Predicting the sin ϕ_s transverse single-spin asymmetry of pion production at an electron ion collider

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OUTLINE

1. Introduction
2. Formalism
3. Numerical Calculation
4. Conclusion

INTRODUCTION

- Transversity $h_1^q(x)$:
  - Fundamental observables to encode nucleon structure
  - Chiral-odd (difficult to probe)

To manifest the effect of $h_1^q(x)$ in a process, another chiral-odd function is needed to couple with transversity to ensure chirality conservation.

- Some approaches to extract transversity function:
  - (TMD) factorization frame work in SIDIS ——Collins function $H^{\perp}$.
  - Collinear factorization formalism in SIDIS——dihadron fragmentation function.
  - In the Drell-Yan process——the antiquark transversity.

INTRODUCTION

- An alternative approach to access transversity in SIDIS——the twist-3 chiral-odd fragmentation function $\widetilde{H}(z)$ serve as a "spin analyzer" .

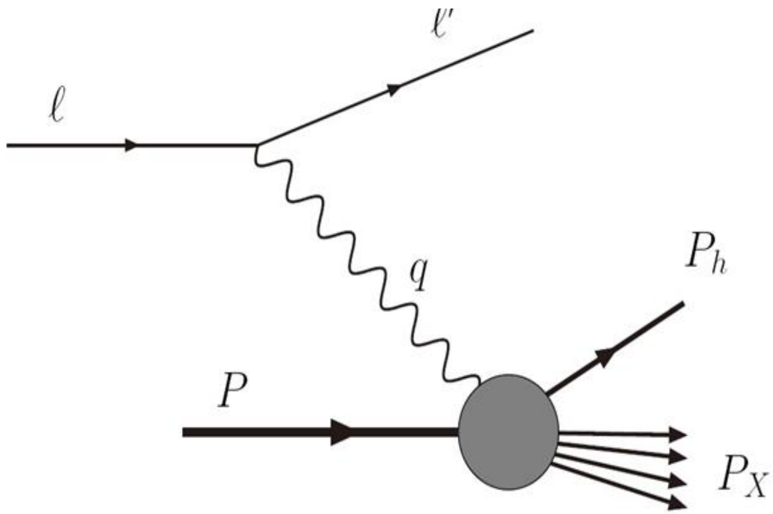
Motivation: In collinear picture, only the coupling between the function $\widetilde{H}(z)$ and the transversity remains as a contribution to the $\sin\phi_S$ azimuthal modulation in the leptoproduction of a single hadron off a transversely polarized nucleon.

- The advantage of this approach is that the transverse momentum of the final state hadron is not necessarily to be measured, in contrast to the Collins effect.

FORMALISM

- The process under study is the pion electroproduction off a transversely polarized proton target

