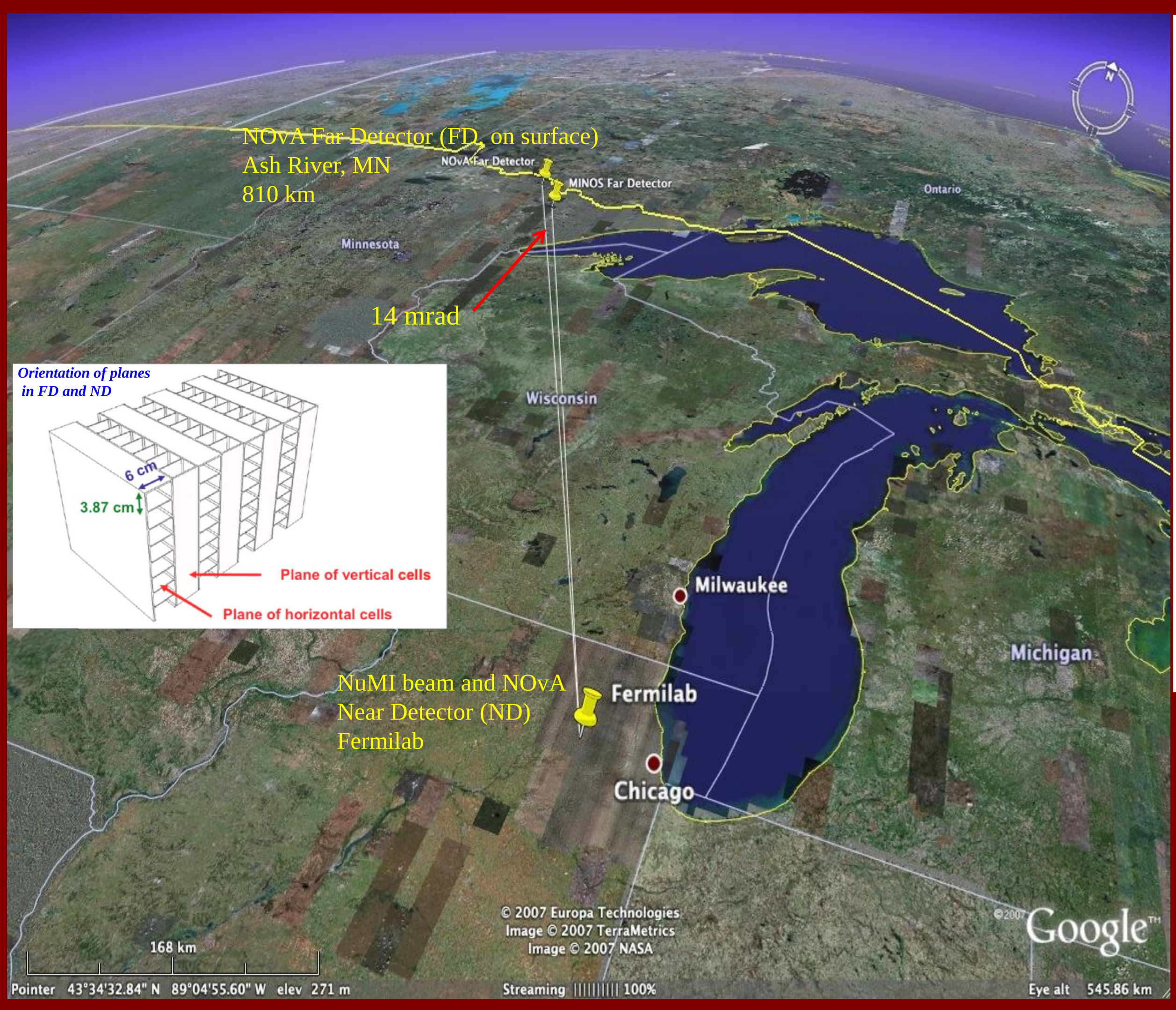
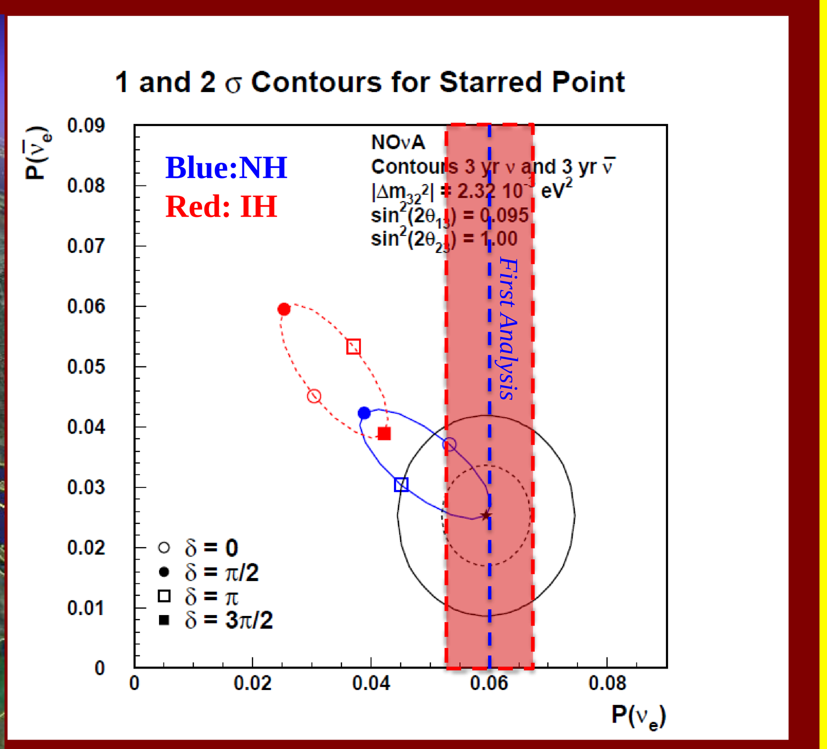
Electron Neutrino Identification for the ν_e Appearance Measurement at NOvA

