Single Spin Asymmetries in a light-front quark-diquark model

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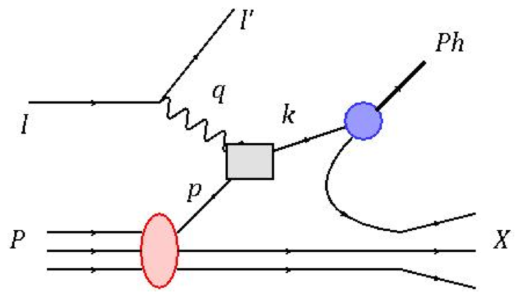
Introduction

- In past few decades several experiment collaborations, e.g., HERMES, COMPASS, JLAB etc., have came up with one of the most exciting features of the nucleons: Single spin asymmetry(SSA).
- These asymmetries indicate existence of non-vanishing transverse momentum of interior partons and collinear picture is no longer sufficient to describe the transverse structure of nucleons.
- The information of asymmetries are encoded into the transverse momentum dependent distributions(TMDs) and fragmentation functions(FFs).
- We calculate the leading twist TMDs in a light-front quark-diquark model(LFQDM) with the wave functions adopted form soft-wall AdS/QCD and give model predictions to the single spin asymmetries. Particularly, here we present model result for Collins asymmetry $A_{UT}^{\sin(\phi_h+\phi_S)}(x,z,\mathbf{P}_{h\perp},y)$ of proton in SIDIS($\ell P\to\ell' hX$) for the π^+ and π^- channels.

$$\ell(\ell)+N(P)\to\ell(\ell')+h(P_h)+X$$



At $P^2_{h\perp}\simeq\Lambda^2_{QCD}\ll Q^2$, the SIDIS cross-section is factorised as

$$d\sigma^{\ell N\to\ell' hX}=\sum_\nu \hat{f}_{\nu/P}(x,\mathbf{p}^2_\perp;Q^2)\otimes d\hat{\sigma}^{\ell q\to\ell q}\otimes\hat{D}_{h/\nu}(z,\mathbf{k}^2_\perp;Q^2),$$

where the first term represents TMDs, the second term represents the hard scattering and the third term is for fragmentation functions(FFs).

- In the experimental measurement the azimuthal asymmetries are found to be non-zero and are defined as

$$A_{S_\ell S_N}=\frac{d\sigma^{\ell P^\uparrow\to\ell' hX}-d\sigma^{\ell P^\downarrow\to\ell' hX}}{d\sigma^{\ell P^\uparrow\to\ell' hX}+d\sigma^{\ell P^\downarrow\to\ell' hX}}\neq 0.$$

- The weighted asymmetry is projected out for the weight $\mathcal{W}$ as

$$A^{\mathcal{W}}_{S_\ell S_N}(x,z,\mathbf{P}_{h\perp},y)=2\frac{\int d\phi_h d\phi_S[d\sigma^{\ell P^\uparrow\to\ell' hX}-d\sigma^{\ell P^\downarrow\to\ell' hX}]\mathcal{W}}{\int d\phi_h d\phi_S[d\sigma^{\ell P^\uparrow\to\ell' hX}+d\sigma^{\ell P^\downarrow\to\ell' hX}]}$$

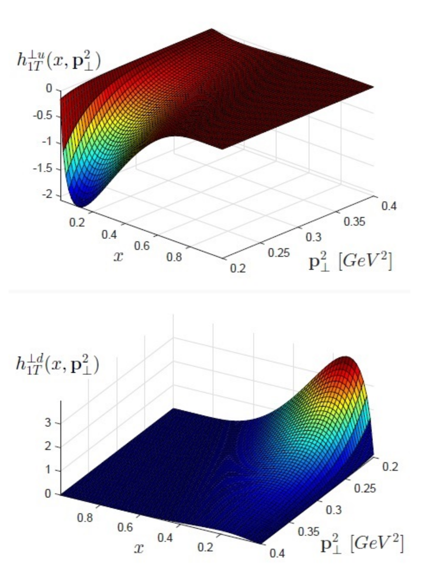
- Where each weighted asymmetry has contribution from particular TMD and particular FF. For example:

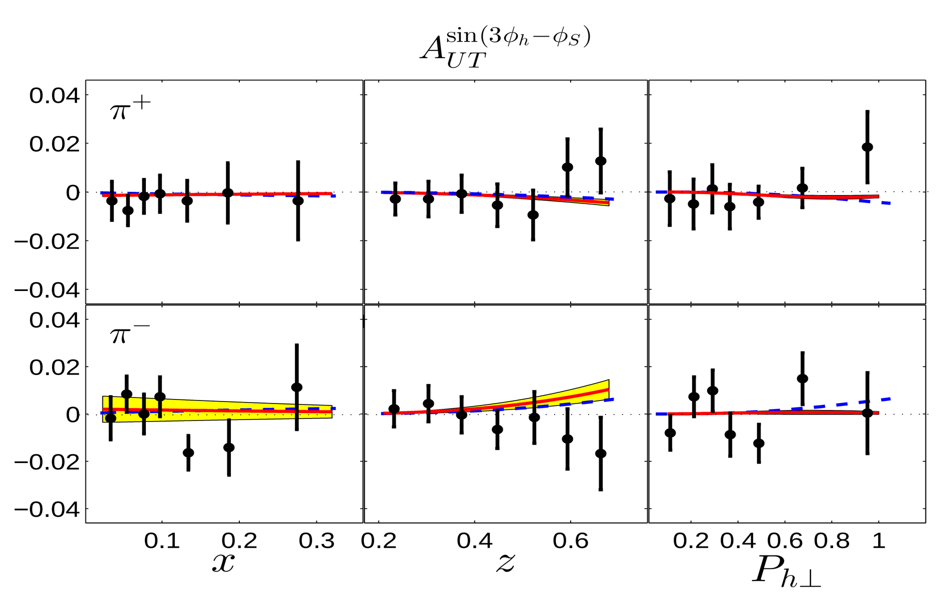
$$\begin{aligned}
\text{Sivers Asymmetry}: \quad & A_{UT}^{\sin(\phi_h-\phi_S)} \sim f_{1T}^\perp\otimes D_1 \ ; \ \mathrm{f}_{1T}^\perp: \text{Sivers func.}\\
\text{Collins Asymmetry}: \quad & A_{UT}^{\sin(\phi_h+\phi_S)} \sim h_1\otimes H_1^\perp \ ; \ \mathrm{H}_1^\perp: \text{Collins func.}\\
& A_{UT}^{\sin(3\phi_h-\phi_S)} \sim h_{1T}^\perp\otimes H_1^\perp\\
& A_{UL}^{\sin\phi_h} \sim h_{1L}^\perp\otimes H_1^\perp \ \ \ldots
\end{aligned}$$

D_1 is the unpolarised FFs and $h_1, h_{1T}^\perp, h_{1L}^\perp$ are the three T-even TMDs.

Model result for $A_{UT}^{\sin(3\phi_h-\phi_S)}$

$A_{UT}^{\sin(3\phi_h-\phi_S)}$ is related to the pretzelocity TMD, $h_{1T}^\perp$. Our model results of $A_{UT}^{\sin(3\phi_h-\phi_S)}$ for the π^+ and π^- channels are compared with the HERMES data





Light-front quark-diquark Model(LFQDM)

- In this model proton is considered as a bound state of a quark and a diquark(of spin-0, singlet or spin-1,triplet) with effective mass and the proton state is written in spin-flavor SU(4) structure as

$$|P;\pm\rangle = C_S|u\ S^0\rangle^\pm + C_V|u\ A^0\rangle^\pm + C_{VV}|d\ A^1\rangle^\pm$$

- The two particle Fock-state expansion for $J^z=\pm 1/2$

$$|u\ S\rangle^\pm=\int\frac{dx\ d^2\mathbf{p}_\perp}{2(2\pi)^3\sqrt{x(1-x)}}\sum_\lambda\psi_\lambda^{\pm(u)}(x,\mathbf{p}_\perp)|\lambda\ \Lambda_S;xP^+,\mathbf{p}_\perp\rangle\Big|_{\Lambda_S=0}$$

$$|\nu\ A\rangle^\pm=\int\frac{dx\ d^2\mathbf{p}_\perp}{2(2\pi)^3\sqrt{x(1-x)}}\sum_\lambda\sum_{\Lambda_A}\psi_{\lambda\Lambda_A}^{\pm(\nu)}(x,\mathbf{p}_\perp)|\lambda\ \Lambda_A;xP^+,\mathbf{p}_\perp\rangle\Big|_{\Lambda_A=1,0,-1}$$

