# Tuning, cross section uncertainties, and ND new physics searches

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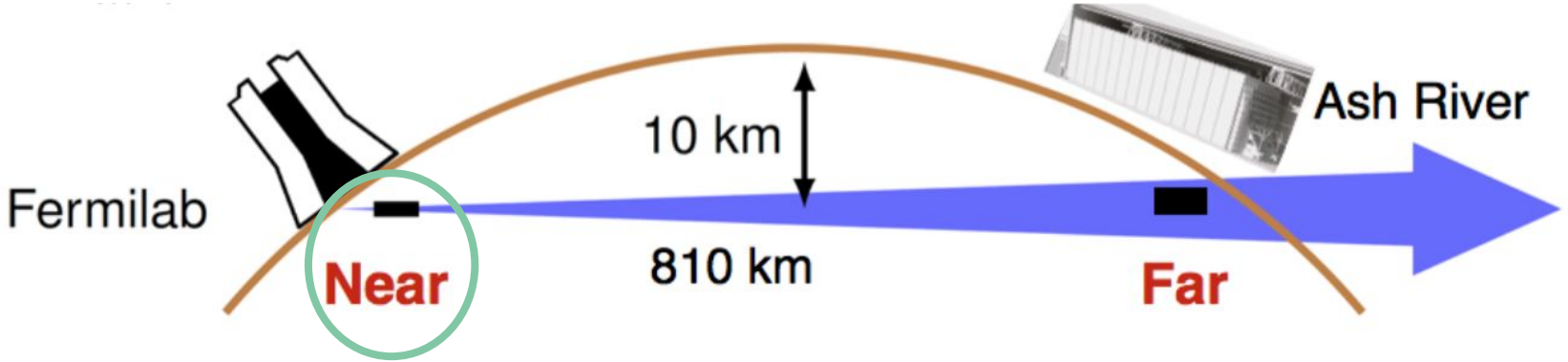
## Accelerator neutrino experiments

Long-baseline accelerator neutrino experiments aim to measure oscillation probabilities using a near detector (ND) and a far detector (FD)



## Near detectors interesting for new physics searches

- Very high intensity
  - New physics typically has low rates => needs high intensity
- Weakly-interacting background
- Already built or are being built!

## What kinds of new physics searches?

Some example models to search for:

- Light (eV-scale) sterile neutrinos (e.g. arXiv:1710.06488)
- Neutrinophilic scalars (arXiv:1901.01259)
- Trident production (arXiv:180710973)
- Light dark matter (arXiv:1107.4580)

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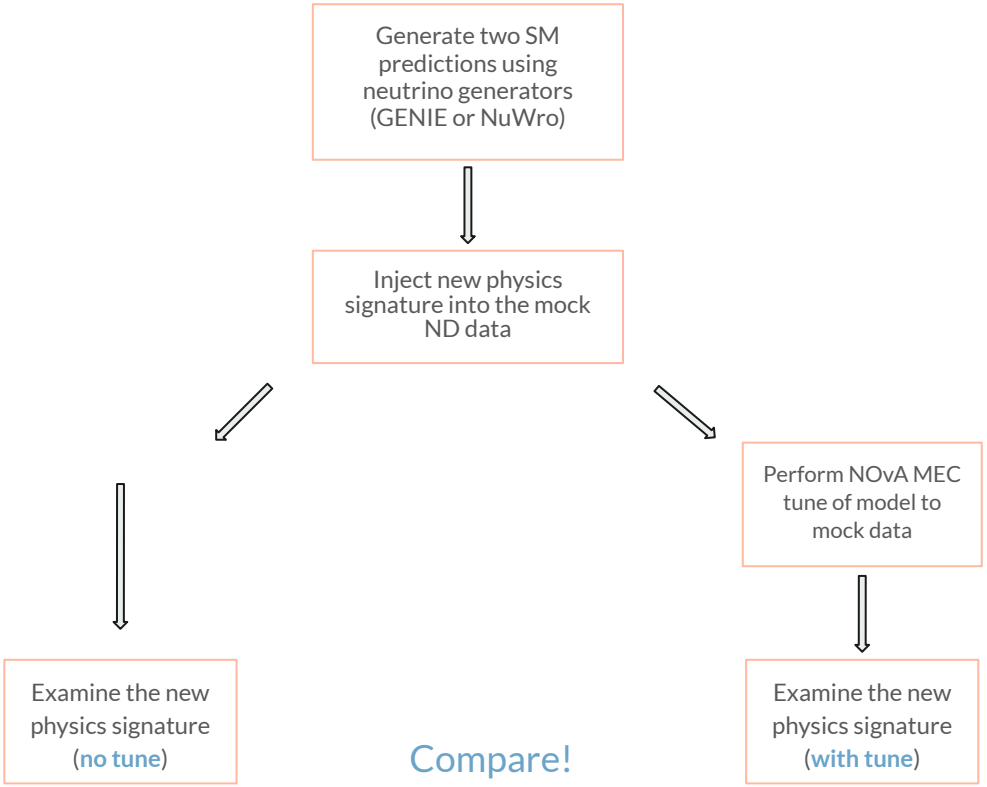
We know that our modeling of cross sections is not perfect, and we are looking for very small new physics signals.