$$e(\ell) + p^{\uparrow}(P) \to e(\ell') + \pi(P_h) + X(P_X),$$



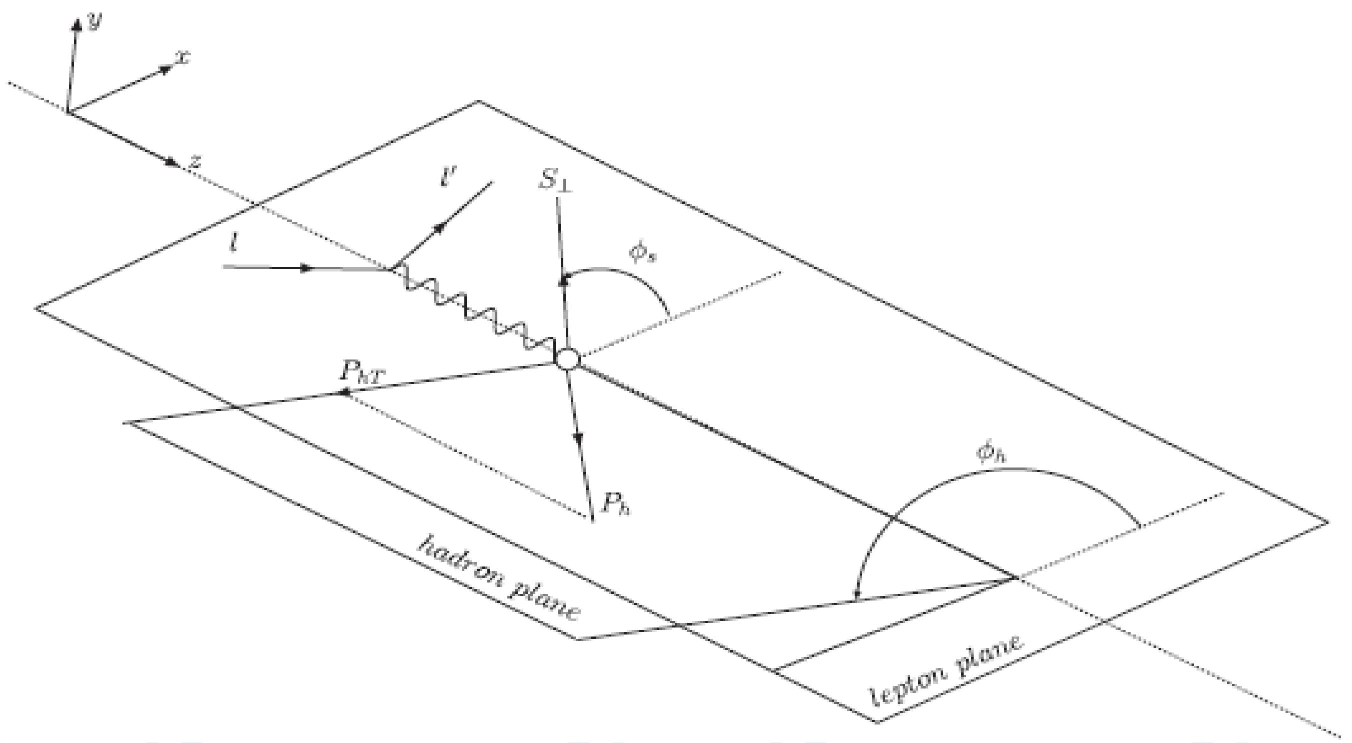
- The invariants used to express the differential cross section

$$x = \frac{Q^2}{2P\cdot q}, \qquad y = \frac{P\cdot q}{P\cdot l}, \qquad z = \frac{P\cdot P_h}{P\cdot q},$$

$$\gamma = \frac{2Mx}{Q}, \qquad Q^2 = -q^2, \qquad s = (P+l)^2.$$

FORMALISM

- The reference frame of the process under study is



FORMALISM

- Up to twist-3 level, the sixfold (x, y, z, ϕ_h, ϕ_S and P_{hT}) differential cross section in SIDIS with a transversely polarized target has the general form

$$\frac{d^6\sigma}{dx\,dy\,dz\,d\phi_h\,d\phi_S\,dP_{hT}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right) \times \sqrt{2\varepsilon(1+\varepsilon)}\Big\{\sin\phi_S F_{UT}^{\sin\phi_S}(x,z,P_T) + \sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}(x,z,P_T) + \text{leading twist terms}\Big\}, \quad (3)$$

Bacchetta et al., JHEP0702, 093 (2007)

FORMALISM

- Perform the integration over the P_{hT}, the differential cross section turns to the form

$$\frac{d^4\sigma}{dx\,dy\,dz\,d\phi_S} = \frac{2\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right) \times \sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S F_{UT}^{\sin\phi_S}(x,z).$$

- The x-dependent and z-dependent asymmetry are defined as

$$A_{UT}^{\sin\phi_S}(x) = \frac{\int dy \int dz \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})\sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin\phi_s}(x,z)}{\int dy \int dz \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})F_{UU}(x,z)},$$

$$A_{UT}^{\sin\phi_s}(z) = \frac{\int dx \int dy \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})\sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin\phi_s}(x,z)}{\int dx \int dy \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}(1+\frac{\gamma^2}{2x})F_{UU}(x,z)}.$$

FORMALISM

- $F_{UT}^{\sin\phi_S}(x,z)$ and $F_{UU}(x,z)$ are the collinear counterpart of the original structure function

$$F_{UT}^{\sin\phi_S}(x,z) = -x\sum_q e_q^2 \frac{2M_h}{Q} h_1^q(x) \frac{\tilde{H}^q(z)}{z},$$

$$F_{UU}(x,z) = x\sum_q e_q^2 f_1^q(x) D_1^q(z),$$

- Twist-3 fragmentation function

$$\tilde{H}^{h/q}(z) = 2z^3 \int_z^\infty \frac{dz_1}{z_1^2} \frac{1}{\frac{1}{z}-\frac{1}{z_1}} \hat{H}_{FU}^{h/q,\Im}(z,z_1).$$

