On the $\sin\phi_R$ azimuthal asymmetry single longitudinal-spin asymmetry in dihadron production in SIDIS

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Outline

- Introduction
- The model calculation of $\widetilde{G}_{ot}^{\sphericalangle}(z, M_h^2)$
- Numerical estimate the azimuthal asymmetry $A_{UL}^{\sin\phi_R}$
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Introduction

- Understanding the parton structure of the nucleon and the fragmentation mechanism of hadrons are the main tasks in QCD and hadronic physics.

- The azimuthal asymmetries in SIDIS process have been recognized as useful tools.

- In recent years, the study of dihadron production in SIDIS has received a lot of attention.
  S. Gliske, A. Bacchetta, and M. Radici, Phys. Rev. D 90, 114027 (2014).
  A. Bacchetta and M. Radici, Phys.Rev. D 69, 074026 (2004).

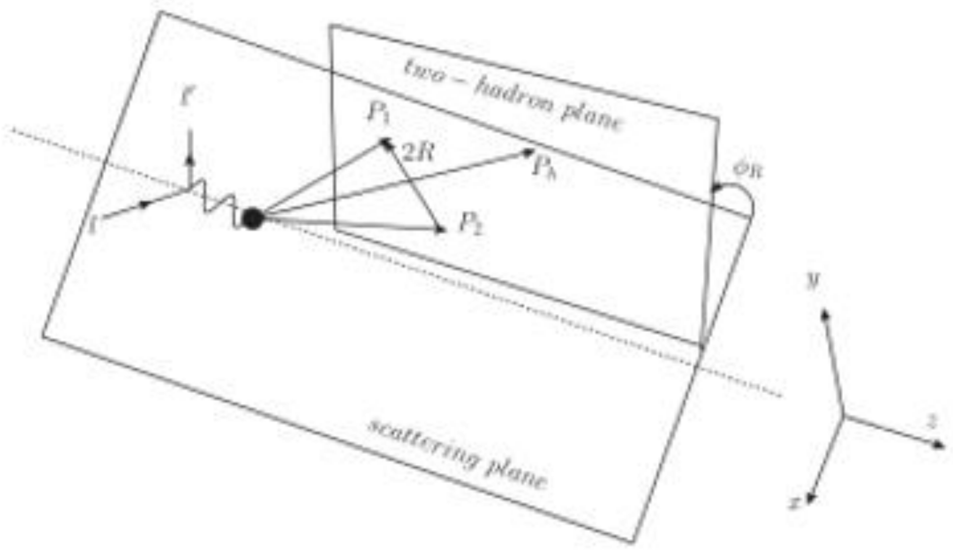
- Recently, some results on the azimuthal spin asymmetries in dihadron production were obtained by the COMPASS, HERMES collaboration and so on.
  A. Airapetian et al. [HERMES Collaboration], J. High Energy Phys 0806, 017 (2008).
  S. Sirtl, in 22nd International Symposium on Spin Physics (SPIN 2016) Urbana, IL, USA

- The spectator model has been applied to calculate the dihadron fragmentation function (DiFF) of pion pair.
  A. Bacchetta and M. Radici, Phys. Rev. D 74, 114007 (2006).

Introduction

- The process under study the dihadron production in SIDIS off a longitudinally polarized proton target as follow

$$\mu(\ell) + p^{\rightarrow}(P) \longrightarrow \mu(\ell') + h^+(P_1) + h^-(P_2) + X,$$



Introduction

- We adopt the following kinematical variables

$$x = \frac{k^+}{P^+}, \qquad y = \frac{P\cdot q}{P\cdot l}, \qquad z_i = \frac{P_i^-}{k^-},$$
$$z = \frac{P_h^-}{k^-} = z_1 + z_2, \qquad Q^2 = -q^2, \qquad s = (P+l)^2,$$
$$P_h = P_1 + P_2, \qquad R = (P_1 - P_2)/2, \qquad M_h = \sqrt{P_h^2}.$$

