Abstract

RESEARCH IN ELEMENTARY PARTICLE PHYSICS

A PROPOSAL TO THE U.S. DEPARTMENT OF ENERGY

THE UNIVERSITY OF TEXAS AT ARLINGTON

Physics Department, 502 Yates Street, Arlington, Texas 76019, USA.

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Co-Principal Investigator:	Andrew Brandt
Co-Principal Investigator:	Jaehoon Yu
Co-Principal Investigator:	Amir Farbin
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FOA number: **DE-FOA-0001604**

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:** Andrew Brandt (50%), Kaushik De, Andrew White, Jaehoon Yu, Amir Farbin, Haleh Hadavand
- **Intensity Frontier PI's:** Jaehoon Yu, Jonathan Asaadi
- **Detector Research and Development PI:** Andrew Brandt (50%)

Lead PI: Andrew White

The numbers below are OLD - will be replaced with the 2017-20 values

	Name	Research Area	Year 1 Budget	Year 2 Budget	Year 3 Budget	Total Budget
Lead-PI	Andrew White	Energy Frontier	$165,589	$162,762	$168,261	$496,612
co-PI	Andrew Brandt	Energy Frontier	$180,190	$188,578	$186,387	$555,155
co-PI	Kaushik De	Energy Frontier	$234,204	$234,204	$241,351	$709,759
co-PI	Amir Farbin	Energy Frontier	$0	$102,645	$106,245	$208,890
co-PI	Haleh Hadavand	Energy Frontier	$89,018	$87,920	$92,073	$269,011
	Total	Energy Frontier	$669,001	$776,109	$794,317	$2,239,427
co-PI	Jaehoon Yu	Intensity Frontier	$49,468	$102,645	$106,245	$258,358
co-PI	Jonathan Asaadi	Intensity Frontier	$107,098	$107,098	$110,876	$325,072
	Total	Intensity Frontier	$156,566	$209,743	$217,121	$583,430
co-PI	Andrew Brandt	Detector R&D	$87,998	$87,998	$90,831	$266,827
	Total	Theoretical Research	$87,998	$87,998	$90,831	$266,827
	Grand Total	**All areas**	$913,565	$1,073,850	$1,102,269	$3,089,684

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

Part I
UTA Group Introduction

UTA Group Introduction

Part II

Research at the Energy Frontier

PI Summary: Andrew White

PI Summary: Kaushik De

PI Summary: Andrew Brandt

PI Summary: Haleh Hadavand

1 The ATLAS Experiment

The ATLAS Experiment

1.1 Atlas Subject One (PI: PersonOne, PersonTwo)

1.2 Atlas Subject Two (PI: PersonOne, PersonTwo)

1.2.1 Atlas Sub-Subject (PI: PersonOne, PersonTwo)

2 International Linear Collider Project (PI: White)

ILC Experiment

Part III
Research at the Intensity Frontier

Executive Summary

The Intensity Frontier (I.F.) group of the University of Texas at Arlington started in 2014 with 0.5 FTE 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 a strong I.F. program, the group recently hired a full time I.F. junior faculty, Dr. Jonathan Asaadi. While PI Farbin has decided to transition back to the Energy Frontier (E.F.), the overall strength of the group has grown double to two full PI's with the successful transition of PI Yu to full time I.F.

Beyond the addition of a new faculty member, the UTA I.F. group has made significant contributions to the LArIAT, LBNE/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 now become a co-convenership of the DUNE Beyond the Standard Model physics group beginning September 2015. UTA was also the host of the first off-Fermilab-site DUNE collaboration meeting in January, 2016, in which over 150 collaborators participated. Farbin and Yu have been supervising a student who has been contributing to the 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 leading to the first measurement of the π^--Argon cross-section and now will transition to serve as co-spokesperson (starting Fall 2016). The UTA group has also joined SBND (through Asaadi's existing affiliation) and the ICARUS experiment (with Yu as institutional board member) and has been contributing to the refurbishment of the light detection system with the hire of a new post-doctoral researcher (and an existing ICARUS collaborator), Dr. Andrea Falcone.

In this document, we propose to complete the ongoing effort on MiniBooNE (Yu), and continue/add significant contributions to SBND (Asaadi, Yu), MicroBooNE (Asaadi), ICARUS (Asaadi, Yu) and the Deep Underground Neutrino Experiment, DUNE (Asaadi, Yu) with vital contributions to the two protoDUNE projects. These experiments are carefully selected to leverage our group's growing technical and analysis expertise utilizing liquid argon time projection chambers. 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.

The work on MiniBooNE is limited to data analysis from the beam dump data taken in 2014 for a low mass dark matter search. This is anticipated to complete in the early stage of this renewal proposal period with the graduation of Sepideh Shahsavarani, Farbins Ph.D. student. This student will stay on the I.F. program for another two years till she completes her Ph.D. under the joint advisement of Farbin, Yu, and Asaadi and is expected to contribute to the other I.F. efforts. Concurrently, a second graduate student (Zack Williams) will be funded via Asaadi's start-up to allow for a transition of research duties upon Shahsavarani's graduation. Other new graduate students are being trained to take part in our I.F. program but will be supported through toehr funding sources at the university until resources become available with the graduation of senior students. Asaadi will continue to play a leadership role on LArIAT together with Yu on data analysis and operations with the expected winding down of the project in the next 1-2 years.

UTA Strategic Plan

The UTA group will have contributions and responsibilities across the Fermilab the short-baseline neutrino (SBN) program as well as the long-baseline neutrino (LBN) program. A primary goal of the group throughout the period of this proposal is to contribute to the success of the construction and execution of these experiments. 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 and dual phase prototype detectors, protoDUNE's at CERN neutrino platform. This work is intended to 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 timeline and deserve immediate attention early in the period of this renewal proposal, primarily due to protoDUNEs' data taking schedule. 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 shutdown of the CERN accelerators at the end of 2018 is critical. Moreover, the protoDUNE projects are on the critical path for the success of the U.S. flagship experiment, DUNE. The SBN experiments are also seen by the UTA group as a high priority, but given that Fermilab will continue provide beams to these experiments through at least 2021, the impact of any delays in the construction and operation of the two future experiments is less critical.

Figure **??** along with Tables **??** and **??** attempts to summarize the timeline, projects, and associated personnel resources that will execute the research described in greater detail in the subsequent sections. The 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 and then ramping this effort 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 will allow our group to maintain a constant level of contribution from both the PI's and the post-doctoral and graduate researchers on all four experiments.

Deep Underground Neutrino Experiment (DUNE)

DUNE 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 ($P(\nu_\mu \to \nu_e)$) compared to the appearance of electron antineutrinos from a beam of muon antineutrinos and $P(\bar{\nu}_\mu \to \bar{\nu}_e)$) as well as the precise measurement of the ν_e energy spectrum measured at the far detector. The UTA group aims to play a major role in this U.S. flagship experiment in both single phase and dual phase protoDUNE experiments.

protoDUNE: The UTA group will be contributing to both the protoDUNE Dual Phase (DP) and Single Phase (SP) detectors. Asaadi and Yu expect to play a major role in various detector component construction, installation, and commissioning as well as data taking during the early two years of this proposal. This work will lay the foundation to contributing to the DUNE experiment.

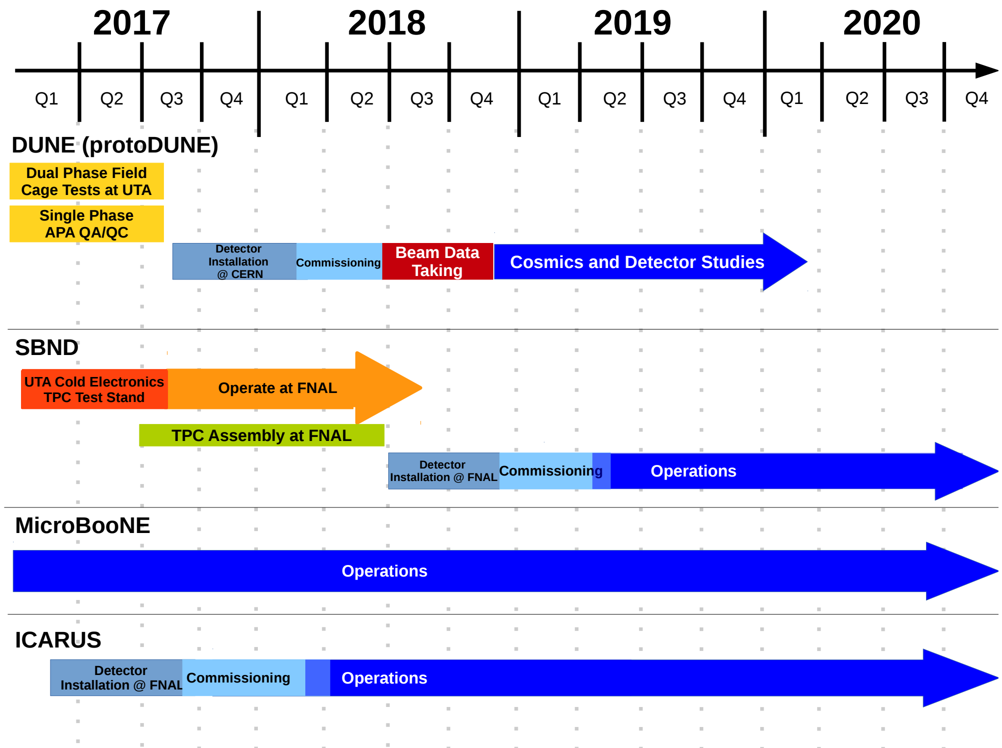

Figure 1: Timeline of the strategic projects proposed .

- **ProtoDUNE SP-APA QA/QC:** 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.

