Exclusive DVMP process in *ep* Collisions ($J/\psi(ee^{+})$)

Olaiya A. Olokunboyo (olaiya.olokunboyo@unh.edu)
University of New Hampshire

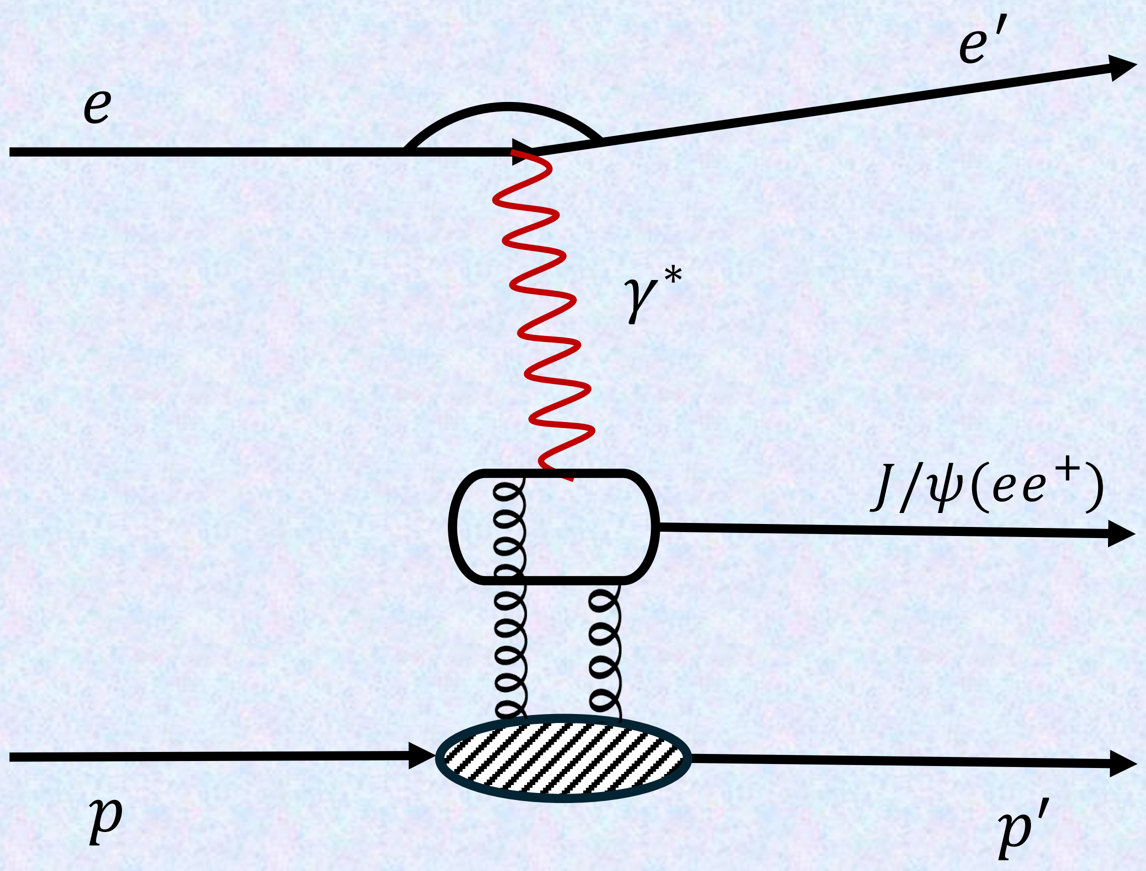
Supervisor: Prof. Nathaly Santiesteban
Mentors: Alex Jentsch, Kong Tu, and Jihee Kim

July 15th 2026

Physics Motivation

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

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

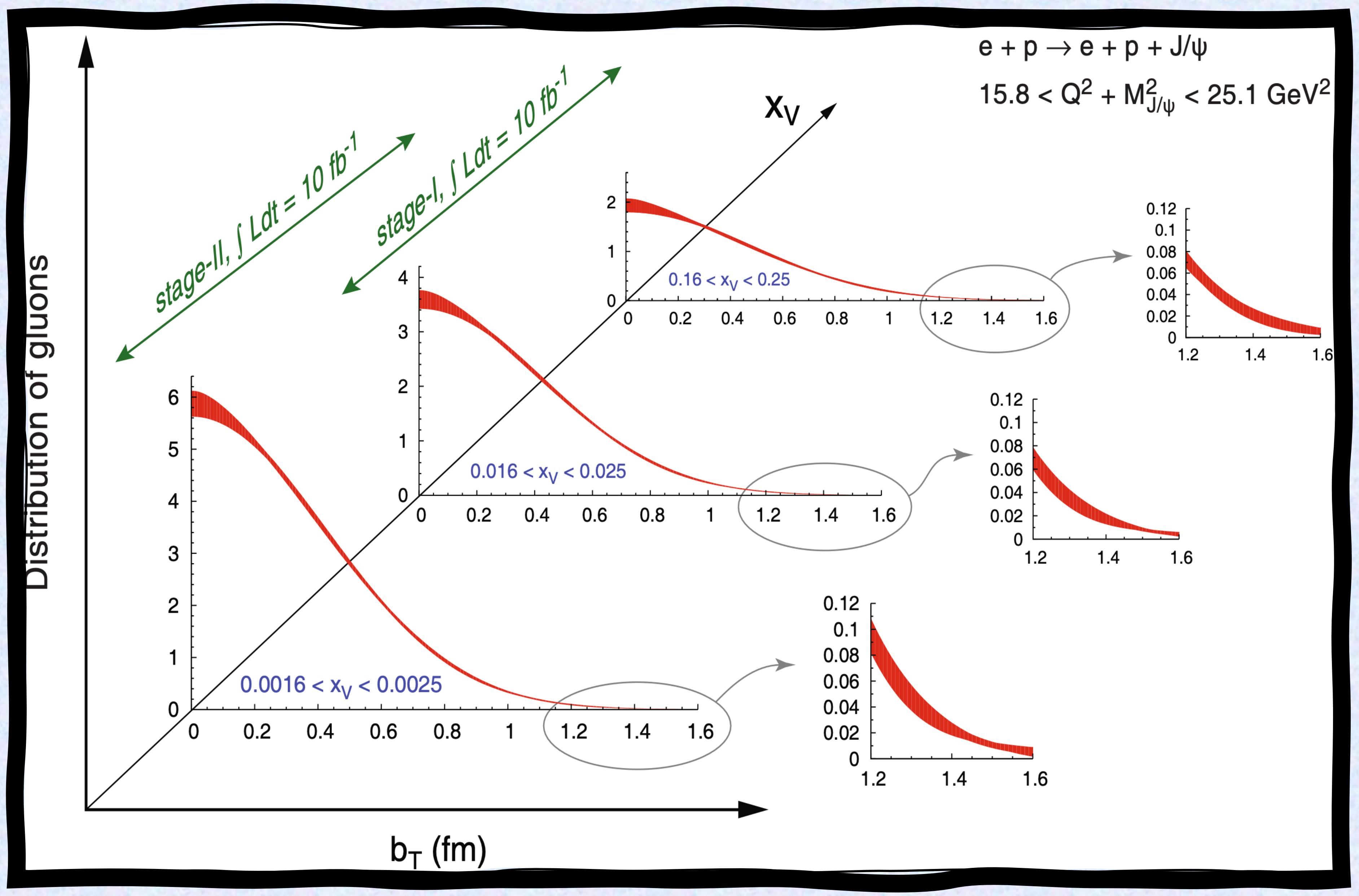


Why this channel matters:

- Dominated by gluon exchange → direct sensitivity to gluon GPDs
- The heavy charm mass provides a hard scale → controlled pQCD description
- t-dependence enables spatial imaging of gluons in the proton
- Fully exclusive final state → clean event selection and precision kinematics

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

- Access gluon Generalized Parton Distributions through exclusive J/ψ production
- Measure the t-dependence of the cross section
- Extract the transverse spatial distribution of gluons in the proton



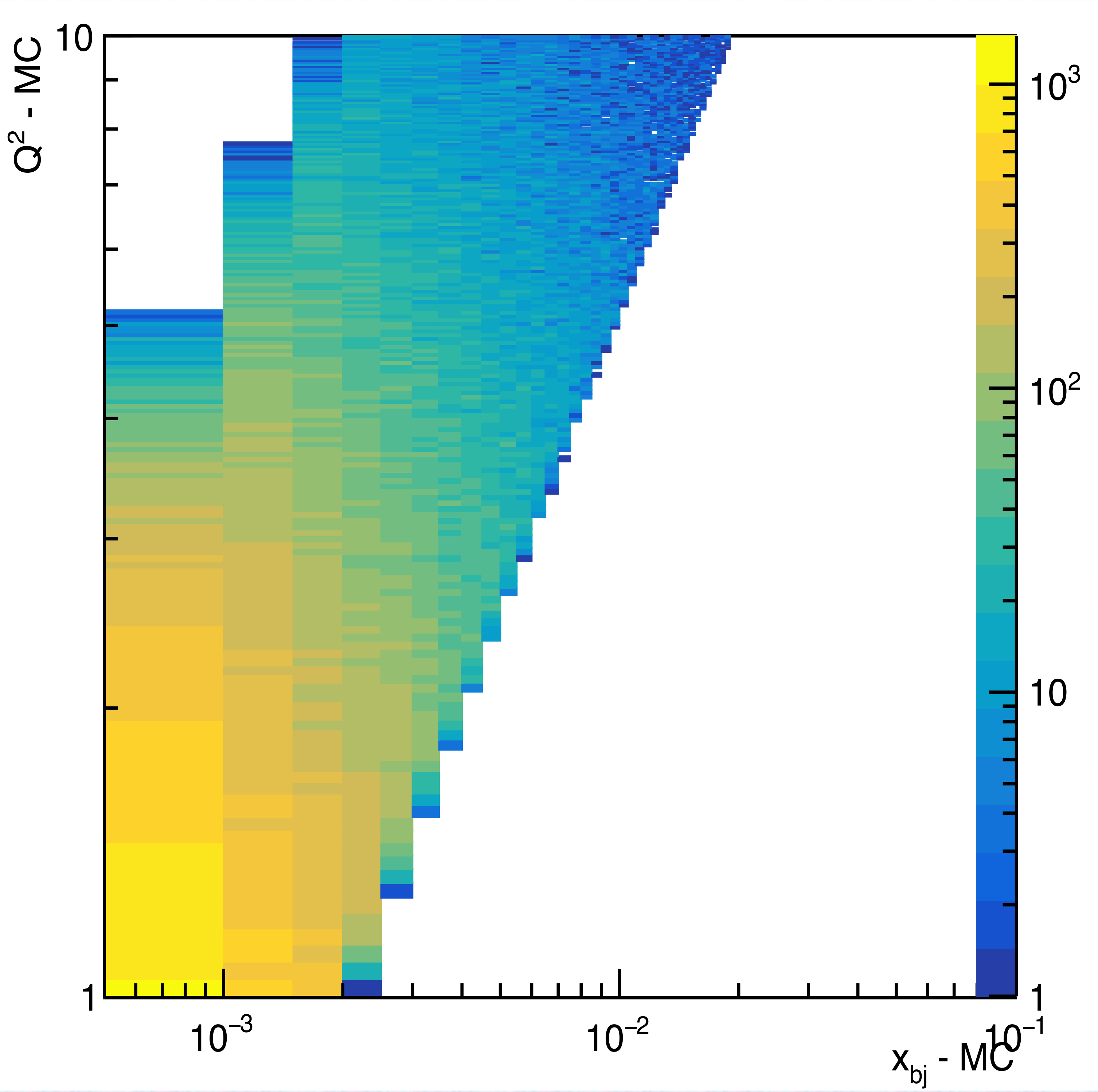
Extract the t-dependence to obtain the *gluon* spatial distribution