- The momenta P_h^μ, k^μ and R^μ thus can be written as

$$\begin{aligned}
P_h^\mu &= \left[P_h^-, \frac{M_h^2}{2P_h^-}, \vec{0}\right], \\
k^\mu &= \left[\frac{P_h^-}{z}, \frac{z(k^2+\vec{k}_T^2)}{2P_h^-}, \vec{k}_T\right], \\
R^\mu &= \left[\frac{|\vec{R}|P_h^-}{M_h}\cos\theta, -\frac{|\vec{R}|M_h}{2P_h^-}\cos\theta, |\vec{R}|\sin\theta\cos\phi_R, |\vec{R}|\sin\theta\sin\phi_R\right] \\
&= \left[\frac{|\vec{R}|P_h^-}{M_h}\cos\theta, -\frac{|\vec{R}|M_h}{2P_h^-}\cos\theta, \vec{R}_T^x, \vec{R}_T^y\right],
\end{aligned}$$

Introduction

- There are several useful expression of the scalar products as follows

$$P_h \cdot R = 0,$$
$$P_h \cdot k = \frac{M_h^2}{2z} + z\frac{k^2 + |\vec{k}_T|^2}{2},$$
$$R \cdot k = (\frac{M_h}{2z} - z\frac{k^2 + |\vec{k}_T|^2}{2M_h})|\vec{R}| \cos\theta - \vec{k}_T \cdot \vec{R}_T.$$

- The differential cross section for an unpolarized target and a longitudinally polarized target can be cast to

$$\frac{d^6\sigma_{UU}}{d\cos\theta\, dM_h^2\, d\phi_R\, dz\, dx\, dy} = \frac{\alpha^2}{Q^2 y}\left(1 - y + \frac{y^2}{2}\right)\sum_q e_a^2 f_1^a(x)\, D_1^a(z, M_{hh}^2, \cos\theta),$$
$$\frac{d^6\sigma_{UL}}{d\cos\theta\, dM_h^2\, d\phi_R\, dz\, dx\, dy} = -\frac{\alpha^2}{Q^2 y} S_L\, 2(1-y)\sqrt{2-y}\sum_a e_a^2 \frac{M}{Q}\frac{|\boldsymbol{R}|}{M_h} \sin\theta \sin\phi_R$$
$$\times\left[x h_L^a(x) H_1^{\sphericalangle,a}(z, M_h^2, \cos\theta) + \frac{M_h}{Mz} g_1(x)\widetilde{G}^{\sphericalangle,a}(z, M_h^2, \cos\theta)\right].$$

Z. Lu, Phys. Rev. D 90, 014037 (2014).
A. Bacchetta and M. Radici, Phys. Rev. D 74, 114007 (2006).

A. Bacchetta, F. Conti, and M. Radici, Phys. Rev. D 78, 074010 (2008).

Model calculation

The twist-3 DiFF $\widetilde{G}^{\sphericalangle}$ arises from by the quark-gluon-quark correlator

$$\widetilde{\Delta}_A^{\alpha}(z,k_T,R) = \frac{1}{2z}\sum_X\int\frac{d\xi^+ d^2\xi_T}{(2\pi)^3}e^{ik\cdot\xi}\langle 0|\int_{\pm\infty^+}^{\xi^+}d\eta^+\mathcal{U}^{\xi_T}_{(\infty^+,\xi^+)} \times gF_\perp^{-\alpha}\mathcal{U}^{\xi_T}_{(\eta^+,\xi^+)}\psi(\xi)|P_h,R;X\rangle\langle P_h,R;X|\bar{\psi}(0)\mathcal{U}^{0_T}_{(0^+,\infty^+)}\mathcal{U}^{\infty^+}_{(0_T,\xi_T)}|0\rangle\,|_{\eta^+=\xi^+=0,\eta_T=\xi_T}\,.$$

