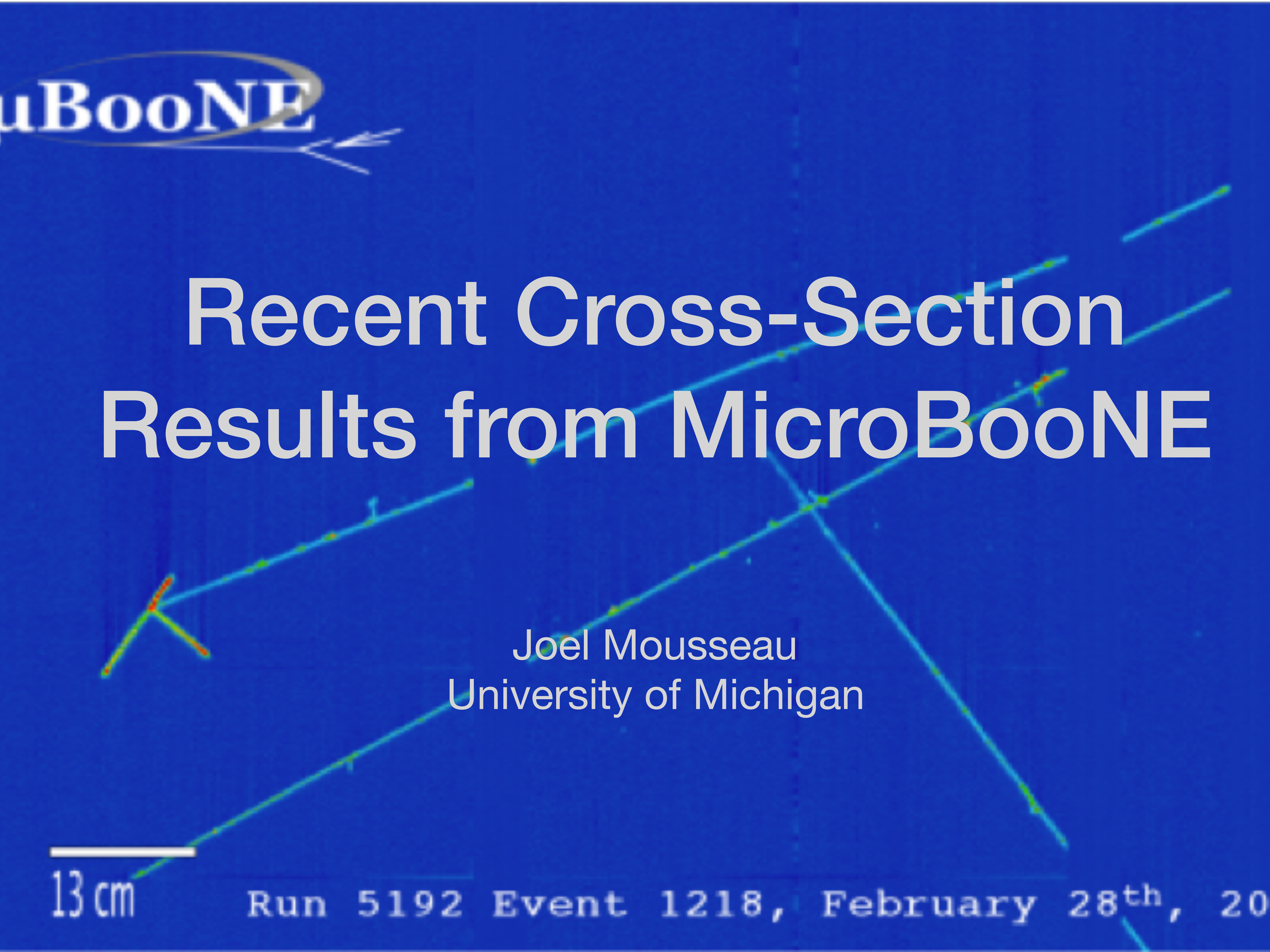
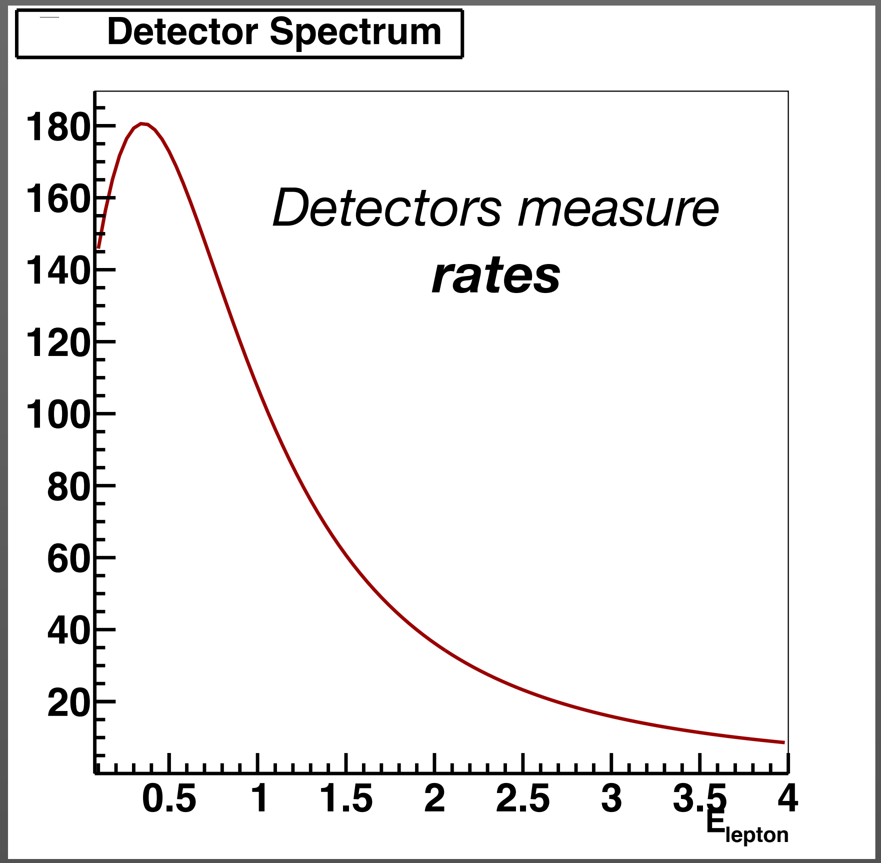
Recent Cross-Section Results from MicroBooNE

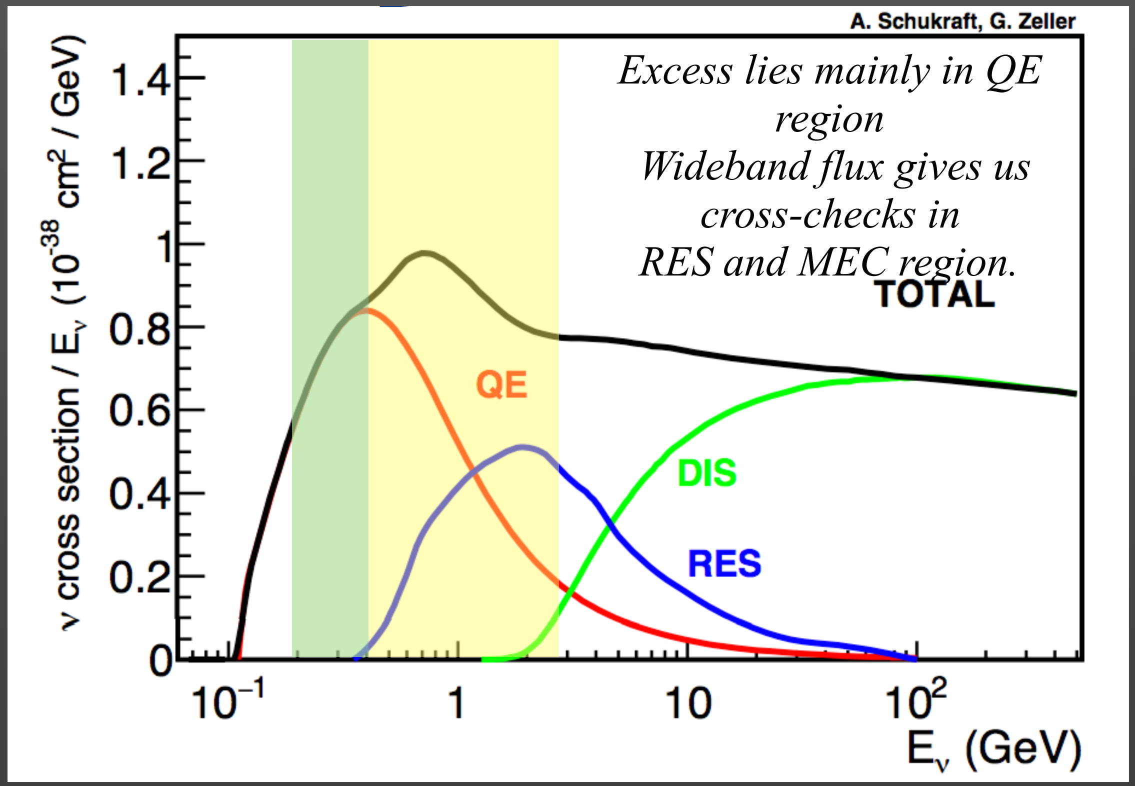
Joel Mousseau
University of Michigan



Studying Neutrino - Argon Cross Sections

- Cross sections are necessary for formulating a *prior* neutrino flux for disappearance / appearance measurements.
- Identify reactions / topologies that act as signals and backgrounds for a MiniBooNE-like excess.

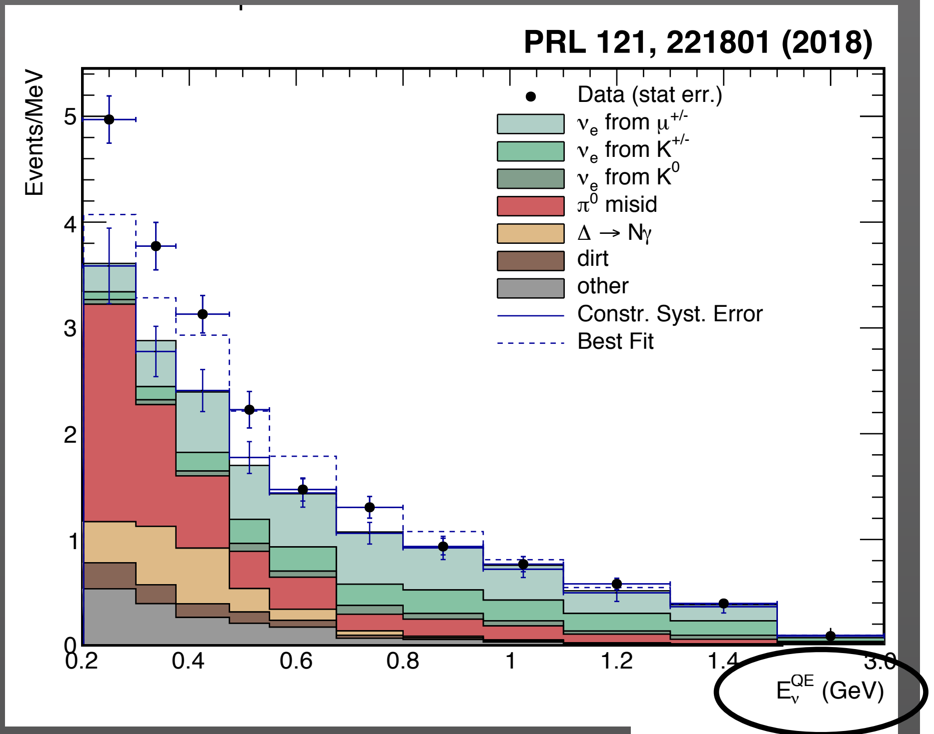




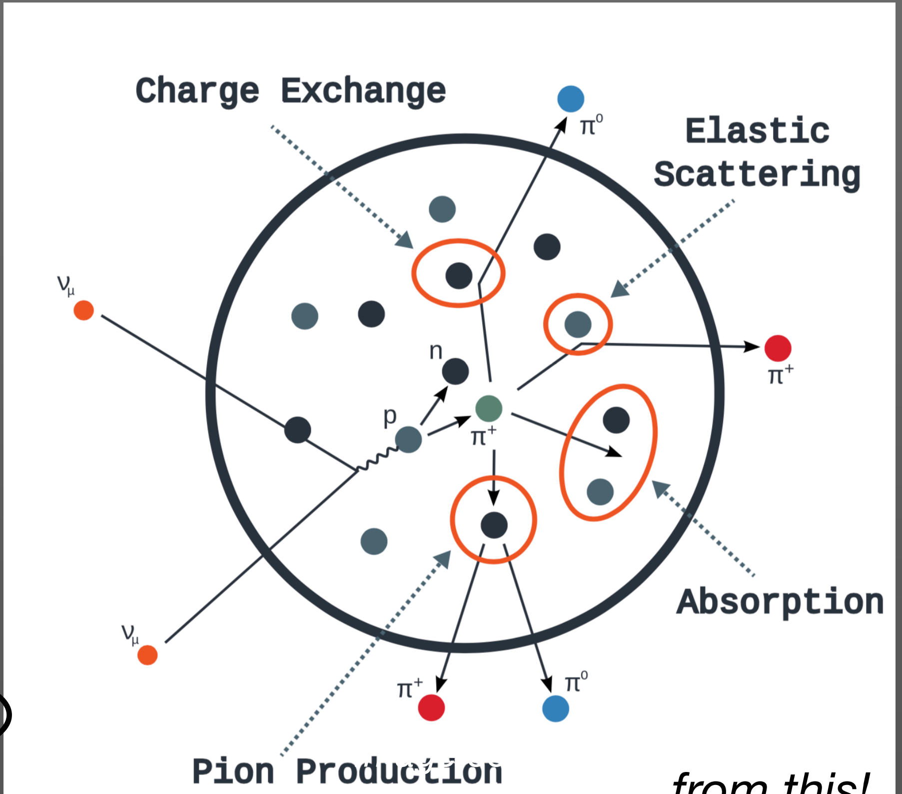
- Provide a resource for studying advanced electroweak nuclear physics:
  - Short range correlations
  - Meson-Exchange currents
  - Random Phase Approximation

Studying Neutrino - Argon Cross Sections

- Our LEE search relies on a measurement of *inferred* neutrino energy.

