KINEMATIC FITTING OF NEUTRAL CURRENT EVENTS IN DEEP INELASTIC ep COLLISIONS.

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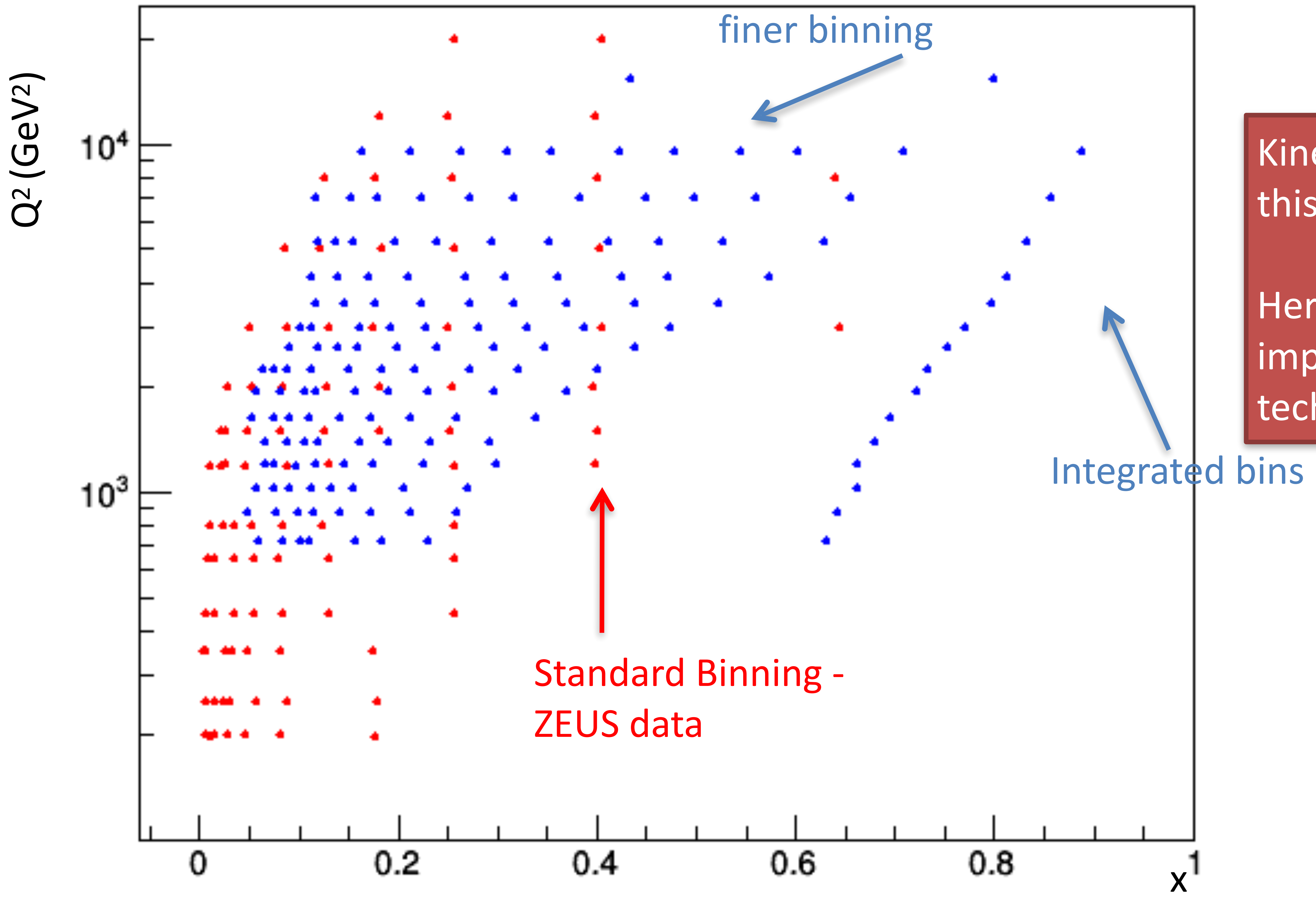
Measurement of neutral current $e^{\pm}p$ cross sections at high Bjorken x with the ZEUS detector

