Electron scattering experiments for neutrino cross sections

LDMX Zoom meeting

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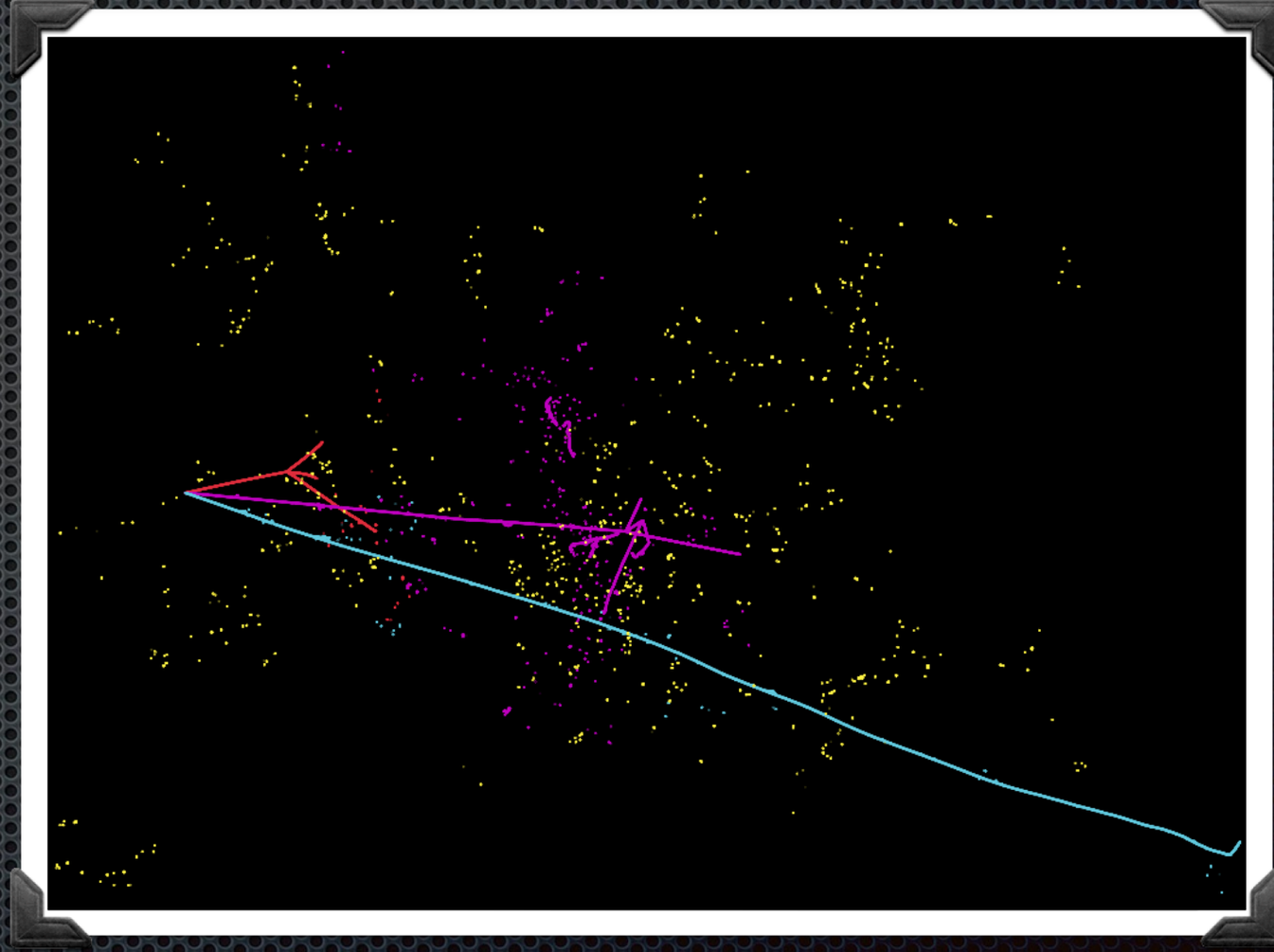
Measuring neutrino energy at DUNE/NOvA

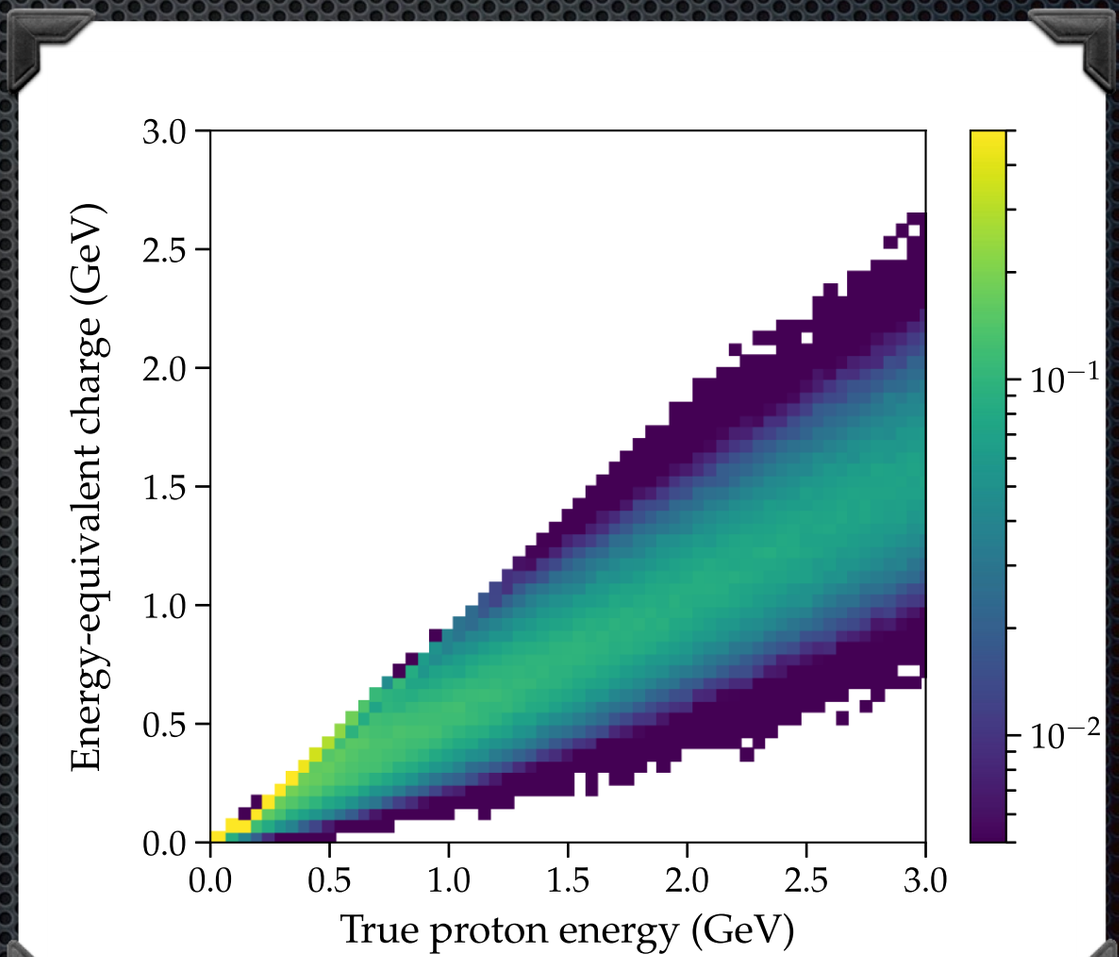
- In 1-4 GeV beams, a variety of final states are produced:
  - protons,
  - pions,
  - gammas,
  - neutrons
- Because the final-state mass varies, lepton kinematics alone is insufficient to infer E_ν
- Have to use calorimetric reconstruction: measure the energy of all final-state particles



