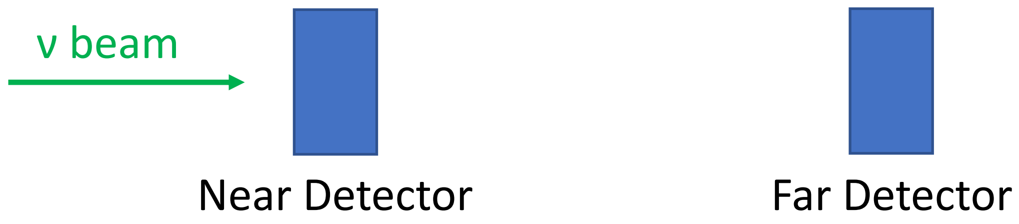
Measuring CLAS12 D(e,e'π) Cross Sections for e4ν

Caleb Fogler for the CLAS Collaboration

Neutrino Experiments

- Neutrino oscillations



Compare flux at near and far detectors

Neutrino Flux:

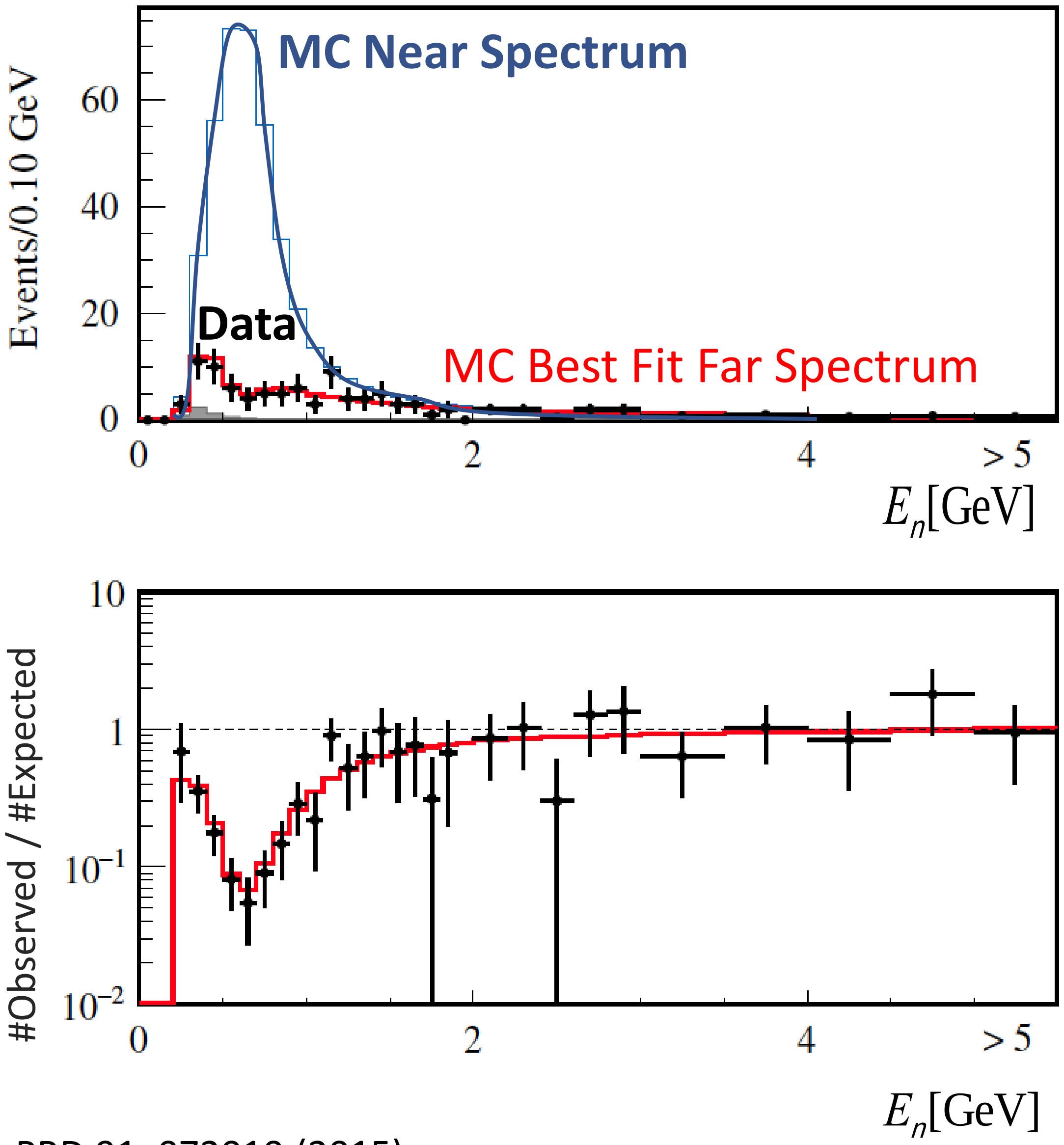
$$\Phi_\alpha(E,L) = \left[1 - P_{\nu_\alpha \to \nu_\beta}(E,L)\right] \Phi_\alpha(E,0)$$

Far — Near

$$N_\alpha(E_{rec},L) = \int \Phi_\alpha(E,L)\sigma(E) f_\sigma(E,E_{rec})dE$$

Measured — Flux — Simulated

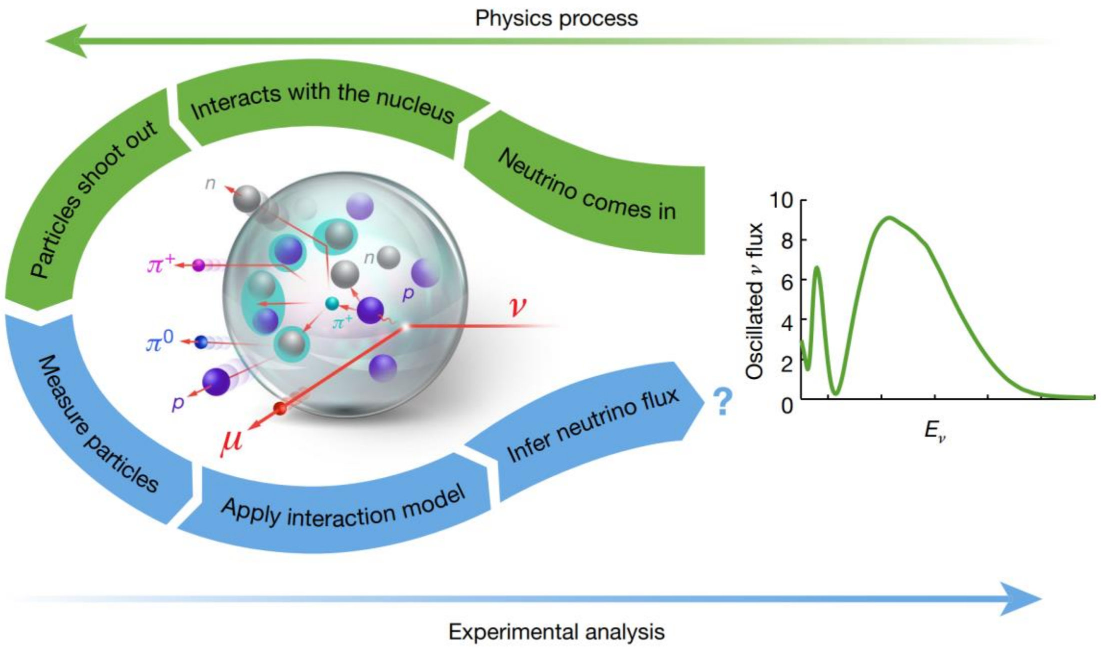
Need neutrino energy to get flux



PRD 91, 072010 (2015)