After integrating out $\vec{k}_T$, one obtains

$$\widetilde{\Delta}_A^{\alpha}(z,\cos\theta,M_h^2,\phi_R) = \frac{z^2|\vec{R}|}{8M_h}\int d^2\vec{k}_T\widetilde{\Delta}_A^{\alpha}(z,k_T,R).$$

The dihadron fragmentation function $\widetilde{G}^{\sphericalangle}$ is obtained from

$$\frac{\epsilon_T^{\alpha\beta}R_{T\beta}}{z}\widetilde{G}^{\sphericalangle}(z,\cos\theta,M_h^2) = 4\pi\mathrm{Tr}[\widetilde{\Delta}_A^{\alpha}(z,\cos\theta,M_h^2,\phi_R)\gamma^-\gamma_5].$$

Model calculation

The function can be expanded in the relative partial waves of the pion pair system. Up to the p-wave level we obtain

$$\widetilde{G}^{\sphericalangle}(z, \cos\theta, M_h^2) = \widetilde{G}_{ot}^{\sphericalangle}(z, M_h^2) + \widetilde{G}_{lt}^{\sphericalangle}(z, M_h^2)\cos\theta.$$

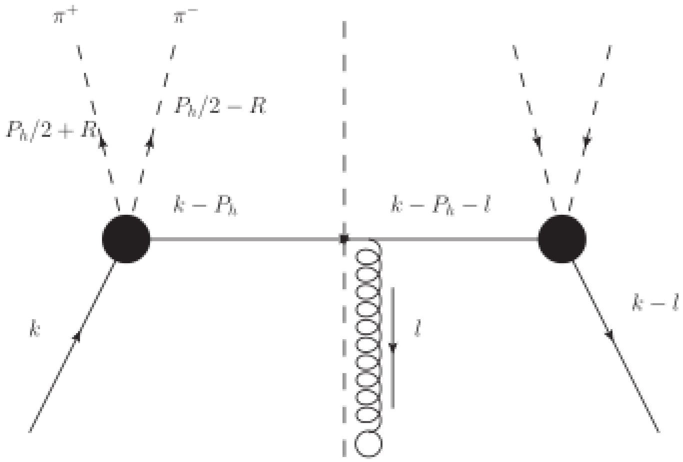
For simplicity, we will not consider the cosθ-dependent terms in the expansion of DiFFs

The quark-gluon-quark correlator for dihardon fragmentation in the spectator model can be written as

$$\widetilde{\Delta}_A^{\alpha}(k, P_h, R) = i\frac{C_F\alpha_s}{2(2\pi)^2(1-z)P_h^-}\frac{1}{k^2-m^2}\int\frac{d^4l}{(2\pi)^4}(l^- g_T^{\alpha\mu} - l_T^{\alpha}g^{-\mu})$$
$$\frac{(\not{k}-\not{l}+m)(F^{s\star}e^{-\frac{k^2}{\Lambda_s^2}} + F^{p\star}e^{-\frac{k^2}{\Lambda_p^2}}\not{R})(\not{k}-\not{P}_h-\not{l}+m_s)\gamma_\mu(\not{k}-\not{P}_h+m_s)(F^s e^{-\frac{k^2}{\Lambda_s^2}} + F^p e^{-\frac{k^2}{\Lambda_p^2}}\not{R})(\not{k}+m)}{(-l^- \pm i\epsilon)((k-l)^2-m^2-i\epsilon)((k-P_h-l)^2-m_s^2-i\epsilon)(l^2-i\epsilon)},$$

Model calculation

The diagrammatic representation of the correlation function $\widetilde{\Delta}_A^\alpha$ in the spectator model



Where the vertices F^s, F^p have following forms

$$F^s = f_s\,,$$

$$F^p = f_\rho \frac{(M_h^2 - M_\rho^2) - i\Gamma_\rho M_\rho}{(M_h^2 - M_\rho^2) + \Gamma_\rho^2 M_\rho^2} + f_\omega \frac{(M_h^2 - M_\omega^2) - i\Gamma_\omega M_\omega}{(M_h^2 - M_\rho^2) + \Gamma_\omega^2 M_\omega^2}$$

$$- i f'_\omega \frac{\sqrt{\hat{\lambda}(M_\omega^2, M_h^2, m_\pi^2)}\Theta(M_\omega - m_\pi - M_h)}{4\pi\Gamma_\omega^2[4M_\omega^2 m_\pi^2 + \hat{\lambda}(M_\omega^2, M_h^2, m_\pi^2)]^{\frac{1}{4}}}\,.$$

