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. Summary and Conclusion

INTRODUCTION

- Transversity $h_1^q(x)$:
  - Fundamental distribution to encode the nucleon structure
  - Chiral-odd
- Some approaches to extract transversity function:
  - (TMD) factorization frame in SIDIS ——Collins function.
  - Collinear factorization in SIDIS——dihadron fragmentation function.
  - Drell-Yan process——the antiquark transversity.

INTRODUCTION

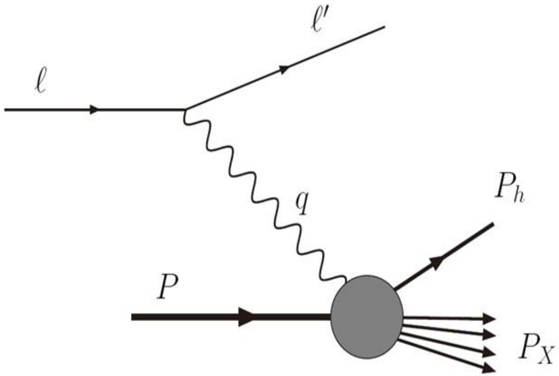
- An alternative approach to access transversity in SIDIS——the twist-3 chiral-odd fragmentation function $\widetilde{H}(z)$ serves as a “spin analyzer” .

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

FORMALISM

- SIDIS with unpolarized electron beam and transversely polarized target

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



The invariants defined as

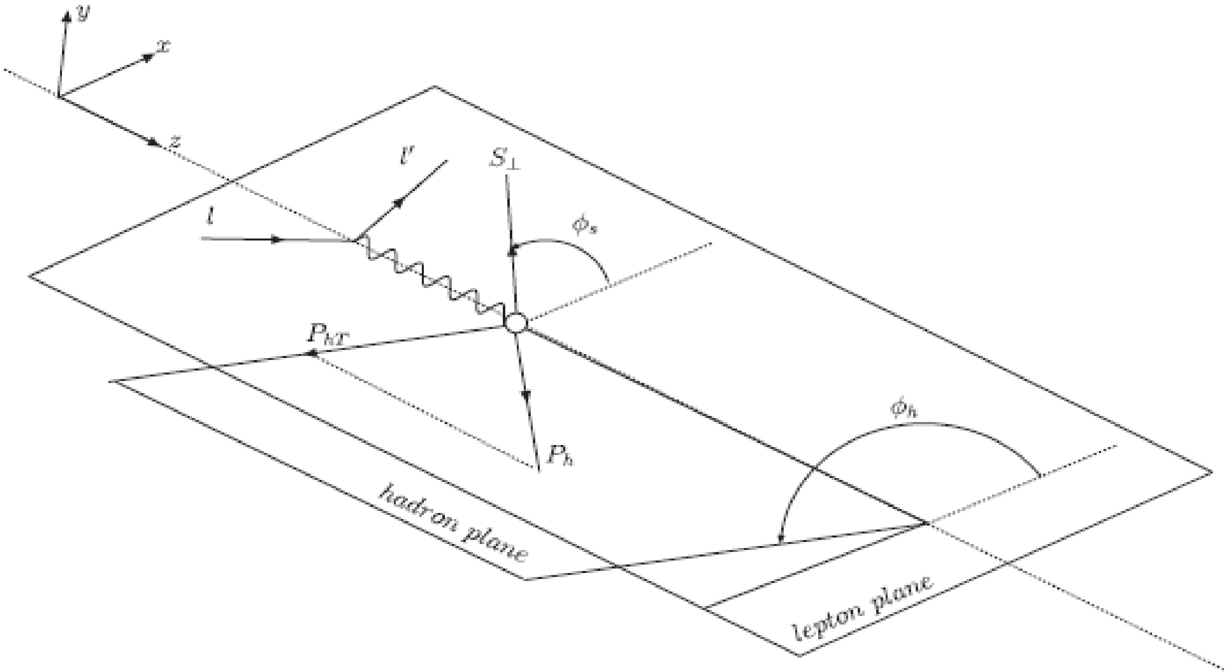
$$x = \frac{Q^2}{2P \cdot q}, \qquad y = \frac{P \cdot q}{P \cdot l}, \qquad z = \frac{P \cdot P_h}{P \cdot q},$$

