Experience from ArgoNeuT

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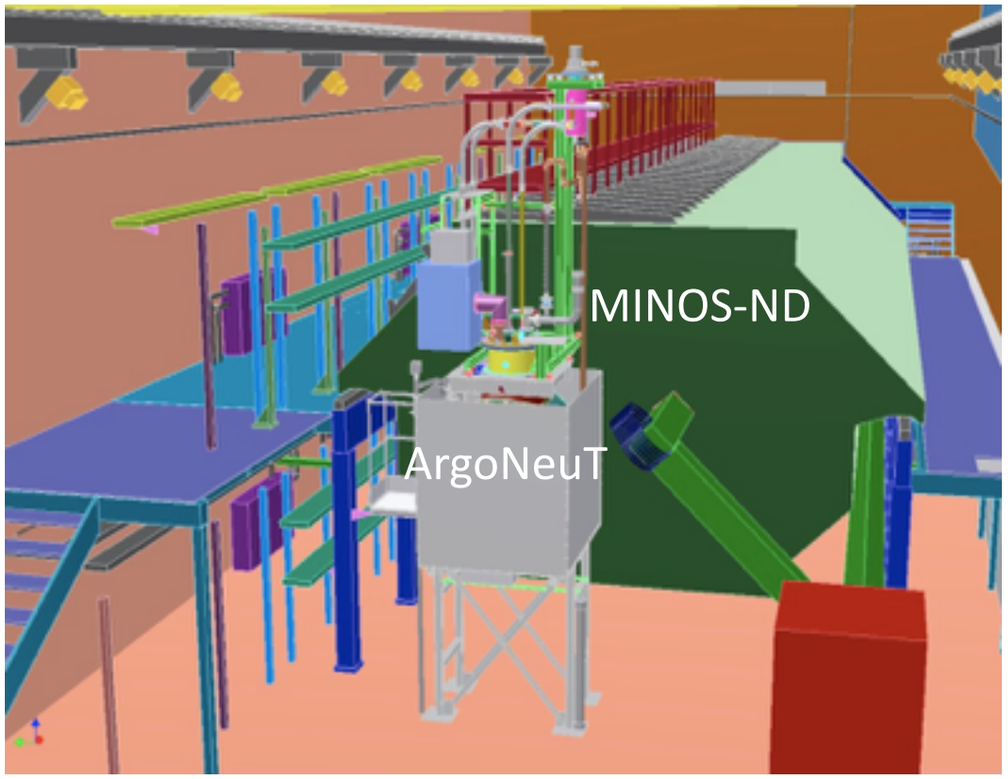
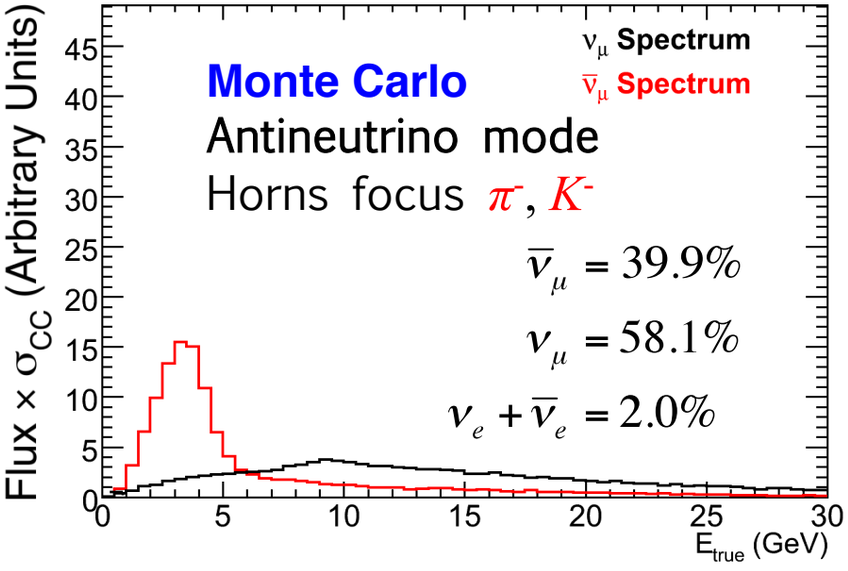
Oct 19, 2015

LArTPC Reconstruction Assessment and Requirements Workshops

ArgoNeuT - Argon Neutrino TesT

- First TPC in a neutrino beam in the US
- Sitting in NuMI beam
- Located in front of MINOS near detector
- 47×40×90 cm³ (170 L), wire spacing 4 mm
- 2 planes with 480 wires
- Data taking: 9/14/2009 - 2/22/2010
  - 2 weeks in neutrino mode
  - 5 months in anti-neutrino mode





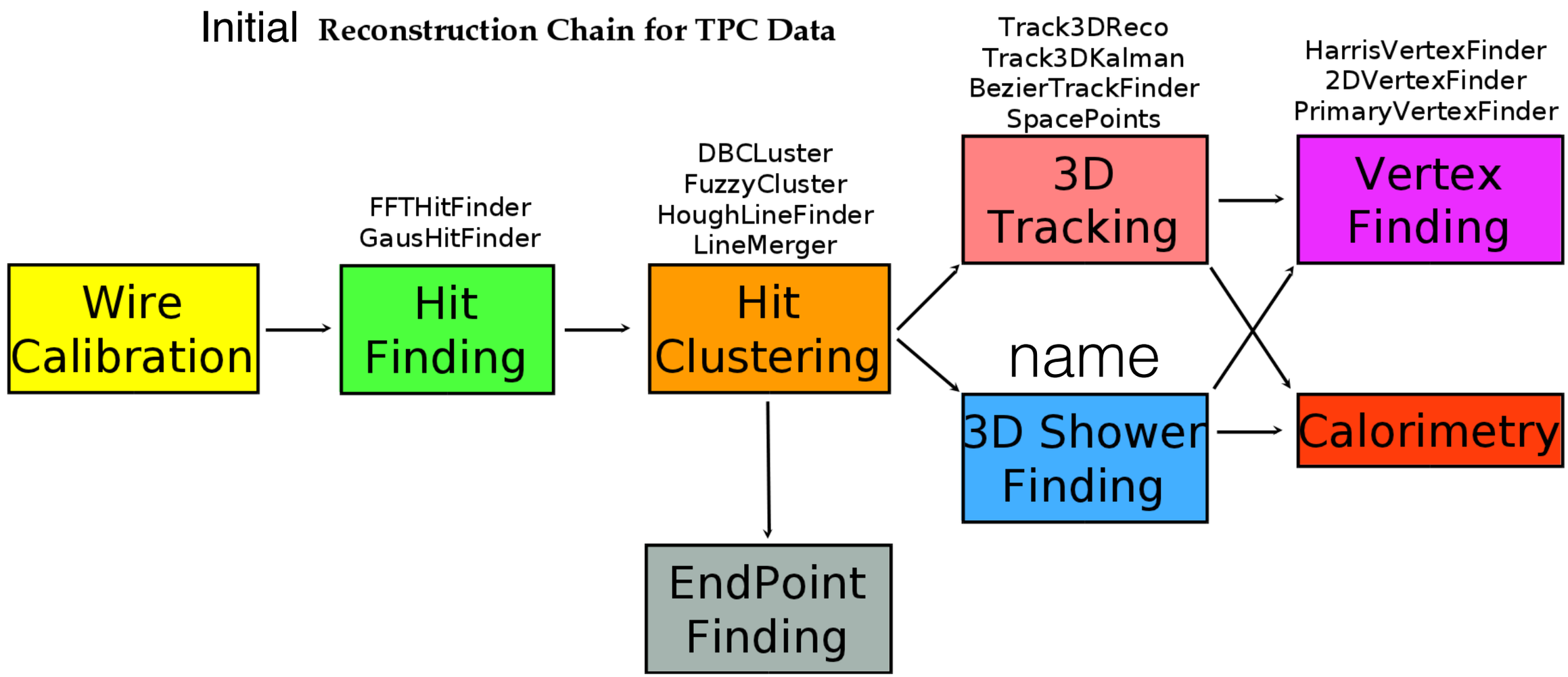
ArgoNeuT and LArSoft

- ArgoNeuT was the first user of LArSoft after Brian Rebel et al. started this project.
- Pioneered in development and validation of simulation and reconstruction tools.
- Physics analyses done using LArSoft.

Simulation

- GENIE generator (GENIEHelper in nutools).
- GEANT simulation, recombination, attenuation, diffusion.
- Electronics simulation.
- No photon simulation.

Reconstruction



Signal Processing

Bruce Baller
Brian Page, Carl Bromberg

Convolution & De-convolution

Convolution

ADC = Shaper Out = Signal ⊗ Preamp ⊗ Shaper

Complex Multiplication

Fourier Transform

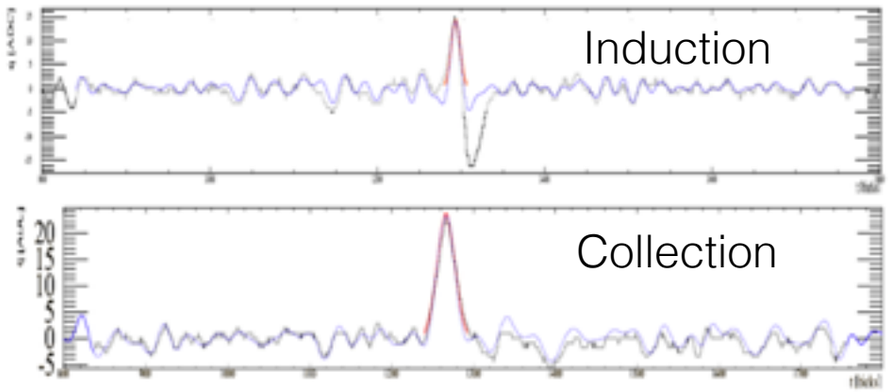
ADC = $\mathcal{F}^{-1}$ { ($\mathcal{F}$(Signal) * $\mathcal{F}$(Preamp) * $\mathcal{F}$(Shaper) }

De-convolution

Signal = $\mathcal{F}^{-1}$ { ($\mathcal{F}$(ADC) / ($\mathcal{F}$(Preamp) * $\mathcal{F}$(Shaper)) }

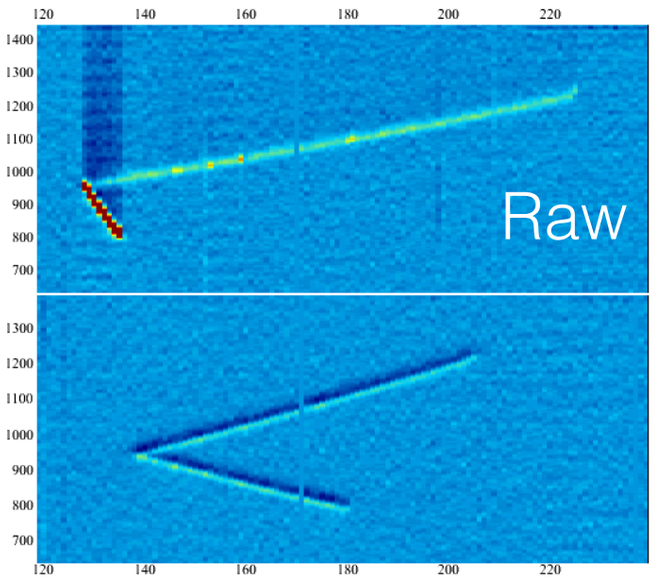
De-convolution & Filter

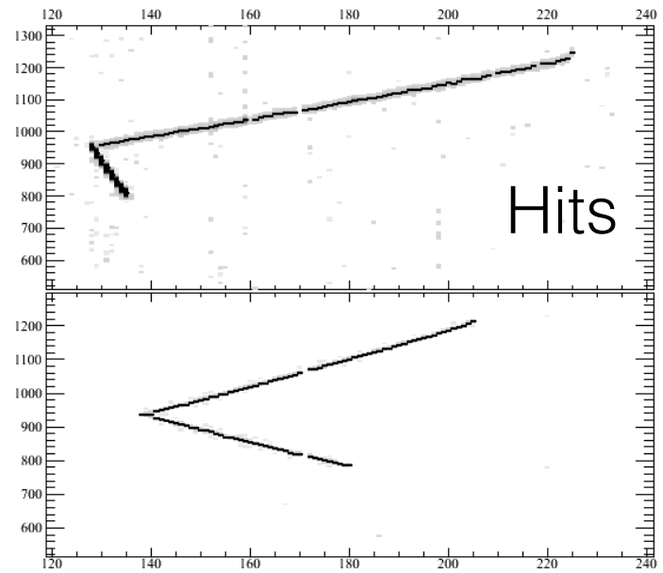
Signal = $\mathcal{F}^{-1}$ { Filter * $\mathcal{F}$(ADC) / ($\mathcal{F}$(Preamp) * $\mathcal{F}$(Shaper)) }

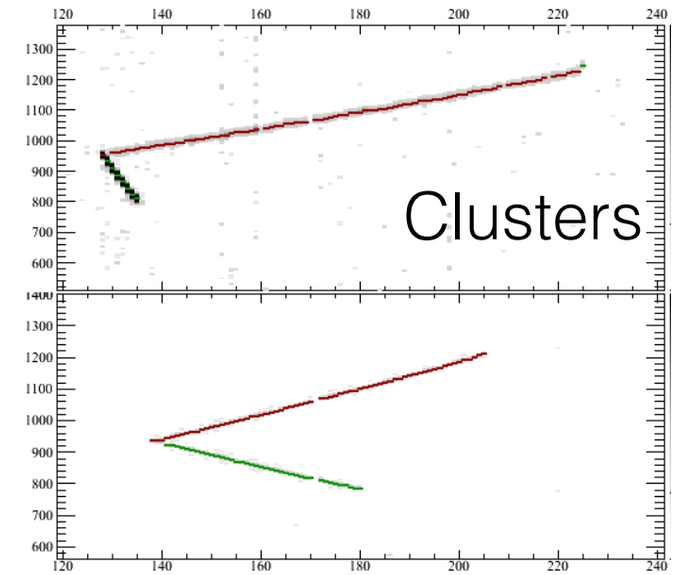


- Using deconvolution to remove effects of electronics and field responses.

