

Simulation Study of Deeply Virtual π^0 Production with the ePIC detector at the EIC

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On behalf of the ePIC collaboration

Oct 20, 2026

MENU 2026, Stony Brook University

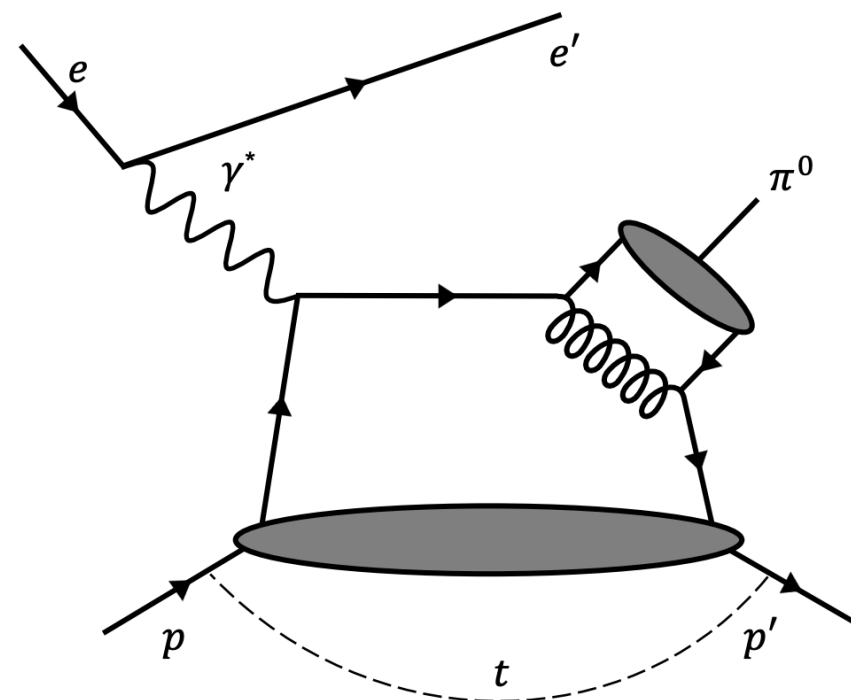
Outline

- Physics motivation
- EIC and ePIC detector
- Simulation samples
- Event reconstruction and selection
- Early science projection results
- Machine background study
- Summary and outlook

Motivation: Probe chiral-odd GPDs

- Generalized Parton Distributions (GPDs)
 - 3D Imaging: relate transverse position of partons to their longitudinal momentum
 - Chiral-even GPDs
 - Quark-helicity conservation
 - Accessible via Deeply Virtual Compton Scattering (DVCS) [Oliver Jevons' talk on Thu 09:25](#)
 - Chiral-odd GPDs
 - Quark-helicity flip (processes are suppressed)
 - Difficult to access (poorly constrained)
 - **Deeply Virtual π^0 Production is sensitive to chiral-odd GPDs**

Deeply Virtual π^0 production
 $e + p \rightarrow e' + p' + \pi^0$

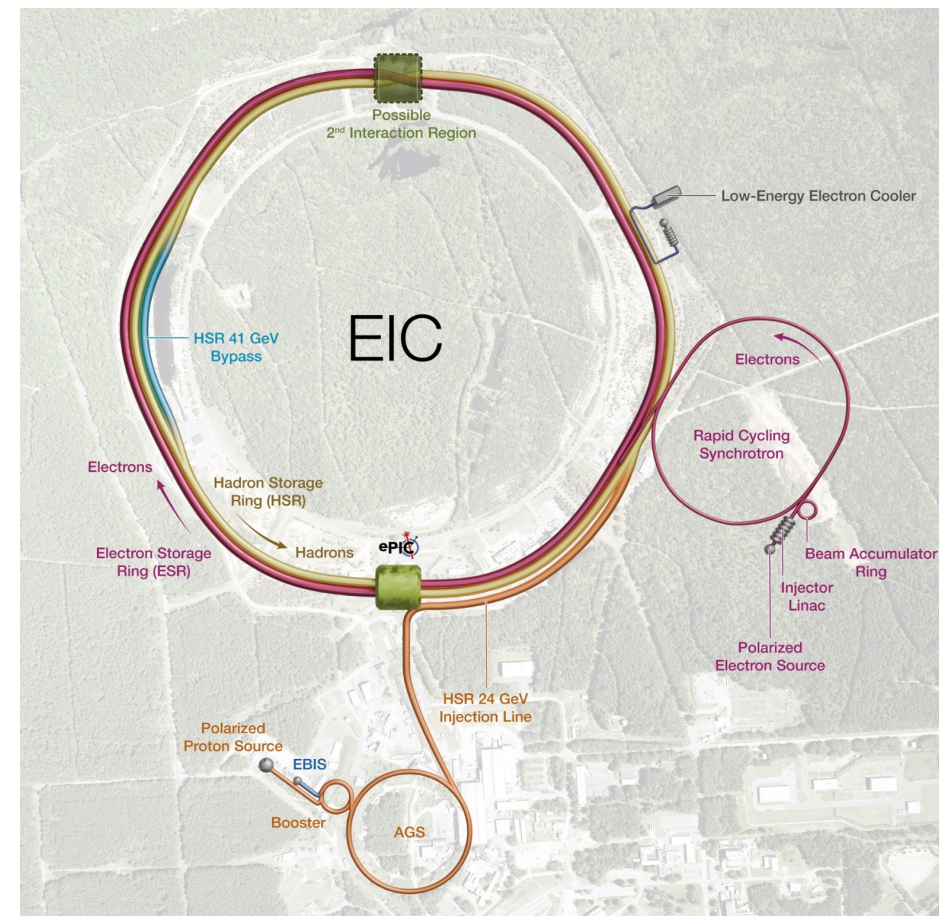


EIC and early science period

- Electron-Ion Collider (EIC)
 - A unique high-energy, high-luminosity collider with polarized beams
- EIC Early Science Period

