Systematic Uncertainties and Cross-Checks for the NOvA Joint $\nu_\mu + \nu_e$ Analysis

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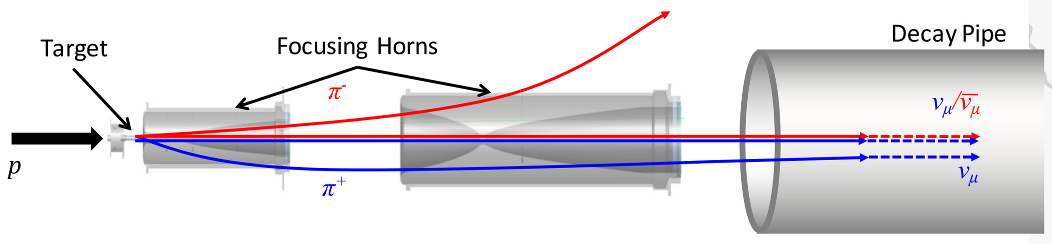
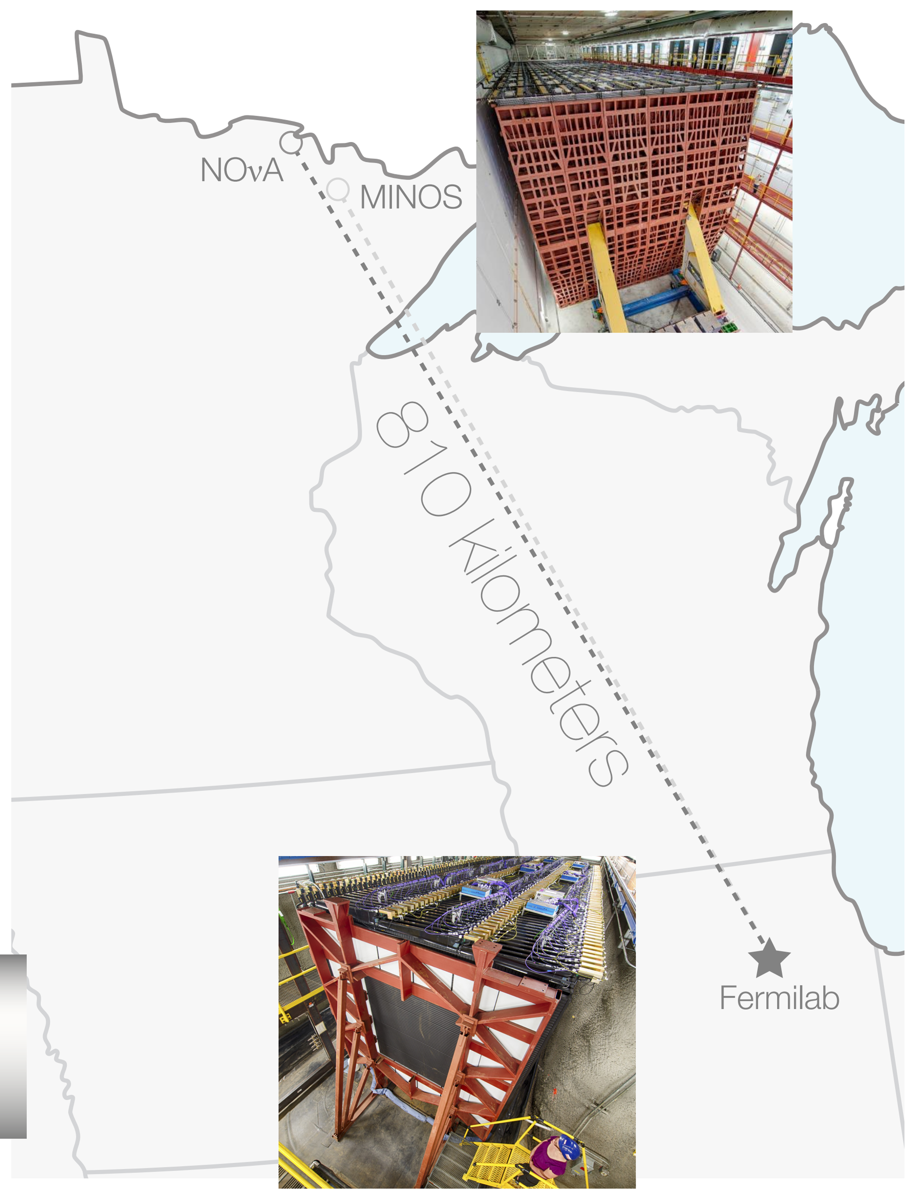
1 Introduction:

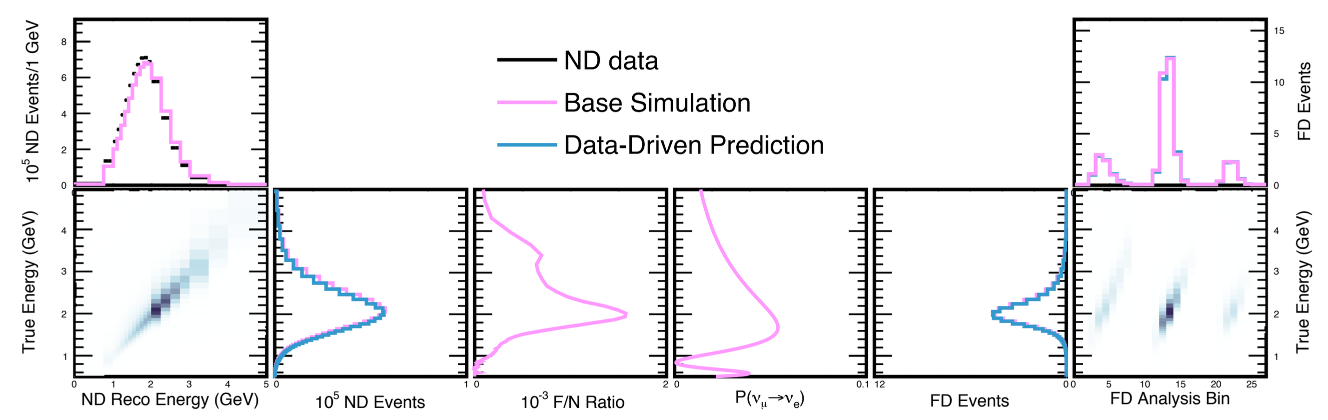
- NOvA is a two detector long baseline neutrino oscillation experiment.
- The two detectors, one located 1 km from the beam target at Fermilab and the other located 810 km away in Minnesota, are functionally equivalent.
- The main analyses are the disappearance of muon neutrinos and the appearance of electron neutrinos in Fermilab's NuMI beam.
- These are used to make measurements of the neutrino mass hierarchy, the octant of the large mixing angle, and CP violation.
- Assessment of systematic uncertainties and cross check studies are crucial steps in making precise measurements.



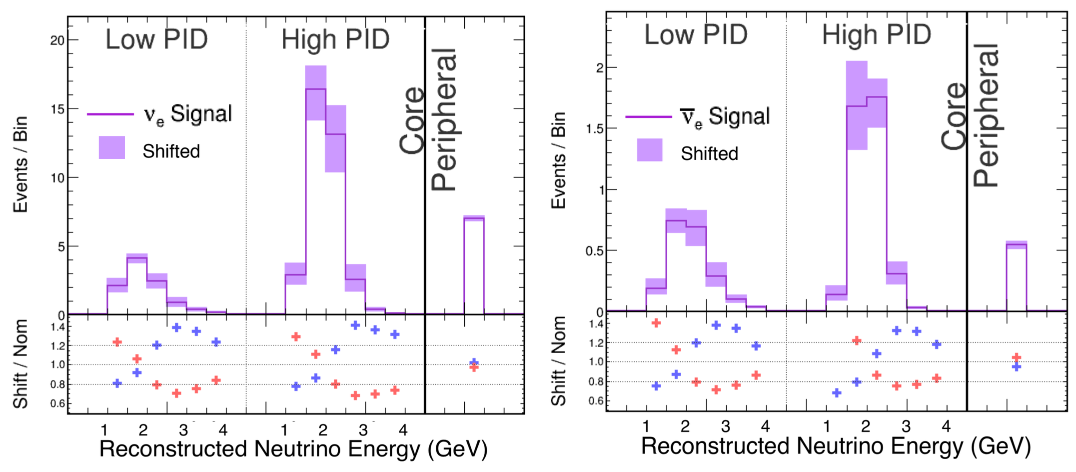


2 Evaluating Systematics

- The ND selected ν_e are oscillated to the far detector in decomposed components to make a prediction of the background components. The ν_e signal prediction is made by oscillating ND selected ν_μ to the FD.