Jianming Bian, University of Minnesota for the NOvA collaboration

NuMI Off-Axis ν_e Appearance Experiment (NOνA)





ν_e appearance measurement:

- Measure $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$ with neutrino and anti-neutrino beams.
- Investigate the neutrino mass hierarchy and CP-violation.
- First analysis: a cut-and-count analysis using 2.74×10^{20} POT of neutrino running to measure $P(\nu_\mu \rightarrow \nu_e)$.

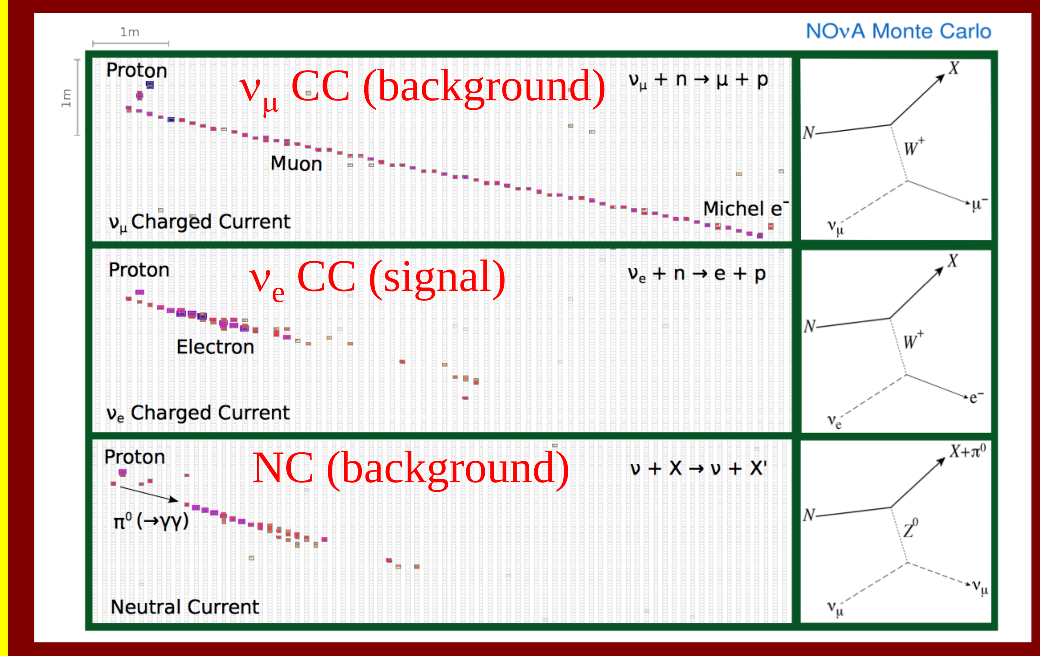
Main features of NOvA:

- An upgrade of the NuMI beam intensity from 400 kW to 700 kW.
- NOvA's detectors consist of plastic (PVC) extrusions filled with liquid scintillator, with wavelength shifting fibers (WLS) connected to avalanche photodiodes (APDs). Extrusions are assembled in alternating layers of vertical and horizontal extrusions plane ($0.15X_0$).
- A 14 kt far detector located 14 mrad off the NuMI beam axis at a distance of 810 km from Fermilab at Ash River, MN.
- A 300 ton near detector located 14 mrad off the NuMI beam axis at a distance of 1 km.

ν_e identification in NOvA

A ν_e event is identified in charged current (CC) interactions where the ν_e converts into an electron, two PIDs are developed:

- **LID**: Artificial neural network using shower shape based likelihood for particle hypotheses (primary)
- **LEM**: Matching events to a Monte Carlo library



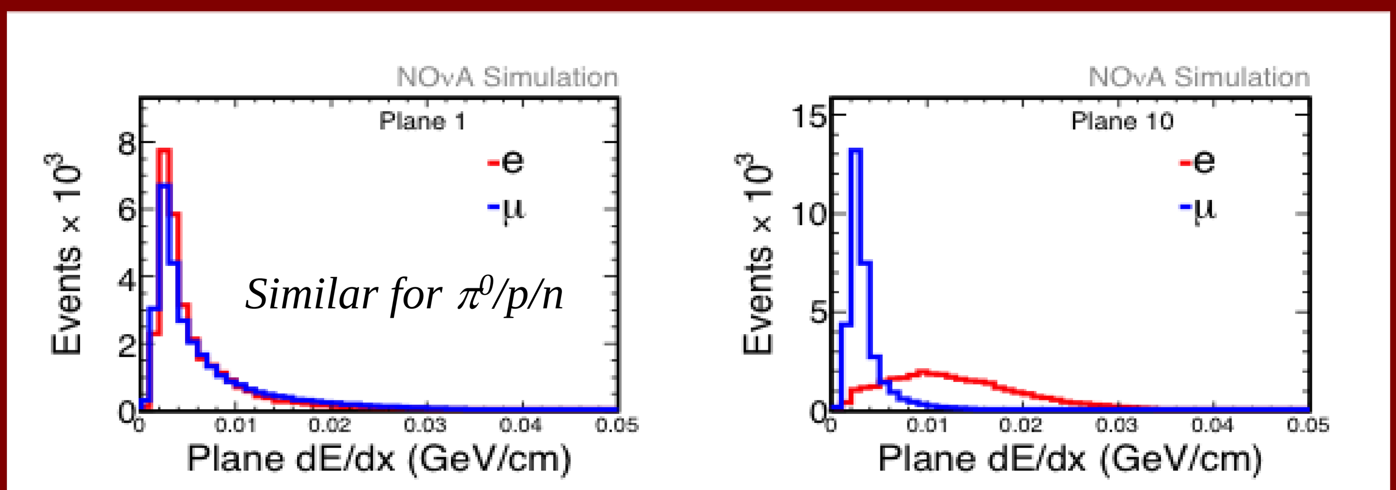
Muon: a long minimum ionizing particle (MIP) track

