QE Studies in NOvA Near Detector Prototype

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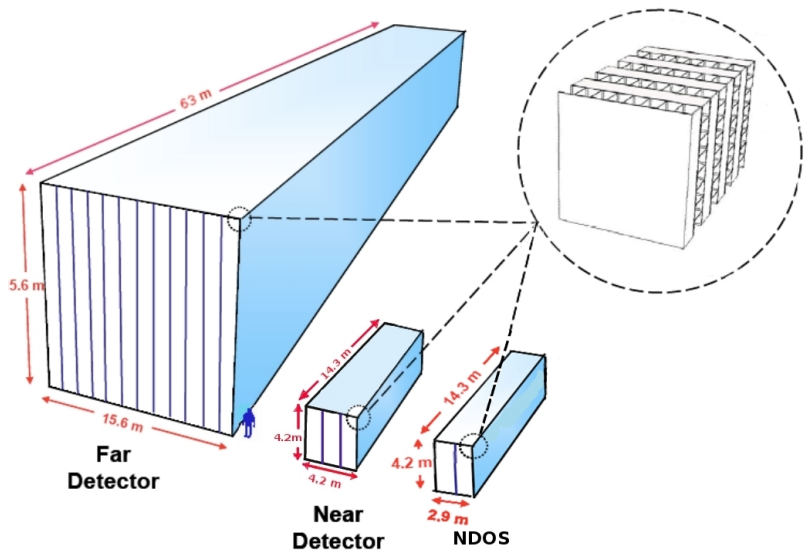
NOvA Experiment

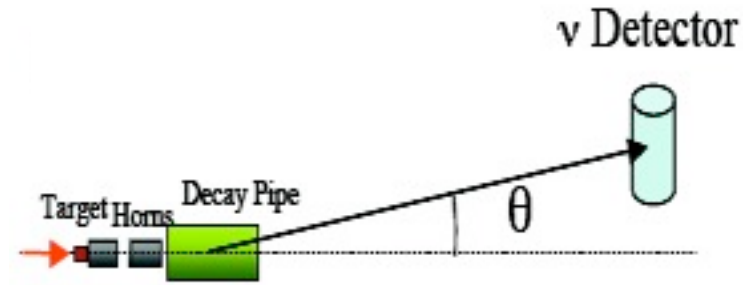
NuMI Off-axis ν_e Appearance Experiment

- Physics Goals for NOvA
- NOvA will study ν_e appearance in ν_μ and $\bar{\nu}_\mu$ beam.
- Measure the θ_{13} and search for the mass ordering.
- Search for the CP violation phase δ.
- Precise measurement of θ_{23} and Δm^2_{32}.
- Cross section measurements.



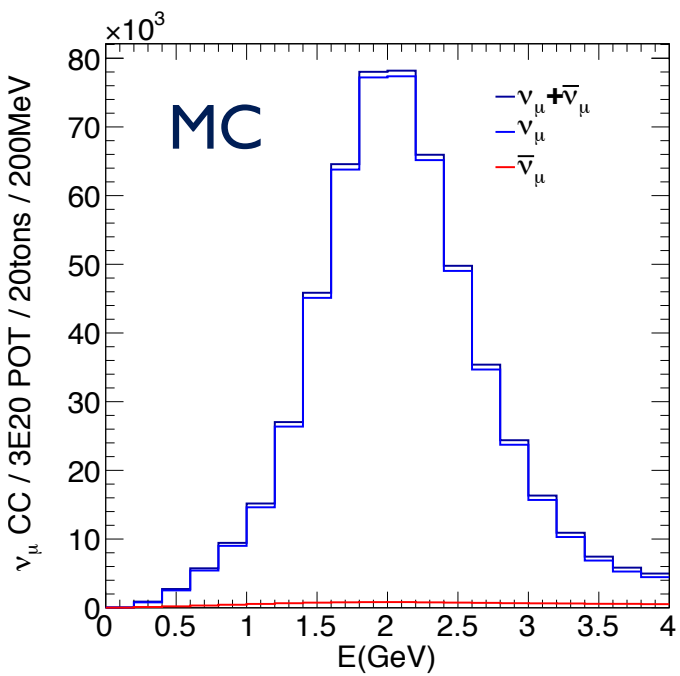
Off Axis Design

- NOvA uses off-axis design:
  - NOvA 14mrad off-axis angle.
  - Near detector prototype 110mrad.