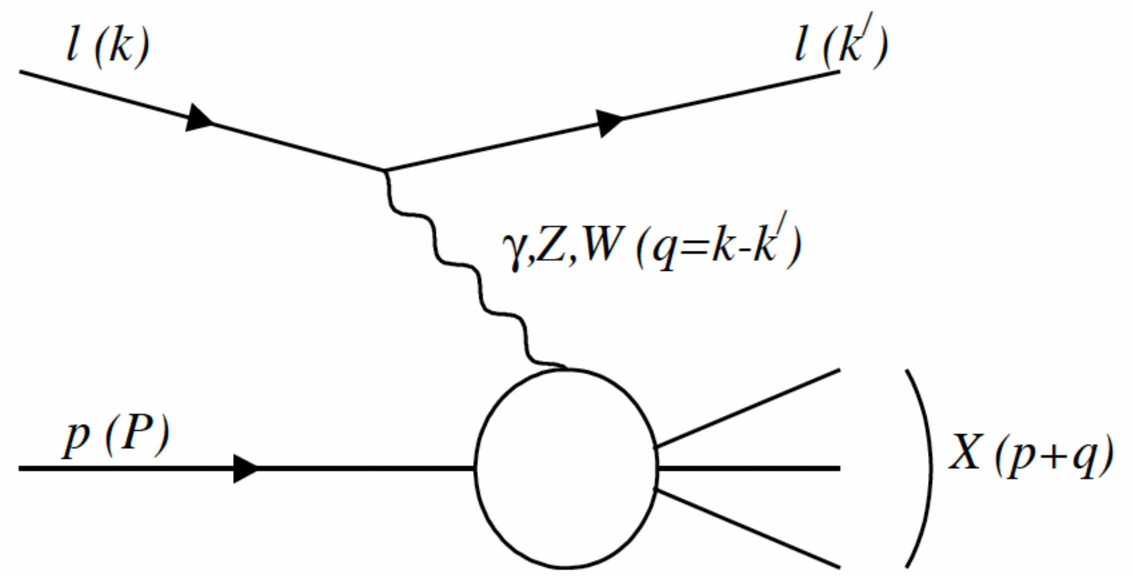
H. Abramowicz *et al.* (ZEUS Collaboration)
Phys. Rev. D **89**, 072007 – Published 8 April 2014



Kinematic Fitting was used in this analysis.

Here, we discuss an update/ improvement to these techniques

$eP \rightarrow eX$



$$
\begin{aligned}
s &= (k+P)^2 , \\
W^2 &= (q+P)^2 = p_{\prime}^2 , \\
x &= \frac{Q^2}{2P \cdot q} , \\
y &= \frac{q \cdot P}{k \cdot P} , \\
\nu &= \frac{q \cdot P}{m_N} .
\end{aligned}
$$

in principle the kinematics can be reconstructed from two variables (e.g., energy and angle of scattered electron)

Electron Method:

$$
\begin{aligned}
Q^2 &= 2E_e E_e^{\prime}(1+\cos\theta_e) \\
y &= 1 - \frac{E_e^{\prime}}{2E_e}(1-\cos\theta_e) \\
x &= \frac{Q^2}{sy}
\end{aligned}
$$

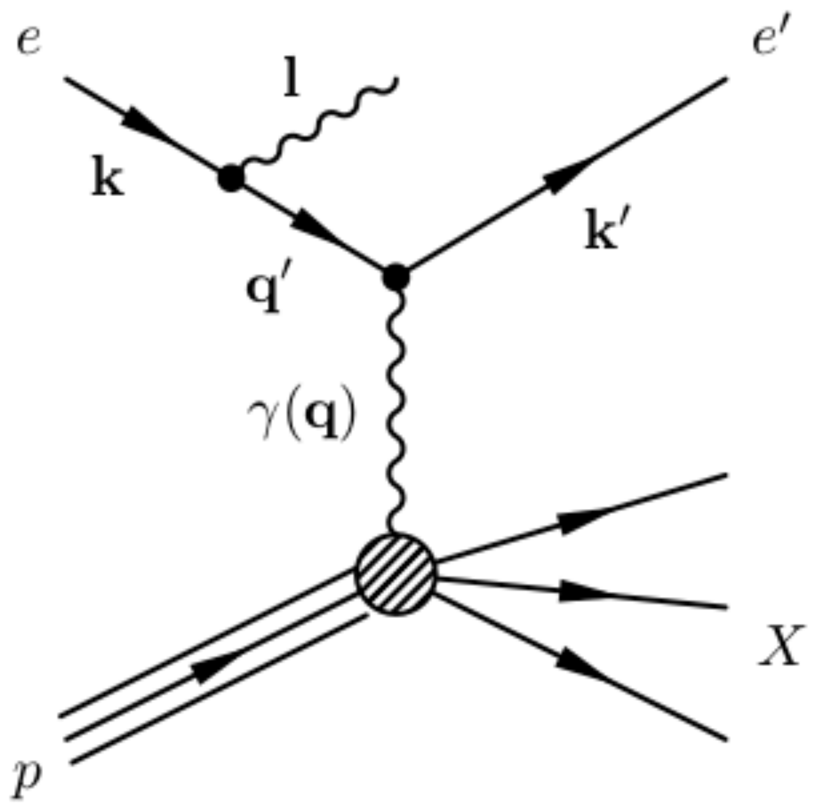
Hadron Method:

$$
\begin{aligned}
\delta_{had} &= \sum_{i=1}^{\#hadrons} E_i(1-\cos\theta_i) \\
&= E_{had} - p_{z\,had} \\
y &= \frac{\delta_{had}}{2E_e} \\
Q^2 &= \frac{p_{t\,had}^2}{1-y} \\
x &= \frac{Q^2}{sy}
\end{aligned}
$$

