



Deep Virtual J/ψ ($e^+ e^-$) Meson Production at ePIC

$$e + p \rightarrow e' + J/\psi(ee^+) + p'$$

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Analysis Note: [10.5281/zenodo.21770935](https://zenodo.org/record/21770935)

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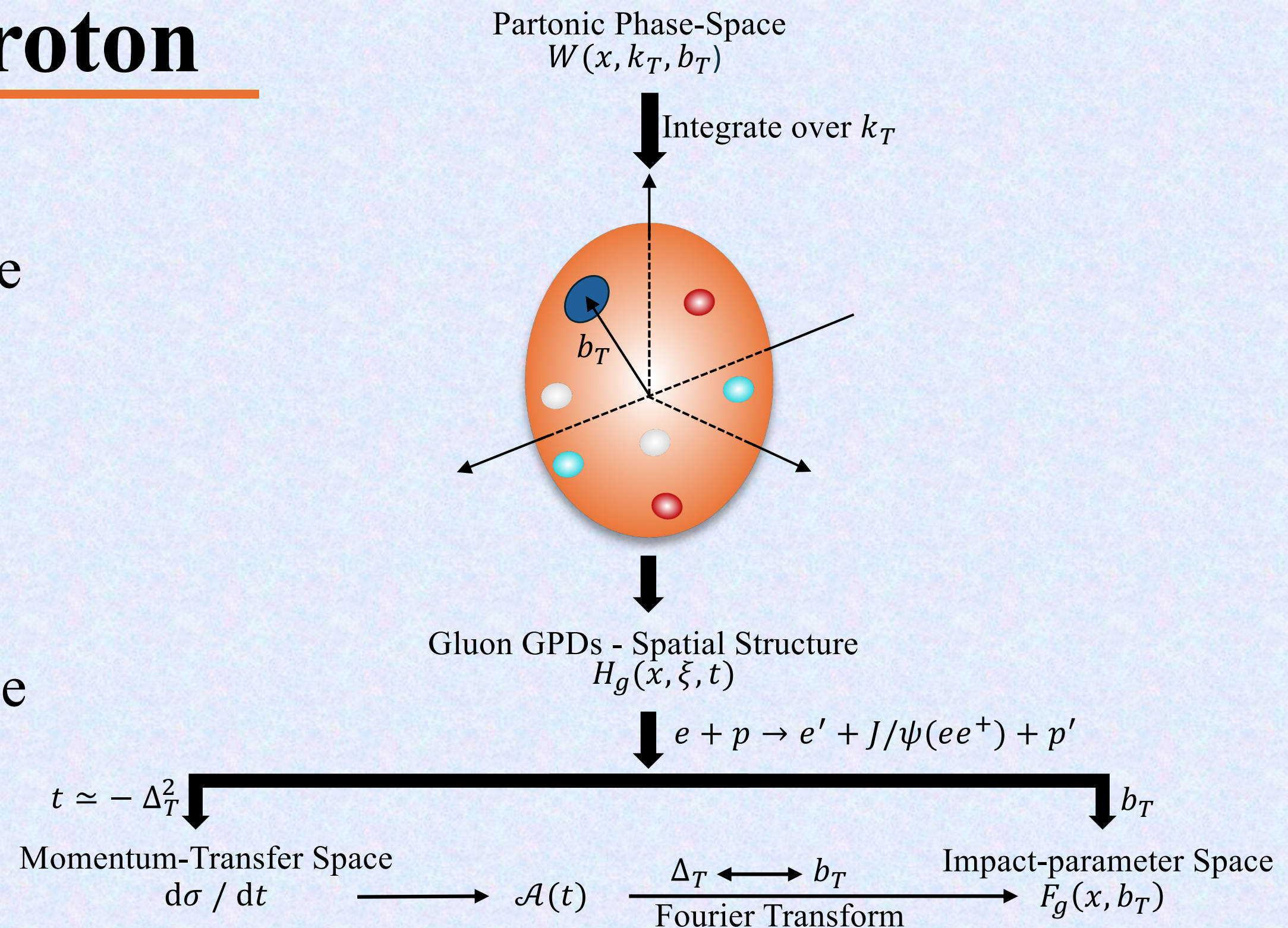
**University of
New Hampshire**



**U.S. DEPARTMENT OF
ENERGY**

The EIC: Imaging the Proton

- Understand the quark and gluon structure of the proton
- Map partons in both momentum and position - toward 3D nucleon imaging
- Probe gluon dynamics over a broad range of x and Q^2

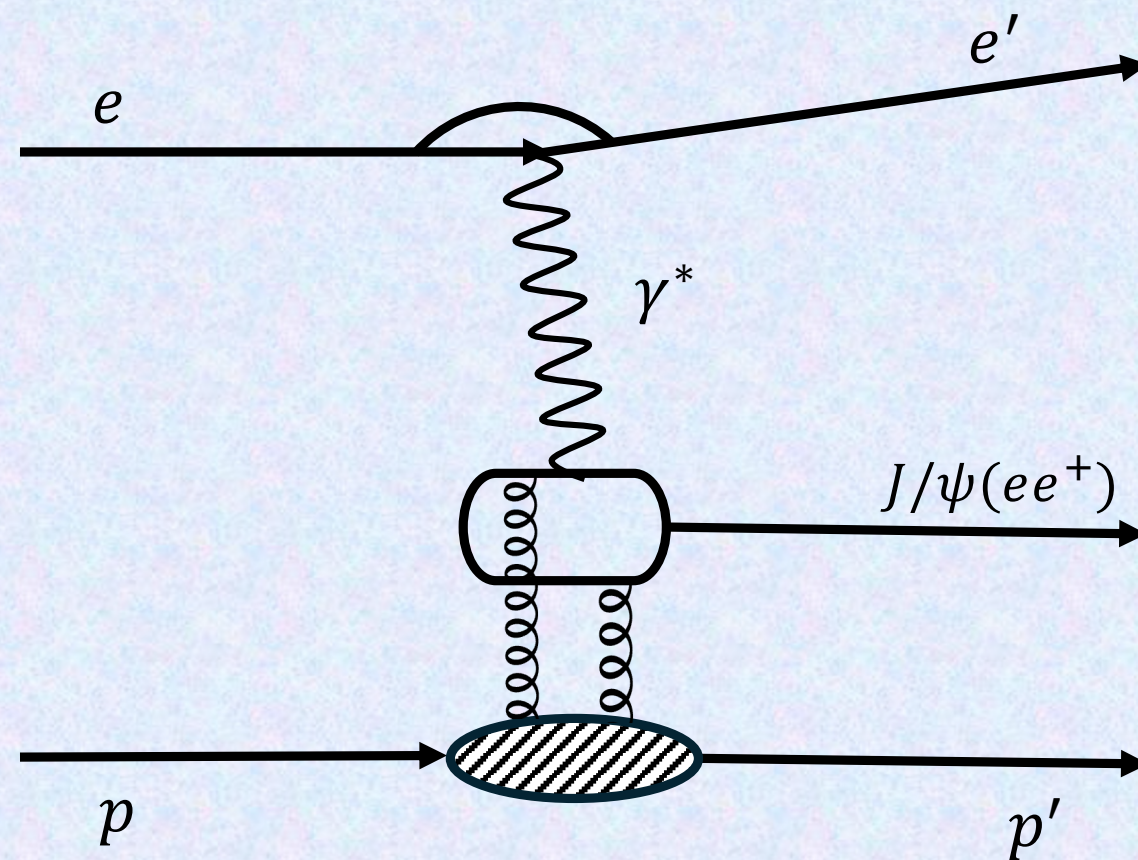


Exclusive processes provide access to GPDs and transverse spatial imaging

Nuclear Physics News, 31(4), pp. 15–19. doi:
 10.1080/10619127.2021.1954435
Nucl.Phys.A 1026 (2022) 122447

Exclusive $J/\psi \rightarrow ee^+$ production

$$e + p \rightarrow e' + J/\psi(ee^+) + p'$$



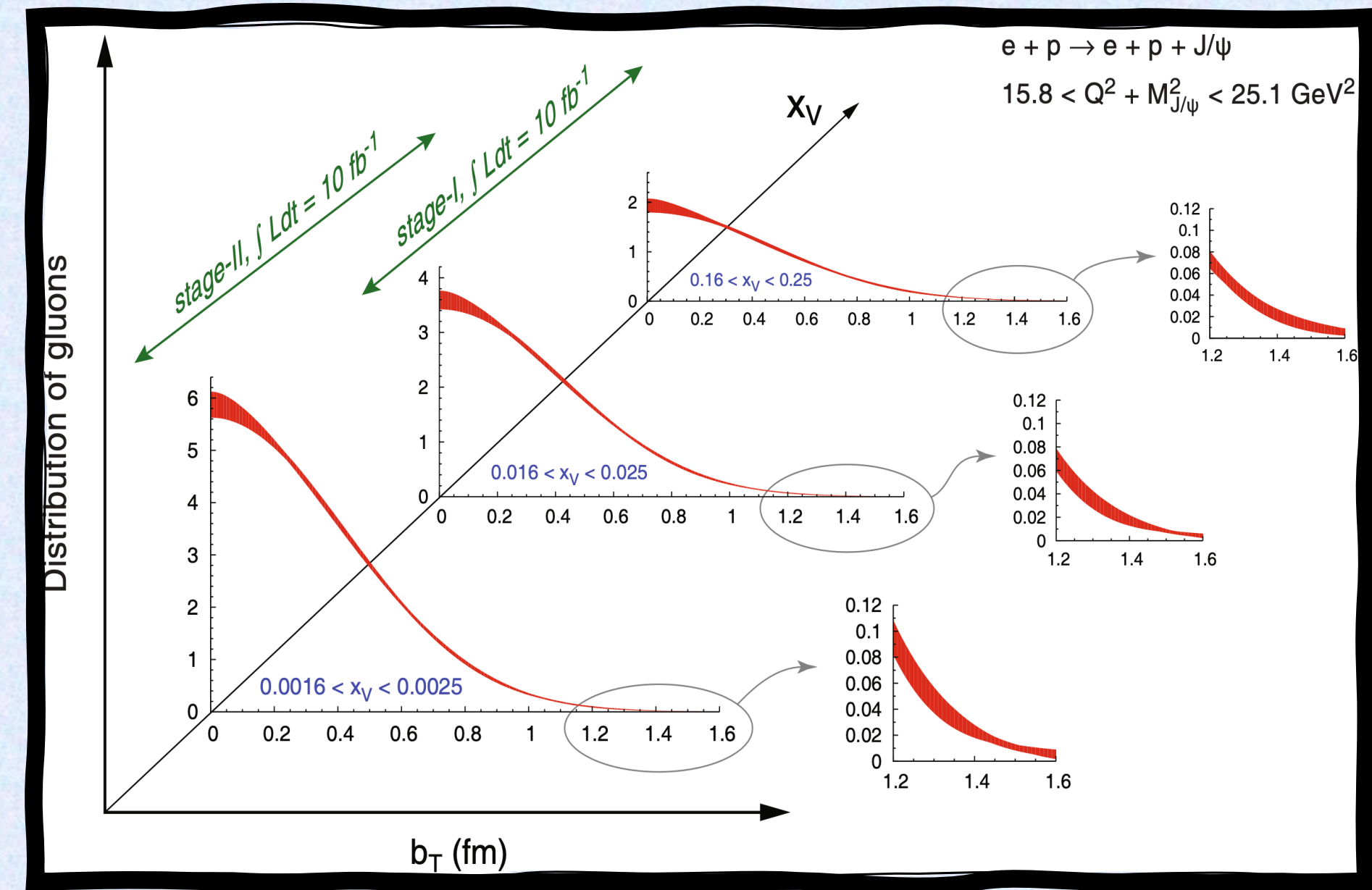
Why this channel matters:

- Dominated by gluon exchange $\rightarrow$ direct sensitivity to gluon GPDs
- The heavy charm mass provides a hard scale $\rightarrow$ controlled pQCD description
- Fully exclusive final state $\rightarrow$ clean event selection and precision kinematics

$J/\psi \rightarrow e^-e^+$ is a golden channel for **3D gluon imaging at the EIC**