See Rongrong Ma's talk (Mon) for details

Species	Beam energy (GeV)	Integrated Luminosity	Electron-beam polarization	Hadron-beam polarization
$e + p$	9×130	1.0 fb^{-1}	LONG	T and/or L
$e + p$	9×275	2.5 fb^{-1}	LONG	T and/or L
$e + D$	9×130	1.5 fb^{-1}	LONG	NO
$e + {}^3\text{He}$	9×166	1.5 fb^{-1}	LONG	T and/or L
$e + \text{Ag}$	9×115	1.0 fb^{-1}	NO	N/A
$e + \text{Au}$	9×100	1.0 fb^{-1}	LONG	N/A



ePIC detector

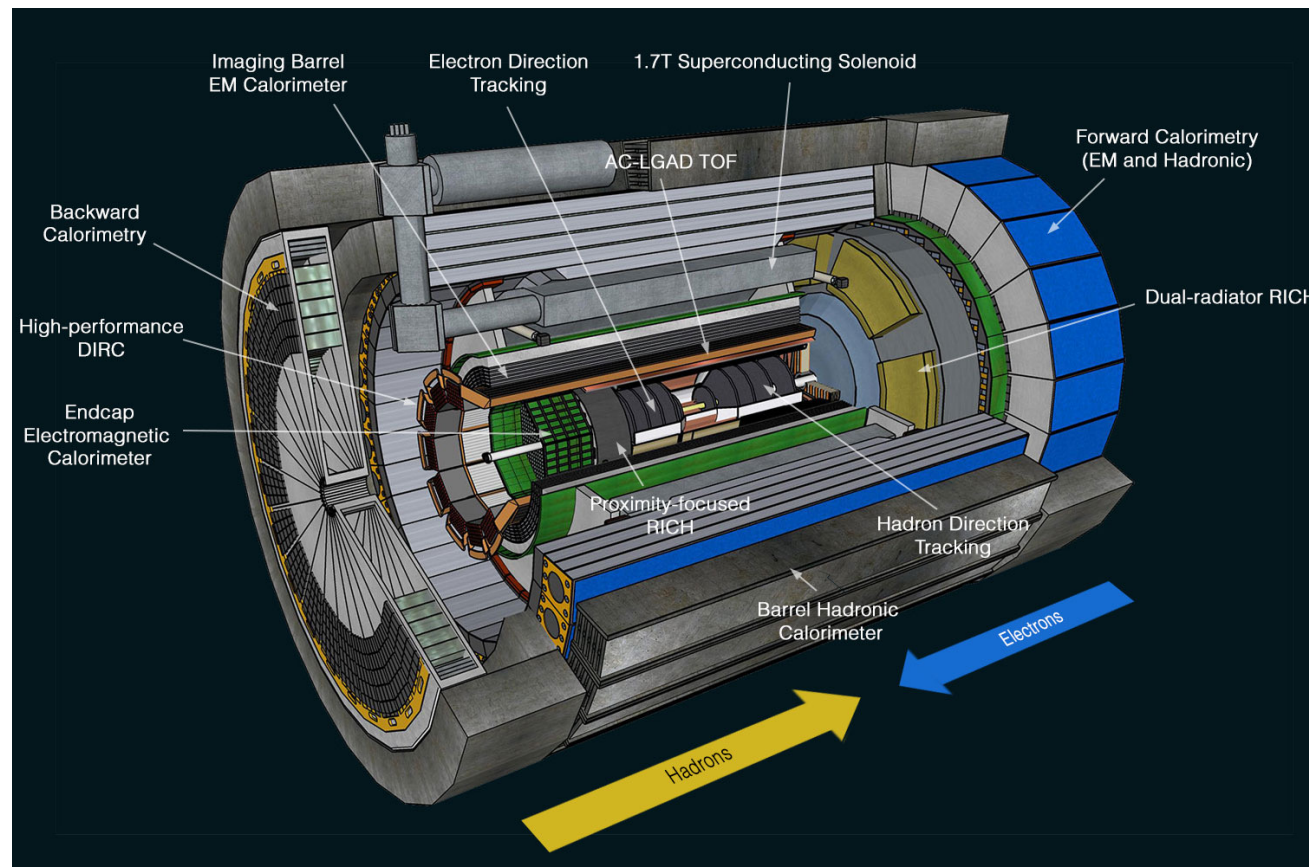
- General-purpose detector at EIC

- Hermetic and high-precision tracking
- Broad calorimetric coverage ($-3.8 < \eta < 3.8$ for central detector)
- Far-forward and far-backward systems

- For $DV\pi^0 P$ process

- $ep \rightarrow e'p'\pi^0 (\rightarrow \gamma\gamma)$
- e' : detected in backward region (tracker + calorimeter)
- γ : detected in mid-rapidity and forward calorimeters
- p' : detected in far-forward detectors

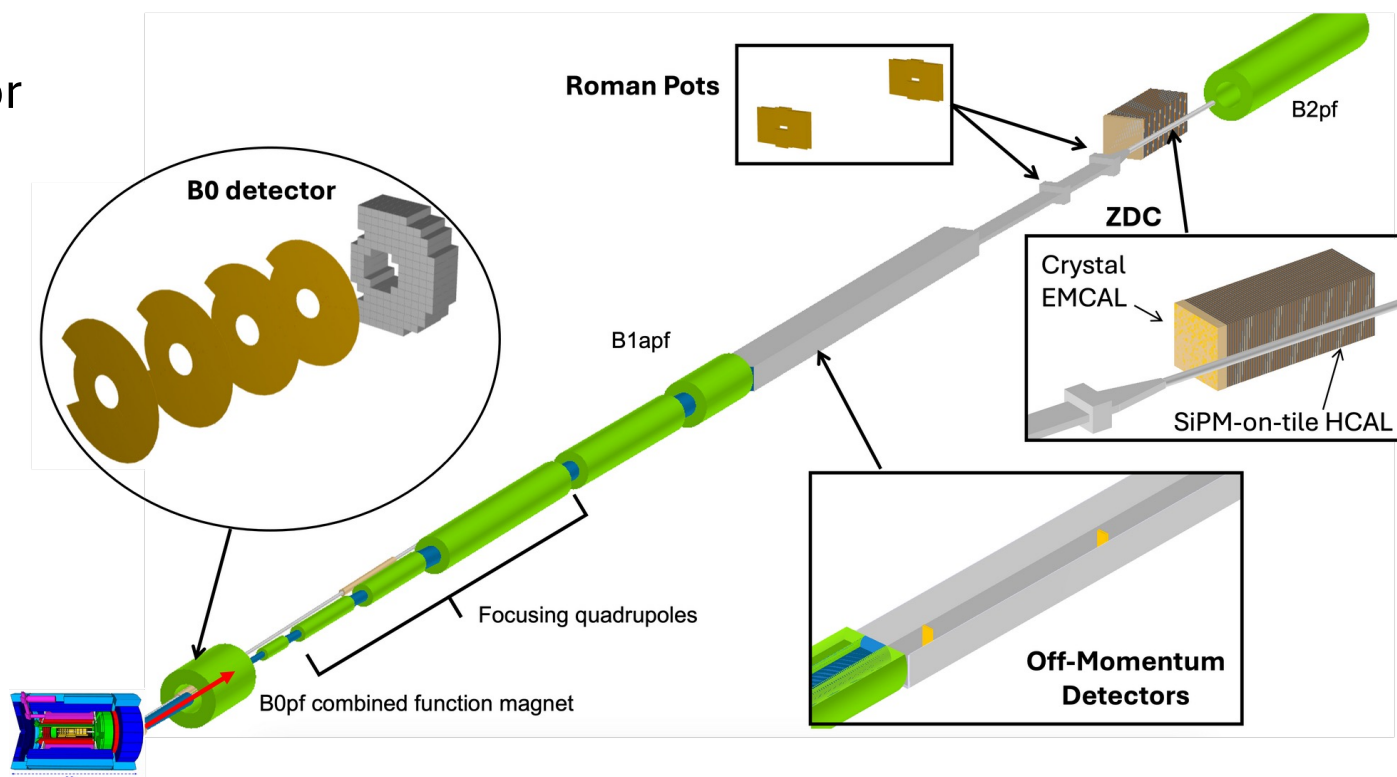
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ePIC central detector

