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Recent Results from ArgoNeuT and Status of MicroBooNE

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Abstract

Liquid Argon Time Projection Chamber (LArTPC) detectors hold the key to answering the outstanding questions about the role of neutrinos in the Standard Model of Particle physics and beyond. Their fine granularity combined with calorimetric capabilities allows for precision measurements that answering these questions will require. Here, we discuss the recent results from the ArgoNeuT experiment as well as the status and prospects for MicroBooNE, both a part of the US-based LArTPC neutrino program.

Keywords: neutrinos, liquid argon, time projection chamber, cross-sections
2000 MSC: 14.60.Lm, 14.60.St, 13.15.+g, 25.30.Pt

1. Liquid Argon Time Projection Chambers in Neutrino Physics

The Liquid Argon time Projection Chamber (LArTPC) [1] allows taking snapshots of neutrino events with a precision comparable to bubble-chambers, at the same time allowing scaling to multi-kton detectors and digitizing the 3D and calorimetric information.

A LArTPC detects charged particles resulting from neutrino interactions by registering the resulting ionization electrons drifted in the electric field on its anode sense wires. Images from at least two planes allow for 2D reconstruction with the third dimension coming from the time of drift known e.g. from scintillation light registered by PhotoMultipliers (PMTs). Calorimetric information is obtained from quantity of charge acquired on the wires.

1.1. The US Based LArTPC Neutrino Program

ArgoNeuT [2] and MicroBooNE [3], running on the higher energy NuMI and lower energy Booster neutrino beams, respectively, are both part of the US-based LArTPC neutrino program which aims develop the technology performing relevant and important physics measurements on the path to measure CP violation in the neutrino sector with the LBNE/LBNF experiment [4]. These are combined with an active R&D program which includes test-beam experiments [5] and dedicated proof-of-principle measurements [6].

2. The ArgoNeuT Experiment

The ArgoNeuT experiment ran for 6 months in 2009 in the MINOS [7] Near Detector hall at Fermilab and acquired 1.35×10^{20} POT (Protons on Target) of NuMI beam events, mainly in anti-neutrino mode. The Presence of the MINOS-ND has been extremely valuable by providing the charge and momentum measurements of muons not-contained in the ArgoNeuT TPC. While ArgoNeuT has already published measurements, like that of the Charged Current muon neutrino inclusive cross-section on argon and others [8], in this work we focus on more recent analyses, published in 2014 or still ongoing.

2.1. Muon-Neutrino Analyses

The analyses involving muon-neutrinos can be split into two categories: benchmark, standard candle results and exclusive channel cross-section measurements both comparable to those obtained in different detectors and measurements enabled by the LArTPC technology which would be difficult or impossible without it.

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In the first group is the muon-neutrino Charged Current (CC) inclusive cross-section. This observable, being accessible to all detector technologies, can be considered a benchmark or a standard candle result and allows comparison between different experiments. ArgoNeuT has used the NuMI anti-neutrino mode to measure the CC inclusive differential cross-section for anti-neutrino interactions on argon for the first time [9]. Benefiting from the charge sign differentiation provided by the MINOS-ND, a measurement of the neutrino CC-inclusive cross-section was also performed, at a higher energy, than the previous ArgoNeuT measurement. The results are shown in Fig. 1.

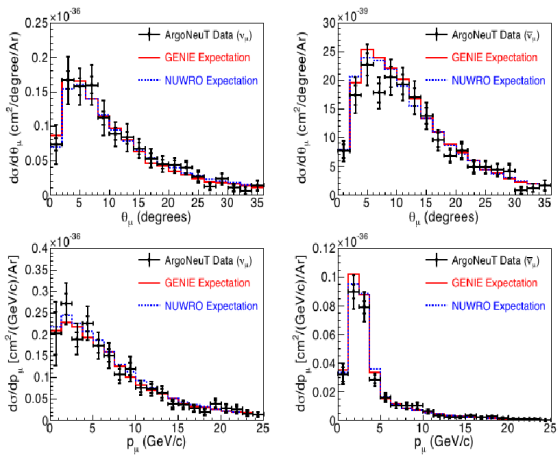

Figure 1: The ν_μ CC-inclusive differential cross-section measurements performed in ArgoNeuT. The variables are outgoing muon angle θ_μ (top) and muon momentum (bottom) for neutrino (left) and anti-neutrino (right) modes.

