Study of $\nu_\mu + e$ elastic scattering in MINERνA experiment at NuMI beam line

Jaewon Park
University of Rochester

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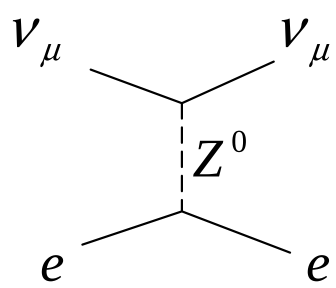
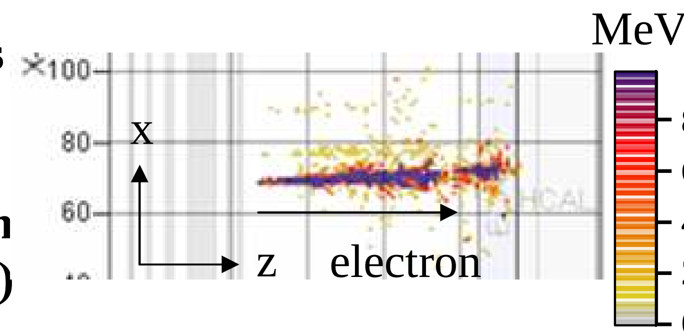
Goal: Flux Measurement From Event Counting

$$\nu_\mu + e \rightarrow \nu_\mu + e$$

$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$



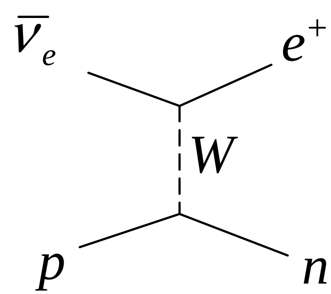
Very clean physics channel but it has tiny cross section. (~1/2000 to neutrin nucleon scattering)



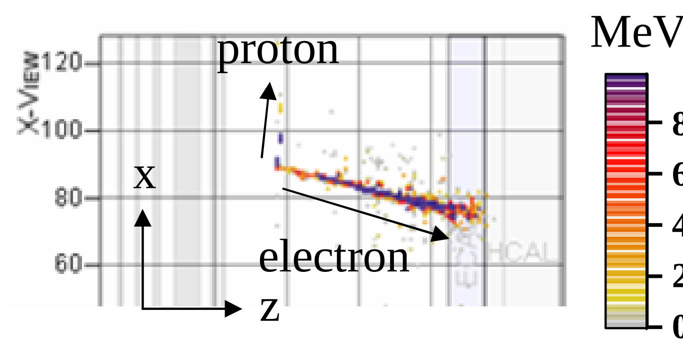
- Well known pure leptonic process is used to get ν_μ flux information
- ν_μ scattering off on light electron has small center of mass energy, so it can have only small momentum transfer, Q^2 , which produces very forward electron final state

$$\nu_e + n \rightarrow e^- + p$$

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



Electron neutrino fraction in flux is small ~ 1%.



- Electron neutrino flux will be measured using charged current quasi-elastic (CCQE) process
- If recoiled nucleon is not observed, two processes look similar

Signal and Background Processes

All can look like single electron final state

$$\nu_\mu + e \rightarrow \nu_\mu + e$$
$$\bar{\nu}_\mu + e \rightarrow \bar{\nu}_\mu + e$$

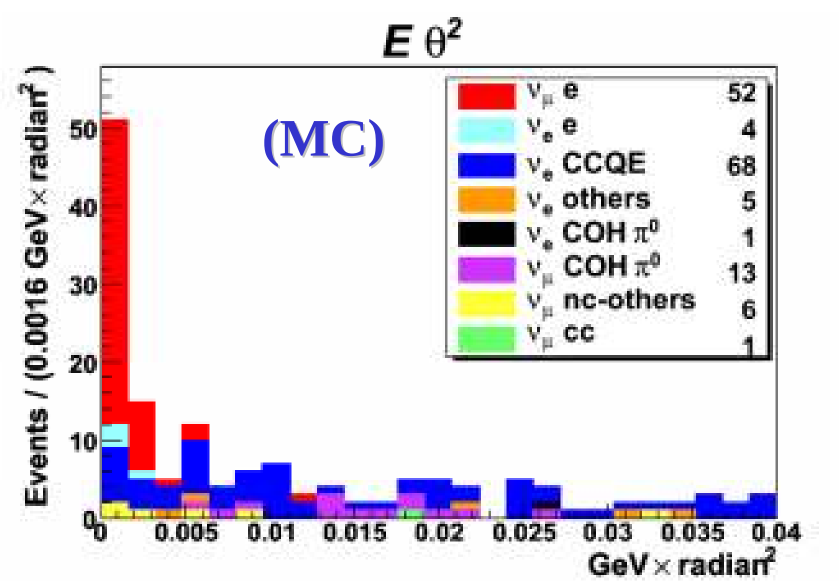
It produces a very forward electron
It can be separated from background using ***Eθ²***

