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TMD Heilicty Distribution Study

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Collaborators: Tianbo Liu, Bo-Qiang Ma, Peng Sun, Yuxiang Zhao

Outline

Outline

1.1,Introduction —— motivation

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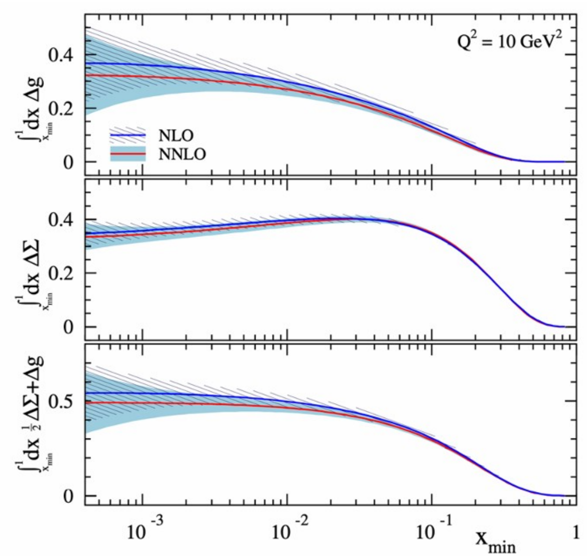
1, Visible world is made up of nucleon, which dominantly consistent of neutron and proton.

2, Proton spin crisis and Wigner rotation $\Delta u_L + \Delta d_L + \Delta s_L = 1.$

J. Ashman et al. (European Muon Collaboration), Nucl. Phys. B 328, 1 (1989)
B. Adeva et al. (Spin Muon Collaboration), Phys. Lett. B 420, 180 (1998)
K. Ackerstaff et al. (HERMES Collaboration), Phys. Lett. B 464, 123 (1999)
M. Alekseev et al. (COMPASS Collaboration), Phys. Lett. B 660, 458 (2008)

NNLO



$$J = \frac{1}{2}\Delta\Sigma + L_q^{JM} + \Delta G + L_g$$

R. Jaffe and A. Manohar, Nucl.Phys. B337 (1990) 509

$$\Delta\Sigma = \int_0^1 g_1(x)dx$$

E. P. Wigner, Annals Math. 40, 149 (1939)
H. J. Melosh, Phys. Rev. D 9, 1095 (1974)

$$\Delta q = \int \mathrm{d}^3\mathbf{p} M_q [q^{\uparrow}(p) - q^{\downarrow}(p)] = \langle M_q \rangle \Delta q_L$$

B.-Q. Ma, J. Phys. G 17, L53-L58 (1991)
B.-Q. Ma, Z.Phys. C 58, 479 (1993)

I. Borsa, M. Stratmann, W. Vogelsang, D. de Florian, R. Sassot, Phys.Rev.Lett. 133, 151901 (2024)

1.1,Introduction —— motivation

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1, Visible world is made up of nucleon, which dominantly consistent of neutron and proton.

2, Proton spin crisis and Wigner rotation

E. P. Wigner, Annals Math. 40, 149 (1939)
H. J. Melosh, Phys. Rev. D 9, 1095 (1974)

3, Wigner Melosh rotation and contribution transverse momentum

$$\Delta q = \int \mathrm{d}^3\mathbf{p} M_q \left[q^{\uparrow}(p) - q^{\downarrow}(p)\right] = \langle M_q \rangle \Delta q_L$$

B.-Q. Ma, J. Phys. G 17, L53-L58 (1991)
B.-Q. Ma, Z.Phys. C 58, 479 (1993)

$$M_q = \left[(p_0 + p_3 + m)^2 - \mathbf{p}_\perp^2\right] / [2(p_0 + p_3)(m + p_0)]$$

$$g_1(x) \rightarrow g_{1L}(x, p_T)$$

4, SIDIS experiment and measurement: $A_{LL} \propto \frac{g_{1L}}{f_1}$ from CLAS and HERMES

CLAS, Phys. Lett. B 782, 662 (2018); HERMES, Phys. Rev. D 99, 112001 (2019)

5, Well-developed factorization theory, energy evolution schemes and reasonable TMD f1 D1 extraction

J. C. Collins and D. E. Soper, Nucl. Phys. B 193, 381 (1981)
X. d. Ji, J. P. Ma, and F. Yuan, Phys. Lett. B 597, 299 (2004)
X. d. Ji, J. p. Ma, and F. Yuan, Phys. Rev. D 71, 034005 (2005)
S. M. Aybat and T. C. Rogers, Phys. Rev. D 83, 114042 (2011)
I. Scimemi and A. Vladimirov, J. High Energy Phys. 06 (2020) 137

1.2,Introduction —— definition

A. Bacchetta, M. Diehl, K. Goeke, A. Metz, P. J. Mulders and M. Schlegel,
JHEP02, 093(2007)

TMDs		Quark polarization		
		Unpolarized (U)	Longitudinally polarized (L)	Transversely polarized (T)
Nucleon polarization	U	f_1 Unpolarized		$h_1^\perp$ Boer–Mulders
	L		g_{1L} Helicity	$h_{1L}^\perp$ Longi-transversity
	T	$f_{1T}^\perp$ Sivers	g_{1T} Trans-helicity	h_1 Transversity $h_{1T}^\perp$ Pretzelosity

Nucleon spin   Quark spin

helicity distribution

$$\Phi_{ij}(x,p_T) = \int \frac{d\xi^- d^2\xi_T}{(2\pi)^3} e^{ip\cdot\xi} \langle P|\bar{\psi}_j(0)\,\mathcal{U}^{n_-}_{(0,+\infty)}\,\mathcal{U}^{n_-}_{(+\infty,\xi)}\,\psi_i(\xi)|P\rangle\Big|_{\xi^+=0}$$

Only leading twist

$$\Phi(x,p_T) = \frac{1}{2}\Big\{ f_1\, \not{n}_+ - f_{1T}^\perp \frac{\epsilon_T^{\rho\sigma} p_{T\rho} S_{T\sigma}}{M}\, \not{n}_+ + g_{1s}\gamma_5\, \not{n}_+ + h_{1T}\frac{[\not{S}_T, \not{n}_+]\gamma_5}{2} + h_{1s}^\perp \frac{[\not{p}_T, \not{n}_+]\gamma_5}{2M} + i\, h_1^\perp \frac{[\not{p}_T, \not{n}_+]}{2M}\Big\}$$

$$g_{1s}(x,p_T) = S_L\, g_{1L}(x,p_T^2) - \frac{p_T\cdot S_T}{M}\, g_{1T}(x,p_T^2)$$

$$\Phi^{[\Gamma]} = \frac{1}{2}\mathrm{Tr}[\Phi\Gamma]$$

$$\Phi^{[\gamma^+\gamma_5]} = S_L g_{1L} - \frac{p_T\cdot S_T}{M} g_{1T}$$

$$f_{j/h}(x) = \frac{1}{2x(2\pi)^3}\sum_a \int d^2\boldsymbol{k}_T \frac{\langle P,h|b^\dagger_{k,\alpha,j} b_{k,\alpha,j}|P,h\rangle}{\langle P,h\mid P,h\rangle}$$