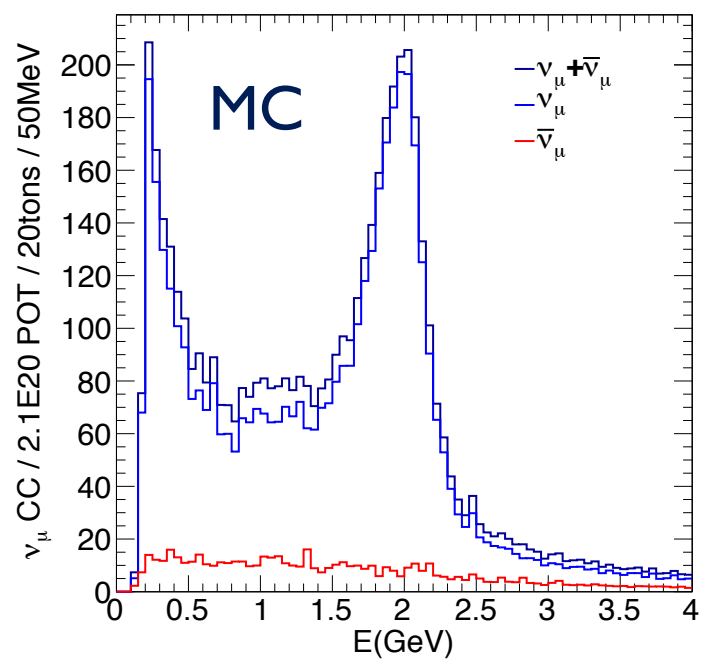


$$E_\nu = \frac{0.43 E_\pi}{1 + \gamma^2 \theta^2}$$

Near Detector energy spectrum



Near Detector Prototype energy spectrum

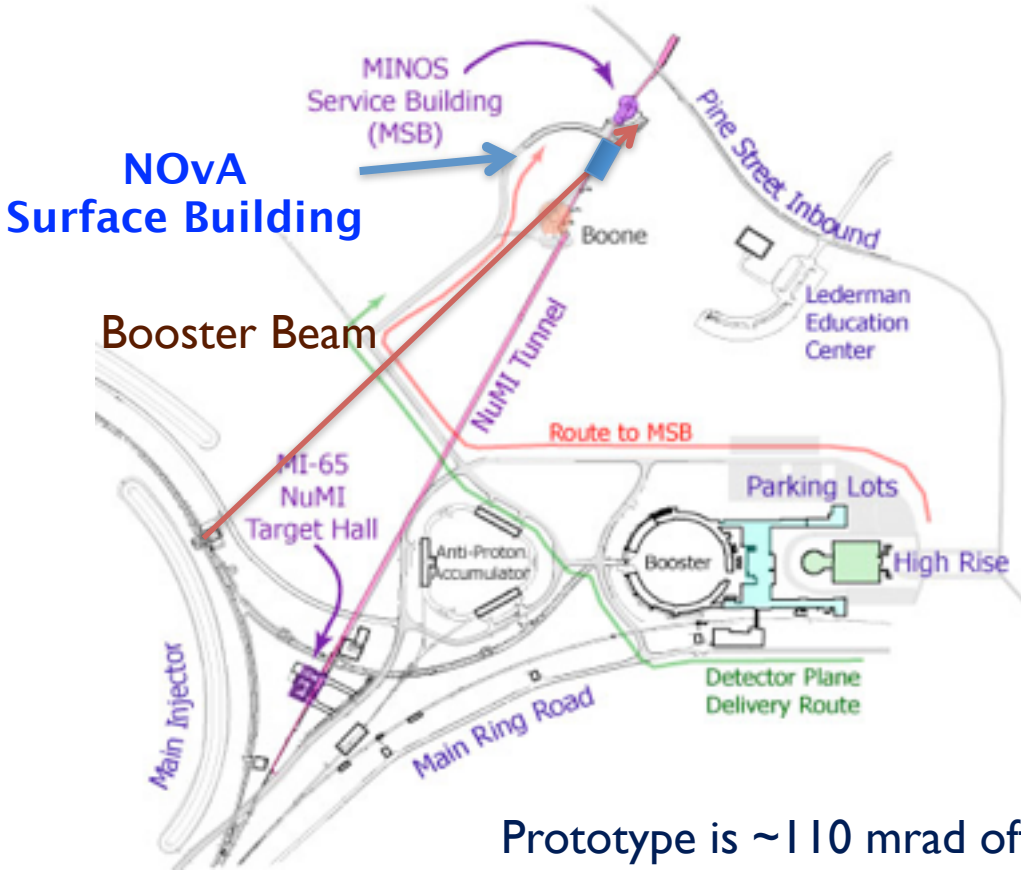


Near Detector Prototype

Detector located on the surface at Fermilab

Prototype detector collected data from December 2010 to April 30 2012

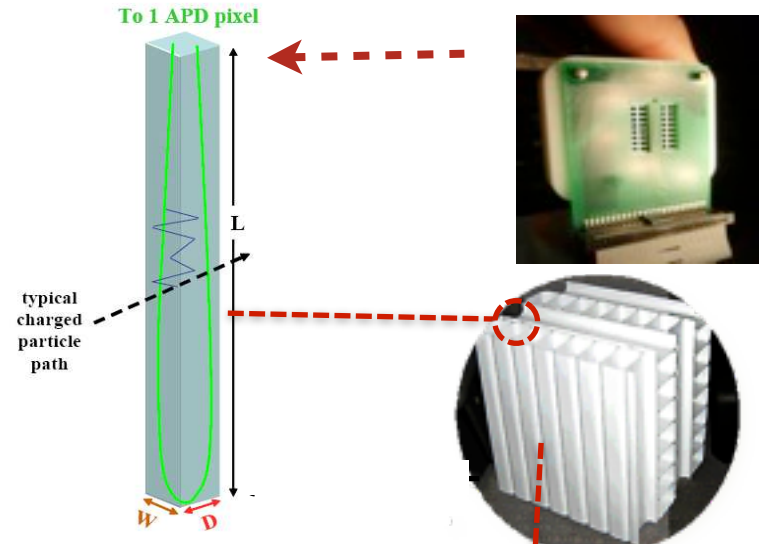
Thanks to AD for the delivered beam!



Prototype is ~110 mrad off axis of the NuMI beam and on axis of the Booster

Near Detector Prototype

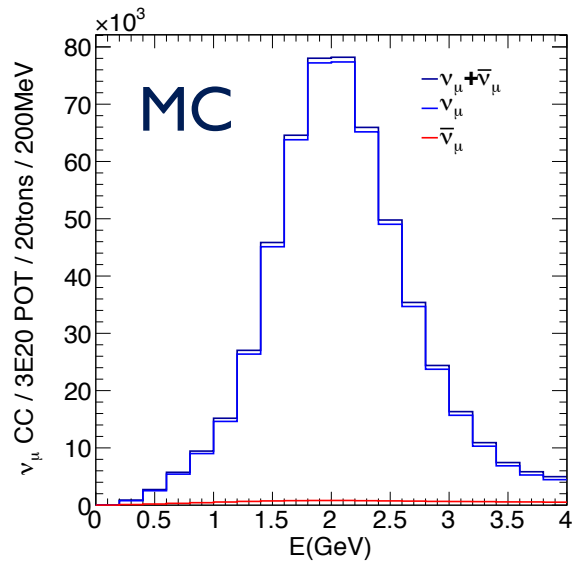
- Detector made of rigid plastic (PVC) module.
- Filled with liquid scintillator.
- Uses Avalanche photodiode (APD).