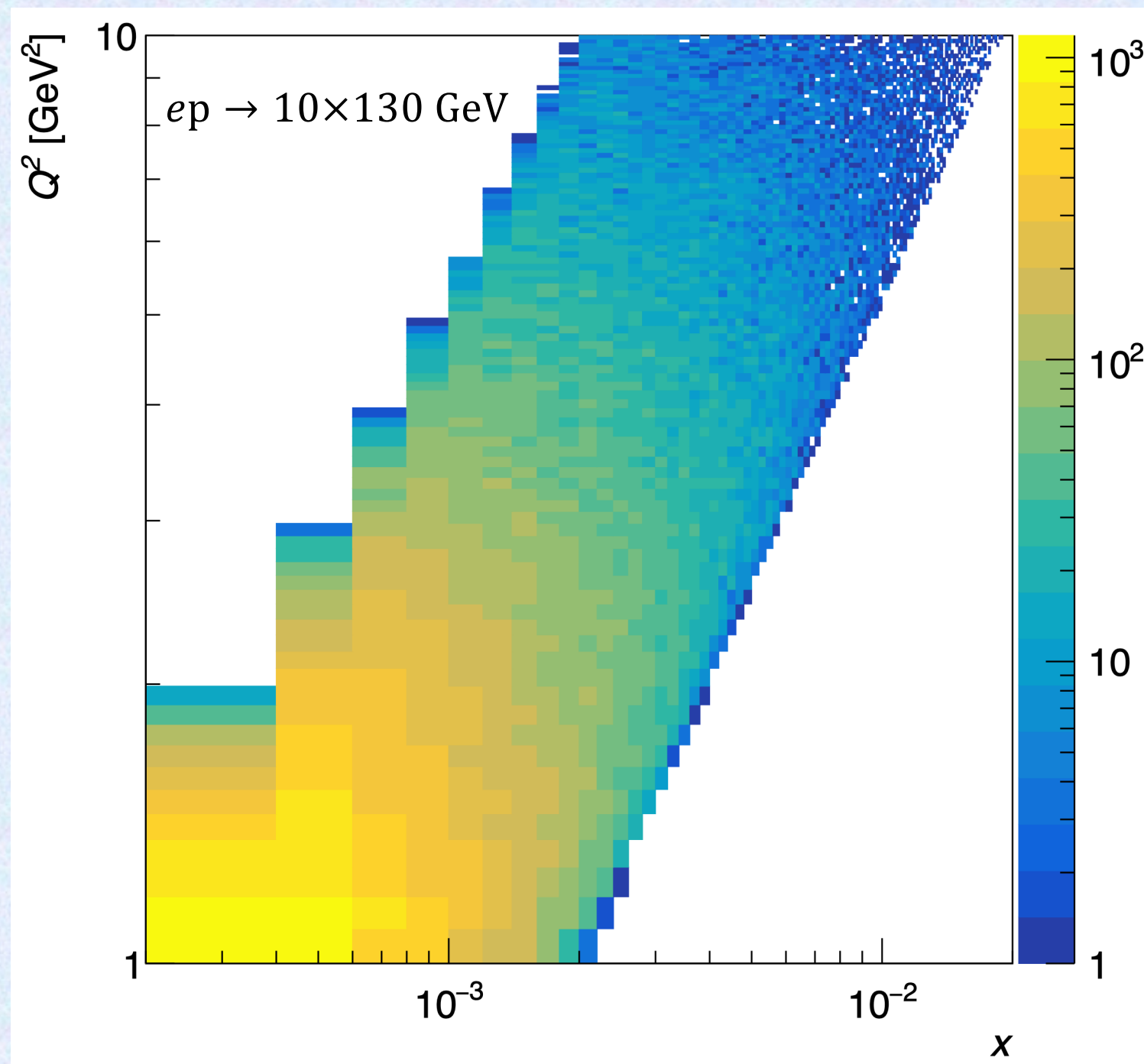
Physics Goals

- Access gluon Generalized Parton Distributions (GPDs) through exclusive J/ψ production.
- Measure the t -dependence of the cross section.
- Extract the transverse spatial distribution of gluons in the proton.
- The momentum transfer t is Fourier conjugate to the transverse impact parameter b_T , enabling spatial imaging of gluons.



Eur.Phys.J.A 52 (2016) 9, 268
Nucl.Instrum.Meth.A 361 (1995) 197-208

Sample Generation with lAger



lAger, modular Monte Carlo framework for events simulation applicable to both fixed-target experiments and collider setups.

➤ lAger3.6.1-1.0

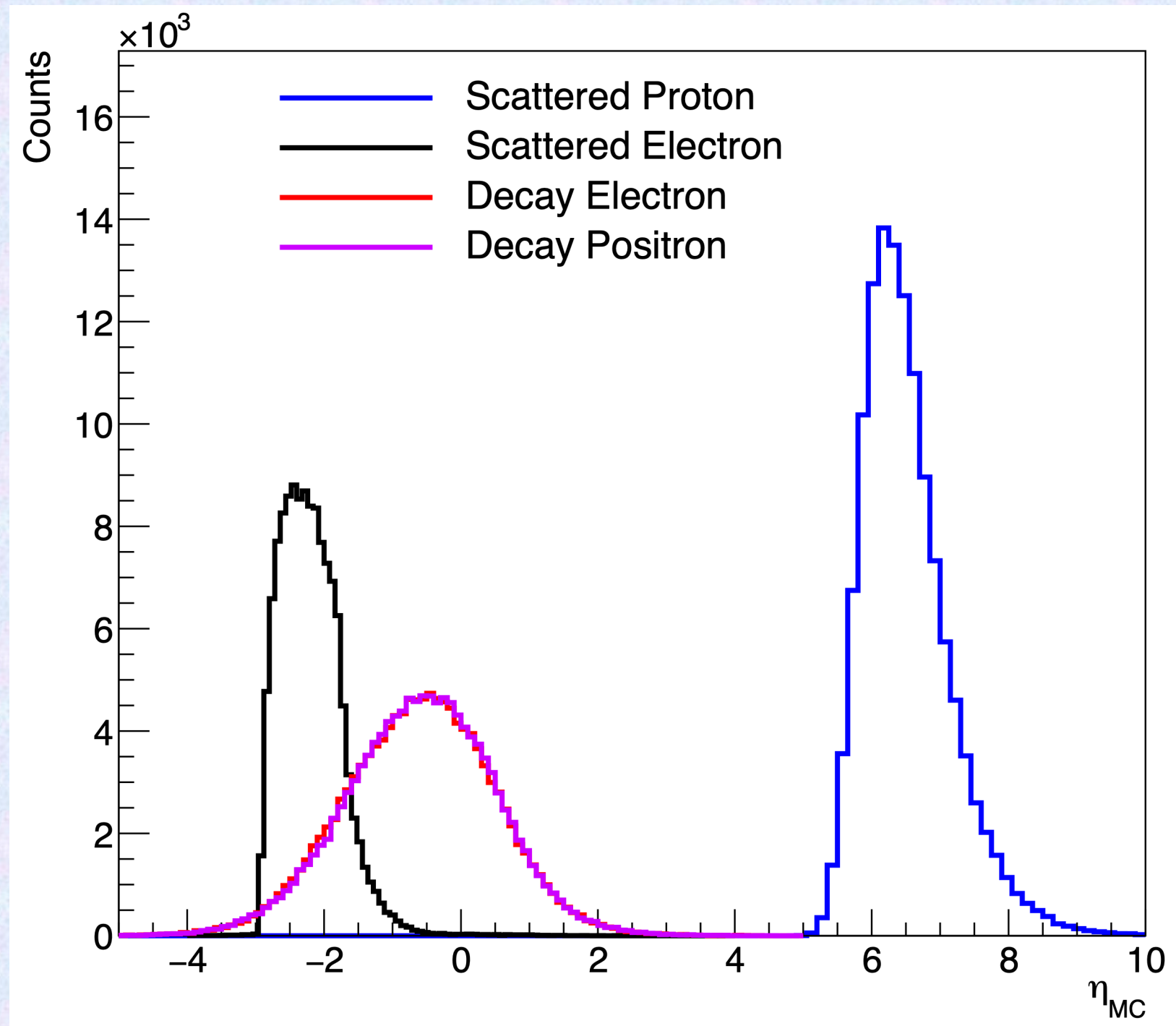
Generator Level Kinematic Ranges

- $e + p$: 10×130 GeV
- $1 < Q^2 < 10$
- $0 < x_{bj} < 1$
- $0.1 < y < 1$
- **Events:** $N = 199,430$
- **Integrated luminosity:** $L_{int} = 10 \text{ fb}^{-1}$

The results presented are based on ePIC April Simulation Campaign, **26.04.1**

*S. Joosten. Argonne l/A-event Generator. GitLab repository, 2021.
url: https://eicweb.phy.anl.gov/monte_carlo/lager.*

All Final-State Particles



$$e + p \rightarrow e' + J/\psi(ee^+) + p'$$

All particles are well separated in η and fall into distinct detector regions

- ✓ Scattered electrons go into the backward region in η
- ✓ Decay electrons and positrons go into the central region
- ✓ Recoiling protons go into the very forward region

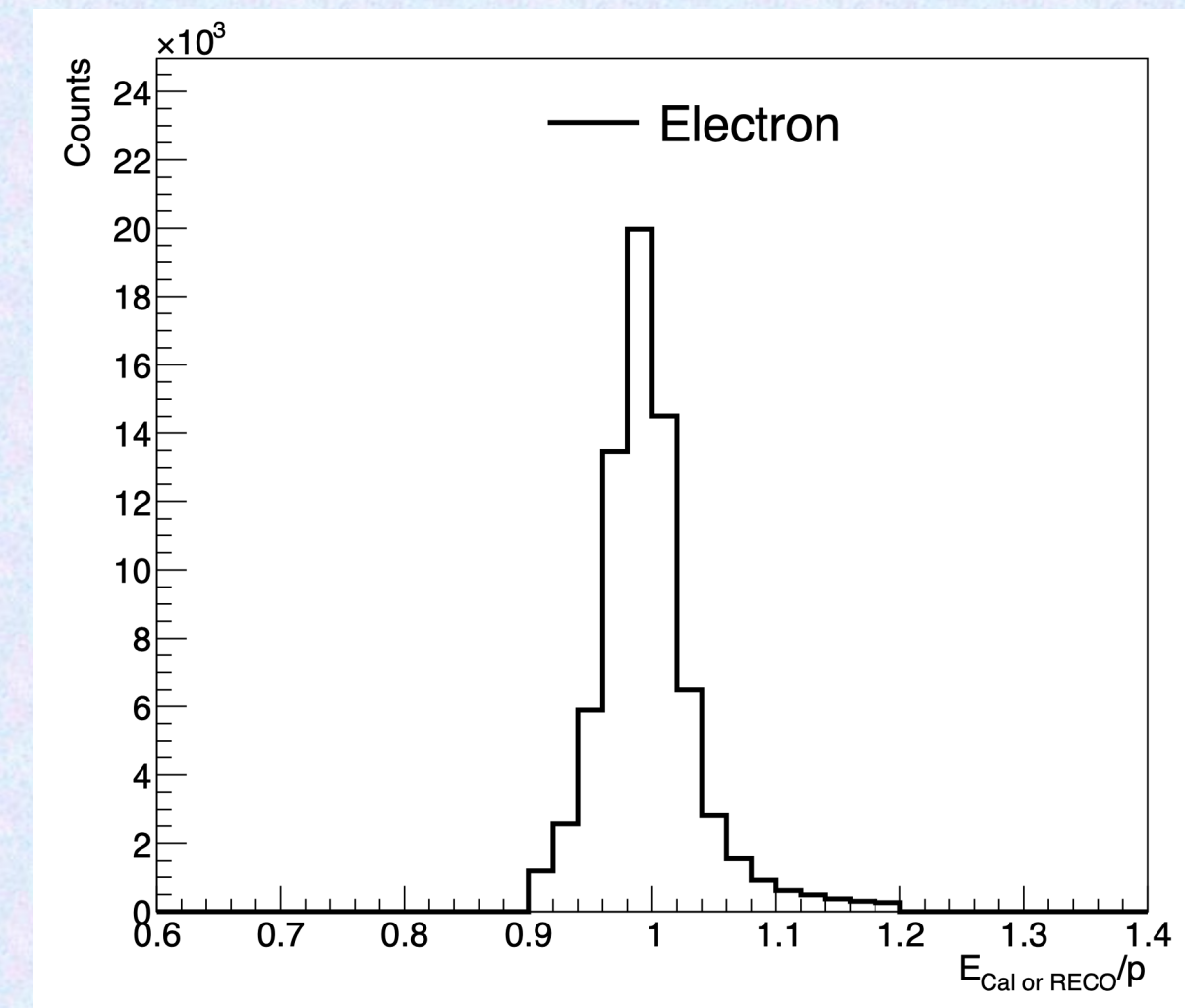
Leptons Identification Summary

Electron / Positron Selection

- Require 3 tracks
- Energy–momentum deposition:
 $0.9 < E/p < 1.2$

J/ψ Candidate

- ✓ Formed from e^+e^- pair
- ✓ Invariant mass window:
 $2.9 < M_{e^+e^-} < 3.2 \text{ GeV}$



