RESEARCH IN ELEMENTARY PARTICLE PHYSICS

A PROPOSAL TO THE U.S. DEPARTMENT OF ENERGY

THE UNIVERSITY OF TEXAS AT ARLINGTON

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Co-Principal Investigator:	Kaushik De
Co-Principal Investigator:	Andrew Brandt
Co-Principal Investigator:	Jaehoon Yu
Co-Principal Investigator:	Amir Farbin
Co-Principal Investigator:	Haleh Hadavand
Co-Principal Investigator:	Jonathan Asaadi
Co-Principal Investigator:	David Nygren
Co-Principal Investigator:	Benjamin Jones

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DOE/Office of Science Program Office: **High Energy Physics**

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PAMS Letter of Intent tracking number: LOI-0000014874

Research Subprograms:
Experimental Research at the Energy Frontier in High Energy Physics
Experimental Research at the Intensity Frontier in High Energy Physics
Detector Research and Development in High Energy Physics

Cover Page Supplement

List of Research areas:

- **Energy Frontier PI's:** Kaushik De, Andrew White, Andrew Brandt, Amir Farbin, Haleh Hadavand
- **Intensity Frontier PI's:** Jaehoon Yu, Jonathan Asaadi
- **Detector Research and Development PI's:** Andrew Brandt, Jonathan Asaadi, David Nygren, Benjamin Jones

Lead PI: Andrew White

	Name	**Research Area**	**Year 1 Budget**	**Year 2 Budget**	**Year 3 Budget**	**Total Budget**
Lead-PI	Andrew White	Energy Frontier	$130,156	$132,428	$160,555	$423,139
co-PI	Kaushik De	Energy Frontier	$262,290	$268,294	$274,477	$805,061
co-PI	Andrew Brandt	Energy Frontier	$121,491	$124,144	$185,892	$431,526
co-PI	Amir Farbin	Energy Frontier	$221,356	$226,832	$232,472	$680,659
co-PI	Haleh Hadavand	Energy Frontier	$163,892	$167,227	$170,661	$501,780
	Total	Energy Frontier	$899,185	$918,924	$1,024,057	$2,845,165
co-PI	Jaehoon Yu	Intensity Frontier	$238,522	$247,962	$252,168	$738,651
co-PI	Jonathan Asaadi	Intensity Frontier	$173,432	$231,214	$234,918	$639,563
	Total	Intensity Frontier	$411,954	$479,175	$487,086	$1,378,215
co-PI	Andrew Brandt	Detector R&D	$81,177	$83,499	$45,913	$210,589
co-PI	Jonathan Asaadi	Detector R&D	$33,658	$34,258	$34,876	$102,792
co-PI	David Nygren	Detector R&D	$17,545	$17545	$17,545	$52,635
co-PI	Benjamin Jones	Detector R&D	$39,718	$40,318	$33,361	$113,397
	Total	Detector R&D	$172,098	$175,620	$131,695	$479,412
	Grand Total	**All areas**	$1,483,237	$1,573,718	$1,642,837	$4,699,792

Table 1: Name and Yearly Budget for Proposals with Multiple Research Areas.

Part I
Common Introduction

This proposal requests base funding support for the High Energy Physics (HEP) program at the University of Texas at Arlington (UTA). It covers the research plans of nine PI's in three different research subprograms. Activities of the PI's in the HEP group at UTA are highly coherent and synergistic across research areas, while maintaining the traditional independence of faculty members to pursue their own research interests. We accomplish this balance through the practices listed below.

- **Team building:** Major activities are pursued by teams comprising of multiple PI's and postdoctoral fellows. This is especially important for international scale experiments like ATLAS and DUNE, where large groups are involved from UTA.
- **Resource sharing:** Human and physical resources in the group are shared by multiple PI's. For example, postdoctoral fellows work with multiple PI's, which enhances their training while providing cost savings to the group.
- **Synergistic activities:** All activities are chosen to be closely affiliated with existing responsibilities within the group. For example, PanDA software expertise is matched with distributed computing operations experience, and the new low-mass dark matter searches in the intensity frontier experiments are carried out across closely coupled projects.
- **Core involvement:** All aspects of experimental work are maintained as core expertise within the HEP group, leading to successful physics results across experiments. For example, detector hardware, detector electronics, computing and statistical analysis are equally valued and expertise is maintained at UTA in each area.

The success of the HEP team effort at UTA has led the university administration to approve the formation of one of the first "Organized Research Center of Excellence (ORCE)" at UTA, the ORCE:HEP, which provides an umbrella for the research activities of the nine PI's in this proposal. The Center provides a crucial structure of organizational support for the work plan proposed here.

The shared expertise, infrastructure and organization of the HEP group at UTA provides excellent value for the investment by DOE in the base program. Every dollar in DOE funding is highly leveraged. We describe an ambitious program of work in this proposal while requesting a modest level of investment from the base program.

In subsequent sections of the proposal, the common threads described are numerous. Our expertise in detector development and computing at the Energy Frontier closely matches our new responsibilities at the Intensity Frontier. Software and computing activities directly benefit and enhance the productivity of physics results. Exploration of the Higgs leads naturally into the search for supersymmetry. Many other such synergies are described in the remainder of this proposal.

The nine PI's of this proposal are highly active and well known within the field for their expertise. Two of our PI's are DOE Outstanding Junior Investigator (OJI) or Early Career Research Program (ECRP) winners. We have world renowned expertise in hadronic calorimetry, having designed, built and operated calorimeters at many frontier experiments. Our distributed computing innovations are recognized internationally, in HEP and beyond. We have two decades of experience and leadership in SUSY. We have key responsibilities in Higgs physics. With the new emphasis on dark matter, cutting across all areas of HEP research, we are poised to pursue new discoveries vigorously using all of our combined expertise.

Part II
Research at the Energy Frontier

As shown in Table 1, the UTA EF group consists of 5 active faculty, with 4 FTE effort in ATLAS (half of Andy White's activity is his continued leadership role in the ILC, while Andrew Brandt is half-funded by the Detector R&D frontier). Overall, the PI level of effort in the Energy Frontier has increased by 1 FTE compared to our previous Comparative Review: Haleh Hadavand has joined the UTA HEP group as an Assistant Professor. She is very active in ATLAS and highly regarded in Higgs physics and is convenor of the charged Higgs sub-group. She is co-leading with Brandt a new HL-LHC R&D effort at UTA to construct the LVPS (Low Voltage Power Supply) system for the Scintillating Tile Calorimeter in ATLAS. This has synergy, through the sharing of an engineer, with the existing TileCal Preprocessor effort led by Kaushik De, a key member of ATLAS for more than 20 years. We have requested an additional $164k in the EF budget to support Hadavand's work. Otherwise, the budget request in the first year of this proposal is at the same level as the last year of our previous grant. For our 4 senior PI's we request flat funding even though we expect a much higher level of productivity given our new responsibilities, and since Amir Farbin is now focusing 100% on ATLAS.

In Table 2, we show the fractional contribution of each PI to experiments at the Energy Frontier (EF).

		2017	2018	2019
ATLAS	Kaushik De	1.0	1.0	1.0
	Amir Farbin	1.0	1.0	1.0
	Haleh Hadavand	1.0	1.0	1.0
	Andrew White	0.5	0.5	0.5
	Andrew Brandt	0.5	0.5	0.5
ILC	Andrew White	0.5	0.5	0.5

Table 2: Fractional level of effort for each PI by research area within the Energy Frontier.

We begin this section with individual summaries of the plans for each PI, which will be followed by details of the research plans organized by research areas and research topics. We begin with ATLAS, followed by the ILC. Within each research area, we describe the many topics pursued by our group at UTA, laying out the research objectives, proposed methods and timetables.

PI Summary: Kaushik De

I am currently supported under the DOE base program at the level of 1.05 postdoc, 1 graduate student, two months of summer salary, and a small travel and M&O budget. I request the same level of continued support to pursue an ambitious research plan for the next three years. My group proposes to: support the ATLAS Tile Calorimeter ITC originally built by my group, perform urgent software development and computing operations activities which have been identified as the highest priority by ATLAS management for the ongoing Run 2 at the LHC, complete several SUSY papers in search for stop quarks, conclude HL-LHC Upgrade Research and Development on the TileCal Trigger and DAQ interface Pre-processor board, and continue my ongoing responsibilities as Deputy US ATLAS Software and Computing Manager. I currently receive some funding from other sources for computing, operations and service activities in ATLAS: which supports a researcher from US ATLAS project funds for tile calorimetry, three computing professionals from a DOE ASCR grant, five computing specialists through the US ATLAS project, and additional people through the university. These additional sources of funding dramatically enhance the primary goals of my DOE base program. As described in this proposal, the combined synergy of these multiple projects and sources of support will allow my group to make a huge contribution to the success of ATLAS, and to the physics mission of DOE.

Past Accomplishments of PI De's Group: With continuous support under the DOE base program for the past 20 years, my group has played a leading role in two of the highest priority DOE supported programs: the DØ experiment at Fermilab and the ATLAS experiment at the LHC. I have contributed to all phases of these two experiments, leading to the discovery of two of the most highly sought fundamental particles: the top quark and the Higgs boson. My work and leadership has been especially important during the past decade in ATLAS, where I have led a team of universities to build a unique part of the ATLAS calorimeter, and pioneered a new model of distributed computing for HEP that is now used internationally by HEP, NP and other data science experiments. Over the past two decades, I have personally contributed steadily to narrowing the path in the search for supersymmetry. I have also played an active role in outreach. As we enter the next exciting decade in particle physics, with continued DOE base support, my group is poised to make contributions in the field of HEP at an even higher level.

I graduated a Ph.D. student in ATLAS in 2015, Smita Darmora, who was funded thorugh the DOE base program. Her thesis explored difficult regions in stop parameter space using a multivariate technique (precursor to Deep Learning). While the stop was not found, stringent limits were places and the results were included in ATLAS published papers. I also graduated a PhD student in Computer Science, Mikhail Titov, who was funded through my DOE ASCR grant.

Giulio Usai, a postdoctoral researcher in my group, supported 55% by the base program, is the ATLAS Tile Calorimeter Upgrade co-coordinator. He is leading the TileCal Test Beam effort at CERN, while also supervising Tile Upgrade R&D for ATLAS world-wide. At UTA, we are leading the HL-LHC Tile PPR TDAQi board development project with support from the base program and US ATLAS upgrade project.

I supported 3 postdoctoral researchers for 6 months each during the past 3 years through the base program: David Cote who led SUSY Missing Et subgroup, HeeYeun Kim who prepared Twiki for future graduate students, and Smita Darmora who continued stop analysis for Run 2 and ran a Summer School in HEP for High School students. All three of these short term hires have moved on to new careers. I plan to hire a new postdoc, jointly with Amir Farbin (50-50 split in support) for the next three years.

While contributions to SUSY, calorimetry and other areas are important to ATLAS, my contributions to the field of distributed computing over the past five years have had the most impact. I proposed and led the development of many major elements of the ATLAS computing model, especially PanDA (Production and Ditributed Analysis System for ATLAS). Thousands of physicists use PanDA daily to run millions of jobs at hundreds of computing centers worldwide. I have provided intellectual leadership for this project since the beginning. Today PanDA is supported by CERN IT, OSG, multiple international laboratories, and is used by or is under testing by AMS, ALICE, and many non-HEP communities with Big Data. UTA continues to be an important center for PanDA development.

I am the US ATLAS Deputy Software and Computing Manager (DSCM) and serve on the US ATLAS Management Board. In my role as DSCM, I co-supervise thirty million dollars in NSF and DOE funding, and co-manage the technical work of about fifty people in three National Laboratories and dozens of universities.

Future Milestones for PI De's Group: The three pillars of scientific discovery in energy frontier research: detector, computing and physics analysis are all covered by the program of work of my team. The primary milestones of the program of work proposed here are:

2017 continue support for the Intermediate Tile Calorimeter during Run 2, complete development and commissioning of PanDA Harvester and PanDA Pilot 2.0, generate Monte Carlo samples for the 14 TeV run, continue support of ATLAS and US ATLAS Software snd Computing at many levels, and complete first passs of LHC Run 2 data analysis in search of stop.

2018 complete work on new model of HPC computing in HEP and Big Data sciences through DOE ASCR funded work at Oakridge National Laboratory, continue PanDA development and operations, publish SUSY discovery or limits for third generation searches and additional new models motivated by data, complete Ph.D. work of my student Jared Little.

2019 complete R&D of TileCal PPR TDAQi board, complete implementation of virtual facilities model for ATLAS computing, continue PanDA development and operations, publish results from SUSY studies.

Future Plans for PI De's Group: My group is involved in extremely high priority program of work in the ATLAS experiment, in support of detector, computing, and physics. The plan of work for each area is coordinated in weekly meetings with various levels of ATLAS and US ATLAS management. The overall goal is to conclude successfully Run 2 of the LHC, followed by physics measurements and new discoveries, interspersed with R&D for the HL-LHC. I have sketched out detailed plan of work in subsequent parts of this proposal. The scope of the entire program of work is extensive. Support of my work through the DOE base program will be much appreciated and critical to the success of ATLAS.

The training of students and postdocs is crucial to my contributions to particle physics. All the postdoctoral scientists in my team, irrespective of their sources of support, play a leadership role in ATLAS. They are trained to contribute to the experiment in deep and meaningful ways. For example, Nurcan Ozturk is the ATLAS Distributed Computing Deputy Coordinator, and the US ATLAS Software Manager. Giulio Usai is the TileCal Upgrade coordinator and Test Beam coordinator. Armen Vartapetian coordinates ADCoS. Paul Nilsson is PanDA pilot lead developer. Fernando Barreiro is ADC WFMS coordinator. Anyone knowledgeable about ATLAS computing and physics will acknowledge my contributions and that of my team.

In summary, I present a program of work here for the next three years that is crucial to the success of ATLAS and the DOE HEP Energy Frontier mission. A modest level of base program support is requested: one student, one postdoc, two months of summer support and a small travel budget. The leveraged contributions to ATLAS from this basic support will be huge and critically important, across detector development, software and computing, and physics discoveries. We hope that the work proposed here will lead to the next eagerly anticipated discovery of physics in ATLAS: supersymmetry.

PI Summary: Amir Farbin

The the three drivers of my research are New Physics (NP) searches, software and computing challenges, and calorimetry. In the past three years, these pursuits have kept me grounded in the LHC, where the frontiers of these areas reside, while my focus was on the Intensity Frontier, where I helped instantiate the US's Long Baseline Neutrino and UTA's neutrino programs. On September

1, 2016, my term as DUNE's Deputy Software and Computing Coordinator (DS&CC) ended. I chose not to ascend to full coordinator because it required a 100% commitment that would severe me from the LHC. Free of my Intensity Frontier commitments and on sabbatical (Faculty Development Leave), I have just changed my focus back to the ATLAS experiment and the 100% Energy Frontier program I outline in this proposal.

My ATLAS group, which now consists of postdoc Louise Heelan, recently graduated and soon departing PhD student Daniel Bullock, and new graduate student Leslie Rogers, has a long history of leadership (twice as subconveners) in the search for strongly produced squarks and gluinos. These searches are where the LHC derives the most stringent sparticle mass limits. My DOE Early Career Research Program grant allowed me to bring the unconventional "Razor" technique to ATLAS in early Run 1 and followed through with three iterations of searches [1–3], most recently in 13 TeV data for ICHEP2016 using a generalization of the Razor [4] technique called Recursive Jig-saw Reconstruction (RJR) [5] to enhance sensitivity to compressed SUSY spectra scenarios (see section 1.2.1). My interest in this technique stems from its potential to enable broader yet maximally sensitive searches, which will become more relevant as data-doubling time for Run 2 analysis get exponentially longer. Sections 1.2.3 and 1.2.4 propose a program that evolves in this direction while also targeting difficult regions, such as compressed SUSY spectra, and exploring the most advanced techniques.

Heelan is maintains for the ATLAS workbook and analysis software documentation, and runs the ATLAS software tutorials, responsibilities that we picked up while I was serving as ATLAS's Physics Analysis Tools (PAT) coordinator. This activity is project supported and will not be covered in this proposal due to space constraints, but nonetheless has been a great success and is widely appreciated. Heelan's work was critical to the success of the analysis software (xAOD) migration during Long Shutdown 1 (LS1), and remains as an important conduit to the latest developments in ATLAS software.

A decade ago, I participated in the installation, commissioning, and operation of the Tile Hadronic Calorimeter (TileCal). In recent years, my group has continued to contribute to the study, operations, and upgrade of TileCal, through run coordination (me and Heelan), primary editing (i.e. writing) of the Tile performance paper (Heelan), and maintenance and upgrade responsibilties for the front-end electronics and mobile test systems (Bullock). I have not and will not explicitly request support for such activities and so they are also not covered here to save space. Nonetheless, my and Heelan's roots are in the TileCal and calorimetry. We value this close connection to the detector, and will continue to qualify ATLAS students with TileCal tasks and are likely to take part in TileCal activities as we have in the past.

My physics program in neutrinos, which will end with my student Sepideh Shahsavarani's graduation in 2018, is also focused on NP through searches for sub-GeV Dark Matter (DM) potentially produced in the neutrino beamline. Using miniBooNE's recent dedicated off-axis run, Shahsavarani participates in the nearly complete DM-nucleon scattering search while also leading the DM-electron scattering search. She is simultaneously pursuing neutrino-Argon proton cross section measurements in LArIAT. Meanwhile, I just concluded serving as DUNE's Deputy S&C Coordinator, where I helped design and lead the computing for the next generation of HEP experiments, bringing in experience from the LHC, and building bridges between the Frontiers. I am not requesting any funding in the Intensity Frontier, so these activities are not detailed in this proposal.

Recently, Deep Learning (DL) –an emerging branch of Machine Learning that promises better and faster algorithms that are easier to develop and scale– has grabbed my interest, specifically with challenges of High Luminosity LHC (HL-LHC) computing in mind. My efforts in this area has grown from a hobby to a major thrust of research. I have been applying DL to a variety of HEP problems in several different experiments via collaborations with numerous HEP and DL colleagues.

Early on, I was the first to demonstrate DL image classification potential in LArTPC neutrino experiments [6] and Gas TPC neutrinoless double-beta decay experiments [7]. I have jump-started many HEP collaborators by providing working examples, support, GPUs, and producing large public data samples, while personally tackling some of the most difficult problems. Section 1.7 highlights 2 of 4 thrusts of DL projects aimed at specific LHC problems: event classification and calorimeter reconstruction. The latter is an extension of my nearly complete efforts in TPCs to the ATLAS Calorimeter. My considerable lead in the application of DL to HEP has yielded numerous workshop and conference presentations and organization roles in the past year [6, 8–15], including the only DL talk at ICHEP 2016 [7]. Almost all of my proposed work will include a DL component, and I will be jump-starting efforts by Asaadi, Jones, Hadavand, and Brandt to incorporate DL into their programs.

The transition back to 100% Energy Frontier provides an opportunity for me to pursue new software areas in ATLAS. For Run 3, ATLAS needs to migrate to a Multi-threaded version of their Athena framework, where I have a long history of contributions. Meanwhile ATLAS is woefully short of software expertise and manpower. I propose to dedicate my focus in ATLAS computing to aspects of this migration related specifically to the Trigger and GPUs, as described in section 1.10. My now extensive experience with frameworks, Event Data Model, GPUs, and co-processors lead me to believe that a new framework may be warranted for HL-LHC. I will play a leading role in organizing the framework discussions in the community-wide white paper orchestrated by Pete Elmer, Mike Sokoloff (U. Cincinnati), and Mark Neubauer in preparation for a NSF SI2 HL-LHC Software Center proposal. Ideally we will organize a workshop that will pull together framework experts across experiments, many of whom I had the opportunity to closely work with as DUNE DS&CC. All of these activities will greatly benefit from my proposed deep involvement in ATLAS Core Trigger software, where I intend to assume critical responsibilities and leadership roles.

I find myself at the boundary of several distinct areas in HEP and HEP Experiments. For a long time, I've straddled the fence between Physics and Computing. My strong computing skills and expertise have lead me to assume roles generally assumed by computing oriented staff scientists and engineers who often haven't touched real data for a long time, and seldom tackled by professors, like me, with also close connections to data analysis and detectors. For the past three years, I have had one foot in the Intensity Frontier and the other in the Energy Frontier, developing a unique perspective of computing on both fronts and establishing working relationships with many core developers at Fermilab and CERN. My recent successes in the DL have pushed me to boundaries of cutting edge Data Science and HEP, yielding collaborations with new HEP experiments and Data Scientists. And I propose here to cross a new boundry between offline and trigger software.

Long term accomplishments: TileCal Trigger Coordinator (twice during installation in 2005-7 and operations in 2010). ATLAS Analysis Model Coordinator (2006-7). TileCal Deputy Run Coordinator (2010). ATLAS Physics Analysis Tools Convener (2011-13). DOE Early Career Research Program grand award (2010-15). DUNE Deputy S&C Coordinator (2015-6).

Accomplishments during previous funding period: DUNE S&C Coordinator. SUSY squark and gluino sub-group convenorship and related publications (Run 1 summaries and Run 2 ICHEP2016). Introduction and multiple publications of Razor and Recursive Jig-saw (ICHEP2016) based searches. Publication of Tile Performance paper. TileCal Run Coordinator. Key role in LS1 xAOD Analysis Software Migration. Leadership in the introduction of Deep Learning to multiple HEP experiments. Participation in sub-GeV Dark Matter searches with miniBooNE. PhD defense of ATLAS student Bullock.

Summary of milestores/plans for next funding period: *Trigger:* 2016-17: Initial work by Farbin on migration of ATLAS Trigger to Run 3 athenaMT Framework. 2017-20: Dedicated 50% postdoc effort to Trigger Migration. 2018-21: Direct contributions and leadership in athenaMT migration, commissioning, and operation. 2017: GPU Demonstrator in TensorFlow Study.

Deep Learning Calorimetry: 2016: Completion of LArTPC, NEXT, and LCD Calorimeter DL Papers. 2017: DL for Photon ID with ATLAS. 2017-18: DL for e/gamma Energy reconstruction. 2018-19: DL for electromagentic/hadronic cluster identification and hadronic energy reconstruction.

SUSY: 2016-mid 2017: Deep Learning projects/papers on SUSY Event Topology and Compressed Spectra using Snowmass Data. 2017: Migration to signature-based searches and development of RJR/DL ISR Compressed Spectra search and Develop $bbll$ + MET search. Summer 2017 and Summer 2018: Updates of squark and gluino searches. Spring 2018: Compressed Spectra search. Summer 2019: $bbll$ + MET search, develop General Search.

PI Summary: Haleh Hadavand

I started my postdoc position with Southern Methodist University on the ATLAS experiment in late 2005. I joined the online monitoring software effort at CERN and within a few months developed a histogram naming system for the online histograms and modified an existing/decommissioned software for histogram collection to work properly within a new release. I also started designing and laying down the foundations for the ATLAS data quality monitoring system. I was one of the main visionaries, designers, and developers for this system which is still used both online and offline by ATLAS. My main development contribution was the plug-in algorithms that could be loaded at any point into the system, the online display, and the online time series analysis [16, 17].

During commissioning of cosmics before LHC collisions I setup the entire online monitoring chain from histogram production to final DQ assessments of monitoring data. This required thorough understanding of the offline software, within the High Level trigger, and the online environment, software, and tools. I was the first to develop software to produce η vs ϕ plots of clusters within the LAr and Tile calorimeters online, use the gatherer to collect histograms from various monitoring nodes, display the histograms, apply DQ, and time series assessment of the data quality information. This work gives me a very thorough understanding of the monitoring system on ATLAS both online and offline.

I worked on photon physics within the exotic channels of UED diphoton + Missing Et and Randall Sundrum(RS) Graviton to diphotons. I was a main contributor to both anlayses. The UED analysis was one of the first 20 published papers out of the ATLAS experiment [18] for which I served as a co-editor. For the RS Graviton analysis I provided the statistical framework for the final limits. I was a co-editor for the resulting conference note and paper [**?**, 19].

Since I joined UTA in July 2012 I have been working on the charged Higgs to $\tau^{+}\nu$ in fully hadronic final states. I have been part of three conference results and two publications [20–23]. My role on the Run 1 measurement was the high mass background estimation of the $\tau \rightarrow$ jets background and the statistical treatment leading to the final limits for the analysis. I produced Run 2 projections for this analysis and determined that with only a few fb^{-1} of data evidence of signal can be observed. I also produced the first intermediate mass samples for the charged Higgs in the mass range of 160-180 GeV. This was work done with collaboration with theorists to reconcile interference terms in this region. For the Run 2 analysis I motivated using the MET trigger instead of the tau+MET trigger used in Run 1. This choice greatly reduced the trigger and background systematics. The background suffered from low statistics when using the tau+MET trigger since the trigger imposed a medium tau selection. My work on this charged Higgs final state has resulted in my appointment to the charged Higgs convenership position thereby overseeing all charged Higgs activities on the ATLAS experiment.

As charged Higgs convener I have motivated new charged Higgs final state searches (five new channels) thereby expanding the groups responsibility and visibility. I have been in contact with theorists and am the main contact for MC generation of charged Higgs final states putting me in a unique position to deliver the MC samples for newly motivated final states. One of these new channels is a decay to SUSY final states which would have a signature of three leptons plus missing ET. Two of these leptons would be same flavor and opposite sign. Several independent evidence of an excess in multi-lepton events have been reported on the ATLAS experiment [24].

In April 2016 I was appointed to the position of charge account manager (CAM or L3 manager) for the low voltage power supplies (LVPS) for the Tile calorimeter for HL-LHC. This account will manage about $1 million of labor, travel, and materials and supplies over a 6 year period. I have been working closely with Andrew Brandt, the institutional representative for UT Arlington, on this project. More details about this project are highlighted in section **??** and the schedule is detailed in table 4.

Plans I have a very ambitious physics plan for the next three years which consists of charged Higgs physics and a new analysis endeavor into Z boson + X searches. I also have many responsibilities as charged Higgs convener and CAM for the LVPS upgrade for the Tile calorimeter for HL-LHC. My student Hussein Akafzade will graduate by mid-2019 on charged Higgs while I ramp up a new student to work on Z+X analysis starting in 2017. This new student will be funded by the grant upon Akafzade's departure. The analyses I propose will use cutting edge techniques to increase sensitivity including the use of tau polarization for distinguishing Higgs decays from W boson decays, use of Deep Learning in conjunction with Brandt and Farbin, Matrix Element Methods, and new di-tau reconstruction algorithm. The Z boson + X analysis will cover five final states within one analysis by using a parametric fit to the background in control regions and searching for new particles in the mass range of 4 GeV to several TeV. This type of combined search is unprecedented on ATLAS. I continue to motivate new charge Higgs final states as the charge Higgs convener and follow the progress of the new analyses being added to the group. There are several important milestones for the LVPS upgrade project in the next three years. These include the design and fabrication of the LVPS elevated temperature test stand (burn-in station), the version 8.2 prototype, and the testing and integration into the vertical slice test.

Milestones

- FY16 - Publish results for charged Higgs on 2016 dataset including the tau-lepton channel.
- FY16-17 - Design and fabrication of Tile LVPS burn-in station.
- FY17 - Publish charged Higgs results using τ polarization.
- FY17 - Take new graduate student for Z+X analysis.
- FY17 - Hire new postdoc to work on charged Higgs and Z+X analyses.
- FY18 - Develop analysis suite for Z+X analysis.
- FY18 - Publish Z+X results using Higgs mass constraint.
- FY18 - Publish charged Higgs results using deep learning techniques for selection and/or tau reconstruction.
- FY18-19 - LVPS V8.2 prototype.
- FY18-19 - Testing and integration of LVPS into vertical slice test.
- FY19 - Charged Higgs results with Matrix Element Methods.
- FY19 - Graduate student Akafzade graduates on charged Higgs analysis.
- FY18 - Publish Z+X results with no mass constraints.

PI Summary: Andrew P. White

Accomplishments

- Founder of UTA High Energy Physics Group 1991
- Inventor of the DZero Experiment Intercryostat Detector
- Inventor of Gas Electron Multiplier (GEM) based Digital Hadron Calorimetry
- American Physical Society Fellowship - 2011
- Recipient of UTA Distinguished Record of Research Award, May 2009
- Analysis contact for Run 1, and Run 2 Vector Boson Fusion Higgs To Invisible Decays
- Spokesperson for the SiD Detector Concept for the International Linear Collider (2010-)
- Chairman of the Physics Research Council for DESY, Hamburg/Zeuthen, Germany (2012 2015)
- Member of the U.S. Department of Energy National Reviews of Detector Research and Development at National Laboratories, 2009, 2012
- Served on national review committees and was a member of the Department of Energy, HEPAP Subpanels on the Future of Particle Physics in the United States (1998 and 2007)
- Member of the ECFA Detector Panel (2012-2016)
- Member of the ATLAS Tile Calorimeter Speakers' Committee (2014-)
- Member of the US ATLAS Analysis Support Group
- Universities Representative on the Americas Linear Collider Committee (2012-)
- N. American representative for the CALICE (Calorimetry for Linear Colliders) Collaboration
- Member of the Management Board for the Micro Pattern Gas Detector Collaboration/CERN, RD-51
- Instigator and original leader of the DZero Experiment New Phenomena physics group
- Co-designer of the ALEPH (CERN) Experiment Inner Trigger and Tracking Chamber (1982-4)
- Invited to lead numerous physics and detector working groups at large national and international high energy physics meetings

Milestones

- FY16 - Publish Run 1 results from Higgs to invisible decays analysis - done.
- FY17 - Publish Run 2 2015-16 results from Higgs to invisible decays analysis.
- FY17 - Take on new graduate student for Higgs/invisible analysis, ITC qualification tasks.
- FY17 - Complete study of ITC E-cells new segmentation, energy resolution study.
- FY17 - Complete full simulation of SiD AHCAL, barrel + endcaps.
- FY17-18 - Develop design of SiD AHCAL barrel module.
- FY17-18 - Complete plans for ATLAS ITC Tile/Fiber replacements in LS2.
- FY18-19 - Co-convene the full Run 2 Higgs to Invisible analysis.
- FY18-19 - Prepare (with ATLAS Tile Institutes) tile/fiber assemblies for installation in LS2.
- FY18-19 - Expand SiD Consortium in preparation for drafting SiD Technical Design Report.
- FY18-19 - Begin first draft of SiD Technical Design report.
- FY19 - Publish result for Run 2 Higgs to Invisible analysis, possible interpretive paper(s).
- FY19 - Contribute effort to installation and testing of the new ATLAS ITC E-cells.

Plans

With the discovery of the Higgs boson great opportunities exist for understanding this fundamentally new state of matter, and for discoveries associated with existence. In this regard, I am committed to the continuing success of the ATLAS Experiment's physics program through analysis of current and future data in the search for invisible decays of the Higgs, and through support work on the Intermediate Tile Calorimeter, and data quality validation shifts. Taking on a new graduate student, I will continue our study of the optimal segmentation of the new ITC E-cells. I will work to identify suitable replacement ITC tile and fiber materials and provide expertise in their installation and re-commissioning. I will work on the extension of the VBF-Higgs to invisible analysis, and paper publication, using existing data and, with my student, I will develop analysis strategies for analyzing the 14 TeV data accumulated at high instantaneous luminosity and pileup. The full exploration of the Higgs sector will require precision studies of couplings at the percent level or below. The best prospect for achieving such precision measurements in the foreseeable future lies with the International Linear Collider. As Spokesperson for the SiD Detector Concept for the ILC, I will continue to lead its development and promote its realization within the global HEP community. I will work towards securing a U.S. role in the ILC project in Japan and develop the site-specific implementation of SiD at the selected Kitakami location. With the SiD Executive Committee and the Institutional Board, I will create the team that will produce the SiD Technical Design Report over a 2-3 year period, and guide the process of subsystem technology selections. I will represent SiD on the Linear Collider Physics and Detectors Executive Board, and the Americas Linear Collider Committee, and with interactions with funding agency(s). I will work to build the SiD Collaboration in all regions. Locally at UTA, I will pursue the implementation of scintillator/SiPM hadron calorimetry for SiD, together with its full simulation.

PI Summary: Andrew Brandt

1 The ATLAS Experiment

Faculty PI: Kaushik De, Amir Farbin, Haleh Hadavand, Andrew White, Andrew Brandt

The UTA HEP group joined the ATLAS collaboration in the early days of planning for the experiment at the LHC, 21 years ago. Since then, we have participated in every aspect of the experiment: design, construction, commissioning, computing, management, and physics analysis. The work done by our group has benefited every aspect of ATLAS, and led to the successful physics program of the experiment. Currently, our group has 5 active PI's in ATLAS, which makes UTA one of the larger university groups in ATLAS. We have an excellent record of synergistic accomplishments among the members of our group, and among the various externally funded projects. While the DOE base program provides about one third of the funding for our activities in ATLAS, the impact of this funding is magnified many fold by the various synergies in our group in advancing the core mission of DOE-HEP.

Currently, the 5 PI's active in ATLAS from the UTA group include 3 members who are devoting 100% of their research time on ATLAS: PI's De, Farbin and Hadavand. One PI, White, is half time on ATLAS, and half time on the ILC. Another PI, Brandt, is half time on ATLAS and half time on related detector development research. The total PI FTE level is 4 on ATLAS. Consequently, we request 8 months of PI summer salaries for ATLAS in this proposal. This represents an increment of 2 months of summer salary for our new junior faculty member, Haleh Hadavand.

We currently support 2.6 postdoctoral researchers in ATLAS. We request this to be increased to 3.1 postdocs, where a half postdoc is added for our junior faculty. One postdoc will work on Higgs physics, supervised by Hadavand and Brandt. One postdoc will work on SUSY searches and Deep Learning, supervised by De and Farbin. We will continue to support 0.55 FTE postdoc Usai under PI De, who will continue as the ATLAS TileCal Upgrade and Test Beam co-coordinator. We will also continue to support 0.55 FTE postdoc Louise Heelan under PI Farbin. The remainder of support for Usai and Heelan are leveraged through the US ATLAS project. Both are stationed at CERN and perform critical service tasks for ATLAS, while also contributing to physics analyses.

We request support for 4 graduate students for the 5 PI's in ATLAS. Jared Little is already stationed at CERN. We will draw the rest from the excellent pool of new students at UTA, many of whom are already working with ATLAS PI's.

In the following sections we describe each research topic that the UTA group is involved in.

Physics Activities in ATLAS

1.1 Higgs Physics (PI: Brandt, Hadavand, White)

On July 4, 2012 ATLAS and CMS announced the observation of a new particle consistent with a Standard Model (SM) Higgs Boson [25, 26], ending the 50 year search for the elusive final SM particle. This landmark discovery fulfills a prime objective of the LHC by providing evidence for a Higgs field that gives mass to fundamental particles through their coupling to the field thus uncovering the mechanism for electroweak symmetry breaking. UTA has a long history in Higgs physics including critical roles in observation and property measurements of Higgs to WW which was the thesis topic of Hee Yeun Kim (Yu's student). Last Feremenga (Yu's student) will graduate later this year on his work on Diffractive Higgs. Griffith led the effort in evaluating the theoretical uncertainties in the modeling of the Higgs boson and the main Standard Model (SM) backgrounds and was the liaison to the Monte Carlo (MC) Generator group. He also contributed to lowering the uncertainty, the main systematic to this final state, by exploring new MC generators and optimizing control region and signal region definitions. The group has contributed to the discovery of the Higgs particle including critical roles in computing, detector building (ITC), and commissioning (ITC, MBTS, trigger).

Although the SM has been extremely successful at explaining electroweak data, problems with the theory, such as the quadratic divergence of radiative corrections to the Higgs mass (a.k.a. the Hierarchy problem), and unanswered questions, such as the nature of dark matter, drive our search for new phenomena at the TeV scale. We have strong arguments (i.e. naturalness and the "dark-matter miracle") that solutions to these problems and questions may be found at this energy. The leading theoretical solution is Supersymmetry (SUSY) since it not only addresses the hierarchy problem, but can also provide a dark matter candidate and predicts the unification of gauge couplings at the Grand Unified Theory (GUT) scale. We also know that the uncertainty of the current Higgs measurements allow for non-SM decays of the Higgs boson of 26% [27] and that theories with SM+singlets have equivalent level of branching fraction [28].

With the discovery of the Higgs and reasons illuminated above the UTA groups focus has shifted to BSM Higgs phenomena on three fronts: A charged Higgs search in the $\tau\nu$ final state, invisible Higgs search in the VBF channel, and new proposal by Hadavand in the search for Z+X channels. The charged Higgs group is led by Brandt and Hadavand overseeing the work of postdoc Justin Griffith and Hadavand's student Hussein Akafzade. Both Hadavand and Griffith have leadership roles in charged Higgs as the charged Higgs convener and analysis contact for the $\tau\nu$ final state. Akafzade's thesis will be based on the Run 2 dataset of $100 fb^{-1}$ on charged Higgs. Brandt's student John Crouch will take over the charged Higgs analysis by mid-2019. White is the analysis contact for the Vector Boson Fusion Higgs to Invisible Decays for Run 2, having served in the same role for the published Run 1 analysis. White will take on a new graduate student to work on this analysis for the full Run 2 dataset. By mid-2017 Hadavand will take a new student who will work on the Z+X analysis together with a newly hired postdoc working on both charged Higgs and Z+X.

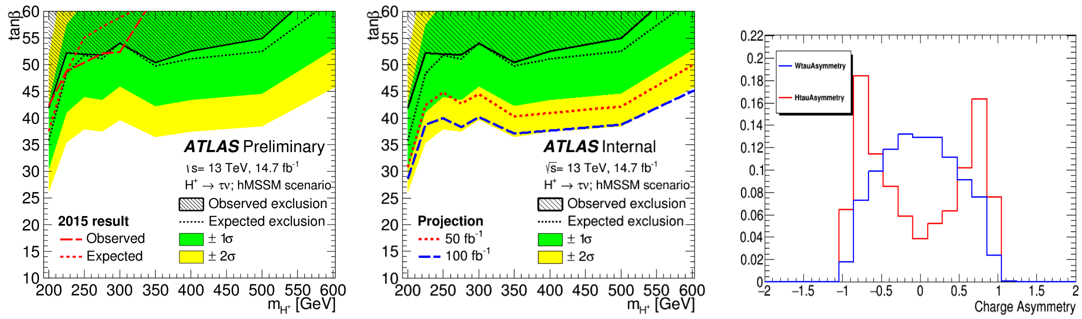


Figure 1: ICHEP 2016 hMSSM exclusions including 2015 exclusion, left; ICHEP 2016 hMSSM exclusions with $50fb^{-1}$ and $100fb^{-1}$ of data projections, middle; Distribution of τ polarization for Higgs and W decays, right;

1.1.1 Charged Higgs (PI: Brandt, Hadavand)

Brandt and Hadavand will continue the search for charged Higgs in the fully hadronic final state of $\tau^+\nu$. The discovery of charged Higgs would be a clear sign of BSM physics and would imply that the 125 GeV Higgs is part of a more complex Higgs sector. The Charged Higgs is predicted by several models such as ones with Higgs triplets and Two-Higgs-Doublet-Models(2HDM) [29–31]. In the MSSM, which is a type II 2 Higgs Doublet Model (2HDM), the main production of charged Higgs at the LHC is t $\rightarrow$ b H^+ for H^+ mass below m_{top}. At charged Higgs masses above m_{top} the main production at the LHC is in association with a top quark. In the MSSM the Higgs sector can be completely determined by the H^+ mass and tan β, the ratio of vacuum expectation values of the 2HDM. For masses below the top mass the $\tau\nu$ decay is dominant for $\tan\beta > 2$.

Hadavand motivated and was responsible for investigating new models for analyzing the intermediate mass region of 160-180 GeV. Only recently have theorists been able to reconcile $t\bar{t}$ interference effects and supply the NLO calculations of the cross section as a function of mass and $\tan\beta$. The addition of this mass region will close the gap m_H vs $\tan\beta$ mass range and also produce competitive results at low $\tan\beta$ vs A $\rightarrow \tau\tau$ and $H^+ \rightarrow t^+$b. The measurements for this region will be performed by the end of 2016.

Hadavand and Griffiths have led the charged Higgs as charged Higgs convener and analysis contact respectively. Under their leadership UTA group has produced the final results including plots and statistical interpretation, estimation of the systematic uncertainties, including theoretical, writing the analysis code, production of common ntuples, and trigger studies (with Jae Yu's student Last Feremenga). This luminosity increase extended the mass reach of the analysis from 250 GeV in Run 1 to 600 GeV in Run 2. The jet to tau background statistics for the Run 2 analysis were vastly improved over Run 1 by using Hadavand's suggestion of only using a missing ET trigger as opposed to a tau plus missing ET trigger. The use of the tau in the trigger implied that a medium selection of taus had to be used in the fake factor method, where in Run 2 a Loose selection could be used therefore greatly enhancing the statistics.

Figure 1 (middle) shows that with the 2018 dataset of 100-150 fb^{-1} of data the analysis is excluding large $\tan\beta$ values so this analysis continues to be an important measurement as more data in accumulated. The group has plans to apply several techniques to improve the analysis sensitivity over it's early Run 2 predecessor. The tasks aimed for these improvements are listed below:

Include tau-lep Channel By the end of 2016 the tau-lep channel (hadronic tau and leptonic top decays) will be added to the analysis. This analysis will rely heavily on infrastructure used for the tau hadronic final state developed by UTA for histogram production, systematic uncertainties, and limit setting. Therefore UTA will be an integral part of the addition of this final state.

Use tau polarization to reduce true tau background The tau polarization can be used to separate the W $\rightarrow\tau\nu$ background from the signal. The intrinsic polarization of W$^+$ is -1 while that of H^+ is +1. The tau polarization is defined as $P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$. A plot of the charge asymmetry, defined as $\Upsilon = \frac{p_T^{track}}{p_T} - 1$, is shown for the signal and background in the $\tau \rightarrow \rho\nu_\tau$ final in figure 1, right. Other 1-prong decays will also have similar separation in the charge asymmetry. The 1-prong decays can be separated from the 3-prong decays in the final fitting machinery and added statistically together. This variable will be used as additional variable to the fit in the 1-prong case.

Use matrix element method to reduce true tau background In addition to the tau polarization one can utilize the event kinematics by utilizing the matrix element method to distinguish the signal from the true tau background originating from $t\bar{t}$ events. This can be done by using the classifier distribution $d(x) = \frac{P_S(x)}{P_S(x) - P_B(x)}$ where P_S and P_B correspond to the weights from the signal and background hypothesis . Hadavand has performed initial tests with MadWeight for achieving this goal. This variable can then be added as one of the variables in the boosted decision trees (BDT).

Use boosted decision trees As mentioned earlier for early Run 2 results the discriminating variable used in the fit was m_T. As an alternative several variables are incorporated into a BDT which is used as the discriminating variable in the fit. Some variables that have been investigated in some preliminary studies are m_T, leading b jet p_T , τp_T, MET, $\Delta\eta(\tau-$leading jet), $\Delta\phi(top-$sub-leading jet).

Determine jet $\rightarrow\tau$ Background from Control Region For Run 1 the systematics for the $\tau \rightarrow$jet background were one the largest in the analysis. Due to low statistics at the high mass a fit above 200 GeV was necessary to get an estimate of the background in that region. This is important since this is the dominant background in the high mass region and without a background model the limit machinery would fail. As an alternative to the matrix method used for the Run 1 published paper one can use a control region with no signal and loosen the selection criteria to introduce more fake taus. This can be done by requiring a zero b-jet region and only requiring a loose tau selection. The normalization of this background can then be derived within the fit to data. This should reduce both the statistical and systematic uncertainty of the analysis.

Apply Deep learning techniques for selection The deep learning technique can be applied to this analysis in two ways. One way would be to use it to distinguish $t\bar{t}$ background from the signal by training on those samples. A comparison of the BDT method described earlier for event selection will be done with respect to this technique. Another way to apply deep learning would be in the tau reconstruction in place of the BDT technique which is used now. This work will be done utilizing Farbin's extensive experience in the field of deep learning.

Optimize Binning for Limits The low statistics in the tail of the mT distribution has made the H$^+$ $\rightarrow\tau\nu$ channel difficult for setting limits. In many cases several systematic variations performed for pull determination would make the fits fail. This has to do with the fact that the data has low stats and is not smooth as opposed to MC samples which did have a smooth shape in the tail and could be fit successfully. By making requirements on signal over background and the number of total background in a given bin and then testing with pull estimation, Hadavand was able to optimize the best binning for both stability and sensitivity. For performing projections to higher luminosities the background is extrapolated to higher masses to determine a realistic scale of the background in this region. After performing the extrapolation the binning is re-optimized for the given luminosity projection, a technique developed by Hadavand.

Milestones

- FY16 - Publish results for charged Higgs on 2016 dataset including the tau-lepton channel.
- FY17 - Publish charged Higgs results using τ polarization.
- FY17 - Hire new postdoc to work on charged Higgs and Z+X analyses.
- FY18 - Charged Higgs results with Matrix Element Methods.
- FY19 - Graduate student Akafzade graduates on charged Higgs analysis.
- FY19 - Brandt student Crouch starts on analysis.
- FY19 - Publish charged Higgs results using deep learning techniques for selection and/or tau reconstruction.

1.1.2 Z+X Scan (PI: Hadavand)

The increased beam energy and intensity in the LHCs Run 2 and 3 will likely provide the best opportunity to discover BSM physics for at least the next ten years. The task of discovering it, however, can be more challenging compared to the SM Higgs, whose mass was well constrained by precision electroweak data and the underlying theory, i.e. the SM, was well understood and extensively tested for over half a century [32–35]. In contrast, the number of theories and models that motivate BSM Higgs searches are significantly larger and more speculative, requiring that a much wider net be cast to cover a broader range of masses and final states.

Hadavand proposes to perform Z boson + X searches using the 125 GeV Higgs to bootstrap her way to search for new exotic decays of the Higgs or other BSM states. The Higgs mass constraint will help aid the search for signal in a specific region. This method is motivated but not limited to the final states listed in Table 3. The search can be further expanded in a model-independent manner by scanning for Z+X where X can be of masses not theoretically motivated. This proposal combines a search within five theoretical models each decaying to ll$\tau\tau$ and/or $\tau\tau$ll, thereby using Hadavand's extensive experience with τ leptons. One analysis covers all of these models thereby increasing the analysis reach.

The Z+X search will primarily probe SUSY models for example Next-to-Minimal Supersymmetric Standard Model (NMSSM) that include an additional scalar singlet or SM +singlet models. It can also be used to discover other states not theoretically motivated therefore investigating new mass regions where potential new particles could exist. Additionally Hadavand proposes searching for a "dark" Z in the mass range $12 <$ m< 60 GeV. A "dark" Z serves as the mediator of a new U(1) gauge symmetry that can serve as the portal to a hidden sector that constitutes dark matter [36].

