Cosmic Ray Background Rejection for First ν_e Appearance Analysis in NOvA

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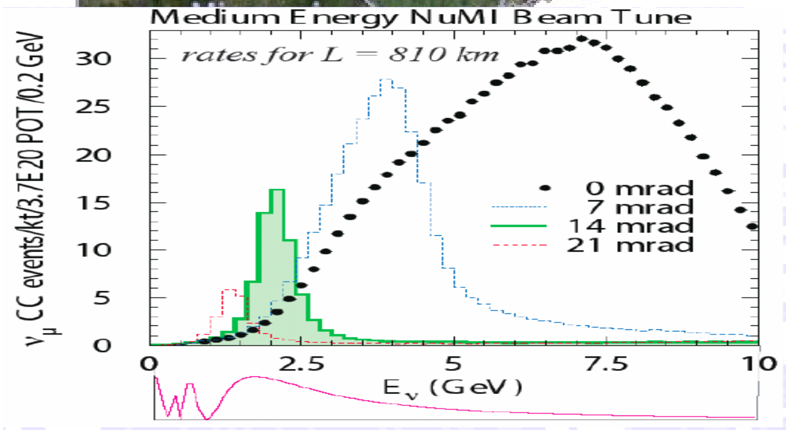
NOvA Experiment

- NOvA is a **long-baseline accelerator** neutrino experiment, using neutrinos from **NUMI** muon neutrino beam at Fermilab.

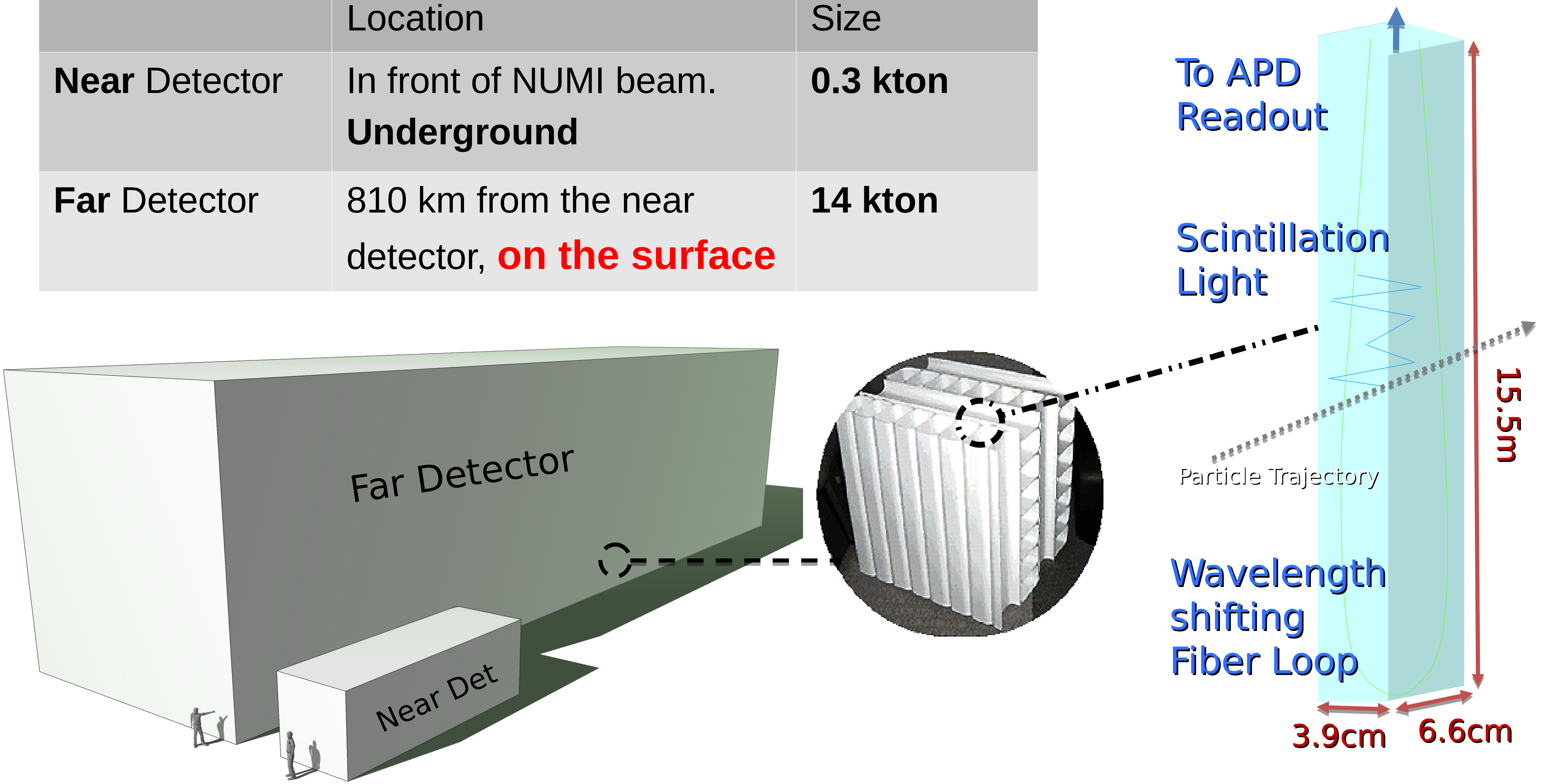
- NOvA has two functionally identical detectors, along the neutrino beam direction **810 km** apart.
  - The detectors are **14 mrad off beam axis**, where the muon neutrino beam narrowly peaks at 2GeV, at which the majority of the beam events match the oscillation maximum.



