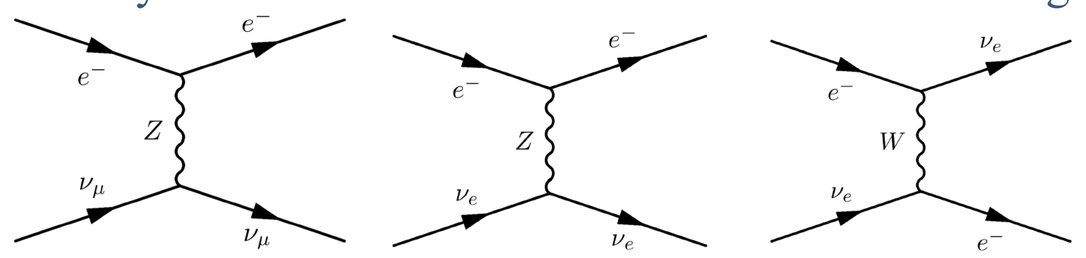
Status of the Measurement of Neutrino-Electron Elastic Scattering in the NOvA Near Detector

Yiwen Xiao (UC Irvine) On Behalf of the NOvA Collaboration

Introduction

Neutrinos can elastically scatter off electrons via neutral current or charge current exchange.



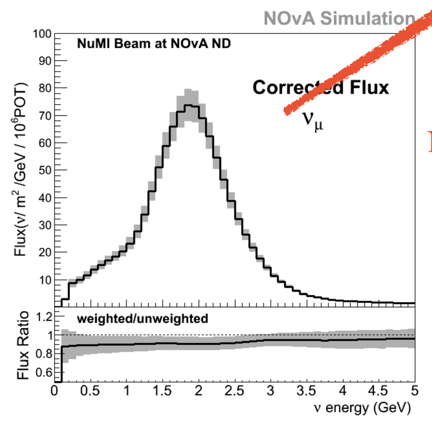
- $\nu - e$ is a pure leptonic process whose total cross section can be calculated to 1% precision in the Standard Model (SM):

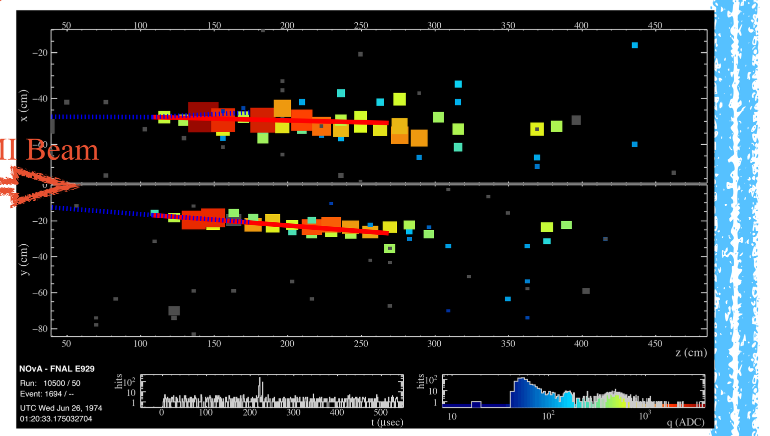
$$\sigma^{(\nu_l e^- \to \nu_l e^-)} \sim 10^{-42}\ (E_\nu/\text{GeV})\ \text{cm}^2$$

- It can be used to constrain neutrino flux and to also benefit for new physics searches (e.g. neutrino magnetic moment, light dark matter search).

