Prospects of electron-nucleus studies at LDMX

NuSTEC Workshop on Electron Scattering

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Many thanks to

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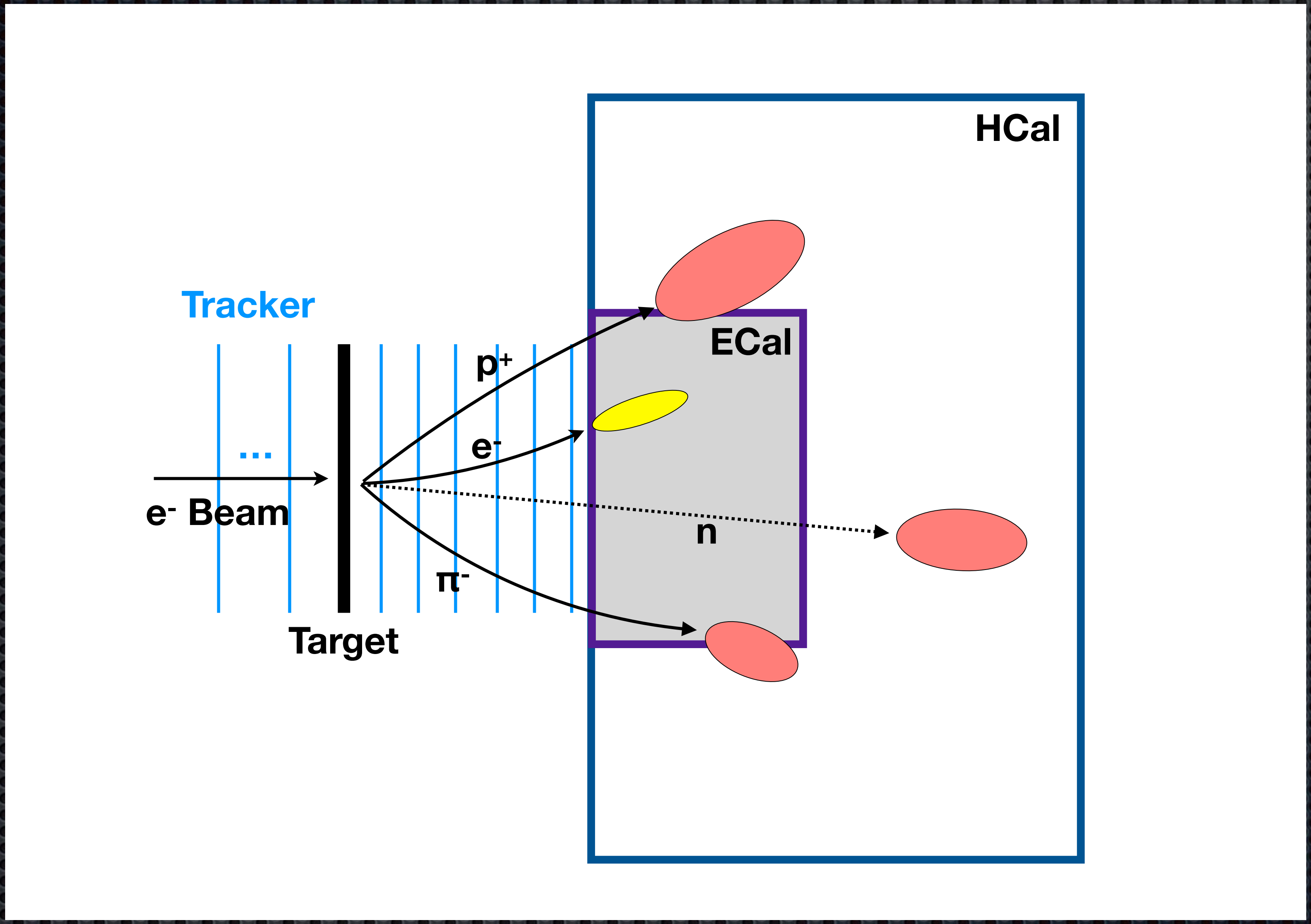
Shirley Li

Exciting opportunity to study e-A physics at SLAC

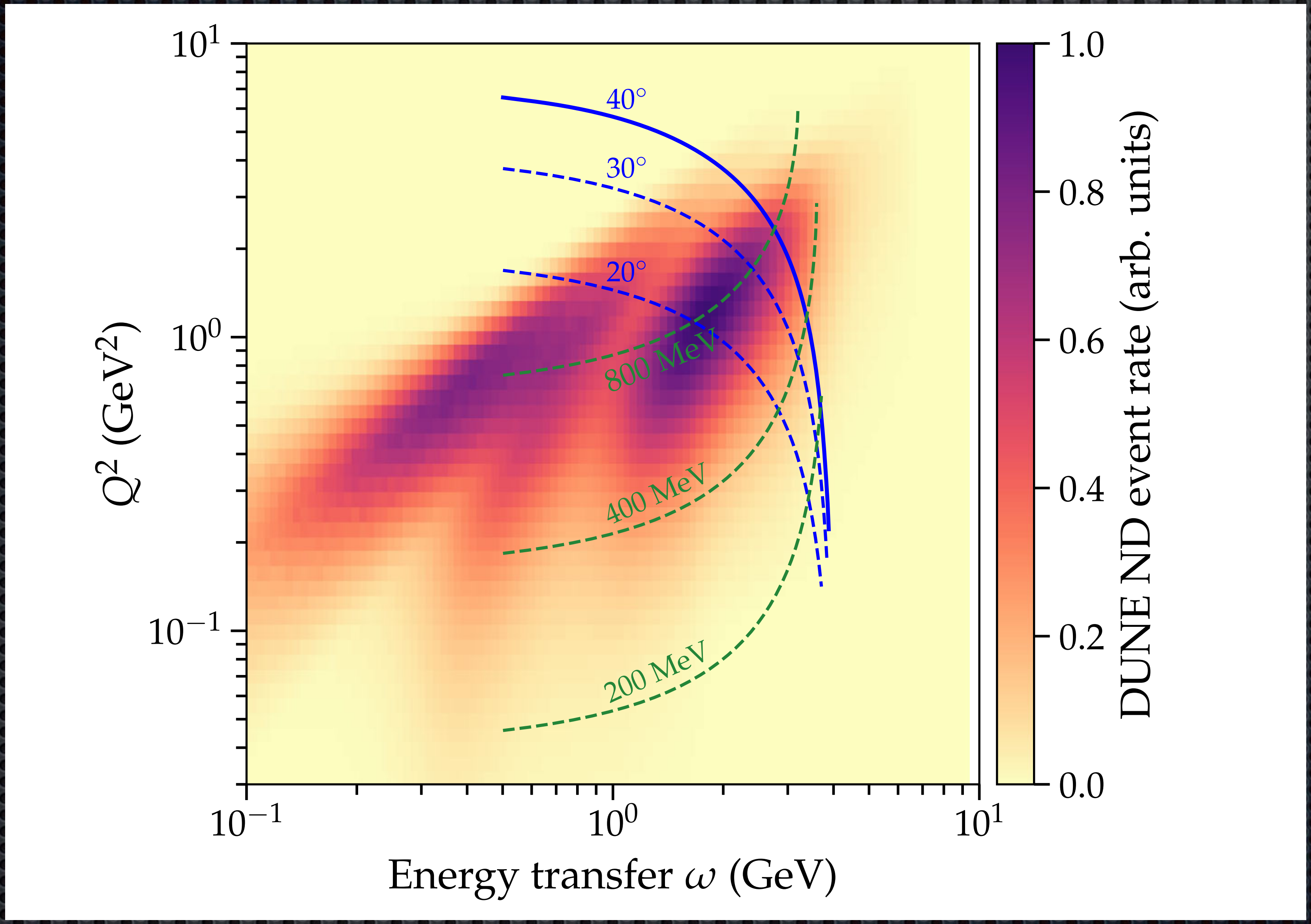
- LDMX (Light Dark Matter eXperiment) detector design was conceived to search for sub-GeV dark matter
- Electron beam energy in the S30XL beamline is 4 GeV (8 GeV), great to make measurements for DUNE
- LDMX happens to have advantageous characteristics: wide angular acceptance of the produced charged hadrons (p, π), good momentum resolution, ability to detect neutrons
- Opportunity to gather both inclusive data and detailed information about the final-state hadronic system

