# Generators and Electronuclear Data

## SLAC mini-workshop

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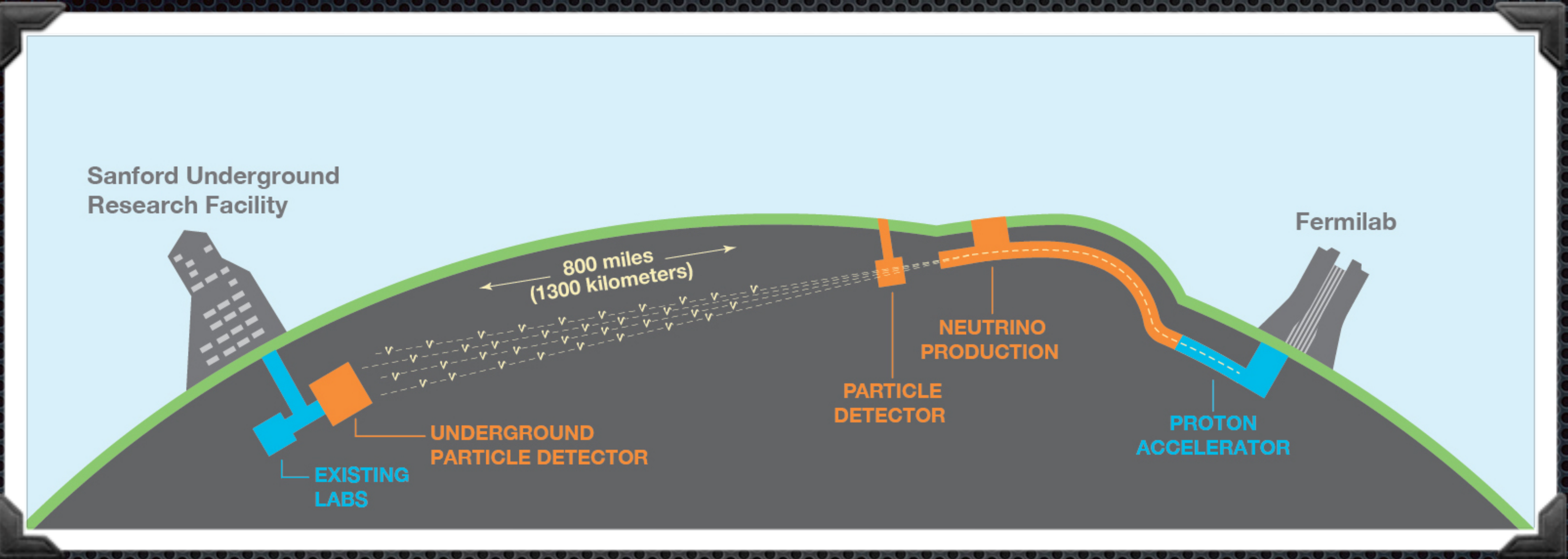
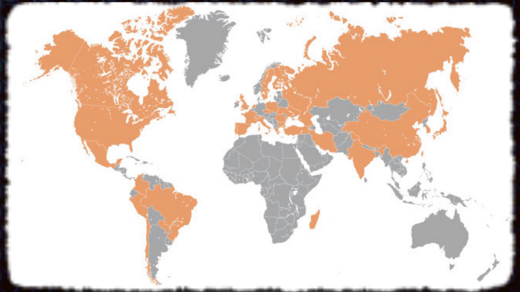
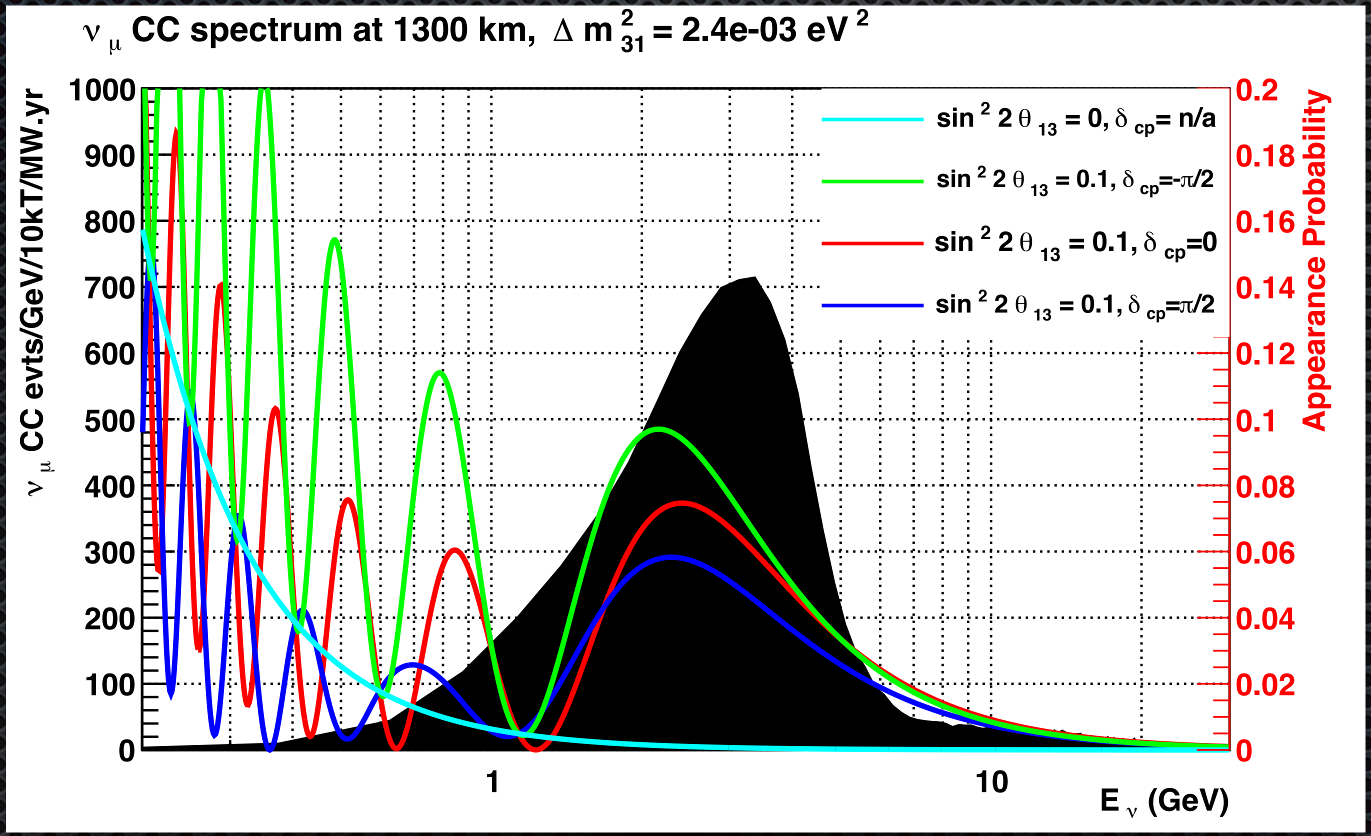
# What's the motivation?