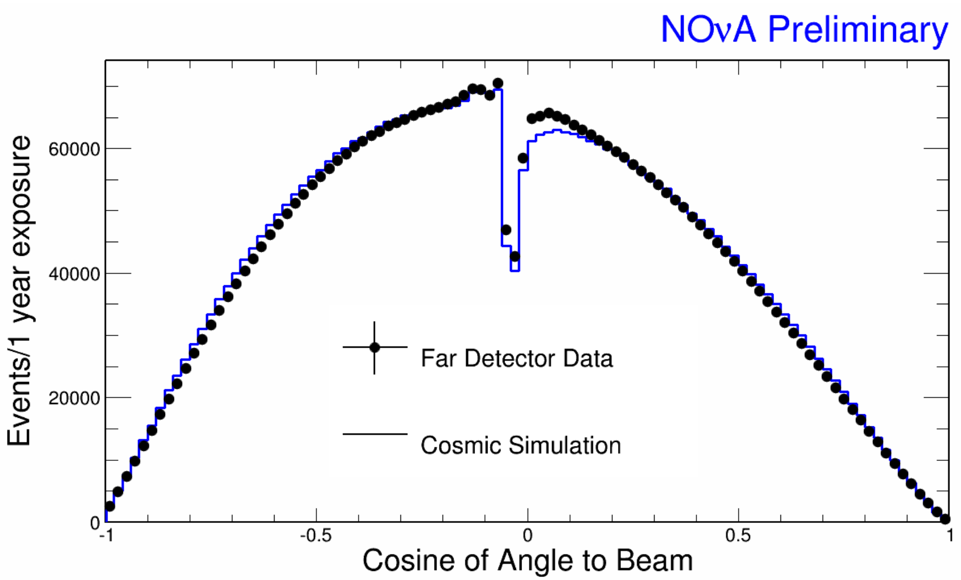
NOvA Detectors

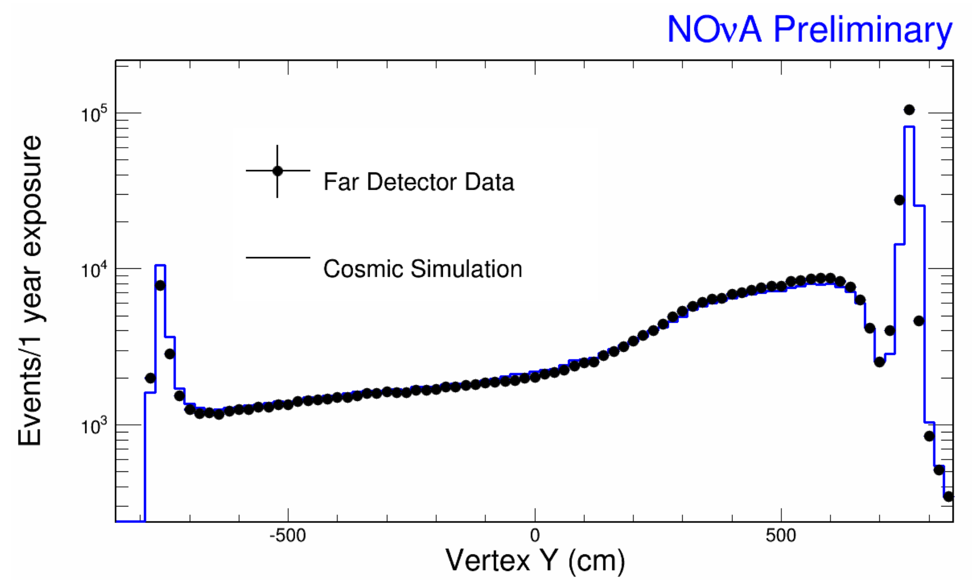
- The NOvA experiment has two functionally identical, finely **segmented liquid scintillator** detectors.

	Location	Size
