Elastic electron-proton scattering in ePIC

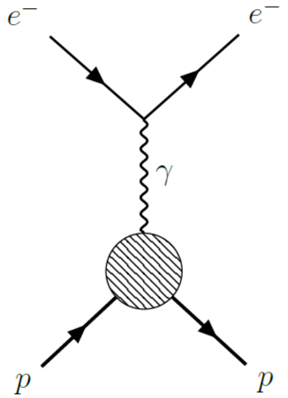
Barak Schmookler (UC Riverside)

A. Pierre-Louis (SBU)

D. Higinbotham (JLab)

Anil Panta (JLab)

Elastic electron-proton scattering at the EIC

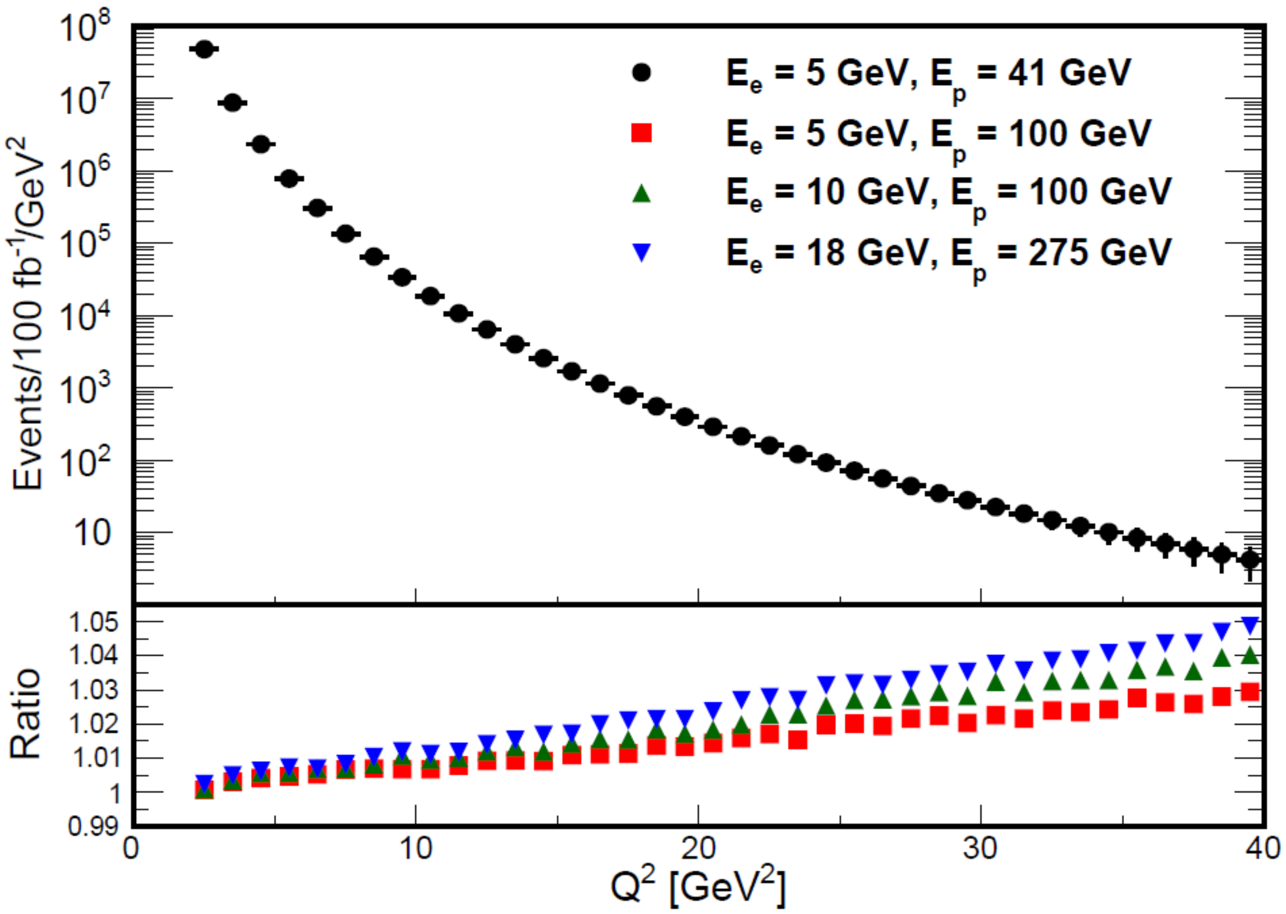


$$\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2}{Q^4}\left[\frac{G_E^2+\tau G_M^2}{1+\tau}\left(1-y-\frac{M_p^2y^2}{Q^2}\right)+\frac{1}{2}y^2G_M^2\right]$$

For elastic e-p scattering, the inelasticity variable will be very small at the EIC:

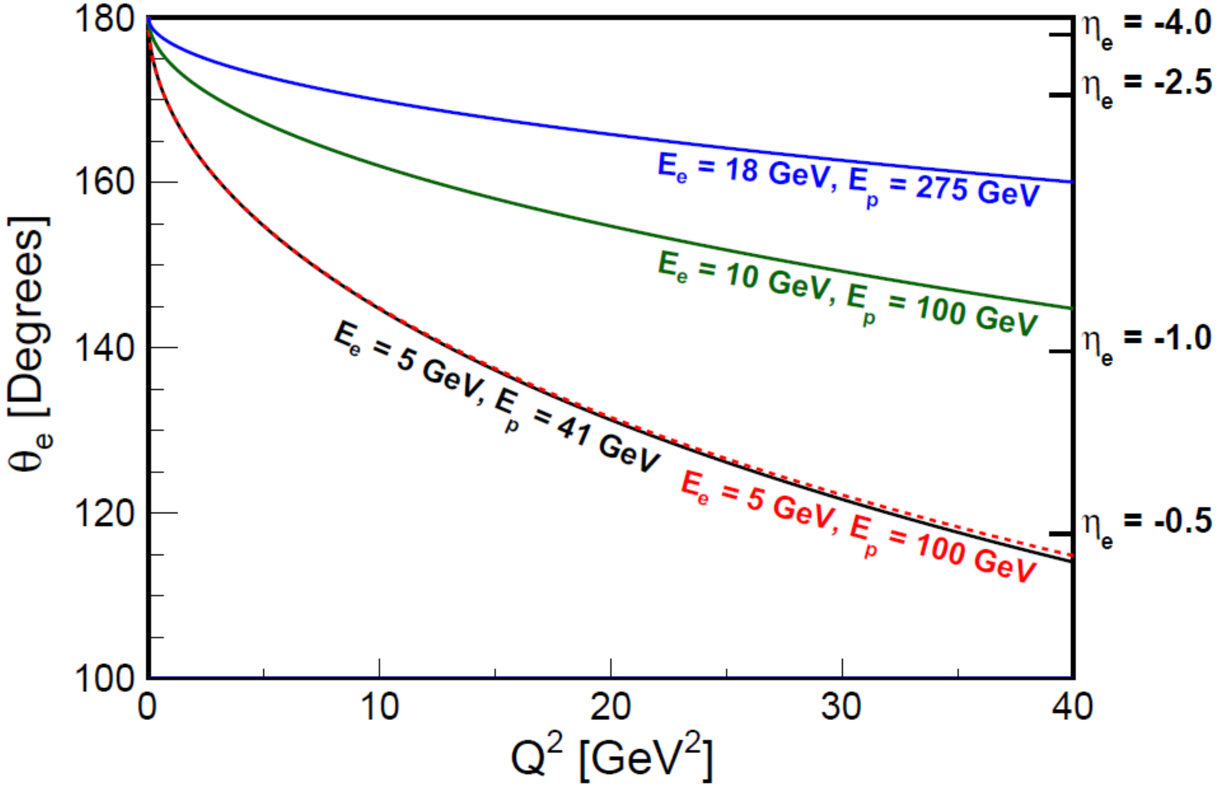
$$s = 4E_eE_p$$
$$x = 1$$
$$Q^2 = sxy$$

$$\Rightarrow \quad \frac{d\sigma}{dQ^2} \approx \frac{4\pi\alpha^2}{Q^4}\left[\frac{G_E^2+\tau G_M^2}{1+\tau}\right]$$

