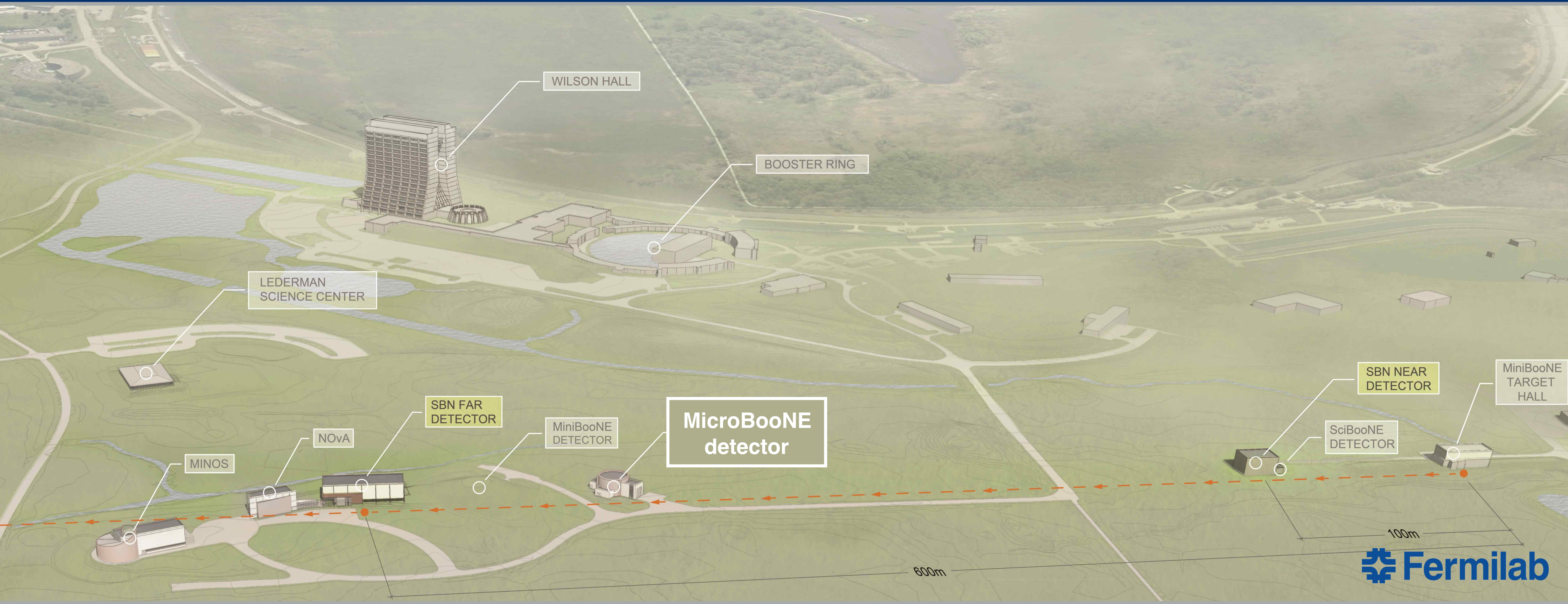
Detector performances and cosmic-ray reconstruction efficiency in MicroBooNE

Stefano Roberto Soleti

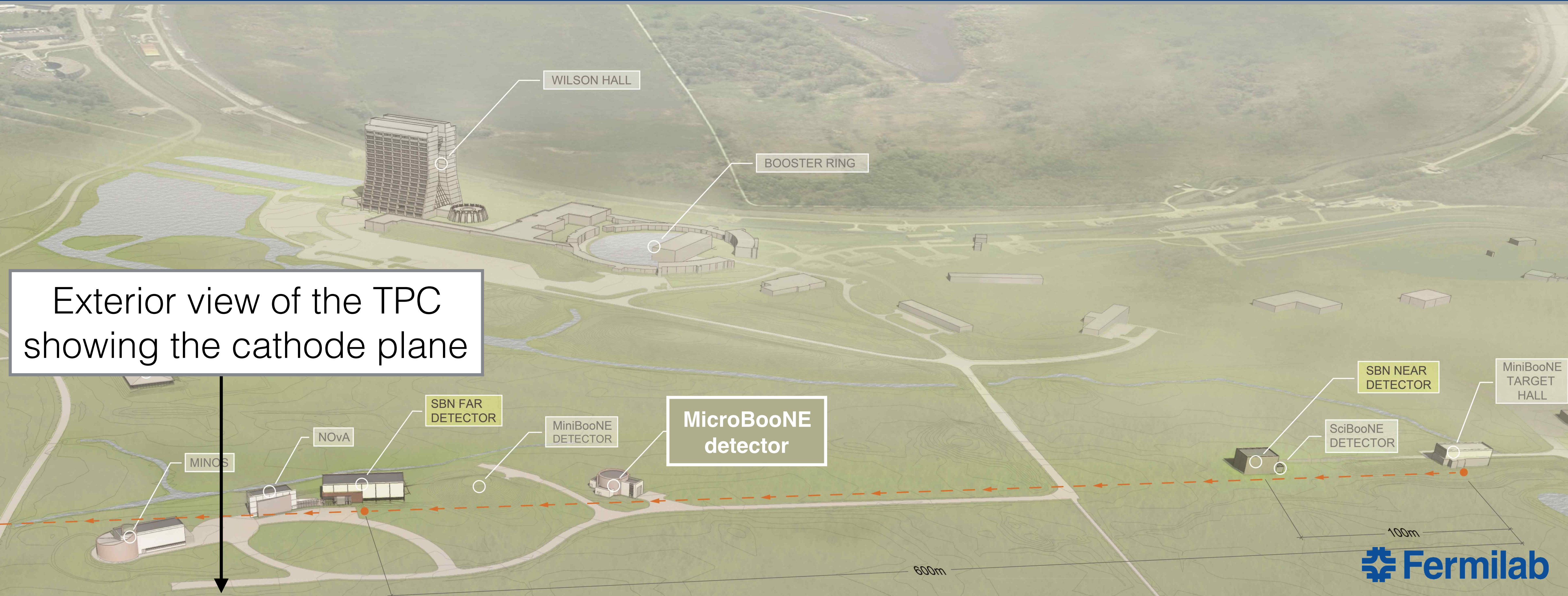
DPF 2017, Fermilab, 31st July 2017

The MicroBooNE experiment



arXiv:1612.05824

The MicroBooNE experiment



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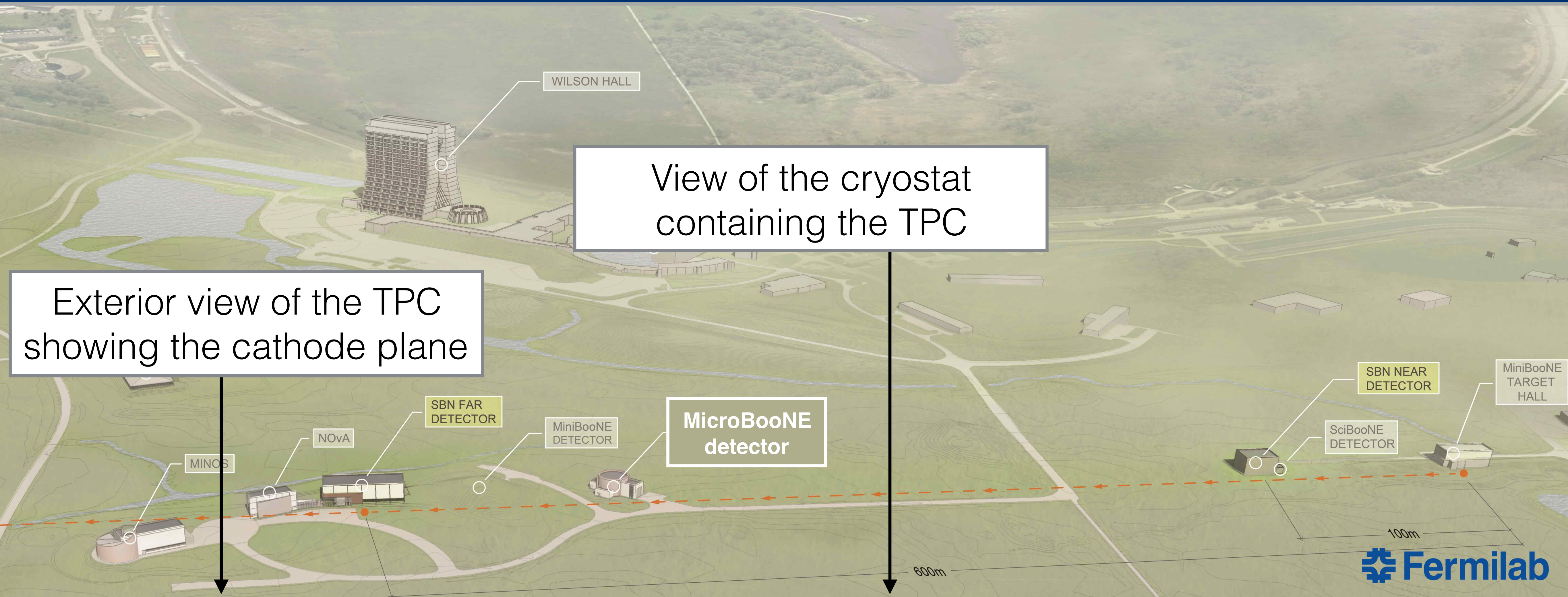
The MicroBooNE experiment

µBooNE

Exterior view of the TPC showing the cathode plane

View of the cryostat containing the TPC



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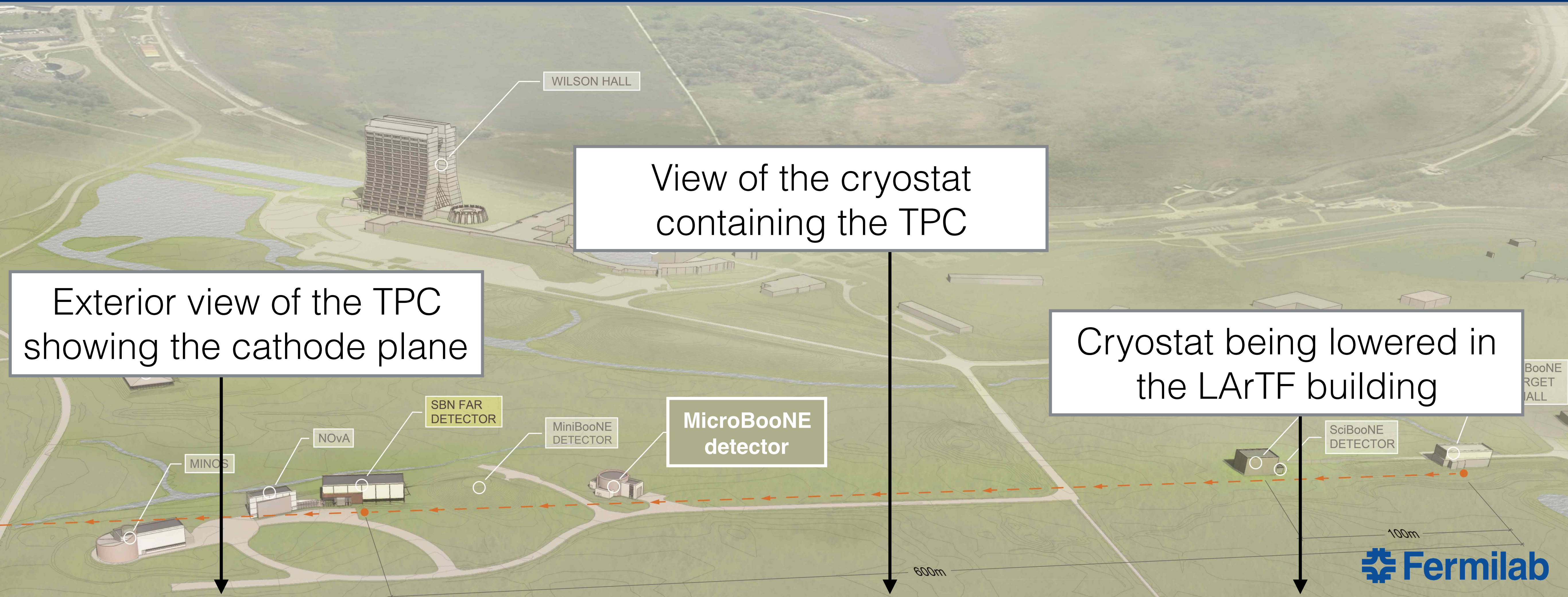

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View of the cryostat containing the TPC

Cryostat being lowered in the LArTF building

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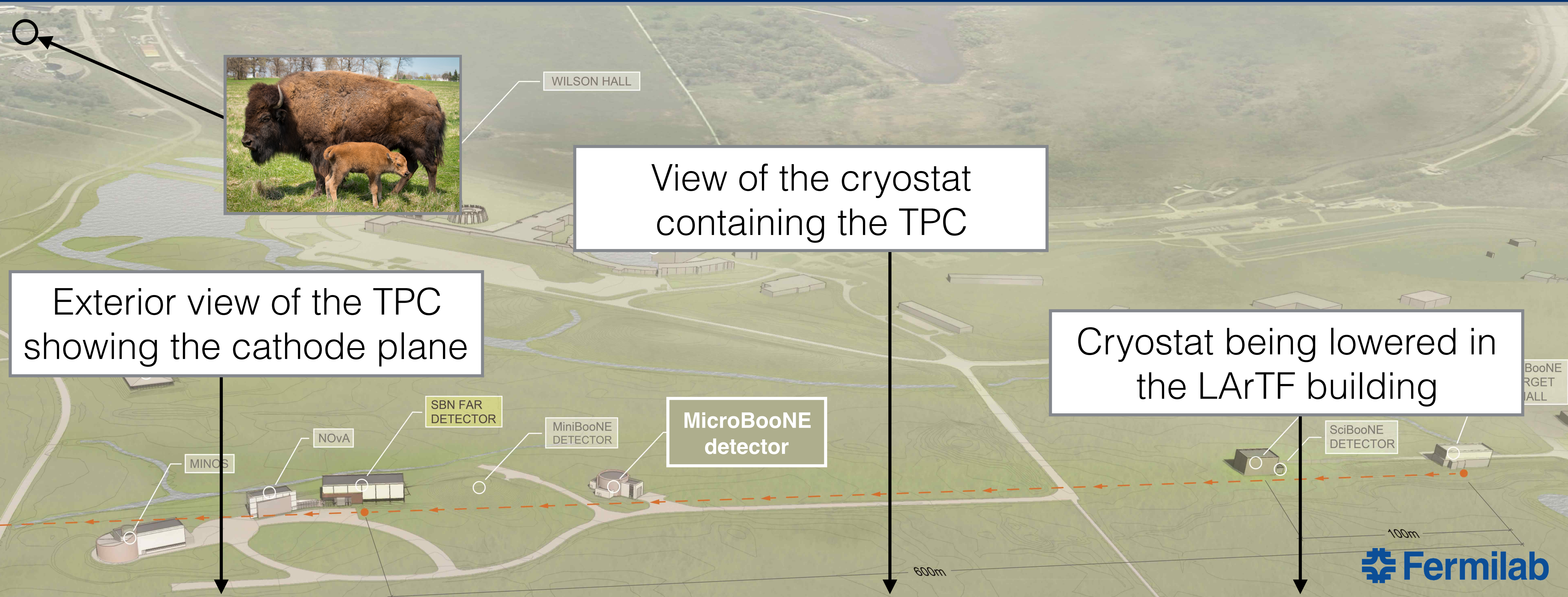

