Charged Current Neutral Pion Production at MicroBooNE

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12th International Workshop
On Neutrino-Nucleus Interactions
In the Few GeV Region
L'Aquila, Italy
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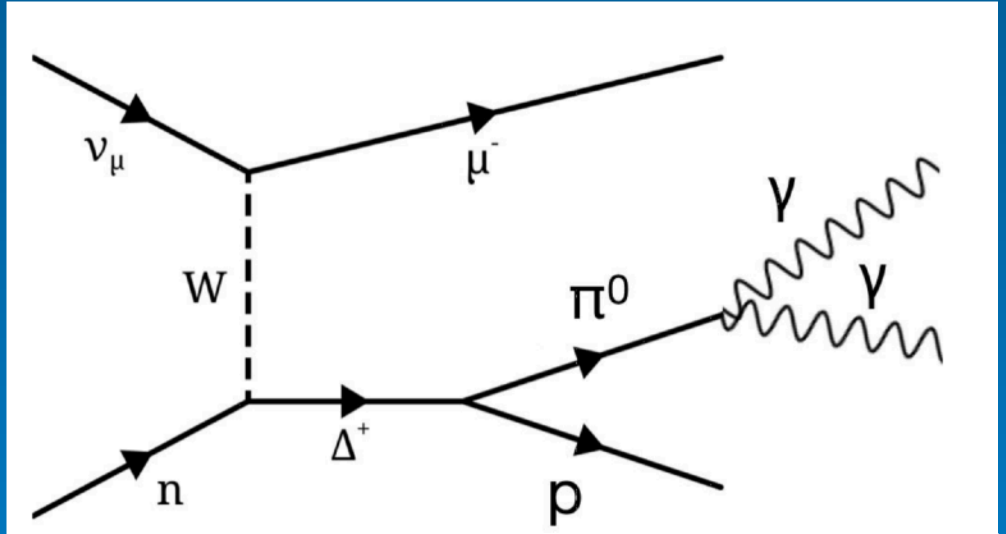
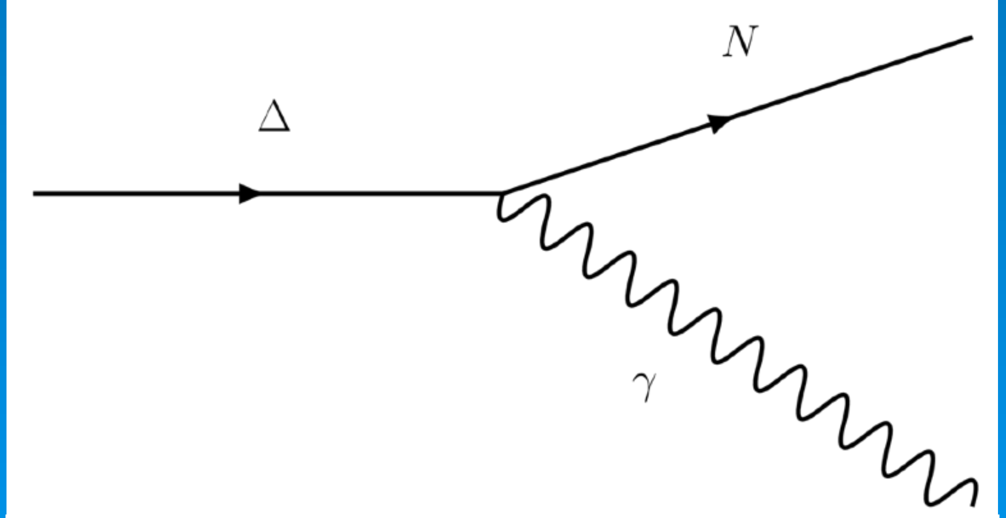
Sources of Photon Production

- At BNB energies, most originate from Decay of Δ to π^0.
- Sources we classify as background:
  - Radiative delta decay (Δ→ɣ+N)
  - π^0 from re-scattering (charge exchange)
  - Higher mass resonances.
- Further sources:
  - Anomalous (constrained by radiative delta decay).
  - Nuclear de-excitation (sub 10 MeV).

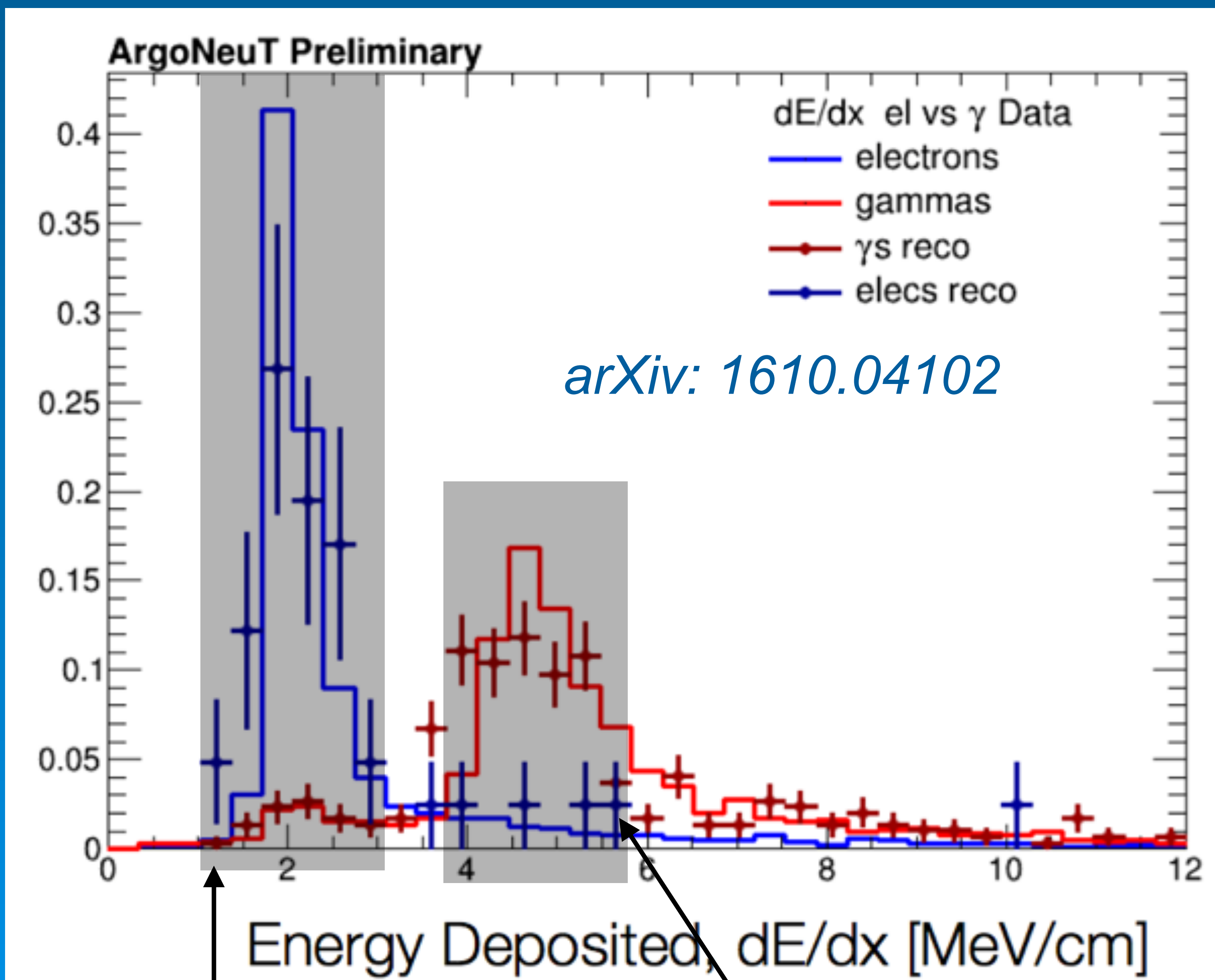


Dominant at BNB Energies



0.5% BR

Photon Detection with LArTPCs

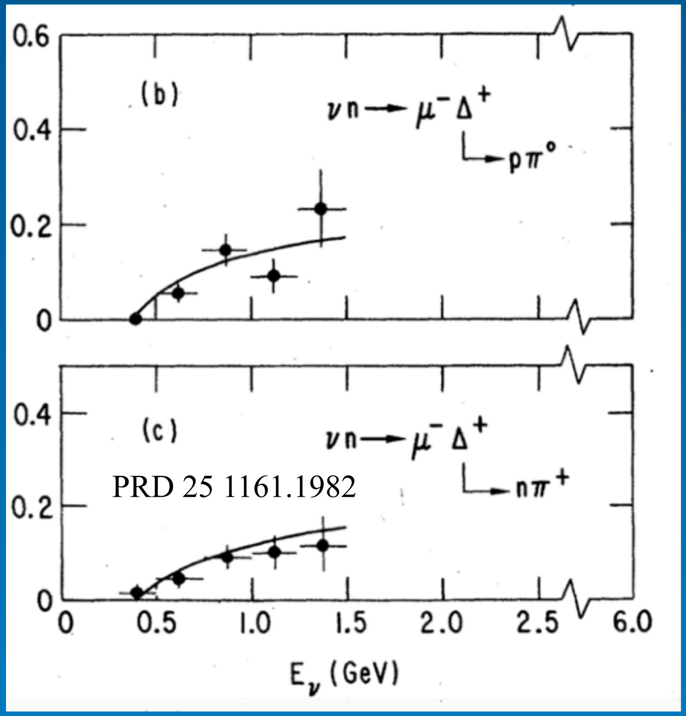


Colton's Talk

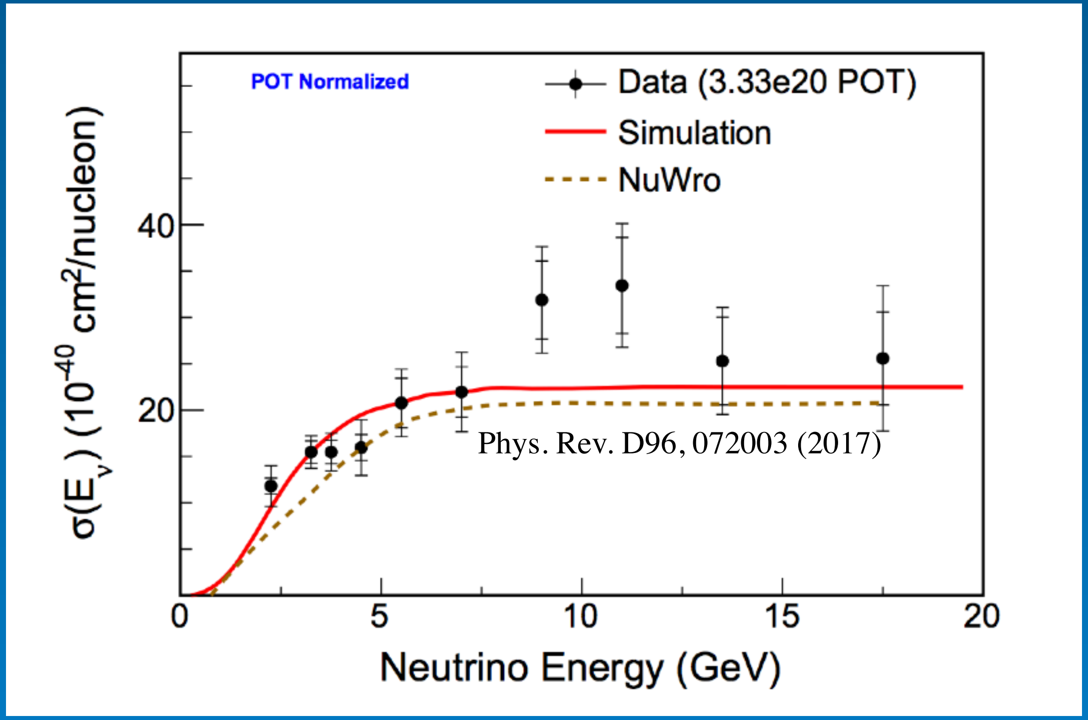
This Talk

- Electron-gamma separation one of the hallmarks of LArTPCs.
- Measure energy deposition along a particle's trajectory.
- Gammas pair-produce into two electrons, dE / dx. profile follows 2 electrons.
- *Challenge is reconstructing showers from gammas*

