Automated Selection of ν_e from NuMI using MicroBooNE

Prospects for the Charged-Current Inclusive Cross Section

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On Behalf of the MicroBooNE Collaboration

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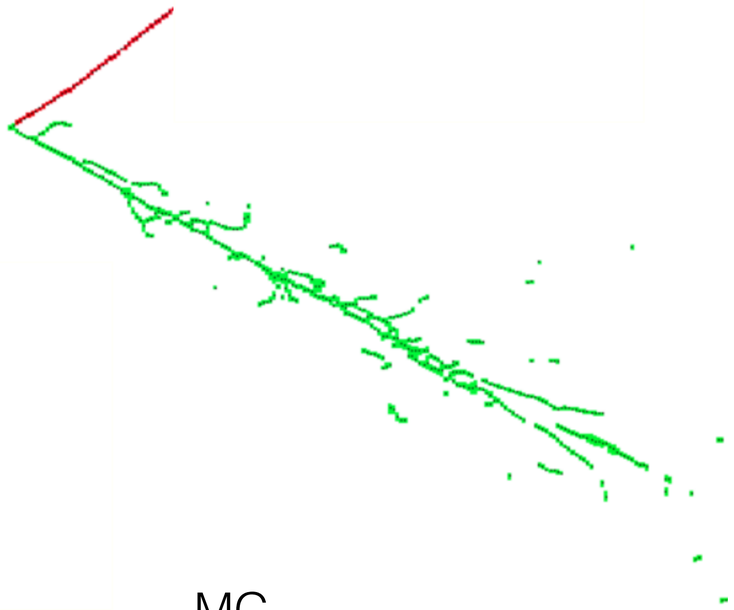
MANCHESTER 1824
The University of Manchester

μBooNE

Introduction



MC
Sample Topology
Reconstructed using Pandora

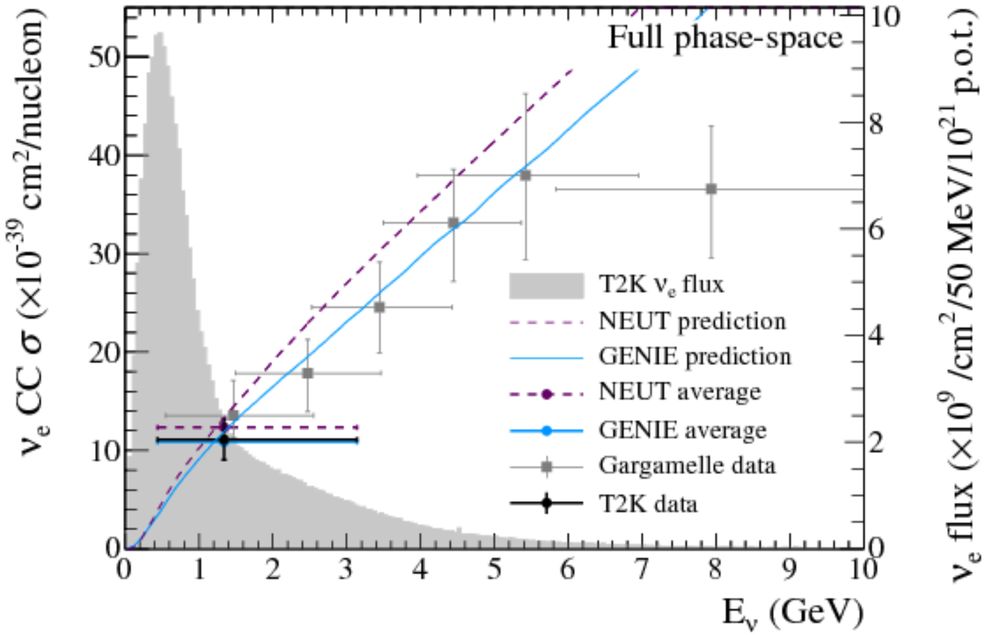
- This talk focuses mainly on the fully-automated selection of data ν_e CC events from the NuMI beam in MicroBooNE.
- We demonstrate the ability to use dE/dx in MicroBooNE to differentiate between electron-like and photon-like showers to enhance the event selection.
- A Monte Carlo closure test is presented with expected sensitivity to the data cross section, where the input cross section is extracted from the selection using MC.
- This will lead to the near-future measurement of the first ν_e CC cross section on argon.

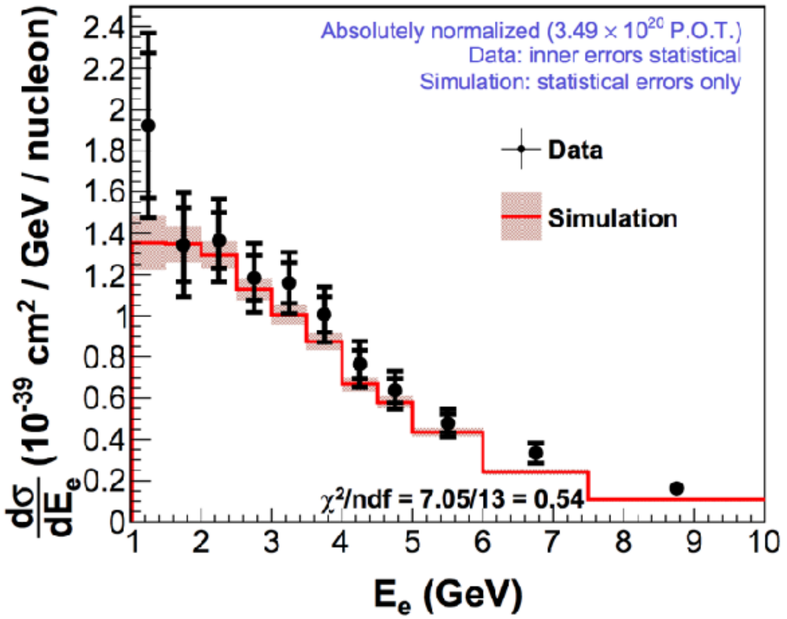
Motivation

- Electron neutrinos are the golden channel for CP-violation, mass ordering and low mass sterile neutrino searches in liquid argon detectors (DUNE, SBN).

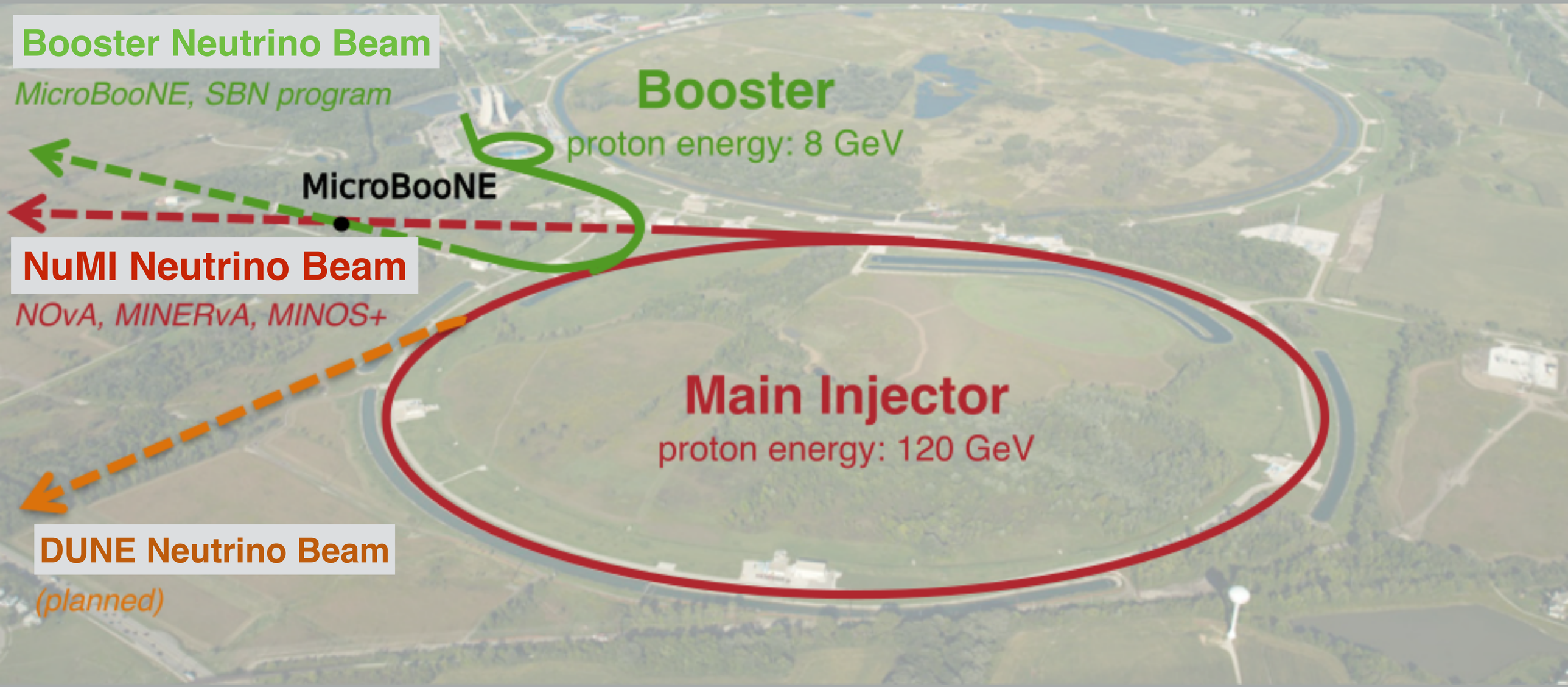
- These measurements will use neutrinos in the region of 1 GeV, where nuclear interactions are most interesting.

- The electron neutrino cross-section on argon has never been measured before (and there are only a few measurements on other targets).





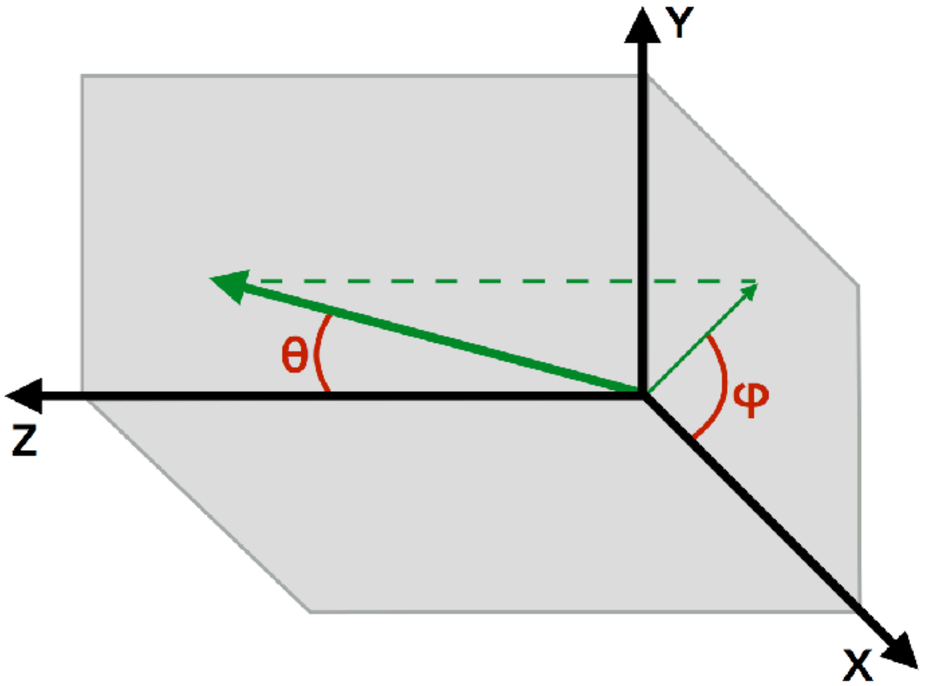
[1] T2K, arXiv:1407.7389
[2] Minerva, arXiv:1509.05729v9


Booster Neutrino Beam
MicroBooNE, SBN program
Booster
proton energy: 8 GeV
MicroBooNE
NuMI Neutrino Beam
NOvA, MINERvA, MINOS+
Main Injector
proton energy: 120 GeV
DUNE Neutrino Beam
(planned)

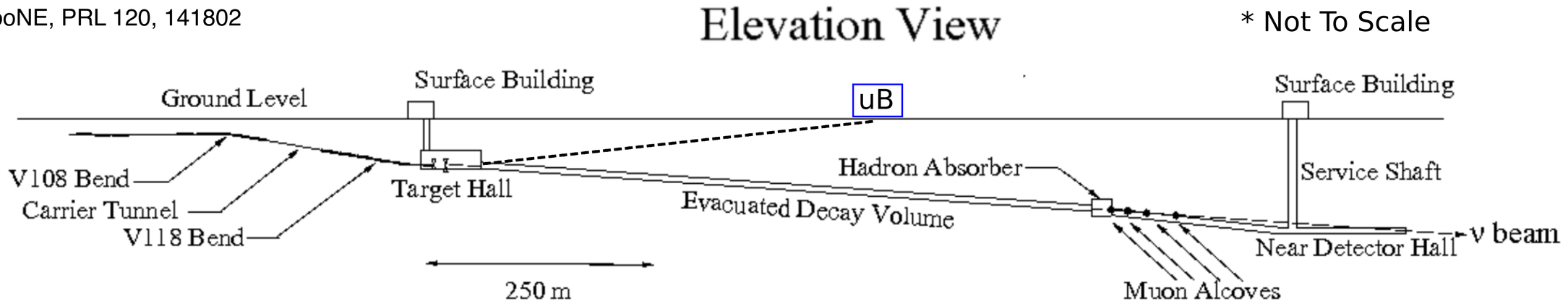
NuMI & MicroBooNE

- MicroBooNE is located off-axis from the NuMI beamline by 8 degrees.
- The primary contribution of the flux comes from the NuMI target.
- Projecting into MicroBooNE coordinates, this is an angle of Φ ~ 27 degrees, θ ~ 40 degrees.
- The NuMI absorber also produces a flux of kaon decay-at-rest neutrinos, visible in MicroBooNE (and MiniBooNE).