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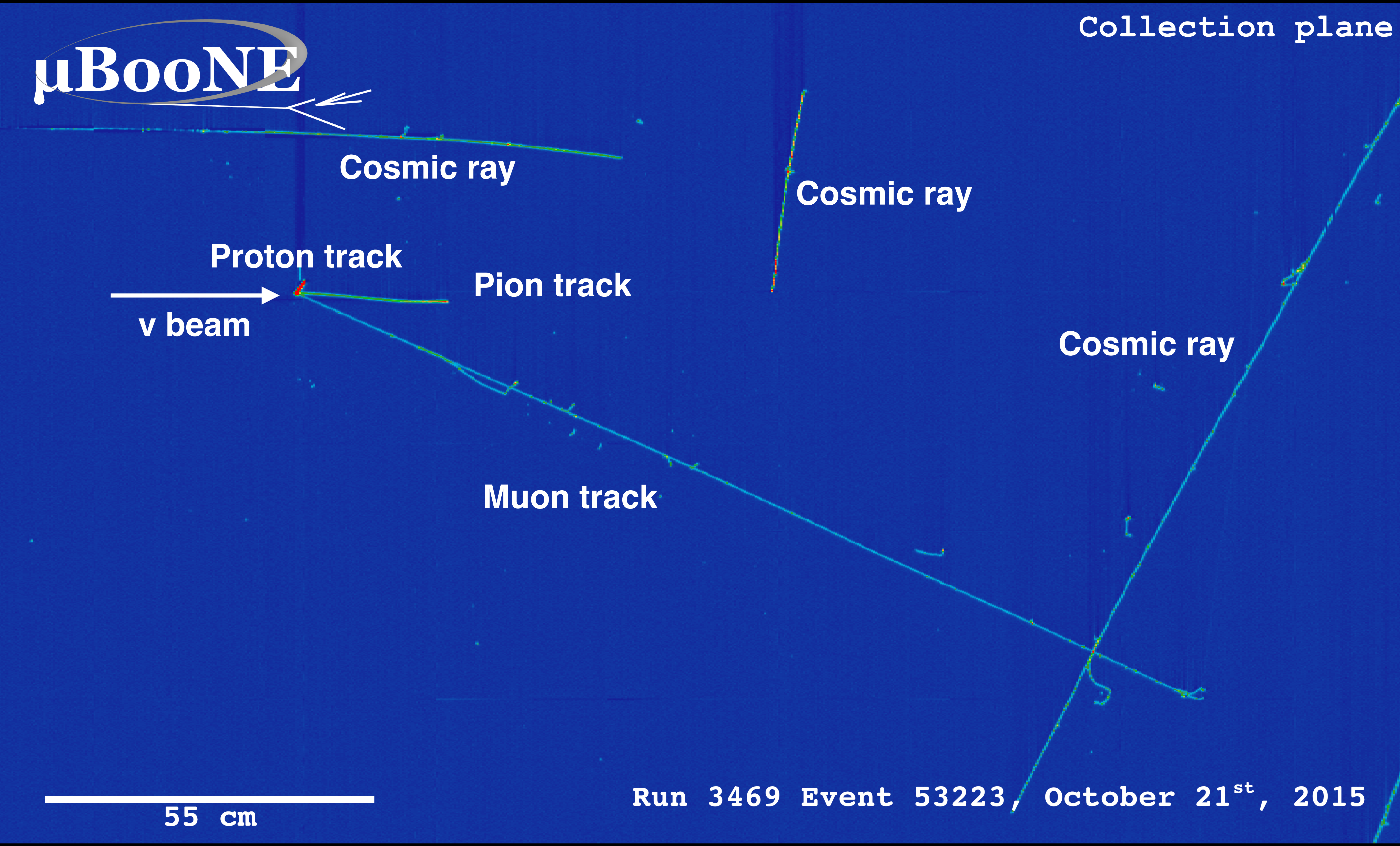
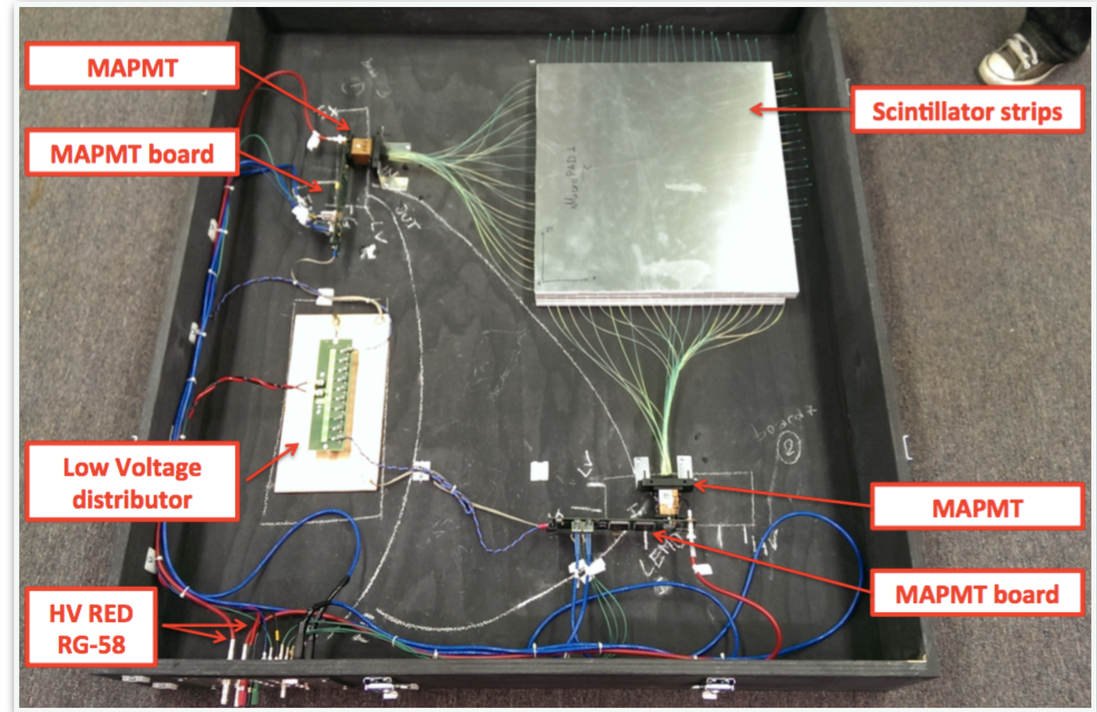
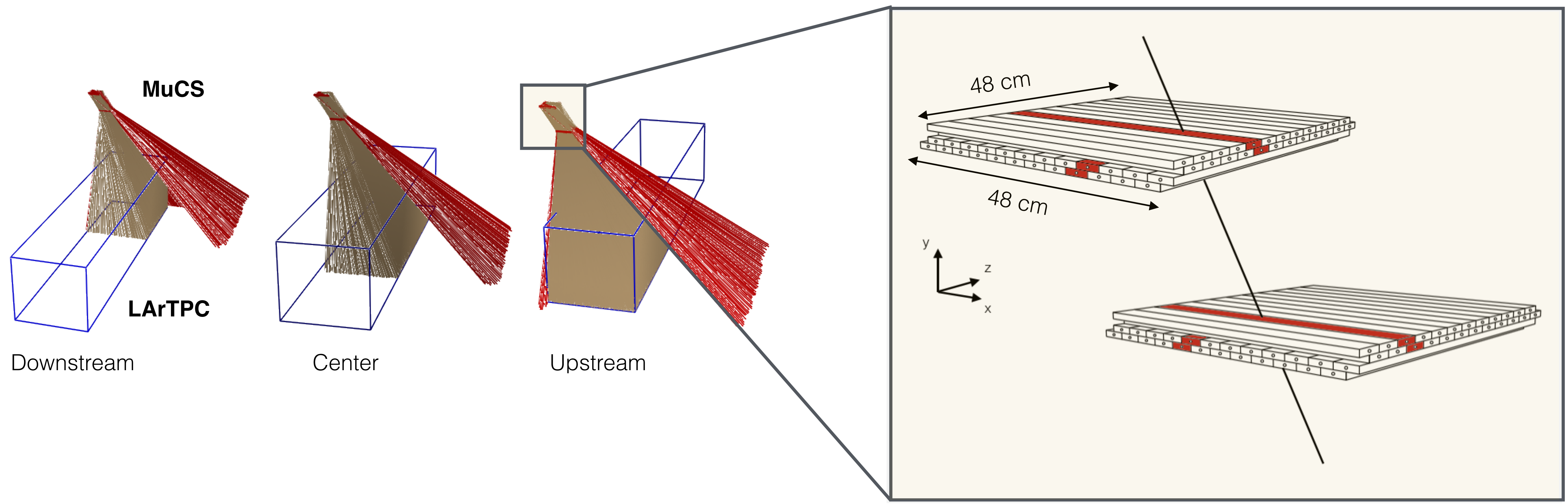


Collection plane
μBooNE
Cosmic ray
Cosmic ray
Proton track
Pion track
ν beam
Cosmic ray
Muon track
55 cm
Run 3469 Event 53223, October 21st, 2015

The Muon Counter Stack

- 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).





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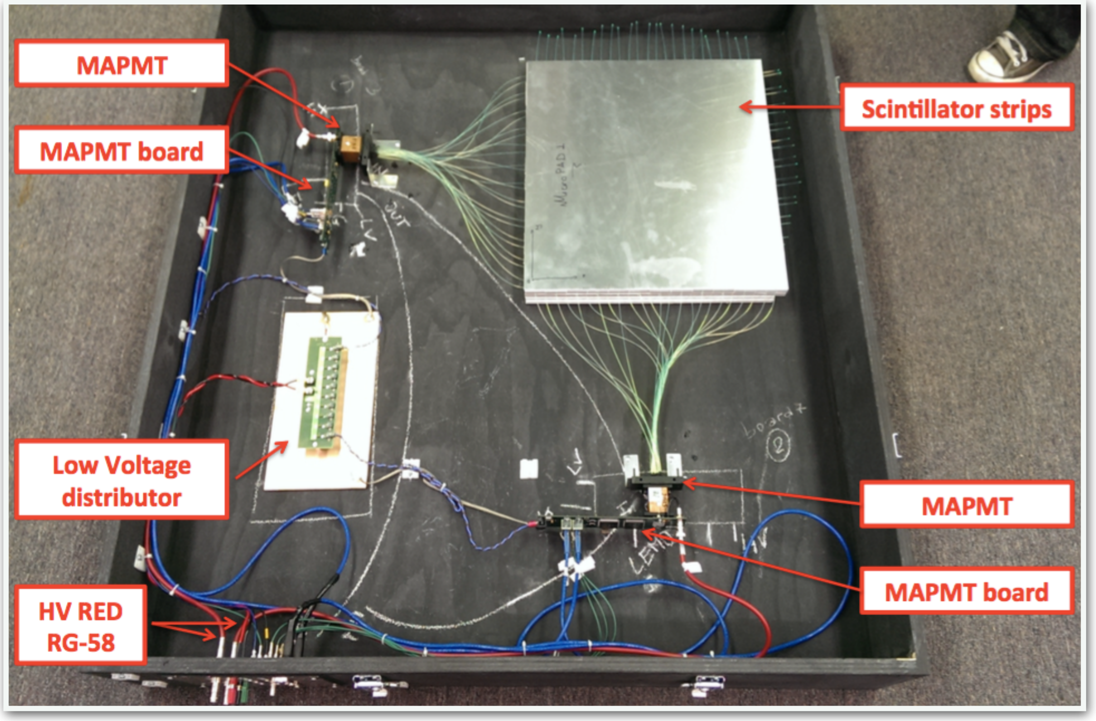
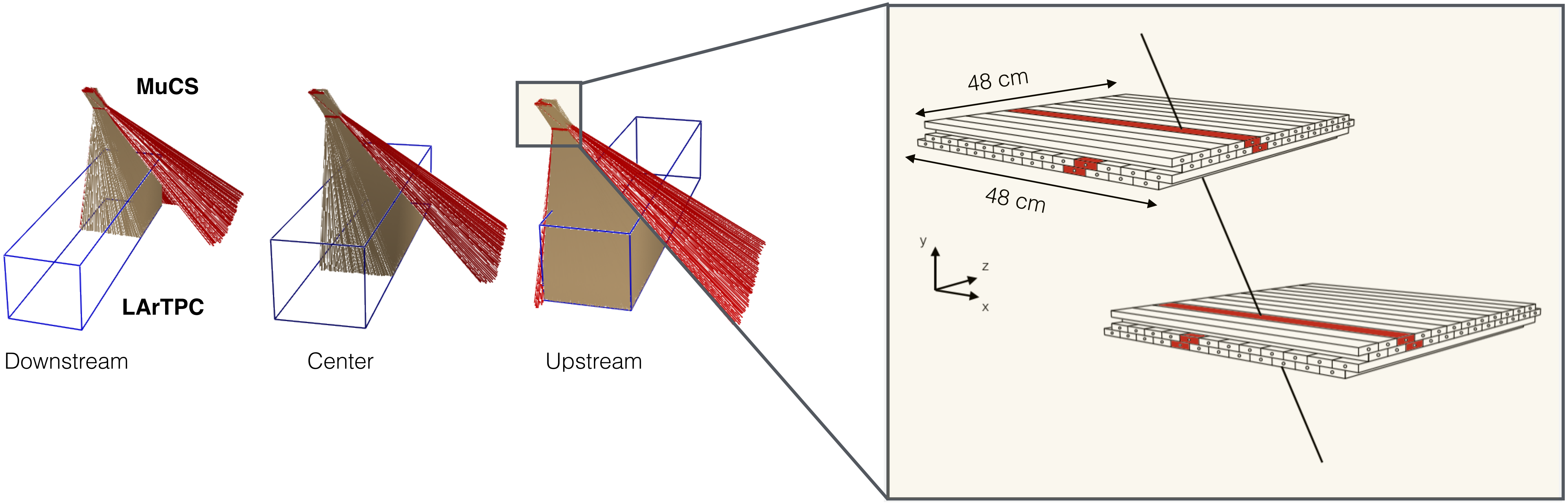
- A small muon counter stack (MuCS) has been installed on top of the TPC to help with several studies:
  - **Data reconstruction efficiency**
  - Optical system - TPC matching efficiency
  - Trigger efficiency
  - **Detector performances** (space-charge effect, collected charge, collected light…)





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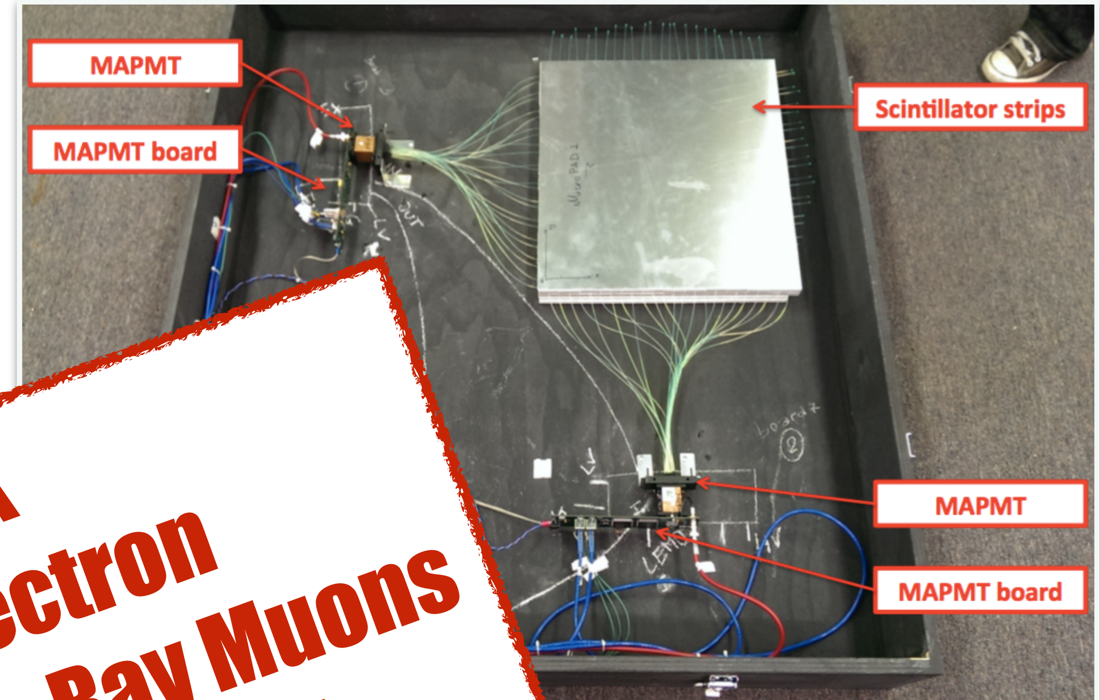
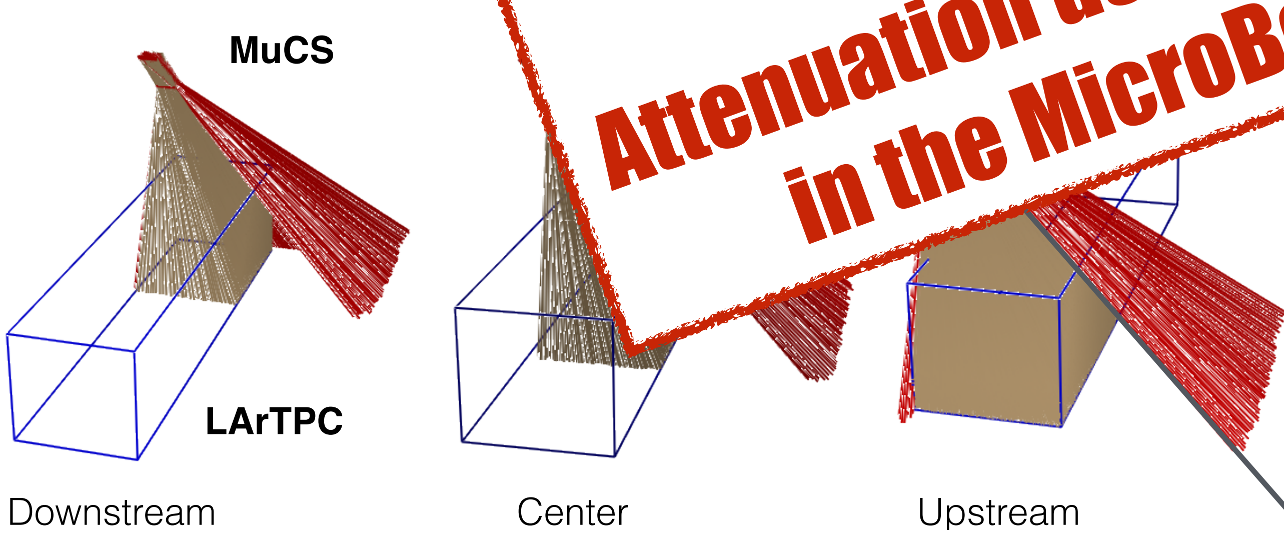
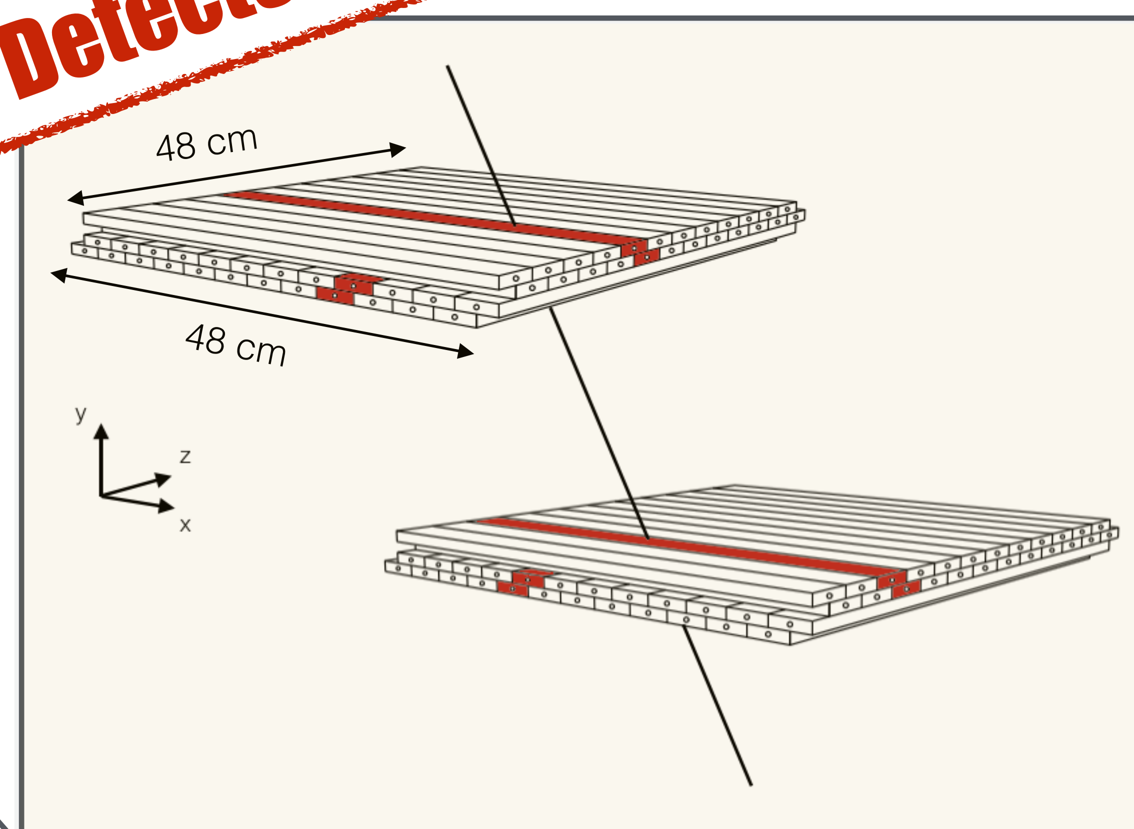


See Varuna's talk "Measurement of Electron Attenuation using Cosmic Ray Muons in the MicroBooNE Detector"!