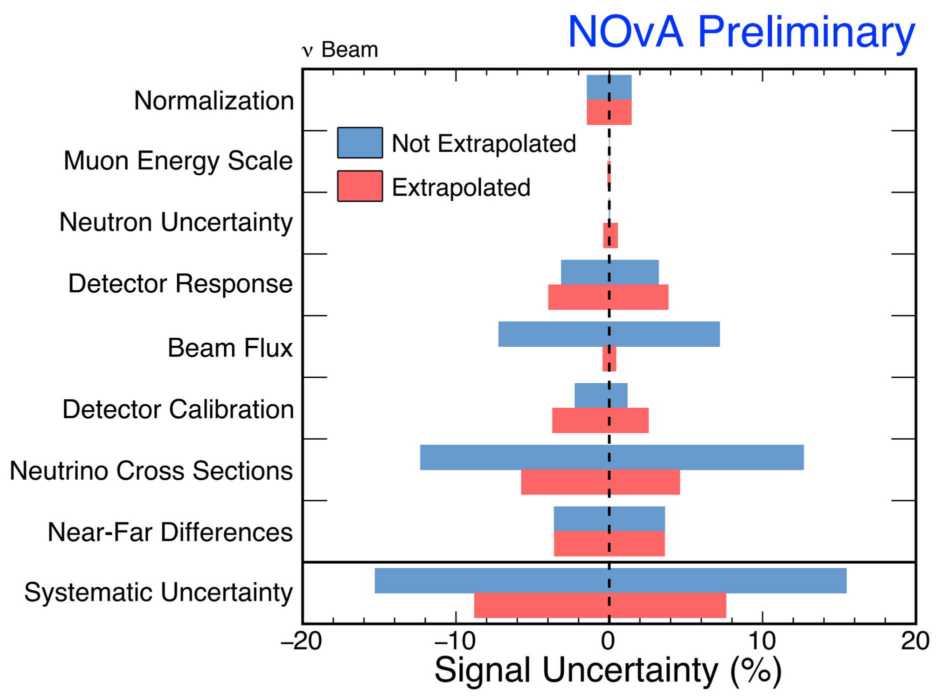
- Sources of systematic uncertainties are measured by producing shifted ND and FD simulation samples by either event reweighing or producing specially shifted files.
- The extrapolation process is carried out using these modified simulation samples and the effect of the systematic can be evaluated by comparing the predicted number of events.

