“Thank you all, you made it to the end of 2025 with our intense meeting schedule! Really appreciate your engagement ”

– Stephen and Kong

Early Science Paper status – end of 2025

Exclusive/diffraction/tagging (EDT) working group

Stephen Kay and Kong Tu

Dec 15, 2025

Studies that have been active since the summer of 2025 or before

Year	Species	Energy (GeV)	Luminosity/year (fb^-1)	Electron polarization	p/A polarization	Selected processes in this work
1	eRu/Ag	10x115	0.9	No (commissioning)	N/A	Diffractive DIS
2	eD ep	10x130	11.4 4.95-5.33	LONG	NO TRANS	Tagged DIS with spectator tagging DVCS, DVMP, DEMP
3	ep	10x130	4.95-5.33	LONG	TRANS and/or LONG	DVCS, DVMP, DEMP
4	eAu ep	10x100 10x250	0.84 6.19-9.18	LONG	N/A TRANS and/or LONG	Diffractive Vector-Meson DVCS, DVMP, DEMP
5	eAu eHe3	10x100 10x166	0.84 8.65	LONG	N/A TRANS and/or LONG	Diffractive Vector-Meson Tagged DIS with spectator tagging

ep

- DVCS (Oliver)
- DVpi0P (Jihee)
- DEMP (Stephen K)
- DVMP (Olaiya)

*ep/*A

- eA diffractive phi (Maci)
- DDIS (Hadi)
- eHe3 (Win)
- *Deuteron tagging (Jan & Alex)

Physics overview

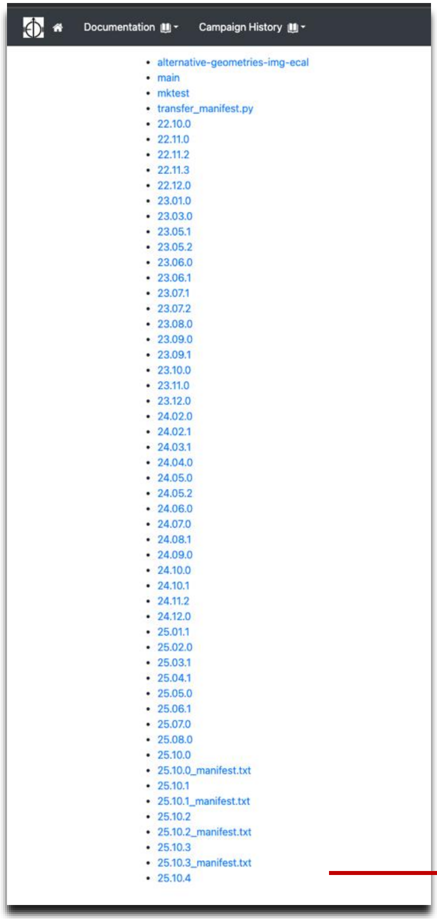
- Imagining of the proton/meson - quarks and gluons
  - Generalized Parton Distributions (GPD), structure functions.
- Study of neutron structure (spin dependent and spin independent.)
- Diffractive structure function of proton and nuclei
- Imagining of heavy nuclei

What makes EIC unique for studying these physics:

1. *Acceptance - central and forward region*
2. *High luminosity*
3. *Beam polarization.*
4. *Wide kinematic reach in Q2 and x*

Simulation and software campaigns

Big thanks to the production team!

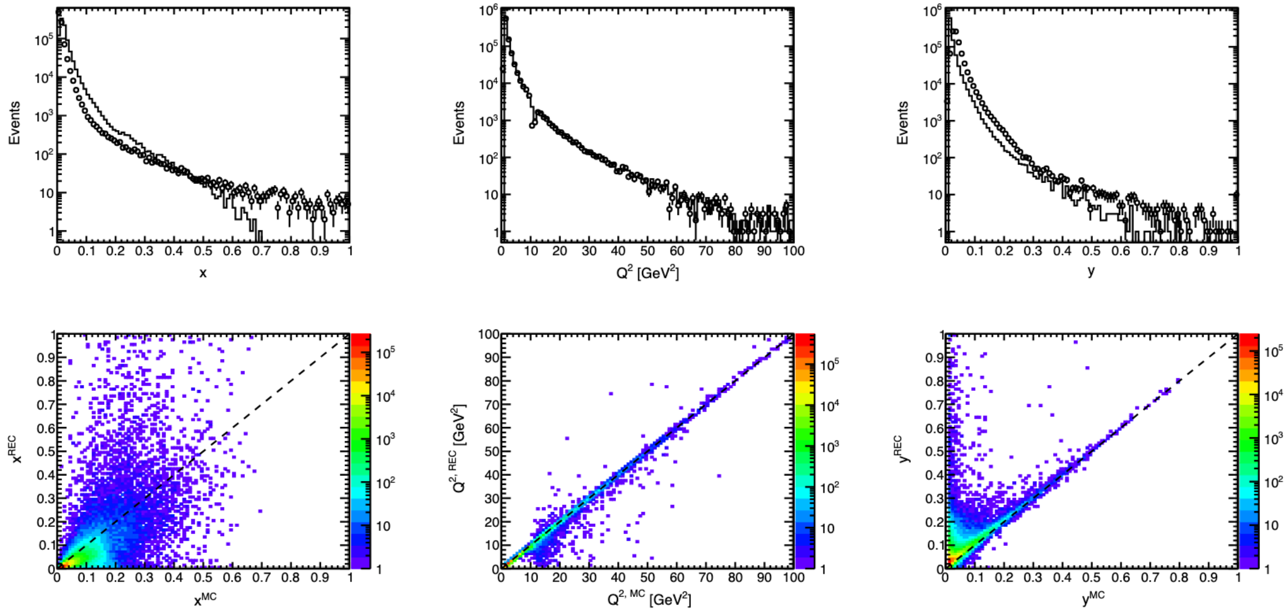


All results in this summary will be based on Oct, 2025 campaigns

Some newest samples have machine background for selected processes

Common selections on DIS

- A central task for DIS event is the scattered electron. Everyone in the group has done this and had communications with inclusive group.



Jihee's analysis note

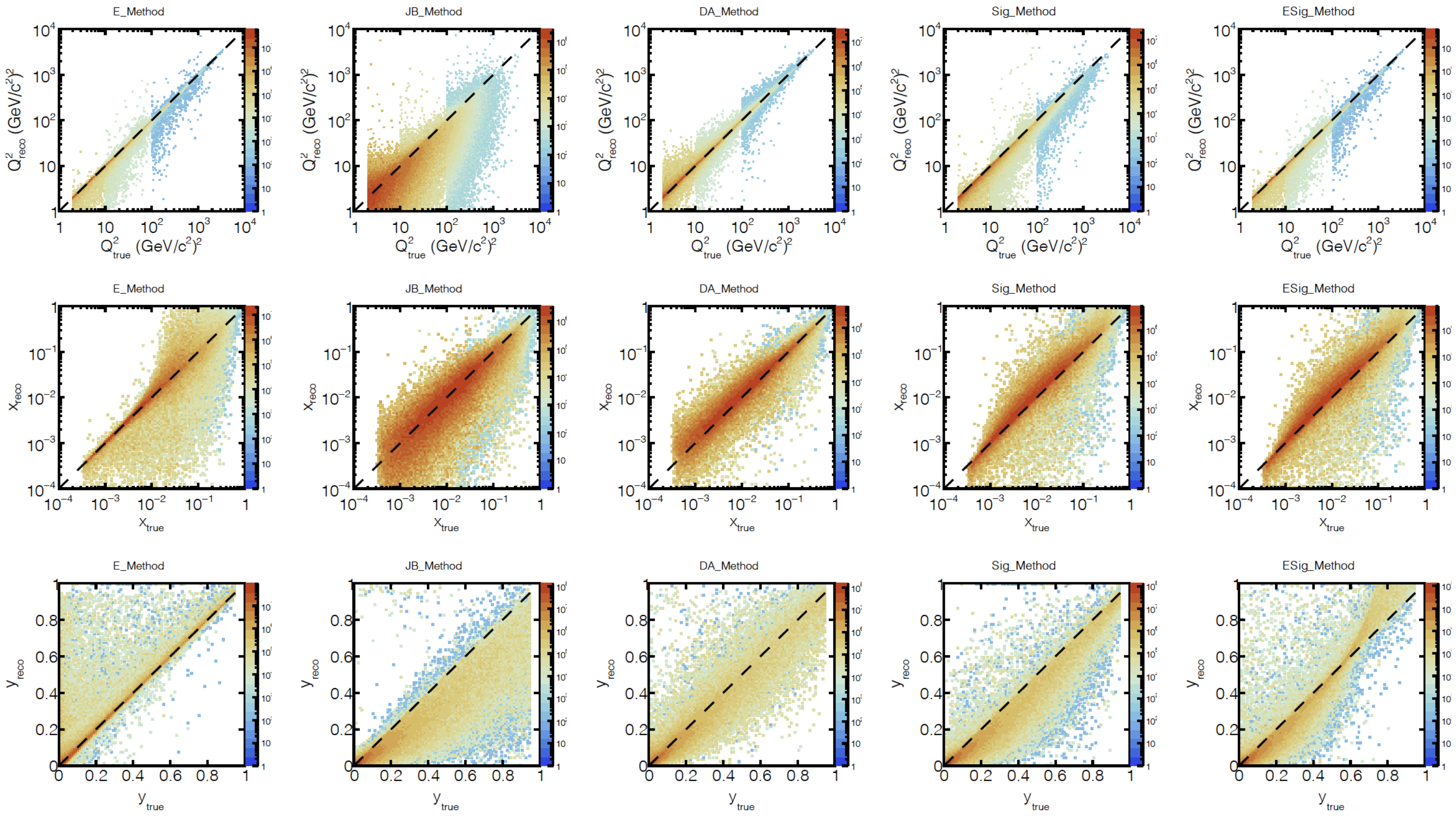
- Backward EMCal cluster for energy
- Position from tracking (x,y) or (eta, phi)
- Truth association with MC to ensure e' when there is ambiguity.
- $0.8 < E/p < 1.2$

* 18 < E-pz < 22 cut for some analyses.
(we should have all analyses followed.)