J. Collins, Foundations of Perturbative QCD, (2011).

Outline

2.1, Theoretical formalism——SIDIS

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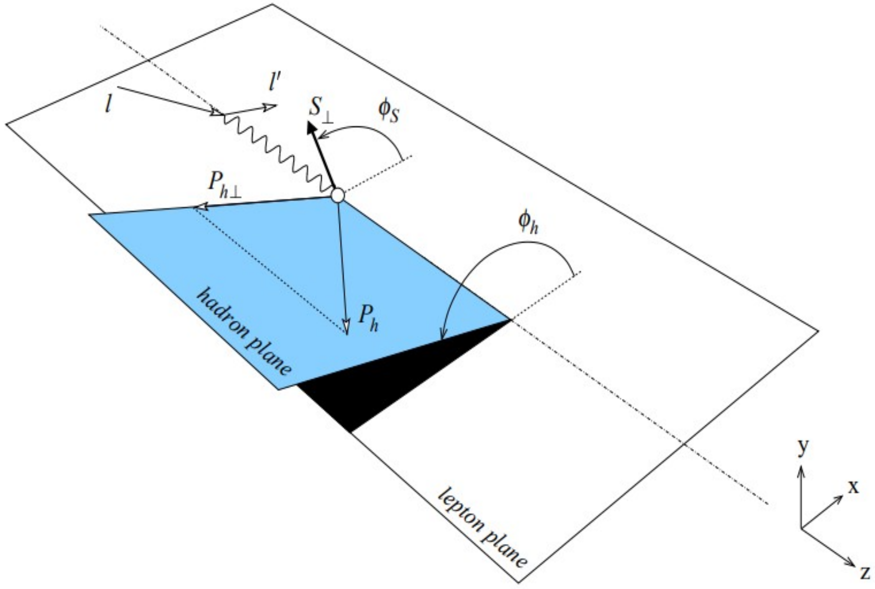
Alessandro Bacchetta, Markus Diehl, Klaus Goeke, Andreas Metz, Piet J. Mulders and Marc Schlegel, JHEP02, 093(2007)

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

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



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

18 structure functions

2.2, Theoretical formalism——SIDIS

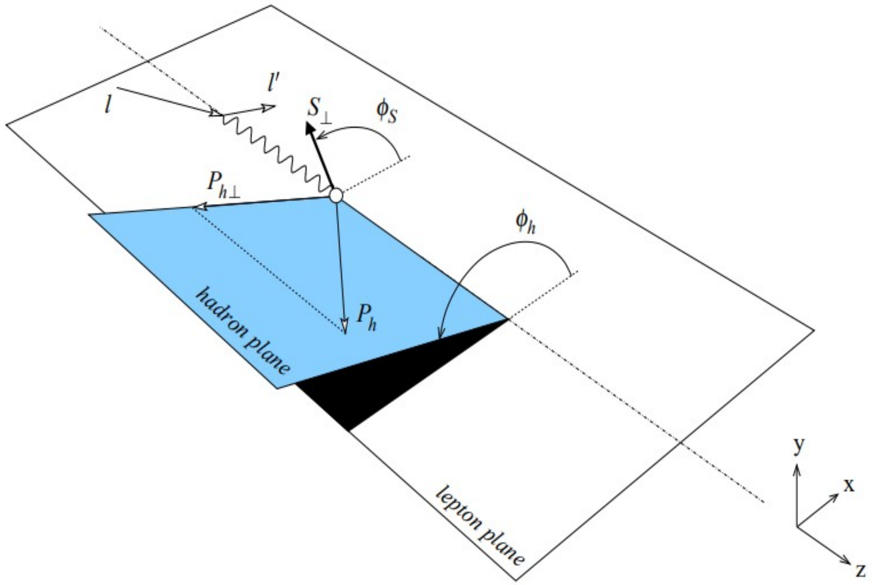
Alessandro Bacchetta, Markus Diehl, Klaus Goeke, Andreas Metz, Piet J. Mulders and Marc Schlegel, JHEP02, 093(2007)

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

$$F_{LL} = \mathcal{C}[g_{1L} D_1]$$

$$F_{LL}^{\cos\phi_h} = \frac{2M}{Q}\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(x e_L H_1^{\perp} - \frac{M_h}{M} g_{1L}\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(x g_L^{\perp} D_1 + \frac{M_h}{M} h_{1L}^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

$$x g_L^{\perp} = x\tilde{g}_L^{\perp} + g_{1L} + \frac{m}{M} h_{1L}^{\perp}$$



2.3, Theoretical formalism——DSA

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Alessandro Bacchetta, Markus Diehl, Klaus Goeke, Andreas Metz, Piet J. Mulders and Marc Schlegel, JHEP02, 093(2007)

$$\begin{aligned} A_{LL}(\phi_h) &= \frac{1}{|S_\perp||\lambda_e|} \frac{[d\sigma_{LL}(+,+) - d\sigma_{LL}(-,+)] - [d\sigma_{LL}(+,-) - d\sigma_{LL}(-,-)]}{d\sigma_{LL}(+,+) + d\sigma_{LL}(-,+) + d\sigma_{LL}(+,-) + d\sigma_{LL}(-,-)} \\ &= \sqrt{1-\varepsilon^2} F_{LL} / (F_{UU,T} + \varepsilon F_{UU,L}) \\ &\quad + \sqrt{2\varepsilon(1-\varepsilon)} \cos\phi_h F_{LL}^{\cos\phi_h} / (F_{UU,T} + \varepsilon F_{UU,L}) . \end{aligned}$$

$$A_{LL}|_{CSA} = \sqrt{1-\varepsilon^2} \frac{F_{LL}}{F_{UU,T} + \varepsilon F_{UU,L}} .$$

$$\begin{aligned} A_{LL}^{\cos\phi_h}|_{CSA} &= \langle 2\cos\phi_h \rangle_{LL} \\ &= \sqrt{2\varepsilon(1-\varepsilon)} \frac{F_{LL}^{\cos\phi_h}}{F_{UU,T} + \varepsilon F_{UU,L}} \end{aligned}$$

$$\varepsilon = \frac{1 - y - \frac{1}{4}\gamma^2 y^2}{1 - y + \frac{1}{2} y^2 + \frac{1}{4}\gamma^2 y^2},$$