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

Process under study

FORMALISM

- The reference frame of the process under study is



Reference frame

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

Bacchetta et al., JHEP0702, 093 (2007)

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

General form of differential cross section

FORMALISM

- The structure functions can be written as

$$F_{UT}^{\sin(2\phi_h-\phi_S)} = \frac{2M}{Q}\mathcal{C}\left\{\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T\right)^2-\boldsymbol{p}_T^2}{2M^2}\left(xf_T^{\perp}D_1-\frac{M_h}{M}h_{1T}^{\perp}\frac{\tilde{H}}{z}\right)\right.$$
$$-\frac{2\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T\right)\left(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T\right)-\boldsymbol{k}_T\cdot\boldsymbol{p}_T}{2MM_h}\left[\left(xh_TH_1^{\perp}+\frac{M_h}{M}g_{1T}\frac{\tilde{G}^{\perp}}{z}\right)\right.$$
$$\left.\left.+\left(xh_T^{\perp}H_1^{\perp}-\frac{M_h}{M}f_{1T}^{\perp}\frac{\tilde{D}^{\perp}}{z}\right)\right]\right\},$$

$$F_{UT}^{\sin\phi_S} = \frac{2M}{Q}\mathcal{C}\left\{\left(xf_TD_1-\frac{M_h}{M}h_1\frac{\tilde{H}}{z}\right)\right.$$
$$\left.-\frac{\boldsymbol{k}_T\cdot\boldsymbol{p}_T}{2MM_h}\left[\left(xh_TH_1^{\perp}+\frac{M_h}{M}g_{1T}\frac{\tilde{G}^{\perp}}{z}\right)-\left(xh_T^{\perp}H_1^{\perp}-\frac{M_h}{M}f_{1T}^{\perp}\frac{\tilde{D}^{\perp}}{z}\right)\right]\right\},$$

TMD structure functions

FORMALISM

- Perform the integration over the P_{hT}, only the $\sin\phi_S$ structure function survives, the differential cross section turns to the form

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

with $F_{UT}^{\sin\phi_S}(x,z)$ being the collinear counterpart of the original structure function

$$F_{UT}^{\sin\phi_S}(x,z) = \int d^2\boldsymbol{P}_{hT}F_{UT}^{\sin\phi_S}(x,z,P_{hT}) = -\int d^2\boldsymbol{P}_{hT}\frac{2M_h}{Q}\mathcal{C}\left[h_1\frac{\tilde{H}}{z}\right]$$

$$= -x\frac{2M_h}{Q}\sum_q e_q^2\int d^2\boldsymbol{k}_T\,z^2\int d^2\boldsymbol{p}_T h_1^q(x,\boldsymbol{k}_T^2)\frac{\tilde{H}^q(z,\boldsymbol{p}_T^2)}{z}$$

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

$$\tilde{H}^q(z) = z^2\int d^2\boldsymbol{p}_T\tilde{H}^q(z,\boldsymbol{p}_T^2).$$

Integrated cross section

FORMALISM

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

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

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

with $F_{UU}(x,z)$ being the collinear unpolarized structure function

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

FORMALISM

- The $\widetilde{H}(z)$ related to the imaginary part of the twist-3 fragmentation function $\hat{H}^q(z, z_1)$ via

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

- The information of $\hat{H}_{FU}^{q,\Im}(z, z_1)$ was extracted at the scale $Q^2 = 1\ \mathrm{GeV}^2$ as

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

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

The parameterization of $\widetilde{H}(z)$

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^-.

FORMALISM

- At the initial scale $Q^2 = 2.41\ \mathrm{GeV}^2$, we adopt the standard parametrization for the transversity

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

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

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

The parameterization of $h_1(x)$

NUMERICAL CALCULATION

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

- Adopt two different choices to evolve $\widetilde{H}$:

  - Evolve as the unpolarized fragmentation function D_1.