- It is "standard lore" that DUNE (Deep Underground Neutrino Experiment) needs them
  - $1B+ international project, the flagship of the US domestic HEP program for the next 10-15 years
  - 1,000+ members from 30+ countries, and growing



# Goal: precision studies of neutrino oscillations *as a function of energy*

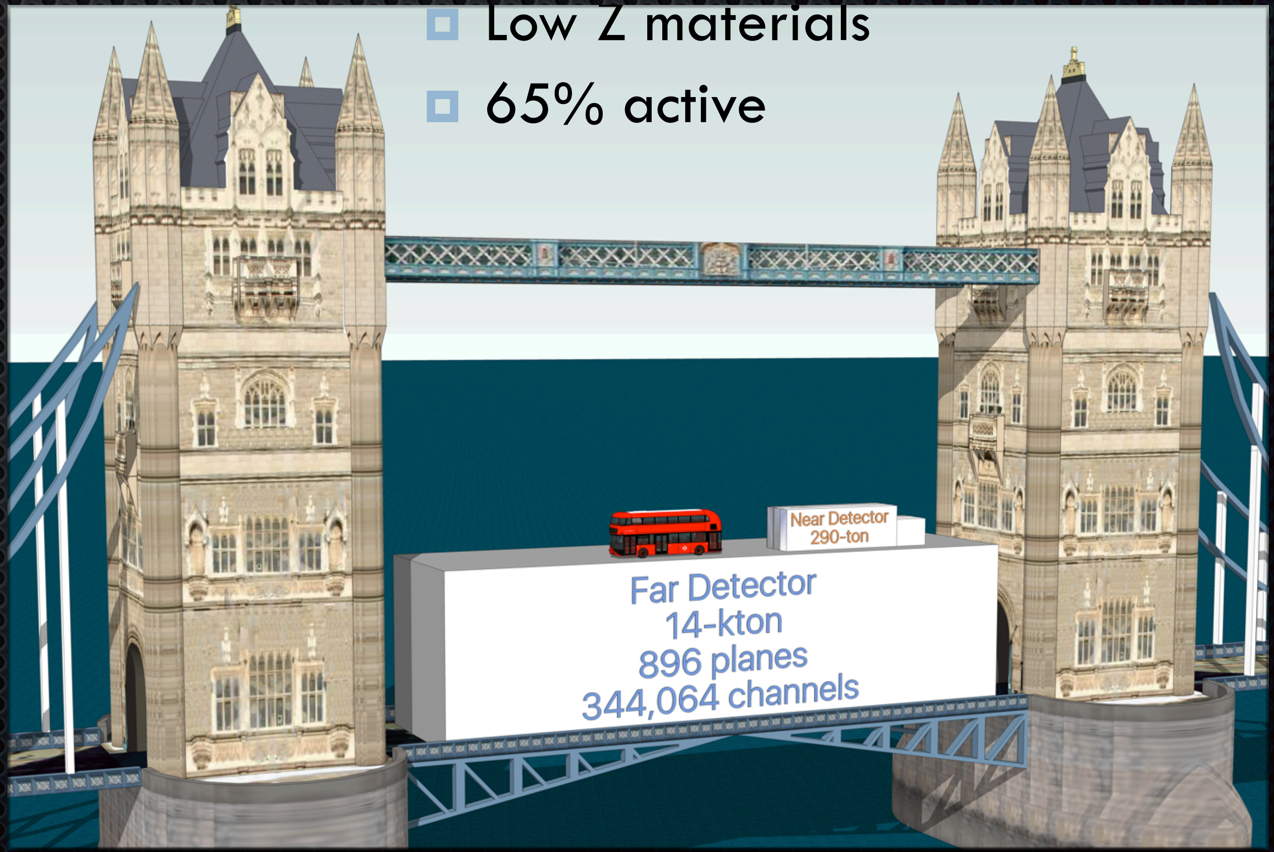



- If the energy could be accurately measured with a near and far detector, we wouldn't need to know much about cross sections

# In fact, we don't even have to wait for DUNE

- Consider the NOvA experiment (Fermilab to Northern Minnesota, 810 km baseline)

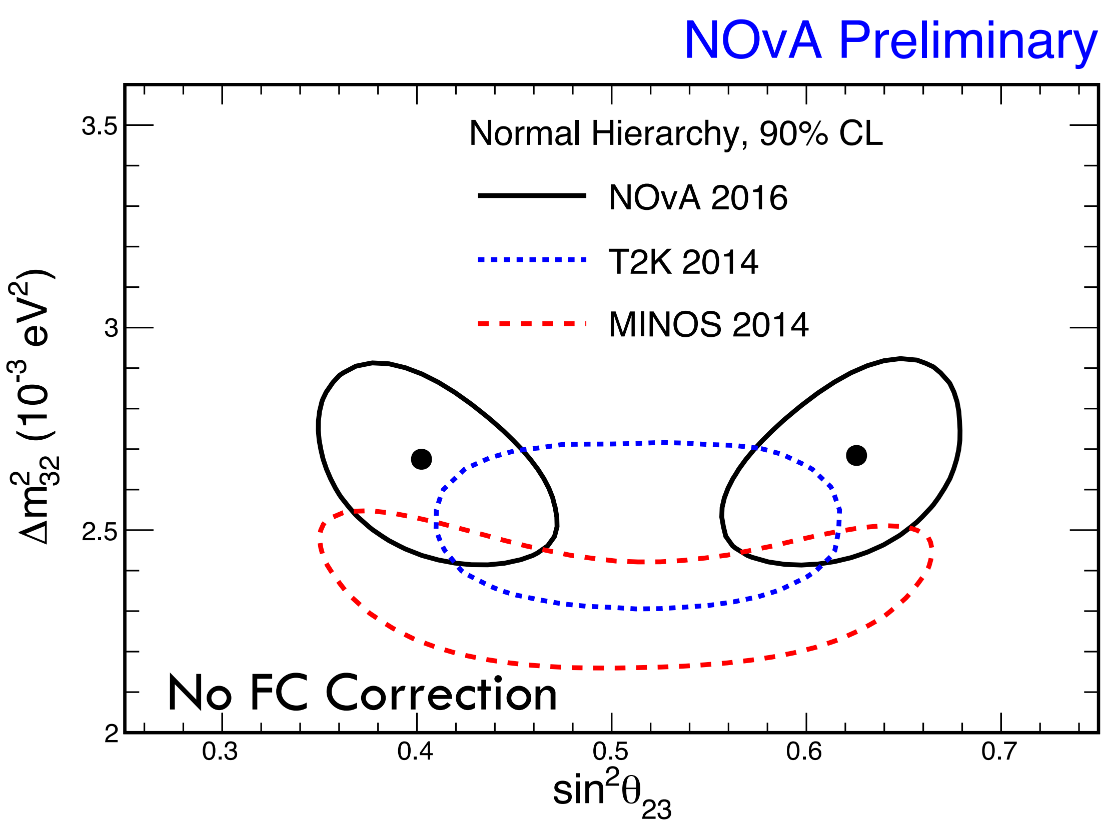
- Good sensitivity to the "atmospheric" parameters ($\theta_{23}$ and $\Delta m^2_{23}$)

