Single π^- Production Cross Section

Brittany Cohen

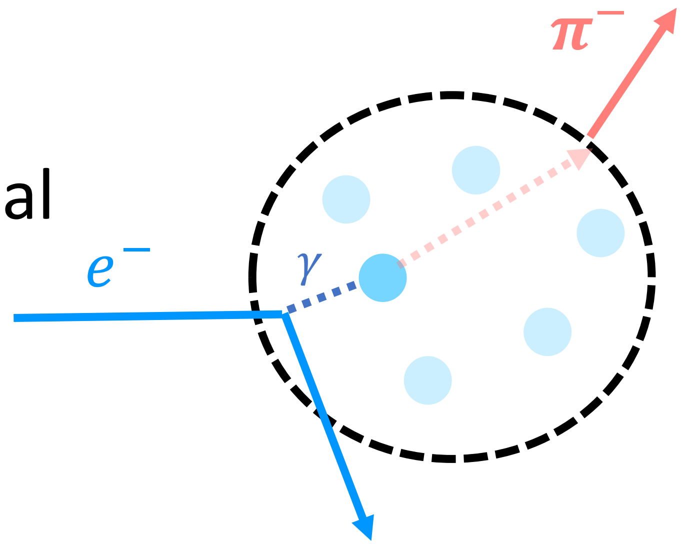
European Research Council
Established by the European Commission
TEL AVIV UNIVERSITY אוניברסיטת תל אביב

Table of Contents

Signal Definition

Event Selection

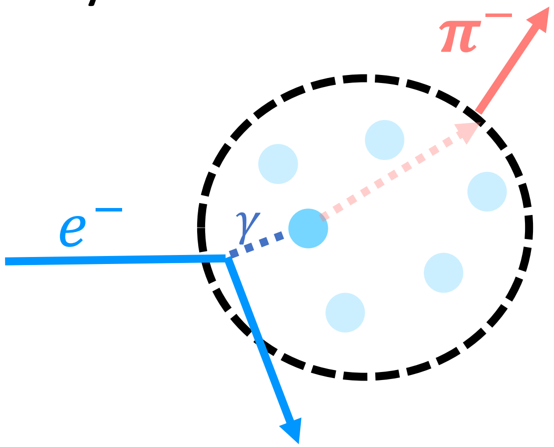
- **Electron-scattering on Carbon at 1.161, 2.261 and 4.461 GeV**
- We compare GENIE Monte Carlo to CLAS6 ^{12}C(e,e'1π^-)
- Final state particles: $1\pi^-, 0\pi^+, 0\gamma$
  - indicating no neutral pions
- We applied no cuts on the number of nucleons in the final state
  - Any number of protons
  - Any number of neutrons
- Same cuts on Q^2, momentum and angle of final state particles as in Julia's analysis.



MC and Data Comparison

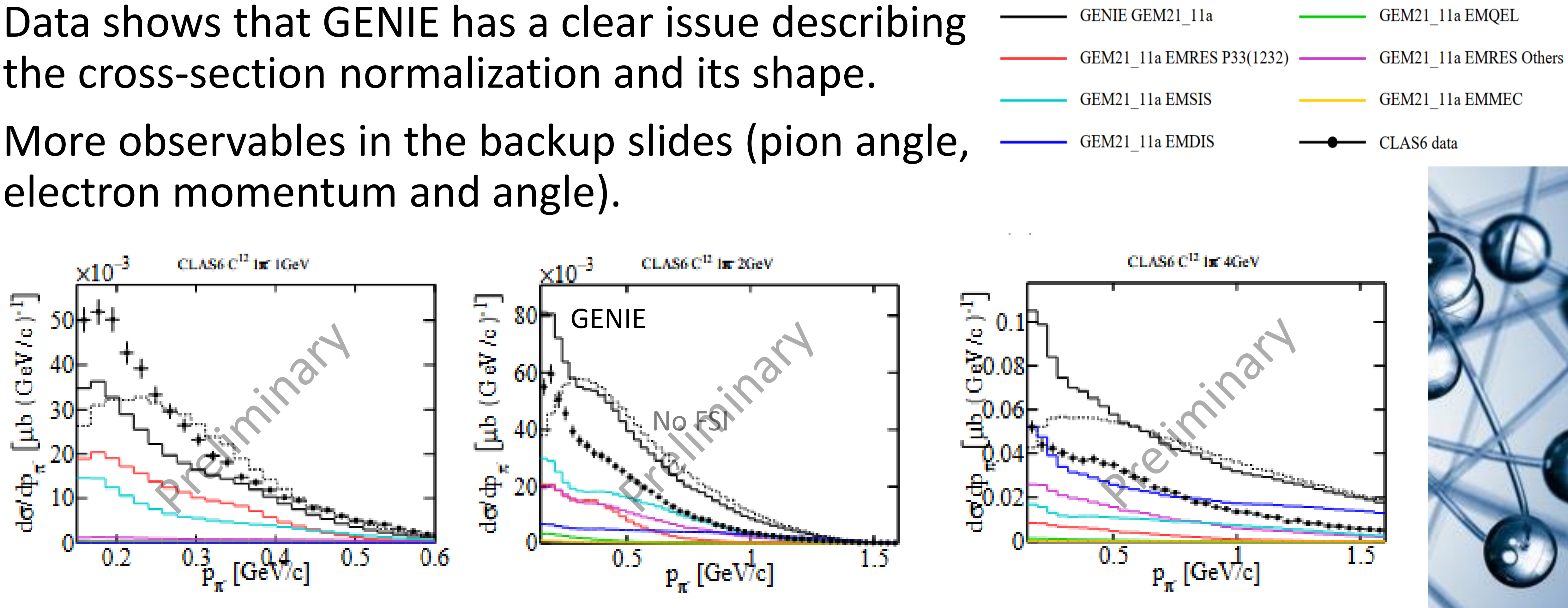
MC Simulation and Data

- We apply the momentum and angle cuts on both data and simulation.
- The results account for:
  - Acceptance & efficiency corrections (applied to the data)
  - Background subtraction (applied to the data, correction using data-driven model)
  - Particle momentum smearing (applied to the MC)
  - Same analysis procedure as CLAS6 $^{12}C(e,e'1p1\pi^{-})$ analysis by J.Tena Vidal and in [Nature volume 599, pages 565–570 (2021)]
- Not including (yet):
  - Radiative corrections



Detected Particle Kinematics

- Data shows that GENIE has a clear issue describing the cross-section normalization and its shape.
- More observables in the backup slides (pion angle, electron momentum and angle).



