Status of the MicroBooNE Neutrino Oscillation Experiment

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Aspen 2016
January 16, 2016
MicroBooNE is a neutrino experiment at Fermilab

- A 170 ton liquid argon time-projection chamber (LArTPCS)
- sits 470 m from start of the Booster Neutrino Beam — a mostly muon neutrino beam
MicroBooNE Goals

- Investigate the nature of the MiniBooNE excess
- Measure neutrino-argon cross sections
- Perform R&D for future LArTPCs, in particular DUNE (a long-baseline oscillation experiment which will look for CP violation)

cryostat at home at LArTF
Neutrino Anomalies

MiniBooNE one of several experiments to report an excess or deficit of events

Anomalies seen in several kinds of experiments

One possible interpretation: ~eV² oscillations with sterile neutrinos

<table>
<thead>
<tr>
<th>Experiment name</th>
<th>Type</th>
<th>Oscillation channel</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSND</td>
<td>Low energy accelerator</td>
<td>muon to electron (antineutrino)</td>
<td>3.8σ</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>High(er) energy accelerator</td>
<td>muon to electron (antineutrino)</td>
<td>2.8σ</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>High(er) energy accelerator</td>
<td>muon to electron (neutrino)</td>
<td>3.4σ</td>
</tr>
<tr>
<td>Reactors</td>
<td>Beta decay</td>
<td>electron disappearance (antineutrino)</td>
<td>1.4-3.0σ (varies)</td>
</tr>
<tr>
<td>GALLEX/SAGE</td>
<td>Source (electron capture)</td>
<td>electron disappearance (neutrino)</td>
<td>2.8σ</td>
</tr>
</tbody>
</table>
A little background on MiniBooNE:

Located in the BNB — just a little further than MicroBooNE
A little background on MiniBooNE:

Located in the BNB — just a little further than MicroBooNE

MicroBooNE looking at the same flux (0.5 to 1 GeV numu neutrinos)
A Cherenkov detector: sphere with PMTs filled with mineral oil
A Cherenkov detector: sphere with PMTs filled with mineral oil

Charged particles produce Cherenkov radiation, which leaves ring of hits

Note: rings from electrons and photons very similar
Observed a 3 sigma excess of electron-like events

But is this excess really from nue-appearance oscillations?

If electron: sterile neutrinos

If photons: unaccounted background? hint of exotic physics?
Need definitive electron vs. gamma separation — *MicroBooNE is built for this!*
The MicroBooNE detector

- 170 ton (70 ton active) liquid argon TPC
- 250 cm x 250 cm x 10 m TPC volume
- -70 kV cathode voltage
TPC Working Principle

1. Charged particles interact in Ar
   • Ionize electrons
   • Produce scintillation light
2. Ionization $e^-$ drift toward anode
3. Wire planes detect drift $e^-$
**TPC Working Principle**

1. Charged particles interact in Ar
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**Electric Field**

- $\sim 500 \text{ V/cm}$

**Cathode**

- @ $-100 \text{ kV}$ (plate)

**Anode**

- (wire plane)

**Scintillation Light**

- Detected by PMTs
1. Charged particles interact in Ar
   - Ionize electrons
   - Produce scintillation light
2. Ionization e⁻ drift toward anode
3. Wire planes detect drift e⁻

Max drift time = 1.6 ms

light gives time of interaction — vital to reconstruct drift distance
TPC Working Principle

1. Charged particles interact in Ar
   - Ionize electrons
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LArTPCs

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Three wire planes at different angles gives 2D position of hits
time between flash of light and first charge seen, gives depth

\[ \sum = 8256 \text{ wires w/ pitch = 3mm} \]

\((Y, Z) = \text{coincidence on wire}\)

Picture courtesy of J. Assadi

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LArTPCs

- Result are images of charged particle tracks/showers
- Provide info to distinguish between electrons and photons
LArTPCs

- Use track separation and dE/dx measured at front of tracks to discriminate between electron vs. photons

![Diagram showing electron vs. photon tracks]

**Electron track**

- 1 MIP

**Photon track**

- Converted to electron track (2 MIPs)

Important tool to investigate MiniBooNE excess

- Solid lines: MC
- Hashes: data tagged via eye-scanning using track separation
A Step Towards DUNE

• In addition to MiniBooNE excess, MicroBooNE will perform R&D in hardware and software that will lay the groundwork for DUNE

• first step towards precision measurements of cross sections — key systematic
MicroBooNE Construction

Start: 2013
- TPC construction: 2013
- PMT system installation: Dec 2013
- Moving day! June 23rd, 2014
- TPC insertion: Dec 23rd, 2013
- Foamed in! July 2014
- Cabled up! Sept. 2014
- All electronics in! Dec. 10, 2014

End: 2014

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MicroBooNE Commissioning

- Started Summer 2015

- Goals Achieved
  - Demonstrate necessary purity for drifting charge and collecting scintillation light
  - Hold cathode voltage
  - Calibrate light collection system

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Electron drift lifetimes after two-week filtration process

Example of R&D success

Electron drift time from cathode to anode (2.5 m): 2.3 ms (@ 70 kV cathode voltage)

Measurements taken with a purity monitor inside the cryostat.