Schematic design



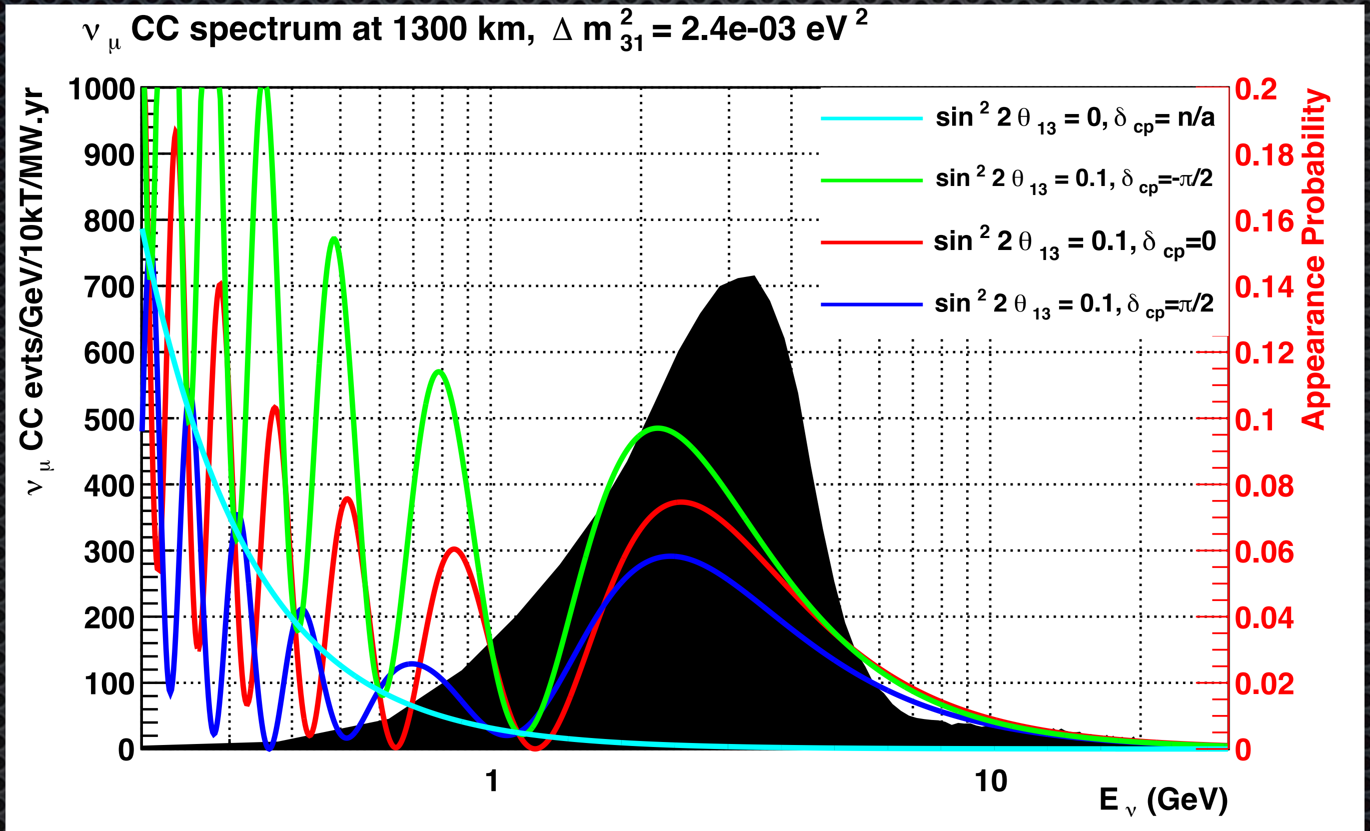
Tracking acceptance in the forward 40° cone,
HCal in the 65° cone

Schematic design



Simulated events in DUNE (heat map) vs coverage in electron angle and pT

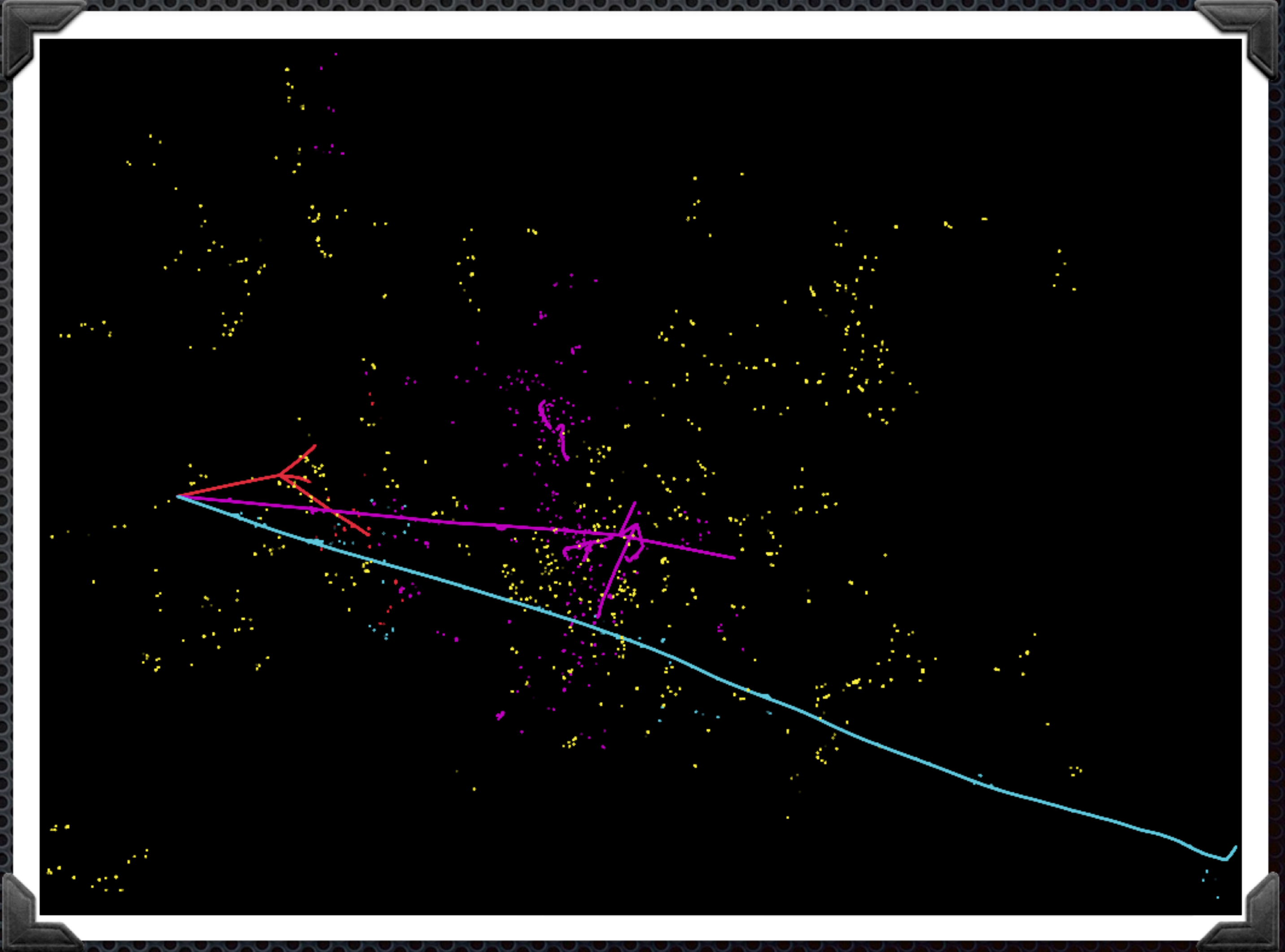
Goal: precision studies of neutrino oscillations *as a function of energy*



- Reconstruction of energy is key and for this we need accurate cross section models

