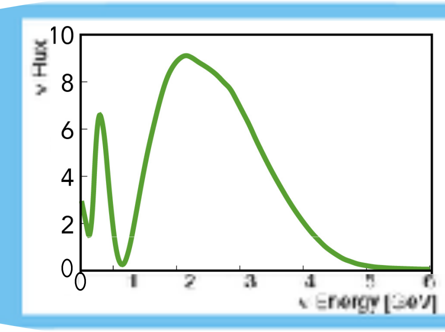
Electrons for neutrinos

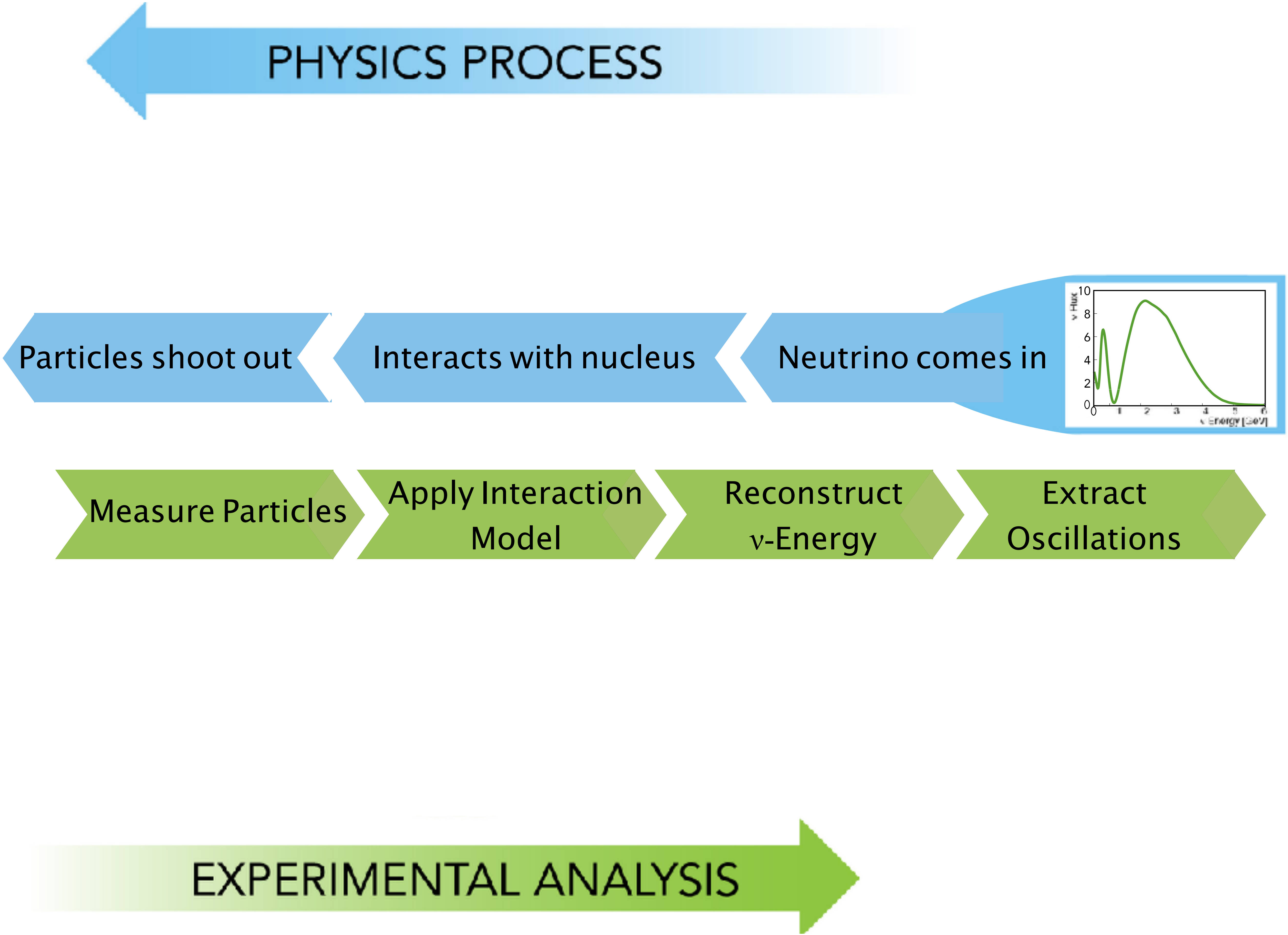
Adi Ashkenazi

02/10/2021 IPPP topical meeting

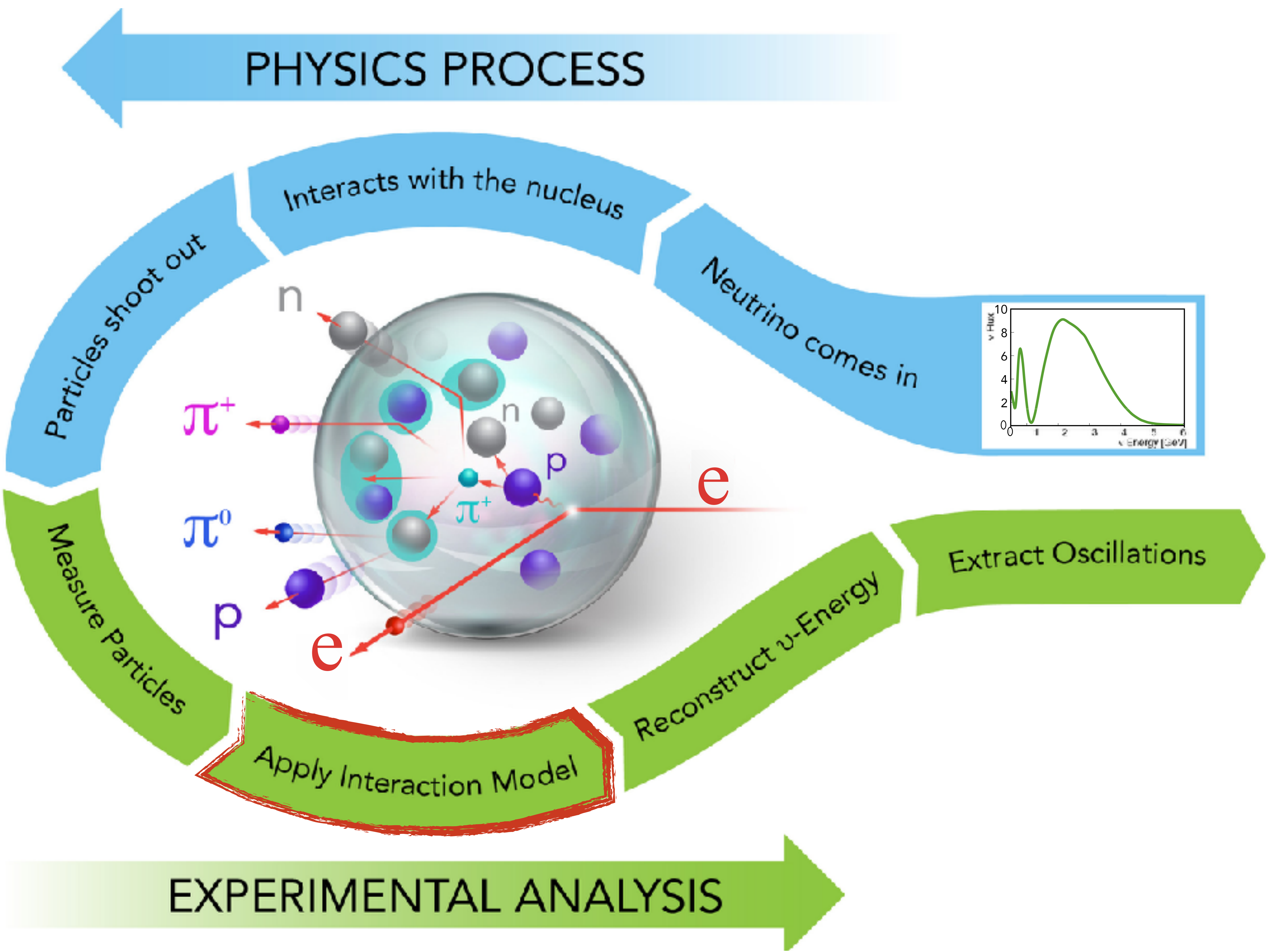
PHYSICS PROCESS

Particles shoot out ← Interacts with nucleus ← Neutrino comes in



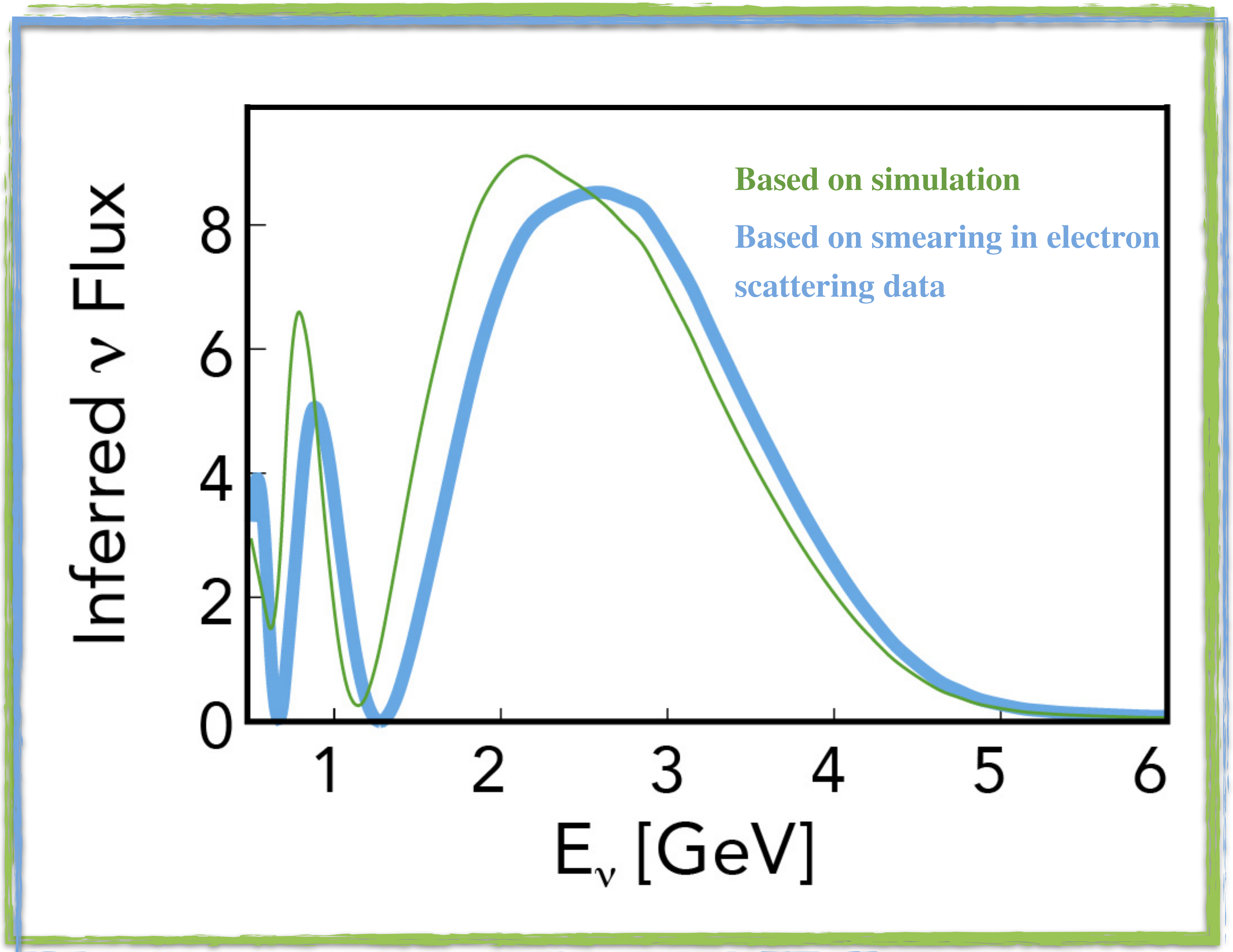


PHYSICS PROCESS
Particles shoot out
Interacts with nucleus
Neutrino comes in
10
8
6
4
2
0
Measure Particles
Apply Interaction Model
Reconstruct ν-Energy
Extract Oscillations
EXPERIMENTAL ANALYSIS


PHYSICS PROCESS
Interacts with the nucleus
Particles shoot out
Neutrino comes in
n
π+
π0
p
e
π+
Measure Particles
Apply Interaction Model
Reconstruct υ-Energy
Extract Oscillations
EXPERIMENTAL ANALYSIS

Miss-modelling might impact mixing parameters

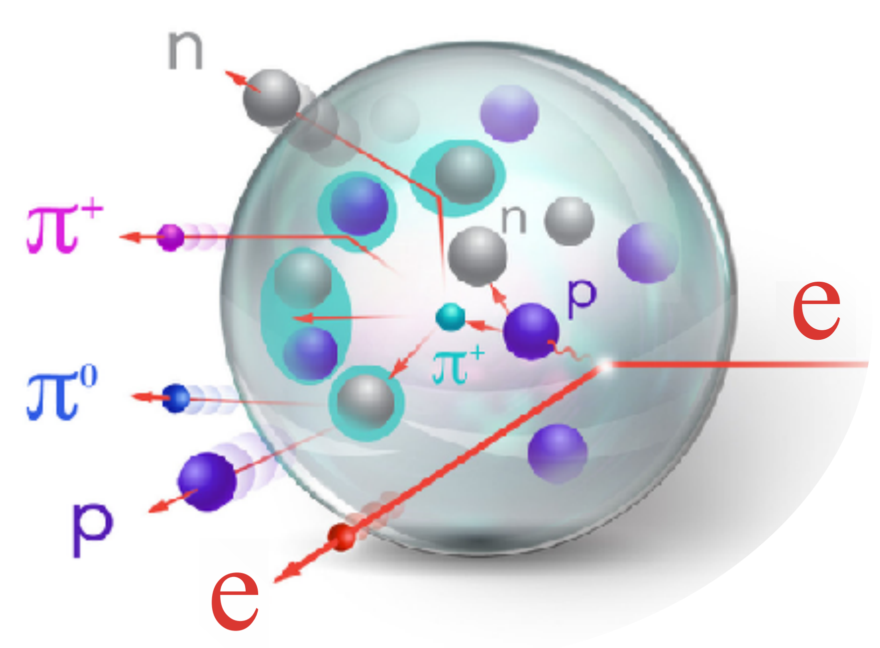
Extract Oscillations



Why Electrons?