Algorithm	Q^2	Inelasticity y	Bjorken x
Electron (E)	$2E_0E_e(1+\cos\theta_e)$	$1-\frac{E_e(1-\cos\theta_e)}{2E_0}$	$\frac{Q^2}{4E_0E_ey}$
Jacquet-Blondel (JB)	$\frac{p_{t,h}^2}{1-y}$	$\frac{\delta_h}{2E_0}$	
Double-Angle (DA)	$\frac{4E_0^2}{\tan(\frac{\theta_e}{2})(\tan(\frac{\theta_e}{2})+\delta_h/p_{t,h})}$	$\frac{\delta_h/p_{t,h}}{\tan(\frac{\theta_e}{2})+\delta_h/p_{t,h}}$	
Sigma (Σ)	$\frac{E_e^2\sin^2\theta_e}{1-y}$	$\frac{\delta_h}{\delta_h+E_e(1-\cos\theta_e)}$	
E-Sigma ($e\Sigma$)	Q_E^2	$\frac{Q_E^2}{4E_0E_ex_\Sigma}$	x_Σ

Comparison with different methods (Win)

Win’s eHe3 analysis note



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Win’s eHe3 analysis note

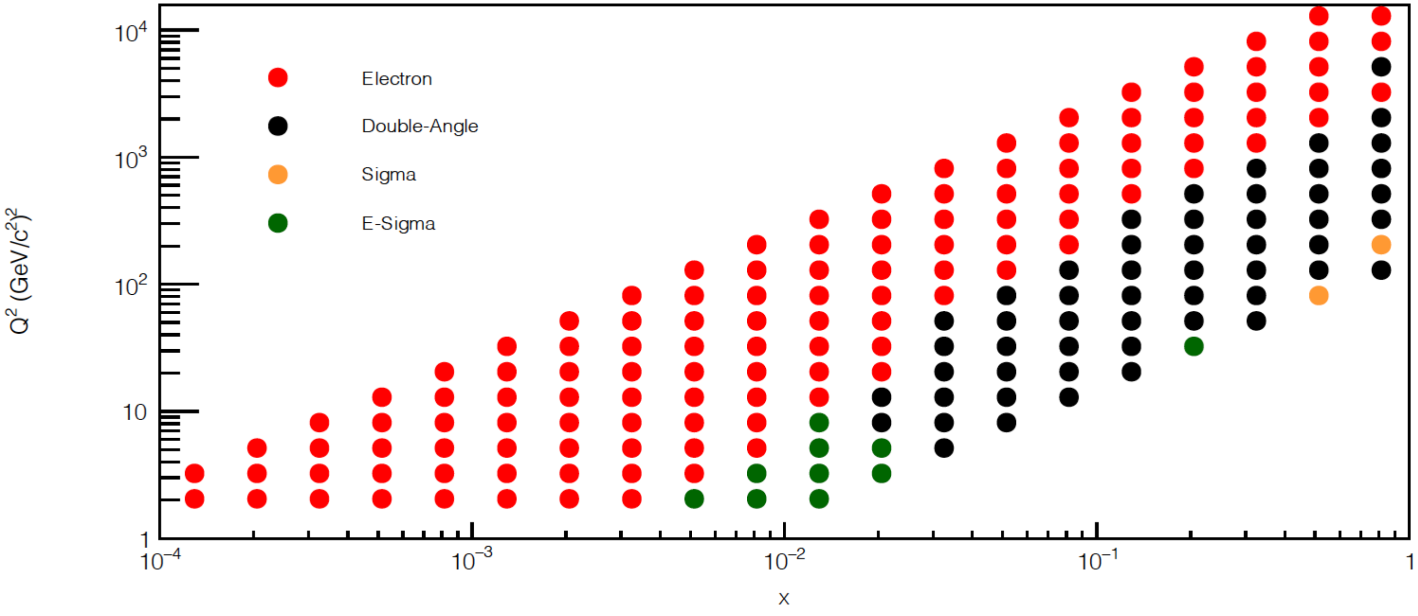
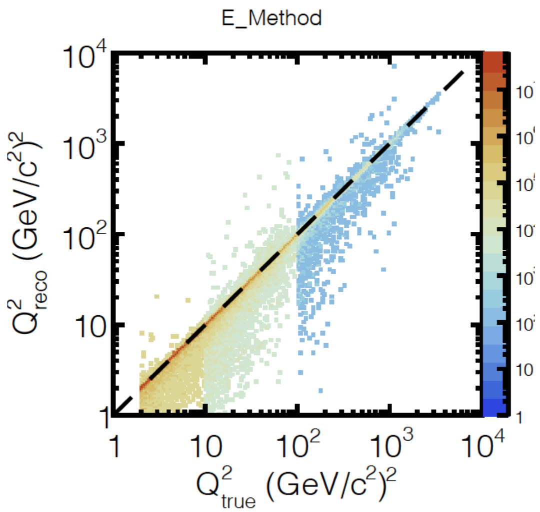


Figure 10: Highest efficiency algorithm for each kinematic bin. Efficiency is determined by the number of events reconstructed in the correct bin using each reconstruction algorithm over the true number of events in the bin calculated using MC information.

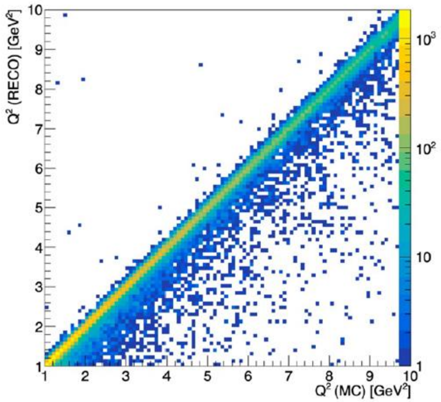
Keep in mind that no radiative effect is included here, which is clearly a to-do next

Are all analyses have the same x,Q2 selections or performances?