$$\nu_e n \rightarrow e^- p$$
$$\bar{\nu}_e p \rightarrow e^+ n$$

Check vertex activity to reject

$$\nu_\mu A \rightarrow \nu_\mu A \pi^0$$

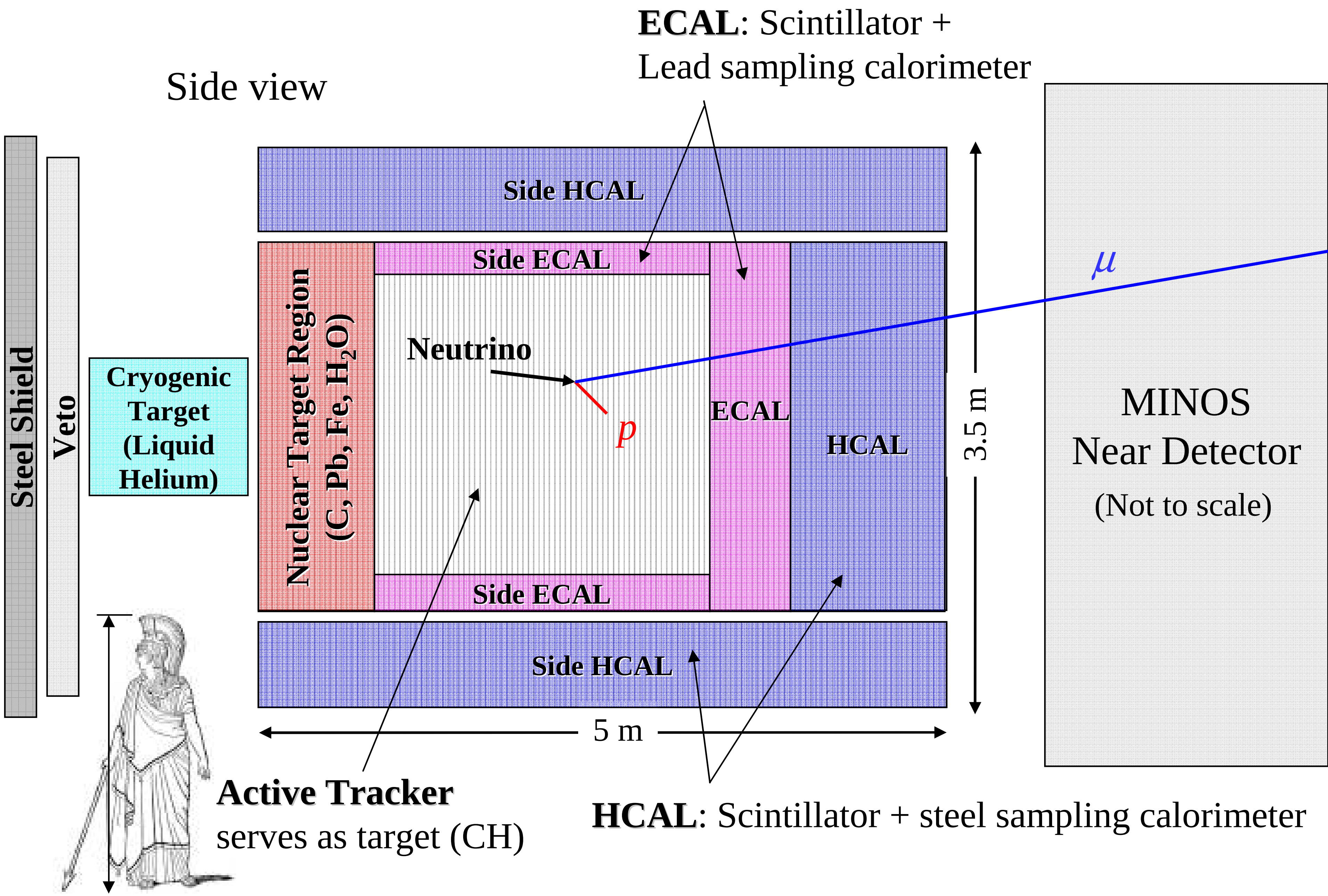
1. Only one of two gammas is detected
   − dE/dx at the beginning is different from electron
2. High energy π^0 decays into two gammas with very small opening angle
   − Check transverse energy distribution



E: Energy of electron candidate
θ: Theta of electron candidates w.r.t. beam direction

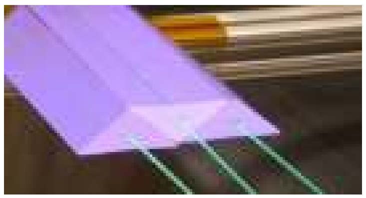
MINERνA Detector

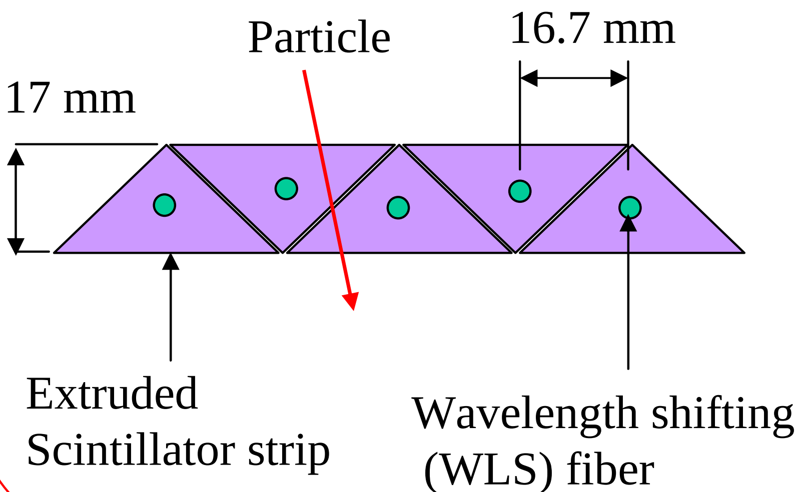
- MINERvA detector is made of a stack of “MODULES” (See next slide)