- Electrons and Neutrinos have:
  - Similar interactions
    - Vector vs. Vector + Axial Vector
  - Many identical nuclear effects
    - Ground state (spectral function)
    - Final state interactions

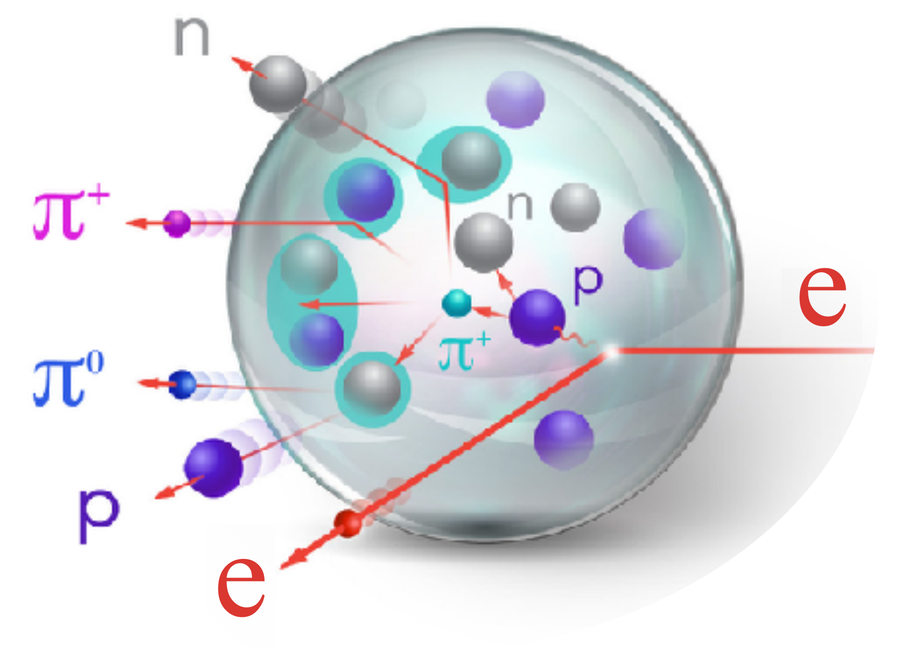
Electron beams have known energy



e4ν: Playing the Neutrino game

Analyse electron data as neutrino data

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



e4ν Collaboration

Modelling development

Data Analysis

Implications on neutrino studies

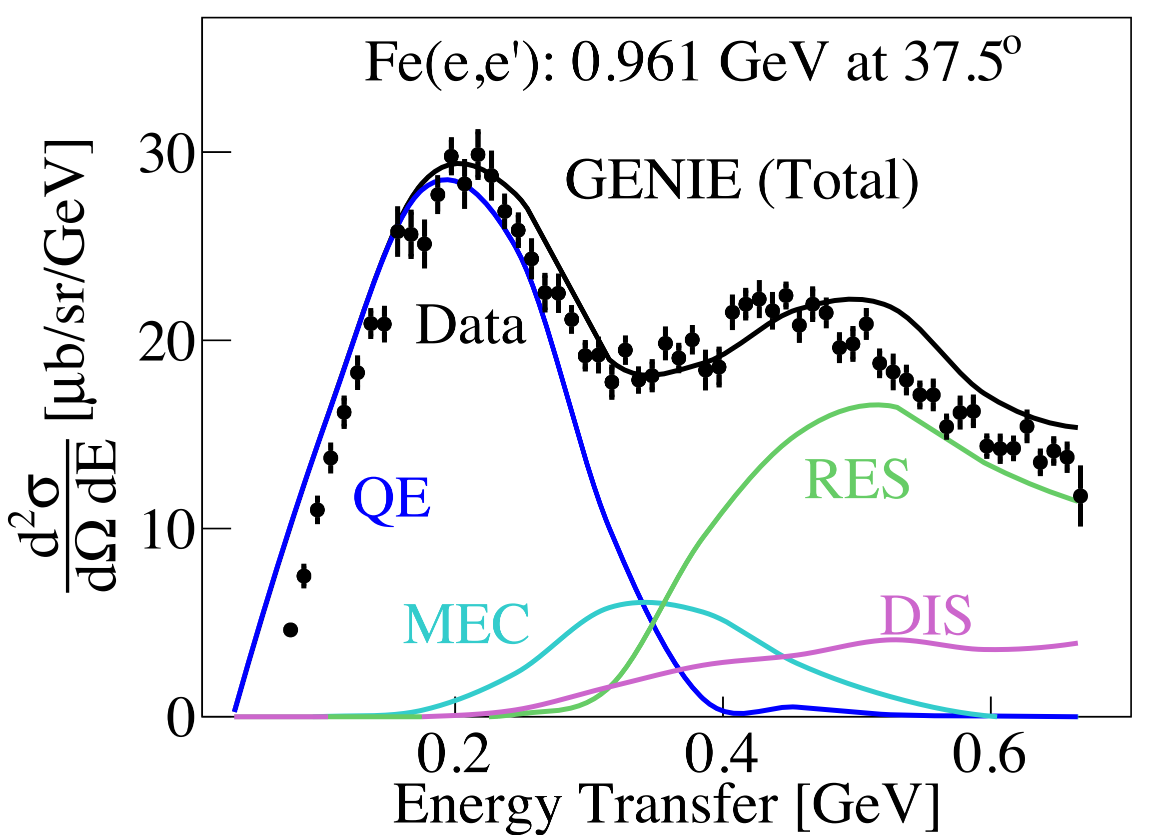
Tuning

Modelling development

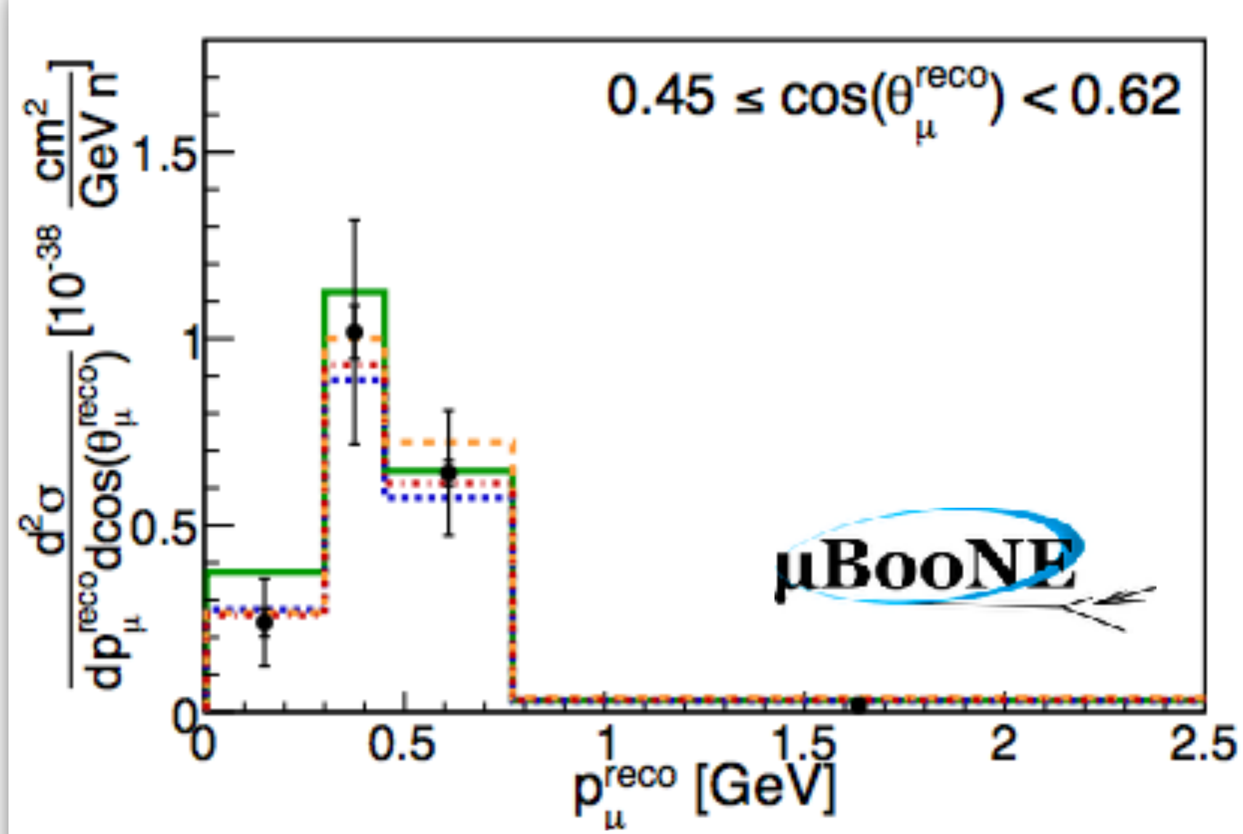
Our efforts are concentrated on Genie

Latest version v3.0.6 tune G18_10a_02_11a

Nicely reproducing inclusive results for both neutrino and electrons

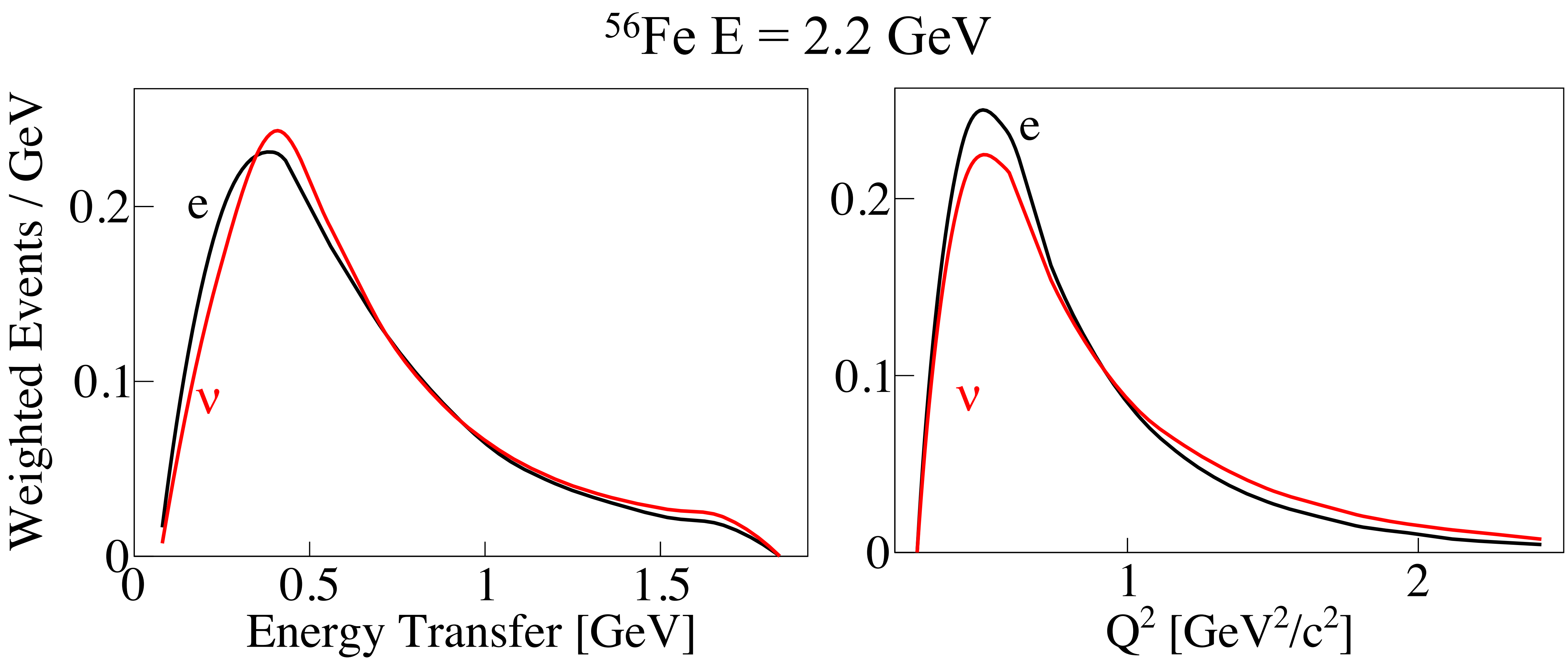


arXiv:2009.07228 [nucl-th]



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

1p0π electrons vs. neutrinos



Genie v3.0.6 tune G18_10a_02_11a   Electron were weighted by Q^4

For more details see backup slides

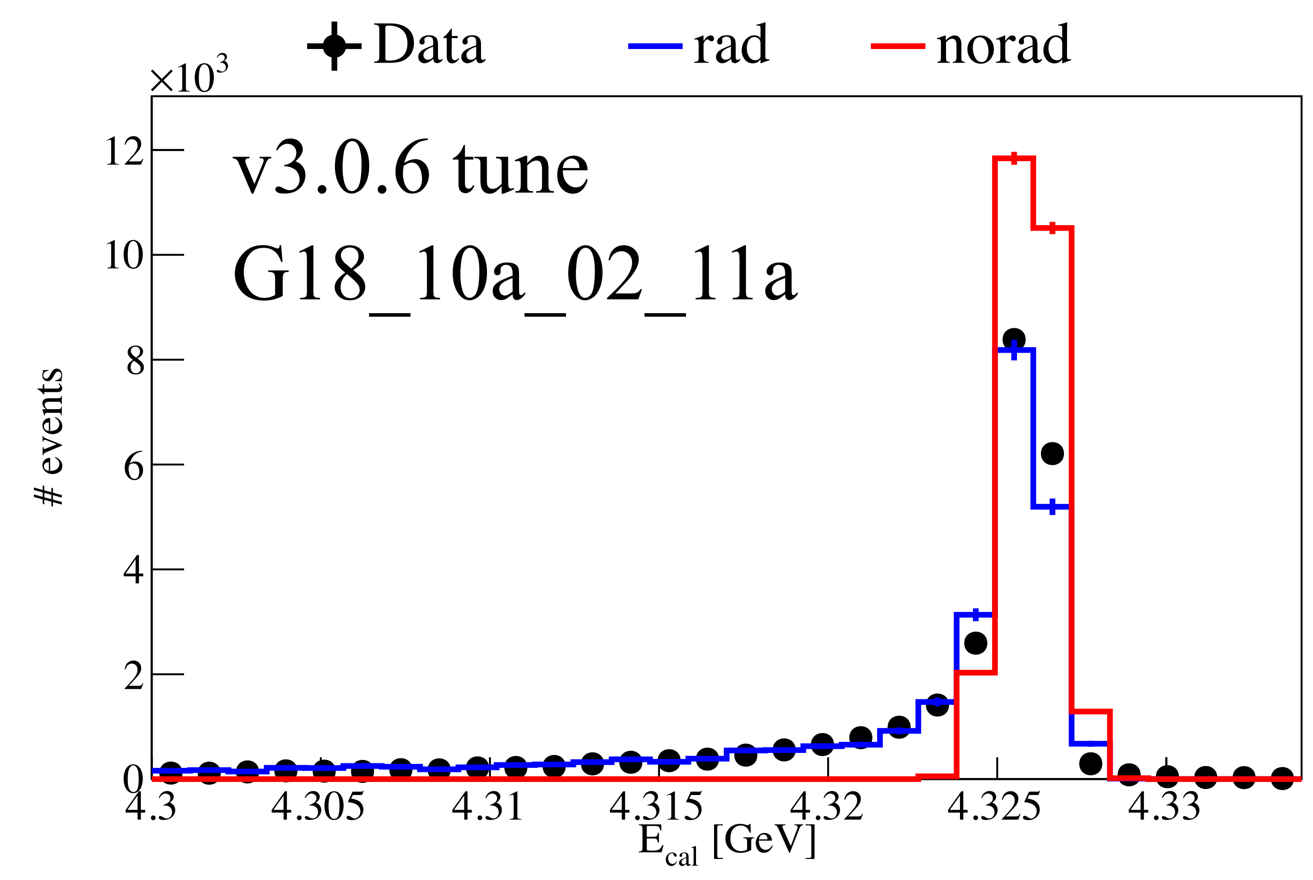
Modelling development

In this talk:

- SuSAv2 (G19)
- Rosenbluth QE & Empirical MEC (G2018)

In addition:

- **Radiative corrections**: working with Wackeroth group from (U Buffalo)



First version based on Mo and Tsai

CLAS Detector

Large acceptance, Open Trigger

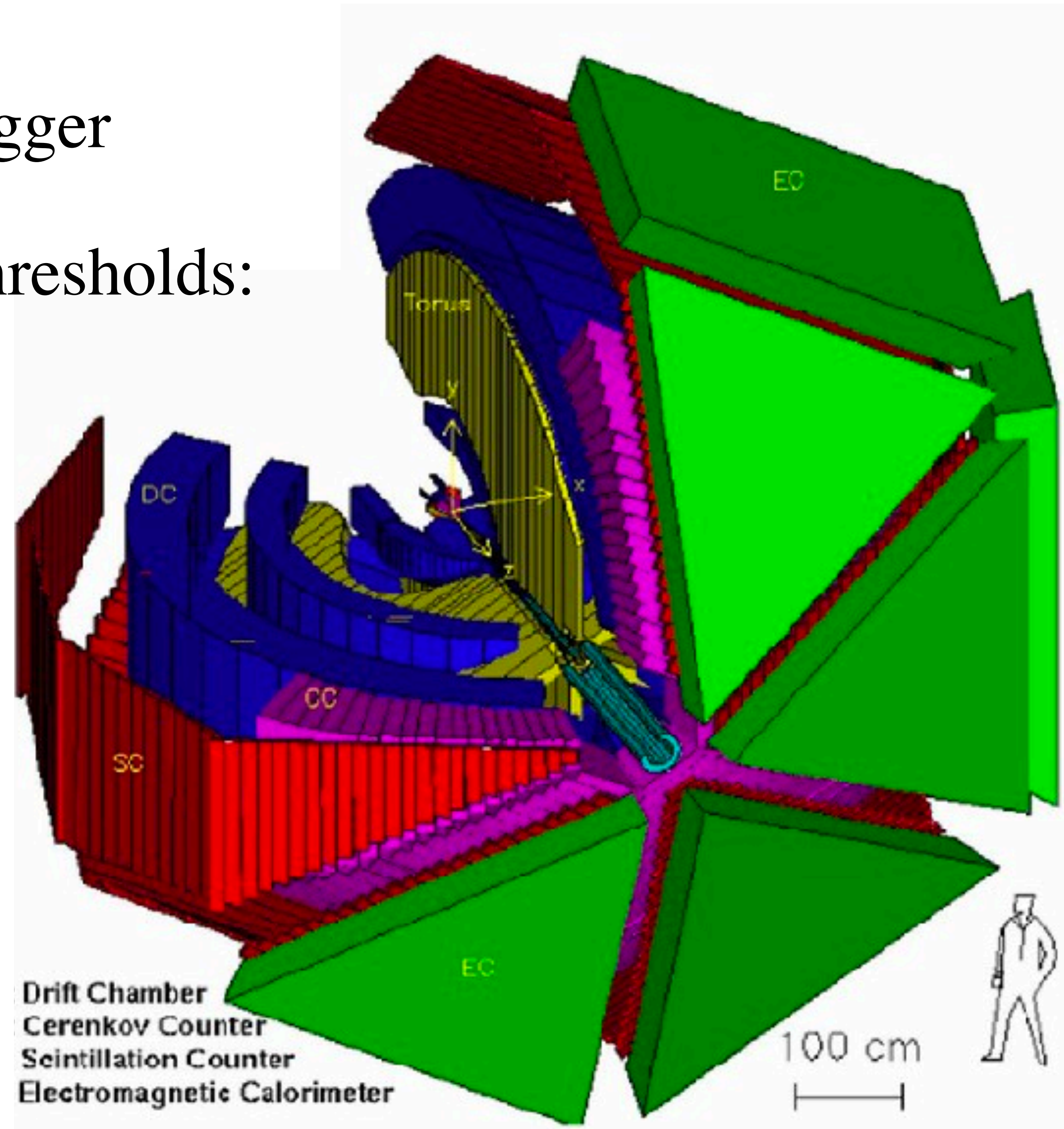
Charged particle detection thresholds:

$\theta_e > 15^o$

$P_p > 300$ 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

1p0π Event Selection

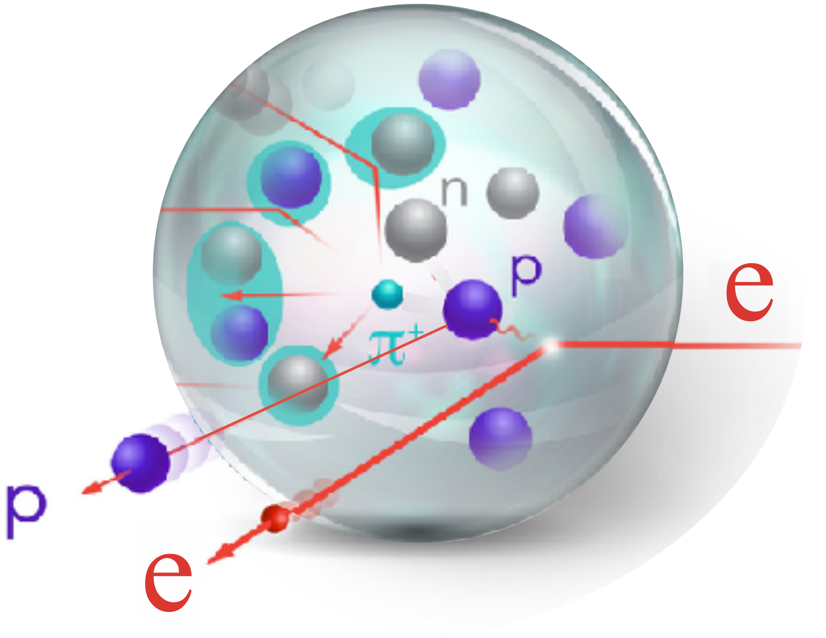
Focus on Quasi Elastic events:

1 proton above 300 MeV/c

no additional hadrons above threshold:

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

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



Data

CLAS6 A(e,e'p) Data

Targets:

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

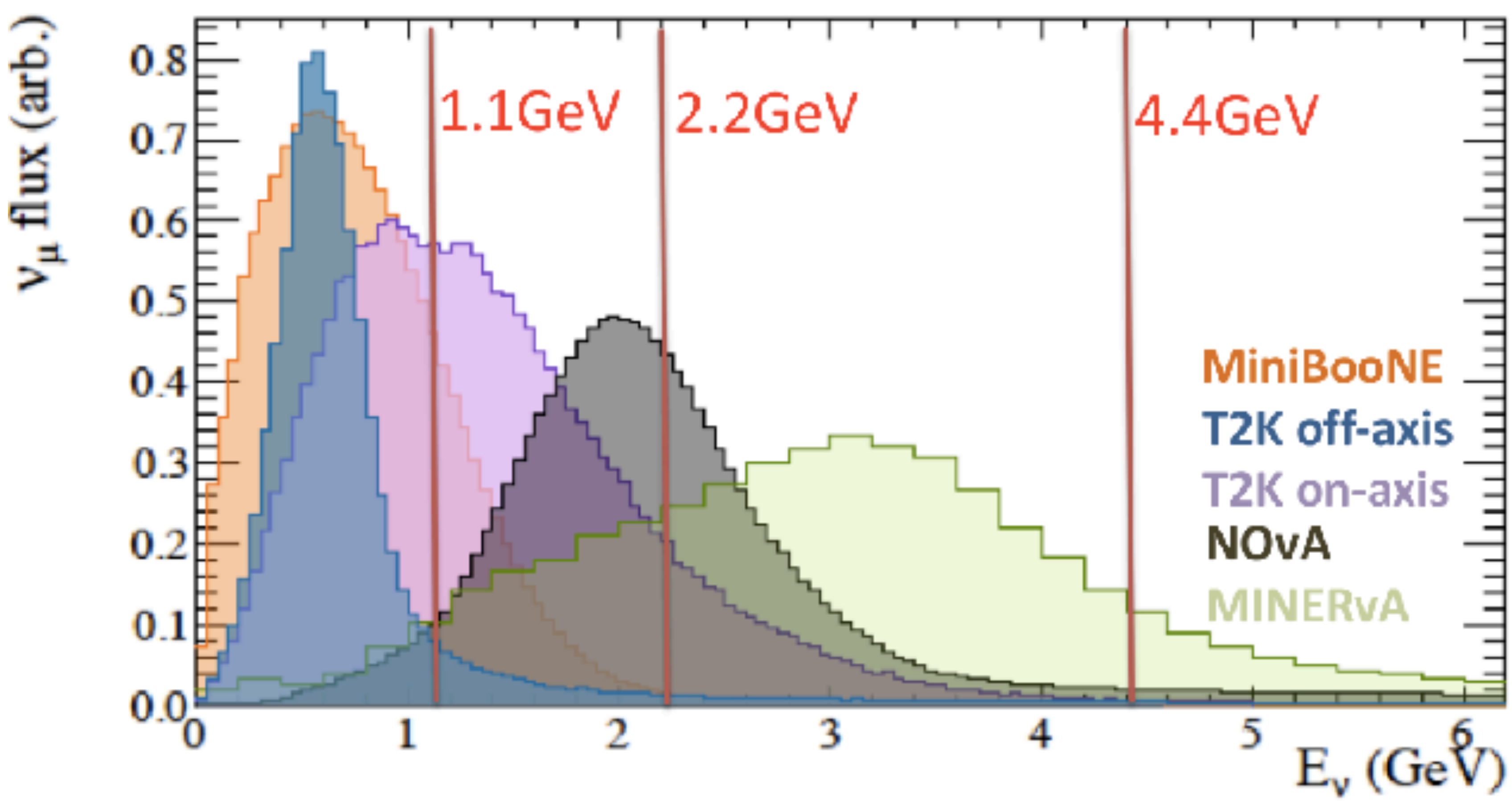
H_2O

CH

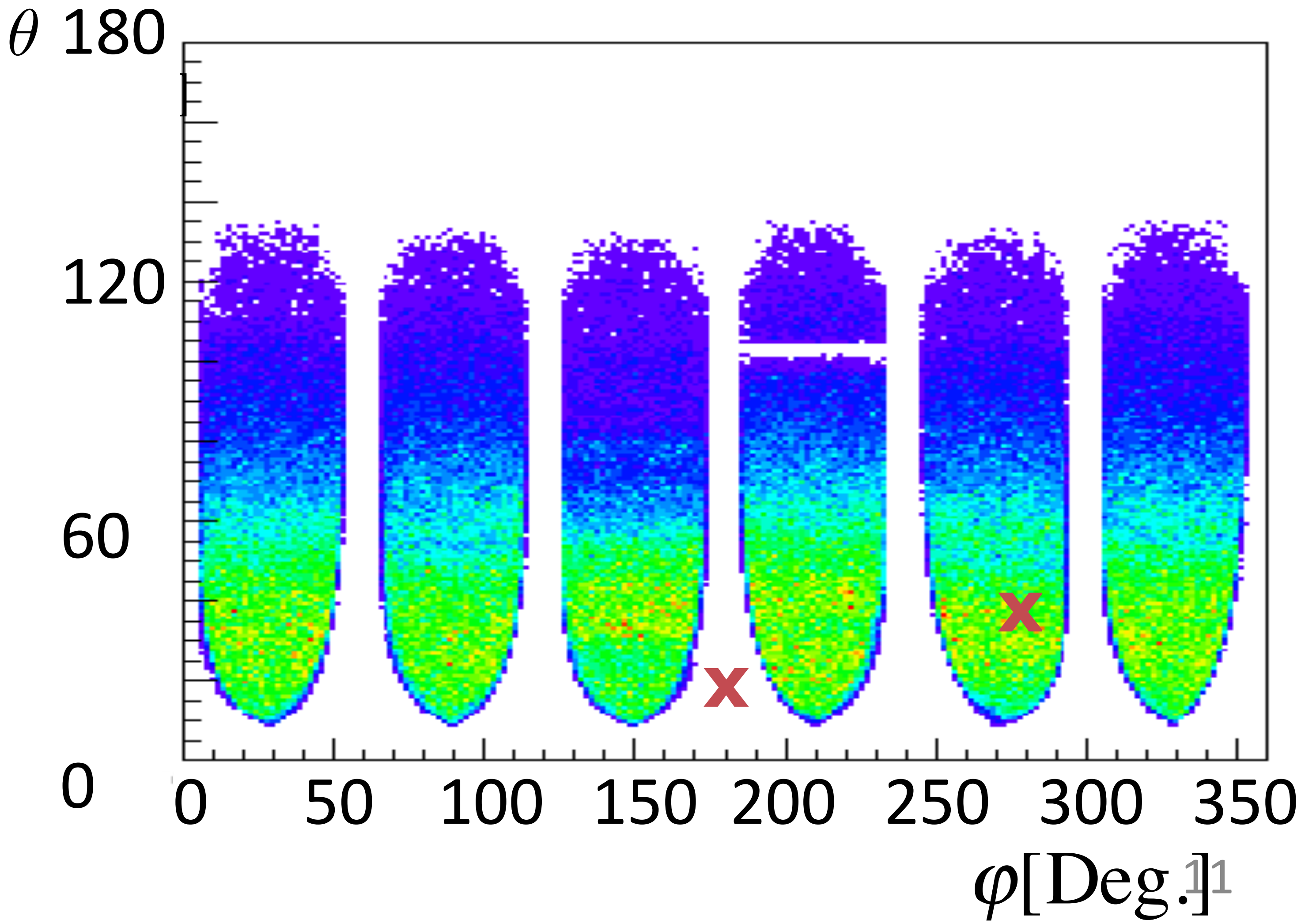
Ar

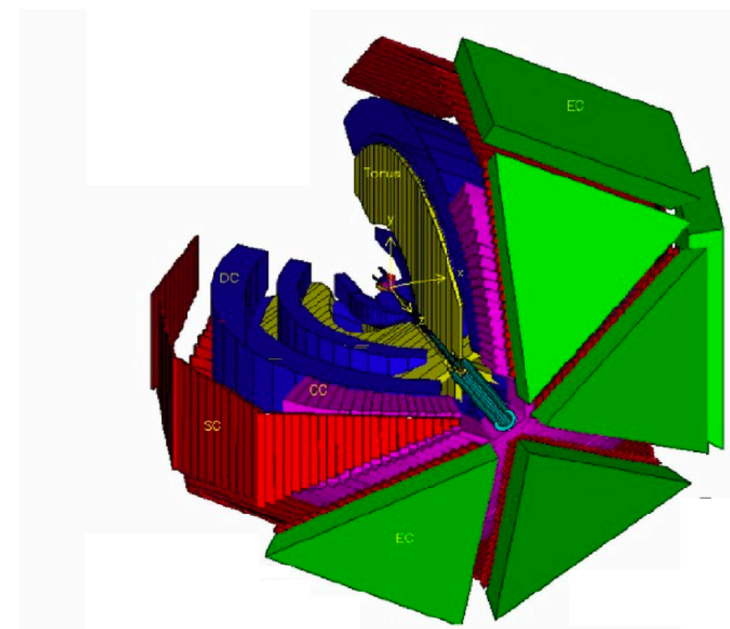
Energies around:

1,2,4 GeV

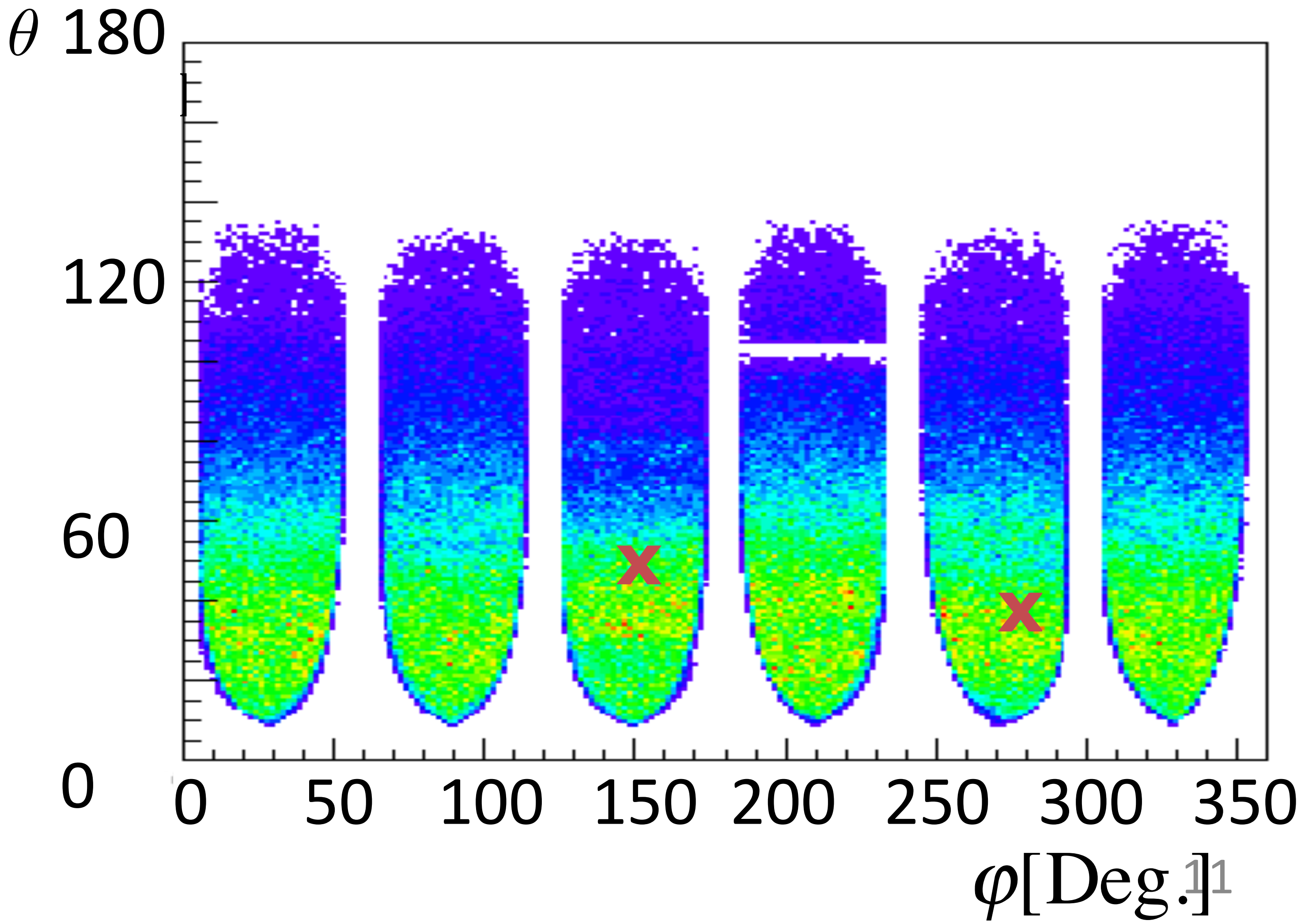


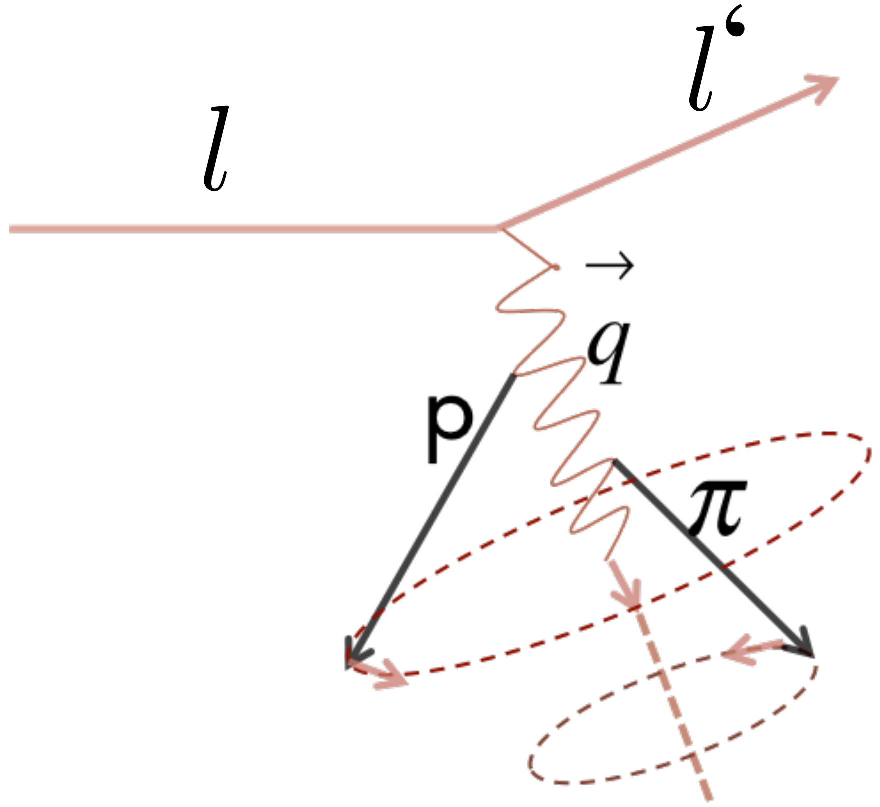
Subtract for events w/ undetected hadrons