Near Detector	In front of NUMI beam. **Underground**	**0.3 kton**
Far Detector	810 km from the near detector, **on the surface**	**14 kton**



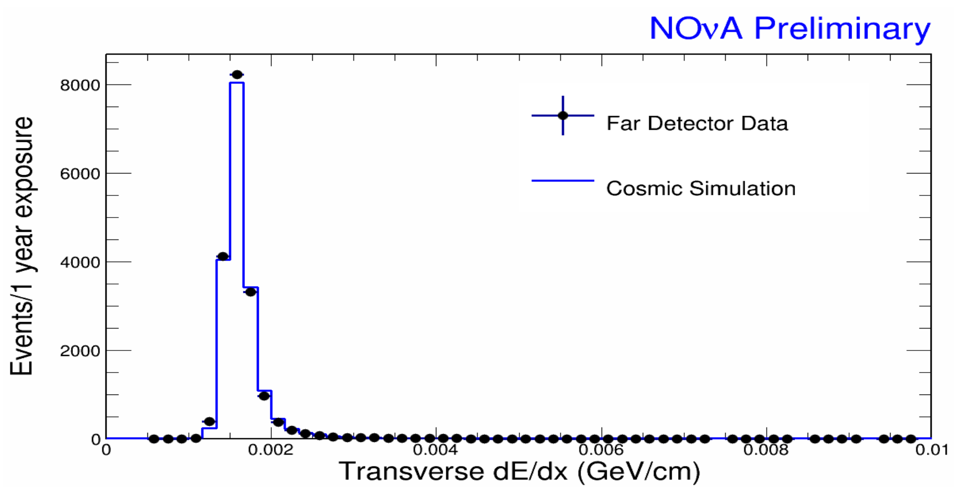
Data Versus MC Comparisons for Reconstruction Variables