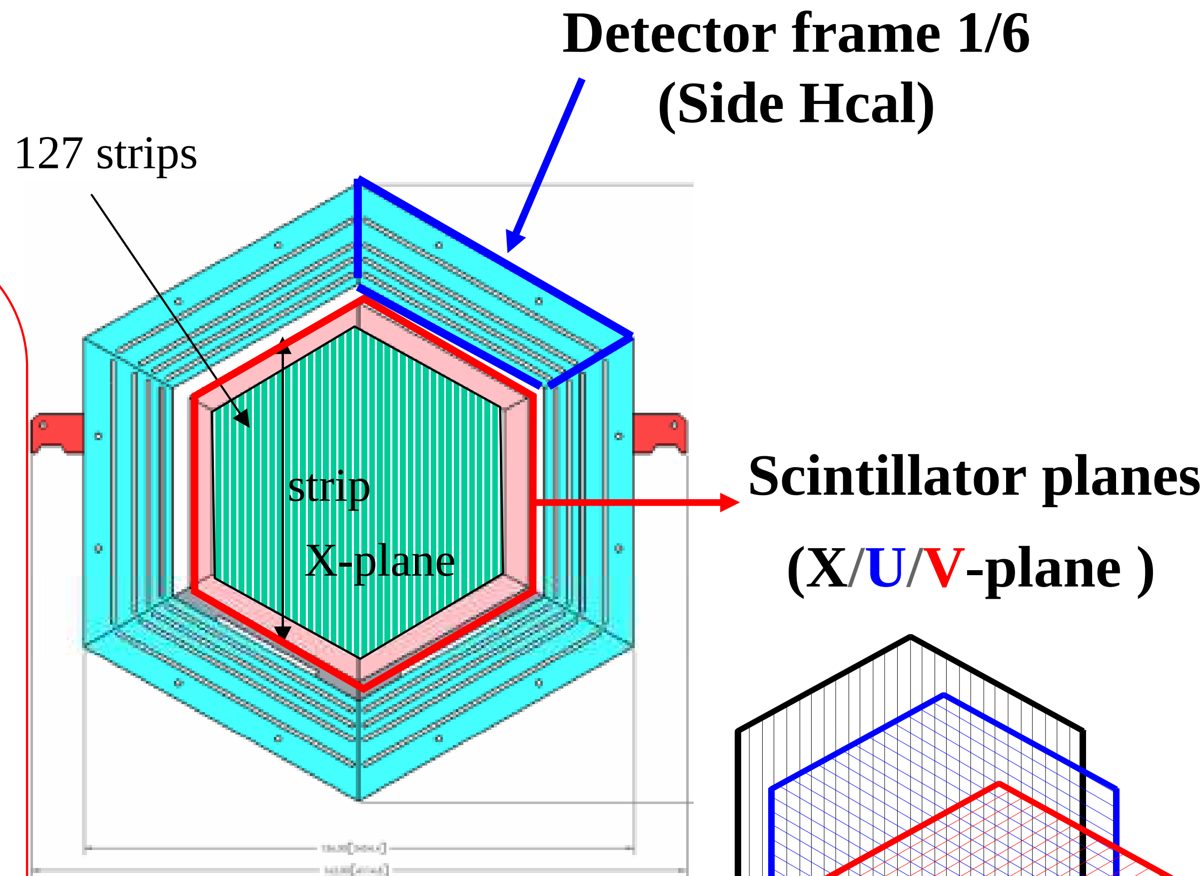


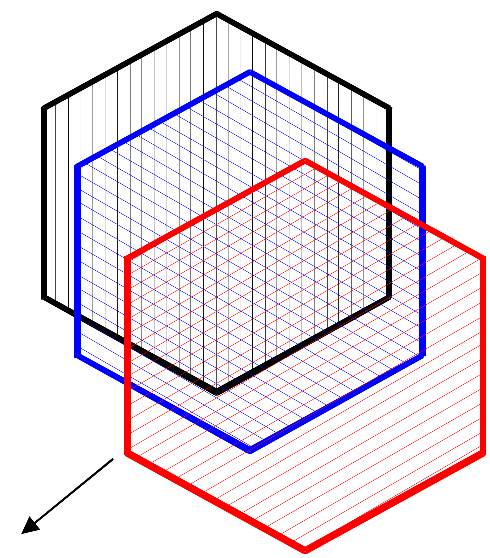
Detector Module

Scintillator plane consists of
Extruded scintillator strips
and Wavelength shifting fibers