Model calculation

We choose Λ-cutoffs having the form

$$\Lambda_{s,p} = \alpha_{s,p} z^{\beta_{s,p}} (1-z)^{\gamma_{s,p}},$$

The on-shell condition of the spectator gives the relation between k^2 and the transverse momentum $\vec{k}_T$

$$k^2 = \frac{z}{1-z}|\vec{k}_T|^2 + \frac{M_s^2}{1-z} + \frac{M_h^2}{z}.$$

Then, we can obtain the final result

$$\widetilde{G}_{ot}^{\triangleleft}(z, M_h^2) = \frac{\alpha_s C_F z^2 |\vec{R}|}{8(2\pi)^4 (1-z) M_h} \frac{1}{k^2 - m^2} \int d|\vec{k}_T|^2 e^{-\frac{2k^2}{\Lambda_{sp}^2}} \Big\{ \mathrm{Im}(F^{s*} F^p)\, C + \mathrm{Re}(F^{s*} F^p)(k^2 - m^2) m_s \big[(A + zB) - I_2\big] \Big\}.$$

Model calculation

Where the coefficients A and B come from the decomposition of the integral

$$\int d^4 l \frac{l^\mu \delta(l^2)\delta((k-l)^2 - m^2)}{(k - P_h - l)^2 - m_s^2} = A k^\mu + B P_h^\mu,$$

And have the expressions

$$A = \frac{I_1}{\lambda(M_h, m_s)} \left(2k^2 \left(k^2 - m_s^2 - M_h^2\right) \frac{I_2}{\pi} + \left(k^2 + M_h^2 - m_s^2\right) \right),$$

$$B = -\frac{2k^2}{\lambda(M_h, m_s)} I_1 \left(1 + \frac{k^2 + m_s^2 - M_h^2}{\pi} I_2 \right).$$

$$I_1 = \int d^4 l \delta(l^2)\delta((k-l)^2 - m^2) = \frac{\pi}{2k^2}\left(k^2 - m^2\right),$$

$$I_2 = \int d^4 l \frac{\delta(l^2)\delta((k-l)^2 - m^2)}{(k - P_h - l)^2 - m_s^2} = \frac{\pi}{2\sqrt{\lambda(M_h, m_s)}} \ln\left(1 - \frac{2\sqrt{\lambda(M_h, m_s)}}{k^2 - M_h^2 + m_s^2 + \sqrt{\lambda(M_h, m_s)}} \right),$$