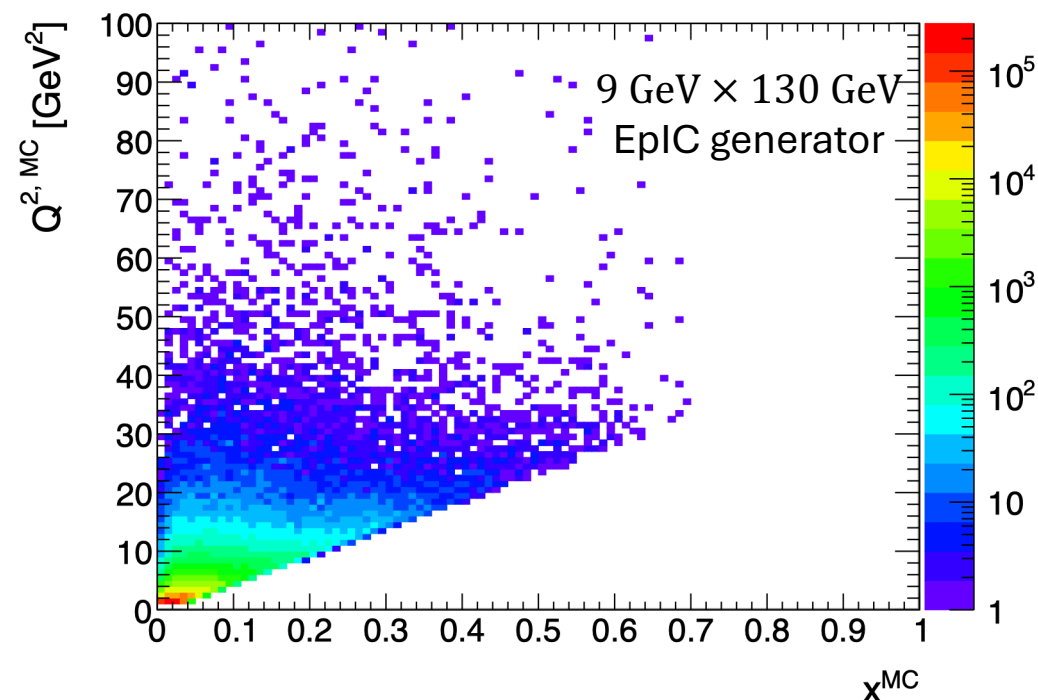
ePIC far-forward detectors

- For $DV\pi^0 P$ process
 - $ep \rightarrow e'p'\pi^0 (\rightarrow \gamma\gamma)$
 - p' : detected in B0 detector or Roman Pots
- B0 detector
 - $5.5 < \theta < 20$ mrad
- Roman Pots
 - $0 < \theta < 5$ mrad



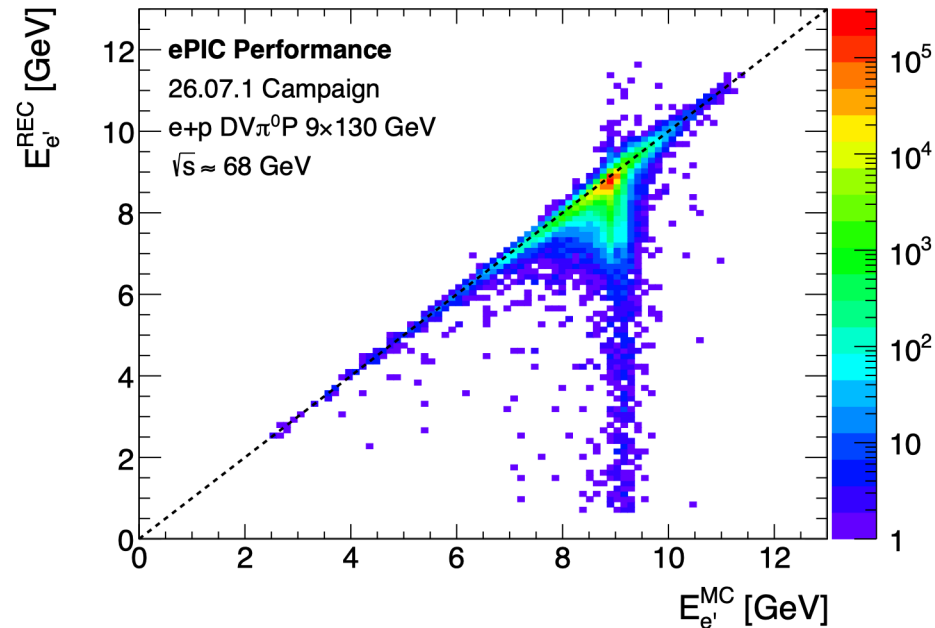
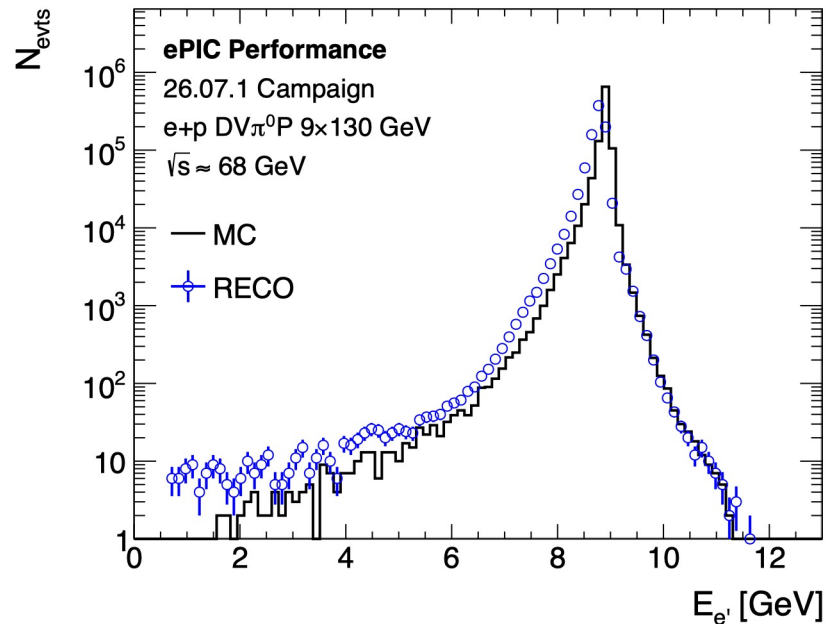
Simulation samples