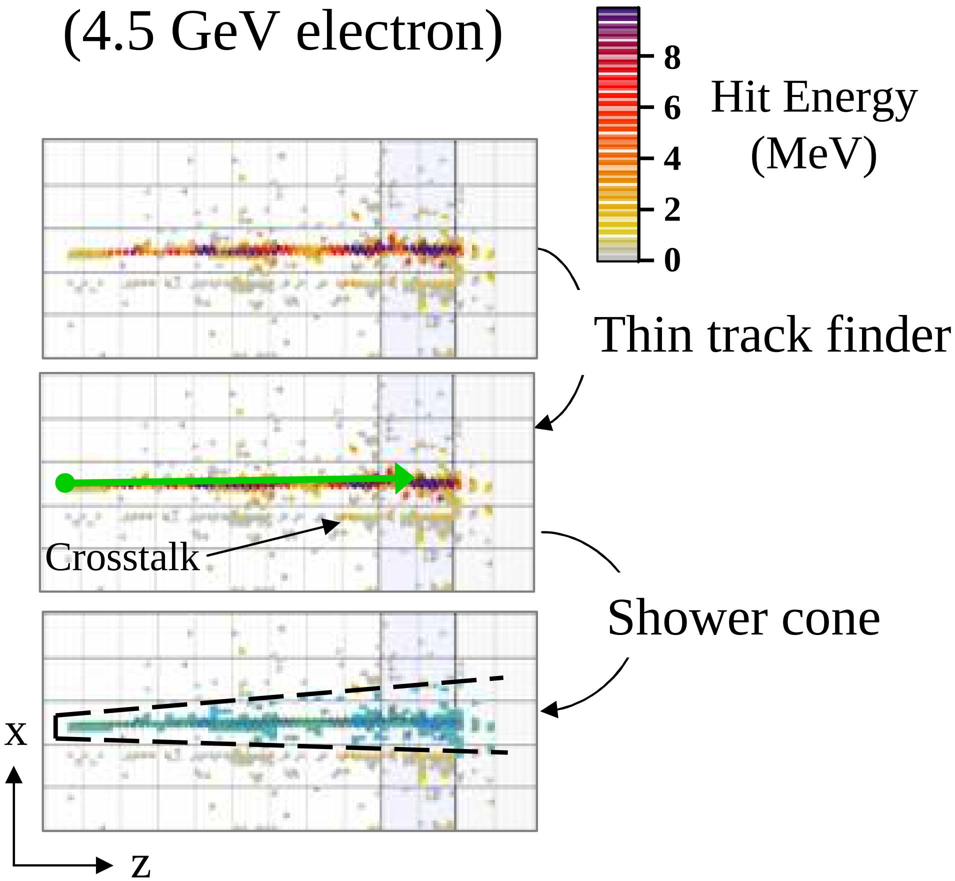




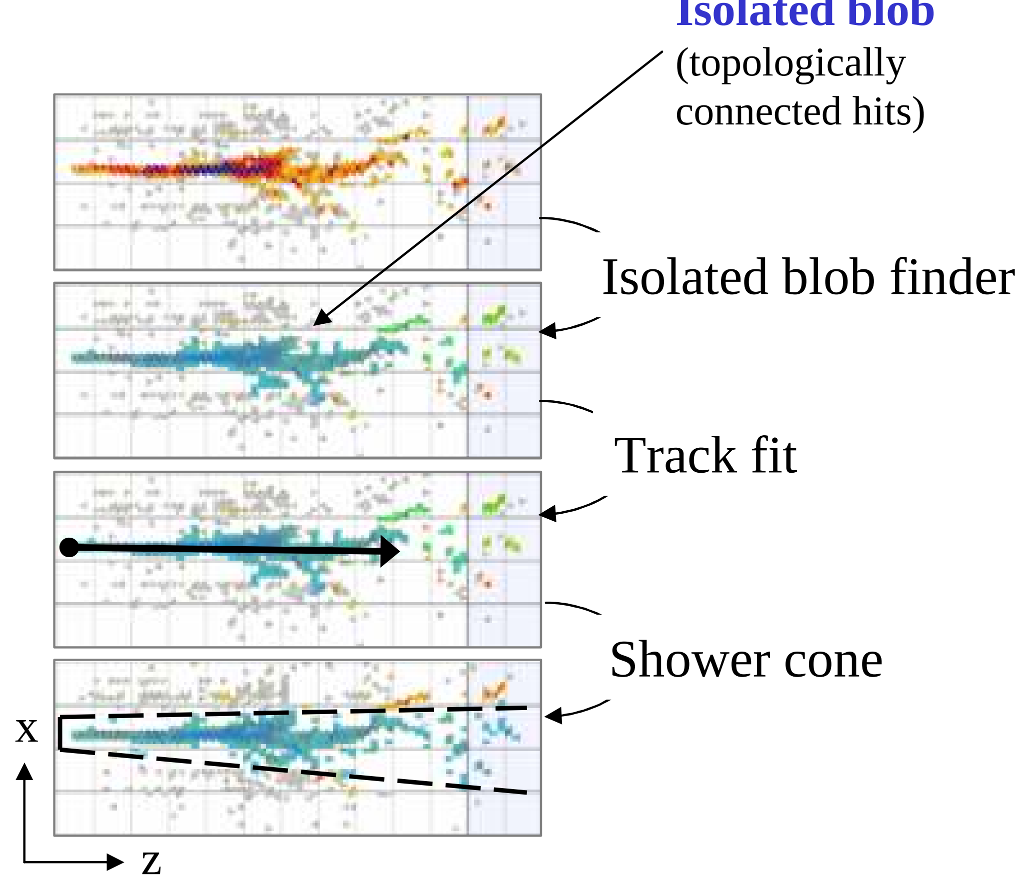
- X, U, V coordinates are combined to make 3D tracking

Single EM Shower Reconstruction

Track-like shower
(4.5 GeV electron)

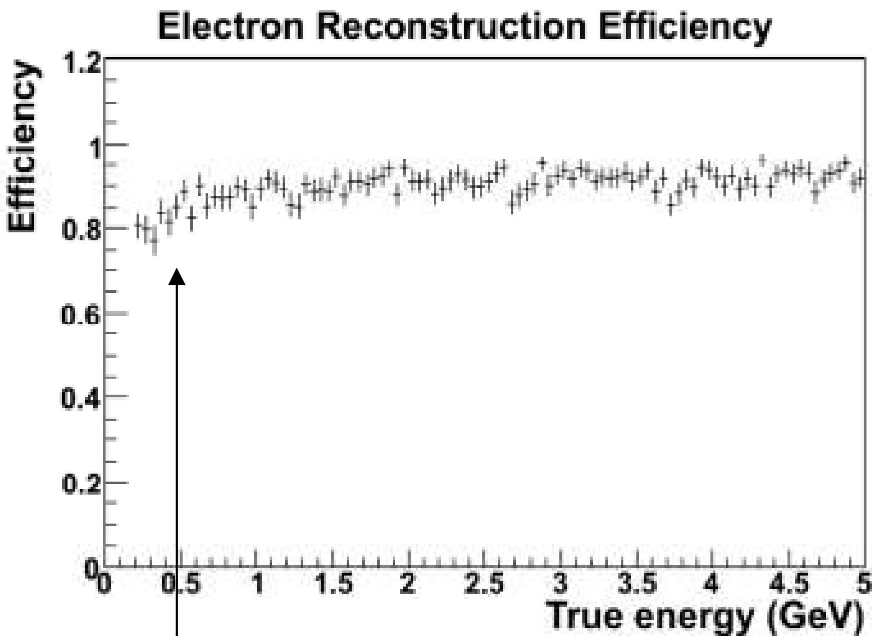


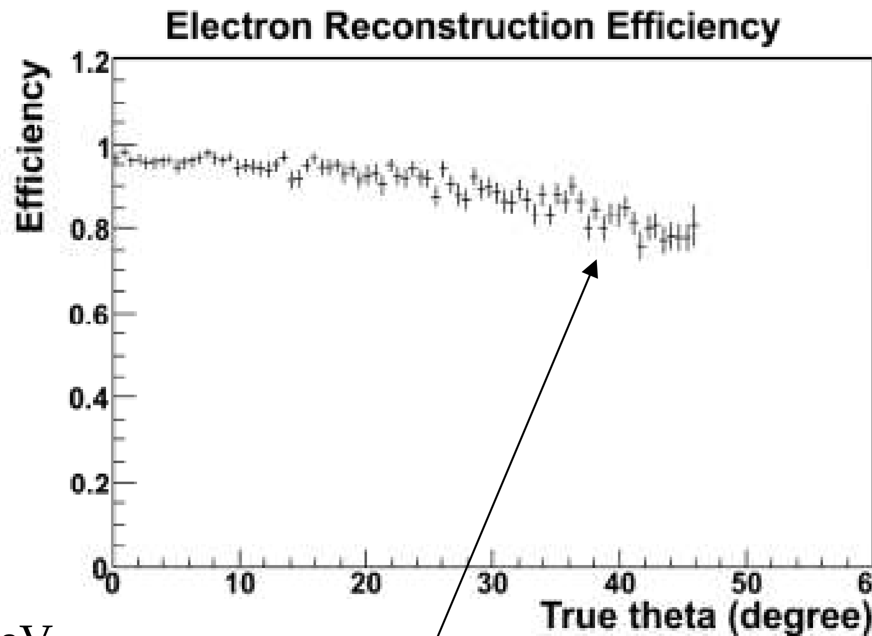
Fuzzy shower
2.9 GeV electron



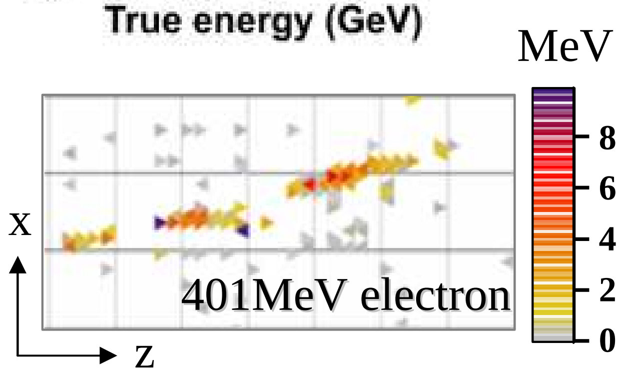
- Once vertex and direction is known, shower cone can be applied
- When (thin) track finder fails on fuzzy shower, isolated blob finder is used and then track fitter can handle fuzzy shower

