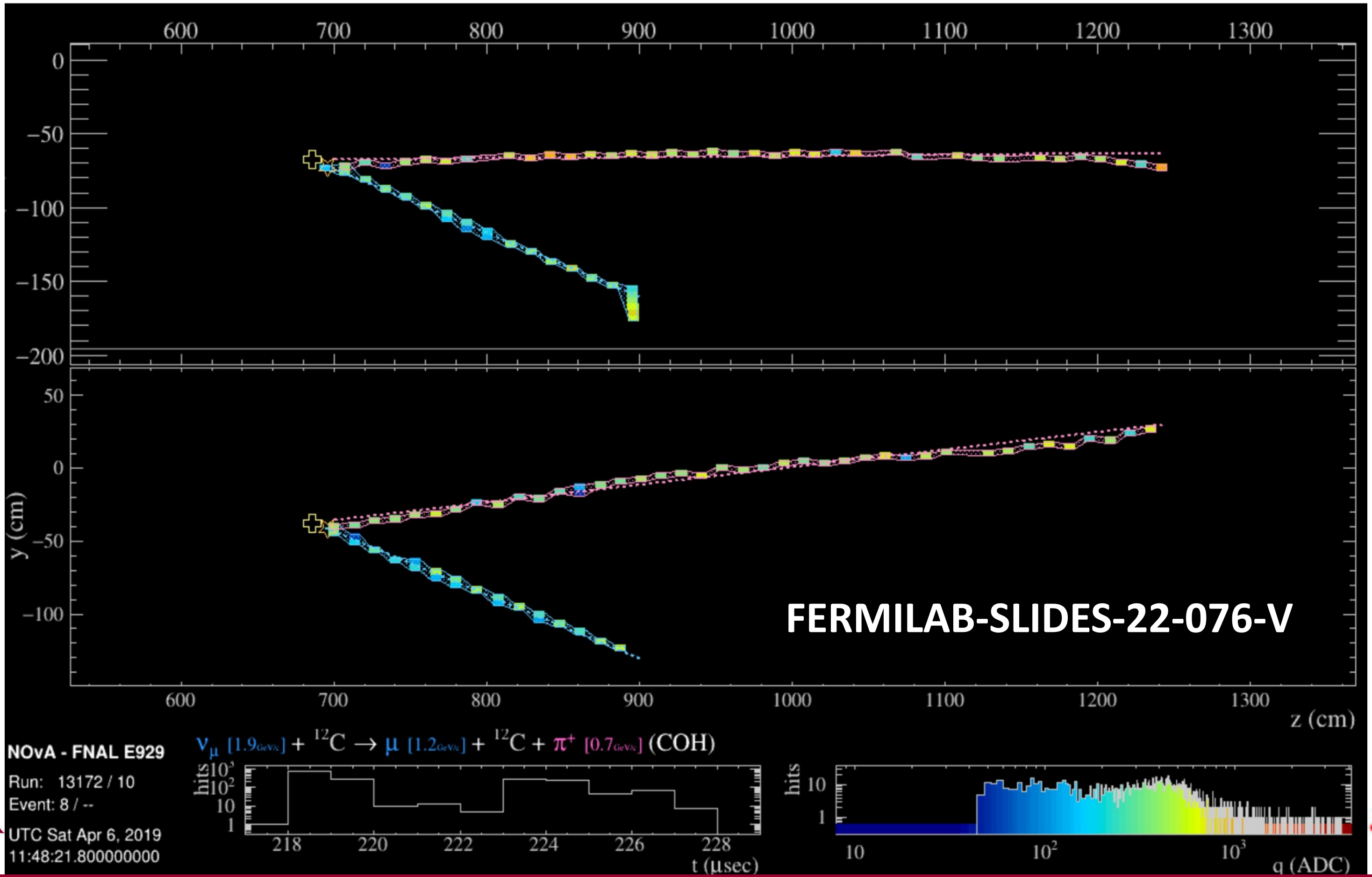
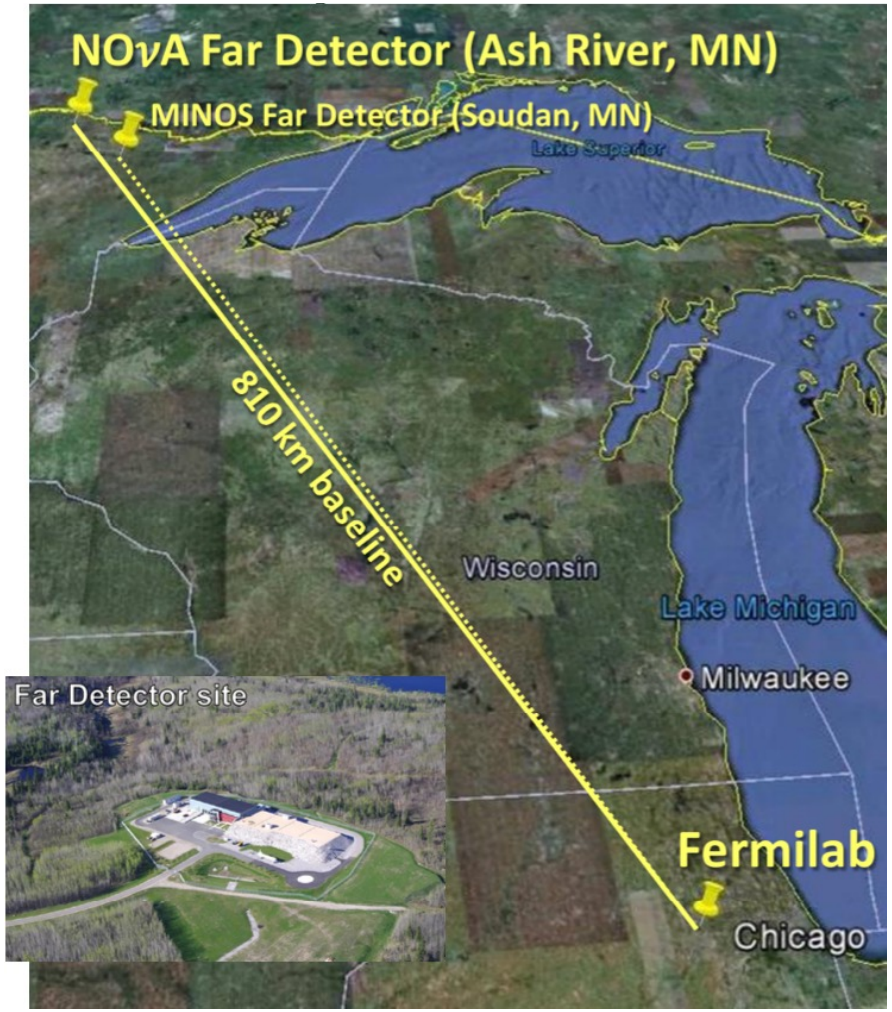
Status of the measurement of the ν_μ CC Coherent π^+ Production in the NOvA Near Detector

On behalf of the NOvA collaboration



UNIVERSITY OF SOUTH CAROLINA

The NOvA Experiment

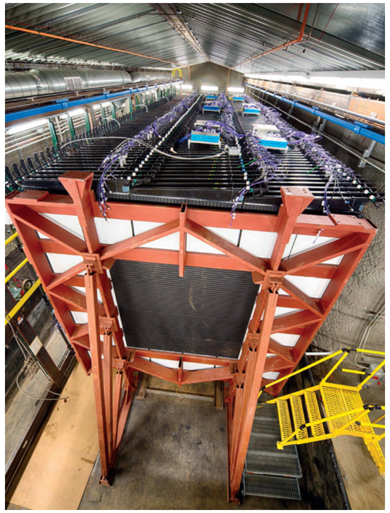


- A neutrino oscillation experiment with 810 km baseline, two structurally identical detectors, NuMI ν_μ 700 kW beam, off-axis

Main physics goals:

- $\nu_\mu \rightarrow \nu_e$ Oscillations
- Cross-section studies
- Sterile Neutrino studies
- Exotics
- More...