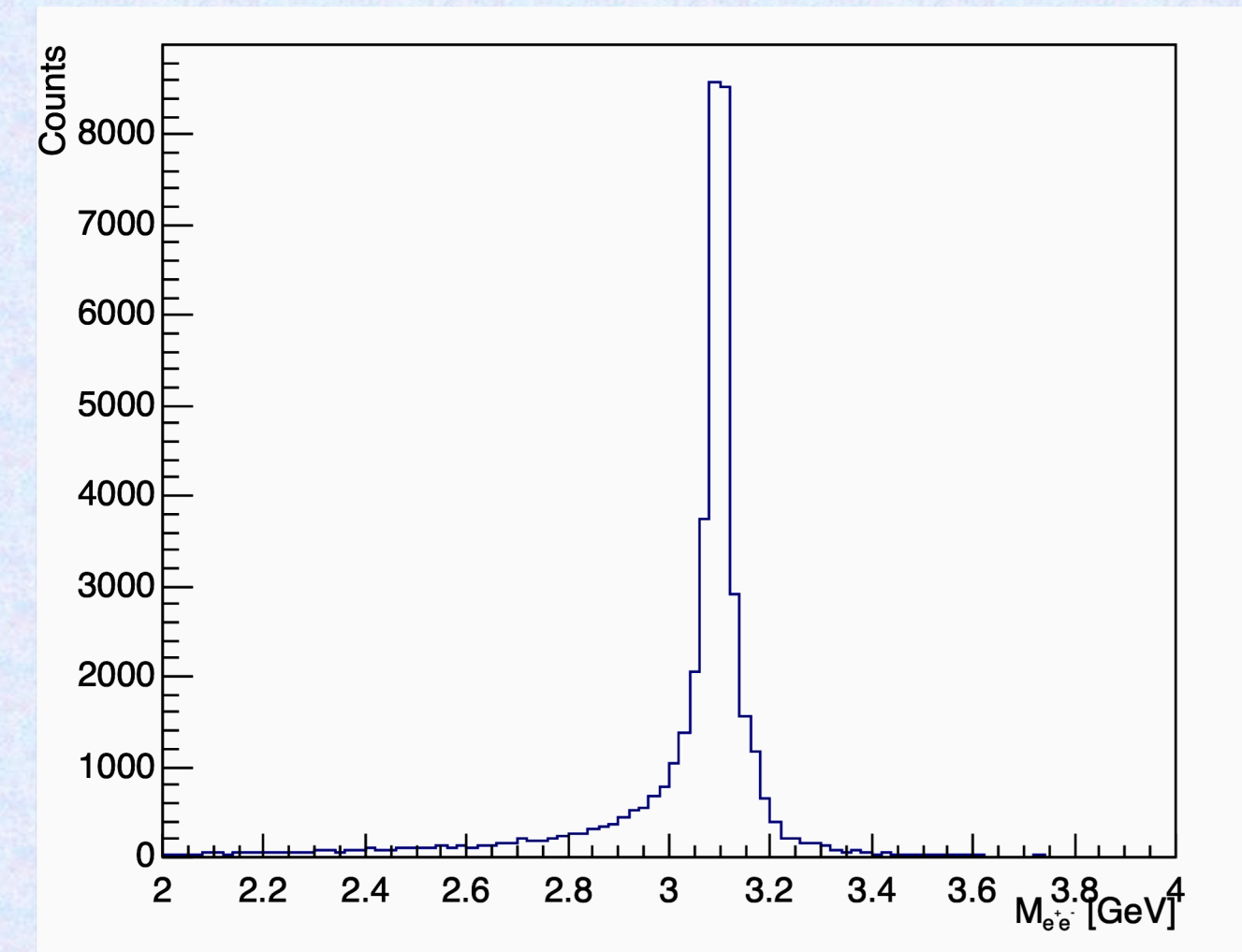
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Leptons Identification Summary

Scattered Electrons

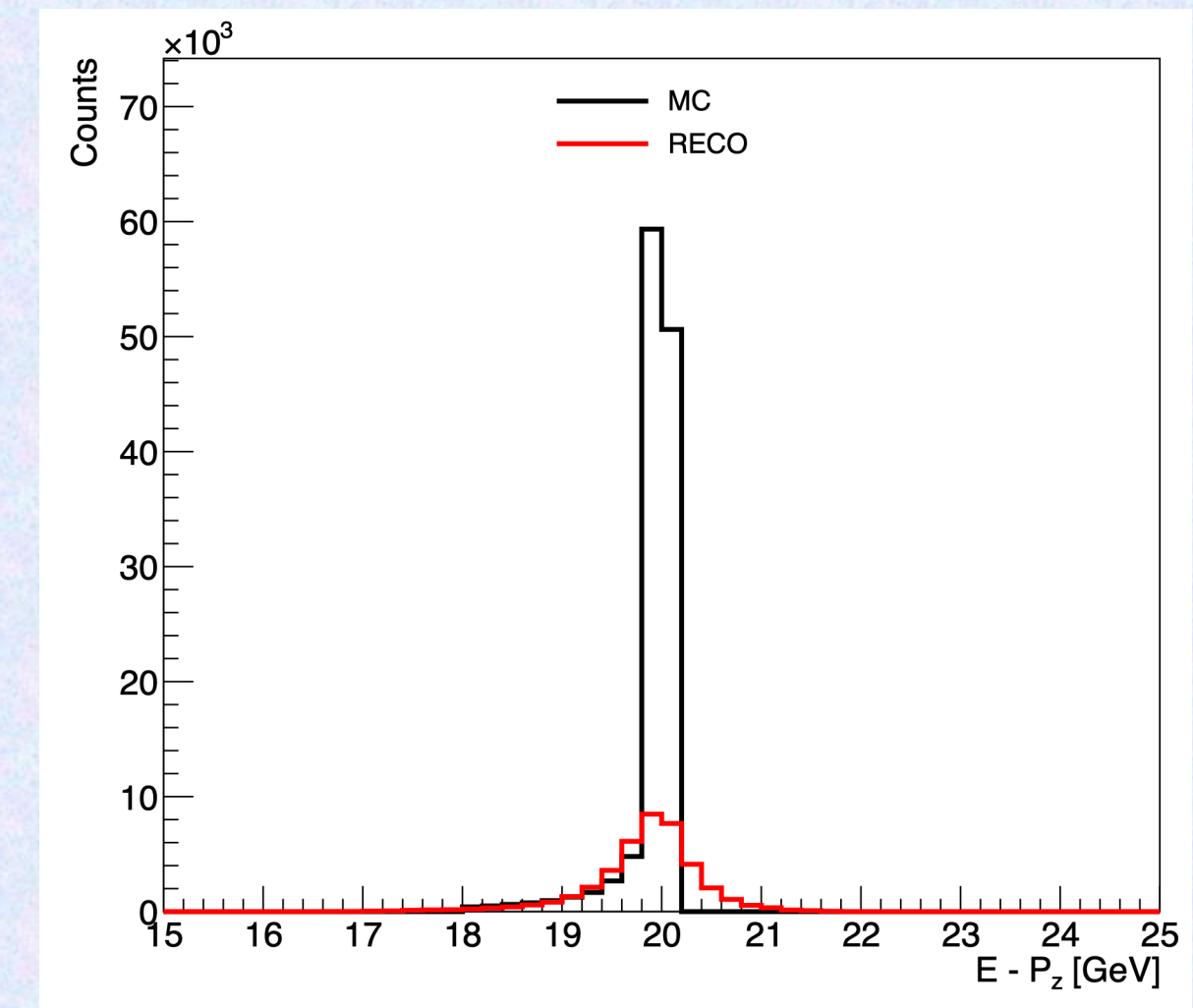
- Suppress Photoproduction & Radiative Backgrounds
- Longitudinal energy balance cut:

$$15 < E - p_z < 25 \text{ GeV}$$

Track-Cluster Matching

- Between the reconstructed electron track and the corresponding calorimeter cluster.
- Most candidates are concentrated at small ΔR
 $\left(\sqrt{\Delta\eta^2 + \Delta\phi^2}\right)$, indicating good spatial matching. We require

