First neutrino physics results of the ArgoNeuT experiment, and first tracks with CMOS preamplifiers operating at 87K.

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Abstract. Using a 175-liter LArTPC followed by the MINOS near detector in the Fermilab NuMI beamline, the ArgoNeuT collaboration has made a measurement of inclusive muon production in charged-current interactions of neutrinos with a mean energy of ~4 GeV. Also, a group working at Fermilab has observed cosmic-ray muon tracks in a small 3-plane LArTPC instrumented with CMOS preamplifiers immersed in the 87K liquid argon.

1. Introduction

The LArTPC technology holds out great promise to be the ideal detector for short- and long-baseline neutrino experiments in studies of their interactions and oscillations. It is also well suited for searches for nucleon decay in the stable argon nucleus and for a number of other rare processes such as detection of supernova in the neighborhood of our galaxy. Recently, two important steps have been taken to generate confidence in the LArTPC technology: topical neutrino physics results have been obtained from the ArgoNeuT experiment and cosmic ray muon tracks have been observed using CMOS preamplifiers operating in the liquid argon.

2. ArgoNeuT first ν-physics results

From a total of 8.5×10^{18} protons on the NuMI target with the horns set to focus positive mesons (neutrino-mode), the ArgoNeuT collaboration, as shown in figure 1, has made a (preliminary) measurement of inclusive muon production in charged-current (CC) interactions in a neutrino beam with a mean energy of ~4 GeV. The LArTPC had a 175-liter active volume and 240 wires on a 4 mm pitch, in each of two views using ±30° stereo. A general description of the hit finding and tracking techniques were described in a paper [1] presented at the first in this series of conferences, GLA2010. Important for the CC analysis was the cooperation of the MINOS collaboration [2]. They provided the momentum, charge, and location of muon candidates found in the near detector for each NuMI spill, allowing the MINOS near detector (subsequently, just MINOS) to serve as a muon spectrometer for ArgoNeuT.

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ArgoNeuT

Figure 1 The ArgoNeuT collaboration and logo.

The CC analysis is fully described in a Ph.D. thesis [3], and a paper in preparation. The analysis used software optimized on the tracks of through-going muons and on candidate neutrino events

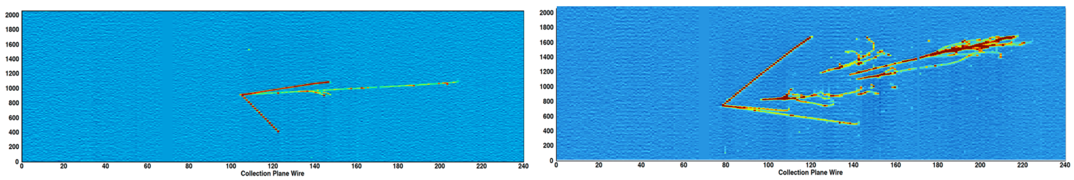

Figure 2. Collection-plane displays of two ν-interactions in ArgoNeuT; the color red indicates a projected ionization of > 2 m.i.p. Forward track (in event on left) can match with a muon in MINOS.

preselected by scanning, such as those shown in figure 2. However, the muon inclusive production analysis was performed on all neutrino-mode spills without reference to the scanning information. Briefly, the analysis proceeds by identification of a neutrino interaction vertex in the liquid argon and all vertex-associated tracks are projected to the initial point on each muon track reconstructed in MINOS. As shown later, a rather mild cut was imposed on the agreement in position and angle that defined a match between ArgoNeuT and MINOS tracks. Fiducial volume cuts were applied to make it probable that sufficient track length was available for projection to MINOS, and to remove through-going muons faking a neutrino interaction. Events with a match to a negatively charged muon in MINOS were selected for the neutrino CC interaction sample.