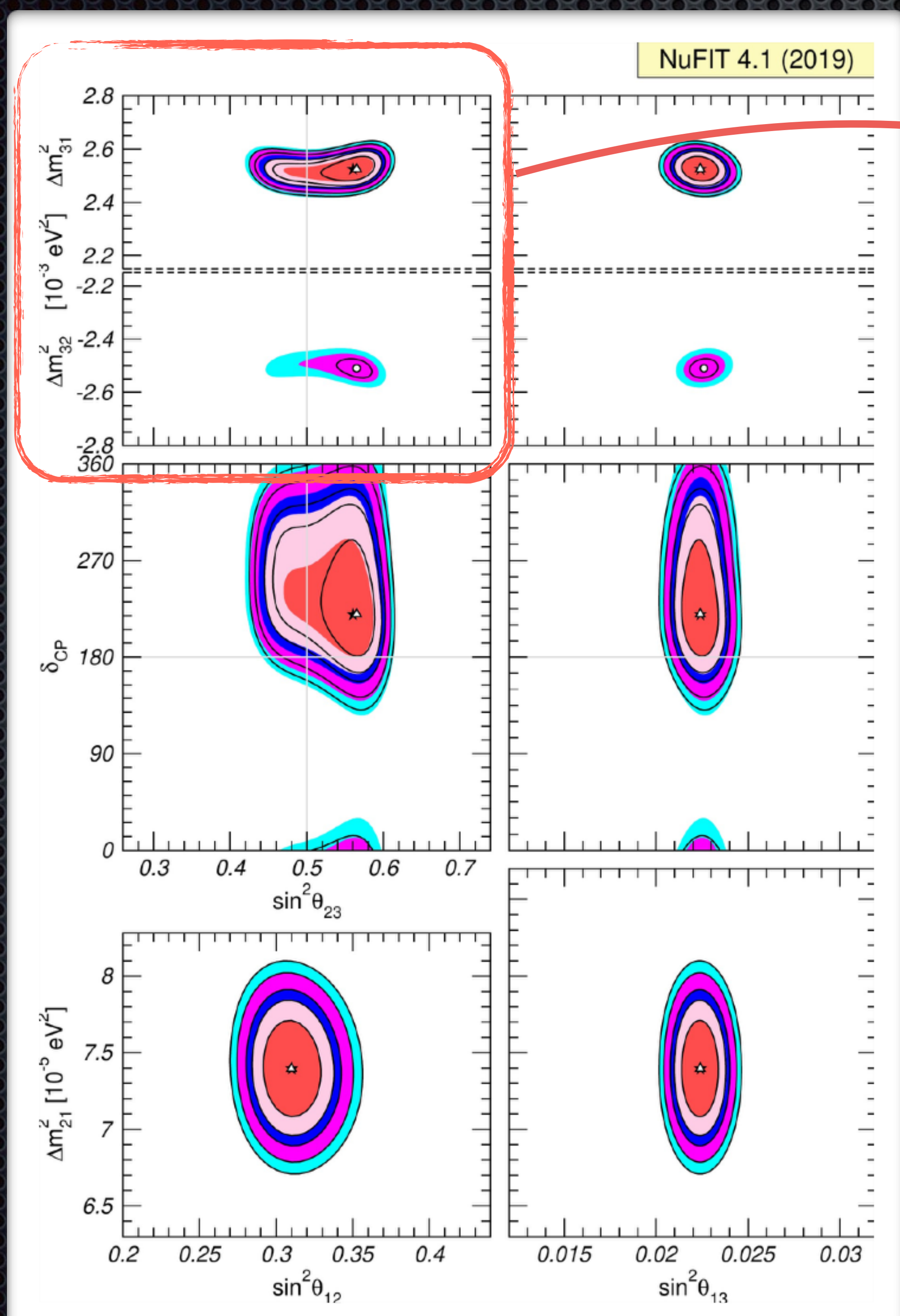
Measuring neutrino energy at DUNE/NOvA

- In the beam of 1-4 GeV, a variety of final states are produced, with protons, pions, and neutrons
- Because of this, lepton kinematics alone is insufficient to infer E_ν
- Have to use calorimetric reconstruction: measure energy of all final-state particles
- Generators are needed to fill in missing information
  - E.g., neutron losses, low-energy p/pi-discrimination, etc



see arXiv:1811.06159, arXiv:2007.13336

Does this really matter for oscillation measurements?