- The light-front wave functions:

$$\psi_{\lambda\Lambda}^{\pm(\nu)}(x,\mathbf{p}_\perp)=\quad N^\nu f(x,\mathbf{p}_\perp,\lambda,\Lambda)\ \varphi_i^{(\nu)}(x,\mathbf{p}_\perp)\Big|_{i=1,2}$$

- Modified soft-wall AdS/QCD wave function for two particle bound state:

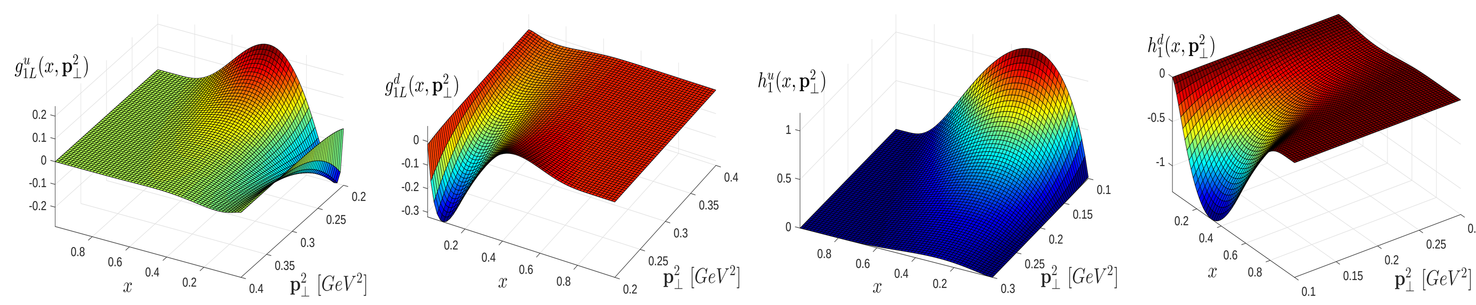
$$\varphi_i^{(\nu)}(x,\mathbf{p}_\perp)=\frac{4\pi}{\kappa}\sqrt{\frac{\log(1/x)}{1-x}}x^{a_i^\nu}(1-x)^{b_i^\nu}\exp\left[-\delta^\nu\frac{\mathbf{p}_\perp^2}{2\kappa^2}\frac{\log(1/x)}{(1-x)^2}\right].$$

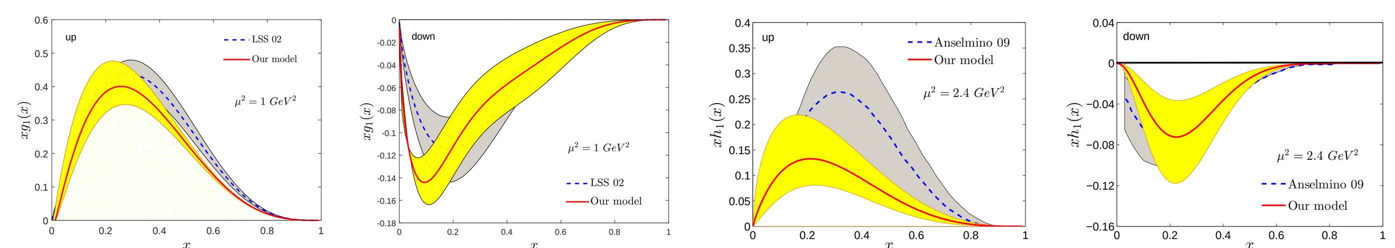
- We determine the parameters a_i^ν, b_i^ν, δ^ν by fitting the experimental data of the Dirac $F_1(Q^2)$ and Pauli $F_2(Q^2)$ form factors.

Helicity and Transversity

In the SIDIS process, the TMDs correlator is defined as (at leading twist $\Gamma=\gamma^+,\gamma^+\gamma^5$ and $i\sigma^{j+}\gamma^5$)