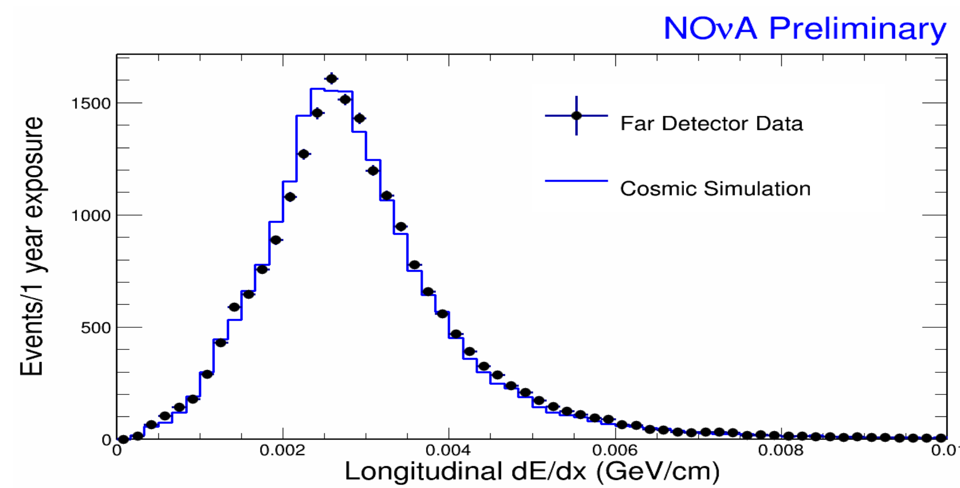


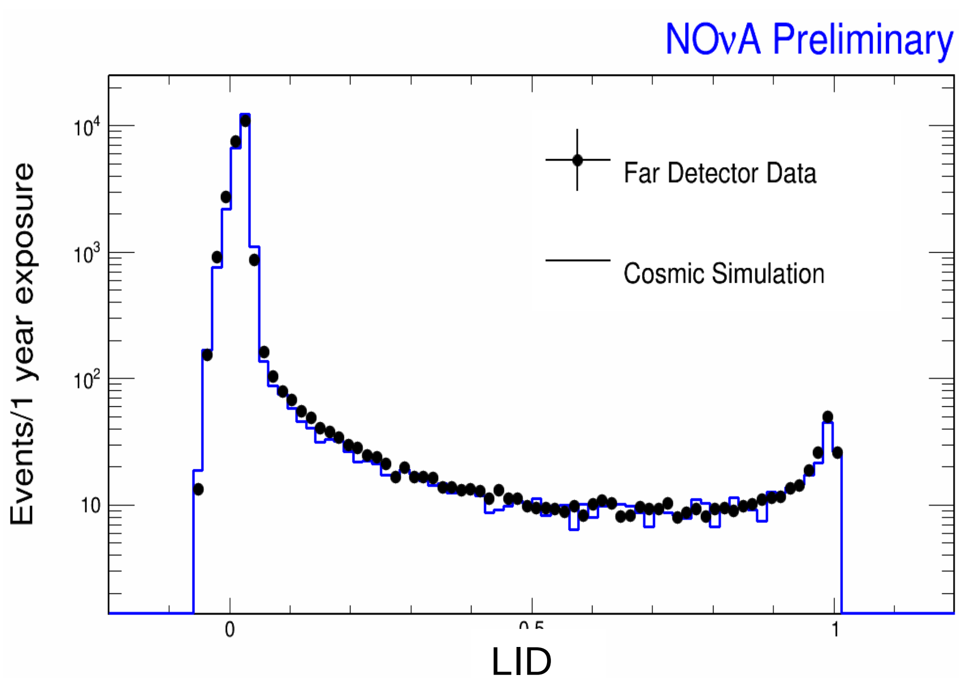


- Data versus Monte Carlo comparisons specifically for two reconstruction variables,
  - Left: The cosine of the angle of reconstructed track with respect to the beam direction.
  - Right: The reconstructed vertex position in Y coordinate.
- The comparison of data to Monte Carlo simulations demonstrates that basic reconstructed variables are modeled well in our simulation.