Hadavand's strategy is to combine several final states and channels to increase statistics and look for a bump using a bump-hunting procedure Hadavand developed as a first pass. The approach removes the need for setting limits in a fine granularity in the discriminating variable, thereby greatly speeding up the statistical analysis. This speedup will allow for quicker turn around of searches in the absence of signal. In the end the full statistical treatment as recommended for

Analysis	Channels $\rightarrow$	$\tau\tau$ ll	ll $\tau\tau$	Theory
Z Scan	$h \rightarrow ZZ^*$	✓	✓	SM
	$A \rightarrow Zh$		✓	MSSM, NMSSM
	$h \rightarrow$ ZZ(dark)	✓	✓	dark U(1) gauge
	$X(h) \rightarrow Za$ for a l=μ	✓	✓	NSSM, SM+singlet

Table 3: Table showing channels and accessible final states and theoretical models for several BSM models including the standard model h $\rightarrow$ZZ* channel [**?**]. The mass of the scalar singlet a and Z(dark) are $4 < m(a) < 10$GeV $15 < m(Z(dark)) < 60$GeV respectively.

ATLAS will be performed to present the final results but this first pass will allow for flexibility in the search.

For the Z scan Hadavand proposes to perform two mass scans constraining the given particle combination to the Z mass and scanning in the 'other' particle. For example, Z(ll) other($\tau\tau$) and Z($\tau\tau$)other(ll) would be two separate scans of the 'other' particle after requiring that the event has a Z boson in the final state. The mass range of the scan would go from 4 GeV to several TeV and each object would be a resonance in that mass spectrum. The ee and $\mu\mu$ channels are added together in one spectrum since they have similar resolution and hence can increase the statistics for bump-hunting. The two scans, one with taus and the other with l=μ,e can then be combined together with a statistical framework.

Of course the 4 lepton final state is one that is extensively tested for the SM ZZ* final state. This analysis would add the ll$\tau\tau$, $\tau\tau$ll final states to this channel for the first time. The resolution will not be as favorable as the 4 lepton final state but by constraining the on shell Z to decay to $\tau\tau$ one can improve the mass resolution. These final states can add further sensitivity to this channel specially as the LHC gathers more data. With about 10 fb^{-1} of data at the center of mass energy $\sqrt{s}$ = 13 TeV the 4 lepton analysis observed 3 events per category including a combination of electrons and muons. The efficiency for tau reconstruction is lower (30-40% as opposed to around 80%) than the electron and muon channels and in addition poses a more challenging final state due to the existence of neutrinos. However on average $35/80 \times 4 \sim 2$ $(2\tau 2e, 2\tau 2\mu, 2e2\tau, 2\mu 2\tau)$ events/$10fb^{-1}$can be added to this channel [37] increasing the total statistics by 2/12=17%.

By scanning for particles after selecting the Z boson one will get clear mass separation of the 'other' particle. The requirement of the Z boson in the event will also reduce backgrounds. Table 3 shows that many of the signals come from h, the 125 GeV Higgs. Looking for the h mass would result in an overlap between the various final states and would make it difficult to know which final state actually contributed. But by looking for the 'other' particle a clear mass separation is presented. This method is also less restrictive on the analysis since one would not put any explicit selection on the mass of the 'other' particle. In addition, another discriminating variable can be added to combine the Z and the 'other' particle and see if indeed one does reconstruct the hypothesized mass of the originating particle. For example restricting the Z($\tau\tau$)other(ll) mass to be within the Higgs mass window to see if it will make the peaks in the other(ll) become clearer.

The SM ZZ* is the only channel that is not a resonance in the other(ll) spectrum. It will have to be fit simultaneously as if it were a separate signal sitting on top of the Drell-Yan background. Using the bump-hunter to pick out this peak is not favorable since it is not a resonant peak and it can overlap with other signal. By studying the shapes in MC and doing a parametric fit to the data one can determine the level of SM contribution to the mass spectrum. In the end when reconstructing the 'other' mass one would see clear bumps for the particles a, Z(dark), h in order of mass. The search can extend to high masses in case some other massive objects happens to appear in association with a Z boson.

1.1.3 Selection and Backgrounds to Z

The selection for this analysis is still to be determined but would require a di-lepton pair with $80 <$m(ll)< 100 GeV for the ee, and $\mu\mu$ channels and would require the use of the Missing Mass calculator for tau mass reconstruction to determine the selection window around the Z mass. In addition a medium/tight selection of the di-leptons will be made for the 'other' particle. When reconstructing the 'other' mass one can parameterize the fit to the background from a control region and extend it to the entire range of the mass. At low mass there will be resonant standard model particles which can be modeled with a combination of simulations and the use of the control regions. The backgrounds include Jψ ,Υ, Z, $t\bar{t}$ background, and Drell-Yan non-resonant background. In the intermediate mass there will be SM Z+h and ZZ* background as well.

1.1.4 Task List

A list of main tasks needed to perform this analysis are listed below:

Determine Algorithm for Boosted/Collimated di-tau Pair Identification Since the proposal is a general search where an unknown particle can decay to a Z boson and another potentially unknown particle, some events will have highly boosted and/or highly collimated di-tau pairs that regular tau reconstruction does not treat. There has been work on ATLAS in this front aimed for reconstructing the channel A $\rightarrow$Z(ll) h($\tau\tau$) [38]. In this case the p_T of the di-tau system is quite high of the order of 500 GeV. In other cases the p_T of the di-tau system can be small but they can be highly collimated. This has been seen in the h $\rightarrow$a($\mu\mu$) a($\tau\tau$) analysis. In fact the algorithm developed for A $\rightarrow$Z(ll) h($\tau\tau$) would not work for this channel because of the large p_T cut and the fact that it is seeded by a large R (1.0) Jet. Large R jets only have calibration available for p_T larger than 200 GeV. So Hadavand proposes to develop a high p_T di-tau algorithm and a low p_T highly collimated algorithm where standard jets of R of 0.4 can be used. A boosted decision tree (BDT) can be developed using the jet substructure information. The variables suggested to be used in the BDT or further studied within a Deep Neural Network are the following:

- core energy fractions, $f_{core}^{sub(lead)} = \frac{\sum_{cells}^{\Delta R=0.1} p_{p,cell}}{\sum_{cells}^{\Delta R=0.2} p_{T,cell}}$
- The subjet energy fractions $f(sub)lead_{subjet} = \frac{p_T{}^{subjet}}{p_T{}^{Jet}}$
- leading track momentum fractions $f(sub)lead_{subjet} = \frac{p_T{}^{leadTrack}}{p_T{}^{subjet}}$
- the maximum track distance Rmax
- the number of tracks n(sub)leading track.

Additionally, we propose an alternate method of di-tau reconstruction targeted at semi-leptonic decays. Due to Griffiths' work on making tau reconstruction dual-use, an analyzer can now take a reconstructed tau candidate that has 2 or 4 associated tracks, check whether one of the tracks is associated to an identified electron or muon, remove this track from the tau candidate, recompute the standard hadronic tau identification variables, and finally recompute the tau identification discriminant. Studies still need to be performed as some variables cannot be fully recomputed after full reconstruction due to the dependence of calorimeter cells or vertexing which is only available during athena reconstruction. We plan to either provide corrections for any variables and/or provide a re-tuned MVA discriminant using a Deep Neural Network.

Write General Analysis Suite for xAODs This analysis has leptons including taus in the final states so the analysis suite can be generalized but always adding a constraint of having a Z boson in the final state. Since this search is inclusive where any particle can decay to Z+X, the analysis suite must be very general. However, on top of the general analysis suite one can build tools to make additional requirements on the specific states. For example if there is mass constraint that can be imposed such as the mass of the Higgs.

Determine Background Parameterization from Control Regions, $ll, l = \mu, e$ scan Two control regions (CRs) are used in this analysis to constrain the SM backgrounds in the final fit to the data. The first region, CRj, is used to constrain the low mass SM resonances and Drell-Yan dominated non-resonant background. The second region, CRb, is used to constrain the $t\bar{t}$ non-resonant background. Both regions are defined by first requiring a tagged ll candidate. CRj is further required to have at least one selected jet and not be b-tagged. CRb is required to have at least two selected jets that have been b-tagged. Any events which are in one of the SRs are excluded from the two CRs.

Determine Background Parameterization from Control Regions, $\tau\tau$ scan ; Postdoc, Graduate Student, Hadavand The control region used to determine the parametrization of the jets faking tau objects is defined as having two same sign tau leptons and inverting one of the tau identification criteria. Simulation is used to predict the shape of the contribution from events with two true leptons and hadronically-decaying tau that are either correctly reconstructed or reconstructed from leptons or leptonically-decaying taus. These two parameterizations of the two backgrounds are then used to fit to the data as a more sophisticated template method. The sidebands of the Z boson can be used to validated this approach.

Parameterize Background As described in section 1.1.3 the backgrounds to the multiple BSM analysis will be J/ψ, v, $t\bar{t}$ Drell-Yan, and Z tails. One can parameterize these background from the control regions described above then fit for the normalization within the signal region similar to what is done in the $\tau\tau\mu\mu$ analysis on ATLAS [39]. The SM ZZ* is a non-peaking background which may be difficult to model. This background and the SM resonant backgrounds can be parameterized with MC and used in the fits. Hadavand has extensive experience with parameterized fits from the BABAR experiment and can guide Hadavand's graduate student to model the various SM backgrounds.

Perform two separate scans in Z final state In the decay of Y $\rightarrow$Z + X the mass of X can be reconstructed as X(ee), X($\mu\mu$), and X($\tau\tau$). The three Z scans look at the X(ee),X($\mu\mu$), and X($\tau\tau$) mass spectrum. For the X(ll), l=e,μ spectrum the Z will be reconstructed as Z($\tau\tau$). For the X($\tau\tau$) spectrum the Z will be reconstructed in Z(ll), l=e,μ. The X(ee) and X($\mu\mu$) can be potentially combined if the resolution of the particles are similar enough. The X($\tau\tau$) will not be combined with X(ll) l=e,mu since the resolution is quite different and the bump-hunter would not gain in looking for two overlapping bumps of vastly differing resolutions. The use of the bump-hunter will allow for a first statistical pass at the data to determine if there is an existence of signal in the samples.

Develop and Optimize Bump-hunter to Scan Data Hadavand has previously worked on a bump-hunting technique that would be independent of the signal model used, called Signal Parameter Independent Fit (SPIF). Using the parametrization described above for the background modeling, a fit is performed on the data and a window where signal is expected is removed. The background is then extrapolated within this window and the difference of the number of events in the window versus the fit extrapolation is determined. A p-value is determined for the difference between the number of events in the window and the extrapolated background within the window. A scan is done using as input the step size and a range of window sizes. Several scans are performed changing the window size and step size iteratively until the p-value no longer improves within a specified precision. Once all iterations are performed, the window(s) with the smallest p-value(s) is(are) reported. If the bump-hunter analysis reports no significant signal then a coarser binning can be used for the limit setting saving time and CPU power.

Milestones

- FY17 - Take new graduate student for Z+X analysis.
- FY17 - Hire new postdoc to work on charged Higgs and Z+X analyses.
- FY18 - Develop analysis suite for Z+X analysis.
- FY18 - Publish Z+X results using Higgs mass constraint.
- FY19 - Publish Z+X results with no mass constraints.

1.1.5 Higgs Decays to Invisible Particles (PI: White)

A key question for the Higgs boson is whether it couples to the dark matter. If dark matter is indeed composed of particles, then presumably the 125 GeV Higgs, or some other Higgs boson, is at least partially responsible for their mass generation (assuming that the new particles have a weak interaction). We will continue to explore this possible connection by searching for evidence of Higgs decays to invisible particle(s). Limits on the decay of the Higgs to invisible particles from the LHC experiments can be used in turn to set limits on the process of dark matter particle-nucleon scattering, which are highly competitive with those from direct searches. The spin-independent cross-section for dark matter scattering on nucleons via Higgs exchange is directly related to the invisible width of the Higgs.

The most promising channel for this analysis is Higgs production through Vector-Boson Fusion (VBF) as shown in Figure 1.1.5 (left). The signature for this process, with an invisible Higgs decay, is two forward jets, widely separated in pseudorapidity, and large missing transverse energy. There is also a smaller signal contribution from gluon-fusion plus two jets. The two main backgrounds are $Z(\rightarrow \nu\nu)$ +jets and $W(\rightarrow \ell\nu)$ +jets (including τ decays), where the charged-lepton in the final state is not identified in the detector. There are also small backgrounds from the strong production of jets (multijet), $t\bar{t}$, and diboson production. For the Run 1 analysis White served as contact editor together with Ketevi Assamagan(BNL), and Bill Quayle(LBNL). 20.3 fb-1 of data at 8 TeV were analyzed and a limit of 28% was set on the branching ratio of the H(125) to invisible particles at 95% confidence level (with an expected limit of 31%) [**?**]. This was the best limit set by all ATLAS and CMS analyses for Run 1. The use of a $W(\rightarrow \ell\nu)$ control region, as well as the $Z(\rightarrow \ell\ell)$ control region, to estimate the $Z(\rightarrow \nu\nu)$ +jets background was a significant factor in setting our low Run 1 limit. Figure 1.1.5 (right) also shows the limit, as a function of mass, that our analysis sets on the Higgs-nucleon cross-section, and the comparison with direct search limits. White presented the ATLAS and CMS results on invisible decays of the Higgs at the LHCP2015 Conference in St. Petersburg, Russia. [**?**]

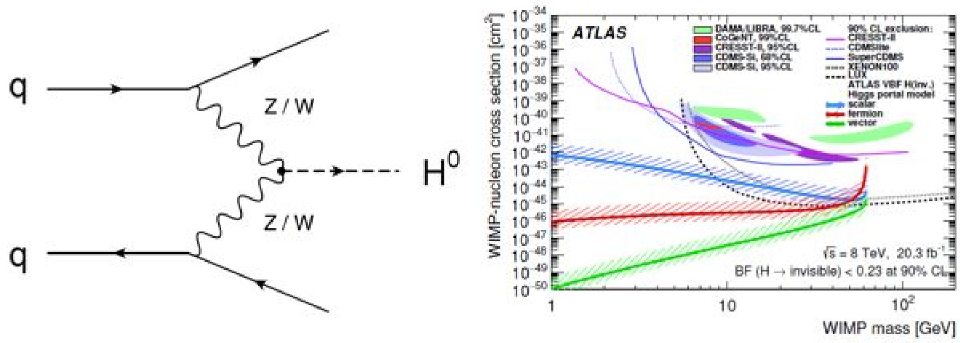


Figure 2: (left) Higgs production via Vector-Boson Fusion. (right) WIMP nucleon cross section as a function of the WIMP mass.

The increased Higgs production cross-section at 13 TeV, and the higher integrated luminosity from Run 2 will allow us to probe this process with significantly increased sensitivity over our Run 1 results. White (working with Alex Madsen (DESY)) is analysis contact for the Run 2 Higgs to Invisible analysis. Weekly meetings are held to coordinate the contributions to the analysis: data/Monte Carlo samples and comparisons, trigger(s), control regions specification, theory uncertainties, and limit setting. We have also been holding workshops at critical times to advance the analysis. Given the rate at which ATLAS is acquiring integrated luminosity, we expect in 2016 to reach the point at which we begin to be limited by systematic errors rather than statistically limited. In this respect investigations are ongoing into potential methods for cancellation of systematics in efficiency ratios versus the usual application of transfer factors from control to signal regions. Specific contributions from UTA to the Run 2 analysis include calculating the electroweak corrections to the the VBF Higgs signal, and providing the parton distribution function (pdf) uncertainties on the signal. For the electroweak corrections, we have set up HAWK [**?**] on the UTA Tier 3 in multi-threaded mode as more than 10^9 events are needed to achieve sufficiently precise corrections. HAWK provides the calculation of differential EW correction factors, which can be used as differential EW reweighting factors to improve QCD-based predictions. The results of the HAWK calculations are shown in Figure 1.1.5 - the reweighting factors have essentially a linear dependence on the Higgs Pt, and a linear fit yields the required electroweak correction.

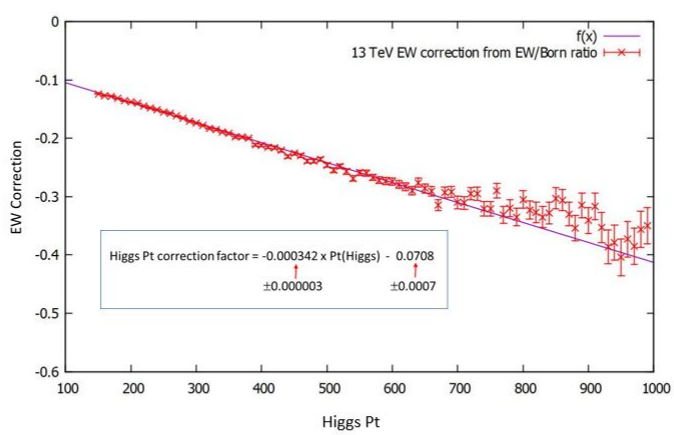


Figure 3: Electroweak corrections to the Higgs pT distribution in the VBF selection.

For the calculation of the VBF signal pdf uncertainties, UTA has been running the generator Powheg v.2 [?] which allows the storage of multiple weights for each event. Our original VBF signal dataset was created using the CT10 pdf set. There are now recommended pdf sets for LHC Run 2 which combine CT14, MMHT2014, and NNPDF3.0 [?]. Currently, after exchanges with Higgs and Exotics group colleagues we have chosen to use the PDF4LHC15-nlo-30-pdfas set. This is a Hessian set that allows straightforward calculation of the uncertainties, which is the variation in the number of weighted events passing the VBF selection. This work is being carried out by UTA Honors undergraduate student Darshan Chalise under White's direction. UTA will continue to provide both the electroweak and pdf uncertainties for future versions of our analysis.

The current analysis plan is to write a paper based on the 2015-16 data set, estimated to comprise about 30 fb^{-1}. The goal is to have this result ready for Moriond 2017. White will take on a new graduate student in the Fall 2016 semester. This student will work on the 2017-18 extension of the VBF Higgs to Invisible analysis. Going forward we will focus on improvements and changes to the analysis that will be necessitated by the rising instantaneous luminosity - pileup mitigation, particularly for forward jets, and reduction of the systematics for the jet energy scale and resolution. Work in these areas will form part of White's new student's ATLAS qualification tasks. Of significant physics interest, with reducing limits on the Higgs to invisible branching ratio, will be our ability to exclude models that predict an enhanced value of this ratio. There is a natural evolution of White's physics interest in this topic also with the ILC project (see the ILC section below), which will allow much stronger constraints to be set on Higgs to invisible decays.

VBF HIggs to Invisible Analysis Timetable of Activities

2017

- New UTA graduate student starts work on ATLAS
- Publish Run 2 paper based on 2015-16 dataset
- Work on ”interpretation” paper for Run 2 results, DM-nucleon limits and more
- Study strategies for reduction of jet systematics
- Update Higgs to Invisible limit as more data becomes available

2018

- Graduate student pursues ATLAS qualification with work on strategies for reduction of jet systematics
- Contribute data/MC comparisons and cutflow checks
- Provide updated electroweak signal corrections, and pdf uncertainties
- Graduate student begins year at CERN
- Work on branching ratio limit from full Run 2 dataset

2019

- Publish full Run 2 result
- Work on analysis strategies beyond Run 2

1.2 SUSY Physics (PI: De, Farbin)

Despite no evidence of Supersymmetry (SUSY) in LHC Run 1 and early Run 2 data, this extension of the Standard Model's symmetries continues to remain the most compelling mechanism to avoid the fine-tuning problem of the electroweak symmetry breaking mechanism (the hierarchy or naturalness problem), while also providing Gauge Unification and a Dark Matter candidate. The current highly successful LHC run, with a significant increased center of mass energy and integrated luminosity, provides a brief window where data-doubling time at a new energy is short and large strides can be made in the search for new particles. As LHC nears end of Run 2, further strides will require more sensitive techniques that can target difficult regions while also searching broadly for excesses.

This section overviews activities and plans of UTA SUSY group, consisting of faculty De and Farbin, postdocs Usai, Heelan, and new hire in 2017, and students Darmora, Bullock, Little, and Rogers.

1.2.1 Squarks and Gluino (PI: Farbin)

The most stringent limits on sparticles generally come from inclusive searches for strongly produced light squarks and gluinos, in particular into all hadronic final states. In ATLAS, these searches are performed within the inclusive squark and gluino SUSY sub-group, composed of approximately 140 members and presently split into eight paper streams based on the number of jets and lepton flavors in the final state. UTA has been involved in these searches since beginning of Run 1, twice convening this subgroup (UTA postdocs David Cote and Heelan), and most recently supervising several public papers and conference notes for ICHEP 2016 [3, 40–52]. Heelan also directly contributed to the search for SUSY in all hadronic states, which is a flagship SUSY search.

Between 2010-15, Farbin's ECRP grant supported introduction of novel "event view" techniques to search for SUSY, with the Razor reconstruction technique [4] in 2011 [1] and 2012 [2]. The most recent iteration of this line of searches, based on an extension called the Recursive Jigsaw Reconstruction (RJR), was fully integrated into the mainstream Run 2 search performed for ICHEP2016 [3] and was the final topic of Bullock's now completed PhD thesis [53]. The RJR groups all final state objects into hemispheres based on assumptions (or views) about how the decay is proceeding, providing an uncorrelated basis of observables consisting of energy scales (masses, transverse quantities) and scaleless variables (like angles between hemispheres and ratios of energy scale variables). RJR-based selections generally only partially overlap with standard selections (i.e. based on missing transverse momentum, H_{T}, etc.), for example bringing in an observed 50% additional events in the all hadronic final state and thereby extending both the phase space and the statistical reach of such searches (if properly combined).

The RJR views used for ICHEP2016, shown in figure 4, were designed to search for SUSY produced by squark or gluino pair production and direct decay to final states containing jets and the lightest supersymmetric particle. While this RJR technique had a standalone expected sensitivity similar to that of the standard technique, RJR extended sensitivity by also targeting difficult phase-space regions with views of Compressed Spectra (CSS) scenarios where all final state objects are assumed to recoil off an ISR jet [5]. In CSS, small mass splittings between the heavier produced sparticle and lightest SUSY particle (LSP) lead to soft final state objects and missing transverse momentum that fail traditional scale-depended background suppression selections.

As evident in the ICHEP2016 conference note [3], the RJR ISR event view extended the squark and gluino exclusion limits with respect to the standard effective mass analysis for the squark-squark and gluino-pair production cases by as much as 50% and 100%, respectively, reducing mass differences sensitivity by 50 GeV to $\Delta m(\tilde{q} - \chi_1^0) = 100$ GeV at $m_{\tilde{q}} = 700$ GeV and $\Delta m(\tilde{g} - \chi_1^0) = 50$ GeV at $m_{\tilde{g}} = 925$ GeV. For Run 2, Farbin's student Bullock helped Rogan (Harvard) and Jackson (Adelaide) implement and commission a Razor-based high-level trigger that uses only scale-less quantities and therefore enhances CSS trigger efficiencies. This trigger is not yet used in Run 2 searches because the prescale threshold for the missing energy triggers are still below the expectations and the corresponding optimization of the running Razor trigger.

1.2.2 Stop Searches (PI: De)

The heavy mass of the top quark could lead to its supersymmetric partner being the lightest squark. PI De's group has been searching for the stop in DØ and ATLAS since the discovery of the top quark. So far, this has led to multiple successful Ph.D. thesis from both Tevatron and LHC data – but alas

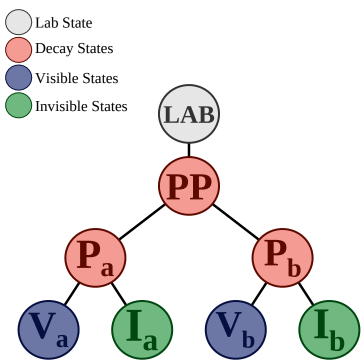


Figure 4: Recursive Jigsaw Reconstruction event views for three scenarios: (a) Two sparticles (P_a and P_b) are pair-produced with each decaying to one or more visible particles (V_a and V_b) which are reconstructed in the detector, and two systems of invisible particles (I_a and I_b) whose four-momenta are only partially constrained. (b) An additional level of decays can be added when requiring more than two visible objects. (c) Strong sparticle production with an ISR decay tree for use with small mass-splitting spectra, where a single sparticle system S decays to a set of visible momenta V and invisible momentum I, and recoils off of a jet radiation system ISR.

no sign of the stop. De's latest student, Smita Darmora, defended her Ph.D. thesis on the search for the stop in August, 2015. Her work was co-supervised by base funded researcher Guilio Usai. The title of her thesis was: "Search for a Supersymmetric Partner to the Top Quark using Multivariate Analysis Technique."

Smita's search focussed on the decay of the stop quark to a chargino and a bottom quark. The chargino subsequently decays to a lepton and missing Et (which comes from the missing neutrino and the missing LSP). The final state is then missing Et with two opposite sign leptons and two b-jets. The primary backgrounds to this channel are top pair production, di-boson production and Z plus jets. The compressed mass spectrum from the chargino-neutralino mass difference leads to soft leptons among the decay products, making this search challenging. We optimized the search separately for soft leptons and hard leptons. Initially, Smita tried a cut based analysis. To improve on the results obtained from the cut based analysis, a multivariate analysis was attempted. This led to a significant increase in the search sensitivity.

The multivariate analysis (MVA) technique used for this search employed a "supervised learning" algorithm. A Boosted Decision Tree (BDT) technique was used with a Gradient boosting algorithm, commonly known as BDTG. The TMVA training used eleven classifiers. In rank of importance, missing Et, ratio of leptonic and jet Pt's, and angle between lepton and missing Et had the highest importance. Ten of the chosen variables had non-zero significance. After a long and complicated analysis, Figure 5 shows the 95% confidence limit exclusion limit for a 300 GEV mass stop obtained by Smita.

The analysis of Run 1 data is completed. We are continuing the search for stop quark pairs produced in final states with two leptons with Run 2 data. At this stage, Jared Little is setting up our code to run with the new derived data format for Run 2. Darmora and Usai are also involved. We are trying to understand the background distributions in Run 2, with it's higher energy and luminosity. Most of the Monte Carlo samples have already been generated. We are setting up a cut based analysis. We expect to complete the cut based analysis in early 2017. Later in 2017, we will train the TMVA analysis. Both the same sign and opposite sign lepton samples will be analyzed. We will also optimize the analysis for soft leptons. We plan to explore more sophisticated Deep

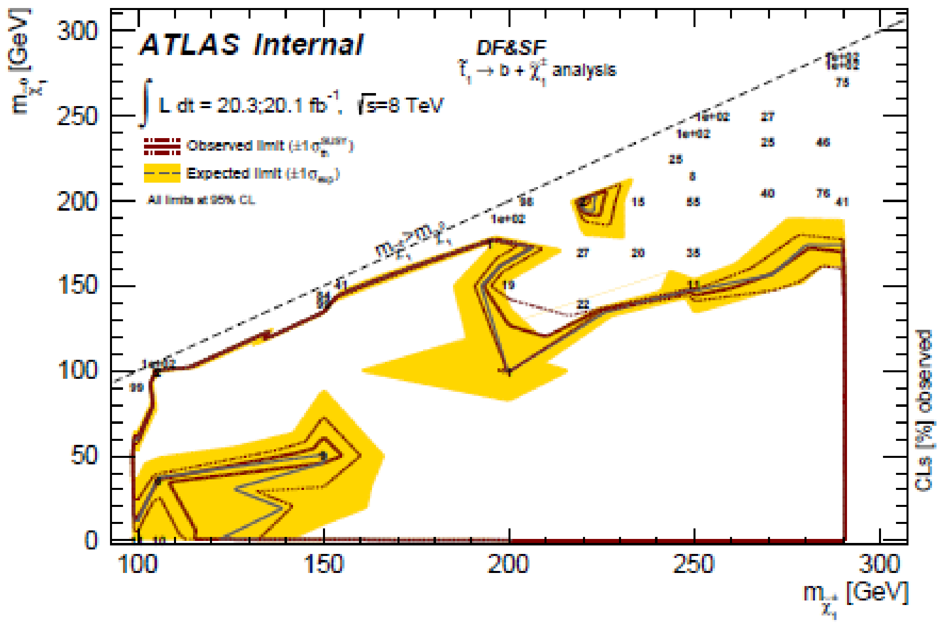


Figure 5: Exclusion limit for a 300 GeV mass stop obtained by combining MET trigger and Lepton trigger samples from a Ph.D. thesis written by Smita Darmora.

Learning techniques to increase the sensitivity of this search. By the end of 2018, we will be ready to do the analysis with 100 fb^{-1} of data. By the spring or summer of 2019, we will present the results with this large data sample. Finally, in 2020 we will conclude this search with the full Run 2 data sample.

1.2.3 Run 2 Searches (PI: Farbin)

The unique and novel tools and high level of technical proficiency that is characteristic of Farbin's SUSY group renders them extremely efficient at participating in mainstream searches while simultaneously exploring and employing leading edge techniques in complimentary efforts. Due to a long history with the Analysis Software Group (ASG), SUSY software, and ATLAS software tutorials, the group is in many ways the best equipped and most experienced in ATLAS in easily navigating the required technical obstacles of manipulating data and performing analyses. RJR and the associated RestFrames [54] toolkit are also such an asset. A new tool is Deep Learning, an area where Farbin's breadth and depth of efforts is unmatched in HEP.

The ATLAS SUSY working group currently plans two more full rounds of searches in Run 2, which no doubt will include the flagship inclusive searches for squarks and gluinos. Considering UTA's long history with these searches, and the fact they are generally under-manned, Farbin's group will continue to lend critical manpower to these efforts, by embedding graduate student Rogers and new postdoc shared with De in the large dedicated teams.

The ATLAS SUSY group is also considering a reorganization of searches from model-based (e.g. squarks and gluons, stop, electro-weak chargino, etc.) back to signature based (i.e. all hadronic, one lepton, etc.), where each signature will include a large number of signal regions targeting different models. This change will be welcomed by Farbin's group as it more closely mirrors their first Razor-based search [1] and Farbin's long term plans for general searches. As this reorganization occurs, Farbin's group will work to help define RJR-based regions for signatures beyond the all hadronic final states, by ensuring that appropriate RJR views are constructed for every search and corresponding observables are available to analyzers as they define signal regions.

As the gains in SUSY reach from Run 2's energy and luminosity boost are exploited in the first Run 2 exclusion limits, subsequent searches will require dedicated effort to identify and target difficult phase-space regions and increasingly sophisticated techniques to extend reach. At the end of Run 1 both ATLAS and CMS scanned feasible parameters in the phenomenological MSSM (pMSSM) [55, 56] to understand the strengths and weaknesses of traditional searches [57, 58]. Then UTA postdoc David Cote was one of the primary drivers of this effort. In the pMSSM the 105 free parameters of the MSSM are reduced to 19 by making assumptions based on theoretical and experimental results. Millions of SUSY signals were generated by varying those 19 free parameters uniformly (within some allowed physical range). These studies helped inform several strategies Farbin's group will pursue as they continue to design and carry out SUSY searches. The two most important are

- **Cross-section optimized searches:** While exclusion limits on large cross-sections processes, such as strongly produced squarks and gluinos, can be extended to higher masses (i.e. lower cross-sections) with more integrated luminosity, LHC searches are insensitive to high cross-section scenarios where traditional scale-dependent observables such as H_{T} (scalar sum of momenta) and missing energy are small. In addition, since searches are optimized to extend mass limits, which rely on cross-sections from Simplified Models where only relevant new particles with 100% branching fractions are added to the SM, sensitivity to smaller cross-sectionS at lower masses are often sacrificed. Farbin's group will rely on the Razor trigger and the RJR techniques to address the former problem, while working to define additional signal regions to address the latter.

- **Compressed spectra and initial state radiation:** The low p_{T} spectra (a.ka. soft) of decay products in CSS prohibit differentiation from Standard Model processes and fail standard trigger selections. Mono-jet signatures can probe these models, as they searches for a single high p_{T} jet, presumed from initial state radiation (ISR), and missing transverse momentum. The RJR ISR technique, as applied for ICHEP2016 and detailed in [5], provides the most powerful method for generically searching for any CSS scenarios, and without dependence on the SUSY decay. Farbin's group will collaborate with Rogan and Jackson to develop such CSS general search in ATLAS. In addition, using the samples in [5], Farbin is presently collaborating with Rogan and Jackson to target CSS with Deep Learning techniques, with a goal of a rapid non-ATLAS paper.

1.2.4 SUSY Search R&D (PI: Farbin)

Farbin proposes to work towards the R& D of three new techniques for SUSY searches. The first attempts to classify the topology of every event. For example, consider the $bbll$ + MET final state which can come from a large number of SUSY and SM processes, for example stop pair production with $\tilde{t} \to t\tilde{\chi}^0$, stop pair production with $\tilde{t} \to b\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{\pm} \to \tilde{\chi}_o W^{\pm}(\to l\nu)$ or $\tilde{\chi}^{\pm} \to l\tilde{\nu}(\to \tilde{\chi}^0\nu)$, chargino pair-production with $\chi_2^0 \to Z(\to ll) + \tilde{\chi}_1^0$ and $\chi_2^0 \to h(\to bb) + \tilde{\chi}_1^0$, or fully leptonic SM $t\bar{t}$. The RJR allows constructing views and associated observables for all such topologies, enabling discrimination by directly comparison of observables from different views, a handle used in the RJR-ISR CSS technique described above. Using a Parameterized Deep Learning Classifier [59], which builds a neutral network optimal for any mass in the decay tree, Farbin was able to correctly identify a few signal topologies over 95% of the time [15]. The vision here is a signature-based search in-line with SUSY WGs plans, where events are sorted into topologies. Farbin's group in collaboration with Rogan and Jackson will fully explore the $bbll$ + MET final state and lead SUSY WGs towards this approach. The Long-term vision of this thrust is to apply the technique across large number of final states, working towards a general search with the entirety of the Run 2 data during LS2.

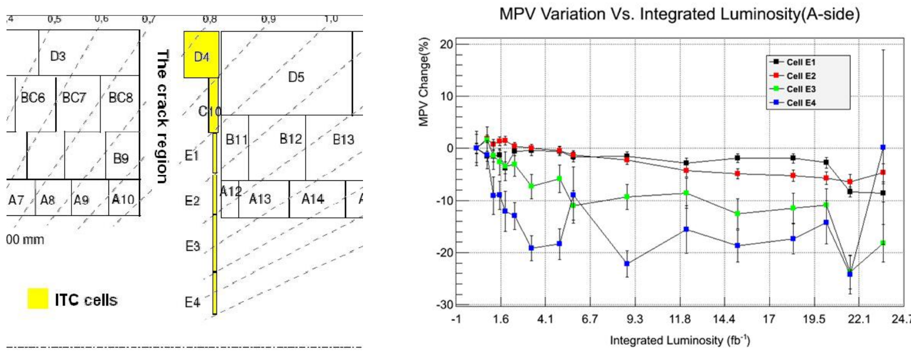
The second technique is to simply use Deep Learning classifiers as the multivariate tool to improve background rejection. Farbin is already pursing this direction with the CSS search described above. Farbin will also assist in upgrading existing multi-variate based searches, for example the stop search performed by De described in section 1.2.2, to the potentially more powerful DNNs. It is also rather straightforward to evaluate the potential of DNNs to improve other non-MVA based searches, for example those planned by Hadavand and Brandt in section 1.1.1. While DNNs based on traditional high-level observables like masses and angles (a.k.a. features) may provide modest improvements, DNNs can also be used to identify additional handles by using 4-vectors as input. Such studies typically find that 4-vectors outperform traditional features, suggesting presence of additional unexplored handles. The problem is that most searches rely on some orthogonal observable, otherwise unused in the MVA, to build sidebands for background estimation. A 4-vector based DNN's output will likely be highly correlated with any such observable, prohibiting designating unbiased sideband regions. While there are avenues to tackle this problem, direct application of DNNs in searches is not necessary to reaping their benefits. Instead, 4-vector based DNNs can usually also indirectly help by identifying new features (i.e. observables) than can be added to the traditional analysis.

Detector Related Activities in ATLAS

1.3 Intermediate Tile Calorimeter (PI: De, White)

Intermediate Tile Calorimeter, [PI: De, White] The Intermediate Tile Calorimeter (ITC) was designed to fill the gaps between the central barrel calorimeter and the extended barrel calorimeters, and was built at UTA. Figure 6(a) shows a schematic view of part of the ATLAS calorimeter, showing the components of the ITC. For particles which originate at the nominal interaction point, the ITC extends over approximately $0.8 < |\eta| < 1.6$. The region $0.8 < |\eta| < 0.9$ contains 311 mm thick steel-scintillator stacks, similar in design to standard Tile Calorimeter submodules. Between $0.9 < |\eta| < 1.0$, the stacks are 96 mm in the z-direction. The combined $0.8 < |\eta| < 1.0$ region of the ITC is called the plug. In combination with the support structure for the scintillators, it is called the ITC submodule. For the forward region, the active elements of the ITC consist of scintillator only due to space constraints. The scintillators between $1.0 < |\eta| < 1.2$ are called the gap scintillators, while those between $1.2 < |\eta| < 1.6$ are called cryostat scintillators. Some additional scintillators, designated E4-prime were installed in 2015, covering $1.6 < |\eta| < 1.72$ and a small sector in ϕ, in order to explore the possibility of extending ITC coverage for improved electron and jet measurements. Together, all these ITC detectors improve the measurement of total energy in the intermediate region, thereby improving the jet and $\not{E}_T$ resolution of ATLAS.

The ITC was proposed by PI De, who has served as the US ITC project manager (level 2) for the past 15 years. This unique detector was fully designed, constructed and is now maintained by US groups. De's group will continue to play a crucial role in ATLAS hadronic calorimetry. De's postdoc Usai, who is supported 20% under the base program for ATLAS service work (Usai is supported 45% through project funds), coordinates UTA work on TileCal. Usai is located at CERN. He supervises the work of UTA graduate students stationed at CERN that perform service work on



(a) (b)

Figure 6: Left - Layout of the Intermediate Tile Calorimeter. Right - Average change for ITC E-modules vs. integrated luminosity for Run 1.

TileCal. He works with De's students Darmora and Little to provide regular calibration updates of the ITC using the Cesium (Cs) calibration system. Usai also played a major role in developing the MobiDick4 portable DAQ system, which is being used during LS1 to check and repair Tile eletronics.

It is anticipated that the E cell scintillators will need to be replaced in the long shutdown in 2019, due to the expected high levels of radiation damage. White, with postdoctoral associate Park, previously carried out studies of radiation damage using Gaussian plus Landau fits to the signal distributions for all E-cell channels. This proved to be a very challenging exercise due to the high degree of variabilty of the signal profiles. Nevertheless, results were obtained as shown in Figure 6(b). Most of the decrease in response can be atributed to the downward response of the PMT's due to continual exposure to light during the run, as shown by the laser illumination of the photocathodes. However, there was a few percent decrease on top of this effect that was attributed to radiation damage. This approach to monitoring decreased response has now been replaced with the use of minimum bias data plus the laser measurements. The replacement of the E-cells scintillator affords the opportunity to revisit the η and ϕ segmentation of the cells. In order to determine the best layout for optimization of energy resolution in this region, UTA has been working with the Tiblisi group to examine the distributions of jet energy fractions in the E-cells. The work at UTA has been carried out by Honors undergraduate student Niyusha Davachi under White's supervision. As an example, Figure 1.3 shows the fractional energy contribution for each of the E-cells, for QCD jet events where the jet axis lies in E4, for three groupings of adjacent ϕ cells (3,5, and 7). By studying these fractional energies for jets within all the E cell η ranges, we will optimize both the use of the deposited energies for jet reconstruction, and the propose potential new layout(s) for the E cells. This work is ongoing with the goal of providing a recommended layout of the new E-cells scintillator in late 2017/18, when the new tiles will have to be ordered.

While the scintillator replacement is not within the scope of US ATLAS work for Phase I, the UTA group has made contributions to the estimation of the expected integrated radiation dose during Run 2, to the specification and identification of radiation-hard scintillator, and will be involved in the procurement, installation and testing of the new tiles. This work will also be included in the qualification tasks for White's new graduate student.

ATLAS Tile Calorimeter Service: White has been a member of the Tile Calorimeter Speakers' Committee, with responsibility for major conferences such as IEEE_NSS and DIS, and for the review of Tile proceedings and notes.

ATLAS Tile Calorimeter Timetable of Activities: Our work on the Tile Calorimeter/ITC for

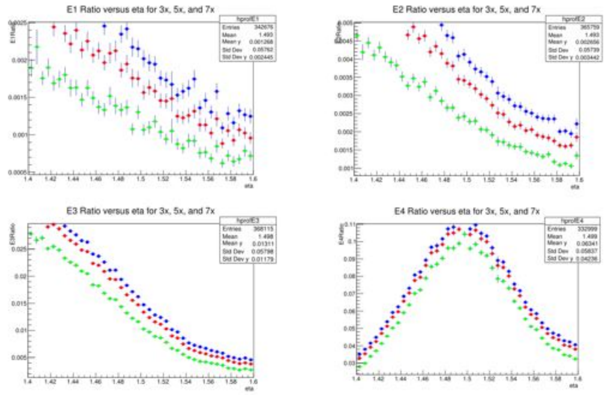


Figure 7: Fractional contribution to jet energy by the Ei (i = 1,2,3,4) cells for the case where the jet axis lies in the E4 range, $1.4 < |\eta| < 1.6$.

Phase I will be carried out in collaboration with colleagues in CERN and Tblisi.

2017

- Complete the study of the optimal use of exisiting E cells for improving jet energy resolution
- Update expected radiation doeses for E cells based on known and projected Run 2 luminosities.
- Study/propose alternative E cells configurations for the 2019 tile replacements
- Continue as a member of the Tile Calorimeter Speakers' Committee.
- Contribute DQ Validator shifts

2018

- Complete plans for ATLAS ITC Tile/Fiber replacements in LS2.
- Investigate the availablity of radiation-hard scintillator for new ITC tiles.
- Prepare (with ATLAS Tile Institutes) tile/fiber assemblies for installation in LS2.
- Graduate student begins time at CERN, with Tile Calorimeter qualification tasks.
- Contribute DQ Validator shifts

2019

- Study effects of radiation on light yield/transmission for dismounted ITC tiles.
- Contribute effort to installation and testing of the new ATLAS ITC E-cells.
- Graduate student returns to UTA.

1.4 MET Trigger (PI: Brandt)

The missing transverse energy ($\not\!\!E_T$) trigger is an essential trigger for numerous physics searches in ATLAS, including two searches led by UTA: the search for an invisible Higgs in the Vector Boson Fusion production mode; and the search for a charged Higgs decaying to a tau lepton and its associated neutrino. The $\not\!\!E_T$ trigger is preferable in the invisible Higgs search due to the high rates of forward jets, and the relatively low efficiency of a pure VBF trigger studies are ongoing on the feasibility of combining VBF and $\not\!\!E_T$ topologies with use of the L1Topo (topological processor). On the other hand the $\not\!\!E_T$ trigger is preferred over tau or multi-jet triggers in the H$^+$ $\Rightarrow \tau\nu$ search due to inefficiencies in the tau triggers and the bias a tau trigger introduces in the data driven background estimation techniques.

For a $\not\!\!E_T$ only trigger to be effective for searches it should remain unprescaled. For the 2016 data taking period a trigger with $\not\!\!E_T$ > 50 GeV at the hardware trigger level (L1) is effective at controlling the rate into the high level trigger (HLT), and it was envisioned that a requirement of at least 80 GeV on the vector sum of topological clusters would be sufficient to control the rates out of the HLT for the entire year. It became clear after a few months of data taking that the trigger rate growth with increased luminosity would soon be unsustainable. UTA Graduate Student, Last Feremenga, studied the feasibility of maintaining the cluster based $\not\!\!E_T$ triggers by recalculating the vector sum without forward clusters, which might be more susceptible to multiple interactions He showed that while efficiency was unaffected by restricting the cluster eta position, the rates were also largely unchanged. A trigger which replaced the cluster sum of 80 with a sum of the jets $met > 90GeV$, was better behaved, but the excellent performance of the LHC necessitated an increase in threshold to 110 GeV for the ICHEP data set. As of September 2016, it was decided that this trigger would not be tenable for the rest of the run. Rather than raise the threshold again, our efficiency studies indicated that it was better to add a requirement on the vector sum of all cells above noise threshold,.

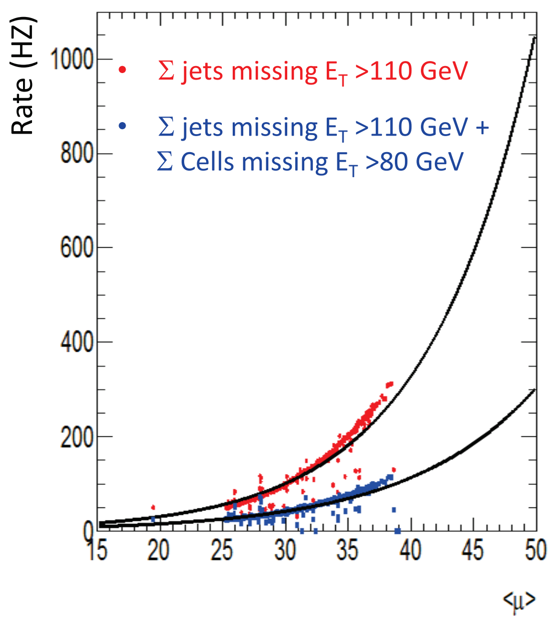


Figure 8: Rates vs $< \mu >$ for the 110 GeV jet sum with (blue) and without (red) the additional requirement that the vector sum of the cells is greater than 70 GeV.

This solution lowers the rate sufficiently for the 2016 data taking, but as seen in Figure 1, the exponential rate dependence on $< \mu >$ remains.

The understanding of the $\not\!\!E_T$ trigger rates will remain a high priority for many analyses moving forward in 2017 and beyond as the pileup conditions at the LHC become more intense. We plan to help fully understand the issue and devise longer-term solutions. Based on our previous trigger experience with forward jets, pileup, and topology tools, we have several ideas to help develop a longer term solution improve. Some potential improvements include: adding a minimum p_T requirement on jets that go into the vector sum, placing a minimum p_T requirement on the leading jet in the event, ensuring the leading jet is not collinear with the $\not\!\!E_T$, suppression of pileup jets using FTK tracks in conjunction with the offline JVT algorithm, etc.

Computing Activities in ATLAS

UTA has a long history of contributions to ATLAS computing for the past 20 years. For example, UTA physicists advocated the use of C^{++} and the adoption of an object oriented paradigm when ATLAS collaboration was started. We performed some of the earliest GEANT calculations to motivate the design of the ITC Calorimeter built at UTA. After construction of the ATLAS detector, UTA involvement in ATLAS Computing intensified with participation and leadership in all the Monte Carlo Data Challenges (DC0, DC1, DC2...). Over the past 10 years, UTA has been deeply involved in ATLAS Distributed Computing (ADC), as well as in other areas of Software and Computing (S&C) in support of the LHC physics goals. UTA hosts the SouthWest Tier 2 center, and is a cornerstone of the highly innovative PanDA system, now being used widely in many data intensive sciences. We lead US distributed computing operations, and many other areas of service and support activities. While most of the funding for computing activities is supported through other grants, UTA base funding provides the intellectual underpinning of the highly successful UTA contributions. In the following sections we describe some of the many service roles that UTA plays in S&C.