Track Reconstruction



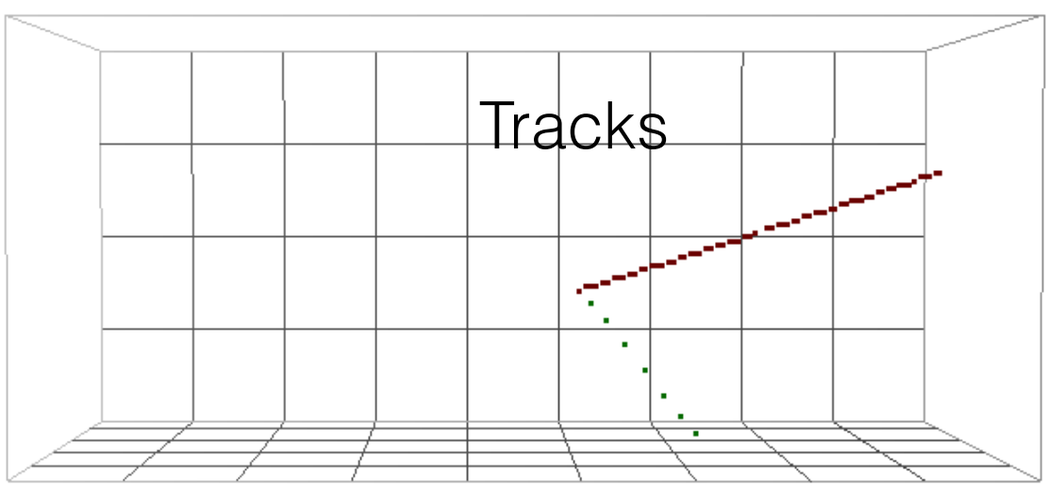




Deconvolution
GausHitFinder

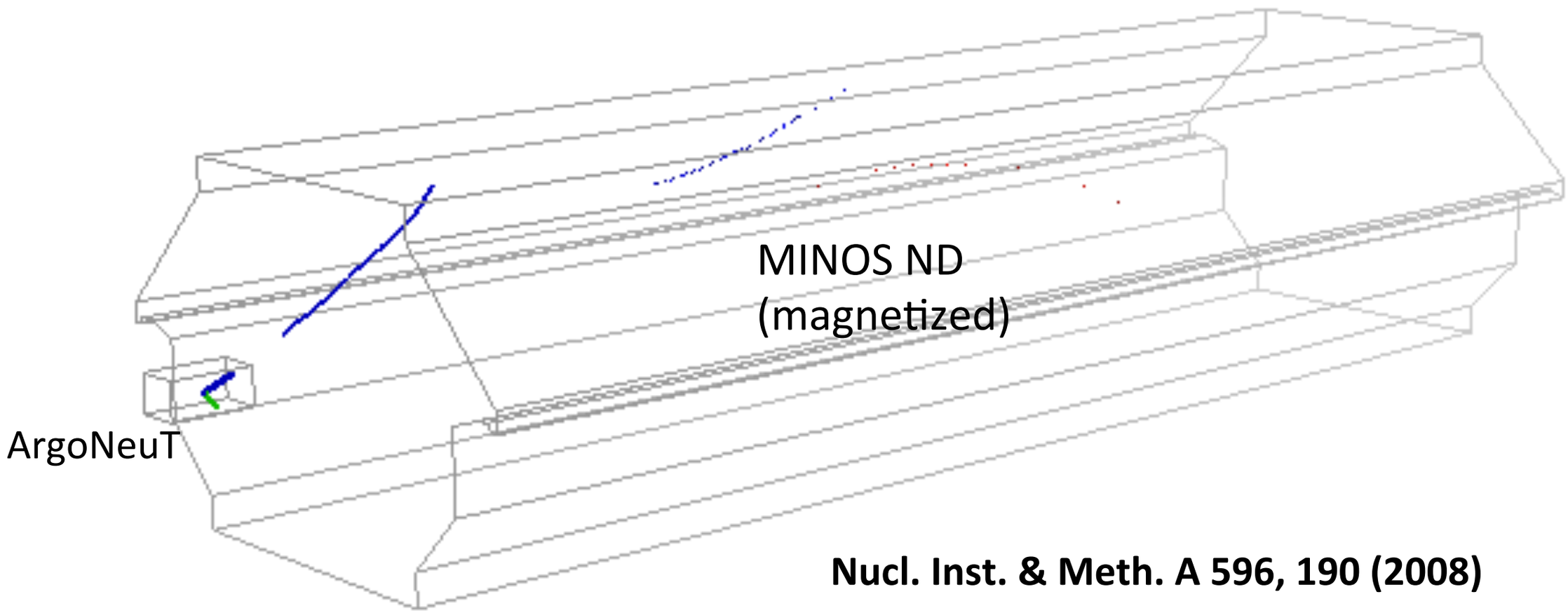
DBCluser/Hough/LineMerger
ClusterCrawler

Track3DReco
CosmicTracker



Traditional method:
2D->3D using time matching

MINOS Track Matching

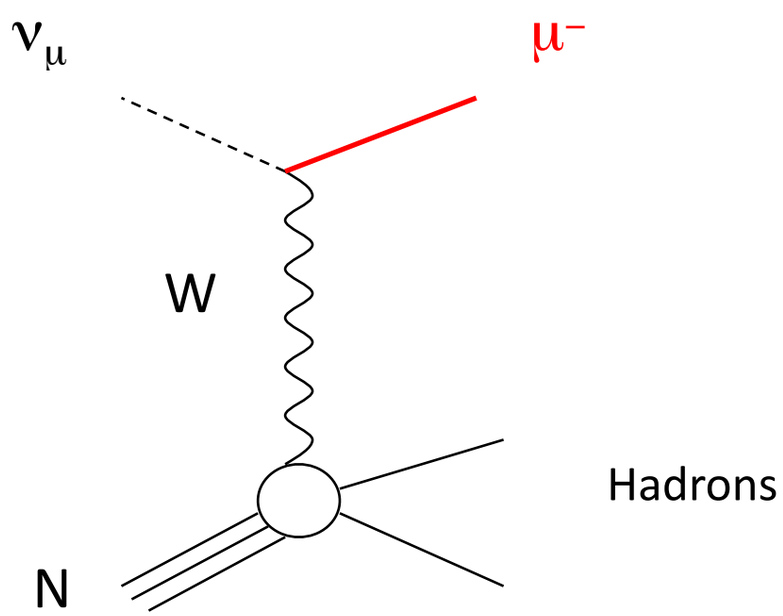


Nucl. Inst. & Meth. A 596, 190 (2008)

- Use MINOS as muon spectrometer to measure muon momentum and charge.
- Wrote algorithm to match ArgoNeuT tracks with MINOS tracks.
- Merge matched MINOS tracks into larsoft files.

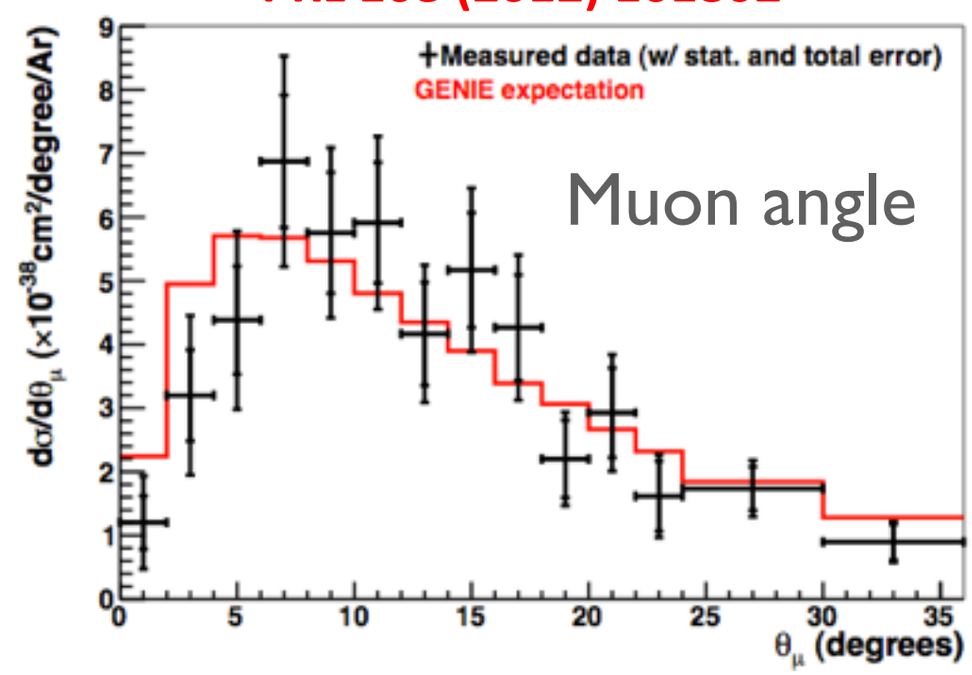
CC-inclusive cross sections (8.5e18 POT)

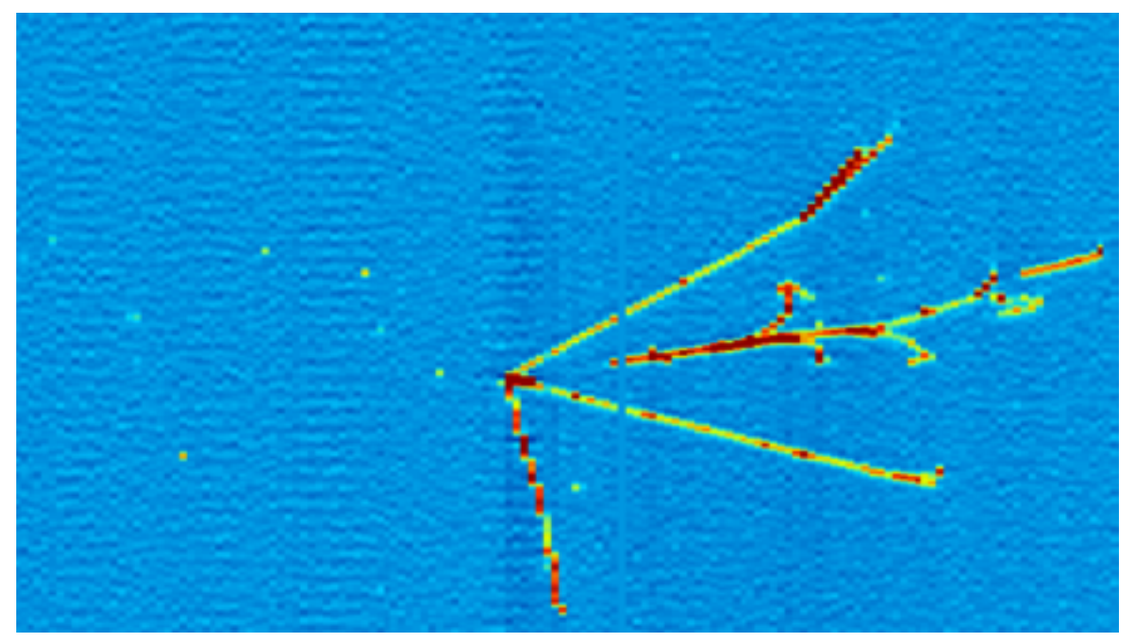
Charged Current (CC)