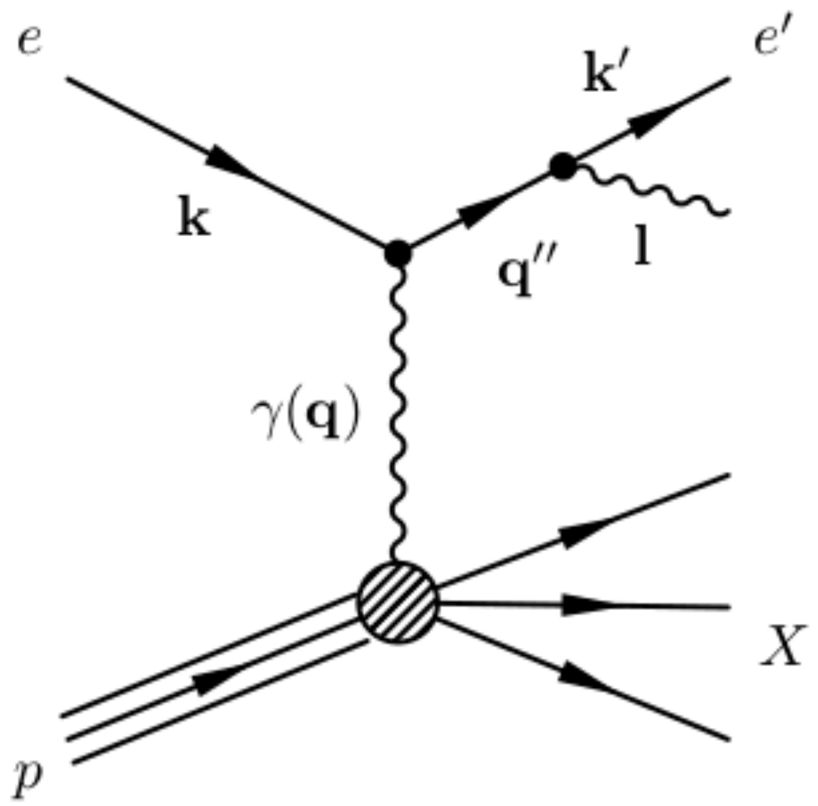
Double Angle Method:

$$
\begin{aligned}
\cos\gamma &= \frac{p_{t\,had}^2 - \delta_{had}^2}{p_{t\,had}^2 + \delta_{had}^2} \\
Q^2 &= 4E_e^2 \frac{\sin\gamma(1+\cos\theta_e)}{\sin\gamma + \sin\theta_e - \sin(\theta_e+\gamma)} \\
x &= \frac{E_e}{E_p} \frac{\sin\gamma + \sin\theta_e + \sin(\theta_e+\gamma)}{\sin\gamma + \sin\theta_e - \sin(\theta_e+\gamma)}
\end{aligned}
$$

Reconstructing the kinematics in the presence of radiation leads to errors when only two measured quantities taken into account



Initial State Radiation



Final State Radiation

Kinematic Fit: Use the information from the electron and hadronic system to reconstruct three pieces of information.
Bayesian approach - build in knowledge of distributions

$$P(x, y, E_\gamma \,|\, \mathbf{D}) \propto P(\mathbf{D} \,|\, x, y, E_\gamma) P_0(x, y, E_\gamma)$$

E_γ Energy of ISR photon

Q^2 defined from the exchanged boson.

$$x = \frac{Q^2}{2P \cdot q}, \qquad y = \frac{Q^2}{s'x}, \qquad s' = (k + P - E_\gamma)^2$$