(a) 1 GeV π^- momentum (e) 2 GeV π^- momentum (i) 4 GeV π^- momentum

Reconstructed E_e - Method 1

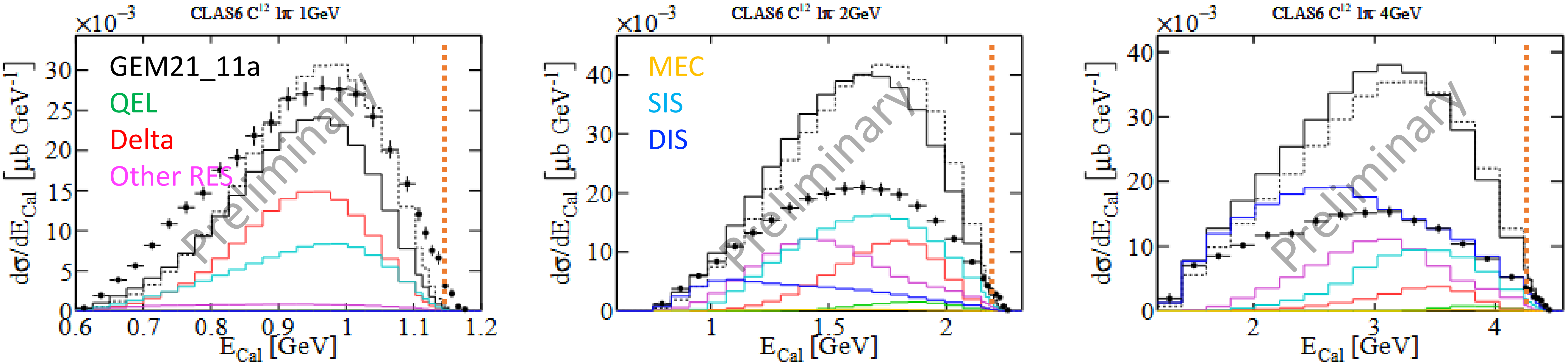
- In this first method, we attempt to reconstruct the energy using the calorimetric approach.
- We define the calorimetric energy as:

$$E_{cal} = E_{e'} + E_{\pi^-}$$

- We don't account for nucleons in the final state.

Reconstructed E_e - Method 1

- This method fails to reconstruct the correct beam energy:
  - Due to missing particles.
  - Nucleons and multiple pion production events.
- Shape and normalization not well described by GENIE.
- This data tells us that GENIE cannot describe the bias in the reconstructed energy.



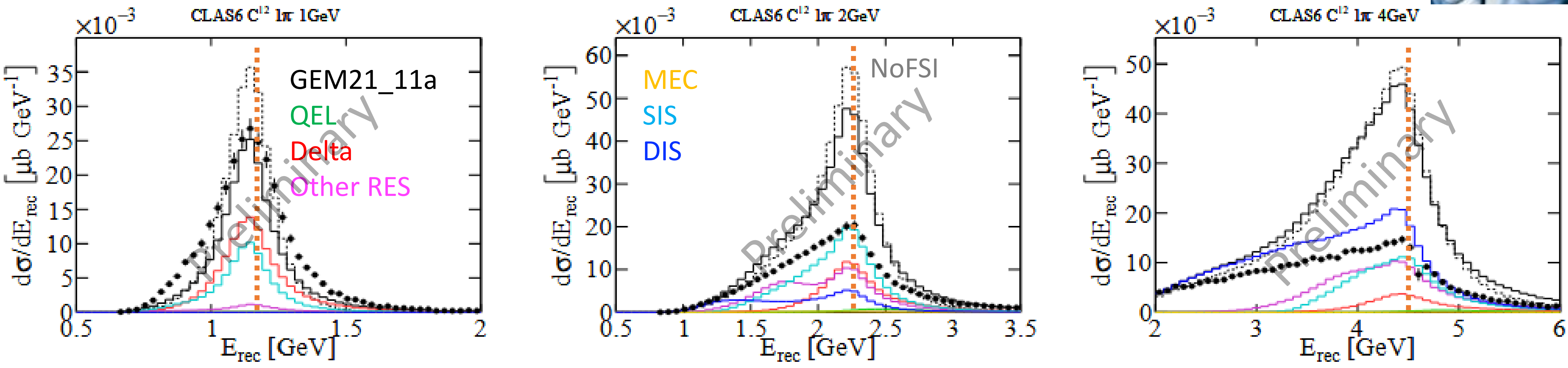
Reconstructed E_e - Method 2

- Improved method – Given that we detect the pion and the outgoing electron kinematics, we can reconstruct the initial energy assuming there is an undetected nucleon.
- Approach used in MiniBooNE (Cherenkov detector):

$$E_{rec} = \frac{2m_{e'}^2 + m_\pi^2 - 2M_N(E_{e'} + E_\pi) + 2p_{e'}^\mu \cdot p_{\pi,\mu}}{2\left(E_{e'} + E_\pi - |p_{e'}|\cos\Theta_{e,e'} - |p_\pi|\cos\Theta_{e,\pi} - M_N\right)}$$

Reconstructed E_e - Method 2

- Can Reconstruct beam energy position
  - Tails due to additional particles under thresholds.
- Shapes of MC and data plots are similar at 1GeV.
- Tail grows with energy due to multiple-pion production at higher E



Reconstructed $\boldsymbol{W}$

- We want to understand the impact of imperfect energy reconstruction on W.
- We calculated the reconstructed W: ($p_N^\mu = m_N$ - assume at rest)

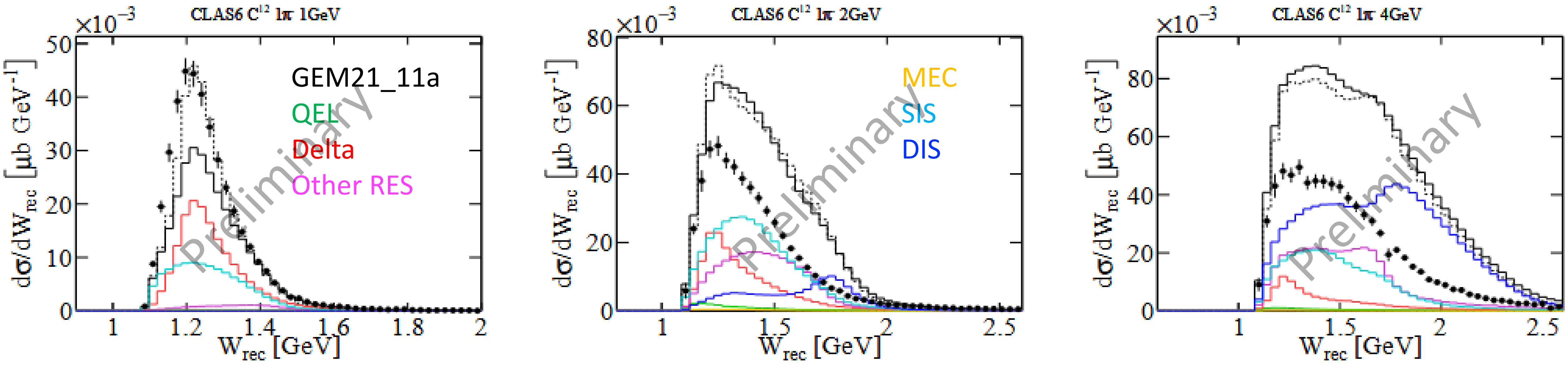
$$W_{rec} = \left|p_N^\mu + q_{rec}^\mu\right| = \left|p_N^\mu + \left(p_{e,rec}^\mu - p_{e'}^\mu\right)\right|, \qquad \boldsymbol{p}_{e,rec} = \begin{pmatrix} 0 \\ 0 \\ E_{e,rec} \end{pmatrix}$$

$$W_{true} = \left|p_N^\mu + q_{true}^\mu\right| = \left|p_N^\mu + \left(p_{e,true}^\mu - p_{e'}^\mu\right)\right|$$