Electron: ionizes in the first few planes then starts a shower

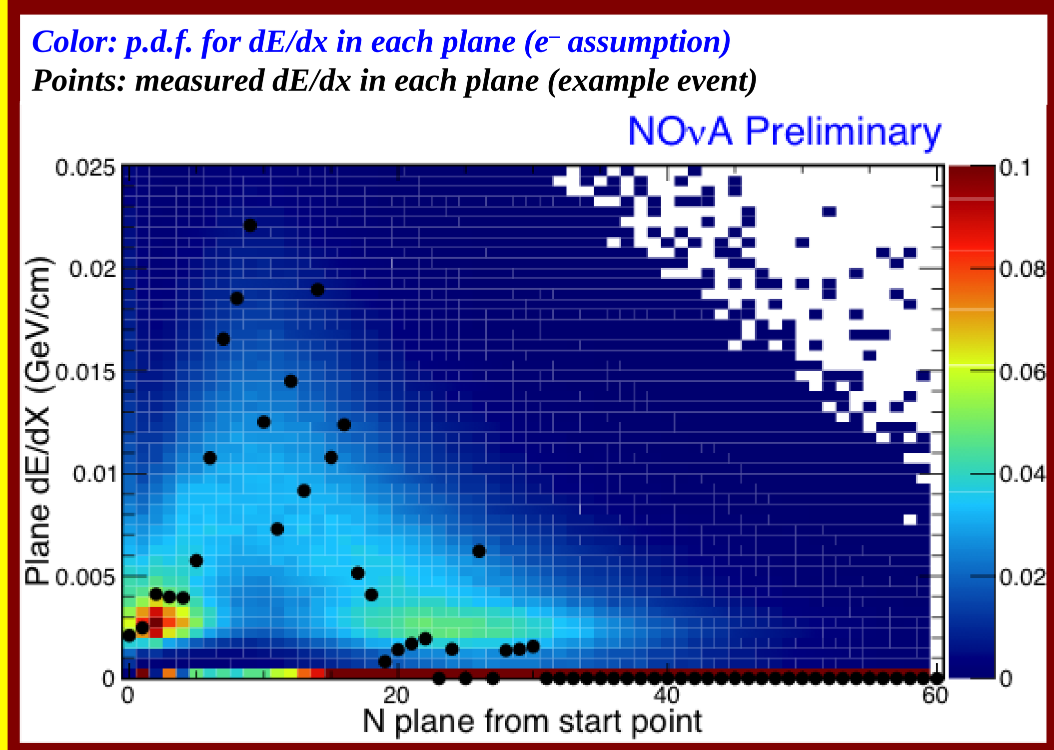
Photon: a shower with a gap in the first few planes

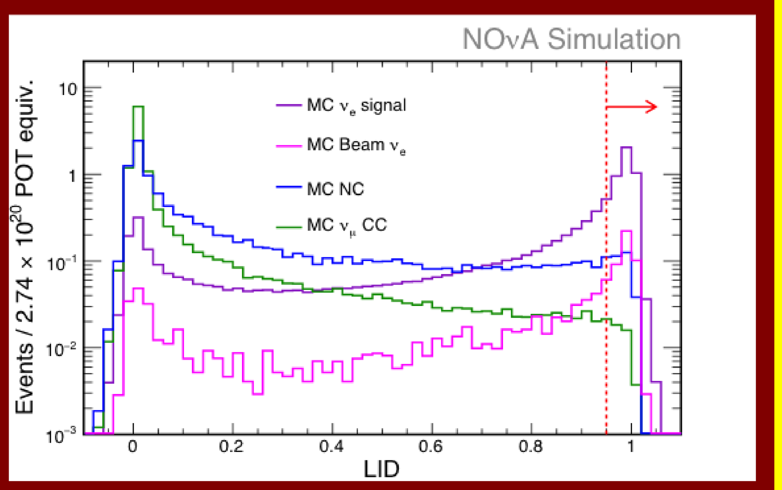
Likelihood-based Identifier (LID)

- Reconstructed prong energy profile, vertex and event topology go in to LID.
- For an unidentified particle, we compare its energy loss per length (dE/dx) with the expected dE/dx histograms by each longitudinal and transverse slice to construct the probability and likelihood for each particle hypotheses.