MicroBooNE Coordinate System

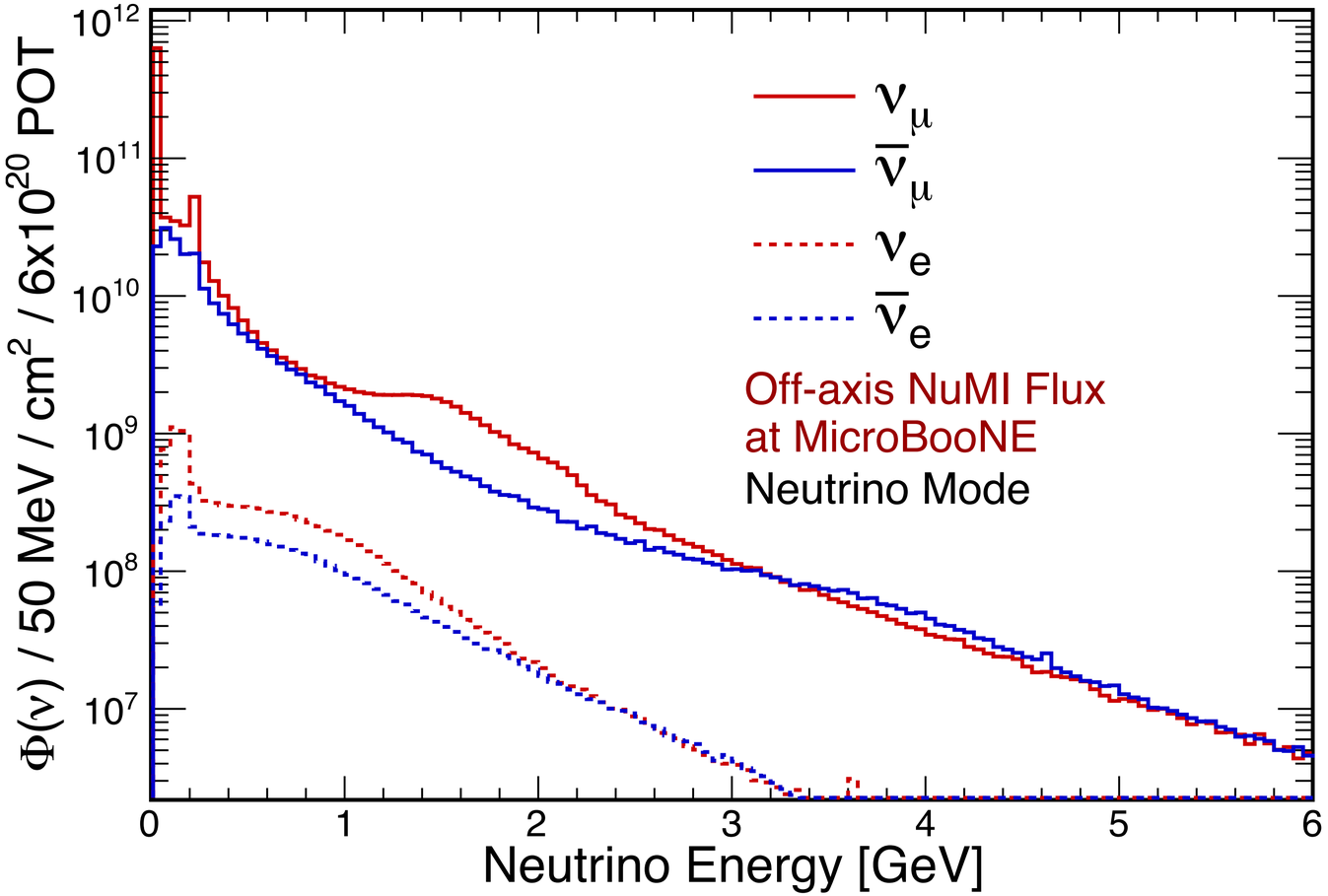


MiniBooNE, PRL 120, 141802



P. Adamson et al., The NuMI Neutrino Beam, arXiv:1507.06690

NuMI & MicroBooNE



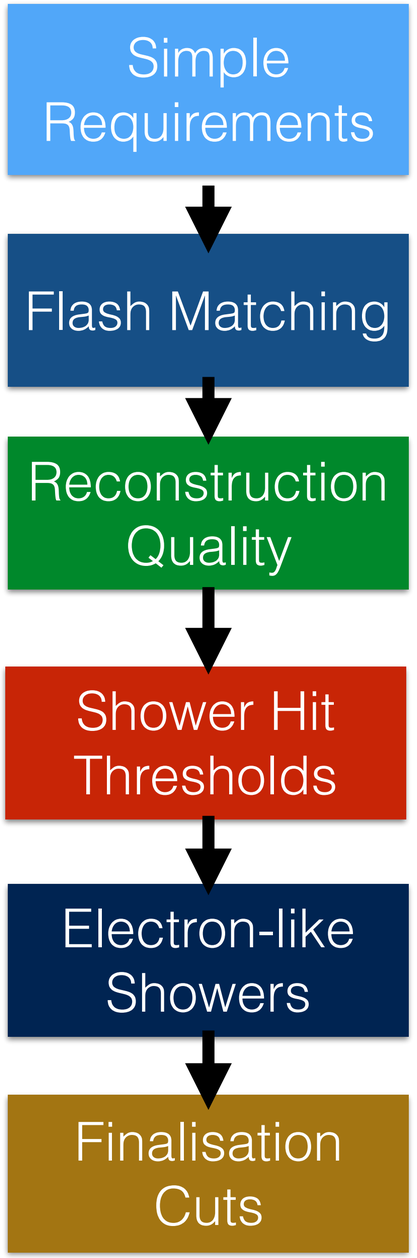
	<Energy $\nu_e+\bar{\nu}_e$>	ν_e Fraction
BNB	~900 MeV	0.5%
NuMI	~640 MeV	5%

- NuMI flux at MicroBooNE has wider high-energy tail than BNB.
- NuMI has much higher intrinsic ν_e component, resulting predominantly from kaon decays.

Selection Overview

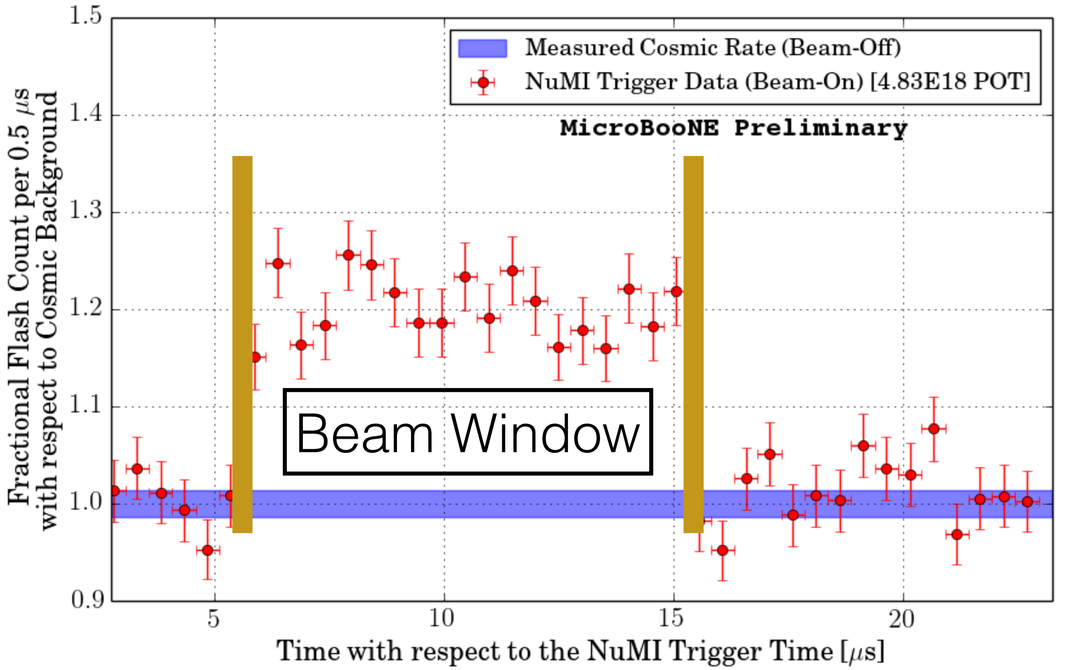
- Inclusive ν_e + ν_eCC selection using the *Pandora* reconstruction framework.
- No requirements are made for the number of tracks or ancillary showers.
- Note: the “leading shower” - the shower object with the most associated TPC activity, it taken as the electron candidate.

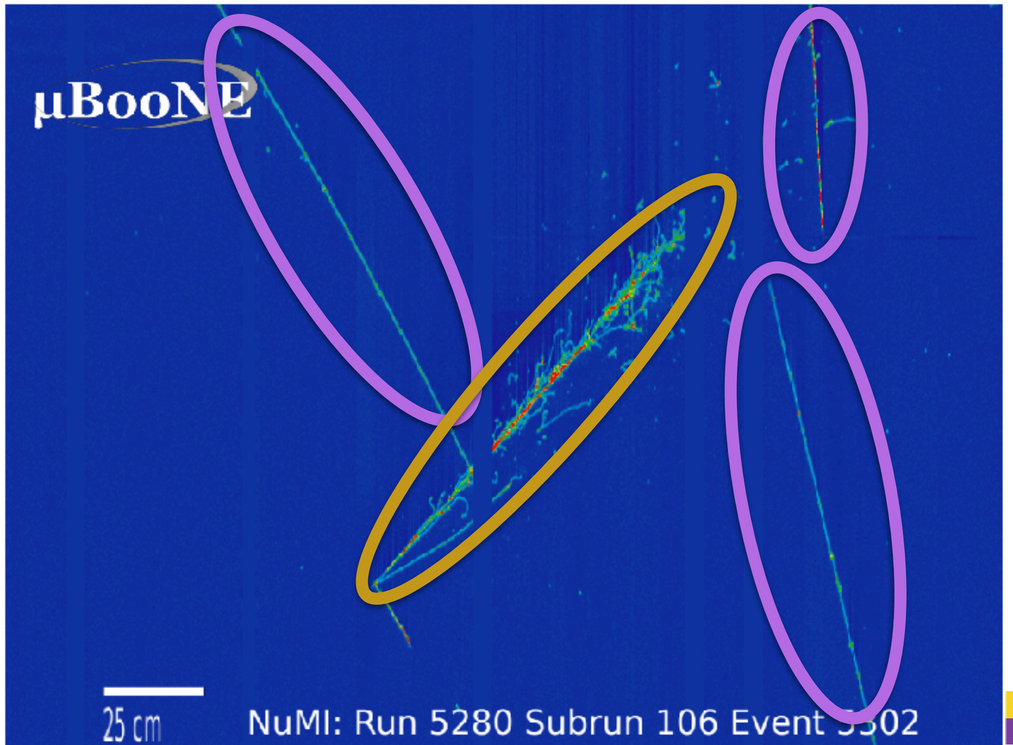
- Brand-new results from MicroBooNE!
- First time looking at $\nu_e + \overline{\nu}_e$ events in liquid argon using a fully-automated method.



Flash Matching

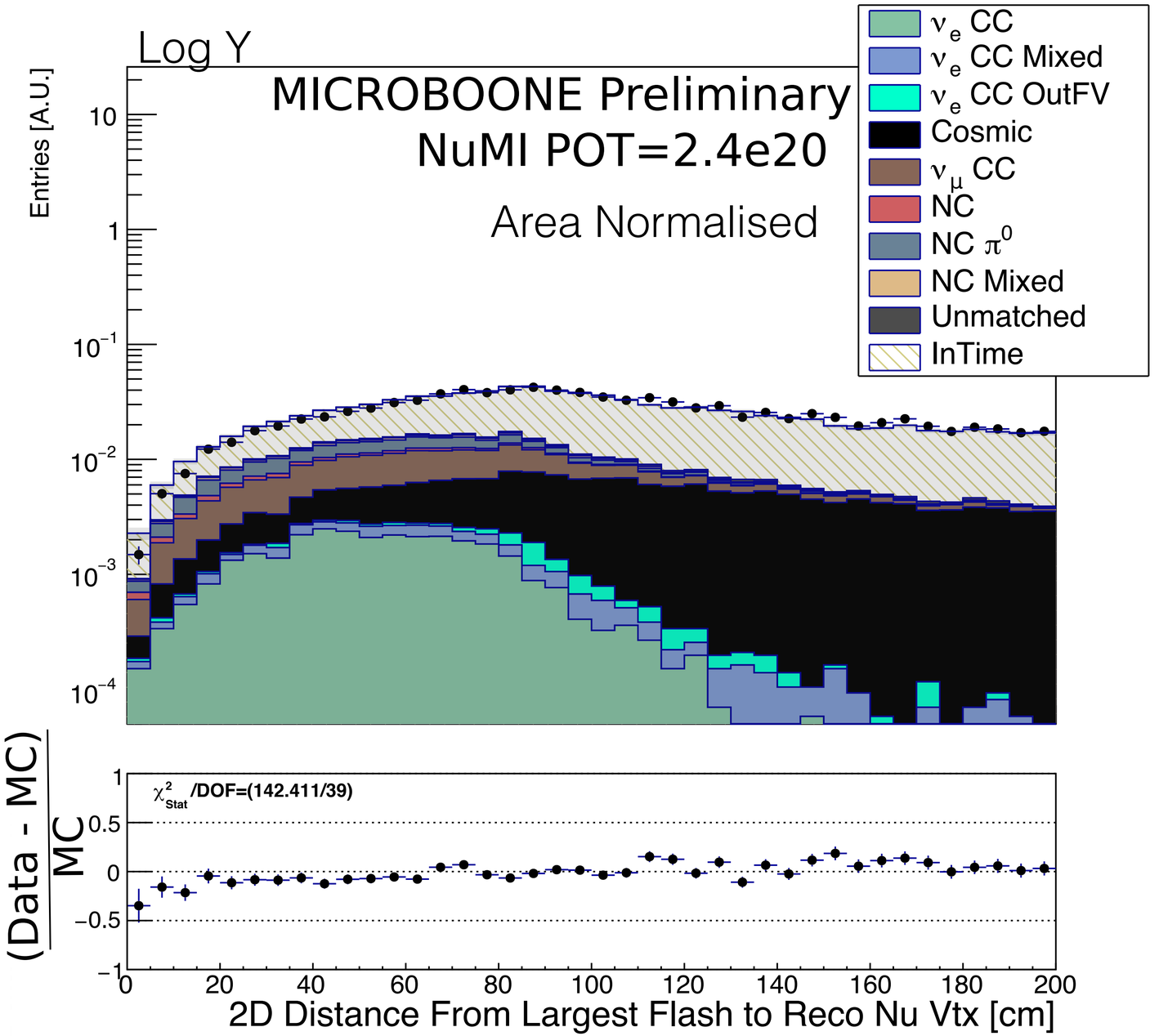
- We use the philosophy similar to previous talks (see. Anne S. & Marco D. T.).
- Attempt to match optical and charge information to the neutrino interaction.
- Because NuMI beam window is longer than BNB, cosmic rejection is even more important.
- Future analyses will be able to employ the Cosmic Ray Tagger (CRT) to further improve cosmic rejection.





Flash Matching

- Here we use a simple, but robust form of flash-matching.
- Signal events are closer to the flash than centre than cosmic background events.
- The best cut value differs when the flash centre is upstream or downstream (here) of the reconstructed neutrino vertex.



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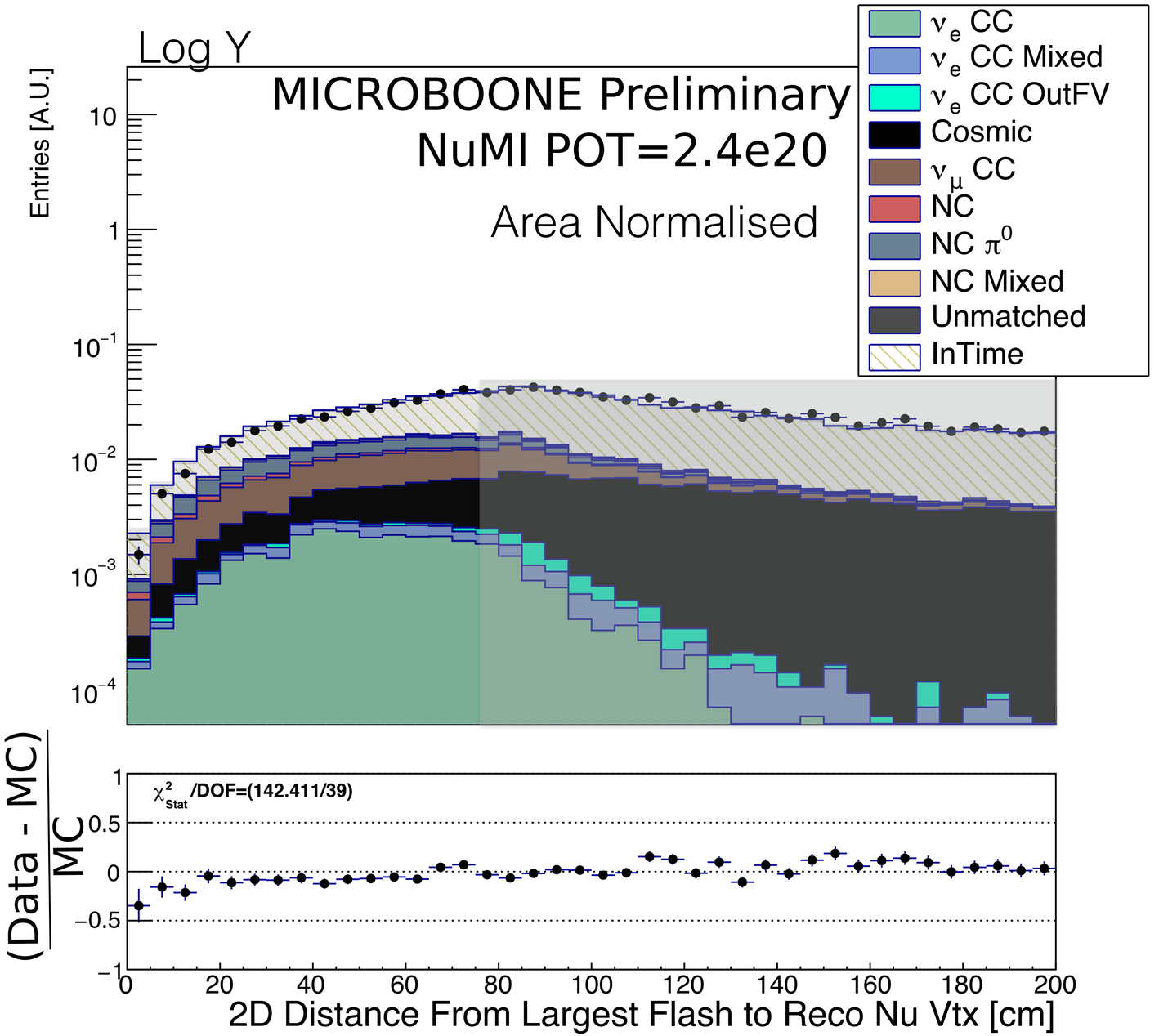
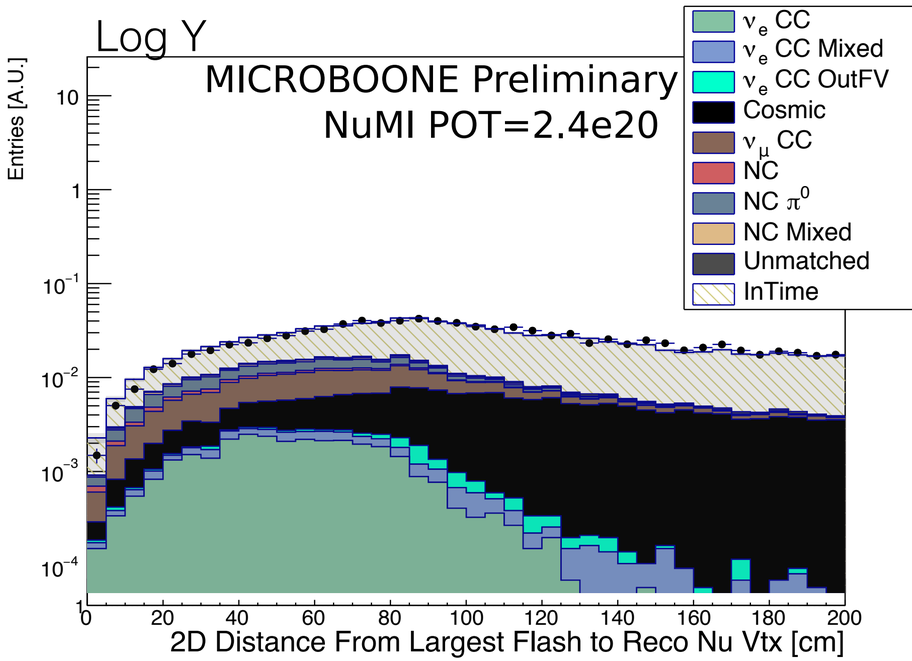