2.4, Theoretical formalism——structure functions

Alessandro Bacchetta, Markus Diehl, Klaus Goeke, Andreas Metz, Piet J. Mulders and Marc Schlegel, JHEP02, 093(2007)

$$F_{UU,T} = \mathcal{C}[f_1 D_1]$$
$$= x\sum_q e_q^2 \int \mathrm{d}^2\boldsymbol{p}_T\, \mathrm{d}^2\boldsymbol{k}_T \delta^{(2)}(\boldsymbol{p}_T - \boldsymbol{k}_T - P_{h\perp}/z) f_1(x, p_T^2) D_1(z, k_T^2)$$
$$= x\sum_q e_q^2 \int_0^\infty \frac{|b|\mathrm{d}|b|}{2\pi} J_0\left(\frac{|b||P_{h\perp}|}{z}\right) f_1(x,b) D_1(z,b).$$

$$F_{LL} = \mathcal{C}\left[g_{1L} D_1\right]$$
$$= x\sum_q e_q^2 \int_0^\infty \frac{b_T db_T}{2\pi} J_0\left(\frac{b_T P_{hT}}{z}\right) g_{1L,q\leftarrow H}(x, b_T) D_{1,q\to h}(z, b_T).$$

$$F_{LL}^{\cos\phi} = \frac{2M}{Q}\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(x e_L H_1^\perp - \frac{M_h}{M} g_{1L}\frac{\tilde{D}^\perp}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(x g_L^\perp D_1 + \frac{M_h}{M} h_{1L}^\perp \frac{\tilde{E}}{z}\right)\right]$$
$$\approx -\frac{2M}{Q}\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}(g_{1L}D_1)\right]$$
$$= -\frac{2M^2}{Q} x\sum_q e_q^2 \int_0^\infty \frac{b_T^2\, \mathrm{d}b_T}{2\pi} J_1\left(\frac{b_T P_{hT}}{z}\right) g_{1L,q\leftarrow H}^{(1)}(x, b_T) D_{1,q\to h}(z, b_T).$$

PDF:

$f_1(x, k_T)$

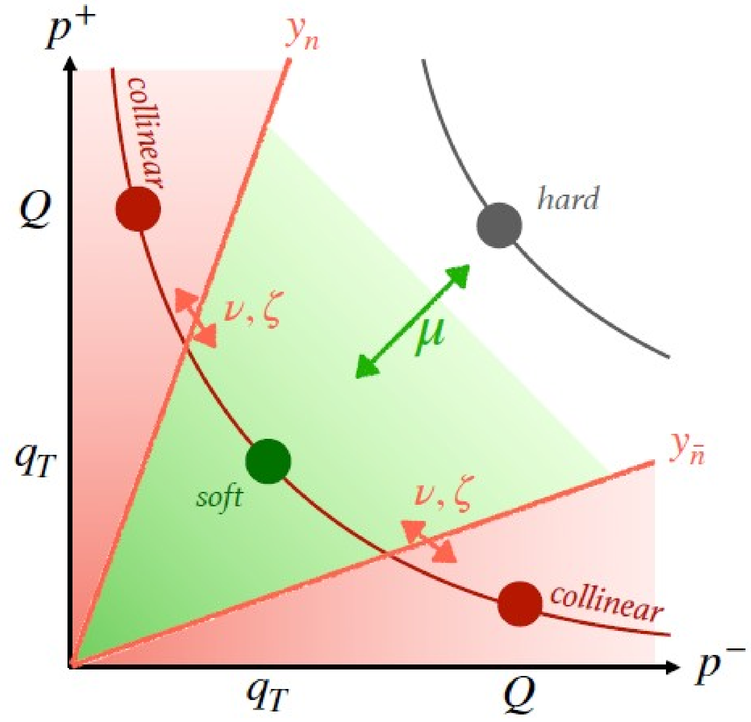
$g_{1L}(x, k_T)$

FF:

$D_1(x, p_T)$

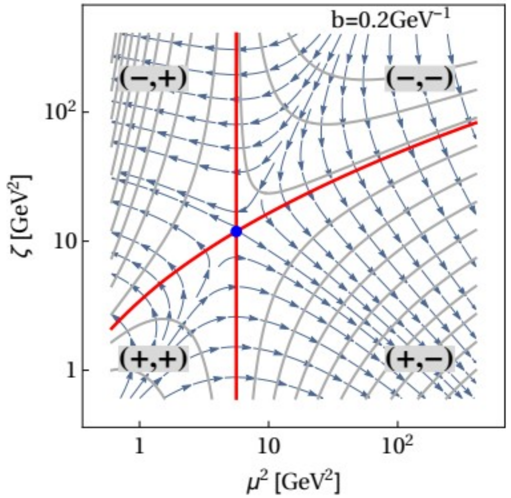
2.5, Theoretical formalism—— TMD evolution

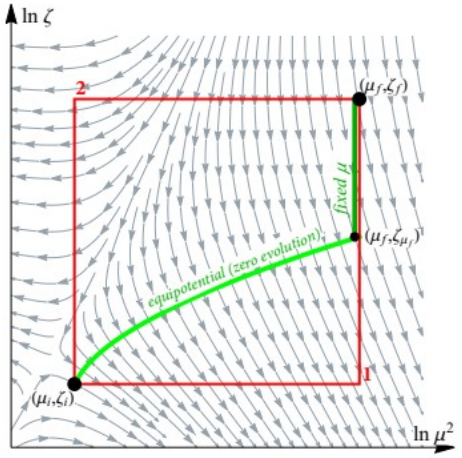
S. M. Aybat and T. C. Rogers, Phys. Rev. D 83, 114042 (2011)
I. Scimemi and A. Vladimirov, J. High Energy Phys. 08 (2018) 003.



$$\mu \frac{d\mathcal{F}(x,b;\mu,\zeta)}{d\mu} = \gamma_F(\mu,\zeta)\mathcal{F}(x,b;\mu,\zeta)$$

$$\zeta \frac{d\mathcal{F}(x,b;\mu,\zeta)}{d\zeta} = -\mathcal{D}(\mu,b)\mathcal{F}(x,b;\mu,\zeta)$$





TMD Handbook
e-Print:2304.03302

$$R[b;(\mu_i,\zeta_i)\to(Q,Q^2)] = \left[\frac{Q^2}{\zeta_\mu(Q,b)}\right]^{-\mathcal{D}(Q,b)}$$

Ignazio Scimemia and Alexey Vladimirovb, JHEP06, 137(2020)

Outline

3.1, World SIDIS data

TABLE II. World SIDIS data that reported by HERMES and CLAS.

Data set	Run	Hadron beam	Lepton beam	point number	Process	Measurement
HERMES [1]	1996-2000	H_2	27.6 GeV $e^{\pm}$	80,30	$e^{\pm}p \to e^{\pm}\pi^{+}X$	A_{LL},$A_{LL}^{\cos\phi}$
HERMES [1]	1996-2000	H_2	27.6 GeV $e^{\pm}$	80,30	$e^{\pm}p \to e^{\pm}\pi^{-}X$	A_{LL},$A_{LL}^{\cos\phi}$
HERMES [1]	1996-2000	D_2	27.6 GeV $e^{\pm}$	80,30	$e^{\pm}d \to e^{\pm}\pi^{+}X$	A_{LL},$A_{LL}^{\cos\phi}$
HERMES [1]	1996-2000	D_2	27.6 GeV $e^{\pm}$	80,30	$e^{\pm}d \to e^{\pm}\pi^{-}X$	A_{LL},$A_{LL}^{\cos\phi}$
HERMES [1]	1996-2000	D_2	27.6 GeV $e^{\pm}$	79,30	$e^{\pm}d \to e^{\pm}K^{+}X$	A_{LL},$A_{LL}^{\cos\phi}$
HERMES [1]	1996-2000	D_2	27.6 GeV $e^{\pm}$	78,30	$e^{\pm}d \to e^{\pm}K^{-}X$	A_{LL},$A_{LL}^{\cos\phi}$
CLAS [4]	2009	$^{14}NH_3$	6 GeV e^{-}	21,21	$e^{-}p \to e^{-}\pi^{0}X$	A_{LL},$A_{LL}^{\cos\phi}$
Total				498,201		

