ELECTRONS FOR NEUTRINOS

Adi Ashkenazi
adishka@mit.edu

Snowmass21 NF06 Electron Scattering Workshop
12/14/2020

Objectives

Leverage wide phase space exclusive electron scattering data for the benefit of neutrino experiments

- Benchmark neutrino event generators
- Constrain modelling systematic uncertainties
- By analysing as many channel as possible
- Testing incoming energy and A dependencies

Working Groups

Modelling development

Data Analysis

Implications on neutrino studies

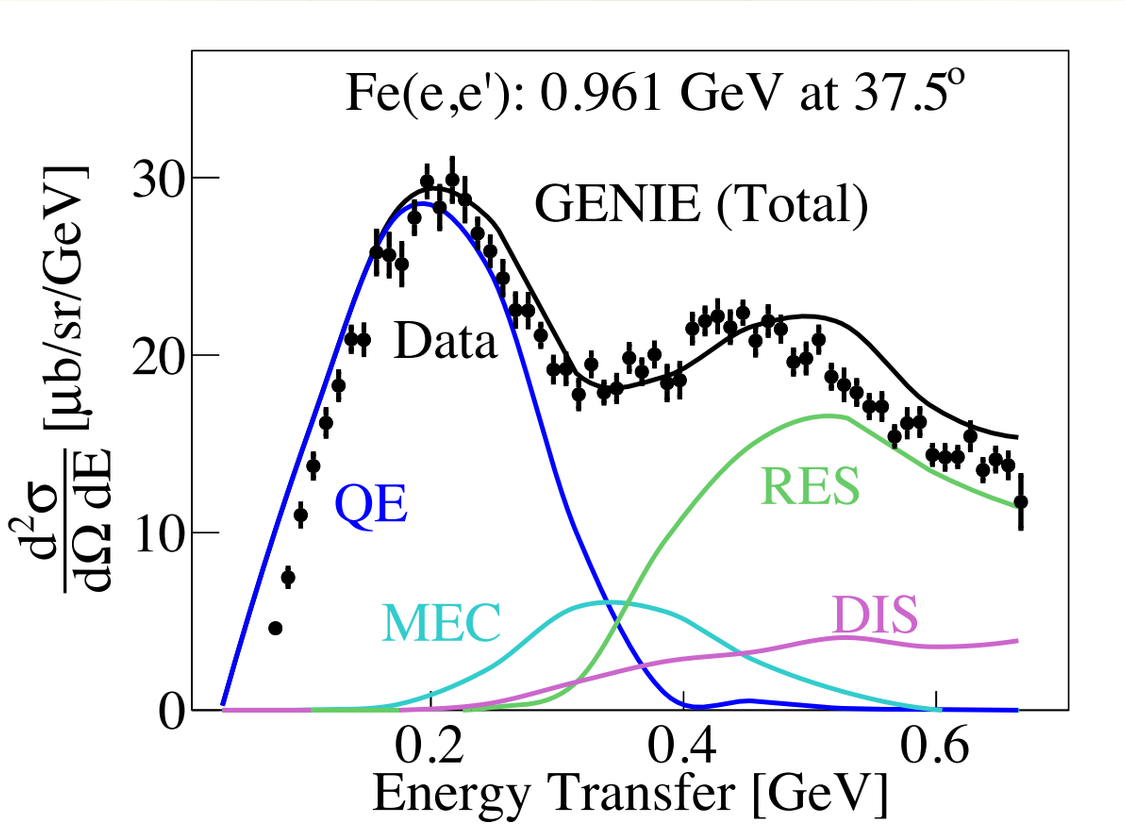
Tuning

Modelling development

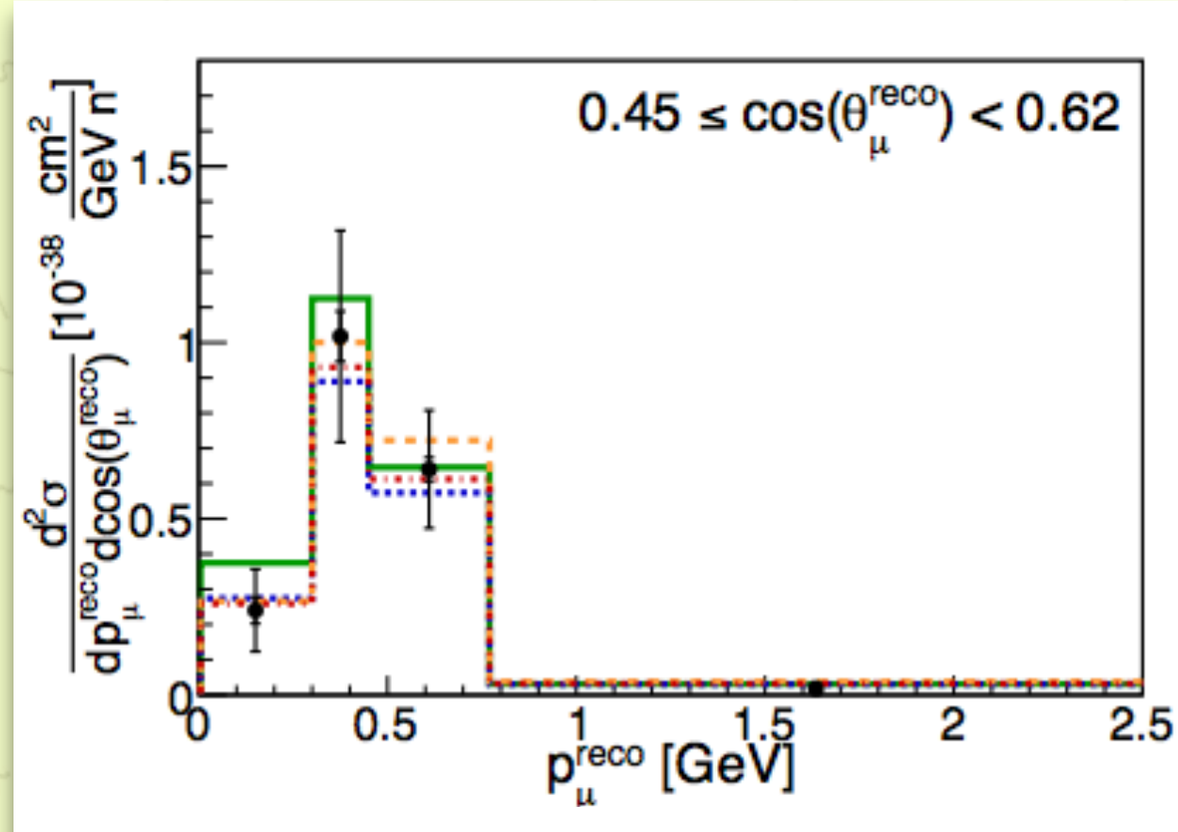
Our efforts are concentrated on *Genie*

Latest version v3.0.6 tune G18_10a_02_11a

Nicely reproducing inclusive results



arXiv:2009.07228 [nucl-th]

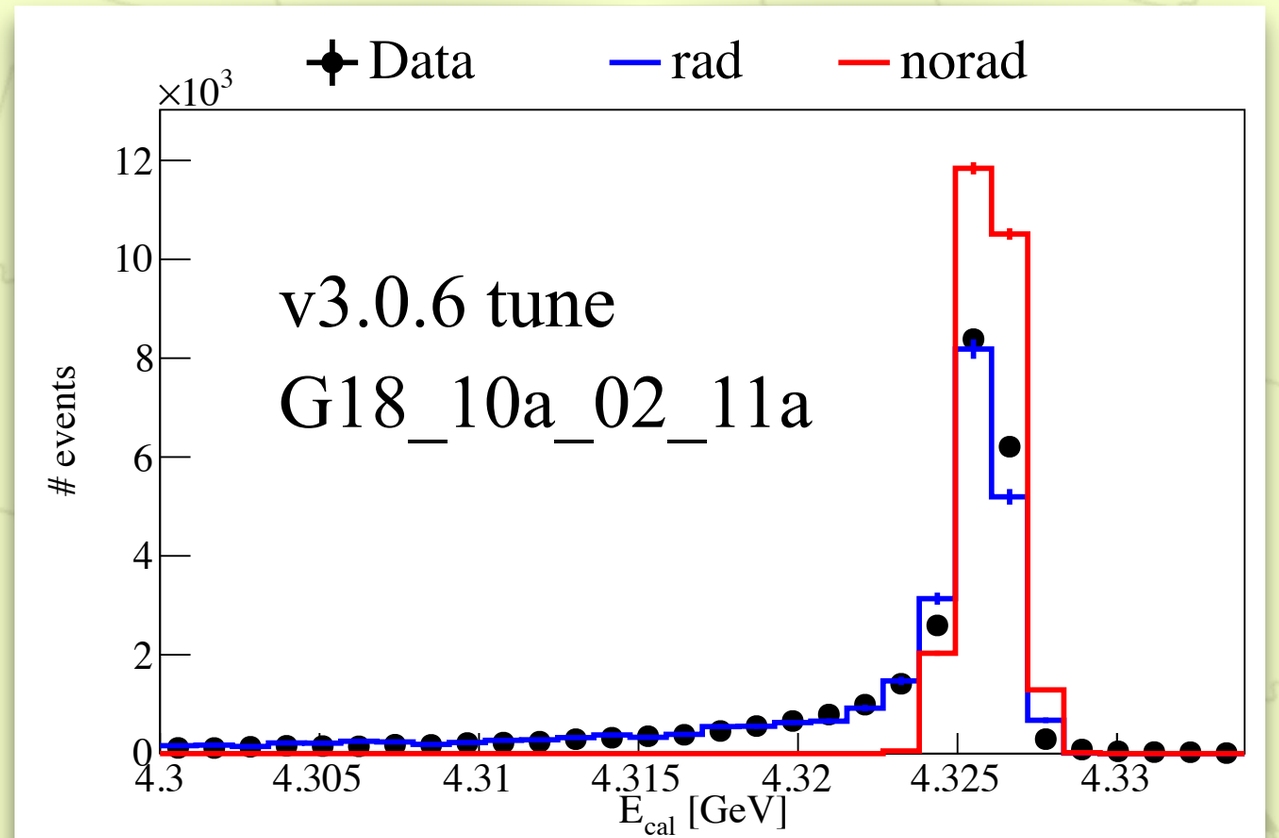


Phys. Rev. Lett. 123, 131801 (2019)

Modelling development - ongoing efforts

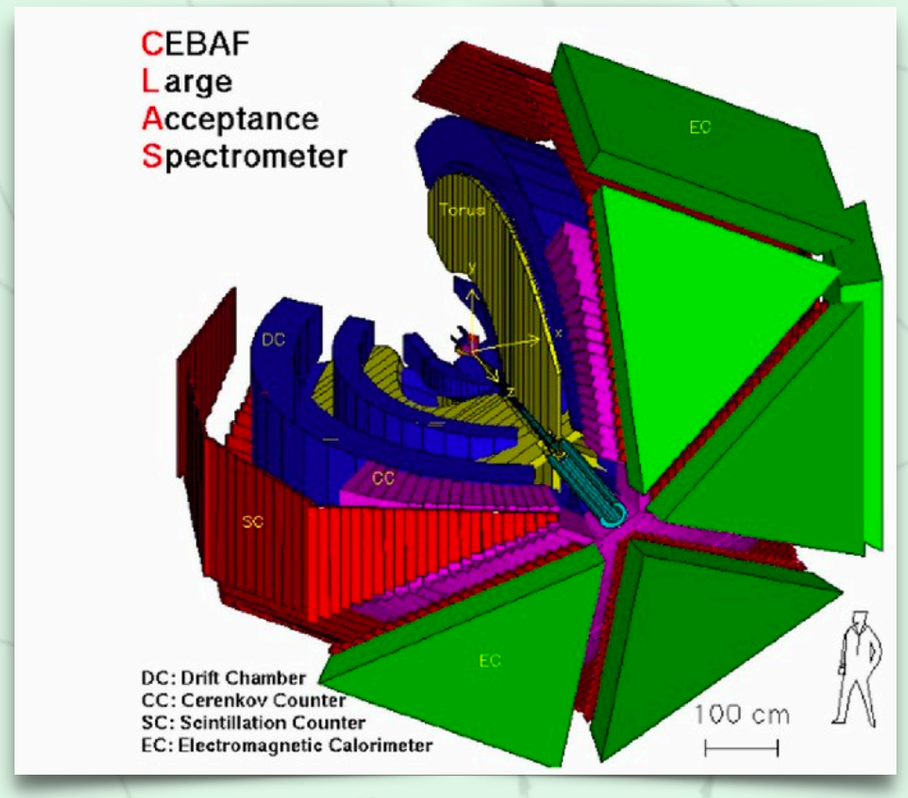
- **SuSAv2:** Steven Gardiner
- **Radiative corrections**: working with Wackeroth group from (University at Buffalo)
- **Nieves for electrons**
- **Coulomb corrections**
- and more

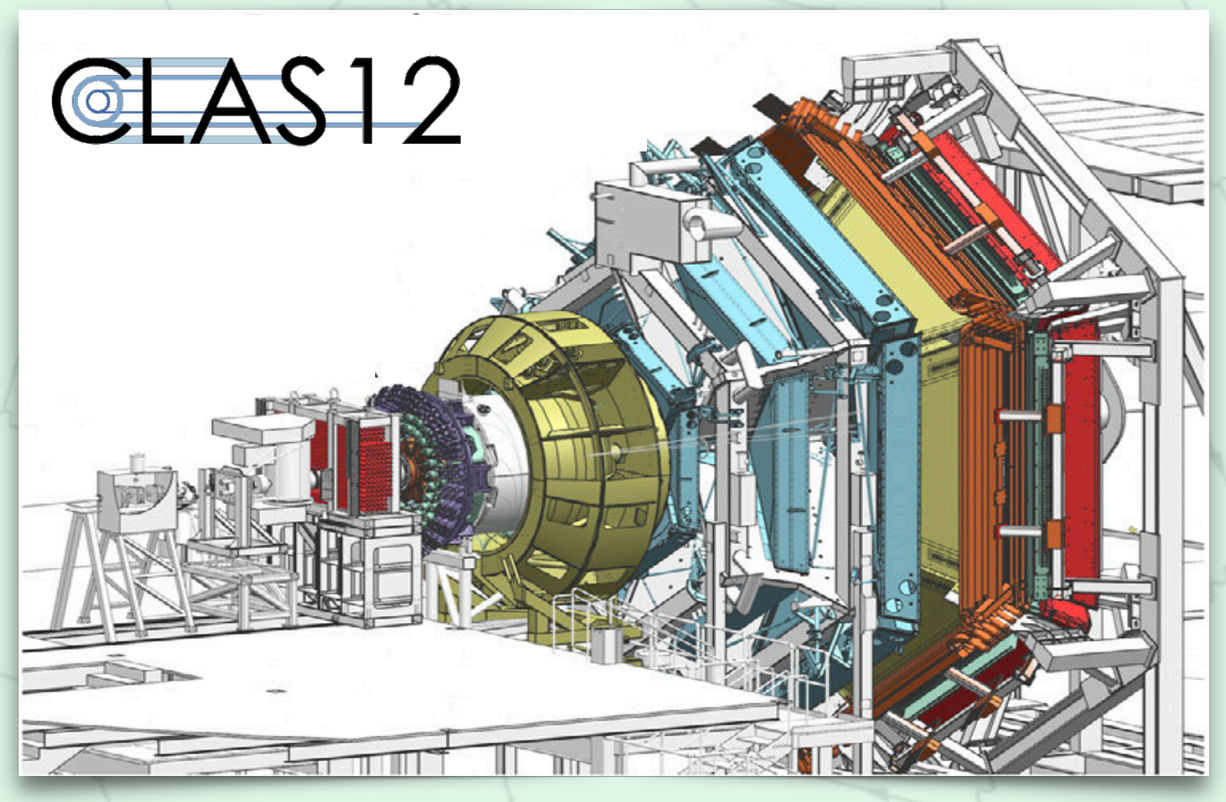
We would be happy to expand to other generators



First version based on Mo and Tsai

Data Analysis - Opportunities





Data mining - available now!