1.5 ATLAS Distributed Computing (PI: De)

Computing was acknowledged during the Higgs discovery talk in July, 2012, as one of the foundational pillars of ATLAS. Under the leadership of PI De, UTA has played a critical role in the success of ATLAS distributed computing. The members of our group hold key positions in distributed computing leadership, both in software (PanDA) and distributed production and analysis, while also operating the SouthWest Tier 2 Center at UTA. De is currently the US ATLAS Deputy Software and Computing Manager, PanDA co-Coordinator, and ATLAS SouthWest Tier 2 Coordinator. His PanDA computing activities are funded through a grant from the Advanced Scientific Computing Research (ASCR) division of DOE. All the members of De's computing group are funded through this grant or through US ATLAS M&O (project) funds. The activities of De's group provide enormous benefit to ATLAS physics results.

Distributed computing enables the three thousand physicists in ATLAS to analyze the huge volume of data from the ATLAS experiment quickly and effortlessly at the hundreds of computing centers available within the collaboration. Physics results are not constrained by local computing resources - everyone has access to all the resources equally. The PanDA software, originally proposed by De and still co-led by De, revolutionized the paradigm of scientific computing in the age of Big Data. PanDA is used by ATLAS physicists to run a million jobs every day. PanDA is not only used by ATLAS, but is also being actively used or tested for adoption by many HEP and NP experiments, including the AMS experiment on the space station. PanDA is a unique US invention which accelerates scientific discoveries. The center of gravity of PanDA is at UTA and Brookhaven National Laboratory (BNL). International partners include CERN IT, and collaborators in Russia (DUBNA) and Taiwan, along with many ATLAS collaborating institutes.

PanDA provides enormous benefit to the base program at UTA, in addition to the key role it plays in ATLAS scientific goals. The following people from UTA are working on PanDA, SouthWest Tier 2, and distributed computing support, while fully funded through sources other than the base program.

- Senior researcher: Armen Vartapetian, US Computing Operations Coordinator, co-Coordinator of ATLAS ADCoS (ATLAS Distributed Computing operations Shifts).
- Senior researcher: Nurcan Ozturk, ATLAS Distributed Computing co-Coordinator, US ATLAS Software manager (in charge of all US ATLAS software development).

- Computing specialist: Mark Sosebee, US computing operations support, system specialist at ATLAS SouthWest Tier 2 center at UTA.
- Computing specialist: Paul Nilsson, lead software developer of the PanDA pilot code.
- Computing specialist: Patrick McGuigan, system manager of ATLAS SouthWest Tier 2 center at UTA.
- Software developer: Danila Oleynik, use of PanDA at DOE's Oakridge National Laboratory.
- Software developer: Fernando Barreiro, PanDA core services developer, co-Coordinator of ATLAS WFMS (WorkFlow Management Systems) working group.
- Computing specialist: Mayuko Maeno, computing operations and software installation support.

1.6 ATLAS SouthWest Tier 2 (PI: De)

The SouthWest Tier 2 center (SWT2) located at UTA, the University of Oklahoma, and Langston University is funded by the NSF M&O program for USATLAS and through local support from the university. De is the director of the Tier 2 center, which consistently ranks as one of the top ten computing centers in ATLAS. While SWT2 is an important ATLAS-wide resource, the close proximity of almost 5 Petabytes (PB) of storage and over 5000 CPU slots plays a crucial role in the success of the base program at UTA, though no base funding is spent on the Tier 2 center. Working in conjunction with the local Tier 3 center at UTA, SWT2 enables the generation of rapid physics results by the UTA group.

For the next three year period proposed here, we expect SWT2 to help with the core physics goals of our group: the exploration of the Higgs boson, and the search for supersymmetry. Data processing, local storage and software caches will lead to expedited physics results in Run 2. This local computing expertise is particularly helpful to beginning graduate students.

1.7 Deep Learning (PI: Farbin)

The world is in the midst of a renaissance in Machine Learning and Artificial Intelligence, known as Deep Learning, driven by the emergence of large data sets, powerful Graphical Processing Units (GPUs) processors, and new techniques to train billion-neutron multi-layer artificial neural networks. Systems trained on raw and sometimes unlabeled data, can now recognize objects, detect human emotion and intent, play video games, translate between languages, generate mathematical proofs, sometimes better than humans and most importantly with minimal engineering. Developed in University Machine Learning labs, DL has led Google, Facebook, and other industry-leading companies to rethink everything, building Artificial Intelligence teams, software, processors, and cloud services, and demonstrating impressive feats.

Beyond better performance, new capabilities demonstrated by Deep Learning drive the unprecedented excitement across various fields and domains. Deep Neural Networks (DNNs), can learn features from raw data, eliminating need for expensive hand coded feature engineering, e.g. Event Reconstruction. They can find these features in unlabeled data (for HEP example see [60]), opening new tools for analyzing complex and poorly understood data. They can generate complex data starting with only examples, enabling simulation without a model and providing speed when there is a model. They can filter noise and compress data, find anomalies, and solve problems we do not know how to solve algorithmically.

Space constraints prohibit pedagogical discussion of Deep Learning and probing fine details of the activity described and planned out in this section. Surveys of DL activity in HEP and much of these details can be found in Farbin's recent talks [6, 8–15]. His HEP Software Foundation HSF presentation [13] details DL's impact on software and requirements. The ATLAS Machine Learning workshop presentation details the calorimetry and other ATLAS applications [12]. And the Harvard Big Data Conference [15] talk overviews DL across HEP. Farbin's DL activity is organized into thrusts that sometimes span multiple experiments. Many of these efforts will conclude with planned papers in the upcoming months.

Four thrusts of DL activity directly targeting the LHC will persist, of which will be described in this section because they will most immediately effect ATLAS and will involve individuals funded by this grant: Simple Classification and Calorimeter Reconstruction. Another thrusts is encapsulation of Matrix Elements in DNNs for Next to Leading Order (NLO) and Next to NLO (NNLO) computations and Matrix Element Method (MEM), a product of collaborations with Tancredi Carli (CERN), ATLAS's next Deputy Physics Coordinator and Tobias Golling's group (U. Geneva). The final thrust is core contributions to the TrackingML challenge, aimed at soliciting solutions to HL-LHC tracking problems, primarily driven by Andreas Salzburger (CERN) and David Rousseau (LAL).

In order to accelerate the progress of collaborators, including local students of Brandt, Hadavand, Asaadi, and Jones and the broad ATLAS community, Farbin has developed a Deep Learning Tutorial covering a variety of DNN tasks. The tutorial introduces a thin framework (DLKit) [61] developed by Farbin that simplifies running large-scale DL studies. This system was exercised on the GPUs of Oakridge's Titan HPC, a first for HEP, with help of Sergey Panitkin (BNL). Postdoc Heelan, who manages the ATLAS software tutorials and workbook, will introduce the DL tutorial at the October 3rd session, with submission to Titan via PANDA WMS a goal for a future iteration. It is also noteworthy that, since access to GPUs is often the biggest obstacle to DL, Farbin has granted access to the GPU system he as built with his undergrads to two dozen HEP scientists from 6 experiments (LArIAT, DUNE, MicroBooNE, NEXT, CMS, ATLAS).

Simple Classification with Deep Learning The first application of DL in HEP demonstrated that (fully-connected) DNNs out-perform shallow networks and derive new "features" from 4-vectors beyond traditional observables. Farbin recently demonstrated this simple application of DNNs with help of Chris Rogan (Harvard) and Paul Jackson (Adelaide). They showed that 4-vector based DNNs out-performed a Jigsaw-based DNNs in correctly distinguishing between different SUSY-like decay topologies, yielding above 95% accuracy [15]. This work is in a step in an effort to build DNNs that generically classify events and enable unsupervised general searches for new phenomena. As described in section 1.2.3, Farbin and his collaborators are also applying DNNs to compressed-SUSY scenarios, building on the experience of the ICHEP 2016 Jig-saw result and following Rogan and Jackson's recent paper [5]. Signal and background classification tasks are the first and simplest and can be easily enhanced by replacing traditional classifiers with DNNs. Groups in ATLAS are applying this idea to tasks like b-jet or boost-object tagging. Farbin will also be aiding Hadavand and Brandt to apply the technique to tau identification and Charged Higgs searches, as described in section 1.1.1.

Calorimeter Reconstruction with Deep Learning Starting in 2014, Deep Convolution Neural Networks (CNNs) have exponentially improved performance on ImageNet, a one-million image classification challenge [62], to now super-human performance [63]. An obvious application of CNNs is classification tasks, such as particle identification, in "imaging" detectors such as Time-Projection Chambers (TPCs), Cherenkov Imaging detectors, and high granularity Calorimeters. The first application in HEP of this idea was in the Nova collaboration, where they were able to obtain 40% better electron efficiency for same background rate as their best techniques [64].

In the fall of 2015, Farbin demonstrated two applications of CNNs to neutrino experiments, which can be extrapolated to calorimetry at the LHC. The first was in LArTPC, and has evolved to a collaboration with Pierre Baldi and Peter Sadowski at UCI to perform particle identification and energy reconstruction in LArIAT experiment. Using an unprecedentedly large public sample of 15 million events produced at UTA, this effort has employed sophisticated networks and cost functions, and long hyperparameter scans and training times to achieve impressive classification performance and tackle tricky energy reconstruction issues.

The second was in the neutrinoless double beta decay ($0\nu\beta\beta$) experiment NEXT, which relies on high pressure xenon (HPXe) Gas TPC, read out by SiPMs to produce 3-D images. Using Farbin's simple technique and GPU systems, graduate student Josh Renner (Valencia) has demonstrated significant better topological based rejection of critical single electron backgrounds over traditional techniques. An innovative use of DNNs here is to help optimize detector design by comparing different detector granularities and relative contribution of physics processes to degrading performance. This activity is detailed in a paper (with Farbin as co-author along with the NEXT collaboration) that is nearly ready for submission.

The ATLAS Electromagnetic and Hadronic calorimeters produce 3D images of variable granularity in η, ϕ versus depth (i.e. the LAr presampler to the Tile D layers) of energy deposits. Particles, such as photons, are identified by their characteristic shower profiles, with their energies determined via a weighted fit of layer-wise deposits calibrated to test beam and Z decays. Any improvement, for example in photon identification or energy resolution, can dramatically effect searches and measurements, for example producing narrower Higgs peaks with less background. The fine lateral segmentation of ATLAS's calorimeter makes it suited for application of CNN for classification and energy regression. Indeed several factors give hope that significant improvements can be achieved with more sophisticated techniques. For example, energy reconstruction in the LAr Electromagnetic calorimeter currently does not use shower shape information and is not correcting for variations in the LAr calorimeter's characteristic accordion structure. Similarly the hadronic calibration does not use sampling information. Such effects would be naturally exploited by a CNN.

While the techniques, tools, and experience Farbin developed for LArTPC and NEXT can be directly applied to the ATLAS calorimeter, the LHC presents new unique and interesting challenges. The variable granularity can likely be built into the CNN architectures. Since simulation does not faithfully reproduce the shower shapes, simulation trained CNNs can be initially calibrated on $Z \to ee$ or testbeam data. While training on data is also possible, for example training on data Z decays using likelihood-based cost functions that account for Z line-shape and calorimeter resolution, an interesting direction is hybrid training with adversarial networks. An example of this technique simultaneously trains the classification or regression network with and an adversarial network learning to distinguish data and simulation. The full network is then trained until data and simulation cannot be distinguished.

Another potentially high impact of DNNs to calorimetry is fast showering. Full Geant4 shower simulation in the ATLAS calorimeter takes of order of an hour. Fast shower techniques such as shower libraries or high dimensional binning of shower observables generally suffer from intractable memory requirements. Zach Marshall (Berkeley) has demonstrated more efficient storage of shower observables in shallow neural networks. DNNs may provide a much more powerful technique. Starting with examples only, Generative DNNs have been demonstrated to generate new images of faces, furnished rooms, or text in style of a specific author (e.g. Shakespeare). Two generative techniques are likely relevant to calorimetry. The first is Generative Adversarial Networks, which starting from random input trains a network that simultaneously produces the desired output and attempts to distinguish generated from real examples. The network is trained when it no longer can make the distinction. Variational Autoencoders train a 2 part network: one that “encodes” real examples into a latent lower dimensional representation of Gaussian distributed variables, and another that “decodes” to an image trained to reproduce the original. Once trained, the decoder can be primed to then generate new examples.

A significant obstacle to applying CNNs to the ATLAS calorimeter is accessibility to data. The energy deposits into the 200k cells require significant storage and are only retained in the difficult to access Event Summary Data (ESD). With a baseline of $\approx$ 1 in 10^4 jet rejection, CNN training will require large samples of specially filtered EM-like jet backgrounds, finely binned to compensate for drop in jet-cross section. Finally, due to ATLAS's strict data-sharing policies, collaboration with DL experts is difficult. Farbin and graduate student Leslie Rogers are working to address these issues and assemble appropriate ATLAS training sets,

In meantime, Farbin has been collaborating with CMS colleagues Maurizio Pierini (CERN) and Jean-Roch Vlimant (CalTech) to generate simpler public datasets where application of DNNs to calorimetry can be explored in collaboration with DL experts and without unnecessary complications. Starting with the high granularity LCD CLIC calorimeter concept [65], they have so far simulated 2 million photon and neutral pions and presented first classification studies in July 2016 [66]. With the goal a paper by the end of 2016, Farbin is currently applying the energy regression techniques developed in LArTPC to this dataset.

Exploring and implementing these techniques in ATLAS will be a part of Rogers' PhD thesis, building on Farbin's ATLAS software and DL experience and Heelan's extensive background with the calorimeter (e.g. she is the editor of the Tile performance paper) and test beam. The goal is to first tackle photon identification and then photon/electron calibration. Of critical importance will be handling of pile-up. If successful, the technique will be implemented in ATLAS's framework for further study and use by other collaborators. Extension of the technique to EM/hadronic cluster identification and calibration will be the next natural step. In addition postdoc Griffiths, who contributes significantly to τ identification, will investigate CNN applications to τs.

Upgrade Activities in ATLAS

1.8 Tile Low Voltage Power Supply(LVPS) Upgrade (PI: Brandt, Hadavand)

In preparation for High Luminosity LHC (HL-LHC), various upgrades of the ATLAS detector to cope with the new conditions are being planned. One of these projects, involving the replacement of the 2048 low voltage power supplies (LVPS) required for operation of the ATLAS Tile hadronic calorimeter, became available last year. Building on UTA's connections in the TileCal since its inception, Hadavand and Brandt assembled a group and proposed that UTA take over this project. Our proposal was well-received, consequently, Hadavand is now the L3, or deliverable manager, of this project for the ATLAS detector while Brandt is the institute contact. The construction phase of this 6-year 1 million dollar project is expected to be covered by an NSF MREFC proposal in progress.

Starting in 2023 the LHC will be shutdown for 2.5 years in preparation for HL-LHC upgrade to achieve 5.0 $\times 10^{34}/cm^2s$. Hadavand and Brandt have assumed the responsibility for the testing and production of half of the entire 2048 low voltage power supplies (LVPS) needed for HL-LHC running, a project that will cost about 1 million dollars over the next few years, the bulk of which is anticipated to be provided by an NSF MREFC grant. Hadavand is the deliverables manager or CAM for the low voltage power supplies overseeing the work of UT Arlington as well as that of Northern Illinois University which is responsible for integrating the UTA power supplies into boxes that will go into the detector. The UT Arlington group also has responsibilities on the Tile Pre-processor for HL-LHC. We currently share an electrical associate (EA), Seyedali Moeyadi, on these two projects. The EA has worked closely with our research faculty Guilio Usai at CERN and has been involved in the June TileCal test beam. We have also procured funding from the university for an electrical engineering (EE) PhD student, Michael Hibbard, whose thesis will be based on this project.

We are currently in a transition phase assuming responsibility for the project as Argonne National Labs, who designed and built previous versions of power supplies is assuming responsibilities in the upgraded tracking detector. They have produced a working prototype, but the final design of the power supplies including interface changes to account for other system upgrades is scheduled for 2018, and will be our responsibility. A timeline of the project is as follows (more details are shown in table 4): During 2017 the research and development component of the project will be in the design of the elevated temperature testing apparatus (Burn-in Station) for the power supplies. Such a system is necessary to age the components and identify power supplies with early mortality rates. A temperature analysis of the system has also been performed to determine whether the cooling capabilities of the system are sufficient for running the power supplies in redundant mode, where the current is twice the nominal. This is a fallback mode in case of a power supply failure, the other supply in the drawer can provide power to the full drawer. After determining changes needed from components interfacing to the LVPS such as the ELMB++ a small number of prototype LVPS will be made in 2019 with the new design. These LVPS will be assembled into boxes by NIU and sent to CERN for testing in the vertical slice test. From 2019-2022 we will be producing LVPS in batches testing and burning them in for quality control. This is a huge undertaking and will require a detailed and well-documented plan that a set of undergraduate students will follow for testing the LVPS.

Task	Personnel	Start Date	End Date
New Burn-in Station Design and Fabrication	Hibbard, EA, EE	01/30/17	12/15/17
Prototype	-	01/29/18	08/30/19
Procurement of brick components for prototype V8.2 bricks	Hibbard, EA	01/29/18	05/11/18
Basic Check-out and burn-in (Prototype)	Hibbard, EA	04/22/19	05/24/19
Prototype Review	EE, EA	05/27/19	08/30/19
Integration and testing of vertical slice	Hibbard, EA	06/03/19	07/26/19
Finalize V8.3 pre-production design	EA, EE	07/29/19	08/23/19
LVPS pre-production design review	EA, EE	08/26/19	08/30/19
Pre-production	-	09/2/19	12/30/20
Check-out and burn-in tests on pre-production bricks	EA, undergrads	07/06/20	09/25/20
Ship bricks to CERN	EA	09/28/20	10/02/20
Integration tests at CERN and final review	EA	10/05/20	12/31/20
Production	-	01/04/21	04/08/22
Production PCB Assembly	EE,EA	04/12/21	06/04/21
Check-out and burn-in (16 to start and find any issues)	undergrads	04/19/21	04/30/21
Check-out and burn-in (64 to confirm production)	undergrads	05/03/21	05/28/21
Check-out and burn-in (1000)	undergrads	05/31/21	04/08/22

Table 4: The HL-LHC Tile LVPS upgrade schedule.

1.9 Tile PPR Upgrade (PI: De)

The HL-LHC upgrade will require major changes to ATLAS Tile Calorimeter electronics and data readout. UTA will construct half of the Tile Calorimeter pre-processor boards, which provide an important interface between on-detector electronics and the data acquisition and trigger systems. Currently, the other half of the boards will be provided by the University of Valencia. The two institutions are collaborating on the design and R&D. This project is an important responsibility in the HL-LHC Upgrade project, and under the coordination of US ATLAS management.

For this project, we will perform the design and fabrication of the Trigger DAQ interface (TDAQi) blades which are the rear transition modules of the Tile calorimeter back-end preprocessor (PPR). These boards configure the processed data from the front-end electronics and route data to the DAQ system via the FELIX module and to the L0/L1 Calo and Muon trigger system through dedicated links. UTA is responsible for the production of 32 boards. Additional tasks are parts procurement, monitoring of outsourced assembly, burn-in of cards in a dedicated setup with validation testing and repairs when needed, and installation and commissioning at CERN. This activitiy is funded through the US ATLAS HL-LHC construction and upgrade R&D projects. PI De and postdoctoral researcher Usai, both of whom partially funded through the base program, will be managing this project. In Figure 9 we show the current prototype of the PPR TDAQi board.

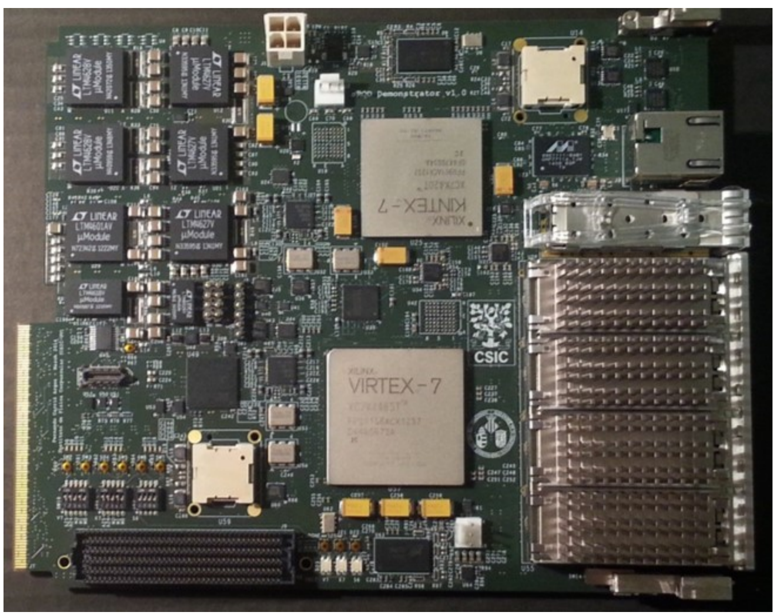


Figure 9: Prototype of the TileCal PPR TDAQi board being deigned for HL-LHC at UTA in collaboration with the University of Valencia.

During the period of this base proposal, 2017-20, we will focus on design and prototyping work, setting up test stands, validating the prototypes, finalizing the design, and begin preproduction activities. Fabrication of the boards will begin in 2021.

1.10 Core Trigger Software (PI: Farbin)

Following the recommendations of the 2014 ATLAS Future Framework Requirements Group Report [67], the ATLAS Phase I Software Upgrade will entail a massive migration to athenaMT, a multi-threaded evolution of ATLAS's current framework. This migration requires significant redesign and rewrite of existing software components and algorithms. An aggressive planned schedule delivers basic functionality by 2016, begins select migration in 2017, and performs bulk migration in 2018-19 in preparation for full integration in 2020 and start of data Run 3 data-taking in 2021. A cornerstone of this migration is the merger with the ATLAS trigger, where high pile-up and L1 rates necessitate use of offline algorithms. A key trigger component is a new incarnation of the Event View concept which enables partial event processing in regions of interest. Numerous technical and design issues must be addressed in both the offline and trigger for athenaMT's first release at the end of 2017 and subsequent algorithm migration, a formidable task especially in light of a significant lack of manpower and requisite expertise.

Trigger athenaMT Migration Farbin proposes to redirect his focus, which has been very recently freed from coordinating DUNE Software & Computing, to the trigger athenaMT migration. Given Farbin's long history with ATLAS offline software development and management, broad knowledge of HEP software framework, and extensive experience with parallel and GPU computing, the upcoming trigger coordinator Jeorg Stelzer (CERN) and core trigger software coordinators John Baines and Tomasz Bold have enthusiastically welcomed Farbin's much needed commitment to this effort.

Farbin will commence initial work immediately during his current sabbatical, taking on migration of the e/gamma trigger chain starting with TopoCluster calorimeter clustering algorithm and then continuing on through the Trigger Software Upgrade's extensive workplan. The in-depth experience gained here will allow Farbin to gradually shift from algorithm migration to design and implementation of core trigger components relating to Event Views, Menu, Decision, Prescales, Monitoring, and so on. We propose that a new UTA postdoc begin gradually assuming these efforts in mid-2017, dedicating 50% of his/her effort and freeing Farbin for bigger contributions to this area, possibly through management and leadership roles similar to his convenership of the Physics Analysis Tools group.

As a hobby project, Farbin and Hilliard will also attempt to revitilize the ATLAS GPU Trigger Demonstrator [68], which was not able to demonstrate cost-effective benefits of using GPUs in the trigger. As a test of the viability of the rapidly evolving Deep Learning infrastruture to manage traditional HEP workloads, they will migrate the GPU Demonstrator to TensorFlow (TF) [69], Google's open source distributed computation framework developed for Deep Learning applications. The system will be studied on Farbin's 48 core, 7 GPU, 10 Gb linked systems, with data pre-converted to tensors that flow through TF ops wrapping kernels of the existing GPU-Demonstrator algorithms. It is noteworthy that Hilliard had obtained support from Fermilab (under supervision of Jim Kowalkowski) to perform a similar R&D exercise with LArTPC event processing, with support from TensorFlow developers, during summer 2016, but instead took a Silicon Valley internship.

2 International Linear Collider Project (PI: White)

The study of the Higgs sector continues to be a major part of the HEP physics program, and will continue to be for the next 10 - 20 years. The full exploration of this sector will require the combination of the upgraded, high luminosity LHC plus precision results from a lepton collider. The lepton collider that is closest to being realized is the International Linear Collider in Japan. UTA has been engaged, since 2002, in studies for the SiD Detector Concept for the ILC. This work has been an investment in the future of HEP for our group, and is consistent with our approach of having an involvement in each generation of colliders. The SiD Detector Concept was one of two designs validated by the International Detector Advisory Group. Since 2012, White has served as co-Spokesperson for SiD, with co-Spokesperson Marcel Stanitzki(DESY). The SiD design study achieved an important milestone with the production of the Detailed Baseline Design (DBD) [**?**] together with the TDR for the ILC Accelerator. The DBD is a compreshensive statement of an advanced detector design (see Figure 2 (left)) [**?**] that will enable the study of a full range of TeV scale physics. This includes precision Higgs measurements, a detailed study of top physics, which is closely connected to the phenomenon of electroweak symmetry breaking, and a sensitive probe of new physics, such as that from additional gauge bosons and extra dimensions at high mass scales, in a program that is complimentary to that at the LHC. The reach of the ILC in precision measurements of Higgs couplings is shown in Figure 2 (right). The branching ratio for Higgs to invisible decays can be probed at the 1/2% level at the ILC. This is the level at which theoretical studies (Ref. xx) show that significant effects from new physics can be expected. The ILC is thus a discovery machine both through direct searches and precision measurements.

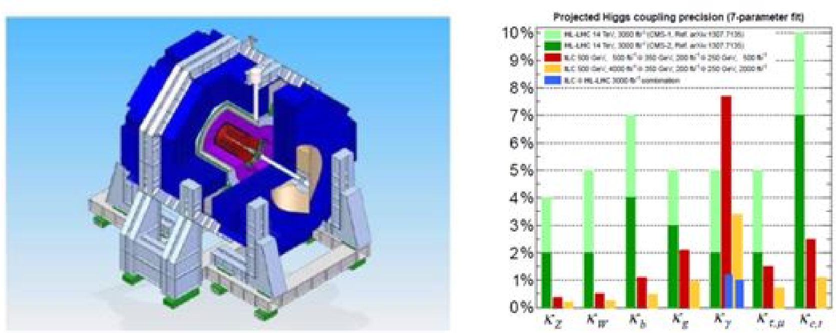


Figure 10: (left) The SiD Detector (right) Higgs couplings projection for ILC and LHC.

Since the writing of the DBD, many further physics and detector optimization studies have been carried out, including the following areas:

- **Pixel tracker option.** Studies of the benefits of a coherent pixel technology implimentation for the vertex detector and silicon tracker combination.
- **Hadron calorimeter** New baseline technology choice for the hadron calorimeter: scintillator/steel instead of RPC/steel. UTA's role in the SiD hadron calorimeter is discussed in the next section.
- **Flux return/muon steel** Redesign of the solenoid flux return to reduce the external field and facilitate easier handling and transportation of steel components.
- **Backgrounds** Studies of the effects of pair, $\gamma\gamma$, and beam muon backgrounds on reconstruction of tracks, jets.
- **Multiplicity studies** Evaluation of the required pipeline depth for the KPix chip - used in all systems except the vertex detector.
- **Foward region** Redesign of the LumiCal, BeamCal, and other components to reflect the new common L* for SiD and ILD.
- **SiD Simulation** A complete reworking of the SiD simulation in the DD4HEP framework - with UTA providing the details of the hadron calorimeter.

Recently, SiD decided to form the SiD Consortium to formalize the membership of this pre-collaboration. SiD now has 30 institutions from the U.S.(55%), Europe (40%) and Asia (5%). We have a set of rules for membership, application procedures for potential new members, and an Institutional Board that meets at each major ILC event. As SiD Spokesperson White has the following roles:

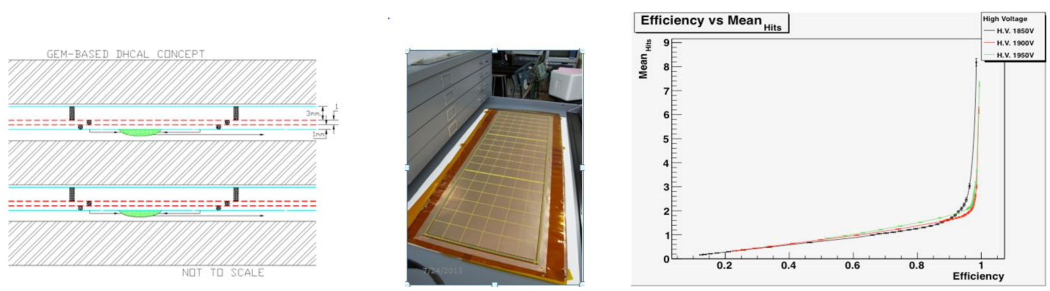
- **Overall Leadership.** Responsible for the physics and technical leadership of the SiD Detector Concept, including appointment of sub-group leaders and promotion of SiD within the Linear Collider and High Energy Physics community within the U.S. and worldwide.
- **Head of the SiD Executive Committee.** Responsible for the overall strategy and guidance of the SiD Consortium, and calling and chairing weekly meetings.
- **SiD Representation** External committees and at ILC conferences. SiD Spokespersons are members of, or report to, a number of external committees such as the Executive Committee of the Physics and Detectors section of the Linear Collider Organization.
- **Americas Linear Collider Committee** White also serves as the at-large universities' representative on the Americas Linear Collider Committee.

In their report, P5 described the ILC physics case as ”extremely strong”, and support for the ILC Project was included in all scenarios. Earlier a HEPAP Facilities Panel (on which White served) concluded that ”The ILC accelerator and detectors enable a research program that will address questions of very great scientific importance, and both the accelerator and the detectors are *absolutely central.*”. The Project is currently under evaluation by the Japanese MEXT organization. Recently a U.S. DoE - MEXT Working Group was established, and a list of priority areas identified for focus while the project is under evaluation. There is very strong political, industrial, and community support for the ILC in Japan and a decision is expected in the next 2 years. There has been a series of high-level political and industrial visits by Japanese delegations to the U.S. and White has participated as a representative of the U.S. HEP community. ICFA has restructured the Linear Collider Collaboration with a format designed to carry the project through the next period prior to the final construction decision. If the ILC project is to be realized, the involvement of the U.S. is essential - there simply is not the required cryomodule production capacity in the rest of the world. In order to prepare for potential participation, it is therefore critical that the U.S. maintain its long term intellectual leadership in the project by continued investment in Physics and Detector studies.

Hadron Calorimetry for SiD, [PI: White] UTA has for 14 years worked on the development of hadron calorimetry for a future lepton collider. Our graduate and undergraduate students have benefitted significantly from participation in this work, and have made valuable contributions. Future experiments make severe demands on achieving excellent the jet energy resolution. Much of the new physics program for the ILC requires high-precision measurements of jet energies and jet-jet invariant masses. Studies have shown that there is a basic requirement of at least $30\%/\sqrt{E}$, at 100 GeV or 3-4% in general for jet energy resolution. This need arises from the requirement for precision Higgs studies, and precision measurements of the masses and other properties of new particles that may be discovered in the next few years at the LHC. A prime physics example of the need for this precision is the reconstruction and separation of hadronic decay modes of W and Z bosons, on an event-by-event basis. Hence there has existed a need for the development of a new type of hadron calorimetry.

The hadron calorimeter is an essential component of the Particle Flow Algorithm (PFA) approach to achieving the required jet energy resolution. The PFA approach has been developed and extensively used in physics studies by both of the main ILC detector groups, SiD and ILD. It has also been used in LHC jet reconstruction. Most of the calorimeter development work to provide technical solutions to implementing PFA-orineted systems has been carried out by the CALICE Collaboration [**?**]. White and Felix Sefkow (DESY) were asked to be the authors/main editors of a Reviews of Modern Physics paper on ”Experimental tests of particle flow calorimetry”. This paper was published [**?**] in early 2016 and represents a statement and synthesis of developments of PFA calorimetry. As reflected by this paper, there has emerged a choice of technologies in which to implement the hadron calorimeter for SiD. The technology must support individual charged particle tracking through the calorimeter, allow detailed imaging of energy depositions for track-shower association and separation of closeby showers, while providing good energy resolution for the direct measurement of the energies of neutral particles. Highly granular calorimetry, as required for Particle Flow, has recently been adopted by CMS for an upgrade of its forward calorimetry. White proposed [?] a digital hadron calorimeter implementation using Gas Electron Multiplier (GEM) technology [?]. GEM offers a robust solution with sufficient amplification in a double-foil configuration, and a thin active layer. This last requirement is important since a typical lepton collider hadron calorimeter would have about forty layers, with the entire system contained inside superconducting coil – the cost of which must be limited.

Figure 11(a) shows the basic GEM-DHCAL idea introduced by White. The concept of embedding the front-end electronics as part of the active layer has been realized through the development of the KPiX 1024-channel chip by SLAC (with a series of earlier versions also having been tested at UTA). KPiX is specifically designed for the time structure of the ILC beam, and requires a synchronous environment to operate at full efficiency. To implement a full digital hadron calorimeter system would clearly require large area chambers. UTA has developed a series of prototype GEM-DHCAL chambers (see Figure 11(b)) with fine ($1cm \times 1cm$) cells. A key characteristic of an active layer suitable for use in a digital hadron calorimeter is a low hit multiplicity per track per layer while maintaining a high hit efficiency. Figure 11(c) shows that our GEM chamber(s) indeed have this desired performance characteristic. The GEM-DHCAL development work has given us very valuable experience with respect to the implementation of the hadron calorimeter for SiD.

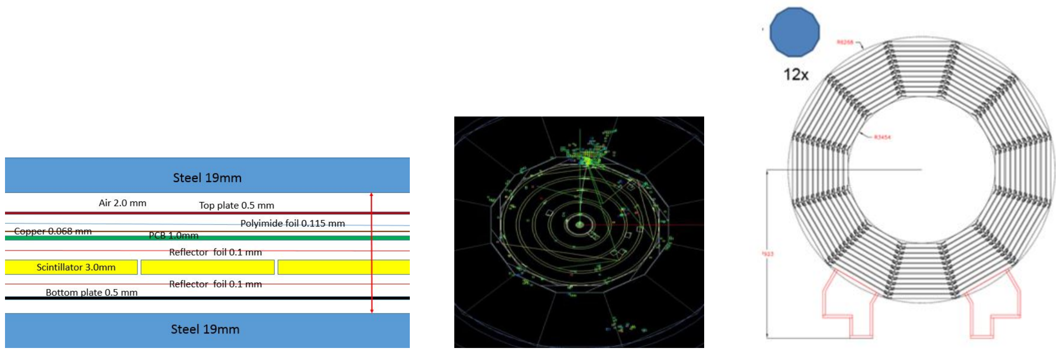


(a) (b) (c)

Figure 11: (a) GEM Digital Hadron Calorimeter Schematic. (b) large chamber under construction. (c) Multiplicity vs. hit efficiency.

The recently adopted, and current, baseline technology for the SiD hadron calorimeter, for detector simulation and physics studies, is small scintillator tiles with SiPM readout, and steel absorber plates. This approach has been the subject of considerable work by CALICE.

UTA plans to take a leading role within SiD in the development, design, prototyping, and construction of the SiD hadron calorimeter system based on the scintillator/SiPM/steel technology. As a first step, UTA has undertaken the implementation of this technology in the DD4HEP [?] framework for the SiD simulation. White has been working with two undergraduate students to specify the details of the hadron calorimeter simulation. Figure 12(a) shows the details of the implementation of the active layer of the hadron calorimeter in the SiD simulation. CALICE studies have shown that $3cm \times 3cm$ cells yield the required jet energy resolution, and we have used this cell size for SiD. Figure 12(b) shows the first result for the barrel simulation with a single incident charged particle. Once the full hadron calorimeter simulation is complete, we will make extensive comparisons between our simulations and the results of the CALICE beam tests for a variety of incident particles. SiD has chosen a 12-fold design for the hadron calorimeter (see Figure 12(c)). Taking the CALICE active layer design as input, we will develop a 40-layer module design. This will require the construction and testing of a representative size prototype of an active layer, specification of layer assembly techniques (possibly automated), and mechanical module prototypes.



(a) (b) (c)

Figure 12: (a) SiD AHCAL Barrel layer schematic. (b) SiD AHCAL simulation - single pion. (c) SiD AHCAL Barrel 12-sided structure.

All this activity will be a precursor to the SiD Technical Design Report, the timescale for which depends on the overall progress on the ILC project. We anticipate 2-3 years to complete the TDR, once resources are available.

SiD Timetable of Activities A decision on the ILC Project is expected in 2018. This timetable reflects this anticipated schedule. The activities below reflect White's role as SiD Spokesperson and the planned work at UTA on the SiD hadron calorimeter.

2017

- Guide and pursue the optimization studies for all SiD subsystems
- Initiate and guide further physics studies in response to new LHC results
- Expand the SiD Consortium, particularly in Europe and Asia
- Work with the U.S.- Japan Caucus and the ALCC to prepare the case for U.S. support of the ILC
- Represent SiD at national and international Linear Collider conferences
- Complete the full simulation of the SiD baseline hadron calorimeter, and verify performance vs. CALICE results
- Develop initial hadron calorimeter barrel and endcap module concepts

2018

- Continue the first five tasks from 2017
- Work with Japanese colleagues to provide input from SiD to inform the anticipated ILC Project decision by MEXT
- Begin the framework for the SiD Technical Design Report
- Develop production and assembly procedures for SiD hadron calorimeter actve layers, and module integration

2019 Subject to the ILC Project proceeding:

- Continue the general tasks from 2017/18
- Prepare the SiD Experiment initial submission in response to anticipated call for expressions of interest/proposals
- Establish initial areas of responsibilities for SiD member institutes in the transition from the SiD Consortium to the SiD Collaboration

- Begin full engineering design and prototyping for SiD hadron calorimeter modules

Part III
Research at the Intensity Frontier

Executive Summary

We present a well coordinated and strategically planned three year renewal proposal that further strengthens UTA's Intensity Frontier (IF) program with the focus on the neutrino experiments at Fermilab, which use the Liquid Argon Time Projection Chamber (LArTPC) technology. The IF group of the University of Texas at Arlington (UTA) started in 2014 with 0.5 FTE each of PI Jaehoon Yu and of PI Amir Farbin aiming for a balanced program between US-based and non-US based experiments. In order to continue to build up a strong IF program, the group recently hired a full time IF junior faculty, Dr. Jonathan Asaadi. The overall strength of the group has doubled to two full PI's with the hire of Asaadi, the transition of Yu to full time IF, and Farbin's transition back to the Energy Frontier (EF) in this funding cycle.

Beyond the addition of a new faculty member, the UTA IF group has made significant contributions to the Liquid Argon In A Test-beam (LArIAT) experiment, Long Baseline Neutrino Experiment (LBNE)/Deep Underground Neutrino Experiment (DUNE) and MiniBooNE experiments. Farbin played a key role of deputy computing coordinator for the DUNE project and Yu has served as a co-convener for the LBNE R&D Coordination group. Yu's role has evolved to a co-convenership of the DUNE Beyond the Standard Model (BSM) physics group in September 2015. UTA also hosted the first off-Fermilab-site DUNE collaboration meeting in January, 2016, in which over 150 collaborators participated.

Farbin and Yu have been supervising a Ph.D. student (Sepideh Shahsavarani) who has been contributing to the MiniBooNE beam-dump dark matter search with first results expected in fall 2016. Asaadi has continued his roles on MicroBooNE, serving as the convener of the Astro-Particle and Exotics group through August 2016 and a lead TPC-Expert for the experiment. Asaadi has also played a leadership role on LArIAT serving as the analysis coordinator in 2015 and 2016. This lead to the first measurement of the π^--Argon cross-section and he will now transition to serve as a co-spokesperson (starting fall 2016). The UTA group has joined the SBND and the ICARUS experiment and has been contributing to the refurbishment of the light detection system with the hire of a new post-doctoral researcher (an existing ICARUS collaborator) with Asaadi's start-up funds.

In this document, we propose to complete the ongoing efforts on MiniBooNE beam dump data analysis (Yu) and LArIAT (Asaadi, Yu) and continue/add significant contributions to SBND (Asaadi, Yu), MicroBooNE (Asaadi), ICARUS (Asaadi, Yu) and DUNE (Asaadi, Yu) with important contributions to both the single and dual phase protoDUNE projects. These experiments are carefully selected to leverage our group's growing technical and analysis expertise on LArTPC. Moreover, in order to accomplish the work laid out in this proposal, the UTA group will leverage Asaadi's start-up to provide an additional (beyond what is requested here) post-doctoral researcher (Dr. Andrea Falcone) in year one and two of this proposal. Dr. Falcone will play a leadership role on the ICARUS and SBND experiments during construction, installation and commissioning, moving to Fermilab in time with the transfer of the refurbished ICARUS detector.

This plan will enable our group to make significant contributions to the US neutrino physics program and maintain our leadership in future experiments, such as DUNE.

UTA Strategic Plan

The UTA group will have contributions and responsibilities across the Fermilab short-baseline neutrino (SBN) and the long-baseline neutrino (LBN) programs. The primary strategic goal of the group throughout the period of this proposal is to contribute to the success of the construction and execution of these experiments, focusing on LArTPC technology. We aim to position ourselves to make major contributions to the DUNE project by playing leadership roles in the design and construction of the single phase (SP) and dual phase (DP) prototype detectors (protoDUNE) at CERN neutrino platform. This work will allow UTA to be a world leading institution for the construction and data analysis of the DUNE detector. Synergistic with this goal, our active participation in the construction, commissioning and operation of the SBN experiments - MicroBooNE, SBND, and ICARUS - allows us to enhance our expertise in LArTPC technology, produce valuable physics results, and gain experience in near/far oscillation analyses utilizing the data from these detectors.

Among the various tasks described below, we consider protoDUNE to be under the most restrictive time-line and deserving of immediate attention early in the period of this renewal proposal. Since the availability of charged particle beams at CERN's neutrino platform is dictated by the CERN accelerator complex upgrade schedule, having the protoDUNE detectors ready before the start of LHC heavy ion run in October 2018 is critical. Moreover, the success of the protoDUNE projects plays a key role in the success of the U.S. flagship experiment, DUNE. The SBN program is critical to the overall success of the LArTPC program in the U.S. and will provide important (and potentially discovery level) measurements and thus garners a great deal of effort from UTA throughout this proposal.

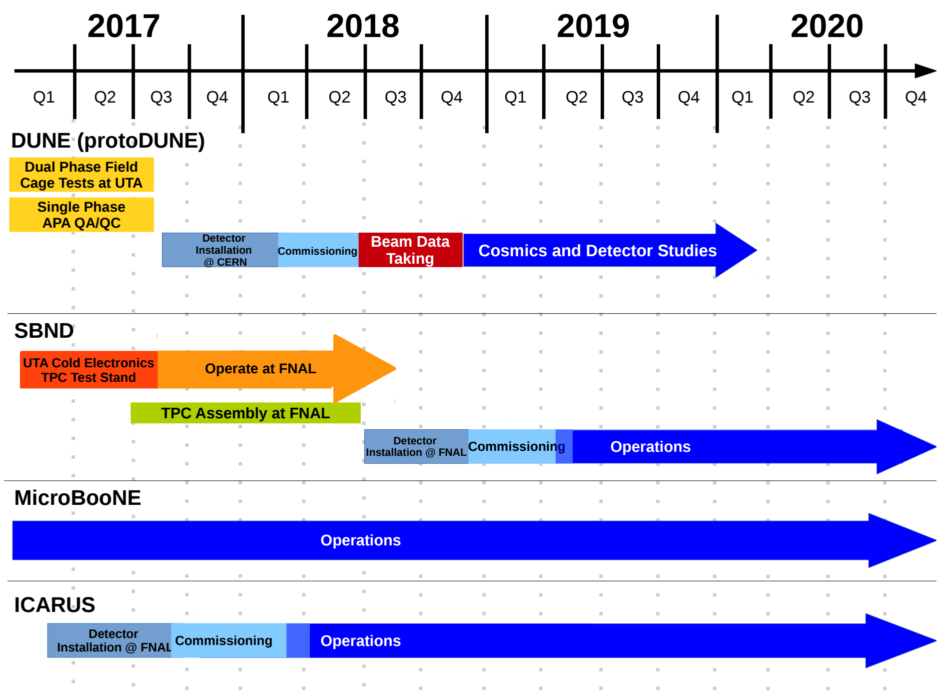


Figure 13: Timeline of the proposed projects

Figure 13 summarizes the time-line for the projects to be executed during the funding period of this proposal based on the latest information at the time of writing this proposal. These projects are described in greater detail in subsequent sections. The overarching strategic goal is to have Asaadi focus on the short and mid-term experiments such as MicroBooNE and SBND with a smaller portion of his time on ICARUS and DUNE initially which will then ramp up over time. Meanwhile, Yu will focus on the long and mid-term experiments such as DUNE and ICARUS with a gradually increasing portion over time on the whole SBN program. This enable our group to maintain a constant level of contribution from both the PI's and the post-doctoral and graduate researchers on all four LArTPC experiments.

Tables 5 summarizes the proposed projects and associated PI who will take a lead role during proposal as well as where the effort will be located. The division of projects and PI effort is designed to find synergy between the time-line and when each effort is to take place. This will allow Asaadi and Yu to maximize their impact across the neutrino program.

IF Summary of Proposed Work

Experiment	Project	Location	Lead PI
DUNE	protoDUNE SP-APA QA/QC and installation	UTA/CERN	Asaadi
	BSM Physics	UTA	Yu
	protoDUNE DP-FC Construction	UTA/CERN	Yu
SBND	Cold Electronics TPC Test-stand	UTA/FNAL	Asaadi
	Detector Construction, Installation, and Commissioning	FNAL	Yu
	Cross-Section Data Analysis	UTA/FNAL	Asaadi
MicroBooNE	TPC Detector Expert	UTA/FNAL	Asaadi
	Detector Operations	UTA/FNAL	Asaadi
	Cross-Section Data Analysis	UTA/FNAL	Asaadi
ICARUS	Detector Installation and Commissioning	FNAL	Asaadi
	NuMI Off-Axis Cross-Sections & Low-mass Dark Matter	UTA/FNAL	Yu
MiniBooNE	Beam Dump Dark Matter Search	UTA/FNAL	Yu

Table 5: Overview of the UTA projects across the Intensity Frontier

Table 6 summarizes the projects and associated personnel resources that will execute the research described in greater detail in the subsequent sections. The requested post-doctoral efforts are divided evenly between DUNE and the SBN programs with an additional post-doctoral researcher and graduate student coming from Asaadi's start-up funds. The graduate students will contribute to hardware on both DUNE and the SBN programs, but will focus on the SBN for their thesis analyses.

The Short Baseline Neutrino (SBN) Program

The SBN program, described in more detail in Section 3, aims to conclusively address the experimental hints of sterile neutrinos through the utilization of three LArTPC detectors. The SBN plays an essential component for our group by continually producing physics results throughout the construction period of the DUNE experiment and contributing to the development of LArTPC technology. Below we outline the projects associated with the SBN program and reference the sections where the work is described in more detail.