Neutrino Experiments

- Neutrino experiments are difficult
  - Large beam energy spread
  - Small cross sections
- Need to reconstruct incident beam flux from scattered particles



$$N_\alpha(E_{rec}, L) = \int \Phi_\alpha(E, L)\sigma(E) f_\sigma(E, E_{rec}) dE$$

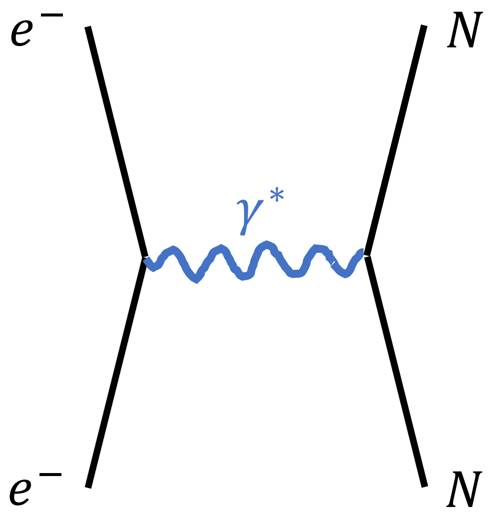
Measured   Flux   GENIE

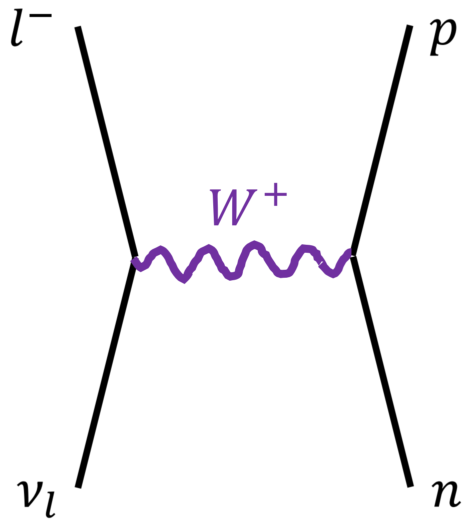
- Need event generators to extract the neutrino flux from data
  - GENIE = Generates Events for Neutrino Interaction Experiments

How to validate GENIE?

Electrons vs. Neutrinos

- Monoenergetic
- Larger cross sections
- Similar interactions
  - Electro-weak
  - Currents





If GENIE can describe neutrinos, it can describe electrons

EM Current:

$$j_\mu^{em} = \bar{u}\gamma^\mu u$$

Vector

Charge-Coupling Weak Current:

$$j_\mu^{\pm} = \bar{u}\frac{-ig_W}{2\sqrt{2}}(\gamma^\mu - \gamma^\mu\gamma^5)u$$

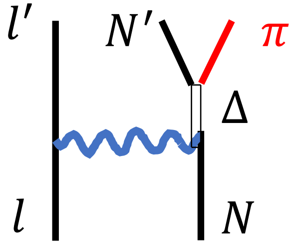
Vector Axial

Motivation

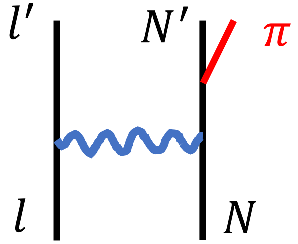
- GENIE badly describes inclusive p(e,e’) and D(e,e’) scattering in pion production region
  - GENIE parameters are being tuned to better describe the data

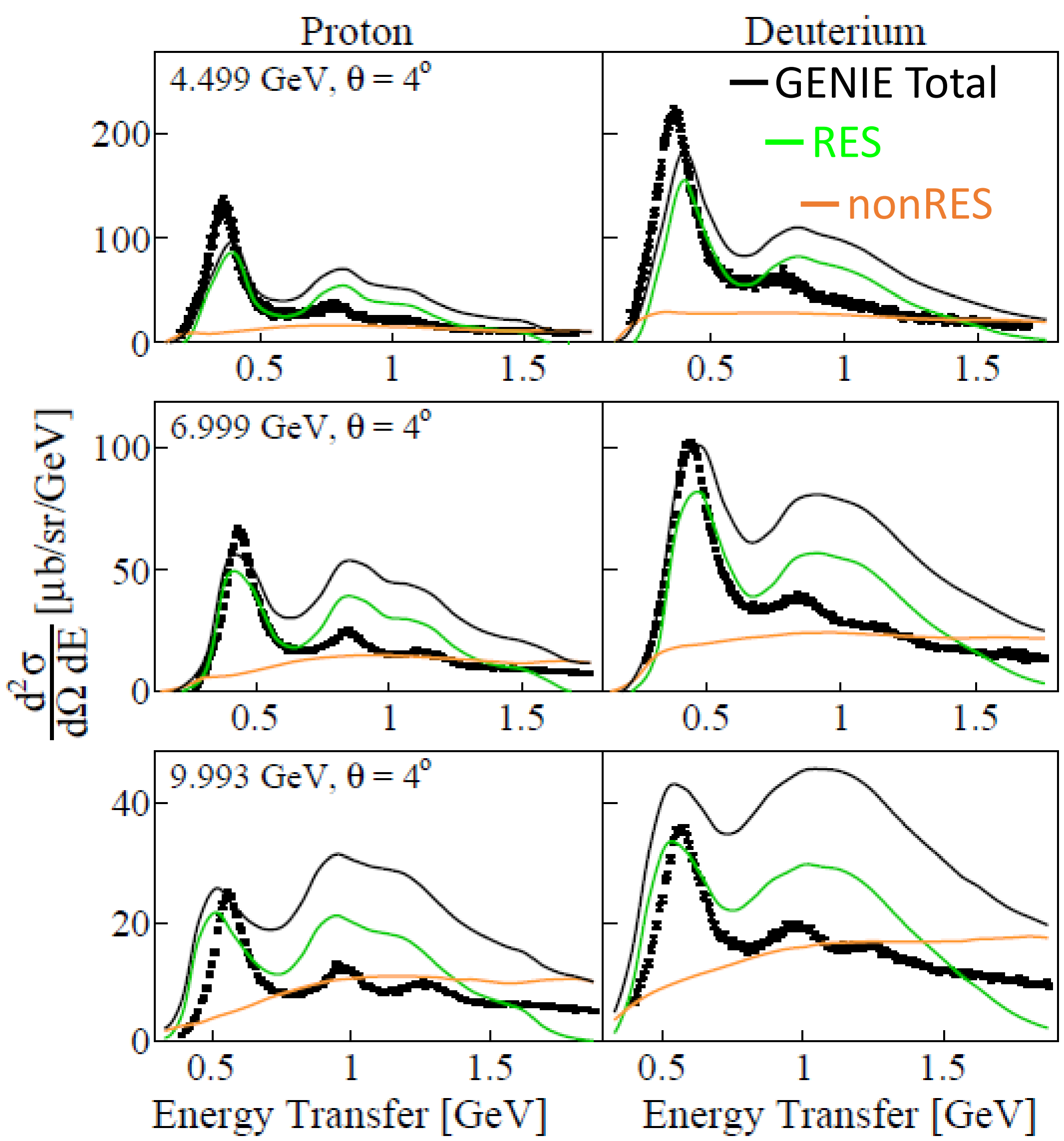
- I will measure 4.2 GeV RG-B D(e,e’π) cross sections with CLAS12 to further improve GENIE

Resonant



Non-Resonant

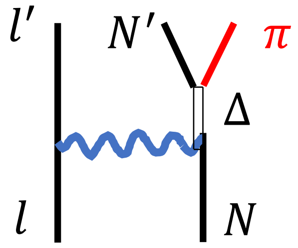




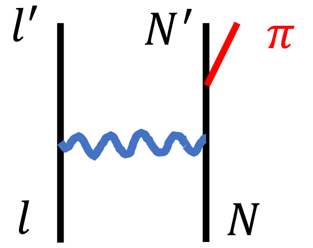
PRD 103, 113003 (2021)

