Beam electron neutrino cross section measurement in ND

Motivation

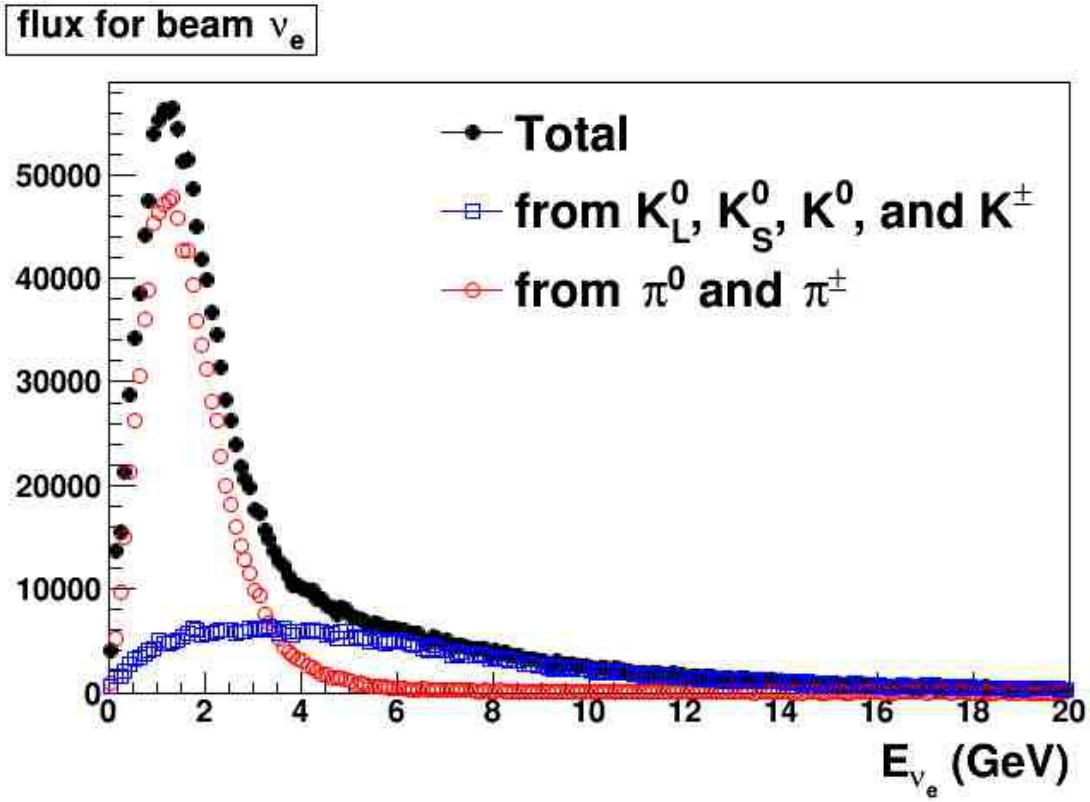
- Study the event generator and flux producer for electron neutrino interaction.
- Benefit the electron neutrino appearance analysis:
  - Validate MC prediction as the FD background is calculated based on the extrapolation.
  - Understand the ND energy response and measurement for electron neutrinos.
  - ...

Flux integrated cross section

$$\sigma = \frac{N_{data} - N_{bkg}}{\phi \cdot T \cdot \epsilon}$$

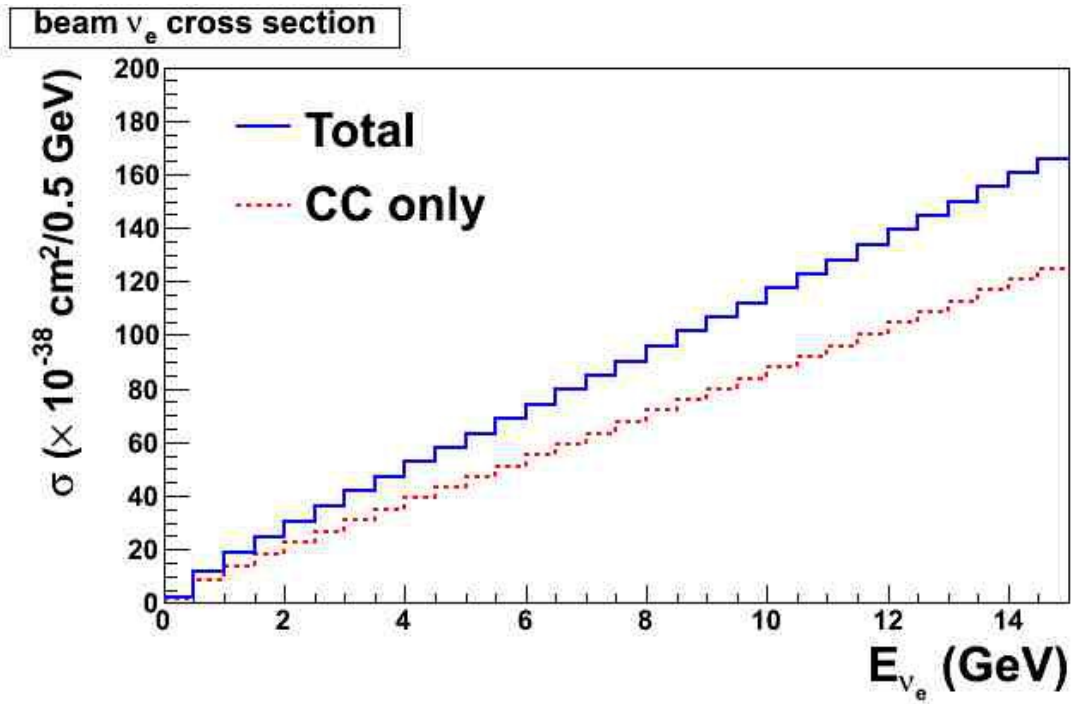
- N_{data} is number of selected data events
- N_{bkg} is number of selected background events
- Φ is the flux
- T is the number of nucleons on target
- ε is the event selection efficiency including the geometry acceptance and electron neutrino reconstruction/identification efficiency