$$A_r = A - E_\gamma$$

$$E = xyP + A_r(1-y)$$

$$F = x(1-y)P + yA_r$$

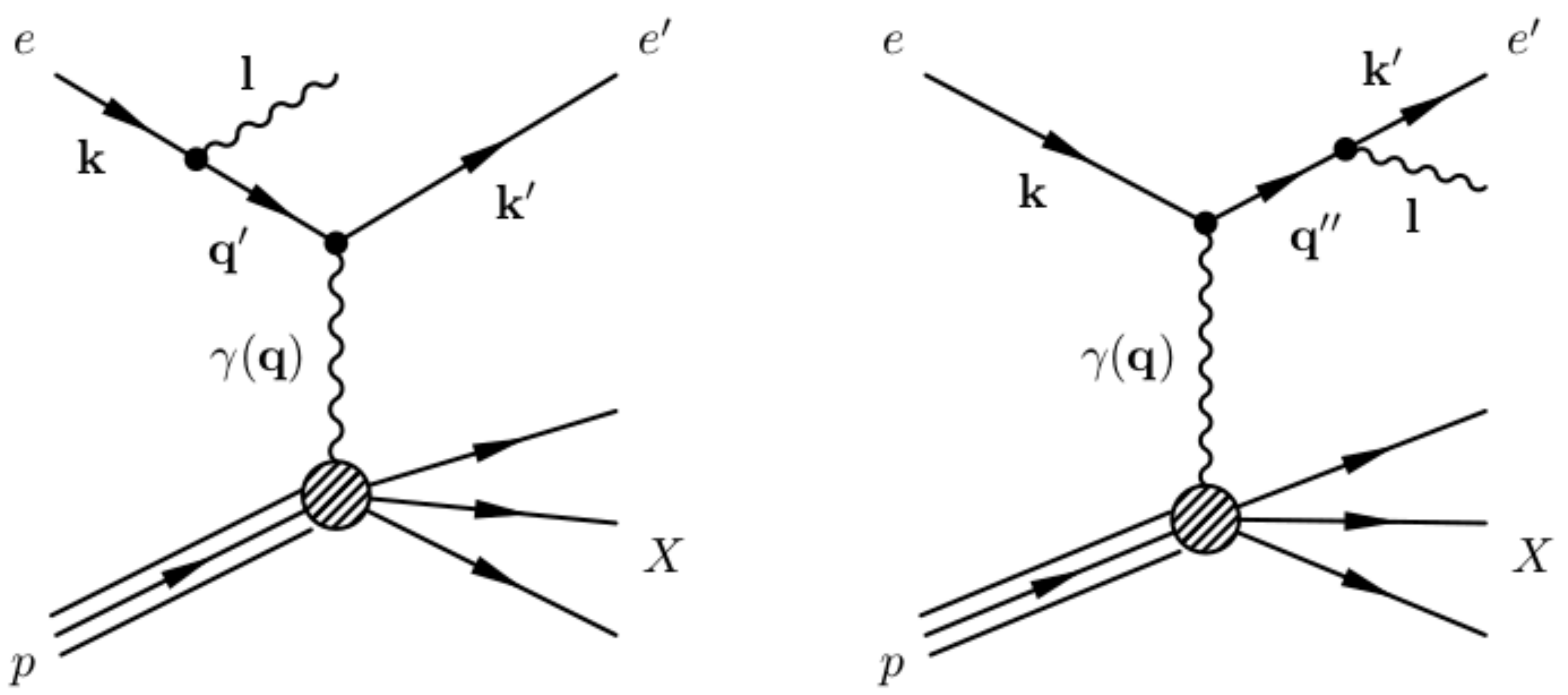
$$\cos\theta = \frac{xyP - A_r(1-y)}{xyP + A_r(1-y)}$$

$$\cos\gamma = \frac{x(1-y)P - yA_r}{x(1-y)P + yA_r}$$

$$\mathbf{D} = \{E, \theta, P_T^{\text{had}}, \delta_{\text{had}}\}$$

$$\left.\begin{aligned} P_T^{\text{had}} &= F \sin\gamma \\ \delta_{\text{had}} &= F(1-\cos\gamma) \end{aligned}\right\} \text{from X final state}$$

Reconstructing the kinematics in the presence of radiation leads to errors when only two measured quantities taken into account



Initial State Radiation **Final State Radiation**

Bayesian approach - build in knowledge of distributions

$$P(x, y, E_\gamma \,|\, \mathbf{D}) \propto P(\mathbf{D} \,|\, x, y, E_\gamma) P_0(x, y, E_\gamma)$$

$$\begin{aligned} P_0(x, y, E_\gamma) &= P_0(x, y) P_0(E_\gamma) \\ P_0(x, y) &\propto \frac{(1-x)^5}{x^2 y^2} \\ P_0(E_\gamma) &\propto \frac{1 + (1 - E_\gamma/(E_e - E_\gamma))^2}{E_\gamma/(E_e - E_\gamma)} \end{aligned}$$

