TMD at EicC

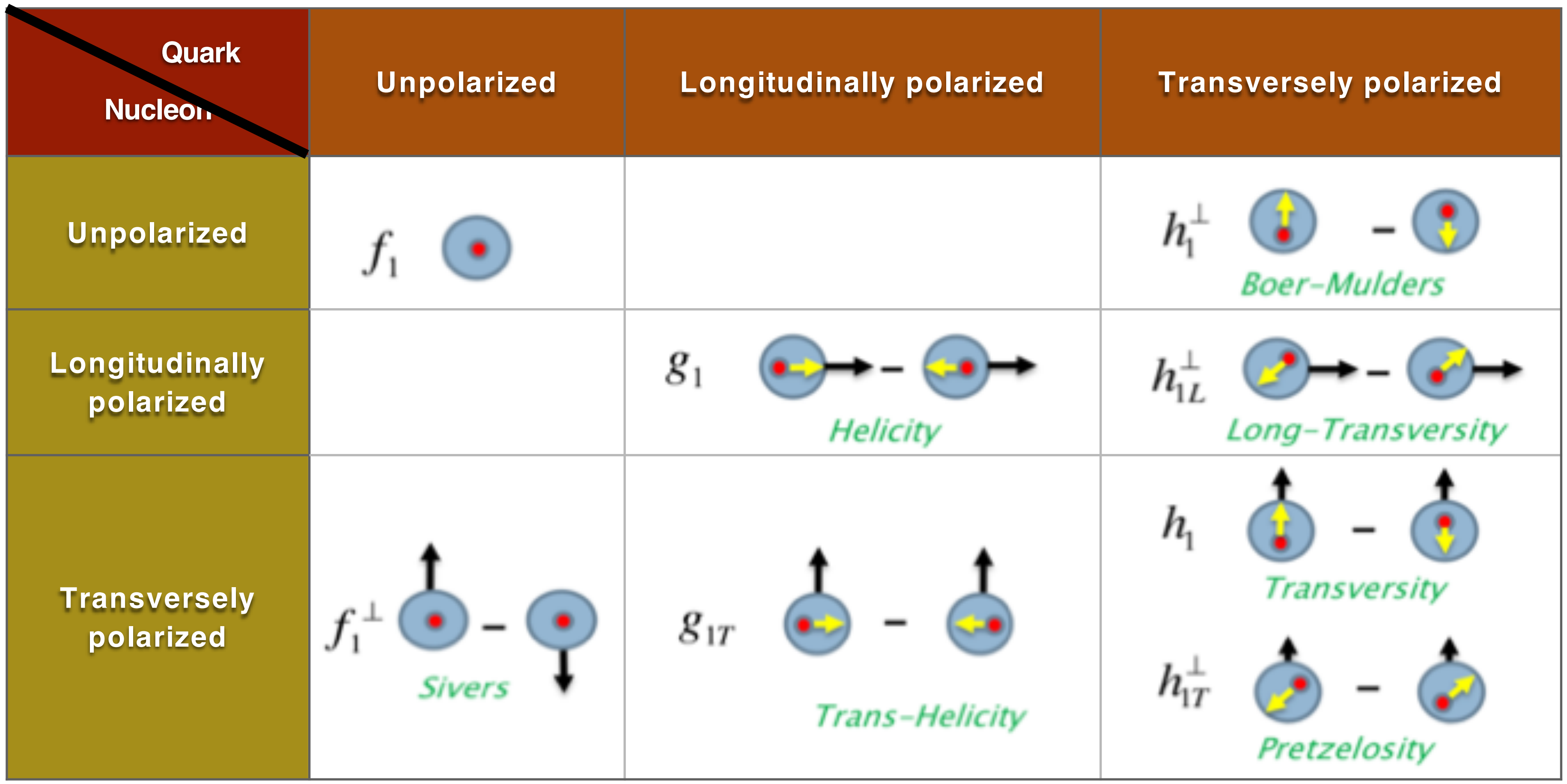
Zhi Yang

Institute of Modern Physics, CAS

Outline

- Introduction
  - TMD
  - SIDIS
- Simulation and projection
  - Angular-momentum coverage
  - Asymmetry uncertainty
- Summary

TMD: transverse-momentum-dependent parton distribution



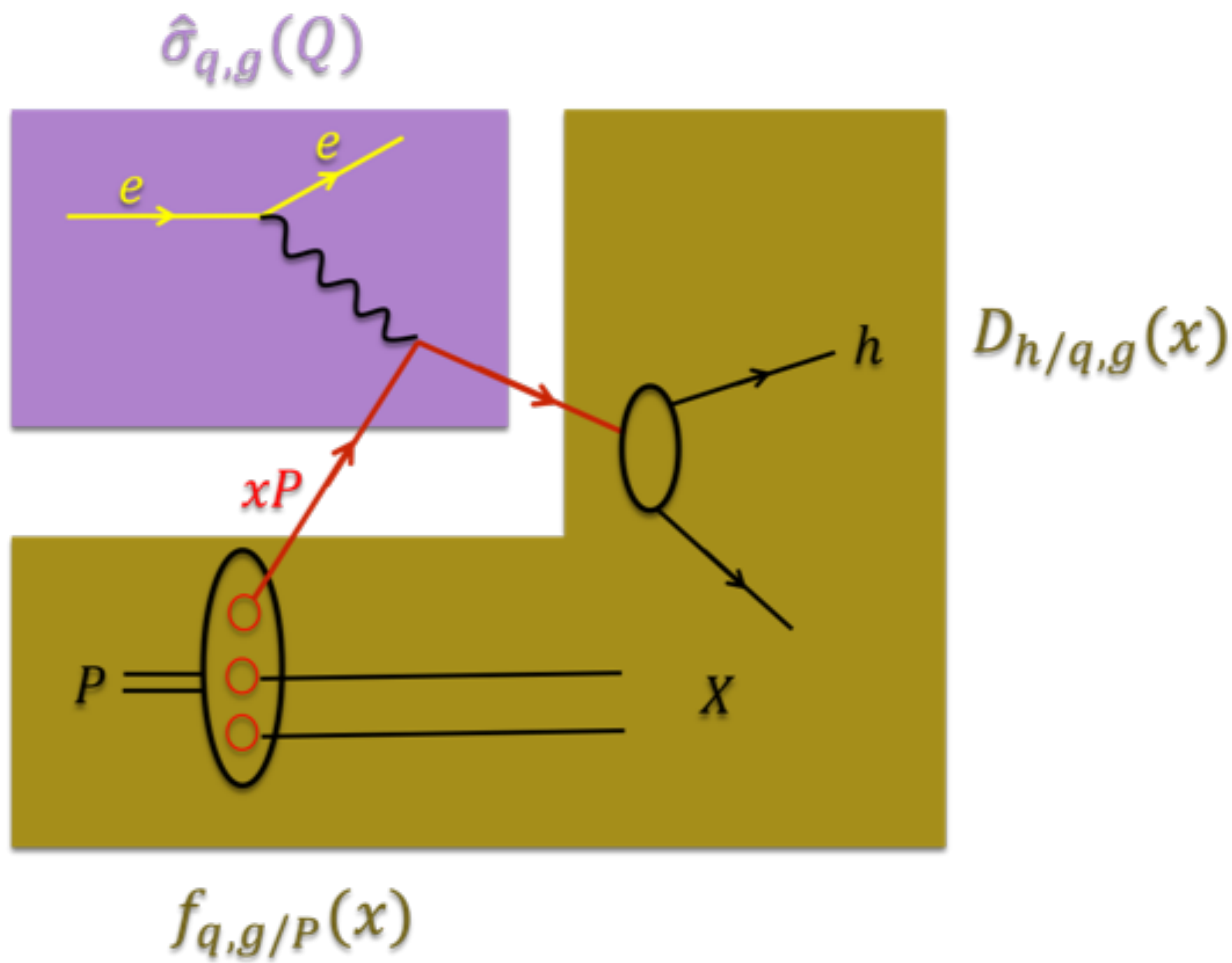
- Eight transverse-momentum-dependent parton distributions exist at leading twist categorized by the nucleon and quark spin ;
- The unpolarized one f_1 have been extracted with excellent precision in deep inelastic scattering (DIS);
- All can be accessed in semi-inclusive deep inelastic scattering (SIDIS).