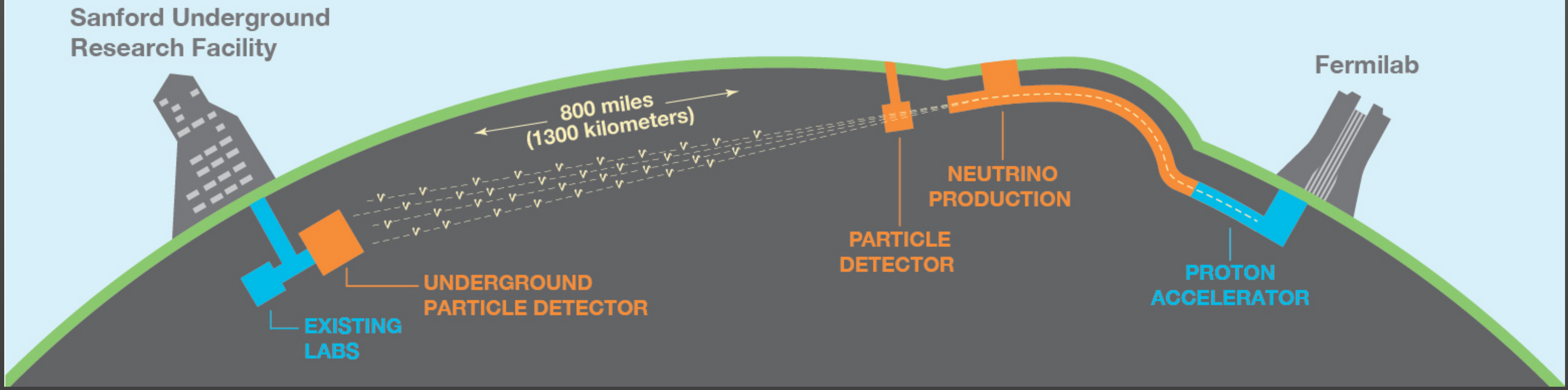


Find This…

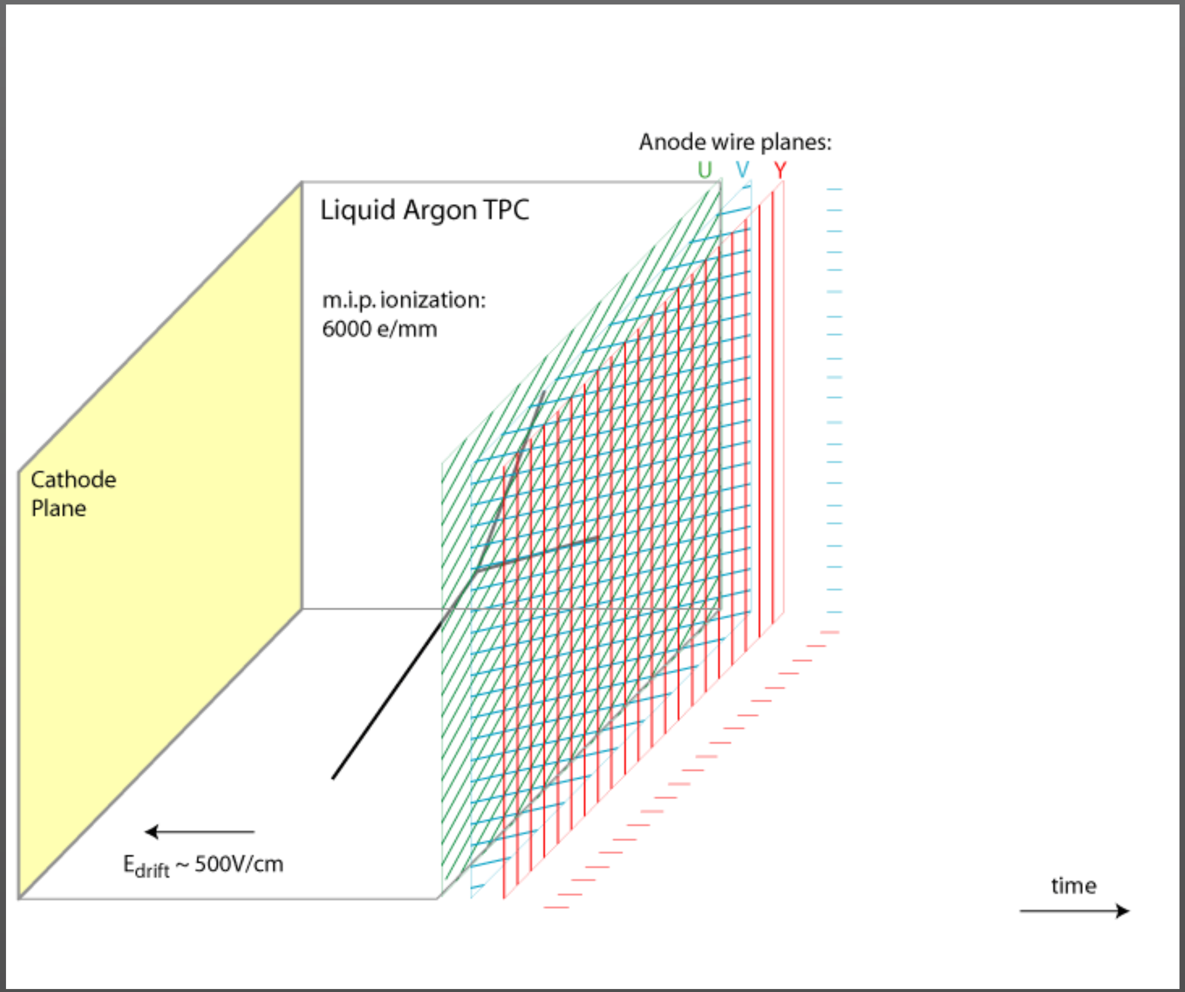


…from this!

Same is true for measuring CP violation!



MicroBooNE Detector

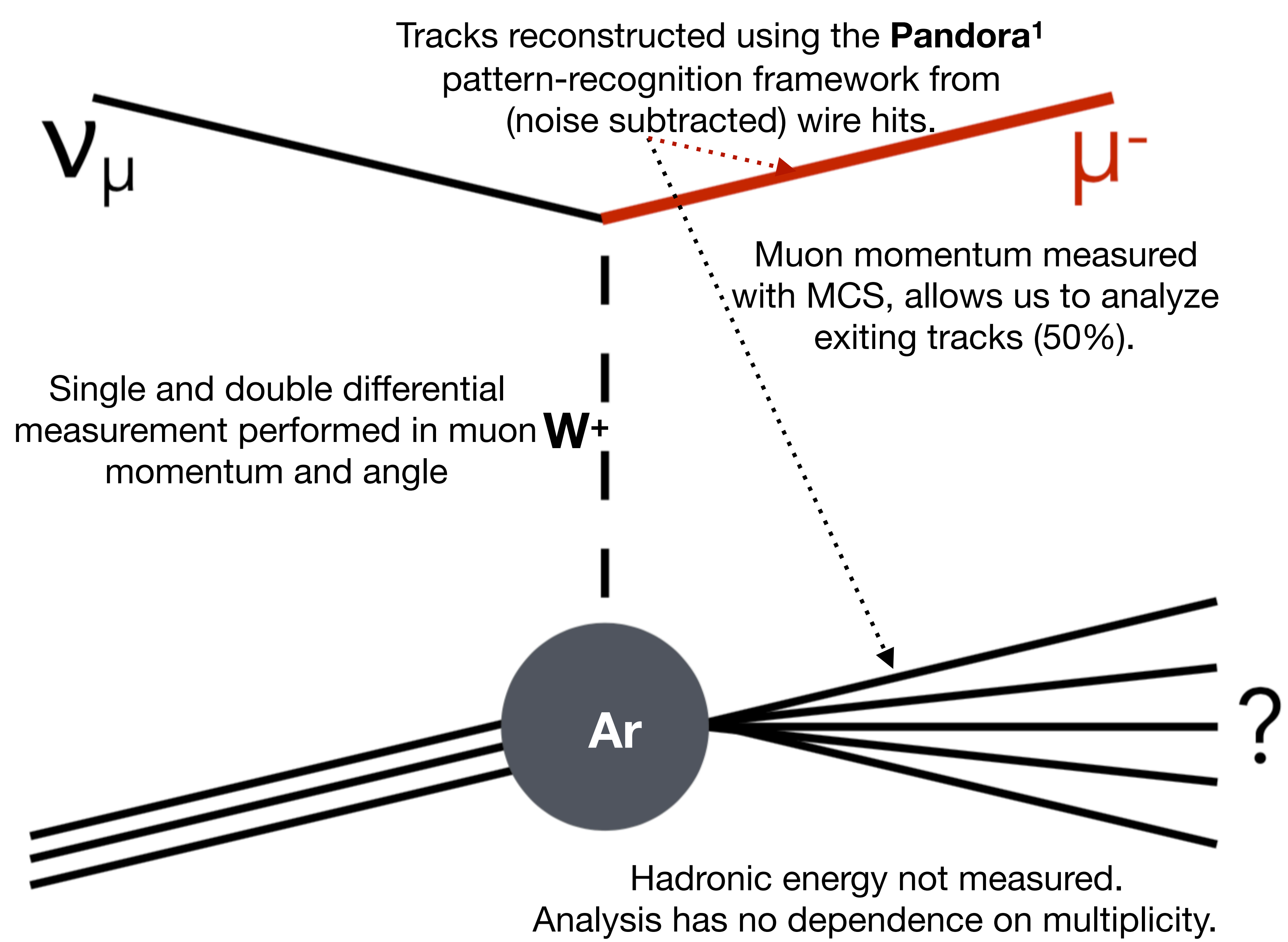


- 85-ton active volume Liquid argon TPC.
- Many advantages to LArTPC:
  - Excellent position, energy resolution.
  - 4π charged particle acceptance.
  - Large argon nucleus give sensitivity to nuclear effects

- Many challenges with LArTPCs:
  - Large argon nucleus give sensitivity to nuclear effects.
  - Drift model requires a detailed simulation.

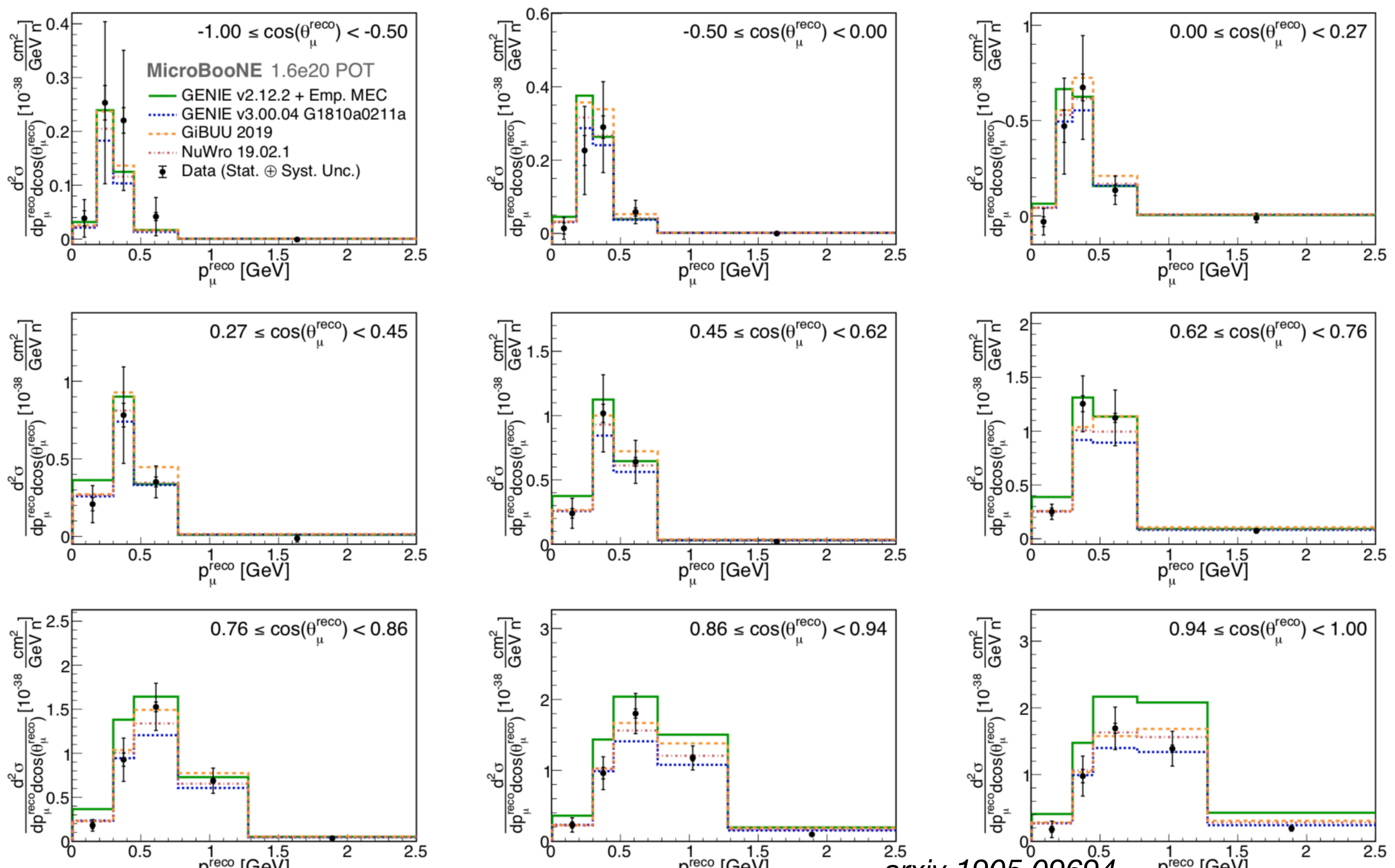
Charged Current Inclusive Analysis

- Cosmic rejection cuts form the basis of a *charged current inclusive* analysis, which looks for events with a neutrino induced muon and anything else.



1) *Eur. Phys. J. C 78, no. 1, 82 (2018)*

Charged-Current Inclusive Analysis



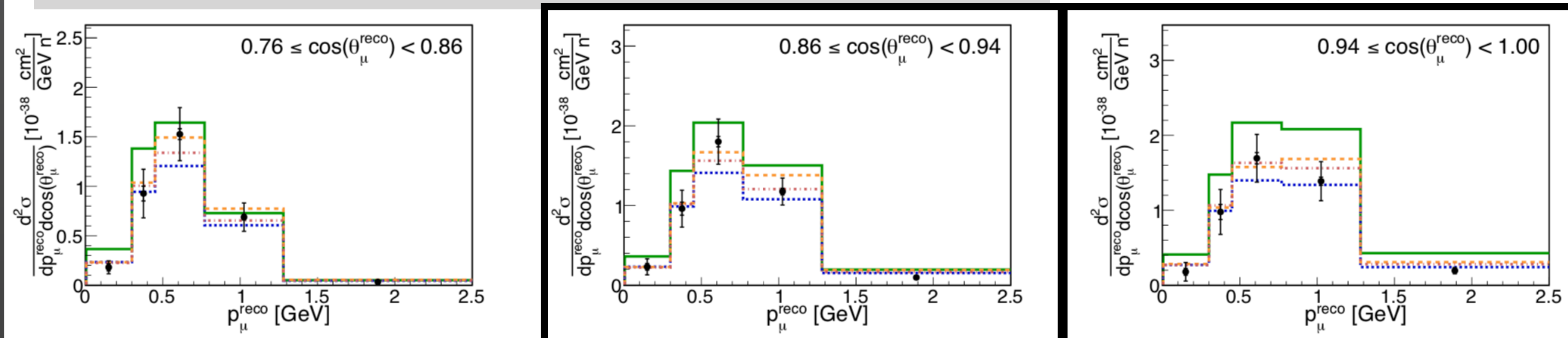
arxiv 1905.09694

- First double-differential result on argon.