**How does this impact potential searches at the ND, and how might we deal with this issue?**

# Process

**Goal**:

- Use generators as a tool to investigate impact of cross section modeling on new physics searches
- Test one potential approach to mitigating cross section uncertainties: ND tune

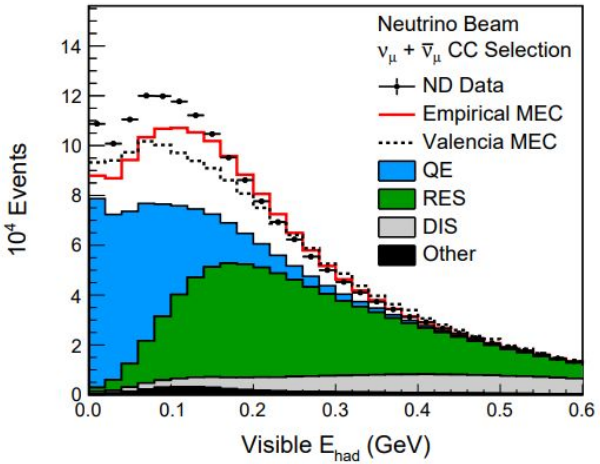


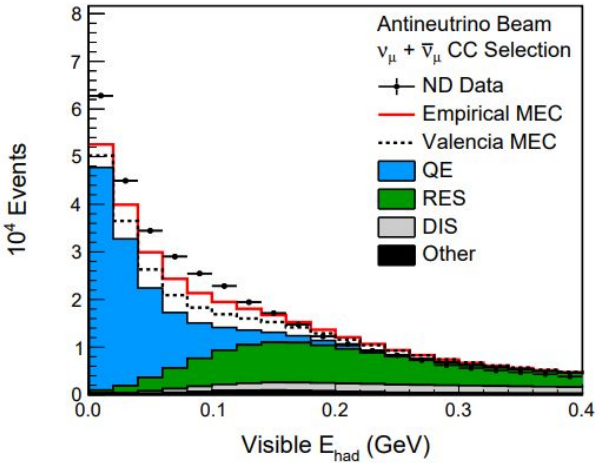
## NOvA MEC tune

NOvA collaboration, arXiv:2006.08727

First step: adjustments to input parameters guided by other experimental results

How to account for remaining discrepancy? Assume it's due to MEC mis-modeling and adjust the MEC contribution to match **NOvA ND data**



# NOvA MEC tune

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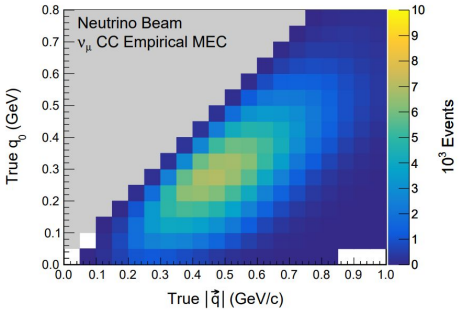
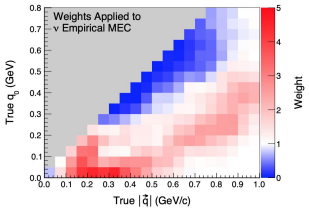
How to adjust for remaining discrepancy? Adjust the MEC contribution bin-by-bin