see arXiv:1811.06159,
10.1103/PhysRevD.99.036009

Calorimetry challenge

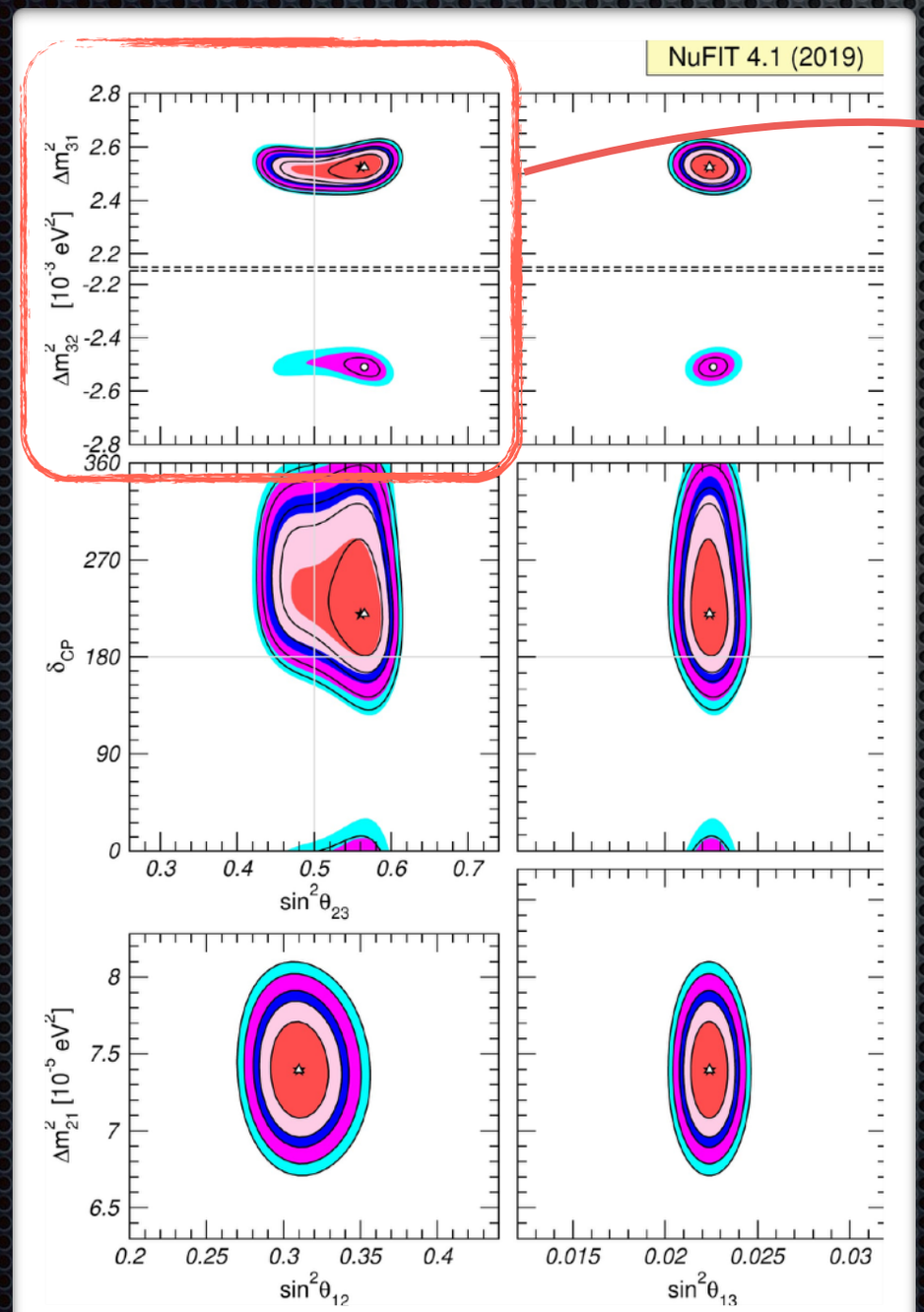
- Directly connecting ionization charge to neutrino energy is a non-trivial task!
  - low-energy p/pi- discrimination
  - neutron losses
- *Generators are needed to fill in missing information*
  - Predicting the composition and properties of the hadronic final state



see arXiv:2007.13336,

DOI: 10.1103/PhysRevD.102.096005

Does this really matter for oscillation measurements?