- $DV\pi^0 P$ in ep collisions
 - $9 \text{ GeV} \times 130 \text{ GeV}$ (1M events projected to 1.0 fb^{-1})
 - $9 \text{ GeV} \times 275 \text{ GeV}$ (1M events projected to 2.5 fb^{-1})
- EpIC Monte Carlo Generator [Eur.Phys.J.C 82 \(2022\) 9, 819](#)
 - $1 < Q^2 < 100 \text{ GeV}^2$
 - $0.002 < x < 0.7$
 - $0.01 < y < 0.85$
 - $0.01 < -t < 1.6 \text{ GeV}^2$
- ePIC Simulation Campaign 26.07.1
 - Full detector simulation
 - Full event reconstruction



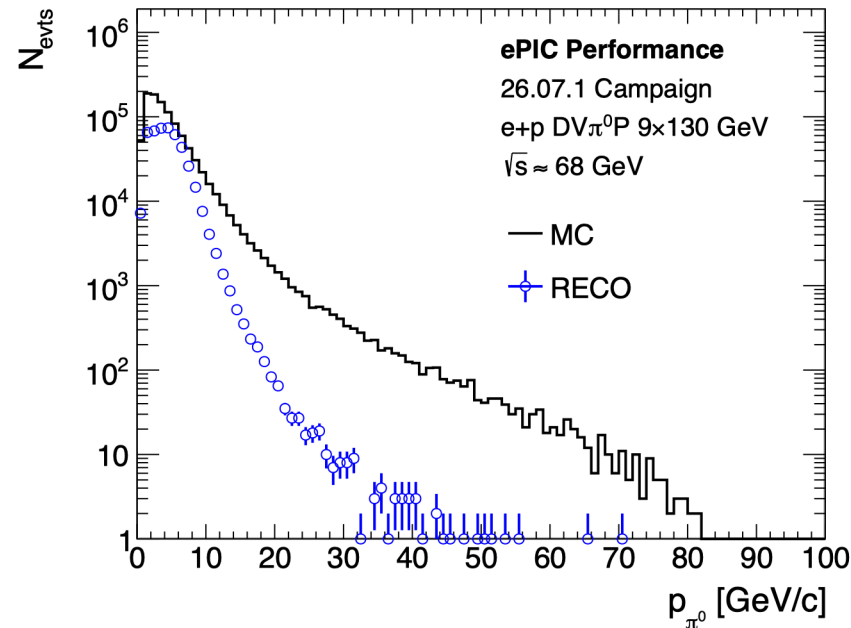
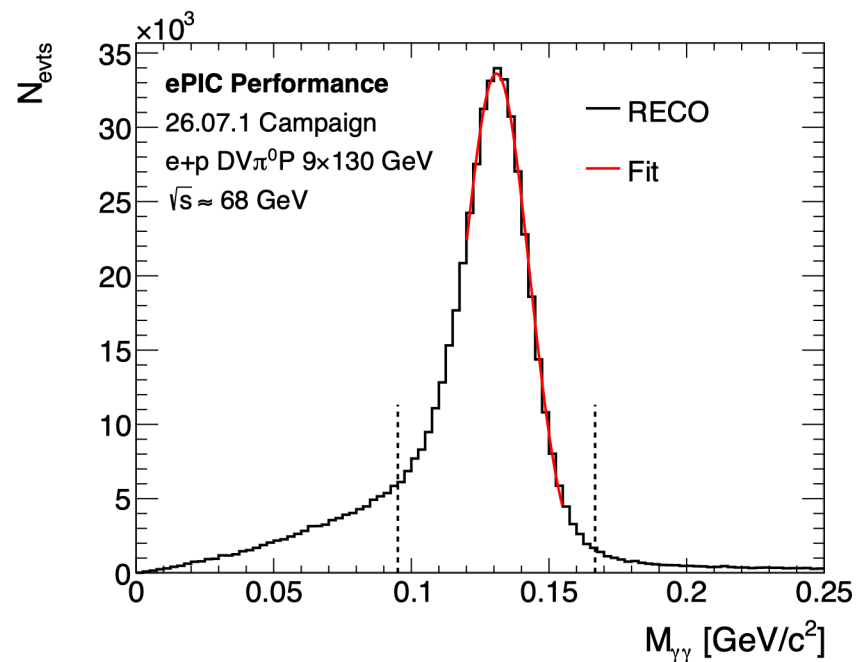
e' reconstruction

- e' selection
 - Negative charged track correctly matched to ECAL cluster
 - $0.8 < E/p < 1.2$, E from calorimeter and p from tracker
- e' acceptance and efficiency
 - 89% for both the 9 GeV $\times$ 130 GeV and 9 GeV $\times$ 275 GeV samples

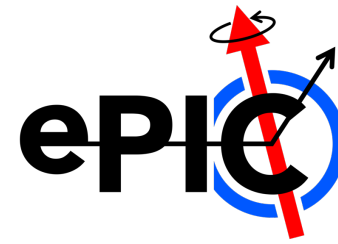


π^0 reconstruction

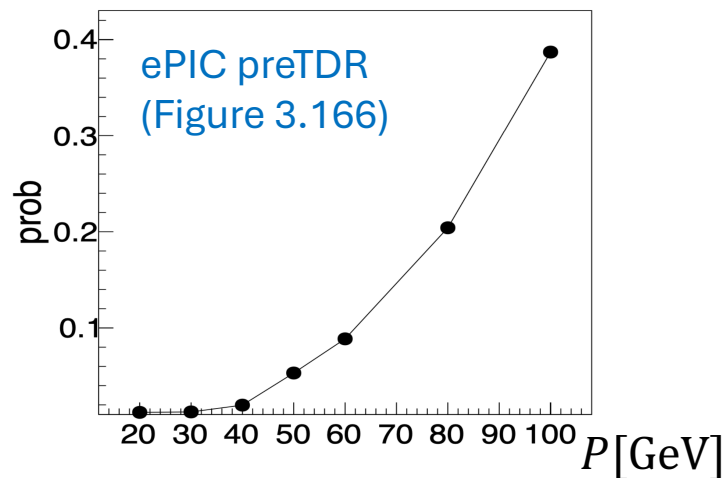
- π^0 selection
 - $m_{\gamma\gamma}$ within $\pm 3\sigma$ of the mean ($0.095 < m_{\gamma\gamma} < 0.167$ GeV)
- π^0 acceptance and efficiency
 - 45% for the 9 GeV $\times$ 130 GeV sample and 46% for the 9 GeV $\times$ 275 GeV sample
 - Efficiency loss at large p_{π^0} mainly due to the $\gamma\gamma$ merging in the calorimeters