J/ψ is gluon-dominated, not quark-dominated

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

Simulation Sample lAger



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

- ➢ lAger3.6.1-1.0

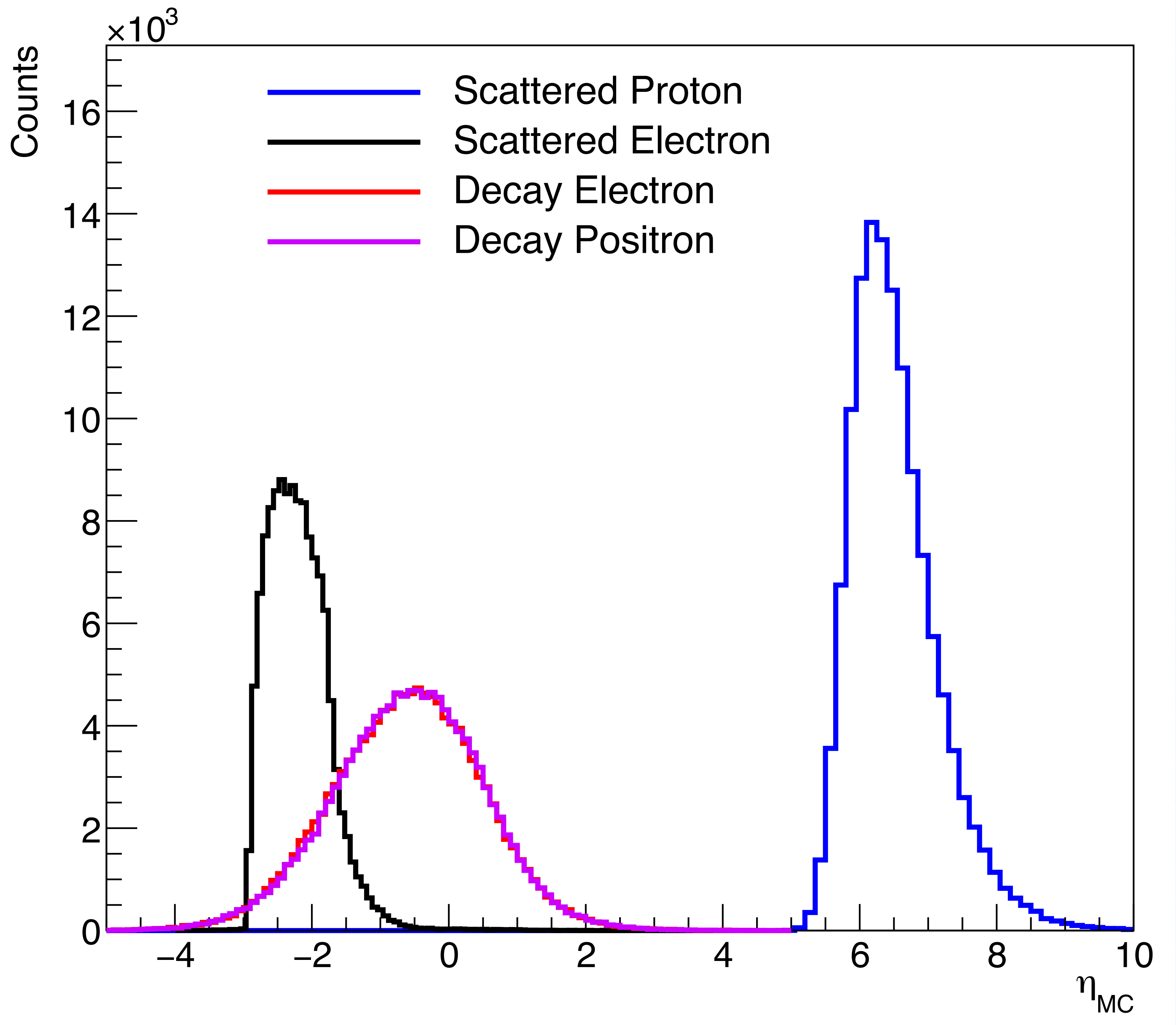
Generator Level Kin. Ranges

- $1 < Q^2 < 10$
- $0 < x_{bj} < 1$
- $0.1 < y < 1$

The results presented are based on ePIC April Simulation Campaign **25.04.1** $(10 \times 130 \text{ GeV}^2)$

DVMP Kinematics

All Final-State Particles



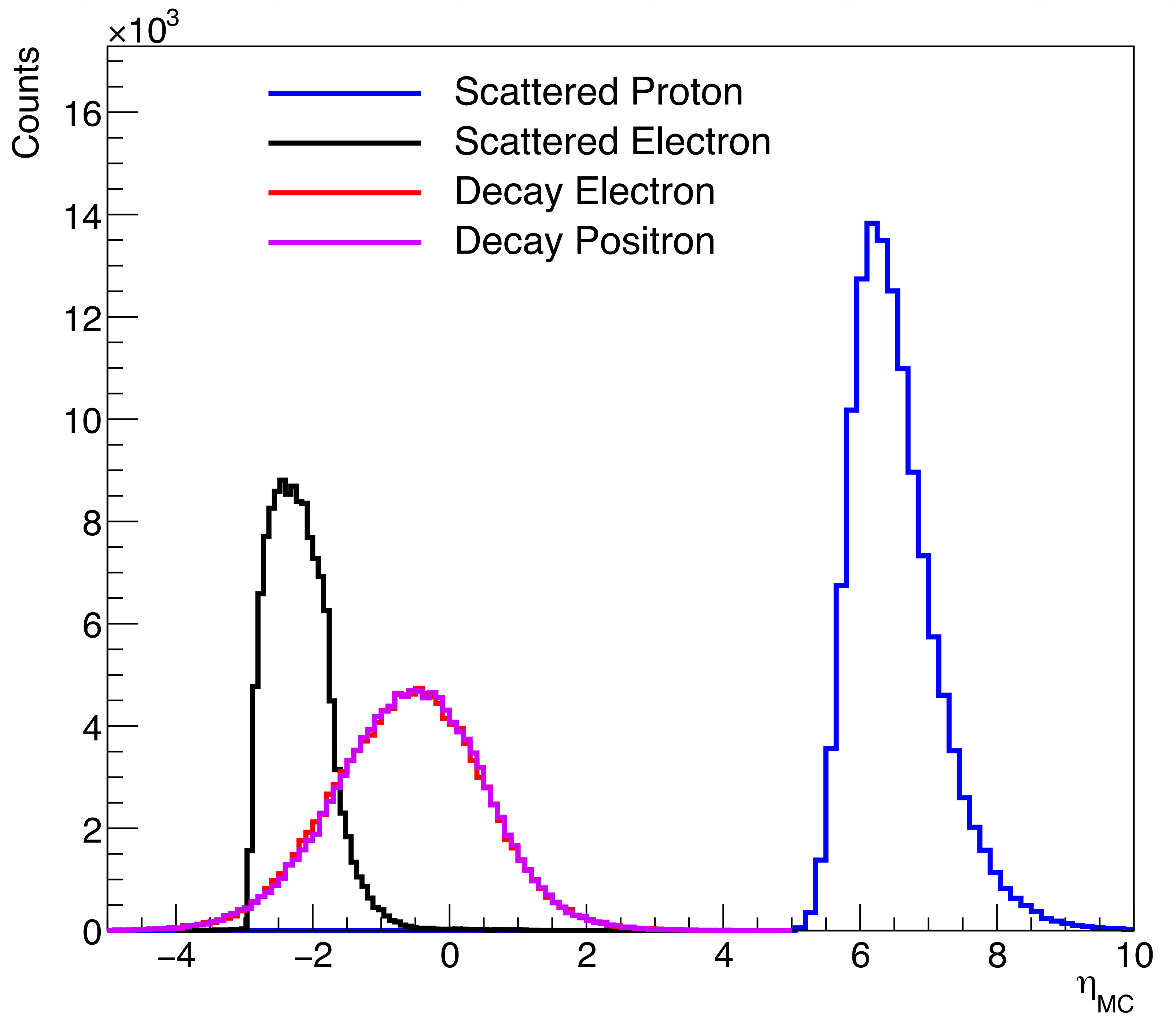
$$e + p \rightarrow e' + J/\psi(ee^{+}) + p'$$

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

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

DVMP Kinematics

All Final-State Particles



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

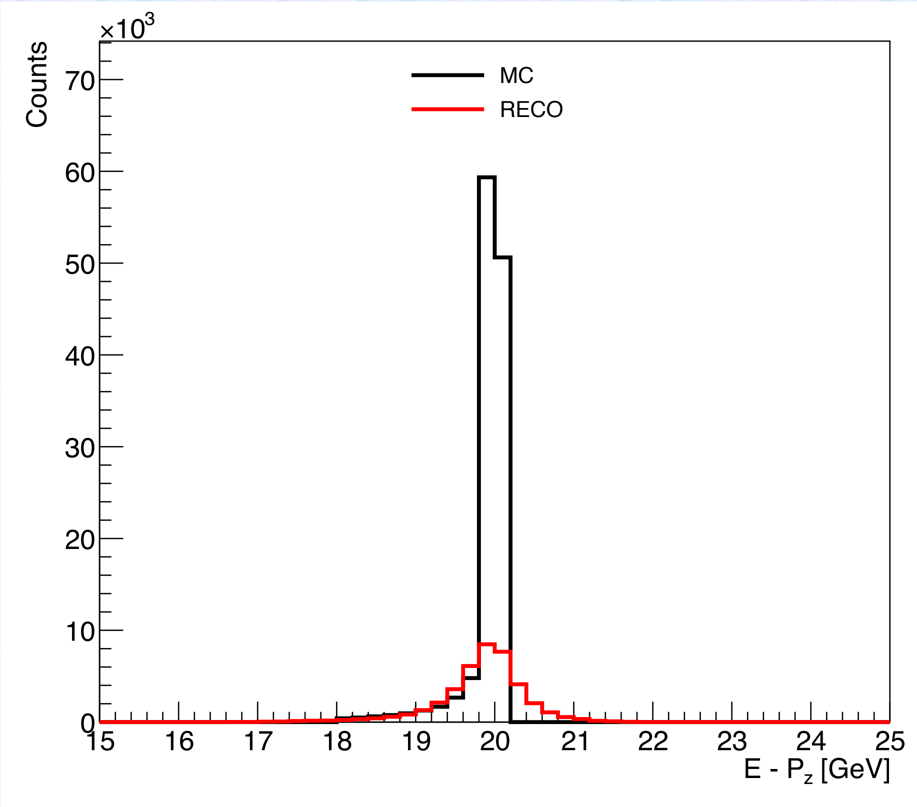
Scattered and Decayed electrons, since 2 electron candidates are present per event

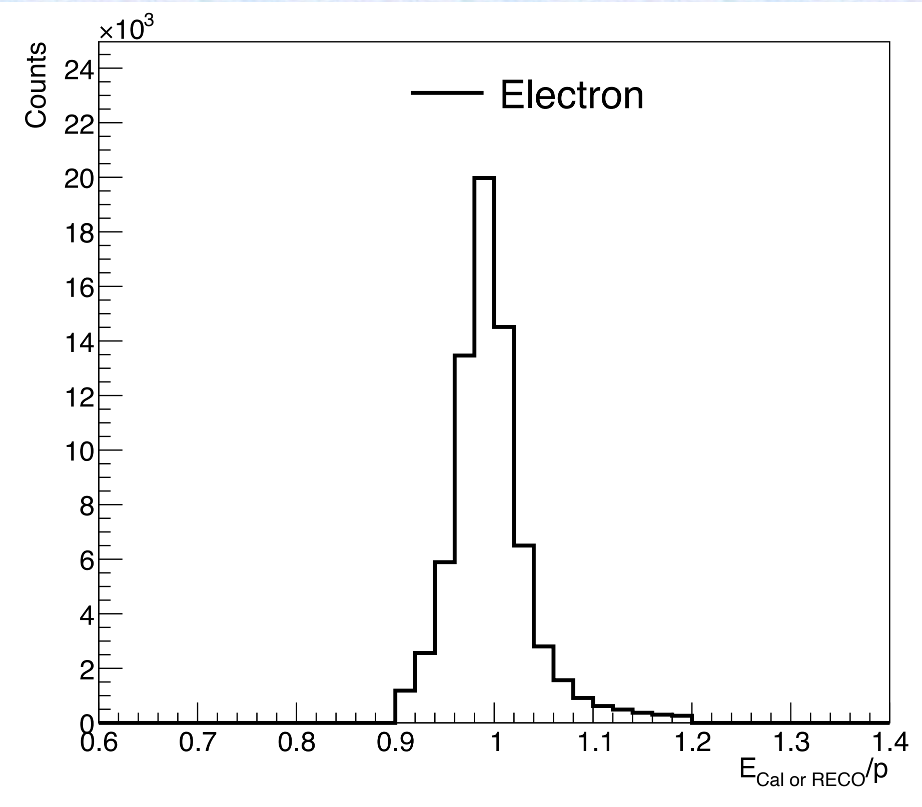
Both candidates are tested as possible $J/\psi \rightarrow ee^+$ decay electrons, using invariant mass check,