MC Reconstruction Efficiency





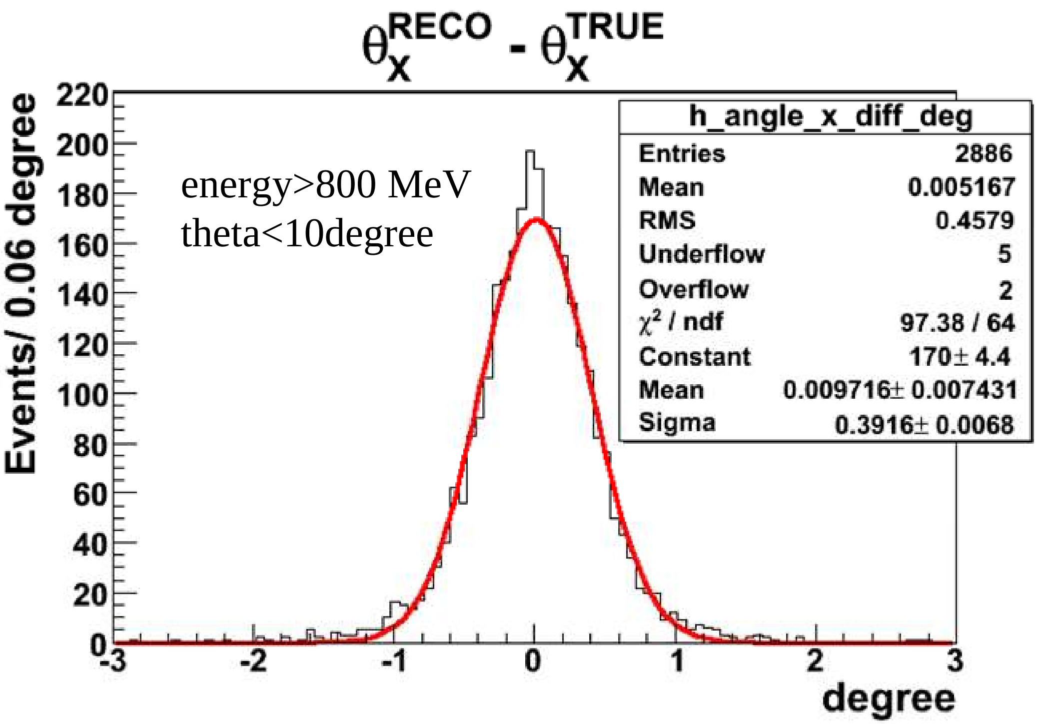
Low energy electron sometimes produces splash shower

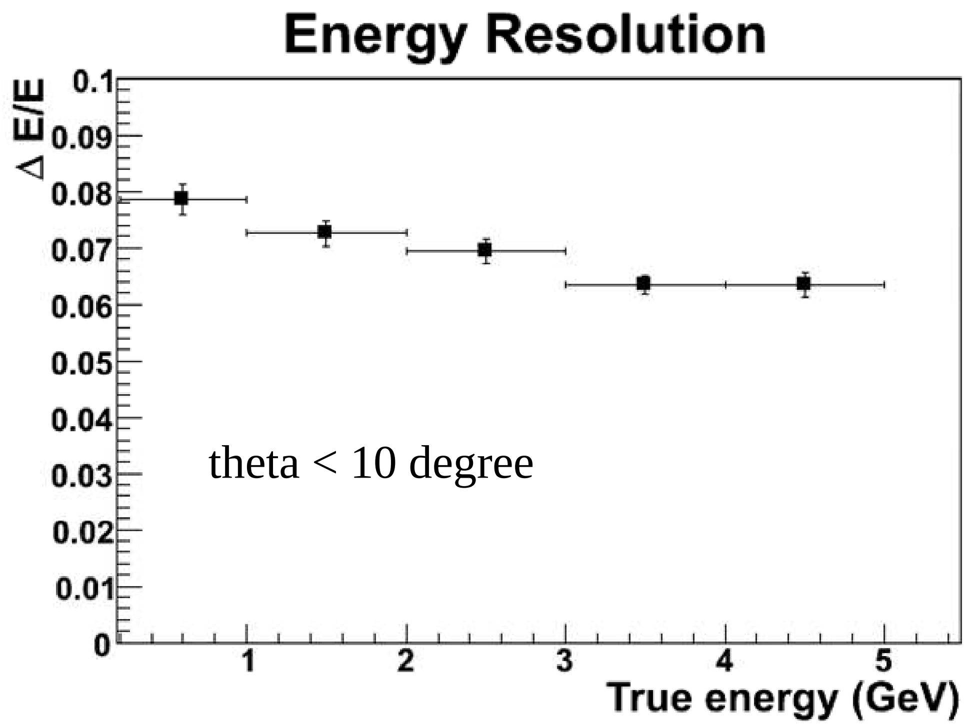


Big theta angle electron tends to exit to sides, which leaves less hits in tracking volume

- Electron particle gun is used to calculate efficiency
  - Energy: 0.2 ~ 5 GeV, Theta: 0~45 degree
- **Reconstruction efficiency is 0.96 for small angle** (angle <10 degree, energy>400MeV)