Model calculation

and

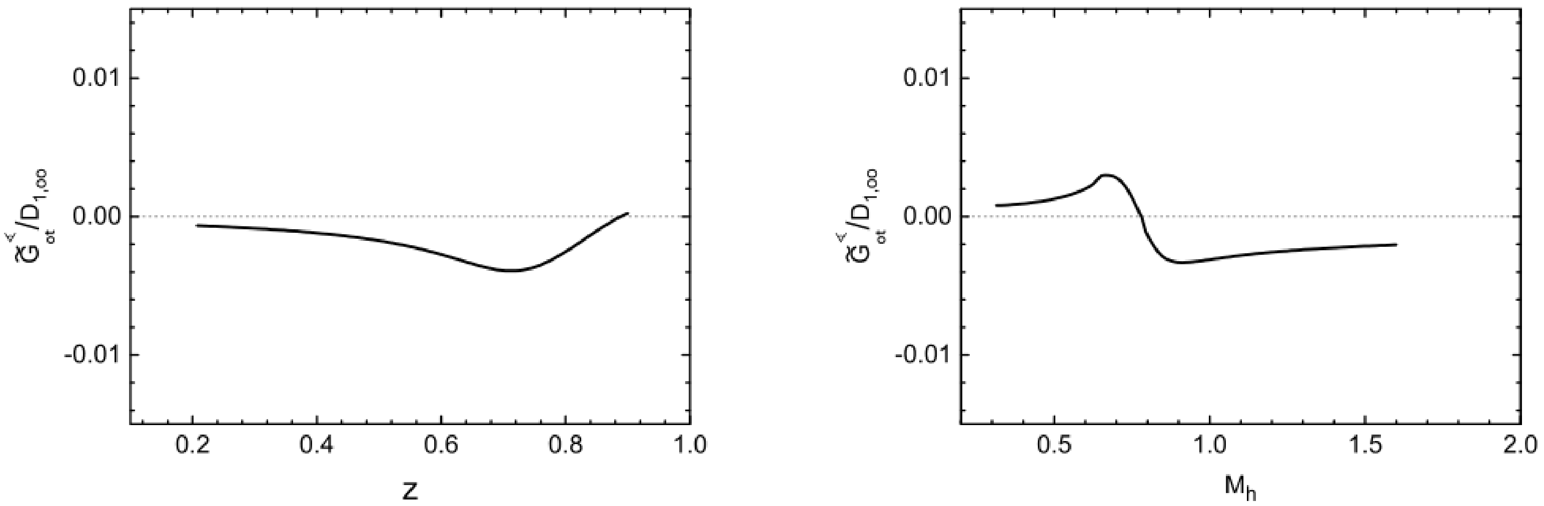
$$\lambda(M_h, m_s) = (k^2 - (M_h + m_s)^2)(k^2 - (M_h - m_s)^2).$$

The coefficient C has the form

$$C = m \int_0^1 dx \int_0^{1-x} dy \frac{-2\left[(x+y)k \cdot P_h - y M_h^2\right] + (k^2 - m^2)}{x(1-x)k^2 + 2k \cdot (k - P_h)xy + xm^2 + y^2 m_s^2},$$

Numerical estimate

The numerical result for $\widetilde{G}_{ot}^{\sphericalangle}(z, M_h^2)$ dependent on z and M_h as follows，



The region $0.2 < z < 0.9$ and $0.3\text{GeV} < M_h < 1.6\text{GeV}$.

The fitting parameters results are

$$\alpha_s = 2.60\text{GeV}\,, \quad \beta_s = -0.751\,, \quad \gamma_s = -0.193\,,$$
$$\alpha_p = 7.07\text{GeV}\,, \quad \beta_p = -0.038\,, \quad \gamma_p = -0.085\,,$$
$$f_s = 1197\text{GeV}^{-1}\,, \quad f_\rho = 93.5\,, \quad f_\omega = 0.63\,,$$
$$f'_\omega = 75.2\,, \quad M_s = 2.97 M_h\,, \quad m = 0.0\text{GeV}(\text{fixed})\,.$$

Numerical estimate

The $A_{UL}^{\sin\phi_R}$ asymmetry of dihadron production in the single longitudinally polarized SIDIS expressed as

$$A_{UL}^{\sin\phi_R}(x,z,M_h^2) = -\frac{\sum_a e_a^2 \frac{|\vec{R}|}{Q}\left[\frac{|M|}{M_h} x h_L^a(x) H_{1,ot}^{\sphericalangle,a}(z,M_h^2) + \frac{1}{z} g_1(x) \widetilde{G}_{ot}^{\sphericalangle}(z,M_h^2)\right]}{\sum_a e_a^2 f_1^a(x) D_{1,oo}^a(z,M_h^2)}.$$

Following the COMPASS convention, the depolarization factors are not included in the numerator and denominator.