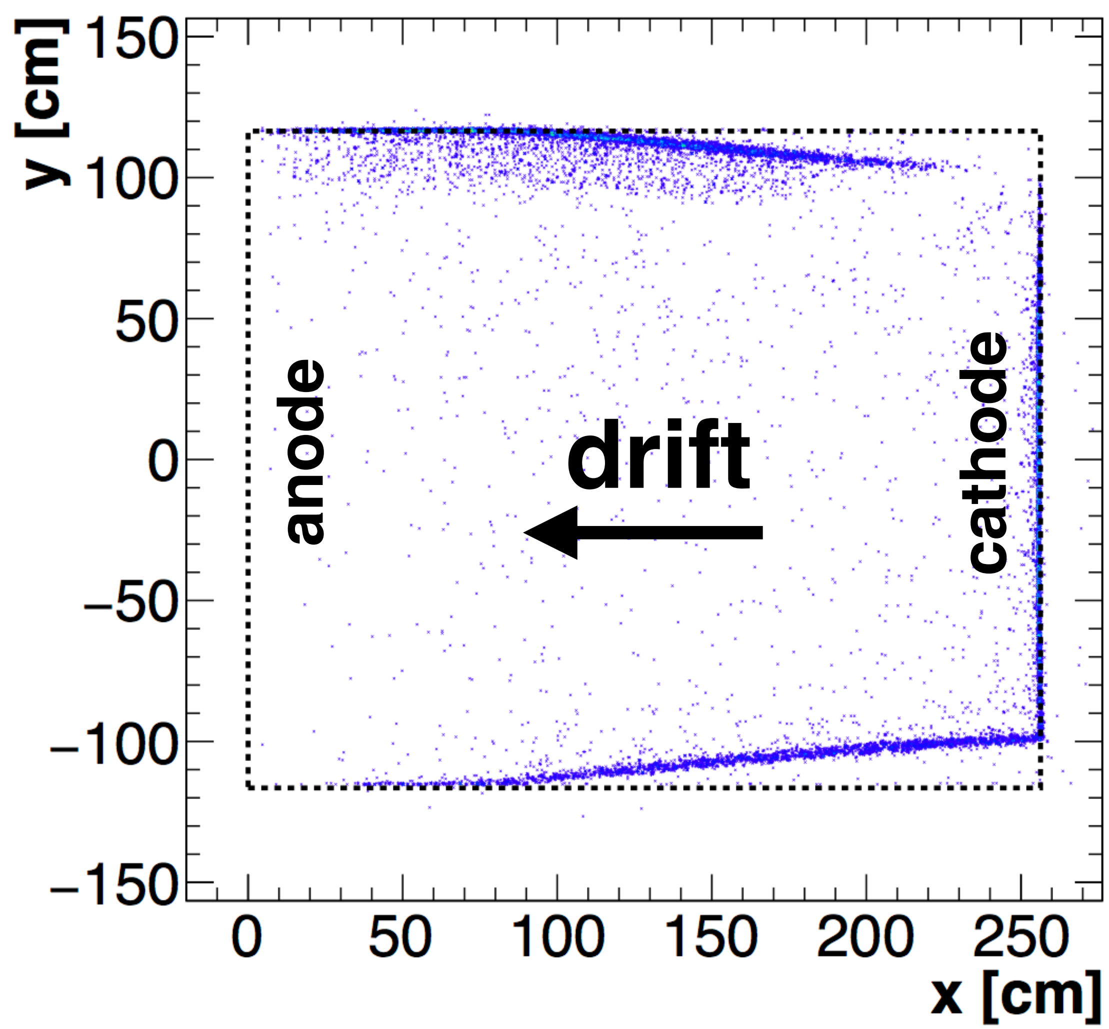




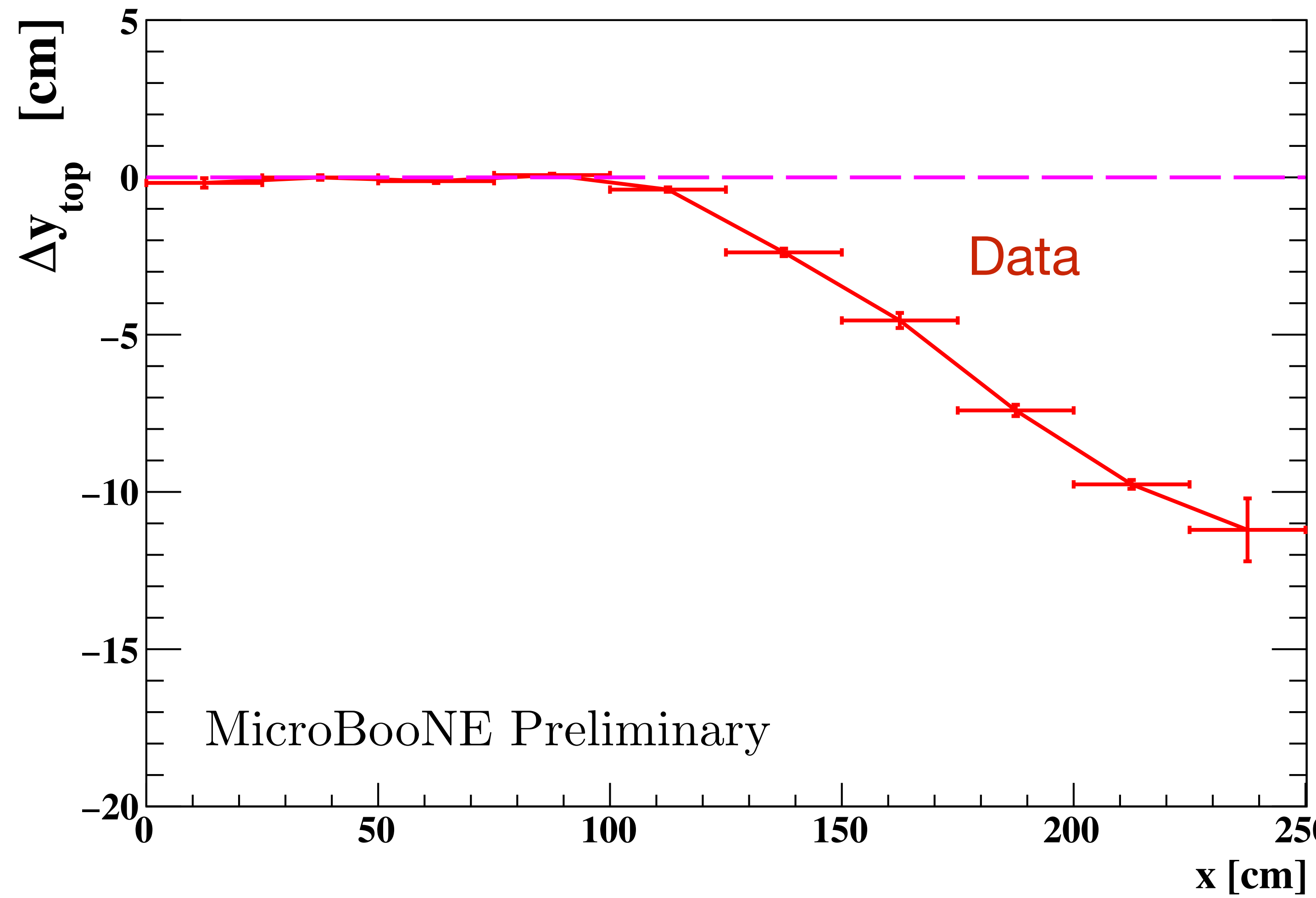
MuCS and space-charge effect

- 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.



MICROBOONE-NOTE-1018-PUB



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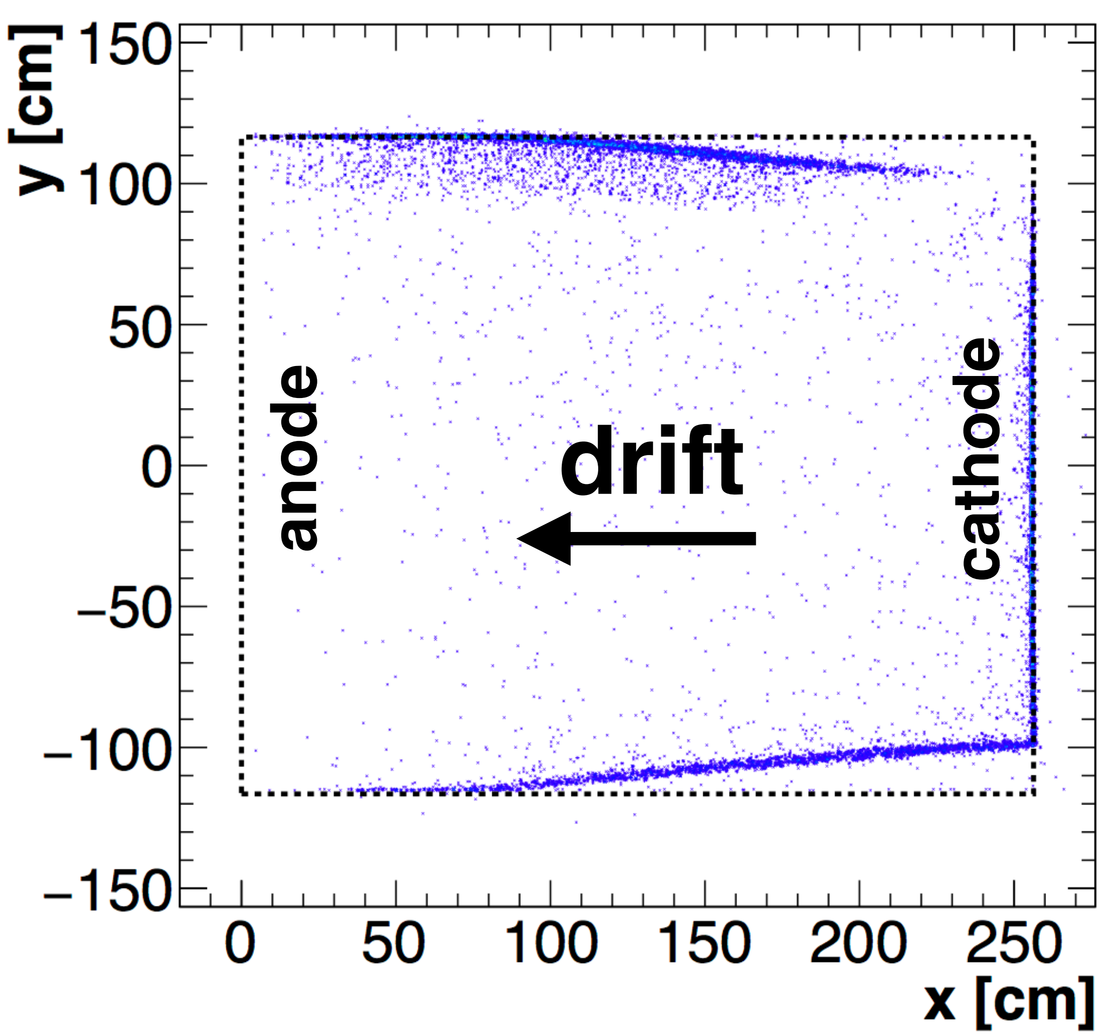

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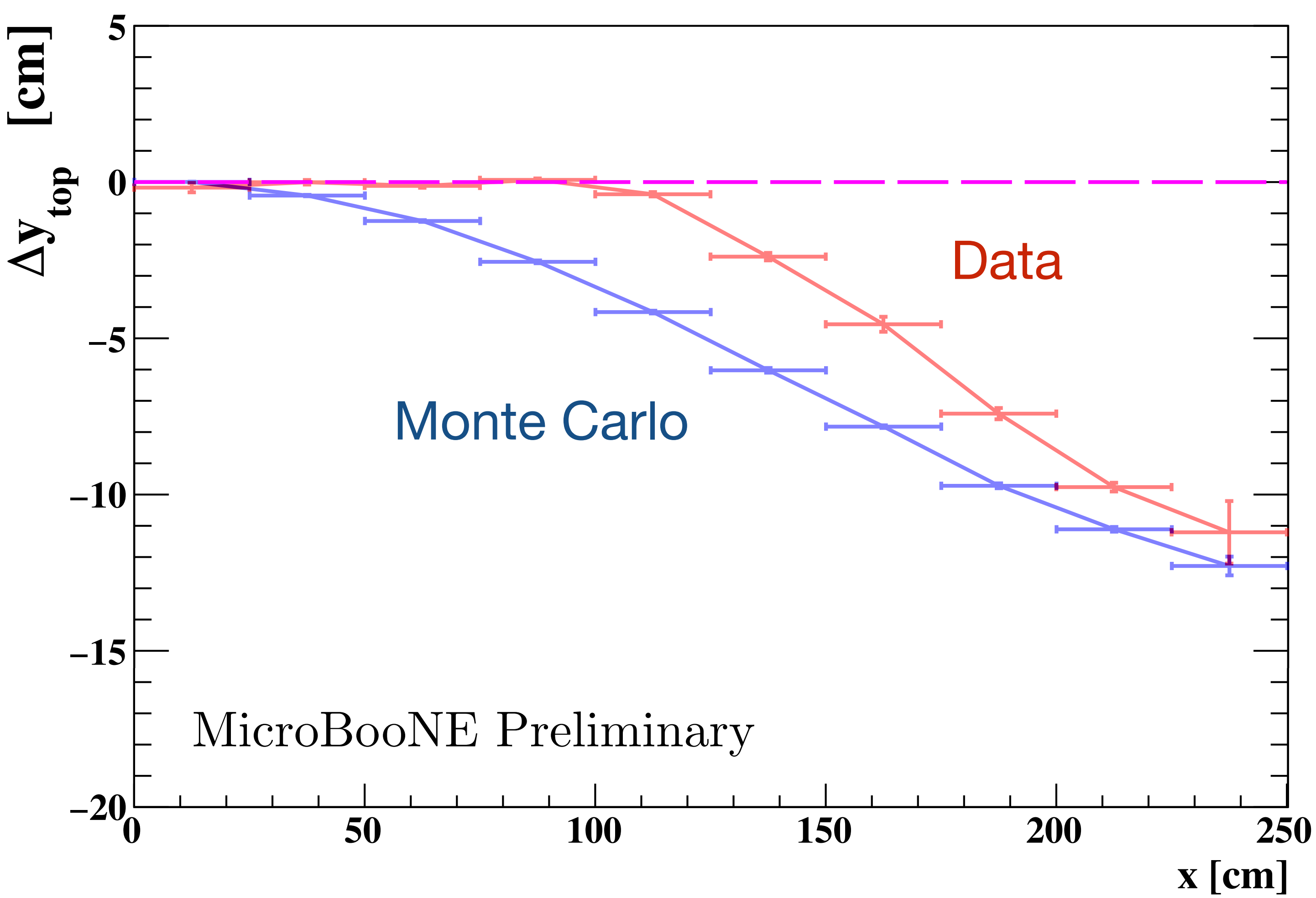
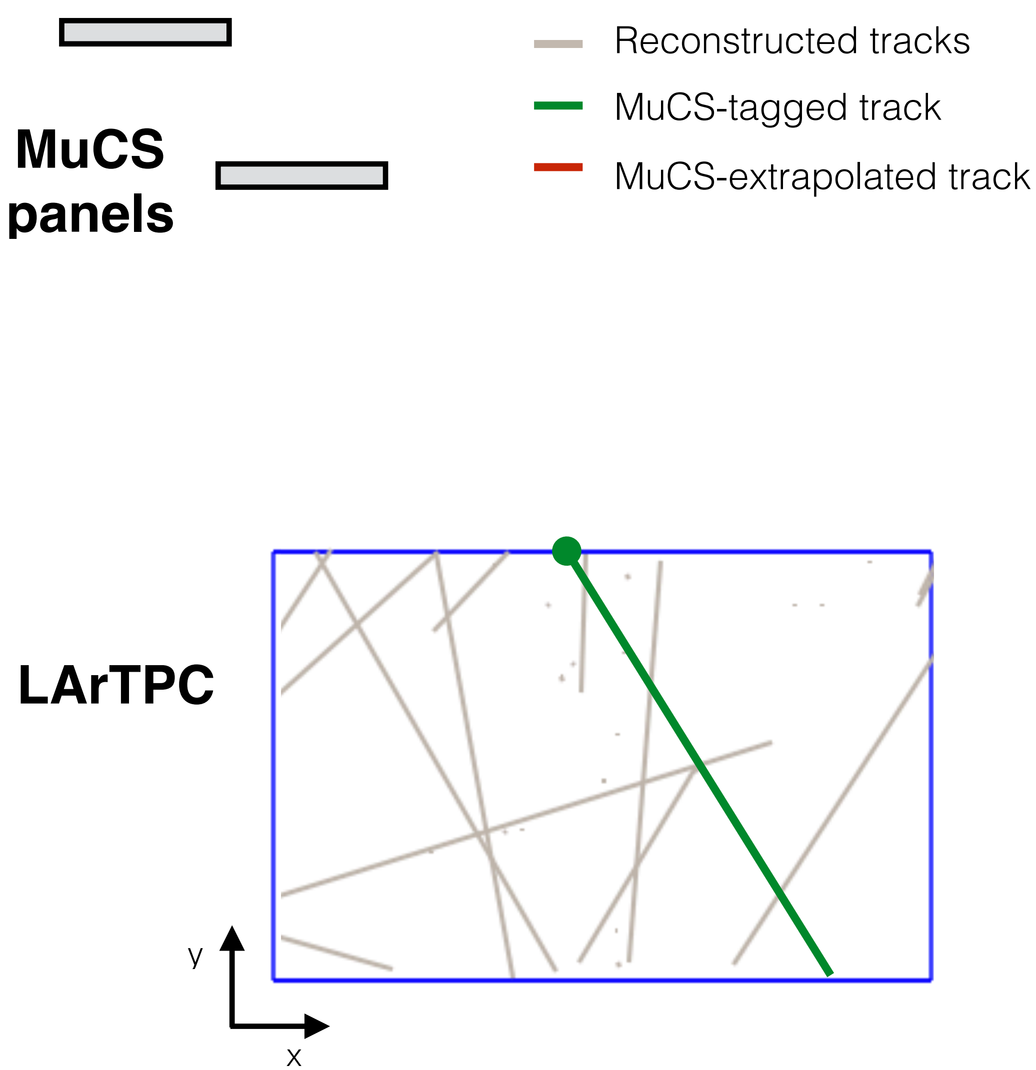
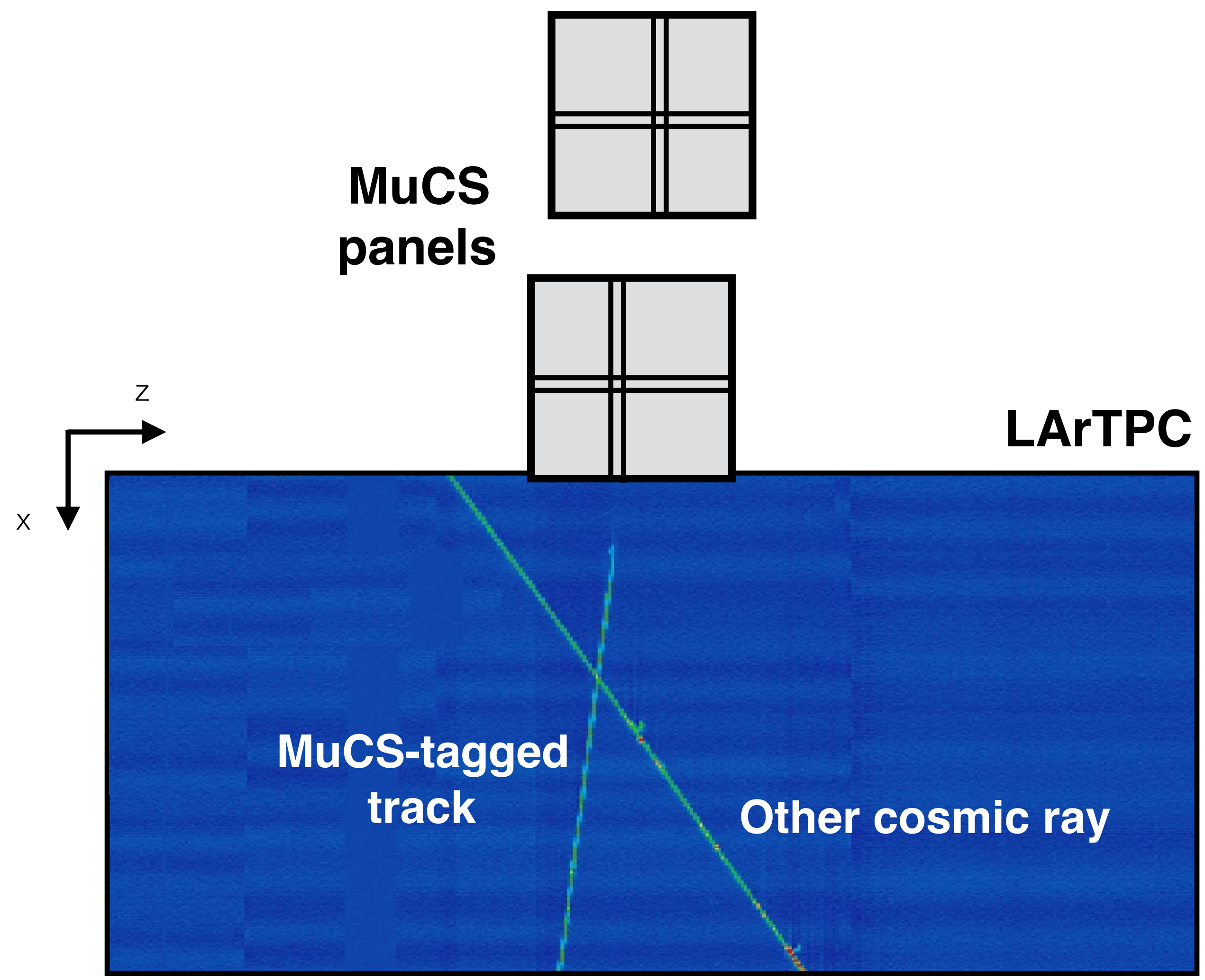