Migrate

Simulation binned in $|\vec{q}^{\,reco}|$ and $q_0^{reco}$

Fit

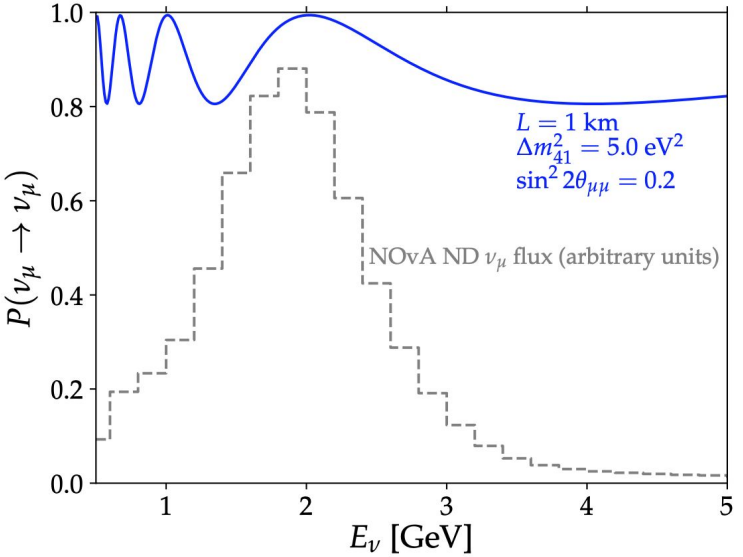
NOvA ND data binned in $|\vec{q}^{\,reco}|$ and $q_0^{reco}$

## Sterile neutrino signal

- Induce oscillations around L (km)/E (GeV) ~ 1

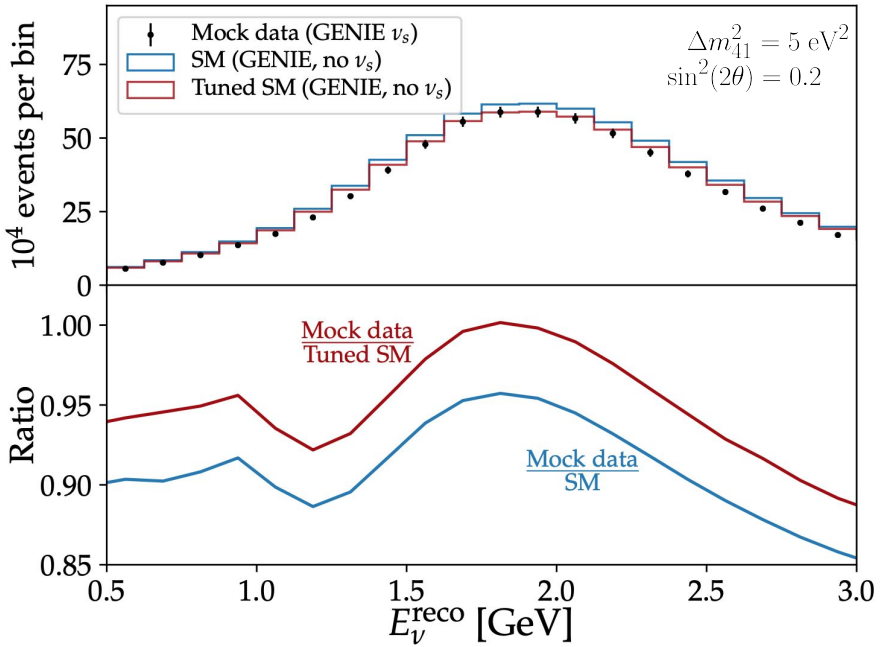
$$P(\nu_\mu \to \nu_\mu) \simeq 1 - \sin^2 2\theta_{\mu\mu} \sin^2\left(\frac{\Delta m^2_{41} L}{4E_\nu}\right)$$

- Existing near detectors can also search for sterile neutrinos!



