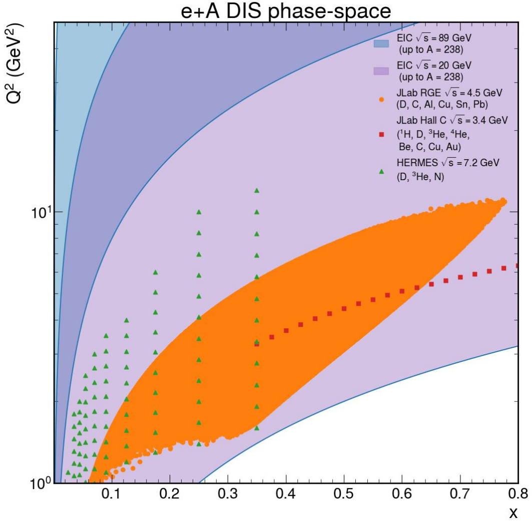
Updates on RG-E inclusive analysis

Ryan Milton
UC Riverside

CLAS Collaboration Meeting
November 19th, 2025

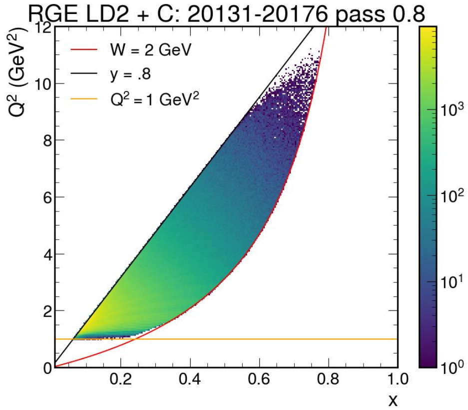
Overview of analysis

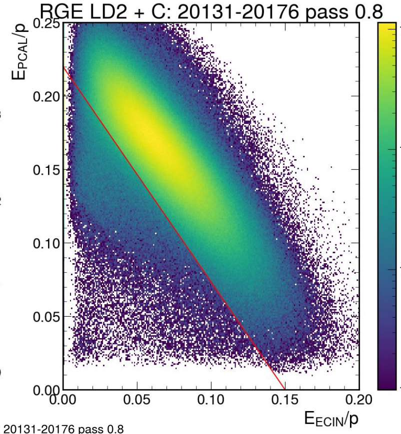
- Goal: $d\sigma/dxdQ^2$ for different nuclei with RGE
- Currently focusing on LD2 + C data from runs 20131-20176 pass 0.8
- Using <1% of the data from these runs (.023 mC/21.81 mC)

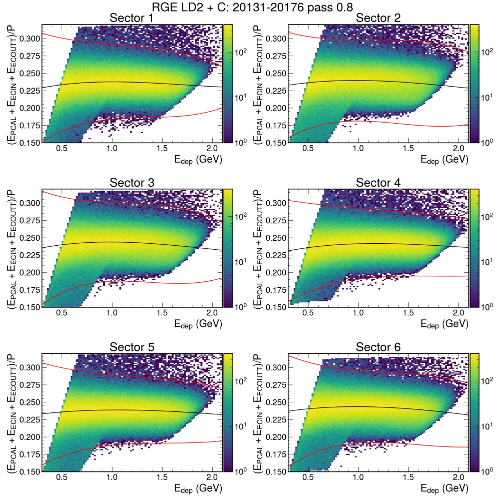


Summary of electron selection

- Electron selection follows selection from RG-A and RG-M
- DIS cuts: Q^2 > 1 GeV^2,W > 2 GeV,y < 0.8
- Extra cuts: θ > 5° , 2 GeV < p < 8 GeV
- Fiducial cuts on PCAL V & W, DC distance to edge
- Partial sampling fraction cut on E_{PCAL}/p vs. E_{ECIN}/p
- Tighten SF vs. E_{dep} to μ ± 3.5σ

