HERMES measurements of transverse spin asymmetries

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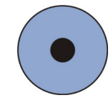
topics:
- transversity distribution
- Sivers distribution

Transversity

Spin structure of the nucleon:

unpolarized distribution f_1 (well known) $f_1 =$ 

helicity distribution g_1 (known) $g_1 =$ 

most precise flavor-separated data by HERMES: PR**D71**,012003 (2005)

transversity distribution h_1 (unmeasured) $h_1 =$ 

Why transversity is interesting:

- completes leading-twist picture of nucleon
- weaker Q^2 evolution than f_1 and g_1
- no gluon transversity
- related to tensor charge (predictions available from LQCD)

helicity sum rule:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L^q + L^g$$

transverse spin sum rule:

$$\frac{1}{2} = \frac{1}{2}\sum_{a=q,\bar{q}}\int dx\, h_1^a + \sum_{a=q,\bar{q},g} L_T^a$$

(PR**D70**,114001,2004)

Transversity @ HERMES

Transversity is studied in 3 ways at HERMES:

	Transversity "signature"		
• $e\,p^{\uparrow} \rightarrow e\,h\,X$ $(h = \pi^{\pm}, \pi^{0}, K^{\pm})$ SSA relates to $h_1 \otimes H_1^{\perp}$	hadron transverse momentum distribution	➡	Collins mechanism
• $e\,p^{\uparrow} \rightarrow e\,h\,h\,X$ $(h\,h = \pi^{+}\pi^{-})$ SSA relates to $h_1 H_1^{\sphericalangle}$	hadron-pair relative trans. mom. distribution	➡	"Interference fragmentation"
• $e\,p^{\uparrow} \rightarrow e\,h^{\uparrow}\,X$ $(h = \Lambda^{0})$ DSA relates to $h_1 H_1$	hadron transverse polarization		

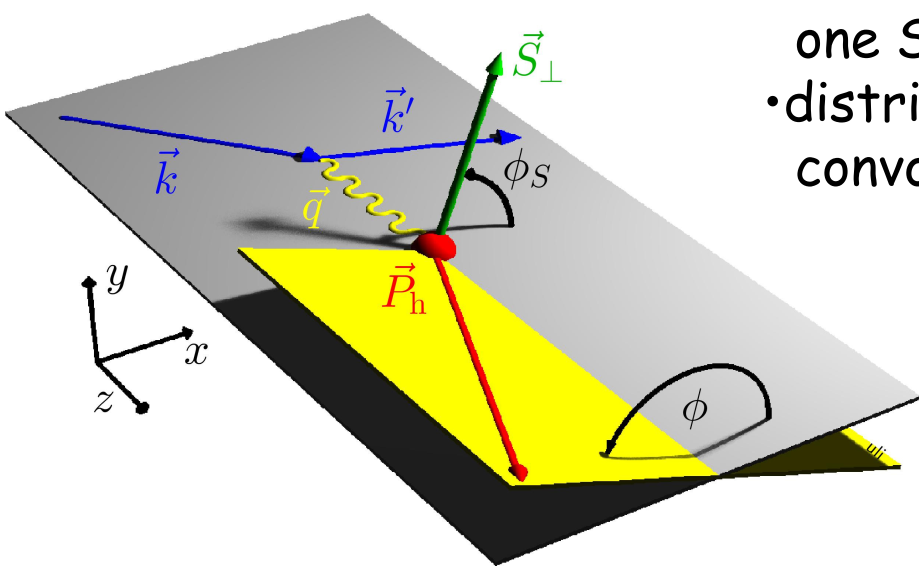
$e\,p^{\uparrow} \rightarrow e\,h\,X$

$$A_{UT} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

Collins amplitude

Sivers amplitude

$$\propto -2|\mathbf{S}_{\perp}|\sin(\phi+\phi_S)\frac{\sum_q e_q^2\, h_1^q \otimes H_1^{\perp q}}{\sum_q e_q^2\, f_1^q \otimes D_1^q} - 2|\mathbf{S}_{\perp}|\sin(\phi-\phi_S)\frac{\sum_q e_q^2\, f_{1T}^{\perp q} \otimes D_1^q}{\sum_q e_q^2\, f_1^q \otimes D_1^q}$$

