

μ BooNE

Toward a differential measurement of the ν_e CC1eNp cross section in MicroBooNE

Katrina Miller, on behalf of the MicroBooNE Collaboration

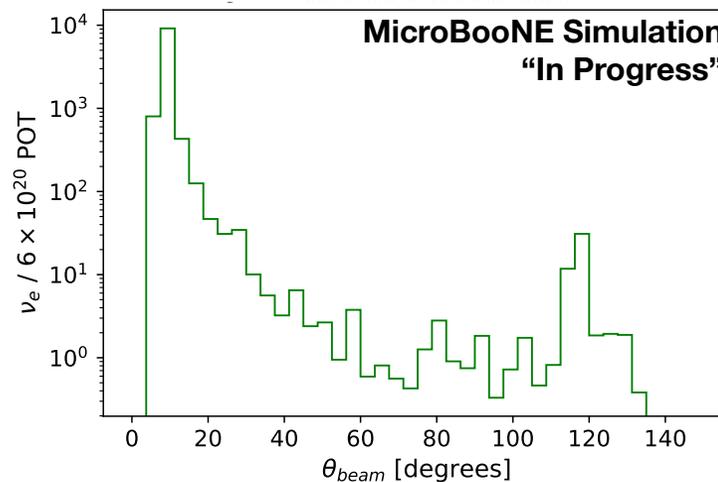
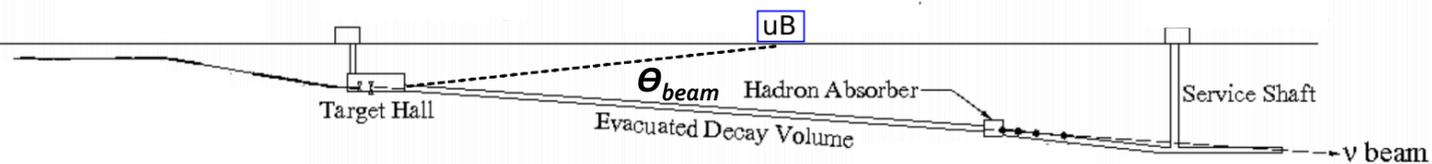
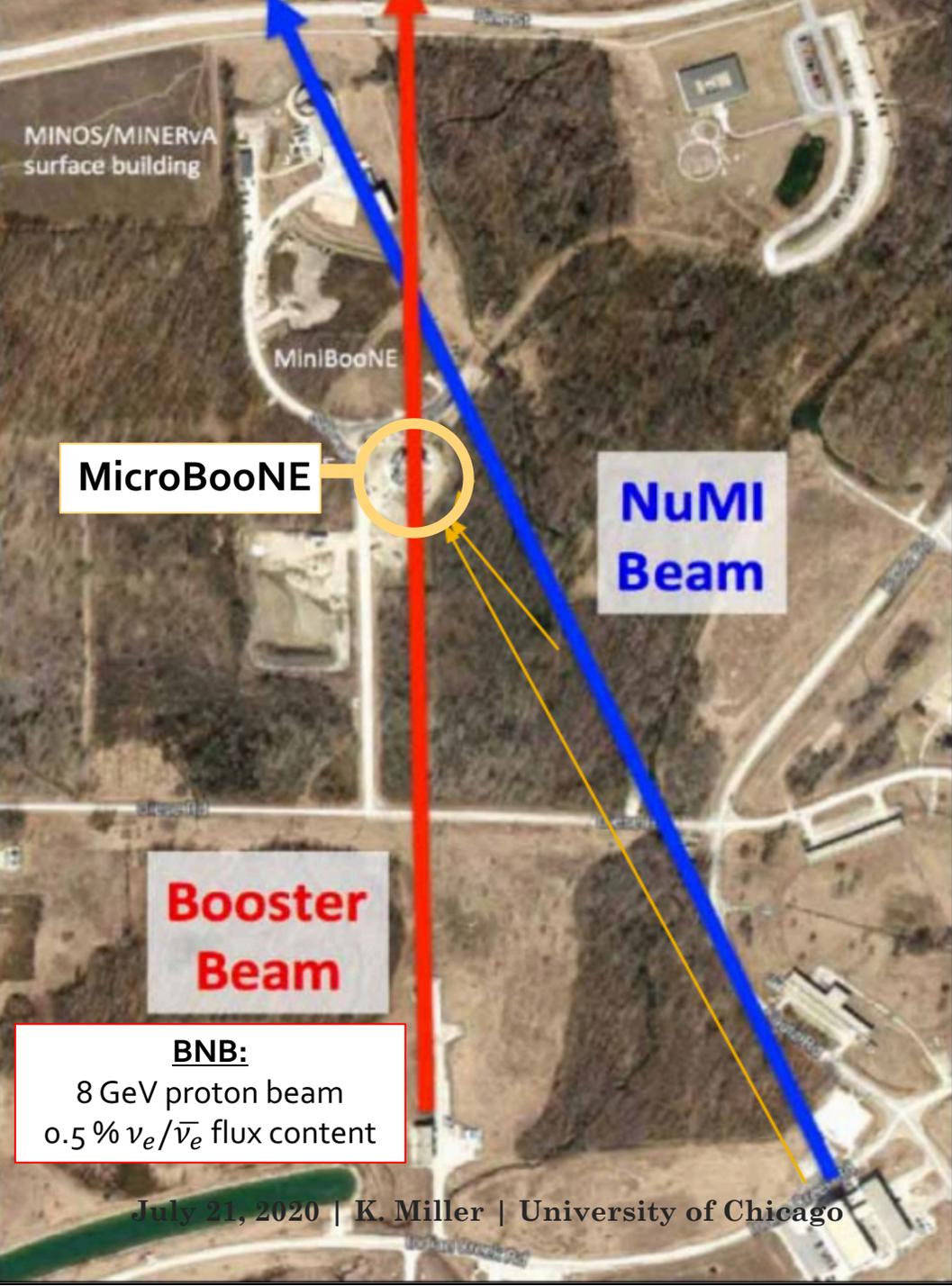
New Perspectives 2020

July 21, 2020



THE UNIVERSITY OF
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The NuMI Beamline



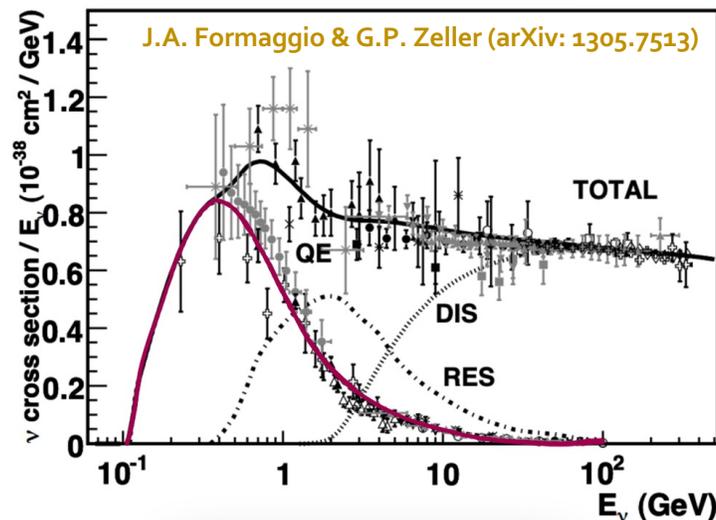
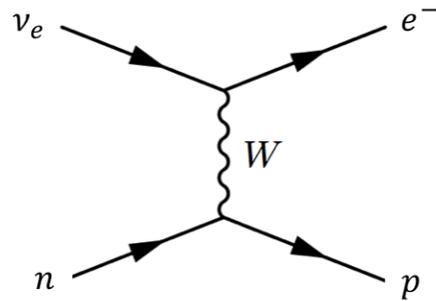
Neutrinos at the Main Injector (NuMI):

- Neutrinos from NuMI enter MicroBooNE at angles $\sim 10\text{-}140^\circ$ from the beamline
- 120 GeV proton beam + Off-axis nature = Greater $\nu_e/\bar{\nu}_e$ flux content ($\sim 5\%$)
- Excellent source for $\nu_e/\bar{\nu}_e$ cross section studies!

ν_e Cross Sections in LArTPCs

"uncertainty on the ν_e and $\bar{\nu}_e$ cross-sections... [is] the second-largest single source of systematic uncertainty in the CP asymmetry measurement."
(T2K Collaboration, Nature vol. 580, p. 339–344, 2020)

Charged-current quasi-elastic (CCQE) interactions

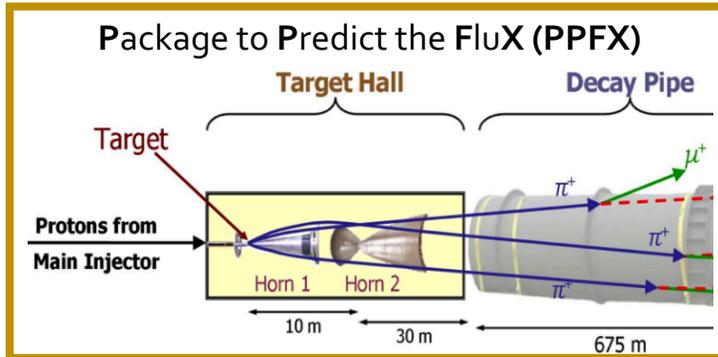


- Vital to reach discovery precision in the ν_e appearance oscillation channel
 - neutrino mass ordering, CP violation, existence of sterile neutrinos
- Limited data available on ν_e cross sections overall
 - CC inclusive, CCQE-like differential results on carbon (T2K, MINERvA)
 - Only result on argon: Flux-averaged CC inclusive – 13 events (ArgoNeut)
- **No exclusive differential ν_e -Ar cross sections currently exist**
- CC1eNp: mostly CCQE → a dominant interaction in SBN & DUNE

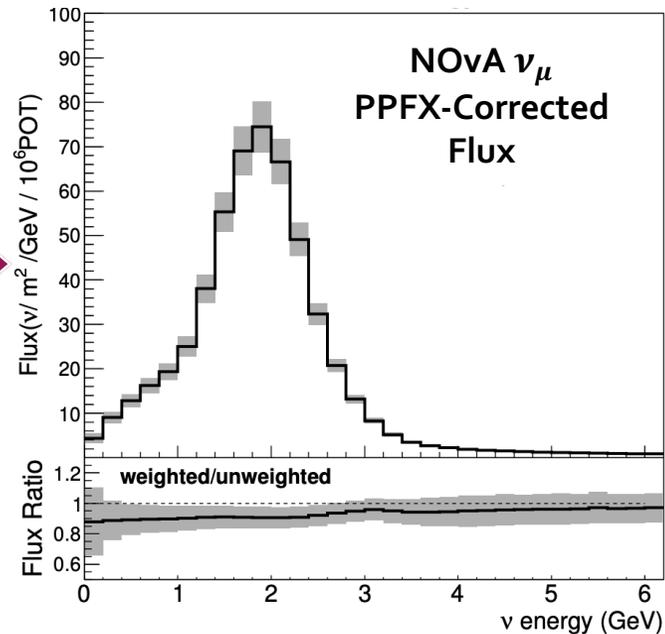
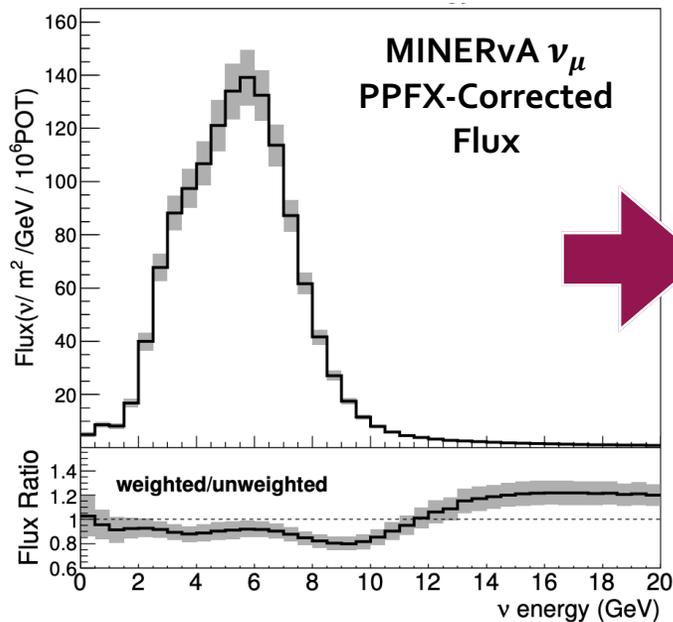
What is needed to measure the cross section?