Likelihood-based Identifier (LID)

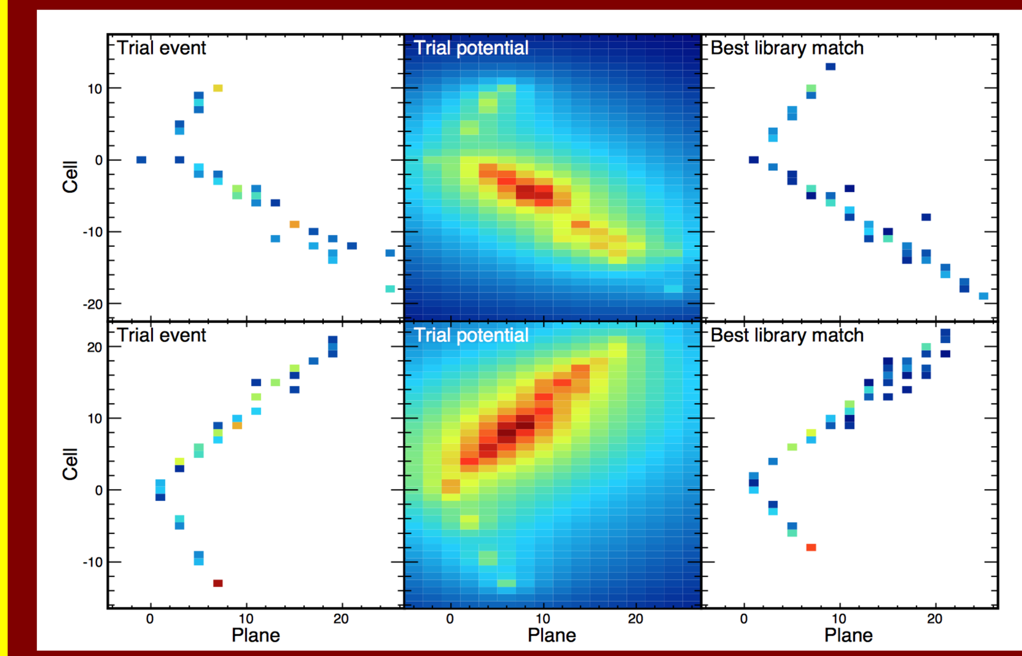


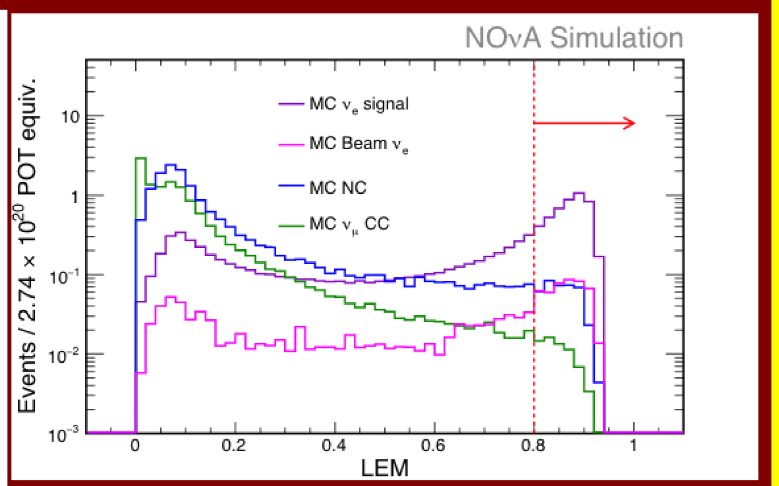


- Summing over these longitudinal/transverse likelihoods we have overall longitudinal and transverse likelihoods for each type of particle.
- The difference of log-likelihoods indicates the identity of the particle, for example: LL(e/μ)=LL(e)-LL(μ).