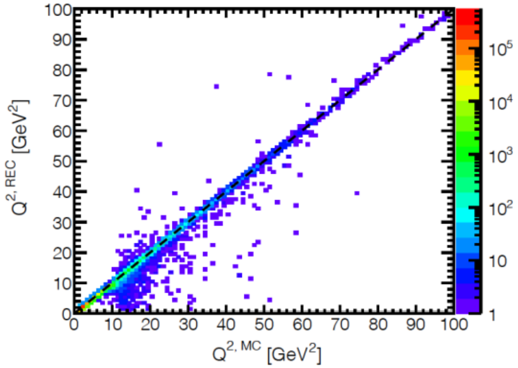
Electron method



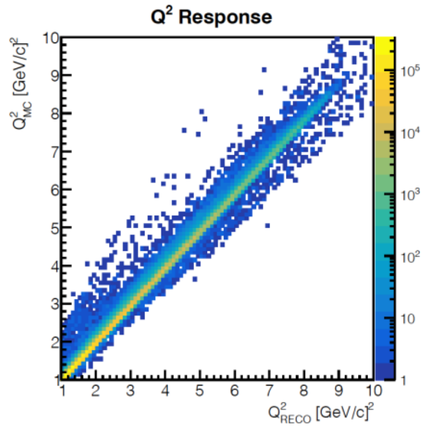
eHe3



DVMP



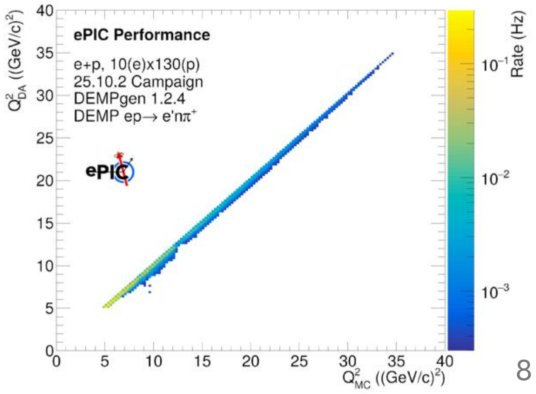
pi0



eA phi

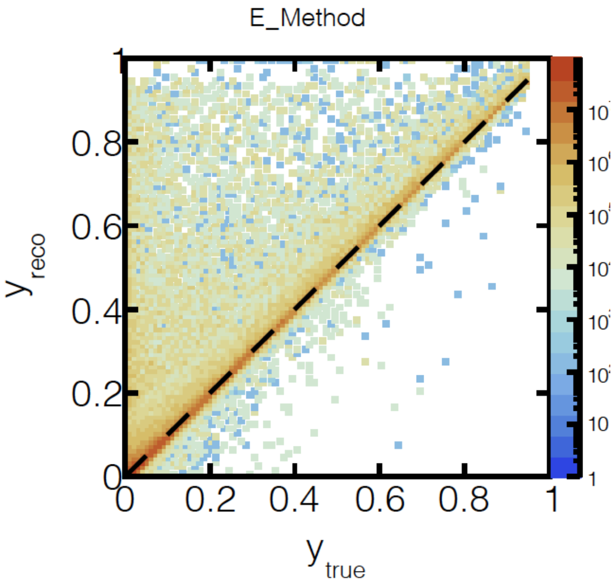
DVCS and DDIS are missing in their analysis notes

DEMP
DA method

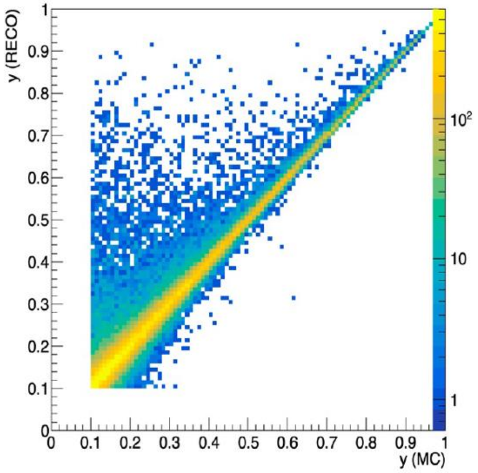


Inelasticity distribution y

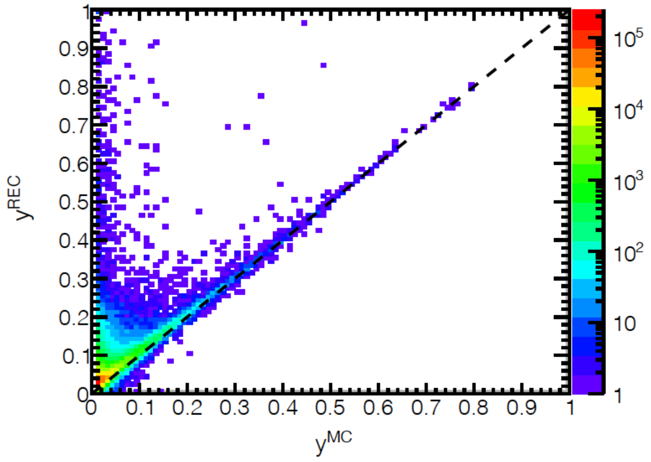
Electron method



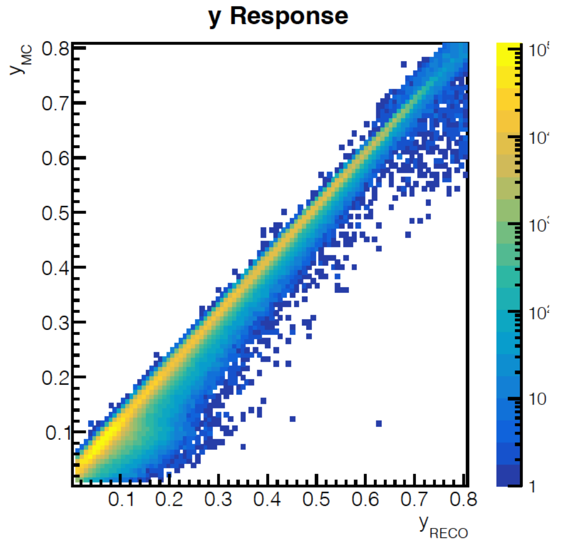
eHe3



DVMP



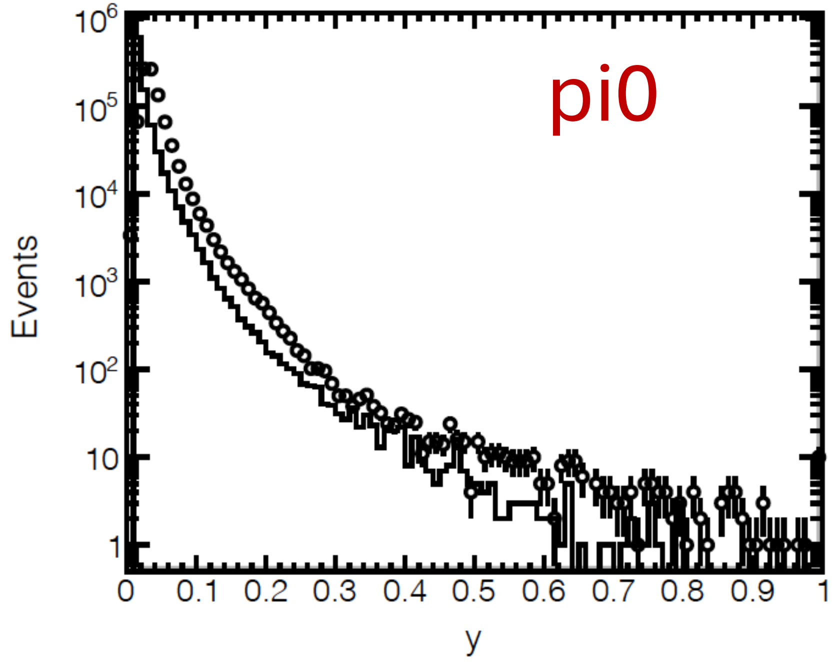
pi0

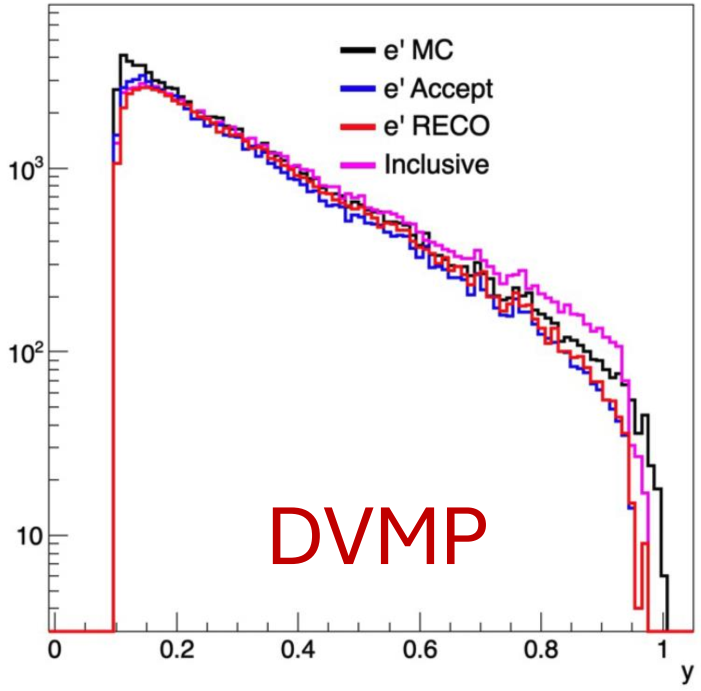


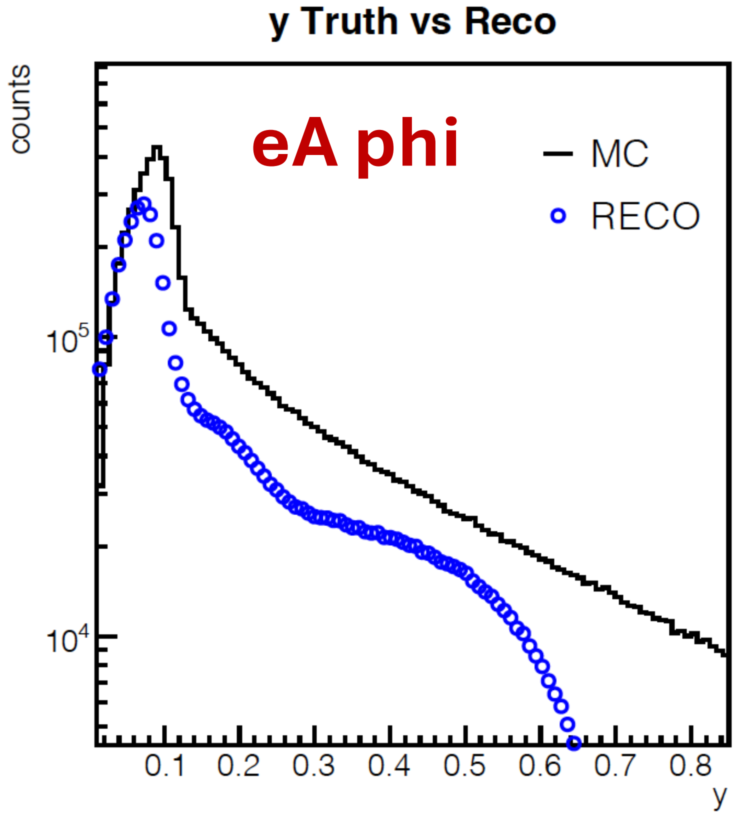
eA phi

DVCS, DEMP, and DDIS are missing in their analysis notes

For example!







