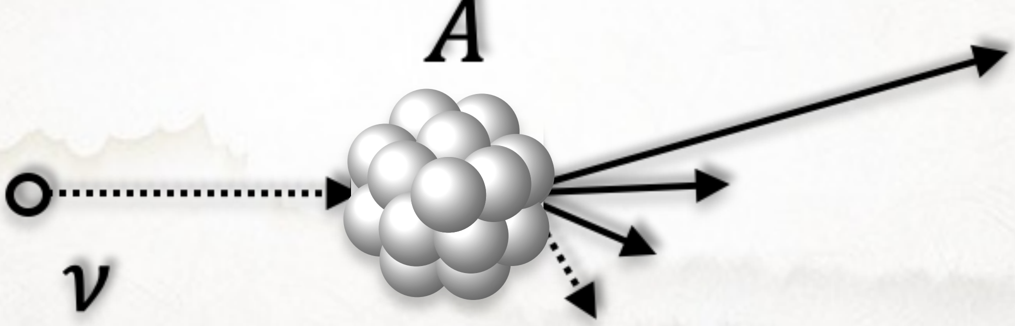
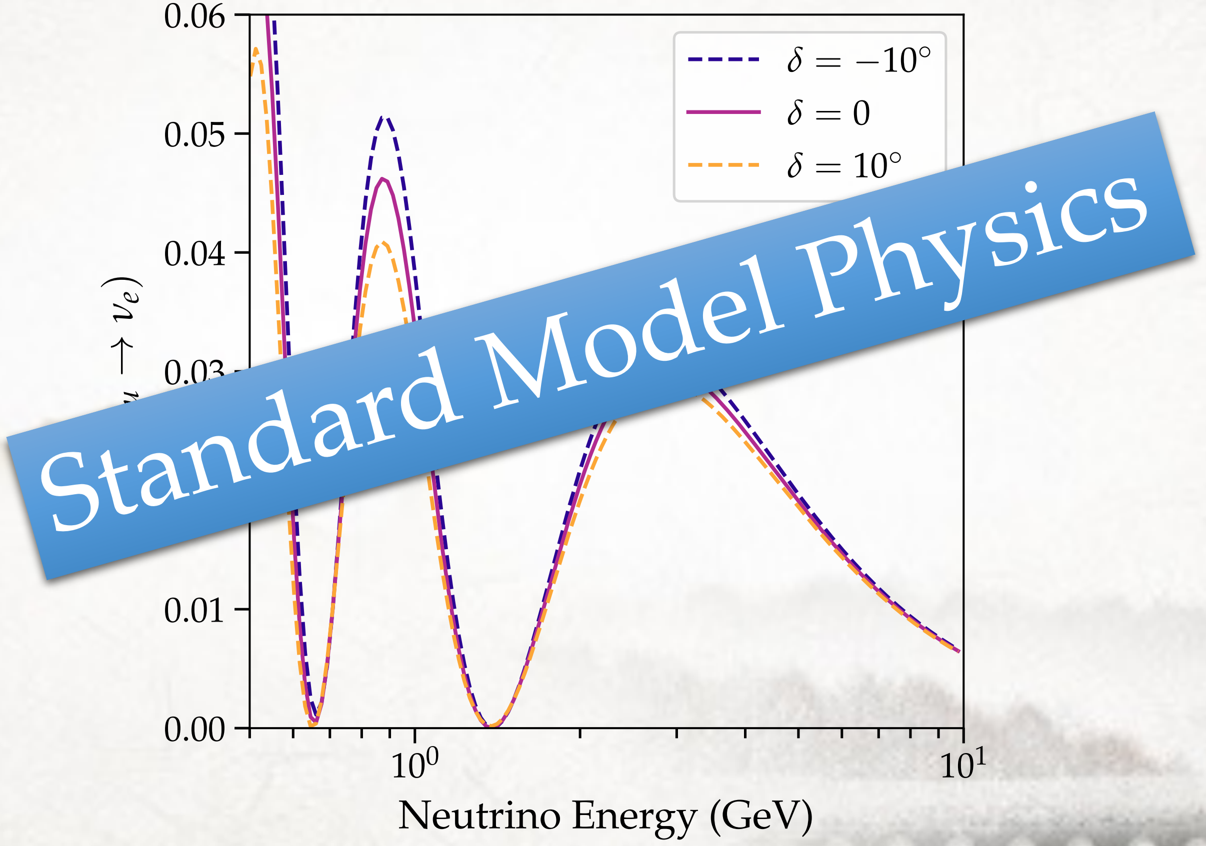
The Impact of Neutrino-Nucleus Interaction Modeling on New Physics Searches



Shirley Li (Fermilab)

Benchmark: Precision Goals for DUNE

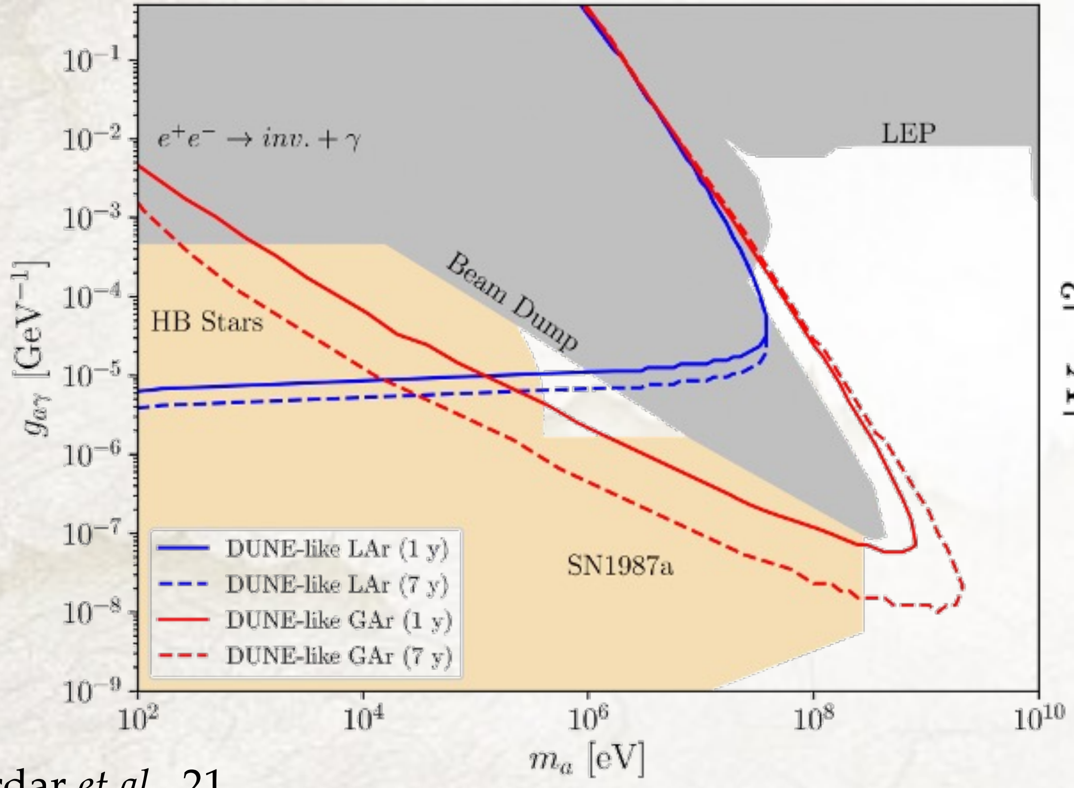
Oscillation probabilities at DUNE for projected 1-σ precision