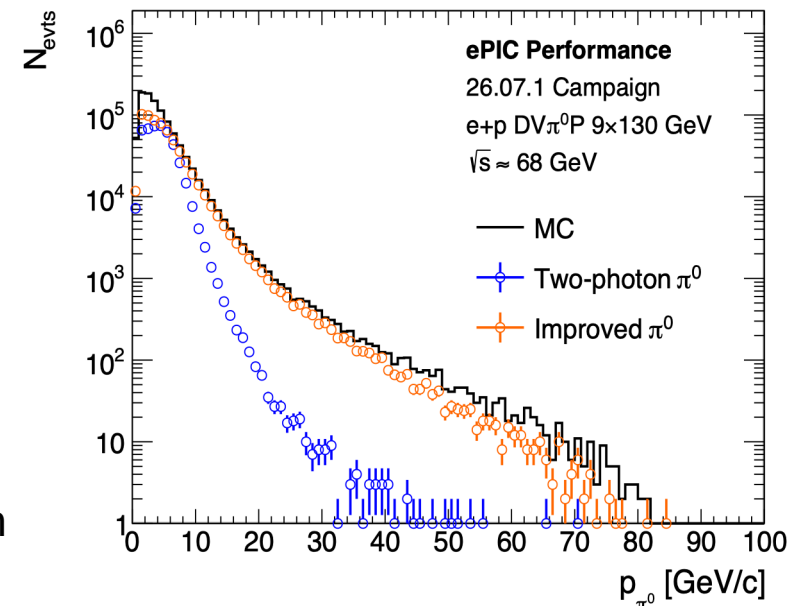
π^0 reconstruction: Potential improvement



- Standalone ML studies show a potential improvement for future reconstruction
 - Neural Network classifies a cluster as a single photon or a merged π^0 di-photon [ePIC preTDR](#)
 - For the forward calorimeter, probability of misidentifying π^0 as a single photon reduced from 80% (shower-shape cuts) to $\sim 10\%$ at 60 GeV
- Merged di-photon cluster can be reconstructed as π^0 using its energy and direction with the π^0 mass assigned
- π^0 efficiency can be potentially increased from 45% to $\sim 65\%$

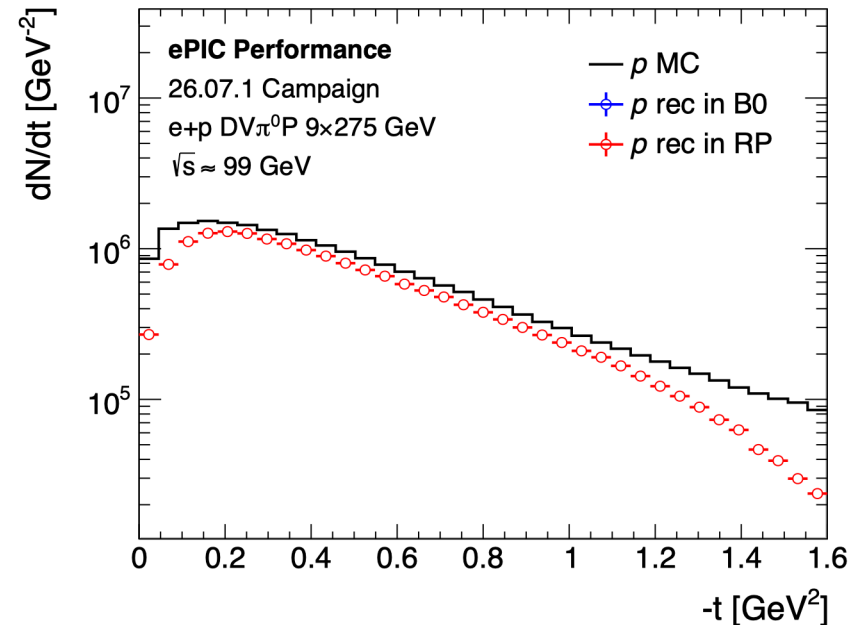
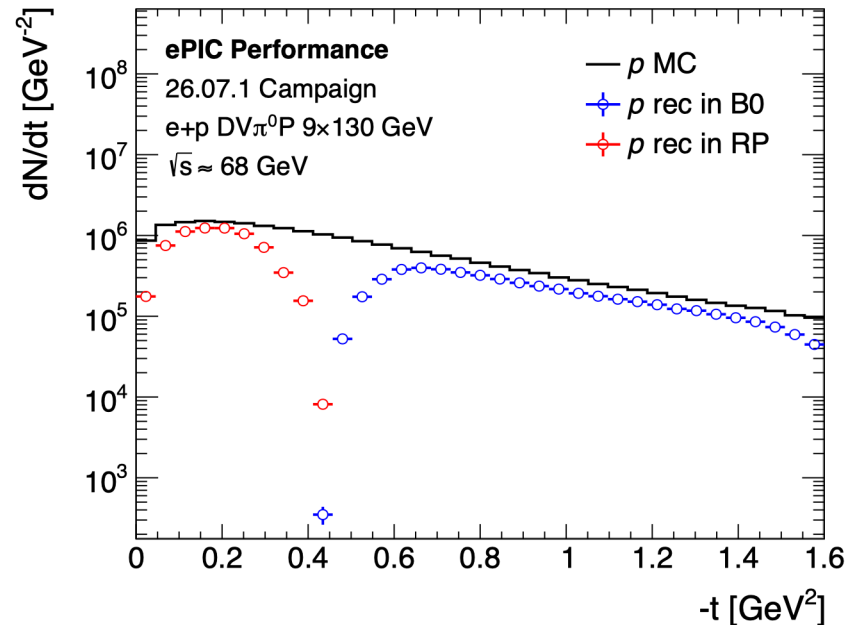


Probability of misidentifying π^0 as a single photon vs. energy (GeV) for the forward calorimeter



