Detector performances and cosmic-ray reconstruction efficiency in MicroBooNE

Stefano Roberto Soleti
DPF 2017, Fermilab, 31st July 2017
The MicroBooNE experiment

Exterior view of the TPC showing the cathode plane
The MicroBooNE experiment

View of the cryostat containing the TPC

Exterior view of the TPC showing the cathode plane

MicroBooNE detector

View of the cathode frame and structural supports to which cathode sheets are fastened. Bottom: Interior view of cathode plane as viewed from the upstream end of the LArTPC, showing cathode sheets. Note that the cathode sheets are polished, so a reflection is clearly present in this photograph.
The MicroBooNE experiment

Exterior view of the TPC showing the cathode plane

View of the cryostat containing the TPC

Cryostat being lowered in the LArTF building
The MicroBooNE experiment

Exterior view of the TPC showing the cathode plane

View of the cryostat containing the TPC

Cryostat being lowered in the LArTF building
• Being MicroBooNE located near the surface, **cosmic muons can be a source of backgrounds** to many analyses (~10 cosmic muons per 2.2 ms drift time).
• Being MicroBooNE located near the surface, cosmic muons can be a source of backgrounds to many analyses (~10 cosmic muons per 2.2 ms drift time).

• A small muon counter stack (MuCS) has been installed on top of the TPC to help with several studies:
  - **Data reconstruction efficiency**
  - Optical system - TPC matching efficiency
  - Trigger efficiency
  - **Detector performances** (space-charge effect, collected charge, collected light...)

The Muon Counter System (MuCS), described in detail in [Ref], is designed to provide a trigger on through-going muons that intersect all four bi-layers of LArTPC. The MuCS DAQ that reads out the Multi-Anode PMTs is separated from the DAQ system of the main detector. It records the hit patterns of the 500 scintillator stripes, while the main DAQ stores the TPC and PMT signals during the readout time of 4.8 ms.

The MuCS triggers at a rate of nearly 3 Hz: given a DAQ integration window of 100 ns, the accidental coincidental rate is less than 0.01% and it has been considered negligible for our study. We are then assuming that there is only one cosmic ray in the TPC that went through the MuCS.

The MuCS-merged dataset information can be obtained from the TPC and PMT systems of the main detector. It records the hit patterns of the 500 scintillator stripes, while the main DAQ stores the TPC and PMT signals during the readout time of 4.8 ms. A cosmic ray passing through the MuCS boxes will hit the scintillator stripes, producing a signal in one strip corresponding to a MuCS hit. From the height of the panels and the position of the hit stripes, it is then possible to extrapolate the trajectory of the cosmic ray.

The first intersection point between the MuCS-extrapolated track and the TPC is defined as the reconstructed tracks.

This analysis has been performed on three datasets, acquired with different geometrical configurations of the MuCS and the LArTPC. Brown tracks correspond to cosmic rays hitting both MuCS boxes and the TPC, while red tracks go through only the MuCS and miss the TPC.
A small muon counter stack (MuCS) has been installed on top of the TPC to help with several studies:

- Detector performances
- Optical system - TPC matching efficiency
- Trigger efficiency
- Data reconstruction efficiency
- Collected charge
- Collected light
- Cosmic-ray reconstruction efficiency

Muons can be a source of backgrounds to many analyses (~10 cosmic muons per 2.2 ms drift time).

The Muon Counter System (MuCS), described in detail in [reference], is designed to provide a trigger on through-going muons that intersect all four bi-layers of the scintillator strips. The MuCS trigger is propagated to the MicroBooNE trigger board and provides a trigger window against cosmic rays down to the TPC, which we define as a MuCS-extrapolated track.

The reconstructed track with the closest starting point to the MuCS defines the starting time of the cosmic ray. Monte Carlo simulation of the possible MuCS trajectories in the three different setups used is shown in Figure 2. The first intersection point between the MuCS-extrapolated track and the TPC is defined as the starting point of the cosmic ray. The hits in the MuCS are used to obtain a point for each box and extrapolate a track through the TPC and PMT systems of the main detector. The data follows a processing path that merges the MuCS hit patterns and extrapolated trajectories with the TPC hits, that are fed to the MicroBooNE reconstruction chain and will be assembled to form a reconstructed track.

The MuCS is located near the surface, cosmic rays can be a source of backgrounds to many analyses (~10 cosmic muons per 2.2 ms drift time).