Electron neutrino flux



Fiducial window: -1.5m < Vx < 1.5m
-1.5m < Vx < 1.5m
0.5m < Vz < 1.1m

True cross section from GENIE



Number of nucleons on target

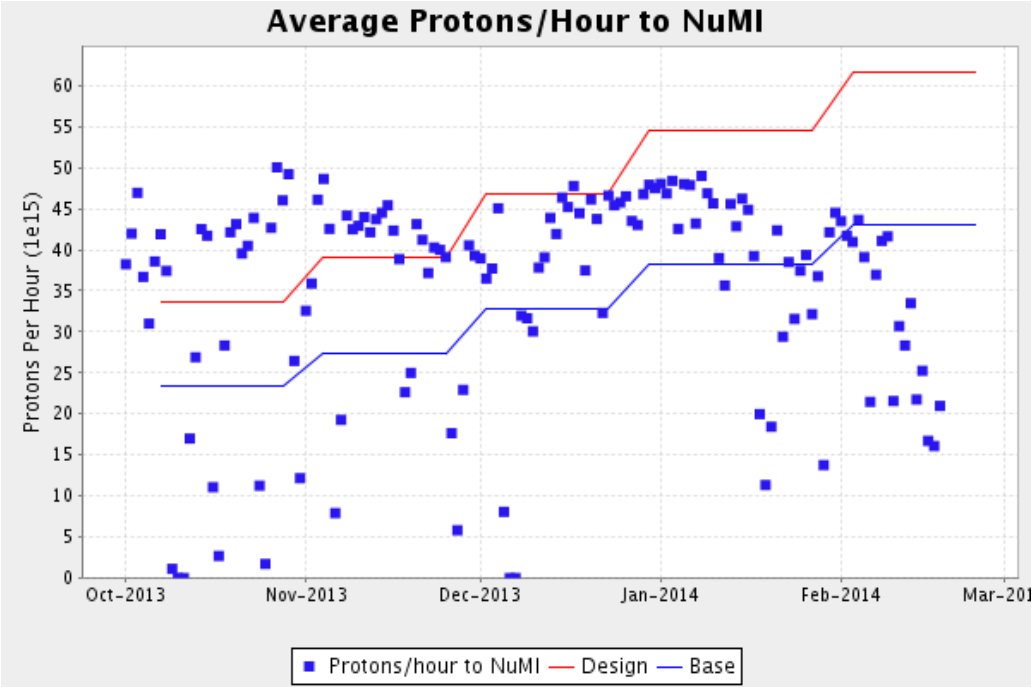
Mass (tons)	Total	Fiducial
Scintillator oil	121.9	45.98
PVC	133.87	50.49

scintillator oil	mass fraction (%)	molar weight (g/mol)	# neutrons (per molecule)	*T*
CH_2	94.64	14.03	6	1.23E31
C_9H_{12}	5.23	120.19	54	7.14E29
$C_{15}H_{11}NO$	0.139	221.25	103	1.97E28
$C_{24}H_{22}$	0.0016	310.43	144	2.25E26

