Recent results on angular momentum and strangeness in the nucleon

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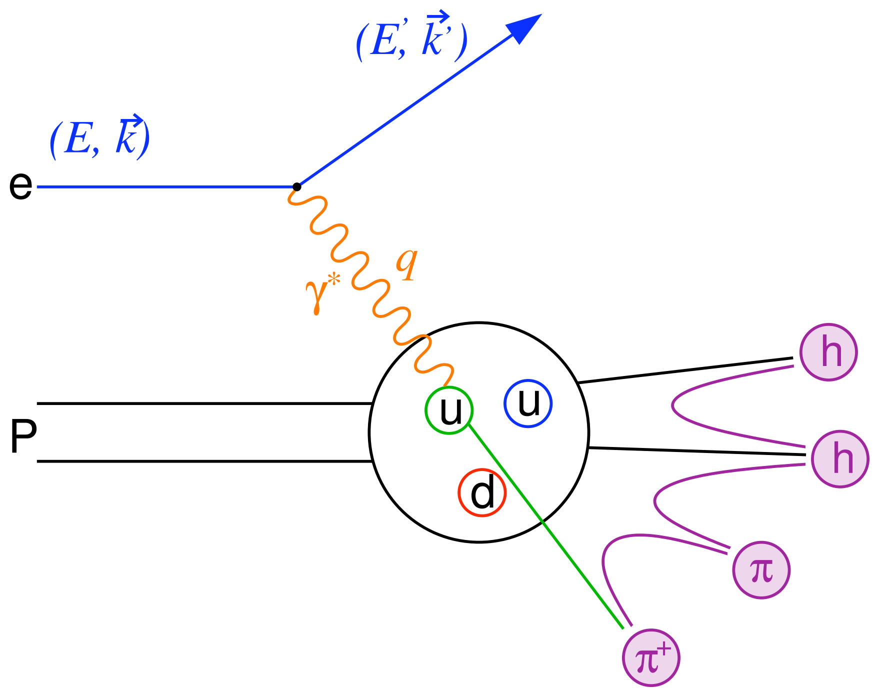
(DESY)

for the hermes collaboration

- Transverse single-spin asymmetries on hydrogen target
  ⇒Collins and Sivers effects
- extraction of strange quark distributions from an isoscalar deuteron target

DIS: probing the nucleon structure

$e^{+,-}$ @ 27.6 GeV (HERA)



$$Q^2 = -q^2 = -(k-k')^2$$
$$\nu \overset{lab}{=} E - E'$$
$$x = \frac{Q^2}{2M\nu}$$
$$z \overset{lab}{=} \frac{E_{\rm had}}{\nu}$$

Targets:
H: $\langle P_{\rm trans}\rangle \sim 74\pm6\%$
D: $\langle P_{\rm long}\rangle \sim 84.5 \pm3.5\%$

Cross section contains Distribution Functions and Fragmentation Functions:

$$\sigma^{ep\to eh} \sim \sum_q \mathrm{DF}^{p\to q} \otimes \sigma^{eq\to eq} \otimes \mathrm{FF}^{q\to h}$$

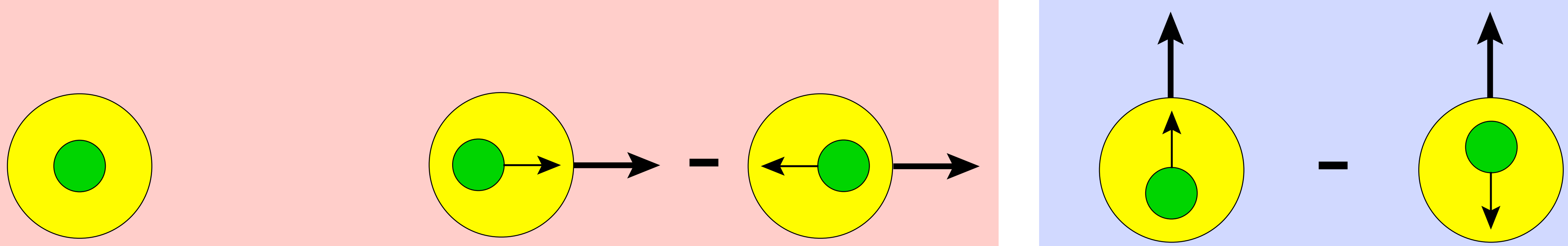
DF: distribution of quarks in the nucleon
FF: fragmentation of (struck) quark into hadronic final state

Distribution functions

Leading twist:

3 DFs survive integration over transverse quark momenta

momentum distribution	helicity distribution	transversity distribution
$q(x)$	$\Delta q(x)$	$\delta q(x) = h_1^q(x)$