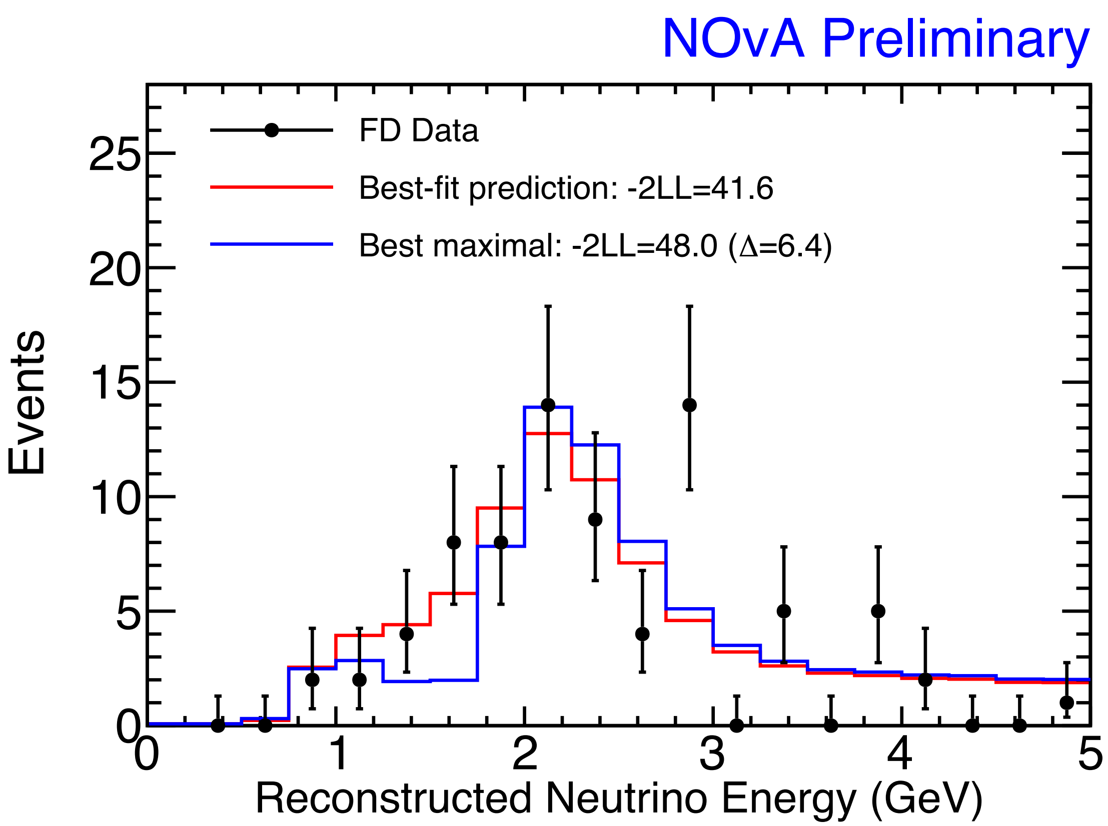



# NOvA at Neutrino 2016








Best Fit (in NH):

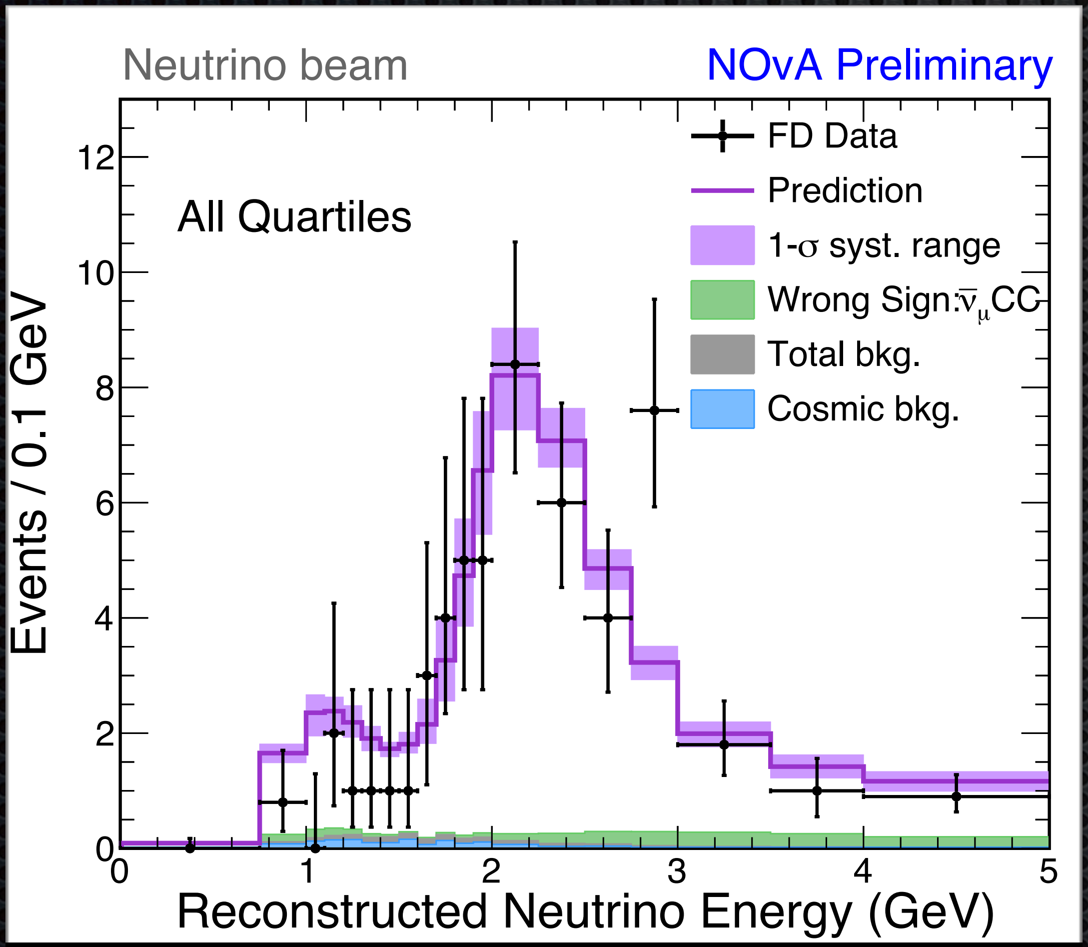
$$|\Delta m^2_{32}| = 2.67 \pm 0.12 \times 10^{-3}\mathrm{eV}^2$$

