Subleading-twist effects in single-spin asymmetries in semi-inclusive DIS on a longitudinally polarized hydrogen target

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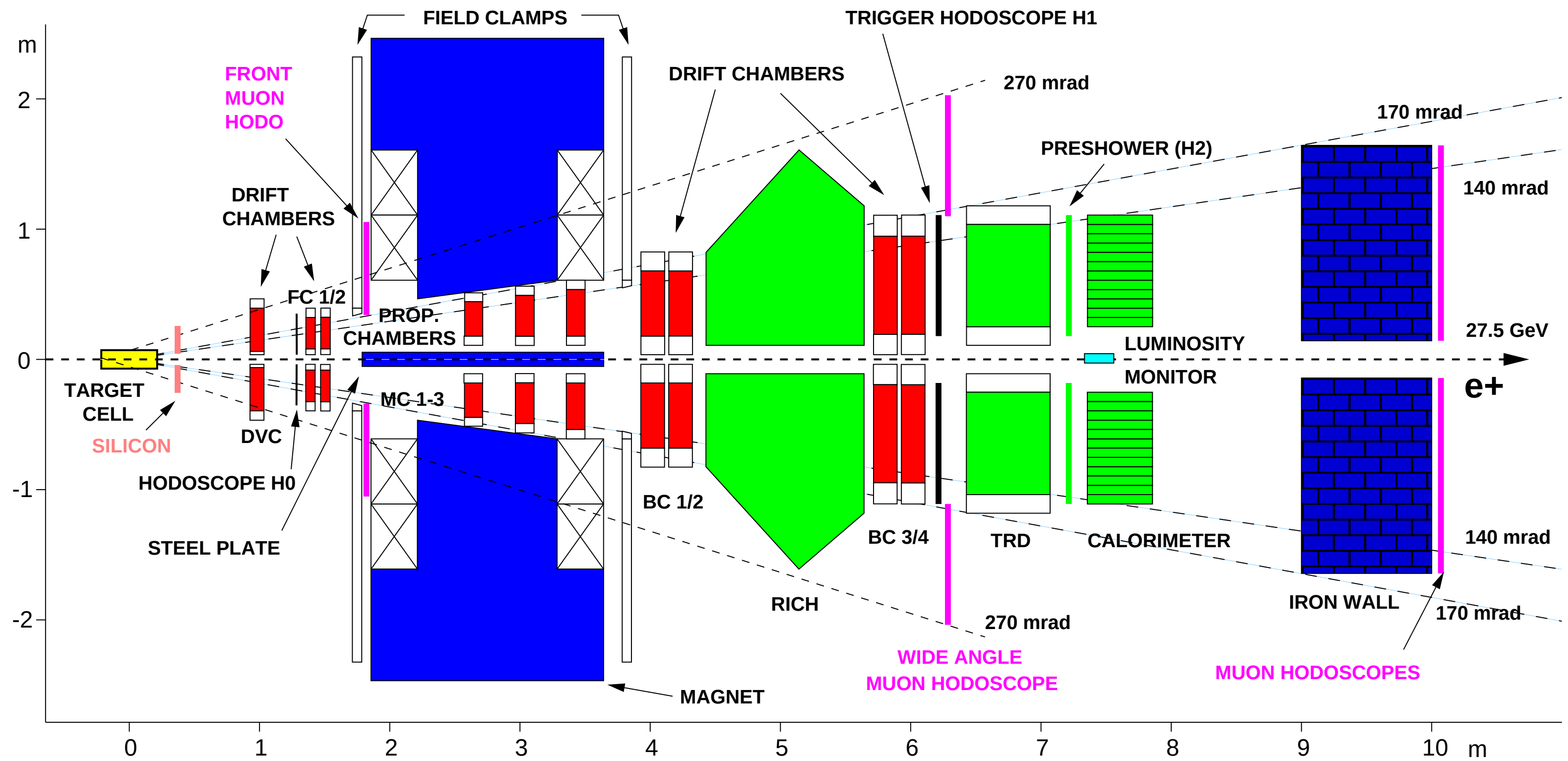
HERMES at DESY