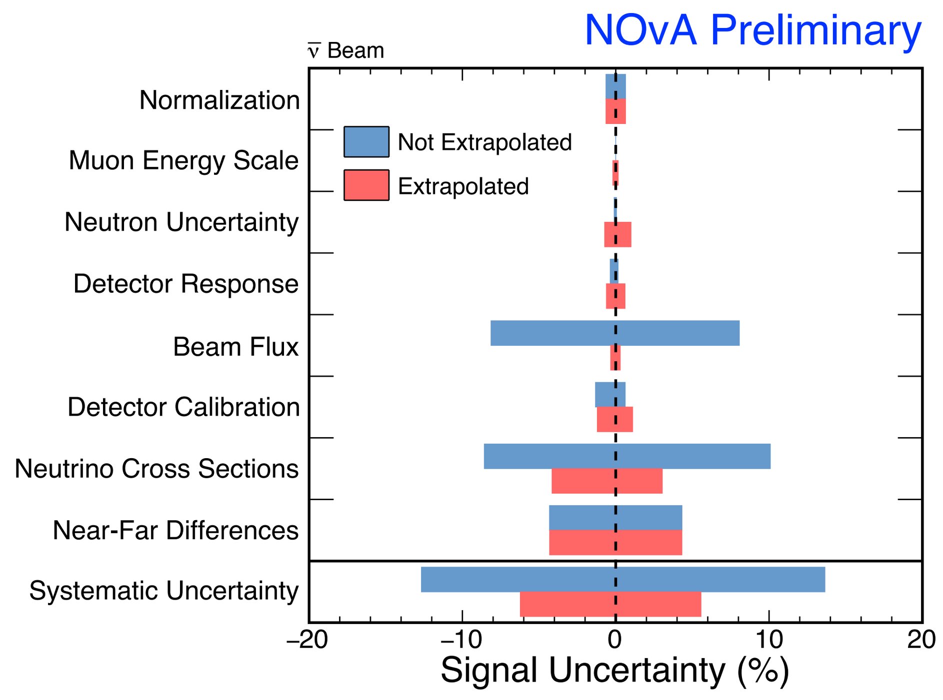


- Extrapolated FD prediction in 3 PID bins for the dominant absolute calibration systematic is shown here as an example with the systematic error band.
- In the neutrino mode the systematic shift is -2.81% / +1.37% , whereas in antineutrino mode, it is +0.58% / -0.59%.

