Simulations in NC and CC at EIC

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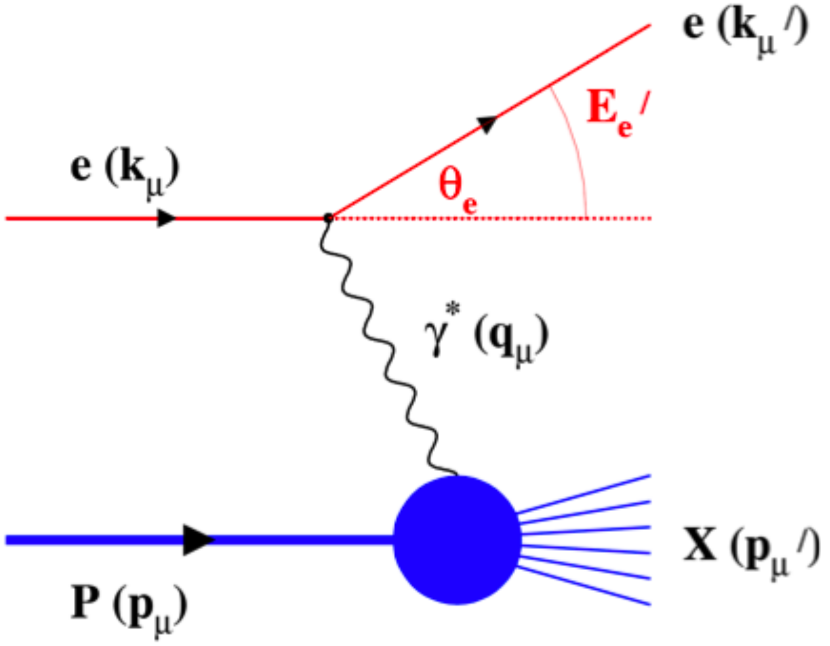
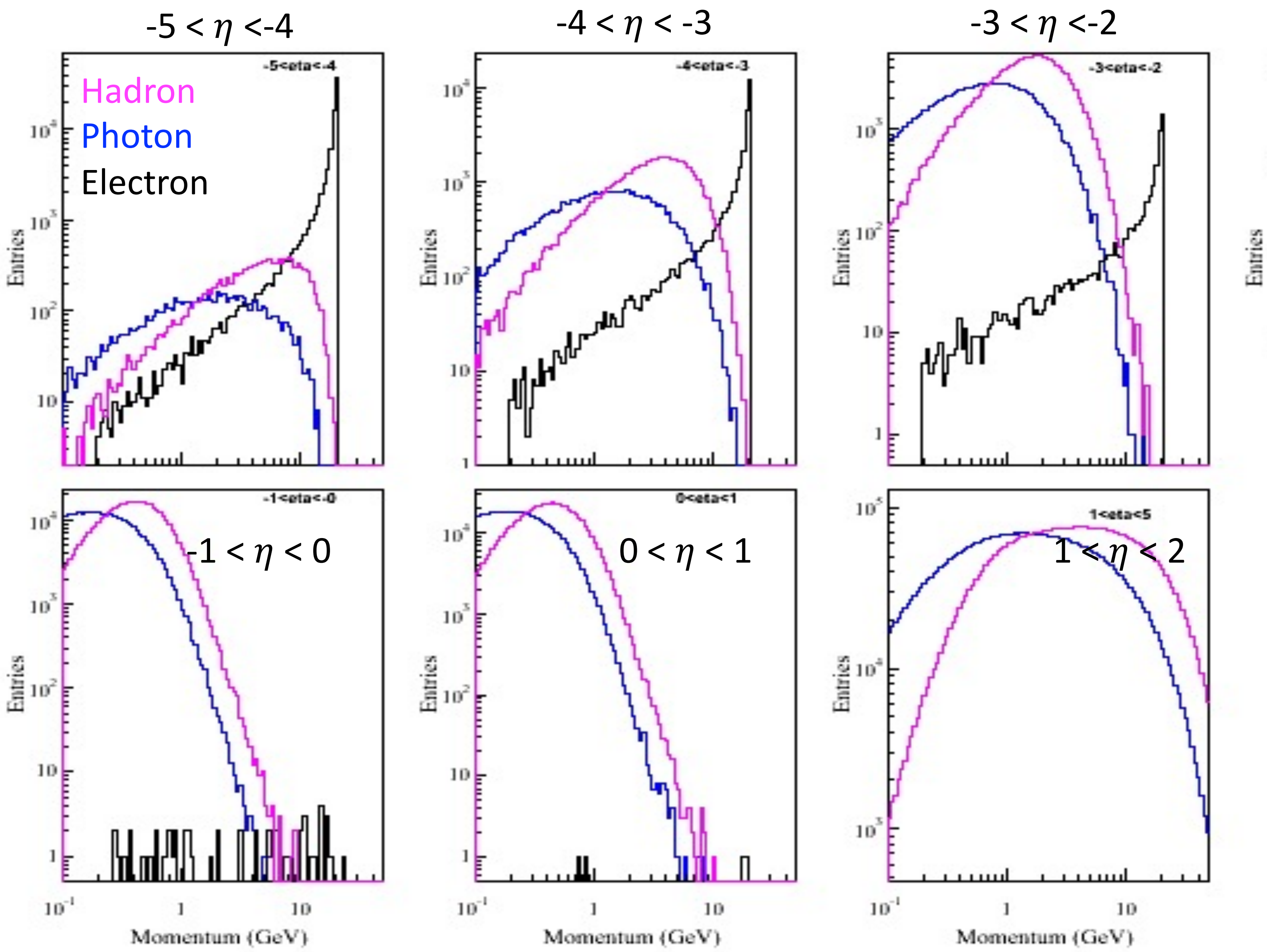
The work included in the following slides is from what I did for EIC yellow report

Simulations in NC through measuring outgoing electron

- Electron Identification
- Effect from kinematics reconstruction method
- Effect from EIC smear



Electron PID: Momentum distributions



ep collisions: 20 $\times$ 250 GeV

- Hadron and photon suppressions are required in backward direction to ensure good electron identification.

NC: Kinematics reconstruction through e'

$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e (1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

https://wiki.bnl.gov/eic/index.php/DIS_Kinematics

$$\frac{\delta x_e}{x_e} = \frac{1}{y_e}\frac{\delta E'_e}{E_e} \oplus \left[\frac{x_e}{E_e/E_p} - 1\right]\tan\frac{\theta'_e}{2}\delta\theta'_e$$

$$\frac{\delta y_e}{y_e} = \left(1 - \frac{1}{y_e}\right)\frac{\delta E'_e}{E_e} \oplus \left[\frac{1}{y_e} - 1\right]\cot\frac{\theta'_e}{2}\delta\theta'_e$$

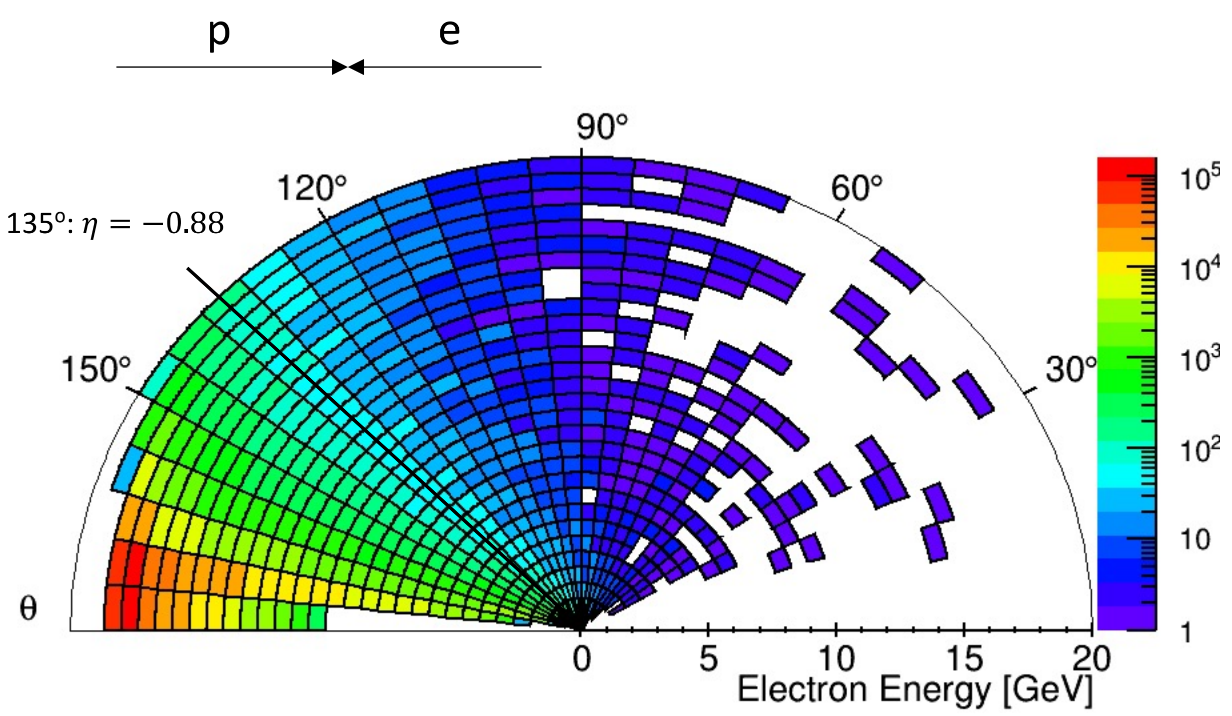
diverges for $y_e \rightarrow 0$ depends on E'_e

$$\frac{\delta Q_e^2}{Q_e^2} = \frac{\delta E'_e}{E_e} \oplus \tan\frac{\theta'_e}{2}\delta\theta'_e$$

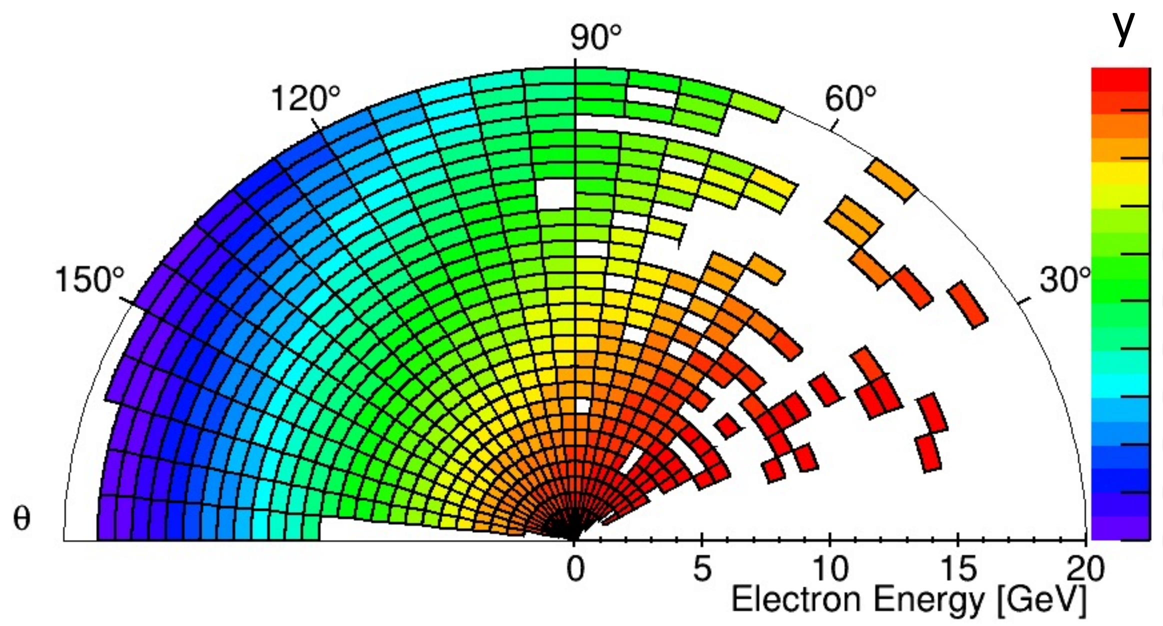
diverges for $\theta'_e \rightarrow 180^o$ depends on E'_e and θ'_e