< 50 ppt of O₂

Design goal
Digitized PMT Waveforms From Readout
Cosmic rays make time coincident large amplitude waveforms

PMT Channel Number

64 MHz Sample Tick

μBooNE

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Light System Commissioning

Digitized PMT Waveforms From Readout

Cosmic rays make time coincident large amplitude waveforms

Hit PMT Positions

μBooNE

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Digitized PMT Waveforms From Readout

Cosmic rays make time coincident large amplitude waveforms
raw signals from wire plane — no filtering
3D Reconstruction

Fully automated reconstruction

Run 1532, Event 1
08/17/2015, 04:03 PM

~ 2.3 ms drift time
4.8 ms recorded event length

MicroBooNE is at the surface. Neutrino interactions will be overlayed by multiple cosmic muon tracks.

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Identifying Neutrinos

- Using the first two weeks of data (starting Oct. 15th), we set out to identify neutrino events using automated event filter

induction plane 1:

collection plane:

induction plane 2:
Identifying Neutrinos

- Using the first two weeks of data (starting Oct. 15th), we set out to identify neutrino events using automated event filter

collection plane:

• **ingredients:**
  - Optical reconstruction
  - Noise removal
  - TPC Hit extraction
  - 2D reconstruction (clusters)
  - 3D track reconstruction
  - Cosmic removal based on optical flashes and track geometry
  - Vertex reconstruction
Optical Analysis

- Not every beam spill will produce a neutrino interaction in the detector. Most events contain only cosmic induced tracks.

- **Cosmic muon tracks come randomly.** Neutrinos come during the beam spill window.

  Duration of a readout event: 4.8 ms

  Duration of a beam spill: 1.6 μs

Timing of scintillation light signals detected with the PMT light system.

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Events

Run 3469 Event 53223, October 21st, 2015

(collection plane view)
Events

Run 3469 Event 53223, October 21st, 2015

( collection plane view )

ν beam

μBooNE

Cosmic muon

p ( red = highly ionizing )

π?

μ

ν beam

55 cm

time

Wire number

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Summary

MicroBooNE will provide data to help resolve of the MiniBooNE anomaly while providing valuable R&D to the long term effort towards DUNE.

Commissioned summer 2015 and now taking physics data.

First neutrino events seen.

Be on the look out for results in the near future.
Thanks for your attention
• SBND will provide a detailed characterization of the beam before oscillations can occur

• This allows for the cancelation of many of the dominant systematics
Intermediate Program: SBND

- The proposal leveraged the expertise gained by MiniBooNE both for the neutrino flux and the uncertainties on that flux.

- By using a series of three LAr TPCs we are able to greatly reduce the photon-like backgrounds compared to MiniBooNE.

- Given its large mass and far location ICARUS provides exquisite sensitivity to a potential oscillated signal.
Intermediate Program: SBND

SBND, 6.6e+20 POT (100m)

MicroBooNE, 1.32e+21 POT (470m)

ICARUS T600

ν mode, CC Events
Reconstructed Energy
80% νe Efficiency
Stat., X-Sec., Flux, Cosmics, Dirt
νe Only Fit

- 90% CL
- 3σ CL
- 5σ CL

Harvard LPPC Seminar
Taritree Wongjirad (MIT)
Intermediate Program: SBND

SBN total (2x MicroBooNE only run)

MicroBooNE
Events

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Run 3493 Event 41075, October 23rd, 2015
First neutrino events

Run 3493 Event 41075, October 23rd, 2015

π⁰ \rightarrow γ + γ?

(collection plane view)
• LSND: observed anti-electron neutrino appearance
  • Pion decay at rest source: muon anti-neutrinos
  • Liquid scintillator detector measuring light from inverse beta decay
• LSND: observed anti-electron neutrino appearance
• saw an excess of neutrino interactions compared to expectation assuming no oscillations
LSND

- Can interpret LSND excess as oscillation signature
- oscillations with $\Delta m^2 \sim 1 \text{ eV}^2$
- bigger than SM mass splittings — allows 2 neutrino approximation for fit
- Oscillation frequency different from other measurements

oscillation with $\Delta m^2 \sim 1 \text{ eV}^2$
Scintillation Light

Light yield ~ few 10,000’s of photons per MeV (dependences on E field, particle type and purity)

Wavelength of emission is 128nm

Light with two characteristic time constants:
- fast component, 6 ns
- slow component, 1500 ns

Argon is highly transparent to its own scintillation light.