Neutrino Mode

PRL 108 (2012) 161802

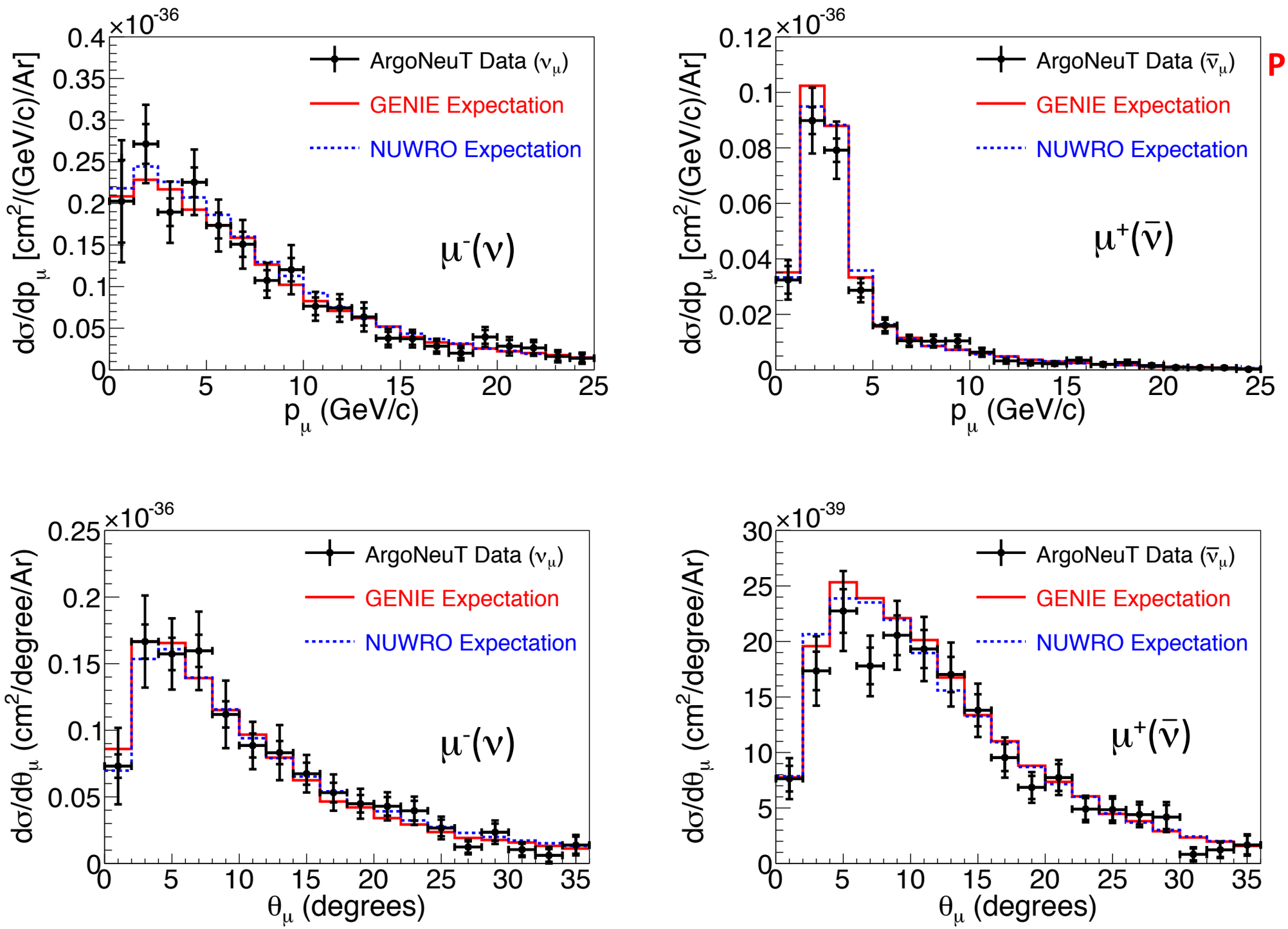




- Interaction vertex in fiducial volume
- Track matched to muon in MINOS
- Negatively charged muon in MINOS
- Fully automated reconstruction