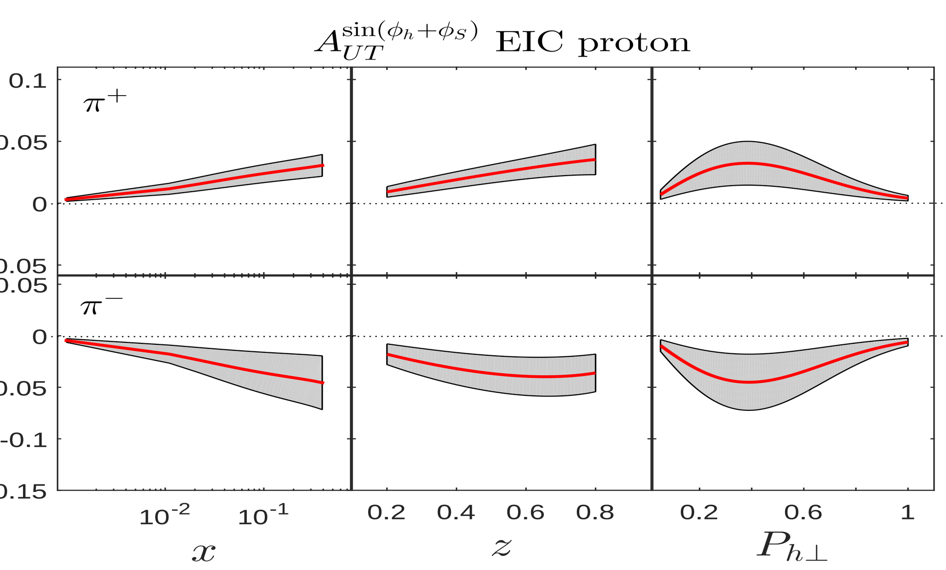
$$\Phi^{\nu[\Gamma]}(x,\mathbf{p}_\perp;S)=\frac{1}{2}\int\frac{dz^-d^2z_T}{2(2\pi)^3}e^{ip.z}\langle P;S|\overline{\psi}^\nu(0)\Gamma\mathcal{W}_{[0,z]}\psi^\nu(z)|P;S\rangle\Big|$$





	g_A^u	g_A^d	$g_A=g_A^u-g_A^d$	g_T^u	g_T^d	$g_T=g_T^u-g_T^d$
LFQDM:	0.71 ± 0.09	$-0.54^{+0.19}_{-0.13}$	$1.25^{+0.28}_{-0.22}$	$0.37^{+0.06}_{-0.05}$	$-0.14^{+0.05}_{-0.06}$	$0.51^{+0.12}_{-0.11}$
Data.:	0.82 ± 0.07	-0.45 ± 0.07	1.27 ± 0.14	$0.59^{+0.14}_{-0.13}$	$-0.20^{+0.05}_{-0.07}$	$0.79^{+0.19}_{-0.20}$

Prediction for EIC kinematics



$$0.001<x<0.4,\ 0.2<z<0.8,\quad 0.05<P_{h\perp}<1, 0.01<y<0.95$$
$$\sqrt{s}=45GeV\quad \mu^2=100\ GeV^2$$

Collins Asymmetry

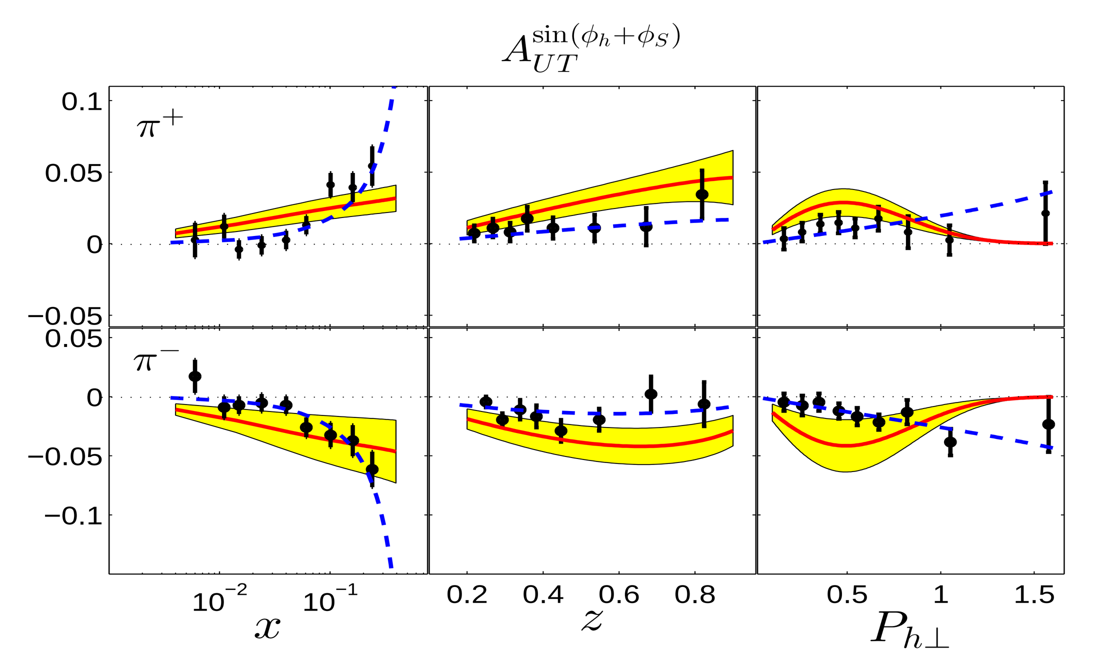
- Collins asymmetry provides correlation between the transversely polarised quark in a transversely polarised nucleon and transverse momentum of the produced hadron.
- Collins asymmetry (has contribution from transversity TMDs, $h_1^\nu(x,\mathbf{p}_\perp)$) is defined as