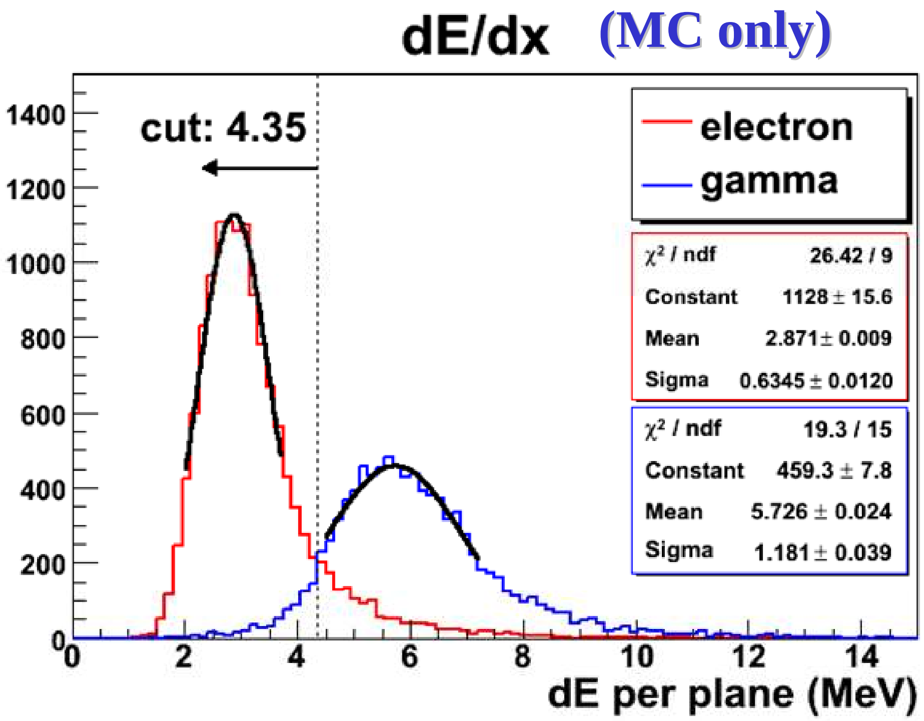
MC Angular and Energy Resolution

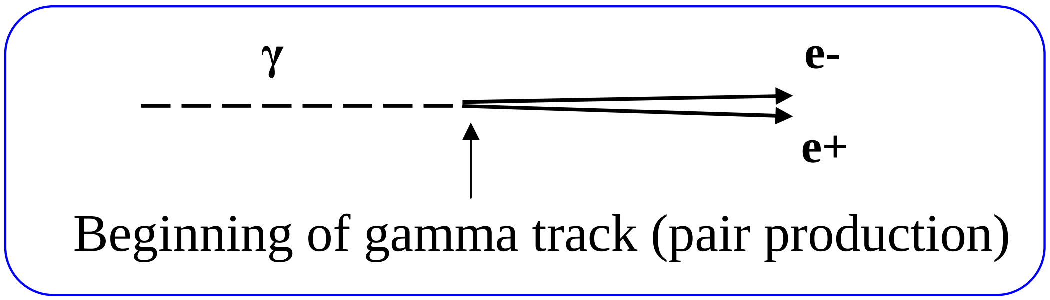


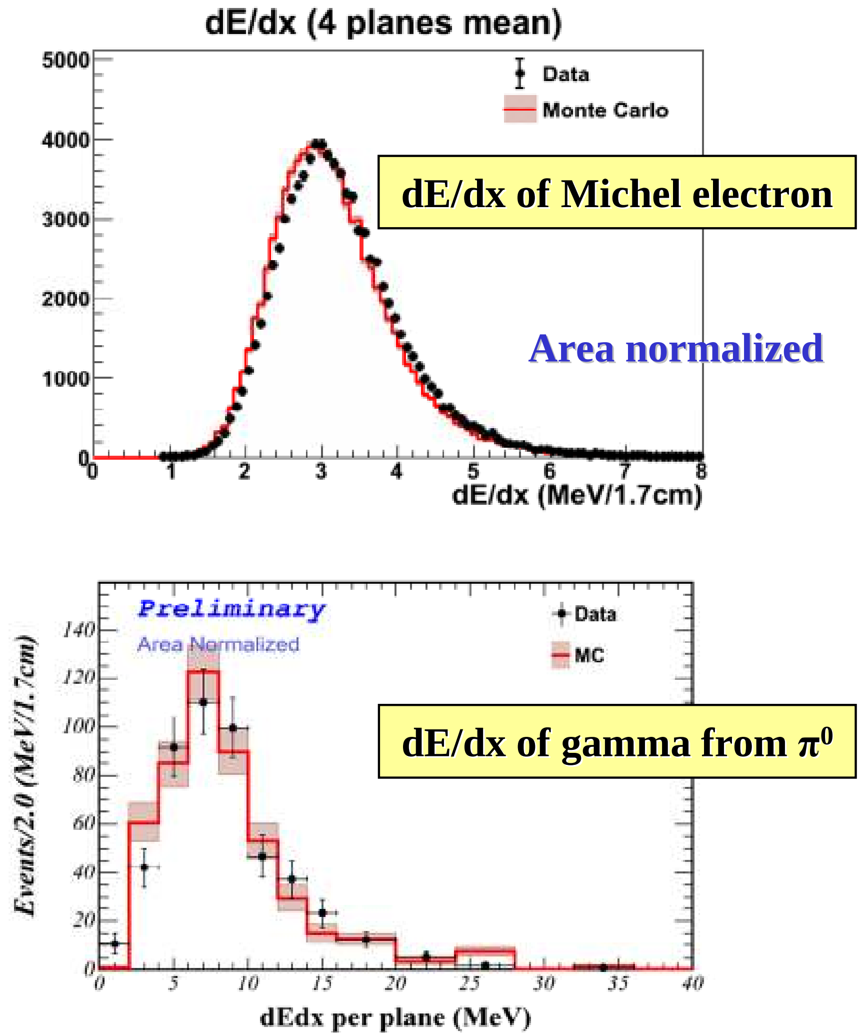


- Precise angular reconstruction is critical to separate ν_μ e elastic scattering from ν_e CCQE
- Energy resolution: 6~ 7%