NOvA Near Detector

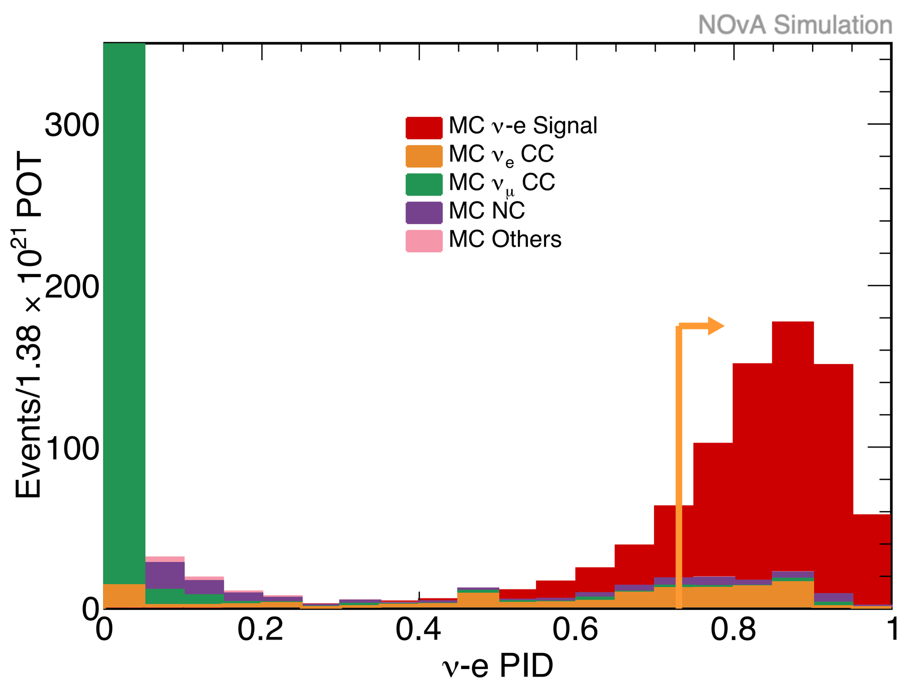
- NOvA is a long-baseline experiment optimized to observe the oscillation of muon neutrinos to the electron neutrinos.
- The NOvA near detector (ND) is located 1 km downstream from the proton beam target and lies 100 m underground at Fermilab.
- The target region of the ND is 100 tons of liquid scintillator. It is located at 14.6 mrad off-axis from the NuMI beamline.
- The large neutrino flux at the ND provides a rich dataset for measuring neutrino cross sections.
- Neutrino cross-section measurements performed at the near detector are affected by the large uncertainty of the absolute neutrino flux.
- Flux uncertainty of 10% is dominated by models of hadron production and beam focusing.

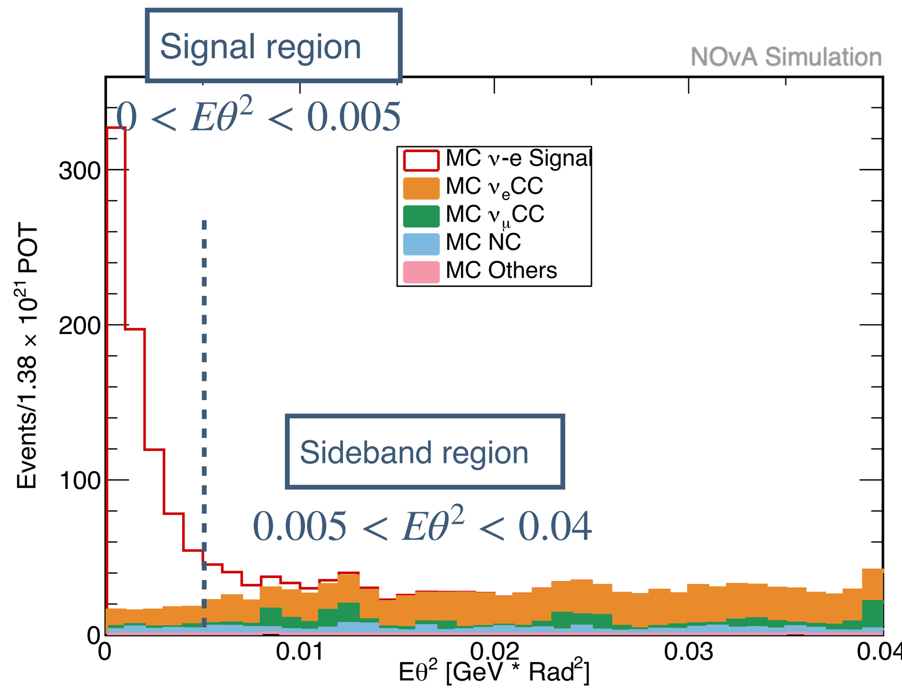




Event Identification and $\nu - e$ Signal Selection

- $\nu - e$ scattering is a rare process in the presence of a high rate of neutrino interactions.
- The $\nu - e$ signal topology is a single, highly forward electron shower.
- Our selection requires small values of $E_e\theta_e^2 \approx 2m_e(1-y)$, where E_e is the energy of the most energetic EM shower and θ is its angle with respect to the beam
- Two event classifiers based on the Convolutional Neural Network (CNN) were trained to classify events.
  - $\nu - e$ PID: to separate $\nu - e$ scattering events from backgrounds.
  - e/π^0 PID: to further rejects backgrounds with a π^0 in the final state.
- Sideband region is 7x larger than the signal region to normalize the background and reduce uncertainties