MicroBooNE (Asaadi): Asaadi has been an essential member of the construction, commissioning, operation and data analysis on MicroBooNE. With Asaadi being a young-tenure track faculty member, it is essential for him to be able to produce physics results in early years of the proposal. Given this, Asaadi will focus on operations and data analysis, presented in greater detail in Section 3.2.

- **Detector Operations and TPC Detector Expert:** Section 3.2.1
- **Cross-section Data Analysis:** Section 3.2.2

SBND Tasks (Asaadi, Yu): UTA's effort on SBND is presented in greater detail in Section 3.1. Asaadi will play the lead role as institutional representative with Yu in discussions with the SBND management for joining the collaboration prior to the start of this funding period.

- **Cold Electronics TPC Test-stand (Asaadi):** Section 3.1.1
- **Detector Construction, Installation, and Commissioning (Yu):** Section 3.1.2
- **Cross-Section Data Analysis (Asaadi):** Section 3.1.3

Summary of PI, Postdoc, and Graduate Personal

Personnel	Associated Task	Years Supported	Source of Support
Postdoc 1 (Animesh Chatterjee)	protoDUNE SP/DP SBND Operations and Data Analysis ICARUS Operations and Data Analysis	2017 - 2020	UTA Base Grant
Posdoc 2 (TBN)	protoDUNE SP/DP MicroBooNE Operations and Data Analysis SBND Cold Electronics Test Stand	2017 - 2020	UTA Base Grant
Postdoc* (Andrea Falcone)	ICARUS/SBND Installation and Commissioning MicroBooNE Operations and Data Analysis	2017 - 2019	UTA Start-up funds
Graduate Student 1 (Garrett Brown)	protoDUNE SP/DP SBND/ICARUS Operations and Data Analysis	2017 - 2020	UTA Base Grant
Graduate Student 2a (Sepideh Shahsavarani)	MiniBooNE Data Analysis protoDUNE DP	2017 - 2019	UTA Base Grant
Graduate Student 2b * (Zack Williams)	SBND Cold Electronics Test Stand, SBND Construction, Installation, and Commissioning MicroBooNE Operations and Data Analysis	2017 - 2019 2019 - 2020	UTA Start-up funds UTA Base Grant
Prof. Jonathan Asaadi	SBN/DUNE	2017 - 2020	UTA Base Grant
Prof. Jae Yu	DUNE/SBN	2017 - 2020	UTA Base Grant

Table 6: Table summarizing the personnel working on the project described in this proposal. Note: Personnel marked with "*" denote that their effort is supported for some phase of the project utilizing Asaadi's start-up funds. This is done to maximally leverage the UTA group across both DUNE and the SBN program.

ICARUS (Asaadi, Yu): UTA group has joined the experiment as a member with Yu as the institutional board representative as one of the handful of U.S. groups to participate in it. Our efforts have been augmented by utilizing Asaadi's start-up funds to support a post-doctoral researcher to help lead the refurbishment and integration of ICARUS, described in more detail in Section 3.3.

- **Installation, Commissioning, and Detector Operations (Asaadi):** Section 3.3.1
- **NuMI Off-Axis Cross-Sections** & **Dark Matter Searches (Yu):** Section 3.3.2

Long Baseline Neutrino Program (LBN) The LBN program, described in more detail in Section 4, aims to address the questions of the neutrino mass hierarchy and CP-violation in the lepton sector by measuring the asymmetry between appearance of electron neutrinos from a beam of muon neutrinos ($P(\nu_\mu \rightarrow \nu_e)$) compared to the appearance of electron antineutrinos from a beam of muon antineutrinos and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$) as well as the precise measurement of the ν_e energy spectrum measured at the far detector. The UTA group aims to play a leading role in this U.S. flagship effort throughout the next decade and does this with contributions to the protoDUNE detectors.

DUNE (Asaadi, Yu): The UTA group will be contributing to both the protoDUNE Dual Phase (DP) and Single Phase (SP) detectors. Asaadi and Yu expect to play major roles in detector component construction, installation, and commissioning as well as data taking during the first two years of this proposal. This work will lay the strong foundation to contributing to the DUNE experiment and is described in greater detail in Section **??**. Along with this, UTA hopes to play a critical role in the physics profile for the DUNE experiment through contributions to the physics working groups.

- **ProtoDUNE Single Phase-Anode Plane Assembly QA/QC (Asaadi):** Section 4.1.1
- **ProtoDUNE Dual Phase-Field Cage Construction (Yu):** Section 4.1.2
- **DUNE Beyond the Standard Model Physics (Yu):** Section 4.1.3
- **LBNF Beam Simulation (Yu):** Section 4.1.5

With this strategic plan in place, the activities proposed aim to ensure synergy between the SBN and LBN efforts and to optimize our use of resources. What follows is a broad introduction to the compelling physics which motivates this research program as well as a more detailed sketch of the program of work which is intended to be executed in the intensity frontier.

Physics Introduction

The discovery that neutrinos undergo oscillation in their flavor, and thus are massive particles, serves as one of the first pieces of evidence for physics beyond the Standard Model (SM) of particle physics. The prevailing description of neutrino oscillations provided by the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix characterizes the flavor change as a result that the neutrino flavor eigenstates (ν_e, ν_μ, ν_τ) are a linear combination of the neutrino mass eigenstates (ν_1, ν_2, ν_3). The translation from the mass eigenstates to the flavor eigenstates is governed by three angles $\theta_{i,j}$, where i and j correspond to the mass eigenstates with $i < j$, and a phase δ which determines magnitude of charge-parity (CP) violation within the neutrino sector. The ordering of the neutrino mass states, known as the mass hierarchy, as well as the size of the CP-violating phase δ are, as yet, unknown. These quantities remain a major unknown piece of the Standard Model of particle physics and offer the opportunity to answer such fundamental questions as:

1) **What is the origin of the matter/antimatter asymmetry in the universe?**
2) **Do we understand the fundamental symmetries of the universe?**
3) **Is the three-flavor paradigm of the Standard Model for neutrino oscillation the accurate description for neutrino interactions?**

Into this landscape, there exists a set of series of experimental measurements which suggest that the three-flavor paradigm of neutrino oscillations is incomplete. Two general classes of anomalous observations may point to additional physics beyond SM in the neutrino sector.

- **The disappearance signal in low energy electron anti-neutrinos from reactor neutrino experiments [?] *("Reactor Neutrino Anomaly")* and Mega-Curie radioactive electron neutrino sources in Gallium [?, ?] *("Gallium Anomaly")***
- **The electron-like excess from muon neutrino (and anti-neutrino) particle accelerators *("LSND/MiniBooNE Anomaly")* [?, ?]**

Neither of these anomalies can be explained by the standard three-flavor oscillations of SM and may hint at the existence of additional neutrino states with larger mass difference ($\Delta m^2_{new} \geq 0.1 eV^2$) which participate in the mixing of the flavour states (referred to as "sterile neutrinos"). Definitive evidence of the existence of new neutrino states would be a revolutionary discovery with broad implications for both particle physics and cosmology. Moreover, in order for future accelerator based neutrino experiments to disentangle the mass hierarchy and search for CP-violation, the oscillation framework must be concretely known and precisely measured.

In addition to these questions, recent theoretical interest (see Refs. [?, ?, ?, ?]) suggests high flux neutrino beam experiments, such as those used to address the questions in neutrino physics, have potential to provide the possibility of studying the models for Low-mass Dark Matter (LDM). The possibility to probe areas of LDM + mediator parameter space which currently are not covered by either direct detection or collider experiments offers an exciting opportunity for new physics. The models suggest that upon striking the target, the proton beam could produce a new mediator particle, **V**, either directly through $pp(pn) \rightarrow \mathbf{V}$ or indirectly through the production of a π^0 or a η meson which then promptly decays into two SM photons of which one couples to the heavy mediator. For the case where $m_V > 2m_{DM}$, the mediator will quickly decay into a pair of DM particles. These relativistic DM particles from the beam will travel along the beam-line (similar to the neutrinos) and could be detected in a sufficiently sensitive neutrino detector and provide evidence of the existence of LDM. These particles can then be detected through neutral-current like interactions either with electrons or nucleons in the detector.

Liquid Argon Time Projection Chambers (LArTPCs) offer fine-grain tracking as well as powerful calorimetry and particle identification capabilities making them ideal detectors for studying neutrino-nuclei interactions. The combination of millimeter scale tracking capabilities, outstanding calorimetry through a fully active/sampling detector, and powerful particle identification made by combining the ionization along the particle trajectory (dE/dX) and the topological information, have made LArTPC's the premier neutrino detector technology choice for the future and provide an excellent detector to search for non-standard interactions in the existing beam-lines. For these reasons, this detector technology has been chosen for both the study of neutrino oscillations over relatively short baselines (< 1 km) and long baselines (> 1000 km).

PI Summary: Jaehoon Yu

Accomplishments

Since I have been in transition in the past three years, my accomplishments in the Energy Frontier (EF) are also summarized here along with those in IF.

Accomplishments in Energy Frontier Program

- Graduated a Ph.D. student, Dr. Heeyeun Kim in 2015
- Expect to graduate another Ph.D. student, Mr. Feremenga by the end of the current funding cycle
- Co-supervised a postdoctoral fellow, Dr. Justin Griffiths
- Served on various Higgs editorial boards as a member
- Contributed to publication of a couple of $H \rightarrow WW$ papers as an author; Phys. Rev. D 92, 012006 (2015), arxiv:1412.2641 and JHEP 08 (2016) 104, arxiv:1604.02997
- Contributed to publication of a couple $H^+ \rightarrow \tau + \nu$ papers as an author; JHEP03 (2015) 088, arxiv:1412.6663 and Phys. Lett. B 759 (2016) 555-574, arxiv:1603.09203
- Contributed to publication of exclusive production of Higgs paper as an author; Phys. Rev. D 94, 032011 (2016)
- Served as an ATLAS leader shifter for 13 TeV data taking in 2016
- Serving as a member of the search committee for the deputy US ATLAS Physics Support Manager

Accomplishments in Intensity Frontier Program

- Co-lead Detector R&D Coordination group of LBNE through Jan. 2015
- Contributed to the transition from LBNE to DUNE working on collaboration governance
- Hosted the first off-Fermilab-site DUNE collaboration meeting at UTA in Jan. 2016
- Co-leading the Beyond the Standard Model physics group of DUNE
- Contributed to LBNE Physics Book; arXiv:1307.7335
- Contributed to various beam-line systematic and optimization studies
- Contributed to LBNE/DUNE hadron monitor development
- Contributed to WA105 $3 \times 1 \times 1\ \mathrm{m}^3$ prototype construction during the sabbatical stay in Sept. 2015 - May 2016
- Established an SiPM coupling R&D facility.
- Lead UTA group to join WA104, ICARUS experiment
- Supervised numerous undergraduate students on IF tasks, including beam-line optimization related ones
- Supervised postdoctoral fellow Dr. Animesh Chatterjee for his contributions to DUNE, LArIAT, and MiniBooNE

Milestones

DUNE BSM Physics

- **Complete Initial DUNE BSM Physics list document**: Late 2016
- **Complete Systematic Sensitivity Studies**: Late 2017/Early 2018
- **Refine Sensitivity Studies**: Mid 2018
- **Contribute to writing the DUNE Technical Design Report (TDR)**: Mid 2018

protoDUNE Experiment

- **Complete DP Field Cage (FC) Design and establish QA/QC Plan**: Late 2016/Early 2017
- **Complete FC submodule assembly, functional prototype testing and shipping**: Mid 2017
- **Detector Installation, Commissioning, and Operations**: Late 2017 - Mid 2018
- **Data Taking and Analysis**: Mid 2018 - 2019
- **Contribute to DUNE TDR**: Mid 2018

SBND Experiment

- **Join the experiment**: Early 2017
- **Detector Construction and Installation**: Early 2018 - Mid/late 2018
- **Commissioning and Opeartion**: Starting Mid/late 2018
- **Data Analysis**: 2019

ICARUS Experiment

- **Installation and Commissioning**: Early 2017
- **Data Taking and Expert Training**: Early 2018
- **NuMI Off-Axis Cross-Sections & Dark Matter Searches**: Early 2019

Plans

In this funding cycle, I will be leading the DUNE program, protoDUNE DP and the ICARUS detector during the construction, installation and commissioning . In particular, I am responsible for assembly, functional testing and installation of the protoDUNE DP field cage (FC). The submodules of the protoDUNE DP FC will be built and tested at UTA and be shipped to CERN for installation by mid 2017. I plan on being stationed at CERN in fall 2017 together with a postdoctoral fellow and a graduate student for installation of them. My schedule will be coordinated with Asaadi to maintain a constant level of PI effort on SBN program and protoDUNE and to maximize the impact of our personnel resources. Once I return to the US from CERN in 2018, I will be focusing on SBN program to ensure the success of these programs and our group's role in SBND and ICARUS experiments on their construction, installation, commissioning and operation. This plan will enable our group to maintain respectful number of personnel on both DUNE and SBN programs and enhance necessary expertise to play crucial roles in construction and eventual physics data analysis of DUNE.

The physics I will focus on in this proposal is the Low-mass Dark Matter (LDM) searches in DUNE and SBN experiments, along with the cross-section analyses across the SBN jointly with Asaadi. In particular, based on the production angle of LDM in high intensity proton beams, it is also feasible to perform a parasitic experiment in ICARUS off of the NuMI neutrino beams. A systematic sensitivity study for DUNE LDM searches will be completed for an inclusion into the DUNE TDR. I will lead the DUNE BSM subgroup to complete systematic and realistic sensitivity studies of various topics within the group to contribute to the DUNE TDR.

PI Summary: Jonathan Asaadi

Accomplishments

LArIAT Experiment

- **LArIAT Co-Spokesperson**: Beginning September 2016
- **LArIAT Analysis Coordinator**: Lead the first measurement of the inclusive π^--Argon cross-section shown in Figure 14 (paper in preparation).

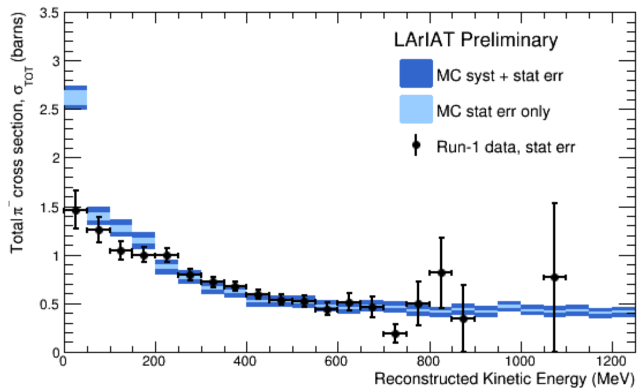


Figure 14: First inclusive π^--Argon cross-section.

MicroBooNE Experiment

- **TPC Commissioning Coordinator**: Developed and executed the commissioning plan for the MicroBooNE TPC
- **Lead TPC Expert**: Develop the expert documentation for the TPC and coordinate the expert shifts
- **Astro-Particle and Exotics Working Group Convener**: Lead one of the MicroBooNE working groups and contribute to a preliminary proton decay background analysis [].

ArgoNeuT Experiment

- **Lead Analyzer on the "Measurement of ν_μ and $\bar{\nu}_\mu$ Neutral Current $\pi^0 \to \gamma\gamma$ Production in the ArgoNeuT Detector"** : First measurement of NC-π^0 production on argon
- **Contributer to "First Observation of Low Energy Electron Neutrinos in a Liquid Argon Time Projection Chamber"**: Paper in preparation

University of Texas Arlington

- **Establishment of Cryogenic Laboratory**: Building a facility capable of purifying and recirculating liquid argon for use in detector R&D and testing.

Milestones

protoDUNE Experiment

- **APA QA/QC Documentation and Testing**: Early 2017
- **Detector Installation, Commissioning, and Operations**: Late 2017-2018
- **Data Taking and Analysis**: Mid 2018 - 2019

SBND Experiment

- **Cold Electronics Test Stand**: Delivery to FNAL Summer 2017
- **Detector Construction**: Mid 2017 - Mid 2018
- **Commissioning and Data Taking**: Starting Mid 2018

- **Cross-Section Analysis**: Preliminary studies beginning late 2019

MicroBooNE Experiment

- **Charged Current Coherent π Analysis**: 2017 - 2019
  - Sensitivity Study: Summer 2017
  - Preliminary Data Analysis for Conferences: Mid 2018
  - Publication Result: Early 2019
- **Data Taking and Expert Training**: 2017 through 2020

ICARUS Experiment

- **Installation and Commissioning**: Early 2017
- **Data Taking and Expert Training**: Mid 2017 - 2020
- **NuMI Off-Axis Cross-Sections**
  - Sensitivity Study: Late 2017
  - Preliminary Data Analysis for Conferences: Late 2018
  - Publication Result: Late 2019

Plans

In this funding cycle, I plan on leading UTA on the SBN program during the construction, installation and commissioning of the various SBN detectors. In parallel, I intend to contribute to the single phase protoDUNE program by being stationed at CERN during the crucial months in the leadup to first beam. By coordinating with Yu, the UTA IF group can maintain a constant PI effort on SBN and protoDUNE and strategically place our graduate students and postdoctoral researchers where the need is greatest during each of the three years. Moreover, by leveraging my start-up I intend to have one post-doc beyond what is requested in this funding to be stationed full time at FNAL during the ramp-up phase of the SBN. This will also help in the training of new detector experts and smooth the transition from commissioning to operations by having a single person present throughout. In tandem, a new remote operation station at UTA will allow researchers to contribute to data taking and expert shifts while still stationed at UTA.

The physics I will focus on during the years of this proposal will be the cross-section analyses across the SBN, as outlined in the subsequent sections. This selection both plays to my experience from ArgoNeuT and LArIAT, where I have lead two cross-section analyses which have been the first of their kind, as well as allows me to produce publication quality results during my early years as an assistant professor. Understanding of the cross-sections is both crucial for the LArTPC detector technology by providing a “standard candle” for reconstruction and identification of events, but also plays a major role in understanding the systematics associated with the flagship oscillation analyses to be performed.

3 The Fermilab Short-Baseline Neutrino Program

The conclusive assessment of the experimental hints of sterile neutrinos becomes high priority for the field of neutrino physics. The Fermilab Short-Baseline Neutrino (SBN) program offers the unique opportunity to definitely address the “LSND/MiniBooNE” anomaly through the utilization of three LArTPCs detectors and well characterized Booster Neutrino Beam (BNB). The SBN program offers a rich physics program with the ability to perform the most sensitive search to date for the existence of sterile neutrinos at the eV mass-scale. The Short-Baseline Near Detector (SBND) will be a new 112 ton LArTPC and serve as the near detector to the SBN program located 110 meters downstream of the BNB target. SBND will measure the un-oscillated neutrino flux from the BNB and enable searches in both the neutrino appearance and disappearance channels. The MicroBooNE detector is an 89 ton active mass LArTPC located 470 meters downstream of the BNB target (just in front of the MiniBooNE experiment). MicroBooNE serves as the pioneer LArTPC experiment on the BNB and will lay the groundwork for the oscillation analysis. The far detector will utilize the upgraded ICARUS-T600 experiment, previously installed and operated at the Gran Sasso Laboratory, and will be located in a new building 600 meters from the BNB target. ICARUS's large detector mass provides the SBN program with the experimental sensitivity to definitively search for the existence of eV mass-scale sterile neutrinos.

3.1 Short-Baseline Near Detector (SBND) (PI: Asaadi, Yu)

The SBND experiment is designed to build upon the many years of LArTPC R&D and serve as a test-bed for the future long baseline neutrino experiment. SBND's design is to construct a membrane cryostat in a new experiment hall located 110 meters from the BNB target. The cryostat will house the full TPC consisting of one central cathode plane assembly (CPA) and four anode plane assemblies (APAs) which will have three wire planes with three millimetre spacing (similar to the ICARUS design) and the first two induction planes oriented at $\pm 30°$ to the beam axis and the final plane oriented vertically. SBND will be a 5.0 m $\times$ 4.0 m $\times$ 4.0 m (l$\times$w$\times$h) TPC with 112 tons of active volume. SBND will also have a light detection system based on a hybrid of the ICARUS cryogenic PMT's and the proposed DUNE light-guide with silicon photomultiplier (SiPMs) on the end. This light detection system will be embedded behind the APA structure on both sides of the TPC.

One new unique aspect of the SBND detector will be the inclusion of the entire front end readout chain being moved into the liquid argon. The front end electronics are composed of 16-channel analogue front end ASIC which provides amplification and shaping, a 16 channel analogue to digital converter ASIC which provides digitization, buffering, and multiplexing as well as a cold FPGA which provides second multiplexing and voltage regulation. This technical improvement in readout electronics will provide improved signal-to-noise as well as allow for the development of an efficient zero-suppression scheme implemented in the FPGA to greatly reduce the total data volume. Many bench tests of the readout electronics have been performed and show excellent performance. The full integration test with an operating TPC, however, has not been successfully performed (given the many problems seen by the DUNE 35ton prototype) and is an absolutely necessary service task the UTA group is planning to spearhead.

3.1.1 SBND Cold Electronics Teststand (PI: Asaadi)

Figure 15 shows a schematic of what a test-stand utilizing the "Blanche" cryostat currently installed at the Proton Assembly Building (PAB)at Fermilab. This cryostat is engineered to have for delivery of purified liquid argon in addition to a system to circulate, re-condense, and purify boil-off argon. An identical cryostat is currently being built and will be delivered to UTA late 2016. This cryostat will work in conjunction with the liquid argon purification system currently in operation at UTA, built using start-up funds from Asaadi, and will allow UTA to play an important role in detector R&D in the coming years.

Inside the cryostat, a small scale TPC equipped with prototype SBND cold readout electronics installed along side a pair of light guide bars can be deployed and read out through a 14" inch cold signal feedthrough as designed for the SBND detector. External to the cryostat, scintillator paddles can be positioned to act as an external trigger. Since the cryostat is a copy of an existing

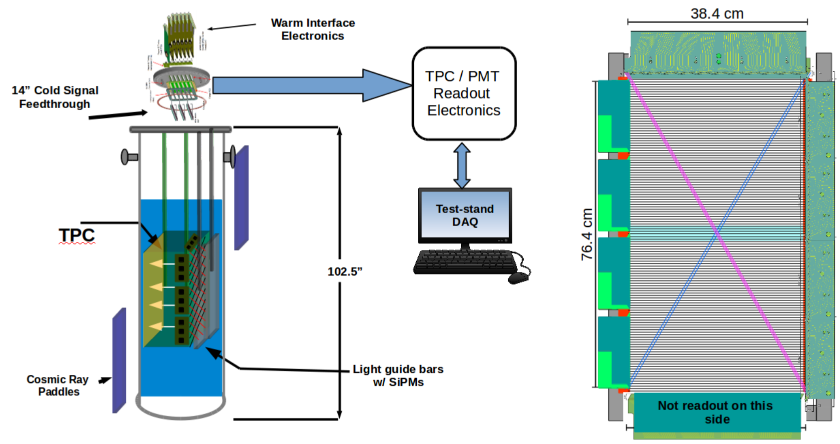


Figure 15: Conceptual design of the SBND cold electronics vertical slice test-stand. Integration of both cold or warm electronics, light collection system, cosmic ray paddles and warm interface electronics allows for a complete testing of the entire readout system prior to deployment in the experiment and to provide a platform for DAQ debugging outside the actual the experiment. The current design has 768 channels (256 collection, 512 induction) utilizing six motherboards for SBND.

one at FNAL, upon the completion of the test the top flange and the TPC detector will be shipped to FNAL for longer term use for SBND (and potentially other future LArTPCs). Additional material costs, such as the electronics, power supplies and cabling are expected to be provided by SBND project funds and Asaadi's start-up funds. A UTA postdoctoral researcher and graduate student will be developing the readout software into a common DAQ software package used by other LArTPC based experiments known as the artDAQ framework. This common platform ensures that the work done by those supported in this proposal can have a greater impact on future planned LArTPCs as well as allowing them to benefit from the work that has already been done by others.

The test-stand enables a robust set of tests for the integration of many newly developed readout electronic components prior to their deployment in the experiment, providing opportunities to discover and fix any unforeseen problems, such as bias voltage line for the TPC wires behaving in an unexpected way and causing pick-up noise, cross-talk between the light detection system and the TPC readout, and the incorrect configuration of electronics settings because of software bugs.

3.1.2 SBND Construction, Installation, and Commissioning (Asaadi, Yu)

The UT Arlington group is positioned to play a major role in the construction, installation and commissioning of the SBND detector and its DAQ system. Given Asaadi's experience on MicroBooNE and LArIAT in which he played a lead role of TPC expert during construction, commissioning, and operations as well as the experience of the post-doctoral researchers already with the group (Falcone on ICARUS and Chatterjee on LArIAT) UTA can offer hands-on leadership during the construction phase of the experiment.

During the construction phase for the TPC (foreseen in mid 2017 through mid 2018), Falcone is expected to be in residence at FNAL and will be spending 50% of his time on SBND. During that same time, a to-be-named post-doc will join him at FNAL with a focus on SBND TPC construction. Having these two present will allow for a rapid ramp-up on the project. At the same time, the cold electronics test-stand is expect to be moved from UTA to FNAL for operations. A graduate student, Zach Williams is expected be on SBND and be in residence at FNAL in the summer 2017. With his time already spent on UTA cold electronics test stand, continuing to contribute to the DAQ development and aiding in the construction and installation of the cold electronics on the TPC will enable him to make significant contributions to the experiment. Asaadi and Yu plan to spend a significant portion of their time at FNAL in the bottom half of 2017 and top half of 2018, respectively, to help oversee these activities and contribute to the construction of the experiment.

Following the construction and installation phase, one post-doc and one graduate student are expected to stay with the SBND experiment, spending a significant portion of their time and play a role as detector experts during the commissioning and initial data taking. The aim here is to share their expertise across the SBN program, but to have a reliable source of experts in residence at FNAL for SBND. While stationed at UTA, graduate and undergraduate students will have the opportunity to take remote shifts on this experiment utilizing UTA's remote shift station currently residing in UTA's cryogenics lab. This remote station has already been used to take shifts on the LArIAT experiment and is currently being commissioned to be able to take remote shifts for the MicroBooNE experiment. UTA group plans on expanding this station to play a role as a sattellite control station for LArTPC experiments, namely MicroBooNE, SBND, ICARUS and DUNE, coming online well in advance of SBND data taking.

3.1.3 SBND Data Analysis (Asaadi, Yu)

SBND will provide important physics measurements during its early operations in addition to providing an overall flux normalization to the key SBN oscillation analysis. SBND will collect statistics very quickly to confirm the nature of the MiniBooNE excess as measured by MicroBooNE. If MicroBooNE were to confirm the MiniBooNE excess as originating from electron-like sources, SBND could quickly determine if there were an oscillation component to the electron-like signal by measuring the rate. Conversely, if MicroBooNE were to determine the MiniBooNE excess as originating from photon-like sources, SBND can cross-check if the source is an unaccounted for beam like background or from cosmogenic like backgrounds. Regardless of the outcome on MiniBooNE excess, SBND will play a critical role as the near detector to the SBN program, collecting high statistics data.

SBND will also provide critical neutrino cross-section measurements at a statistical precision unprecedented by any other LArTPC experiments. SBND will collect approximately two million neutrino interactions per 2.2×10^{20} protons on target, with 1.5 million ν_μ charged current (CC) interactions and 12,000 ν_e CC interactions in one year. With such statistics, many precision cross-section measurements become possible, and improvements on first and second generation analyses from MicroBooNE can be explored in the first year of data taking.

Furthermore, by collecting approximately 100,000 neutral current (NC) π^0 events per year a full characterization of the leading background cross-section to the long baseline CP-violation (CPV) analysis can be performed. Figure 16 shows the only NC$-\pi^0$ result on an argon nucleus from the ArgoNeuT collaboration [**?**]. This analsysis was lead by Asaadi, and thus UTA group is uniquely positioned to lead the next generation analysis with a much larger statistics sample. A significant reduction of this systematic uncertainty in the cross-section will improve the experimental reach of CPV in the future experiments such as DUNE and benifit the short-baseline ν_e oscillation analysis.

3.2 Micro-Booster Neutrino Experiment (MicroBooNE) (PI: Asaadi)

The MicroBooNE experiment is the first detector deployed at the SBN facility and represents the next step in LArTPC technology. It is a 10.3 m $\times$ 2.5 m $\times$ 2.3 m TPC with 89 tons of active

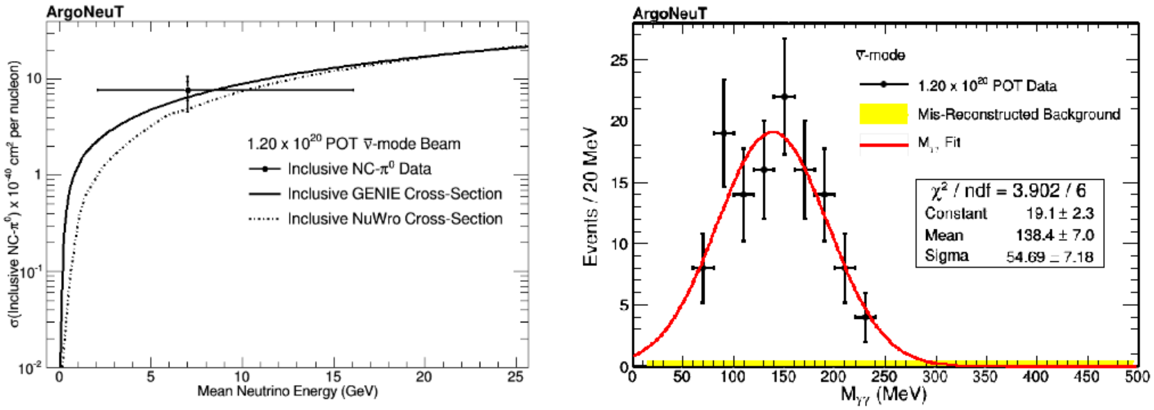


Figure 16: The only existing NC-π^0 measurement on argon from the ArgoNeuT collaboration. Asaadi was the leading analyzer on this result and intends to leverage the large statistics sample to be collected by SBND to provide a low energy measurement of this cross-section, which is a leading source of the systematic uncertainty in both the short and long-baseline oscillation results.

volume. The TPC has three instrumented wire planes with the first two induction planes oriented at $\pm 30°$ to the beam axis and the third plane oriented vertically. Both the pitch and wire spacing are chosen to be 3 mm. Additionally there are thirty two 8” cryogenic photomultiplier tubes (PMTs) which provide the t_0 for an interaction by recording the scintillation light produced when the charged particles interact in LAr. In the summer of 2015 MicroBooNE was filled with LAr and began commissioning. With the rapid success of the system, MicroBooNE has been taking neutrino data starting October, 2015. Figure 17 shows an event display of an automatically identified neutrino candidate event collected by utilizing both light and charge information.

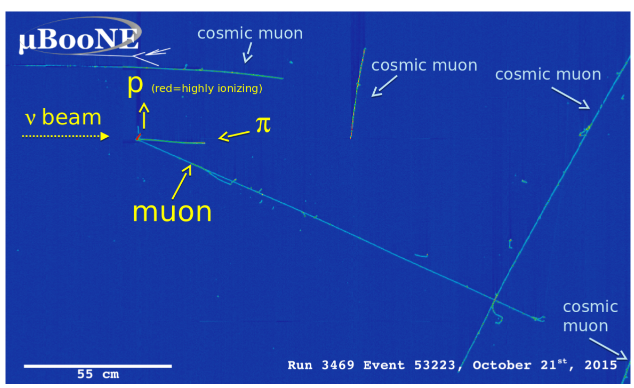


Figure 17: Event display of an automatically identified neutrino interaction utilizing the light and charge readout in MicroBooNE.

One of the most compelling measurements MicroBooNE will make is to confirm or refute the nature of the MiniBooNE low-energy electron neutrino excess. Utilizing the particle identification powers of the LArTPC (specifically the dE/dX discrimination), MicroBooNE will be able to differentiate the electron-like electromagnetic showers from those photon-like. Moreover, the dominant background in the MiniBooNE analysis, NC-π^0 production, can be significantly reduced using the powerful imaging techniques of a LArTPC. The analysis techniques for the low energy excess search will be developed in the common software framework LArSoft. Since LArSoft is designed to be common use of LArTPC experiments, the reconstruction techniques and analysis strategies developed on MicroBooNE will have direct applicability to other LArTPC experiments.

MicroBooNE will also be able to measure many high-statistic cross-sections at $E_\nu < 1$GeV. At this energy range, the impact of various nuclear effects such as final state interactions and short-range nucleon correlation are poorly understood. These nuclear effects can change the classification of neutrino-nucleus ($\nu - n$) interaction, and thus change the measured cross-section. The fine grain tracking offered by LArTPCs allows for the classification of $\nu - n$ interaction in terms of final state particles instead of using simplifications such as the quasi-elastic scattering assumption. Moreover, with a proton threshold measured as low as 21 MeV of kinetic energy [**?**], these nuclear effects can be measured with high statistics using neutrinos as a probe. The broader neutrino cross-section community is anticipating how MicroBooNE results compare to previous measurements.

3.2.1 MicroBooNE Operations

Asaadi will continue to play a major role in the data taking and operations of the MicroBooNE detector. He has served as the TPC commissioning leader and now as the TPC operations expert. Asaadi has only recently stepped down as Astro-Particle and Exotics working group convener, but remains active in this group for the foreseeable future where a natural synergy exists within the UTA group given Yu's role as a DUNE BSM co-onvener. MicroBooNE will explore the physics capabilities of LArTPC including classification of low energy events as a background for supernova neutrinos and searching for cosmogenic backgrounds related to proton decay analysis.

One post-doctoral researcher supported by the funds requested in this proposal will spend part of his/her time working on the MicroBooNE operations and is expected to be trained to serve as the TPC operations expert. This is in addition to the efforts expected from the postdoc supported by Asaadi's start-up funds in the first two years of this proposal. Besides the data taking shift requirements, he/she is also expected to play a role in the online DAQ/data quality management as a training for the planned work on the SBND DAQ described in the previous section. With MicroBooNE just finishing the commissioning of their continuous readout data stream ("supernova data stream"), UTA will be able to play a role in supporting the analysis and further improvement of this system. The graduate student supported by this proposal is also expected to take shifts on MicroBooNE and participate in the expert training. While stationed at UTA, graduate and undergraduate students will take remote shifts on this experiment utilizing UTA's remote shift station described earlier.

3.2.2 MicroBooNE Data Analysis

Being a driving force on early neutrino cross-section analysis is a good way to have impact on the physics program at MicroBooNE. The postdoctoral researchers and the graduate student are expected to work on neutrino cross-section analysis using the early data in addition to the measurements done once the full SBN program is operational. This data set will provide first glimpses into the short-baseline analysis. Following up on previous low statistics cross-sections measured by ArgoNeuT is one way which UTA can have immediate impact and leverage previous experience through Asaadi's major role.

One such cross-section measurement of immediate interest, shown in Figure 18 is the charged current coherent charged pion production (CC Coh-π). This result is of particular interest since it is an example of a relatively simple topology, but one where theory and experiment do not agree. Previous attempts to measure this cross-section at low energy by the SciBooNE and K2K collaborations have been unsuccessful. On the other hand, the analogous neutral current process (NC Coh-π^0)has been observed at low energy. To further complicate this picture, two higher energy measurements from ArgoNeuT and Minerva both show observation of CC Coh-π although somewhat at odds with various modern neutrino generator predictions. In this regard, the initial MicroBooNE data set will be a valuable tool in disentangling this issue and many other cross-section oddities and allow for a better construction of ν-Ar scattering models. Researchers from UTA are expected to play a leading role in the analysis of CC Coh-π data sample in MicroBooNE and begin exploration of the NC Coh-π production. This analysis is expected to build on the work began in ArgoNeuT [?] and builds on the groups expertise for charged pion identification developed through the work in LArIAT.

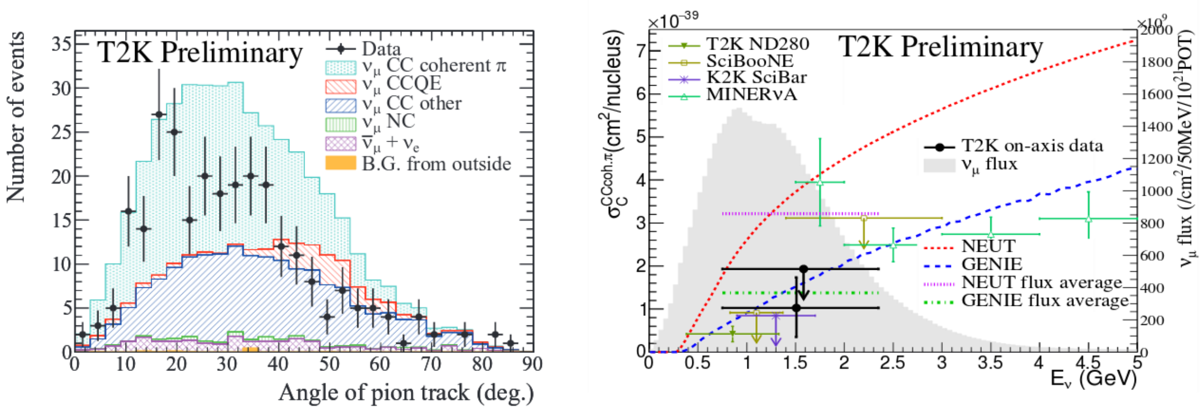


Figure 18: Recent results from T2K [?] showing the tension which exists from the low-energy and high energy measurements of the cCC Coh-π production. With the SciBooNE and K2K experiments showing no evidence of this process at $E_\nu < 1$ GeV but ArgoNeuT and Minerva both measuring this process at higher energy. Moreover, the recent results from T2K disagree with the current cross-section models.

The tools developed for data analysis and reconstruction in MicroBooNE will have transferability to the other SBN LArTPC experiments through the use of the common software package, LArSoft. UTA group has developed expertise on LArSoft with Asaadi contributing to the development and planning of it and will continue to contribute to its further development as a tool to perform a synthesized analysis across the SBN.

3.3 ICARUS Experiment (PI: Asaadi, Yu)

The ICARUS-T600 detector is the largest LArTPC experiment ever actualized containing 760 tons of purified liquid argon (476 tons of active mass). Comprised of two 300 ton modules, each module in the ICARUS detector is comprised of a common cathode and a TPC with dimensions 18.0 m $\times$ 1.5 m $\times$3.2 m (l$\times$w$\times$h). The TPC has three instrumented wire planes with the first two induction planes oriented at $\pm60^\circ$ to the beam axis and the final plane oriented horizontally. Both the pitch and wire spacing are chosen to be 3 mm which provides superb resolution for imaging interactions inside the detector. In 2010, the entire T600 detector was brought online at Gran Sasso where it completed a three year neutrino run in the CERN to Gran Sasso (CNGS) neutrino beam corresponding to 8.6×10^{19} protons-on-target. The successful operation of a large LArTPC experiment in an underground facility with over 90% data taking efficiency (collecting $\sim$3000 neutrino events) and achieving high argon purity and long argon lifetime represents a major technological milestone for LArTPC's. In 2014 the ICARUS-T600 detector was decommissioned and transported to CERN to undergo a refurbishment and upgrade in anticipation of its future non-underground operation at Fermilab's SBN program.

The importance of the ICARUS-T600 to the experimental reach of the SBN program is shown in Figure 19. Plotted is the significance with which an experimental configuration covers the 99% confidence level (C.L.) for the allowed sterile neutrino mixing from the LSND experiment as a function of Δm^2 (the mass difference between the active and sterile neutrinos) for the simplest 3+1 model. The gray bands represent ranges of Δm^2 where LSND result excluded at 99% C.L. The presence of the ICARUS-T600, by providing a large sensitive mass at the far detector location, is absolutely imperative for the SBN program to achieve a definitive (5σ) coverage of the wide range of LSND allowed region.

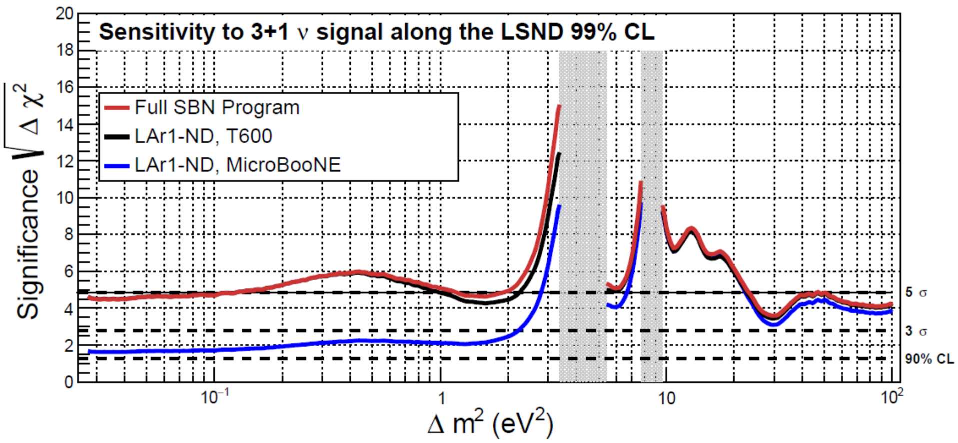


Figure 19: The experimental sensitivity for $\nu_\mu \to \nu_e$ oscillations including backgrounds and systematics assuming a nominal three year exposure in the BNB for the SBND (appears as LAr1-ND in the plot) and ICARUS experiments and a six year exposure for the MicroBooNE experiment.

For these reasons, UTA group has already begun contributing to the ICARUS experiment with the continued stationing of the post-doctoral researcher Andrea Falcone at CERN to continue his contributions to the upgrade of the ICARUS light detection system. The upgraded light detection system is currently being installed with 90-PMTs per TPC providing an estimated 5% photo-cathode coverage. The increased coverage (previously ICARUS has $\sim 1\%$ coverage) will allow for excellent trigger efficiency for neutrino induced events as well as providing cosmogenic background rejection. Falcone is also leading the work to develop the readout electronics for the light detection system and integrating them into the common data acquisition system (artDAQ) used by MicroBooNE and SBND.

3.3.1 Installation, and Commissioning (Asaadi, Yu)

Through the participation in installation, commissioning and data taking of SBND and MicroBooNE as well as leveraging on the experience of Falcone's work on ICARUS, the researchers supported by this proposal will be well positioned to contribute to the installation, commissioning and first data analysis of the ICARUS LArTPC upon its arrival at Fermilab. Having a robust team of researchers based at Fermilab to provide expertise and support for ICARUS experiment will ensure a successful execution of the SBN program.

Falcone is expected to travel with the ICARUS detector when it moves to Fermilab in early 2017 and play a key role in the commissioning the light system DAQ. At the same time he will be training the other UTA (TBN) post-doctoral and graduate researchers on the ICARUS system to ensure a smooth first data taking in mid to late 2017. These detector experts are expected to remain in residence at FNAL during the initial operations of the detector and play a key role in early data analysis. The graduate and undergraduate students resident at UTA will have the opportunity to take remote shifts on this experiment utilizing remote shift station at UTA, described earlier.

3.3.2 ICARUS Data Analysis (Asaadi, Yu)

In addition to providing the necessary sensitivity in the $\nu_\mu \to \nu_e$ oscillation channel, the large mass and long length of the detector allow for more complete containment of high energy muons and electromagnetic showers from $\pi^0 \to \gamma\gamma$ decays. This characteristics of ICARUS and the deployment of a near detector, SBND in the BNB beamline, a complimentary sterile neutrino search looking for ν_μ disappearance as well as NC disappearance becomes possible. Contributing to both of these osciallation analyses is a natural fit for the UTA group given its efforts on MicroBooNE and SBND cross-sections measurements. The extended length of the ICARUS-T600 detector provides better π/μ separation (since pions have a higher cross-section to interact) and more accurate muon energy reconstruction (since more muons will be fully contained), increasing the sensitivity in the ν_μ disappearance channel.

Similarly, by targeting a clearly identifiable neutral current process (such as NC$-\pi^0$ production) the disappearance rate can be measured at both the near (SBND) and far detector (ICARUS) to search for the sterile neutrino signature in a complimentary way to the ν_e appearance. ICARUS's large volume ensures near complete photon shower containment and thus increases the statistics available for a NC$-\pi^0$ disappearance search.

On top of the three detector SBN program, the stand-alone T600 detector can offer physics insights through the study of neutrino cross-sections at energies pertinent to future neutrino experiments, such as DUNE. The ICARUS experiment can do this because it will see a significant off-axis component of the neutrinos from the Main Injector (NuMI) beam. The NuMI beam uses 120 GeV protons to produce a higher energy neutrino beam than the BNB. ICARUS is expected to collect one neutrino event every 150 seconds from the NuMI beam in the energy range of 0-3 GeV. Such high energy neutrino cross-section data on an argon target will provide valuable input to the DUNE experiment and offer experimental measurements of detector efficiencies and event reconstruction techniques at these higher energies. The neutrino energy distribution for ν_e and ν_μ charged current interactions from the NuMI beam in ICARUS is shown in Figure 20.

In addition, given its location with respect to the NuMI beam-line, it is also possible to explore searching for low-mass dark matter (LDM) produced in the NuMI target with a dramatically reduced neutrino background. Synergistic to UTA's role in the DUNE BSM physics group, ICARUS provides an excellent opportunity to search for LDM using the 750kW high power proton beams at NuMI beamline and the off-axis nature of the ICARUS.

4 The Fermilab Long-Baseline Neutrino Program

Precision neutrino oscillation measurements are the cornerstone of the long-baseline neutrino program. Utilizing beams of neutrinos fired over long distance allows for the enhancement of these measurements via matter effects. These effects lead to a asymmetry between $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation probabilities. This effect allows for the probing of CP-violating effects as well as the determination of the neutrino mass hierarchy.

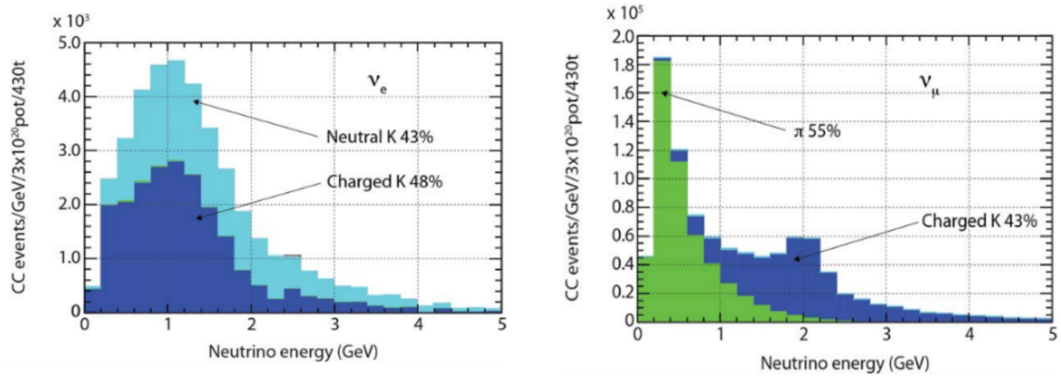


Figure 20: Neutrino rates taken from Reference [] for the NuMI beamline for one year of exposure ($\sim 3.0 \times 10^{20}$POT. Left: CC-ν_e energy distribution originating from kaon decay. Right: CC-ν_μ energy distribution with one component coming from pion decay and another broader distribution coming from kaon decay. These interaction energies are especially relevant as input to the DUNE experiment.

