Status of the MicroBooNE Experiment

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Outline

- Motivations
- MicroBooNE LArTPC
- Physics Goals
- Detector Performance
- Recent Results
- Conclusions
Short Baseline Oscillation $\nu_\mu \to \nu_e$ Anomalies

LSND (Liquid Scintillator Neutrino Detector):

Looking for an electron appearance signal in a $\nu_\mu$ beam.

$E_\nu = 20 - 55$ MeV
Baseline = 30 m

MiniBooNE Result:

Neutrino mode:
- Excess: $162.0 \pm 47.8$ (3.4$\sigma$)

Antineutrino mode:
- Excess: $78.4 \pm 28.5$ (2.8$\sigma$)

Combined:
- Excess: $240.3 \pm 34.5 \pm 53.6$
- 3.8$\sigma$ significance

Excess of low energy electromagnetic events in neutrino and antineutrino mode.

But MiniBooNE can’t differentiate between electrons and gammas!
Fermilab’s Booster Neutrino Beam (BNB)

Linac
- Length: 150m
- Proton Energy: 400 MeV

Booster
- Circumference: 468m
- Proton Energy: 8 GeV

Fermilab’s low-energy neutrino beam
\[ \langle E_{\nu} \rangle \approx 700 \text{ MeV} \]
Short Baseline Neutrino (SBN) Program

**Linac**
- Length: 150m
- Proton Energy: 400 MeV

**Booster**
- Circumference: 468m
- Proton Energy: 8 GeV

**Protons**
- 476 tons
- 89 tons
- 112 tons

**Neutrinos**
- ICARUS-T600
- MicroBooNE
- Short Baseline Near Detector (SBND)

Dedicated Talk on SBN Program by Matt Bass in next session!
The MicroBooNE LArTPC

LArTPC provides Excellent Resolution and Calorimetry!

* **Liquid Argon Time Projection Chamber:**
  - Three planes of wire at 3mm pitch
    - One Collection plane at $0^\circ$ from vertical
    - Two induction planes at $\pm 60^\circ$
  - Total 8256 channels
  - 2.5 m drift length

* **Optical System:**
  - 32 cryogenic photomultiplier tubes (PMT)
  - LED based light injection system

* **UV Laser Calibration System**

* **External Muon Tagger System**

* 170 tons of purified LAr (active mass ~89 tons)
First $\nu$ Interactions from BNB

Fully automated event selection – first time for LArTPCs

Collection plane view

Run 3493 Event 41075, October 23rd, 2015
Case 1: The neutral $\gamma (\pi^0)$ is observed as a gap between vertex and EM shower or between showers.

Case 2: If the gap is too small to be observed, the charge at the start of the shower can be reconstructed through a measurement of $dE/dx$. 

Decay of a 1 GeV $\pi^0$ to two photons.
**Physics Goals**

- MiniBooNE low energy excess of electron-like events
- Cross-section measurement in ~1 GeV range
- Understanding nuclear effects
- Exotics and non-beam physics

**Detector R&D**

- Cold front end analog Electronics
- LAr fill without evacuation (gas argon purge)
- Challenges with near surface operation
- Data Handling
- UV laser calibration system

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**Neutrinos interacting with nucleons**

Lots of interesting (nuclear) physics over all energy ranges.

Many open questions need experimental & theoretical input!

MicroBooNE: perfect to explore the QE regime!

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**See next talk by Xiao!**
Detector Performance & Data Taking
Purity Monitor is a drift chamber installed in the cryostat that measures the fraction of charge detected at its anode relative to its cathode, $Q_A/Q_C$

**MicroBooNE-NOTE-1003-PUB.pdf**
MicroBooNE DAQ and Fermilab Booster Neutrino beam are running extremely well!
Some Recent Results
TPC Noise Filtering

Wire Noise Level in MicroBooNE

PSNR: Peak Signal to Noise RMS

* Software noise filter is applied which improves peak-signal-to-noise ratio by a factor of 2

* Results in $\text{ENC} < 400 \text{ e}^-$ for longest wires
Challenges in TPC Signal Calibration:

* Noise Filtering
* Dynamic Induced Charge
* Field Response Calibration

Exercised Two-dimensional deconvolution technique to extract number of ionized electronics from wire planes
Michel Electrons from Cosmic data

Tons of cosmic in data due to detector being at surface!

