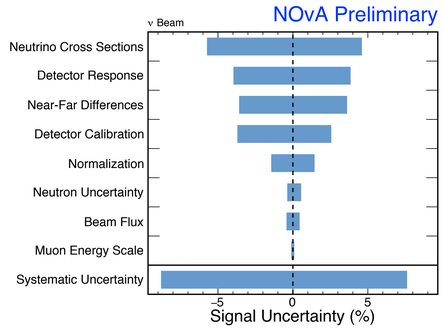
# Status of the Inclusive Electron and Muon Neutrino Charged-Current Cross-Section Measurement in the NOvA Near Detector

Matthew Judah[1], Shih-Kai Lin[1], Leonidas Aliaga Soplin[2], Biswaranjan Behera[2,3], Pengfei Ding[2], Kanika Sachdev[2]
[1]Colorado State University, [2]Fermilab, [3]IIT Hyderabad
For the NOvA Collaboration

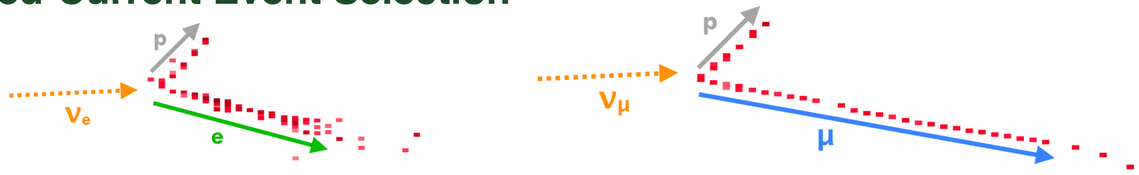
## Introduction

- Precision measurements of neutrino oscillation parameters require better knowledge of neutrino-nucleus interactions.
- The Near Detector (ND) is exposed to a large flux of 1-3 GeV neutrinos giving a better understanding of the $\nu_e$ and $\nu_\mu$ charged-current (CC) inclusive cross sections.



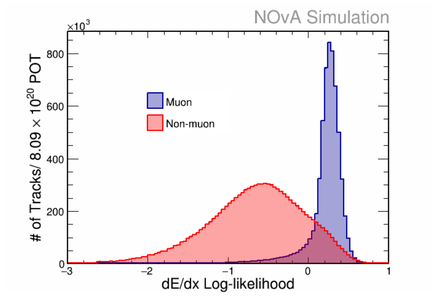

**(Right) Uncertainty on expected number of $\nu_e$ appearance events due to each systematic : cross-section model uncertainties are a large source of systematic error**

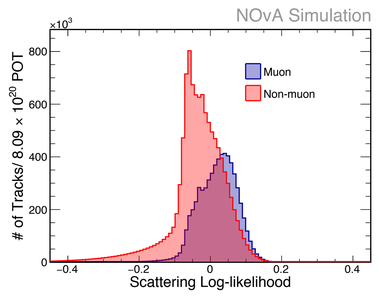
## Charged-Current Event Selection

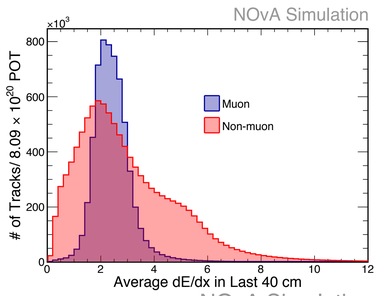



- Selection of neutrino events with charged leptons in the final state has been optimized on NOvA ND simulation based on G4NuMI, GENIE, and GEANT.
- Selected events are required to be fully contained and interact in the fiducial volume.