- At the energy scale $Q^2 = 1\ \mathrm{GeV}^2$, $\hat{H}_{FU}^{h/q,\Im}(z,z_1)$ has been extracted as

$$\frac{\hat{H}_{FU}^{\pi^+/(u,\bar{d}),\Im}(z,z_1)}{D_1^{\pi^+/(u,\bar{d})}(z) D_1^{\pi^+/(u,\bar{d})}(z/z_1)} = \frac{N_{\rm fav}}{2I_{\rm fav}J_{\rm fav}} z^{\alpha_{\rm fav}}(z/z_1)^{\alpha'_{\rm fav}} \times (1-z)^{\beta_{\rm fav}}(1-z/z_1)^{\beta'_{\rm fav}},$$

K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak, Phys. Rev. D 89, 111501 (2014)

FORMALISM

- The π^- fragmentation functions may be fixed through charge conjugation

$$\hat{H}_{FU}^{\pi^-/(d,\bar{u}),\Im}(z, z_1) = \hat{H}_{FU}^{\pi^+/(u,\bar{d}),\Im}(z, z_1)$$

$$\hat{H}_{FU}^{\pi^-/(u,\bar{d}),\Im}(z, z_1) = \hat{H}_{FU}^{\pi^+/(d,\bar{u}),\Im}(z, z_1)$$

- The π^0 fragmentation functions are given by the average of the fragmentation functions for π^+ and π^-.

- At the initial scale $Q^2 = 2.14\ \mathrm{GeV}^2$, we adopt the standard parametrization for the transversity

$$h_1^q(x) = \frac{1}{2}\mathcal{N}_q^T(x)[f_1^q(x) + g_1^q(x)],$$

$$\mathcal{N}_q^T(x) = N_q^T x^\alpha (1-\beta)^\beta \frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha \beta^\beta}.$$

M. Anselmino *et al.* Phys. Rev. D 87, 094019 (2013)

NUMERICAL CALCULATION

- Kinematics at EIC covers a wide range of Q ⟶ QCD evolution of the transversity and fragmentation functions $\widetilde{H}$ ⟶ implement LO QCD evolution

- Adopt two different choices to evolve $\widetilde{H}$:
  - Evolve as the fragmentation function D_1.

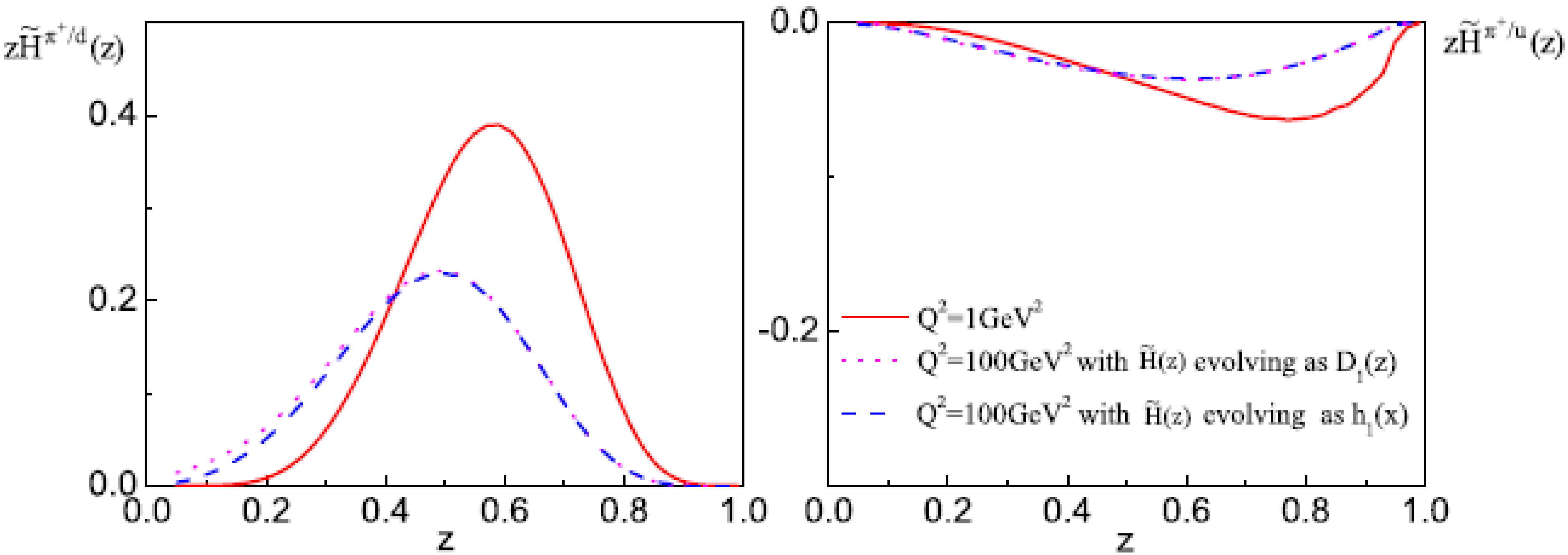
    K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak, Phys. Rev. D 89, 111501 (2014)