Charged-Current Inclusive Analysis

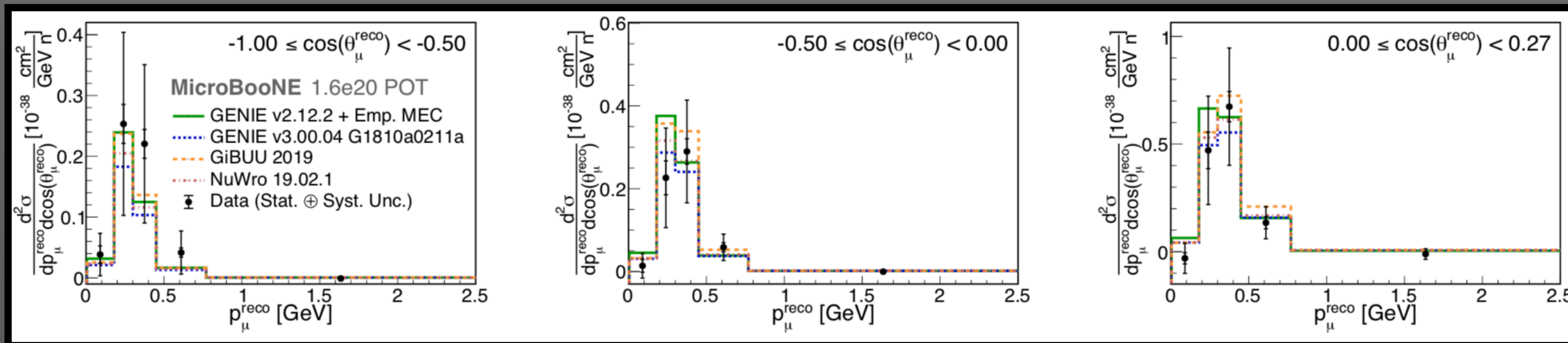
Model Set	Chi2	N Bins
GENIE v2 (with MEC)	245.9	42
GENIE v3	108.8	42
NuWro 19.02.1	126.5	42
GiBUU (2019)	172.9	42

- Majority of tension in the most forwarding going bins.
- GENIE v3 (incorporating RPA effects) gives the best description.



- Data with associated efficiency and correlation matrix here

Uncertainty Evaluation

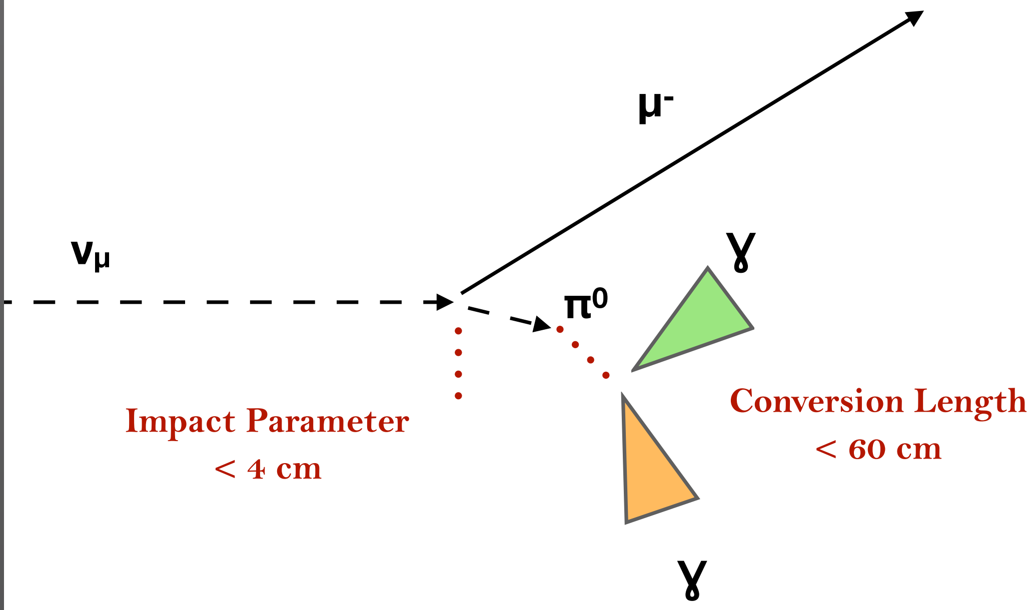


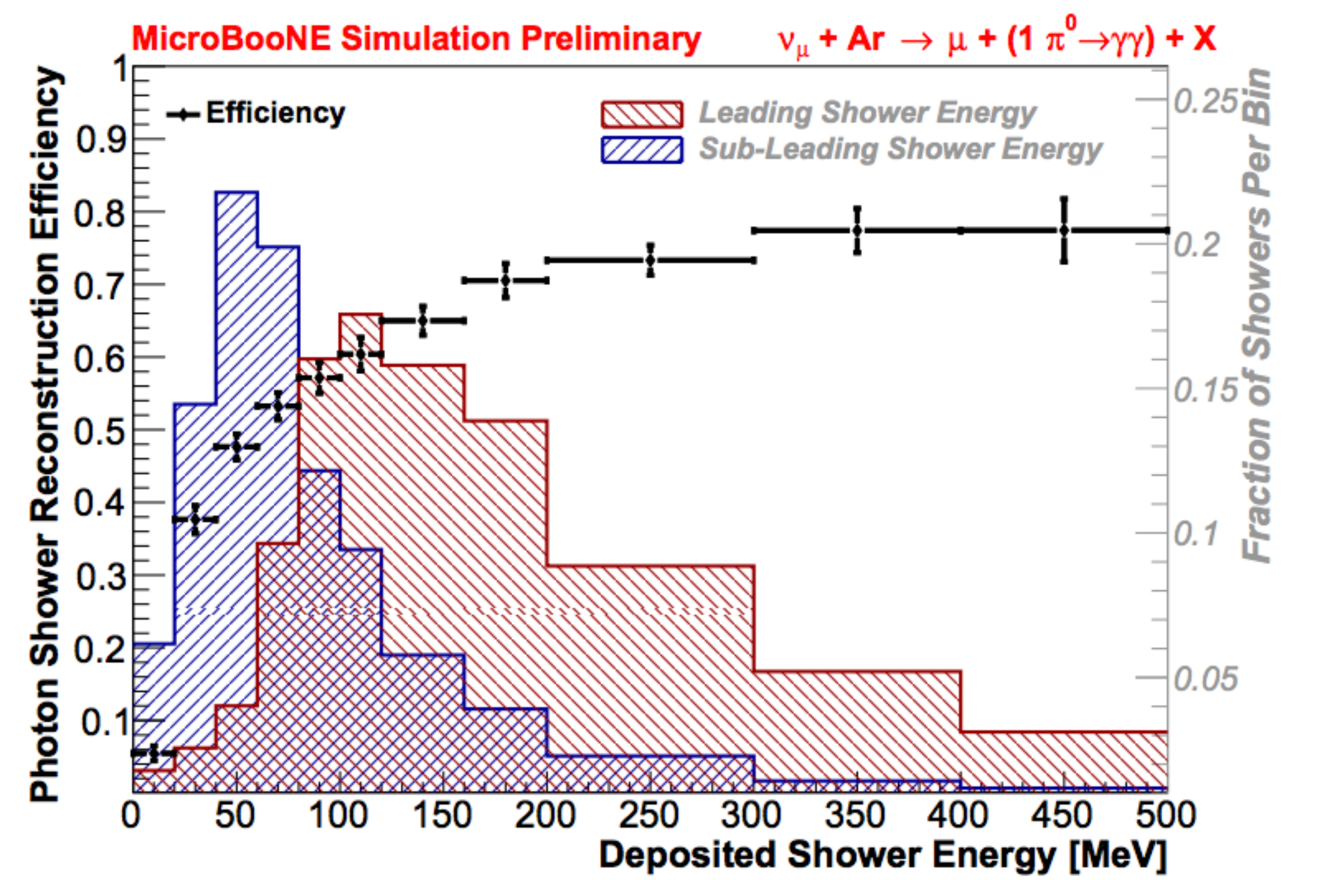
Leading Systematic Contributions	
Source	**Relative Err.**
Detector Model	16.2%
Neutrino Flux	12.2%
Events outside TPC	10.9%
All Others	< 5%

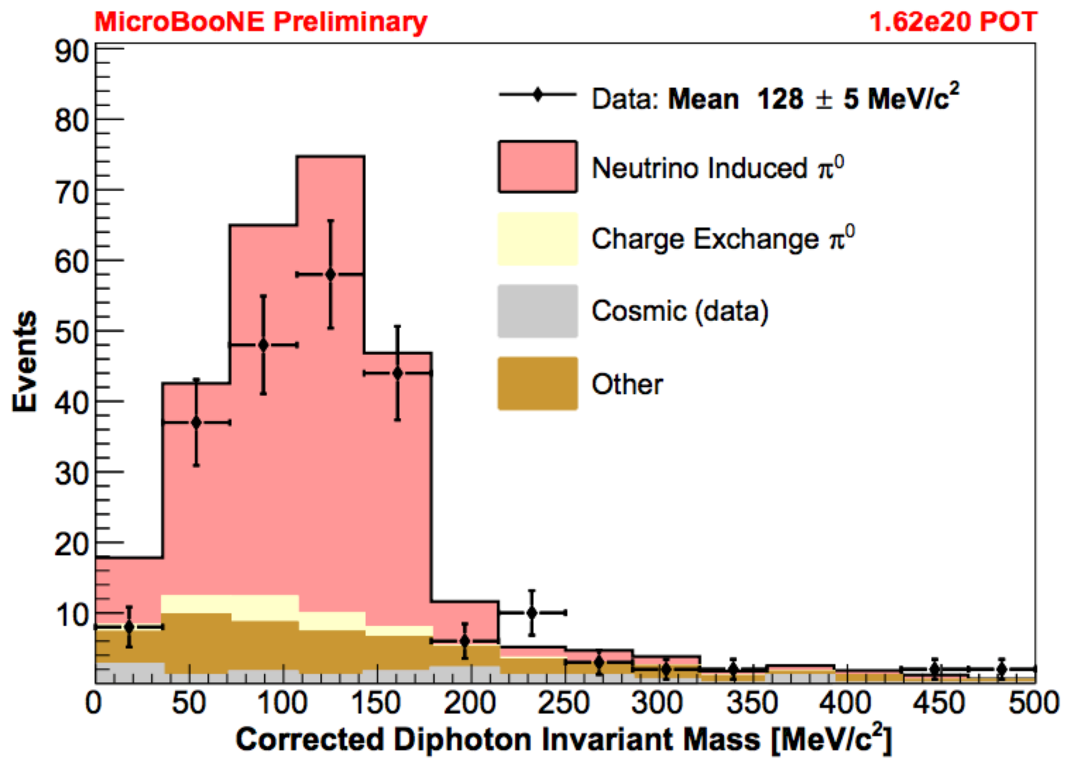
- Uncertainties largest in regions dominated by background (low momentum, backward going).
- Strongly correlated across bins, detector modeling has a strong impact on efficiency.

Charged Current π^0 Selection

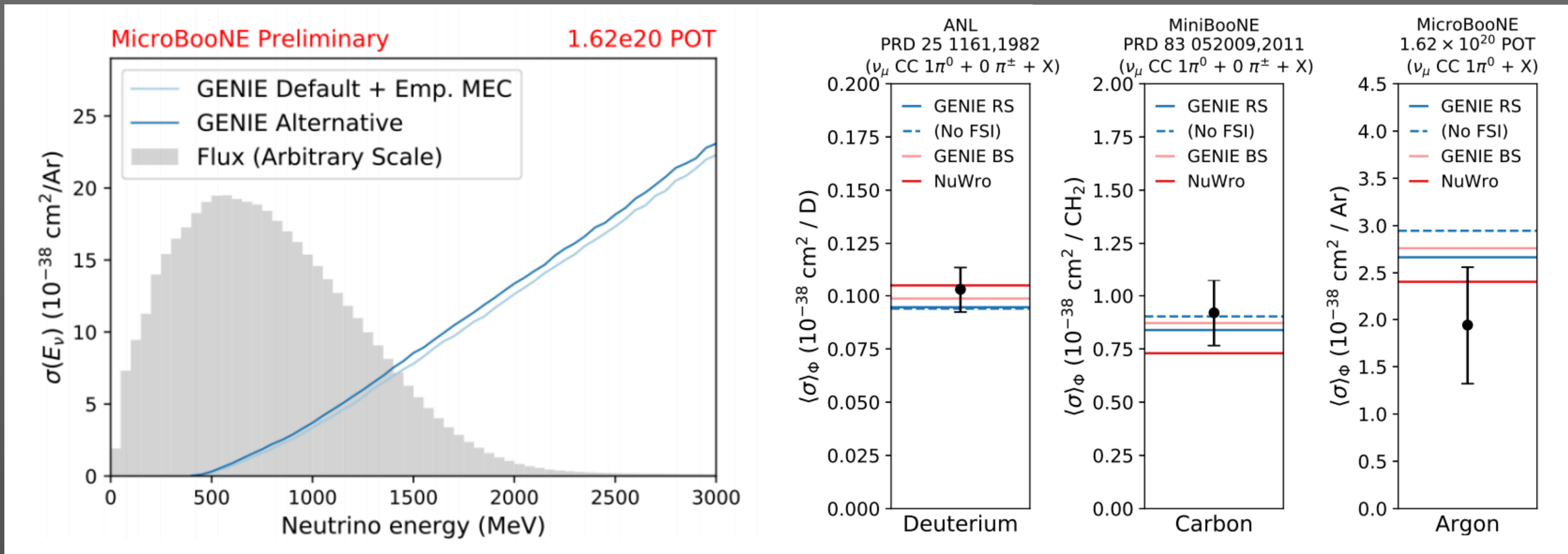
- Excellent channel for benchmarking EM shower performance.
- First ever measurement in a LArTPC with automated shower reconstruction.
- Low energy showers difficult to tag, require at least one shower in analysis. Two for mass-peak.