Model Descriptions

Resonant Production



Non-Resonant Production

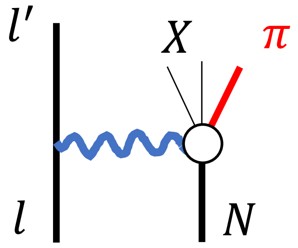


Onepigen

Nucl.Phys. A645 (1999) 145-174
arXiv:nucl-th/9807001v2

- Single pion event generator
  - Gives D(e,e’pi+) and D(e,e’pi-)
- MAID2007 unitary isobar model Eur. Phys. J. A**34**, (2007) 69-97
  - Fit to world data
  - Resonant and non resonant pion production

DIS Production



GENIE

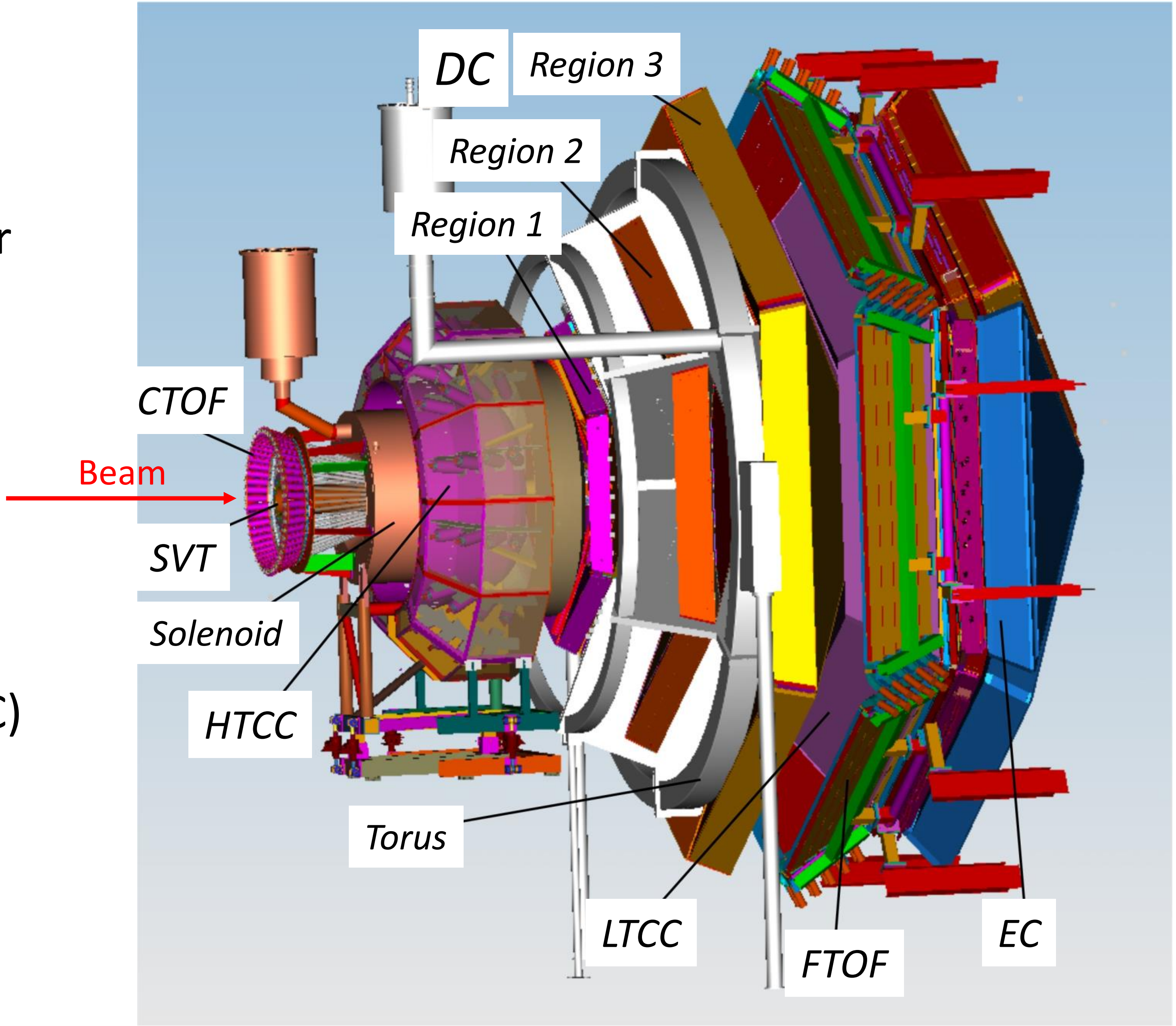
PRD 103 (2021) 113003

- Phenomenological semi-classical event generator
- Quasi-elastic scattering
- Baryon resonance production (Berger-Sehgal) PRD 76 (2007) 113004
  - Relativistic harmonic oscillator quark model
  - Includes known resonances from W < 2 GeV
- DIS and non resonant production (Bodek-Yang) J. Phys. G: Nucl. Part. Phys. 29 (2003) 1899–1905
  - Uses scaling variables fit to GRV98 LO PDFs that describe electron/muon data

CLAS12

- Forward Detector:
  - High Threshold Cerenkov Counter (HTCC) identifies scattered electrons
  - Drift Chambers (DC) measure charged particle momenta
  - Forward Time-of-Flight (FTOF) measures time-of-flight of charged particles
  - Electromagnetic Calorimeters (EC) identifies scattered electrons
    - Includes Pre-shower Calorimeter (PCAL)
- Central Detector:

  Not used in this analysis



Cut Summary

Electron Cuts:

- Electron PID
- DC fiducial cuts
- ECAL fiducial cuts
- Vertex cuts

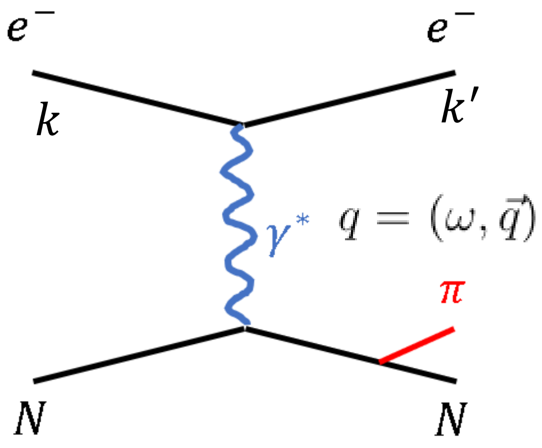
Pion Cuts:

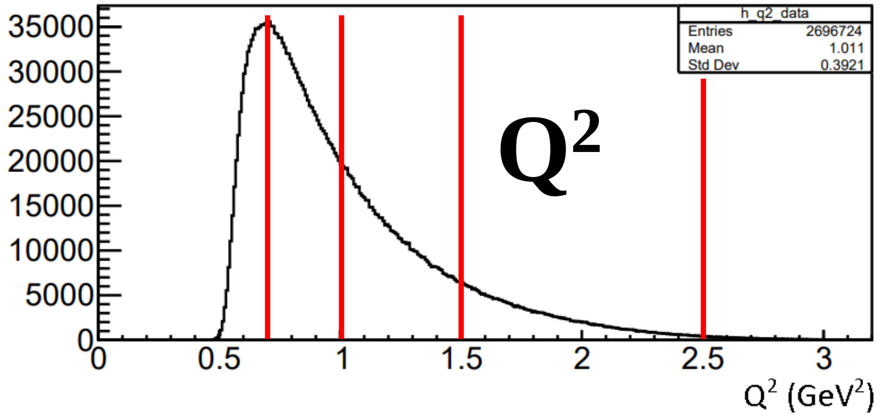
- Pion PID
- DC fiducial cuts
- Vertex cuts