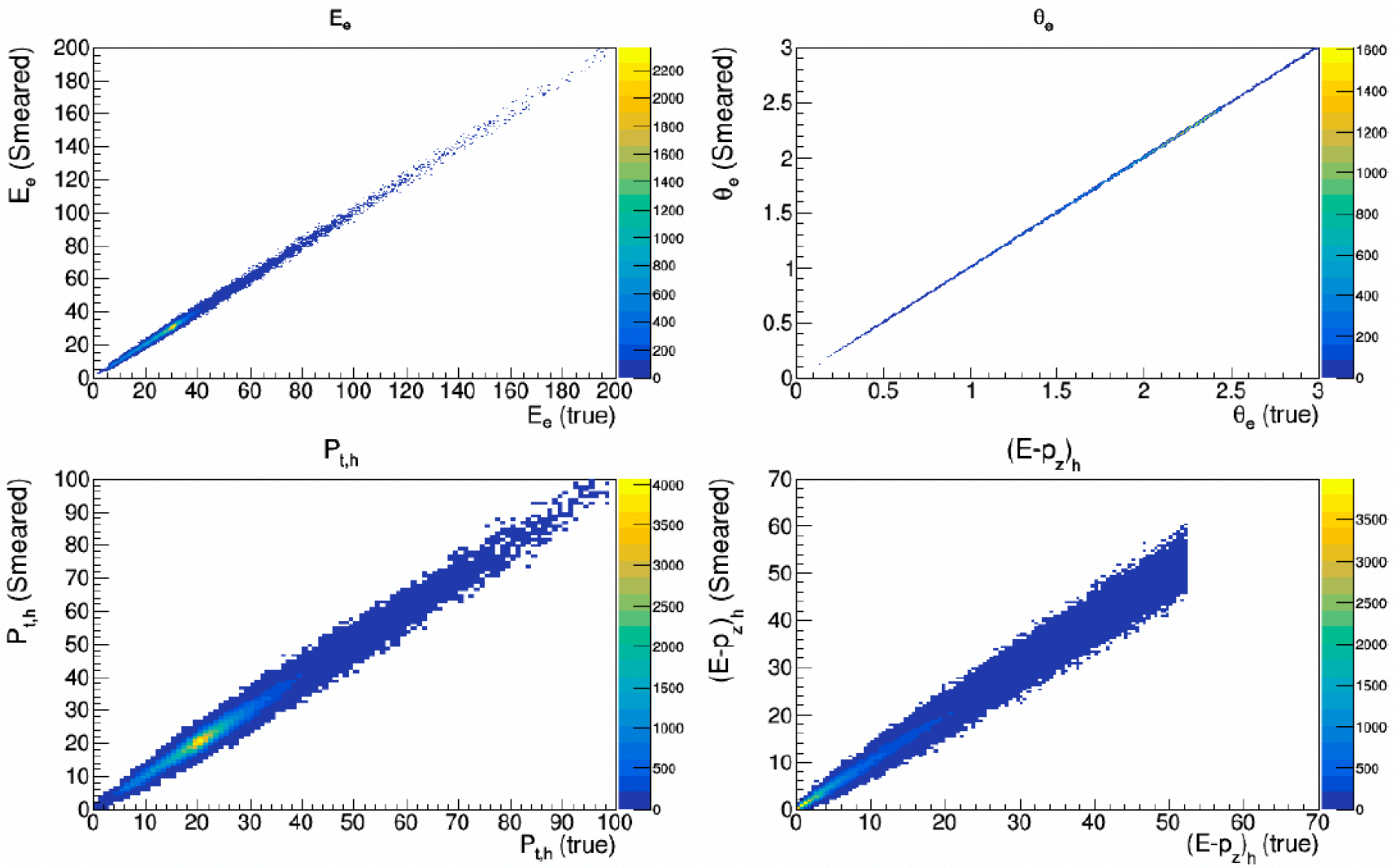
$$\begin{aligned} P(\mathbf{D} \,|\, x, y, E_\gamma) &= P(E, \theta, P_T^{\text{had}}, \delta_{\text{had}} \,|\, x, y, E_\gamma) \\ &= P(E, \theta \,|\, x, y, E_\gamma) P(P_T^{\text{had}}, \delta_{\text{had}} \,|\, x, y, E_\gamma) \\ &\approx P(E \,|\, x, y, E_\gamma) P(\theta \,|\, x, y, E_\gamma) P(P_T^{\text{had}} \,|\, x, y, E_\gamma) P(\delta_{\text{had}} \,|\, x, y, E_\gamma) \end{aligned}$$

Each term taken here as Normal distribution with measured value distributed around predicted value with a known resolution.

Correlations between electron, hadron variables should eventually be taken into account.

Simulation Study

1. RAPGAP used to generate ep scattering events
2. HERACLES implements QED effects
3. $A = 27.6$ GeV, $F = 920$ GeV (HERA values)
4. $Q^2 > 400$ GeV^2, $y < 0.8$ (initially studied for ZEUS high-x)
5. $\delta_{\text{had}} > 2.5$ GeV as resolution at smaller values needs study