CC-inclusive Cross Sections

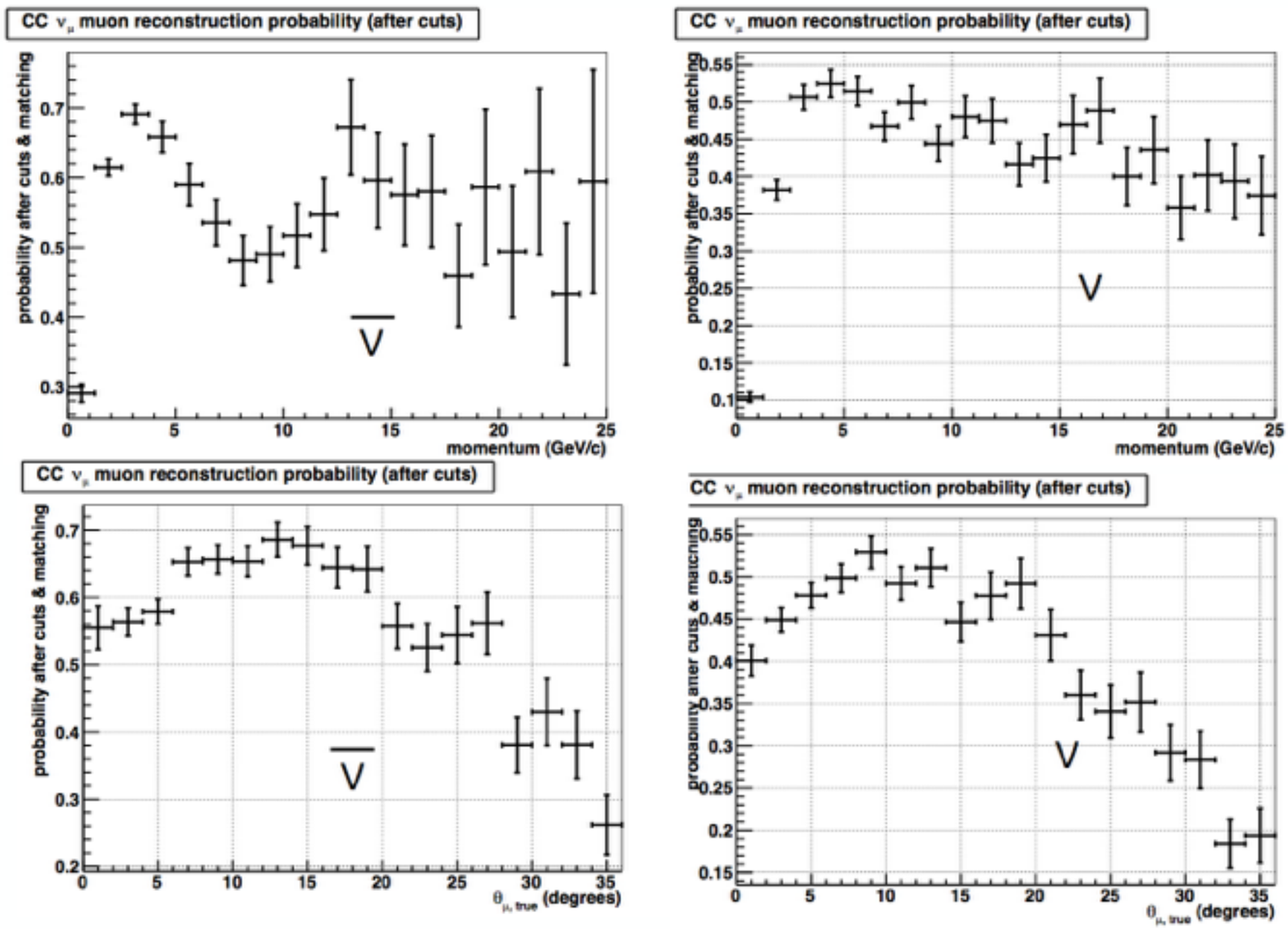
Anti-neutrino Mode



PRD 89 (2014) 112003

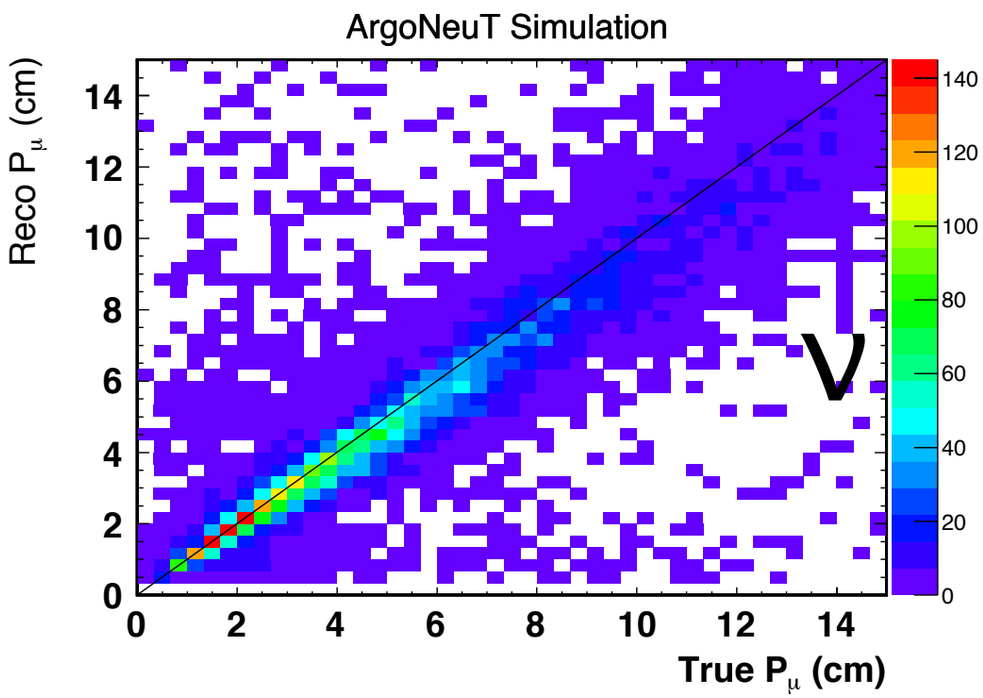
1.2e20 POT

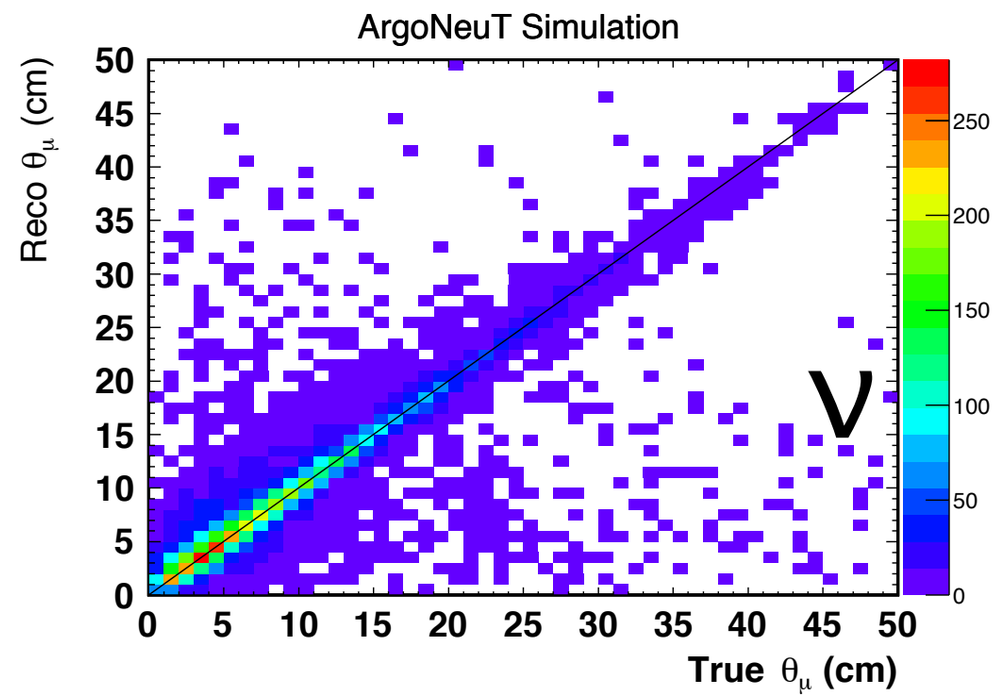
Selection efficiencies

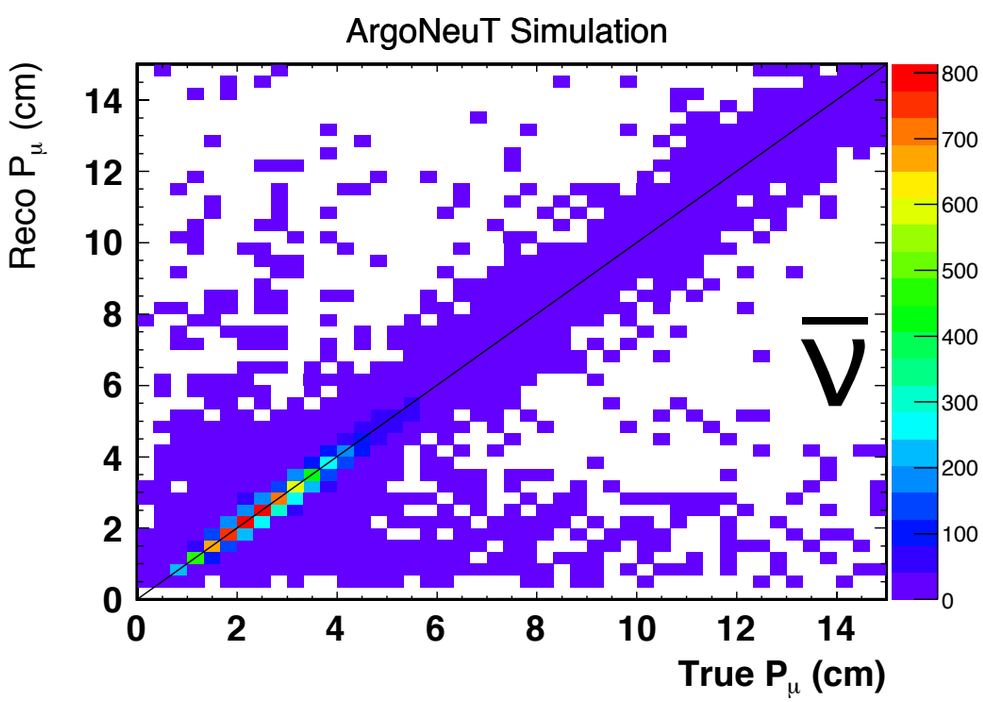


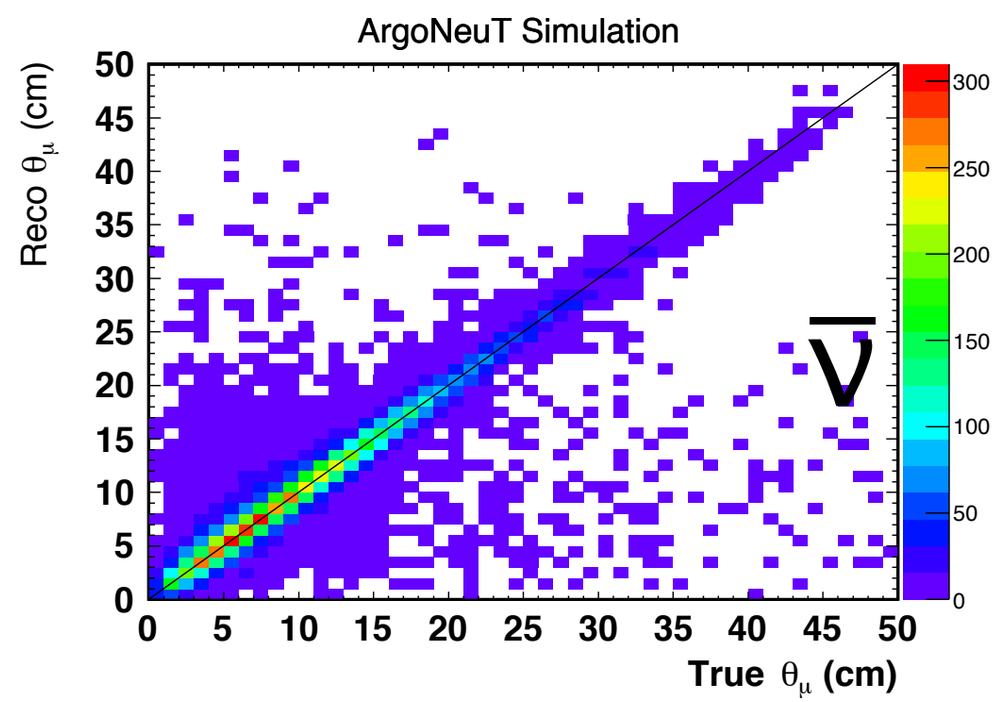
Overall efficiency is 42% (59%) for neutrinos (antineutrinos).

Reconstruction Resolutions









Resolution: 5-10%

Resolution: 1degree

Calorimetry Reconstruction

- LArTPC provides a 3D imaging of charged particle interactions with fine spatial and energy resolution.

- Proton/pion separation through the energy deposition vs range measurements.

  - Understanding the detector calorimetric response.

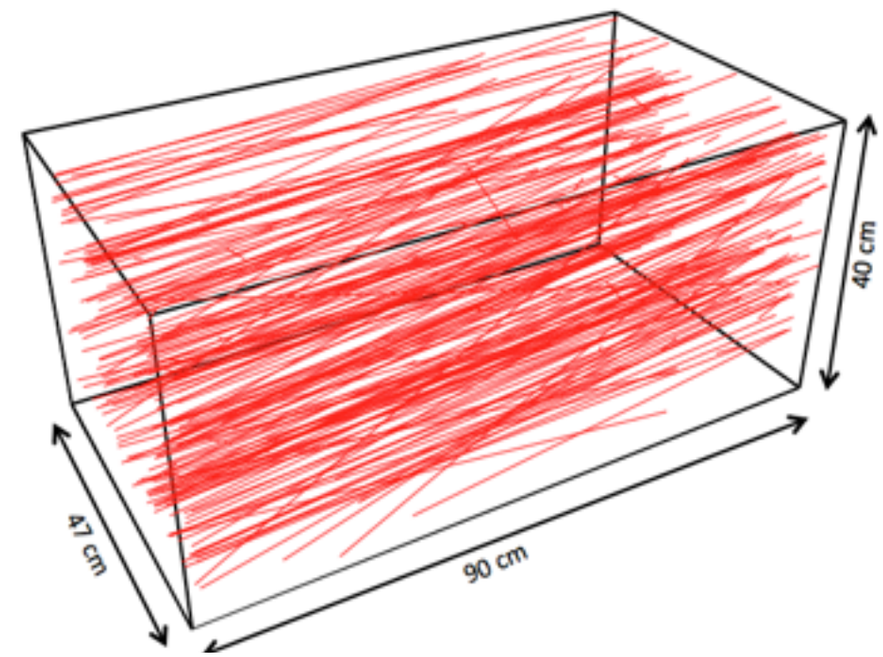
- Ornella Palamara led the effort of calorimetry reconstruction, Bruce Ball, Andrzej Szelc and myself contributed.

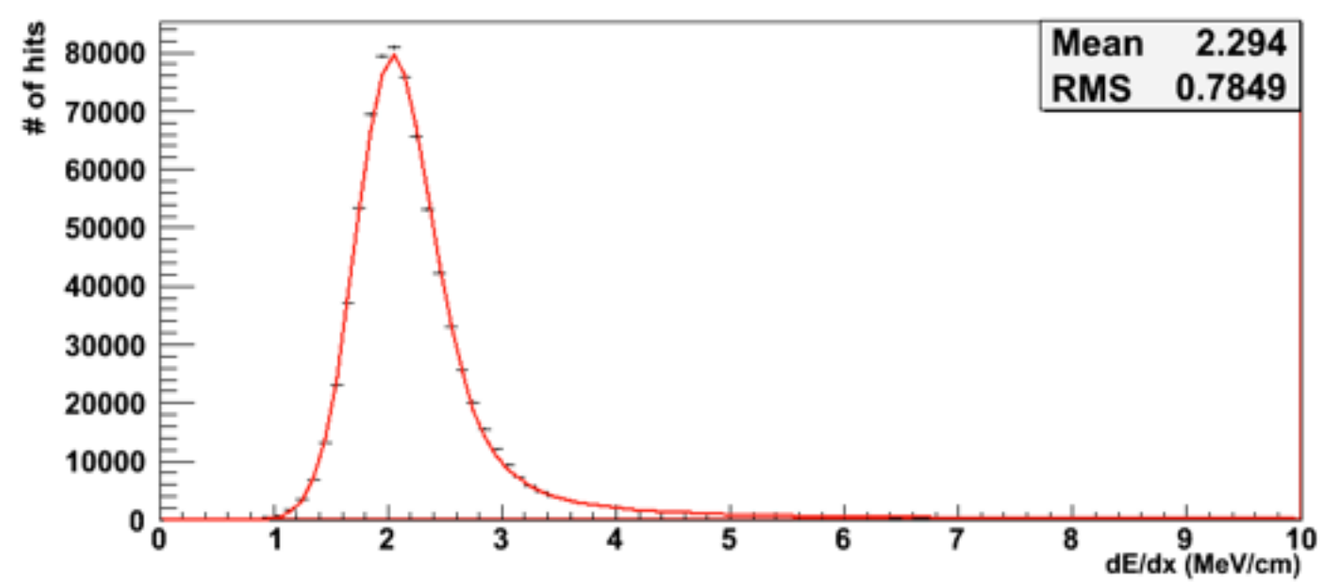
$$\frac{dQ}{dx}(ADC/cm) \rightarrow \frac{dQ_e}{dx}(e/cm) \rightarrow \frac{dQ'_e}{dx}(e/cm) \rightarrow \frac{dE}{dx}(MeV/cm)$$

Electronics calibration | Lifetime correction | Recombination correction

Detector Calibration with Through-going Muons

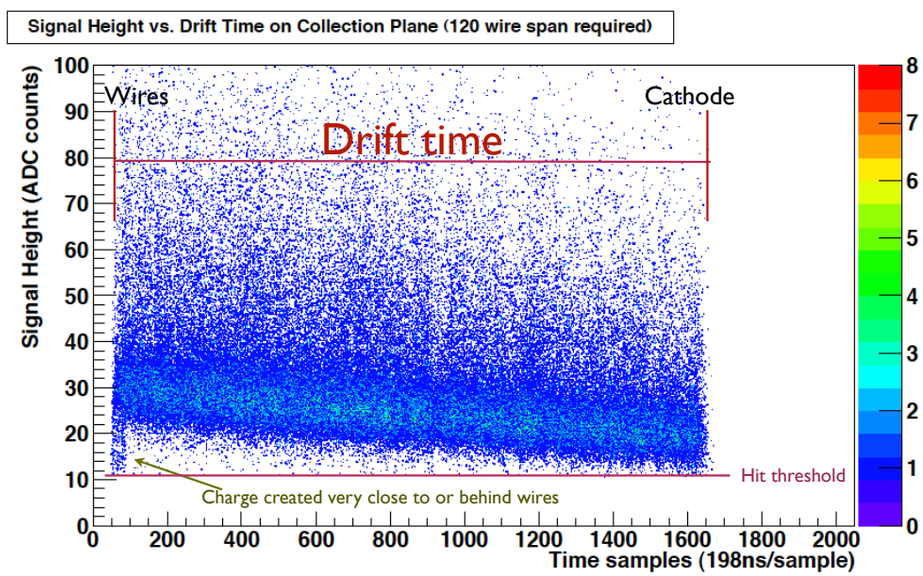
- A large sample of neutrino induced through-going muons are useful for detector calibration
- Test geometric and calorimetric reconstruction in the ArgoNeuT detector
- f_{cal} = 7.6 ADC/fC
- JINST 7 (2012) P10020; arXiv:1205.6702

