SSA with longitudinally polarised targets + beam at hermes

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on behalf of the HERMES collaboration

INFN Frascati

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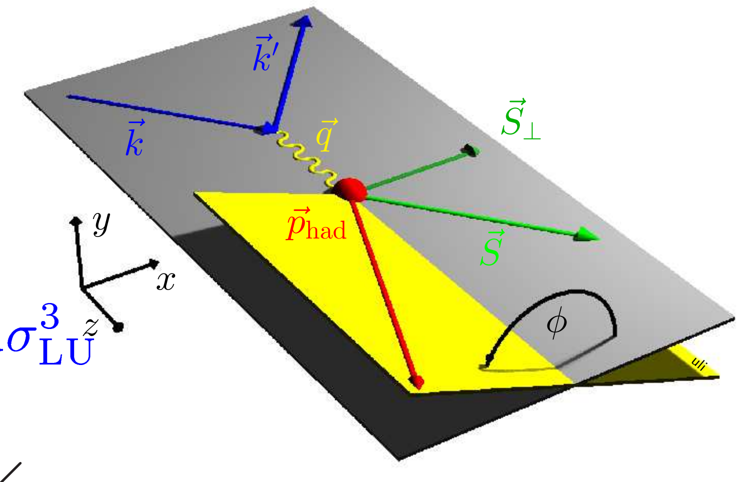
– Workshop on Transversity –

October 6-7, 2003; Athens, Greece

- single-spin azimuthal asymmetries in sidis
- the HERMES experiment
- target-spin + beam-spin azimuthal asymmetries
- outlook

DIS+SIDIS cross section



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

$h_1^\perp \otimes H_1^\perp \swarrow$ $\qquad$ $\boxed{e \otimes H_1^\perp} \swarrow$

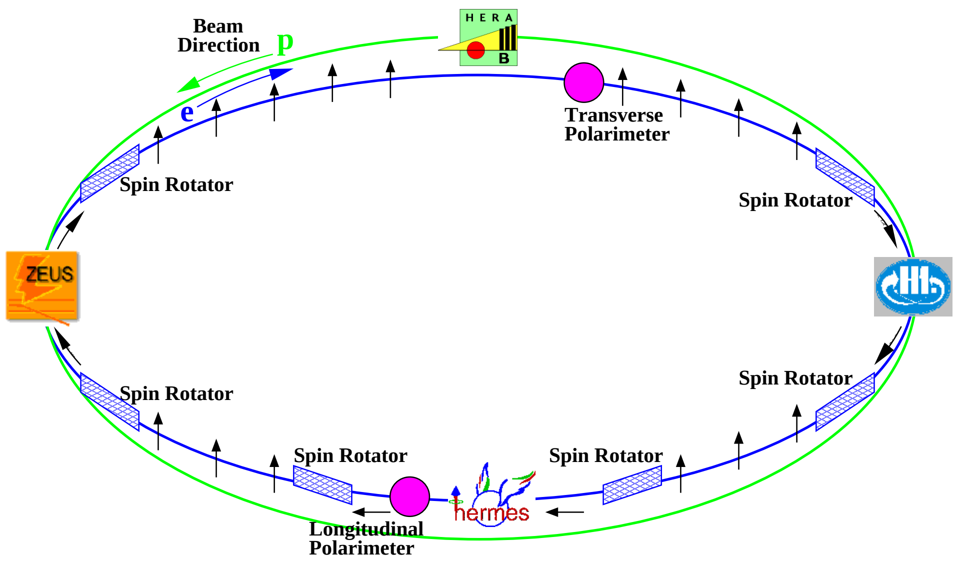
$$+S_{\rm L}[\sin 2\phi\, d\sigma^4_{\rm UL} + \frac{1}{Q}\sin\phi\, d\sigma^5_{\rm UL}] + \lambda S_{\rm L}[\, d\sigma^6_{\rm LL} + \cdots$$

$\boxed{h_{1\rm L}^\perp \otimes H_1^\perp} \swarrow$ $\qquad$ $\boxed{h_{\rm L} \otimes H_1^\perp} \swarrow$

$$+S_{\rm T}[\sin(\phi+\phi_S)\, d\sigma^7_{\rm UT} + \sin(\phi-\phi_S)\, d\sigma^8_{\rm UT} + \sin(3\phi-\phi_S)\, d\sigma^9_{\rm UT} + \frac{1}{Q}\sin(2\phi-\phi_S)\, d\sigma^{11}_{\rm UT}]$$

$\boxed{h_1 \otimes H_1^\perp} \swarrow$ $\qquad$ $f_{1\rm T}^\perp \otimes D_1 \swarrow$ $\qquad$ $h_{1\rm T}^\perp \otimes H_1^\perp \swarrow$

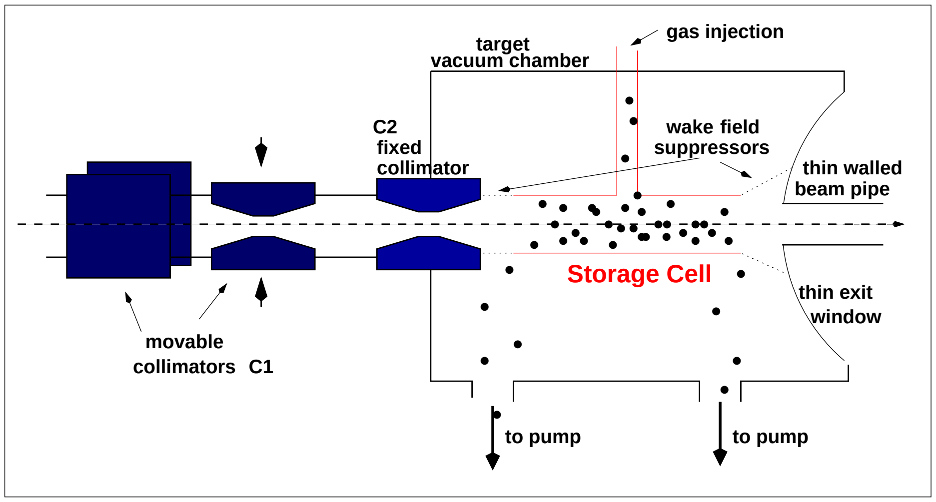
HERA $e^{\pm}$ beam — Hermes internal gas target



polarisation measured by two Compton polarimeters:

$$\langle P \rangle \simeq (55 \pm 2_{\rm sys})\%$$

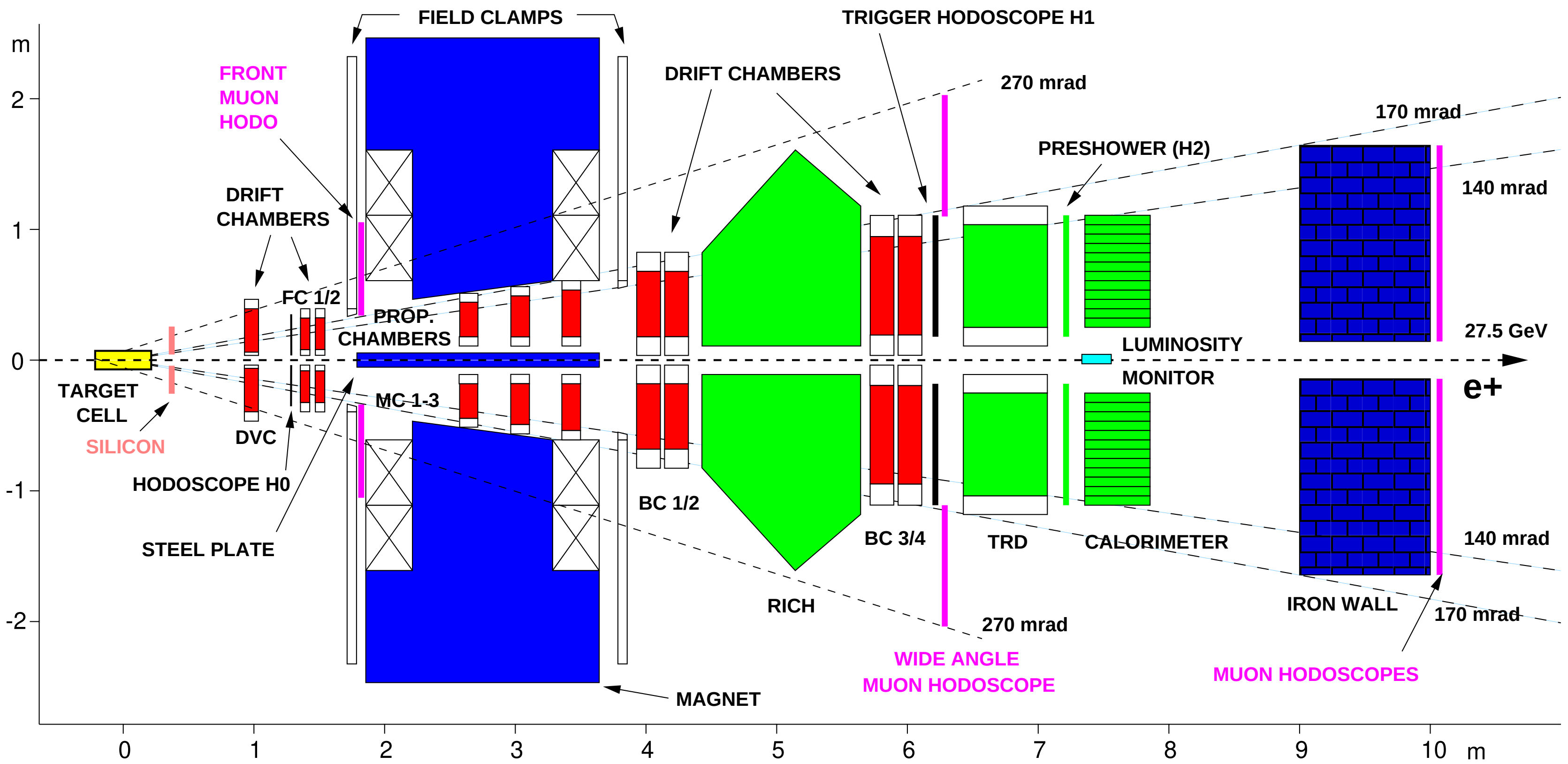
$$\Rightarrow \boxed{A_{\rm LU}}$$



H, D target: cell filled by atomic beam source: $\rho = 7.6 \cdot 10^{13}$ atoms/cm^2

$$\langle P \rangle \simeq (85 \pm 4_{\rm sys})\%$$

$$\Rightarrow \boxed{A_{\rm UL}}$$



tracking: 57 tracking planes $\Rightarrow \delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ mrad

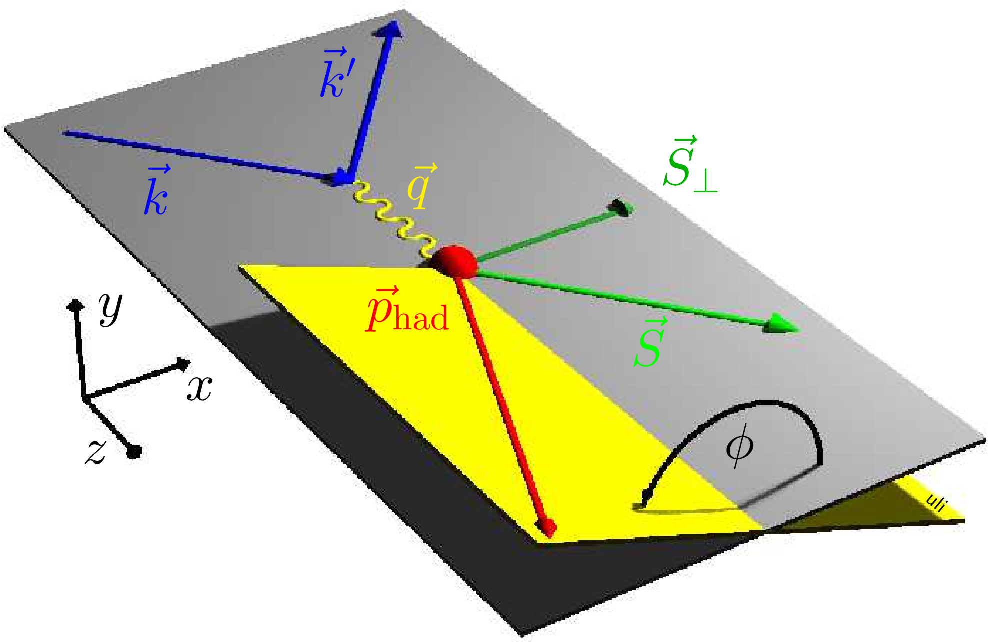
particle ID: (cerenkov) RICH, TRD, preshower, calorimeter

$\Rightarrow$ ID for π: $\epsilon >$ (90) 98 % for $p > (5)\,1$ GeV

sidis kinematic: $0.02 < x < 0.5$ for $Q^2 > 1$ GeV^2 and W$^2 > 4$ GeV^2

single-spin azimuthal asymmetry (ssa)

$\boxed{\vec{\mathrm{e}} + \vec{\mathrm{p}}(\vec{\mathrm{d}}) \rightarrow \mathrm{e}' + \mathrm{X} + \mathrm{h}}$



$$A_{\mathrm{UL(LU)}}(\phi) = \frac{1}{\langle |S| \rangle} \cdot \frac{N^{\rightarrow}(\phi) - N^{\leftarrow}(\phi)}{N^{\rightarrow}(\phi) + N^{\leftarrow}(\phi)}$$

$\downarrow$

$\boxed{\text{fit}}$

$\downarrow$

$A^{\sin \mathrm{n}\phi}_{\mathrm{UL(LU)}}(\phi) \cdot \sin \mathrm{n}\phi,$ n=1, 2

