Azimuthal asymmetries in meson electroproduction at hermes

Delia Hasch
on behalf of the HERMES collaboration

INFN Frascati

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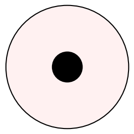
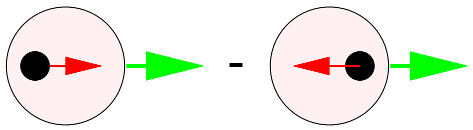
- introduction
- target-spin + beam-spin azimuthal asymmetries
- outlook

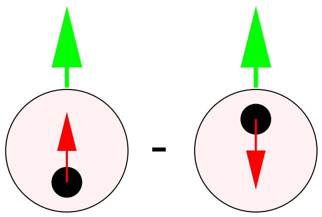
$$\Phi^{\rm LO}_{\rm corr}(x) \quad = \quad \frac{1}{2}\,[\, f_1(x) \;+\; S_{\rm L}\, g_1(x)\gamma_5 \;+\; h_1(x)\,\gamma_5\, \not{S}_T \,]\; \not{n}_+$$

f_1 =


spin averaged (O.K.)

g_{1L} =


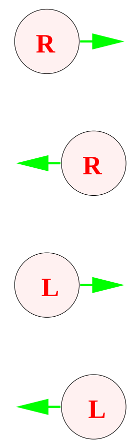
helicity difference (O.K.)

h_1 =


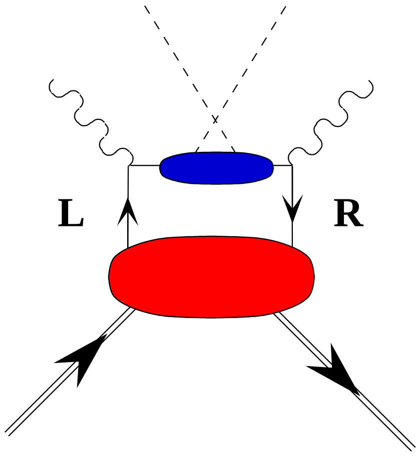
helicity flip (→WANTED←)

transverse spin state =
off-diagonal state in the helicity basis:

$$\begin{pmatrix} f_1 + g_1 & 0 & 0 & 2\,h_1 \\ 0 & f_1 - g_1 & 0 & 0 \\ 0 & 0 & f_1 - g_1 & 0 \\ 2\,h_1 & 0 & 0 & f_1 + g_1 \end{pmatrix}$$



transversity — how to measure in SIDIS

$h_1 = \frac{1}{2}$ 

→ **chiral odd**
→ observed only in combination with another chiral odd structure

→ interference fragmentation: $A_{\rm T}$ (l$\text{p}_\perp$ → l + (π^+,π^-) + X)

→ final state polarisation:
spin-1/2 (Λ) and spin-1 (ρ) fragmentation ⟶ see talks by H.C. Chiang, U. Stösslein

→ Collins effect: $A_{\rm T}$ (l$\text{p}_\perp$ → l + π + X)

$$A_{\rm T} = \langle \sin\phi \rangle_{\rm UT} \propto h_1(x) \otimes H_1^\perp(z, k_T)$$

... azimuthal asymmetries

DIS+SIDIS cross section

[Mulders and Tangermann, NP B461 (1996) 197]

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

$f_1 \swarrow$

$$+S_L[\sin 2\phi\, d\sigma^3_{UL} + \frac{1}{Q}\sin\phi\, d\sigma^4_{UL}] + \lambda S_L[d\sigma^5_{LL} + \frac{1}{Q}\cos\phi\, d\sigma^6_{LL}]$$

$h_{1L}^{\perp} \swarrow$ $\qquad$ $g_{1L} \swarrow$

$$+S_T[\sin(\phi+\phi_S)d\sigma^7_{UT} + \sin(3\phi-\phi_S)d\sigma^8_{UT} + \frac{1}{Q}\sin(2\phi-\phi_S)d\sigma^9_{UT}]$$