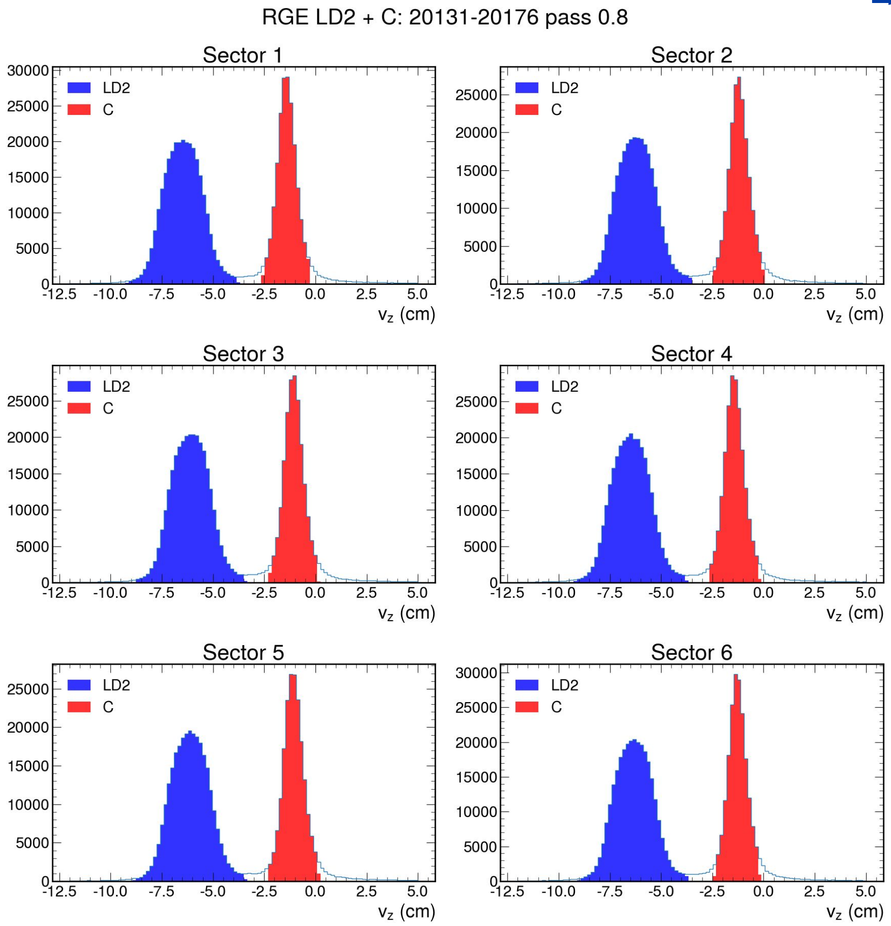






Target selection

- Fit z vertex distribution with sum of two Gaussians
- LD2: $\mu_{LD2} \pm 3\sigma_{LD2}$
- C: $\mu_C \pm 5\sigma_C$



Calculating absolute cross sections for inclusive DIS

$$\frac{d^2\sigma_i}{dx\,dQ^2} = \frac{1}{\underbrace{\Delta x}_{\text{dimensionless}} \cdot \underbrace{\Delta Q^2}_{\text{GeV}^2}} \cdot \frac{\overset{\text{counts}}{\overbrace{N_i}}}{\underbrace{R_i}_{\text{dimensionless}} \; \underbrace{\eta_i}_{\text{dimensionless}}} \cdot \frac{\overset{\text{cm}^2 \to \text{pb}}{\overbrace{CPB}}}{\underbrace{\mathcal{L}_{\text{int}}}_{\text{cm}^{-2}}} \cdot \underbrace{C_{c,i}}_{\text{dimensionless}}$$

$$\left[\frac{d^2\sigma}{dx\,dQ^2}\right] = \frac{1}{[\Delta x][\Delta Q^2]} \cdot \frac{[N]}{[\eta][R]} \cdot \frac{[CMB]}{[\mathcal{L}_{\text{int}}]} \cdot [C_c] = \frac{1}{(1)(\text{GeV}^2)} \cdot \frac{(\text{counts})}{(1)(1)} \cdot \frac{(\text{cm}^2 \to \text{pb})}{(\text{cm}^{-2})} \cdot (1) = \frac{\text{pb}}{\text{GeV}^2}$$

- $\Delta x \Delta Q^2$: kinematic bin volume
- N_i: Number of reconstructed electrons in bin i that pass cuts
- R_i: Radiative correction in bin i
- η_i: acceptance and efficiency correction in bin i
- CPB: cm^2 to pb conversion factor of 1×10^{36}
- $\mathcal{L}_{int}$: integrated luminosity for runs
- $C_{c,i}$: Coulomb corrections in bin i

Motivated by Equation 4 from V. Klimenko, et al. (CLAS Collaboration), Phys. Rev. C **112**, 025201 (2025).