Same electron energy, same detector, same selections, differences are needed to be understood.

Physics observable *t* for most of analyses

- Projective method, **eA phi** (new, https://arxiv.org/abs/2502.15596)
- Without proton, **DVMP, DVpi0P** (Method L or eXBE)
- Direct proton detection, **DVCS**, **DVpi0P, DVMP** (BABE)
- Fully reconstructed final-state, **DEMP** (xBABE)

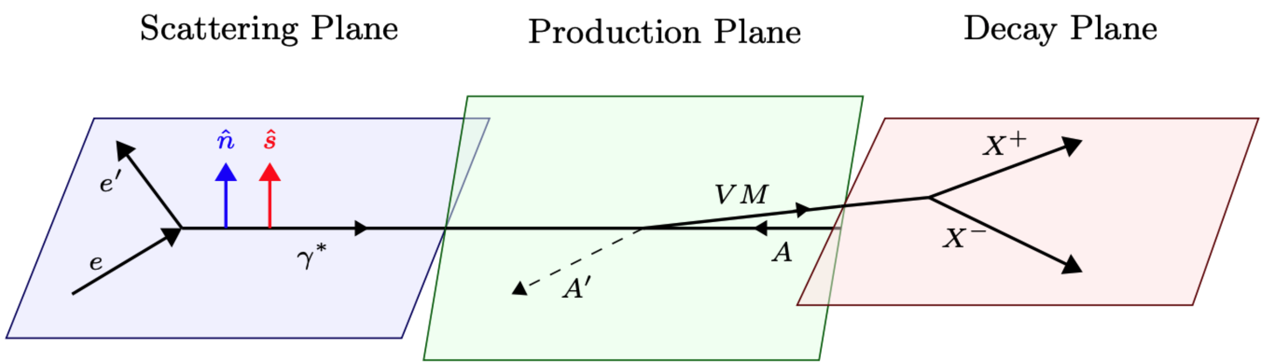
$$t_{\text{method L}} = -\left[\left(P_{p'}^{corr} - P_p\right)^2\right]$$

$$t = (P_p - P_{p'})^2$$

*missing mass cut is in placed for most analysis due to the overly constrained final-state and to suppress backgrounds (later)

Comment: For direct proton detection, xBABE can be tried. For eXBE or method L regions, new projective methods can be tried to improve further the t resolution.

Projective imaging method – no detected ion



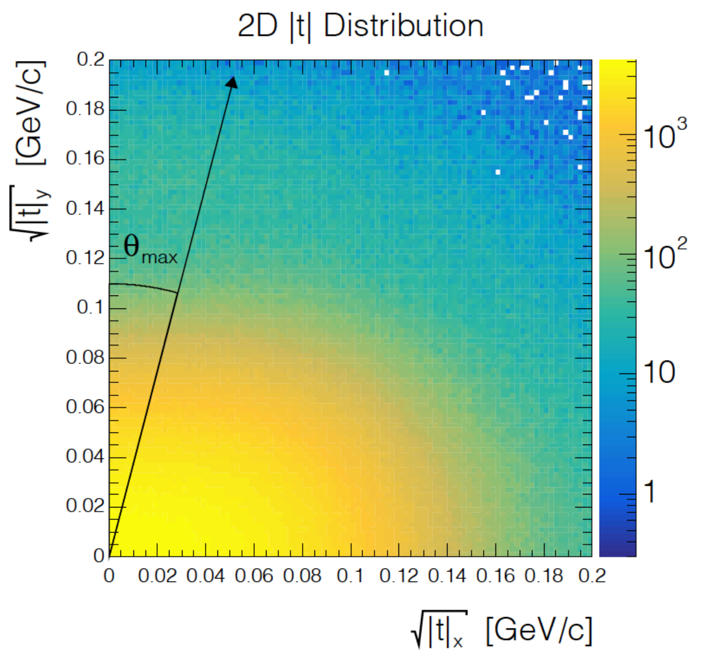
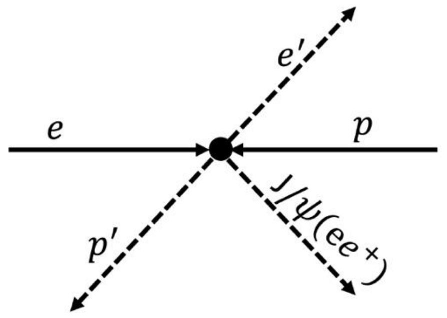
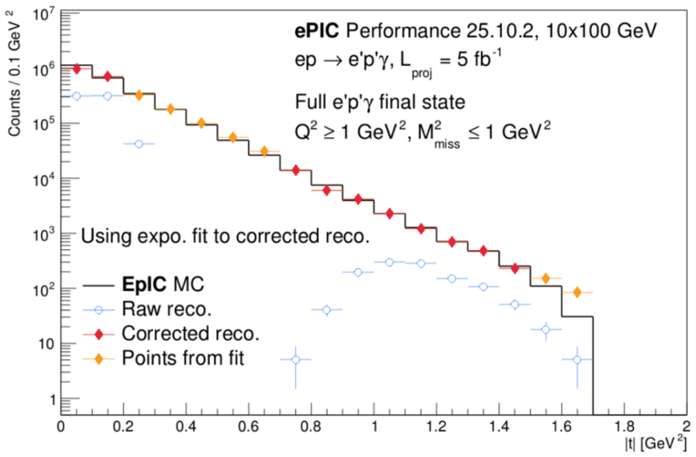


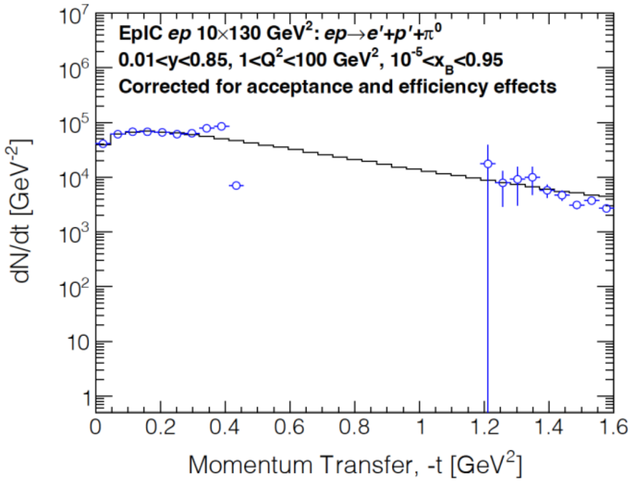
Figure 16: $|t| = q^2$ distribution in 2-dimensions. The wedge cut is shown by the angle θ_{max} to demonstrate the projection technique.