PVC	mass fraction (%)	molar weight (g/mol)	# neutrons (per molecule)	*T*
C_2H_3Cl	80	62.5	30	1.06E31
TiO_2	15	79.87	39	2.03E30
$C_{36}H_{70}O_4Ca$	0.6	607.01	268	7.33E28
$C_{20}H_{42}$	0.9	282.55	120	1.06E29
$C_{12}H_{20}O_5$	0.2	244.28	112	2.54E28
$C_{21}H_{42}O_4$	0.2	358.55	158	2.44E28
$C_5H_8O_2$	3.1	100.12	46	3.94E29

$$T = 2.63 \times 10^{31}$$

NuMI beam data

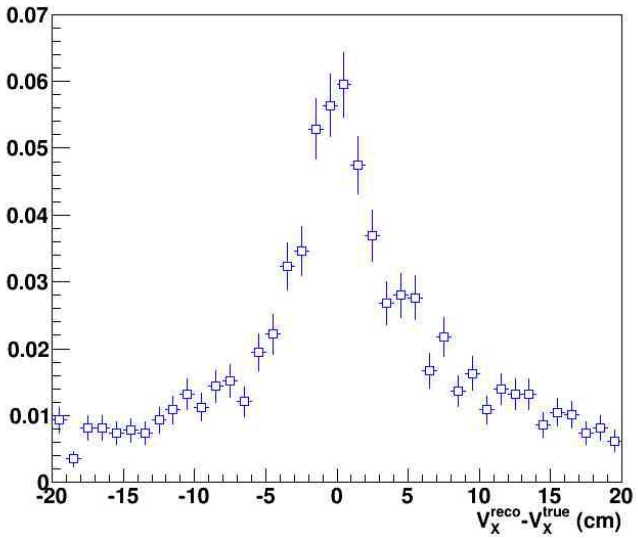


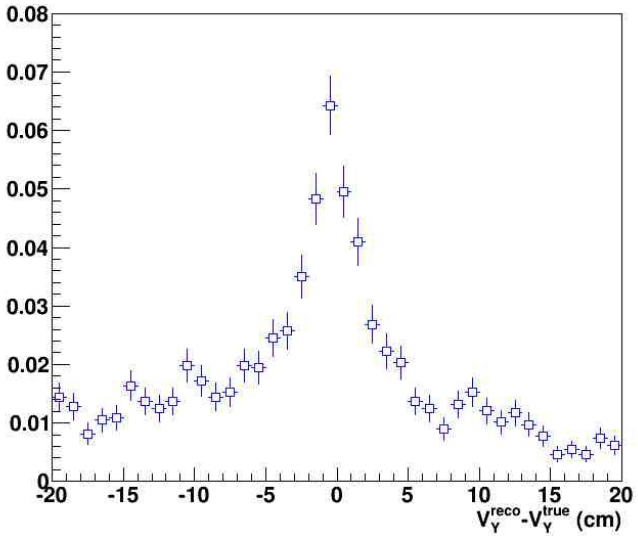
For 3 months, we might get ~8.64E19 POT, use this number for event normalization

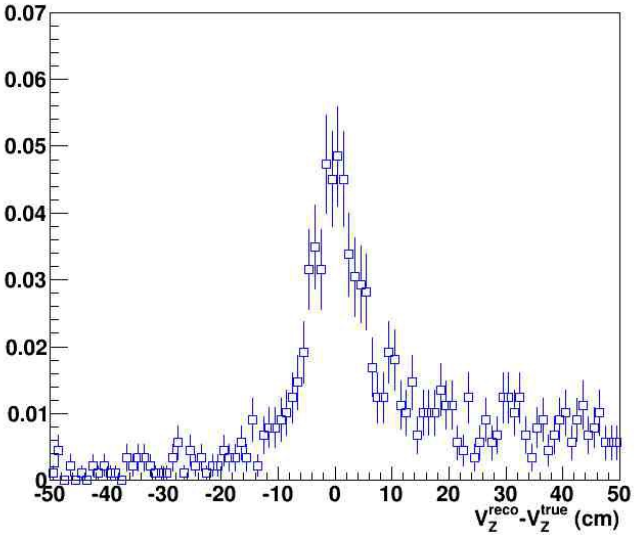
Event Selection Criteria

- Pre-selection
  - $\sum E_{cells}$ > 0.25 GeV
  - 10 < # of cells < 300
  - # of planes < 140
  - length of longest track < 400 cm
- Vertex cuts
  - -150 cm < Vx < 150 cm
  - -150 cm < Vy < 150 cm
  - 50 cm < Vz < 1100 cm