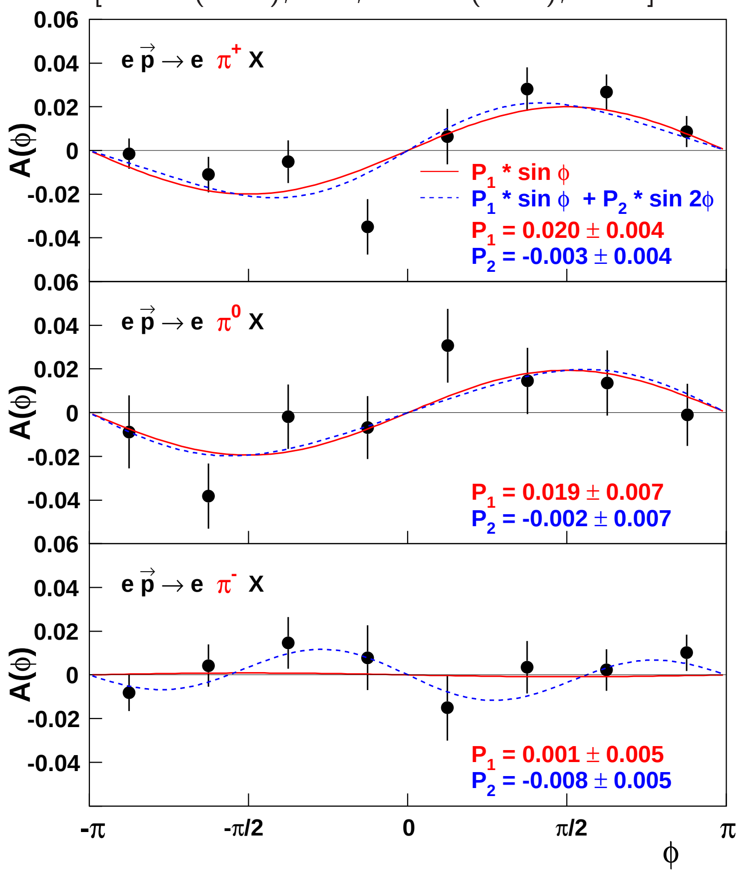
transverse component in γ^* frame:

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

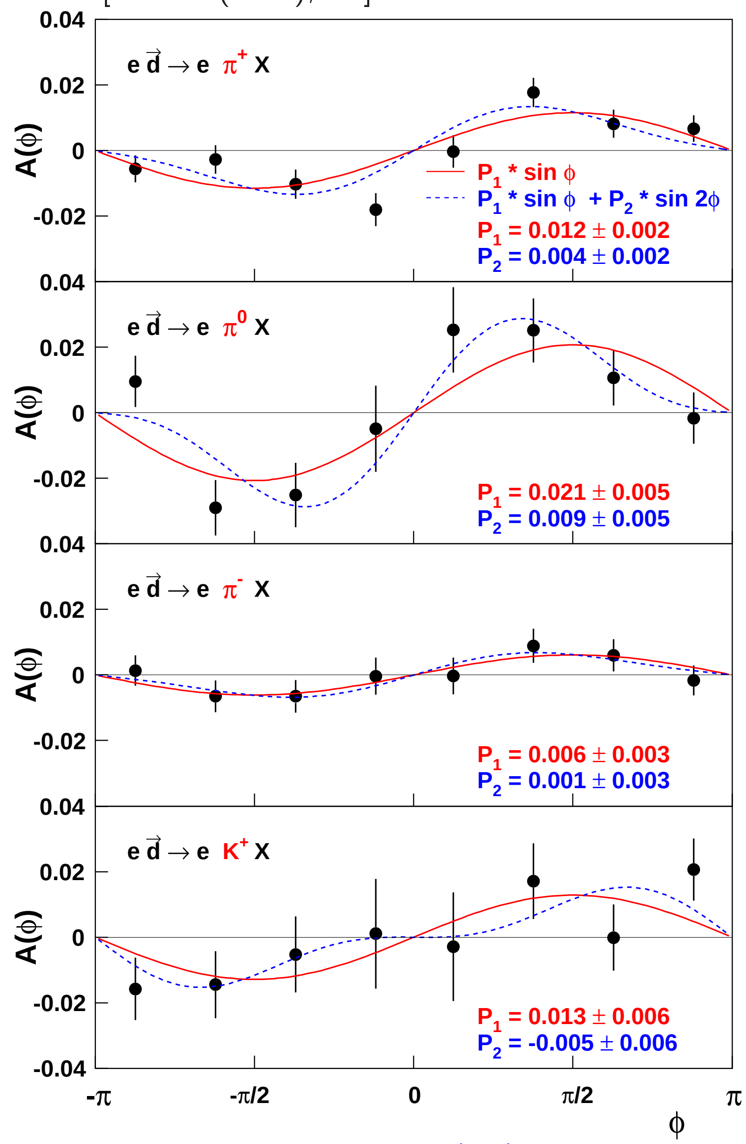
$$\sim 0.15 \cdot \mid S \mid$$

target SSA A_{UL}

[PRL84(2000),4047; PRD64(2001),97101]



[PLB562(2003),182]



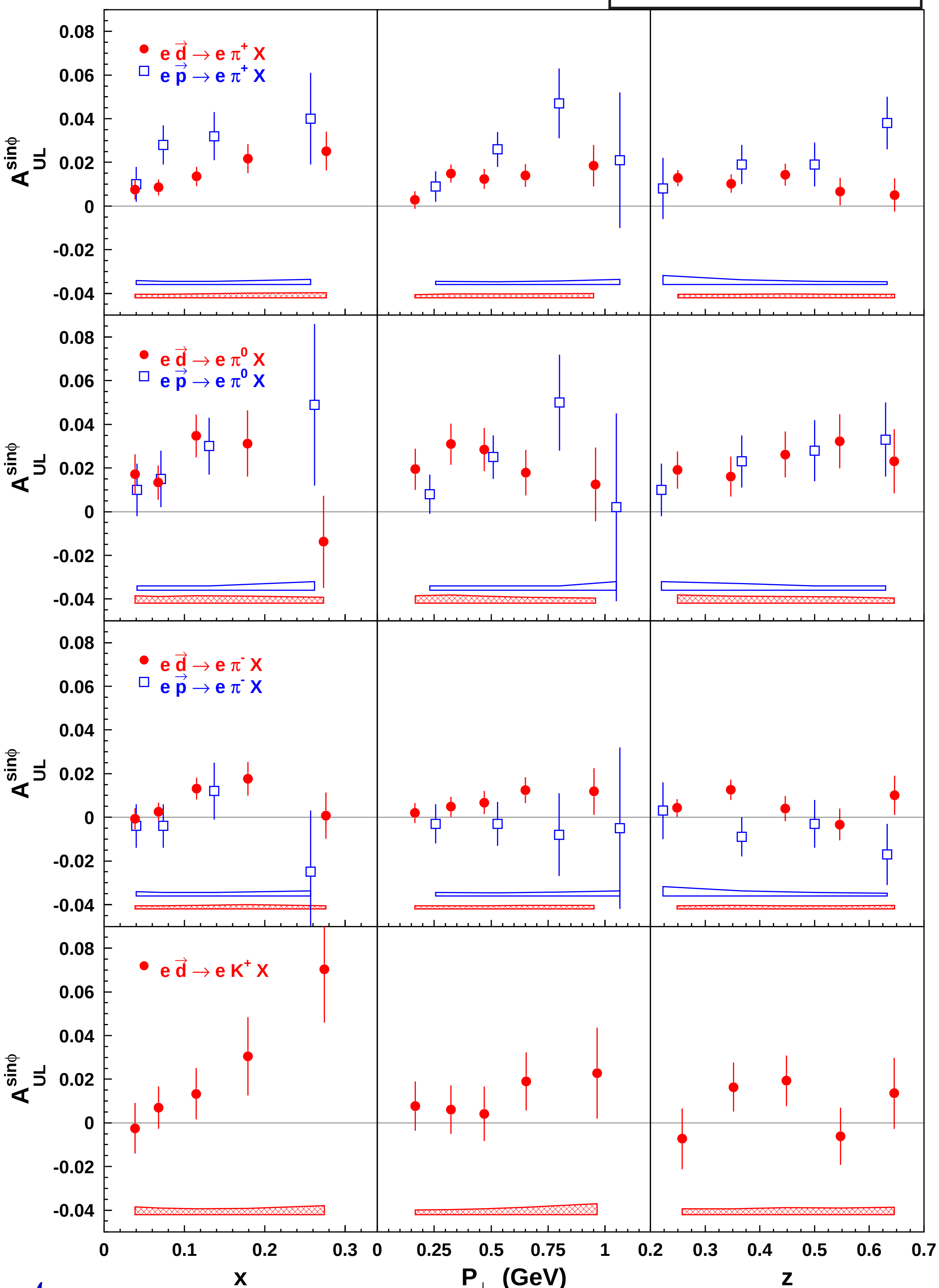
$\langle x \rangle = 0.09$, $\langle Q^2 \rangle = 2.4$ GeV^2