4.1 Deep Underground Neutrino Experiment (DUNE) (PI: Asaadi, Yu)

The Deep Underground Neutrino Experiment (DUNE) [**?**] will utilize massive LArTPC's to measure the CP violating phase (δ_{CP}) in the neutrino sector and determine the neutrino mass hierarchy. DUNE will use a high power proton beam capable of producing a large number of neutrinos and antineutrinos directed from Fermilab towards massive underground LArTPC detectors located in the Sanford Underground Research Facility (SURF) in Lead, South Dakota. By measuring the asymmetry between appearance of ν_e from a beam of ν_μ compared to the appearance of $\overline{\nu}_e$ from a beam of $\overline{\nu}_\mu$ as well as the precise measurement of the ν_e energy spectrum at the far detector, the measurement δ_{CP} and the determination of the neutrino mass hierarchy can be done in the same experiment. In order to achieve these goals, DUNE will require three essential components:

1) High power neutrino beam:

   A neutrino beamline designed to provide sufficient intensity in an energy range to enhance the sensitivity to the first and second oscillation maxima. The beam comes from a conventional, horn-focused neutrino beamline generated from 60 GeV - 120 GeV protons from the Fermilab Main Injector designed for initial operation at proton-beam power of 1.2 MW with the capability to support an upgrade to 2.4 MW. The beam will be sign-selected to provide separate neutrino and antineutrino beams to enable measurement of δ_{CP} and the neutrino mass hierarchy as well as precision measurements of oscillation parameters.

2) Large mass underground far detector:

   The far detector is designed to be a 40 kt LArTPC consisting of four 10 kt detectors. These detectors will be stationed 4850 feet below the surface in caverns located at SURF in order to reduce the number of cosmic rays in time with the neutrino beam to $\sim$1% of the expected background. These detectors are capable of precision $\nu_\mu/\overline{\nu}_\mu$ and $\nu_e/\overline{\nu}_e$ identification and energy measurements to provide definitive measurement of δ_{CP} and mass hierarchy.

3) Precision near detector:

   The near detector, which is exposed to an intense flux of neutrinos, also enables a wealth of fundamental neutrino interaction measurements. The current reference design for the DUNE near detector includes a NOMAD-inspired [?] fine-grained tracker consisting of a 3.5 m$\times$3.5 m$\times$6.4 m central straw-tube tracker, a lead-scintillator sampling electromagnetic calorimeter, a 4.5 m$\times$4.5 m$\times$8.0 m large-bore warm dipole magnet surrounding the straw tube tracker and the calorimeter providing a magnetic field of 0.4 T, and RPC-based muon detectors sandwiched in the steel of the magnet as well as upstream and downstream of the tracker.

In the subsequent sections, we describe in detail the project listed in the strategic plans. The primary goal of the projects listed in this section are to ensure the group to play leadership role in construction of first two 10 kt modules of DUNE as well as in physics topics of the group's interest.

4.1.1 ProtoDUNE Single Phase APA QA/QC (PI: Asaadi)

Given that the highest priority of DUNE is to establish and demonstrate the functionality of its baseline technology, namely the single phase LArTPC, Asaadi will be focusing on the quality assurance, quality control, and commissioning of the anode plane assemblies (APA's) for protoDUNE SP. This work will help building up infrastructure, expertise, and capabilities necessary to contribute and lead in the DUNE SP far detector construction. He plans on resident at CERN in the first half of 2018 coordinating with Yu in order to make contributions to both protoDUNE experiments and to manage UTA IF personnel during the construction and installation period of protoDUNE experiments.

The QA/QC testing plan being developed in collaboration with Univeristy of Wisconsin's Physical Science Laboratory (PSL, who are building the APA's) and the DUNE APA conveners (Tim Bolton and Mitch Soderberg) will be first executed at the construction site (PSL) and then again at CERN prior to installation. UTA members will be present during the testing both at PSL and CERN to aid in the successful installation and commissioning of the SP protoDUNE experiment. The testing plan developed for the protoDUNE SP is intended to have applicability to UTA's efforts on DP, where common technology is present.

4.1.2 Field Cage for protoDUNE Dual Phase (PI: Yu)

Field cages provide uniform electric fields for ionization electrons to drift to anodes for the detection in the Time Projection Chamber. The baseline design for DUNE LArTPC is that of the single phase in which the ionization electrons created by the secondary particles resulting in neutrino-nucleon interactions drift in LAr and get detected on the anode plane that resides inside the liquid phase of argon. An alternative design is the dual phase design in which the ionization electrons drift vertically and then be extracted into the gaseous phase of argon for an amplification through a large area gas electron multiplier (LEM). The dual phase detector provides a complementary technology with a potentially lower energy threshold and pixelated readout which eliminates degeneracy associated with wire based readout.

During Yu's sabbatical at CERN in Sept. 2015 through May 2016, he began working on the WA105 $1m \times 1m \times 3m$ prototype. This work provided an opportunity for Yu to join the WA105 collaboration and begin work on the larger $6m \times 6m \times 6m$ prototype as the first U.S. collaborating institution. The large scale dual phase technology is still in the R&D phase with many technological challenges to be overcome and thus is currently a lower priority compared to the single phase LArTPC effort. However, U.S. participation in this effort is beneficial to the development of the dual phase detector alternate technology and strengthening the international nature of DUNE collaboration, an essential ingredient in its success.

UTA aims to play a lead role in the in the design and construction of the protoDUNE experiments and thus allow us to gain the expertise to contribute to the construction of the first DUNE far detector module in the early 2020's. The dual phase field cage (FC) is an example of a component of the dual phase and single phase detectors where common aspects of the detector design and construction can be found. Yu, with input from DUNE management, has agreed to take on the responsibility for the design and construction of the dual phase field cage in collaboration with the University of Zurich, CERN, and Fermilab.

Figure 21 shows the current conceptual design of the FC for the DP protoDUNE experiment. The concept is to use a compartmentalized structure of sub-modules that consist of several straight profiles to provide voltage differentials for the generation of a uniform drift field in the bulk liquid argon. The use of straight profiles made of either aluminum or stainless steel makes the pre-assembly and shipment of sub-modules convenient, efficient and potentially cost effective.

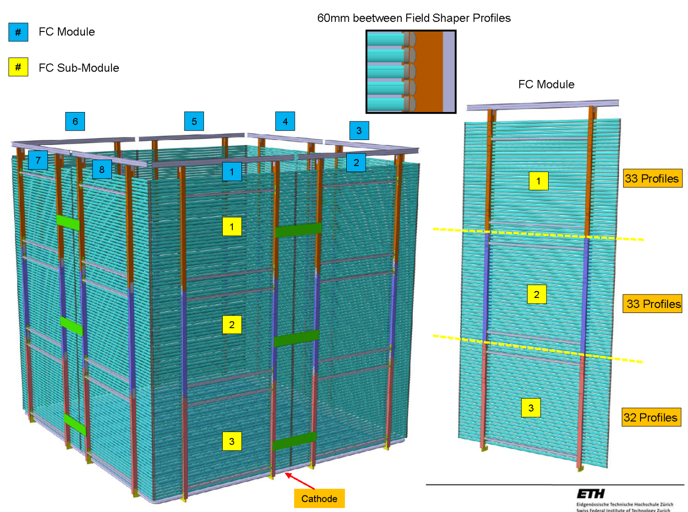


Figure 21: Conceptual schematic drawing of the field cage assembly for dual phase protoDUNE. Three sub-modules make up one module, two of which covers one $6m \times 6m$ side. Total of 6 modules, 18 sub-modules are needed.

At present, it has been agreed that either CERN or Fermilab will be responsible for purchasing and production of the necessary mechanical parts, including the I-beams that act as the spine of the sub-module and the profile. The DUNE project funds will be used to purchase the electrical parts: voltage divider boards, resisters and varistors for surge arresting, and the production of electronic boards the field cage. UTA will work in collaboration with the single phase field cage groups (Brookhaven Labs, Stony Brook University, and Louisiana State University) as well as University of Zurich to design the mechanical and electrical components of the dual phase FC. UTA will be responsible for pre-assembly of the sub-modules, mounting and testing of electrical components, and a functional prototype testing in as large a field cage sub-module as possible prior to shipping to CERN for installation.

Our postdoctoral researcher, Animesh Chatterjee will be stationed at CERN starting from October 2016 through mid January 2017 to work with the Zurich and CERN groups to finalize both mechanical and electrical designs of the FC for DP protoDUNE and to help leverage commonality with the SP design as much as possible.

The protoDUNE time scale has a hard deadline to complete beam data taking before the scheduled LHC heavy ion run in October 2018. Therefore, it is essential for our group to contribute early in the process, as outlined in our strategic plan. To meet these goals, Yu plans on staying at CERN bottom half of 2017, utilizing the remaining funds from the agreements with LAPP and ETH to cover the costs for local stay at CERN and the teaching buyout, respectively. A UTA postdoctoral fellow will also be stationed at CERN together with a graduate student to help with both single and dual phase protoDUNE installation and commissioning. Yu will then return to the US early 2018 at which time Asaadi will be stationed at CERN for the first half of 2018 to continue the effort on the protoDUNE experiments.

We believe this task will help UTA to build up necessary infrastructure for field cage construction in preparation for the first two 10kt modules of DUNE and strengthen our position to make essential contribution to the success of DUNE.

4.1.3 Beyond the Standard Model physics group leadership (PI: Yu)

In addition to the standard neutrino physics topics, neutrino mass hierarchy and CP violation phase measurements in the neutrino sector, the required high intensity proton beams provide ample opportunities for DUNE to look for physical phenomena beyond the Standard Model. UTA has been the leading proponent in searching for Low mass Dark Matter (LDM) in high intensity proton beams from the start of the IF group in 2014. For this work, Yu has been leading the BSM physics working group of DUNE since its inception in 2015 and has grown the group to play a significant role within the collaboration. Yu plans on ensuring various BSM topics be included in the DUNE Technical Design Report (TDR) to be released in summer 2019.

In order to coordinate the group in an effective manner, Yu quickly organized the group into five subgroups based on primary physics interests and to provide necessary simulation and analysis tools specialized to support the BSM group physics analyses. The five subgroups are the simulation and software group led by UTA's postdoctoral fellow, Chatterjee and four physics subgroups that cover LDM search (Yu, Chatterjee), the Sterile Neutrino Search, the Non-standard Neutrino Interactions searches and Heavy Neutrino searches. Additional physics topics would continued to be added to the group's interest but these four physics topics are the primary topics to be studied in the coming 1.5 to 2 year time scale with the goal to provide the results for DUNE TDR. In preparation for TDR, the group plans on producing a document that contains the initial list of topics and tasks to complete to provide sensitivity studies for TDR, along with the milestones for the group to follow, by the end of 2016.

4.1.4 Search for Low-mass Dark matter (PI: Yu)

As described in Section III, high power proton beams necessary for high flux neutrino beams enable experiments to search for BSM phenomena. The particular interest of our group is the potential for discovering LDM particles in high precision detectors. The LDM particles produced in the target through the decay of a mediator (e.g. dark photons) can be detected through neutral-current like interactions either with electrons or nucleons in the detector. Since the signature of DM events looks just like those of the neutrinos, the neutrino beam provides the major source of background for the LDM signal.

Several ways have been proposed to suppress neutrino backgrounds by using the unique characteristics of the DM in the beam. Since DM will travel much slower than the neutrinos, due to its much higher mass, the arrival time of the LDM signal in the detector can be used to distinguish LDM from neutrinos. Additionally, since the electrons struck by LDM will have a more forward direction than those from neutrino interactions and the scattering angle of the electrons from the interaction may be used to reduce backgrounds, taking advantage of fine angular resolution a LArTPC can provide. Finally, a special run can be devised to turn off the focusing horn to significantly reduce the charged particle flux that will produce neutrinos. A major goal of the study currently underway is ensure the inclusion of the sensitivity estimate in a near detector to DUNE TDR.

Finally, given the large mass of ICARUS detector and its off-axis location with respect to the NuMI target, it may also be feasible to search for LDM from the NuMI beam. Since ICARUS is single phase LArTPC, such a study in ICARUS will enable a more realistic and systematic study in preparation for the search in DUNE.

4.1.5 Beam Optimization and Hadron Monitor for LBNF (PI: Yu)

UTA group has been contributing to beam simulations for optimization and systematic uncertainty studies of the Long Baseline Neutrino Facility (LBNF). All new students joining the group are required to learn ROOT and G4LBNF, the GEANT4 based beam simulation package, as part of their training process. Since most of these tasks are well defined, each student can be assigned to the given task and write up the report after the completion. Many undergraduate students were able to make useful contributions in these tasks and made presentations at beam simulation group meetings. We plan on continue contributing to the beam simulation group's tasks for various studies, including an improved decay pipe radius dependence of CPV sensitivity, target dimension and material dependence of neutrino flux and magnetic field map computations and display. The three new undergraduate students will be assigned of additional tasks that are helpful for beam optimization group based on the discussion with the leadership of the group. This will allow students to continue improving their analysis skills while working on hardware projects described below and prepare them for participating in data analysis in SBN experiments described in previous sections. As part of this effort, Yu will work closely with LNBF group on development of hadron monitor, an essential element for understanding neutrino flux and reducing systematic uncertainties from it.

Part IV

Research in Detector R& D

The UTA high energy physics group has a long history of detector development. Kaushik De and Andrew White had leadership roles in the design and construction of the Dzero Intercryostat Detector and the ATLAS Intermediate Tile Calorimeter, while Andrew Brandt proposed and led the design and construction of the Dzero Forward Proton Detector.

The primary detector R&D topic of the UTA group for the past several years has been Brandts work designing the timing detector for the ATLAS Forward Proton (AFP) detector, In the past few years the focus has been on characterizing, and testing microchannel plate photomultiplier tubes (MCP-PMT) with a goal of developing tubes that are capable of picosecond-level operation for extended periods in a high rate environment. These studies have previously been supported by the Texas ARP program 2007, DOE ADR awards in 2008 and 2012, an NSF SBIR Phase 1 proposal in 2011, and ATLAS R&D funds in 2013. Brandt is currently in the second year of a two-year DOE R&D grant dedicated to MCP-PMT lifetime studies.

This proposal consists of two distinct initiatives. In the first, Brandt proposes to complete development of an improved lifetime measurement method and apply it to new long life MCP-PMTs. This would then segue into studies of the Large Area Picosecond Photodetector (LAPPD) [**?**] products, namely a 6 cm $\times$ 6 cm MCP-PMT being produced at Argonne National Lab and also the 20 cm $\times$ 20 cm flat panel MCP-PMT under development at Incom Inc. [**?**]. The emphasis would be applying accelerated cost-effective lifetime measurement methods to these large-area devices.

The recent addition of senior faculty detector expert David Nygren along with junior faculty Ben Jones and Jonathan Asaadi has opened up a new area of detector R&D at UTA, namely scintillation light from noble elements (xenon gas/liquid argon). The synergy between the high pressure xenon gas focus of Nygren and Jones (with interest in applications in neutrinoless double beta decay), and the that of liquid argon and Asaadi (with application in neutrino oscillation experiments) is obvious and is outlined below. The two topics detailed in the following narrative are linked through the sharing of equipment and facilities and the varied backgrounds and experience of the researchers.

PI Summary: Benjamin Jones

Accomplishments

High Pressure Xenon Gas R&D

- **SMFI Barium tagging**: Demonstrated barium-ion induced response of SMFI dyes; Wrote a conceptual paper on new barium tagging technique [70].
- **HPGXe gas system**: Design and construction for barium tagging R&D and xenon detector development at UTA.

Liquid Argon R&D

- **Bo test stand and LAr optical properties**: Assembled and operated the Bo Vertical Slice Test [71], characterizing the MicroBooNE optical system from PMT to readout electronics in liquid argon, and now used for DUNE studies. Measured and published effects of dissolved nitrogen [72] and dissolved methane [73] on liquid argon scintillation light.
- **Contributions to MicroBooNE optical systems**: Developed the MicroBooNE optical system from design to deployment [74]. Proposed and installed the MicroBooNE flasher subsystem

for PMT calibration [75].

- **Light-guide detectors for LArTPCs**: Contributed to first demonstration of light guide detectors for LArTPCs [76, 77]. Performed R&D on chemistry and optimization of wavelength shifting coatings [78, 79]. Developed accurate calculations of light propagation [80].
- **High-voltage Protection for LArTPCs**: Proposed, tested and installed the MicroBooNE surge protection system, the first system of its kind to be implemented in a cryogenic detector [81].
- **Author of LArSoft optical physics simulation**: Primary author of the LArSoft optical simulations, used for MicroBooNE, DUNE, LArIAT and SBND experiments.

IceCube Experiment

- **Sterile neutrino analysis**: Lead analyzer in the IceCube search for sterile neutrinos, which set the worlds strongest limit, rejecting sterile neutrinos allowed by appearance experiments including MiniBooNE and LSND at 99% confidence level [82].

Milestones

SiPMWheel

- **Manufacture long-attenutation length plate coatings**: Late 2017
- **Quantify plate performance in air**: Late 2017-Early 2018
- **Build xenon test stand for electroluminescence light tests**: Late 2018
- **Detailed study and experimental optimization of plate detectors**: 2019
- **Quantification of performance for ton-scale HPGXe detector with simulation**: 2019-2020

Plans

As a new faculty member at UTA, I am involved in two primary research activities: 1) exploitation of beyond-standard-model neutrino physics capabilities of the IceCube detector, 2) development of high pressure xenon gas detectors for neutrinoless double beta decay. The latter activitiy involves aspects of detector R&D which have major symbioses with the needs of the DUNE and protoDUNE detectors. As evidence of this, my past experience with liquid argon detectors is already proving to have a high degree of relevance for the challenges of realizing ton-scale high pressure xenon gas detectors. Particular areas of overlap include light collection and high voltage distribution, where I have significant expertise. Technology developed for pressure xenon gas detectors is equally expected to provide advances for liquid argon TPC detectors. In the case of optical detection, these advances are much needed to achieve DUNE's ambitious low energy physics goals.

Thus, in collaboration with the liquid-argon-focused intensity frontier group at UTA, I intend to develop the presented generic photon detector R&D concept, which will be of relevance for all detectors which rely on noble element scintillation light. This collaborative R&D research will be undertaken alongside work on the NEXT experiment and also the IceCube experiment, both to be funded from other sources. At the end of this three year cycle, we plan to have optimized and demonstrated this concept in both liquid argon and xenon gas, and simulated its applicability for kiloton-scale LArTPC and ton-scale HPGXe detectors.

PI Summary: David Nygren

Accomplishments

Invention of the Time Projection Chamber

- Demonstration of strong diffusion suppression over long drift distances using parallel drift and magnetic fields in high-pressure argon-methane.
- First demonstration of full 3-D track capture in a large system
- First realization of asynchronous waveform sampling using linear analog CCD.
- Worlds best particle identification using truncated dE/dx method
- Spokesman for PEP-4

Creation of high-pressure xenon TPC concept to search for neutrinoless double beta decay,

- Based on an electroluminescent gain stage for excellent energy resolution.
- High-pressure gas offers detailed event topology information that facilitates gamma-ray rejection factors approaching 10^7.
- Co-spokesman of the NEXT Collaboration.

Invention of column-based pixel array architecture for high-luminosity applications

- used in ATLAS, CMS, and other applications (with Jacques Millaud, LBNL)

Invention of low-dose mammography system

- Based on x-ray quantum-counting with edge-on silicon strips in slot-scan geometry. High detection efficiency with excellent scatter rejection yields a factor of three smaller dosage to tissue.
- In clinics.

First proposed development of astronomy-grade deep-depletion large-format CCDs using high-purity silicon at LBNL

- (realized by Steve Holland, LBNL).

Invention of a directional dark matter (WIMP) concept based on columnar recombination in a dense gas.

- Track and external electric field alignment leads to enhancement of possible scintillation signal from recombination, with corresponding depletion of ionization signal.

Conceived and led design for first deployment of novel waveform capture technology for high-energy neutrino astrophysics deployed in a deep ocean setting (NESTOR).

- Based on novel ultra low-power ultra-high speed high-dynamic range waveform capture circuitry.

Conceived and led design of novel waveform capture technology for KamLAND

- Exploiting same novel low-power ultra-high speed high-dynamic range waveform capture circuitry.

Conceived and led the electronic design of a decentralized electronic architecture with an all-digital network for ultra-high energy neutrino astrophysics for IceCube, a $270M project at the South Pole.

Milestones

SiPMWheel

- **Manufacture long-attenutation length plate coatings**: Late 2017
- **Quantify plate performance in air**: Late 2017-Early 2018
- **Build xenon test stand for electroluminescence light tests**: Late 2018
- **Detailed study and experimental optimization of plate detectors**: 2019
- **Quantification of performance for ton-scale HPGXe detector with simulation**: 2019-2020

Plans

I intend to supervise two undergraduate students who will work on this topic to gain research experience and provide additional manpower for simulation and hardware tasks. The project will utilize the high pressure xenon gas system which has been constructed in our lab for detector development, targetted at NEXT. Members of the group will provide support to adapt this aparatus to this cross-cutting detector R&D project.

5 SiPMWheel (Asaadi, Jones and Nygren.)

5.1 Introduction: A large-area, position-sensitive, energy-resolving light collector

The designs of scintillation light collection systems for noble element time projection chambers (TPCs) are driven by two main requirements:

- Photons with very short wavelengths (128 nm in Ar, 175 nm in Xe) must be collected.
- Large surface areas must be instrumented to collect as much light as possible, with a channel count kept low in order not to drive up the system cost.

Although some VUV-sensitive light detectors are available [83, 84], their quantum efficiency at these wavelengths is typically not high, and their surface area per channel is not large. To sensitize visible light detectors to VUV photons a wavelength shifter is often employed, absorbing in the UV and emitting in the visible. A common choice is tetra-phenyl butadiene (TPB) [79, 85–90]. A fraction of the visible light thus emitted can then be detected by a standard photon detector like a silicon photomultiplier (SiPM) or a photomultiplier tube (PMT). Several geometries have been considered, including through-plate systems [74, 91], high-reflectivity foils [92, 93], and light-guides [76, 77, 94]. Light guide systems have the advantage that large areas can be sensitized with only a moderate channel count. However, they have the disadvantages that light losses through non totally-internally-reflected rays, and surface scattering and re-absorption effects [80] are significant, and that the collection efficiency depends on the geometrical position of light arrival, making calorimetric reconstruction of localized events difficult.

We propose to develop a new large-area wavelength-shifting detector based on the light-guiding concept, with significantly improved collection efficiency and calorimetric performance. This concept is motivated by the needs of the NEXT neutrinoless double beta decay experiment [95] and by low energy physics analyses such as those of supernova neutrinos, proton decay and solar neutrinos in large liquid argon TPC detectors like DUNE [96, 97]. The pervasiveness of noble-element TPCs in particle physics is so widespread that light collection solutions with strong position and / or strong calorimetric resolution potential are likely to be widely applicable. Use cases as a primary scintillation detector may include noble element dark matter searches and other surface and underground liquid argon TPC detectors; and as an electroluminescent energy plane may include the DUNE two-phase far detector and possible argon gas near detector.

5.2 Research team, existing facilities, and details of request

This project will be led by Profs. Jonathan Asaadi, Ben Jones, and David Nygren at UTA. It will make use of existing liquid argon and high pressure xenon gas purification systems which are already operational at UTA and shown in Figure 22.

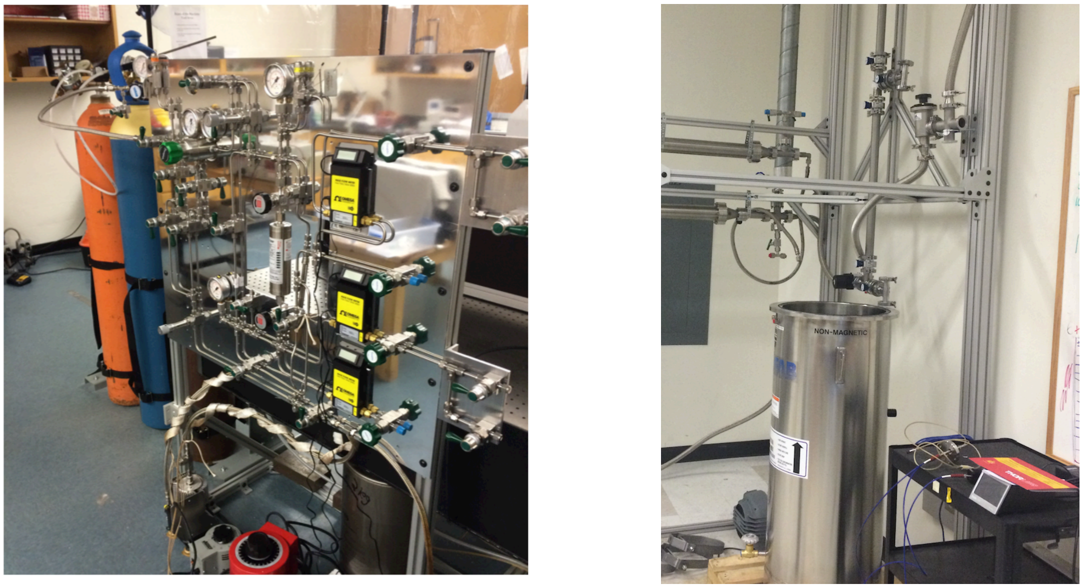


Figure 22: Left: Existing high pressure xenon gas purification and recirculation system in the lab of Nygren and Jones. Right: Existing liquid argon purification system in lab of Asaadi.

This project also leverages the experience of these researchers. Nygren is the inventor of the time projection chamber [98] and a pioneer of electroluminescent xenon detectors for neutrinoless double beta decay [95,99–103]. He is spokesperson of the NEXT collaboration and developed a test stand that demonstrated energy resolution near the intrinsic limit of xenon gas [104] (1% FWHM at 662 keV), the worlds most precise energy resolution from a xenon detector. Asaadi is a prominent member of the MicroBooNE [105], SBND [106], DUNE [107] and LArIAT [108] collaborations, with expertise in liquid argon TPC detector design, development and construction [81]. Jones has extensive experience in noble element light collection, including the developing "Wunderbar" light-guide detectors for large LArTPCs [76,77,80]; assembling and operating the Bo liquid argon optical test stand at Fermilab [71–73]; exploring wavelength shifter properties and photochemistry [79]; and simulating light in liquid argon [80, 109].

Most supporting equipment for this project is already available or will be purchased from University funds, including the test stands, data acquisition systems and SiPMs, all of which were already acquired for other projects. To pursue this research we request support for:

1. Personnel: one FTE graduate student (in the form of two students at 50% effort level each), and two part-time undergraduate.

2. M&S costs: to include argon and xenon supply, as well as fluors and plate materials, SiPM board development and printing, connectors, cables and mechanical parts.

5.3 Detection concept and comparison to existing devices

The detector we plan to develop will use an array of silicon photomultipliers (SiPMs) coupled around the perimeter of a TPB coated plate. As with bar-type light-guide detectors (hereafter referred to as "bars"), shown in Figure 23, top, VUV photons absorbed at the coating surface are re-emitted in the blue, some of them into the totally internally reflected modes of the polymer plate. In contrast to bar detectors, the SiPMWheel is instrumented at many points around the perimeter.

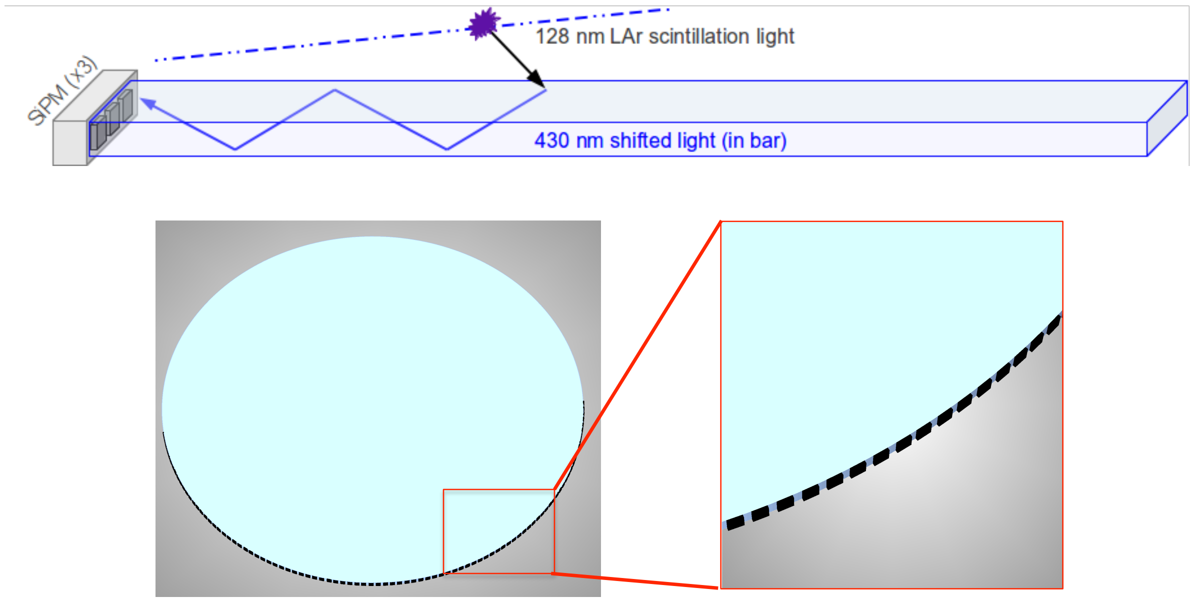


Figure 23: Top: Example of operation of bar detectors, like the "Wunderbar" - image from [110]. Bottom: Drawing of plate detector we propose to develop.

This provides significant advantages which we hope to demonstrate: 1) the sensitive surface area is maximized relative to the allowed path-length between emission and detection, which optimizes light collection efficiency against losses during propagation; 2) the fraction of solid angle outside the totally internally reflected range is much reduced, leading to a higher trapped light yield 3) by reading out all SiPMs, geometrical information about the event can be extracted - as well as being intrinsically useful, this position information allows for a correction to be applied to improve calorimetric response.

In this section we derive some quantitative comparisons between our proposed SiPMWheel detector and the more typical bar-type geometry. We assume the same coating properties can be achieved over a 2D surface for both plates and bars (fabrication of the "Wunderbar" is easily generalizable [76]) and that the bar length / plate radius are free parameters to be optimized for each device.

When comparing different light collection technologies it is important to define a useful Figure of merit (FOM). The following FOMs, though by no means exclusive, appear to represent reasonable ways to assess the light collector performances for our intended use cases:

1. For illumination by a distant light source, how many photons can be captured per SiPM?
2. For illumination by a distant light source, how many photons can be captured per detection unit (one plate or one bar with many coupled SiPMs)?
3. For illumination by a distant light source, how many photons can be captured per unit surface area?
4. For localized light deposits at different positions near the surface, what is the collection efficiency and how uniform is it?

The parameters of the detector geometry may be optimized differently to satisfy each criterion for both bar and SiPMWheel detectors. As simplifying assumptions we assume that the thickness of

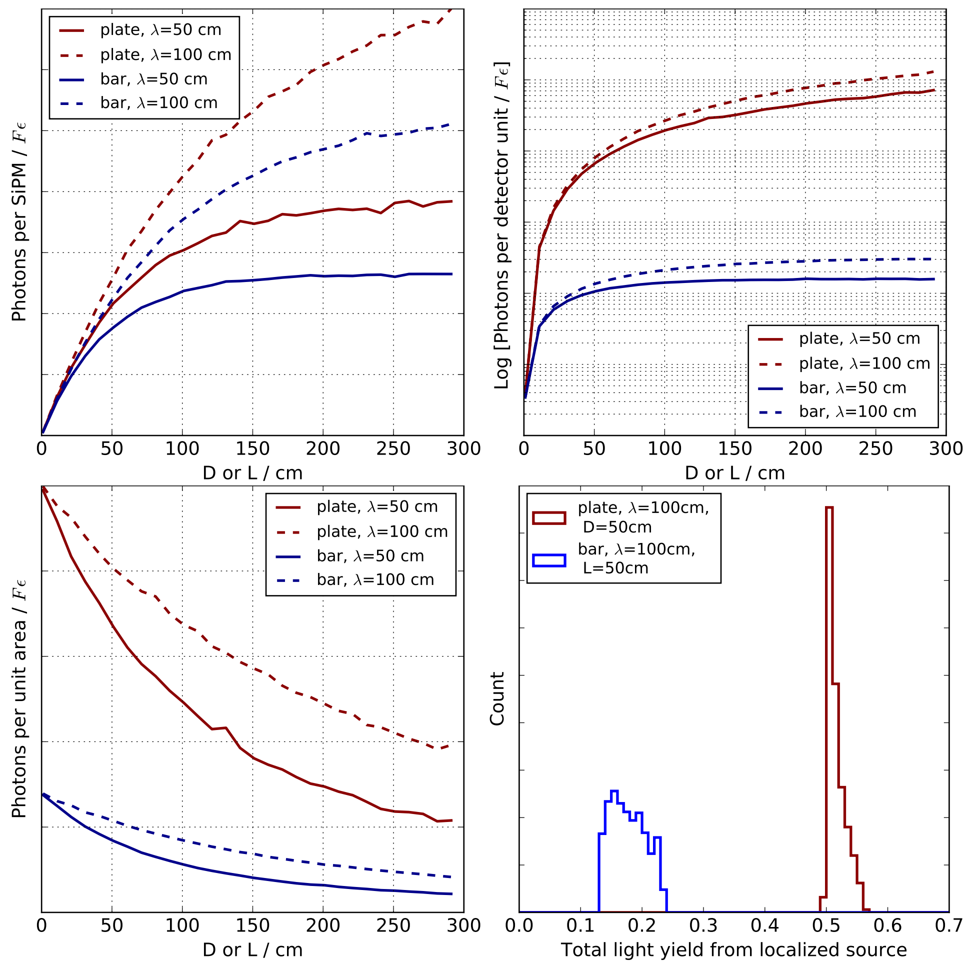


Figure 24: Comparison of plate-type to bar-type detectors with various figures of merit described in the text. The plate significantly outperforms the bar-type detector in all cases. Top left: photons per SiPM. Top right: Photons per detector unit. Bottom left: Photons per unit area. Bottom right: total yield and spread from localized mono-energetic sources.

the plastic sheet used to make both the bar and plate is equal to the SiPM width, which we take to be 5mm. We assume both can be prepared with the same coating quantum efficiency ϵ, are cut from the same material (acrylic with refractive index n=1.5), and that attenuation in the light guide is exponential in light-ray length parallel to the coated surface (this is known to be invalid at very short distances but is a reasonable approximation for longer path lengths [80]). We consider two values of the parallel attenuation length λ that appear reasonable based on past studies, $\lambda = 50$ cm and $\lambda = 100$ cm [76, 80]. Finally we assume that the 5 mm SiPMs are placed with 5 mm spacing between each, which gives three SiPMs per bar, or as many as can fit around the radius of the plate detector. The FOMs above are compared using the output of a simple ray tracing simulation.

FOM (1) is compared in Figure 24, top left. For both detector types, the collection efficiency increases as the device becomes larger, saturating at a distance comparable to the attenuation length, as expected. The plate-type detector has consistently higher collection efficiency and a higher saturated value. This is primarily due to the loss of supercritical rays in the bar detector, which the plate detector does not suffer from.

Whether the most useful Figure of merit is the light yield per channel or the light yield per detector unit depends on which factor is limiting in the experimental design or budget. A moderate improvement in FOM (1) corresponds to an enormous improvement in FOM (2) because each plate detector has a large number of SiPM channels, whereas each light guide detector has only 3. This comparison is shown in Figure 24, top right (note log scale). The improvement in FOM (3), the light collected per unit area, is intermediate between these two cases, and is shown in Figure 24, lower left. In all cases, our proposed detector represents a major improvement.

FOM (4), the stability of the light yield for light at different locations, is quantified in Figure 24, lower right, which shows example total light yield distributions for localized deposits in random positions across a device with 50 cm length / diameter and 100 cm attenuation length. Note that no photon counting fluctuations are included in these distributions - they show only the changing light yield due to differences in the detector response at different locations. Though much improved over the bar-type detector, the energy resolution obtained by simply integrating photons is still not sufficient for sub-% precision calorimetry. However, the light yield is correlated with the light source position, which in the case of the SiPMWheel, can be extracted from the distribution of light between SiPMs. The position resolution and hence the quality of the correction depend strongly on the number of photons detected, and will vary between applications, improving into the sub-percent regime as the detected photon count becomes increasingly large. The quality of this correction and the optimal method for applying it is something we plan to explore in both simulation- and hardware-based studies if this proposal is funded.

6 Electroluminescent TPC use case: The NEXT Experiment

The NEXT collaboration is a primarily US-European collaboration with the goal of developing a ton-scale, ultra-low-background neutrinoless double beta decay detector using high pressure ^{136}Xe gas (GXe) as the active medium. This technology has energy resolution far surpassing other xenon-based detectors, and a reconstructable topological signature for neutrinoless double beta decay events which is absent in liquid xenon (LXe) or xenon-doped liquid scintillator (LSXe). The projected background indices, which will ultimately limit experimental sensitivity at the ton scale, are 9 counts per ton per year per ROI (ctyR) for GXe, 130 ctyR for LXe and 210 ctyR for LSXe, as assessed by an independent review [111].

The NEXT detector is based on an electroluminescent TPC concept. Ionization charge is drifted towards a high-field region where it is amplified through nearly fluctuation-less electroluminescent gain. Each electron is accelerated in the field of the amplification region, creating excited xenon atoms which decay radiatively, emitting 175 nm light. This light is collected by two subsystems. Directly behind the electroluminescent region is a tracking array of SiPMs on a 1 cm grid. These record an image of the amplified event and allow for event topological reconstruction. Their placement is sufficiently sparse that the integrated light yield per MeV depends on the precise geometry of the event too strongly to provide a calorimetric measurement with the required precision of $\sim$1% FWHM - this is shown schematically in Figure 26, top left. Addition of more SiPMs to give a complete tiling is possible but costly. Even if this were implemented, the dark rate of the many SiPMs would likely produce fluctuations in the measured energy that prevent near-intrinsic resolution from being achieved.

To circumvent this limitation, in the present generation of the NEXT detector, the calorimetric reconstruction of the event is handled by a different subsystem consisting of low-radioactivity PMTs at the cathode end. Light emitted in the electroluminescent region is reflected around the detector by PTFE foils and shifted to the blue by TPB coatings, and detected by the PMTs of the“energy plane”. With this arrangement, energy resolutions corresponding to 0.63% FWHM at $Q_{\beta\beta}$ have

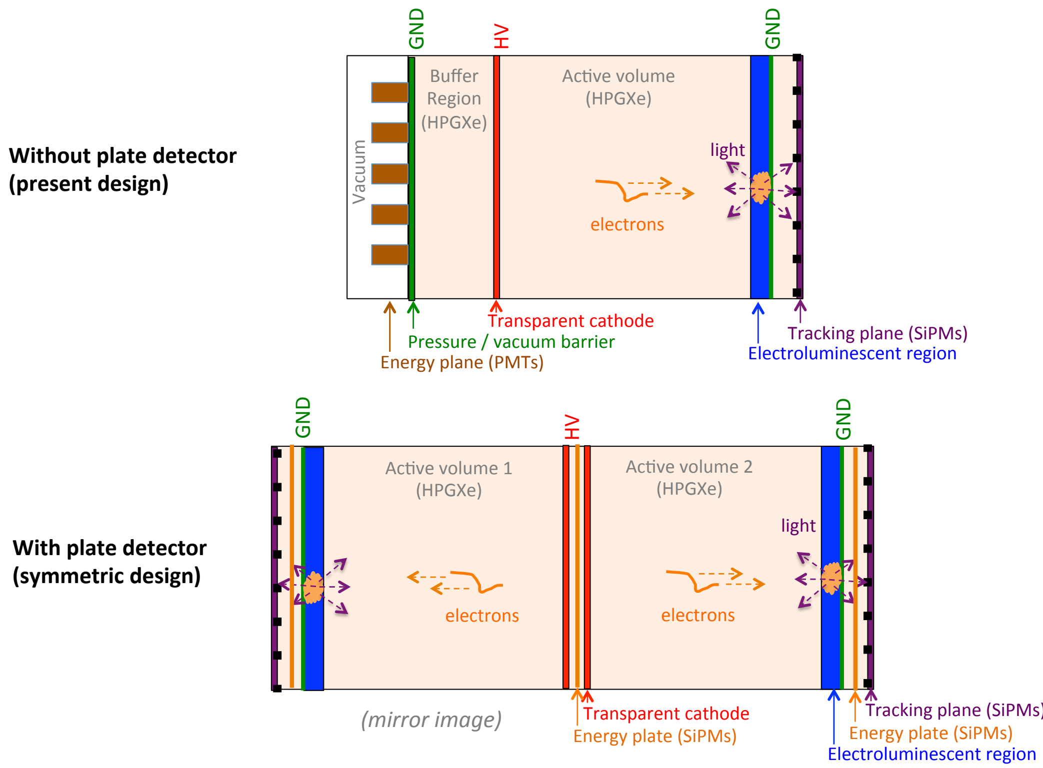


Figure 25: Top: Existing asymmetric TPC design, where energy must be recorded using the PMT-based "energy plane". Bottom: Symmetric design that could be realized using a high-resolution "plate detector". Plate detectors may be deployed at the anode region, the cathode region, or both.

been demonstrated [104]. A sketch is shown in Figure 25, top.

This two-plane solution is not without drawbacks. Even the low-radioactivity photomultiplier tubes represent a significant fraction of NEXT-100's radioactivity budget, contributing approximately 0.4 counts per ton per keV per year in each of bismuth at thallium backgrounds at $Q_{\beta\beta}$, representing the largest absolutely measured background contribution. The PMTs must be operated outside of the high-pressure region which introduces an engineering challenge, requiring an evacuated volume to be optically coupled to the active region at 15 bar. Finally, the PMTs must be operated in a low-field region which leads to the HV being graded down in a short "buffer region", wasting valuable xenon mass and introducing a region of larger HV stress.

A highly efficient calorimetric plate detector as we have described would allow a significant improvement to the NEXT design. Instead of measuring energy at the cathode, a wavelength-shifting plate between the electroluminescent mesh and the tracking plane could be used to integrate light emission from the mesh. Since the plate has a uniform collection surface, dependencies of the light yield on event geometry does not spoil its resolution, as shown in Figure 26, bottom left. The light which is not guided into the plate escapes through the back surface to be used for tracking. The plate also provides a focussing effect shown in Figure 26, right, removing high-angle rays from electroluminescence and potentially improving the tracking resolution of the detector. It is also plausible to add another energy plane detector behind a transparent cathode. This adds the electrical complications of SiPMs being operated at high voltage, but increases the calorimetric area by a factor of two. Finally, because the vacuum region and buffer region are no longer necessary,

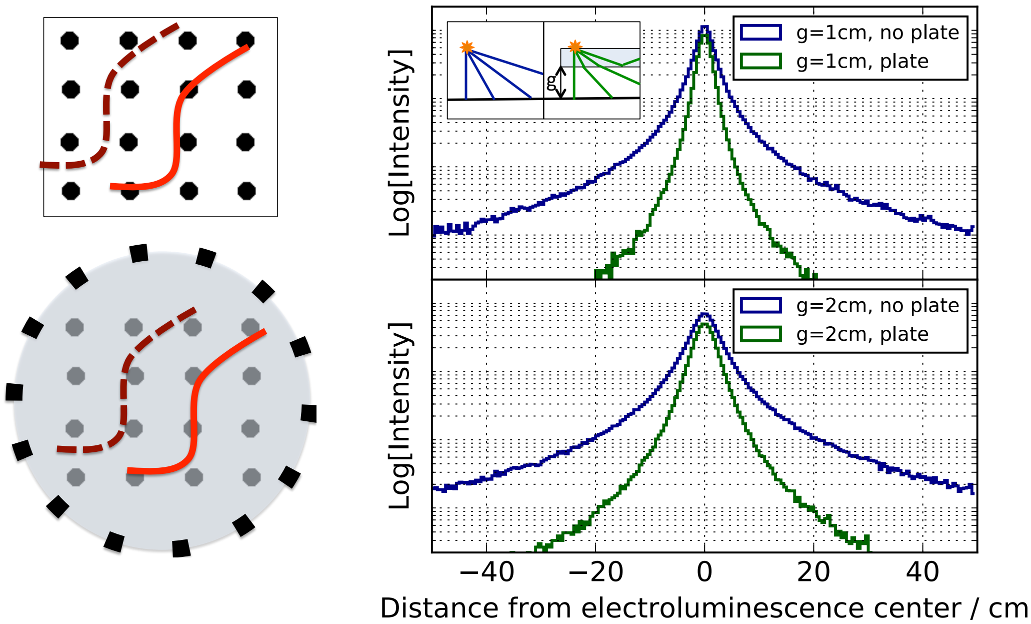


Figure 26: Left: Track energy measurement with tracking plane only (top), and tracking plane + plate (bottom). Right: Focussing effect of plate on transmitted electrolumiscence light, which may improve tracking resolution in NEXT.

this design allows a symmetric TPC to be realized, using the GXe volume in a highly efficient way and simplifying the delivery of HV. This concept is shown in Figure 25, bottom.

6.1 Single-phase LArTPC use case: DUNE

Light collection in surface-based TPCs plays a critical role of identification of cosmogenic backgrounds which would swamp true neutrino events in the absence of an optical trigger [112]. In deep underground detectors like DUNE, where cosmogenic backgrounds are much reduced, the main goal of light collection systems is fundamentally different. Rather than being primarily a tool to reject energetic off-beam cosmic ray events, the light collection system allows extension of the physics program to low energy, non-beam physics.

The importance of light collection for non-beam physics is primarily related to establishing the position of the event in the drift direction through precise timing. This is vital in order to apply a lifetime correction and thus obtain a well calibrated energy for the event from the TPC. Most of the off-beam neutrino physics goals of DUNE rely on energy reconstruction, either to identify the signal events or to learn about the physics of their sources.

The following are cases where a sensitive light collection system is vital for achieving the physics goals of DUNE:

- *Detection of supernova neutrinos* [96]. A high efficiency for detecting 5 MeV electrons has been cited as the detector goal for adequately performing this physics. This is to be contrasted to the design goal of the MicroBooNE optical system, the largest running LArTPC optical system in the USA, which was to efficiently trigger on 40 MeV protons across the (much smaller) fiducial volume. Clearly, to meet DUNE's ambitious off-beam physics goals, high light-yield technologies surpassing existing systems are required.

- *Studies of solar neutrinos with DUNE* [97] have been discussed. This also requires sensitivity to few-MeV energy deposits across the fiducial volume, with the physics capability extending as the achievable trigger threshold is reduced. This physics will be greatly enhanced by any improvement in light collection efficiency.