SIDIS

Factorization:

X. D. Ji et al. Phys. Rev., D71:034005, 2005

- Perturbative part:
  Hard scattering.
- Non-perturbative parts:
  Transverse-momentum-dependent fragmentation function (FF);
  TMD.



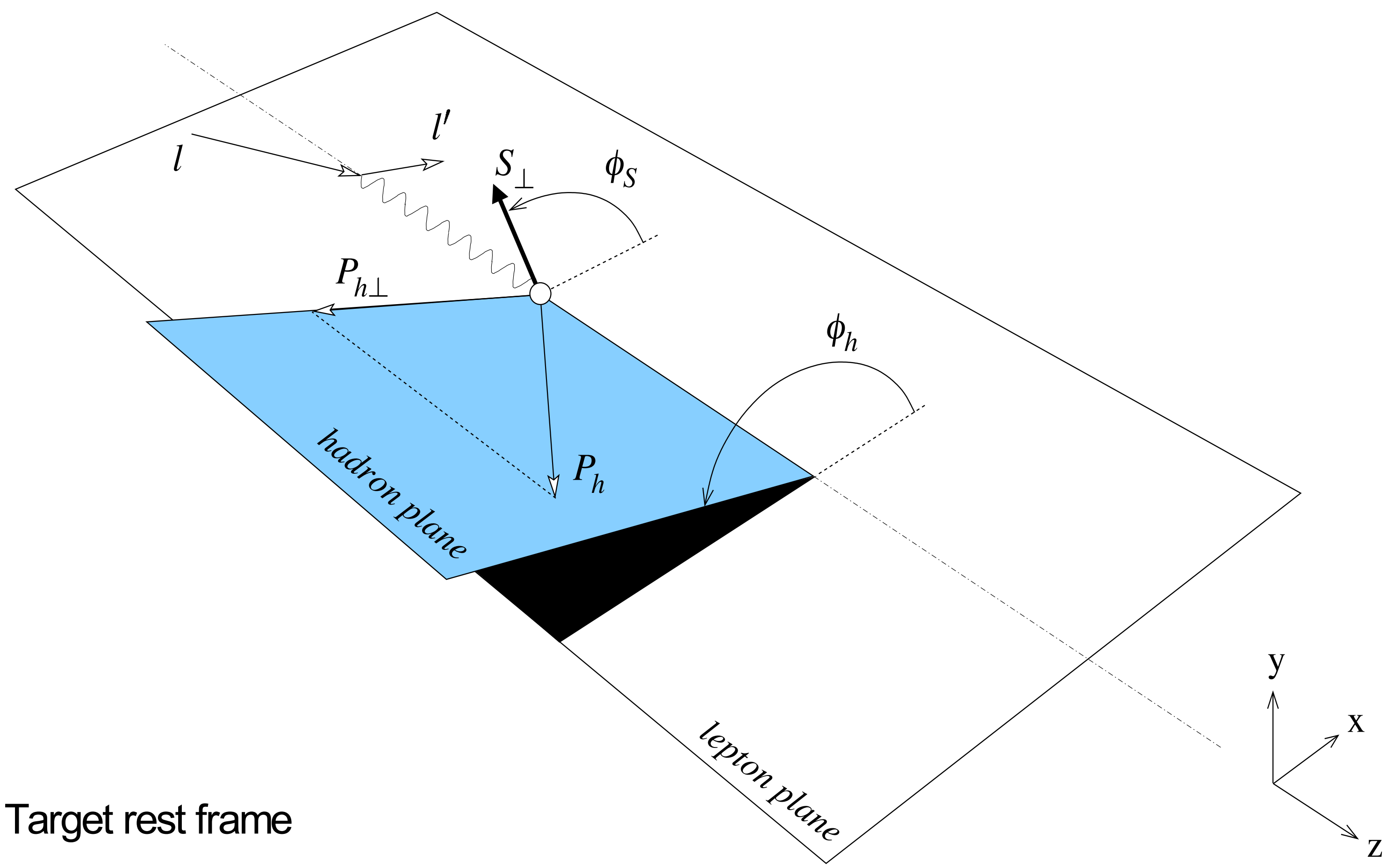
SIDIS

In total, 18 structure functions $F(x, z, Q^2, P_T)$

A.~Bacchetta et al. JHEP02(2007)093

$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} \\
&= \frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right) \\
&\times \Big\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h} + \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
&\quad + S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] + S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
&\quad + |\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} \\
&\qquad + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
&\quad + |\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\qquad + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}
\end{aligned}
$$

SIDIS



Target rest frame

$$x = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot P_e^i}$$

$$z = \frac{P \cdot P_h}{P \cdot q}$$

- ❑ Simulate the SIDIS process with differential cross section:

$$\frac{d\sigma}{dxdyd\psi dzd\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{y^2}{2x}\right)F_{UU,T}$$

Simulation

The structure function $F_{UU,T}$ is the convolution of TMD and FF:

$$F_{UU,T} = x \sum_a e_a^2 \int d^2\boldsymbol{p}_\perp f_1(x, \boldsymbol{p}_\perp^2) D(z, |\boldsymbol{P}_\perp - z\boldsymbol{p}_\perp|^2)$$