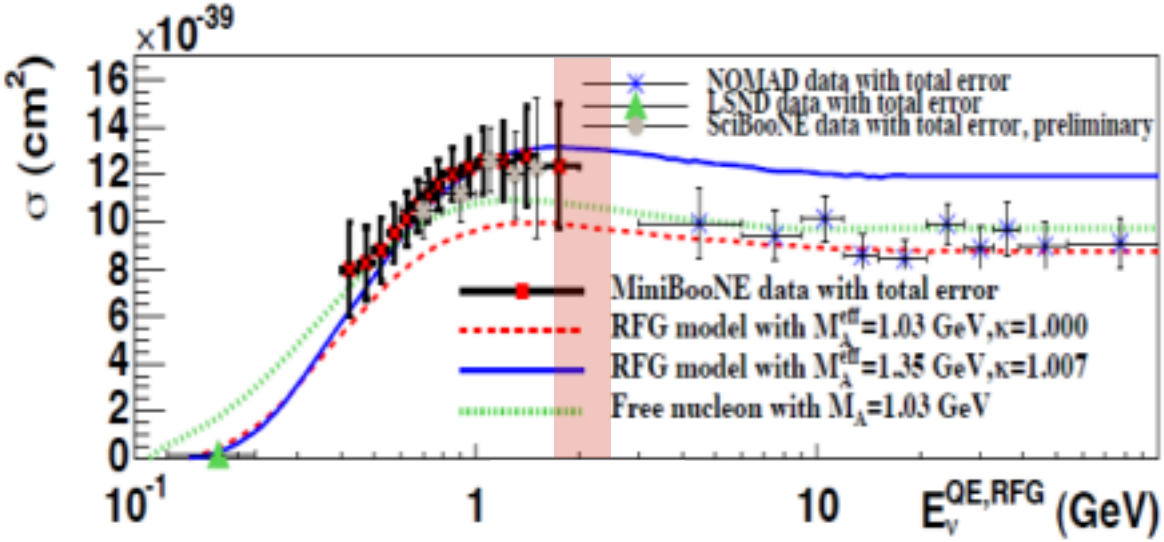


- Prototype detector used to test all detector systems: assembly technique, DAQ, APD installation, scintillator filling, electronic installation.
- Detector calibration.
- Investigate the detector design performance.
- Study Quasi-elastic interactions.

Motivation for QE Studies

- NOvA Near Detector energy spectrum is peaked at 2GeV.
- Prototype provides the opportunity to start the study of QE
- Experiments measured quasi-elastic cross section, they show some disagreements around 2GeV.
- NOvA Near Detector will collect high event rates, 3 years of ν_μ beam and 3 years of $\bar{\nu}_\mu$ beam.

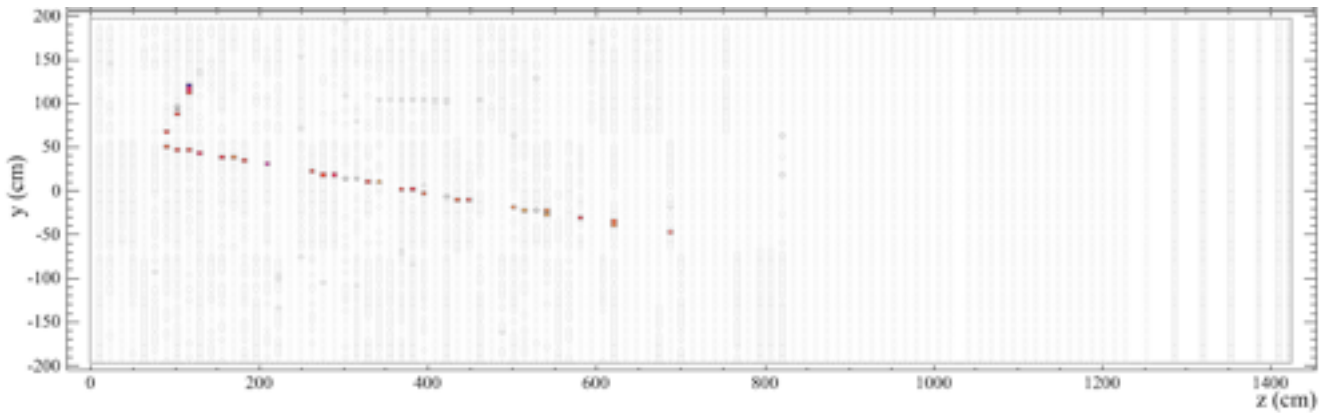




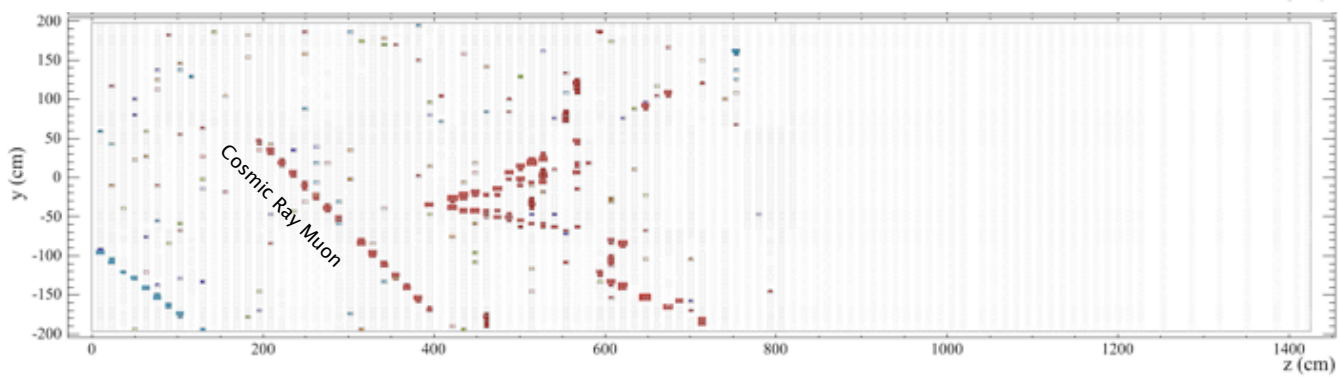
M. O. Wascko, Nuclear Physics B Proceeding Supplement 00