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

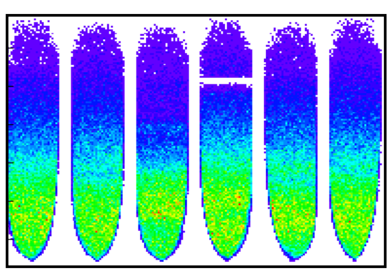
Subtracting QE like background

Presenting cross section —New—

New estimation for the integrated luminosity for the CLAS6 runs

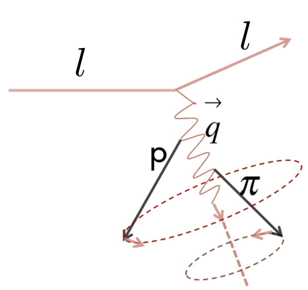
Applying simulation based acceptance correction, radiative corrections

Systematics:



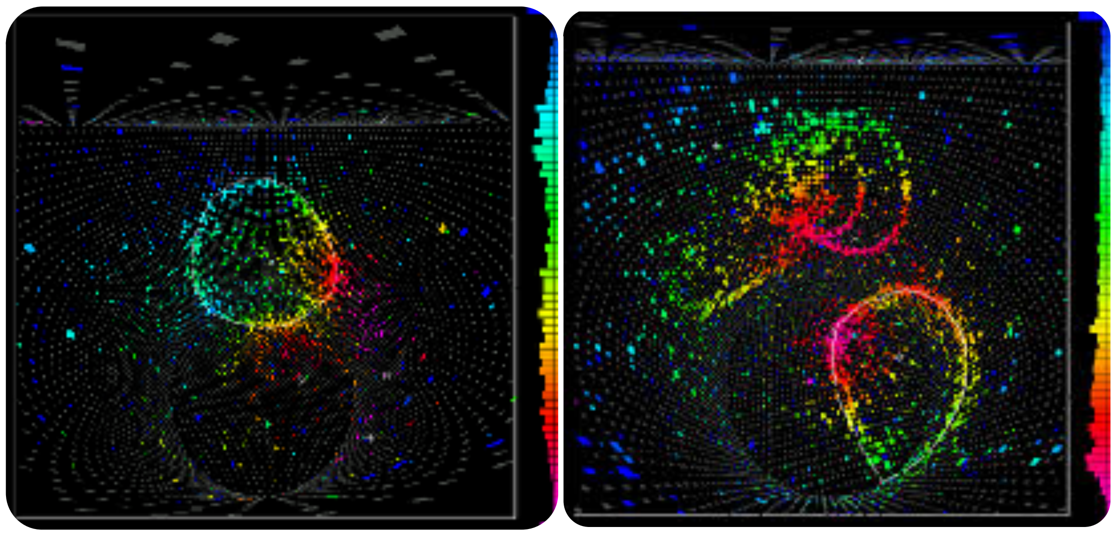
- Comparing independent measurement in each sector.

- Varying CLAS acceptance and photon identification cuts



- $\phi_{q\pi}$ independence of the for background subtraction

Incoming Energy Reconstruction

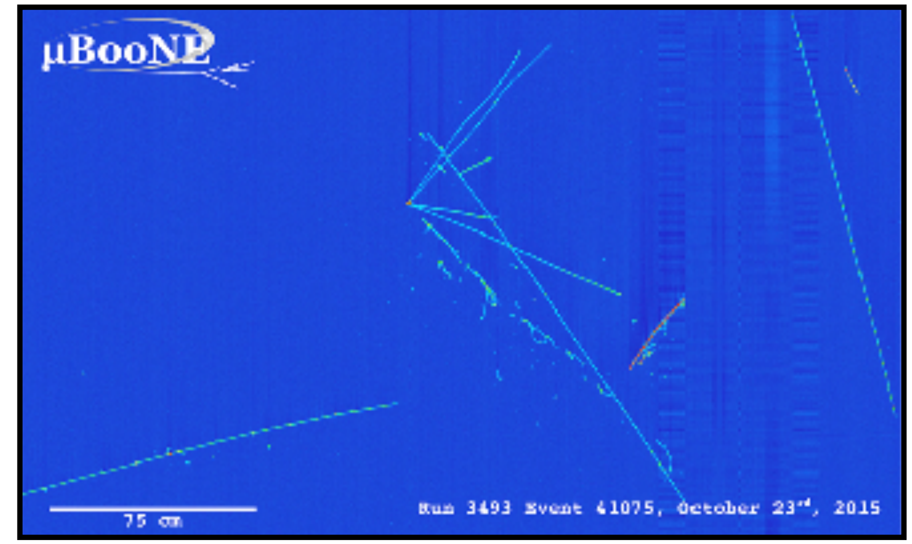


Cherenkov detectors:

Assuming QE interaction

Using lepton only

$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l|\cos\theta_l)}$$



Tracking detectors:

Calorimetric sum

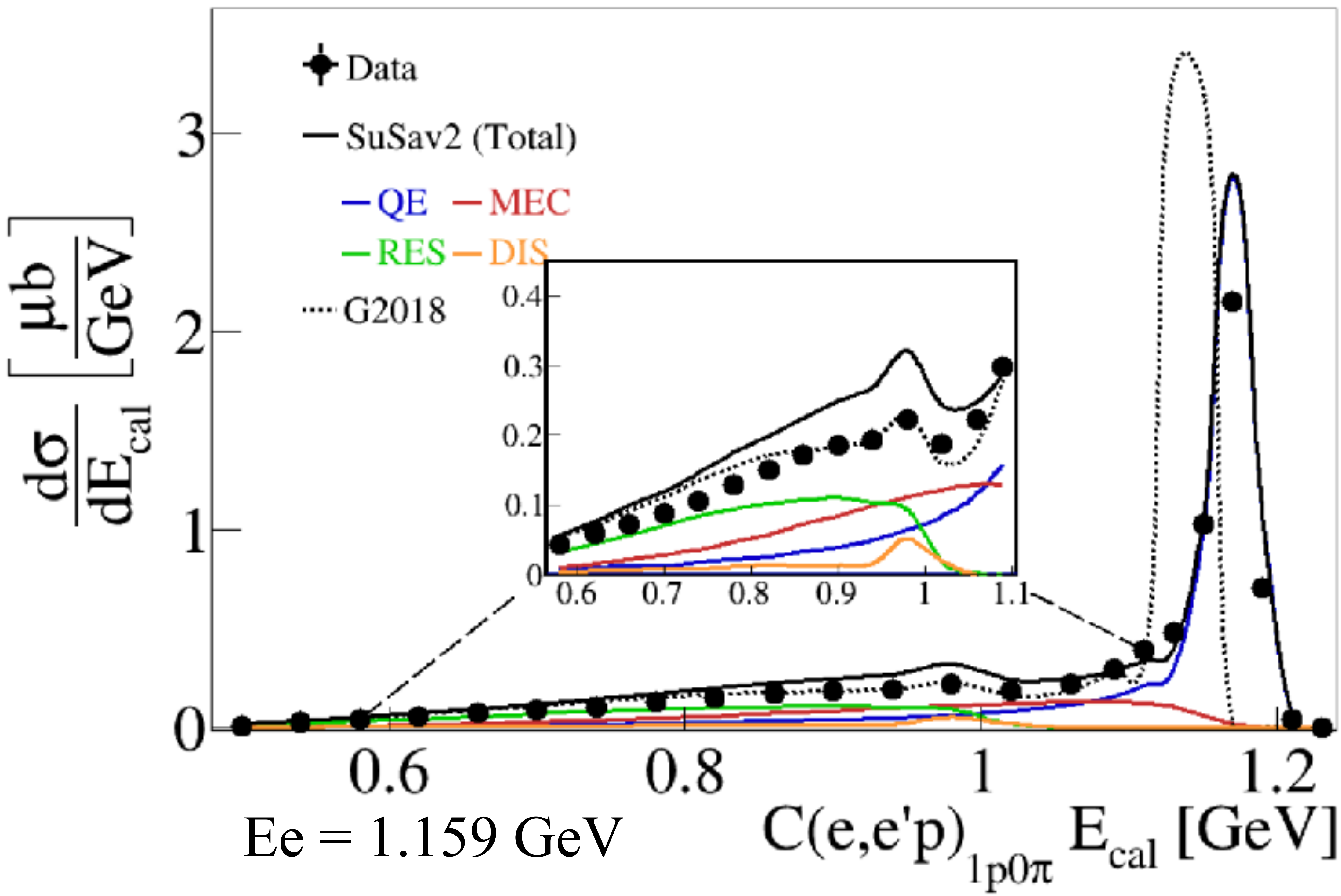
Using All detected particles

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon$$

[1p0π]