# Sterile neutrino signal: same generator

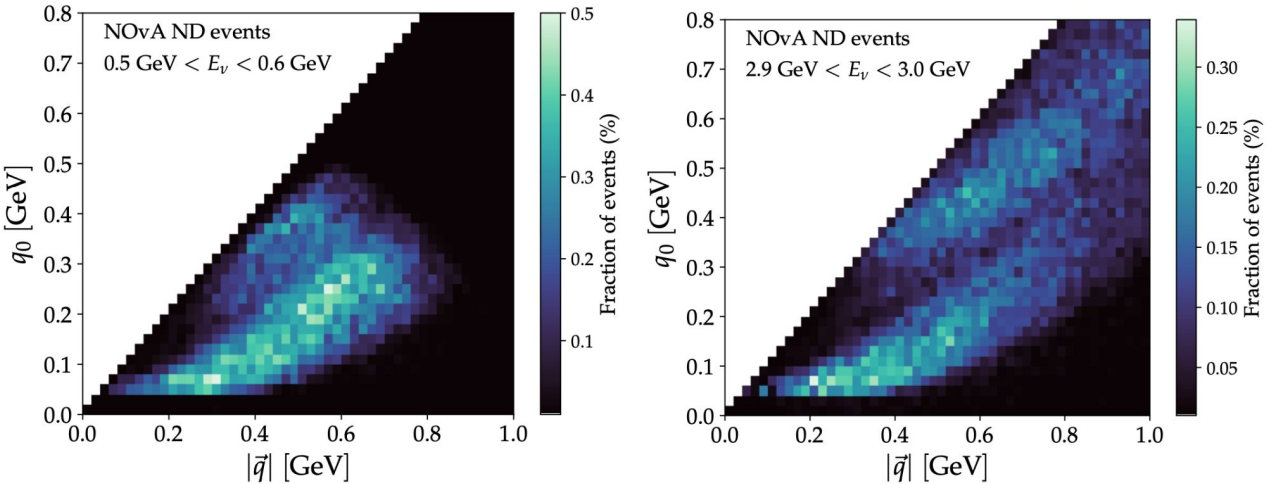
- Use GENIE to generate both the mock data and the simulation
  - This allows us to see the effect of the tuning without other complications
- We are not tuning to the oscillations!




NC, Li, Machado, arXiv:2210.03753

# Sterile neutrino: shape in the tune plane

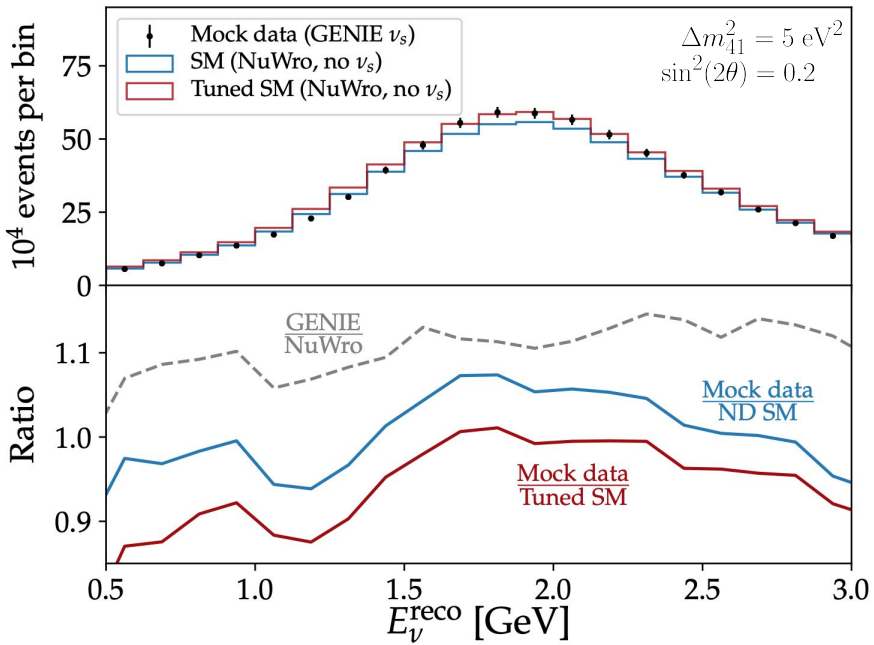
Why doesn't the tuning procedure remove the oscillations? Neutrino energy isn't directly correlated with tune parameters




NC, Li, Machado, arXiv:2210.03753

# Sterile neutrino: mis-modeling impact

- More realistic: take a different generator for the model
  - This gives us a proxy for mis-modeling between our models and nature
- Signature affected due to disagreement in generators