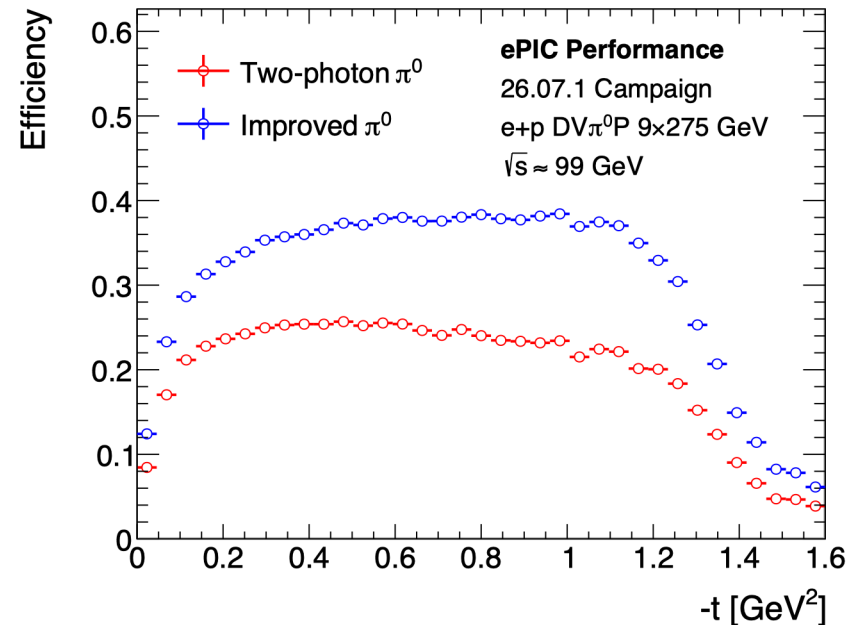
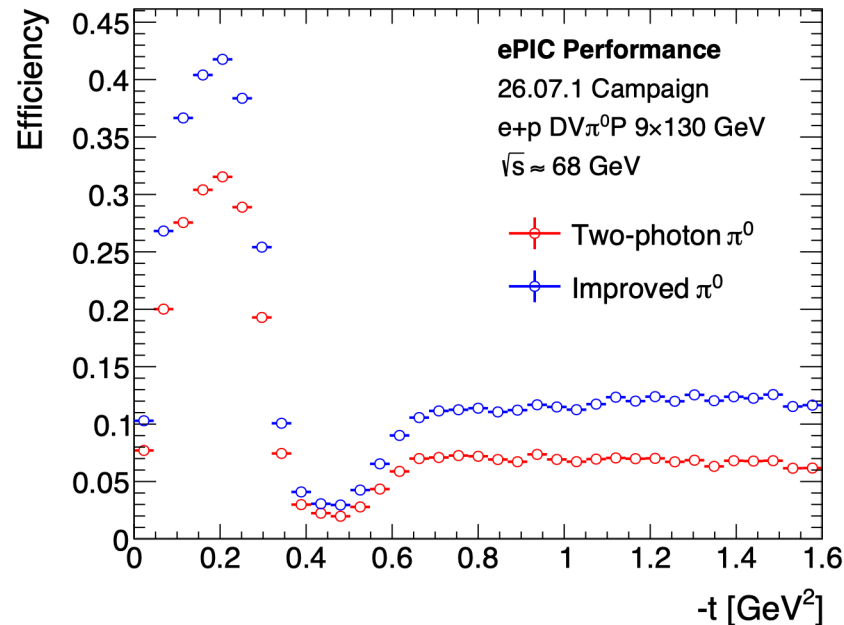
p' reconstruction

- p' selection
 - $5.5 < \theta_{B0} < 20$ mrad for B0 detector or $0 < \theta_{RP} < 5$ mrad for Roman Pots
- p' acceptance and efficiency
 - 54% for 9 GeV $\times$ 130 GeV sample, RP for low $-t$ and B0 for high $-t$
 - Gap at $-t \sim 0.45$ GeV² due to the transition between RP and B0 acceptance
 - 79% for 9 GeV $\times$ 275 GeV sample, RP only



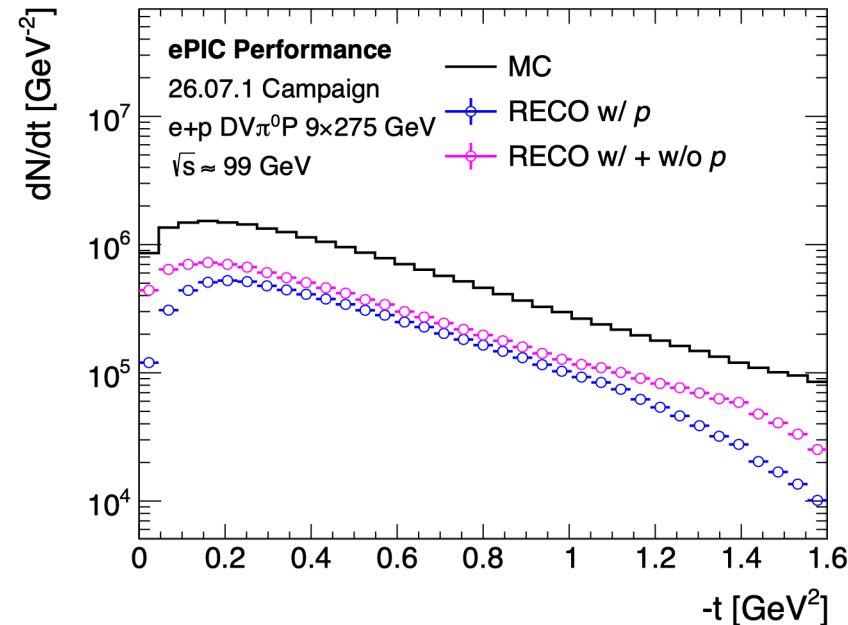
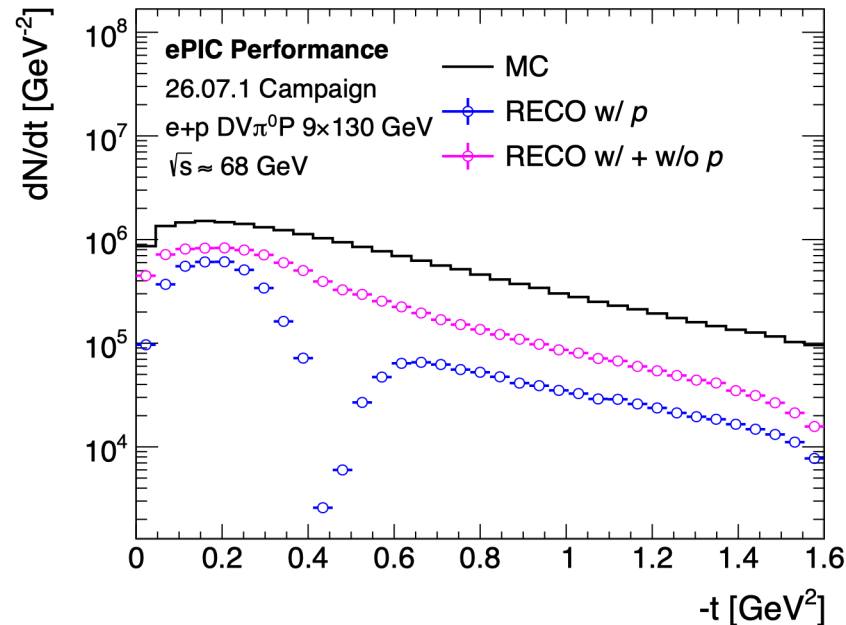
Event selection and efficiency