Calculating absolute cross sections for inclusive DIS

$$\frac{d^2\sigma_i}{dx\,dQ^2} = \frac{1}{\underbrace{\Delta x}_{\text{dimensionless}} \cdot \underbrace{\Delta Q^2}_{\text{GeV}^2}} \cdot \frac{\overbrace{N_i}^{\text{counts}}}{\boxed{\underbrace{R_i}_{\text{dimensionless}}}\ \underbrace{\eta_i}_{\text{dimensionless}}} \cdot \frac{\overbrace{CPB}^{\text{cm}^2 \to \text{pb}}}{\underbrace{\mathcal{L}_{\text{int}}}_{\text{cm}^{-2}}} \cdot \boxed{\underbrace{C_{c,i}}_{\text{dimensionless}}}$$

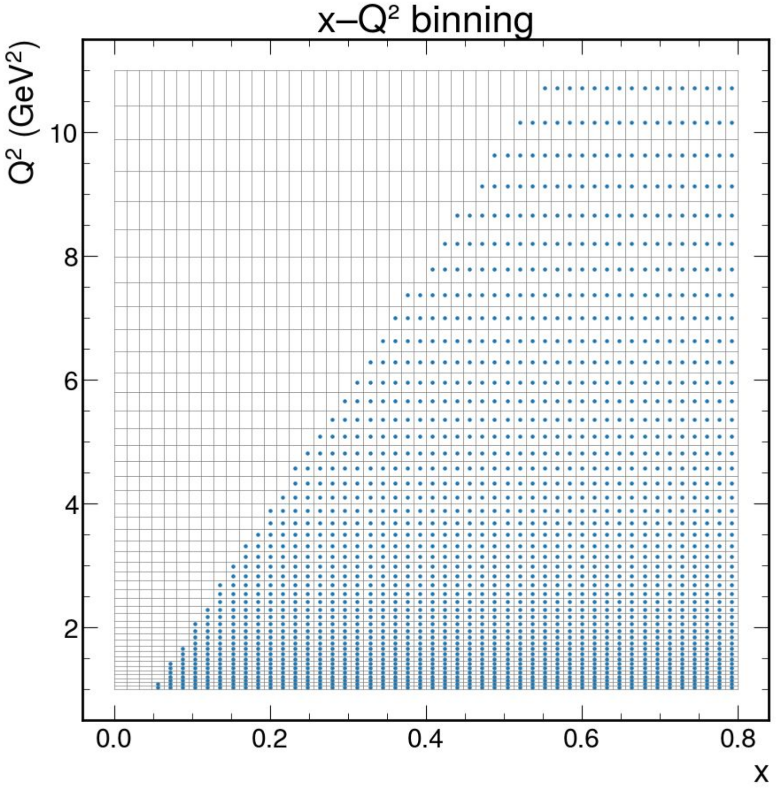
$$\left[\frac{d^2\sigma}{dx\,dQ^2}\right] = \frac{1}{[\Delta x][\Delta Q^2]} \cdot \frac{[N]}{[\eta][R]} \cdot \frac{[CMB]}{[\mathcal{L}_{\text{int}}]} \cdot [C_c] = \frac{1}{(1)(\text{GeV}^2)} \cdot \frac{(\text{counts})}{(1)(1)} \cdot \frac{(\text{cm}^2 \to \text{pb})}{(\text{cm}^{-2})} \cdot (1) = \frac{\text{pb}}{\text{GeV}^2}$$

- $\Delta x \Delta Q^2$: kinematic bin volume
- N_i: Number of reconstructed electrons in bin i that pass cuts
- R_i: Radiative correction in bin i
- η_i: acceptance and efficiency correction in bin i
- CPB: cm^2 to pb conversion factor of 1x10^{36}
- $\mathcal{L}_{int}$: integrated luminosity for runs
- $C_{c,\,i}$: Coulomb corrections in bin i

Motivated by Equation 4 from V. Klimenko, et al. (CLAS Collaboration), Phys. Rev. C **112**, 025201 (2025).