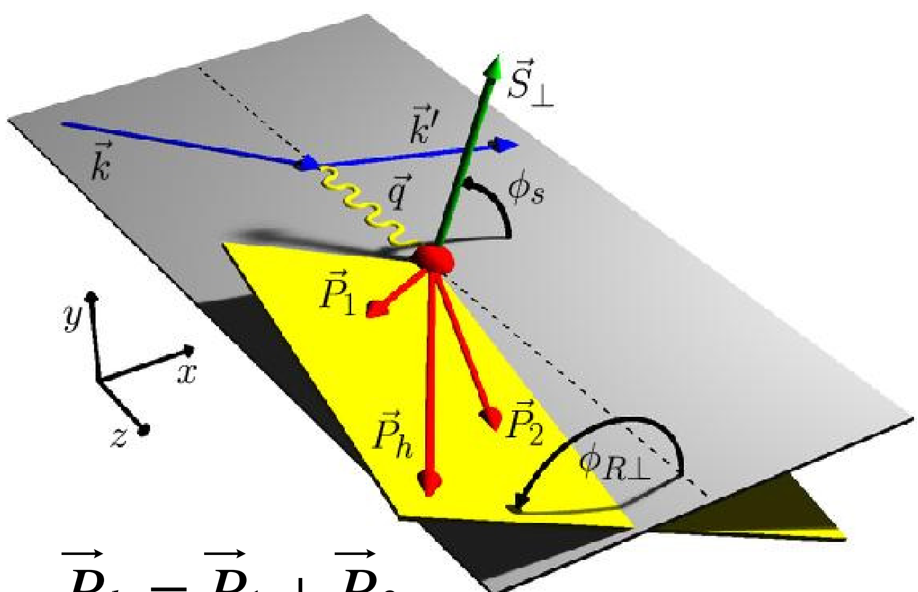


- Several interesting amplitudes contained in one SSA
- distribution and fragmentation functions convoluted in transverse momentum space

$e\,p^{\uparrow} \rightarrow e\,\pi^{+}\pi^{-}\,X$

$$A_{UT} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \qquad \propto |\mathbf{S}_{\perp}| \sin(\phi_{R\perp} + \phi_S) \frac{\sum_q e_q^2 \, h_1^q H_1^{\sphericalangle,sp}}{\sum_q e_q^2 \, f_1^q D_1^q}$$

$$H_1^{\sphericalangle,sp}(z, M_h^2) =$$ interference fragmentation between pion pair in s-wave and p-wave



$$\vec{P}_h = \vec{P}_1 + \vec{P}_2$$

Advantages:

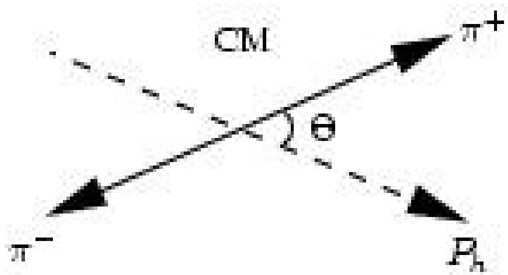
- direct product of transversity and fragmentation function (no convolution)
- easier to calculate Q^2 evolution

Disadvantages:

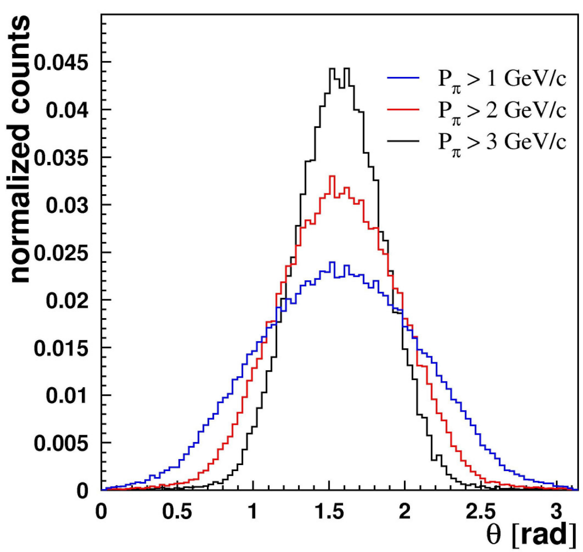
- less statistics
- cross section depends on 9 variables (sensitive to detector acceptance effects)