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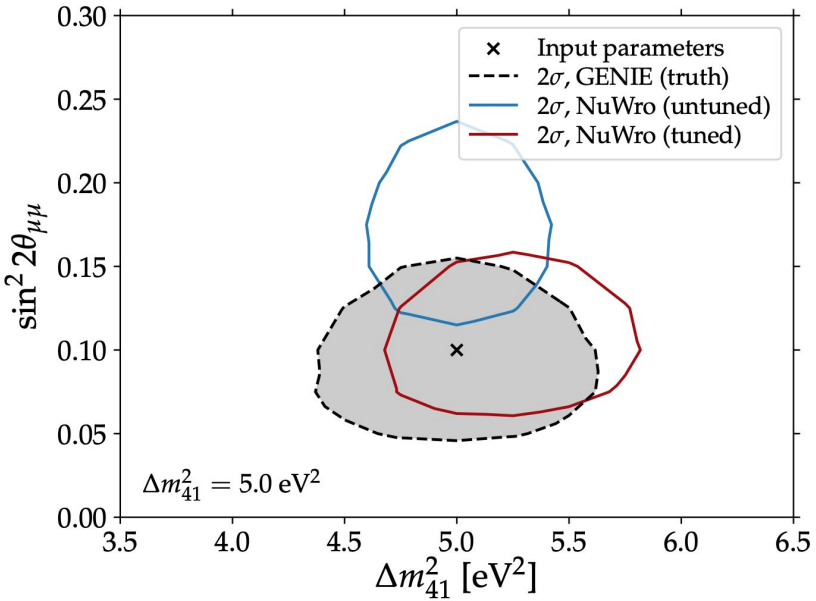
# Sterile neutrino: sensitivity check

- Two cases:
  - Same generator for data and model (grey filled)
  - Different generators (color unfilled)
- Direct fit to ND and FD rates
- Simultaneous fit and tune
- Chi-squared fit with a covariance matrix
- Systematic uncertainties:
  - Overall normalization: 20%
  - Near-to-far spectral correlated: 2%
  - Uncorrelated bin-to-bin: 2%

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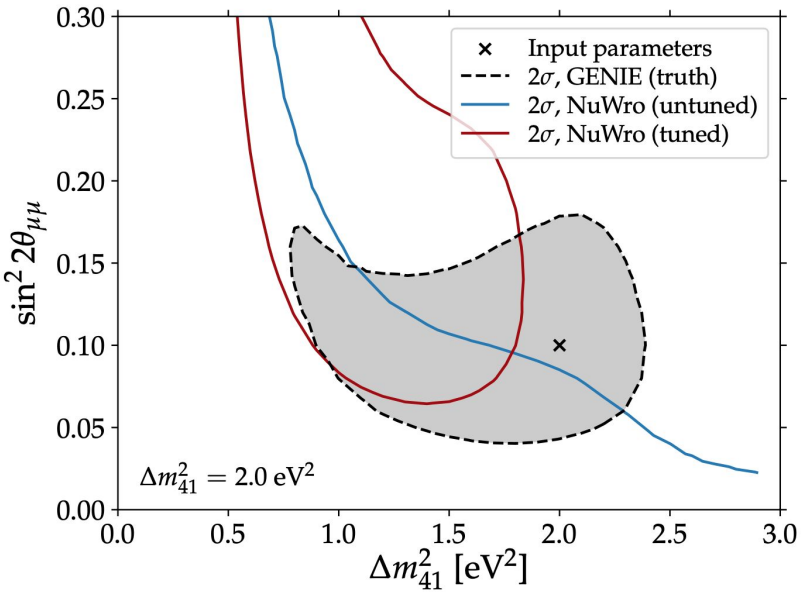
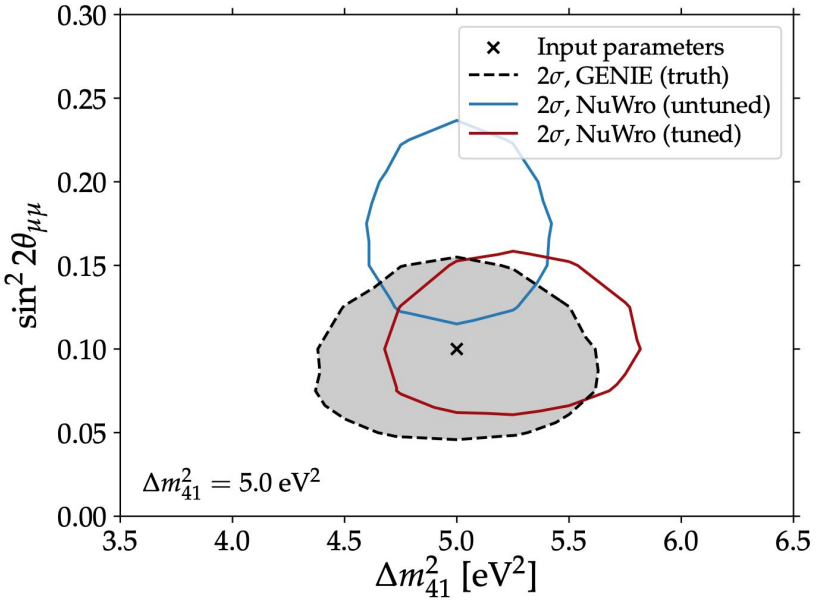
# Sterile neutrino: sensitivity check