$$\Delta R < 0.4$$



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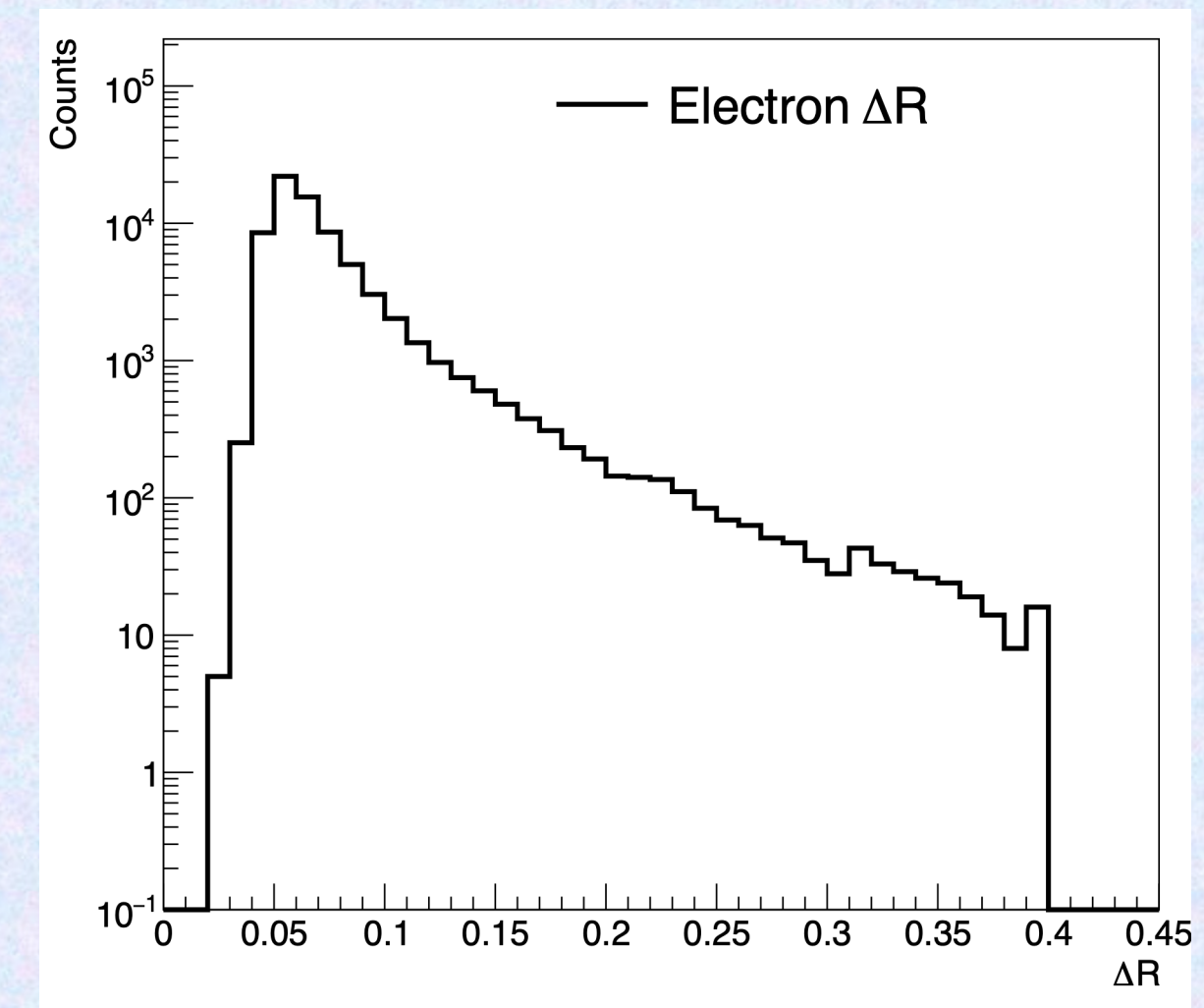
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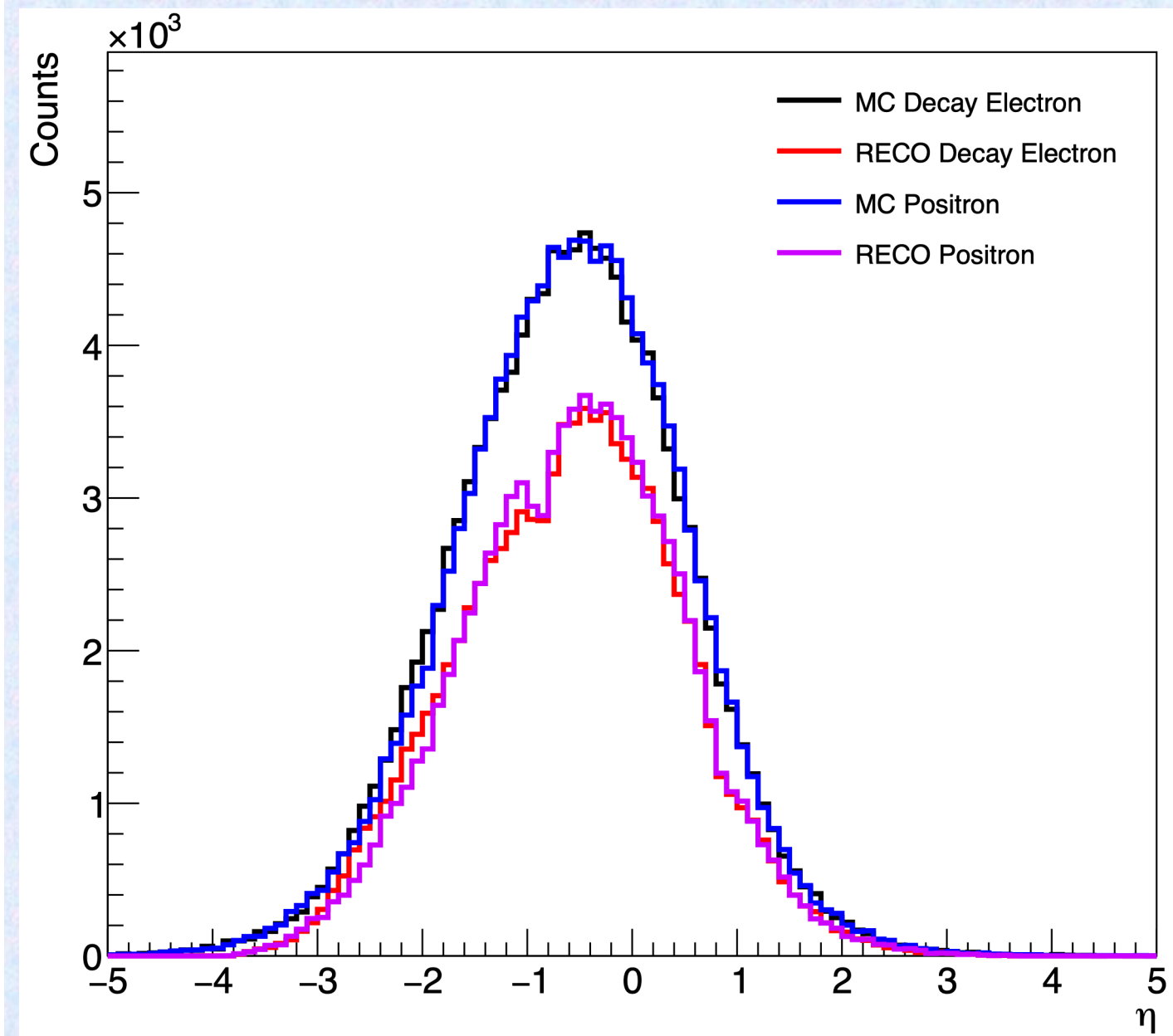
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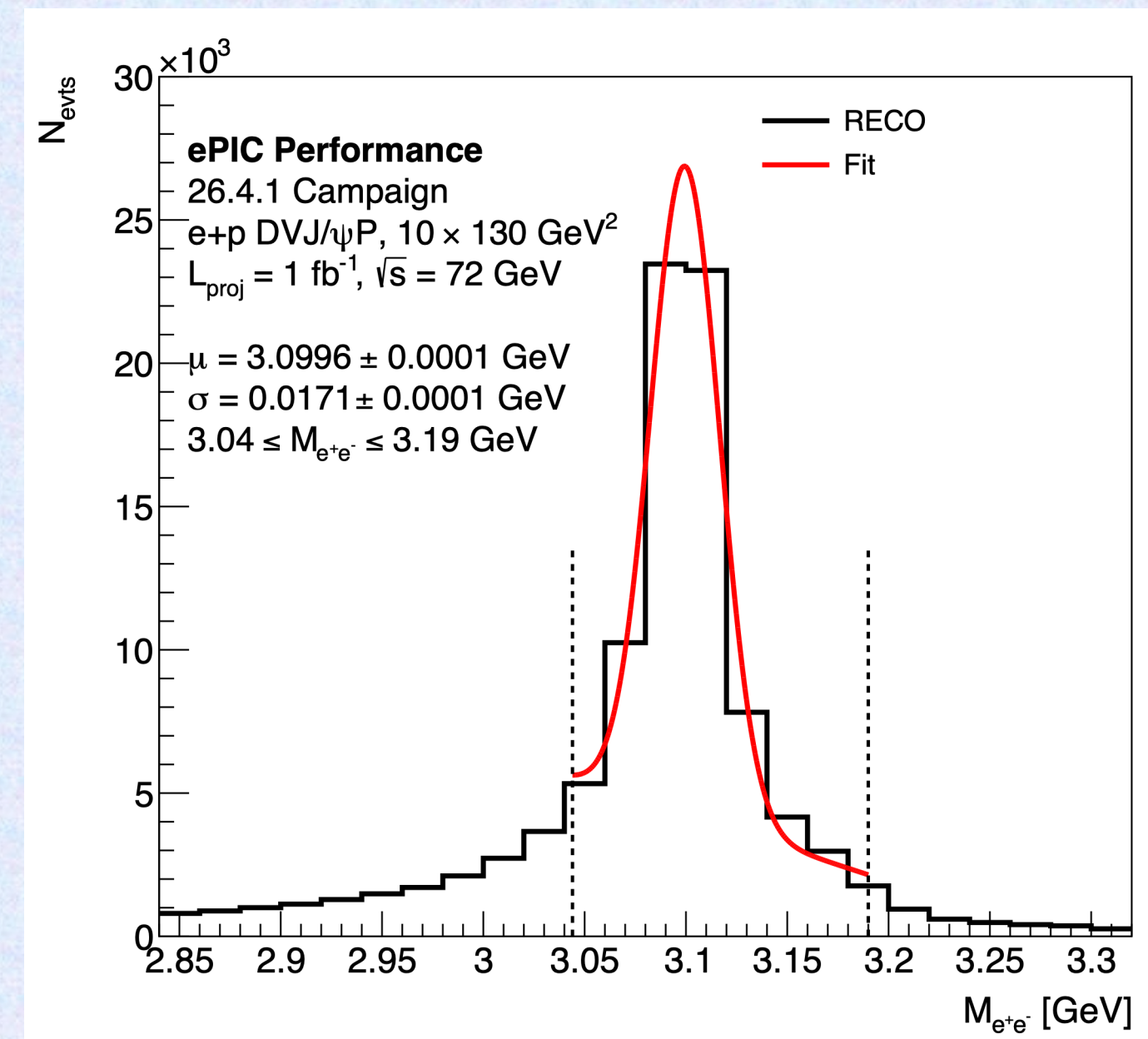


Invariant $M_{J/\psi}$ Reconstruction



- Correct lepton assignment
- Detector resolution
- Clean J/ψ signal extraction

Good agreement between **MC** and **RECO** confirms: Proper electron-positron identification, and no significant acceptance bias.



Width, $\sigma \approx 17$ MeV with excellent mass resolution and signal purity

On the Scattered Proton

Proton Selection: within angular acceptance in **B0** or **Roman Pot (RP)**

- $6 < \theta_{p \text{ in } B0}^{RECO} < 20$ mrad, and
- $0 < \theta_{p \text{ in } RP}^{RECO} < 4.7$ mrad

There is a gap of ≈ 1.3 mrad between the B0 and RP

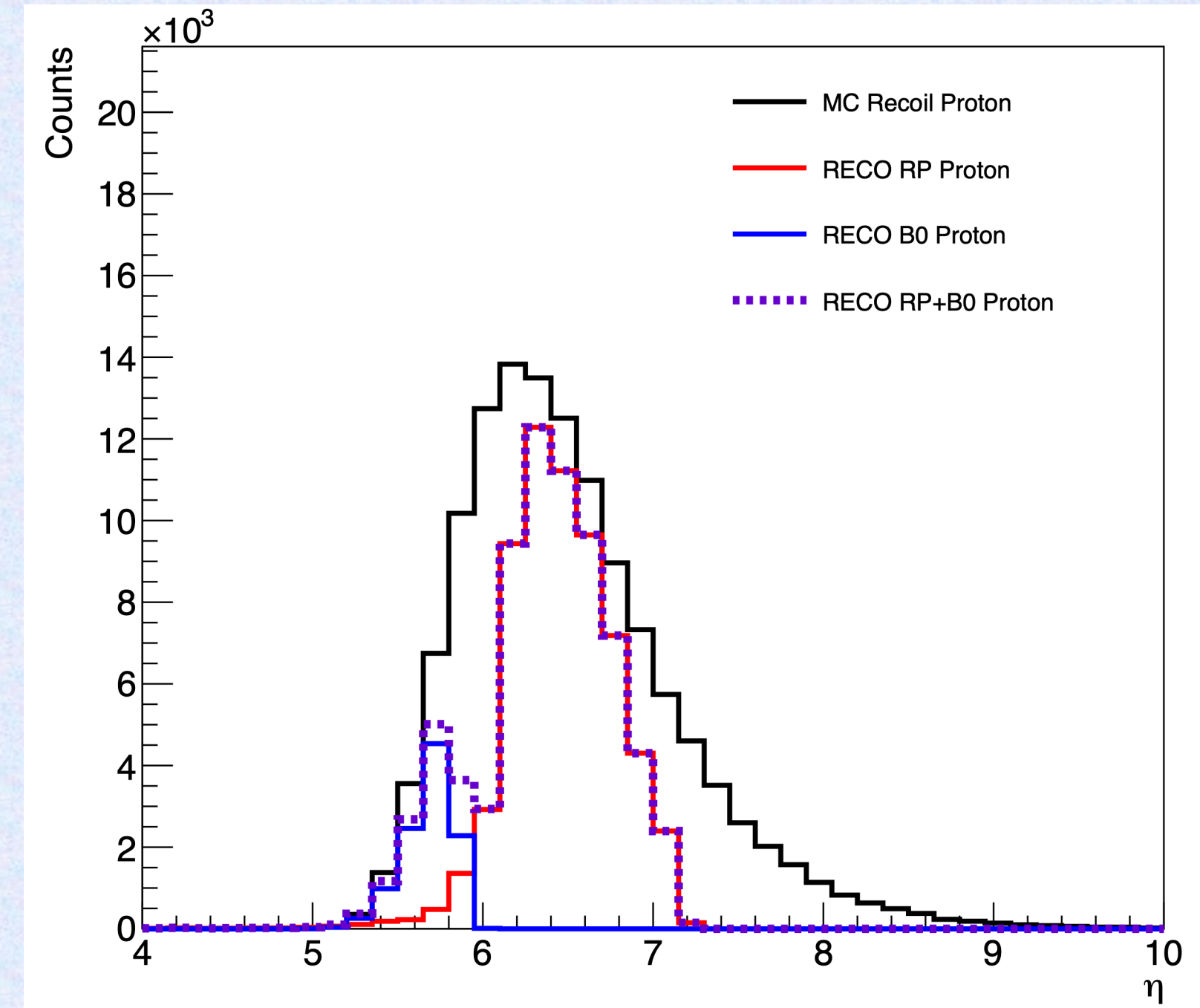
RP Proton Cuts

- $\eta > 4$
- Positive charge
- $p_T > 0.2$ GeV
- 25 mrad counter-rotation along y-axis