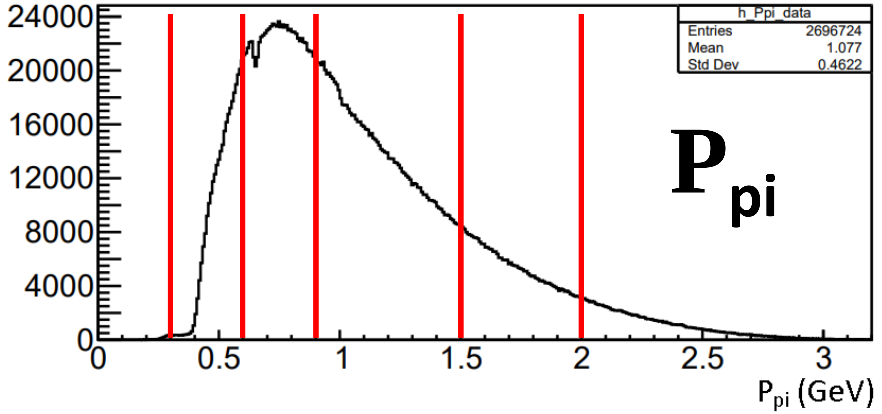
- Plotted vs W
- D(e,e') binned in θ_e
- D(e,e'pi) binned in θ_{piq}, P_{pi}, and Q^2