Smearing taken for hadronic variables as

$$\sigma_{P_T^{\text{had}}} = 0.35\sqrt{P_T^{\text{had}}}$$

$$\sigma_{\delta_{\text{had}}} = 0.35\sqrt{\delta_{\text{had}}}$$

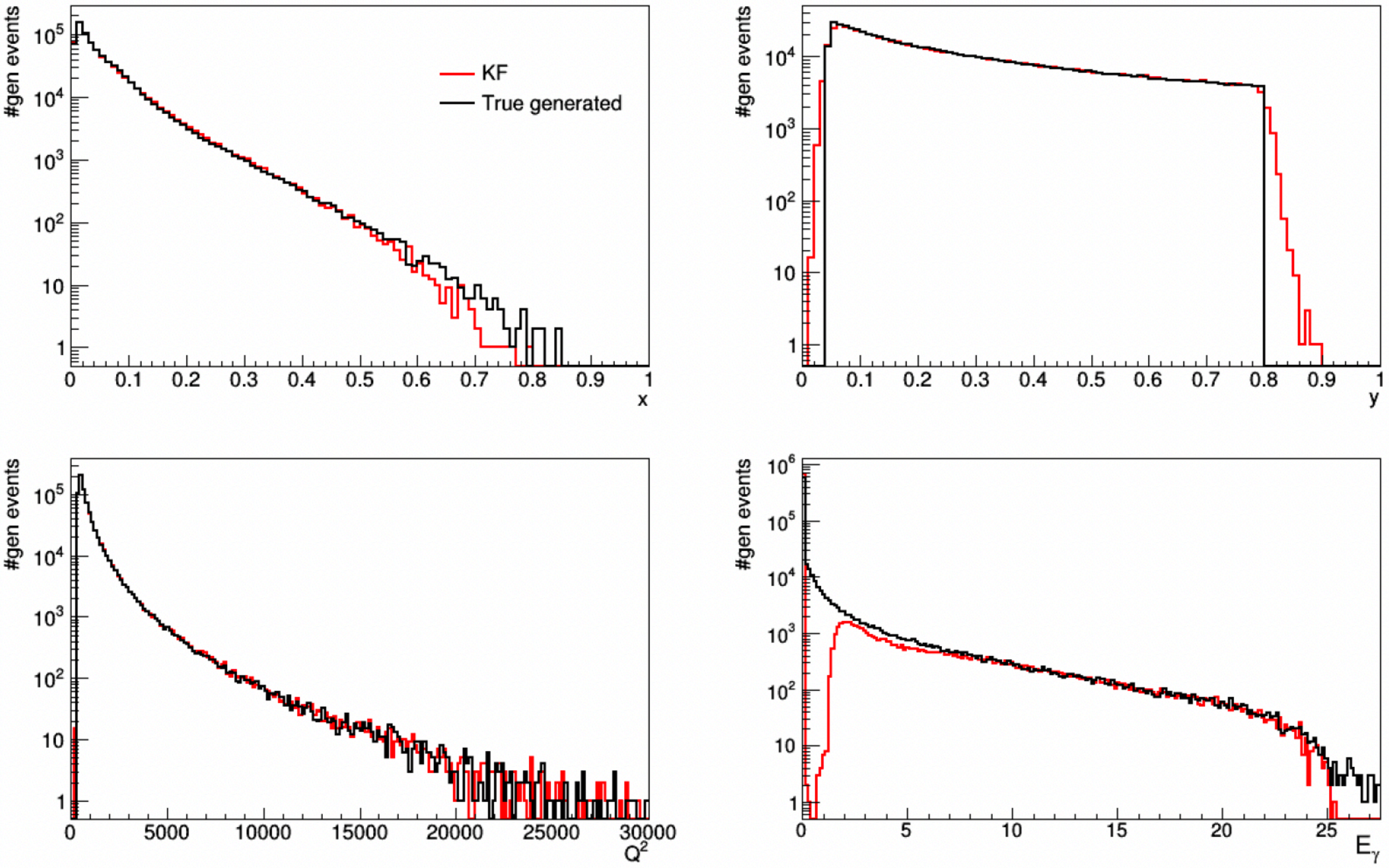
$$\sigma_E = 0.2\sqrt{E} \oplus 0.008$$ (ZEUS values, R. Aggarwal, PhD thesis)

$$\sigma_\theta = 0.0025\sqrt{\theta}$$ (ZEUS values, R. Aggarwal, PhD thesis)

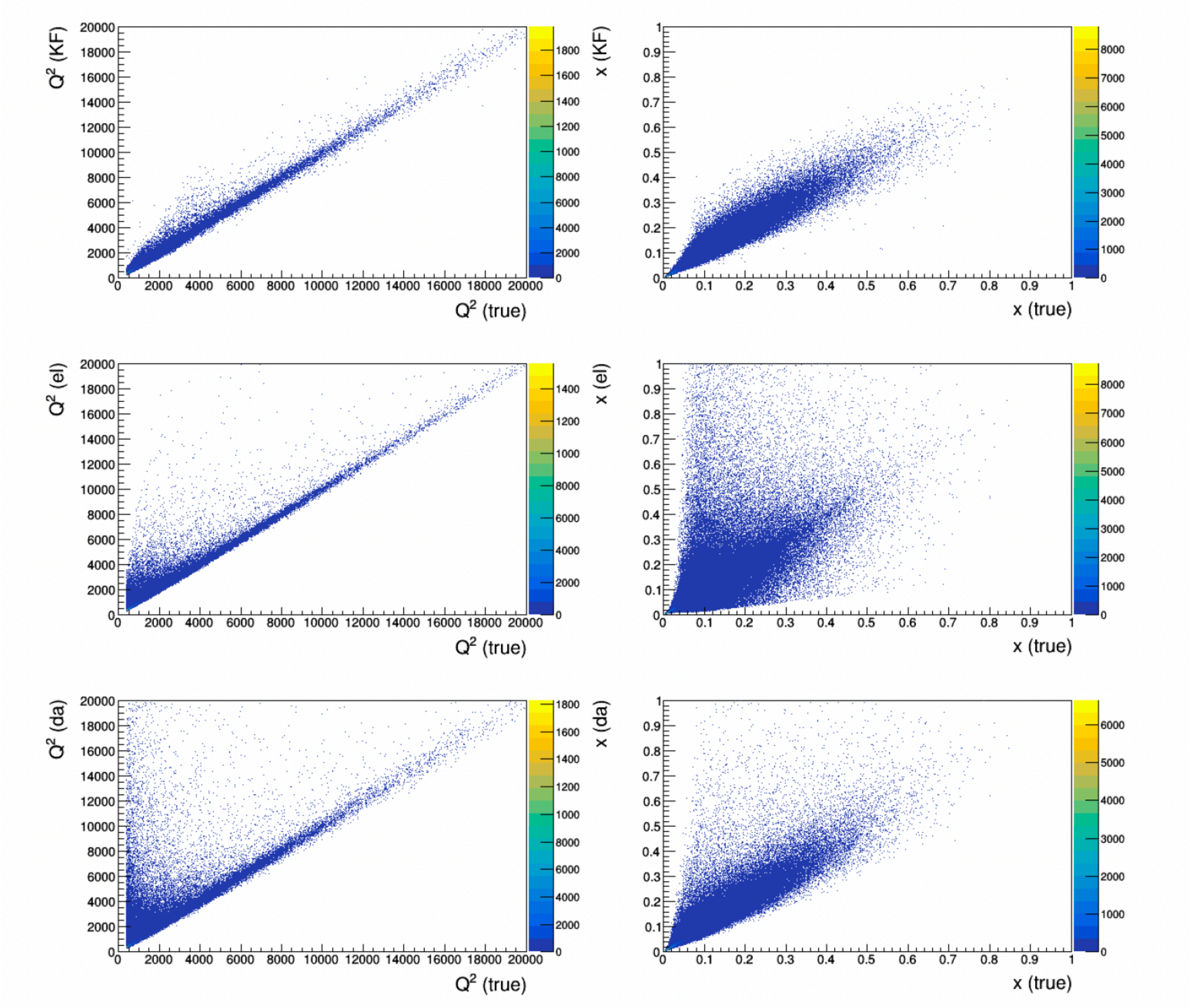
These values are used to generate ‘measured’ quantities, and the same resolutions are used in the likelihood term