B0 Proton Cuts

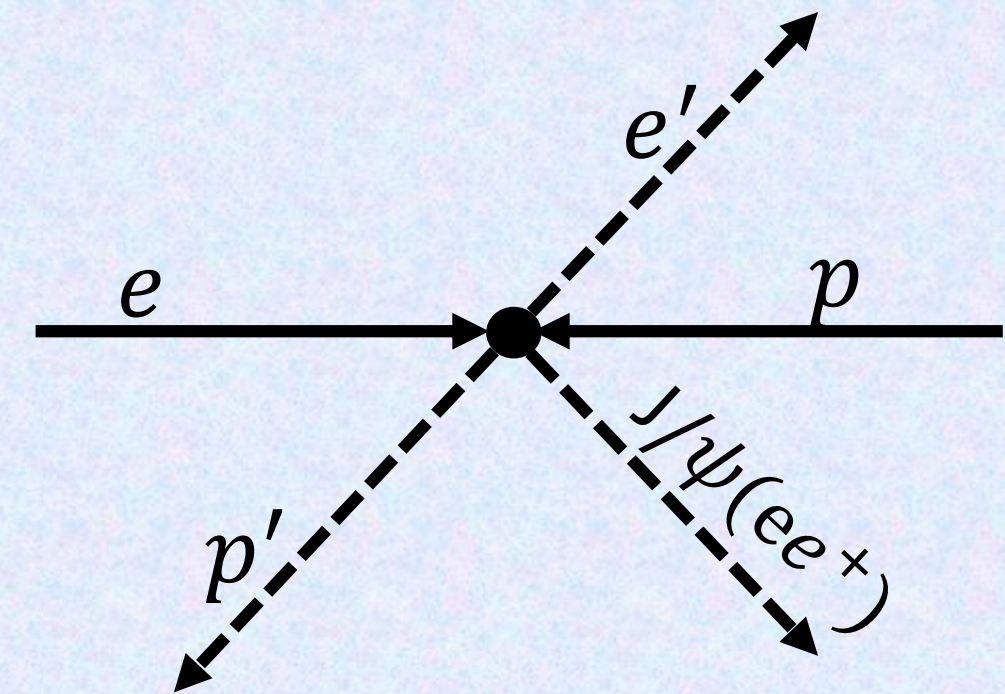
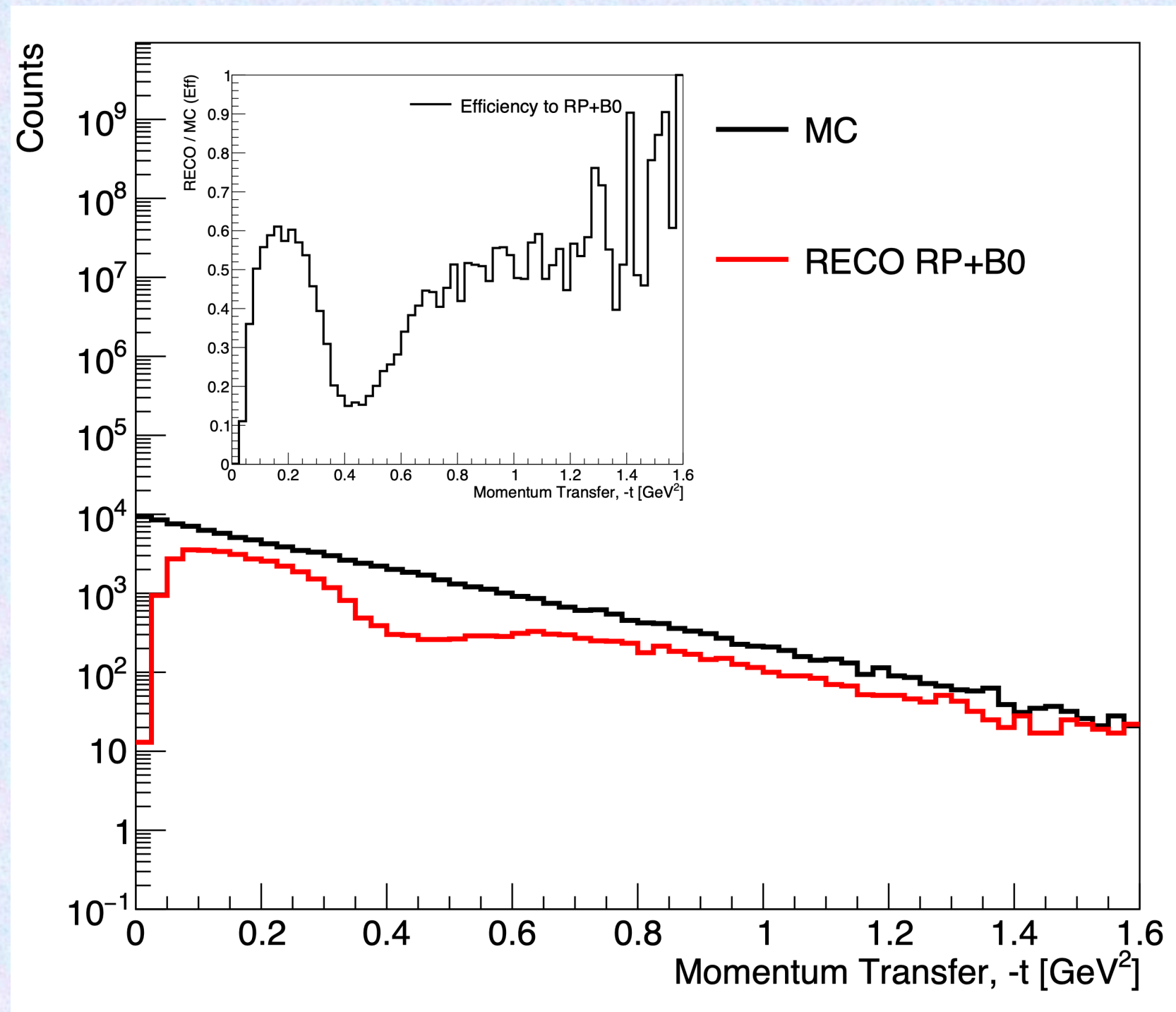
- $\eta > 4$
- Positive charge
- 25 mrad counter-rotation along y-axis

RP+B0 provide complementary coverage



t – Distribution Reconstruction

Method 1: Proton Recoil



The squared four-momentum transfer at the proton vertex is defined as:

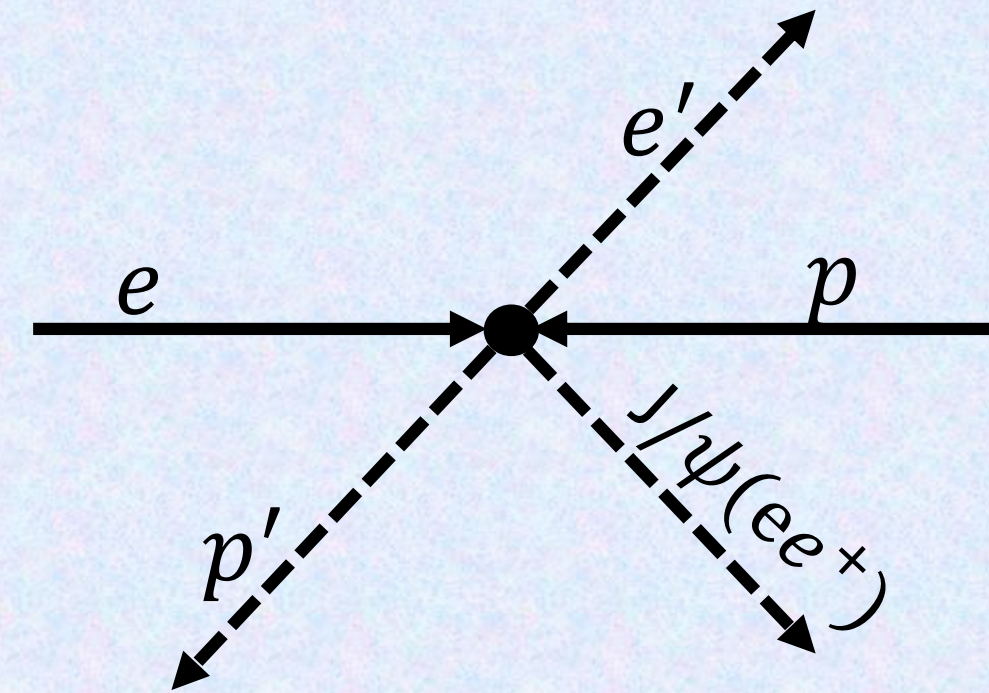
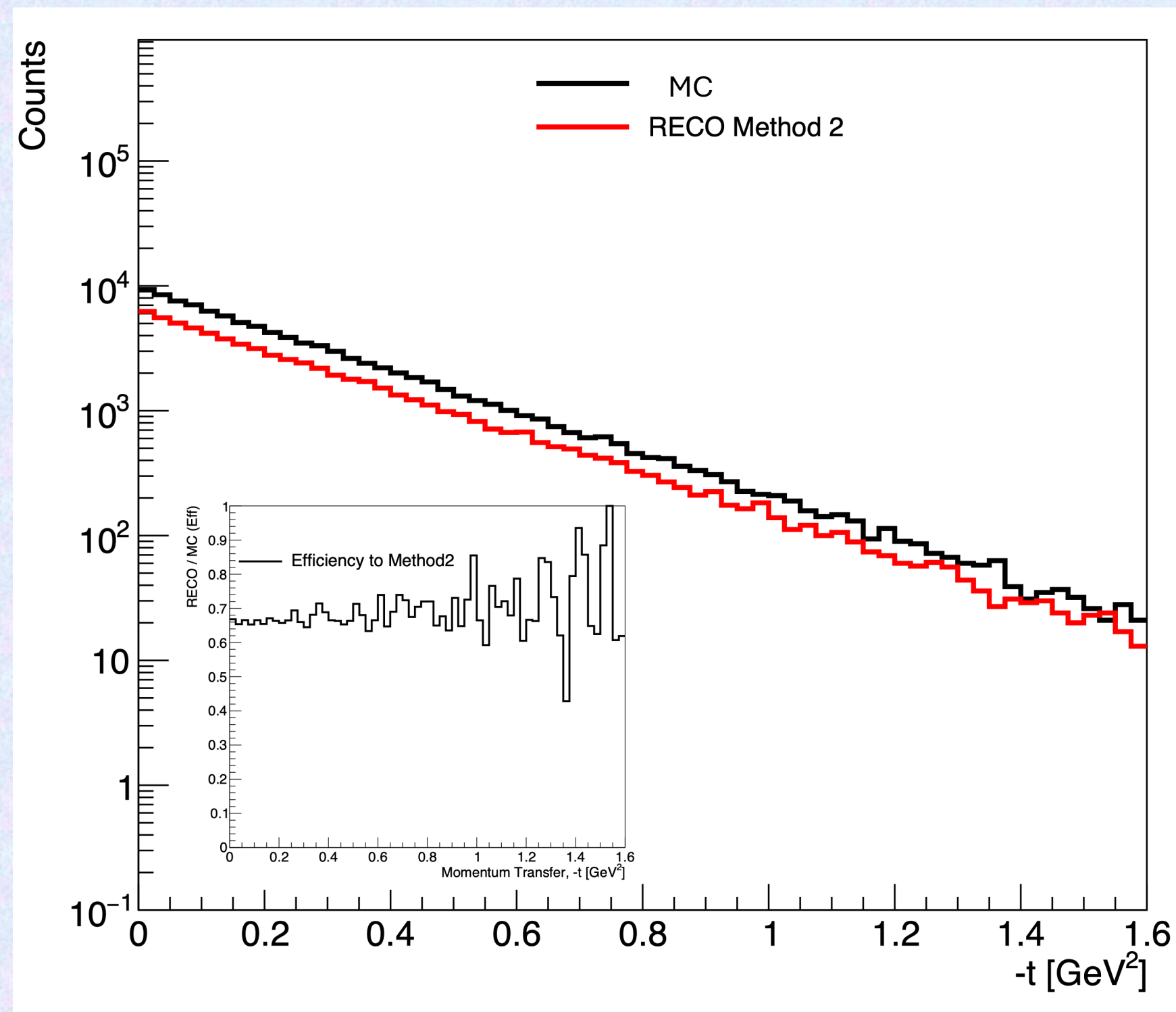
$$t_{Method\ 1} = (p - p')^2$$

p = initial proton four-momentum

p' = final-state proton (or recoil system) four-momentum

t quantifies how much momentum is transferred to the target during the interaction