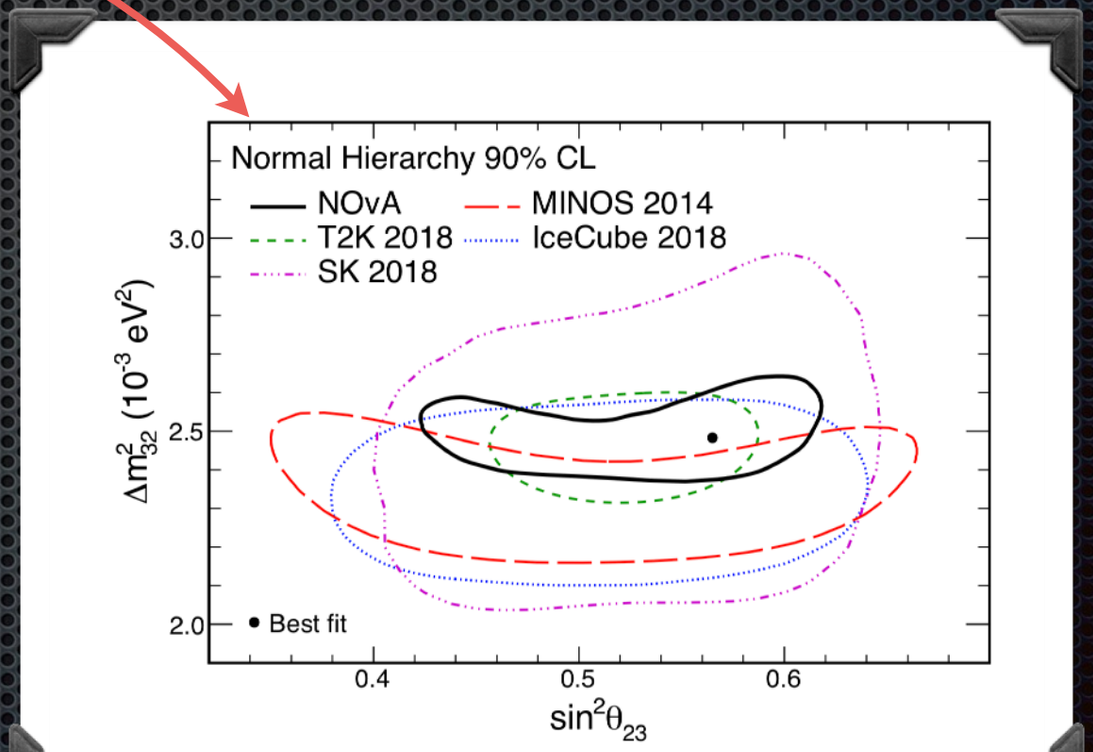


Figure from NOvA, arXiv:1906.04907

NOvA 2019

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