Azimuthal asymmetries in pion electroproduction

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for the hermes collaboration

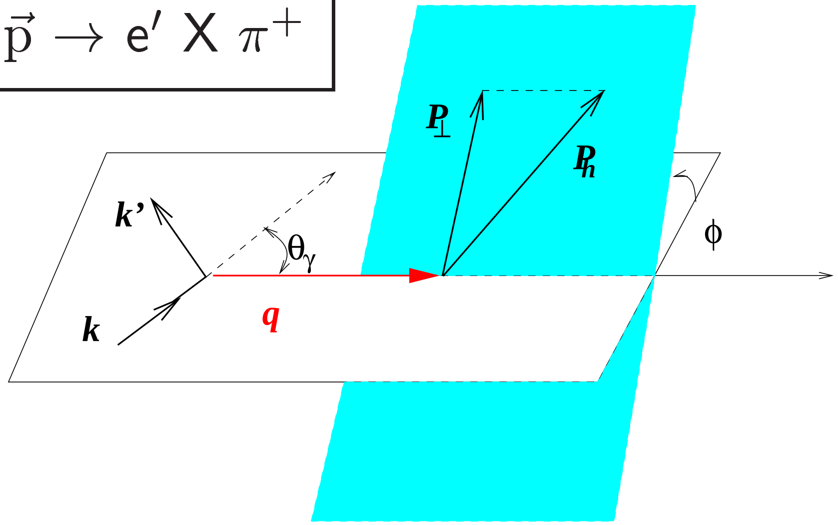
- What ?
- Why ?
- Results
- Summary & Outlook

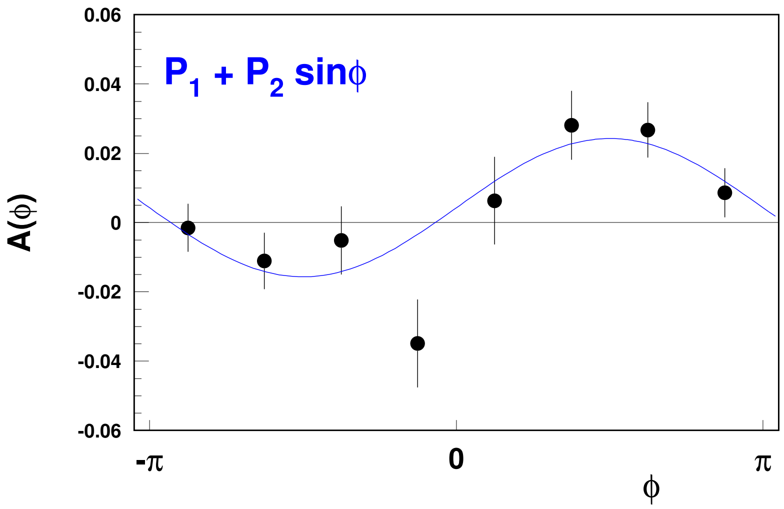
WHAT ? azimuthal asymmetry $\boxed{\text{e } \vec{\text{p}} \rightarrow \text{e}' \text{ X } \pi^+}$

consider distribution of pions in the angle ϕ = azimuthal angle of pion relative to lepton scattering plane, around the q vector

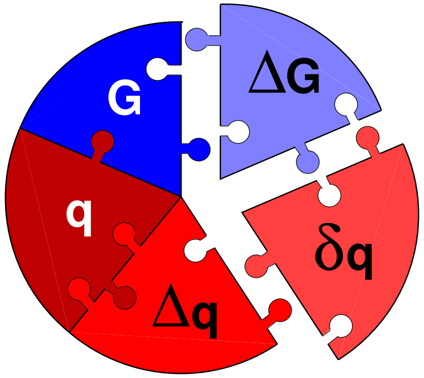
$$A(\phi) = \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

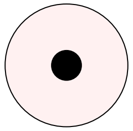
$\boxed{\text{e } \vec{\text{p}} \rightarrow \text{e}' \text{ X } \pi^+}$





WHY ? motivation I

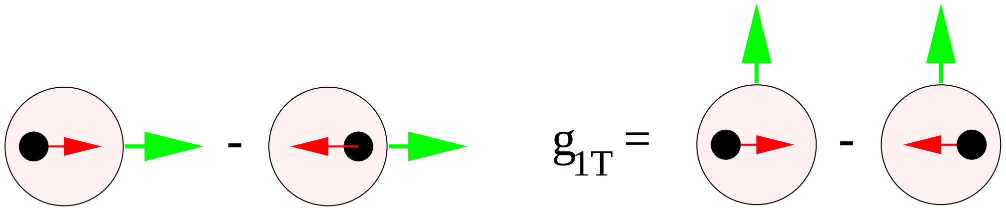


f_1 =  Unpolarised quarks in unpolarised nucleon

$\Rightarrow q(x)$:
spin averaged
(very well known)

Longitudinal quarks in

g_{1L} = … g_{1T} =

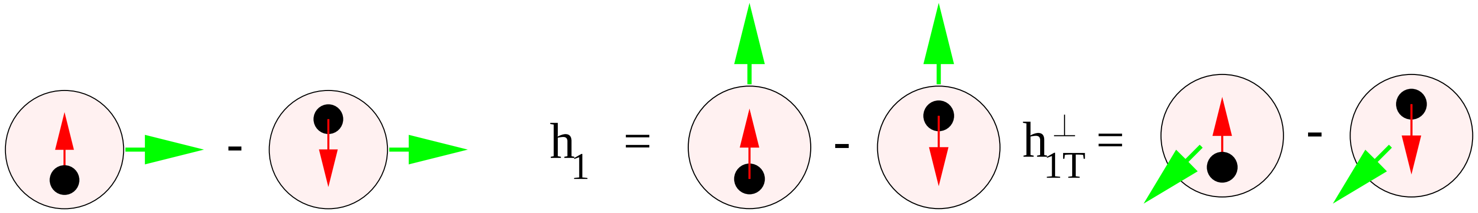


longitudinal and transverse nucleons

$\Rightarrow \Delta q(x)$:
helicity difference
(well known)

