Prospects for Making the First Neutrino Interaction Measurements on Argon at Low Energy with MicroBooNE

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Why Neutrino Interactions On Argon at Low Energy?

LAr targets in the current generation of neutrino and dark matter experiments.

- Low energy (~1 GeV) neutrino interactions in LAr give physics signals (time projection chambers, scintillation) for ν physics
- Contributes understanding of nuclear effects, nucleon structure. Improves models used for more science.
LAr TPC Detector

• 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.

**Choice of Argon**

- Lots of ionization & scintillation light
- When purified (<0.1 ppb), long ionization drift distances
- Excellent dielectric properties (very large voltages)

<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]</td>
<td>4.2</td>
<td>27.1</td>
<td>87.3</td>
<td>120.0</td>
<td>165.0</td>
<td>373</td>
</tr>
<tr>
<td>@ 1atm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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</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>
</tr>
<tr>
<td>[cm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction Length</td>
<td>568.4</td>
<td>82.22</td>
<td>85.77</td>
<td>61.80</td>
<td>58.29</td>
<td>83.33</td>
</tr>
<tr>
<td>[cm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>Scintillation λ [nm]</td>
<td>80</td>
<td>78</td>
<td>128</td>
<td>150</td>
<td>175</td>
<td></td>
</tr>
</tbody>
</table>

- Dense noble liquids - ν good target
- Relatively cheap (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects

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MicroBooNE Goals

Physics

• Investigate MiniBooNE low-E $\nu_e$ excess
• Measure low-energy cross sections and particle multiplicities on argon

LAr TPC R&D

• Cold, submerged preamplifiers
• High voltage system
• LAr recirculation & purification
• Long-drift reconstruction for $\nu$-induced events
MiniBooNE investigated LSND result: 
\((ν_μ \rightarrow ν_e)\) consistent with \(Δm^2 \sim 1\,eV^2\).

\[
P(ν_μ \rightarrow ν_e) = \sin^2 2θ \sin^2 (1.27 \frac{Δm^2 L}{E})
\]

\[
Δm_{\text{solar}}^2 \sim 10^{-5}\,eV^2 \quad Δm_{\text{atm}}^2 \sim 10^{-5}\,eV^2
\]
Observed 200-475 MeV excess in $\nu_e$-type events

Similar L/E as LSND

Allowed $\Delta m^2$, $\sin^2(2\theta)$ regions overlap with LSND

Also: Nature of low-E events?
Detector Technology

Some efficiency even below Cherenkov threshold

\[ e/\gamma \quad p \quad \mu \quad \pi^0 \rightarrow \gamma\gamma \]


NuFact 2013, Beijing
Detector Technology

dE/dx at shower vertex distinguishes $e$ (1 MIP) from $e^+e^-$ (2 MIPs)
### MicroBooNE: Stats

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cryostat Volume</strong></td>
<td>170 Tons</td>
</tr>
<tr>
<td><strong>TPC Volume (l x w x h)</strong></td>
<td>89 Tons (10.4m x 2.5m x 2.3m)</td>
</tr>
<tr>
<td><strong># Electronic Channels</strong></td>
<td>8256</td>
</tr>
<tr>
<td><strong>Electronics Style (Temp.)</strong></td>
<td>CMOS (87 K)</td>
</tr>
<tr>
<td><strong>Wire Pitch (Plane Separation)</strong></td>
<td>3 mm (3mm)</td>
</tr>
<tr>
<td><strong>Max. Drift Length (Time)</strong></td>
<td>2.5m (1.5ms)</td>
</tr>
<tr>
<td><strong>Wire Properties</strong></td>
<td>0.15mm diameter SS, Cu/Au plated</td>
</tr>
<tr>
<td><strong>Light Collection</strong></td>
<td>32 8” Hamamatsu PMTs</td>
</tr>
</tbody>
</table>
MicroBooNE PMTs

32 PMTs viewing LAr through TPB-coated, wavelength-shifting plates

LAr scintillation ~ 128 nm

More than triggering: Precise timing & important location information
Laser Calibration

Nd:YAG (1064nm) $\Rightarrow$ 266 nm wavelength
Perfectly straight ion tracks through the detector.
Calibrates the electric field

- 10 Hz max. pulse rate
- 60 mJ max
- 4-6 ns pulse width
- 0.5 mrad divergence
Laser Calibration

View from one laser port into TPC
MicroBooNE Cryostat

Jason St. John  
NuFact 2013, Beijing
Assembled TPC test-fitted in cryo vessel with PMTs in place
Cryovessel Design & Support

Not shown: 18” spray-applied foam insulation jacket
Custom-engineered foam cradle will support cryovessel

In place here at the LAr Testing Facility
Justin Tillman has been putting a lot of effort into modeling the piping and the enclosure.

Building work is 95% complete.

Piping work is 80% complete.

Shop drawings can be made once the 3D design is done.

Lab F is being cleaned out to make room for cryogenic piping construction.
MicroBooNE

Completed facility looks just like the drawings!