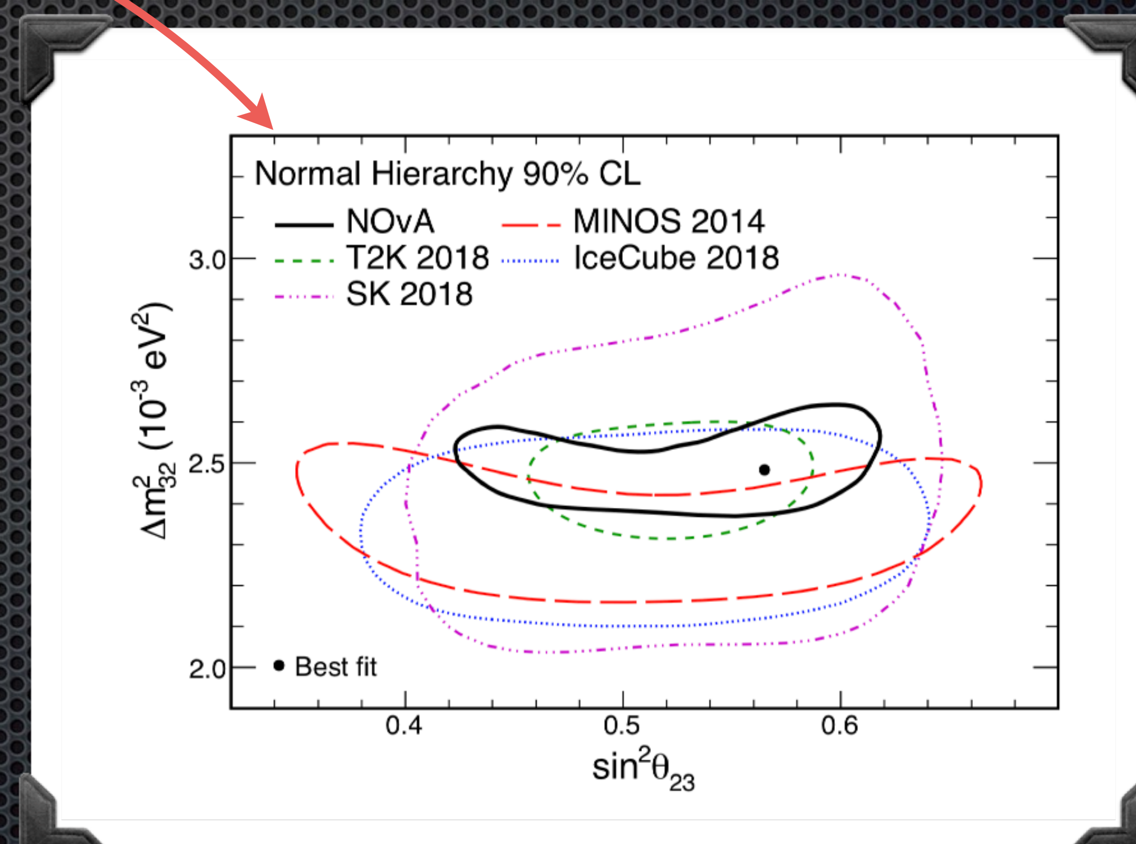


Figure from NOvA, arXiv:1906.04907

NOvA 2019

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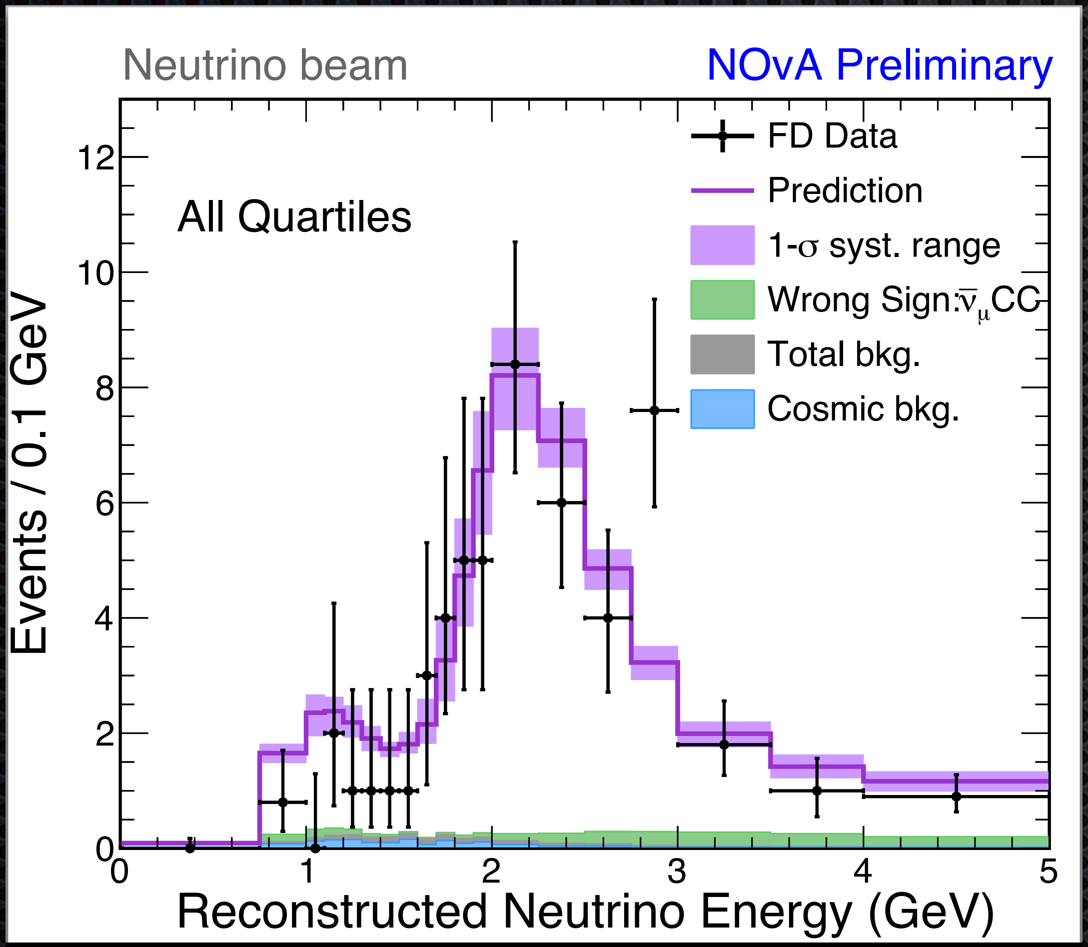
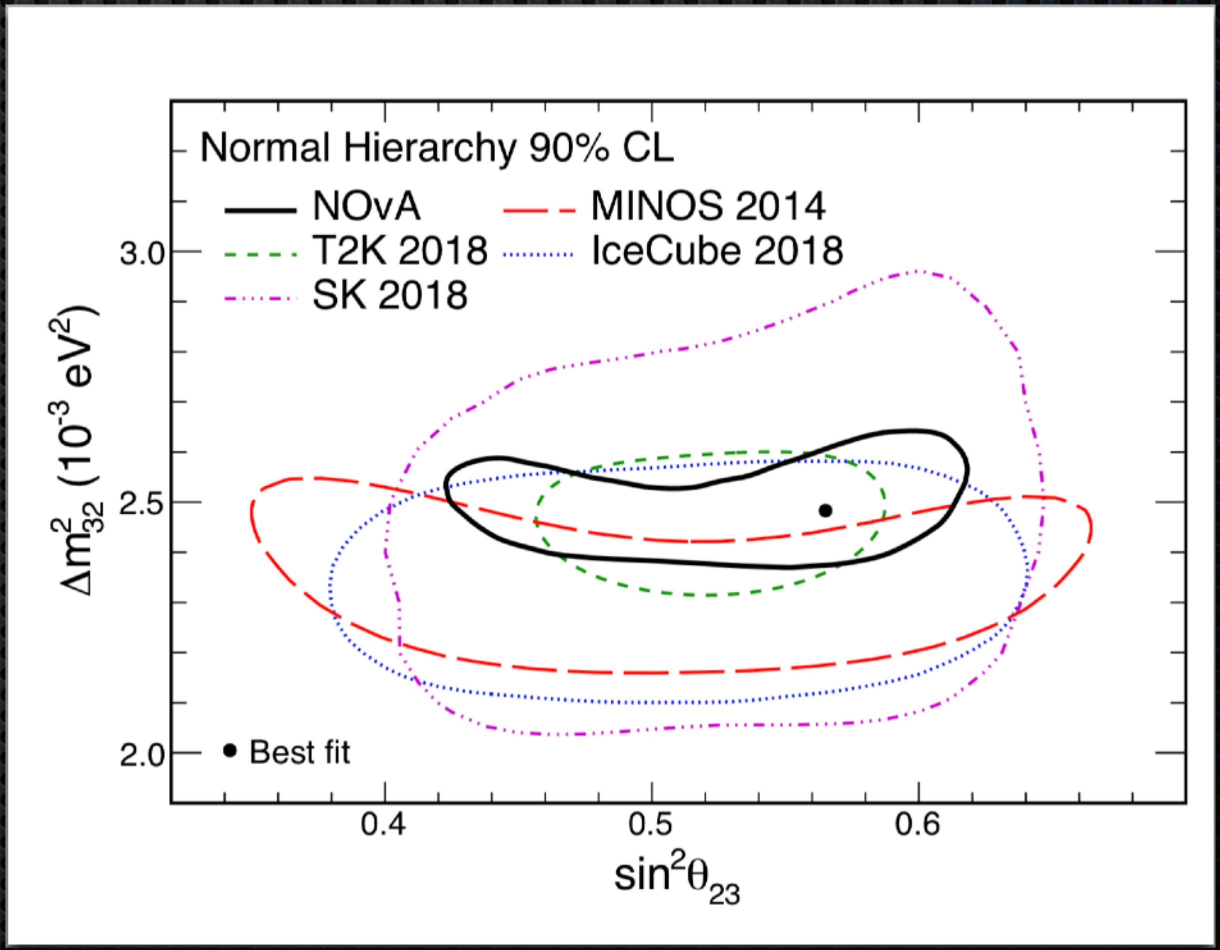
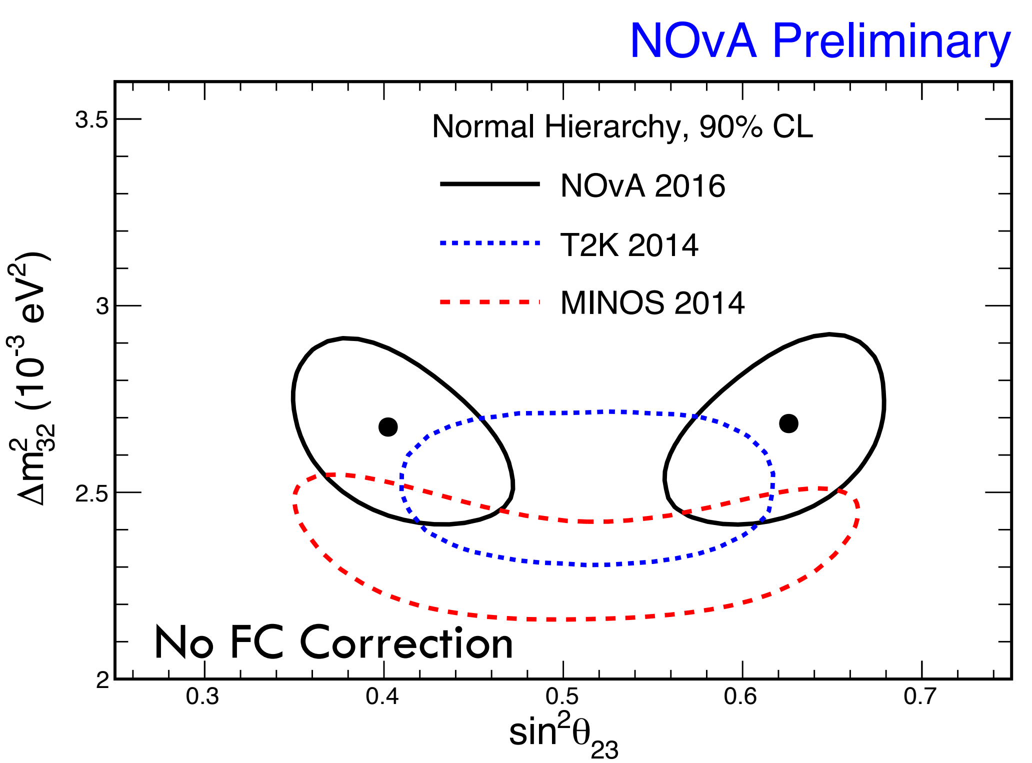