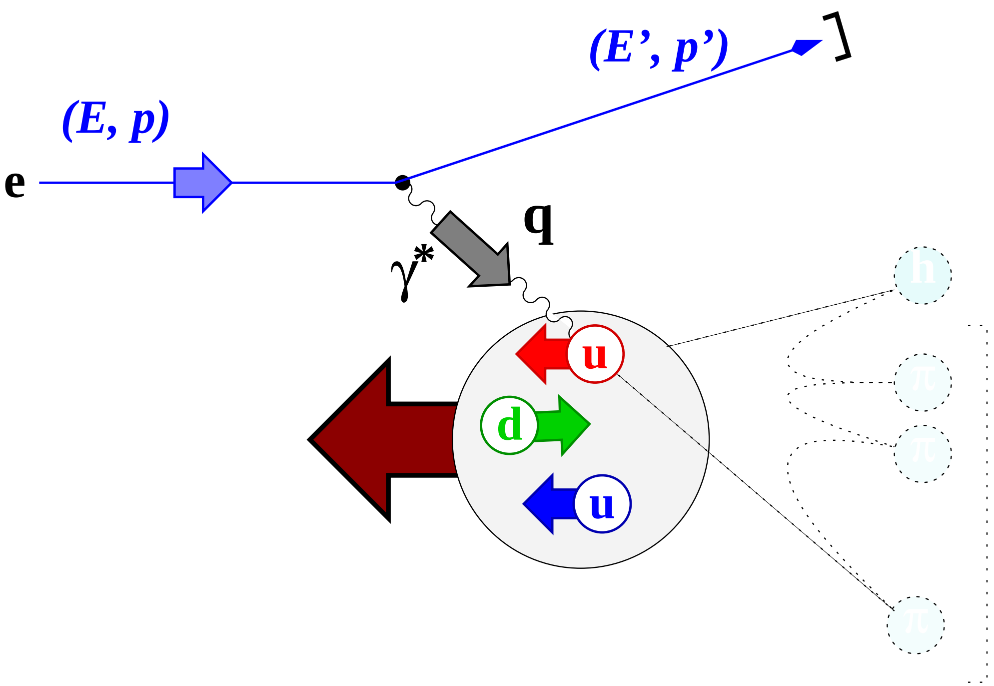
The HERMES Spectrometer



- Internal storage cell: pure gas target (polarized or unpolarized)
- Forward acceptance spectrometer: 40 mrad $\leq \Theta \leq$ 220 mrad
- Tracking: 57 tracking planes: $\delta P/P = (0.7 - 1.3)\%$, $\delta\Theta \leq 0.6$ mrad
- PID: Cherenkov (RICH after 1997), TRD, Preshower, Calorimeter

Lepton Deep Inelastic Scattering

use well-known probe to study hadronic structure:



$$Q^2 \overset{\text{lab}}{=} 4EE' \sin^2\left(\frac{\Theta}{2}\right)$$

$$\nu \overset{\text{lab}}{=} E - E'$$

$$W^2 \overset{\text{lab}}{=} M^2 + 2M\nu - Q^2$$

$$y \overset{\text{lab}}{=} \frac{\nu}{E}$$

$$x \overset{\text{lab}}{=} \frac{Q^2}{2M\nu}$$

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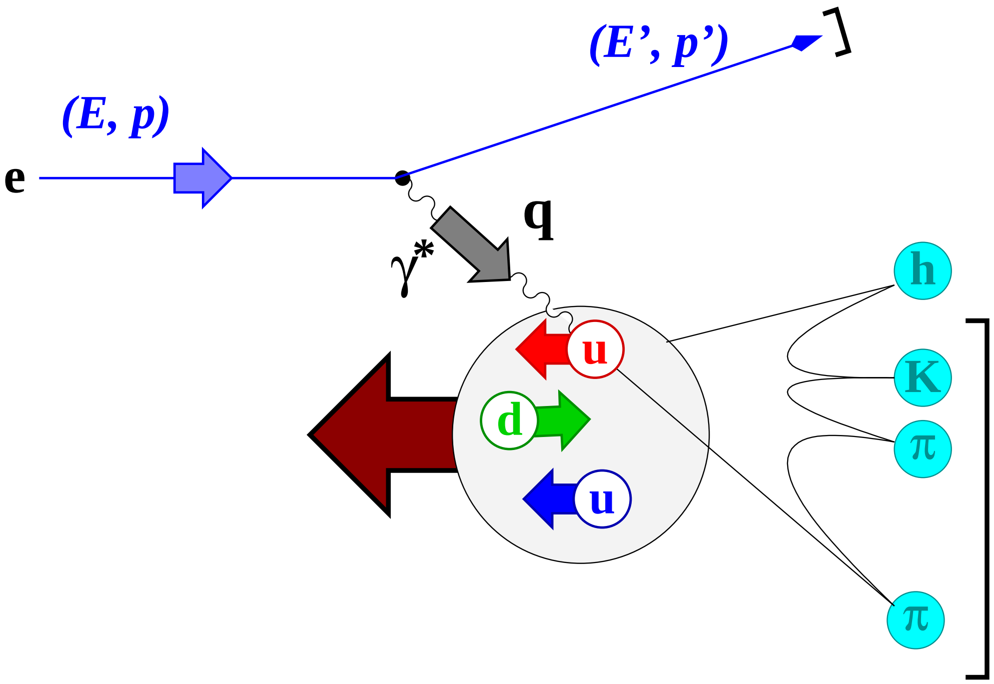