Vertex resolution

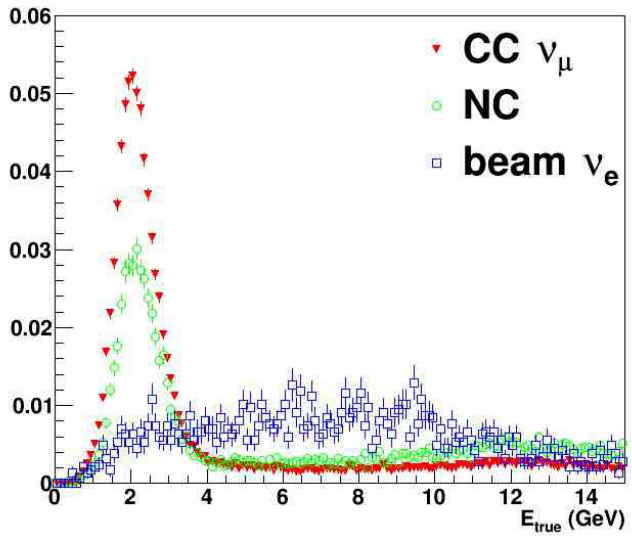


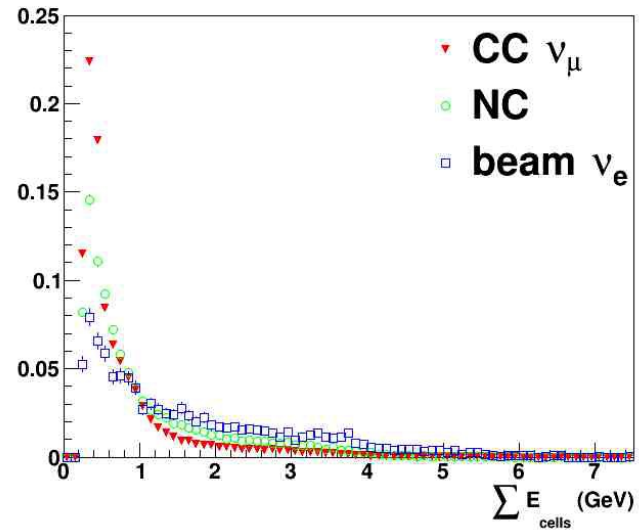


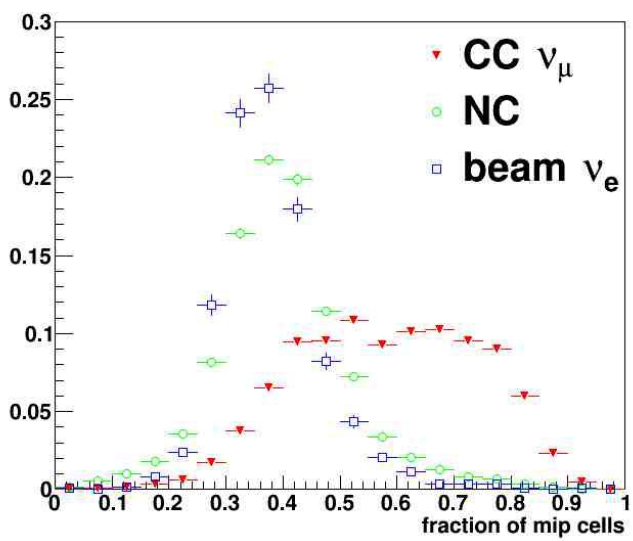


Vertex cuts need be studied in details to consider the effect for the energy.