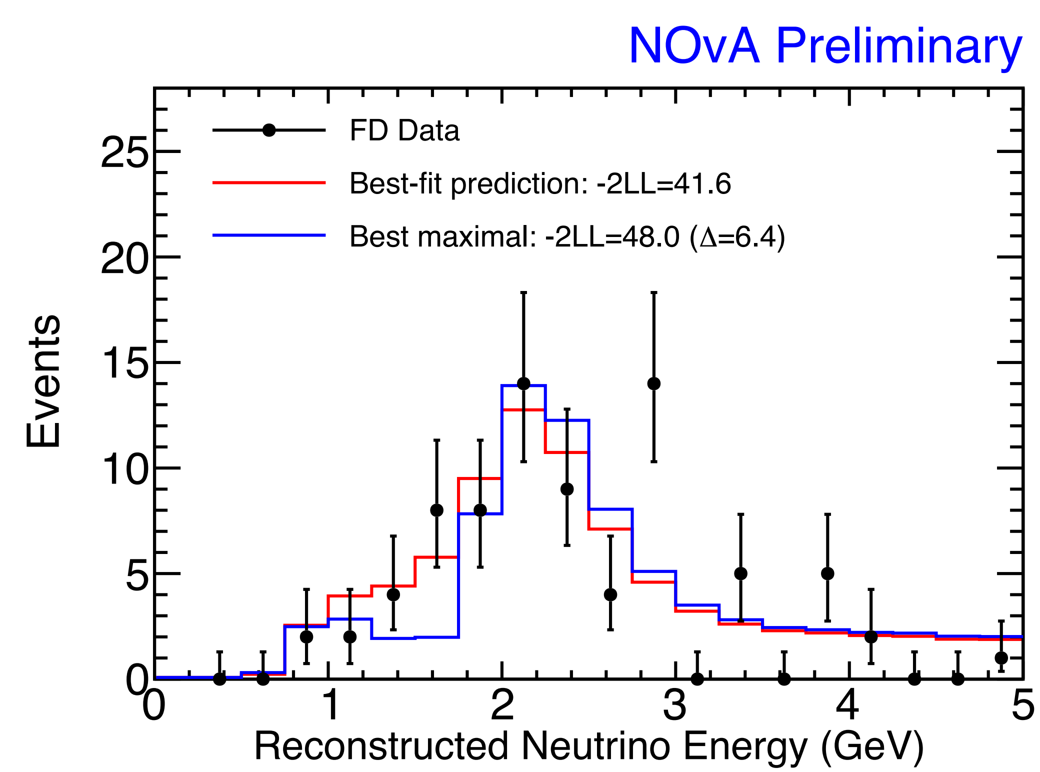


- $\theta_{23} = \pi/4$ implies a steeply rising spectrum

cf. NOVA 2016

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





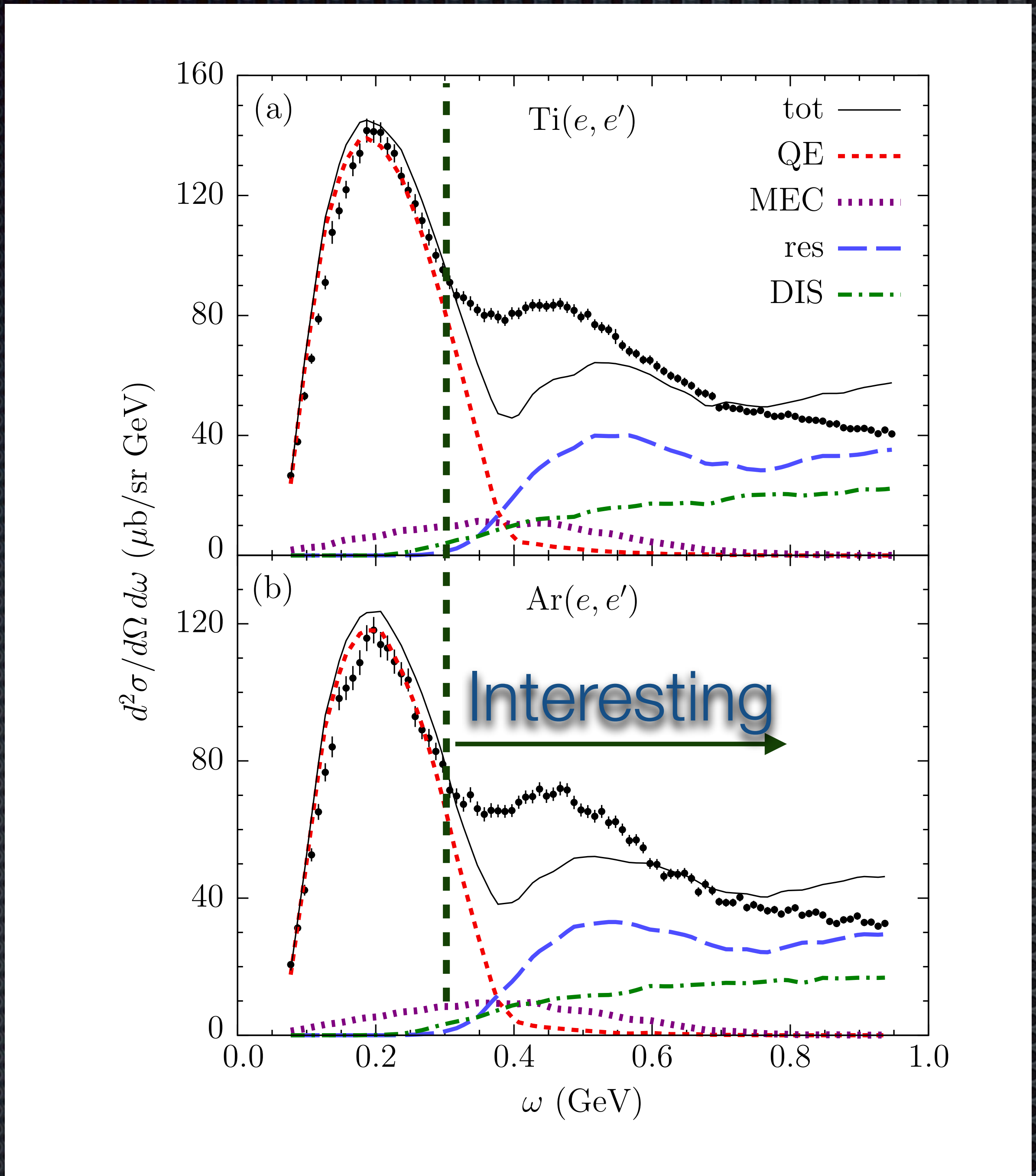
Best Fit (in NH):