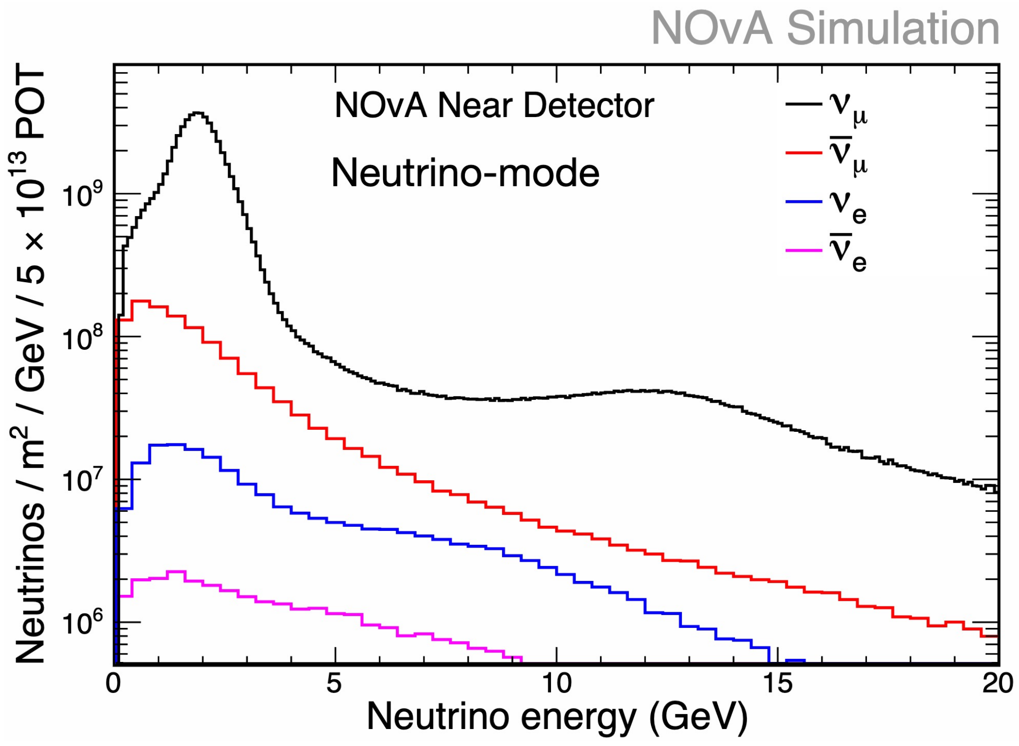
Far Detector

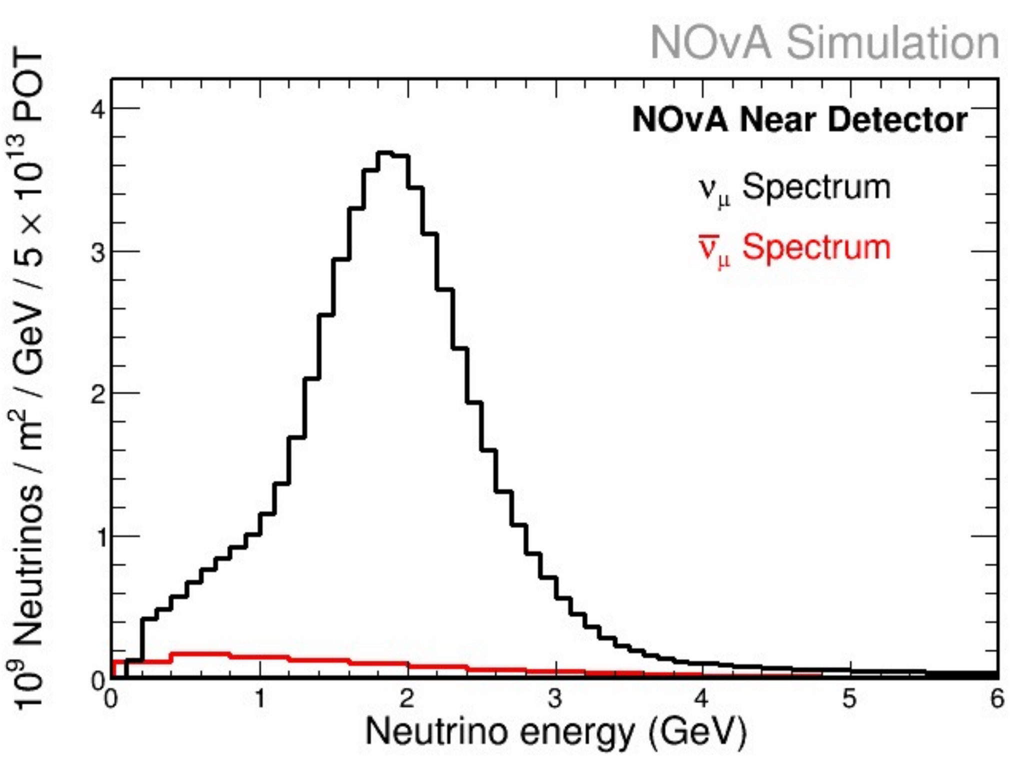


Near Detector

High statistics collected at the Near Detector can be used to study neutrino cross sections!