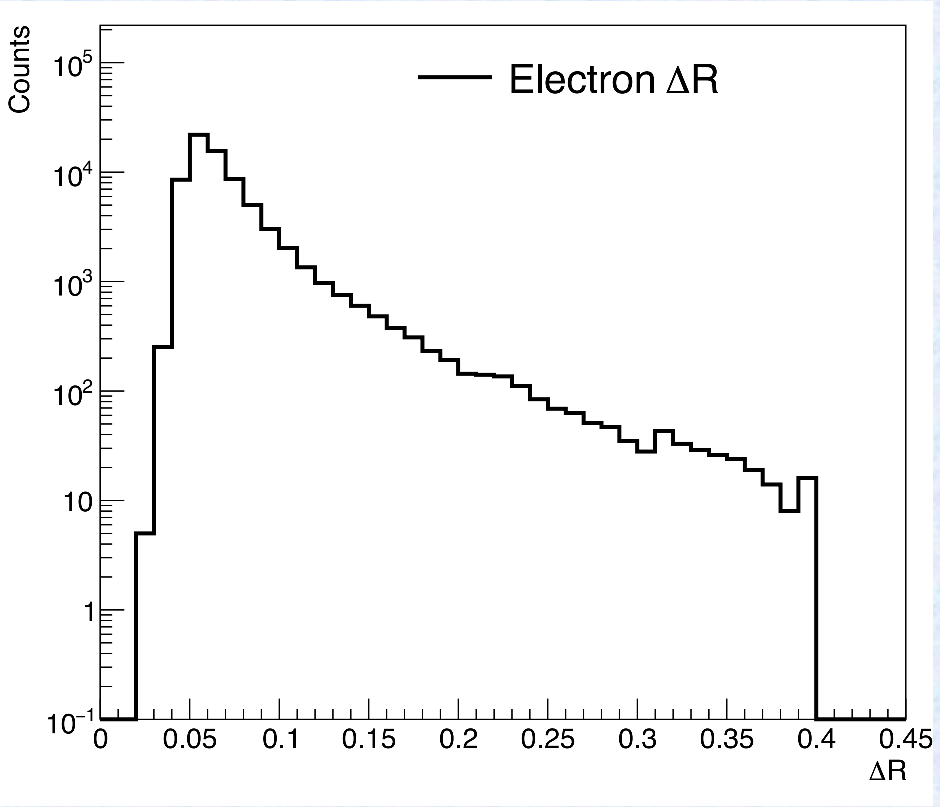
$$2.9 < M_{J/\psi} < 3.2$$

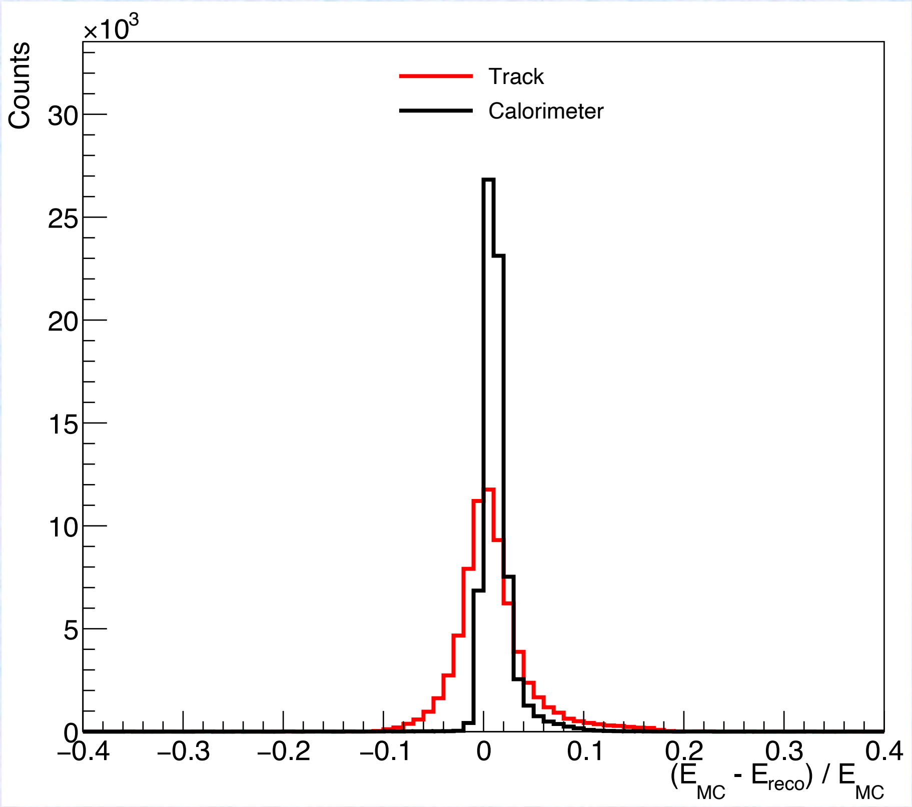
to separate the electrons.

η' Acceptance and Reconstruction









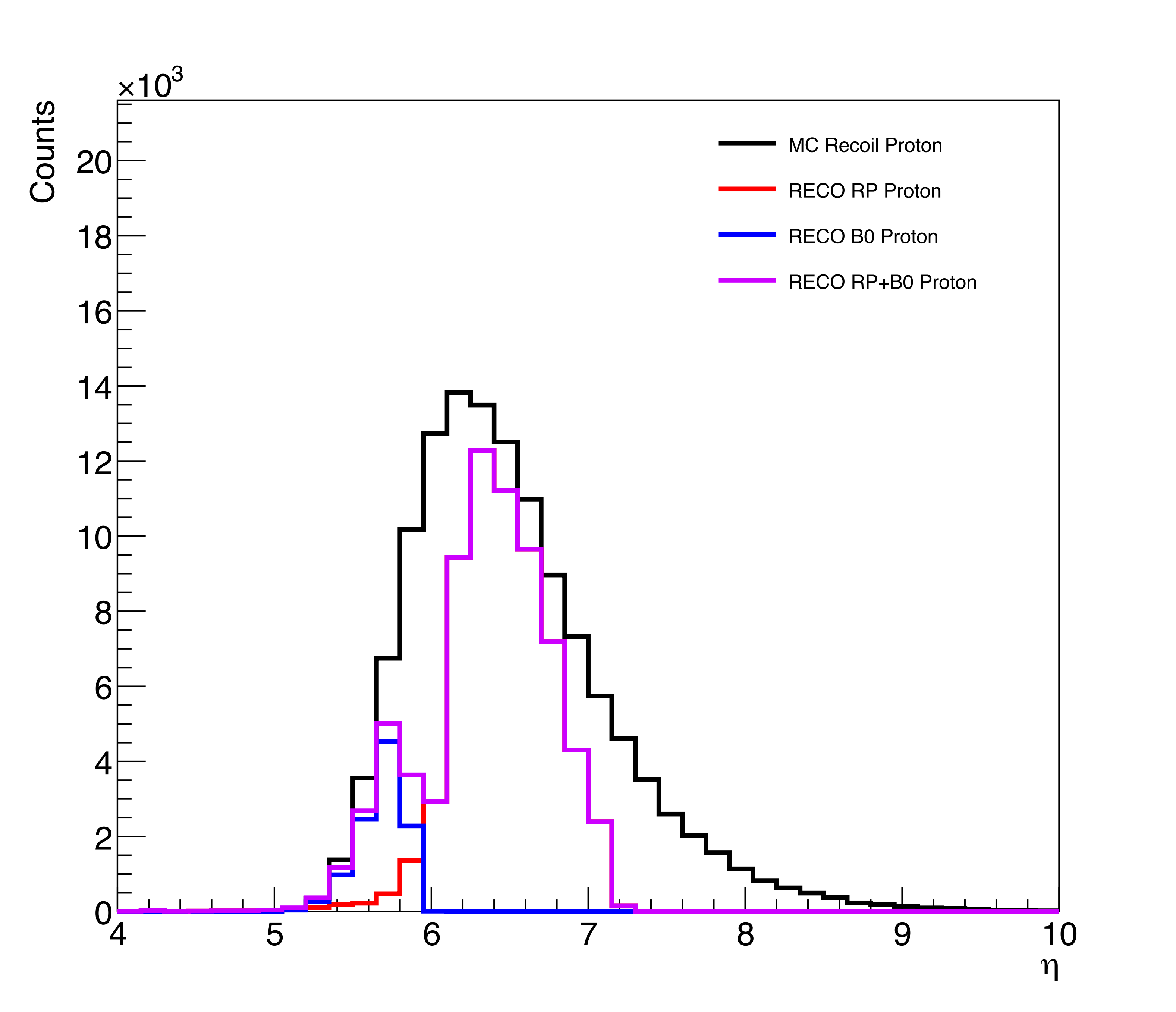
Quality Cuts

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

$$0.9 < E/p < 1.2$$

$$\Delta R < 0.4$$

On the Scattered Proton

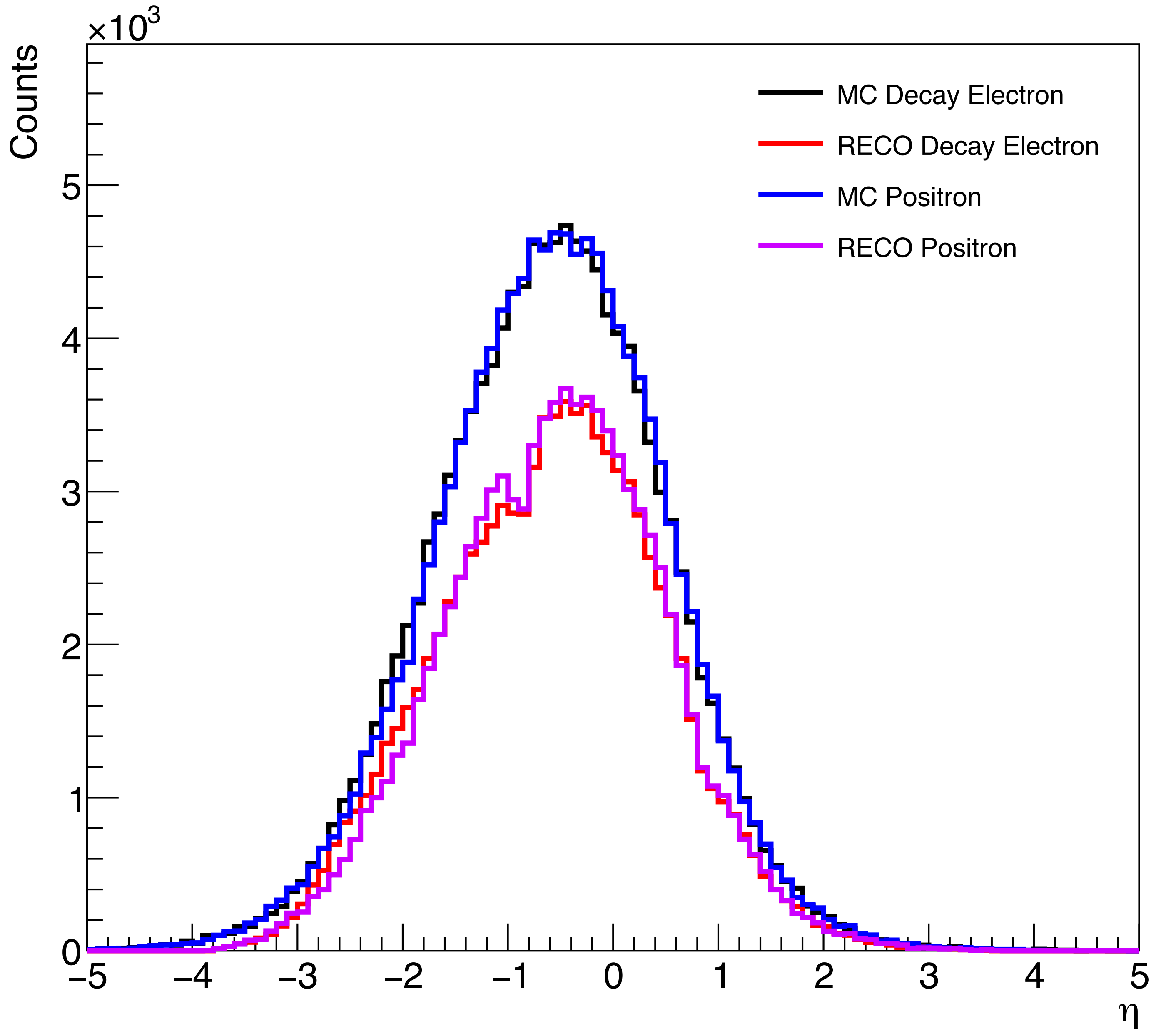


Good Proton Selection: within angular acceptance in **B0** or **Roman Pot (RP)**

$6 < \theta^{RECO}_{p\ in\ B0} < 20$ mrad and $0 < \theta^{RECO}_{p\ in\ RP} < 4.7$ mrad