The t-2 PMTs are read out by a DAQ system, separated from the DAQ system that reads out the TPC and PMT systems of the main detector. It records the hit patterns of the Multi-Anode PMTs, which are connected to wavelength shifting fibers. The fiber collection is made up of scintillator strips placed into two separate, light-tight boxes. Each planar module is made up of scintillator strips placed into two separate, light-tight boxes. Each strip contains a wavelength shifting fiber, connected to a Multi-Anode PMT. The construction of the MuCS is described in detail in [reference].

This analysis has been performed on three datasets, acquired with different MuCS setups in the three end, at the center and at the downstream end of MicroBooNE. A three-dimensional schematic of the possible MuCS trajectories in the three different setups is shown in Figure 3.
MuCS and space-charge effect

- The positive argon ions can cause a **distortion in the electrical field** of the TPC.
- Using MuCS-triggered events it is possible to quantify this **space-charge effect** (SCE).

**SCE simulation qualitatively reproduces effect.**
- Agrees in normalization and base shape features.
- Offset near anode probably caused by **liquid argon flow**.
- Can impact track/shower reconstruction and calorimetry.

**Figure 7:** Predicted/measured SCE distortions as a function of the drift coordinate at the top of the TPC for simulation, \( y_{MC\ top}(x) \) (a), and data, \( y_{Data\ top}(x) \) (b).

The magenta dashed line represents the offsets expected if there were no SCE in the detector (zero). The offsets in data are found to be similar in magnitude as those predicted by simulation, though distortions near the TPC anode are found to be smaller than the simulation suggests.
MuCS and space-charge effect

- The positive argon ions can cause a **distortion in the electrical field** of the TPC.
- Using MuCS-triggered events it is possible to quantify this **space-charge effect** (SCE).

**SCE simulation qualitatively reproduces effect.**
- Agrees in normalization and base shape features.
- Offset near anode probably caused by **liquid argon flow**.
- Can impact track/shower reconstruction and calorimetry.

---

**Figure 7:** Predicted/measured SCE distortions as a function of the drift coordinate at the top of the TPC for simulation, $y_{MC\text{top}}(x)$ (a), and data, $y_{Data\text{top}}(x)$ (b).

The magenta dashed line represents the offsets expected if there were no SCE in the detector (zero). The offsets in data are found to be similar in magnitude as those predicted by simulation, though distortions near the TPC anode are found to be smaller than the simulation suggests.
Reconstructing MuCS data

- Each MuCS event is triggered by a cosmic ray going through both MuCS panels.
- Each MuCS event will contain more than one reconstructed cosmic-ray track (~10 cosmic rays per 2.2 ms).
- We find the reconstructed track with the starting points closest to the intersection between the extrapolated MuCS trajectory (MuCS-extrapolated track) and the TPC, within a maximum distance (MuCS-tagged track).
- Number of MuCS-tagged tracks is corrected by the purity and the acceptance of the cut on the maximum distance.
Each MuCS event is **triggered by a cosmic ray going through both MuCS panels.**

Each MuCS event will contain **more than one reconstructed cosmic-ray track** (~10 cosmic rays per 2.2 ms).

We find the **reconstructed track with the starting points closest to the intersection** between the extrapolated MuCS trajectory (**MuCS-extrapolated track**) and the TPC, within a maximum distance (**MuCS-tagged track**).

Number of MuCS-tagged tracks is corrected by the purity and the acceptance of the cut on the maximum distance.

---

<table>
<thead>
<tr>
<th>MuCS-tagged track</th>
<th>MuCS-extrapolated track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstructed tracks</td>
<td></td>
</tr>
</tbody>
</table>

---

* schematic representation, not to scale
Efficiency measurement

- Using the \((X_{\text{top}}, y_{\text{top}}, z_{\text{top}})\) and \((X_{\text{bottom}}, y_{\text{bottom}}, z_{\text{bottom}})\) points given by the MuCS panels, it is possible to measure the reconstruction efficiency as a function of \(\theta\), \(\phi\) and extrapolated length in the TPC \(L\).