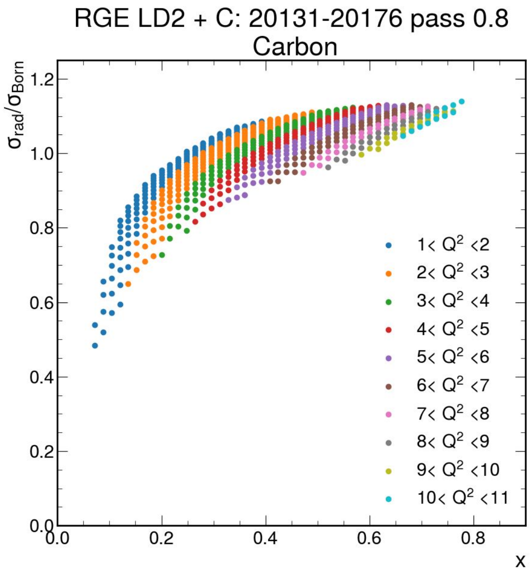
Radiative and Coulomb corrections procedure

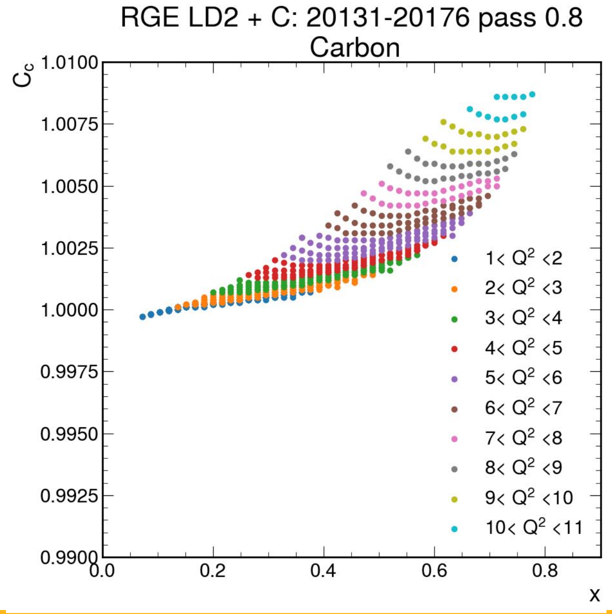
- Define x-Q^2 binning and only keep bin centers where $y<1$
  - $y=Q^2/(2E_{beam}m_px)$
- Plug bin centers into EXTERNALS
- Calculate radiative corrections and Coulomb corrections for carbon



Radiative and Coulomb corrections for carbon

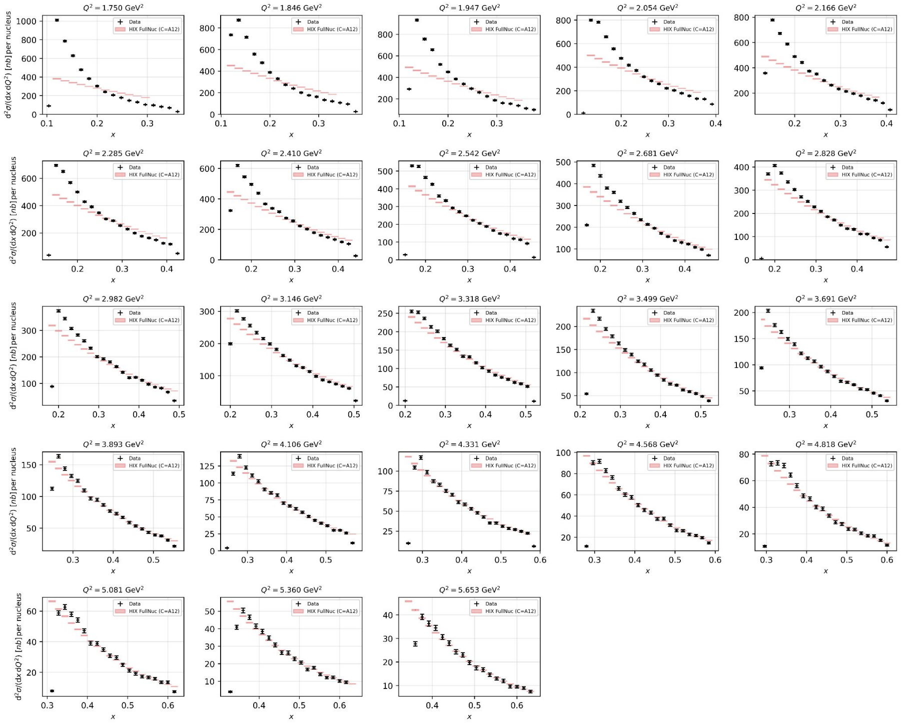
- Coulomb correction for carbon has little impact
- Due to y<0.8 cut, the largest radiative correction is about 0.5