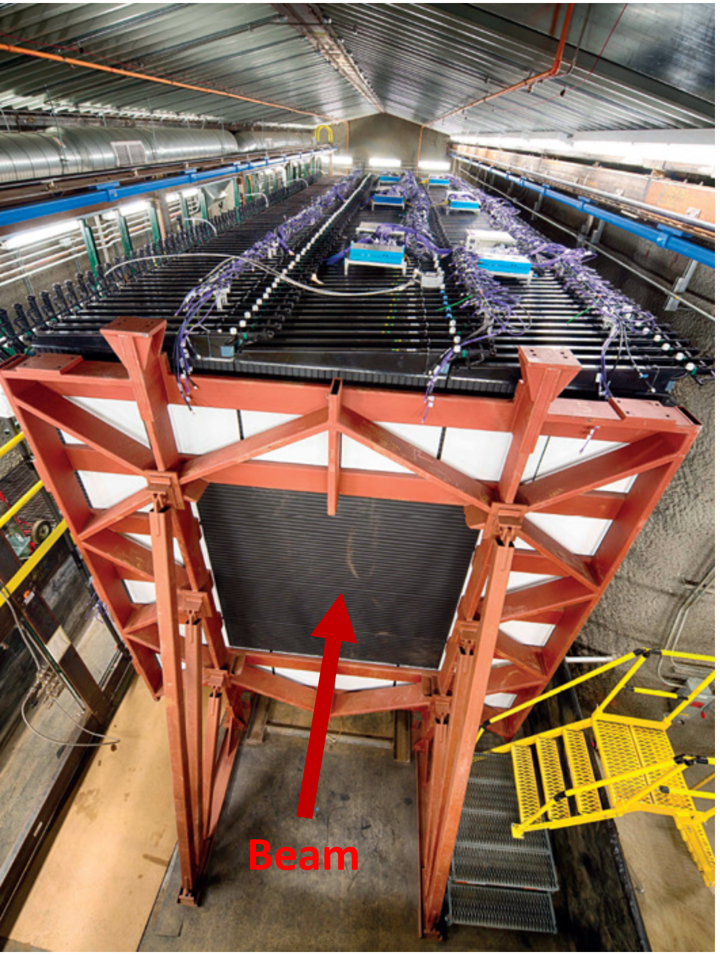
NOvA Beam Flux



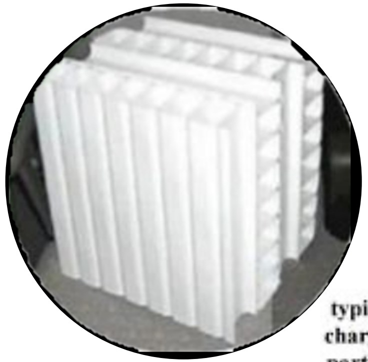


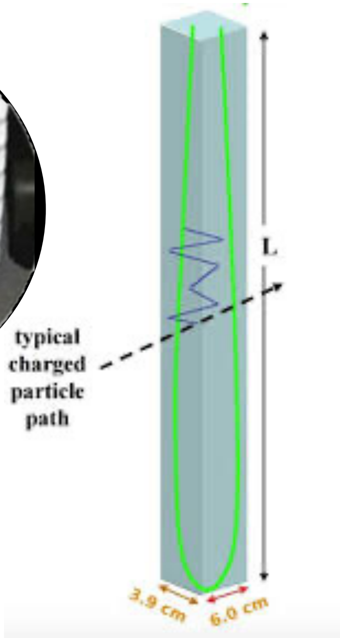
- Near detector is 14.5 mrads off-axis and flux has a peak between 1 and 5 GeV
- receives high neutrino flux contains 96% pure ν_μ beam and 1% of ν_e and $\bar{\nu}_e$
- provides a rich data set for measuring cross sections

The NOvA Near Detector



NOvA Near Detector located at MINOS underground facility

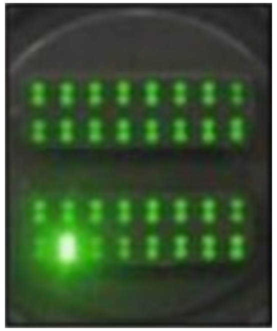




Alternating horizontal and vertical planes for 3D reconstruction

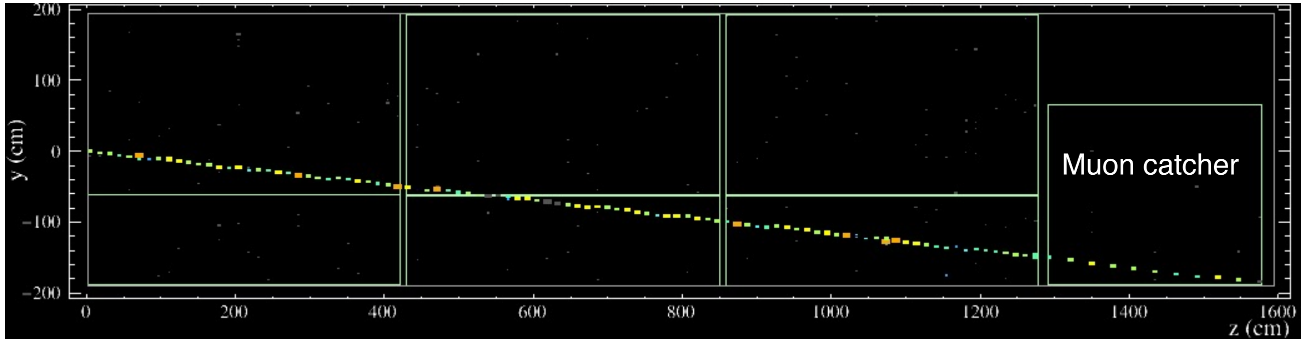
C-H	77%
Cl	16%
TiO_2	6%

Detector Composition



Array of wavelength shifting fibers ends interface with avalanche photo diode

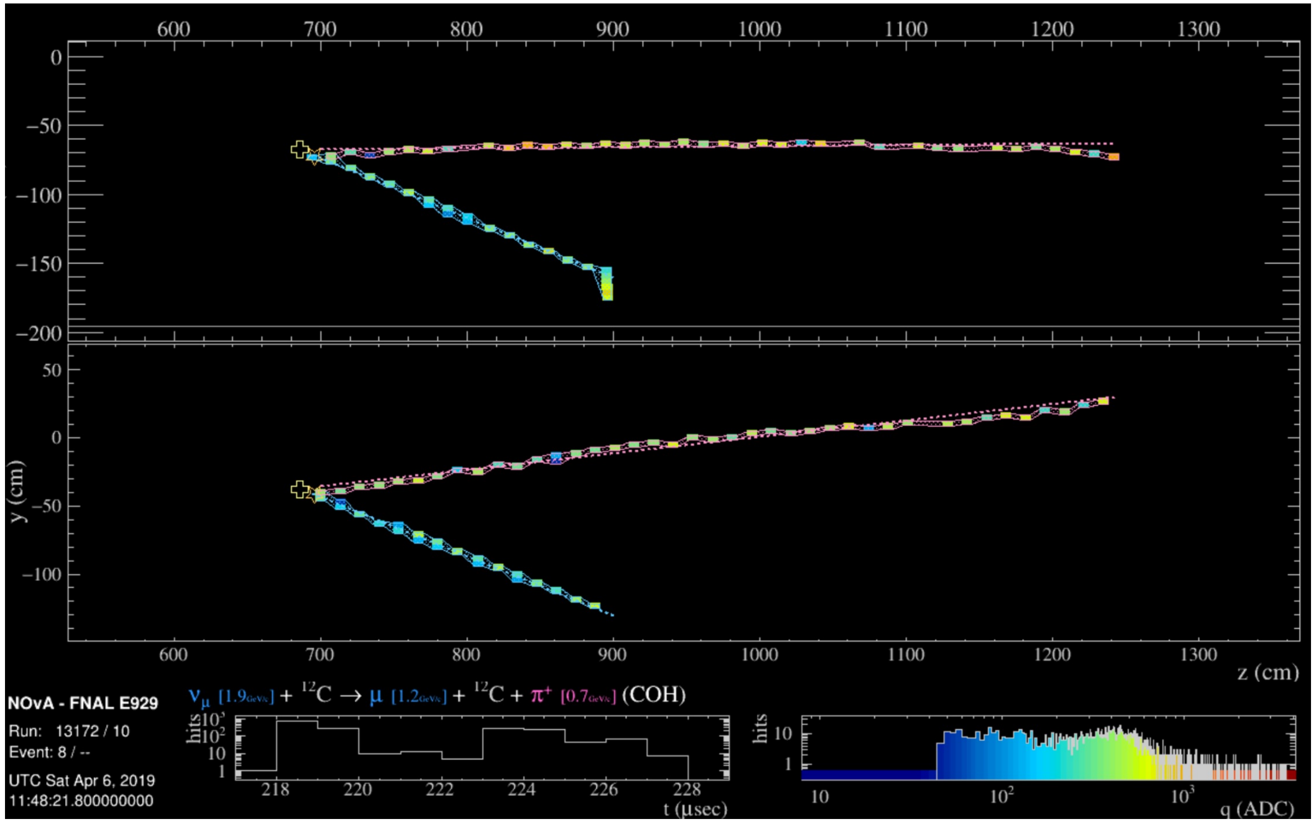
Wavelength shifting fibers read out by a single pixel on Avalanche Photodiode