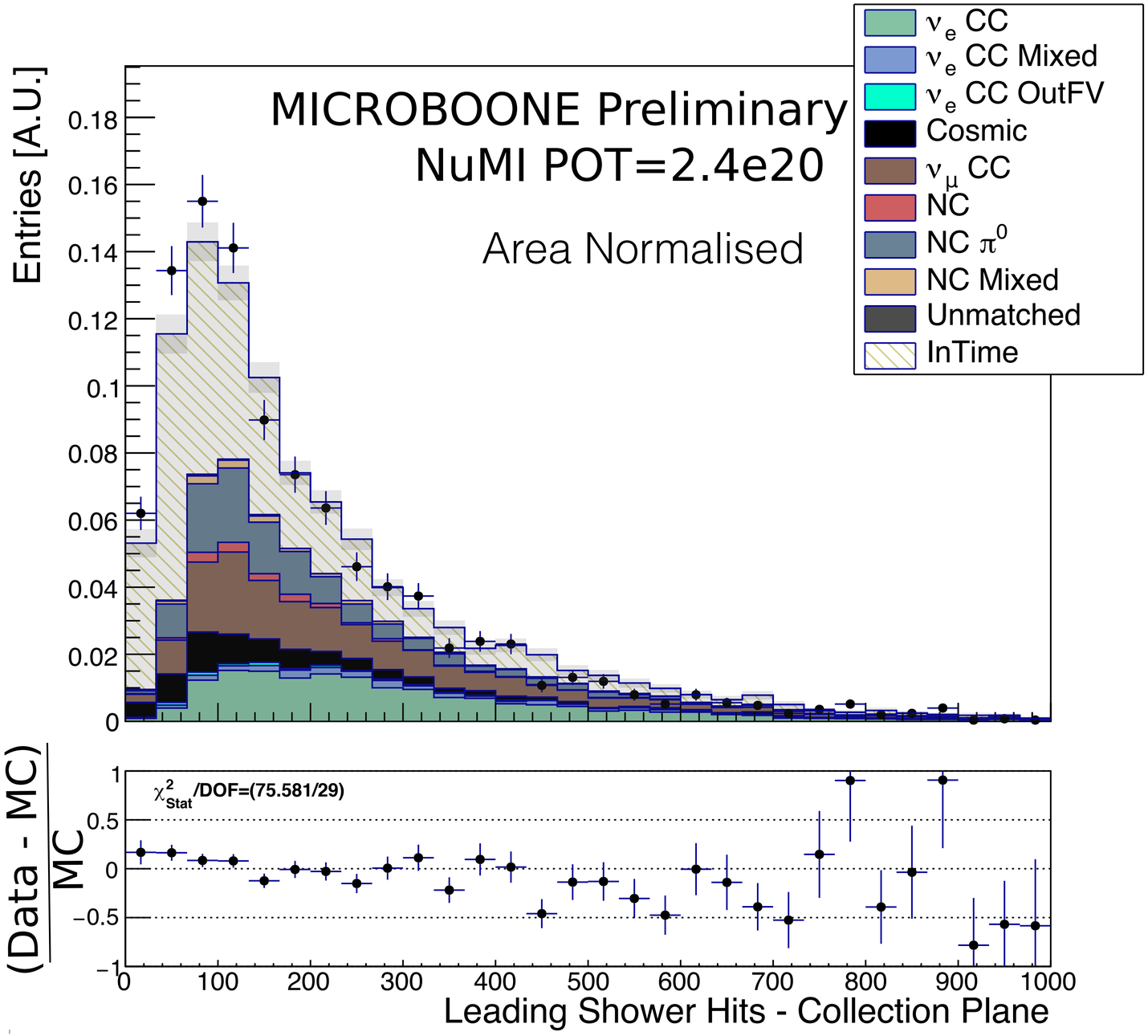
Selection Performance

- Following the flash matching cut and basic requirements of a reconstructed flash, we remove 99.1% of the cosmic events.
- However, the selection purity is only about 4% at this stage (We still have a way to go!).
- Cosmics are still the dominant background.
- We need to look at shower quality cuts to make more progress.



Shower Quality

- A minimum threshold on the number of hits helps with two things:
  - Improves quality of selected showers.
  - Removes some tracks which were reconstructed as showers.
- Shown here: number of hits for the leading shower on the collection plane only.



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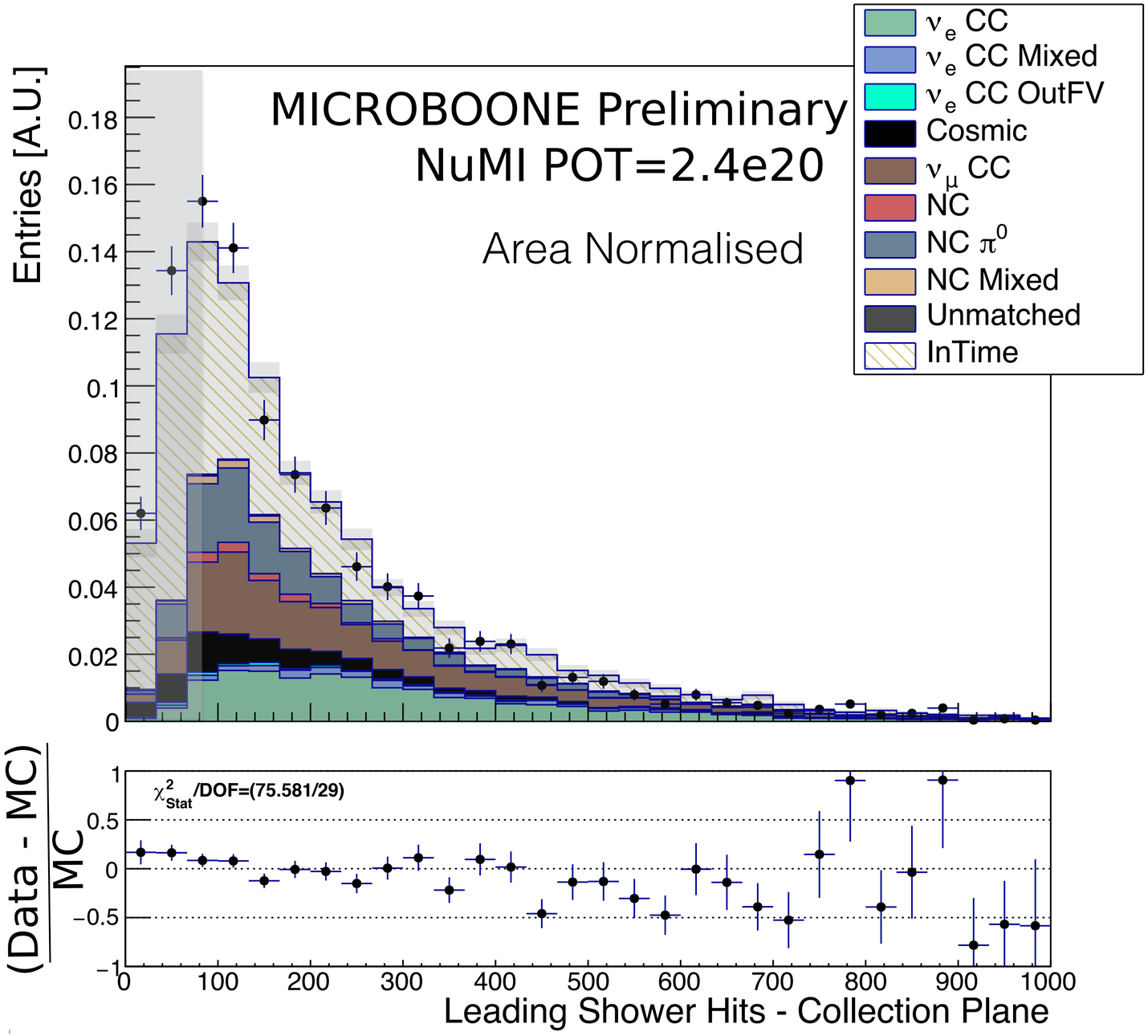
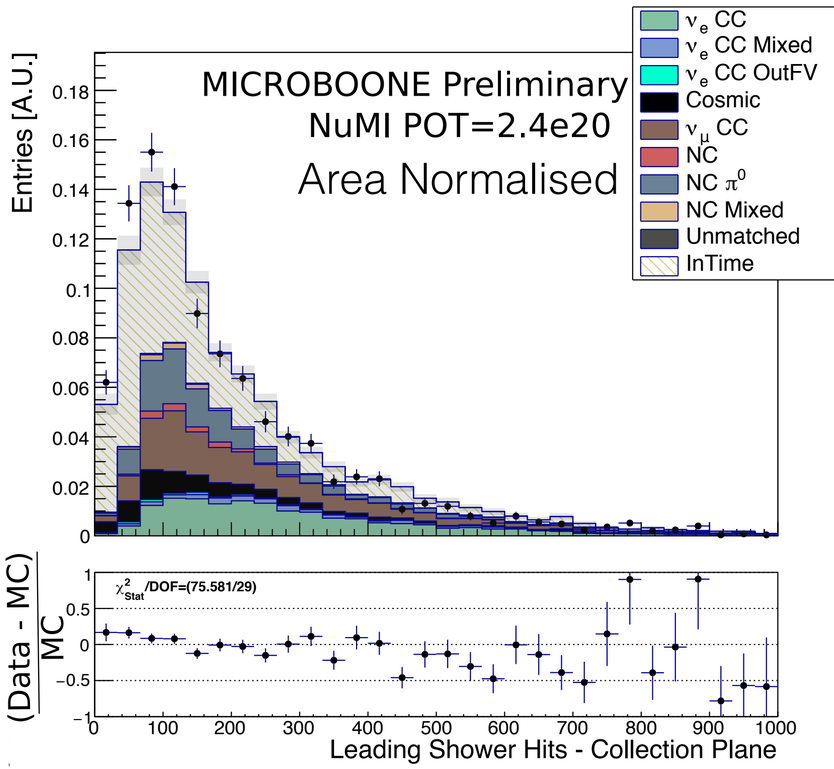


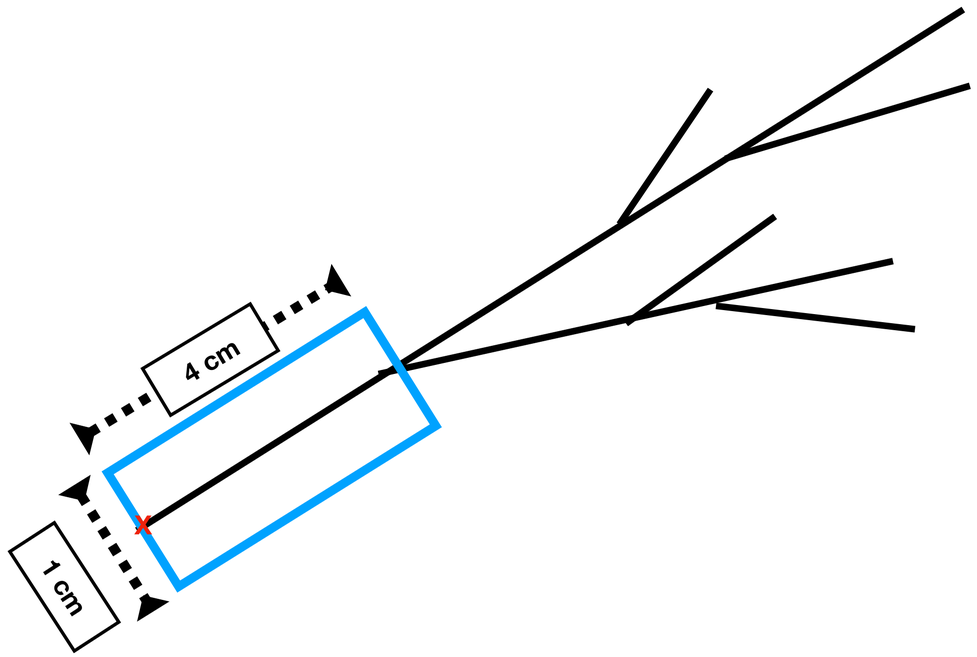
Selection Performance

- After we apply the hit thresholds, the overall purity increases to about 20%.
- Before - cosmic contamination was the dominant background.
- Now - NC pi0 background is also becoming a relevant contaminant.
- Therefore, we need to look at removing photon-induced background showers.