Outline

4.1,Fit ——parametrization & evolution

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Ignazio Scimemia and Alexey Vladimirovb, JHEP06, 137(2020)

unplorazed pdf & ff parametrization :

$$f_{1;f\leftarrow h}(x,b)=\sum_{f'}\int_x^1\frac{dy}{y}C_{f\leftarrow f'}(y,b,\mu_{OPE})f_{1,f'\leftarrow h}\left(\frac{x}{y},\mu_{OPE}\right)f_{NP}(x,b),$$

$$D_{1;f\to h}(z,b)=\frac{1}{z^2}\sum_{f'}\int_z^1\frac{dy}{y}y^2\mathbb{C}_{f\leftarrow f'}(y,b,\mu_{OPE})d_{1,f'\to h}\left(\frac{z}{y},\mu_{OPE}\right)D_{NP}(z,b),$$

$$\mu_{OPE}^{PDF}=\frac{2e^{-\gamma_E}}{b}+2GeV,\qquad \mu_{OPE}^{FF}=\frac{2e^{-\gamma_E}z}{b}+2GeV,$$

$$f_{NP}(x,b)=\exp\left(-\frac{\lambda_1(1-x)+\lambda_2 x+x(1-x)\lambda_5}{\sqrt{1+\lambda_3 x^{\lambda_4}\boldsymbol{b}^2}}\boldsymbol{b}^2\right),$$

$$D_{NP}(x,b)=\exp\left(-\frac{\eta_1 z+\eta_2(1-z)}{\sqrt{1+\eta_3(\boldsymbol{b}/z)^2}}\frac{\boldsymbol{b}^2}{z^2}\right)\left(1+\eta_4\frac{\boldsymbol{b}^2}{z^2}\right),$$

Ignazio Scimemia and Alexey Vladimirovb JHEP08, 003(2018)

evolution :

$$F(x,b;Q,Q^2)=R(b,Q)f_{q\leftarrow h_1}(x,b),\qquad R(b,Q)=\left(\frac{Q^2}{\zeta_Q(b)}\right)^{-\mathcal{D}(b,Q)},$$

4.2,Fit ——parametrization & evolution

TMD helicity function parametrization :

$$g_{1L}(x,b) = \sum_{f'} \int_x^1 \frac{d\xi}{\xi} \Delta C_{f \leftarrow f'}(\xi, b, \mu_{\mathrm{OPE}}) \times g_{1L}^{f'}\left(\frac{x}{\xi}\right) g_{\mathrm{NP}}(x,b),$$

$$g_{1L}^f(x) = N_f \frac{(1-x)^{\alpha_f} x^{\beta_f} (1+\epsilon_f x)}{n(\alpha_f, \beta_f, \epsilon_f)} g_1^f(x, \mu_0),$$

$$g_{\mathrm{NP}}(x,b) = \exp\left[-\frac{\lambda_1(1-x) + \lambda_2 x + \lambda_5 x(1-x)}{\sqrt{1+\lambda_3 x^{\lambda_4} b^2}} b^2\right],$$

q	N_q	α_q	β_q	ε_q	λ_1	λ_2	λ_3	λ_4	λ_5
u	N_u	α_u	β_u	ε_u	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5
d	N_d	α_d	β_d	ε_d	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5
$\bar{u}$	$N_{\bar{u}}$	0	0	0	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5
$\bar{d}$	$N_{\bar{d}}$	0	0	0	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5
$s, \bar{s}$	N_s	0	0	0	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5
g	N_g	0	0	0	λ_1	λ_2	e^{ℓ_3}	λ_4	λ_5

Ignazio Scimemia and Alexey Vladimirovb JHEP08, 003(2018)

evolution : $g_{1L}(x,b;Q,Q^2) = R(b,Q)\, g_{1L}(x,b)$. $R(b,Q) = \left(\frac{Q^2}{\zeta_Q(b)}\right)^{-\mathcal{D}(b,Q)}$,

4.3, World SIDIS data used

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TABLE III. World SIDIS data that reported by HERMES and CLAS satisfy $\delta < 0.5$.

Data set	Run	Hadron beam	Lepton beam	point number	Process	Measurement
HERMES [1]	1996-2000	H_2	27.6 GeV $e^\pm$	42	$e^\pm p \to e^\pm \pi^+ X$	A_{LL}
HERMES [1]	1996-2000	H_2	27.6 GeV $e^\pm$	42	$e^\pm p \to e^\pm \pi^- X$	A_{LL}
HERMES [1]	1996-2000	D_2	27.6 GeV $e^\pm$	41	$e^\pm d \to e^\pm \pi^+ X$	A_{LL}
HERMES [1]	1996-2000	D_2	27.6 GeV $e^\pm$	40	$e^\pm d \to e^\pm \pi^- X$	A_{LL}
HERMES [1]	1996-2000	D_2	27.6 GeV $e^\pm$	40	$e^\pm d \to e^\pm K^+ X$	A_{LL}
HERMES [1]	1996-2000	D_2	27.6 GeV $e^\pm$	39	$e^\pm d \to e^\pm K^- X$	A_{LL}
CLAS [4]	2009	$^{14}NH_3$	6 GeV e^-	9	$e^- p \to e^- \pi^0 X$	A_{LL}
Total				253		

$$Q^2 > 1\,\mathrm{GeV}^2.$$

$$\delta = \frac{P_T}{zQ} < 0.5.$$

4.4,Fit —— method

1, world data (HERMES, CLAS)

