Electrons for Neutrinos

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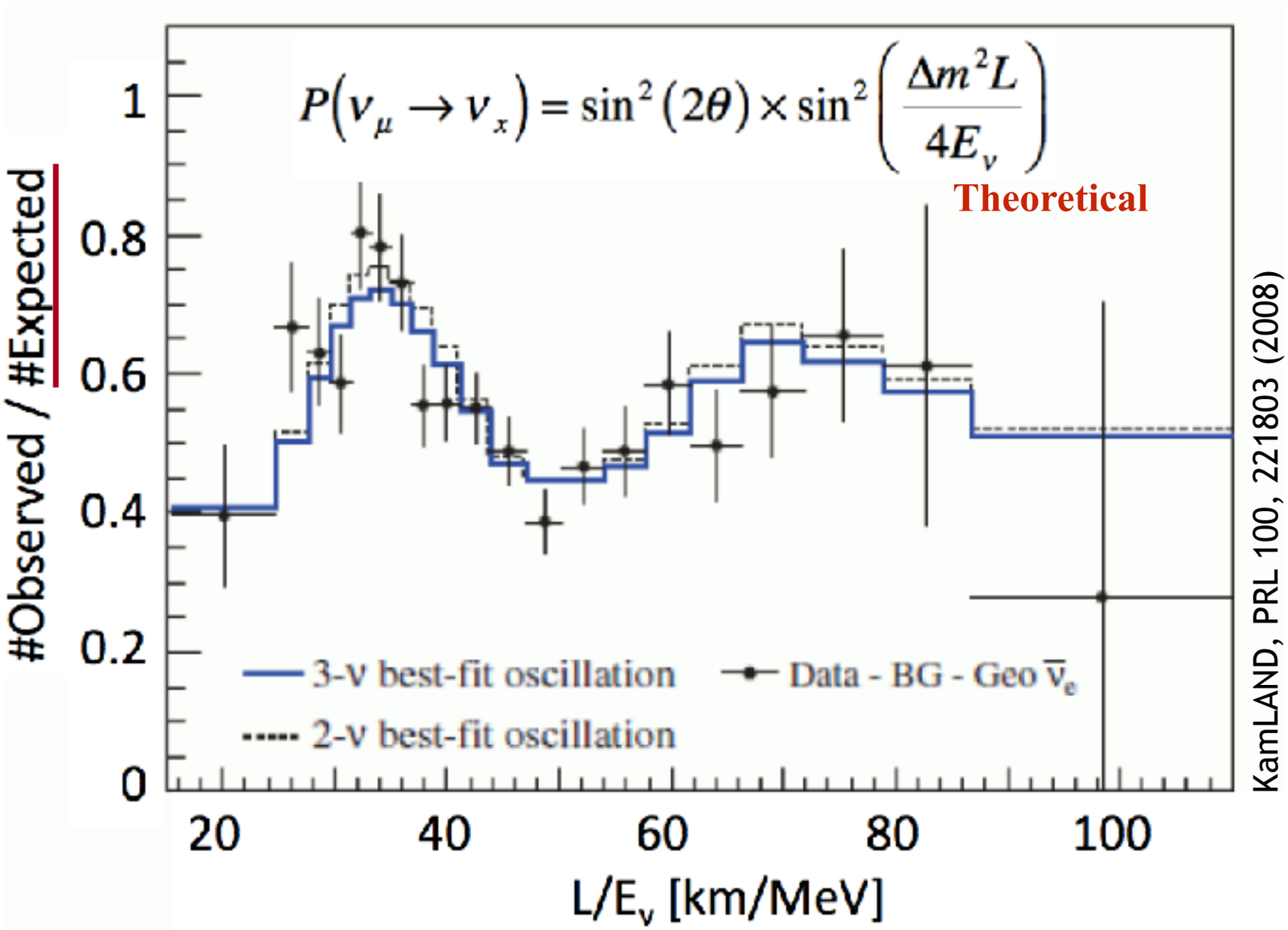
Outline

- Motivation
- Simulation
- A(e,e’) Data
- A(e,e’p) Data
- Future Plans

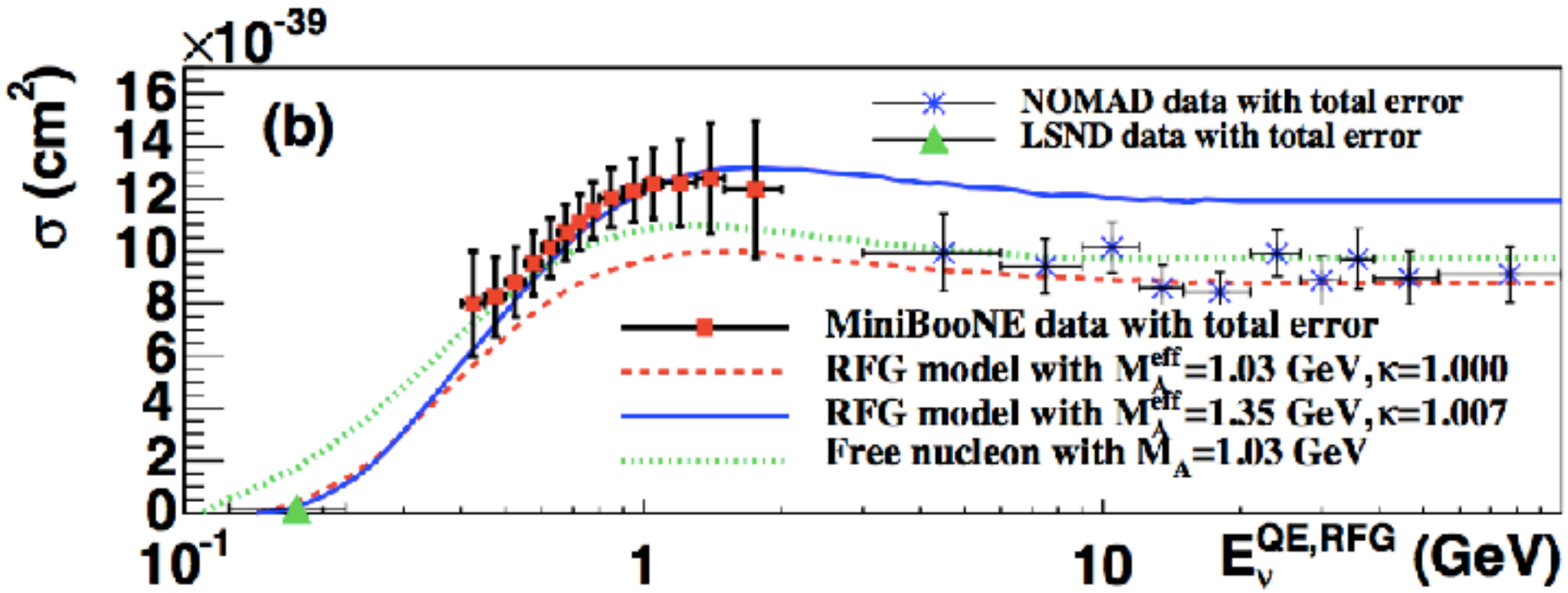
Oscillations Require incoming E_ν Reconstruction



Incoming Energy Recosnstruction

Energy reconstruction from final state lepton

Highly model dependent



Energy Reconstruction Approaches

- Improved theory

- **External constraints on nuclear model**
  - Use near detector
    - Where we wish to probe nuclear physics and no oscillation effects
    - But the flux model and the nuclear model are convoluted

e 4 ν : Wide Phase Space Electron Data

- In the semi classical regime the final state is similar.
- Known incoming energy can test its reconstruction.

Keeping in mind:

EM and not weak interaction is the dominant.

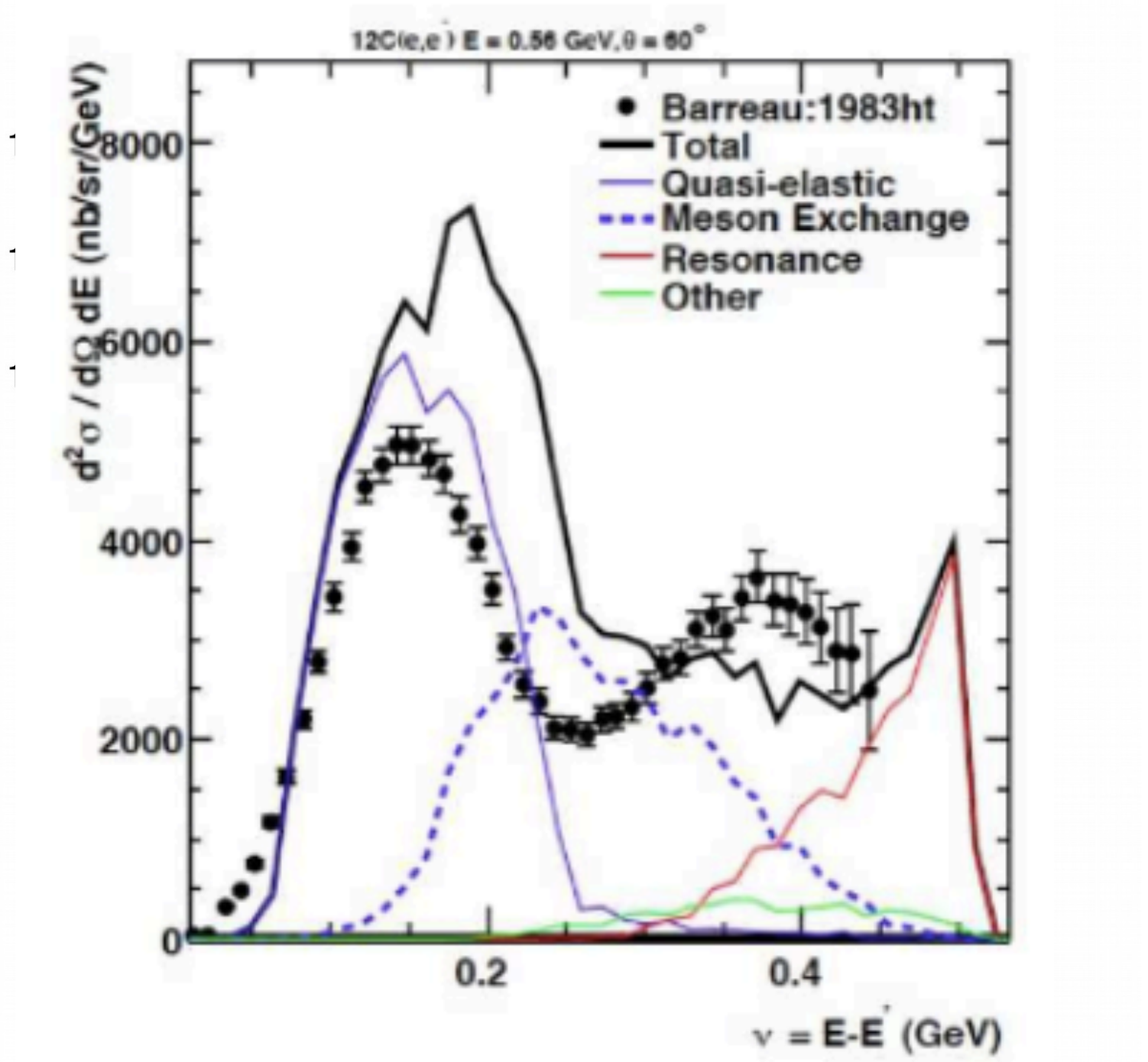
Different radiative effects.

GENIE Simulation

Nuclear model	Correlated fermi gas model
QE	Lewellyn Smith for neutrino
	Rosenbluth CS for electrons
MEC	Empirical Dytman model
Resonances	Rein Sehgal
FSI	data driven

GENIE is calculating each contribution separately and then summing them up

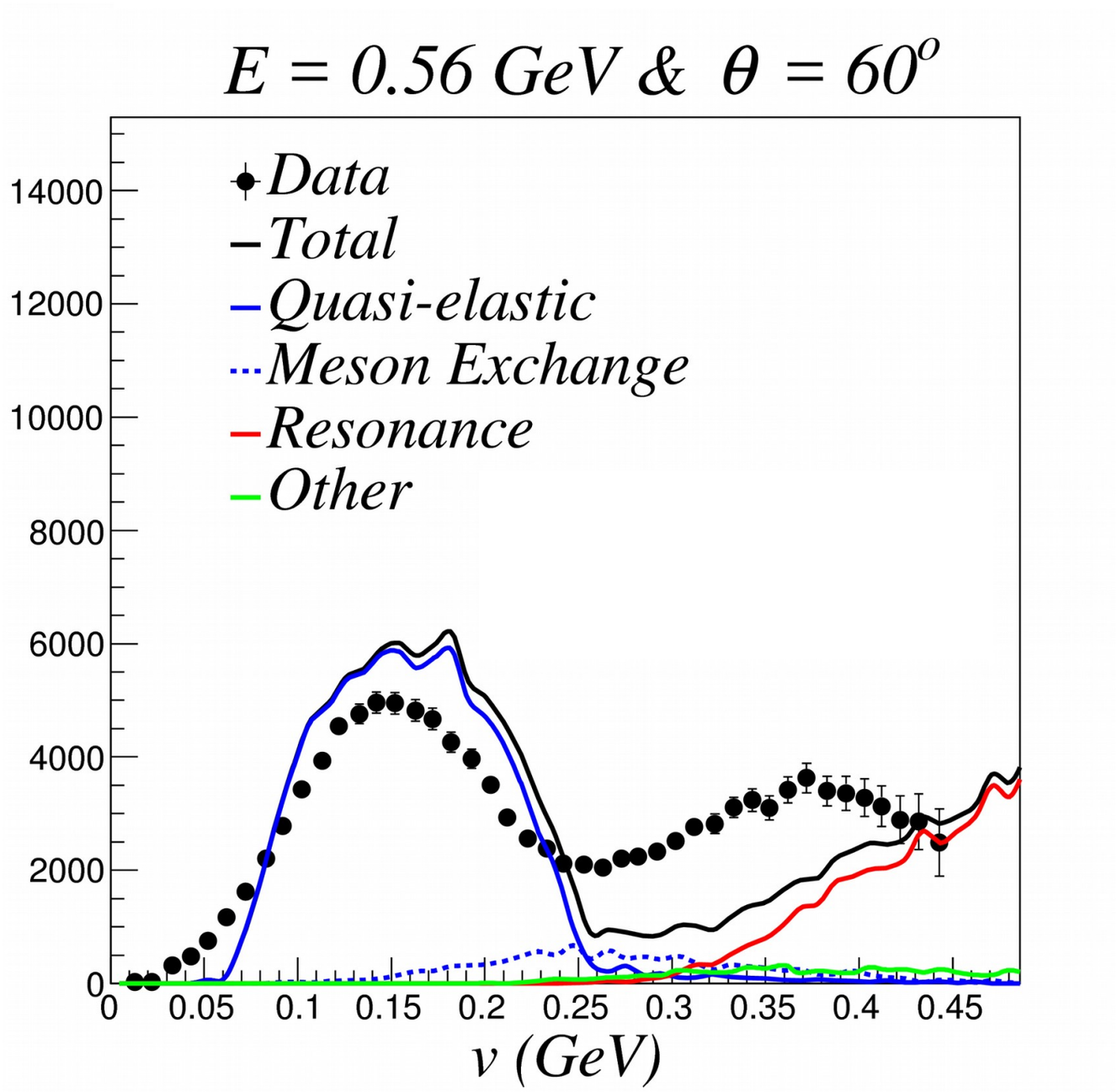
MC vs. (e,e’) Data: Large Disagreements



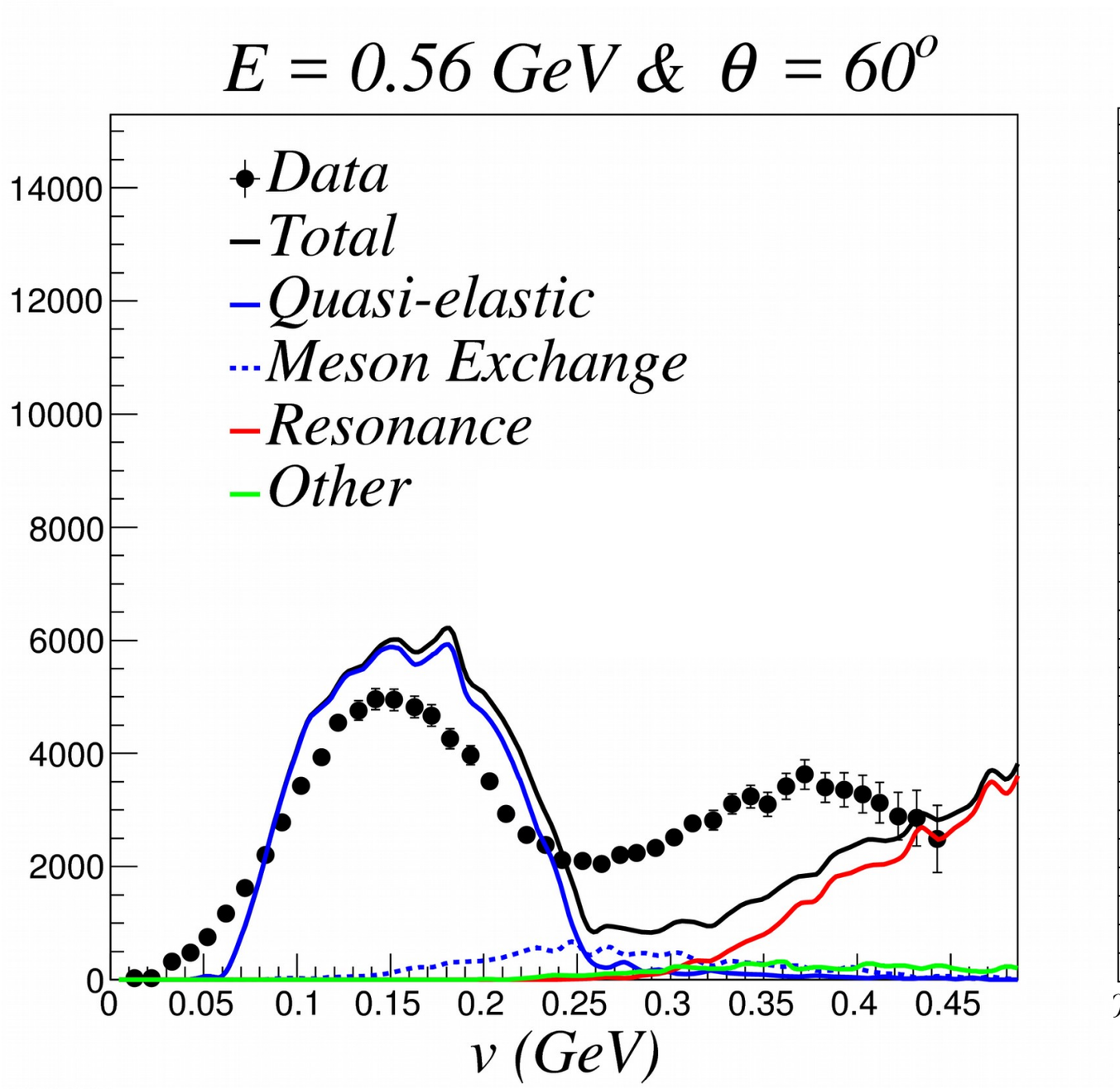
*data from Saclay (1983), arXiv: 1304.6014

MC vs. (e,e') Data: Large Disagreements

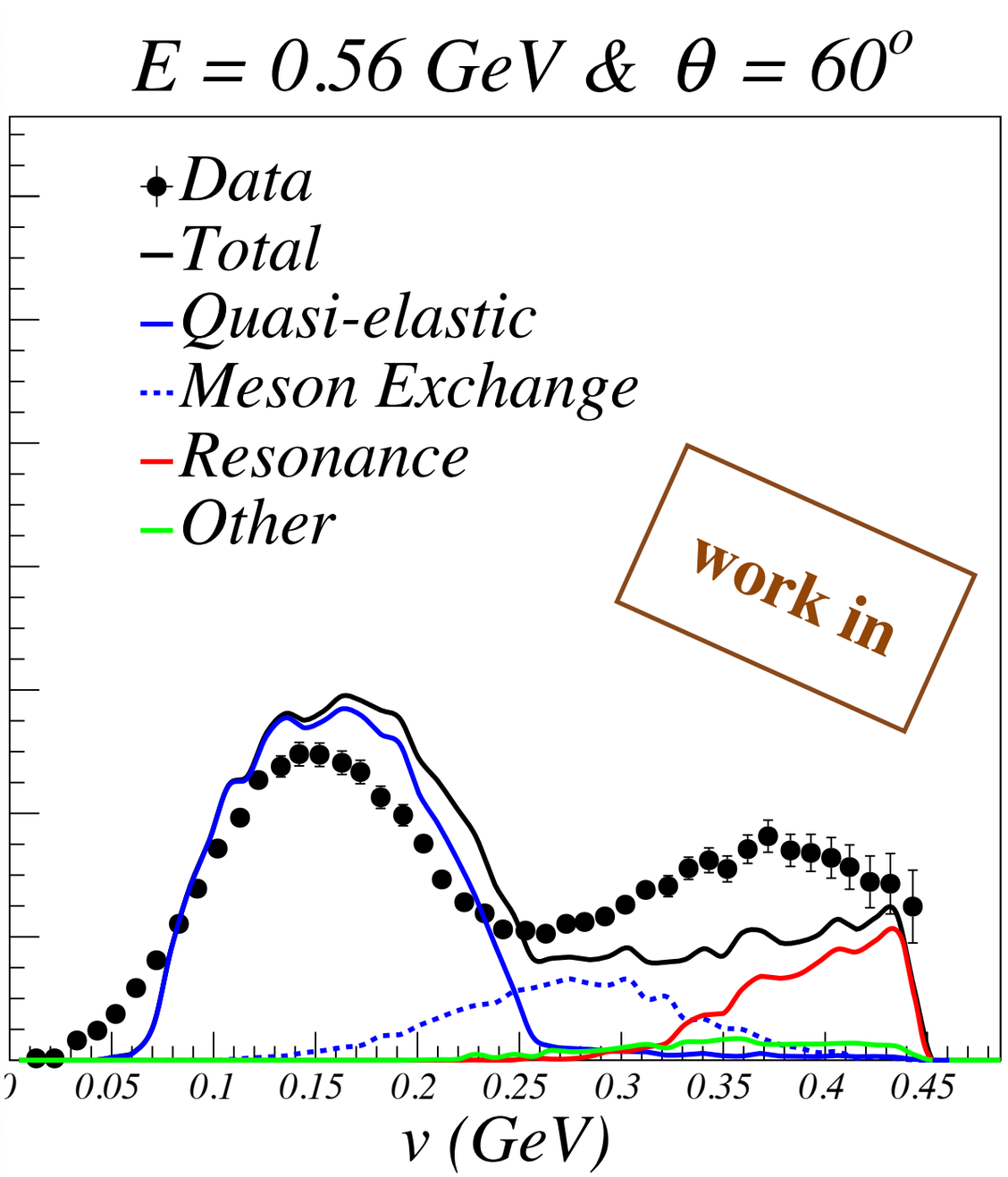
Latest GENIE Version



MC vs. (e,e') Data: Improved Agreement



Before



after improvements

CLAS A(e,e'p) Data

Incoming Electron beam 1 - 5 GeV

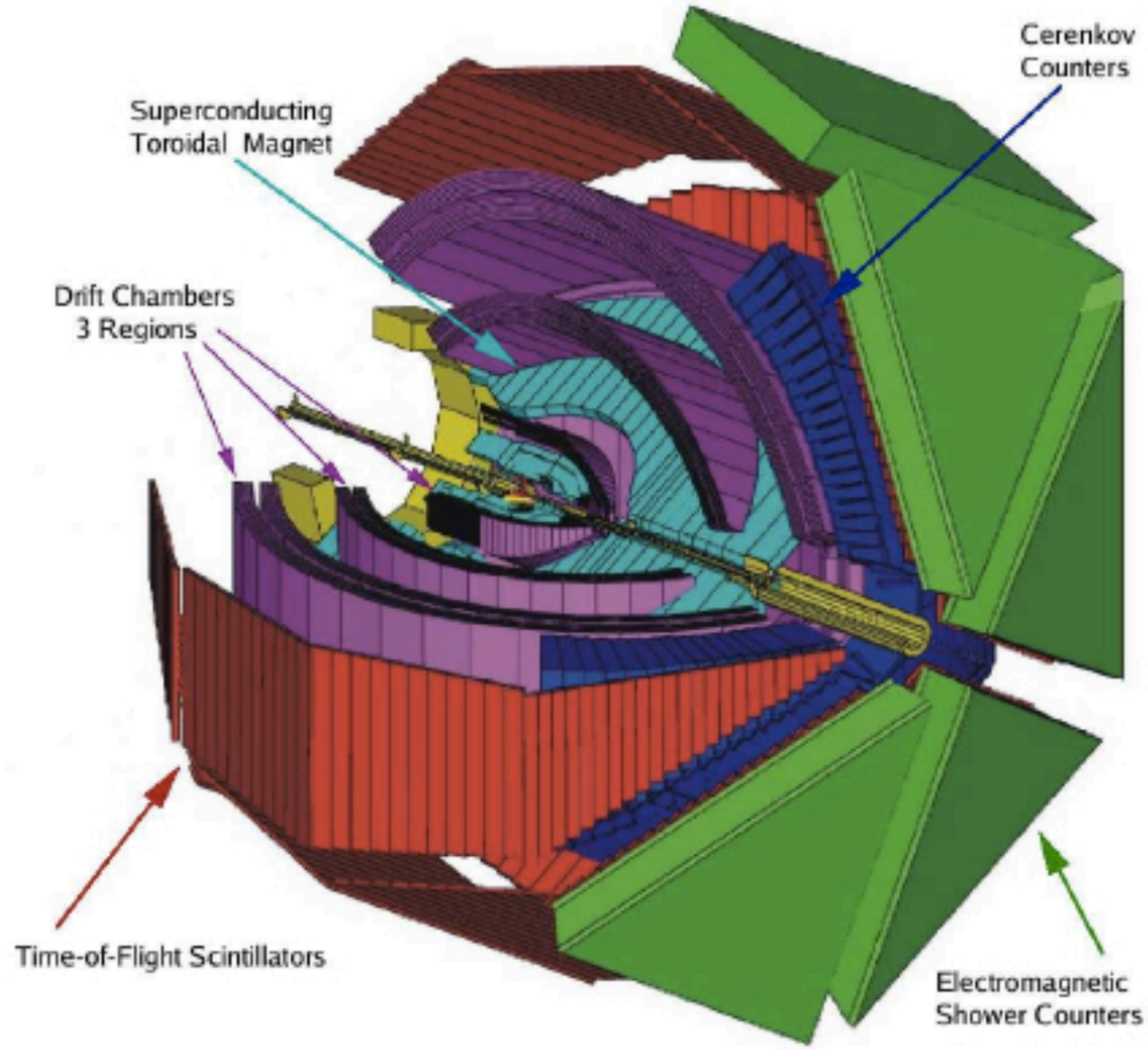
Large acceptance

Sub detectors:

- Tracking in a toroidal field
- TOF scintillators
- Cherenkov detector
- EM calorimeter

Detection threshold: 300 MeV/c

Open Trigger



CLAS A(e,e'p) Data

E2 experiment:

Beam energies : 2.2, 4.4 GeV

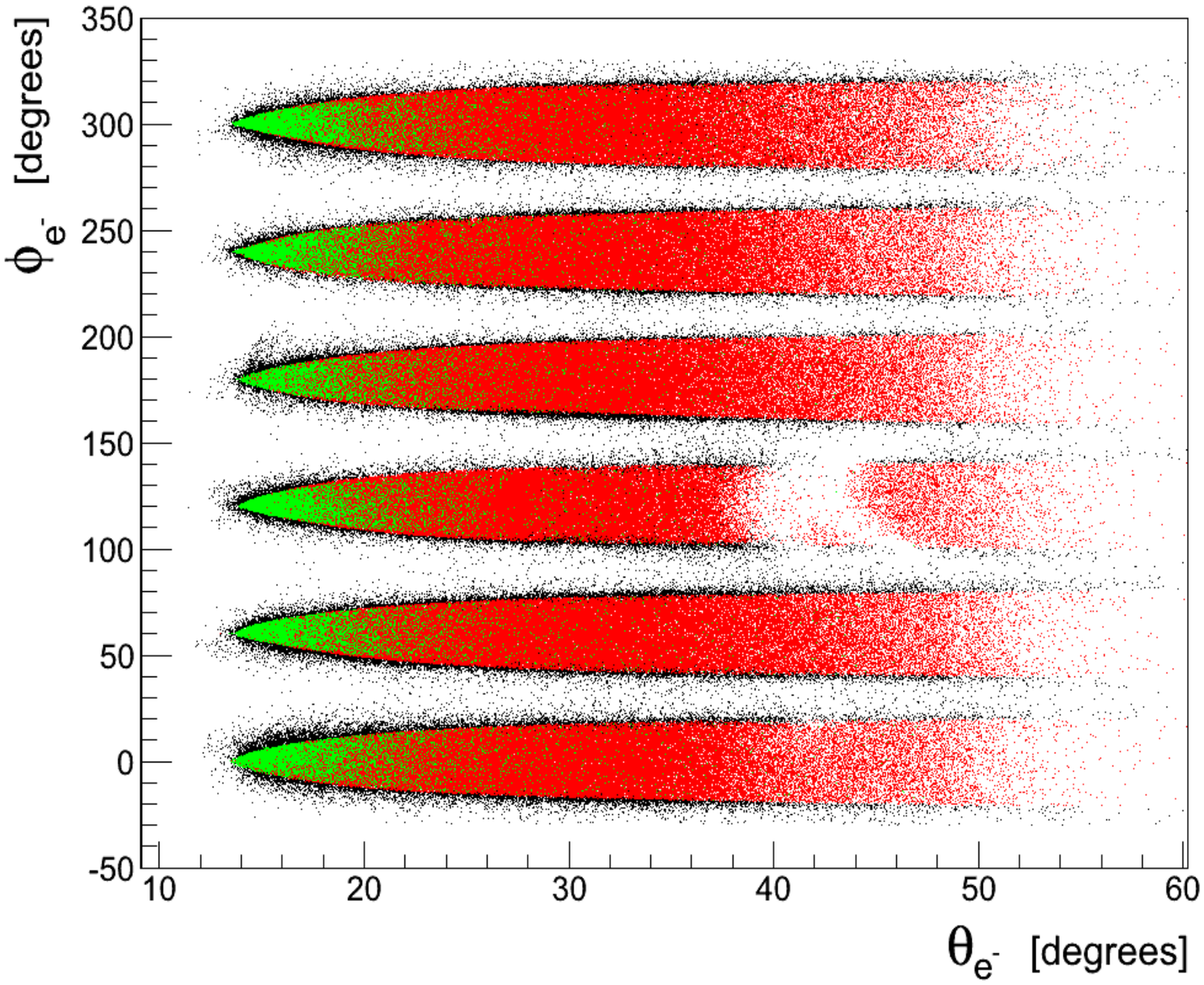
Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe

E2G experiment (less statistics):

Beam energy: 5 GeV

Elements: ^{2}D, ^{12}C, ^{27}Al, ^{56}Fe, ^{208}Pb

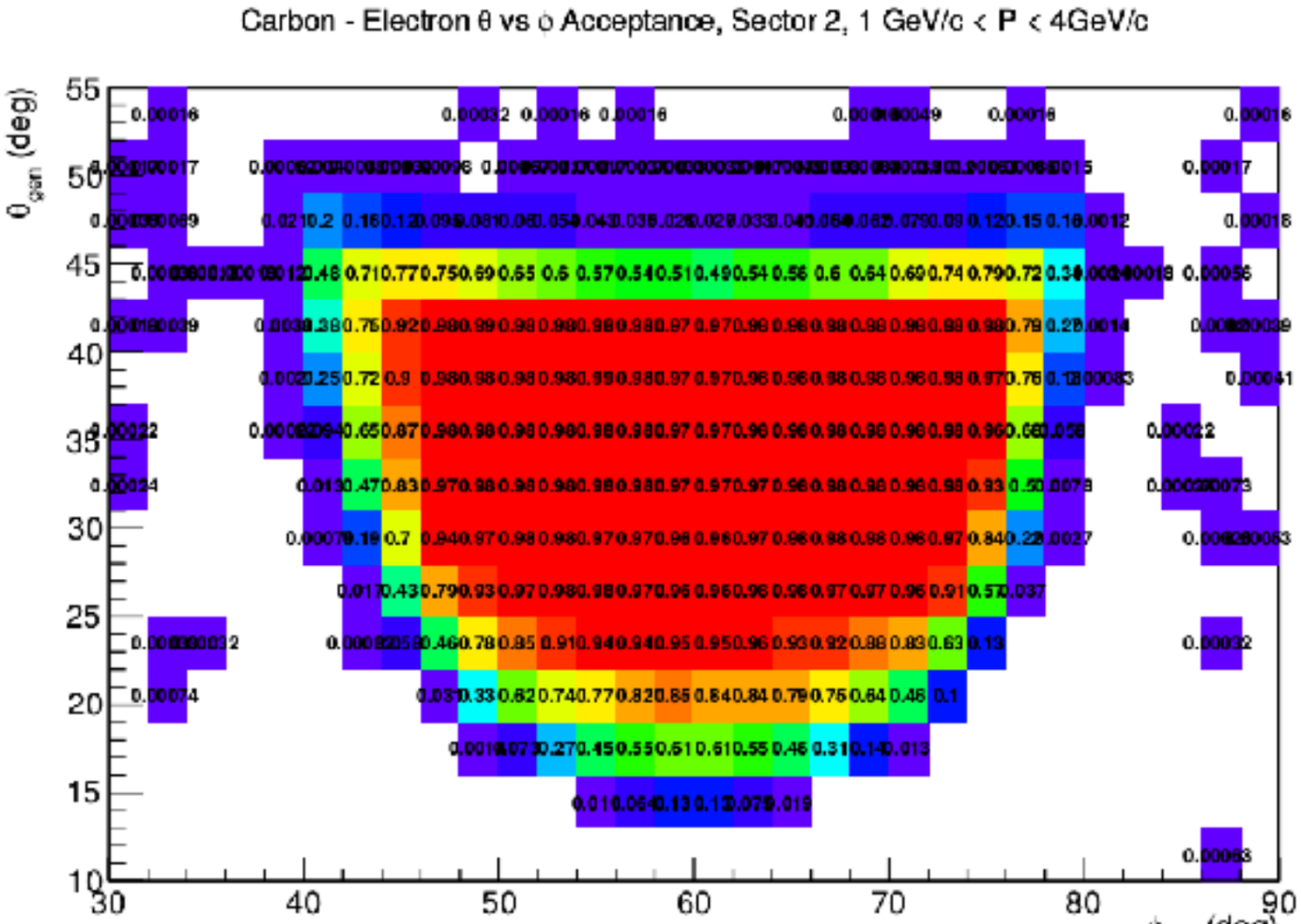
CLAS: Large (imperfect) acceptance



CLAS: Acceptance maps availble

CLAS has a different efficiency, which we will publish as acceptance maps for public use for each:

- Target
- Particle type
- Particle momentum



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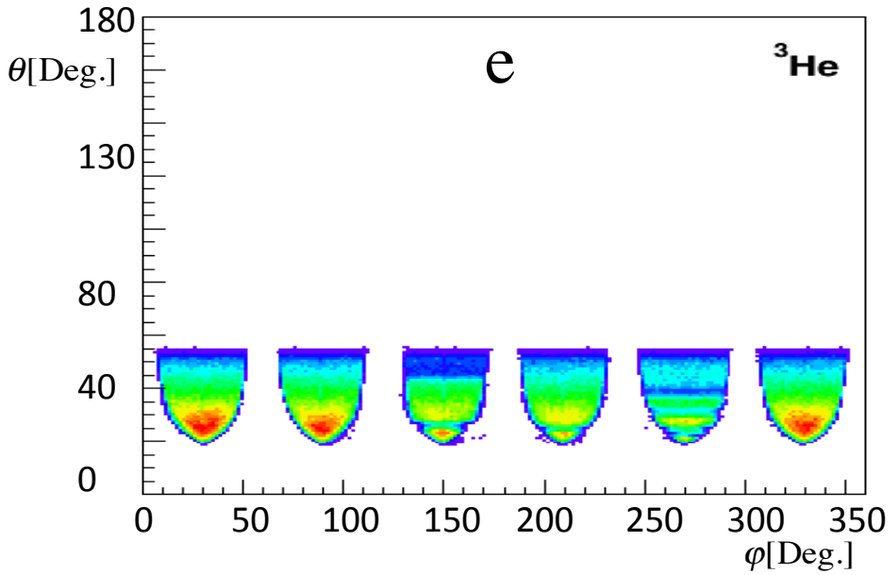
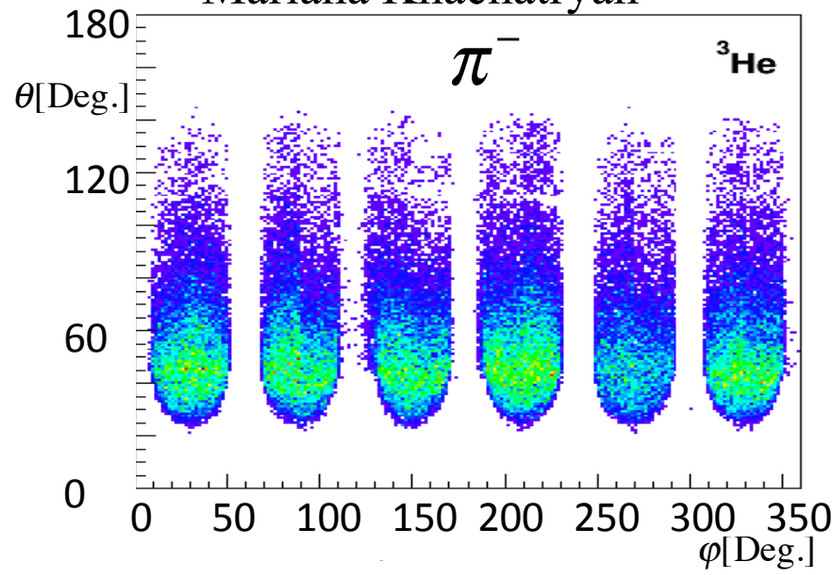
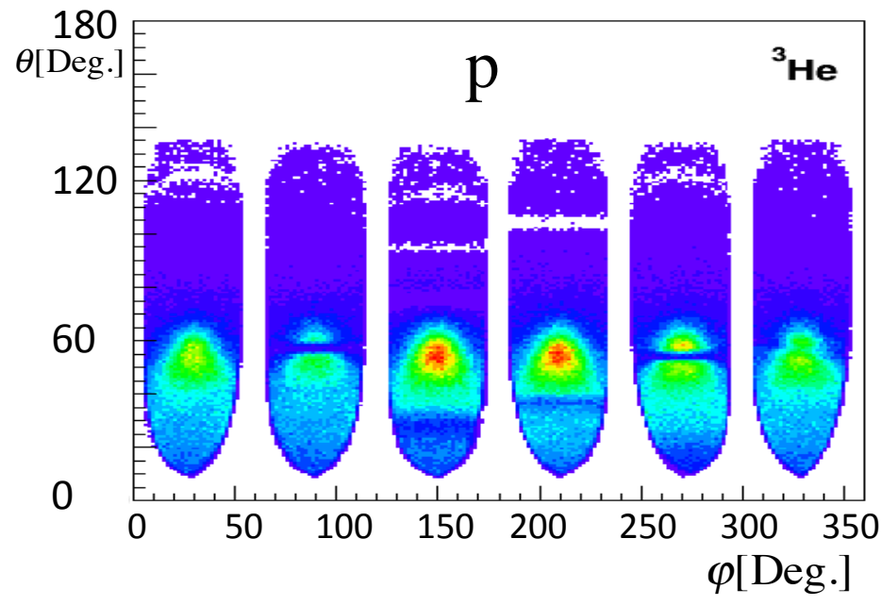
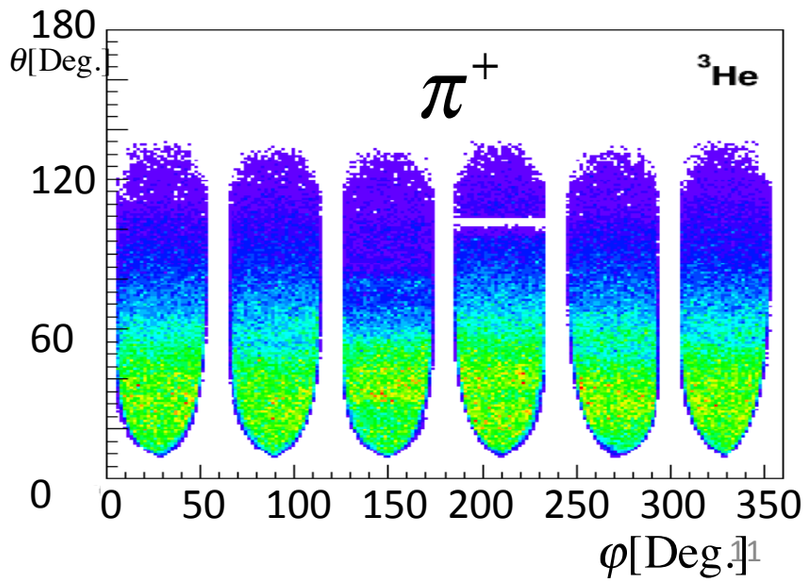
A(e,e'p): 2.2 GeV ^{3}He



Mariana Khachatryan







A(e,e'p): 2.2 GeV ^{3}He

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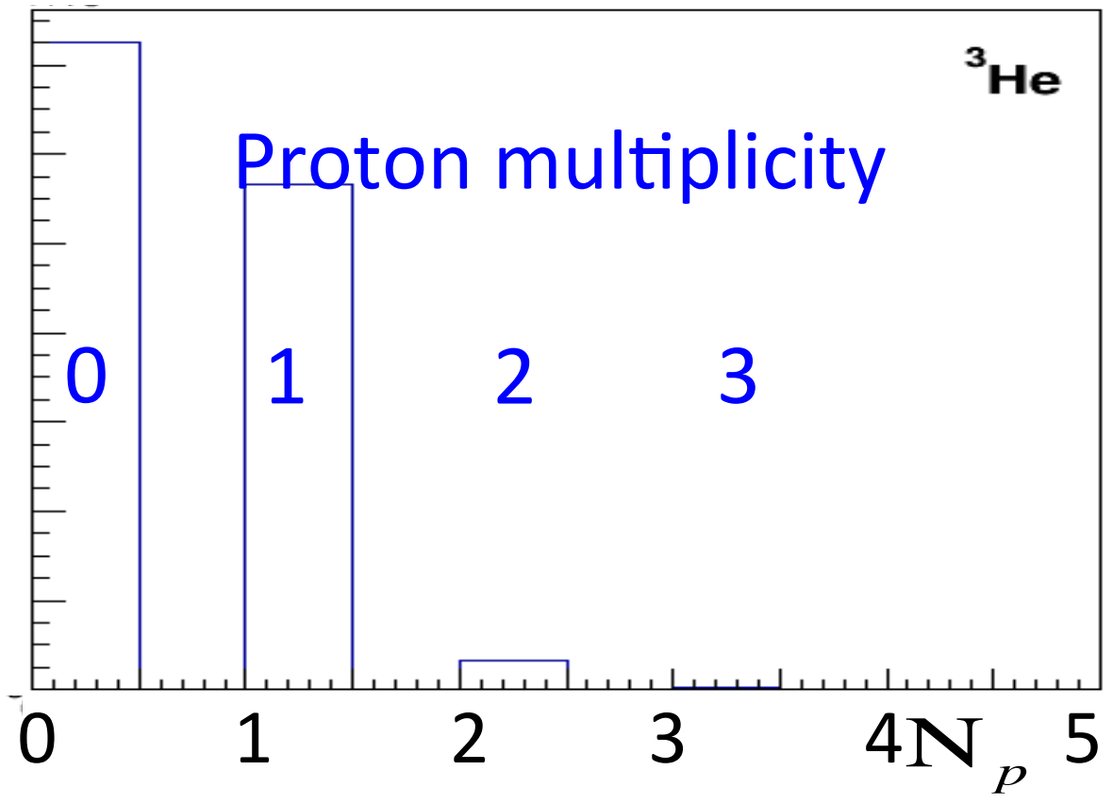
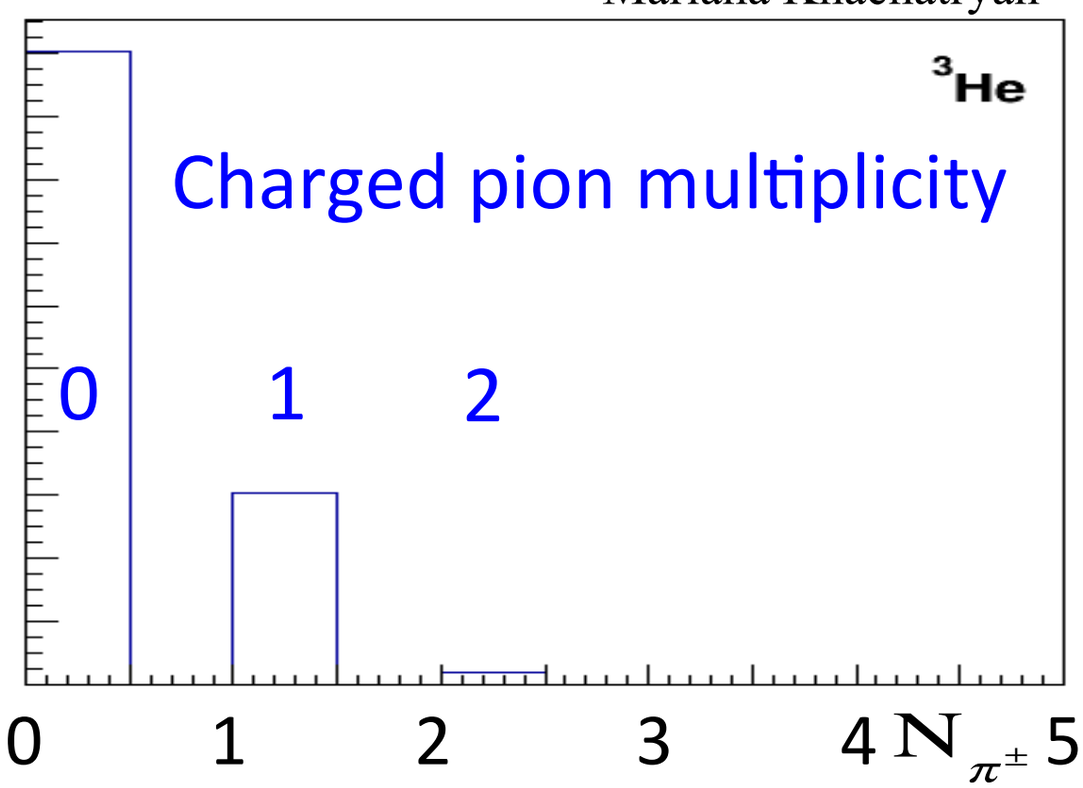




A(e,e'p) Event Selection

Focus on QE events:

1 proton with momentum larger than 300 MeV/c

no additional charged hadrons

CLAS Fiducial cuts for proton and electron

A(e,e'p) Data Scaling

Due to the difference between the neutrino vs. electron differential cross section

We're applying an event by event weight:

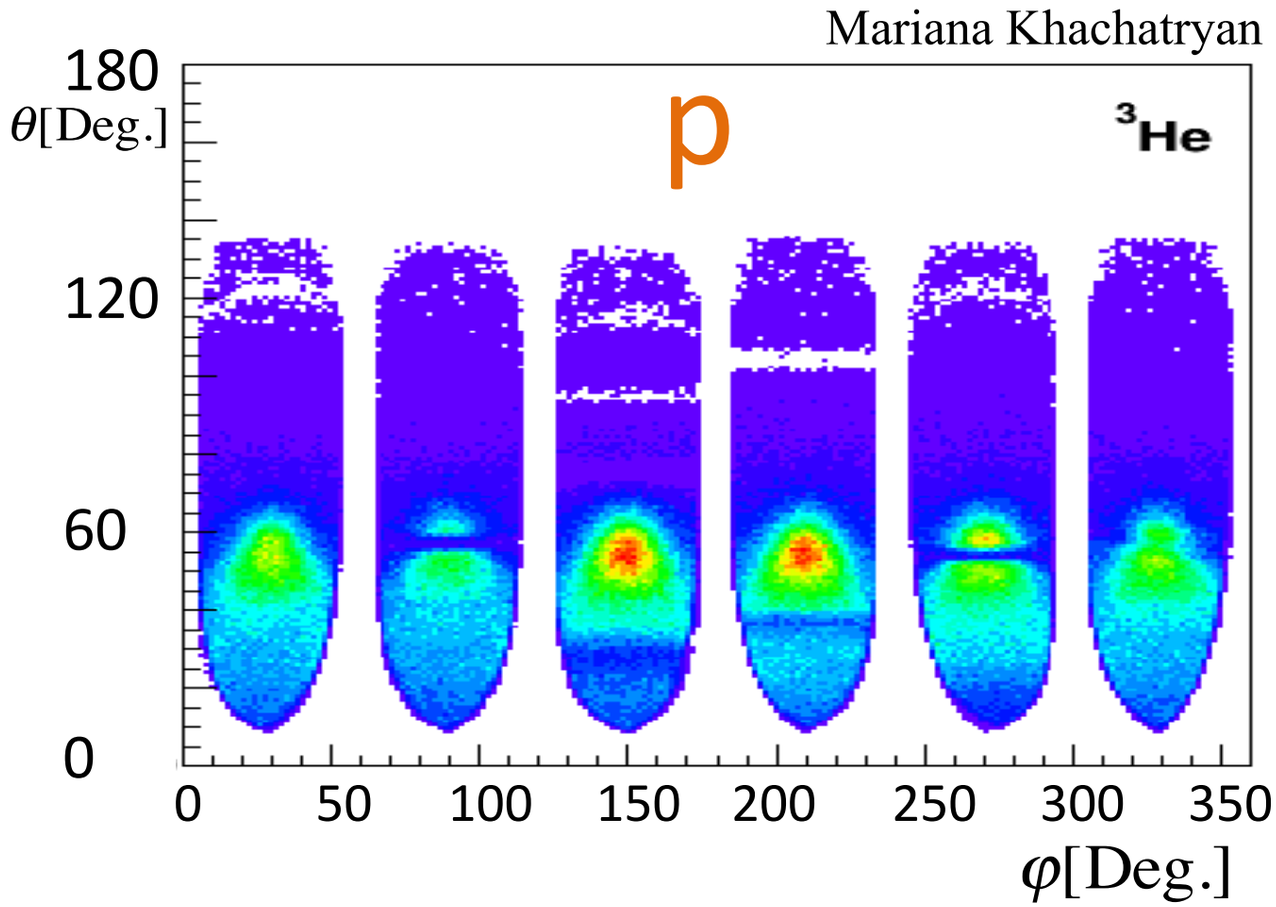
$$1/\sigma_{\mathrm{Mott}}$$

To make sure we're looking at the kinematically interesting regions

Background Subtraction

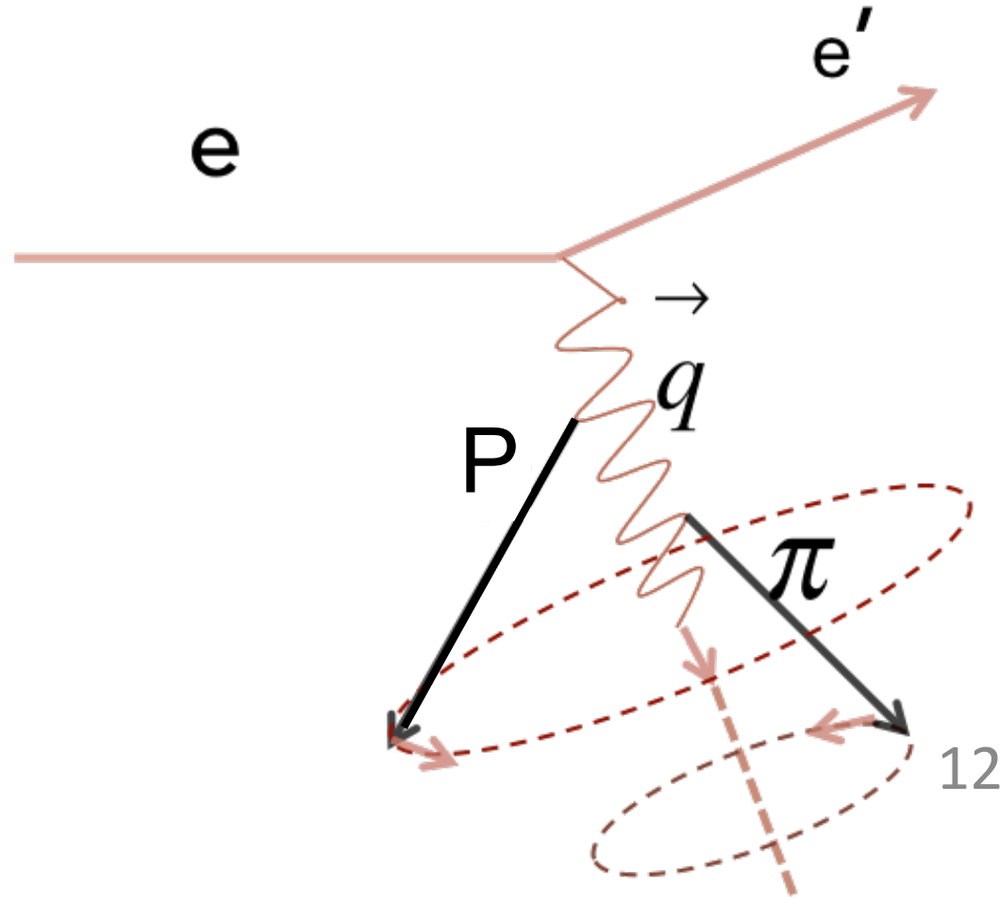
A(e,e'p) events could have undetected pions / protons / …

Data-based subtraction: given the detector acceptance map, any event with an additional hadron (e.g. A(e,e'pp)), implies more events of its kind where one of the hadron was not detected => Can use to subtract.



Background Subtraction

Two proton / pion subtraction method:



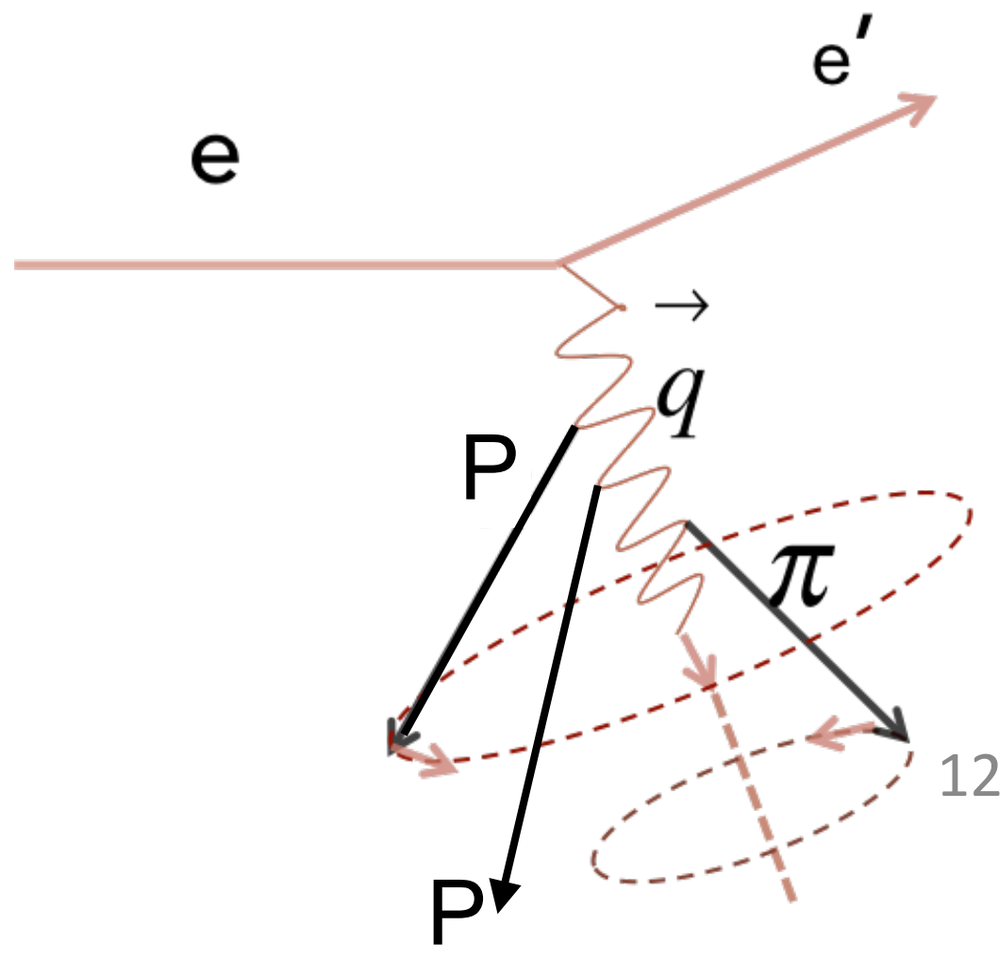
Using events with two hadrons, rotating the two outgoing hadron system around the q vector, each time checking if only the proton was detected

Subtract contribution to QE-like events from the final distributions

Background Subtraction

Multiple proton subtraction method

Using the same method and carefully not double counting the 2p cointribution



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Incoming Energy Reconstruction

Two methods for calculating the incoming energy:

$$E_{\nu}^{\text{kin}} = \frac{2M\varepsilon + 2ME_1 - m_l^{\prime}}{2(M - E_1 + |k_1|\cos\theta)}$$

$\varepsilon \approx 20$ MeV single nucleon separation energy

M-nucleon mass

m_1 outgoing lepton mass

k_1 – lepton three momentum

θ – lepton scattering angle

$$E_{\text{Calorimetric}} = E_e^{'} + \sum T_p + E_{\text{Binding}} + \sum E_{\pi}$$

E_{Binding} – Binding energy

T_p – kinetic energy of knock out proton

$E_e^{'}$ – energy of scattered electron

E_{π} – energy of produced meson

In use in Cherenkov detectors

Assuming QE interaction

In use in Tracking detectors

Need good hadronic reconstruction

A(e,e'p): Energy Reconstruction

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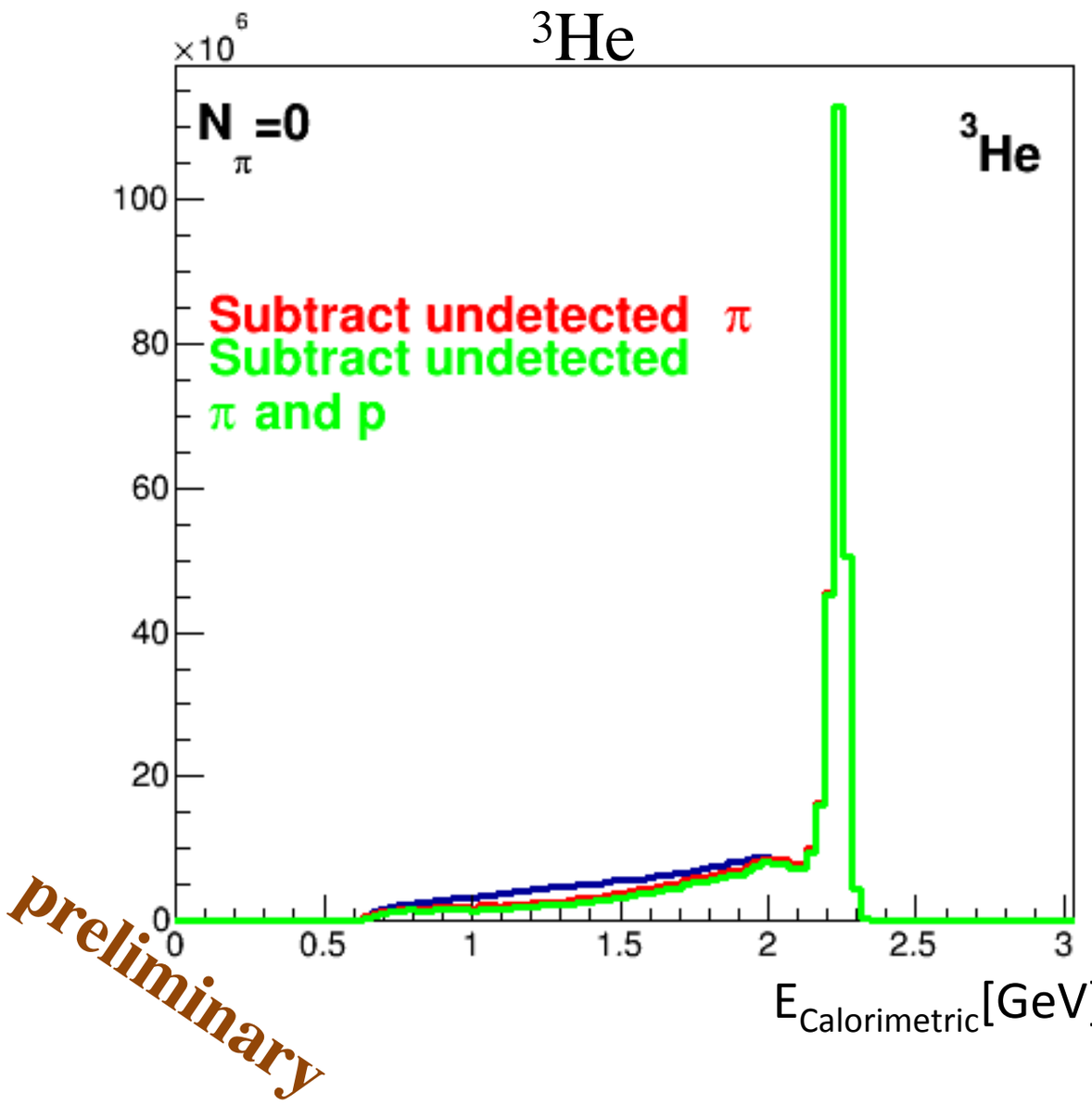
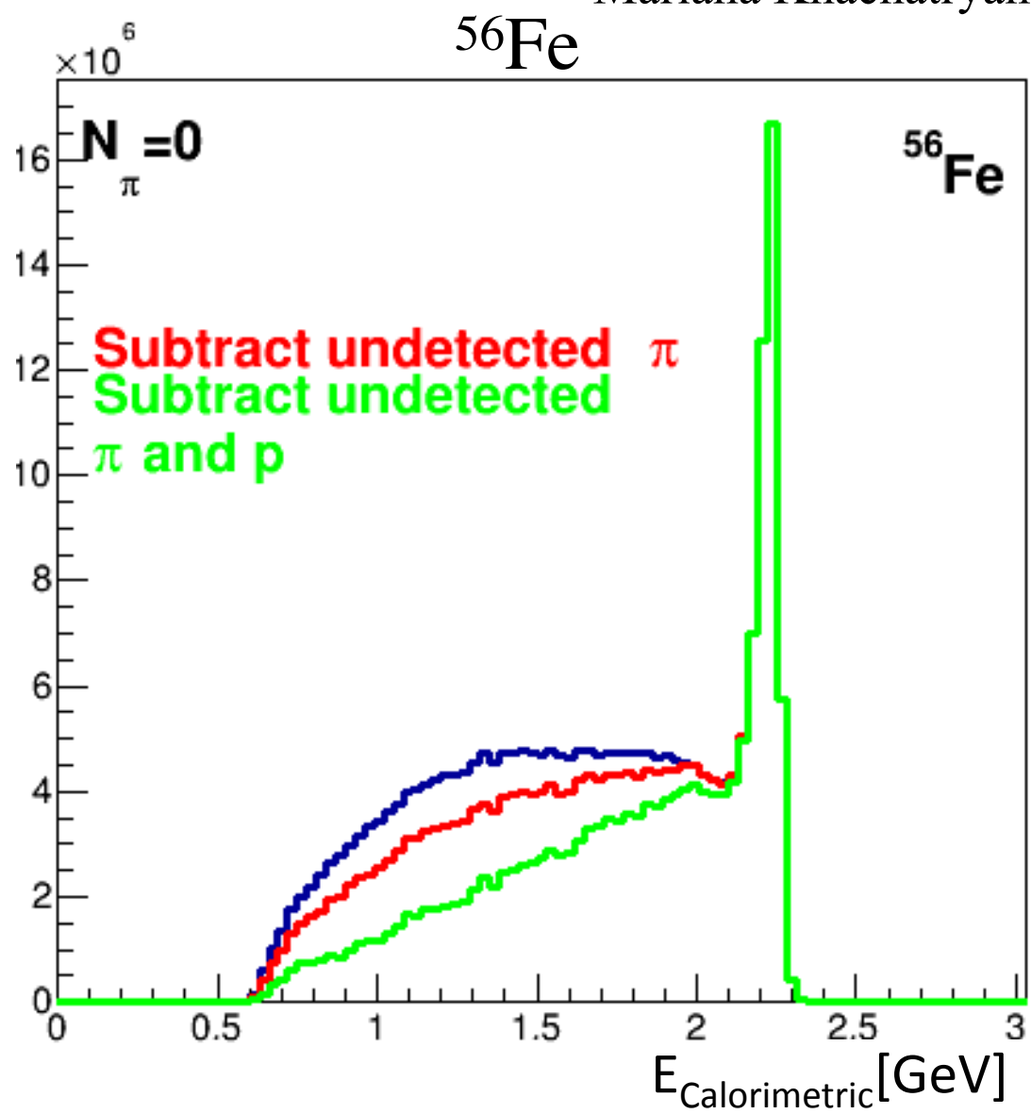
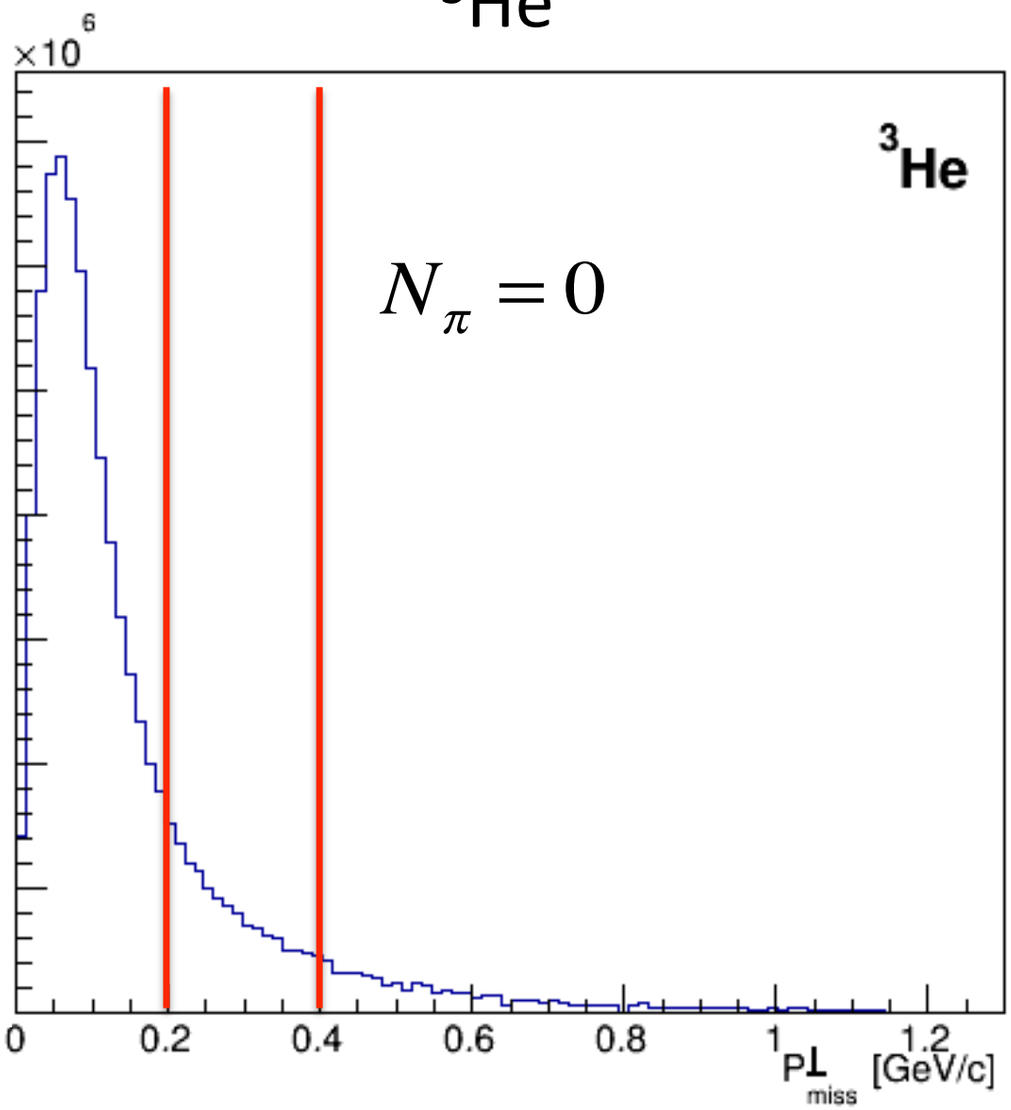




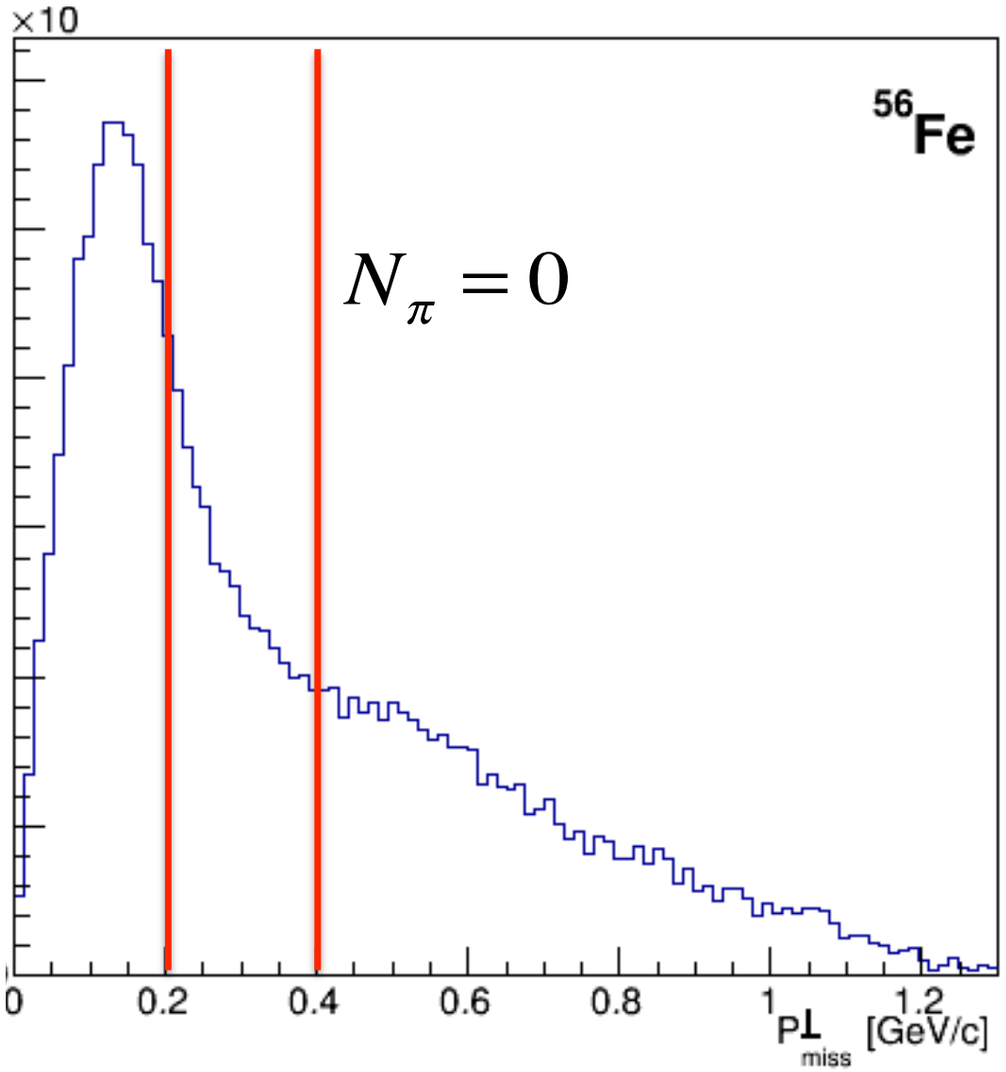
A(e,e'p): Missing Transverse Momentum

$$\vec{P}_{\perp}^{\,\mathrm{miss}} = \vec{P}_{\perp}^{\,e'} + \vec{P}_{\perp}^{\,p}$$