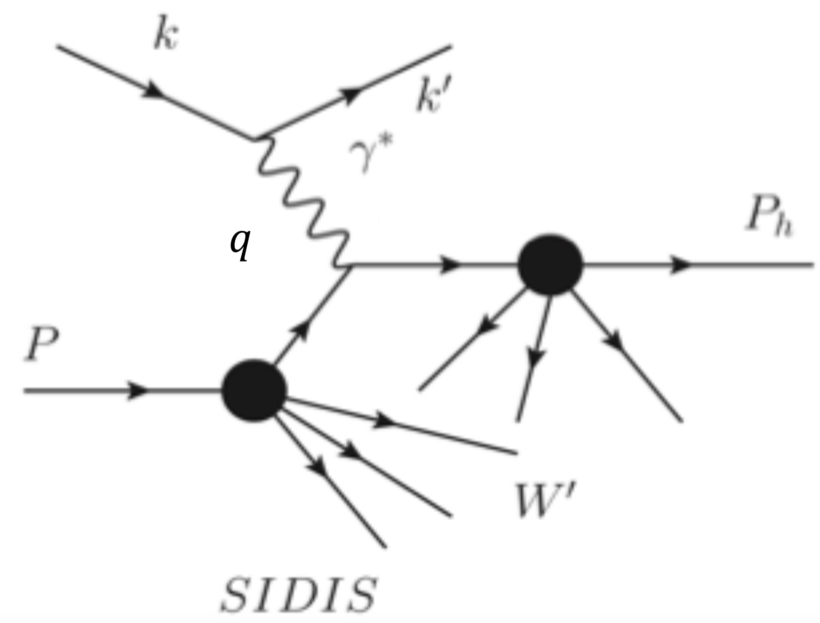
The widely used Gaussian approximation for the transverse momentum dependence,

$$f_1(x, \boldsymbol{p}_\perp^2) = f(x,0) e^{-R_H^2 \boldsymbol{p}_\perp^2},$$
$$D(z, \boldsymbol{k}_\perp^2) = D(z,0) e^{-R_H^2 \boldsymbol{k}_\perp^2}.$$

- $f(x,0)$: unpolarized PDF, well studied in DIS and other processes;
- $D(z,0)$: describe the process of the struck quark fragmenting into a hadron,

  can be obtained from ($e^+ + e^- \longrightarrow h^\pm + X$) data.

Simulation



❑ Cuts:

Deep scattering : $Q^2 = -q^2 > 1$

Inelastic scattering and avoid the resonance region :

$$W = \sqrt{(q+P)^2} > 2.3$$

Avoid the resonance region :

$$W' = \sqrt{(q+P-P_h)^2} > 1.6$$

Favor the current fragmentation region :

$$0.2 < z = \frac{P \cdot P_h}{P \cdot q} < 0.8$$

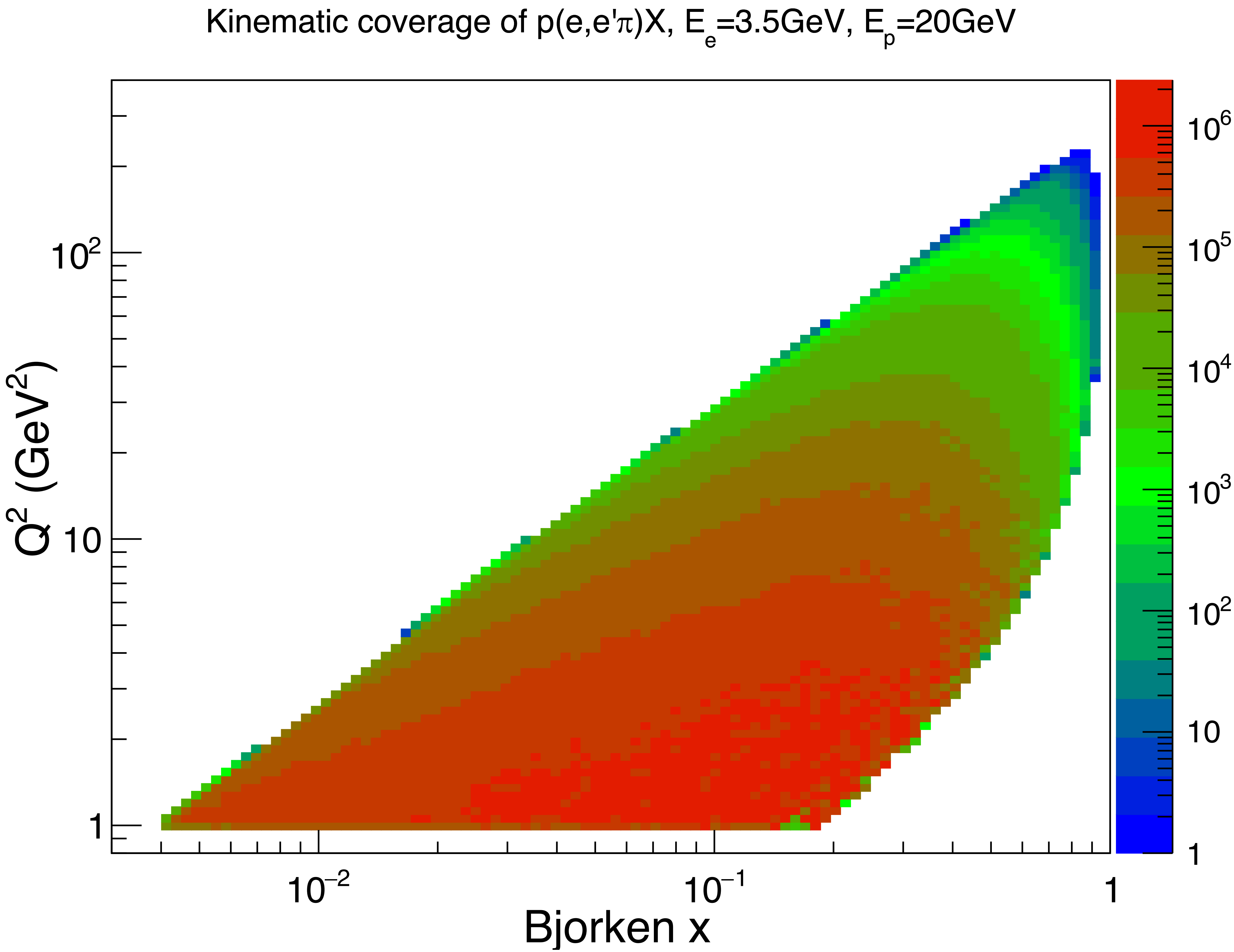
❑ EicC-I:

Beam energy 3.5×20 GeV

Luminosity $10^{33}\ cm^{-2}s^{-1}$

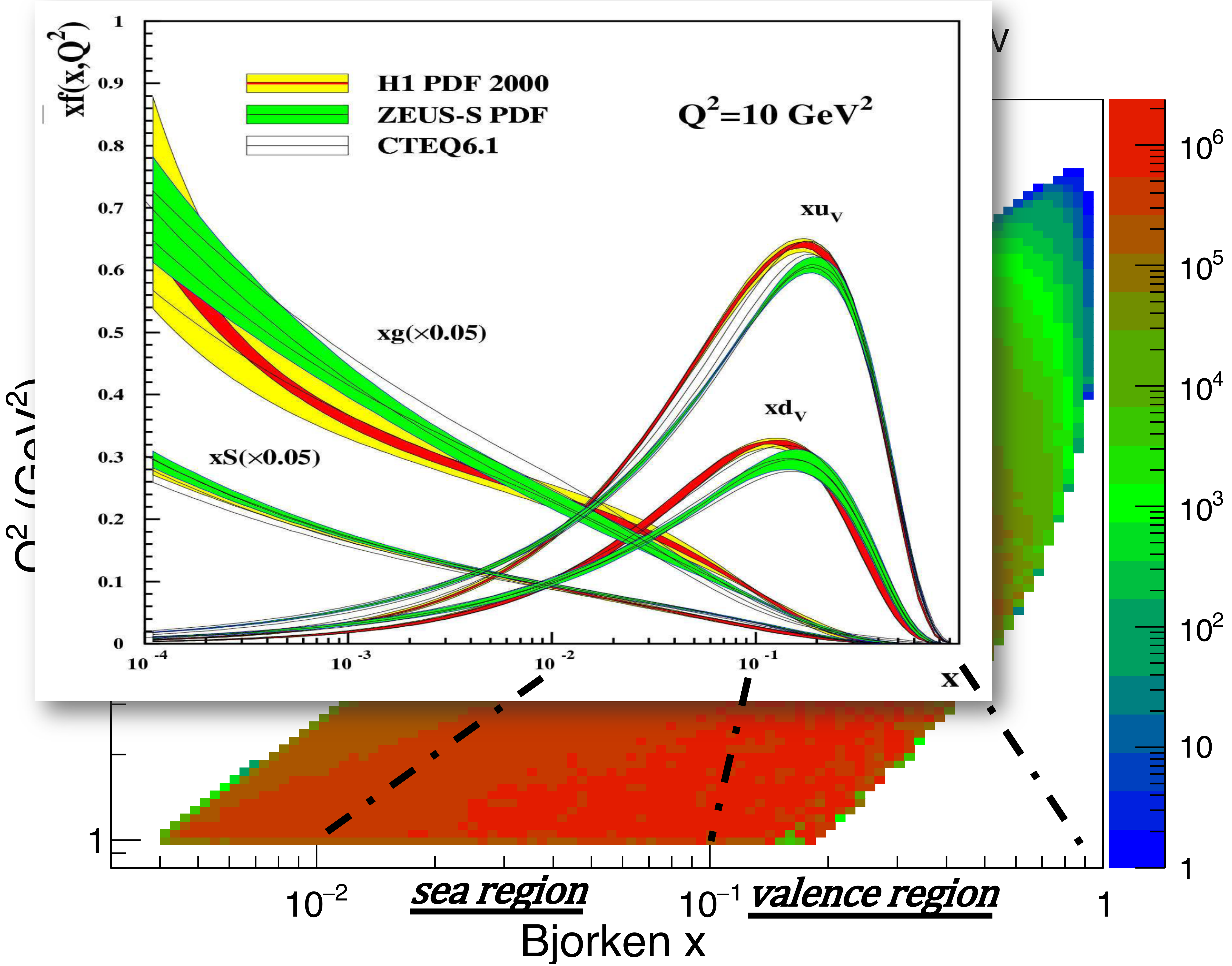
❑ Run time： 365 days

Simulation



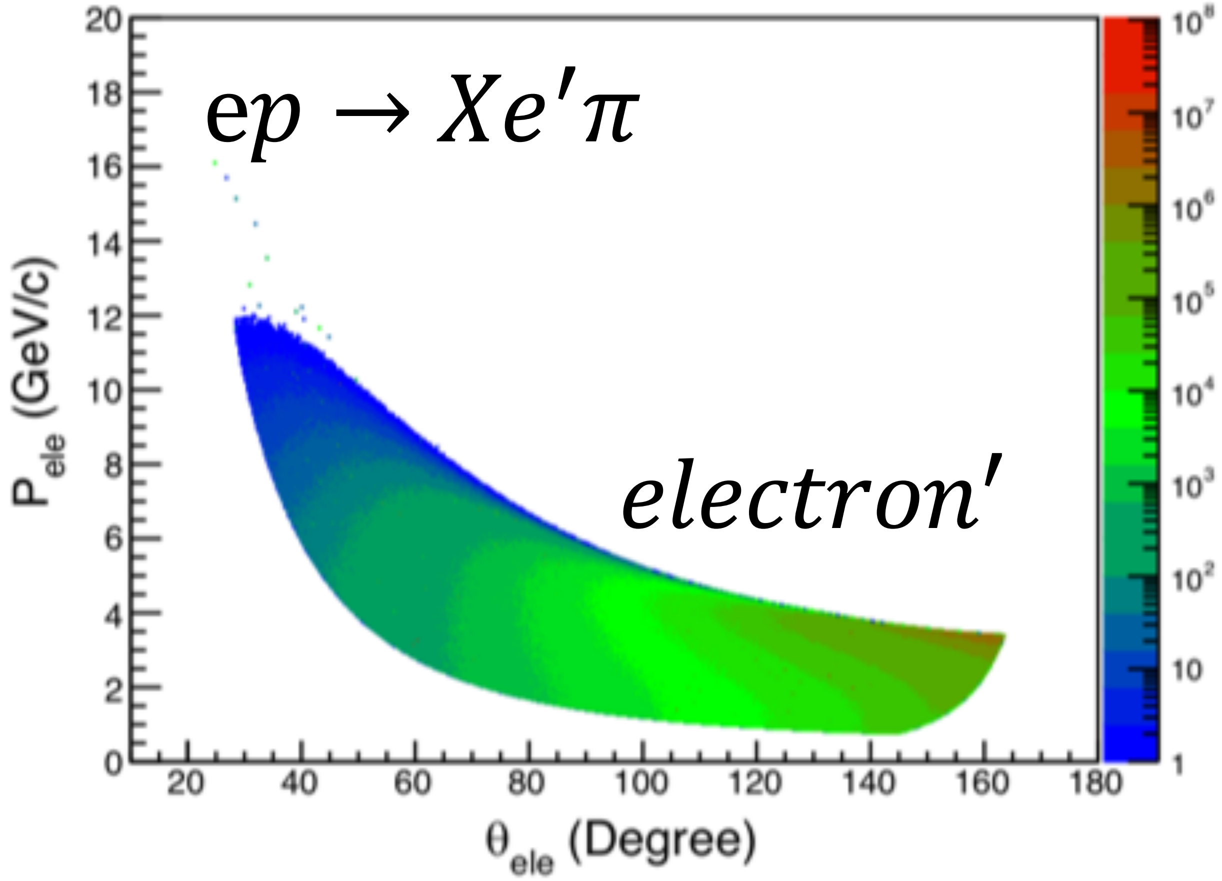
Kinematic coverage of p(e,e'π)X, E_e=3.5GeV, E_p=20GeV
10^2
10
1
Q^2 (GeV^2)
10^{-2}
10^{-1}
1
Bjorken x
10^6
10^5
10^4
10^3
10^2
10
1