Precisions should be $\leq 5\%$

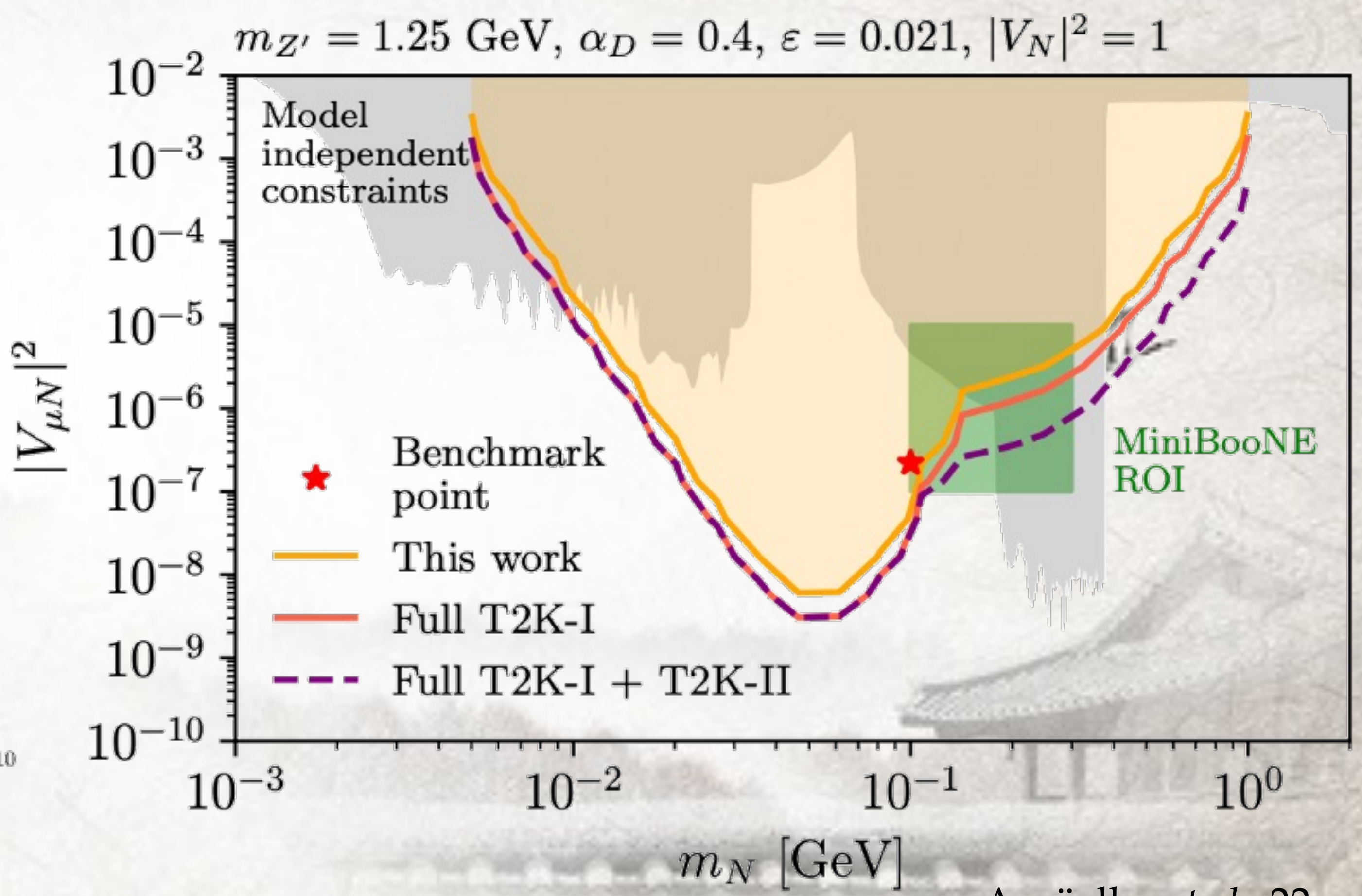
Benchmark: New Physics Searches

ALP @ DUNE



Brdar *et al.*, 21

HNL @ T2K

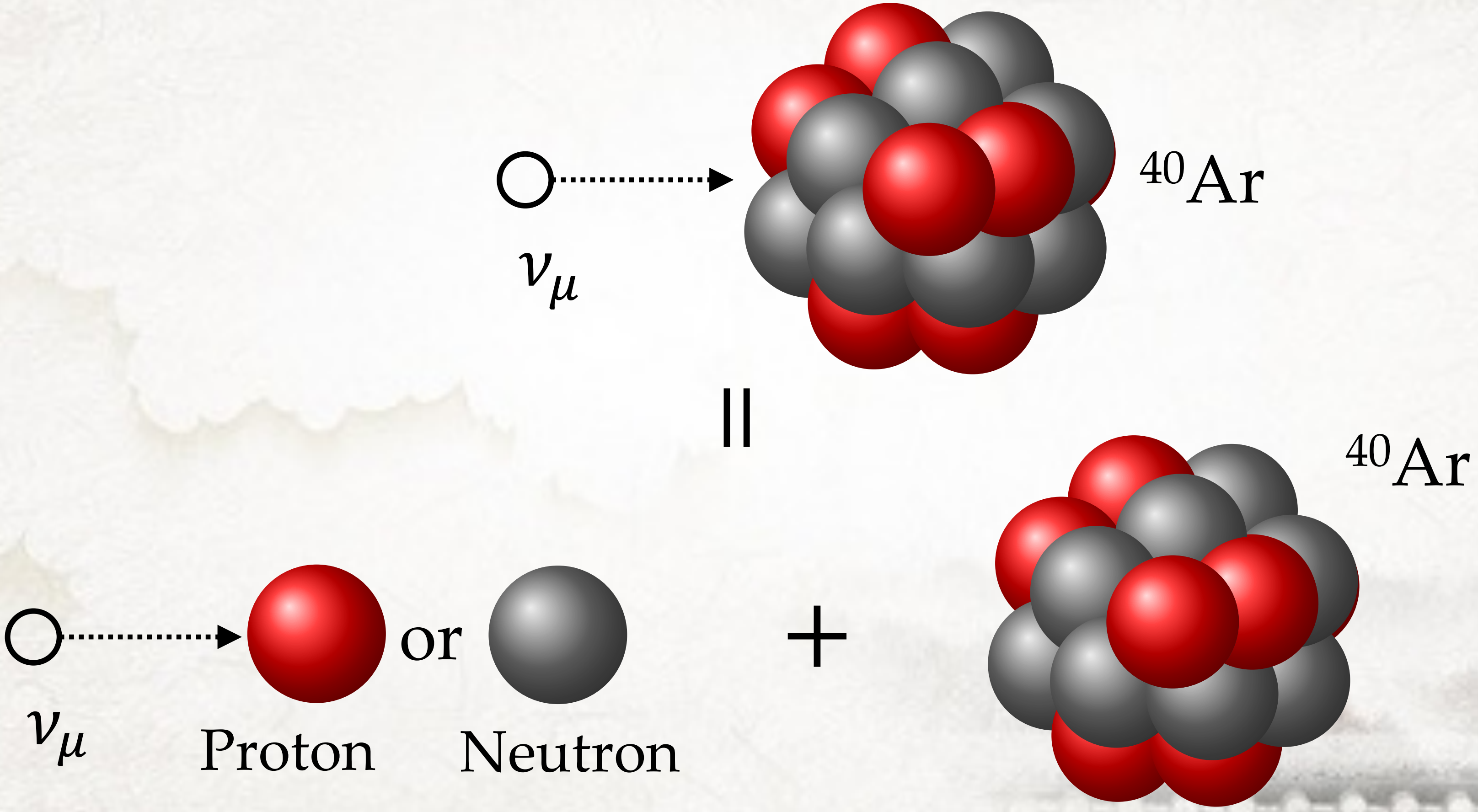


Argüelles *et al.*, 22

Precisions should be $\ll 1$

ν-Nucleus Cross Sections In A Nutshell

ν beam energy: 0.5 GeV – 5 GeV

