First measurement of oscillation parameters with the neutrino and antineutrino beam in NOvA

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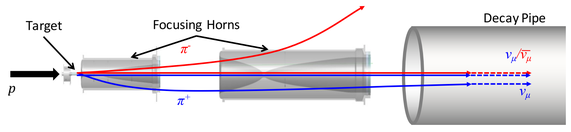
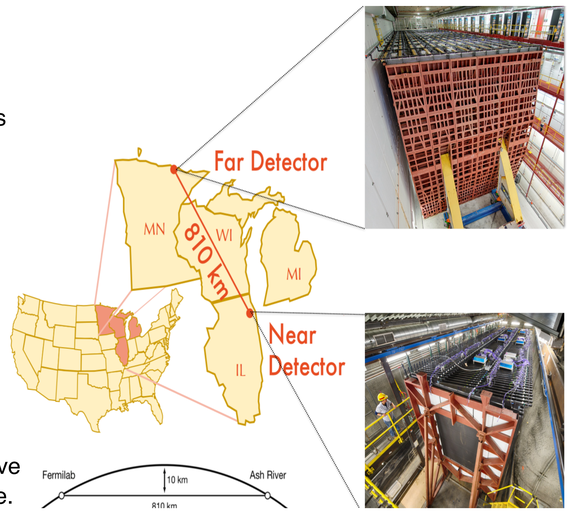
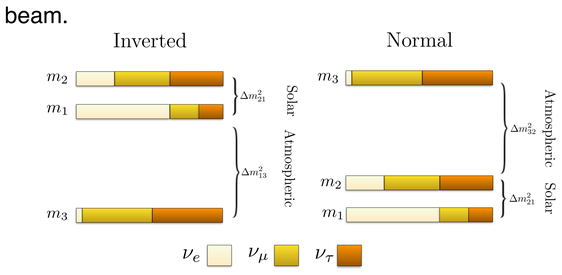
1 Introduction:

- The NOvA experiment is a long baseline neutrino oscillation experiment utilizing the world's most powerful ν_μ beam at the NuMI beam facility, Fermilab.
- The two detectors, one located 1 km from the beam target at Fermilab and the other located 810 km away in Minnesota, are functionally equivalent, fine-grained, low-Z liquid scintillator calorimeters, sitting 14 mrad off to the NuMI beam axis.
- The primary analyses are the disappearance of muon neutrinos and the appearance of electron neutrinos in Fermilab's NuMI beam.



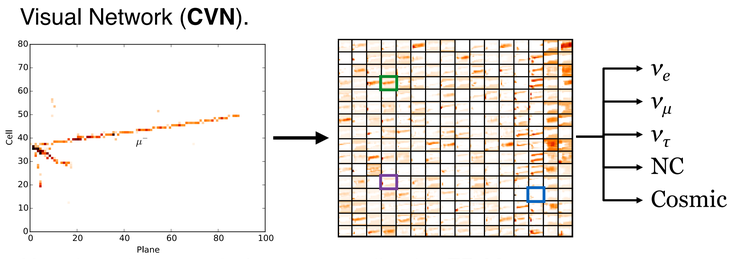


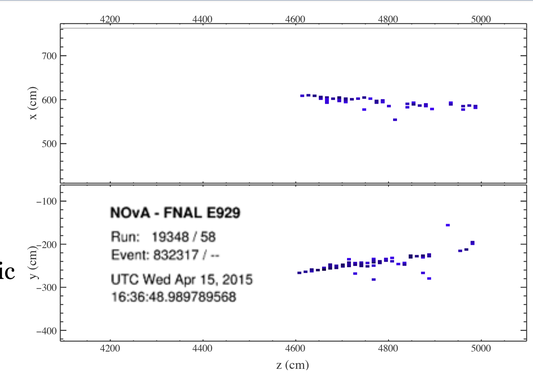


- These are used to determine the neutrino mass hierarchy, resolve the octant of the θ_{23} mixing angle, and probe δ_{CP} violating phase.