$e\, p^{\uparrow} \rightarrow e\, \pi^{+}\pi^{-} X$

$$A_{UT} = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \propto |\mathbf{S}_{\perp}| \sin(\phi_{R\perp} + \phi_S) \sin\theta \frac{\sum_q e_q^2\, h_1^q \left[H_1^{\sphericalangle,sp} + H_1^{\sphericalangle,pp} \cos\theta \right]}{\sum_q e_q^2\, f_1^q \left[D_1 + D_1^{sp} \cos\theta + D_1^{pp} \frac{1}{4}(\cos^2\theta - 1) \right]}$$



need to account for incomplete θ coverage: due to momentum selection $P_\pi > 1$ GeV !!!



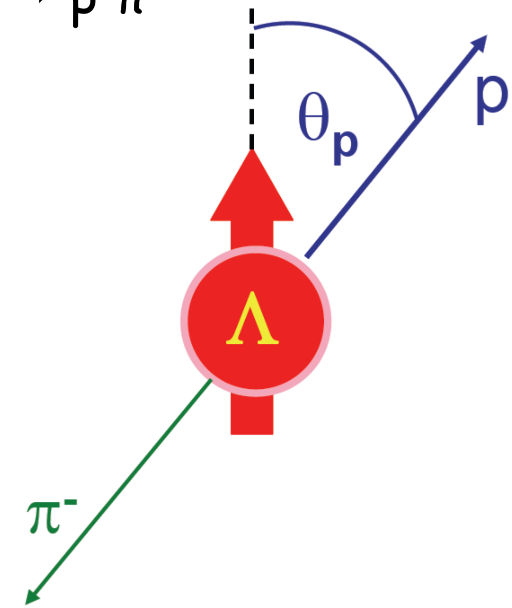
note: true
for any experiment!

$e\,p^{\uparrow} \rightarrow e\,\Lambda^{0\uparrow}\,X$

Λ^0 polarization is obtained through weak decay: $\Lambda^0 \rightarrow p\,\pi^-$

$$\frac{dN}{d\Omega} = \frac{dN_0}{d\Omega}(1 + \alpha\, S_\Lambda \cos\theta)$$

$$\mathbf{S}_\Lambda \propto \mathbf{S}_\perp \frac{\sum_q e_q^2\, h_1^q H_1^{q\rightarrow\Lambda}}{\sum_q e_q^2\, f_1^q D_1^{q\rightarrow\Lambda}}$$