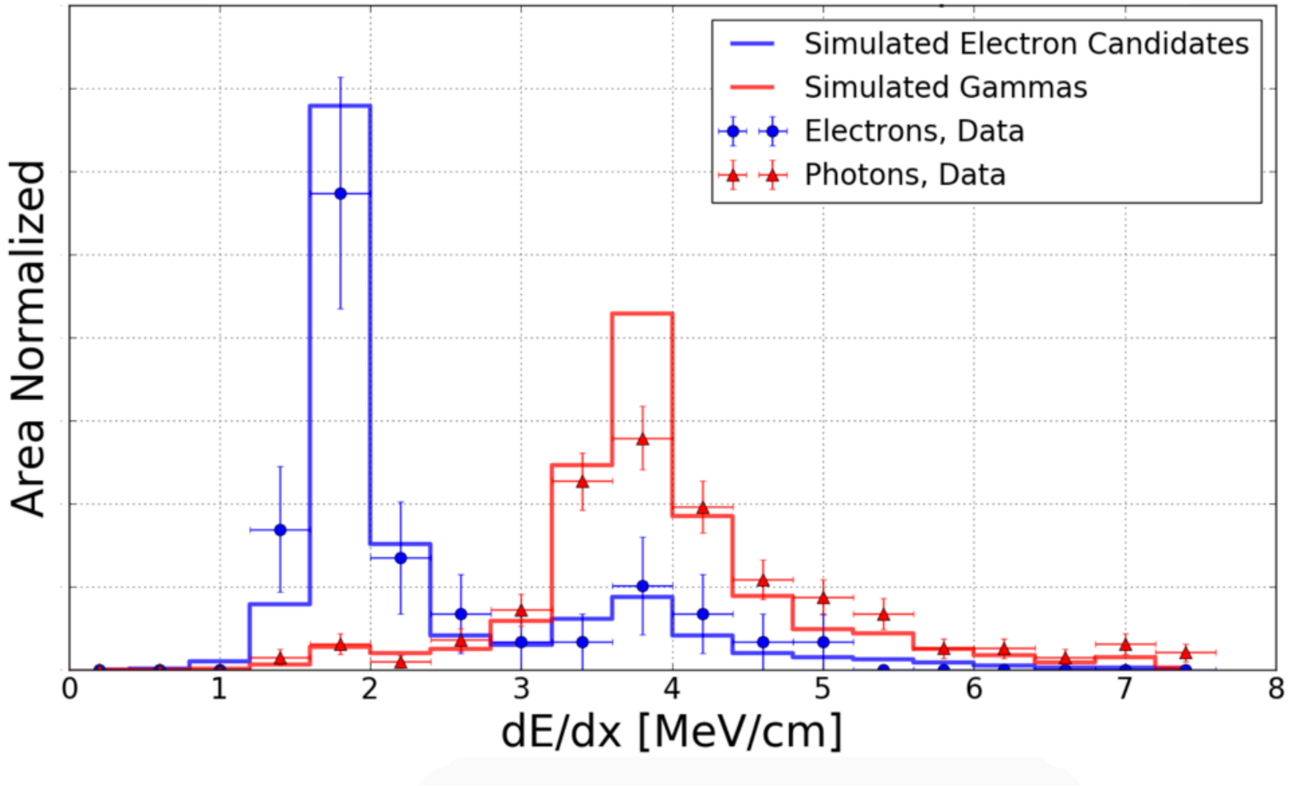
Calculation of Shower dE/dx

- Using the method outlined by ArgoNeuT:
  - Construct a 1 x 4 cm box in the shower direction.
  - Sample the charge depositions on the wires.
  - Taking the median charge and dividing by the deposition length gives the dQ/dx of the shower.
  - We correct for the electronics gain factor and recombination to calculate the dE/dx.



dE/dx in ν_e selection

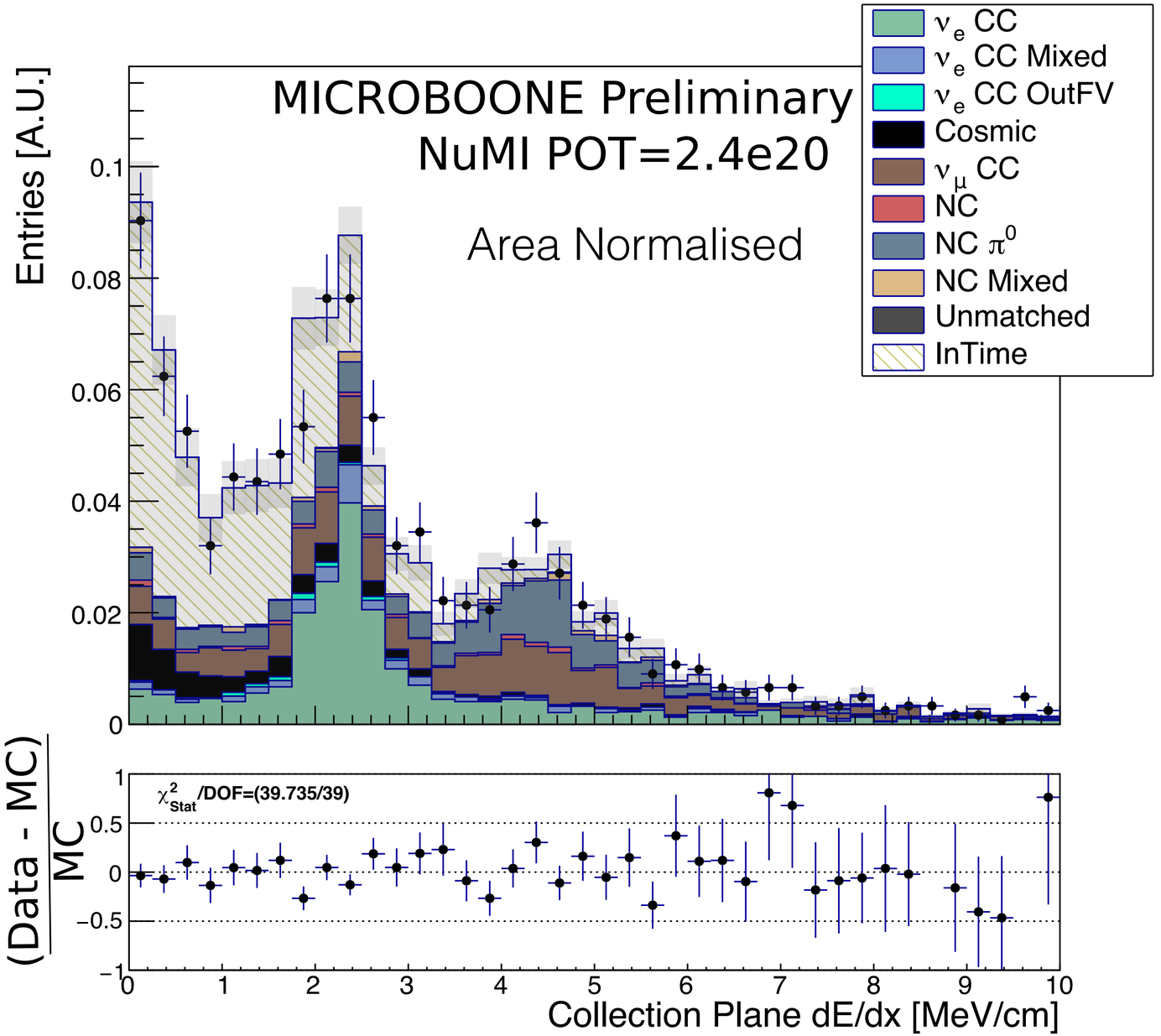
- A challenging background to remove for ν_e selections are photons showers.
- ArgoNeuT first demonstrated the ability to use dE/dx to separate electron-like and photon-like showers in LAr in data.
- This selection cut is also critical for MicroBooNE's ν_e selections.



ArgoNeuT Collaboration, First Observation of Low Energy Electron Neutrinos in a Liquid Argon Time Projection Chamber, arXiv1610.04102v2

Shower dE/dx

- As anticipated, the ν_e signal events are peaked in the MIP region.
- 2 x MIP peak dominated by photons from pi0 decay.
- We can cut on the leading shower dE/dx to isolate the MIP peak.



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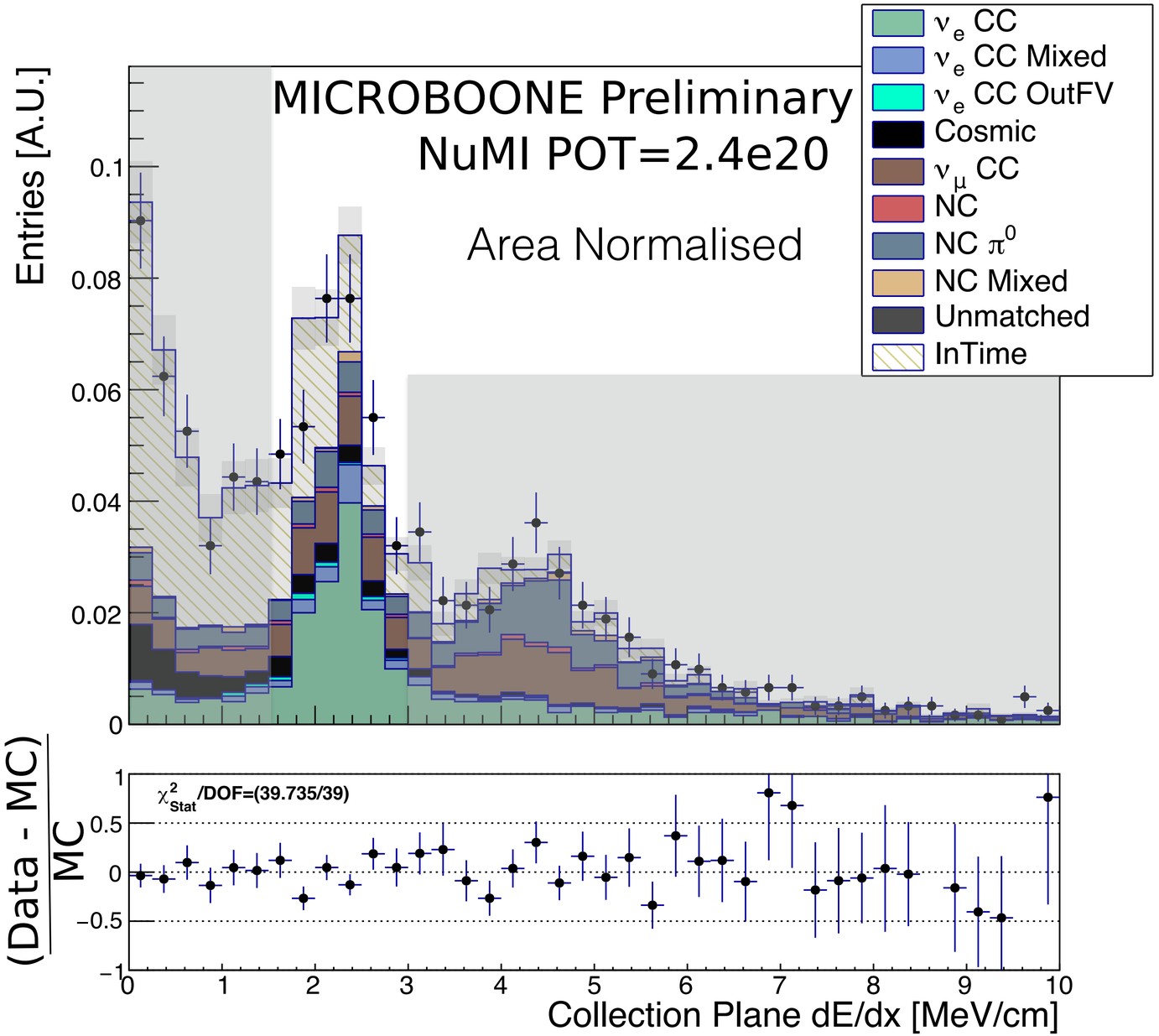

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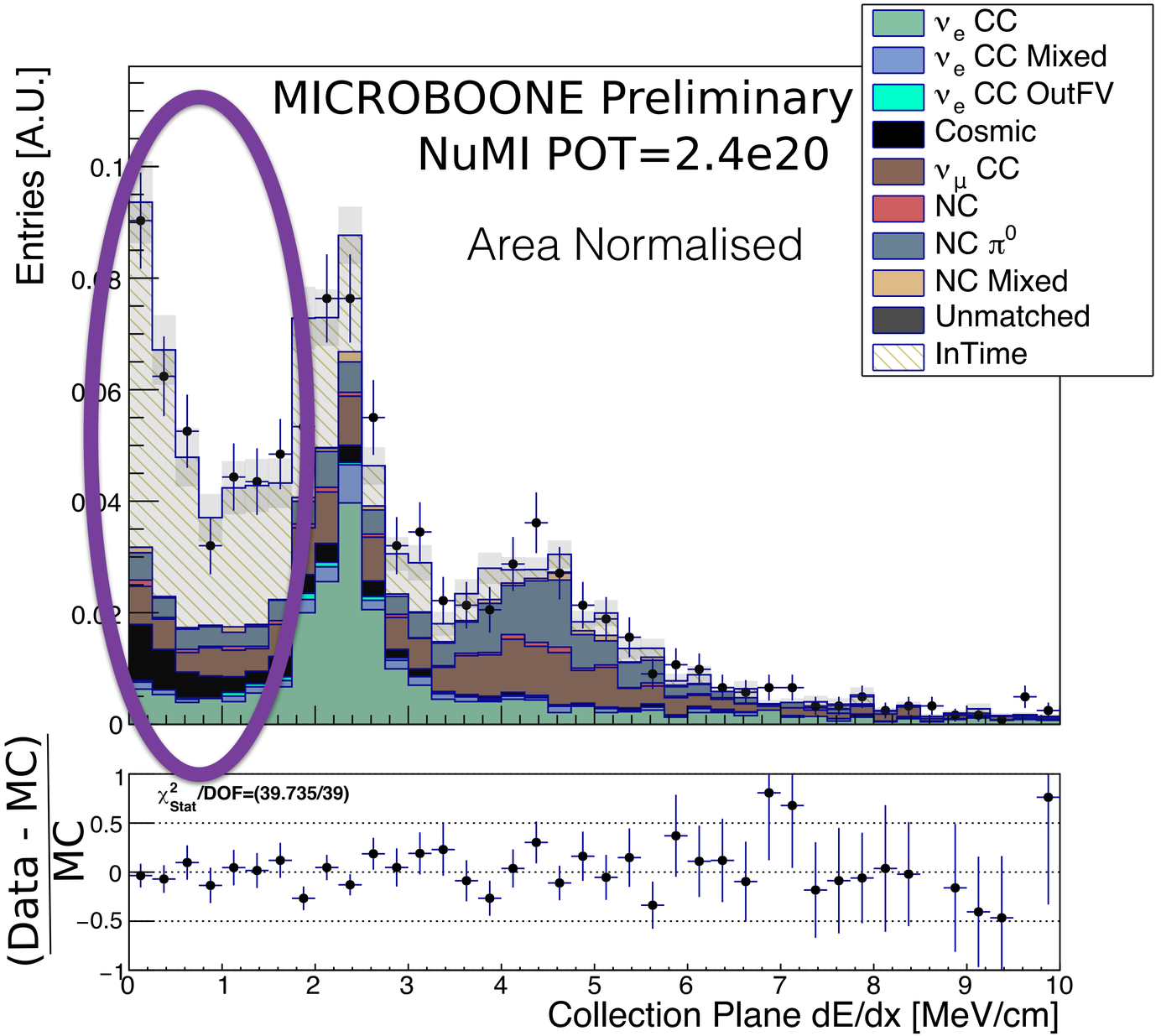