$\langle z \rangle = 0.38$, $\langle P_\perp \rangle = 0.44$

(0.43)

$A_{\rm UL}^{\sin\phi}$ kinematic dependences

$0.2 < z < 0.7$



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

longitudinal polarised target has 2 components:

$\boxed{S_{\mathrm{L}}/S \approx 1}$ and $\boxed{S_{\mathrm{T}}/S \approx 1/\mathrm{Q}}$

$$\langle \frac{|\,P_{\mathrm{h}\perp}\,|}{M_{\mathrm{h}}} \sin\phi \rangle_{\mathrm{UL}} \propto \Big[\, S_{\mathrm{T}} \sum_{a,\bar{a}} (\, e_a^2 x\, h_1^a(x)\; H_1^{\perp a}(z)\,)$$

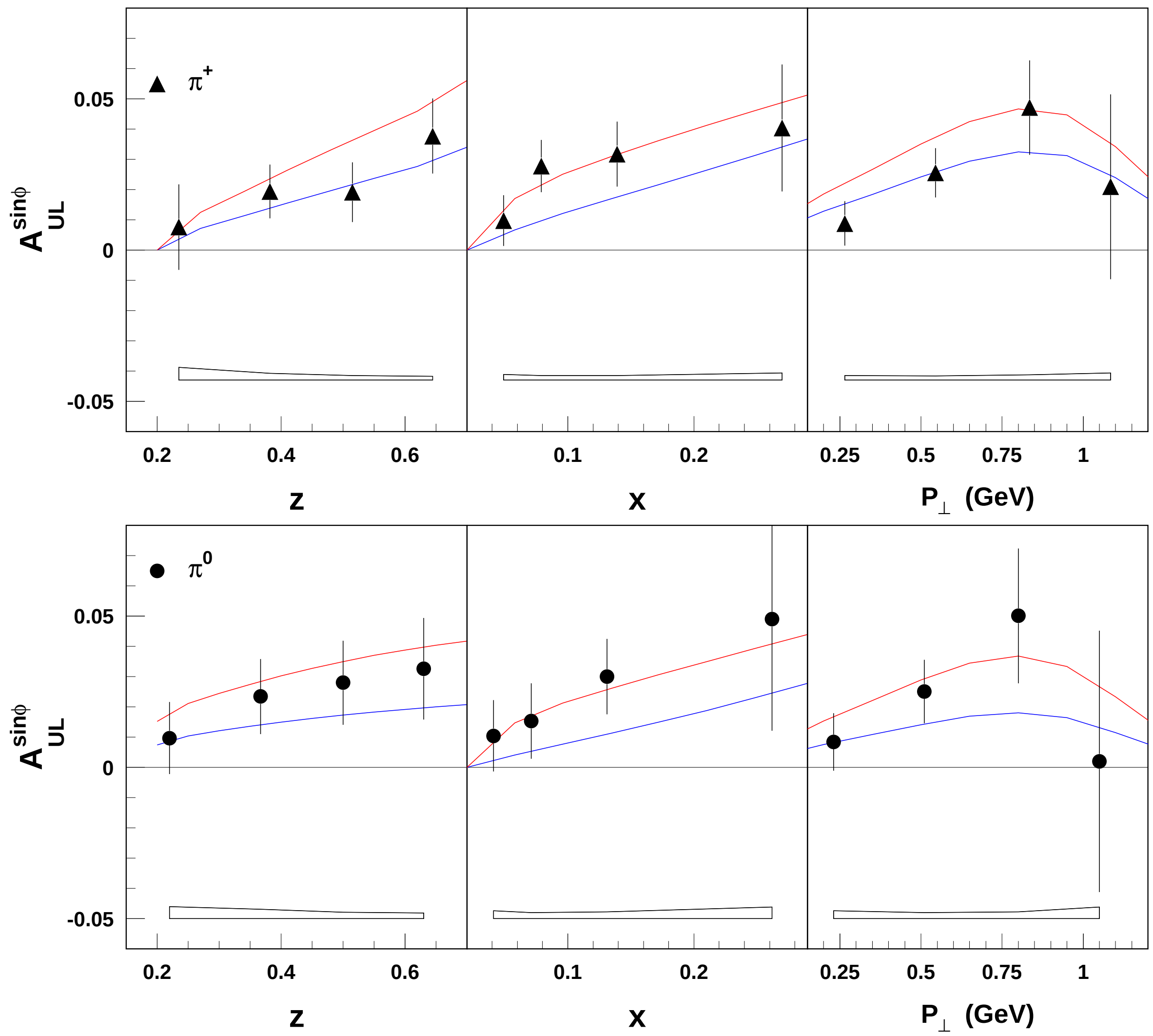
$$+ \frac{1}{Q}\, S_{\mathrm{L}} \sum_{a,\bar{a}} (\, e_a^2 x\, h_{\mathrm{L}}^a(x)\; H_1^{\perp a}(z)\,)\, \frac{2(2-y)}{\sqrt{1-y}} + \cdots \Big]$$

$$\langle \frac{|\,P_{\mathrm{h}\perp}^2\,|}{M\,M_{\mathrm{h}}} \sin 2\phi \rangle_{\mathrm{UL}} \propto S_{\mathrm{L}} \sum_{a,\bar{a}} (\, e_a^2 x\, h_{1\mathrm{L}}^{\perp a}(x)\; H_1^{\perp a}(z)\,)$$