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

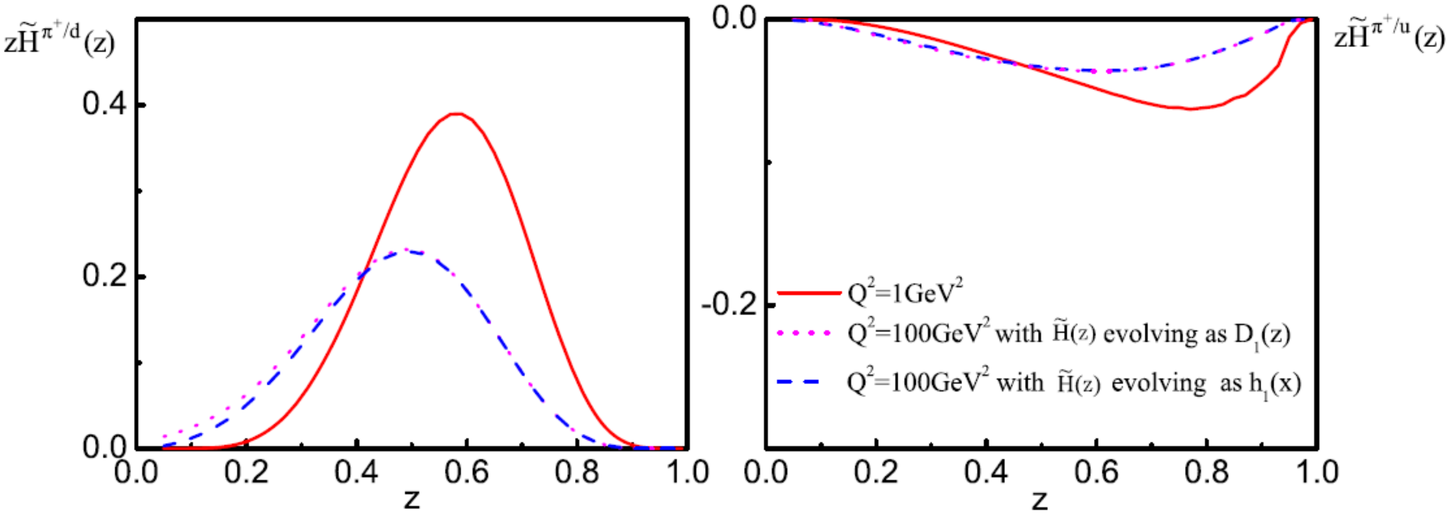
  - Evolve as the transversity $h_1(x)$.