- **We focus on the second method as it is the only one which can reconstruct the beam position.**
- **By comparing W_{rec} and W_{true}, we can estimate the real bias in this reconstructed observable.**

Reconstructed *W*

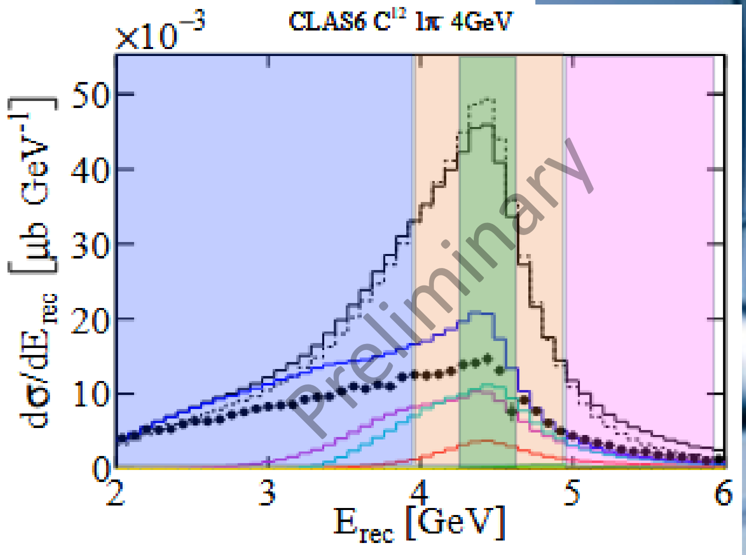
- Normalization is off for the different energies.
- Shape differences exist, but less significant.



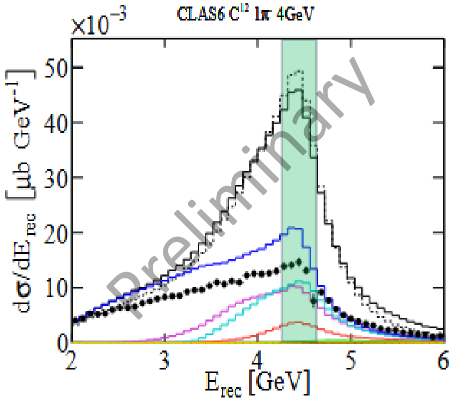
- How much does it differ from the actual distribution?

Reconstructed *W*

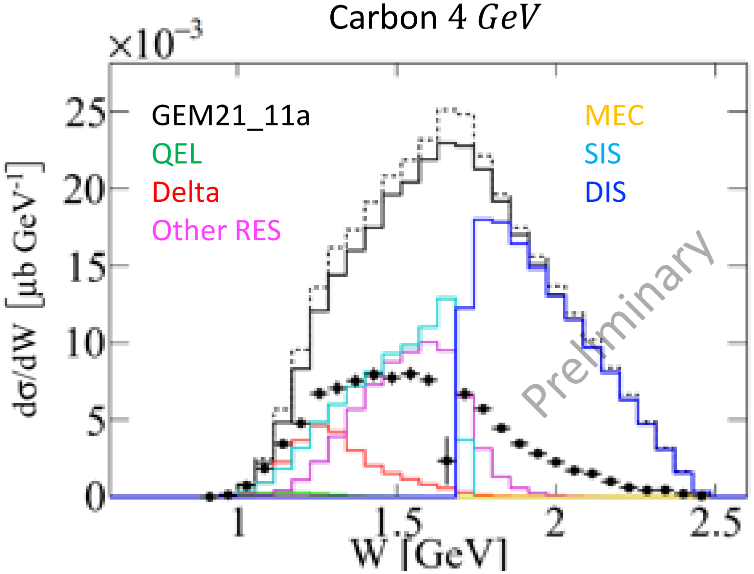
- We applied cuts on energy reconstruction accuracy.
- We compared the reconstructed W to W calculated using the known beam energy for both MC simulation data and CLAS6 data.
- We only show the 4GeV case.

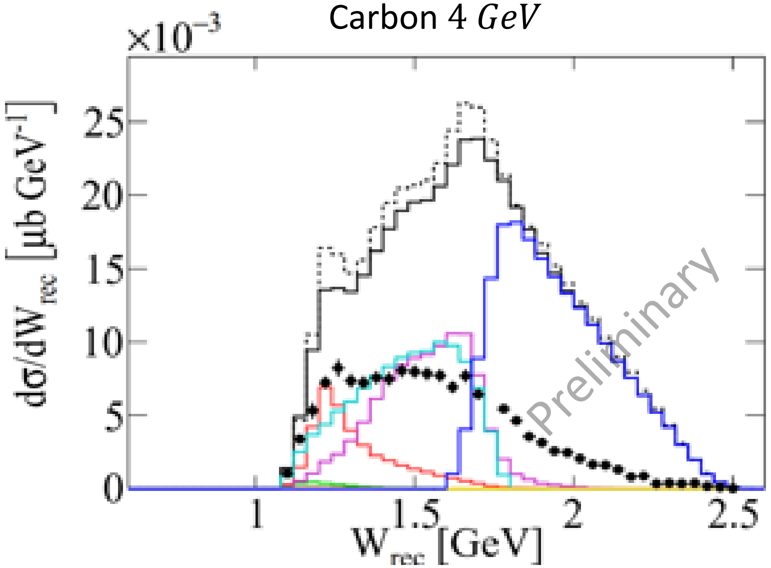


5% Accuracy:



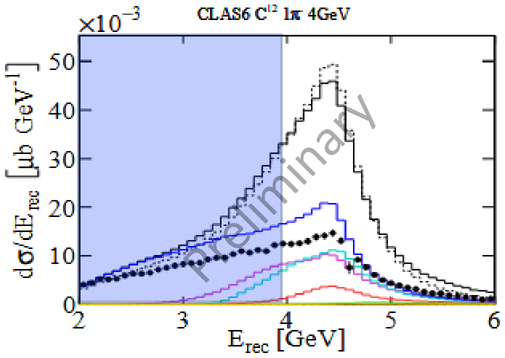
W and W_{rec} very similar





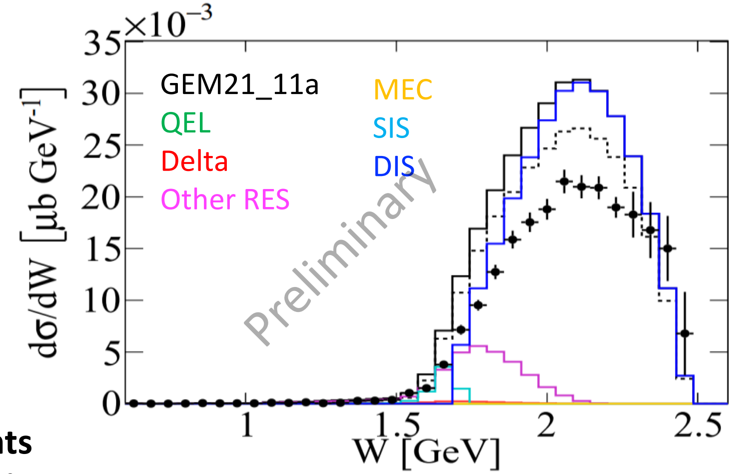
Reconstructed W

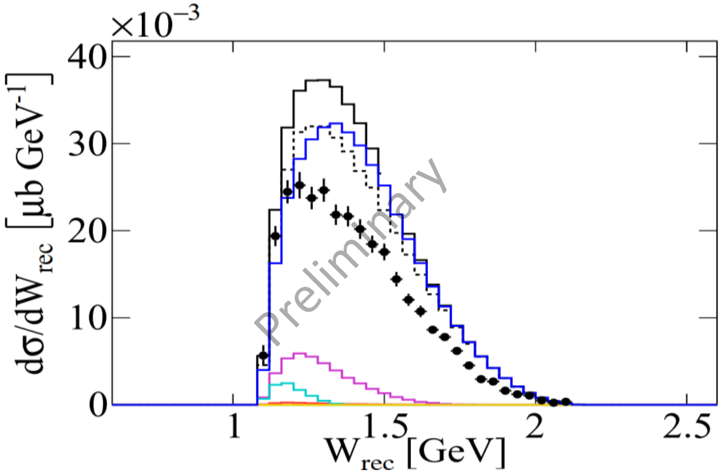
$E_{rec}<E_e$ -20%:



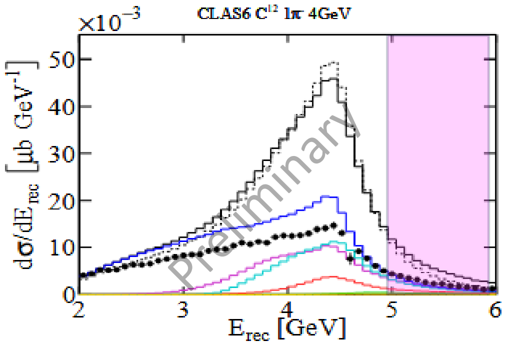
Tail dominated by multi-pion production events

True W > 2 GeV but W_{reco} still peaks at delta region

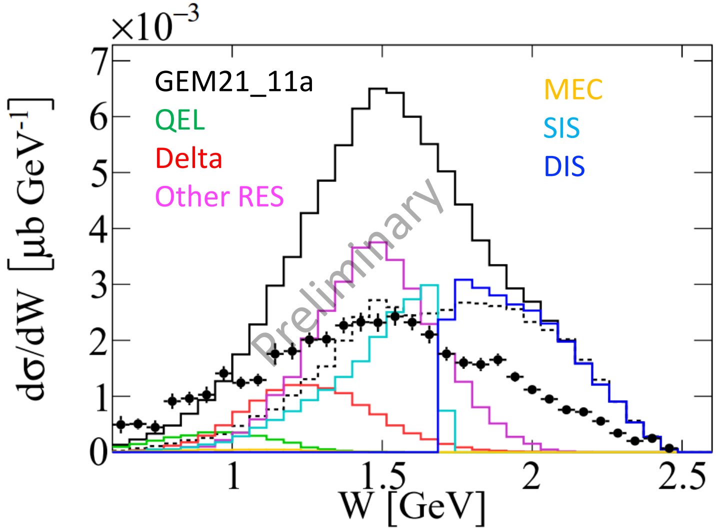


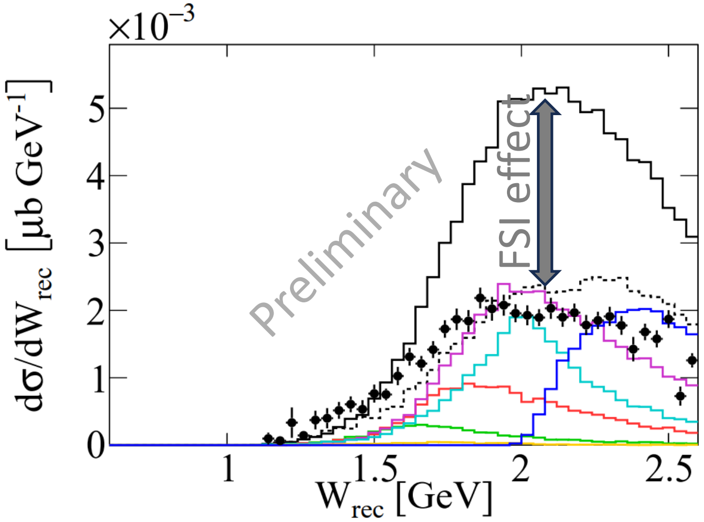


$E_{rec}>E_e$ +20%:



Dominated by events which contribute to high W_{rec} due to FSI





Conclusions

Conclusions

- First look at events with a single charged pion.
  - Same analysis as published in the $1p0\pi$ study and Julia's $1p1\pi^{\pm}$ study.
- Data highlights issues with GENIE normalization and shape.
- We tested two energy reconstruction methods which are of interest for oscillation experiments.
  - Calorimetric approach cannot describe the true energy, bias not well described by MC.
  - MiniBooNE reconstruction techniques can reconstruct the peak. Large tails due to missing particles at 2 and 4 GeV.
- W_{rec} directly affected by bias in energy reconstruction.
  - Low reconstruction accuracy for E results in W far above or below the true value.
- This new data will be very useful to test and improve new energy reconstruction techniques.

Thank You!

European Research Council
Established by the European Commission

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

Backup Slides

Event Selection

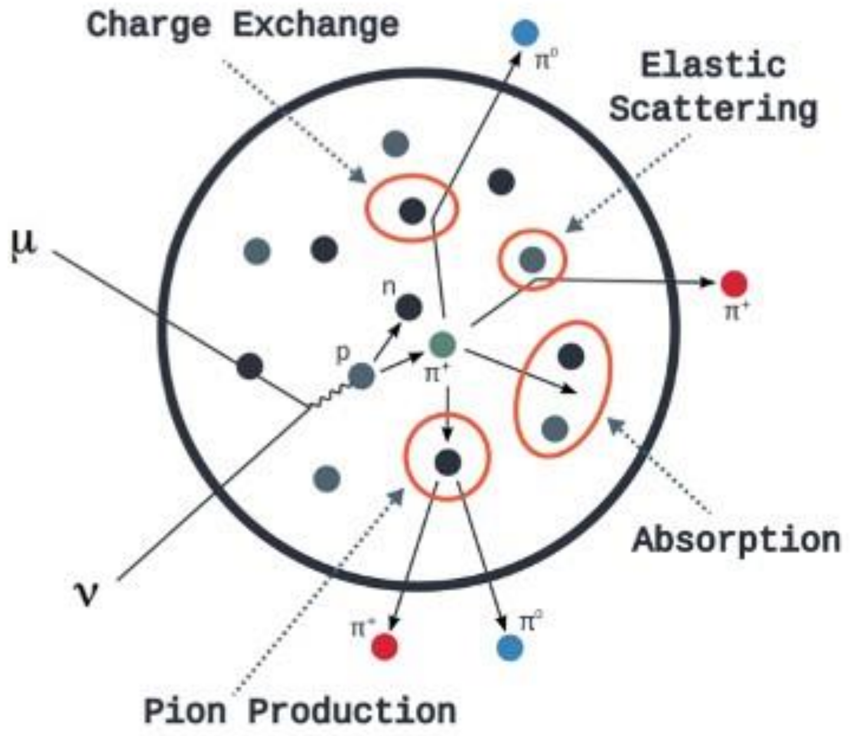
Cuts consistent with previous CLAS6 analysis:
Nature volume 599, pages 565–570 (2021)