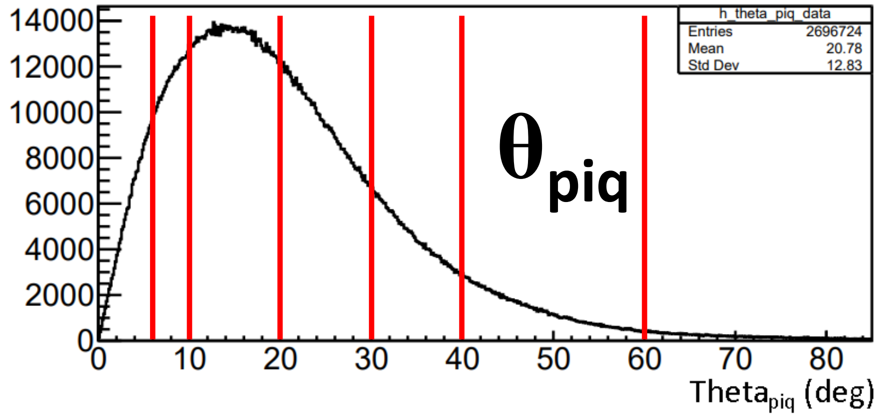
$$Q^2 = -q^2 = (k - k')^2$$

$$W = \sqrt{M_N^2 + 2M_N\omega - Q^2}$$

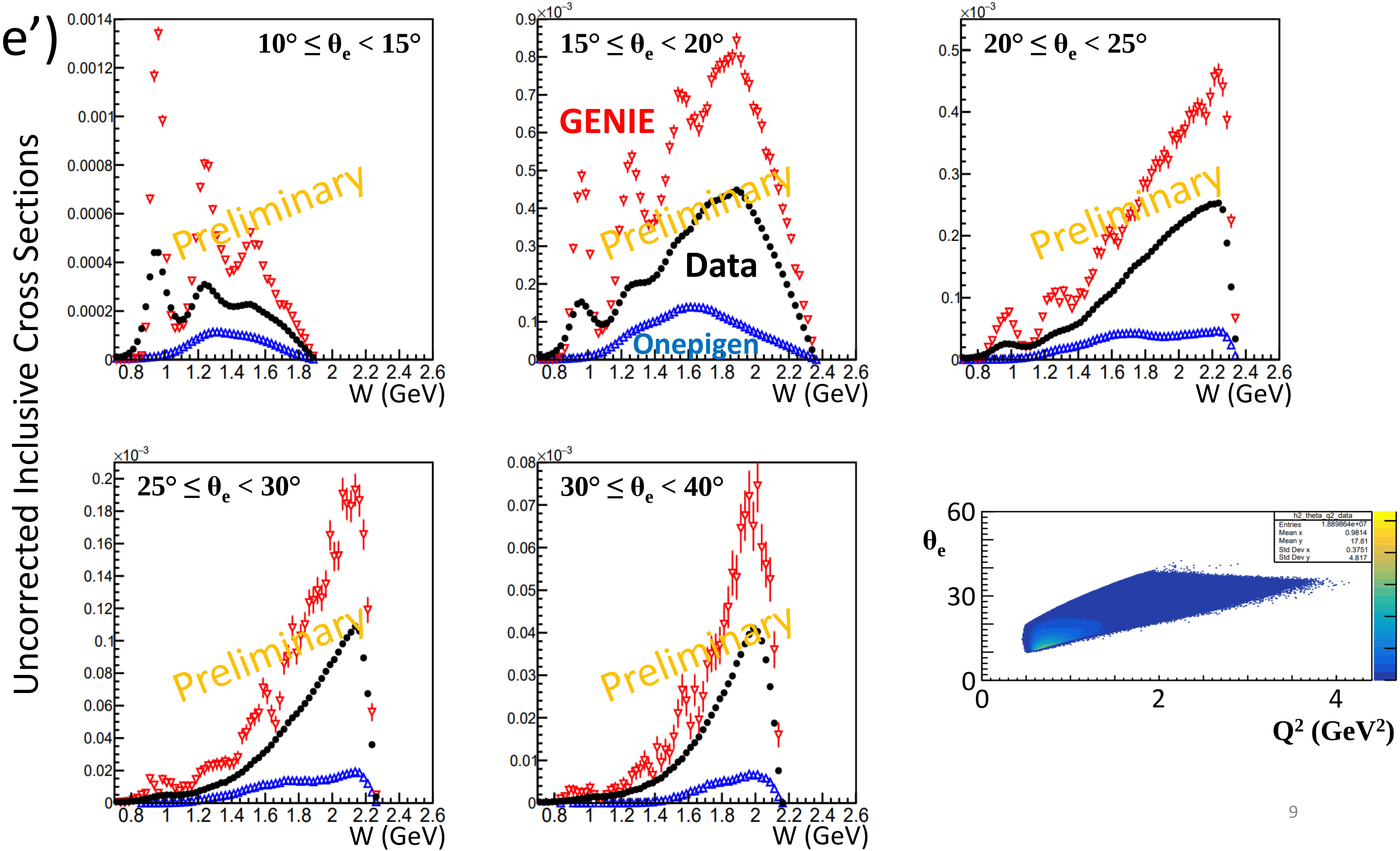






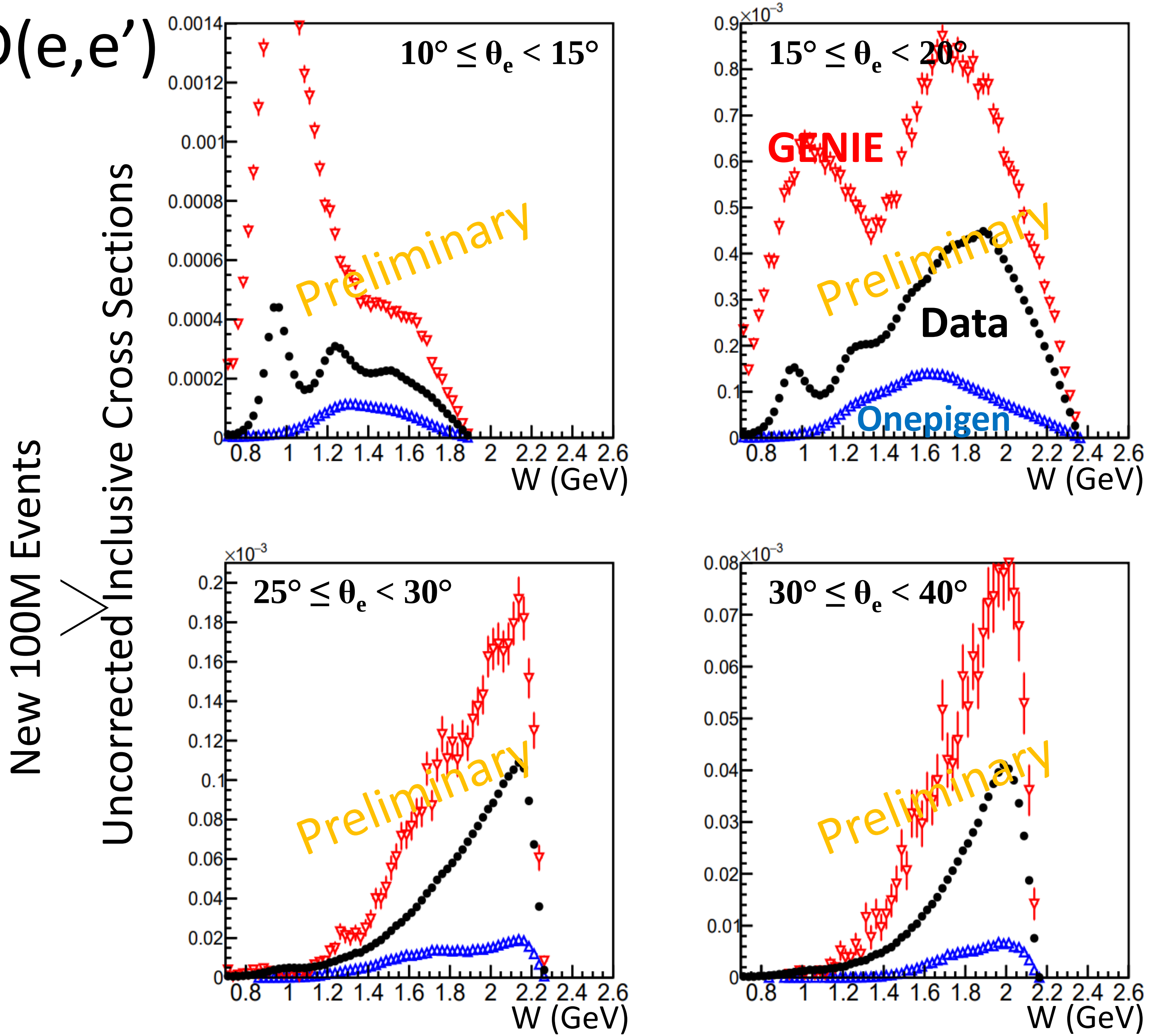


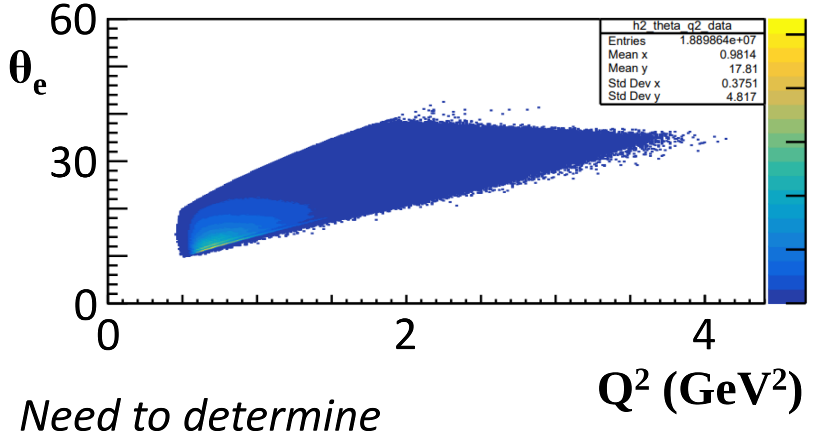
D(e,e')



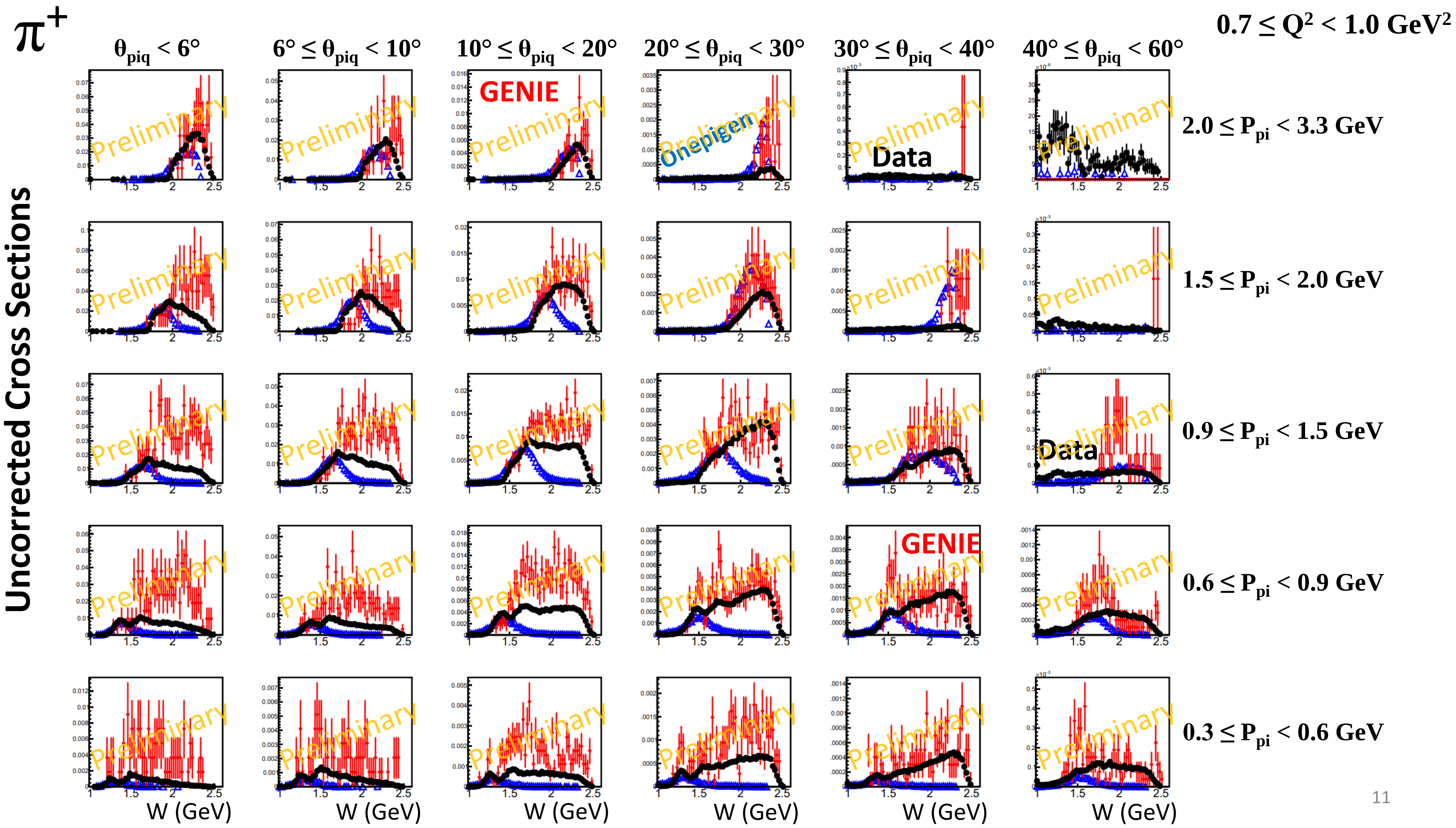
Uncorrected Inclusive Cross Sections
10° ≤ θe < 15°
15° ≤ θe < 20°
20° ≤ θe < 25°
25° ≤ θe < 30°
30° ≤ θe < 40°
GENIE
Data
Onepigen
Preliminary
W (GeV)
θe
Q² (GeV²)
h2_theta_q2_data
Entries 1.889864e+07
Mean x 0.9814
Mean y 17.81
Std Dev x 0.3751
Std Dev y 4.817