Transverse quarks in

$h_{1L}^{\perp}$ = … h_1 = … $h_{1T}^{\perp}$ =



longitudinal and transverse nucleons

$\Rightarrow \delta q(x)$:
helicity flip
unknown

WHY ? transversity

- in absence of relativistic effects: $\delta q(x) = \Delta q(x)$
- q and $\bar{q}$ contribute with opposite signe to $\delta q(x)$
  $\rightarrow$ predominantly sensitive to valence quark polarisation
- $\delta q(x)$ does not mix with gluons $\rightarrow$ different Q^2 evolution
- sum rule: first moment $\rightarrow$ tensor charge; reliably calculable in lattice QCD:
  $\delta\Sigma = \sum_f \int_0^1 \mathrm{d}x(\delta q_f - \delta\bar{q}_f) = 0.562 \pm 0.088$ at $Q^2 = 2$ GeV^2
- bounds:
  $f_1(x) > 0$ and $|\, g_1(x) \leq f_1(x)\,|$ $\quad |\, h_1(x)\,| \leq \frac{1}{2}(f_1(x) + g_1(x))$
- $h_1(x)$ is CHIRAL ODD
  can only be measured in combination with another chiral odd structure

chirality

- unpolarised quark density and longitudinal quark polarisation densities:
  $f_1, g_1, \ldots \rightarrow$ **chiral even**

- transverse quark polarisation densities $h_1 \rightarrow$ **chiral odd**

helicity basis: $\quad |{\perp \atop \top}\rangle = \frac{1}{\sqrt{2}}(|+\rangle \pm i|-\rangle)$

$d\sigma_{\perp \atop \top} \propto \langle {\perp \atop \top}| \cdots |{\perp \atop \top}\rangle$

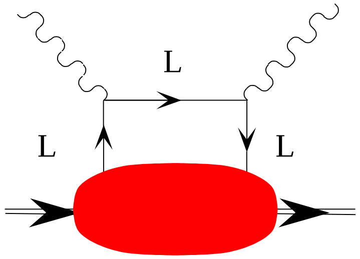
$d\sigma_\perp - d\sigma_\top \propto \langle +| \cdots |-\rangle + \langle -| \cdots |+\rangle \qquad \rightarrow$ **helicity flip**

all hard QCD and electroweak processes preserve chirality

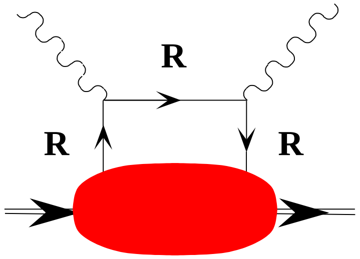
$$\Rightarrow H + h = H' + h' \rightarrow (H, h; H', h') \quad \rightarrow \begin{array}{lll} 1. & (+,+;+,+) & f_1\text{: } 1. + 2. \\ 2. & (+,-;+,-) & g_1\text{: } 1. + 2. \\ 3. & (+,-;-,+) & h_1\text{: } \quad 3. \end{array}$$

Collins FF

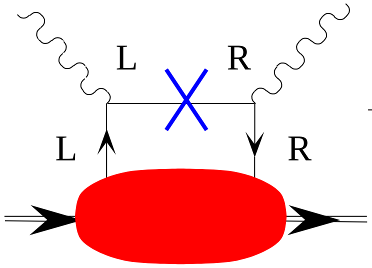
$$f_1\,(g_1) = \frac{1}{2}$$



$$+\,(-)$$

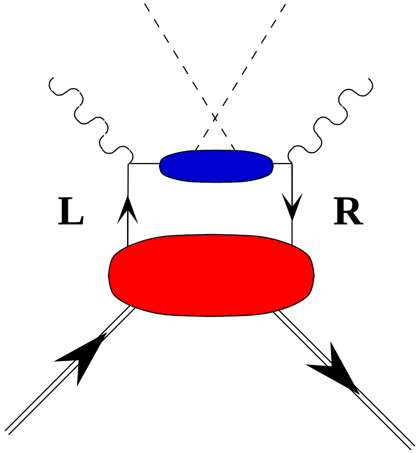


$$h_1 = \frac{1}{2}$$



$$\frac{\delta m}{\sqrt{Q^2}}$$

$\Longrightarrow$



Collins fragmentation function $H_1^{\perp}$

[J. Collins, Nucl.Phys. B396(1993), 161]