- **ProtoDUNE DP-FC :** Yu will be working on design, construction and installation of the field cage (FC) for ProtoDUNE DP detector. While the dual phase technology for DUNE is an alternative choice of the technology, the design of the field cage for ProtoDUNE DP shares a large fraction of its design with the single phase. The material, the shape of the FC profile loop, the use of straight unlinked FC profile loop, and the resistor dividor chain as well as the surge arrestor are examples of common aspects between the two technologies. UTA will participating in the design, construction and installation of ProtoDUNE DP FC and position our group to build up necessary infrastructure and expertise to play a strong role in the FC construction of both SP and DP technologies for the DUNE far detector. We also consider the success of this project and the participation of U.S. groups to DP technology essential not only in preparing for the construction of first and second 10kt DUNE modules but also in playing an important diplomatic role in keeping the truly international character of the DUNE collaboration.

DUNE Beyond the Standard Model Physics: UTA has been a leading participant in searching for low mass dark matter in high intensity proton beams from the start of the I.F. group in 2014. For this work, Yu has been leading the BSM physics working group of DUNE since September 2015

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	UTA/FNAL	Yu
MiniBooNE	Beam Dump Dark Matter Search	UTA/FNAL	Yu

Table 2: Overview of the UTA projects across the Intensity Frontier

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 to be released in summer 2019.

The Short Baseline Neutrino (SBN) Program

The SBN program aims to conclusively address the experimental hints of sterile neutrinos through the utilization of three LArTPC detectors. An essential component for our group is to continually be producing physics results throughout the construction period of DUNE experiment and contributing to the development of LArTPC technology. In this regard, the SBN program at Fermilab provides the perfect mix short and mid-term projects for our group to continue producing new physics results and train young physicists for the future.

SBND: Given the large overlap of the collaborators between MicroBooNE and SBND, Asaadi is well recognized in the collaboration. Therefore, Asaadi will be the institutional representative to the collaboration and lead the effort on SBND. Yu is in discussions with the SBND management for his joining to the collaboration prior to the start of this funding period in 2017 and will contribute to the efforts outlined below and presented in greater detail in Section 3.1.

- **Cold Electronics TPC Test-stand**
- **Detector Construction, Installation, and Commissioning**
- **Cross-Section Data Analysis**

MicroBooNE: 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 the first years of the proposal. Given this, Asaadi will focus on operations and data analysis outlined below and presented in greater detail in Section 3.2

- **Cross-section Data Analysis**
- **Detector Operations**

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 3: 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.

- **TPC Detector Expert**

ICARUS: With the inclusion of the ICARUS experiment, this completes the short-baseline neutrino oscillation experiment utilizing a low energy neutrino beam. For this reason, the UTA group deems the success of ICARUS as an essential component of the SBN. In line with that, our 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. Moreover, we have been utilizing Asaadi's start-up funds to support a post-doctoral researcher to help lead the refurbishment and integration of ICARUS. During the funding period here our efforts include the following, presented in greater detail in Section 3.3.

- **Installation and Commissioning**
- **Detector Operations**
- **NuMI Off-Axis Cross-Sections**

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.

2.1 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 $(\nu_e, \nu_\mu, \nu_\tau)$ are a linear combination of the neutrino mass eigenstates (ν_1, ν_2, ν_3). The rotation 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. In addition, the flavor change of the neutrinos depends on the ratio of neutrino energy and the distance traveled by the neutrino (often referred to as the baseline) as well as the difference in the square of the mass eigenstates Δm^2_{ji}. Neutrinos produced in the atmosphere [**?**, **?**, **?**], in nuclear reactors [**?**, **?**, **?**], in the sun [**?**, **?**, **?**], as well as in man-made particle accelerators [**?**, **?**, **?**] have been used to study the phenomenon of neutrino oscillations. The exact 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 one of the last major pieces 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 experimental 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 the 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 accounted for by the standard three-flavor oscillations of the SM and may hint at the existence of additional neutrino states with larger mass difference ($\Delta m^2_{new} \geq 0.1eV^2$) 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.

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. When a neutrino interacts with an atom in the liquid argon multiple final state charged particles as well as electromagnetic objects (such as photons and electrons) can be produced. When the charged particles traverse the liquid argon they produce ionization which drifts along the electric field inside the TPC towards a set of wire planes which are oriented at different angles with respect to each other. The drifting ions produce an electric signal on the wire planes, which is read out of the detector. By knowing the drift speed of the ions and the timing of the interaction as well as the deposition of charge on the wires a three-dimensional image of the interaction can be reconstructed. The information of the charge deposition in addition to the topological information allows for particle identification and calorimetric reconstruction. This allows, for example, the ability to disentangle electron initiated electromagnetic showers from photon initiated showers by looking at the displacement in the start of the electromagnetic shower from a primary vertex as well as analysing the energy deposited in the first centimetres of the shower (dE/dX), shown schematically in Fig. **??**.

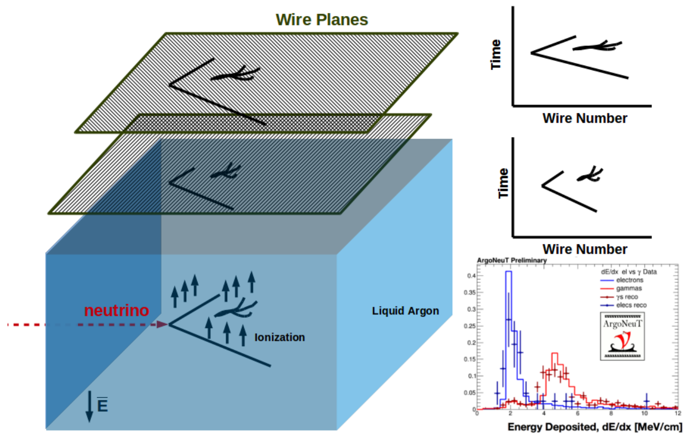

Figure 2: Operating principals of LArTPC detectors.

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). 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 LArTPCs the premier neutrino detector technology choice for the future.

Recently, a great deal of interest has been paid to the possibility of studying the models for Low-mass Dark Matter (LDM) production at low-energy, fixed-target experiments (see Refs. [**?**, **?**, **?**, **?**]. High flux neutrino beam experiments, such as DUNE, have been shown to provide coverage of DM + mediator parameter space which cannot be covered by either direct detection or collider experiments. Upon striking the target, the proton beam can produce the dark photons 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 a Standard Model photon and a dark photon. For the case where $m_V > 2m_{DM}$, the dark photons will quickly decay into a pair of DM particles. These relativistic DM particles from the beam will travel along with neutrinos to the DUNE near detector.

The DM particles can then 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 DM 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 with much higher masses, the timing of the DM events in the near detector. In addition, since the electrons struck by DM will be much more forward direction than those from neutrino interactions, the angle of these electrons may be used to reduce backgrounds, taking advantage of fine angular resolution DUNE near detector 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. If DUNE near detector were LArTPC, since the entire detector volume will be active, the effective number of DM events detected will be much higher with the detector of the same mass.

Given these new theoretical background, high intensity proton beams that are needed for DUNE will provide sensitivity to mass ranges inaccessible at direct-detection experiments such as CDMS and XENON [**?**]. We believe this effort has the potential of expanding DUNE's physics motivation beyond neutrinos, super-novae, and proton decays. For this work, Yu and the postdoctoral fellow, Chatterjee have been working on integrating the existing MadGraph c [**?**] based simulation package into the existing LBNE/DUNE fast simulations. A version of this package has already been prepared for Non-Standard Model Neutrino Interaction studies for the DUNE BSM physics group.

2.2 Accomplishments of PI Yu's on Intensity Frontier Program

A quick summary of PI Yu's accomplishments is provided in the list below.

- Served as the Long Baseline Neutrino Experiment Detector R&D Co-coordinator
- Contributed to the transition from LBNE to DUNE working on collaboration governance
- Serving as the co-convener of the Beyond the Standard Model physics group of DUNE
- Responsible for the Dual Phase ProtoDUNE Field Cage
- Supervised numerous undergraduate students to contribute to the LBNF beam line systematics and optimization studies
- Supervised postdoctoral fellow Dr. Animesh Chatterjee for his contribution to DUNE, LArIAT, and MiniBooNE
- Contributed to WA105 $3 \times 1 \times 1\ \mathrm{m}^3$ prototype construction during the sabbatical stay in Sept. 2015 - May 2016

2.2.1 Magnetic Field Map Simulation Study in LBNF Brown, Yu

A new graduate student, Garrett Brown has joined the physics department Ph.D. program January 2016 and was assigned in implementing the G4LBNE code for magnetic field mapping and displaying the field overlaid on LBNF beamline components. His first attempt was to sample the volume of the beamline by uniformly stepping point by point in 3D Cartesian coordinates and sampling the field value at each point by checking which volume the point was residing in and measuring the volume's field value at that point, or using 0 if there was no volume at that point. The problem he encountered was transforming the world coordinate of the 3D point to the local coordinate with respect to the geometry of the placement's volume. GEANT4 does not store any hierarchical information regarding the transformations between geometry, so it is up to the user to keep track of objects' transformations. Given the complication due to relying on correctly determining if a point was inside of the volume, he ultimately used geantino moving under the influence of the electromagnetic equation of motion and record the magnetic field value which GEANT4 provides. This method provided a placement independent magnetic field map. Figure on the left of Fig. **??** shows the result of this method in the current three horn system. A further test of the comparisons of magnetic field map is necessary in order to verify the functionality of this software.