1. Accurate flux prediction
2. High purity, high statistics sample of CC1eNp events

Updating the NuMI Flux Prediction

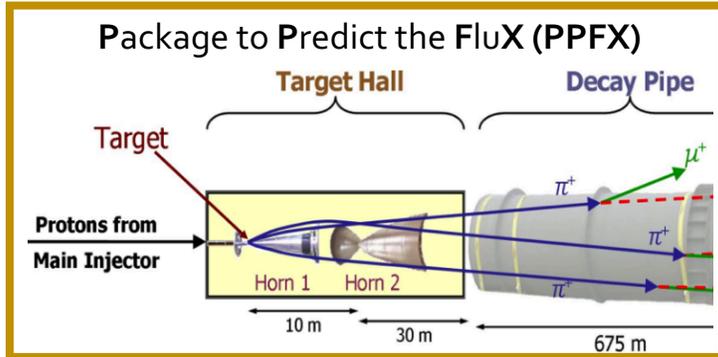


- **PPFX**: An experiment-agnostic reweight package developed by MINERvA to correct the NuMI GEANT₄ simulation using external hadron production data

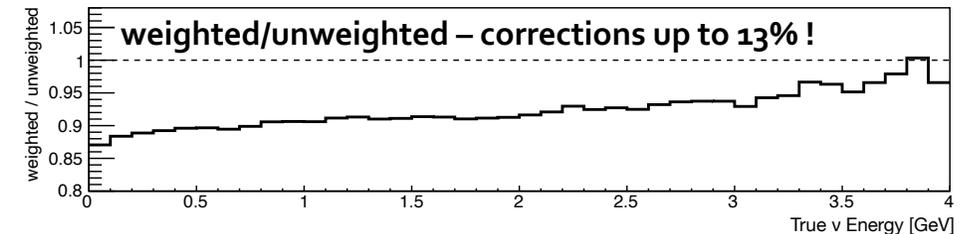
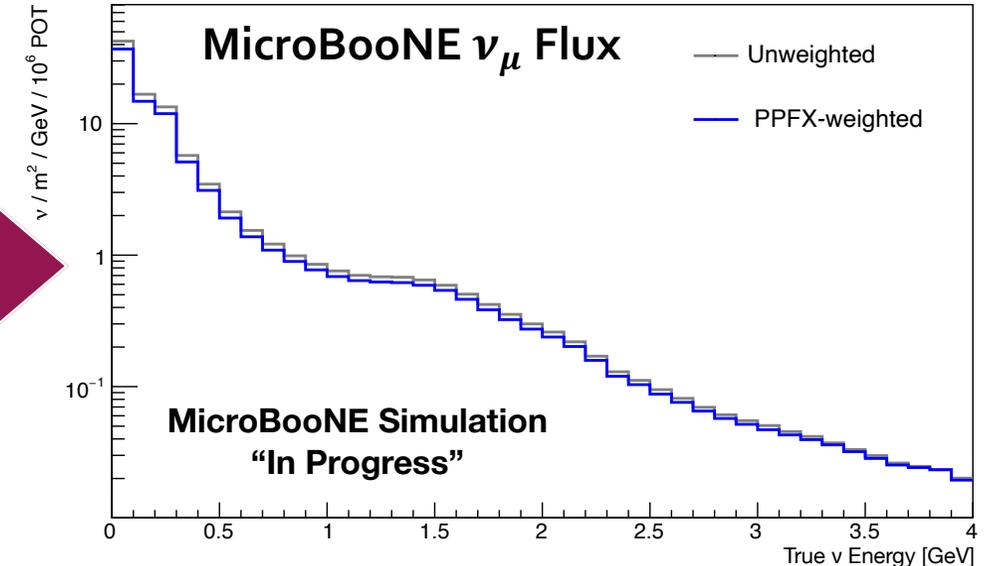
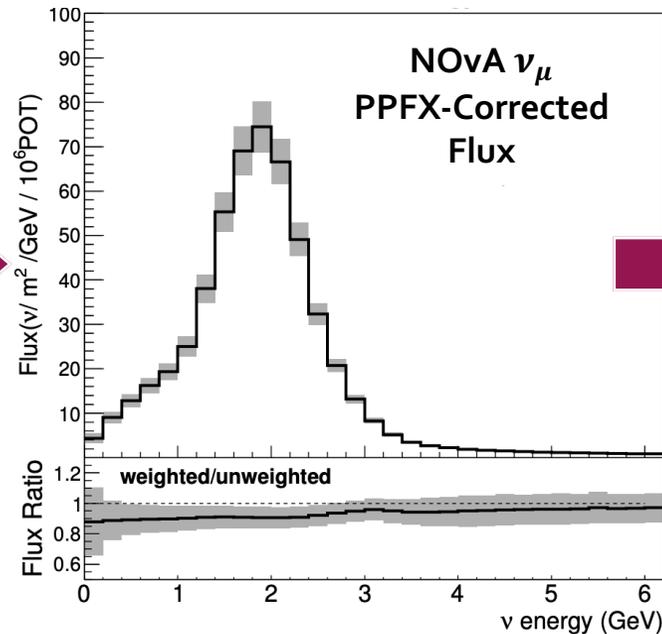
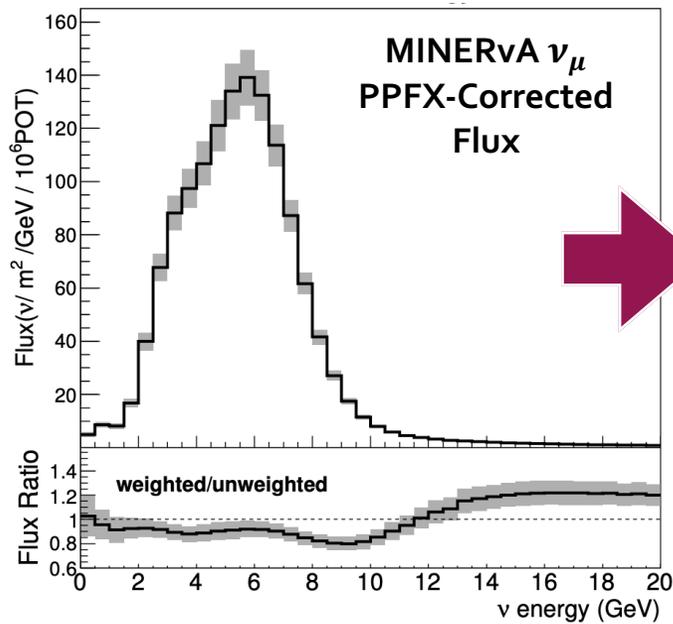


source: <https://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2016-03.pdf>

Updating the NuMI Flux Prediction



- **PPFX**: An experiment-agnostic reweight package developed by MINERvA to correct the NuMI GEANT₄ simulation using external hadron production data
- **Dedicated, cross-collaboration effort** to update the NuMI flux prediction at MicroBooNE using the PPFX software

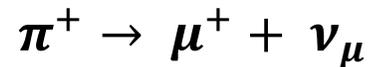


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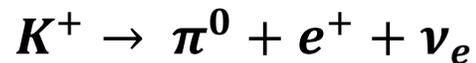
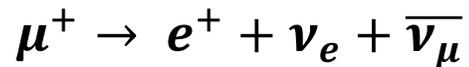
Updating the NuMI Flux Prediction

- PPFX equips us with the most accurate NuMI flux prediction at MicroBooNE to date

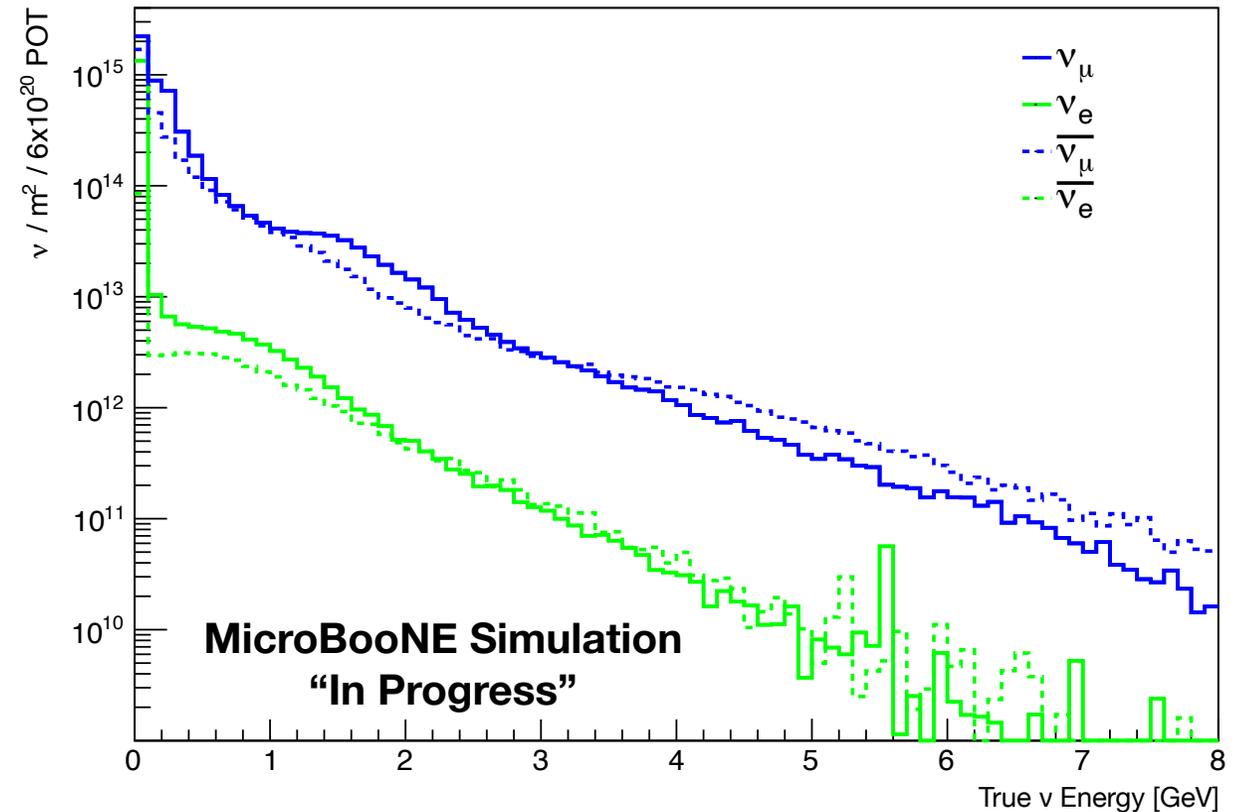
- ν_μ flux dominated by pion decays:



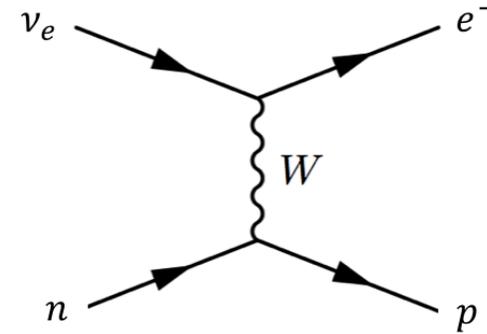
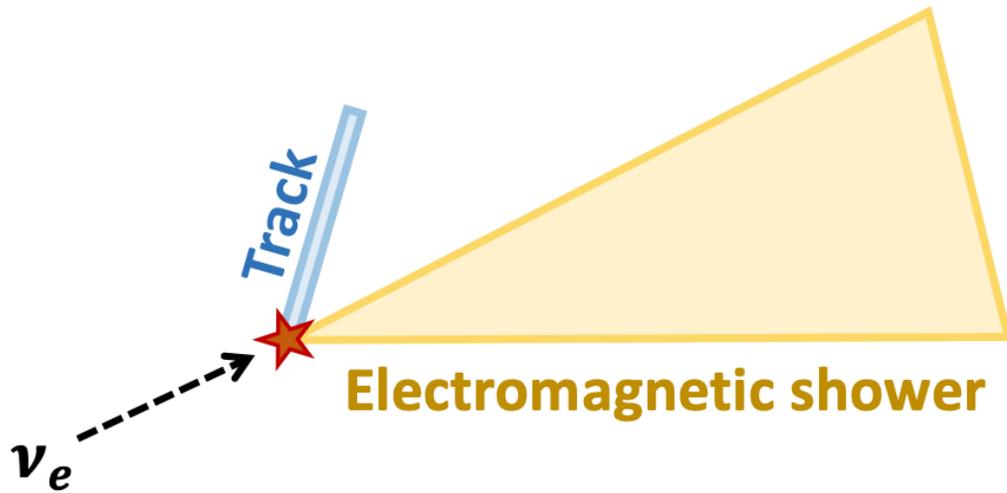
- ν_e flux dominated by muon & kaon decays:



PPFX-Corrected NuMI Flux at MicroBooNE (FHC)



Event Selection: CC1eNp Topology



Charged-current interactions

- neutrino \rightarrow charged lepton partner
- isospin of the nucleon flips

1eNp event signature

- 1 electron shower, attached to neutrino interaction vertex
- $N > 0$ tracks: short, highly ionizing