^{3}He



^{56}Fe



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A(e,e'p): 2.2 GeV Calorimetric Energy

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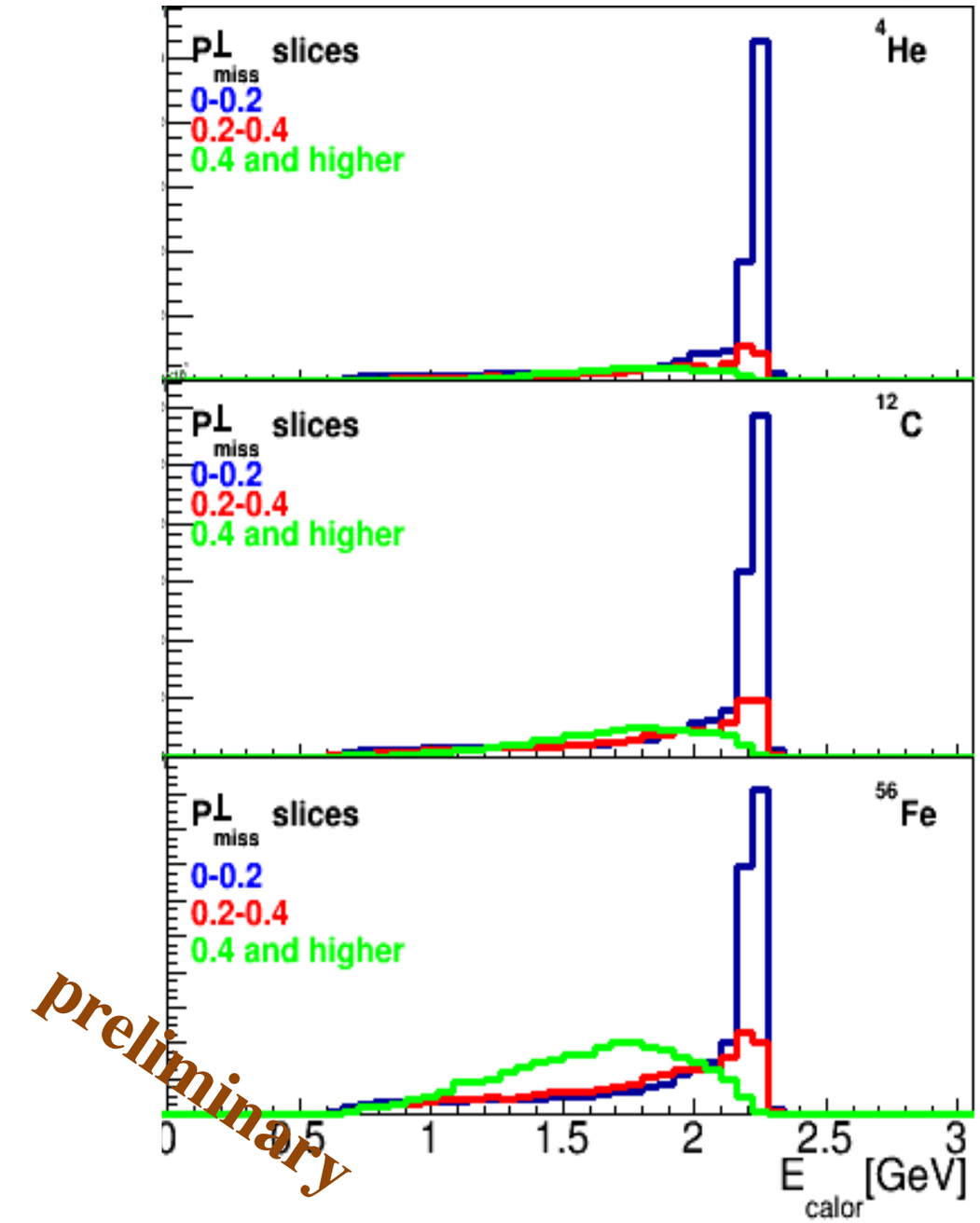
Increased tail for heavier nucleis.

Increased non QE background for higher values of missing transverse momentum.



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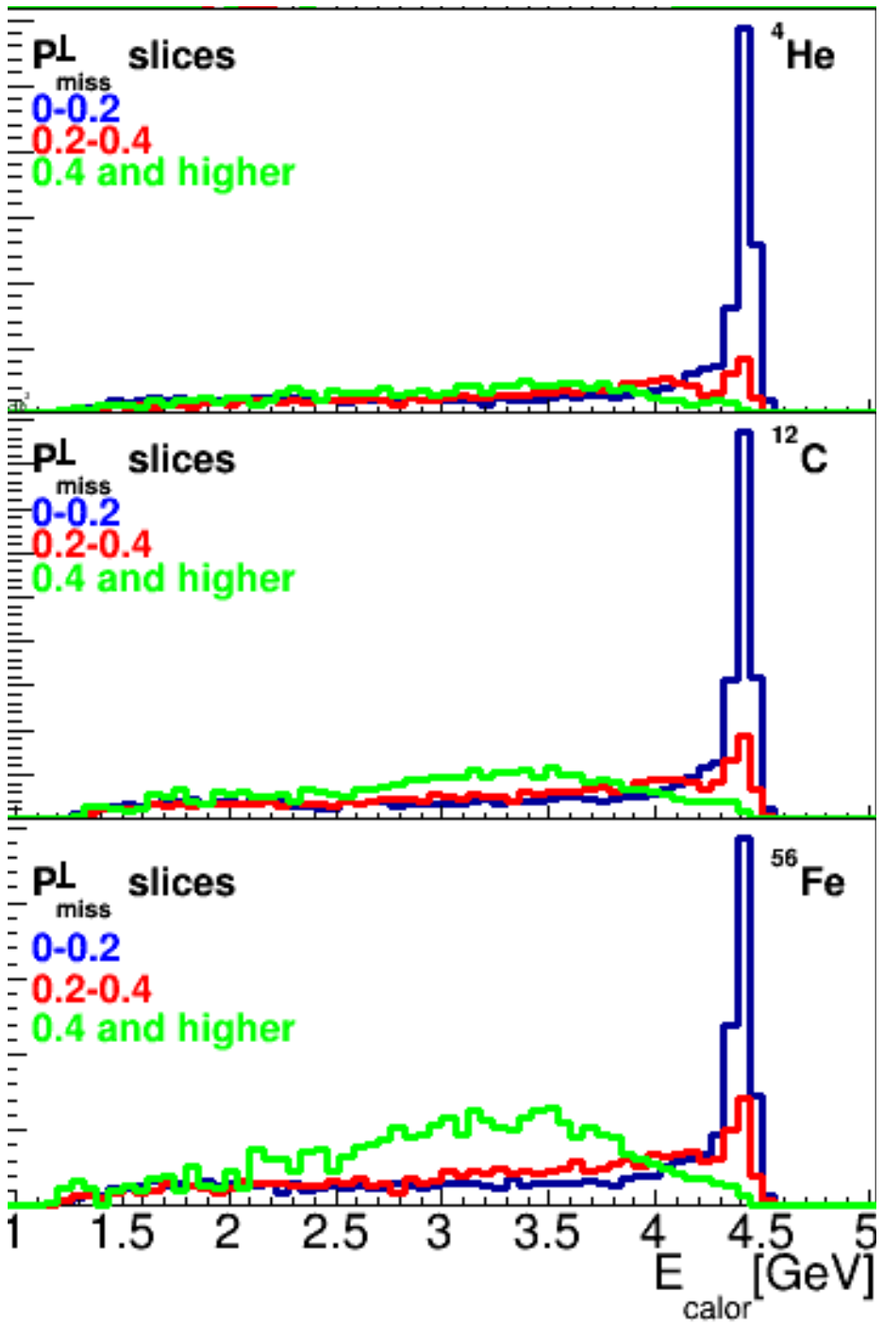
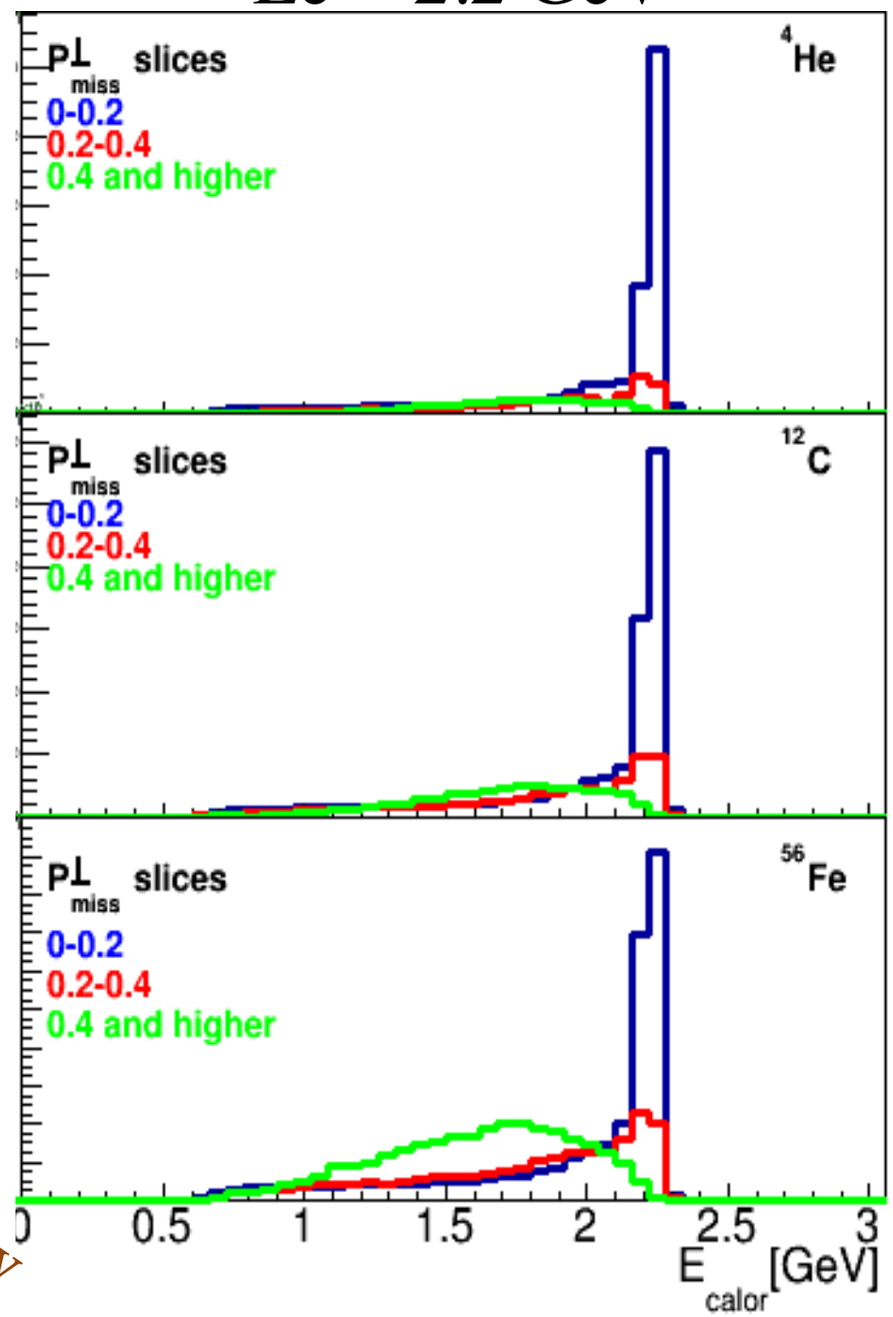
Data

CLAS A(e,e’,p) - Results electron calorimetric energy

Ee = 4.4 GeV



Ee = 2.2 GeV



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A(e,e'p): 2.2 GeV Leptonic Energy

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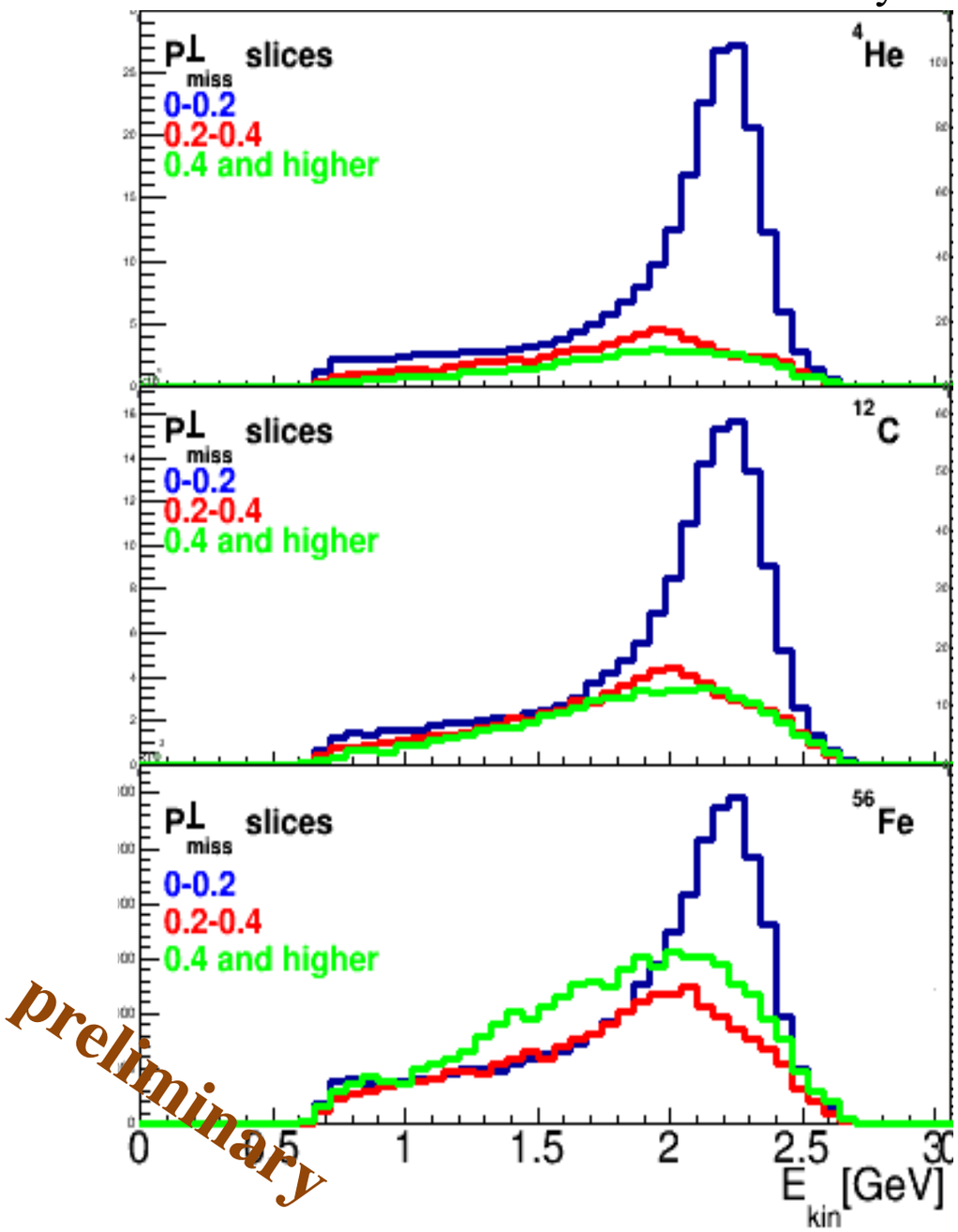
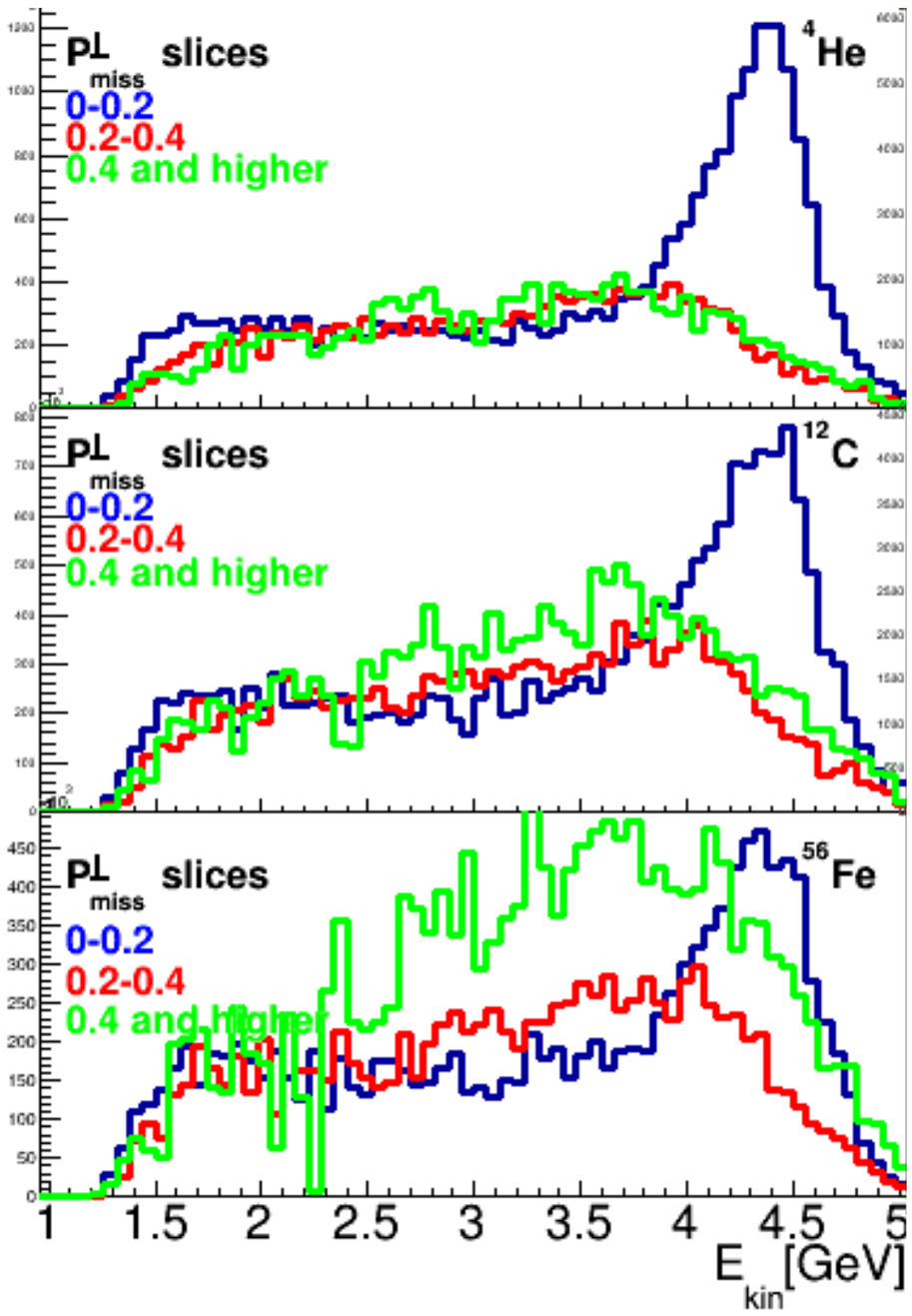
Worse resolution for leptonic energy.

Increased tail for heavier nucleis.

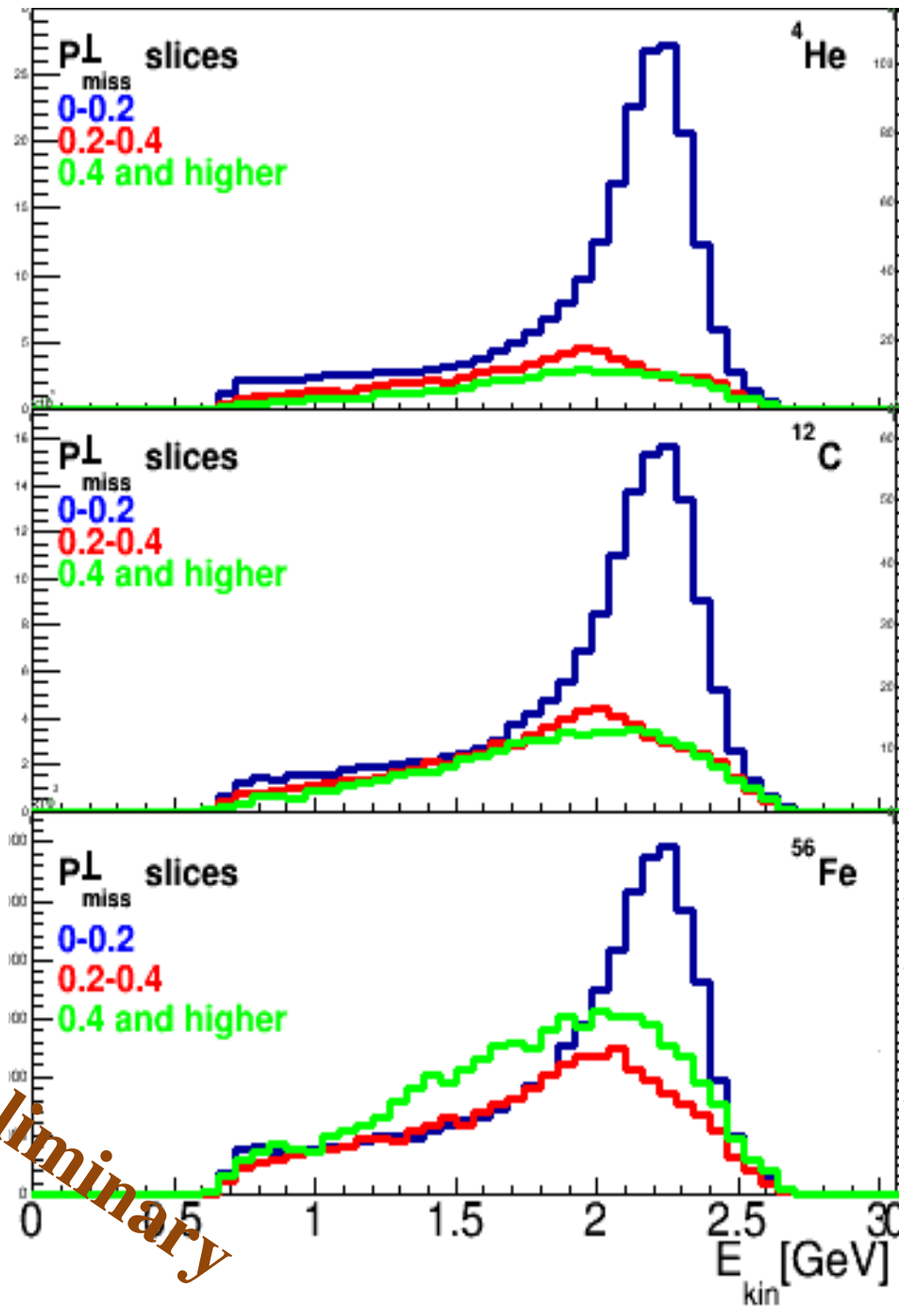


A(e,e'p): 2.2, 4.4 GeV Leptonic Energy

Ee = 4.4 GeV



Ee = 2.2 GeV



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Data Simulation Comparison

Reminder:

1 proton above 300 MeV/c

no additional charged hadrons

CLAS Fiducial cuts for proton and electron

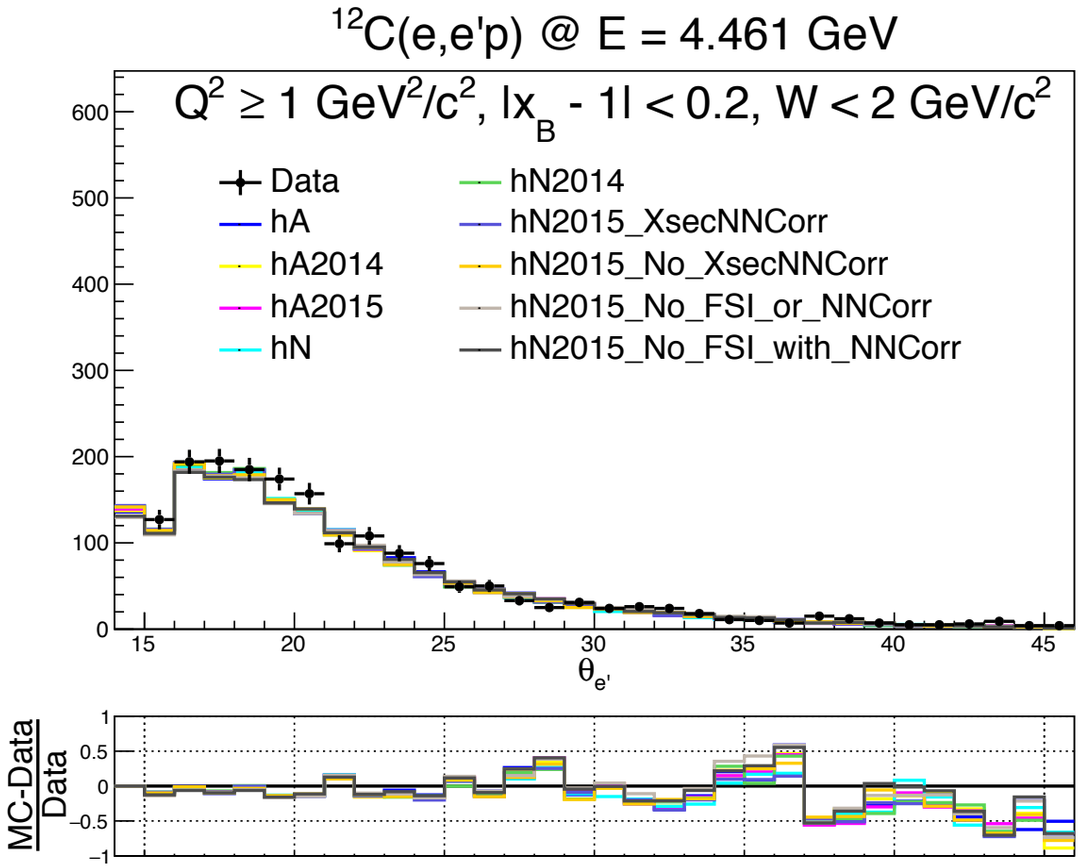
Additional Kinematics:

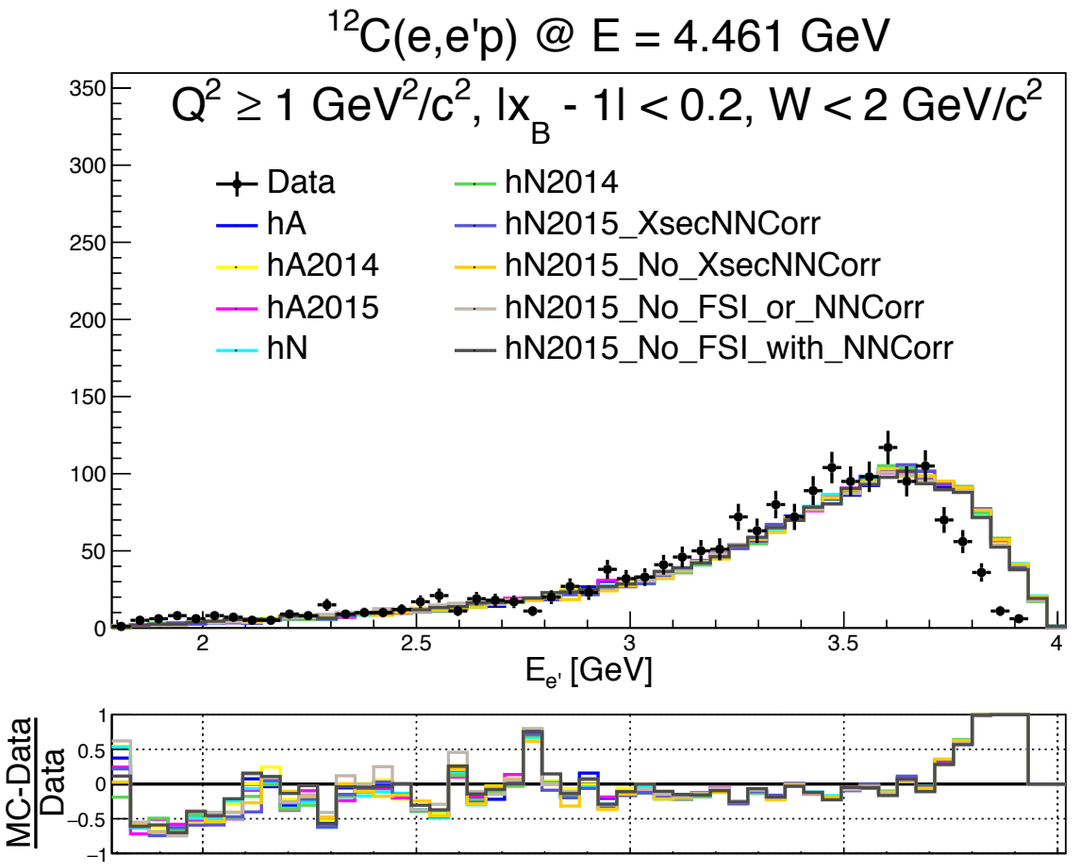
$Q^2 > 0.5\ GeV^2/c^2$

$W < 2\ GeV/c^2$

$|X_B - 1| < 0.2$

MC vs. (e,e’p) Data: Electron





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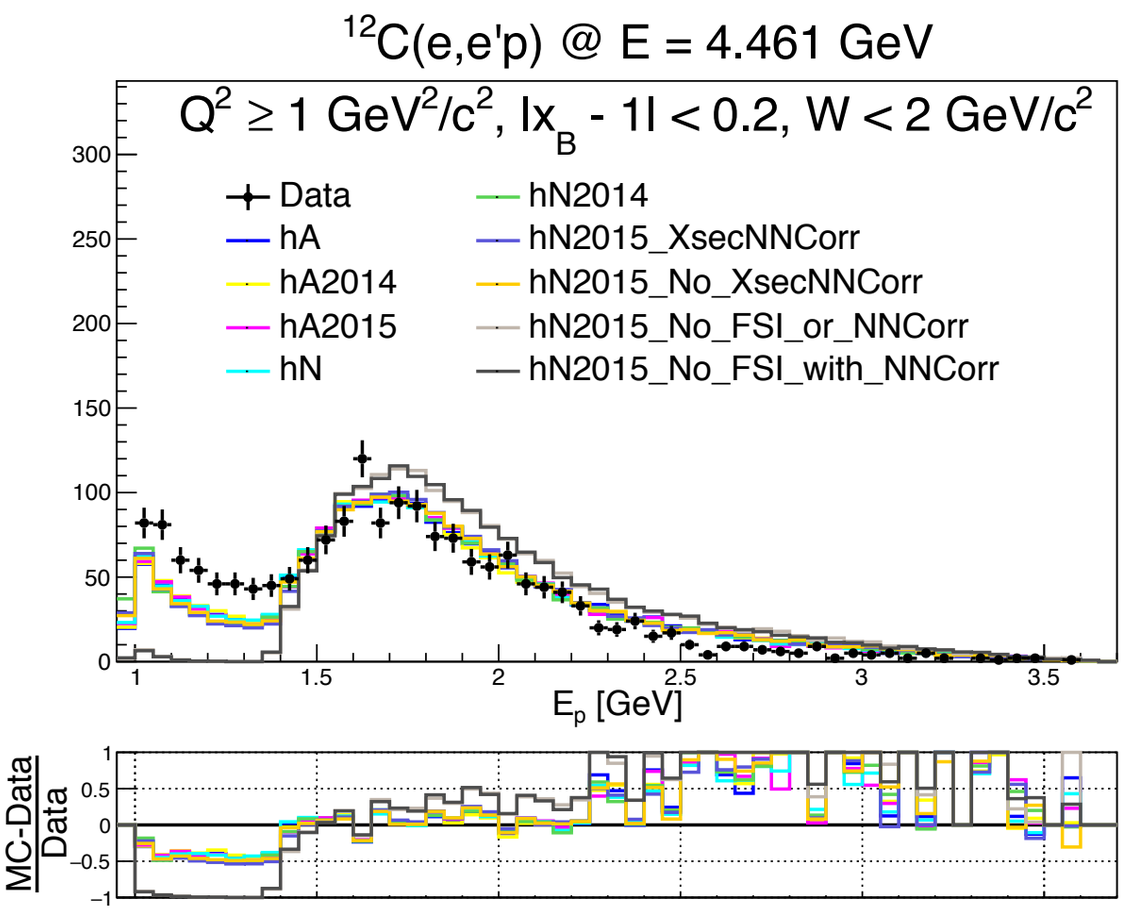
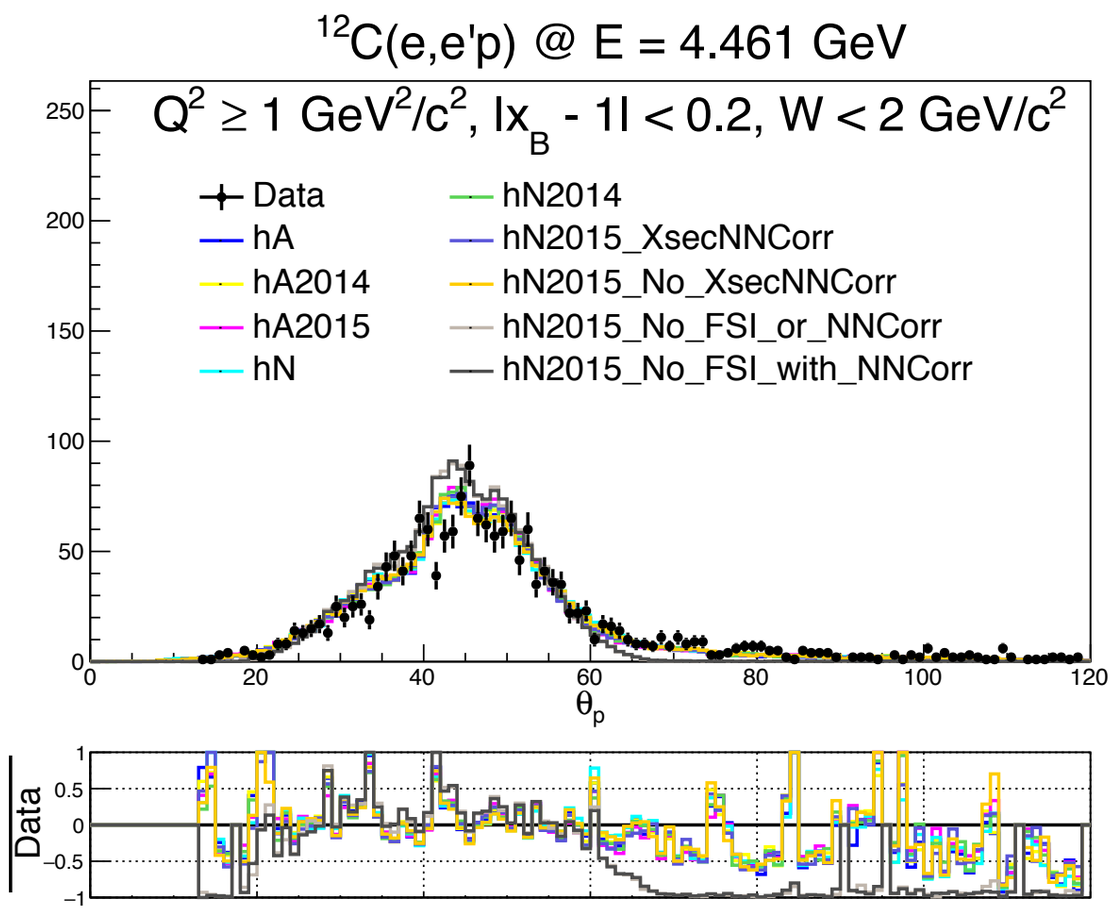
Before Background Subtraction

MC vs. (e,e’p) Data: Proton





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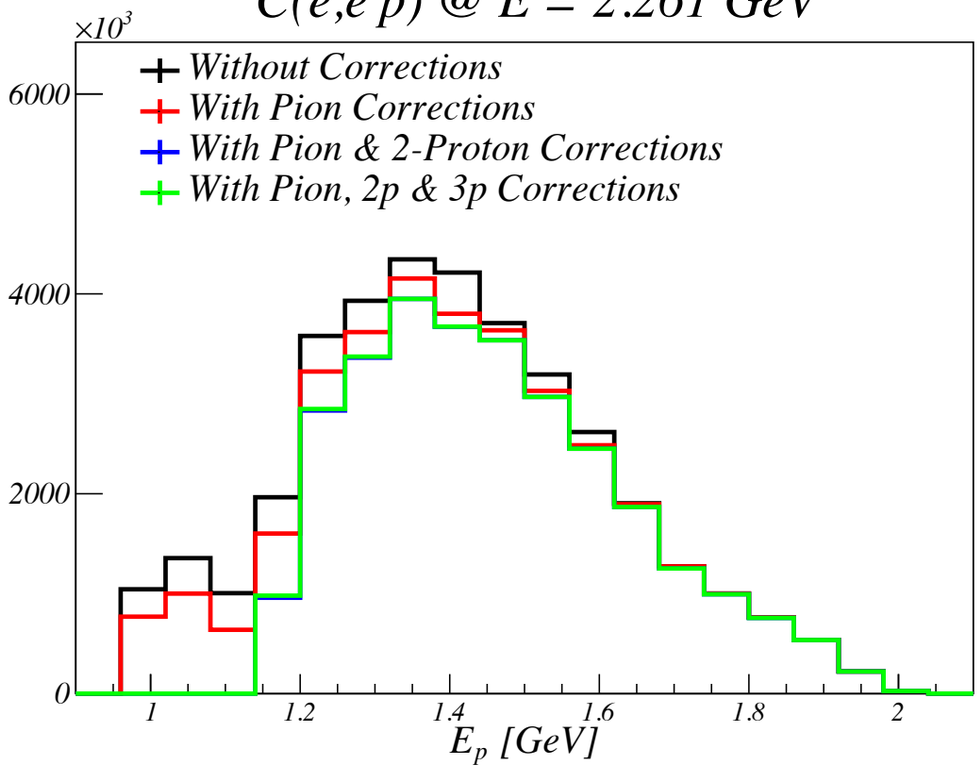
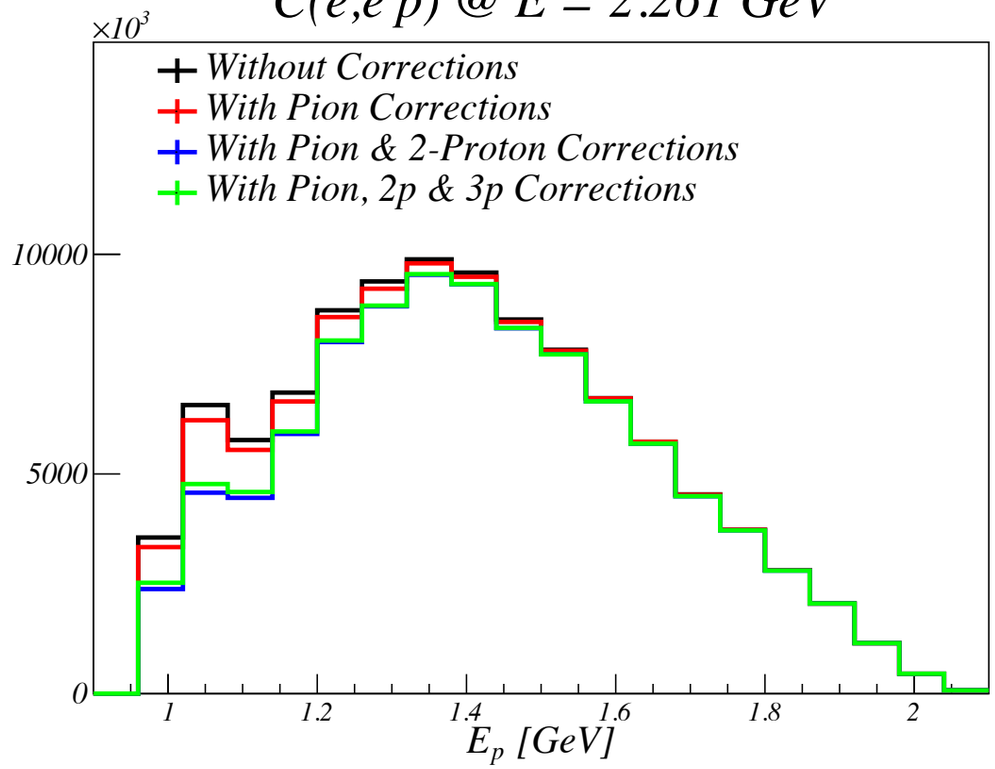
Before Background Subtraction

MC vs. (e,e'p) Data: Proton Background Subtraction Effect

Simulation



Data



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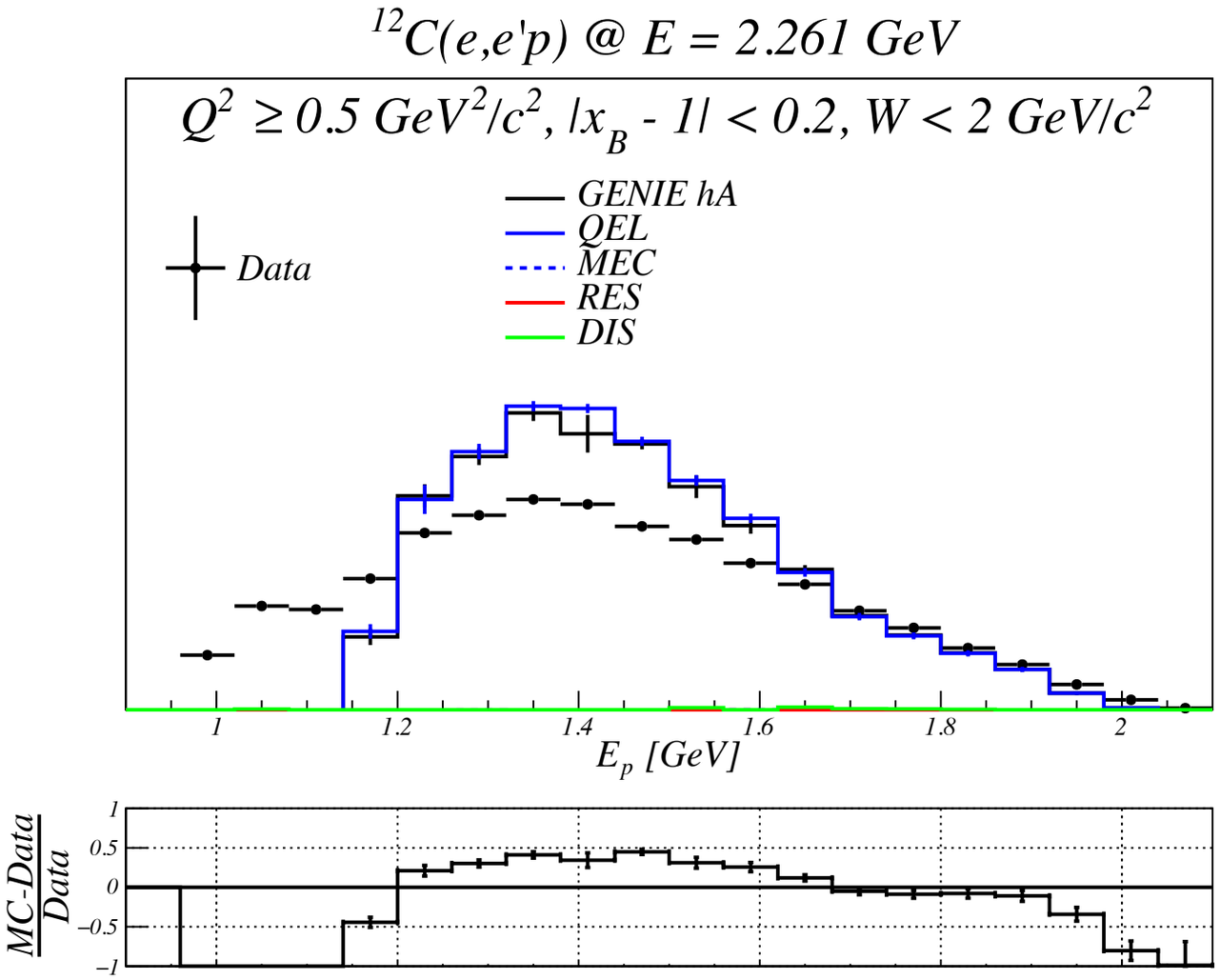
MC vs. (e,e'p) Data: Proton Background Subtraction Effect



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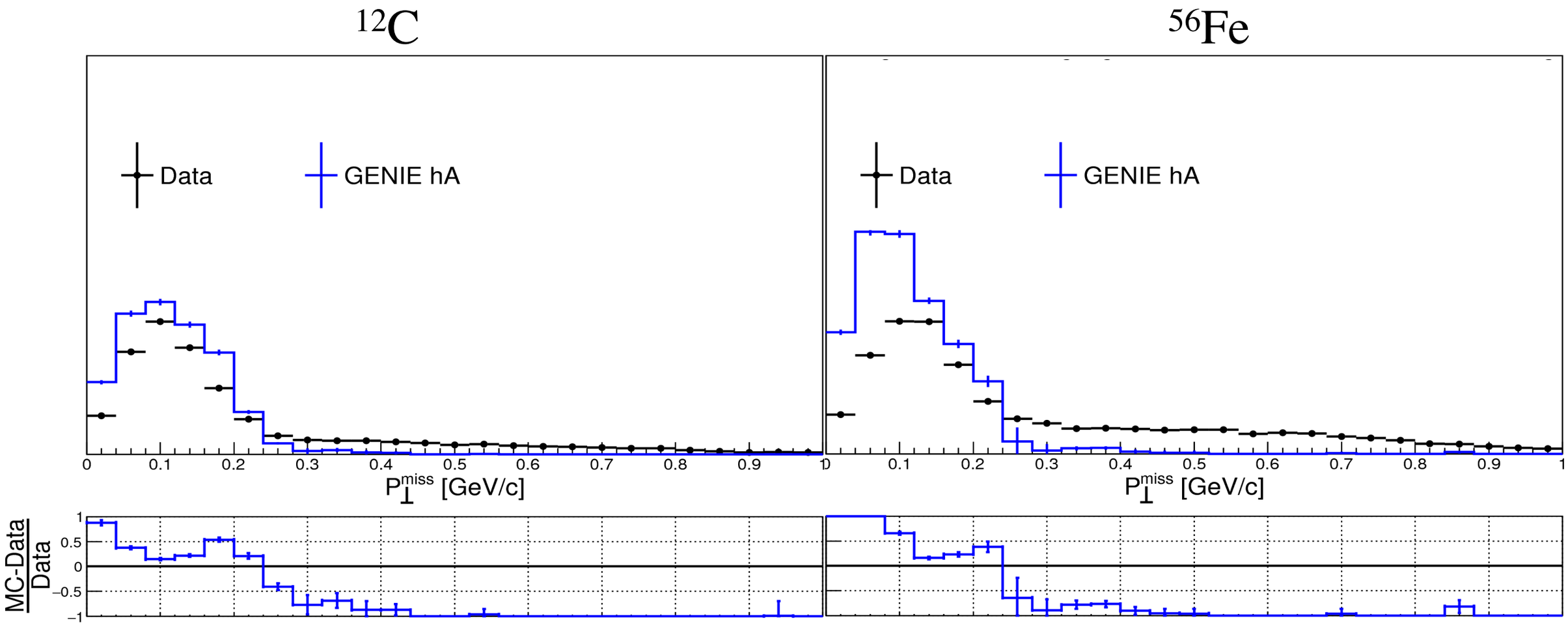
Data Simulation Comparison