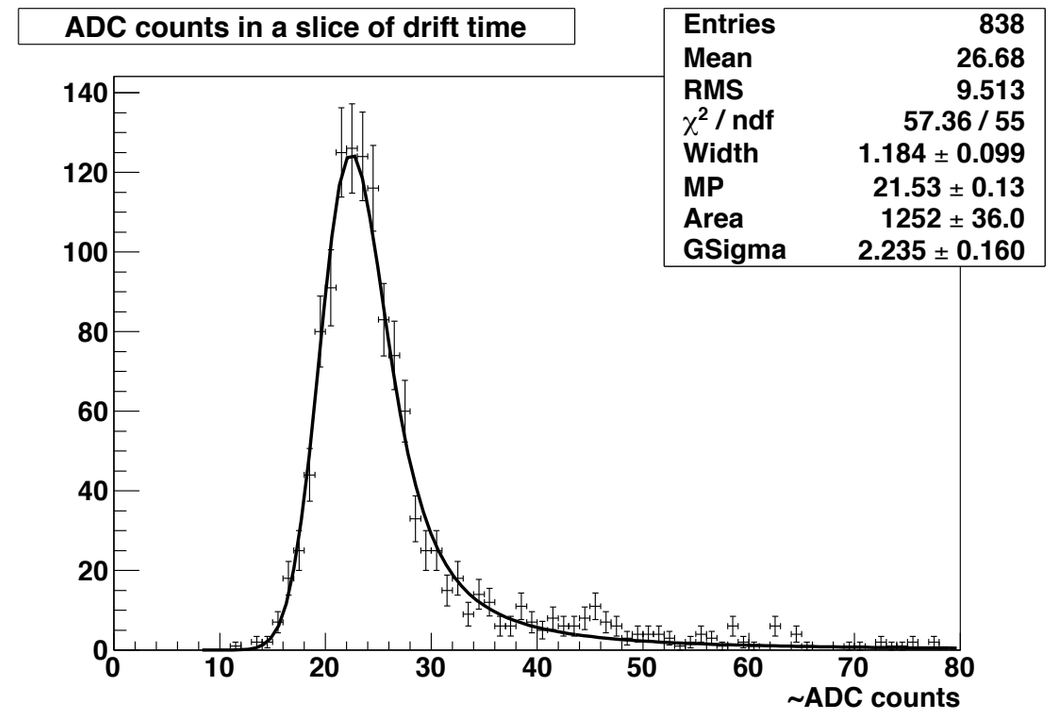




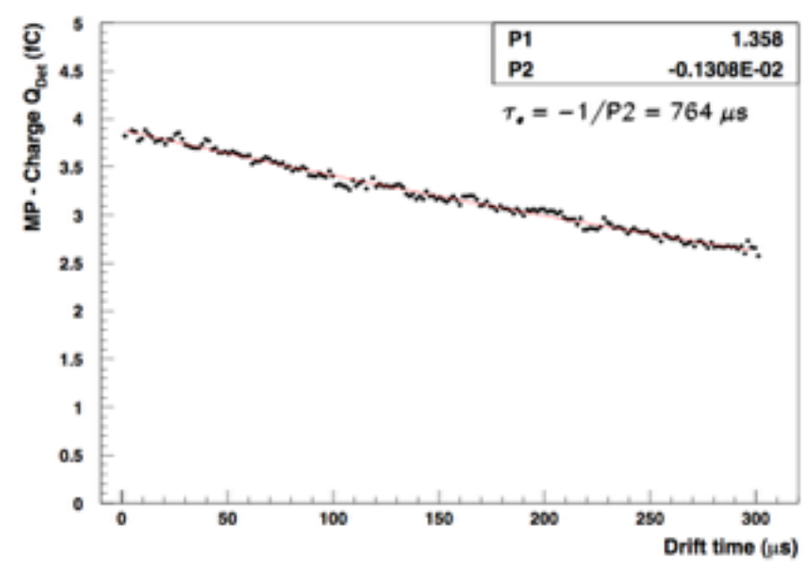
<dE/dx>=2.3±0.2 MeV/cm, in good agreement with theoretical expectations for $\langle E_\mu \rangle$=7.0 GeV

Electron Lifetime





- Measure dQ/ds vs drift time using through-going muons.
- Fit to Landau convoluted with Gaussian.
- Standard technique to determine electron lifetime: LongBo, MicroBooNE, LArIAT etc.

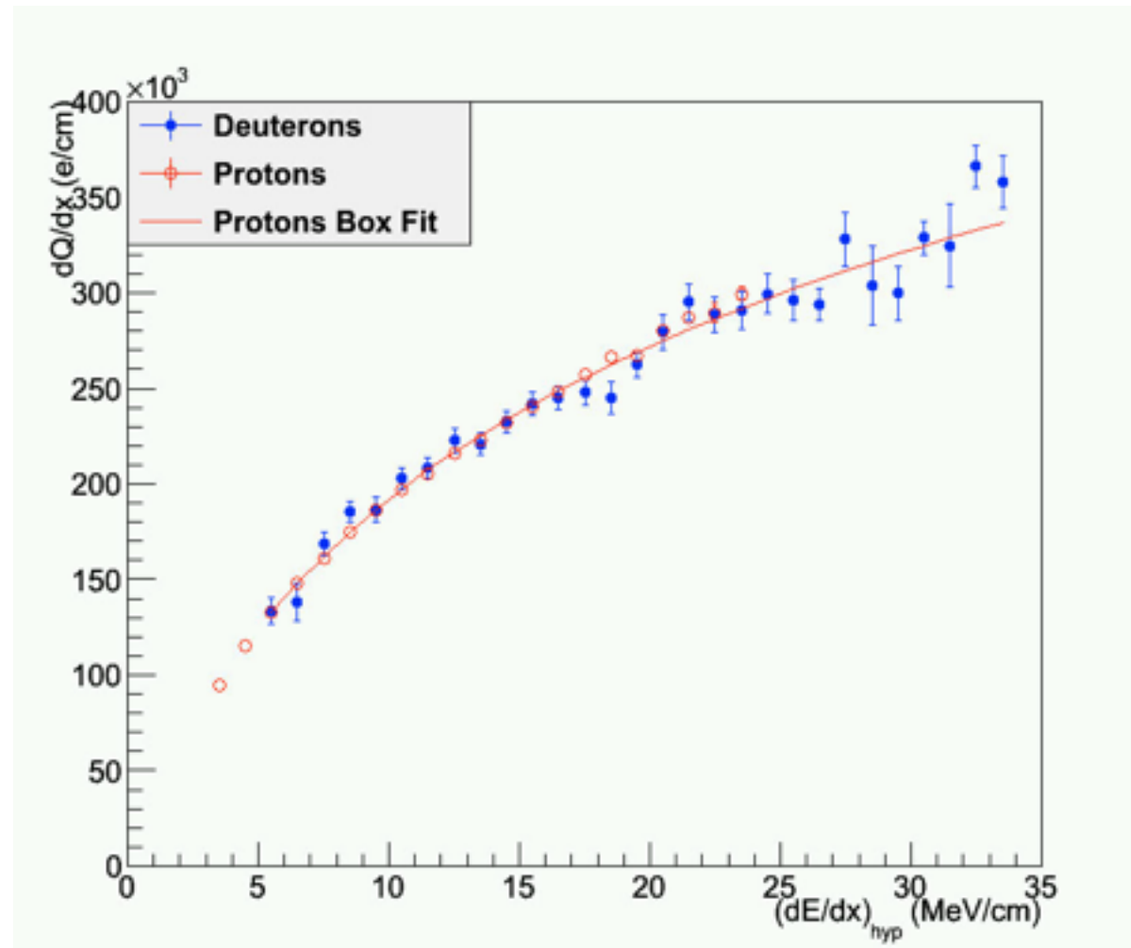


JINST 7 P10019 (2012)
arXiv: 1205.6747

Recombination Studies

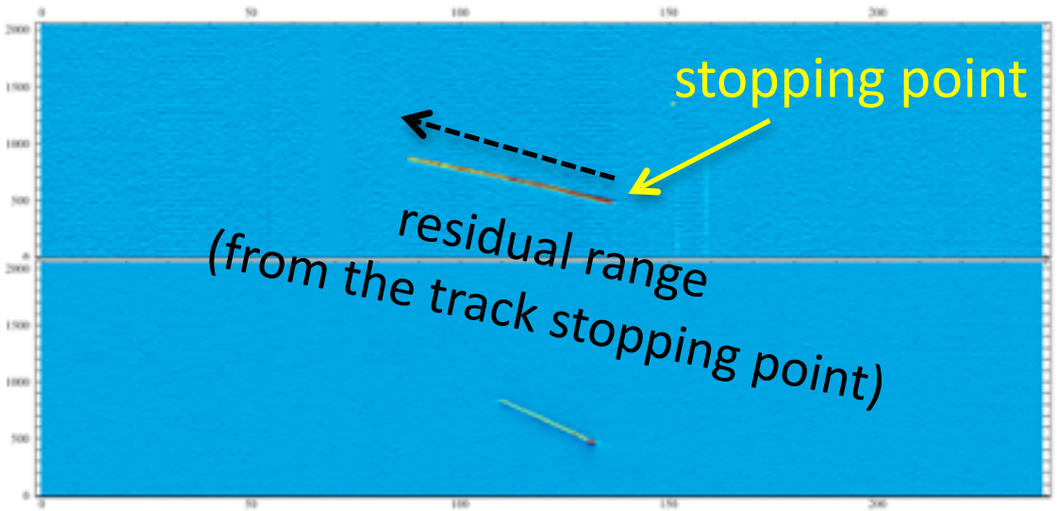
Bruce Baller

- Study the recombination of electron-ion pairs produced by ionizing tracks using fully reconstructed stopping protons and deuterons
- Results in agreement with ICARUS with extended dE/dx range and smaller uncertainties
- Also study the dependence of recombination on the track angle
- arXiv: 1306.1712, JINST 8 (2013) P08005