- Q^2 cuts at 0.1, 0.4 and 0.8 GeV^2.
- We applied cuts for momentum and angle of the final-state particles:

Particle	Momentum Cut [GeV]	Scattering Angle Cut [Deg]
e^-	0.35	$\theta_e^{1.1} \geq 17° + \frac{7°}{p_e\ [GeV]}$
		$\theta_e^{2.2} \geq 16° + \frac{10.5°}{p_e\ [GeV]}$
		$\theta_e^{4.4} \geq 13.5° + \frac{15°}{p_e\ [GeV]}$
γ	0.3	$8° \leq \theta_\gamma \leq 45°$
π^+	0.2	$\theta_\pi \geq 12°$
π^-	0.15	$\theta_\pi^{1.1} \geq 17° + \frac{4°}{p_\pi\ [GeV]}$
		$\theta_\pi^{2.2,4.4} \geq 25° + \frac{7°}{p_\pi\ [GeV]}, p_\pi < 0.35GeV$ $\theta_\pi^{2.2,4.4} \geq 16° + \frac{10°}{p_\pi\ [GeV]}, p_\pi > 0.35GeV$

Event Types

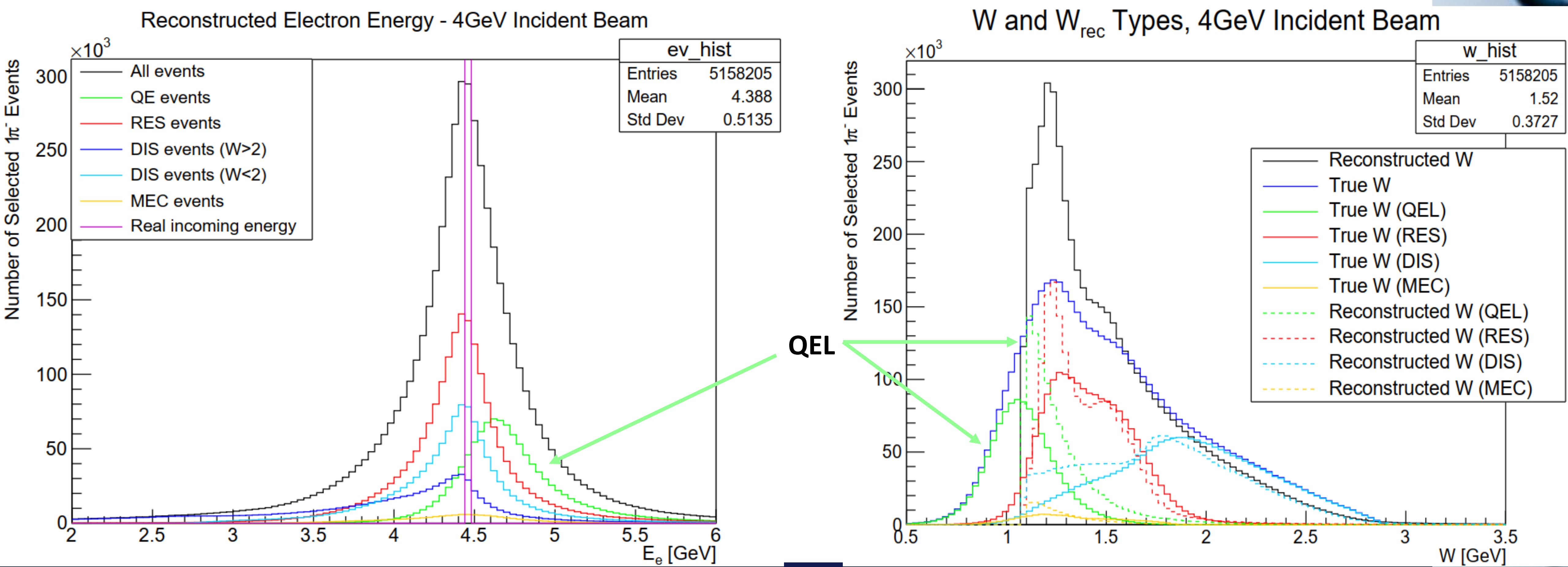
- There are several different scattering types that occur during a collision:
  - QEL scattering
  - RES scattering
  - MEC scattering
  - DIS and SIS scattering
- FSI – we measure final state particles that don't correspond to the actual collision



MC Results

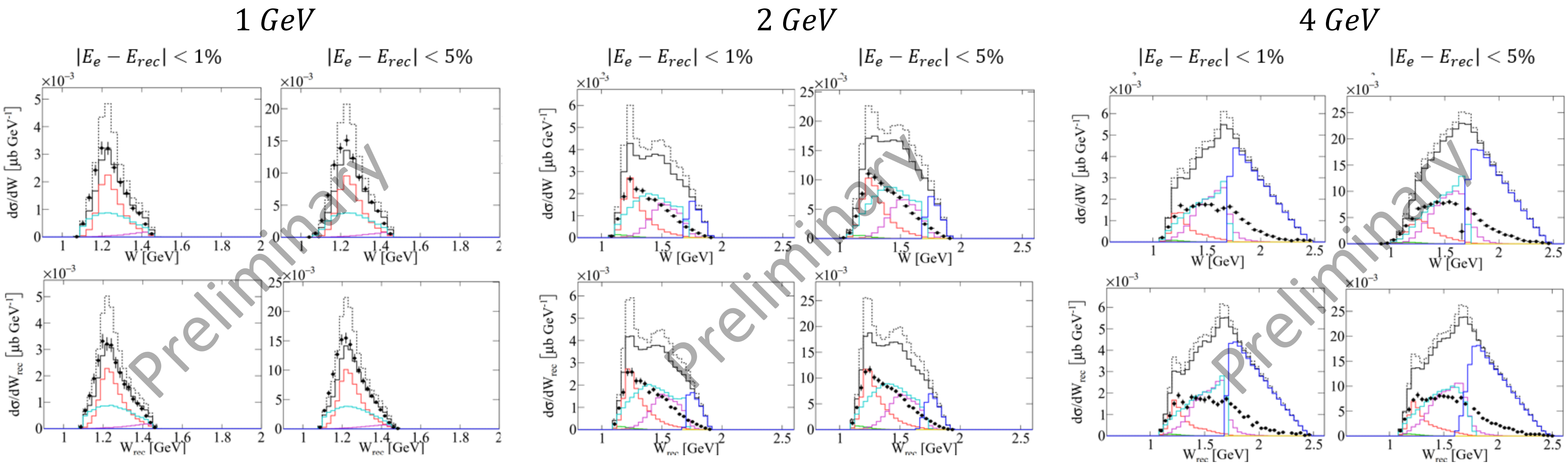
MC Results

- DIS tail to the left, QEL events shifted to the right as expected.
- Too many QEL events due to a problem with the simulation.