Method 2: Inferred Outgoing Proton Momentum



From;

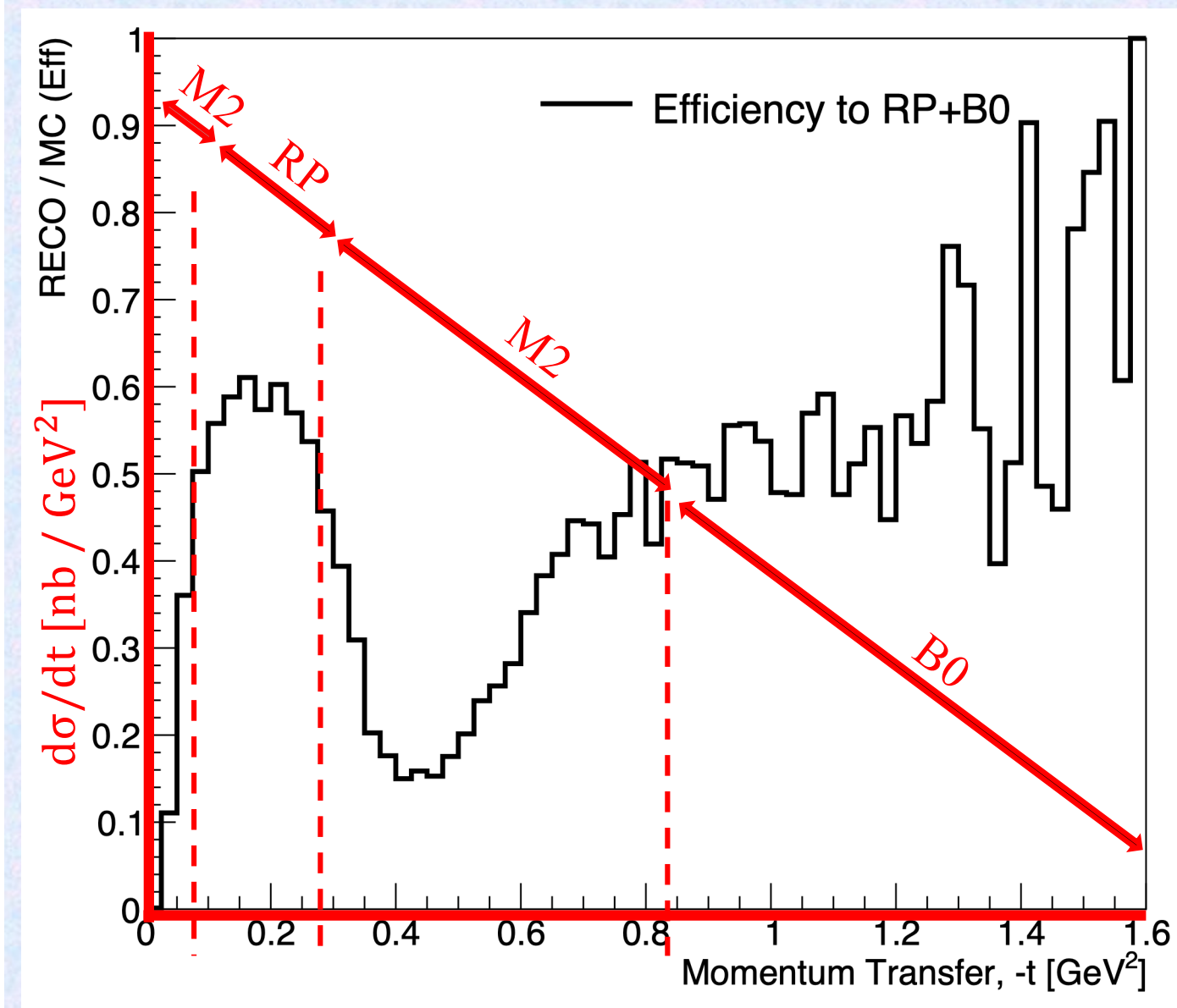
$$P_{p'} = P_e + P_p - P_{e'} - P_{J/\psi(ee^+)}$$

we derive;

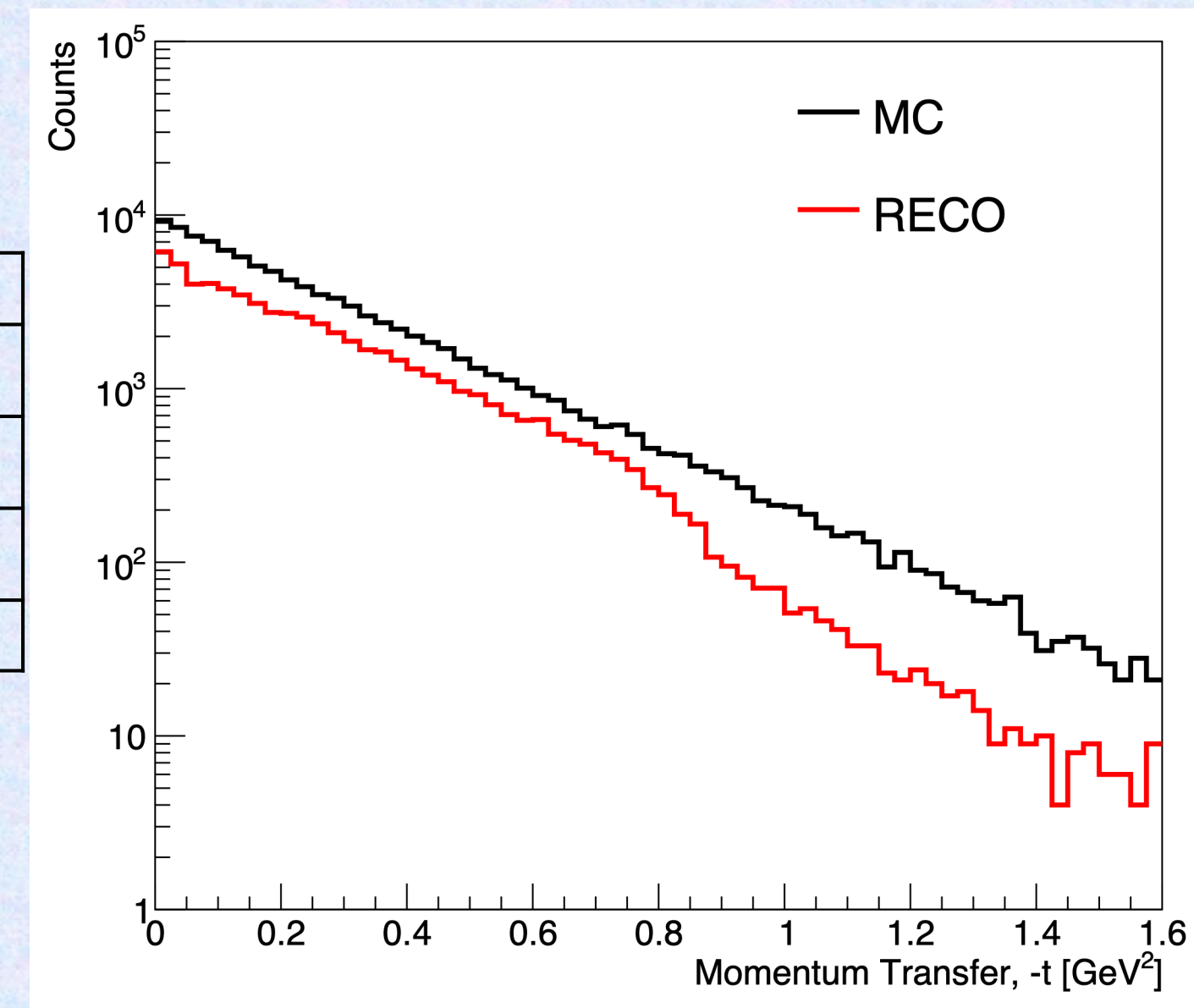
$$t_{\text{Method 2}} = (p - p'_{\text{corr}})^2$$

t – Distribution Reconstruction

Method 1 / Method 2: $t_{reco} = \begin{cases} t_{Method\ 2}; & \text{Method 2 regions} \\ t_{proton}; & \text{RP/B0 regions} \end{cases}$

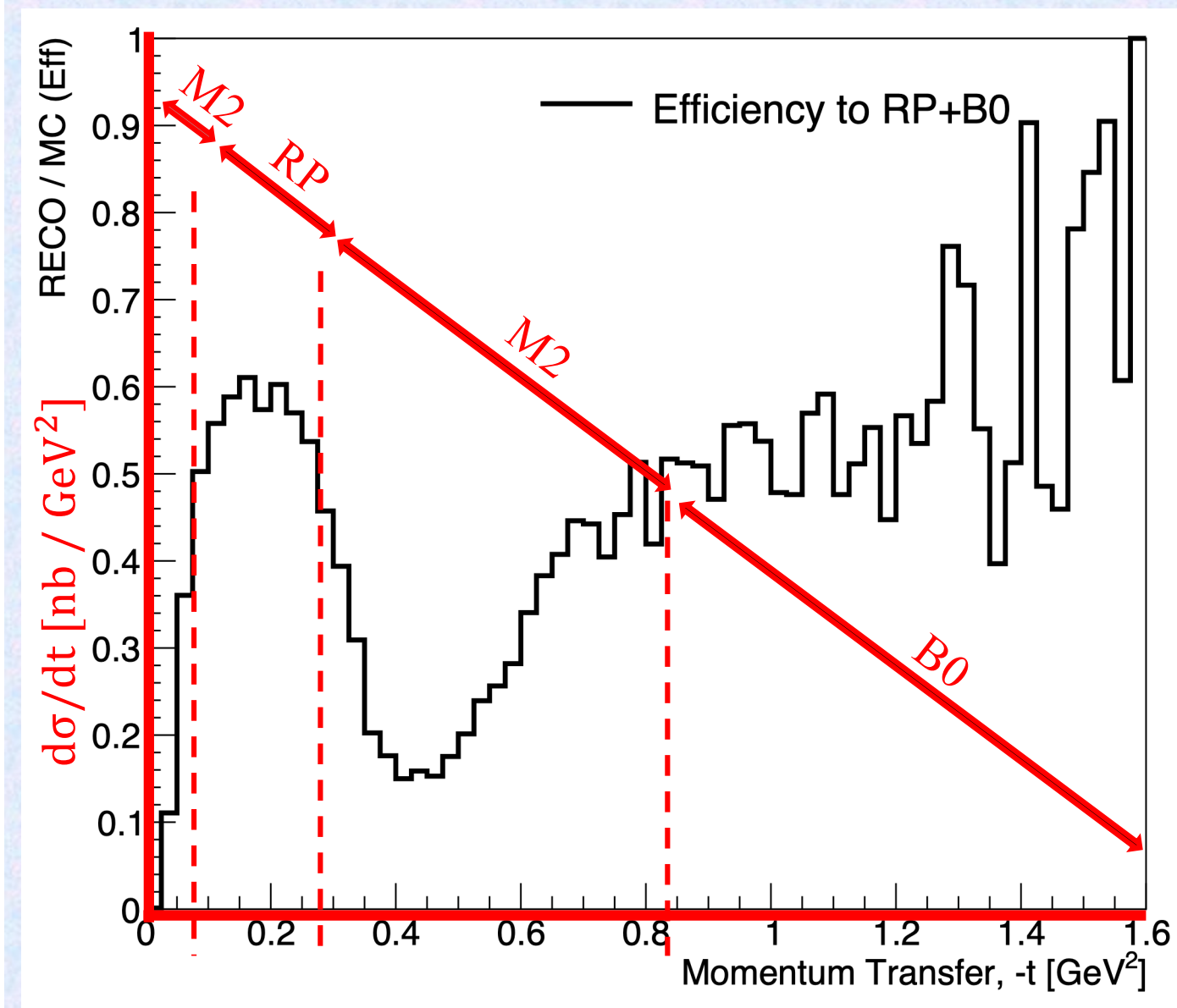


$-t$ Range [GeV^2]	Reconstruction Method
$(0.000 \leq -t < 0.078)$	Method 2 (M2)
$(0.078 \leq -t < 0.270)$	Roman Pot (RP)
$(0.270 \leq -t < 0.830)$	Method 2 (M2)
$(0.830 \leq -t < 2.000)$	B0