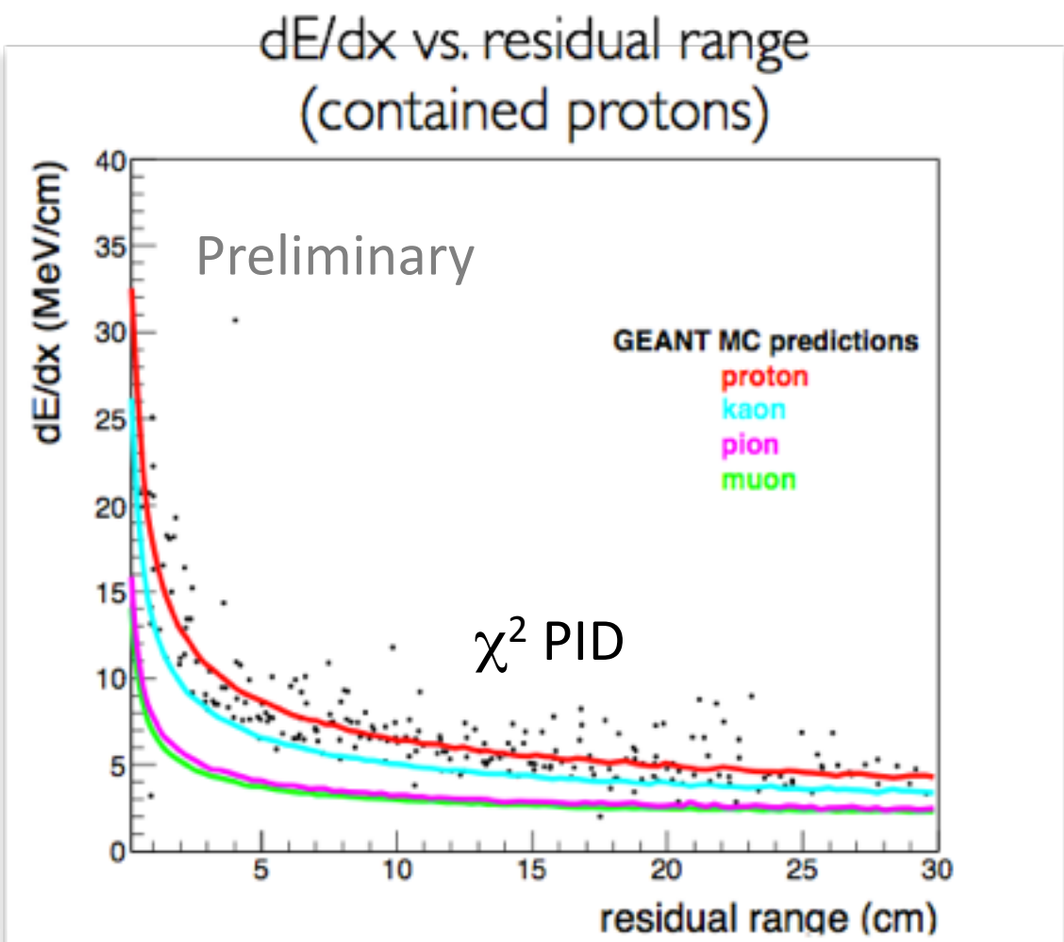


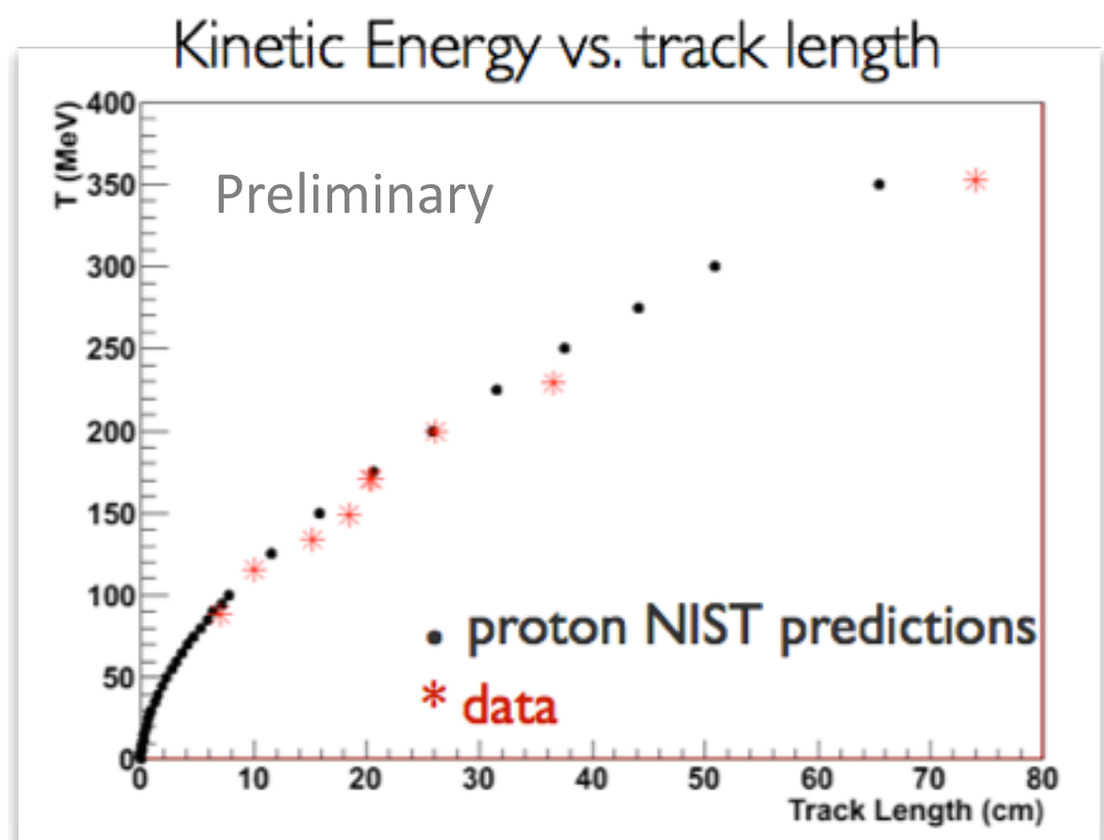
Developed Modified Box Model of recombination parameterization

Calorimetric ParticleID



- Measurement of:
  - dE/dx vs. residual range along the track
  - kinetic energy vs. track length

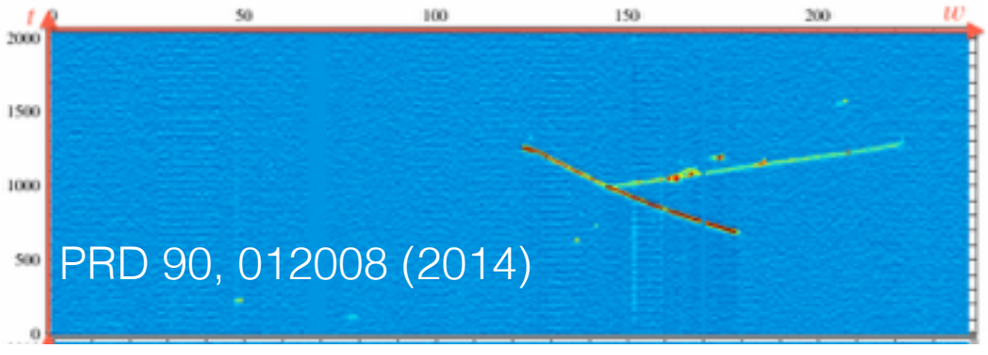




Calorimetry reconstruction is used by all LArTPC experiments.

Topological Analysis 1μ+Np

- A first Topological analysis is developed by the ArgoNeuT experiment: 1μ+Np (0π)
  - Sensitive to nuclear effects
  - Observation of back-to-back proton pairs

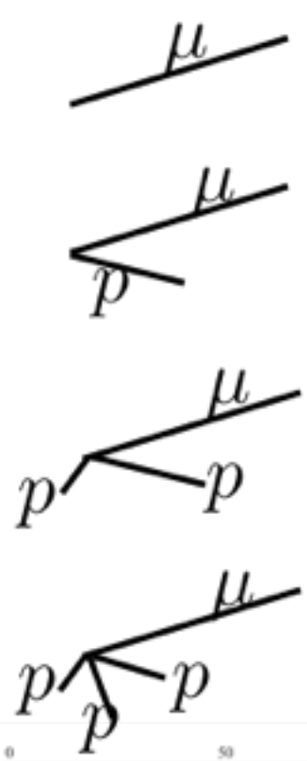


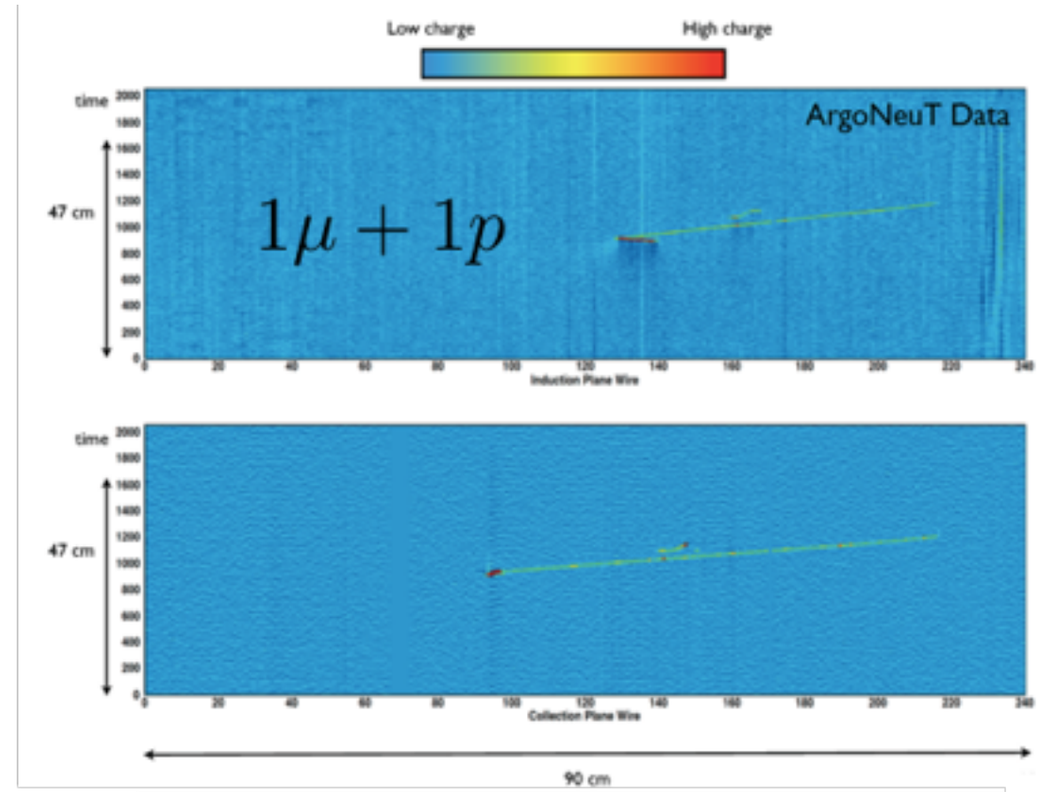
- Analysis steps
  - automated reconstruction (muon angle and momentum)
  - visual scanning
    - hit selection
  - automated track and calorimetric reconstruction
    - Background (pion) removed

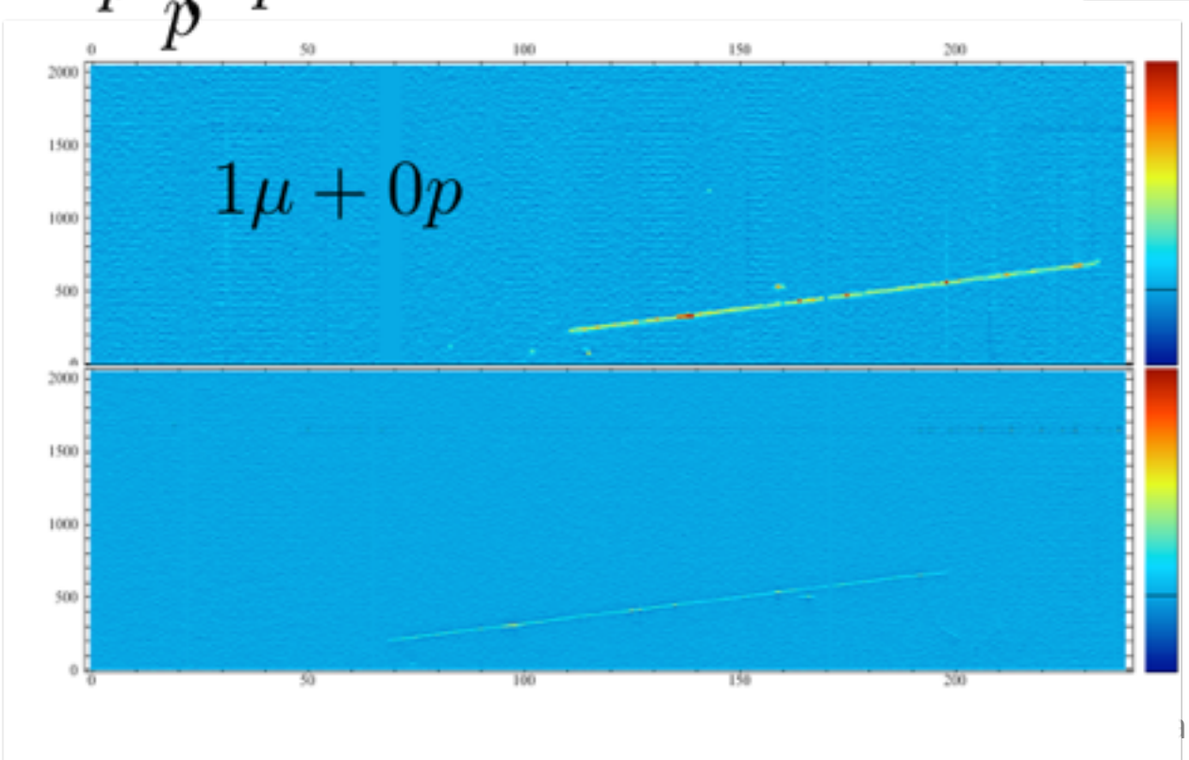
Proton angle and momentum

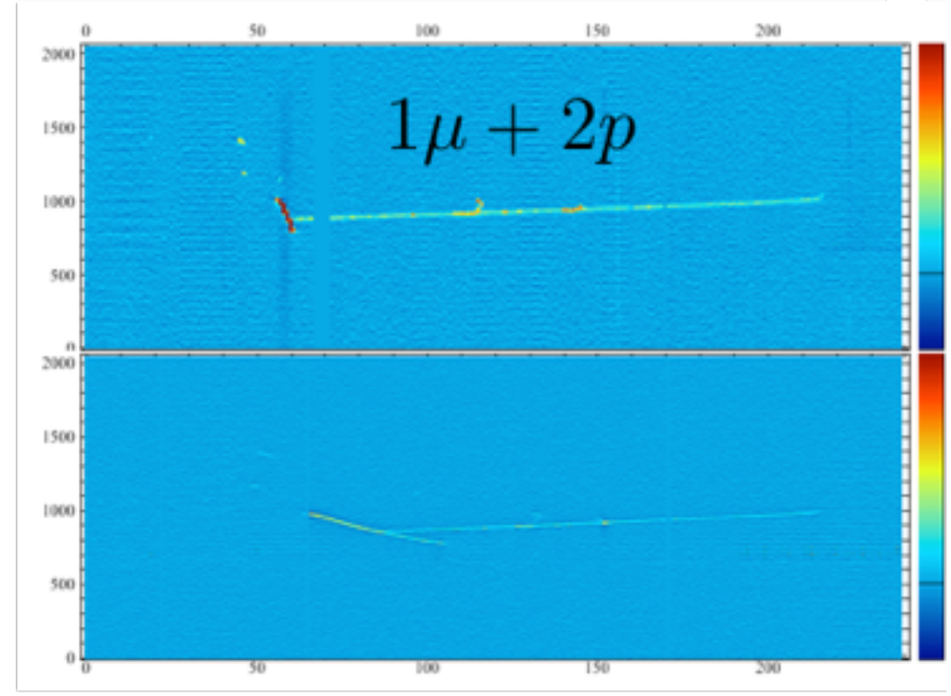
- GENIE MC:
  - Estimate efficiency of the automated reconstruction, detector acceptance and proton containment (for PID)
  - estimate backgrounds
    - NC background
    - Wrong-sign (WS) background
    - π^0 with both γ not converting