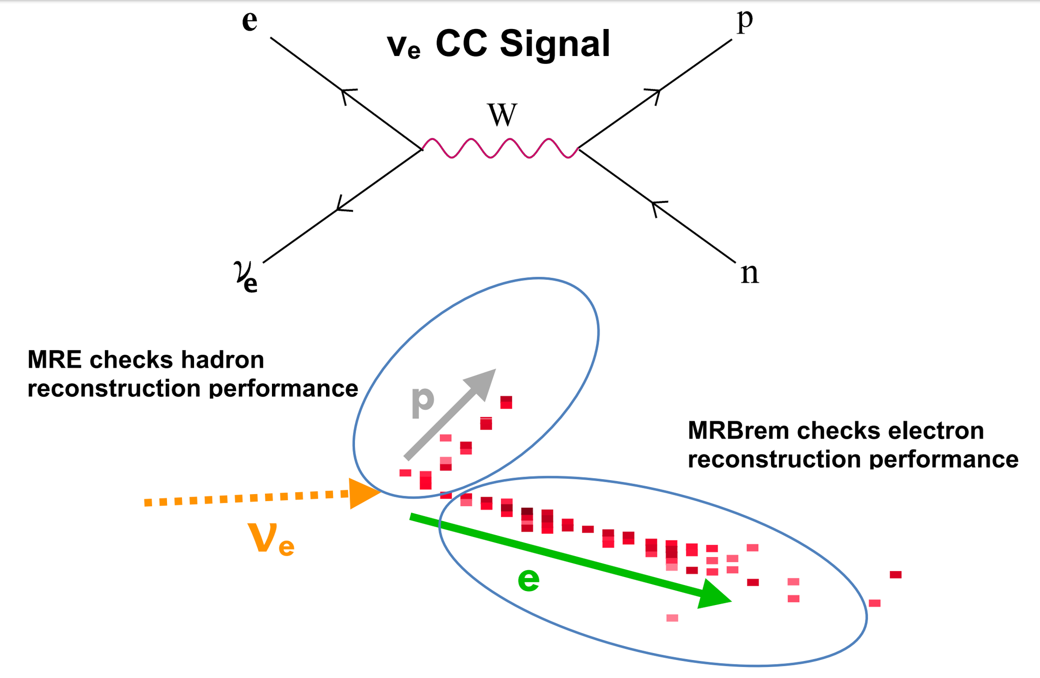
3 Systematics

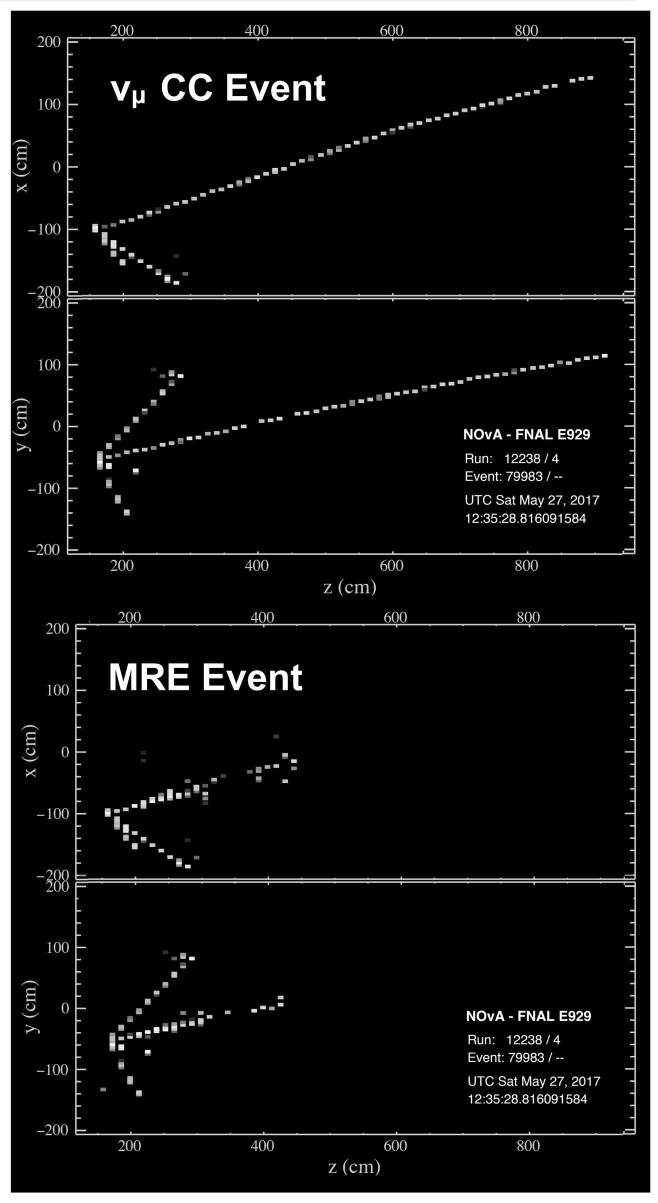
- The ND is functionally equivalent to the FD. Using this, extrapolating ND spectra to FD spectra greatly reduces systematic uncertainties.
- The overall uncertainty in the ν_e signal is reduced from 15% to 8.5% for neutrinos and from 12.5% to 5.5% for anti-neutrinos.