- Particle likelihoods for the leading shower, amongst other event topology variables, are used as inputs to an Artificial Neural Net (ANN) for the final PID.
- ν_e selection is LID>0.95, according to max. S/sqrt(B).
- Signal efficiency of 34% relative to the contained sample.
- Reject 99% of beam backgrounds.
- After all selection cuts, achieves a rejection of 1 in 10^8 for cosmogenic backgrounds.

Library Event Matching ν_e Identifier (LEM)



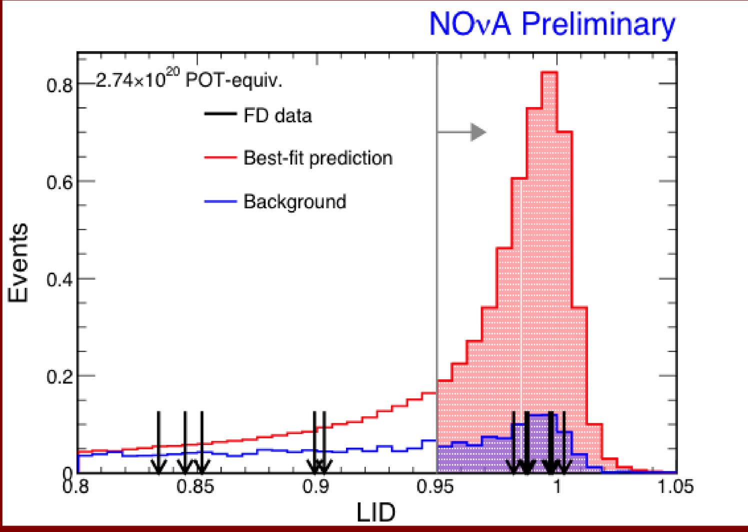


- ν_e selection is LEM>0.8
- Physics performance is similar to LID
- 62% overlap of LID/LEM selected signals

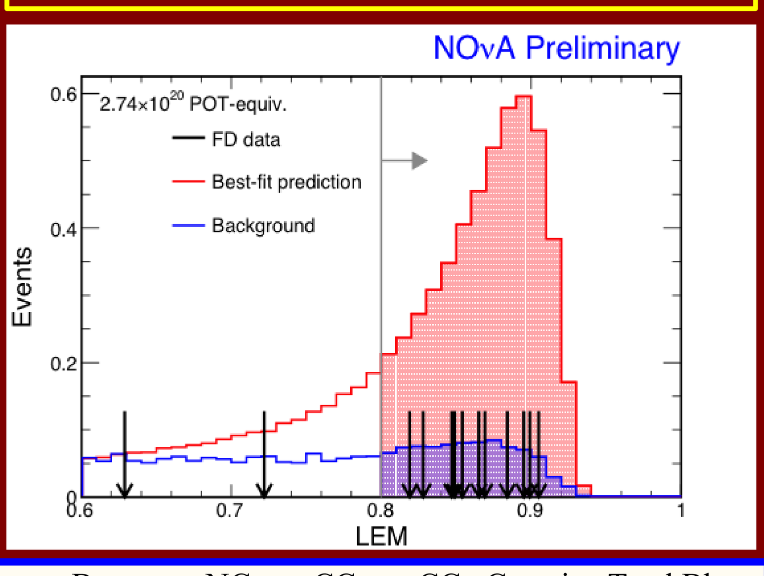
- Compare an unknown trial event to an enormous MC library, using individual cell hits rather than high-level reconstructed variables.
- Extract the pattern function (potential) for the trail event by cell, including both position and charge information.
- Loop over all events in the library, place each event on the pattern function to calculate match value and record the 1000 best matching library events.
- Five matching goodness variables based on the 1000 best matching events, along with the calorimetric energy of the trial event are trained in a BDT to form the PID (LEM).