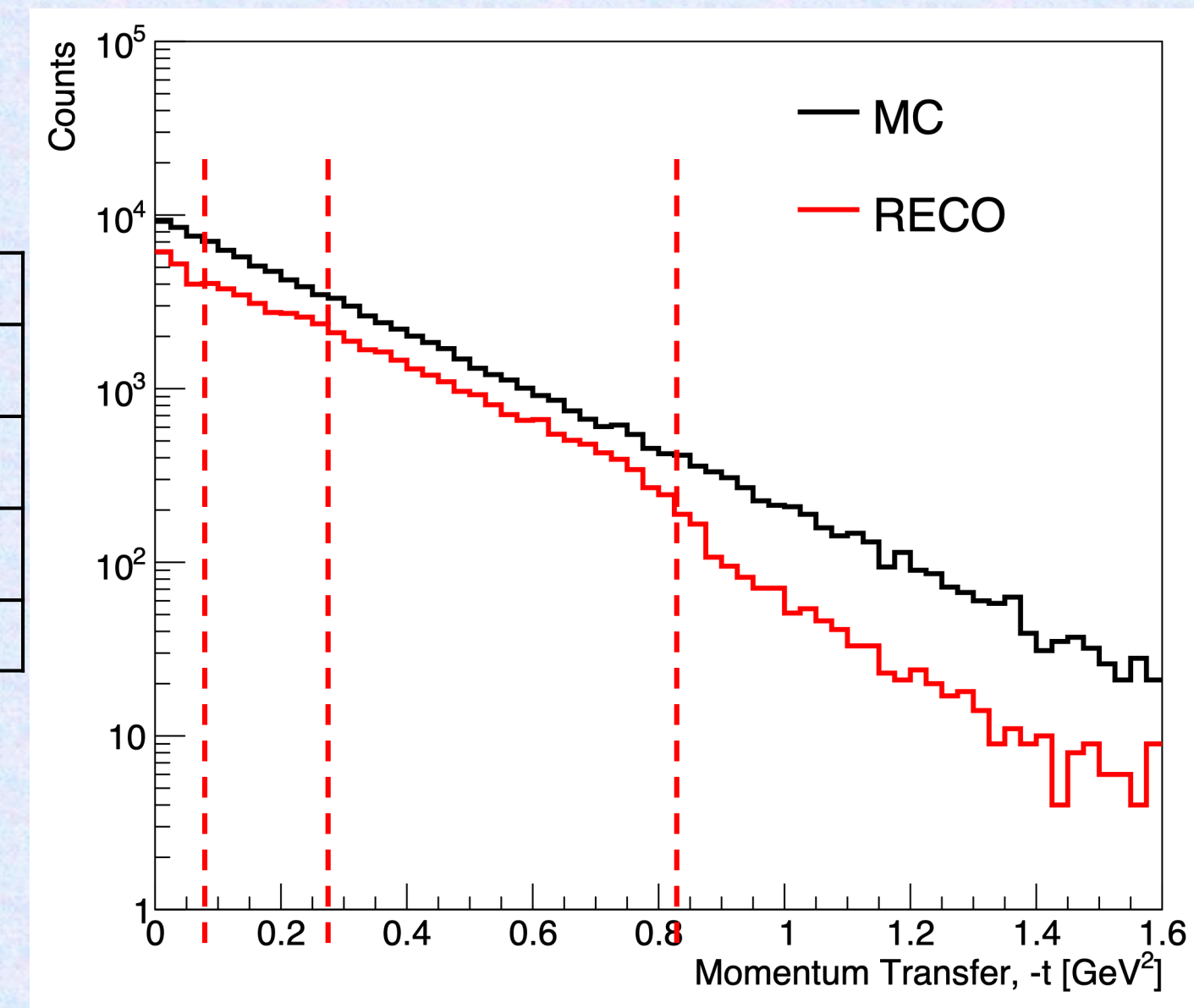


t – Distribution Reconstruction

Method 1 / Method 2: $t_{reco} = \begin{cases} t_{Method\ 2}; & \text{Method 2 regions} \\ t_{proton}; & \text{RP/B0 regions} \end{cases}$



$-t$ Range [GeV ²]	Reconstruction Method
$(0.000 \leq -t < 0.078)$	Method 2 (M2)
$(0.078 \leq -t < 0.270)$	Roman Pot (RP)
$(0.270 \leq -t < 0.830)$	Method 2 (M2)
$(0.830 \leq -t < 2.000)$	B0



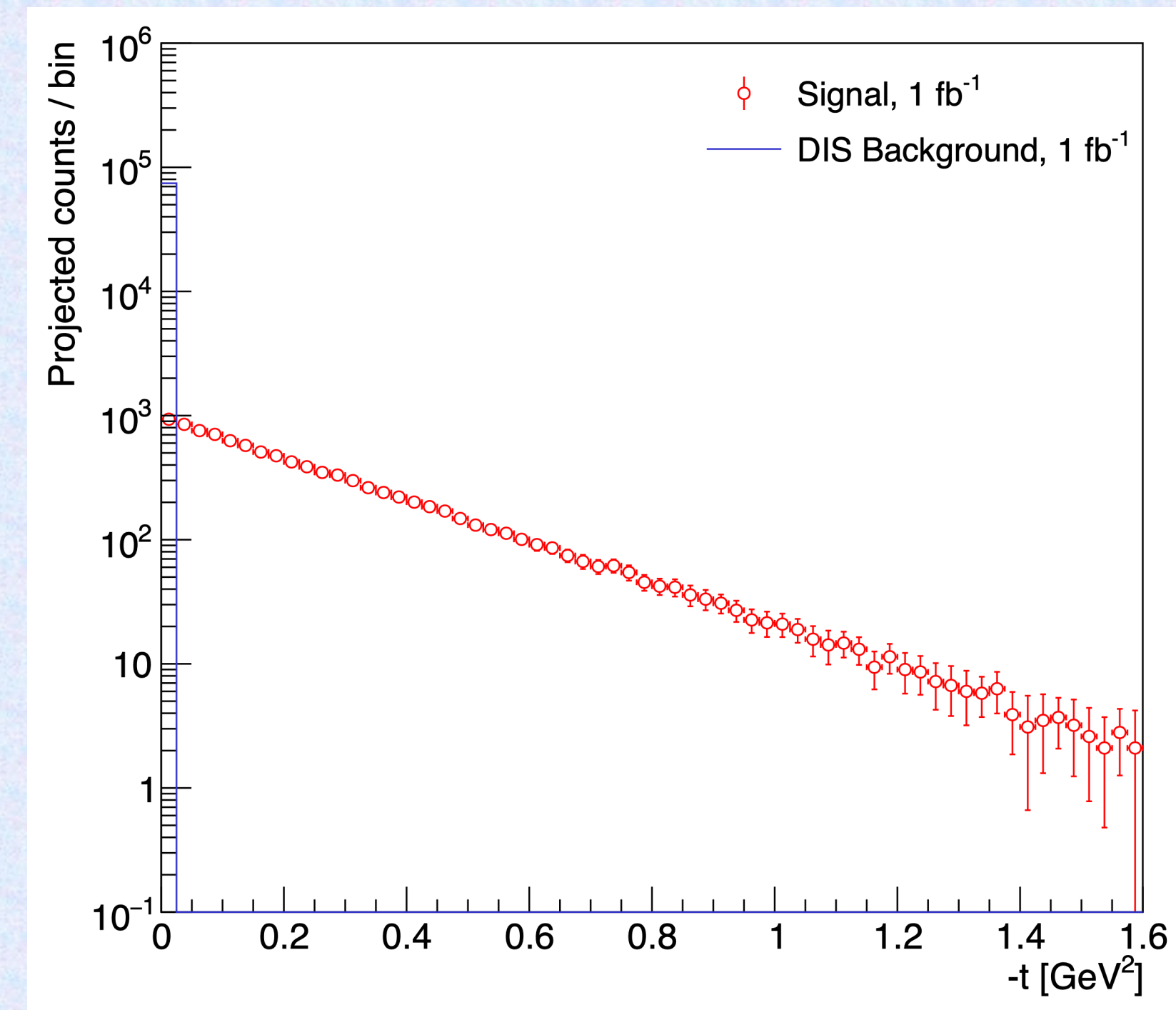
Why consider DIS?

- *ep* DIS has a **much larger cross section** than exclusive J/ψ production.
- Hadrons, particularly **charged pions**, can be misidentified as $e^\pm$ and mimic a $J/\psi \rightarrow e^-e^+$ candidate.

Sample: from Pythia

After full selection

- **RP+B0 (Method 1):** 0 DIS events
- **Method 2:** 2 DIS events



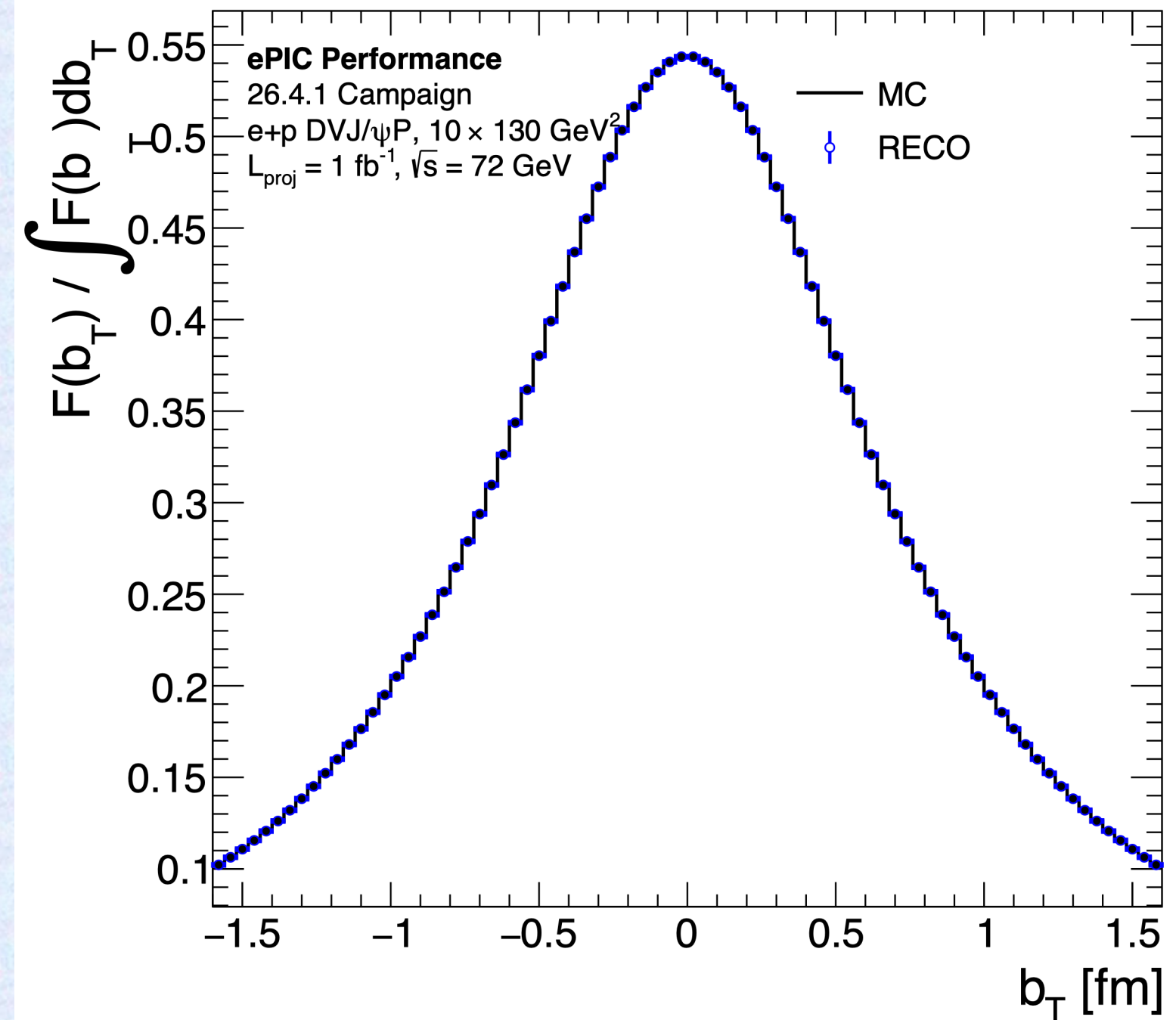
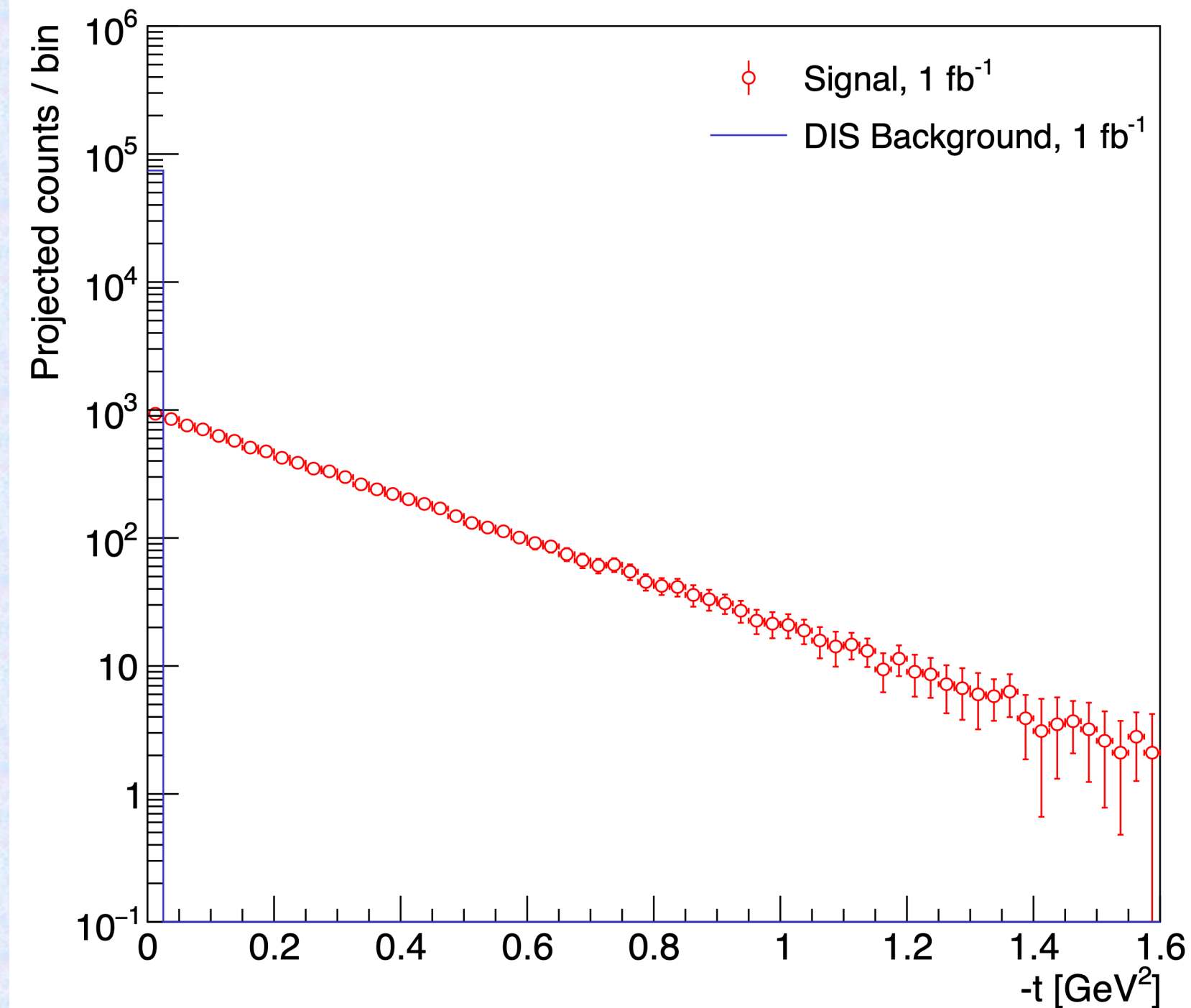
Both signal and DIS samples are normalized to 1 fb^{-1} . Residual DIS contamination is therefore not a problem after the full exclusive J/ψ selection.