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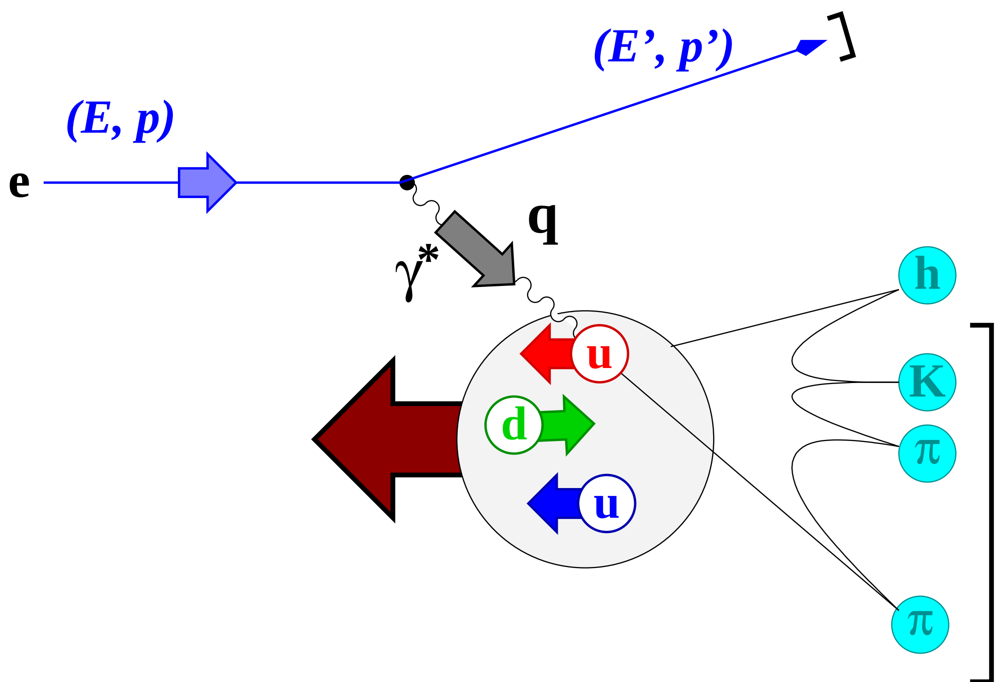

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Factorization $\Rightarrow \sigma^{ep\rightarrow ehX} = \sum_q DF^{p\rightarrow q} \otimes \sigma^{eq\rightarrow eq} \otimes FF^{q\rightarrow h}$

(quark distribution $\otimes$ hard scattering $\otimes$ hadron formation)