Event Topology

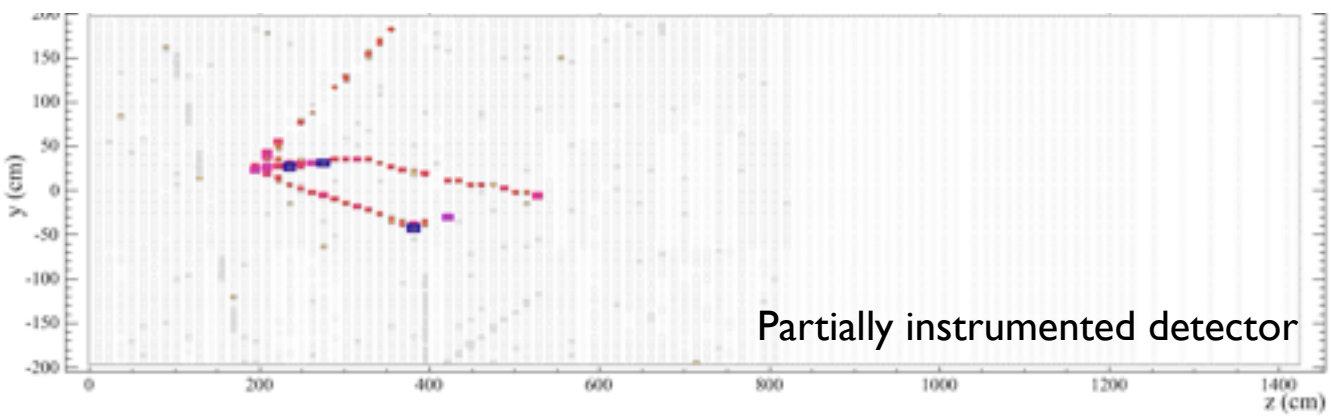
Data



CC candidate:
Long muon and short track proton candidate



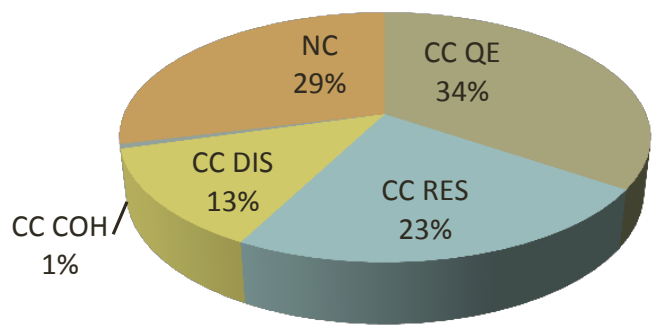
Multi-prong candidate:
NC candidate event



Multi-prong candidate:
Pions and a muon candidate

Quasi-elastic Studies

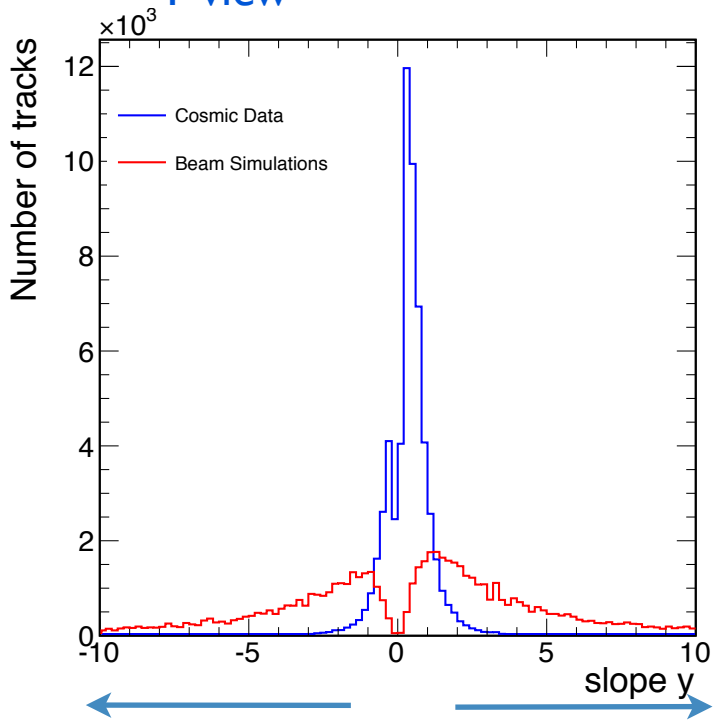
- Developing a selection criteria to identify the QE interactions and reject background.
  - Background for the QE interactions:
    1. Cosmic muons.
    2. Resonance (RES), Deep Inelastic (DIS), Neutral Current (NC), Coherent (COH) interactions.



Cosmic Background

- Cosmic muons:
  - Prototype detector is exposed to cosmic rays, we use a selection to reject the cosmic background: timing cut and the slope of the tracks in the Y view.