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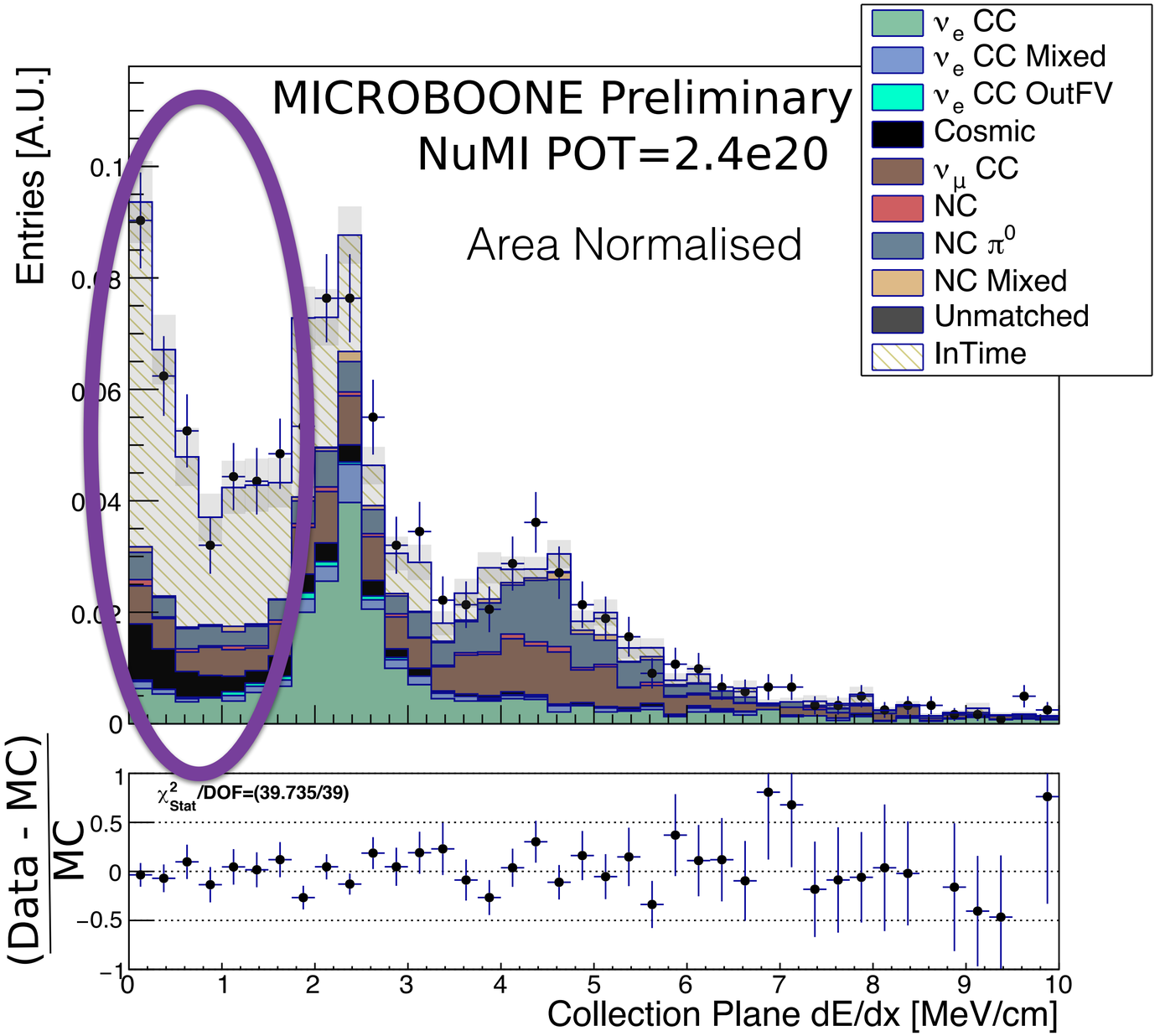
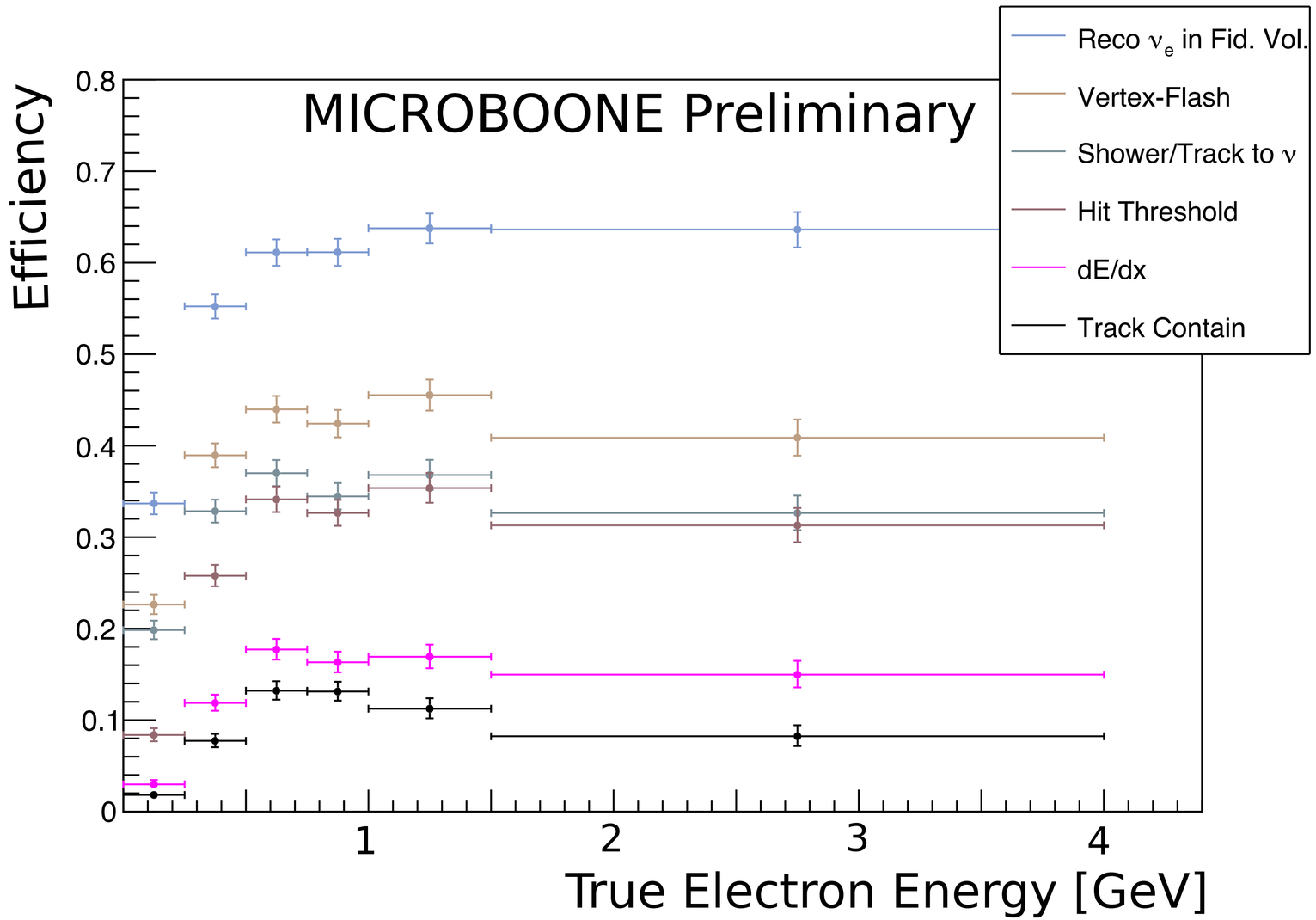
- 2 x MIP peak dominated by photons from pi0 decay.
- We can cut on the leading shower dE/dx to isolate the MIP peak.
- Showers at low dE/dx are aligned with the collection plane wires - both dE and dx are difficult to measure.
- By including calorimetry information from the induction planes, we expect to recover these events.



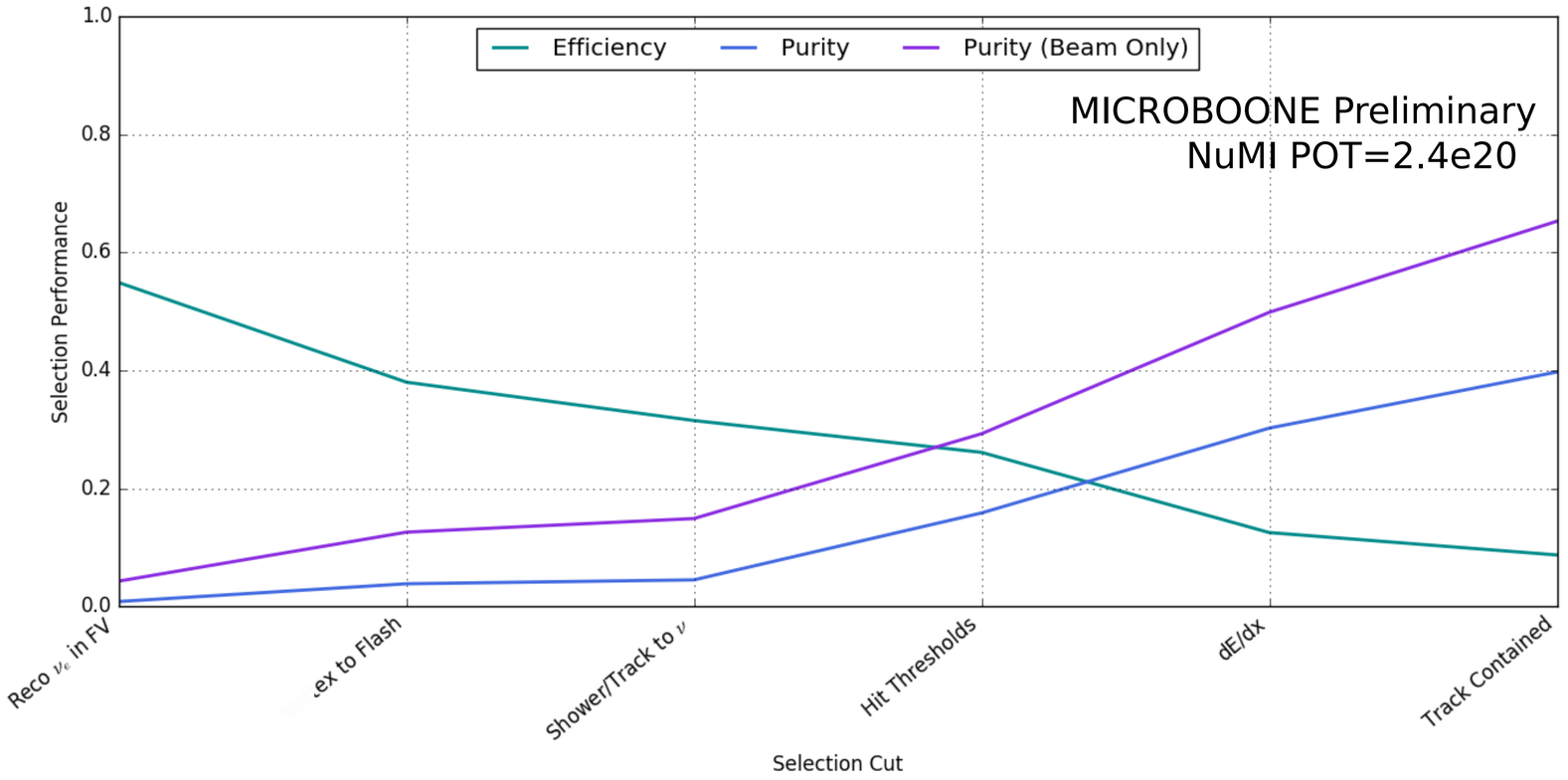
Selection Efficiency

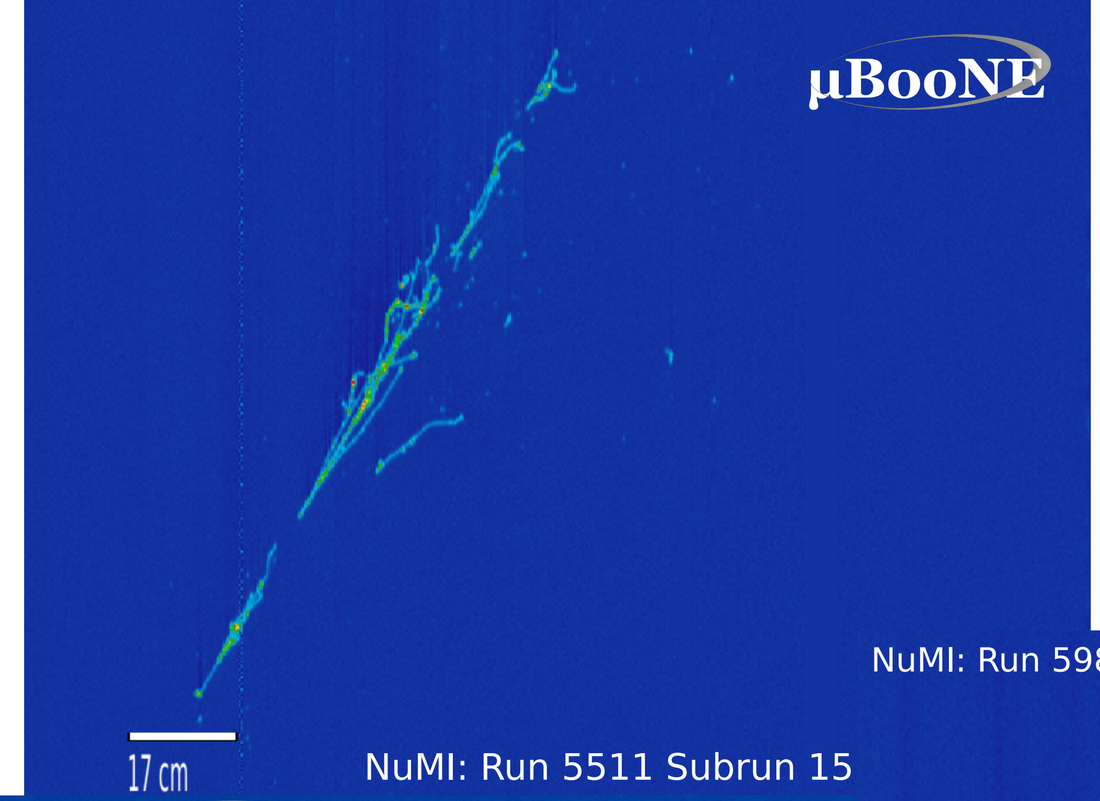
- Evolution of the selection efficiency as a function of the true electron energy.
- Performance is best above 500 MeV.
- Most selection cuts cause a relatively uniform decrease in efficiency.
- With improvements to reconstruction, we expect substantial gains in efficiency.