Data Versus MC Comparisons for Particle Identification Variables



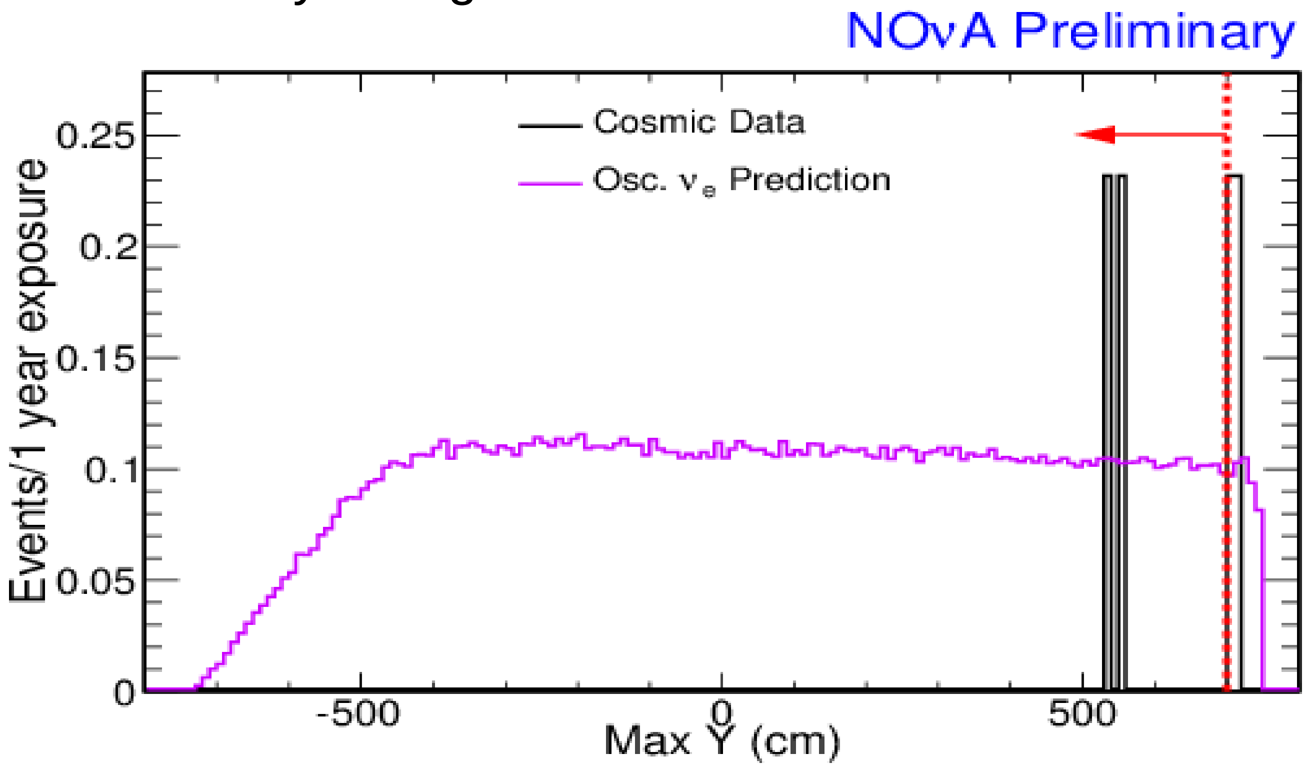




- LID is one of the electron neutrino particle ID algorithms
  - It is based on shower shape and likelihood comparisons to various particle hypotheses.
- Cosmic ray data shows agreement with MC for these particle ID variables for events along the beam direction.

