The ArgoNeuT and MicroBooNE Experiments at Fermi National Accelerator Laboratory

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Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) are imaging detectors that offer exceptional capabilities for studying neutrinos.

- The ArgoNeuT and MicroBooNE experiments, described in this talk, provide unique opportunities for interesting physics measurements and important LArTPC hardware development.
Liquid Argon Neutrino Detectors

- Ionization produced in neutrino interactions is drifted along E-field to highly segmented wireplanes.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.
- Calorimetry information is extracted from wire pulse characteristics.
- Copious scintillation light also available for collection and triggering.

Refs:
The ArgoNeuT Project

- ArgoNeuT (a.k.a. - Fermilab T962) deployed a ~175 liter LArTPC in Fermilab NuMI neutrino beam.
- Located directly upstream of MINOS near detector, which is used for full muon reconstruction and sign selection.
- Collected $1.35 \times 10^{20}$ Protons on Target (POT), predominantly in antineutrino mode.

NuMI Beam at Fermilab

MINOS Hall at Fermilab
ArgeoNeuT: Detector Details

Cryostat Volume  |  500 Liters
---|---
TPC Volume     |  175 Liters (90cm x 40cm x 47.5cm)
# Electronic Channels |  480
Electronics Style (Temp.) |  JFET (293 K)
Wire Pitch (Plane Separation) |  4 mm (4 mm)
Electric Field |  500 V / cm
Max. Drift Length (Time) |  0.5 m (330 μs)
Wire Properties |  0.15mm diameter BeCu

Refs:

1.) *The ArgeoNeuT detector in the NuMI low-energy beam line at Fermilab*, C. Anderson et al., arXiv:1205.6747
ArgoNeuT Data Event

• Not only is ArgoNeuT able to characterize vertex activity in CCQE-like events, it can also differentiate neutrinos from anti-neutrinos with the help of the MINOS near detector.

• Comparing neutrino and anti-neutrino CCQE-like events may provide some sensitivity to a possible multinucleon channel, involving 2p (2n) pre-FSI final states for neutrino (anti-neutrino) events.

ArgoNeuT is largely blind to neutrons!

Charged-Current Quasi-Elastic (CCQE) Candidate

\[ \nu_\mu \rightarrow \mu^-_{\text{pp}} \]

\[ \nu_\mu \rightarrow \mu^+_{\text{nn}} \]

ArgoNeuT + MINOS
• First Results: Using 2 weeks of neutrino-mode data \((8.5 \times 10^{18} \text{ POT})\), the differential cross-section for inclusive charged-current muon neutrino production was measured.

• Analysis Selection:
  ▶ Track originating within ArgoNeuT fiducial region.
  ▶ Match to corresponding track in MINOS near detector.
  ▶ MINOS track is negatively charged.

• First such measurement on Argon!

\[
\frac{\partial \sigma (u_i)}{\partial u} = \frac{N_{\text{measured},i} - N_{\text{background},i}}{\Delta u_i \epsilon_i N_{\text{targ}} \Phi}
\]
ArgoNeuT Physics

- Analyses in Progress:
  - Charged-Current Inclusive cross-section in antineutrino mode.
  - Charged-Current Quasi-Elastic exclusive analysis.
  - Stopping Protons to measure recombination behavior.
  - Hyperon Production
  - Initial measurements of dE/dx Particle ID effectiveness.

- Multinucleon Correlations, producing additional final-state activity, should be observable/measurable in ArgoNeuT.

![Graph of dE/dx vs residual range](image1)

**GEANT4 MC predictions**

- p
- k
- π
- μ

![Track length (cm)](image2)

* Data (9 events) vs theory: NIST Table

Refs:
1. Analysis of a Large Sample of Neutrino-Induced Muons with the ArgoNeuT Detector, C. Anderson et al., arXiv:1205.6702
The MicroBooNE Experiment

• MicroBooNE will operate in the Booster neutrino beam at Fermilab starting in early 2014.
• Combines timely physics with hardware R&D necessary for the evolution of LArTPCs.
  ‣ MiniBooNE low-energy excess
  ‣ Low-Energy neutrino cross-sections
  ‣ Cold Electronics (preamplifiers in liquid)
  ‣ Long drift (2.5m)
  ‣ Purity without evacuation.
MicroBooNE: Detector Details

- MicroBooNE will be located in new Liquid Argon Test Facility (LArTF), just upstream of MiniBooNE location.

- Building construction is well underway.
MicroBooNE: Detector Details

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<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Cryostat Volume</td>
<td>150 Tons</td>
</tr>
<tr>
<td>TPC Volume (l x w x h)</td>
<td>89 Tons (10.4m x 2.5m x 2.3m)</td>
</tr>
<tr>
<td># Electronic Channels</td>
<td>8256</td>
</tr>
<tr>
<td>Electronics Style (Temp.)</td>
<td>CMOS (87 K)</td>
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<tr>
<td>Wire Pitch (Plane Separation)</td>
<td>3 mm (3mm)</td>
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<tr>
<td>Max. Drift Length (Time)</td>
<td>2.5m (1.5ms)</td>
</tr>
<tr>
<td>Wire Properties</td>
<td>0.15mm diameter SS, Cu/Au plated</td>
</tr>
<tr>
<td>Light Collection</td>
<td>~30 8” Hamamatsu PMTs</td>
</tr>
</tbody>
</table>

Collection Plane Wire Assembly

TPC

Teppei Katori and MicroBooNE PMTs: IUPAP Young Scientist Prize Winner. See his talk on Tue., July 10!
Address the MiniBooNE low energy excess

- MiniBooNE is a Cerenkov detector that looks for $\nu_e$ appearance from a beam of $\nu_\mu$.
- Does MicroBooNE confirm the excess?
- If confirmed, is the excess due to an electron-like or gamma-like process?