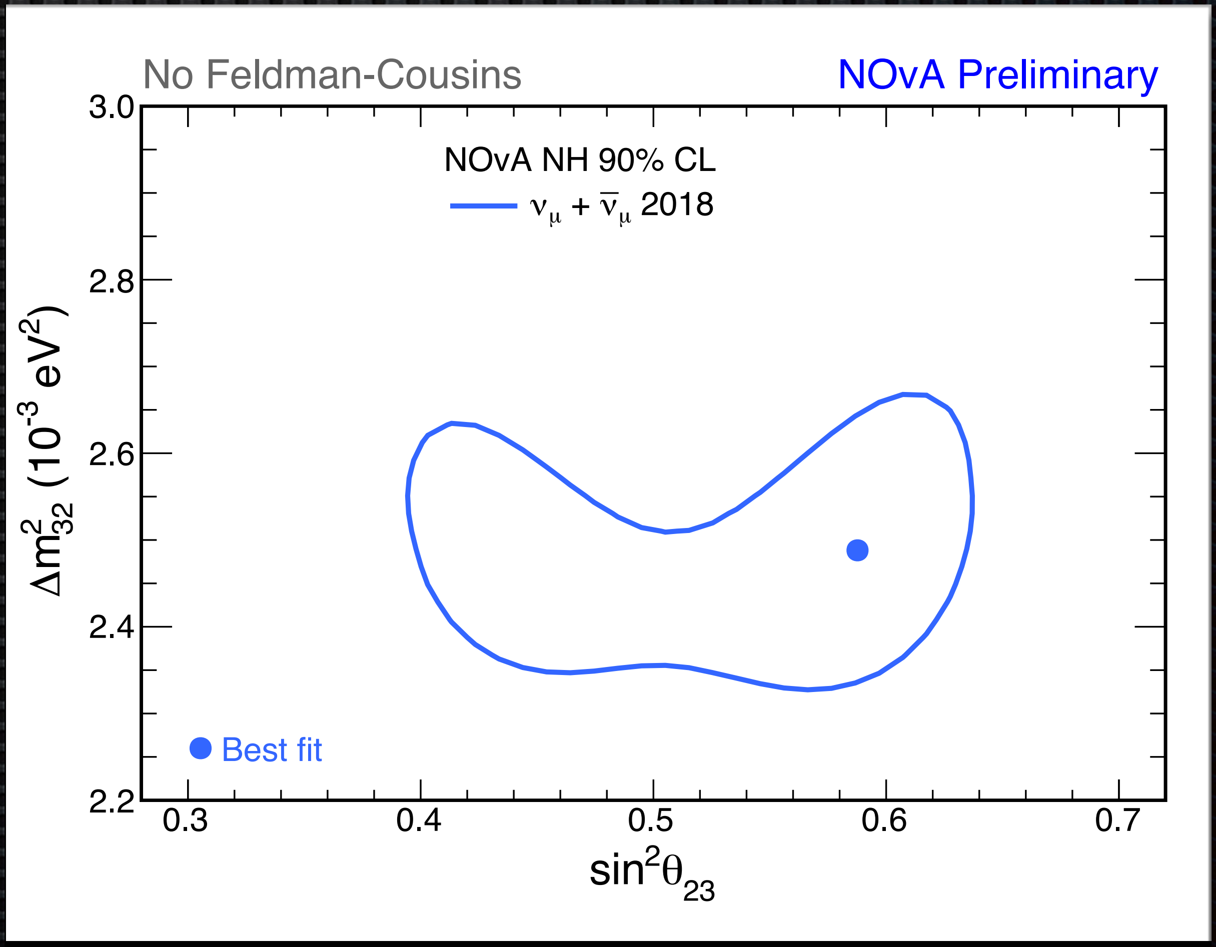
$$\sin^2\theta_{23} = 0.40^{+0.03}_{-0.02}(0.63^{+0.02}_{-0.03})$$