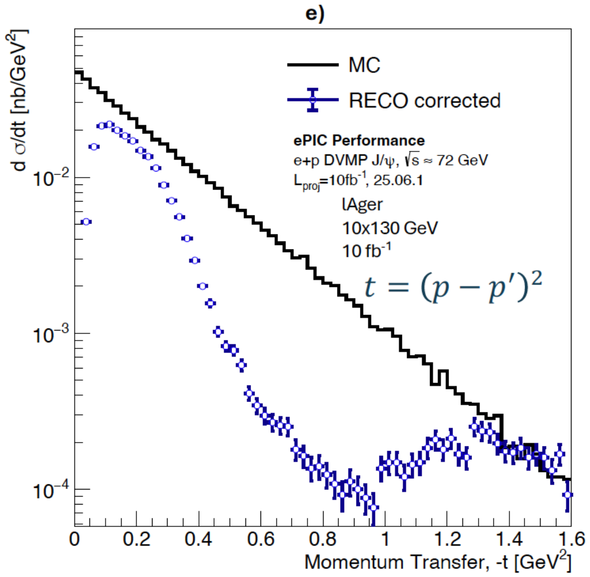
This method is best to solve the issue of poor momentum resolution at very backward region (eta ~ -3.5).
It projects t (momentum transfer) to the direction that is perpendicular to the electron plane

The gap region for 10x130 ep using RP and B0









- We need to fill this gap by using the rest of the final-state with assumption of the missing particle - proton (Method L or eXBE)

- The region that we use RP and B0 needs to have sufficient acceptance, with at least 50% acceptance (this number can be studied in more details)

Tagging protons

Win’s eHe3 analysis note

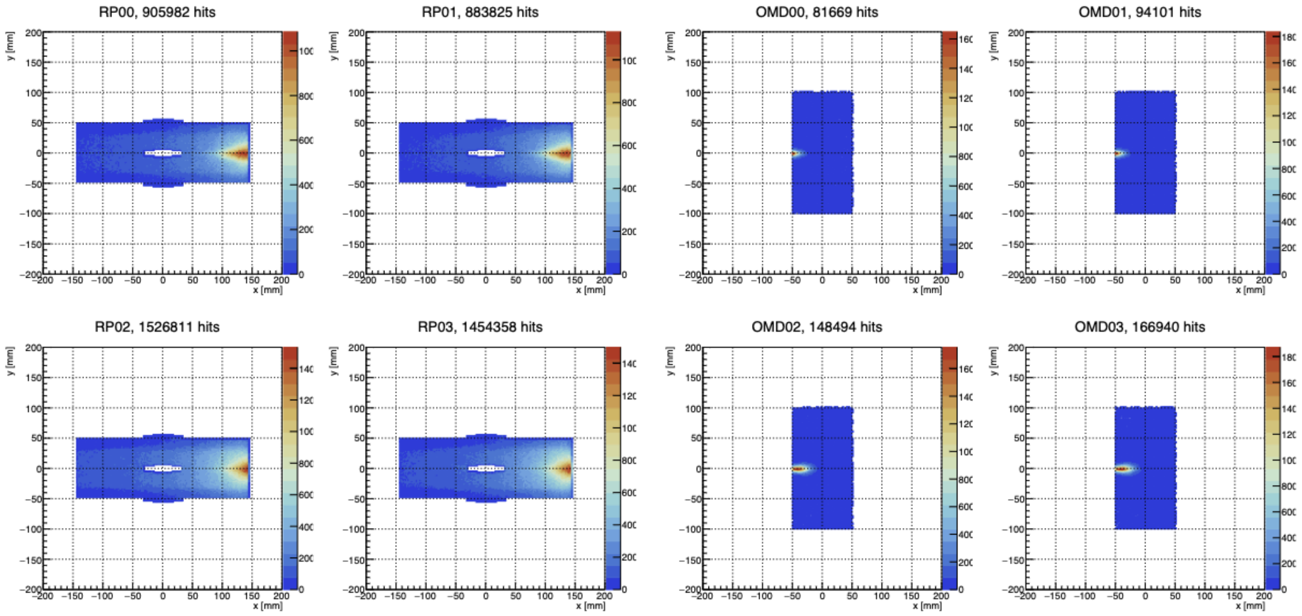


Figure 12: Hits on Roman Pot and Off-Momentum Detector planes for 10 $GeV^2 < Q^2 < 100$ GeV^2 in the detector local coordinates. Smaller detector number in the title is located closer to the central detectors, and larger detector number is farther away.

Comments to all other analyses: AN needs to add QA plots for FF detectors as well. Now they are missing.

Results

Results – proton (DXXX)

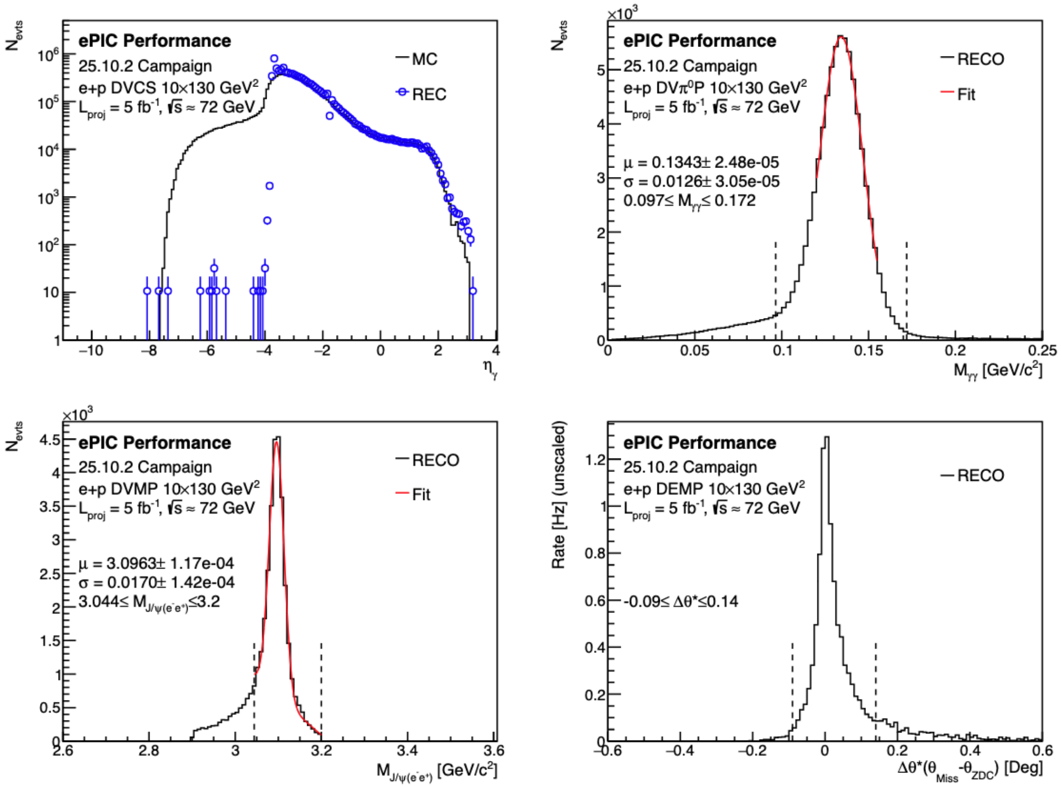
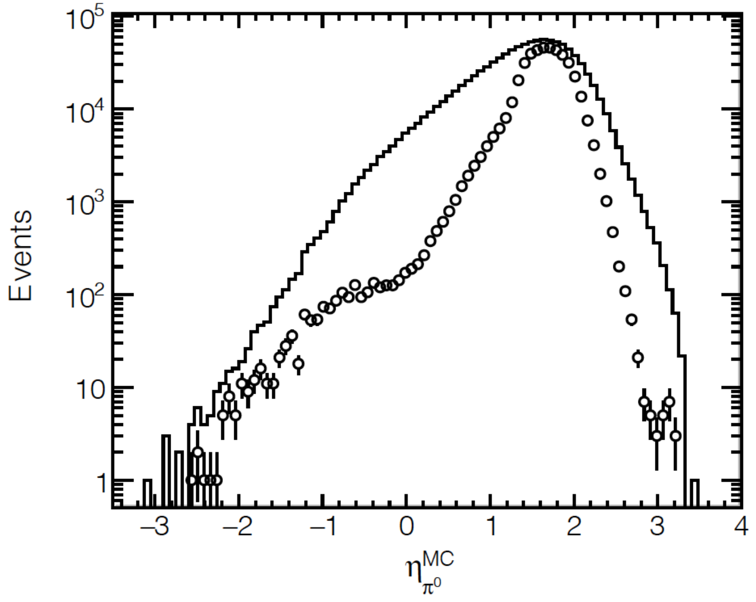
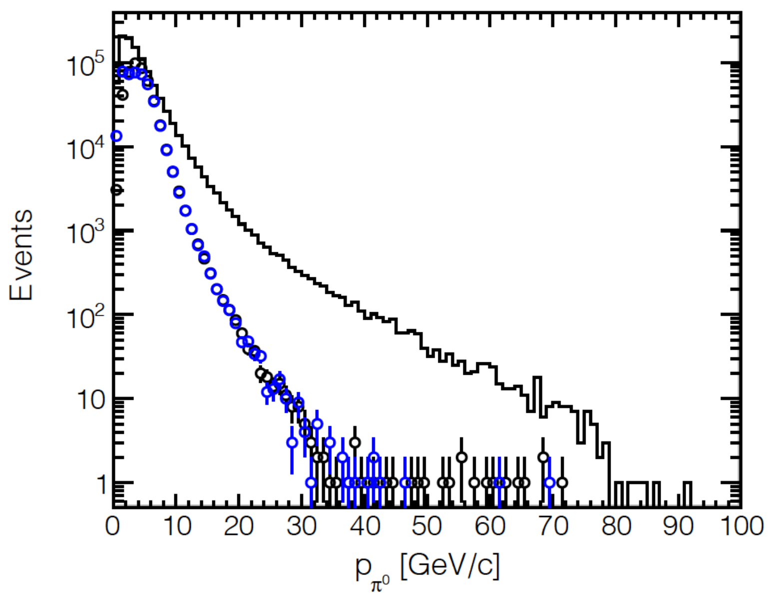


FIG. 4: Reconstructed distributions of key observables for each deep exclusive process: (top left) Pseudo-rapidity distribution of the DVCS photon. (top right) Reconstructed π^0 invariant mass distribution for exclusive π^0 production. (bottom left) Reconstructed J/ψ invariant mass distribution for DVMP. (bottom right) Angular difference between the reconstructed neutron and the missing momentum calculated from the combined scattered electron and pion.