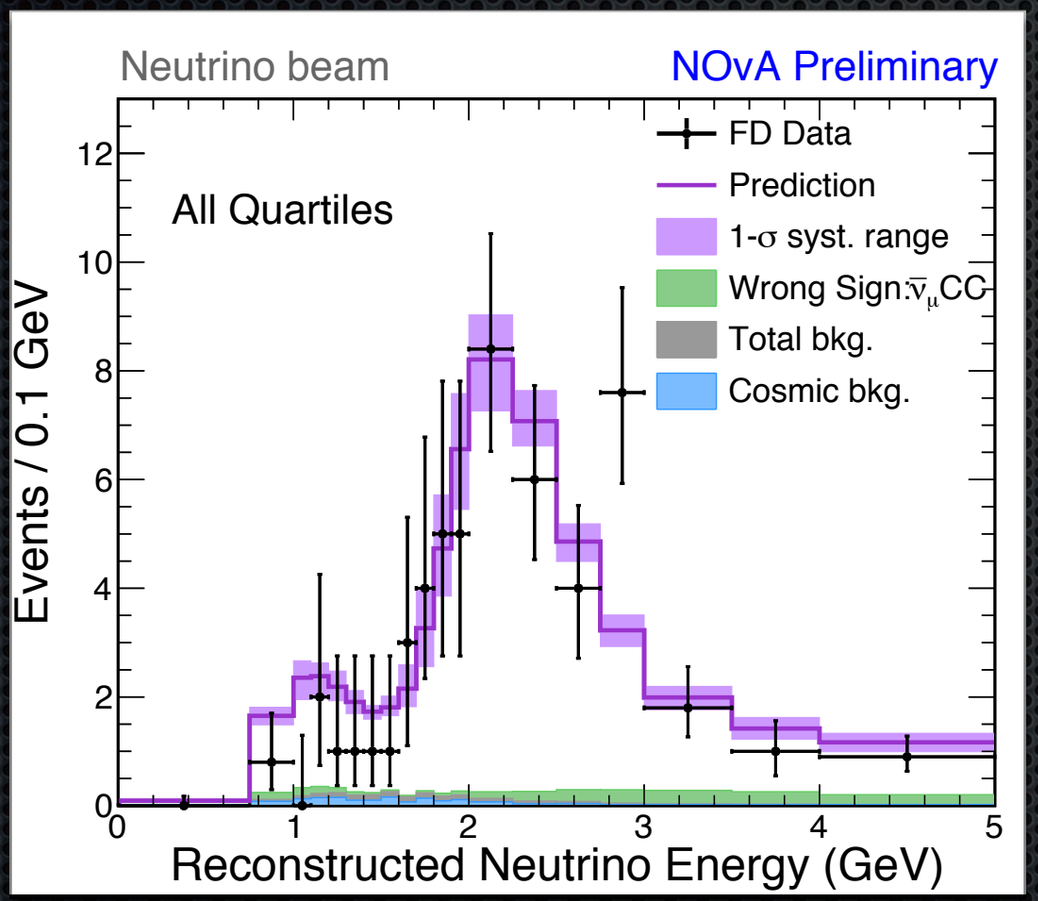
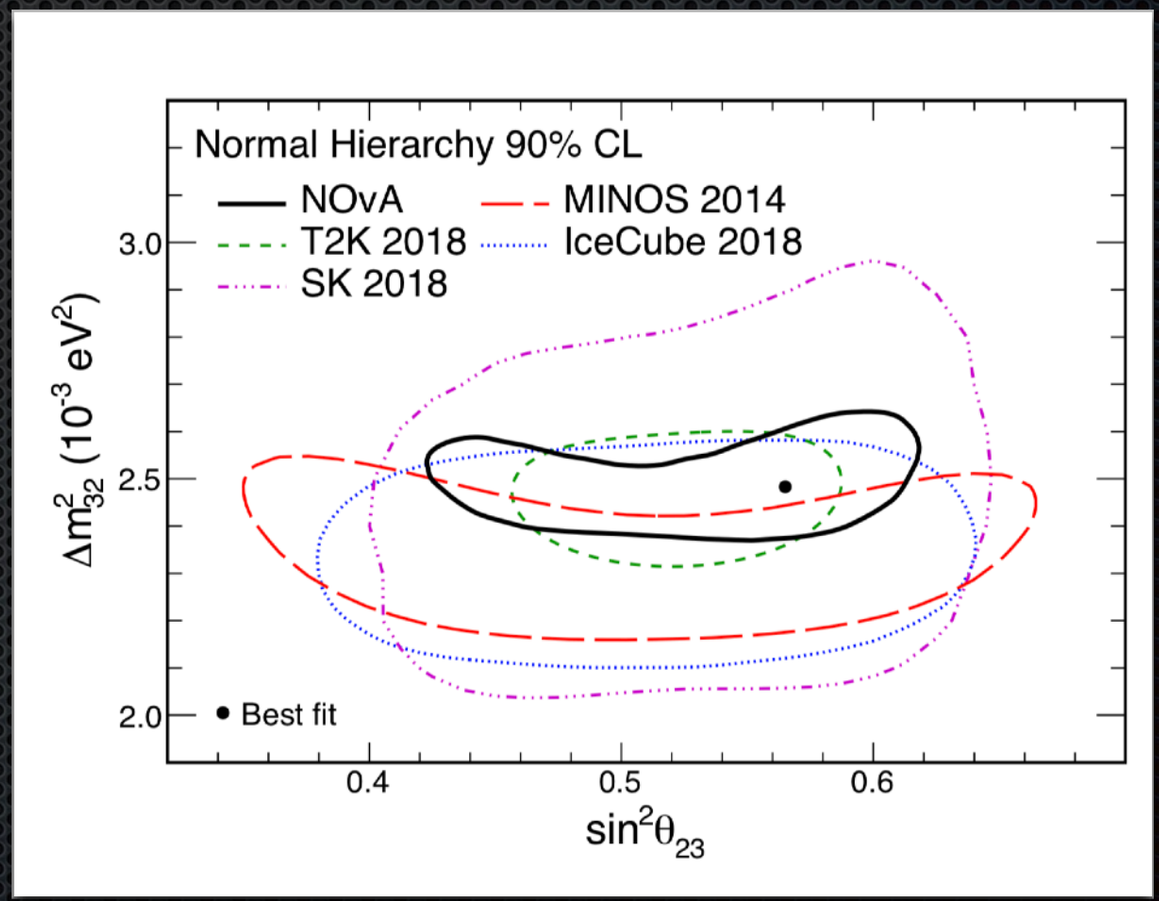
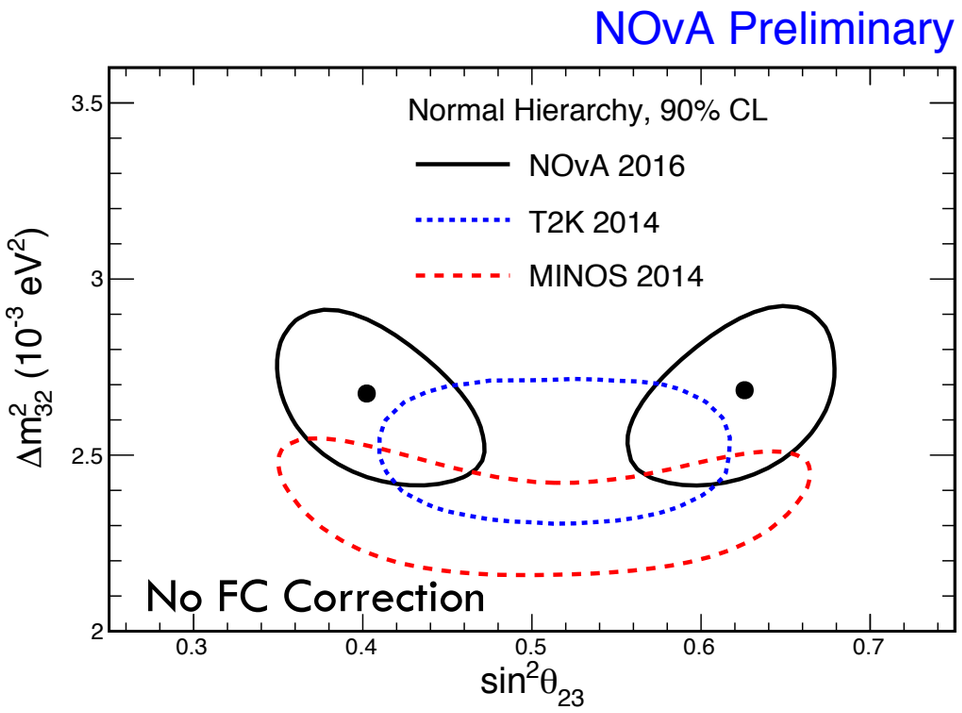