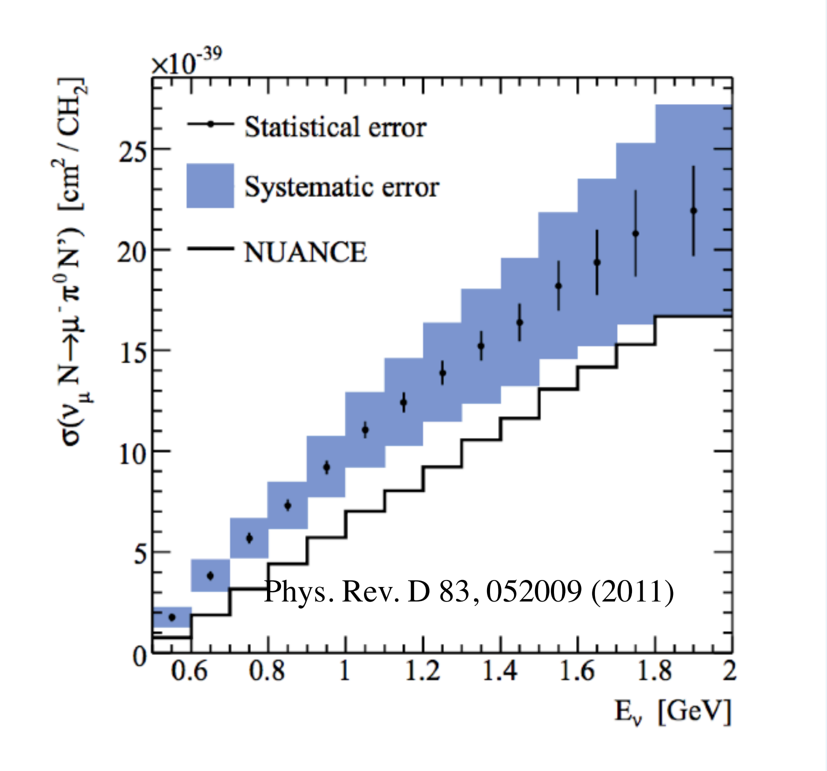
CC π^0 Production with Neutrinos



ANL



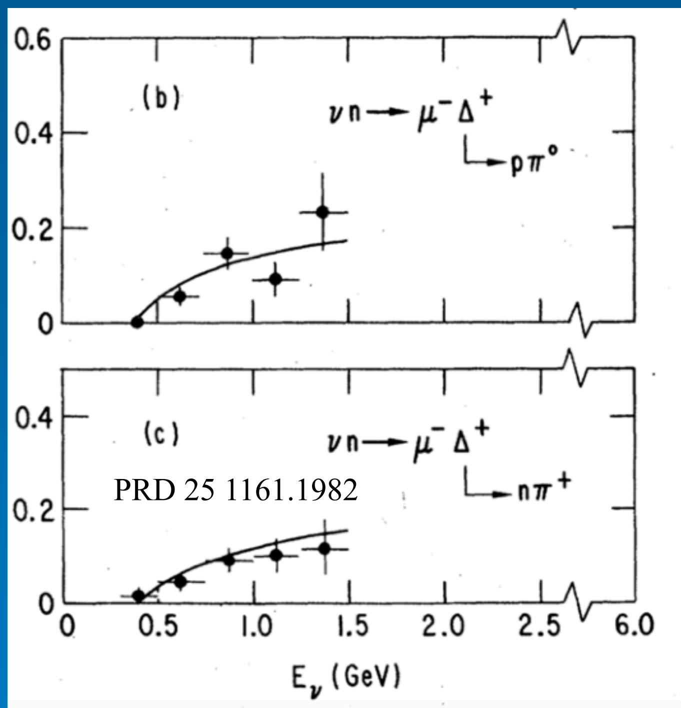
MINERvA



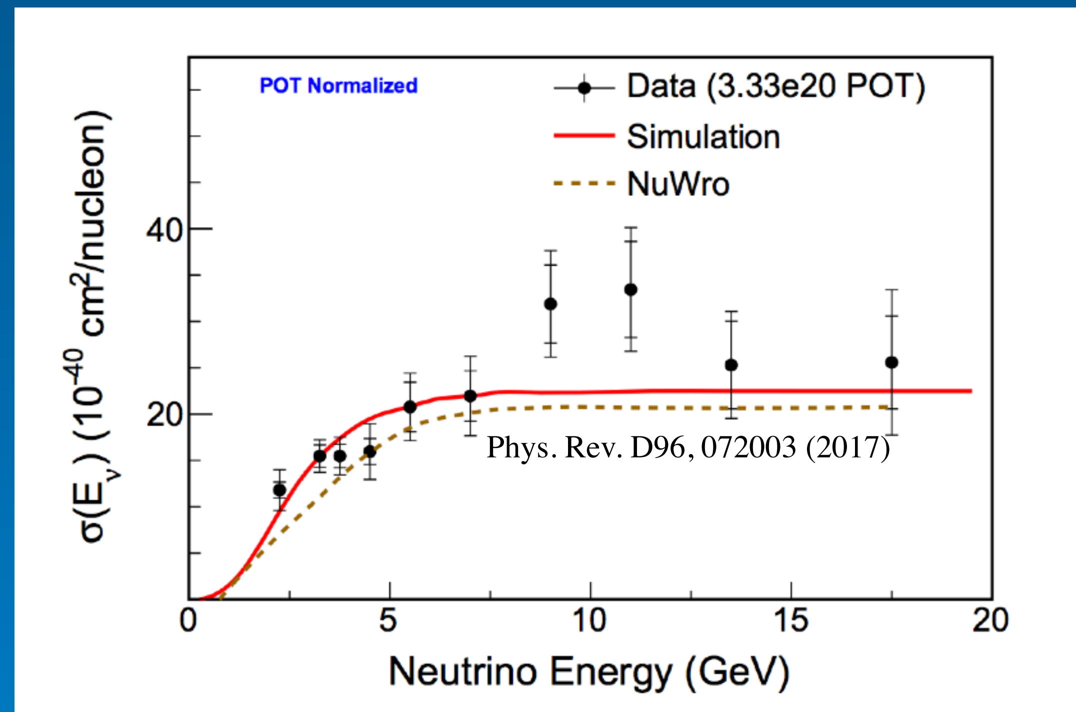
MiniBooNE

- Many energy ranges and target media explored.
- Nuclear effects expected to scale as $A^{2/3}$ cross-section as N.
- Argon largest nucleus measured to date!

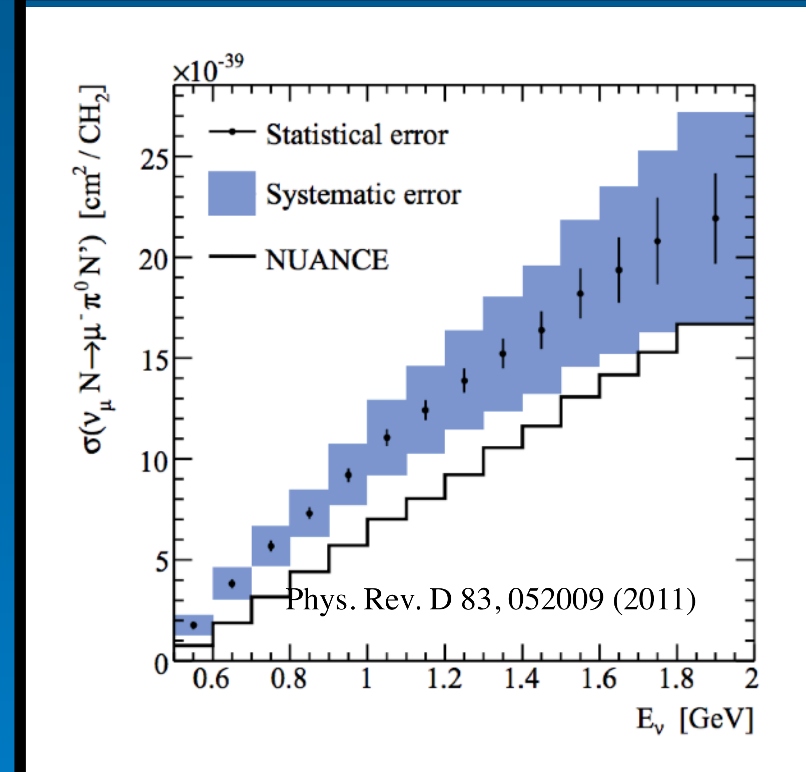
CC π^0 Production with Neutrinos



ANL



MINERvA

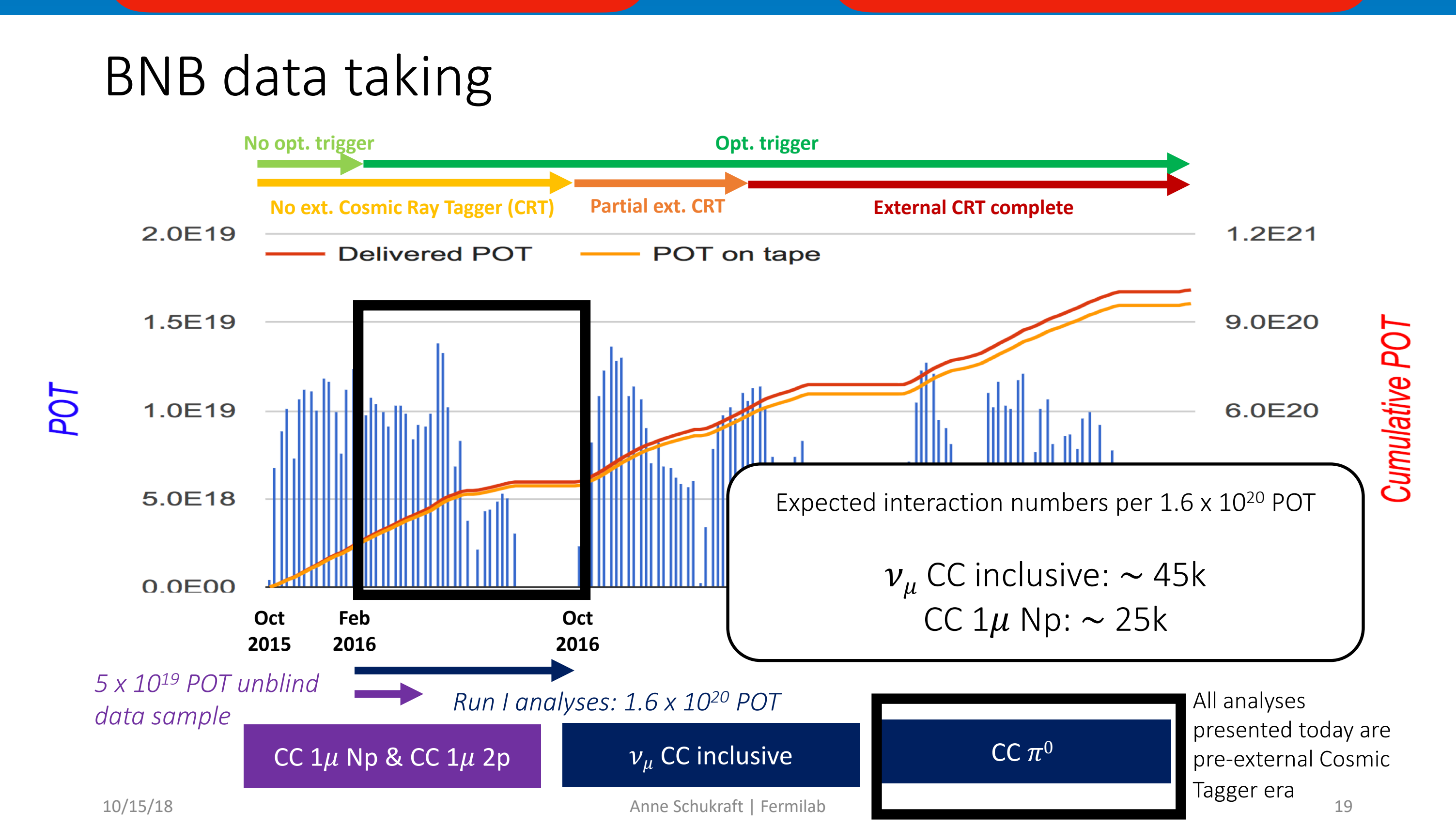


MiniBooNE

- Focus on MiniBooNE: same beam line as MicroBooNE.
- MiniBooNE signal: $\nu_\mu + CH \rightarrow \mu^- + \pi^0 +$ *plus no other mesons.*
- MicroBooNE: $\nu_\mu + CH \rightarrow \mu^- + \pi^0 + X$