- Reconstruction replies on measuring E'_e and θ'_e after identification of the outgoing electrons
- Limitation: Resolution diverges at y → 0, $\theta'_e \rightarrow 180^o$

Low y and high θ_e'



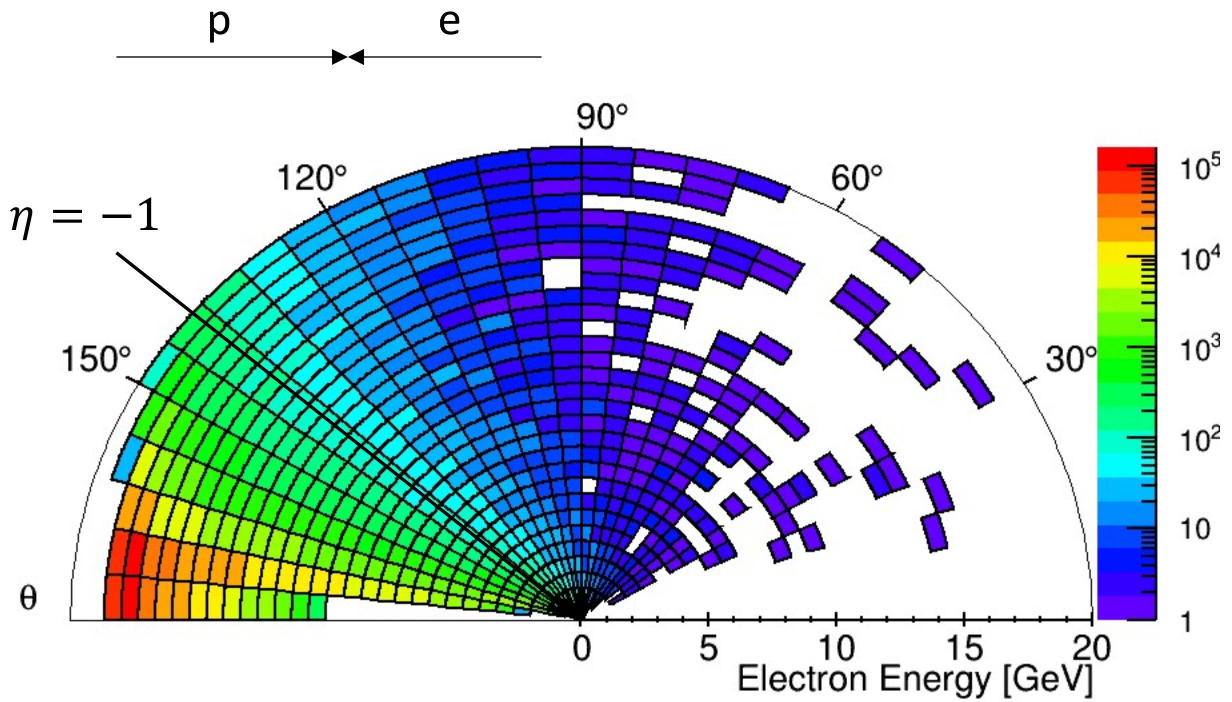
Outgoing electron hit map



y distribution map on electron

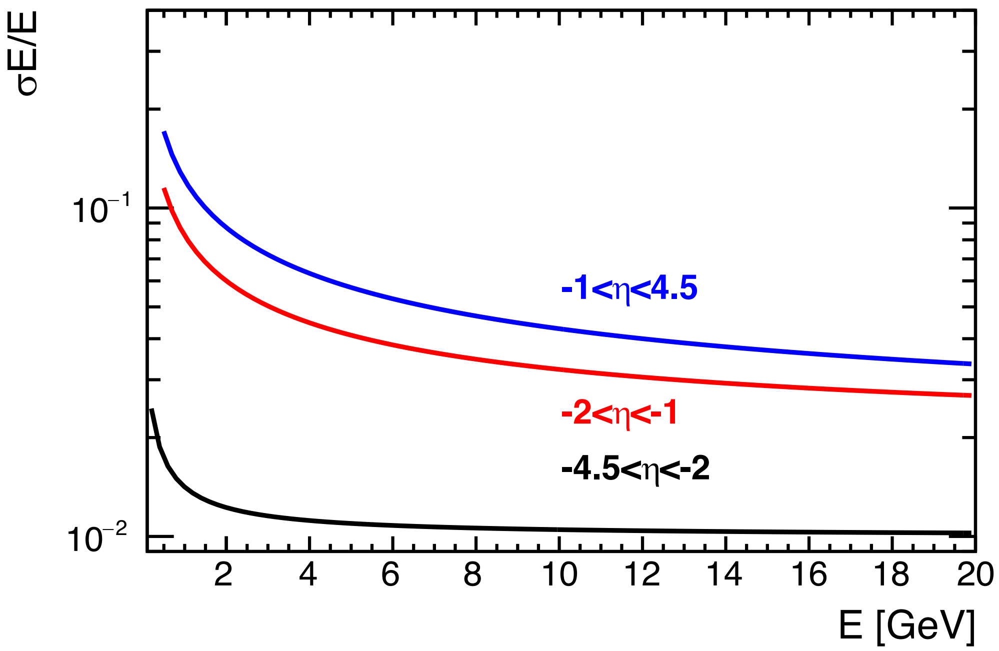
- y → 0: electron energy is high; very backward direction
- Minimum y cut is required to ensure high resolution: widely used cut y > 0.01 at EIC

EIC Smear



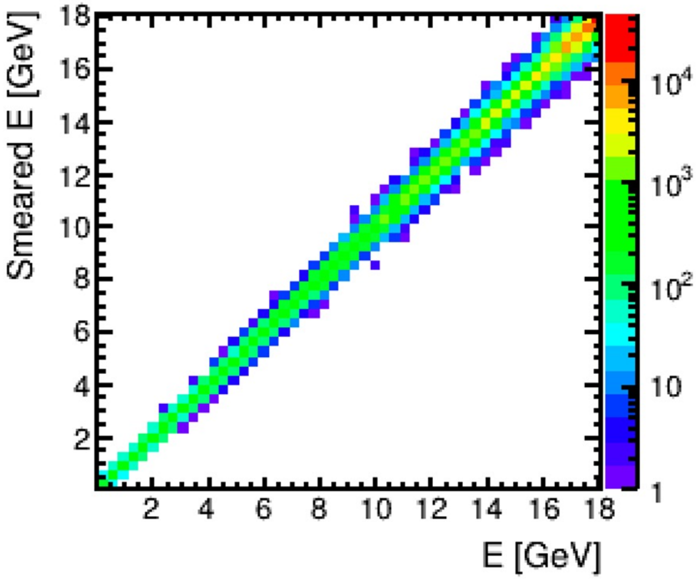
Outgoing electron hit map

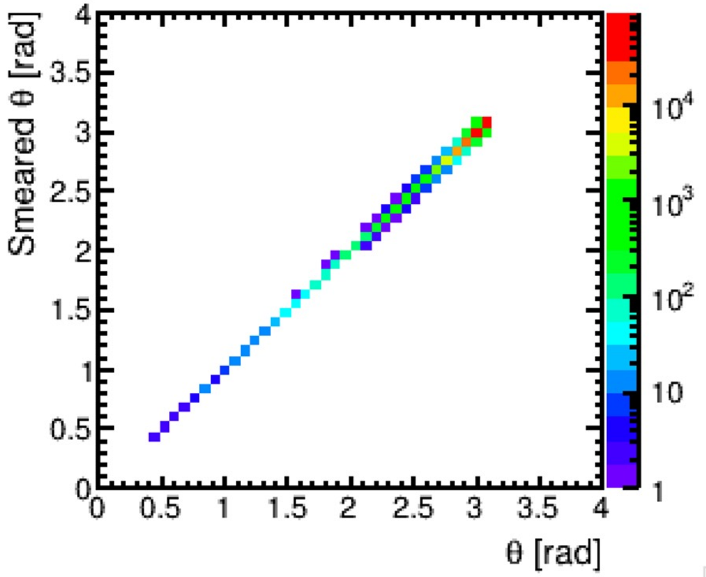
Parameters for EMCal smearing can be found in following slides



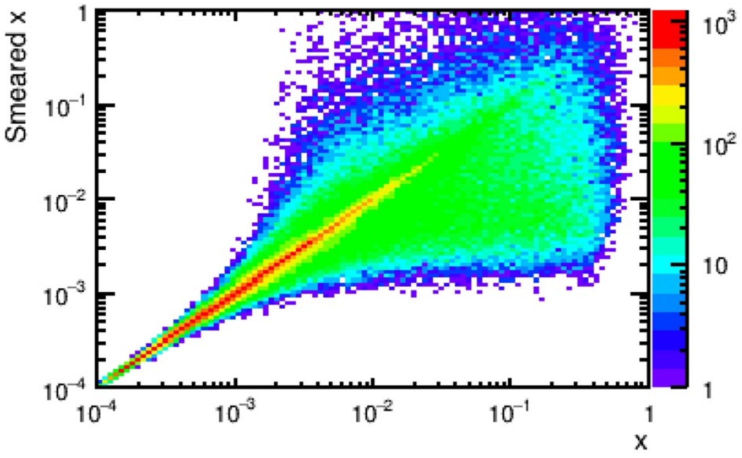
- Energy resolution -2< η < -1 ~ 0.07 at E > 2 GeV; -4.5< η < -2 ~ 0.01 at E > 2 GeV
- Energy resolution -1< η < 4.5 is not good: widely used cut y < 0.95 at EIC
- Energy resolution diverges at very low E