Some distributions after vertex cuts

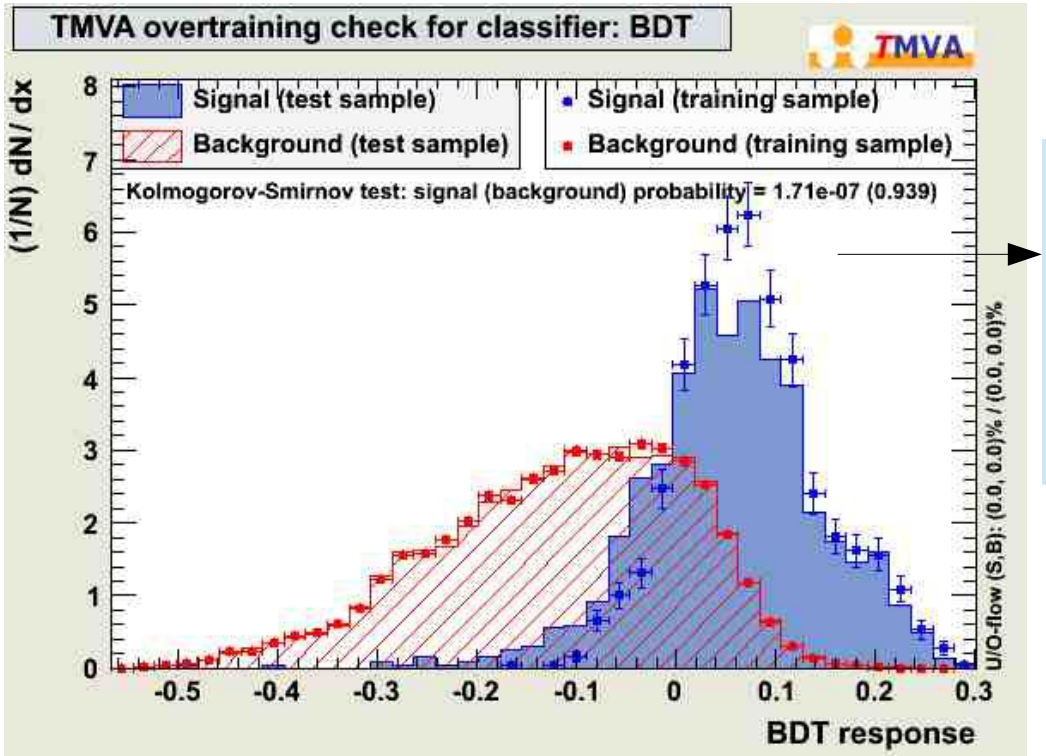






Further cuts on fraction of mip cells and sum energy of all cells are needed to reduce the dominant backgrounds.

PID



Limited by the statistics, have not run through all available MC samples, prefer to wait for the new MC samples.

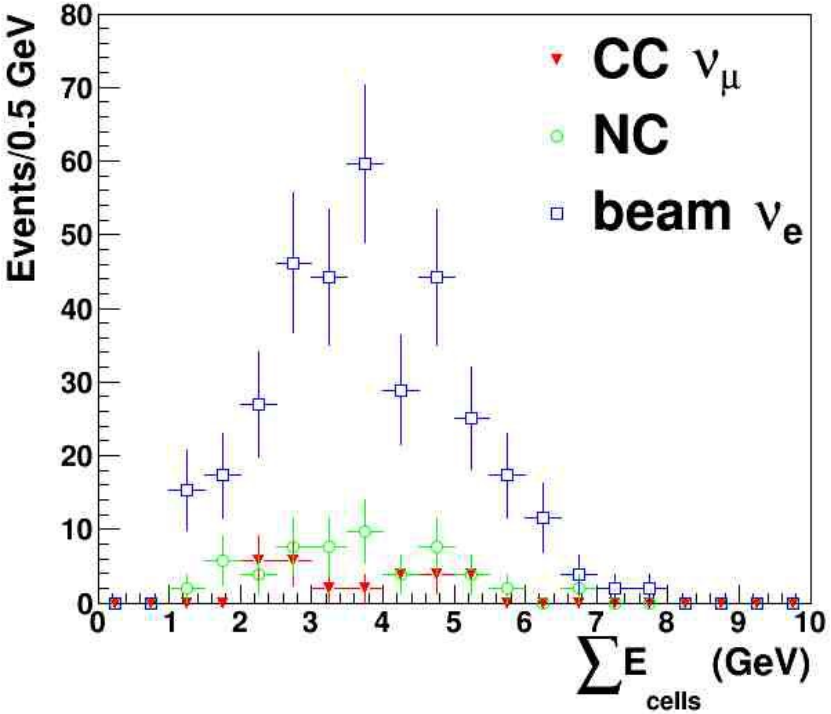
As the energy spectrum for the beam nue is totally different by comparison with the oscillated nue.
Build a dedicated PID using 15 inputs as shown in docDB# 2.

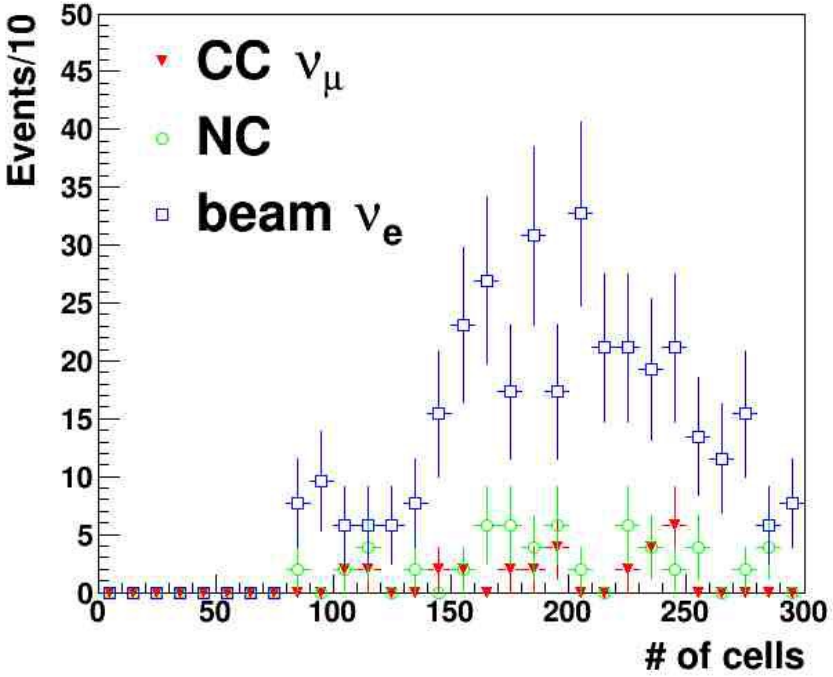
Event yields

	signal	CC numu bkg	NC bkg
Pre-selection	9587	195489	57054
Vertex cuts	5680	116297	33931
Fmip < 0.5	5232	39262	29025
Ecells > 0.5 GeV	4318	28878	19873
BDT > 0.05	2832	5904	4762
BDT > 0.1	1608	835	1223
BDT > 0.15	800	127	256
BDT > 0.2	344	27	56
BDT > 0.25	40	19	12