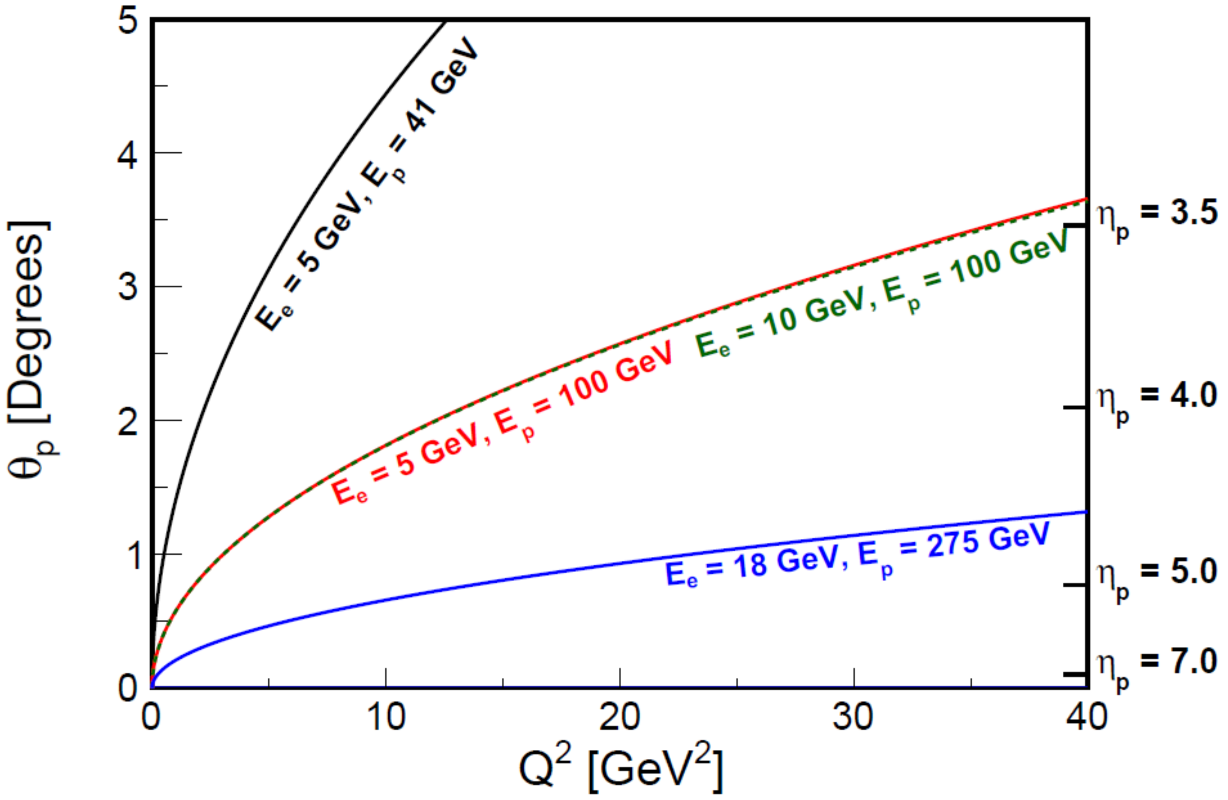


Elastic e-p scattering: EIC kinematics

$$\cos\theta_e = \frac{yE_p - (1-y)E_e}{yE_p + (1-y)E_e}$$



$$\cos\theta_p = \frac{-yE_e + (1-y)E_p}{yE_e + (1-y)E_p}$$



Elastic e-p scattering: EIC kinematics

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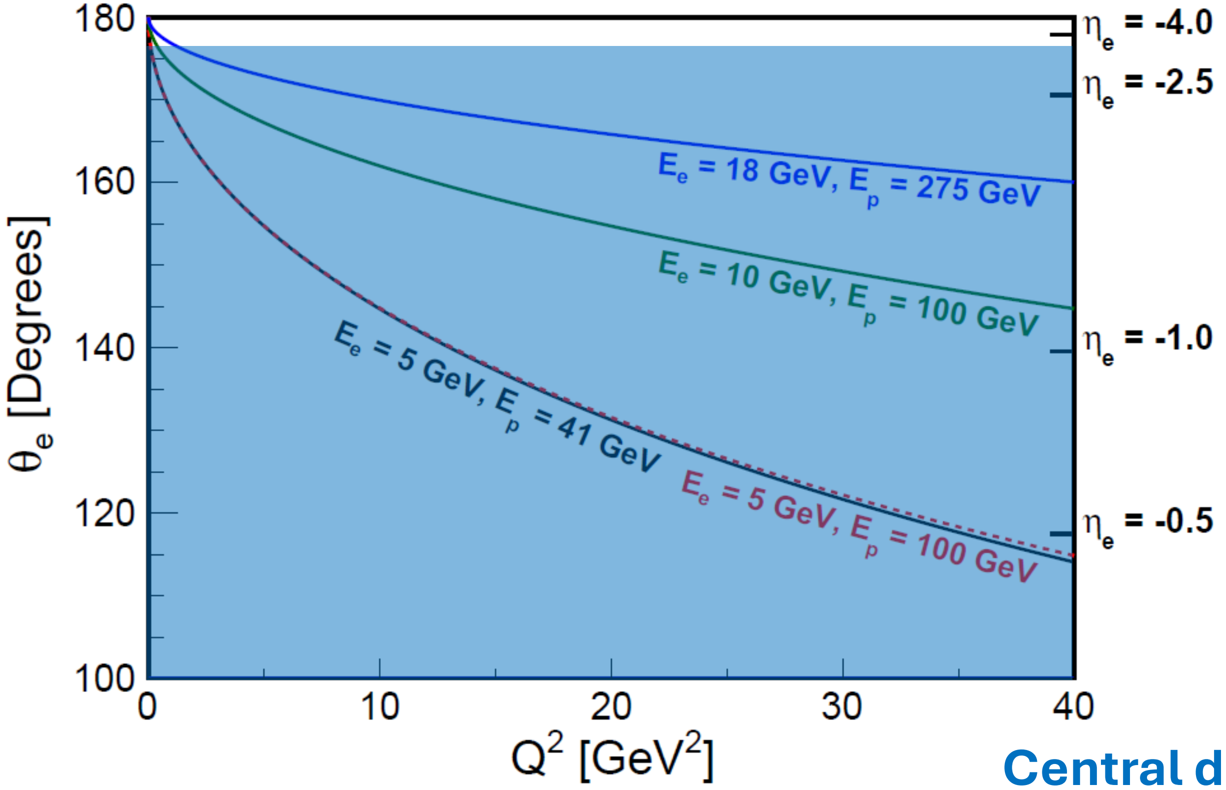
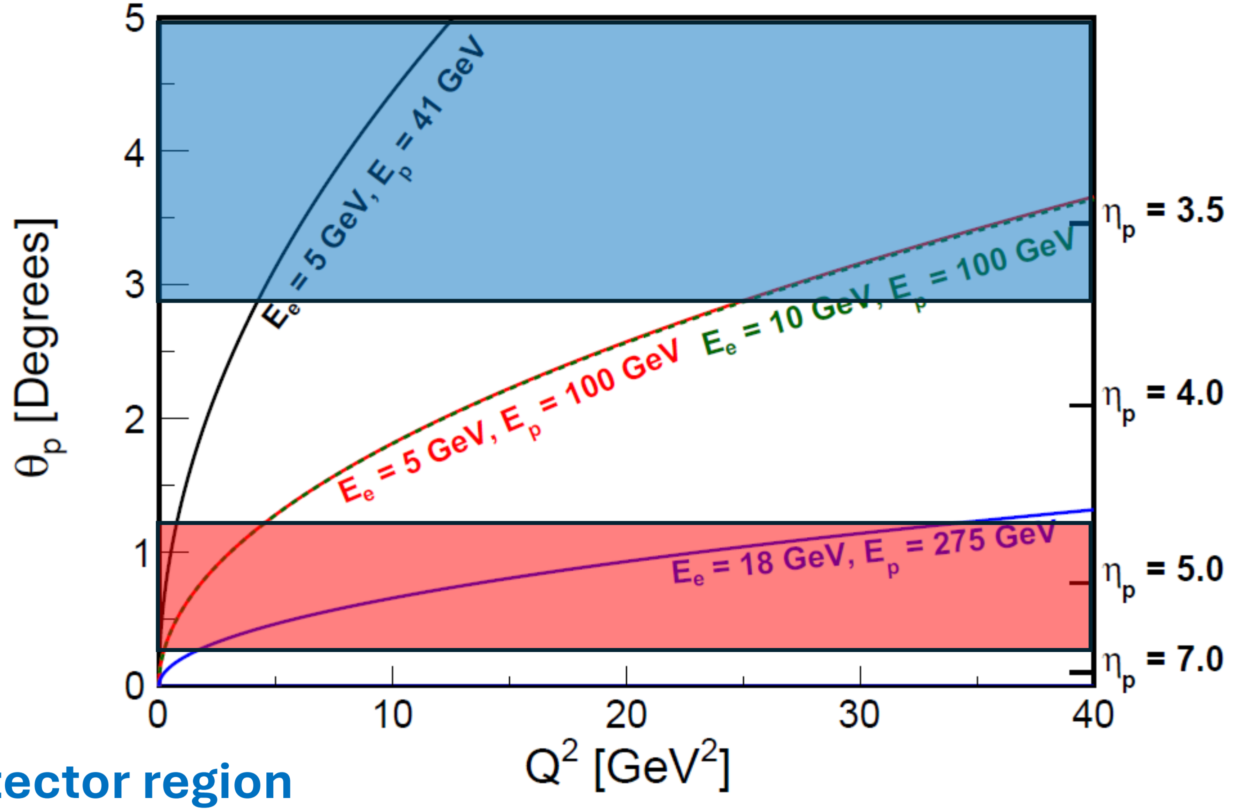