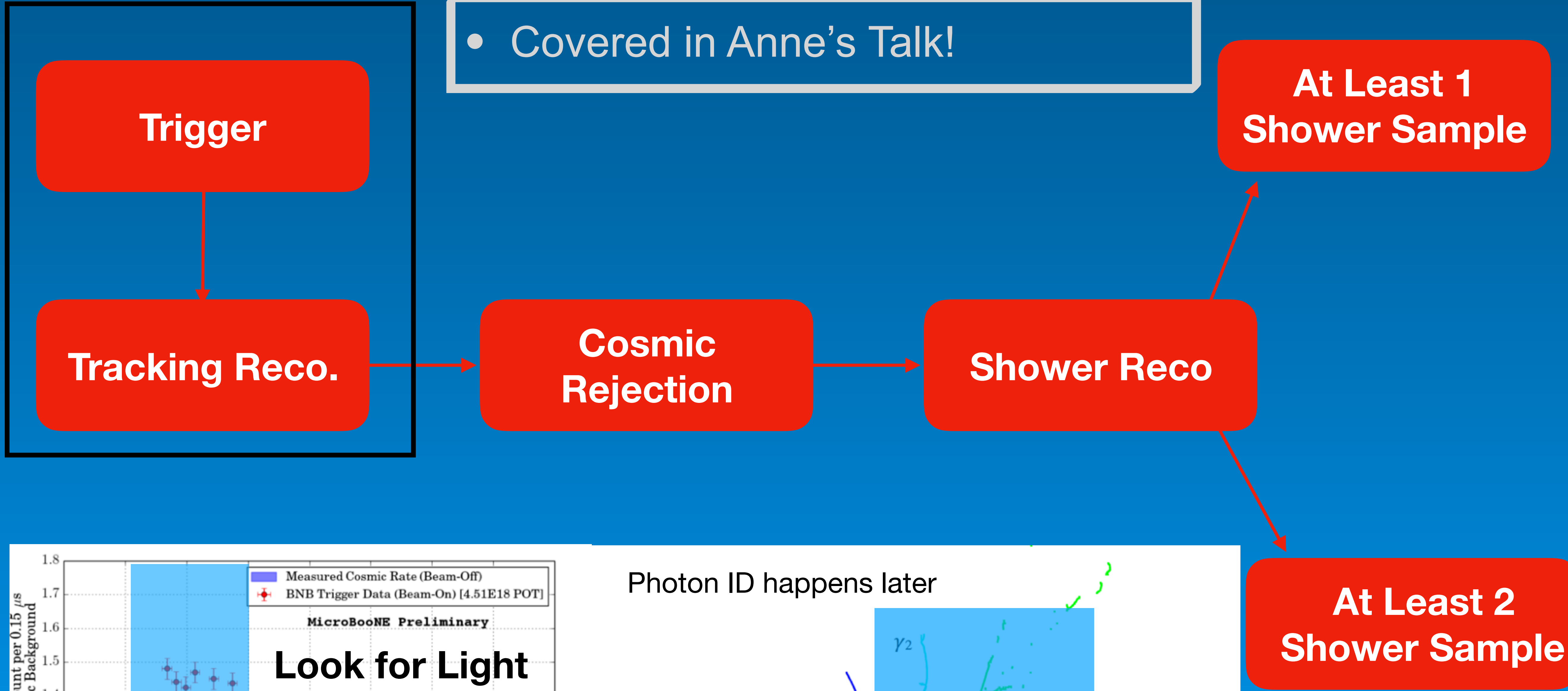
Event Selection

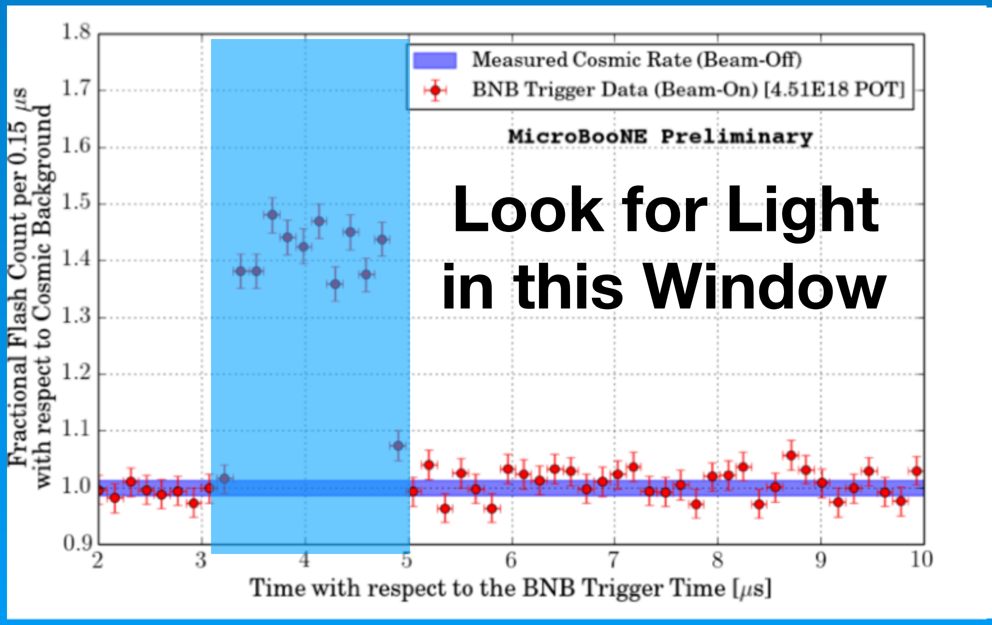
Trigger → Tracking Reco. → Cosmic Rejection → Shower Reco → At Least 1 Shower Sample / At least 2 Shower Sample

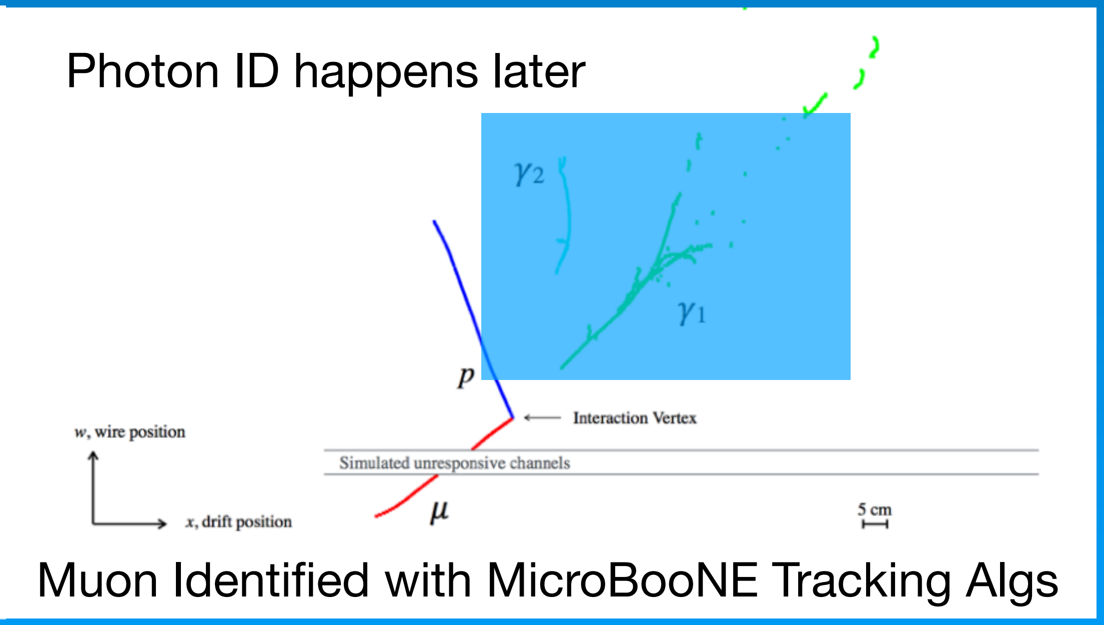


Event Selection

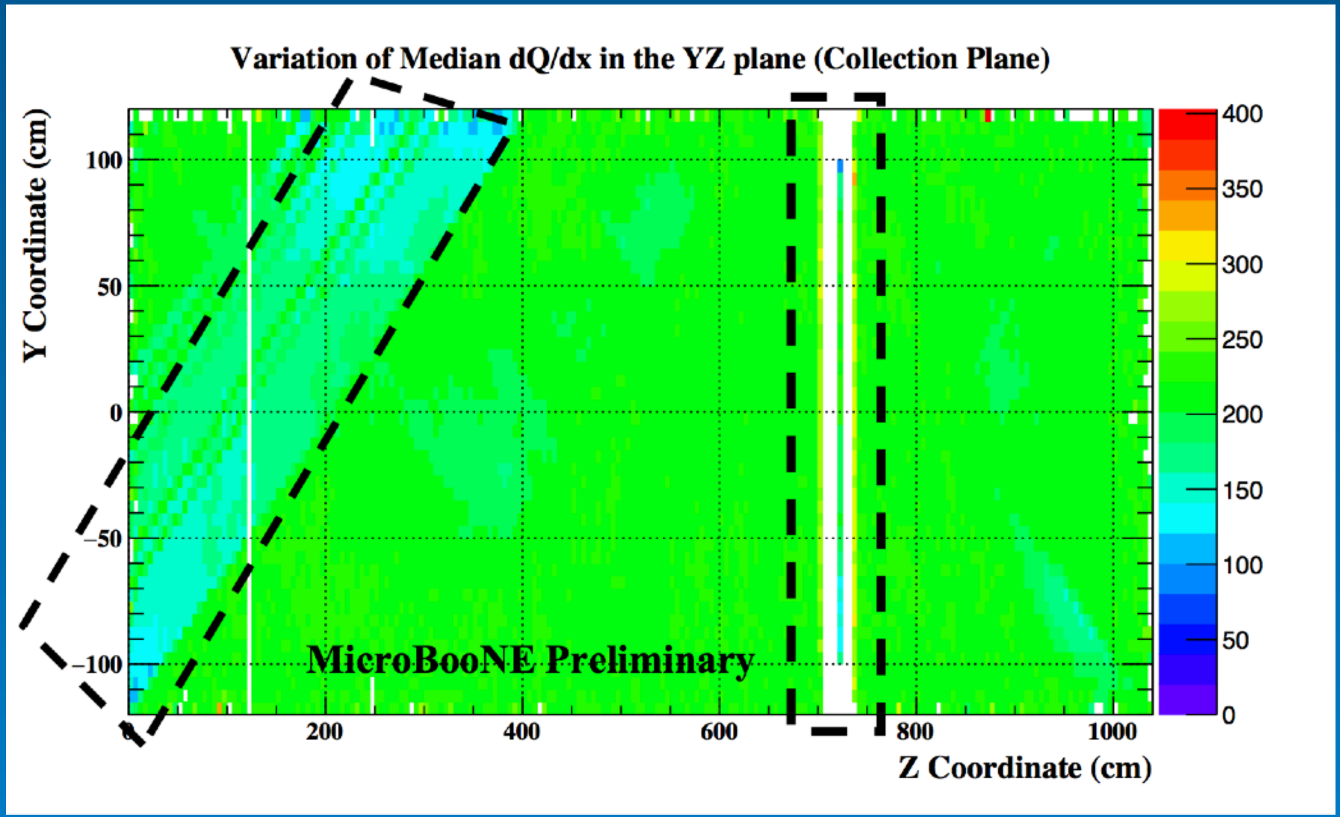
- Covered in Anne's Talk!