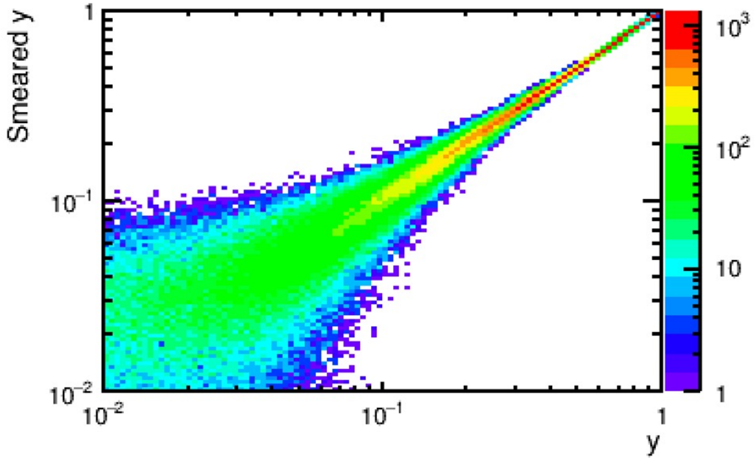
Smeared final electrons and kinematics





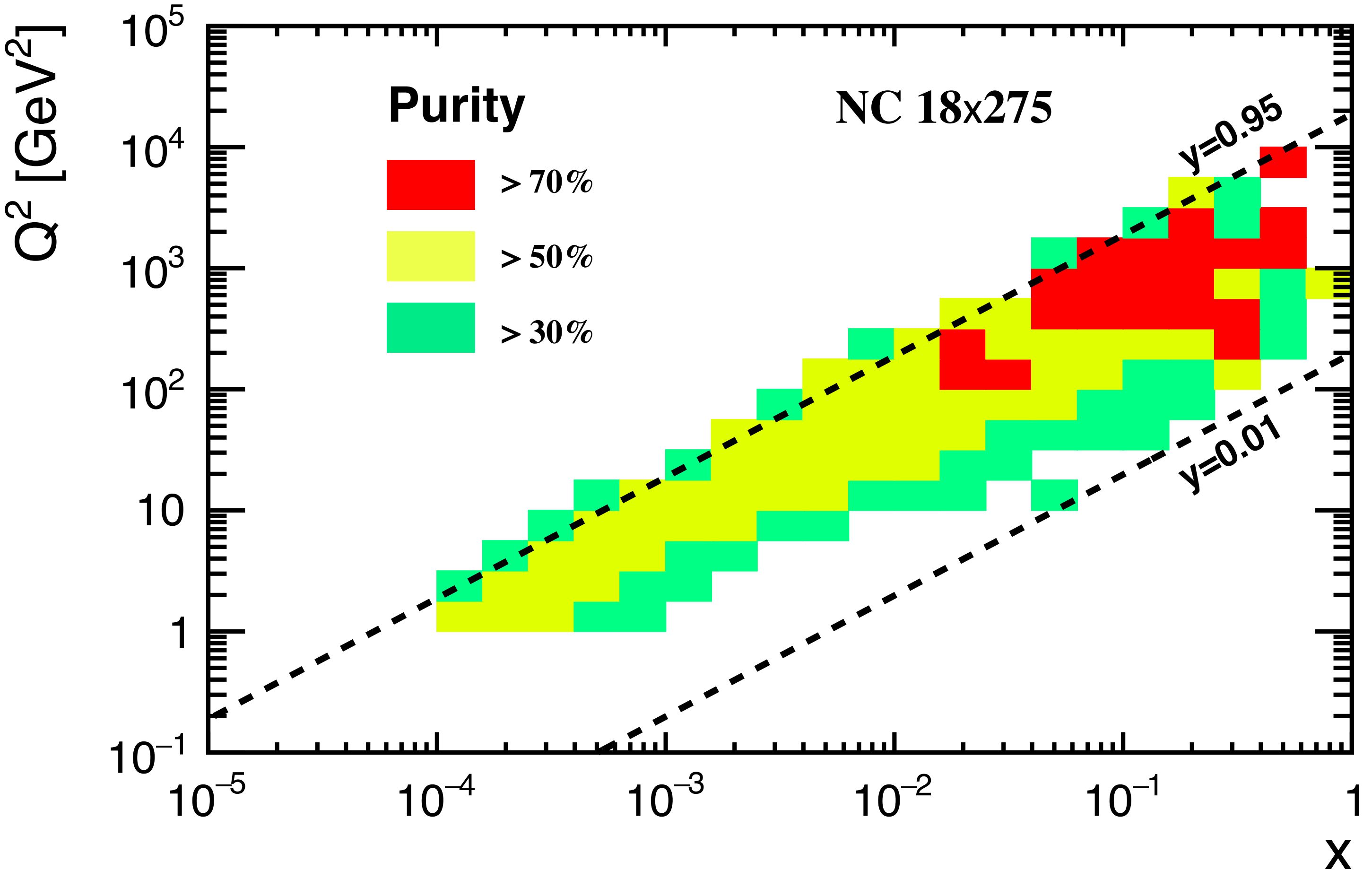
Kinematics of smeared electron





Kinematics of smeared x and y

Purity

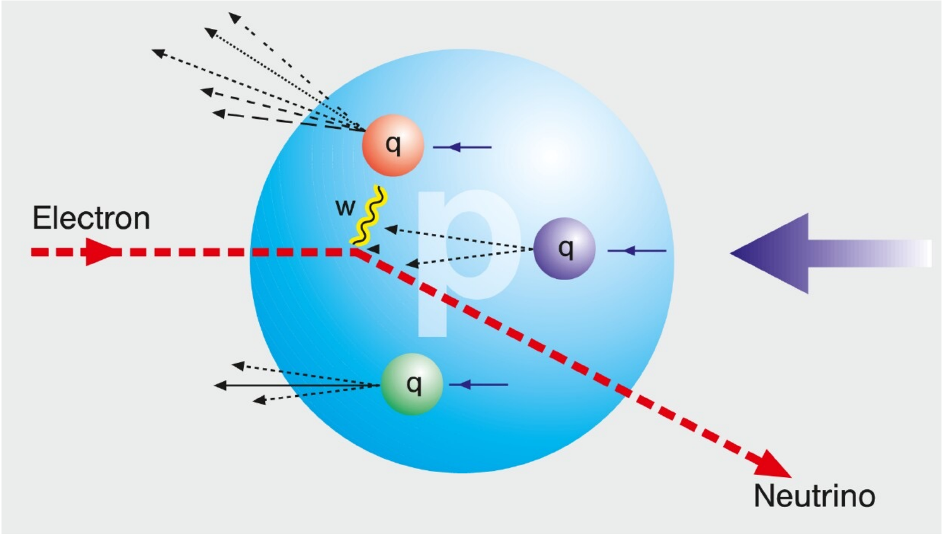


- Purity is defined as the fraction of events reconstructed in a given x-Q^2 bin that were generated in the same bin
- It reflects the bin migration into a reconstructed kinematic bin (x_R, y_R, $Q^2{}_R$) after including detector smearing effect

Simulations in CC through measuring hadronic system

- **Radiation effect**
- **Jacquet-Blondel method:**
  - **PID for hadronic system**
  - **Detector acceptance**
- **Effect from EIC smear**

DJANGOH is used for CC simulation

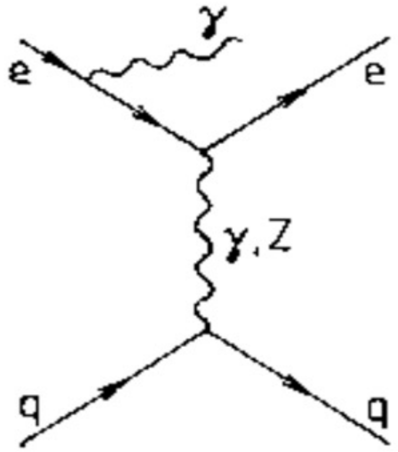


True level	trueX	trueY	trueQ^2	kinematic variables of the event at the hard scattering vertex, used to do impact study
Radiative level	x	y	Q^2	calculated from neutrino
Reconstructed level	x^{rec}	y^{rec}	Q^2_{rec}	reconstruct by Jacquet-Blondel method through hadronic final state to reconstruct kinematics

Radiative correction

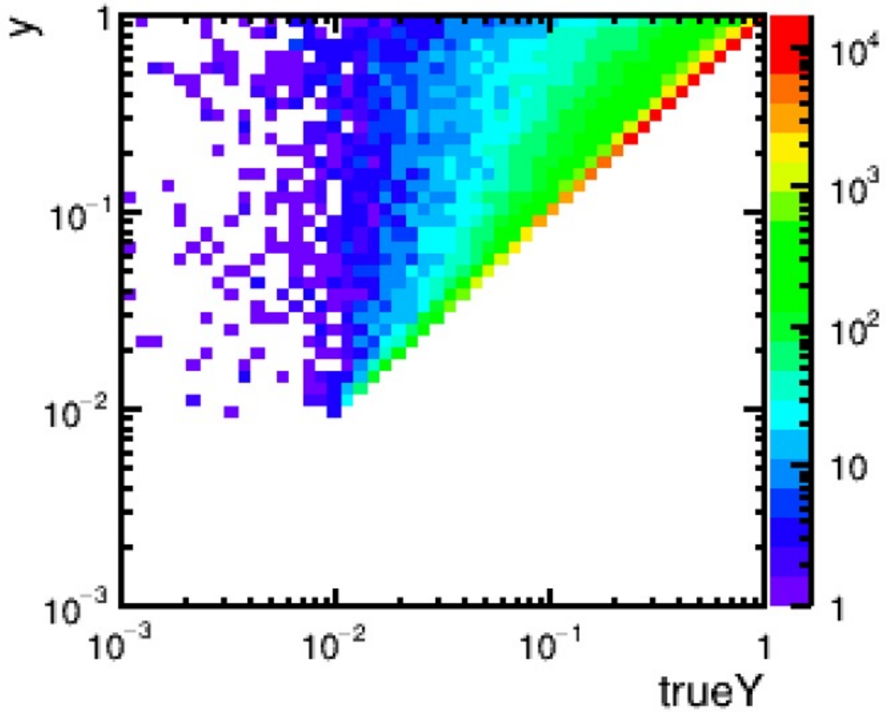
Take radiative effect on y for explanation

NC for illustration



initial

trueY < y

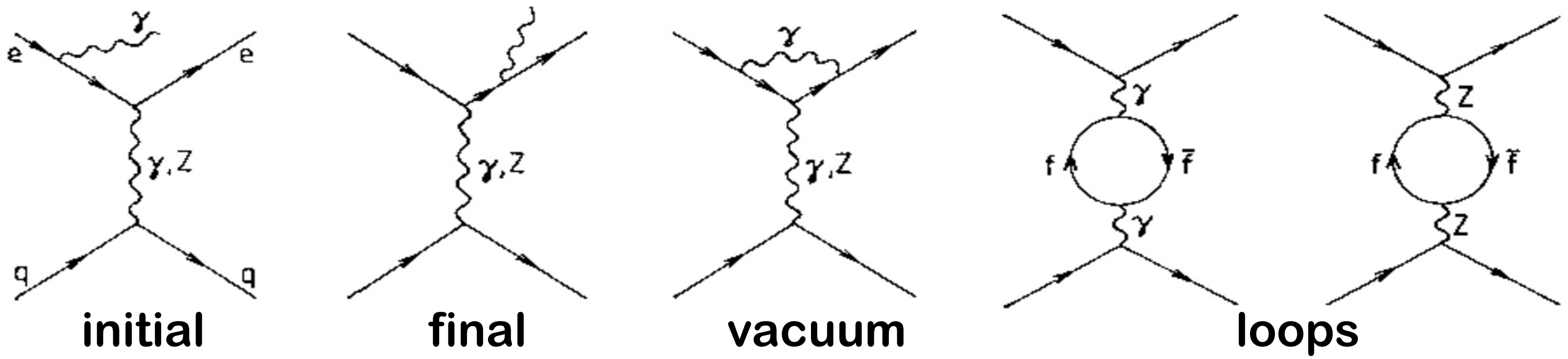


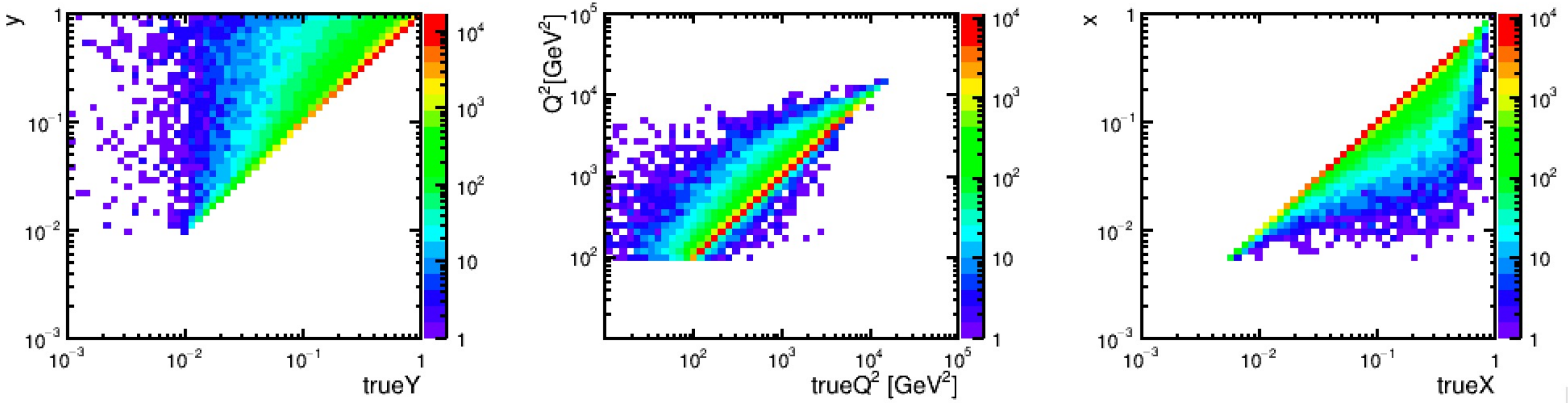
	Energy of exchanged photon (E_γ)	y = E_γ / E_e
Radiative level (y)	E_γ = E_e - $E_{e'}$	(E_e - $E_{e'}$)/E_e
True level (trueY)	E_γ = E_e - $E_{e'}$ - radiative photon's energy	(E_e - $E_{e'}$ - radiative photon's energy)/E_e