$h_1 \swarrow$ $\qquad$ $h_{1T}^{\perp} \swarrow$

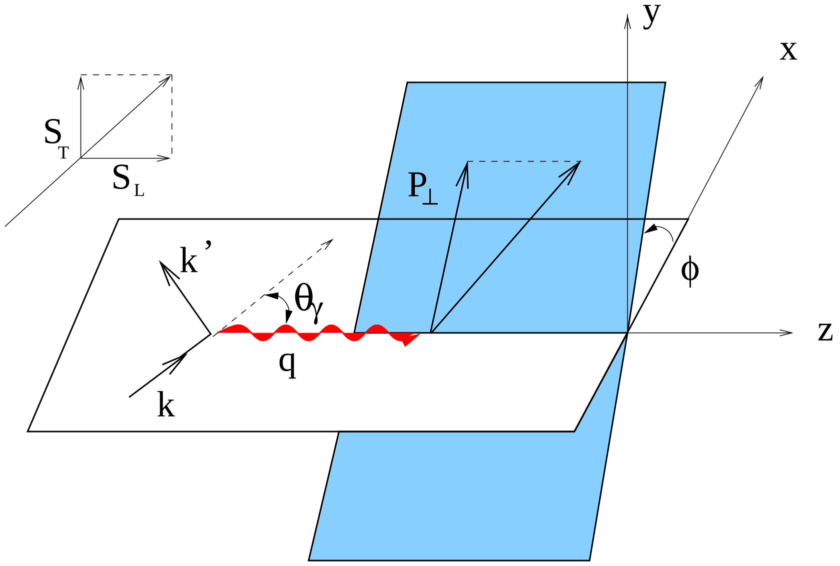
$$+\lambda S_T[\cos(\phi-\phi_S)d\sigma^{10}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_S)d\sigma^{11}_{LT}]$$

$g_{1T} \swarrow$

$$\sigma^{\mathrm{eH}\to\mathrm{ehX}} = \sum_{\mathrm{q}} f^{\mathrm{H}\to\mathrm{q}} \otimes \sigma^{\mathrm{eq}\to\mathrm{eq}} \otimes D^{\mathrm{q}\to\mathrm{h}}$$

$\Downarrow$ chiral-odd DF $\qquad$ $\Downarrow$ chiral-odd FF

$\Rightarrow$ single-spin azimuthal asymmetries (SSA), where either the **beam** *or* **target** is **polarised**



$P_\perp$ pion transverse momentum

ϕ azimuthal angle of π around the virtual-photon direction

$$S_{\mathrm{T}} = |\,S\,| \sin\theta_\gamma$$
$$\simeq |\,S\,| \frac{2Mx}{Q}\sqrt{1-y} \sim 0.15$$

target single-spin azimuthal asymmetry

$$A(\phi)_{\mathrm{UL}} = \frac{1}{\langle P \rangle} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

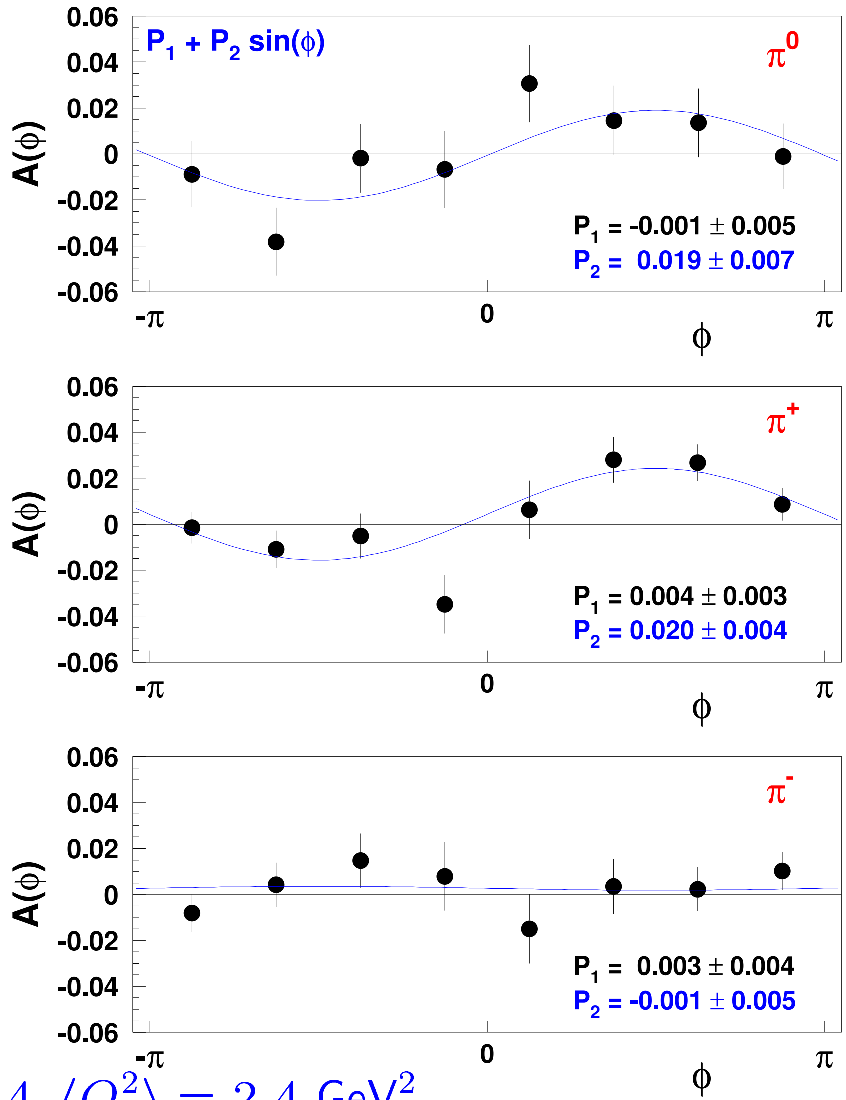
$\langle P_{\mathrm{H}} \rangle = 0.86$, $\langle P_{\mathrm{D}} \rangle = 0.84$