  - Evolve as the transversity $h_1(x)$.

    Motivation: $\widetilde{H}$ is a chiral-odd fragmentation function.

NUMERICAL CALCULATION

- Result of $z\widetilde{H}^{\pi^+/d}$(left panel) $z\widetilde{H}^{\pi^+/u}$(right panel) at the initial scale $Q^2 = 1\ \mathrm{GeV}^2$(solid lines) and the evolved results at $Q^2 = 100\ \mathrm{GeV}^2$
  - Dotted lines: evolving as D_1, dashed lines: evolving as h_1



NUMERICAL CALCULATION

- The kinematical region available at EIC

$$Q^2 > 1\ \mathrm{GeV}^2, \quad 0.001 < x < 0.4, \quad 0.01 < y < 0.95,$$

$$0.2 < z < 0.8, \quad \sqrt{s} = 45\,\mathrm{GeV}, \quad W > 5\,\mathrm{GeV},$$

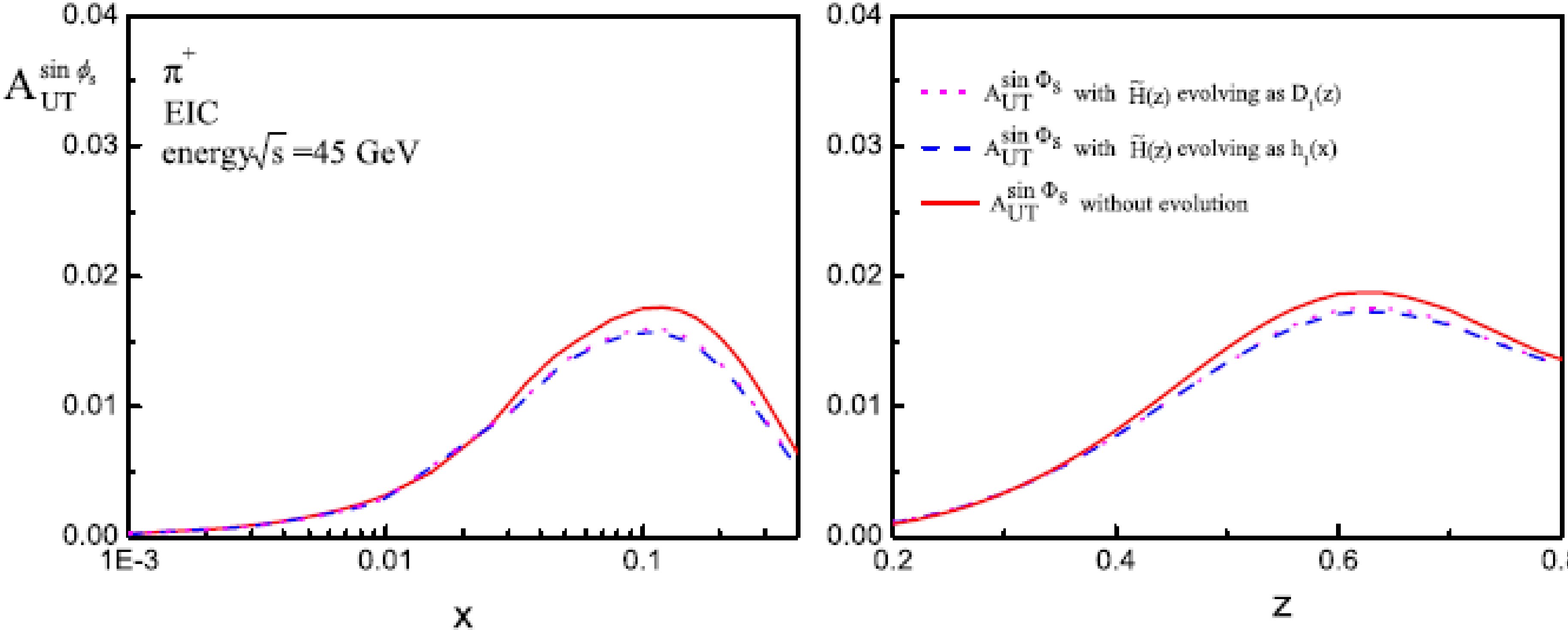
$$W^2 = (P+q)^2 \approx \frac{1-x}{x} Q^2.$$