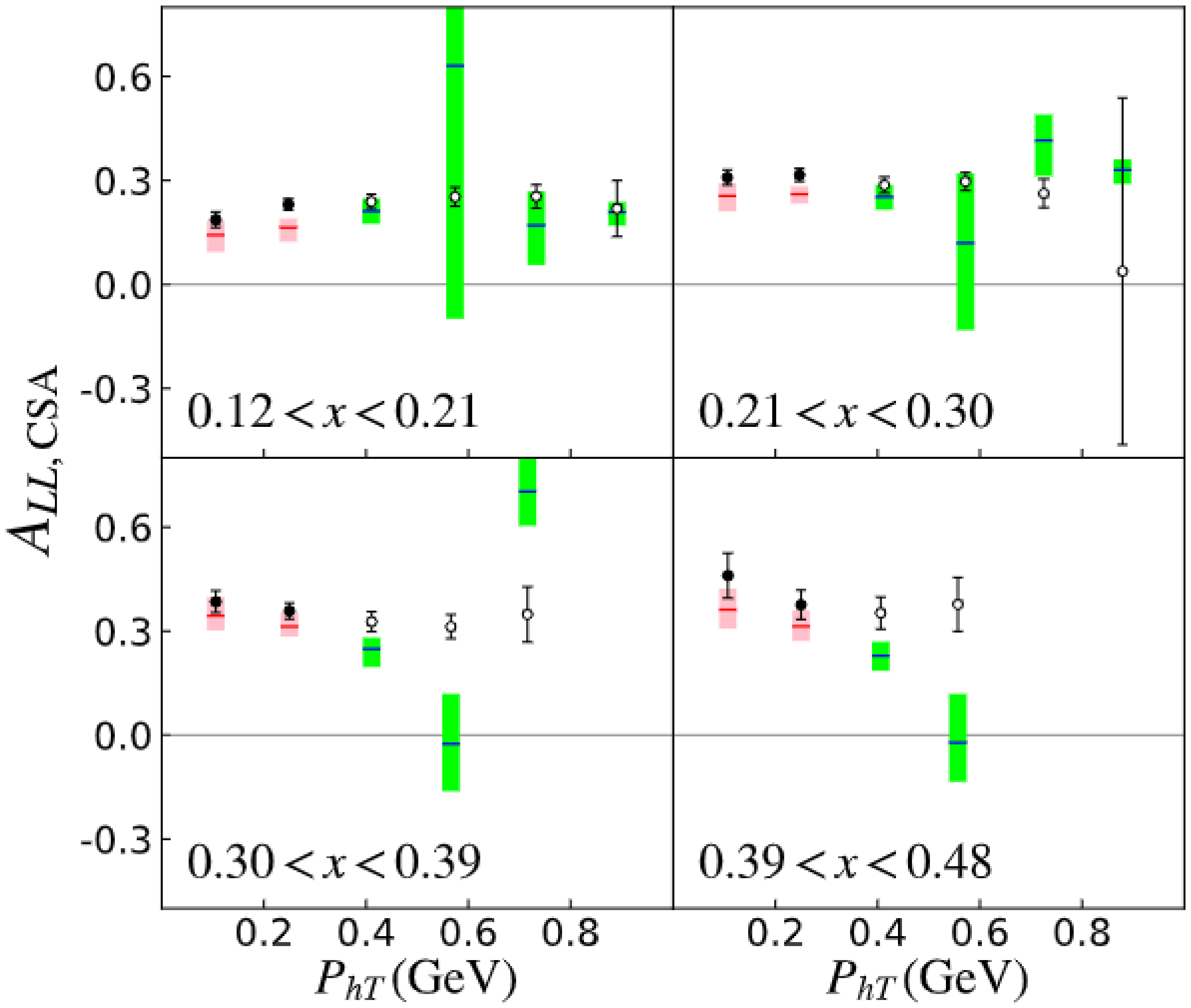
2, replicas generated using central values & uncertainty of world data

3, fit each replica independently

4, every thing we want to know can be described as the central values and standard deviations of result that from those fits.