## Muon Identification

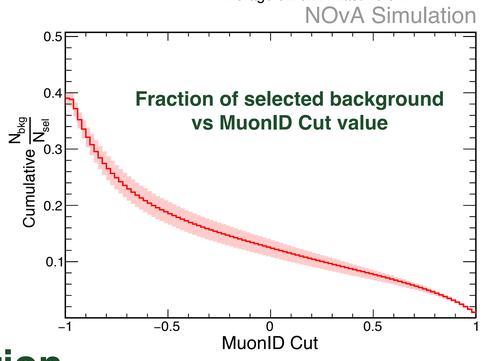


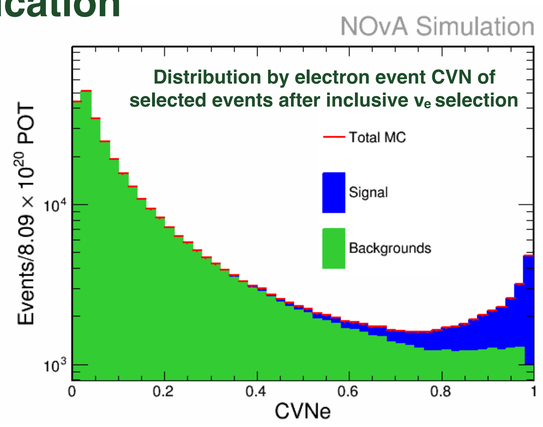

A Boosted Decision Tree (MuonID) was trained on track properties with limited model dependence

- dE/dx log-likelihood
- Scattering log-likelihood
- Average dE/dx in last 10 cm of track
- Average dE/dx in last 40 cm of track

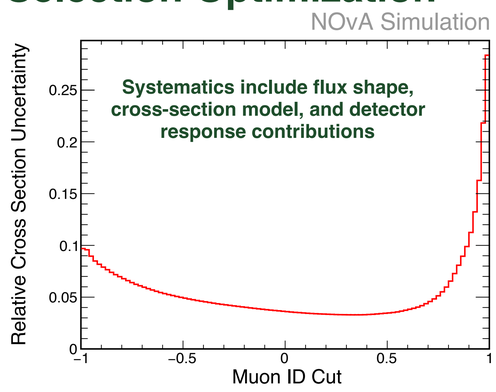



## Machine Learning For Electron Identification

- Inclusive $\nu_e$ analysis uses machine learning techniques to identify events with electron-like showers (CVNe).
- NOvA has also developed a single particle classifier to identify reconstructed clusters.
- Both methods achieve better identification than traditional reconstruction techniques used in NOvA.




## Selection Optimization



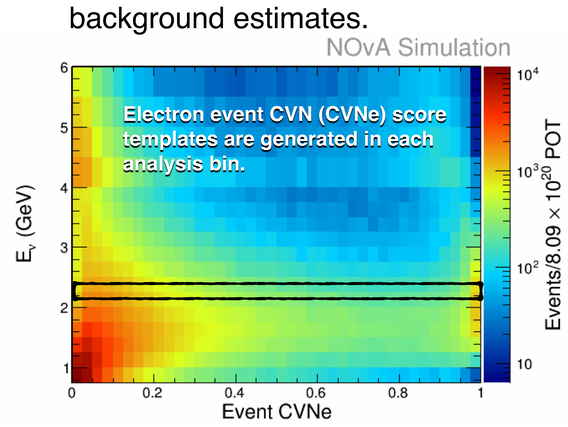

Each analysis' selection is optimized by minimizing the uncertainty on the total cross section:

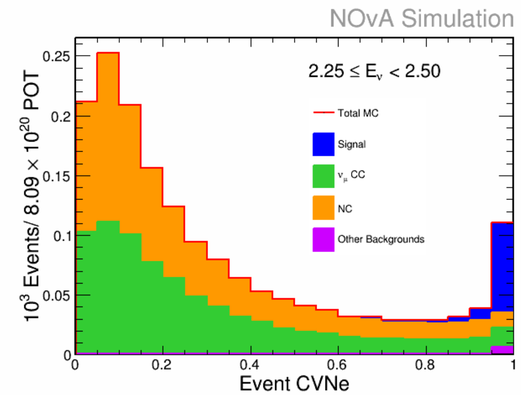
$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{(N_{\mathrm{sel}}^{\mathrm{stat}})^2 + (N_{\mathrm{bkg}}^{\mathrm{stat}})^2 + (\delta N_{\mathrm{bkgd}}^{\mathrm{syst}})^2}{(N_{\mathrm{sel}} - N_{\mathrm{bkg}})^2} + (\frac{\delta\epsilon}{\epsilon})^2}$$

- $\nu_\mu$ selection is 22% efficient and 90% pure
- $\nu_e$ selection is 39% efficient and 49% pure

## Template Fit For $\nu_e$ Signal Estimate

- Inclusive $\nu_e$ analysis uses a data driven technique to extract signal and background estimates.