- *Proton decay* [113]. Golden chanels for proton decay in DUNE include $p \to K^+\nu$, $p \to K^0\mu^+$ and $p \to K^+\mu^-\pi^+$. Detecting these modes requires not only to trigger on the off-beam events (likely not too challenging due to the large Q-value in the decays), but also identification of the kaon and muon daughters. Reliable identification is difficult with the TPC alone, since in many cases the "kink" in the outgoing track where the daughter particle decays is not strongly pronounced. It is thus of benefit to access the detailed time-structure of the event, and reconstruct the muon, and potentially even kaon events in time. A high collection efficiency with the optical system may allow this temporal reconstruction.

The present baseline design for the DUNE optical system is a system based on bar detectors. We have shown in Section 5.3 that the SiPMWheel is expected to improve upon the collection efficiency of similarly prepared bars when measured either per-SiPM, per-unit-area, or per-detector. The SiPMWheel also provides positional information - this will be valuable in cases where multiple events arrive within one drift window, as, for example, during the initial peak of flux from a nearby supernova. As with bars, the installation of SiPMWheels between mostly-transparent anode plane assemblies is possible as a deployment strategy. Two-side-coated as well as one-side-coated devices are also possible for this application.

6.2 Proposed program of work

The request in this proposal is primarily for personnel to develop this technology using already existing resources. We hope to acquire funding for two graduate students who will spend 50% of their research time for 3 years. The other 50% of each will be dedicate to analysis work and funded from other sources. One undergraduate will also support the team.

In the first year, development will focus on bench-top work, not involving noble element test stands. This includes learning to produce high quality optical coatings and testing them for efficiency and attenuation length in air, closely following and improving upon previous work with bar coatings (student 1, working primarily with Jones); and commissioning of a DAQ system capable of reading out large SiPM arrays and efficiently processing the data from these (student 2, working primarily with Asaadi). Possible improvements beyond the present state-of-the-art include the addition of coating stabilizing additives to improve fluorescence yield and the exploration of high refractive index polymers. Simulation topics relating to detector optimization and expected performance will be instigated as an undergraduate project in the first year. In the second year, bench-top experience will transition into noble element environments; with Nygren and Jones, one graduate student will build a subsystem as part of an existing high pressure xenon gas test stand whereby localized electroluminescent emission can be produced near the SiPMWheel surface at various positions to study its energy and position resolution. The other student will work with Asaadi to integrate the SiPMWheel detector with his planned liquid argon calibration test stand, where an independent program of work to deploy radioactive calibration sources in large liquid argon TPCs will already be underway. With these sources, the plate performance in liquid argon will be studied. The undergraduates will assist with one or both activities. The final year will involve a program of optimization of the detector, potentially along separate trajectories for use in LAr and GXe. At the end of the three year program we hope to have demonstrated strong energy- and position-reconstruction performance and suitability of the SiPMWheel as both an electroluminescence and primary scintillation light detector.

7 MCP-PMT Lifetime Studies (Brandt)

7.1 Introduction: MCP-PMT Lifetime Studies

Microchannel Plates are traditionally lead-glass disks with a regular array of tiny tubes of order 10μm diameter. In the presence of a strong electric field, each of these parallel micro-channels, acts as a continuous-dynode electron multiplier. When combined with a photocathode, the resulting device has direct sensitivity to charged particles and energetic photons and is thus widely used where detection of low levels or light are required, such as astrophysics, bio-imaging, and night vision. MCP-based photomultiplier tubes exhibit a wide range of desirable features: large gain, excellent spatial and temporal resolution, and insensitivity to large magnetic fields, making them quite attractive for many high energy physics applications.

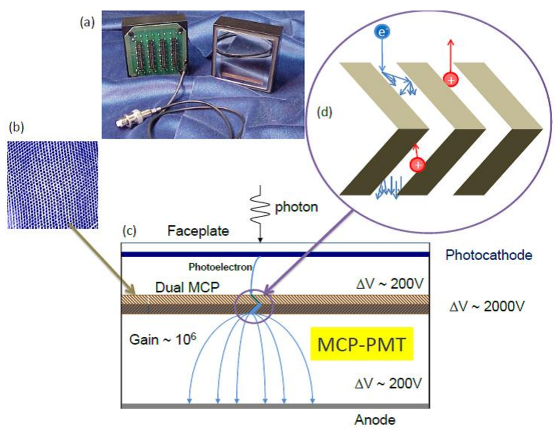


Figure 27: (a) a 64 channel Photonis Planacon MCP-PMT (b) an MCP (c) cartoon of the operation of an MCP-PMT (d) inset shows emission of positive ions that degrade the photocathode.

Figure 27(a) shows a photograph of a 64 channel Planacon MCP-PMT produced by Photonis [**?**], one of the leading manufacturers of MCP-PMTs, and a strong proponent of and contributor to MCP-PMT development. Figure 27(b) shows a photograph of an MCP, while Figure 27(c) shows a cartoon of the MCP-PMT operation: the photo-electron is accelerated by an electric field toward a pore of the MCP in which it is multiplied, giving a typical total gain of 106; the charge is then collected on the anode giving an output pulse with a much shorter transit time (¡1 ns) than typical PMTs as well as a narrower transit time spread (30-40 ps), resulting in excellent time resolution. While the high voltage accelerates the electrons towards the device anode, the positive ions created from impurities in the commercial lead-silicate MCPs are accelerated back towards the photocathode (Fig. 1(d)) and eventually cause it to be irreversibly damaged, resulting in a degraded quantum efficiency (QE). MCP-PMT lifetime is generally defined as the amount of integrated charge the phototube can absorb before its quantum efficiency (QE) degrades to 50% of the initial value [**?**]. Photocathode damage is assumed to be a function of integrated charge, so high flux applications are particularly sensitive to lifetime concerns.

7.2 Selected Developments in Fast Timing

Building on the success of Cherenkov-based particle ID detectors such as the BaBar experiments DIRC detector [?] the Nagoya group [?] took a leading role in fast timing studies for the Belle 2 Super B factory, demonstrating that a piece of quartz and an MCP-PMT could provide 5 ps timing resolution [?]. Even though this Nagoya detector did not have suitable geometry for use in an accelerator, it was vastly superior to the previous standard for time-of-flight detectors of about 100 ps [?], and thus contributed to a surge of interest in fast timing and MCP-PMTs. A series of fast timing workshops mostly organized by Henry Frisch (Chicago) sprung up covering different proposed detector geometries, various photo-sensors, and fast electronics. Within the MCP-PMT community, two main groups emerged with largely orthogonal interests and approaches 1) Large Area 2) Small High Rate.

The Large Area Picosecond Photo Detector (LAPPD) [?] initiative sought to revolutionize the MCP-PMT industry by developing a totally new large low cost flat panel 20 cm $\times$ 20 cm MCP, replacing the traditional lead glass MCP with a lower cost borosilicate option, which is less expensive and less brittle. This large group, spanning several National Labs and universities, received significant DOE funding motivated by finding a lower cost alternative to the thousands of standard phototubes required to instrument a large. LAPPD made significant progress on several fronts, but the task list proved to be long and quite challenging. Among the non-trivial challenges was replacing the lead glass flexibility and functionality with a stiffer glass such as borosilicate and developing a suitable photocathode. Abandoning lead glass MCPs requires among other things new methods of producing the array of microchannels, and new processes, for example, atomic layer deposition (ALD) [?] to provide the emissive and resistive layers needed for the multiplication functionality. The second group, which pursued a more evolutionary approach, attempting to make minor modifications to existing devices was a loosely connected group comprised mainly of timing leaders from several different experiments including Mike Albrow, Jerry Vavra, Albert Lehmann, and Brandt.

7.3 UTA Impact on Fast Timing

Brandt has been working on fast timing issues since 2006, initially as part of the FP420 (ATLAS/CMS) R&D project [?]. Although the ultimate reason for UTAs involvement was to build a fast timing system for the ATLAS Forward Proton detector, the timing detector R&D was generic and could largely be applied to any high rate fast timing application. By late 2008, it was clear that the main challenge to building a robust 10 ps timing detector for the LHC would be the MCP-PMT rate and life time. Since Arradiances ALD coating applied to MCPs had been demonstrated to provide excellent gain and suppress outgassing, it seemed likely that replacing standard MCPs with these upgraded ones in an otherwise standard MCP-PMT would improve the lifetime. To speed the development, Brandt arranged a meeting in 2009 with the principals from Arradiance and both the MCP and PMT branches of Photonis, leading to the submission of successful NSF Phase 1 SBIR proposal in 2011. Despite the Phase I success, Phase II was not funded primarily due to a perceived weakness in the commercialization plan. Since then Argonne and Hamamatsu/Nagoya have been active in the ALD arena.

Over the subsequent couple of years, Arradiance and UTA worked closely with Photonis on the lifetime issue: with Arradiance applying the alumina coating to the pores of the MCPs, Photonis incorporating these modified MCPs into Planacons, and UTA testing the devices. The modified MCPs were macroscopically identical to standard ones, so could use the standard production line, avoiding some of the developmental issues that delayed LAPPD. UTA and Photonis both characterized first generation devices funded by the SBIR, and obtained lifetimes in excess of 2 C/cm^2,well-correlated to the results of gain and ion feedback measurements that Arradiance conducted prior to the ALD MCPs inclusion in the phototube. This implied that it should be possible to improve the ALD performance more economically by optimizing the external MCP performance. Idiosyncrasies in the timing distribution uncovered by UTA led to a modification of the process, resulting in the second generation ALD PMT that has been running at Erlangen for years, reaching near 10 C/cm2 before expiring.

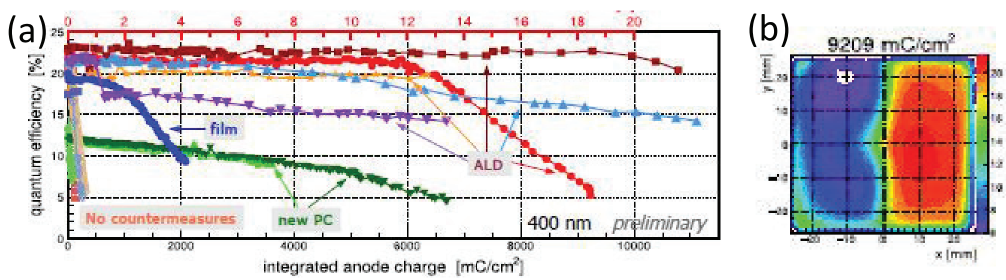


Figure 28: (a) Results of long term lifetime tests at Erlangen: lifetime test of 2nd generation Planacons (red) compared to the old standard tubes (green, black, pink), a Hamamatsu ion barrier tube (blue), and a recent high vacuum tube (BINP) (b) A half covered ALD Planacon tube indicates that the damage is mostly local.

Figure 28(a) shows an Erlangen lifetime measurement of the 2nd generation ALD Planacons (red) compared to standard tubes (green, black, pink), the Hamamatsu ion barrier tube (blue), and a new enhanced lifetime tube with a better vacuum and a more robust photocathode. (BINP). The Planacons with Arradiance ALD coating are the longest lifetime tubes in the 8 to 10 C/cm^2 range, while the Hamamatsu ion barrier tubes lifetime was a respectable, but inferior 1.8 C/cm^2, resulting in their switch to an ALD version in the middle of their production run. Their tests showed lifetimes ranging from a few to 20 C/cm^2 with a mean of about 9 C/cm^2 [**?**]. In the last year they have made unspecified ALD improvements and claim to be on track for 20 C/cm^2 [**?**].

7.4 Work in Progress

It has been demonstrated that by using ALD techniques one can reliably construct an extended lifetime MCP-PMT of $\tilde{1}0$ C/cm^2 without degrading performance appreciably. While this is a tremendous accomplishment, for these devices to be a viable option for usage in very high rate environments, such as those expected for LHC experiments, it is desirable to gain a further factor of 3 or 4 to attain the target of 30 C/cm^2. Our current proposal in progress is to combine ALD technique that reduce the emission of positive ions responsible for photocathode damage with an active ion barrier that features a variable voltage mesh that can be used to repulse the positive ions that got through the ALD and keep them from reaching the photocathode. Preliminary measurements on the active ion barrier (grid tube) indicated a factor of at least 4 improvement in lifetime.

In our ongoing proposal (through April, 2017) we noted that we could accelerate the process by using tubes with EDR (extended dynamic range) MCPs, such that we can operate in a linear regime and obtain currents of at least 1 μampcm^2, which would give us 1 C/cm^2 every 12 days. We also noted that if the damage is a local phenomena than we could make more than one lifetime measurement per device, which would not only be cost effective but would allow us to study the mechanism of the lifetime damage by using one tube for several measurements, one could in principle limit the systematic uncertainty due to variation in performance between devices. We also planned to study after-pulsing rates and distributions and look for correlations between after-pulsing and lifetime. We proposed to use new mini-planacons (these 1 in $\times$ 1 in,tubes are basically one-fourth of a planacon) for the studies, since they were less expensive and our budget is modest.

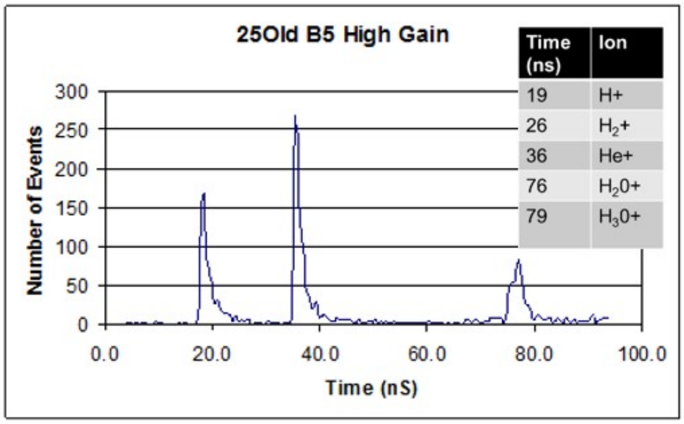


Figure 29: Ion feedback measurement in a Planacon.

Based on our experience and new developments we have modified our program somewhat. We determined that the mini-planacon is not suitable for the studies, as it is too small to make multiple independent measurements. We determined that one has to be very rigorous with the pre-lifetime tests as it is prudent to tune the front and backstage voltage, which affect collection efficiency and shower size, respectively. This is necessary since the ALD tubes have an intrinsically higher gain, and consequently require less high voltage across the MCP– with a fixed voltage divider this results in less high voltage across the front and back stage as well, so we developed variable voltage dividers. Figure 3 shows a representative after pulsing measurement. We found that some after pulsing measurements were subject to subtle noise effects that were not evident in other measurements due to relatively low rates and small time windows, became relevant for the long lifetime tubes. Finally, with the LAPPD R&D effort winding down, DOE is interested in seeing life time measurements of the Incom, and Argonne devices (see Appendix 9).

7.5 Proposed Research and Methods

Building on a successful R&D effort that has seen the MCP-PMT lifetime increase by a factor of 50 from 0.2 to 10 C/cm2 our goal is to demonstrate a life time of 30 C/cm^2. This goal is supported by the following objectives.1)Assess the viability of multiple measurements per device. If it can be demonstrated that one could get several consistent measurements from the same tube this would not only reduce cost, but reduce systematic uncertainty that stems from tube to tube variation. 2) Determine if the method of damage to the tube is correlated to the lifetime by comparing the life time under different aging conditions. Is high rate low gain equivalent to low rate high gain? Is a blue pulsed LED equivalent to a continuous white light source? 3) Set up a dedicated test station where several tubes can be simultaneously measured. 4) Determine whether the overall after pulsing rate or a subset of it is correlated with lifetime 5) Characterize and life test LAPPD MCP-PMTs.

7.6 Work Plan

The group that will carry out the project work consist of the PI, a post-doc working half time on the project, an early career graduate student and two undergraduates. We have been trying to operate without a post-doc, but there is a lot of details and subtleties to the issues, and the absence of mid-level management has slowed progress. These tests will be carried out at the UTA Picosecond Test Facility (PTF) in the Chemistry and Physics Research building. The PTF was established using funds from the Texas Advanced Research Program and the Department of Energy Advanced Detector Research program. The main components are a light-tight box containing a Hamamatsu PLP-10 pulsed picoseconds laser, with 405 and 635 nm laser diode heads, various associated optical equipment (lenses, mirrors, beam splitters, and filters), electronics including a precision programmable CAEN N1470 high voltage unit, specialized fast amplifier circuit boards with low noise mini-circuit amplifiers and programmable attenuators, precision constant fraction discriminators (¡5 ps resolution), and two fast scopes a LeCroy 6 GHz Wavemaster 8620A and a LeCroy 6 GHz, 40 Gs/s 760zi-a WavePro oscilloscope. The amplifiers and CFDs were developed by Stony Brook with a sub-award from Brandts second DOE ADR grant.

The students will carefully pre-test each tube before lifetime testing it in order to establish a performance baseline. This includes the initial amplitude, gain, transit time, after pulsing rate, etc. We will use the 6 GHz LeCroy 8620 Wavemaster scope to monitor the pulse amplitude, number of photoelectrons, and time resolution. We have written automatic scripts that take data once/hr, then the scope sleeps for 55 minutes and repeats the cycle.

The ability to do multiple measurements with one device is an important element in the plan, and must be resolved before we can life test the unique tubes. The pixel-based life time approach assumes that the lifetime damage is essentially a local phenomenon. Figure 2(b) showed the damage to a tube where the left half was exposed and the right half was not. It appears that the damage is a local effect, but since a tube is good until it starts going bad, this is not definitive. We will do a definitive test with an old 4 channel Planacon and sequentially expose one quadrant while monitoring all four. Ideally the 4 measurements are consistent, or at least follow a reproducible trend. We can apply a similar approach with an old 64 channel tube, taking 3×3 pixel regions in each of the four corners of the tub and illuminating the central pixel, for example, pixels (2,2), (2,7), (7,2), (7,7). This would leave a buffer of the central two rows and columns between the four quadrants, in principal isolating them. One could then apply the light source to the above cells or one of the nine cell grids. Four independent measurements per tube would be very useful.

There are two main modes of operation that require long life tubes, the LHC mode has high rate (several MHz), 10 pes, and a moderate gain of about 1x105 while the Panda approach has high rate, 1 pe, and high gain (1x106). Although both tests cannot be done simultaneously, it is important to cross check the lifetime with each approach, to verify that the new tube will be suitable for both modes of operation. A different quadrant would be used for the PANDA test after the LHC test is complete. With the special low resistance versions of the tubes, we can obtain currents in excess of 1 A/cm^2 or more, corresponding to a Coulomb/cm^2 of charge every 12 days. The more extreme second approach to accelerating the lifetime measurement is to run the tube in a partially saturated mode, the realm where the current is no longer increasing linearly with laser repetition rate. We can investigate our expectation that the lifetime scales with the extracted charge and not the input charge from the number of incident photons.

The next step is to develop a dedicated lifetime test stand capable of accelerated testing of multiple tubes.With the current grant we have purchased most of the necessary components that we could not scrounge: the light source (LED, laser), optical equipment (lens, mirrors, filters), the phototubes being tested and associated tube holders, a few cables, amplifiers and their associated low voltage, high voltage for the MCP-PMT, fibers to distribute the light, etc. Tests have typically been performed using the PLP-10 laser, which has variable repetition rate from 1 Hz to 100 MHz, with neutral density filters used to control the amount of light incident on the tube. We are adding a pulsed LED setup in a second light tight box, allowing for multiple simultaneous lifetime tests to be carried out. The establishment of a dedicated lifetime component of the PTF is essential as the lifetime of the tubes increase, and for systematic studies, and allows the standard setup to be used in parallel for characterization.

When the preliminaries are finished we will test four tubes to pin down the lifetime correlations. Photonis is providing three custom tubes at a deep discount: an ALD tube, a grid tube, and the combined ALD-grid tube. The fourth MCP-PMT which we have in-hand will be a standard Photonis tube to serve as a control.

The final work plan includes testing the LAPPD tubes, which are anticipated to have long lifetime due to the use of an alternate glass from lead glass, but have not been lifetime tested. This is beyond the scope of Argonnes MCP operations, and also INCOM does not have this capability in house.

7.7 Resources required

This proposal heavily leverages previous investment by the Department of Energy in Professor Brandt and his Picosecond Test Facility, and the LAPPD collaboration. Most of the equipment resources needed for this proposal are already part of the Picosecond Test Facility. The new Photonis tubes are paid for and should be delivered by the end of 2017. The LAPPD group will provide us their device(s) in exchange for testing. The only cost is personnel, one month of summer salary each year for the PI, and 50% of a post-doc the first two years to help complete the dedicated lifetime station, and supervise locally financed undergraduate students who will be performing some of the tests. The post-doc will help oversee the test stand construction, and help interface the test stand with the LAPPD devices. In the third year, we do not anticipate development, but rather fairly routine testing, so two undergraduates are expected to be capable of finishing the work associated with this proposal timeline of tasks is as follows.

7.8 Timeline

From now until March we will validate the quadrant-based lifetime approach with an existing device and debut our accelerated testing with second quadrant tube. 4/1/17-9/30/17 pretest 3 Photonis custom tubes, (tune front and backstage voltage), life test of the custom tubes.10/1/17-3/31/18 Evaluate Argonne tube with laser, figure out how to use striplines? 4/1/18-9/30/18 Lifetime of 20×20 evaluate a traditional (no stripline) 6×6 10/1/18-3/31/19 finish with LAPPD testing 4/1/19-3/31/20 additional life tests and other measurements as needed.

The technical and intellectual merits of this proposal are noteworthy. The life time has been extended by a factor of about 50 in the last 5 years. Further lifetime improvement will be attempted through the optimization of nanofilm combined with the active ion barrier. UTA and Arradiance Inc. have developed techniques to study ion generation both in the MCP test stand and in situ examination of the MCP-PMT after-pulsing which correlated to lifetime can determine the root cause of lifetime degradation. The LAPPD devices are nearing completion and could have excellent lifetime and find a niche in the market.

The broader impacts of this proposal are substantial. Image intensification detection devices incorporating MCPs are currently widely used in applications where single photon counting or low light level detection is required, but cannot be used in high rate environments. Super-Belle II and

Panda are evaluating the use of MCP-PMTs, and the long-life device could easily become a staple of HEP experiments. The impact of an improved lifetime device extends beyond cutting edge particle physics experiments as detectors with exciting discovery potential in the areas of CP violation and Higgs properties, to homeland security and night vision applications. The testing of the new MCP-PMTs will continue to be partially carried out by undergraduate students at UTA, which ranks in the top 15 in the country in student diversity. This proposal thus supports the specific mission of DOE for the HEP community and leads to great research opportunities for undergraduates.

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Part V
Appendix: Biographical Sketch

Curriculum Vitae
Dr. Andrew P. White
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7.9 EDUCATION AND TRAINING

- **Ph.D. in Experimental High Energy Physics, Westfield College, University of London (1969-1972)**
- **B.Sc (Honours) Physics, University of Southampton, U.K., (1965-1969)**

7.10 RESEARCH AND PROFESSIONAL EXPERIENCE

- **Professor of Physics, University of Texas at Arlington (1991-present)**
- **Research Scientist, High Energy Physics Group, University of Florida (1985-1991)**
- **Staff Physicist, High Energy Physics Group, Imperial College, University of London (1973-1985) (this included a period of work based at SLAC 1974-1976)**
- **Research Associate, HEP, Westfield College, University of London (1972-1973)**
- **Research Assistant, HEP, Westfield College, University of London (1969-1972)**

7.11 PUBLICATIONS:

1. ATLAS Collaboration, “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ”, Phys. Lett. B 716 (2012) 1-29.
2. ATLAS and CMSCollaborations,“Search for invisible decays of a Higgs boson using vector-boson fusion in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector”JHEP01 (2016) 172.
3. ATLAS and CMSCollaborations, “Search for Invisible Decays of the Higgs boson at the LHC”, A. White on behalf of the ATLAS and CMS Collaborations, Proceedings of LHCP 2015 Conference, St. Petersburg, Russia, August 2015
4. International Linear Collider, Technical Design Report, Volume 4, Detectors; http://www.linearcollider.org/ILC/Publications/Technical-Design-Report
5. “Experimental tests of particle flow calorimetry”, Felix Sefkow, Andy White, et al, Rev. Mod. Phys. 88, 015003 (2016)
6. ”Development of a Gas Electron Multiplier-based Digital Hadron Calorimeter”, A White et al 2012 J. Phys.: Conf. Ser. 404 01203

7.12 SYNERGISTIC ACTIVITIES

1. **D0 Intercryostat Detector:**: Invented the Intercryostat Detector for D0 used to correct the energies of particle/jets due to substantial losses in dead material.
2. **GEM-based Digital Hadron Calorimetry:**: Invented and developed the concept of Gas Electron Multiplier based digital calorimetry for high resolution jet energy measurements at colliders
3. **SiD Spokesperson:**: Spokesperson for the SiD Detector Concept for the International Linear Collider; leading and guiding all aspects of the concept towards its realization
4. **CALICE Collaboration:**: North American Representative for the CALICE Collaboration developing all aspects of calorimetry for future linear colliders.
5. **CERN RD51 Collaboration:**Deputy Chair and Member of the Management Board for RD51 - Micro-pattern Gas Detector Collaboration.

7.13 COLLABORATORS AND CO-EDITORS

- **ATLAS Experiment:** Ketevi Assamagan BNL, Joey Huston (MSU), Bill Quayle - U.Wits, Young Kee Kim - U.Chicago, Tae Hong - U.Pittsburgh, Elliot Lipeles - U. Penn., Alexander Madsen - DESY
- **SiD Detector Concept:** M.Breidenbach, J.Jaros, T. Barklow SLAC, M.Demarteau - ANL, H.Weerts ANL, J. Brau - U.Oregon, J.Strube - PNNL, M.Stanitzki (DESY)
- **CALICE Collaboration:** F.Sefkow - DESY, J.Repond - ANL, K.Kawagoe - Kyushu U.
- **RD51 Collaboration:** M. Hohlman - FIT

7.14 GRADUATE AND POSTDOCTORAL ADVISORS AND ADVISEES

1. **Mark Sosebee**, Ph.D., *University of Texas at Arlington,*
2. **Richard Bonde**, Ph.D., *University of Texas at Arlington*, **2015**
3. **Carlos Medina**, M.S., *Colorado School of Mines,***2010**
4. **Fajer Jafaari**, M.S., *University of Texas at Arlington and Tarrant County College,***2010**

1. **Dr. Seongtae Park**, Postdoctoral Fellow
   University of Texas at Arlington, **2010-2014.**
2. **Dr. Mark Sosebee**, Postdoctoral Fellow
   University of Texas at Arlington, **1996-present.**

Curriculum Vitae

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Education and Training

B.A./M.A., *Physics/Honors Curriculum, Summa Cum Laude*, Hunter College of CUNY, Class Rank 1/734	**1978-81**
Sc.M., *Physics*, Brown University	**1982**
Ph.D., *Physics*, Brown University	**1988**

Research and Professional Experience

Director, Center of Excellence in HEP, UT Arlington	**2011-**
Professor, University of Texas at Arlington	**2003-**
Associate Dean, Honors College, UT Arlington	**1999-2003**
Associate Professor, University of Texas at Arlington	**1997-2003**
Assistant Professor, University of Texas at Arlington	**1993-1997**
Research Fellow, University of Michigan	**1989-1992**
Research Associate, Indiana University	**1988-1989**

Publications – closely related to proposed project

1. The ATLAS Experiment at the CERN Large Hadron Collider, The ATLAS Collaboration, G. Aad et al., JINST 3 (2008) S08003.
2. The ATLAS Simulation Infrastructure, The ATLAS Collaboration, G. Aad et al., Eur. Phys. J. C (2010) 70: 823–874.
3. Contributions to CHEP15 (eight papers on Computing in HEP): http://indico.cern.ch/event/304944/session/10/contribution/100/author/2.
4. SUSY1
5. SUSY2

Synergistic Activities

a) **Leadership in Physics at the New Frontier**: leading a large group of researchers and students at UTA in the cutting edge research projects in the ATLAS experiment at the Large Hadron Collider at CERN, Geneva, Switzerland, since 1995. Many masters and Ph.D. students and postdocs in Physics supervised.

b) **Big Data Innovation**: led the development of a new paradigm in computing over the past decade: the PanDA software, which provides physicists automatic access to hundreds of supercomputing centers internationally. Thousands of physicists analyze data and publish results in multiple High Energy Physics (HEP) experiments using PanDA. Supervised/co-supervised many masters and Ph.D. theses in Computer Science on PanDA.

c) **New Discoveries**: played key roles in many aspects of the HEP experiments that discovered two fundamental particles in physics over the past two decades: the top quark at the Tevatron, and the Higgs boson at the LHC.

d) **New Physics searches**: early proponent of the search for the supersymmetric partner of the top quark in both the D0 and the ATLAS experiments at the LHC. Supervised multiple Ph.D. students who completed theses in D0 and ATLAS on this topic.

e) **Supercomputing technology**: founding director of the SouthWest Tier 2 supercomputing center, located at UTA and Oklahoma University. Funded by multiple grants from National Science Foundation, and the Department of Energy.

Collaborators
The D0 collaboration (see http://www-d0.fnal.gov/~madaras/authorlist.html)
The ATLAS collaboration (see
http://graybook.cern.ch/programmes/experiments/lhc/ATLAS.html)

Graduate and Postdoctoral Advisors
Prof. Mildred Widgoff (Brown University), Prof. Andrej Zieminski (Indiana University), Prof. Homer Neal (University of Michigan).

Graduate Student Advisees
Yan Song (IBM), Barry Spurlock (UTA), Rishiraj Pravahan (AT&T), Smita Darmora (UTA), Jared Little (UTA), Ted Eltzroth (unknown), Nevzat Guler (unknown), Richard Kaiser (NRC), Yu Xia (unknown).

Postdoctoral Associates
Elizabeth Gallas (Oxford), Jia Li (deceased), Mark Sosebee (UTA), Armen Vartapetian (UTA), Nurcan Ozturk (UTA), Paul Nilsson (BNL), Alden Stradling (UTA), Giulio Usai (UTA), David Cote (Ciena).

ANDREW BRANDT, PH.D.

UNIVERSITY OF TEXAS AT ARLINGTON

A. Education and Training:

College of William and Mary	Physics, Economics	B.S., 1985
University of California, Los Angeles	Physics	M.S., 1988
University of California, Los Angeles	Physics	Ph.D., 1992
Fermi National Accelerator Laboratory	Postdoctoral Fellow	1992-1995
Fermi National Accelerator Laboratory	Wilson Fellow	1996-1999

B. Research and Professional Experience:

2010 – Professor, The University of Texas at Arlington, Texas
2004-2010 Associate Professor, The University of Texas at Arlington, Texas
1999-2004 Assistant Professor, The University of Texas at Arlington, Texas

C. Publications related to the proposed project:

1. ``Search for charged Higgs bosons decaying via $H^+ \rightarrow \tau\upsilon$ in fully hadronic final states using pp collision data at √s = 8 TeV, with the ATLAS detector," (ATLAS Collaboration), JHEP03 88 (2015); arxiv:1412.6663."
2. "Search for charged Higgs bosons produced in association with a top quark and decaying via $H^+ \rightarrow \tau\upsilon$ using pp collision data recorded at √s = 13 TeV by the ATLAS detector, Phys. Lett. B 759 (2016) 555-574, arxiv:1603.09203.
3. "Expected Performance of the ATLAS Experiment: Detector Trigger and Physics," ATLAS Collaboration, arXiv:0901.0512 CERN-OPEN-2008-020. ISBN: 978-92-9083-321-5.
4. "Expected pileup values at the HL-LHC," ATL-UPGRADE-PUB-2013-014.
5. "The FP420 R&D Project: Higgs and New Physics with Forward Protons at the LHC," FP42Collaboration, arXiv:0806.0302v2 [hep-ex]; J. Inst.: 2009_JINST_4_T10001. "A Forward Proton Detector at DZero," A. Brandt *et al*., Fermilab Proposal P-900, FERMILAB-PUB-97-377.
6. ``Letter of Intent for the Phase-I Upgrade of the ATLAS Experiment," CERN-LHCC-2011-012 LHCC-I-020; https://cds.cern.ch/record/1402470
7. "A Particle Consistent with the Higgs Boson Observed with the ATLAS Detector at the Large Hadron Collider", Science 338 (2012) 1576-1582"
8. ``Design of Cherenkov bars for optical part of Time-of-flight detector in Geant 4," A.Brandt, L. Nozka; Optics Express. http://www.opticsinfobase.org/oe/upcomingissue.cfm
9. ``Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC," New J. Phys. 13 053033 (2011); CERN-PH-EP-2010-079; arXiv:1012.5104.
10. "Search for the Standard Model Higgs Boson in Tau Lepton Pair Final States" V. M. Abazov et al. (D0 Collaboration), Phys. Rev. D 88, 052005;arXiv:1203.4443.

D. Synergistic Activities:

1. Established and led ATLAS Trigger Rates Group (2008-2010)
2. U.S ATLAS L2 Manager for AFP in Phase 1 Upgrade CD-0 (2012-2013)
3. Supervised grad students on Diffractive Higgs, SM Higgs, and post-doc on charged Higgs (2010-2016)
4. Spokesman of T958, Fermilab Test Beam Experiment on picosecond timing (2006-2015)
5. Proposed, initiated, and led DZero Forward Proton Detector group (1996-2006)

E. Collaborators and Other Affiliations

Collaborators: ATLAS Collaboration, Hal Evans (Indiana), Elliot Lipeles (Penn), Mark Oreglia (Chicago), Michael Reeijjsenbeek (Stony Brook)

Graduate and Postdoctoral Advisors:

Graduate – H. Montgomery (Jefferson Lab)

Postdoctoral – P. Schlein (UCLA, deceased)

Thesis Advisor and Postgraduate-Scholar Sponsor:

Past graduate students:

Michael Strang (Ph.D. Physics, 2005) Ohio State; Pedro Duarte (M.Sc. Physics, 2007) Data Engineer Altx, Berkeley, CA; Arnab Pal (Ph.D. Physics, 2013) Ninah Consulting, Gurgaon, India; Ian Howley (Ph.D. Physics, 2013) NASA Marshal Space Flight Center.

Post-doctoral Fellows:

Christophe Royon (2000-2002) Kansas, Pierrick Hanlet (2001-2002) Illinois Institute of Technology, Duncan Brown (2004-2007) Fermilab, Edward Sarkisyan-Grinbaum (2008-2012) CERN,
Justin Griffiths (2013-) UTA

Amir Farbin

University of Texas Arlington
Department of Physics
P.O. Box 19059
Arlington, TX, 76019

e-mail: afarbin@uta.edu

Education and Training

Massachusetts Institute of Technology **Cambridge, MA**
Sep 93 - Jun 1997
S.B. in Physics. Thesis advisor: Louis Osborne.

University of Maryland **College Park, MD**
Aug 97 - June 03
Ph.D. in Physics. Thesis advisor: Hassan Jawahery.

Postdoctoral Research Assistant **BaBar Group- UMD**
June 03 - April 04

Research Associate **ATLAS- University of Chicago**
May 04 - Feb 05

Research Fellow **ATLAS- CERN**
March 05 - August 07

Research and Professional Experience

Associate Professor (Tenured) **University of Texas Arlington**
September 2012-Present
Collaborator on ATLAS, DUNE, MiniBooNE, and LArIAT experiments. DUNE Deputy Comuting Coordinator. ATLAS contributions include Supersymmetry searches, physics analysis tool leadership and development, Tile Hadronic Calorimeter operations and leadership, and ATLAS software tutorials and documentation.

Assistant Professor **University of Texas Arlington**
August 07 - September 2012
2009 DOE Early Career Reseach Program (ECRP) Award for “Model-Independent Dark-Matter Searches at the ATLAS Experiment and Applications of Many-core Computing to High Energy Physics”.

Recent Relevant Publications and Presentations

- ATLAS Collaboration, *Further searches for squarks and gluinos in final states with jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector* , Tech. Rep. ATLAS-CONF-2016-078, CERN, Geneva, August, 2016. http://cds.cern.ch/record/2206252
- ATLAS Collaboration, *Search for squarks and gluinos in final states with jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur.Phys.J. C76 (2016) no.7, 392, arXiv:1605.03814.
- ATLAS Collaboration, *Summary of the searches for squarks and gluinos using $\sqrt{s} = 8$ TeV pp collisions with the ATLAS experiment at the LHC*, JHEP 10 (2015) 054, arXiv:1507.05525.
- ATLAS Collaboration, *Multi-channel search for squarks and gluinos in $\sqrt{s}$ = 7 TeV proton-proton collisions with the ATLAS Detector*, Eur.Phys.J. C73 (2013) 2362, arXiv:1212.6149.

- R.Acciarri *et al.* [DUNE Collaboration], "Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report Volume 2: The Physics Program for DUNE at LBNF".

Collaborations

- Member of the ATLAS Collaboration (2004-present).
- Member of the LBNE and DUNE Collaborations (2013-present).
- Member of the LArIAT Collaboration (2012-present).
- Member of the miniBooNE Collaboration (2012-present).
- Member of the NEXT Collaboration (2016-present).
- Member of the BaBar Collaboration (1998-2005).

Advisors and Mentorship

- Undergraduate Advisors: T. Arias (MIT), L. Osborne (MIT).
- Ph.D. Advisor: H. Jawahery (University of Maryland).
- Postdoctoral Advisors: H. Jawahery (University of Maryland), F. Merritt (University of Chicago).
- Postdoctoral Mentorship: (all at University of Texas at Arlington): A. R. Stradling, R. Pravahan (AT&T Foundry, Palo Alto), Louise Heelan (UTA), David Cote (Ciena Telecommunications, Ottawa, Canada).
- Graduate Mentorshop (all at University of Texas at Arlington): P. C. Vajhula (current affilication unknown), Heather Brown (Hewlett-Packard), Daniel Bullock (UTA), Sepideh Shahsavarani (UTA).

Haleh Hadavand

Education and Training

Undergraduate: University of Maryland College Park **College Park, MD**
Sep 1995 - Jun 1999
Degree: BS in Physics, June 1999.

Graduate: University of California San Diego **La Jolla, CA**
Aug 1999 - Sept 2005
Degree: Ph.D. in High Energy Physics Dissertation: "The Measurement of CP Asymmetries in the Three-body Charmless B_d Meson Decay to $K^0_S K^0_S K^0_S$ at BABAR "
Thesis adviser: David MacFarlane.

Research and Professional Experience

Assistant Professor **University of Texas Arlington**
Nov 2014 - Present

Research Faculty **University of Texas Arlington**
July 2012 - Oct 2014

Postdoctoral Fellow **Southern Methodist University**
Sept 2005-July 2012

Graduate Research Assistant **UCSD on BABAR experiment**
Jun 1999 - Sept 2005

Relevant Publications

[1] The ATLAS Collaboration, Search for charged Higgs bosons produced in association with a top quark and decaying via $H^{\pm} \to \tau\nu$ using pp collision data recorded at $\sqrt{s} = 13$ TeV by the ATLAS detector, Phys. Lett. B 759 (2016) 555-574, arxiv:1603.09203.

[2] The ATLAS Collaboration, "Search for charged Higgs bosons decaying via $H^{\pm} \to \tau^{\pm}\nu$ in fully hadronic final states using pp collision data at $\sqrt{s} = 8$ TeV with the ATLAS detector", JHEP03 (2015) 088.

[3] The ATLAS Collaboration, "A Search for Charged Higgs Bosons in the τ +jets Final State with pp Collision Data Recorded at $\sqrt{s} = 8$ TeV with the ATLAS Experiment", ATLAS-CONF-2013-090 (2013).

[4] The ATLAS Collaboration, "Search for extra dimensions using diphoton events in 7 TeV proton-proton collisions with the ATLAS detector", Phys. Lett. B **710**, 538-556 (2012).

[5] The ATLAS Collaboration, "Search for Diphoton Events with Large Missing Transverse Energy in 7 TeV Proton-Proton Collisions with the ATLAS Detector", Phys. Rev. Lett. **106**, 121803 (2011).

[6] Ilchenko, Y., Cuenca-Almenar, C. , Corso-Radu, A., Hadavand, H. Kolos, S, Slagle, K., Taffard, A.,"Data Quality Monitoring Display for ATLAS experiment", J. Phys. Conf. Ser. **219**, 022035 (2010).

[7] H. Hadavand [ATLAS Collaboration], "Commissioning of the ATLAS offline software with cosmic rays", J. Phys. Conf. Ser. **119**, 032021 (2008).

[8] S. Kolos, A. Corso-Radu, H. Hadavand, M. Hauschild, R. Kehoe, "A software framework for Data Quality Monitoring in ATLAS", J. Phys. Conf. Ser. **119**, 022033 (2008).

[9] B. Aubert *et al.* [BABAR Collaboration], "Branching Fraction and CP Asymmetries in $B^0 \to K^0_S K^0_S K^0_S$", Phys. Rev. Lett. **95**, 011801 (2005).

[10] B. Aubert *et al.* [BABAR Collaboration], "Measurement of the B^+/B^0production ratio from the $\Upsilon(4S)$meson using $B^+ \to J/\psi$ K$^+$ and $B^0 \to J/\psi K^0_S$decays", Phys. Rev. D **69**, 071101 (2004). "New Physics results from the BABAR Collaboration", July 2005.

Synergistic Activities

Invited Talks

[11] Lake Louise Winter Institute, Lake Louise, Alberta, Canada, "Beyond-the-Standard Model Higgs and Invisible Higgs Decays Using the ATLAS Experiment", February 2014.

[12] Photon 2011 Conference at Spa, Belgium, "New Physics Searches with Photons at the ATLAS and CMS Experiments", May 2011.

[13] Beyond Standard Model Physics Conference, Boston, MA., "Beyond the Standard Model Photon Physics at the ATLAS and CMS Experiments at the Large Hadron Collider", June 2009.

Leadership Experience

- Charged Higgs convenor on the ATLAS experiment.
- Co-editor of paper and conference note on extra dimension diphotons resonances [0, **?**].
- co-editor and analysis contact for paper *Search for Diphoton Events with Large Missing Transverse Energy in 7 TeV Proton-Proton Collisions with the ATLAS Detector* [0].

Collaborators and Co-editors

Maria Pilar Casado, Universitat Autònoma de Barcelona, Arnaud Ferrari, Uppsala University, Thomas Junk, Fermilab, Anna Kopf, Freiburg University, Allison McCarn, Univerisity of Michigan, Henrik Ohman, Uppsala University, Michael Pitt, Weizmann Institute of Science, John Parsons, Columbia University, Nikolaos Rompotis, University of Wisconsin, Jana Schaarschmidt, Weizmann Institute of Science, Stephen Sekula, Southern Methodist University, Camila Rangel Smith, Uppsala University, Michelle Stancari, Fermilab, Micheal Pitt, Weizmann Institute of Science, Dhiman Chakrabory, Northern Illinois University.

Graduate and Postdoctoral Advisors and Advisees

Yuriy Ilchenko, UT Austin, David MacFarlane, Stanford University, Bob Kehoe, Southern Methodist University, Ryszard Stroynowski, Southern Methodist University.