CHARGED CURRENT π⁰



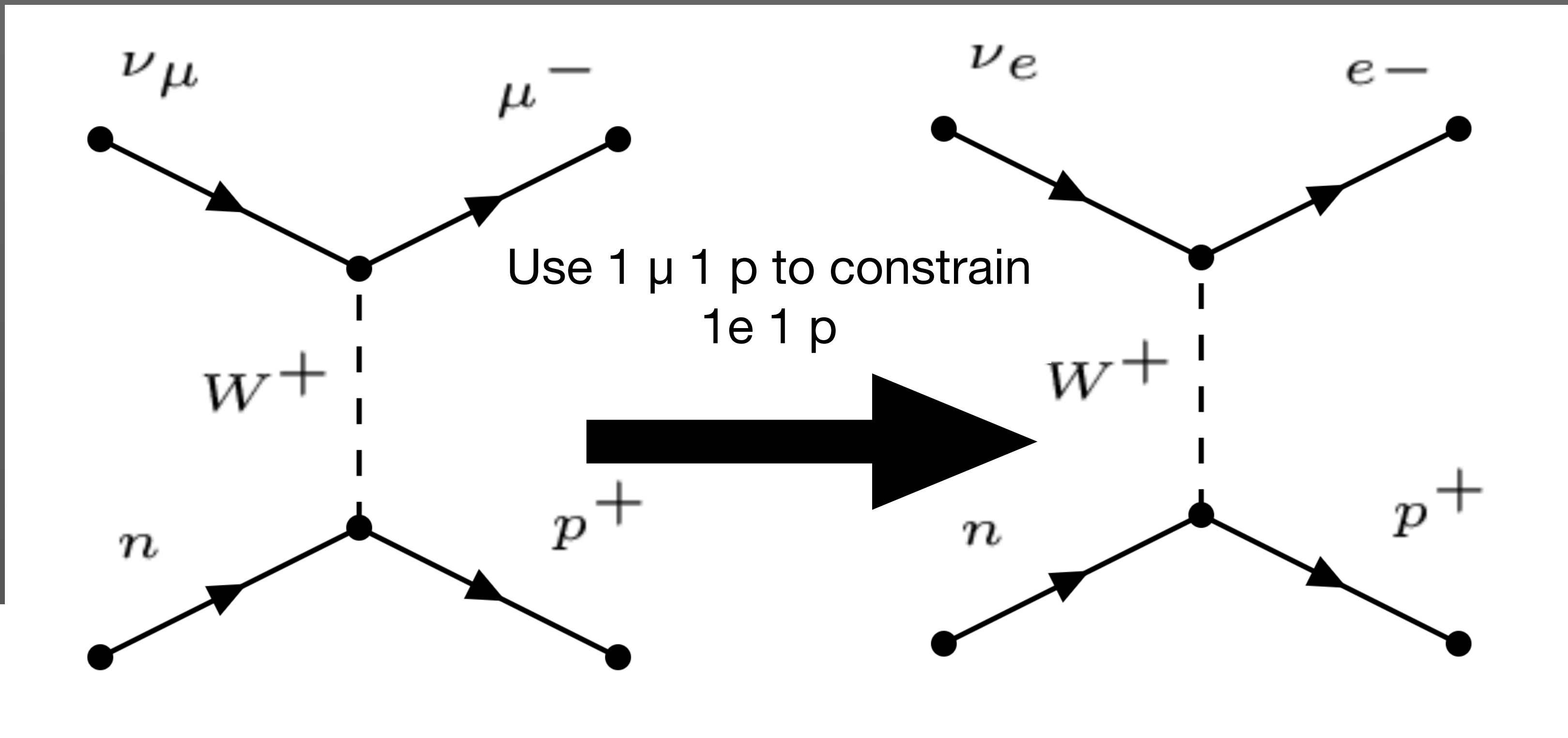
- Similar selection as Inclusive, only now require at least one photon induced shower in addition to μ⁻.
- *A* Scaling of FSI in GENIE compatible across D, C and Ar.
- Our measurement is consistent with GENIE and NuWro.

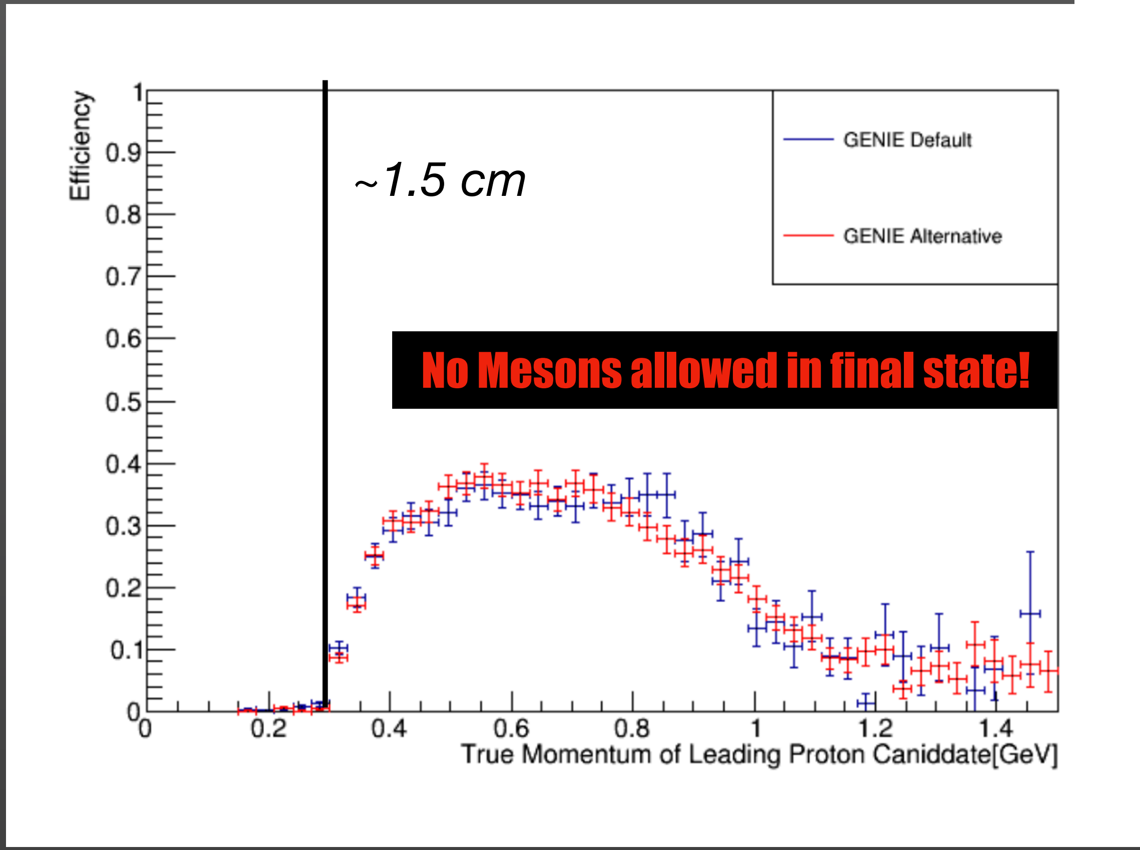
Type	% Error	Affected Measurement
Flux	16%	Flux division, Background Estimation
Cross-Section	17%	Background Estimation
Detector Modeling	21%	Background Estimation Efficiency Correction

Follow on analysis will have higher efficiency and smaller errors.

Cross Sections with Proton Final States

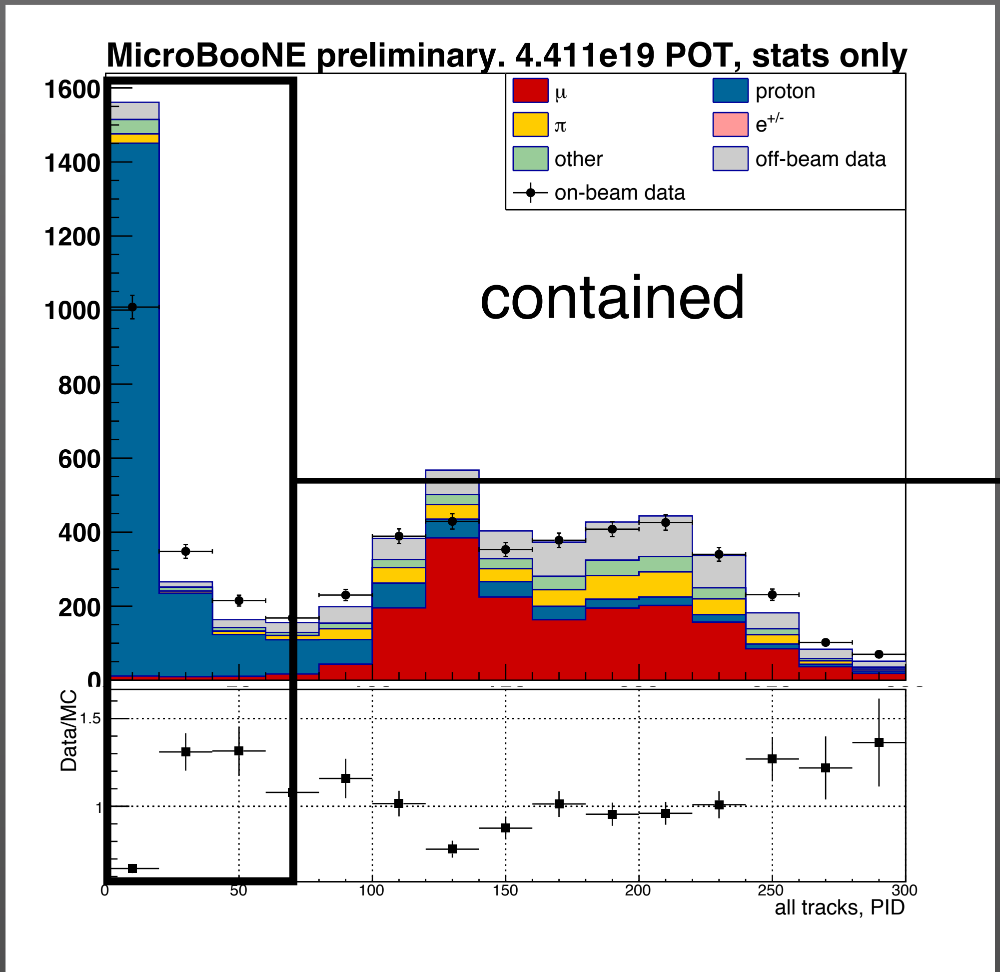
- Final states with 1 proton and no mesons arguably most important cross section for MicroBooNE.

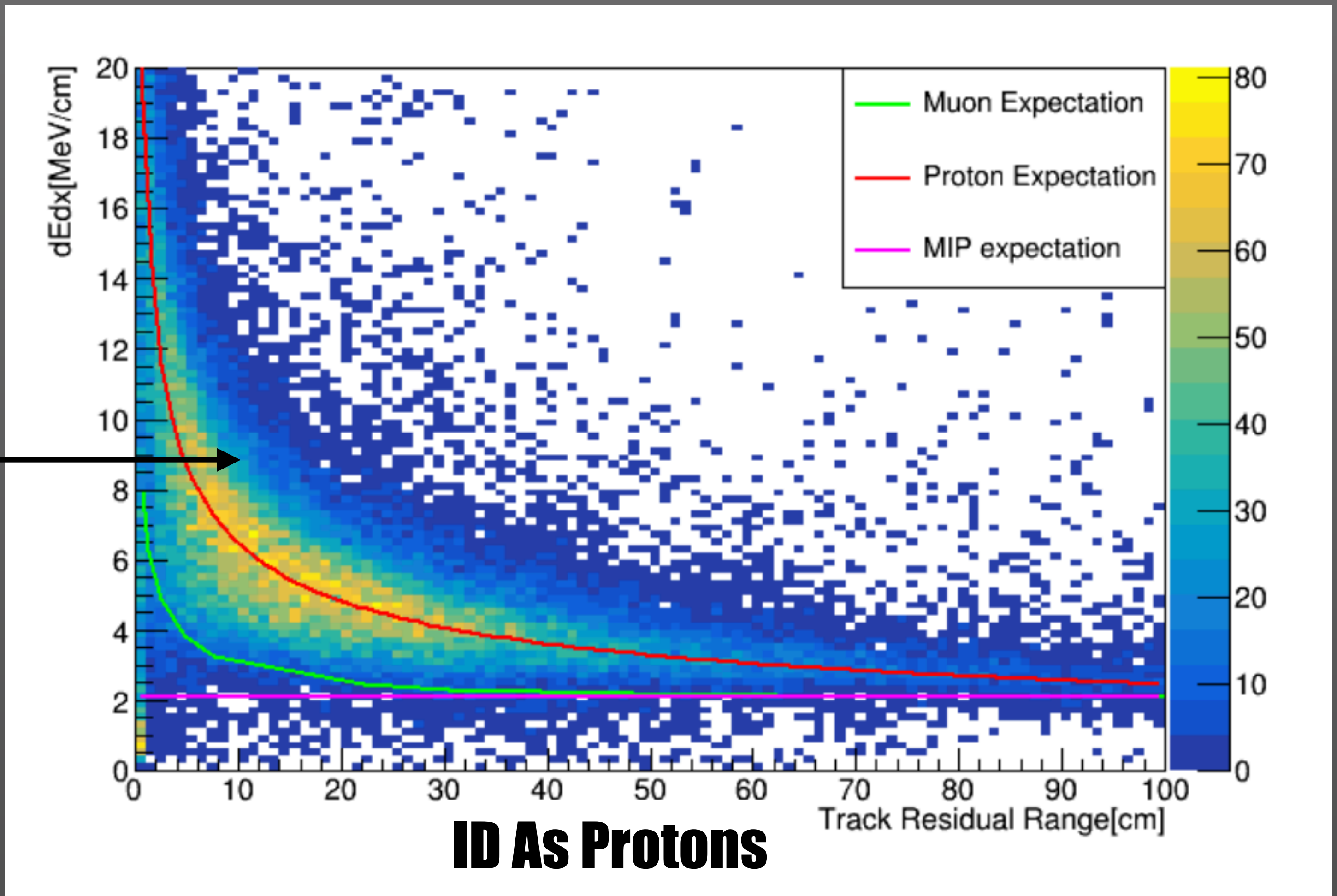




- Future SB neutrino experiments use 1e 1p as a potential sterile signature.
- LAr TPCS can detect and reconstruct protons at lower momenta than scintillator detectors (~300 MeV/c).