$\rightarrow$ **chiral odd**

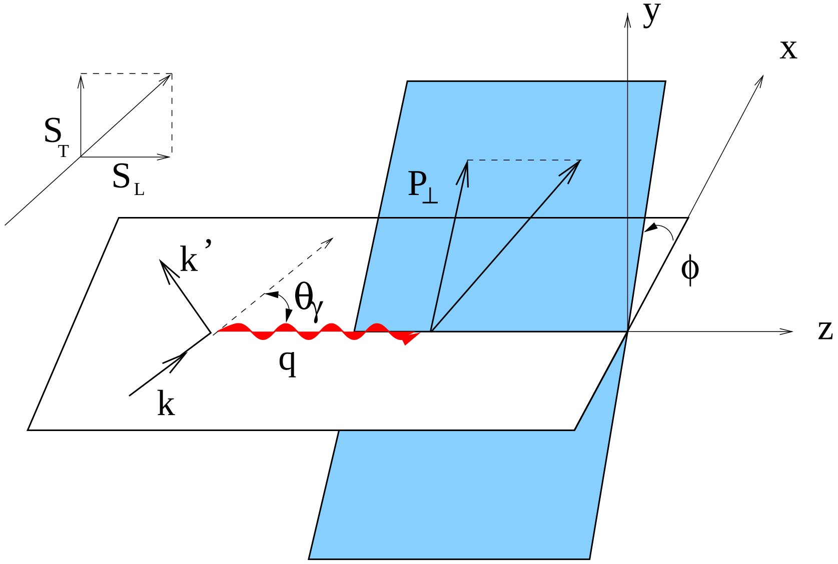
$\rightarrow$ combines with the transversity distribution in the initial nucleon to produce an **experimentally observable asymmetry** sensitive to the transversity

semi-inclusive DIS

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

$\Downarrow$ 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

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

single-spin azimuthal asymmetry

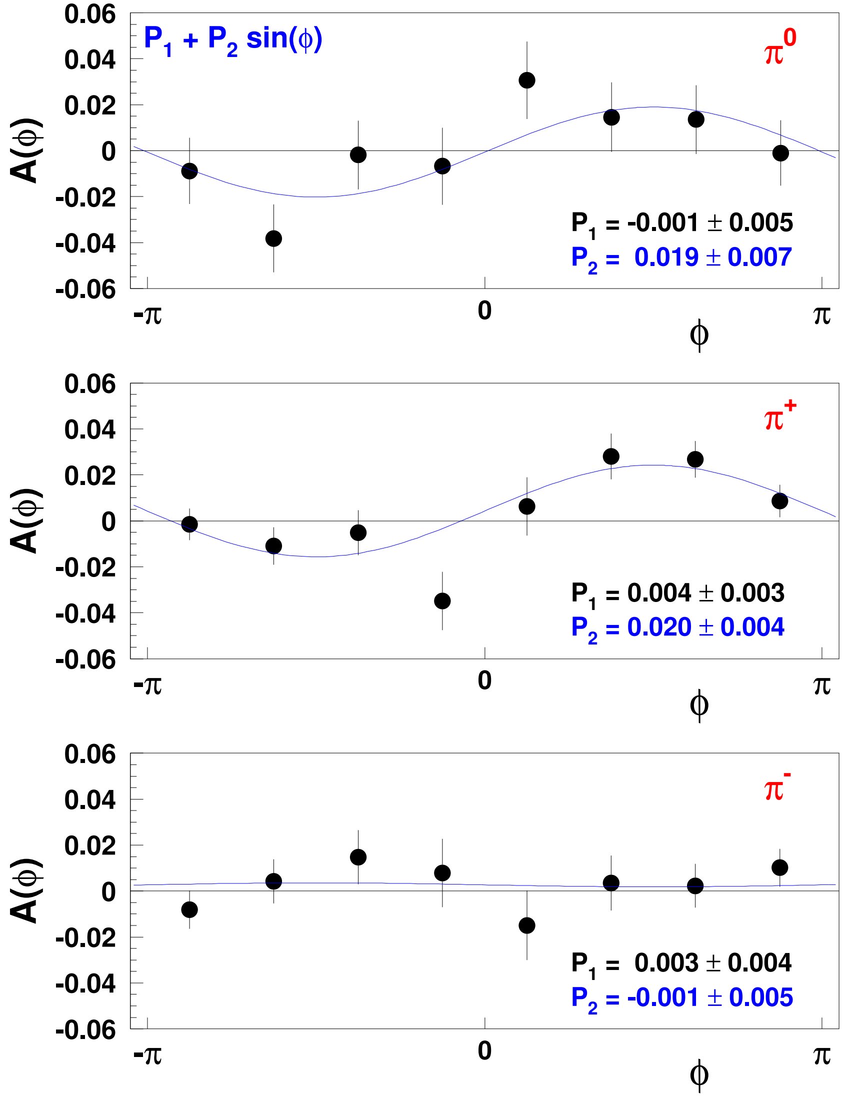
HERMES 1996/97: *longitudinal* polarised proton target

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

$+/-$ denote opposite target helicity states

UL **U**npolarised beam and **L**ongitudinal polarised target

average target polarisation magnitude $\langle P\rangle = 0.86$



DIS+SIDIS cross section

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

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

$f_1 \swarrow$

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

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

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

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

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

$g_{1T} \swarrow$

azimuthally weighted asymmetries

analysing powers for target longitudinal polarisation:

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

$$W(\phi) = \sin\phi, \sin 2\phi, ..., \cos\phi, \cos 2\phi, ...$$

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

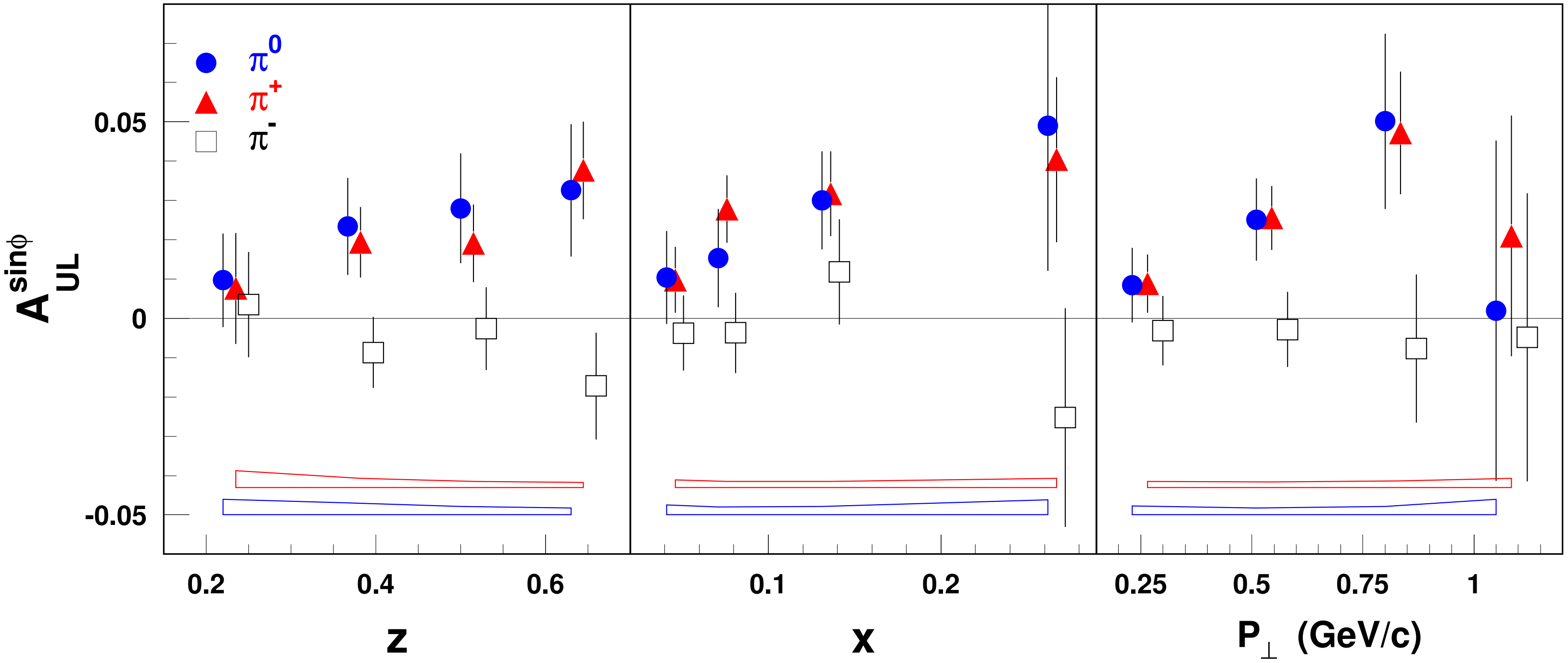
HERMES: longitudinal polarised target: ($S_{\mathrm{T}} \propto \sin\theta_\gamma$) first term contributes with 15% to 20%

$h_{\mathrm{L}}(x)$ includes interaction dependent twist-3 part

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

azimuthally weighted asymmetries

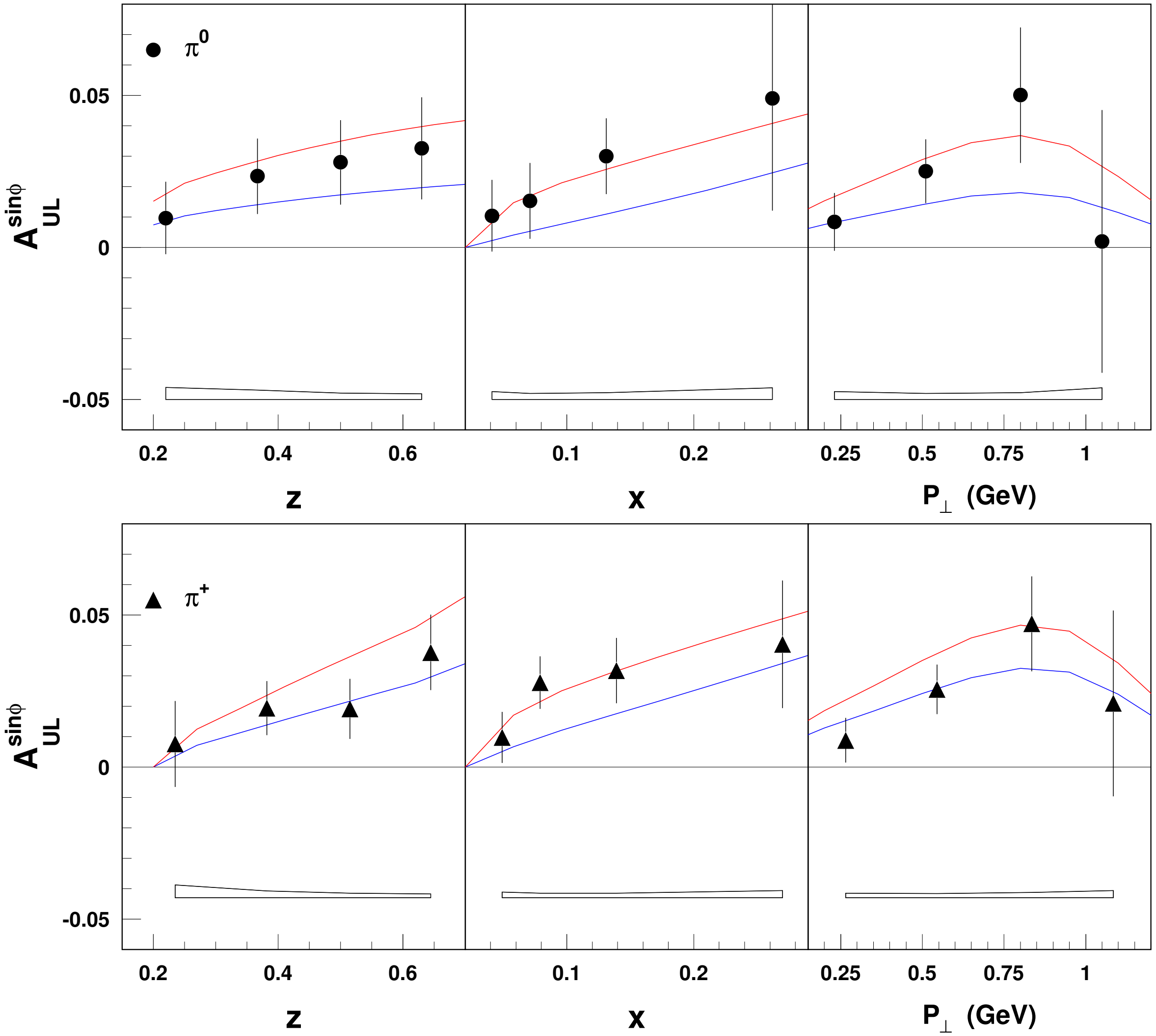
[PRL 84, 4047 (2000)] and [PRD 64, 097101 (2001)]