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

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

Maximal mixing excluded at 2.5σ

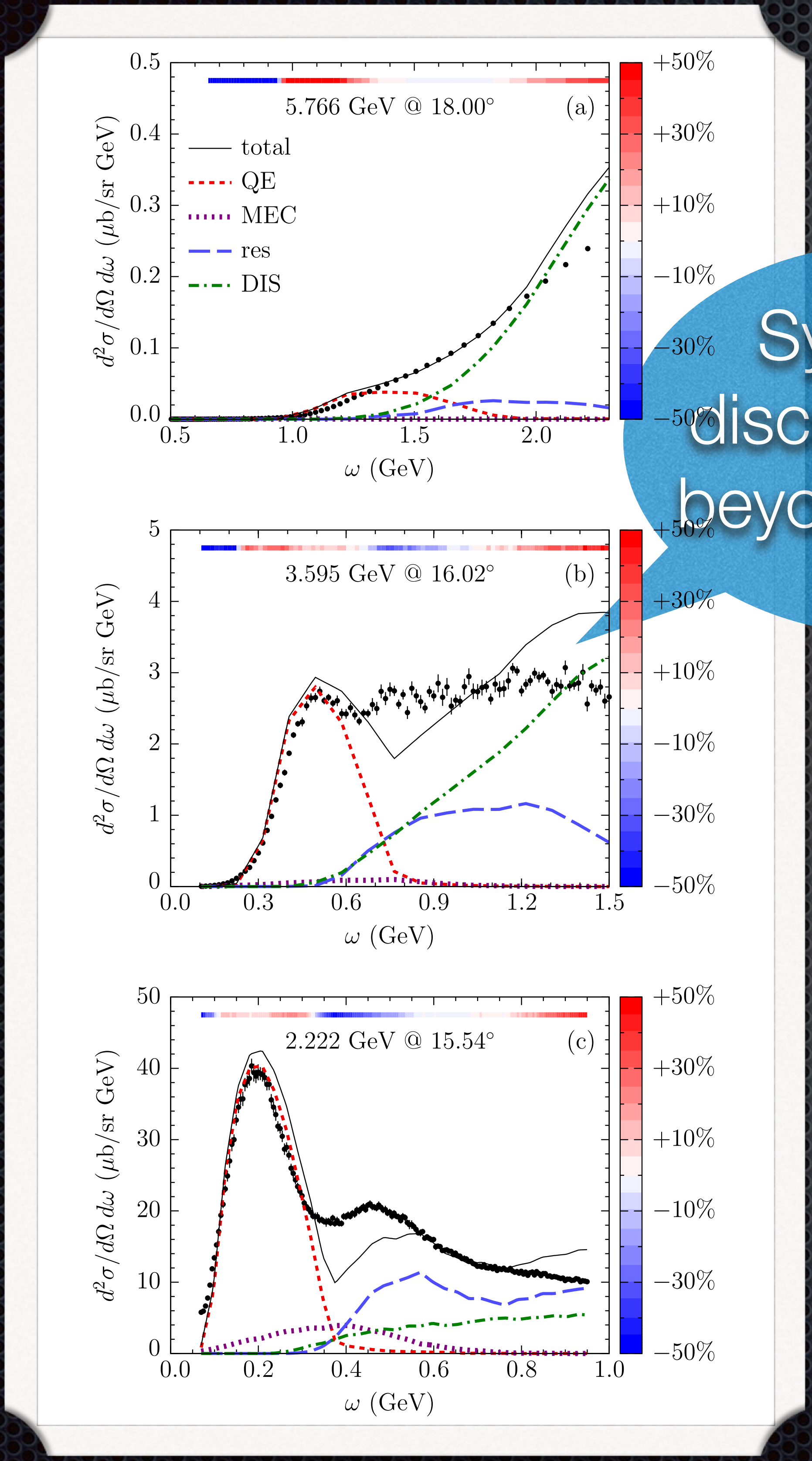
Invitation



2.2 GeV electron beam
JLAB

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

Different kinematic regimes



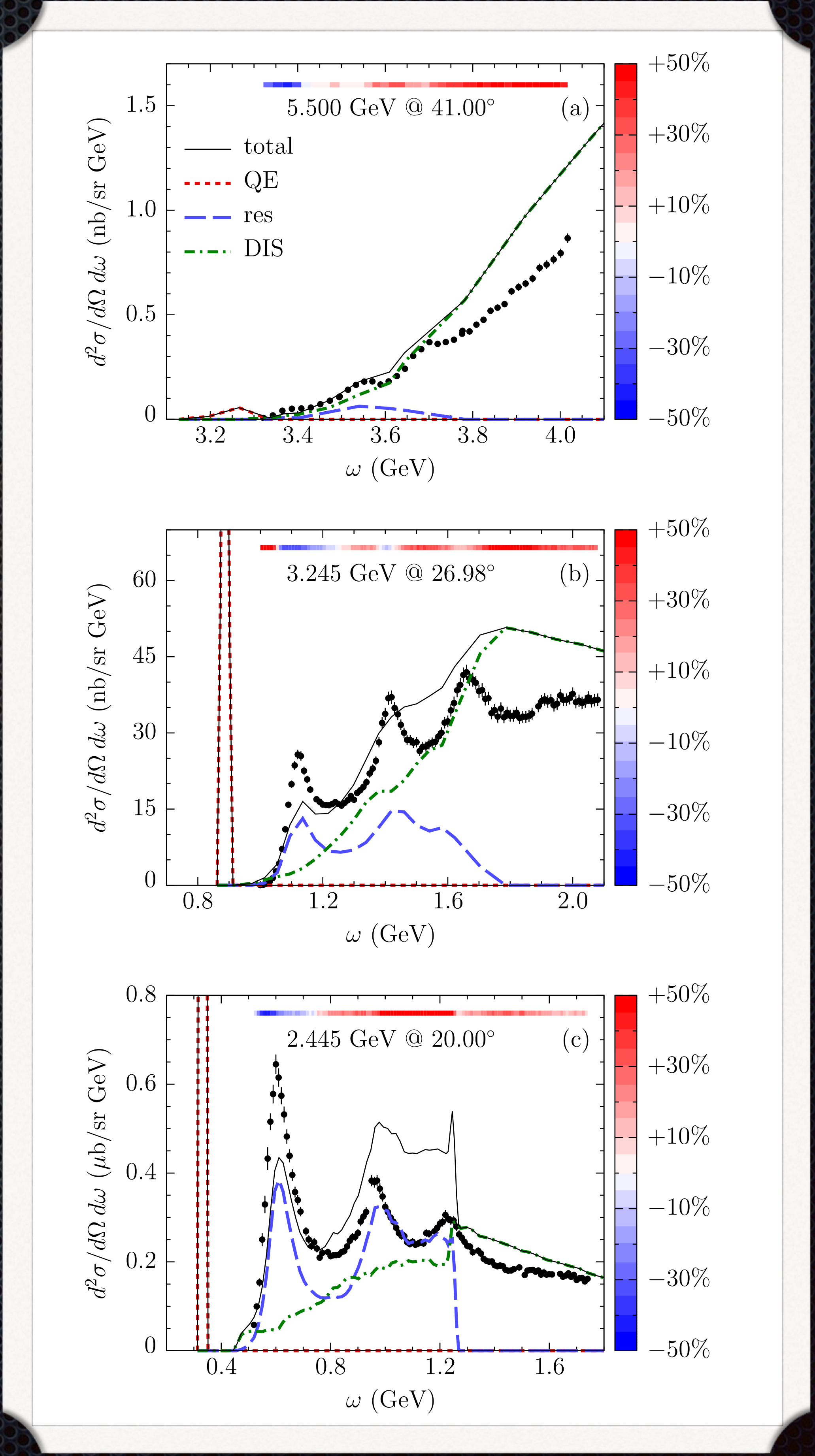
Systemic discrepancies beyond CCQE

- Problems with many other datasets
- Can be systematically studied using carbon

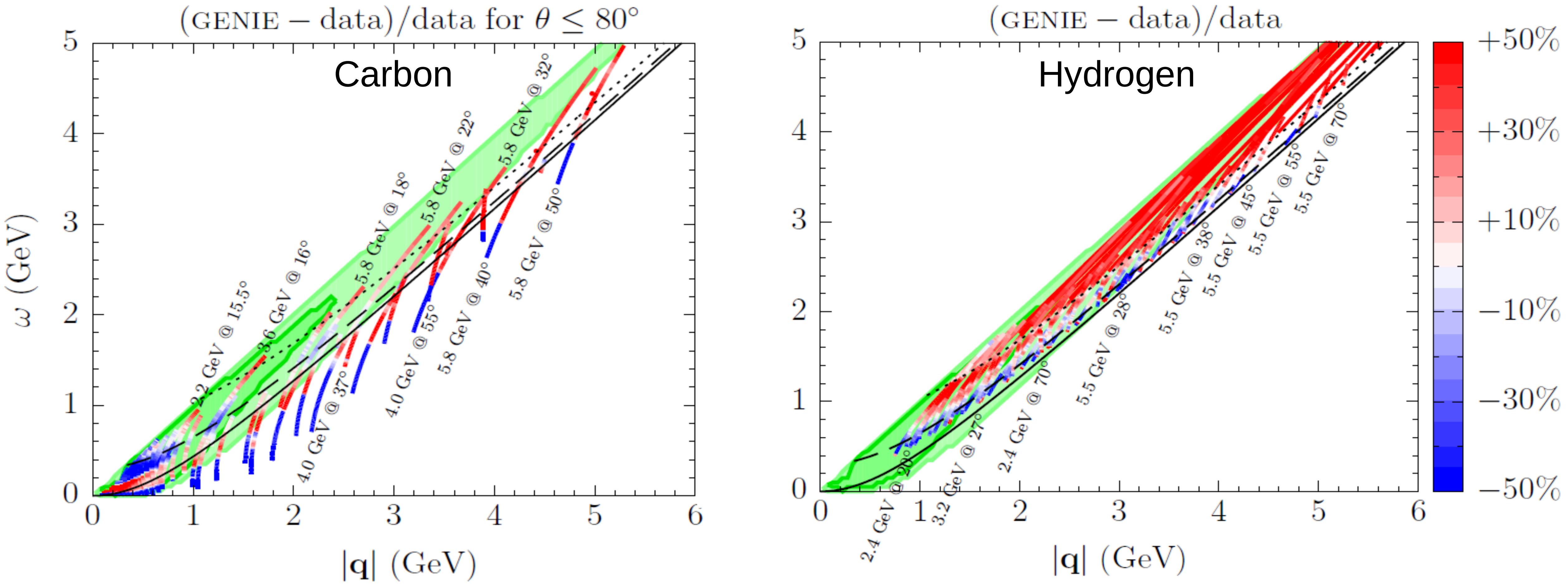
Decisive test: comparison to hydrogen and deuterium