$$A_{UT}^{\sin(\phi_h+\phi_S)}(x,z,\mathbf{P}_{h\perp},y)=\frac{4\pi^2\alpha^2\frac{(1-y)}{sxy^2}\mathcal{C}\left[\frac{P_{h\perp}-z(\hat{\mathbf{P}}_{h\perp}\cdot\mathbf{p}_\perp)}{zM_h}h_1^\nu(x,\mathbf{p}^2_\perp)H_1^{\perp\nu}(z,\mathbf{k}_\perp)\right]}{2\pi^2\alpha^2\frac{1+(1-y)^2}{sxy^2}\mathcal{C}[f_1^\nu(x,\mathbf{p}^2_\perp)D_1^{h/\nu}(z,\mathbf{k}_\perp)]}$$

- In the LFQDM:

$$A_{UT}^{\sin(\phi_h+\phi_S)}=\frac{\frac{2(1-y)}{sxy^2}\frac{P_{h\perp}\sqrt{2e}}{M_h}\sum_\nu e_\nu^2\hat{h}_1^\nu(x)}{\frac{1+(1-y)^2}{sxy^2}\sum_\nu e_\nu^2 N_{f_1}^\nu\frac{\ln(1/x)}{\pi\kappa^2}\left[T_1^\nu(x)-\frac{\langle m_\perp^2\rangle}{M^2}T_2^\nu(x)\right]}$$
$$\times\frac{\mathcal{N}_\nu^C(z)D_1^{h/\nu}(z)\frac{\langle k^2{}_\perp\rangle_C^2\langle p^2{}_\perp\rangle_x}{\langle k^2{}_\perp\rangle\langle P^2{}_{h\perp}\rangle_C}\frac{e^{-\mathbf{P}^2_{h\perp}/\langle P^2{}_{h\perp}\rangle_C}}{\langle P^2{}_{h\perp}\rangle_C}}{D_1^{h/\nu}(z)\langle p^2{}_\perp\rangle_x\frac{e^{-\mathbf{P}^2_{h\perp}/\langle P^2{}_{h\perp}\rangle}}{\langle P^2{}_{h\perp}\rangle}}.$$

The Collins asymmetry in this model is shown below and compared with the COMPASS data.



Where, '—' represent QCD evolution of $f_1(x,\mathbf{p}^2_\perp)$, and '- - -' is for parameter evolution of $f_1(x,\mathbf{p}^2_\perp)$.

- A complete QCD evolutions of all the leading twist TMDs are not known. h_1^ν is kept at initial scale.
- Parameter evolution approach assumes that the evolution information encoded into the parameters(PRD94,094020(2016)) of this model generates the TMD evolution.
- The fragmentation functions $H_1^{\perp\nu}(z,\mathbf{k}_\perp)$ and $D_1^{h/\nu}(z,\mathbf{k}_\perp)$ are taken as phenomenological inputs.

Conclusions and future directions

- The light-front quark-diquark model(LFQDM) inspired by soft-wall AdS/QCD predicts the TMDs whose PDF limits satisfy the phenomenological extractions quite well.
- Model prediction to the Collins asymmetry and $A_{UT}^{\sin(3\phi_h-\phi_S)}$ show well agreement with the COMPASS and HERMES data.
- Work in progress to predict Sivers asymmetry in this model.

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