Reconstructing MuCS data

- 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.





*schematic representation, not to scale

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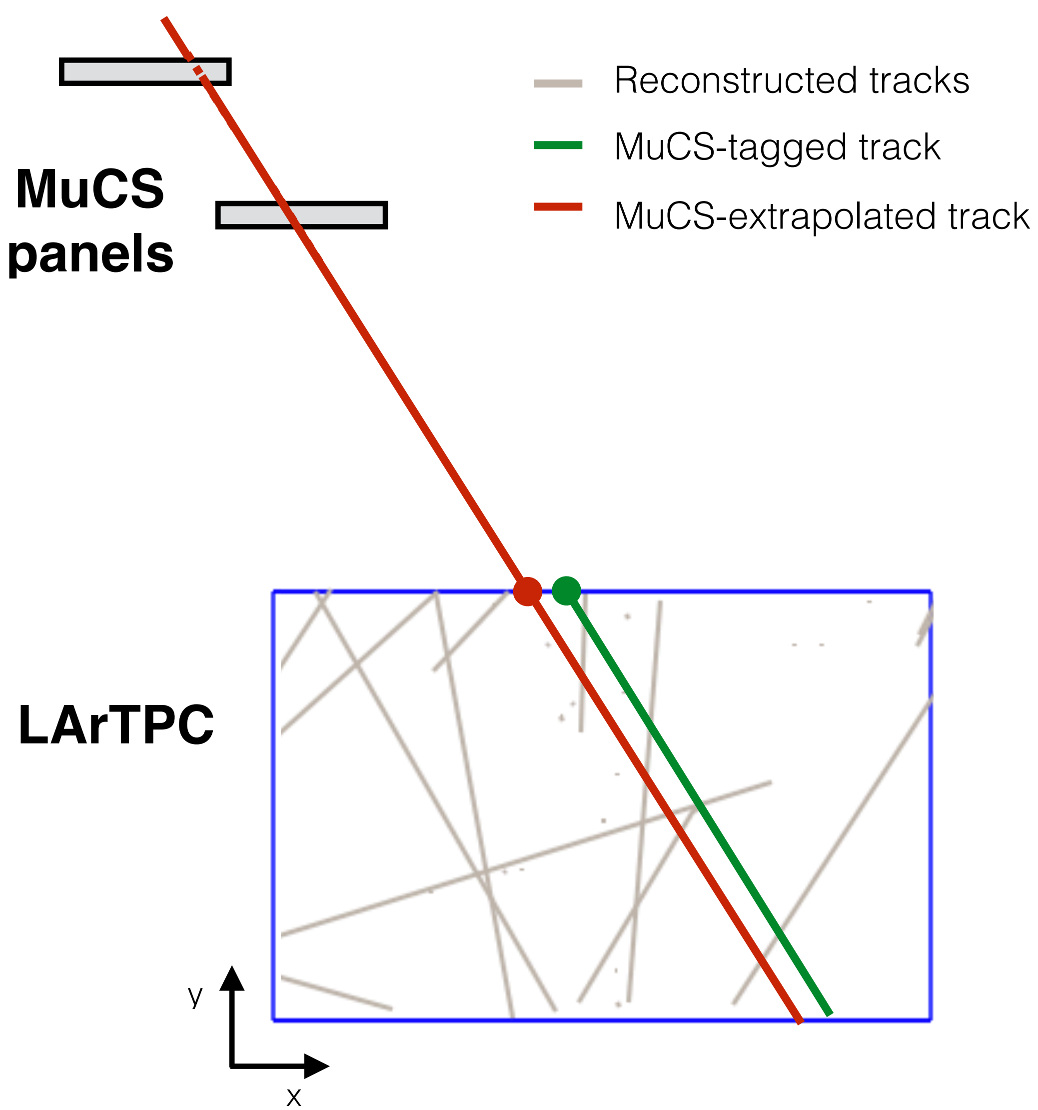

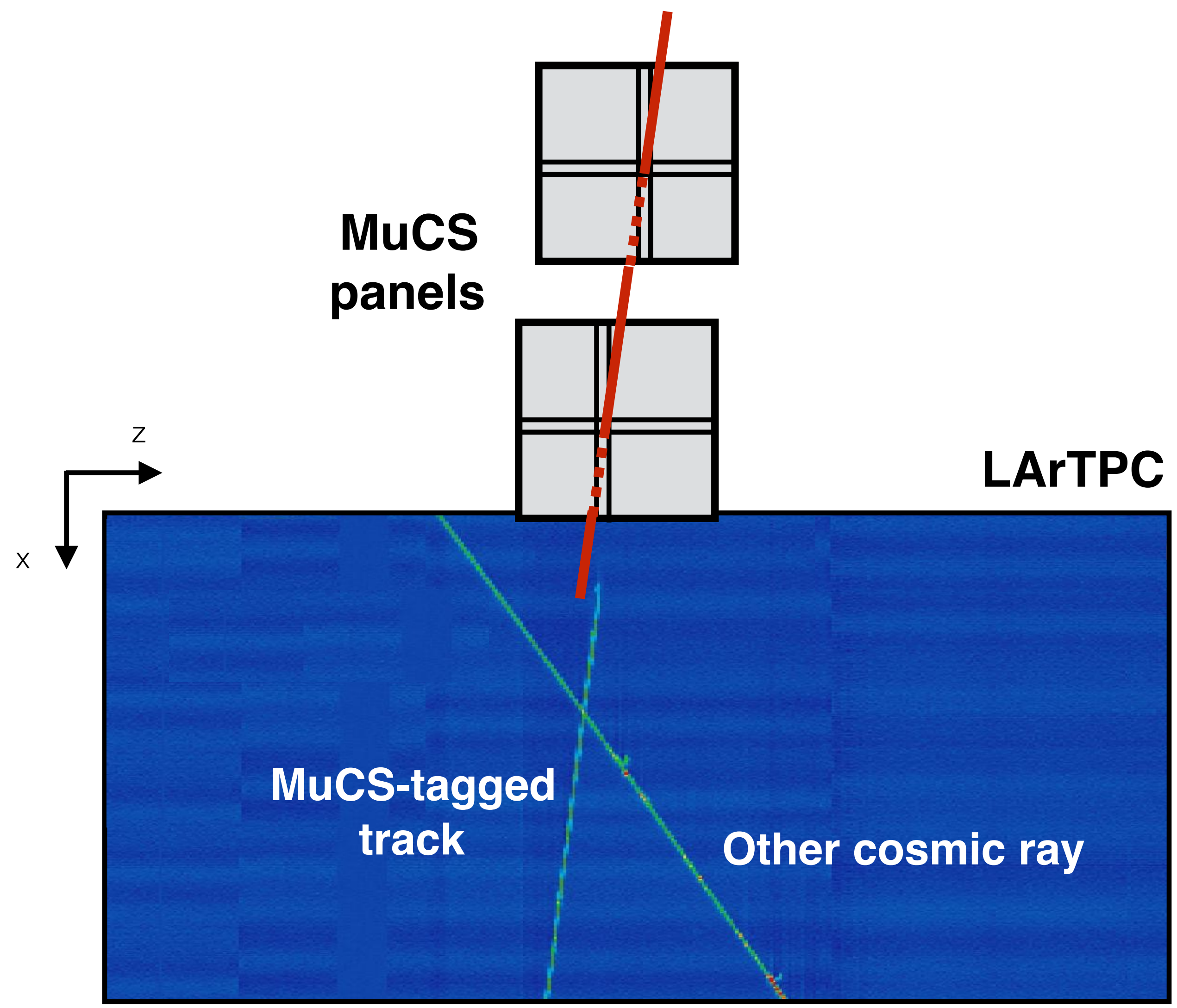

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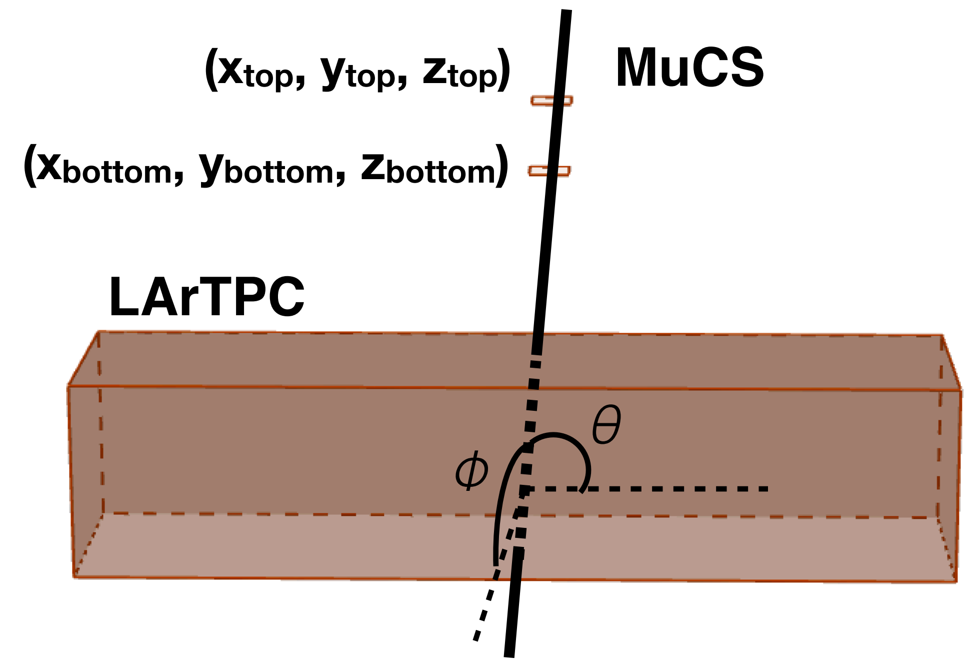
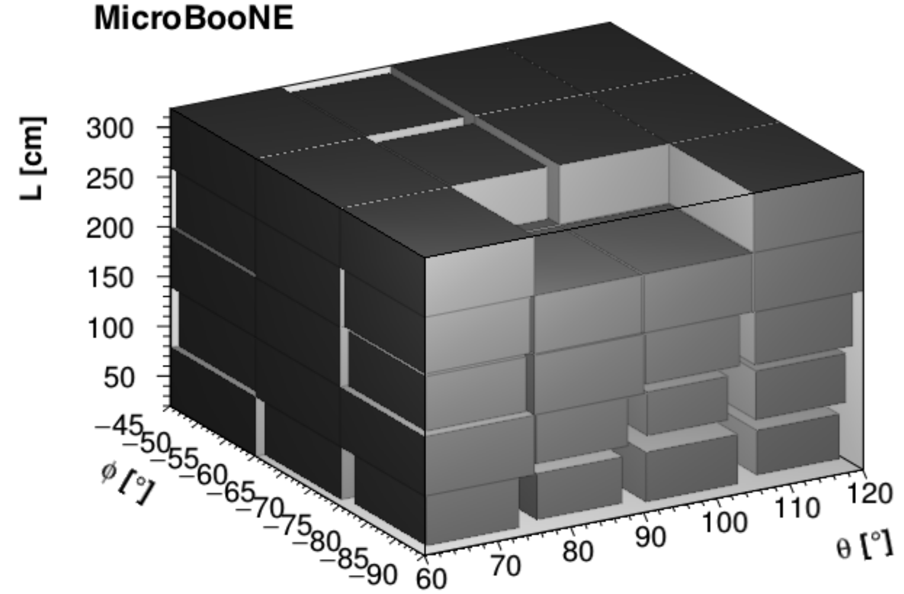
Efficiency measurement

- Using the **(x_{top}, y_{top}, z_{top})** and **(x_{bottom}, y_{bottom}, z_{bottom})** points given by the MuCS panels, it is possible to measure the reconstruction efficiency as a function of θ, ϕ and extrapolated length in the TPC L.



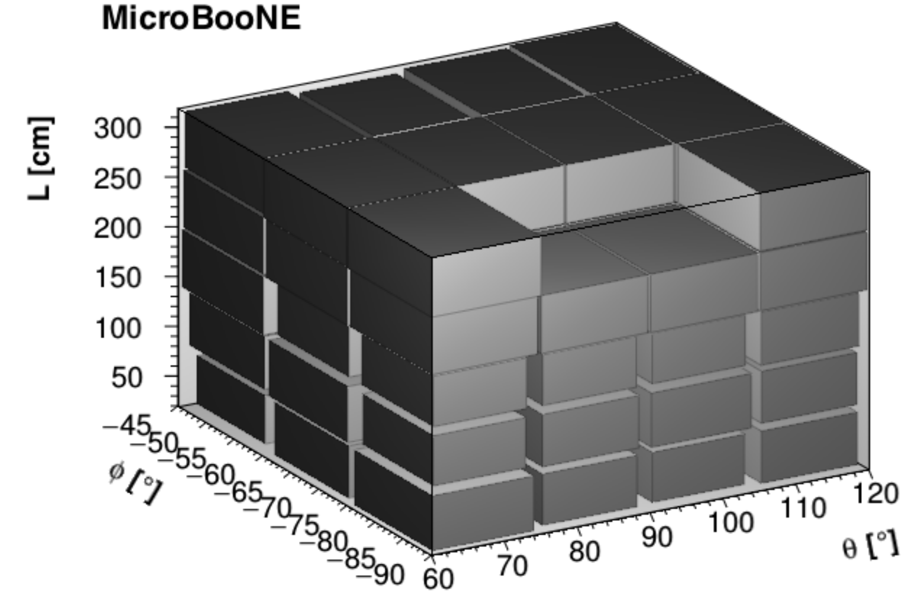
Monte Carlo

$$\epsilon_{\mathrm{MC}} = \frac{\text{N. of reconstructed cosmic rays}}{\text{N. of generated cosmic rays}} = 97.4 \pm 0.1\,\%$$