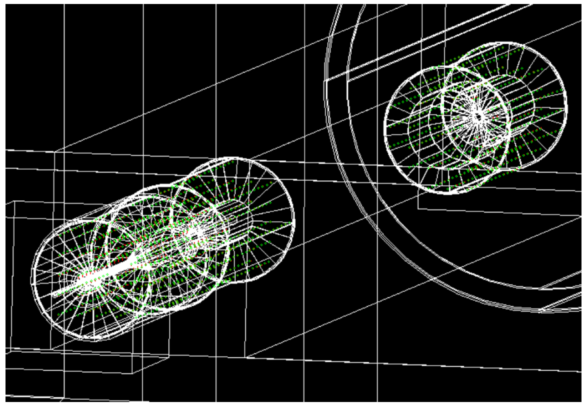

Figure 3: (left) The three polycone horns of the DUNE beamline and their magnetic fields mapped out. (right)

2.2.2 Charged Pion Total Cross section on Argon in LArIAT Chatterjee, Yu

We have studied the charged pion-nucleus total interaction cross section in liquid argon performed at the Liquid Argon In A Testbeam (LArIAT) experiment. Pion interactions with matter have been a central topic in particle physics for decades. Over the past forty years, an extensive set of pion scattering experiments have been conducted at various meson factories. LArIA[1]T program is consist of full calibration of the argon TPC in a dedicated beam line. The main goal of the LArIAT experiment is to measure pion-argon total and exclusive cross-section, 3D imaging, good particle identification and precise calorimetric reconstruction.

The layout of the LArIAT experiment consists of two main parts: the liquid argon-related components and the beam-related components. The liquid argon-related part consists of the LArTPC detector, the liquid argon scintillation light detector, the LArTPC read-out cold electronics, the liquid argon cryostat, and the cryogenic system connected to the cryostat for liquid argon cooling and purification. The beam-related part consists of a series of beam counters such as the TOF detector, multi-wire proportional chambers (MWPCs), Cherenkov detector, and veto paddles are aligned along the LArIAT beam line for PID tagging and momentum selection. The analysis presented here of LArIAT data from Run-I aims to develop pion identification algorithms based on the information from LArIAT beamline detectors and from the pion topology in liquid argon. The procedure to achieve the measurement is based on the reconstruction and selection of charged pion events, the analysis of the calorimetric information along the track in the TPC, the vertex finding and the evaluation of the total cross section applying a ”Sliced TPC” method. The result of the first measurement [**?**] of Pion-Argon total cross-section has been shown in the plot on the left of Fig. **??**.

LArIAT has completed taking Run 2 data for 6 months from February 2016. Using the increase data set, we are studying charge sign determination of muon without using magnetic field information. The sign of the particle charge (without magnetic field) can be obtained for stopping particles in LArTPC by statistical analysis based on topological criteria. For example, μ^+ undergo decay only, with e+ emission of known energy spectrum. Stopping μ^- may either decay or be captured by nuclei.

Figure 4: (left) First measurement of Pion-Argon Total cross-section at LArIAT (right) .

2.2.3 Proton Beam Alignment Monitor Chatterjee, Yu

Proton Beam Alignment Monitor (PBAM) will check the alignment of the proton beam in the neutrino beamline(LBNF). We have done the simulation study of the Monitor at the beamline. Dimension of the Monitor we have consider for the simulation is $1m \times 1m$, gas gap of 1 mm thick which is filled with Ar gas. Monte-carlo simulation has been done with G4LBNE package with the v3r3p7 version. we have taken 5×10^6 POT with the Nominal configuration, proton energy 120 GeV and horn current is 230 kA.

Most of the un-interacted protons are picked at the center of the Monitor, hence it will be important to design the Monitor into pixel like structure to get better position resolution of the proton at the center. We have done the simulation of the Monitor with different pixel size to get the optimum resolution of the monitor. Optimum resolution of any pixels is considered when sigma of the position distribution is within the pixel size. We are working with Fermilab accelerator division to finalize the monitor design. Our next step will be implementation of the monitor design.

2.2.4 Software for DUNE Beyond Standard model group

We have developed a software framework for the study of NSI. The software is mainly based on GLOBES [**?**] neutrino simulator. The expected neutrino flux provided by the beam simulations group can be taken and input to the simulator for the BSM subgroups to study the physics sensitivity for each topic. Neutrino cross-section and detector properties are taken from DUNE CDR. We have done preliminary estimate of the constraints on the NSI parameter for DUNE.

2.2.5 Search for sub-GeV Dark matter

We are working to write a Monte carlo code for the search of sub-GeV dark matter using LBNF beam line at DUNE experiment. Models of sub-GeV dark matter typically involve a scalar or fermionic dark matter and vector or scalar mediator. In our model we have considered 120 GeV proton scattering with a target produces dark matter. We have also calculated the neutrino background signal at position of the DUNE near detector location. We have tried to estimate the optimum angle between the detector location and beamline for which we get minimum neutrino background. Our main goal is to design a software framework for DUNE beyond standard model group. We are now in a stage of getting final simulation results about NSI parameter. We are also in a processes of getting preliminary result of dark matter search study.

2.2.6 Field Cage for Proto DUNE Dual Phase LArTPC

We are working on the design and simulation of Field cage of Dual Phase of LArTPC for DUNE. The field cage design will be composed of field-shaping coils made with stainless steel.The coils are supported by 32 off-hanging columns of G-10CR glass fibre/epoxy-laminated sheet insulating material, built in the form of chains, and suspended from the tank deck structure, as shown in Fig. **??**. Each coil is designed as a series of fully welded infill tubes intended to fit between pairs of hanging support columns to form one section of the field cage. The prototype dual phase detector WA105 will be tested at 1 kV/cm over a 6-m drift. We are simulating the field cage to provide an optimal design. We will measure electric field across the whole drift volume along with the other mechanical issues.

2.2.7 Data analysis with 35 ton LArTPC

35-Ton LAr-TPC is a prototype detector for DUNE experiment. 35-Ton detector is placed at PC4 at Fermilab. It is mainly taking cosmic muon data with integrated TPC and photon detectors. The detector has the success of seeing muon tracks with TPC. We are working to find the tracking efficiency of the detector. We are also working to understand the detector using the cosmic data. Complete the data analysis and include the result on 35-ton detector paper .

2.2.8 GosSiP and Photon Detector Coupling Studies R. Musser

GosSiP is a simulation package for SiPMs that allows the user to vary multiple characteristic parameters of the detector. These parameters are important to understand because of their correlation to the signal that the SiPM generates. An important aspect of these parameters is their dependency on temperature, given that SiPMs will be working in LAr. This affects the overvoltage applied to the detector, which in turn determines the characteristic parameters. Originally, GosSiP did not have the ability to determine the effects that various temperatures have on a SiPM. Musser was able to implement this element into the simulation based on the effect of varying temperatures on the SiPM characteristic parameters reported in Ref. [**?**, **?**]. The temperature dependences of each of the characterization parameters were analyzed and fit to the most appropriate functional form that reflects the dependencies. These equations were then implemented into the code that allowed GosSiP to calculate the parameters with respect to the temperature. Comparing the values of a room temperature simulation to a simulation at -196^oC shows drastic variations. There was a 56% and 7% increase in PDE and gain respectively. Conversely, there was a 56% and a 54% decrease in DCR and crosstalk respectively. These changes resulted in a 69% increase in mean charge strictly due to a decrease in temperature. With the ability to account for temperature dependence, GosSiP is now an even more valuable and accurate simulation package.

While simulations of SiPMs are important, physical tests are needed in order to obtain a more complete picture. A total of 40 SensL SiPMs were collected for characterization tests. PCBs were designed and manufactured for testing of the SiPMs. A GUI in LabVIEW was created in order to collect and analyze the data from the SiPMs. This allows for instant analysis of the characteristic parameters, which will be verified with further analysis in ROOT. Since the boards with the SiPMs attached arrived, we have been soldering SMA connector to the boards for readout and bias voltage purposes. With a few boards completed, we have begun testing some of the SiPMs with a pulsating 420 nm LED. Figure 1 shows the output of a 6×6 mm SensL SiPM to an oscilloscope that confirms the board is working correctly.

Although the temperature dependence implementation in GosSiP is important, the SiPMs used to model the behavior are relatively old due to the rapid advancements of the SiPM technology. Complete temperature dependence studies of newer SiPMs are needed to form an even more accurate simulation package. Characterization studies of the 40 SiPMs will begin shortly. The PDE, gain, DCR, cross-talk, and after-pulse are going to be the main focus and will be calculated for every SiPM with varying bias voltage. This will ultimately lead us to study the optimized coupling for a SiPM and a scintillator.

2.2.9 Effect of Decay Pipe Radius to Neutrino Flux and CP Violation Sensitivity Study

My area of focus was the beam-line itself, located at Fermilab. Here is where the decay pipe is located, which is a standard 2 meters in length. I began at 1 meter and increased the parameter by 0.05 meters. This data was then inputted into the graph below, which demonstrates the integrated flux as a faction of the radius. As one can observe, flux loss is noted at every increment, no matter how small the decrease from the standard 2 meters. Next I began running CP Violation Sensitivity tests on a different number of parameters. It was observed that CP Violation was higher as the radius increased to 2 meters, and no violation existed at degrees 0 and 180.

Figure 5: (left) The ratio of the integrated neutrino flux as a function of decay pipe radius with respect to the design radius of 2m. (right) Impact to the CP violation sensitivity for change of decay pipe for 2m radius vs 1m.

PI Summary: Jonathan Asaadi

3 The Fermilab Short-Baseline Neutrino Program

The conclusive redress of the experimental hints of sterile neutrinos thus becomes high priority for the field of neutrino physics. The Fermilab Short-Baseline Neutrino (SBN) program, shown in Fig. **??**, offers the unique opportunity to definitely address the “LSND/MiniBooNE” anomaly through the utilization of three liquid argon time projection chambers (LArTPCs) detectors and the decade old 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 a 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.

