DVπ^0P Update: Exclusive π^0 Production in ep

Jihee Kim (jkim11@bnl.gov)

Brookhaven National Laboratory

01/23/2026

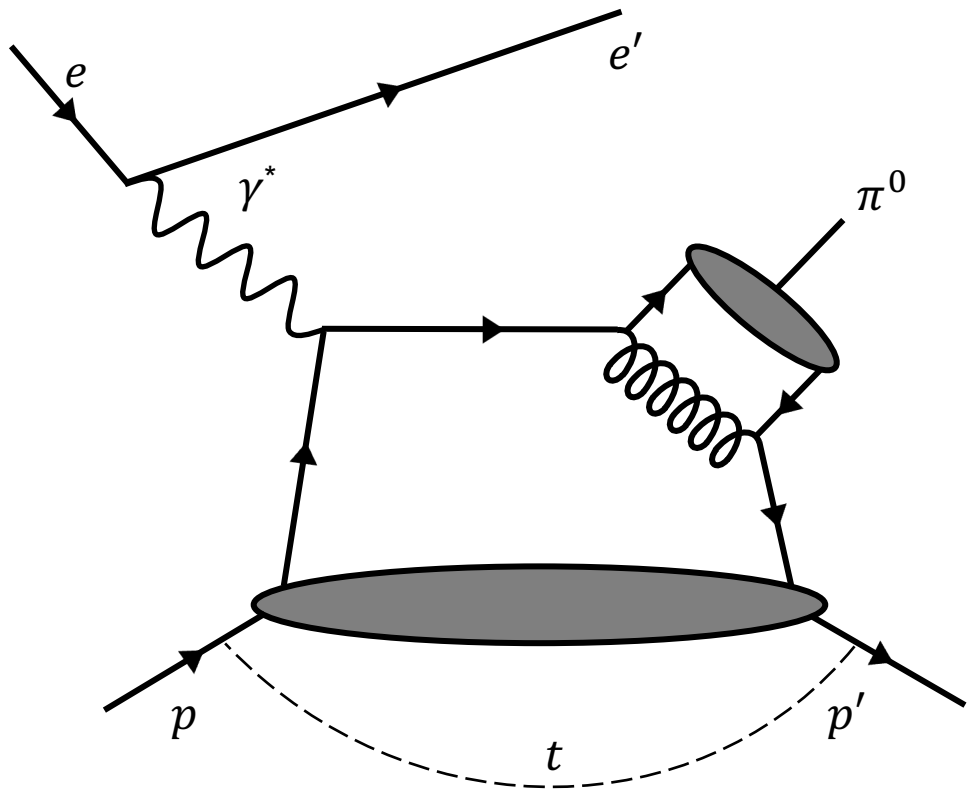
@BrookhavenLab

January 2026 ePIC Collaboration Meeting – Exclusive, Diffraction, and Tagging PWG Workfest

Physics Motivation

Exclusive π^0 production

$$e + p \rightarrow e' + p' + \pi^0$$



- **3D Imaging**: GPDs (polarized and transversity)
- **Spin**: Quark orbital angular momentum

Explored in fixed-target experiments, and extendable to collider mode at EIC

- High proton polarization
- Broad kinematic coverage (low-x and high-Q^2)

Requires careful consideration,

- Potential background to DVCS

Physics Goals

Generalized Parton Distributions (GPDs)

Extract t-distribution to access spatial distribution of quarks

Quark Orbital Angular Momentum (OAM)

Perform a feasibility study of longitudinal single-target spin asymmetry
(Theory predicts strong sensitivity to quark OAM[1] + no experimental measurement exists to date)

[1]Phys. Rev. Lett. 133, 051901 (2024), arXiv:2312.01309

Background

Estimate rate of single-photon misidentification[2] that can mimic DVCS signal
Evaluate inclusive DIS and machine backgrounds that can mimic DVπ^0P signal

[2]Phys. Rev. D 112, 036010 (2025), arXiv:2503.05908

Physics Goals

Generalized Parton Distributions (GPDs)

Extract t-distribution to access spatial distribution of quarks

Quark Orbital Angular Momentum (OAM)

Perform a feasibility study of longitudinal single-target spin asymmetry
(Theory predicts strong sensitivity to quark OAM[1] + no experimental measurement exists to date)

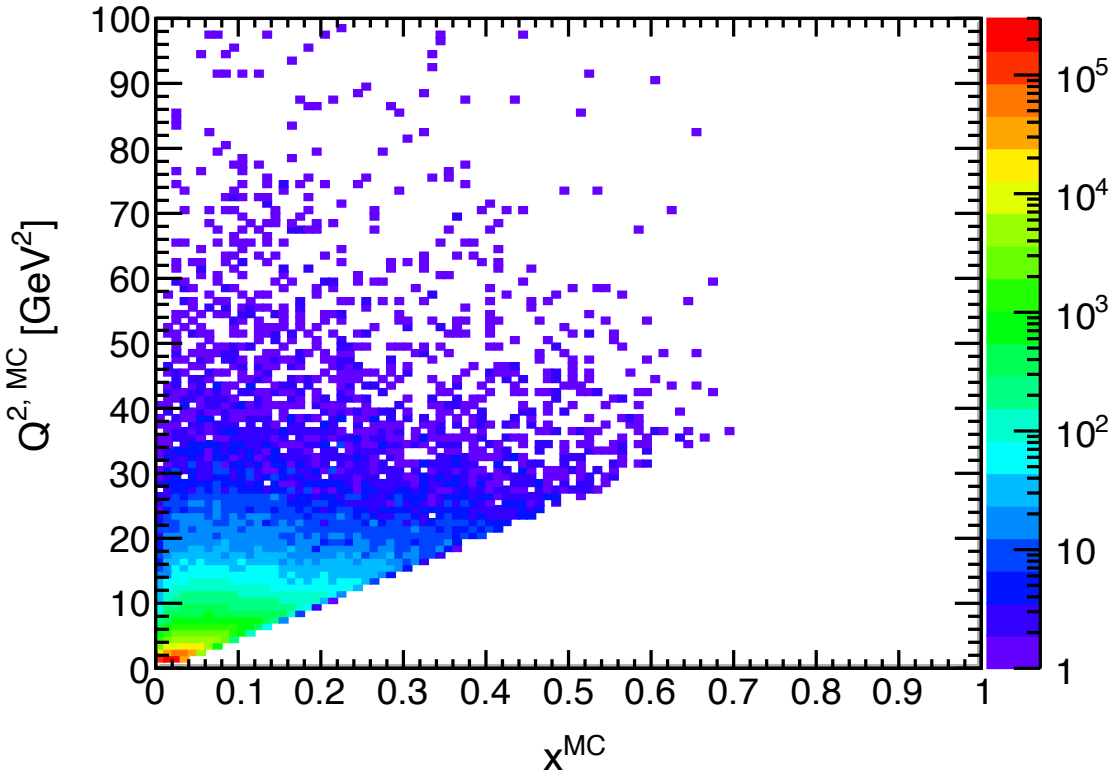
[1]Phys. Rev. Lett. 133, 051901 (2024), arXiv:2312.01309

Background

Estimate rate of single-photon misidentification[2] that can mimic DVCS signal
Evaluate inclusive DIS and machine backgrounds that can mimic DVπ^0P signal

[2]Phys. Rev. D 112, 036010 (2025), arXiv:2503.05908

Simulation Sample



EpIC Monte Carlo Generator

Event generation ranges:

$1 < Q^2 < 1000$

$10^{-5} < x_B < 0.95$

$0.01 < |t| < 1.6$

$0.01 < y < 0.85$

All results are based on

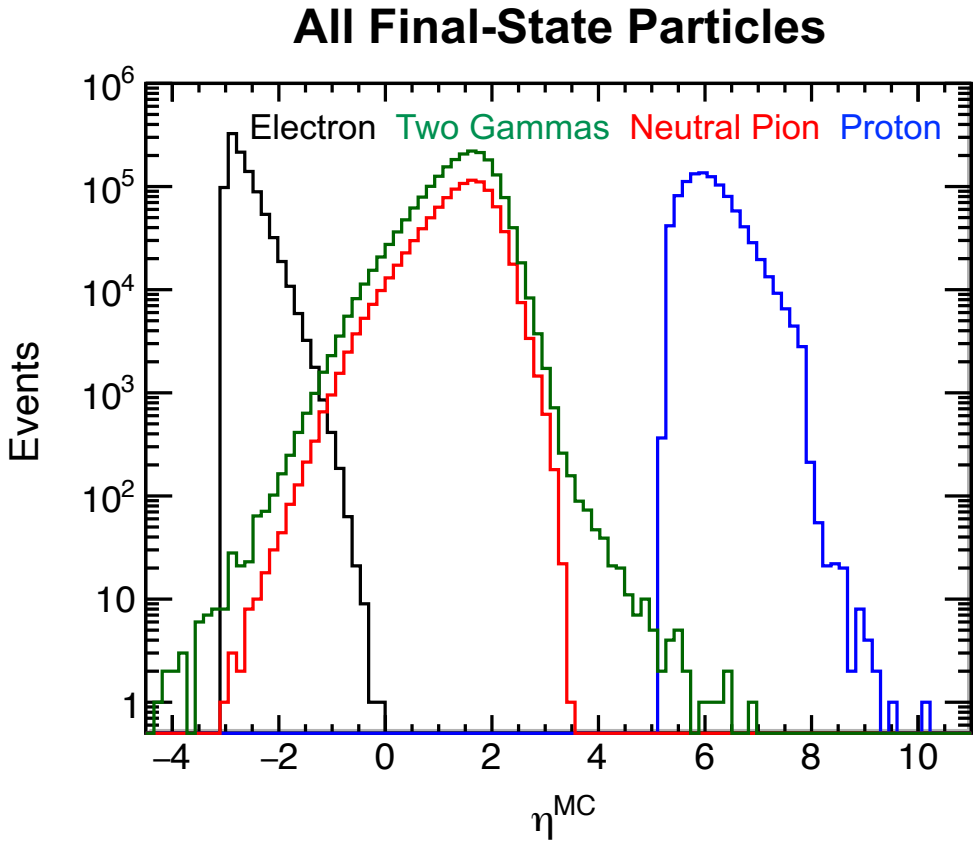
ePIC October Simulation Campaign

25.10.2 (10×130 GeV^2) **– signal**

25.10.3 (5×41 GeV^2) **– physics background**

25.10.4 (18×275 GeV^2) **– machine background**

DVπ^0P Kinematics



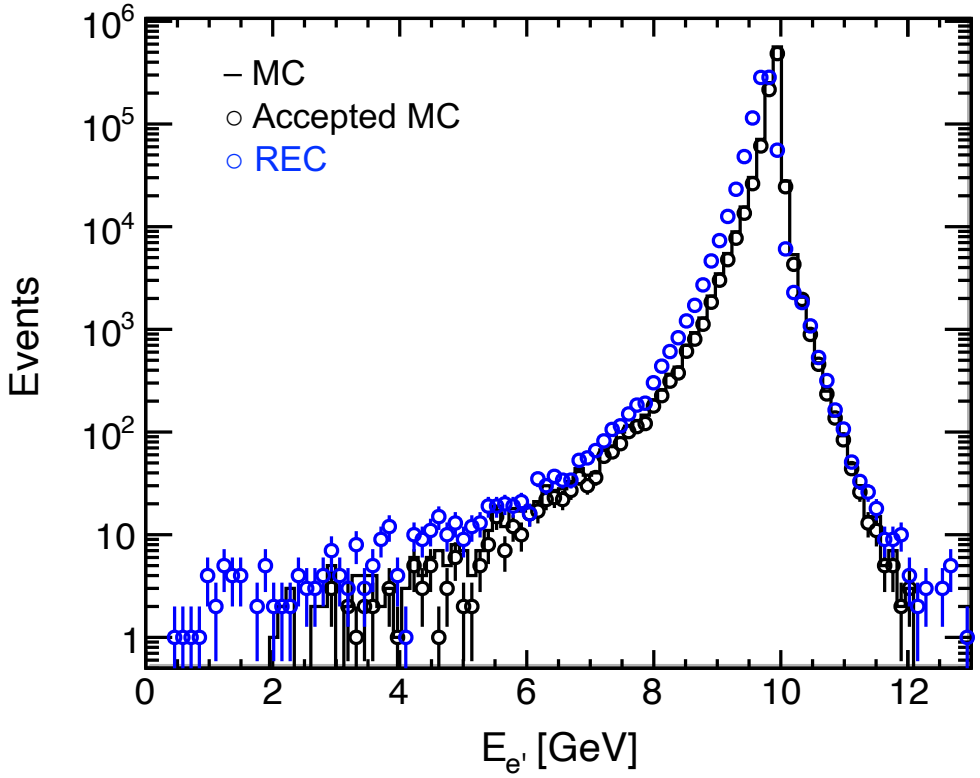
Relatively clean kinematics

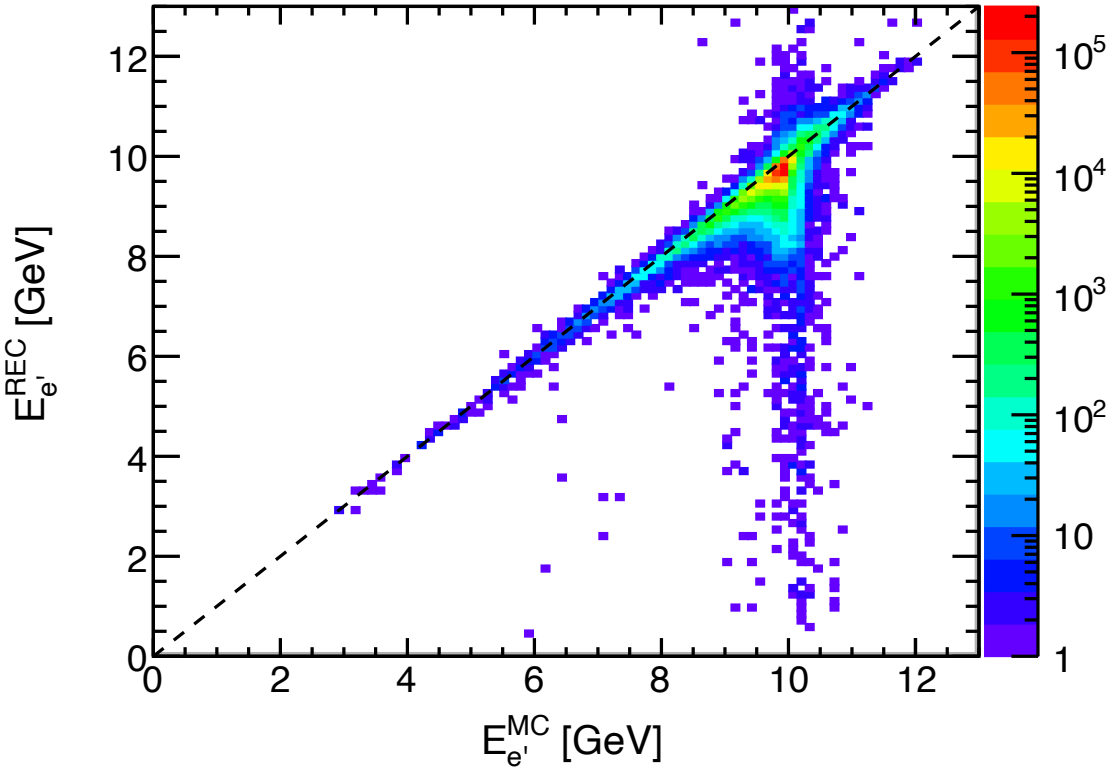
Minimal overlap between final-state particles

Detector Signatures

- Scattered electron:
  - Detected in backward region (Tracker + Calorimeter)
- Scattered proton:
  - Detected in Far-Forward tracker
- Neutral pion ($\pi^0 \rightarrow \gamma\gamma$):
  - Detected in mid-rapidity and forward calorimeters

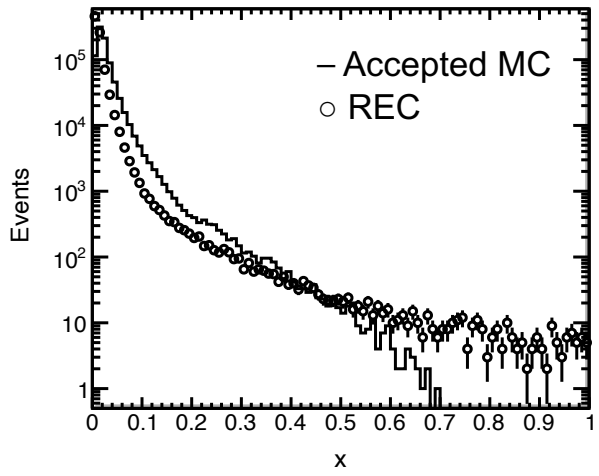
e' Acceptance and Reconstruction

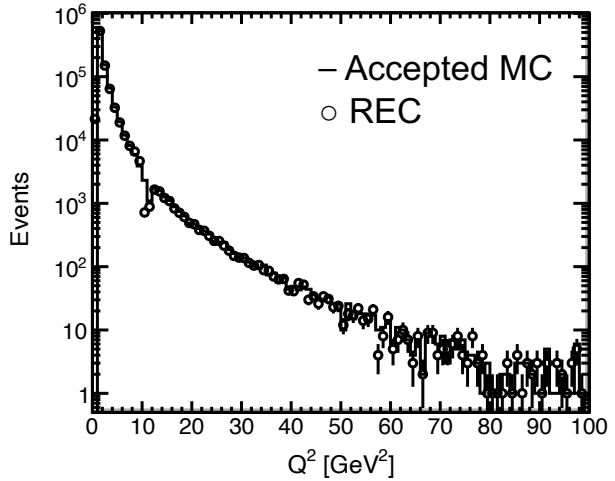


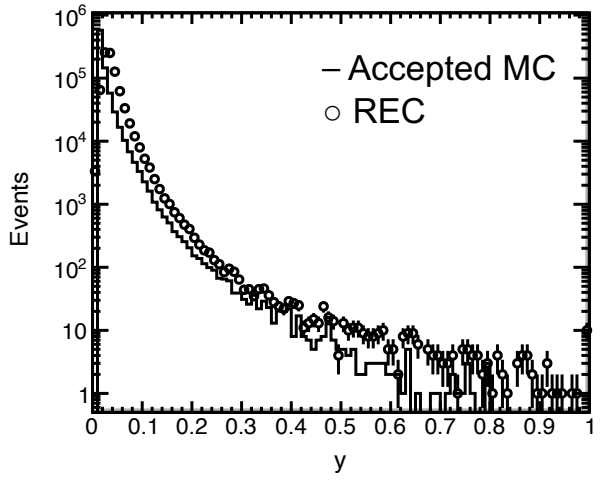


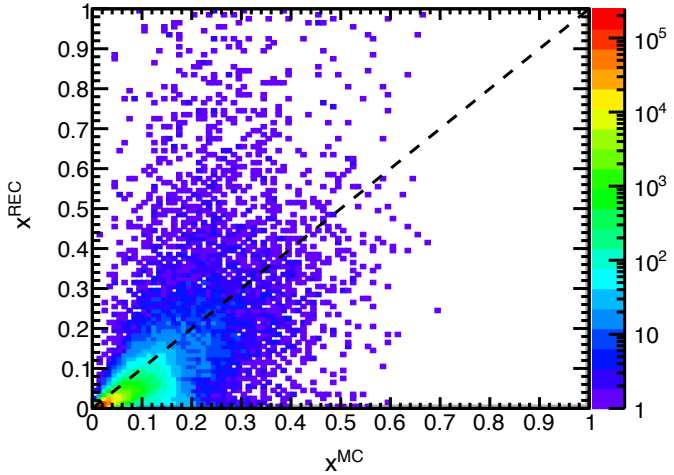
Good Electron Selection: with truth-association E/p cut ($0.9 < E/p < 1.2$).
Potential to improve scattered-electron reconstruction via calorimetry calibration.

