

## NOvA Experiment

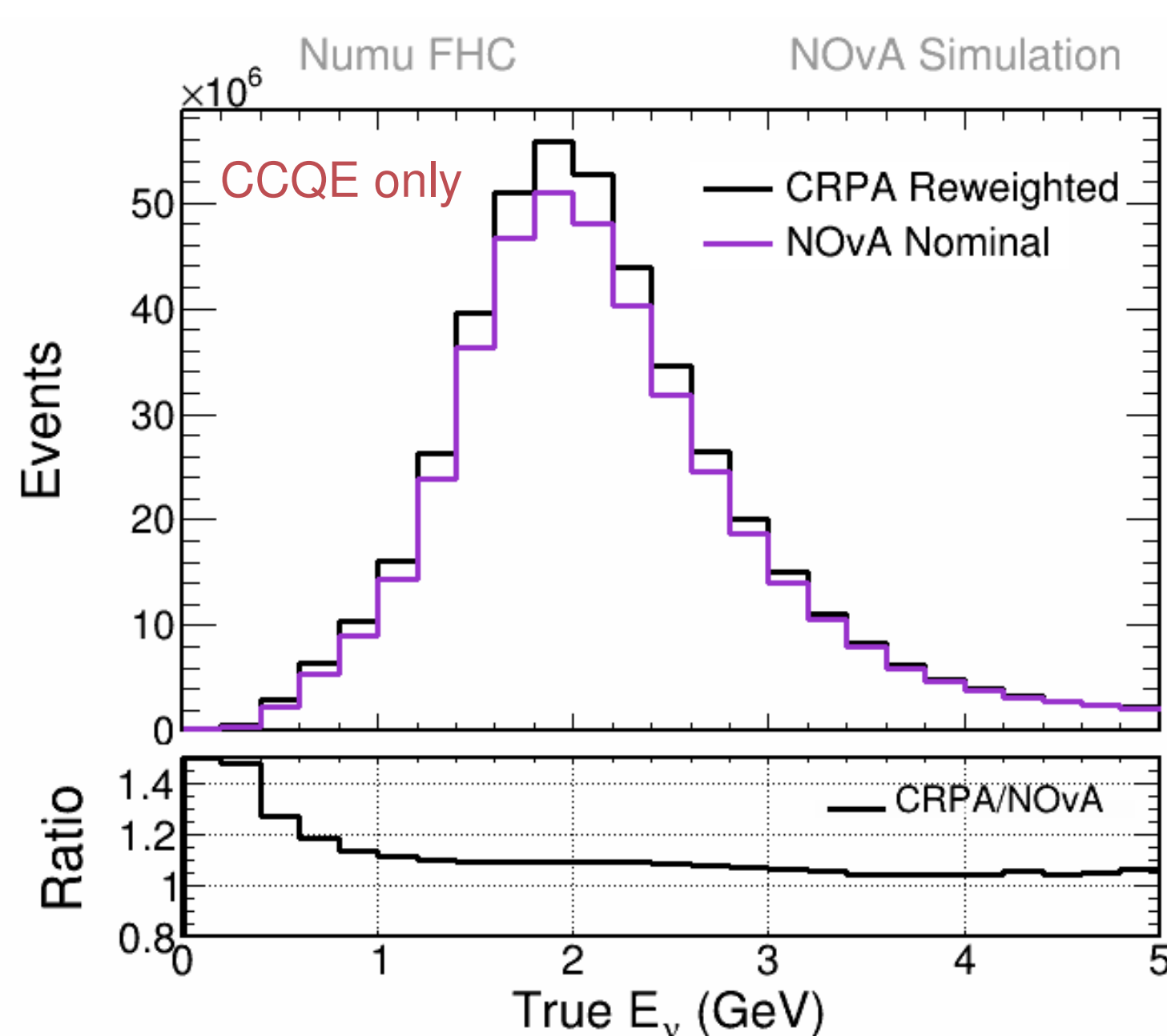
- The NuMI off-axis  $\nu_e$  Experiment (NOvA) [1] is a long-baseline neutrino oscillation experiment that aims to measure three flavor oscillation parameters
- Two identical liquid scintillator detector: the near detector (ND) is at Fermilab, whereas the far detector (FD) is at Ash River, Minnesota, 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

