Impact of the HF-CRPA Model on Neutrino Oscillation Parameter Measurements in NOvA

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NOvA Experiment

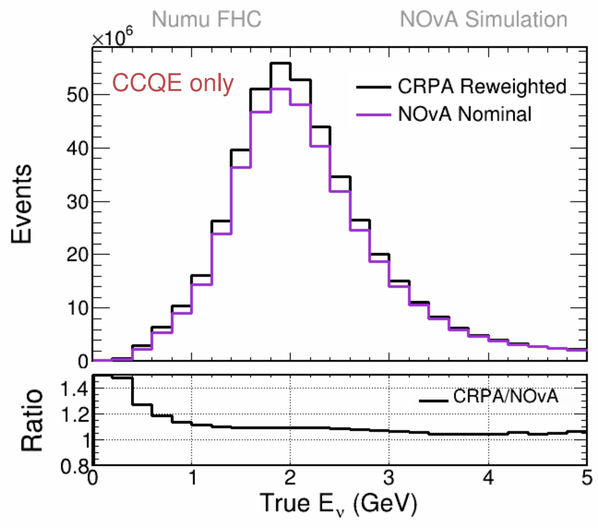
- The NuMI off-axis ν_e Experiment (NOvA) [1] is a long-baseline neutrino oscillation experiment that aims to measure three flavor oscillation parameters
- Two identical liquid scintillator detector: the near detector (ND) is at Fermilab, whereas the far detector (FD) is at Ash River, Minnesota, 810 KM away from Fermilab.
- Uses NuMI neutrino beam of energy peaked at 2 GeV.

Interaction model used in NOvA

- NOvA uses GENIE model-dependent simulations to extrapolate FD oscillated predictions from ND data.
- It uses the GENIE 3.0.6 with NOvA tuned configuration N18_10j_00_000
- Model used for interaction
  - Quasi-elastic (QE): Valencia 1p1h Z-expansion axial form factor
  - Final state Interaction (FSI): hN Semi Classical Cascade Custom fit to external pion scattering data

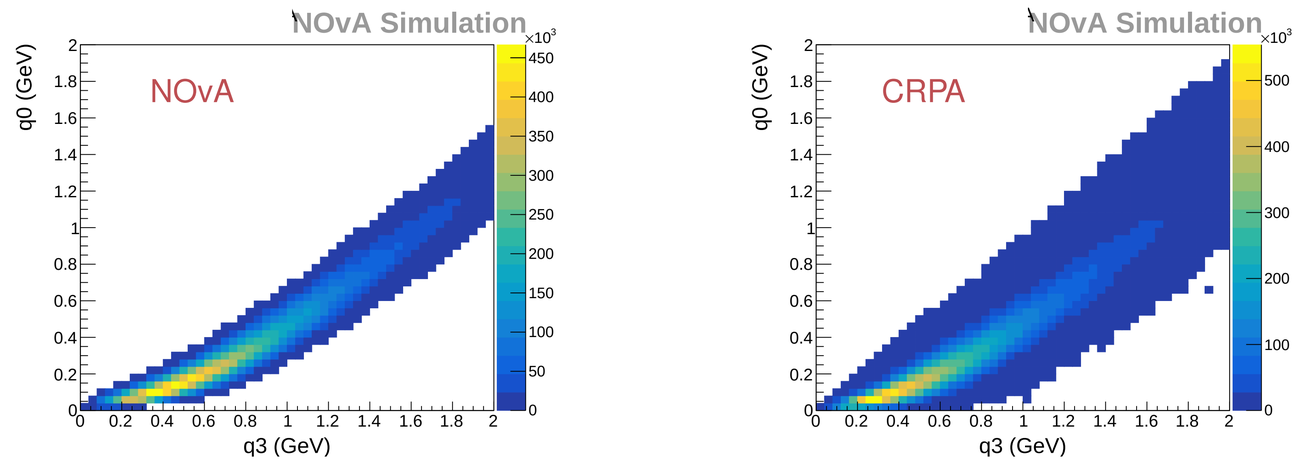
HF-CRPA CCQE model

- The current model used in NOvA is good at describing the general behavior of the QE cross-section.
- The Hartree-Fock (HF) mean field model for charge current (CC) QE with continuum random phase approximation (CRPA) [2] is another way of describing CCQE in the low momentum transfer region.
- The treatment of final-state interactions (FSI) in HF-CRPA leads to significantly different predictions for muon and electron neutrino cross sections at low-energy transfers
- It enhances the cross-section in the low energy region significantly and overall $\sim$ 8-10 % increase in cross-section.