Comparison to PDF predictions

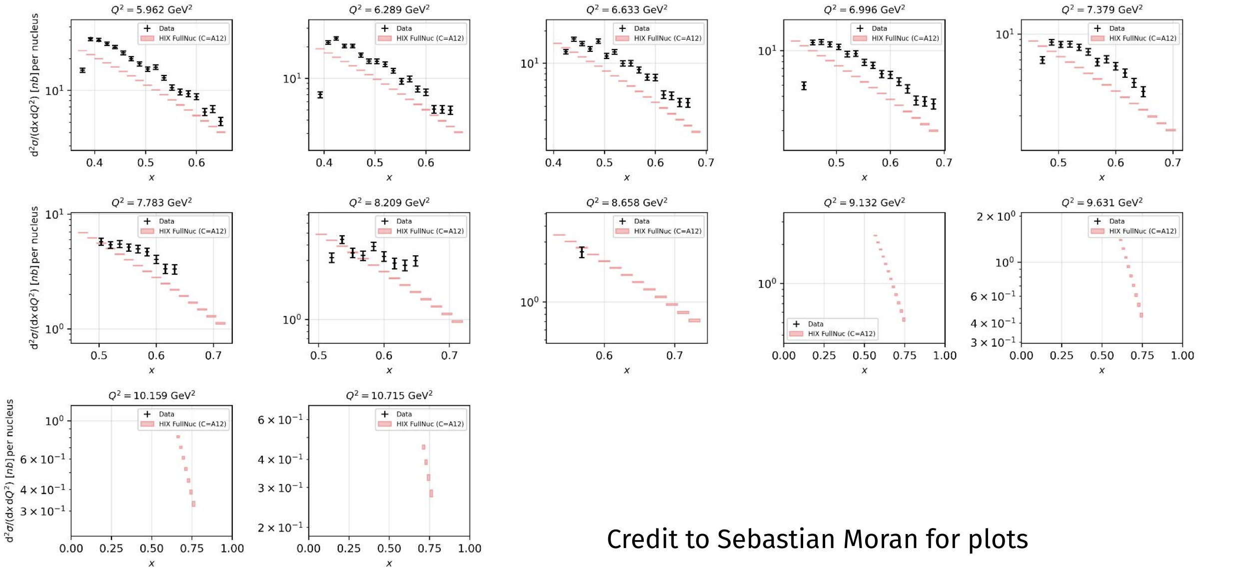
- Without any acceptance and efficiency corrections, we compare to theory predictions for carbon
- For integrated luminosity, using 2.1×10^{40} cm^{-2} * .001 (.1% of run data)
- Use Yadism to get cross sections from PDFs
    - A. Candido, et al., Eur.Phys.J.C 84 (2024) 7, 697
- Using nCTEQ15HIX PDF set
    - E. P. Segarra, et al., Phys. Rev. D **103**, 114015



Credit to Sebastian Moran for plots

Comparison to PDF predictions

- Dropping bins with large error bars
- Overall see good agreement between data and predictions, with disagreement at lower and higher Q^2 values