Side view of NOvA Near Detector and Muon catcher

Charged Current Coherent Interaction

- An inelastic interaction produces a lepton and a pion in the forward direction
- Nucleus (A) stays in its initial state

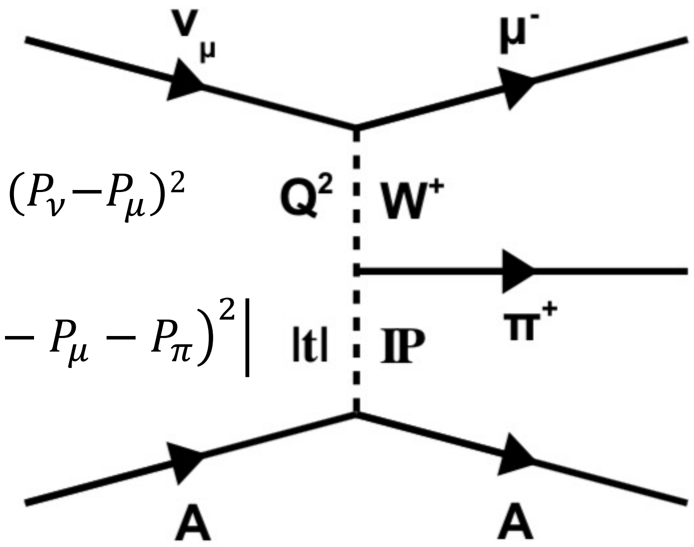


$$\nu_l + A \rightarrow l^- + \pi^+ + A$$

$$\bar{\nu_l} + A \rightarrow l^+ + \pi^- + A$$

$$Q^2 = (P_\nu - P_\mu)^2$$

$$|t| = \left|(P_\nu - P_\mu - P_\pi)^2\right|$$



MINERVA Collaboration [arXiv:1409.3835]

- The square of the four-momentum exchanged with the nucleus, |t|, must be small

Motivation

- **Theoretical Interests:**

Coherent models are not well tested

Provides detailed tests for hypothesis such as:
- CVC (Conserved Vector Current)
- PCAC (Partially Conserved Axial Current)
- HDM (Hadron Dominance Model)

- **Experimental Interests:**

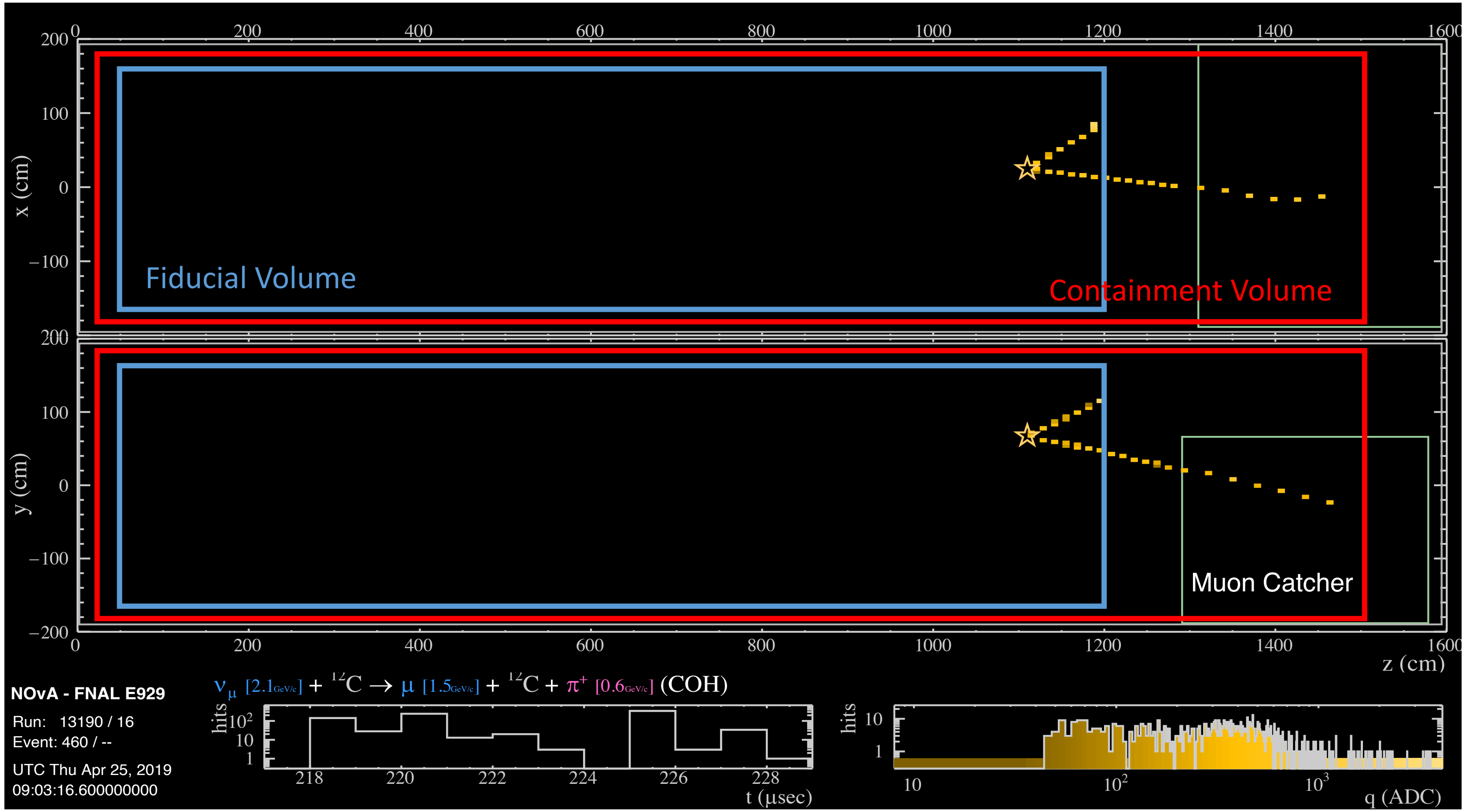
Reconstructing E_ν is more accurate compared to other channels (i.e. $E_\nu = E_\mu + E_\pi$)

NOvA cross-section results will be useful for upcoming DUNE experiment

Coherent pion production can be mistaken for quasi-elastic scattering when the π^+ is misidentified as a proton or is not detected

