Status of the ArgoNeuT and MicroBooNE Experiments

Mitch Soderberg
on behalf of the ArgoNeuT and MicroBooNE collaborations
Recontres du Vietnam Flavour Conference
Introduction

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

- I will give a brief overview of recent LArTPC activities in the U.S., focusing on the ArgoNeuT and MicroBooNE experiments at Fermilab.

- These near-term activities are helping to bring the LArTPC technology to maturity for use in future long-baseline and short-baseline programs.
Neutrino Interactions

- Neutrino experiments that will search for CP-violation are operating in an energy-regime where several competing processes are active.

- Nuclear targets in these experiments (e.g. - Carbon, Argon, Oxygen, etc…) introduce complications that can skew picture of observed interactions.
Why Liquid Argon for Neutrinos?

- Bubble chamber quality images combined with calorimetry.
- Scalable to largest sizes necessary for neutrino CP-violation searches.

![ArgoNeuT Event](image_url)

The 'Neutrino Event'

![12-foot bubble chamber @ Argonne National Laboratory](image_url)
Liquid Argon Neutrino Detectors

Neutrino Interaction in ArgoNeuT

Pixel size:
4mm x 0.3mm

Drift Coordinate →

~96cm

Color is proportional to amount of charge collected
ArgoNeuT

- LArTPC operated in Fermilab’s NuMI neutrino beam.
- Located upstream of MINOS near detector, which provides muon reconstruction and sign selection.
- Collected $1.35 \times 10^{20}$ Protons on Target (POT).

<table>
<thead>
<tr>
<th>Parameter</th>
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<tr>
<td>Cryostat Volume</td>
<td>500 Liters</td>
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<tr>
<td>TPC Volume</td>
<td>175 Liters (90cm x 40cm x 47.5cm)</td>
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<td># Electronic Channels</td>
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<td>Electronics Style (Temp.)</td>
<td>JFET (293 K)</td>
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<tr>
<td>Electric Field</td>
<td>500 V/cm</td>
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<td>Max. Drift Length (Time)</td>
<td>0.5 m (330 μs)</td>
</tr>
<tr>
<td>Wire Properties</td>
<td>0.15mm diameter BeCu</td>
</tr>
</tbody>
</table>

Refs:
• “Standard candle” measure of inclusive charged-current cross-sections have been performed using both antineutrinos and neutrinos. First time ever on argon target.
• Helps establish performance of our evolving reconstruction tools.

![Graphs showing measurements of inclusive muon neutrino and antineutrino charged current differential cross sections on argon in the NuMI antineutrino beam.](image)

**FIG. 1:** The measured differential cross-sections in muon (top) angle and (bottom) momentum.

**FIG. 2:** The measured differential cross-sections in muon (top) angle and (bottom) momentum.

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“Standard candle” measure of inclusive charged-current cross-sections have been performed using both antineutrinos and neutrinos. First time ever on argon target. Helps establish performance of our evolving reconstruction tools.

Ref:
Multiplicty of protons in charged-current events with 0 pions in final state can help tune nuclear modeling.

Ref:

1.) The detection of back-to-back proton pairs in Charged-Current neutrino interactions with the ArgoNeuT detector in the NuMI low energy beam line, R. Acciarri et al, Phys. Rev. D 90, 012008 (2014)

2.) First Measurement of Neutrino and Antineutrino Coherent Charged Pion Production on Argon, R. Acciarri et al, paper in progress
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The granularity of the LArTPC allows seeing actual final state interaction vertex.

Observing proton multiplicities...

A. M. Szelc, Neutrino 2014, Boston 2

The detection of back-to-back proton pairs in Charged-Current neutrino interactions with the ArgoNeuT detector in the NuMI low energy beam line, events with 0 pions in final state can help.....

Small energy transfer to the nucleus:

Microscopic Models

PCAC Models

nucleus stays in the ground state.

forward going • excitation of the

Valid for high neutrino energies, used in all neutrino generator......

P LArTPC enabled,

P • µ
e

Rein-Seghal, Berger-Sehgal, Schalla-Paschos

New, Alvarez-Ruso, Hernandez, Nieves, Nakamura

signal by the BDT is show in Figure 1.

minimised by smearing the training data. An

nation power and the dependance of the BDT

the muon and pion tracks is overlapping. The

track. The last of these parameters was added

stopping power of the first third of the muon

from the TPC's calorimetry, the reconstructed

variate Analysis [21] was used to create a

candidate events. This event sample contains

data yields 30 antineutrino and 24 neutrino

pion interacts with the argon nucleus.

lapping tracks or complex topologies when the

track reconstruction ine

• other effects can also produce multiple protons)

First measurement of charged-current coherent pion production on argon target.