- x-dependence: valence quark dominance
- $P_\perp$-dependence: dominant role of intrinsic k_T
- $\pi^- \approx 0$: u quark dominance in proton

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

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



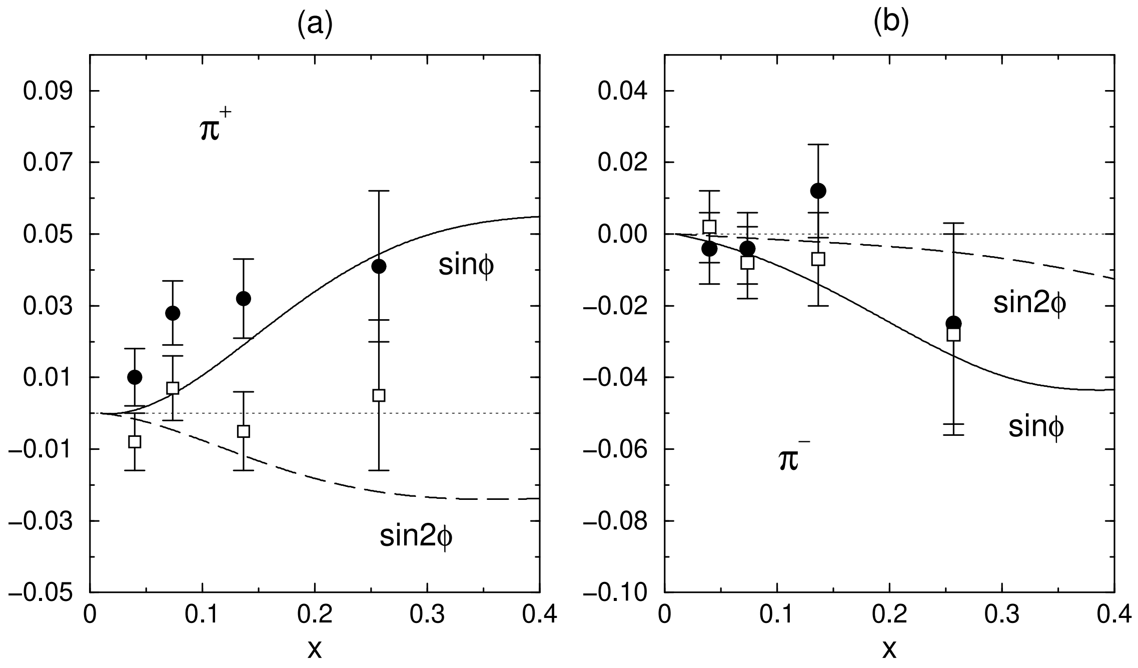
$$h_{\rm L}(x) = h_1(x) - \frac{\rm d}{{\rm d}x} h_{1\rm L}^{\perp(1)}(x) \approx h_1(x)$$

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

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

'Collins guess' for $H_1^\perp$

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



[for models: M.Wakamatsu, hep-ph/0012331]

$A_{UL}^{\sin 2\phi}$

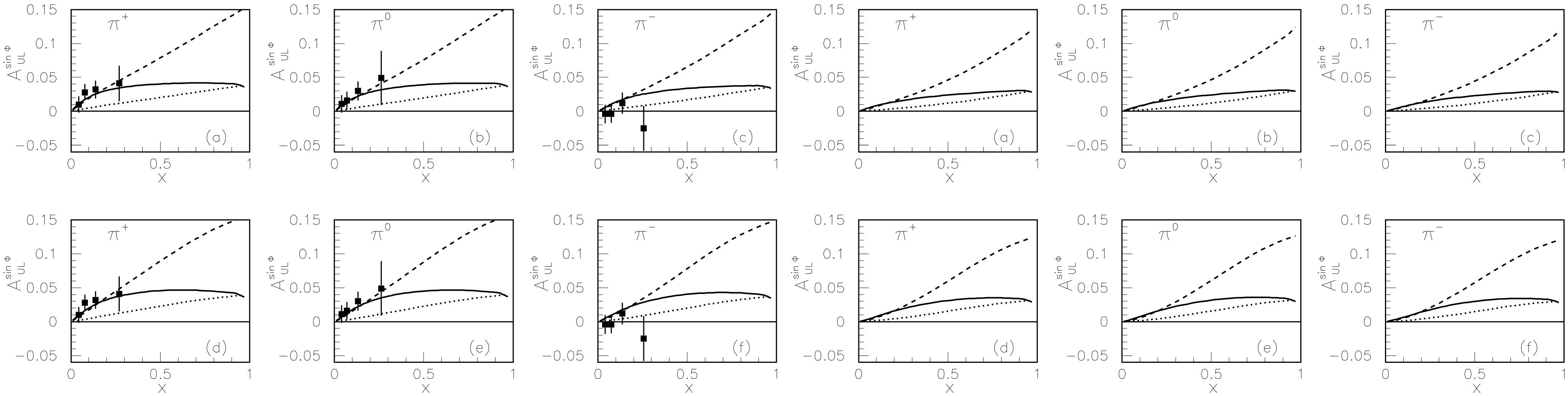
π^+	$-0.002 \pm 0.005 \pm 0.010$
π^-	$-0.005 \pm 0.006 \pm 0.005$
π^0	$0.006 \pm 0.007 \pm 0.003$