^{4}He, ^{12}C, ^{56}Fe

1, 2, 4 GeV

Low detection threshold

$\theta_e > 15^o$

Data taking - summer 2021

^{12}C, **^{40}Ar** at 2, 4 GeV

^{2}D,^{4}He,^{12}C, **^{40}Ar**,^{40}Ca, ^{48}Ca,^{120}Sn at 6 GeV

Low detection threshold

$\theta_e > 5^o$ x10 luminosity [10^{35} $cm^{-2}s^{-1}$]

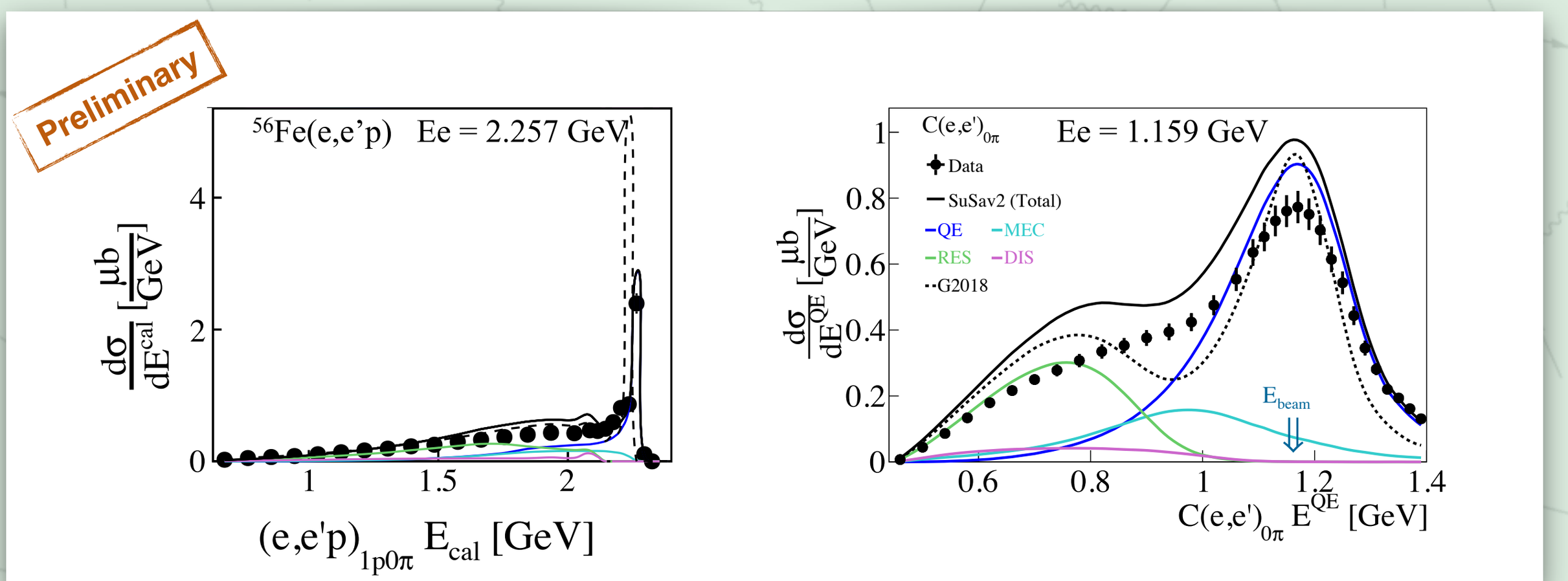
First Analysis recently submitted for publication

Analyse electron data from CLAS as neutrino data

- Select lepton + proton final state (1p0π)
- Scale by $\sigma_{\nu N}/\sigma_{eN} \propto 1/Q^4$ to probe relevant phase space
- Reconstruct incoming lepton energy
- Compare to event generators

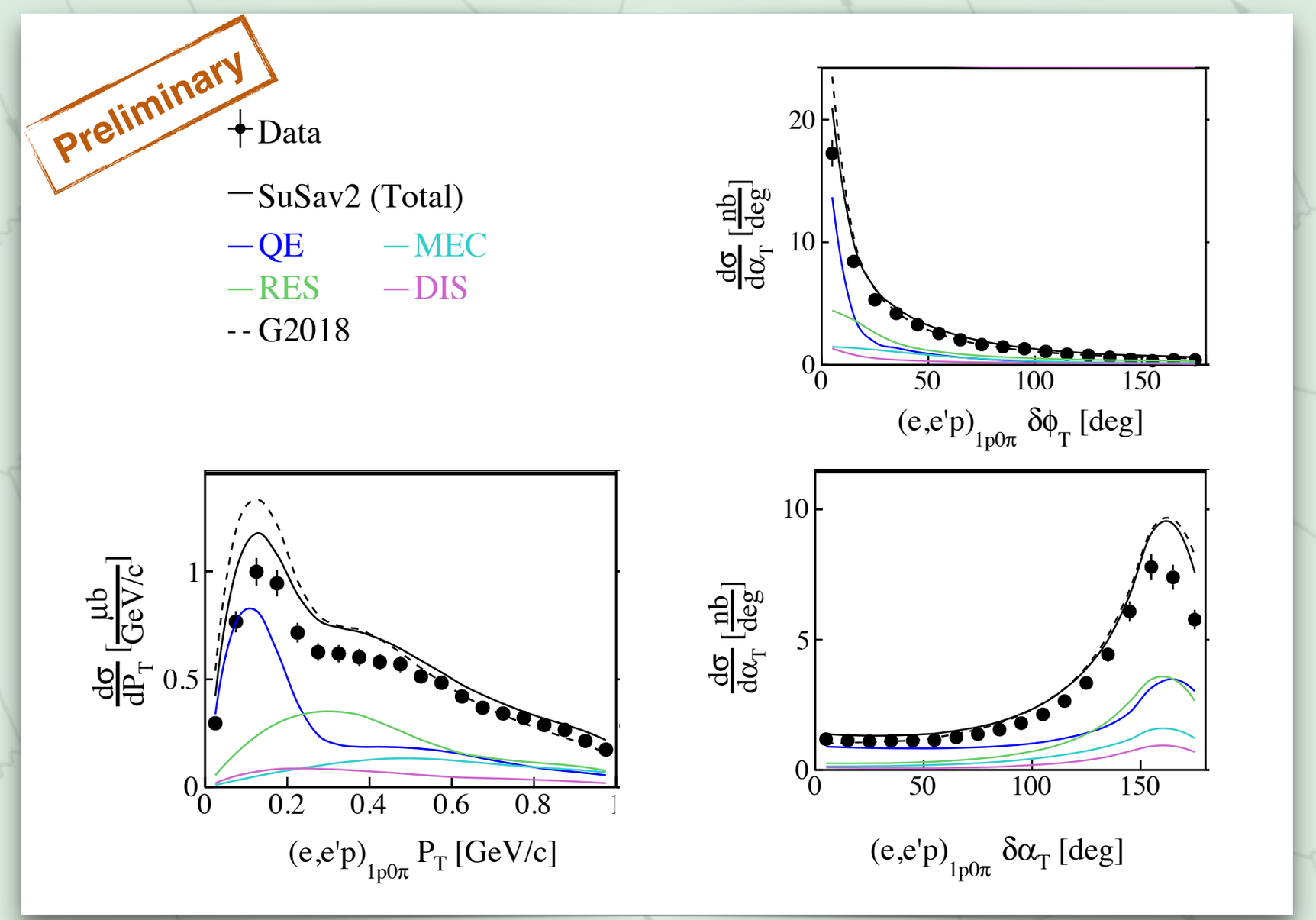
First Analysis recently submitted for publication

A 1e1p0π analysis, focusing on QE-like events



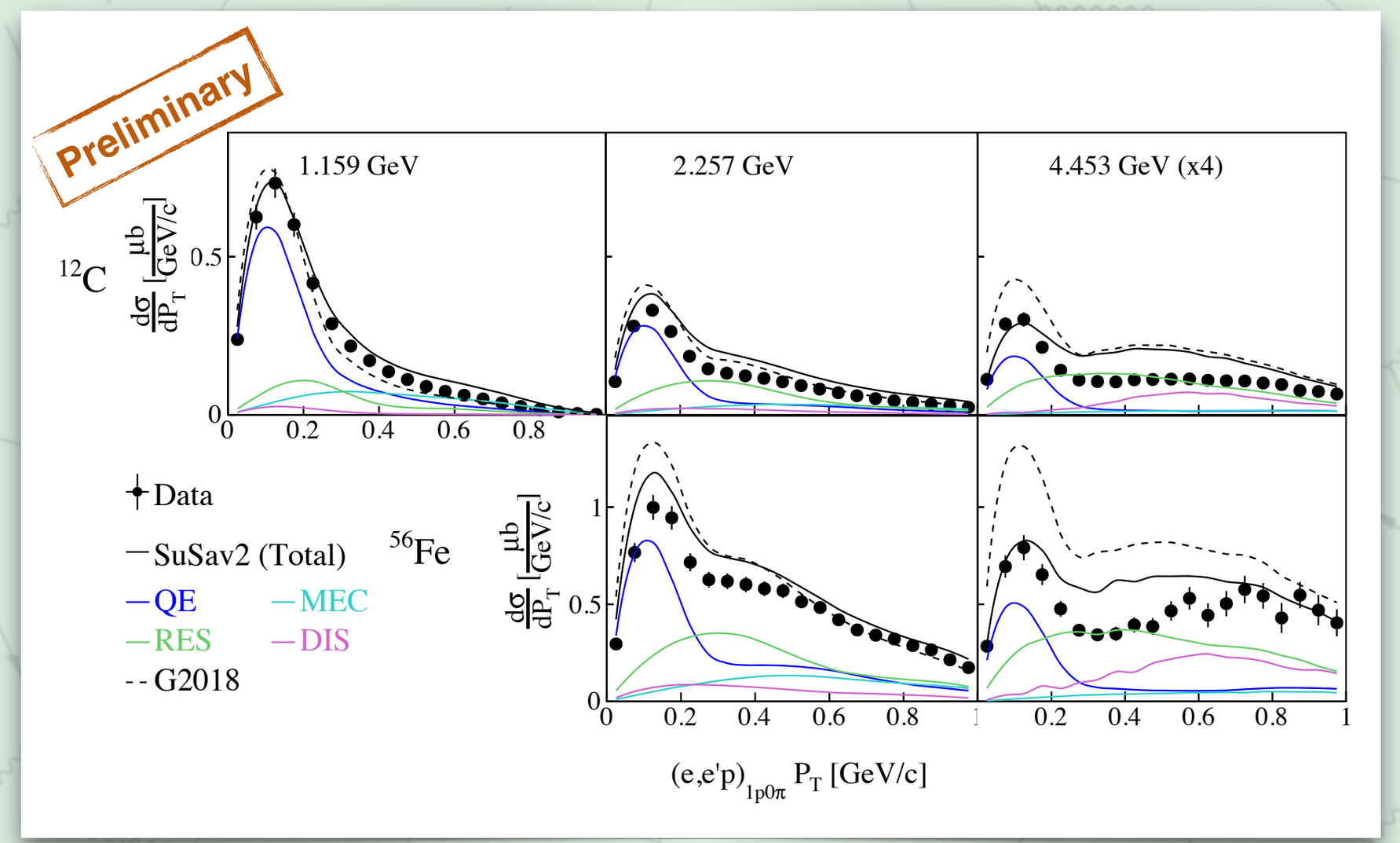
First Analysis recently submitted for publication