Central detector region

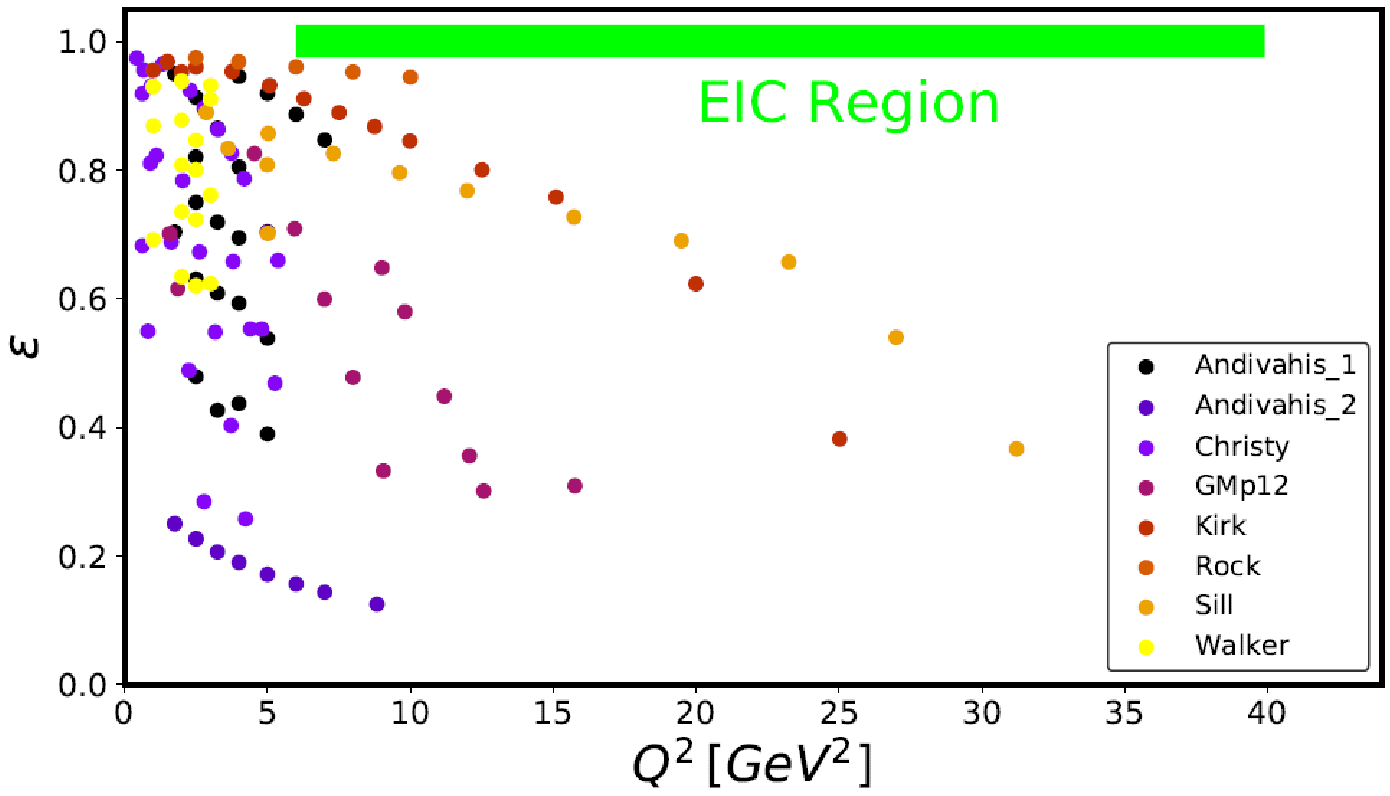
Far-forward detector region

EIC Q^2-ε coverage – high Q^2

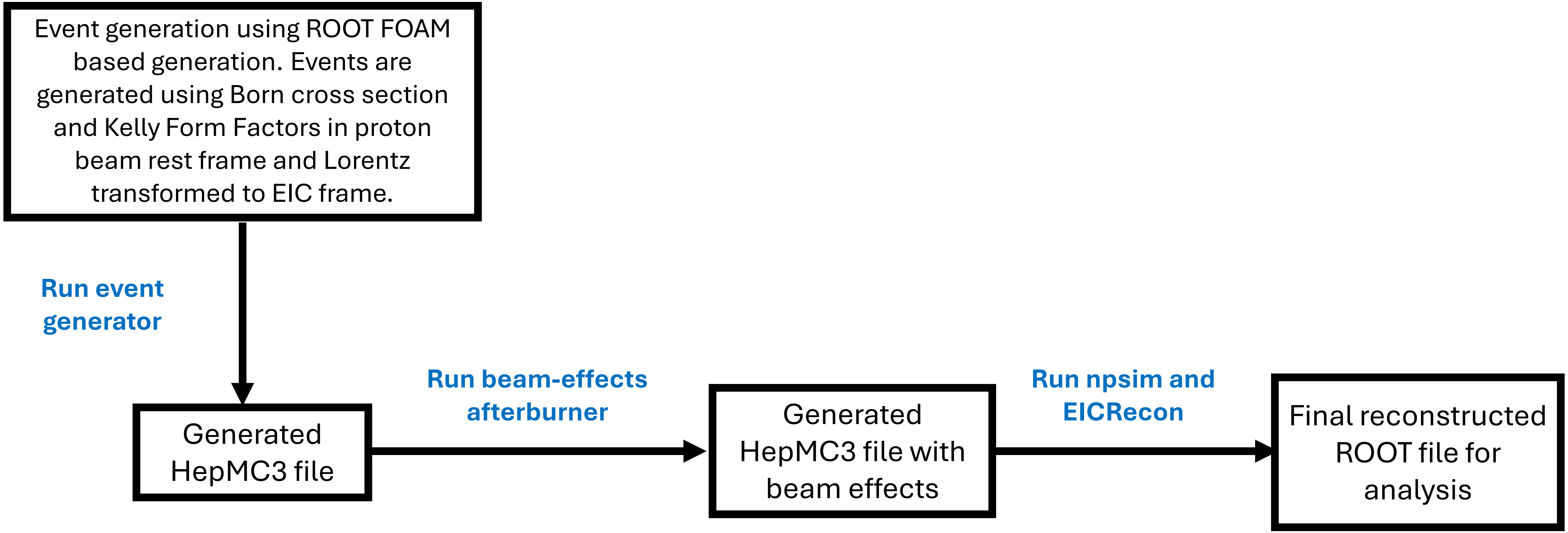
The EIC will be able to measure the elastic e-p cross section in the range **5 (GeV/c)^2 < Q^2 < 40 (GeV/c)^2**. This would be the highest Q^2 ever measured for e-p elastic scattering, and it would be the first time the elastic cross section is measured at a high-energy collider.

Using these new measurements in global analyses would provide additional constraints on potential ε-dependent effects.

Moreover, the over-constrained kinematics of elastic scattering would allow these events to be used for important detector calibration purposes.