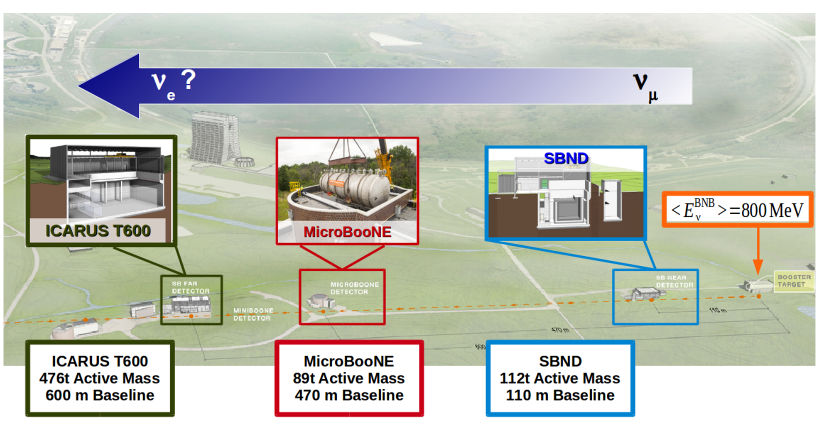

Figure 6: Overview of Fermilab’s Booster Neutrino Beamline (orange dashed line) campus with the location and description of the three SBN detectors.

The first experiment to observe an electron-like excess in the electron neutrino appearance channel was the LSND experiment [?] at Los Alamos National Laboratory. LSND used a decay-at-rest pion beam to produce muon anti-neutrinos ($\bar{\nu_\mu}$) in the energy range between 20-53 MeV and a distance of 30 meters from the liquid scintillator based detector. After five years of running, LSND reported an excess electron like events corresponding to a 3.8σ evidence for $\bar{\nu_\mu} \to \bar{\nu_e}$ oscillations occurring with a Δm^2 of ~ 1eV^2. This suggests an oscillation beyond the SM three flavor neutrino oscillation which occurs at an $L/E_\nu \sim 1$m/MeV. To test for the appearance of this anomalous oscillation, the MiniBooNE experiment [?] at Fermilab utilized 700 MeV muon neutrinos produced from the Booster Neutrino Beam at a baseline of 540 meters (thus giving a similar L/E_ν to LSND). MiniBooNE identified muon and electron neutrino interactions by their characteristic Cherenkov rings inside a scintillator detector. As shown in Figure **??**, in ten years of data taking in both neutrino and anti-neutrino running MiniBooNE observed a 3.5σ excess in ν_e candidates and a 2.8σ excess in $\bar{\nu_e}$ candidates. This excess of events observed by MiniBooNE can be due to electrons from ν_e interactions as well as from single photon backgrounds, since these two final states are indistinguishable to the Cherenkov imaging detector.

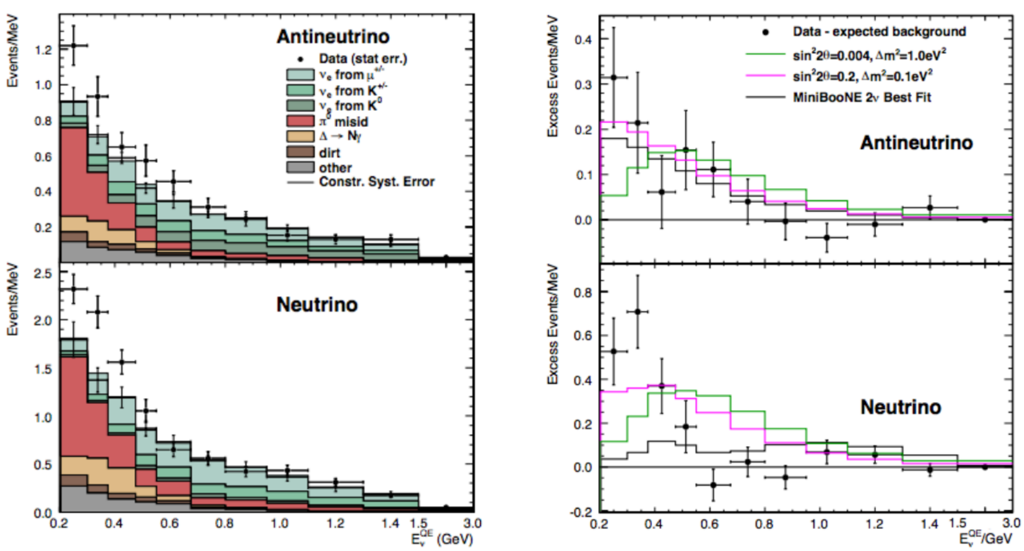

Figure 7: Left: Electron anti-neutrino ($\bar{\nu_e}$) and neutrino (ν_e) candidate events shown with the predicted backgrounds in MiniBooNE. Right: Background subtracted event rates in MiniBooNE as well as different sterile neutrino models overlayed with the data.

A common interpretation of this data is to posit the existence of one or more additional sterile neutrino states with masses at or below the eV range. This interpretation requires mixing of the sterile state(s) with both the electron and muon neutrino flavor states. Constraints from sterile mixing from ν_μ and neutral current disappearance data [**?**, **?**] leads to significant tension between the ν_e appearance data and the ν_μ disappearance data.

To disentangle the open question of how to interpret the LSND/MiniBooNE anomaly, both an excellent neutrino detector technology as well as a robust experimental program is required. The liquid argon time projection chamber (LArTPC) offers physics capabilities ideally suited for the study of neutrino interactions. By combining millimetre scale tracking capabilities, outstanding calorimetry by having a fully active/sampling detector, and powerful particle identification made by combining the ionization along the particle trajectory (dE/dX) and the topological information, LArTPCs have been chosen to be the premier neutrino detector technology.

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. As shown in Figure **??**, the conceptual design is to construct a membrane cryostat in a new on 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 $\pm 30^{\circ}$ 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.

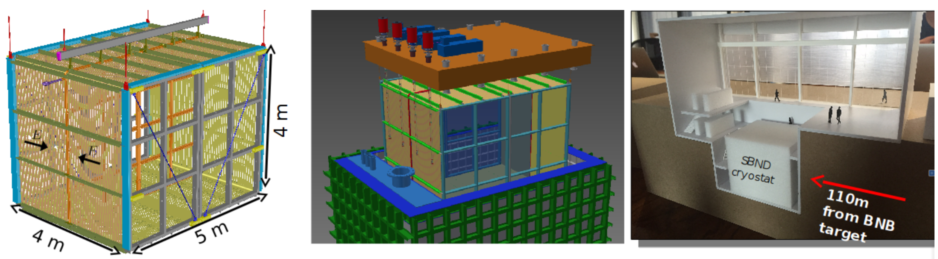

Figure 8: Conceptual design of the SBND TPC, cryostat, and detector hall.

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 shows excellent performance, however a full integration test with an operating TPC has not been successfully performed (given the many problems seen by the 35ton prototype) and serves as an absolutely necessary service task the UTA group is planning to spearhead.

3.1.1 Cold Electronics Teststand

Figure **??** shows a schematic of what this test-stand would look like utilizing the "Blanche" cryostat currently installed at the Proton Assembly Building (PAB)at Fermilab. This cryostat is engineered to have delivered purified liquid argon into the cryostat as well as circulate, re-condense, and purify boil-off argon. A duplicate of this cryostat is currently being built and will be delivered in late 2016 to UTA. This cryostat will work in conjunction with the liquid argon purification system currently in operation at UTA. This system is built using start-up funds from PI Asaadi and will allow UTA to play an important role in the ability to do detector R&D in the coming years.

Inside this cryostat, a small scale TPC equipped with prototype cold readout electronics from SBND installed along side a pair of light guide bars can be deployed and readout through a 14"

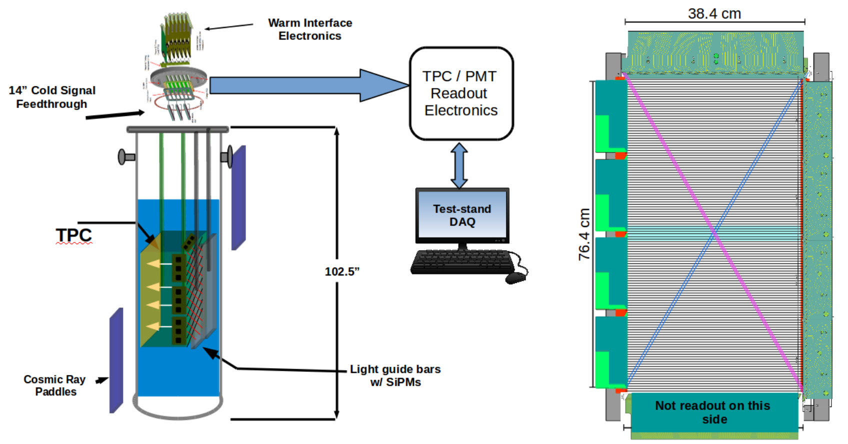

Figure 9: Conceptual design of the SBND cold electronics vertical slice test-stand. Integration of both cold or warm electronics, light collection system, cosmic ray paddles, as well as warm interface electronics allows for complete testing of the entire readout system prior to deployment in the experiment and a platform for DAQ debugging outside the actual the experiment. The current design has 768 channels (256 collection, 512 induction) utilizing six SBND designed motherboards.

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 one at FNAL, upon its completion the top flange and 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 Prof. Asaadi's start-up funds.

This test-stand can allow for a robust set of tests for the integration of many new readout components prior to their deployment in the experiment. This critical step was not taken during the MicroBooNE assembly and as a result a number of problems with the readout electronics were not detected in advance of attempting to commission the detector. These problems included the bias voltage line for the TPC wires behaving in an unexpected way and causing pick-up noise to be seen on the electronics, cross-talk between the light detection system and the TPC readout, and the incorrect configuration of electronics settings because of software bugs. While many of these issues were able to be solved during the commissioning phase, they slowed the progress of transitioning to data taking and caused unnecessary harm to the experiment. Moreover, this test-stand will provide a platform for testing and debugging of the DAQ software and readout electronics configuration without interrupting the operation of the SBND experiment.

The postdoctoral researcher and graduate student supported by this work 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.