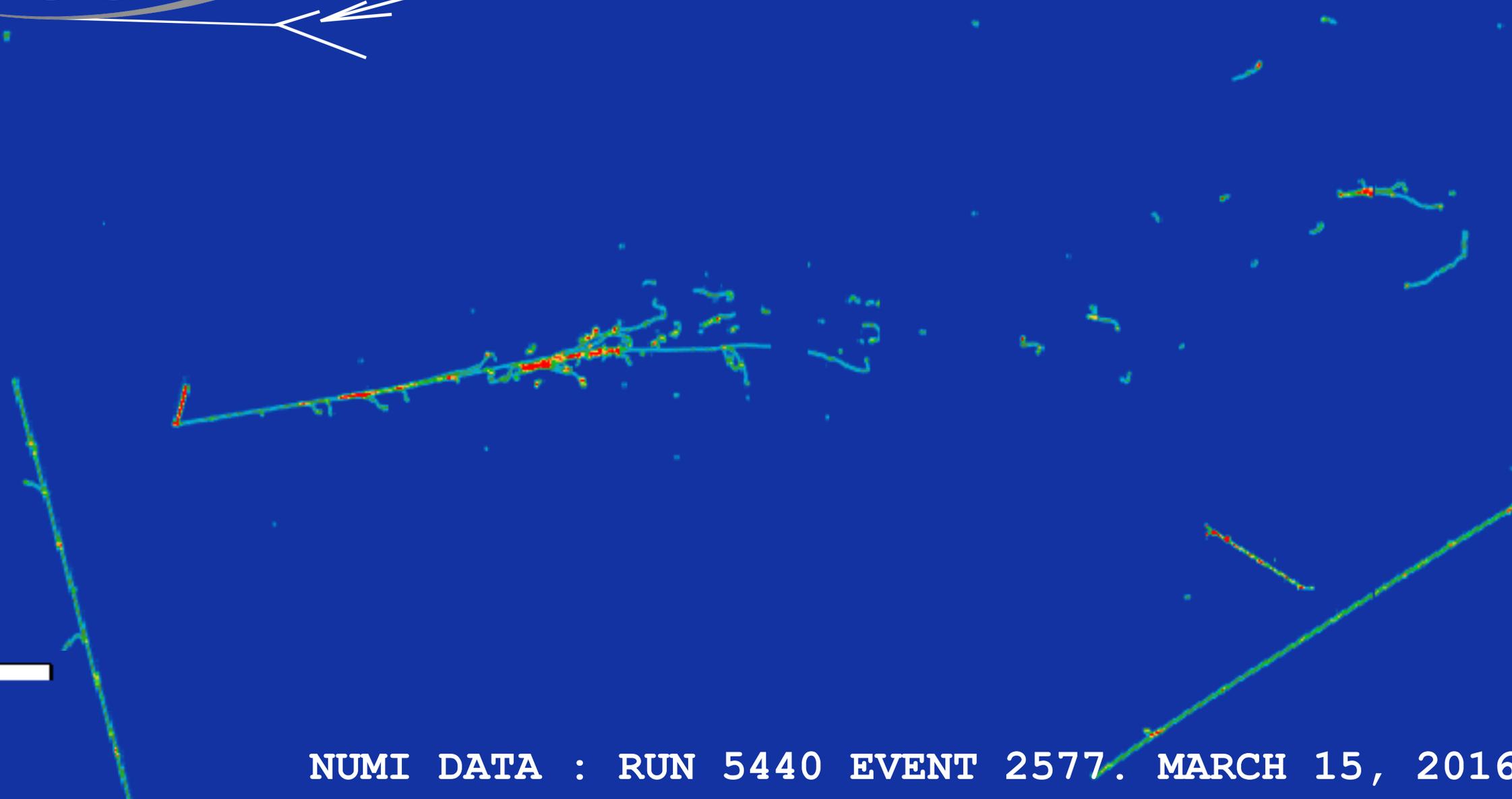
μ BooNE

Selected 1eNp signal candidate
*Color corresponds to energy deposit!

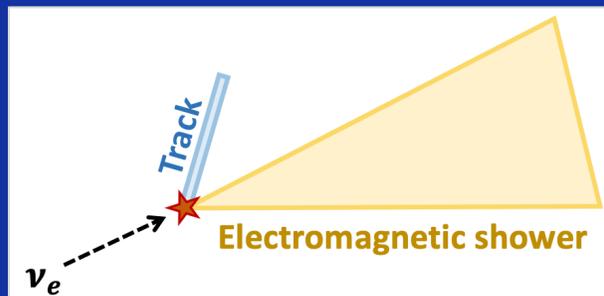


23 cm

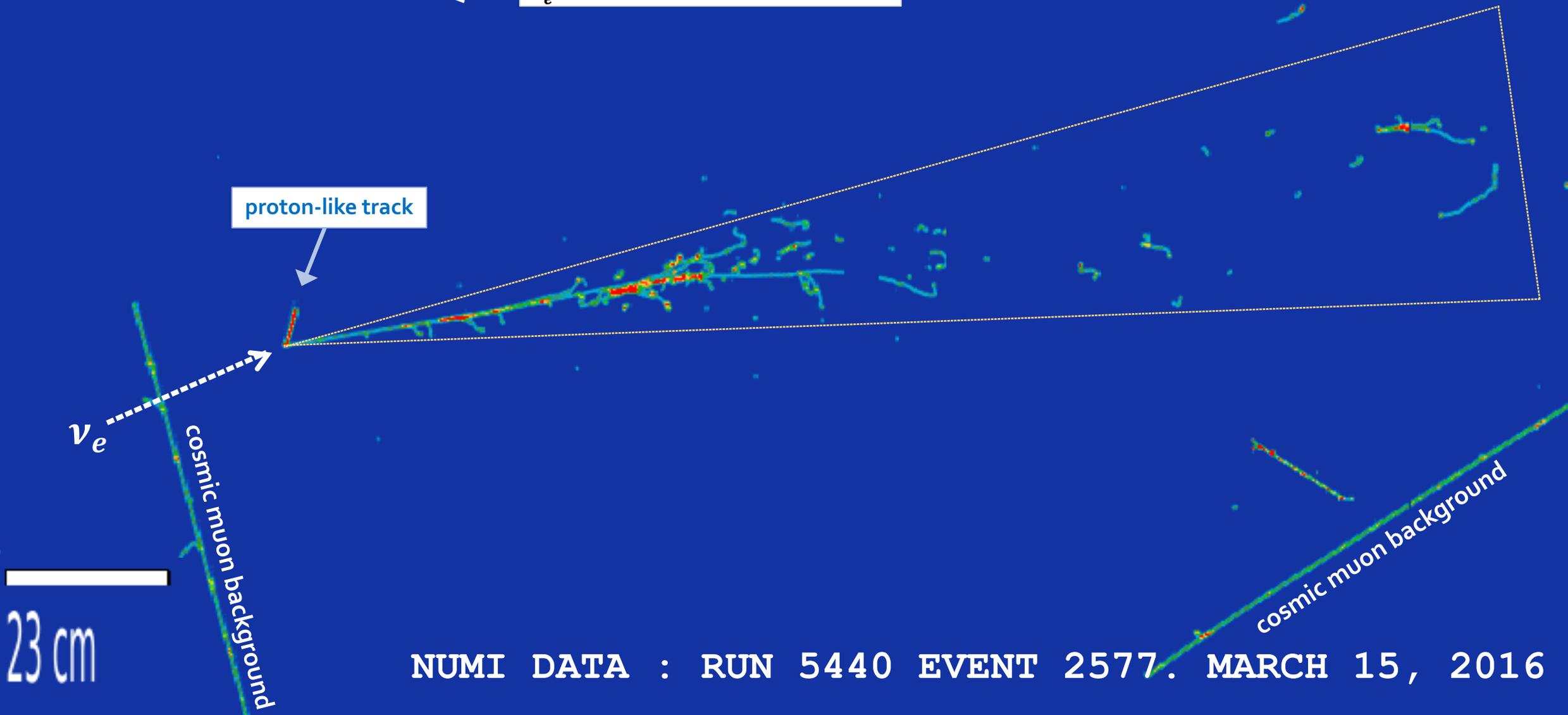
NUMI DATA : RUN 5440 EVENT 2577. MARCH 15, 2016



μ BooNE



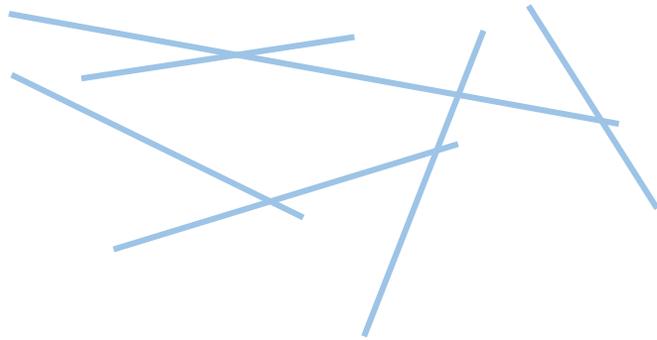
Selected 1eNp signal candidate
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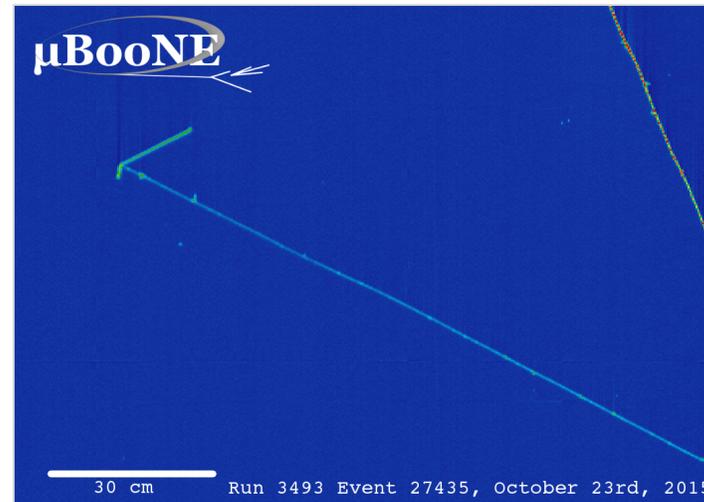
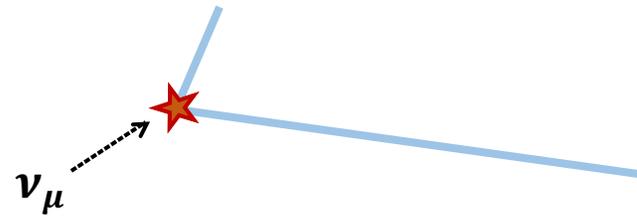
NUMI DATA : RUN 5440 EVENT 2577. MARCH 15, 2016

Event Selection: Background Rejection

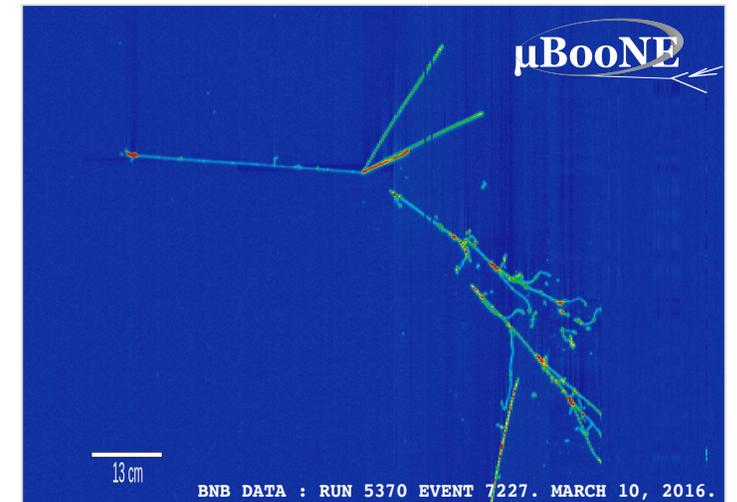
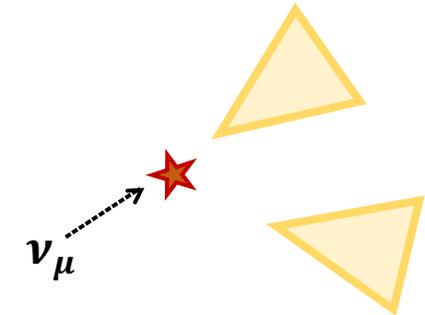
Cosmic muons