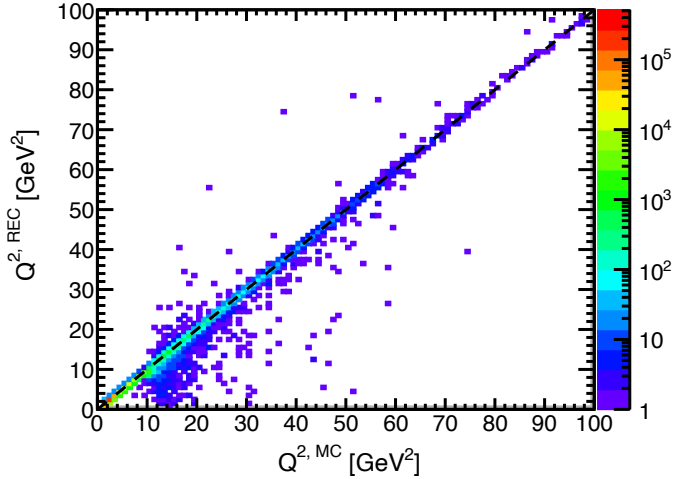
DIS Kinematics After Electron Selection

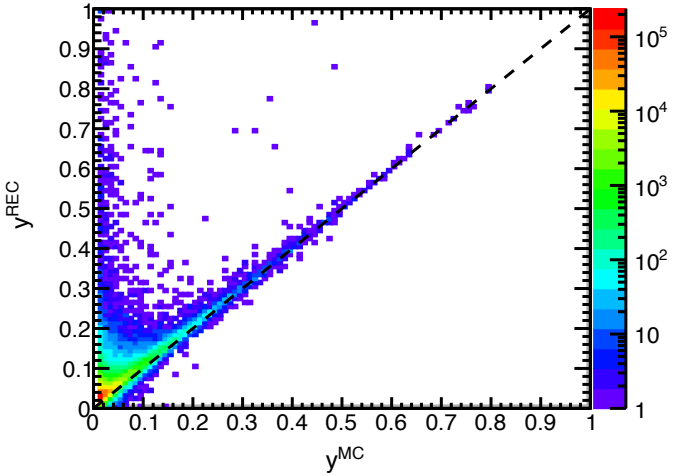




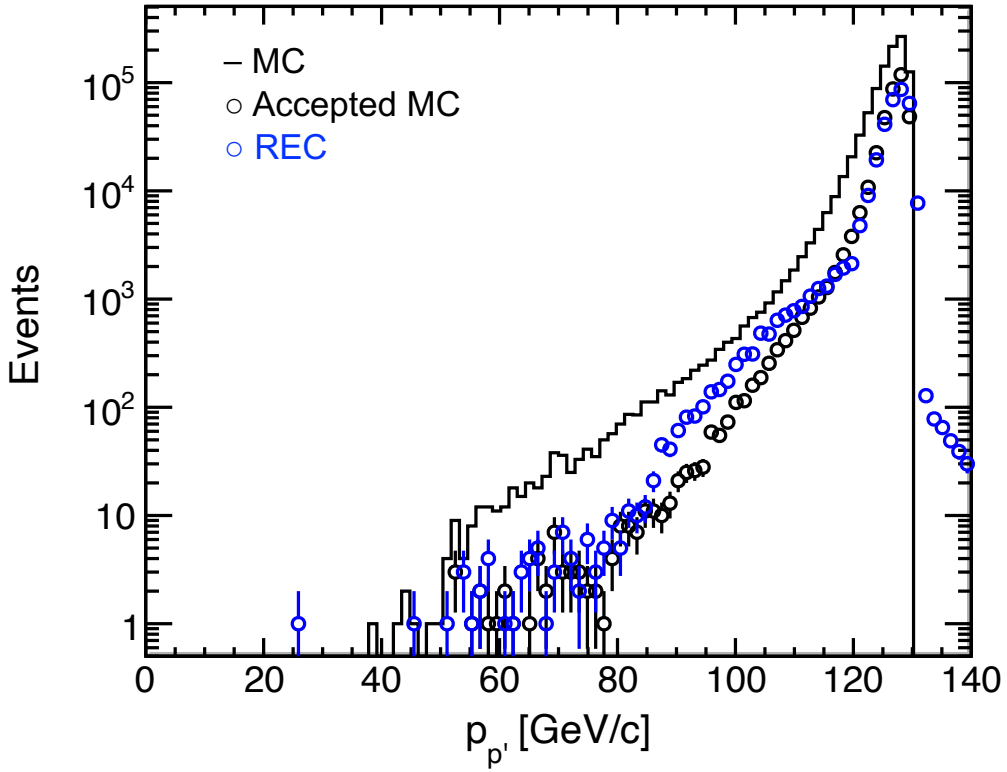


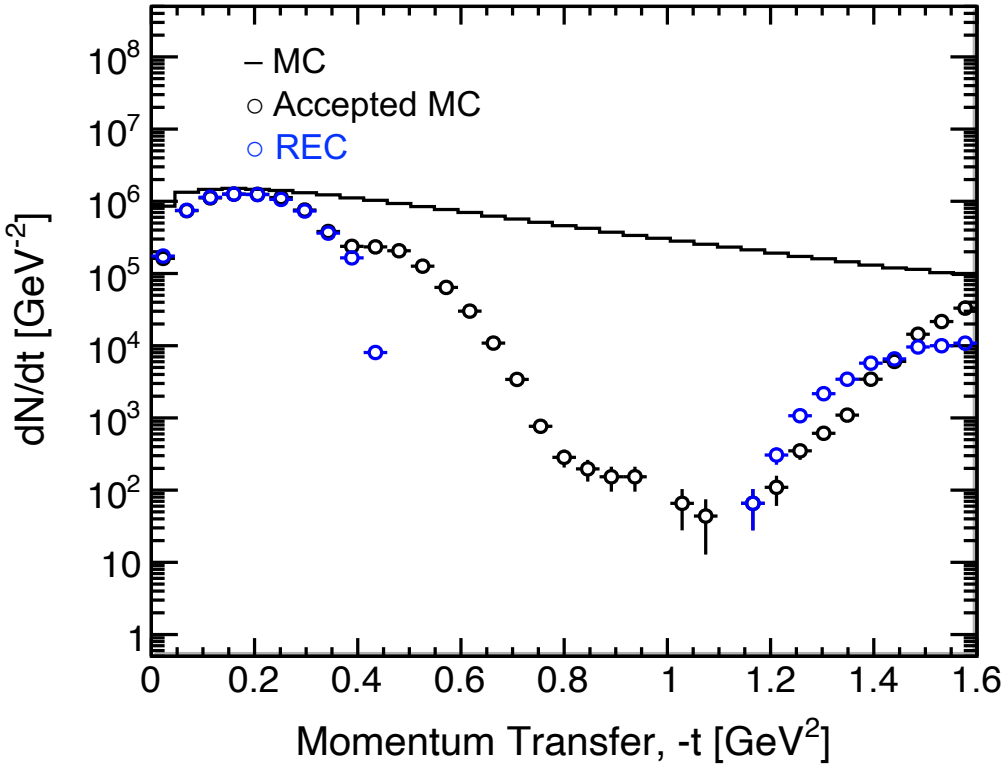






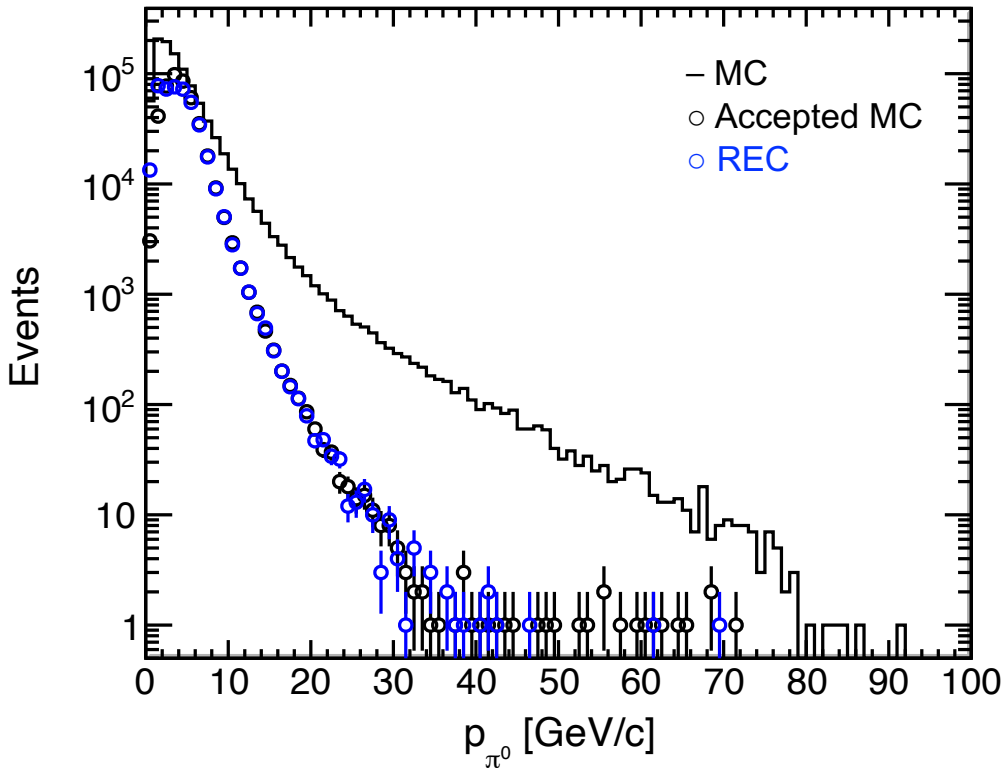
p' Acceptance and Reconstruction

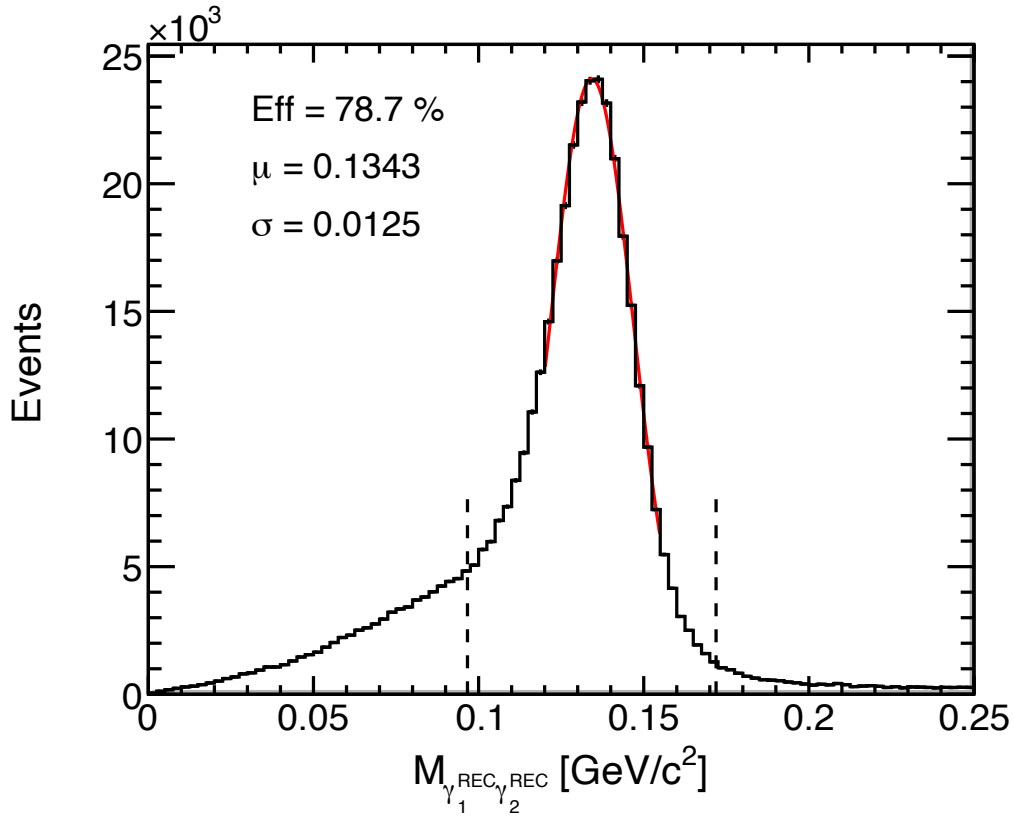




Good Proton Selection: within angular acceptance in B0 or Roman Pot
(5.5 mrad < $\theta^{\mathrm{REC}}_{\mathrm{p\ in\ B0}}$ < 20 mrad and 0 mrad < $\theta^{\mathrm{REC}}_{\mathrm{p\ in\ RP}}$ < 5 mrad).

π^0 Acceptance and Reconstruction



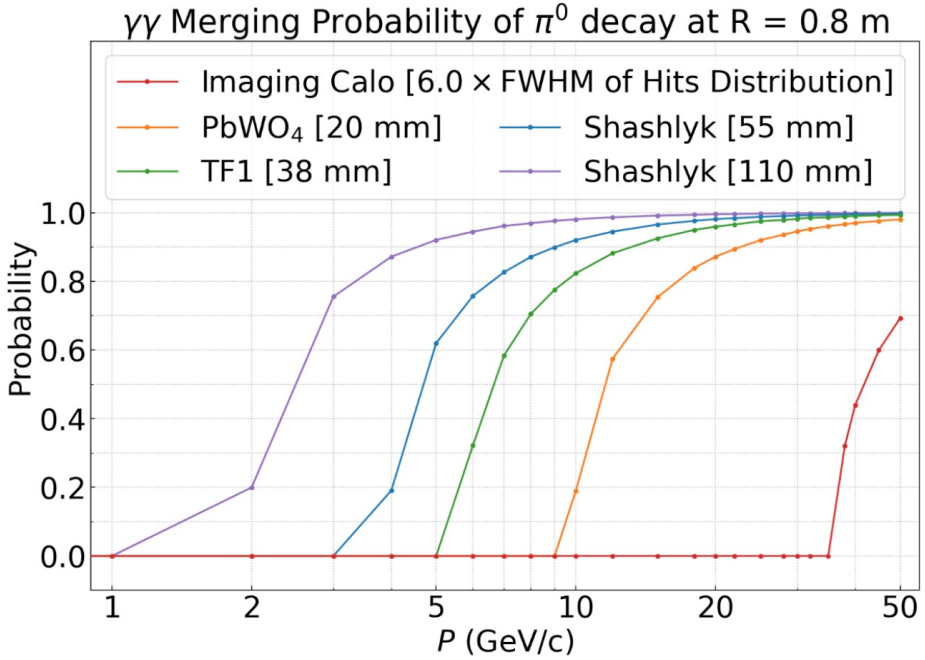


Acceptance loss observed in Low- or high-momentum neutral pions.
"Good" reconstructed neutral pions defined as those within $\pm$ 3σ **of the mean.**

Potential Improvement – π^0 Acceptance

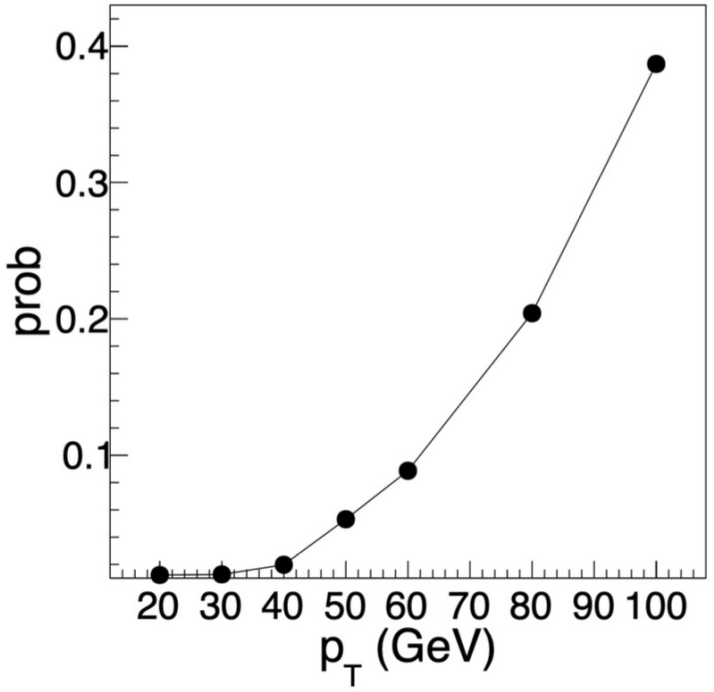
[1]Taken from ePIC preTDR v3.1 (Figure 3.155 (b) on page 194)
[2]Taken from ePIC preTDR v3.1 (Figure 3.166 on page 213)

Mid-rapidity[1]



Upper limit of $\gamma\gamma$ merging probability at η = 0,
up to p_{π^0} **~ 35 GeV** can be separable.

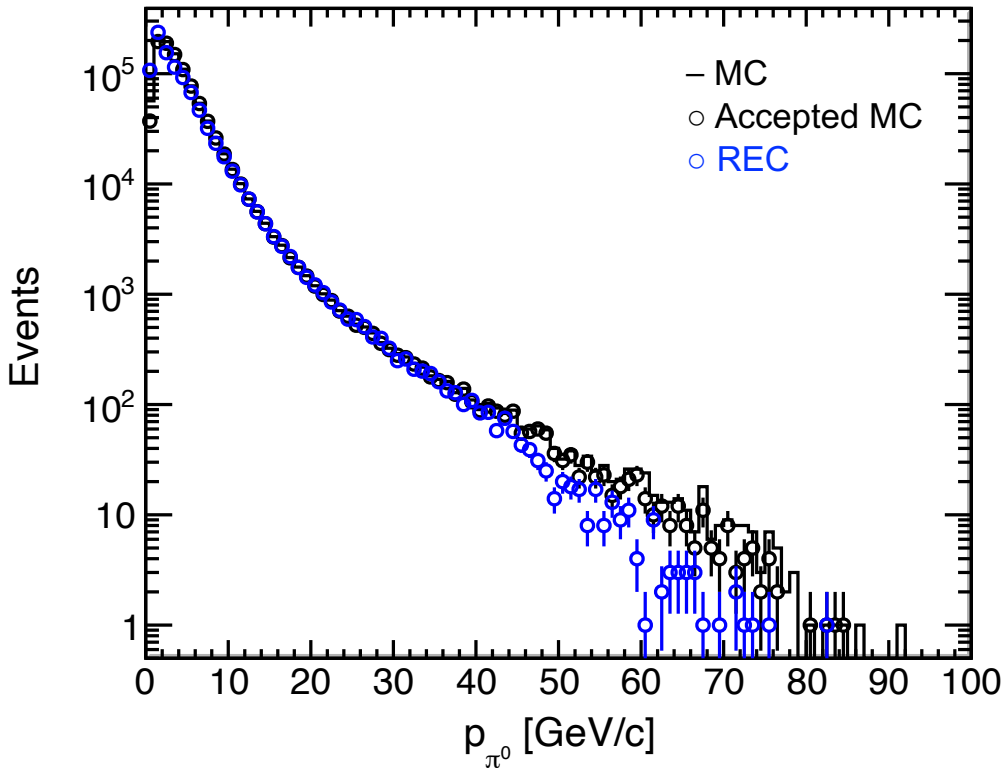
Forward[2]