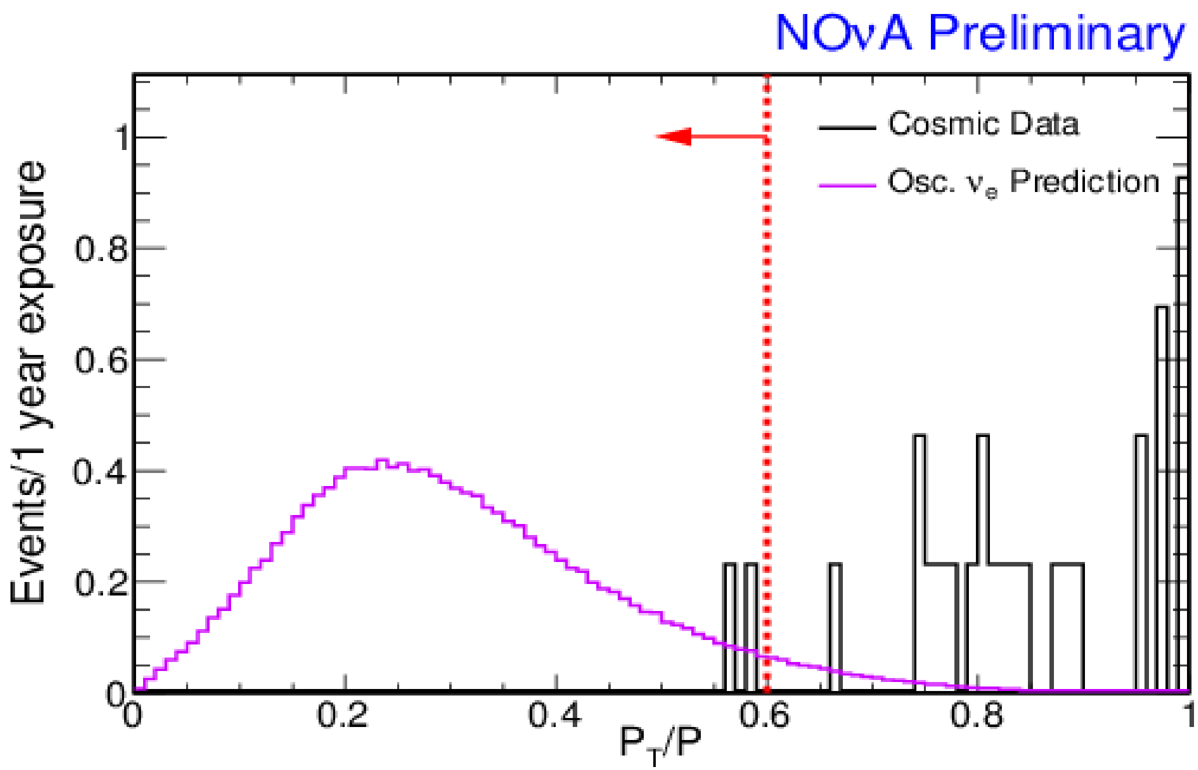
Cosmic Ray Background Rejection

- We have a set of selection cuts, including quality, containment, and particle ID cuts. After these cuts, we study a few additional variables to further separate signal from cosmic ray background events.



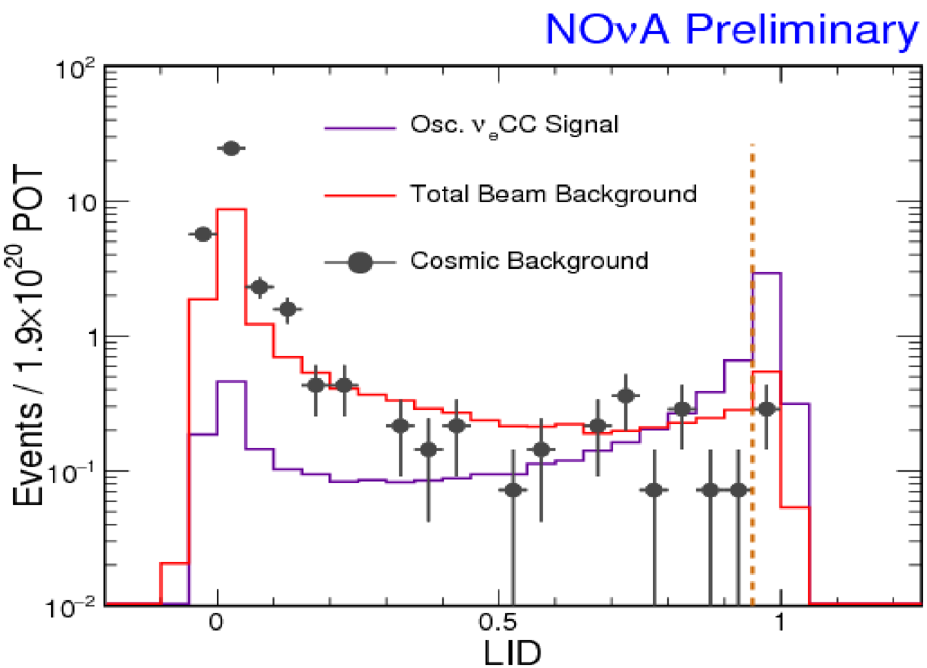
- One of the variables is Max Y, the larger value of either the start or stop Y position of the most energetic shower.
- Cut on this variable rejects cosmic background entering from top of the detector.