ν_μ CC events

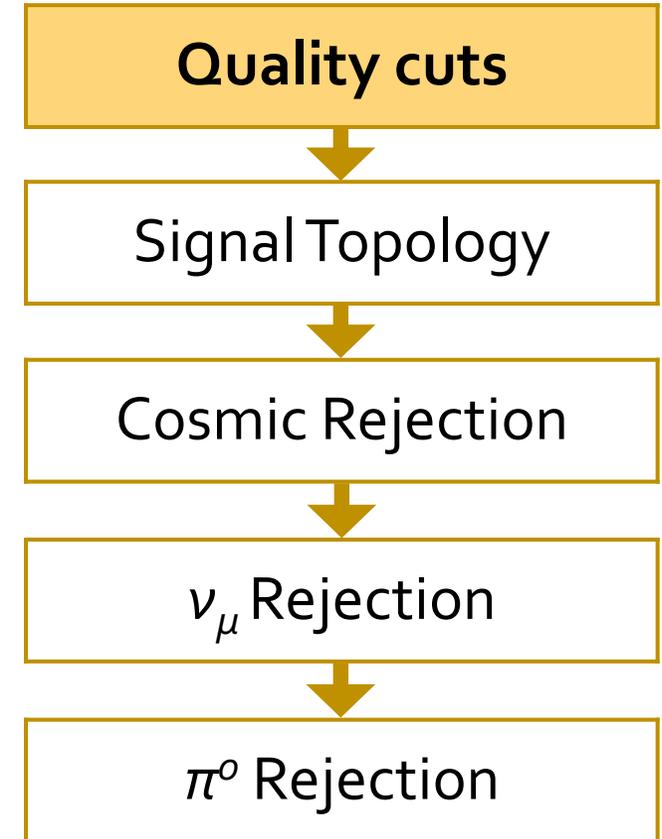
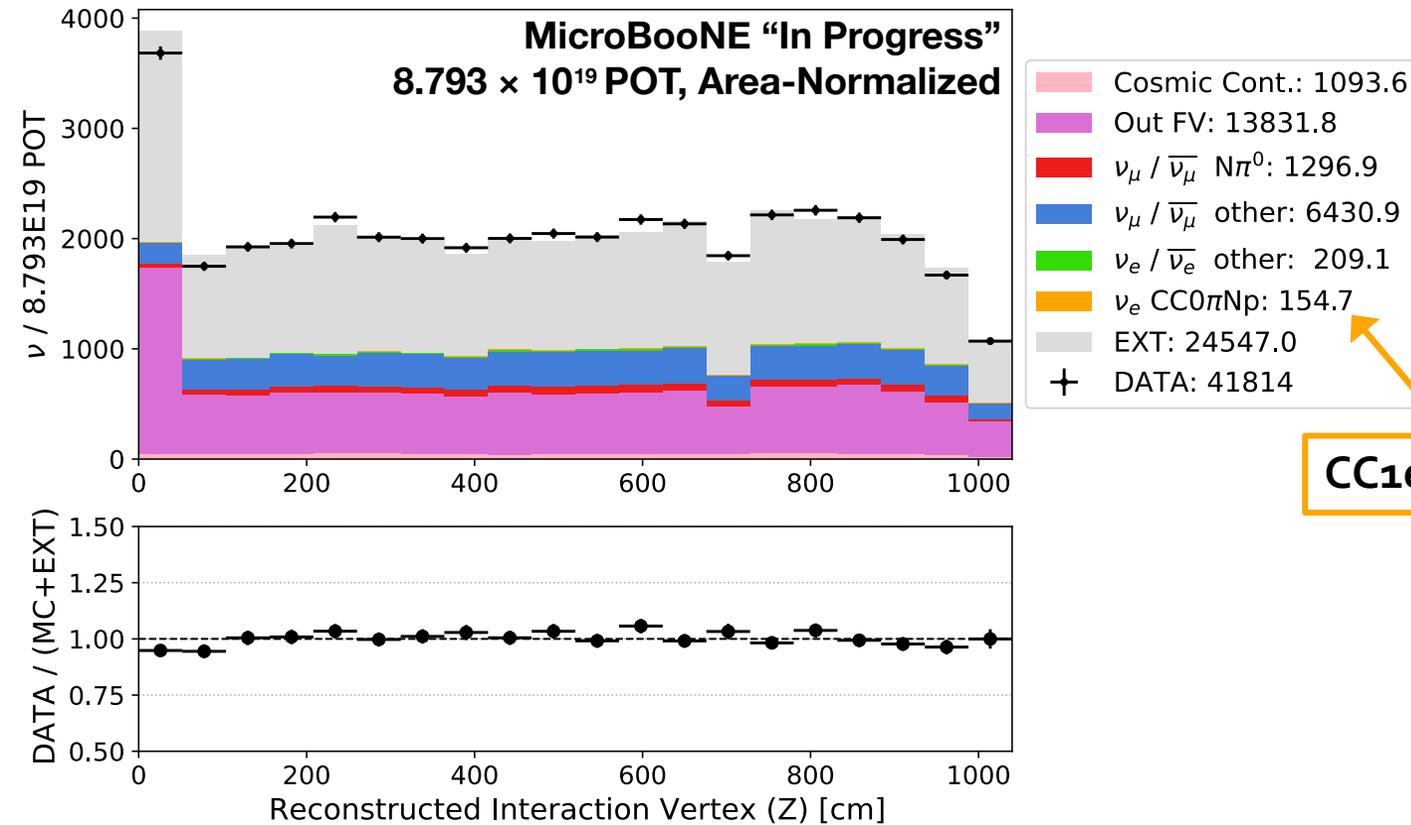


$\pi^0 \rightarrow \gamma\gamma$ events

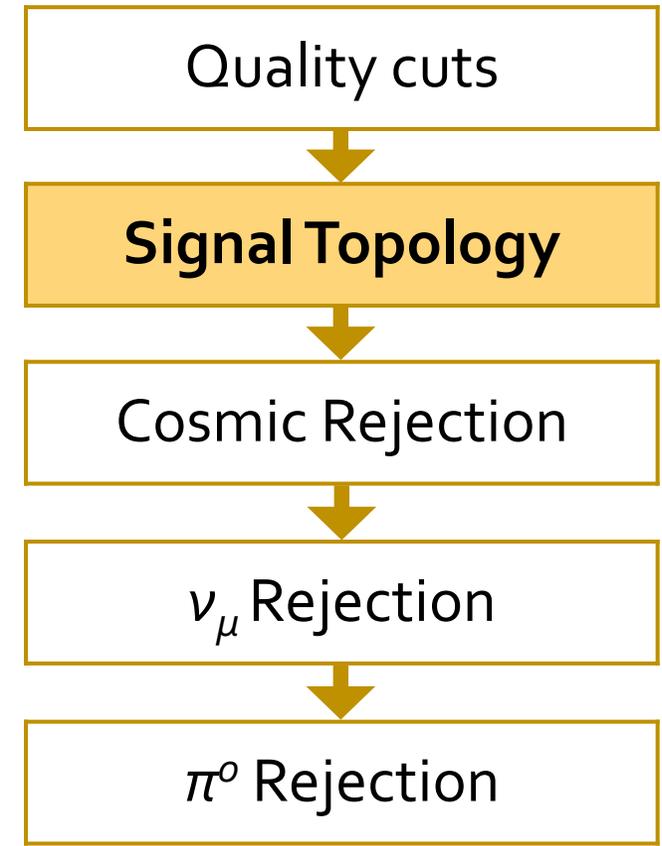
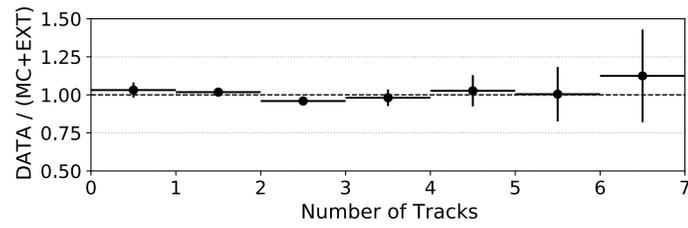
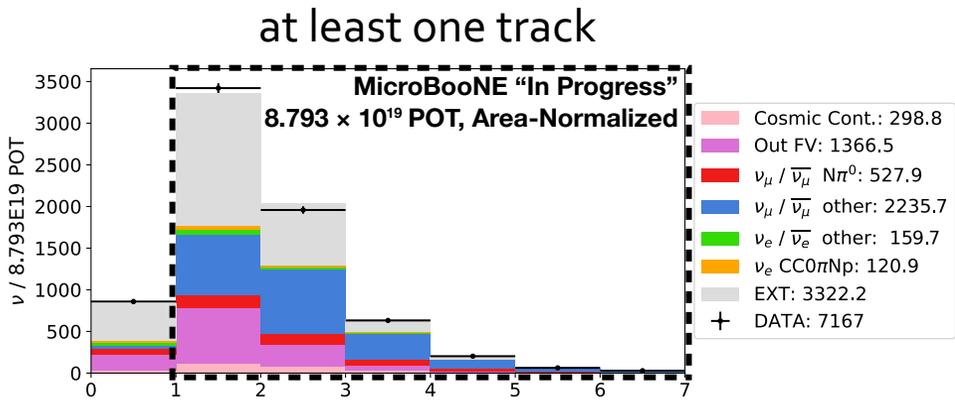
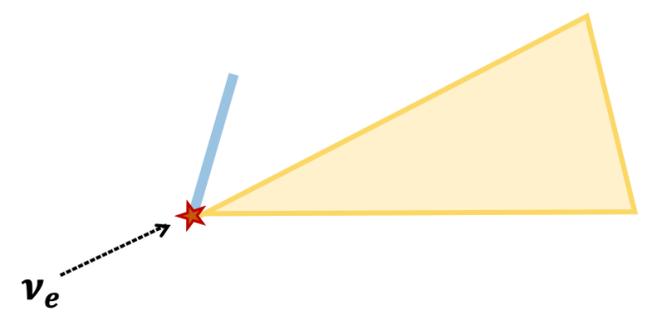
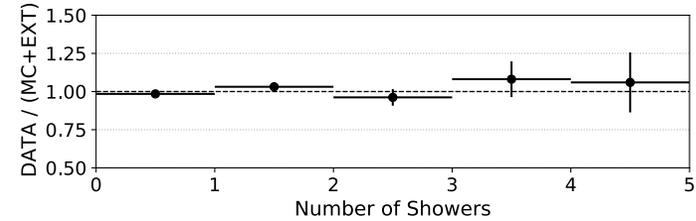
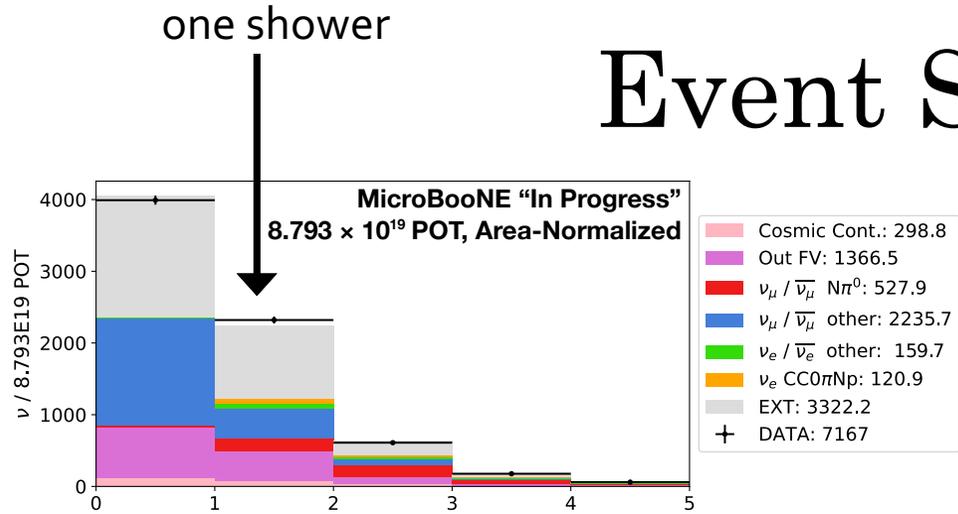


Event Selection Algorithm

Select well-reconstructed events away from TPC edges with neutrino candidate present

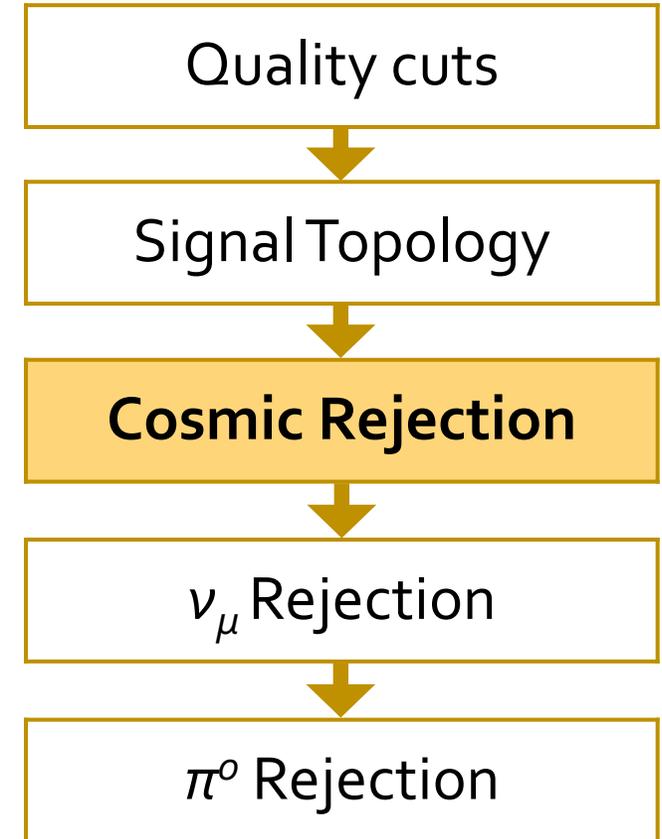
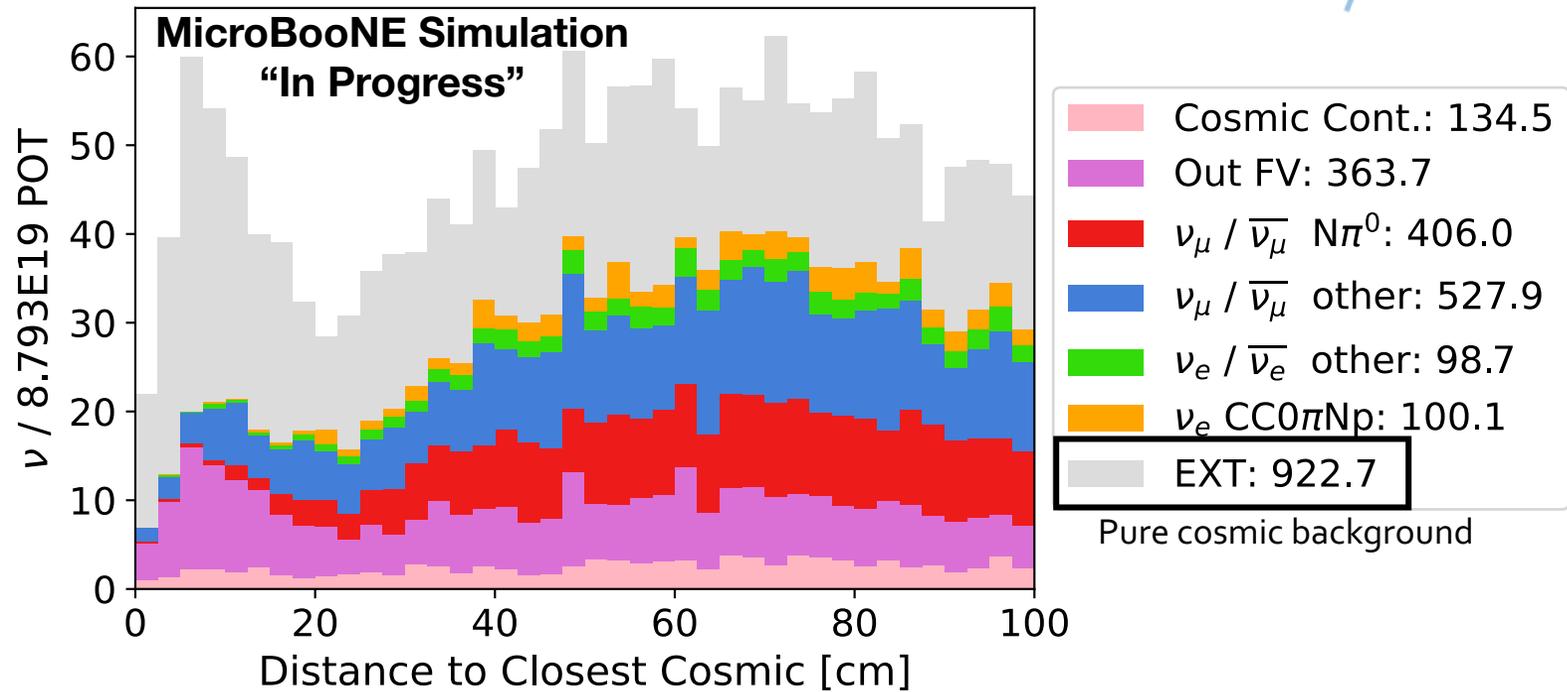
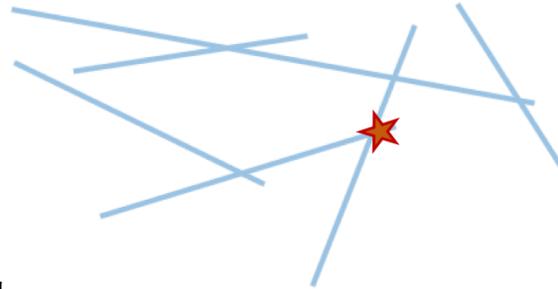