To evaluate the efficiency for reconstructing a CC interaction, the GENIE [4] event generator was used to generate flux-normalized events. The generator used fluxes above 3 GeV based on measured

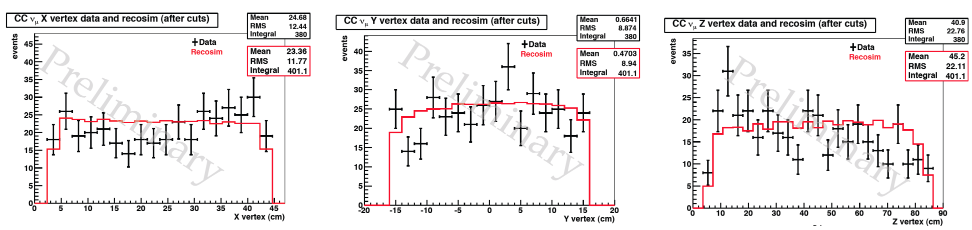

Figure 3. From the left, the X, Y, and Z vertex distributions for data (points) and for events generated with the CC interaction model through the detector simulation (in red).

values determined by the MINOS collaboration [2], while below that energy the flux is based on predictions [3] of a meson production and beam transport model. The tracks generated in these interactions were sent through a GEANT-4 simulation of the ArgoNeutT and MINOS detectors. Backgrounds due to neutral current and anti-neutrino interactions, as well as through-going muons generated by upstream interactions were effectively removed by the fiducial and MINOS matching cuts. Of the 379 data events remaining after the cuts, less than 5% can be attributed to these backgrounds.

The vertex location of the data events and of the flux-normalized GENIE events are in reasonable agreement, as shown in figure 3, as are the matches of a LAr track projected to MINOS track, as shown in figure 4. The overall normalization, in particular, is in excellent agreement with the data. Thus, the CC cross-section model in the GENIE event generator with corrections for detector performance reproduces the event rates as seen in the experiment.

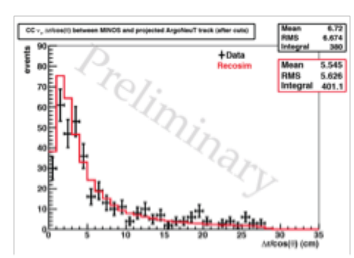

Figure 4. Match in $\Delta r/\cos\theta$ of tracks in the two detectors.

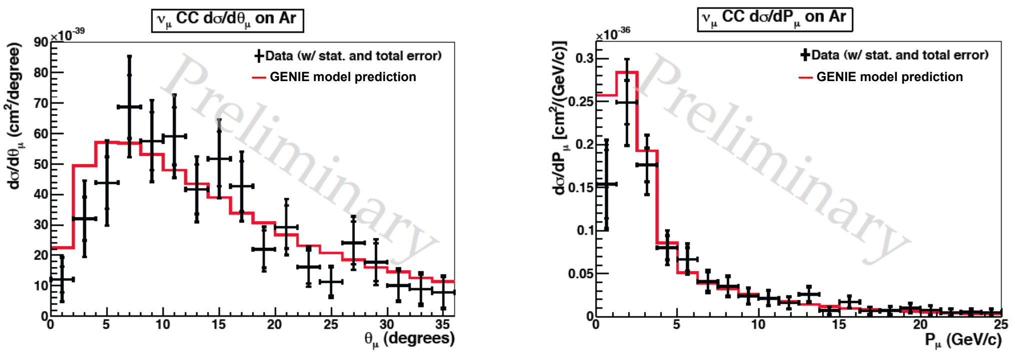

Figure 5. Shown are the muon neutrino CC differential cross sections (per argon nucleus) in muon angle (left), and momentum (right), for data and the GENIE MC predictions.

The preliminary results on CC muon inclusive differential cross section (per argon nucleus) in the variables, muon momentum and angle, as shown in figure 5, are in reasonable agreement with the model. The ArgoNeuT collaboration is extending this study to a characterization of the number of charged tracks and neutral pion decays associated with CC interactions. Also, a subset of these events will have a topology consistent with quasi-elastic interactions in the Argon nucleus.