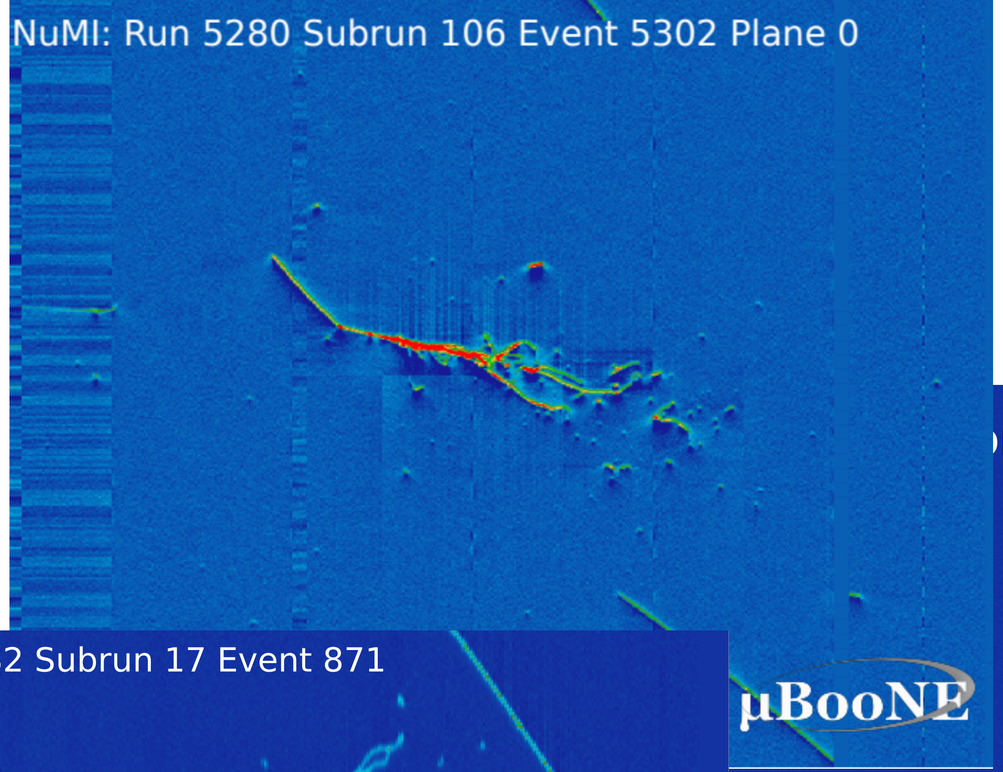


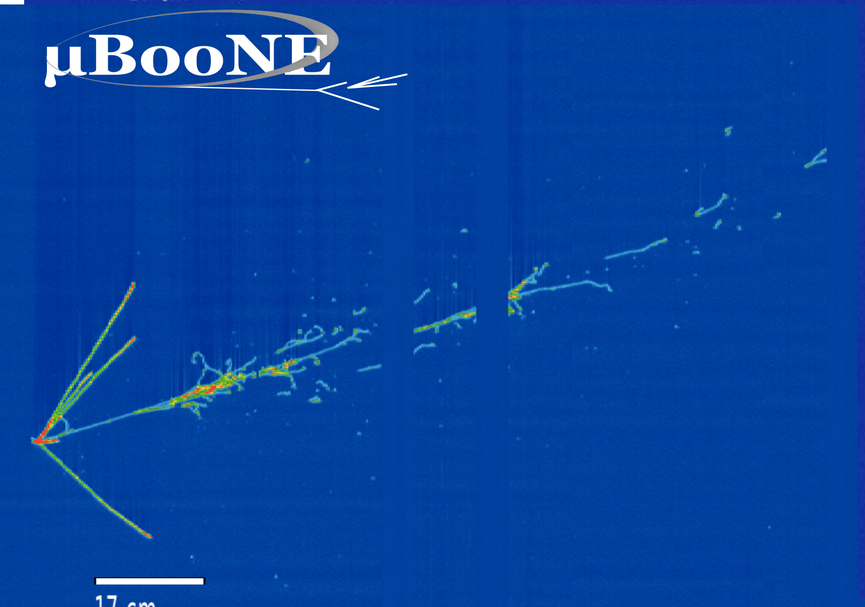
Selection Performance

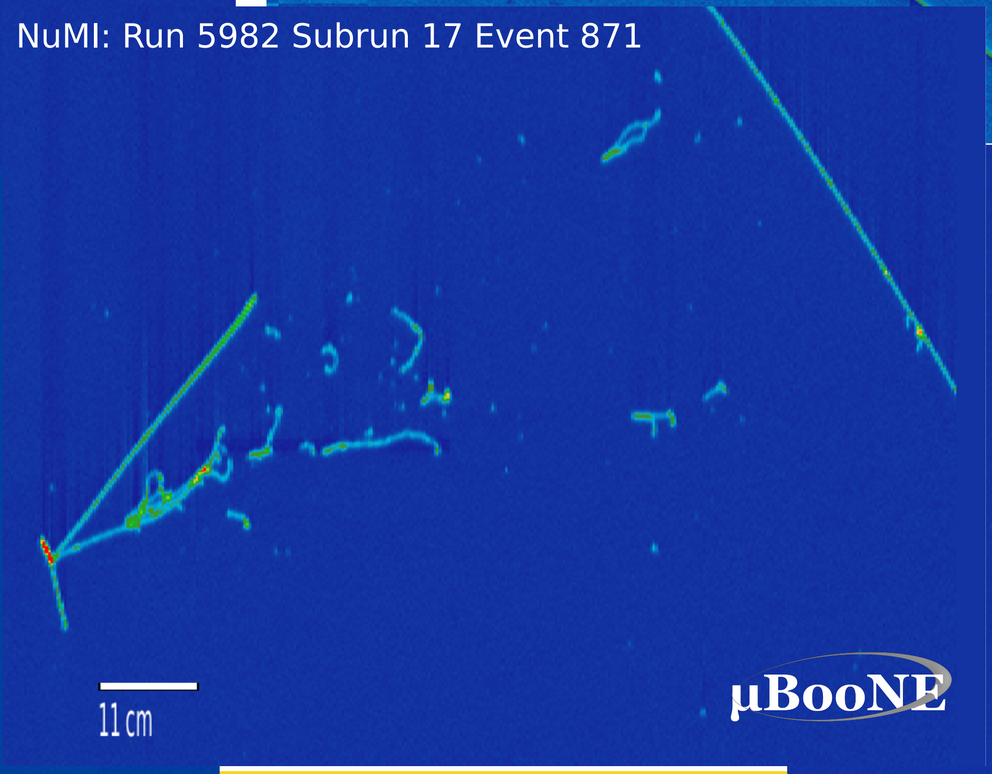
- (Blue) Overall selection purity (~40%):
  - Largest increases come from applying the hit thresholds and the dE/dx cut.
- (Purple) Beam-only selection purity (~65%):
  - Assuming we perfectly remove all off-beam cosmics.
  - This could be the case for data with the MicroBooNE's cosmic-ray tagger (CRT).

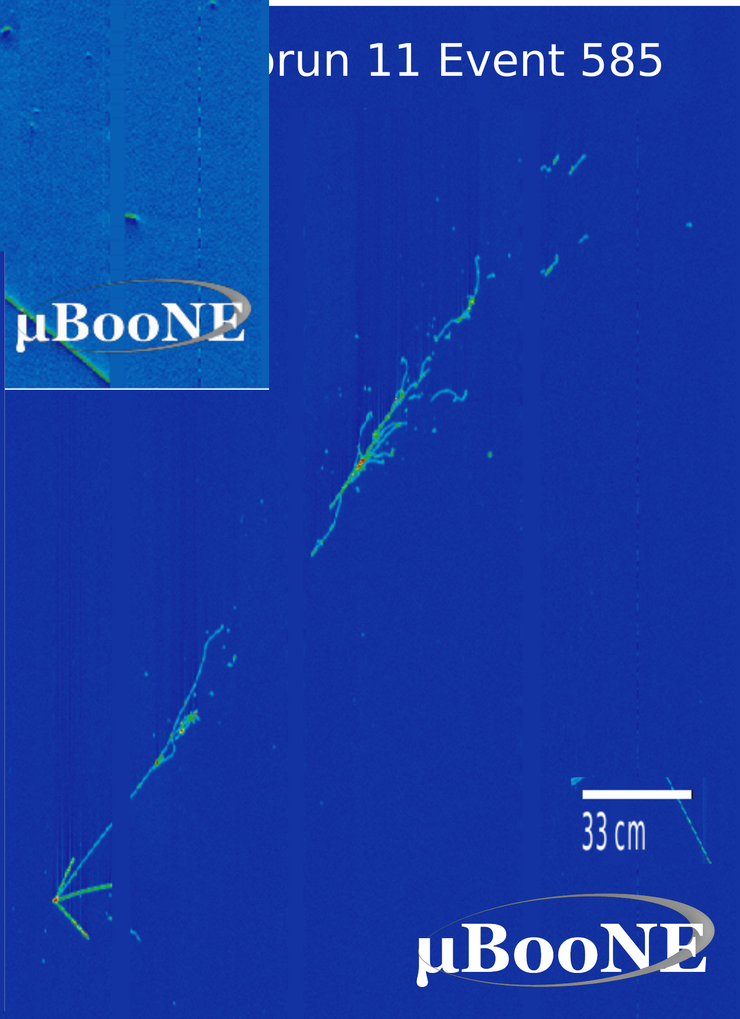






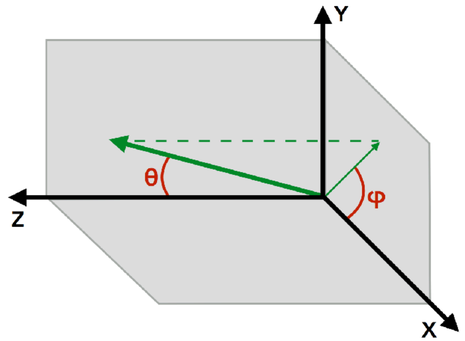




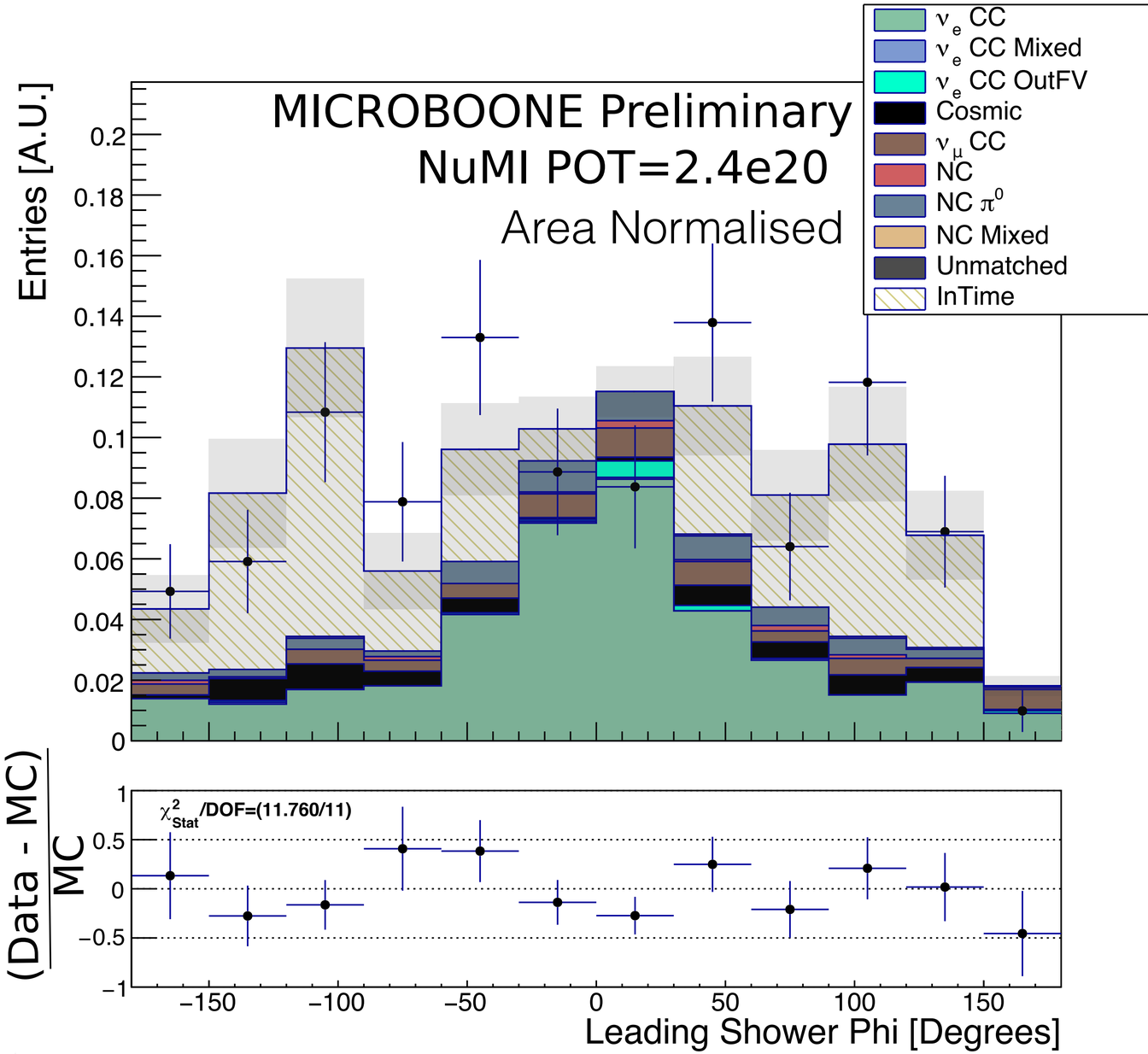


NuMI DATA: RUN 10811, EVENT 2549. APRIL 9, 2017.

Shower Φ

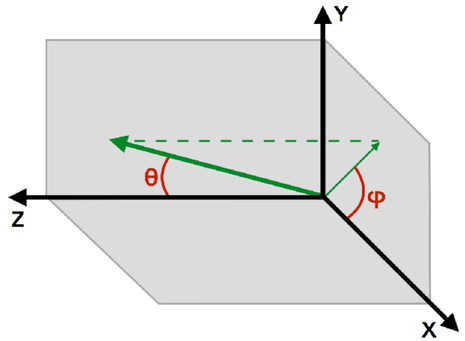


- Off-axis nature of NuMI gives rise to the shape of this distribution.
- The peak in the signal events is consistent with the NuMI target direction.
- Cosmic events are grouped around +/- 90 degrees, as they're often reconstructed as upwards or downwards going.



uB Coordinates

Shower Φ



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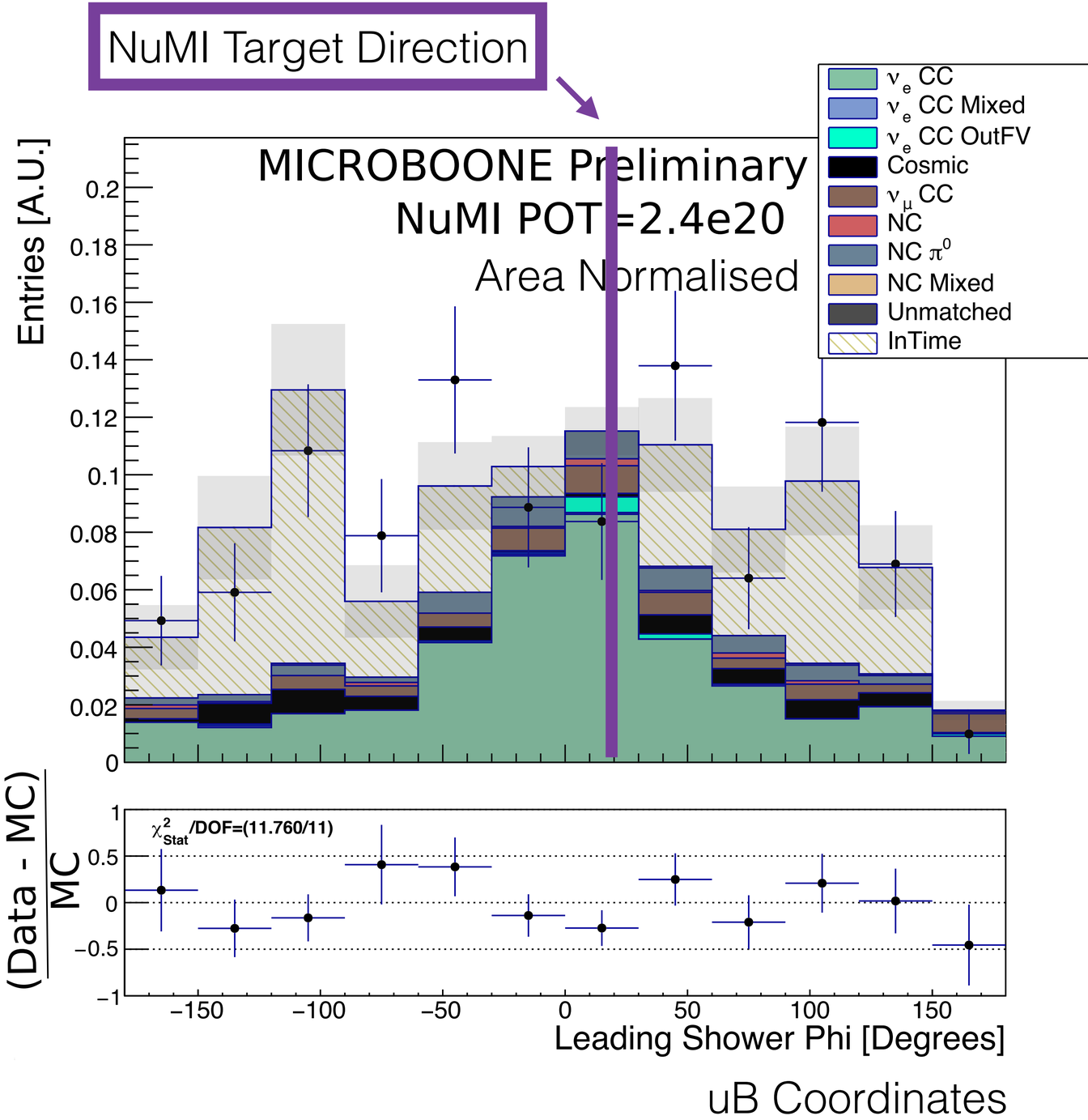
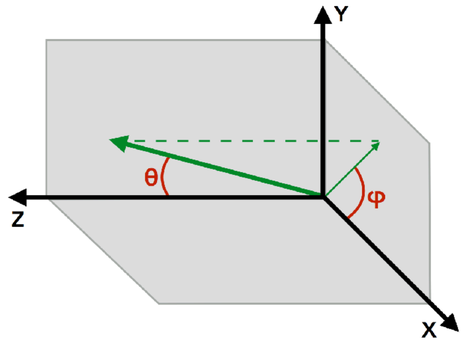
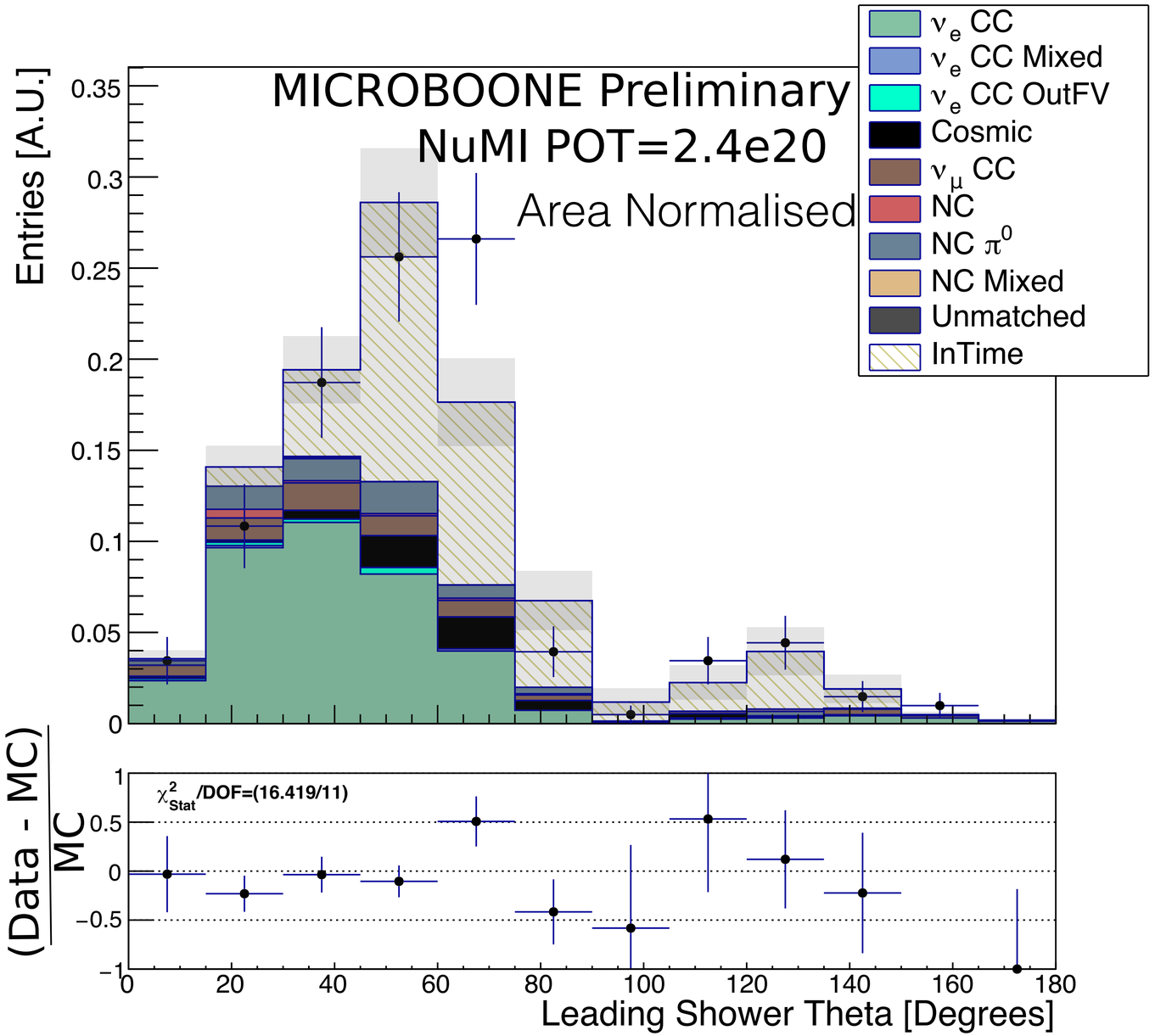