4 MRE Cross-Check:

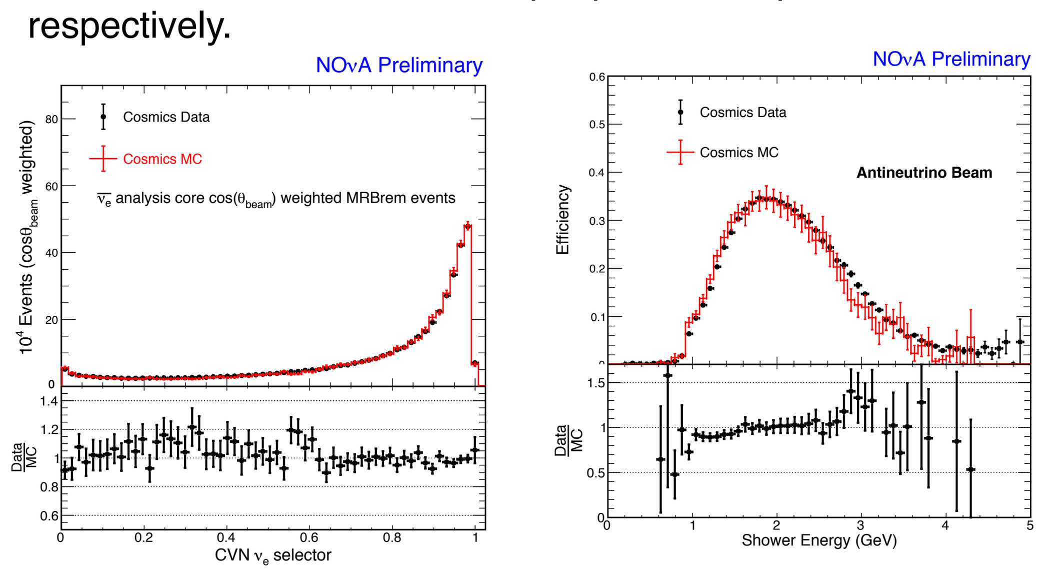


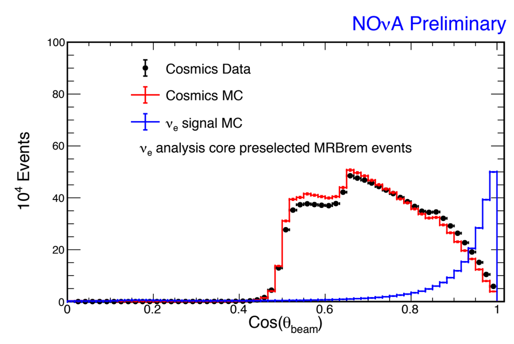


- The ND data allows a close look at backgrounds to the ν_e appearance signal, but offers little information about what may be expected of the signal events.
- Muon removed electron (MRE) events are constructed from ν_μ CC interactions by removing the primary muon track and simulating an electron in its place. Performed on both data and simulation.
- This combines electron showers that are simulate well, with hadronic shower from data, which aren't well simulated, and helps understand how the mismodelling of hadronic showers impacts ν_e selection.

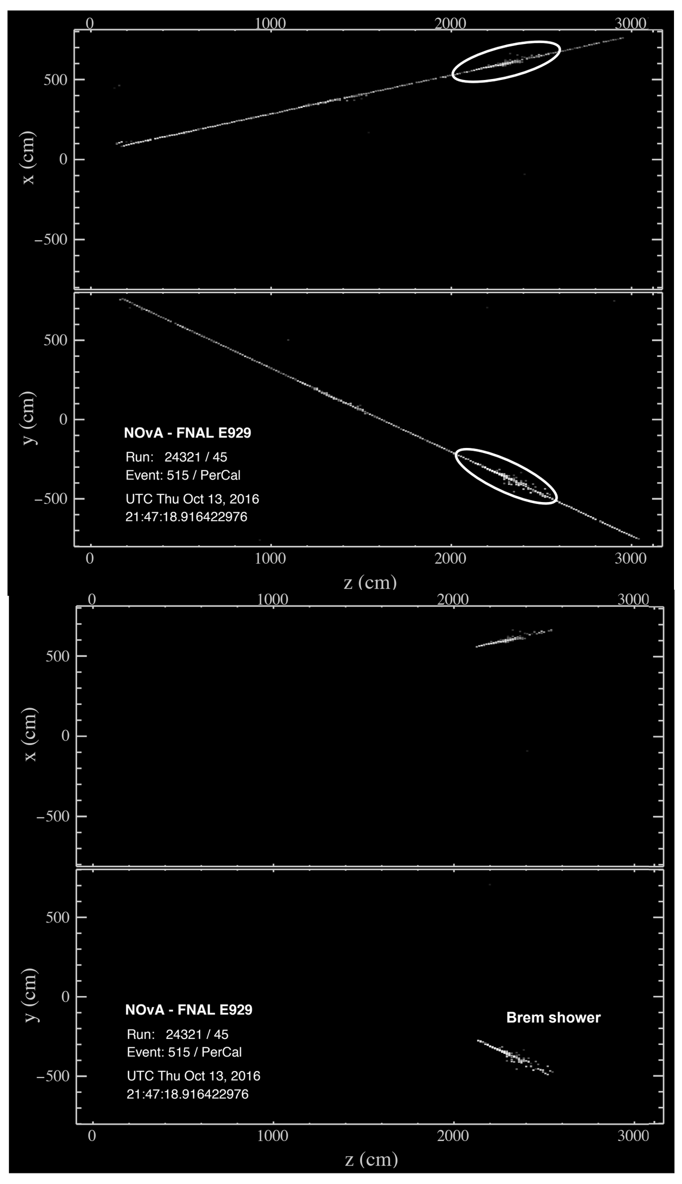
5 MRBrem Cross-Check:

- A key cross-check for the ν_e signal induced electromagnetic (EM) shower PID selection efficiency in FD, is to compare with that of Muon-Removed Bremsstrahlung Showers (MRBrem) PID selection efficiency.
- In 2018 neutrino analysis, the data/MC difference is of the order of 6% in core and 7% in peripheral samples respectively.