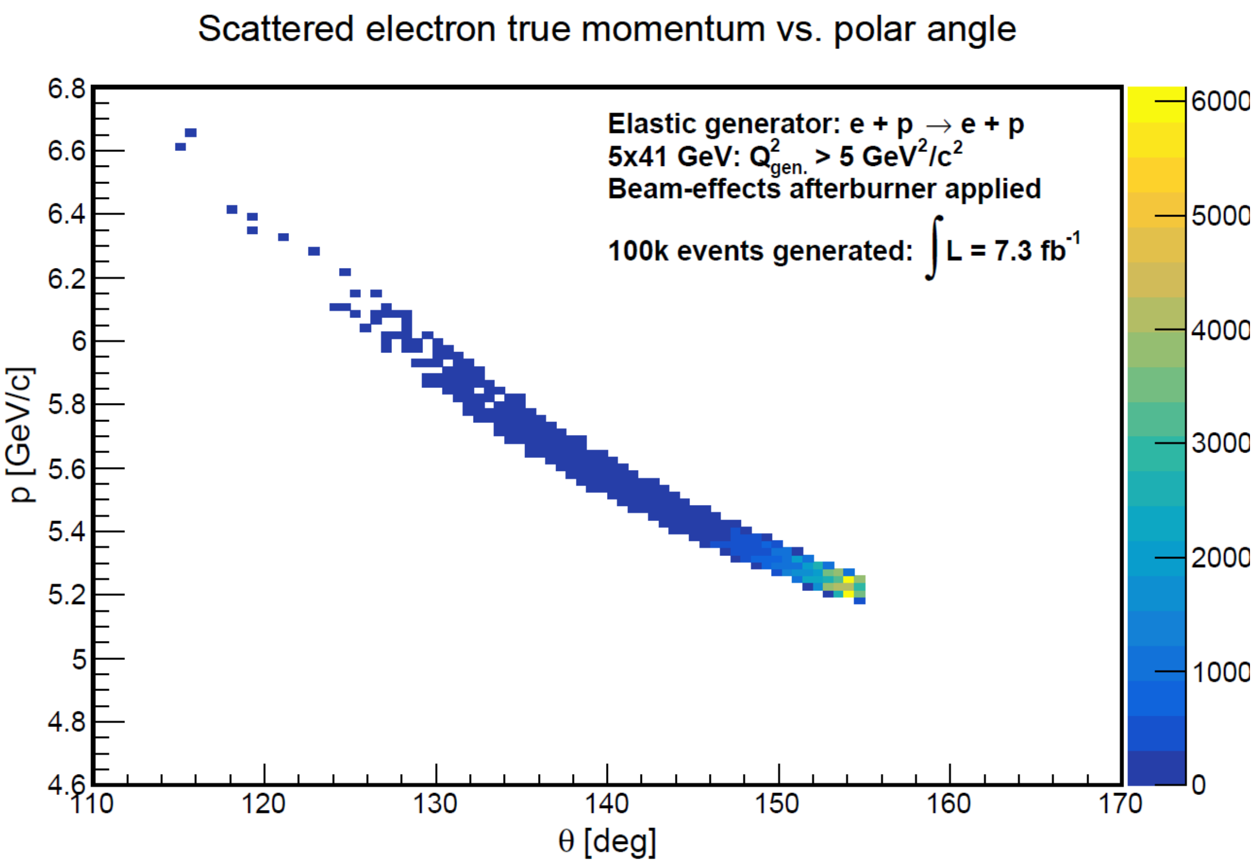


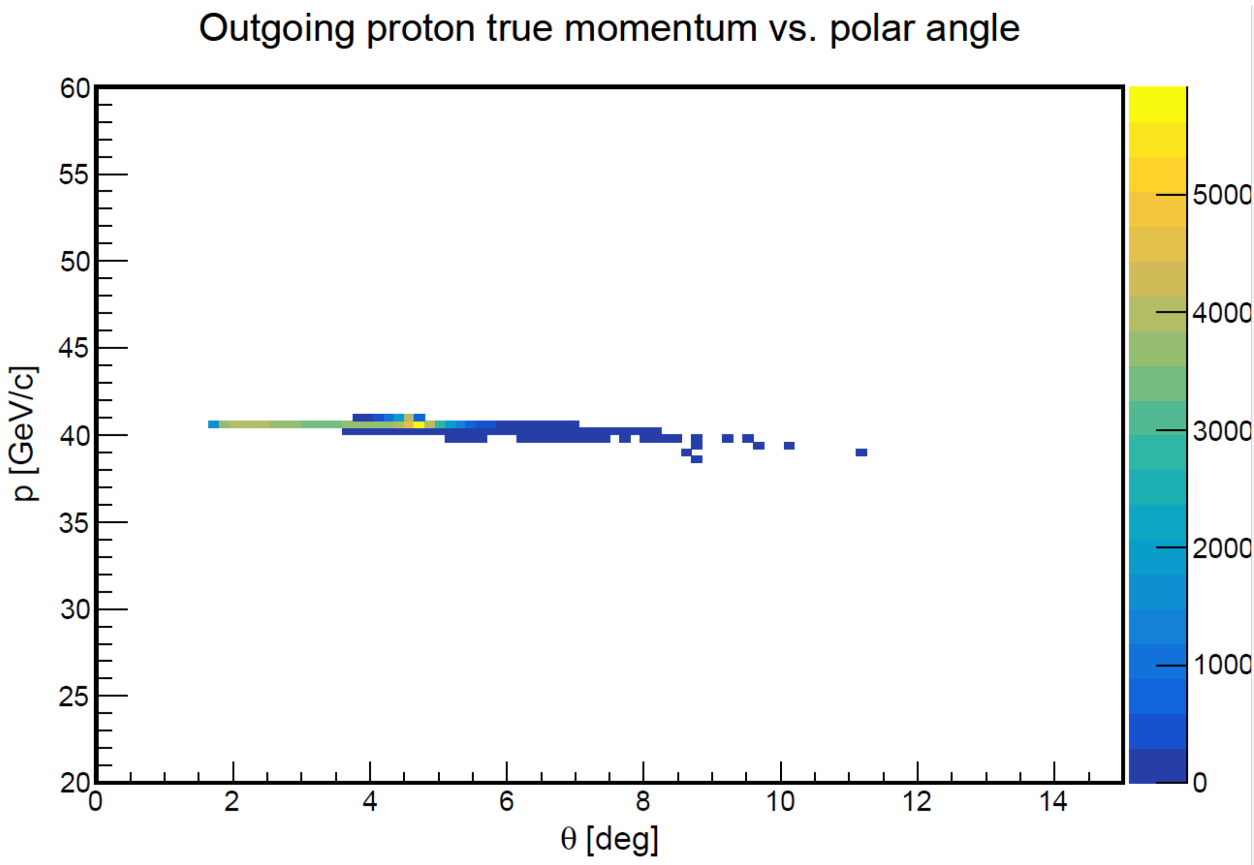
Simulation


Event generation using ROOT FOAM based generation. Events are generated using Born cross section and Kelly Form Factors in proton beam rest frame and Lorentz transformed to EIC frame.
Run event generator
Generated HepMC3 file
Run beam-effects afterburner
Generated HepMC3 file with beam effects
Run npsim and EICRecon
Final reconstructed ROOT file for analysis

Particle reconstruction – central detector

5 GeV e^- x 41 GeV p

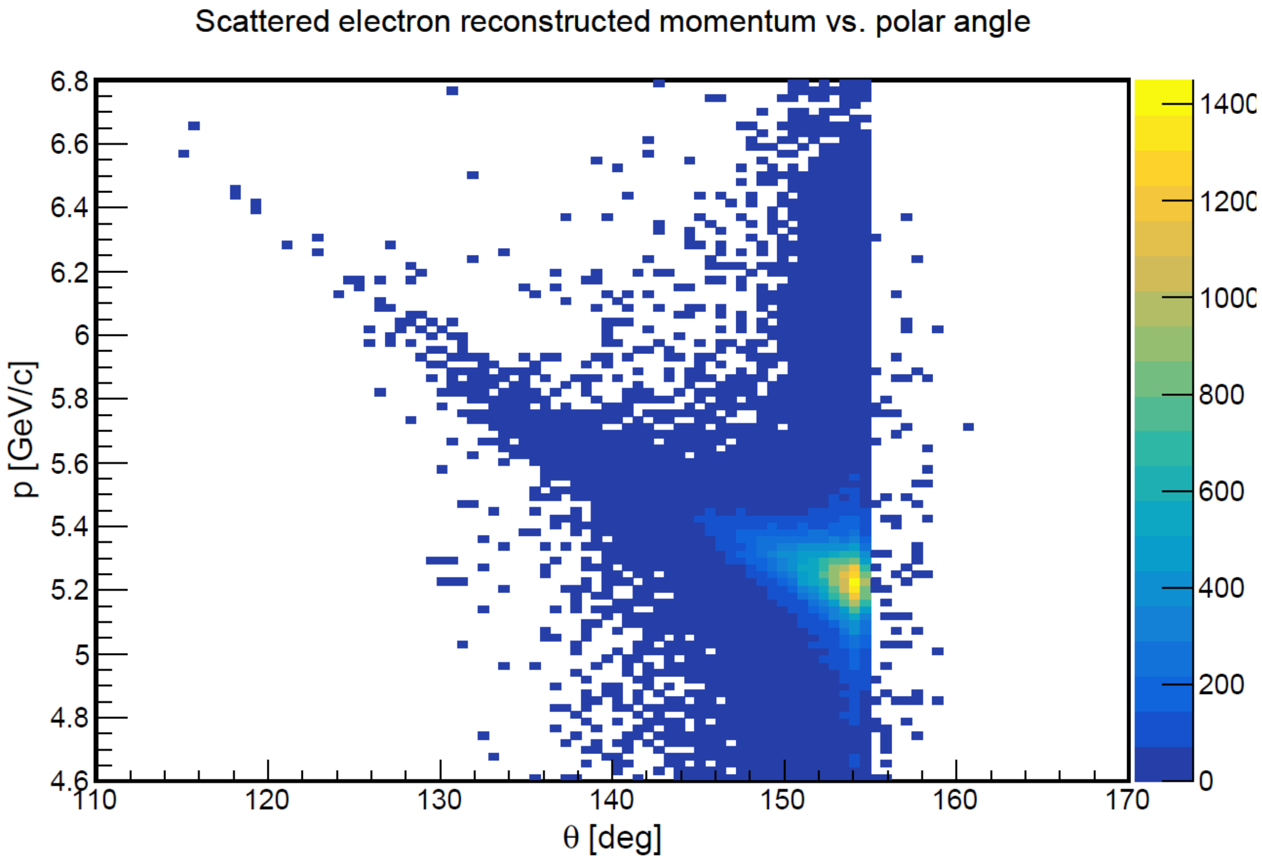


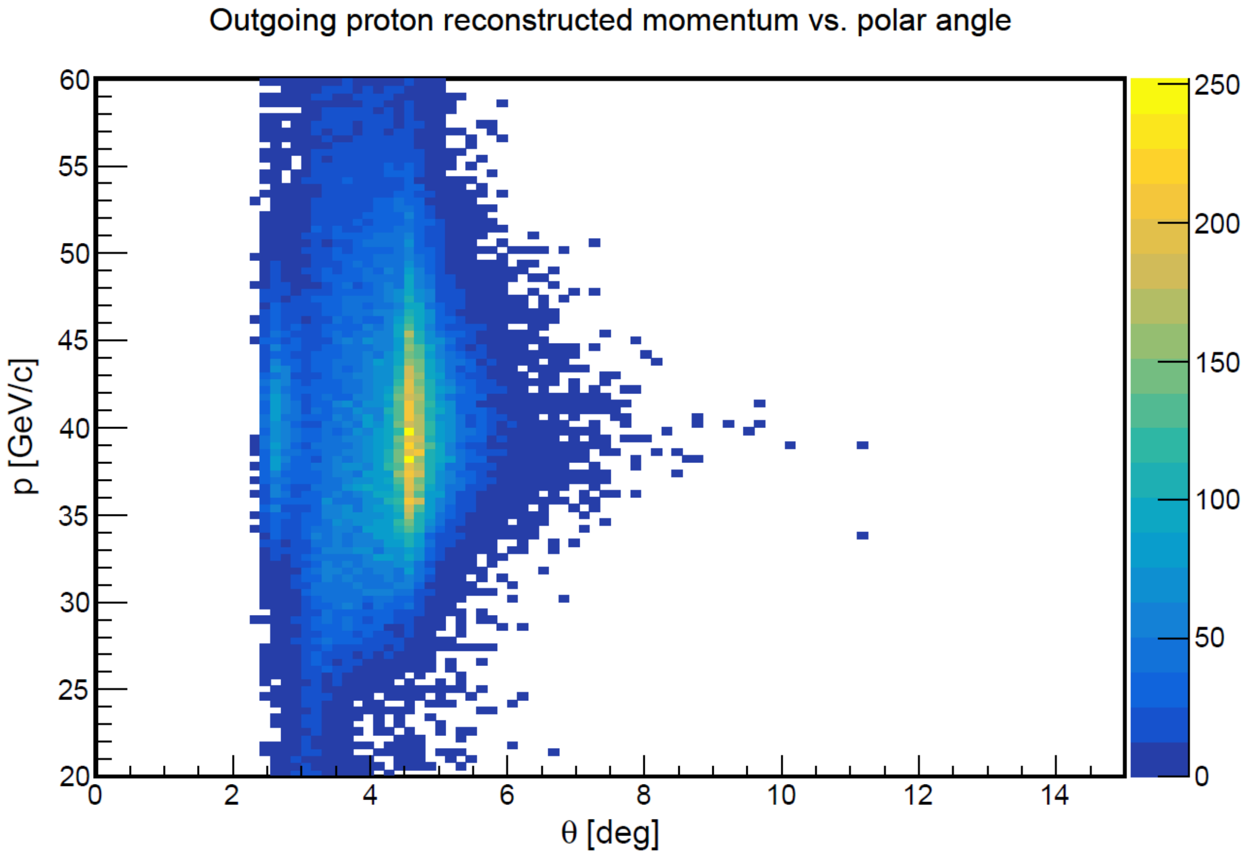


Particle reconstruction – central detector

5 GeV e^- x 41 GeV p

Reconstruction is done using ReconstructedChargedParticles collection.
We require a |PDG| value > 0, which means there is a geometric (eta-phi) match between the reconstructed track and the generated particle.