Radiative effect

Data sample : Int L = 10 fb^{-1}, Kinematics settings: 0.01<y<0.95, 10^2 GeV^2 <Q^2<10^5 GeV^2

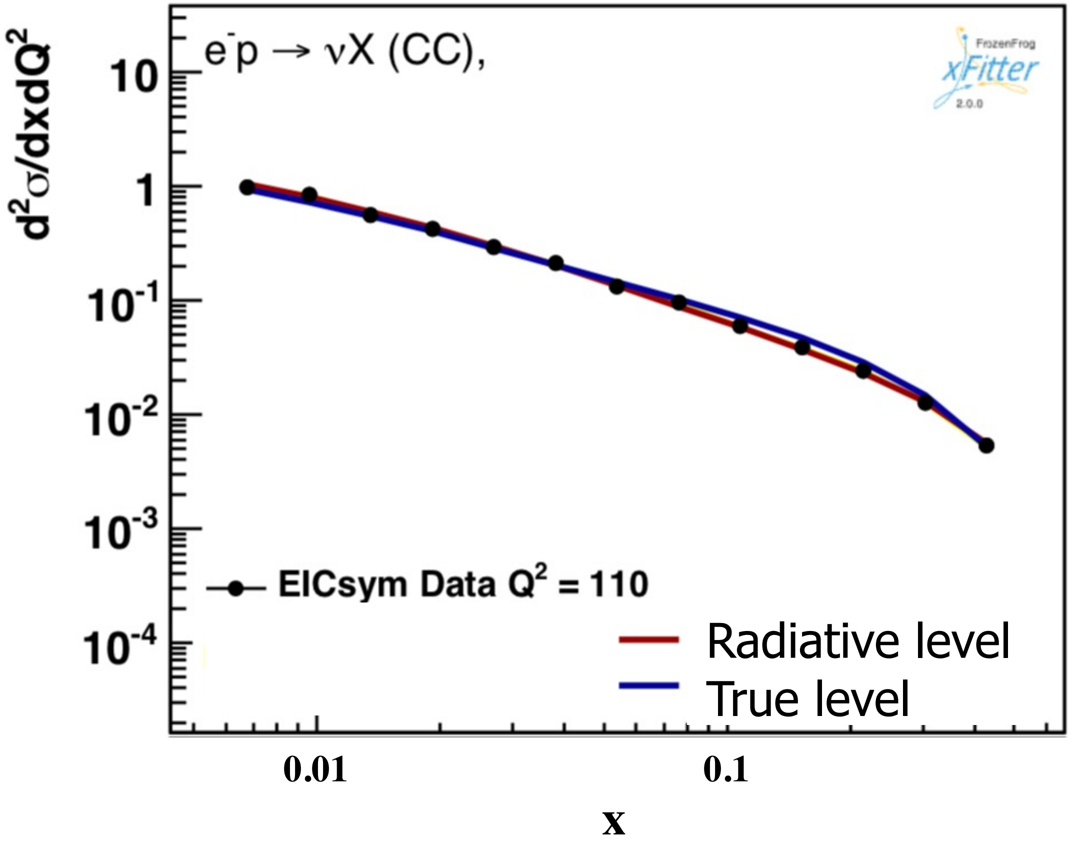
NC for illustration

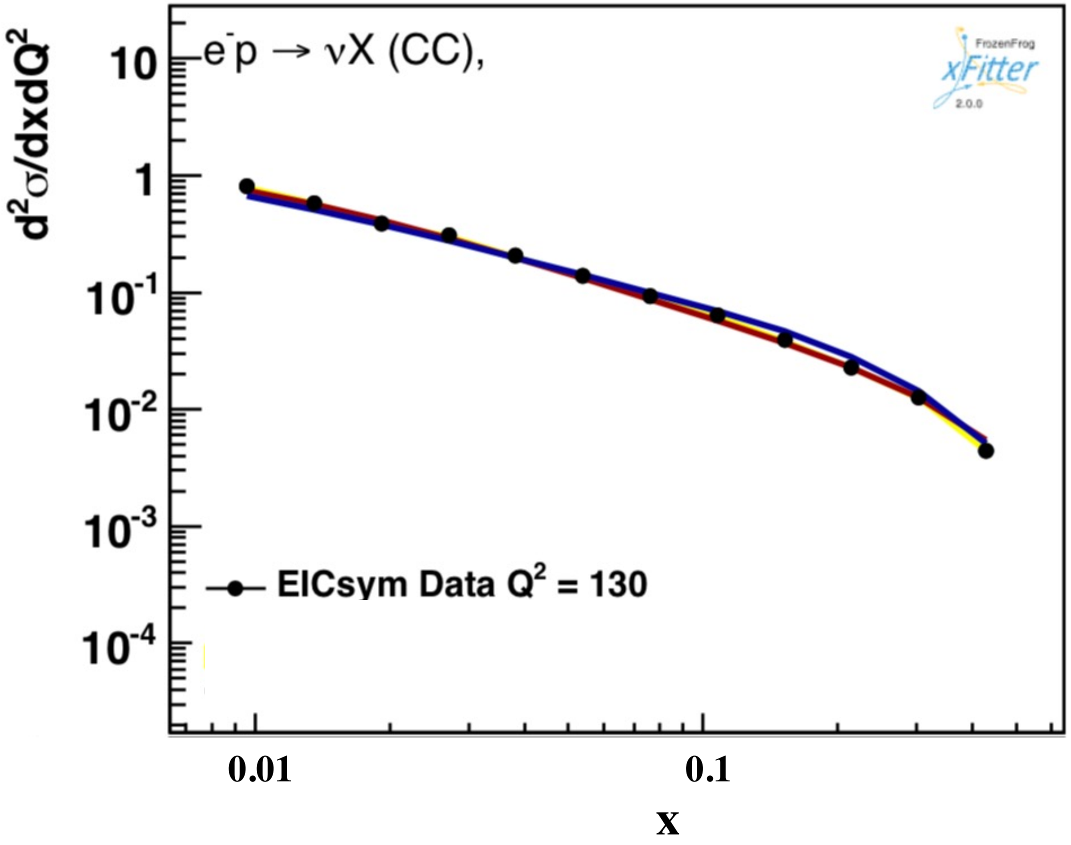




- Djangoh includes radiative effects (radiative vs true): in some events y is smaller than trueY; x is larger than trueX

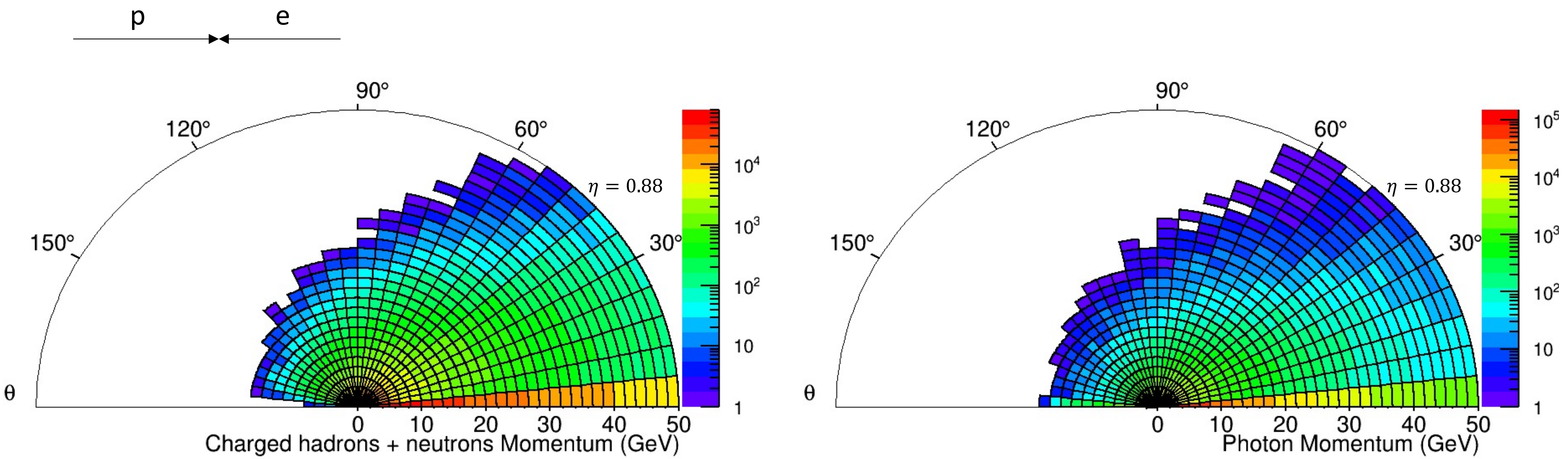
Radiative effect





Radiative effect at x~>0.07

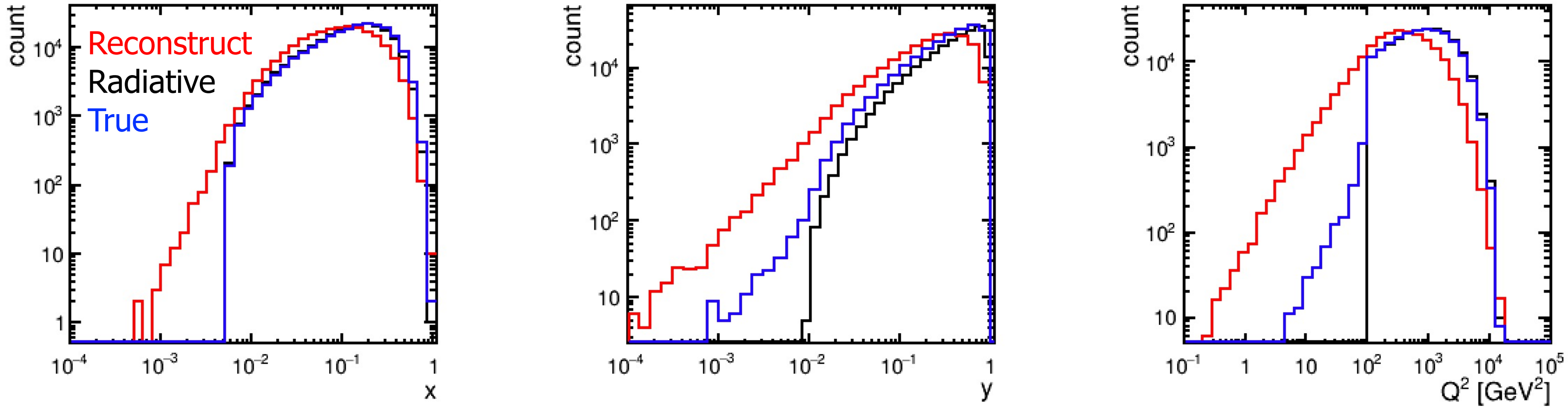
JB method: Final state particles Hit Map



- Final state particles: mainly in middle and forward direction
- Very forward particles with high momentum are produced from proton beam remnant