LID and LEM selected FD events

LID (Primary result) 6 FD events



LEM 11 FD events

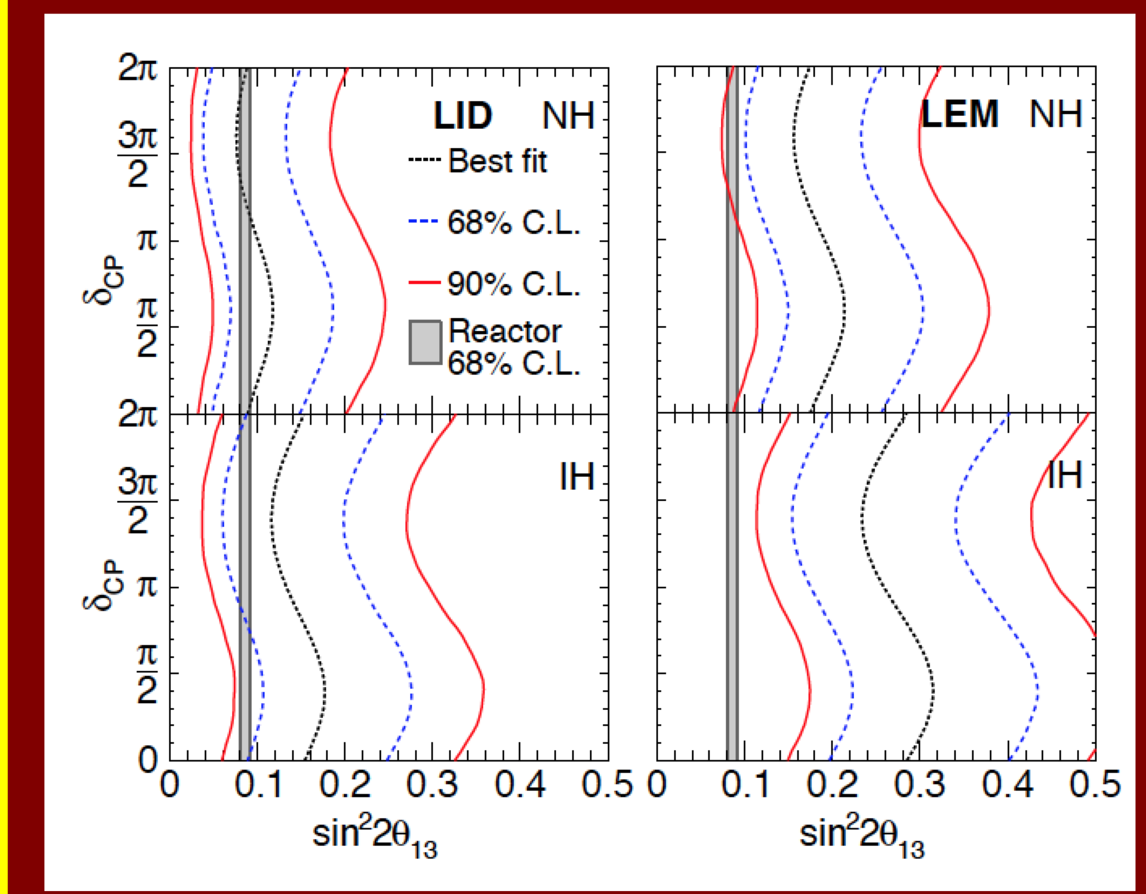


Signal	[NH, $\delta = 3\pi/2$, $\theta_{23} = \pi/4$]	
Pred.	LID	5.62 ± 0.99 events
	LEM	5.91 ± 0.89 events