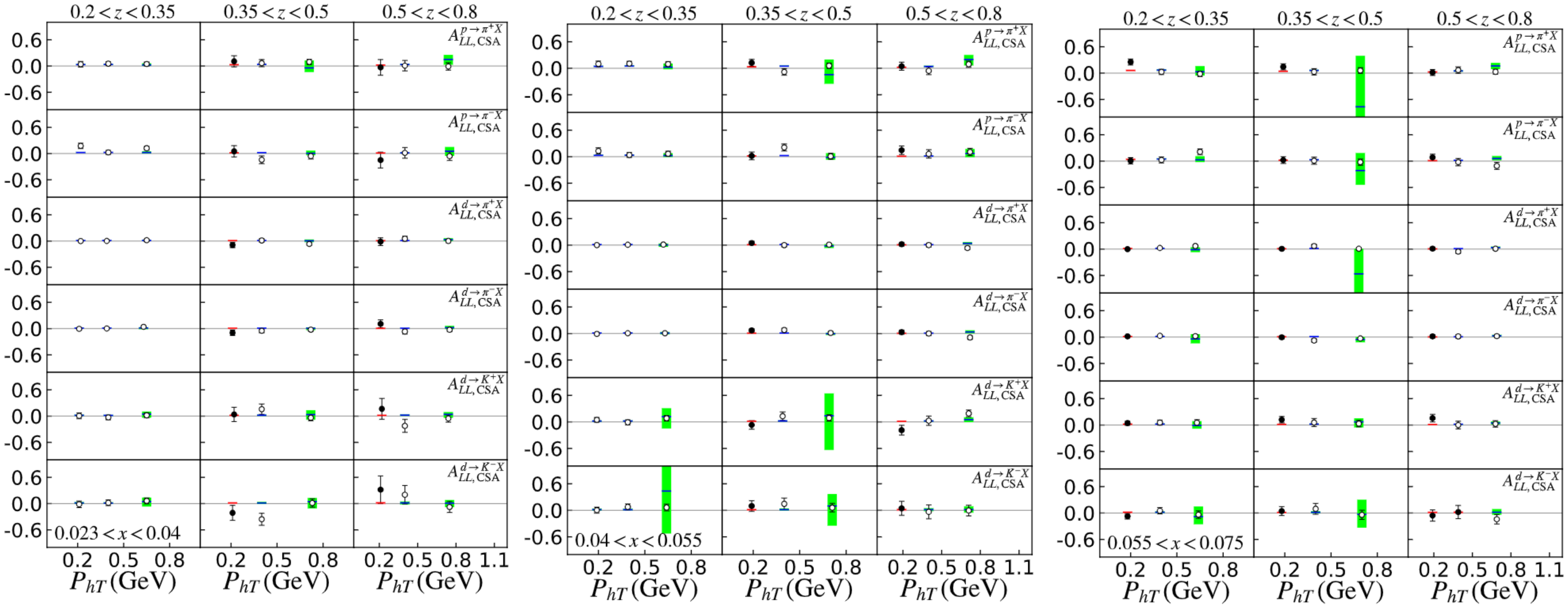
4.5,Fit —— world data

CLAS



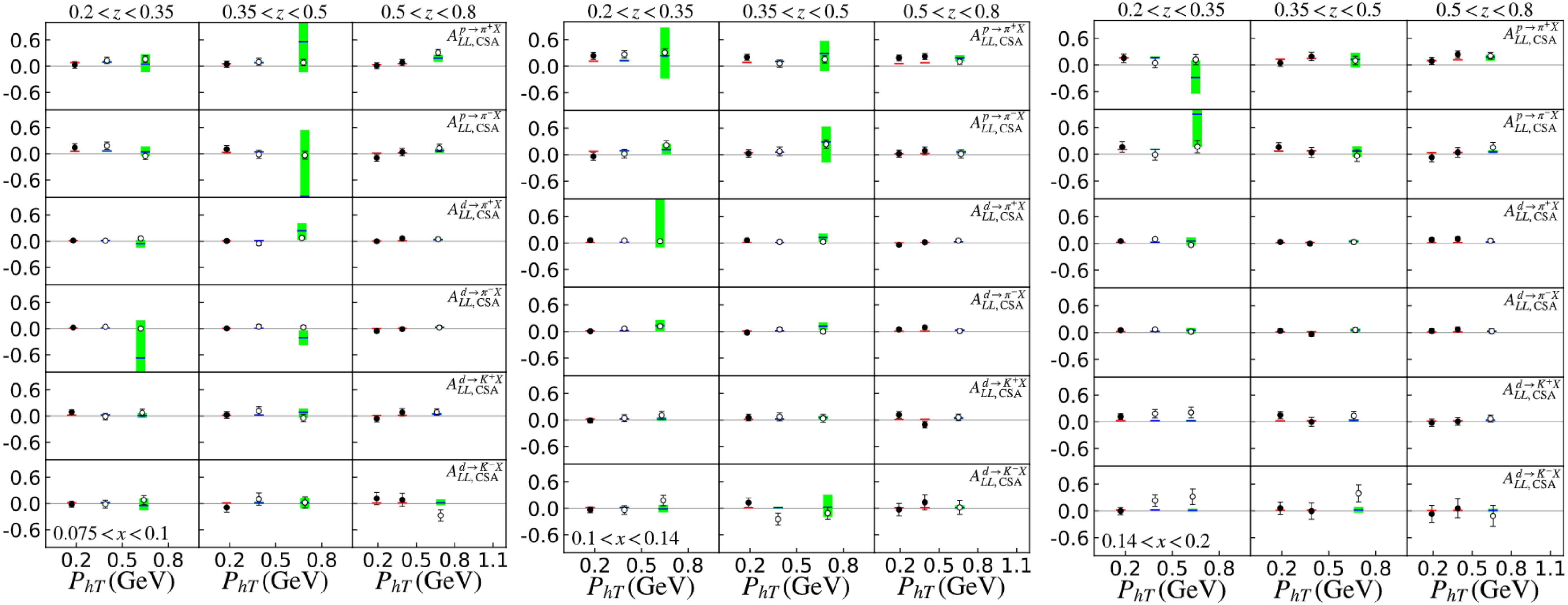
4.5,Fit —— world data

HERMES



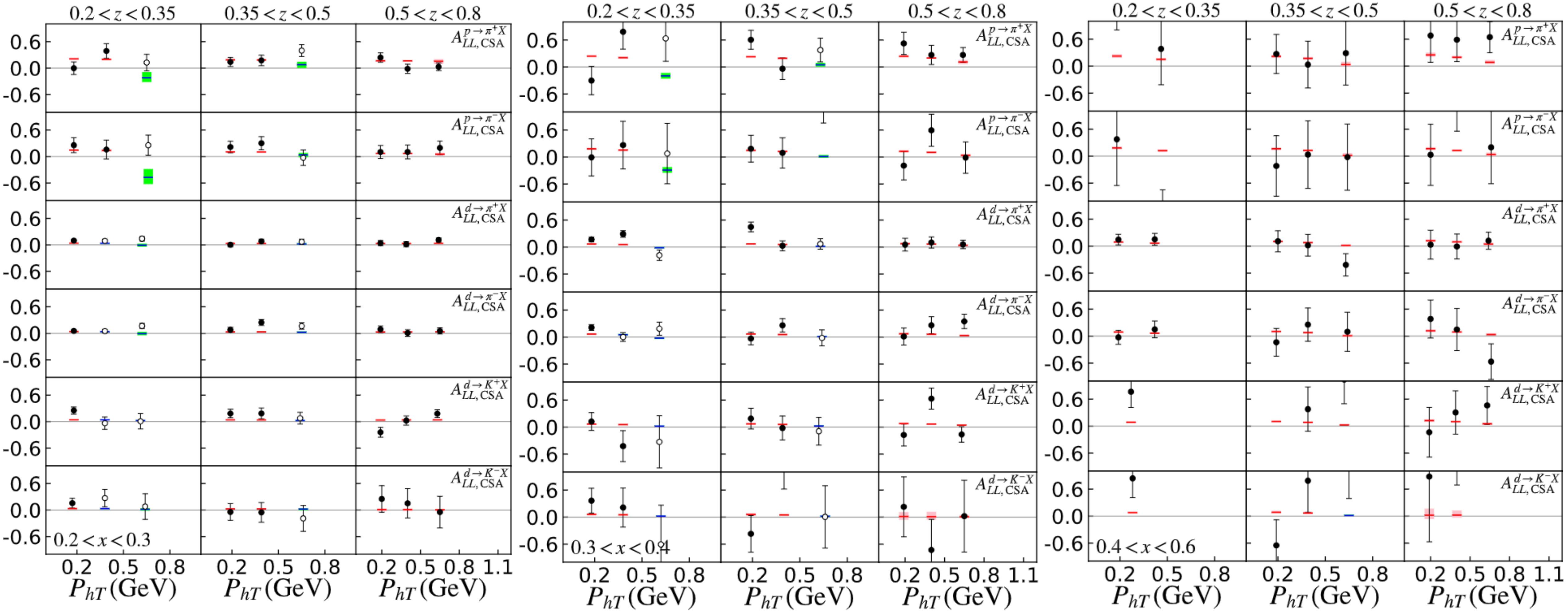
4.5,Fit —— world data