Note that in practice, possible systematic shifts will have to be taken into account. Needs detailed studies for individual detectors.

Comparison of Kinematic variables from KF to the true generated values



Comparison of KF reconstruction to electron and double angle method



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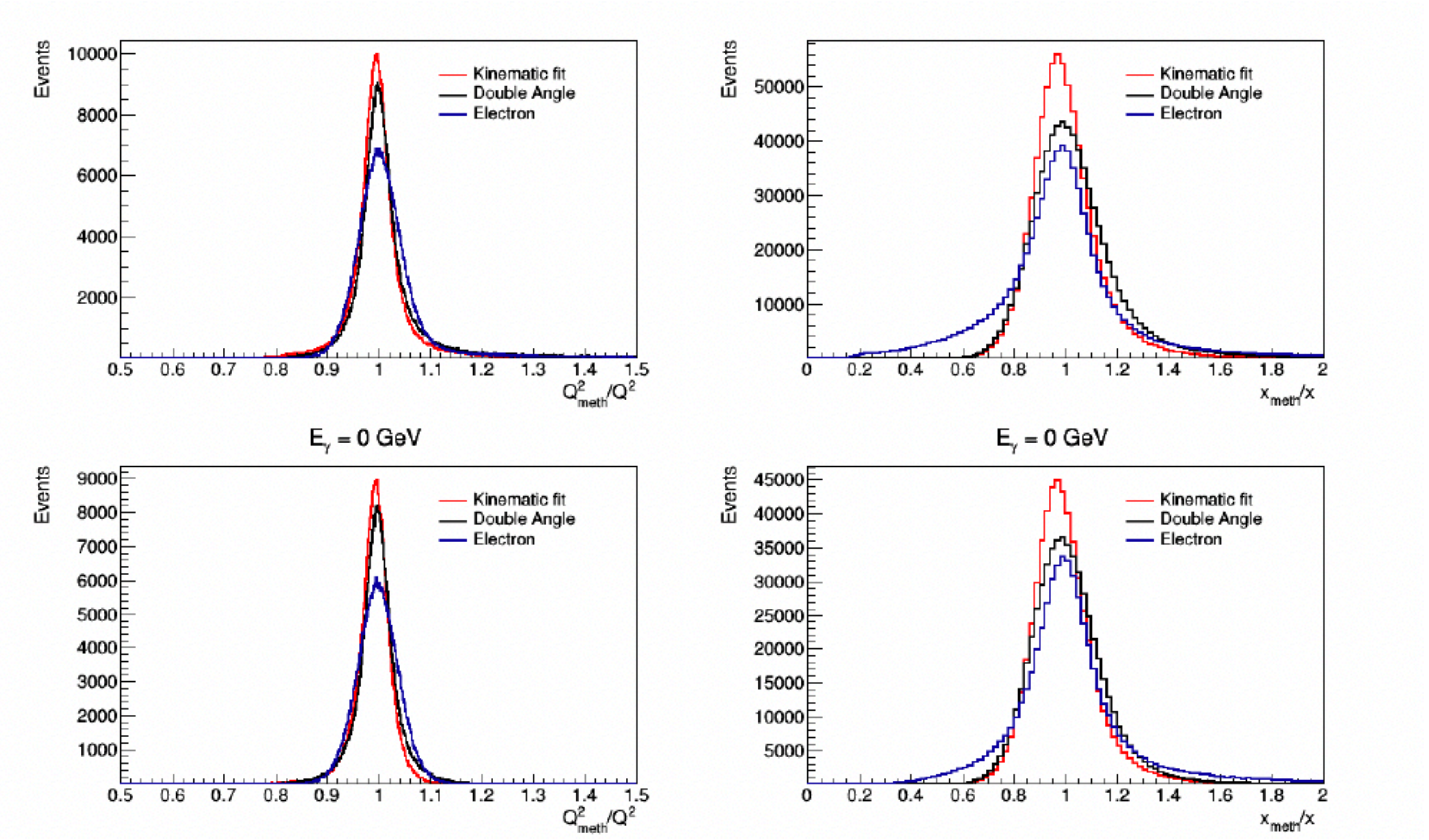

