Recent Results from MicroBooNE

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Flavour Physics Conference,
Quy Nhon, Vietnam
August 18th - 2017
MicroBooNE in the SBN Program

- Three Detector configuration
- Common Technology (LArTPC)
- Main neutrino beam: BNB
- MicroBooNE and ICARUS also receive NuMi beam

ICARUS-T600 (2018)
476 t LAr active mass
@600 m from BNB target

MicroBooNE (2015)
89 t LAr active mass
@470 m from BNB target

SBND (2019)
112 t LAr active mass
@110 m from BNB target
MicroBooNE Physics Goals

Neutrino Oscillations

- **Neutrino mode:**
  - Excess: 162.0 ± 47.8 (3.4\(\sigma\))

- **Antineutrino mode:**
  - Excess: 78.4 ± 28.5 (2.8\(\sigma\))

- **Combined:**
  - Excess: 240.3 ± 34.5 ± 53.6
  - 3.8\(\sigma\) significance

  PRL 2013, 110, 161801

Neutrino Interactions

- **Cross-section measurement**
  - in ~1 GeV range

PDG 2015, Rev.

Supernova Neutrinos

Proton decay

u

d

X

e^+

u

d
MicroBooNE: LArTPC R&D

- Cold front-end electronics
- Laser Calibration system
- Understand & mitigate effects of surface operation
- Long drift (2.5 m)
- Large data volumes to store & reconstruct
- Dedicated supernova data stream

And more …

Charge readout
3 wires planes:
- 2 induction planes
- 1 collection plane

Optical readout:
32 PMTs with TPB WLS screens behind wires. Scintillation light provides trigger information.

JINST 12, P02017 (2017)
Charge readout

3 wires planes (8256 wires / 3 mm pitch):
- 2 induction planes (U and V at +/- 60°)
- 1 collection plane (Y), vertically oriented

273 V/cm

Neutrino Detection in Liquid Argon
MicroBooNE Operations

Installation and commissioning completed in October 2015

Neutrino interactions:

**BNB:**
- ~14000 $\nu_\mu$ CC interactions
- ~55000 $\nu_\mu$ NC interactions

**NuMI:**
- ~60000 $\nu_\mu$ CC int. & ~12000 $\bar{\nu}_\mu$ CC int.
- ~25000 $\nu_\mu$ NC int. & ~8000 $\bar{\nu}_\mu$ NC int.

BNB Protons On Target

NuMI Protons On Target

Switch to antineutrino-mode on 02/20/2017
Electron drift lifetime

• MicroBooNE drift distance (cathode to anode): 2.56 m

• High-purity LAr is critical for the operation of a LArTPC

Using a combination of gaseous purge and liquid argon purification (no evacuation), design requirements were exceeded

Measure electron lifetime > 6 ms
The CRT will be used for cosmic removal and detector physics studies

- Plastic scintillator modules with SiPMs readout
- Custom electronics for digitisation and triggering (now licensed by CAEN)
- 73 modules in 4 planes surrounding the cryostat
- 85% coverage for through going muons
Cosmic Ray Tagger System

Installation and commissioning completed in March 2017

CRT self triggered by two orthogonal modules
- 1D spatial resolution < 2cm
- Timing resolution ~3ns.

Currently implementing merge of CRT data into MicroBooNE data stream
Already 7 publications and many public notes. The collaboration is very active in using the data already gathered.

**MicroBooNE Publications (so far)**

- **Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE**
  - MicroBooNE Public Note 1024

- **Pandora pattern recognition**
  - MicroBooNE Public Note 1015

- **Proton Track Identification in MicroBooNE Simulation for Neutral Current Elastic Events**
  - MicroBooNE Public Note 1025

**Today’s talk:**
- Noise characterisation
- Event reconstruction
- Low energy response
- Space charge effect
Wire Noise Filtering

• Low-noise operation of readout electronics is critical for reconstruction purposes.

• Using first year data, several noise sources in the TPC were identified and mitigated.

• Hardware upgrades and noise filtering techniques improved the signal to noise ratio on all planes >16.

JINST 12, P08003 (2017)
Pandora pattern recognition

- Pandora provides a multi-algorithm approach to automated pattern recognition for LArTPC detectors such as MicroBooNE.

- Addresses problem with $O(100)$ algorithms to build the event (each algorithm addresses a specific task in a particular topology).

- PandoraSDK provides the software infrastructure to manage the algorithm chain. *Eur. Phys. J. C* 75, no. 9, 439.

Matching of true-reconstructed particles

$$CCQEL \nu_\mu \rightarrow \mu + p$$

<table>
<thead>
<tr>
<th>#Matched Particles</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3+</th>
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<tr>
<td>$\mu$</td>
<td>1.3%</td>
<td>95.8%</td>
<td>2.9%</td>
<td>0.1%</td>
</tr>
<tr>
<td>$p$</td>
<td>8.9%</td>
<td>87.3%</td>
<td>3.6%</td>
<td>0.2%</td>
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</tbody>
</table>

arxiv:1708.03135, submitted to EPJC.
Accumulated positive LAr ions creates a Space Charge Effect (SCE) in the TPC, distorting reconstructed tracks.

A small muon tagger (MuCS) installed above the TPC was used to study the SCE with reconstructed entry and exit points for muons…

… and determine the necessary corrections to the SCE

MicroBooNE Public Note 1018
Similar studies can be performed (& improved) by using:

- A steerable UV Laser Calibration source producing straight tracks across the TPC

*JINST 9, T11007 (2014)*

- Cosmic Ray Tagger system providing larger coverage for crossing muons

MuC5s - CRT coverage comparison
Michel electrons

- Michel electrons produced by decay at rest of cosmic muons are used for low energy response studies.

- At these energies, up to 50 MeV, ionization electrons and bremsstrahlung contribute similarly to electron energy loss in LAr.

Fully-automated set of algorithms for reconstructing these EM showers.

arxiv:1704.02927, submitted to JINST
Neural Networks

- Machine Learning (Neural Networks for image recognition) used for analysis of high quality images provided by MicroBooNE
  
  *JINST 12, P03011 (2017)*

- Studies with MC data demonstrate the potential of these tools for particle ID and finding neutrino events and vertex interactions.

**Application to BNB data soon**

- **PID:** $e$ vs $\gamma$

- Neutrino interaction finding
Successful automated reconstruction and neutrino event selection using LArSoft

MicroBooNE Public Note 1010

Optical reconstruction in coincidence with beam spills

First kinematic event distributions
• **MicroBooNE** is the first operating detector of the SBN program, collecting and analysing data since October 2015.

• More than $6.0e20$ BNB ($8.5e20$ NuMI) POT have been collected.

• Algorithms for **automatic reconstruction** are functioning.

• Continuous **upgrades to hardware and software** further improve detector performance.

• Installation of an external **Cosmic Ray Tagger** System for mitigating surface operation effects.

• Several **analyses and publications** already out and more to follow (Noise Characterisation, Michel electrons, Neural Networks, etc.).
Thank you!!!
Cảm ơn!!!