    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



Evolution of $\widetilde{H}(z)$

NUMERICAL CALCULATION

- The kinematical region available at EIC

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

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

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

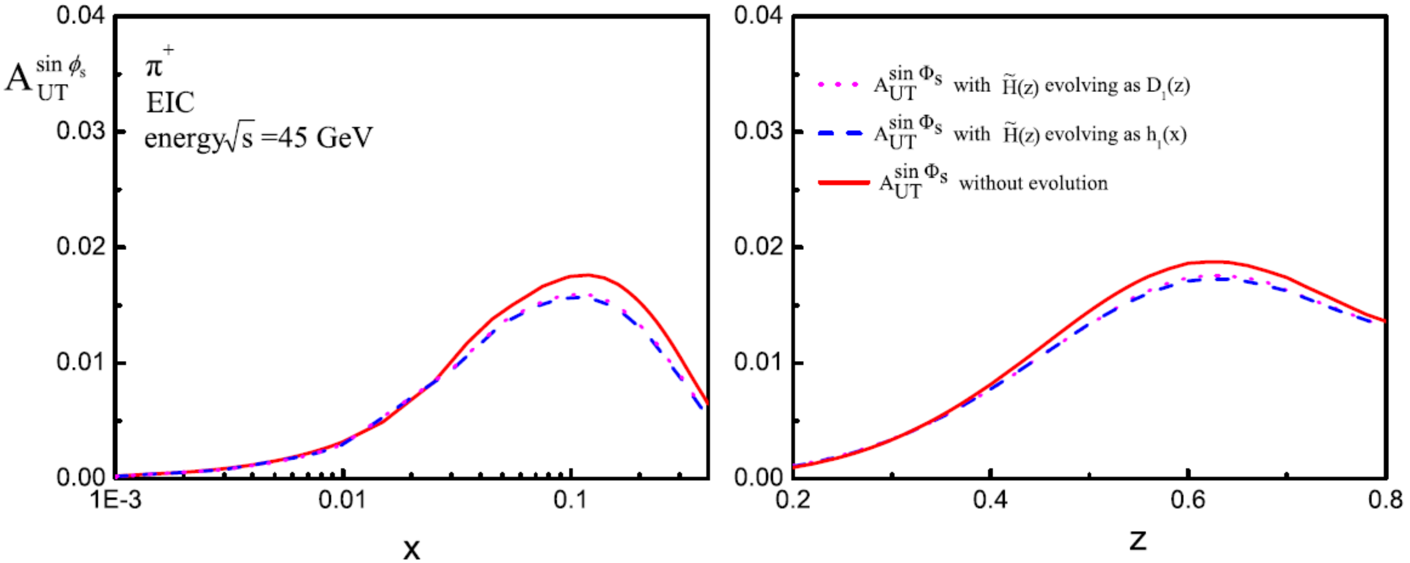
A. Accardi et al., arXiv:1212.1701

- Parameterization 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

Kinematical and parameterization

NUMERICAL CALCULATION

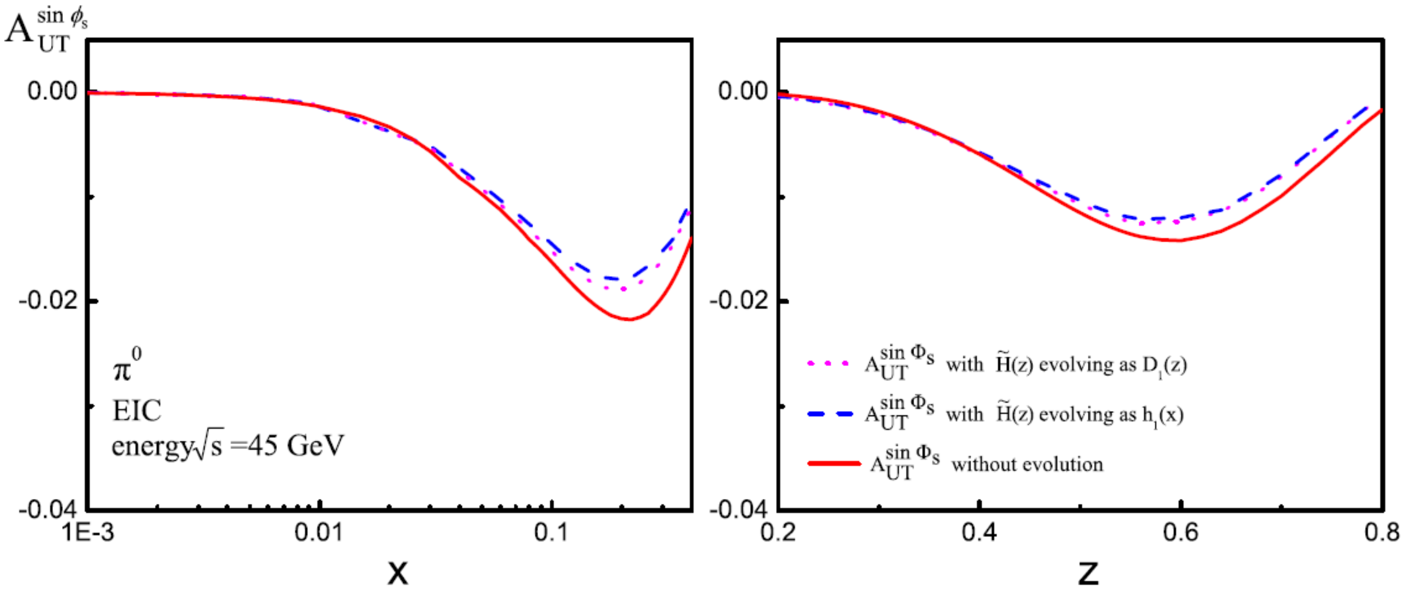
- Transverse SSA $\sin\phi_S$ of π^+ production in SIDIS at EIC for $\sqrt{s}$ =45 GeV. The left panel shows the x-dependent asymmetry, while the right one shows the z-dependent asymmetry.