$Q^2 > 1$ GeV^2, $W > 2$ GeV, y < 0.85
$0.023 < x < 0.4$

$4.5 < E_{\pi^\pm} < 13.5$ GeV (Cerenkov: 96,97)
$2.0 < E_{\pi^\pm, K^+} < 15.0$ GeV (RICH: 98-00)

π^0: $E_\gamma >$ GeV (neutral cluster)
$0.1 < m_{\gamma\gamma} < 0.17$ GeV

$0.2 < z < 0.7$, $P_\perp > 0.05$ GeV



$\langle x \rangle = 0.09$, $\langle y \rangle = 0.57$, $\langle z \rangle = 0.48$, $\langle P_\perp \rangle = 0.44$, $\langle Q^2 \rangle = 2.4$ GeV^2

target SSA

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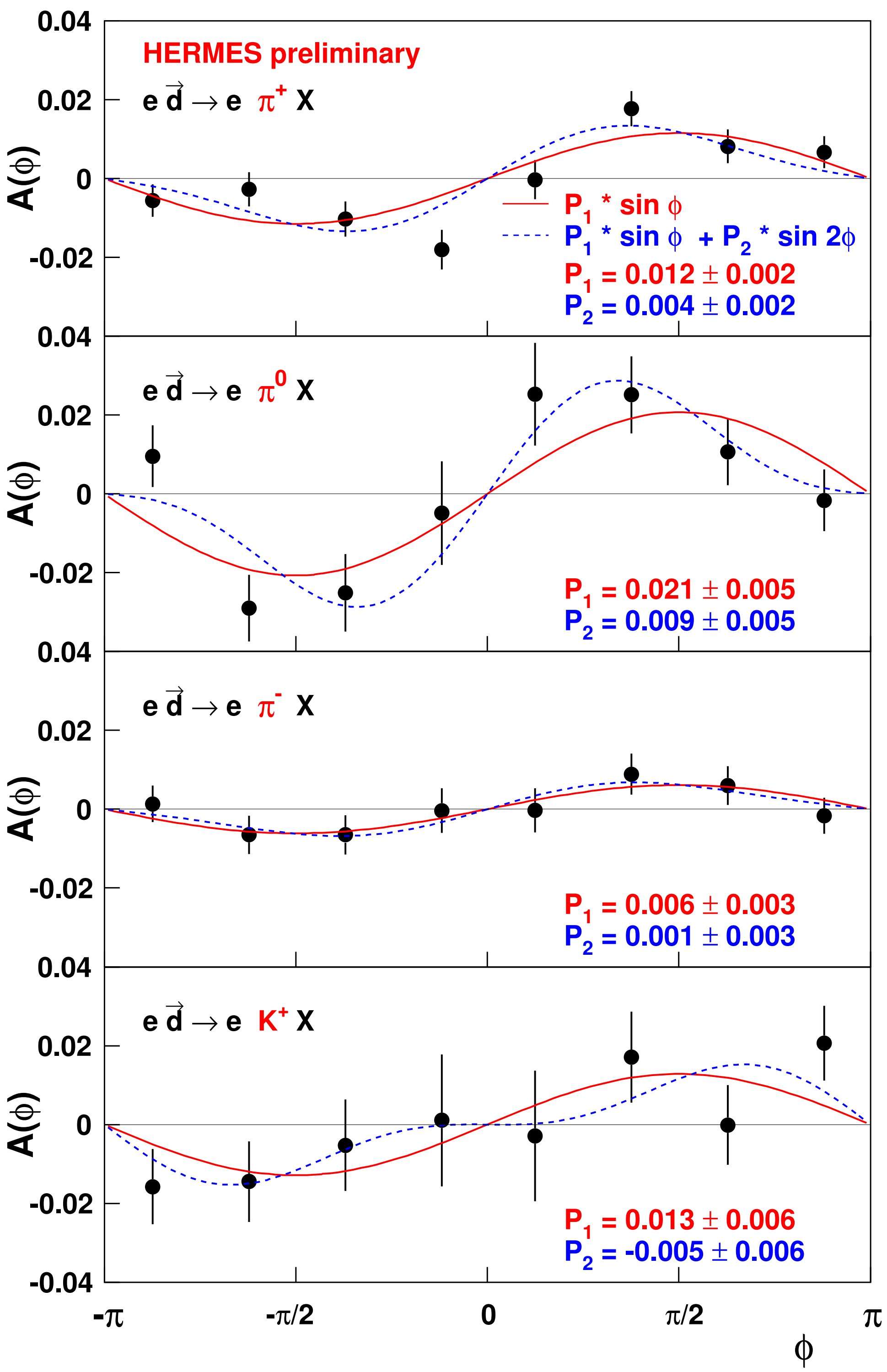


azimuthally weighted asymmetries

analysing powers for target longitudinal polarisation:

$$A_{\mathrm{UL}}^{W} = \frac{\sum_{i=1}^{N^+} W(\phi_i^+) - \sum_{i=1}^{N^-} W(\phi_i^-)}{\frac{1}{2}[N^+ + N^-]} \quad \Leftrightarrow \quad A_{\mathrm{UL}} = A_{\mathrm{UL}}^{W} \cdot W(\phi)$$