Identifying Protons

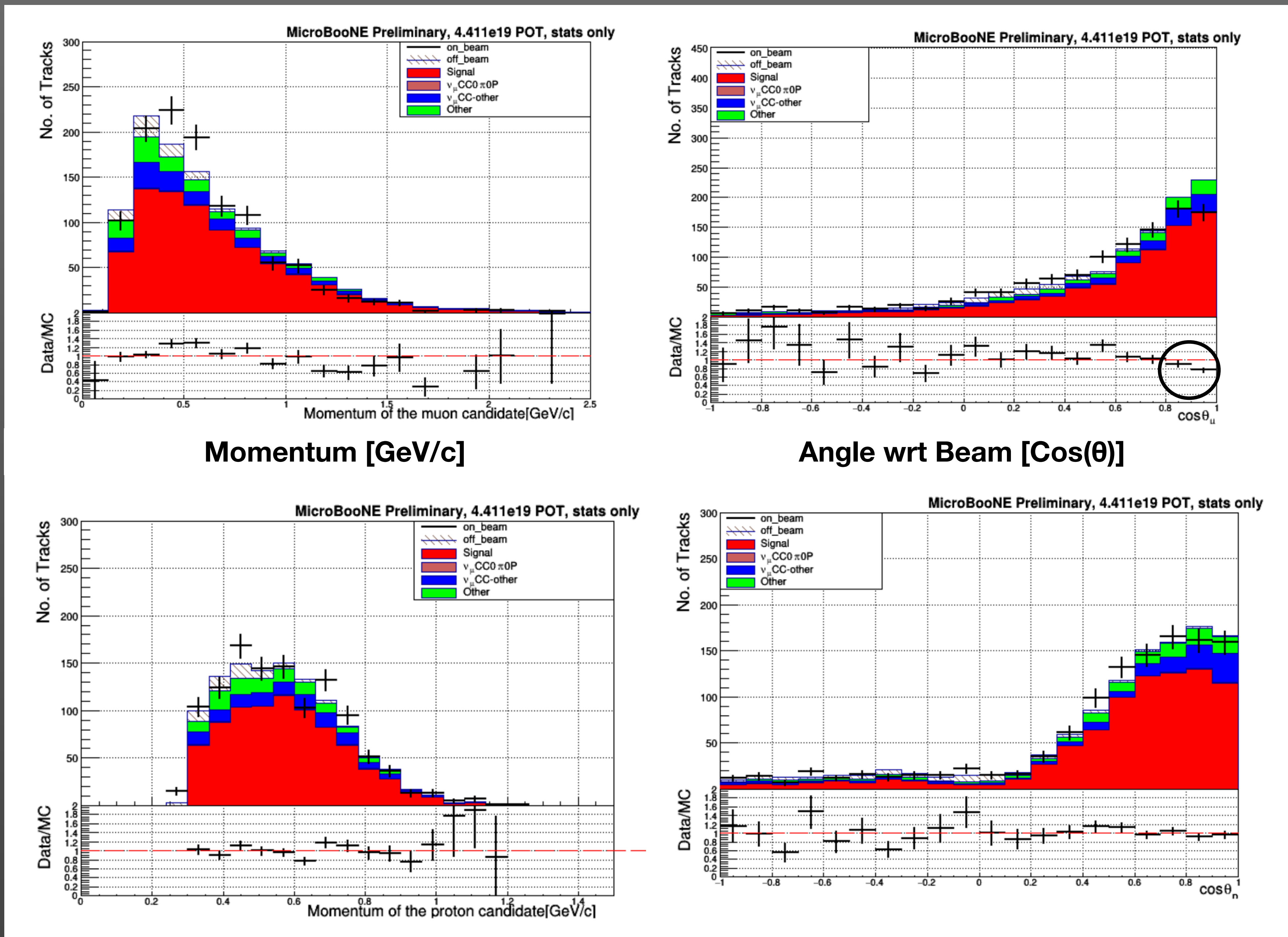




- Protons reconstructed by identifying the Bragg peak of particles as they stop.
- Fit track's dE/dx vs. Residual range to Bethe-Bloch expectation for protons.
- Improved simulation with data measured *E* field will improve our modeling of this observable.

For Leading Proton:	
Efficiency	**Purity**
85.2%	92.6%

Charged-Current N Protons

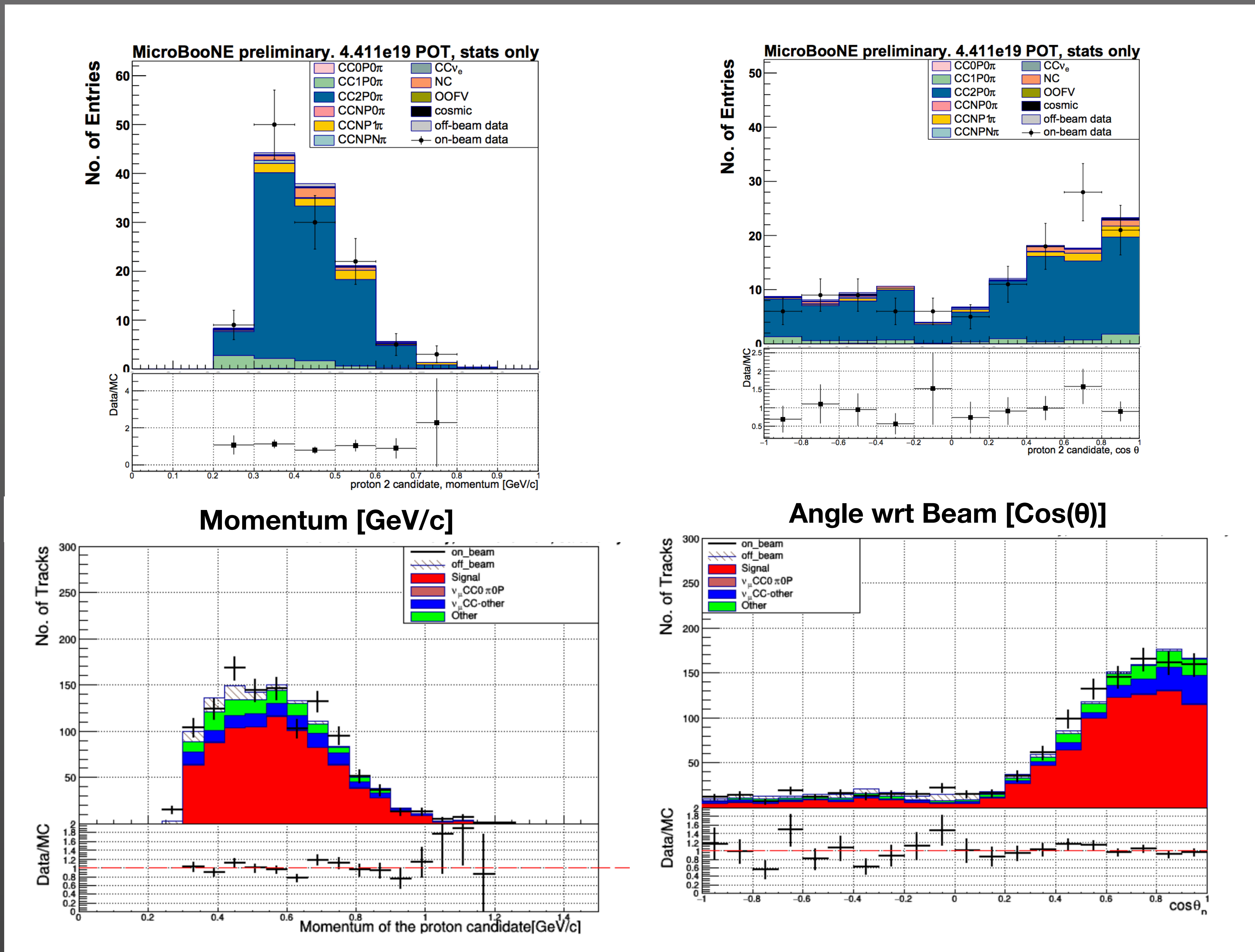


Muon Variables

Leading Proton Variables

- Proton kinematics show better shape agreement than muon kinematics.

Charged-Current N Protons



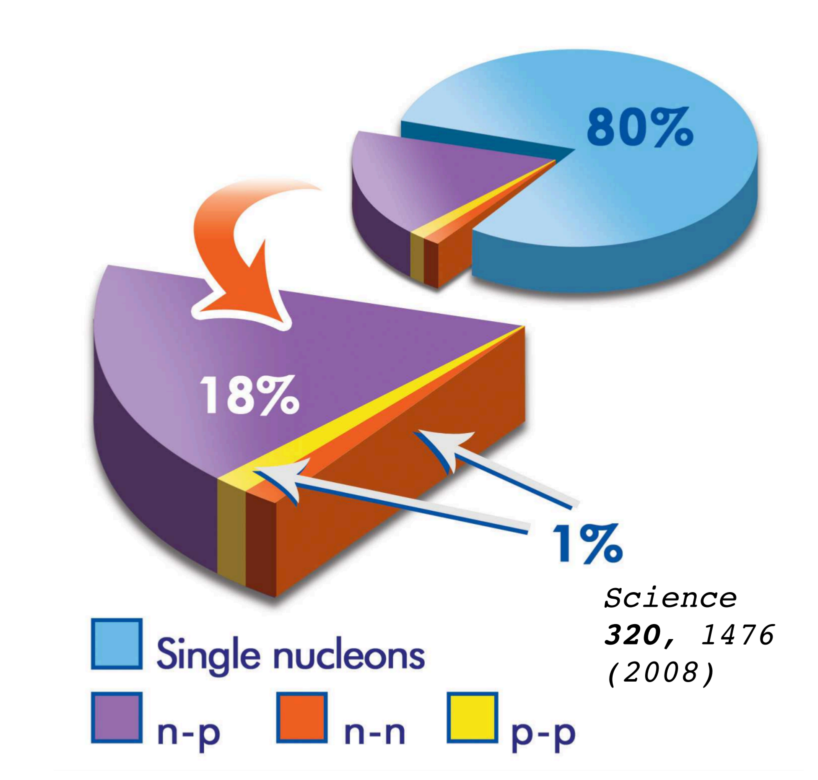
Second Leading Proton Variables

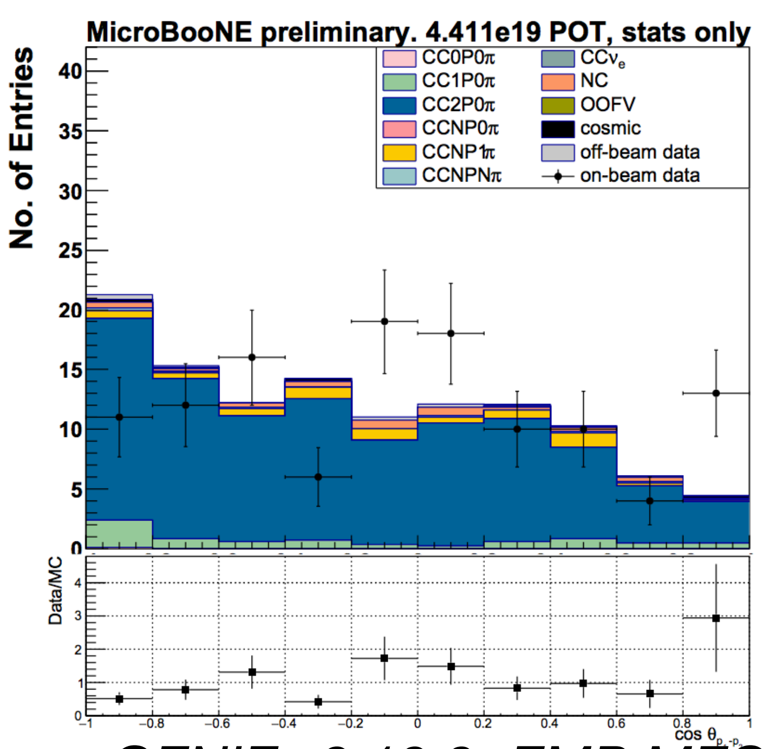
Leading Proton Variables

- Caveat: Top row requires *exactly* two protons in final state.

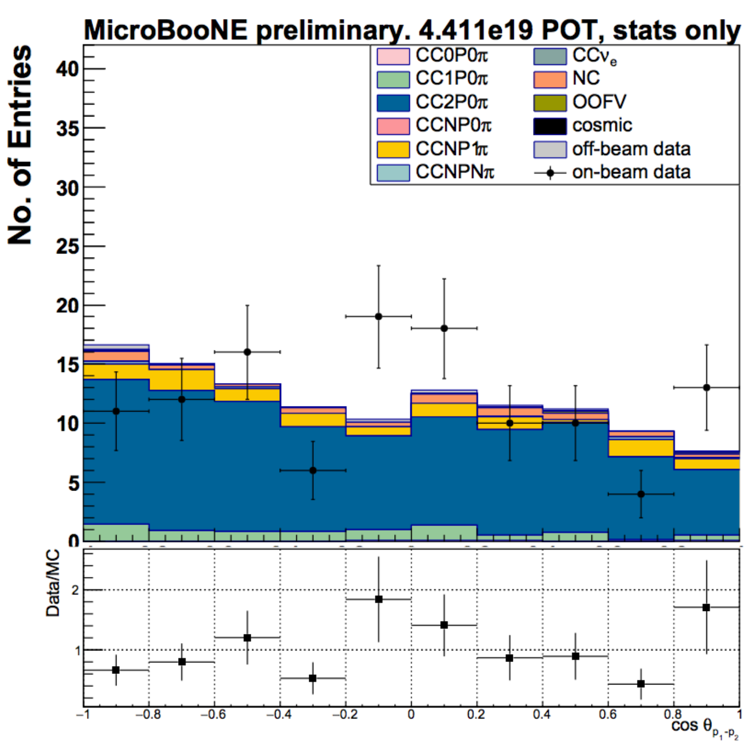
CHARGED-CURRENT 2 PROTON

- e^- nuclear experiments show strong evidence for interactions off nucleon pairs.
- Signature is two protons knocked out back to back in CM frame.