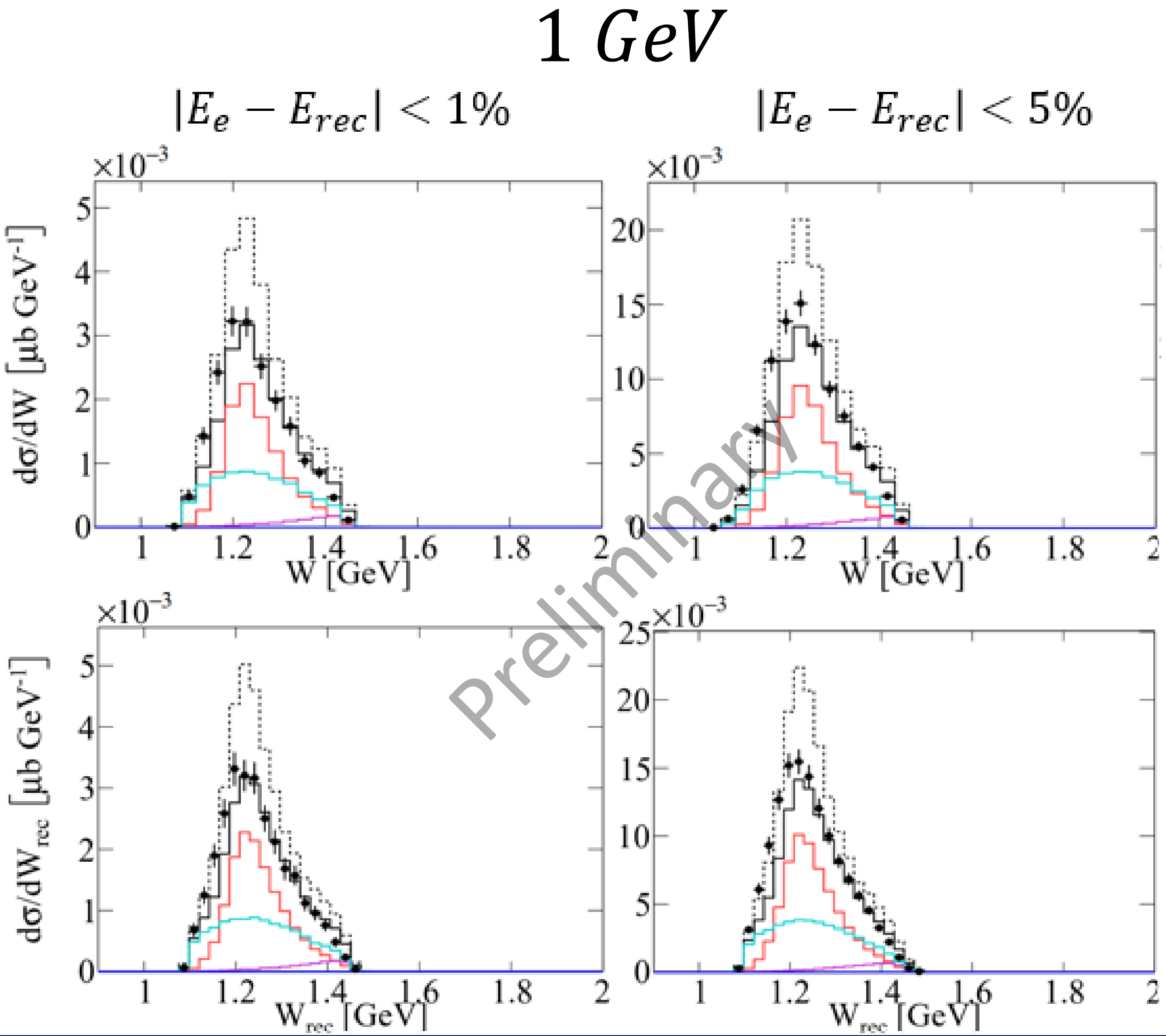
$|E_{rec} - E_e| < 1\%$ and 5% Cut

- Similar shapes for W (top row) and W_{rec} (bottom row) at 1% accuracy.
- Minor divergence between W and W_{rec} at 5% accuracy for 2 and 4GeV beam energies.



