Developing Wire-Cell techniques to improve a high-efficiency high-purity neutrino selection in the MicroBooNE LArTPC

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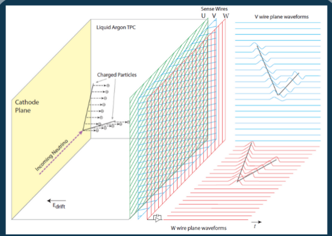
MicroBooNE

- **MicroBooNE** is a ~94 ton fully active **Liquid Argon Time Projection Chamber** (LArTPC).
- The signature measurement is to resolve the **Low Energy Excess** (LEE) from MiniBooNE.
- Due to its **surface location**, the detector is exposed to 20-30 cosmic ray muons per 4.8 ms readout window.
- There are **200 cosmic rays for every neutrino** observed before applying the following cosmic ray taggers: **charge-light matching**, **throughgoing muon tagger**, **stopped muon tagger**, and **light mismatch tagger**.

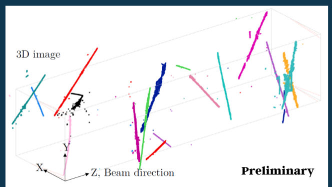


A graphic demonstrating the wire plane readout imaging neutrino-induced charged particles.

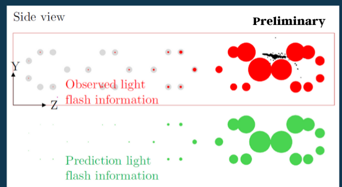
The inside of the MicroBooNE detector, including the 32 Photomultiplier Tubes (PMTs).

Charge-Light Matching

- **A slow charge drift time** (2.4 ms) allows a dozen cosmic rays to fit in the drift window consistent with the Booster Neutrino Beam (BNB) timing.
- **For each charge cluster a flash is predicted** based on the charge intensity and location.
- By comparing predicted vs observed flash patterns, we simultaneously attempt to **match all clusters to their associated flashes**.
- The prompt PMT-flash timing lets us **rule out 97% of background cosmic rays** as inconsistent with the BNB timing.

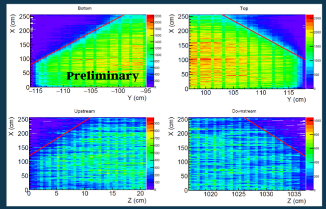


A neutrino event (black) among numerous cosmic rays (multicolor).

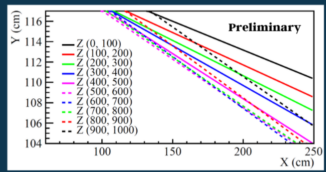


The predicted flash (green) from the TPC charge activity, matched to the PMT observed flash (red).

Space Charge Boundary



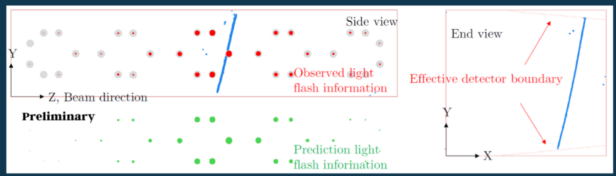
Effective space charge boundaries (red) plotted on top of the data (green) used to determine them.



Position dependent effective detector boundaries overplotted for each meter along the beam axis.

- The remaining cosmic removal algorithms rely on precise detector boundary knowledge.
- Constant cosmic ray bombardment plus an applied electric field strips away electrons, leaving behind the heavier and slower Ar+ ions. This creates a buildup of space charge that **distorts the electric field and electron drift paths**.
- **A precise position-dependent effective detector boundary** was mapped by observing where cosmic ray charge-detection stopped abruptly near the detector boundary.

Throughgoing Muon (TGM) Tagger



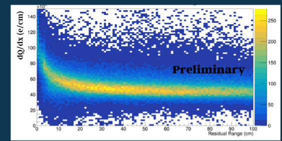
A throughgoing muon detected by its double boundary intersection, seen through the beam view on the right. The slanted dashed lines are the effective space charge boundary.

- Most cosmic rays (and few neutrino tracks) start and end outside the detector, showing up as **nearly-straight lines that intersect the detector boundary at both ends**.
- Charge-light matching provides a precise drift time and therefore drift position. Together with the space charge boundary map, this allows for **precision detection of any detector boundary intersection**.
- The TGM tagger then removes straight-line clusters that intersect the boundary on both ends.

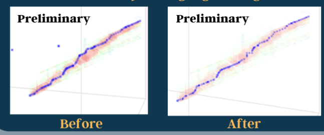
Stopped Muon (STM) Tagger

- The **end-of-track Bragg Peak energy deposition rate** identifies STMs from outgoing neutrino-induced particles, but requires a trajectory fit to be measured.
- 3D Particle trajectories are fit to reconstructed charge points.
- This fit relies on an accurate initial guess. **Charge hits are connected in a graph using a Minimum Spanning Tree (MST)**, which is traversed to form an initial trajectory guess.
- This MST doesn't preference high-charge hits along the true trajectory, allowing room for fit errors.
- **A Steiner Terminal MST is used instead to incorporate high-charge info** via preferenced Steiner Terminals for a robust trajectory guess.

Muon Bragg Peak dQ/dx vs Residual Range

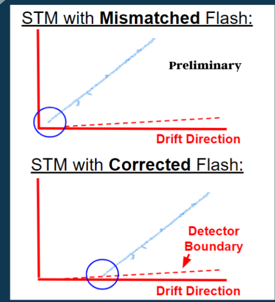


Trajectory fit (blue) to charge points (red) before and after incorporating high-charge info



Light Mismatch Tagger

- **Some cosmic rays are incorrectly matched to neutrino flashes.** They are ignored by the STM and TGM taggers because **they have incorrect drift times and lack boundary intersections.**
- Poorly matched clusters are reexamined and **new matches are considered.** If a new drift time moves the cluster to a boundary intersection, the **TGM and STM taggers are reapplied. Tagged cosmics are removed**, improving neutrino selection purity.



Results

The efficiency, reduction factor (relative in parentheses), and neutrino-to-cosmic ratio are shown below after each cosmic rejection algorithm. Only neutrinos originating in the fiducial volume (95% of active volume) are counted.

Cut	ν_μ CC efficiency	ν_μ NC efficiency	cosmic-ray reduction	ν : cosmic-ray
Hardware trigger	100%	100%	1 (1)	1 : 20k
Offline light filter	98.3%	85.4%	0.01 (0.01)	1 : 210
Charge-light matching	92.1%	53.6%	2.6×10^{-4} (0.026)	1 : 6.4
TGM rejection	88.9%	52.1%	4.4×10^{-5} (0.17)	1.1 : 1
STM rejection	82.9%	50.3%	1.4×10^{-5} (0.32)	2.8 : 1
LM rejection	80.4%	35.9%	6.9×10^{-6} (0.50)	5.2 : 1

Preliminary

References: MICROBOONE-NOTE-1084-PUB, MiniBooNE LEE (arXiv:1805.12028v2)

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