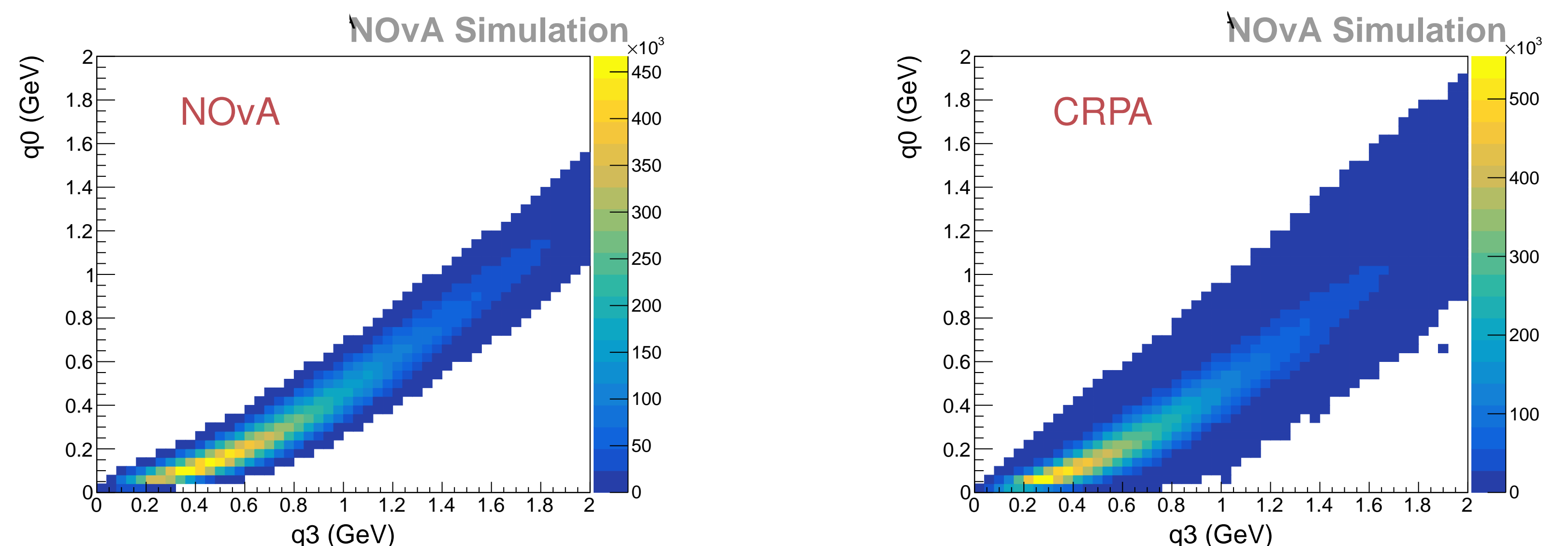
## HF-CRPA CCQE model

- 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.



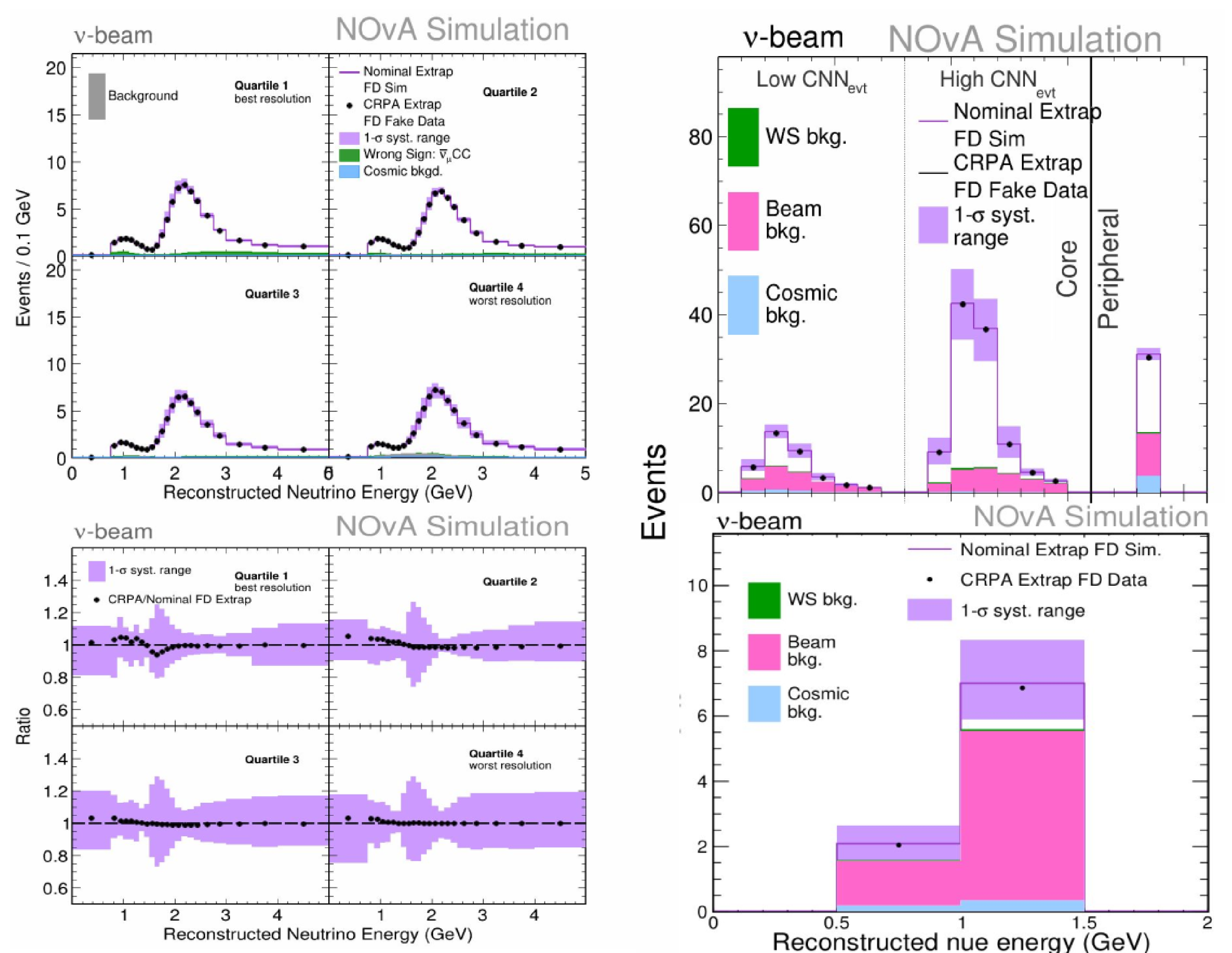
## Implementation of HF-CRPA model in NOvA

- 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
  - $\Delta m_{32}^2$  : resulting bias  $\sim 0.1\%$  ( $\sim 7\%$  of  $1\sigma$  interval)
  - $\sin^2 \theta_{23}$  : resulting bias  $\sim 0.4\%$  ( $\sim 4\%$  of  $1\sigma$  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)

### ACKNOWLEDGEMENT

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