Missing transverse momentum



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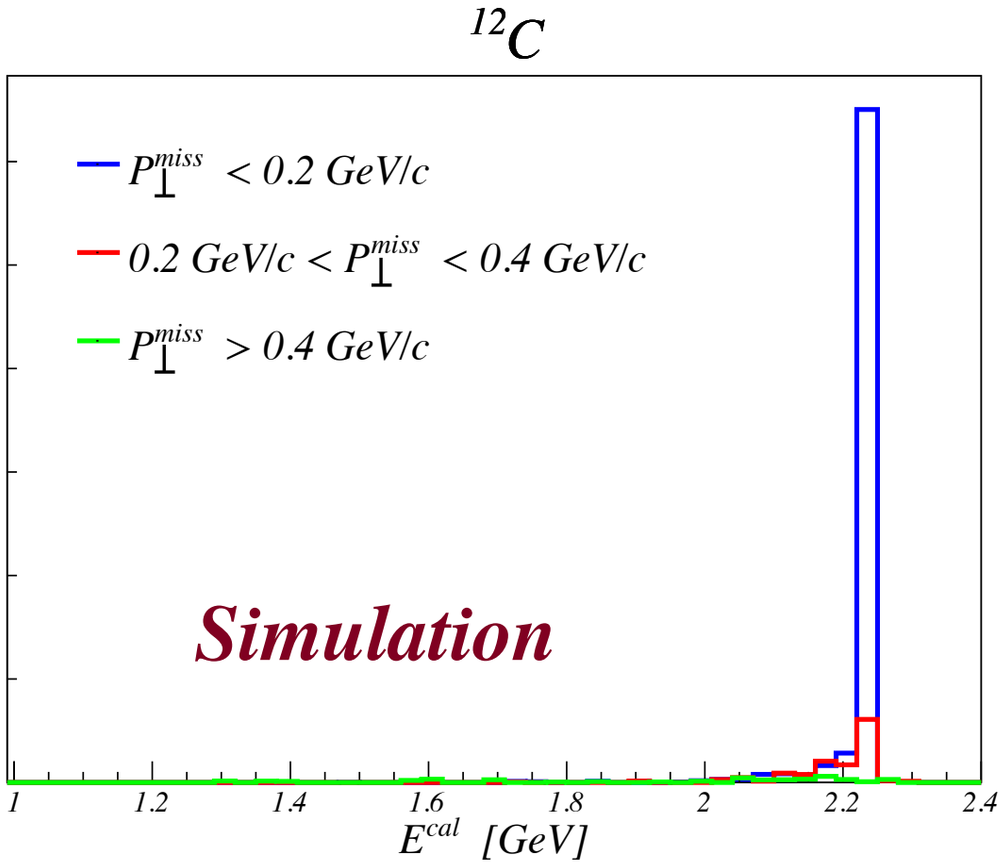
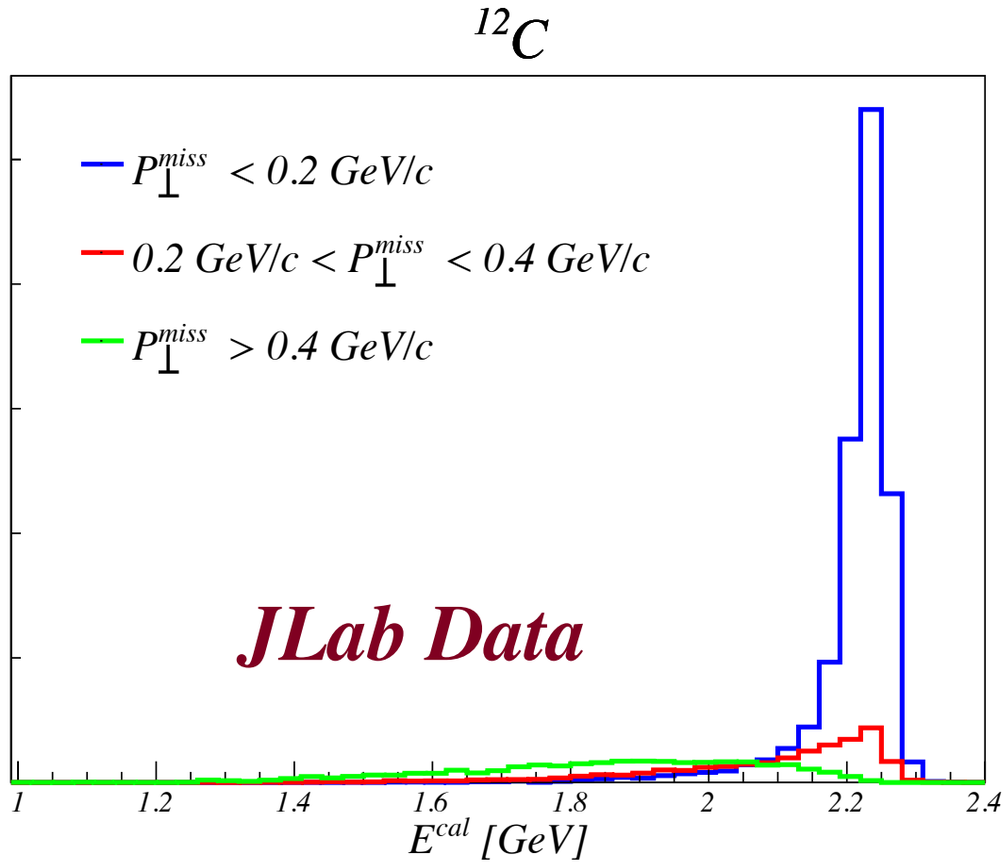
MC vs. (e,e'p) Data

Incoming Energy Reconstruction Disagrees





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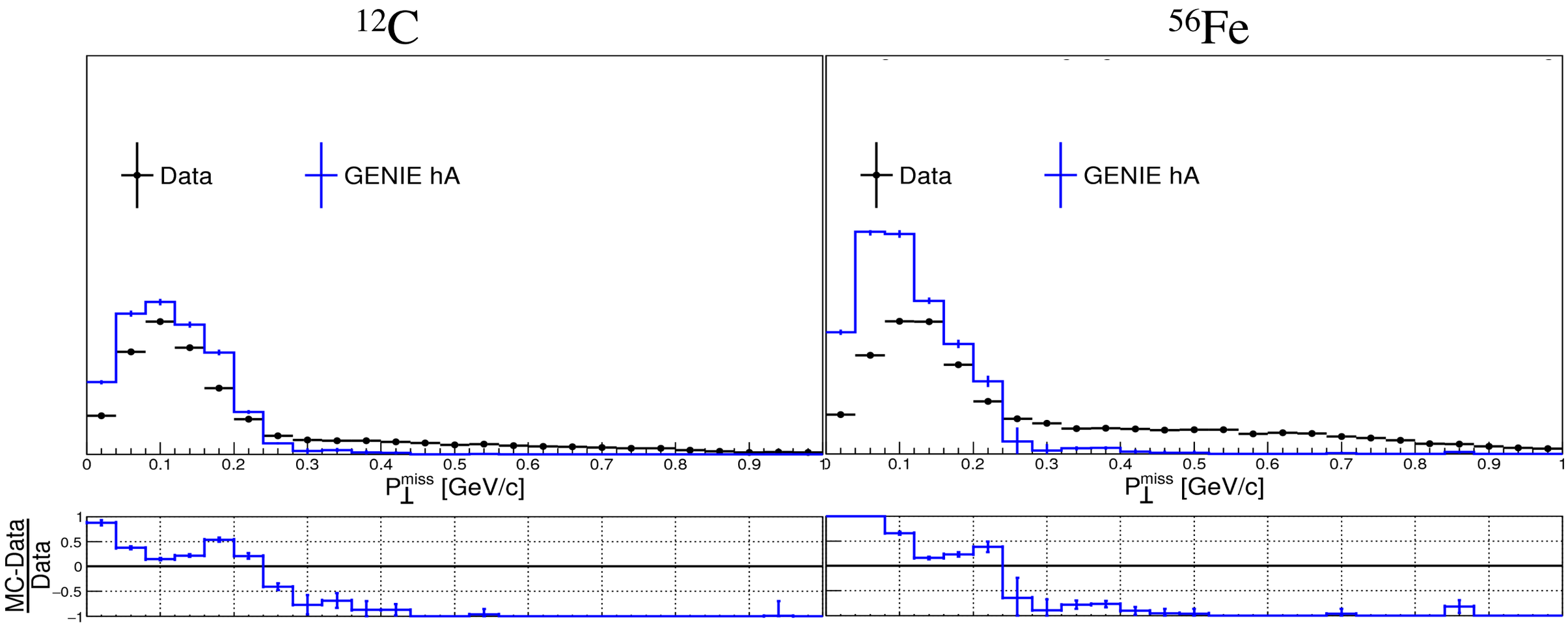
Data Simulation Comparison

Missing transverse momentum



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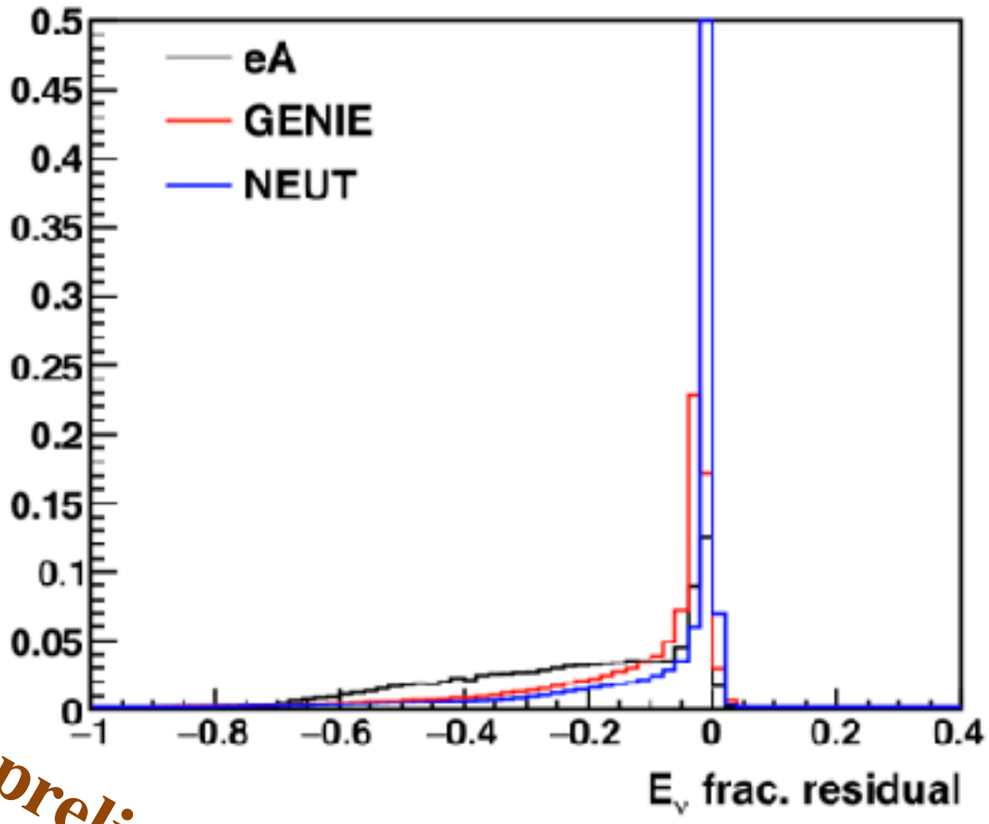
Projected implication on DUNE analysis

The expected energy at DUNE far detector as reconstructed using the energy feed down from A(e,e'p) data and simulation



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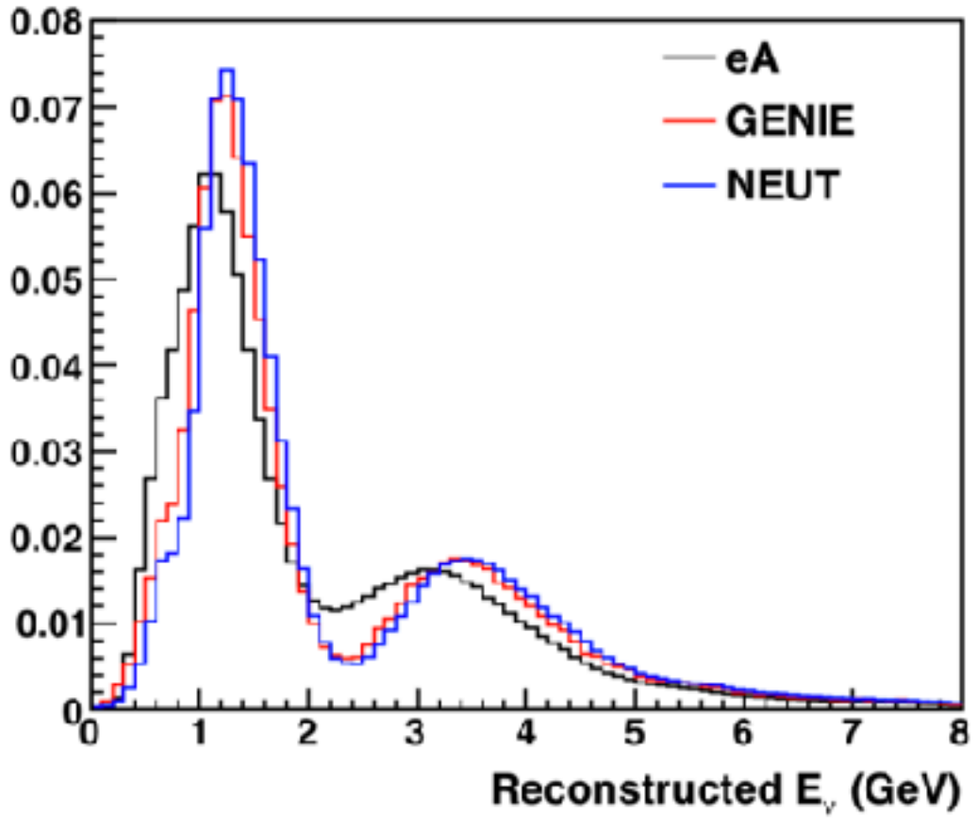
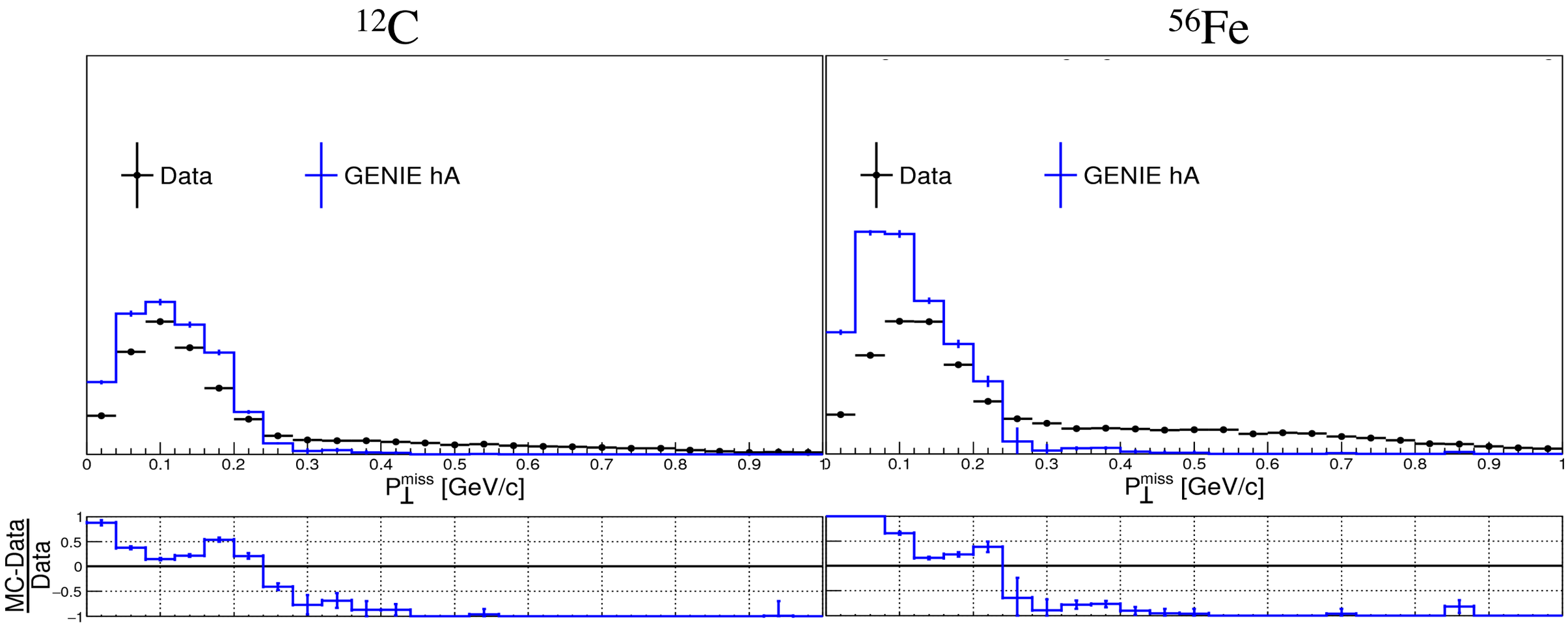


Chris Marshall
see also talk by Kendall Mahn

Data Simulation Comparison

Missing transverse momentum



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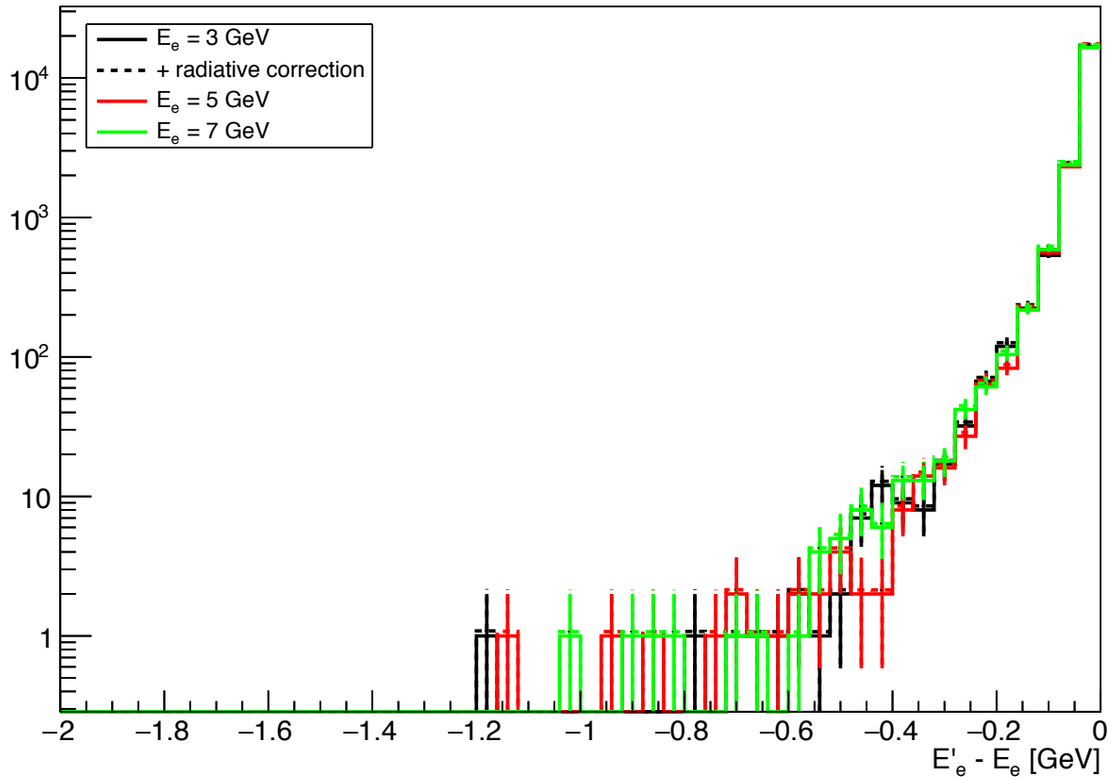
Simulation

GENIE - Radiative Corrections

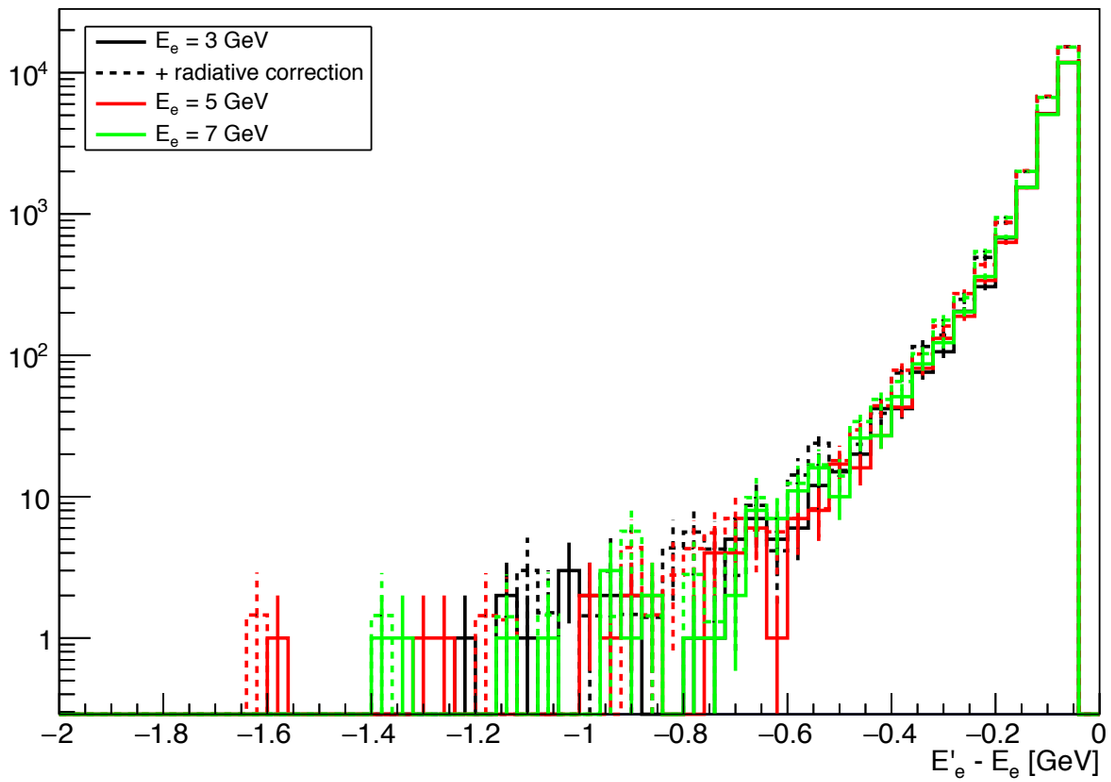
A joint experimental-theoretical effort at Fermilab led by M. Betancourt

Currently study the soft radiation effect on :

H



^{12}C

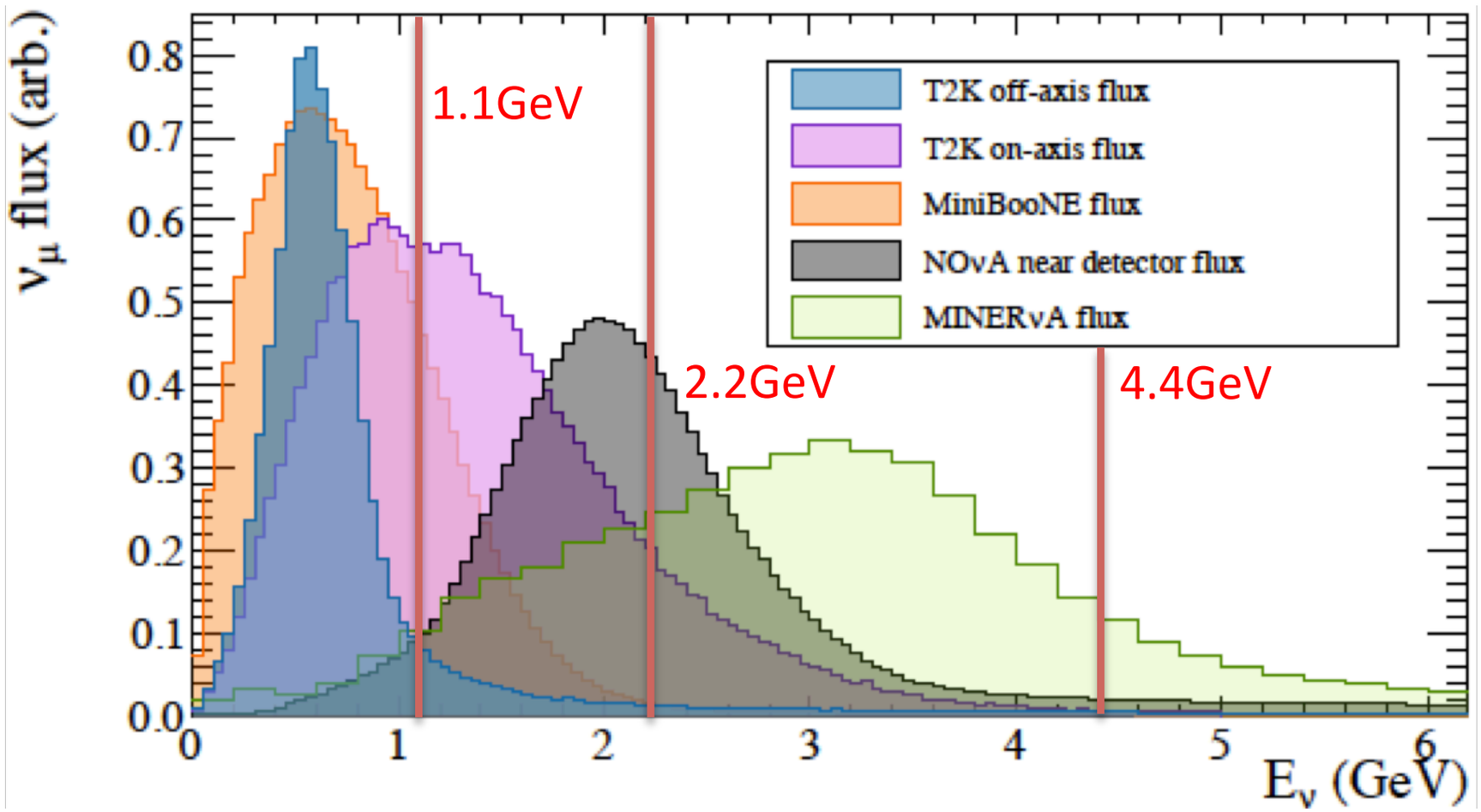


The following results will not include these effects.