Jaehoon Yu
Department of Physics, University of Texas at Arlington, Box 19059, Arlington, TX 76019
E-mail:jaehoonyu@uta.edu, URL:http://www-hep.uta.edu/∼yu/
Phone: (817) 272-2814 (office), -2266 (physics dept.), (817)808-9605 (cell)
FAX: (817) 272-3637 (dept)

EDUCATION AND TRAINING

- **Research Associate**, Fermi National Accelerator Laboratory, **1996-1998**
- **Research Fellow**, University of Rochester, **1993-1996**
- **Ph.D.**, Physics, State University of New York, Stony Brook, **1993**
- **M.S.**, Physics,State University of New York, Stony Brook, **1992**
- **M.A.**, Physics, Korea University, Seoul, South Korea, **1985**
- **D.S.**, Physics, Korea University, Seoul, South Korea, **1983**

RESEARCH AND PROFESSIONAL EXPERIENCE

- **Professor**, University of Texas at Arlington, **2012–present**
- **Associate Professor**, University of Texas at Arlington, **2006–2012**
- **Assistant Professor**, University of Texas at Arlington, **2001–2006**
- **Associate Scientist**, Fermi National Accelerator Laboratory, **1998-2001**

SELECTED PUBLICATIONS

1. ATLAS Collaboration, Measurement of exclusive $\gamma\gamma \to W^+W^-$ Production and search for exclusive Higgs boson production in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, Phys. Rev. **D 94**, 032011 (2016)
2. ATLAS Collaboration, Measurements of the Higgs boson production and decay rates and coupling strengths using pp collision data at s=7 and 8 TeV in the ATLAS experiment, arXiv:1507.04548 [hep-ex]
3. Georges Aad et al., ATLAS Collaboration, Study of (W/Z)H production and Higgs boson couplings using HWW decays with the ATLAS detector, JHEP 1508 (2015) 137.
4. Keisuke Fujii et al., Linear Collider Physics Panel, Physics Case for the International Linear Collider, arXiv:1506.05992 [hep-ex].
5. CMS and ATLAS Collaborations, Combined Measurement of the Higgs Boson Mass in pp Collisions at s=7 and 8 TeV with the ATLAS and CMS Experiments, Phys.Rev.Lett. 114 (2015) 191803.
6. Georges Aad et al., ATLAS Collaboration, Search for a Charged Higgs Boson Produced in the Vector-Boson Fusion Mode with Decay HWZ using pp Collisions at s=8TeV with the ATLAS Experiment, Phys.Rev.Lett. 114 (2015) 23, 231801.
7. C. Adams et al., LBNE Collaboration, The Long-Baseline Neutrino Experiment: Exploring Fundamental Symmetries of the Universe, arXiv:1307.7335 (2014)
8. H. Frisch, C. Hast, E. Ramberg, M. Artuso, A. Seiden, M. Wetstein, M.C. Sanchez & J. Fast, et al, Compendium of Instrumentation Frontier Whitepapers on Technologies for Snowmass 2013
9. Georges Aad et al., ATLAS Collaboration, Search for dark matter in events with heavy quarks and missing transberse momentum in pp collisions at s =7 TeV with the ATLAS detector arXiv:1410.4031 (2014)
10. Georges Aad et al., ATLAS Collaboration, Search for neutral Higgs boson of the minimal supersymmetric standard model in pp collisions at s =8 TeV with the ATLAS detector JHEP 1411 (2014) 056

SYNERGISTIC ACTIVITIES

1. **Aug. 2016 present:** Executive Board member, WA105 experiment at CERN
2. **Nov. 2015 present:** Institutional Board member, ICARUS experiment at CERN/Fermilab
3. **Sept. 2015 present:** DUNE Beyond the Standard Model physics group co-convener
4. **Mar. 2015 present:** Institutional Board representative, Deep Underground Neutrino Experiment at Fermilab
5. **Aug. 2013 Jan. 2015:** LBNE R&D Coordinating committee co-convener

COLLABORATORS:ATLAS, CALICE, SiD, LBNE, LArIAT and ORKA Collaborations

GRADUATE AND POSTDOCTORAL ADVISORS

- **Dr. Robert Bernstein**, Fermilab, PostDoctoral Advisor:**1996–1998**
- **Prof. Frederick Lobkowitz (deceased)**, Univ. of Rochester, PostDoctoral Advisor:**1993–1996**
- **Prof. Robert L. McCarthy**, SUNY Stony Brook, Thesis Advisor:**1988–1993**

POSTDOCTORAL ADVISEES

1. **Dr. Animesh Chatterjee**, Postdoctoral Fellow, University of Texas at Arlington, **2014-present.**
2. **Dr. Justin Griffiths**, Postdoctoral Fellow, University of Texas at Arlington, **2012-present.**
3. **Dr. Seongtae Park**, Senior Postdoctoral Fellow, University of Texas at Arlington, **2010-2014**
4. **Dr. Hyunwoo Kim**, Postdoctoral Fellow, University of Texas at Arlington, **2004-2007, currently an associate scientist at Fermilab**
5. **Mr. Sudhamshi Reddy**, Software Engineer, University of Texas at Arlington, **2007-2009, currently on UTA Computer Science and Engineering Ph.D. candidate**

GRADUATE STUDENT ADVISEES

1. **Garrett Brown**, Ph.D., Univ. of Texas at Arlington, **2016 - present**
2. **Last Feremenga**, Ph.D., Univ. of Texas at Arlington, **expected to graduate in 2016**
3. **Heeyeun Kim**, Ph.D., Univ. of Texas at Arlington, **2015 - Researcher at Harvard Medical School**
4. **Dr. Jacob Smith**, Ph.D., Univ. of Texas at Arlington, **2013–PostDoc at U. of Maryland**
5. **Dr. Hyeonjin Kim**, Ph.D., Univ. of Texas at Arlington, **2010–PostDoc at U. of Stockholm, Sweden**
6. **Dr. Venkatesh Kaushik**, Ph.D., Univ. of Texas at Arlington, **2007–** EMC^2
7. **Jacob Smith**, M.S., Univ. of Texas at Arlington, **2010–Continued into the Ph.D. program at UTA**

Biographical Sketch
Jonathan Asaadi

Education and Training

Institution	**Location**	**Major**	**Degree & Year**
Undergraduate Institution	University of Iowa	Physics	B.S. 2004
Graduate Institution	Texas A&M University	Physics	M.S. 2007
Graduate Institution	Texas A&M University	Physics	PhD. 2012
Postdoctoral Institution	Syracuse University	Neutrinos	2012-2015

Research and Professional Experience

Assistant Professor	University of Texas Arlington	2015 – Present
Postdoctoral Researcher	Syracuse University	2012 – 2015

Publications

- "*Measurement of* ν_μ *and* $\bar{\nu}_\mu$ *Neutral Current* $\pi^0 \rightarrow \gamma\gamma$ *Production in the ArgoNeuT Detector*",
Submitted to PRD (2014), arXiv:1511.00941 (Primary author and primary analyzer)

- "*Testing of High Voltage Surge Protection Devices for Use in Liquid Argon TPC Detectors*",
JINST 9 P09002 (2014), arXiv:1406.5216 (Primary author and primary analyzer)

- "*The detection of back-to-back proton pairs in Charged-Current neutrino interactions with the ArgoNeuT detector in the NuMI low energy beam*"
Phys. Rev. D 90, 012008 (2014), arXiv:1405.4261 (Reviewer and collaborator)

- "*Measurements of Inclusive Muon Neutrino and Antineutrino Charged Current Differential Cross Sections on Argon in the NuMI Antineutrino Beam*"
Phys. Rev. D 89, 112003 (2014), arXiv:1404.3698 (Collaborator)

- "*A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam*"
arXiv:1503.01520 (Collaborator)

- "*ArgonCube: a no*vel, fully-modular approach for the realization of large-mass liquid argon TPC neutrino detectors"
CERN-SPSC-2015-009 ; SPSC-I-243 (Contributing author and analyzer)

- "*LAr1-ND: Testing Neutrino Anomalies with Multiple LArTPC Detectors at Fermilab*"
Snowmass White Paper SNOW13-00176, arXiv:1309.7987 (Collaborator)

- "*Signature-based search for delayed photons in the exclusive photon plus missing transverse energy events from proton anti-proton collisions with center of mass energy = 1.96 TeV*"
Phys. Rev. D 88, 031103 (2013), arXiv:1307.0474 (Primary author and primary analyzer)

- "*LArIAT: Liquid Argon In A Testbeam*"
arXiv:1406.5560 (Collaborator)

Synergistic Activities

- Neutrino Detector R&D Facilities Workshop
Organizing Committee Member, January 2016

- **The Liquid Argon TPC Reconstruction Assessment and Requirement Workshop**
Organizing Committee Member, November 2015

- Albert Einstein Center Visiting Fellow 2014, Laboratory for High Energy Physics (LHEP), University of Bern Switzerland

- **Coordinating Panel for Advanced Detectors (CPAD) Instrumentation Frontier Meeting**
Invited Talk “New Technologies for Neutrino Oscillations”, October 2015

- 25th Workshop on Weak Interactions and Neutrinos (WIN2015)
Invited Talk “The Fermilab Short-Baseline Neutrino Program”

Collaborators

Collaborators and Co-Editors:

Adam Aurisano	University of Cincinnati	Collaborator
Bruce Baller	Fermilab	Collaborator
Tim Bolton	Kansas State University	Collaborator
Carl Bromberg	Michigan State University	Collaborator
Flavio Cavanna	Fermilab	Collaborator
Eric Church	Pacific Northwest National Laboratory	Collaborator
Janet Conrad	Massachusetts Institute of Technology	Collaborator
Bhaskar Dutta	Texas A&M	Graduate Advisor
Antonio Ereditato	Bern University	Collaborator
Bonnie Fleming	Yale University	Collaborator
Teruki Kamon	Texas A&M University	Graduate Advisor
Igro Kreslo	Bern University	Collaborator
Ornella Palamara	Fermilab	Collaborator
Jennifer Raaf	Fermilab	Collaborator
Brian Rebel	Fermilab	Collaborator
Mitch Soderberg	Syracuse University	Post-doctoral Advisor
Josh Spitz	University of Michigan	Collaborator
Andrzej Szlec	Manchester University	Collaborator
David Toback	Texas A&M University	Graduate Advisor (Chair)
Michele Weber	Bern University	Collaborator
Tingjun Yang	Fermilab	Collaborator
Geralyn Zeller	Fermilab	Collaborator

Graduate Advisors and Postdoctoral Sponsors
Prof. David Toback (Texas A&M)
Prof. Mitch Soderberg (Syracuse University)

David Nygren

Biographical Sketch

Education and Training

Whitman College, Washington	Mathematics and Physics	B.A., 1960
University of Washington, Seattle, Washington	Physics	Ph.D., 1967
Nevis Laboratories, Columbia University, New York	Postdoctoral researcher	1967-1969

Research and Professional Experience

2014 – Presidential Distinguished Professor, The University of Texas at Arlington
2014-2015 Division Director, Acting, LBNL Physics Division
2004-2014 Distinguished Scientist, LBNL
1999-2009 LBNL Senior Staff
1997-2004 Physics Division Fellow, LBNL
1992-1997 Senior Research Associate, Nevis Laboratories
1990-1992 Assistant Professor, Columbia University

Selected Publications (ordered by relevance)

1. "Operation and first results of the NEXT-DEMO prototype using a silicon photomultiplier tracking array", NEXT Collaboration, *Journal of Instrumentation* 8 (2013) P09011
2. "Ionization and scintillation response of high-pressure xenon gas to alpha particles", NEXT Collaboration, *Journal of Instrumentation* 8 (2013) P05025,
3. "Near-Intrinsic Energy Resolution for 30 to 662 keV Gamma Rays in a High Pressure Xenon Electroluminescent TPC", NEXT Collaboration, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 708 (2013) 101-114,
4. "High-pressure Xenon Gas Electroluminescent TPC for 0-ν ββ Decay Search", D. Nygren, *Nuclear Instruments and Methods in Physics Research Section **A**: Accelerators, Spectrometers, Detectors and Associated Equipment* **603 (**2009) p337-348
5. "Optimal detectors for WIMP and 0-ν ββ searches: Identical high-pressure xenon gas TPCs" D. Nygren, *Nuclear Instruments and Methods in Physics Research Section **A**: Accelerators, Spectrometers, Detectors and Associated Equipment.* **581** (2007) 632-642
6. "*First Observation of PeV-energy Neurinos with IceCube*", IceCube Collaboration, Physical Review Letters 111 (2013) 021103, arXiv:1305.5356
7. "A negative-ion TPC with ultra-high energy resolution for 0-ν double beta decay search in ^{136}Xe", D. R. Nygren. *Third Symposium on Large TPCs for Low-energy Rare Events* (Paris, France, 11-12 December 2006) *Journal of Physics: Conference Series* **65** (2007) 012003 doi:10.1088/1742-6596/65/1/012003
8. "High Resolution X-ray Imaging Using a Silicon Strip Detector", E. Beuville, R. Cahn, B. Cederstrom, M. Danielsson, A. Hall, B. Hasegawa, L. Luo, M. Lundqvist, D. Nygren, E. Oltman, J. Walton, *IEEE Transactions of Nuclear Science* 45: 3059-3063 (1998).
9. "Measurement of the Kaon Content of Three Prong τ Decays", by TPC/Two Gamma Collaboration, *Physical Review* D50:13 (1994).
10. "Performance of a Time Projection Chamber", D. Fancher, H.J. Hilke, S. Loken, P. Martin, J.N. Marx, D.R. Nygren, P. Robrish, G. Shapiro, M. Urban and W. Wenzel, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 161:383 (1979).

Synergistic and Public Service Activities

1. DOE Review of LZ –CD2/3 April 2016
2. DOE Review of National Laboratory R&D
3. DOE Institutional Review of FNAL – February 2015
4. DOE Particle Detector R&D Review Panel– November 2013
5. DPF Snowmass 2013: Advisor for Gas Detection Techniques
6. DOE Early Career Award: Proposal Review Committee 2013
7. DOE Review of Samurai TPC Project MSU, 2013

Collaborators

IceCube Collaboration
NEXT Collaboration

Collaborators and Co-editors:

Azriel Goldschmidt, LBNL, Nuclear Science Division
Juan Jose Gomez-Cadenas, IFIC, Valencia, Spain
Francis Halzen, University of Wisconsin, Madison
John Hauptman, Iowa State University
James Siegrist, Director, Office of High Energy Physics, DOE
Bob Stokstad, LBNL, Nuclear Science Division, retired

Graduate and Postdoctoral Advisors and Advisees:

Graduate – Robert W. Williams, University of Washington, Seattle
Postdoctoral – Jack Steinberger, Columbia University, New York

Thesis Advisor and Postgraduate-Scholar Sponsor:

Graduate Students:
Jordan Benson (current), Marjorie Shapiro (now at UC Berkeley), Nick Hadley (now at University of Maryland, John Huth (now at Harvard University)

Postgraduate-scholars:
Ben Jones (now at UTA), Carlos A. B. de Oliveira

Benjamin Jones

Biographical Sketch

Education and Training

Mass. Institute of Technology	Ph.D. in Physics	2010-2015
University of Bristol	Undergraduate research assistant	2009-2010
Cambridge University	B.A. M.Sci (Nat Sci)	2004-2009

Research and Professional Experience

Assistant Professor	University of Texas at Arlington	2016-present
Postdoctoral researcher	University of Texas at Arlington	2015-2016

Selected Publications (ordered by relevance)

1. *Improved TPB-coated Light Guides for Liquid Argon TPC Light Detection Systems*, Z. Moss, L. Bugel, G. Collin, J.M. Conrad, B.J.P. Jones, J. Moon, M. Toups and T. Wongjirad JINST 10 (2015) no.08, P08017
2. *Demonstration of a Lightguide Detector for Liquid Argon TPCs*
L. Bugel, J.M. Conrad, C. Ignarra, B.J.P. Jones, T. Katori, T. Smidt and H.-K. Tanaka, Nucl.Instrum.Meth. A640 (2011) 69-75
3. *A Simulation of the Optical Attenuation of TPB Coated Light-guide Detectors*
B.J.P. Jones JINST 8 (2013) C10015
4. *Photodegradation Mechanisms of Tetraphenyl Butadiene Coatings for Liquid Argon Detectors,* B.J.P. Jones, J.K. VanGemert, J.M. Conrad, A. Pla-Dalmau, JINST 8 (2013) P01013
5. *The Effects of Dissolved Methane upon Liquid Argon Scintillation Light*
B.J.P. Jones, T. Alexander, H.O. Back, G. Collin, J.M. Conrad, A. Greene, T. Katori, S. Pordes and M. Toups, JINST 8 (2013) P12015
6. *A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level,* B.J.P. Jones, C.S. Chiu, J.M. Conrad, C.M. Ignarra, T. Katori and M. Toups JINST 8 (2013) P07011
7. *Single Molecule Fluorescence Imaging as a Technique for Barium Tagging in Neutrinoless Double Beta Decay,* B.J.P. Jones, A.D. McDonald, D.R. Nygren, arXiv1609:04019, (2016) submitted to JINST
8. *Searches for Sterile Neutrinos with the IceCube Detector,* M.G. Aartsen *et al.* (IceCube Collaboration), Phys.Rev.Lett. 117 (2016) no.7, 071801
9. *Dynamical pion collapse and the coherence of conventional neutrino beams*
B.J.P. Jones, Phys.Rev. D91 (2015) no.5, 053002
10. *Testing of High Voltage Surge Protection Devices for Use in Liquid Argon TPC Detectors* J. Asaadi, J.M. Conrad, S. Gollapinni, B.J.P. Jones, H. Jostlein, J. M. St. John, T. Strauss, S. Wolbers and J. Zennamo, JINST 9 (2014) P09002

Synergistic Activities

1. Served as reviewer for Department of Energy SBIR (Small Business Innovation and Research) proposals.

2. Field cage project leader for the NEXT experiment

3. Served as analysis reviewer for two IceCube oscillations working group physics analyses.

4. Organizer of UTA high energy physics summer school 2016

5. Recent outreach talks:
   "A Taste of Research at UTA", Talk for high school students visiting UTA physics department
   "*Neutrino Telescopes and New Physics"* Lunch Talk for the UTA Society of Physics Students
   "*Detecting Neutrinos with Liquid Argon"*, public talk and museum event for the Neutrino2014 conference
   "*From Symmetries to Neutrinos"*, after-school talk on physics for 16-18 year olds at King Edwards School, Stratford-Upon-Avon, UK
   "*Discovering the Ingredients of the Universe"*, Guest lecture for "From Big Bangs to Black Holes" physics course at Roosevelt University, Chicago, IL

Collaborators

IceCube Collaboration	2014 – present
NEXT Collaboration	2015 – present
DUNE Collaboration	2013 – present
MicroBooNE Collaboration	2010 – 2015

Collaborators and Co-editors:

Arguelles Delgado, Carlos (MIT), Back, Henning (Princeton), Grant, Darren (University of Alberta), Gollapini, Sowjanya (KSU), Halzen, Francis (UW Madison), Jostlein, Hans (Fermilab), Karle, Albrecht (UW Madison), Katori, Teppei (Queen Mary University of London), Koskinen, Jason (NBI Copenhagen), Lockwitz, Sarah (Fermilab), Mufson, Stuart (Indiana University), Pordes, Stephen (Fermilab), Salvado Serra, Jordi (IFIC Valencia), St John, Jason (Fermilab), Strauss, Thomas (Fermilab), Toups, Matthew (Fermilab), Wolbers, Steven (Orgeon State University)

Graduate and Postdoctoral Advisors and Advisees:

Conrad, Janet (MIT) – Graduate Advisor
Nygren, David (UT Arlington) – Postdoctoral Advisor

Current and Pending Support: Andrew Brandt

Support: ☒ Awarded ☐ Pending
Sponsor: DOE **Award/Identifying Number:** 209151
Proposal Title: Research in Experimental Elementary Particle Physics (co-PI)
Total Award Amount for the Entire Award Period (including indirect costs): $2,520,000
Award Period: 5/01/2014- 3/31/2017
Number of Person-months per year to be devoted to the project: 1.0
Abstract: Base funding for the UTA HEP group to support their summer salaries, post-docs, students, and travel. This umbrella proposal encompasses various activities in the energy frontier primarily for ATLAS: data analysis in Higgs and SUSY, trigger development, major leadership roles in computing, etc., with a modest effort in ILC development and leadership; and the intensity frontier ranging from Lariat to Dune.

Support: ☒ Awarded ☐ Pending
Sponsor: DOE **Award/Identifying Number:** 215078
Proposal Title: Development of a Long Life Photomultiplier Tube for High Flux Applications (PI)
Total Award Amount for the Entire Award Period (including indirect costs): $125,000
Award Period: 6/01/2015- 3/31/2017
Number of Person-months per year to be devoted to the project: 1.0
Abstract: This project seeks is concerned with the development of long-life microchannel plate (MCP) photomultiplier tubes (PMTs), capable of high rate operation. Its goals are the optimization of lifetime testing methods including the efficacy of multiple lifetime measurements per device, expedited lifetime measurements, and after-pulsing studies that seek to correlate lifetime with the amount of specific heavy ions.

Support: ☒ Awarded ☐ Pending
Sponsor: Department of Education **Award/Identifying Number:**
Proposal Title: Reaching Goals in Physics with GAANN Fellowships (Co-Pi)
Total Award Amount for the Entire Award Period (including indirect costs): $536,688
Award Period: 9/01/2016- 8/31/2019
Number of Person-months per year to be devoted to the project: 0.5
Abstract: This proposal provides funding for physics graduate students with demonstrated need for financial aid, and includes a supervised teaching requirement.

Support: ☐ Awarded ☒ Pending
Sponsor: DOE **Award/Identifying Number:**
Proposal Title: Research in Experimental Elementary Particle Physics (co-PI)
Total Award Amount for the Entire Award Period (including indirect costs): $
Award Period: 4/01/2017- 3/31/2020
Number of Person-months per year to be devoted to the project: 2.0
Abstract: Renewal of base funding for the UTA HEP group to support their summer salaries, post-docs, students, and travel. This umbrella proposal encompasses various activities in the energy frontier primarily for ATLAS: data analysis in Higgs and SUSY, trigger development, major leadership roles in computing, and TileCAl, with a modest effort in ILC development and leadership; and the intensity frontier ranging from Lariat to Dune.

Current and Pending Support: Kaushik De

Support: ☒ Awarded ☐ Pending	
Sponsor: NSF	**Award Number**: NSF PHY-1119200
Title of the Funded Research Project: The U.S. ATLAS Research Program: Empowering U.S. Universities for Discoveries at the Energy Frontier	
Total Award Amount for the Entire Award Period (including indirect costs): $1,611,368	
Award Period: 10/01/15 - 9/30/16	
Number of Person-months per year to be devoted to the project by the PI: 2.0	
Abstract: UTA is a sub-contractor of the NSF US ATLAS Operations program cooperative agreement managed by Columbia University. This cooperative agreement supports M&O, S&C and R&D activities on the ATLAS experiment at the LHC. Activities at UTA include the operation of the SouthWest Tier 2, PanDA software development, US Computing Operations, Analysis support and documentation, and TileCal detector operation and upgrade R&D. These support activities are critical to the success of the ATLAS physics program.	

Support: ☒ Awarded ☐ Pending	
Sponsor:	**Award Number**: BNL Contract #229206
Title of the Funded Research Project: The U.S. ATLAS Research Program	
Total Award Amount for the Entire Award Period (including indirect costs): $282,000	
Award Period: 10/01/14 - 9/30/16 (NCE)	
Number of Person-months per year to be devoted to the project by the PI: 0	
Abstract: UTA receives DOE funding for M&O and S&C activities in support of the US ATLAS Research Program through Brookhaven National Laboratory. Supported activities at UTA include the operation of the SouthWest Tier 2, and TileCal detector operation and upgrade R&D. These support activities are critical to the success of the ATLAS physics program.	

Support: ☒ Awarded ☐ Pending	
Sponsor: DOE	**Award Number**: DOE DE-SC0011686
Title of the Funded Research Project: High Energy Physics Base Funding	
Total Award Amount for the Entire Award Period (including indirect costs): $890,000	
Award Period: 05/01/16 - 04/31/17	
Number of Person-months per year to be devoted to the project by the PI: 2.0	
Abstract: This proposal requests support for a program of research in elementary particle physics at The University of Texas at Arlington. We propose studies of the recently discovered Higgs boson, and searches for new particles in nature which may be responsible for dark matter, at the ATLAS Experiment at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, and the Silicon Detector (SiD) at the proposed International Linear Collider. The SiD is a novel concept for a future experiment in particle physics. Our program of work involves detector research and development, and distributed computing innovations. Together, the ATLAS Experiment and SiD can provide a deep understanding of two fundamental forces of nature: electromagnetism and the weak nuclear force, in addition to allowing for the discovery of associated new particles suggested by theory. In a new direction for the group, support is also requested for participation in the future Long Baseline Neutrino Experiment (LBNE), which will explore the masses of the neutrinos that are involved in the weak nuclear interactions and search for low-mass dark matter in the beam, and the ORKA Experiment, that will search for signs of new physics in the rare decays of the K-meson, a particle only produced in high energy collisions. Finally, we propose to carry out theoretical studies of the dark matter that exists in large quantities around and between galaxies, in terms of its interactions with astrophysical objects, and its possible creation in low-energy, high beam intensity experiments.	

Support: ☒ Awarded ☐ Pending	
Sponsor: DOE	**Award Number**: DOE DE-SC008635
Title of the Funded Research Project: Next Generation Workload Management and Analysis System for Big Data	
Award Period: 9/01/12 - 08/31/16 (NCE)	
Total Award Amount for the Entire Award Period (including indirect costs): $746,908	
Number of Person-months per year to be devoted to the project by the PI: 1.0	
Abstract: One of the largest scientific collaborations ever assembled, the ATLAS experiment at the Large Hadron Collider (LHC), is designed to explore the fundamental properties of matter for the next decade. An important foundation underlying the impressive success of ATLAS data processing and analysis is the Production and Distributed Analysis (PanDA) workload management system. We propose here a program to develop a generic version of PanDA which can be easily used by many data intensive sciences. With a modest investment of effort, we can enable easy adoption of PanDA by others. We propose generalizing PanDA as a meta-application, providing location transparency of processing and data access, for High Energy Physics, other data-intensive sciences, and a wider exascale community.	

Support: ☒ Awarded ☐ Pending	
Sponsor: DOE	**Award Number**: DOE DE-SC0016280
Title of the Funded Research Project: Big PanDA Workflow Management on Titan for High Energy and Nuclear Physics and for Future Extreme Scale Scientific Applications	
Award Period: 7/01/16 - 06/30/18	
Total Award Amount for the Entire Award Period (including indirect costs): $1.063,000	
Number of Person-months per year to be devoted to the project by the PI: 1.0	
Abstract: Scientific priorities in High Energy and Nuclear Physics continue to serve as drivers of integrated computer and data infrastructure. The lack of scalable and extensible workload management capabilities across heterogeneous computing infrastructure, however presents a barrier to the scientific progress. BigPanDA represents important conceptual advances and novel capabilities to workload management. We propose to deploy and bring into production BigPanDA workflow management techniques on the Oak Ridge Leadership Computing Facility (OLCF) Titan supercomputer. This will significantly and positively impact scientific communities in High Energy and Nuclear Physics, and beyond, for current and future leadership computing facilities.	

Current and Pending Support: Amir Farbin

Support: ☒ Awarded ☐ Pending	
Sponsor: NSF	**Award Number**: NSF PHY-1119200
Title of the Funded Research Project: The U.S. ATLAS Research Program: Empowering U.S. Universities for Discoveries at the Energy Frontier	
Total Award Amount for the Entire Award Period (including indirect costs): $1,611,368	
Award Period: 10/01/15 - 9/30/16	
Number of Person-months per year to be devoted to the project by the PI: 2.0	
Abstract: UTA is a sub-contractor of the NSF US ATLAS Operations program cooperative agreement managed by Columbia University. This cooperative agreement supports M&O, S&C and R&D activities on the ATLAS experiment at the LHC. Activities at UTA include the operation of the SouthWest Tier 2, PanDA software development, US Computing Operations, Analysis support and documentation, and TileCal detector operation and upgrade R&D. These support activities are critical to the success of the ATLAS physics program.	

Support: ☒ Awarded ☐ Pending	
Sponsor: DOE	**Award Number**: DOE DE-SC0011686
Title of the Funded Research Project: High Energy Physics Base Funding	
Total Award Amount for the Entire Award Period (including indirect costs): $890,000	
Award Period: 05/01/16 - 04/31/17	
Number of Person-months per year to be devoted to the project by the PI: 2.0	
Abstract: This proposal requests support for a program of research in experimental high energy physics at The University of Texas at Arlington. It includes studies of the recently discovered Higgs boson, searches for new particles, detector improvement, and large scale computing for the ATLAS Experiment at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, and an initiative for a future experiment, the Silicon Detector Concept (SiD), at the proposed International Linear Collider. Together, the ATLAS Experiment and SiD, can provide a deep understanding of the nature of the combination of two of natures fundamental forces: electromagnetism and the weak nuclear force, in addition to allowing discovery of associated new particles suggested by theory. In a new direction for the group, support is also requested for participation in the future Long Baseline Neutrino Experiment (LBNE) exploring the masses of the neutrinos that are involved in the weak nuclear interactions, and the ORKA Experiment that will search for signs of new physics in the rare decays of the K-meson, an elementary particle only produced in high energy collisions. Finally, we propose to carry out theoretical studies of the dark matter that exists in large quantities around and between galaxies, in terms of its interactions with astrophysical objects, and its possible creation in low energy high beam intensity experiments.	

Current and Pending Support: Andrew P. White

Support: ☒ Awarded ☐ Pending

Sponsor: DOE **Award Number**: DOE DE-SC0011686

Title of the Funded Research Project: Research in Elementary Particle Physics

Total Award Amount for the Entire Award Period (including indirect costs): $890,000

Award Period: 04/01/16 - 03/31/17

Number of Person-months per year to be devoted to the project by the PI: 2.0

Abstract: This project supports the work of the UTA HEP group for the Energy and Intensity Frontiers. For the Energy Frontier, activities for the ATLAS experiment include leadership in computing and software, support for the operation and calibration of the Tile Calorimeter, physics studies in the SUSY and Higgs sectors, and upgrade work on TDAQi and low voltage power supplies. Also for the Energy Frontier, we have a Spokesperson role in the SiD Consortium for the International Linear Collider. Activities for SiD include the development of the design of the SiD Detector, establishing the SiD Consortium as a precursor to a full detector collaboration, promotion and coordination all aspects of detector R\&D and physics and performance studies, and representation of SiD within the HEP community nationally and internationally. For the Intensity Frontier efforts include optimization of LBNF beam line for DUNE, Design and construction of proton beam alignment monitor (PBAM) for DUNE, aka hadron monitor, optimization of Optical Coupling for DUNE photo detectors, DUNE 35t Data Analysis and Operations, studies for subGeV Dark Matter, Phase I LArIAT experiment data analyses, MiniBooNE beam dump data analysis, and contributions to Fermilab onsite long baseline experiments.

Support: ☐ Awarded ☒ Pending

Sponsor: DOE **Award Number**:

Title of the Funded Research Project: Research in Elementary Particle Phyiscs

Total Award Amount for the Entire Award Period (including indirect costs): $?????

Award Period: **04**/01/17 - 03/31/20

Number of Person-months per year to be devoted to the project by the PI: 2.0

Abstract:

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Current and Pending Support: Haleh Hadavand

Current and Pending Support
Support: ☒ Awarded ☐ Pending
Sponsor: NSF ATLAS Project Funds **Award/Identifying Number:** NSF PHY-1119200
Title of the Proposal: The U.S. ATLAS Research Program: Empowering U.S. Universities for Discoveries at the Energy Frontier
Total Award Amount for the Entire Award Period (including indirect costs): $58,000
Award Period: **1/30/16-9/30/16**
Number of Person-months per year to be devoted to the project: 0.0
Abstract: UTA is a sub-contractor of the NSF US ATLAS Operations program cooperative agreement managed by Columbia University. This cooperative agreement supports M&O, S&C and R&D activities on the ATLAS experiment at the LHC. Activities at UTA include the operation of the SouthWest Tier 2, PanDA software development, US Computing Operations, Analysis support and documentation, and TileCal detector operation and upgrade R&D. These support activities are critical to the success of the ATLAS physics program.

Current and Pending Support
Support: ☐ Awarded ☒ Pending
Sponsor: NSF **Award/Identifying Number:** 1654772
Title of the Proposal: Search for Beyond Standard Model Phenomena with Tau Leptons and Higgs
Total Award Amount for the Entire Award Period (including indirect costs): $810,011
Award Period: **2017 – 2021**
Number of Person-months per year to be devoted to the project: 2 months/year
Abstract: This proposal investigates search for Beyond Standard Model Phenomena with Tau Leptons and Higgs on the ATLAS experiment. This includes charged Higgs searches in the $\tau\nu$ final state and a Z boson + X search including leptons and taus in the final states. The Z+X combines five analyses into one scan by using a parametric fit to the background over a range of 4 GeV to a few TeV. This proposal also includes the R&D and production efforts for High Luminosity LHC for the Tile Scintillating Calorimeter low voltage power supplies.

Support: ☒ Awarded ☐ Pending
Sponsor: Department of Education **Award/Identifying Number:**
Proposal Title: Reaching Goals in Physics with GAANN Fellowships (Co-Pi)
Total Award Amount for the Entire Award Period (including indirect costs): $536,688
Award Period: 9/01/2016- 8/31/2019
Number of Person-months per year to be devoted to the project:
Abstract: This proposal provides funding for physics graduate students with demonstrated need for financial aid, and includes a supervised teaching requirement.

Current and Pending Support: Jaehoon Yu

Support: ☒ Awarded ☐ Pending	
Sponsor: DOE	**Award Number**: DOE DE-SC0011686
Title of the Funded Research Project: Research on Elementary Particle Physics	
Total Award Amount for the Entire Award Period (including indirect costs): $890,000	
Award Period: 04/01/16 - 03/31/17	
Number of Person-months per year to be devoted to the project by the PI: 2.0	
Abstract: This proposal requests support for a program of research in elementary particle physics at The University of Texas at Arlington. We propose studies of the recently discovered Higgs boson, and searches for new particles in nature which may be responsible for dark matter, at the ATLAS Experiment at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, and the Silicon Detector (SiD) at the proposed International Linear Collider. The SiD is a novel concept for a future experiment in particle physics. Our program of work involves detector research and development, and distributed computing innovations. Together, the ATLAS Experiment and SiD can provide a deep understanding of two fundamental forces of nature: electromagnetism and the weak nuclear force, in addition to allowing for the discovery of associated new particles suggested by theory. In a new direction for the group, support is also requested for participation in the future Long Baseline Neutrino Experiment (LBNE), which will explore the masses of the neutrinos that are involved in the weak nuclear interactions and search for low-mass dark matter in the beam, and the ORKA Experiment, that will search for signs of new physics in the rare decays of the K-meson, a particle only produced in high energy collisions. Finally, we propose to carry out theoretical studies of the dark matter that exists in large quantities around and between galaxies, in terms of its interactions with astrophysical objects, and its possible creation in low-energy, high beam intensity experiments.	

Support: ☒ Awarded ☐ Pending	
Sponsor: National Cancer Institute, National Health Institute	**Award Number**: 1R15CA199020-01A1
Title of the Funded Research Project: Boosting photo-induced cancer therapies through real-time image guidance	
Total Award Amount for the Entire Award Period (including indirect costs): $415,336	
Award Period: 04/01/16 - 03/31/19	
Number of Person-months per year to be devoted to the project by the PI: 0.2	
Abstract: We propose to use the position-sensitive gas electron multiplier (GEM) detector and advanced spatiotemporal image processing to enable real-time image guided PITs. The GEM technology is a recent advance of the revolutionary digital imaging of gas detectors using multiwire proportional chambers (MWPC), which won Georges Charpak a Nobel Prize for Physics in 1992. The advantages of GEM-based devices include: intrinsic spatial resolution of 50 µM or better; rate capability lager than 1MHz/mm^2; easy achievable gains above 10$^{5;}$ allowing detection of single electrons; efficiency for minimum ionizing particles close to 100%. In additional to its excellent detection performance, the flexibility of GEM can be used for a miniature device with the easy integration of an NIR fiber for therapeutic purpose. In this project, for the first time, we propose to develop a multifunctional device using GEM technology for PITs, called Ò{\bf Beta Image Guided Light-Induced Therapeutic device (BIGLITE)}, which can achieve simultaneous imaging and photo-induced therapy.	

Support: ☒ Awarded ☐ Pending	
Sponsor: NSF	**Award Number**: 1639157
Title of the Funded Research Project: Support for Biennial African School of Fundamental Physics 2016	
Total Award Amount for the Entire Award Period (including indirect costs): $28,215	
Award Period: 07/01/16 - 06/30/17	
Number of Person-months per year to be devoted to the project by the PI: 0.01	
Abstract: This proposal is in support of the forth school in the biennial series. The aim of the school is to build the capacity to harvest, interpret, and exploit the results of current and future physics experiments with particle accelerators, and to increase proficiency in related applications such as medicine, and technologies, such as grid computing. The schools are based on a close interplay between theoretical, experimental and applied physics. The organizing committee consists of a number of people key in the above areas, from both inside and outside Africa. Sub-Saharan Africa is under-represented in sub-atomic physics and this school will serve to provide more opportunities for students to become aware of and to participate in this field.	

Support: ☒ Awarded ☐ Pending	
Sponsor: Fermi National Accelerator Laboratory	**Award Number**: N/A
Title of the Funded Research Project: Application for Neutrino Physics Center Fellowship	
Award Period: 07/01/16 - 06/30/17	
Total Award Amount for the Entire Award Period (including indirect costs): $10,000	
Number of Person-months per year to be devoted to the project by the PI: 1.5	
Abstract: The major goals of this project are to understand the behavior of the membrane cryostat, develop and design the beam hadron monitor and optimize the beam line components for DUNE experiment. These funds enable the PI to contribute directly to DUNE experiment through an extended stay at FNAL.	

Support: ☒ Awarded ☐ Pending	
Sponsor: CNRS, France	**Award Number**: 1263101510
Title of the Funded Research Project: MOU for Research on WA105 Dual Phase Detector and DUNE	
Award Period: 10/01/15 - 12/31/17	
Total Award Amount for the Entire Award Period (including indirect costs): $36,728	
Number of Person-months per year to be devoted to the project by the PI: 1.0	
Abstract: The major goal of this project is to contribute to the setup of WA105 and understanding DUNE cryostats.	

Support: ☒ Awarded ☐ Pending	
Sponsor: Brookhaven National Lab (DOE)	**Award Number**:
Title of the Funded Research Project: Development of SiPM Coupling with Scintillation Counters for Range Stack Detector	
Award Period: 10/01/13 - 09/30/16	
Total Award Amount for the Entire Award Period (including indirect costs): $46,000	
Number of Person-months per year to be devoted to the project by the PI: 0.1	
Abstract: The Range Stack (RS) in ORKA detector plays an essential role in particle identification, especially the pions from Kaon decays from muons. It must be able to measure the energy, range and decay sequence of charged particles emerging from the target with a good position resolution. In addition, it must able to assist photon veto (PV) detector by identifying them with good efficiency for the photons converting before getting into the PV system. These funds have been repurposed to support LBNE/DUNE photo detector R&D of the same topic.	

Current and Pending Support: Jonathan Asaadi

Current and Pending Support
Support: ☐ Awarded ☒ Pending
Sponsor: NSF **Award/Identifying Number: 1654507**
Title of the Proposal: CAREER: A novel fully modular liquid argon neutrino detector for the Deep Underground Neutrino Experiment
Total Award Amount for the Entire Award Period (including indirect costs): $1,114,875
Award Period: **2017 - 2021**
Number of Person-months per year to be devoted to the project: 2 months/year
Abstract: This proposal puts forward the development of a new modular liquid argon time projection chamber (LArTPC) neutrino detector to be used as a near detector for the Deep Underground Neutrino Experiment (DUNE). The ultimate goal of this project is to demonstrate the feasibility of constructing and operating identical but separate LArTPC modules in a common bath of liquid argon. Each module features a relatively short drift length and at a fully independent TPC with its own readout, light detection system, cryogenics, and services.

Support: Awarded X Pending
Sponsor: DOE **Award Number**: (Current proposal) N/A
Title of the Funded Research Project: Research in Elementary Particle Phyiscs
Total Award Amount for the Entire Award Period (including indirect costs): $4,699,792
Award Period: 04/01/17 - 03/31/20
Number of Person-months per year to be devoted to the project by the PI: 2.0
Abstract: The High Energy Physics Group at the University of Texas at Arlington proposes a three-year program of research in the Energy and Intensity Frontiers, and in Detector Research and Development. We will continue our long term strong role in the ATLAS experiment, continue our ramp up of Intensity Frontier effort, prepare for long term participation in the International Linear Collider, and to increase our detector R&D efforts in pursuit of new innovations.

Current and Pending Support: Benjamin Jones

Support: Awarded X Pending	
Sponsor: DOE	**Award Number**: (Current proposal) N/A
Title of the Funded Research Project: Research in Elementary Particle Phyiscs	
Total Award Amount for the Entire Award Period (including indirect costs): $4,699,792	
Award Period: 04/01/17 - 03/31/20	
Number of Person-months per year to be devoted to the project by the PI: 0.0	
Abstract: The High Energy Physics Group at the University of Texas at Arlington proposes a three-year program of research in the Energy and Intensity Frontiers, and in Detector Research and Development. We will continue our long term strong role in the ATLAS experiment, continue our ramp up of Intensity Frontier effort, prepare for long term participation in the International Linear Collider, and to increase our detector R&D efforts in pursuit of new innovations.	

Current and Pending Support: David Nygren

Support: Awarded X Pending	
Sponsor: DOE	**Award/Identifying Number:** (Current proposal N/A
Title of the Funded Research Project: Research in Elementary Particle Phyiscs	
Total Award Amount for the Entire Award Period (including indirect costs): $4,699,792	
Award Period: 04/01/17 - 03/31/20	
Number of Person-months per year to be devoted to the project by the PI: 0.0	
Abstract: The High Energy Physics Group at the University of Texas at Arlington proposes a three-year program of research in the Energy and Intensity Frontiers, and in Detector Research and Development. We will continue our long term strong role in the ATLAS experiment, continue our ramp up of Intensity Frontier effort, prepare for long term participation in the International Linear Collider, and to increase our detector R&D efforts in pursuit of new innovations.	

FACILITIES AND OTHER RESOURCES

The University of Texas (UTA) is the second largest university in the UT system with around 35,000 students. It is a comprehensive doctoral university located in the Dallas-Ft. Worth metroplex. HEP was selected as one of the first ”Organized Research Center of Excellence” at UTA in 2011. PI De is the Director of the ORCE:HEP Center, which also includes faculty from commology, astrophysics, space sciences, and computtational sciences. The combined synergy of these activities, along with substantial commitment of university resources, provides strong support to the core DoE HEP mission at UTA. Overall, the university has invested over two million dollars to support HEP research activities.

A prime example of UTA's investment in science was the provision of the 120,000 sq.ft. Physics and Chemistry Research Building in 2006. This building houses a high bay area for HEP, our ATLAS Tier 2 center, three detector development laboratories, an HEP conference room, faculty offices, and postdoc and graduate student offices. The building houses an excellent Physics mechanical workshop with the capabilities to manage large scale detector construction..

One finished lab space at UT Arlington's Physics and Chemistry Research Builiding is a 700 sq. feet lab space with the necessary ventilation for cryogenic experiments to take place. This lab space has recently been completed with a purification and pressure based gas recirculation system for liquid argon detector R&D. This finished lab space also houses desk space, computers, soldering stations, and work space for the undergraduate detector sensor lab as well as a intensity frontier remote operations station. This remote operation station has already been used to take shifts on the LArIAT experiment and is being expanded for remote shift taking on MicroBooNE, SBND, and ICARUS.

A 700 sq foot unfinished lab space adjacent to the purified liquid argon lab and located off the high-bay area has a 3 ton crane for detector construction and assembly. This lab space is located directly adjacent to the UTA physics department machine shop which can be used during detector testing and construction.

In addition to this lab space, the UTA HEP group have retained our previous office suite in Science Hall, and this area has been rennovated as the ATLAS Tier 2 operations and visitors area. The lab space in the basement of Science Hall now houses the purified gaseous xenon system as well as a laboratory space for testing Single Molecule Fluorescence Imaging.

UTA also hosts the SouthWest Tier 2 center (SWT2) for ATLAS, which is one of the largest computing centers for ATLAS, providing over 3000 cores and 3 petabytes of storage. The UTA HEP Tier 3 center is co-located with the Tier 2, providing easy access to ATLAS data.

Equipment

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: EF Year 1

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		White		Lead PI				2	28,308	8,492	36,800
2.	Prof.	Kaushik		De		co-PI				2	33,018	9,905	42,923
3.	Prof.	Andrew		Brandt		co-PI				1	12,294	3,688	15,982
4.	Prof.	Amir		Farbin		co-PI				2	20,666	6,200	26,866
5.	Prof.	Haleh		Hadavand		co-PI				2	17,090	5,127	22,217
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 144,788

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
3.1	Post Doctoral Associates				167,400	50,220	217,620
4	Graduate Students				96,000	9,600	105,600
3	Undergraduate Students				15,000	1,275	16,275
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
10.1	Total Number Other Personnel					Total Other Personnel	339,495

Total Salary, Wages and Fringe Benefits (A+B) 484,283

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: EF Year 1

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	127,820
Total Travel Cost	127,820

E. Participant/Trainee Support Costs	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: EF Year 1

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	12,500
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	36,560
9.	
10.	
Total Other Direct Costs	49,060

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	661,163

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	296,563	152,730
2.	Off Campus IDC	26	328,038	85,290
3.				
4.				
			Total Indirect Costs	238,020

Cognizant Federal Agency
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	899,183

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: EF Year 2

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		White		Lead PI				2	29,157	8,747	37,904
2.	Prof.	Kaushik		De		co-PI				2	34,009	10,203	44,212
3.	Prof.	Andrew		Brandt		co-PI				1	12,663	3,799	16,462
4.	Prof.	Amir		Farbin		co-PI				2	21,286	6,386	27,672
5.	Prof.	Haleh		Hadavand		co-PI				2	17,603	5,281	22,884
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 149,134

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
3.1	Post Doctoral Associates				172,422	51,727	224,149
4	Graduate Students				98,880	9,888	108,768
3	Undergraduate Students				15,000	1,275	16,275
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
10.1	Total Number Other Personnel					Total Other Personnel	349,192

Total Salary, Wages and Fringe Benefits (A+B) 498,326

RESEARCH & RELATED Budget {A-B} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: [x] Project [ ] Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: EF Year 2

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2.	Foreign Travel Costs	127,820
	Total Travel Cost	127,820

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: EF Year 2

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	12,500
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	36,560
9.	
10.	
Total Other Direct Costs	49,060

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	675,206

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	304,598	156,868
2.	Off Campus IDC	26	334,046	86,852
3.				
4.				
	Total Indirect Costs			243,720

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	918,926

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: EF Year 3

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		White		Lead PI				2	30,032	9,010	39,042
2.	Prof.	Kaushik		De		co-PI				2	35,029	10,509	45,538
3.	Prof.	Andrew		Brandt		co-PI				1	13,043	3,913	16,956
4.	Prof.	Amir		Farbin		co-PI				2	21,925	6,577	28,502
5.	Prof.	Haleh		Hadavand		co-PI				2	18,131	5,439	23,570
6.													0
7.													0
8.													0
9.	Total Funds requested for all Senior Key Persons in the attached file												
												Total Senior/Key Person	153,608

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
3.6	Post Doctoral Associates				206,238	61,872	268,110
4.5	Graduate Students				114,577	11,457	126,034
3	Undergraduate Students				15,000	1,275	16,275
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
11.1	Total Number Other Personnel					Total Other Personnel	410,419
						Total Salary, Wages and Fringe Benefits (A+B)	564,027

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: EF Year 3

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2.	Foreign Travel Costs	137,420
	Total Travel Cost	137,420

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: EF Year 3

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	12,500
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	41,130
9.	
10.	
Total Other Direct Costs	53,630

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	755,077

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	326,878	168,341
2.	Off Campus IDC	26	387,069	100,638
3.				
4.				
			Total Indirect Costs	268,979

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	1,024,056

J. Fee	Funds Requested ($)

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		447,528
Section B, Other Personnel		1,099,107
Total Number Other Personnel	31.3	
Total Salary, Wages and Fringe Benefits (A+B)		1,546,635
Section C, Equipment		0
Section D, Travel		393,060
1. Domestic	0	
2. Foreign	393,060	
Section E, Participant/Trainee Support Costs		0
1. Tuition/Fees/Health Insurance	114,520	
2. Stipends	0	
3. Travel	0	
4. Subsistence	0	
5. Other	0	
6. Number of Participants/Trainees	0	
Section F, Other Direct Costs		0
1. Materials and Supplies	37,500	
2. Publication Costs	0	
3. Consultant Services	0	
4. ADP/Computer Services	0	
5. Subawards/Consortium/Contractual Costs	0	
6. Equipment or Facility Rental/User Fees	0	
7. Alterations and Renovations	0	
8. Other 1	0	
9. Other 2	0	
10. Other 3	0	
Section G, Direct Costs (A thru F)		2,091,445
Section H, Indirect Costs		750,720
Section I, Total Direct and Indirect Costs (G + H)		2,842,165
Section J, Fee		0

NOTE: Make sure your email is addressed to the SC program manager and that you attach all additional pages that should contain extra budget items and the required written budget item justification.

7.15 Budget Justification for the ATLAS Program

Preamble: This section provides the budget justifications for the ATLAS experiment and includes the PIs White, De, Brandt, Farbin, and Hadavand. A canonical cost of living adjustment rate of 3% is applied to all salaries in years two and three. The total budget for ATLAS for the three years is $2,656,887.

The tasks carried out on-campus versus off-campus incur substantially different indirect rates 51.5% on-campus versus 26% off-campus.

1. Year 1

    - **Senior Personnel**: Summer salary for PIs requested is $97,222. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
    - **Postdoctoral Researcher**: A request for 3.1 postdoctoral fellows is made using the base salary of $54,000 per annum for a total of 167,400. The fringe benefit rate is 30% of the request. Since it is anticipated to have 1 postdoctoral fellow on-campus and 2.1 off campus at CERN, the indirect rates for this cost are 51.5% and 26% respectively for the relevant portion of the cost.
    - **Graduate Students**: A request for 4 graduate students support is made at the base rate of $24,000 per annum for a total of $96,000. The fringe benefit rate is 10% of the request. Since it is anticipated to have 2 graduate students on-campus and 2 off-campus at CERN, indirect rate for this cost 51.5% and 26% respectively.
    - **Undergraduate Students**: A request of 3 undergraduate students support is made at the base rate of $5,000 per annum for a total of $15,000. They will be located on-campus therefore an indirect rate of 51.5% is applied to this rate.
    - **Travel and Cost of Living Adjustment**: A total request of $110,700 for travel and COLA support for postdoctoral fellow and graduate student is made. Of this amount, the travel support is $49,500. An indirect rate for this cost of 26% off-campus is applied.
    - **STEM Tuition**: Graduate student tuition support for one student is requested at the rate of $9,140 per annum for a total of $36,560. This cost does not incur indirect cost.
    - **M&O**: A modest request for maintenance and operation cost of $2,500 per PI is requested per annum for a total of $12,500 to support various costs. This request is subject to on-campus indirect rate of 51.5%.
    - **Total Fringe Benefit**: The total cost for the fringe benefit is $80,520 .
    - **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $222,435 .
    - **Grand Total for Year 1**: The grand total request for year 1 for ATLAS is $840,348.