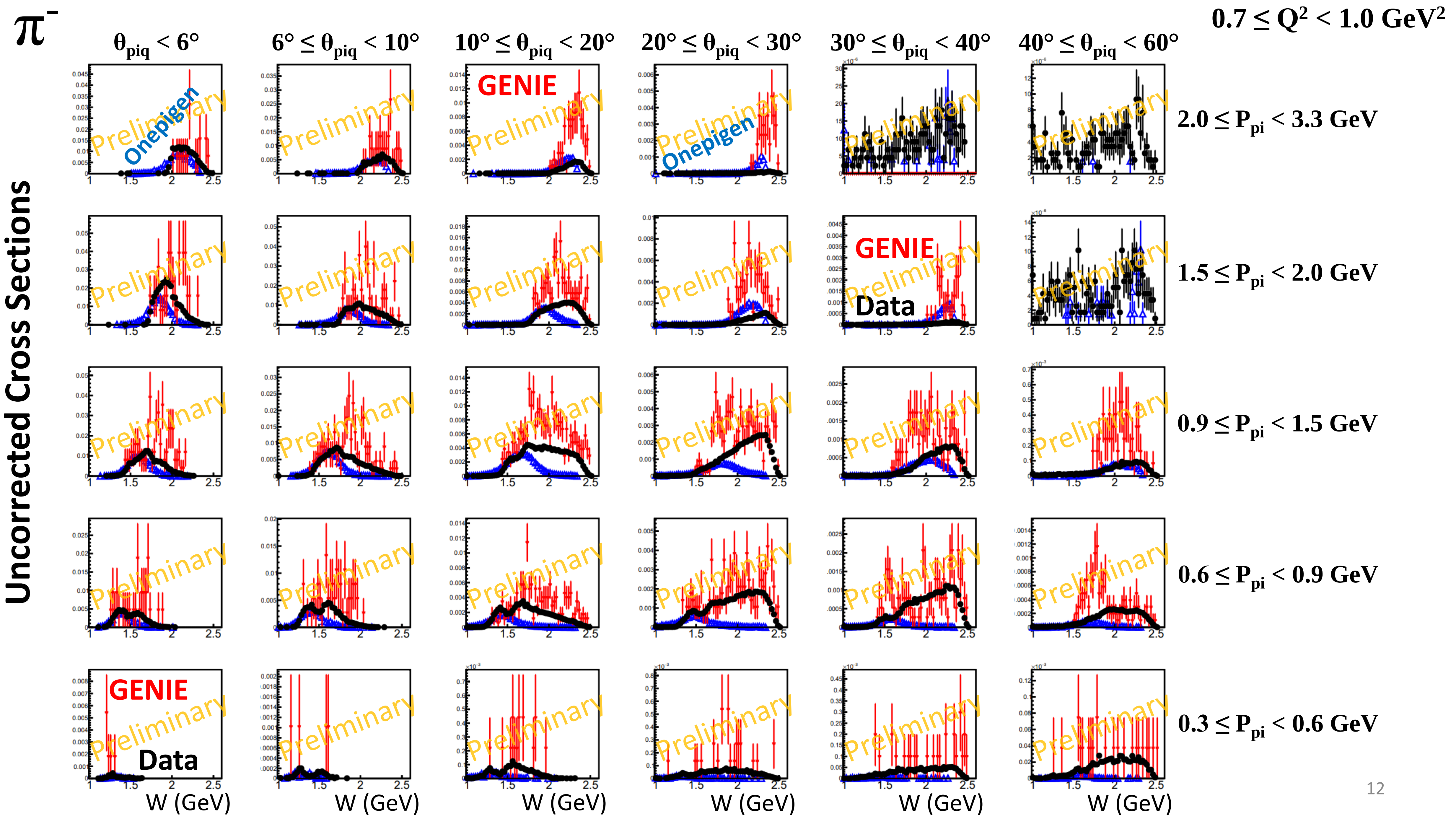
D(e,e')





Need to determine scaling issue with new GENIE events


π+
0.7 ≤ Q² < 1.0 GeV²
θpiq < 6°
6° ≤ θpiq < 10°
10° ≤ θpiq < 20°
20° ≤ θpiq < 30°
30° ≤ θpiq < 40°
40° ≤ θpiq < 60°
2.0 ≤ Ppi < 3.3 GeV
1.5 ≤ Ppi < 2.0 GeV
0.9 ≤ Ppi < 1.5 GeV
0.6 ≤ Ppi < 0.9 GeV
0.3 ≤ Ppi < 0.6 GeV
Uncorrected Cross Sections
W (GeV)
GENIE
Onepigen
Data
Preliminary



π^-
$0.7 \leq Q^2 < 1.0$ GeV^2
Uncorrected Cross Sections
$\theta_{piq} < 6°$
$6° \leq \theta_{piq} < 10°$
$10° \leq \theta_{piq} < 20°$
$20° \leq \theta_{piq} < 30°$
$30° \leq \theta_{piq} < 40°$
$40° \leq \theta_{piq} < 60°$
$2.0 \leq P_{pi} < 3.3$ GeV
$1.5 \leq P_{pi} < 2.0$ GeV
$0.9 \leq P_{pi} < 1.5$ GeV
$0.6 \leq P_{pi} < 0.9$ GeV
$0.3 \leq P_{pi} < 0.6$ GeV
GENIE
Onepigen
Data
Preliminary
W (GeV)