Maximal mixing excluded at 2.5σ

# NOvA at Neutrino 2018

## Refined energy reconstruction

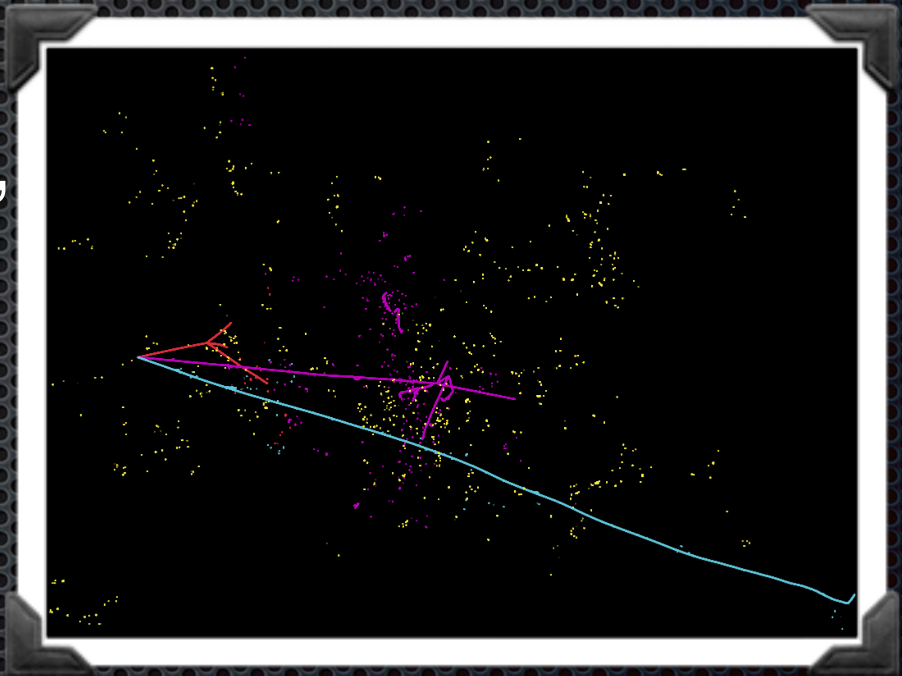



- Maximal mixing is no longer strongly disfavored

# Measuring neutrino energy at DUNE

- In the beam of 1-4 GeV, a variety of final states are produced, with protons, pions, and neutrons (see Ulrich's talk)
- Because of this, DUNE has to use the calorimetric method
- As a calorimetric detector DUNE is not perfectly hermetic
- There are several missing energy channels, and they dictate energy resolution (see Shirley's talk)



see arXiv:1811.06159,

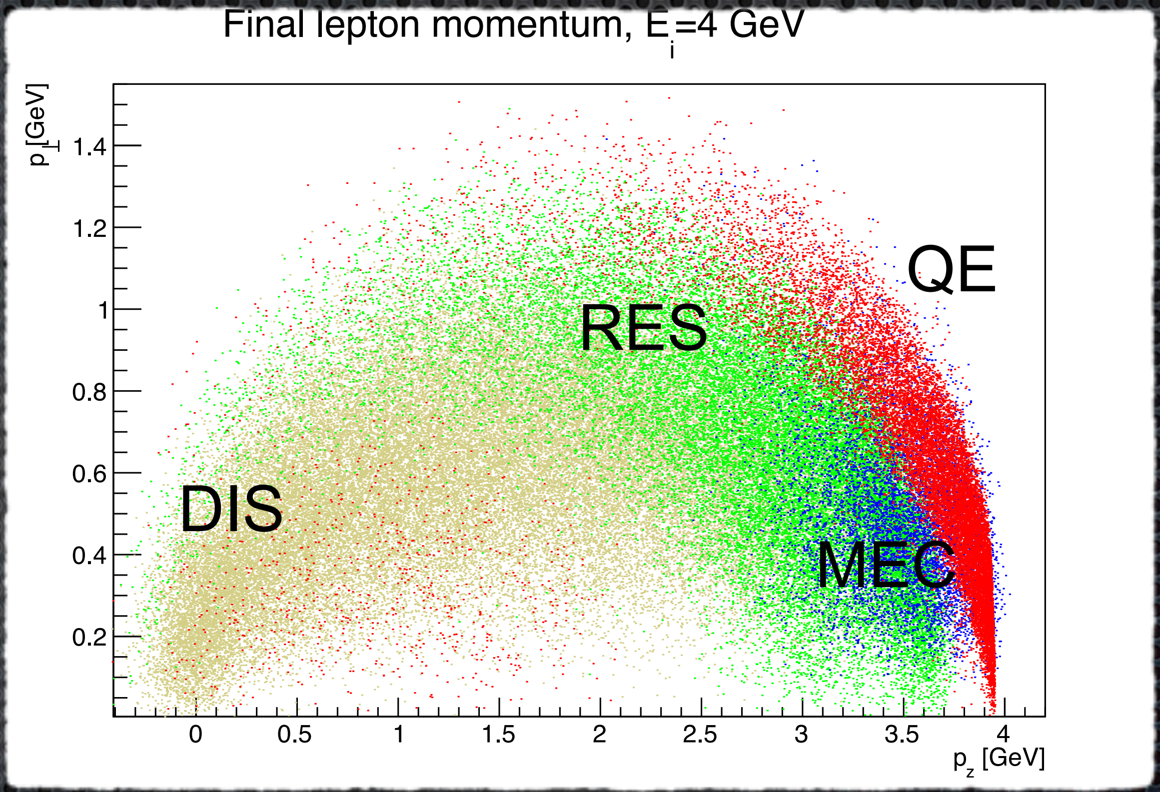
10.1103/PhysRevD.99.036009

# How cross section uncertainties enter oscillation studies

- Generator predictions are used to fill the missing information (subthreshold energy deposits, missing particle-ID info, nuclear breakup by wandering neutrons, etc, etc)
- Accurate predictions for both charge lepton and the hadronic system (energies, composition) are key
- Mistakes can have profound consequences