2. Year 2

    - **Senior Personnel**: Summer salary for PIs requested is $100,139. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
    - **Postdoctoral Researcher**: A request for 3 postdoctoral fellows is made using the base salary of $55,620 per annum for a total of$172,422 . The fringe benefit rate is 30% of the request. Since it is anticipated to have 1 postdoctoral fellow on-campus and 2 off campus at CERN, the indirect rates for this cost are 26% off-campus and 51.5% on-campus for the relevant portion of the cost.
    - **Graduate Students**: A request for 4 graduate students support is made at the base rate of $24,720 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have 2 graduate students on-campus and 2 off-campus at CERN, indirect rate for this cost 51.5% and 26% respectively.
    - **Undergraduate Students**: A request of 3 undergraduate students support is made at the base rate of $5,000 per annum for a total of $15,000. They will be located on-campus therefore an indirect rate of 51.5% is applied to this rate.

- **Travel and Cost of Living Adjustment**: A request of total of $110,700 for travel and COLA support for postdoctoral fellow and graduate student is made. Of this amount, the travel support is $49,500. An indirect rate for this cost of 26% off-campus is applied.
- **STEM Tuition**: Graduate student tuition support for one student is requested at the rate of $9,140 per annum for a total of $36,560. This cost does not incur indirect cost.
- **M&O**: A modest request for maintenance and operation cost of $2,500 per PI is requested per annum for a total of $12,500 to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $82,891.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $227,849.
- **Grand Total for Year 2**: The grand total request for year 2 for ATLAS is $856,134.

3. Year 3

   - **Senior Personnel**: Summer salary for PIs requested is $103,143. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
   - **Postdoctoral Researcher**: A request for 4 postdoctoral fellows is made using the base salary of $57,289 per annum for a total of . The fringe benefit rate is 30% of the request. Since it is anticipated to have 1 postdoctoral fellow on-campus and 3 off campus at CERN, the indirect rates for this cost are 26% off-campus and 51.5% on-campus for the relevant portion of the cost.
   - **Graduate Students**: A request for 5 graduate students support is made at the base rate of $25,462 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have 3 graduate students on-campus and 2 off-campus at CERN, indirect rate for this cost 51.5% and 26% respectively.
   - **Undergraduate Students**: A request of 3 undergraduate students support is made at the base rate of $5,000 per annum for a total of $15,000. They will be located on-campus therefore an indirect rate of 51.5% is applied to this rate.
   - **Travel and Cost of Living Adjustment**: A request of total of $110,700 for travel and COLA support for postdoctoral fellow and graduate student is made. Of this amount, the travel support is $49,500. An indirect rate for this cost of 26% off-campus is applied.
   - **STEM Tuition**: Graduate student tuition support for one student is requested at the rate of $9,140 per annum for a total of $36,560. This cost does not incur indirect cost.
   - **M&O**: A modest request for maintenance and operation cost of $2,500 per PI is requested per annum for a total of $12,500 to support various costs. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $ 97,745.
   - **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $252,816.
   - **Grand Total for Year 3**: The grand total request for year 3 for ATLAS is $960,405.

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: IF Year 1

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Jaehoon		Yu		co-PI				2	27,024	8,107	35,131
2.	Prof.	Jonathan		Asaadi		co-PI					18,768	5,630	24,398
3.													0
4.													0
5.													0
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 59,529

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.5	Post Doctoral Associates				81,000	24,300	105,300
2	Graduate Students				48,000	4,800	52,800
4	Undergraduate Students				20,000	1,700	21,700
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
7.5	Total Number Other Personnel					Total Other Personnel	179,800

Total Salary, Wages and Fringe Benefits (A+B) 239,329

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: IF Year 1

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	6,000
2.	Foreign Travel Costs	33,350
	Total Travel Cost	39,350

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: IF Year 1

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	5,000
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	18,280
9.	
10.	
Total Other Direct Costs	23,280

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	301,959

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On campus IDC	51.5	152,304	78,437
2.	Off campus IDC	26	127,142	31,558
3.				
4.				
			Total Indirect Costs	109,995

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	411,954

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: IF Year 2

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Jaehoon		Yu		co-PI				2	27,835	8,350	36,185
2.	Prof.	Jonathan		Asaadi		co-PI				2	19,331	5,799	25,130
3.													0
4.													0
5.													0
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 61,315

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
2	Post Doctoral Associates				111,240	33,372	144,612
2	Graduate Students				49,440	4,944	54,384
4	Undergraduate Students				20,000	1,700	21,700
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
8	Total Number Other Personnel					Total Other Personnel	220,696

Total Salary, Wages and Fringe Benefits (A+B) 282,011

RESEARCH & RELATED Budget {A-B} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: IF Year 2

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	6,000
2.	Foreign Travel Costs	50,600
	Total Travel Cost	56,600

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: IF Year 2

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	5,000
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	18,280
9.	
10.	
Total Other Direct Costs	23,280

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	361,891

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	119,783	61,688
2.	Off Campus IDC	26	218,096	55,596
3.				
4.				
			Total Indirect Costs	117,284

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	479,175

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: IF Year 3

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Jaehoon		Yu		co-PI				2	28,670	8,601	37,271
2.	Prof.	Jonathan		Asaadi		co-PI				2	19,911	5,973	25,884
3.													0
4.													0
5.													0
6.													0
7.													0
8.													0
9.	Total Funds requested for all Senior Key Persons in the attached file												
												Total Senior/Key Person	63,155

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
2	Post Doctoral Associates				114,577	34,373	148,950
2	Graduate Students				50,923	5,092	56,015
4	Undergraduate Students				20,000	1,700	21,700
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
8	Total Number Other Personnel					Total Other Personnel	226,665
						Total Salary, Wages and Fringe Benefits (A+B)	289,820

RESEARCH & RELATED Budget {A-B} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: IF Year 3

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	6,000
2.	Foreign Travel Costs	54,200
	Total Travel Cost	60,200

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ☐ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: IF Year 3

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	5,000
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	18,280
9.	
10.	
Total Other Direct Costs	23,280

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	373,300

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	94,429	48,631
2.	Off Campus IDC	26	254,858	65,154
3.				
4.				
			Total Indirect Costs	113,785

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	487,085

J. Fee	Funds Requested ($)

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		184,000
Section B, Other Personnel		627,162
Total Number Other Personnel	23.5	
Total Salary, Wages and Fringe Benefits (A+B)		811,162
Section C, Equipment		0
Section D, Travel		0
1. Domestic	18,000	
2. Foreign	138,150	
Section E, Participant/Trainee Support Costs		0
1. Tuition/Fees/Health Insurance	54,840	
2. Stipends	0	
3. Travel	0	
4. Subsistence	0	
5. Other	0	
6. Number of Participants/Trainees	0	
Section F, Other Direct Costs		0
1. Materials and Supplies	15,000	
2. Publication Costs	0	
3. Consultant Services	0	
4. ADP/Computer Services	0	
5. Subawards/Consortium/Contractual Costs	0	
6. Equipment or Facility Rental/User Fees	0	
7. Alterations and Renovations	0	
8. Other 1	0	
9. Other 2	0	
10. Other 3	0	
Section G, Direct Costs (A thru F)		1,037,152
Section H, Indirect Costs		341,063
Section I, Total Direct and Indirect Costs (G + H)		1,378,215
Section J, Fee		0

NOTE: Make sure your email is addressed to the SC program manager and that you attach all additional pages that should contain extra budget items and the required written budget item justification.

7.16 Intensity Frontier Program Budget Justification

Preamble: This section provides the budget justifications for PIs Yu and Asaadi for the intensity frontier. Detailed description for each of the items is given in year one. A canonical cost of living adjustment rate of 3% is applied to all salaries and STEM tuition in the subsequent years. Years two and three of the proposal contain fewer details as in year one, but instead reflect the base rate and where noted any significant changes in effort.

The tasks carried out on-campus versus off-campus incur substantially different indirect rates (51.5% on-campus versus 26% off-campus), therefore the requests are made with the specifications based on the personnel allocation plan specified in the Table 7.

PI Name	Category	ON/OFF Campus	Year 1	Year 2	Year 3
Jaehoon Yu	PI	ON	100%	100%	100%
	Postdoc	ON	50%	0%	0%
	Postdoc	OFF	100%	100%	100%
	GRA	ON	50%	50%	0%
	GRA	OFF	50%	50%	100%
	UG	ON	75%	55%	75%
	UG	OFF	25%	25%	25%
Jonathan Asaadi	PI	ON	100%	100%	100%
	Postdoc	ON	50%	0%	0%
	Postdoc	OFF	100%	100%	100%
	GRA	ON	50%	50%	0%
	GRA	OFF	50%	50%	100%
	UG	ON	75%	55%	75%
	UG	OFF	25%	25%	25%

Table 7: UTA Intensity Frontier Personnel Resource Allocation Plan

Since PI Asaadi has a component of research which appears in the Detector R&D section of this proposal, we include a Table 8 which shows the breakdown of percentage effort across the froniters. A similar table appears in the Detector R&D section for completeness.

Name and Yearly FTE for Senior Investigators with multiple HEP subprograms or Research Thrusts

	Proposal Project Period: 2017 - 2020					
	Budget Period 2017-2018		**Budget Period 2018-2019**		**Budget Period 2019-2020**	
Name	Intensity Frontier	Detector R&D	Intensity Frontier	Detector R&D	Intensity Frontier	Detector R&D
Jonathan Asaadi	85%	15%	85%	15%	85%	15%

Table 8: Effort Table for Investigators with multiple HEP Subprograms in the Intensity Frontier

PI: Jaehoon Yu

1. **Cumulative - 3 years**
   - **Senior Personnel**: Two months summer salary for Yu is requested at the current rate of $121,607 per 9 month academic year, equivalent to $13,512 per month for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. The total request for this item is $83,528. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%. Yu will lead the protoDUNE construction efforts, contribute to the SBND construction and installation, as well as leading analyses on ICARUS and sensitivity studies related to BSM physics for DUNE.
   - **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $54,000 per annum for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. The total requested amount for this item is $166,909. The fringe benefit rate is 30% of the request. Since it is anticipated to have the postdoctoral fellow 50% on campus and 50% off campus for tasks at CERN, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Currently Dr. Animesh Chatterjee who has been with the group for 21 months is supported through this request. This researcher is expected to contribute to protoDUNE construction, installation, and data taking as well as analysis on the SBN
   - **Graduate Students**: Support for one graduate student is requested at the base rate of $24,000 per annum for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. The total request for this item is $74,182. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at Fermilab, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Yus student Garrett Brown is currently supported via teaching assistant support in the department. Yu is in the process of recruiting a couple of additional students strategically spaced in time. This student is expected to contribute to protoDUNE construction, installation, and data taking and will perform one of the cross-section analyses outlined in the proposal either on SBND or ICARUS.
   - **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, such as systematic studies of beam line components for LBNF. A request for two undergraduate support is requested at the base rate $5,000, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $30,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students to spend 75% on campus and 25% off campus for tasks at Fermilab and at CERN during the summer, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. The undergraduate students currently in the group are R. Musser, E. Amador, M. Avilla, N. Smith and V. Cervantes.
   - **Travel and Cost of Living Adjustment**: We request $10,000 per year for travel, totalling $30,000. In addition, COLA support for postdoctoral fellow and graduate student are requested at a total of $46,350 subject under 26% off-campus indirect rate. Of this amount, the travel support $15,000 is requested to be allocated to the funds at UTA and be subject to on-campus rate of 51.5% and $15,000 be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. COLA is requested to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 for postdoc for Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
   - **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140 per annum, totalling $27,420. This cost does not incur indirect cost.
   - **M&S**: A modest maintenance and services cost of $2,500 per annum, totalling $7,500 is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit for three year period is $85,099.
   - **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%)

and off-campus (26%) described above is $187,664.

- **Grand Total for Year 1**: The total request for Yu for the three year period is $738,651.

2. Year 1

- **Senior Personnel**: Two months summer salary for Yu is requested at the current rate of $121,607 per 9 month academic year, equivalent to $13,512 per month. The total request for this item is $27,024. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5.
- **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $54,000 per annum. The fringe benefit rate is 30% of the request. Since it is anticipated to have the postdoctoral fellow 50% on campus and 50% off campus for tasks at CERN, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Currently Dr. Animesh Chatterjee who has been with the group for 21 months is supported through this request.
- **Graduate Students**: Support for one graduate student is requested at the base rate of $24,000 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at Fermilab, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Yus student Garrett Brown is currently supported via teaching assistant support in the department. Yu is in the process of recruiting a couple of additional students strategically spaced in time.
- **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, such as systematic studies of beam line components for LBNF. A request for two undergraduate support is requested at the base rate $5,000, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students to spend 75% on campus and 25% off campus for tasks at Fermilab and at CERN during the summer, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. The undergraduate students currently in the group are R. Musser, E. Amador, M. Avilla, N. Smith and V. Cervantes.
- **Travel and Cost of Living Adjustment**: We request a total of $17,950 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA and be subject to on-campus rate of 51.5%. Of the remaining $12,950, we request $5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The remaining $7,950 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 for postdoc for Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
- **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140 per annum. This cost does not incur indirect cost.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $27,557.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $66,351.
- **Grand Total for Year 1**: The grand total request for year one for Yu is $238,522.

3. Year 2

- **Senior Personnel**: Two months summer salary for Yu is requested after applying a 3% canonical cost of living adjustment, at the rate of $125,255 per 9 month academic year. The total request for this item is $27,835. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
- **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $55,620 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit

rate is 30% of the request. Since it is anticipated to the postdoctoral fellow is 100% off campus for tasks 50% at Fermilab and 50% at CERN, the indirect rate for this cost is 26%.

- **Graduate Students**: Support for one graduate student is requested at the base rate of $24,720 per annum after a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at CERN, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost.
- **Undergraduate Students**: This request for two undergraduate support is at the base rate $5,000. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. The proportion of undergraduates on and off campus tasks is the same as year 1, and the indirect cost is applied the same as that of year 1.
- **Travel and Cost of Living Adjustment**: We request a total of $28,300 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA as in year 1. Of the remaining $23,300, we request $5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The remaining $18,300 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 per month for postdoctoral fellow at Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
  It is worthwhile to note that this increase in travel cost request compared to year 1 is offset by the reduction in the indirect cost, thanks to taking advantage of the 26% off-campus rate.
- **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140 per annum. This cost does not incur indirect cost.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $28,358.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $61,488, reduced compared to year 1 due to the allocation of personnel to off-campus.
- **Grand Total for Year 2**: The total request for year two for Yu is $247,962.

4. Year 3

- **Senior Personnel**: Two months summer salary for Yu is requested after applying a 3% canonical cost of living adjustment, at the rate of $129,013 per 9 month academic year. The total request for this item is $28,670. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
- **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $57,289 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 30% of the request. Since it is anticipated to the postdoctoral fellow is 100% off campus for tasks 50% at Fermilab and 50% at CERN, the indirect rate for this cost is 26%.
- **Graduate Students**: Support for one graduate student is requested at the base rate of $25,462 per annum after a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% off campus for tasks at Fermilab (50%) and at CERN (50%), the applied indirect is 26% off-campus rate.
- **Undergraduate Students**: This request for two undergraduate support is at the base rate $5,305, after a 3% canonical cost of living adjustment. The total cost for this request is $10,610. The fringe benefit rate for an undergraduate student is 8.5%. The proportion of undergraduates on and off campus tasks is the same as year 1, and the indirect cost is also applied the same as that of year 1.
- **Travel and Cost of Living Adjustment**: We request a total of $30,100 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA as in year 1. Of the remaining $25,100, we request

$5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The remaining $20,100 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 per month for postdoctoral fellow at Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
It is worthwhile to note that this increase in travel cost request compared to year 1 is offset by the reduction in the indirect cost, thanks to taking advantage of the 26% off-campus rate.

- **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140. This cost does not incur indirect cost.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $29,184.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $59,825, reduced compared to year 1 or 2 due to the greater allocation of personnel on off-campus.
- **Grand Total for Year 3**: The total request for year three is $252,168.

7.16.1 PI: Jonathan Asaadi

1. **Cumulative - 3 years**
   - **Senior Personnel**: Two months summer salary for Asaadi is requested at the current rate of $84,460 per 9 month academic year, equivalent to $7,038 per month for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. The total request for this item is $58,010. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.Asaadi will lead the SBN construction efforts, installation, and operations effort as well as play a role in the installation and commissioning of the protoDUNE single phase detector. Asaadi will focus on neutrino cross-sections from MicroBooNE and SBND.
   - **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $54,000 per annum for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. During year one of the proposal, the request is for one-half of the postdoc, with the anticipation that it will take some time to hire a new person. The total requested amount for this item is $139,909. The fringe benefit rate is 30% of the request. Since it is anticipated to have the postdoctoral fellow 50% on campus and 50% off campus for tasks at CERN, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. This postdoctoral researcher is expected to play a critical role on MicroBooNE operations and SBND construction and installation. This person is expected to help spearhead the early data analysis on SBND.
   - **Graduate Students**: Support for one graduate student is requested at the base rate of $24,000 per annum for the first year and a canonical 3% cost of living adjustment is applied in subsequent years. The total request for this item is $74,182. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at Fermilab, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Asaadi's student Zach Williams is currently supported via teaching assistant support in the department. Zach will lead the coherent pion cross-section on MicroBooNE as well as play a role in SBND cold electronics testing. Asaadi is in the process of recruiting additional students strategically spaced in time.
   - **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project. A request for two undergraduate support is made at the base rate $5,000 per student, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $30,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students to spend 75% on campus and 25% off campus for tasks at Fermilab and at CERN during the summer, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. These students are expected to help with the operation and data taking of the cold electronics test stand as well as work on simulation associated with the cross-section analyses. The undergraduate students currently in the group are Ilker Parmaksiz and Nhan Pham.
   - **Travel and Cost of Living Adjustment**: We request $10,000 per year for travel, totalling $30,000. In addition, COLA support for postdoctoral fellow and graduate student are requested at a total of $49,800 subject under 26% off-campus indirect rate. Of this amount, the travel support $15,000 is requested to be allocated to the funds at UTA and be subject to on-campus rate of 51.5% and $15,000 be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. COLA is requested to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 for postdoc for Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
   - **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140 per annum, totalling $27,420. This cost does not incur indirect cost.
   - **M&S**: A modest maintenance and services cost of $2,500 per annum, totalling $7,500 is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit for three year period is $69,344.

- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $153,399.
- **Grand Total for Year 1**: The total request for Asaadi for the three year period is $639,563.

2. Year 1
    - **Senior Personnel**: Two months summer salary for Asaadi is requested at the current rate of $84,460 per 9 month academic year, equivalent to $7,038 per month. The total request for this item is $18,768. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
    - **Postdoctoral Researcher**: A request of $27,000 for half postdoctoral fellow is made using the base salary of $54,000 per annum. This is because we anticipate that it will take about half a year to fill the position. The fringe benefit rate is 30% of the request. Since it is anticipated to have the postdoctoral fellow is going to be located at Fermilab (25%), the indirect rate for this cost is 26% off-campus for the relevant portion of the cost.
    - **Graduate Students**: Support for one graduate student is requested at the base rate of $24,000 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at Fermilab, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. Asaadis student, Zach Williams, is currently supported via teaching assistant support in the department. Asaadi is in the process of recruiting an additional students strategically spaced in time.
    - **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, LArTPC slow control component work utilizing arduino based micro-controllers. A request for two undergraduate support is requested at the base rate $5,000, equivalent t to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students to spend 75% on campus and 25% off campus for tasks at Fermilab and at CERN during the summer, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost. The undergraduate students currently in the group are Ilker Parmaksiz and Nhan Pham.
    - **Travel and Cost of Living Adjustment**: We request a total of $21,400 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA and be subject to on-campus rate of 51.5%. Of the remaining $16,400, we request $5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The remaining $11,400 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 per month for postdoctoral fellow at Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
    - **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140 per annum. This cost does not incur indirect cost.
    - **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
    - **Total Fringe Benefit**: The total cost for the fringe benefit is $16,980.
    - **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $43,644.
    - **Grand Total for Year 1**: The total request for year one is $173,432.
3. Year 2
    - **Senior Personnel**: Two months summer salary for Asaadi is requested after applying a 3% canonical cost of living adjustment, at the rate of $86,994 per 9 month academic year. The total request for this item is $19,331. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
    - **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $55,620 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit

rate is 30% of the request. Since it is anticipated to the postdoctoral fellow is 100% off campus for tasks 50% at Fermilab and 50% at CERN, the indirect rate for this cost is 26%.

- **Graduate Students**: Support for one graduate student is requested at the base rate of $24,720 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 50% on campus and 50% off campus for tasks at CERN, the indirect rate for this cost is 51.5% on-campus and 26% off-campus for the relevant portion of the cost.
- **Undergraduate Students**: This request for two undergraduate support is at the base rate $5,000. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. The proportion of undergraduates on and off campus tasks is the same as year 1, and the indirect cost is also applied the same as that of year one.
- **Travel and Cost of Living Adjustment**: We request a total of $28,300 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA as in year 1. Of the remaining $23,300, we request $5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The remaining $18,300 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 per month for postdoctoral fellow at Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
  It is worthwhile to note that this increase in travel cost request compared to year 1 is offset by the reduction in the indirect cost, thanks to taking advantage of the 26% off-campus rate.
- **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140. This cost does not incur indirect cost.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $25,807.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $55,795, reduced compared to year 1 due to the allocation of personnel to off-campus.
- **Grand Total for Year 2**: The total request for year two for Asaadi is $231,214.

4. Year 3
   - **Senior Personnel**: Two months summer salary for Asaadi is requested after applying a 3% canonical cost of living adjustment, at the rate of $89,604 per 9 month academic year. The total request for this item is $19,911. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
   - **Postdoctoral Researcher**: A request for one postdoctoral fellow is made using the base salary of $57,289 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 30% of the request. Since it is anticipated to the postdoctoral fellow is 100% off campus for tasks 50% at Fermilab and 50% at CERN, the indirect rate for this cost is 26%.
   - **Graduate Students**: Support for one graduate student is requested at the base rate of $25,462 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% off campus for tasks at Fermilab (50%) and at CERN (50%), the applied indirect is 26% off-campus rate.
   - **Undergraduate Students**: This request for two undergraduate support is at the base rate $5,000. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. The proportion of undergraduates on and off campus tasks is the same as year 1, and the indirect cost is also applied the same as that of year 1.
   - **Travel and Cost of Living Adjustment**: We request a total of $30,100 for travel and COLA support for postdoctoral fellow and graduate student. Of this amount, the travel support $5,000 is requested to be allocated to the funds at UTA as in year 1. Of the remaining $25,100, we request $5,000 to be placed in our groups LSA at Fermilab to minimize the indirect cost at UTA. The

remaining $20,100 is for COLA and is subject to off-campus rate of 26%. COLA request to defray the cost differentials between Arlington, TX and Fermilab or CERN is computed based on $300 per month for graduate students and $450 per month for postdoctoral fellow at Fermilab. The rate for CERN is higher at $1,000 per month for students and $1,600 per month for postdoctoral fellow. These COLA rates are consistent with that of Energy Frontier program to ensure the fair treatment of the group personnel.
It is worthwhile to note that this increase in travel cost request compared to year one is offset by the reduction in the indirect cost, thanks to taking advantage of the 26% off-campus rate.

- **STEM Tuition**: Graduate student tuition support for one student is request at the rate of $9,140. This cost does not incur indirect cost.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $26,556.
- **Total Indirect**: The total indirect cost computed using the proportion of the on-campus (51.5%) and off-campus (26%) described above is $53,961.
- **Grand Total for Year 3**: The total request for year three is $234,918.

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: Det Year 1

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		Brandt		co-PI					12,294	3,688	15,982
2.	Prof.	Jonathan		Asaadi		co-PI					0	0	0
3.	Prof.	David		Nygren		co-PI					0	0	0
4.	Prof.	Benjamin		Jones		co-PI					0	0	0
5.													0
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 15,982

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates				27,000	8,100	35,100
1	Graduate Students				24,000	2,400	26,400
2	Undergraduate Students				10,000	850	10,850
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
4	Total Number Other Personnel					Total Other Personnel	72,350

Total Salary, Wages and Fringe Benefits (A+B) 88,332

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: Det Year 1

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	0
2.	Foreign Travel Costs	0
	Total Travel Cost	0

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2017 * End Date: 3/31/2018 Budget Period: Det Year 1

F. Other Direct Costs		Funds Requested ($)
1.	Materials and Supplies	18,500
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	STEM Tuition	9,140
9.		
10.		
	Total Other Direct Costs	27,640

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	115,972

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	108,983	56,126
2.				
3.				
4.				
			Total Indirect Costs	56,126

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	172,098

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: Det Year 2

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		Brandt		co-PI					12,663	3,799	16,462
2.	Prof.	Jonathan		Asaadi		co-PI					0	0	0
3.	Prof.	David		Nygren		co-PI					0	0	0
4.	Prof.	Benjamin		Jones		co-PI					0	0	0
5.													0
6.													0
7.													0
8.													0

9. Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 16,462

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1	Post Doctoral Associates				27,810	8,343	36,153
1	Graduate Students				24,720	2,472	27,192
2	Undergraduate Students				10,000	850	10,850
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
4	Total Number Other Personnel					Total Other Personnel	74,195

Total Salary, Wages and Fringe Benefits (A+B) 90,657

RESEARCH & RELATED Budget {A-B} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: Det Year 2

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	
Total Travel Cost	0

E. Participant/Trainee Support Costs	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 2

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2018 * End Date: 3/31/2019 Budget Period: Det Year 2

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	18,500
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	9,140
9.	
10.	
Total Other Direct Costs	27,640

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	118,297

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	111,307	57,323
2.				
3.				
4.				
			Total Indirect Costs	57,323

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	175,620

J. Fee	Funds Requested ($)

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: Det Year 3

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Prof.	Andrew		Brandt		co-PI					13,043	3,913	16,956
2.	Prof.	Jonathan		Asaadi		co-PI					0	0	0
3.	Prof.	David		Nygren		co-PI					0	0	0
4.	Prof.	Benjamin		Jones		co-PI					0	0	0
5.													0
6.													0
7.													0
8.													0
9.	Total Funds requested for all Senior Key Persons in the attached file												
												Total Senior/Key Person	16,956

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
	Post Doctoral Associates						0
1	Graduate Students				25,462	2,546	28,008
4	Undergraduate Students				20,000	1,700	21,700
	Secretarial/Clerical						0
							0
							0
							0
							0
							0
							0
5	Total Number Other Personnel					Total Other Personnel	49,708
						Total Salary, Wages and Fringe Benefits (A+B)	66,664

RESEARCH & RELATED Budget {A-B} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: Det Year 3

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	0

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2.	Foreign Travel Costs	
	Total Travel Cost	0

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	0

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 3

* ORGANIZATIONAL DUNS: 064234610

* Budget Type: ■ Project ☐ Subaward/Consortium

Enter name of Organization: University of Texas at Arlington

* Start Date: 4/1/2019 * End Date: 3/31/2020 Budget Period: Det Year 3

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	13,500
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	
7. Alterations and Renovations	
8. STEM Tuition	9,140
9.	
10.	
Total Other Direct Costs	22,640

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	89,304

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	On Campus IDC	51.5	82,313	42,391
2.				
3.				
4.				
			Total Indirect Costs	42,391

Cognizant Federal Agency

(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	131,695

J. Fee	Funds Requested ($)

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		49,399
Section B, Other Personnel		196,253
Total Number Other Personnel	7	
Total Salary, Wages and Fringe Benefits (A+B)		245,652
Section C, Equipment		0
Section D, Travel		0
1. Domestic	0	
2. Foreign	0	
Section E, Participant/Trainee Support Costs		0
1. Tuition/Fees/Health Insurance	27,420	
2. Stipends	0	
3. Travel	0	
4. Subsistence	0	
5. Other	0	
6. Number of Participants/Trainees	0	
Section F, Other Direct Costs		0
1. Materials and Supplies	50,500	
2. Publication Costs	0	
3. Consultant Services	0	
4. ADP/Computer Services	0	
5. Subawards/Consortium/Contractual Costs	0	
6. Equipment or Facility Rental/User Fees	0	
7. Alterations and Renovations	0	
8. Other 1	0	
9. Other 2	0	
10. Other 3	0	
Section G, Direct Costs (A thru F)		323,572
Section H, Indirect Costs		155,840
Section I, Total Direct and Indirect Costs (G + H)		479,412
Section J, Fee		0

NOTE: Make sure your email is addressed to the SC program manager and that you attach all additional pages that should contain extra budget items and the required written budget item justification.

7.17 Detector R&D Program Budget Justification

Preamble: This section provides the budget justifications for PIs Brandt, Nygren, Asaadi, and Jones related to the Detector R&D proposal. Detailed description for each of the items is given in Year 1. A canonical cost of living adjustment rate of 3% is applied to all salaries in the subsequent years. Therefore, Year 2 and Year 3 of the budget justification does not contain as much details as year 1 and instead the base rates and significant changes for each item and total amount are listed. Only PI Brandt is seeking any salary support from the Detector R&D activities, Nygren, Asaadi, and Jones are seeking support for personnel and M&S.

The personnel requested for these projects are: one month summer salary and half-time postdoc for PI Brandt; a half-time graduate student for PI Asaadi; a half-time graduate student for PI Jones; support for two undergraduates for PI Nygren. All tasks are carried out on campus, and thus incur an indirect rate of 51.5%.

Name and Yearly FTE for Senior Investigators with multiple HEP subprograms or Research Thrusts

	Proposal Project Period: 2017 - 2020					
	Budget Period 2017-2018		Budget Period 2018-2019		Budget Period 2019-2020	
Name	Intensity Frontier	Detector R&D	Intensity Frontier	Detector R&D	Intensity Frontier	Detector R&D
Jonathan Asaadi	85%	15%	85%	15%	85%	15%
Name	Energy Frontier	Detector R&D	Energy Frontier	Detector R&D	Energy Frontier	Detector R&D
Andrew Brandt	50%	50%	50%	50%	50%	50%

Table 9: Effort Table for Investigators with multiple HEP Subprograms

7.17.1 PI: Andrew Brandt

Cumulative - 3 years

- **Senior Personnel**: One month summer salary for Brandt is requested at the current rate of $110,646 per 9 month academic year, equivalent to $12,294 per month with a 3% canonical cost of living adjustment in year two and three. The total request for this item over all three years is $38,000. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5.
- **Postdoctoral Researcher**: A request for one-half of a postdoctoral fellow in year one and two of this project is made using the base salary of $54,000 per with a 3% canonical cost of living adjustment in year two. The total request for this item over all three years is 54,810. The fringe benefit rate is 30% of the request. Since this postdoctoral fellow will be based on campus the indirect rate for this cost is 51.5% for the relevant portion of the cost.
- **Graduate Students**: No support for a graduate student is sought in this proposal.
- **Undergraduate Students**: A request for support of two undergraduates in year three is made at the base rate $5,000 equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is over all three years $10,000. The fringe benefit rate for an undergraduate student is 8.5% with the indirect rate for this cost is 51.5% on-campus.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this proposal.
- **STEM Tuition**: No STEM tuition is sought in this proposal.
- **M&S**: A modest maintenance and services cost of $2,500 per annum in all three years is requested to support various costs. The total request for this item over all three years is $7,500. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit over all three years $28,693.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is over all three years is $71,586.
- **Total for all years**: The total request for all three years for Brandt is $210,589.

1. Year 1

- **Senior Personnel**: One month summer salary for Brandt is requested at the current rate of $110,646 per 9 month academic year, equivalent to $12,294 per month. The total request for this item is $12,294. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5.
- **Postdoctoral Researcher**: A request for one-half of a postdoctoral fellow is made using the base salary of $54,000 per annum. The fringe benefit rate is 30% of the request. Since this postdoctoral fellow will be based on campus the indirect rate for this cost is 51.5% for the relevant portion of the cost.
- **Graduate Students**: No support for a graduate student is sought in this year.
- **Undergraduate Students**: No support for undergraduates is sought in this year.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
- **STEM Tuition**: No STEM tuition is sought in this year.
- **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $11,788.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is $27,595.
- **Grand Total for Year 1**: The grand total request for year 1 for Brandt is $81,177.

2. Year 2
   - **Senior Personnel**: One month summer salary for Brandt is requested after applying a 3% canonical cost of living adjustment, at the rate of $113,967 per 9 month academic year. The total request for this item is $12,663. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
   - **Postdoctoral Researcher**: A request for one-half of a postdoctoral fellow is made using the base salary of $55,620 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 30% of the request. Since this postdoctoral fellow will be based on campus the indirect rate for this cost is 51.5% for the relevant portion of the cost.
   - **Graduate Students**: No support for a graduate student is sought in this year.
   - **Undergraduate Students**: No support for undergraduates is sought in this year.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: No STEM tuition is sought in this year.
   - **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $12,142.
   - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is $28,384.
   - **Grand Total for Year 2**: The grand total request for year 2 for Brandt is $83,499.
3. Year 3
   - **Senior Personnel**: One month summer salary for Brandt is requested after applying a 3% canonical cost of living adjustment, at the rate of $117,387 per 9 month academic year. The total request for this item is $13,043. The fringe benefit rate is 30% of the request. The indirect rate for this item is the agreed on-campus rate of 51.5%.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: No support for a graduate student is sought in this year.
   - **Undergraduate Students**: This request for support of two undergraduates at the base rate $5,000 equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5% with the indirect rate for this cost is 51.5% on-campus.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: No STEM tuition is sought in this year.
   - **M&S**: A modest maintenance and services cost of $2,500 per annum is requested to support various costs. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $4,763.
   - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is $15,607.
   - **Grand Total for Year 3**: The grand total request for year 3 for Brandt is $45,913.

7.17.2 PI: David Nygren

Cumulative - 3 years

- **Senior Personnel**: No salary for Nygren is sought in this proposal.
- **Postdoctoral Researcher**: No support for a postdoctoral researcher is sought in this proposal
- **Graduate Students**: No support for a graduate student is sought in this proposal.
- **Undergraduate Students**: A request for support of two undergraduates in all three years is made at the base rate $5,000 equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is over all three years $30,000. The fringe benefit rate for an undergraduate student is 8.5% with the indirect rate for this cost is 51.5% on-campus.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this proposal.
- **STEM Tuition**: No STEM tuition is sought in this proposal.
- **M&S**: No maintenance and services cost is requested in this propsal
- **Total Fringe Benefit**: The total cost for the fringe benefit over all three years $2,550.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is over all three years is $20,085.
- **Total for all years**: The total request for all three years for Nygren is $52,635.

1. Year 1
   - **Senior Personnel**: No summer salary for Nygren is requested during this year.
   - **Postdoctoral Researcher**:No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: No support for a graduate student is sought in this year.
   - **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, running various tests, assembly and construction, and data collection. A request for two undergraduate support is requested at the base rate $5,000, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students on campus, the indirect rate for this cost is 51.5% . The undergraduate students currently in the group are I. Safa, and N. Davachi.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: No STEM tuition is sought in this year.
   - **M&S**: No maintenance and services cost is requested in this year.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $850.
   - **Total Indirect**: The total indirect cost using the on-campus rate (51.5%) is $6,695.
   - **Grand Total for Year 1**: The grand total request for year 1 for Nygren is $17,545.
2. Year 2
   - **Senior Personnel**: No summer salary for Nygren is requested during this year.
   - **Postdoctoral Researcher**:No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: No support for a graduate student is sought in this year.
   - **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, running various tests, assembly and construction, and data collection. A request for two undergraduate support is requested at the base rate $5,000, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students on campus, the indirect rate for this cost is 51.5% . The undergraduate students currently in the group are I. Safa, and N. Davachi.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: No STEM tuition is sought in this year.
   - **M&S**: No maintenance and services cost is requested in this year.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $850.
   - **Total Indirect**: The total indirect cost using the on-campus rate (51.5%) is $6,695.
   - **Grand Total for Year 1**: The grand total request for year 2 for Nygren is $17,545.
3. Year 3

- **Senior Personnel**: No summer salary for Nygren is requested during this year.
- **Postdoctoral Researcher**:No support for a postdoctoral researcher is request for this year.
- **Graduate Students**: No support for a graduate student is sought in this year.
- **Undergraduate Students**: Undergraduate students contribute to well defined tasks for the project, running various tests, assembly and construction, and data collection. A request for two undergraduate support is requested at the base rate $5,000, equivalent to $12.5 per hour, 10 hours a week for 40 weeks per year. The total cost for this request is $10,000. The fringe benefit rate for an undergraduate student is 8.5%. Since it is anticipated to have undergraduate students on campus, the indirect rate for this cost is 51.5% . The undergraduate students currently in the group are I. Safa, and N. Davachi.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
- **STEM Tuition**: No STEM tuition is sought in this year.
- **M&S**: No maintenance and services cost is requested in this year.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $850.
- **Total Indirect**: The total indirect cost using the on-campus rate (51.5%) is $6,695.
- **Grand Total for Year 1**: The grand total request for year 3 for Nygren is $17,545.

7.17.3 PI: Jonathan Asaadi

Cumulative - 3 years

- **Senior Personnel**: No salary for Asaadi is requested in this proposal.
- **Postdoctoral Researcher**: No support for a postdoctoral researcher is request in this proposal
- **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,000 per annum in all three years of this proposal with a 3% canonical cost of living adjustment in year two and three. The total cost for this request over all three years is \$37,091. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5% . Asaadis student, Hunter Sullivan, is currently supported via teaching assistant support in the department and will be seeking outside support for the other half.
- **Undergraduate Students**: No support for a undergraduate student is sought in this proposal.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this proposal.
- **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum (\$4,570 for half support). The total cost for this item in all three years is \$13,710. This cost does not incur indirect cost.
- **M&S**: A maintenance and services cost of \$6,000 per annum is requested in all three years to support the running of the cryogenic argon facility. This request will pay for approximately 30 operating days of argon as well as filter material and supplies in each year. The total cost for this item over all three years is \$18.000. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit over all three years \$3,709.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is over all three years is \$30,282.
- **Total for all years**: The total request for all three years for Asaadi is \$102,792.

1. Year 1
   - **Senior Personnel**: No summer salary for Asaadi is requested during this year.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,000 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5% . Asaadis student, Hunter Sullivan, is currently supported via teaching assistant support in the department and will be seeking outside support for the other one-half.
   - **Undergraduate Students**: No support for a undergraduate student is sought in this year.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum, coming to \$4,570 for year 1. This cost does not incur indirect cost.
   - **M&S**: A maintenance and services cost of \$6,000 per annum is requested to support the running of the cryogenic argon facility. This request will pay for approximately 30 operating days of argon as well as filter material and supplies. This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is \$1,200.
   - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is \$9,888.
   - **Grand Total for Year 1**: The grand total request for year 1 for Asaadi is \$33,658.

2. Year 2
   - **Senior Personnel**: No summer salary for Asaadi is requested during this year.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,720 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5%.
   - **Undergraduate Students**: No support for a undergraduate student is sought in this year.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.

- **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum, coming to \$4,570 for year 2. This cost does not incur indirect cost.
- **M&S**: A maintenance and services cost of \$6,000 per annum is requested to support the running of the cryogenic argon facility. This request will pay for approximately 30 operating days of argon as well as filter material and supplies. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is \$1,236.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is \$10,092.
- **Grand Total for Year 1**: The grand total request for year 2 for Asaadi is \$34,258.

3. Year 3
    - **Senior Personnel**: No summer salary for Asaadi is requested during this year.
    - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
    - **Graduate Students**: Support for one-half graduate student is requested at the base rate of \$25,462 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5%.
    - **Undergraduate Students**: No support for a undergraduate student is sought in this year.
    - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
    - **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum, coming to \$4,570 for year 3. This cost does not incur indirect cost.
    - **M&S**: A maintenance and services cost of \$6,000 per annum is requested to support the running of the cryogenic argon facility. This request will pay for approximately 30 operating days of argon as well as filter material and supplies. This request is subject to on-campus indirect rate of 51.5%.
    - **Total Fringe Benefit**: The total cost for the fringe benefit is \$1,273.
    - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is \$10,302.
    - **Grand Total for Year 3**: The grand total request for year 3 for Asaadi is \$34,867.

7.17.4 PI: Benjamin Jones

Cumulative - 3 years

- **Senior Personnel**: No salary for Jones is requested in this proposal.
- **Postdoctoral Researcher**: No support for a postdoctoral researcher is request in this proposal
- **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,000 per annum in all three years of this proposal with a 3% canonical cost of living adjustment in year two and three. The total cost for this request over all three years is \$37,091. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5% . Jones's student, still to be named, is currently supported via teaching assistant support in the department and will be seeking outside support for the other half.
- **Undergraduate Students**: No support for a undergraduate student is sought in this proposal.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this proposal.
- **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum (\$4,570 for half support). The total cost for this item in all three years is \$13,710. This cost does not incur indirect cost.
- **M&S**: A maintenance and services cost of \$10,000 in year one and two of this proposal and \$5,000 in year three is requested. This resource will support plate materials and associated machining, a supply of purified xeonon and argon gas, the necessary flours, solvents, and chemistry supplies for testing, and SiPM board development along with associated cables and connectors. The total cost for this item over all three years is \$25,000. This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit over all three years \$3,709.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is over all three years is \$33,887.
- **Total for all years**: The total request for all three years for Asaadi is \$113,397.

1. Year 1
   - **Senior Personnel**: No summer salary for Jones is requested during this year.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,000 per annum. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5% . Joness student, still to be named, will be supported half from other sources.
   - **Undergraduate Students**: No support for a undergraduate student is sought in this year.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of \$9,140 per annum, coming to \$4,570 for year 1. This cost does not incur indirect cost.
   - **M&S**: A maintenance and services cost of \$10,000 in year one is requested. This resource will support the plate materials and associated machining (\$2,000), the necessary flours, solvents, and chemistry supplies (\$2,000), SiPM board development along with associated cables and connectors (\$2,500), the mechanical mounting and frame machining (\$2,500) as well as a supply of gas argon for preliminary tests (\$1,000). This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is \$1,200.
   - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is \$11,948.
   - **Grand Total for Year 1**: The grand total request for year 1 for Jones is \$39,718.
2. Year 2
   - **Senior Personnel**: No summer salary for Jones is requested during this year.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: Support for one-half a graduate student is requested at the base rate of \$24,720 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit

rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5%.

- **Undergraduate Students**: No support for a undergraduate student is sought in this year.
- **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
- **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of $9,140 per annum, coming to $4,570 for year 2. This cost does not incur indirect cost.
- **M&S**: A maintenance and services cost of $10,000 in year two is requested. This resource will support further plate materials and associated machining ($2,000), a supply of purified xeonon gas ($5,000), as well as a supply of gas argon for preliminary tests ($1,000) the necessary flours, solvents, and chemistry supplies for continued testing ($2,000). This request is subject to on-campus indirect rate of 51.5%.
- **Total Fringe Benefit**: The total cost for the fringe benefit is $1,236.
- **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is $12,152.
- **Grand Total for Year 1**: The grand total request for year 1 for Jones is $40,318.

3. Year 3
   - **Senior Personnel**: No summer salary for Jones is requested during this year.
   - **Postdoctoral Researcher**: No support for a postdoctoral researcher is request for this year.
   - **Graduate Students**: Support for one-half graduate student is requested at the base rate of $25,462 per annum after applying a 3% canonical cost of living adjustment. The fringe benefit rate is 10% of the request. Since it is anticipated to have the graduate student 100% on campus, the indirect rate for this cost is 51.5%.
   - **Undergraduate Students**: No support for a undergraduate student is sought in this year.
   - **Travel and Cost of Living Adjustment**: No COLA or travel is sought in this year.
   - **STEM Tuition**: Graduate student tuition support for one-half student is request at the rate of $9,140 per annum, coming to $4,570 for year 3. This cost does not incur indirect cost.
   - **M&S**: A maintenance and services cost of $5,000 in year three is requested to support the final tests assoiciated with the detector development. This request will pay for a supply of xeonon gas ($5,000). This request is subject to on-campus indirect rate of 51.5%.
   - **Total Fringe Benefit**: The total cost for the fringe benefit is $1,273.
   - **Total Indirect**: The total indirect cost computed using the on-campus (51.5%) rate is $9,787.
   - **Grand Total for Year 3**: The grand total request for year 3 for Jones is $33,361.

Intensity Frontier Data Management Plan

The projects described in the proposal for the intensity frontier do not produce any data on their own; they merely make use of data generated by the activities related to the MicroBooNE, SBND, ICARUS, and DUNE experiments. All experiments have a data management policy consistent with the Department of Energy's data management plan (found here http://science.energy.gov/funding-opportunities/digital-data-management/). This policy conforms with that of the Data Preservation in High Energy Physics (DPHEP) study group, which has described a hierarchy for the types of data that particle-physics experiments produce, and given recommendations for how such data should be preserved for future use.

The types of data these experiments produce include the raw data produced by the detectors, the reconstructed version of the raw data, and simulated events. MicroBooNE, SBND, ICARUS, and DUNE have their own mechanisms for archiving data, including producing both digital and tape storage of raw data, and any data that resides at our institution will merely be a copy of data that is stored permanently by the experiment. Thus, there is no need for this project to separately manage or archive any experimental data. No personally identifiable information is expected to be generated during the execution of the project, and thus no explicit plans to protect confidentiality or personal privacy are used.

The analysis of the experimental data is described in published, peer-reviewed journal articles; summaries of data analyses that are released to the public (often as contributions to conferences); and notes that are circulated internally within the MicroBooNE, SBND, ICARUS, and DUNE as well as public technical notes made available using Fermilab's Technical Publication. The journal articles are archived by the journals themselves, and are also typically available through the arxiv.org e-print archive. The public analysis summaries and internal notes are archived by the MicroBooNE, SBND, ICARUS, and DUNE experiments and are available through Web interfaces. All collaborations encourage frequent and timely publication of results related to the research described in this proposal and thus data generated by the activities described here are expected to have near annual publication releases (through peer reviewed papers and contribution to conferences).

Detector R&D Data Management Plan

The data generated through the projects described in this proposal will be archived on local machines at UTA as well as hosted utilize open-access public code repositories (e.g. gitHub) and cloud back-up (e.g. DropBox). The UTA group has a common DropBox account providing 1 terabyte of cloud based backup for experimental data in addition to the local storage of over 3 TB in lab based computers with an expected lifetime to store the data of ~5 years.

Simple scope traces and detector monitoring data will not be stored, rather relevant experimental data will be archived and backed up on local machines and cloud based accounts. Data analysis code and mechanisms to generate plots and charts will be hosted on open-access public code repositories.

The analysis of the experimental data is to be described in published, peer-reviewed journal articles; summaries of data analyses that are released to the public (often as contributions to conferences); and notes that are circulated internally within the associated collaborations linked to the work (e.g. NEXT/DUNE/etc..). The journal articles are archived by the journals themselves, and are also typically available through the arxiv.org e-print archive.

No personally identifiable information is expected to be generated during the execution of the project, and thus no explicit plans to protect confidentiality or personal privacy are used.