Roof opens for crane to lower cryovessel into place.
Filtered LAr Cryosystem

Purity monitors in vessel and LAr cryo recirculation system

A truck holds ~3500 gallons of LAr. The cryostat: 38,000 gallons
Cross Section Measurements

- Crucial inputs to oscillation measurements
- \( \sigma \nu \) historically not well known in the energy range we care about
- New measurements demonstrate importance of nuclear effects
  - MiniBooNE results a major driver here
  - MicroBooNE probes the same energy region with a more capable detector.
    - Superior resolution and PID
    - \( \mathbf{p} \) reconstructable with kinetic energy as low as 20 MeV

After almost 10 years of FNAL Booster Neutrino Beam operation, flux is well characterized*. Positions MicroBooNE to make expeditious cross section measurements

Cross Section Measurements

Final-state interactions (pion absorption, charge exchange, re-scattering) very important to get right!

$$\nu_\mu + {}^{40}\text{Ar} \rightarrow \mu^- + p + p + n + p$$

Simulated MicroBooNE data

$$\nu_e + {}^{40}\text{Ar} \rightarrow e^- + p + p + \pi^0 + p$$

Estimated for 60-ton TPC

$6.6 \times 10^{20}$ protons on target
**Cross Section Measurements**

Multiple competing processes we need to understand in this region.

MicroBoone’s ability to discriminate particle ID crucial to advancing this understanding.

Rev. Mod. Phys. 84, 13007 (2012)
Summary

On course to fill with LAr in early 2014
Use cosmics to demonstrate cold, submerged preamplifiers and long-drift reconstruction

Begin measuring low energy cross sections

With $\sim 6.6 \times 10^{20}$ POT, expect to address MiniBooNE low-E excess (and a history of $L/E \sim 1$ measurements)

Look for results in the coming year!
Thank You!
更多?
LAr Hydrodynamics

Flow affects temperature & purity variations

Important to know where Ar$^+$ may pool (cosmic and beam contributions)
LAr purity affected by surfaces in the ‘warm’ gas region.
Laser Calibration

Multiphoton ionization

- $\lambda = 266$ nm correspond to $E_\gamma = 4.67$ eV
- For ionization $\sim 14$ eV are needed
- For non-resonant states the lifetime is given by
  \[ \tau_\gamma = \frac{\lambda}{2\pi c} = 1.4 \times 10^{-16} \text{s} \]
- For quasi-resonant states one has
  \[ \tau_\gamma \propto \frac{1}{\Delta E} = \frac{1}{(E_i - E_\gamma)} \]
- The laser has to have enough intensity to allow a three-photon ionization

See also: B. Rossi et al. 2009 JINST 4 P07011
I. Badhrees et al. 2010 New J. Phys. 12 113024
dE/dx at shower vertex distinguishes $e^-$ (1 MIP) from $e^+e^-$ (2 MIPs)
Induction and conduction channels have distinct time profiles in response to drifted charge.
Resonant hadron production with some visible nuclear detritus

\[ \nu_e \text{ Ar} \rightarrow e^+ \pi^- \pi^+ p n \]
**MicroBooNE: Projective Geometries**

Drift direction $x$ common to all 3 views
Projected angles and distances differ
Makes 3D reconstruction possible

Drift $e^-$ in the $-x$ direction
MiniBooNE: Context & Motivation

Observed 200-475 MeV excess in $\nu_e$-type events

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<table>
<thead>
<tr>
<th>Production Mode</th>
<th># Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC QE ($\nu_\mu n \rightarrow \mu^- p$)</td>
<td>60,161</td>
</tr>
<tr>
<td>NC elastic ($\nu_\mu N \rightarrow \nu_\mu N$)</td>
<td>19,409</td>
</tr>
<tr>
<td>CC resonant $\pi^+$ ($\nu_\mu N \rightarrow \mu^- N \pi^+$)</td>
<td>25,149</td>
</tr>
<tr>
<td>CC resonant $\pi^0$ ($\nu_\mu n \rightarrow \mu^- p \pi^0$)</td>
<td>6,994</td>
</tr>
<tr>
<td>NC resonant $\pi^0$ ($\nu_\mu N \rightarrow \nu_\mu N \pi^0$)</td>
<td>7,388</td>
</tr>
<tr>
<td>NC resonant $\pi^+$ ($\nu_\mu N \rightarrow \nu_\mu N' \pi^+$)</td>
<td>4,796</td>
</tr>
<tr>
<td>CC DIS ($\nu_\mu N \rightarrow \mu^- X, W &gt; 2$ GeV)</td>
<td>1,229</td>
</tr>
<tr>
<td>NC DIS ($\nu_\mu N \rightarrow \nu_\mu X, W &gt; 2$ GeV)</td>
<td>456</td>
</tr>
<tr>
<td>NC coherent $\pi^0$ ($\nu_\mu A \rightarrow \nu_\mu A \pi^0$)</td>
<td>1,694</td>
</tr>
<tr>
<td>CC coherent $\pi^+$ ($\nu_\mu A \rightarrow \mu^- A \pi^+$)</td>
<td>2,626</td>
</tr>
<tr>
<td>NC kaon ($\nu_\mu N \rightarrow \nu_\mu K X$)</td>
<td>39</td>
</tr>
<tr>
<td>CC kaon ($\nu_\mu N \rightarrow \mu^- K X$)</td>
<td>117</td>
</tr>
<tr>
<td>Other $\nu_\mu$</td>
<td>3,678</td>
</tr>
<tr>
<td>Total $\nu_\mu$ CC</td>
<td>98,849</td>
</tr>
<tr>
<td>Total $\nu_\mu$ NC+CC</td>
<td>133,580</td>
</tr>
<tr>
<td>$\nu_e$ QE</td>
<td>326</td>
</tr>
<tr>
<td>$\nu_e$ CC</td>
<td>657</td>
</tr>
</tbody>
</table>
Quasi-Elastic cross sections show some tension in RFG model, dipole form-factor approximation.

MicroBooNE can shed light on this, too, with an Ar target, tagging hadrons produced to improve available data.