ϵ is the nucleon separation energy ~ 20 MeV

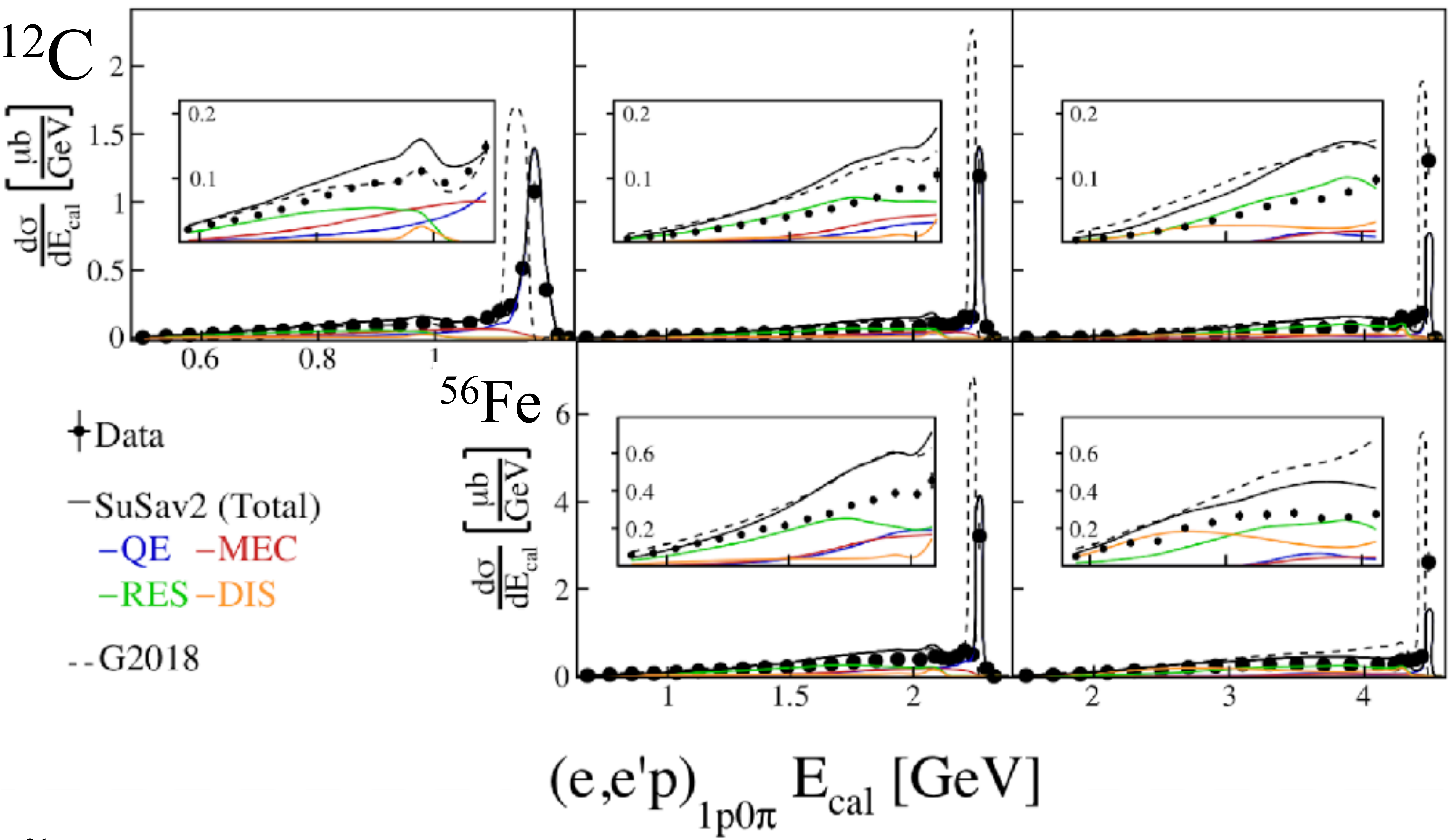
Disagreements between Data and MC



Ee = 1.159 GeV

Disagreements between Data and MC

1.159 GeV 2.257 GeV 4.453 GeV



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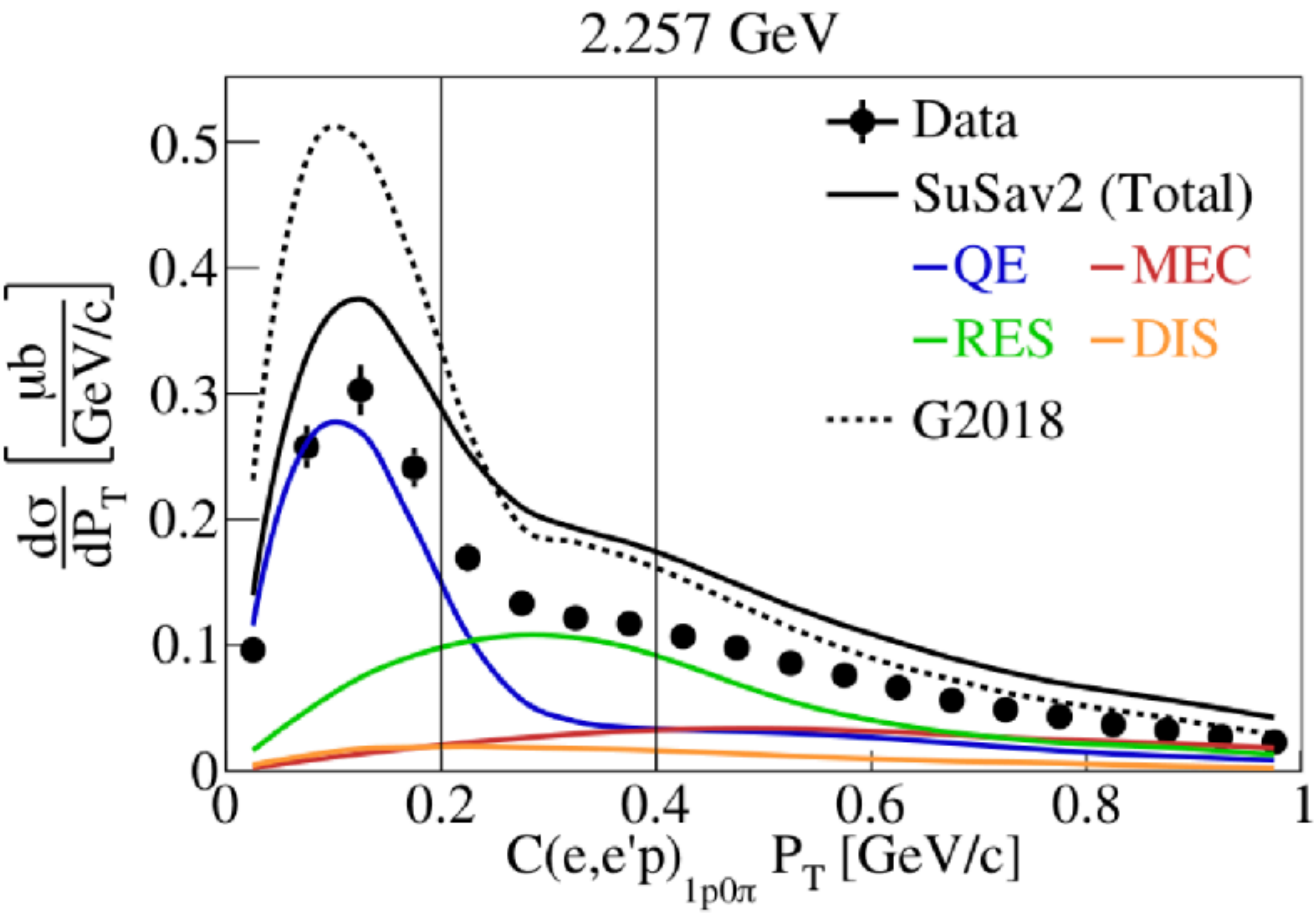
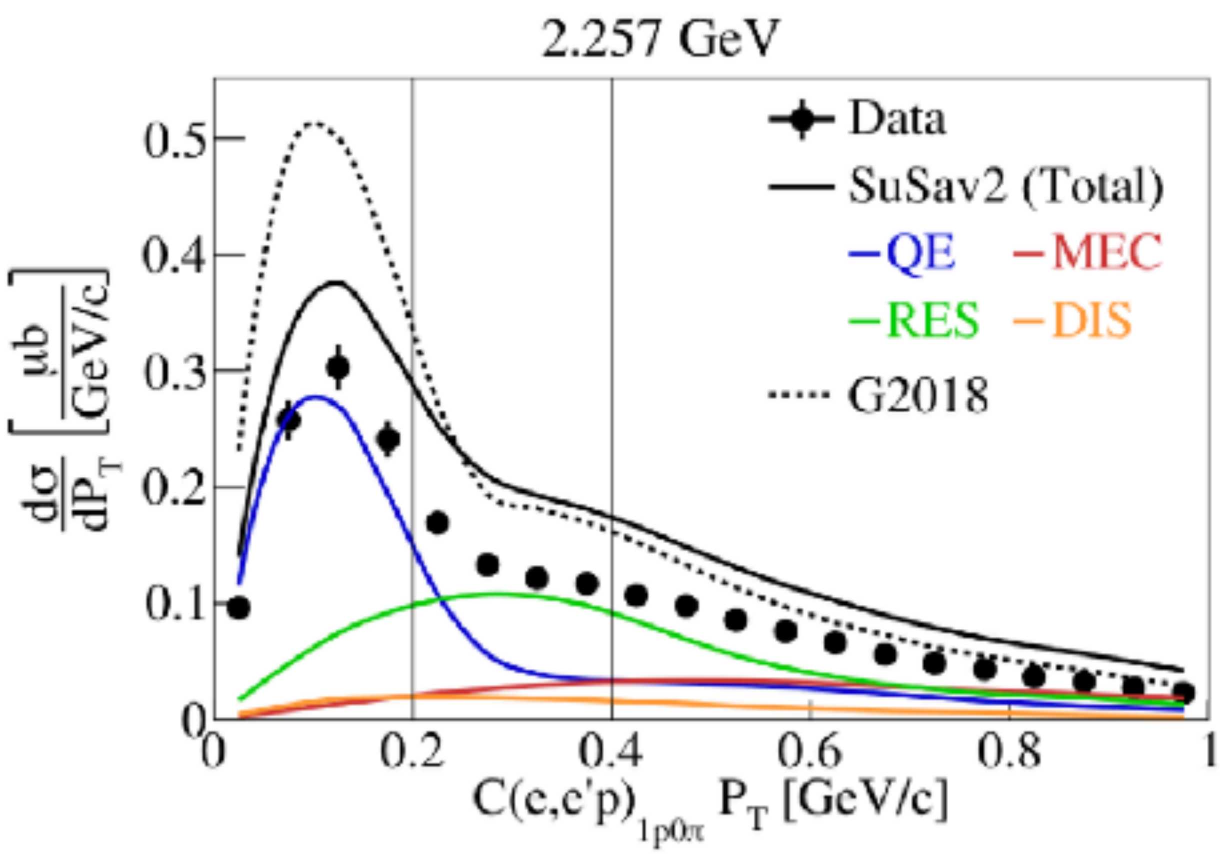
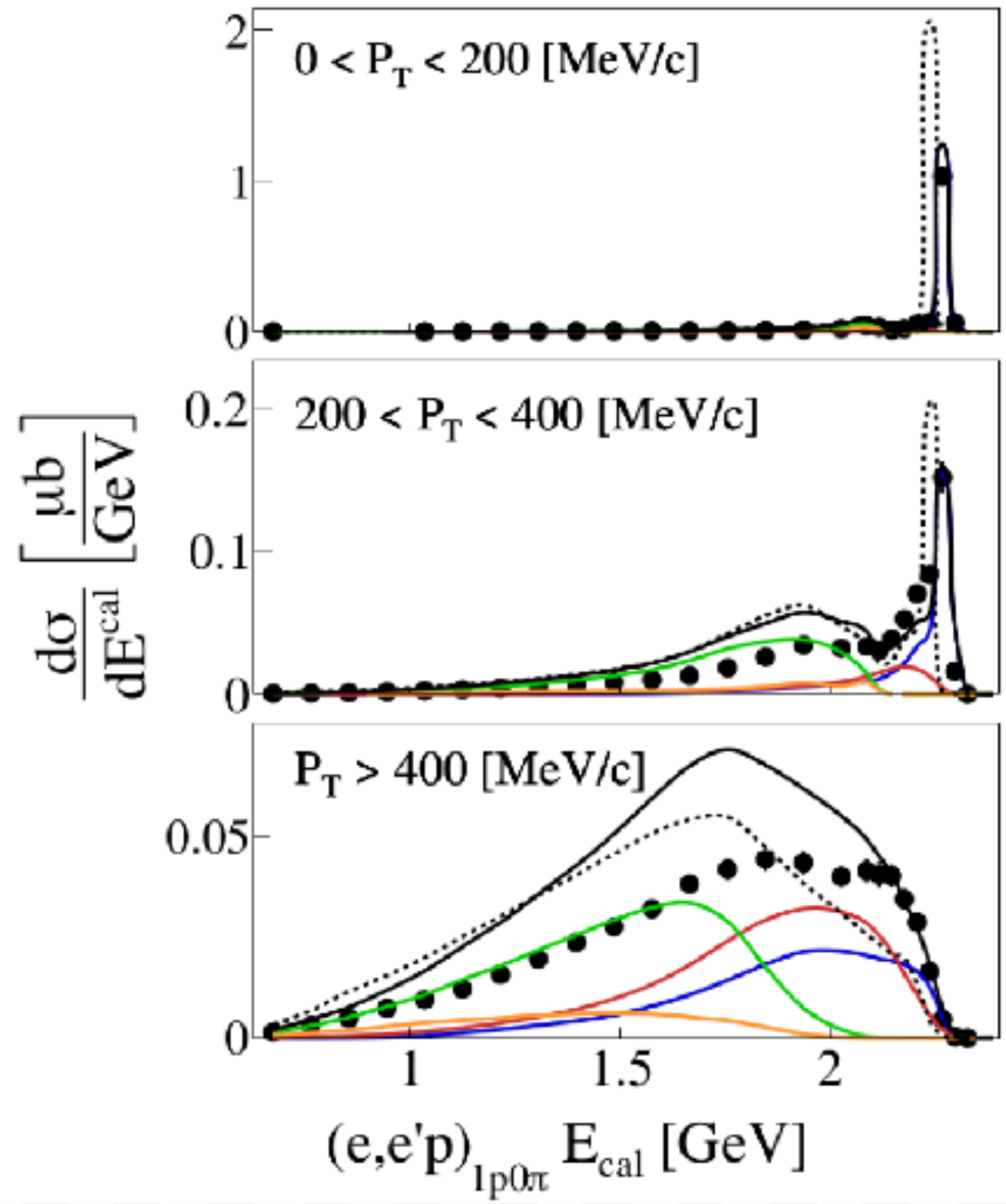


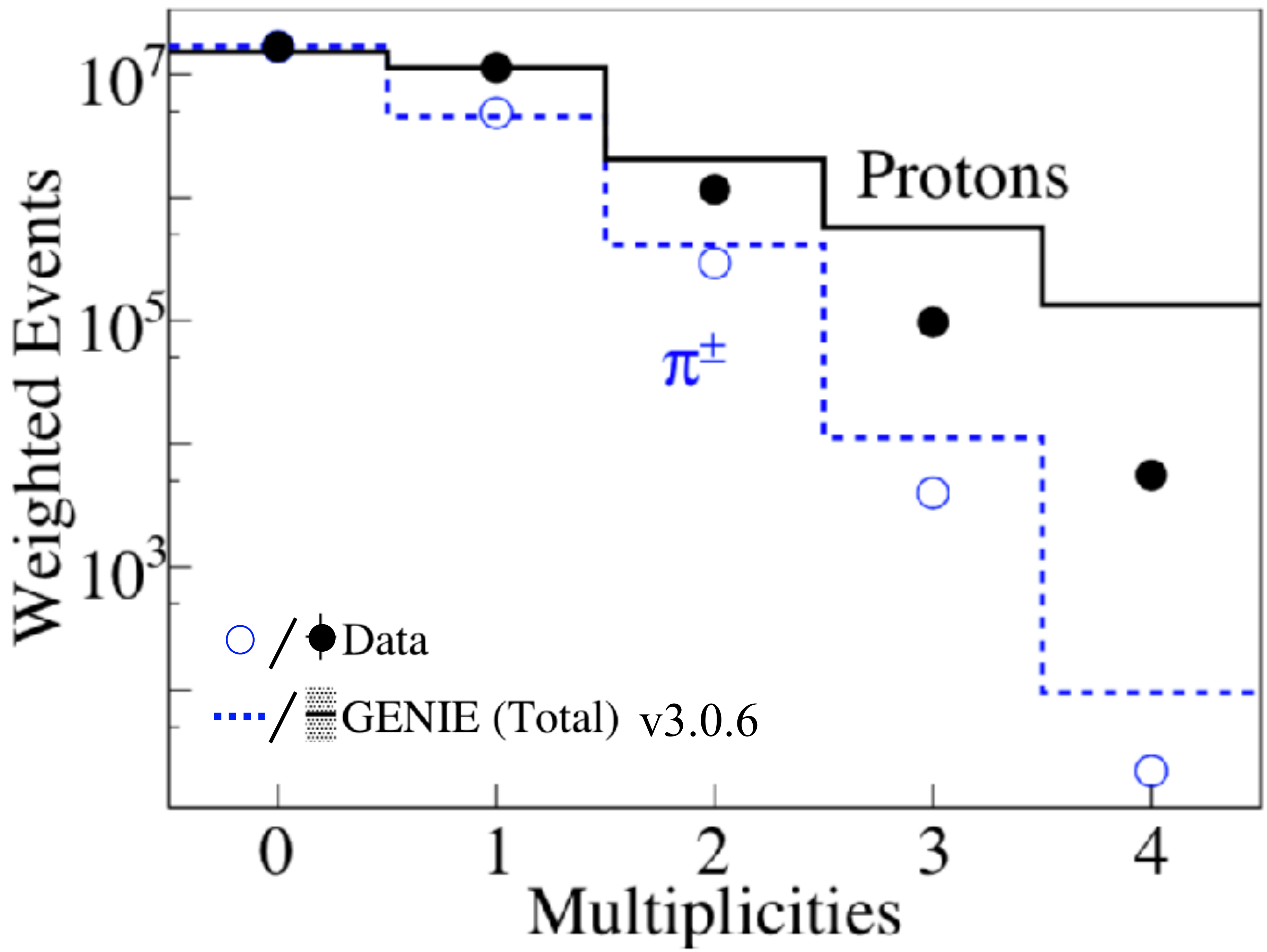
Disagreements between Data and MC





Multiplicities

E = 2.257 GeV ^{12}C



Future Plans -Approved run for CLAS12

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

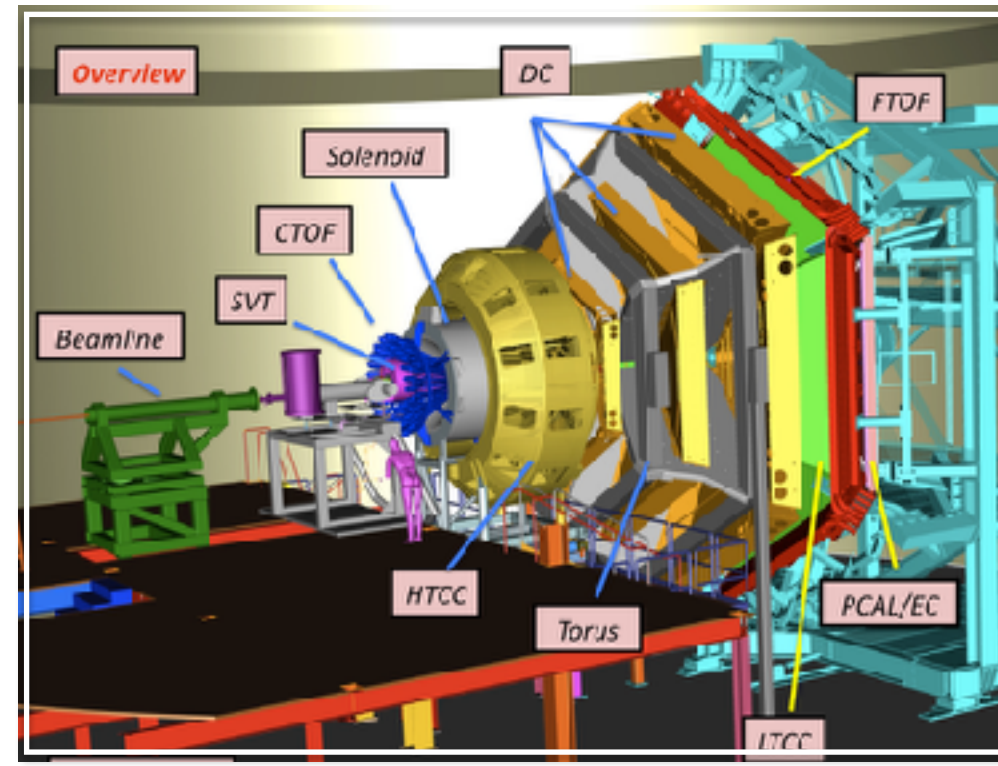
x10 luminosity [10^{35} $cm^{-2}s^{-1}$]

Keep low thresholds

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

1 - 7 GeV (relevant for DUNE)

Running planned for 2021



Overwhelming support from:

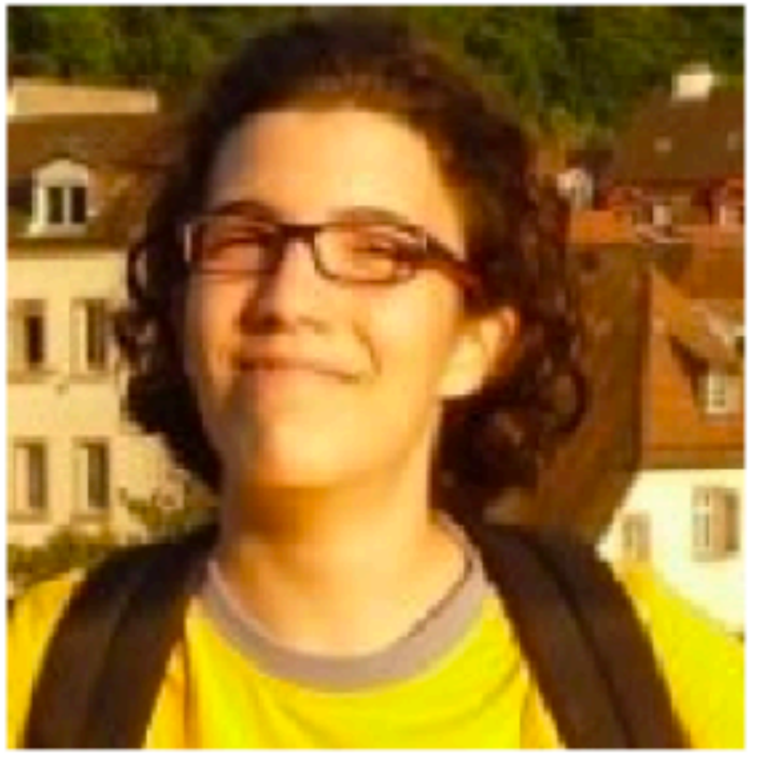
DUNE ICECUBE SOUTH POLE NEUTRINO OBSERVATORY Hyper-Kamiokande T2K NOvA MINERvA