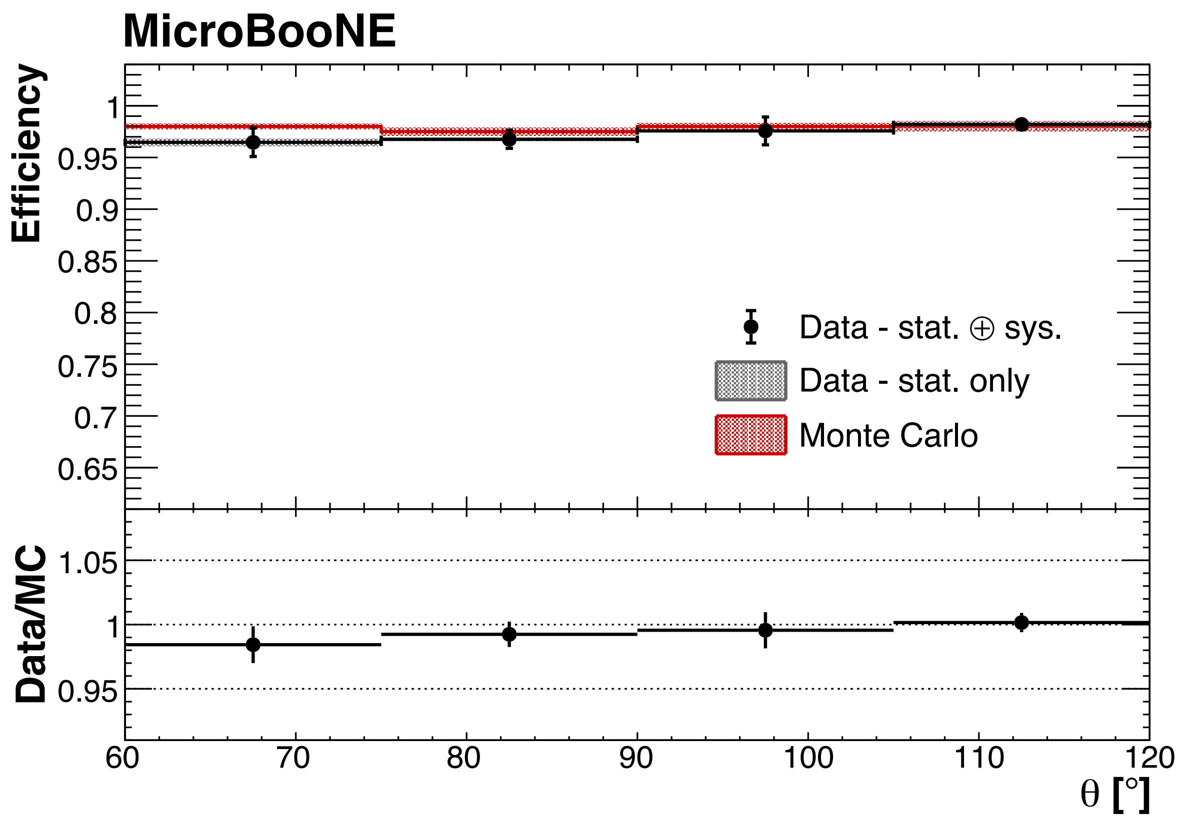
Data

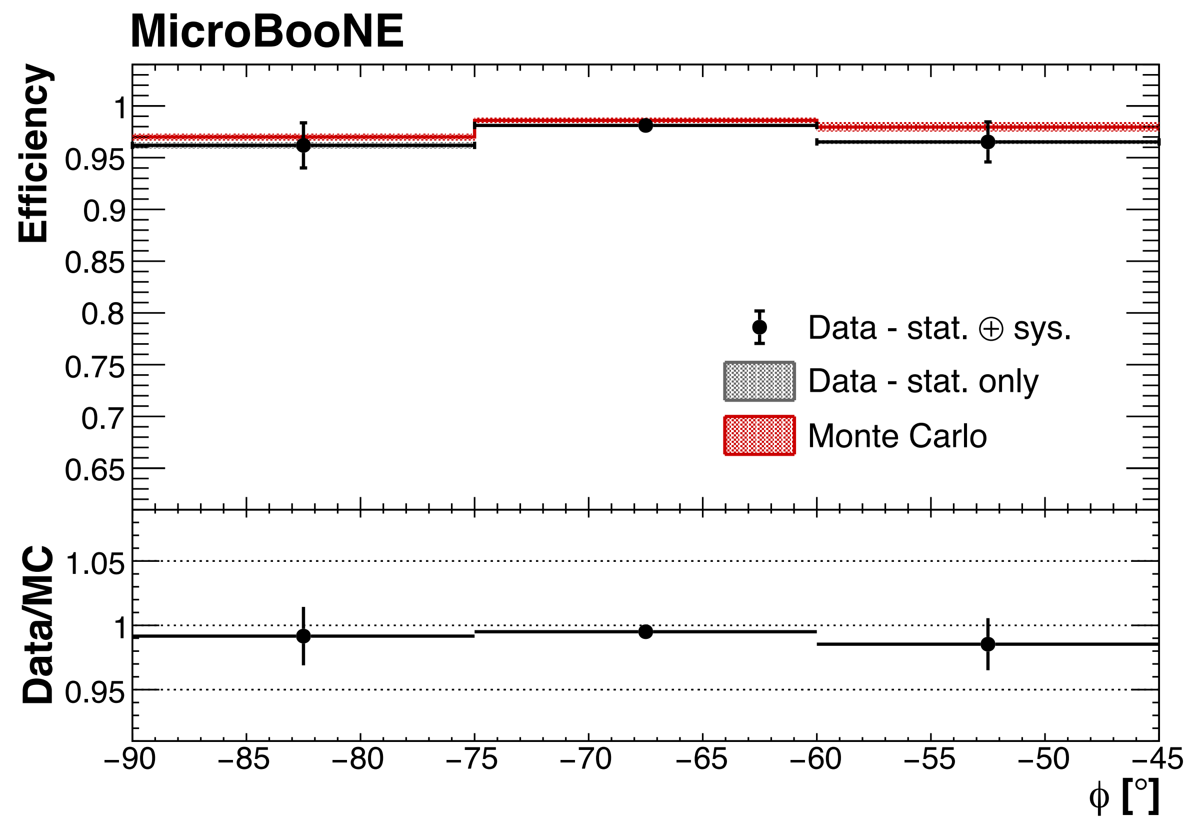
$$\epsilon_{\mathrm{data}} = \frac{\text{N. of reco. MuCS cosmic-ray events}}{\text{N. of MuCS triggered events}} = 97.1 \pm 0.1\ (\text{stat}) \pm 1.4\ (\text{sys})\ \%$$

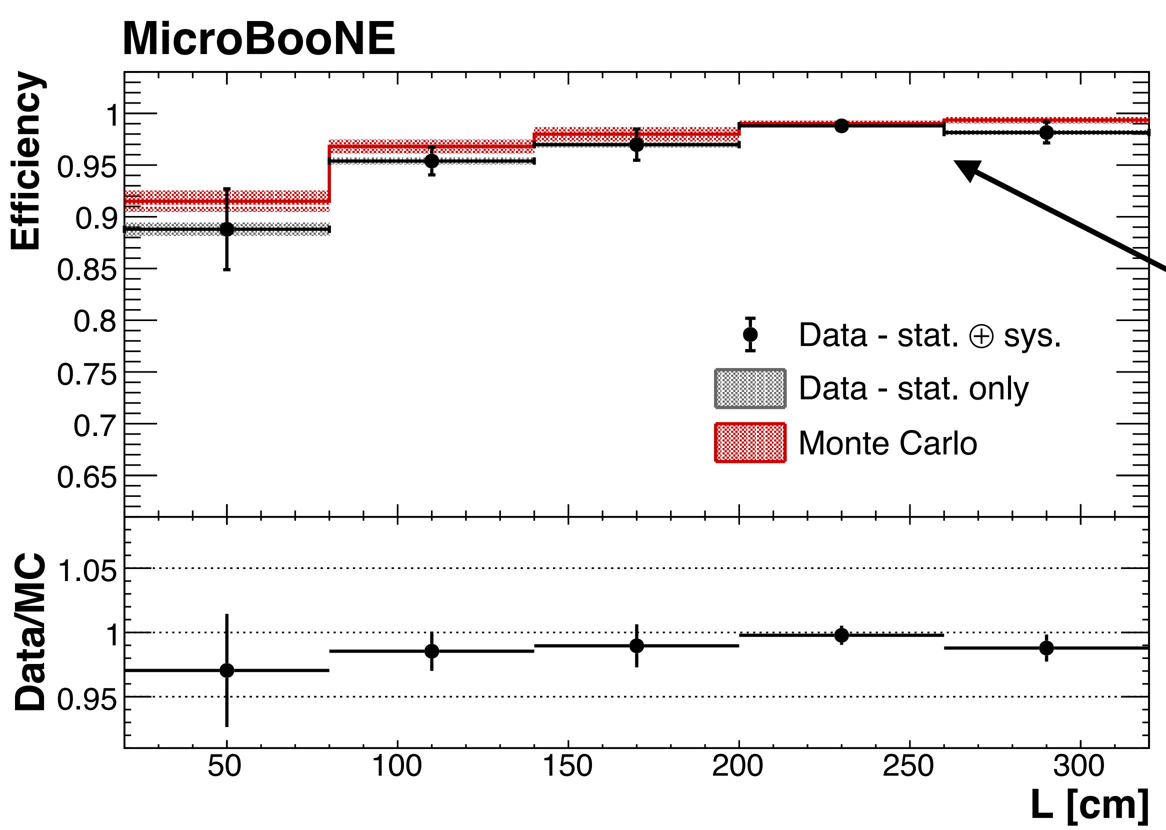


Results

One-dimensional projections







Proportionality between extrapolated length and reconstruction efficiency: larger number of hits means track easier to reconstruct

Results

Two-dimensional projections

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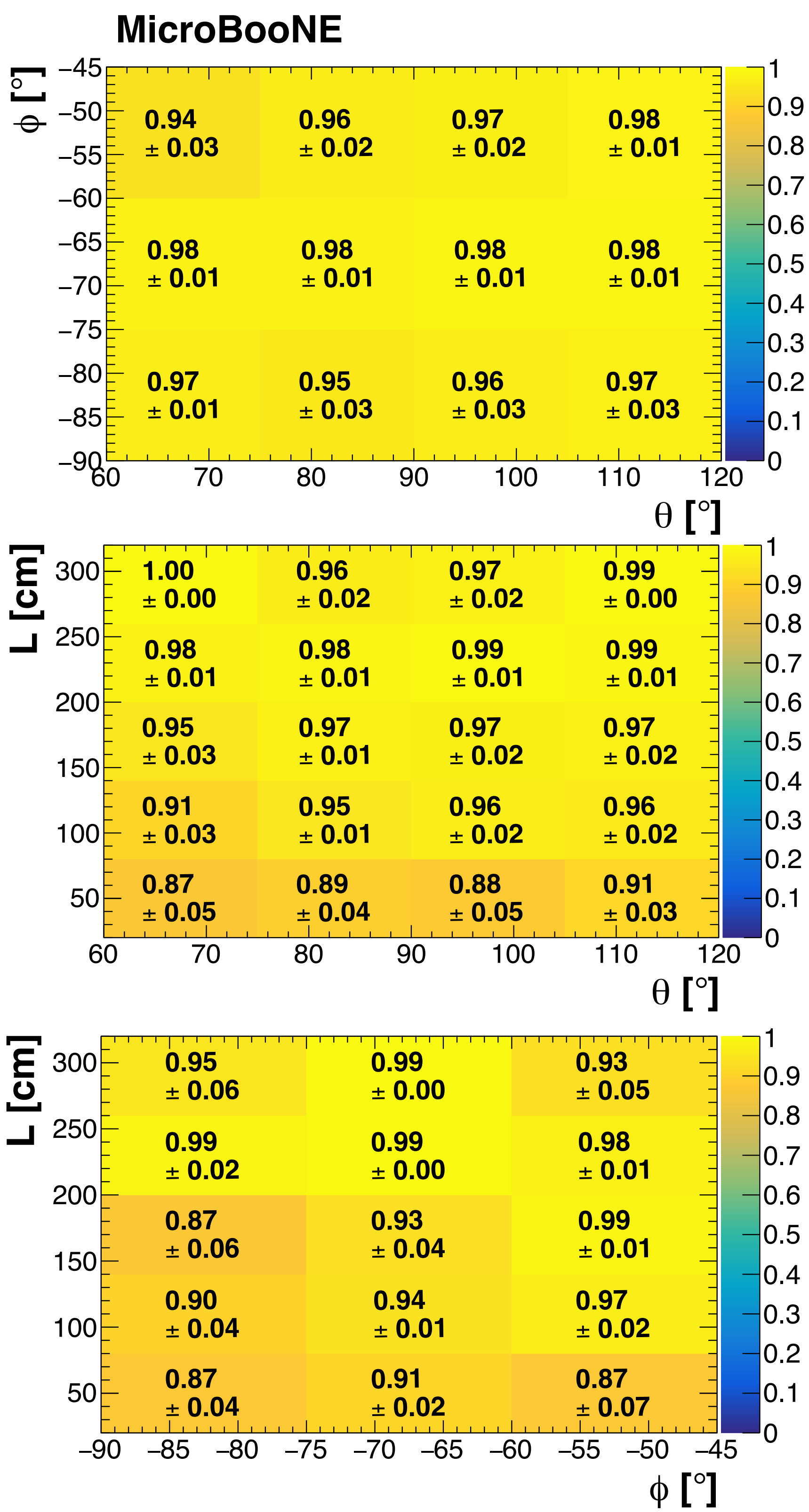
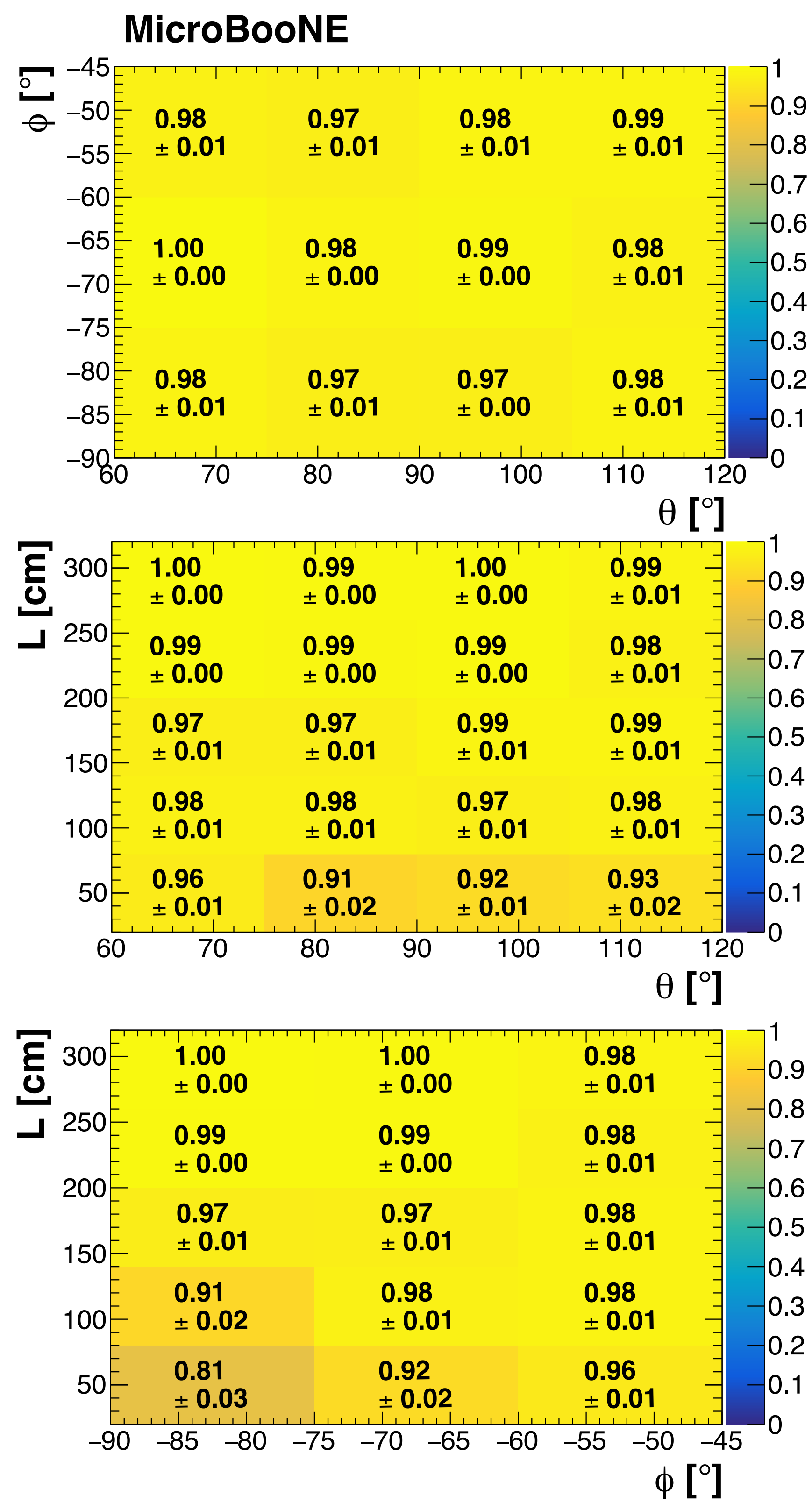
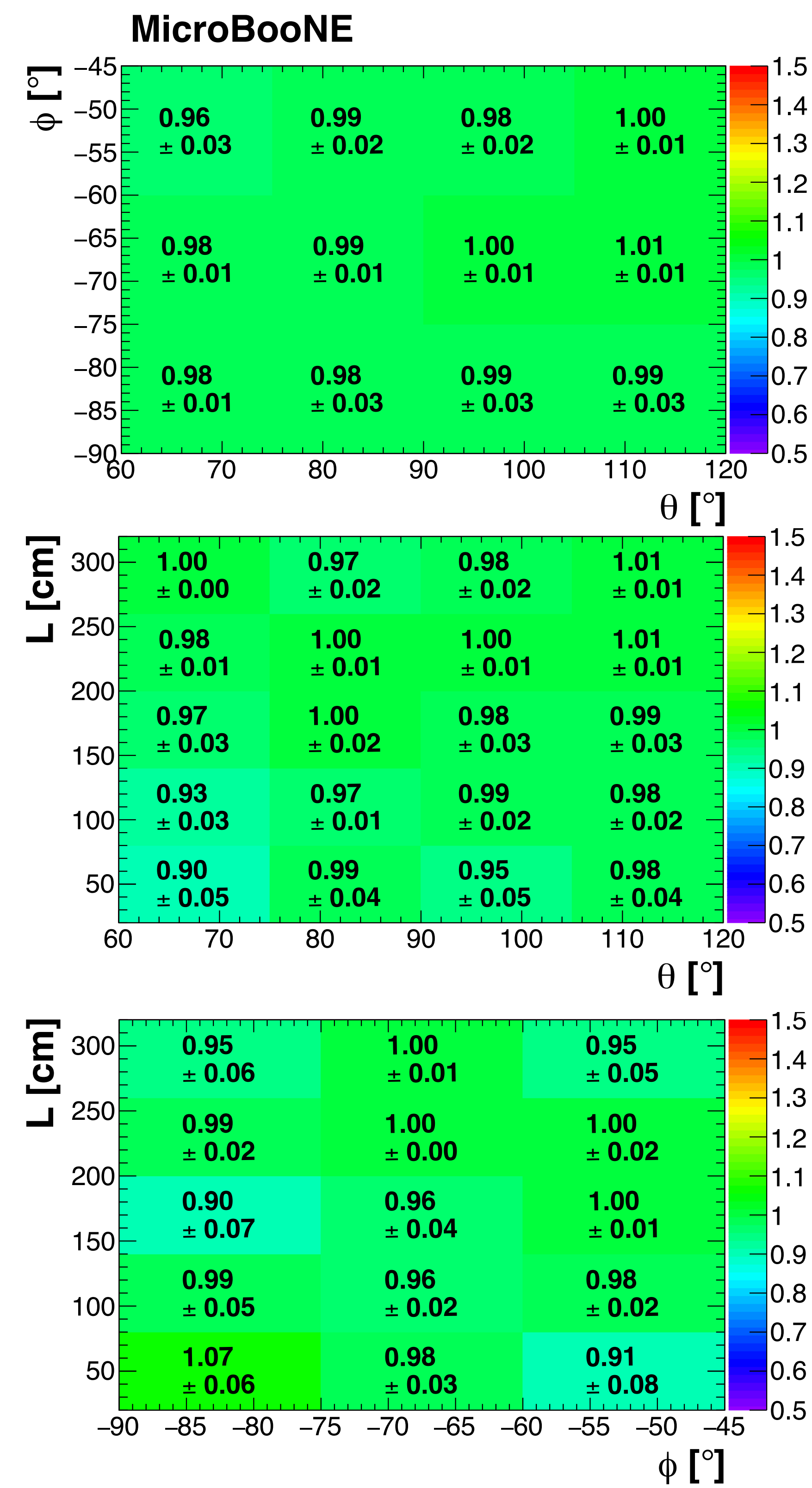