Notable Sources of Uncertainties

- **Luminosity**
1.5%
Global normalization uncertainty
Estimated from: EIC Yellow Report luminosity projection
- **Event Selection**
3%–17%
Dominant contribution; varies across kinematic bins
Estimated from: Variation of analysis selection cuts
- **DIS Background**
0%–1%
Small statistical contribution
Estimated from: Inclusive DIS sample, normalized to the target luminosity
- **Total Systematic Uncertainty**
~3%–18%
Sources combined in quadrature

Event-selection variations dominate the systematic uncertainty, while the DIS background contribution is small.

Early Science Projection Results

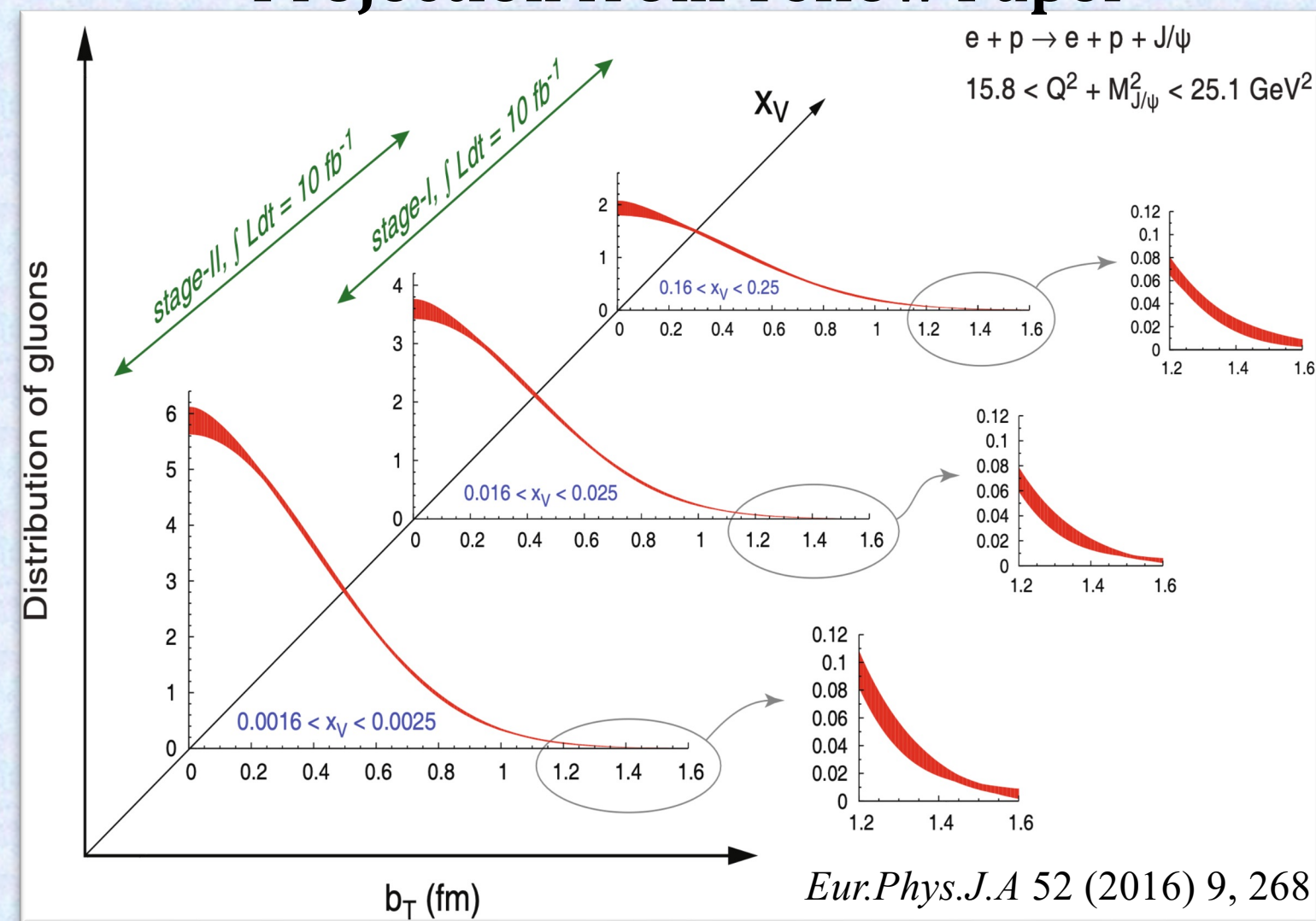


Early science projection for 1 fb⁻¹ ePIC data can provide t -dependent measurements to begin constraining the transverse spatial distribution of gluons in the proton.

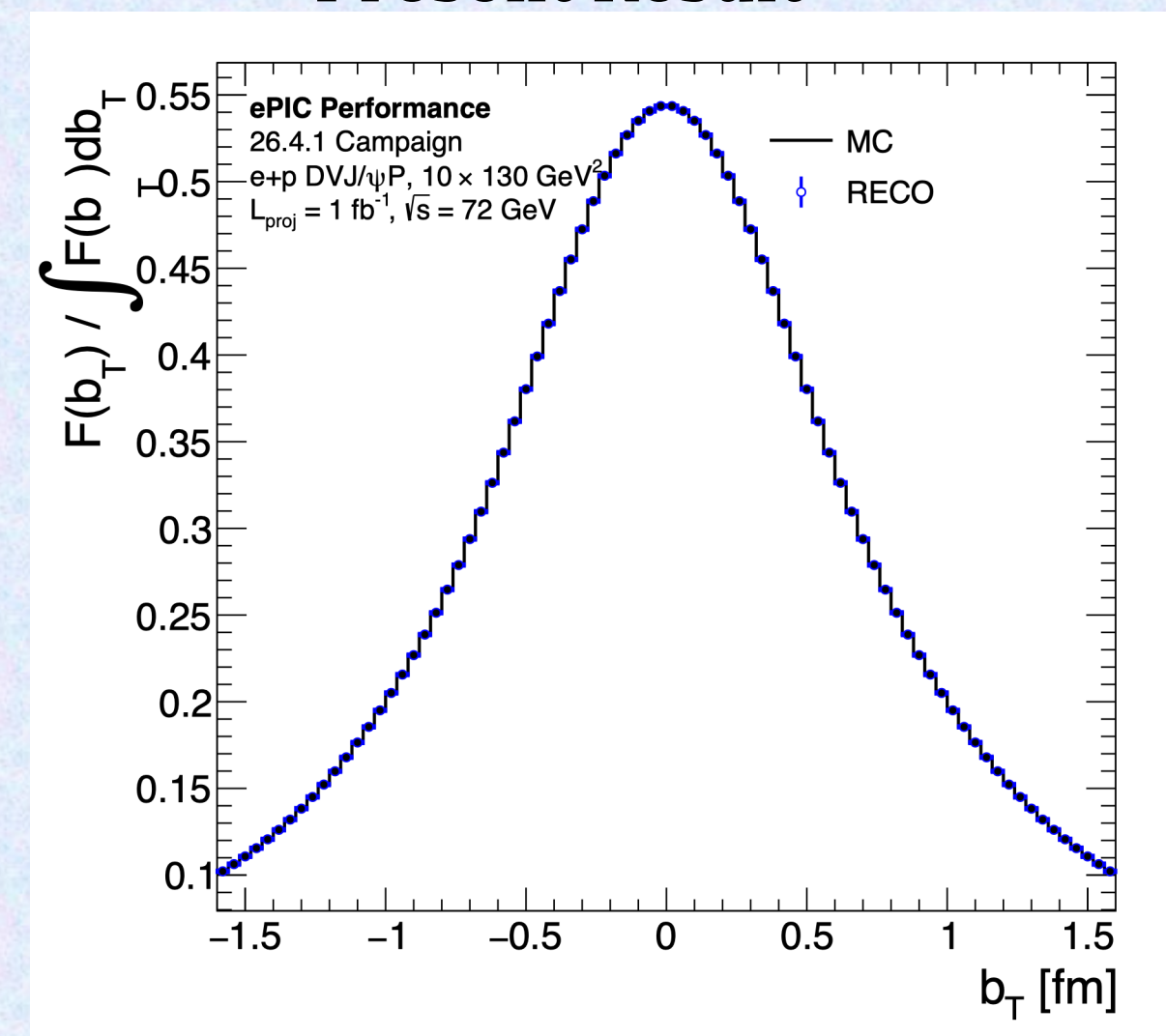
Studies exclusive J/ψ production physics channel at EIC

- ✓ Extracted $d\sigma/dt$ distribution $\rightarrow$ Fourier transformation to get the spatial distribution

Projection from Yellow Paper



Present Result



Thank You