Future plans

Current available data: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe

with incoming 2.2 GeV and 4.4 GeV



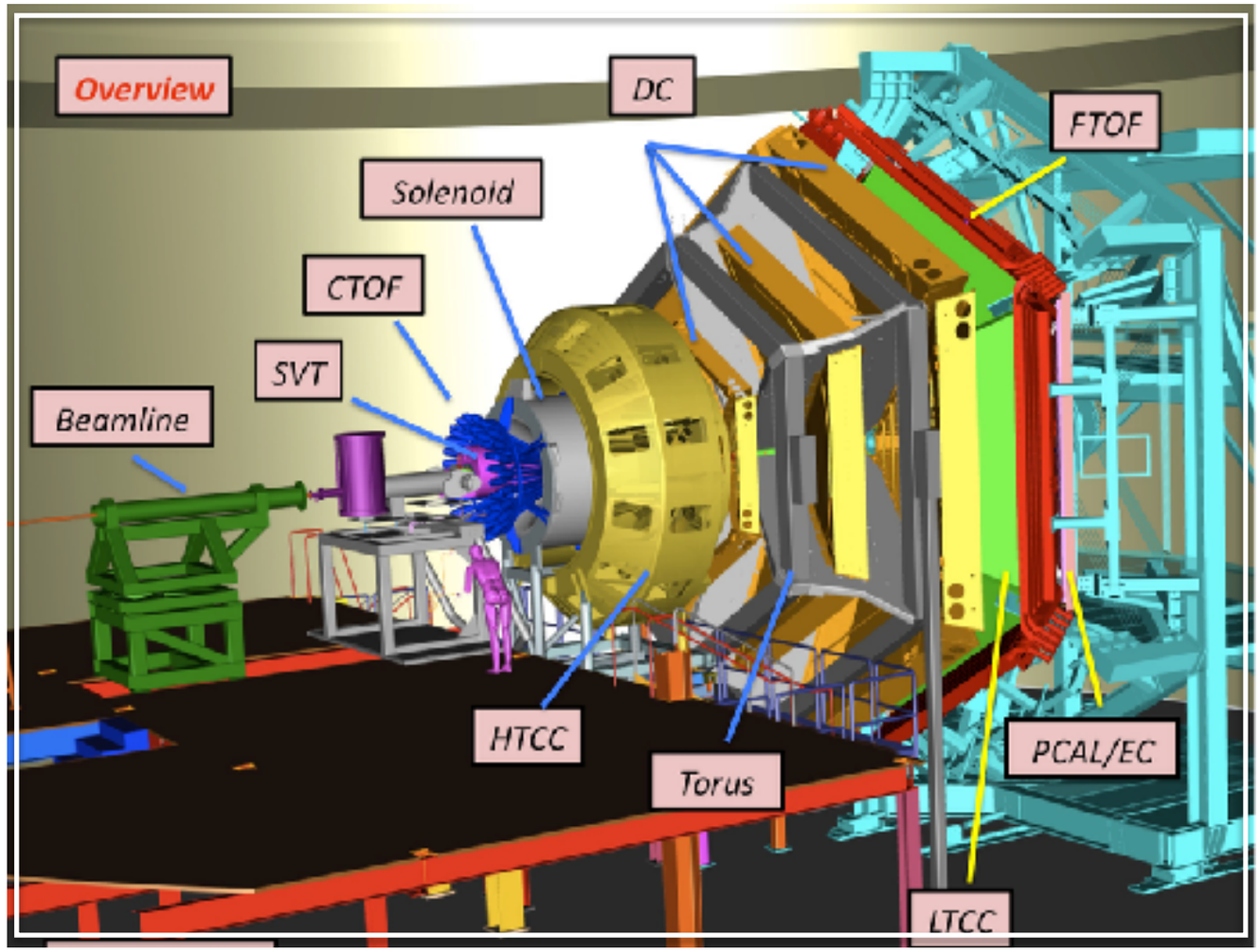
Future Plans

Proposal for CLAS12

Ten times more luminosity

Keeping the low threshold

300 MeV/c



Targets: ^{4}He, ^{12}C, ^{16}O, ^{40}Ar, ^{56}Fe

with incoming electron energies 1.1, 2.2, (3.3), 4.4, 6.6 GeV

Summary

Presenting wide phase space electron scattering data to test the the methods for incoming energy reconstruction for neutrino experiments.

For QE-like events both leptonic and hadronic have bad resolution

- for heavier nuclei

- for high missing transverse momentum

We wish to compare the data to MC to obtain constraints on the nuclei models and show implication on oscillation measurements.

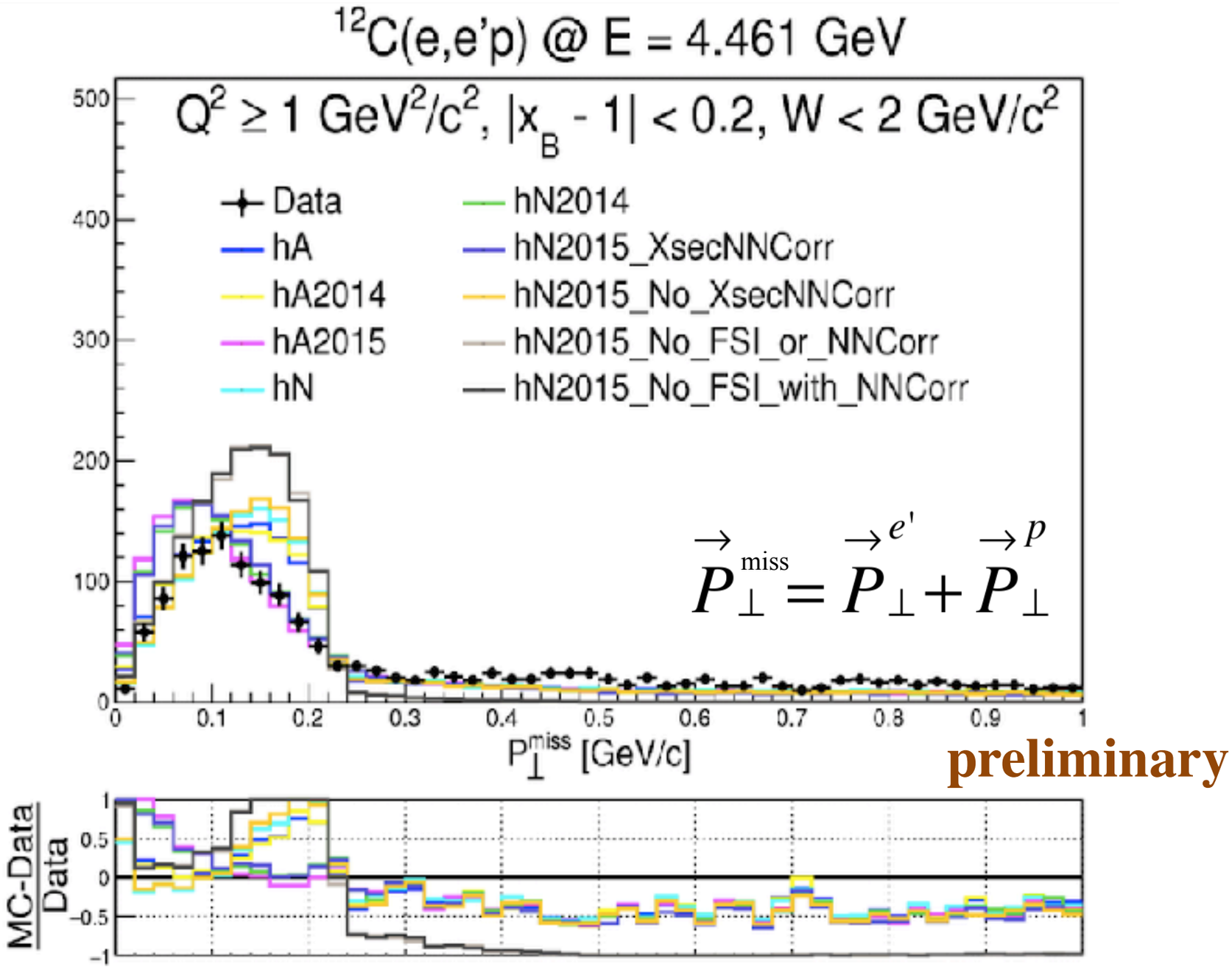
We would like to make this data available for everyone by publishing CLAS acceptance maps.

Looking forward to new data with more relevant nuclei and energies.

Thank you for your attention

Data Simulation Comparison

Missing transverse momentum



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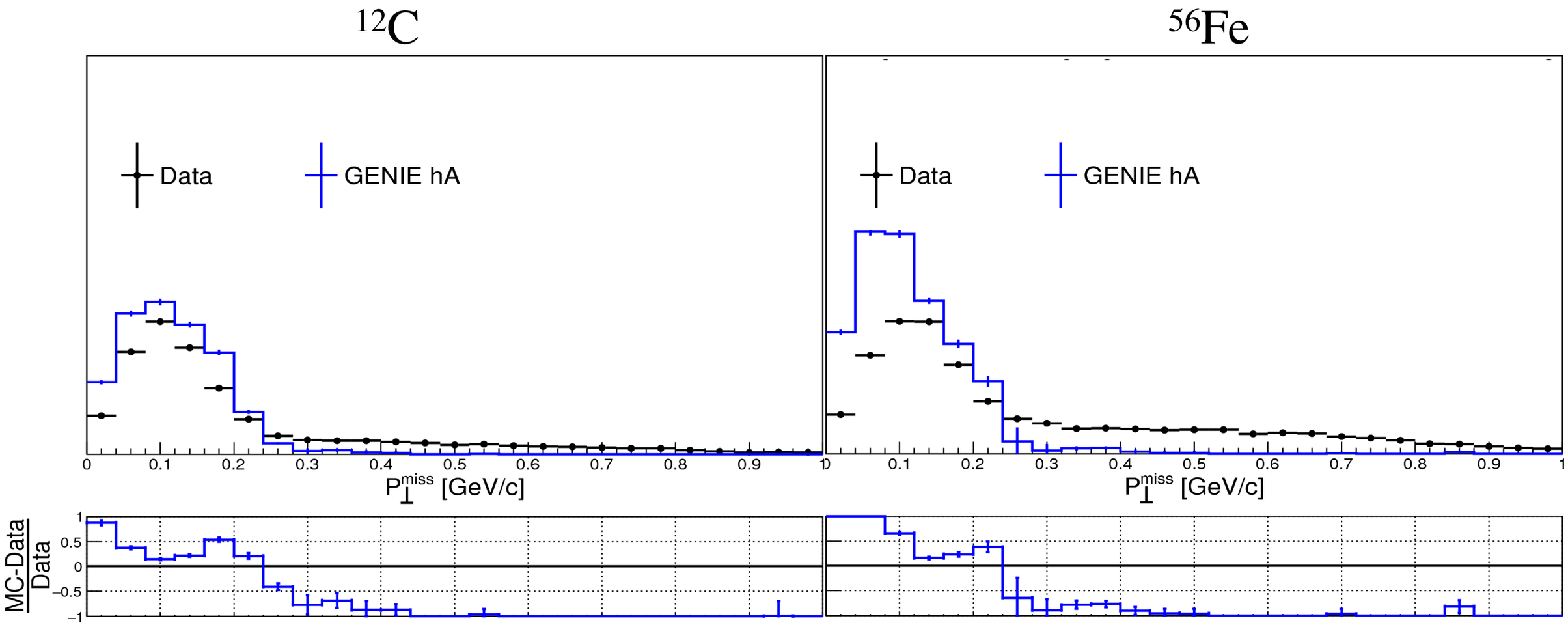
Data Simulation Comparison

Missing transverse momentum



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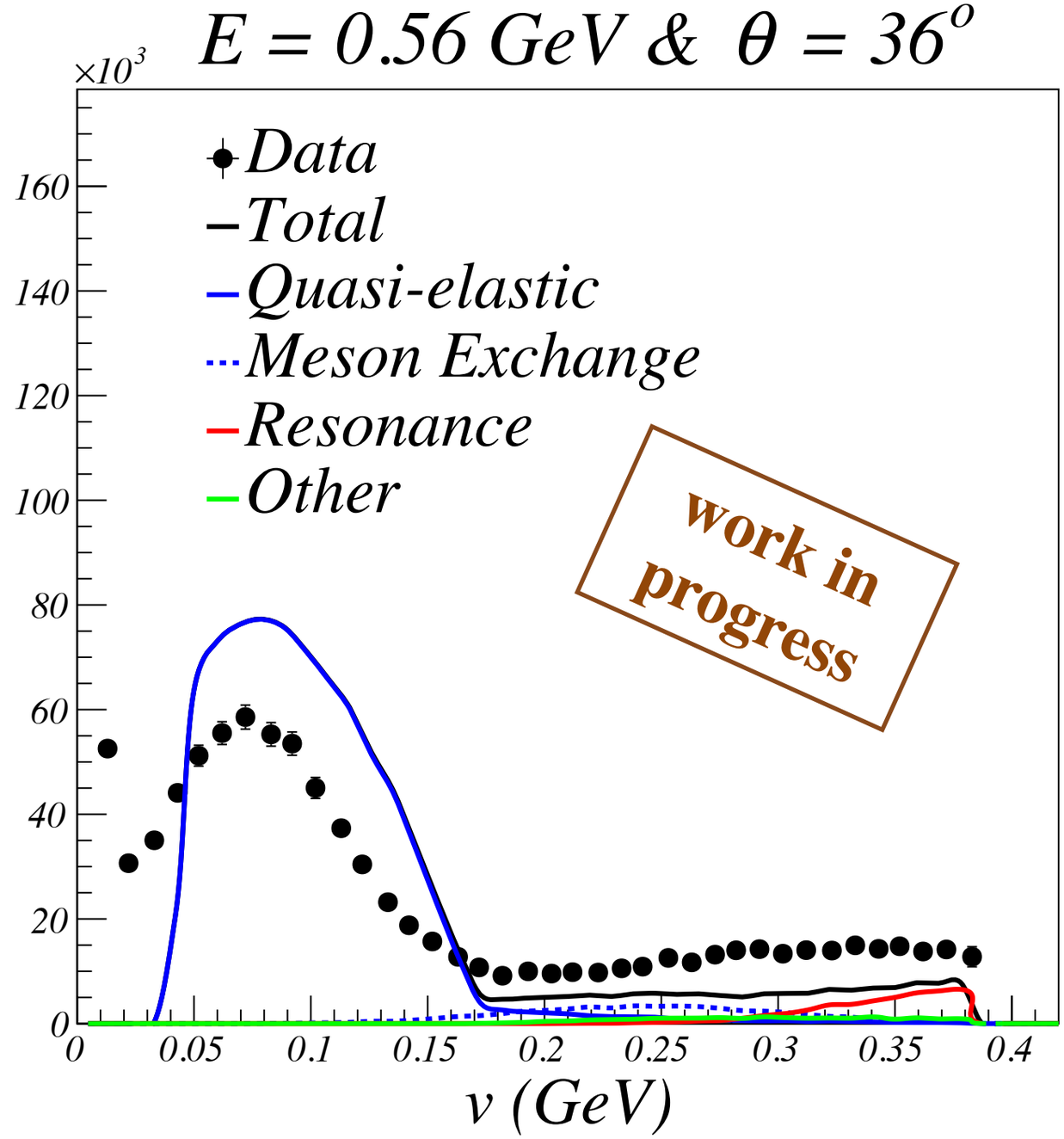
Electron Scattering Data vs. GENIE

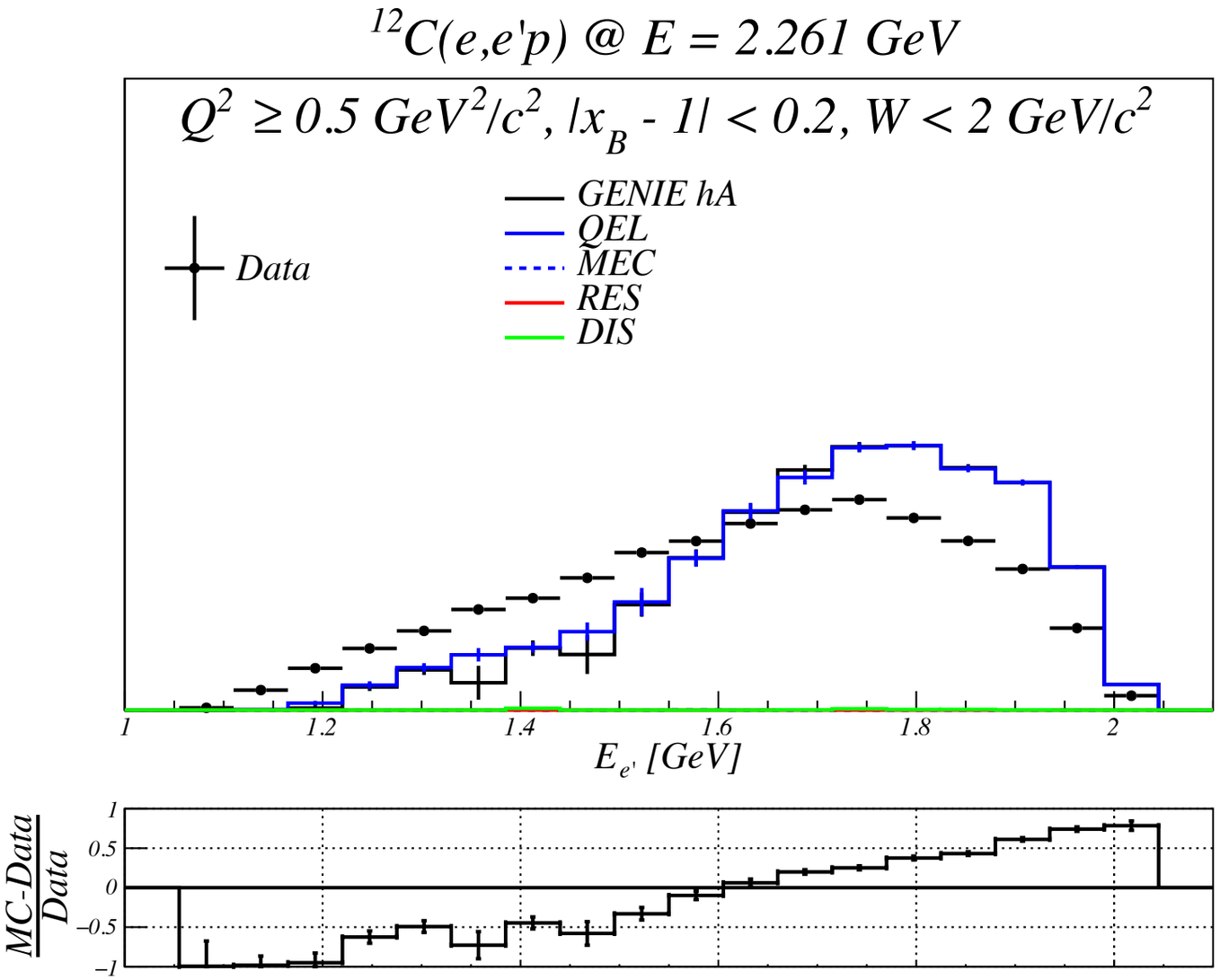
Newest Version of GENIE + Improvements

In the past month we have improved:

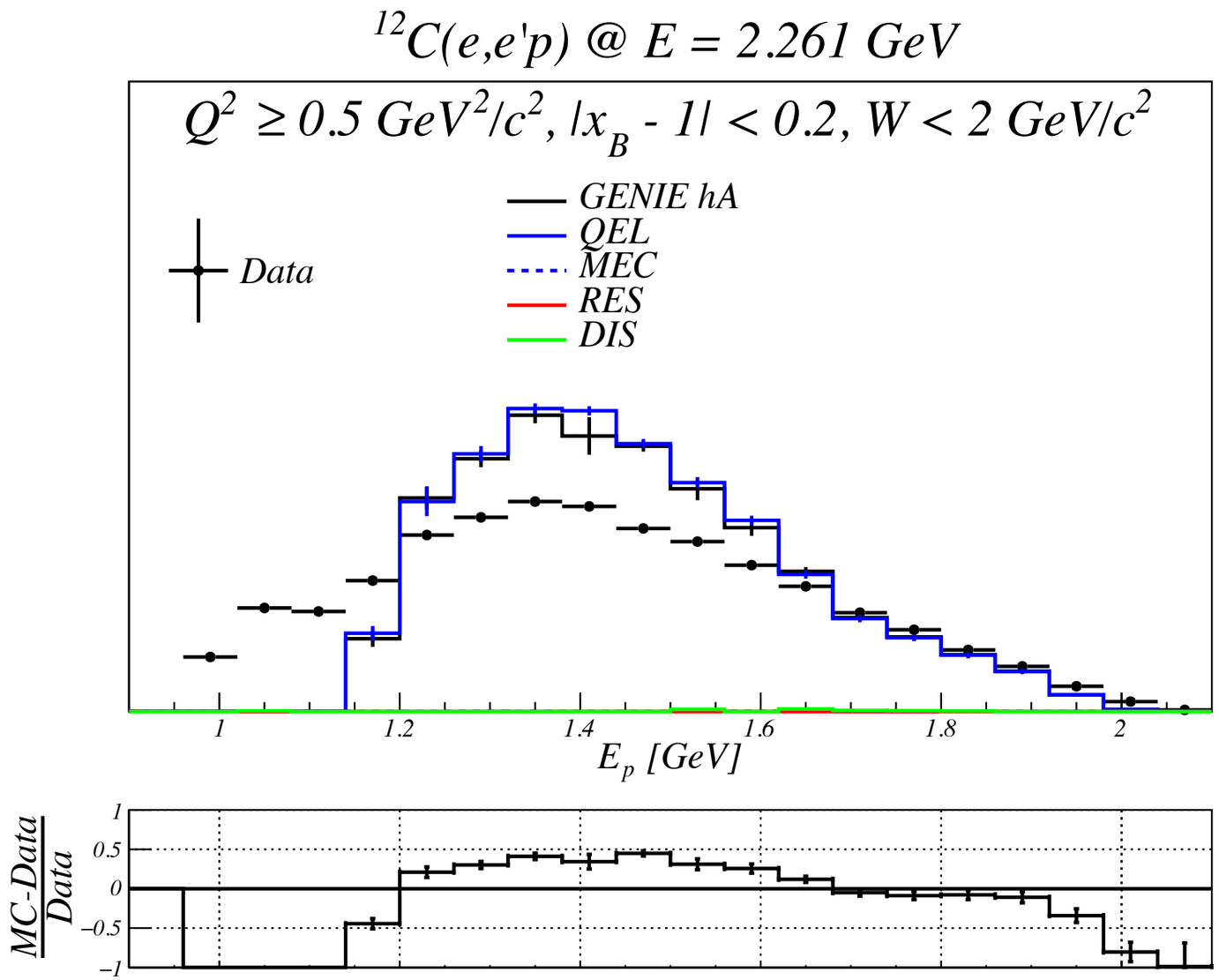
- QE calculation
- MEC calculation
- Resonance calculation
- The comparison code