Shows reconstructed photons, pi0s, Jpsi, and pi+neutron.

One issue that stands out is merged clusters for pi0 decay to two photons.





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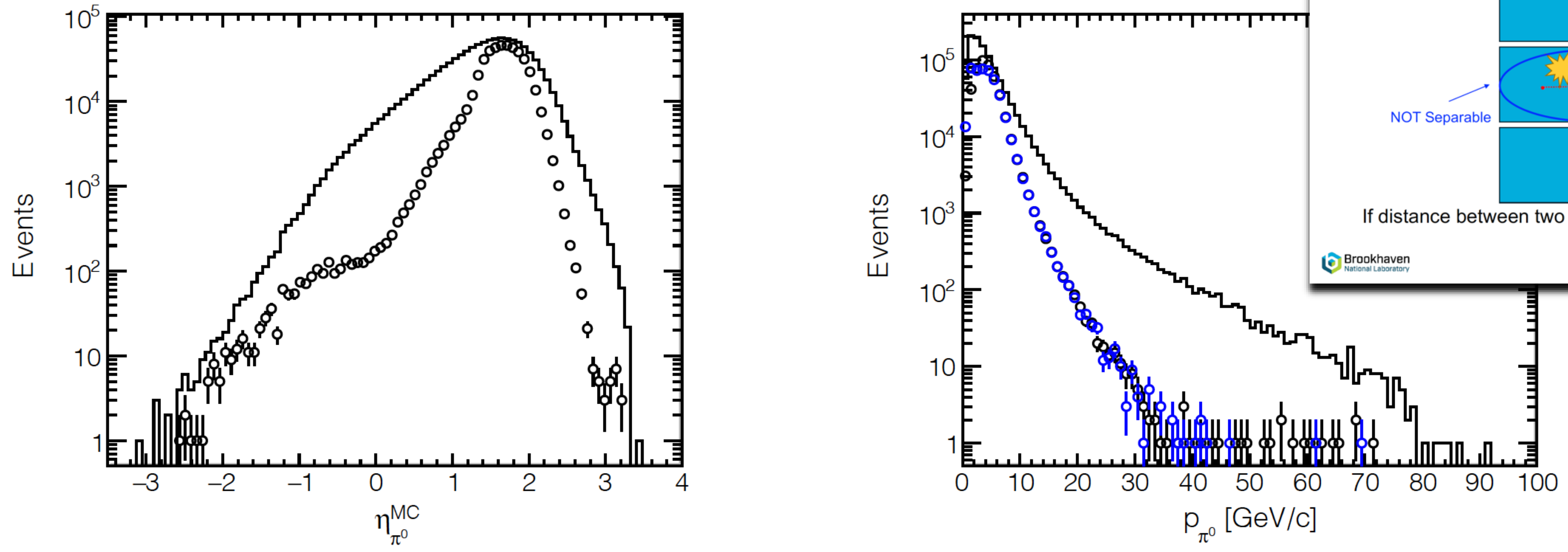
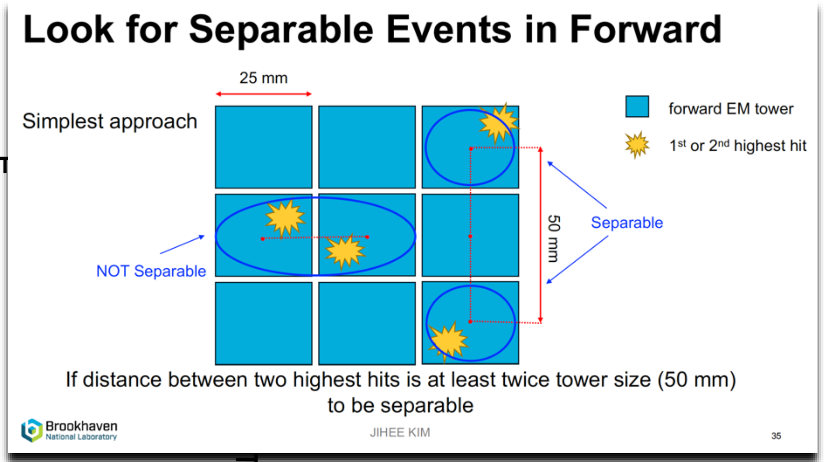


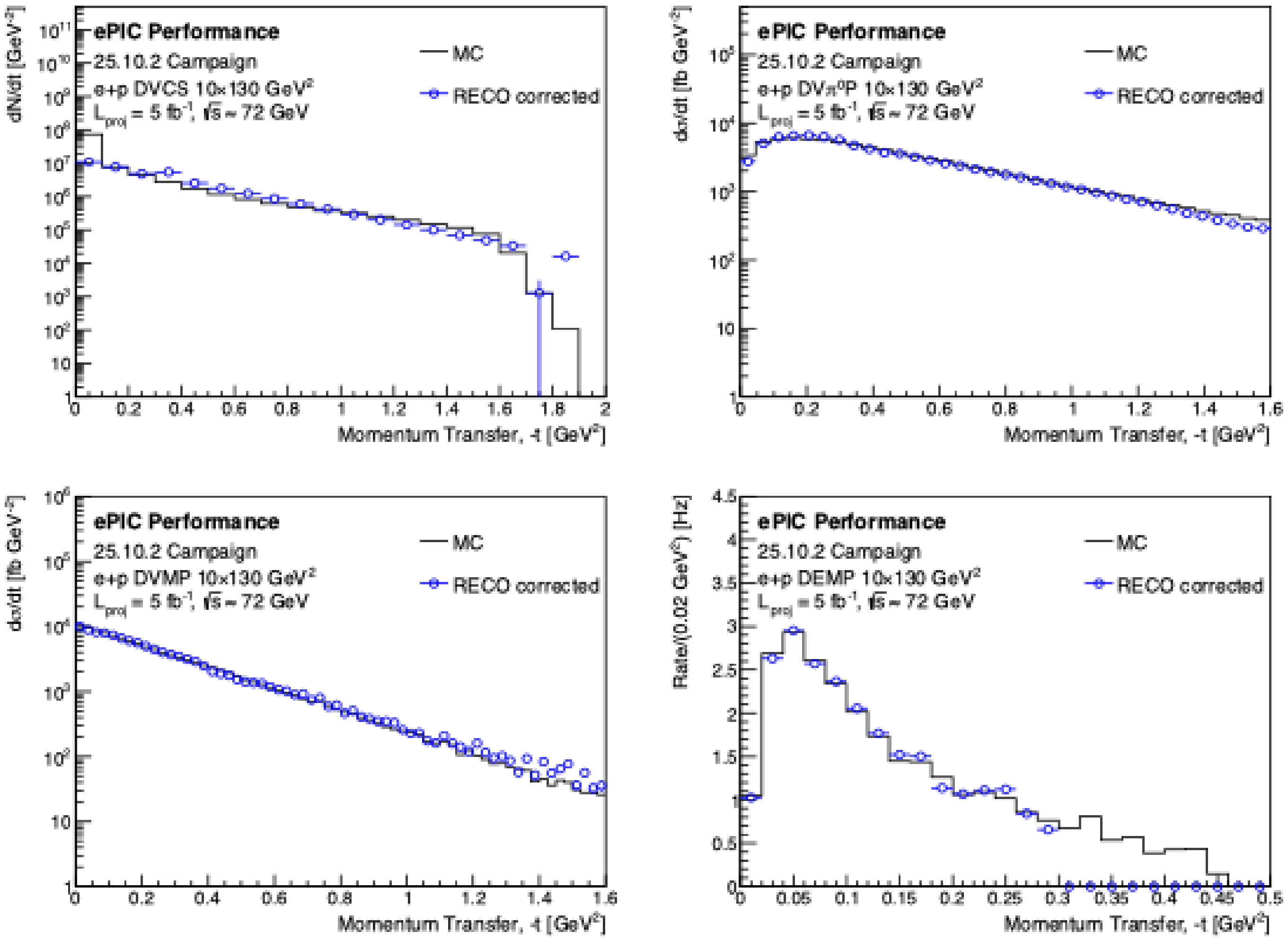


This has been extensively studied by Jihee and there are ways to improve the cluster merging. The efficiency x acceptance improved from **~30% to 70% after splitting the clusters**.

At 5x41 GeV ep, with improved algorithm, this contributes **1.14% to the DVCS** as backgrounds (preTDR).
At 10x130 early science energy, this background is negligible (much smaller.)