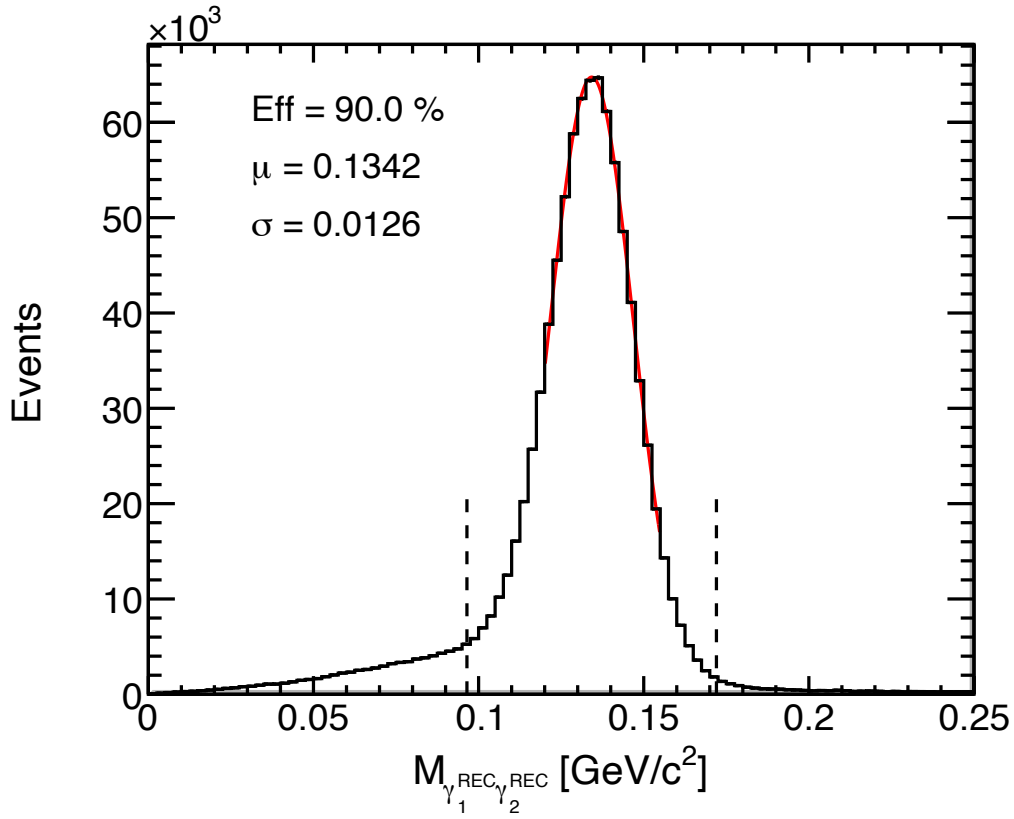


W/SciFi 2.5×2.5 at z = **3.3 m**
Misidentification rate **at 60 GeV** is approximately **10 %**.

Standalone ML studies implemented as a **potential improvement** for future reconstruction.
Targeting **mid-rapidity** and **forward regions**. Acceptance increased from 45 % to 95 %.

π^0 Acceptance and Reconstruction



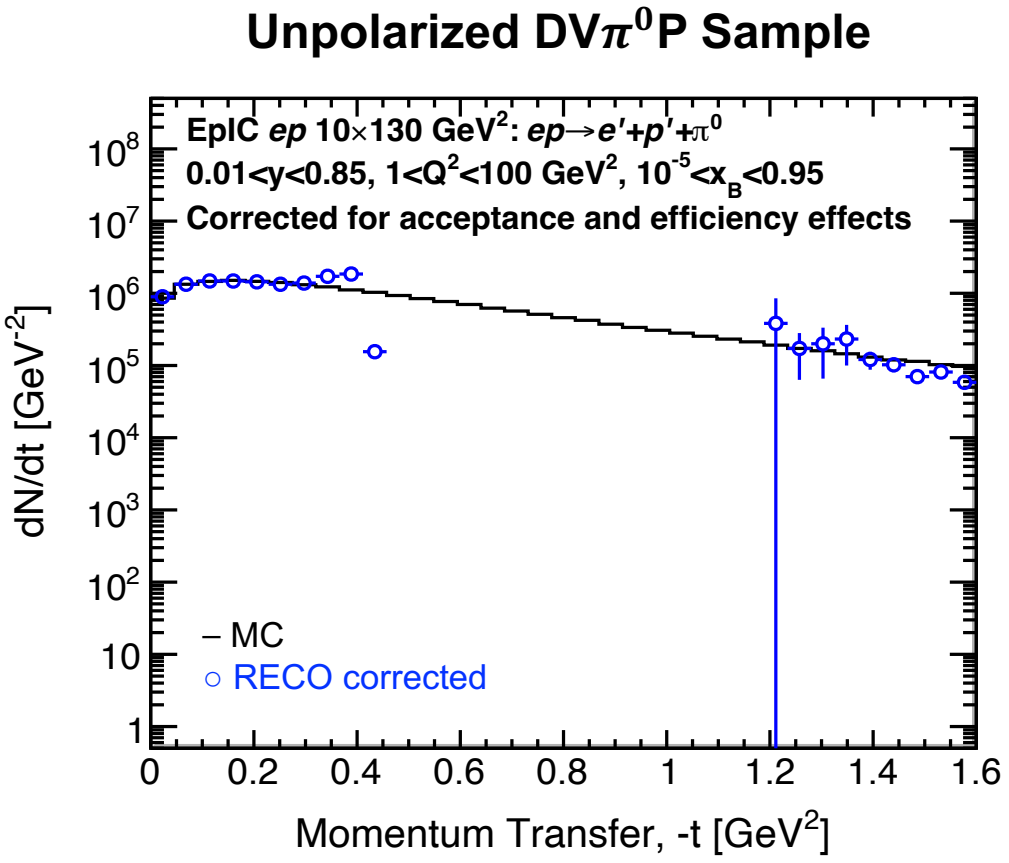


Standalone ML studies implemented as a **potential improvement** for future reconstruction.
"Good" reconstructed neutral pions defined as those within $\pm 3\sigma$ **of the mean.**

Quality Cuts So far

- Good Electron Selection:
  - With truth-association E/p cut (0.9 < E/p < 1.2)
- Good Proton Selection:
  - Within angular acceptance in B0 or Roman Pot
    (5.5 mrad < $\theta^{\mathrm{REC}}_{\mathrm{p\ in\ B0}}$ < 20 mrad and 0 mrad < $\theta^{\mathrm{REC}}_{\mathrm{p\ in\ RP}}$ < 5 mrad)
- Good Neutral Pion Selection:
  - Within ± 0.04 GeV of M_{π^0} (0.096 < $M_{\gamma\gamma}$ < 0.172)
- **Suppress photo-production + radiative corrections**
  - $E - p_z$ cut (15 < $E - p_z$< 25)
- **Exclusivity**
  - All final-state particles are reconstructed
- **Missing Mass**
  - With $|M^2_{\mathrm{Missing}}|$ < 1 GeV^2

t-distribution $t_{\mathrm{BABE}} = (p - p')^2$



This is t-distribution integrated over x, and Q^2

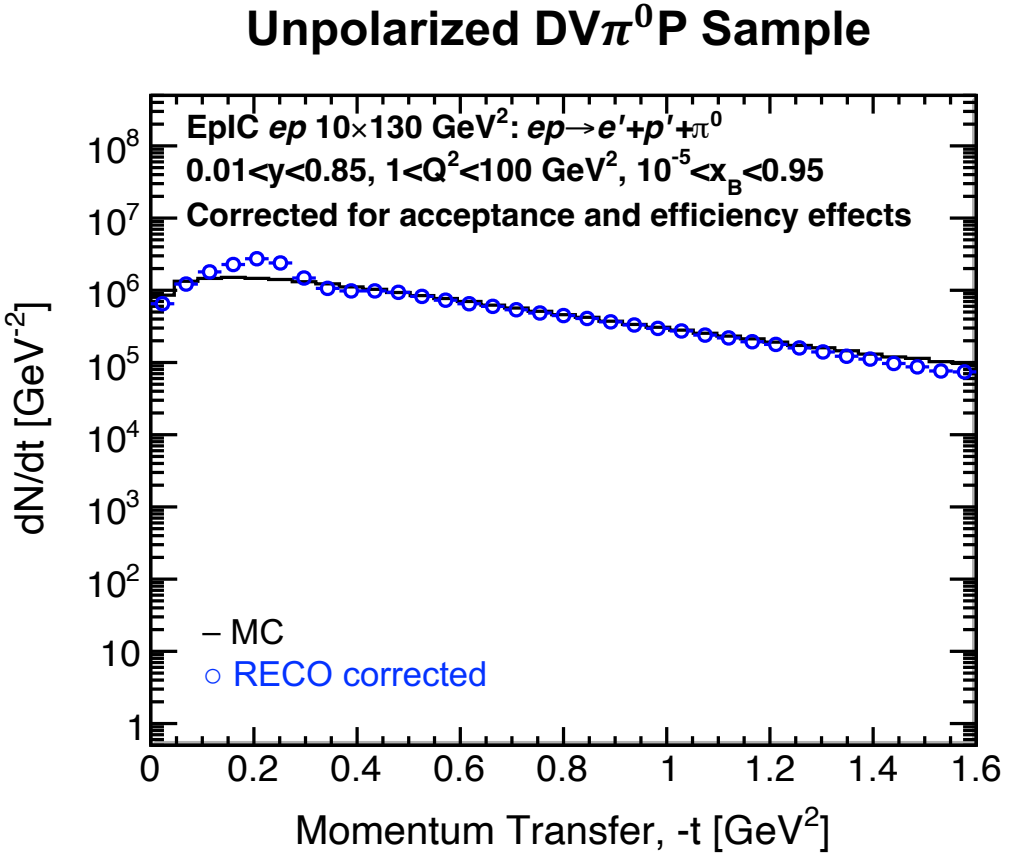
- Good **Proton** Selection:
  - ✓ is reconstructed in B0 or Roman Pot
  - ✓ **Within angular acceptance** in B0 or Roman Pot

$$5.5 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ B0}} < 20 \text{ mrad}$$

$$0 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ RP}} < 5 \text{ mrad}$$

- Good **Electron** Selection:
  - ✓ With truth-association E/p cut ($0.9 < E/p < 1.2$)
- Good **Neutral Pion** Selection:
  - ✓ Within ± 0.04 GeV of M_{π^0} ($0.096 < M_{\gamma\gamma} < 0.172$)
- Suppress photo production + radiative corrections
  - ✓ $\boldsymbol{E - p_z}$ cut ($15 < E - p_z < 25$)
- **Exclusivity** Cut
  - ✓ All final-state particles are reconstructed
- **Missing Mass** Cut:
  - ✓ With $|\boldsymbol{M^2_{Missing}}| < 1$ GeV²

t-distribution $t_{\mathrm{eXBE}} = (p - p'_{corr})^2$



This is t-distribution integrated over x, and Q^2

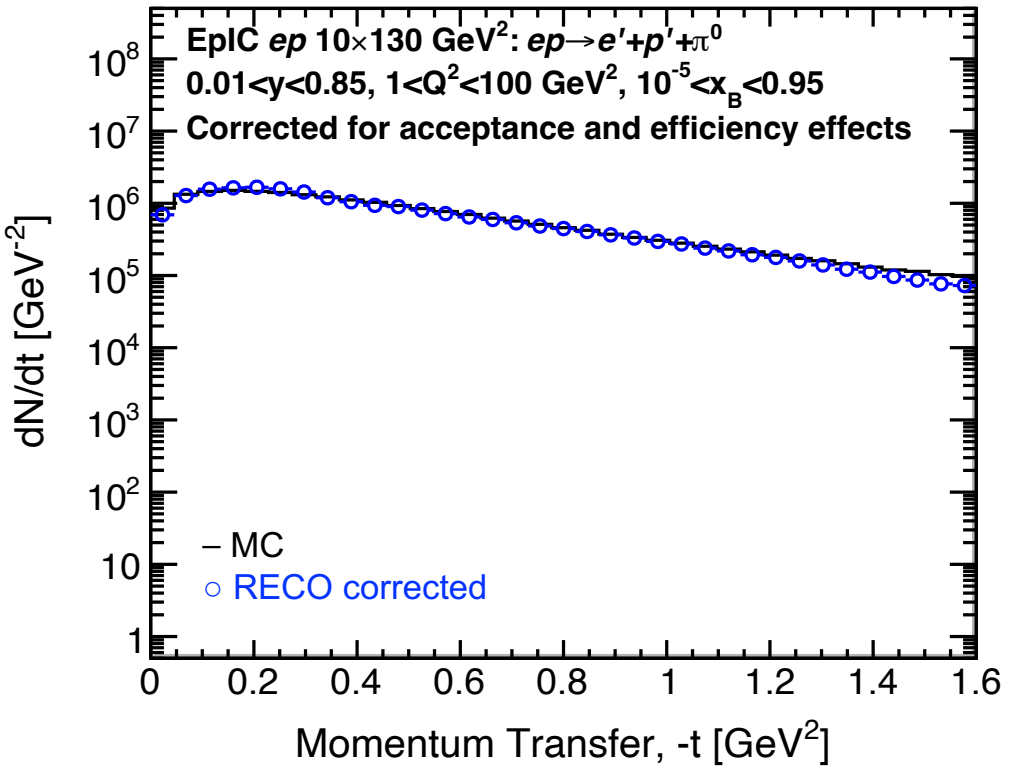
- Good **Proton** Selection:
  - ✓ is reconstructed in B0 or Roman Pot
  - ✓ **Within angular acceptance** in B0 or Roman Pot

$$5.5 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ B0}} < 20 \text{ mrad}$$

$$0 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ RP}} < 5 \text{ mrad}$$