dE/dx for Electron and Gamma Discrimination





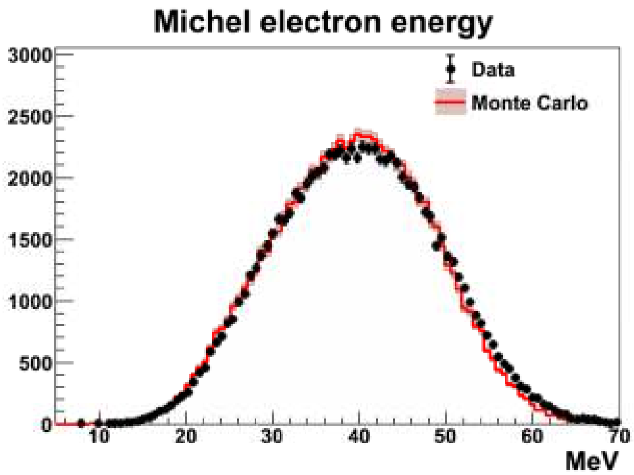


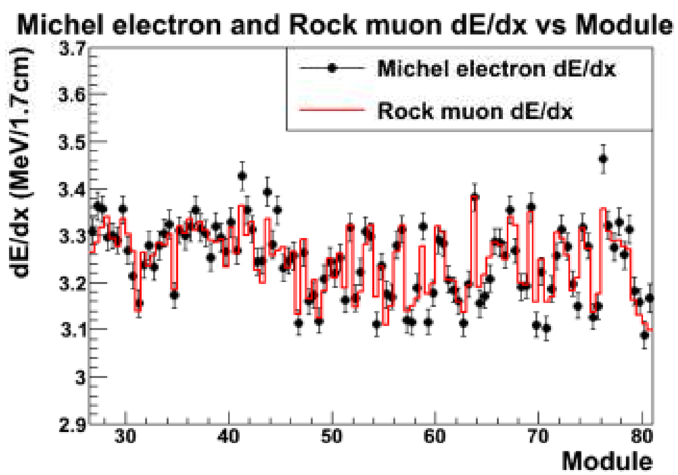
- Neutral current π^0 is decayed into energetic gamma + tiny energy gamma
- dE/dx at the beginning of shower is different for electron and gamma
  - Electron loses energy like MIP (Minimum Ionization Particle)
  - Gamma loses energy like twice MIP

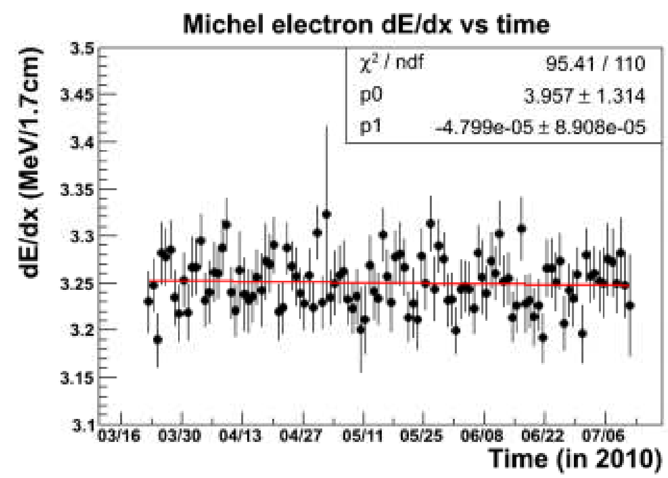
Data Validation using Michel electron

Module to module variation (data)

Energy scale stability (data)

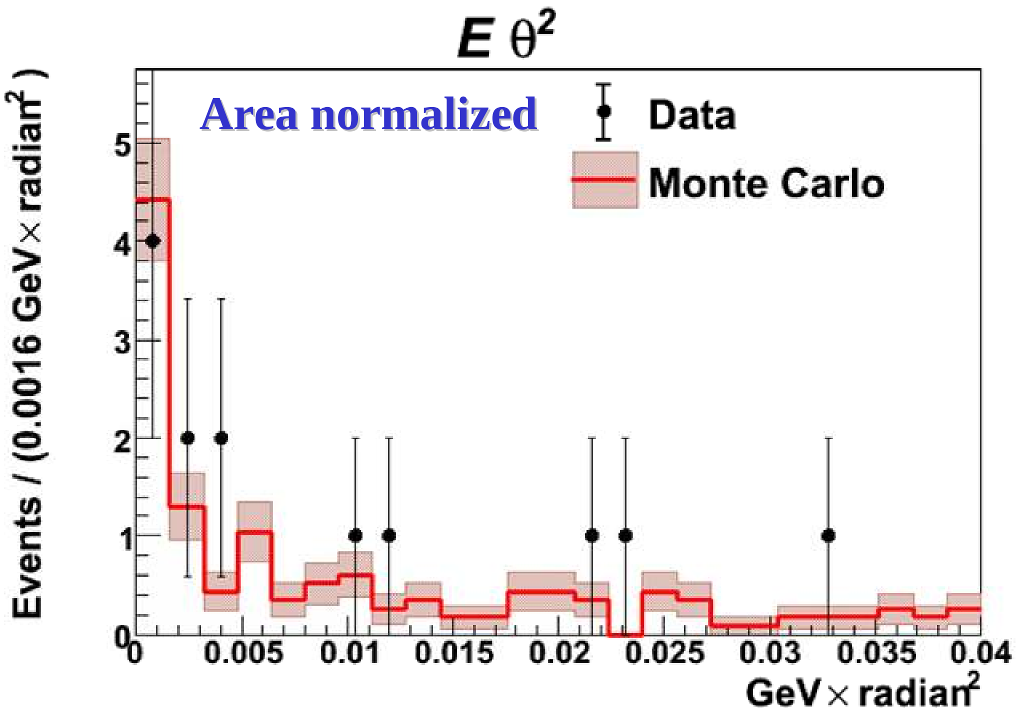


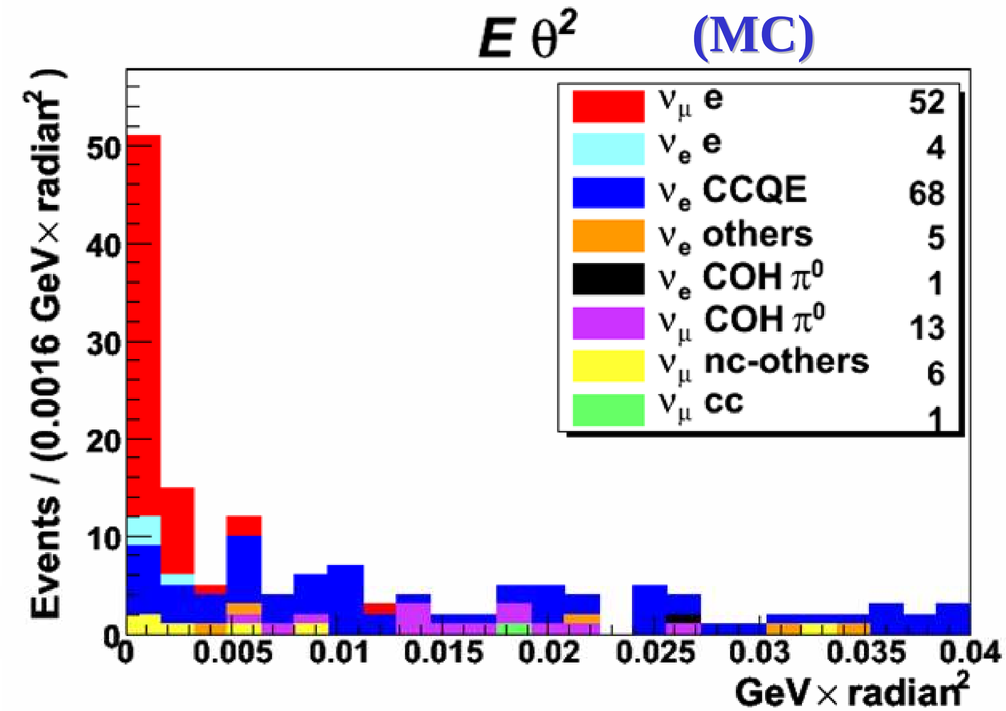




- Michel electron is nice to tool to check calibration
  - Michel energy MC/data comparison
  - Module to module variation is consistent with muon dE/dx
  - Energy scale is stable over time