A. Accardi et al., arXiv:1212.1701

- Parametrization we adopt:
  - unpolarized distribution $f_1^q(x)$
    M. Glück, E. Reya, and A. Vogt, Eur. Phys. J. C 5, 461 (1998)
  - helicity distribution $g_1^q(x)$
    M. Glück, E. Reya, M. Stratmann, and W. Vogelsang, Phys. Rev. D 63, 094005 (2001)
  - unpolarized integrated fragmentation function $D_1^q(z)$
    D. de Florian, R. Sassot, and M. Stratmann, Phys. Rev. D 75, 114010 (2007): LO set

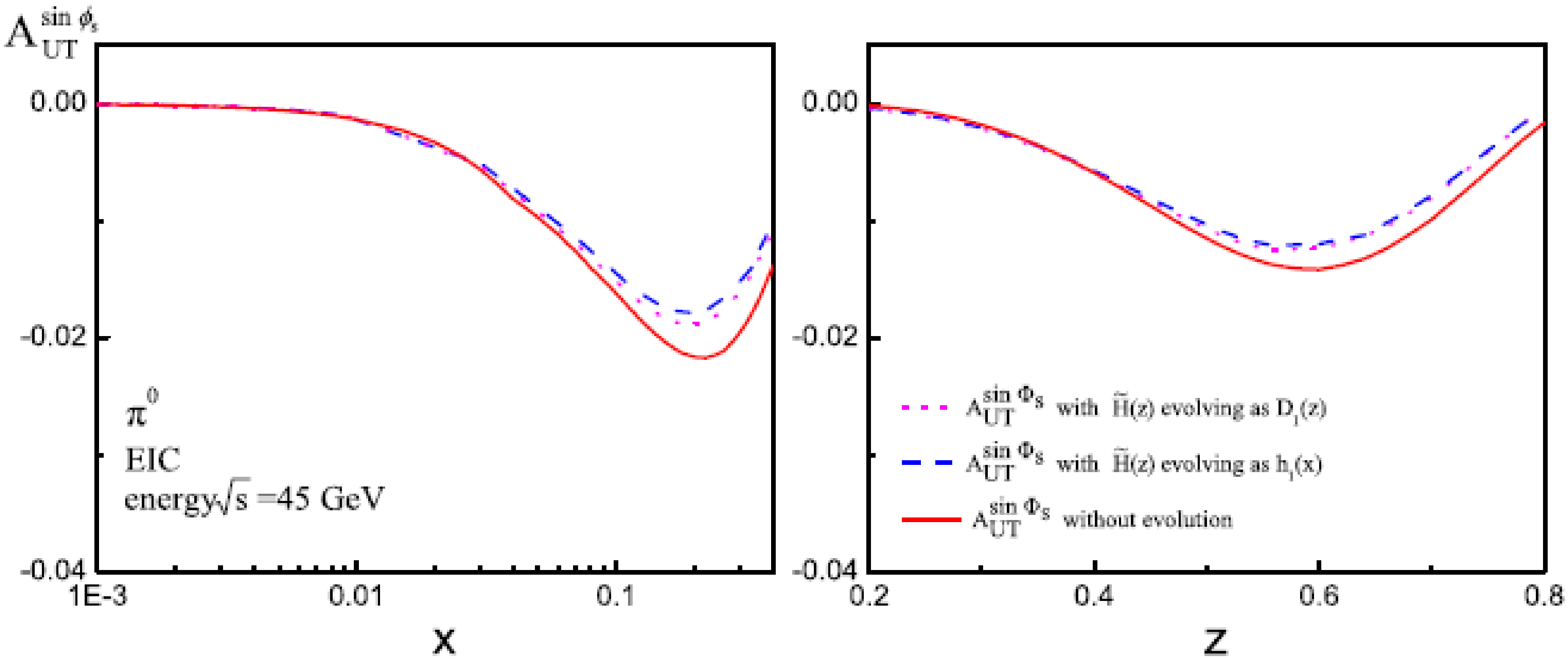
NUMERICAL CALCULATION

- Transverse SSA $\sin\phi_S$ of π^+ production in SIDIS at EIC for $\sqrt{s}$ =45 GeV. The left panel shows the x-dependent asymmetry, while the right one shows the z-dependent asymmetry.