- Good **Electron** Selection:
  - ✓ With truth-association E/p cut ($0.9 < E/p < 1.2$)
- Good **Neutral Pion** Selection:
  - ✓ Within ± 0.04 GeV of M_{π^0} ($0.096 < M_{\gamma\gamma} < 0.172$)
- Suppress photo production + radiative corrections
  - ✓ $\boldsymbol{E - p_z}$ cut ($15 < E - p_z < 25$)
- **Exclusivity** Cut
  - ✓ All final-state particles are reconstructed
- **Missing Mass** Cut:
  - ✓ With $|M^2_{Missing}| < 1$ GeV²

t-distribution $t_{\text{total}} = t_{\text{BABE}} + t_{\text{eXBE}}$



This is t-distribution integrated over x, and Q^2

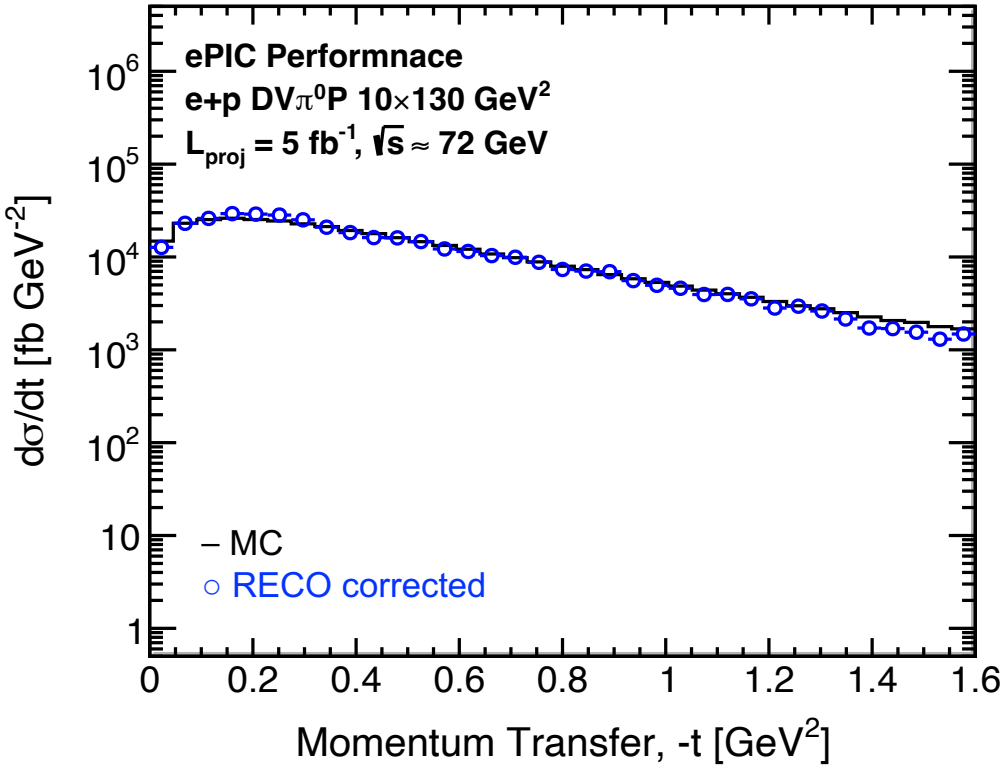
- Good **Proton** Selection:
  - ✓ is reconstructed in B0 or Roman Pot
  - ✓ **Within angular acceptance** in B0 or Roman Pot

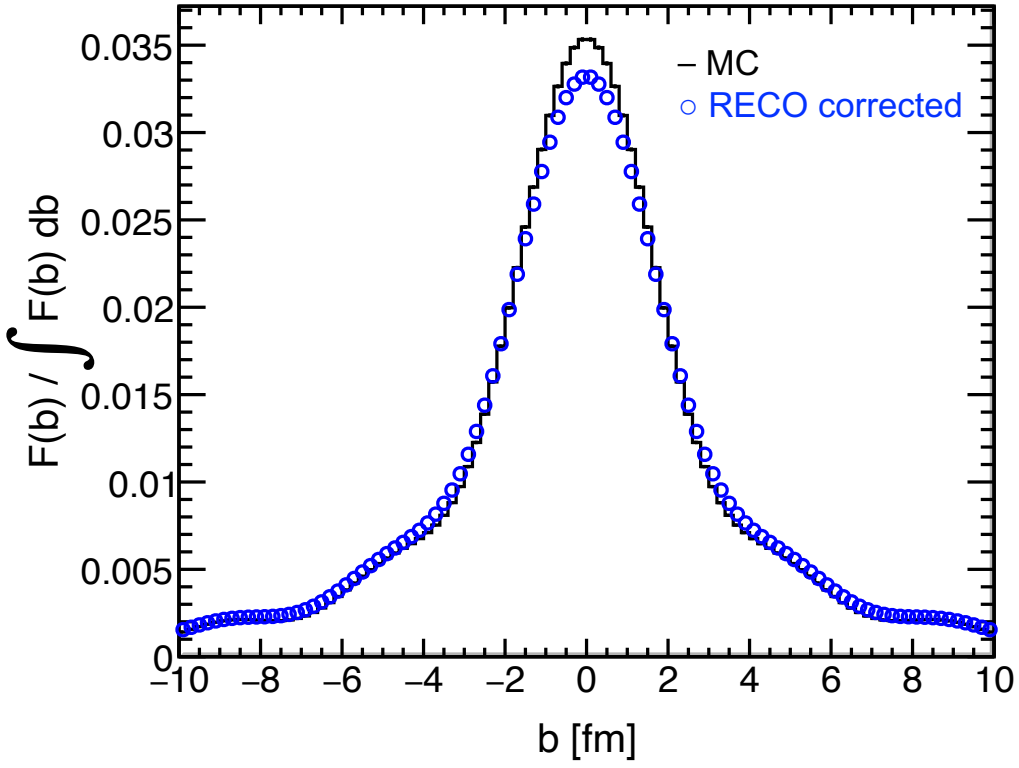
$$5.5 \text{ mrad} < \theta^{\text{REC}}_{\text{p in B0}} < 20 \text{ mrad}$$

$$0 \text{ mrad} < \theta^{\text{REC}}_{\text{p in RP}} < 5 \text{ mrad}$$

- Good **Electron** Selection:
  - ✓ With truth-association E/p cut ($0.9 < E/p < 1.2$)
- Good **Neutral Pion** Selection:
  - ✓ Within ± 0.04 GeV of M_{π^0} ($0.096 < M_{\gamma\gamma} < 0.172$)
- Suppress photo production + radiative corrections
  - ✓ $\boldsymbol{E - p_z}$ cut ($15 < E - p_z < 25$)
- **Exclusivity** Cut
  - ✓ All final-state particles are reconstructed
- **Missing Mass** Cut:
  - ✓ With $|\boldsymbol{M^2_{Missing}}| < 1$ GeV²

Early Science Projection Results





$\frac{d\sigma}{dt}$ distribution with 5 fb^{-1} projection → included realistic fluctuations using Gaussian (mean, error).

Realistic $\frac{d\sigma}{dt}$ distribution → applied Fourier transformation to extract spatial distribution.

Background Study

1) ep Inclusive DIS background
2) Machine Background
3) Physics Background to DVCS

1) ep Inclusive DIS Background

Goal: Evaluate **inclusive DIS background** using **10×130 GeV²** sample.

- Identify inclusive DIS events that mimic exclusive π^0 process
- Simulation details provided by Stephen Maple:
  - Simulation files located at: /gpfs02/eic/maples/RECO_pythia6_ep_early_science/ on RCF @ BNL
  - Two Q^2 ranges: 1 < Q^2 < 10, and 10 < Q^2 < 100

Selection Criteria:

- An event **has four final-state particles** (i.e. e', p', and 2γs)
- An event **pass quality cuts**
  - Selections based on E/p for e', $M_{\gamma\gamma}$ for π^0, $\theta_{p'}$ for p', and $E - p_z$

ep Inclusive DIS Background

Check if

1) Central Detector:
   Exactly three reconstructed particles
   1-1) **One negative** and **two neutral charges**
2) Far-Forward Detector:
   One reconstructed **positive-charge particle**
   Passes **angular acceptance cut (θ_p^{REC})**
3) Electron Candidate:
   Passes **E/p cut**
4) Neutral Pion candidate:
   Passes **$M_{\gamma\gamma}$ (invariant mass) cut**

*Note that no luminosity information is taken into account

Selection	10×130 GeV² 1 < Q² < 10	10×130 GeV² 10 < Q² < 100
1)	11.3232 % (56,616/500,000)	3.3658 % (16,829/500,000)
1-1)	2.1324 % (10,662/500,000)	0.486 % (2,430/500,000)
2)	0.5494 % (2,747/500,000)	0.1132 % (566/500,000)
3)	0.479 % (2,395/500,000)	0.0838 % (419/500,000)
4)	0.14 %* (700/500,000)	0.0114 %* (57/500,000)
Results after considering cross-section contributions:	**5270.6 %**	**1575.9 %**

π^0s can be produced through multiple processes – expected behavior.
Additional selection cut required to suppress DIS background.

ep Inclusive DIS Background

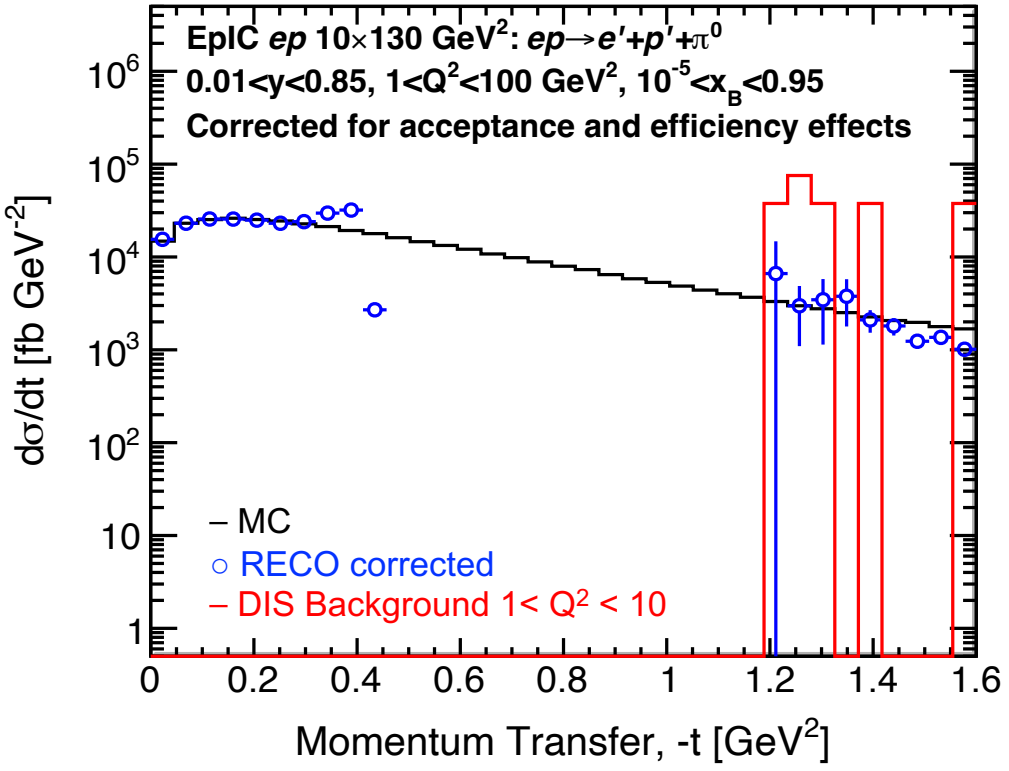
Check if

1) Central Detector:
   Exactly three reconstructed particles
   1-1) **One negative** and **two neutral charges**
2) Far-Forward Detector:
   One reconstructed **positive-charge particle**
   Passes **angular acceptance cut (θ_p^{REC})**
3) Electron Candidate:
   Passes **E/p cut**
4) Neutral Pion candidate:
   Passes **$M_{\gamma\gamma}$ (invariant mass) cut**
5) Missing Mass: ref. $M_{\pi^0}^2 \sim 0.02$ GeV + $E - p_z$
   Passes $M_{Missing}^2$ cut ($|M_{Missing}^2| < 1$ GeV^2)
6) Far-Forward Detector Veto (ZDC)