ArgoNeuT is also analyzing data in order to measure exclusive topologies e.g. coherent pion production [10], which has recently been of interest [11]. In ArgoNeuT the measurement necessitated using a boosted decision tree to select candidate events based on the combined values of several kinematic variables due to the lack of pion containment. The resulting cross-section for ν_μ and $\overline{\nu_\mu}$ are shown in Fig. 2.

A measurement enabled by the LArTPCs granularity is the direct observation of nuclear effects, such as FSI in muon neutrino events. Examples include the observation of events with multiple protons as well as events where the proton direction is opposite to that of the beam. Both of these effects are in disagreement with the basic quasi-elastic model of neutrino interactions often used to model neutrino interactions at these energies.

A striking example of such nuclear effects are events with two back-to-back protons [13] in the lab frame and with back-to-back protons in the Center-of-Mass frame. The former, dubbed "hammer-like", could be interpreted as an indication of the existence of short-range correlated neutron-proton pairs in the argon nucleus. See Fig. 3 (right) for an example of such interactions.

The proton multiplicities measured and observed by ArgoNeuT provide new input for tests of neutrino generators and allow new ways of understanding and modelling the complex nuclear physics at play.

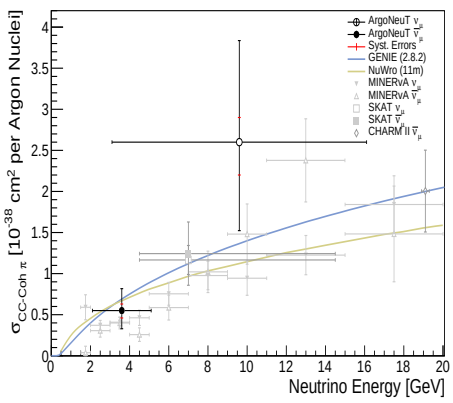

Figure 2: The ν_μ and $\overline{\nu_\mu}$ coherent pion production cross-sections on argon measured by ArgoNeuT.

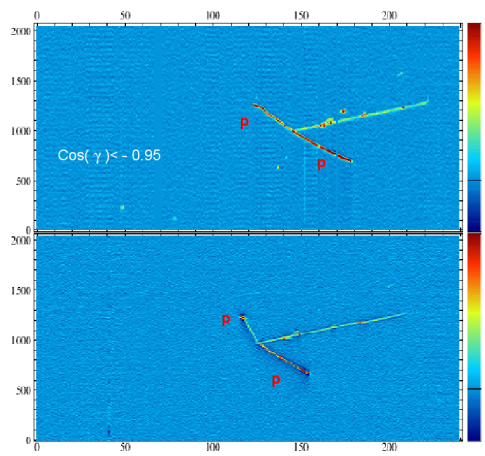

Figure 3: An example of a "hammer" event with back-to-back protons exiting the nucleus observed in ArgoNeuT.

2.2. Electro-Magnetic Shower Analyses

The electron-neutrino appearance channel is the golden channel in CP violation and sterile neutrino

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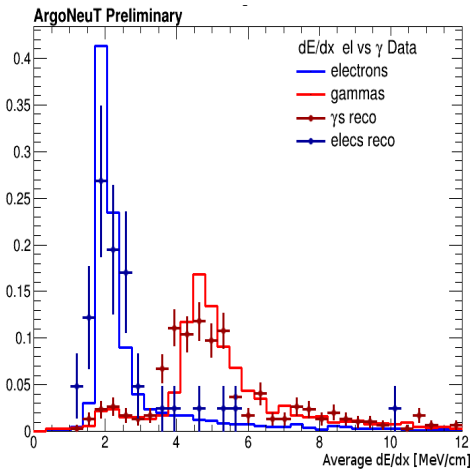