Radiative Correction

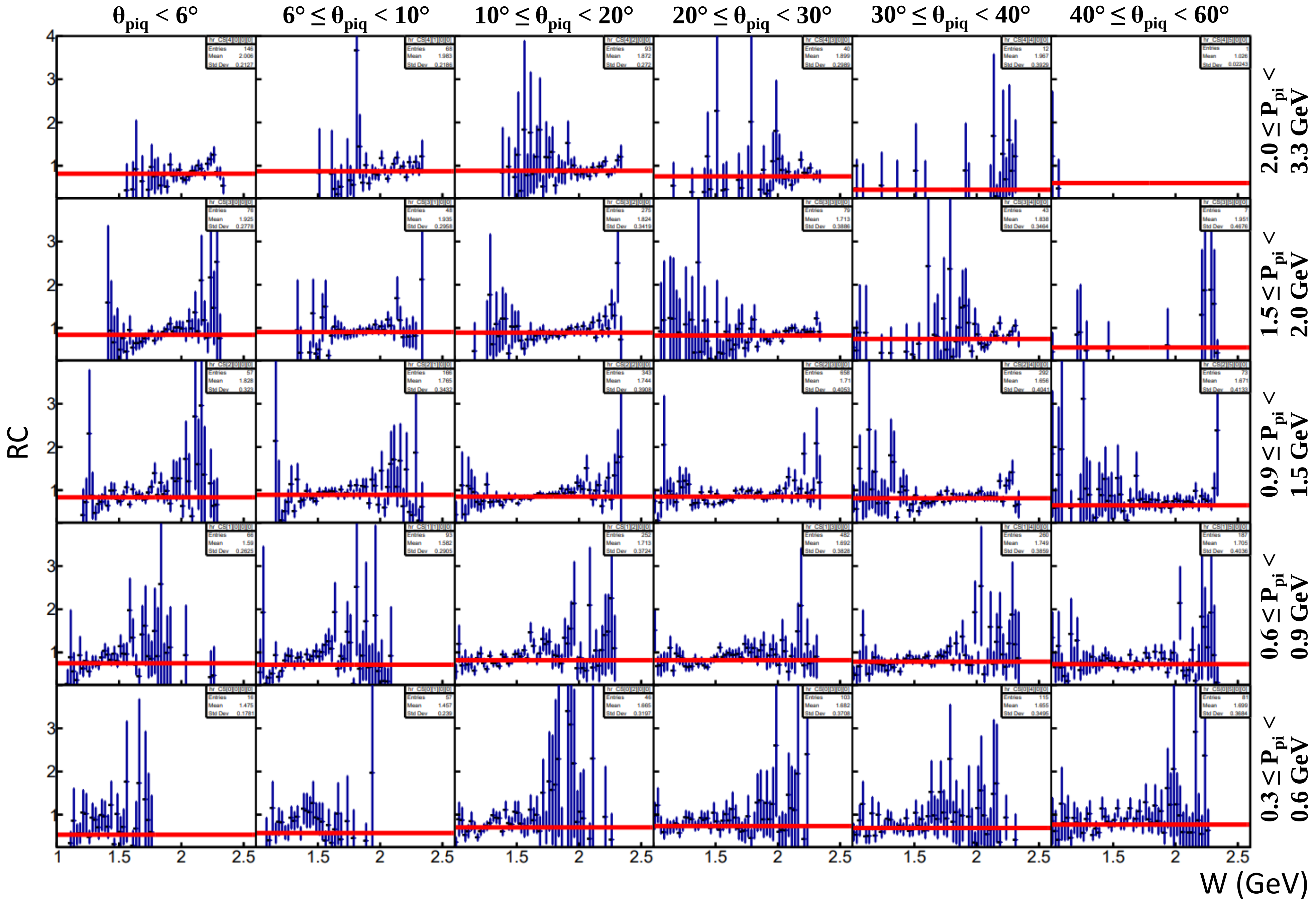
- with onepigen

$$RC = \frac{CS_{rad}^{onepigen}}{CS_{norad}^{onepigen}}$$

$$CS_{norad}^{data} = \frac{CS_{rad}^{data}}{RC}$$

π^+

$0.7 \leq Q^2 < 1.0$ GeV^2



Systematic Uncertainty

- Inclusive sector

$$SysUnc_{sec} = \sqrt{var}$$

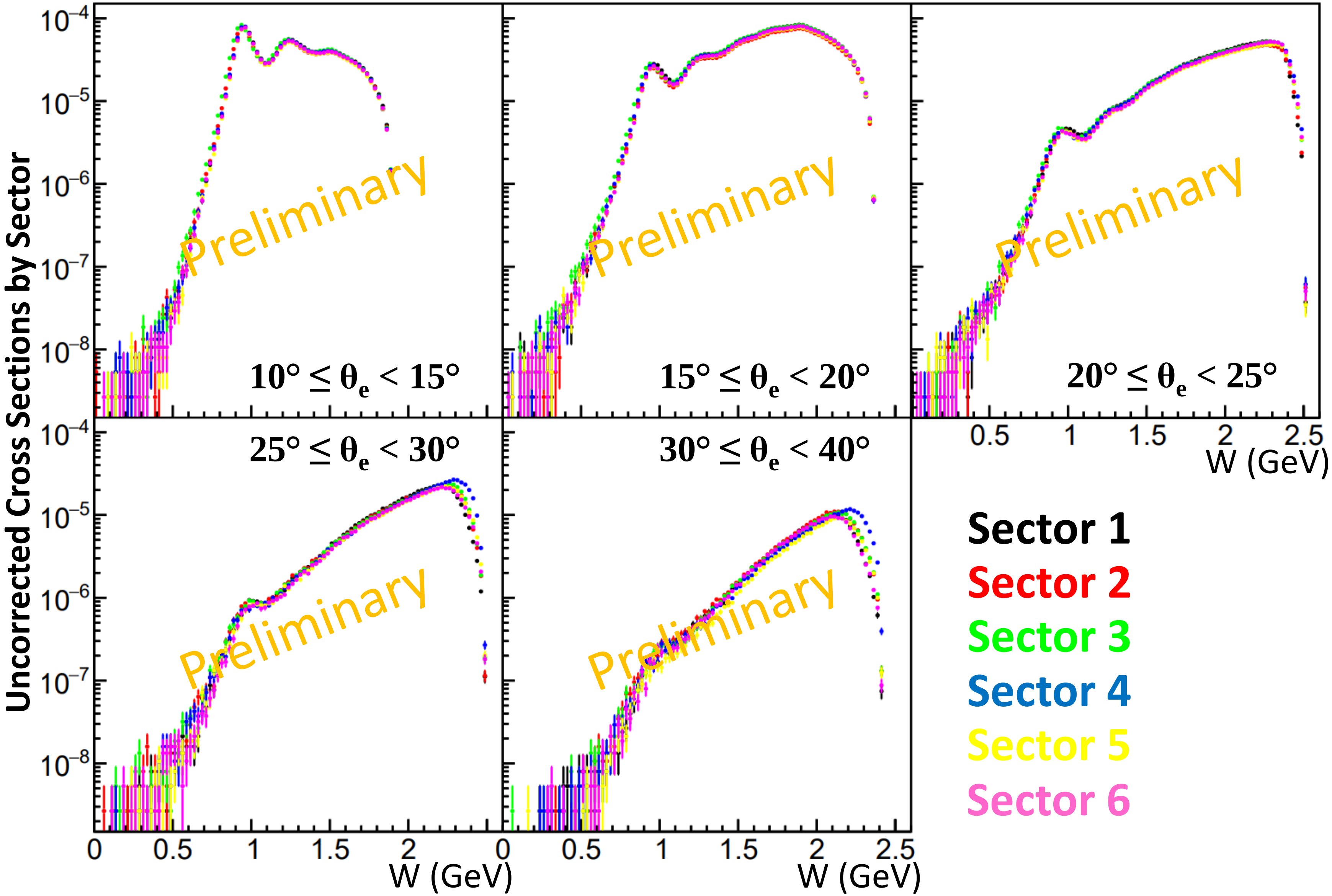
$$var = \frac{1}{5}\sum_{i}^{sec}(y_i - \bar{y})^2 - \frac{1}{6}\sum_{i}^{sec}\sigma_i^2$$

$y_i = data\ point\ for\ sector\ i$

$$\bar{y} = \frac{1}{6}\sum_{i}^{sec} y_i = ave.\ for\ all\ sectors$$

$\sigma_i = statistical\ uncertainty\ of\ y_i$

D(e,e')



Similar analysis also on semi-inc. cross sections

D(e,e')

All sectors divided by Sector 1

$$SysUnc_{sec} = \sqrt{var}$$

$$var = \frac{1}{5}\sum_{i}^{sec}(y_i - \bar{y})^2 - \frac{1}{6}\sum_{i}^{sec}\sigma_i^2$$