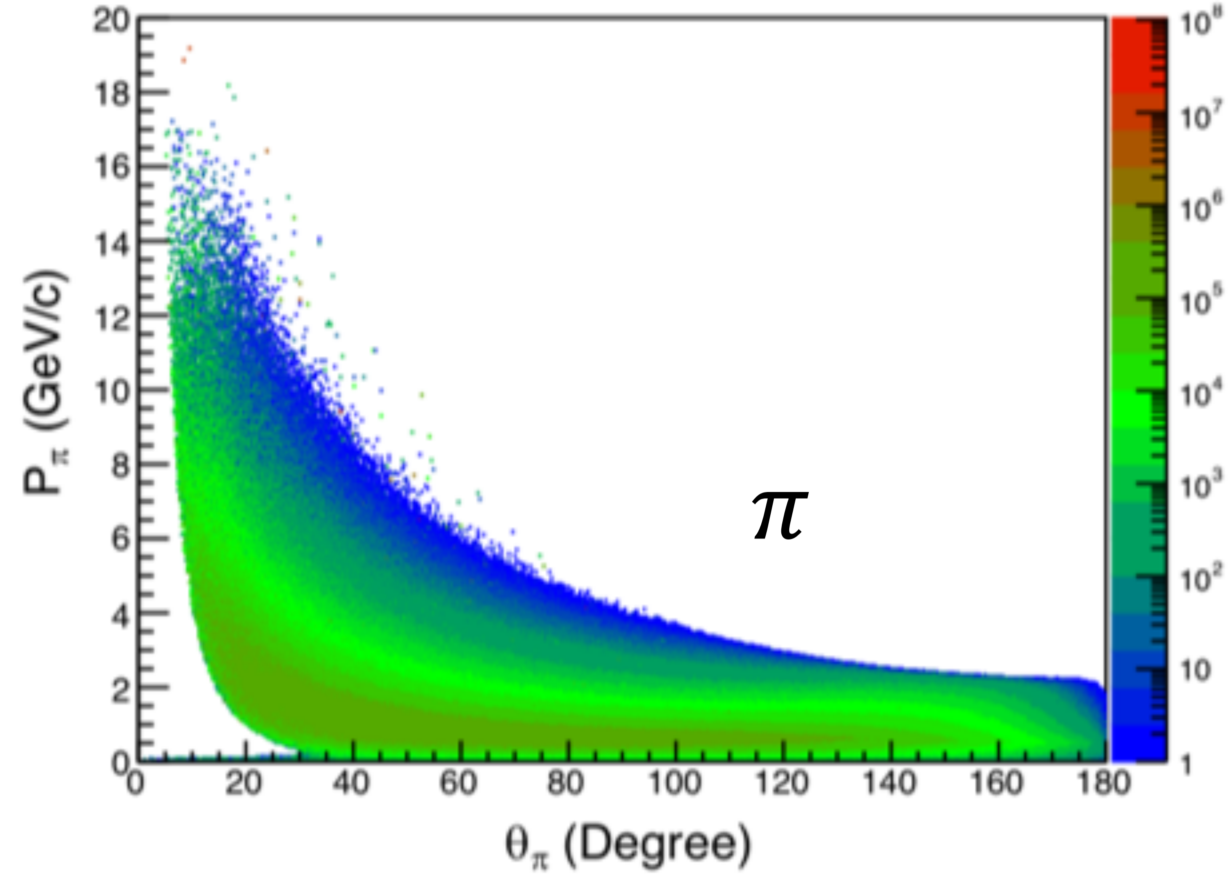
Simulation

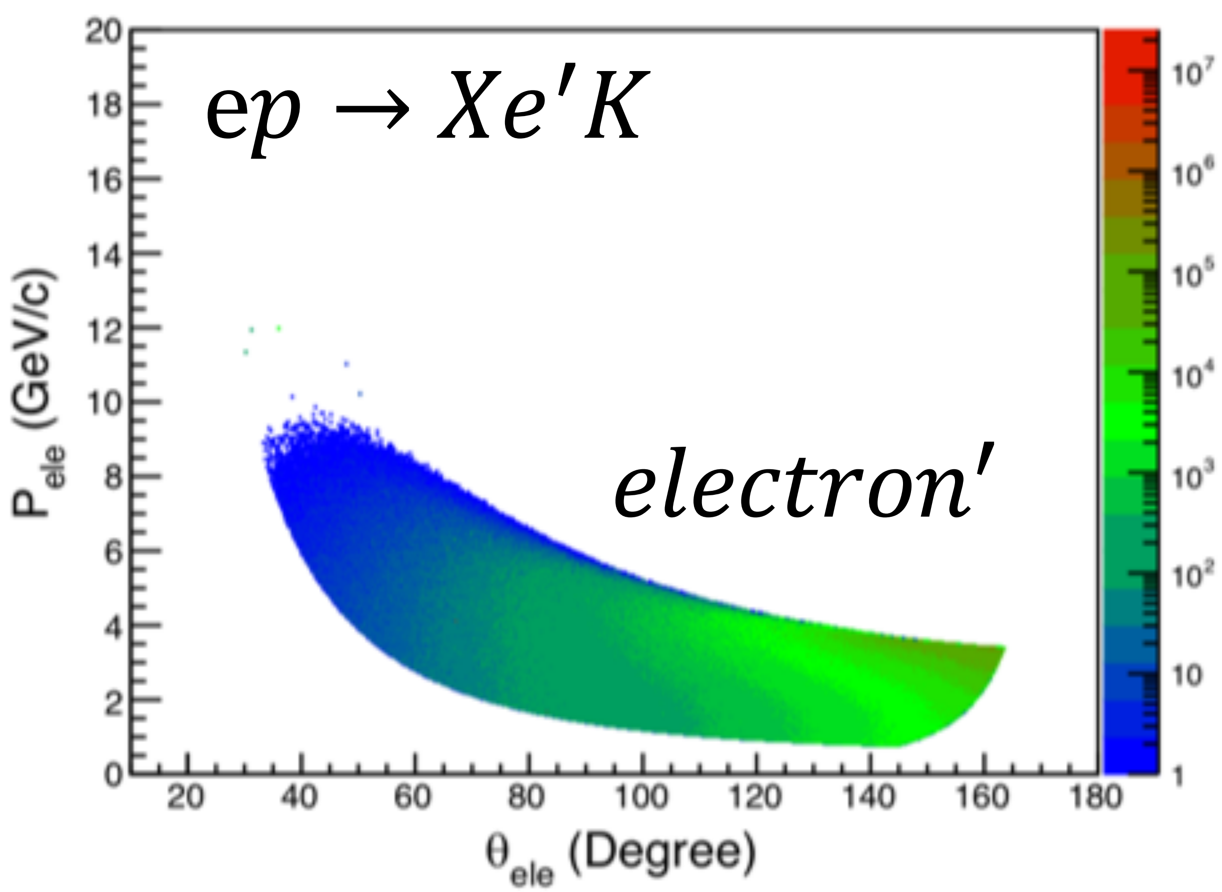


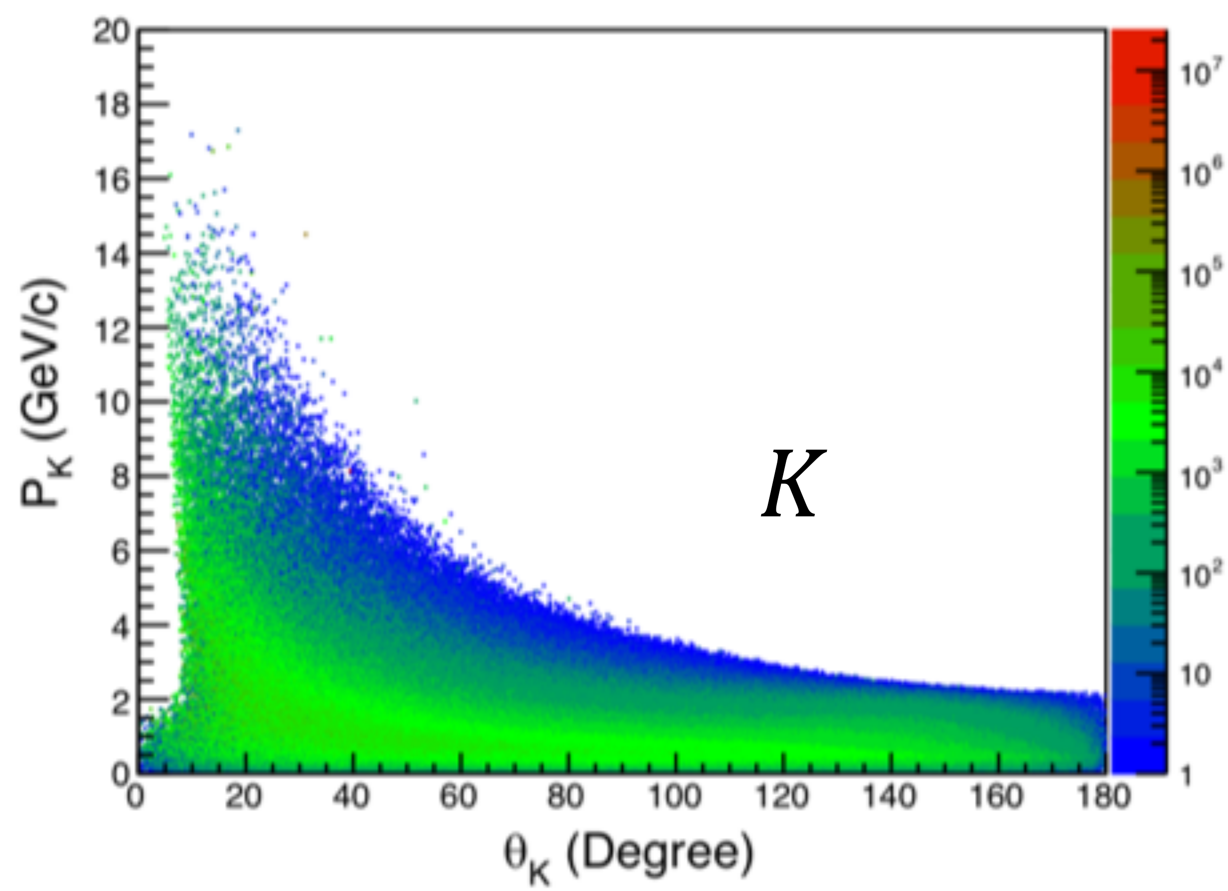
xf(x,Q²)
H1 PDF 2000
ZEUS-S PDF
CTEQ6.1
Q²=10 GeV²
xu_V
xd_V
xg(×0.05)
xS(×0.05)
x
Q² (GeV²)
sea region
valence region
Bjorken x

Angular-momentum coverage









Projection: transverse target single-spin asymmetry

- The target asymmetry is defined as:

$$A_{UT} \equiv \frac{1}{|\boldsymbol{S}_\perp|}\frac{d\sigma_{UT}}{d\sigma_{UU}}$$