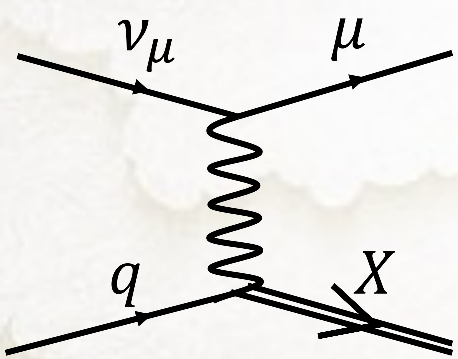


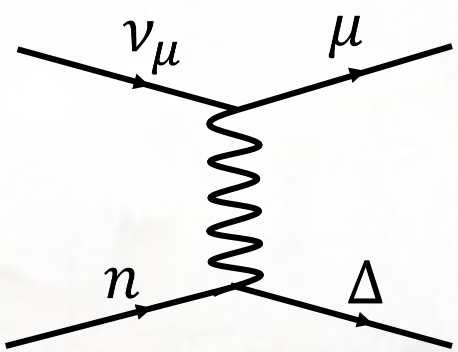
^{12}C, ^{16}O for other experiments

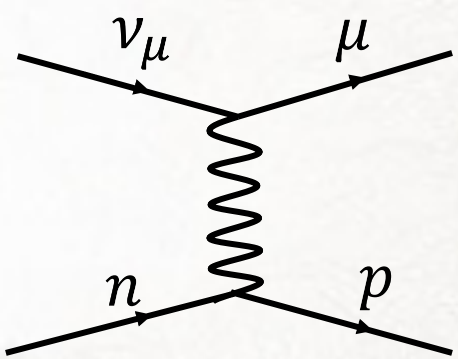
ν-Nucleon Cross Sections In A Nutshell

ν beam energy: 0.5 GeV – 5 GeV

Deep Inelastic Scattering	Resonance production	Quasi-elastic scattering