uB Coordinates

Shower Θ



- The majority of beam events are peaked in the forward direction - also consistent with the NuMI prediction.
- Despite having few events, here we also demonstrate MicroBooNE's ability to select backwards-going events.
- The deficit of events around ~90 degrees comes from the angular acceptance of showers parallel to the collection plane wires.



uB Coordinates

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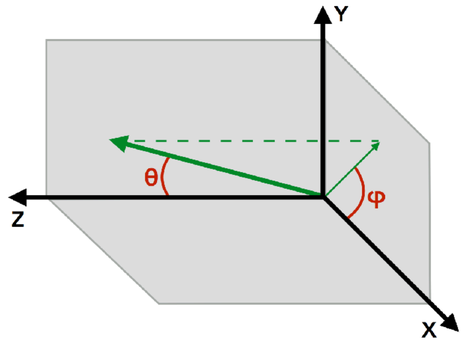

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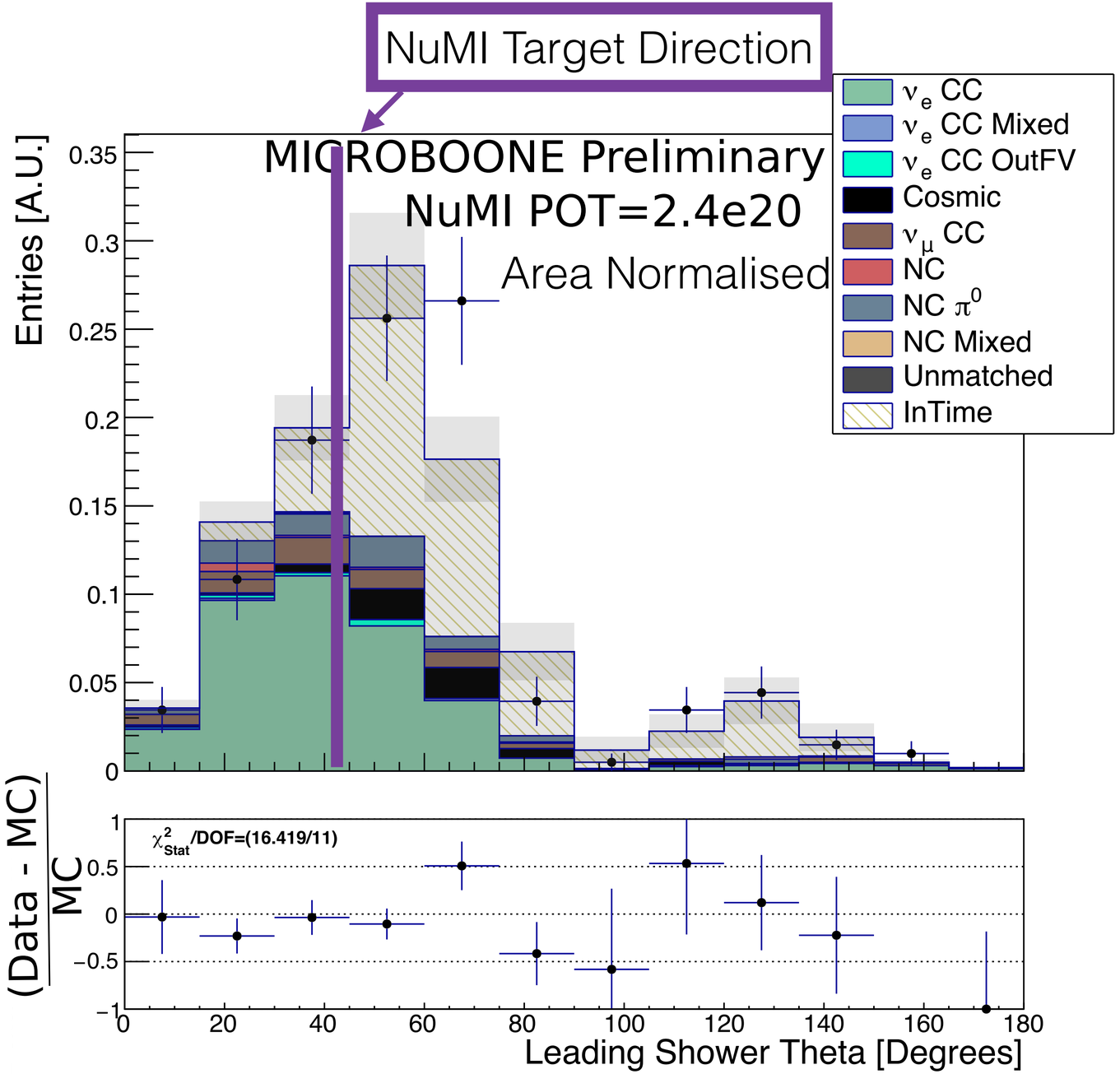
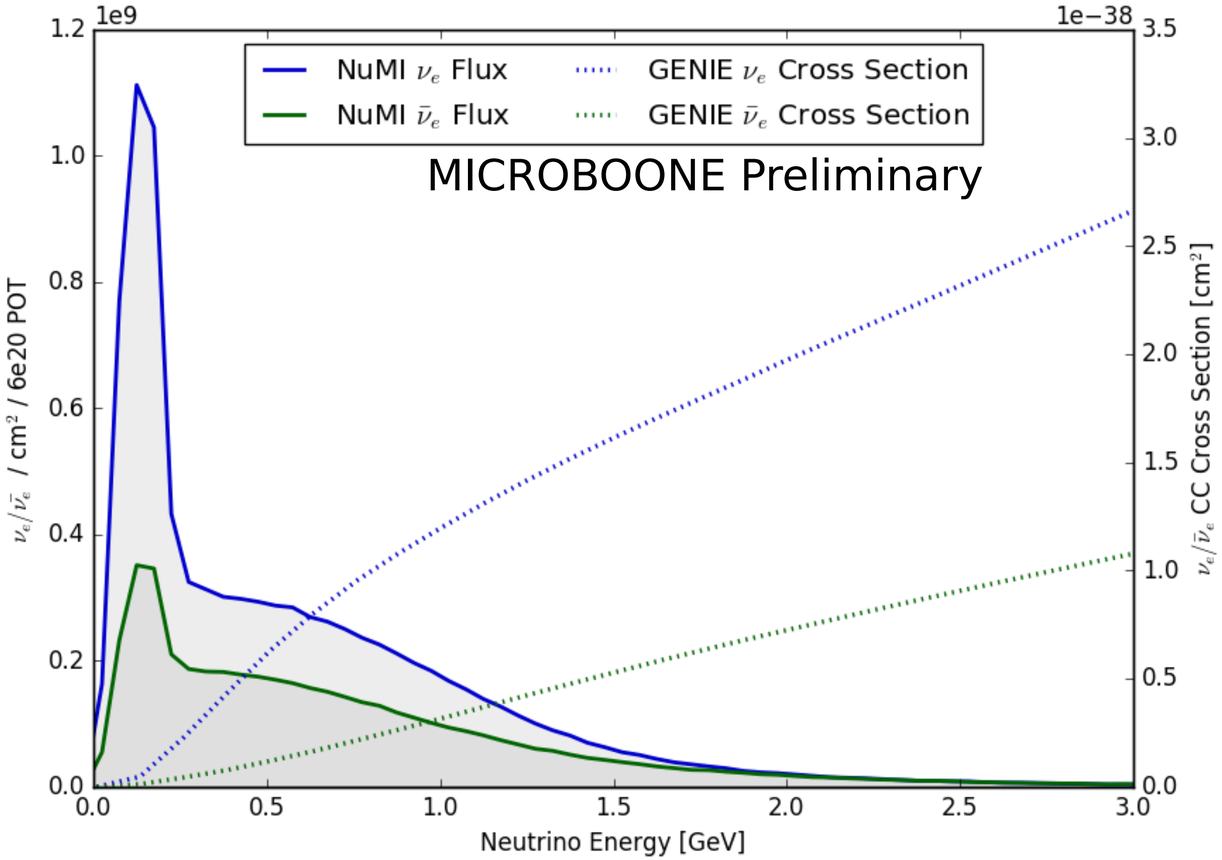


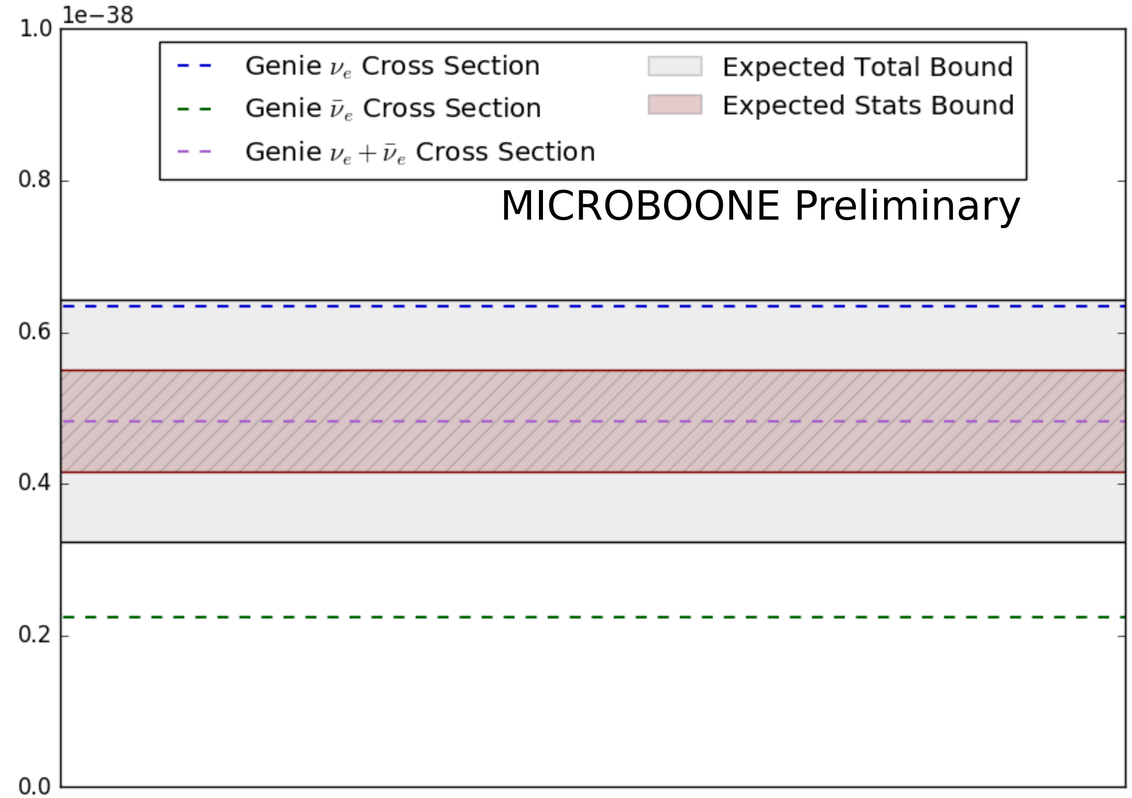
uB Coordinates

Monte Carlo Cross Section Closure Test

- Data cross section still in final steps of analysis, and is coming soon!
- Monte Carlo cross section gives a flavour for the final result on data.
- Using the full selection on MC, we can test if the output of the calculation equals the input.
- This allows us to show expected sensitivity.

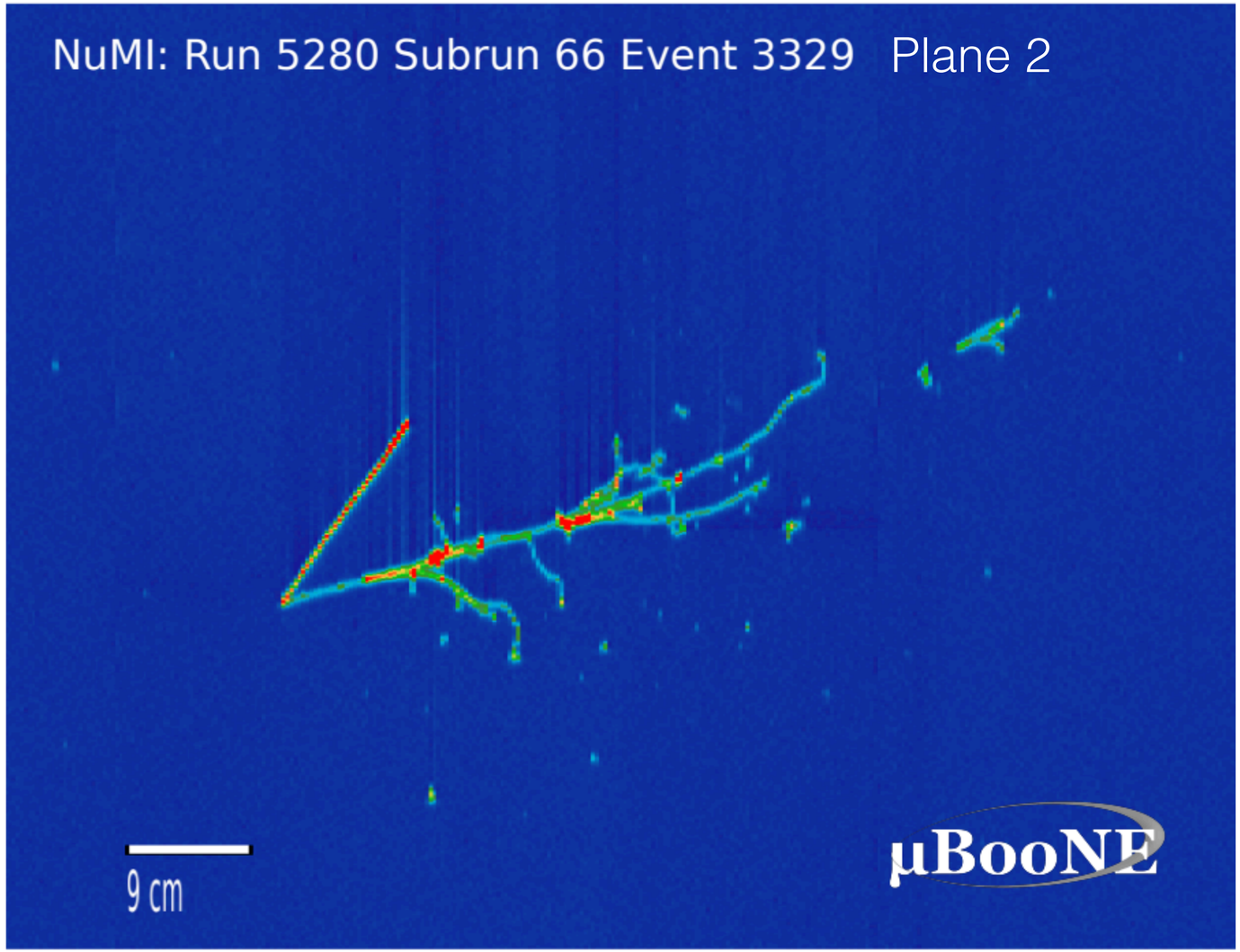
$$\sigma = \frac{N - B}{\epsilon \times N_{Target} \times \Phi_{\nu_e + \bar{\nu}_e}}$$





- Extracted MC cross section matches input.
- This gives us confidence in the selection and up-coming data cross section.
- Total error bound provides expected sensitivity for data cross section.