Detecting LAr Scintillation

- 128 nm not visible to photodetectors — a challenge
- MIT group involved in developing techniques to detect this light
- We use Tetr phenyl butadiene (TPB). Reemits in the blue (peaked 425 nm) Other compounds can also be used

\[
\text{Ar}_2^* \rightarrow 2\text{Ar}
\]
Scintillation Uses

- Provide interaction time ($t_0$) for event reconstruction
- Provide trigger to reduce data rate
  - Limits to data storage system dictate that we can only keep about $\sim 1\%$ of all BNB/NUMI beam spills
  - Keep only spills with light at correct time
- Within spills, match tracks to flashes of light to further reject cosmic ray muon tracks via timing and position
Cosmic Rejection

- Use timing and position information from PMTs to identify beam events from cosmic tracks
- Proof of principle using MC simulations

Geometrical information from light
Likelihood based cosmic rejection
Light Collection

- Besides the charge, scintillation photons also collected

- 32 8” PMTs with tetra-phenyl butadiene (TPB)-coated acrylic plate

- 4 TPB-coated acrylic light guide paddles

(photographed w/o TPB-coated plate)
Argon Piston Purge

MicroBooNE employed a “piston” purge to clear cryostat of air (as opposed to evacuating the cryostat, option only for small vessels)

MicroBooNE tested this technique
Liquid Argon Fill

Fill Completed in 28 days

Delivered argon had a purity that far exceeded specifications (specs: O2<1 ppm, N2<3 ppm)

First delivery (1 of 9 tankers)
**Argon**: target material for many future detectors

Need more experimental data to learn about nuclear effects and neutrino energy reconstruction

**Energy range**: 200 MeV – 2 GeV (QE & RES)

**MicroBooNE simulation**

- All CC events
- CC quasi-elastic events
- CC resonant events
- CC deep-inelastic events
- CC coherent events
- All NC events

**Beta decay**

\[ \nu_\mu \rightarrow \mu^+ X \]

\[ \bar{\nu}_\mu \rightarrow \mu^- X \]

*Only existing v-Ar data*

*CDHS, ZP C35, 443 (1987)*
*GGM-SPS, PL 104B, 235 (1981)*
*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)*
*ArgoNeuT PRD 89, 112003 (2014)*
*ArgoNeuT, PRL 108, 161802 (2012)*
*T2K (Fe) PRD 90, 052010 (2014)*
*T2K (CH) PRD 90, 052010 (2014)*
*T2K (C) PRD 89, 092003 (2013)*
*BEBC, ZP C2, 187 (1979)*
*BNL, PRD 25, 617 (1982)*
*CCFR (1997 Seligman Thesis)*

*Simulation-only* (for ≈ 6 months)
CC-inclusive Xsec

Practicing our first analyses on MC data using fully-automated event reconstruction

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</thead>
<tbody>
<tr>
<td>Predicted no. of events</td>
<td>7968</td>
<td>89.3</td>
<td>1.1%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cosmic only events</td>
<td>3401</td>
<td>-</td>
<td>-</td>
<td>58.3</td>
<td>1.7%</td>
</tr>
<tr>
<td>Cosmics in BNB events</td>
<td>261</td>
<td>-</td>
<td>-</td>
<td>130.5</td>
<td>50%</td>
</tr>
<tr>
<td>NC events</td>
<td>156</td>
<td>-</td>
<td>-</td>
<td>78</td>
<td>50%</td>
</tr>
<tr>
<td>$\nu_e$ and $\bar{\nu}_e$ events</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>22</td>
<td>100%</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$ events</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>2.4</td>
<td>20%</td>
</tr>
<tr>
<td>Total background</td>
<td>3852</td>
<td>-</td>
<td>-</td>
<td>164.3</td>
<td>4.3%</td>
</tr>
<tr>
<td>$\nu_\mu$ CC events</td>
<td>4116</td>
<td>89.3</td>
<td>2.3%</td>
<td>164.3</td>
<td>4.0%</td>
</tr>
</tbody>
</table>

(for $\approx$ 3 months)

MicroBooNE as-designed MC preliminary

Simulation-only
CC-inclusive Xsec

Flux-integrated

MicroBooNE as-designed MC, 5.3e19 POT

MicroBooNE simulation preliminary (for ~ 3 months)

MC analysis result, 5.3e19 POT
GENIE

MicroBooNE as-designed MC, preliminary

Simulation-only
Electron drift lifetimes after two-week filtration process

Electron drift time from cathode to anode (2.5 m): 2.3 ms (@ 70 kV cathode voltage)

Measurements taken with a purity monitor inside the cryostat.
On the same day the detector filled, we turned on the PMTs and saw our first cosmic rays.

Large PMT pulses from two adjacent PMTs
TPC tracks from cosmics

Run 1147 Event 0. August 6th 2015 16:59
TPC tracks from cosmics

raw signals from wire plane — no filtering

Run 1153 Event 40. August 6th 2015 21:07