3. LArTPC readout with CMOS preamplifiers at 87K

To achieve an optimized signal-to-noise ratio (S/N) in a multi-kiloton LArTPC, the preamplifiers are located as close as possible to the wire ends to minimize the preamplifier input capacitance, and are immersed in the liquid Argon at 87K to reduce the intrinsic noise of the front-end transistor. At liquid argon temperatures a CMOS transistor has a better performance, lower cost, smaller package, and is more readily available than the more commonly used JFET [5]. To confirm the expected improvement in S/N over warm electronics, cosmic-ray muon tracks were observed in a LArTPC readout with CMOS preamplifiers immersed in the liquid argon.

A small LArTPC built by Fermilab and used in earlier tests of warm preamplifiers, was reconfigured for the cold electronics test. The cylindrical drift cage is 50cm long, 25cm in diameter, with 3 planes of wires on a 4.8mm pitch, and wire directions $-60°$, $0°$, $+60°$. There are 50 wires in each plane, but the first wire (and last wire) is shorted to its neighbor to yield 48 readout channels.

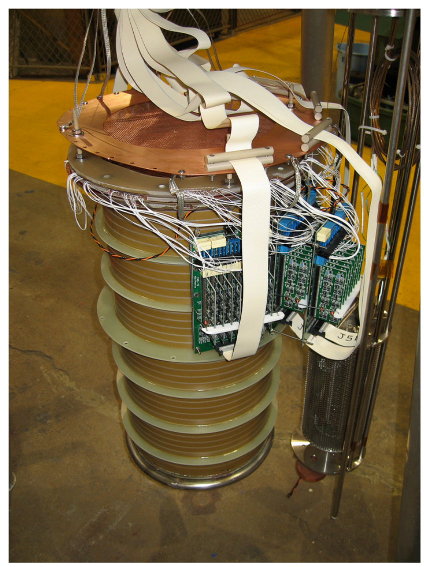

Figure 6. Shown is the cylindrical LArTPC drift cage with CMOS preamplifiers mounted near the wire planes.

Michigan State University (MSU) assembled 72 dual-channel hybrid preamplifiers designed for operation at 87K, using a CMOS transistor chip front-end configured as a charge integrator, followed by a combination of high and low pass filters characterized by a step-function response having a peaking time of about 2.4 microseconds [6]. Preamplifier motherboards (PMB) each carrying 8 dual-channel hybrids, were mounted on brackets, as shown in figure 6, as close as possible to the wire planes. The small diameter cryostat restricted the available space so that short insulated wires were required to connect each PMB to a TPC wire plane. After the cryostat is filled, all preamplifiers are totally immersed in the liquid argon.

Flat cables carried the output of each PMB above the liquid to a warm feedthrough. Cable drivers on the backside of the feedthrough drove signals to ADF2 digitizers [1] sampling at 5 MHz, 2048 samples/channel. Two small counters are located on either side of the cryostat. A muon trajectory through all 4 counters passed through the drift region of the LArTPC and generated a trigger for readout.

In about 1/3 of the triggers a clear muon track is seen crossing the active region of the LArTPC. Occasionally, there were two clear tracks, as shown in figure 7. The display labeled “A” is the 1st induction, “B” the 2nd induction, and “C” the collection plane. Each display exhibits the amplitude of the signal vs. drift-time on each of the 48 readout channels in that plane. The vertical axis is the channel number plus the amplitude/20, and therefore a signal of 20 counts would have an amplitude that just touches the baseline of the next highest wire number. The 120° between the A and C plane wires can cause some confusion. As a guide, short red lines mark the ends of the tracks in each 2D view. Also, each track is numbered (1 or 2) at a corresponding endpoint in time.