Azimuthal Angles in SIDIS Cross Section

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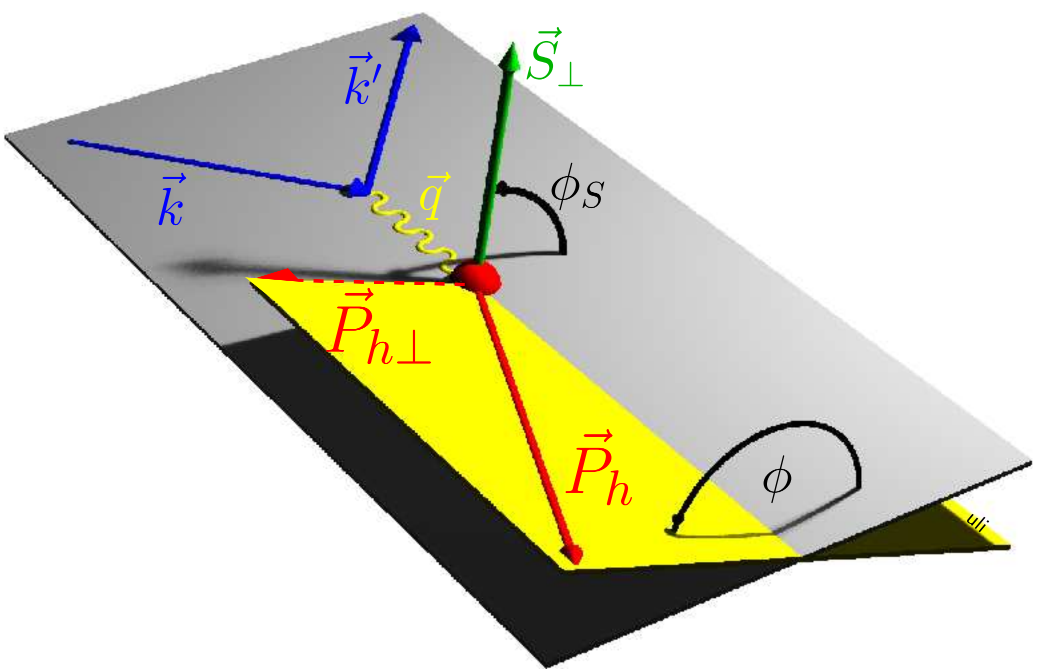

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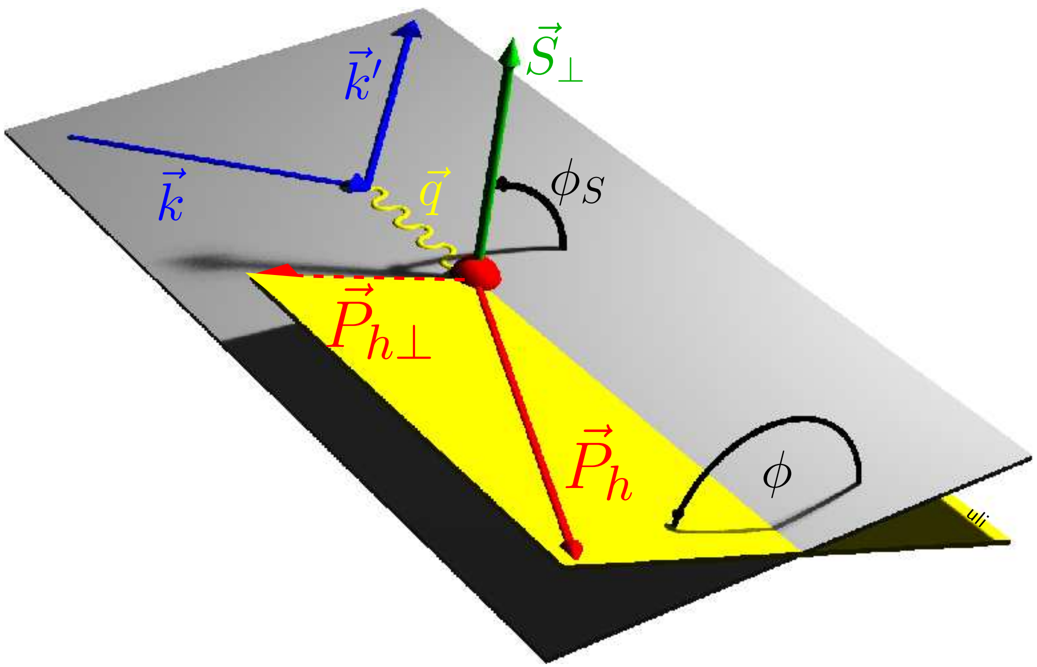

- additional degrees of freedom: ϕ_S and $\vec{P}_{h\perp}$ (ϕ, $P_{h\perp}$)