\[
\epsilon_{MC} = \frac{\text{N. of reconstructed cosmic rays}}{\text{N. of generated cosmic rays}} = 97.4 \pm 0.1\% 
\]

\[
\epsilon_{data} = \frac{\text{N. of reco. MuCS cosmic-ray events}}{\text{N. of MuCS triggered events}} = 97.1 \pm 0.1 \text{ (stat)} \pm 1.4 \text{ (sys)}\% 
\]
Results
One-dimensional projections

Proportionality between extrapolated length and reconstruction efficiency: larger number of hits means track easier to reconstruct.
Results
Two-dimensional projections

Data

Monte Carlo

Data/Monte Carlo
Results
Two-dimensional projections

### Data

<table>
<thead>
<tr>
<th>L [cm]</th>
<th>( \theta [^\circ] )</th>
<th>MicroBooNE</th>
<th>Monte Carlo</th>
<th>Data/Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>60</td>
<td>0.94 ± 0.03</td>
<td>0.98 ± 0.01</td>
<td>0.98 ± 0.01</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>0.96 ± 0.02</td>
<td>0.97 ± 0.01</td>
<td>0.97 ± 0.01</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>0.97 ± 0.03</td>
<td>0.98 ± 0.02</td>
<td>0.98 ± 0.02</td>
</tr>
</tbody>
</table>

### Monte Carlo

<table>
<thead>
<tr>
<th>L [cm]</th>
<th>( \theta [^\circ] )</th>
<th>MicroBooNE</th>
<th>Monte Carlo</th>
<th>Data/Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>60</td>
<td>0.98 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td>0.97 ± 0.01</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>0.99 ± 0.00</td>
<td>0.98 ± 0.02</td>
<td>0.98 ± 0.02</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>0.99 ± 0.01</td>
<td>0.98 ± 0.02</td>
<td>0.98 ± 0.02</td>
</tr>
</tbody>
</table>

### Data/Monte Carlo

<table>
<thead>
<tr>
<th>L [cm]</th>
<th>( \theta [^\circ] )</th>
<th>MicroBooNE</th>
<th>Monte Carlo</th>
<th>Data/Monte Carlo</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>60</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>0.99 ± 0.00</td>
<td>0.99 ± 0.00</td>
<td>0.99 ± 0.00</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>0.98 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td>0.97 ± 0.01</td>
</tr>
</tbody>
</table>

Just submitted to JINST!
• This analysis represents a small-scale demonstration of the method that can be used with the data coming from the Cosmic Ray Tagger, a system of scintillation panels able to tag 85% of the cosmic-ray flux.

• The Cosmic Ray Tagger installation has been completed in January, 2017.
• The angular coverage provided by the CRT is much larger than the one of the MuCS and close to 100%. It will be possible to measure efficiency-corrected quantities, such as the cosmic-ray flux in MicroBooNE, and mitigate the cosmic-ray background.
Cosmic Ray Tagger

Figure 1.1: Rendering showing the LArTPC with proposed muon tagger panel groups (topside, side, and underside).

Figure 1.2: Background rejection by various configurations of the CRT for T600 detector at 600 m from the target. Momentum cut is 200 MeV.

doi:10.3390/instruments1010002
Cosmic Ray Tagger

Figure 1.1: Rendering showing the LArTPC with proposed muon tagger panel groups (topside, side, and underside).

Figure 1.2: Background rejection by various configurations of the CRT for the T600 detector at 600 m from the target. Momentum cut is 200 MeV.

Cosmic Ray Tagger
... to reality! Feedthrough, Pipe & Bottom Panels

- **Topside Panels**
  - Side Panels (Feedthrough Side)
  - Pipe Side
    - 14 Horizontal Modules
    - 13 Vertical Modules

- **Bottom (not shown)**
  - 4 Beam Dir Modules
  - 5 Drift Dir Modules
Figure 1.1: Rendering showing the LArTPC with proposed muon tagger panel groups (topside, side, and underside).

Figure 1.2: Background rejection by various configurations of the CRT for T600 detector at 600 m from the target. Momentum cut is 200 MeV.

Cosmic Ray Tagger

FT Side
6 Horizontal Modules
7 Vertical Modules

Pipe Side
14 Horizontal Modules
13 Vertical Modules

Bottom (not shown)
4 Beam Dir Modules
5 Drift Dir Modules

Side Panels (Feedthrough Side)

Topside Panels

doi:10.3390/instruments1010002
CRT installation tips

Plan ahead, but trust your techs. Cables will be everywhere! (if you don’t think ahead!)