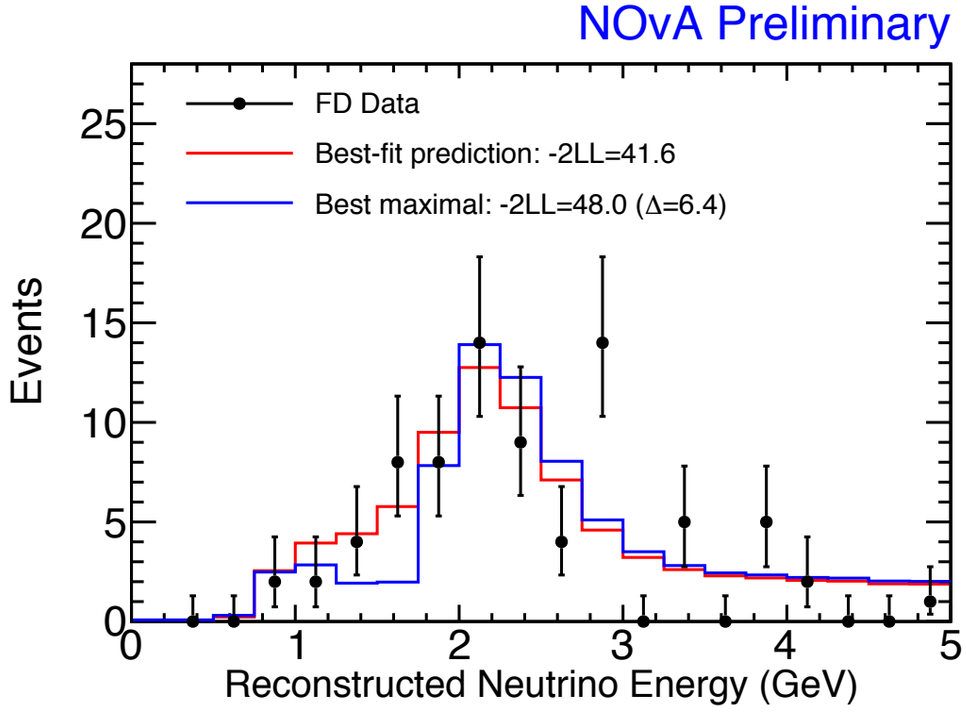


- $\theta_{23} = \pi/4$ implies a steeply rising spectrum

cf. NOVA 2016

- More events in the dip could be interpreted as evidence of nonmaximal mixing





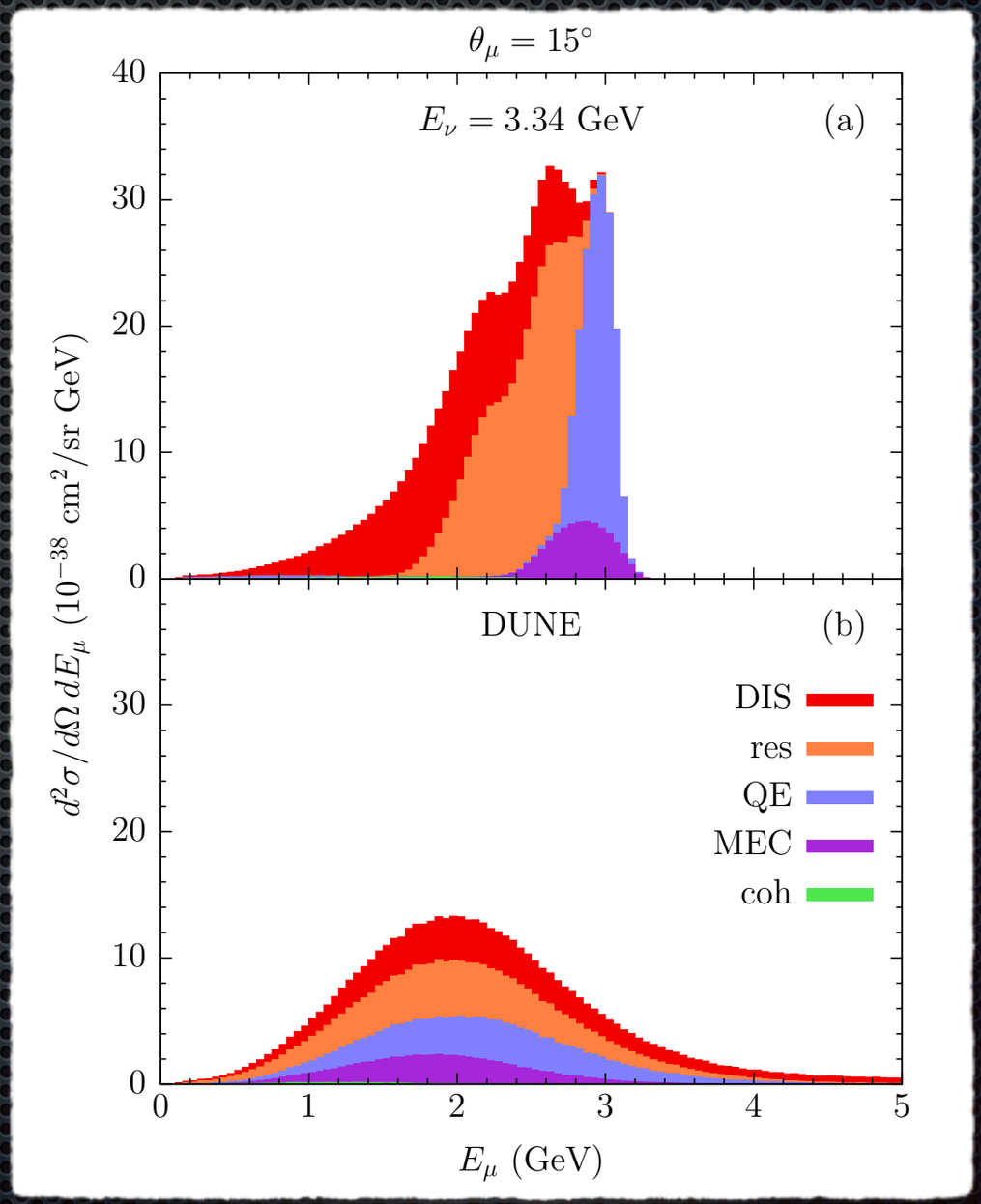
Best Fit (in NH):

$$\left|\Delta m^2_{32}\right| = 2.67 \pm 0.12 \times 10^{-3}\text{eV}^2$$
$$\sin^2\theta_{23} = 0.40^{+0.03}_{-0.02}(0.63^{+0.02}_{-0.03})$$

Maximal mixing excluded at 2.5σ

Neutrino scattering at several GeV

- To model the hadronic system, need accurate physics in the generators:
  - QE, resonant and non-resonant pion production, DIS-like, multi-nucleon
- Testing everything with neutrino scattering is challenging
  - neutrino beams are not monochromatic and energy reconstruction requires good generators, see above!
- Find an independent way to systematically test all these processes