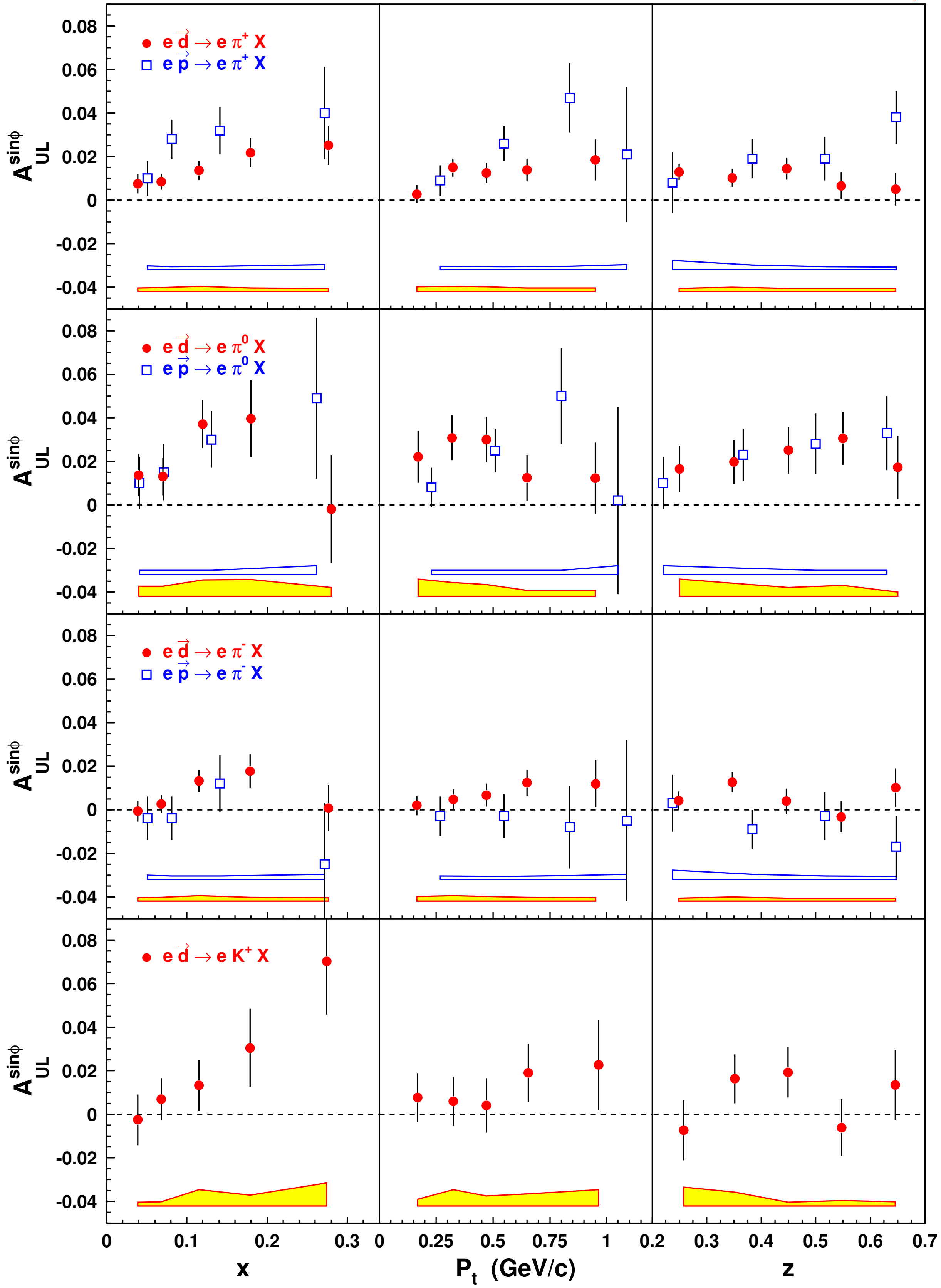
$W(\phi) = \sin\phi,\ \sin 2\phi, \ldots$

$$\langle \frac{P_{\mathrm{T}}}{z M_{\mathrm{h}}} \sin\phi \rangle_{\mathrm{UL}} \propto (1-y)[\, S_{\mathrm{T}} \sum_{a,\bar{a}} (\, e_a^2 x\, h_1^a(x)\ H_1^{\perp a}(z)\,) + \frac{1}{Q} S_{\mathrm{L}} \sum_{a,\bar{a}} (\, e_a^2 x\, h_{\mathrm{L}}^a(x)\ H_1^{\perp a}(z)\,) \frac{2(2-y)}{\sqrt{1-y}} + \cdots]$$