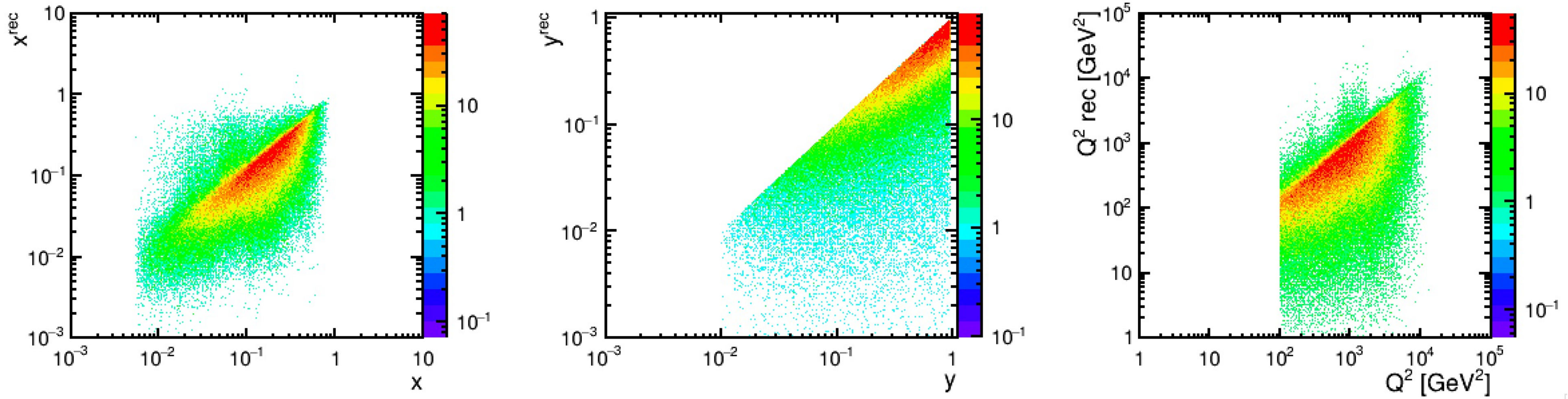
PID impact: final hadrons with full acceptance

Final state $p^{\pm}, K^{\pm}, \pi^{\pm}$ and n: $x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}$; $y^{rec} = \frac{(E-p_z)_h}{2E_e}$; $Q^2_{rec} = \frac{p^2_{t,h}}{1-y_{JB}}$



$$p^2_{t,h} = \left(\sum_h p_{x,h}\right)^2 + \left(\sum_h p_{y,h}\right)^2$$

$$\left(E-p_z\right)_h = \sum_h \left(E_h - p_{z,h}\right)$$

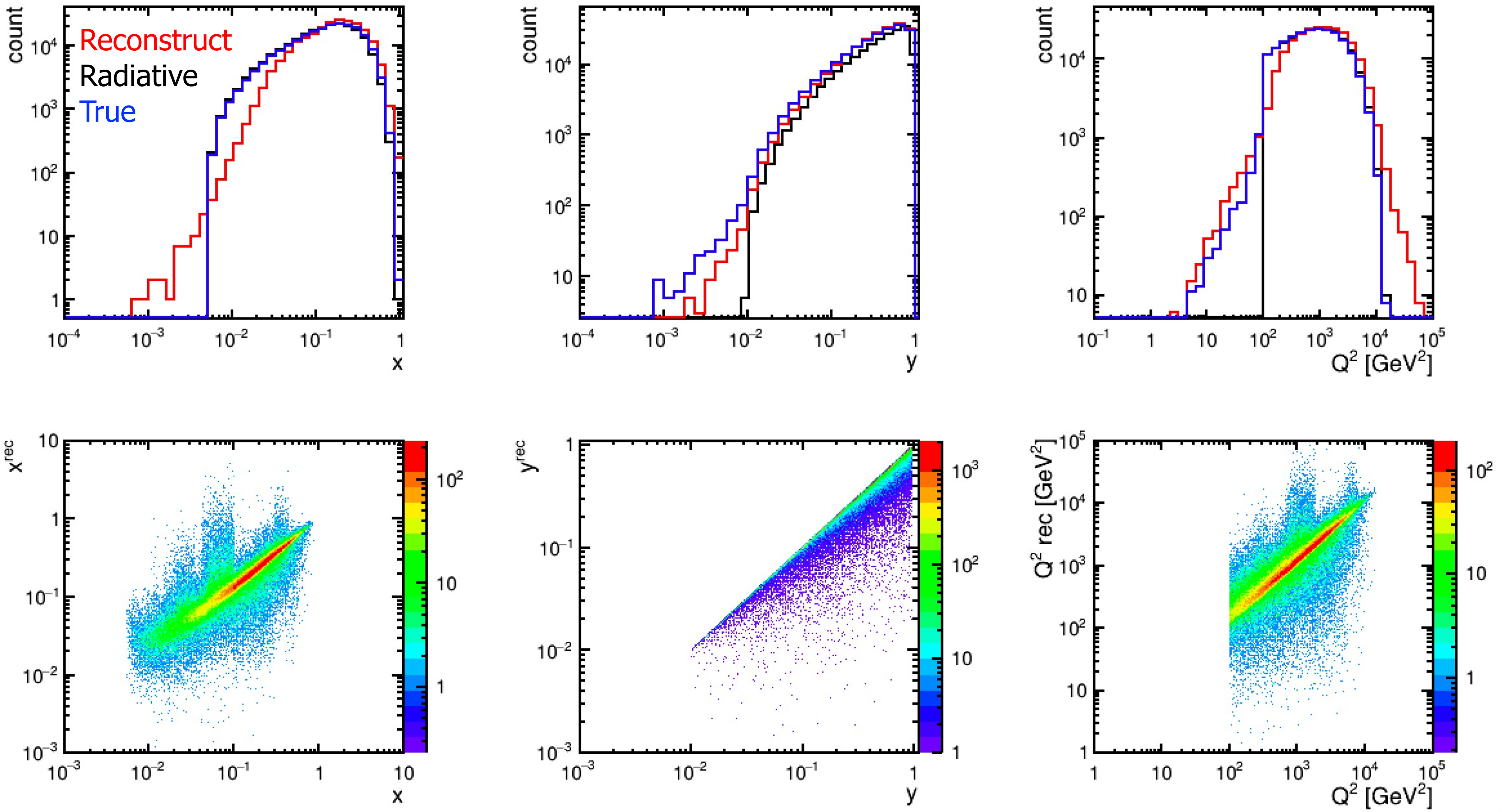


y^{rec} vs y:
y^{rec} is smaller, due to losing contribution from not detected final state particles

PID impact: photons included

Final state $p^{\pm}, K^{\pm}, \pi^{\pm}$,n and γ:

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E-p_z)_h}{2E_e}; \quad Q^2_{rec} = \frac{p^2_{t,h}}{1-y_{JB}}$$



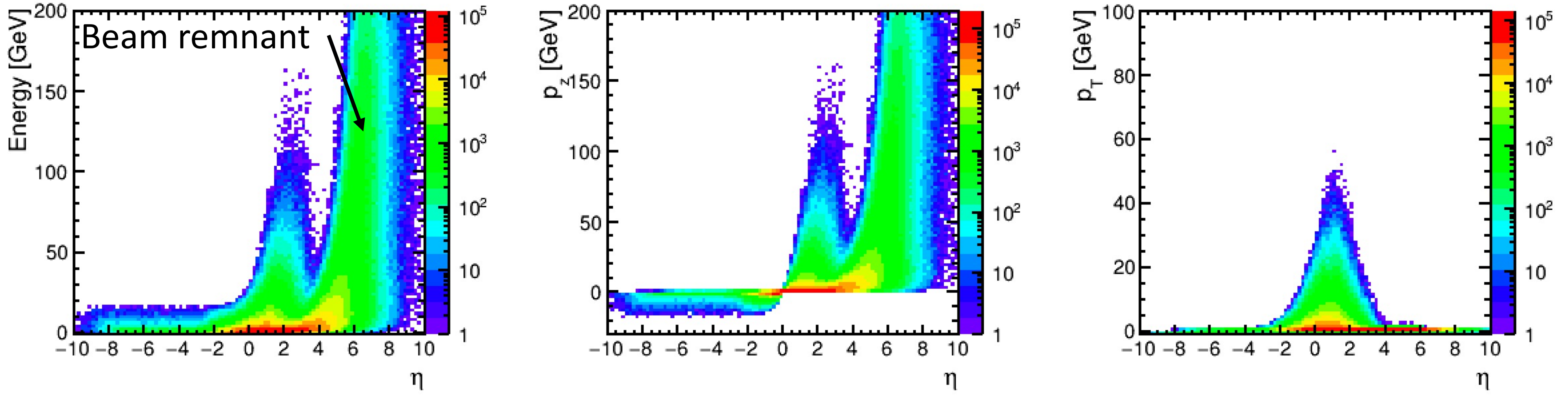
- Final photons are important: cross section is significant

Detector acceptance effect

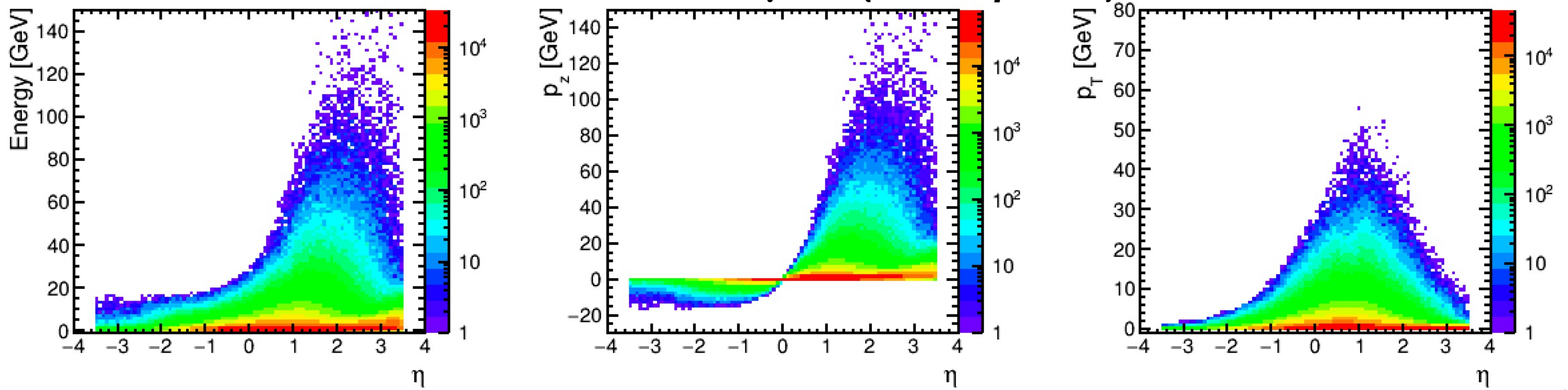
Final state $p^{\pm}, K^{\pm}, \pi^{\pm}$,n and γ:

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E-p_z)_h}{2E_e}; \quad Q^2_{rec} = \frac{p^2_{t,h}}{1-y_{JB}}$$

Perfect detector



Detector accepted (-3.5 < η < 3.5)