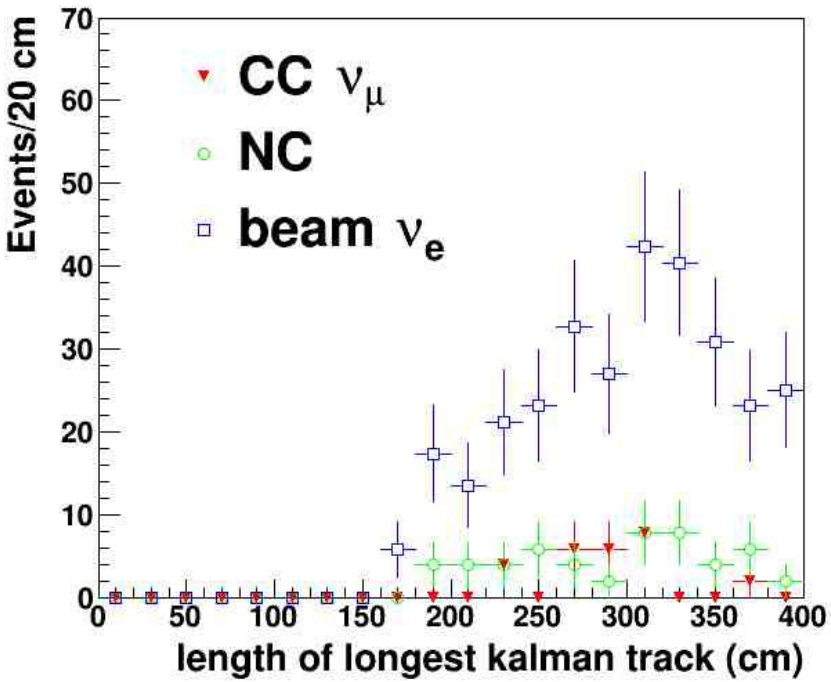
Normalize to 8.64E19 POT.