A 1e1p0π analysis, focusing on QE-like events



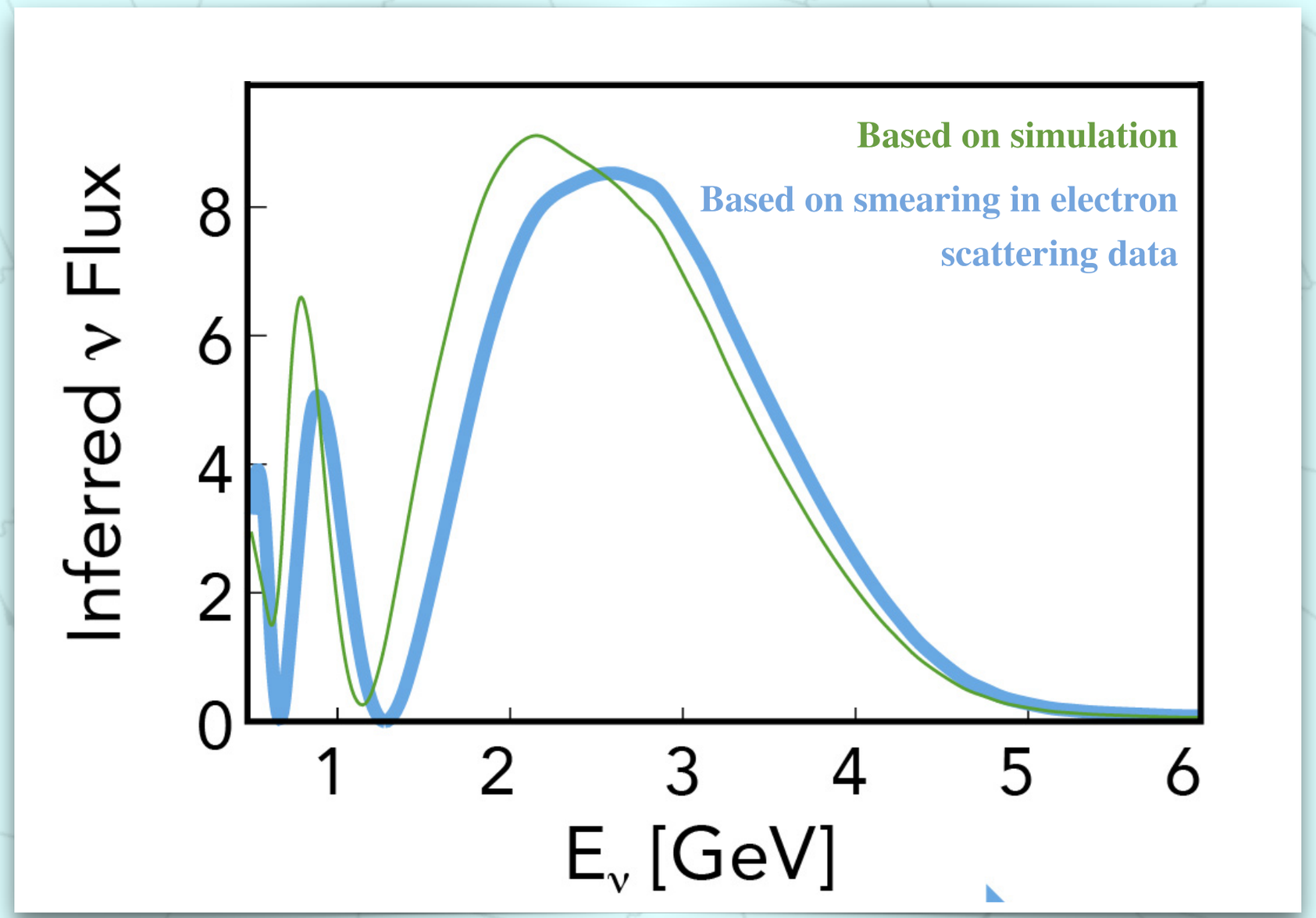
First Analysis recently submitted for publication

A 1e1p0π analysis, focusing on QE-like events



Implication on Neutrinos Working Group

Goal: Demonstrate the importance of our work to the neutrino community



e4v The team - Join us!

Summary

- Testing νA Models using wide phase-space eA data.
- So far with CALS Data showing
  - Data - MC disagreements for QE-like lepton+proton events
    - Especially for high transverse momentum.
  - Large potential impact on DUNE
- Aiming to show impact on neutrino community, improve models, offer dedicated tunes.
- More data coming very soon

Thank you for your attention

Future Plans -Approved run for CLAS12

Acceptance down to 5^{o} $Q^2 > 0.04$ GeV^2

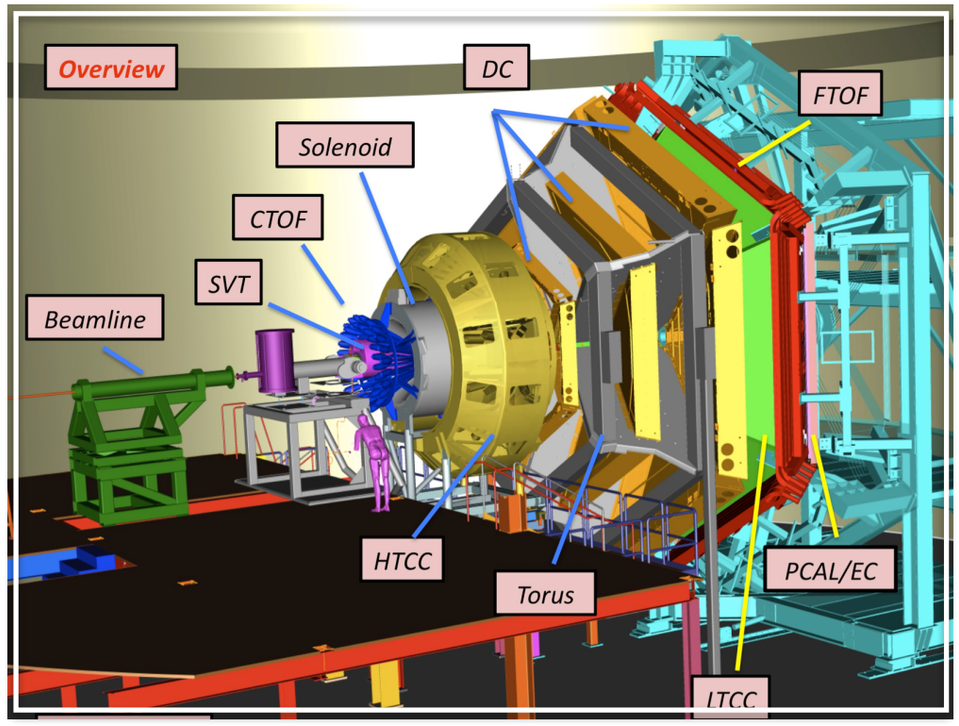
x10 luminosity [10^{35} cm^{-2}s^{-1}]

Keep low thresholds

Targets: ^{2}D, ^{4}He, ^{12}C, ^{16}O, **^{40}Ar**, ^{120}Sn

1 - 7 GeV (relevant for DUNE)

Running planned for 2021



Overwhelming support from:

e4ν Collaboration

- Old Dominion University
- MI
- Jefferson Lab
- Tel Aviv University
- Michigan State
- Fermilab
- U Pittsburgh
- York University, UK
- UCL,
- College of William & Mary,
- U of Texas,
- Arlington,
- Rutgers U,
- U of Maine
- LBL

CLAS Detector

Large acceptance, Open Trigger

Charged particle detection thresholds:

$\theta_e > 15^o$

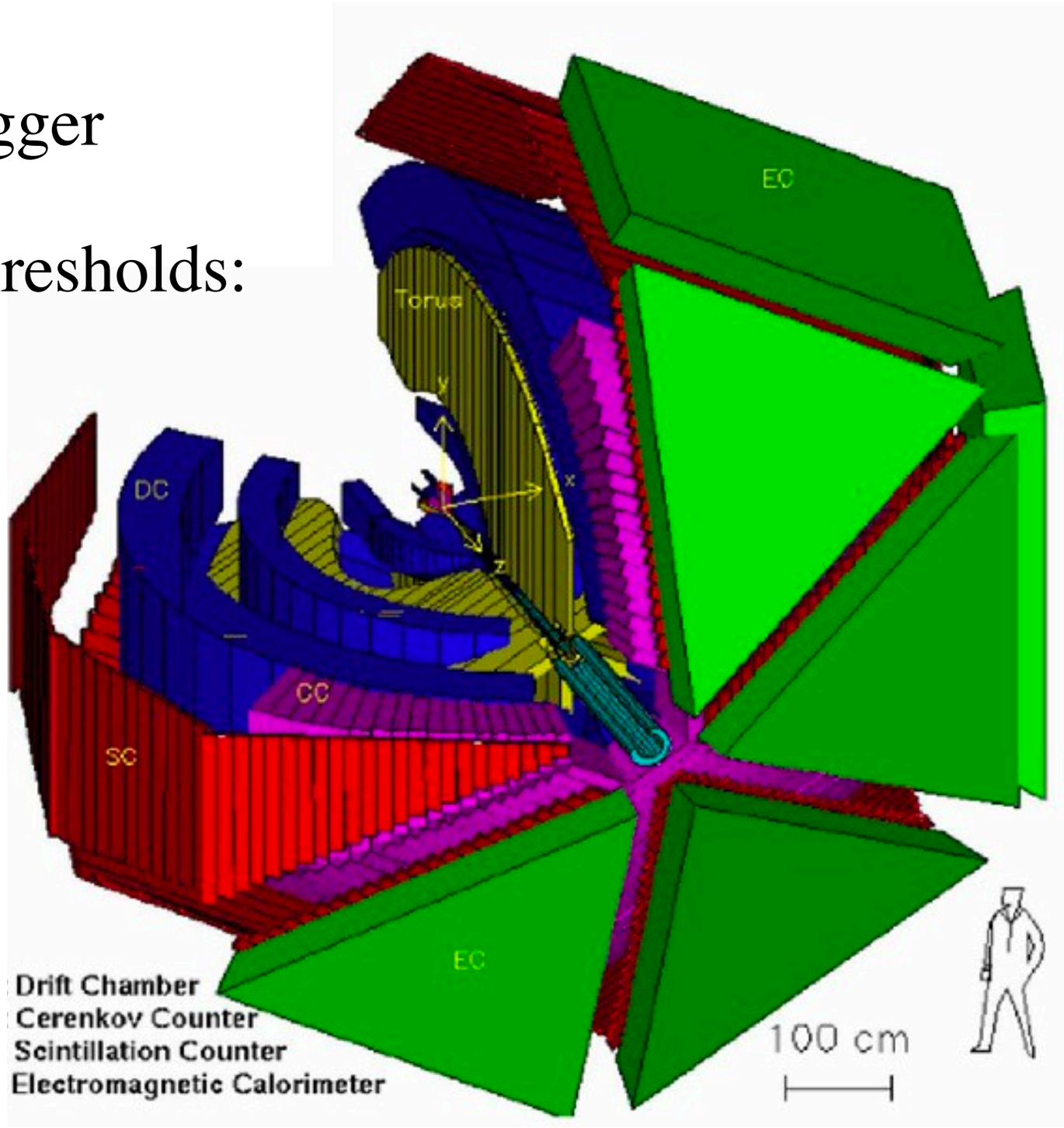
$P_p > 300$ MeV/c

$P_{\pi+/-} > 150$ MeV/c

$P_{\pi 0} > 500$ MeV/c

Targets: ^{4}He, ^{12}C, ^{56}Fe

Energies: 1.1 , 2.2, 4.4 GeV



e4ν 1p0π Event Selection

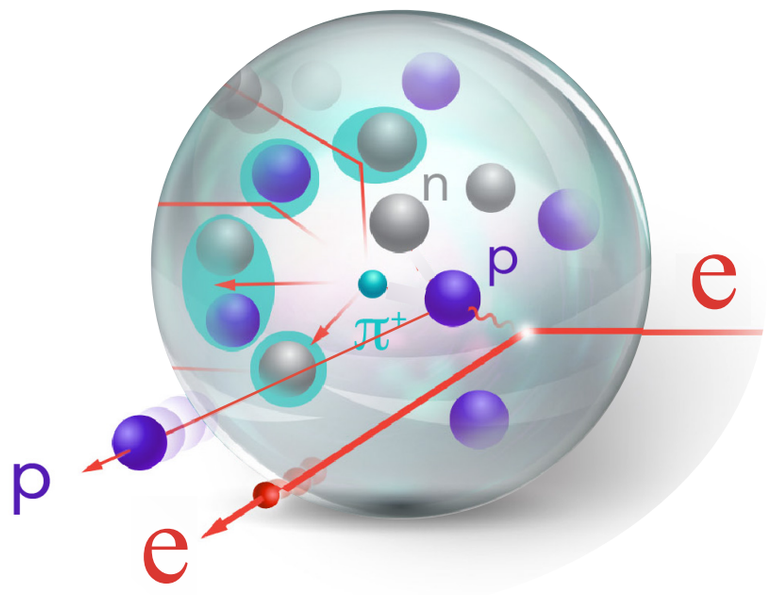
Focus on Quasi Elastic events:

1 proton above 300 MeV/c

no additional hadrons above threshold:

$P_{\pi^{+/-}} > 150$ MeV/c

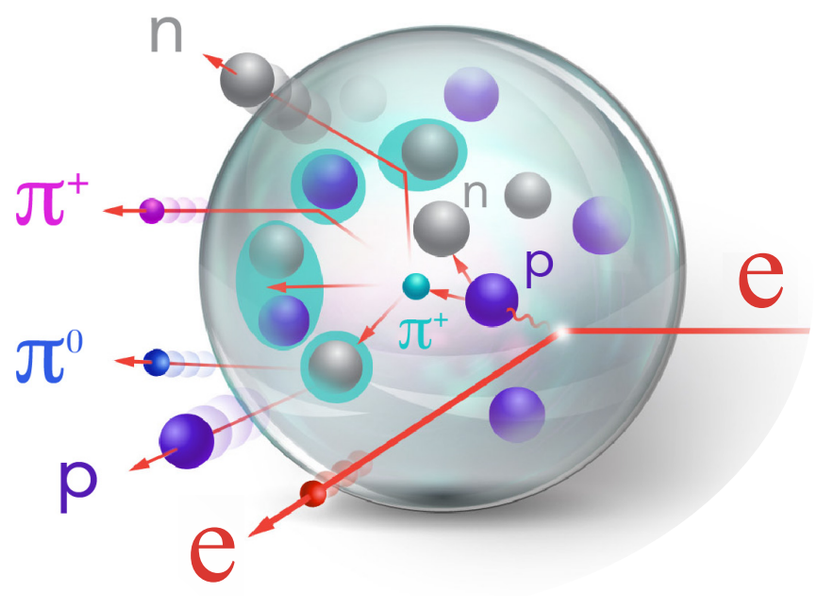
$P_{\pi^0} > 500$ MeV/c



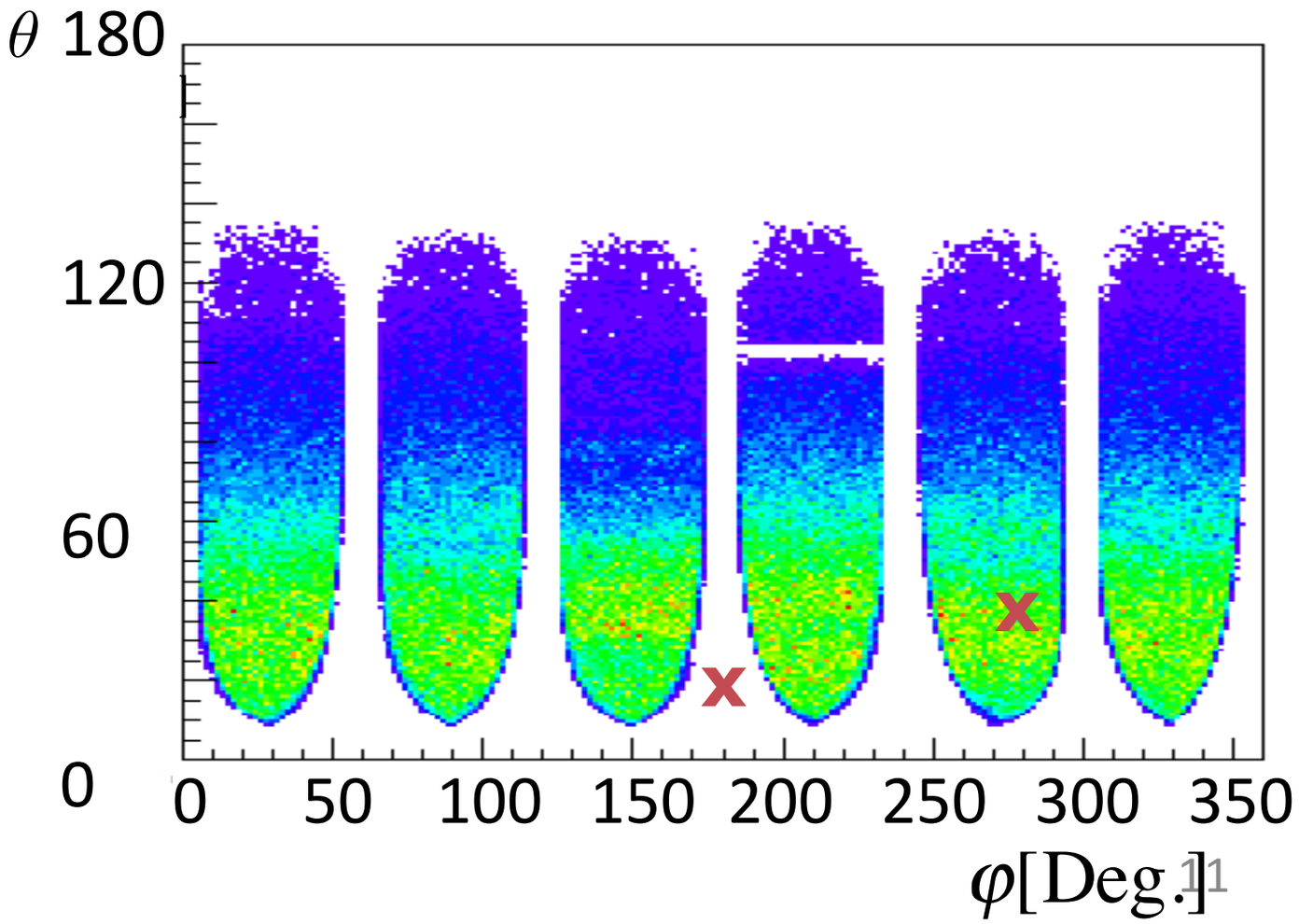
e4ν: Playing the Neutrino game

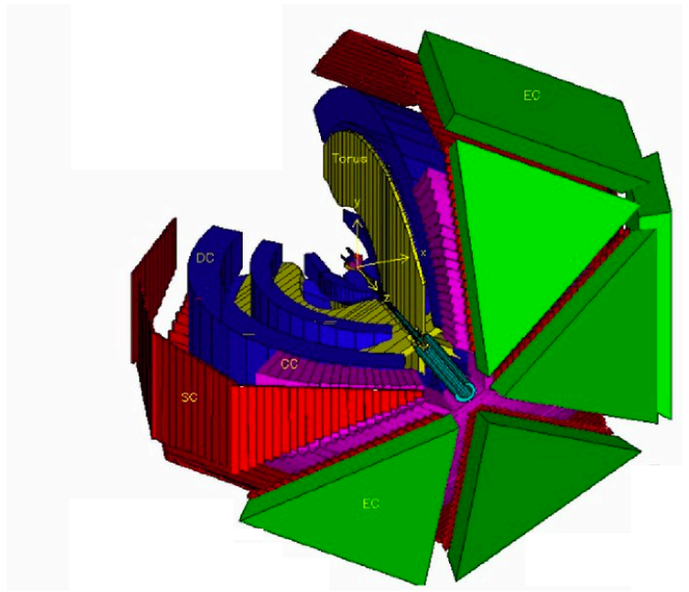
Analyse electron data as neutrino data

- Select lepton + proton final state (1p0π)
- Scale by $\sigma_{\nu N}/\sigma_{eN} \propto 1/Q^4$
- Reconstruct incoming lepton energy
- Benchmark neutrino event generators

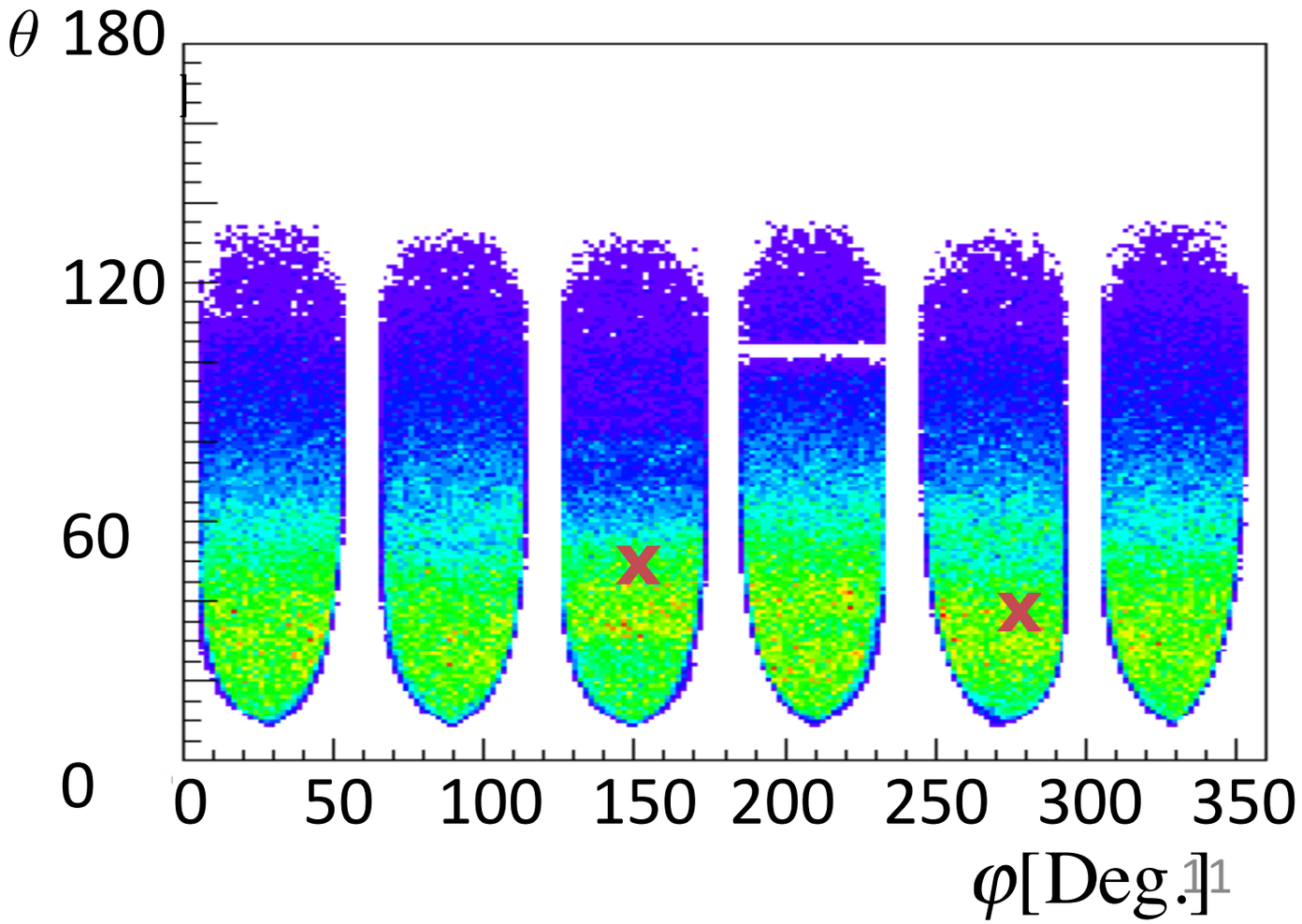


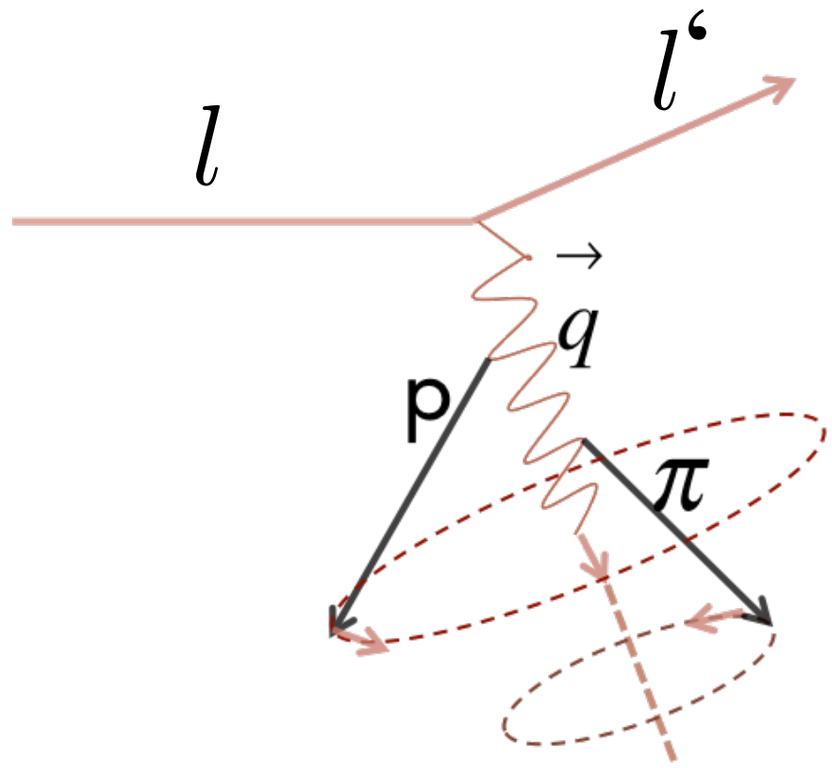
Subtract for events w/ undetected hadrons





Subtract for events w/ undetected hadrons





Using two hadron events:

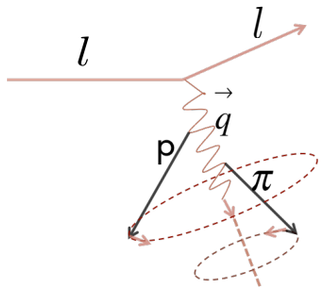
Rotating the two hadrons around q, to determine detection efficiency

Same for final states with more than 2 hadrons

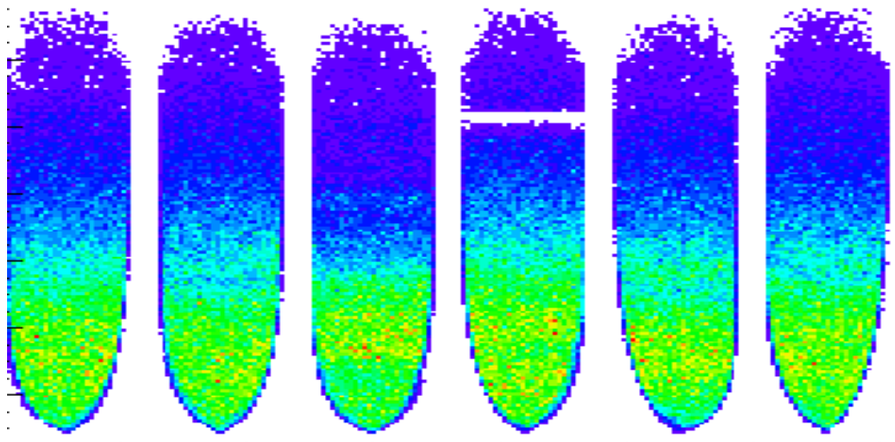
Subtracting QE like background

Systematic Uncertainties

$\phi_{q\pi}$ independence of the pion-production cross section for background subtraction