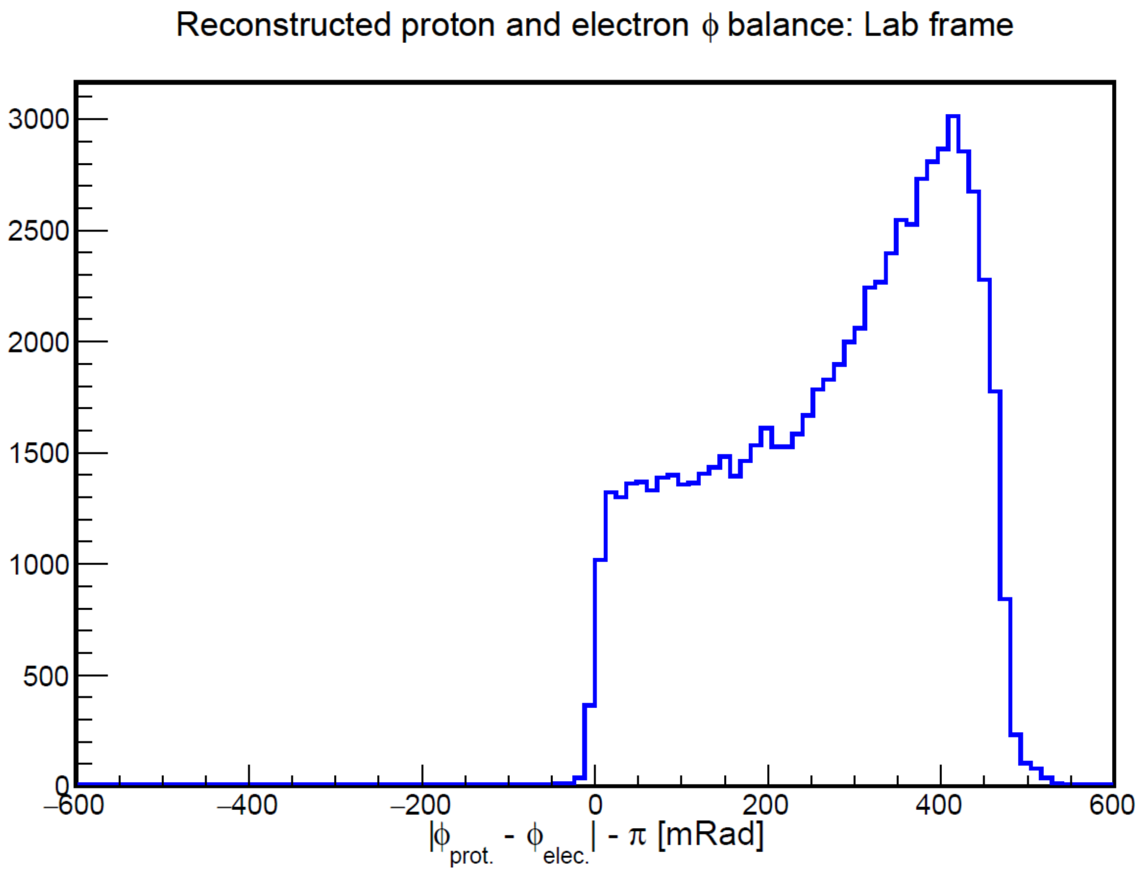


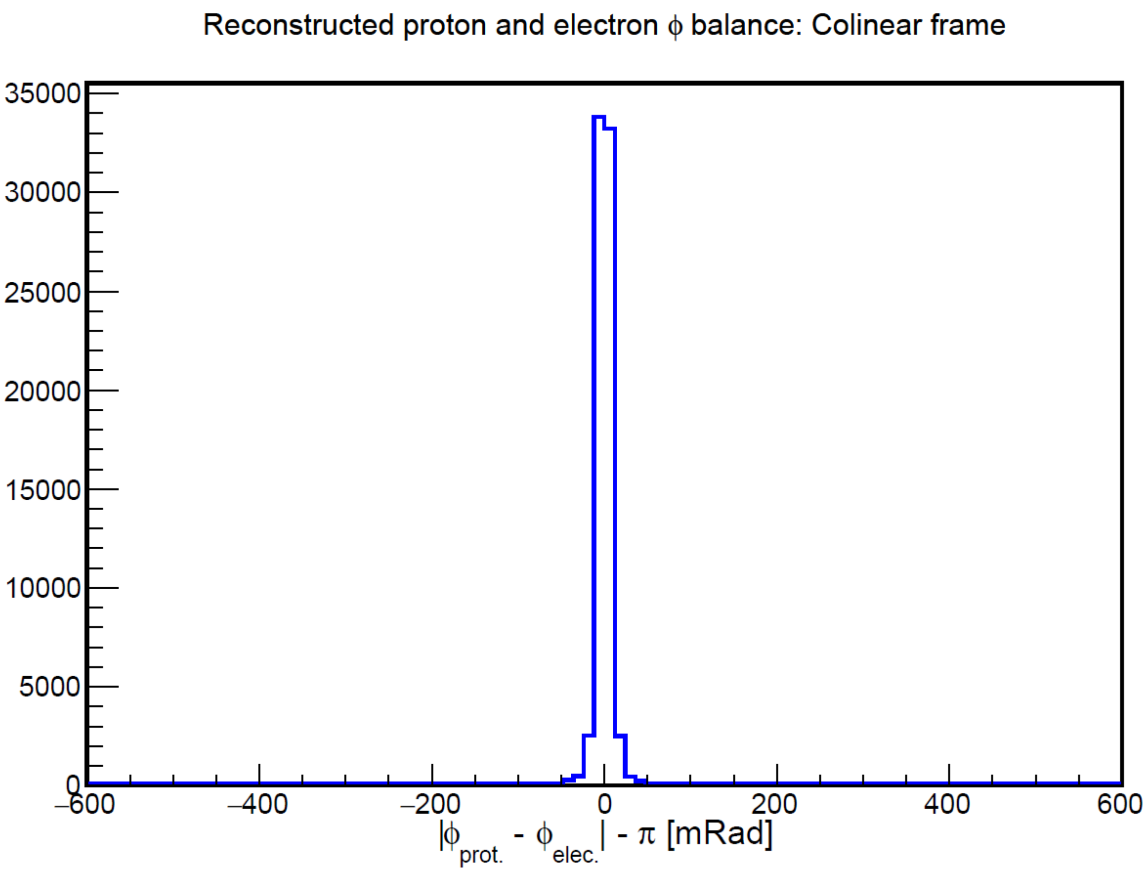


Lab frame reconstruction vs. ‘colinear’ frame reconstruction

Reconstruction in minimally-boosted beam colinear frame. The Lorentz transformation and rotation is done based on this code:

https://github.com/eic/EICrecon/blob/main/src/algorithms/reco/Boost.h





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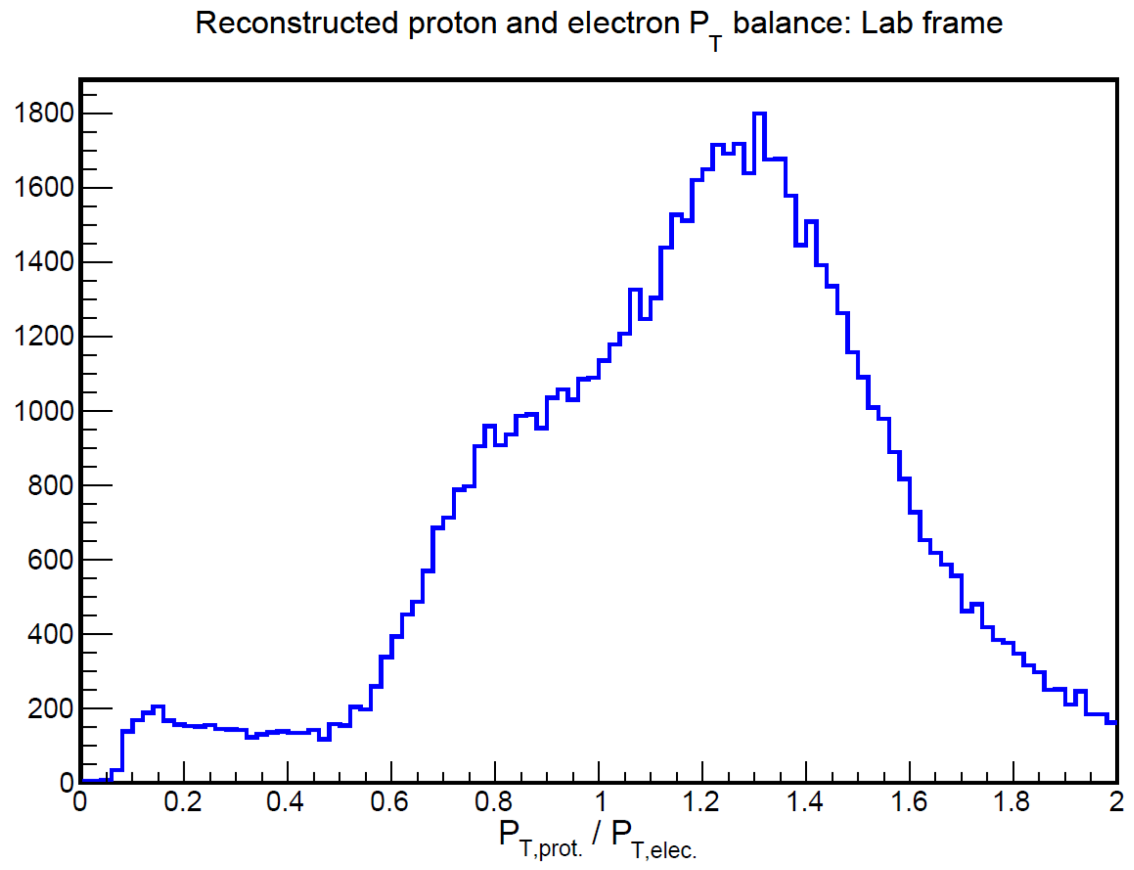