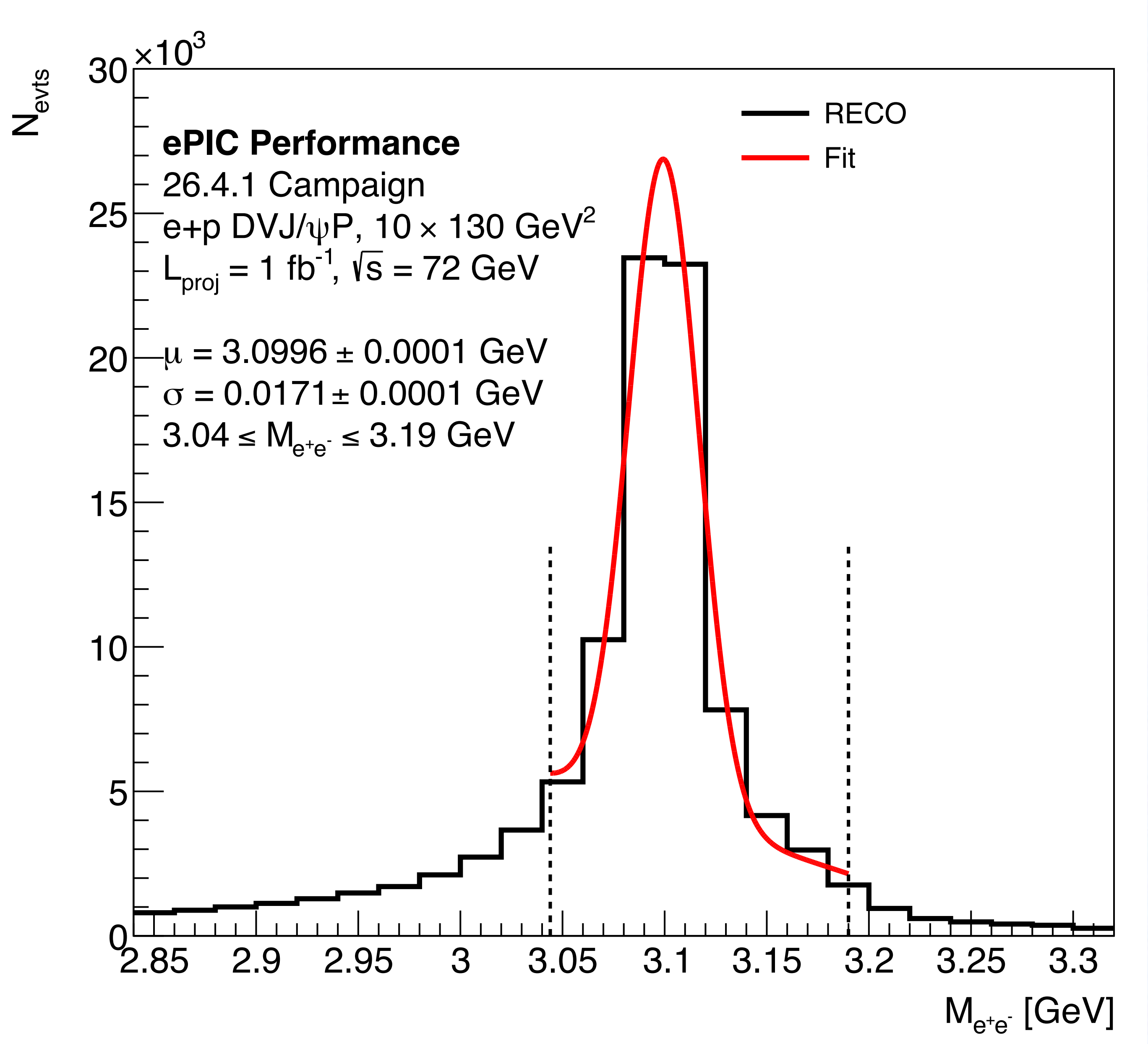
There is a gap of ≈ 1.3 mrad between the B0 and RP

Invariant $M_{J/\psi}$ Reconstruction



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

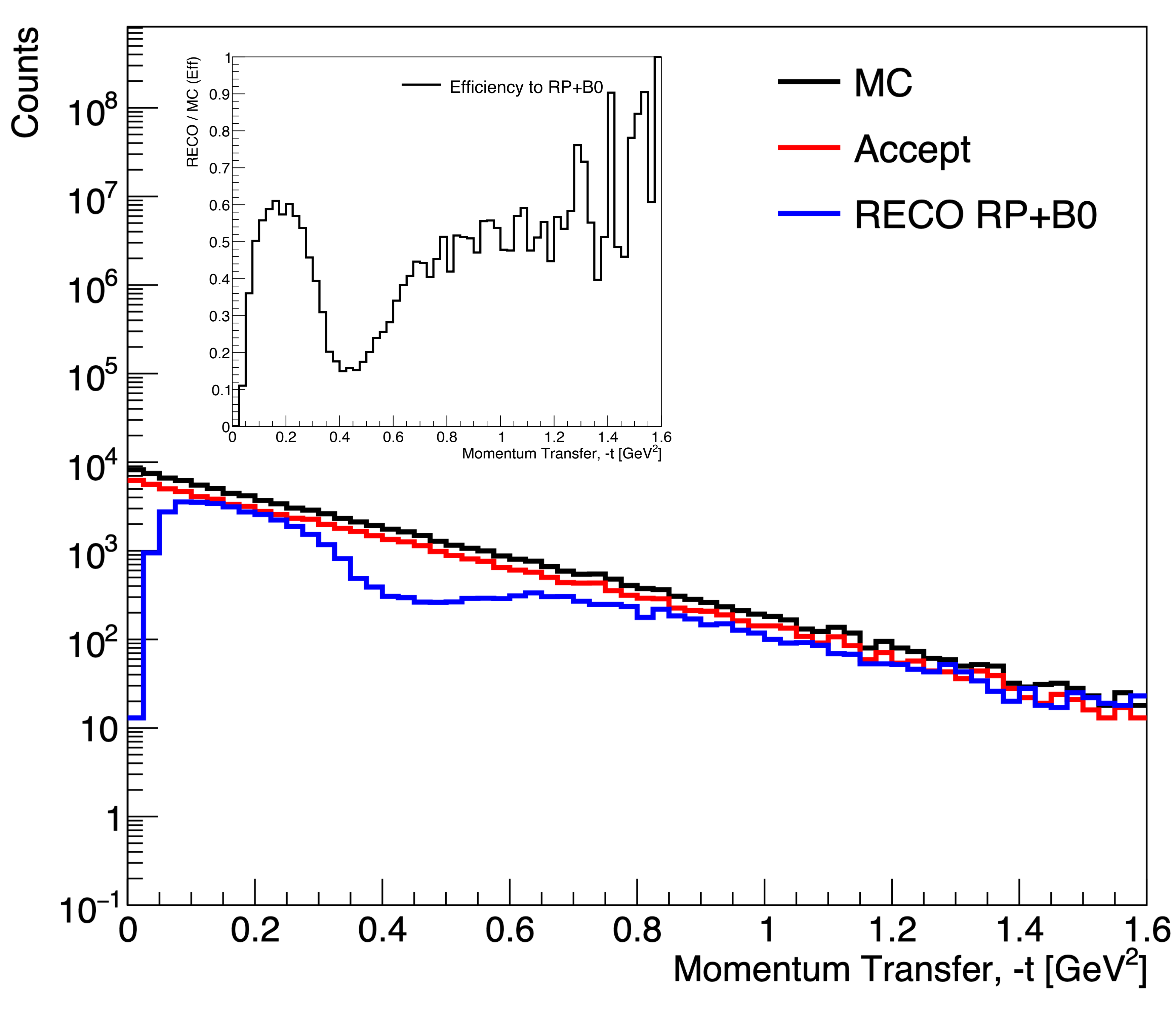
Good agreement between **MC** and **RECO** confirms: Proper electron-positron identification, and no significant acceptance bias.