Finally, such a test-stand can provide an R&D platform for long term testing of future readout components as well as software development for online triggers and zero-suppression schemes without risking downtime on operating neutrino detectors. The trigger schemes envisioned include utilizing multi-core graphical processing units to do online TPC based triggering for rare search events such as proton decay and supernova neutrino triggering. Moreover, by providing a platform for the development of LArTPC's DAQ systems into a common platform such as artDAQ, a greater push to the integration of the data, simulation, and analysis into one common software platform can be accomplished. The events processed utilizing the artDAQ software are immediately readable by the common liquid argon software framework known as LArSoft. Thus, working on this system and the associated neutrino detectors DAQ help promote the use of a common software framework.

3.1.2 Construction, Installation, and Commissioning

The UT Arlington group is positioned to play a major role in the construction and commissioning of the SBND detector and data acquisition system. Given the groups experience from MicroBooNE and LArIAT (where Asaadi played a lead role of TPC expert during construction, commissioning, and operations for both experiments) as well as the experience of the post-doctoral researchers already with the group (Falcone from ICARUS and Chatterjee from LArIAT) UTA hopes to offer hands on leadership during the construction phase.

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. The graduate student Zach Williams is expected to go with this project in the summer of 2017 and be in residence at FNAL. With his time already spent on this project, continuing to contribute to the DAQ development and aiding in the construction and installation of the cold electronics on the TPC is a natural fit. PI Asaadi is expecting to spend a significant portion of his time at FNAL during the second half of 2017 to help oversee these activities and contribute to the construction and phase.

Following the construction and installation phase, one post-doc and one graduate student are expected to stay with the SBND experiment a significant portion of their time to 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.

3.1.3 SBND Data Analysis

SBND will provide important physics measurements during its early operations in addition to providing an overall flux normalization to the key SBN oscillation analysis. Critically, SBND will collect very quickly statistics 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 measure if there is an oscillation component to the electron-like signal by measuring the rate as seen in the near detector. 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 coming from cosmogenic like backgrounds. Regardless of the outcome, SBND will play a critical role in quickly collecting high statistics data as the near detector to the SBN program.

SBND will also provide critical neutrino cross-section measurements at a statistical precision unprecedented by any other LArTPC. SBND will collect approximately two million neutrino interactions per 2.2×10^{20} protons on target (roughly one year of running). With 1.5 million ν_μ charged current interactions and 12,000 ν_e charged current interactions in one year. With such statistics, many precision cross-section measurements (e.g. double differential) 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 NCπ^0 events per year a full characterization of the leading background cross-section to the long baseline CP-violation analysis can be performed. The elimination of this systematic uncertainty in the cross-section will improve the experimental reach of the future planned DUNE experiment.

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

The MicroBooNE experiment serves as the first detector deployed at the SBN facility and represents the next step in LArTPC technology. MicroBooNE is a 10.3 m $\times$ 2.5 m $\times$ 2.3 m TPC with 89 tons of active volume. The TPC, shown in Figure **??**, has three instrumented wire planes with the first two induction planes oriented at $\pm 30°$ to the beam axis and the final plane oriented vertically. Both the pitch and wire spacing is chosen to be 3 mm, which provides superb resolution for imaging interactions inside the detector. Additionally there are 32, 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 the argon.

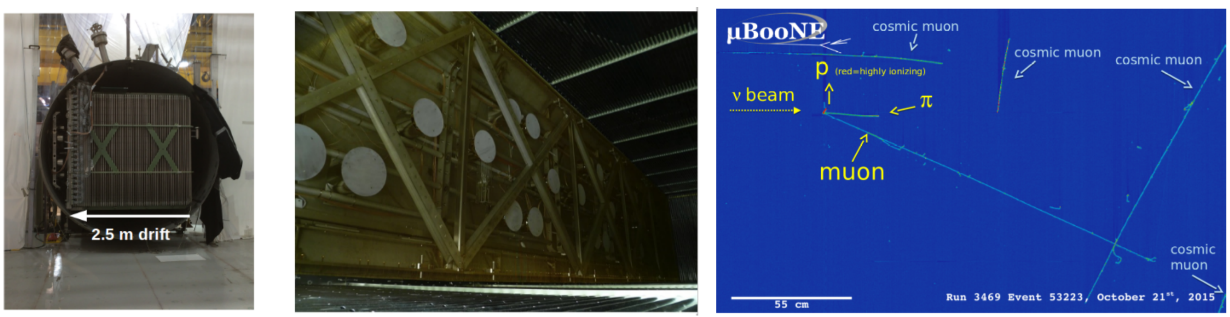

Figure 10: (Left) The MicroBooNE TPC after installation inside the cryostat. (Center) long exposure view of the inside of the TPC. The acrylic disks coated in wavelength shifting material which sit directly in front of the PMTs can be seen behind the wire planes. (Right) One of the first identified neutrino events utilizing the light and charge readout.

In the summer of 2015 MicroBooNE was filled with liquid argon and began commissioning. During this initial commissioning the drift high voltage was brought to $\sim 45\%$ its nominal value and immediately cosmic ray tracks and scintillation light were able to be seen. With the rapid success of the system, MicroBooNE has now transitioned from commissioning to neutrino data taking starting in October of 2015. Figure **??** shows an example of an automatically identified neutrino candidate event collected by utilizing both light and charge information.

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 photon-like electromagnetic showers. Moreover, the dominant background in the MiniBooNE analysis, neutral current π^0 production, can be extremely reduced using the powerful imaging techniques of a LArTPC. The analysis techniques developed for the low energy excess search will be developed in the common software framework known as LArSoft. This software framework is common amongst many of the LArTPC experiments, helping ensure that the reconstruction techniques and analysis strategies developed on MicroBooNE will have applicability to future 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 interaction, and thus change the measured cross-section. The fine grain tracking offered by LArTPCs allows for the classification of neutrino-nucleon 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 event be measured with high statistics using neutrinos as a probe. The broader neutrino cross-section community is anticipating how the results measured by MicroBooNE compare to previous measurements.

3.2.1 MicroBooNE Operations

UT Arlington group will continue to play a major role in the data taking and operations of the MicroBooNE detector. PI Asaadi 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 PI Yu's role as BSM convener on DUNE. 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 this proposal will part of their 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 effort expected to be present from the postdoc supported by startup funds in the first two years of the proposal. In addition to data taking shift requirements, the he/she is also expected to play a role in the online DAQ/data quality management as training for the future planned work on the SBND DAQ. With MicroBooNE just finishing the commissioning of their continuous readout data stream ("supernova data stream"), UTA hopes to play a role in supporting the analysis and improvement of this system. The graduate student supported by this work is also expected to take shifts on MicroBooNE and play a supporting role on the expert training.

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 researcher and graduate student are expected to work on neutrino cross-section analysis using the data taken in the first years of running in addition to measurements done once the full SBN program is operational. This data set will provide many first glimpses into the short-baseline analysis. Following up on previous low statistics cross-sections measured by ArgoNeuT is one way which the UTA can have immediate impact and leverage our previous experience where Asaadi played a major role.

An example of one such cross-section measurement that is of immediate interest, shown in Figure **??**, is the charged current coherent charged pion production (CC Coh-π). This result is of particular interest because 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 proven unsuccessful. However, the analogous neutral current process (NC Coh-π^0)has been observed at low energy. To further complicate the 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. The initial

MicroBooNE data set will be a valuable tool in disentangling this and many other cross-section oddities and allow for a better construction of ν-Ar scattering models.

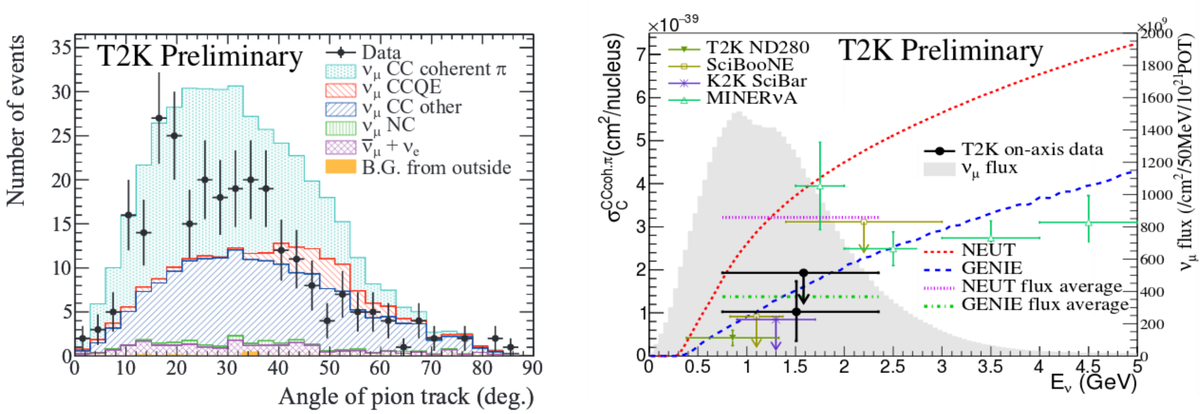

Figure 11: Recent results from T2K [] showing the tension which exists from the low-energy and high energy measurements of the charged-current coherent π production. With the SciBooNE and K2K experiments showing no evidence of this process at $E_\nu < 1$ GeV but ArgoNeuT and Minerva both measuring this 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. The UTA group has developed a good deal of expertise with this software package and will continue to contribute to its 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, the T600 detector initially tested in Pavia, Italy in 2001 where one of the two modules was exposed to surface running for a three month period. Extensive system testing was performed before the complete system was transported to the underground Gran Sasso National Laboratories (LNGS). 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 $> 90\%$ data taking efficiency (collecting ~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. Figure **??** shows one of the two TPC modules at CERN undergoing refurbishment. 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 $\pm 60^\circ$ to the beam axis and the final plane oriented horizontally. Both the pitch and wire spacing is chosen to be 3 mm which provides superb resolution for imaging interactions inside the detector.