Credit to Sebastian Moran for plots

Calculating absolute cross sections for inclusive DIS

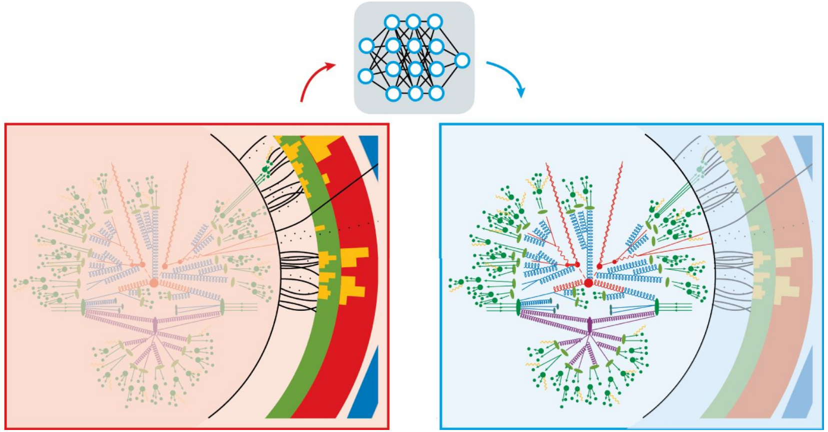
$$\frac{d^2\sigma_i}{dx\,dQ^2} = \frac{1}{\underbrace{\Delta x}_{\text{dimensionless}} \cdot \underbrace{\Delta Q^2}_{\text{GeV}^2}} \cdot \frac{\overbrace{N_i}^{\text{counts}}}{\underbrace{R_i}_{\text{dimensionless}} \boxed{\underbrace{\eta_i}_{\text{dimensionless}}}} \cdot \frac{\overbrace{CPB}^{\text{cm}^2 \to \text{pb}}}{\underbrace{\mathcal{L}_{\text{int}}}_{\text{cm}^{-2}}} \cdot \underbrace{C_{c,i}}_{\text{dimensionless}}$$

$$\left[\frac{d^2\sigma}{dx\,dQ^2}\right] = \frac{1}{[\Delta x][\Delta Q^2]} \cdot \frac{[N]}{[\eta][R]} \cdot \frac{[CMB]}{[\mathcal{L}_{\text{int}}]} \cdot [C_c] = \frac{1}{(1)(\text{GeV}^2)} \cdot \frac{(\text{counts})}{(1)(1)} \cdot \frac{(\text{cm}^2 \to \text{pb})}{(\text{cm}^{-2})} \cdot (1) = \frac{\text{pb}}{\text{GeV}^2}$$

- η_i: acceptance and efficiency correction in bin i
- Not yet incorporating efficiency corrections
- Can further correct cross sections with unfolding

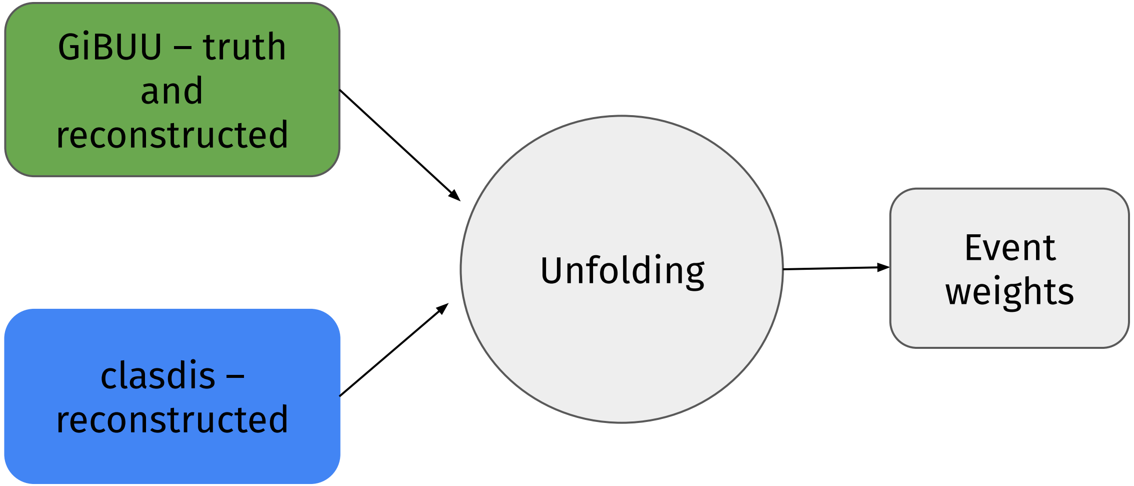
Unfolding procedure

- Given the measured data, want to remove detector effects and bin migration to get true physics information
- Unfolding with an ML-based version of Iterative Bayesian Unfolding
  - IBU used in V. Klimenko, et al. (CLAS Collaboration), Phys. Rev. C 112, 025201 (2025)
  - IBU version we'll use detailed here: R. Milton, et al., *JINST* 20, P05034 (2025)
- Doing the unfolding with multiple observables simultaneously



