第七届全国重味物理与量子色动力学研讨会

河南工業大學
HENAN UNIVERSITY OF TECHNOLOGY

Transverse momentum weighted Sivers asymmetries in SIDIS and Drell-Yan processes at COMPASS

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Based on S. C. Xue, S. Yang, X. Wang, D. M. Li and Z. Lu,

Phys. Lett. B 853, 138644 (2024)

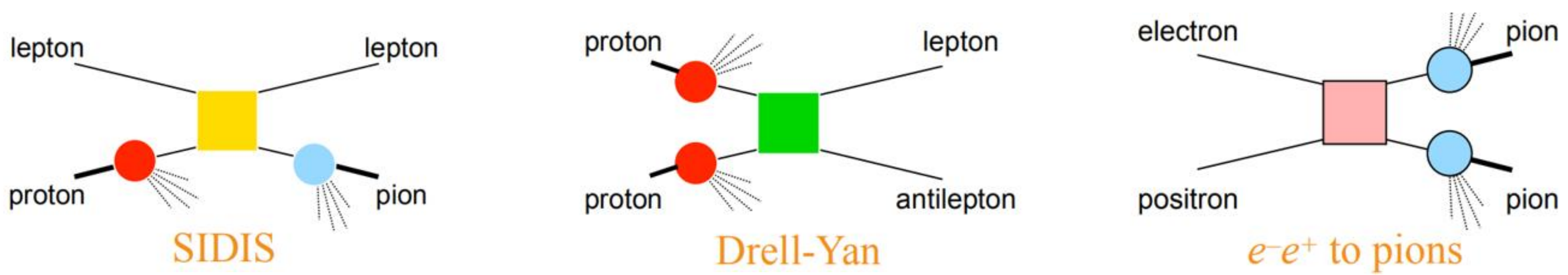
2025年4月21日，南京

目录

- 研究背景
- 理论框架
- 计算结果
- 总结展望

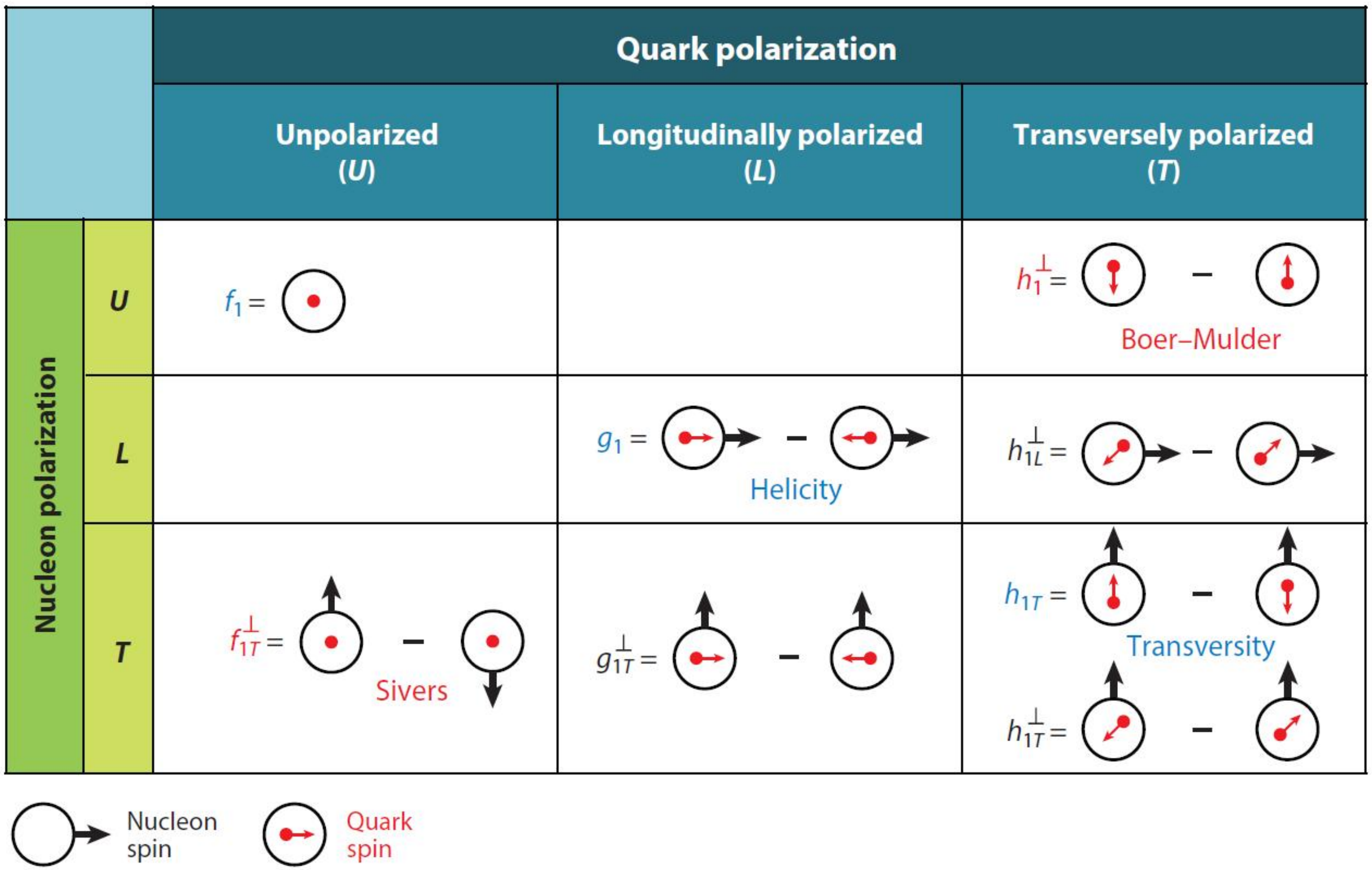
研究背景

- 质子自旋危机
- 用TMD PDF描述核子三维结构
- 获取TMD PDF



研究背景

➢ TMD PDF


Quark polarization
Unpolarized (U)
Longitudinally polarized (L)
Transversely polarized (T)
Nucleon polarization
U
L
T
f_1 =
$h_1^\perp$ =
Boer–Mulder
g_1 =
Helicity
$h_{1L}^\perp$ =
$f_{1T}^\perp$ =
Sivers
$g_{1T}^\perp$ =
h_{1T} =