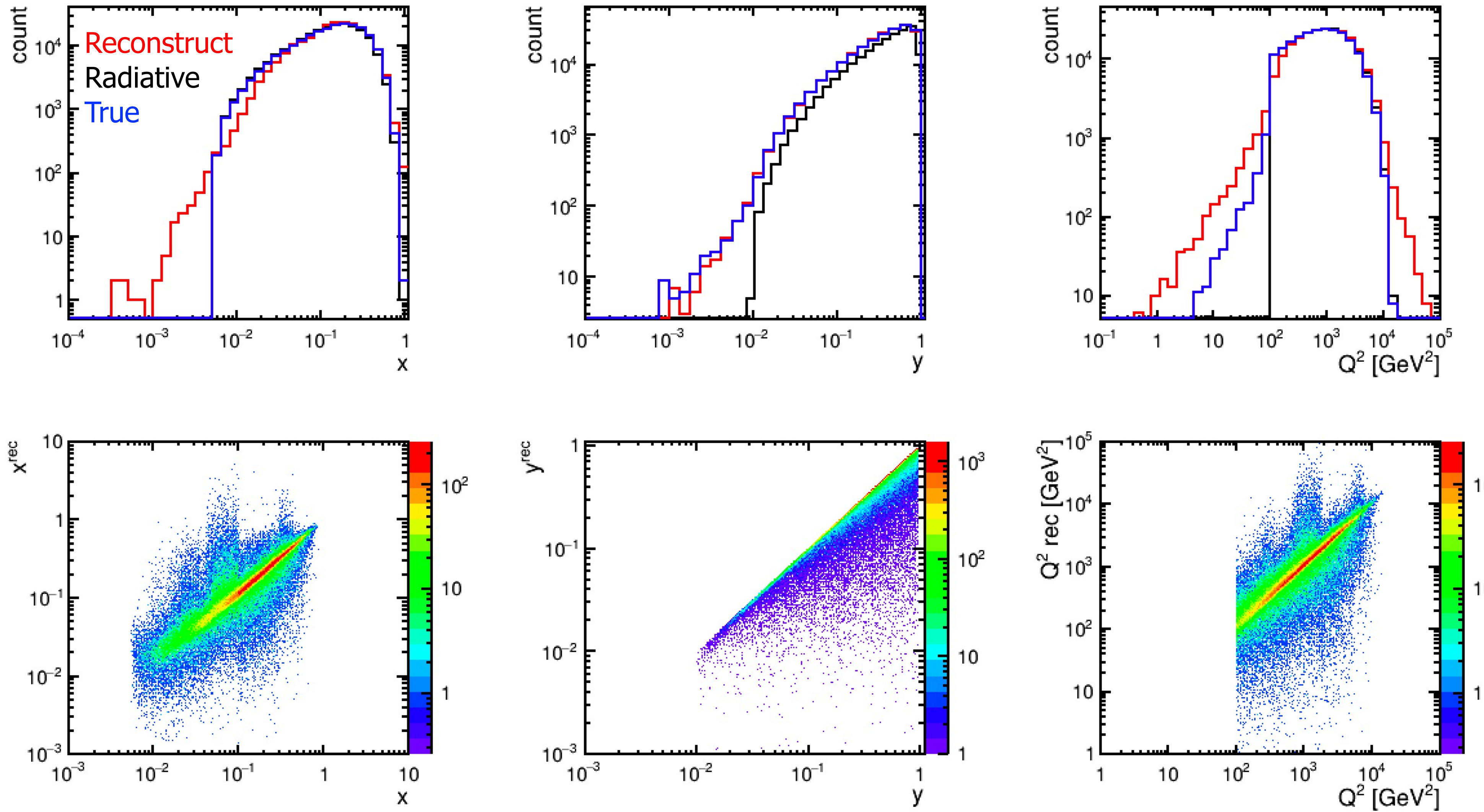


Detector acceptance effect on kinematics

Final state $p^{\pm}, K^{\pm}, \pi^{\pm}$,n and γ:

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E-p_z)_h}{2E_e}; \quad Q^2_{rec} = \frac{p^2_{t,h}}{1-y_{JB}}$$

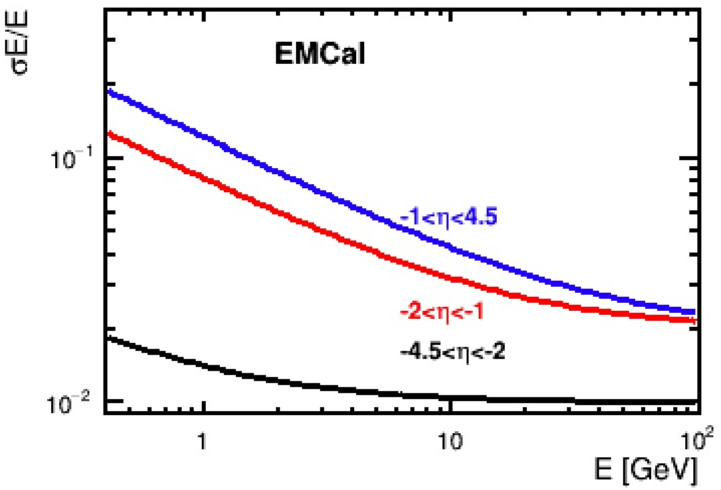
-3.5< η <3.5



Can be compared with s15 to see impact from rapidity cut

EIC Smear: detectors smear input

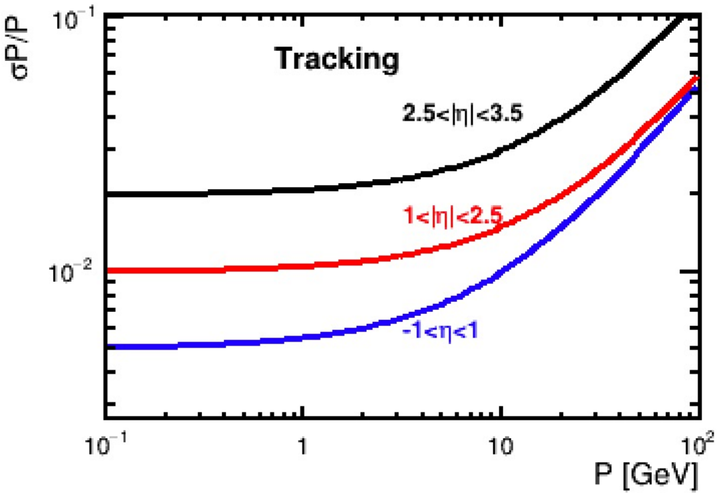
Photons



EMcal: -4.5 < eta < 4.5

eta = -4.5 – -2: sigma_E~sqrt(pow (0.01*E,2) + pow(0.01,2)*E)
eta = -2 – -1: sigma_E~ sqrt(pow (0.02*E,2) + pow(0.08,2)*E)
eta = -1 – 4.5: sigma_E~ sqrt(pow (0.02*E,2) + pow(0.12,2)*E)

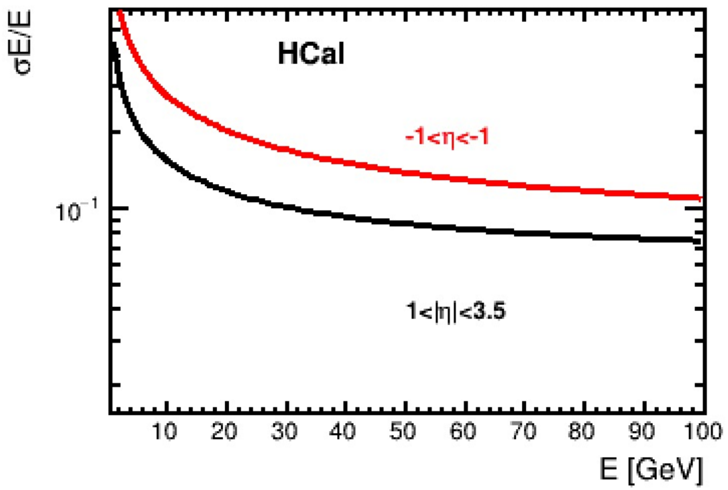
Charged hadrons



Tracking: -3.5 < eta < 3.5

eta = -3.5 – -2.5: sigma_p/p ~ 0.1% p+2.0%
eta = -2.5 – -1: sigma_p/p ~ 0.05% p+1.0%
eta = -1 – +1: sigma_p/p ~ 0.05% p+0.5

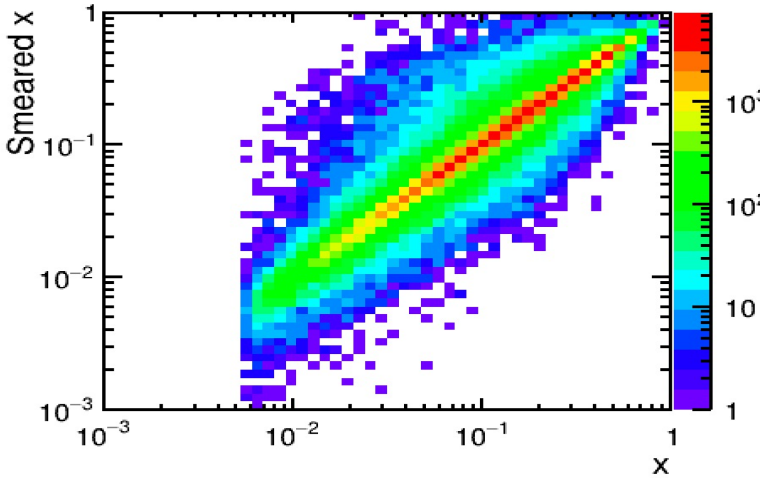
Charged hadrons+neutrons

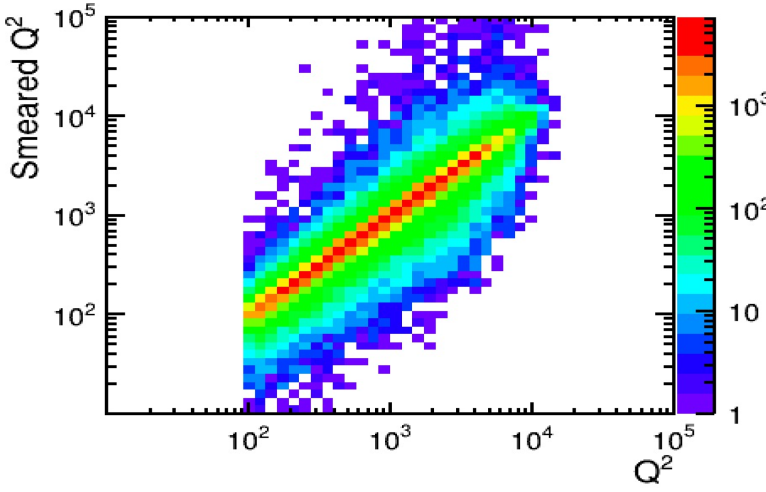


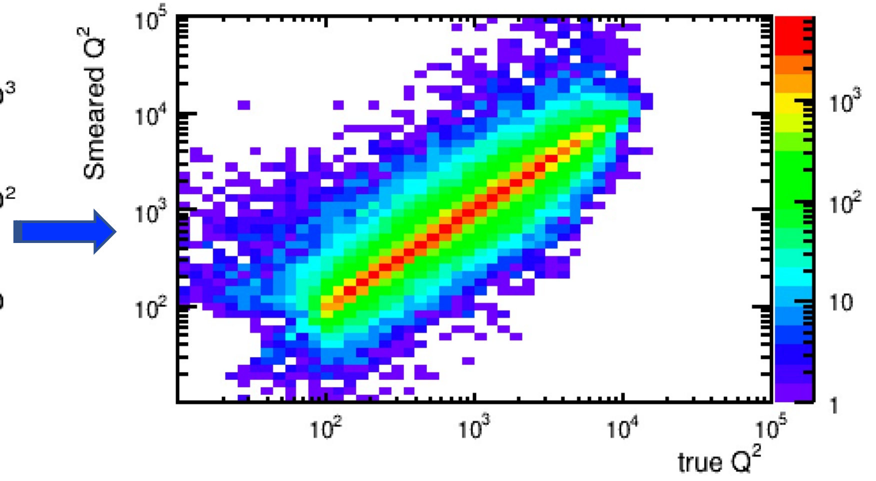
Hcal is -3.5 < eta < 3.5

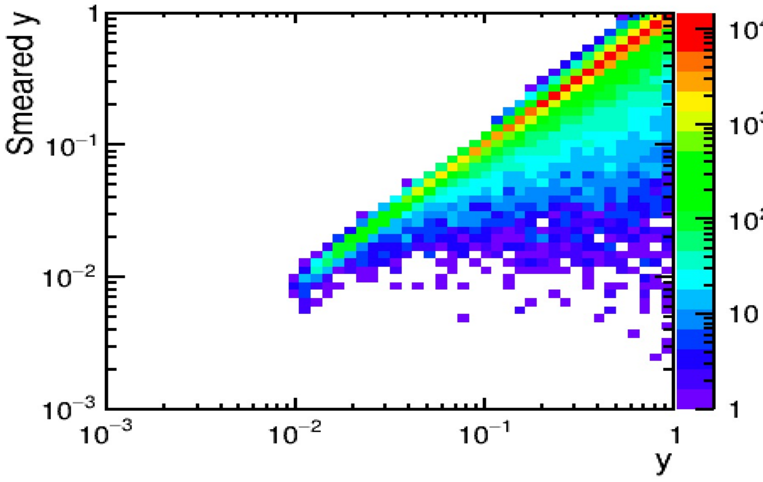
eta = -3.5 – -1: sigma_E ~sqrt(pow(0.06*E, 2) + pow (0.45,2) *E
eta = -1 – 1: sigma_E ~ sqrt(pow(0.07*E, 2) + pow(0.85, 2)*E)