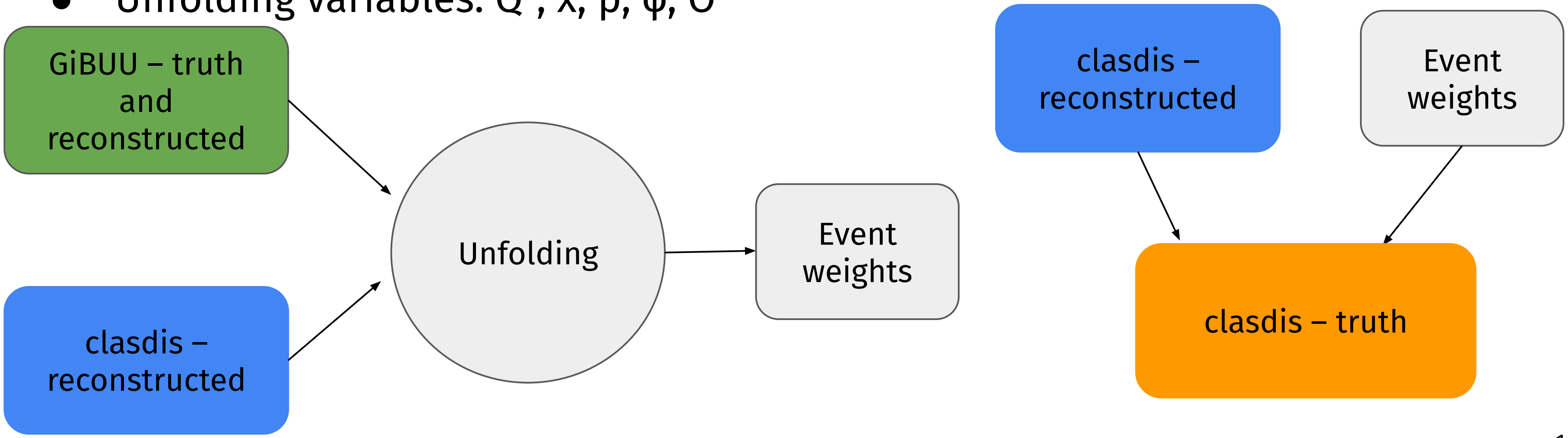
Closure test

- To test the unfolding procedure, use a closure test with two Monte Carlos
- Use clasdis as pseudodata and GiBUU as simulation data. Run each through electron selection. Currently only using 500k events for unfolding
- After unfolding, should get the truth-level clasdis distributions
- Unfolding variables: Q^2, x, p, ϕ, Θ