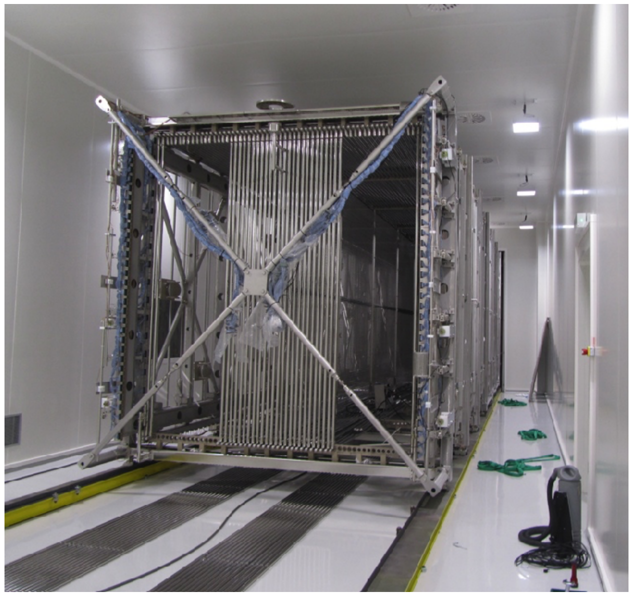

Figure 12: An ICARUS TPC module located at CERN undergoing refurbishment in anticipation of the move to Fermilab in 2017-2018.

The importance of the ICARUS-T600 experiment to the experimental reach of the SBN program is shown in Figure **??**. 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 reports no allowed regions 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 LSND allowed region.

The 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 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 aquisition system (artDAQ) used by the other two SBN experiments.

3.3.1 Installation, and Commissioning

By participating in both the installation, commissioning, and data taking of the SBND and MicroBooNE as well as leveraging on the experience of Dr. Falcone's work on ICARUS already, 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 the ICARUS system will ensure the 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 and data acquisition of the light system. At the same

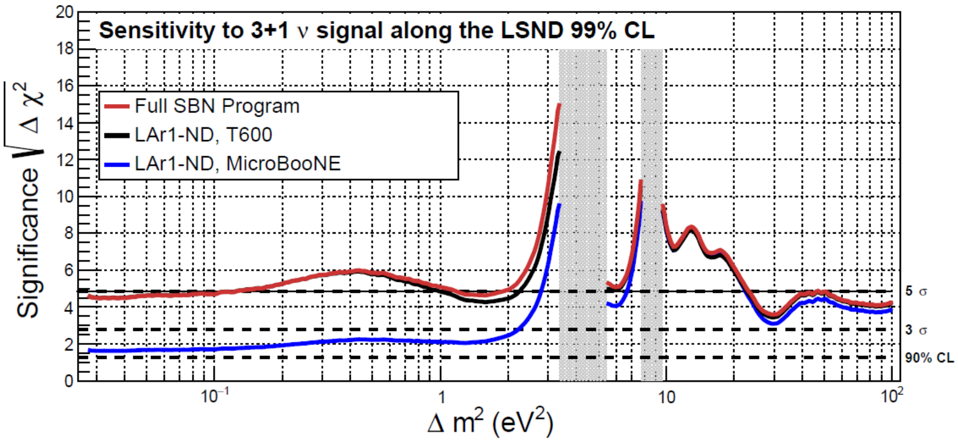

Figure 13: The experimental sensitivity for $\nu_\mu \to \nu_e$ oscillations including backgrounds and systematics assuming a nominal three year exposure in the BNB for the SBND and ICARUS experiments and a six year exposure for the MicroBooNE experiment.

time he will be training the other 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.

3.3.2 ICARUS Data Analysis

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 due to $\pi^0 \to \gamma\gamma$ decays. Using this, and the deployment of a near detector in the BNB beamline, a complimentary sterile neutrino search looking for muon neutrino disappearance as well as neutral current disappearance becomes possible. The extended length of the ICARUS-T600 detector provides better π/μ separation (since pions have a higher cross-section to interact) as well as more accurate muon energy reconstruction (since more muons will be fully contained) thus extending the sensitivity in the muon disappearance channel.

Similarly, by targeting a clearly identifiable neutral current process (such as NCπ^0 production) the disappearance rate can be measured at both the near and far detector 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 NCπ^0 disappearance search.

On top of the three detector SBN program, the stand-alone T600 detector can offer physics insight through the study of neutrino cross-sections at energies pertinent to the future planned Deep Underground Neutrino Detector (DUNE). The ICARUS experiment can due 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.

4 The Fermilab Long-Baseline Neutrino Program

Long-Baseline Neutrino Program

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

We describe in detail the project listed in the stragetic 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 interests.

4.1.1 Beyond the Standard Model physics group leadership - Yu

In addition to the standard neutrino physics topics, neutrino mass hierarchy and CP violation measurements in the neutrino sector, the expected high intensity proton beams provdies ample opportunities for DUNE to look for physical phenomena beyond the Standard Model. Thanks to the consistent efforts of Yu's and other members within the DUNE collaboration, the beyond the Standard Model physics group has been created at the collaboration meeting in Sept. 2015 with Yu as the convener. 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 analysis. The five subgroups are the simulation and software group led by our postdoctoral fellow, Chatterjee and four physics topics what cover Low Mass Dark Matter search (LDM), the Sterile Neutrino Search, the Non-standard Neutrino Interactions 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 Technical Design Report (TDR) scheduled to compelte by summary 2019. In preparation for TRD, the group plans on producing the write up for the initial list of topics and tasks to complete to provide sensitivity studies for TDR, along with the milestones for the group to follow. We anticipate that the list of tasks will be essential for the new members to participate in BSM group's planned studies.

4.1.2 Beam Simulation Tasks for LBNF

UTA group has contributed to beam simulations for optimization and systematic studies of the Long Baseline Neutrino Facility (LBNF). All new students joining the group are required to learn root and beam simulations as part of their training process. Since most of these tasks are well defined, each student can be assigned to the given task until they complete the task and write up the report. Many undergraduate students were able to make helpful contributions in these tasks and made presentations at beam simulation group meetings for tangible contributions. We plan on continue contributing to the beam simulation group's tasks for various studies, including an improved decay pipe radius dependence of the CPV sensitivity, target dimenstion and material dependence of neutrino flux and magnetic field map computations and display. New 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.

4.1.3 APA QA/QC

4.1.4 Field Cage for protoDUNE Dual Phase

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 LAr TPC 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 technology is the LAr TPC that the ionization electrons drift through LAr but then extracted through the strong extraction field at the top of the liquid and detected in the anode in gaseous phase of argon after a signal amplification via an large area gas electron multiplier (LEM), hence the dual phase.

During the period of his sabbatical stay at CERN, Yu has begun to work on WA105, a dual phase $6m \times 6m \times 6m$ prototype testing project at CERN through the participation in the smaller prototype cosmic ray detector in $1m \times 1m \times 3m$. This work provided an opportunity for UTA IF group to join WA105 as the first U.S. group and to position itself well to play a leading role in dual phase. While dual phase technology is currently at a lower priority to the single phase LAr TPC, it is clear that U.S. groups' participation in alternate technology is beneficial in many perspectives, including that of strengthening the international nature of DUNE collaboration an essential ingredient in its success.

As the schedule for DUNE experiment and for the two protoDUNE experiments get clearer, it became apparent that UTA will be able to play an importnat role in design and construction of these experiments. The overarching strategy in identifying the construction was to ensure UTA's contribution to any of the two protoDUNE experiment would aim to direct participation in DUNE from the first 10kt module in early 2020s. One such component easily identifiable is the field cage for which the collaboration is targetting to utilize as much common components as possible for single phase and dual phase protoDUNE detectors. With this premise, Yu has discussed with the DUNE management and has agreed to take the responsibility in design and construciton of dual phase field cage together with the University of Zurich group.

Figure **??** shows the current conceptual design of the field cage for the dual phase protoDUNE experiment. The primay concept of this field cage is to use compartmentalized structure of sub-modules that consist of several straight profiles to provide voltage differentials for the generation of uniform fields. The use of straight profiles made of either aluminium or stanless steel makes the preassembly and shipment of submodules convenient. Each of these submodules will be prepared to the quality to hold high voltages at 180kV (for single phase) or 360kV (for dual phase) over the drift length.

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 submodule and the each profile. The project funds will pay for the purchase electrical parts - voltage divider resisters and varisters for surge arresting - and the production of electronic boards the field cage. UTA will work with the single phase field cage group, including BNL team, and the single phase field cage electronics group at Louisiana State University as well as the University of Zurich group on design of both the mechnical and electrical part of the dual phase field cage. We will be responsible for preassembly of the field cage submodules, mouting of the electric boards, testing of each submodules and performaning functional prototype testing with as large a field cage as possible before shipping the dissembled submodules out to CERN for installation.