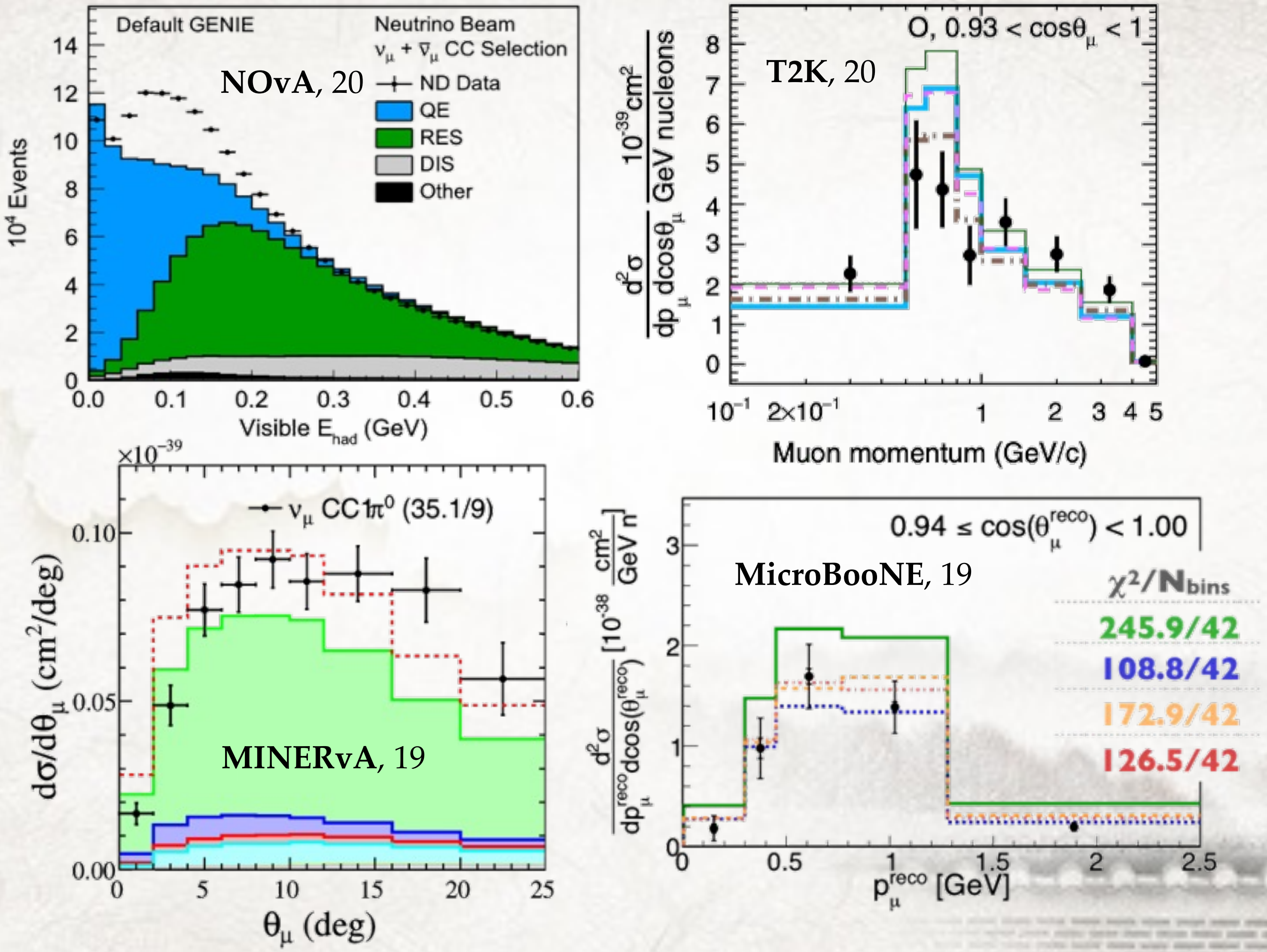


Multiple particles	Nucleon + meson	Single nucleon

No controlled expansion

$Q^2 \cong 1\ \mathrm{GeV}^2$

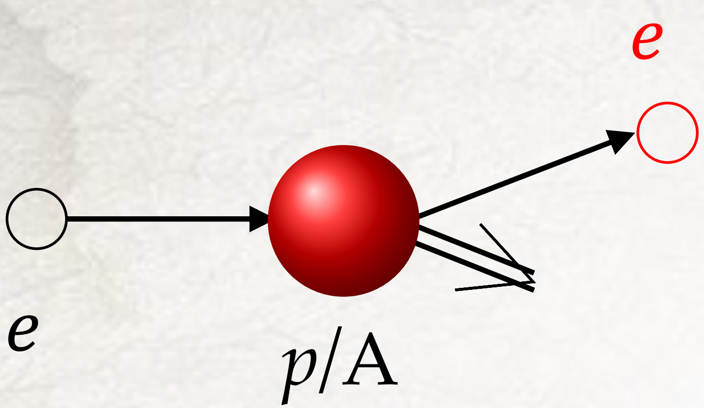
Uncertainty Assessment: Generators vs. ν Data



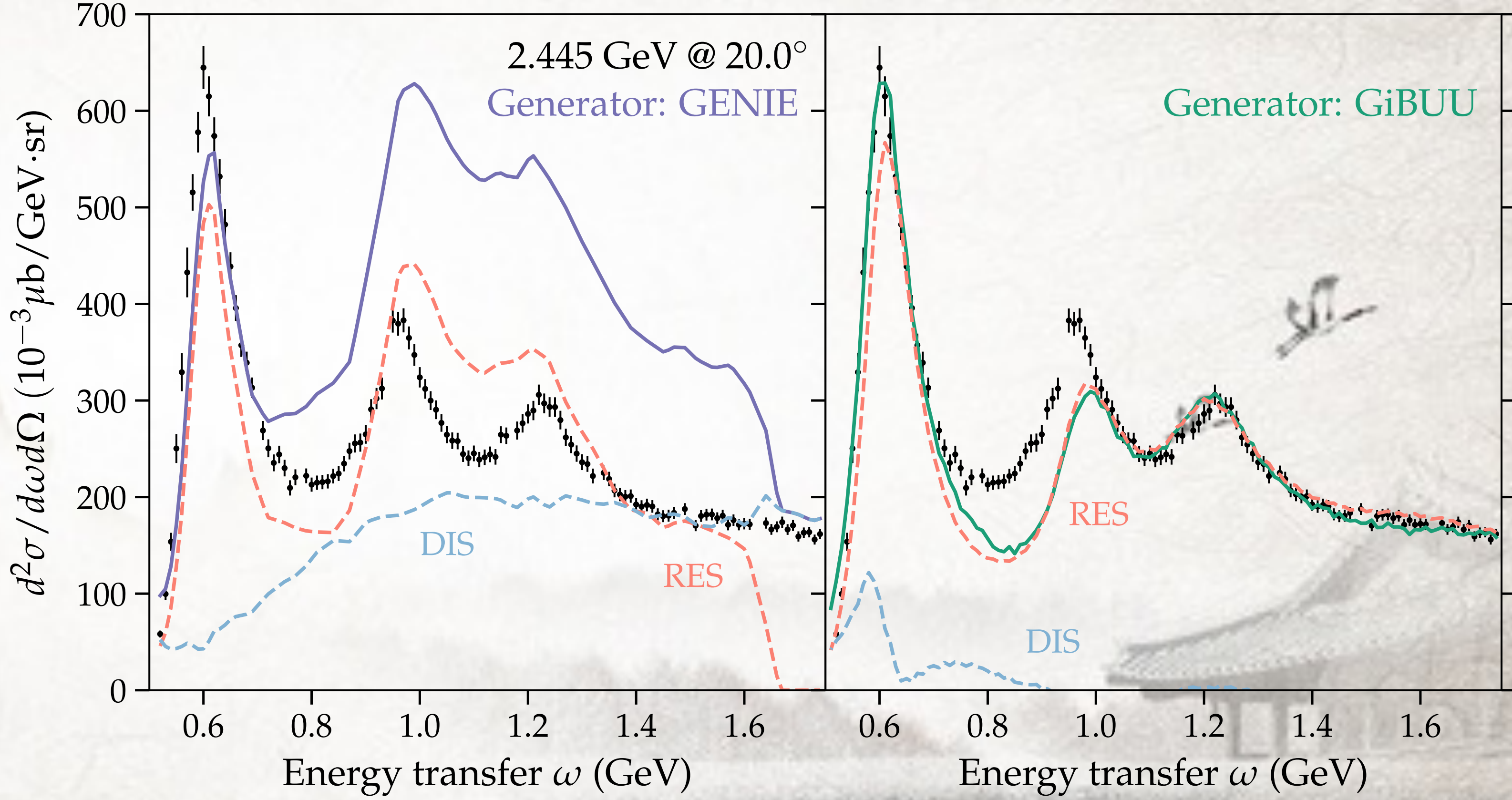
No models/tunes can reproduce all data sets