Varying CLAS π acceptance

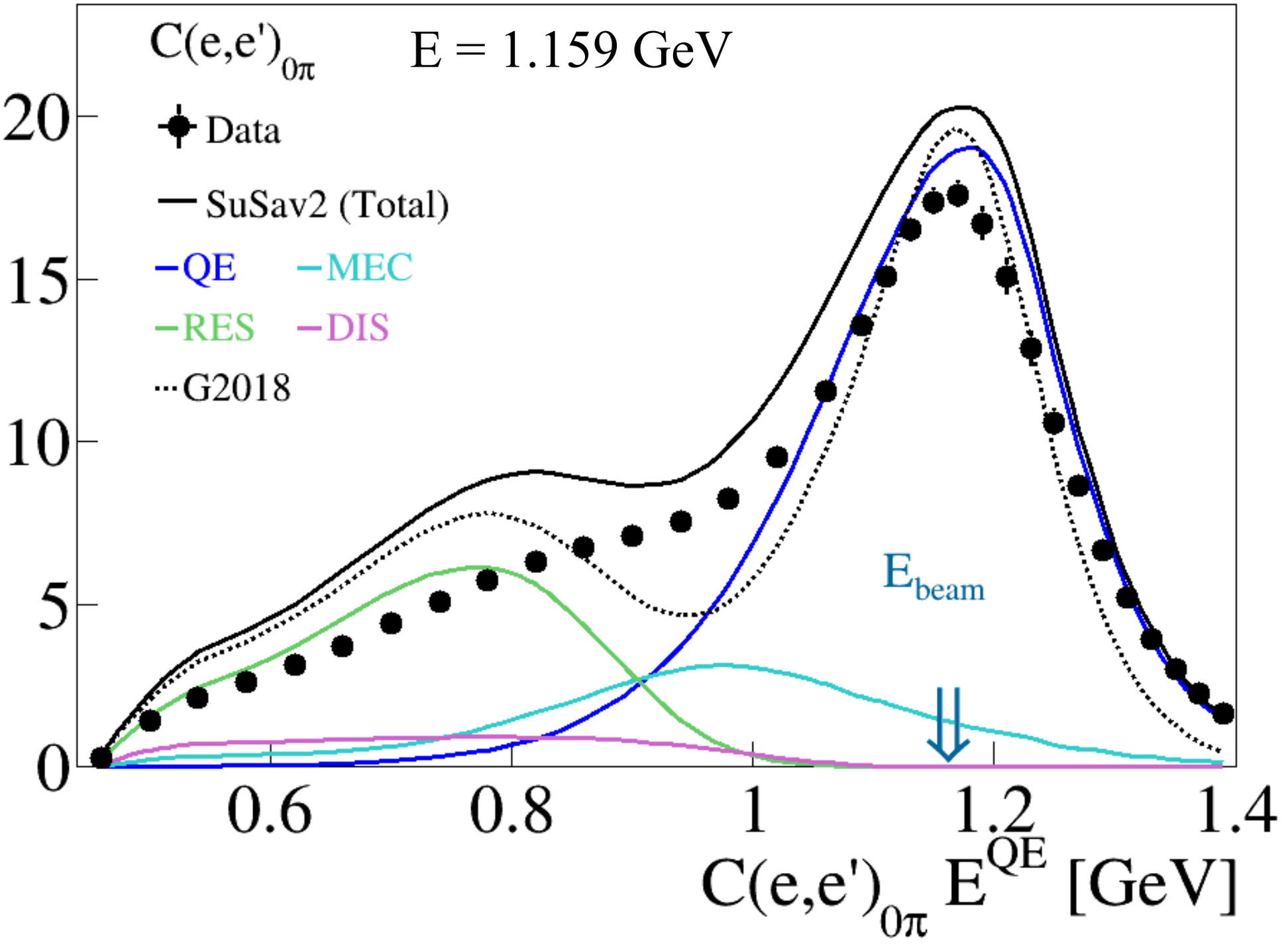


Varying the photon identification cuts

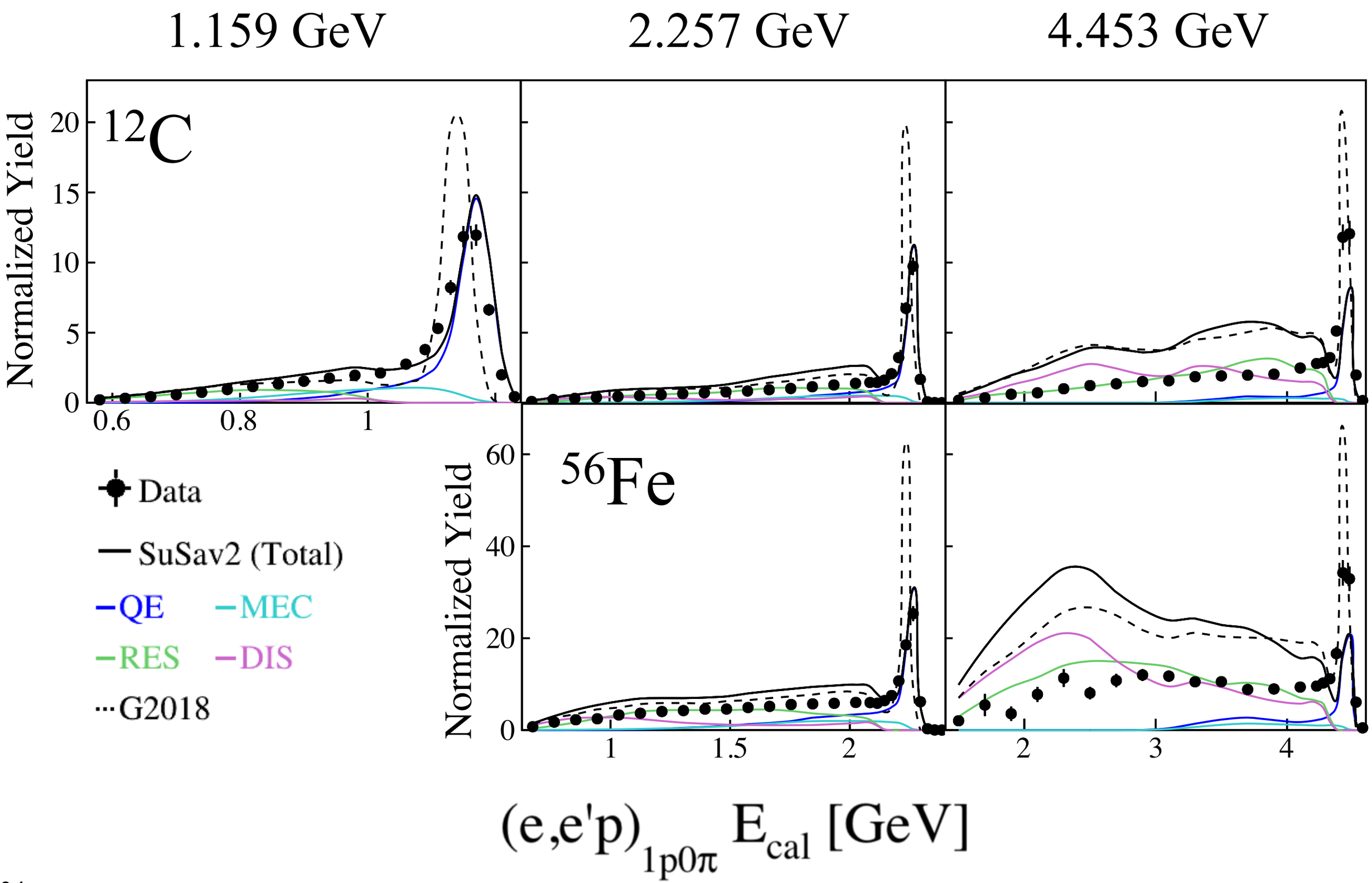
Estimate systematic uncertainties by comparing independent measurement in each sector.

Use Hydrogen elastic scattering for absolute rate measurement.

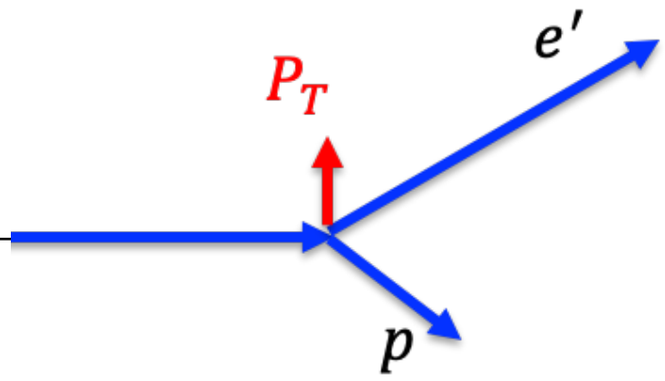
Disagreements between Data and MC

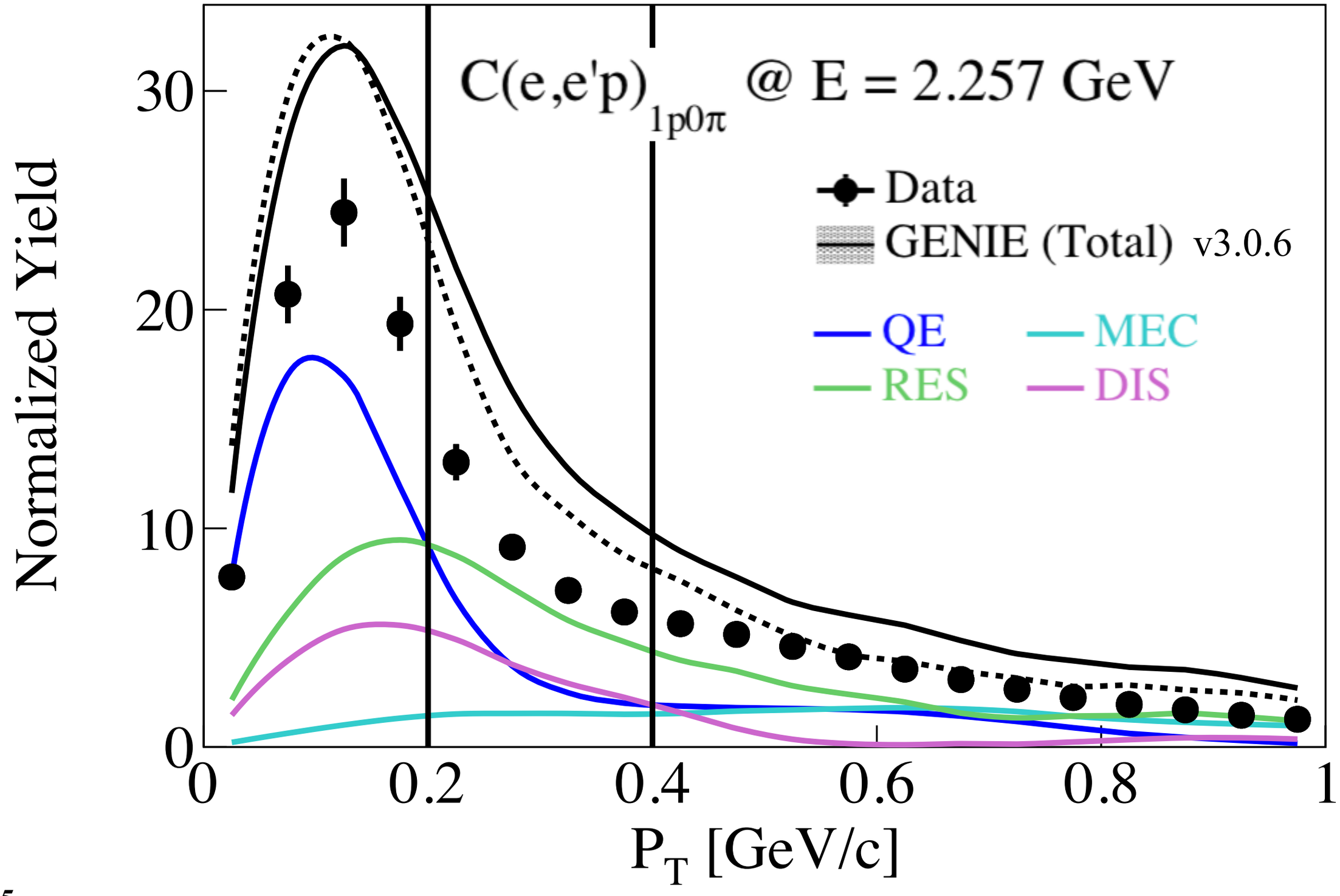


Disagreements between Data and MC

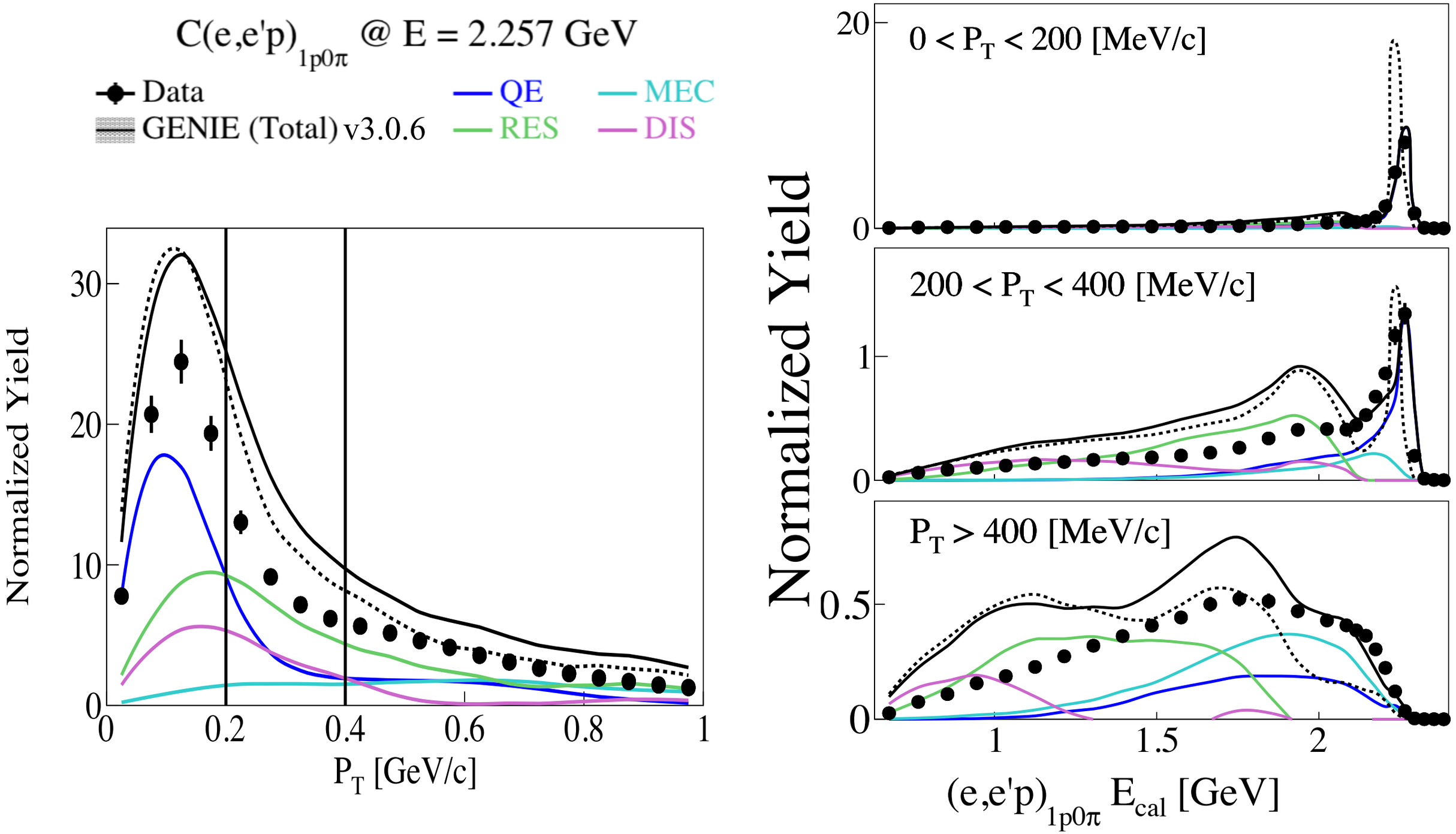


MC vs. (e,e'p) Data: $\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^{p}$