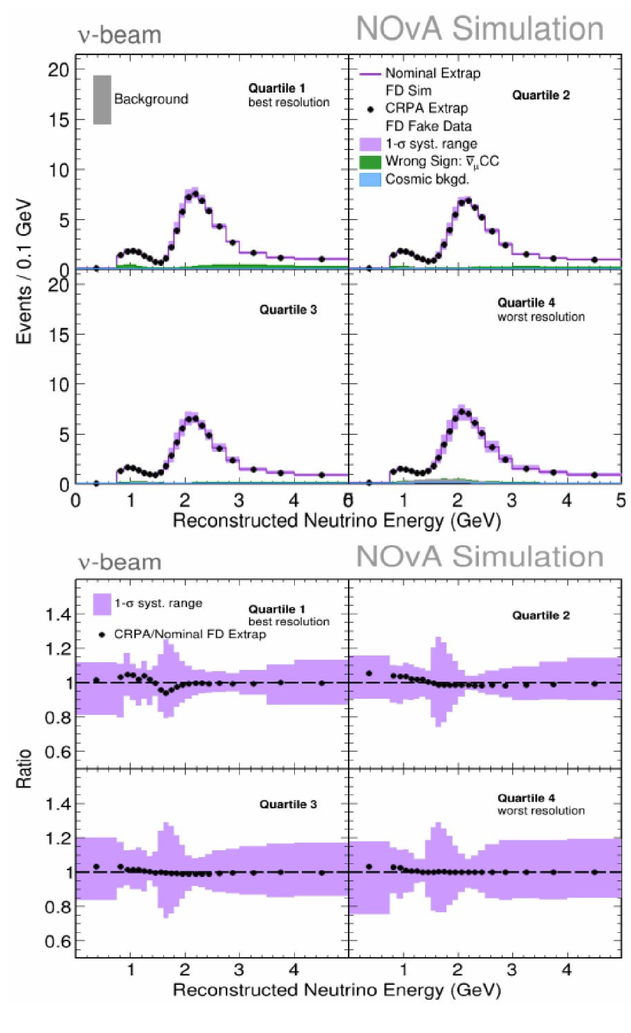
Implementation of HF-CRPA model in NOvA

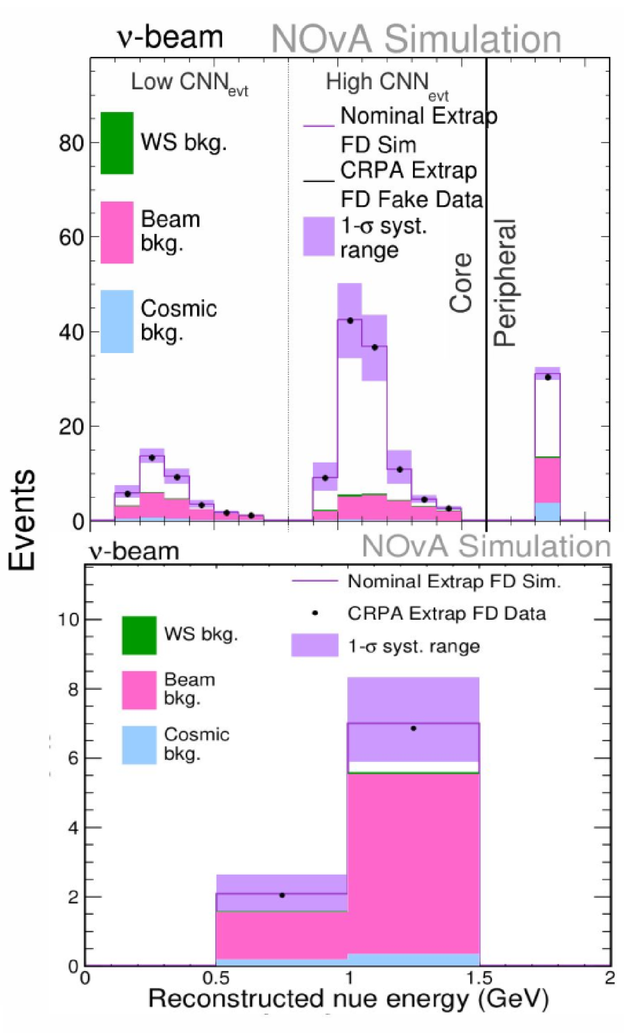
- Used GENIE G21_11a_00_000 tune with CRPASuSAv2Hybrid-QEL model for QE [3].
- Took the ratio of CRPA sample with the NOvA tuned sample in q_0 (energy transfer)-q_3 (three-momentum transfer) phase space and reweighted NOvA tuned sample with the ratio.
- Due to the mismatch in phase space of these two samples and low statistics in the low q_0-q_3 region, the lowest two q_0 bins were merged, and then the ratio was calculated.



Impact on the FD extrapolated prediction

- ND sample is reweighted with CRPA to NOvA ratio and then made the extrapolated prediction at the FD





Summary

- The HF-CRPA model provides $\sim 10\%$ enhancement in the CCQE scattering cross-section
- This has a relatively strong effect in the quartile 1 of FD extrapolated numu
- Overall, the CRPA extrapolated fake data are well within NOvA uncertainty.
- It has a very small effect on oscillation parameters
  - Δm^2_{32} : resulting bias $\sim$ 0.1 % ($\sim$ 7% of 1σ interval)
  - $\sin^2\theta_{23}$: resulting bias $\sim$ 0.4 % ($\sim$ 4% of 1σ interval)

KEY REFERENCES

[1] P. Adamson et al., Phys. Rev. D 93, 051104 (2016)

[2] Pandey. V et al., Phys. Rev. C 92, 024606 (2015)

[3] Dolan. S et al., Phys. Rev. D 106, 073001 (2022)

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