So we can obtain the expressions of the x-dependent, z-dependent and M_h-dependent asymmetry as follows

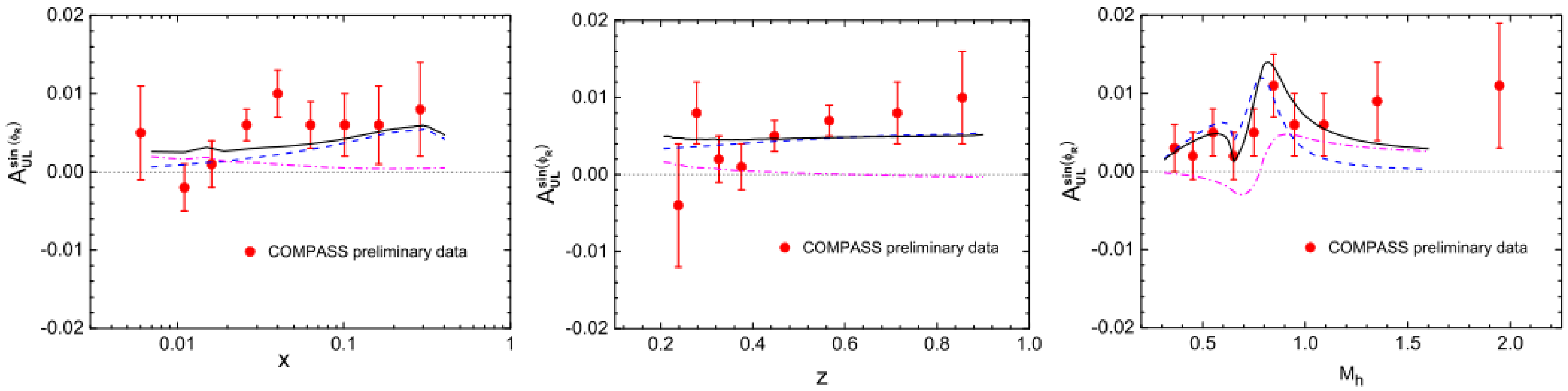
$$A_{UL}^{\sin\phi_R}(x) = -\frac{\int dz \int dM_h 2M_h \frac{|\vec{R}|}{Q}[\frac{|M|}{M_h}(4h_L^u(x)+h_L^d(x))xH_{1,ot}^{\sphericalangle}(z,M_h^2) + \frac{1}{z}(4g_1^u(x)+g_1^d(x))\widetilde{G}_{ot}^{\sphericalangle}(z,M_h^2)]}{\int dz \int dM_h 2M_h (4f_1^u(x)+f_1^d(x)) D_{1,oo}(z,M_h^2)},$$

$$A_{UL}^{\sin\phi_R}(z) = -\frac{\int dx \int dM_h 2M_h \frac{|\vec{R}|}{Q}[\frac{|M|}{M_h}(4h_L^u(x)+h_L^d(x))xH_{1,ot}^{\sphericalangle}(z,M_h^2) + \frac{1}{z}(4g_1^u(x)+g_1^d(x))\widetilde{G}_{ot}^{\sphericalangle}(z,M_h^2)]}{\int dx \int dM_h 2M_h (4f_1^u(x)+f_1^d(x)) D_{1,oo}(z,M_h^2)},$$

$$A_{UL}^{\sin\phi_R}(M_h) = -\frac{\int dx \int dz \frac{|\vec{R}|}{Q}[\frac{|M|}{M_h}(4h_L^u(x)+h_L^d(x))xH_{1,ot}^{\sphericalangle}(z,M_h^2) + \frac{1}{z}(4g_1^u(x)+g_1^d(x))\widetilde{G}_{ot}^{\sphericalangle}(z,M_h^2)]}{\int dx \int dz (4f_1^u(x)+f_1^d(x)) D_{1,oo}(z,M_h^2)}.$$

Numerical estimate

Plot the $A_{UL}^{\sin\phi_R}$ asymmetry at the kinematics of COMPASS



The full circles are the COMPASS preliminary data. The dashed curves denote the contribution from the $h_L H_{1,ot}^{\sphericalangle}$ term, the dashed-dotted curves represent the contribution from the $g_1 \tilde{G}^{\sphericalangle}$ term, and the solid lines display the sum of two contributions.