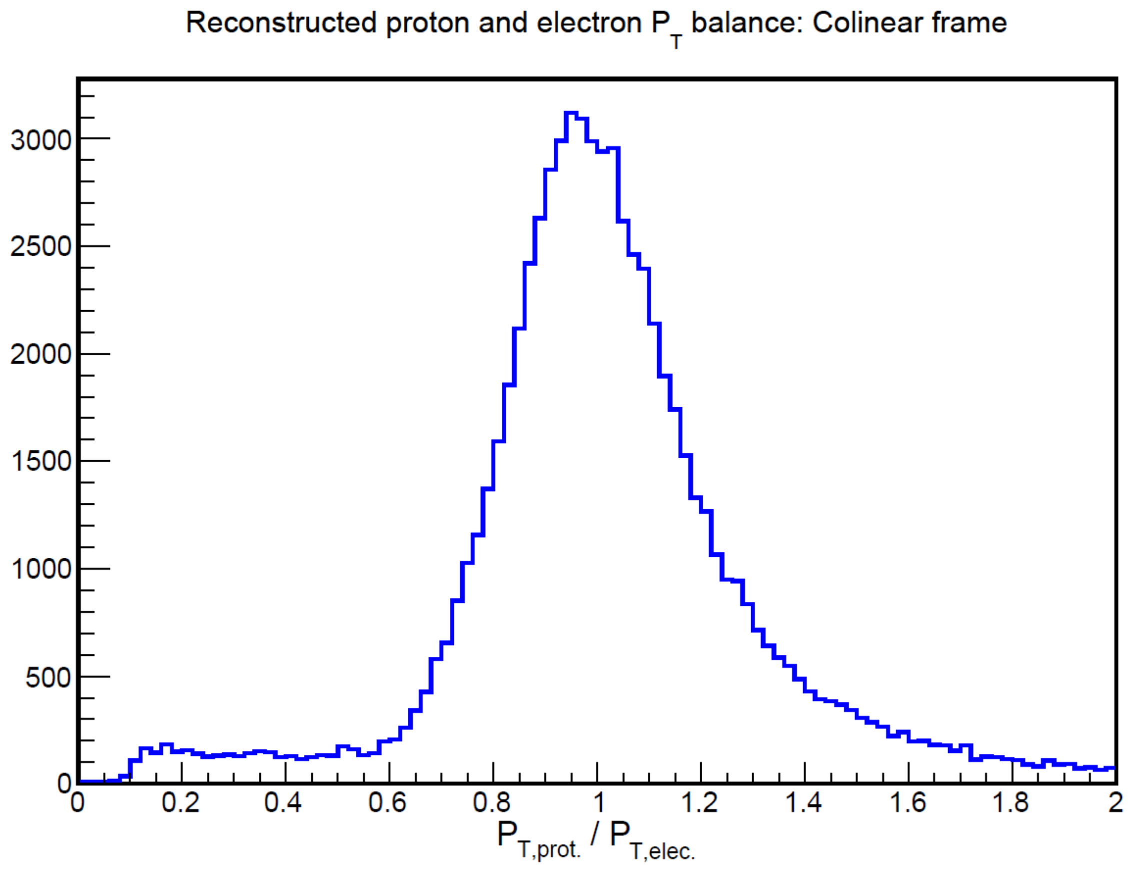

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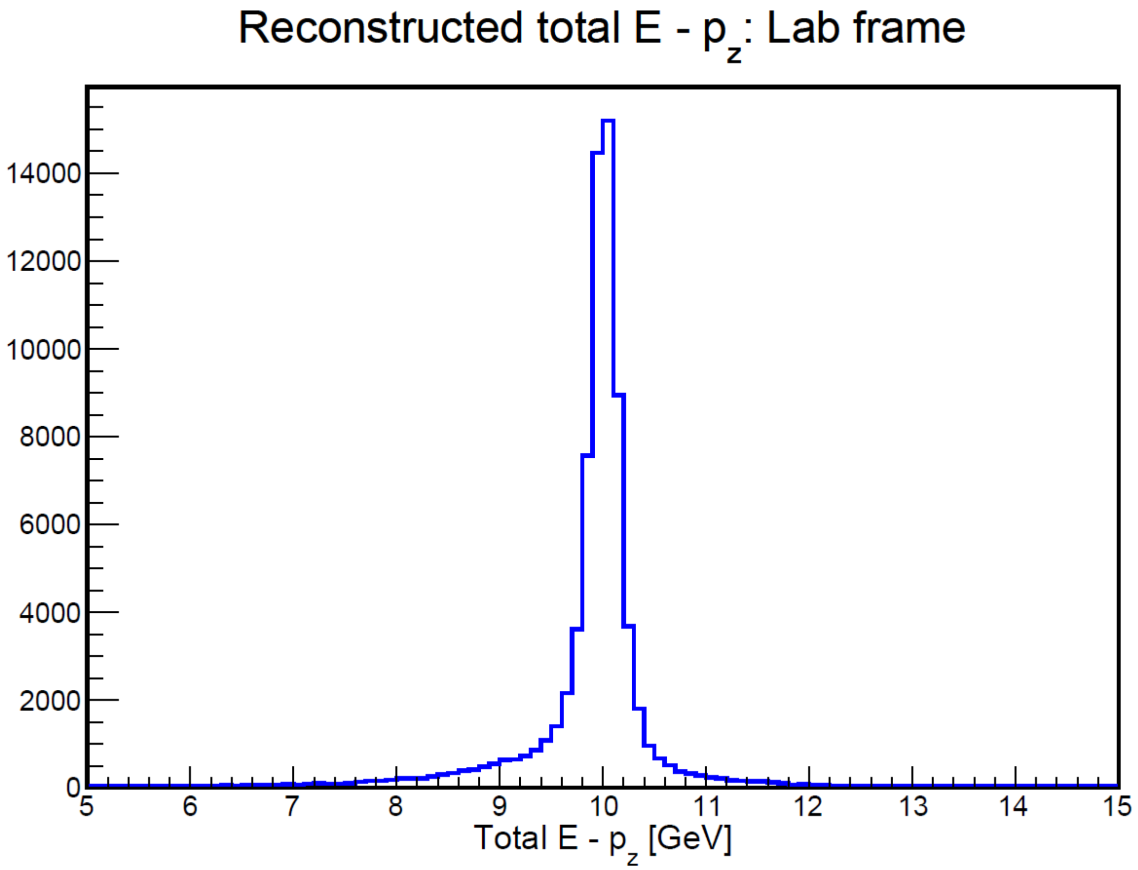
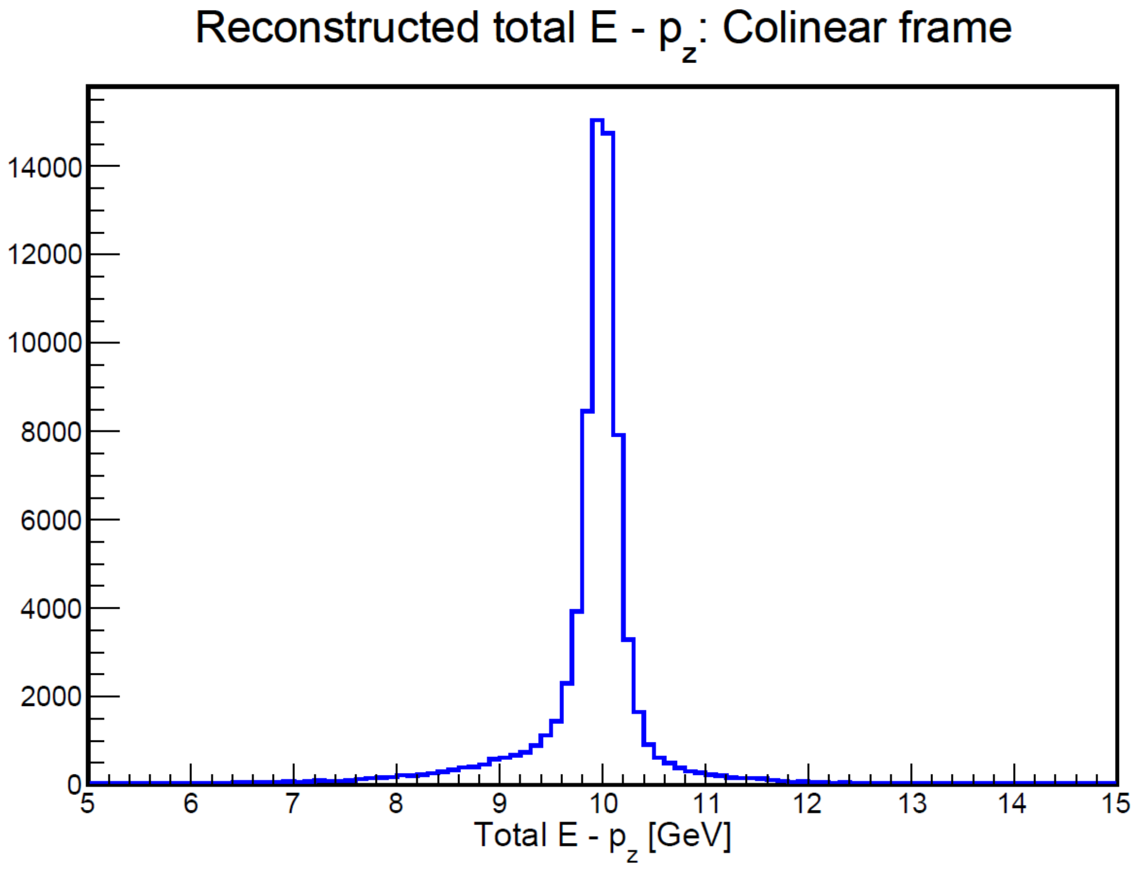