For isoscalar nuclei coherent π^+ and π^- cross sections are same

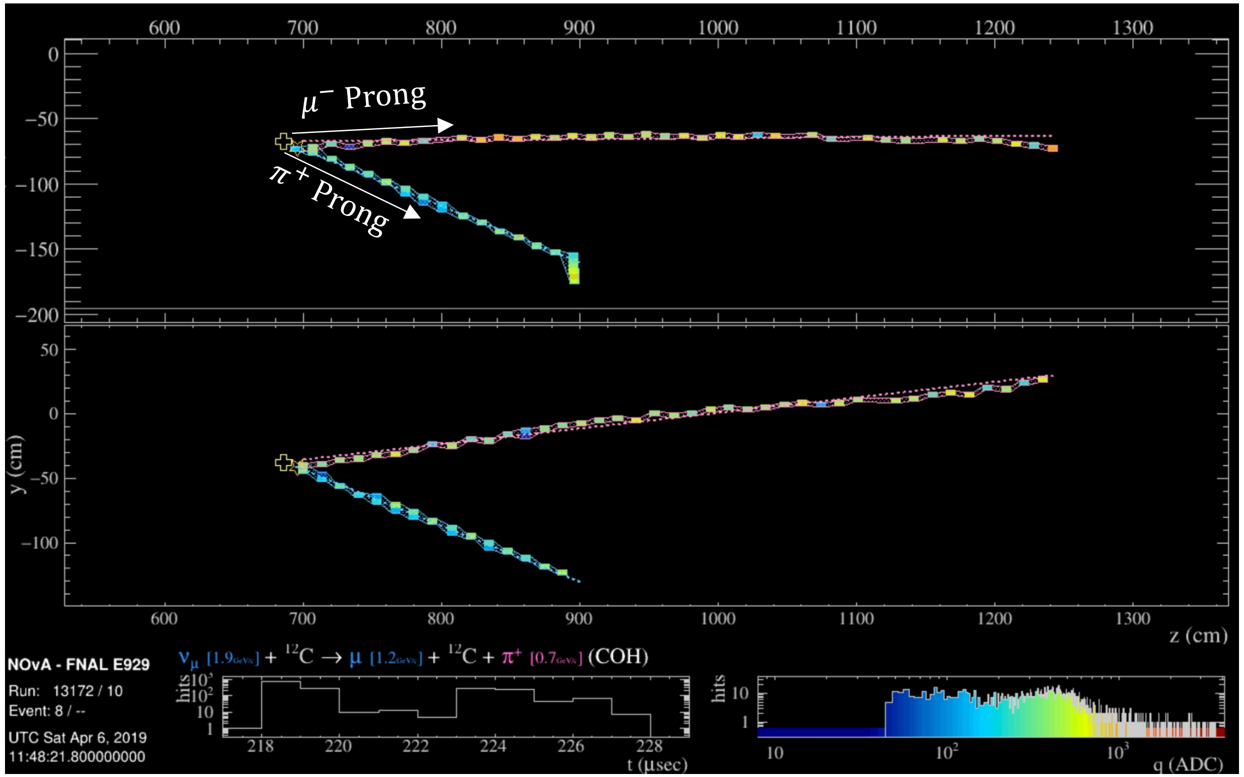
Signal and Background Definitions



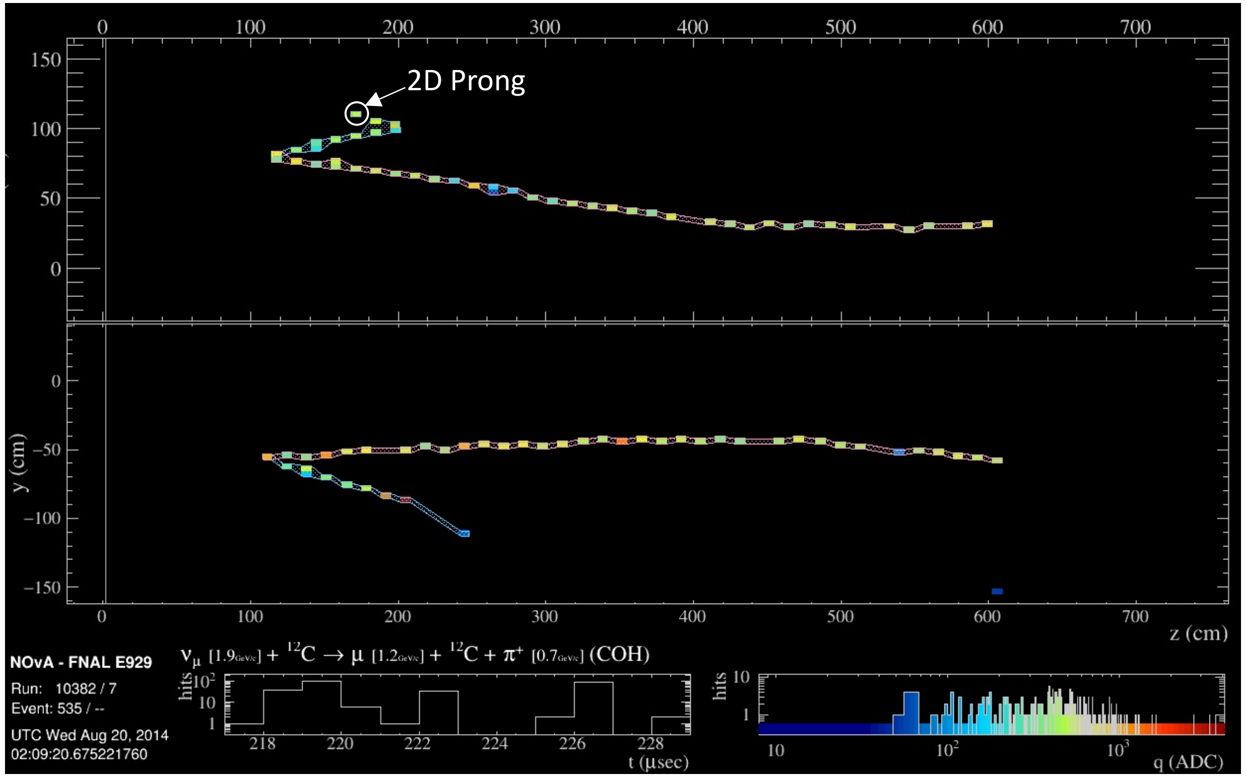
- Signal definition:

  ν_μ CC coherent interactions formed within the fiducial volume

Current Topology



Charged Current Coherent event reconstructed as two 3D prongs



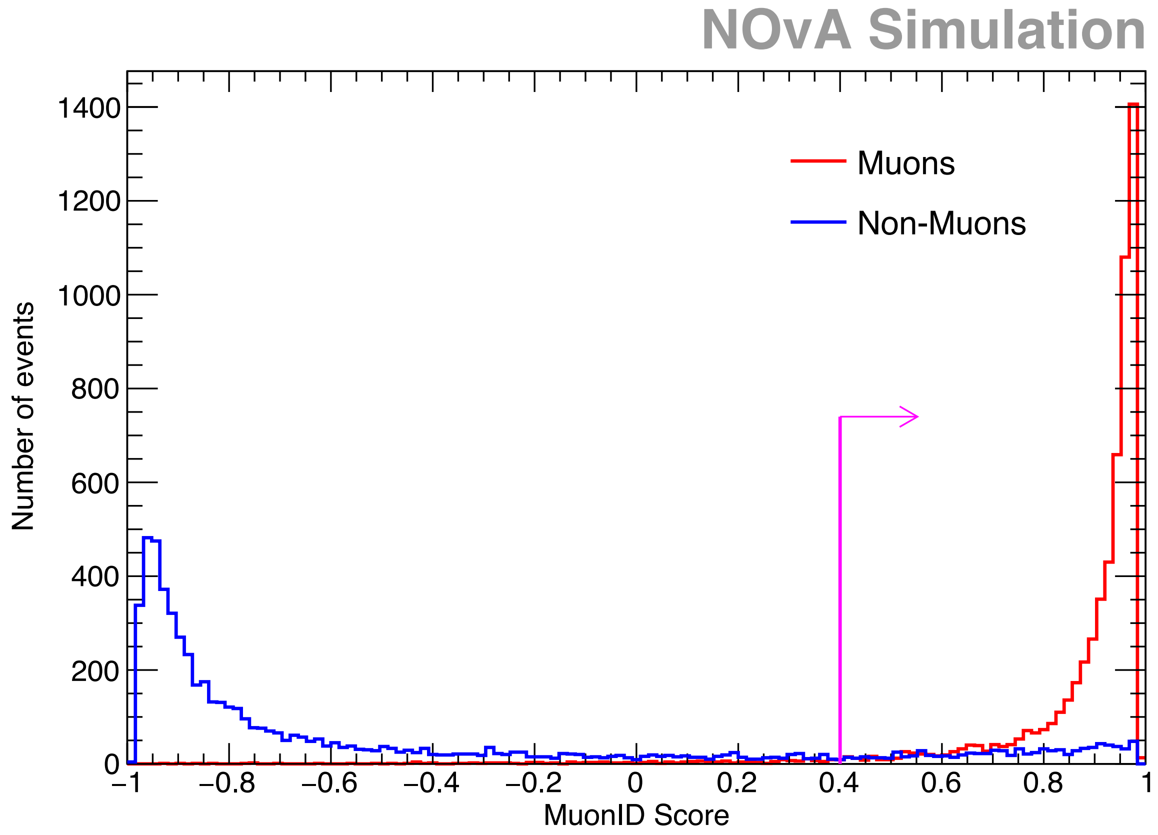
Charged Current Coherent event reconstructed as two 3D prongs and one 2D prong will not be considered