HERMES: longitudinal polarised target: ($S_{\mathrm{T}} \propto \sin\theta_\gamma \propto 1/Q$) first term contributes with 15% to 20%

$A_{UL}^{\sin\phi}$

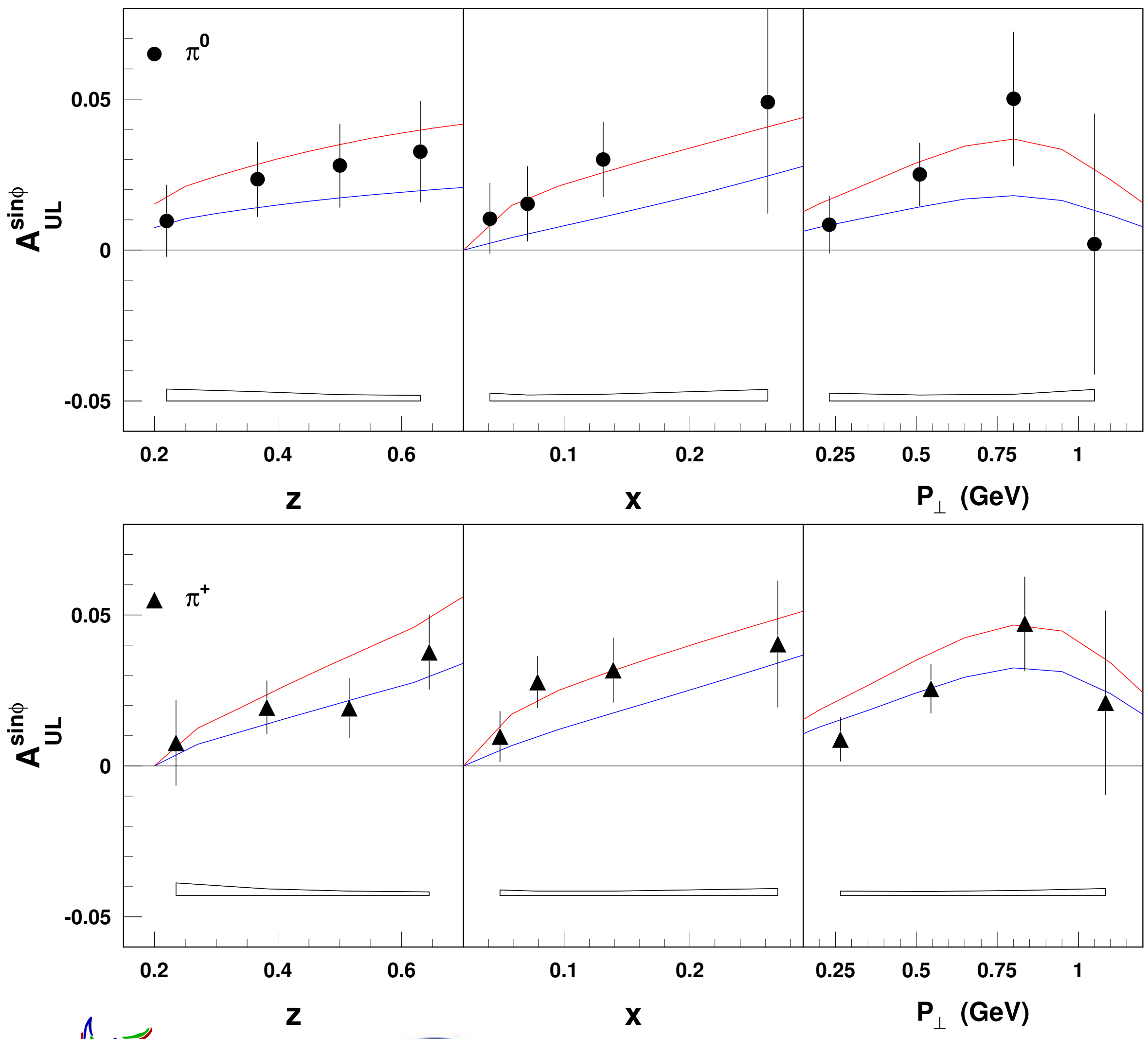
deuteron data is preliminary



model calculations for $A_{\mathrm{UL}}^{\sin\phi}$

[Oganessyan et al., hep-ph/9808368, PLB 483 (2000) 69]