SIDIS Cross Section up to Subleading Order in 1/Q

$$d\sigma = d\sigma^0_{UU} + \cos 2\phi \, d\sigma^1_{UU} + \frac{1}{Q} \cos\phi \, d\sigma^2_{UU} + \lambda_e \frac{1}{Q} \sin\phi \, d\sigma^3_{LU}$$

$$+ S_L \left\{ \sin 2\phi \, d\sigma^4_{UL} + \frac{1}{Q} \sin\phi \, d\sigma^5_{UL} + \lambda_e \left[d\sigma^6_{LL} + \frac{1}{Q} \cos\phi \, d\sigma^7_{LL} \right] \right\}$$

$$+ S_T \left\{ \sin(\phi + \phi_S) \, d\sigma^8_{UT} + \sin(\phi - \phi_S) \, d\sigma^9_{UT} + \sin(3\phi - \phi_S) \, d\sigma^{10}_{UT} \right.$$

$$+ \frac{1}{Q} \left(\sin(2\phi - \phi_S) \, d\sigma^{11}_{UT} + \sin\phi_S \, d\sigma^{12}_{UT} \right)$$

$$\left. + \lambda_e \left[\cos(\phi - \phi_S) \, d\sigma^{13}_{LT} + \frac{1}{Q} \left(\cos\phi_S \, d\sigma^{14}_{LT} + \cos(2\phi - \phi_S) \, d\sigma^{15}_{LT} \right) \right] \right\}$$

σ_{XY}

Beam **Target**

Polarization

Mulders and Tangermann, Nucl. Phys. B 461 (1996) 197

Boer and Mulders, Phys. Rev. D 57 (1998) 5780

SIDIS Cross Section up to Subleading Order in 1/Q

$$
\begin{aligned}
d\sigma = \; & d\sigma_{UU}^{0} + \cos 2\phi \, d\sigma_{UU}^{1} + \frac{1}{Q} \cos\phi \, d\sigma_{UU}^{2} + \lambda_e \frac{1}{Q} \sin\phi \, d\sigma_{LU}^{3} \\
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& + S_T \left\{ \sin(\phi + \phi_S) \, d\sigma_{UT}^{8} + \sin(\phi - \phi_S) \, d\sigma_{UT}^{9} + \sin(3\phi - \phi_S) \, d\sigma_{UT}^{10} \right. \\
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Beam **Target**
Polarization

Terms with 1/Q are so-called 'subleading twist'

SIDIS Cross Section up to Subleading Order in 1/Q

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σ_{XY}: X → **Beam**, Y → **Target**

Polarization

Terms with 1/Q are so-called 'subleading twist'

Azimuthal Single-Spin Asymmetries

$ep \rightarrow e'hX$ – study azimuthal distribution of hadrons:

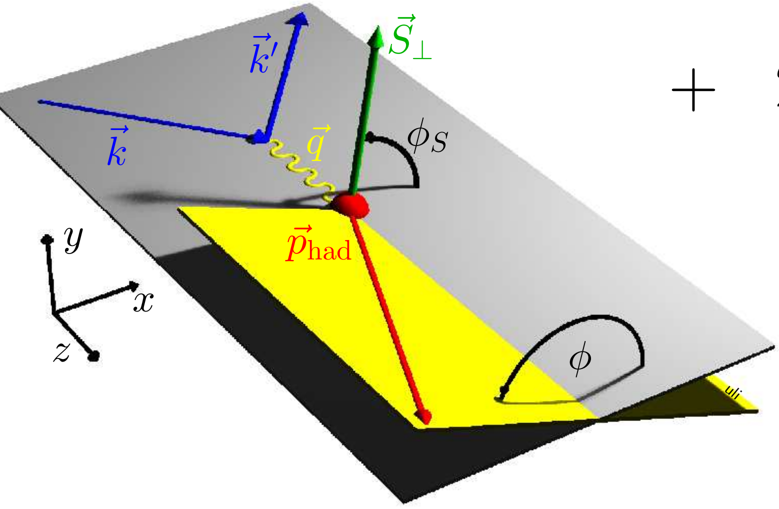
(e.g. Unpolarized beam & Transversely polarized target)

$$A_{UT}(\phi,\phi_S) \equiv \frac{1}{\langle S_\perp \rangle} \frac{\sigma^+(\phi,\phi_S) - \sigma^-(\phi,\phi_S)}{\sigma^+(\phi,\phi_S) + \sigma^-(\phi,\phi_S)}$$