Asymmetry for π^+

NUMERICAL CALCULATION

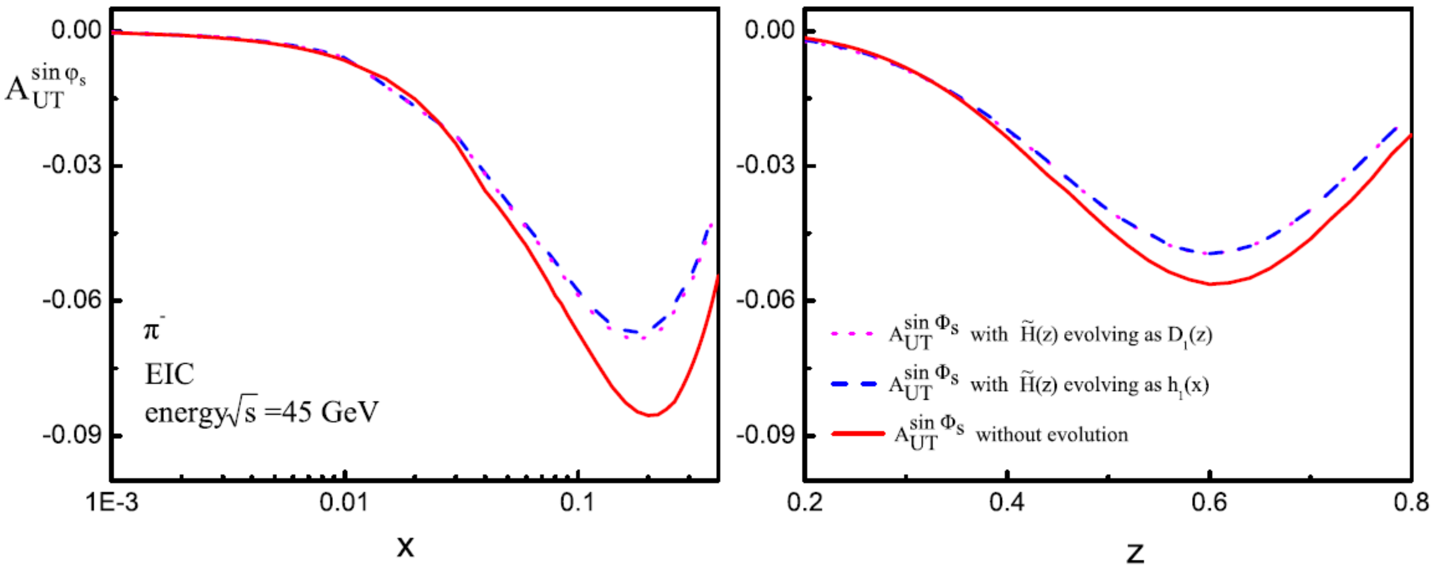
- Similarly, transverse SSA $\sin\phi_S$ of π^0 production.



Asymmetry for π^0

NUMERICAL CALCULATION

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



Asymmetry for π^-

SUMMARY

- We implemented the twist-3 collinear fragmentation function $\widetilde{H}(z)$ to study the $\sin\phi_S$ transverse SSA at EIC through the coupling $h_1 \otimes \widetilde{H}$, in the particular case that the transverse momentum of the final state hadron is integrated out.

- We applied the standard parameterization for the transversity and the available extraction for the fragmentation function $\hat{H}_{FU}^{\pi^+/(u,\bar{d}),\Im}(z, z_1)$

- We included the LO evolution effects for the distribution and fragmentation functions.

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 $\sin\phi_S$ 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.

THANK YOU!