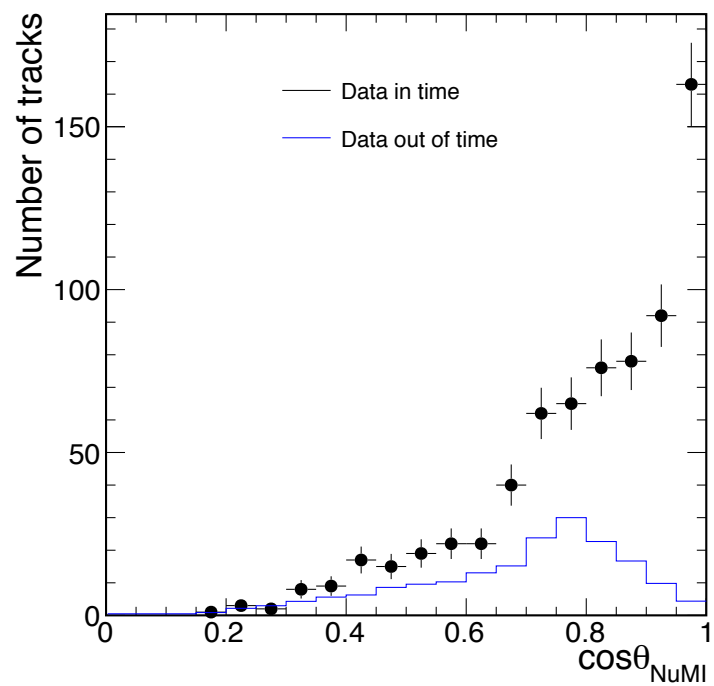
Slope of the tracks in the Y view



slope>1 and slope <-1

$$slope = \frac{Z2 - Z1}{Y2 - Y1}$$

Reconstructed particle tracks angle with respect to the beam direction



Quasi-elastic Selection

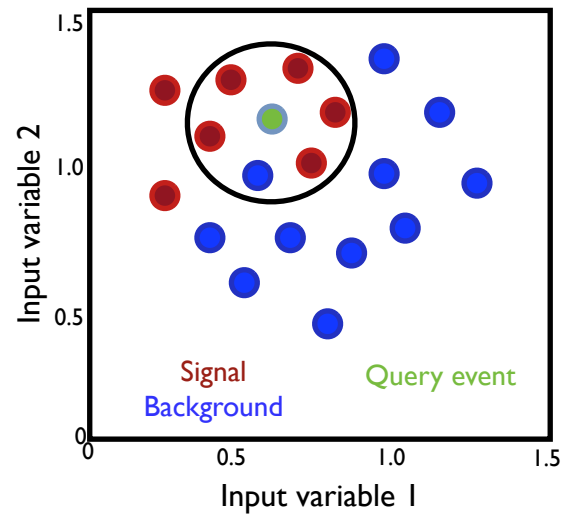
- Using a k Nearest Neighbors Algorithm (kNN) to select muons from QE interactions.
- Nearest Neighbors Algorithm searches for k events that are closest to a query event using the Euclidean distance

$$R = \left(\sum_{i=1}^{n_{var}} |x_i - y_i|^2\right)^{\frac{1}{2}}$$

- Estimates a multidimensional probability density function by counting the number of signal and background events in a small neighborhood around the query event

$$\mathrm{kNN_{ID}} = \frac{k_S}{k_S + k_B}$$

where k_S and k_B are the number of signal events and the number of background events.



Quasi-elastic Selection

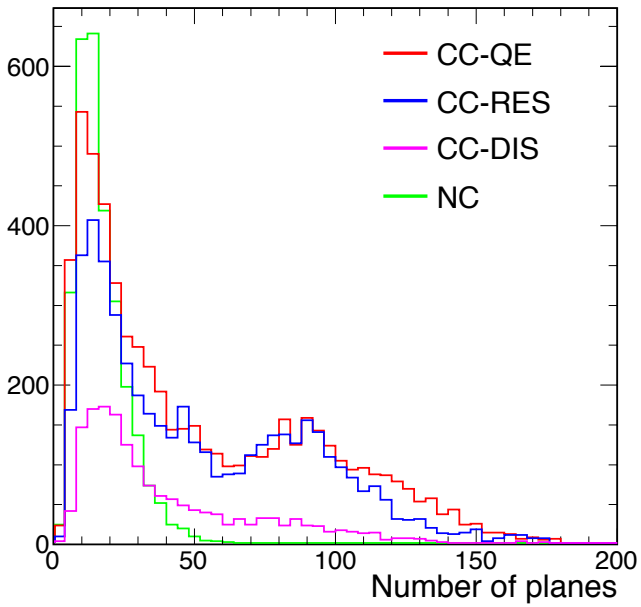
- Preselection cuts:
  - Fiducial volume: 50 cm from the edge of the detector.
  - One reconstructed track.
  - Cosmic cut (slope y <-1 and slope y >1).
  - Fully contained events.
- Using a kNN algorithm to select the QE interactions.