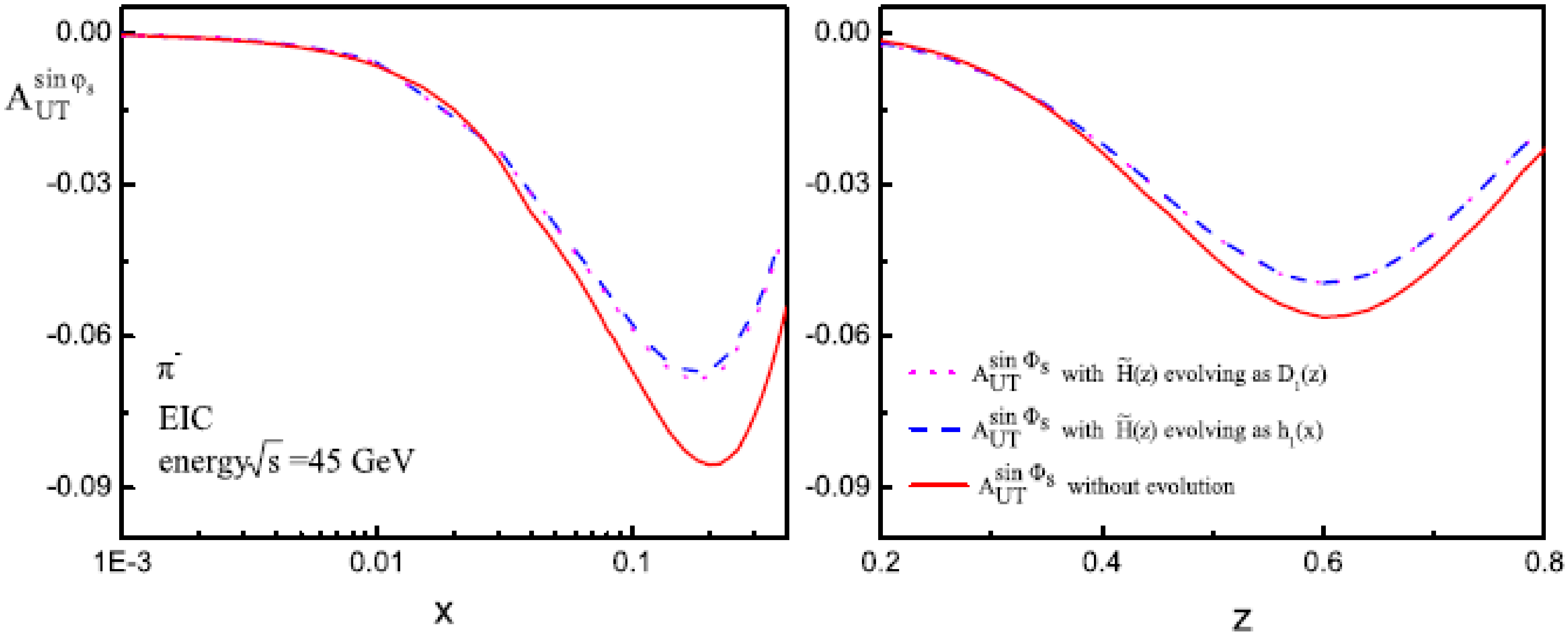
NUMERICAL CALCULATION

- Similarly, transverse SSA $\sin\phi_S$ of π^0 production.



NUMERICAL CALCULATION

- Similarly, transverse SSA $\sin\phi_S$ of π^- production.



CONCLUSION

- The numerical prediction shows that the asymmetries for the charged and neutral pions are all sizable, about several percent.
- It is quite promising that the sin ϕ_S asymmetries of meson production in SIDIS could be measured at the kinematics of EIC.
- The inclusion of the evolution effect may be important for the interpretation of future experimental data.

Thanks for listening！

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