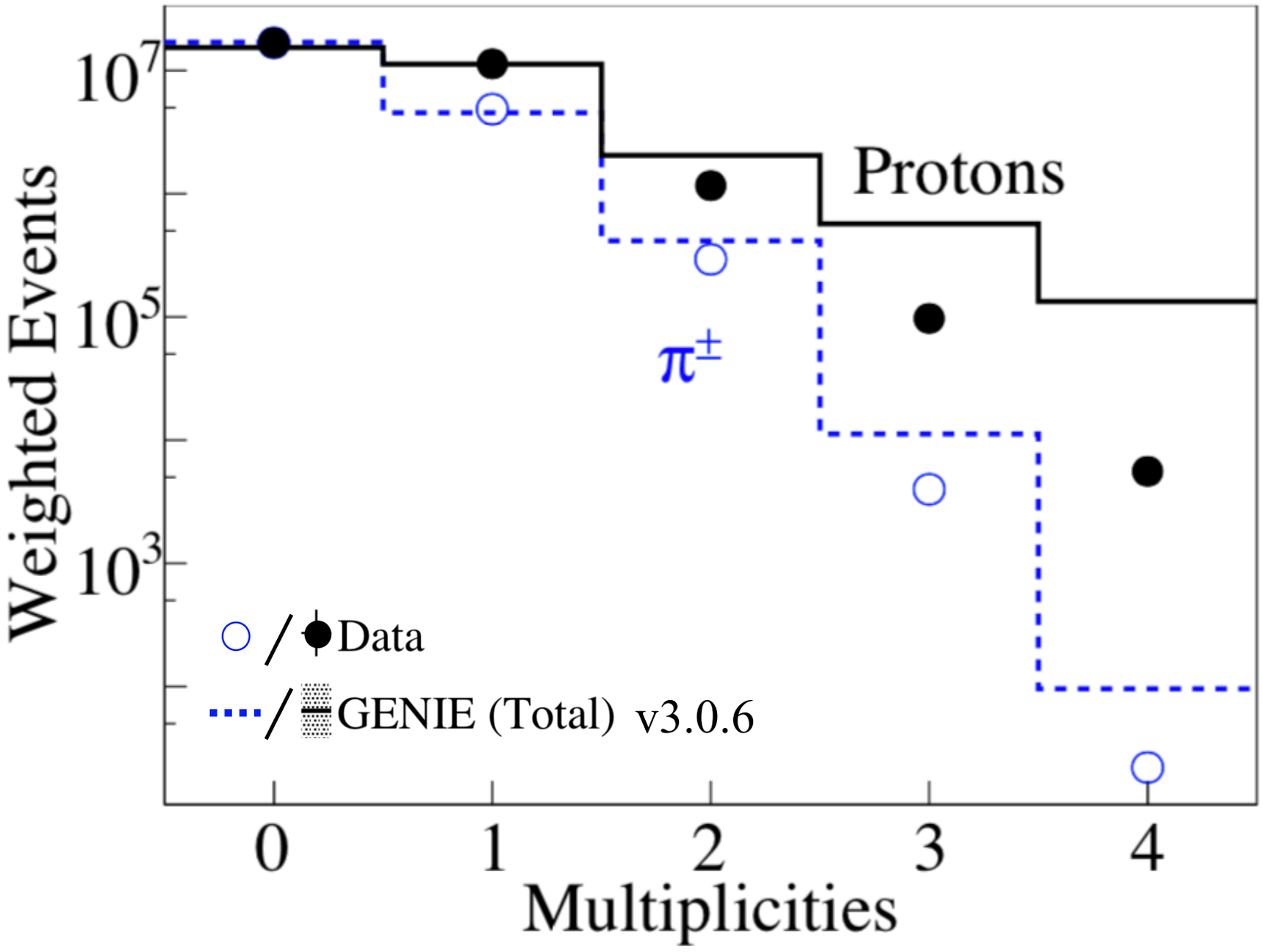


MC vs. (e,e'p) Data: $\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^{p}$

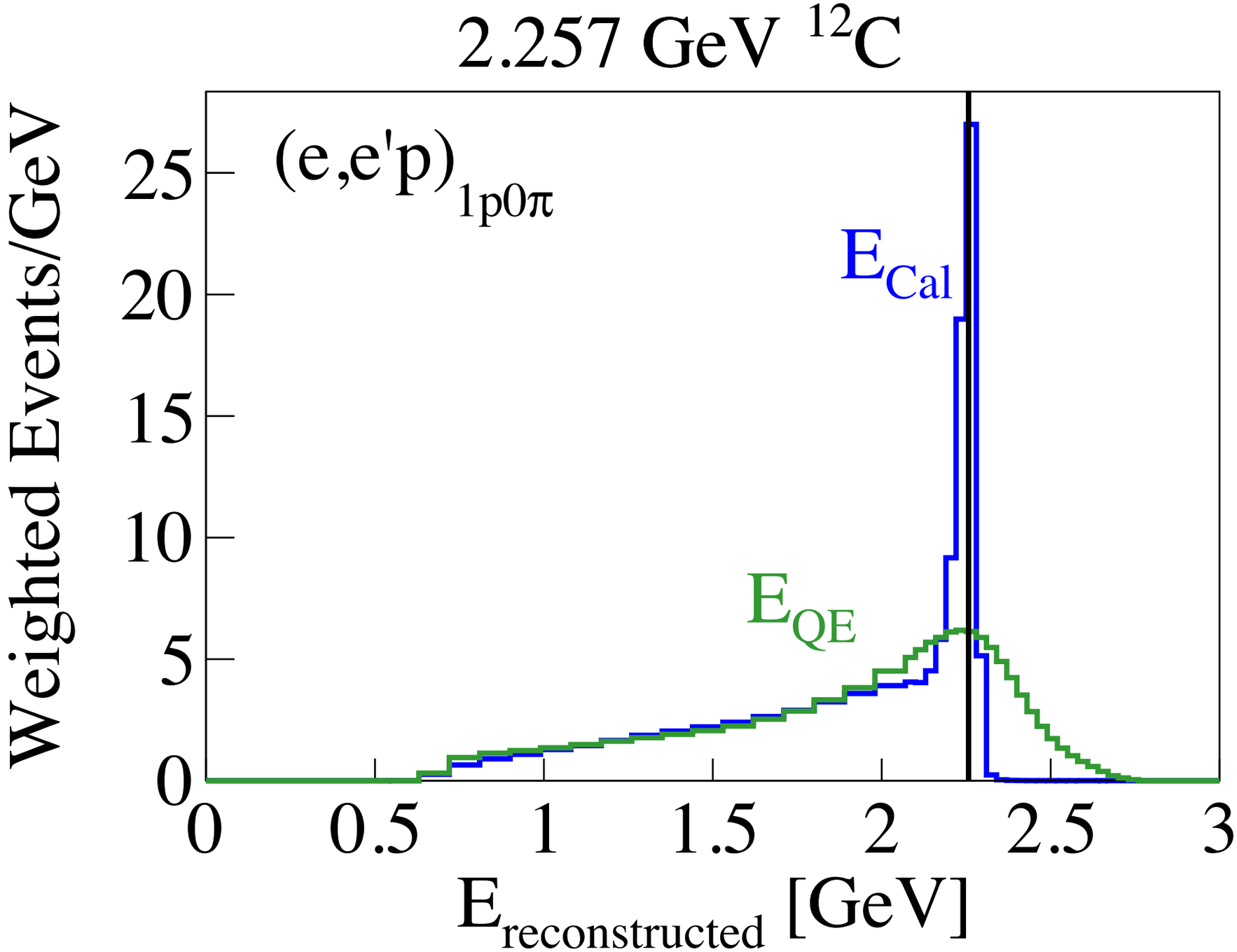


Multiplicities

E = 2.257 GeV ^{12}C



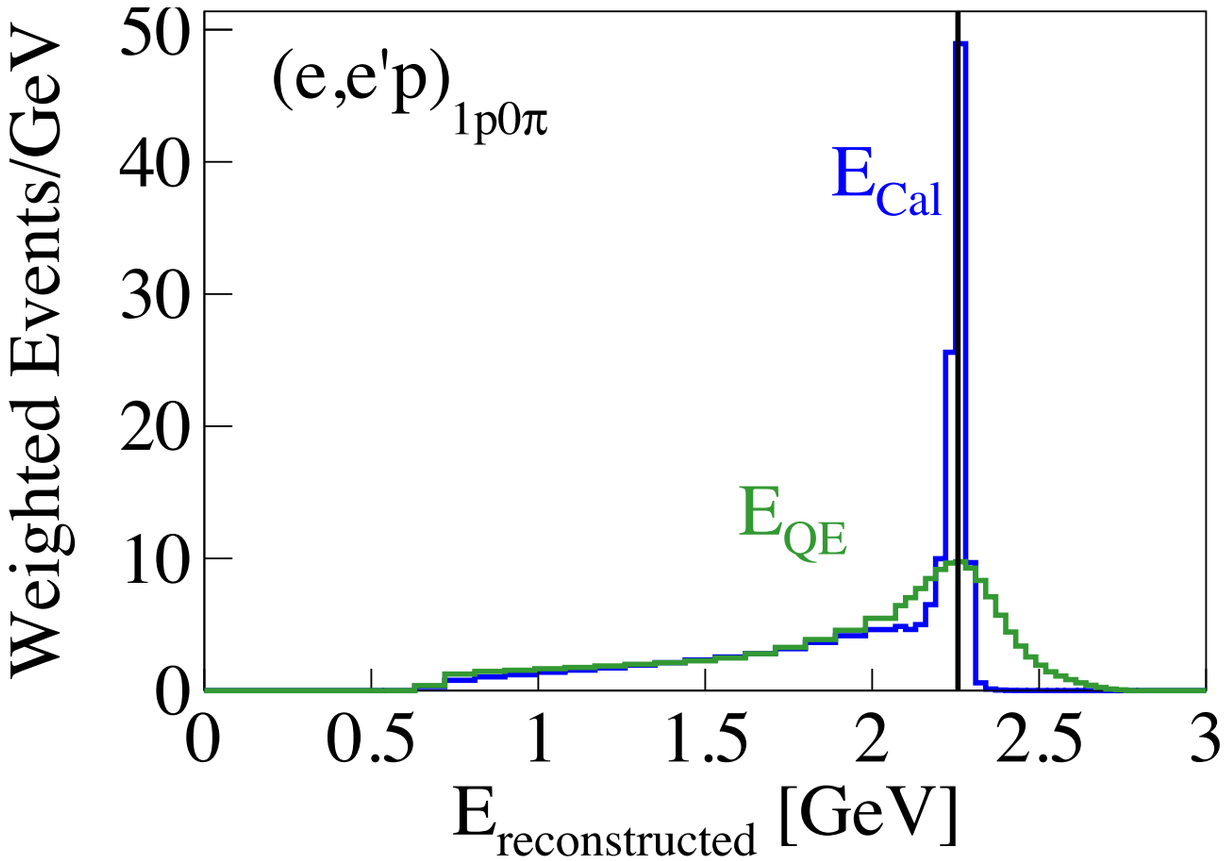
Testing the incoming energy reconstruction