Fermilab GiBUU The Giessen Boltzmann-Uehling-Uhlenbeck Project Genie µBooNE

e4ν The team

Mariana Khachatryan

ODU @ JLab

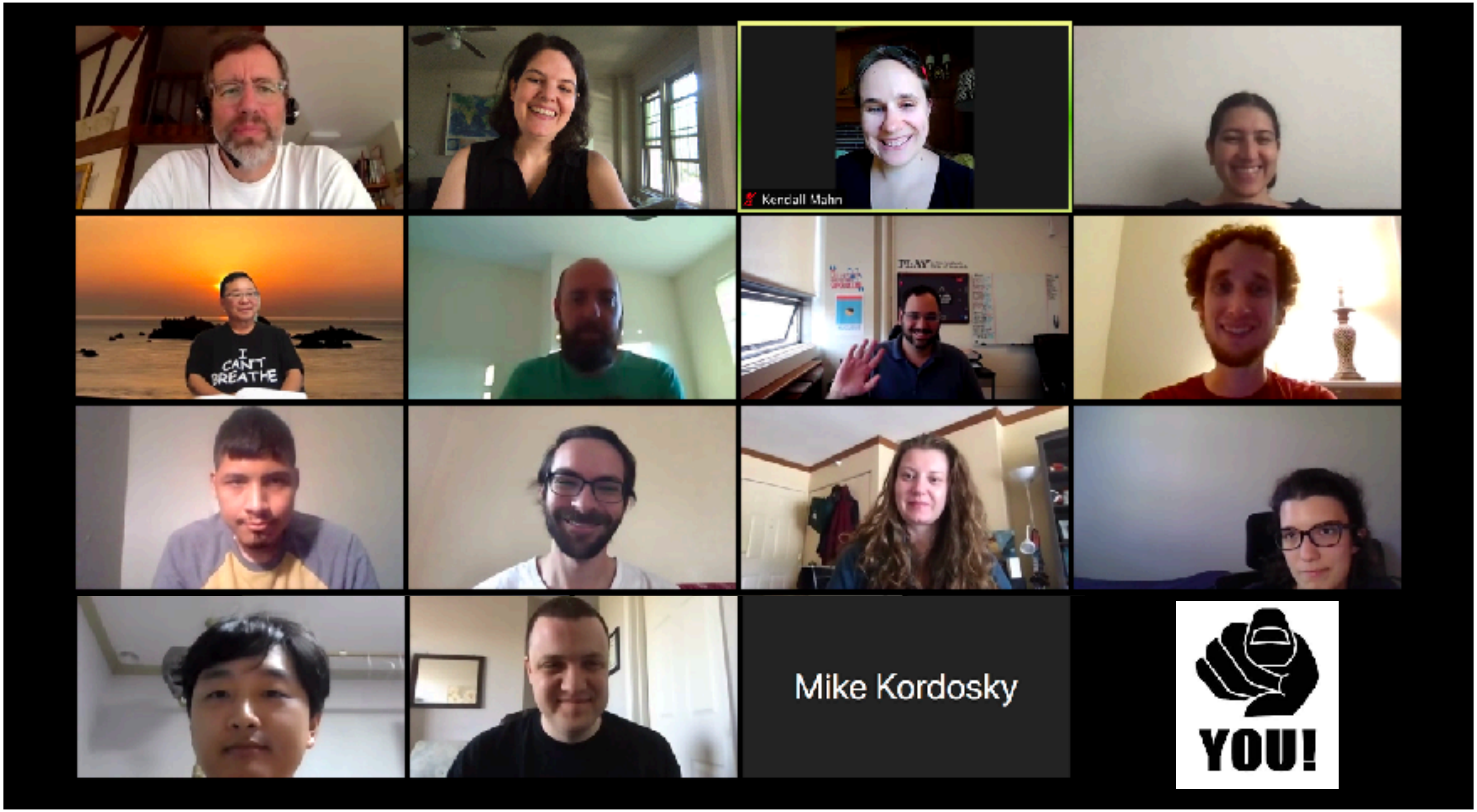


Afroditi Papadopoulou

MIT @ FNAL

Jefferson Lab CSIC Consejo Superior de Investigaciones Científicas

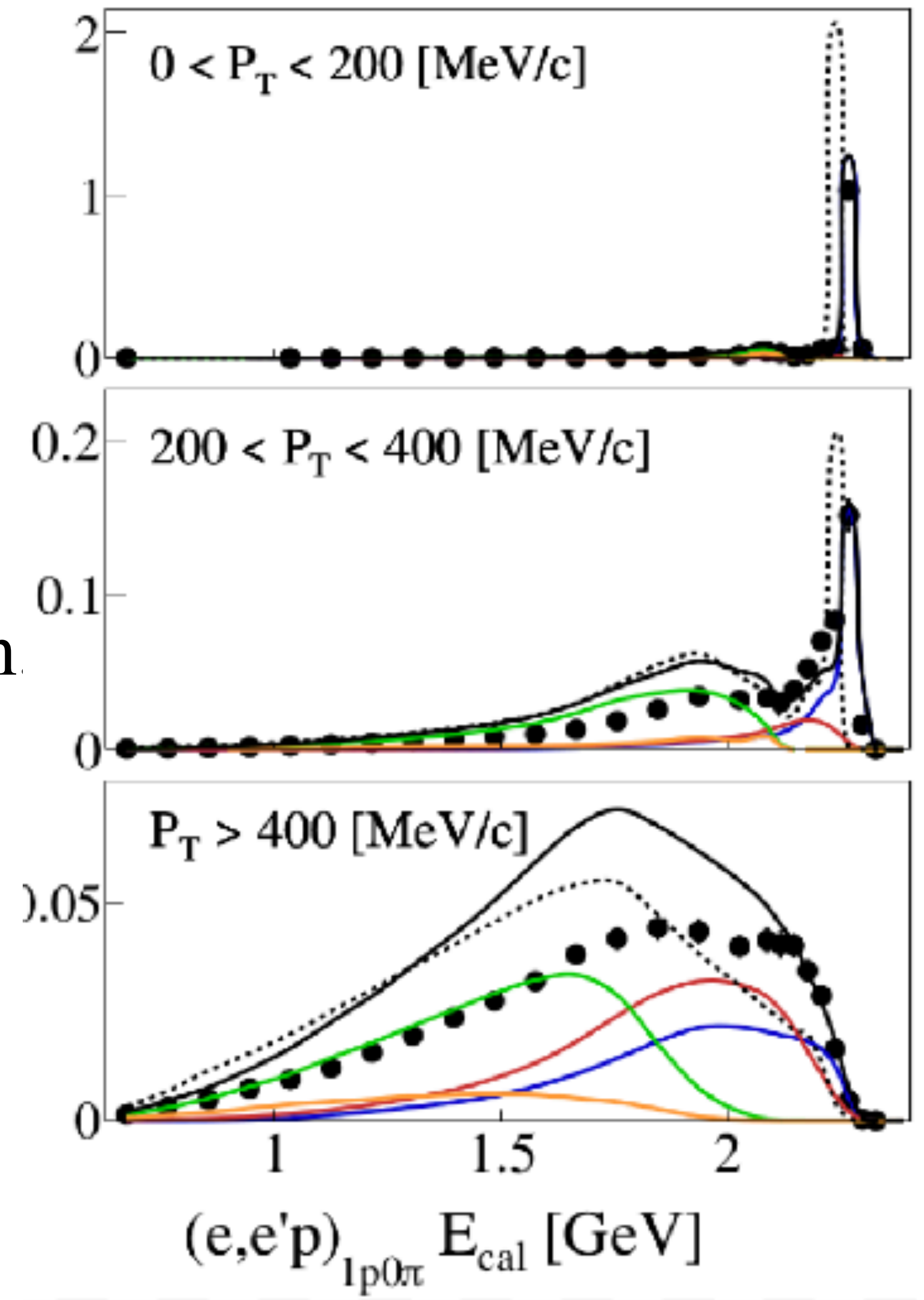
e4ν The team



Contact us: adi@fnal.gov betan009@fnal.gov

Summary

- Testing νA Models using wide phase-space eA data.
- Data-MC disagreements for QE-like lepton+proton events
  - Especially for high transverse momentum.
  - Large potential impact on DUNE
- Our data will help improve models
- More data coming very soon



Thank you for your attention

GENIE Simulation

Genie v3.0.6 tune G18_10a_02_11a

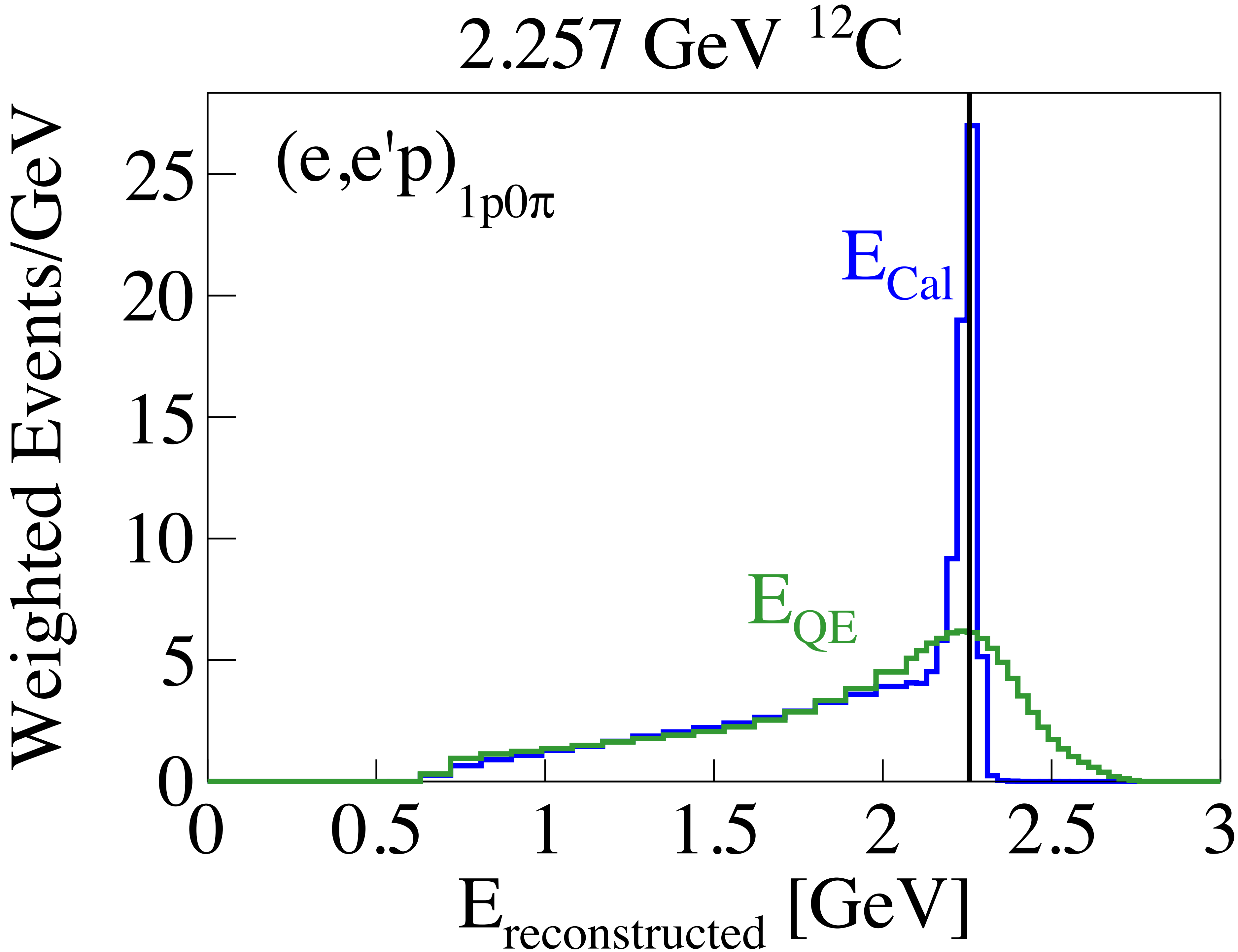
	electrons	neutrinos
Nuclear model	Local fermi gas model	
QE	Rosenbluth CS	Nieves model
MEC	Empirical model	Nieves model
Resonances	Berger Sehgal	
DIS	AGKY	
FSI	hA2018	
Others	Adding radiative correction	

GENIE Simulation

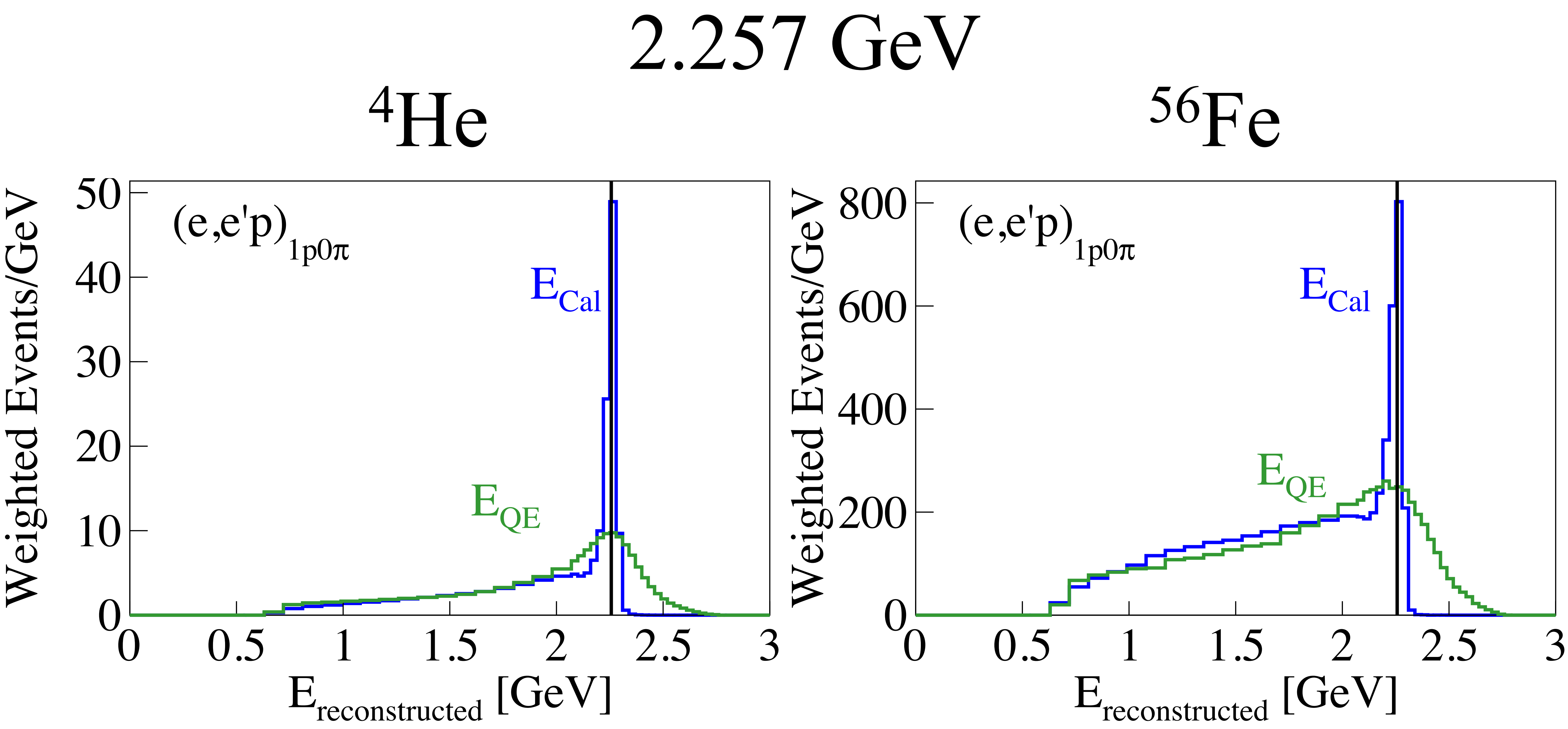
Genie v3.0.6 SuSA

	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 the incoming energy reconstruction