$$= A_{UT}^{Collins}\sin(\phi_h+\phi_S) + A_{UT}^{Sivers}\sin(\phi_h-\phi_S) + A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S)$$

The Collins, Sivers and Pretzelosity functions have different angular dependence, and thus can be separated.

- The projected uncertainty:

M. Anselmino et al. EPJA(2011) 47:35

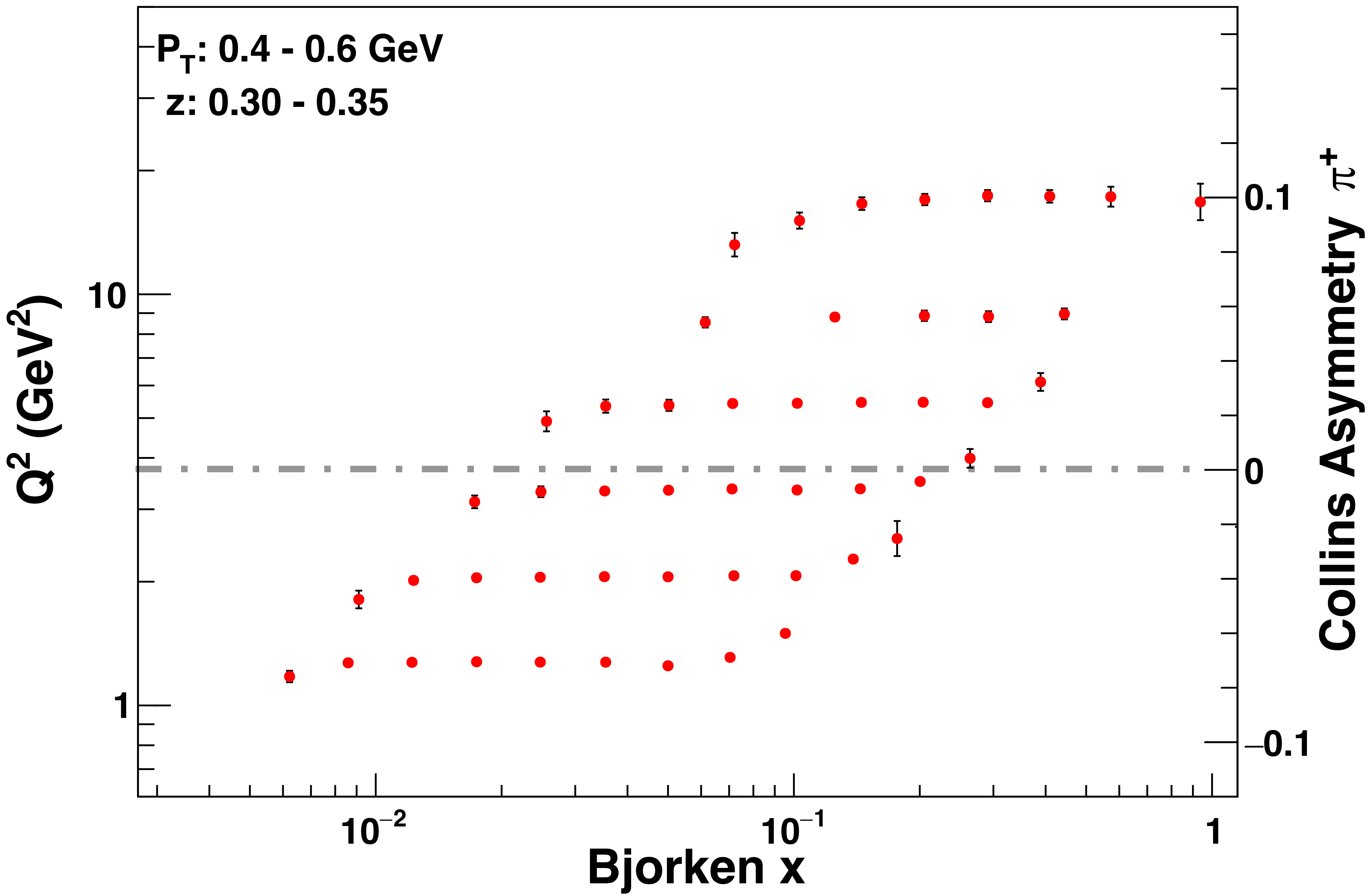
$$\delta A = \frac{1}{P}\frac{1}{\sqrt{N_{raw}}}\sqrt{1-A^2} \approx \frac{1}{P}\frac{1}{\sqrt{N_{raw}}}$$