Transversity
$h_{1T}^\perp$ =
Nucleon spin
Quark spin

研究背景

- **Sivers函数——核子横向自旋结构**

  Phys. Rev. D 41, 83 (1990).

- **Sivers函数是T-odd分布函数**

  Phys. Lett. B 530, 99 (2002) .
  Nucl. Phys. B 642, 344 (2002).
  Phys. Rev. D 67, 054003 (2003).

- **Sivers函数在SIDIS和DY中符号变化性质**

  Phys. Lett. B 530, 99 (2002) .
  Nucl. Phys. B 642, 344 (2002).
  Phys. Lett. B 536, 43 (2002).

研究背景

- 实验测量与Sivers函数相关的TSSA
  - SIDIS测量——HERMES、COMPASS、JLab
  - DY测量——COMPASS
- 理论提取Sivers函数
- 模型计算Sivers函数

  旁观者模型、光锥夸克模型、光前夸克模型、非相对论夸克模型、MIT 袋模型
- 对Sivers函数了解仍然有限

研究背景

- 横向动量加权不对称度

  Phys. Rev. D 54, 1229 (1996).
  Phys. Rev. D 57, 5780 (1998).

- COMPASS研究Sivers函数符号变化性质有优势

  Nucl. Phys. B 940, 34 (2019).
  PoS DIS2019, 186 (2019).