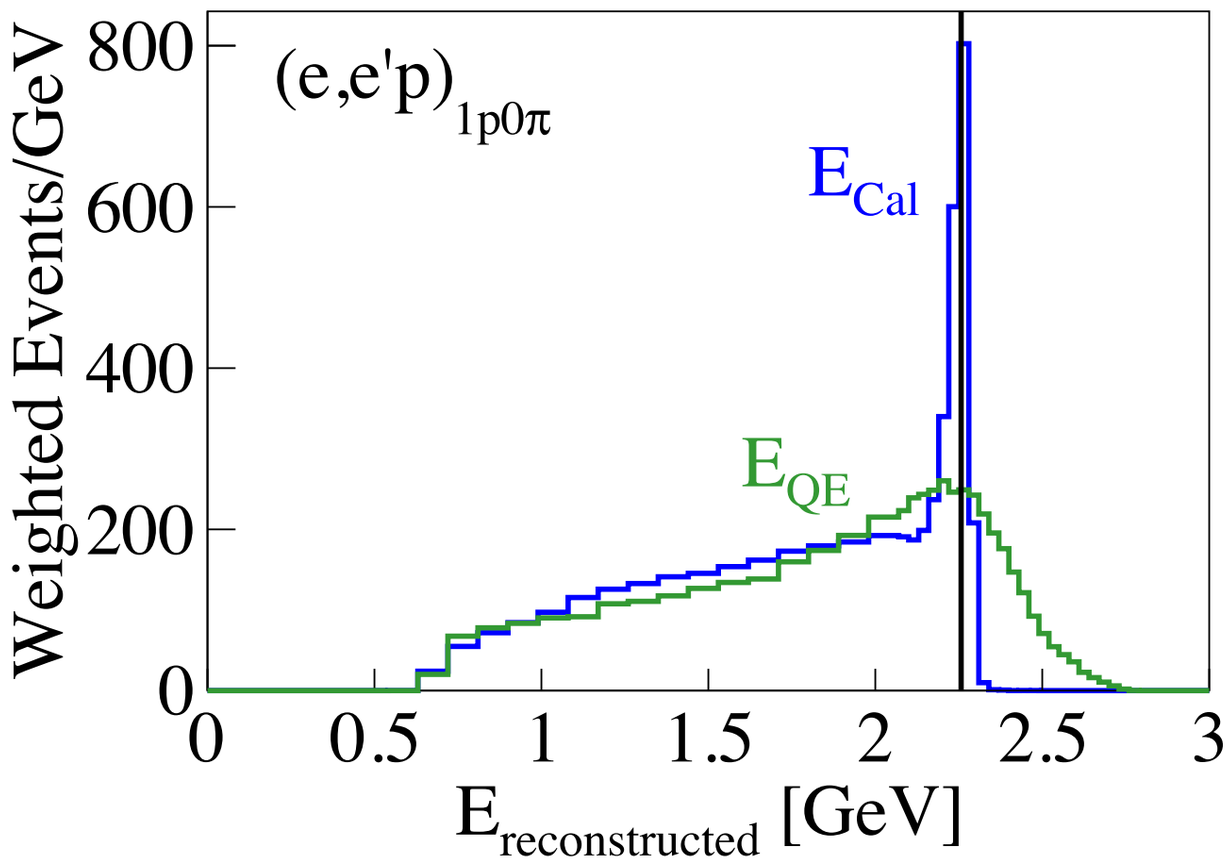
E_{rec} Worse with Higher Mass

2.257 GeV

^{4}He



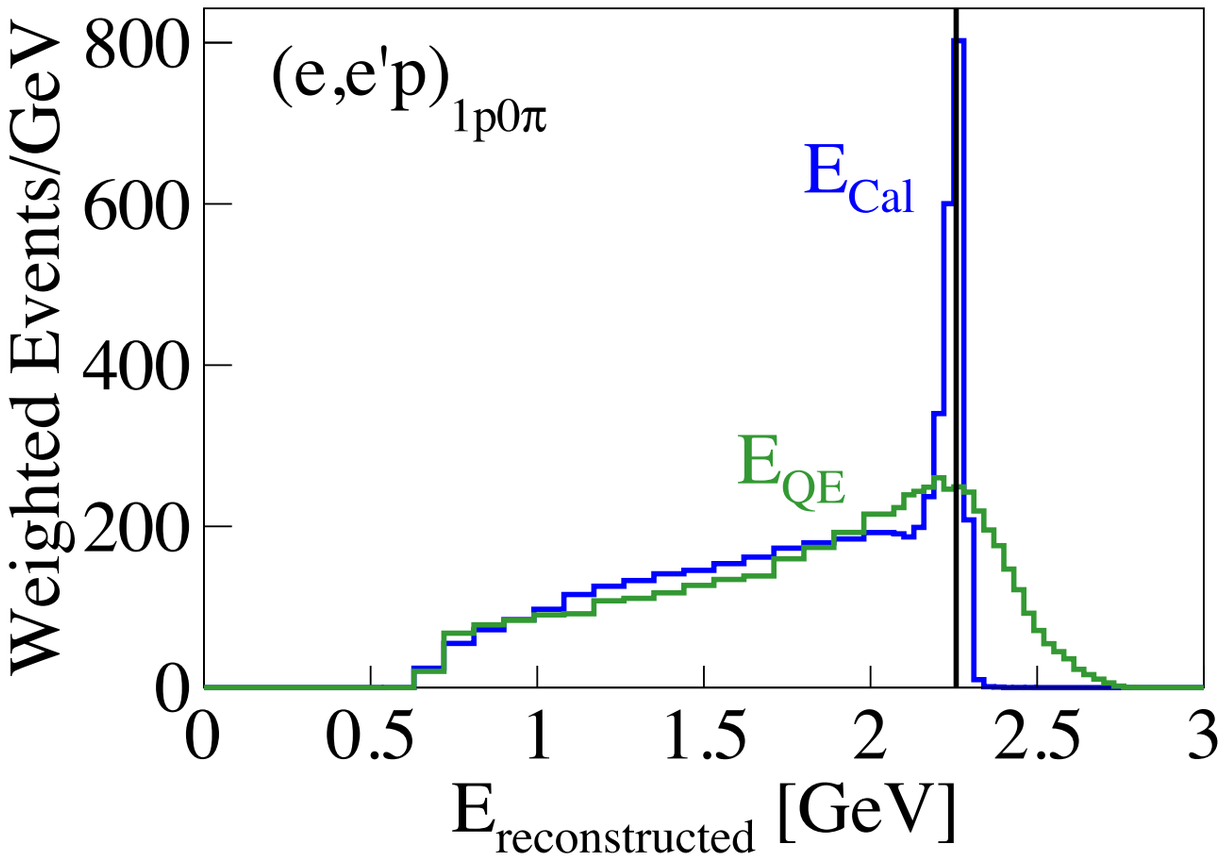
^{56}Fe



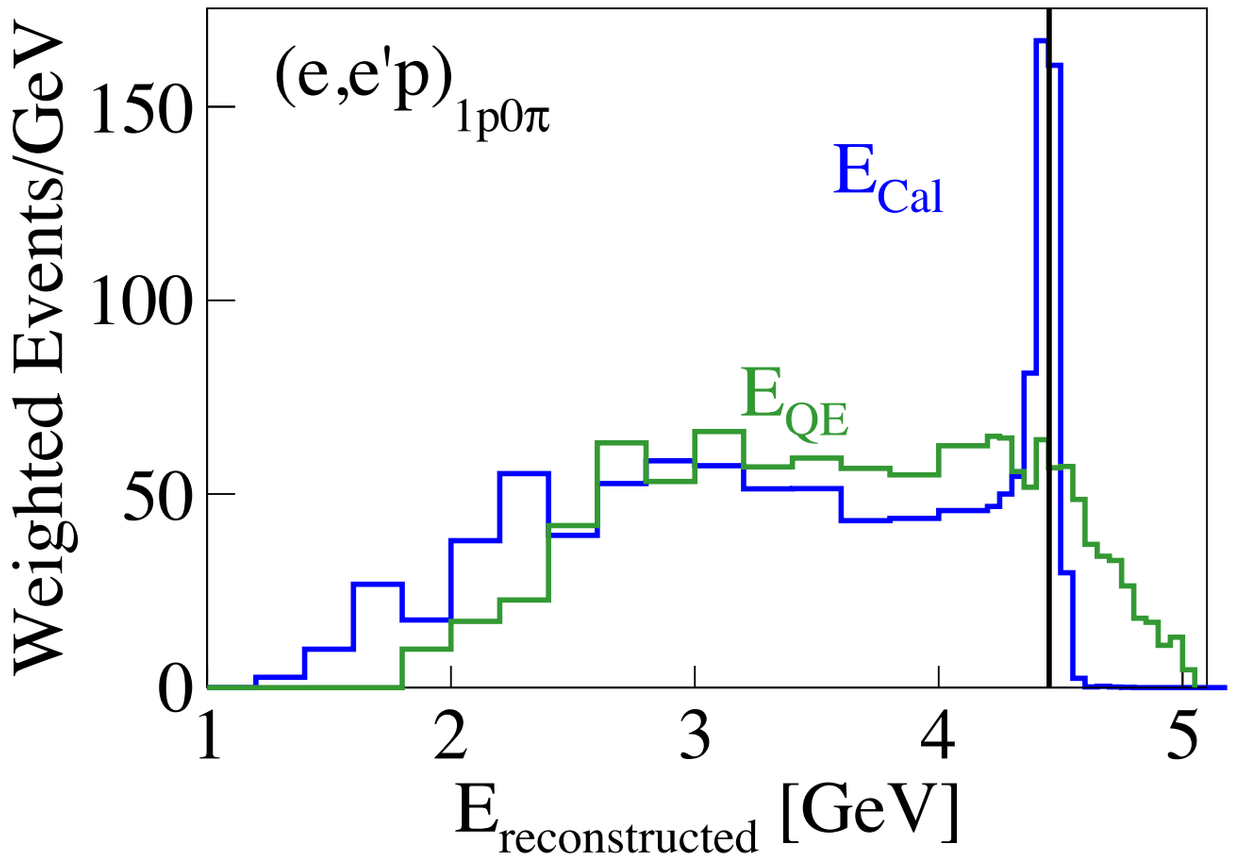
E_{rec} Worse with Higher Energy

^{56}Fe

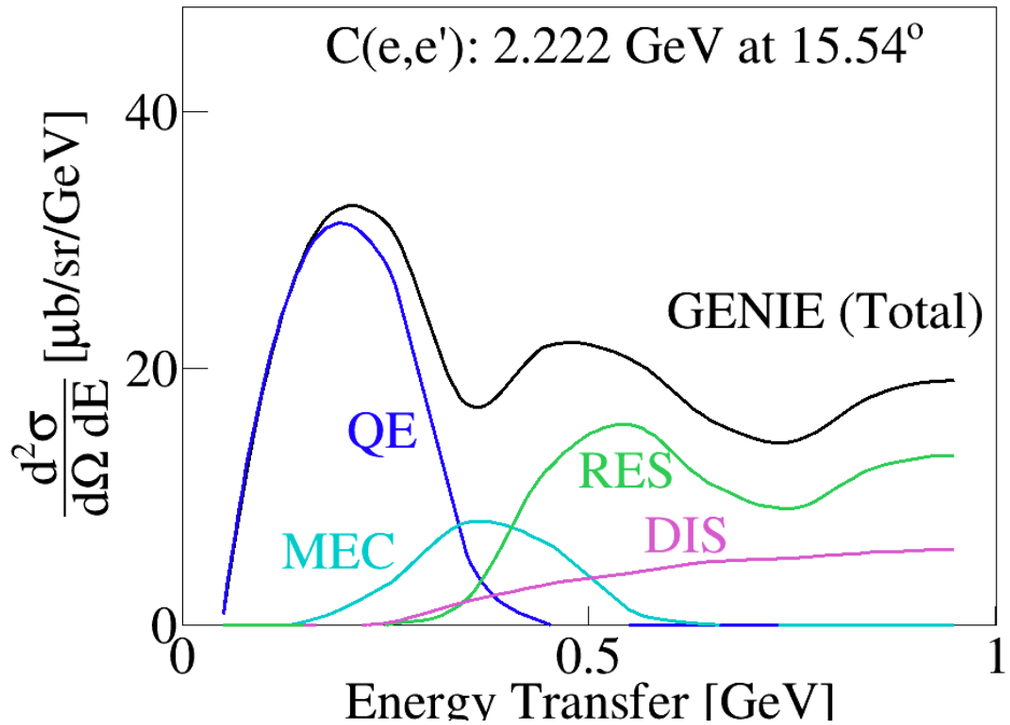
2.257 GeV

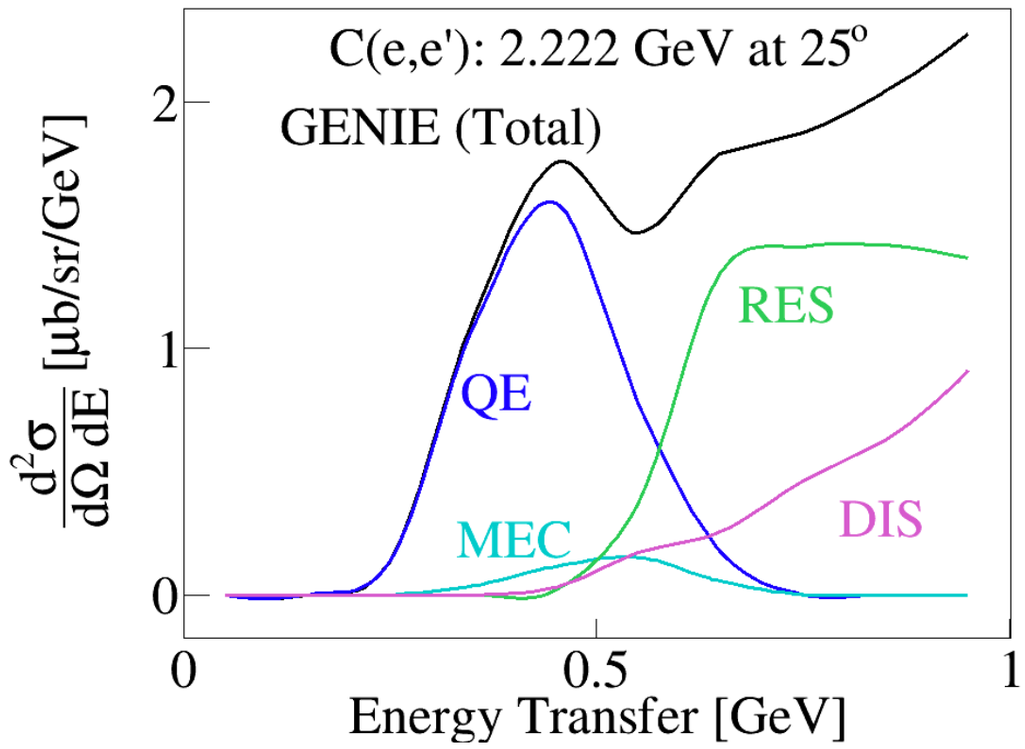


4.453 GeV

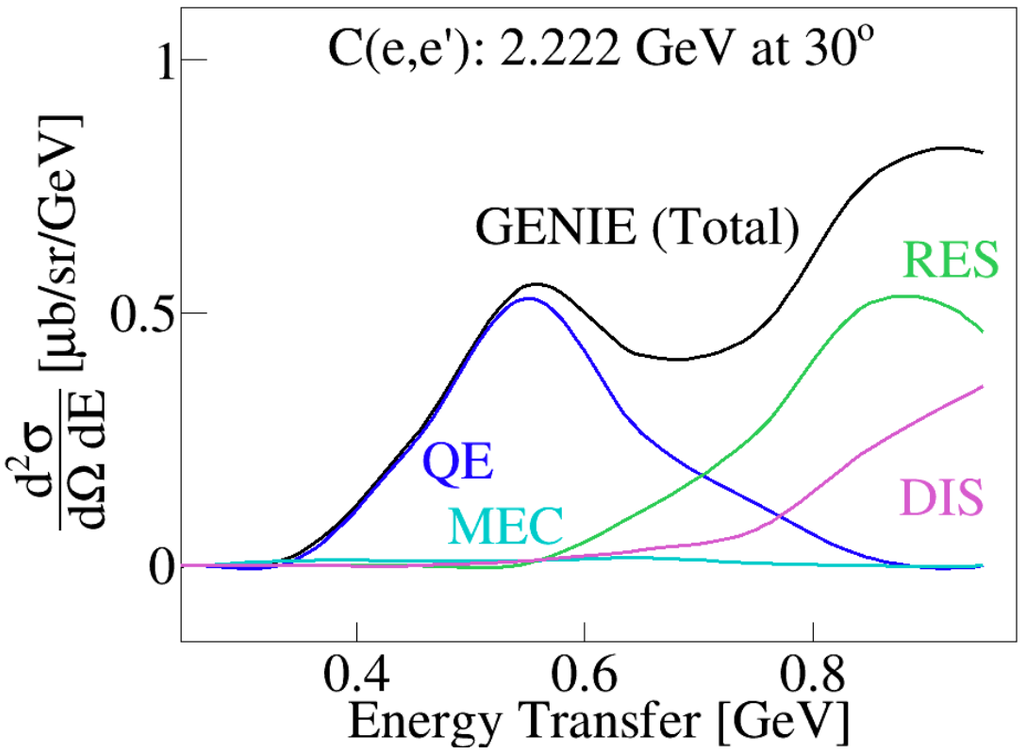


Where did the MEC go?