Studies in MC use channel masks for a partially instrumented detector

Three input variables

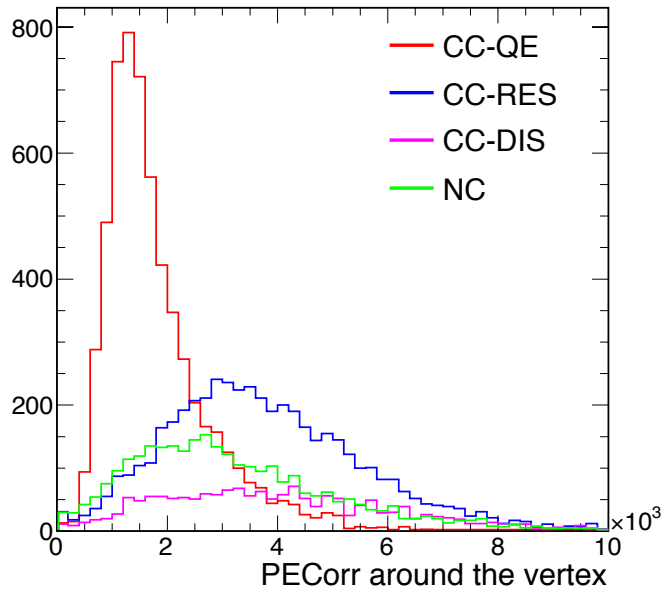
Simulations

Number of planes



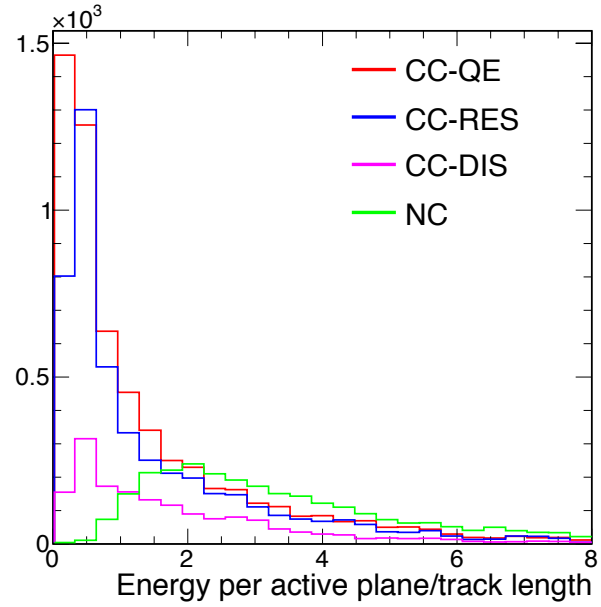
Pions from NC interactions travel shorter distances than CC

Energy around the vertex



RES, DIS and NC deposit more energy around the vertex

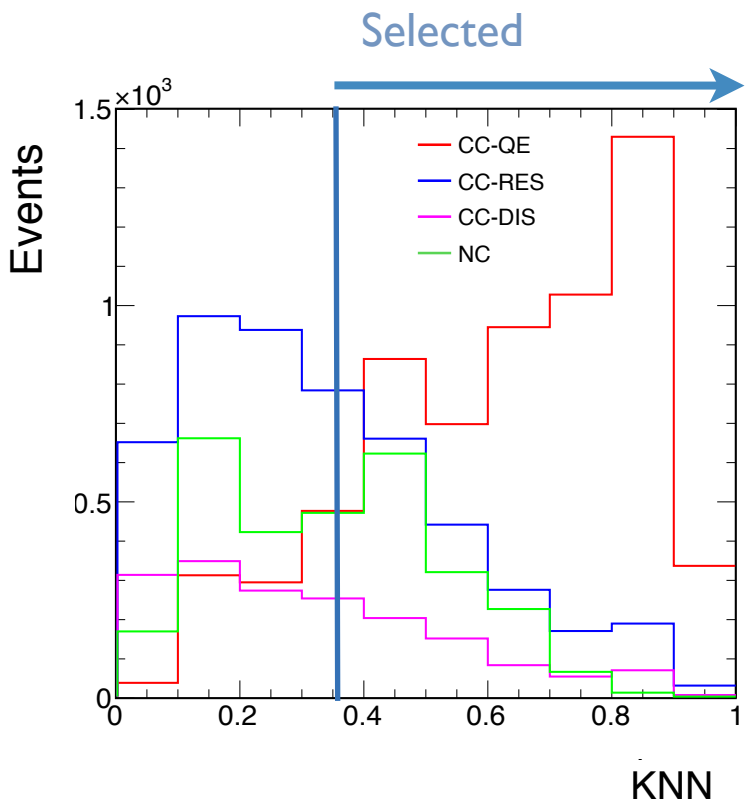
Mean energy per active plane normalized to track length

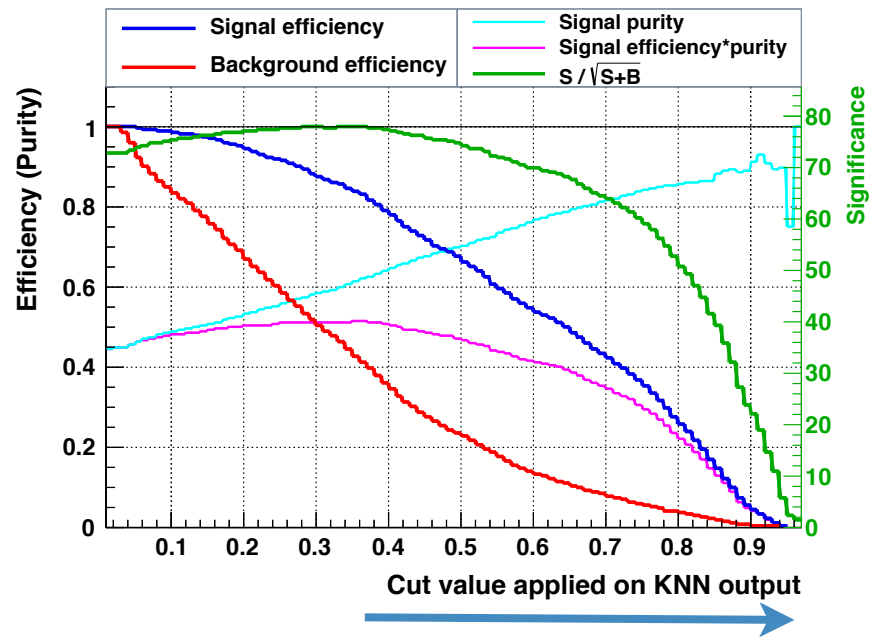


NC interactions deposit more energy per plane

Quasi-elastic Separation

- After training the kNN with the input variables on MC samples QE, RES, DIS and NC events apply it to a different MC sample.