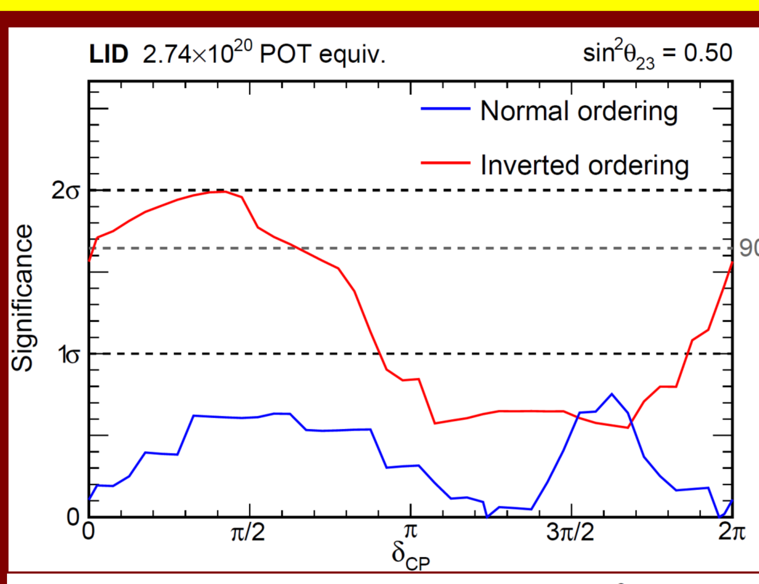
Bkg.		Beam ν_e	NC	ν_μ CC	ν_τ CC	Cosmic	Total Bkg.
Pred.	LID	0.46	0.35	0.05	0.02	0.06	0.94 ± 0.10
	LEM	0.46	0.40	0.06	0.02	0.86	1.00 ± 0.12

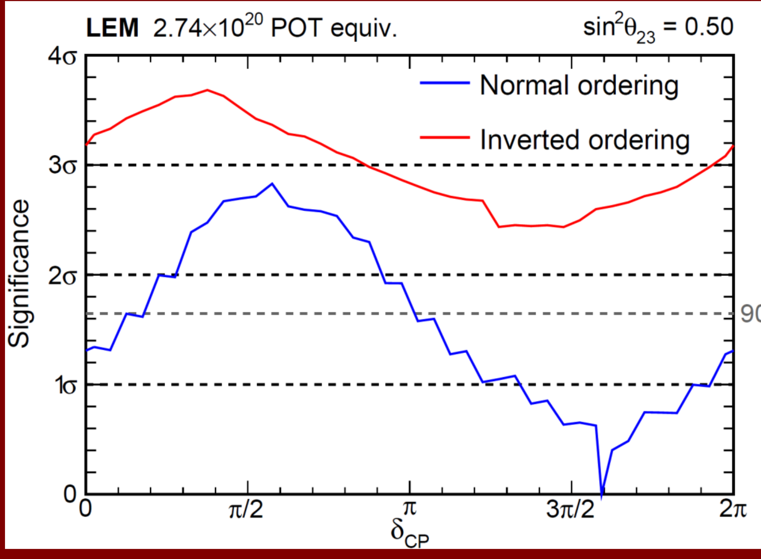
- In the data the (LID only)/(LEM only)/(LID and LEM) events are 0/5/6. The 5 events that are only selected by LEM have LID values in the range 0.7 − 0.95. In addition, 2 of the 5 LEM-only events also fail the energy cut 1.5–2.7 GeV for LID. The observed event counts yield a mutual p-value of 10%.

LID and LEM Results



- LID selected 6 ν_e candidates 3.3σ significance for ν_e appearance (Primary Result)
- LEM selected 11 ν_e candidates 5.5σ significance for ν_e appearance





- LID: NH is favored within 1σ. IH for $\delta_{CP}\in[0, 0.8\pi]$ is mildly disfavored (>1σ).
- LEM: IH is disfavored at >2.2σ. NH for $\delta_{CP}\in[0, \pi]$ is mildly disfavored (>1σ).
- Both prefer normal ordering and δ_{CP} near $3\pi/2$.