Uncertainty Assessment: Generators vs. *e*-*p* Data

Ankowski, Friedland, SL, in prep
Data from Niculescu et al., 00



$$\omega = E_e - E_{e'}$$



- Same primary vertex models, only vector couplings
- Same final-state interactions/ nucleon distributions

Mismodeling at ~ 50-80%

How Are Cross Section Uncertainties Dealt with?

Near detector tuning

Neutrino event generator, e.g., GENIE

Simulate flux

Simulate detector response

Near detector data comparison

Tune model parameters

Tuned event generator

Far detector response

Predictions at far detector

$$P = \frac{N_e(E_\nu, L)/\sigma_e(E_\nu)}{N_\mu(E_\nu, L)/\sigma_\mu(E_\nu)}$$

One needs to take *tuning* into account for cross section phenomenological studies

☹ Each experiment has their own tune

☹ Most experimental tunings are not public

The Example We Follow: NOvA Tuning Procedure

NOvA 2020
2006.08727

Step 1: "Fix" default GENIE (v2.12.2)

1) Adjust m_A from 0.99 to 1.04 GeV
   Reanalysis of ν-deuterium data (Meyer et al., 16)

2) Modify the momentum distributions of the initial nucleons for QE
   MINERvA study (Gran, 17)

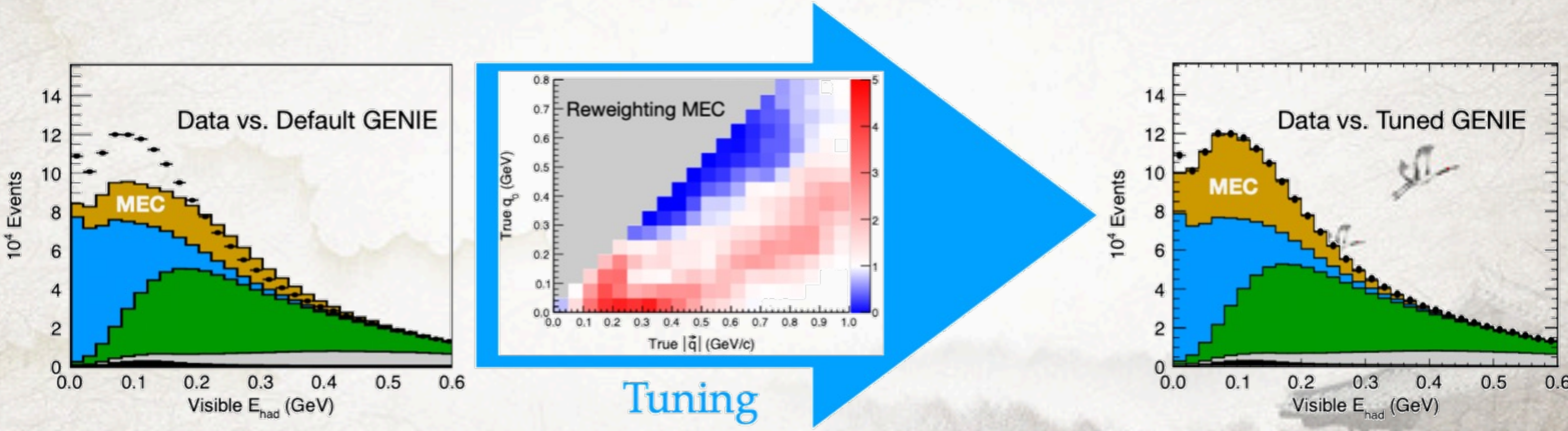
3) Lower ν (and not $\bar{\nu}$) non-resonance pion by 57%
   Reanalysis of bubble chamber data (Rodrigues et al., 16)

4) Suppress resonance production low-Q^2 region
   Motivated by MiniBooNE, MINOS, T2K, MINERvA