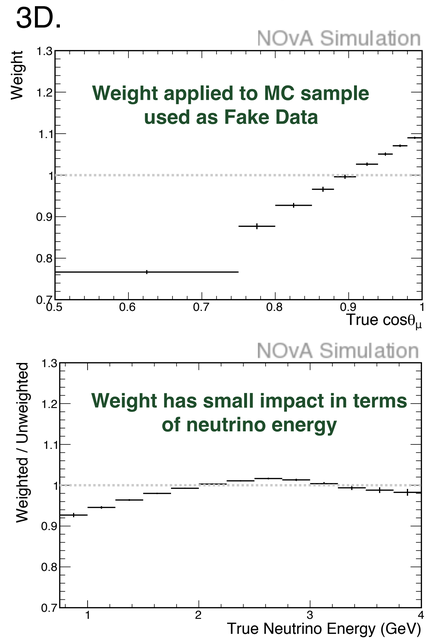


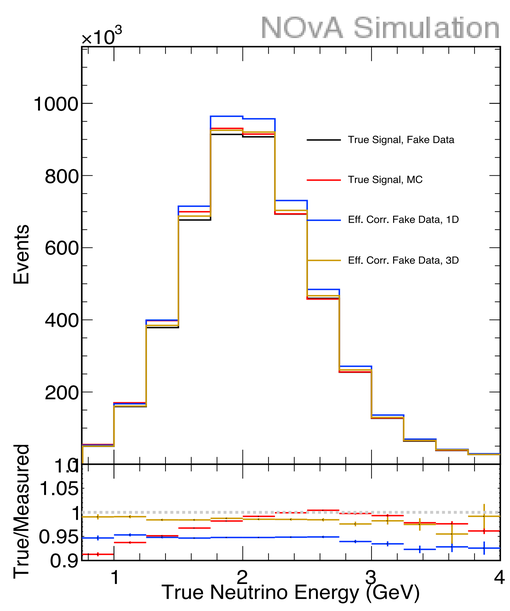




- MC templates are fit to data while taking systematic uncertainties into account

## Multi-Dimensional Approach to Efficiency Correction

- Measurement is done in 3D parameter space - lepton energy, lepton angle, and neutrino energy to keep all information of the dependence on relevant variables.
- The reconstructed spectrum from data is unfolded and efficiency corrected in 3D.

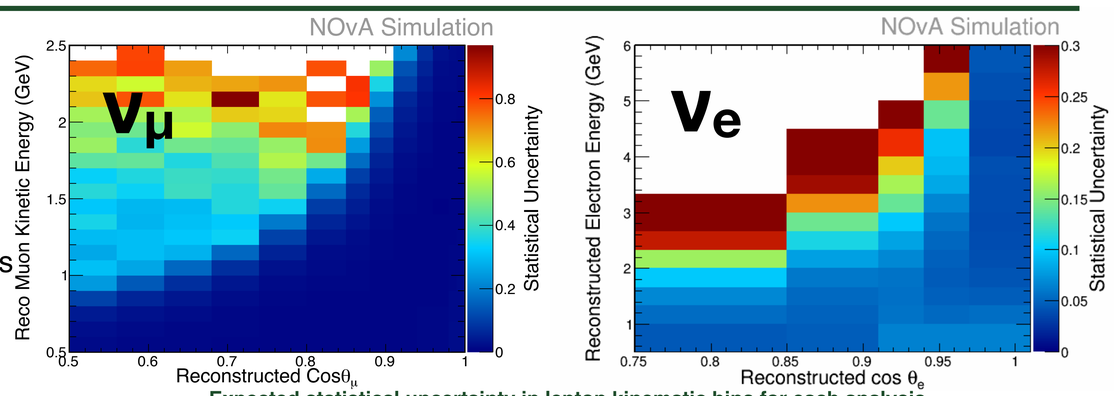



**Example showing the comparisons of multi-dimensional to single dimension efficiency correction using a shifted MC sample**

## Outlook

- $\nu_e$ and $\nu_\mu$ CC inclusive cross-section analyses are close to completion:
  - Systematic uncertainties taken into account
  - Limited model dependence
- Analyses will produce systematics-limited double differential cross-section measurements
  - Statistics allow for the first double-differential $\nu_e$ CC inclusive cross-section measurement in this energy range
- Expecting measurements with 10-15% systematic uncertainties.




**Expected statistical uncertainty in lepton kinematic bins for each analysis**