Conclusion

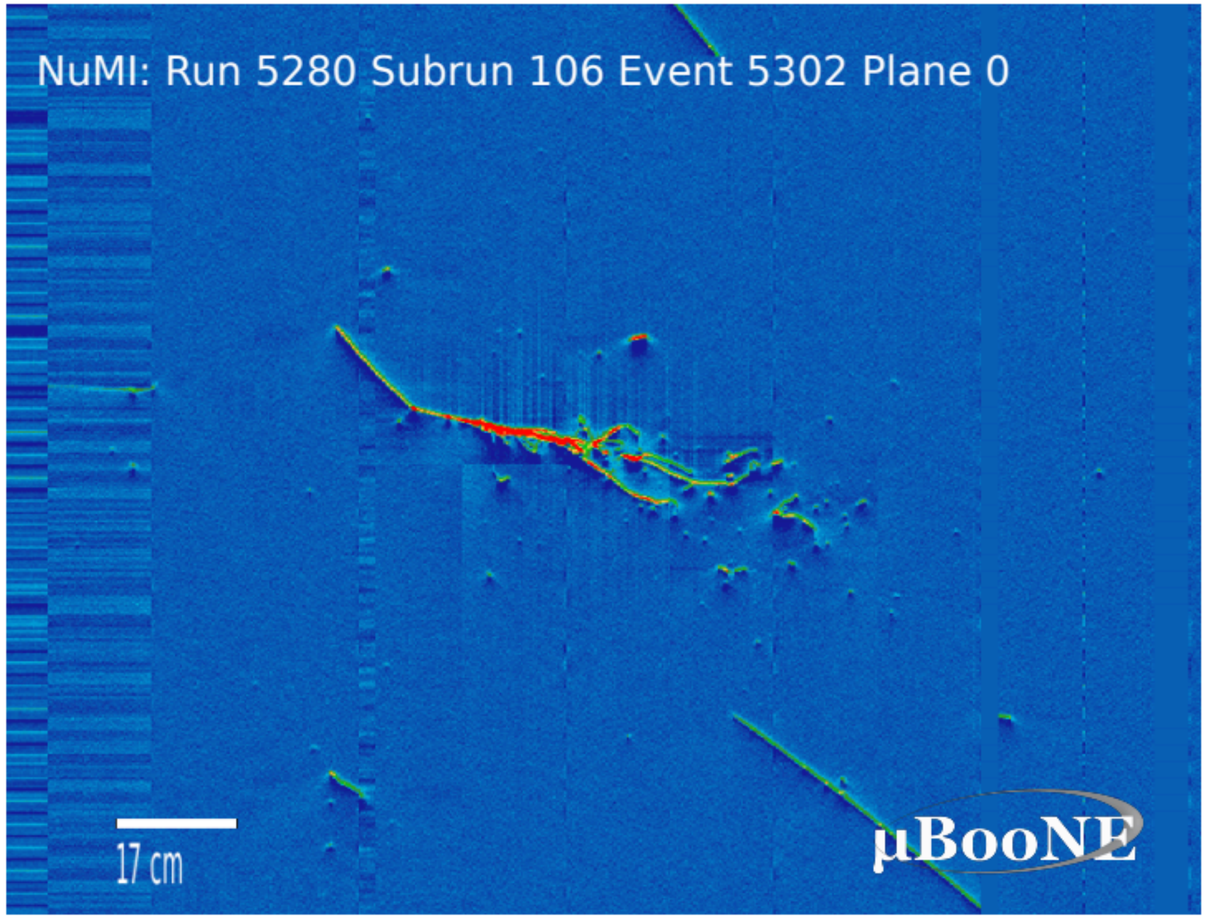


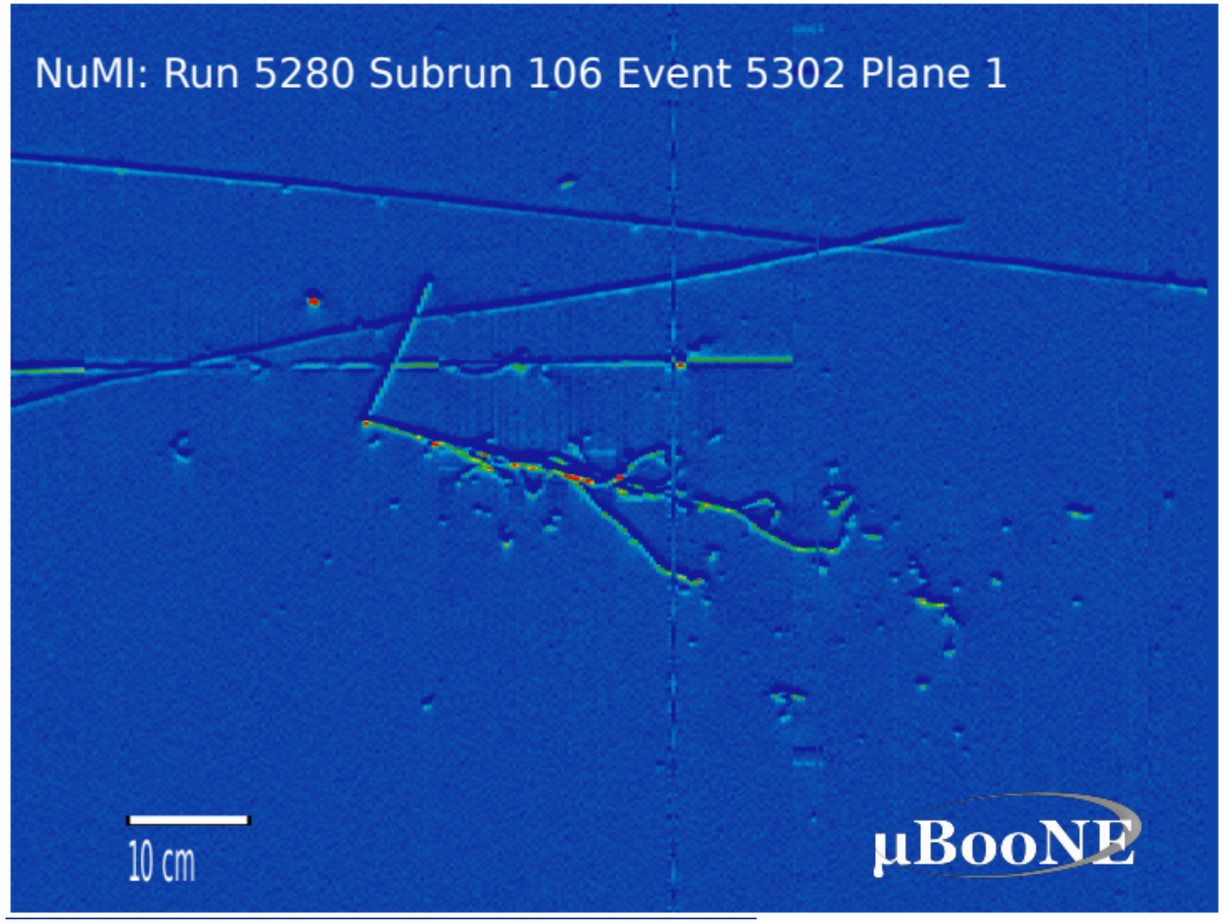
- Demonstrated MicroBooNE's ability to use dE/dx to differentiate between electron-like and photon-like showers.
- Performed MC closure test projecting future measurement of the inclusive ν_e CC cross section on data.
- Displayed results for the most ever ν_e CC interactions selected in data from a liquid argon time projection chamber (~100)!

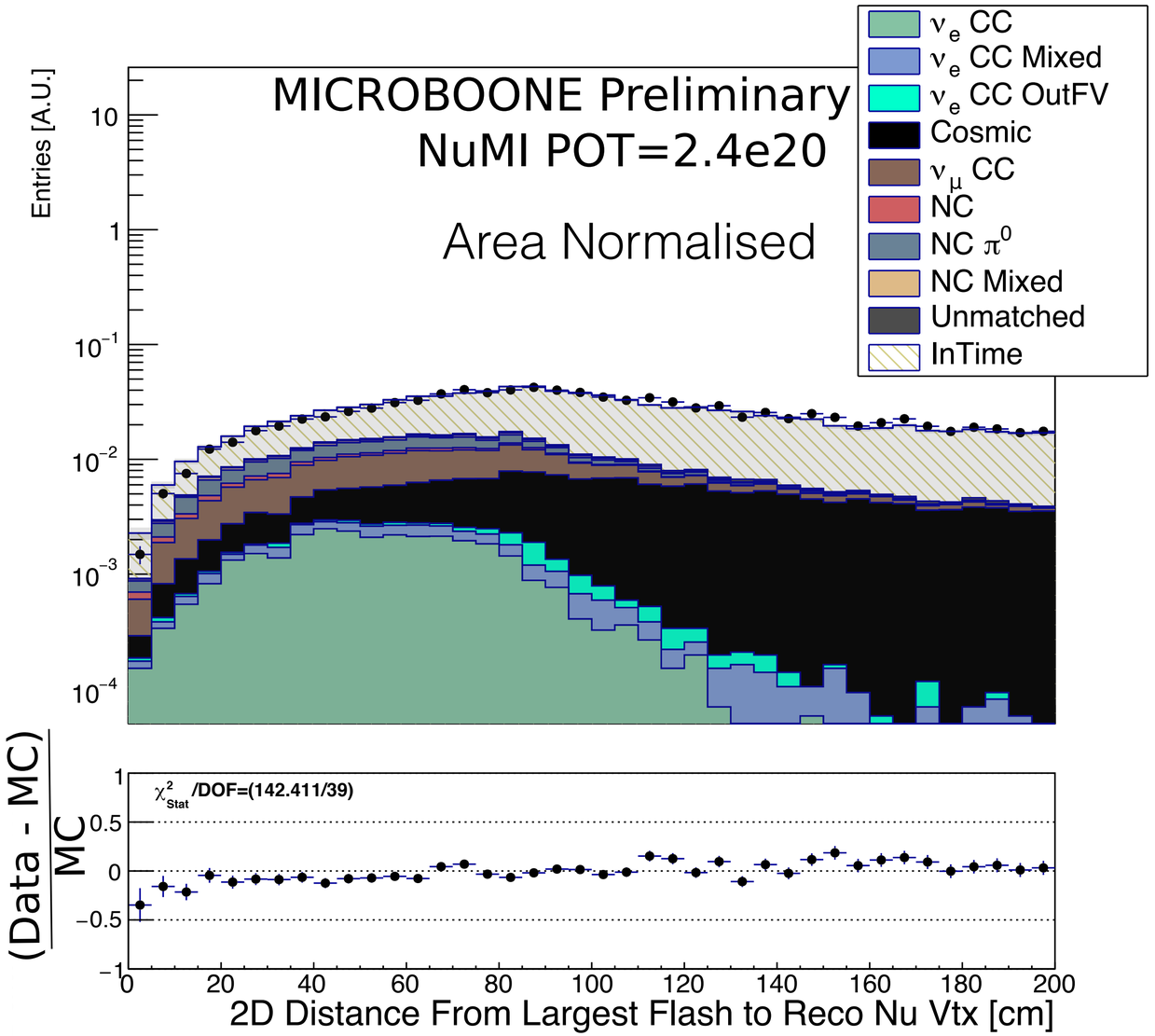
Finding ν_es in Manchester?

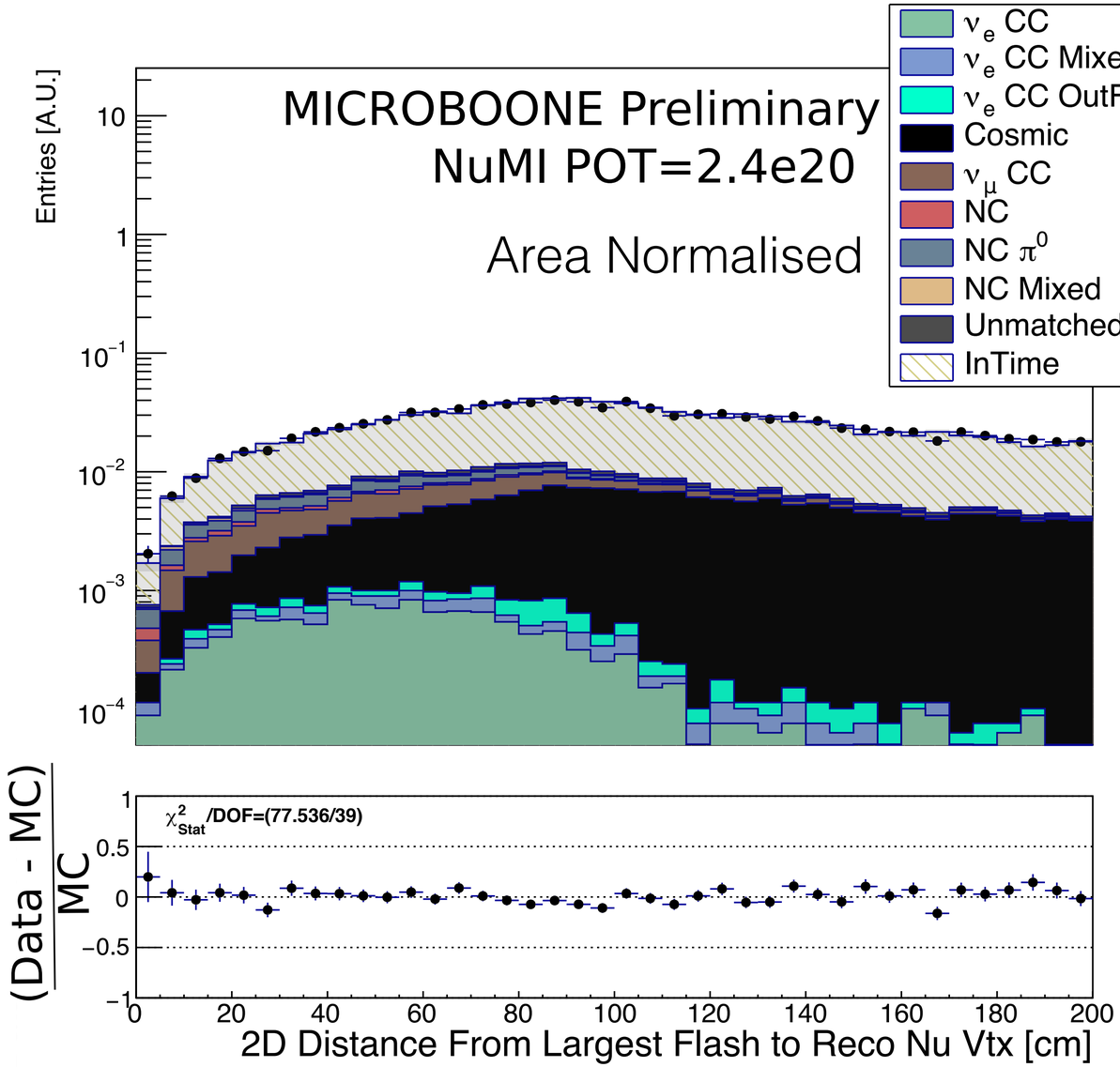
Photo Credit:
Andrzej Szelc

Backup Slides


NuMI: Run 5280 Subrun 106 Event 5302 Plane 0
17 cm
μBooNE


NuMI: Run 5280 Subrun 106 Event 5302 Plane 1
10 cm
μBooNE





Side-by-side View