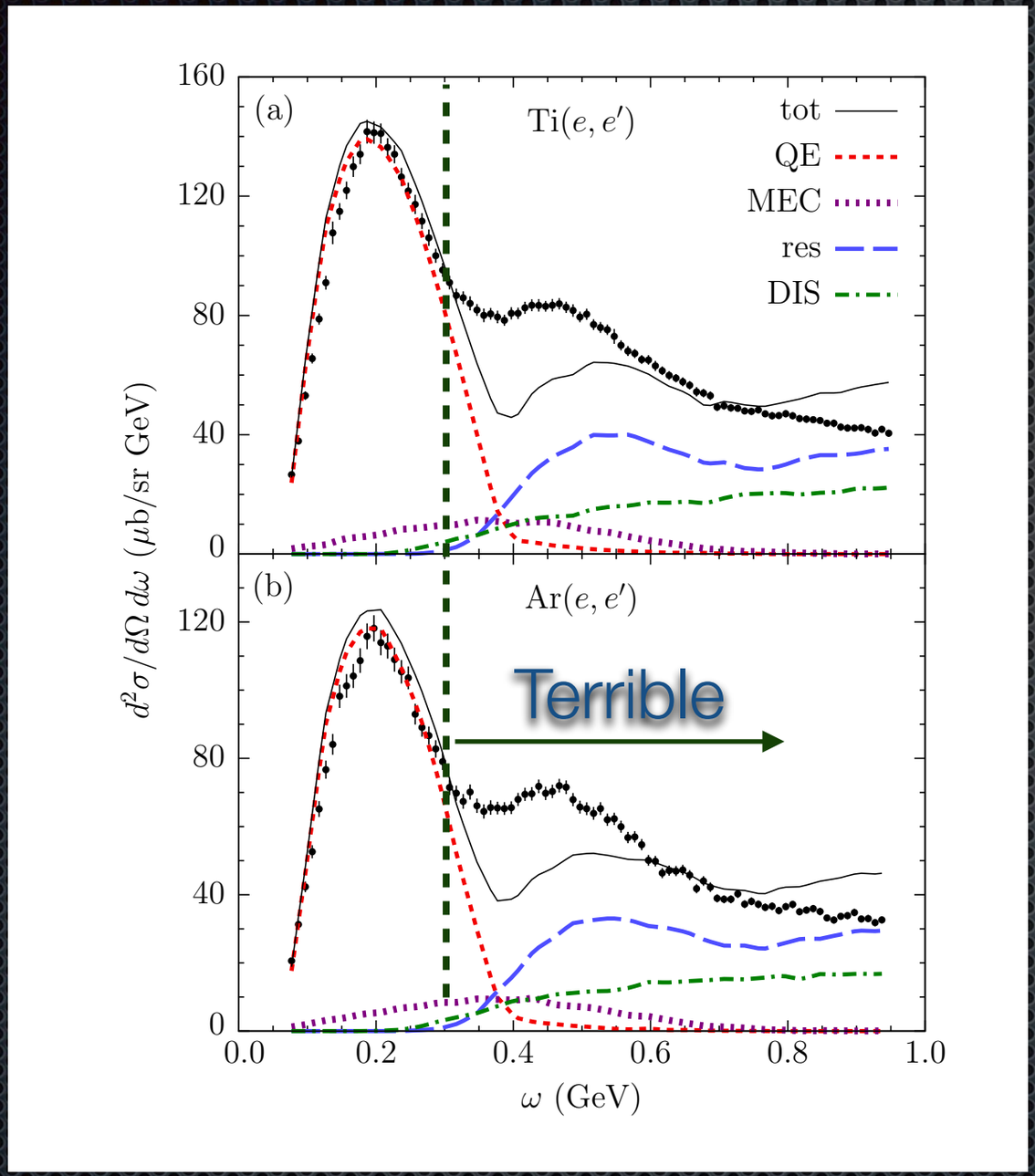


- Figure: e-Print: 2006.11944

Use electron scattering

- Despite the different primary vertex, much physics in common:
  - Initial nucleon momentum distribution (spectral function)
  - Final state interactions
  - DIS limit, hadronization at several GeV, meson exchange currents, etc
  - discussion in Sec. 2 of 1912.06140 [10.1103/PhysRevD.101.053004]
- Systematic study of generator models using a large inclusive electron scattering dataset, last 3 years

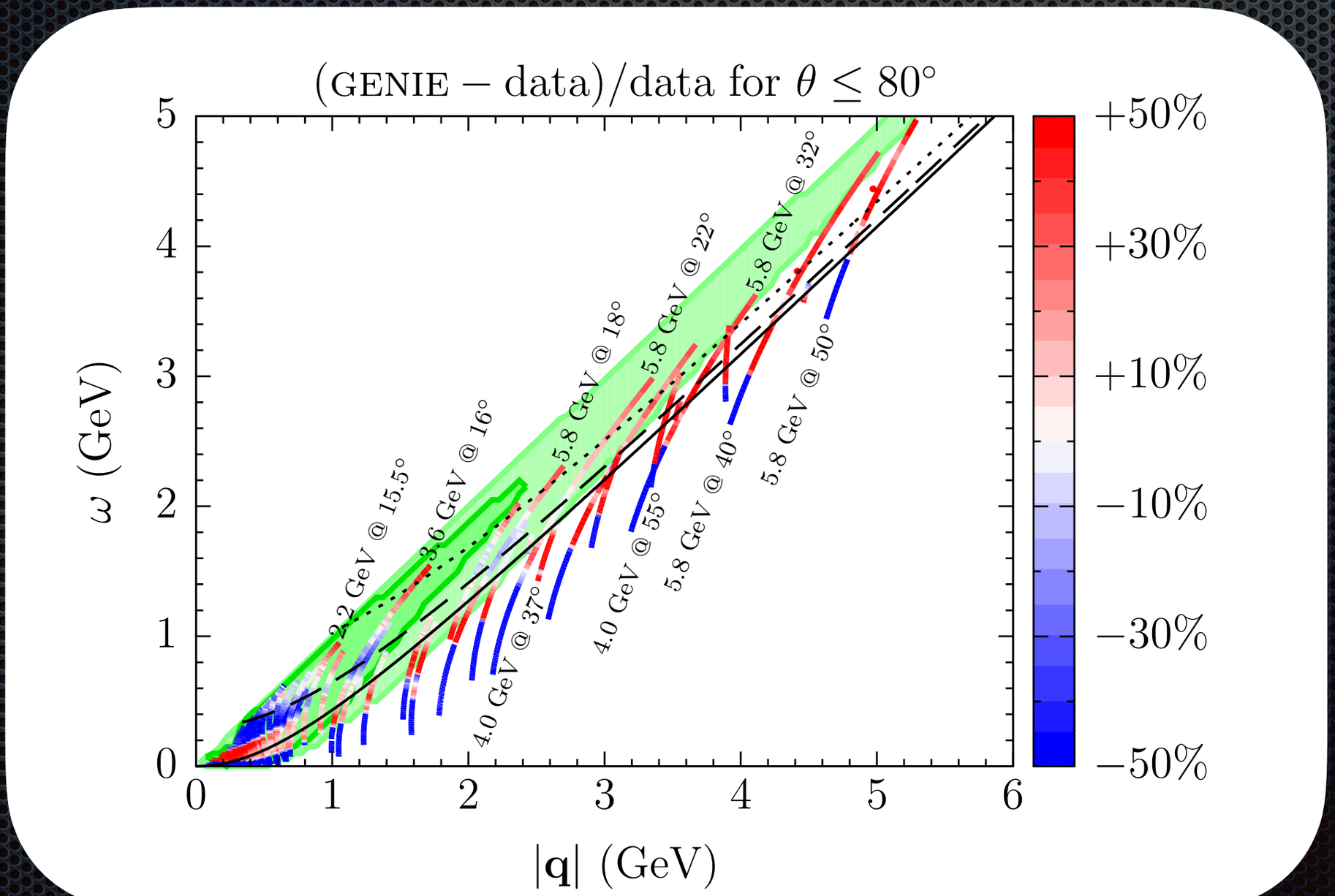
Invitation: GENIE vs JLAB



2.2 GeV electron beam JLAB

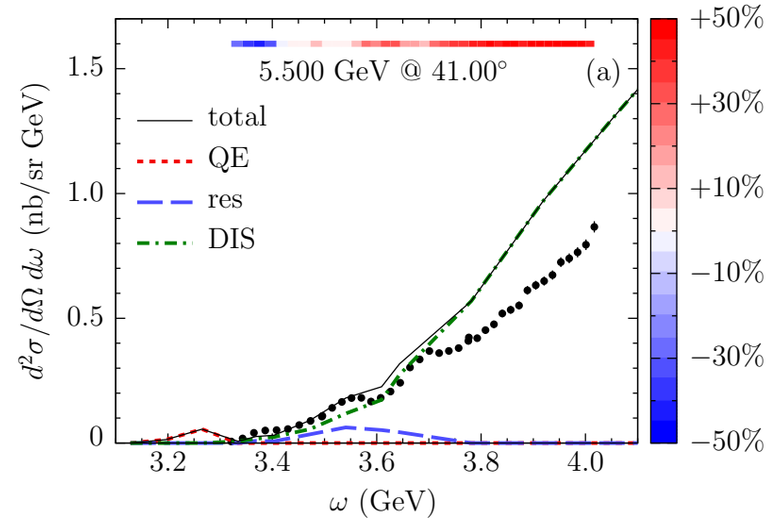
- Predictions beyond the quasielastic peak are in dramatic disagreement with the data