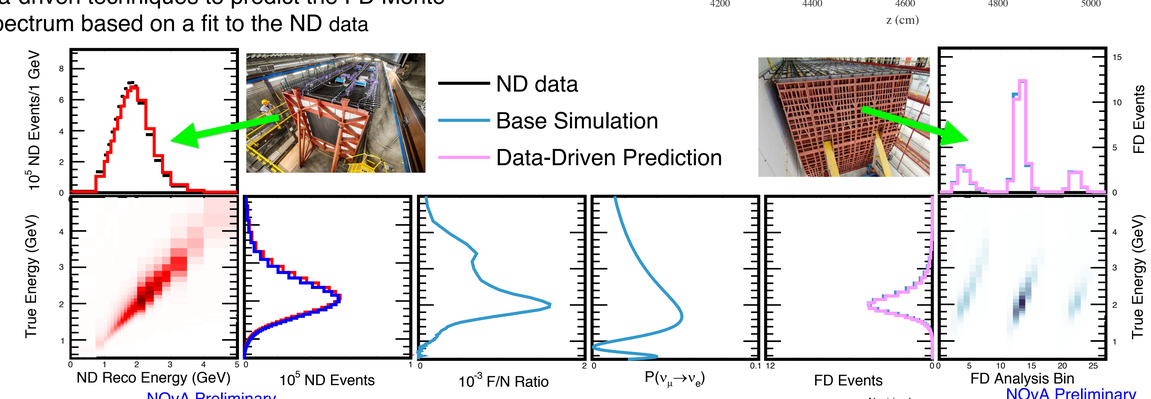
2 Event Predictions:

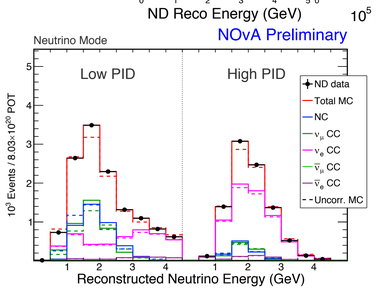
- ν_e event selection includes cosmic rejection, data quality and pre-selection cuts, along with particle identification via a Convolutional Visual Network (**CVN**).



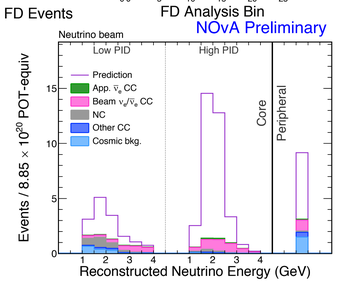


- Use data-driven techniques to predict the FD Monte-Carlo spectrum based on a fit to the ND data



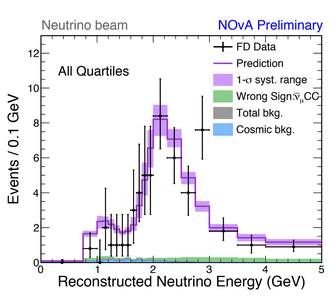


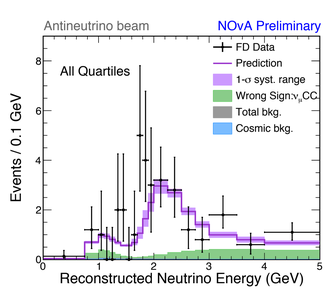
- With ND ν_μ's to predict FD ν_μ sample
- With ND ν_μ's to predict FD ν_e signal
- With ND ν_e's to predict FD ν_e backgrounds



3 ν_μ - disappearance & ν_e - appearance

- Use With 8.85×10^{20} POT in neutrino beam and 6.91×10^{20} POT in antineutrino beam NOvA obtained the following data:



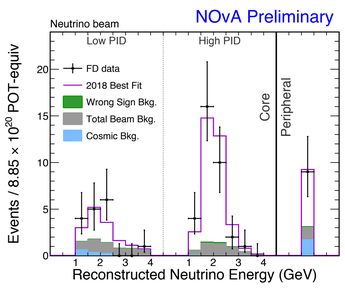


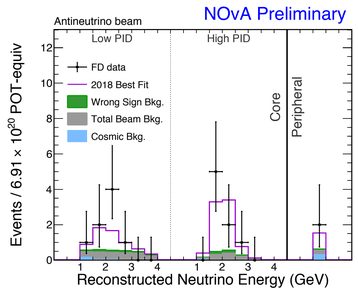
Observed 113 ν_μ CC events			
Total background 11.0 events			
$\bar{\nu}_\mu$ CC	NC	other beam bkg	cosmic
7.24	1.19	0.51	2.07