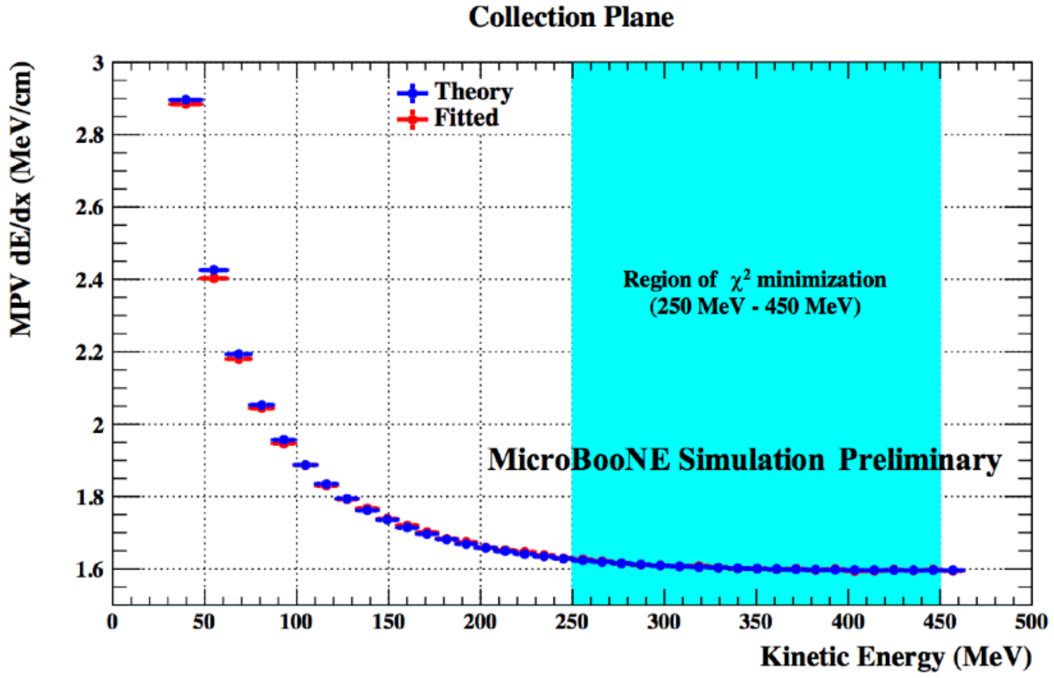


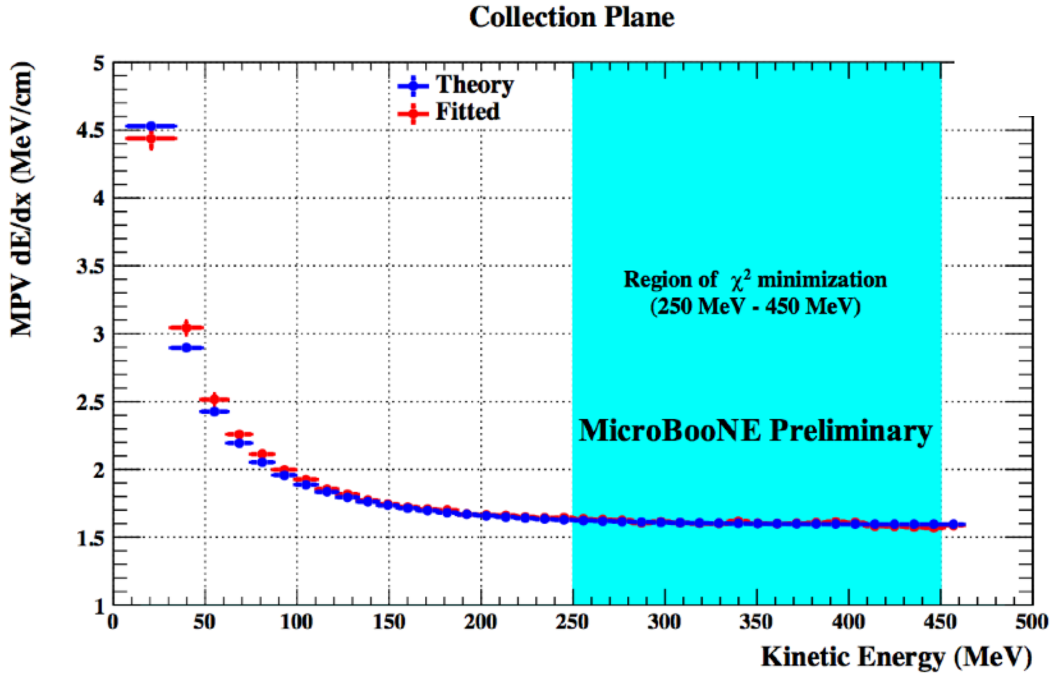
Charge Scale Calibration



- Use a combination of cosmic and neutrino induced muons to calibrate dQ/dx and dE/dx.
- Gross correction of position dependent detector response.
- Performed on collection plane only.

See MicroBooNE Public Note 1038

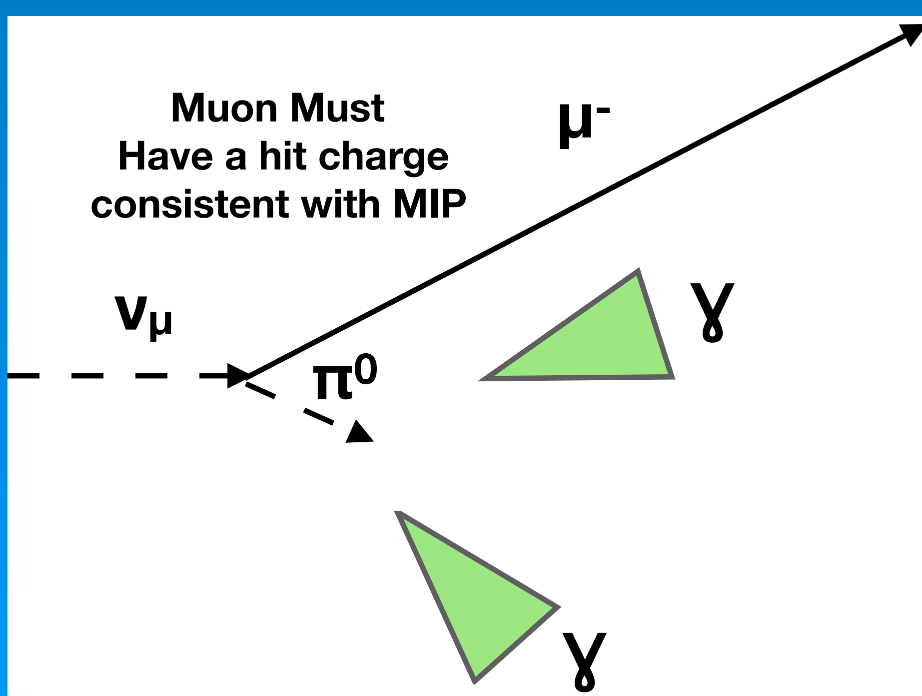


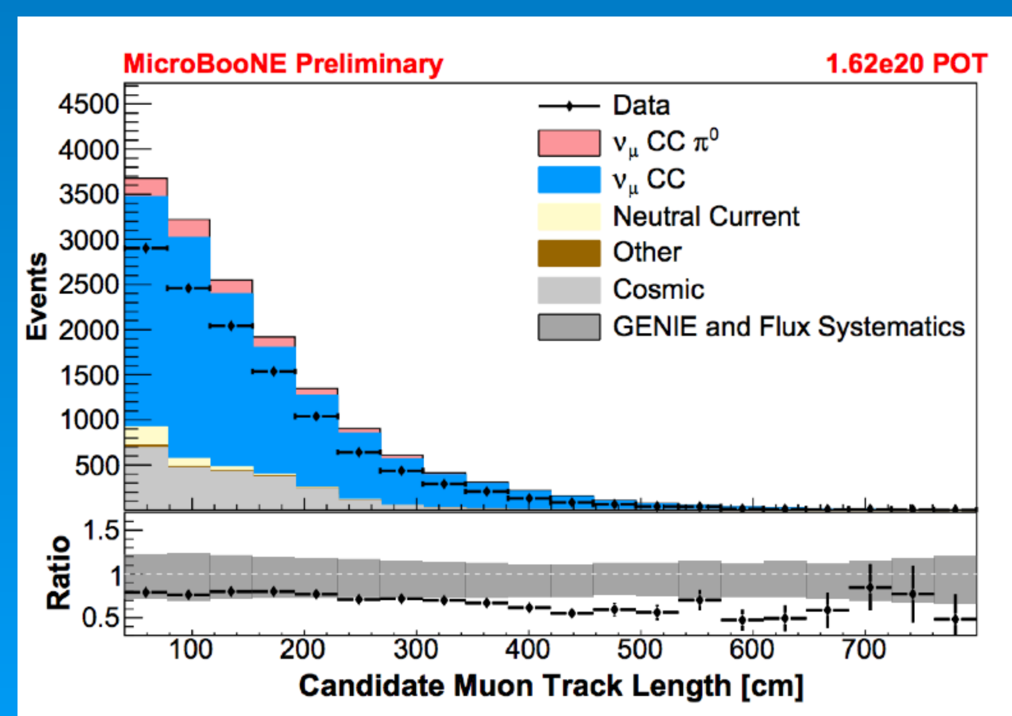


Event Selection

- Combination of geometric, PMT and containment cuts to eliminate hits of non-neutrino origin.