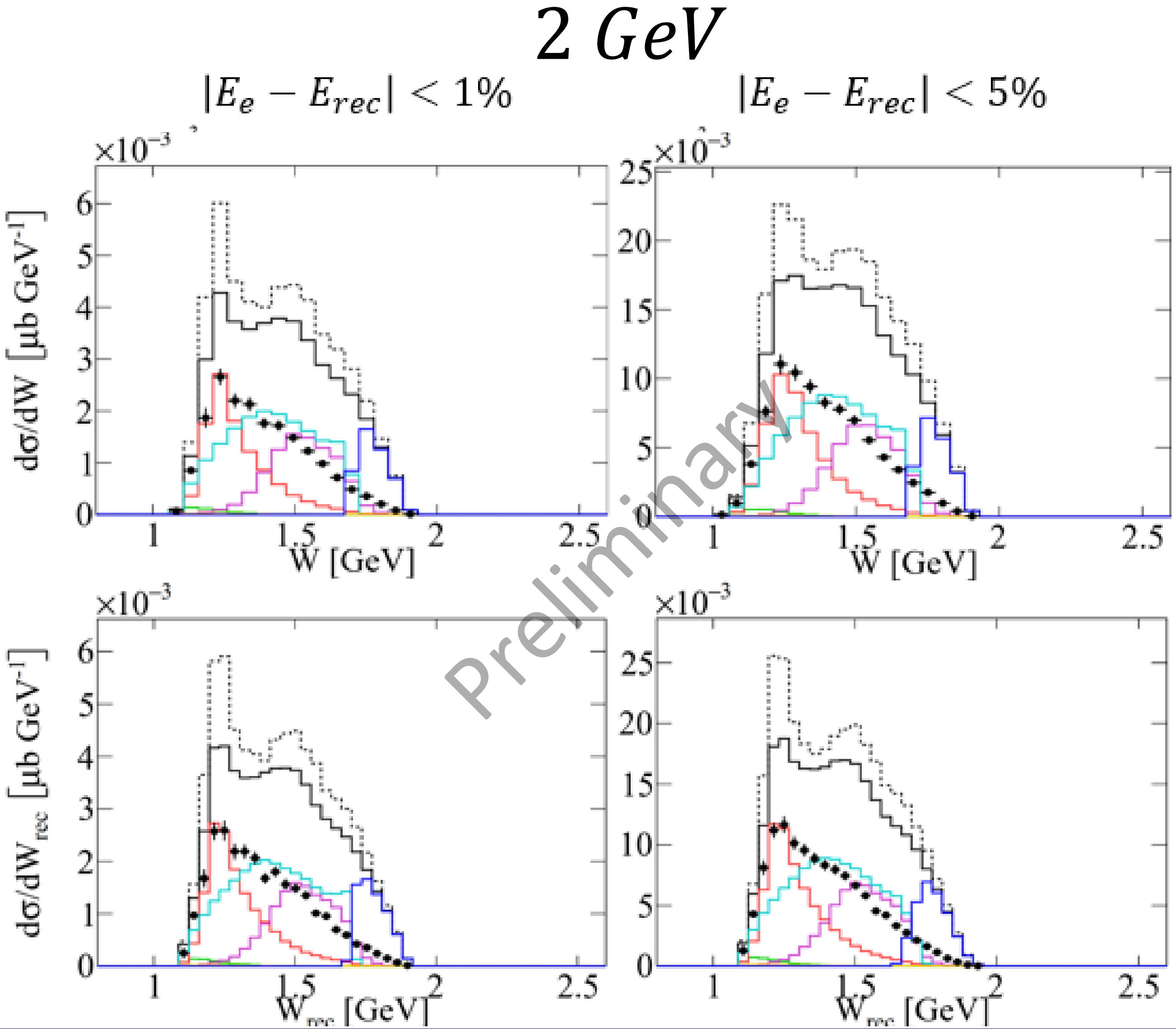
$|E_{rec} - E_e| < 1\%$ and 5% Cut

- Similar shapes for W (top row) and W_{rec} (bottom row) at 1% accuracy.
- Minor divergence between W and W_{rec} at 5% accuracy for 2 and 4GeV beam energies.



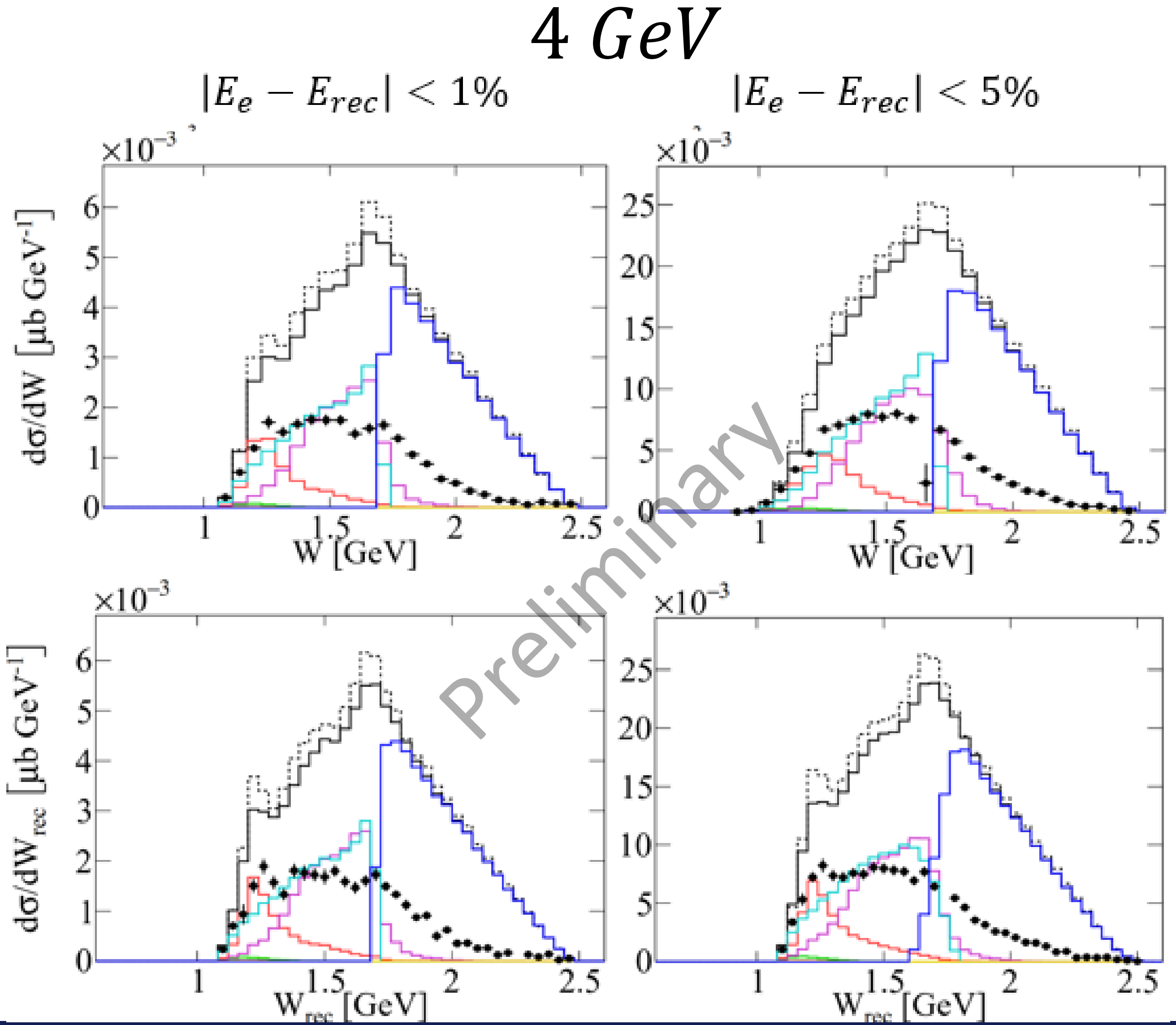
$|E_{rec} - E_e| < 1\%$ and 5% Cut

- Similar shapes for W (top row) and W_{rec} (bottom row) at 1% accuracy.
- Minor divergence between W and W_{rec} at 5% accuracy for 2 and 4GeV beam energies.