*Note that no luminosity information is taken into account

Selection	10×130 GeV² 1 < Q² < 10	10×130 GeV² 10 < Q² < 100
1)	11.3232 % (56,616/500,000)	3.3658 % (16,829/500,000)
1-1)	2.1324 % (10,662/500,000)	0.486 % (2,430/500,000)
2)	0.5494 % (2,747/500,000)	0.1132 % (566/500,000)
3)	0.479 % (2,395/500,000)	0.0838 % (419/500,000)
4)	0.14 %* (700/500,000)	0.0114 %* (57/500,000)
5)	0.0032 %* (16/500,000)	0.0004 %* (2/500,000)
6)	0.002 **(0.0016) %*** (10(**8**)/500,000)	**0.0002 %*** (1/500,000)
Results after considering cross-section contributions:	**60.2 %**	**27.6 %**

t-distribution $t_{\mathrm{BABE}} = (p - p')^2$



This is t-distribution integrated over x, and Q^2

- Good **Proton** Selection:
  - ✓ is reconstructed in B0 or Roman Pot
  - ✓ **Within angular acceptance** in B0 or Roman Pot

$$5.5 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ B0}} < 20 \text{ mrad}$$

$$0 \text{ mrad} < \theta^{\mathrm{REC}}_{\mathrm{p\ in\ RP}} < 5 \text{ mrad}$$

- Good **Electron** Selection:
  - ✓ With truth-association E/p cut ($0.9 < E/p < 1.2$)
- Good **Neutral Pion** Selection:
  - ✓ Within ± 0.04 GeV of M_{π^0} ($0.096 < M_{\gamma\gamma} < 0.172$)
- Suppress photo production + radiative corrections
  - ✓ $\boldsymbol{E - p_z}$ cut ($15 < E - p_z < 25$)
- **Exclusivity** Cut
  - ✓ All final-state particles are reconstructed
- **Missing Mass** Cut:
  - ✓ With $|\boldsymbol{M^2_{Missing}}| < 1$ GeV²

2) Machine Background

Key challenges:

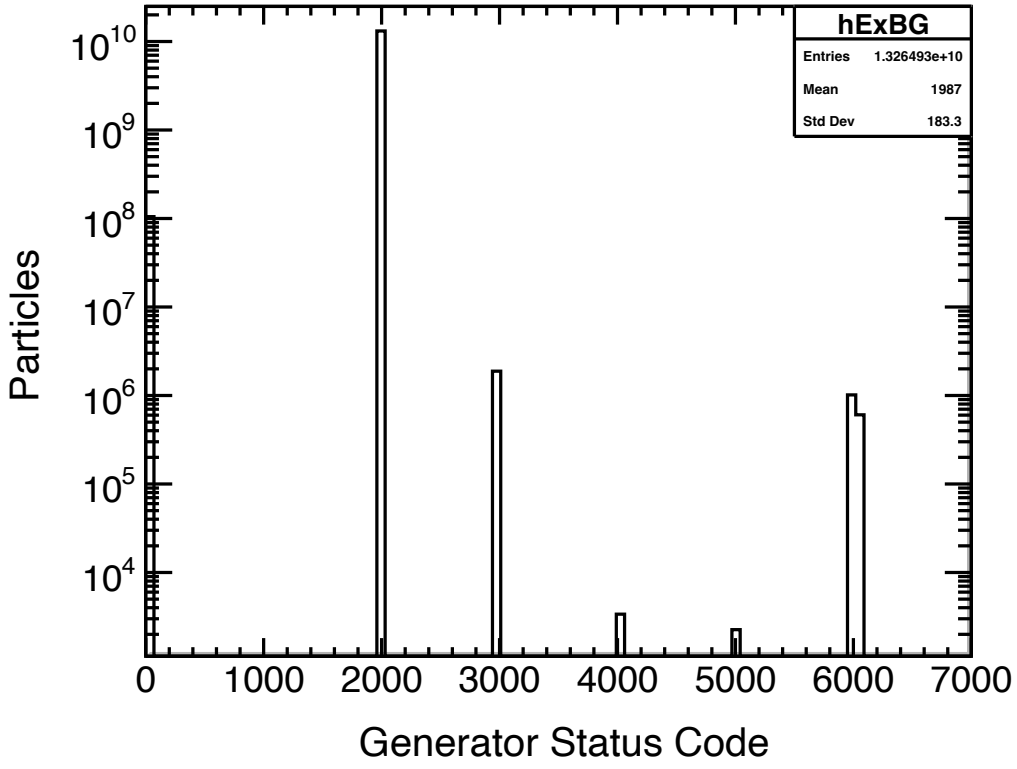
- Difficulty in identifying true signal due to **numerous surrounding particles**
- Risk of **false detection**, where background activity can be misidentified as signal

Goal: Evaluate **machine background** using **18×275 GeV^2** sample.

- Mixed signal and background sample: **One signal embedded per background event**
- Simulation details:
  - Simulation files located at:

    root://dtn-eic.jlab.org///volatile/eic/EPIC/RECO/25.10.4/epic_craterlake/Bkg_Exactly1SignalPer2usFrame/EXCLUSIVE/DVMP/EpIC1.1.6-1.1/unpolarised/18x275/q2_1_1000/
  - Total statistics: ~1M events

Take a Glance at Machine Background



Signal embedded per background event

Quick scan of a small subset of events

Generator status code

< 2000: Signal-related particles including beam particles, decayed, and secondaries from machine background

2000: **Synchrotron radiation photons** (**dominant contribution**)

3000: Electron bremsstrahlung

4000: Electron Touschek scattering (intrabeam scattering)

5000: Electron Coulomb scattering

6000: Proton beam gas interactions

DVπ^0P ep 18×275 GeV^2 – Signal Only

The 18×275 GeV^2 sample represents a **particularly challenging scenario**.

- Higher π^0 momentum leads to **increased photon merging** into a single cluster.
- Simulation sample is available at
  root://dtn-eic.jlab.org///volatile/eic/EPIC/RECO/25.10.3/
  epic_craterlake/EXCLUSIVE/DVMP/EpIC1.1.6-1.1/unpolarised/18x275/q2_1_1000/
- The **same analysis workflow** as used for 10×130 GeV^2 sample was applied.
- Neutral pion (π^0) reconstruction:
  - **20.9 %** (44.3 % at 10×130 GeV^2) of events have **two reconstructed photons**.
  - **65.6 %** (51.7 % at 10×130 GeV^2) of events have **one reconstructed photons**.
  - **13.5 %** (4.0 % at 10×130 GeV^2) of events have **no reconstructed photons**.
- Overall performance with truth-association :
  - Combined p', e', and π^0 acceptance and efficiency in current EICrecon reconstruction pipeline is **~ 1.6 % (27.5 %** at 10×130 GeV^2**)**.

DVπ^0P ep 18×275 GeV² – Signal + Bkg

The 18×275 GeV² sample represents a **particularly challenging scenario**.

- Simulation sample is available at

  root://dtn-eic.jlab.org///volatile/eic/EPIC/RECO/25.10.4/epic_craterlake/Bkg_Exactly1SignalPer2usFrame/EXCLUSIVE/DVMP/EpIC1.1.6-1.1/unpolarised/18x275/q2_1_1000/

- Neutral pion (π^0) reconstruction:

  Each photon is flagged as either a true π^0 photon or machine-background photon

  - For exactly two reconstructed photons: use directly.
  - For > 2 photons: select π^0 candidate via invariant mass.

- Overall performance:
  - Combined p', e', and π^0 acceptance and efficiency in current EICrecon reconstruction pipeline is **~ 0.87 %**.
    - True photons from π^0: **0.845 %**.
    - Mixed photons from machine background: **0.027 %**.
    - Corresponds to **~ 3.1% contamination** in reconstructed events.

3) Physics Background to DVCS

Key challenges:

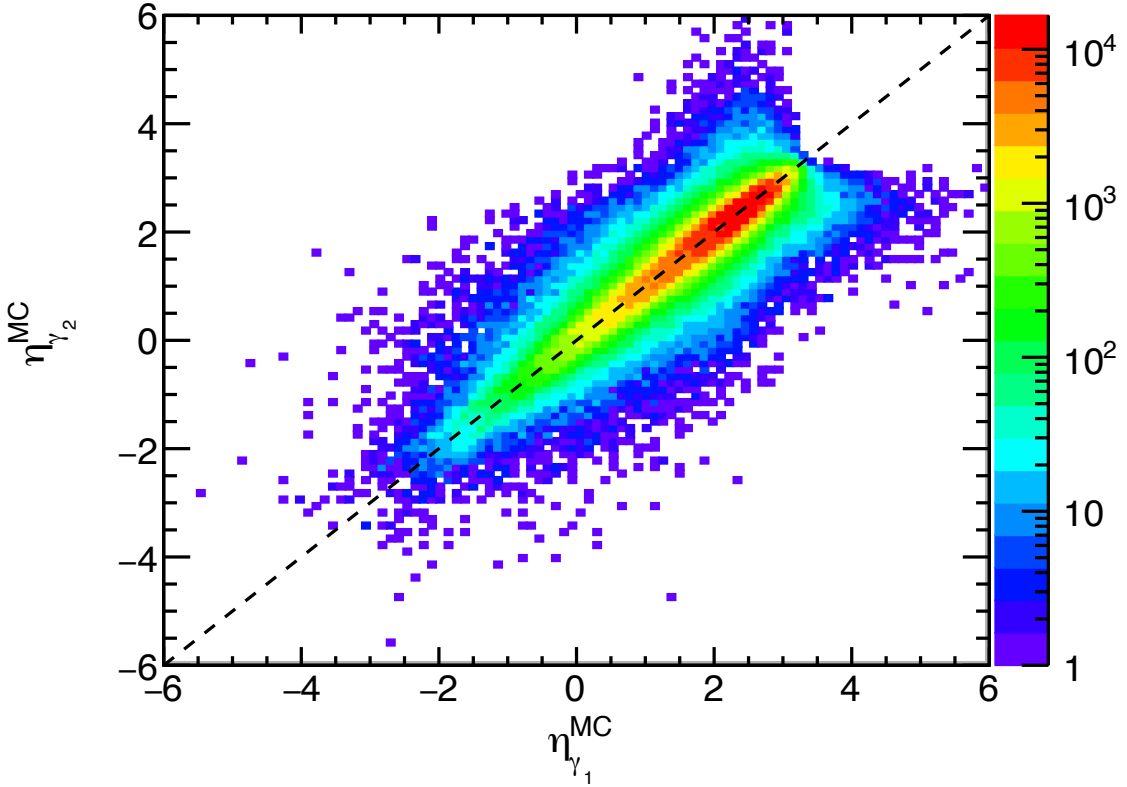
- Where one of gammas from π^0 is mis-identified as DVCS γ
- Due to geometrical acceptance, energy thresholds, and granularity

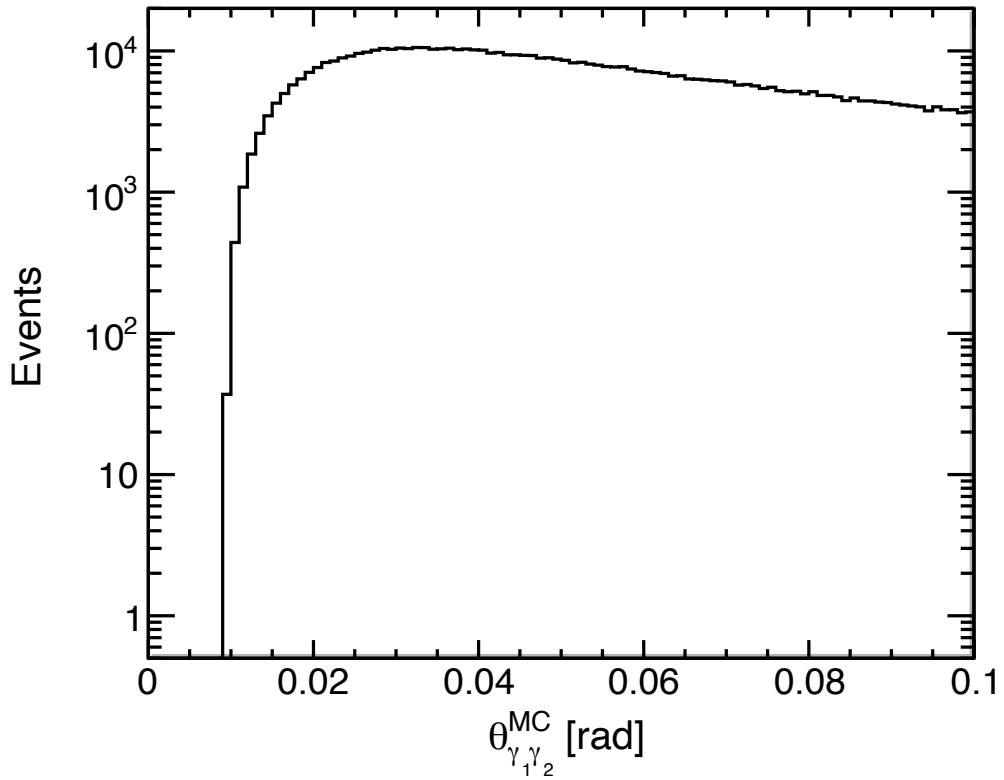
Goal: Estimate rate of single-photon misidentification that can mimic DVCS signal using **5×41 GeV²** sample.