Monte Carlo



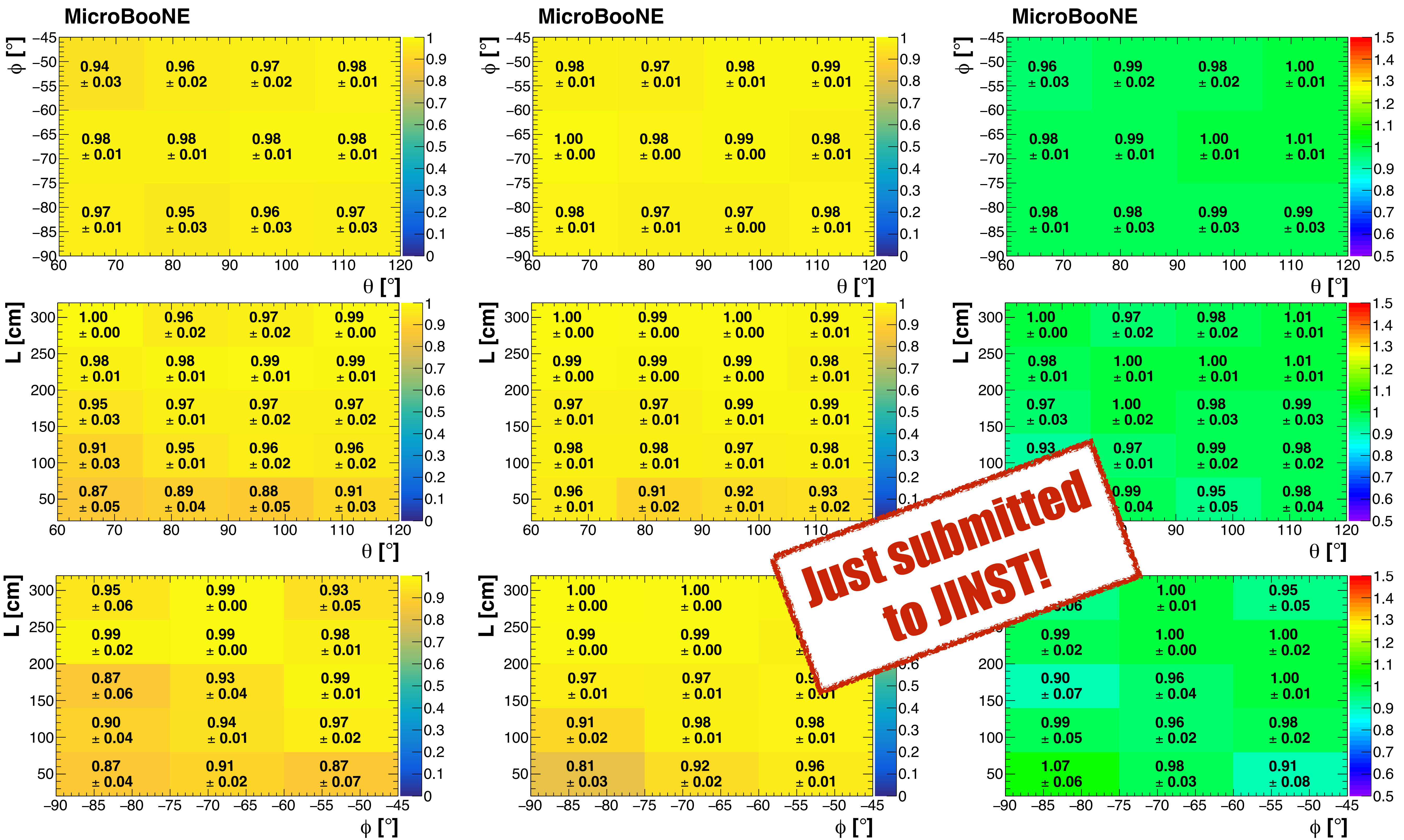
Data/Monte Carlo



Results

Two-dimensional projections

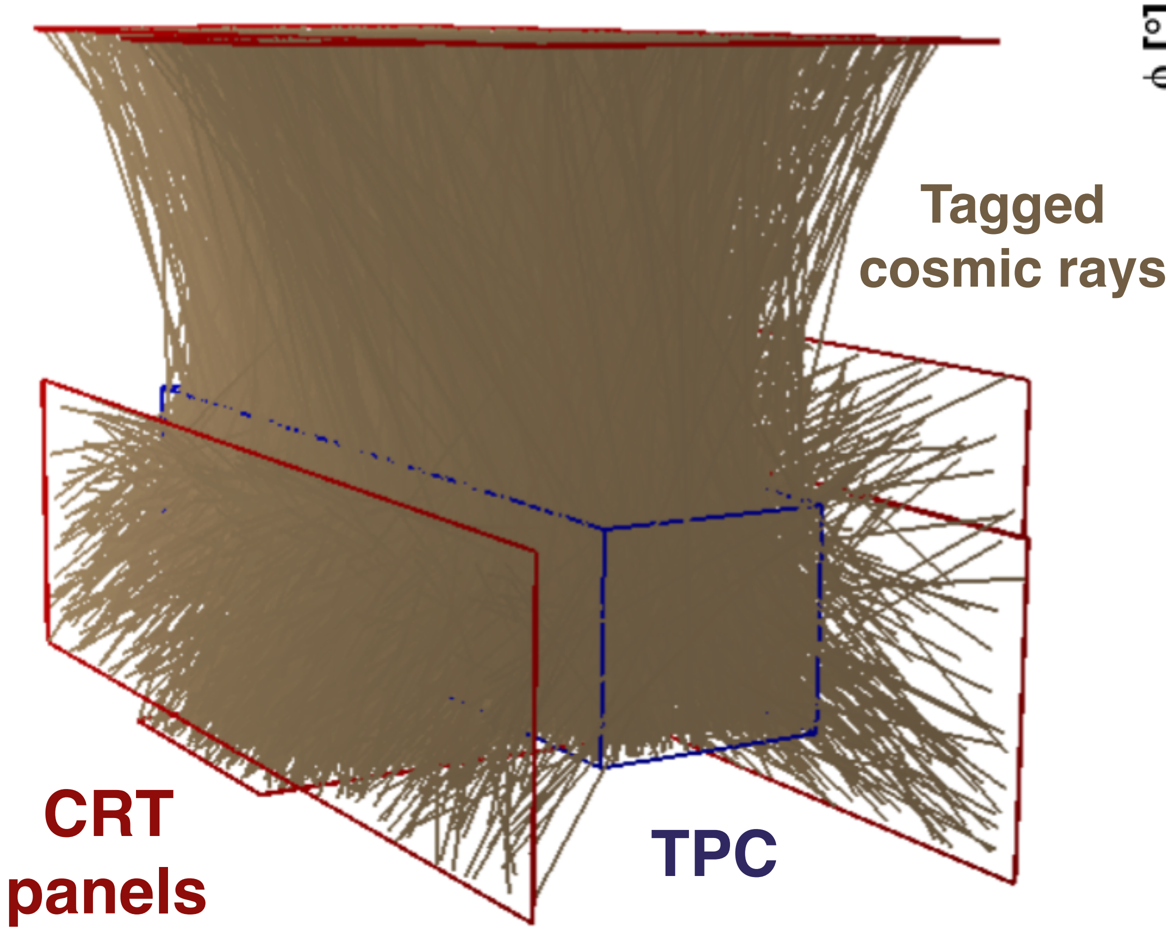
Data | **Monte Carlo** | **Data/Monte Carlo**

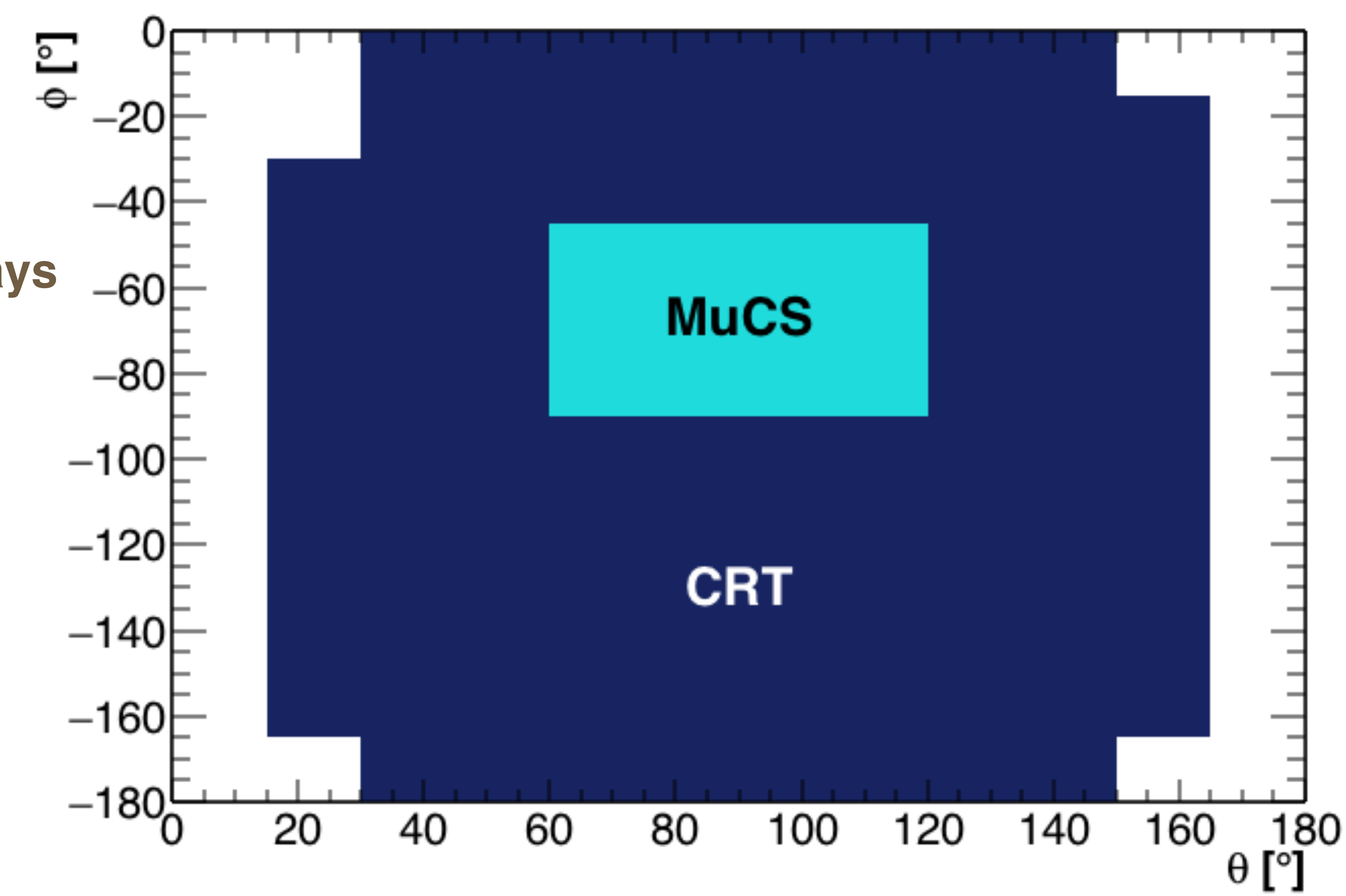


Cosmic Ray Tagger

- 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.

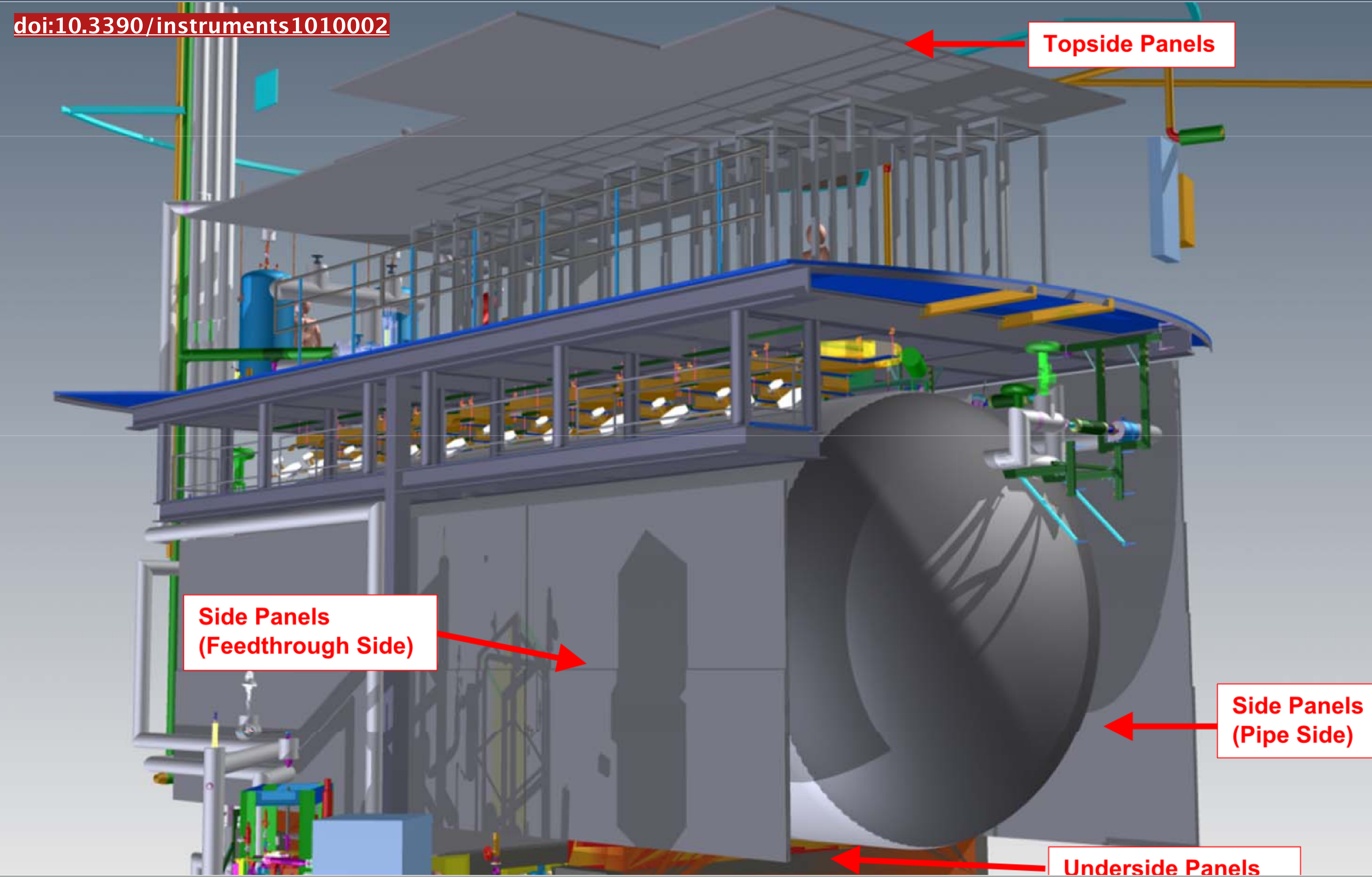
- The Cosmic Ray Tagger installation has been completed in January, 2017.
- The angular coverage provided by the CRT is much larger than the one of the MuCS and close to 100%. It will be possible to **measure efficiency-corrected quantities**, such as the cosmic-ray flux in MicroBooNE, and mitigate the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





Cosmic Ray Tagger

doi:10.3390/instruments1010002



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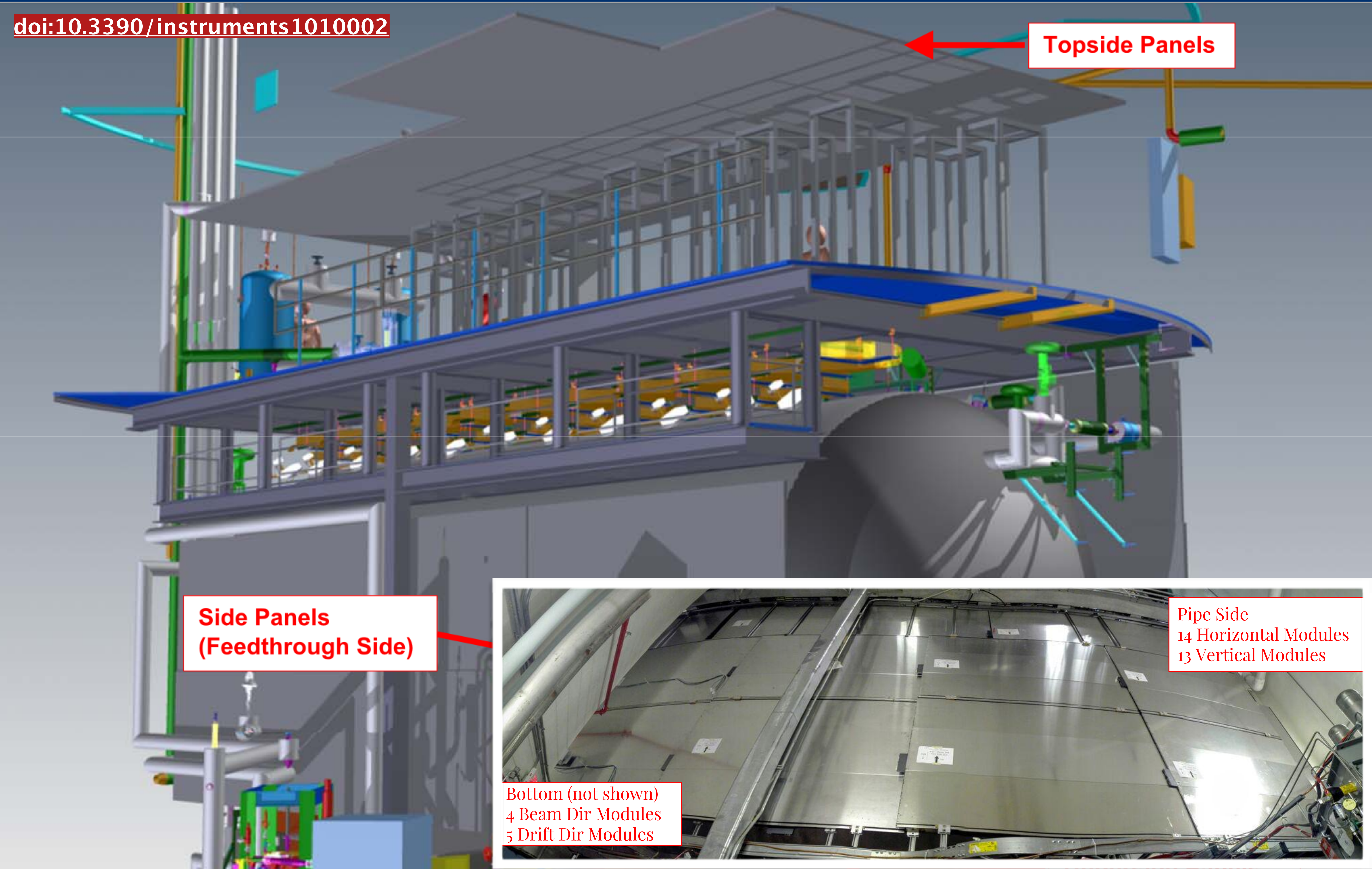