MC vs. (e,e'p) CLAS Data



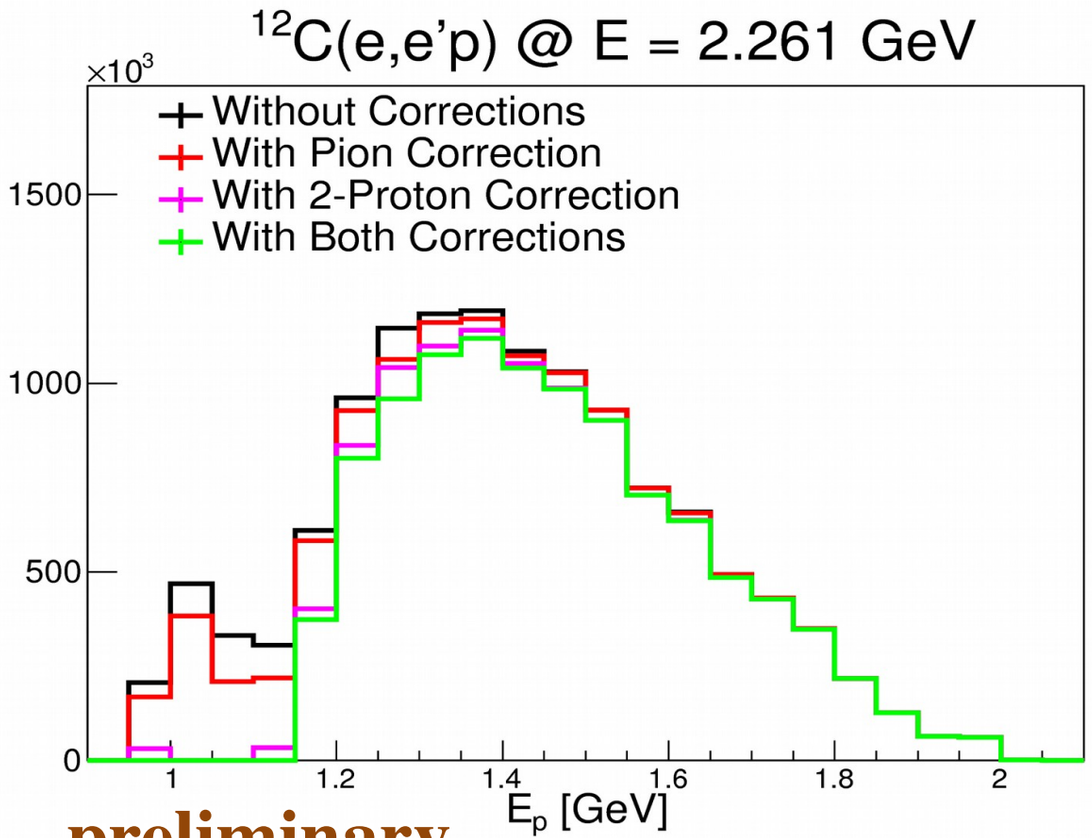
MC vs. (e,e’p) Data: Proton



MC vs. (e,e'p) CLAS Data

Background Subtraction Effect

Simulation



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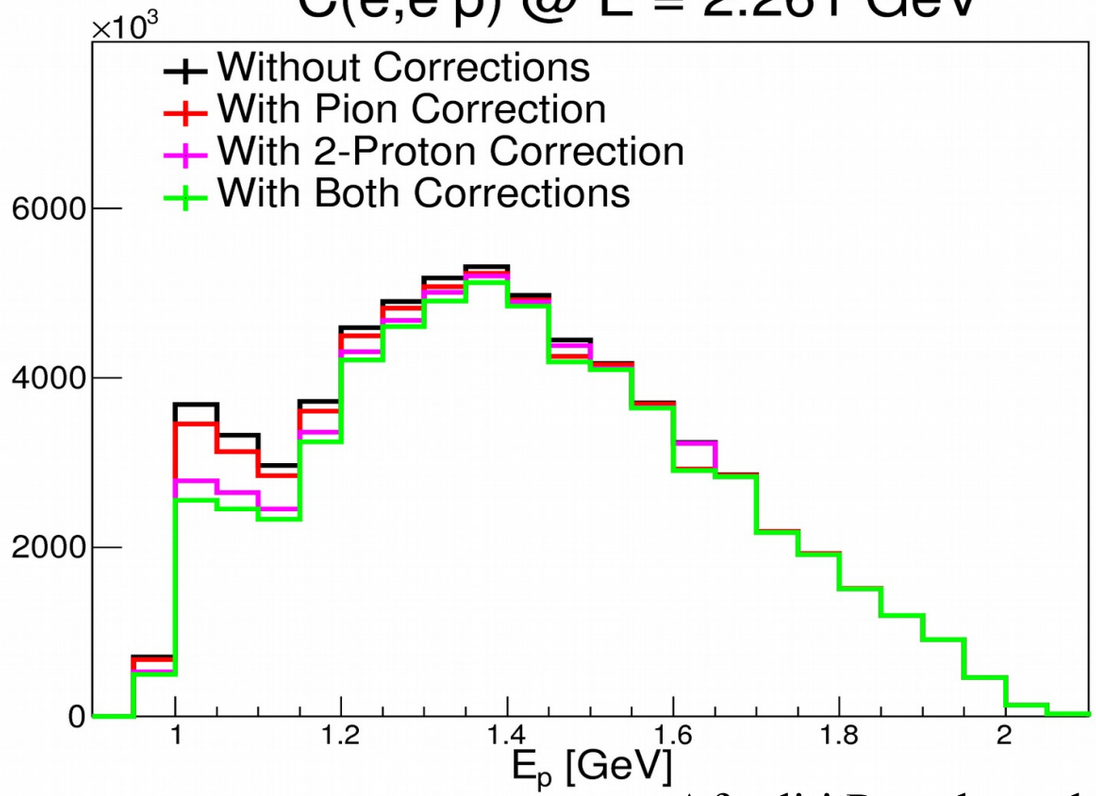
Data



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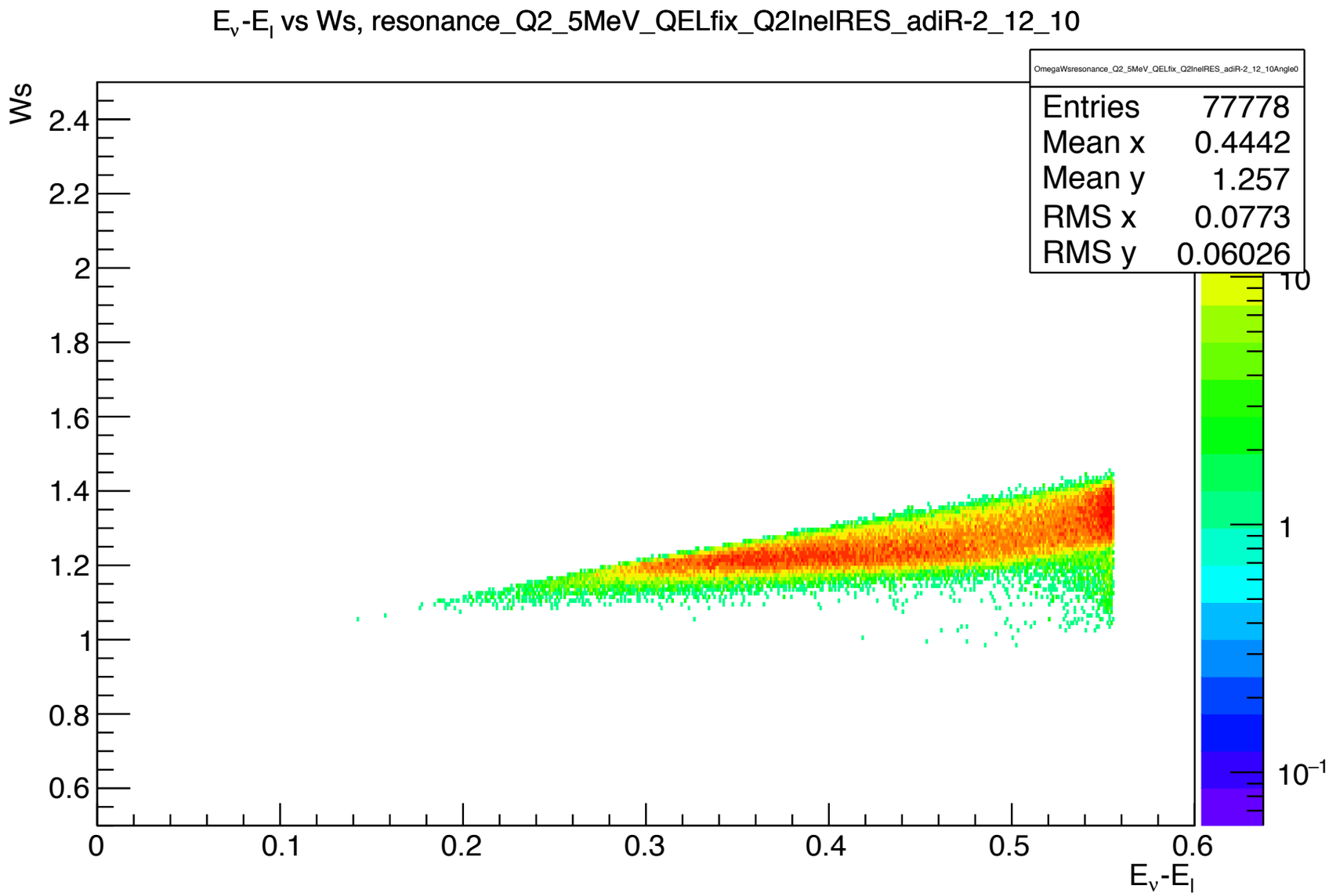
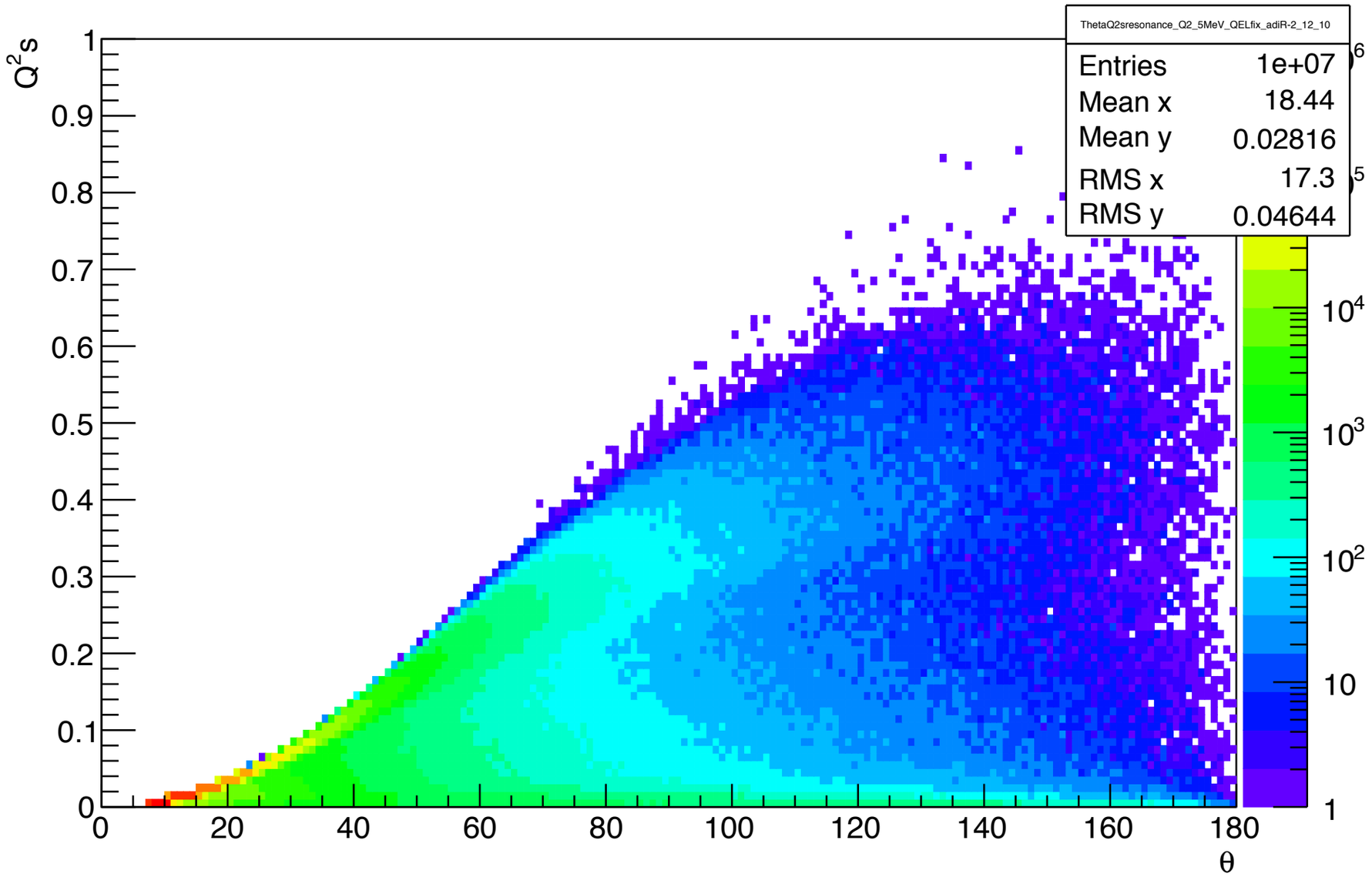
MC vs. (e,e'p) CLAS Data

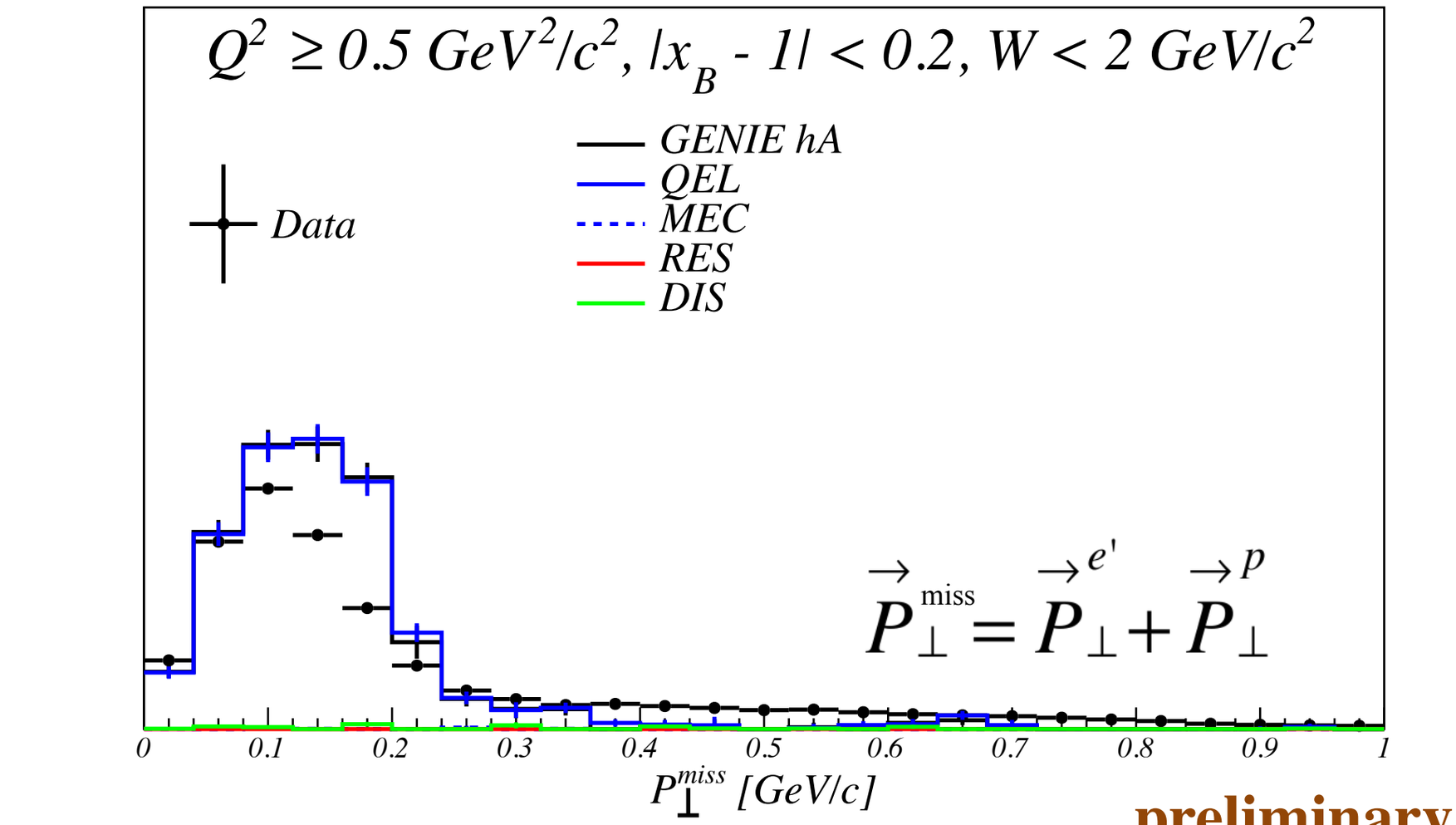


MC vs. (e,e’p) CLAS Data



MC vs. (e,e'p) Data: $\vec{P}_{\perp}^{\,miss}$

Underestimating FSI



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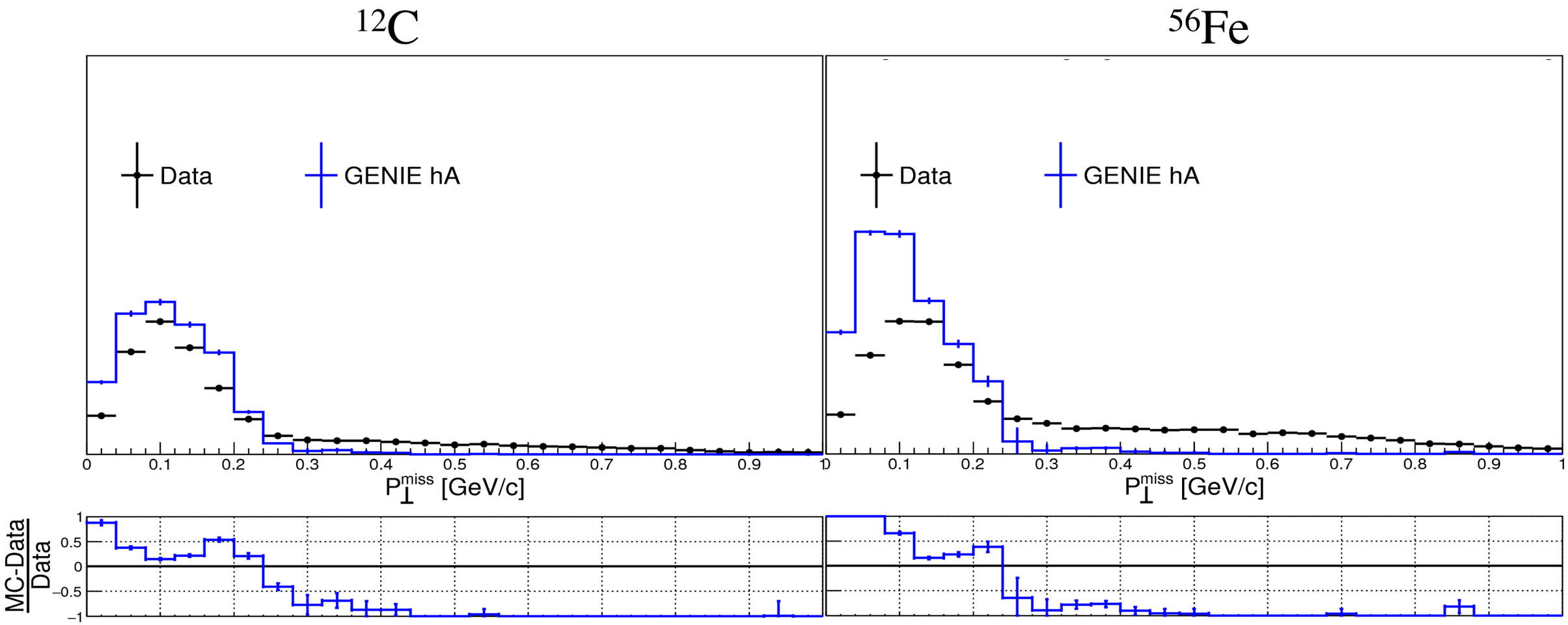
Data Simulation Comparison

Missing transverse momentum



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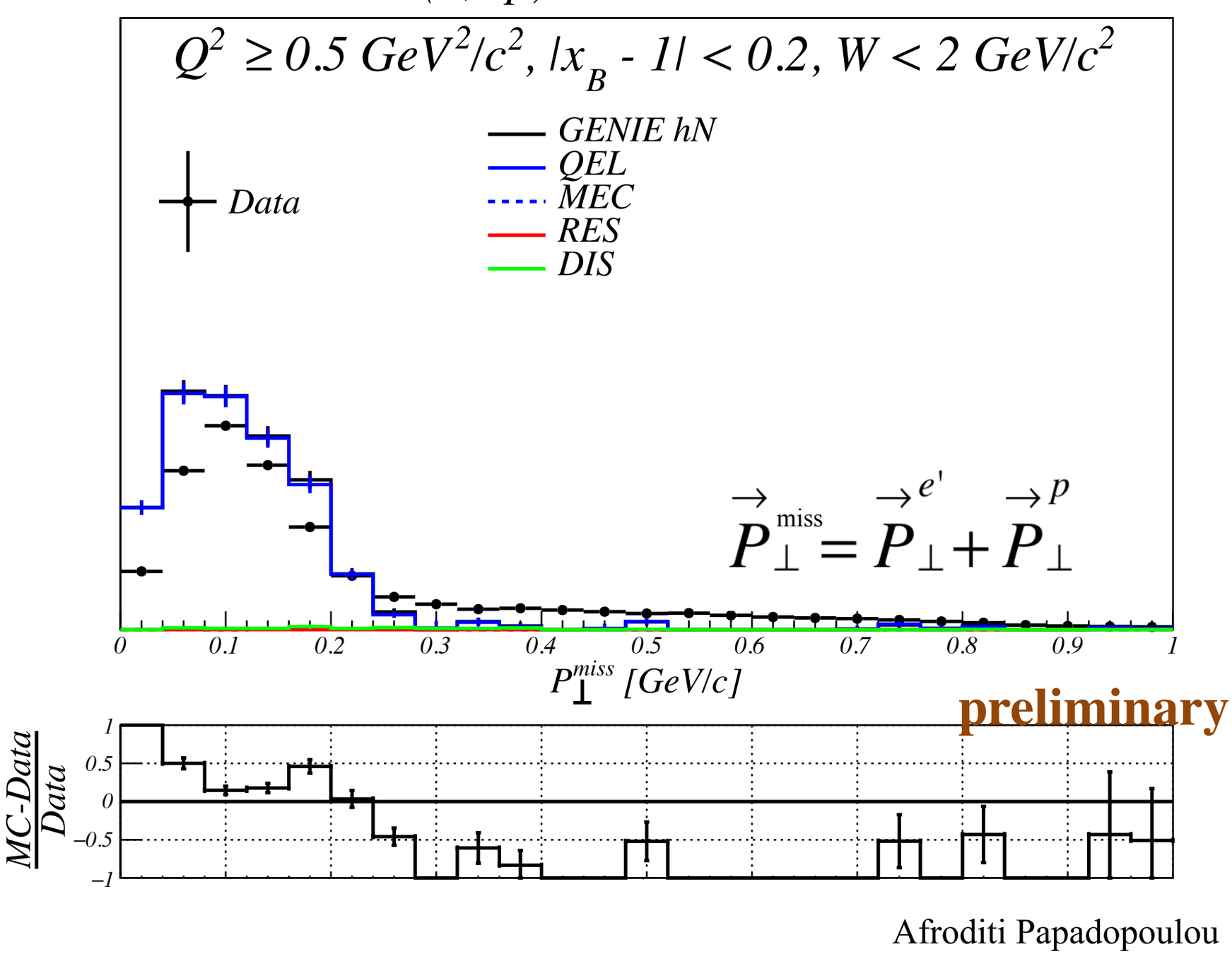
MC vs. (e,e'p) Data: $\vec{P}_{\perp}^{\,miss}$

Underestimating FSI



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