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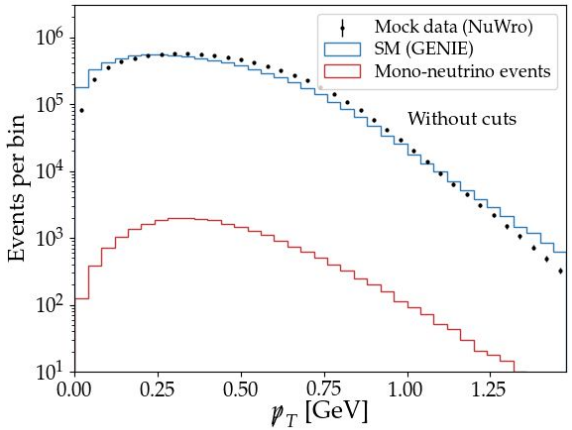
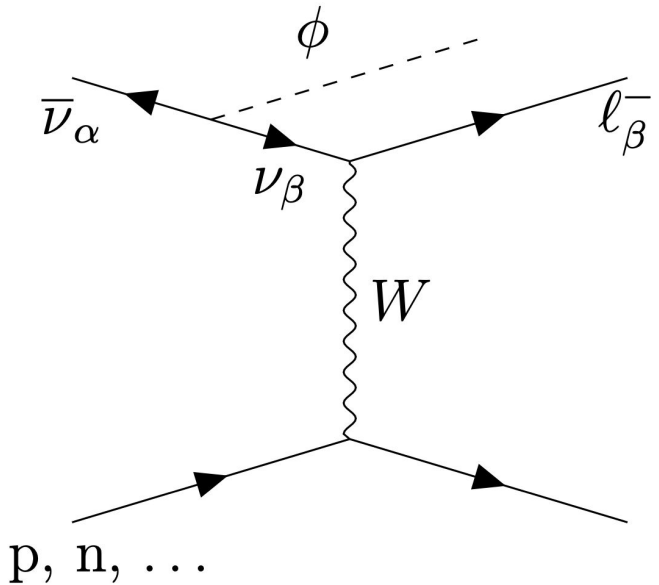
# Mono-neutrino signal

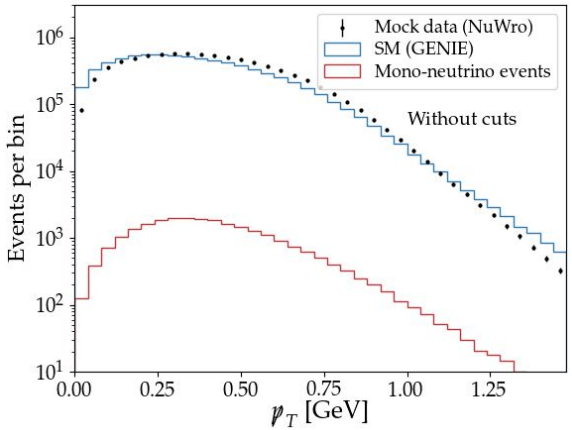
- Neutral scalar, showing up as missing pT
- Sub-percent-level fraction of events: requires cuts to see the signal