HERMES

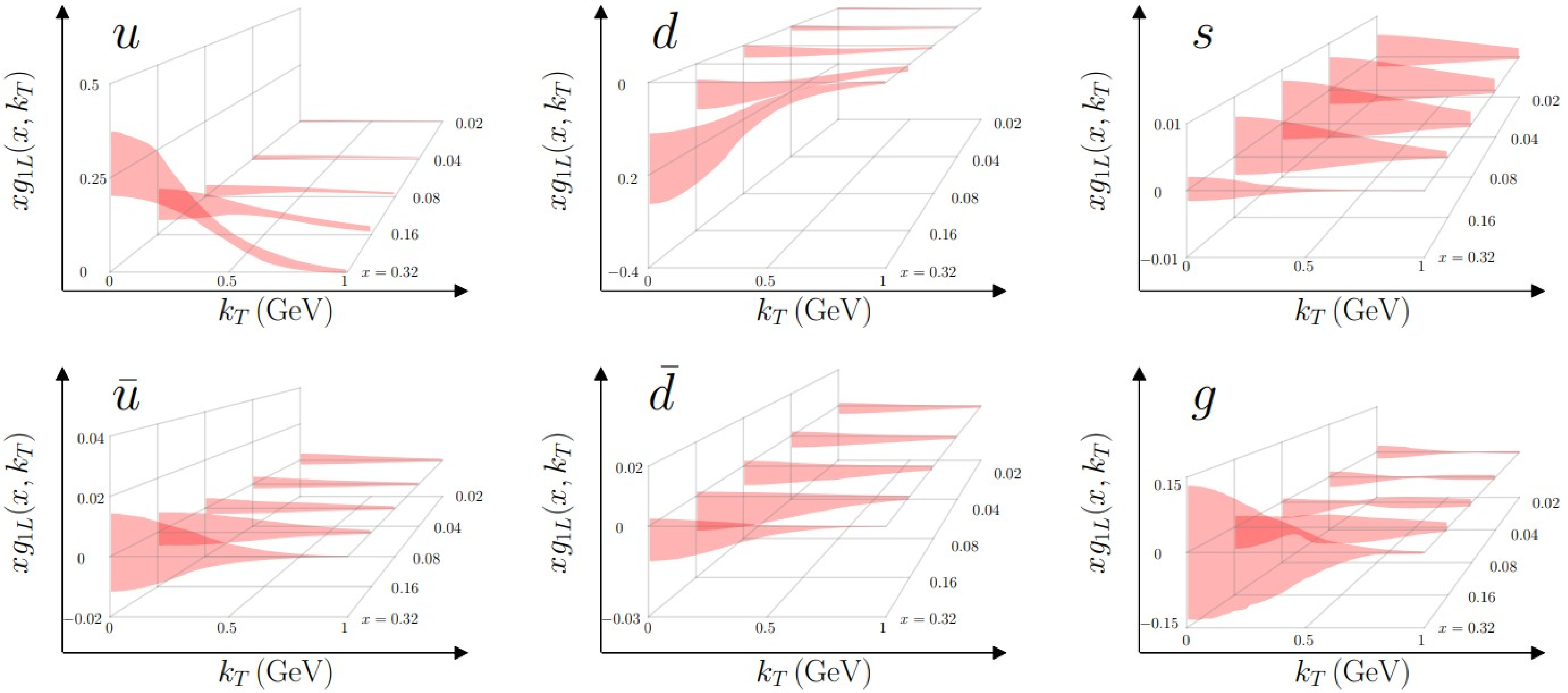


4.5,Fit —— world data

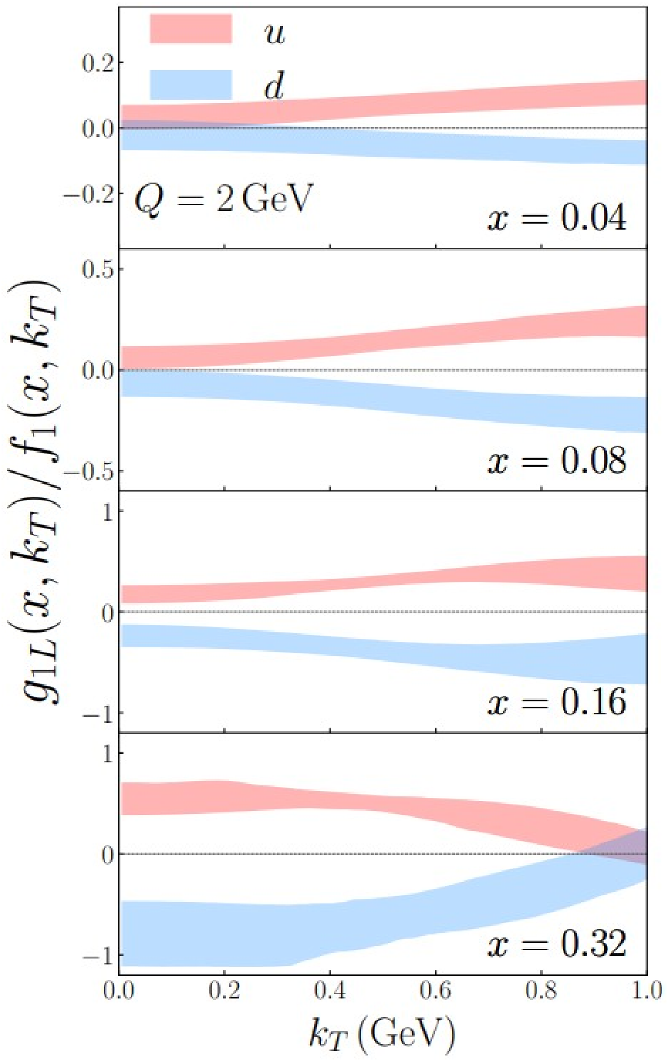
HERMES

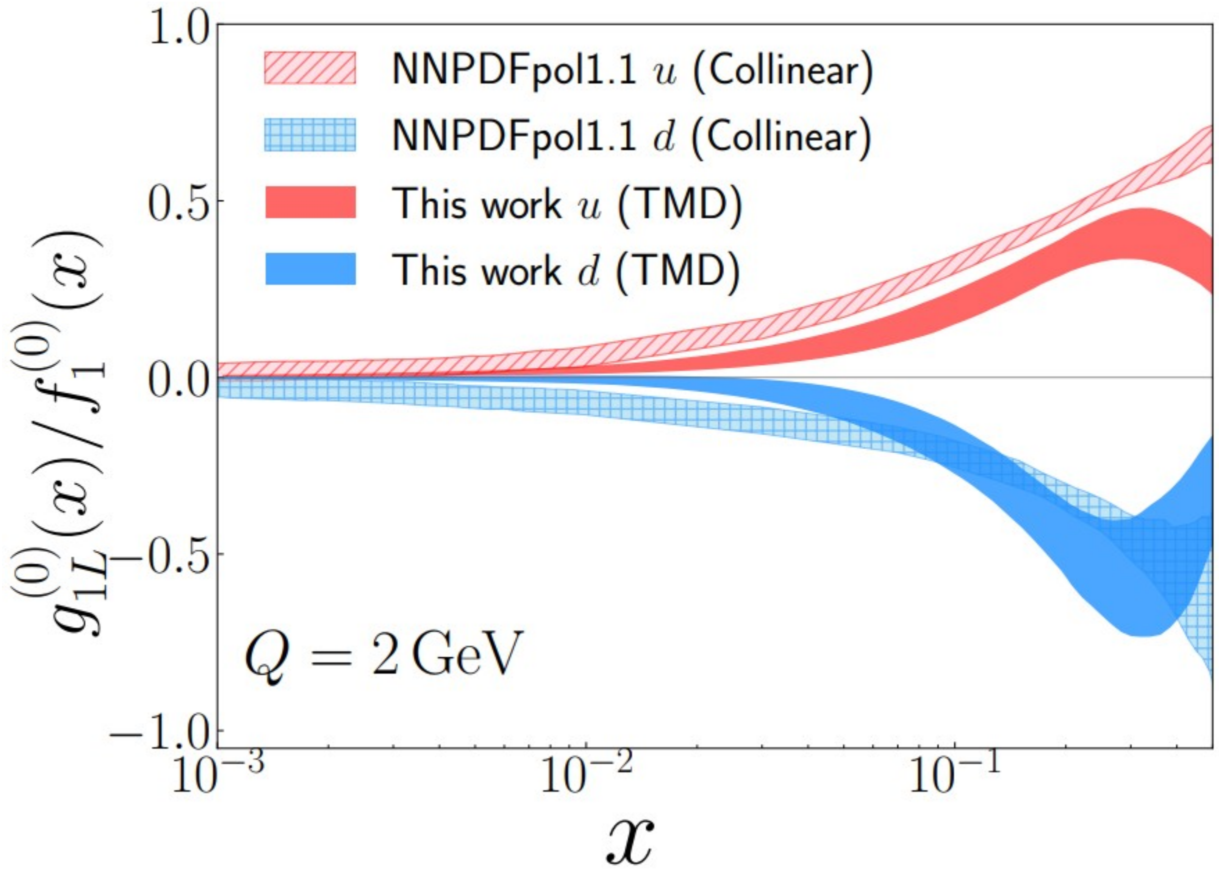


4.7,Fit —— xg1L(x,kT)