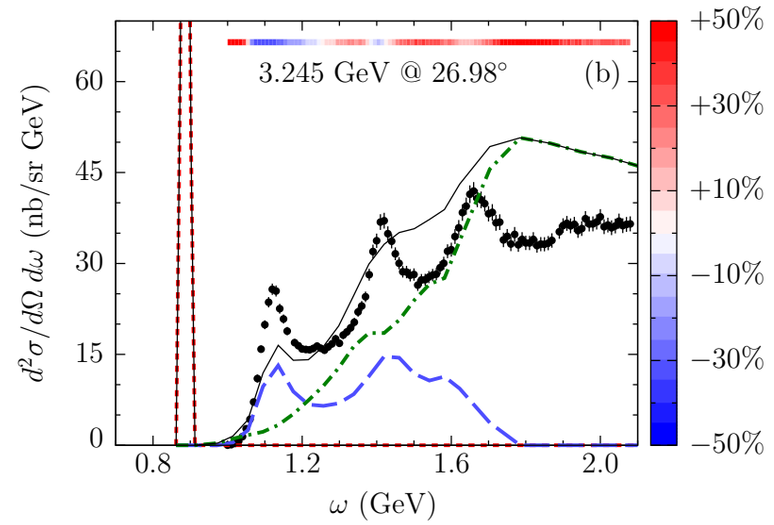
Mapping out the pattern of discrepancies

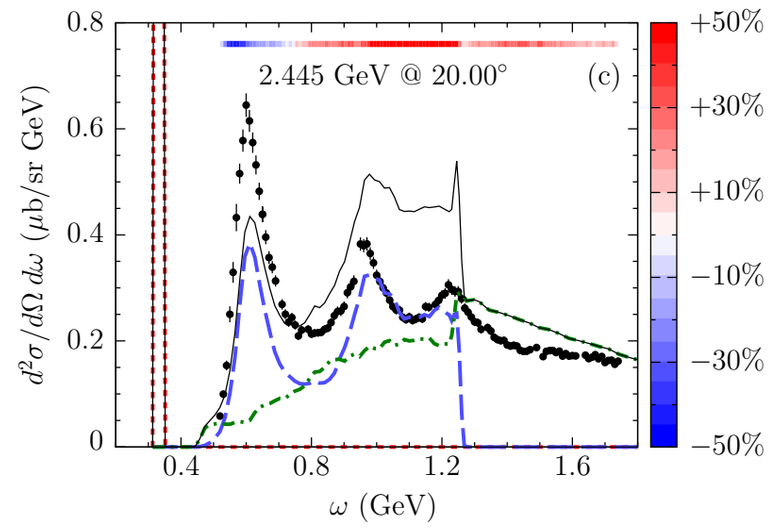


Decisive test: comparison to hydrogen and deuterium

- Surprising findings:
  - Large discrepancies originate in (mis)modeling of hadronic processes