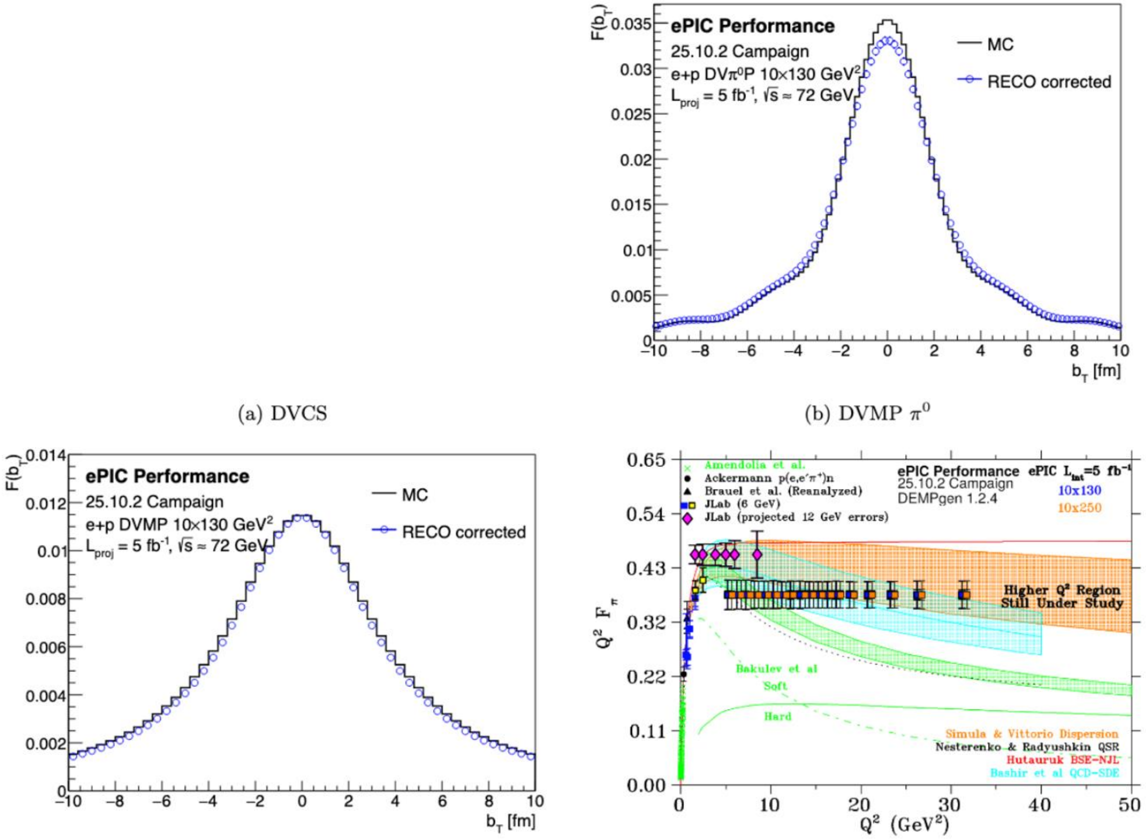
Momentum transfer t distributions

- Only **efficiency and acceptance** corrected.
- Gap region covered by at least one alternative method.
- full t region measured with good resolution (no unfolding and smearing effect exists)



Fourier transformation from momentum to position space

- The remaining difference will and should be taken care of by performing unfolding. That's a natural to-do next after this paper



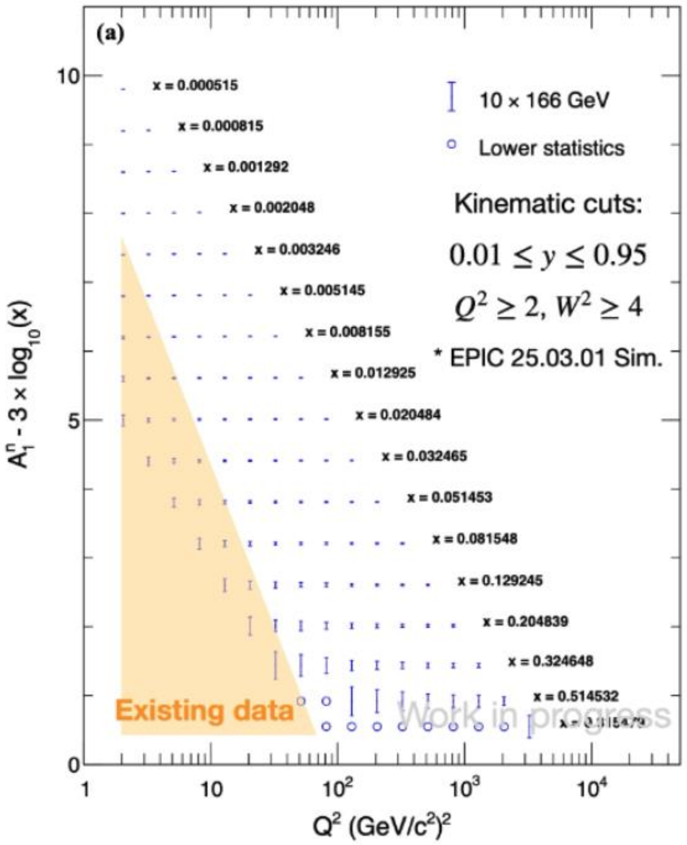
(a) DVCS (b) DVMP π^0

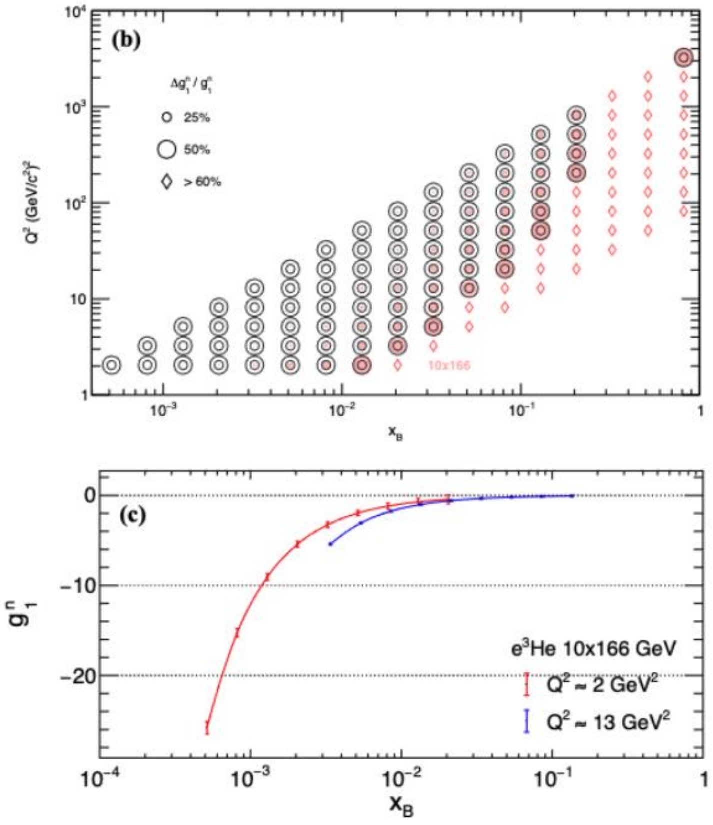
(c) DVMP J/ψ (d) DEMP

Pi0 results will be presented to the PAC Dec 16, 2025; if no objection, the results will be released to the public.

eHe3 double tagging – neutron spin structure function

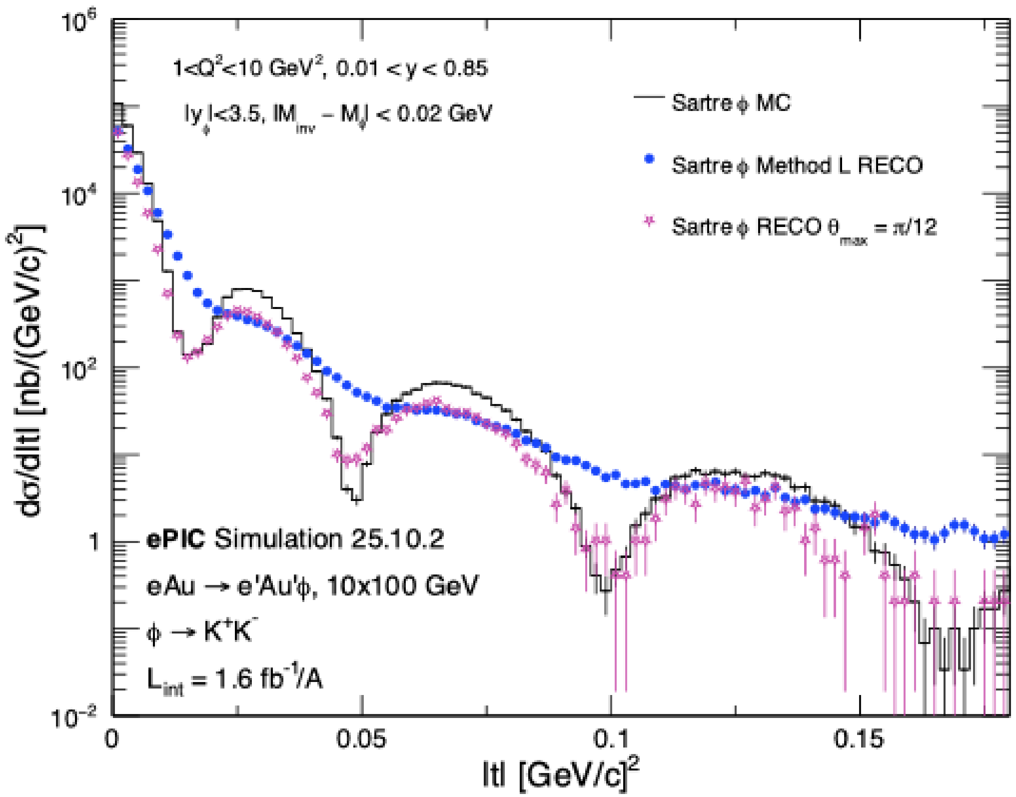
Neutron g1 will be measured the first time in this wide range of kinematics.