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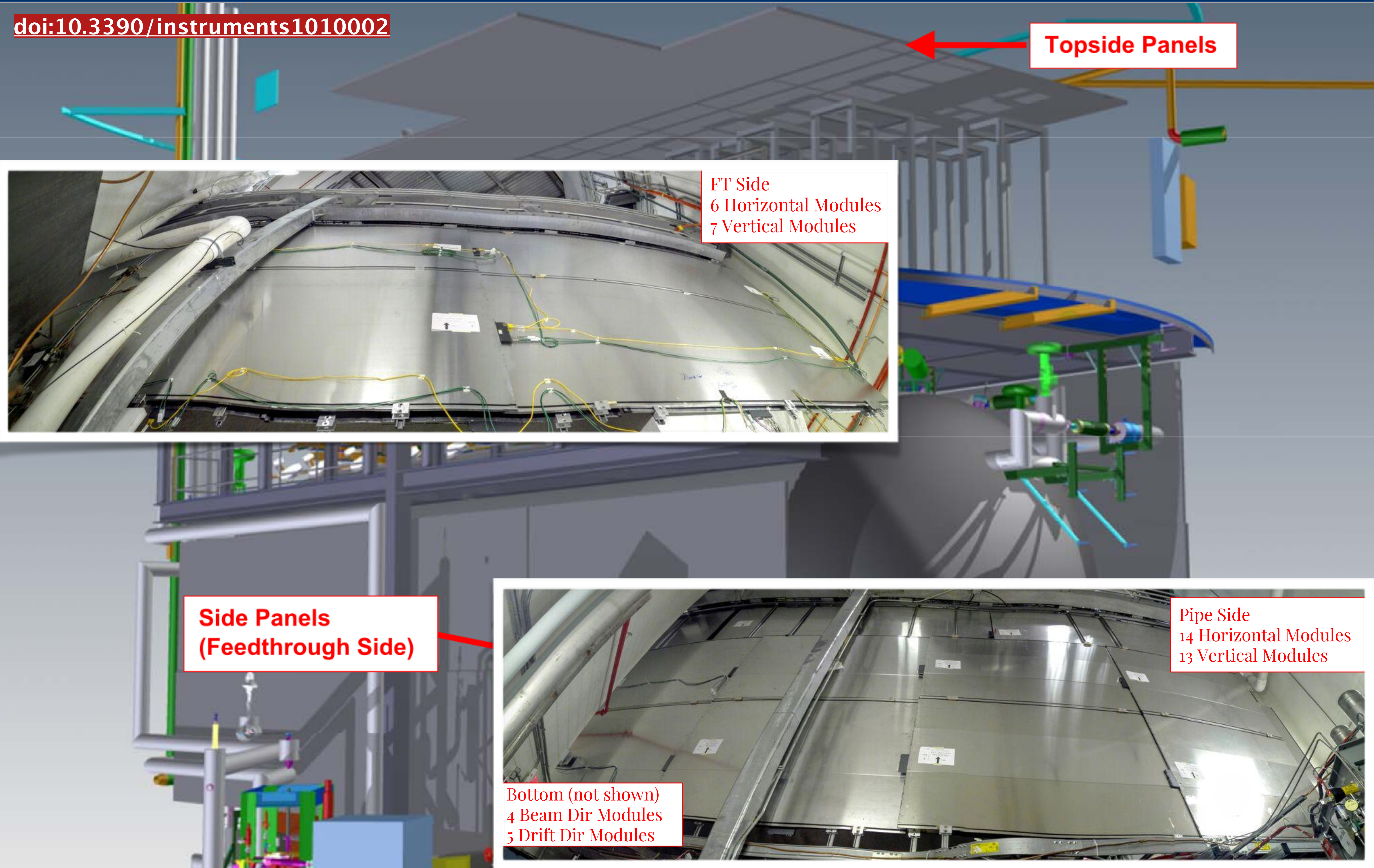


Me

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.

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- 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.

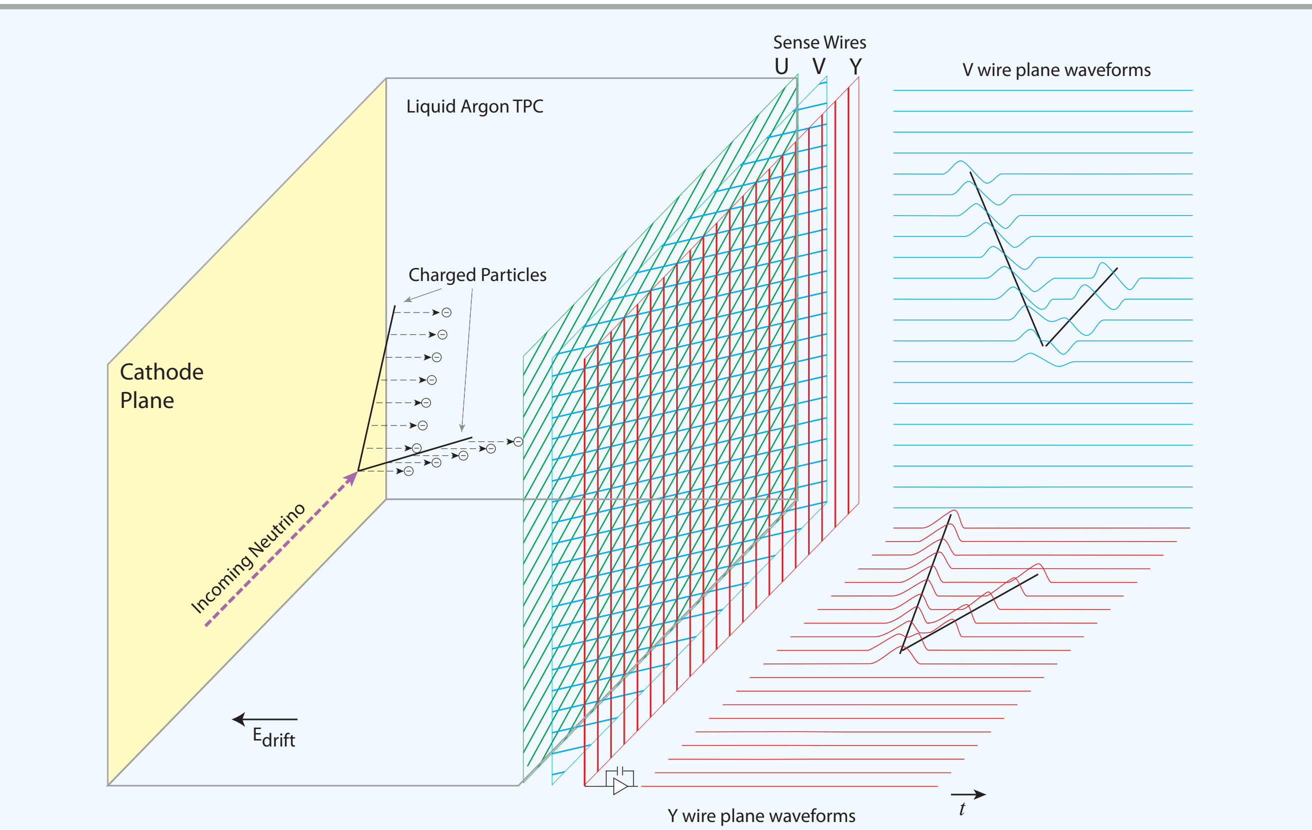
- The finding and **reconstruction efficiency of tracks in MicroBooNE** is in good agreement with the simulation.
- The analysis has been included in a paper submitted to JINST.
- The **Cosmic Ray Tagger** provides increased coverage for efficiency studies and cosmic-ray background mitigation. Extremely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

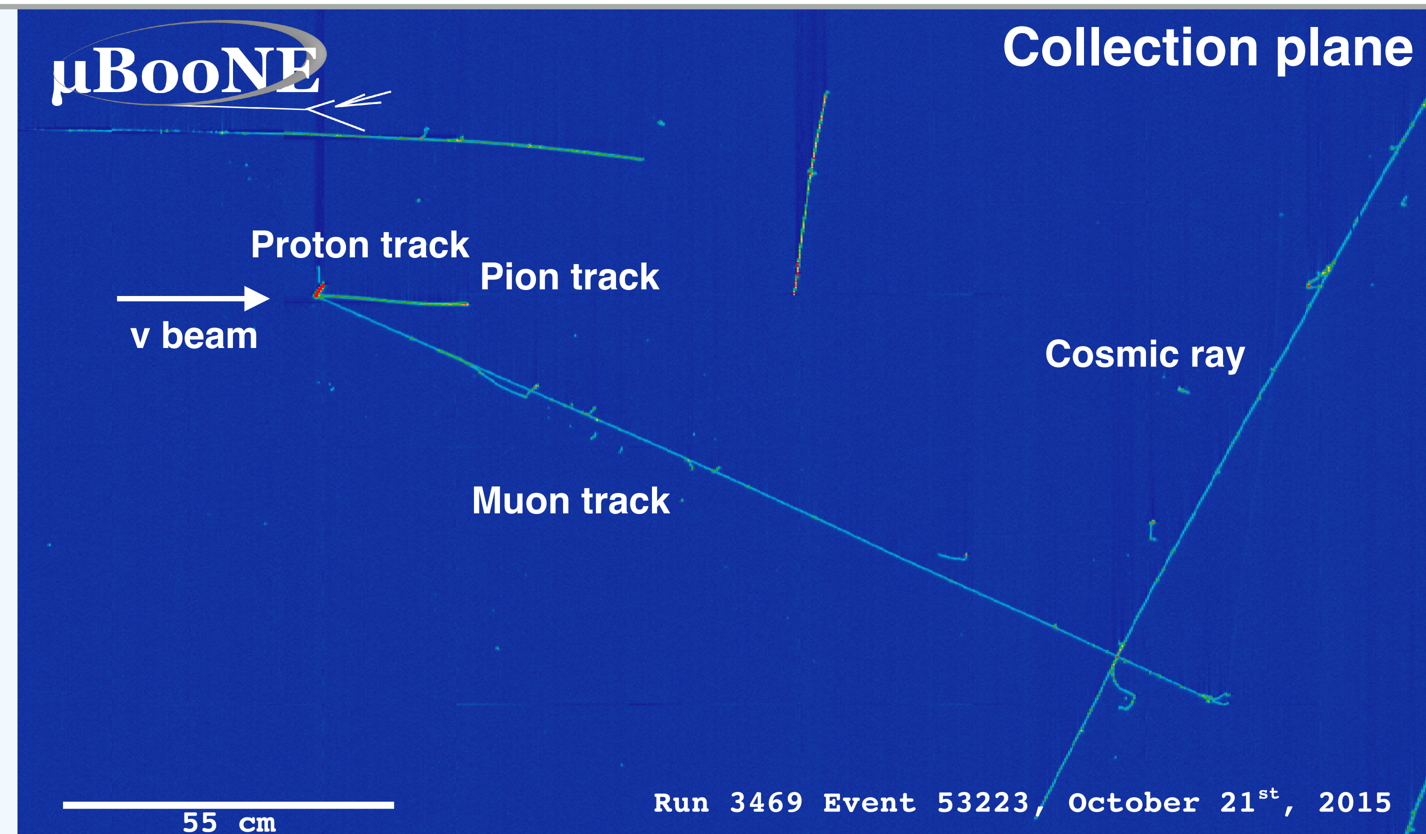

THANK YOU!
KOVAL
About Fermilab

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

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

Data

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

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

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

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

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MuCS Monte Carlo

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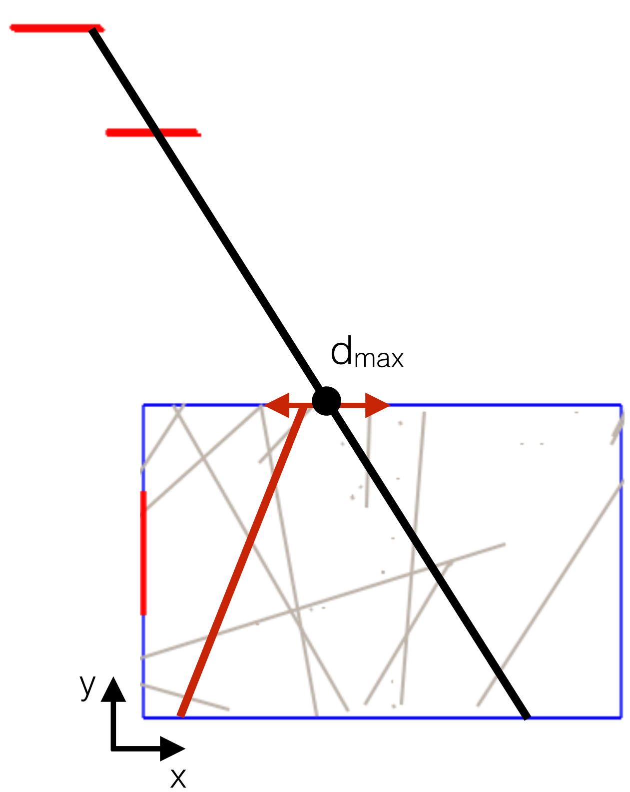

The **reco. event** within d_{max} can be a MuCS cosmic ray but also a random one, close to the extrapolated starting point.

Purity

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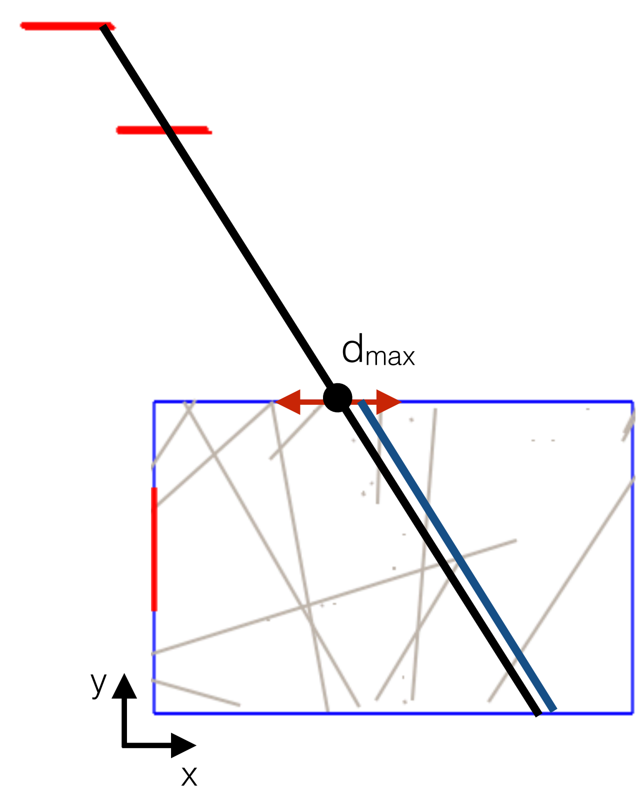
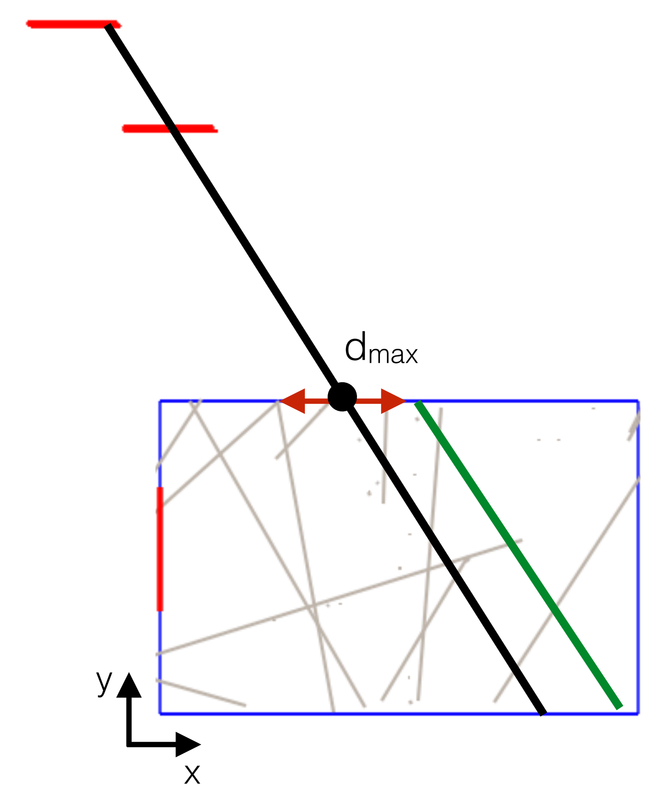


The **reco. MuCS event** is within d_{max} and it corresponds to a MuCS cosmic ray.

1/Acceptance

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

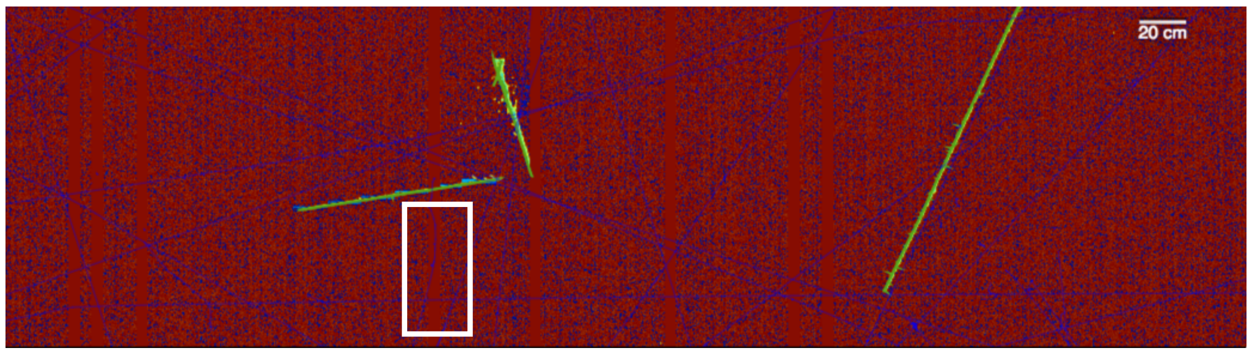


The **MuCS cosmic ray** has been reconstructed but it is outside the d_{max} cut.