Trigger → **Trigger, Tracking Reco.** → **Cosmic Rejection** → **Shower Reco** → **At Least 1 Shower Sample** / **At Least 2 Shower Sample**





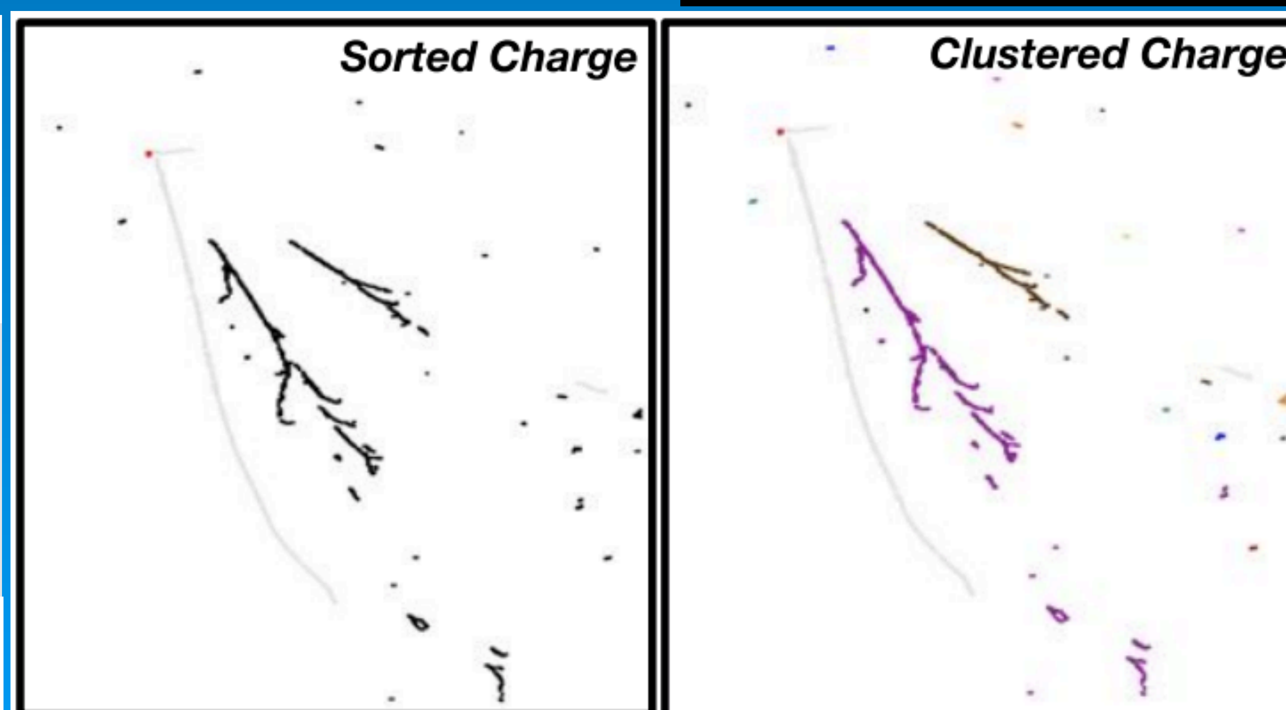
Event Selection

- Hit clusters sorted into "track like" and "shower like."
- Hit clusters must point back to neutrino vertex.
- OpenCV Image recognition.

Trigger → Tracking Reco. → Cosmic Rejection → Shower Reco → At Least 1 Shower Sample / At Least 2 Shower Sample

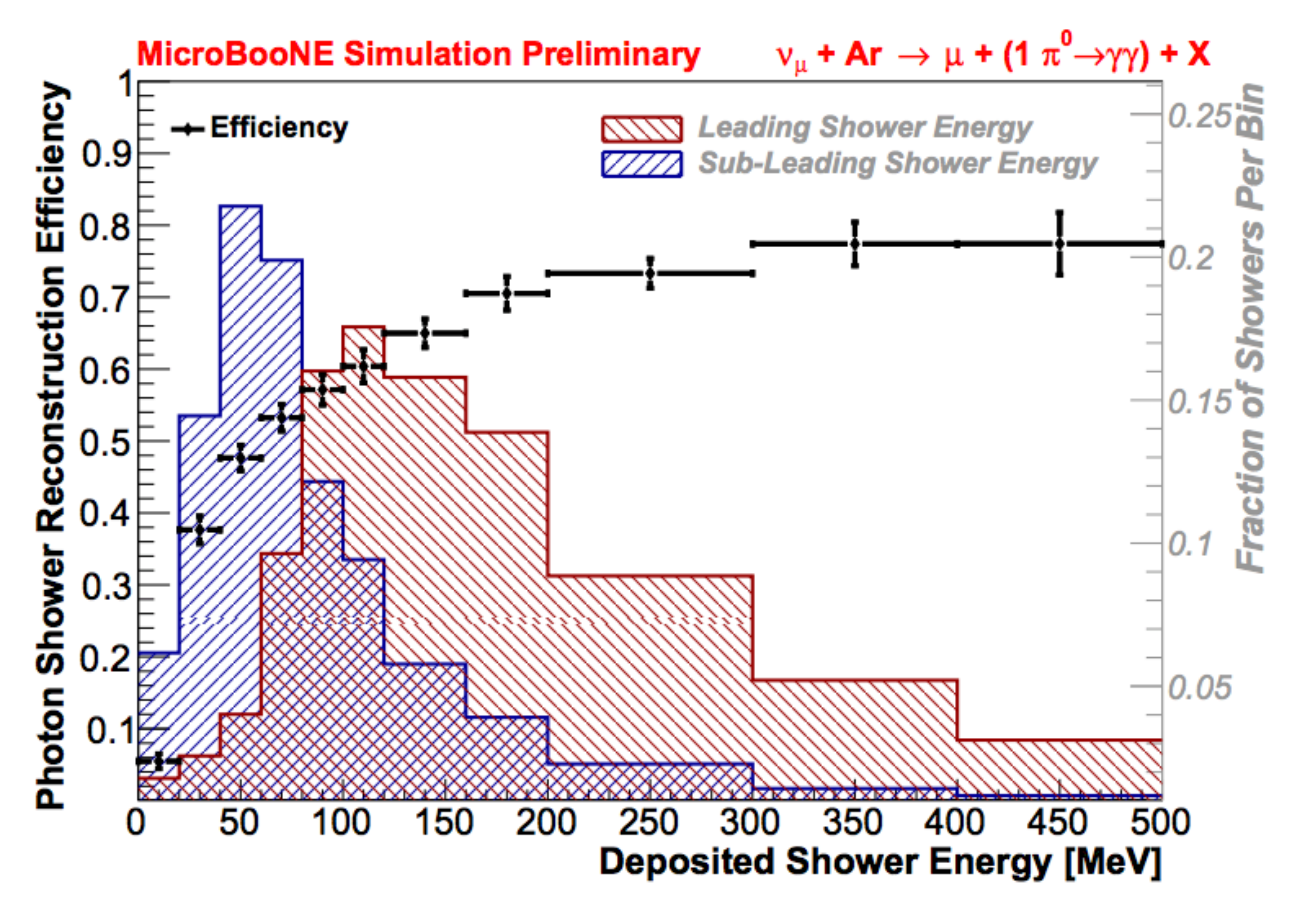
Shower Purity	Shower Completeness
92% (avg.)	63% (avg.)

Conservative clustering to avoid energy from cosmics



D. Caratelli, Columbia U., Ph.D. Thesis

Shower Reconstruction



- Threshold for distinguishing track / shower hits about 50 MeV.
- Consequence of high purity, and track-nature of low energy showers.
- Results in a lower efficiency of reconstructing low-energy showers, but high purity.

Event Selection

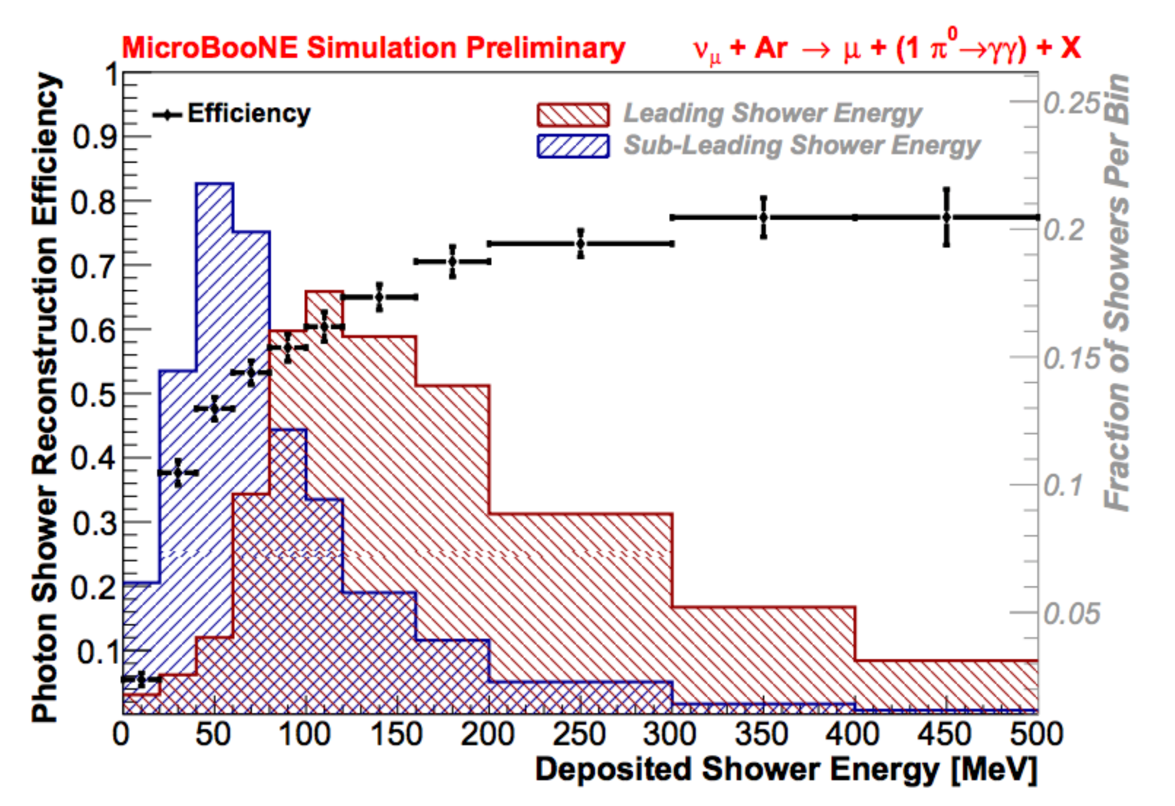
Trigger → Tracking Reco. → Cosmic Rejection → Shower Reco

- Given low efficiency of second shower, we split the analysis into a *single* shower and *two* shower selection.