A: the asymmetry, relatively small;

P: the parameter related to the polarization and efficiency;

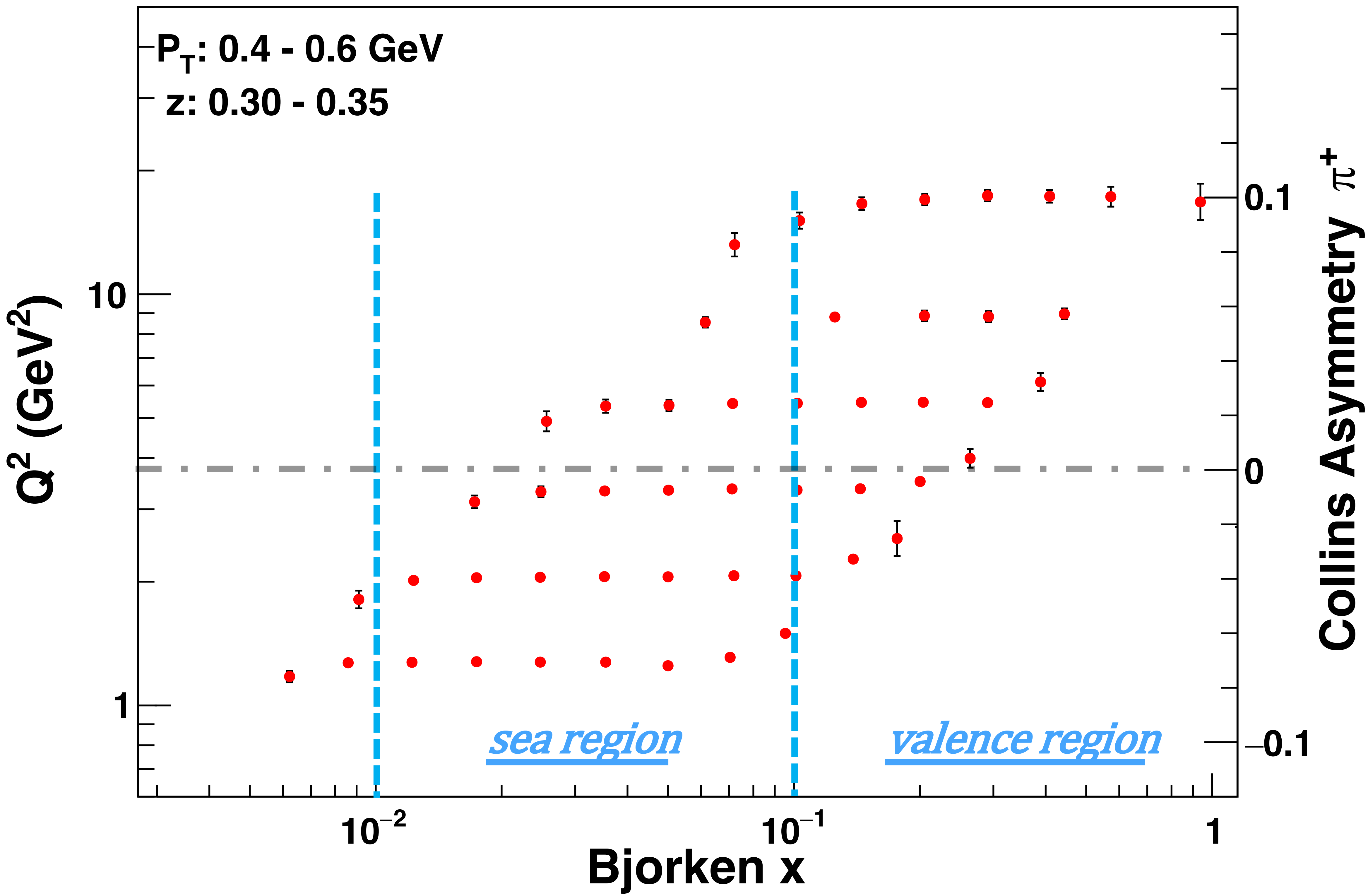
N_{raw}: raw counts.

Collins asymmetry uncertainty for pion in 4D(x, z, p_T and Q^2)