For the completion of the design of the dual phase field cage, our postdoctoral fellow, Animesh Chatterjee will be stationed at CERN starting from October 2016 through mid January 2017. During this period, Chatterjee will work with the ETH and CERN groups to finalize both mechnical and electrical design of the field cage for dual phase protoDUNE and ensure as much a commonality

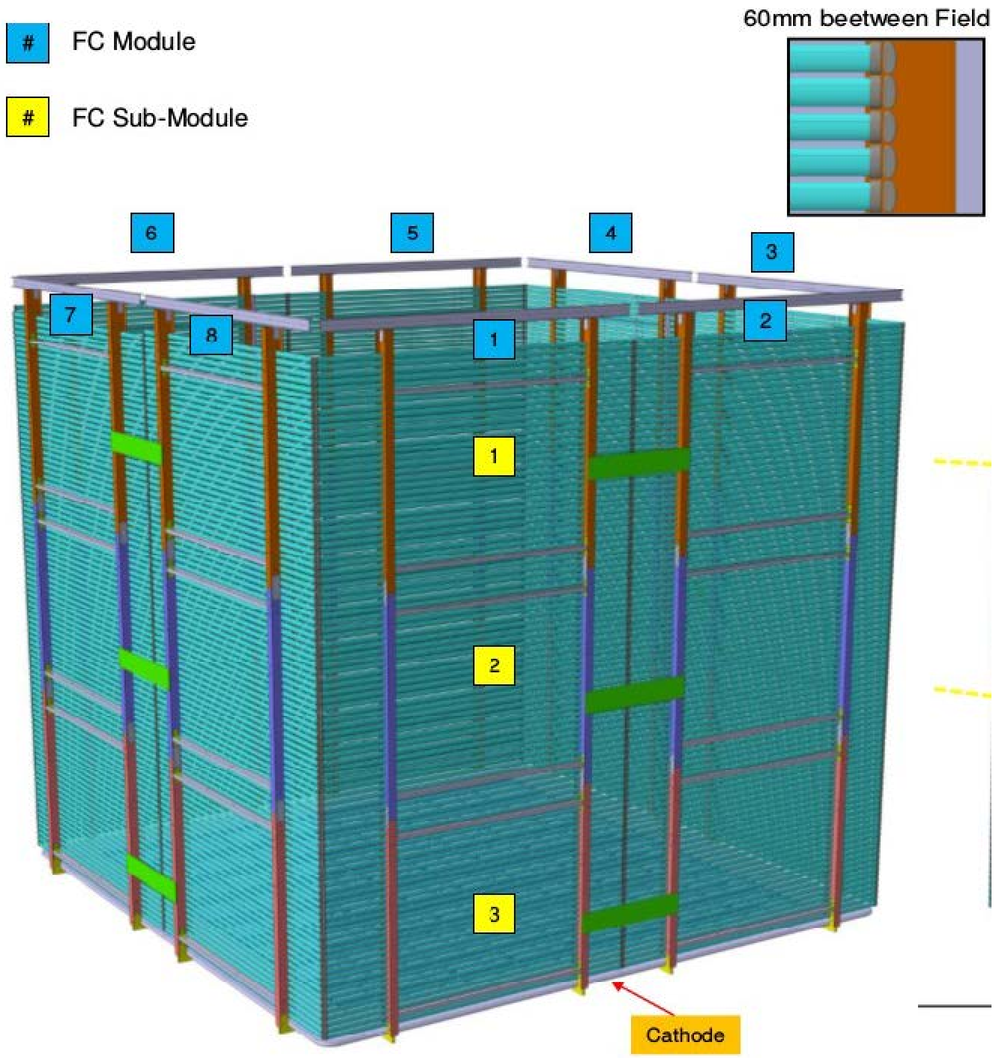

Figure 14: Conceptual skematic drwaing of the field cage assembly for dual phase protoDUNE.

as posisble with that of the single phase. Once these design parameters are agreed with the single phase field cage groups, a production could proceed. The parts for the dual phase field cage will be shipped to UTA for the clean up and preparation of each of the parts, assembly of submodules, mounting of electrical components, and electrical and mechanical testing for a submodule qualification. A sizeable functional prototype field cage of size $6m \times 6m$, an electrically independent unit, will be put together and be subject under high voltage, though it may not be as high as 360kV given that the testing will be performed in air. Once the functional testing completes, the functional prototype will be disassembled and shipped to CERN for the installation.

Since protoDUNE time scale has a hard limit of completing the beam data taking before CERN shutdown in 2018, it is essential for our group to operate under this time restriction in mind as presented in the strategic plan in section **??**. To meet these goals, Yu plans on staying out at CERN in fall 2017, thanks to the remaining funds from the agreements with LAPP and ETH which covers costs for local stay at CERN and the teaching buyout. A UTA postdoctoral fellow will also be stationed out 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 U.S. at the end of year 2017 and Asaadi will be stationed out at CERN for the first half of 2018 to continue fulfilling our responsibilities in both the protoDUNE experiments.

At the time of writing this renewal proposal, the dual phase protoDUNE field cage group is working closely with the group for the single phase to agree on common design parameter for mechnical and electrical components of the field cages, such as the dimension of each profile bars of the field cage, the material, the electrical board design, quality and tolerance of resisters and varisters, etc.

Part IV
Research in Detector R& D

PI Summary: David Nygren

PI Summary: Benjamin Jones

SiPMWheel: a large-area, position-sensitive, energy-resolving light collector (Asaadi, Jones and Nygren.)

5 Introduction

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 [?, ?], 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) [?, ?, ?, ?, ?, ?, ?]. 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 [?, ?], high-reflectivity foils [?, ?], and light-guides [?, ?, ?]. Light guide systems, have the advantage that large areas can be sensitized with only a moderate channel count. However, it has the disadvantage that light losses through non totally-internally-reflected rays, and surface scattering and re-absorption effects [?] 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 [?] 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 [?, ?]. 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.

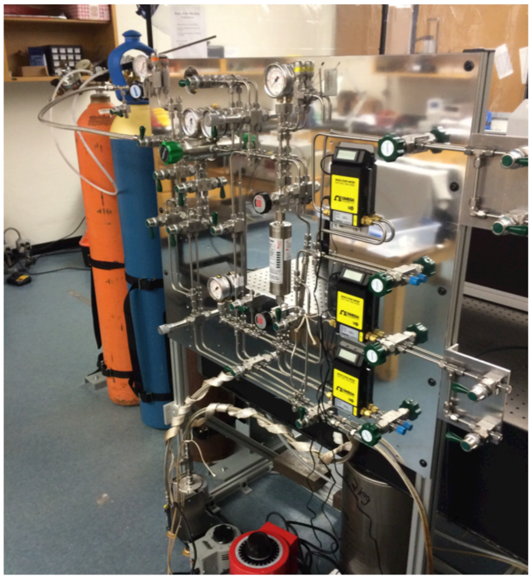

Figure 15: Left: Existing high pressure xenon gas purification and recirculation system in the lab of Nygren and Jones. Right: Existing liquid argon purification system in lab of Asaadi.

6 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 **??**.

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

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 one undergraduate.

2. M&S costs: to include argon and xenon supply, as well as fluors and plate materials.

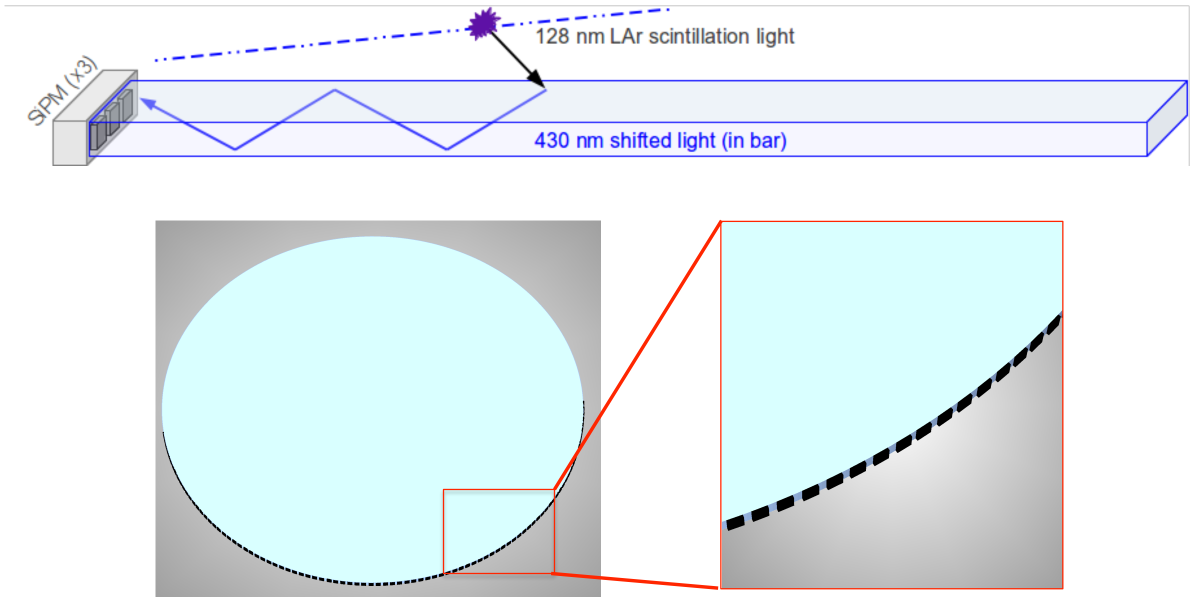

Figure 16: Top: Example of operation of bar detectors, like the "Wunderbar" - image from [**?**]. Bottom: Drawing of plate detector we propose to develop.

7 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 **??**, 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. 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 [**?**]) 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)?