Event Selection Algorithm

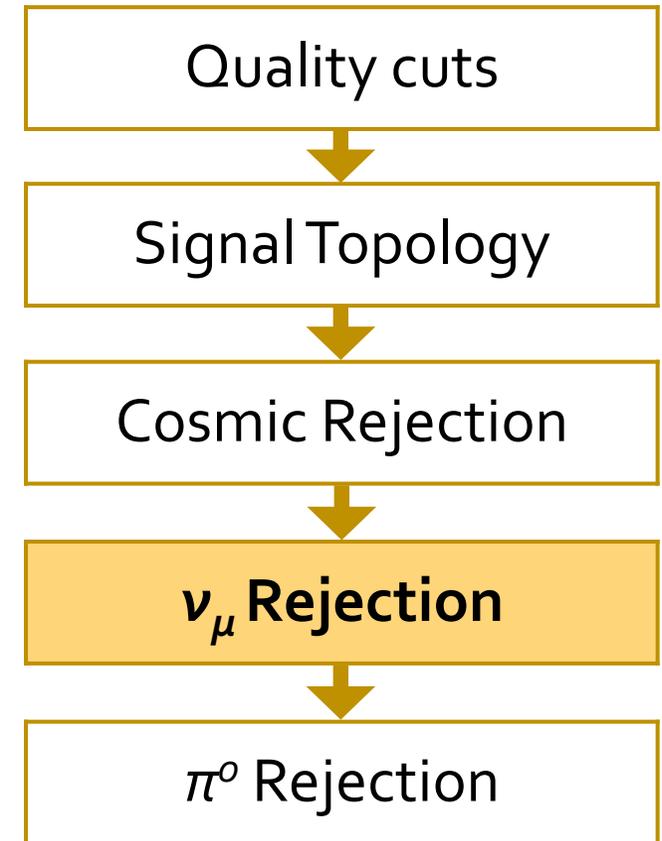
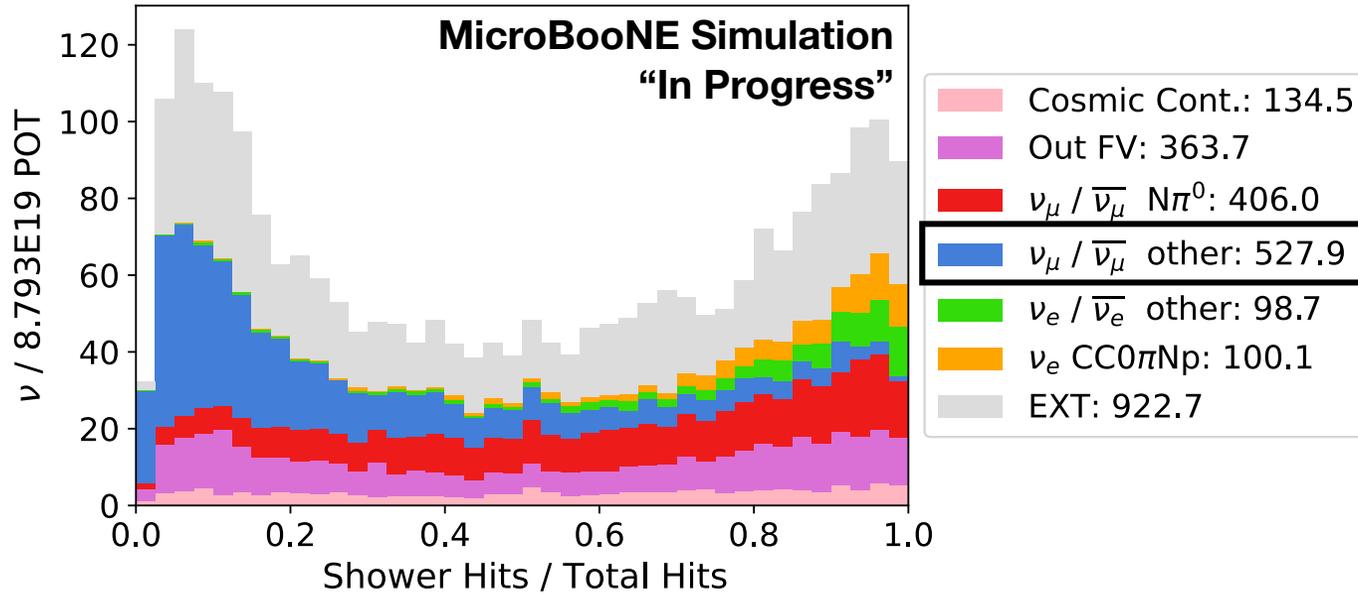


Event Selection Algorithm

Cosmic background misreconstructed as a neutrino interaction

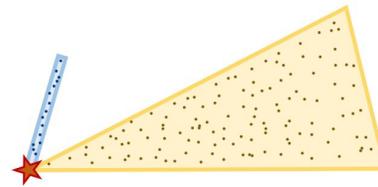
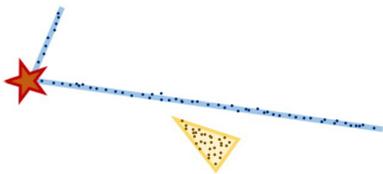


Event Selection Algorithm

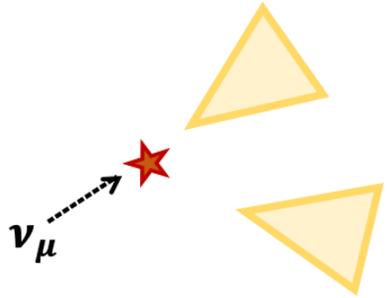


ν_μ CC background: low shower hits ratio

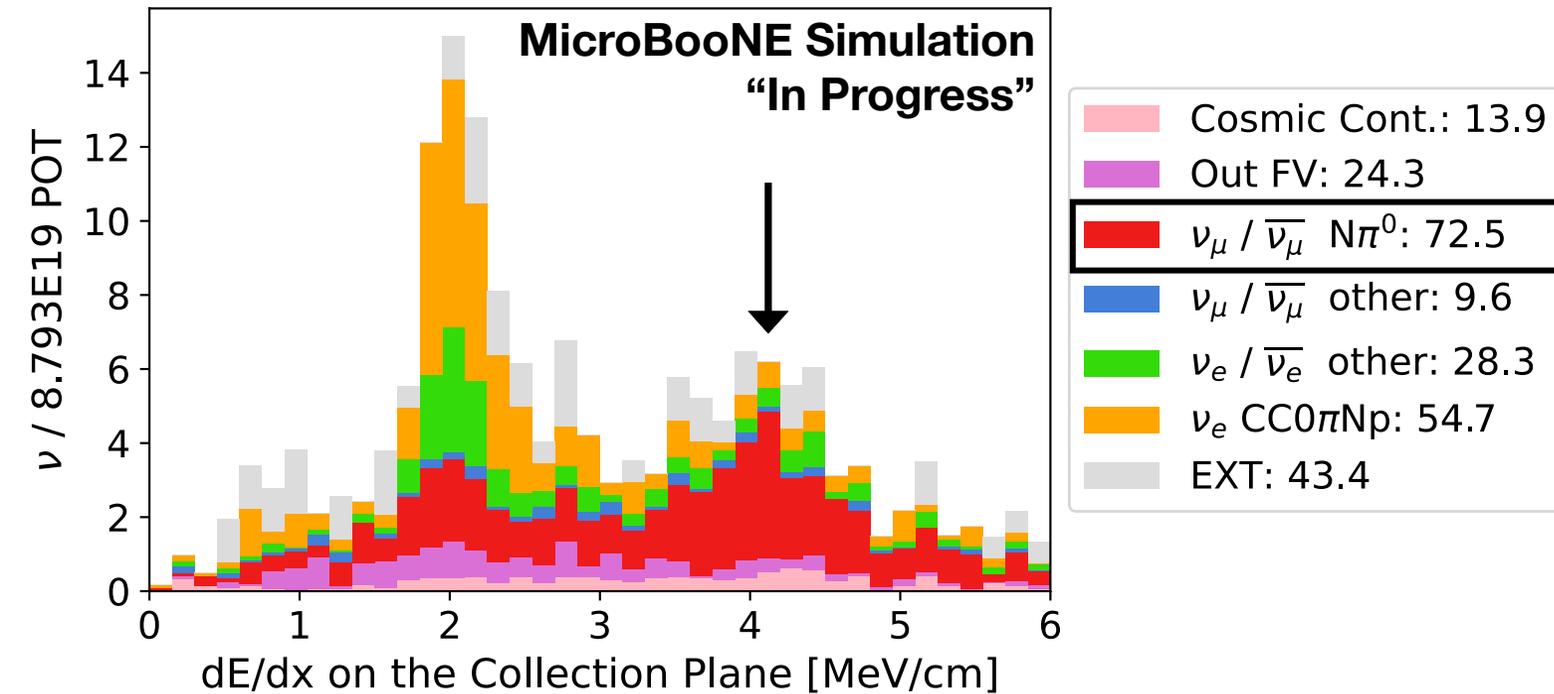
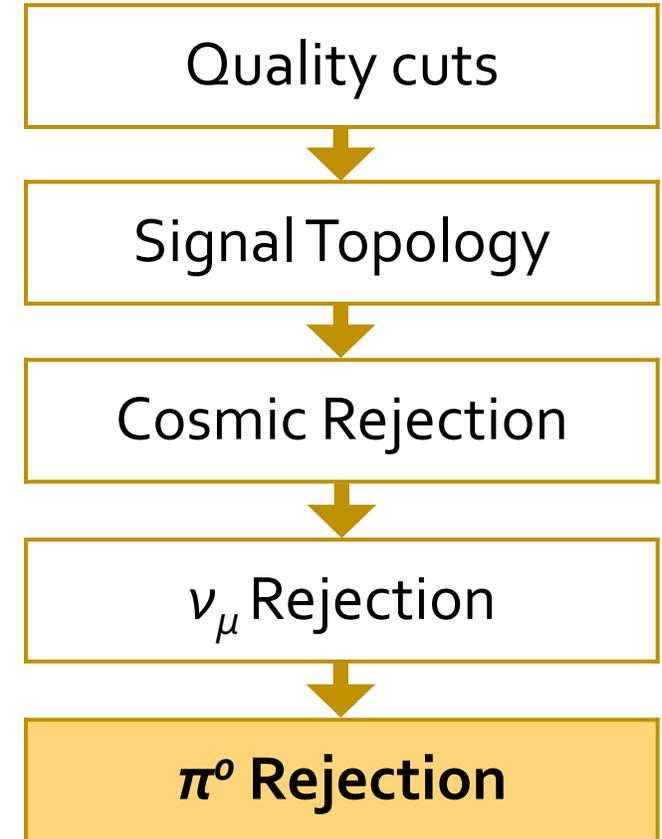
CC1eNp signal: high shower hits ratio