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

π^+	$-0.005 \pm 0.008 \pm 0.004$
π^-	$-0.007 \pm 0.010 \pm 0.004$

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

proton target deuteron target



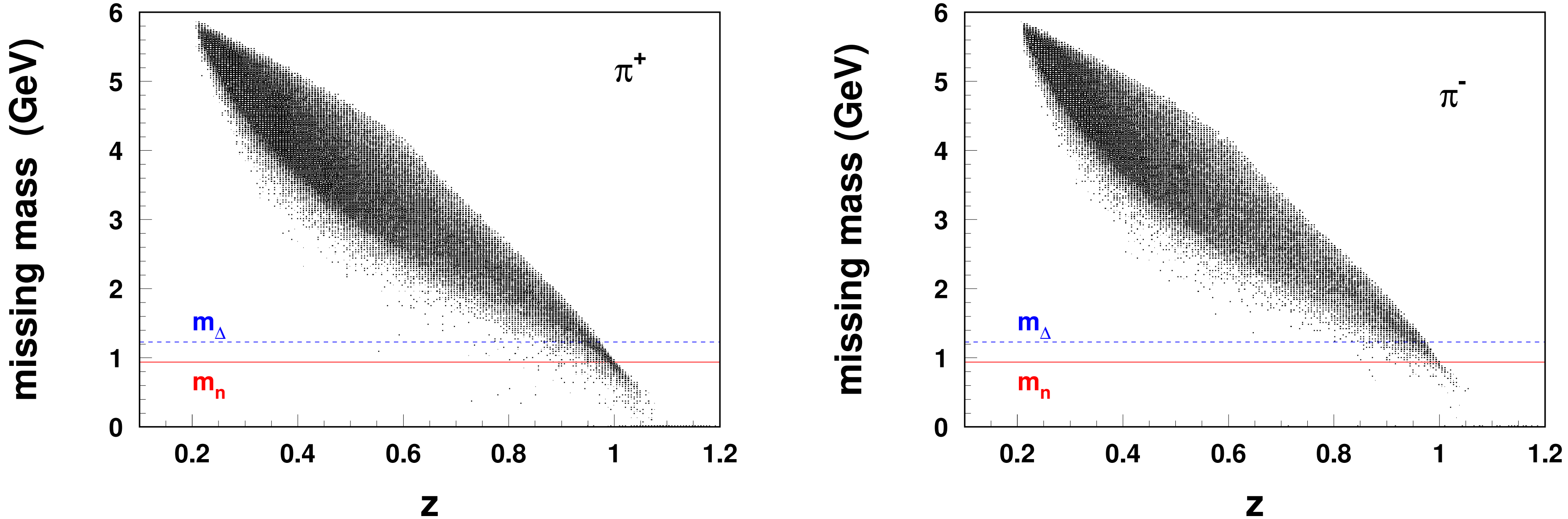
[Ma,Schmidt,Yang hep-ph/0110324]

HERMES results for single-spin azimuthal asymmetries on deuteron target
$\Longrightarrow$ expected soon

exclusive π production

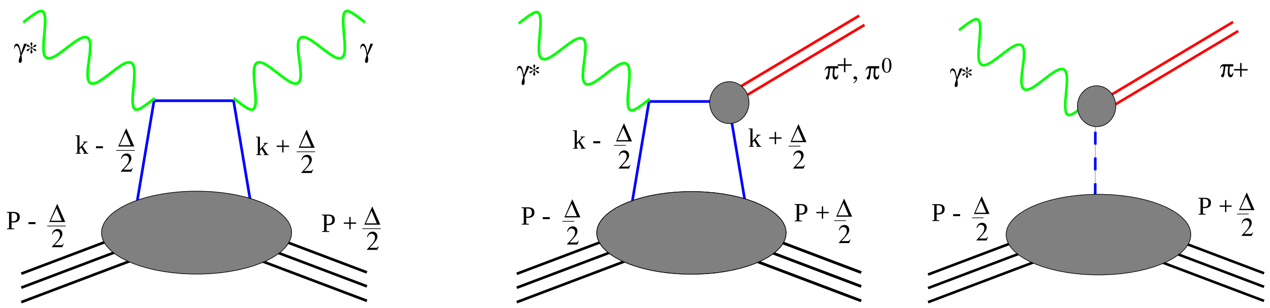
$\boxed{e\ \vec{p} \rightarrow e'\ n\ \pi^+}$

missing mass versus z:



WHY ? __motivation II ___ GPDs

new observables in hard exclusive processes:
Generalised Parton Distributions ($H, E, \tilde{H}, \tilde{E}$)
related to parton distribution functions and
elastic form factors



⇒ access to orbital angular momentum:

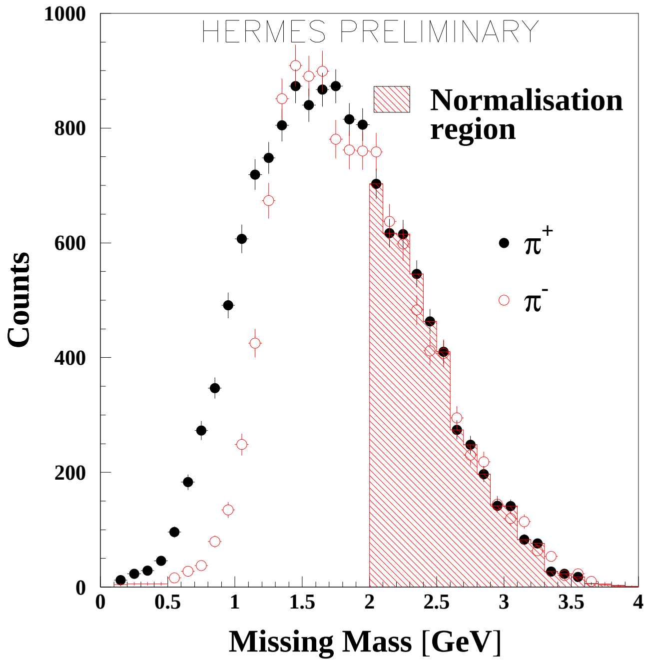
$$\boxed{\int x\mathrm{d}x(H + E) = J_q}$$

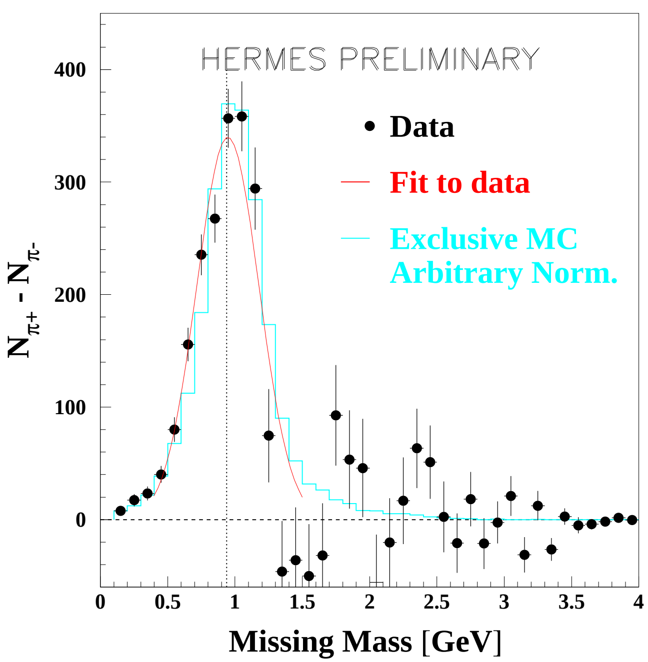
quantum numbers of final state → select different GPDs
DVCS: $H, E, \tilde{H}, \tilde{E}$
vector mesons: H, E
pseudoscalar mesons: $\tilde{H}, \tilde{E}$

quadratic combination of GPDs appear in unpolarised xsection
→ **polarisation** provide **new observable**

$\mathbf{e}\ \vec{\mathrm{p}} \rightarrow \mathbf{e'}\ \mathbf{X}\ \pi^+$

$\mathbf{e}\ \vec{\mathrm{p}} \rightarrow \mathbf{e'}\ \mathbf{n}\ \pi^+$





clear peak at missing mass $\approx \mathrm{M_n}$

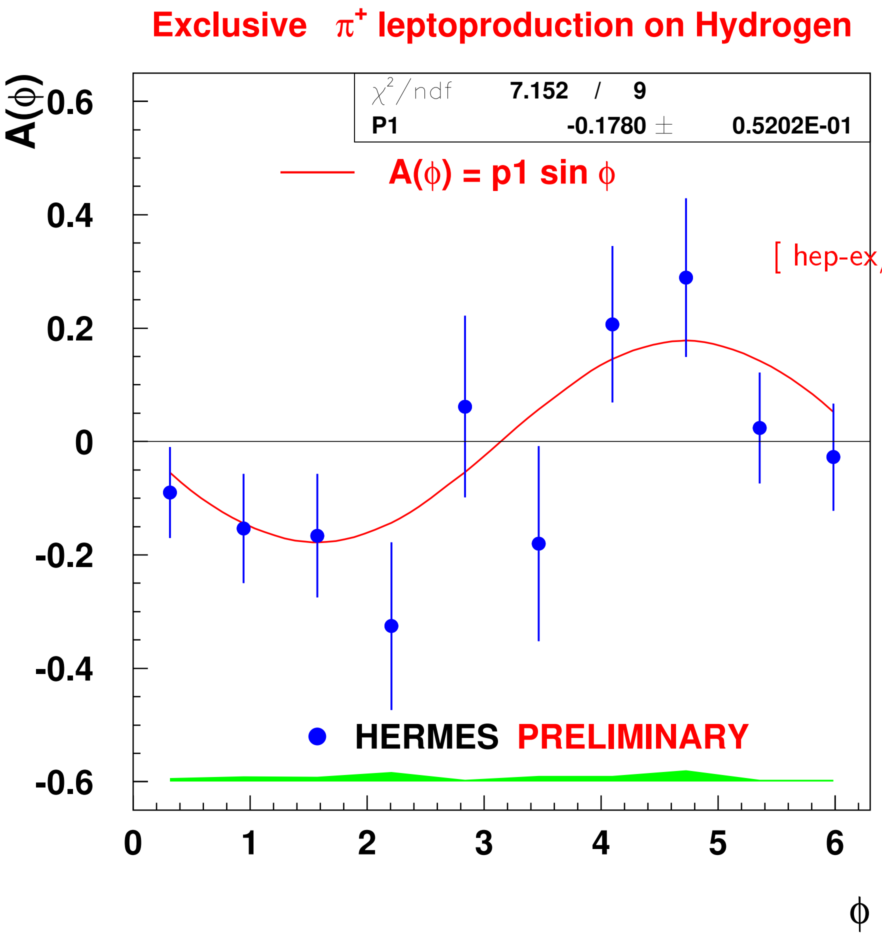
position and width in agreement with GPDs Monte Carlo

possible hints for

$\mathrm{ep} \rightarrow \mathrm{e}'\Delta^{++}\pi^- \quad >$

$\mathrm{ep} \rightarrow \mathrm{e}'\Delta^{0}\pi^+$

single-spin azimuthal asymmetry @ exclusive



[hep-ex/0112002, submitted to PLB]