Event Topology

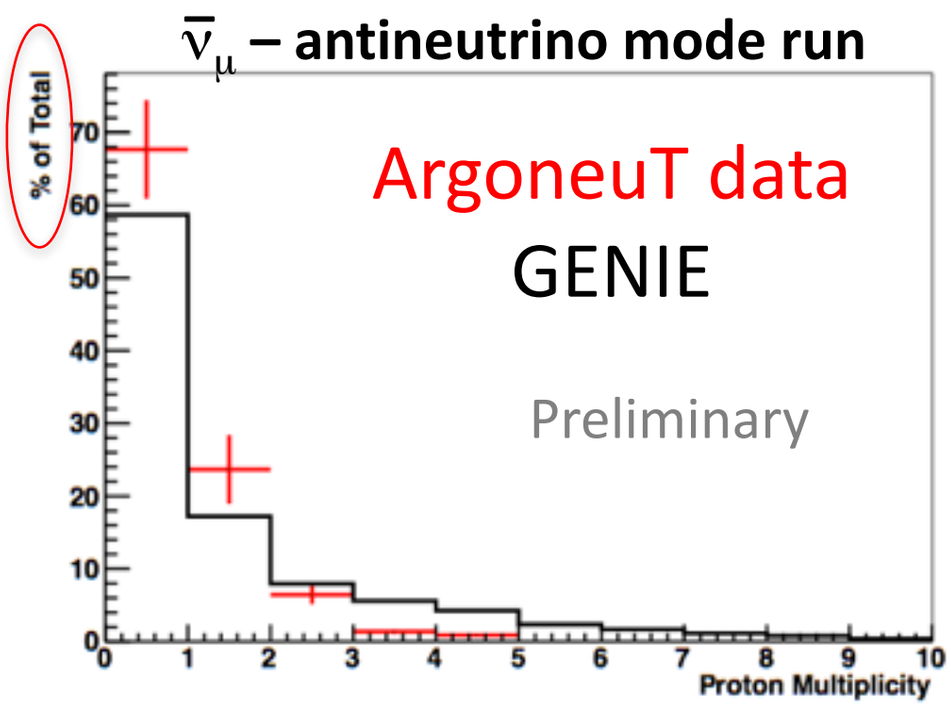


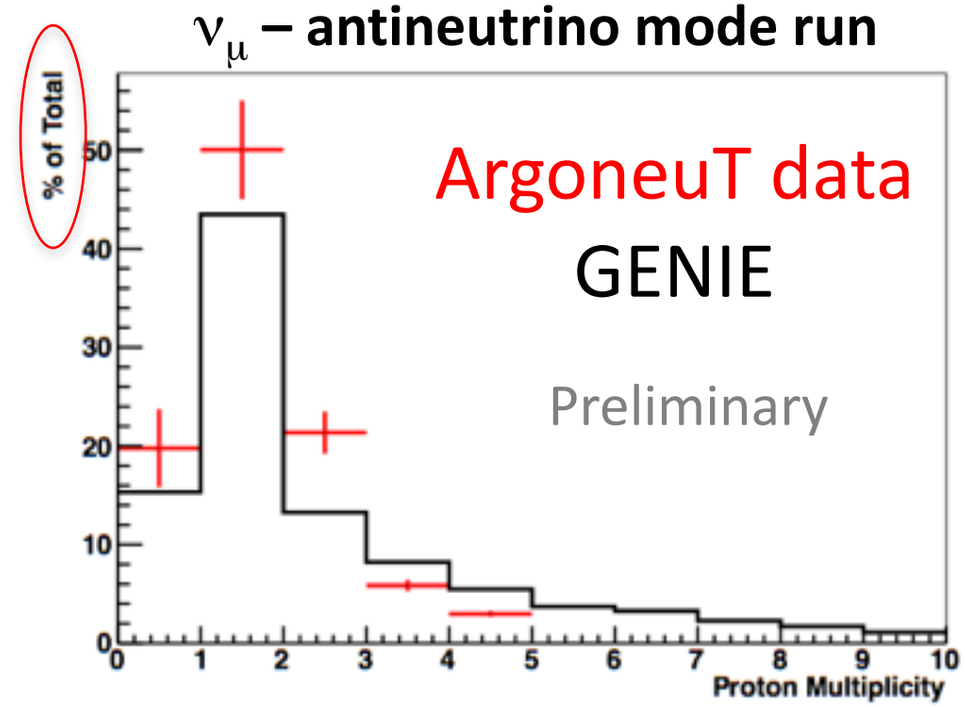




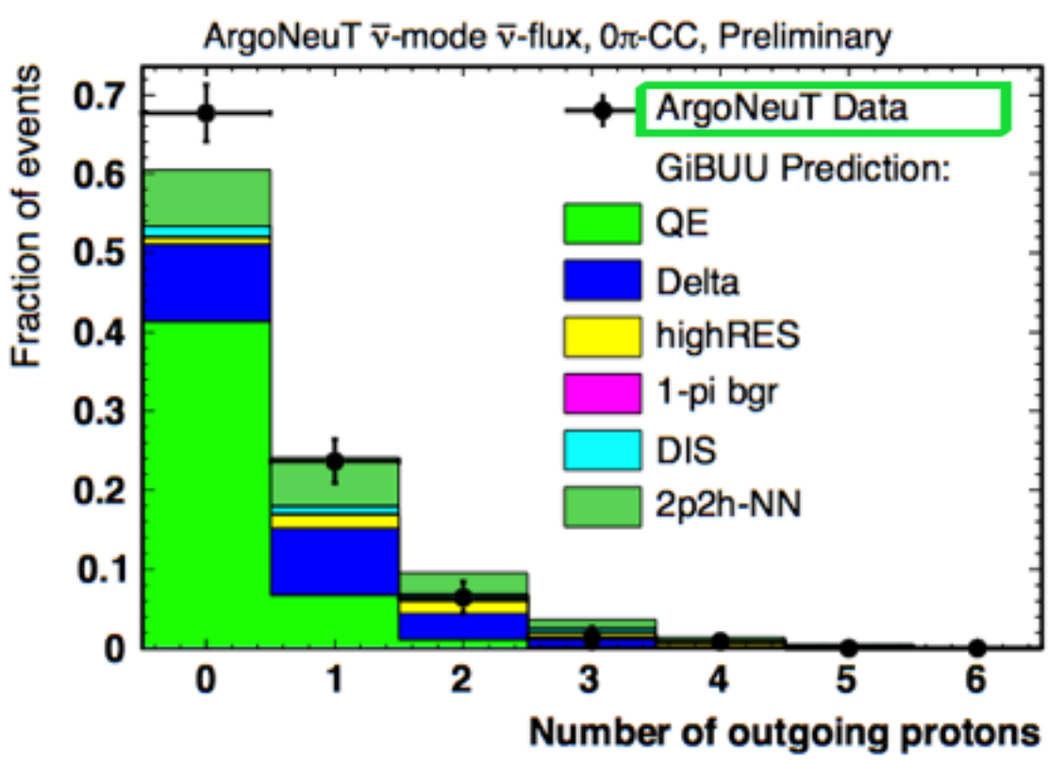


Proton Multiplicity





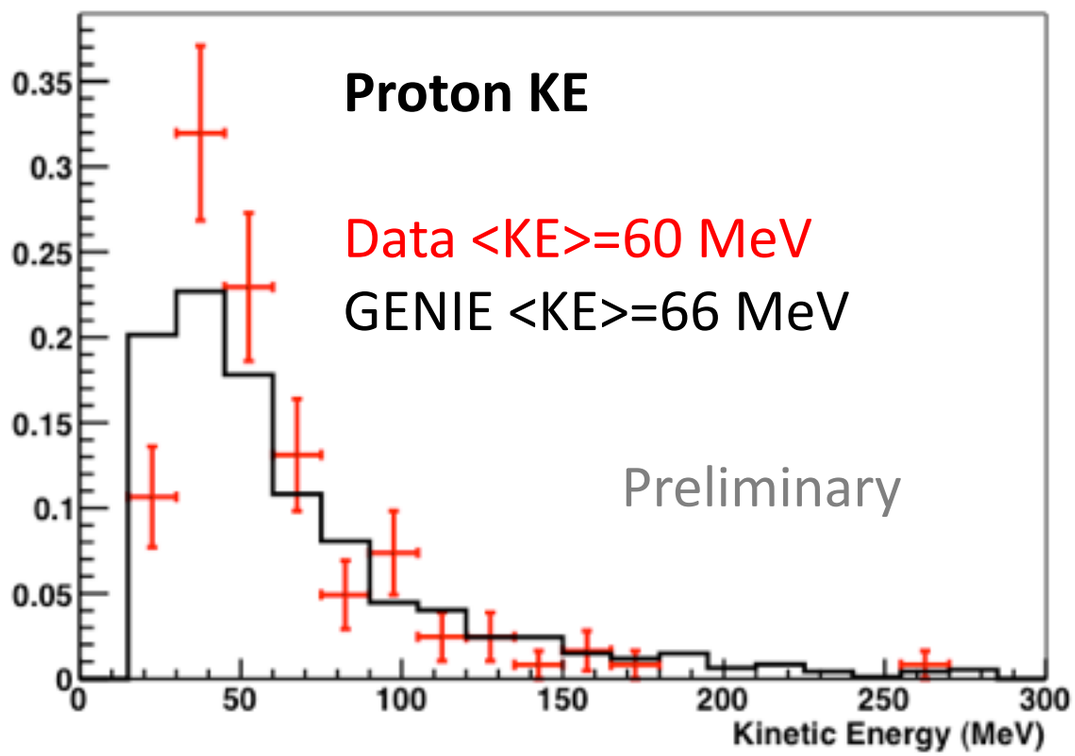
proton threshold:T_p>21 MeV



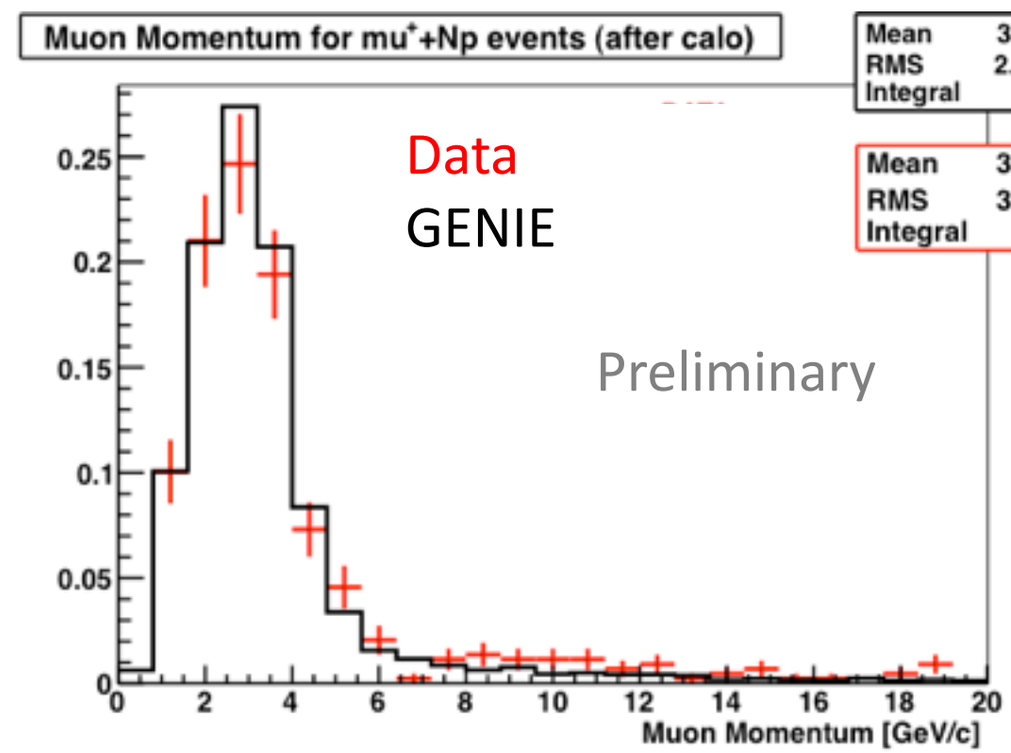
- LAr data can provide an important discriminator among models