4.7,Fit —— polarization





4.7,Fit —— cosphi modulation

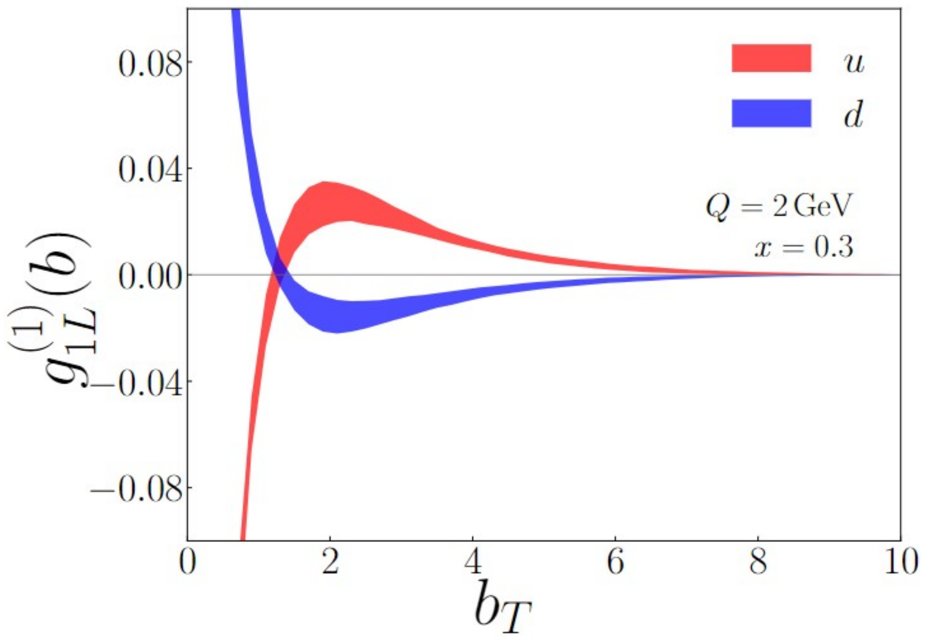
CLAS

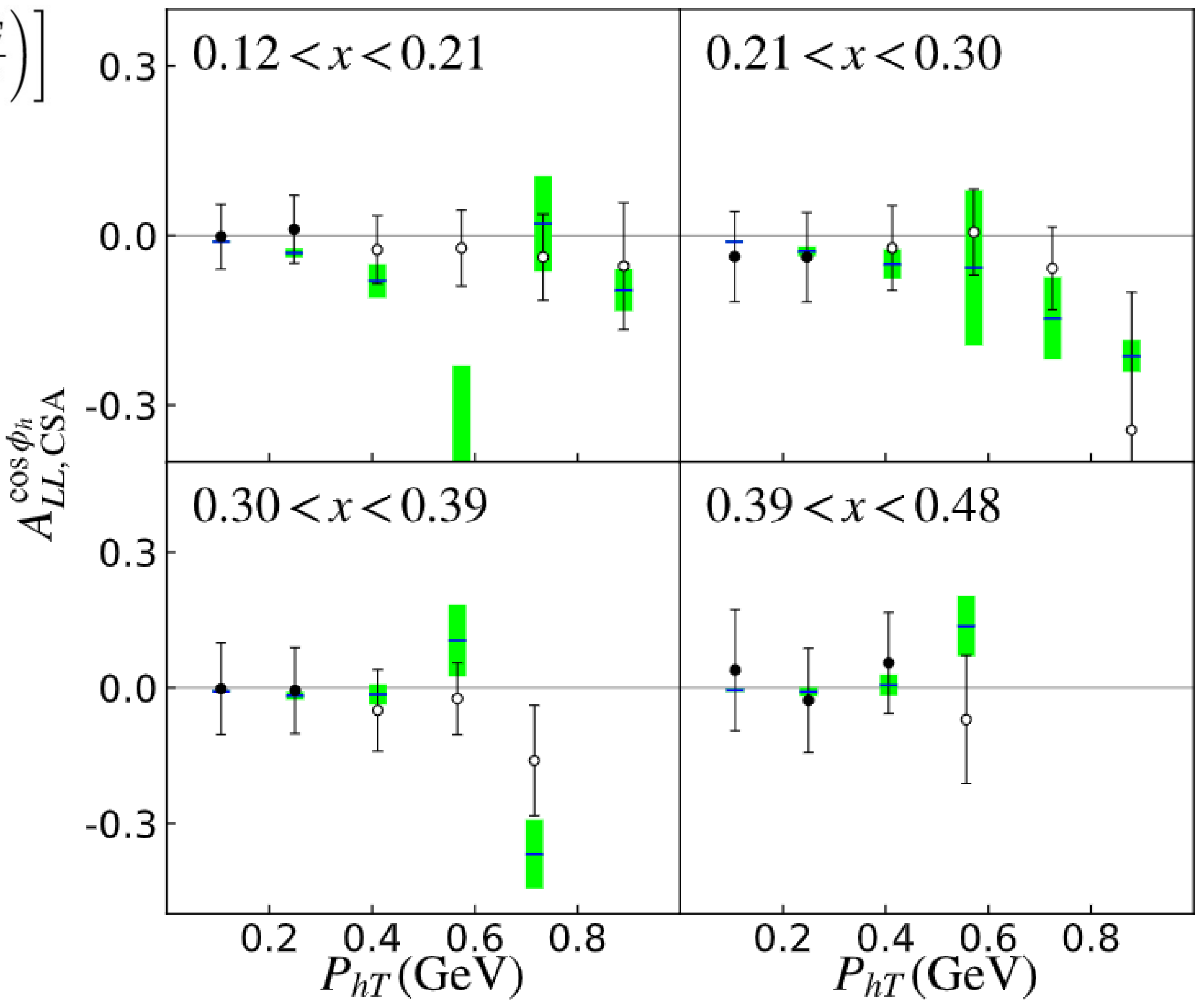
$$F_{LL}^{\cos\phi} = \frac{2M}{Q}\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_h}\left(xe_L H_1^{\perp} - \frac{M_h}{M}g_{1L}\frac{\tilde{D}^{\perp}}{z}\right) - \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}\left(xg_L^{\perp}D_1 + \frac{M_h}{M}h_{1L}^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

$$\approx -\frac{2M}{Q}\mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M}(g_{1L}D_1)\right] \qquad xg_L^{\perp} = x\tilde{g}_L^{\perp} + g_{1L} + \frac{m}{M}h_{1L}^{\perp}$$

$$= -\frac{2M^2}{Q}x\sum_q e_q^2\int_0^{\infty}\frac{b_T^2\,\mathrm{d}b_T}{2\pi}J_1\left(\frac{b_T P_{hT}}{z}\right)g_{1L,q\leftarrow H}^{(1)}(x,b_T)D_{1,q\rightarrow h}(z,b_T)$$

$$g_{1L}^{(n)}(b_T) = n!\left(\frac{-1}{M^2 b_T}\partial_{b_T}\right)^n g_{1L}(b_T)$$





Outline

6, Summary

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1. We have extracted the TMD helicity function with error band from SIDIS data;
2. The x dependence of polarization is consistent with collinear helicity distribution;
3. Around the peak of x dependence, the polarization is concentrate on the low kT region, which is consistent with Wigner Melosh rotation;

4. At low x region, we observe slightly increasing polarization, which imply the abundant dynamics of QCD;

5. The TMD helicity extracted can also explain the cos phi modulation of the DSA measurement of the SIDIS.

Thanks