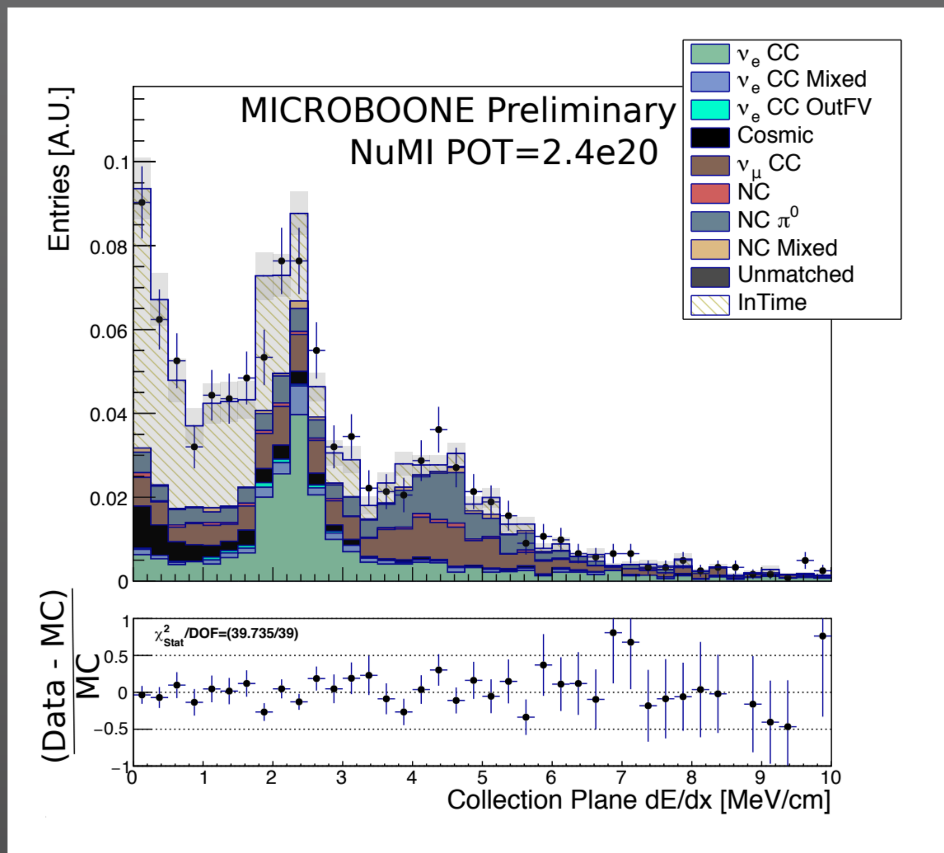
GENIE v2.12.2+EMP MEC



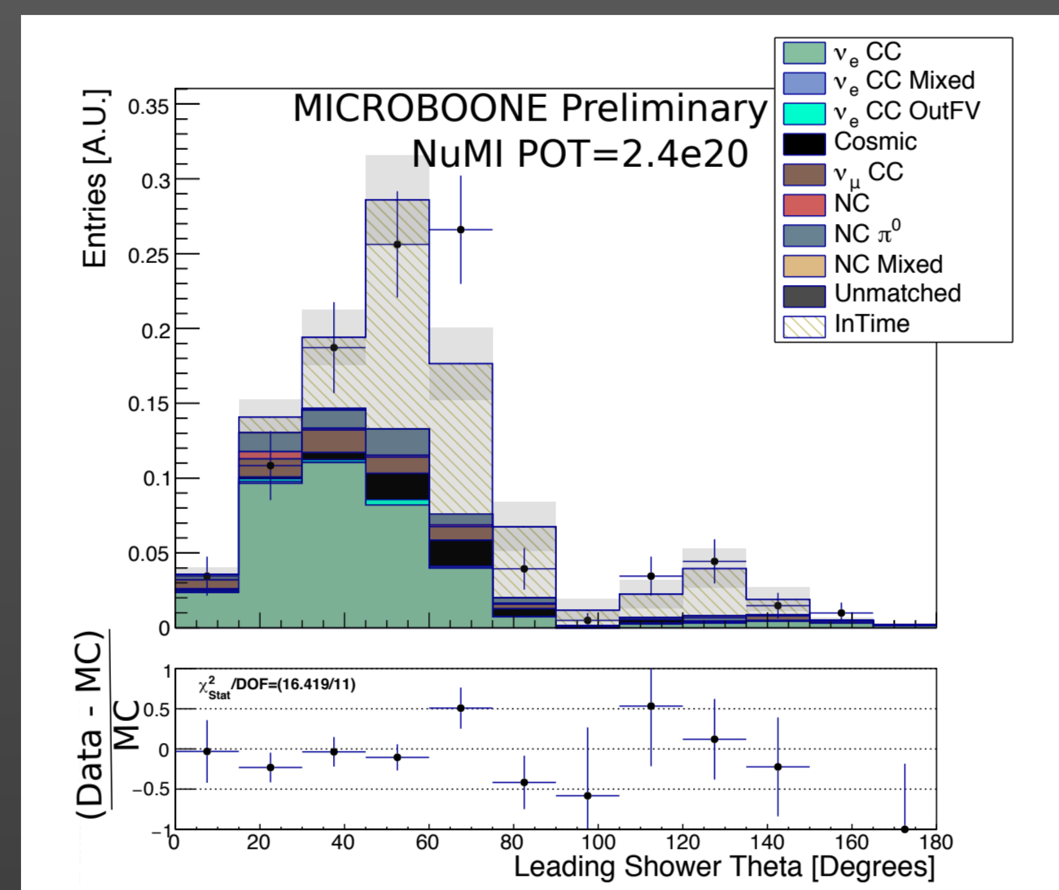
GENIE 1810a0211a

- Searching for evidence of this in MicroBooNE.
- Shape better modeled by incorporating QE nuclear effects.

ν_e-Argon Cross-Section



- Identifying ν_e important for resolving the MiniBooNE LEE.
- Use NuMI (off-axis) beam: ν_e content order of magnitude higher than BNB.



- First ν_e measurement on Argon.
- Only using one plane for PID currently. Leads to inability to detect vertical electrons.
- Simulation of full 3 planes underway.

MICROBOONE-NOTE-1038-PUB

Conclusions

- MicroBooNE is making rapid progress in measuring cross-sections relevant for oscillation and electroweak nuclear physics:
  - CC π^0 **(Paper Published)**
  - Double-differential CCInclusive **(Paper Submitted)**
  - CC N proton **(Paper In-Progress)**
  - CC 2 protons **(Paper In-Progress)**
  - CC Inclusive ν_e **(Paper In-Progress)**
- These measurements form a springboard for resolving the MiniBooNE low energy excess.
- Measurements will be considerable help for theorists and model builders.
- Looking forward to measurements of more exotic processes (K^+, π^+, exclusive ν_e) as time progresses!

Thank you For Listening!

References for MicroBooNE Papers and Public notes on next slide
(https://microboone.fnal.gov/public-notes/)

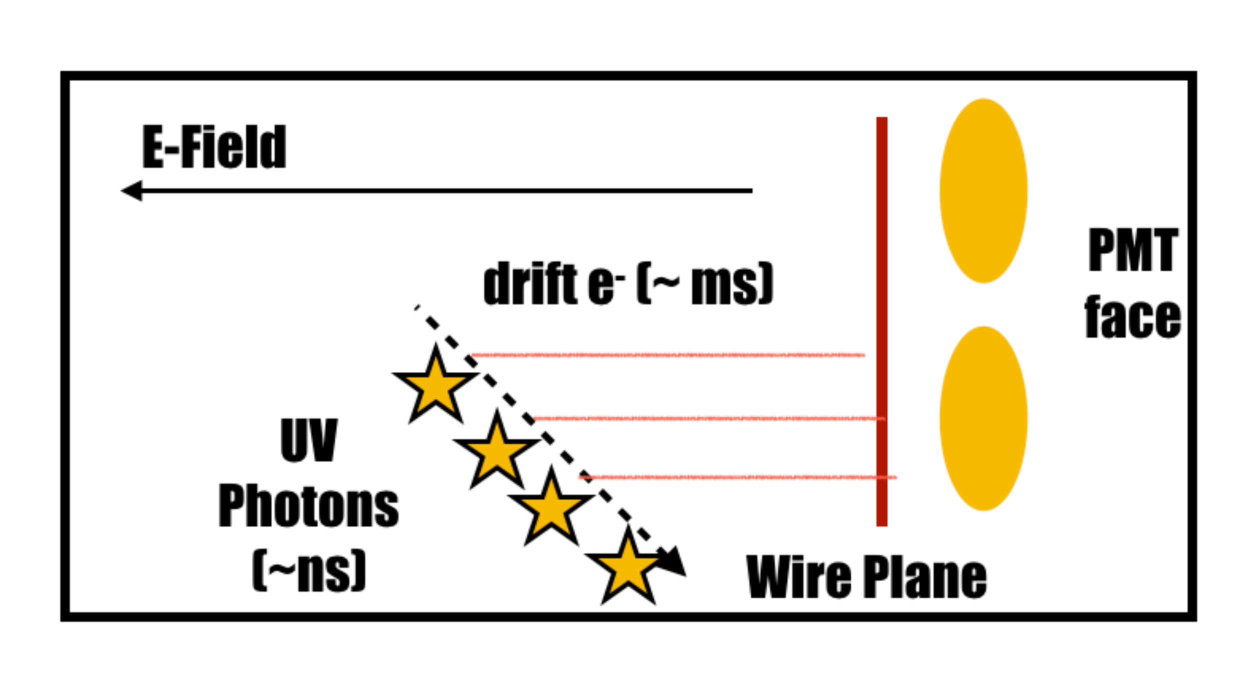
References

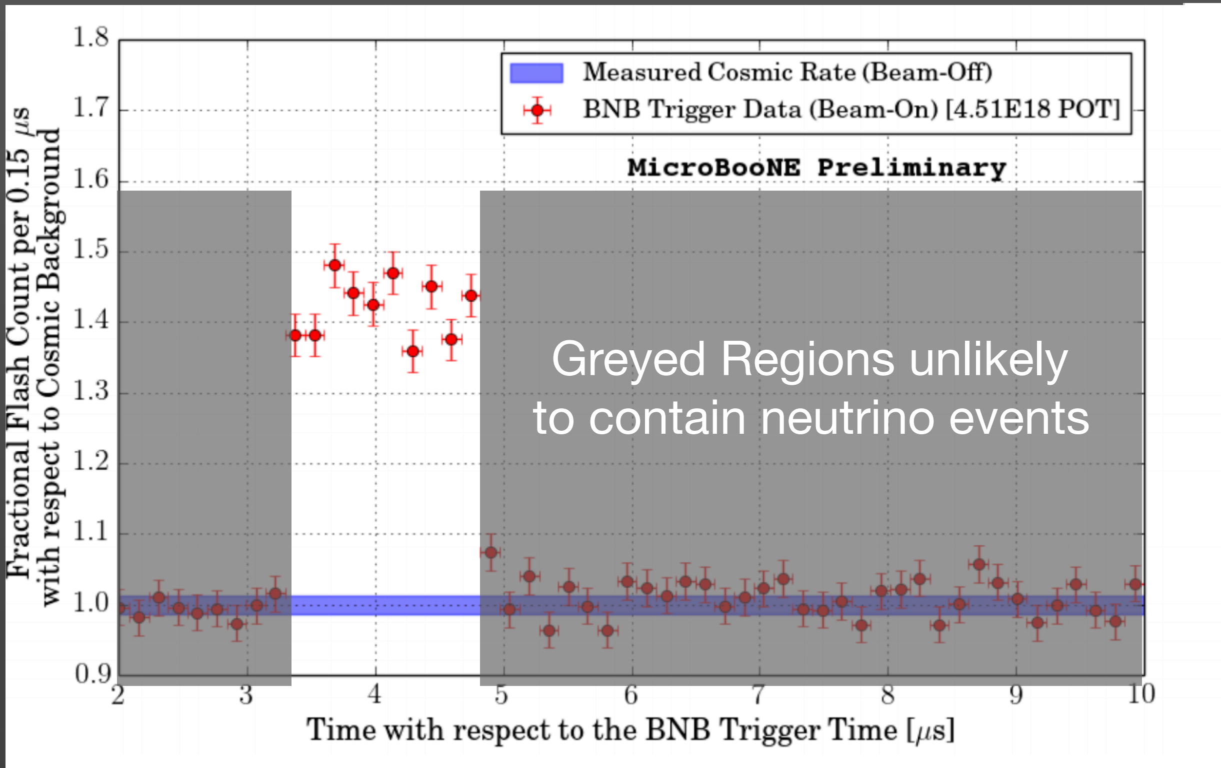
- Charged-Current Inclusive double differential:
  - arXiv 1905.09694 (submitted to PRL)
- Charged-Current single production:
  - PRD 99, 091102(R) (2019)
- Charged-Current ν_e:
  - MICROBOONE-NOTE-1038-PUB
- Charged-Current N protons:
  - MICROBOONE-NOTE-1056-PUB
- Pandora reconstruction:
  - Eur. Phys. J. C 78, no. 1, 82 (2018)
- Multiple Coulomb Scattering:
  - JINST 12, no. 10 P10010 (2017)

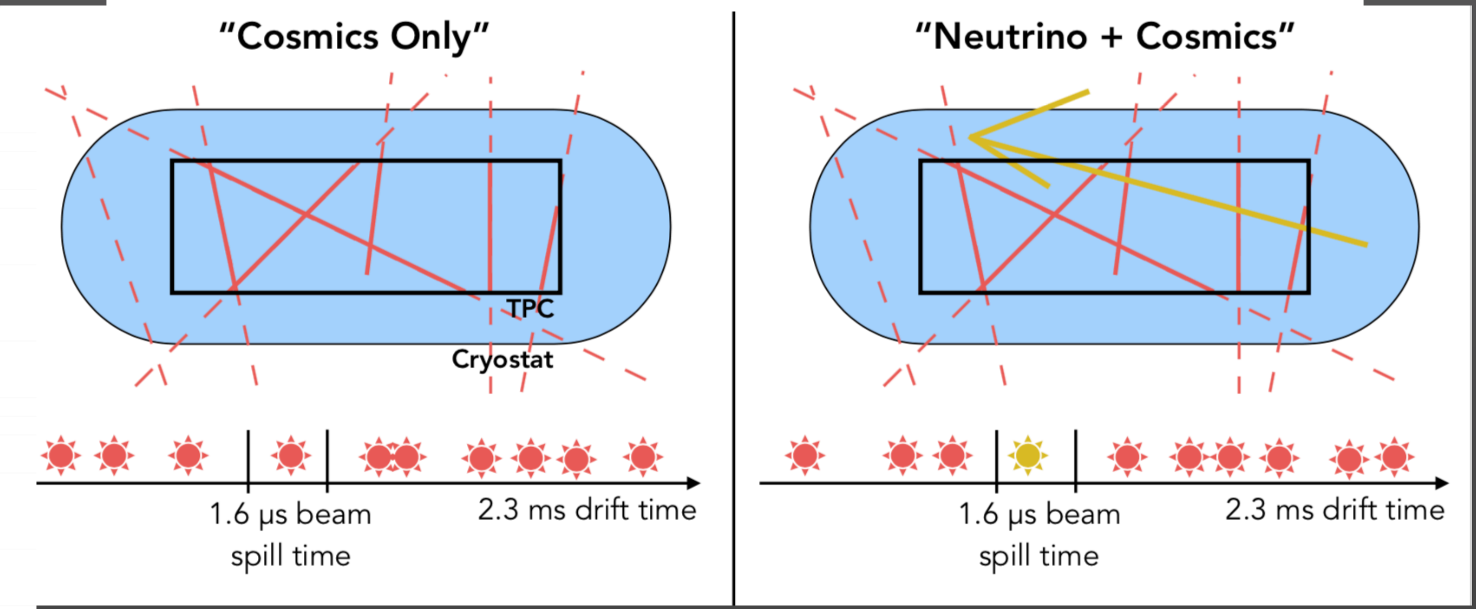
Backup Slides

Cosmic Mitigation

- 32 PMTs are used to detect prompt scintillation light, enables us to search for events in a 1.6 us beam window