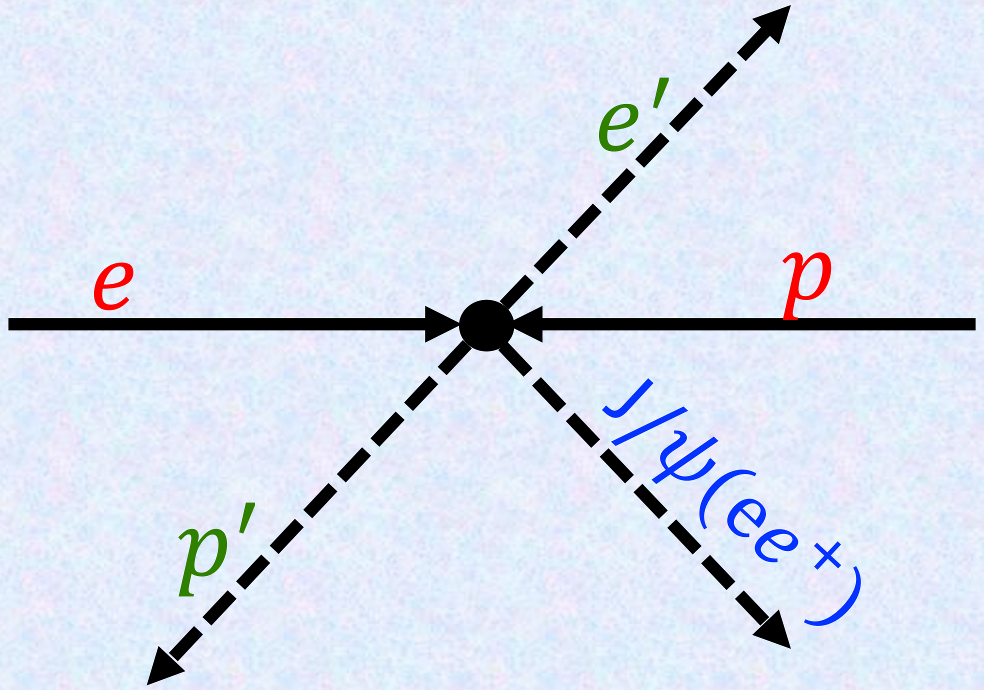


Width, $\sigma \approx 17$ MeV with excellent mass resolution and signal purity

$t - distribution$ Reconstruction

Method 1: Proton Recoil





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

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

where

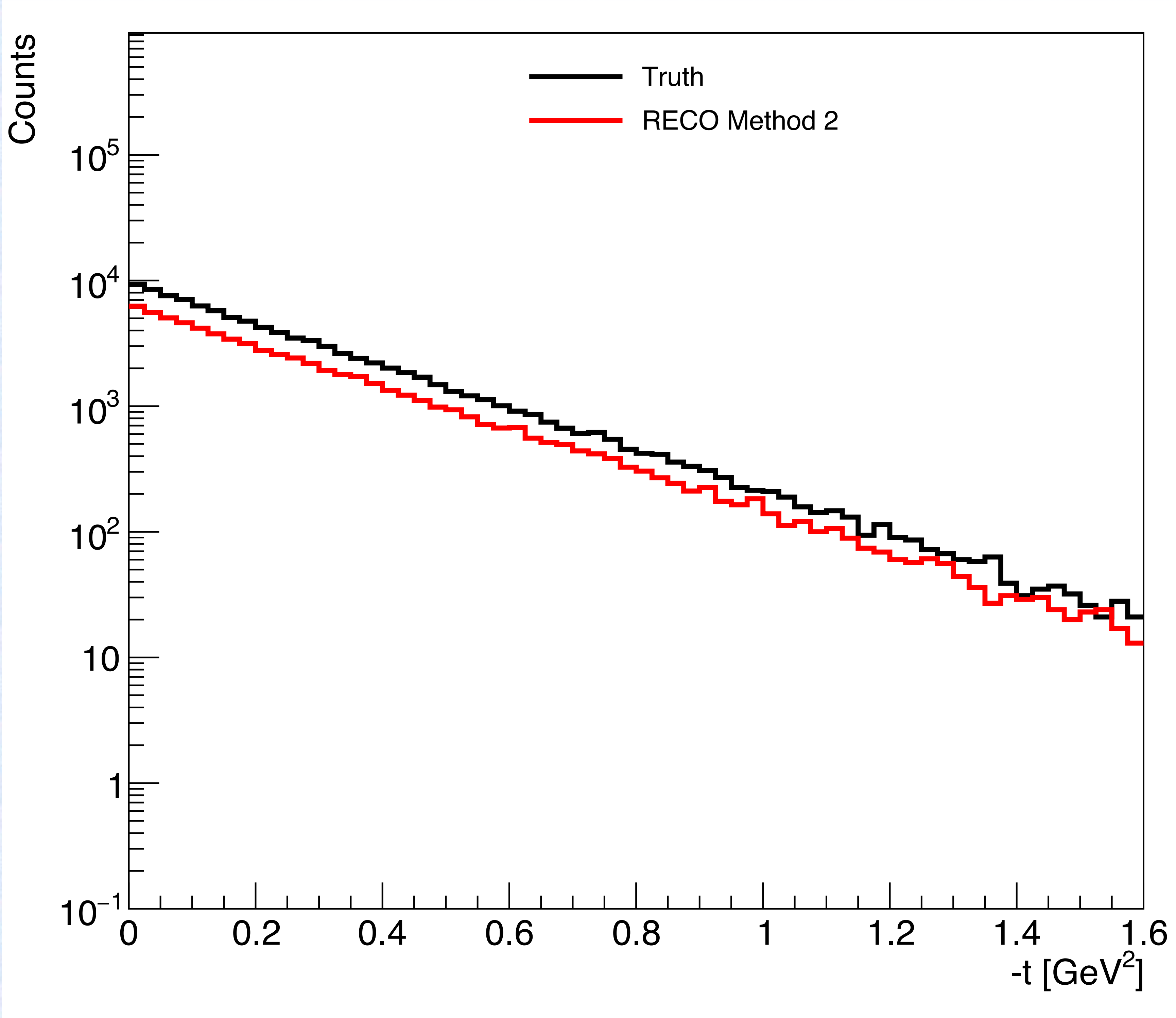
p = initial proton four-momentum

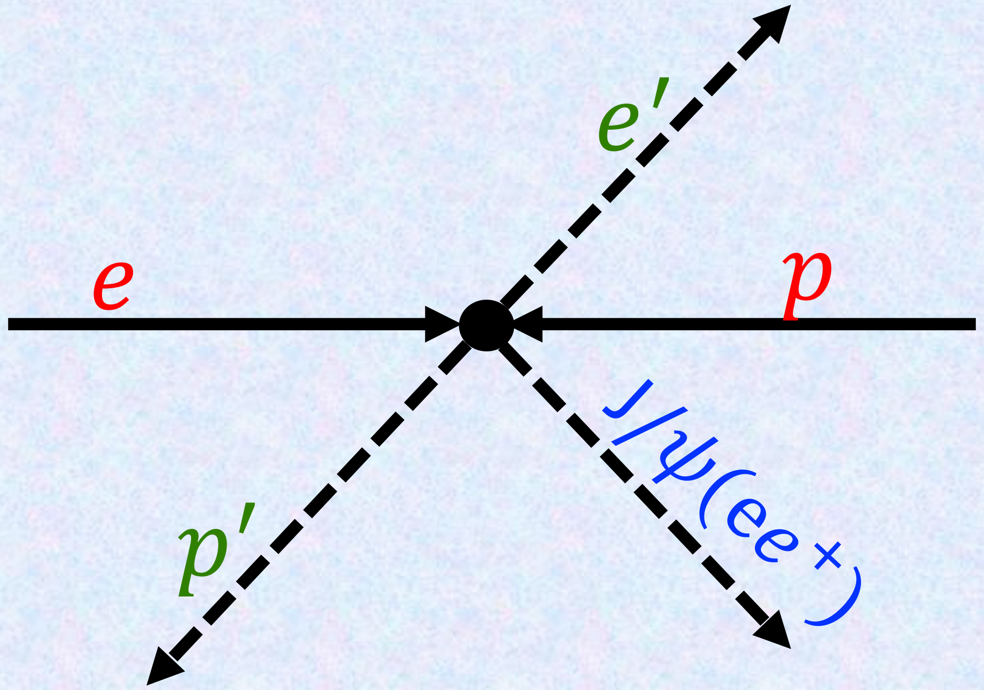
p' = final-state proton (or recoil system) four-momentum

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

$t - distribution$ Reconstruction

Method 2: Corrected Outgoing Proton Momentum





From;

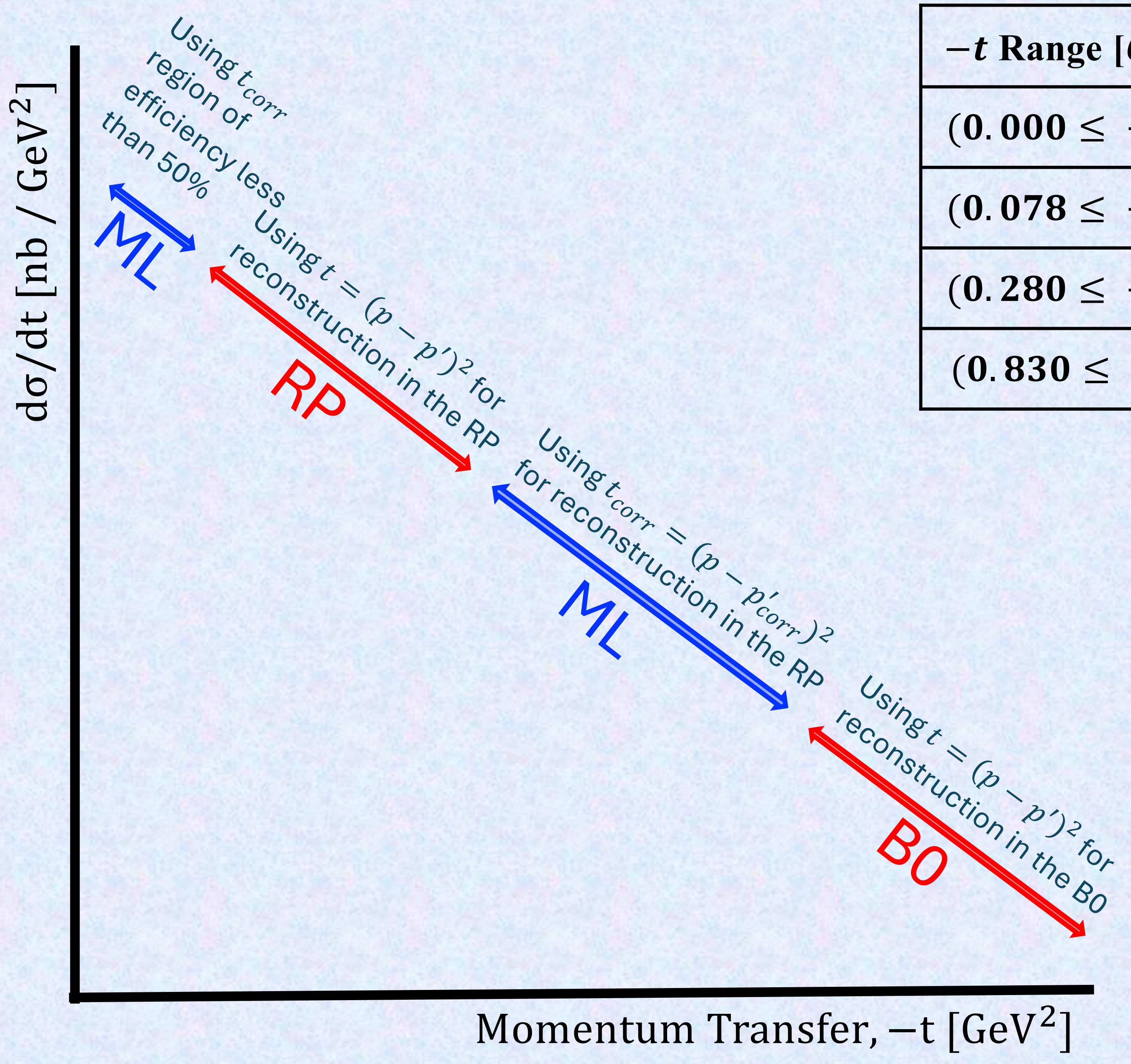
$$P_{p'} = P_e + P_p - P_{e'} - P_{J/\psi(ee^+)}$$

we derive;