- 我们的工作

  - 计算SIDIS过程中的Sivers加权不对称度
  - 计算DY过程中的Sivers加权不对称度

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理论框架

➢ SIDIS中Sivers加权不对称度

$$l(\ell)+p^{\uparrow}(P_p)\longrightarrow l(\ell')+h^{\pm}(P_h)+X(P_X)$$

- **SIDIS微分散射截面**

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_S\,d\phi_h\,d\boldsymbol{P}_{hT}^2}=\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right)\left[F_{UU}+|\boldsymbol{S}_T|\sin(\phi_h-\phi_S)\,F_{UT}^{\sin(\phi_h-\phi_S)}+\ldots\right]$$

- **结构函数**

$$\begin{aligned}F_{UU}&=\mathcal{C}\Big[f_1 D_1\Big],\\ F_{UT}^{\sin(\phi_h-\phi_S)}&=\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_p}f_{1T}^{\perp}D_1\right]\end{aligned}$$

理论框架

- 加权不对称度——简化TMD演化效应
- 加权函数

$$W = \frac{P_{hT}}{zM_p}$$

- Sivers加权不对称度表示

$$A_{UT}^{\sin(\phi_h - \phi_S)\frac{P_{hT}}{zM_p}} = \frac{\int d^2\boldsymbol{P}_{hT}\frac{P_{hT}}{zM_p}F_{UT}^{\sin(\phi_h-\phi_S)}}{\int d^2\boldsymbol{P}_{hT}F_{UU}}$$

理论框架

- **结构函数**

$$\int d^2\boldsymbol{P}_{hT} F_{UU} = \int d^2\boldsymbol{P}_{hT}\,\mathcal{C}\Big[f_1\; D_1\Big]$$
$$= x\sum_q e_q^2 \int d^2\boldsymbol{P}_{hT} d^2\boldsymbol{p}_T d^2\boldsymbol{k}_T \delta^{(2)}\big(z\boldsymbol{p}_T + \boldsymbol{k}_T - \boldsymbol{P}_{hT}\big) f_1(x,\boldsymbol{p}_T^2) D_1(z,\boldsymbol{k}_T^2)$$
$$= \sum_q e_q^2 \left[x f_1(x)\, D_1(z)\right].$$

$$\int d^2\boldsymbol{P}_{hT} \frac{P_{hT}}{zM_p} F_{UT}^{\sin(\phi_h-\phi_S)} = \int d^2\boldsymbol{P}_{hT} \frac{P_{hT}}{zM_p}\mathcal{C}\Big[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_p}\, f_{1T}^{\perp}\, D_1\Big]$$
$$= x\sum_q e_q^2 \int d^2\boldsymbol{P}_{hT} \frac{P_{hT}}{zM_p} d^2\boldsymbol{p}_T d^2\boldsymbol{k}_T \delta^{(2)}\big(z\boldsymbol{p}_T + \boldsymbol{k}_T - \boldsymbol{P}_{hT}\big) \frac{-\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M_p} f_{1T}^{\perp}(x,\boldsymbol{p}_T^2) D_1(z,\boldsymbol{k}_T^2)$$
$$= 2\sum_q e_q^2 \big[x f_{1T}^{\perp(1)}(x)\, D_1(z)\big],$$

- **SIDIS中Sivers加权不对称度**

$$A_{UT}^{\sin(\phi_h-\phi_S)\,\frac{P_{hT}}{zM_p}} = 2\,\frac{\sum_q e_q^2 \big[x f_{1T}^{\perp(1)}(x)\, D_1(z)\big]}{\sum_q e_q^2 \big[x f_1(x)\, D_1(z)\big]}$$

理论框架

➤ DY中Sivers加权不对称度

$$\pi^-(P_\pi) + p^\uparrow(P_p) \longrightarrow \gamma^*(q) + X(P_X) \longrightarrow l^+(\ell) + l^-(\ell') + X(P_X)$$

- **DY微分散射截面**

$$\frac{d\sigma}{dq^4 d\Omega} = \frac{\alpha_{em}^2}{Fq^2}\left[(1+\cos^2\theta)F_{UU} + |\boldsymbol{S}_T|(1+\cos^2\theta)\sin\phi_S\, F_{UT}^{\sin\phi_S} + \cdots\right]$$

- **结构函数**

$$F_{UU} = \mathcal{C}\left[f_{1,q/\pi}\, f_{1,\bar{q}/p}\right],$$

$$F_{UT}^{\sin\phi_S} = \mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_{Tp}}{M_p}\, f_{1,q/\pi}\, f_{1T,\bar{q}/p}^{\perp}\right]$$