- Selection on $DV\pi^0P$
 - $13 < E - P_z < 23$ GeV (summed over all final-state particles)
 - $|M_{miss}^2| < 1$ GeV² for $ep \rightarrow e'p'\gamma\gamma X$
- Total efficiency
 - 19% for 9 GeV $\times$ 130 GeV and 33% for 9 GeV $\times$ 275 GeV considering the potential π^0 improvement



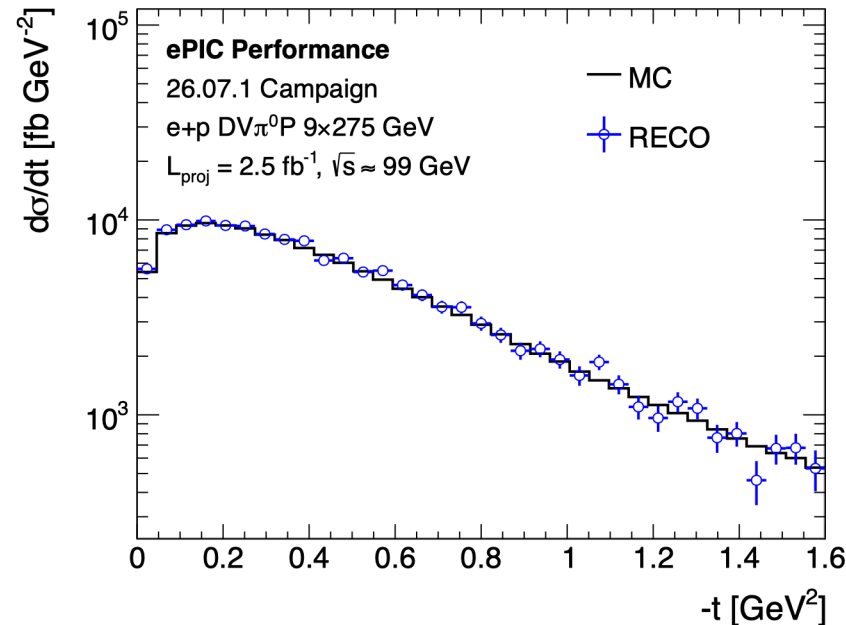
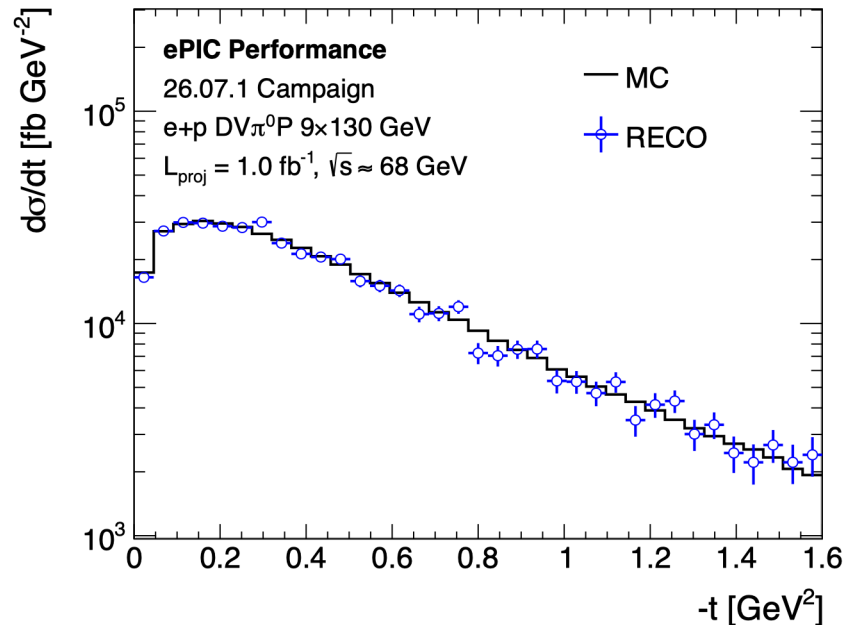
Including events without proton

- Events without a reconstructed proton
 - 42% for 9 GeV $\times$ 130 GeV sample and 20% 9 GeV $\times$ 275 GeV sample
 - $t = (P_p - P'_{\text{corr}})^2$, P'_{corr} is the missing four-momentum $P_p + P_e - P_{e'} - P_{\pi^0}$, corrected to the proton mass
 - However, exclusivity is harder to ensure without proton, limiting the usable events