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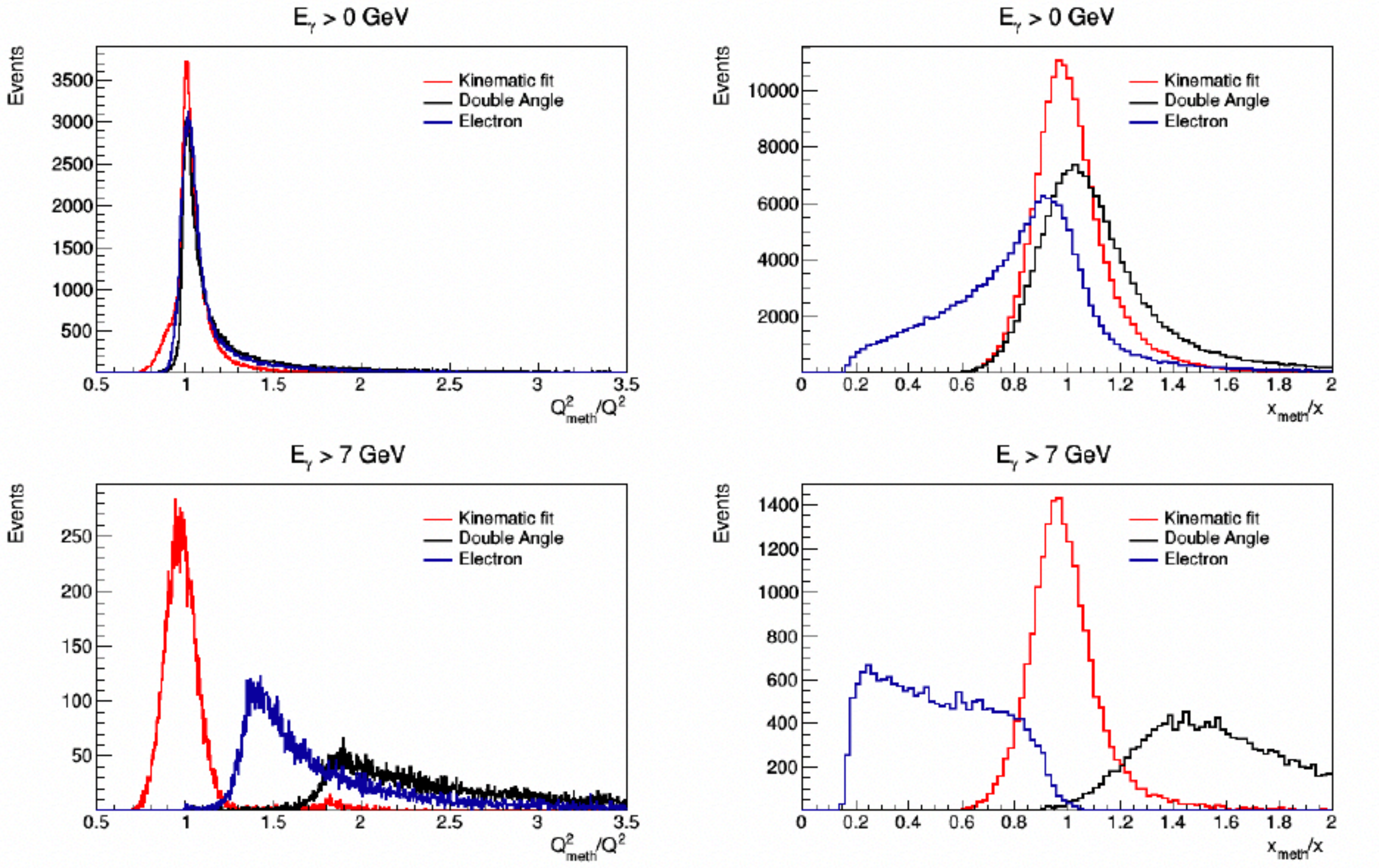

Summary

- Kinematic Fitting uses both energy and angle of the electron and hadron system. Overconstraint allows to extract ISR photon energy and allows to extract uncertainties on an event-by-event basis on reconstructed quantities (not shown in this talk)

- Study of high Q^2 and large x simulated data shows the potential.

- Initial study - needs to be deepened by studying shifts in addition to resolutions, parameter-dependent resolutions, etc.

- Should also be extended to full kinematic range and, e.g., EIC kinematics

- more coming soon (hopefully)