Figure 4: The result of testing the dE/dx separation method on neutrino event samples obtained from NuMI neutrino interactions in the ArgoNeuT detector. Note, that based on the definition of the photon sample, the photon candidate events shown in this plot would have been rejected already by the topological cut in an electron-neutrino appearance search.

searches. The granularity of the LArTPC can be used to significantly suppress photon backgrounds, e.g. coming from Neutral Current π^0 meson decays. Observing a gap between the start of the shower and the interaction vertex unambiguously tags an EM-shower as a photon conversion (topological cut). In case of no vertex activity or a very short gap, the two populations can be differentiated via "dE/dx", since the reconstructed charge in the first part of a photon-originating EM shower will have double the charge of an electron-originating shower (dE/dx cut).

Electron-neutrinos present in the NuMI beam, allow a test of the proof of principle of electron/photon separation with the dE/dx cut using ArgoNeuT data. The electron and photon candidate samples are selected using the topological cut, i.e. electrons are chosen as events with a clear EM-shower and no gap from a visible vertex, whereas photons are required to have a gap from a visible vertex. The energy deposition at the start of the showers is measured for both of these populations and shown together with the Monte Carlo predictions in Fig. 4. This represents the first demonstration of the feasibility of the dE/dx separation method in a LArTPC using neutrino beam events.

ArgoNeuT is also working on measuring the the cross-section for Neutral Current π^0 production. Once measured this will translate into a better understanding of backgrounds in future electron-neutrino searches.

3. The MicroBooNE Experiment

MicroBooNE is the next experiment in the US based LArTPC program. It will run on the Booster Neutrino Beamline at Fermilab just upstream of the MiniBooNE detector location. With 80 tons of active LAr mass in a single liquid argon volume its objective is to determine the nature of electron-neutrino like events observed by the MiniBooNE detector, also known as the MiniBooNE excess [14]. This excess can only be interpreted as oscillations into, a yet undiscovered, sterile neutrino if the excess events were confirmed to be electron-like, indicating electron-neutrino interactions, as opposed to photon-like, suggesting backgrounds or unknown interactions. This distinction was not possible in a Cherenkov detector, but will be possible in MicroBooNE which will take advantage of the capabilities of the LArTPC, demonstrated by e.g. ArgoNeuT.

Other MicroBooNE physics goals include precisely measuring neutrino cross-sections on argon, benefiting from the extremely interesting energy region of the Booster Neutrino beam interactions where the Quasi-Elastic, Resonant interaction channels mix with significant contributions. In addition it is the relevant range for the second oscillation maximum for LBNF.

MicroBooNE will also study backgrounds and develop reconstruction algorithms that will be applicable in future large LAr detectors searching for nucleon decays underground. The detector will be able to observe neutrinos from a SuperNova explosion happening in the galactic center and will also be able to understand the backgrounds for such detection in future experiments.

Apart from the physics goals, MicroBooNE is testing solutions essential for future large liquid argon detectors. Examples include cold electronics, being the first argon detector in a neutrino beam to use the gas piston method [6] instead of evacuation and will have the largest electron drift in a neutrino experiment - 256 cm. MicroBooNE will also implement a UV laser [16], which will allow for calibration of potential field inhomogeneities.

The MicroBooNE TPC has been fully assembled and inserted into the Cryostat. After completing the final tests in-situ, the cryostat was transported to the Liquid Argon Test Facility (LArTF) on the Booster Beam. At the time of writing the cryostat has been covered with insulating foam and the tests of the DAQ electronics and cryogenic system are complete. The detector is scheduled for cool down and filling in the next months.

4. Conclusions

The liquid argon time projection chamber technology is a novel detector for neutrino physics. The technology is being developed in the framework of a vibrant physics and R&D program, centered around Fermilab, which includes performing relevant physics measurements, such as examining neutrino oscillations at short baselines. This will lead to a world class program in the long term with a detector based at the Long Baseline Neutrino Facility set to measure CP violation in the neutrino sector.

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