$$= 2\left\langle \sin(\phi+\phi_S)\right\rangle_{UT} \sin(\phi+\phi_S)$$

$$+ 2\left\langle \sin(\phi-\phi_S)\right\rangle_{UT} \sin(\phi-\phi_S)$$

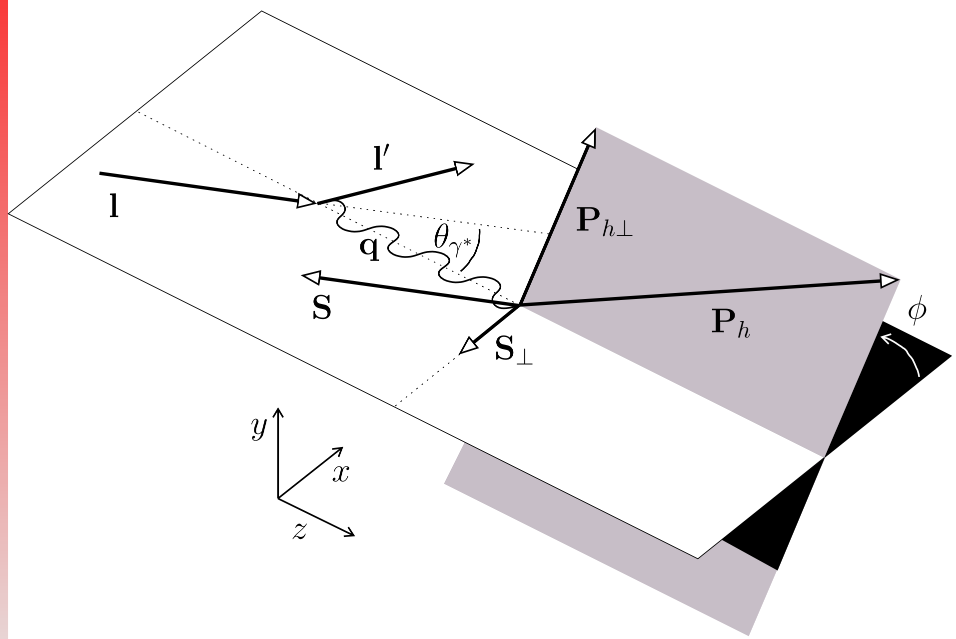
$$+ \ \ldots$$



$\left\langle \sin(\phi+\phi_S)\right\rangle_{UT}$ … Collins Moment

$\left\langle \sin(\phi-\phi_S)\right\rangle_{UT}$ … Sivers Moment

Longitudinally Polarized Target



Experiment: Target Polarization w.r.t. Beam Direction!

⇒ **experimental asymmetries (which have polarization along beam) related to "theory" asymmetries (polarization along virtual photon direction) via:**

[**Diehl and Sapeta, in preparation**]

$$\begin{pmatrix} \langle \sin\phi \rangle_{UL'} \\ \langle \sin(\phi-\phi_S) \rangle_{UT'} \\ \langle \sin(\phi+\phi_S) \rangle_{UT'} \end{pmatrix} = \begin{pmatrix} \cos\theta_{\gamma^*} & -\sin\theta_{\gamma^*} & -\sin\theta_{\gamma^*} \\ \frac{1}{2}\sin\theta_{\gamma^*} & \cos\theta_{\gamma^*} & 0 \\ \frac{1}{2}\sin\theta_{\gamma^*} & 0 & \cos\theta_{\gamma^*} \end{pmatrix} \begin{pmatrix} \langle \sin\phi \rangle_{UL} \\ \langle \sin(\phi-\phi_S) \rangle_{UT} \\ \langle \sin(\phi+\phi_S) \rangle_{UT} \end{pmatrix}$$

($\cos\theta_{\gamma^*} \simeq 1$, $\sin\theta_{\gamma^*}$ up to 15% at HERMES energies)

Contributions to Measured $A_{UL'}$

$$\left\langle \sin\phi \right\rangle_{UL} = \left\langle \sin\phi \right\rangle_{UL'} + \sin\theta_{\gamma^*} \left(\left\langle \sin(\phi+\phi_S) \right\rangle_{UT'} + \left\langle \sin(\phi-\phi_S) \right\rangle_{UT'} \right)$$

$$\left\langle \sin\phi \right\rangle_{UL} \propto \frac{M}{Q}\,\mathcal{I}\left[\frac{\hat{\boldsymbol{P}}_{\boldsymbol{h}\perp}\boldsymbol{k_T}}{M_h} \left(\left(x h_L - \frac{m_q}{M} g_1 \right) H_1^\perp + \frac{M_h}{zM} g_1 G^\perp \right) + \frac{\hat{\boldsymbol{P}}_{\boldsymbol{h}\perp}\boldsymbol{p_T}}{M} \left(\frac{M_h}{zM} h_{1L}^\perp \tilde{H} - x f_L^\perp D_1 \right) \right]$$

Bacchetta et al., Phys. Lett. B 595 (2004) 309

$\Rightarrow$ they are all subleading-twist expressions!