Observed 65 $\bar{\nu}_\mu$ CC events			
Total background 13.7 events			
ν_μ CC	NC	other beam bkg	cosmic
12.58	0.39	0.23	0.46

Observed 58 ν_e CC events					
Expected 30 ($\pi/2$ IH) - 75 ($3\pi/2$ NH) events					
Total background 15.1 events					
$\bar{\nu}_e$ CC	beam ν_e	ν_μ CC	ν_τ CC	NC	cosmic
0.66	6.85	0.63	0.37	3.21	3.33

Observed 18 $\bar{\nu}_e$ CC events					
Expected 10 ($3\pi/2$ NH) - 22 ($\pi/2$ IH) events					
Total background 5.3 events					
ν_e CC	beam ν_e	ν_μ CC	ν_τ CC	NC	cosmic
1.13	2.57	0.07	0.15	0.67	0.71

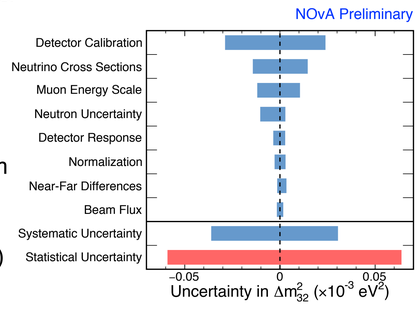


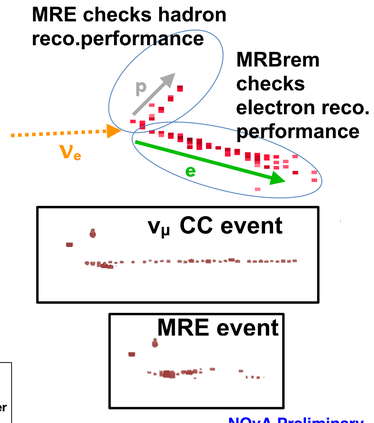


4 Systematics & Muon Removed Crosschecks:

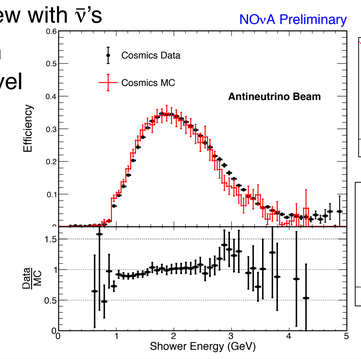
- Systematics are measured using shifted ND & FD simulations, produced by reweighing or special ± 1σ shifted files.

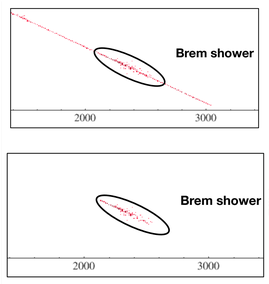
  Most important systematics:
  - Detector Calibration
    – Will be improved by the 2019 test beam program
  - Neutrino cross sections
    – Particularly nuclear effects (RPA, MEC)
  - Muon energy scale
  - Neutron uncertainty - new with $\bar{\nu}$'s

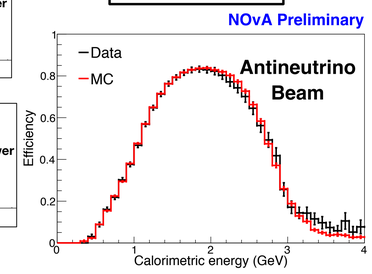




- Efficiency agrees between data and MC at the 2% level for MRE events both in neutrino and antineutrino beams.
- Efficiency of data and simulated brem showers agrees within systematics for neutrino and antineutrino CVN.