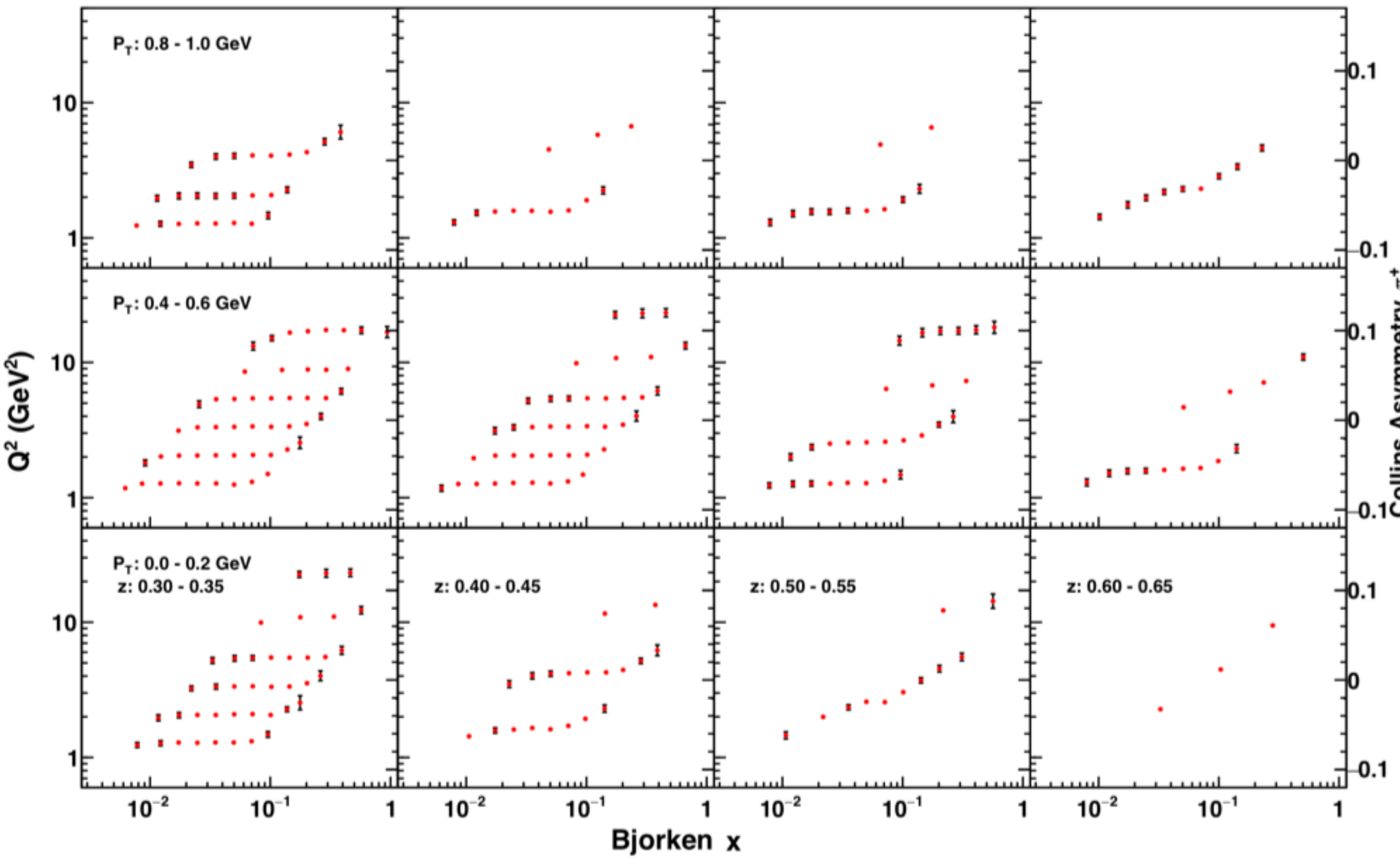
- Position is according to left and x-axis, error bar to the right axis.

Collins asymmetry uncertainty for pion in 4D(x, z, p_T and Q^2)

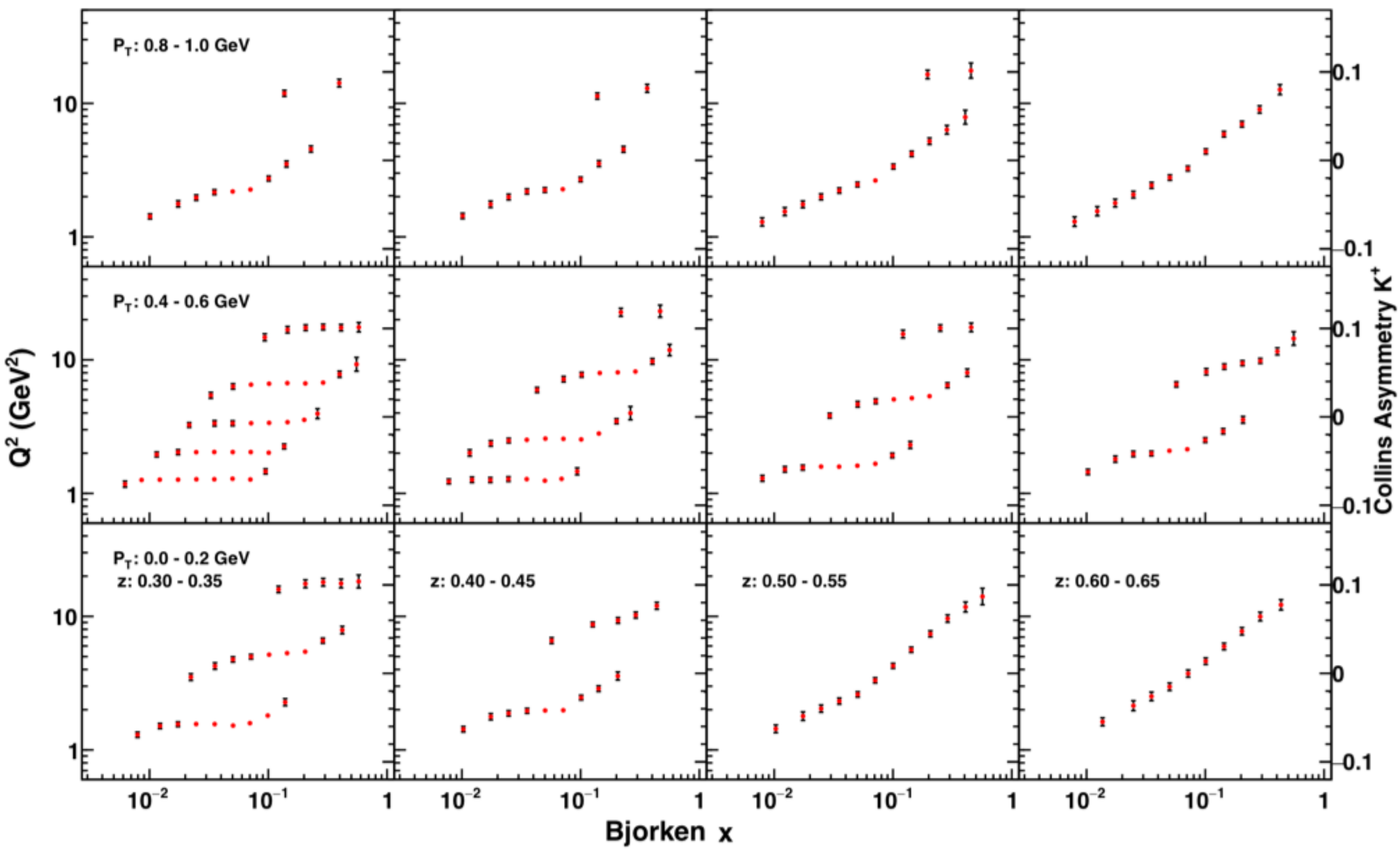


- Position is according to left and x-axis, error bar to the right axis.

Collins asymmetry uncertainty for pion in $4\text{D}(x, z, p_T \text{ and } Q^2)$



Collins asymmetry uncertainty for kaon in $4\text{D}(x, z, p_T \text{ and } Q^2)$



Summary

- ✓ The simulation of the SIDIS process using unpolarized PDF and FF to estimate the statistical error.

- ➢ EicC-I is a promising platform to study TMDs ,

- The asymmetry can be precisely mapped in the full 4D phase space.

- It can cover both valence and sea quark regions.

Thank you!