Ref:
1.) The detection of back-to-back proton pairs in Charged-Current neutrino interactions with the ArgoNeuT detector in the NuMI low energy beam line, R. Acciarri et al, Phys. Rev. D 90, 012008 (2014)
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Particle ID of electrons vs. photons relies on ability to see displaced vertices, and to reconstruct energy at beginning of shower. ArgoNeuT is developing this technique using a small data sample.
ArgoNeuT: Physics

- Excellent resolution allows direct measurement of Hyperon production in neutrino interactions.
- Due to ArgoNeuT’s small size, statistics are very limited and containment is a problem, but several candidates are observed.

Muon is not the only primary track

Event with Displaced Vertex in ArgoNeuT Data

Muon Matched with MINOS with +1 charge

Motivation

- Charge Current Quasi-Elastic (CCQE) Hyperon Production is the Simplest $\nu_{\mu}\mu\Lambda N$ Process after CCQE Neutron Production
- Existing Experimental Data on Hyperon Production via CCQE scattering with anti-neutrinos is Sparse
- CCQE Hyperon Production will have Different Nuclear Response than CCQE Neutron Production due to the absence of Pauli effects for the Hyperons
- LArTPC can SEE a Hyperon. Other Coarser Grained Detectors Probably Cannot
- Much of the ArgoNeuT Data is in $\nu_{\mu\mu}\Lambda$ Mode

\[
\bar{\nu}_\mu + p \rightarrow \mu^+ + \Lambda^0
\]

\[
\Lambda^0 \rightarrow \pi^+ + p
\]

\[
\bar{\nu}_\mu \rightarrow \mu^+ + \Lambda^0, \Sigma^0
\]
The MicroBooNE Experiment

- MicroBooNE will operate in the Booster neutrino beam at Fermilab.
- Combines physics with hardware R&D necessary for the evolution of LArTPCs.
  - MiniBooNE low-energy excess
  - Low-Energy (<1 GeV) neutrino cross-sections
  - Cold Electronics (preamplifiers in liquid)
  - Long drift (2.5m)
  - Purity without evacuation.

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<td>89 Tons (10.4m x 2.5m x 2.3m)</td>
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<td>8256</td>
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<td>Max. Drift Length (Time)</td>
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<tr>
<td>Light Collection</td>
<td>30 8” Hamamatsu PMTs</td>
</tr>
</tbody>
</table>

Refs:
1.) Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines, H. Chen et al., FERMILAB-PROPOSAL-0974
MicroBooNE Installation: June 2014
MiniBooNE: Physics

- Address the “low energy excess” seen by the MiniBooNE experiment.
  - 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 Antineutrino and Neutrino Events](image)

**MiniBooNE $\nu_e$ Appearance Result Excess**
- AntiNeutrino: $78.4 \pm 28.5$ events (200-1250 MeV)
- Neutrino: $162.0 \pm 47.8$ events (200-475 MeV)

Refs:
2. Improved Search for $\nu_\mu \rightarrow \nu_e$ Oscillations in the MiniBooNE Experiment MiniBooNE Collaboration, Phys. Rev. Lett. 110, 161801 (2013)
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.

• Tremendous ongoing progress in development of LArTPC technology, driven by “small” efforts like ArgoNeuT and MicroBooNE.

• Next few years should be very exciting as MicroBooNE come online.

• Informed by these ongoing activities, future massive (~kiloTon) LArTPCs offer potential for discovering CP-violation in neutrino sector, and short-baseline experiments will search for sterile neutrinos.
Thank you!

ArgoNeuT Collaboration

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The University of Texas at Austin
C. Adams, E. Church, B. Fleming, E. Klein, K. Partyka, J. Spitz, A. Szec
Yale University

MicroBooNE Collaboration + Project Team

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Yale University: C. Adams, E. Church, B. Fleming, E. Gramellini, A. Hackenburg, B. Russell, A. Szec
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>
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<th>He</th>
<th>Ne</th>
<th>Ar</th>
<th>Kr</th>
<th>Xe</th>
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<tr>
<td>dE/dx [MeV/cm]</td>
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<td>78</td>
<td>128</td>
<td>150</td>
<td>175</td>
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</tbody>
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2012 PDG

- ANL, PRD 19, 2521 (1979)
- BEBC, ZP C2, 187 (1979)
- BNL, PRD 25, 617 (1982)
- CCFR (1997 Seligman Thesis)
- CDHS, ZP C35, 443 (1987)
- GGM-PS, PL 84B (1979)
- IHEP-ITEP, SJNP 30, 527 (1979)
- IHEP-JINR, ZP C70, 39 (1996)
- MINOS, PRD 81, 072002 (2010)
- NOMAD, PLB 660, 19 (2008)
- NuTeV, PRD 74, 012008 (2006)
- SciBooNE, PRD 83, 012005 (2011)
- SKAT, PL 81B, 255 (1979)

- First Results: Using 2 weeks of neutrino-mode data (8.5×10^{18} 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.

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

Refs:
2.) Neutrino cross section measurements, J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)
2012 PDG

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**MicroBooNE TPC (Nov. 2013)**

**TPC Wires**