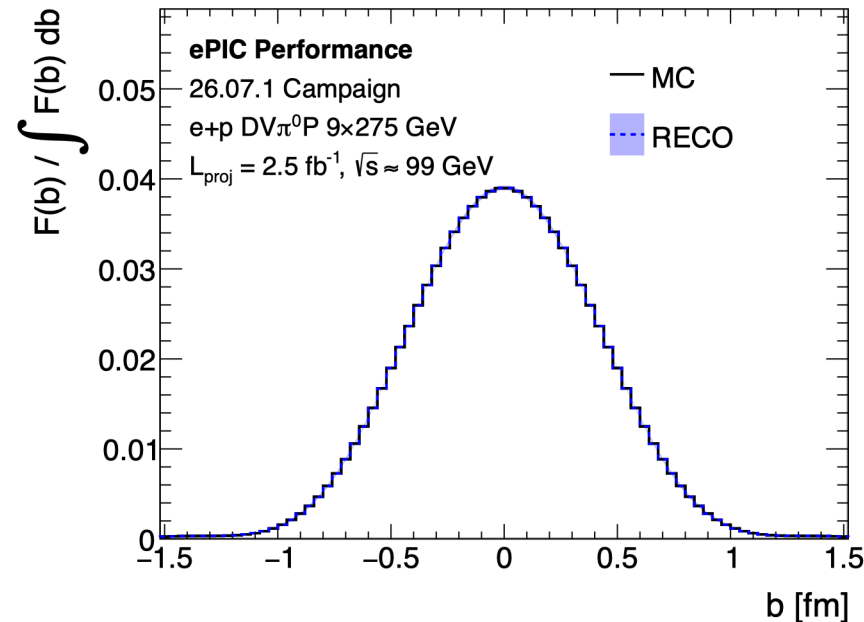
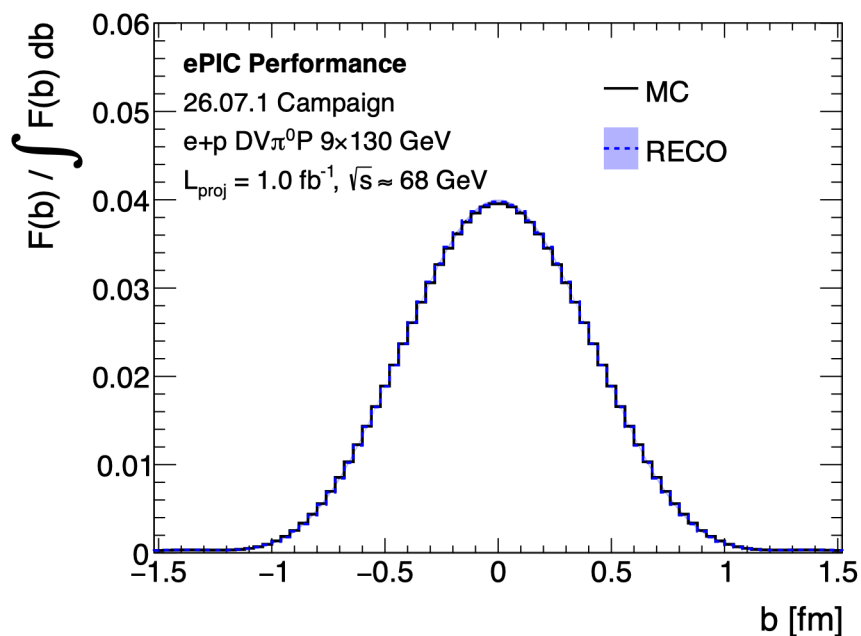
$d\sigma/dt$ distribution

- $d\sigma/dt$ projected to 1.0 fb^{-1} for $9 \text{ GeV} \times 130 \text{ GeV}$ and 2.5 fb^{-1} for $9 \text{ GeV} \times 275 \text{ GeV}$
 - Error bars: statistical uncertainty only
 - Events with and without proton combined
 - Poisson fluctuations applied to the expected yields
 - Acceptance and efficiency corrected



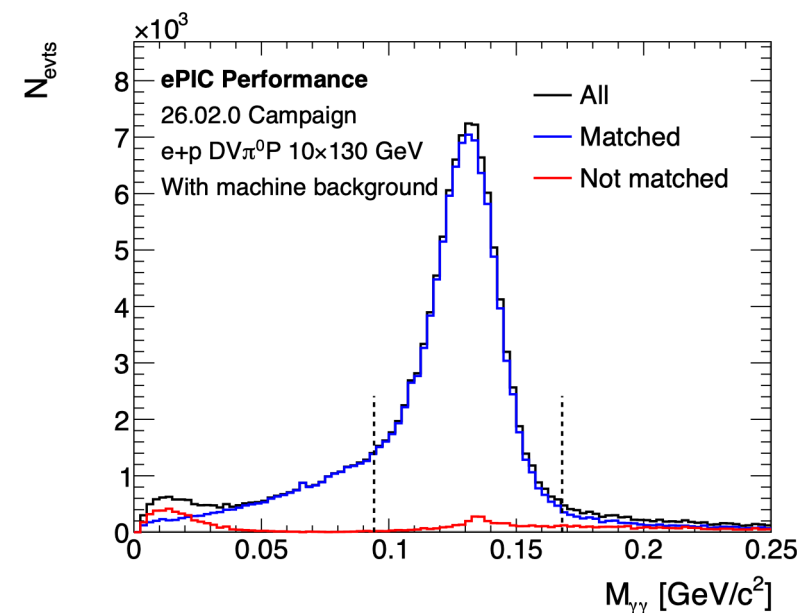
Transverse profile from the t -slope

- $F(b)$ distribution as a function of impact parameter b
 - 2D Fourier transform of an exponential fit to $d\sigma/dt$
 - Error band: $\pm 1\sigma$ from pseudo-experiments
 - Reflects the transverse spatial profile within the nucleon
 - Provides a crucial input for constraining the underlying GPDs



Machine background study

- Machine background adds extra hits and clusters that can fake signal photons
- Studied with 10 GeV $\times$ 130 GeV simulation samples with background from the ePIC 26.02.0 Campaign
 - Background: synchrotron radiation dominant
- π^0 candidate: $\gamma\gamma$ pair with $m_{\gamma\gamma}$ closest to the m_{π^0}
- Purity: fraction of π^0 candidates in which both photons are truth-matched
- With machine background mixed in, the π^0 purity is 81.4%, rising to **96.8%** after the mass-window cut
 - A small peak at the π^0 mass in the unmatched distribution
 - A tiny fraction of photons from real π^0 are not truth-matched
 - The purity might be slightly higher



	Only Signal	Sig + Bkg
Both γ truth-matched	99.8%	81.4%
Both γ truth-matched within the π^0 mass window	100.0%	96.8%

Summary and outlook

- $DV\pi^0 P$ with ePIC provides new insight into the nucleon structure
 - Sensitive to chiral-odd GPDs (complementary to DVCS)
- Simulation study of $DV\pi^0 P$ in ep collisions
 - $d\sigma/dt$ projected to 1.0 fb^{-1} for $9 \text{ GeV} \times 130 \text{ GeV}$ and 2.5 fb^{-1} for $9 \text{ GeV} \times 275 \text{ GeV}$
 - Fourier transform performed to access the transverse spatial profile
- Machine background study
 - The π^0 mass-window cut ensures high purity (96.8%) for the π^0 candidates
- This simulation study provides quantitative benchmarks for future GPD studies at the EIC
- In the future, the analysis could be extended to GTMD studies to access quark orbital angular momentum, as in [PRL 133, 051901 \(2024\)](#)

Thank you!

Backup Slides

Machine background study

- Studied using simulation samples of $10 \text{ GeV} \times 130 \text{ GeV}$ ep collisions from the ePIC 26.02.0 Campaign
 - Signal-only sample
 - Background-mixed sample
 - One signal embedded per background event
 - Background contributions
 - Synchrotron radiation (dominant)
 - Electron bremsstrahlung
 - Electron Touschek scattering
 - Electron Coulomb scattering
 - Proton beam-gas interaction