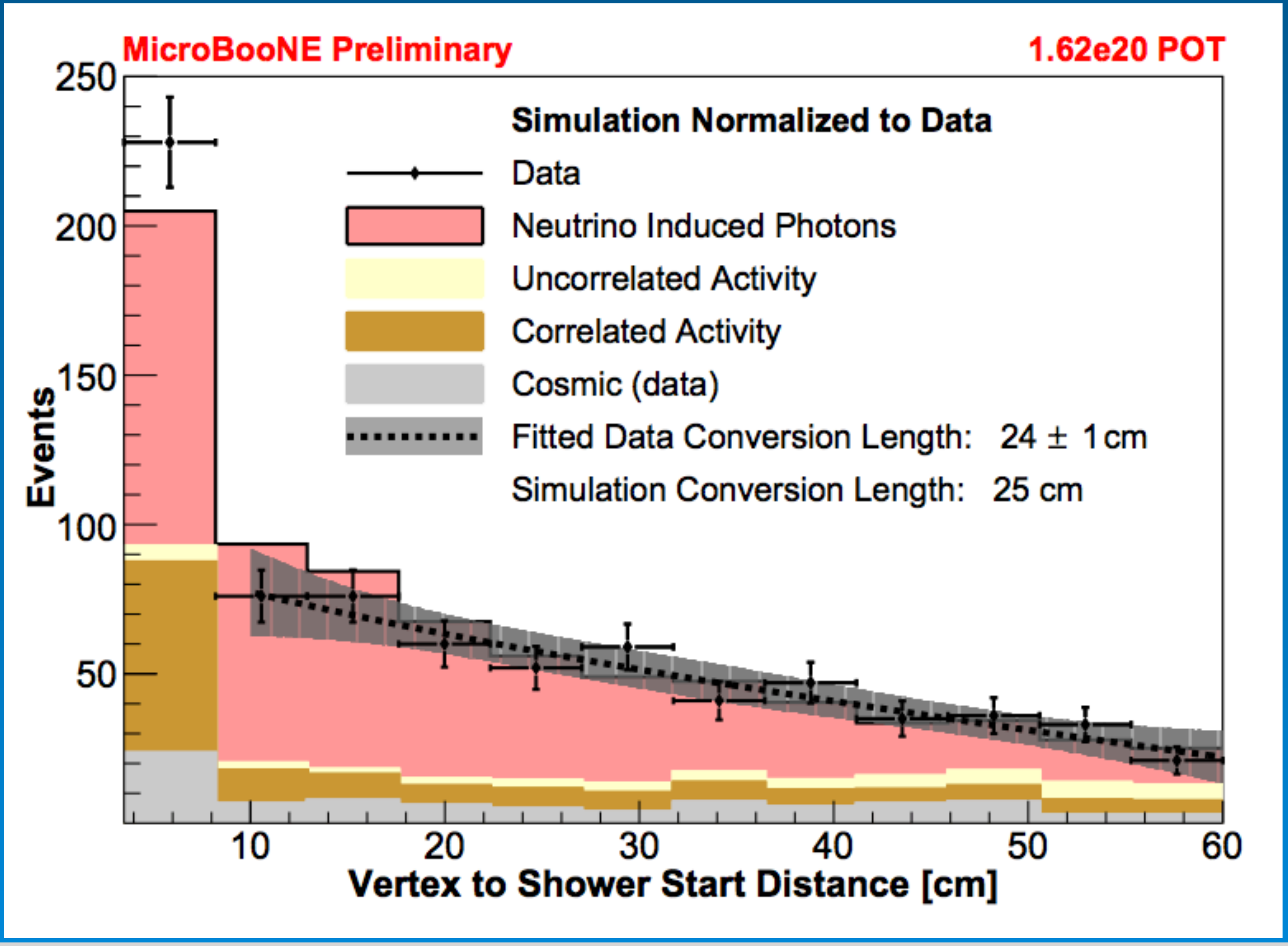
At Least 1 Shower Sample

At Least 2 Shower Sample

- At least 1 shower is higher efficiency.
- At least 2 shower used as cross check.

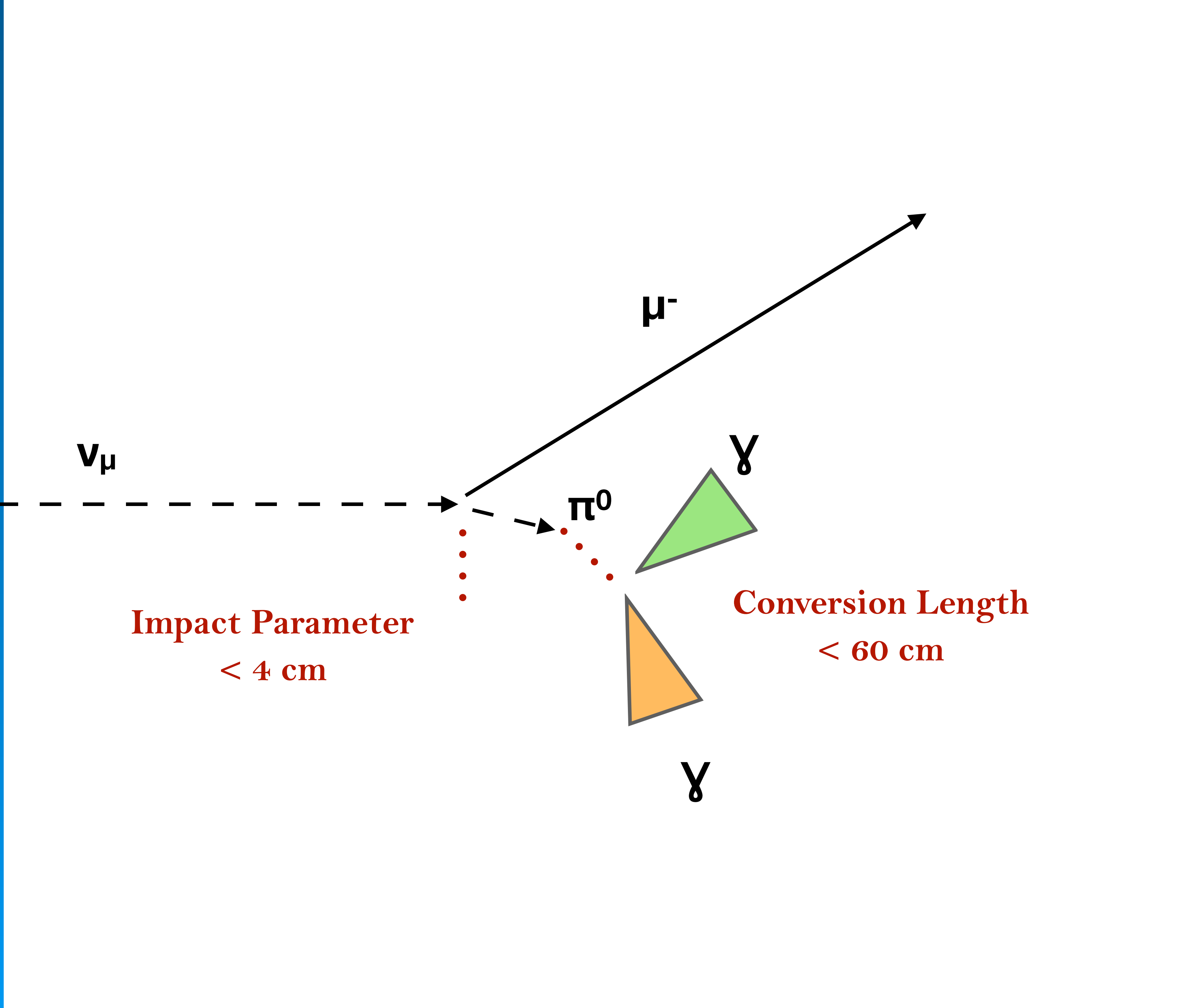


Single Shower Selection



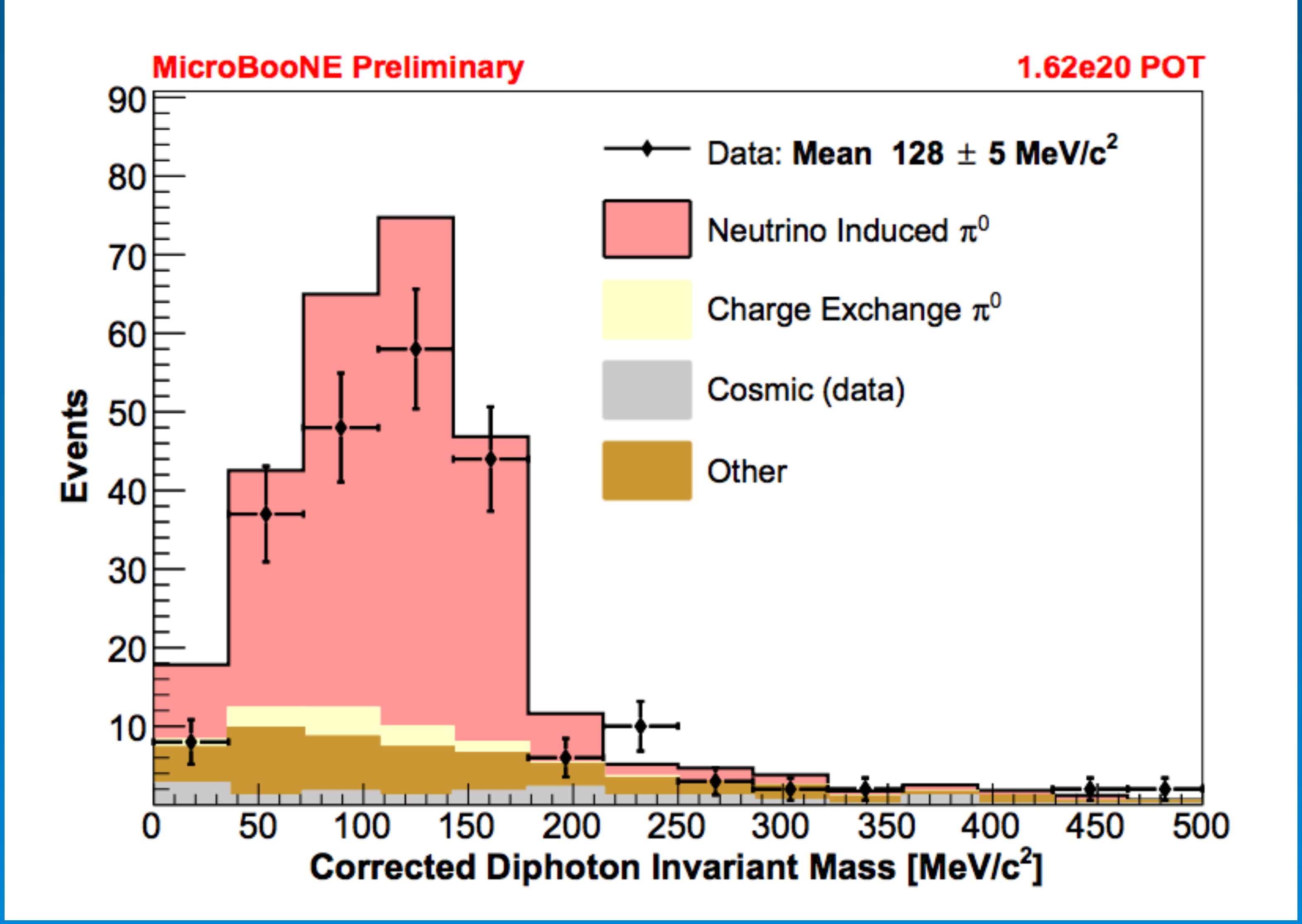
- Measure conversion length of single photon to ensure it is a photon.
- Exclude first bin (large number of non-photons).
- Measured conversion length agrees with Simulation.
- Single shower Efficiency (Purity) 17% (53%).