The signal to noise is clearly quite good. The noise RMS averages 0.53 counts, however there are large variations in the noise RMS between channels with the same gain. The gain was insufficient to raise the noise values to 1-2 counts where peculiarities of the ADC can’t affect the measurements. One such peculiarity is an asymmetry in the widths (in amplitude) leading to successive ADC counts. Therefore, only a preliminary estimate of the signal to noise can be made at this time.

One mm of track-length for a minimum ionizing particle generates very close to 1 fC of drifting electrons. The average collection plane signal seen here, corrected for its angle (typically 30°) with respect to the wire planes and angle (typically 18°) with respect to the coordinate axis of the collection plane, is about 18 counts, or 3.8 counts per mm of track length and 3.8 counts/fC. The RMS of 0.53 counts corresponds to an equivalent nose charge of about 870 electrons. In a wire chamber with a 5 mm pitch, as is envisioned for a future experiment [7], this would yield a S/N = 36, sufficient headroom for an unexpectedly large argon contamination leading to a significantly shortened electron lifetime. The cold CMOS preamplifiers

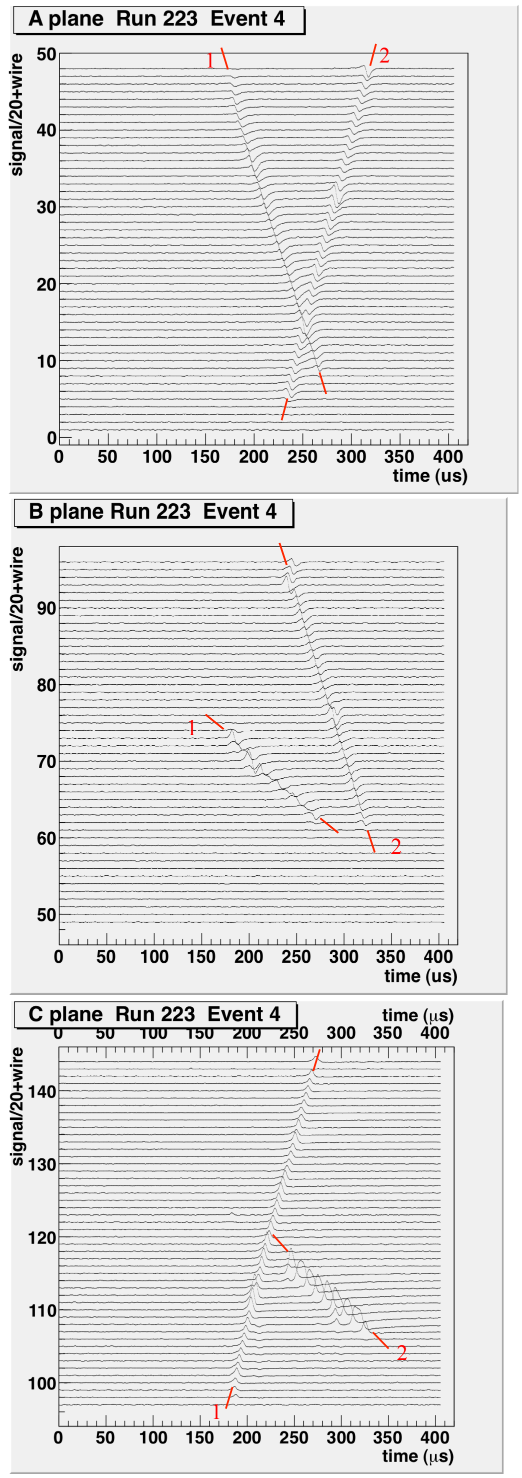

Figure 7. Shown are 3 views of a two-track event readout with cold CMOS preamplifiers. The vertical scale is the wire # plus the signal amplitude divided by 20. To guide the eye, red lines mark the ends of each numbered track, correlated by time.

provide a clear improvement over earlier tests of warm JFET preamplifiers, which had an equivalent noise charge (which is filter dependent) in the range 1200 – 1800 electrons. Tests with a gain increased by a factor of 4 are planned, and afterward, a more reliable S/N estimate will be available.

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