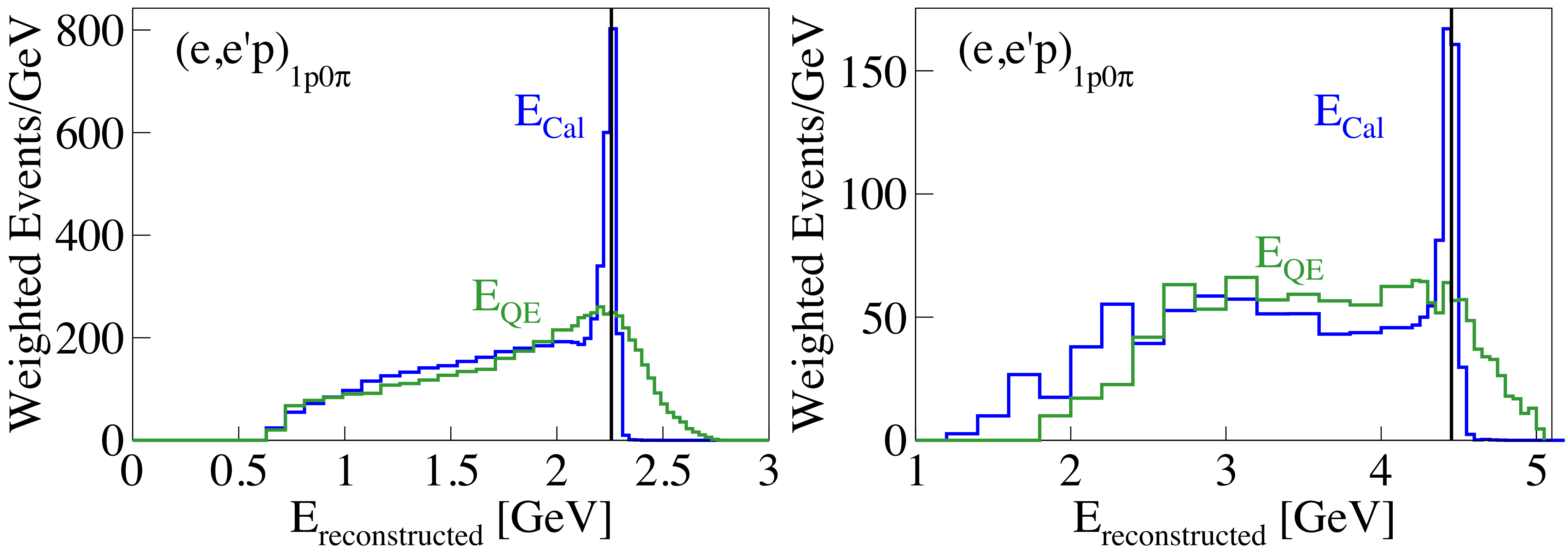
E_{rec} Worse with Higher Mass



E_{rec} Worse with Higher Energy

^{56}Fe

2.257 GeV   4.453 GeV

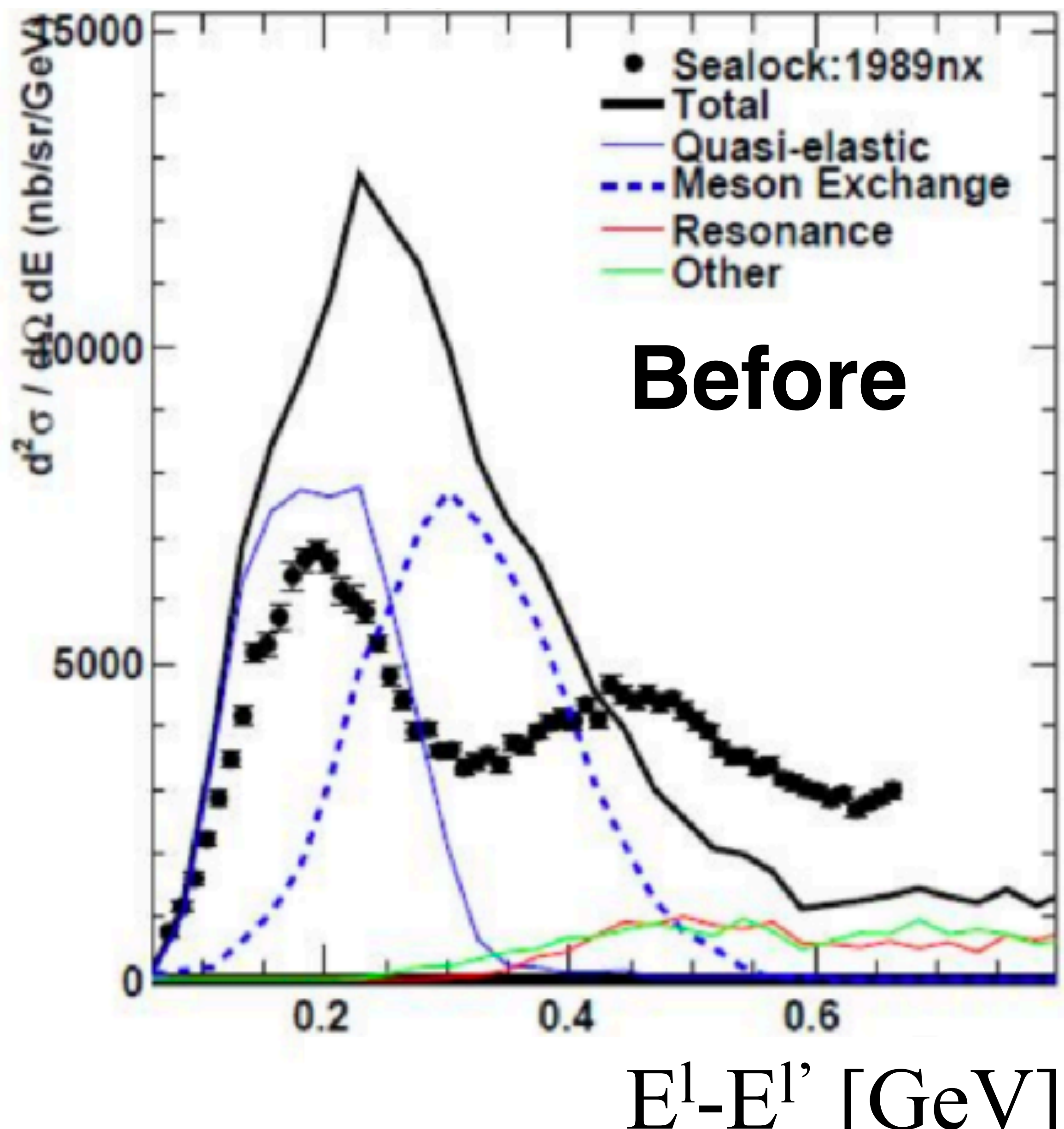


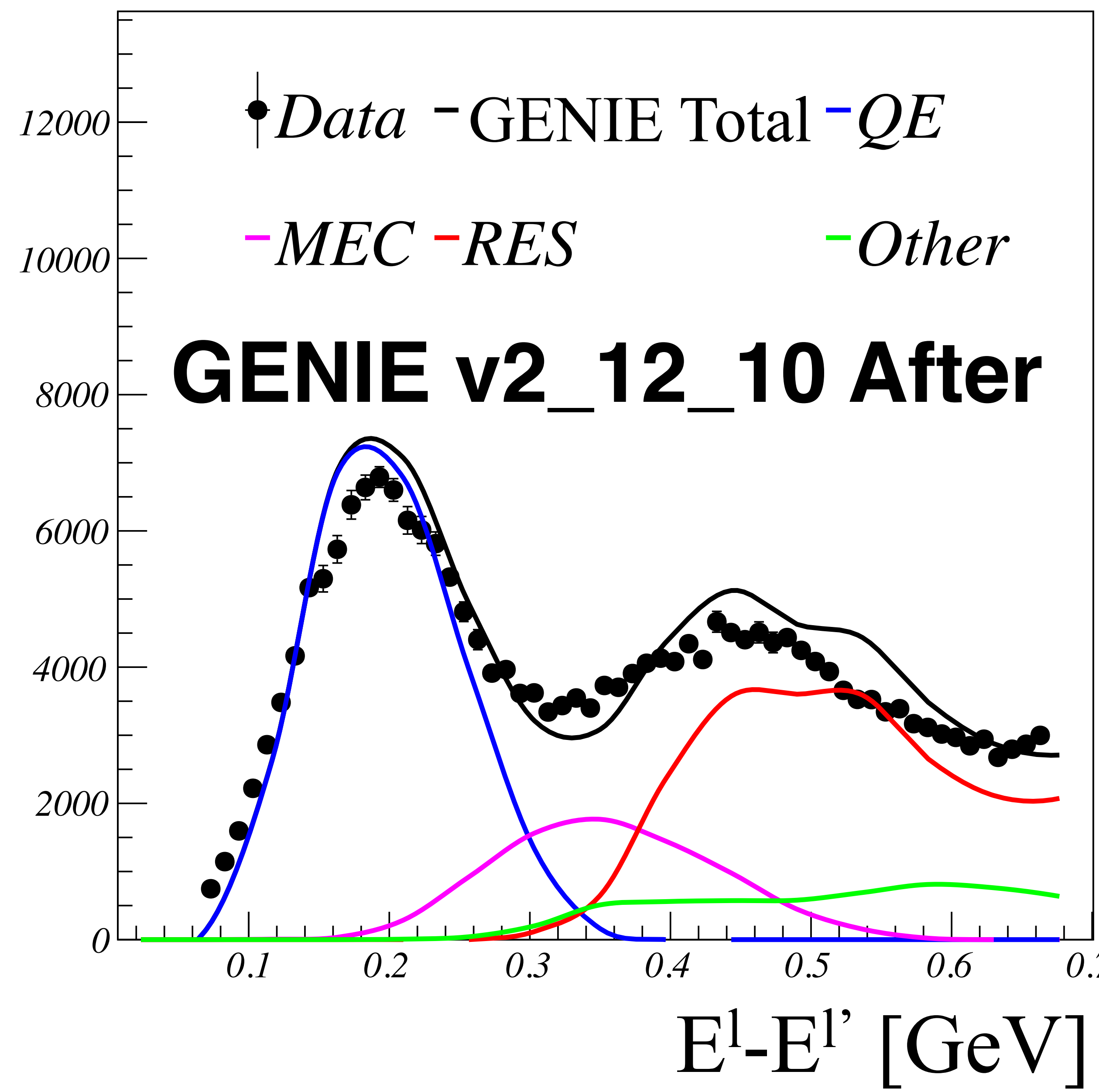
Systematic Uncertainties - Data side

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 ±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.

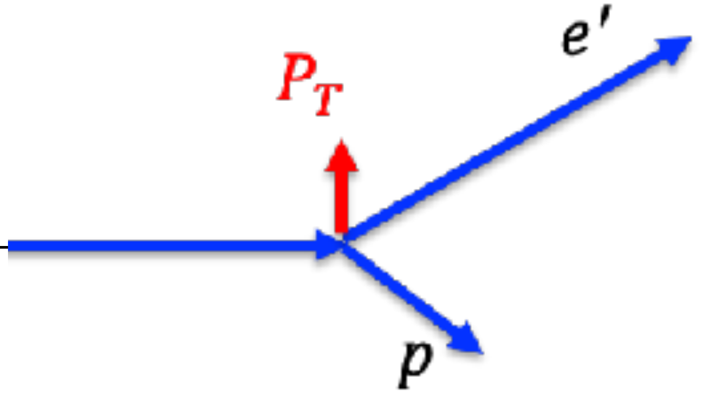
Testing neutrino generators with inclusive electron scattering data

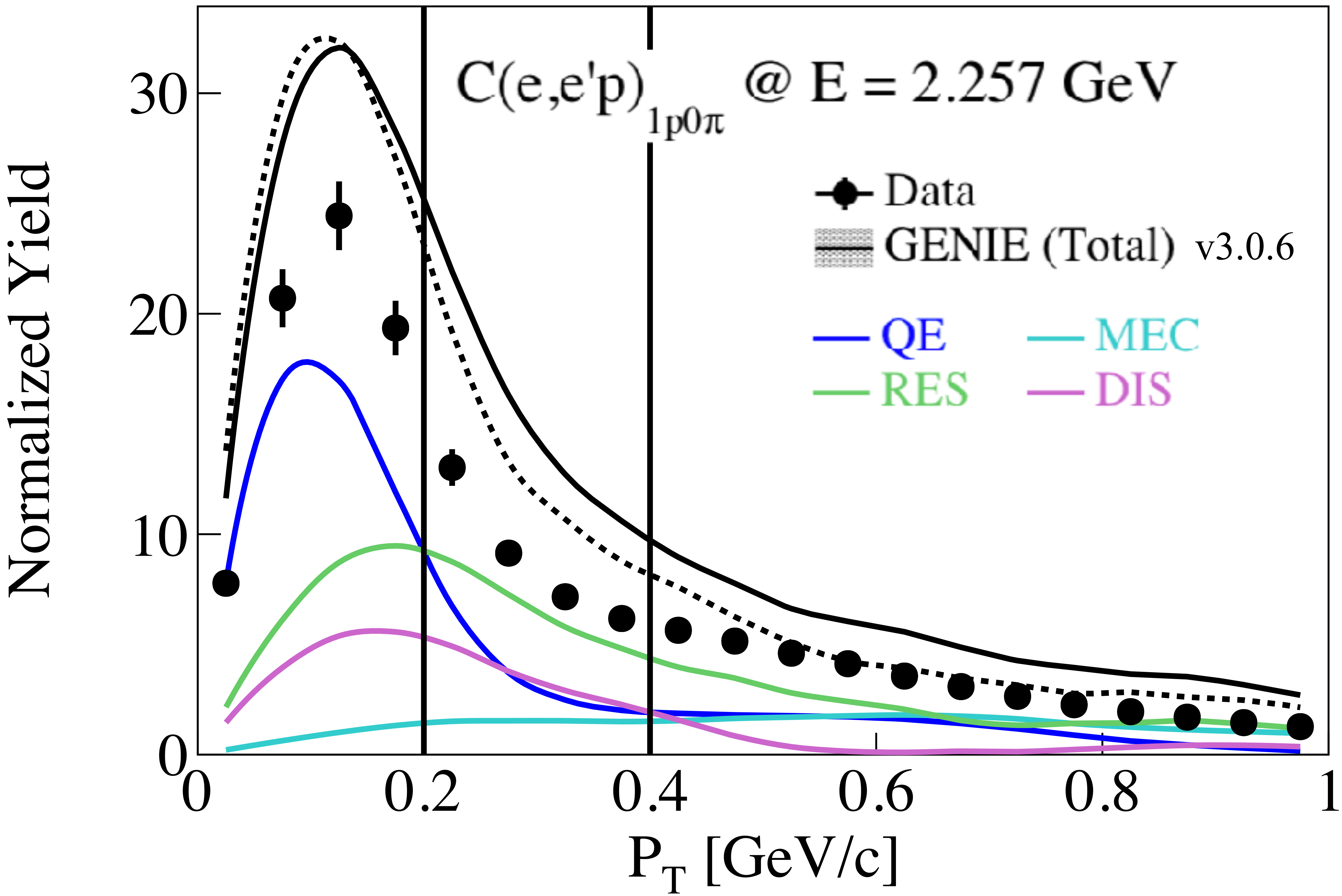
12C(e,e') E = 0.961 GeV $\theta = 37.5^\circ$