* Ideal to study detector’s response to electrons in the tens of MeV energy scale and further develop reconstruction
* Michel electron identified by Bragg peak and kink in the track
* Constant lifetime and recombination correction
* Preliminary calibration using charge injection calibration pulse
* Missing energy from radiated photons accounts for spectral distortions
• Reconstruct tracks and vertices from hit clusters in the different wire plane views

• Interaction time ($t_0$) from PMTs or beam timing used to determine drift coordinate

• Reconstruct data one full drift window after the trigger and in pre-drift and post-drift windows for cosmic rejection

Reconstructed cosmic tracks in MicroBooNE data (assuming $t_0 = t_{\text{trigger}}$)
• Track reconstruction tested by running on cosmic data and MC generated with CORSIKA

• Simulation contains a list of known bad channels, which are masked in data and MC

• Able to reconstruct tracks in regions where only 2 out of 3 wire planes are active with reasonable agreement in data and MC
MicroBooNE is the first and key component of Short Baseline Program and is an important test bed for future multi-kaon LArTPC detectors:
- Address MiniBooNE excess and neutrino-Ar cross section measurement
- Innovation in technology
  - Design, manufacture and use of cold electronics
  - Fill without evacuating
  - Long drift length (HV and purity)
  - Automated reconstruction and improvement in simulation

www-microboone.fnal.gov/publications/publicnotes/index.html
Poster Presentations from MicroBooNE at ICHEP!


Elena Gramellini, Varuna Meddage: A MC study of Kaon Identification Sensitivity in MicroBooNE

Aleena Rafique: Charged Particle Multiplicity Analysis for Cross Section Measurement with the MicroBooNE Detector

Michael Mooney: Characterising LArTPC detector performance with MicroBooNE

Ryan Grosso: Neutral Current Pi0 interactions in MicroBooNE
Thanks!

MicroBooNE Collaboration

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144 collaborators
28 institutions (6 non-U.S.)
35 postdocs
37 graduate students

*spokespeople
* Since 1998 observation of non-zero neutrino mass, neutrino oscillations phenomenon is of great interest

* The oscillations depend on the energy of the neutrinos and the distance they travel

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta_{ij} \times \sin^2 \left( 1.27 \Delta m^2_{ij} \frac{L}{E} \right)$$

The mixing angle, $\theta$, determines the amplitude of the oscillation. $\Delta m^2$ determines the shape of the oscillation as a function of L (or E)

Atmospheric & Long-baseline accelerator neutrinos

$$L/E = 500 \text{ km/GeV}$$
$$\Delta m^2_{atm} = 2.43^{+0.13}_{-0.13} \times 10^{-3} \text{eV}^2$$

$$\begin{pmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{pmatrix} = 
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \theta_{23} & \sin \theta_{23} \\
0 & -\sin \theta_{23} & \cos \theta_{23}
\end{pmatrix} 
\begin{pmatrix}
\cos \theta_{13} & 0 & \sin \theta_{13} e^{-i\phi} \\
0 & 1 & 0 \\
-\sin \theta_{13} e^{i\phi} & 0 & \cos \theta_{13}
\end{pmatrix} 
\begin{pmatrix}
\cos \theta_{12} & \sin \theta_{12} & 0 \\
-\sin \theta_{12} & \cos \theta_{12} & 0 \\
0 & 0 & 1
\end{pmatrix} 
\begin{pmatrix}
\nu_1 \\
\nu_2 \\
\nu_3
\end{pmatrix}$$

3 Neutrino flavor states

Solar & Long-baseline reactor neutrinos

$$L/E = 15,000 \text{ km/GeV}$$
$$\Delta m^2_{sol} = 7.59^{+0.20}_{-0.21} \times 10^{-5} \text{eV}^2$$

Neutrino as a function of L/E
Excellent Resolution and Calorimetry!

**Why argon?**
- Ionization charge can move through macroscopic distances
- High Scintillation yield (40,000 γ/MeV)
- Argon is rather cheap and abundant in nature
- Dense detectors can be made (1.4 g/cm³)

* Ionization electrons detected by a series of wire planes
  - Particle Identification, calorimetry and tracking

* Scintillation light collection system
  - Trigger and t₀ reconstruction
TPC Noise during Cool down and Fill

Time Dependence of Noise in TPC

- Error bars represent the standard deviation of RMS noise over all collection plane wires.

Date

Avg. RMS Noise on Collection Plane Wires [ENC]

2015-05-18
2015-05-23
2015-05-28
2015-06-02
2015-06-07
2015-06-12
2015-06-17
2015-06-22
2015-06-27
2015-07-02

Filling with LAr Begins
TPC Pipes

Successfully passed the CD4 review!

Three wire planes

273 V/cm