The Example We Follow: NOvA Tuning Procedure

NOvA 2020
2006.08727

The main step: MEC tune



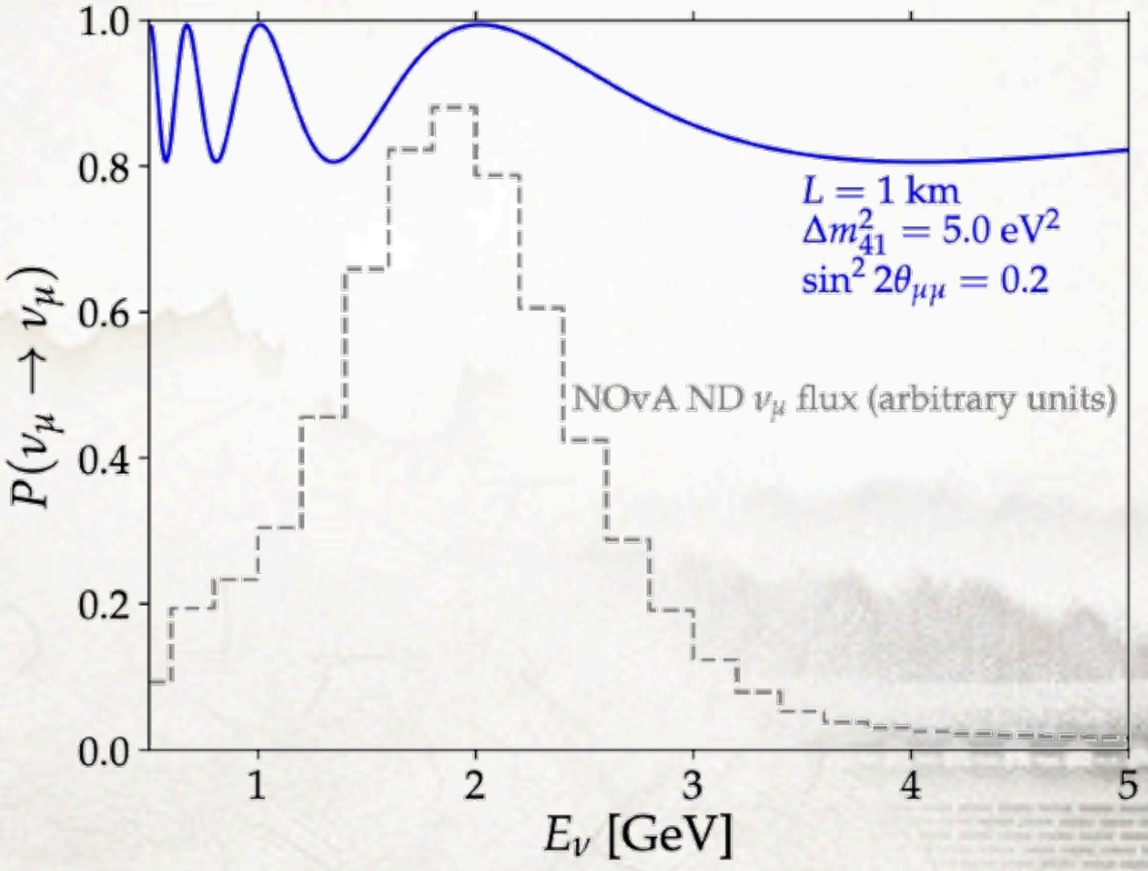
Large changes to MEC cross sections

Added many unphysical degrees of freedom

Case Study 1: Looking for Sterile Neutrinos

Coyle, SL, Machado, 22

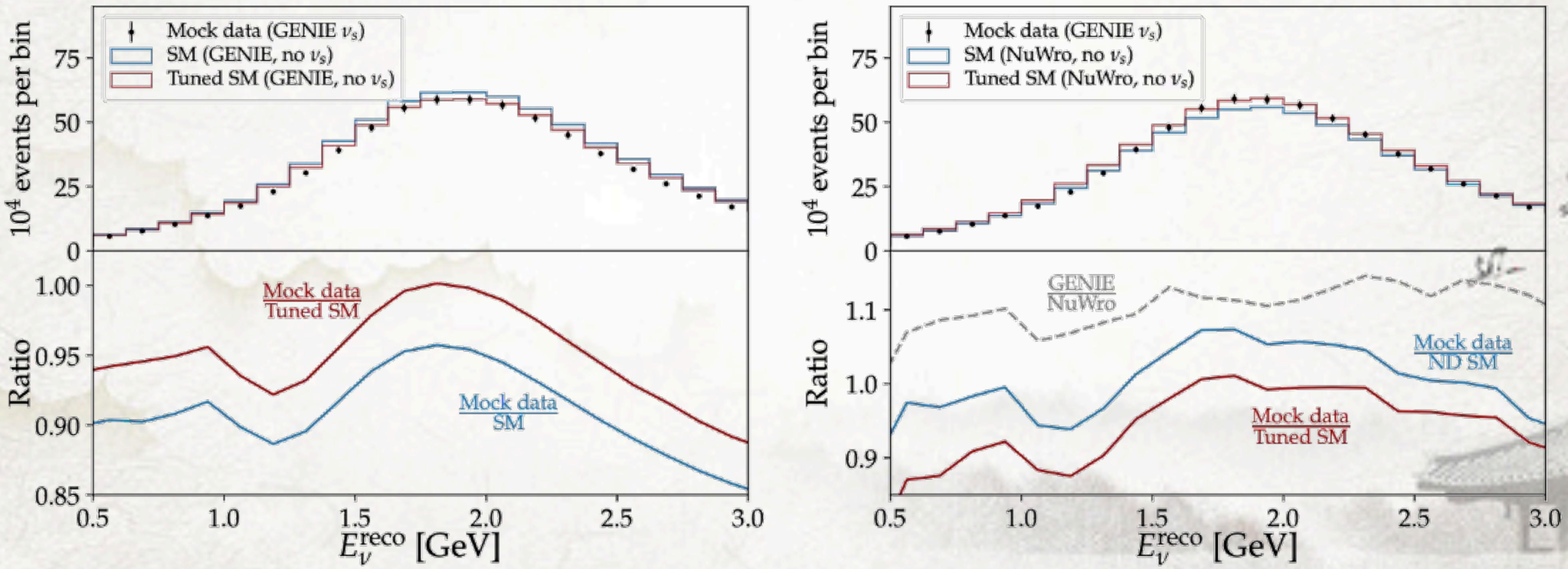
Experimental signature



Sterile Neutrino Tune

Coyle, SL, Machado, 22

Spectra before and after tune



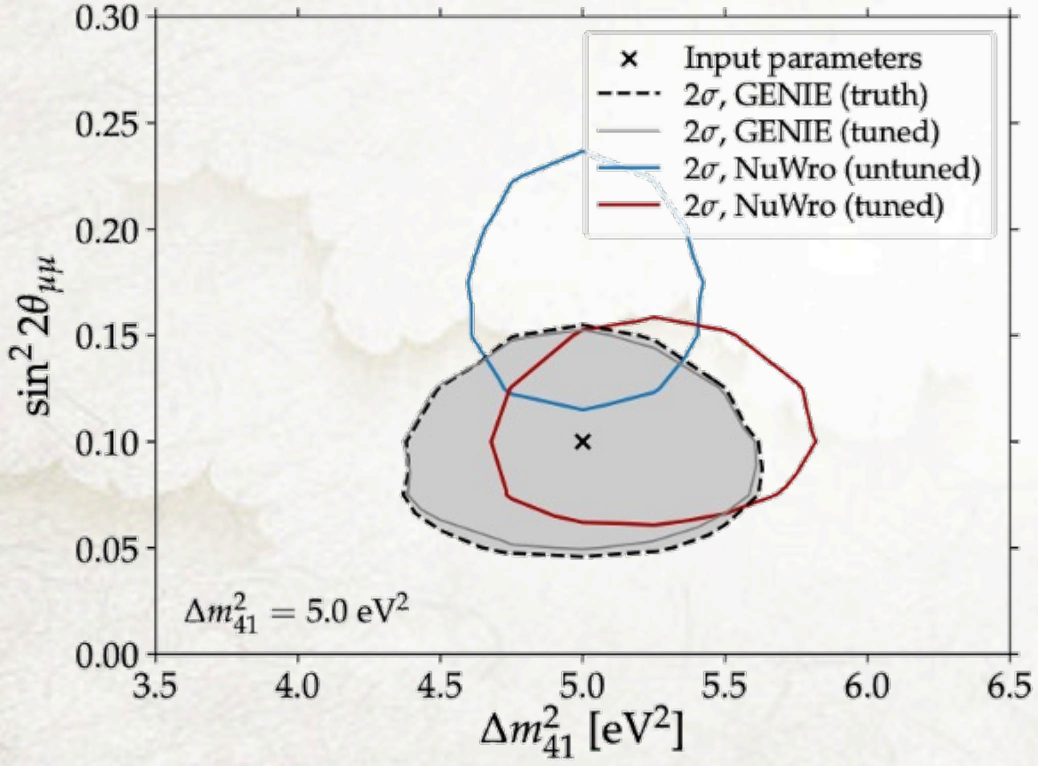
Wiggles do not get washed out,

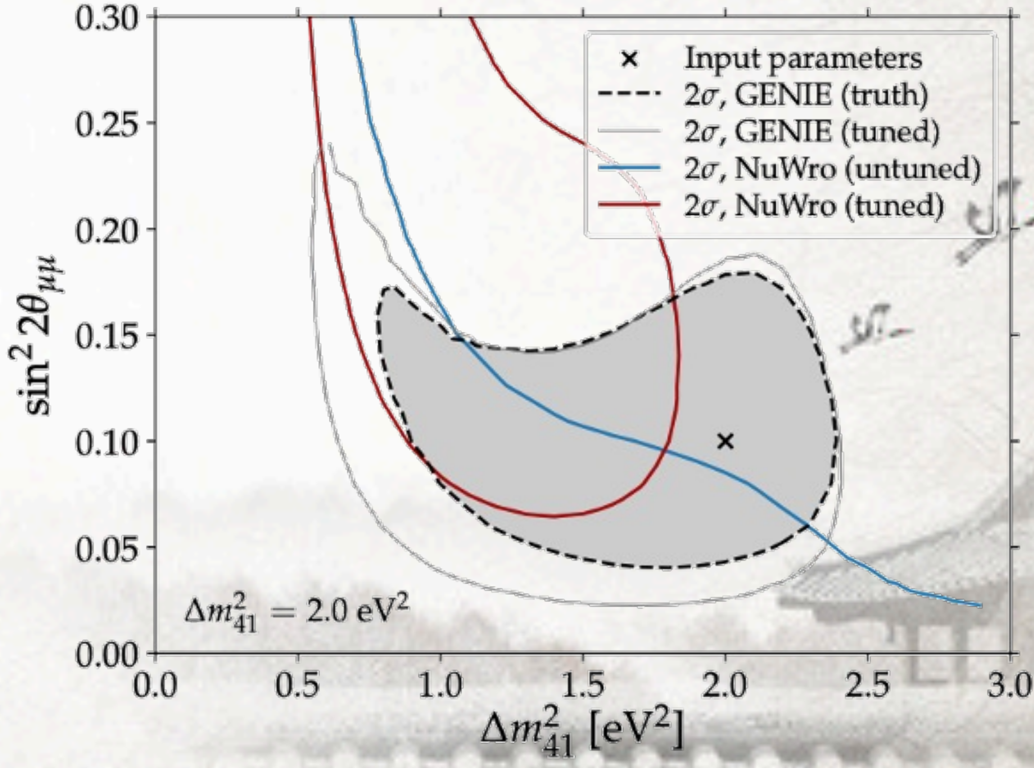