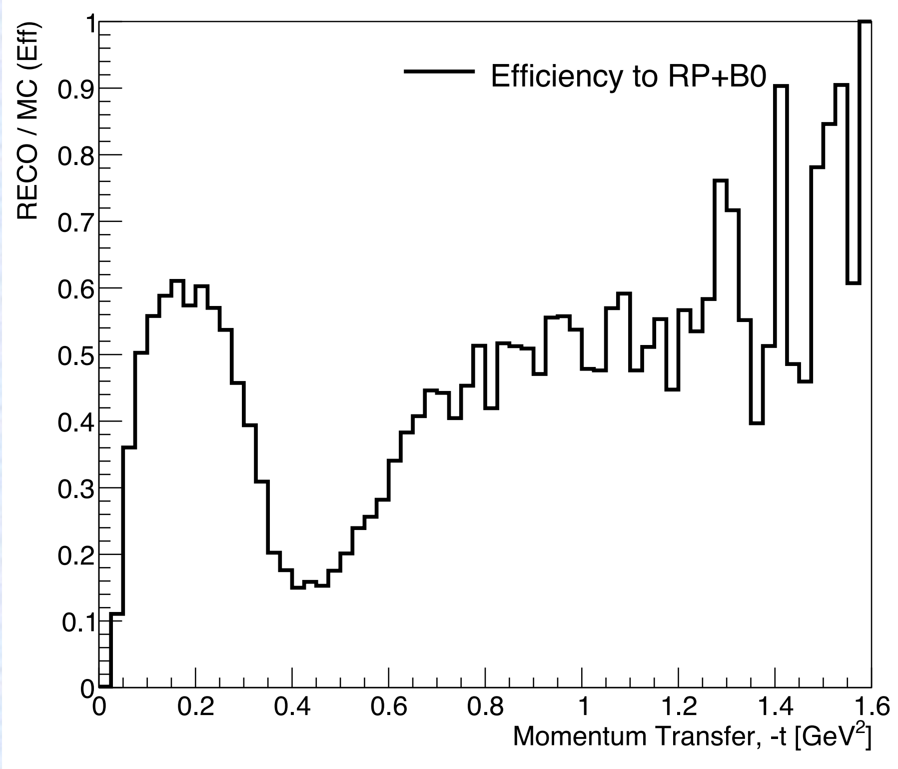
$$t_{Method\ 2} = (p - p'_{corr})^2$$

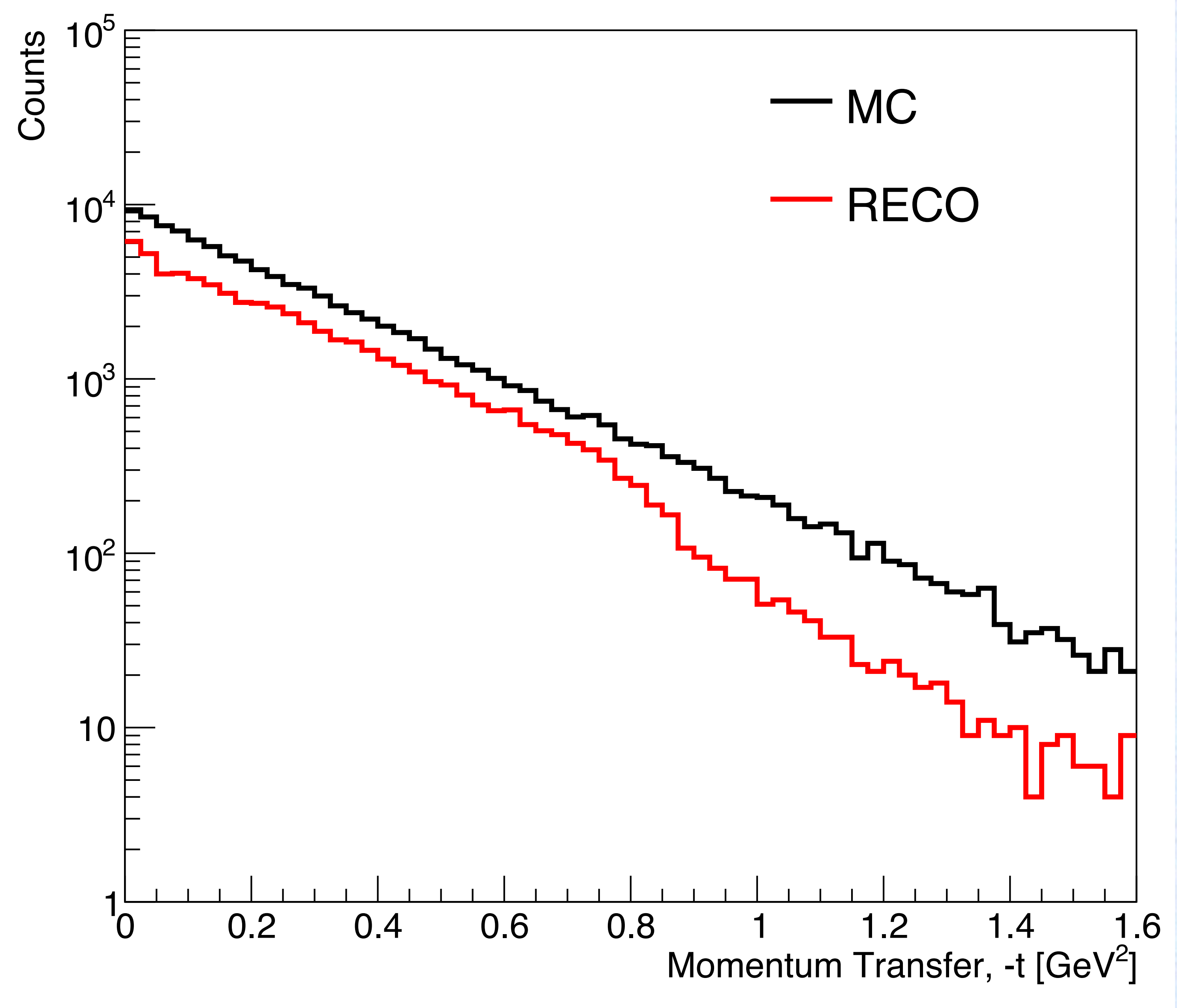
$t - distribution$ Reconstruction

Method 1 + Method 2: $t_{Method\ 1+METHOD\ 2} = (p - p'_{corr})^2 + (p - p')^2$



$-t$ Range [GeV^2]	Reconstruction Method
$(0.000 \le -t < 0.078)$	Method 2 (M2)
$(0.078 \le -t < 0.270)$	Roman Pot (RP)
$(0.280 \le -t < 0.830)$	Method 2 (M2)
$(0.830 \le -t < 2.000)$	B0





ep Inclusive DIS Background

Good Proton Selection
- Reconstructed in **B0 or Roman Pot**
- Within angular acceptance:

$$6 < \theta^{RECO}_{p\ in\ B0} < 20 \text{ mrad}$$
$$0 < \theta^{RECO}_{p\ in\ RP} < 4.7 \text{ mrad}$$

Good Electron / Positron Selection
- Exactly **two oppositely charged tracks** in the Central Detector
- Identified as e and e^-
- Energy–momentum consistency:

$$0.8 < E/p < 1.2$$

Good J/ψ Candidate
- ✓Formed from ee^- pair
- ✓Invariant mass window:

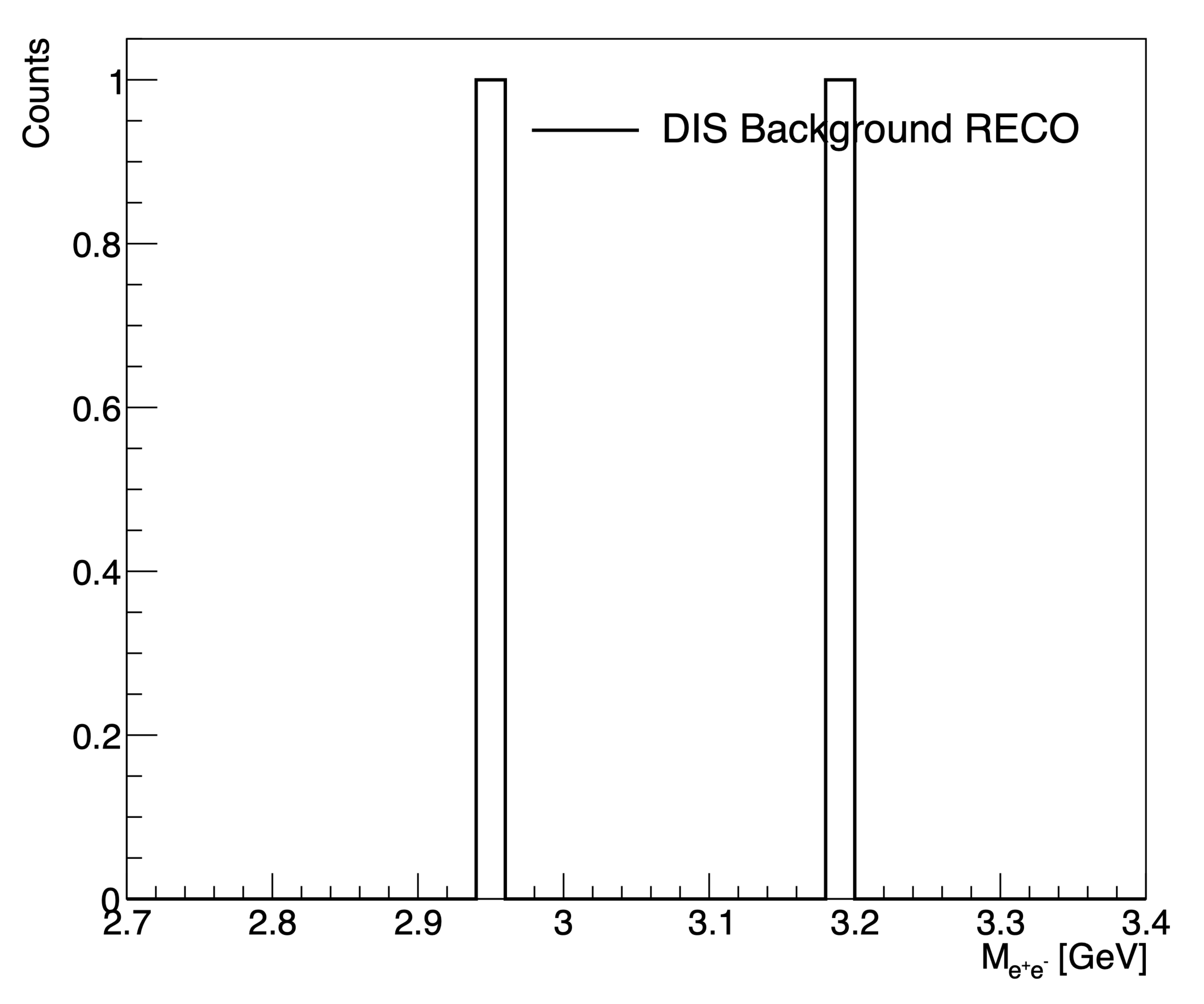
$$2.7 < M_{e^+e^-} < 3.4 \text{ GeV}$$

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

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

Exclusivity Cuts
- ❖All final-state particles reconstructed

A few events - There is no signal, all events are background candidates.



0 events from RP+B0 { $t = (p - p')^2$ } and 2 events from Method L { $t_{cor} = (p - p'_{cor})^2$ }

ep Inclusive DIS Background

A few events - There is no signal, all events are background candidates.

Good Proton Selection

- Reconstructed in **B0 or Roman Pot**
- Within angular acceptance:

$$6 < \theta_{p\ in\ B0}^{RECO} < 20 \text{ mrad}$$

$$0 < \theta_{p\ in\ RP}^{RECO} < 4.7 \text{ mrad}$$

Good Electron / Positron Selection

- Exactly **two oppositely charged tracks** in the Central Detector
- Identified as e and e^-
- Energy–momentum consistency:

$$0.9 < E/p < 1.2$$

Good J/ψ Candidate

✓Formed from ee^-pair

✓Invariant mass window:

$$2.9 < M_{e^+e^-} < 3.2 \text{ GeV}$$

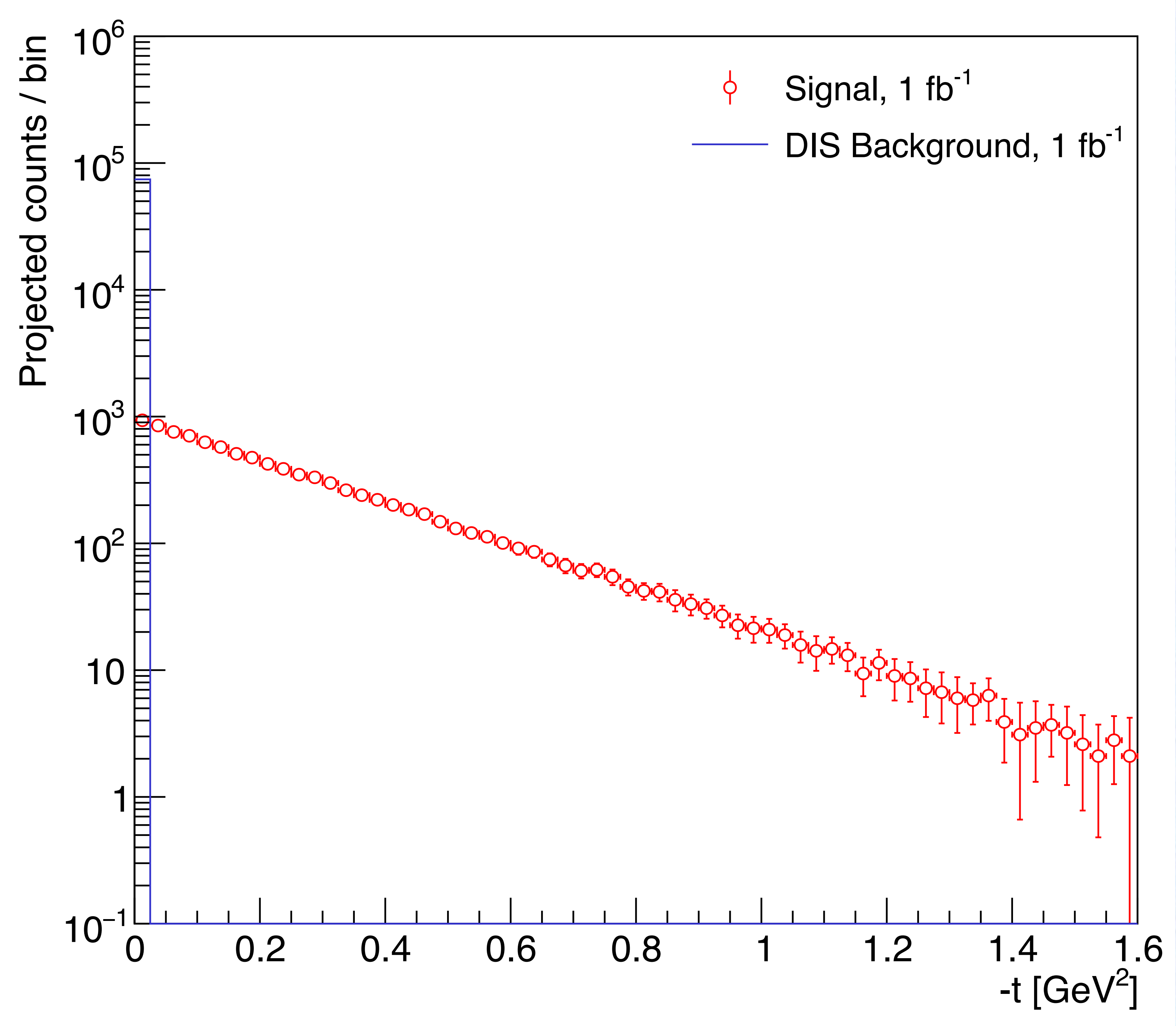
Suppress Photoproduction & Radiative Backgrounds

❑Longitudinal energy balance cut:

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

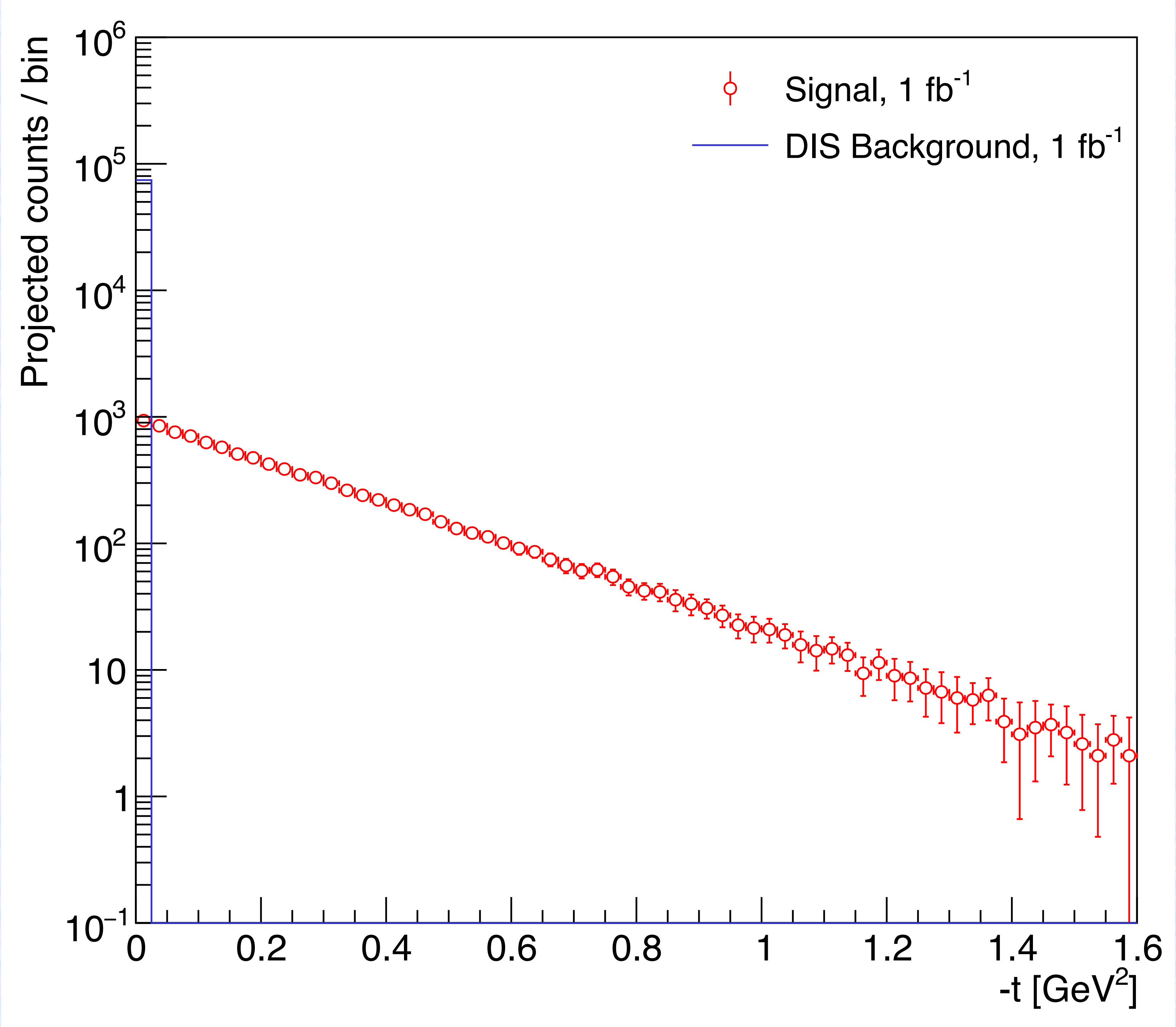
Exclusivity Cuts

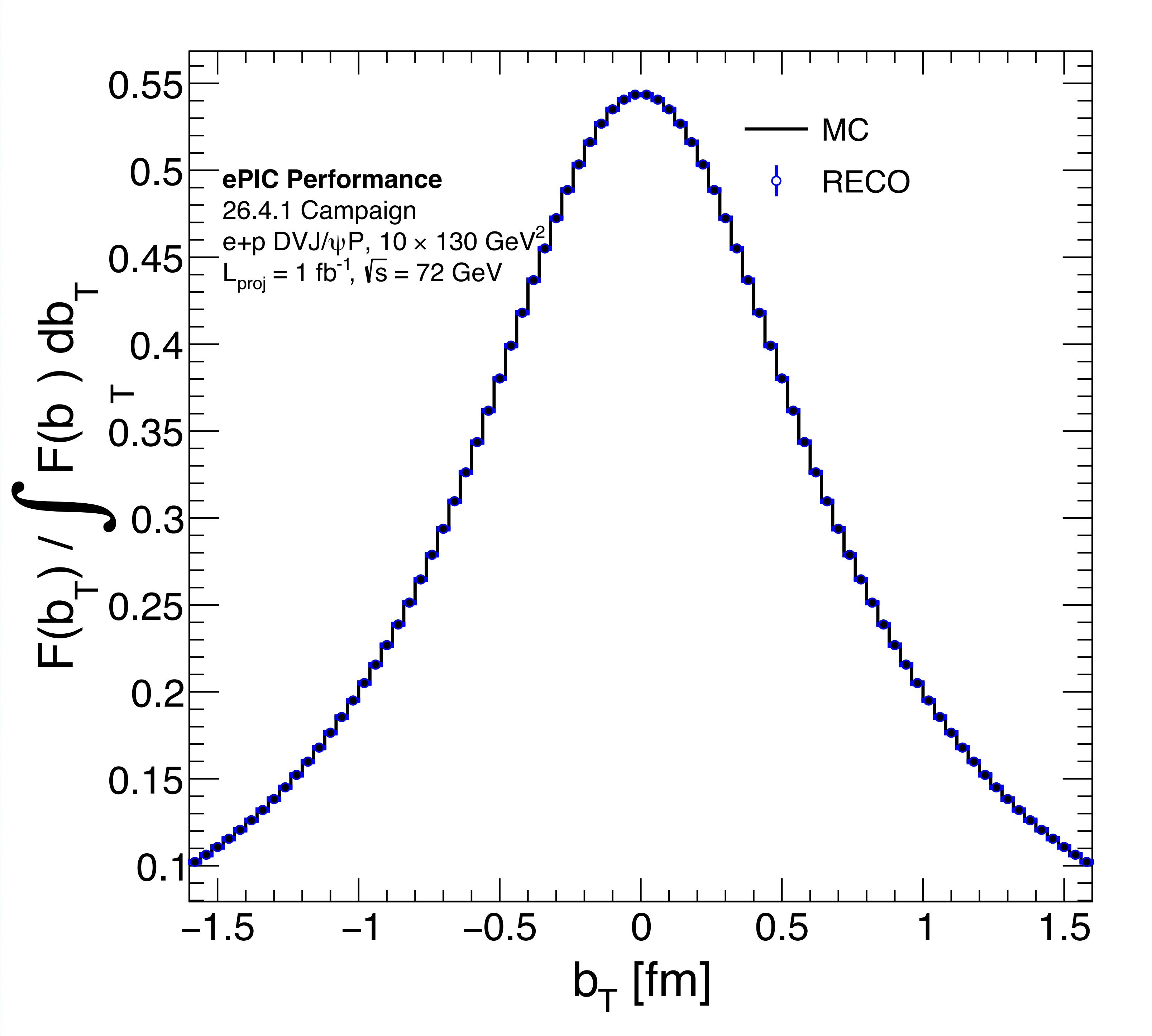
❖All final-state particles reconstructed



0 events from RP+B0 $\{ t = (p - p')^2 \}$ and 2 events from Method L $\{t_{cor} = (p - p'_{cor})^2 \}$

Early Science Projection Results





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

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

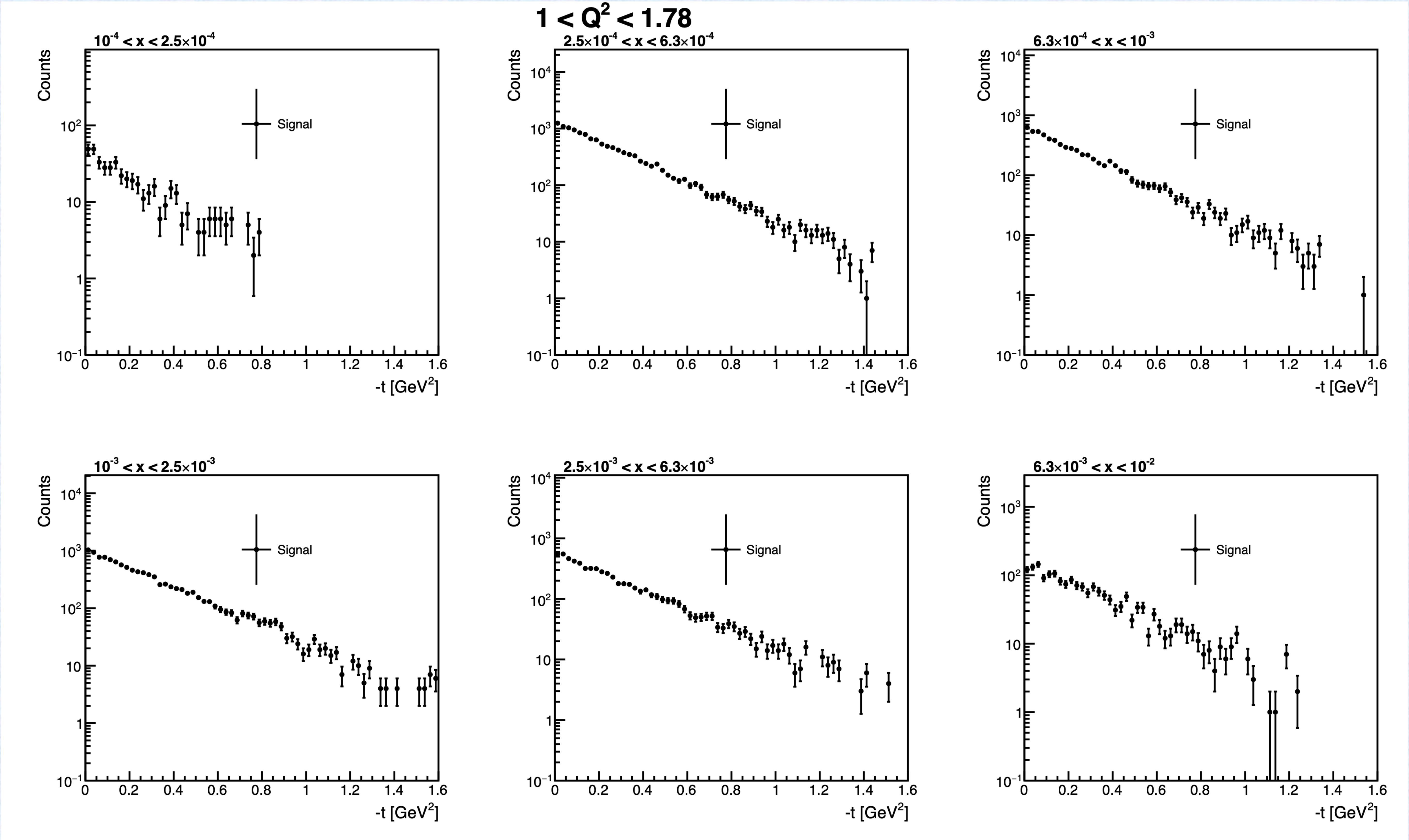
Performance Across (Q^2, x) Phase Space

Bin	$(Q^2)\ Range\ [GeV(^2)]$
1	$1.00 < Q^2 < 1.78$
2	$1.78 < Q^2 < 3.16$
3	$3.16 < Q^2 < 5.62$
4	$5.62 < Q^2 < 10.0$

Bin	(x) Range
1	$10^{-4} < x < 2.5\times 10^{-4}$
2	$2.5\times10^{-4} < x < 6.3\times10^{-4}$
3	$6.3\times10^{-4} < x < 10^{-3}$
4	$10^{-3} < x < 2.5\times10^{-3}$
5	$2.5\times10^{-3} < x < 6.3\times10^{-3}$
6	$6.3\times10^{-3} < x < 10^{-2}$
7	$10^{-2} < x < 2.5\times10^{-2}$
8	$2.5\times10^{-2} < x < 6.3\times10^{-2}$
9	$6.3\times10^{-2} < x < 0.1$
10	$0.1 < x < 0.25$
11	$0.25 < x < 0.7$

Total kinematic bins: $4\ Q^2$ bins $\times 11\ x$ bins $= 44\ (Q^2, x)$bins used in the differential t-distribution study.