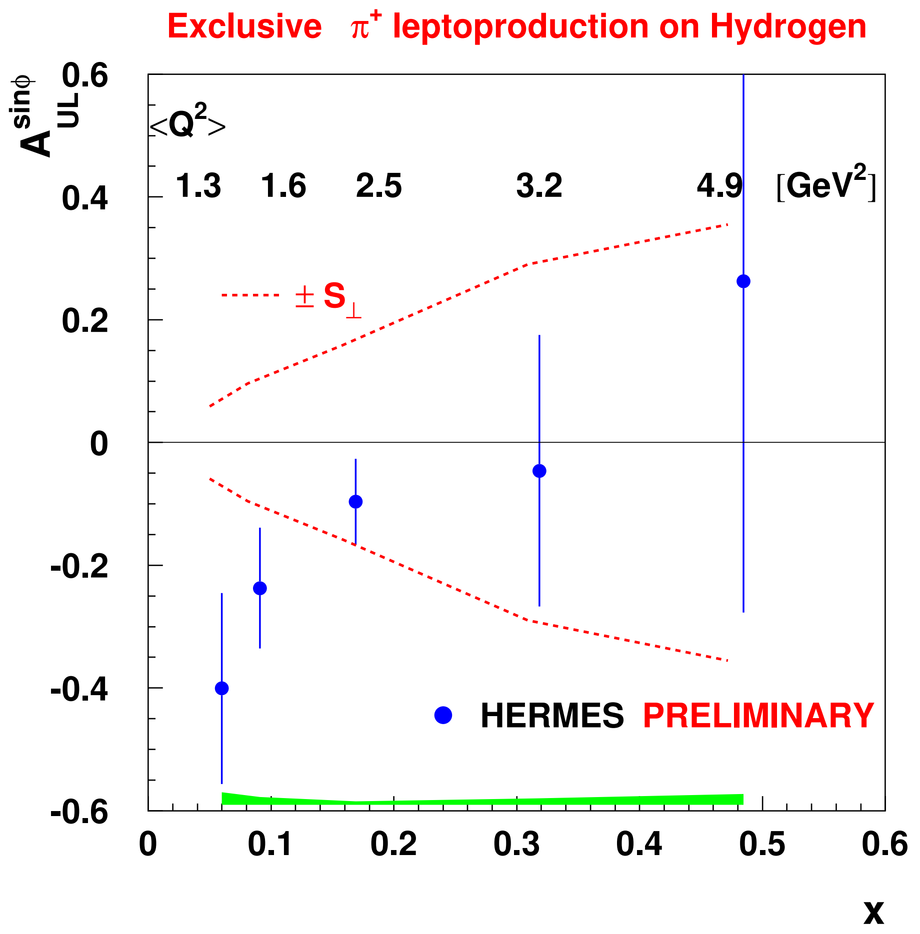
$$A(\phi) = A_{\mathrm{UL}}^{\sin\phi} \cdot \sin\phi$$

$\sin 2\phi$, $\cos\phi$, $\cos 2\phi$ moments

compatible with zero

$$A(\phi) = a\sin\phi + b\sin 2\phi + c\cos\phi + d\cos 2\phi$$

$A_{\mathrm{UL}}^{\sin\phi}$ vs x



$$\sigma_{\mathrm{P}} \sim [S_\perp \sigma_{\mathrm{L}} + S_\| \sigma_{\mathrm{LT}}]$$

$$\downarrow$$

$$S_\perp = S_\perp(x, Q^2)$$

lines indicate limits for any asymmetry arising from *transverse* target component

asymmetry at low x arises from *longitudinal* target component $S_\|$ independently of any model

summary

first observation of single-spin azimuthal asymmetries for semi-inclusive pion electroproduction in DIS:

significant $A_{\mathrm{UL}}^{\sin\phi}$ for π^0 and π^+; $\quad \pi^- \approx 0$

- ∘ u-quark dominance
- ∘ valence quark contribution
- ∘ clear $k_\perp$ contribution (Collins parameterisation)

- ∘ $A_{\mathrm{UL}}^{\sin 2\phi}$ suppressed compared to $A_{\mathrm{UL}}^{\sin\phi}$
- ∘ $A_{\mathrm{LU}}^{\sin\phi}$ compatible with zero

$\Rightarrow$ first evidence of TRANSVERSITY effects in longitudinally polarised target

summary & outlook

first measurement of single-spin azimuthal asymmetry in exclusive π^+ electroproduction:

∘ large negative asymmetry: $A_{\mathrm{UL}}^{\sin\phi} = -0.18 \pm 0.05 \pm 0.01$
∘ asymmetry dominated by *longitudinal* target polarisation component

HERMES-II run 2002^{++}:
measurements with **TRANSVERSE** target polarisation ...

$\Rightarrow$ direct access to h_1
$\Rightarrow$ access to different DF and FF

$\Rightarrow$ possible access to **GPD**s