$\mathrm{e}\vec{\mathrm{p}} \to \mathrm{e}\ \pi\ \mathrm{X}$



approximation:

$$h_{\mathrm{L}}(x) = h_1(x) - \frac{\mathrm{d}}{\mathrm{d}x} h_{1\mathrm{L}}^{\perp(1)}(x) \approx h_1(x)$$

upper limit: $h_1 = (f_1 + g_1)/2$
Soffer inequality

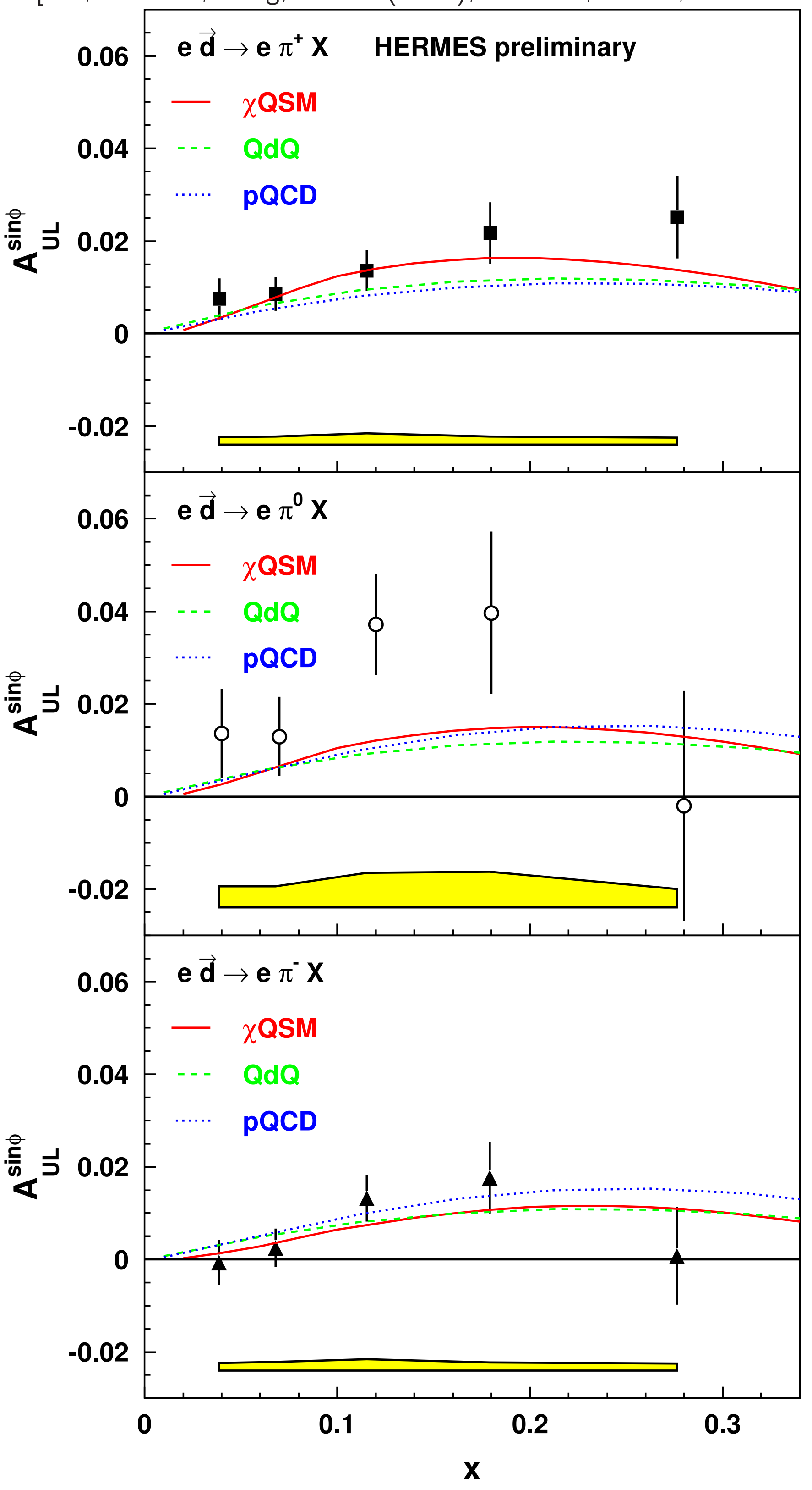
lower limit: $h_1 = g_1$
non-relativistic limit

'Collins guess' for $H_1^\perp$:

$$A_{\mathrm{C}}(z, k_T) = \frac{|\,k_T\,|}{M_h} \frac{H_1^\perp(z, k_T^2)}{D_1(z, k_T^2)} = \eta \frac{M_{\mathrm{C}}\,|\,k_T\,|}{M_{\mathrm{C}}^2 + k_T^2}$$

model calculations for $A_{\mathrm{UL}}^{\sin\phi}$

[Ma, Schmidt, Yang, PRD63(2001); Efremov, Goeke, Schweitzer, EPC24(2002)]



approximation:

$\boxed{h_1(x):}$

$$h_L^a(x) = 2x \int_x^1 dx' \frac{h_1^a(x')}{x'^2} + \tilde{h}_L^a$$

$$\tilde{h}_L \simeq 0$$

$\boxed{H_1^\perp:}$

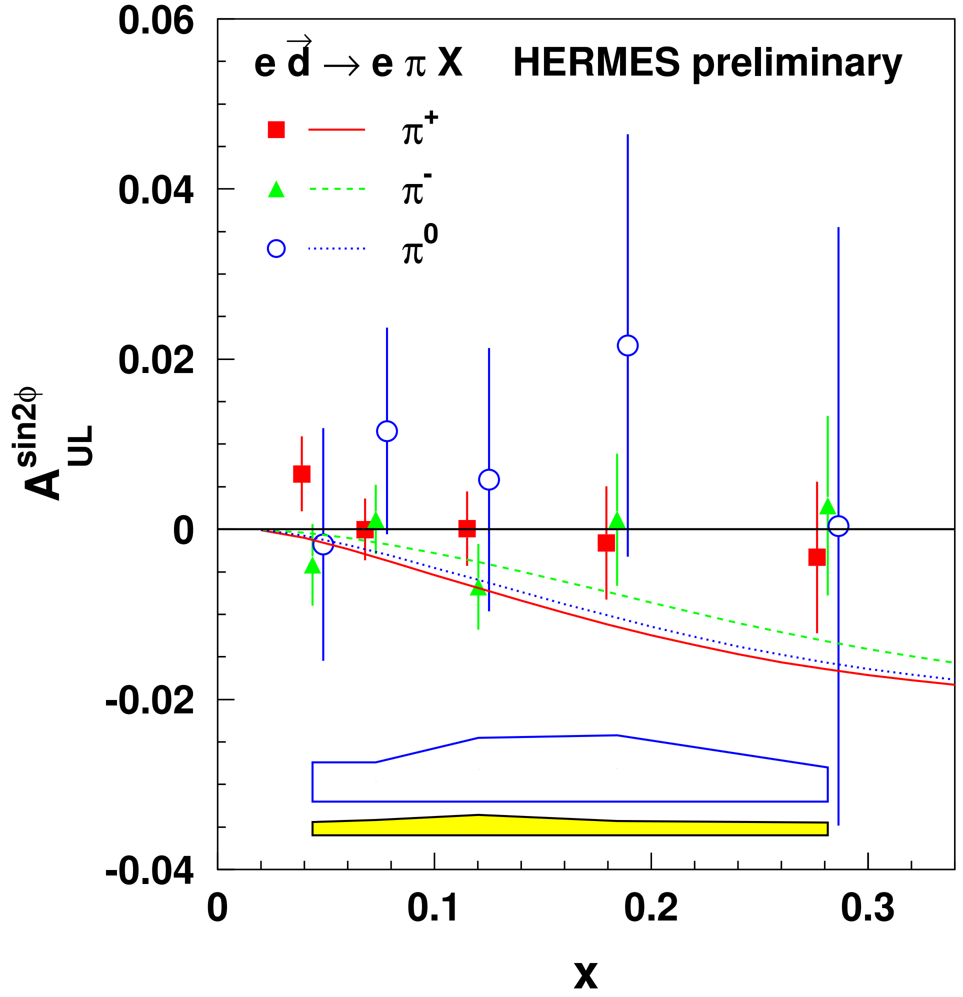
χQCD:

$$\left| \frac{\langle H_1^\perp \rangle}{\langle D_1 \rangle} \right| = (12.5 \pm 1.4)\%$$

QdQ, pQCD:

'Collins guess'

model calculations for $A_{\rm UL}^{\sin 2\phi}$



[Efremov, Goeke, Schweitzer, EPC24, 407 (2002)]

chiral quark-soliton model:

$\boxed{h_1(x)\ :}$

$$h_{\rm L}^a(x) = 2x \int_x^1 {\rm d}x' \frac{h_1^a(x')}{x'^2} + \tilde{h_{\rm L}^a}$$

$$\tilde{h_{\rm L}^a} \simeq 0$$

$\boxed{H_1^{\perp}\ :}$

$$\left| \frac{\langle H_1^{\perp} \rangle}{\langle D_1 \rangle} \right| = (12.5 \pm 1.4)\%$$

remarks on model calculations

$\sin\phi$ moments from proton + deuteron targets well described by various model calculations based on Collins effect ($\sim h_1 \otimes H_1^{\perp}$)

BUT

⇒ @ longitudinally polarised target: S_{T} w.r.t. $\gamma^* \propto 1/Q$

$A_{\mathrm{LU}}^{\sin\phi} \sim$ twist-3: $h_{\mathrm{L}} H_1^{\perp(1)}$ contribution $\approx 75\%$ $\leftarrow$ opposite sign
while $h_1 H_1^{\perp(1)}$ contribution $\approx 25\%$ $\swarrow$ [K. Oganessyan], [Efremov, Goeke, Schweitzer]