Event Selection Algorithm

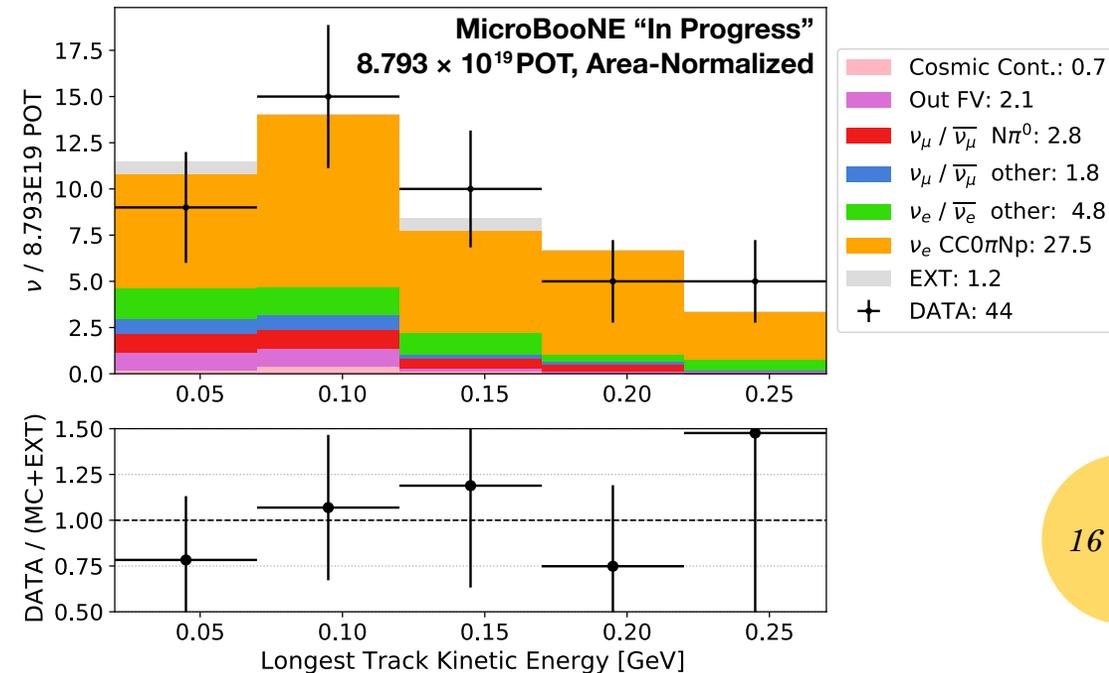
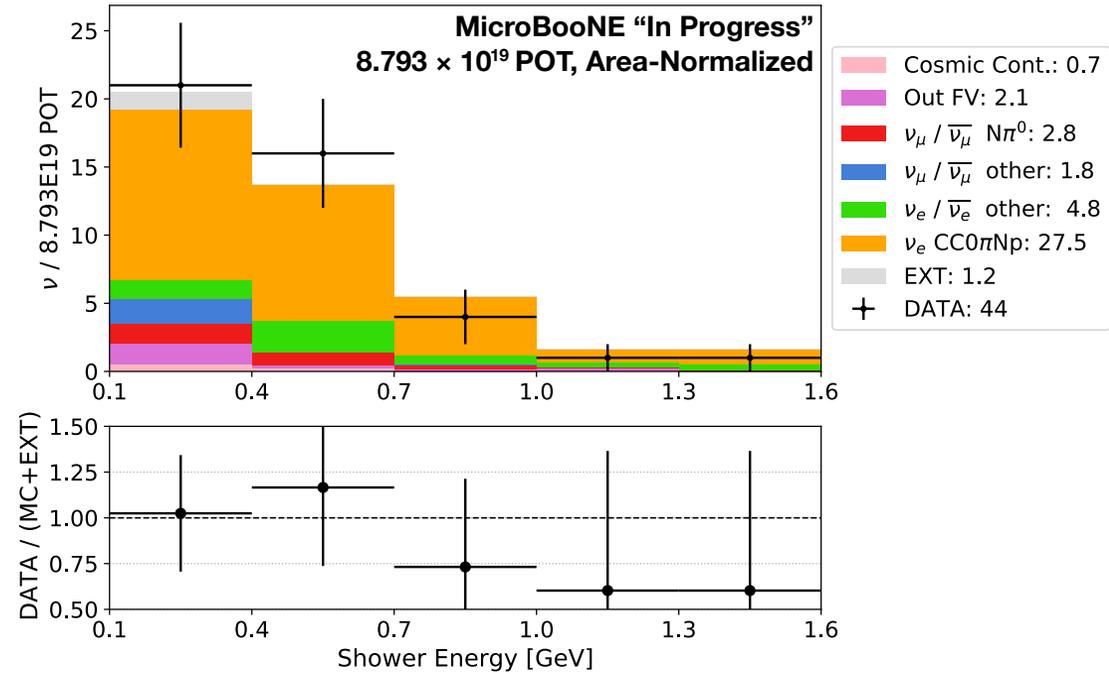


Amount of energy deposited at start of photon-like showers: 2x what we expect from electron-like showers



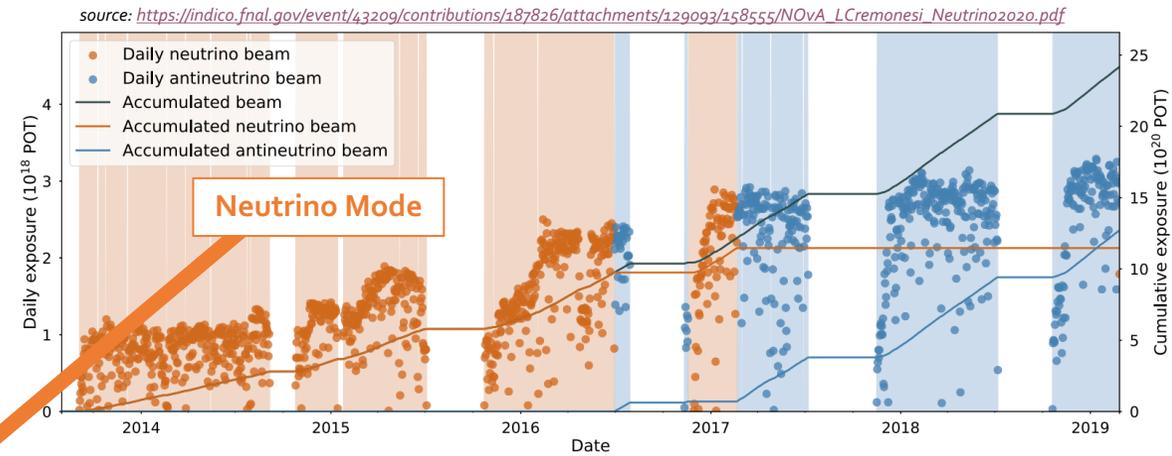
Selection Performance

- High purity post-selection event sample (67%) with significant reduction of all backgrounds
- Optimization studies ongoing!
- Current dataset – 27.5 signal events – good shape agreement with NuMI data

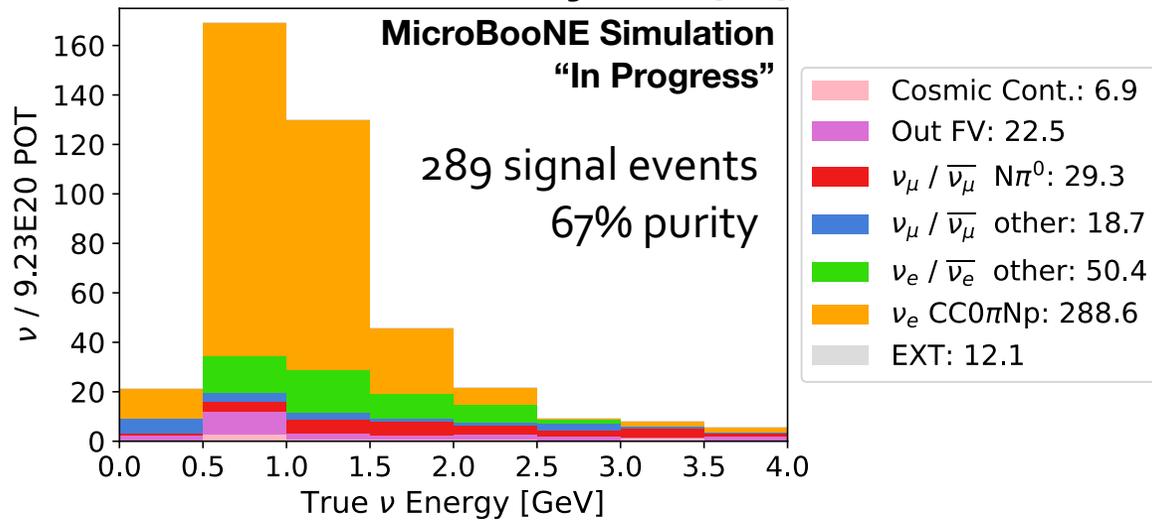


Projected Event Rate

MicroBooNE has collected 9.23×10^{20} POT in Neutrino Mode – **10.5x** what is currently available

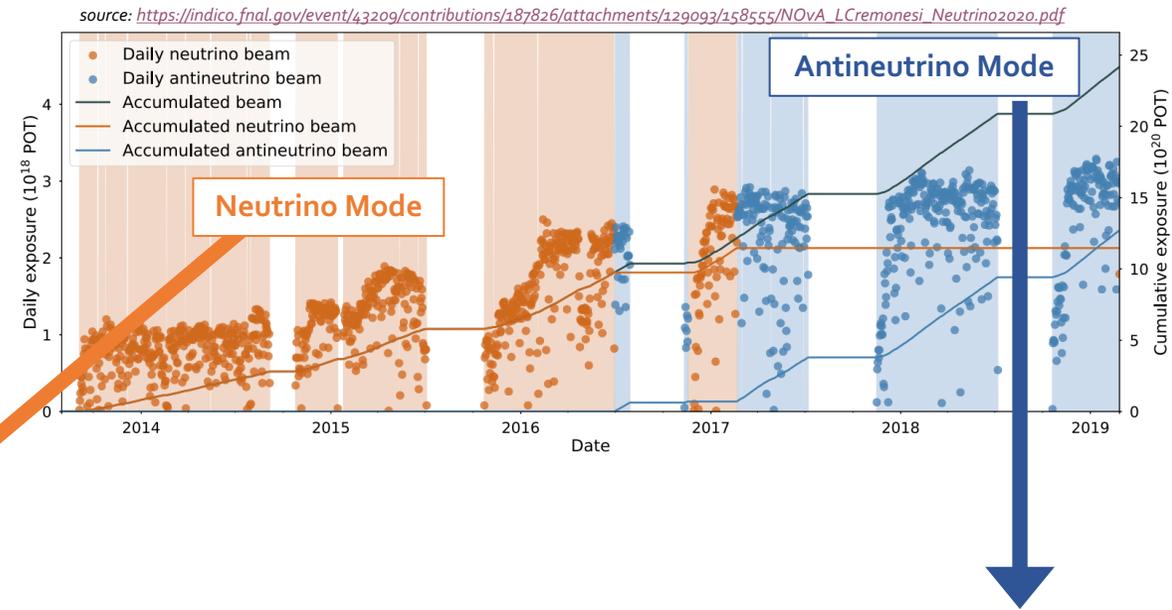


Neutrino Mode -- Projected 9.23×10^{20} POT

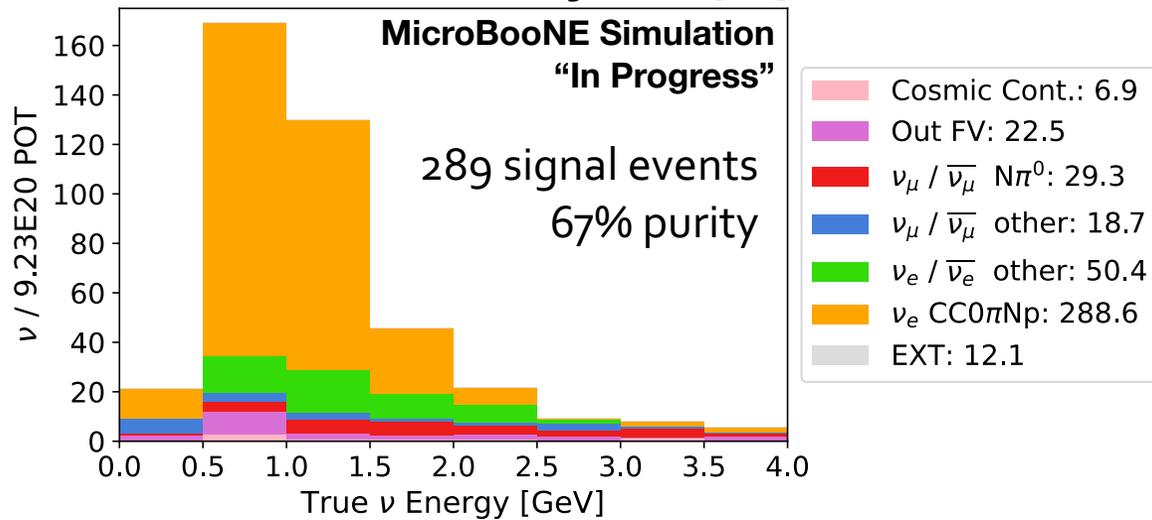


Projected Event Rate

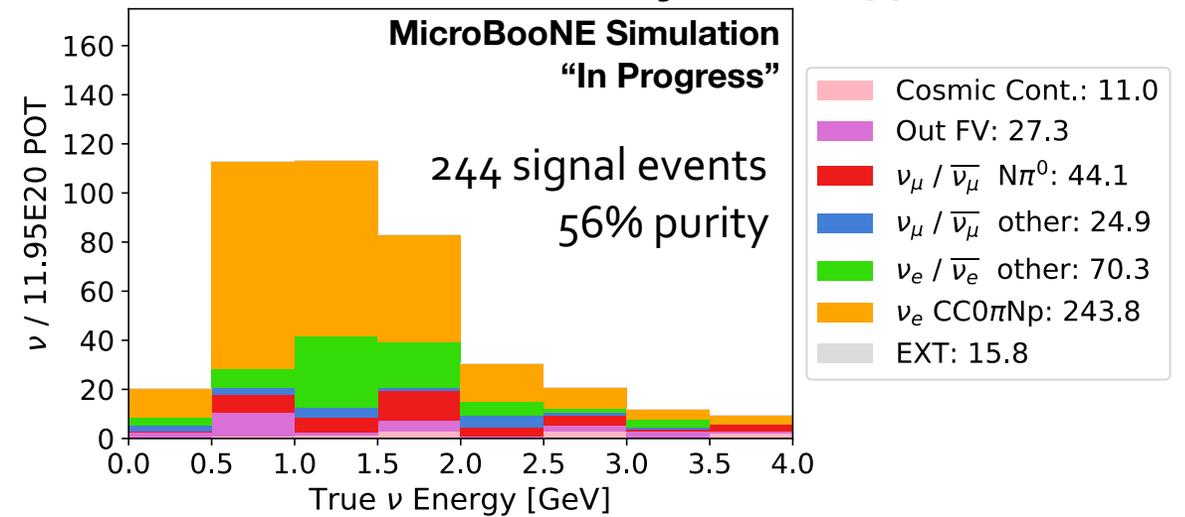
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Neutrino Mode -- Projected 9.23×10^{20} POT