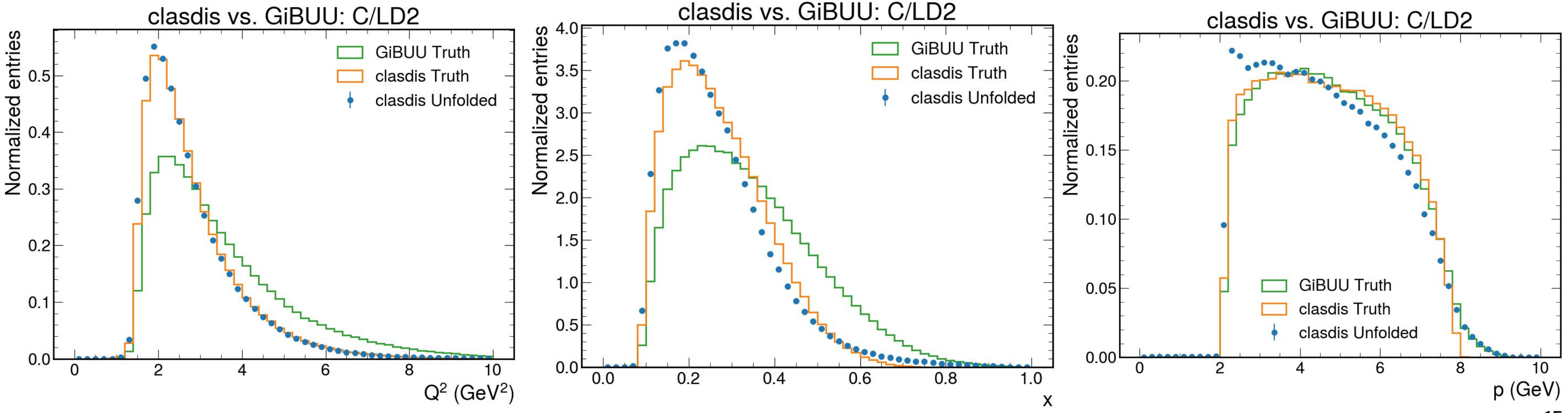
Closure test

- To test the unfolding procedure, use a closure test with two Monte Carlos
- Use clasdis as pseudodata and GiBUU as simulation data. Run each through electron selection. Currently only using 500k events for unfolding
- After unfolding, should get the truth-level clasdis distributions
- Unfolding variables: Q^2, x, p, ϕ, Θ



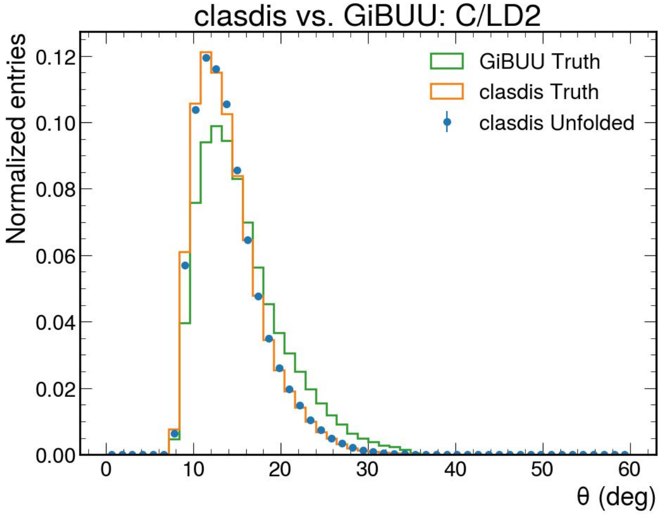
Results of closure test

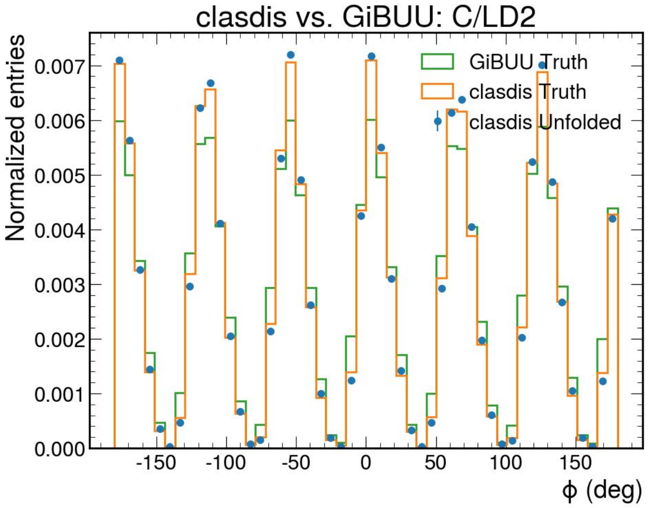
- See overall good agreement between truth and unfolded distributions
- The input to the unfolding are observables from electrons that pass selections. We are not yet correcting for efficiency
- Unfolding multiple observables maintains correlations between them



Results of closure test

- See overall good agreement between truth and unfolded distributions
- The input to the unfolding are observables from electrons that pass selections. We are not yet correcting for efficiency
- Unfolding multiple observables maintains correlations between them





Summary

- Interested in $d\sigma/dxdQ^2$ of nuclei
- Incorporated radiative and Coulomb corrections
- See good agreement between cross sections and theory predictions for carbon
- Unfolding closure test showing promising results
- Next steps:
  - Use pass 0.9 data for analysis
  - Add efficiency corrections to procedure and incorporate into cross section predictions

Thank you!

Backup

clasdis vs. GiBUU

- Generated clasdis and GiBUU samples through OSG using rge_spring2024_LD2-C-sol and rge_spring2024_LD2-C-liq configurations
- clasdis options: --beam 10.5473 --targ deuteron --z 0
- GiBUU options: --targ C (or D) --ebeam 10.5473 --kt 0.64
- Looking at 30 million events for each generator, split evenly between carbon and deuterium
- Run the data through electron selection