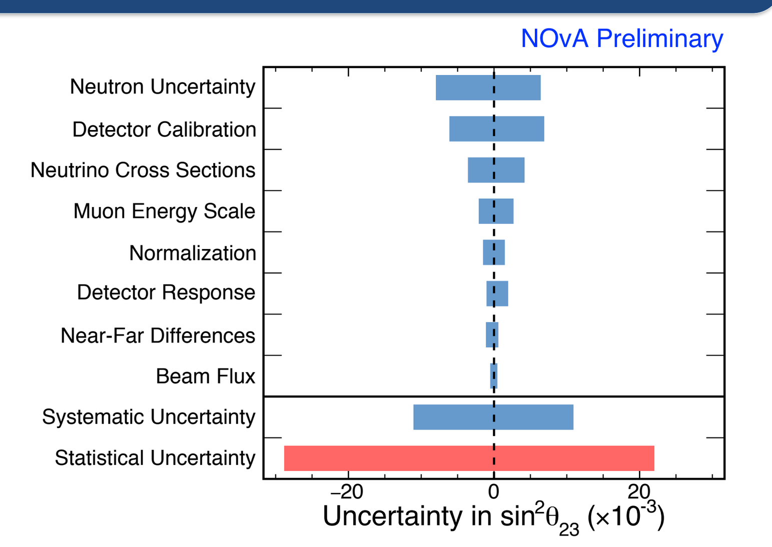


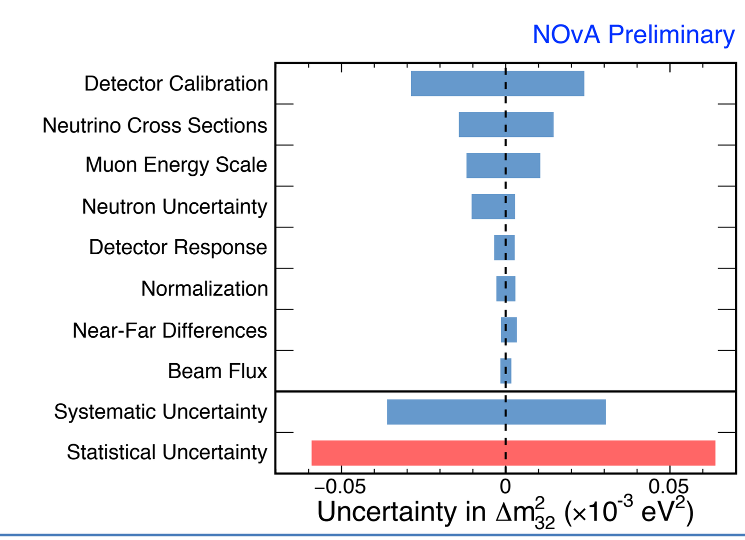
- Good data and MC agreement is found in EM shower selection from cosmic samples.

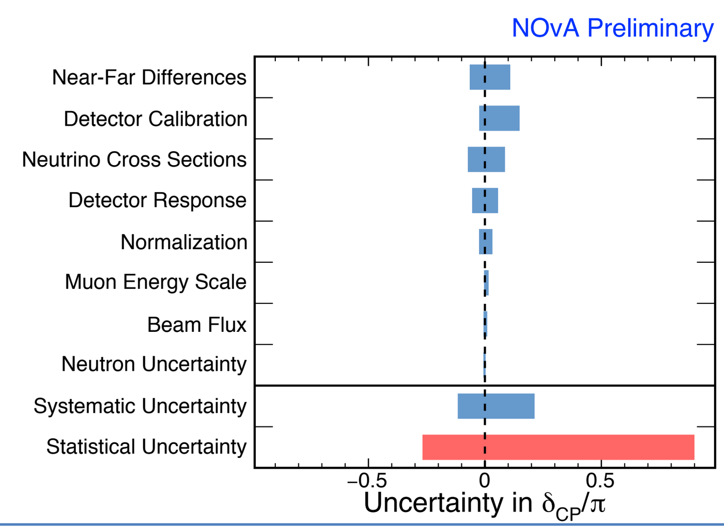


6 Summary and Conclusions:

- Systematics are integral to NOvA oscillation results. We fit the antineutrino and neutrino joint $\nu_\mu + \nu_e$ predictions to extract the oscillation parameters.
- The measurement of the oscillation parameters is primarily limited by statistics.
- MRE and MRBrem cross-check studies show a good agreement between data and MC.







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