⇒ SSA from final state interaction (gluon exchange) $\equiv$ Sivers effect $\sim f_{1T}^{\perp} \otimes D_1$
Collins + Sivers effect show different dependence on z

⇒ for transversely polarised target:

$$\sin(\phi_h^l + \phi_S^l) \sim h_1 \otimes H_1^{\perp} \quad \text{while} \quad \sin(\phi_h^l - \phi_S^l) \sim f_{1T}^{\perp} \otimes D_1$$

$A_{\mathrm{LU}}^{\sin\phi}$

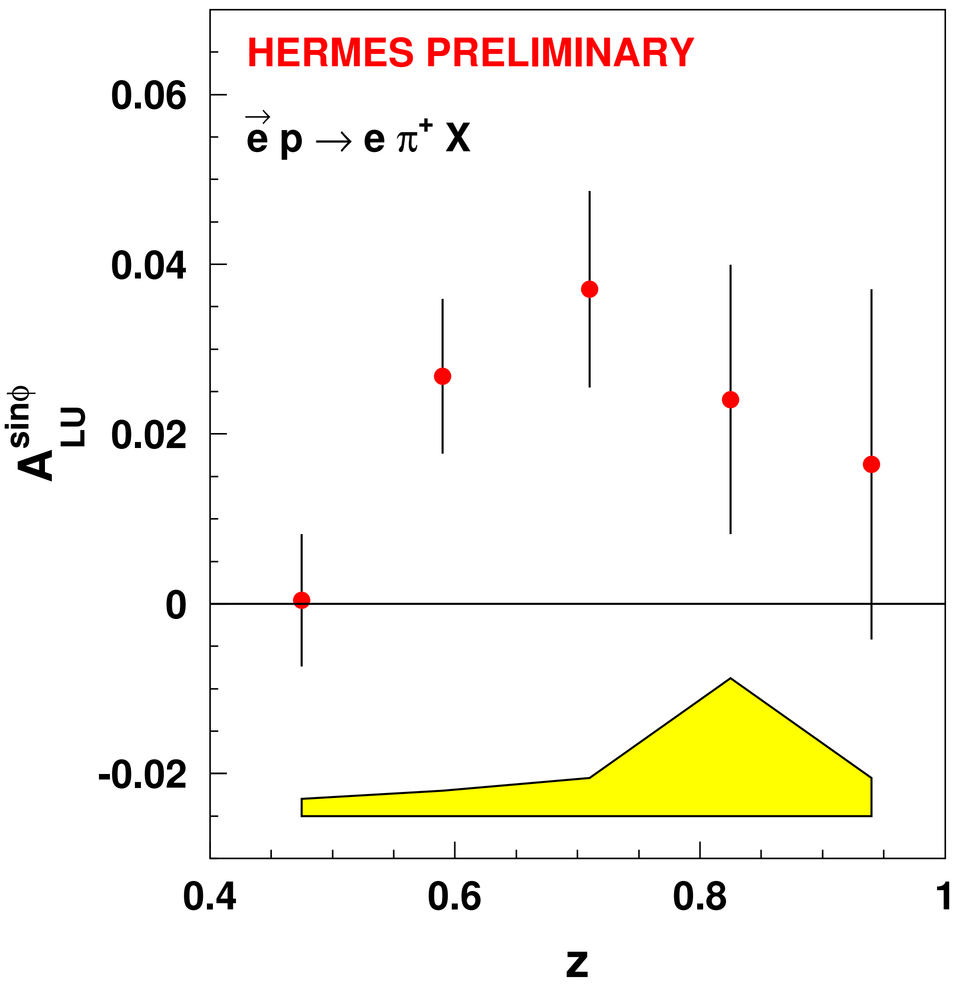
$$A_{\mathrm{LU}}^{\sin\phi}$$

$$= \frac{\sum_{i=1}^{N^+} \sin(\phi_i^+) - \sum_{i=1}^{N^-} \sin(\phi_i^-)}{\frac{1}{2}[N^+ + N^-]}$$

$$\propto \frac{\sum_{a,\bar{a}} (\, e_a^2 x \, e^a(x) \; H_1^{\perp a}(z) \,)}{\sum_{a,\bar{a}} (\, e_a^2 x \, f^a(x) \; D_1^a(z) \,)}$$

$e^a(x)$ ... twist-3 chiral odd DF

$H_1^{\perp a}(z)$ ... Collins FF



summary & outlook

single-target + single-beam spin azimuthal asymmetries measured in $\pi(K)$ electroproduction with longitudinally polarised target and beam

$A_{\mathrm{UL}}^{\sin\phi}$ well described by model calculations based on **Collins effect**

$\Rightarrow$ non-ambiguous measurement of **transversity** will be possible
with transversely polarised target:

$\longrightarrow$ **HERMES run-II 2002++**