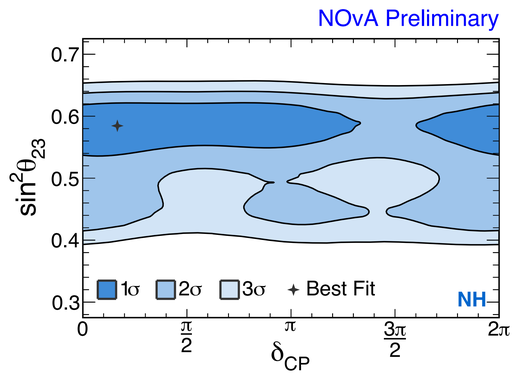


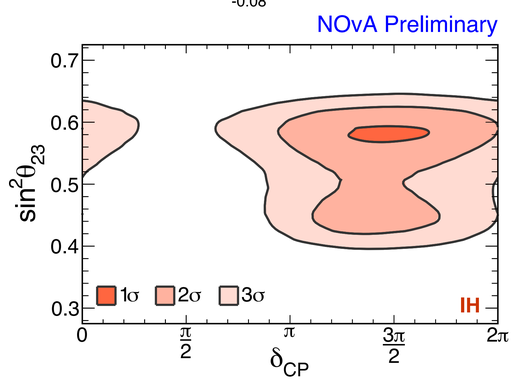


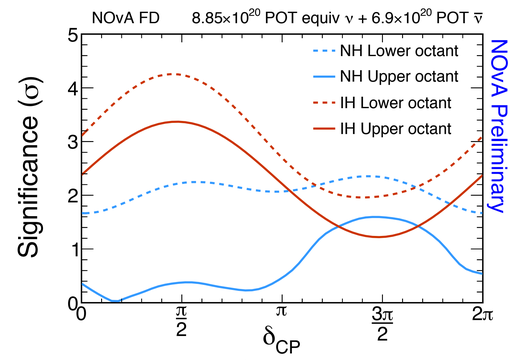


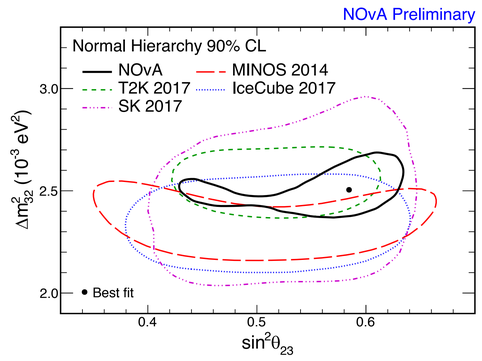
5 Joint $\nu_e + \nu_\mu$ analysis results:

- For the ν_μ disappearance only analysis details see the poster number 35.
  - Best fit :
    - NH, δ_{CP} = 0.17π ,
    - $\sin^2\theta_{23} = 0.58 \pm 0.03$ (UO),
    - $\Delta m^2_{32} = 2.51^{+0.12}_{-0.08} \times 10^{-3}$ eV^2
- The joint $\nu_\mu + \nu_e$ fit in both neutrino and antineutrino modes with systematic uncertainties produces the oscillation parameters measurements:





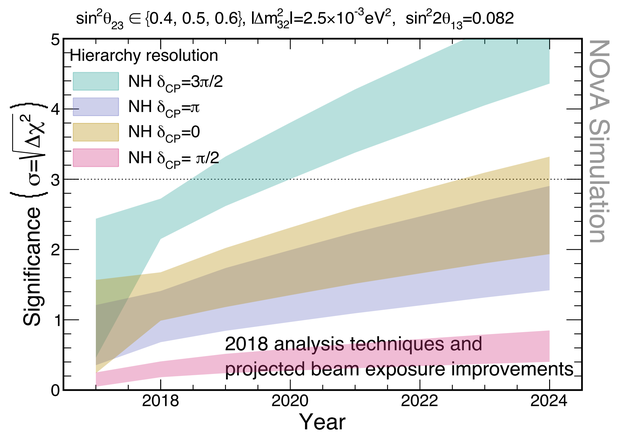




- Reject the area IH, δ_{CP} = π/2 at > 3σ,
- Reject IH, all values of δ_{CP} at 1.8σ
- Consistent with other long-baseline and atmospheric experimen

6 Conclusions and Outlook:

- First NOvA antineutrino data has been analyzed together with of neutrino data.
- We observe > 4σ evidence of $\bar{\nu}_e$ appearance.
- A joint $\nu_e + \nu_\mu$ analysis for the combined dataset:
  – Prefers NH at 1.8σ and disfavor δCP= π/2 at > 3σ.
- For future prospects we assume:
  – 50% neutrino beam and 50% antineutrino beam data per year.
  – Nova's reach can be improved by extended running through 2024 along with proposed accelerator improvement projects and test beam program



- 3σ sensitivity to the hierarchy possible in 2020 with favorable parameters.

- For more details, see "**Latest Results from NOvA**" talk from Dr. Evan Niner on Thursday 06/21.

http://novaexperiment.fnal.gov