Kinematic reconstruction

- The reconstruction of x and Q^2 for elastic events is studied using three methods:
  1. Scattered electron method: Reconstruction using the measured scattered electron's energy (momentum) and polar angle.
  2. Jacquet-Blondel method: Reconstruction using the measured outgoing proton's energy (momentum) and polar angle.
  3. Double-Angle method: Reconstruction using scattered electron's and outgoing proton's measured polar angles.

Reconstruction using scattered electron:

$$y_e = 1 - \frac{E'_e}{2E_e}(1 - \cos\theta_e) \ ,$$

$$Q^2_e = 4E_e E'_e \cos^2(\theta_e/2) \ ,$$

$$x_e = \frac{Q^2_e}{s y_e} \ .$$

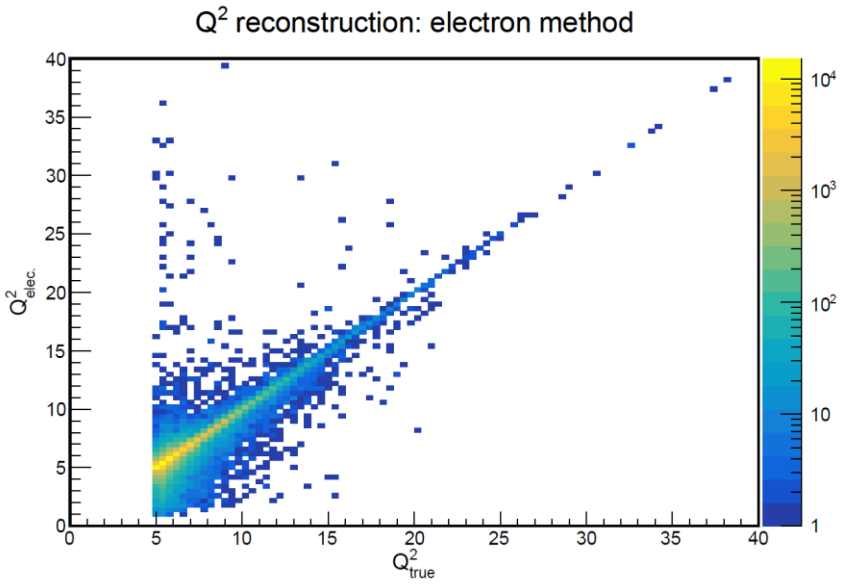
Reconstruction of *x* when using only the scattered electron is expected be poor for elastic events (at very low *y*):

$$\frac{\delta x_e}{x_e} = \frac{1}{y_e} \cdot \frac{\delta E'_e}{E'_e} \bigoplus \left[\frac{1 - y_e}{y_e} \cdot \cot\frac{\theta_e}{2} + \tan\frac{\theta_e}{2}\right] \cdot \delta\theta_e$$