- Large discrepancies originate in (mis)modeling of hadronic processes
  - Notable double counting in the RES->DIS region

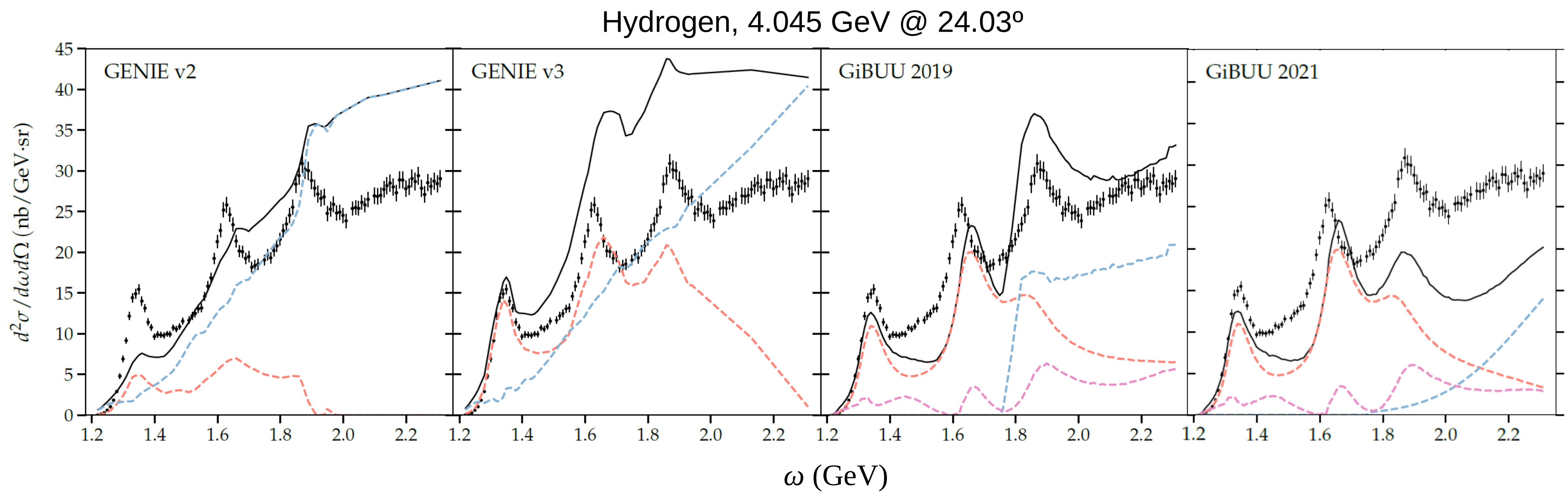
For details, see e-Print: 2006.11944
DOI: 10.1103/PhysRevD.102.053001



Mapping out the pattern of discrepancies



Large discrepancies persist for other generators

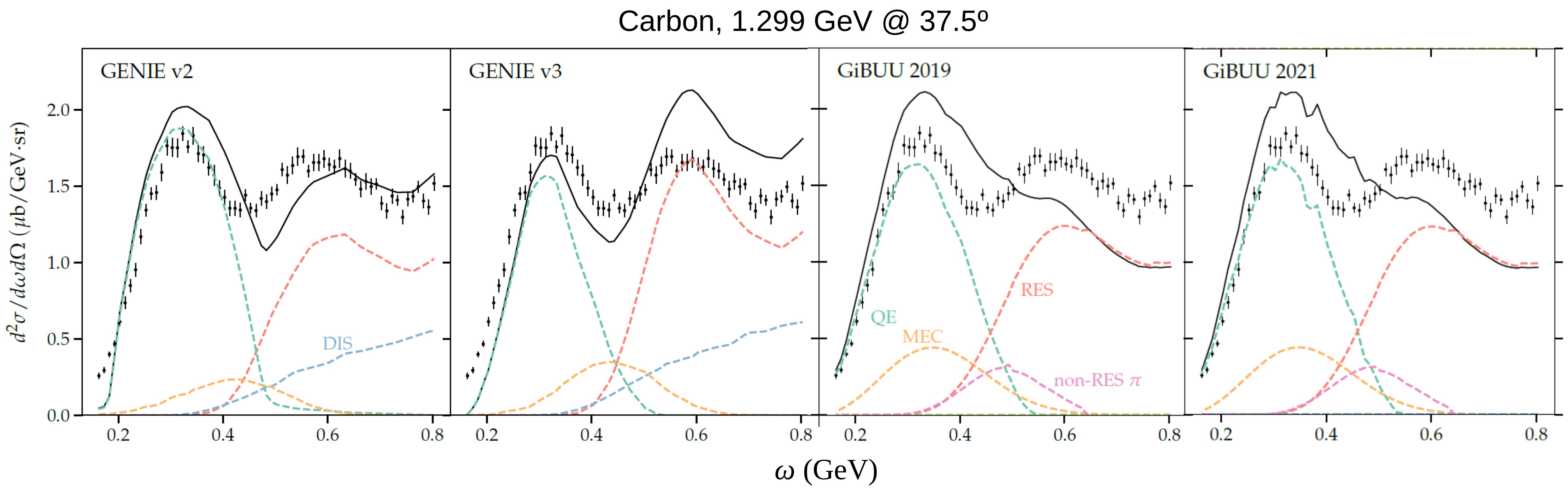


data:
Niculescu *et al.*, PRL 85, 1186 (2000)

A.M.A., A. Friedland & S.W. Li, in preparation

At high energies, the SIS region is especially challenging

Large discrepancies persist for other generators

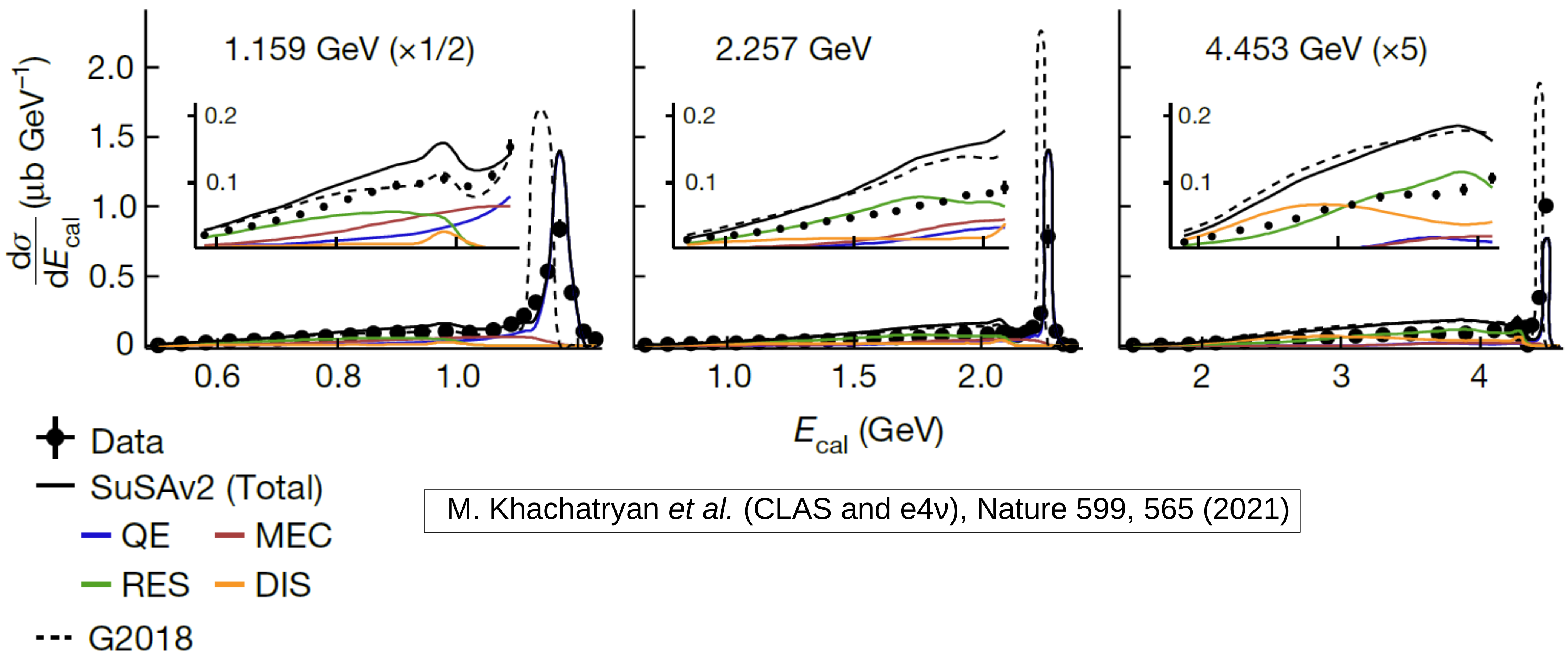


data:
Barreau *et al.*, NPA 402, 515 (1983)