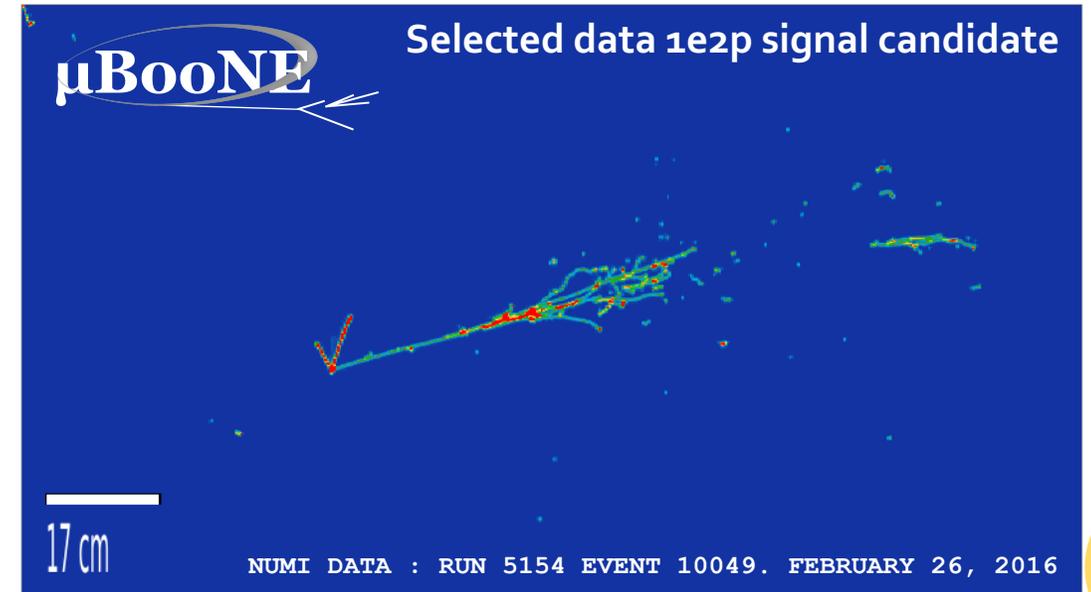
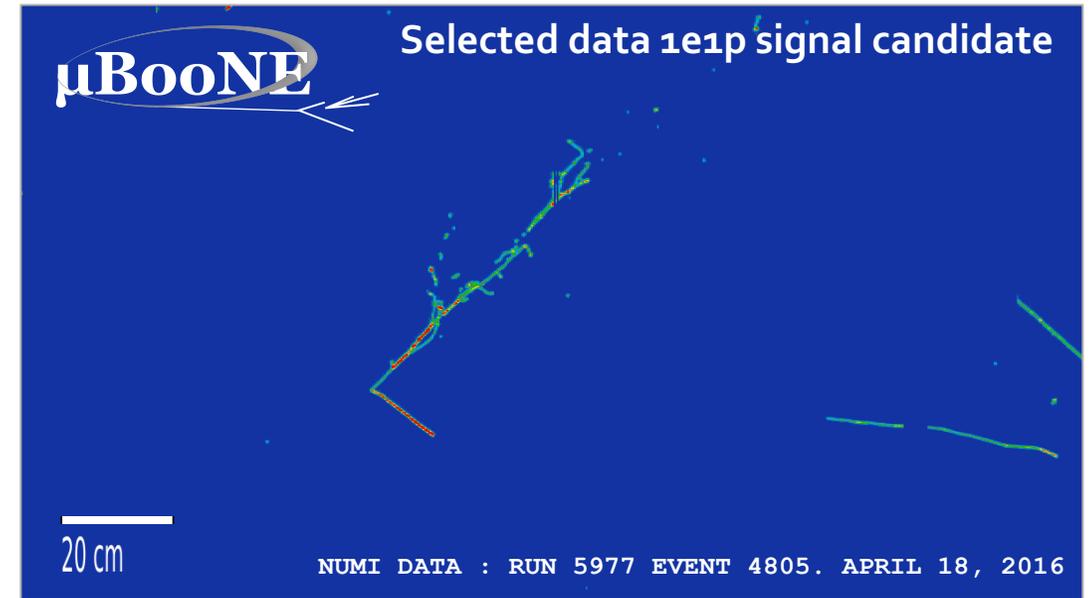
Antineutrino Mode -- Projected 11.95×10^{20} POT



TOTAL PROJECTED = 2.12×10^{21} POT → over 500 signal events!

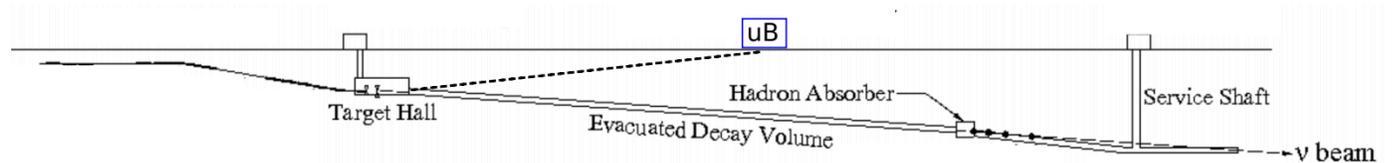
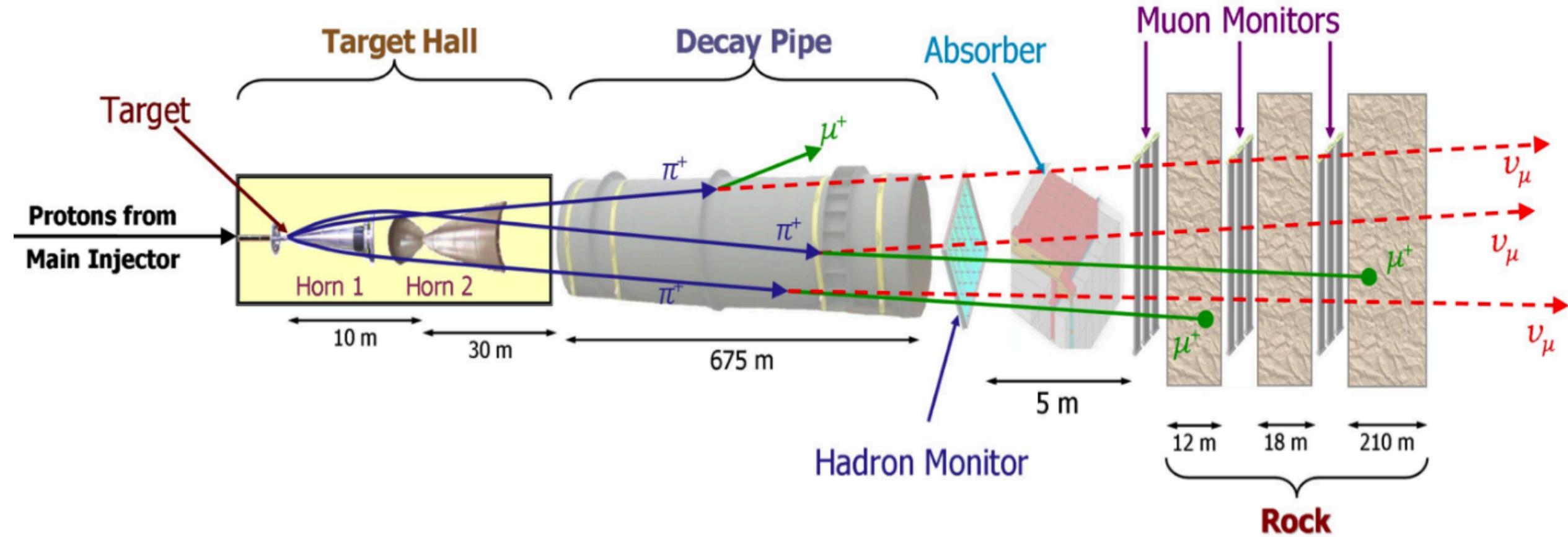
Summary

- ν_e -Ar cross sections **crucial** to the future success of SBN & DUNE
- MicroBooNE is positioned to perform a **world-leading ν_e exclusive (CC1eNp) cross section measurement** using the NuMI dataset:
 - New & improved NuMI flux prediction using PPFX
 - High purity 1eNp event selection
 - Total projected 2.12×10^{21} POT \rightarrow **over 500 signal events!**
- Current progress demonstrates MicroBooNE's powerful ability to measure & reconstruct electron neutrinos



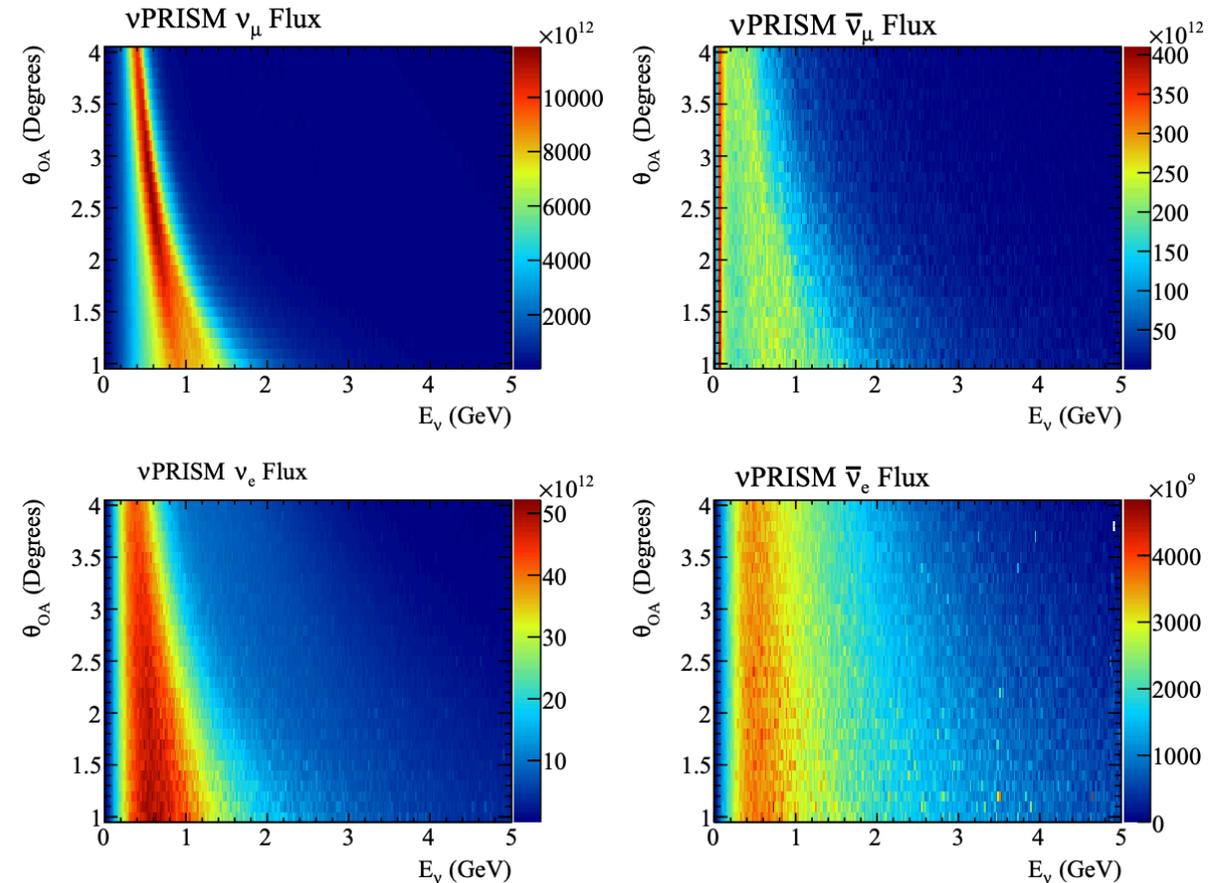
EXTRAS

The NuMI Beamline



Why does the off-axis nature of NuMI yield a higher $\nu_e/\bar{\nu}_e$ flux?