- Method
  - MC-level phase space cuts Same cut on EIC DVCS paper: $0.03 < -t < 1.5$, $0.01 < y < 0.85$, $1 < Q^2 < 100$, $0.00001 < x_B < 0.7$
  - EM Calorimeter information with truth-association scattered electron
  - Minimum cluster energy cut at 0.1 GeV
  - Look for reconstructed events with 1 cluster formed

https://indico.bnl.gov/event/26526/contributions/103508/attachments/60126/103303/ePIC_exclusive_diffraction_tagging_mtg_JKIM_20250224.pdf
Phys. Rev. D 112, 036010 (2025) https://doi.org/10.1103/fy8y-bjc9

2γ Kinematics – η vs η and $\theta_{\gamma\gamma}$





$\gamma\gamma$ **within similar pseudo-rapidity**, meaning very few events where we simply lose a photon by geometric acceptance

Threshold of $\theta_{\gamma\gamma}$ is around 0.01 rad (granularity of forward EMCAL ~ 0.015 rad (ex. tower size))

Initial Results – Physics Bkg to DVCS

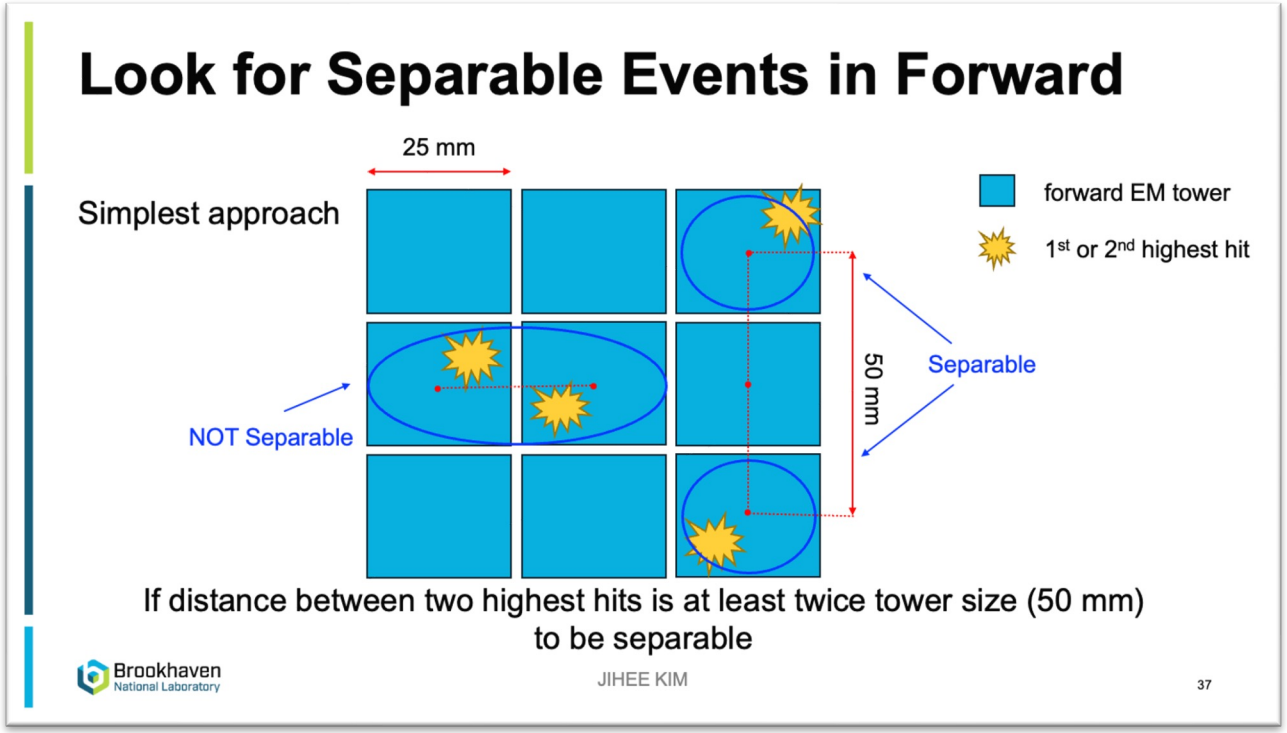
5×41 GeV^2	# of Events	Misidentification
	327,621 / 975,885	**0.335717**

Above summary shows estimated misidentification ($\pi^0 \rightarrow$ DVCS)

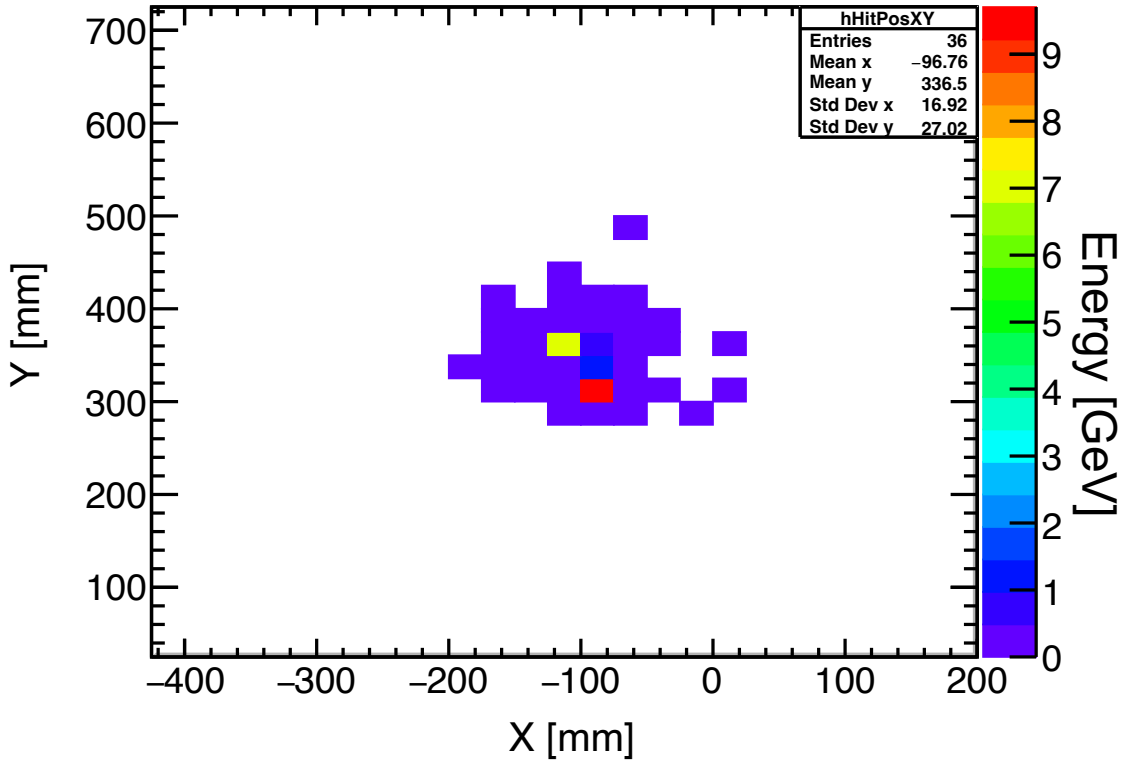
- Current reconstruction pipeline in EICrecon

Initial Results – Physics Bkg to DVCS

5×41 GeV^2	# of Events	Misidentification
	327,621 / 975,885	**0.335717**

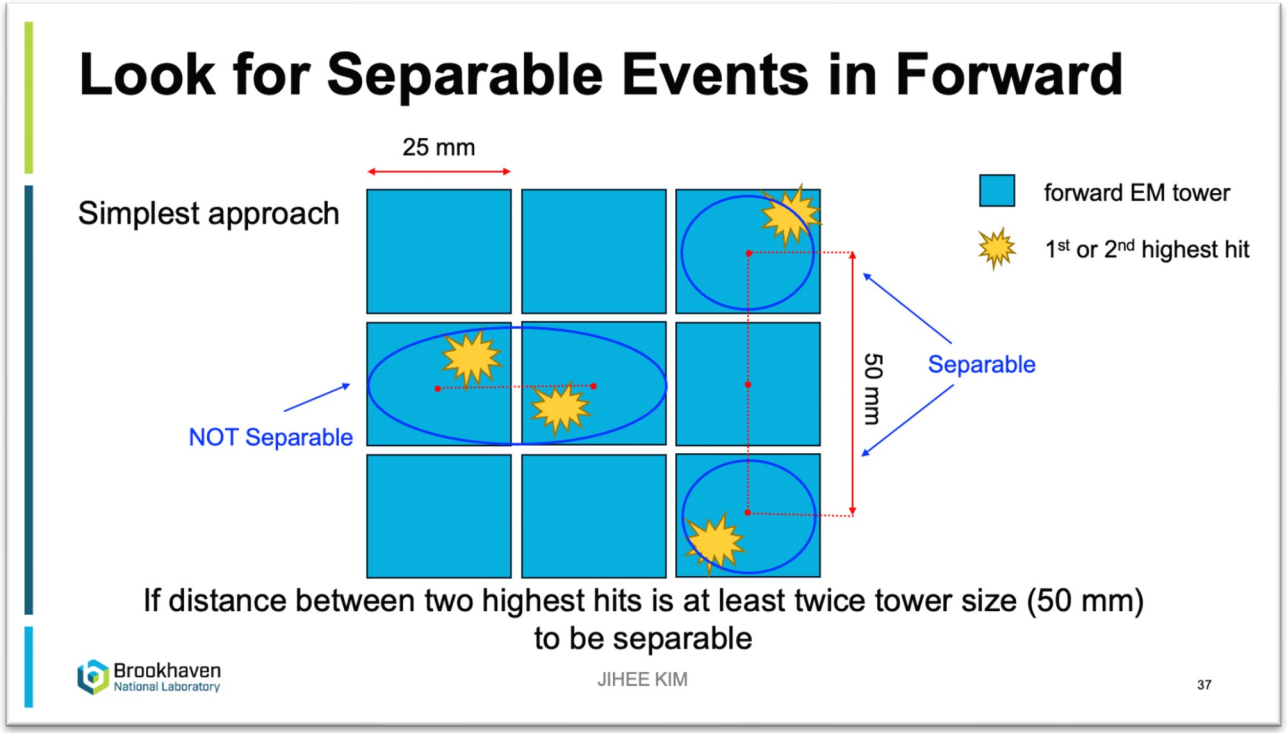


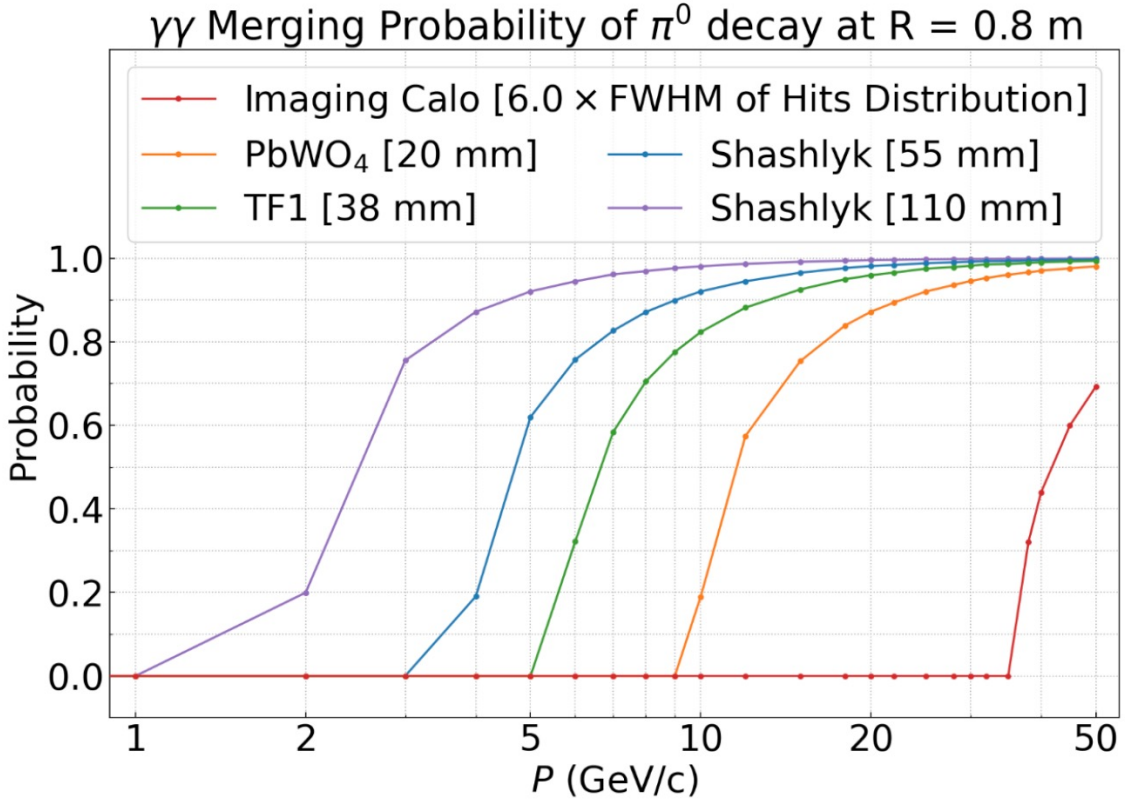
Example with 1 reco. cluster event



Interim Results – Physics Bkg to DVCS

5×41 GeV²	# of Events	Misidentification	# of Events	Misidentification
	327,621 / 975,885	**0.335717**	116,184 / 975,885	**0.119055**