It’s not over until it’s over. AKA you will need to access the electronics after installation (and it’s not going to be always comfortable).

We planned the order, sorted & flagged modules ahead. Followed techs advice on site.
CRT installation tips

Plan ahead, but trust your techs.

Cables will be everywhere! (if you don't think ahead!)

It's not over until it's over. AKA you will need to access the electronics after installation (and it's not going to be always comfortable).

We planned the order, sorted & flagged modules ahead. Followed techs advice on site.
Conclusions

- The MicroBooNE experiment has a **broad physics program** and LArTPC R&D. The detector is up and running: 15 public notes and 5 papers already published.
- A small muon counter stack has the capabilities to assess **several performances** of the LArTPC.
- **Space-charge effect** must be taken into account when reconstructing LArTPC information, but it can be correctly simulated.
Conclusions

• The MicroBooNE experiment has a **broad physics program** and LArTPC R&D. The detector is up and running: **15 public notes and 5 papers already published**.
• A small muon counter stack has the capabilities to assess **several performances of the LArTPC**.
• **Space-charge effect** must be taken into account when reconstructing LArTPC information, but it can be correctly simulated.

• The finding and **reconstruction efficiency of tracks in MicroBooNE** is in good agreement with the simulation.
• The analysis has been included in a paper submitted to JINST.
• The **Cosmic Ray Tagger** provides increased coverage for efficiency studies and cosmic-ray background mitigation. Extremely important for future SBN program (ICARUS, SBND) and DUNE.
Backup slides
The MicroBooNE detector

- Two **induction planes** (U, V) and **one collection plane** (Y)
- Drifted ionization in LAr puts signal on all three planes
  - Drift E field at 273 V/cm, corresponding drift time 2.3 ms.
  - **Cold front-end electronics** (low noise)
- **3D event reconstruction** by combining signals from all three planes (y,z direction) and drift time (x direction)
- PMT system located on the anode side to trigger neutrino events and help reconstruction
Efficiency measurement

MCC7 Monte Carlo

$\varepsilon_{MC} = \frac{N. \text{ of reconstructed cosmic rays}}{N. \text{ of generated cosmic rays}}$

Data

$\varepsilon_{\text{data}} = \frac{N. \text{ of reco. MuCS cosmic-ray events}}{N. \text{ of MuCS triggered events}} = \varepsilon_{\text{tag}} \times P/A = $

$= \frac{N. \text{ of reco. events within } d_{\text{max}}}{N. \text{ of MuCS triggered events}} \cdot \frac{N. \text{ of reco. MuCS cosmic-ray events within } d_{\text{max}}}{N. \text{ of reco. events within } d_{\text{max}}} \cdot \frac{N. \text{ of reco. MuCS cosmic-ray events}}{N. \text{ of reco. MuCS cosmic-ray events within } d_{\text{max}}}$

Tagging efficiency: can be measured both with data and Monte Carlo

Purity: can be measured only with Monte Carlo (needs the truth information)

1/Acceptance: can be measured only with Monte Carlo (needs the truth information)

MuCS Monte Carlo

$\varepsilon_{\text{MuCS-MC}} = \frac{N. \text{ of reco. MuCS cosmic-ray events}}{N. \text{ of generated MuCS cosmic-ray events}} = \varepsilon_{\text{tag}} \times P/A = $

$= \frac{N. \text{ of reco. events within } d_{\text{max}}}{N. \text{ of generated MuCS cosmic-ray events}} \cdot \frac{N. \text{ of reco. MuCS cosmic-ray events within } d_{\text{max}}}{N. \text{ of reco. events within } d_{\text{max}}} \cdot \frac{N. \text{ of reco. MuCS cosmic-ray events}}{N. \text{ of reco. MuCS cosmic-ray events within } d_{\text{max}}}$

Tagging efficiency: can be measured both with data and Monte Carlo

Purity: can be measured only with Monte Carlo (needs the truth information)

1/Acceptance: can be measured only with Monte Carlo (needs the truth information)
MCC7 Monte Carlo

\[ \epsilon_{MC} = \frac{N.\ of\ reconstructed\ cosmic\ rays}{N.\ of\ generated\ cosmic\ rays} \]