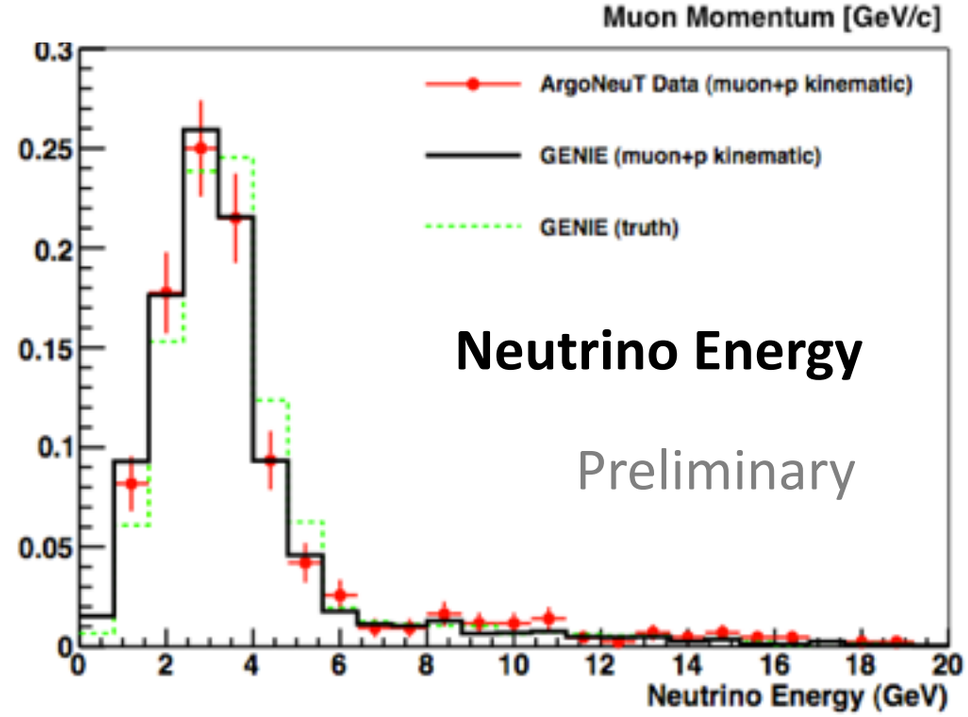
Kinematics Reconstruction (μ^++Np)

ν_μ – antineutrino mode run



Muon Momentum

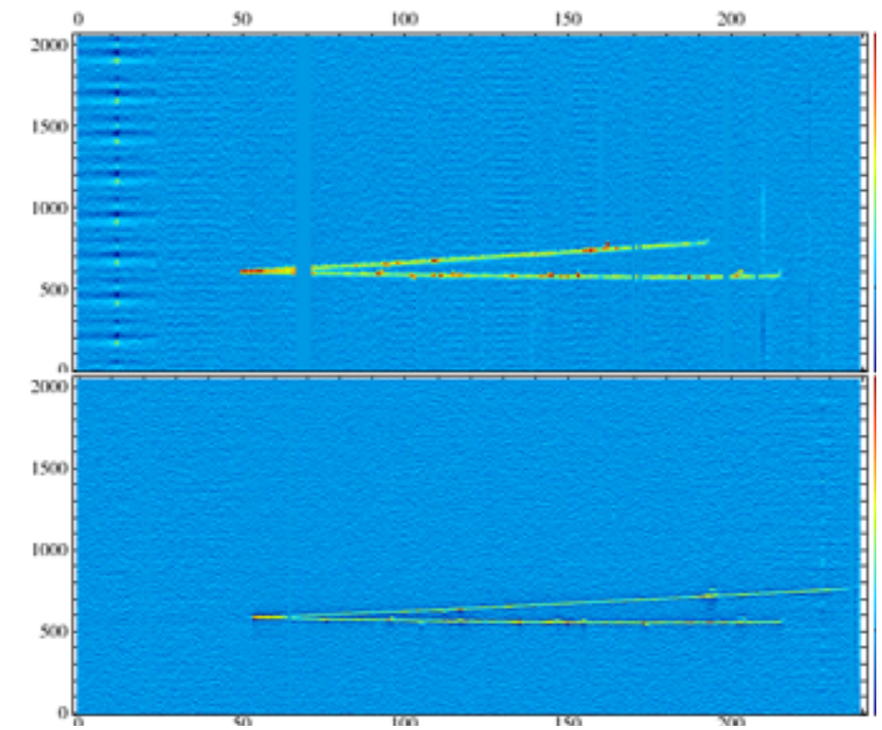


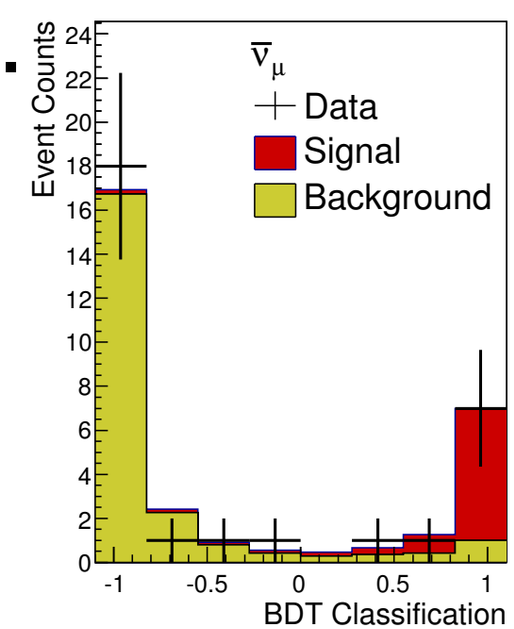


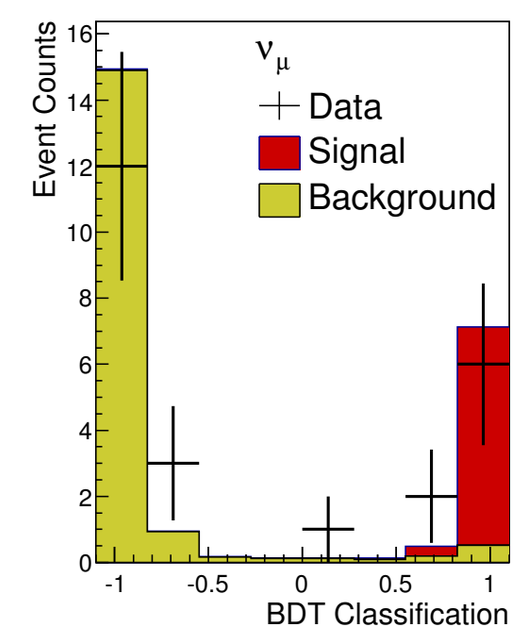
- Neutrino Energy $E_\nu = E_\mu + \Sigma T_p$
- Use all calorimetric information.

Coherent Pion Production

- Simple topology: 1 muon + 1 pion with small open angle.
- Fully automated reconstruction.
- Boosted decision trees to separate signal from background.
- Phys. Rev. Lett. 113, 261801 (2014)
  arXiv: 1408.0598



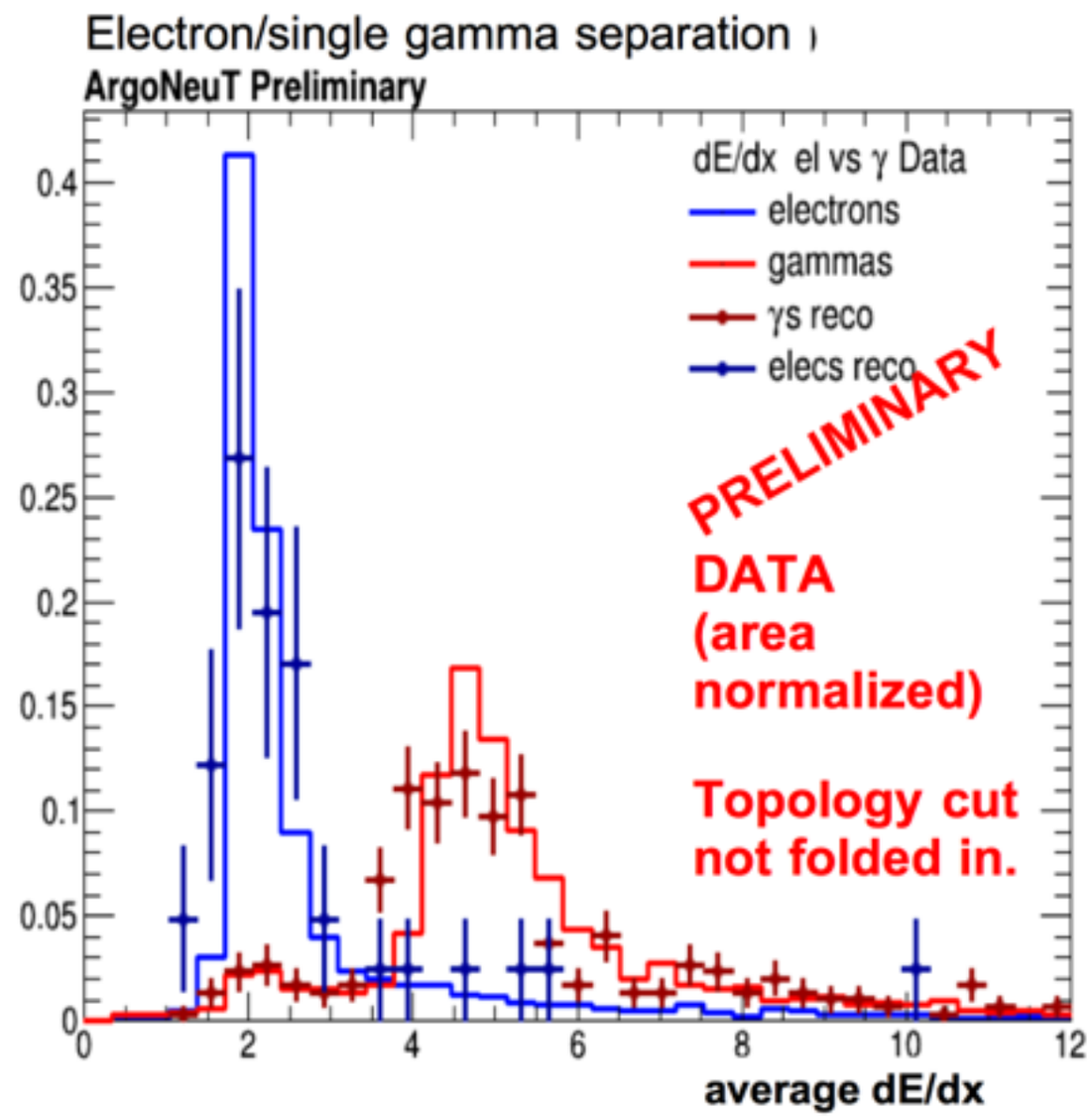




Shower reconstruction

Andrzej Szelc

- Semi-automated reconstruction
- Start with 2D clusters
  - Calculate 2D start points, angles
  - Select shower like clusters
  - Match clusters between different plane views
- Reconstruct 3D shower objects using matched 2D clusters
  - 3D shower axis
  - dE/dx and shower energy
- Overlapping tracks



Another shower related analysis - NC pi0 cross section is in the final internal review

Lessons Learned

- High efficiency in reconstructing MIP particles.
- Need to improve efficiency to reconstruct low energy tracks.
- Vertex reconstruction is important for both track and shower reconstruction.
- Overlapping tracks are hard to reconstruct.
  - Include calorimetry information in tracking.
- Difficulty with 2 planes.