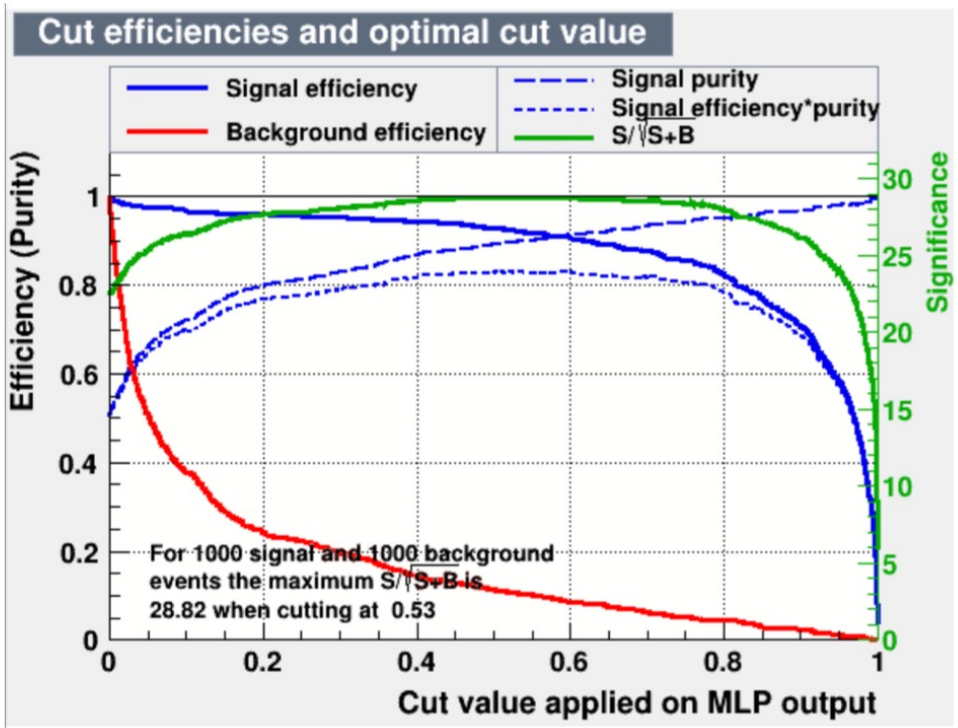


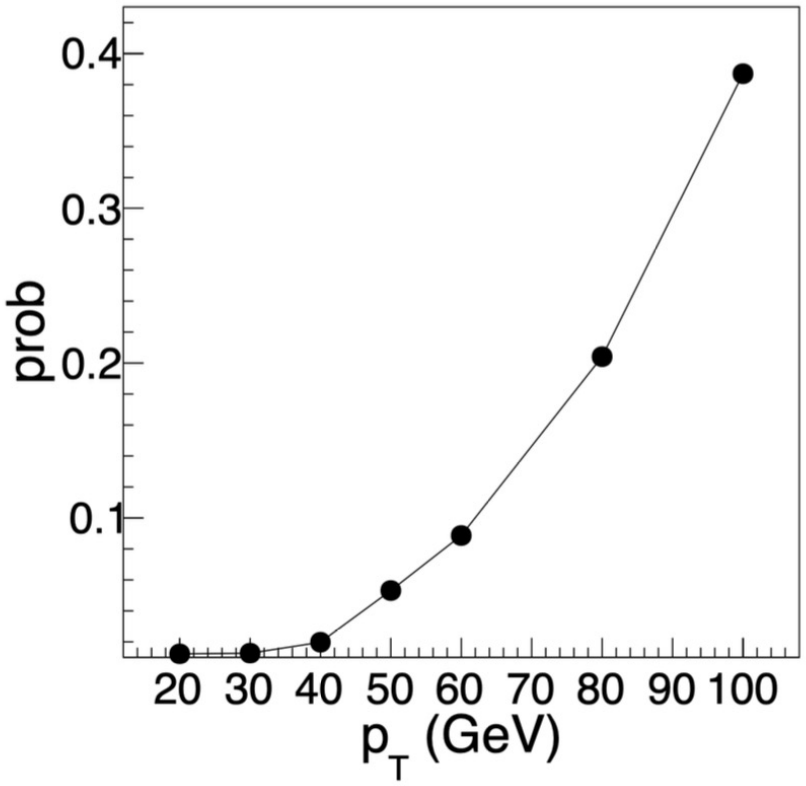


Taken from ePIC preTDR v3.1 (Figure 3.155 (b) on page 194)

Final Results – Physics Bkg to DVCS

5×41 GeV^2	# of Events	Misidentification	# of Events	Misidentification	# of Events	Misidentification
	327,621 / 975,885	**0.335717**	116,184 / 975,885	**0.119055**	1,156 / 975,885	**0.00118457**





Taken from ePIC preTDR v3.1 (Figure 3.166 on page 213)

Physics Background to DVCS

5×41 GeV^2	# of Events	Misidentification	# of Events	Misidentification	# of Events	Misidentification
	327,621 / 975,885	**0.335717**	116,184 / 975,885	**0.119055**	1,156 / 975,885	**0.00118457**

Above summary shows estimated misidentification ($\pi^0 \rightarrow$ DVCS)

- Current reconstruction pipeline in EICrecon
- Potential improvement in Forward (hit-level) & Barrel ML
- Potential improvement in Forward ML

Cross-section considerations:

Pure DVCS $\sigma_{\text{integrated}} \approx 0.47$ nb (All DVCS ~ 1.88 nb), and DVπ^0P $\sigma_{\text{integrated}} \approx 0.18$ nb.

Scaling factor: DVCS vs DVπ^0P ~ 1 : 0.096 $\Rightarrow$ **1.14 %**.

Summary

- Studied exclusive π^0 production physics channel at EIC
  - Extracted $\frac{d\sigma}{dt}$ distribution ⇒ Fourier transformation to extract spatial distribution
- Inclusive DIS Background
  - Multiple π^0 production expected.
  - ~ 60 % background at low-Q^2, mainly at high-t.
  - Limited statistics ⇒ 100 % uncertainty, hard to fully suppress.
- Machine Background
  - ~ 3.1 % contamination from machine-background photons in reconstructed events.
- Physics Background to DVCS
  - Single-photon misidentification: ~ 11.9% (conservative estimate).
  - Background contribution: ~ 1.14 %.

- Analysis Note available here: https://doi.org/10.5281/zenodo.17946081 (needs to be updated)

Backup Slides

From Thomas Ullrich (BNL/Yale)

Method L

- How the method works
  - Calculate p of outgoing A': $p_{A'} = p_A - (p_V + p_{e'} - p_e)$
  - Express and correct the outgoing nucleus in light cone variables:
    - $p^+_{A'} = E_{A'} + p_{z,A'}$
    - $p^2_{T,A'} = p^2_{x,A'} + p^2_{y,A'}$
    - $p^-_{A'} = (M^2_A + p^2_{T,A'})/p^+_{A'}$ where $p^-_{A'}$ is now modified by using the true mass M^2_A.
  - The corrected 4-momentum of the outgoing nuclei is now

$$p^{\text{corr}}_{A'} = \left[p_{x,A'},\ p_{y,A'},\ (p^+_{A'} - p^-_{A'})/2,\ (p^+_{A'} + p^-_{A'})/2\right]$$

  - In short, you are using the true invariant mass of the nucleus to compensate the smearing in the larger component of the electron 4-momentum by modifying $E_{A'}$ and $p_{z,A'}$ simultaneously.
  - Now simply: $t_{\text{corr}} = \left| p_A - p^{\text{corr}}_{A'} \right|^2$

12

Experiment – COMPASS@CERN

Table 2
Summary of the estimated relative systematic uncertainties for the $|t|$ and ϕ-dependent cross sections and the integrated cross section. The values are given in percent. Note that the uni-directional uncertainty $\sigma_\uparrow$ is a positive number, and $\sigma_\downarrow$ is a negative number.

Source	$\sigma^t_\uparrow$	$-\sigma^t_\downarrow$	$\sigma^\phi_\uparrow$	$-\sigma^\phi_\downarrow$	$\sigma_\uparrow$	$-\sigma_\downarrow$
μ^+ flux	2	2	2	2	2	2
μ^- flux	2	2	2	2	2	2
ECAL threshold	5	5	5	5	5	5
acceptance	4	7	4	7	4	7
kinem. fit	0	7	0	7	0	7
ω background	0	1	0	1	0	1
rad. corr.	2	5	2	5	2	5
LEPTO norm.	5–28	3–11	5–51	3–21	8	3
yield mismatch	4–13	3–7	0–12	3–12	9	5
$\sum$	12–29	13–18	12–53	13–25	14	14

Phys. Lett. B805 (2020) 135454; arXiv:1903.12030

Table 2: Summary of the estimated relative systematic uncertainties on the measured $|t|$ and ϕ-dependent cross sections and on the extracted cross-section contributions $\frac{d\sigma_U}{dt} = \frac{d\sigma_T}{dt} + \varepsilon\frac{d\sigma_L}{dt}$ and $\frac{d\sigma_{TT}}{dt}$ in the full kinematic range. The values are given as a percentage. Note that the uni-directional uncertainty $\sigma_\uparrow$ ($\sigma_\downarrow$) has to be used with positive (negative) sign.

source	$\sigma^t_\uparrow$	$\sigma^t_\downarrow$	$\sigma^\phi_\uparrow$	$\sigma^\phi_\downarrow$	$\sigma_{U\uparrow}$	$\sigma_{U\downarrow}$	$\sigma_{TT\uparrow}$	$\sigma_{TT\downarrow}$
μ^+ flux	2	2	2	2	2	2	2	2
μ^- flux	2	2	2	2	2	2	2	2
acceptance	4	4	4	4	4	4	4	4
ECAL0 threshold	5 – 7	1	4 – 8	1	5	1	4	1
ECAL1 threshold	1 – 2	1	1 – 3	1	1	1	1	1
χ^2 of kinematic fit	3	5	2.0 – 5.6	4.0 – 8.8	3	5	3	4
LEPTO background	6 – 10	6 – 10	6 – 16	6 – 16	8.3	8.3	1	1
LEPTO normalisation	2 – 3	2 – 3	2 – 5	2 – 5	2.6	2.6	2	2
ω background	0	1.5 – 2.7	0	1.4 – 5.7	0	2.4	0	2.4
radiative corrections	6	3	6.3	3.6	6	3	2	2
Σ	12 – 16	10.1 – 13.1	11.6 – 22.4	9.6 – 20.1	13.3	11.7	7.7	7.1

Phys. Lett. B870 (2025) 139832; arXiv:2412.19923

Experiments – Hall A and CLAS@JLab

- Typical total systematic uncertainty:

  4 – 8 % 10 %

  (depends on kinematic setting)

Table 5.5: Systematic errors for exclusive π^0 cross-section. The DIS study error includes the systematic from radiative correction, electron identification, and spectrometer acceptance.

Systematic	Value (%)
Exclusivity Cuts	0.5
DIS study	3.5
Clustering threshold	0.5
Photon Energy cut	0.5
Total Quadratic (helicity-independent)	3.6
Beam polarization	1
Total Quadratic (helicity-dependent)	3.75

Phys. Rev. Lett. 127, 152301 (2021); arXiv:2011.11125

TABLE IV. Summary table of systematic uncertainties. B denotes bin-to-bin and O indicates overall uncertainties.

Source	Bin-to-bin or overall	Average uncertainty (%)
Proton ID	B	~2.5
Fiducial cut	B	~4.7
Cut on energy of photon detected in the EC	B	~1.6
Cut on missing mass of the $e'\gamma\gamma$	B	~2.5
Cut on invariant mass of 2 photons	B	~2.9
Cut on missing energy of the $ep'\gamma\gamma$	B	~3.2
Radiative corrections	B	~2.9
Total beam charge on target	O	<1
Target length	O	0.2
Absolute normalization	O	6.0

Phys. Rev. C90, 025205 (2014); arXiv:1405.0988