but can be mimicked by mis-modeling

Sterile Neutrino Results

Coyle, SL, Machado, 22

Sensitivity regions



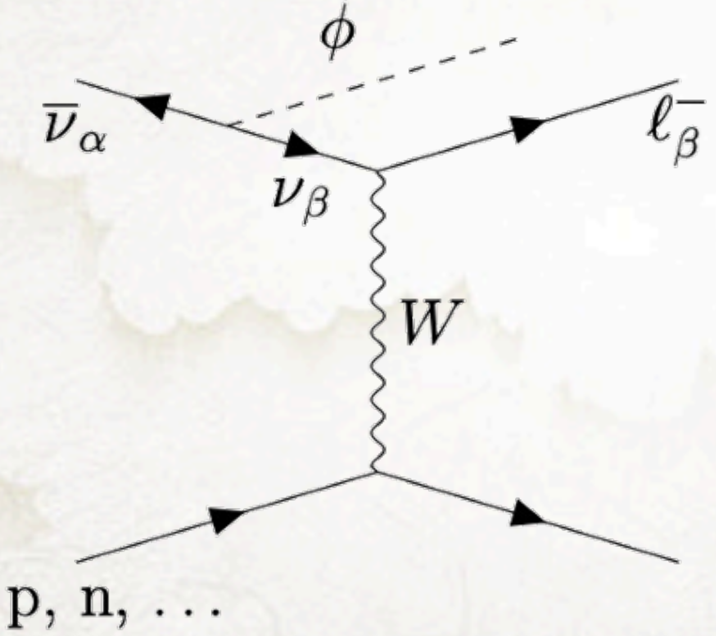


Tuning does not entirely fix cross section mis-modeling

Case Study 2: Looking for Neutrinophilic Scalar

Coyle, SL, Machado, 22

The model

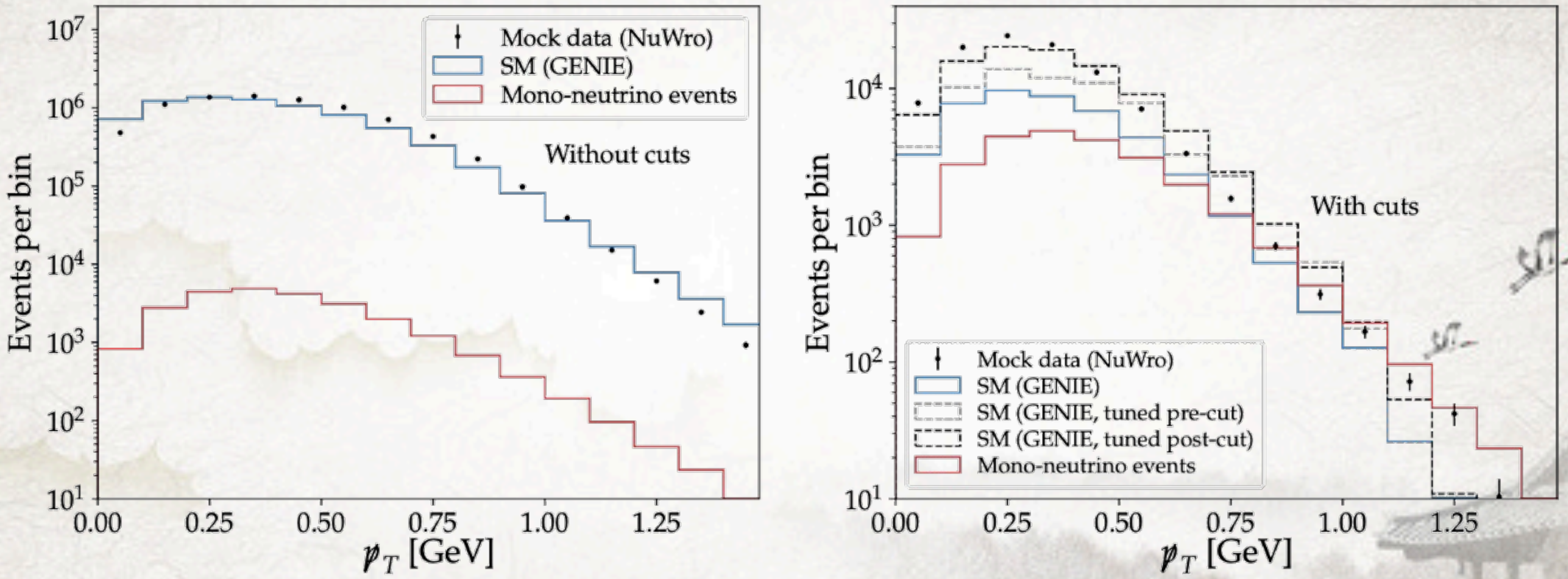


$$\mathcal{O} = \frac{(L_\alpha H)(L_\beta H)}{\Lambda_{\alpha\beta}^2}\phi \to \frac{1}{2}\lambda_{\alpha\beta}\nu_\alpha\nu_\beta\phi$$

Signature: missing p_T

To Cut Or Not To Cut

Coyle, SL, Machado, 22



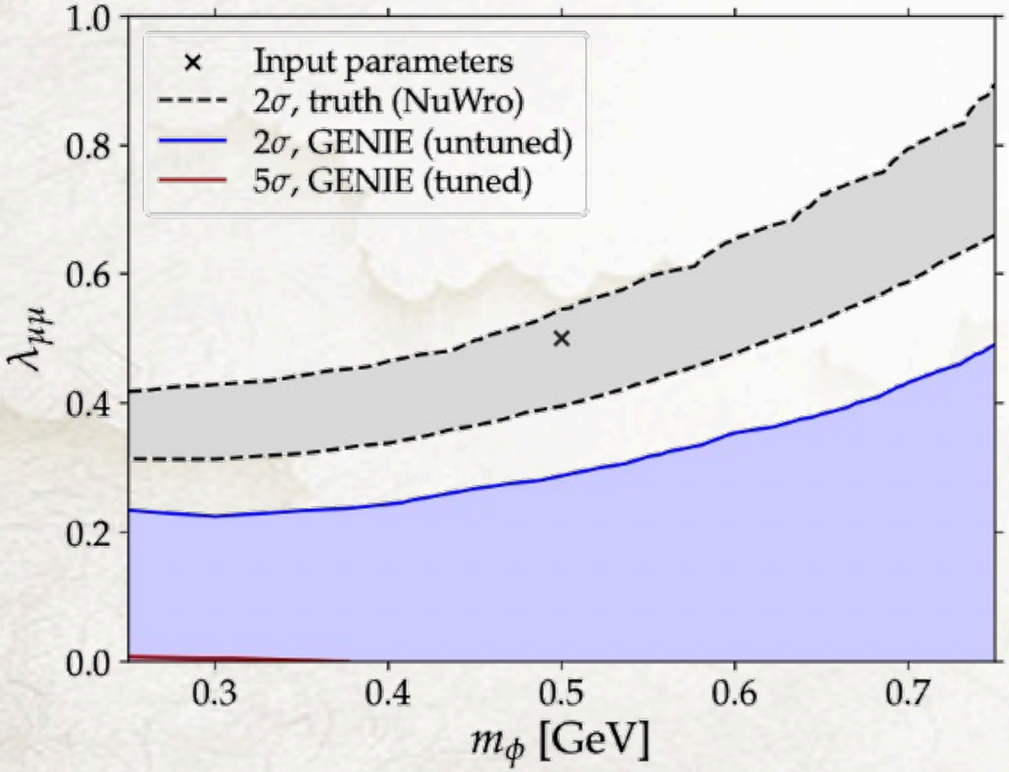
Not cut: background >> signal

Cut: background mis-modeling >> signal

Neutrinophilic Scalar Results

Coyle, SL, Machado, 22

Sensitivity regions



General lessons

New physics likely lives in a corner of phase space

↓

Even worse cross section uncertainties than integrated over entire phase space

Conclusions

1. No complete theoretical framework available; difficult to assess uncertainties
2. Near detector tuning is crucial and has to be taken into account for new physics searches
3. Complicated interplay with experimental procedures