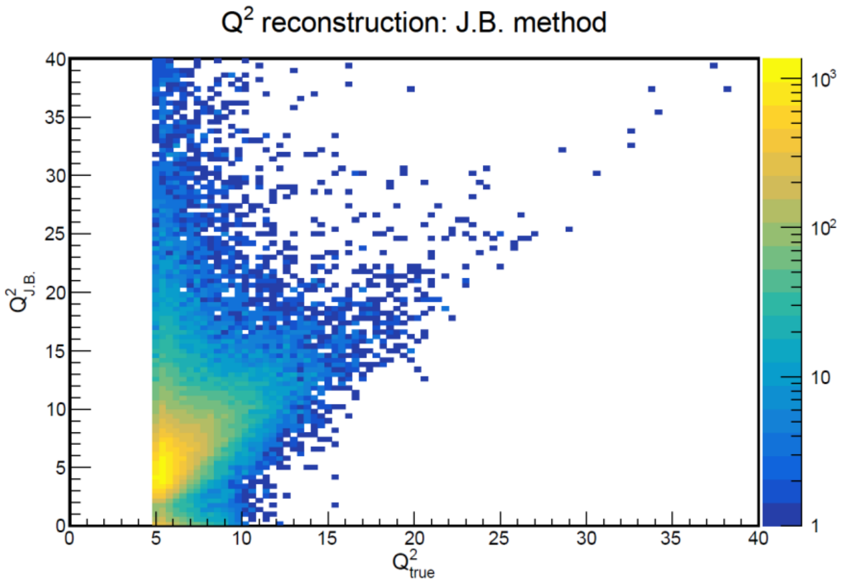
5 GeV e^- x 41 GeV p

Reconstruction of Q^2

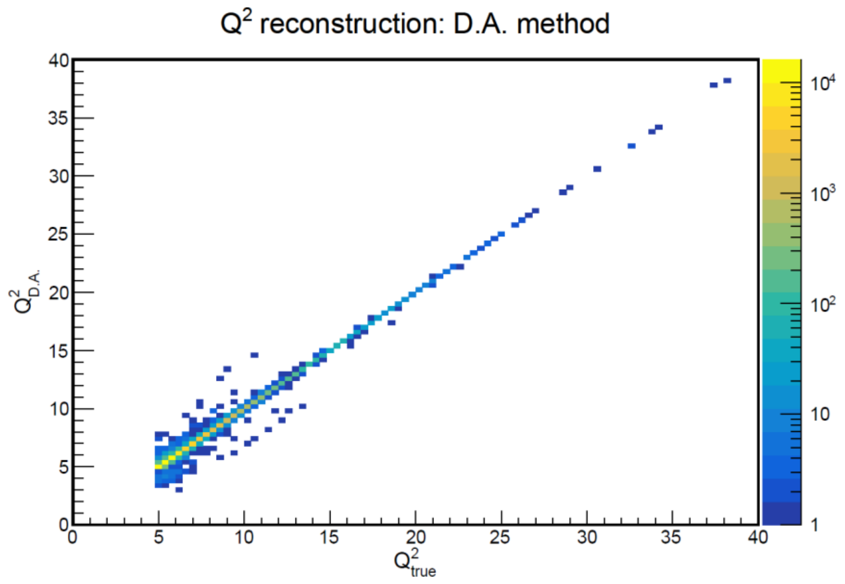
Scattered electron method



Jacquet-Blondel method



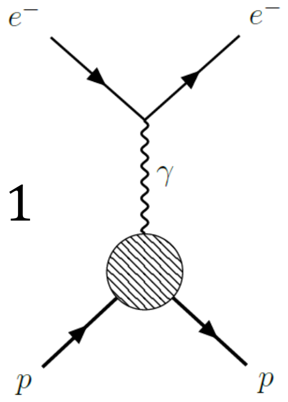
Double-Angle method



5 GeV e^- x 41 GeV p

Reconstruction of x

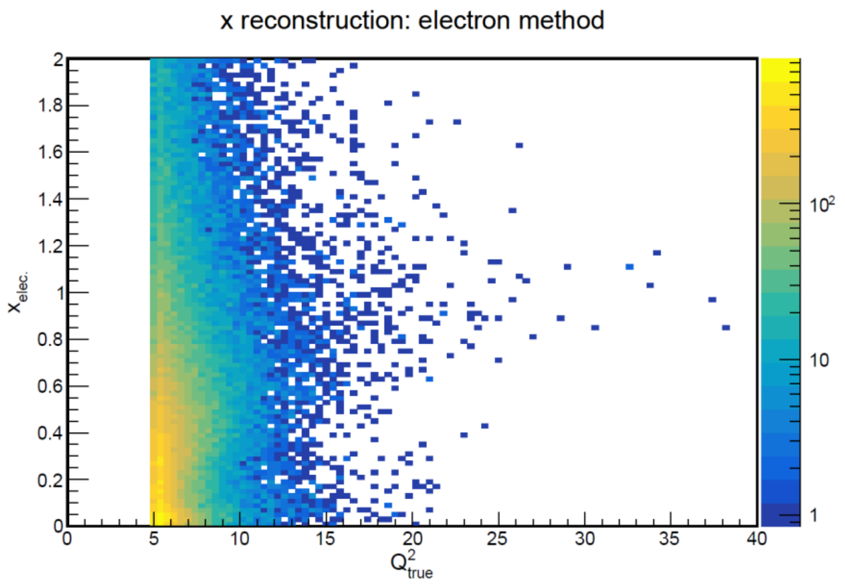
$x = 1$

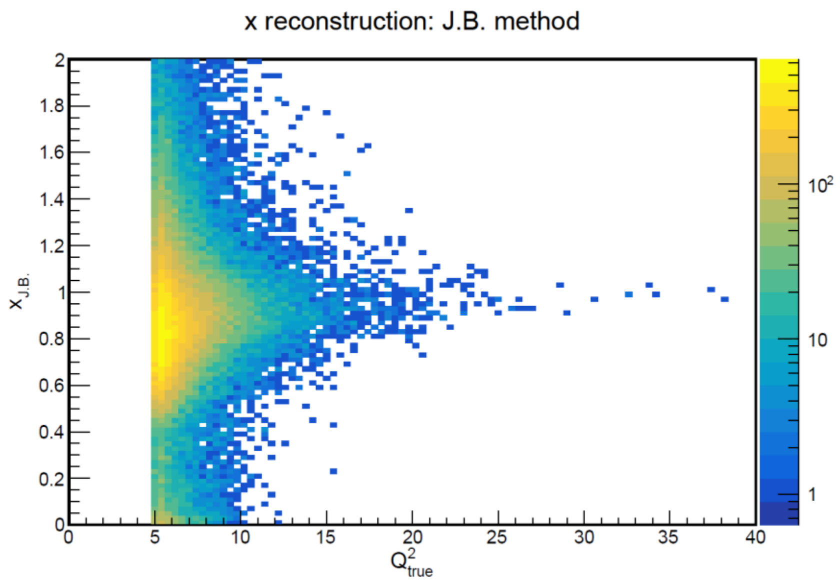


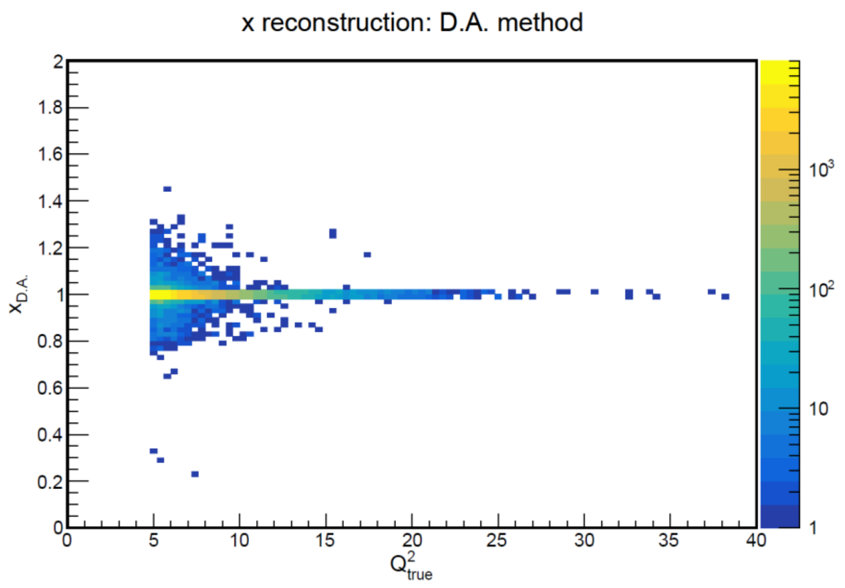
Scattered electron method

Jacquet-Blondel method

Double-Angle method

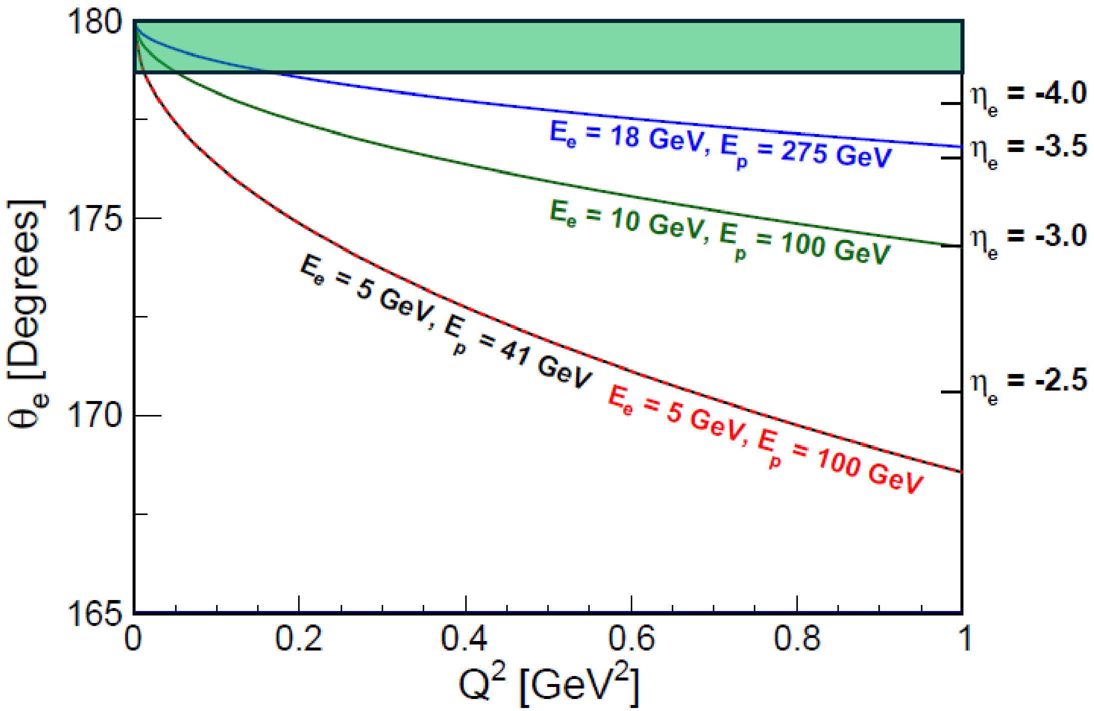






Low Q^2 events and QED effects

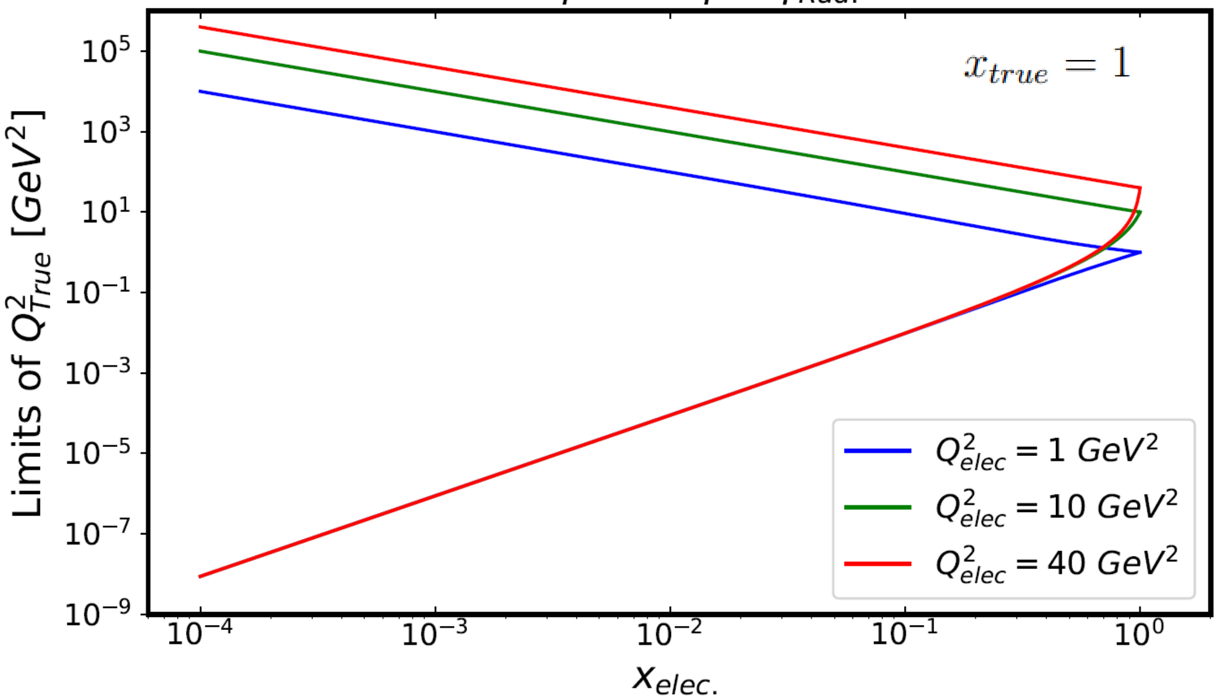
Scattered elastic electron in Far-Backwards region at low Q^2.



$$Q^2_{max,min} = Q^2 \frac{2(1-x_r)(1 \pm \sqrt{1+\gamma^2}) + \gamma^2}{\gamma^2 + 4x_r(1-x_r)}$$

$$\gamma^2 = 4M^2x^2/Q^2, \qquad x_r = x/x_{true}.$$

$e + p \to e + p + \gamma_{Rad.}$



We have generated events including QED effects using Djangoh v4.6.21. These events are stored in HepMC3 format and have been successfully run through the beam-effect afterburner.

Conclusions

- We have studied reconstruction of high Q^2 elastic e-p events using the ePIC simulation.
- Our next steps are to look at higher-energy configurations, where the outgoing proton goes into the far-forward region. We also will look at the events generated with QED effects in more detail.
- The generated and burned HepMC files are stored in a local repository. We can upload them to S3 and start working on a physics benchmark.