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"Future neutrino and dark matter observatories"

This statement includes cyan hyperlinks. It is best viewed digitally.

Who am I?

I am a doctoral candidate at the University of Hawai'i where I research neutrinos (ν's) and dark matter (DM) with liquid argon time projection chambers (LArTPCs). We know embarrassingly little about both yet their influence is ubiquitous.

I split my time between software and hardware; experiment and theory. My work on LArTPC prototypes takes me around the world; Stanford Linear Accelerator Center (SLAC), Fermilab (Illinois), and CERN.

With a formal background in Astrophysics, I am particularly interested in future neutrino and dark matter observatories. Such places are ripe for studying both the micro and macro worlds; particle physics and astrophysics.

What do I do?

I use wired and pixelated LArTPCs to study particle physics - both terrestrial and extra-terrestrial. Most of my work is done at energies below 1 GeV. Specifically, I work on prototypes for the Deep Underground Neutrino Experiment (DUNE).

Over the last four years, I gained expertise in the development and calibration of LArTPCs for neutrino and DM research. Also, I worked with big data and particle physics simulations. I contributed to the development of LArSoft, a shared software across LArTPC experiments, and wrote standalone algorithms and packages modeling ionization charge drift in liquid argon and detector response. Additionally, as a graduate student, I took courses on machine learning (see this quirky exercise) and have written neural networks.

I have been fortunate to be involved in many stages of an experiment, from detector conceptualization and theoretical forecasting of signal sensitivities, to taking data collecting shifts. I took shifts at CERN monitoring a DUNE prototype (ProtoDUNE-SP) whilst it was subjected to a beam of mesons and baryons. The DUNE collaboration has since analyzed that data and will soon publish several cross sections in liquid argon; crucial input for the ν community.

Although, DUNE's primary mission is to explore terrestrial ν oscillations, most of my involvement is astrophysical.

Astrophysical Neutrinos

I used ProtoDUNE-SP to measure delta-rays (δ-rays).

They are ionizing electrons which often accompany other energetic ionizing particles like atmospheric muons. δ-rays may seem unrelated to ν's. However, they share energies with the electrons ejected in supernova/solar ν interactions. In other words, δ-rays are a great 'standard candle' especially deep underground where natural calibration sources are scarce.

δ-rays are a challenging signal. There are no public algorithms to reconstruct their energy.
Hence, I developed a custom image processing algorithm.

The measurement of the δ-rays spectrum is an important contribution to the Low Energy Physics in Liquid Argon (LEPLAr) community (Snowmass 2021) and a demonstration of DUNE's readiness for ν astronomy.

Indirect Search for Dark Matter

DM annihilating in the Sun is expected to produce mono-energetic ν's which can be seen by ν observatories. Using the NuWro Monte Carlo neutrino event generator, the LArSoft detector response software, and the Pandora reconstruction package, I simulated DUNE's response to such ν's and showed that it will be sensitive to low mass DM and competitive with future direct-search experiments.

I assumed that DM annihilates to Standard Model quarks which then hadronize to the known mesons and baryons. Those composite particles then decay further to ν's and other particles. For instance, kaons decaying at rest (KDAR) emit mono-energetic ν's.

In a LArTPC, 236 MeV KDAR ν's are mono-energetic, mono-directional beacons and can knock out leptons and hadrons. I focused on final states with one lepton and one hadron and forecasted DUNE's sensitivity to such an exotic ν flux. Although low energy (below 1 GeV) ν interactions are poorly understood theoretically, and data-simulation discrepancies have been observed in the data taken on hydrocarbon and water targets, I have shown that next-gen LArTPCs can indirectly detect low mass DM, in addition to doing ν physics. This work resulted in a DUNE collaboration publication on which I was the the main analyzer and writer.

Currently, I am thinking more about extending the detectability of low mass DM, specifically, the prospect of using the Migdal effect.

Field Distortions

Ionization trails in LArTPCs are at the mercy of electric fields. An uneven detector field shifts and warps the reconstructed images. Just as astronomers correct for atmospheric turbulence to observe stars, particle physicists must correct for field distortions to image particle interactions. I am working on hardware and software to rectify electric field inhomogeneities in DUNE prototypes.

Surface LArTPCs are flooded by atmospheric muons (μ's). These μ's are expected to slice straight through liquid argon; deviations indicating field distortions. I measured the μ warping in the DUNE Near Detector surface prototypes and developed a corrective software. Underground, on the other hand, μ's are scarce. Another method is necessary.

In collaboration with SLAC and Michigan State University, I participate in the development of a calibration scheme that uses a pattern of photoelectric targets illuminated by UV pulses to measure electric field distortions. A UV laser, guided by optical fibers, illuminates metal targets mounted on the cathode, and the emitted photoelectrons drift across the detector to be read out on the anode. This photoelectric calibration system facilitates a quick measurement of the electric field and drifting electron diffusion, even in a μ-poor environment. To motivate the design of this hardware calibration scheme, I wrote a stand-alone electron drift and detector response simulation.

Cryogenics

Precise knowledge of liquid argon temperature is crucial to LArTPC analyses. The temperature impacts the ionization electron and ion flow, electron recombination (with surrounding atoms) and the overall energy of the readout signals. I helped build and operate a 7m long motorized temperature profiler for ProtoDUNE-SP. This dynamic temperature profiler was a network of RTDs (resistance temperature detectors) inserted and moved via a stepper motor. Through motorized motion, various RTDs occupied the same locations of the detector and the full RTD network cross-calibrated itself in situ.

I worked on the fabrication and commissioning of this system at Fermilab and CERN.
We calibrated the ProtoDUNE temperature with unprecedented 3 mK precision, made comparisons with computational fluid dynamics (CFDs) models, and verified liquid argon recirculation; a critical ingredient for LAr purity and physics analyses.

Teaching

Teaching is extremely symbiotic; benefiting the students and the teachers. Preparing for a class forces a teacher to reflect on the best way to tell a story. Undeniably a practice which molds a better scientist. I have taught at all levels, from general education, through lower and upper division; in both small and large classes. And in the future, I want to be immersed in an environment with high educational standards.