### MiniBooNE $\nu_e$ Appearance Result

**MiniBooNE Result Excess**

(200-475 MeV)

- Neutrino: $128.8 \pm 43.4$ events
- AntiNeutrino: $57.9 \pm 21.6$ events

Refs:
2.) *Updated Oscillation Results from MiniBooNE*, Chris Polly, Neutrino2012 Presentation
MicroBooNE: Physics

• Prove effectiveness of electron/gamma separation technique (e.g. - using dE/dX information), and exploit to characterize any observed MiniBooNE-like “low-E” excess signals.
• Low Energy Neutrino Cross-Section Measurements: CCQE, NC π⁰, Δ→Nγ, etc...
• Study backgrounds relevant for Proton Decay searches in larger detectors (e.g. - Kaon production), and develop SuperNova analysis capabilities.
• Probe the Strange Quark content of Proton.
• Continue development of automated reconstruction (building on ArgoNeuT’s effort).

Example CCQE νₑ event simulated in MicroBooNE Collection Plane (zoomed in view)
Conclusions

- LArTPCs are powerful detectors for studying neutrinos.
- ArgoNeuT data analysis is ongoing. First results published, and we will have more results later this year using full data sample.
- MicroBooNE construction is in progress, and operations will begin in early 2014. MicroBooNE will carry out an extensive physics program, including search for MiniBooNE low-energy excess.
Analysis of this high statistics sample of minimum ionizing tracks demonstrates the reliability of focusing on the complete kinematic reconstruction of neutrino-induced throughgoing muons tracks. Reconstructing the muon from these interactions is imperative for these measurements. This paper presents a unique opportunity to measure neutrino cross sections in the 1-2 GeV energy range. Fully operating from September 711- to February 712, during which thousands of neutrino and antineutrino events were recorded, ArgoNeuT operated in the NuMI low-energy beam line directly upstream of the MINOS Near Detector. Though ArgoNeuT is primarily a R&D project, the data collected provide a unique opportunity to verify the predictions of the Standard Model of particle physics and to search for new physics beyond the Standard Model.
Back-Up Slides
Why Noble Liquids for Neutrinos?

- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified (<0.1ppb), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble liquids are dense, so they make a good target for neutrinos.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects.

<table>
<thead>
<tr>
<th></th>
<th>He</th>
<th>Ne</th>
<th>Ar</th>
<th>Kr</th>
<th>Xe</th>
<th>Water</th>
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<tbody>
<tr>
<td>Boiling Point [K] @ 1atm</td>
<td>4.2</td>
<td>27.1</td>
<td>87.3</td>
<td>120.0</td>
<td>165.0</td>
<td>373</td>
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<tr>
<td>Density [g/cm³]</td>
<td>0.125</td>
<td>1.2</td>
<td>1.4</td>
<td>2.4</td>
<td>3.0</td>
<td>1</td>
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<tr>
<td>Radiation Length [cm]</td>
<td>755.2</td>
<td>24.0</td>
<td>14.0</td>
<td>4.9</td>
<td>2.8</td>
<td>36.1</td>
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<tr>
<td>dE/dx [MeV/cm]</td>
<td>0.24</td>
<td>1.4</td>
<td>2.1</td>
<td>3.0</td>
<td>3.8</td>
<td>1.9</td>
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<tr>
<td>Scintillation [γ/MeV]</td>
<td>19,000</td>
<td>30,000</td>
<td>40,000</td>
<td>25,000</td>
<td>42,000</td>
<td></td>
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<tr>
<td>Scintillation λ [nm]</td>
<td>80</td>
<td>78</td>
<td>128</td>
<td>150</td>
<td>175</td>
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MicroBooNE: TPC

- TPC has 3 instrumented wireplanes (Two Induction at +/-60 from vertical, One Collection with vertical wires).
- Cathode is held at -125kV, setting up 500V/cm drift field.
- Wires are individually terminated around brass ferrules, then positioned on wire carriers.

Schematic of MicroBooNE TPC

Prototype wires and wire carrier boards.
• CMOS preamplifiers located in liquid, attached to TPC.
• 12-bit ADCs sampled at 2MHz (i.e. - 500ns per sample) for 4.8ms (x3 drift window).
• 1-hour data buffering for Supernova detection signal from SNEWS.
MicroBooNE: Cryogenics

- Cryogenic system consists of filters/pumps/etc... for circulating and purifying LAr.
- Cryostat is evacuable (though the plan is not to evacuate) and foam insulated.

Schematic of MicroBooNE Layout

LAPD @ Fermilab
Nuclear effects can alter final-state topology.

ArgoNeuT can see ~50 MeV protons, so “vertex activity” readily observed.