- At our energy scales, most $\nu_\mu/\bar{\nu}_\mu$'s come from 2-body decays – forward-biased, constrained by kinematics
- In contrast, most $\nu_e/\bar{\nu}_e$'s come from 3-body decays – more freedom with kinematics, easier for a neutrino to be produced at higher angles
- Probability of seeing $\nu_\mu/\bar{\nu}_\mu$ drops faster than probability of seeing $\nu_e/\bar{\nu}_e$ as we move to higher angles



source: <https://arxiv.org/pdf/1412.3086.pdf>

Off-axis angle (°)	ν_e Flux 0.3-0.9 GeV	ν_μ Flux 0.3-5.0 GeV	Ratio ν_e/ν_μ
2.5	1.24E+15	2.46E+17	0.507%
3.0	1.14E+15	1.90E+17	0.600%
3.5	1.00E+15	1.47E+17	0.679%
4.0	8.65E+14	1.14E+17	0.760%

How to Set a Cross Section

of events == flux × interaction probability

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

[cm²/nucleon]

$N - B$ ← # of ν_e CC1eNp events observed (total – background)

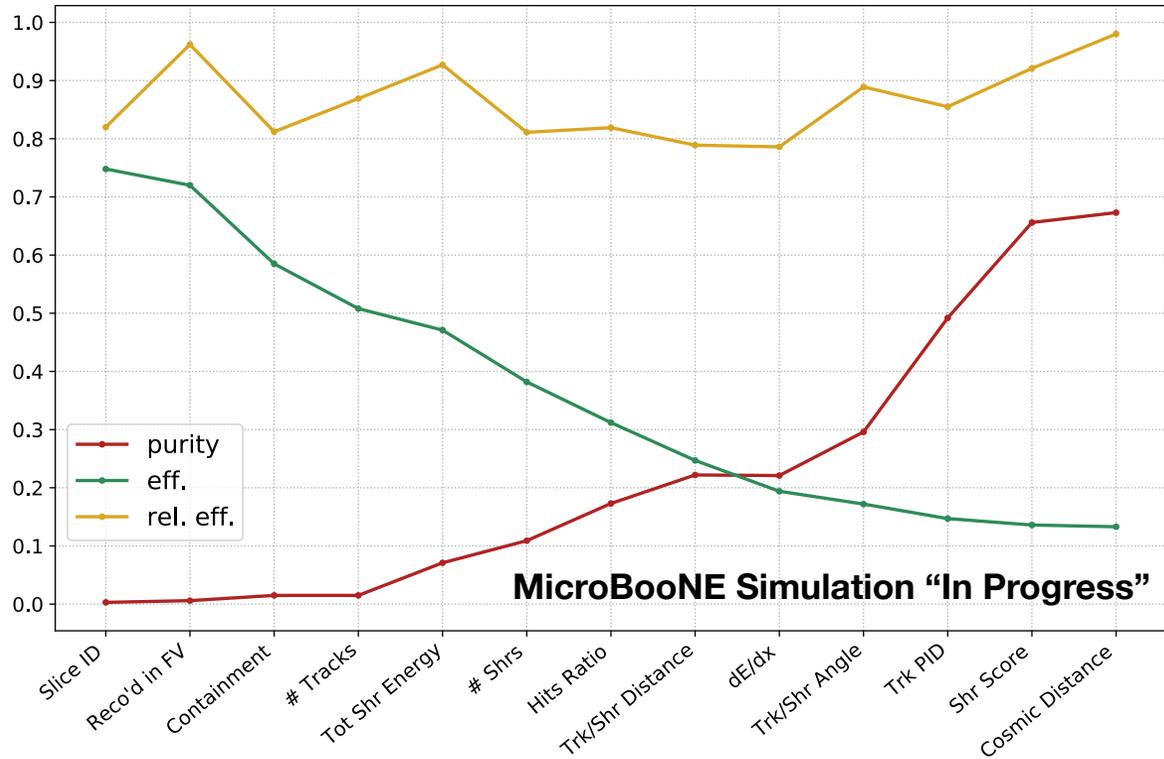
← **ϵ** efficiency – correction factor to scale up observed # of signal events

← **Φ_{ν_e}** accurate prediction of the ν_e flux passing through the detector [1/cm²]

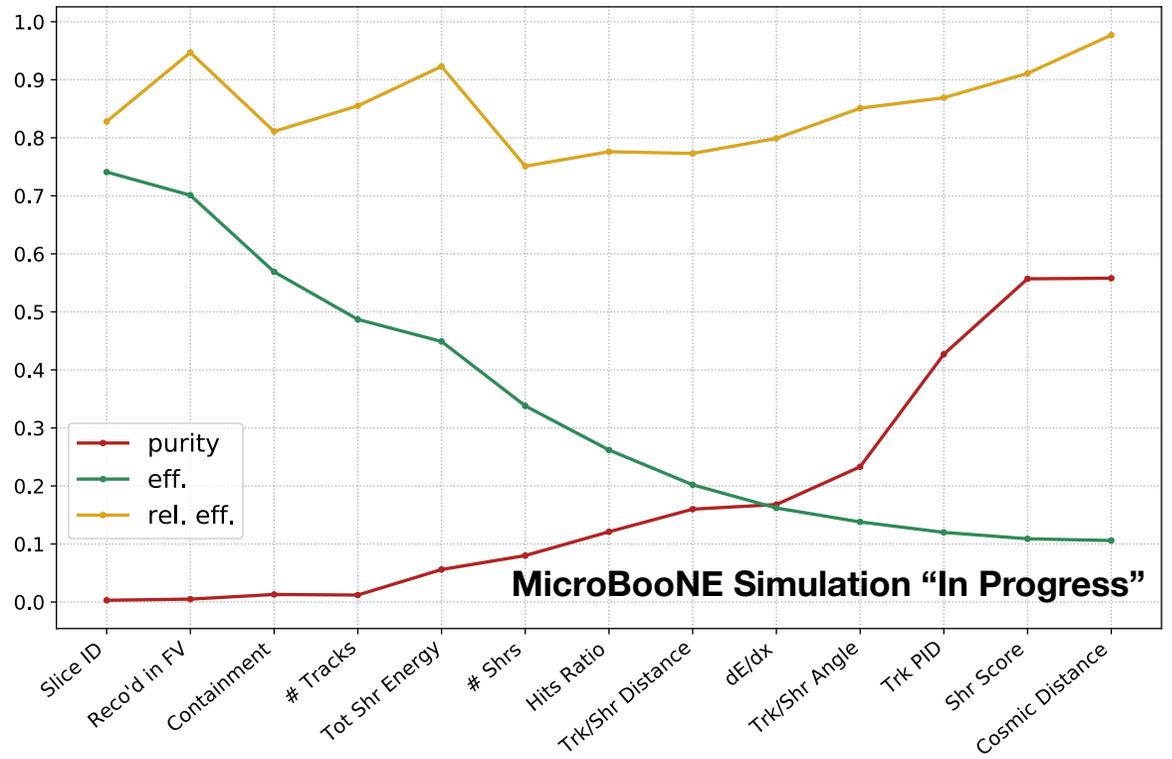
efficiency = $\frac{\text{\# of selected signal events}}{\text{\# generated signal events}}$

Selection Performance

Neutrino Mode

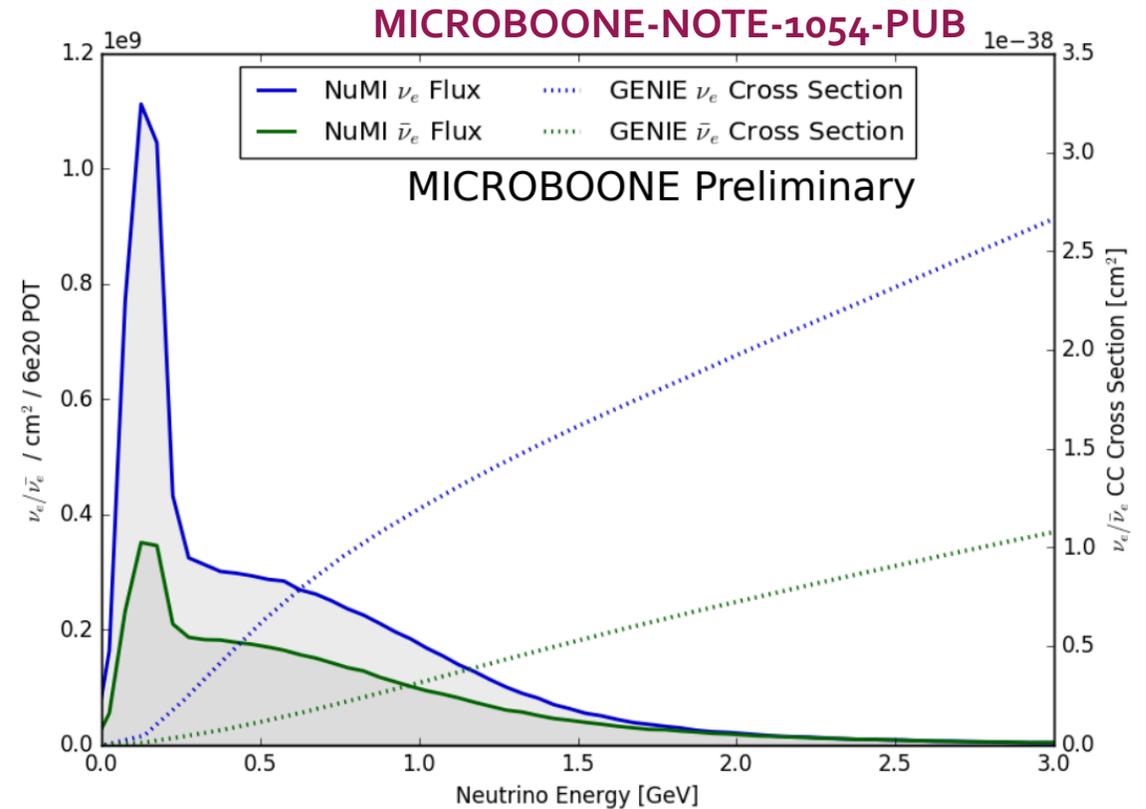
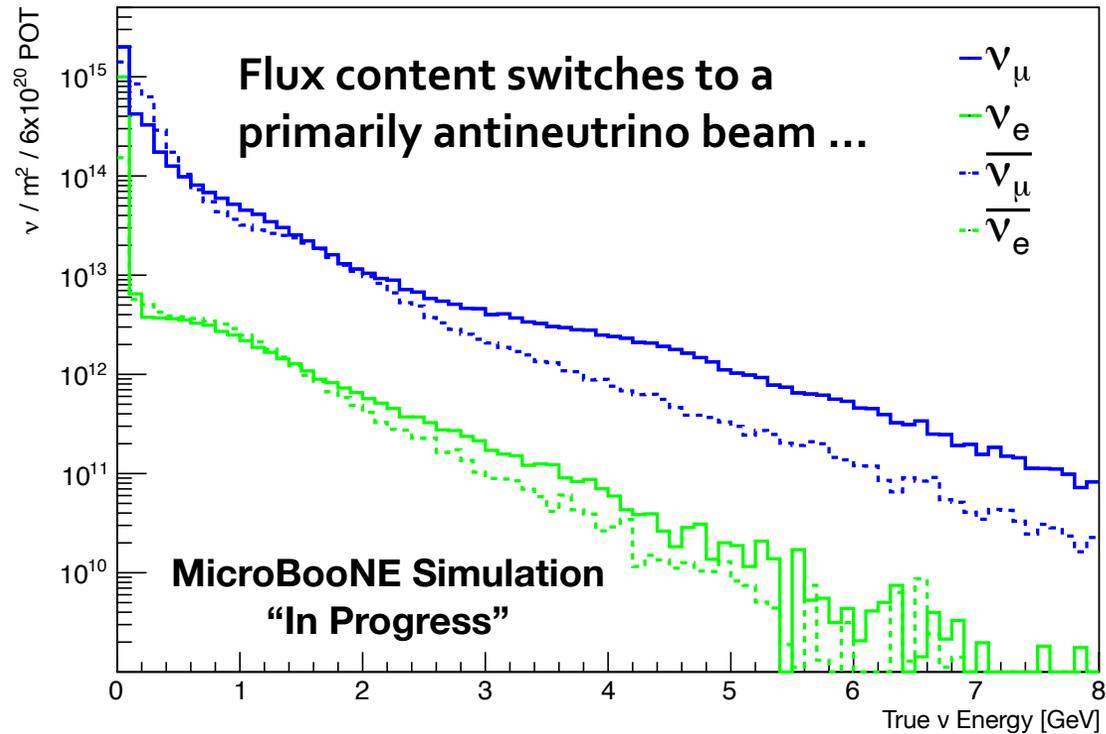


Antineutrino Mode



How can we have a signal-dominated event sample in Antineutrino Mode?

NuMI Flux at MicroBooNE (RHC)



... but the $\nu_e / \bar{\nu}_e$ cross sections stay the same

NuMI POT Collected in MicroBooNE

January 29, 2016 – March 20, 2020