理论框架

- 结构函数

$$
\begin{aligned}
\int d^2\boldsymbol{q}_T F_{UU} &= \int d^2\boldsymbol{q}_T\, \mathcal{C}\Big[f_{1,q/\pi}\; f_{1,\bar{q}/p}\Big] \\
&= \frac{1}{N_c}\sum_q e_q^2 \int d^2\boldsymbol{q}_T\, d^2\boldsymbol{p}_{T\pi}\, d^2\boldsymbol{p}_{Tp}\, \delta^{(2)}(\boldsymbol{q}_T - \boldsymbol{p}_{T\pi} - \boldsymbol{p}_{Tp})\, f_{1,q/\pi}(x_\pi, \boldsymbol{p}_{T\pi}^2) f_{1,\bar{q}/p}(x_p, \boldsymbol{p}_{Tp}^2) \\
&= \frac{1}{N_c}\sum_q e_q^2 [f_{1,q/\pi}(x_\pi)\, f_{1,\bar{q}/p}(x_p)].
\end{aligned}
$$

$$
\begin{aligned}
\int d^2\boldsymbol{q}_T \frac{q_T}{M_p} F_{UT}^{\sin\phi_S} &= \int d^2\boldsymbol{q}_T \frac{q_T}{M_p}\, \mathcal{C}\left[\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_{Tp}}{M_p}\, f_{1,q/\pi}\; f_{1T,\bar{q}/p}^{\perp}\right] \\
&= \frac{1}{N_c}\sum_q e_q^2 \int d^2\boldsymbol{q}_T \frac{q_T}{M_p}\, d^2\boldsymbol{p}_{T\pi}\, d^2\boldsymbol{p}_{Tp}\, \delta^{(2)}(\boldsymbol{q}_T - \boldsymbol{p}_{T\pi} - \boldsymbol{p}_{Tp})\, \frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_{Tp}}{M_p}\, f_{1,q/\pi}(x_\pi, \boldsymbol{p}_{T\pi}^2) f_{1T,\bar{q}/p}^{\perp}(x_p, \boldsymbol{p}_{Tp}^2) \\
&= 2\frac{1}{N_c}\sum_q e_q^2 [f_{1,q/\pi}(x_\pi)\, f_{1T,\bar{q}/p}^{\perp(1)}(x_p)].
\end{aligned} \tag{26}
$$

- DY中Sivers加权不对称度

$$
A_{UT}^{\sin(\phi_S)\frac{q_T}{M_p}} = 2\frac{\sum_q e_q^2 \big[f_{1,q/\pi}(x_\pi)\, f_{1T,\bar{q}/p}^{\perp(1)}(x_p)\big]}{\sum_q e_q^2 \big[f_{1,q/\pi}(x_\pi)\, f_{1,\bar{q}/p}(x_p)\big]}
$$