Background Correction and Systematics Uncertainty

- The integrated neutrino flux in the data can be determined as follows:

$$\Phi(Data) = \Phi(MC) \times \frac{N_{\nu-e}^{Data}}{N_{\nu-e}^{MC}}$$

- Signal yield in Data ($N_{\nu-e}^{Data}$) relies on estimating the background in the signal region, which is subject to systematic uncertainties.
- To improve background subtraction, the Data/MC ratio in the sideband region (dominated by background events) is used to correct the MC background yield in the signal region.

$$N_{\nu-e}^{Data} = N^{Data} - N_{Background,\ corrected}^{MC} = N^{Data} - N_{Background}^{MC} * C_{bkg}$$

- Background Uncertainties:
  - Genie modeling, beam focusing, and detector response.
- Signal Uncertainties:
  - A data-driven method is used to estimate systematic uncertainties in the signal selection efficiency, using Rock muons-induced Bremsstrahlung (MR Brem) in ND Data and MC to mimic electron showers in elastic scattering.

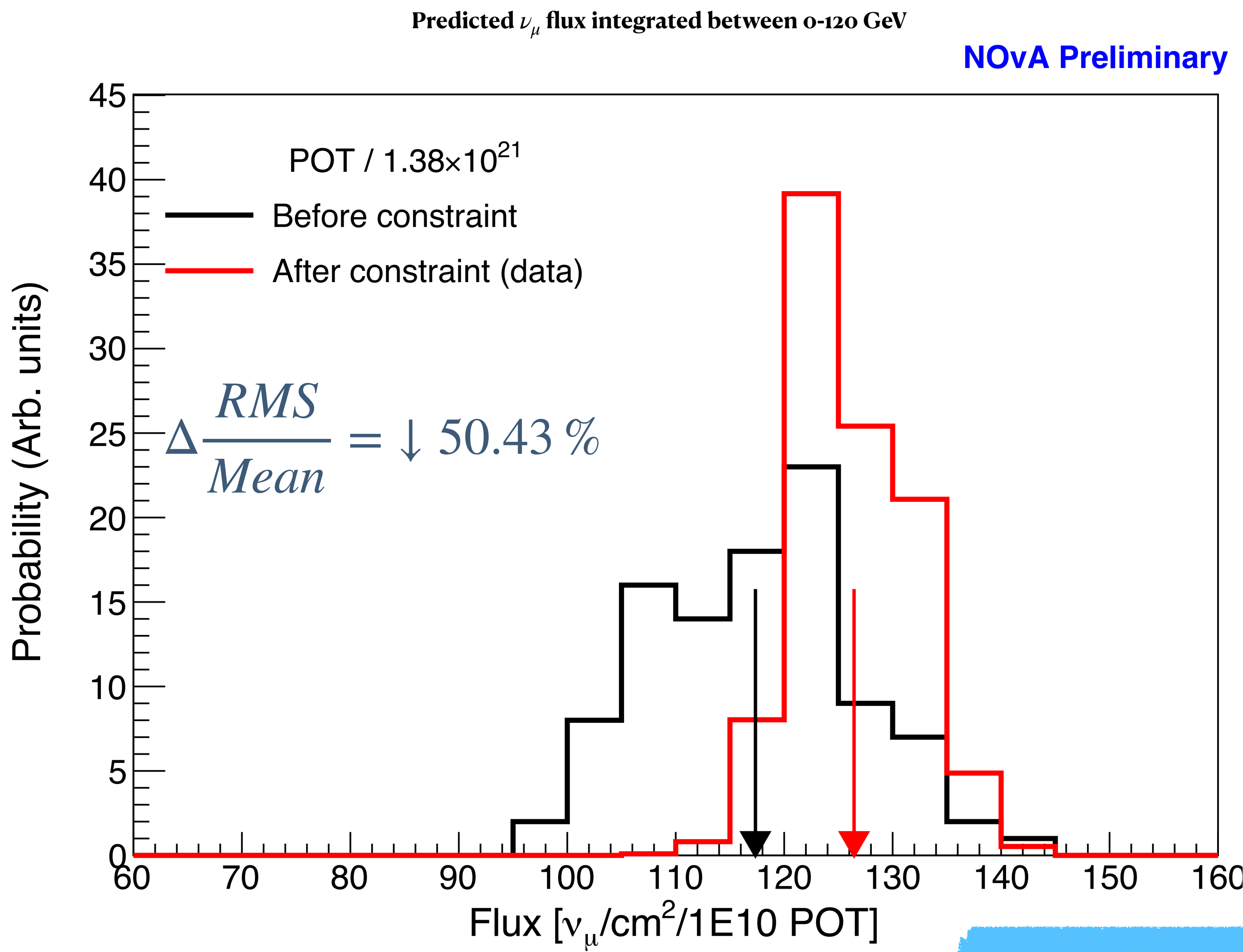
Sources	Uncertainties (%)
Signal Selection	1.8
GENIE	1.15
Beam and Focusing	0.13
Detector	1.98
Total Syst.	2.91