Data

\[ \epsilon_{data} = \frac{N.\ of\ reco.\ MuCS\ cosmic-ray\ events}{N.\ of\ MuCS\ triggered\ events} = \epsilon_{tag} \times P/A = \]

\[ = \frac{N.\ of\ reco.\ events\ within\ d_{\text{max}}}{N.\ of\ MuCS\ triggered\ events} \]

Tagging efficiency: can be measured both with data and Monte Carlo

Purity: can be measured only with Monte Carlo (needs the truth information)

1/Acceptance: can be measured only with Monte Carlo (needs the truth information)

MuCS Monte Carlo

\[ \epsilon_{\text{MuCS-MC}} = \frac{N.\ of\ reco.\ MuCS\ cosmic-ray\ events}{N.\ of\ generated\ MuCS\ cosmic-ray\ events} = \epsilon_{tag} \times P/A = \]

\[ = \frac{N.\ of\ reco.\ events\ within\ d_{\text{max}}}{N.\ of\ generated\ MuCS\ cosmic-ray\ events} \]

Tagging efficiency: can be measured both with data and Monte Carlo

Purity: can be measured only with Monte Carlo (needs the truth information)

1/Acceptance: can be measured only with Monte Carlo (needs the truth information)

Does not depend on \( d_{\text{max}} \)!
Efficiency measurement

**MCC7 Monte Carlo**

$\epsilon_{MC} = \frac{\text{N. of reconstructed cosmic rays}}{\text{N. of generated cosmic rays}}$

**Data**

$\epsilon_{\text{data}} = \frac{\text{N. of reco. MuCS cosmic-ray events}}{\text{N. of MuCS triggered events}} = \epsilon_{\text{tag}} \times P/A = \frac{\text{N. of reco. events within } d_{\text{max}}}{\text{N. of MuCS triggered events}} \times \frac{\text{N. of reco. MuCS cosmic-ray events within } d_{\text{max}}}{\text{N. of reco. events within } d_{\text{max}}}$

- **Tagging efficiency**: can be measured both with data and Monte Carlo
- **Purity**: can be measured only with Monte Carlo (needs the truth information)
- **1/Acceptance**: does not depend on $d_{\text{max}}$

**MuCS Monte Carlo**

$\epsilon_{\text{MuCS-MC}} = \frac{\text{N. of reco. MuCS cosmic-ray events}}{\text{N. of generated MuCS cosmic-ray events}} = \epsilon_{\text{tag}} \times P/A = \frac{\text{N. of reco. events within } d_{\text{max}}}{\text{N. of generated MuCS cosmic-ray events}} \times \frac{\text{N. of reco. MuCS cosmic-ray events within } d_{\text{max}}}{\text{N. of reco. events within } d_{\text{max}}}$

- **Tagging efficiency**: can be measured both with data and Monte Carlo
- **Purity**: can be measured only with Monte Carlo (needs the truth information)
- **1/Acceptance**: does not depend on $d_{\text{max}}$
### Efficiency measurement

#### Tagging efficiency

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{N. of reco. events within } d_{\text{max}}}{\text{N. of MuCS triggered events}} )</td>
<td>N. of reco. events within ( d_{\text{max}} ) ( \text{N. of MuCS triggered events} )</td>
</tr>
</tbody>
</table>

The **reco. event** within \( d_{\text{max}} \) can be a MuCS cosmic ray but also a random one, close to the extrapolated starting point.

#### Purity

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{N. of reco. MuCS cosmic-ray events within } d_{\text{max}}}{\text{N. of reco. events within } d_{\text{max}}} )</td>
<td>N. of reco. MuCS cosmic-ray events within ( d_{\text{max}} ) ( \text{N. of reco. events within } d_{\text{max}} )</td>
</tr>
</tbody>
</table>

The **reco. MuCS event** is within \( d_{\text{max}} \) and it corresponds to a MuCS cosmic ray.

#### 1/Acceptance

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{N. of reco. MuCS cosmic – ray events within } d_{\text{max}}}{\text{N. of reco. MuCS cosmic – ray events within } d_{\text{max}} + \text{N. of reco. events within } d_{\text{max}}} )</td>
<td>N. of reco. MuCS cosmic – ray events within ( d_{\text{max}} ) ( \text{N. of reco. MuCS cosmic – ray events within } d_{\text{max}} ) ( \text{N. of reco. events within } d_{\text{max}} )</td>
</tr>
</tbody>
</table>

The **MuCS cosmic ray** has been reconstructed but it is outside the \( d_{\text{max}} \) cut.
Inefficiency

Missing wires

Collection

Induction 1

Induction 2

Shower-like rays

Collection

Induction 1

Induction 2
Systematic uncertainties

- **Dependence on the $d_{\text{max}}$ cut**: as we saw, there is a small dependence (0.2% difference between best and worst value) of the data reconstruction efficiency on the chosen value of $d_{\text{max}}$. We quote the value of the difference as a systematic uncertainty.