Single Shower Selection



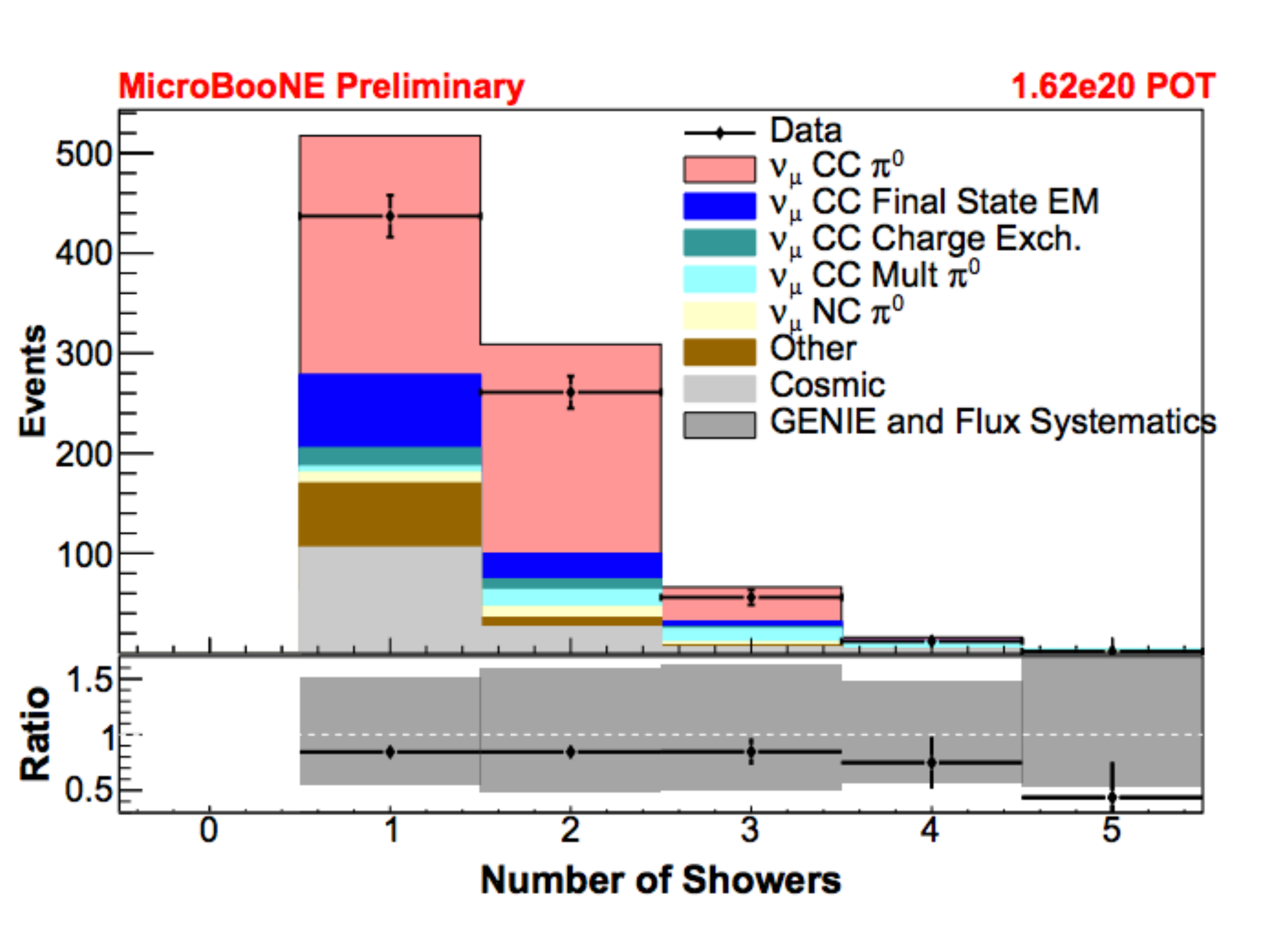
- Final set of selection cuts removes cosmic background
- If two showers in the event, the higher energy shower is selected.
- Overlap exists between 1 and 2 shower samples.
- Each cut ~85% efficient.

Two Shower Selection



- Using two showers with similar cuts correct for missing energy from clustering and hit-thresholding using MC.
- Plot diphoton invariant mass, confirm π^0 mass in data and MC.
- Two shower efficiency (purity): 6% (64%).

Single Shower Backgrounds



- Remaining backgrounds are cosmic, and other resonant events contributing to the single π^0 production.
- Estimate these backgrounds directly from GENIE (45% of events).

Systematic Uncertainties

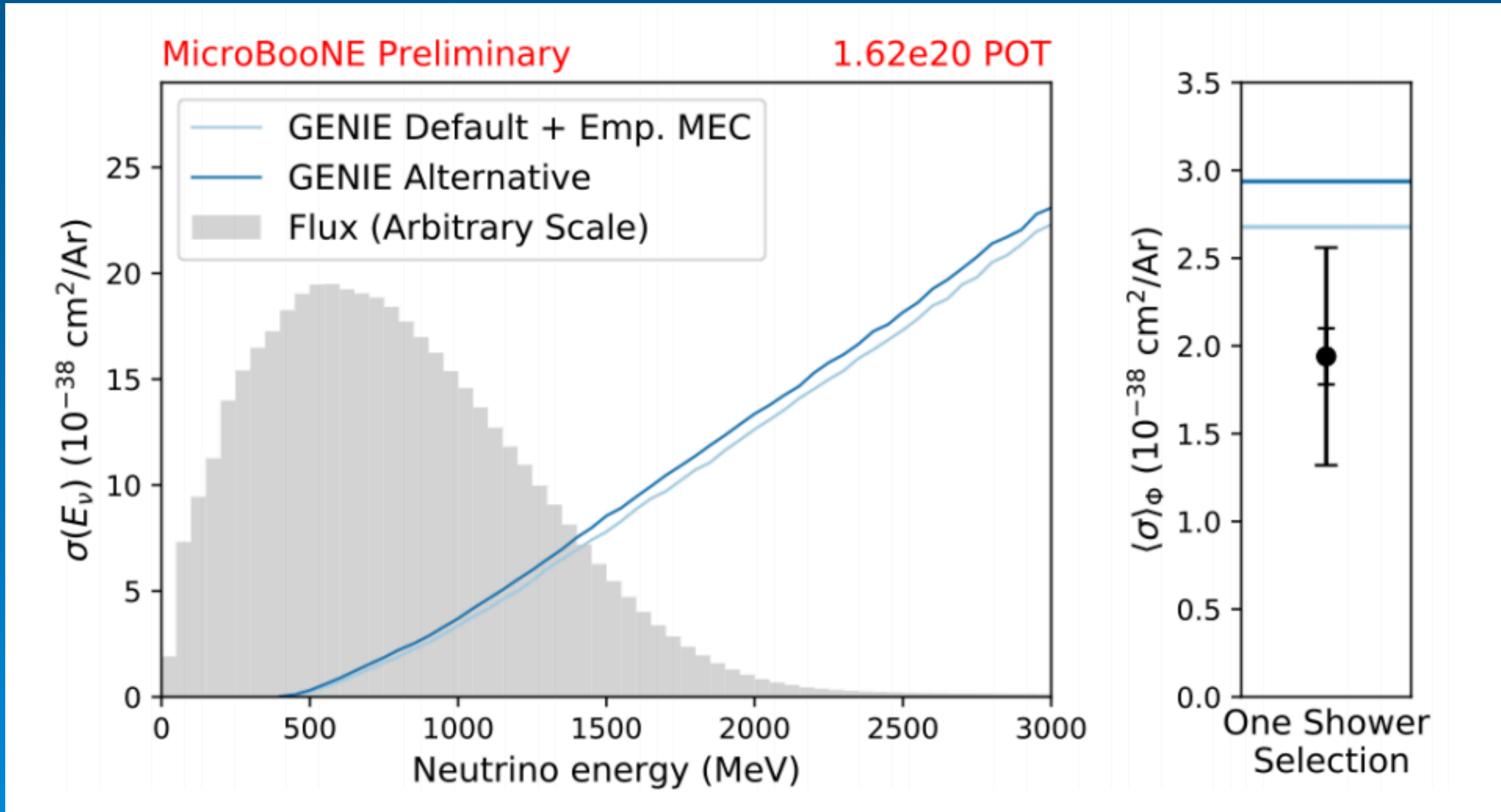
Type	% Error	Affected Measurement
Flux	16%	Flux division, Background Estimation
Cross-Section	17%	Background Estimation Efficiency Correction
Detector Modeling	21%	Background Estimation Efficiency Correction
TOTAL	31%	

Systematic Uncertainties

Type	% Error	Affected Measurement
Detector Modeling	21%	Background Estimation Efficiency Correction

- Major sources of detector modeling uncertainty:
  - Induced charge on neighboring wires.
  - Diffusion of charge as it propagates along the drift direction.
  - Modeling of scintillation light.
- Improvements will come from:
  - Newer MicroBooNE simulation and calibration.
  - Improved shower reco. to detect lower energy showers lead to higher efficiency.

Results (At Least 1 Shower)

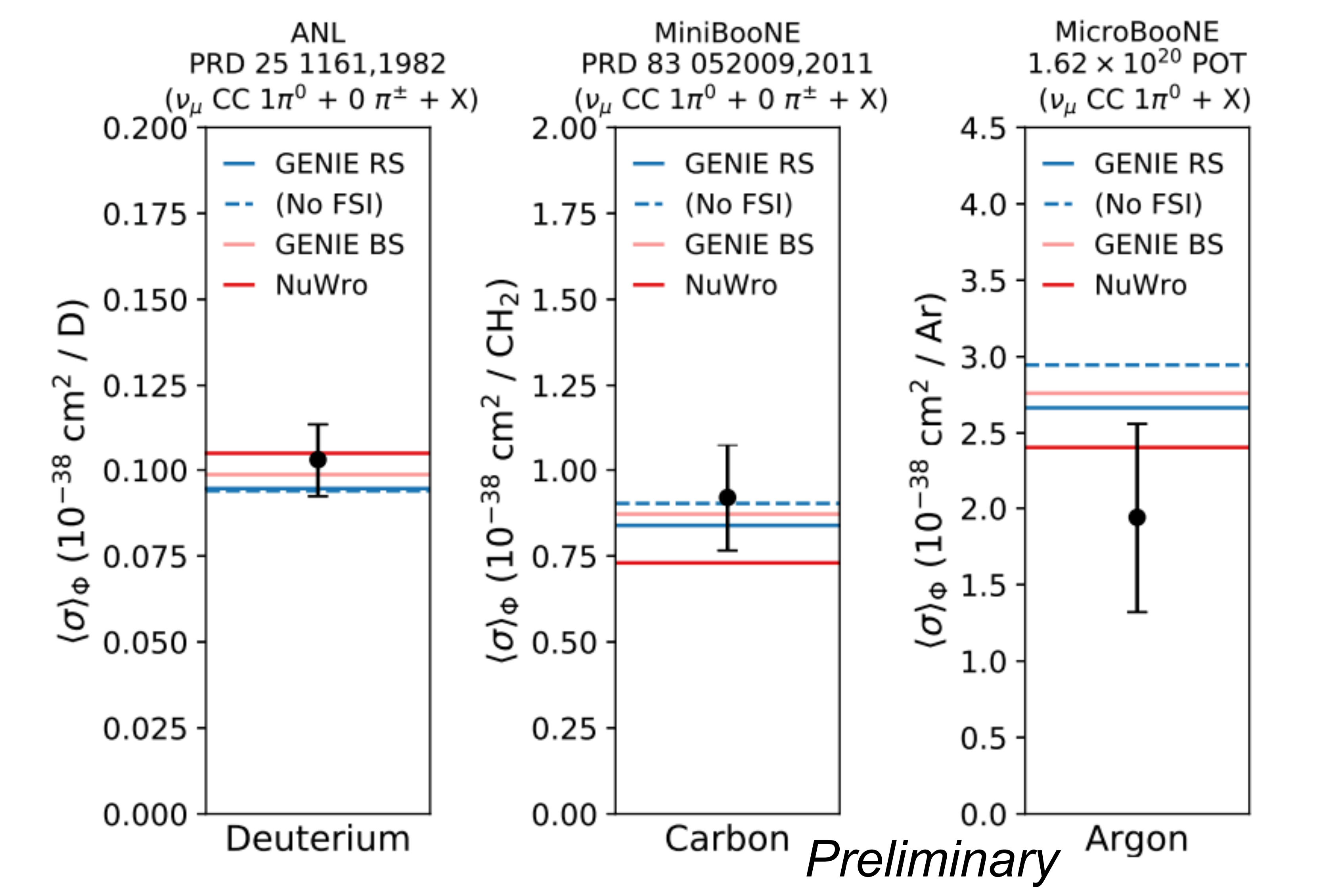


Genie Alternative Uses BS and hA 2014

$$\left\langle \sigma^{\nu_\mu \mathbf{CC}\pi^0} \right\rangle_\Phi = (1.94 \pm 0.16\ [\text{stat.}] \pm 0.60\ [\text{syst.}]) \times 10^{-38}\ \frac{\text{cm}^2}{\text{Ar}}$$

- First ever measurement on Ar.