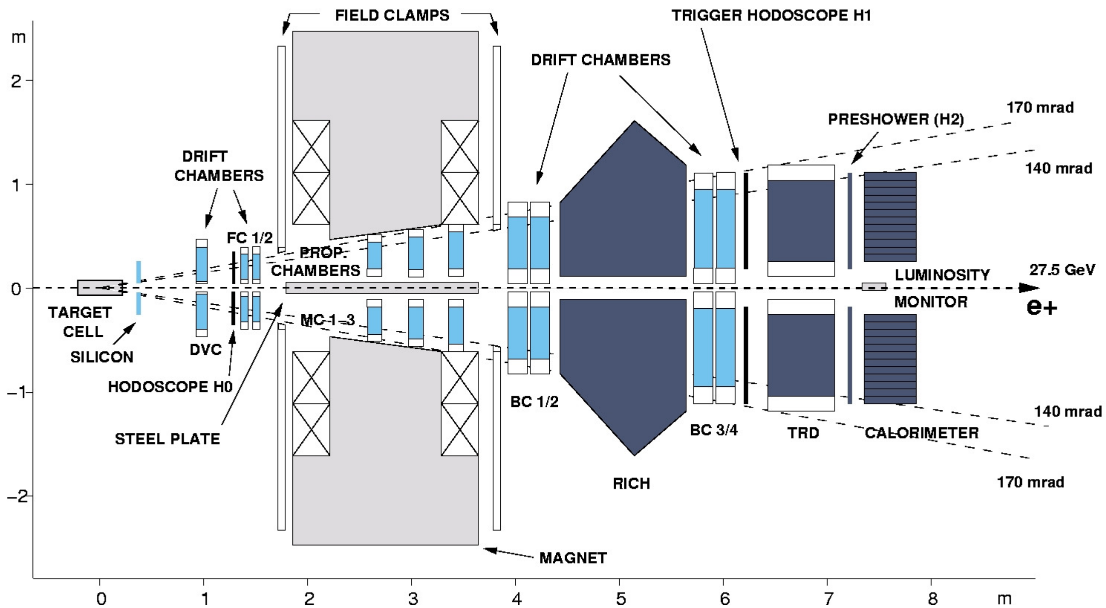


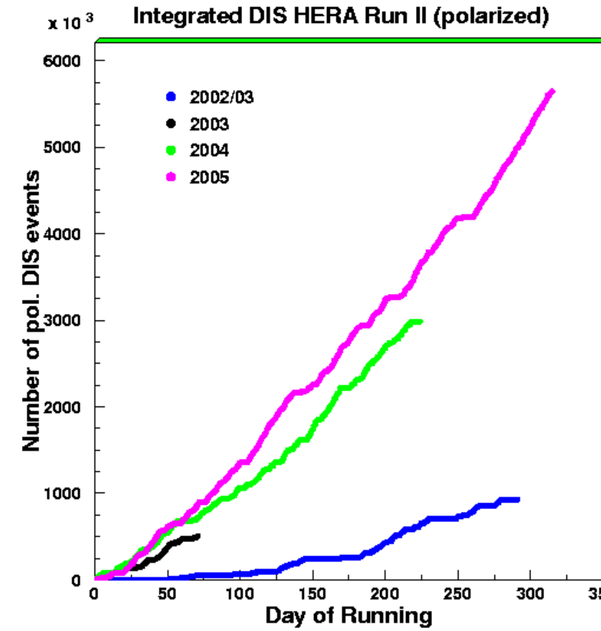
Characteristics:
- direct product of h_1 and H_1
- small Λ^0 yield
- difficult to select Λ's coming from struck quark
- small polarization tranfer expected (comp. long. case)

not very realistic probe of transversity...

No HERMES results available, see:
PhD thesis M. Demey (Mar 2007, UvA)
for results and discussion of analysis on:
The polarization of Λ^0 hyperons in quasi-real photoproduction
(very small average Q^2 ($Q^2 \approx 0.0$)