- **Decay-in-flight and stopped muons**: the cosmic muons hitting the MuCS can decay in flight or be captured before reaching the TPC. In this case, they trigger the MuCS but do not generate a cosmic track in the detector, affecting the measurement of the reconstruction efficiency.

- **Space-charge effect**: the presence of positive argon ions can introduce a distortion in the electric field and cause a displacement of the start and end points of the tracks.

- **Detector non-uniformities**: the presence of regions with noisy or unresponsive wires can give a different value of the reconstruction efficiency depending on the position of the cosmic ray.

- **Monte Carlo cosmic-ray generator**: CORSIKA and CRY give different cosmic-ray rate estimates and have different cosmic-ray energy spectra (MICROBOONE-NOTE-1005-PUB). However, since we are measuring an efficiency, the cosmic-ray rate doesn’t matter and we need to study only the effect of the energy spectrum.

- **Statistical sampling**: since the multiple scattering depends on the energy, low-energy cosmic rays will have a higher probability to be further than $d_{\text{max}}$ from the extrapolated starting point of the MuCS cosmic ray. Thus, the sampling of the few events from the energy spectrum can introduce a bias in the measurement of the efficiency.
**MicroBooNE physics goals**

<table>
<thead>
<tr>
<th>Investigate short-baseline neutrino anomalies</th>
<th>Cross-section measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• LSND excess.</td>
<td>• Precise measurements of (\nu)-Ar cross section for future LAr experiments (DUNE).</td>
</tr>
<tr>
<td>• MiniBooNE low energy excess.</td>
<td>• Probe different theories of nuclear effects in (\nu)-Ar scattering.</td>
</tr>
<tr>
<td>• Reactor neutrino anomalies.</td>
<td></td>
</tr>
</tbody>
</table>

**Supernova neutrino and exotic physics**

<table>
<thead>
<tr>
<th></th>
<th>LArTPC detector R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Supernova neutrinos (~10 MeV) using the SNEWS alert system</td>
<td>• Detector effects to further develop LArTPC technology</td>
</tr>
<tr>
<td>• Proton decay backgrounds study: (K_L^0 + p \rightarrow K^+ + n)</td>
<td>• Space charge effect, wire response, noise studies, electron lifetime…</td>
</tr>
<tr>
<td></td>
<td>• Essential for future experiments.</td>
</tr>
</tbody>
</table>

---

**Figure 1 (color online).** The antineutrino mode (top) and neutrino mode (bottom) event excesses as a function of reconstructed energy. In the antineutrino mode, differences will be of disentangling the various event types. Also shown are the expectations from the best two-neutrino fits.

---

**Supernova neutrino spectrum**

- \(\bar{\nu}_e\), \(\bar{\nu}_\mu\), \(\bar{\nu}_\tau\), \(\bar{\nu}_e\) (top) shows the event excess as a function of reconstructed energy. The distributions for muonlike and electronlike events. The parameters. (top) shows the event excess as a function of reconstructed energy. The distributions for muonlike and electronlike events. The parameters. (top) shows the event excess as a function of reconstructed energy. The distributions for muonlike and electronlike events. The parameters. (top) shows the event excess as a function of reconstructed energy. The distributions for muonlike and electronlike events. The parameters.
**MicroBooNE in a nutshell**

**What is it?**
MicroBooNE is a 85 active mass ton **Liquid Argon Time Projection Chamber** at Fermilab, located:
- on the axis of the Booster Neutrino Beam (BNB);
- off the axis of the Neutrinos at the Main Injector (NuMI) beam.

**How does it work?**
As a charged particle passes through the liquid argon, the argon atom experiences one of two processes, it becomes ionized, or excited. Both paths end by de-excitation via **scintillation**.

Ionized **electrons** travel through the liquid argon in a constant electric field and are **collected by the TPC**.

The **photons** are collected by one of the 32 8-inch **photomultipliers (PMTs)**.