Results



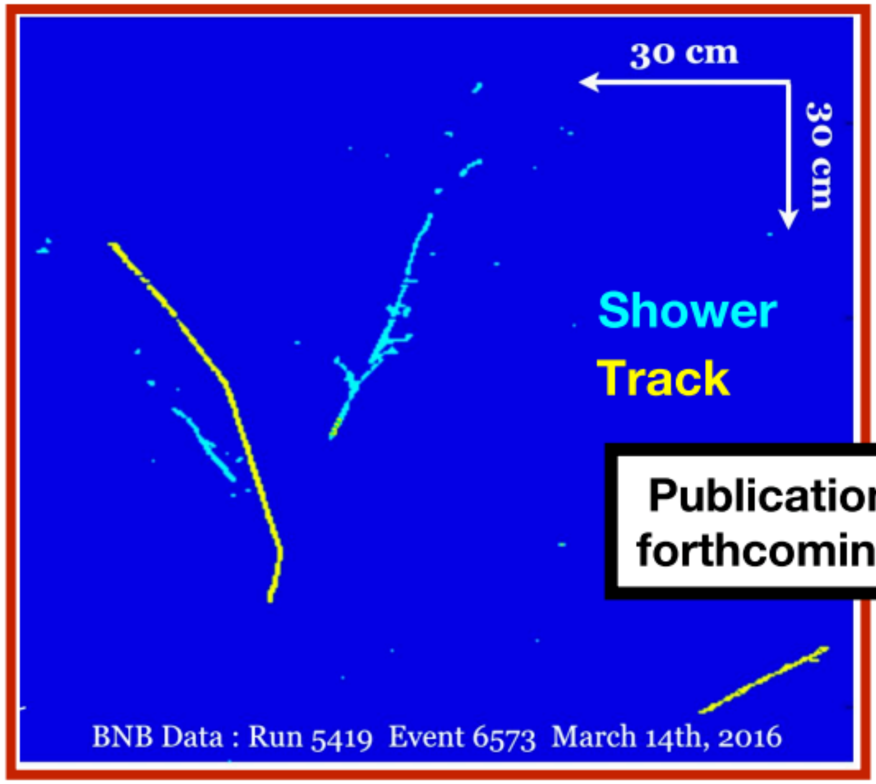
- Compare our result on Argon, to ANL and MiniBooNE results on C and D.
- Starting to probe differences between how different models predict *A* scaling.
- Currently, lack sensitivity to differences in FSI modeling.

Future Measurements

- Large investment in improving MicroBooNE's detector simulation and reconstruction.
- New image recognition, machine learning techniques promise better shower reconstruction, ability to detect lower energy showers

- Much more data in further MicroBooNE runs (x8 more).
- *Enables a differential measurement of π^0 in π^0 and μ^- variables.*

Image Classification Techniques



Conclusions

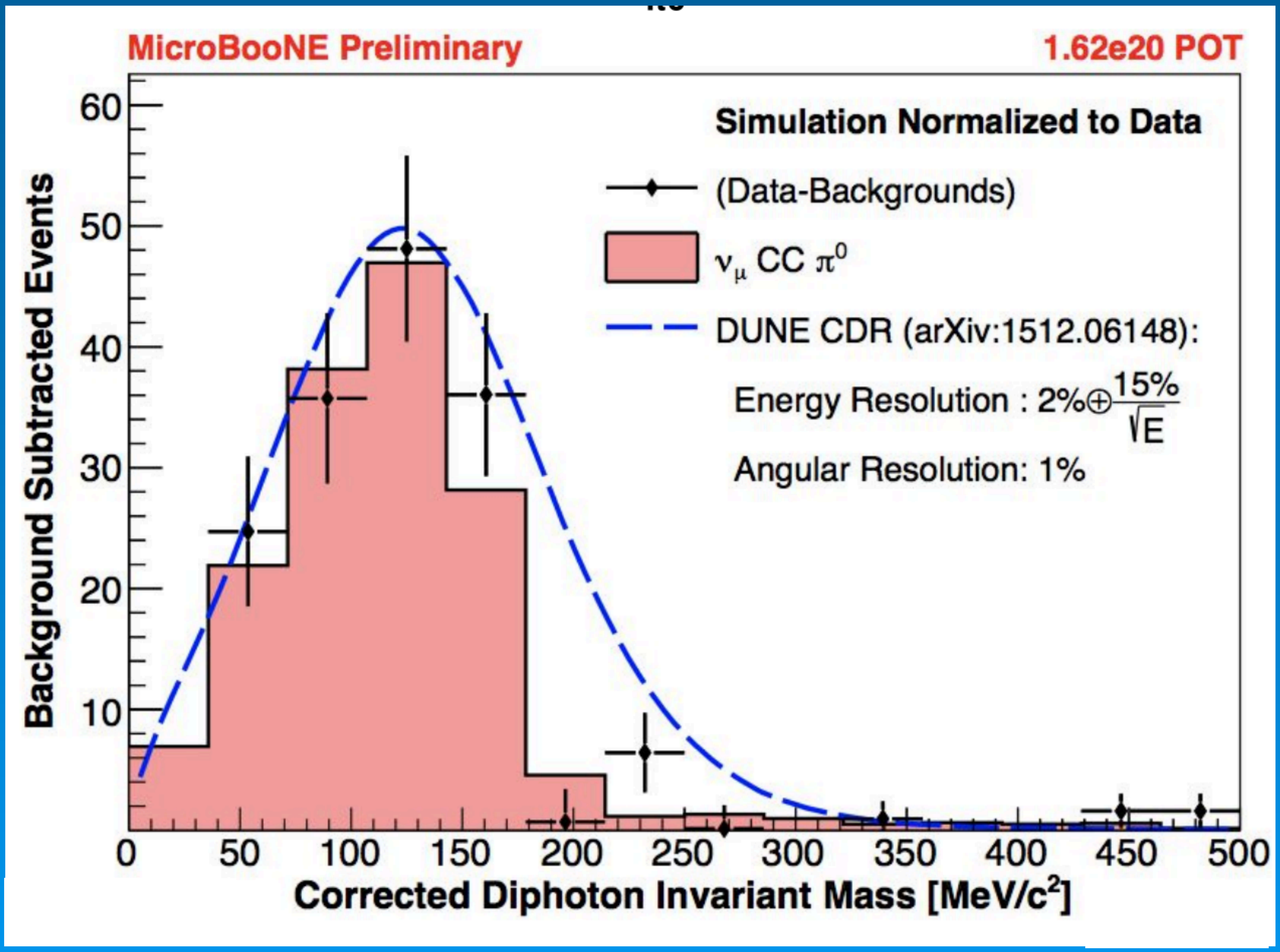
- MicroBooNE has performed a world's first measurement of neutrino induced π^0 production on argon.
- Measured with both single and two photon sub-samples.
  - Both measurements consistent.
  - Select single photon as primary result due to larger efficiency.
- Currently see reasonable agreement with GENIE's A scaling.
- Sensitivity limited by detector model and reconstruction.
  - Improving detector model, including signal modeling.
  - Improving reconstruction, including the ability to detect low energy showers.

Thank you for Your Attention!

All MicroBooNE Public Notes
Available Here:
http://microboone.fnal.gov/public-notes/

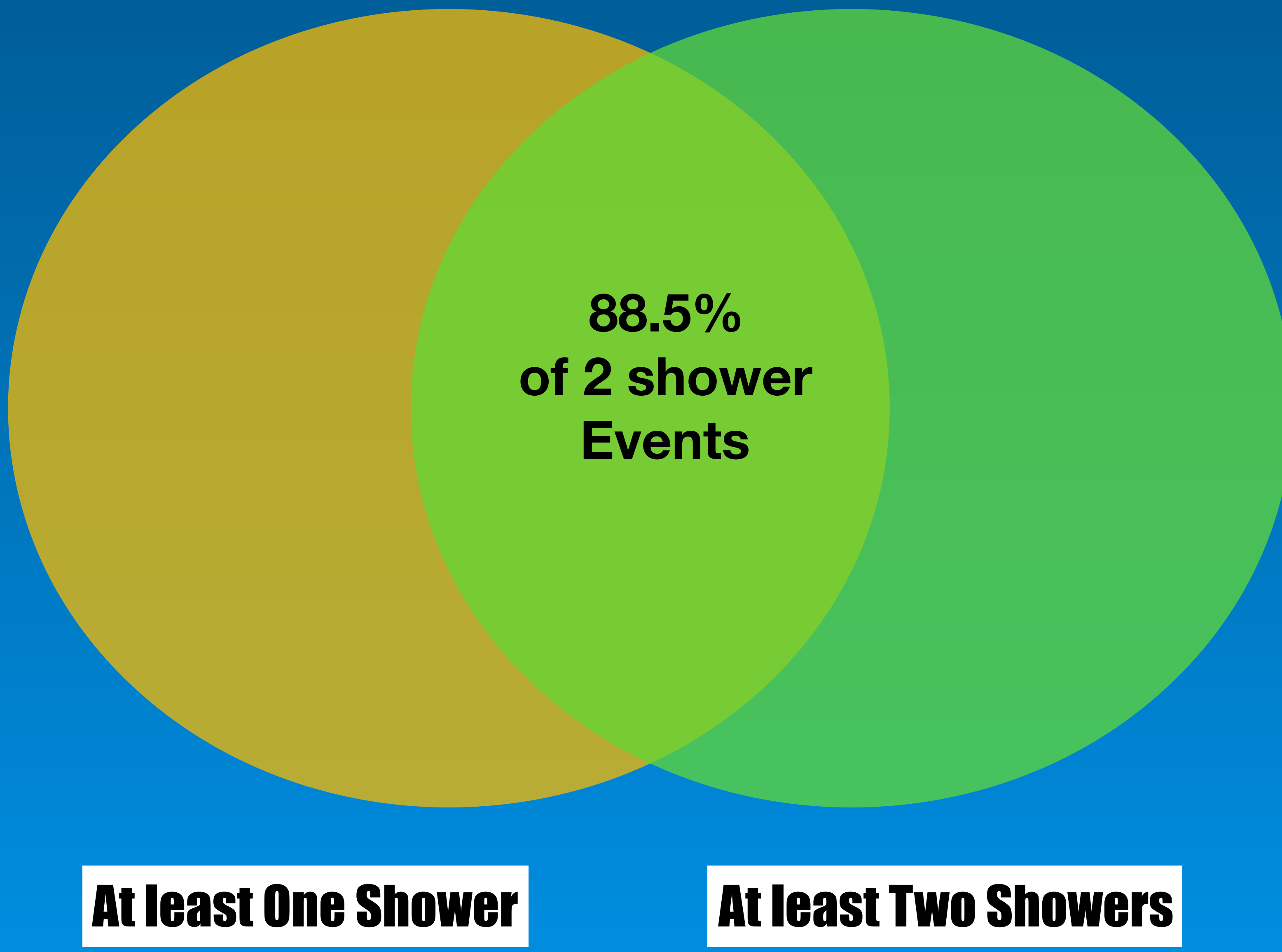
Backup Slides

Energy Correction and Mass Peak



- Corrections applied:
  - Add energy from hits below threshold.
  - Add energy from clusters mis-id as track or cosmic.
- Both corrections derived from MC.
- Do *not* correct for un-contained clusters.

One and Two Shower Comparison



- At least one shower: 1.94 ± 0.16 (stat.) X 10^{-38} cm^2 / Ar
- At least two showers: 1.91 ± 0.24 (stat.) X 10^{-38} cm^2 / Ar