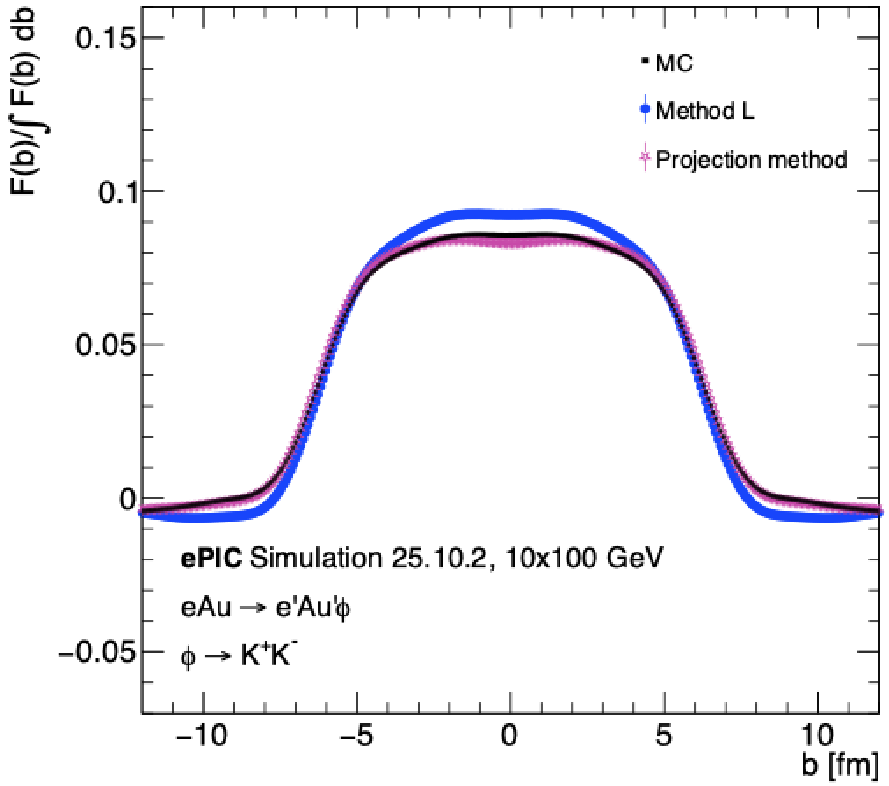




The internal results will be presented to PAC tomorrow Dec 16, 2025. If no objection, the results will be released for public

eA diffractive phi – imaging gluon spatial distributions





Projective imaging method solves this long-standing challenge of resolving diffractive minima in eAu collisions. The internal results will be presented to PAC tomorrow Dec 16, 2025. If no objection, the results will be released for public

Physics Background (e.g., DIS or similar probes)

- The approach is to run all analyses code on inclusive DIS events (PYTHIA). The residue events on the reconstructed level will be quoted as background. after luminosity scaling (to the signal event luminosity).
  - **DVCS** – 3% low Q2, high-t DIS background (much larger at low t with large statistical uncertainty), <1% from pi0 production with merged photons.
  - **DVpi0P**: negligible at low t, up to 100% at high t > 1.2 GeV (limited t range is needed)
  - **DVMP**: up to 40 % (but mass fit should remove most residue)
  - **DEMP**: 0.026% for 10x130 and 0.05% for 10x250 GeV
  - **Diffractive phi**: ~ a few % from incoherent and negligible from DIS.
  - **eHe3**: photoproduction (not in AN yet.)

Comments: details need to be documented in AN

Dominant systematic uncertainty source

	Dominant systematics source	Estimates
DVCS	BH interference?	
DVπ^0P	cluster merging	
DEMP	Scale uncertainty	12%
DVMP	Background estimation and efficiency	
eAu ϕ	Incoherent background and unfolding	
eHe3	Far-forward mistagging rate?	

Comments: we do not need precise determination but a discussion on what you think would be the dominant uncertainty is needed in the AN

Early Science paper for EDT

- The deadline is **~ Dec/Jan 2026 by the collaboration meeting**. We have about a few weeks left.
- Things are needed before we send to the collaboration:
  - A few loose ends on a few analysis, still under investigation.
  - Identify dominant systematic uncertainty source for each analysis.
  - Finish analysis notes with full details on analysis, backgrounds, QA plots.
  - Unify the electron finder selections and have a consistent performance across different analyses
  - Document analyzer’s code in github repository

Paper overleaf

- All available information are implemented; **remaining is pending due to incomplete analysis notes.**
- It's about time to think about the journal – where should we send (for example, PRD, JHEP, or ROPP)

Thank you!
Your feedback is important.

Overleaf EDIT link:
https://www.overleaf.com/8492923158ddynxhgrjvcq#c130b3

The Phase I Exclusive Physics at the Electron-Ion Collider: Opportunities at the ePIC Experiment

ePIC Exclusive Working Group*
(Dated: December 11, 2025)

The first five-year run of the Electron-Ion Collider (EIC), known as Phase I, marks the beginning of a new era in the study of the quantum chromodynamics (QCD). During this initial stage, the EIC will provide high-luminosity collisions of polarized electrons with protons and a variety of nuclear species, enabling a broad and foundational experimental program. This paper presents the strategy for the exclusive physics program with the ePIC experiment during Phase I. Utilizing the collider's high-luminosity polarized beams and state-of-the-art detection systems, ePIC is designed to probe the spatial and momentum distributions of partons inside nucleons and nuclei, explore the onset of gluon saturation, and investigate the spin structure of both free and bound nucleons. We describe initial detector performance, simulation studies, and analysis methodologies developed to tackle central questions in QCD. The Phase I program is expected to deliver critical benchmarks for the EIC's long-term scientific goals, advancing our understanding of hadronic structure and laying the foundation for future discoveries.

CONTENTS

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I. INTRODUCTION

The Electron-Ion Collider (EIC) is a next-generation particle accelerator currently under development at Brookhaven National Laboratory (BNL) in the United States. Designed as a cutting-edge facility for nuclear physics, the EIC will collide high-energy beams of polarized electrons with protons and atomic nuclei. This unique capability will allow scientists to explore the internal structure of matter with unprecedented precision, opening new windows into the fundamental structure of visible matter—particularly its strongly interacting nature, as described by the theory of Quantum Chromodynamics (QCD).

At the heart of the EIC's mission is the goal of imaging the internal structure of nucleons (protons and neutrons) and nuclei in terms of their quark and gluon constituents. Unlike previous accelerators, the EIC will provide high luminosity, a wide range of center-of-mass energies and nuclear species, and full control over the polarization of both the electron and hadron (proton and helium-3) beams. These features will enable precise measurements of parton distribution functions (PDFs), transverse momentum-dependent PDFs (TMDs), and generalized parton distributions (GPDs), offering multidimensional insight into how quarks and gluons generate the mass, spin, and internal dynamics of hadrons. Fundamental questions—such as the origins of mass and spin—are expected to be addressed by the EIC.

The EIC will also shed light on how gluons—the force carriers of the strong interaction—behave inside nuclei, and whether their densities saturate at high energies, as predicted by QCD. Understanding this gluon-dominated regime, sometimes referred to as the Color Glass Condensate, is essential for building a complete picture of nuclear matter under extreme conditions. Beyond its core physics goals, the EIC will serve as a powerful platform for technological innovation, workforce development, and international scientific collaboration, shaping the future of high-energy

Acknowledgments

- We thank the following for their tremendous efforts for the past few months/year:
  - Jihee Kim (BNL)
  - Oliver Jevons (Glasgow)
  - Olaiya Olokunboyo (UNH)
  - Maci Kesler (Kent State)
  - Stephen K (York)
  - Win Lin (SBU)
  - Hadi Hashamiour (INFN)