Performance Across (Q^2, x) Phase Space



This region has the **largest event statistics**.

The t-distribution exhibits a clear exponential falloff.

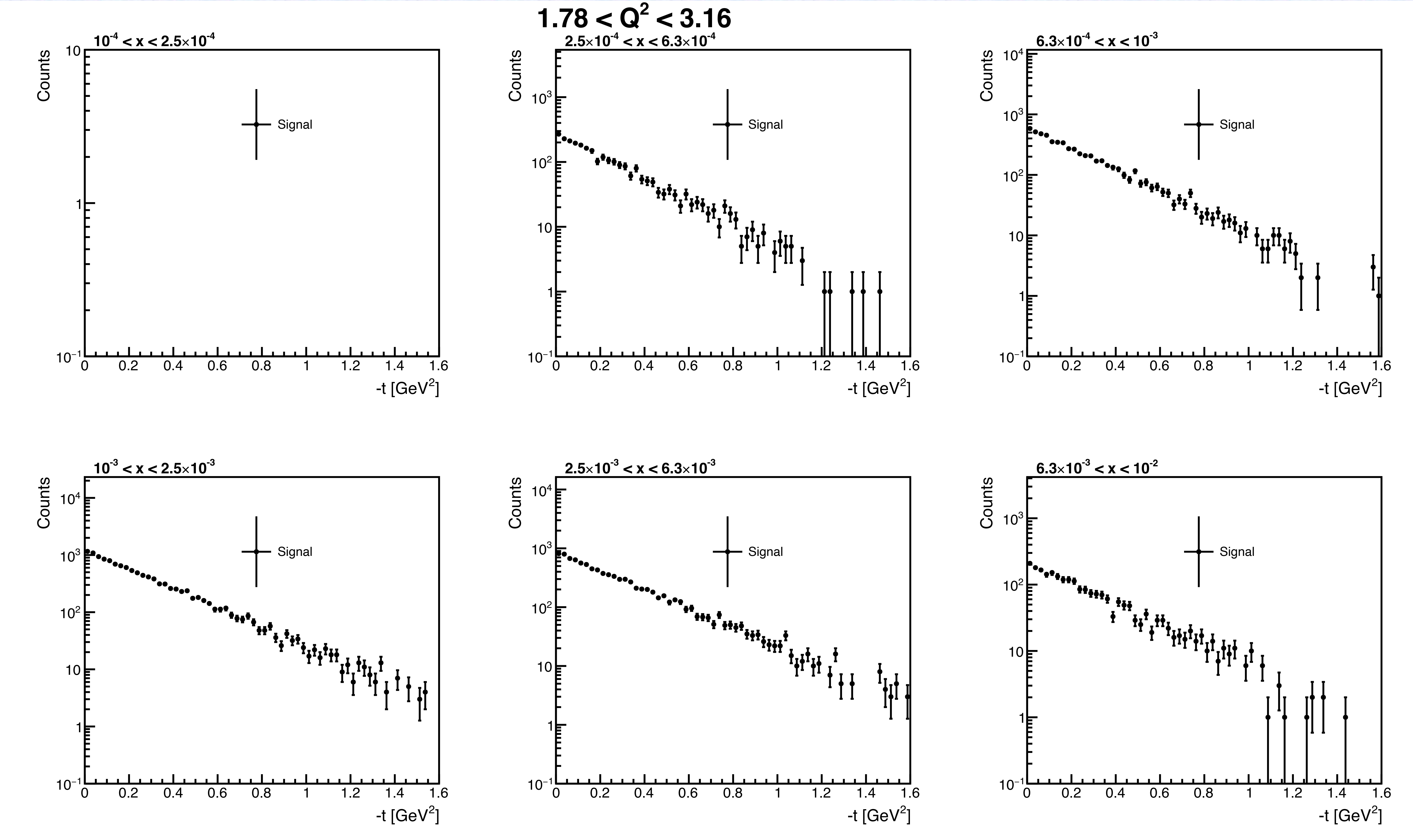
Excellent reconstruction performance is observed over a broad $t$range.

The highest statistics occur around

$$10^{-3} \lesssim x \lesssim 10^{-2}.$$

Statistical fluctuations only become significant at very large t.

Performance Across (Q^2, x) Phase Space



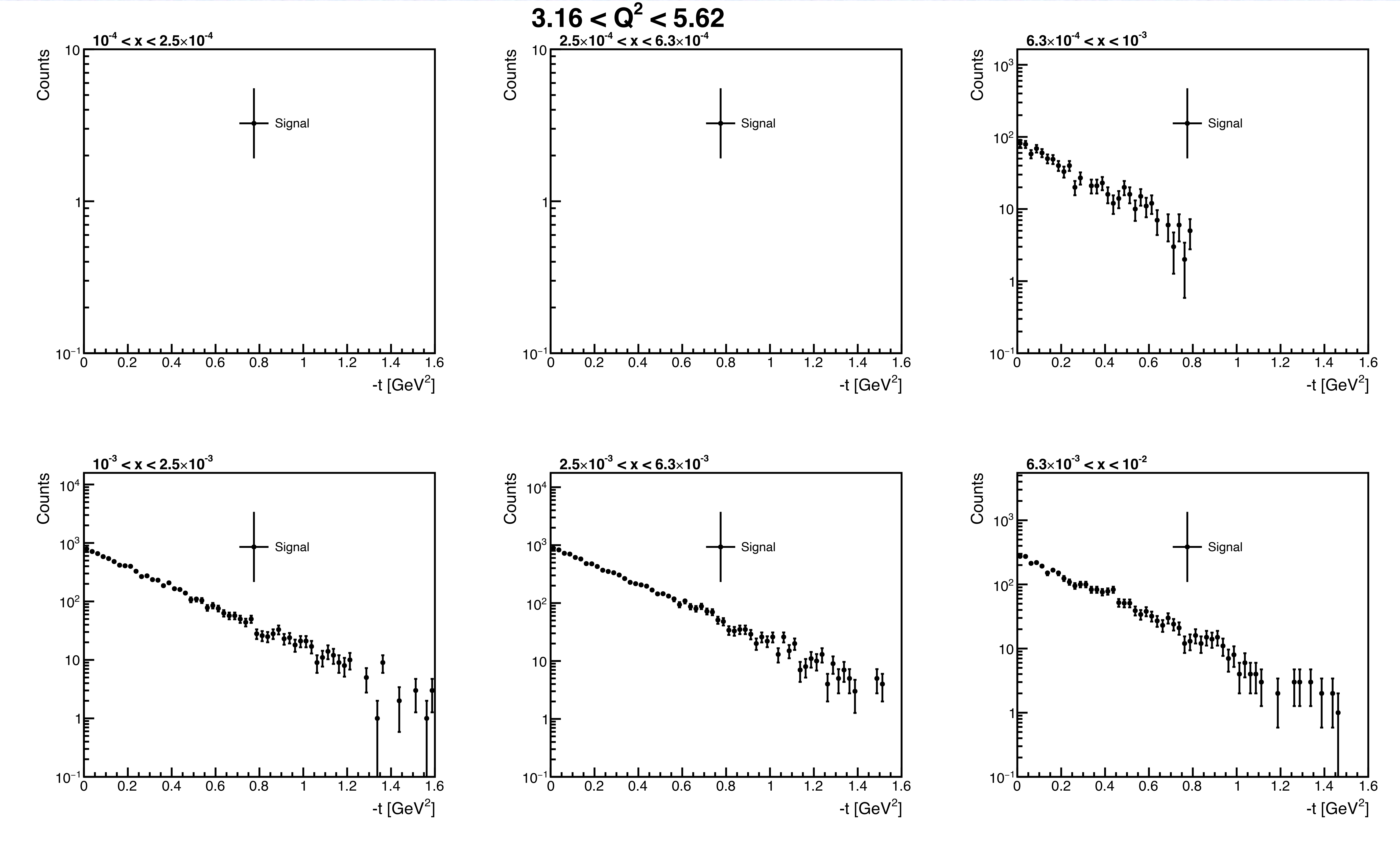
Event statistics begin to decrease.

The exponential t-dependence is still clearly visible.

Most x bins remain well populated.

Detector acceptance and reconstruction remain stable across the accessible t range.

Performance Across (Q^2, x) Phase Space



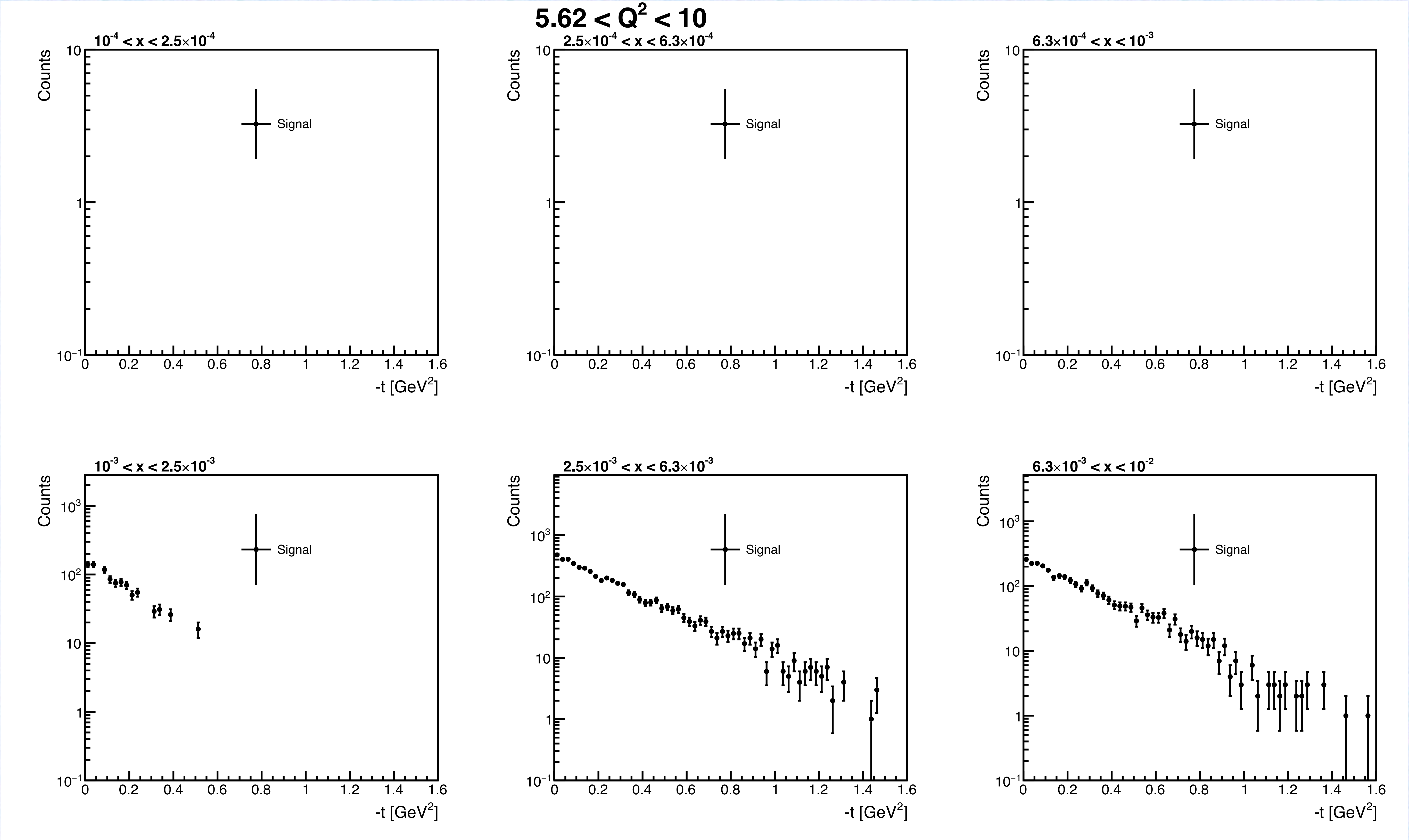
A significant reduction in event yield is observed.

The highest-x bins begin to lose statistics.

Some bins become sparsely populated.

The reconstructed distributions still follow the expected exponential behavior.

Performance Across (Q^2, x) Phase Space



This is the most statistically limited region.

Several low-x and high-x bins contain very few or no events.

Only the central x bins remain sufficiently populated.

Despite limited statistics, the expected t-dependence is preserved in the populated bins.

Thank You