CLAS6: $15^o < \theta_e < 45^o$



Systematic Uncertainties - Data side

1. Background subtraction:
    1. Assuming no $\phi_{q\pi}$ dependency when rotation hadrons system around q vector. H(e, e'pπ) cross sections measured dependency affected the subtracted spectra by about 1%.
    2. Varying the CLAS π acceptance in each sector reduced by10–20%. This changed the resulting subtracted spectra by about 1% at 1.159 and 2.257 GeV and by 4% at 4.453 GeV.
2. Varying the photon identification cuts using its velocity greater than two standard deviations (3σ at 1.159 GeV) below v = c, by $\pm$0.25σ. This gave an uncertainty in the resulting subtracted spectra of 0.1%, 0.5% and 2% at 1.159, 2.257 and 4.453 GeV.
3. Ratio of data to GENIE in the 6 sectors excluding dead regions. leads to 6% uncertainty.

GENIE Simulation

Genie v3.0.6 tune G18_10a_02_11a

	electrons	neutrinos
Nuclear model	Local fermi gas model	
QE	Rosenbluth CS	Nieves model
MEC	Empirical model	Nieves model
Resonances	Berger Sehgal	
DIS	AGKY	
FSI	hA2018	
Others	Adding radiative correction	

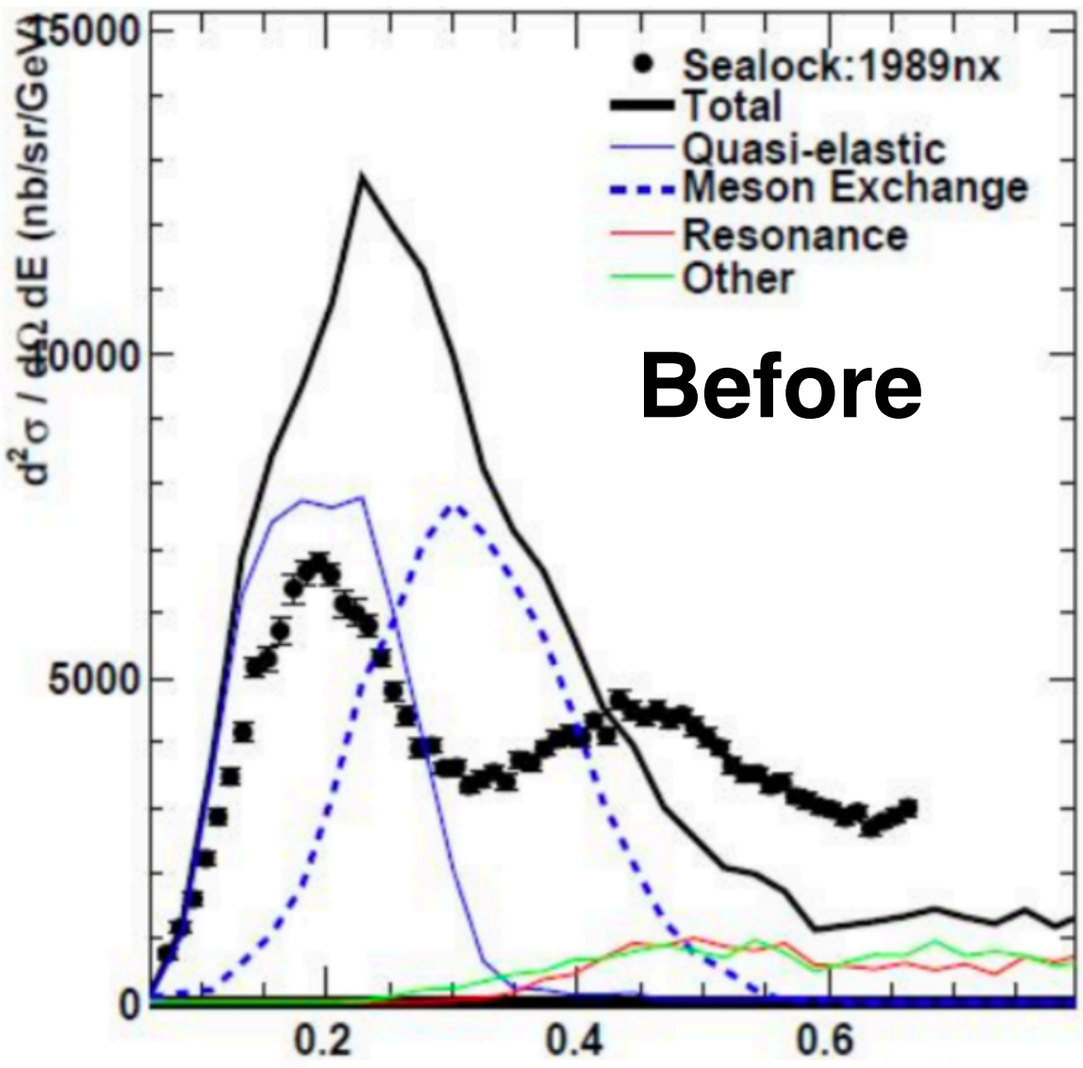
GENIE Simulation

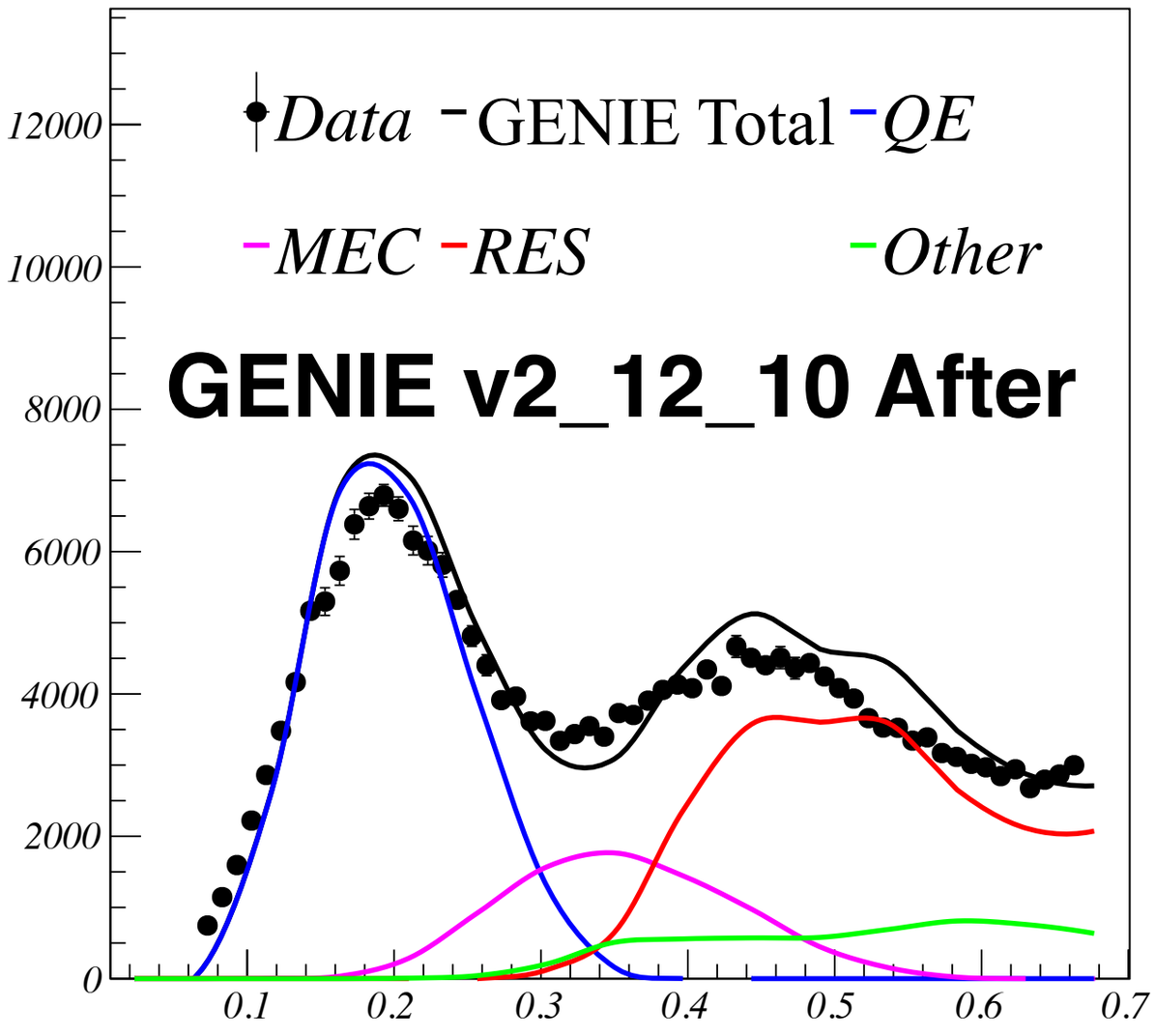
Genie v3.0.6 SuSA

	electrons	neutrinos
Nuclear model	Local fermi gas model	
QE	Rosenbluth CS	Nieves model
MEC	SuSAv2	SuSAv2
Resonances	Berger Sehgal	
DIS	AGKY	
FSI	hA2018	
Others	Adding radiative correction	

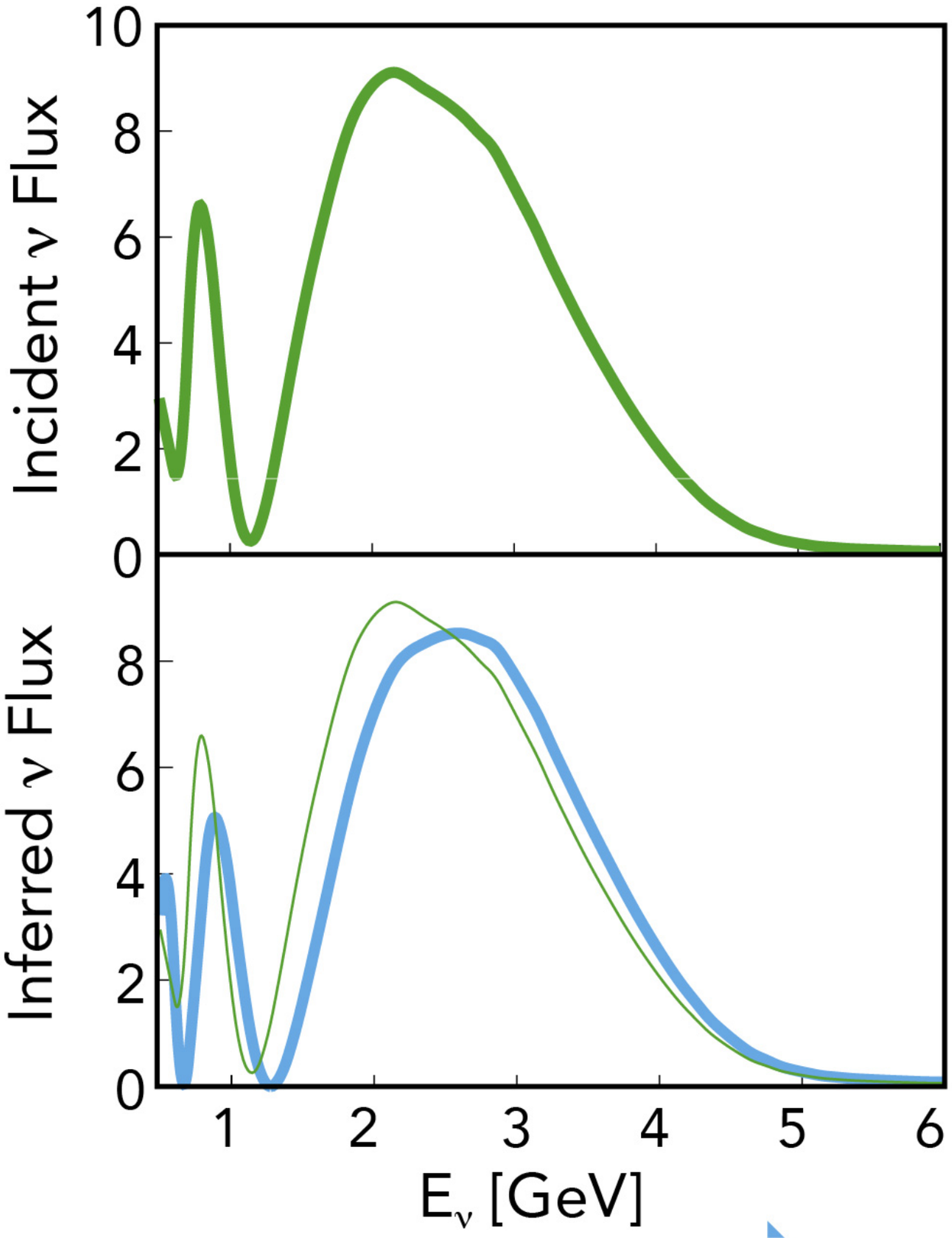
Testing neutrino generators with inclusive electron scattering data

$$^{12}C(e,e') \quad E = 0.961\ \text{GeV} \quad \theta = 37.5^{\circ}$$





Potential implication on DUNE analysis



- ν_e appearance channel (all inclusive)
- Using existing parameter constraints from reactors + others experiments
- Smearing energy based on events with:

1e1p selection

$\theta_e > 15^o$

$P_p > 300$ MeV/c

No $P_{\pi+/-} > 150$ MeV/c

Reconstructed based on simulation

Reconstructed based on smearing in electron scattering data