$y_i = data\ point\ for\ sector\ i$

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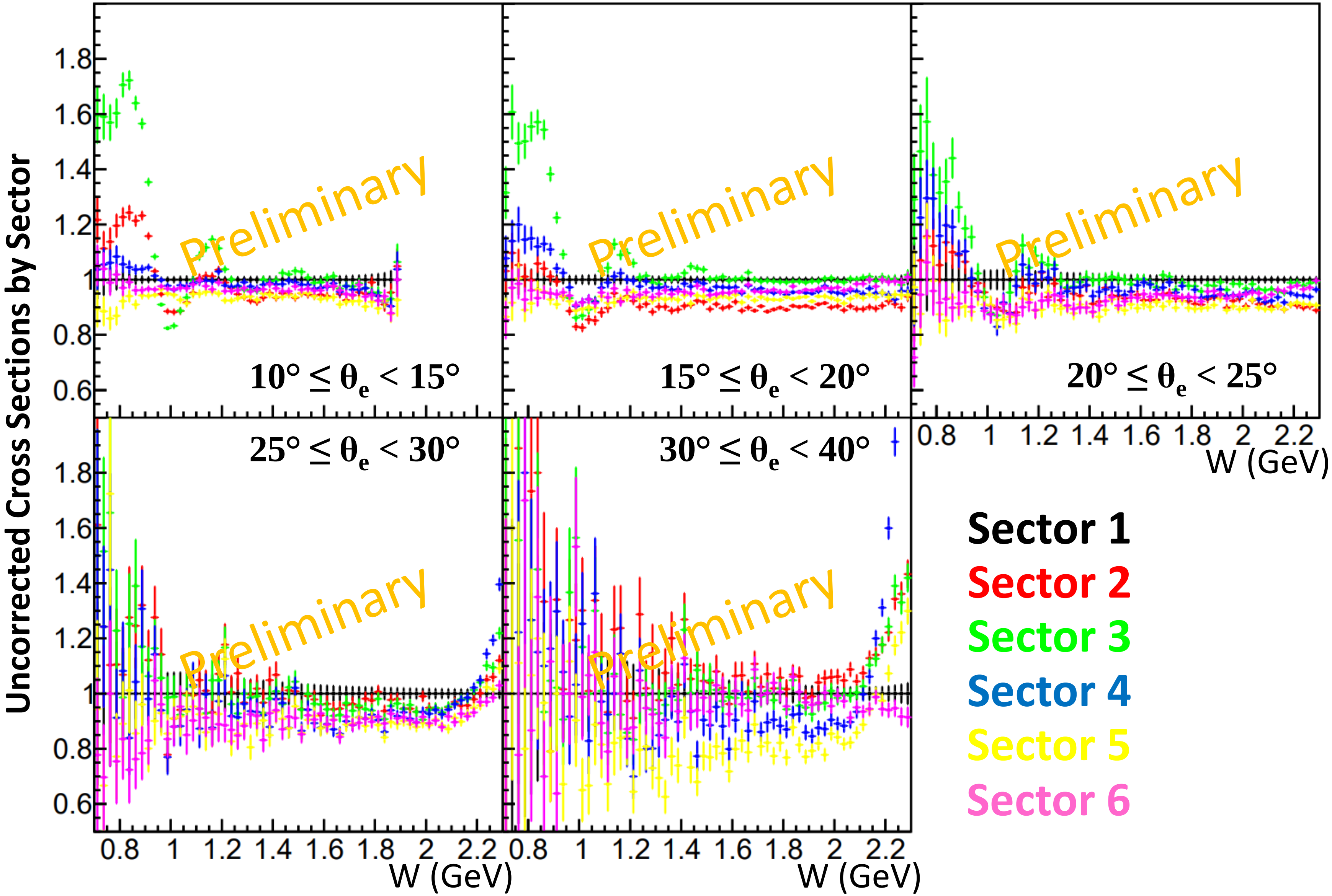


Similar analysis also on semi-inc. cross sections

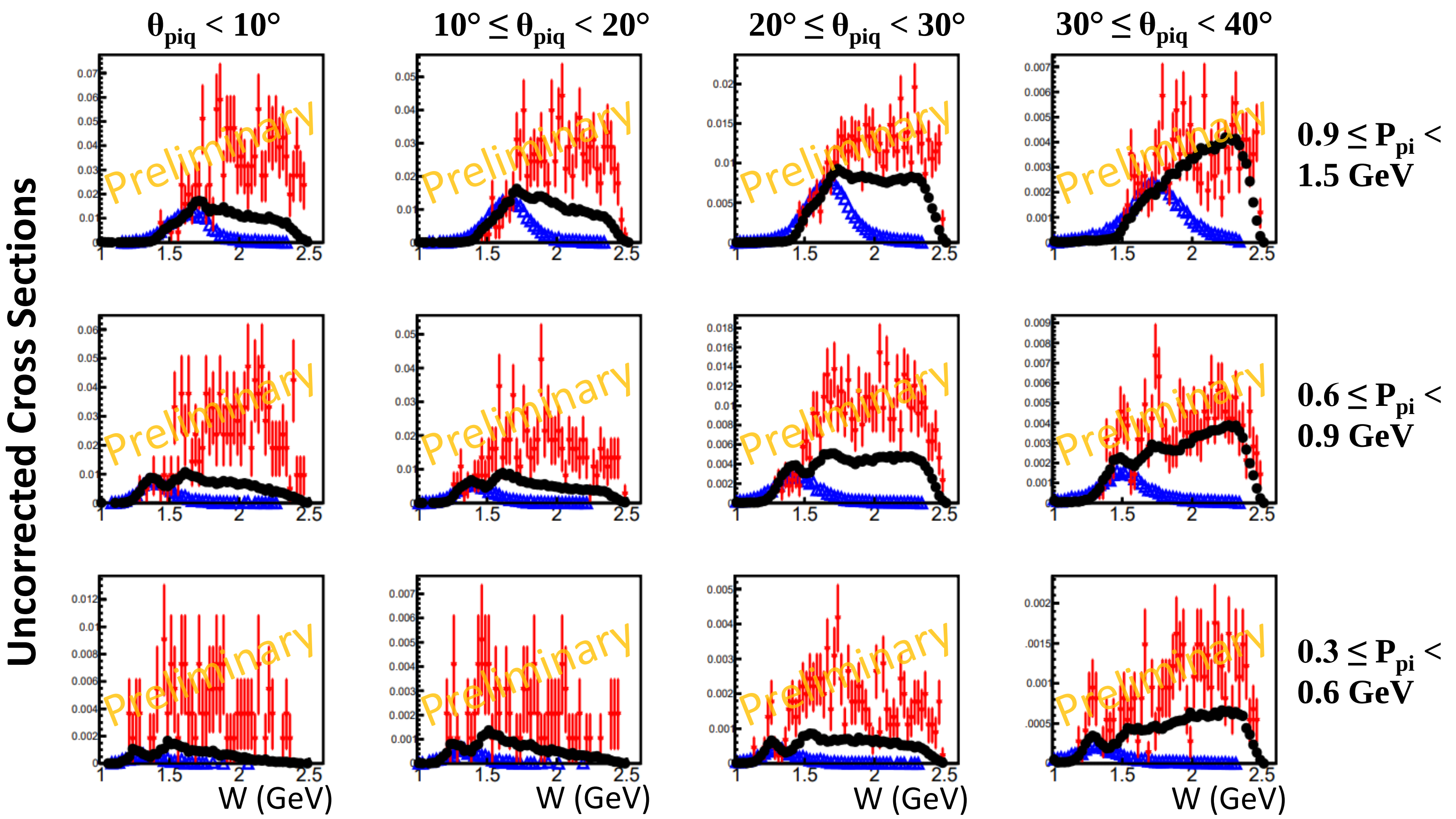
Future Work

π^+ $0.70 \leq Q^2 < 1.0$ GeV^2

- Correction analysis with onepigen
  - Radiative corrections
  - Acceptance corrections

$$CS_{acc\ cor} = CS_{raw} * \frac{CS_{true}^{GENIE}}{CS_{recon}^{GENIE}}$$

- Compare measured cross sections to GENIE and onepigen
  - Correct GENIE new event scaling
  - Compare GENIE resonance models



This will help improve GENIE