$\mathcal{I}[\ldots]$ ... **Convolution integral over intrinsic transverse momenta**

$\left\langle \sin\phi \right\rangle_{UL'}$ ... **Airapetian et al., Phys. Rev. Lett. 84 (2000) 4047**

$\left\langle \sin(\phi\pm\phi_S) \right\rangle_{UT'}$ ... **Airapetian et al., Phys. Rev. Lett. 94 (2005) 012002**

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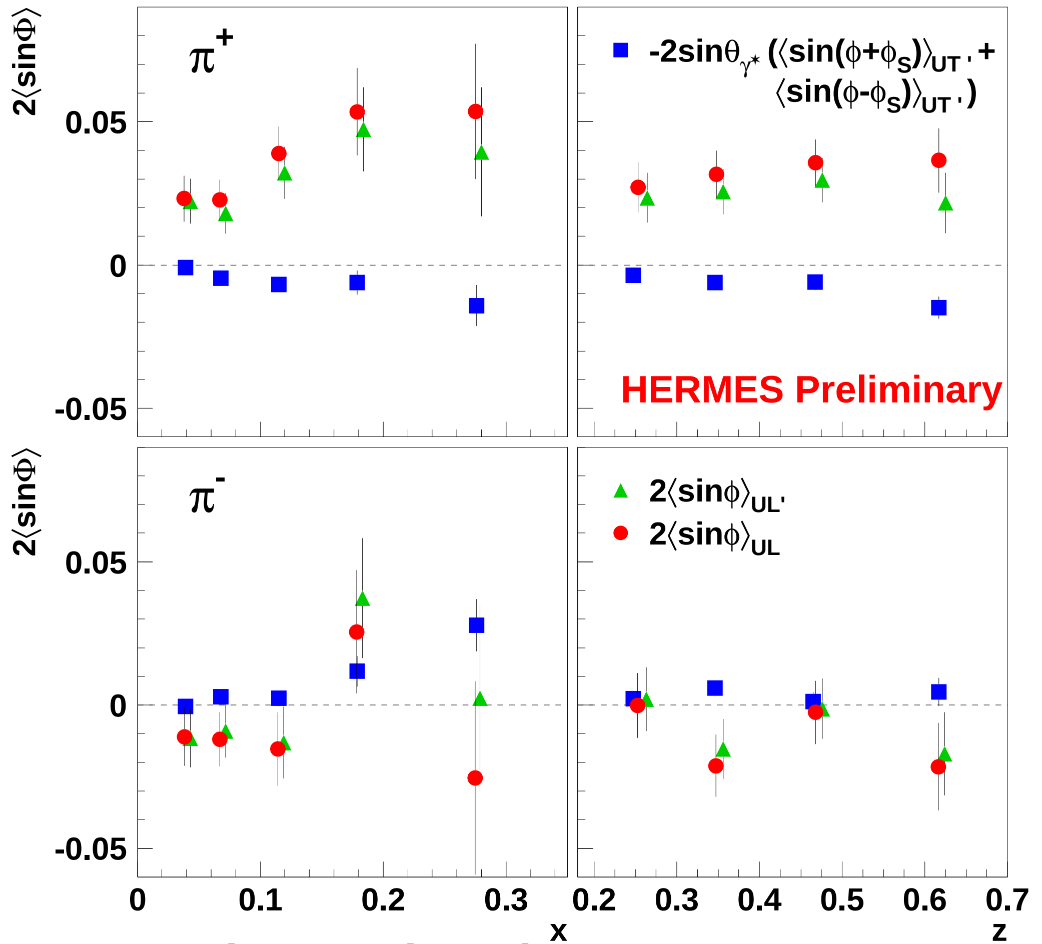

twist-3 dominates $A_{UL'}$!

Conclusion

- semi-inclusive DIS cross section depends not only on x, y, and z but also on ϕ_S and $\vec{P}_{h\perp}$
- different terms can be isolated through azimuthal single (double) spin asymmetries
- HERMES has data with (un)polarized beam and targets
  $\Longrightarrow$ for first time subleading-twist contribution, i.e. $\langle \sin\phi \rangle_{UL}$ to experimental longitudinal target-spin asymmetries extracted
- subleading-twist contribution dominates in experimental longitudinal asymmetries
- clean signal for subleading twist in SIDIS