The HERMES spectrometer

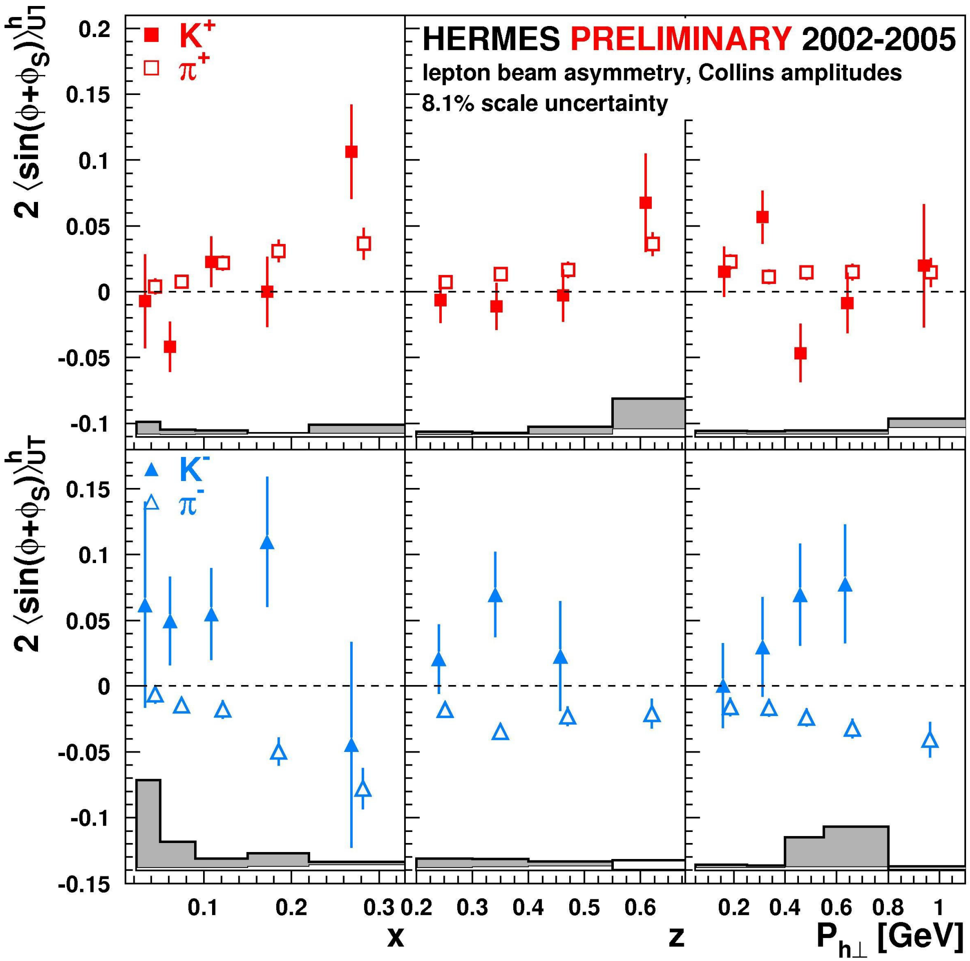




- kinematic range: $0.2 < Q^2 < 20\ GeV^2$, $0.004 < x < 0.9$
  (for $Q^2 > 1\ GeV^2$: $x > 0.02$)
- resolution: $\delta p/p \sim 2\%$, $\delta\theta < 1$ mrad
- lepton/hadron separation: $\varepsilon \sim 98\%$, contamination <1%
- hadron PID (p,K,π) with RICH in range $2 < P < 15$ GeV

Collins amplitudes

$$\langle \sin(\phi+\phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$



results from entire data taking period with transversely polarized target (2002 -2005):

- opposite amplitudes for π^+ and π^-
- unexpectedly large π^- amplitudes, indicating:

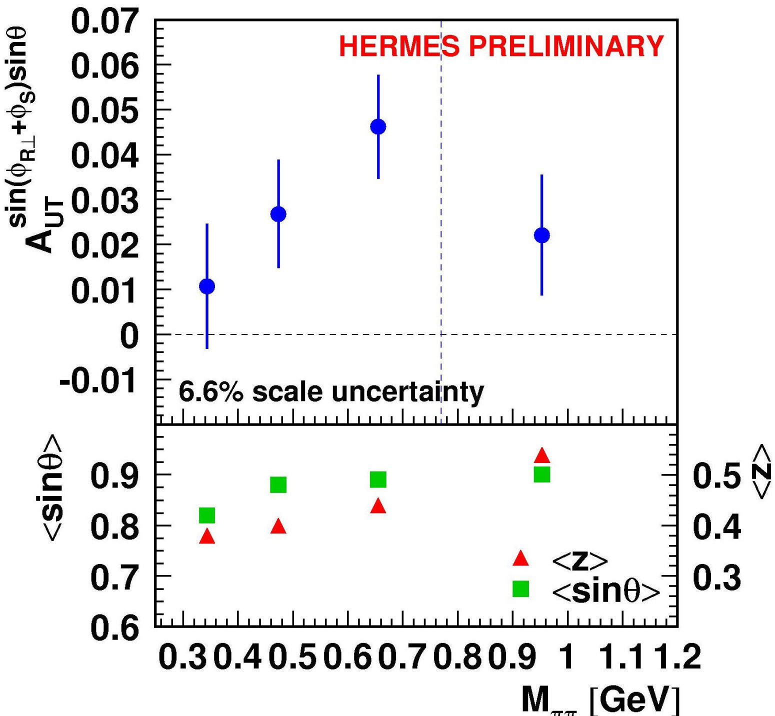
$$H_1^{\perp,\mathrm{unfav}}(z) = -H_1^{\perp,\mathrm{fav}}(z)$$

- amplitudes for kaons not significantly non-zero
- measurement of $H_1^{\perp,q} \otimes H_1^{\perp,\bar{q}}$ performed by:

PRL**96**,232002 (2006)

allowed Anselmino et al. to extract transversity!!! (PR**D75**,054032 (2007); contribution from COMPASS data)

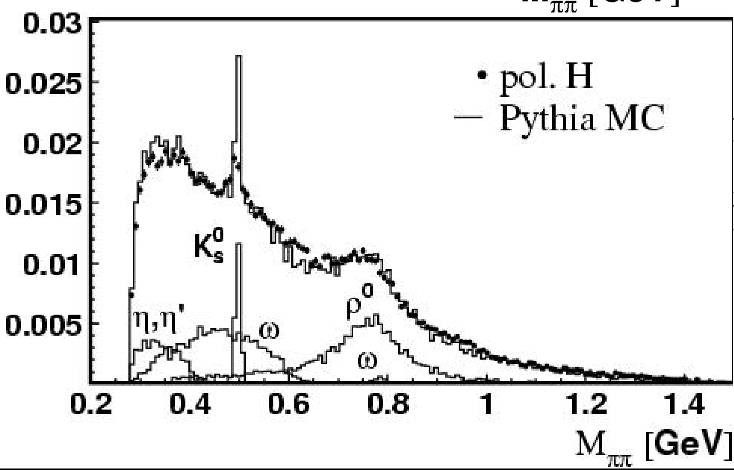
2-hadron asymmetries



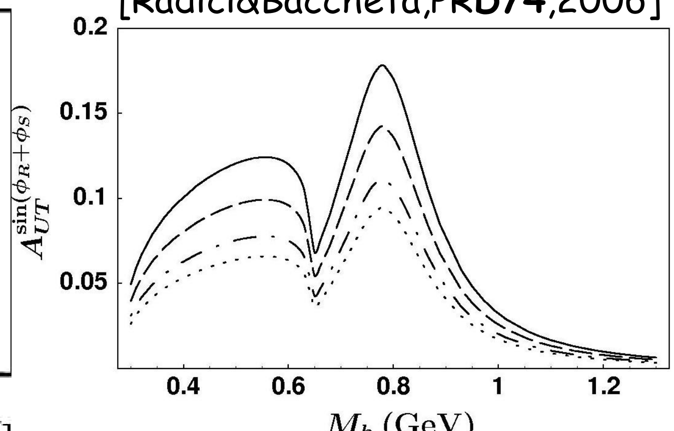
- significantly non-zero amplitudes (2002-2004):
  2-hadron fragmentation probes transversity!
- inconsistent with model of Jaffe et al. for $H_1^{\sphericalangle,sp}$
- model of Bacchetta & Radici:
  - overestimates amplitudes
  - consistent with mass dependence
- MC studies: nonlinear mass dependence of amplitude

→ [0%,+44%] (rel.) systematic uncertainty (detector acceptance effect)

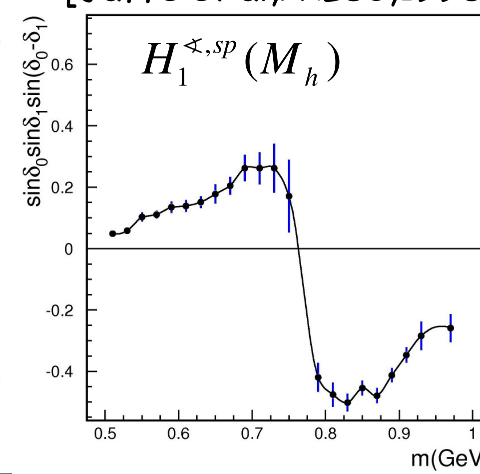
- BELLE intends to measure 2-hadron FF's



[Radici&Baccheta,PR**D74**,2006]

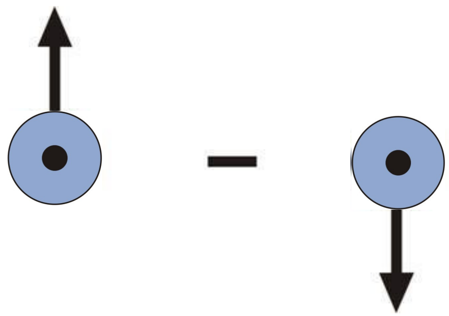


[Jaffe et al,PRL**80**,1998]