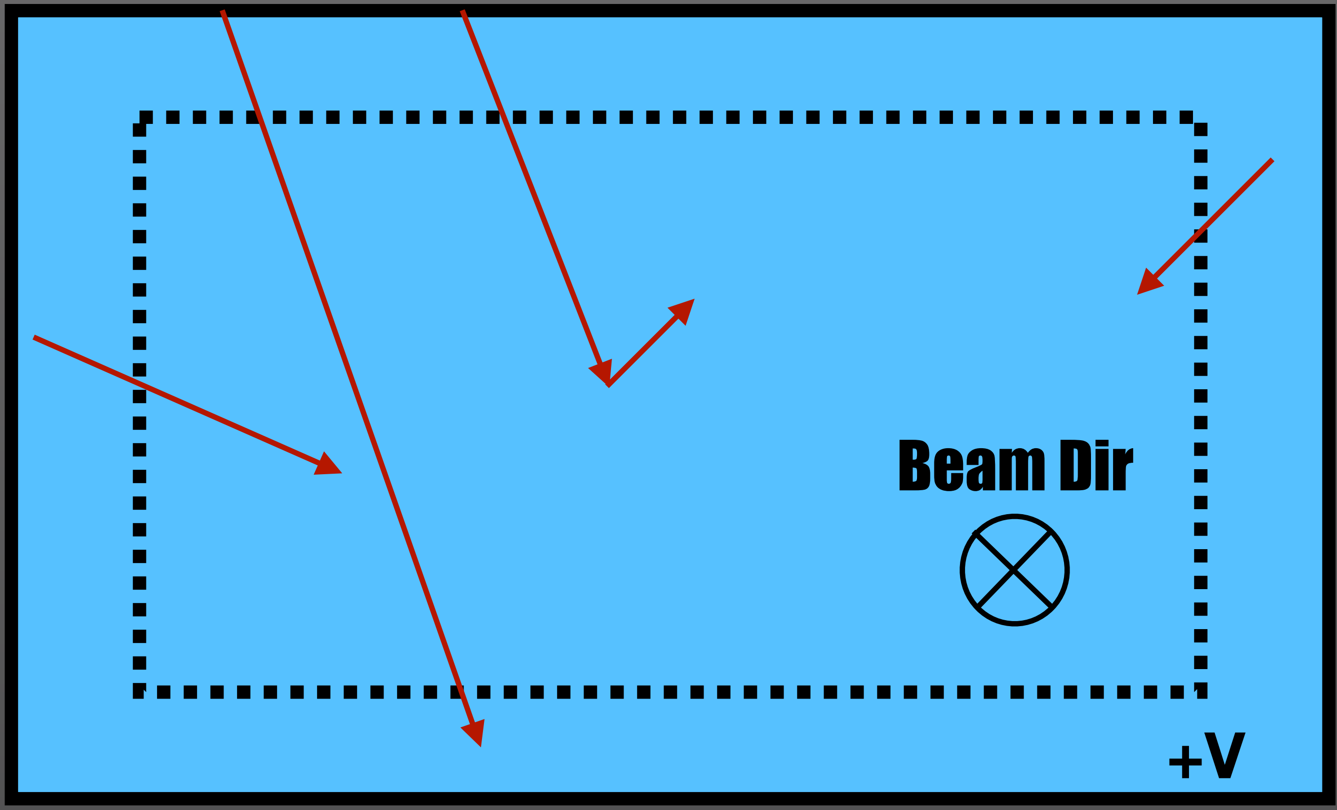


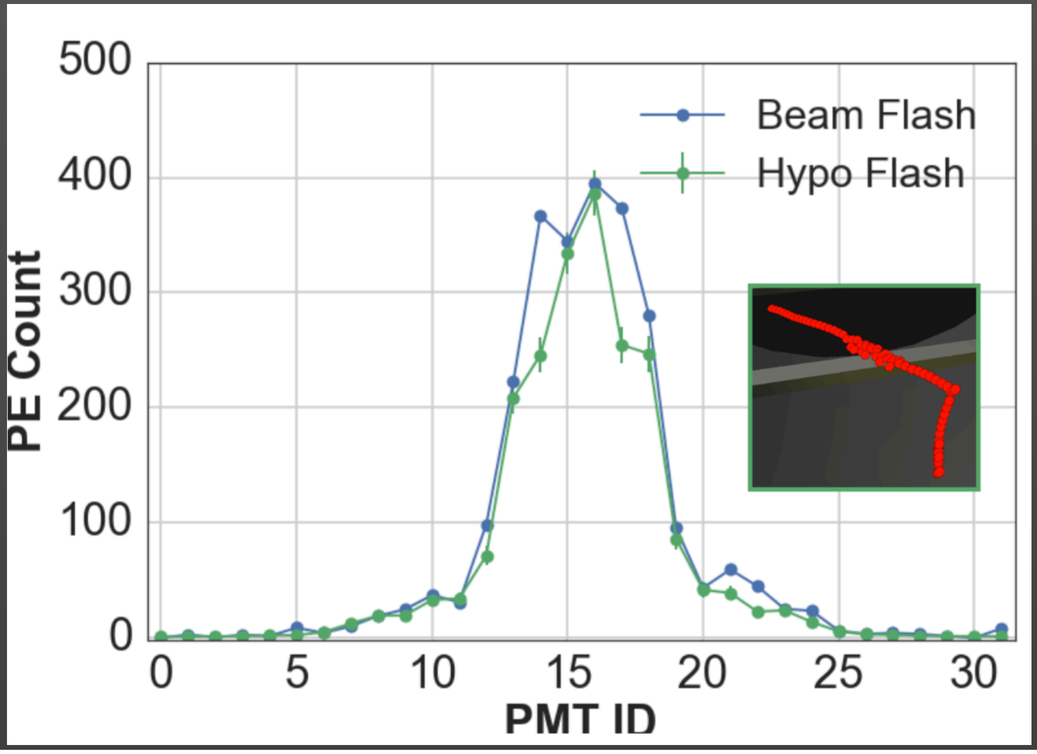


- Still a BG to contend with for overlapping events and beam gates with no neutrino interaction.

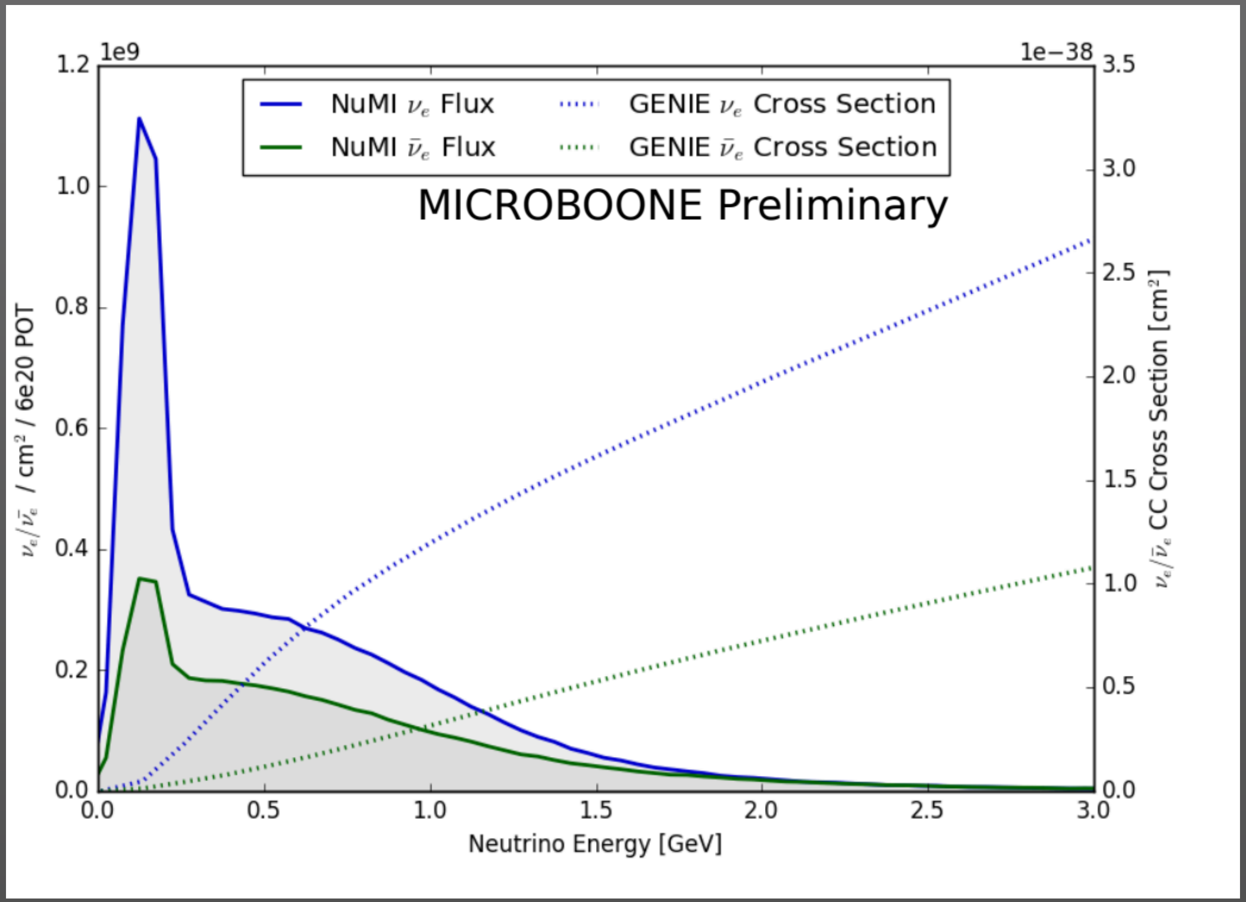
Cosmic Mitigation

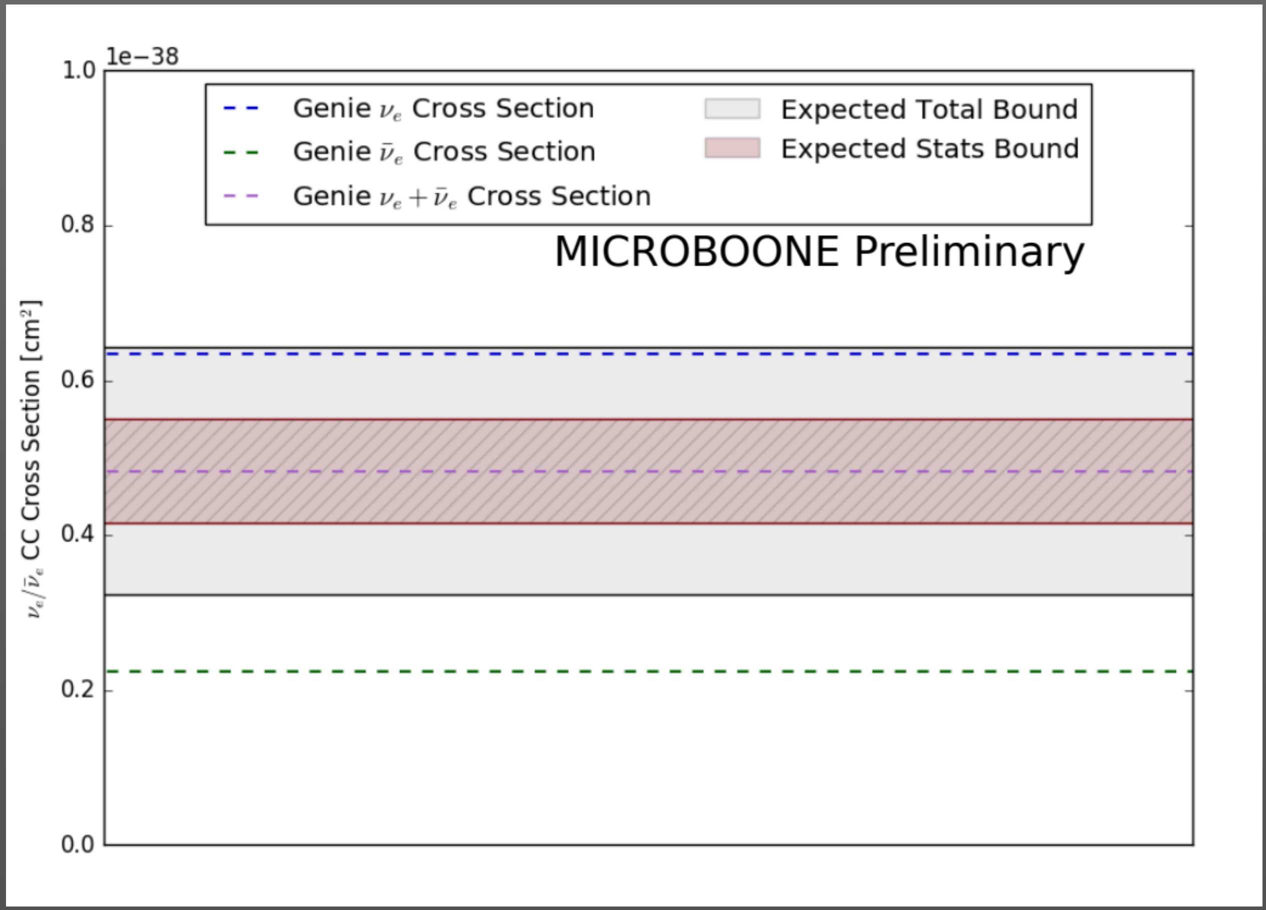
- Remove and tag "obvious" cosmic rays:
  - Stopping muons with michel tagging.
  - Downward or upwarding going thoroughgoing particles.
  - Particles which enter through the sides; cathode or anode.
- Compare the amount of light observed in PMTs to the predicted amount based on the track's position within a beam spill.