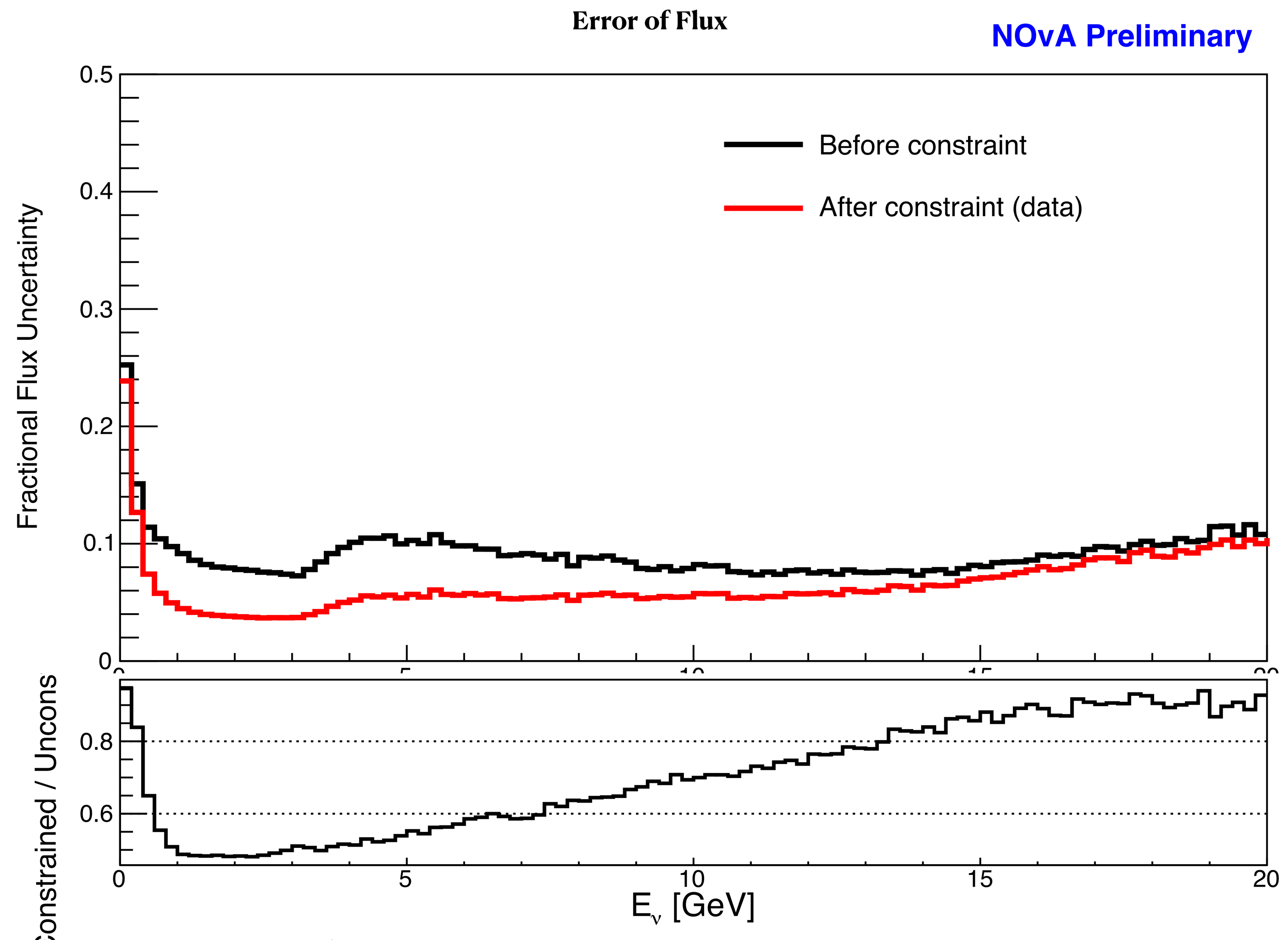
Flux Constraint

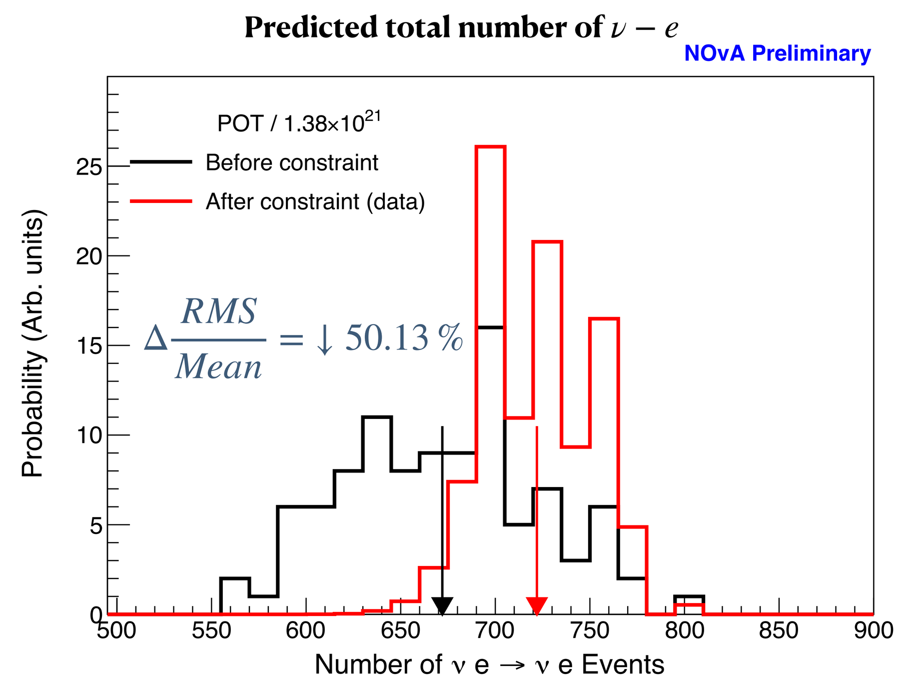
- Following the approach pioneered by MINERvA, we apply Bayes' theorem to combine the ν-on-e scattering measurement with the flux prediction.

$$P(M|N_{\nu-e}) \propto \pi(M)P(N_{\nu-e}|M),\ \ P(N_{\nu-e}|M) \propto e^{-\frac{1}{2}(N-M)\Sigma_N^{-1}(N-M)}$$

- where P(M) is the probability of a flux model (prediction) (Ref: arXiv:1512.07699 and arXiv: 1906.00111)
- $P(N_{\nu e\to\nu e}|M)$: the probability of the neutrino-electron scattering measurement given a model
- N is the vector representing the bin contents of that spectrum in the data, M is the corresponding vector representing the bin contents of that spectrum predicted by model M from one of many PPFX universes, Σ_N is the total data covariance matrix describing all uncertainties on N except those due to the flux model







Summary and Next Steps

- Optimized event selection achieves high signal purity and low background contamination.
  - CNN-based classifiers offer a strong separation between the signal and background.
- Total measurement uncertainty: ~2.9%, which provides a solid input to constrain the ~10% beam-flux uncertainty from external hadron-production measurement.
- ν − e scattering method is promising to constrain the neutrino flux uncertainties to ~ 4%.
- An antineutrino beam study is on the way.

Stay Tuned!