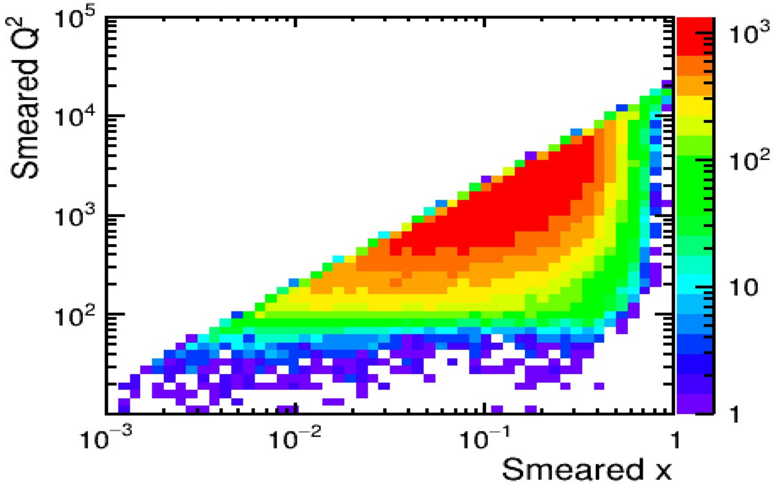
Smeared kinematics











- Smear effect: Correlations between the reconstructed kinematics including detector and radiative level kinematics
- Correlations between the reconstructed Q^2 the trueQ^2

Summary

Simulation studies in NC and CC channels are discussed

Not a full analysis of the physics observables; not a full detector simulation: EIC smear was used

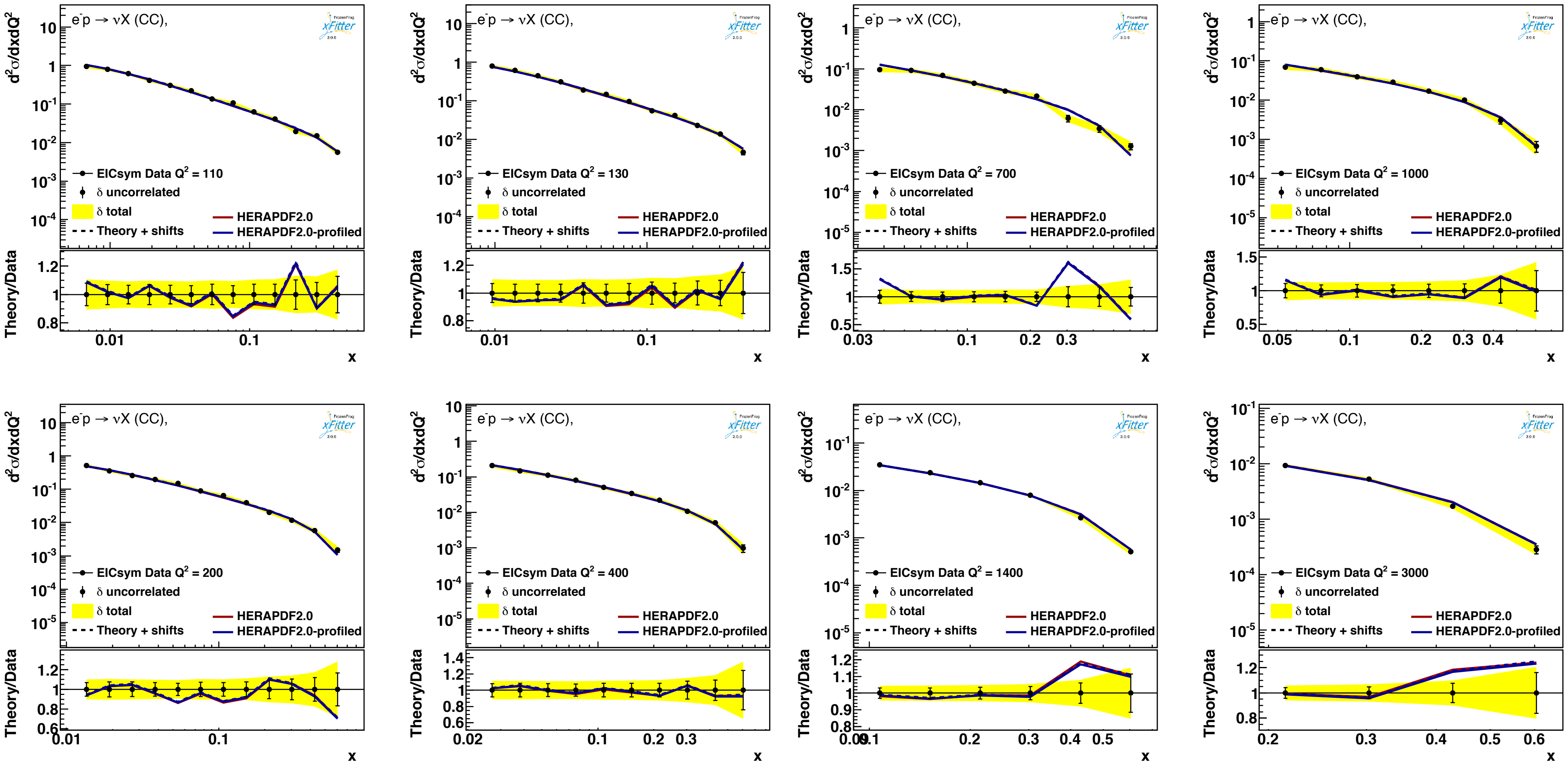
Kinematics resolution can be smeared from several effects:

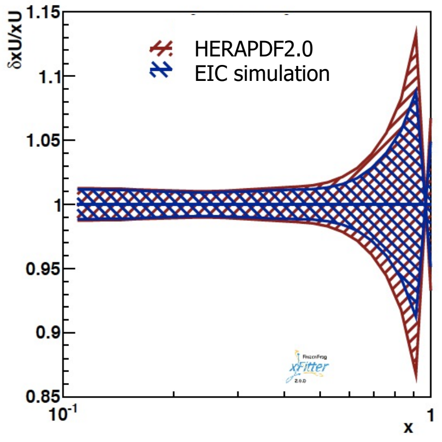
- Electron method: Electron PID, EMCal effect from EIC smear
- JB method: radiative effect, hadron + photon PID, detector acceptance, energy threshold (backup)

There are also other reconstruction methods not discussed: sigma method, double angle method…

Which effects need to be mainly focused on? What level of detector performance is needed?

Reduced cross section at true level with xfitter



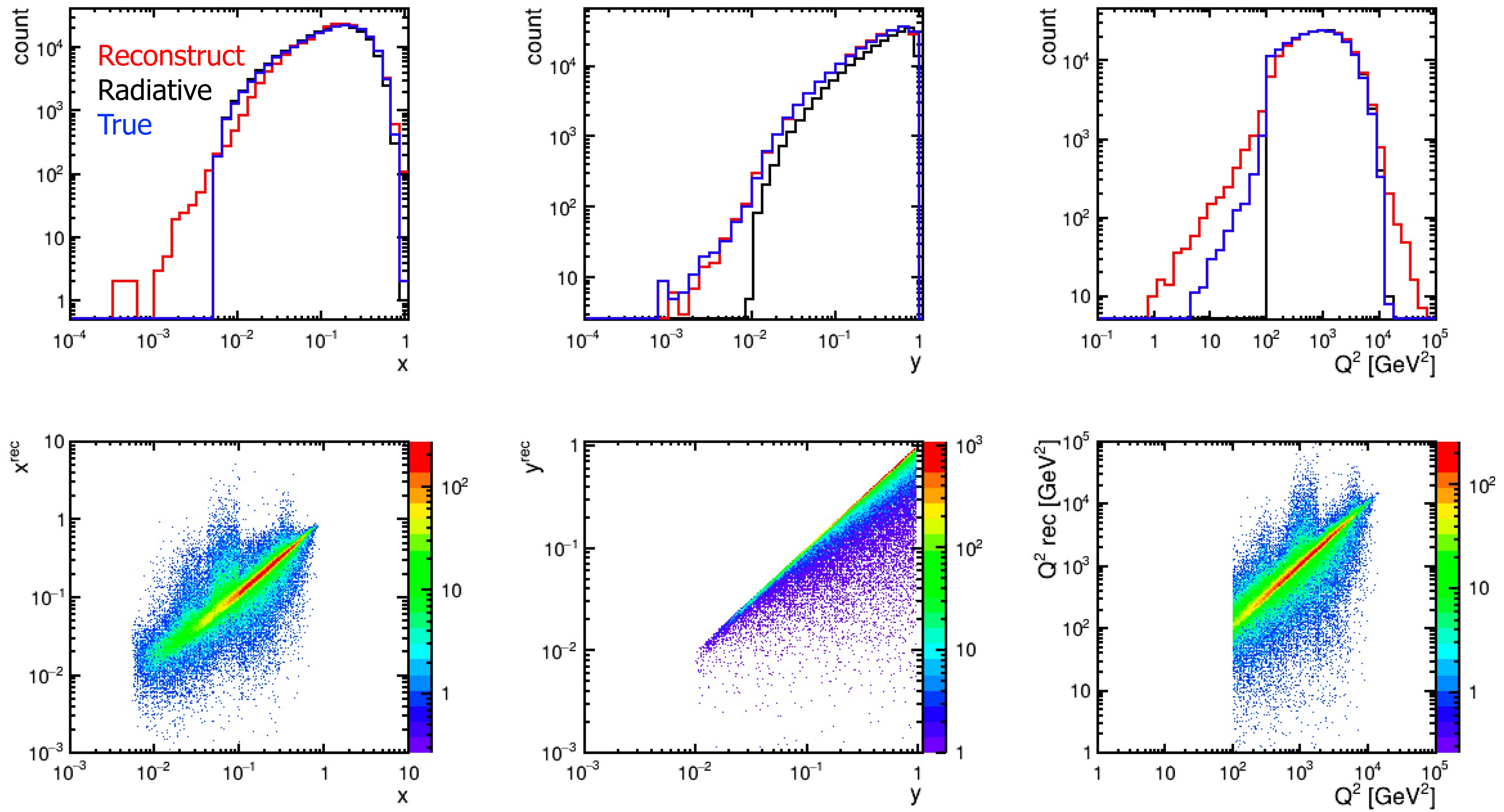


- CC reduced cross sections measured at EIC agree with theory predictions and HERAPDF.
- Reduced cross sections on true level are used for impact study. EIC CC data reduce uncertainty of U at high x.