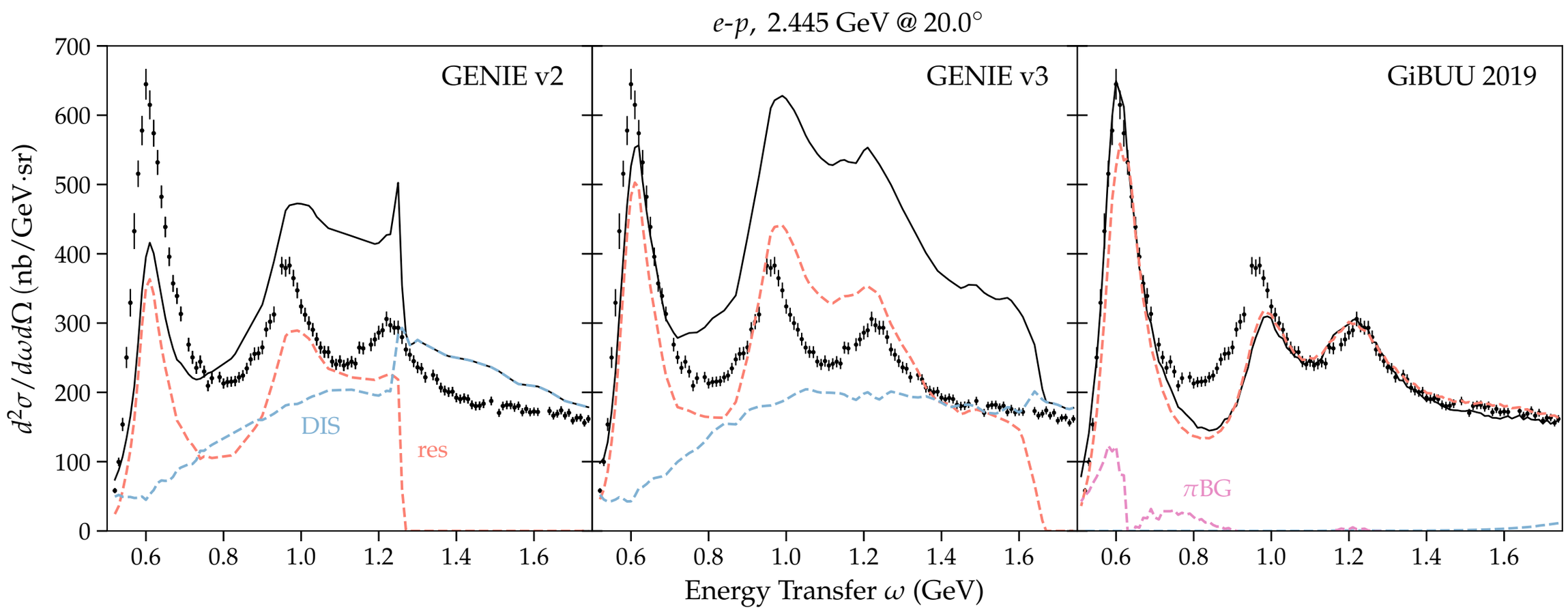






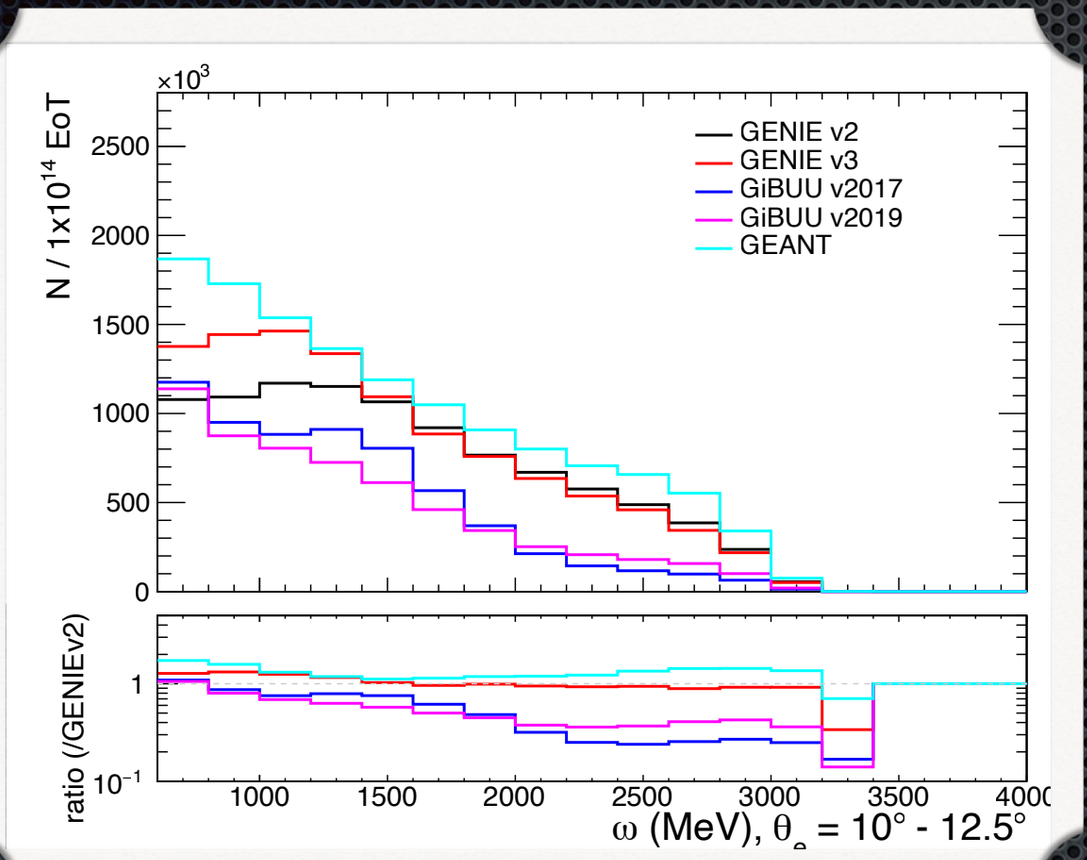
For details, see e-Print: 2006.11944
DOI: 10.1103/PhysRevD.102.053001

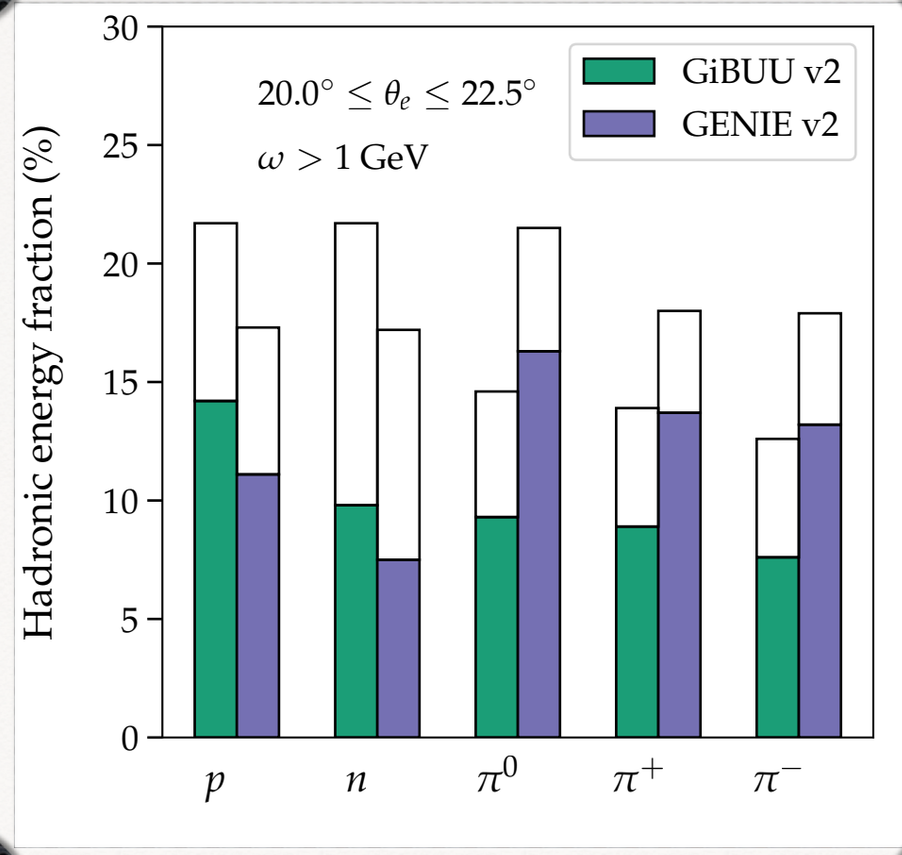
Large discrepancies persist for other generators



Ankowski, A.F., Li, *to appear*

Important: large discrepancies among generator predictions for exclusive channels





Simulation for the LDMX detector

e-Print: 1912.06140 [hep-ph]
DOI: 10.1103/PhysRevD.101.053004

Observation #1

- There are a number of conclusions one can draw from these analyses
  - In some cases, there are specific implementation issues, e.g. Bodek-Yang, Delta peak and QE in sub-GeV
  - In other cases, the problems are more foundational, especially in the “overlaps” between regimes (e.g., RES and DIS; QE, MEC, RES). All generators struggle with this, to a varying degree -> it’s not trivial
- see Artur’s discussion next

Observation #2

- To make progress on the foundational challenges, we need to collect new data
- Both the final-state electron and the hadronic system should be measures
  - Composition and energy distribution between protons, pions, gammas, neutrons
  - Large solid angle coverage in the forward cone