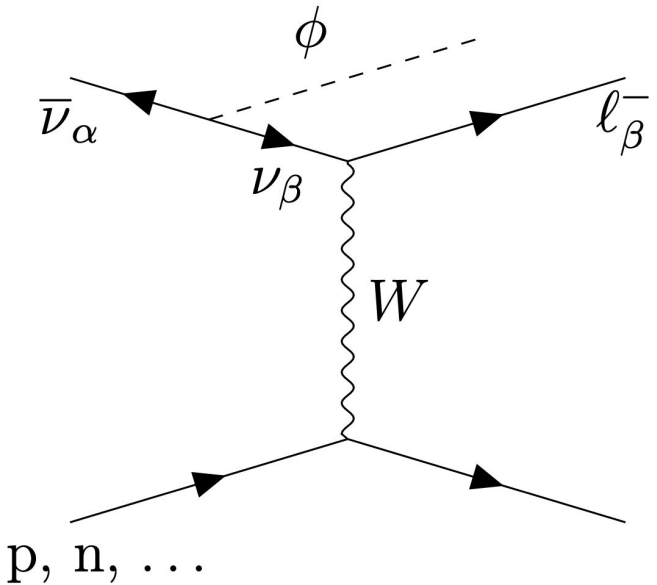


# Mono-neutrino signal

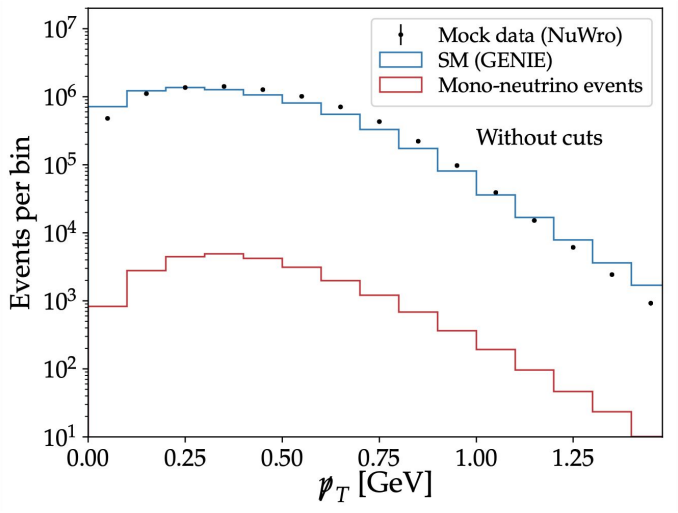
- Neutral scalar, showing up as missing pT
- Cut on 0 pions, 1 proton, no neutrons (KE threshold of 100 MeV)