Cosmic Ray Background Rejection

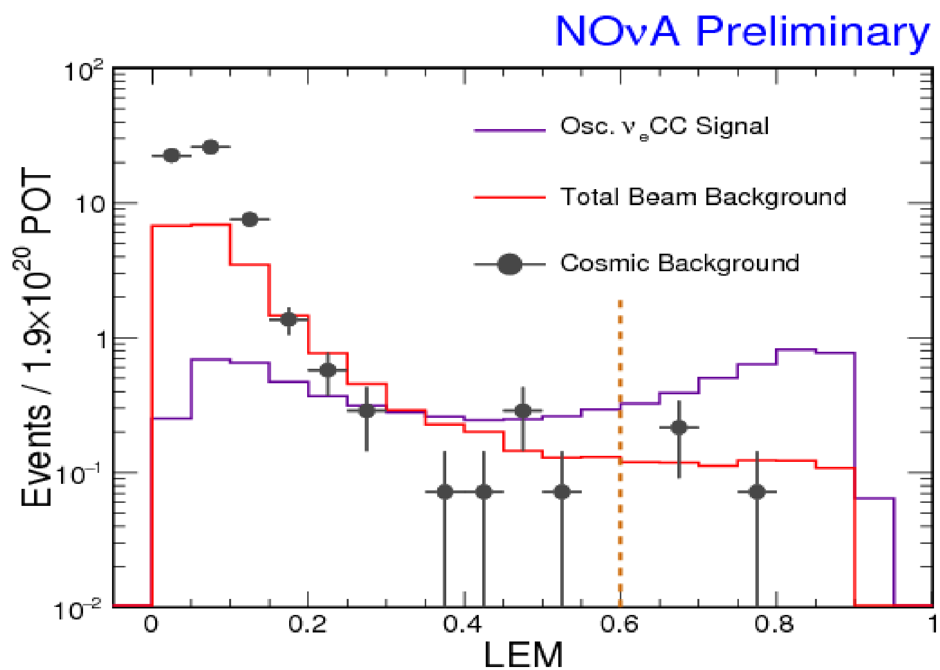


- Another variable is P_T/P, the ratio of event transverse momentum (P_T) by event total momentum (P).
- The cut rejects predominately vertical cosmic rays with large P_T/P and retains the neutrinos that aligns with beam direction with small P_T/P.
- This cut also has a power in rejecting neutral current background, some of which has large P_T/P values.

Electron Neutrino Particle Identifications



Based on shower shape likelihood assuming different particle hypotheses.



Matching events to the signal and beam background events in the library

- Two independent electron neutrino identification algorithms for the first ν_e appearance analysis to select electron neutrino from other event topologies, including cosmic ray background.

Cosmic Ray Background Prediction

	Cosmic background, LID	Cosmic background, LEM
No cut	**1.49E+07**	**1.49E+07**
Containment & quality	**638325**	**967101**
Cosmic rejection	**5409.79**	**5791.31**
Nue selection	**0.29**	**0.29**

- After all the quality, containment, cosmic rejection and ν_e selection cuts, we achieve 5**0 million to 1** cosmic background rejection.
- Based on the out of time numi data, we predict **0.29** cosmic background events in the two particle ID regions, LID and LEM, for 96 sec of livetime, the exposure for the first ν_e analysis sample.

Far Detector Event Prediction

	Osc. ν_e CC	Total bkg.	ν_μ CC	NC	Beam ν_e CC	Cosmic bkg
LID	**3.25**	**1.02**	**0.05**	**0.32**	**0.33**	**0.29**
LEM	**3.48**	**1.14**	**0.05**	**0.41**	**0.36**	**0.29**

- The neutrino signal and beam background event counts are extrapolated from the near detector data and scaled to 1.9e20 POT, POT of the first analysis sample.
  - The oscillation weight is calculated without matter effect and with $\delta_{CP} = 0$ and $\sin^2 2\theta_{13} = 0.095$.
- **We have a method of effectively rejecting cosmic ray background to a level equivalent to other beam background components.**