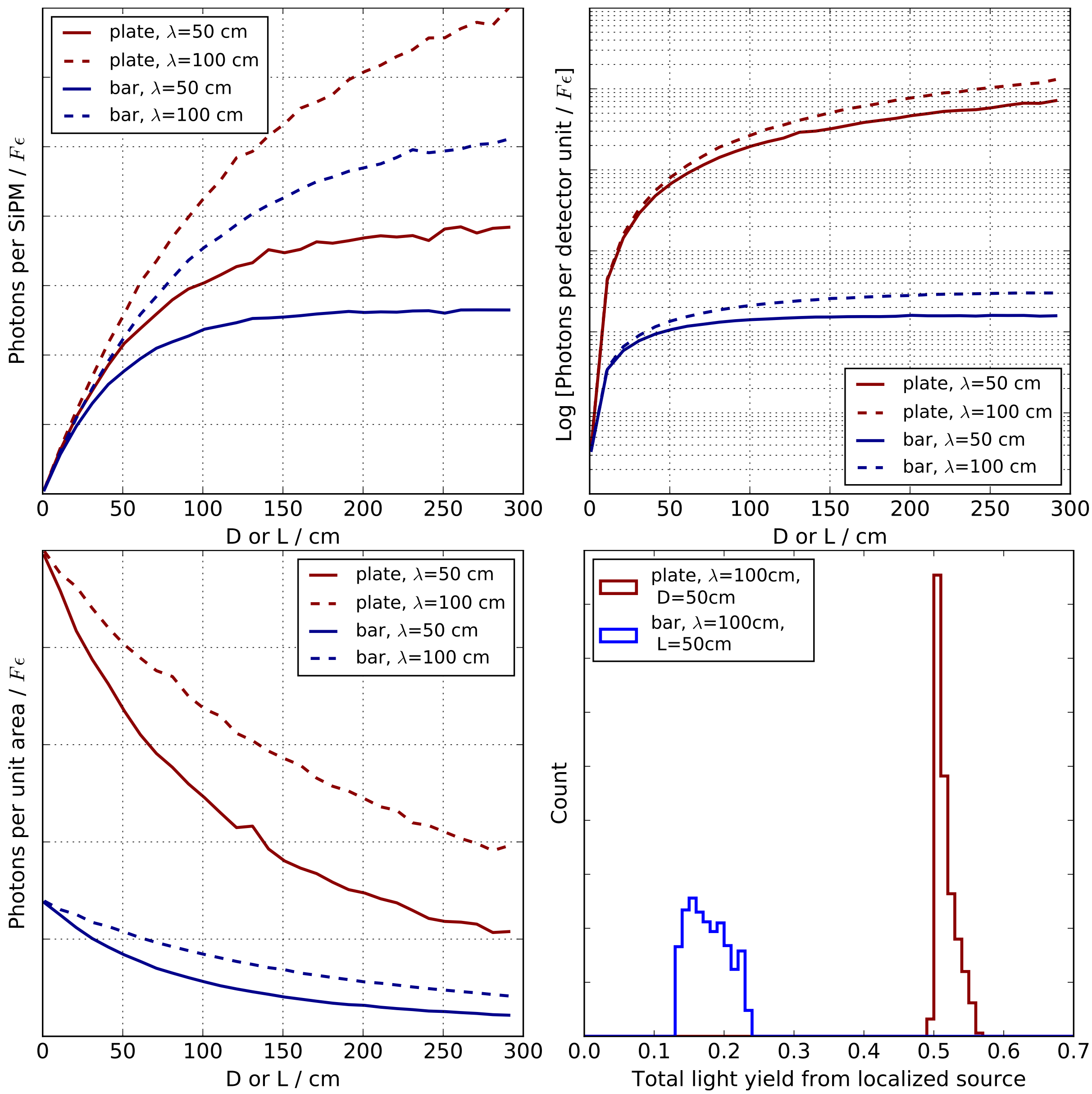

Figure 17: Comparison of plate-type to bar-type detectors with various figures of merit described in the text. The plate significantly outperforms the bar-type detector in all cases. Top left: photons per SiPM. Top right: Photons per detector unit. Bottom left: Photons per unit area. Bottom right: total yield and spread from localized mono-energetic sources.

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, 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 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 [**?**]). We consider two values of the parallel attenuation length λ that appear reasonable based on past studies, $\lambda = 50$ cm and $\lambda = 100$ cm [**?**, **?**]. 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 **??**, 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 **??**, 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 **??**, 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 **??**, 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 in 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.

8 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 [**?**].

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

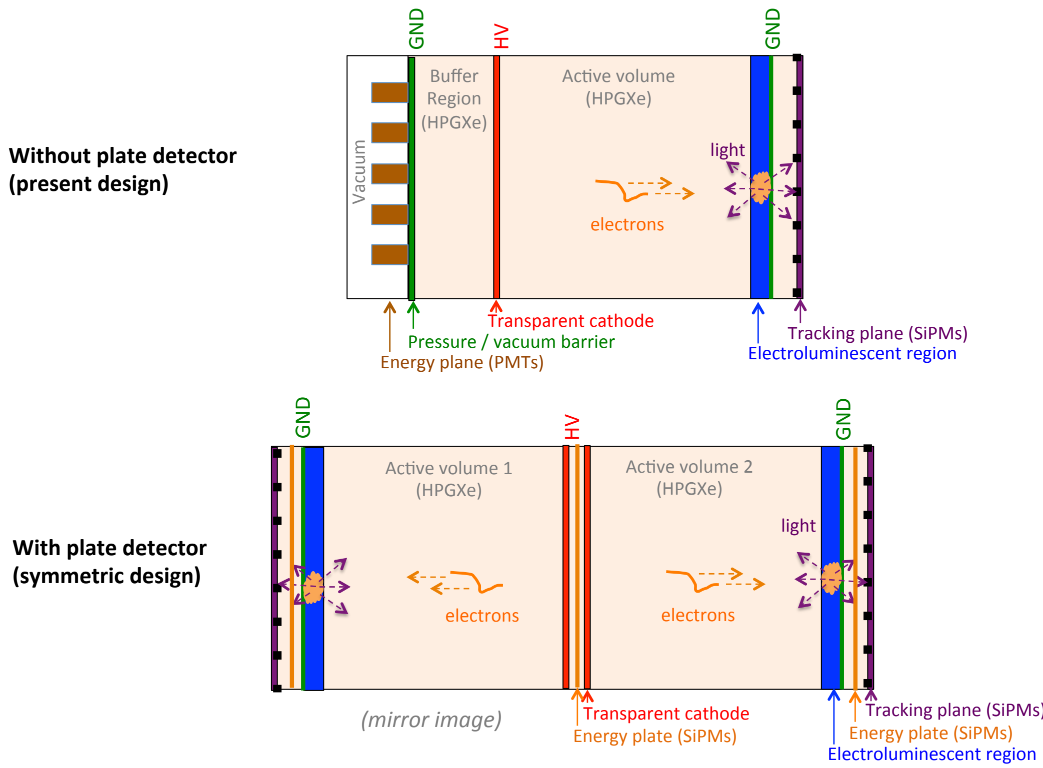

Figure 18: Left: Existing asymmetric TPC design, where energy must be recorded using the PMT-based “energy plane”. Right: Symmetric design that could be realized using a high-resolution ”plate detector”. Plate detectors may be deployed at the anode region, the cathode region, or both.

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 **??**, 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 like produce fluctuations in the measured energy that prevent 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 been demonstrated [**?**]. A sketch is shown in Figure **??**, top.

This two-plane solution is not without drawbacks. Even the low radioactive 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

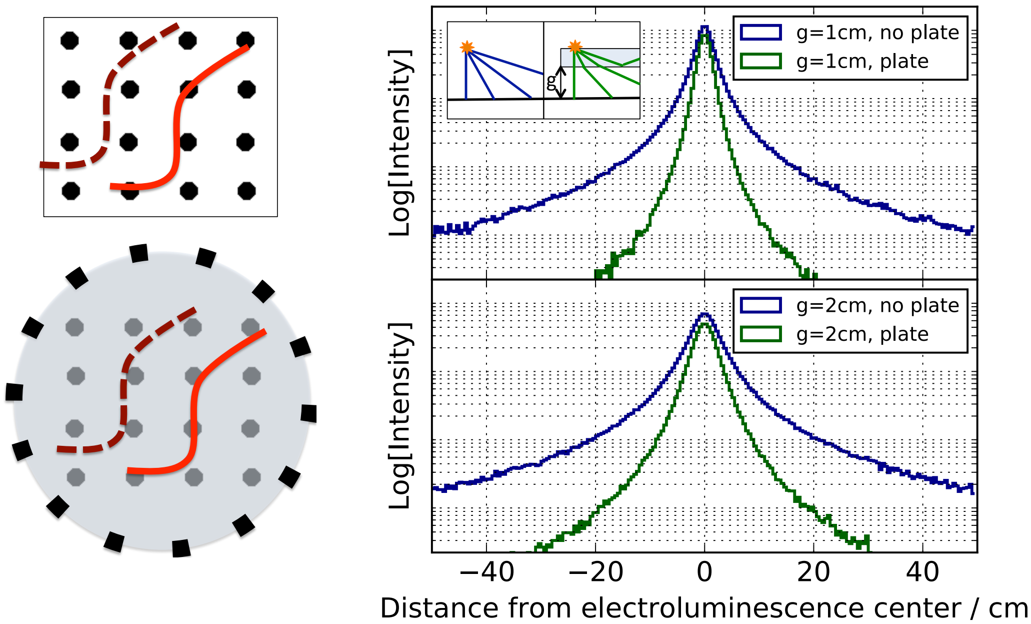

Figure 19: Left: Track energy measurement with tracking plane only (top), and tracking plane + plate (bottom). Right: Focussing effect of plate on transmitted electrolumiscence light, which may improve tracking resolution in NEXT.

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 **??**, 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 , 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 the cathode 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, 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 **??**, bottom.

9 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 [**?**]. 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. 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* [**?**]. 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* [**?**] 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* [**?**]. Golden chanels for proton decay in DUNE include $p \rightarrow K^{+}\nu$, $p \rightarrow K^{0}\mu^{+}$ and $p \rightarrow K^{+}\mu^{-}\pi^{+}$. 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 **??** 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.

10 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 undergraduate 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.

Curriculum Vitae

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10.1 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)**

10.2 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)**

10.3 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

10.4 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.

10.5 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

10.6 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

Kaushik De
Department of Physics, University of Texas at Arlington, Box 19059, Arlington, TX 76019
E-mail: kaushik@uta.edu, URL: http://heppc1.uta.edu/kaushik/index.htm
Phone: (817) 272-2813 (office), -2266 (physics dept.), -2824 (FAX), (682)521-5323 (cell)

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).

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 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.

[2] 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).

[3] 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).

[4] The ATLAS Collaboration, "A Search for High Mass Diphoton Resonances in the Context of the Randall-Sundrum Model in $\sqrt{s} = 7$ TeV pp Collisions", ATLAS-CONF-2011-044 (2011).

[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 [3, 4].

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.

Graduate and Postdoctoral Advisors and Advisees

Rozmin Daya-Ishmukhametova, University of Massachusetts - Amherst, Yuriy Ilchenko, UT Austin, Renat Ishmukhametov, Ohio State 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)

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: 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:	

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.

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.

The 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 center. This remote operation center 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 feet 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 (need words from David and Ben)

UTA 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.