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

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

$e\vec{p} \rightarrow e\ \pi\ X$



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

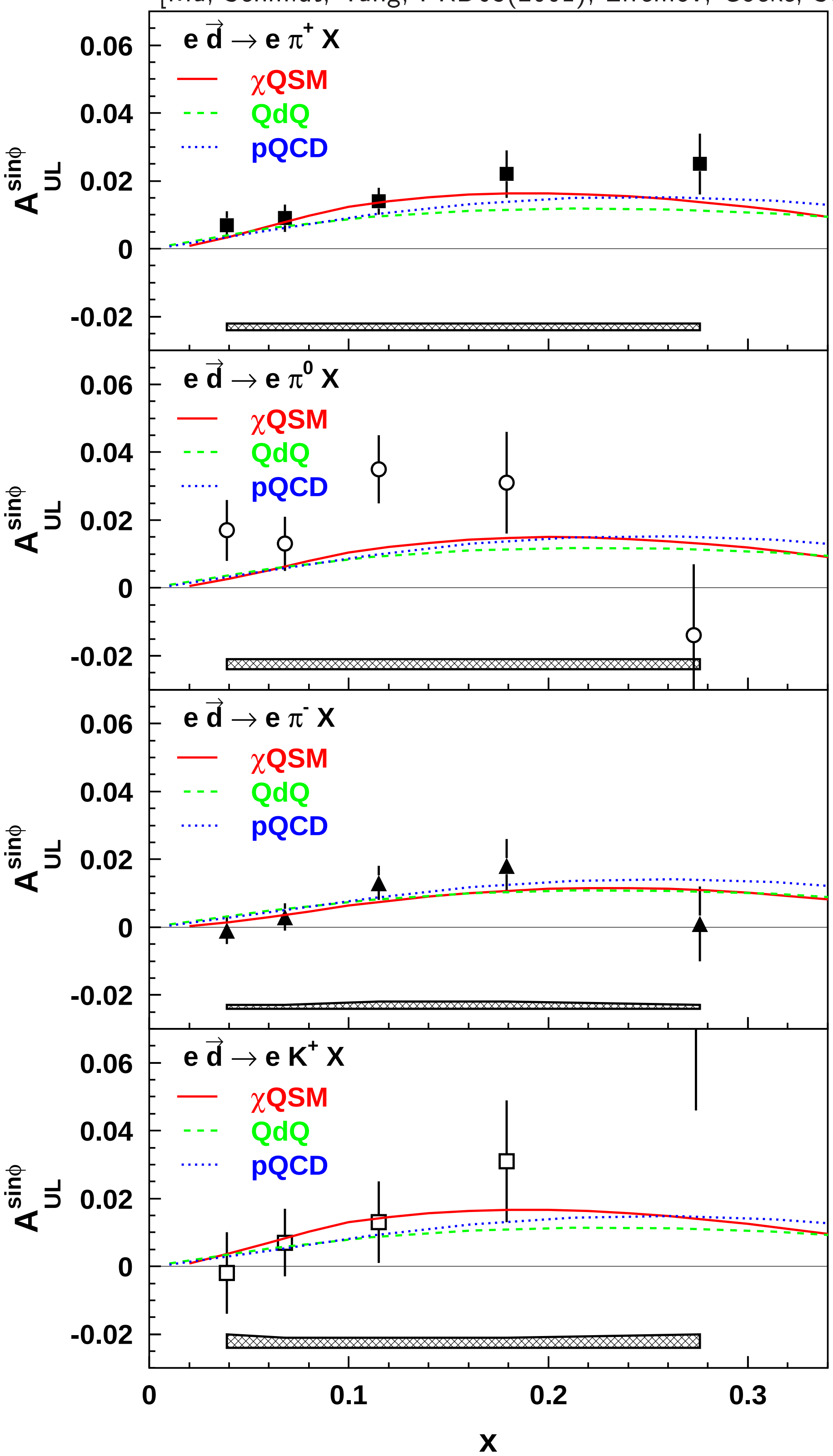
lower limit: $h_1 = g_1$
non-relativistic limit

'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 $A_{\rm UL}^{\sin\phi}$ ___________

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



approximation:

$\boxed{h_1(x):}$

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

$\tilde{h}_{\rm L}^a \simeq 0$

$\boxed{H_1^\perp:}$

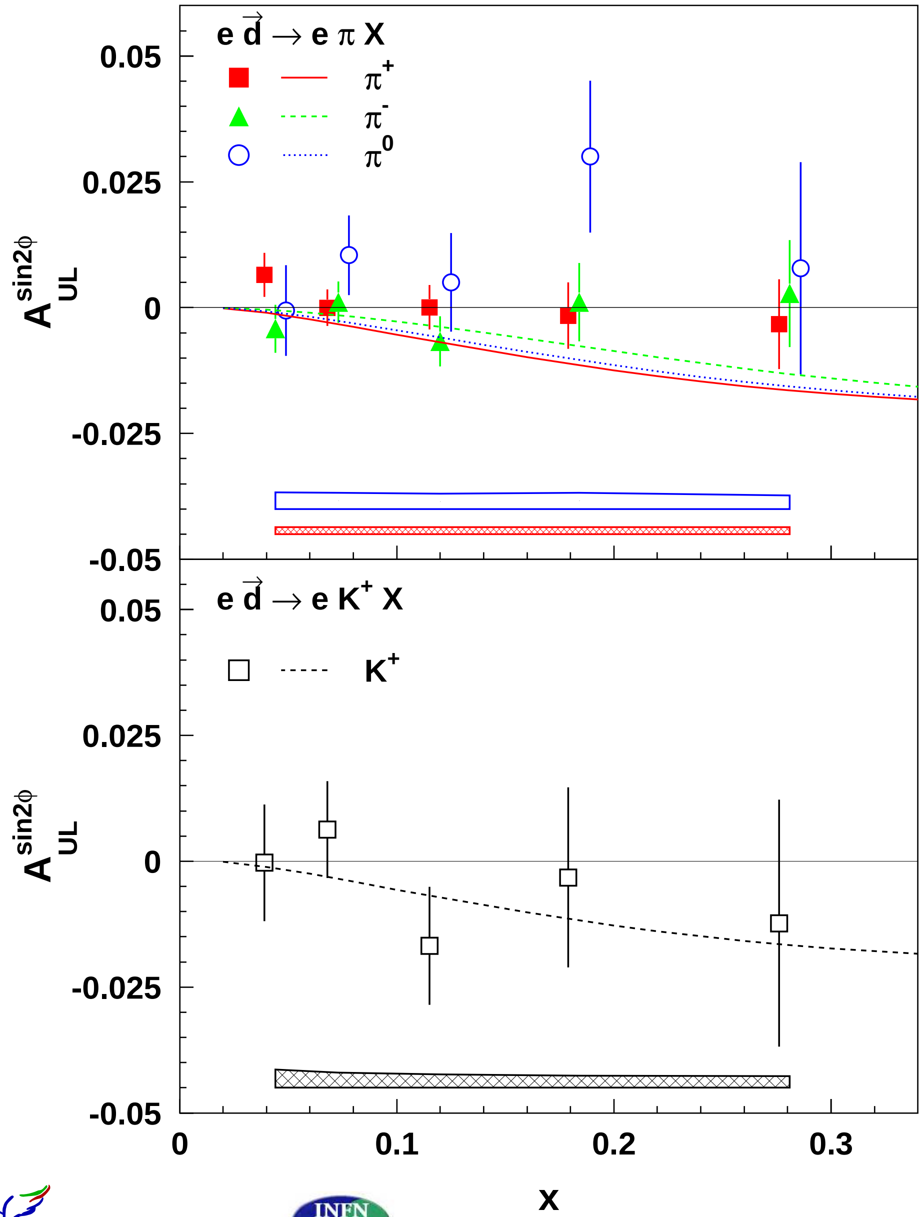
χQSM:

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

QdQ, pQCD:

'Collins guess'

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



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

chiral quark-soliton model:

$\boxed{h_1(x):}$

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

$$\tilde{h}_{\mathrm{L}}^a \simeq 0$$

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

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

remarks on model calculations

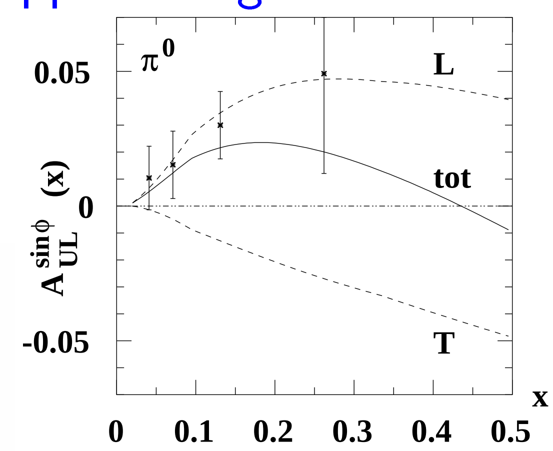
$\sin\phi$ moments from proton + deuteron targets well described by various model calculations based on Collins effect $\sim h_1 \otimes H_1^\perp$

$\boxed{\text{BUT}}$ $\Rightarrow$ @ longitudinally polarised target: S_T w.r.t. $\gamma^* \propto 1/Q$

$A_{UL}^{\sin\phi} \sim$ twist-3: $h_L H_1^{\perp(1)}$ contribution $\approx 75\%$ $\leftarrow$ opposite sign:

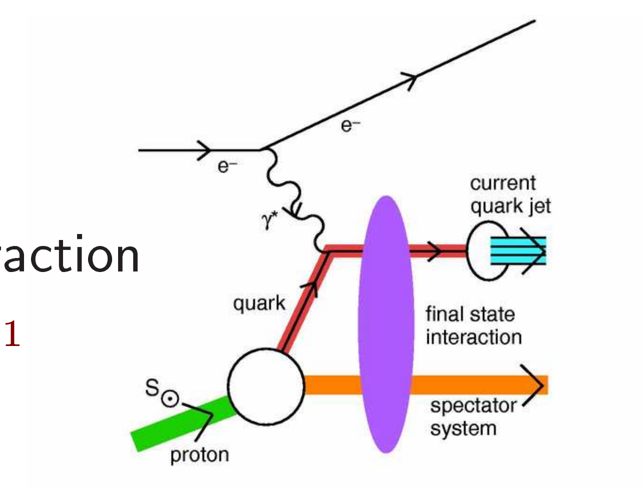
while $h_1 H_1^{\perp(1)}$ contribution $\approx 25\%$ $\swarrow$

[K. Oganessyan], [Efremov, Goeke, Schweitzer]



$\Rightarrow$ other mechanism:

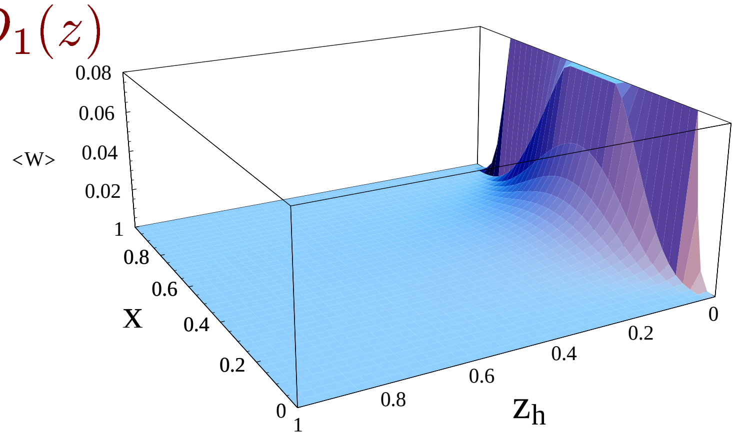
SSA from final state interaction
$\equiv$ Sivers effect $\sim f_{1T}^\perp \otimes D_1$



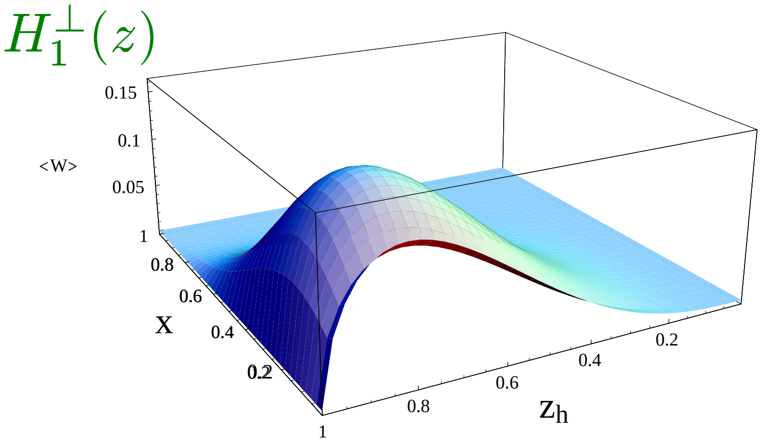
$\cdots$ Collins + Sivers effect show different dependence on z:

Sivers vs Collins

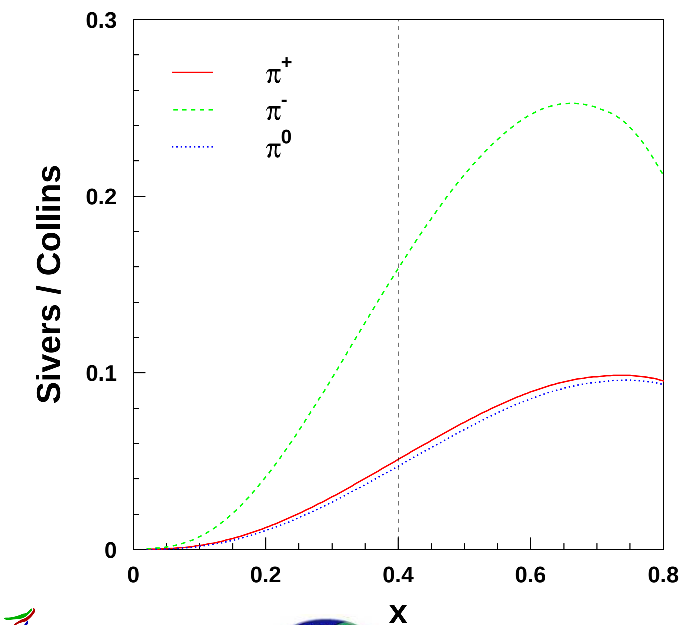
$f_{1T}^{\perp}(x)\otimes D_1(z)$



$h_1(x)\otimes H_1^{\perp}(z)$



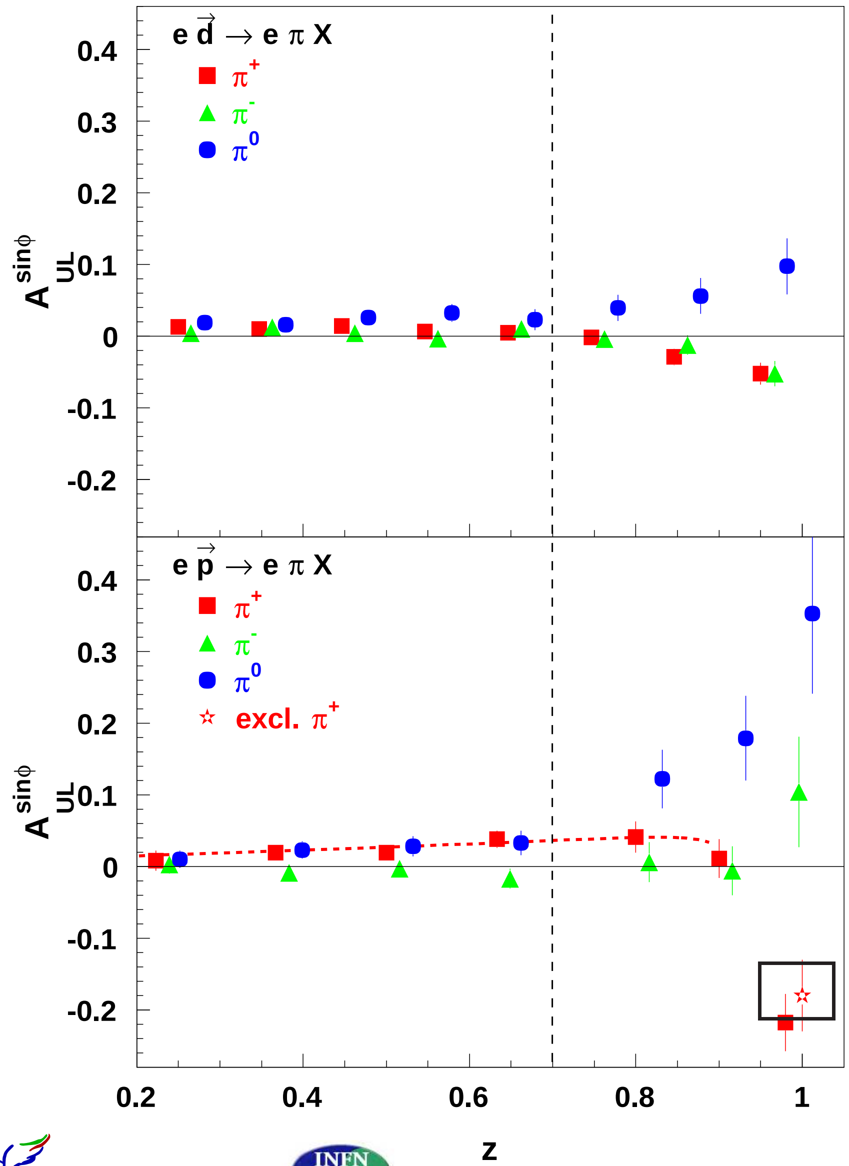
... based on parameterisations fitted to $p\bar{p} \to \pi X$ SSAs [Boglione, Mulders, PRD60(1999)054007]



Sivers/Collins vs. x [Efremov,Goeke,Schweitzer, PLB568(2003)63]

$\to$ HERMES kinematics
$\to$ $\langle H_1^{\perp}\rangle/\langle D_1\rangle = (13.8 \pm 1.8)\%$ at $\langle z\rangle = 0.41$
$\to$ $f_{1T}^{\perp}(x)$ from $p\bar{p} \to \pi X$, $h_1(x)$ from χQSM

$\Rightarrow$ Sivers effect contributes about 1-3 % to *transverse part* of Hermes $A_{\mathrm{UL}}^{\sin\phi}$ for π^+, π^0



curve normalised to data

[Bacchetta,Kundu,Metz,Mulders, hep-ph/0206309]

→ Collins function $H_1^{\perp}(z)$ calculated at 1-loop level in a chiral-invariant model

→ z-dpendence consistent with data

→ another model by Oganessyan et al.

[NPA689(2001)784]

- $h_L \approx h_1$
- $H_1^{\perp}(z)$ 'Collins guess'