A.M.A., A. Friedland & S.W. Li, in preparation

Generally, overlaps between different mechanisms present a lot of conceptual challenge

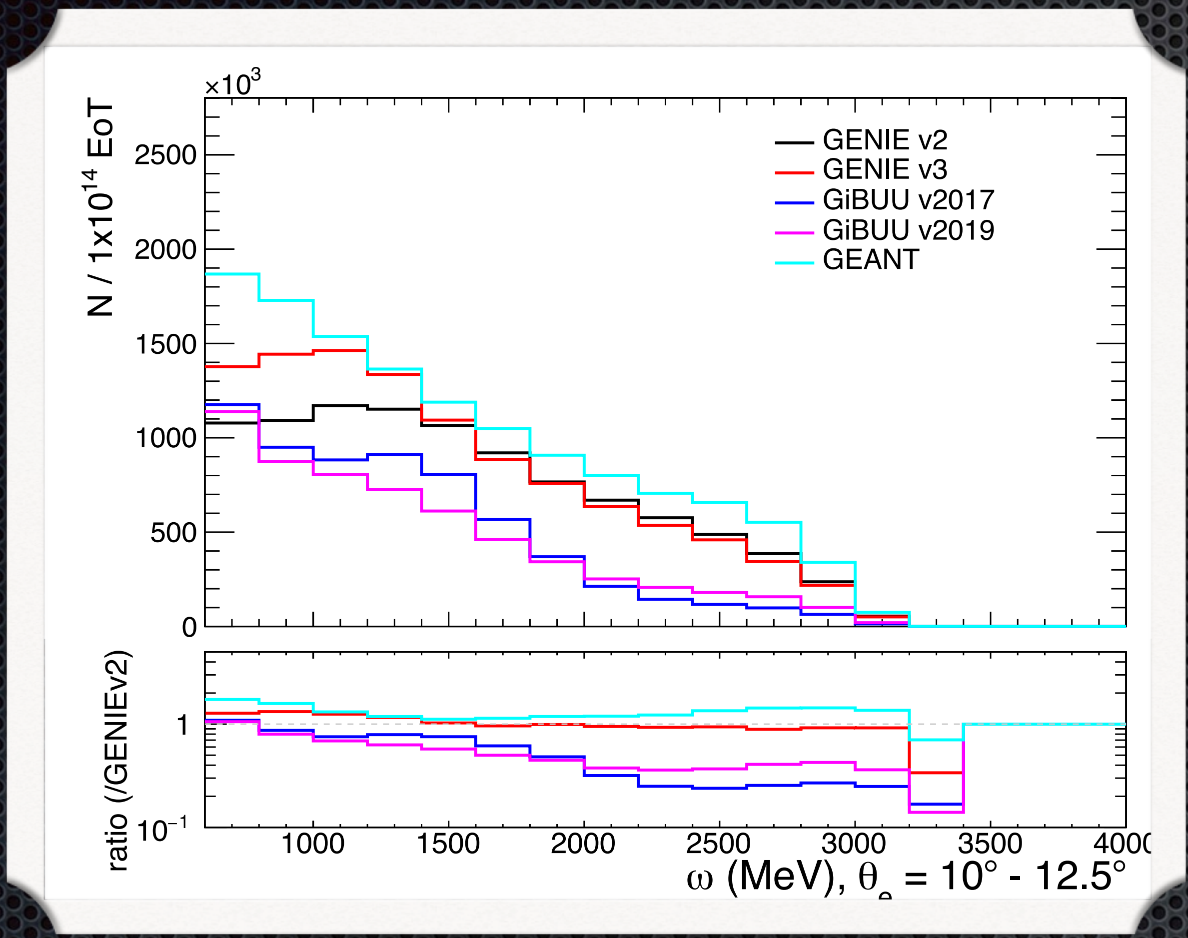
Instructive: comparison with e4nu data

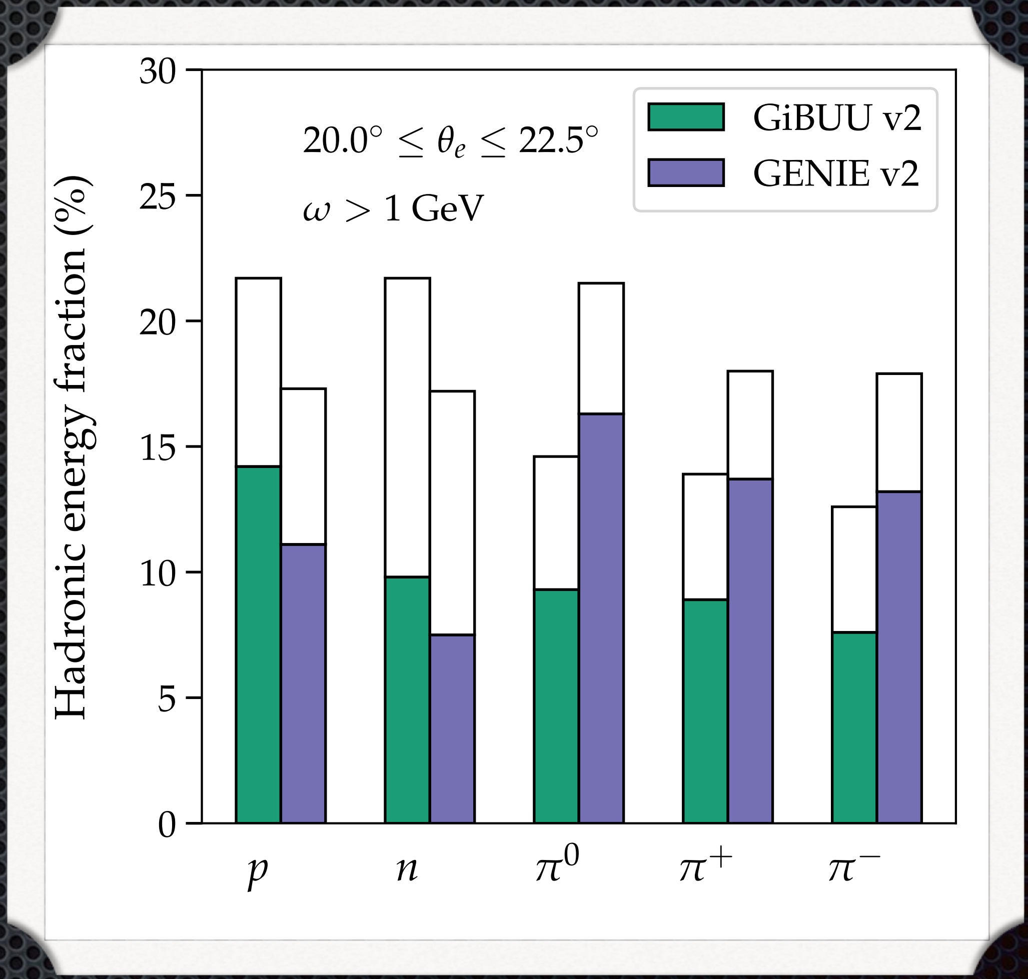


M. Khachatryan *et al.* (CLAS and e4ν), Nature 599, 565 (2021)

The same double-counting is manifested at high E

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

Conclusions I

- 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 -> not trivial

Conclusions II

- To make progress on the foundational challenges, we need new, high-quality 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
  - Ideally, would prefer CLAS (e4nu) + LDMX data