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





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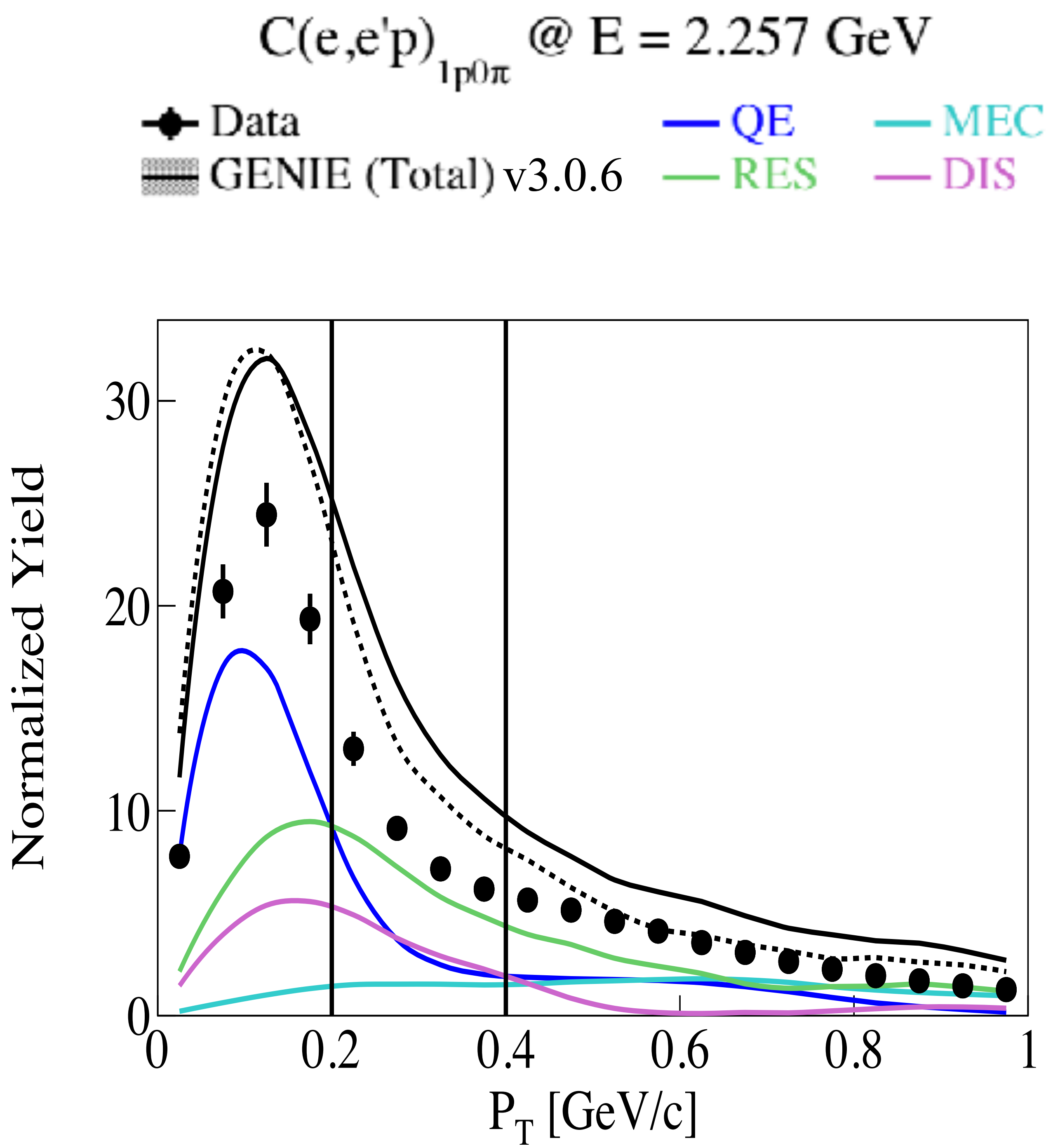
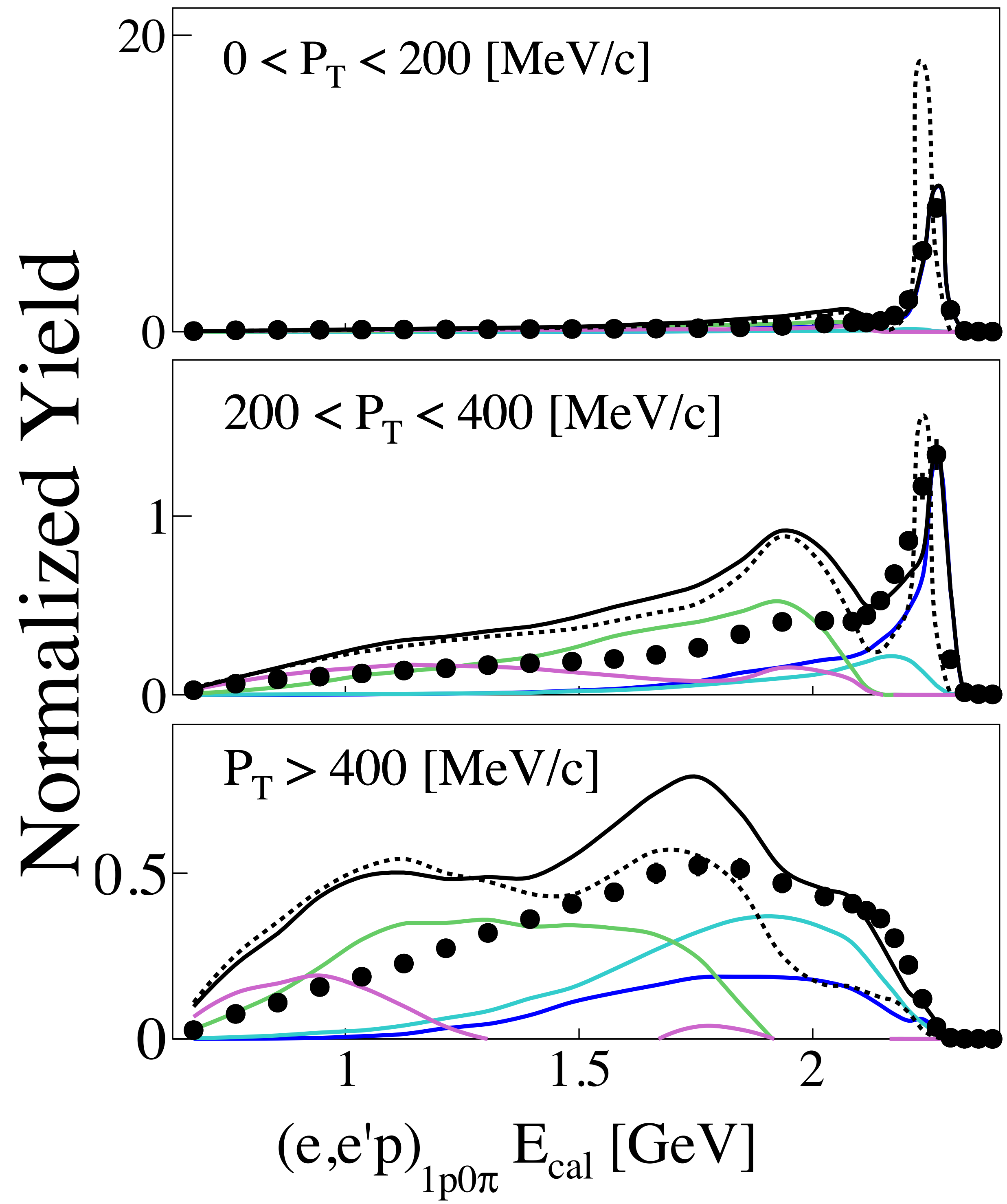
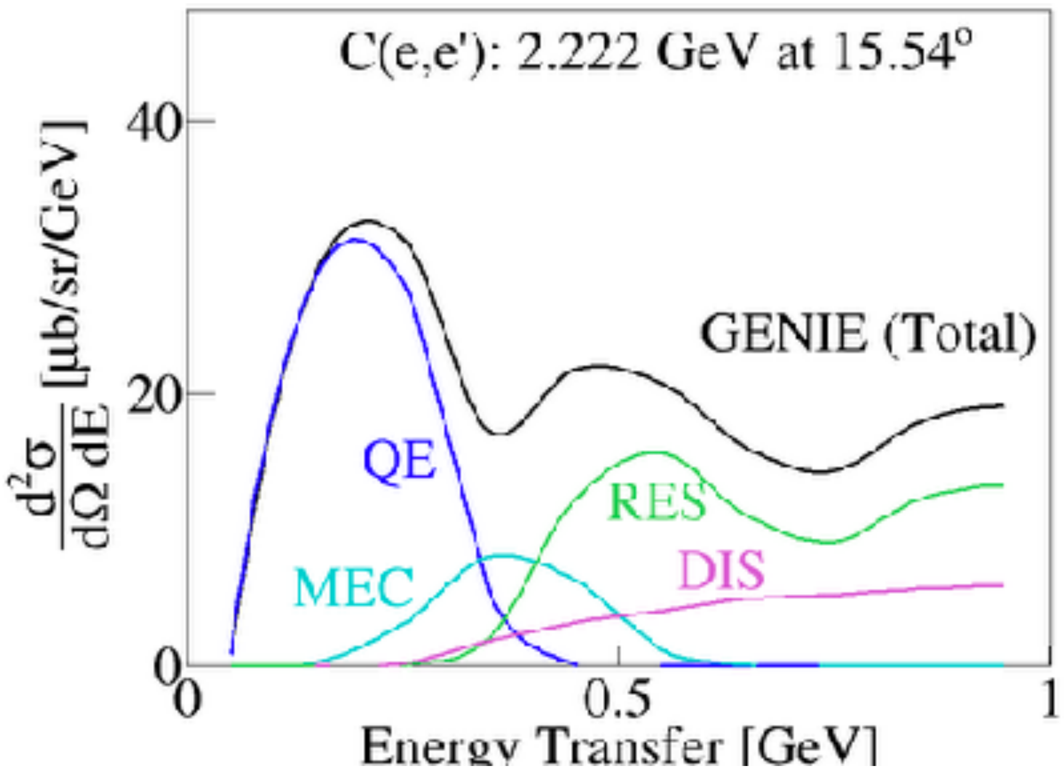
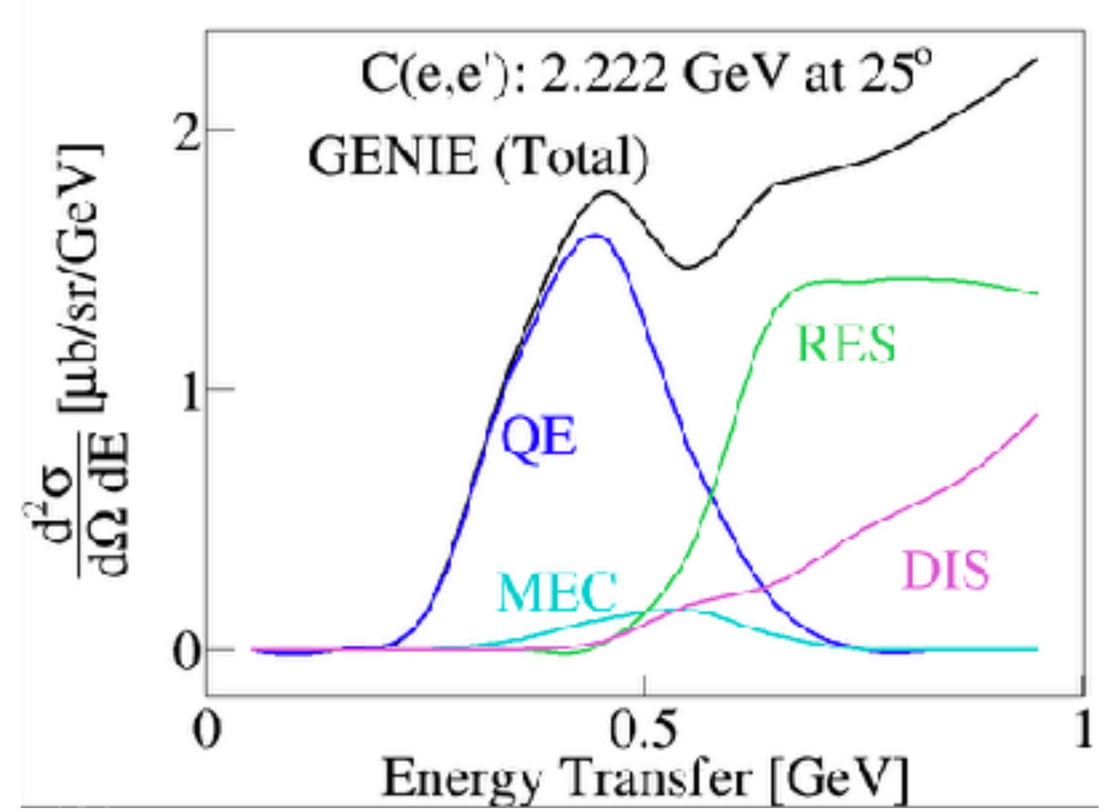


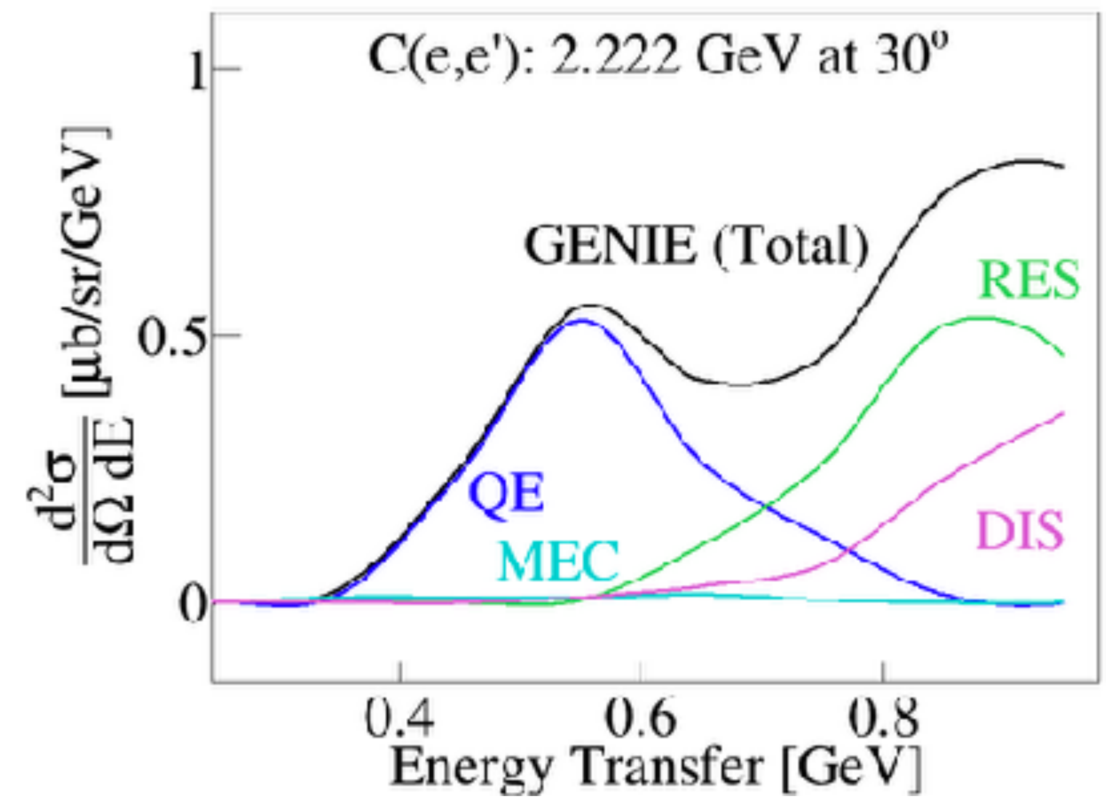


Where did the MEC in G2018 go?

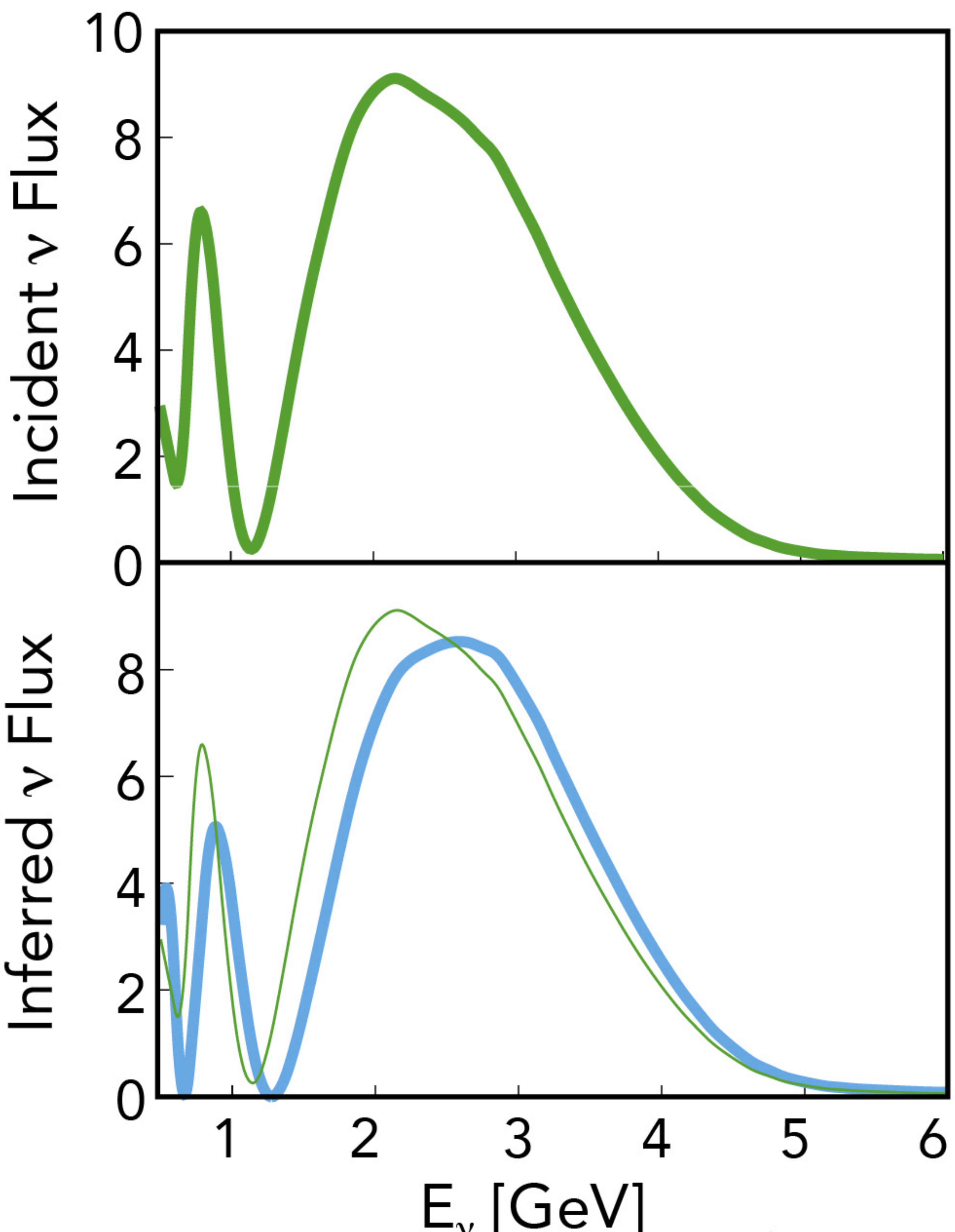




CLAS6: $15^o < \theta_e < 45^o$



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