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计算结果

- 采用Sivers函数的参数化结果

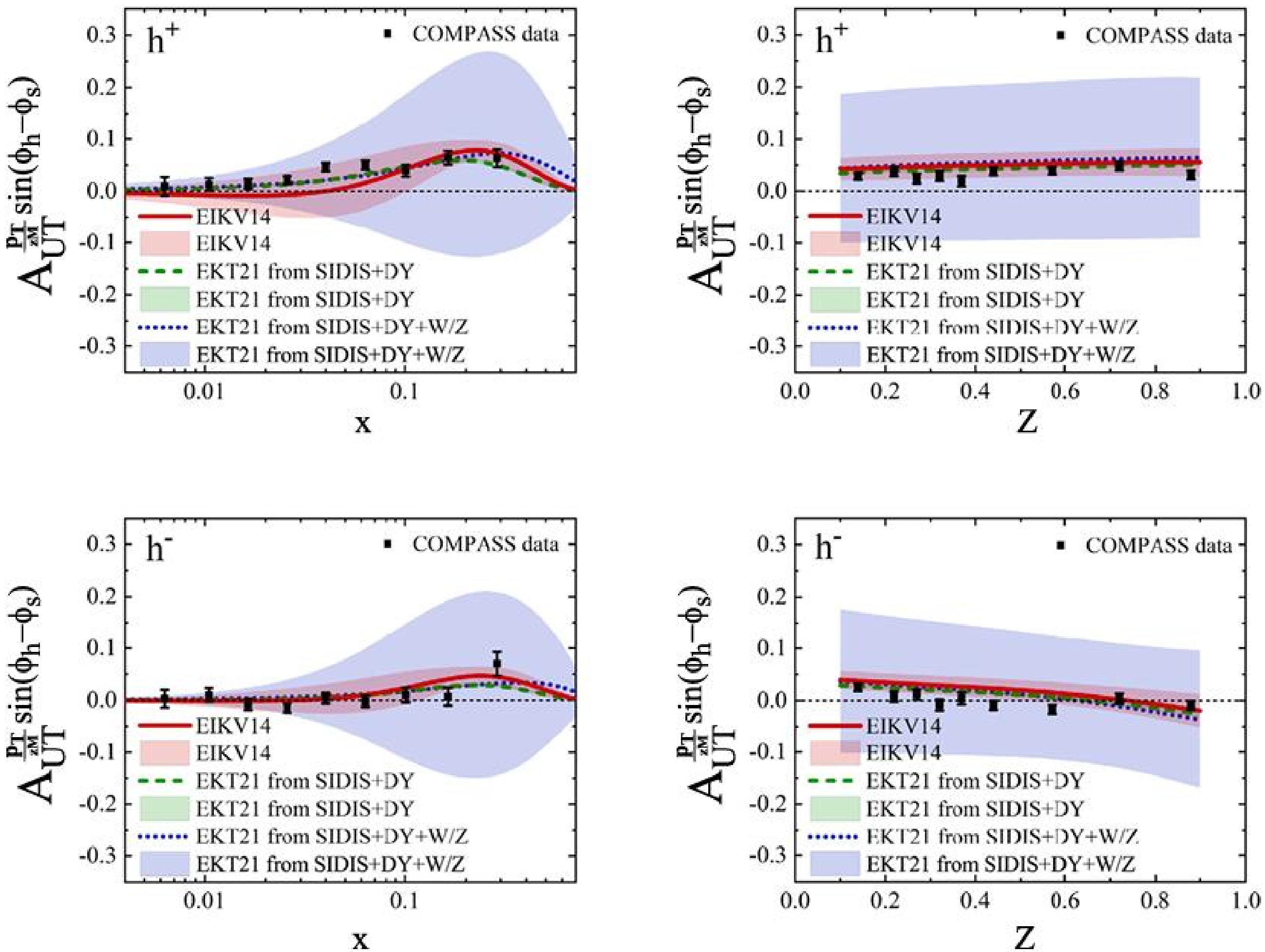
$$T_{q,F}(x,x) = \int d^2 p_T \frac{p_T^2}{M_p} f_{1T}^{\perp}(x,p_T^2) = 2M_p f_{1T}^{\perp(1)}(x)$$

$$T_{q,F}(x,x,\mu) = N_q \frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\beta_q^{\beta_q}} x^{\alpha_q}(1-x)^{\beta_q} f_{1,p}(x_p,\mu)$$

M.G. Echevarria, A. Idilbi, Z.B. Kang, I. Vitev,
Phys. Rev. D 89, 074013 (2014).——EIKV14

M.G. Echevarria, Z.B. Kang, J. Terry,
J. High Energy Phys. 01 (2021) 126.——EKT21 from SIDIS+DY
——EKT21 from SIDIS+DY+W/Z