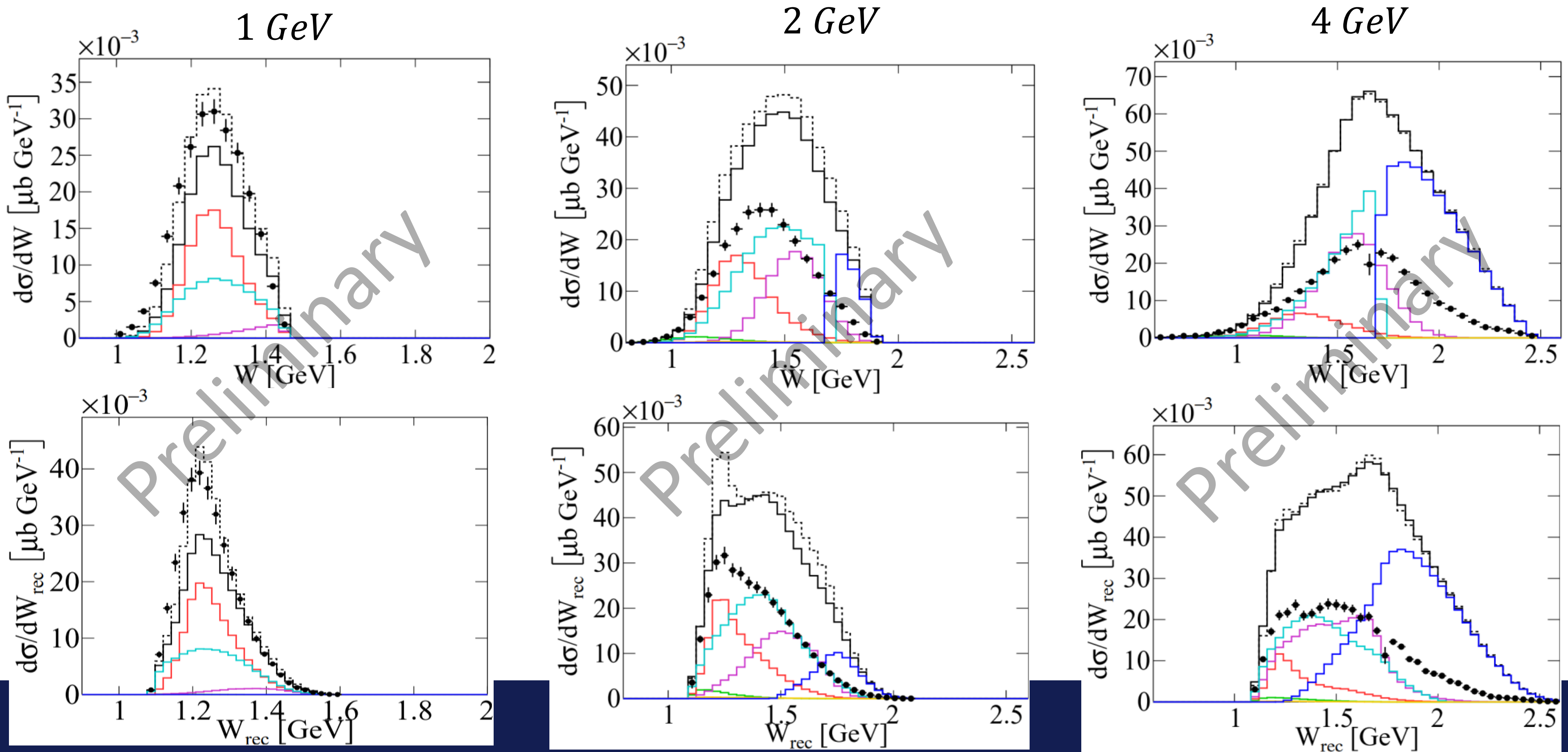
$|E_{rec} - E_e| < 1\%$ and 5% Cut

- Similar shapes for W (top row) and W_{rec} (bottom row) at 1% accuracy.
- Minor divergence between W and W_{rec} at 5% accuracy for 2 and 4GeV beam energies.



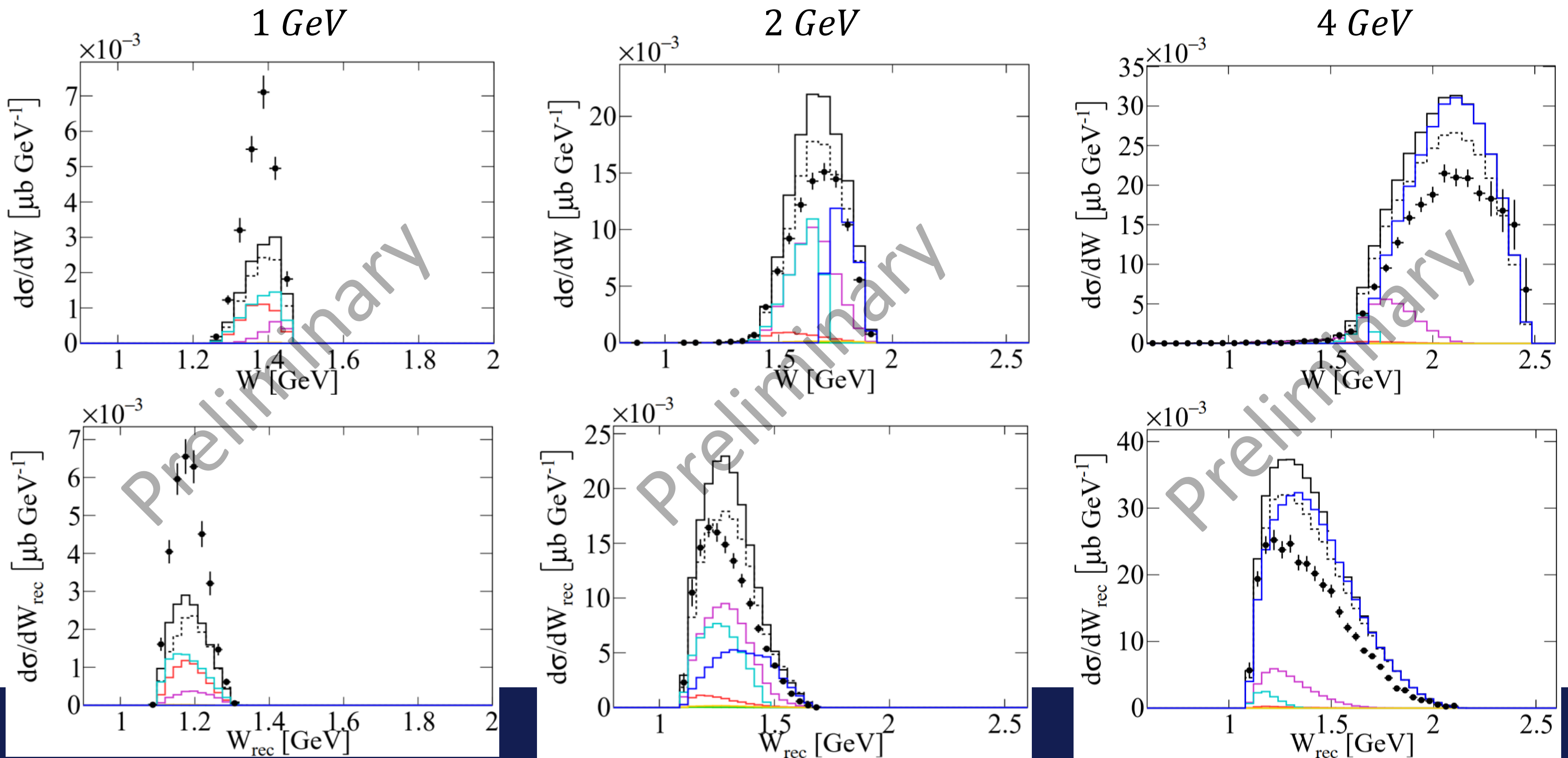
$|E_{rec} - E_e| < 20\%$ Cut

- Reconstructed W shifts away from true W w.r.t 5% and 1% cuts.
- There is more bias on the 4GeV reconstruction than 1GeV reconstruction.



$E_{rec} < E_e - 20\%$ Cut

- Mostly events with multiple undetectable particles. We only measure a part of the total energy of the system so reconstruct below the true W too. Smaller cross-section for 1GeV



$E_{rec} > E_e + 20\%$ Cut

- Events at which reconstructed Ee is a lot higher than true Ee have a higher reconstructed W.