→ results in very similar curve for Hermes kinematics

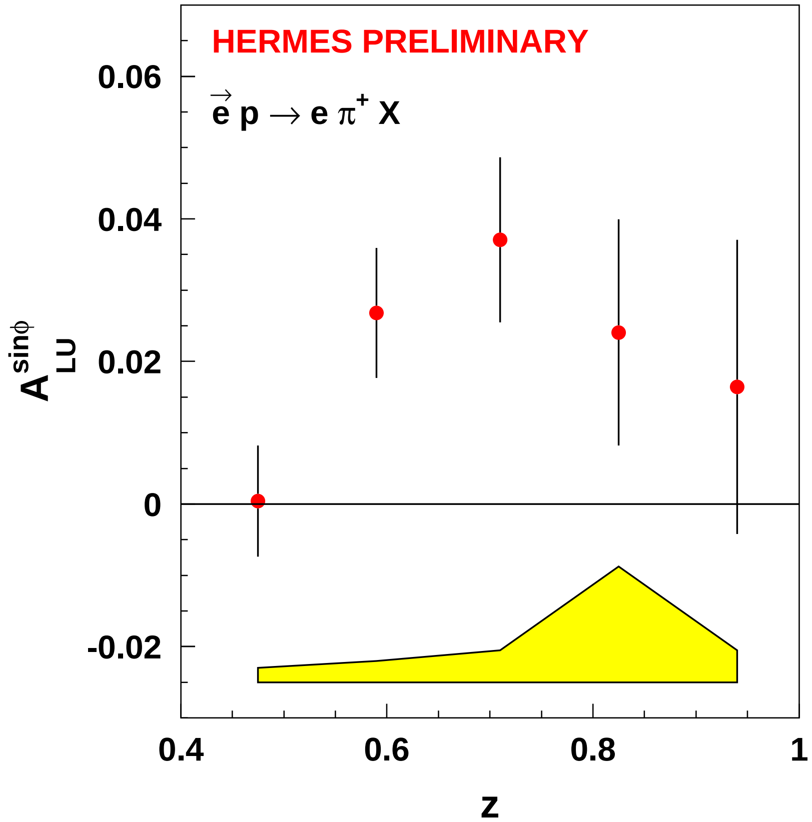
↘ see talk by C. Hadjidakis

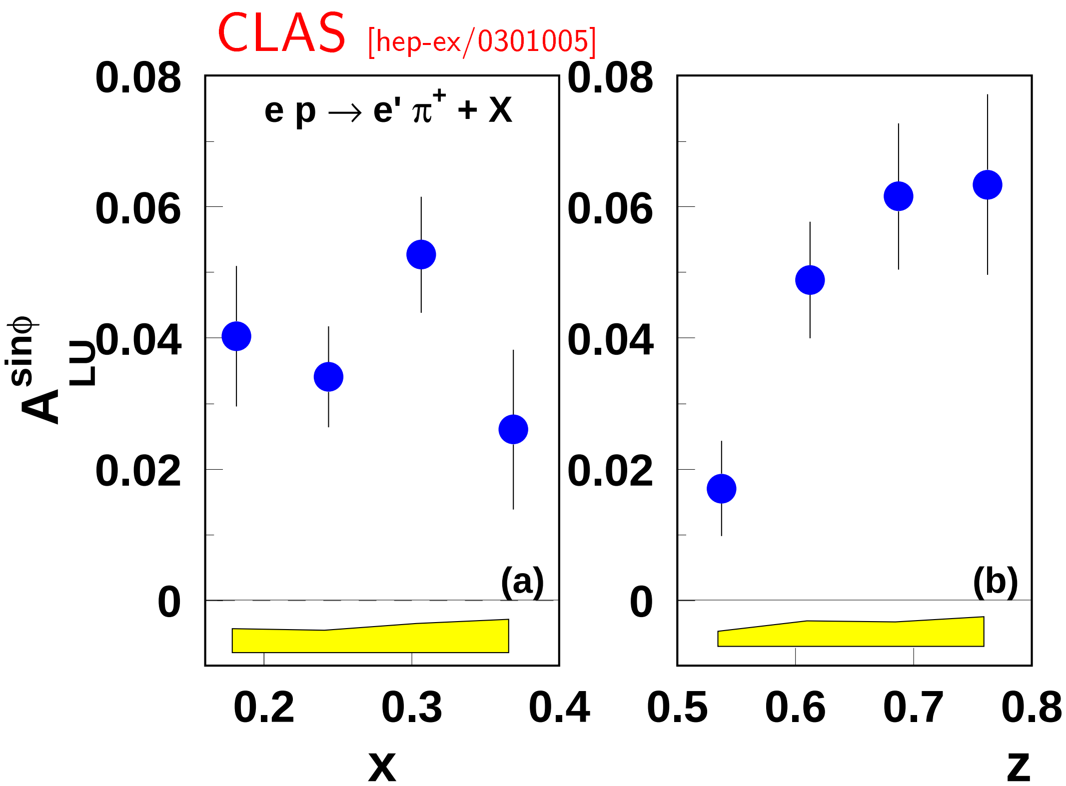
beam SSA $A_{\rm LU}$

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

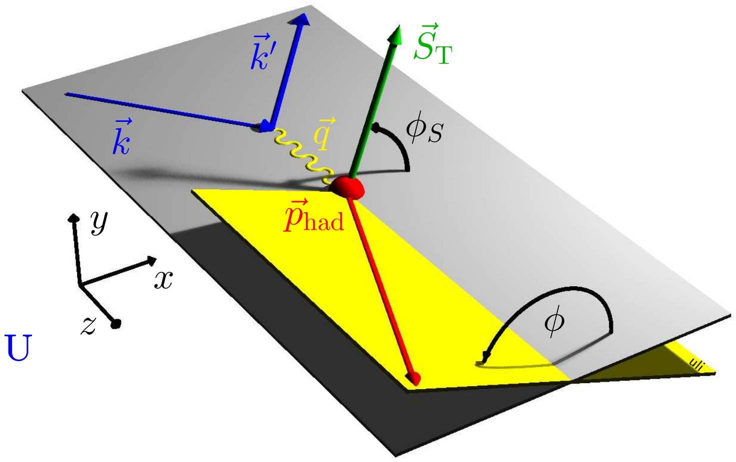
$H_1^{\perp a}(z)$ ... Collins ff

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





DIS+SIDIS cross section



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

$\boxed{h_1^\perp \otimes H_1^\perp} \swarrow$ $\quad$ $\boxed{e \otimes H_1^\perp} \swarrow$

$$+S_{\mathrm{L}}[\sin 2\phi\, d\sigma^4_{\mathrm{UL}} + \frac{1}{Q}\sin\phi\, d\sigma^5_{\mathrm{UL}}] + \lambda S_{\mathrm{L}}[\, d\sigma^6_{\mathrm{LL}} + \cdots$$

$\boxed{h_{1\mathrm{L}}^\perp \otimes H_1^\perp} \swarrow$ $\quad$ $\boxed{h_{\mathrm{L}} \otimes H_1^\perp} \swarrow$

$$+S_{\mathrm{T}}[\sin(\phi+\phi_S)\, d\sigma^7_{\mathrm{UT}} + \sin(\phi-\phi_S)\, d\sigma^8_{\mathrm{UT}} + \sin(3\phi-\phi_S)\, d\sigma^9_{\mathrm{UT}} + \frac{1}{Q}\sin(2\phi-\phi_S)\, d\sigma^{11}_{\mathrm{UT}}]$$

$\boxed{\boxed{h_1 \otimes H_1^\perp}} \swarrow$ $\quad$ $\boxed{f_{1\mathrm{T}}^\perp \otimes D_1} \swarrow$ $\quad$ $\boxed{h_{1\mathrm{T}}^\perp \otimes H_1^\perp} \swarrow$

$\cdots$ see talk by N. Makins

summary & outlook

single-spin azimuthal asymmetries measured in meson electroproduction with longitudinally polarised target and beam:

$\rightarrow$ single-target SSA: $\sin\phi$, $\sin 2\phi$ for π on proton
$\sin\phi$, $\sin 2\phi$ for π and K^+ on deuteron

$\rightarrow$ single-beam SSA: $\sin\phi$ for π^+ on proton
$\sin\phi$ for π^-, π^0, K^+ on proton and deuteron

sidis SSAs involving *longitudinal* target spin have *ambiguous interpretations*

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

$\rightarrow$ z-dependence suggest the Collins ff as 'responsible' T-odd object

$\rightarrow$ Sivers effect has been estimated to give negligible contribution to $A_{\mathrm{UL}}^{\sin\phi}$ at Hermes kinematics

outlook

$\Rightarrow$ other azimuthal asymmetries to be considered:

$$\langle \cos 2\phi \rangle_{\mathrm{UU}} \propto h_1^{\perp} \otimes H_1^{\perp}$$

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

Sivers $\propto \sin(\phi - \phi_S)$ Collins $\propto \sin(\phi + \phi_S)$

$\longrightarrow$ **HERMES run-II 2002-2004**

$\cdots$ first results: see talk by N. Makins