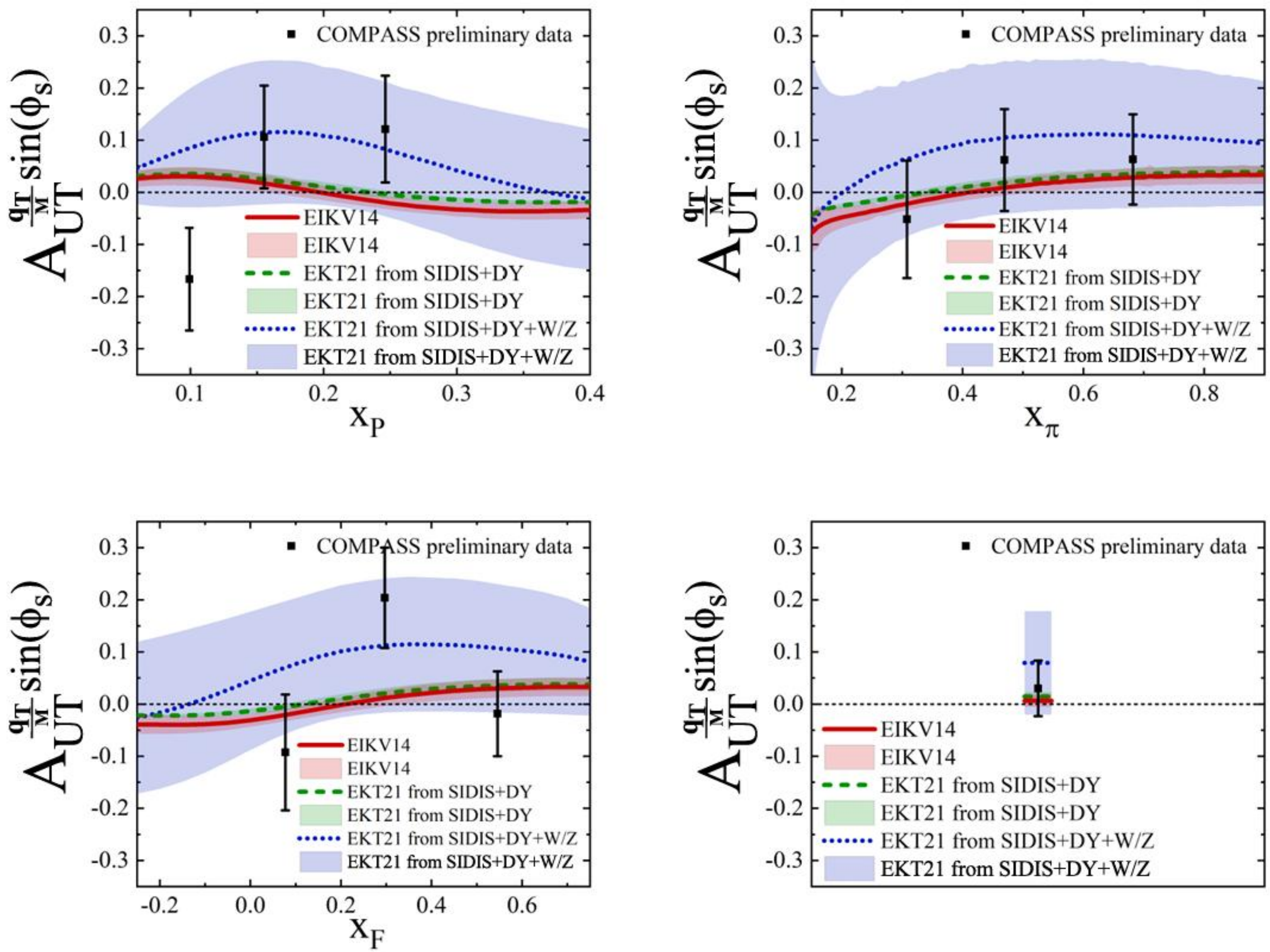
➢ SIDIS中计算结果



h+
COMPASS data
EIKV14
EIKV14
EKT21 from SIDIS+DY
EKT21 from SIDIS+DY
EKT21 from SIDIS+DY+W/Z
EKT21 from SIDIS+DY+W/Z
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0.01
0.1
x
0.0
0.2
0.4
0.6
0.8
1.0
z
h-

计算结果

➢ DY中计算结果



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总结展望

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- 研究了SIDIS和DY过程中的Sivers加权不对称度
- 结果显示SIDIS中理论结果与实验值一致
- 未来高精度实验数据有助于验证Sivers函数普适性

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谢谢!