- Currently analyzing golden event sample

Note: ***Prong is a reconstructed particle candidate that has directional and reconstructed information***

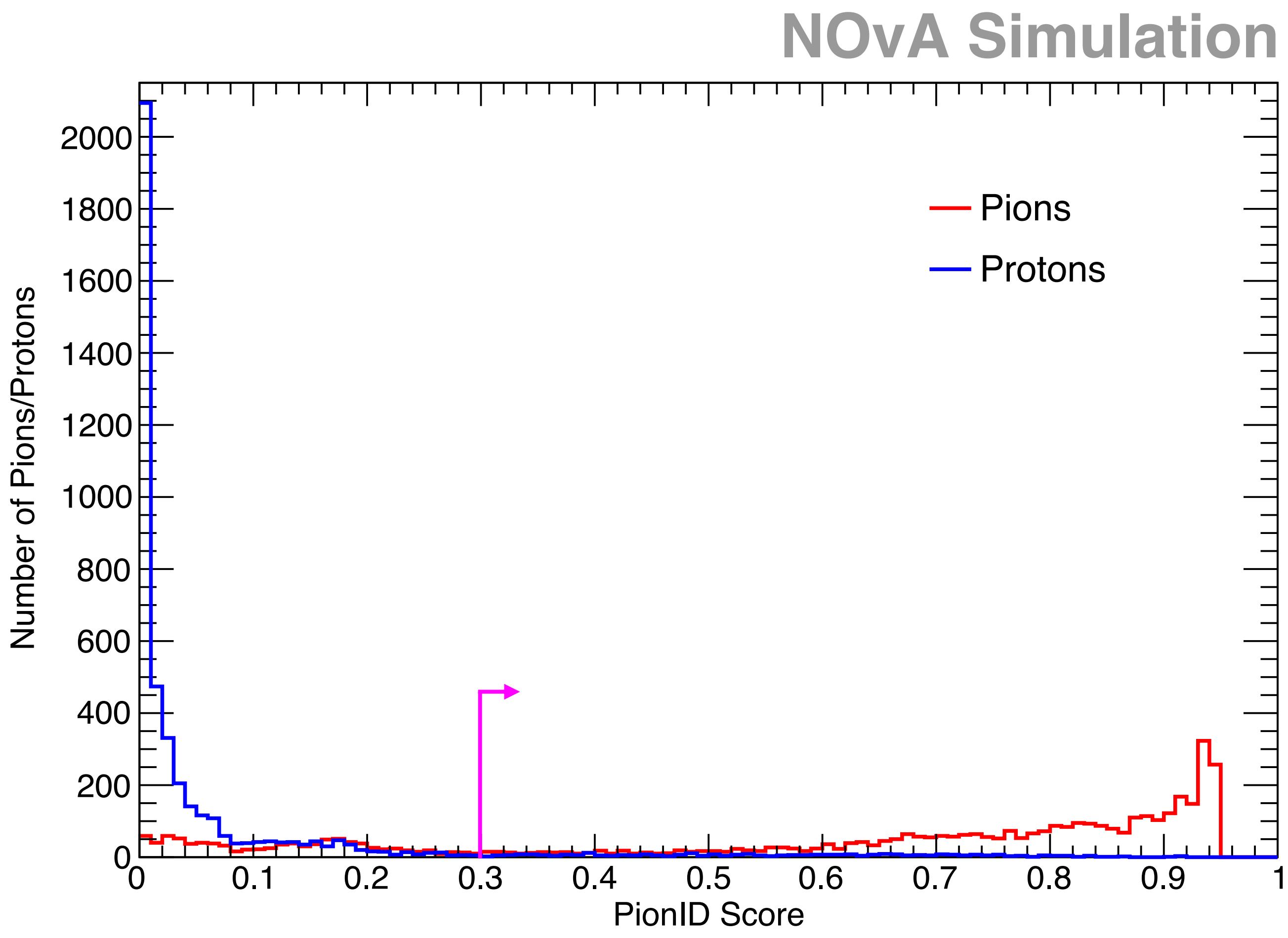
Event Selection

- Created following cuts to separate Signal and the Backgrounds:
  1. Basic Cuts:
     a) Data Quality Cut
     b) Fiducial Cut (As shown in slide 6)
     c) Two Prong Cut (To select clean events with only 2 reconstructed prongs)
     d) Containment Cut: (As shown in slide 6)
  2. Muon ID Cut (BDT trained score made by using dE/dx log likelihood as input to separate Muons from other particles)
     a) Track with the highest MuonID Score will select as Muon Candidate
     b) MuonID Cut value was optimized to separate Muons



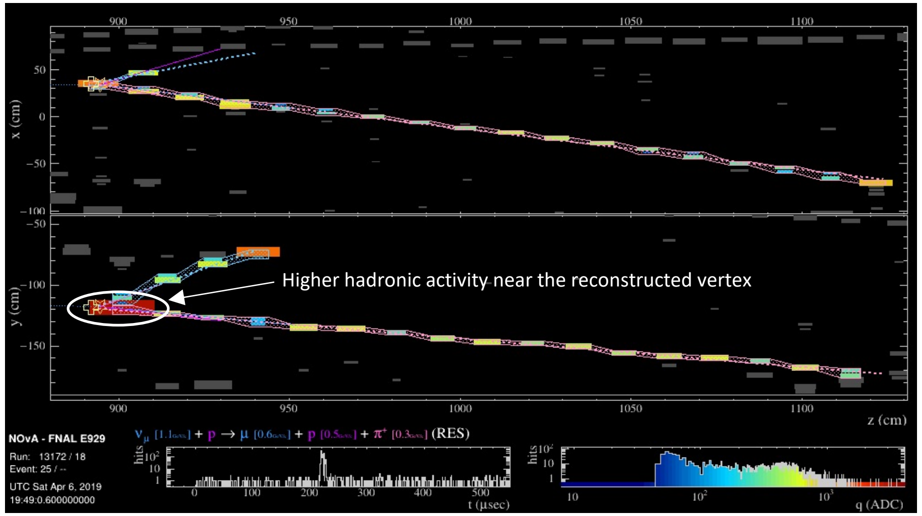
Event Selection (continued..)