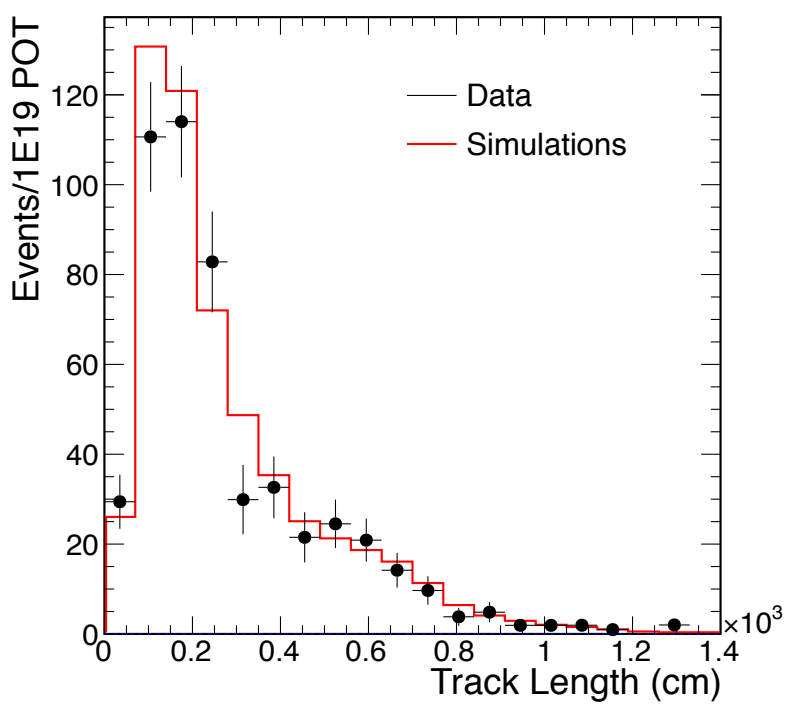


For a partially instrumented detector:
Efficiency 85%
Purity 60%

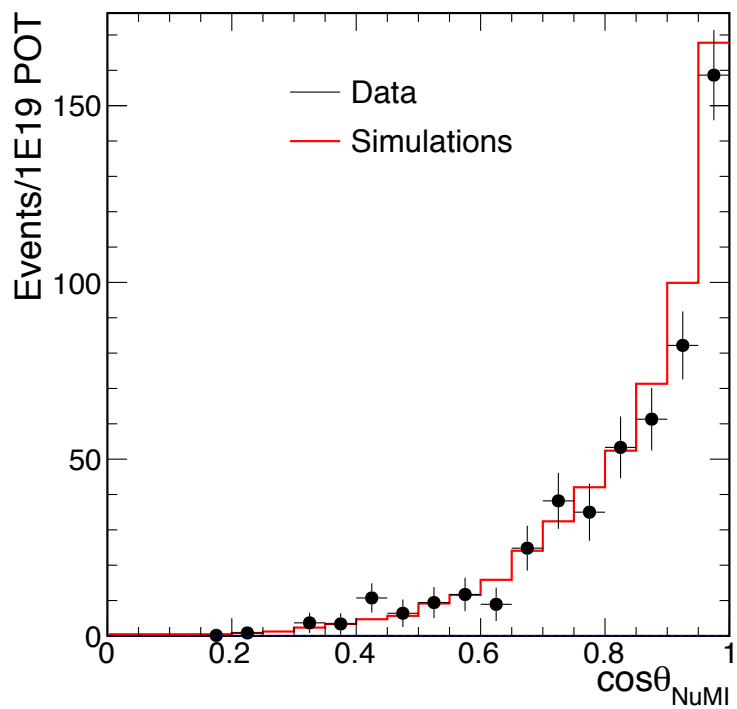
NuMI Neutrino Data

- Prototype collected data for different beam configurations, neutrino and anti neutrino.
- Examples of Data - MC comparisons for the neutrino period from April 2011.
- A selection has been applied to the Data and MC