The  function

"tranverse momentum distribution of unpolarized quarks in a transversely polarized proton"

$f_{1T}^{\perp} =$ 

- chiral-even, naive T-odd function
- non-zero Sivers function implies non-zero orbital angular momentum

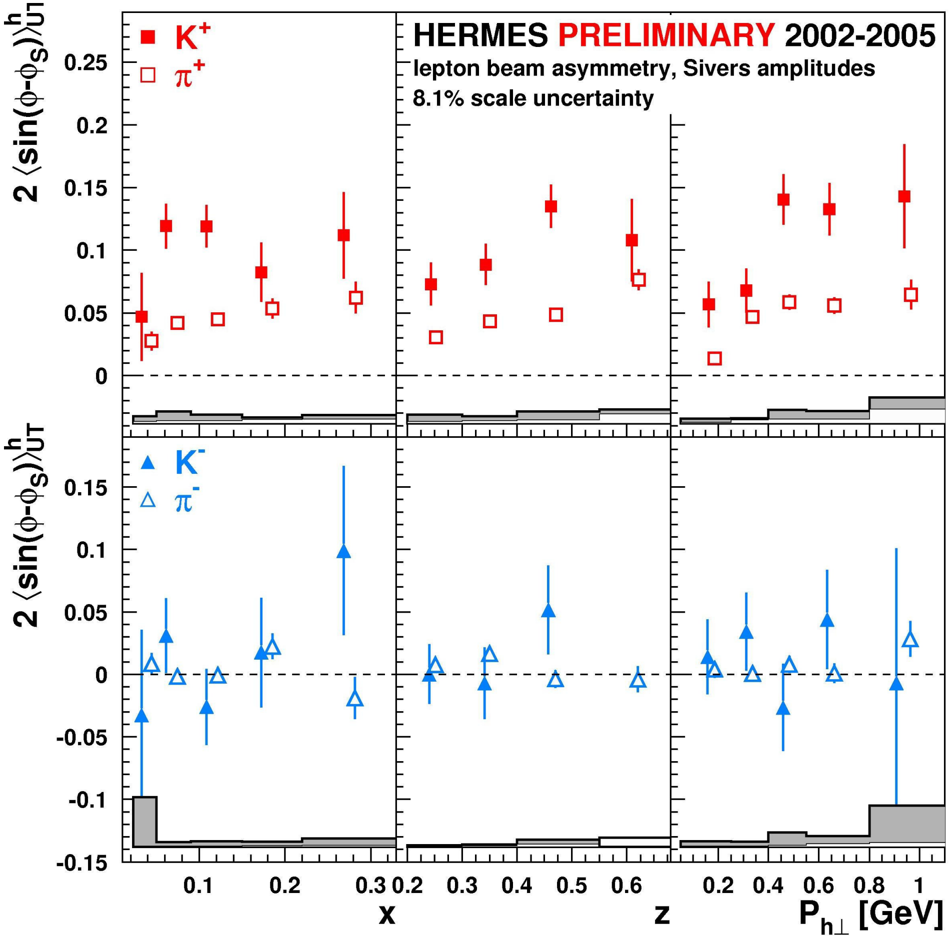
First proposed by Sivers to explain SSA in p $p^{\uparrow} \rightarrow \pi$ X scattering (PR**D41**, 83, 1990)
Proven that it can exist at leading twist by Brodsky, Hwang, Schmidt (PL**B530**, 99, 2002)

universality prediction can be tested:

$$f_{1T}^{\perp}(x)_{DIS} = -f_{1T}^{\perp}(x)_{DY}$$

Sivers amplitudes

$$\langle \sin(\phi - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

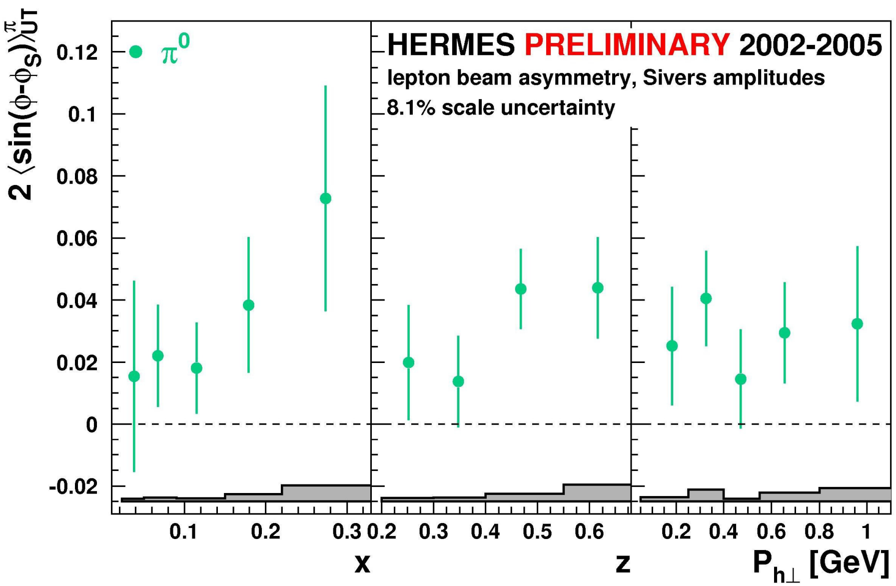


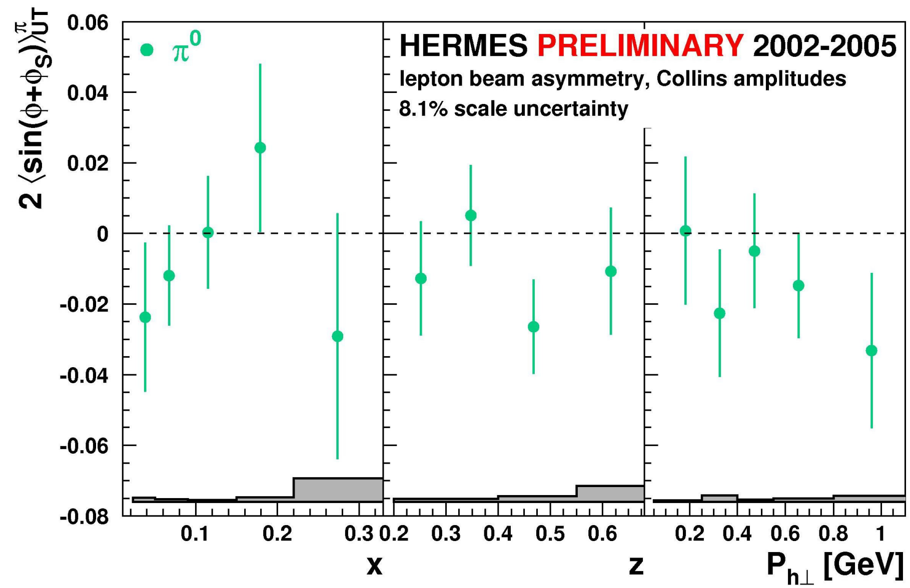
- significantly positive amplitudes for π^+ and K^+ ,which indicates:
  - non-zero L_z^q
  - existence naive T-odd distribution functions

- K^+ amplitude > π^+ amplitude: influence of anti-quarks

- π^- and K^- consistent with zero

SSA's for neutral pions





Using charge conjugation and isospin symmetry, π^+, π^- and π^0 amplitudes can be related:

$$\left\langle \sin(\phi \pm \phi_S) \right\rangle_{UT}^{\pi^+} + C \left\langle \sin(\phi \pm \phi_S) \right\rangle_{UT}^{\pi^-} - (1+C) \left\langle \sin(\phi \pm \phi_S) \right\rangle_{UT}^{\pi^0} = 0$$

HERMES results fulfill isospin symmetry

$$C = \frac{\sigma_{UU}^{\pi^+}}{\sigma_{UU}^{\pi^-}}$$

concluding remarks

- Presented exciting new high(er)-precision results for Collins and Sivers amplitudes from HERMES 2002-2005 data taking period with transversely polarized hydrogen

- Although 2-hadron transverse SSA's have large uncertainties, they are able to distinguish between models and...

- For the 2-hadron transverse SSA's the 2005 data still needs to be included (double the statistics)

Thank you!