Energy threshold impact (1):

EMcal E>100 MeV, Hcal E>250MeV, -3.5<eta<3.5

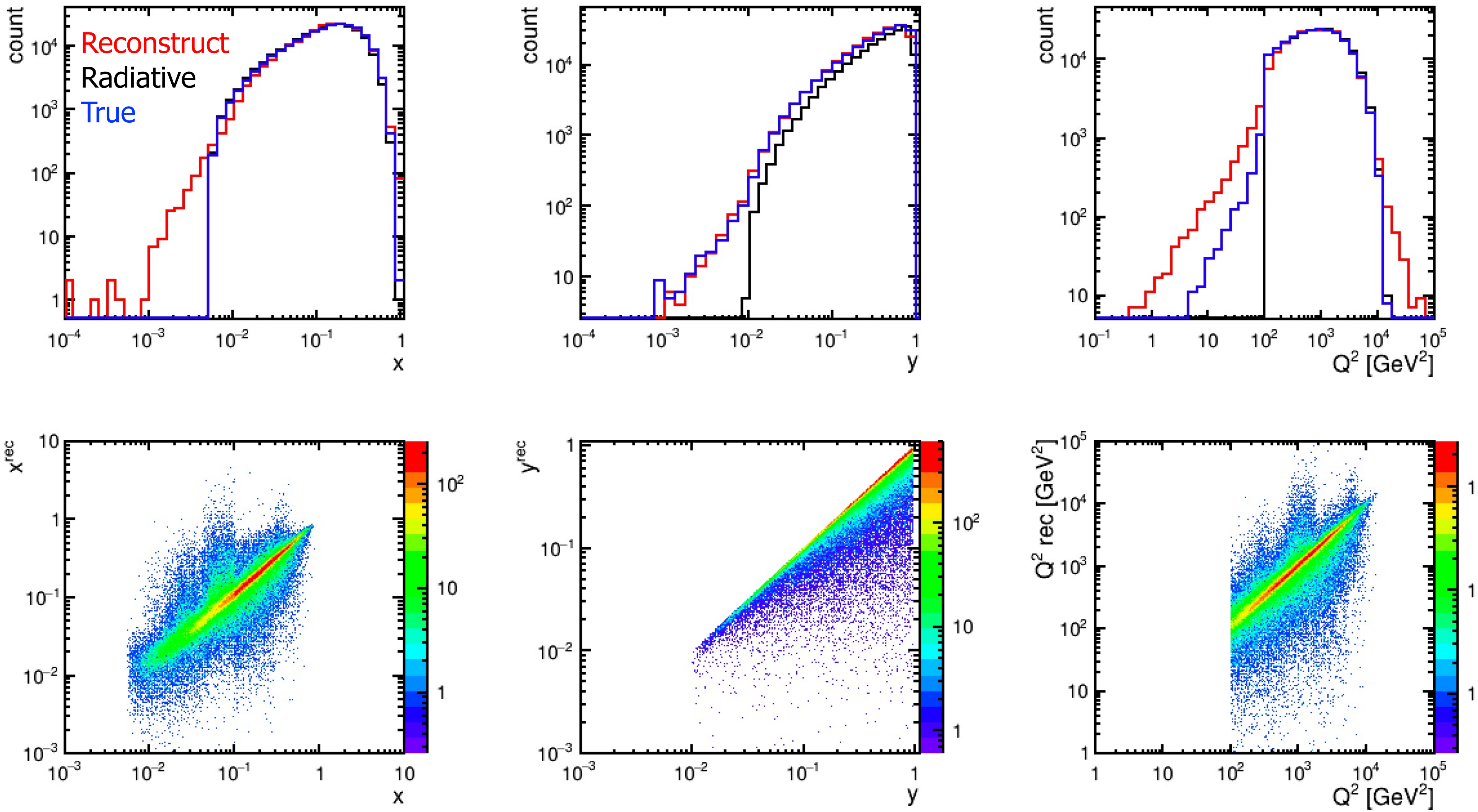
$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E - p_z)_h}{2E_e}; \quad recQ^2 = \frac{p^2_{t,h}}{1 - y_{JB}}$$



Energy threshold impact (2):

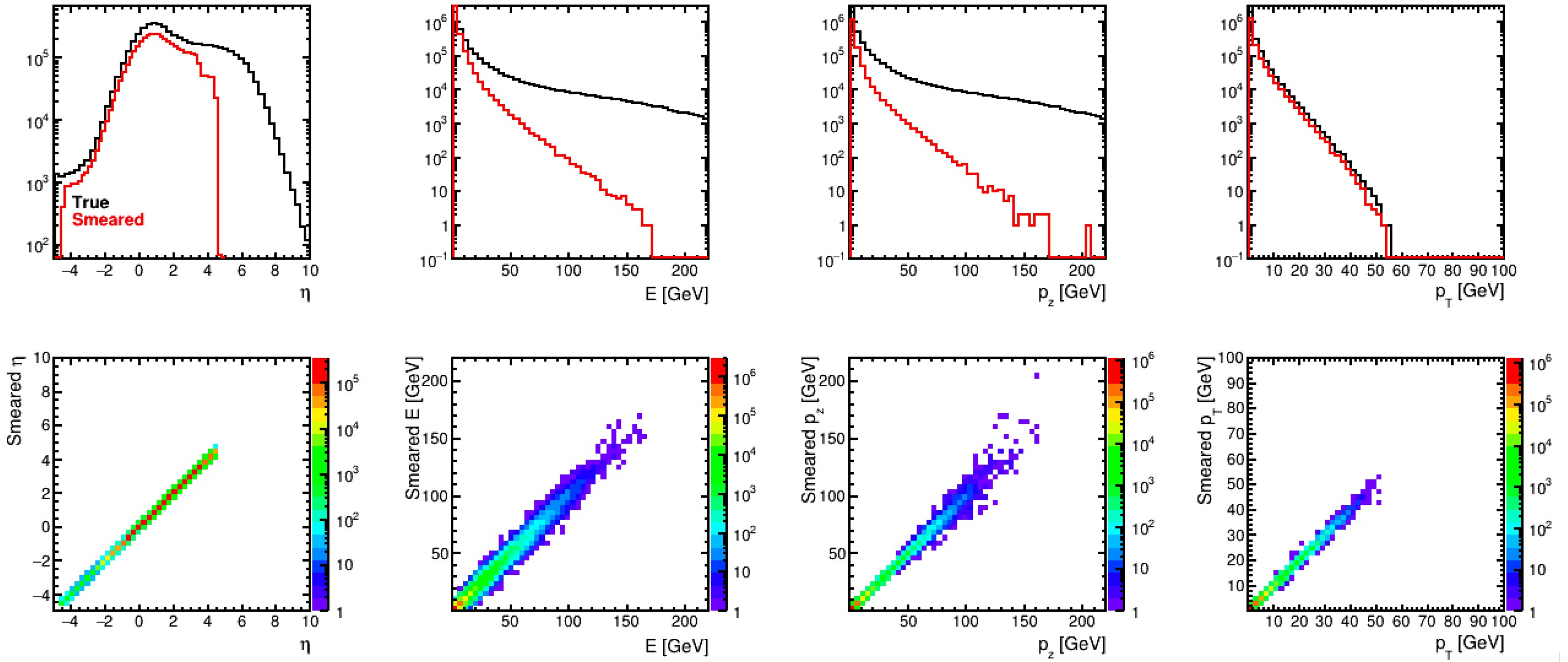
Photon E>250 MeV, Hadron E>500MeV, -3.5< η <3.5:

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E - p_z)_h}{2E_e}; \quad Q^2_{rec} = \frac{p^2_{t,h}}{1 - y_{JB}}$$



EIC Smear: final particles kinematics

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E - p_z)_h}{2E_e}; \quad recQ^2 = \frac{p^2_{t,h}}{1 - y_{JB}}$$



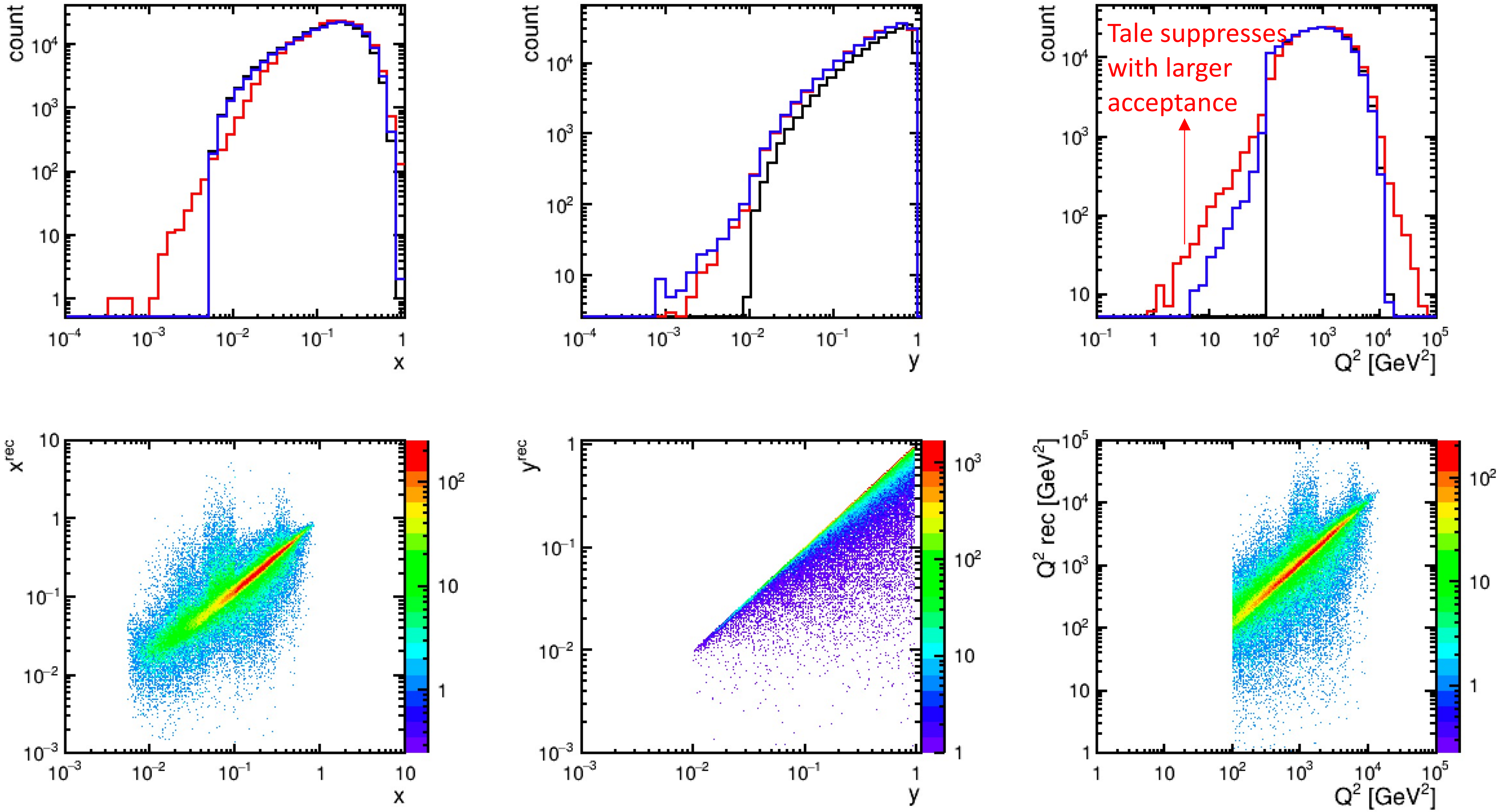
Smeared final particles kinematics: all final photon, pion, proton, neutron and kaon are included.

Detector acceptance effect on kine

$$x^{rec} = \frac{Q^2_{JB}}{s y_{JB}}; \quad y^{rec} = \frac{(E-p_z)_h}{2E_e}; \quad recQ^2 = \frac{p^2_{t,h}}{1-y_{JB}}$$

Detector accepted: all final photon, pion, proton, neutron are included, -4<eta<4

True level, radiative



Resolution map after EIC smearing