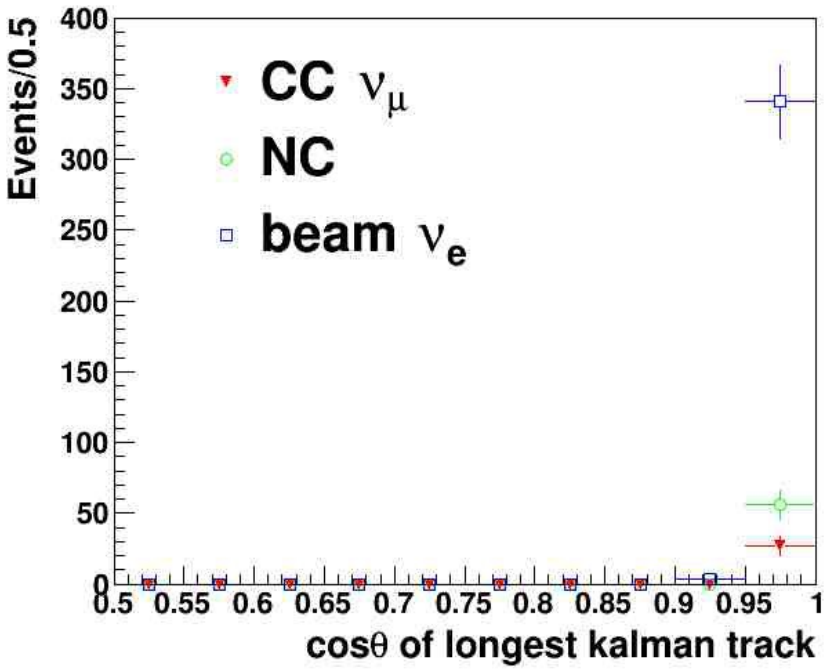
Distributions after BDT>0.2 cut



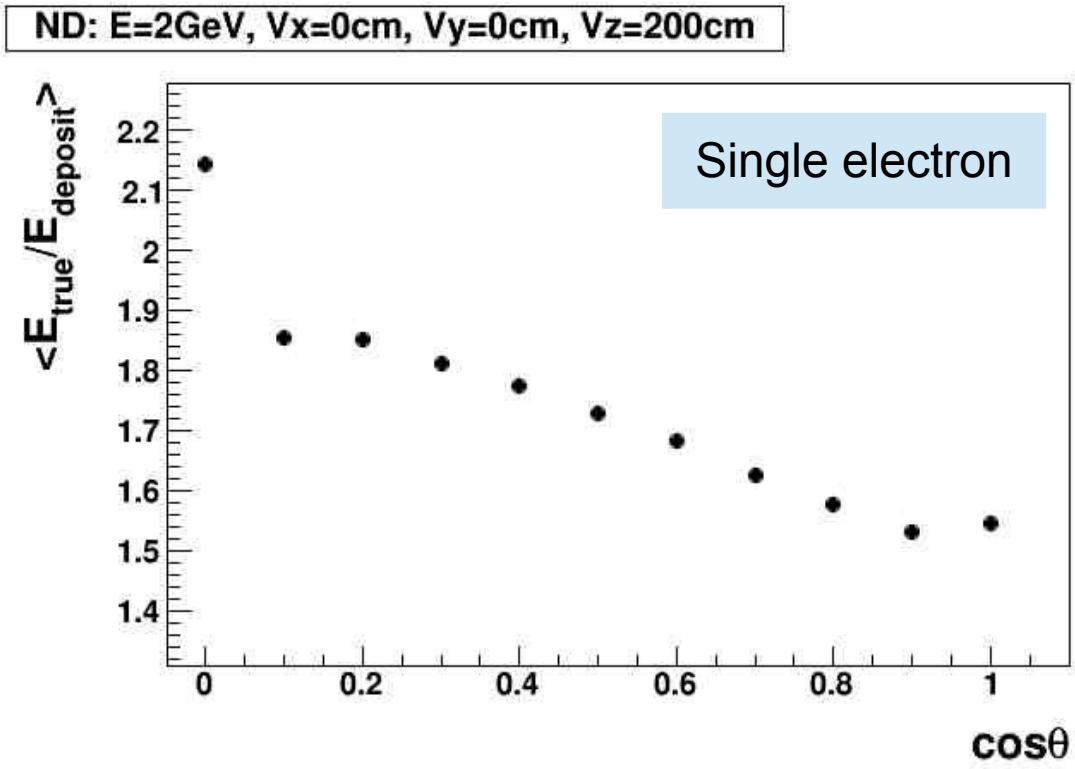


Distributions after BDT>0.2 cut





Energy scale



Plan to add the cosθ cut to eliminate the dependence on the incident angle.
Will also consider the detector edge effect and shower ends.

Differential cross section

$$\frac{d\sigma}{dX_i} = \frac{N^i_{data} - N^i_{bkg}}{\phi_i \cdot T \cdot \epsilon_i \cdot \Delta X_i}$$

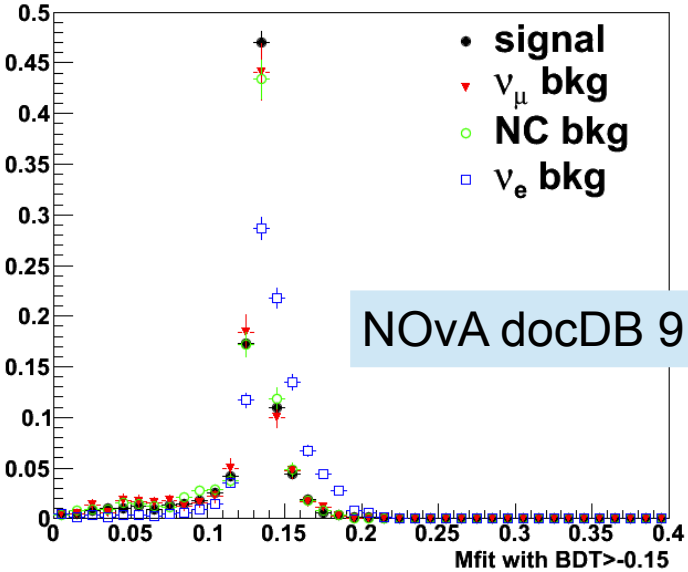
- Derive unfolding methods to unfold the reconstructed quantities to truth level
  - Bin-by-bin migration effect
  - Binning choice considering the data statistics and bin purity
  - Binning center calculation
- ε needs be split to the geometry acceptance and electron neutrino reconstruction/identification efficiency, as we need rely on the GEANT simulation for the acceptance, which would bring model-dependence. The efficiency should be model independent.