Track Length

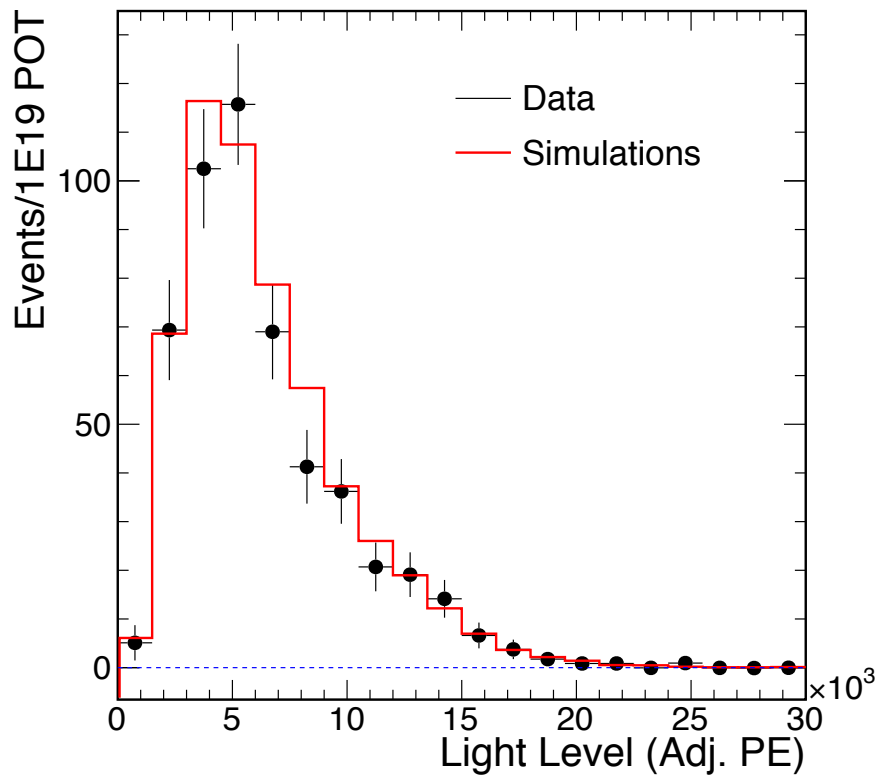


Reconstructed particle tracks angle with respect to the beam direction



NuMI Neutrino Data

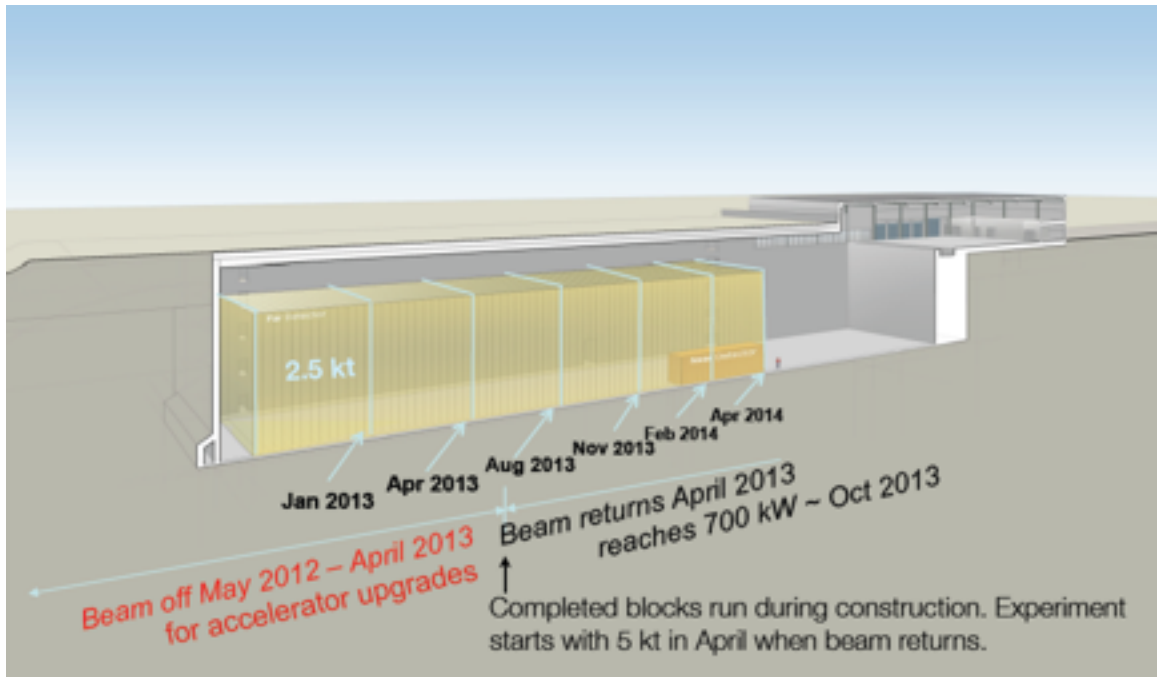
- Visible energy on the detector.
- Neutrino candidate data agree well with simulations.



- Quasi-elastic studies using the Prototype data are underway.

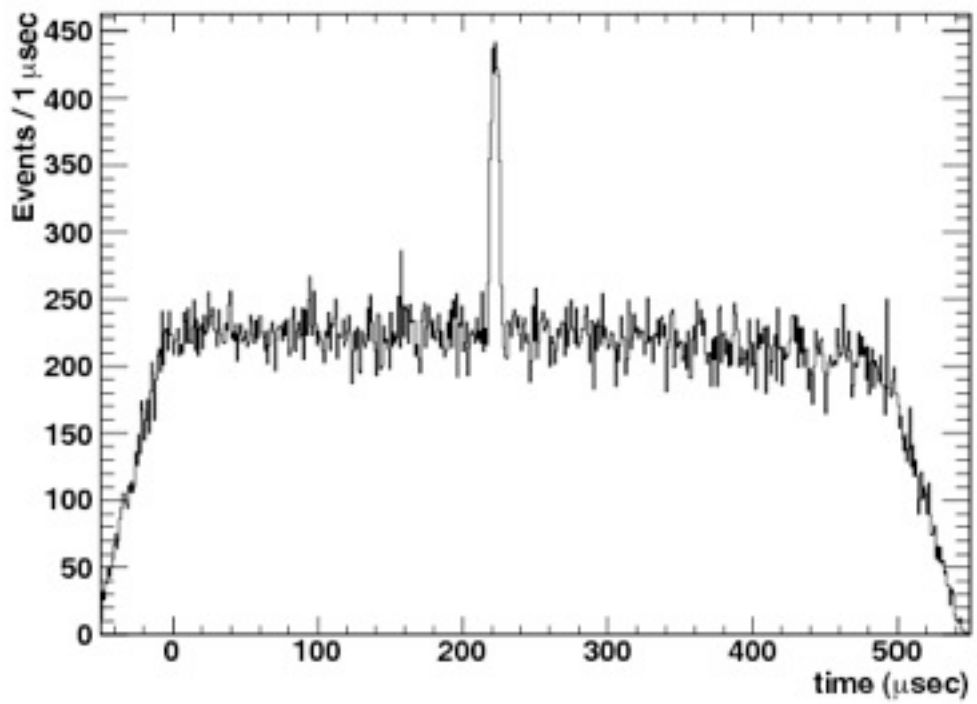
Conclusions

- Studying the Quasi-elastic interactions in the NOvA prototype detector.
- Near Detector will be built and will collect much higher statistics.
- Near Detector construction and installation by next year.
- Time line for the NOvA detectors



Neutrino Data from NuMI

- Data trigger for the NuMI beam is 500 μsec window.
  - The neutrino spill time is 10 μsec.
  - The peak is seen at 222 μsec.
- A time window of 10 μsec is applied to define the data in time.



Assembly and Operations

- Used prototype detector to test assembly techniques and detector parts:
  - Redesigned module manifolds and changed module pressure testing procedure to avoid potential cracks.
- Gained experience in qualifying and filling scintillating oil.
- Tested APDs in realistic operating conditions:
  - Developed surface coating for bare APDs to protect the silicon surface from potential contact with contaminants.
  - Added an active air drying system to keep out condensation due to cooling.