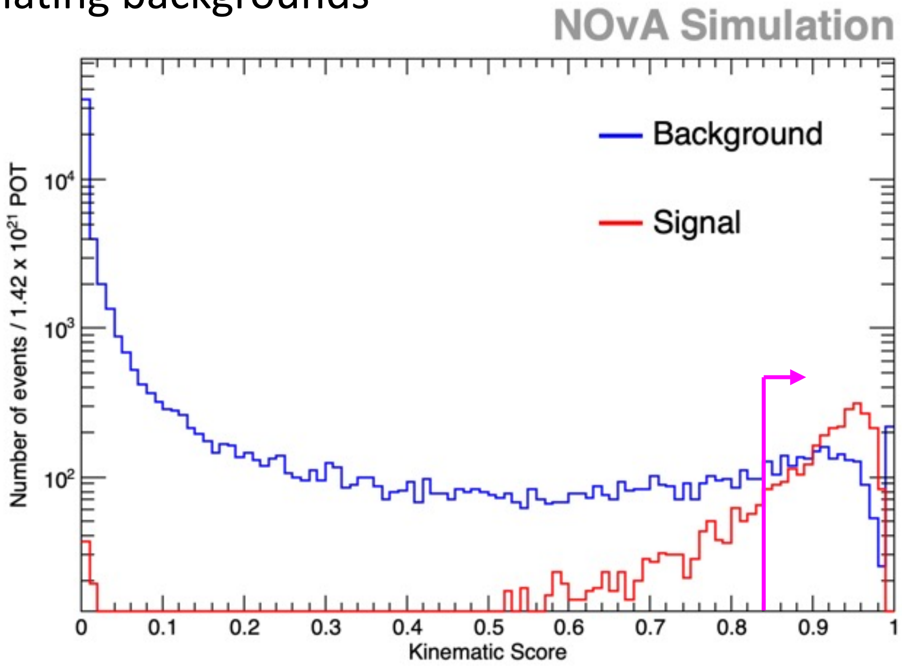
3. PionID Cut:
   a) BDT trained by using hit energy depositions of pion candidates.
   b) Cut value mainly defined to remove protons present in pion candidates from CC QE and CC DIS backgrounds



Event Selection (continued..)

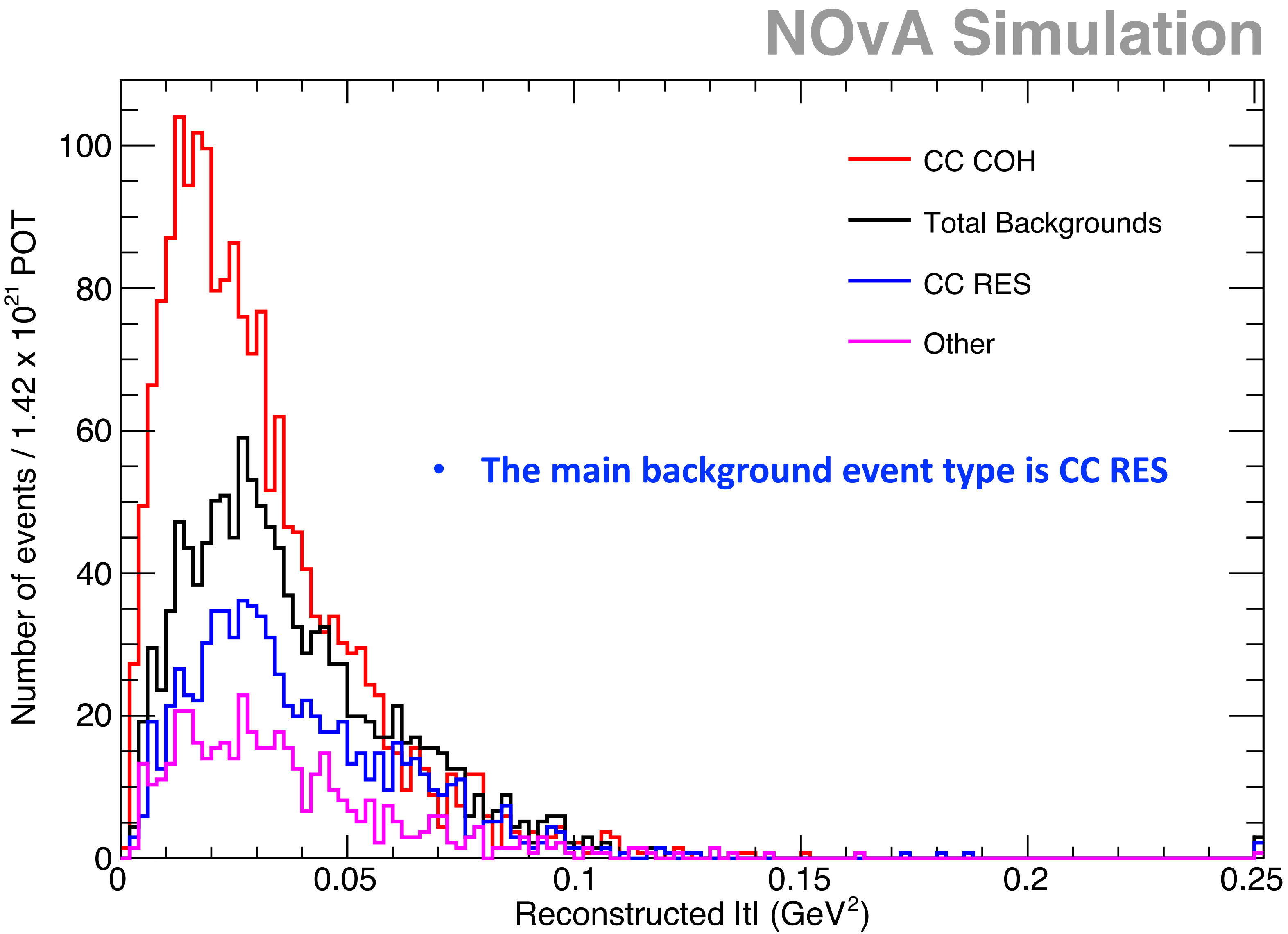
3. Hit Score Cut:
   a) BDT trained by using hit energy deposition to check the hadronic activity around the reconstructed vertex
   b) Cut value mainly defined to remove CC RES dominating backgrounds





4. Kinematic Cut:
   a) BDT trained by using kinematics such as missing transverse momentum, transverse momenta, opening angle and visible angle

Reconstructed |t| (Signal Vs Background)



- The main background event type is CC RES

Summary

- Among all the neutrino-nucleus interactions, CC Coherent interactions have lowest |t|
- After applying event selection, dominant background is CC RES

Cut Name	CC COH	CC RES	Other	Total Bkgd.	Purity (%)	Rel. Eff. (%)
Basic Cuts	4778	80614	272003	352617	1.34	100
Muon ID	4290	65155	193066	258221	1.63	89.77
Pion ID	3211	18285	38820	57105	5.32	67.2
Hit Score	2844	6716	33478	40194	6.61	59.52
Kinematic	1890	812	492	1304	59.17	39.54

- Current purity: ~59% with total signal events: 1890
- MINERvA experiment: Purity: 54% with total signal events: 1628

Next Steps

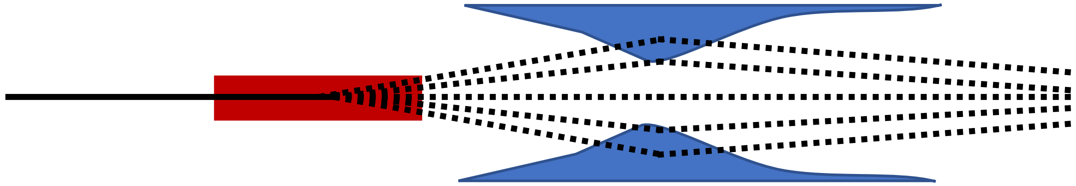
- Finalizing event selection
- Defining kinematic phase space
- Studying full assessment of systematic uncertainties (Calibration..etc)
- Defining background control samples and look at data

Thank you!