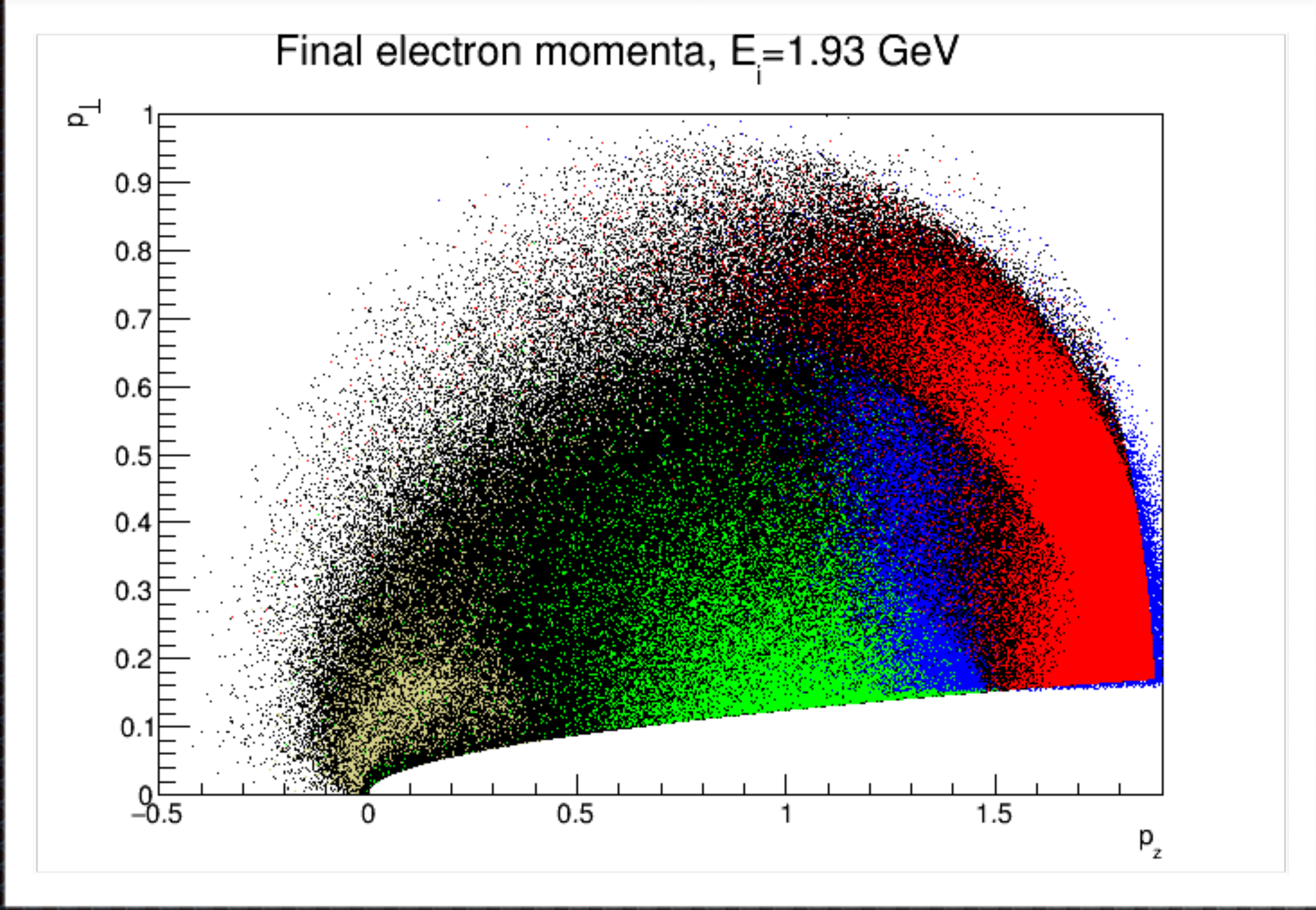
# Neutrino scattering at several GeV

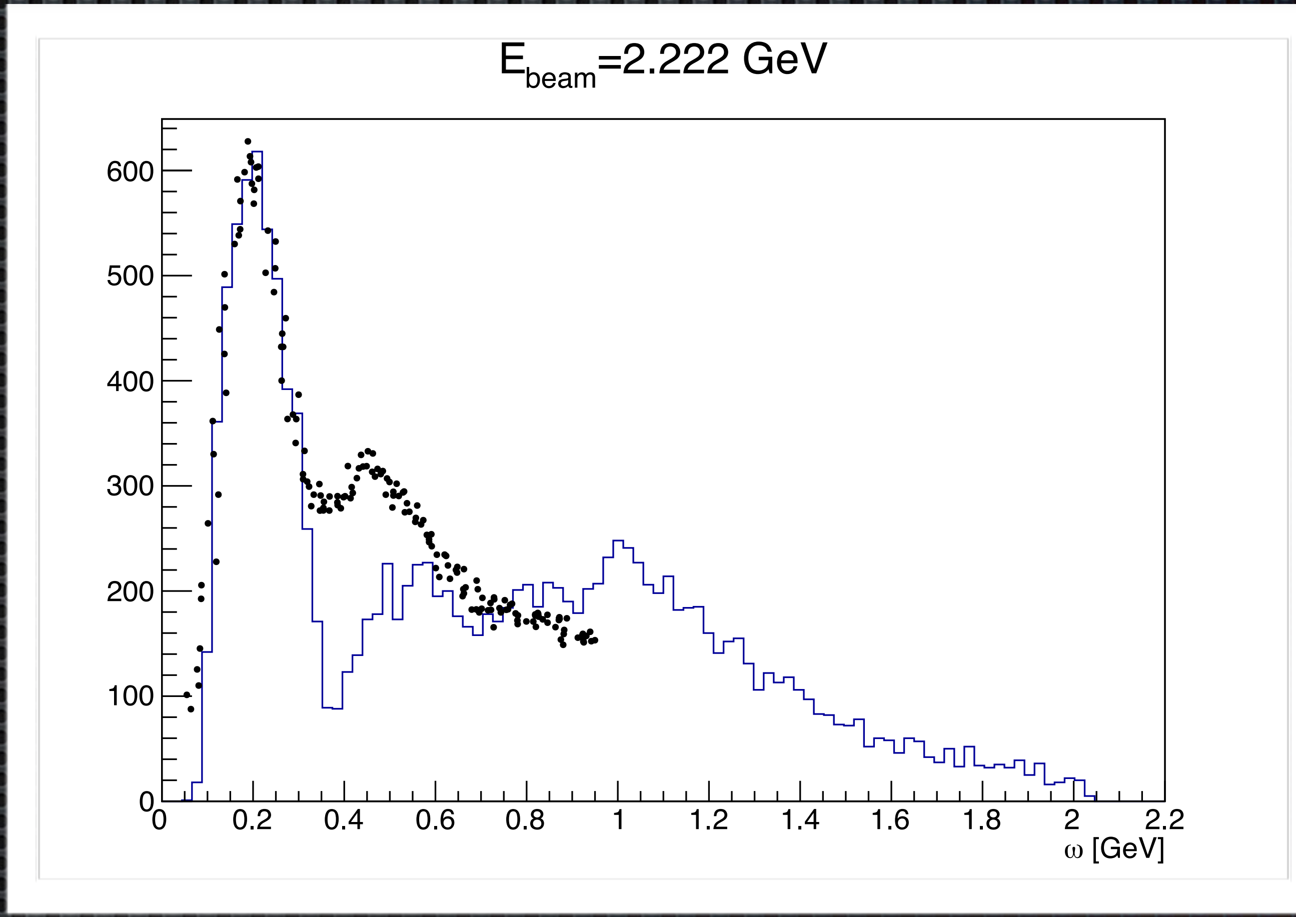
- A number of physical processes: quasi-elastic, resonant and non-resonant pion production, DIS-like, multi-nucleon. Generator codes, e.g. GENIE, try to model this physics.