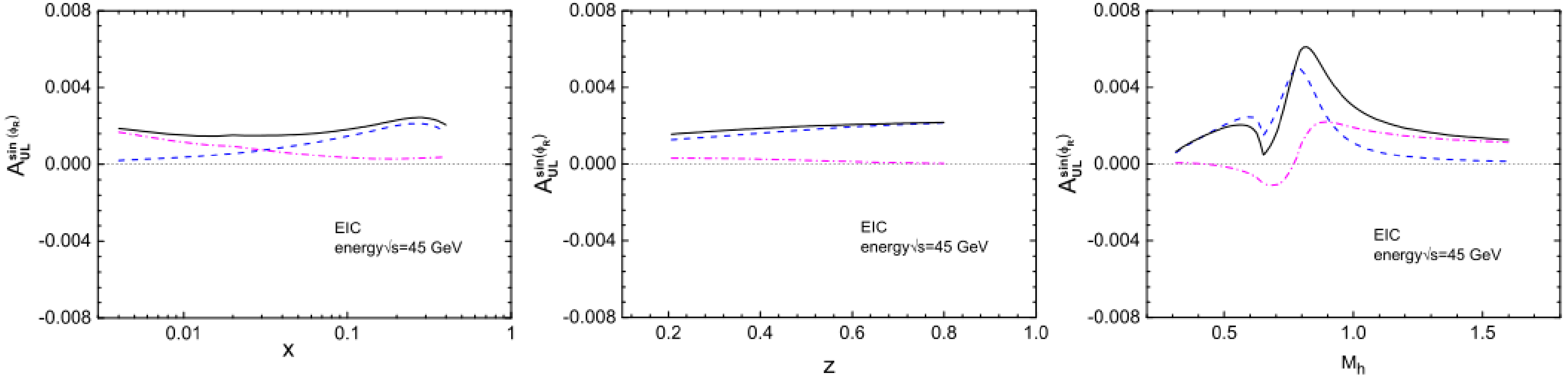
Where the kinematical cuts as follow

$$0.003 < x < 0.4, \quad 0.1 < y < 0.9, \quad 0.2 < z < 0.9,$$

$$0.3\text{GeV} < M_h < 1.6\text{GeV}, \quad Q^2 > 1\text{GeV}^2, \quad W > 5\text{GeV}.$$

Numerical estimate

Plot the $A_{UL}^{\sin\phi_R}$ asymmetry at the future EIC



Where the kinematical cuts as follow

$$\sqrt{s} = 45\text{GeV}, \quad 0.001 < x < 0.4, \quad 0.01 < y < 0.95, \quad 0.2 < z < 0.8,$$
$$0.3\text{GeV} < M_h < 1.6\text{GeV}, Q^2 > 1\text{GeV}^2, \qquad W > 5\text{GeV}.$$

Summary

In this work, we have studied the single longitudinal-spin asymmetry with a sinϕ_R modulation of dihadron production in SIDIS.

- We considered the contributions from the coupling of the twist-3 distributions h_L and the DiFF $H_{1,ot}^{\sphericalangle}$, as well as the coupling of the helicity distribution g_1 and the twist-3 DiFF $\widetilde{G}^{\sphericalangle}$

- We calculated the twist-3 T-odd DiFF $\widetilde{G}_{ot}^{\sphericalangle}$ and found that the contribution to come from the interference of the s and p waves.

- Using the numerical results of the DiFFs, we estimated the $A_{UL}^{\sin\phi_R}$ asymmetry and compared it with the COMPASS measurement.

Summary

- In addition, we also made a prediction $A_{UL}^{\sin\phi_R}$ at the typical kinematics of a future EIC.

- Our study shows that the twist-3 DiFF $\widetilde{G}_{ot}^{\sphericalangle}$ should be considered in phenomenological analysis in order to provide a better understanding of the sinϕ_R asymmetry in dihadron production in SIDIS.

Thanks for your attention!