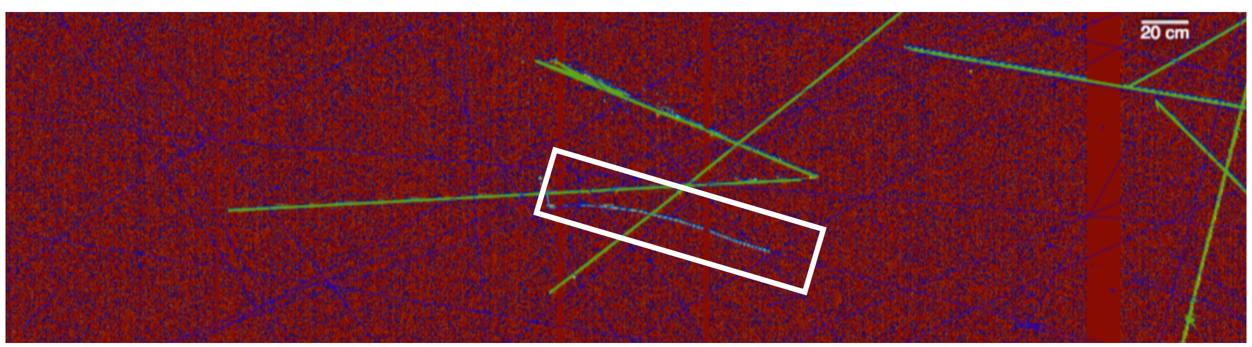
Inefficiency

Missing wires

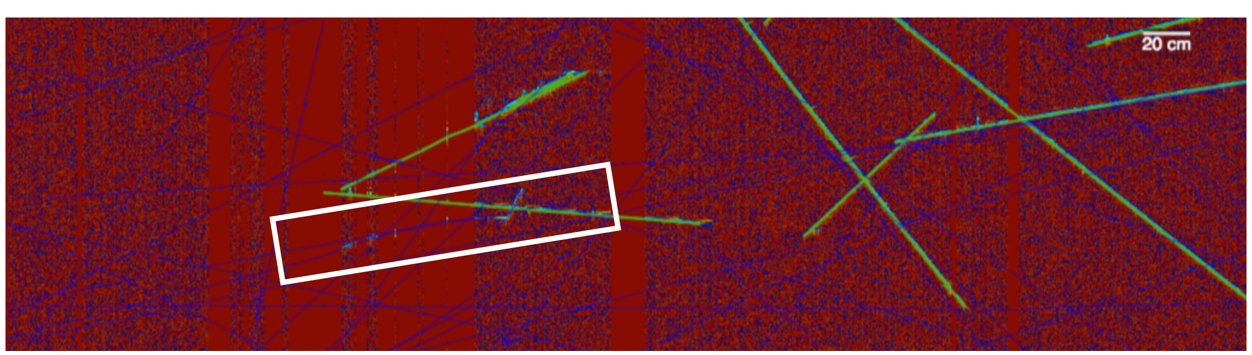
Collection



Induction 1

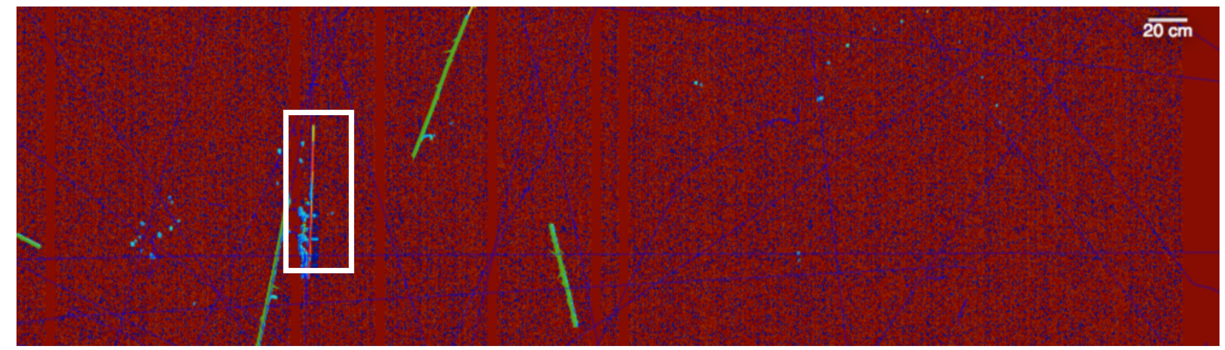


Induction 2

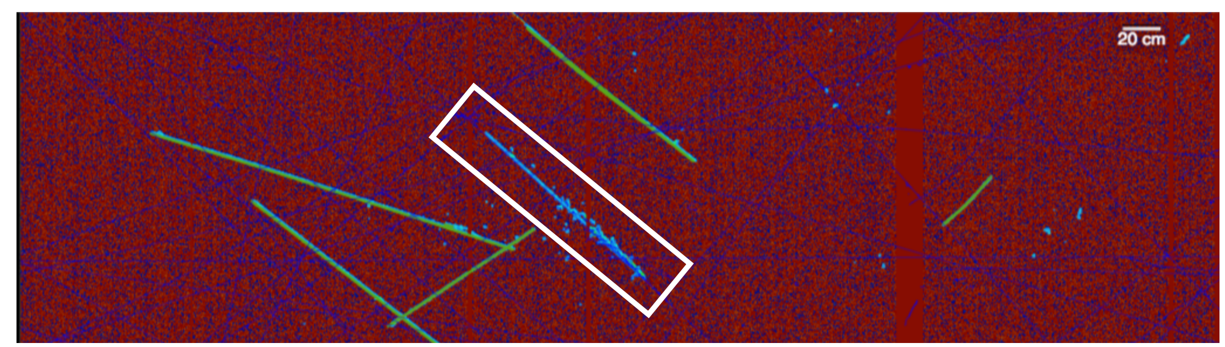


Shower-like rays

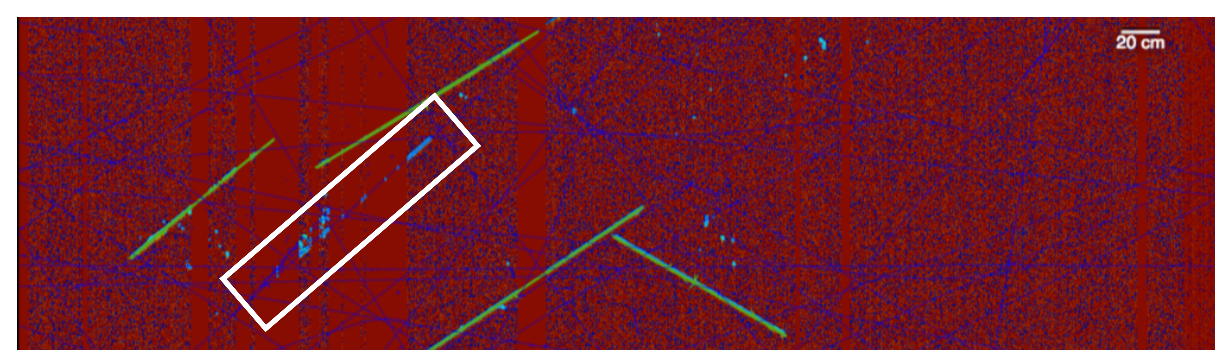
Collection



Induction 1



Induction 2



Systematic uncertainties

- **Dependence on the d_{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_{max}. We quote the value of the difference as a systematic uncertainty.

  0.2%

- **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.

  1.1% + 0.1%

- **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.

  correction

- **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.

  1.1%

- **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.

  negligible

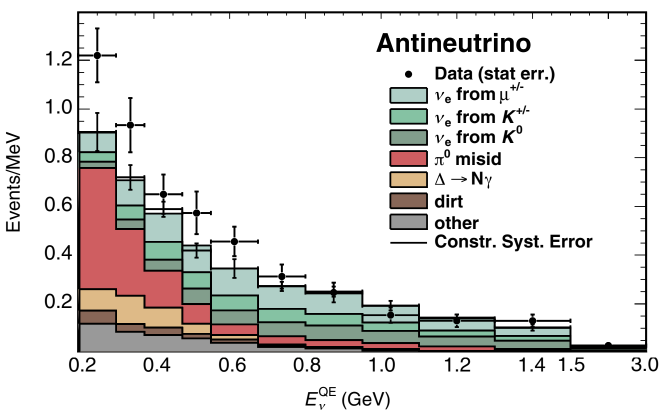
- **Statistical sampling**: since the multiple scattering depends on the energy, low-energy cosmic rays will have a higher probability to be further than d_{max} from the extrapolated starting point of the MuCS cosmic ray. Thus, the sampling of the few events from the energy spectrum can introduce a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

  negligible

MicroBooNE physics goals

Investigate short-baseline neutrino anomalies

- LSND excess.
- MiniBooNE low energy excess.
- Reactor neutrino anomalies.



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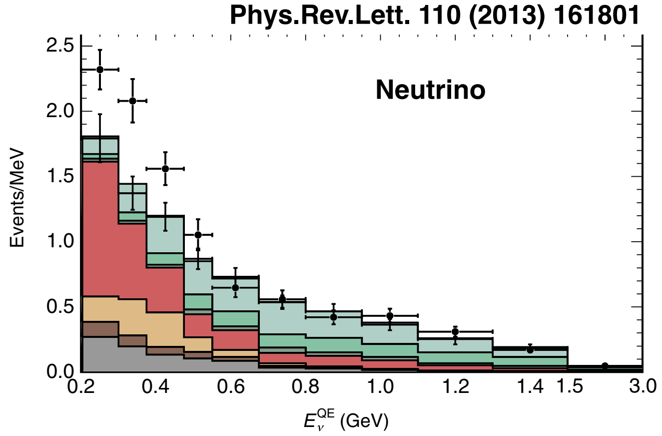
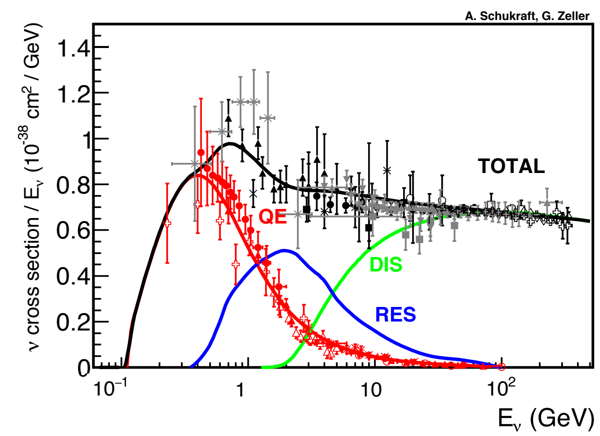


Cross-section measurements

- Precise measurements of ν-Ar cross section for future LAr experiments (DUNE).
- Probe different theories of nuclear effects in ν-Ar scattering.



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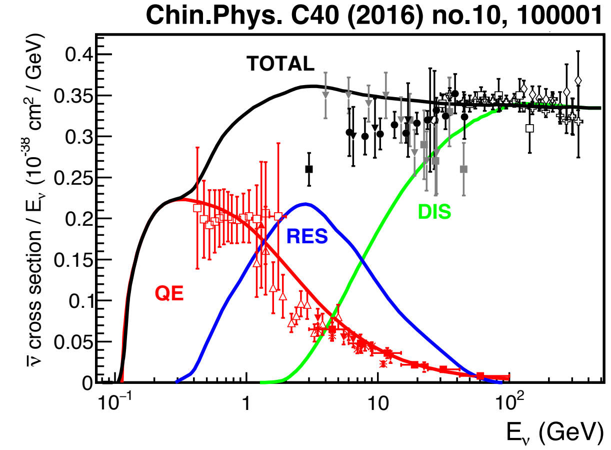
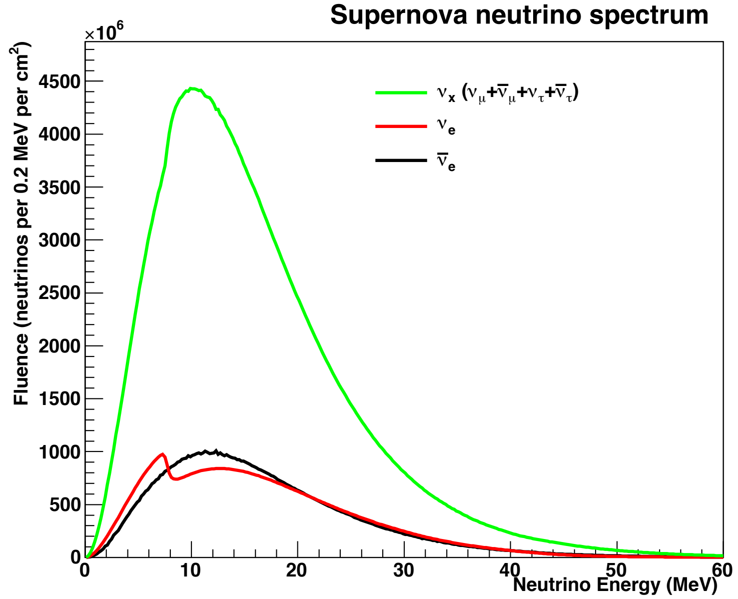


Supernova neutrino and exotic physics

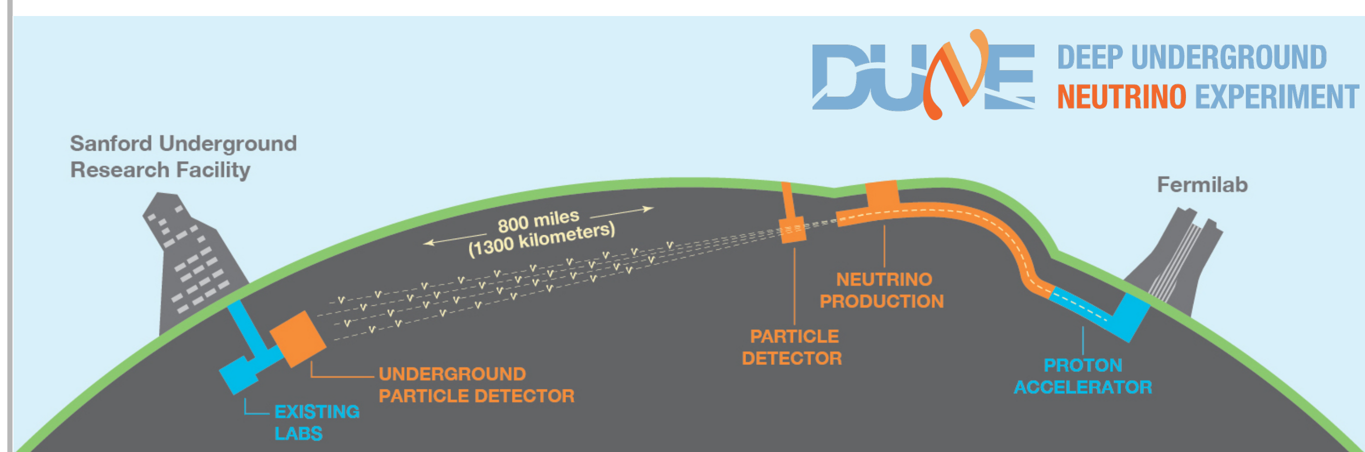
- Supernova neutrinos (~10 MeV) using the SNEWS alert system
- Proton decay backgrounds study: $K_L^0 + p \rightarrow K^+ + n$

Supernova neutrino spectrum



LArTPC detector R&D

- Detector effects to further develop LArTPC technology
  - Space charge effect, wire response, noise studies, electron lifetime…
- Essential for future experiments.

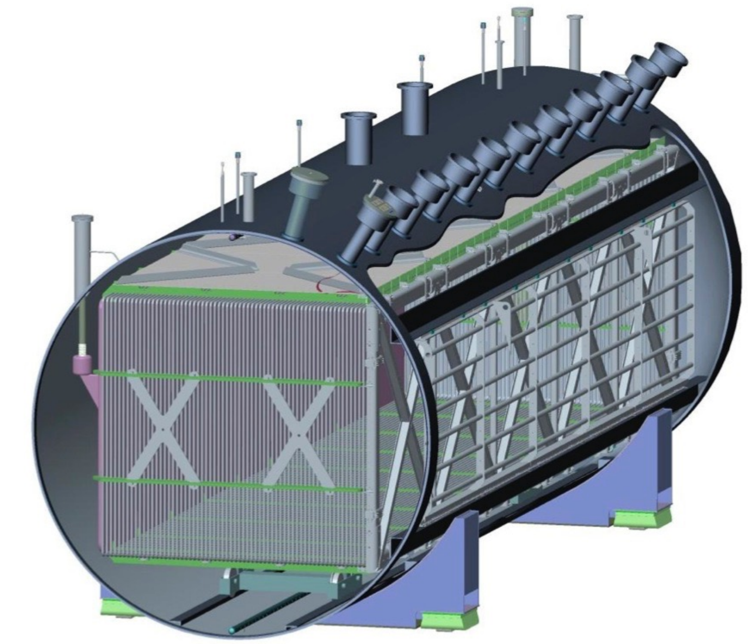


MicroBooNE in a nutshell

What is it?

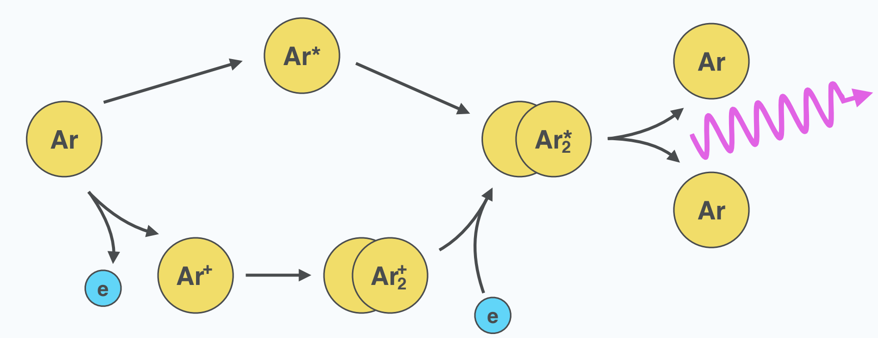
MicroBooNE is a 85 active mass ton **Liquid Argon Time Projection Chamber** at Fermilab, located:

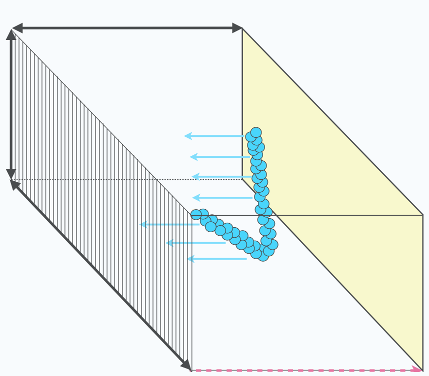
- on the axis of the Booster Neutrino Beam (BNB);
- off the axis of the Neutrinos at the Main Injector (NuMI) beam.



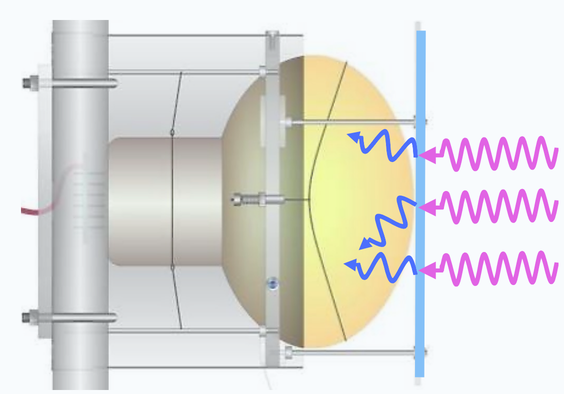
How does it work?

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)**,