Small Sample Result

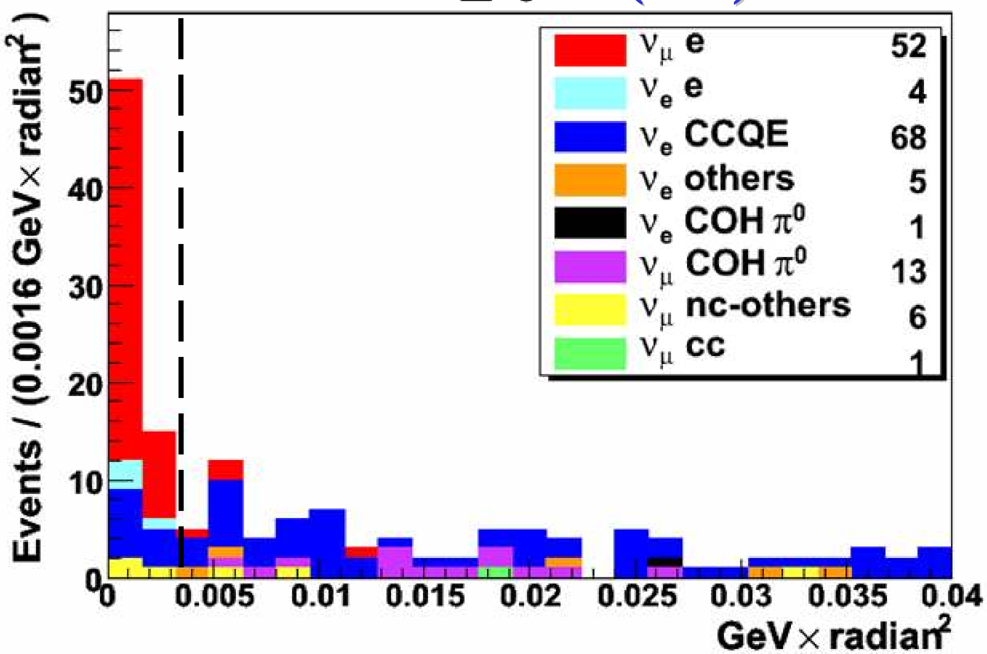




- Beam configuration: Low energy neutrino beam
- **~4%** of accumulated data is used for comparison
- MC sample size: ~30% of collected data
- ν_e CCQE (Charged Current Quasielastic) process is suppressed because single electron-like events are selected

Signal Events

First two bins are signal rich



	All bins	1st two bins	
ν_μ e	52	48	52 signal
ν_e e	4	4	
ν_e CCQE	68	11	
ν_e others	5	0	14 background
ν_e COH π^0	1	0	
ν_μ COH π^0	13	0	
ν_μ nc-others	6	3	
ν_μ cc	1	0	
Total	150	66	

- Number of ν e scattering (ν_μ e and ν_e e) events in this 30% MC: 52 ± 9
  - 17% statistical error
- The projected sample will have ~3 times signal/background (173/47).
- That measurement would produce a statistical uncertainty of 8.6%

Summary

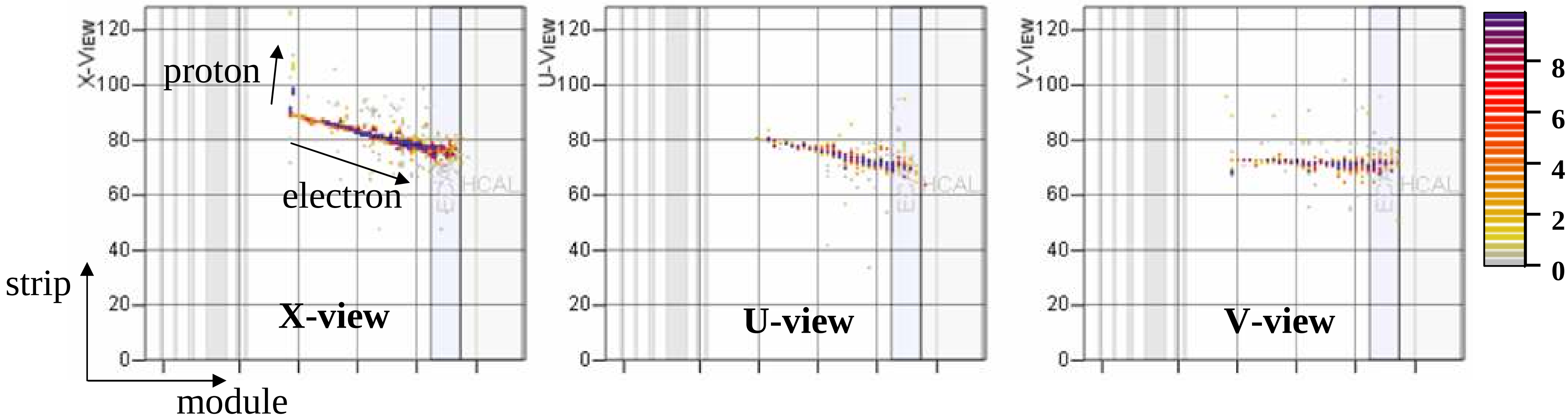
- Good single electron reconstruction is achieved.
- Efficient background rejection is made to isolated *ν e* scattering events
- Preliminary data and MC comparison looks promising
- Projected measurement of *ν e* scattering events using 30% MC shows constraint on flux with 8.6% statistical error
- This method of constraining beam flux will be more powerful with higher event rate in medium energy beam in the future

(Backup Slides)

Event Display (Data)

$\nu_e n \rightarrow e^- p$ candidate event

Hit Energy (MeV)



$\nu_\mu e^- \rightarrow \nu_\mu e^-$ candidate event