Questions?

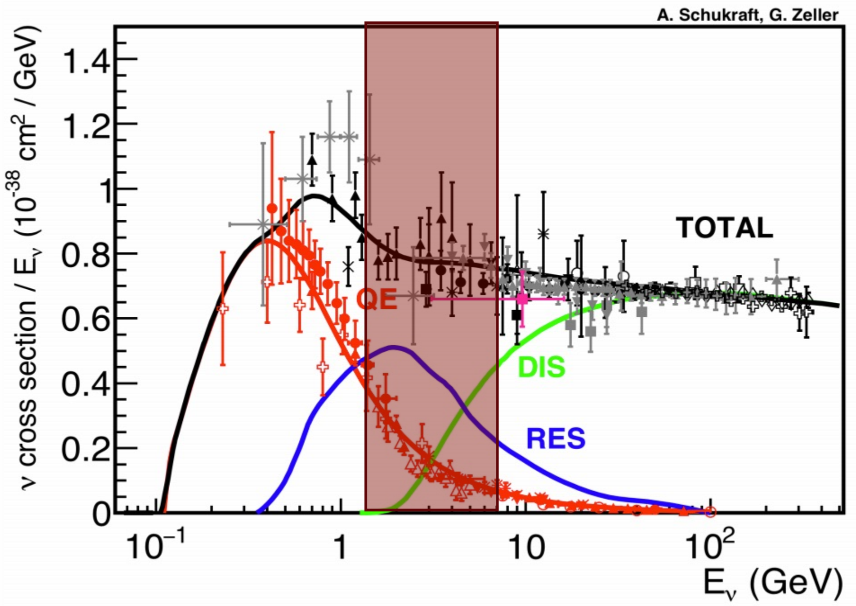
Backups

NOvA Simulation

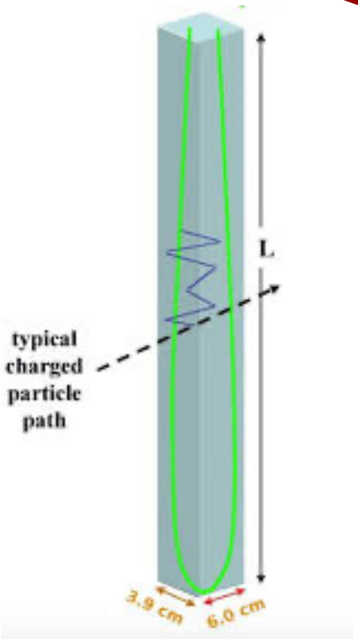


Beamline and flux: G4NuMI

$\boldsymbol{\nu}$-A modelling: GENIE



Detector response:
GEANT4



Readout electronics and DAQ:
Custom simulation routines

Reconstructing |t|

$$|t| = \left|(p_\nu - p_\mu - p_\pi)^2\right|$$
$$\approx \left(\sum_{i=\mu,\pi} E_i - p_{i,L}\right)^2 + \left|\sum_{i=\mu,\pi} \vec{p}_{i,T}\right|^2 ,$$

(Measurement of Total and Differential Cross Sections of Neutrino and Antineutrino Coherent pion Production on Carbon by MINERVA Collaboration [arXiv:1409.3835])

- Assumptions:
  - The recoiling nucleus only takes momentum and no energy (infinitely heavy nucleus)
  - The transverse momentum of the incoming neutrino is zero (w.r.t. beam coordinates system)

$$\therefore p_\nu = \begin{pmatrix} E_\mu + E_\pi \\ 0 \\ 0 \\ E_\mu + E_\pi \end{pmatrix}, p_\mu = \begin{pmatrix} E_\mu \\ p_{\mu_x} \\ p_{\mu_y} \\ p_{\mu_z} \end{pmatrix} \text{ and } p_\pi = \begin{pmatrix} E_\pi \\ p_{\pi_x} \\ p_{\pi_y} \\ p_{\pi_z} \end{pmatrix}$$

Determining P_t and P_l

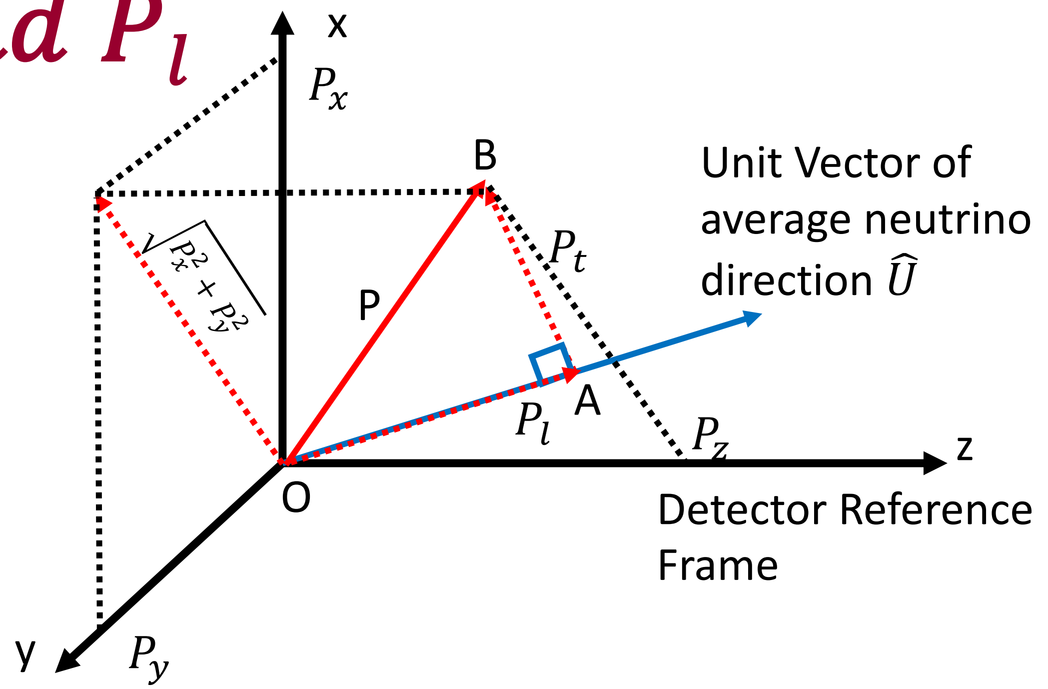
$\vec{P}.\hat{U} = P_l$

$P^2 = P_x^2 + P_y^2 + P_z^2$

$P^2 = P_t^2 + P_l^2$ (By considering OAB Right Angle Triangle)

$P_t^2 = P^2 - P_l^2$

$\therefore P_t = \sqrt{P_x^2 + P_y^2 + P_z^2 - P_l^2}$



Here, P_t and P_l are transverse and longitudinal momenta calculated w.r.t. the beam direction

Here, P_x, P_y and P_z are momentum components of the neutrino observed w.r.t. the detector coordinate system

Here, $\hat{U} = (0.0011401229, -0.06190152, 0.99807253)$ $i.e$ $Average\ Beam\ Direction()$