Systematic uncertainties

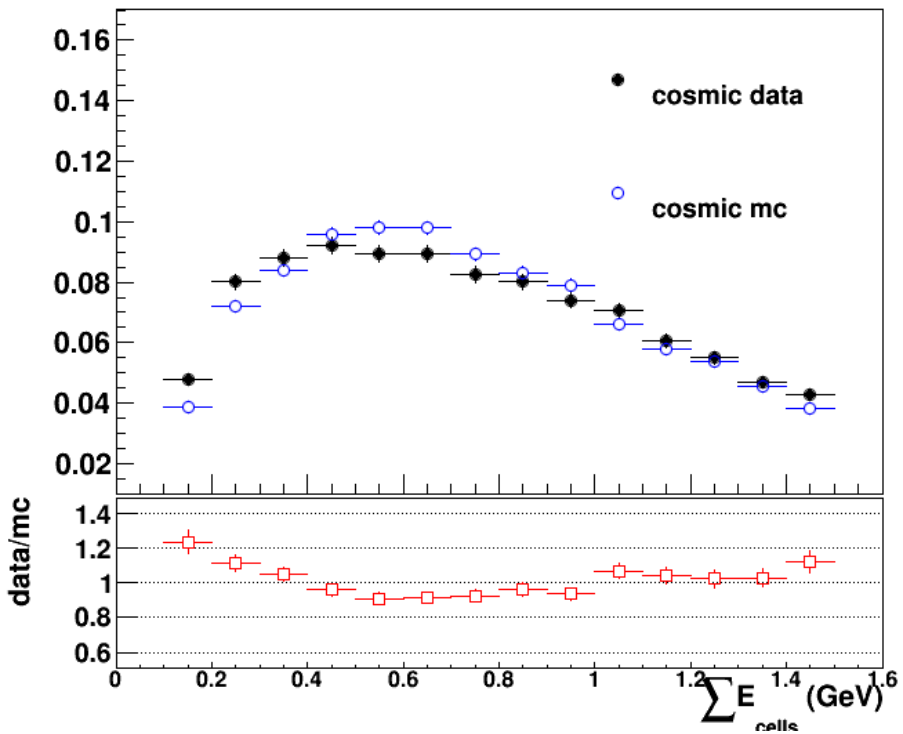
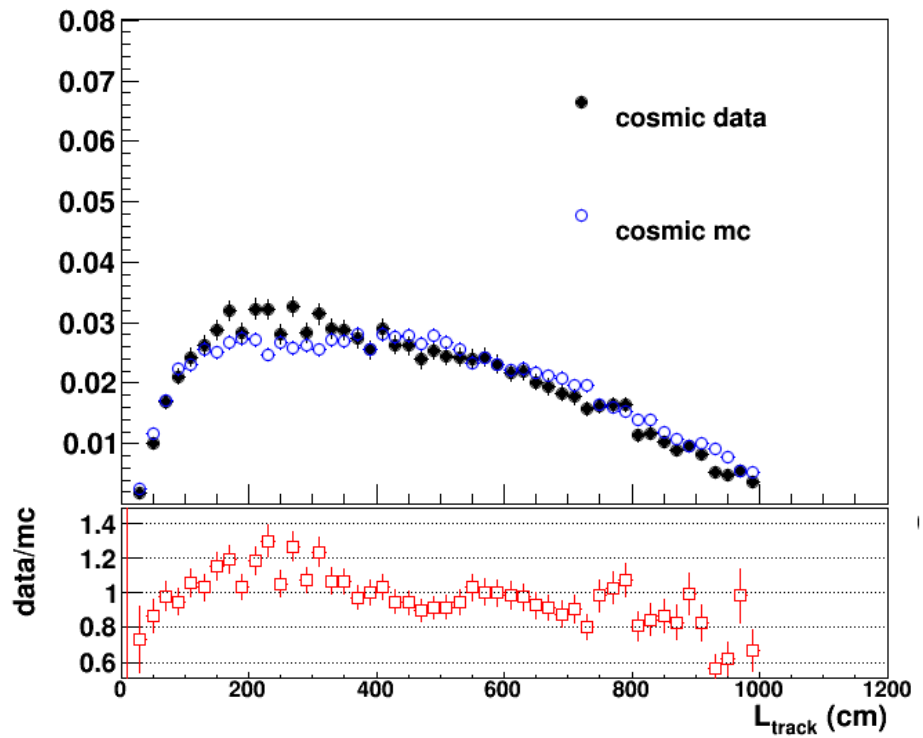
- Data statistics
- Background predictions
- Overall selection efficiency
- Energy scale
- Unfolding method (for diff. X only)
- Neutrino interaction
  - axial mass
  - ...

Summary

- Basic framework for the beam electron neutrino cross section measurement has been built. Will study each piece of puzzles individually, then put them together.
- Investigate other event generators, search for possibility to select pure pi0 in some kinematic region from beam events to calibrate the energy scale and resolution.
- Advertise to get students or new postdocs involved in this analysis.



NOvA docDB 9116

back-up

FD data and MC comparison