- We need to test/validate all this physics as much as possible
  - how *each component* is constrained by the world's best data

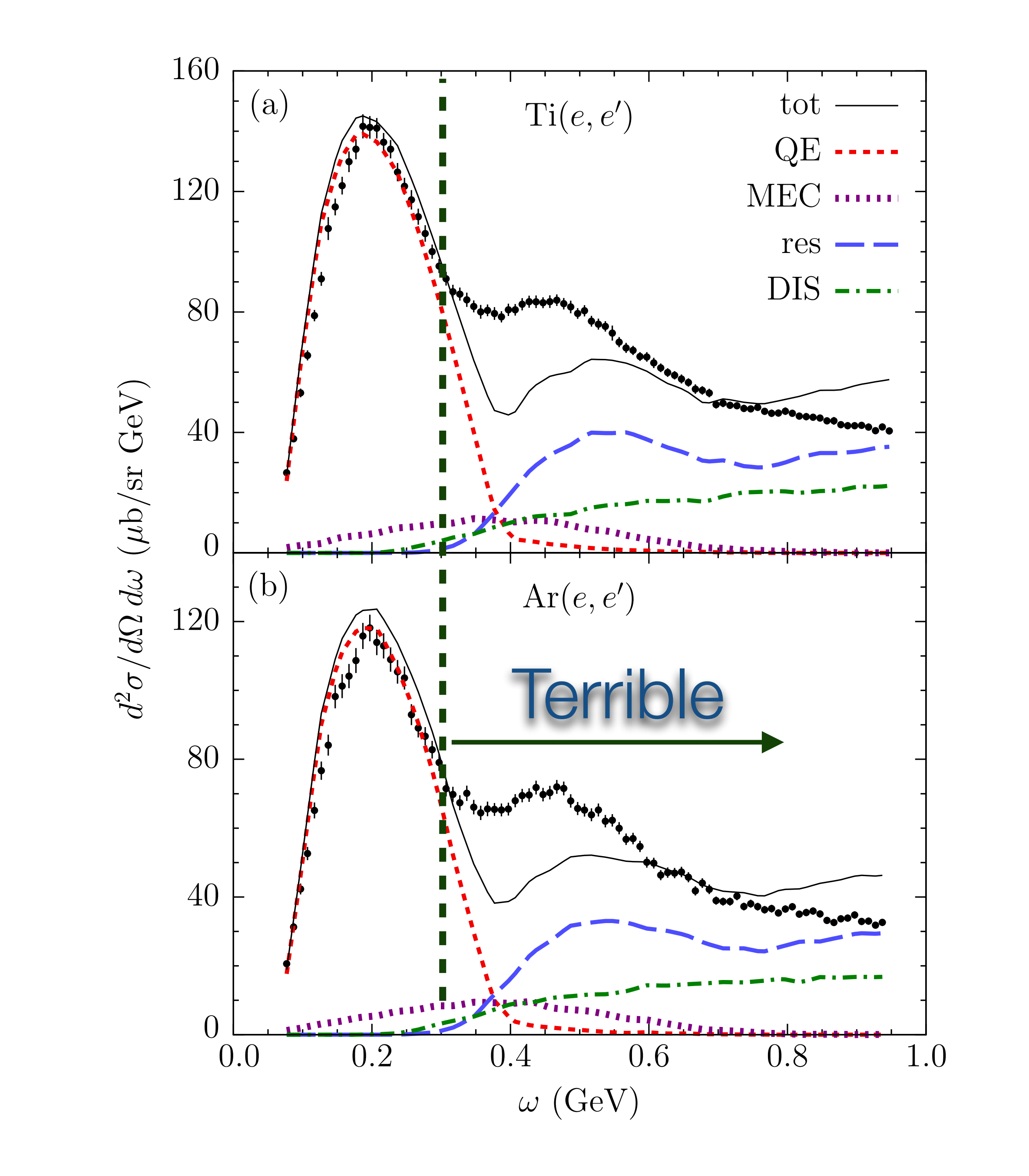
# use electron scattering



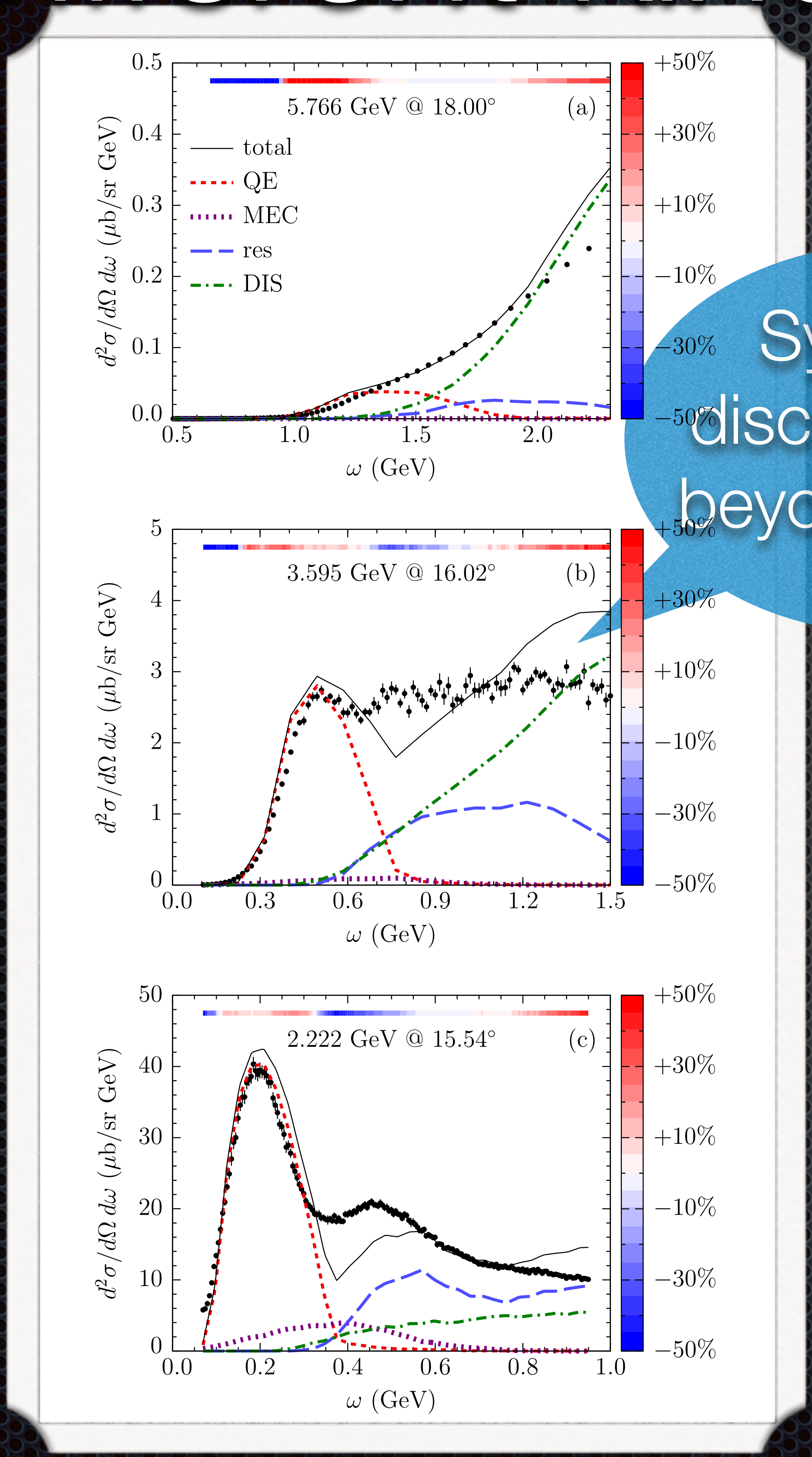

- Common physics includes
  - Initial nucleon momentum distribution (spectral function)
  - Final state interactions
  - Hadronization at several GeV, meson exchange currents, etc
- GENIE generator predictions show dramatic discrepancies with a variety inclusive electron scattering data
  - Artur Ankowski, A.F., Shirley Li, the last 2 years

# Electron scattering comparison




- Everything beyond the QE peak is in dramatic disagreement

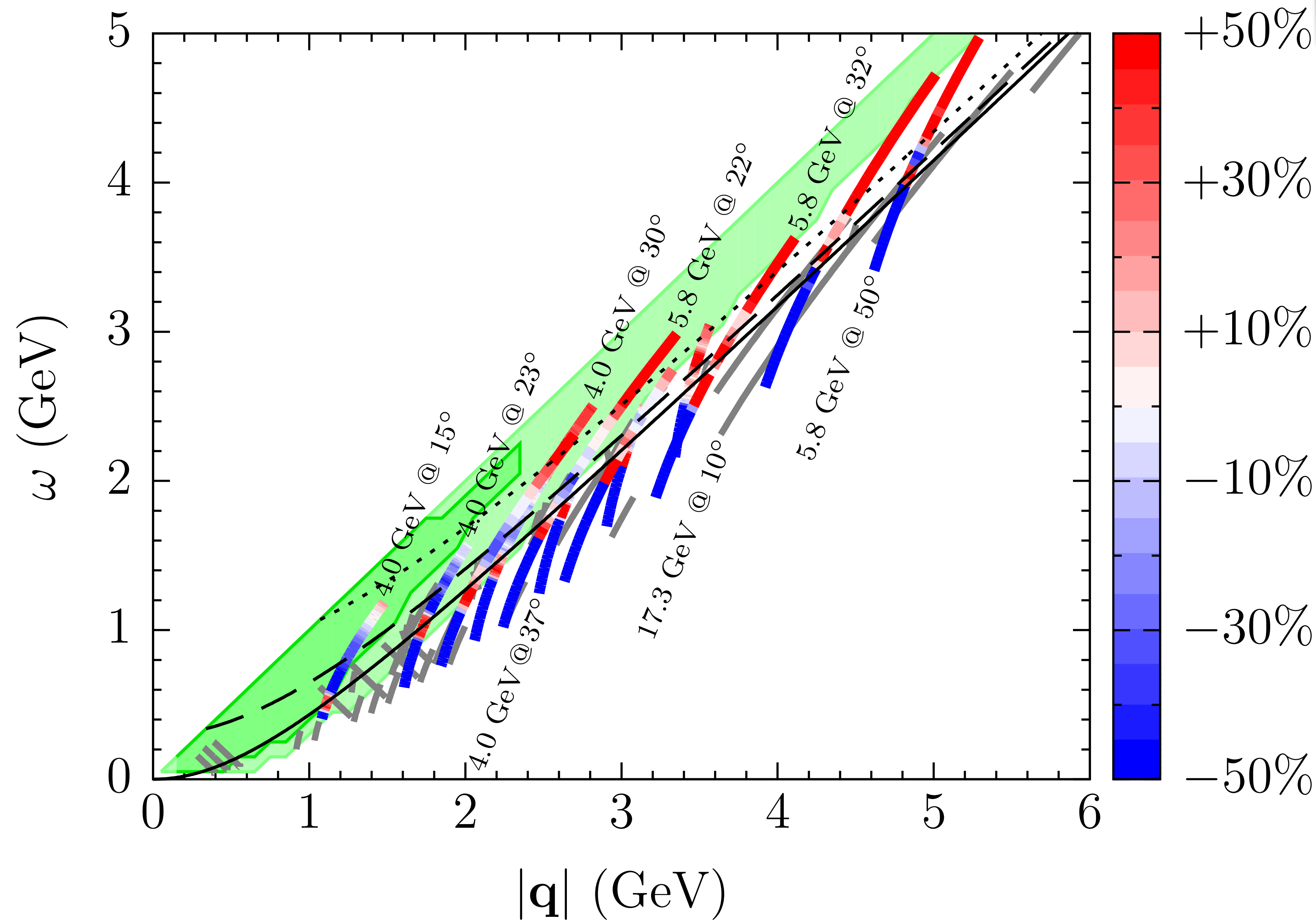
# Different kinematic regimes




Systemic discrepancies beyond CCQE

- Chronic problems with many other datasets.

# Mapping out the pattern of discrepancies




# Opportunity to study this physics at SLAC

- Electron beam energy in S30XL is 4 GeV, ideal range to make measurements for DUNE
- LDMX happens to have potentially advantageous characteristics: wide angular acceptance of the produced particles (p, $\pi$) and good momentum resolution
- The key, as already mentioned, is to gather detailed information about the hadronic system, not only inclusive data
- The idea was discussed at PINS 2017, presented in a talk to LDMX collaboration in 2017, to DOE and SLAC LDRD in 2018

# Opportunity to study this physics at SLAC

- Plan of action:
  - Generate events throughout the regimes of interest (QE and beyond), with as few cuts at the generator level as possible
  - Combine with detector simulations. Establish how much of the interesting physics can be covered under baseline LDMX detector assumptions.
  - Think through the origin of various limitations. Anything that was imposed because the design thought only about dark stuff? Anything that could be improved with a modest fee?
  - The results should tell us whether LDMX is indeed capable of a dual physics program, or if a dedicated experiment would be preferred