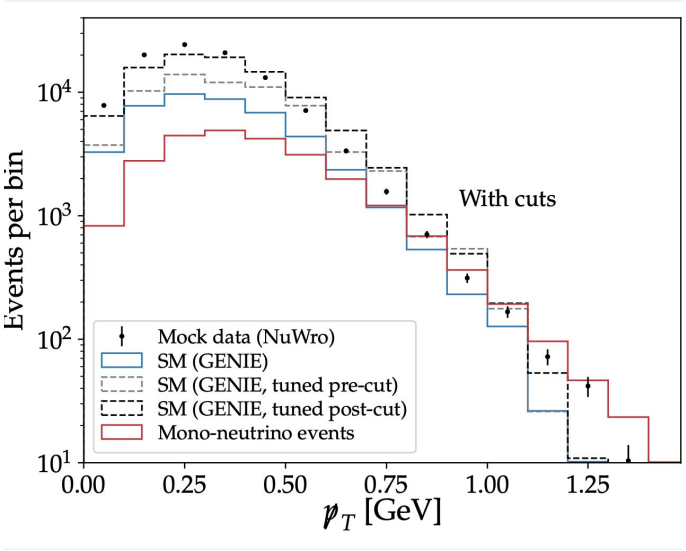


# Generators don't respond the same to cuts

NC, Li, Machado, arXiv:2210.03753

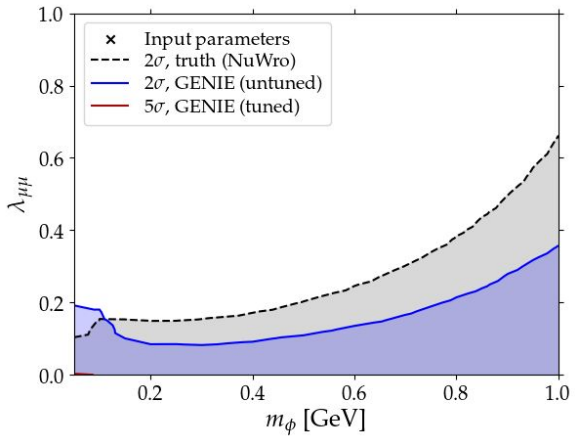


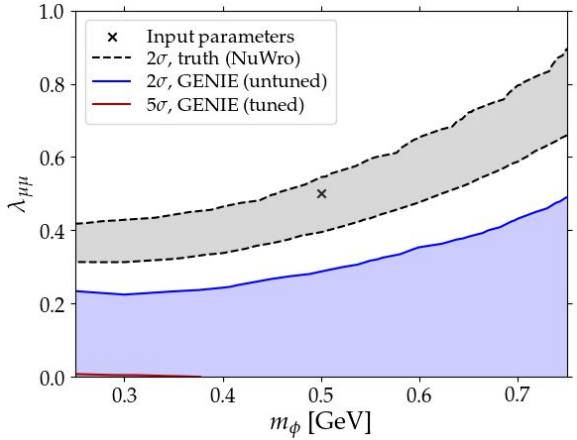



# Mono-neutrino: (non)sensitivity plot

NC, Li, Machado, arXiv:2210.03753

- Different generators, simultaneous fit and tune, tuning after cuts
- Generator disagreement dominates over new physics



# Conclusions

- Cross section mis-modeling can impact our interpretation of new physics searches
- A near detector tune does not resolve these issues (perhaps not a surprise)
- This is not the final word on ND new physics searches; this is just a first step
  - BSM integration into generators would improve analyses
  - Use full covariance matrices
  - We have focused here on new physics signals that involve neutrino-nucleus scattering; other new physics signals may be less impacted
- Improvements in  our theoretical predictions and new experimental solutions are needed
  - Timing, location in detector?
  - Kinematic separation from background?
  - New tuning procedures?
  - Can we find a general approach, or must it depend on the particular BSM signal?

# Thank you!

# Tuning: NOvA

NOvA collaboration, arXiv:2006.08727

Start by implementing some changes to the base GENIE based on other experimental results

- Adjust CCQE $M_A$ input value from neutrino-deuteron scattering data (arXiv:1603.03048)
- Adjust nuclear momentum distribution from MINERvA (arXiv:1705.0293)
- Reduction to non-resonant single pion production from bubble chamber data (arXiv:1601.01888)

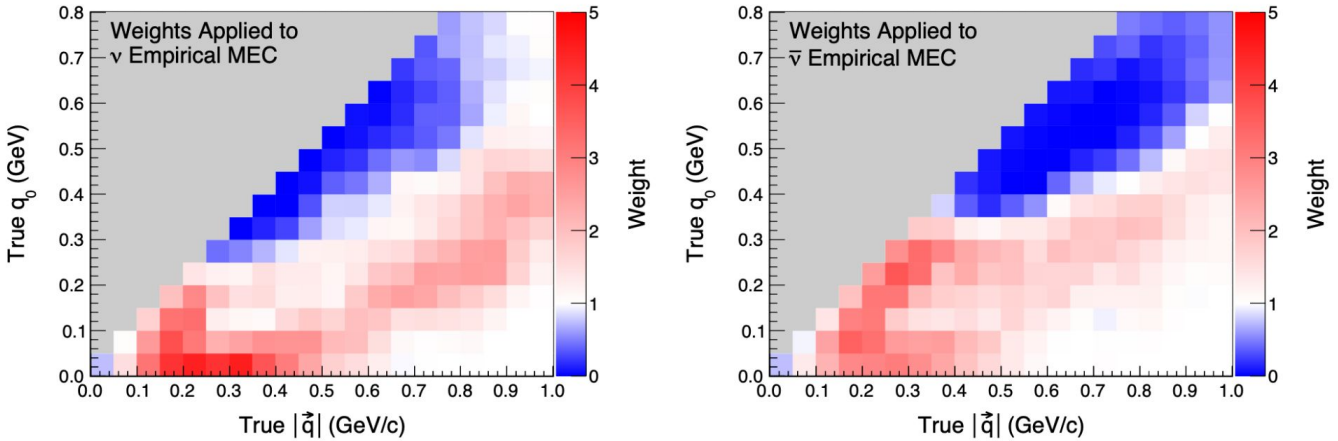



FIG. 4. The weights, in three-momentum and energy transfer, applied to simulated Empirical MEC interactions to produce the fitted NOvA 2p2h predictions described in the text, for neutrinos (left) and antineutrinos (right). Gray indicates kinematically disallowed regions, where no weights are applied.

NOvA collaboration, arXiv:2006.08727

# Generators and cuts