ν_e-Argon Cross-Section

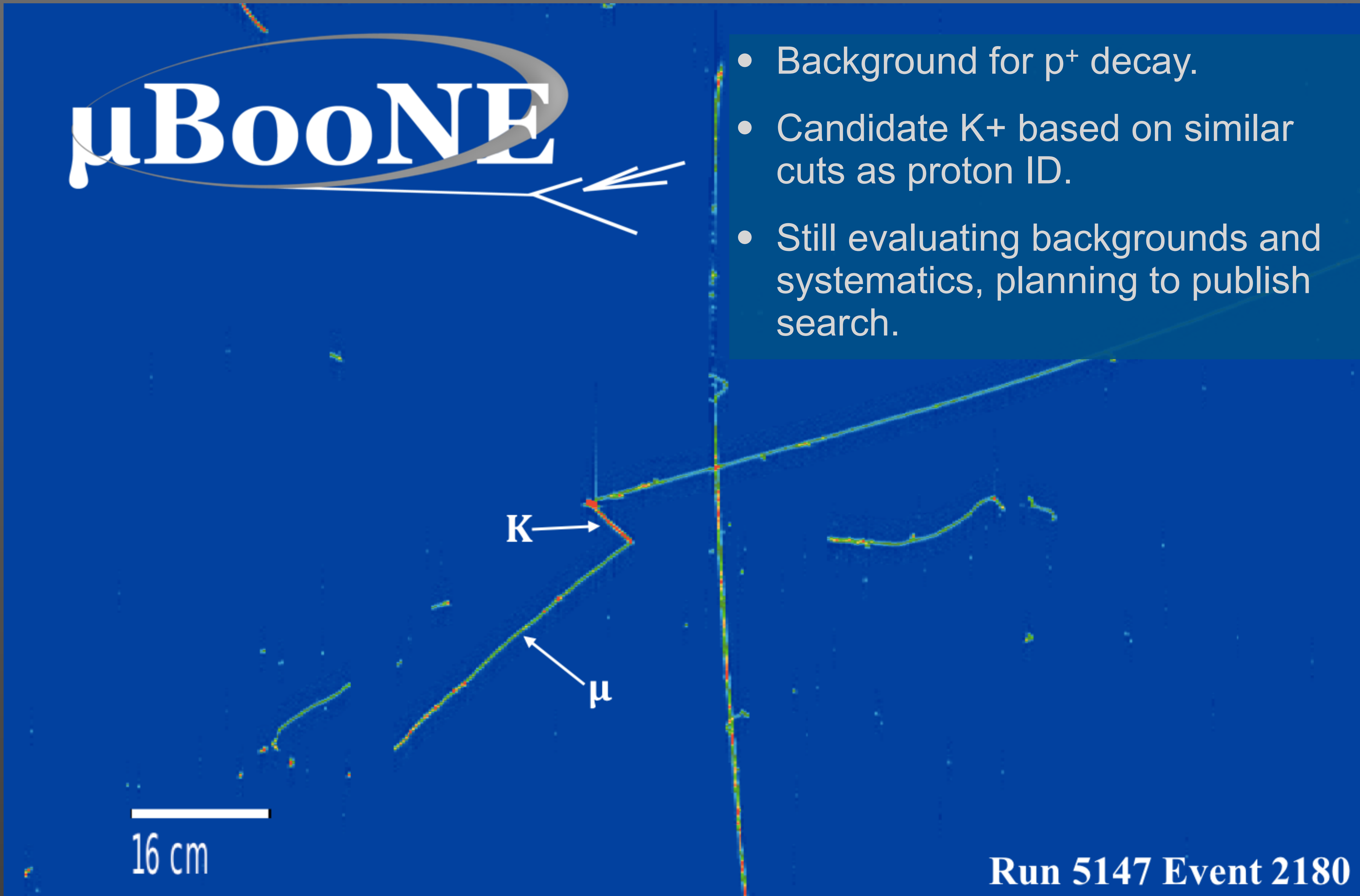




- Relevant energy range (left) and expected sensitivity (right).
- Modeling of off-axis NuMI flux extremely difficult, power of this measurement comes from being able to positively ID electrons, and cross-check LEE signal analysis.

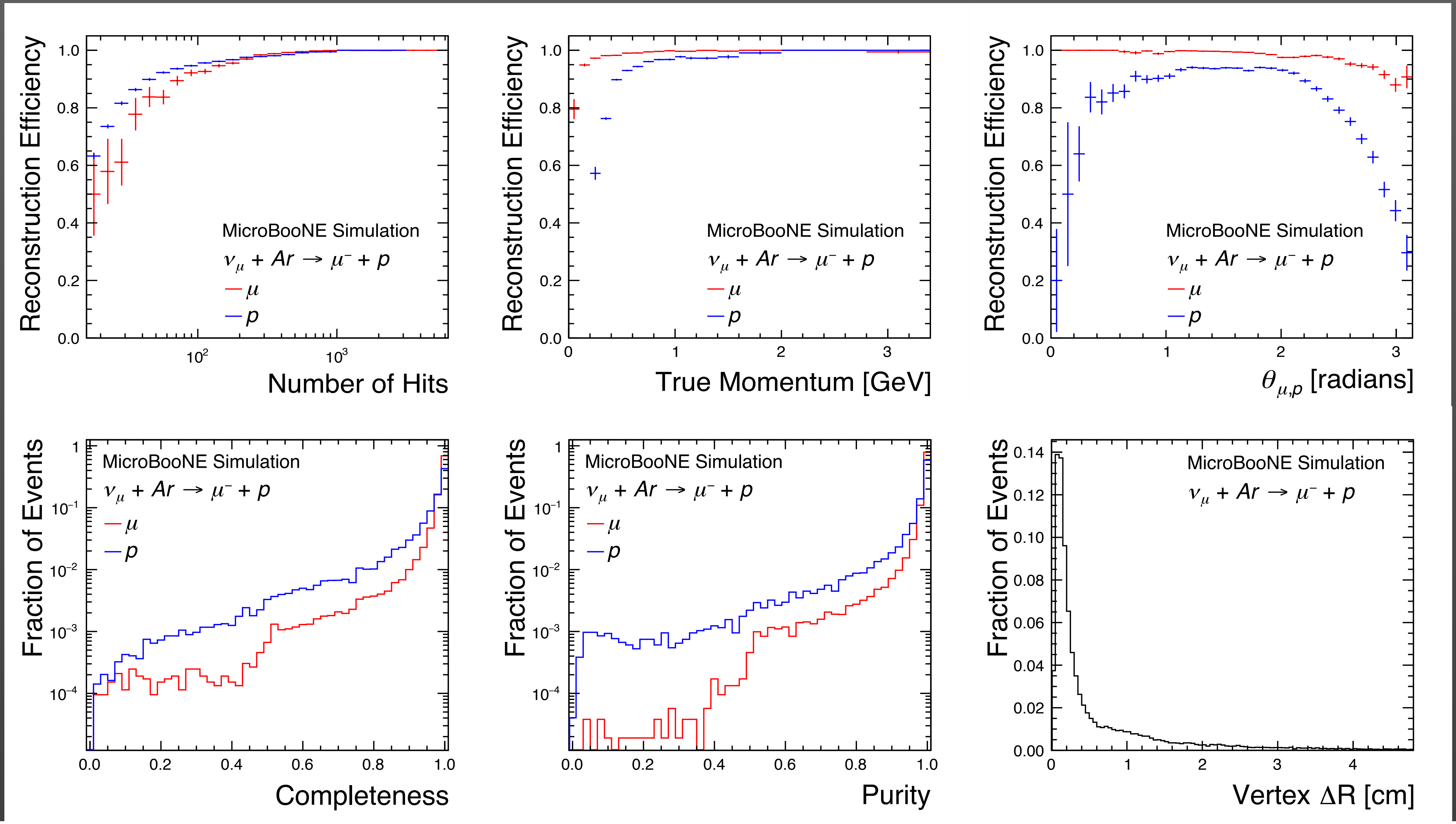
Neutrino Induced Kaons

- Background for p^+ decay.
- Candidate K+ based on similar cuts as proton ID.
- Still evaluating backgrounds and systematics, planning to publish search.

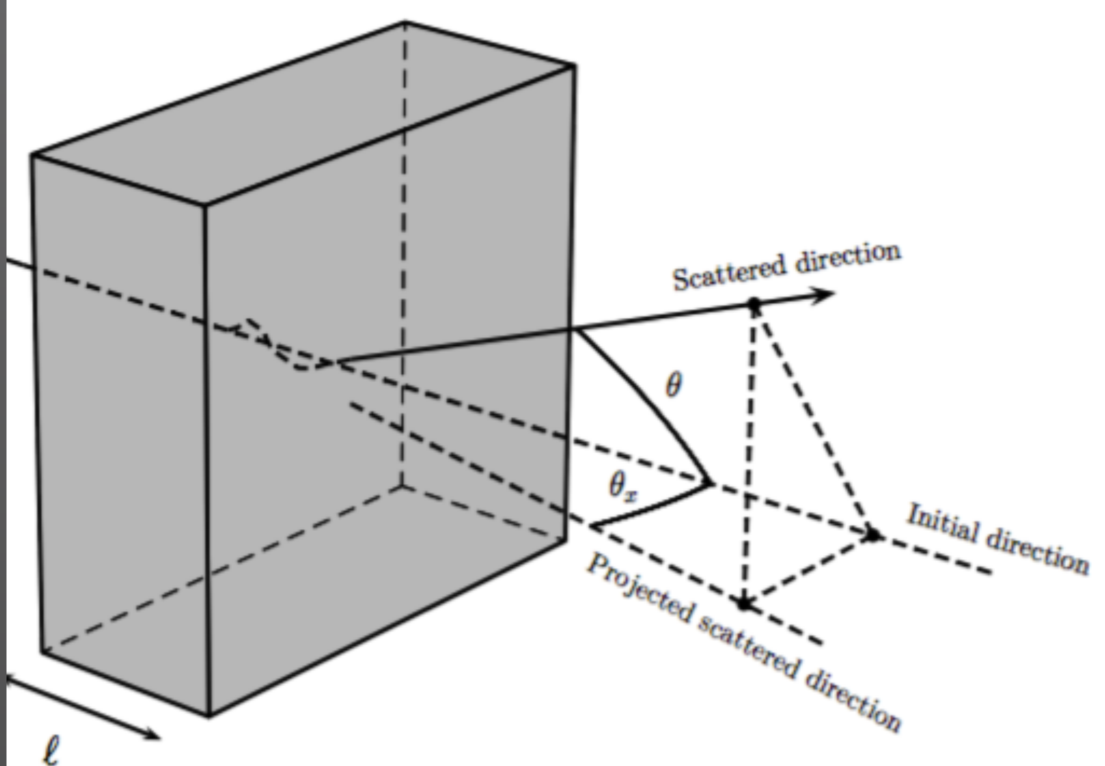


Pandora reconstruction

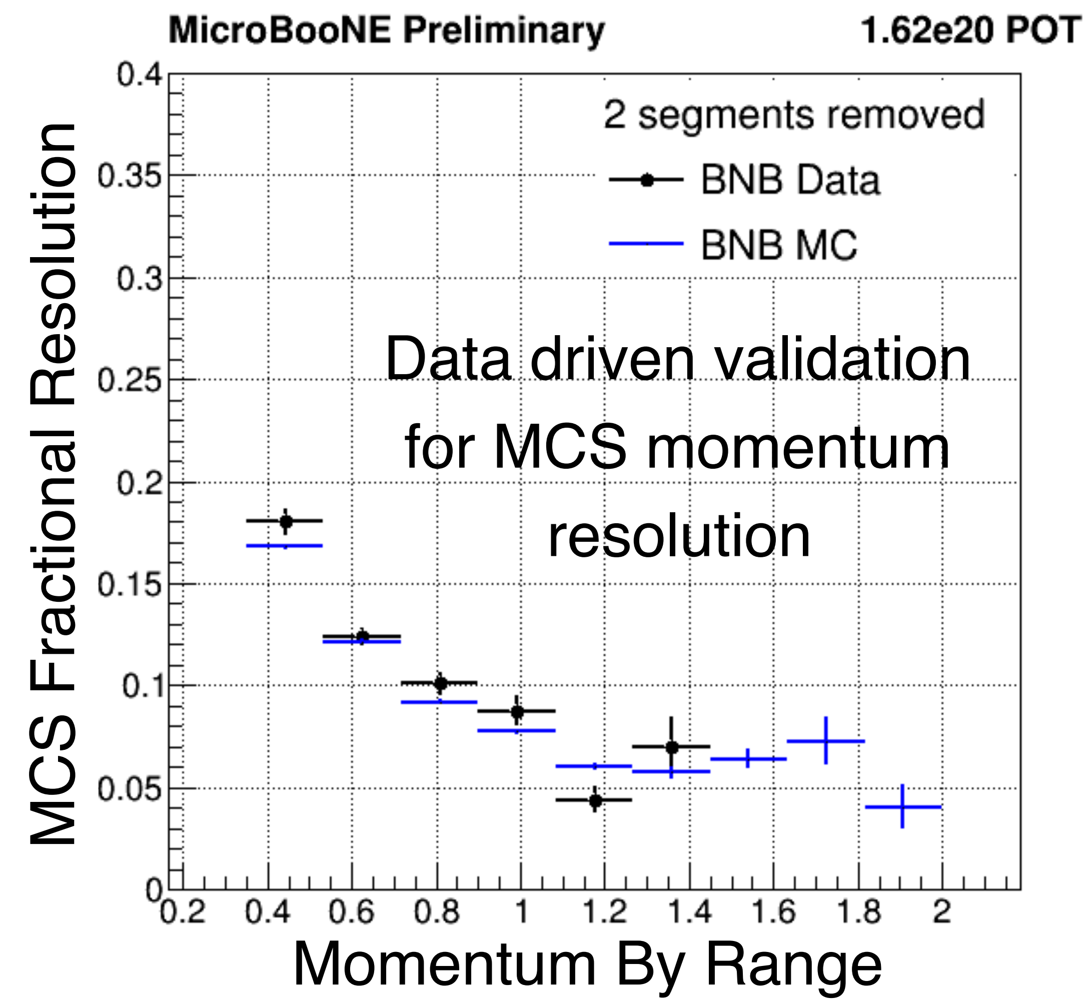
•Reconstruction begins with "hit finding:" locating hits from waveforms along the wires, and deconvolving the signal to an (x, u, v, t) coordinate.
•Hits clustered together to form cluster objects, clusters stitched into 3D tracks and showers.



Multiple Coulomb Scattering



$$\sigma_o^{\mathrm{HL}} = \frac{S_2}{p\beta c} z \sqrt{\frac{\ell}{X_0}} \left[1 + \epsilon \times \ln\left(\frac{\ell}{X_0}\right)\right]$$



Momentum resolution well-modeled at large momentum

- Highland formula relates rms of scattering to p.