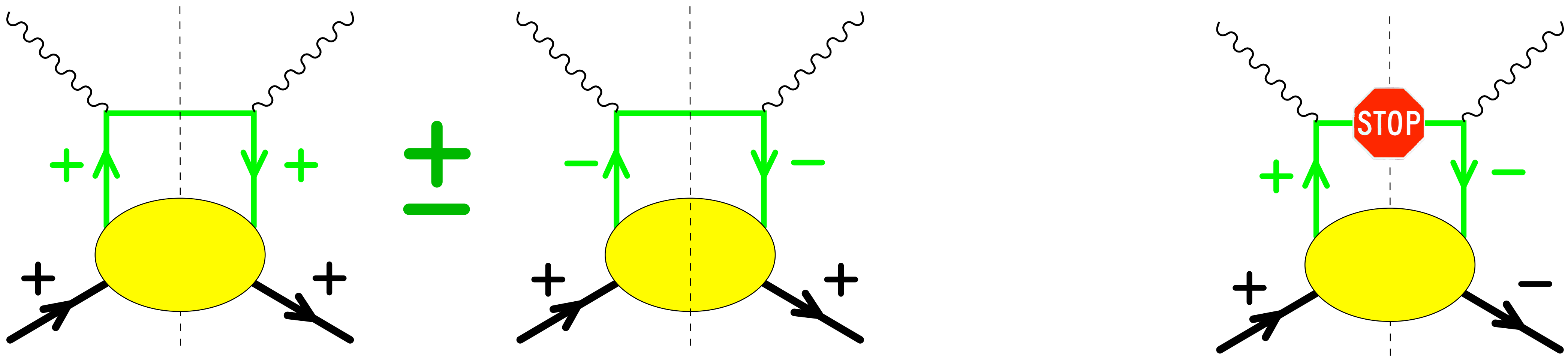
helicity basis

basis of transv. spin eigenstates

all three DFs needed for complete description of the nucleon!

Transversity δq

- non-relativistic quarks: $\Delta q = \delta q$
- δq: helicity-flip of the quark ⇒chiral-odd



$+ \Rightarrow q(x)$ $\quad - \Rightarrow \Delta q(x)$ $\qquad \delta q(x)$

Transversity δq

- non-relativistic quarks: $\Delta q = \delta q$
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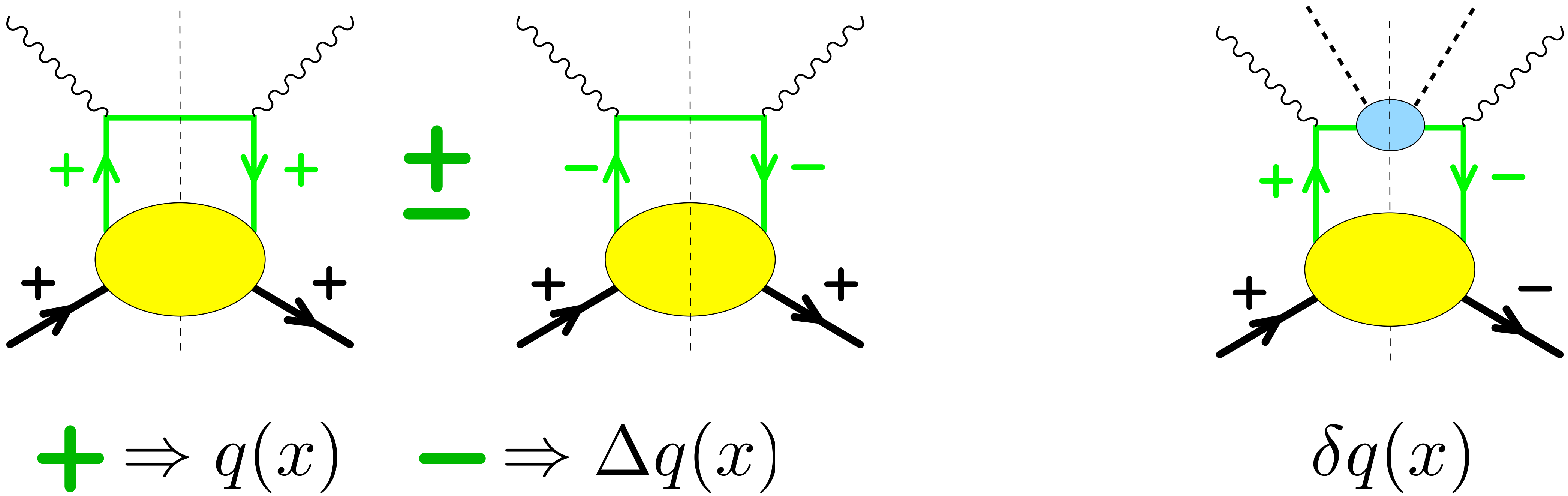
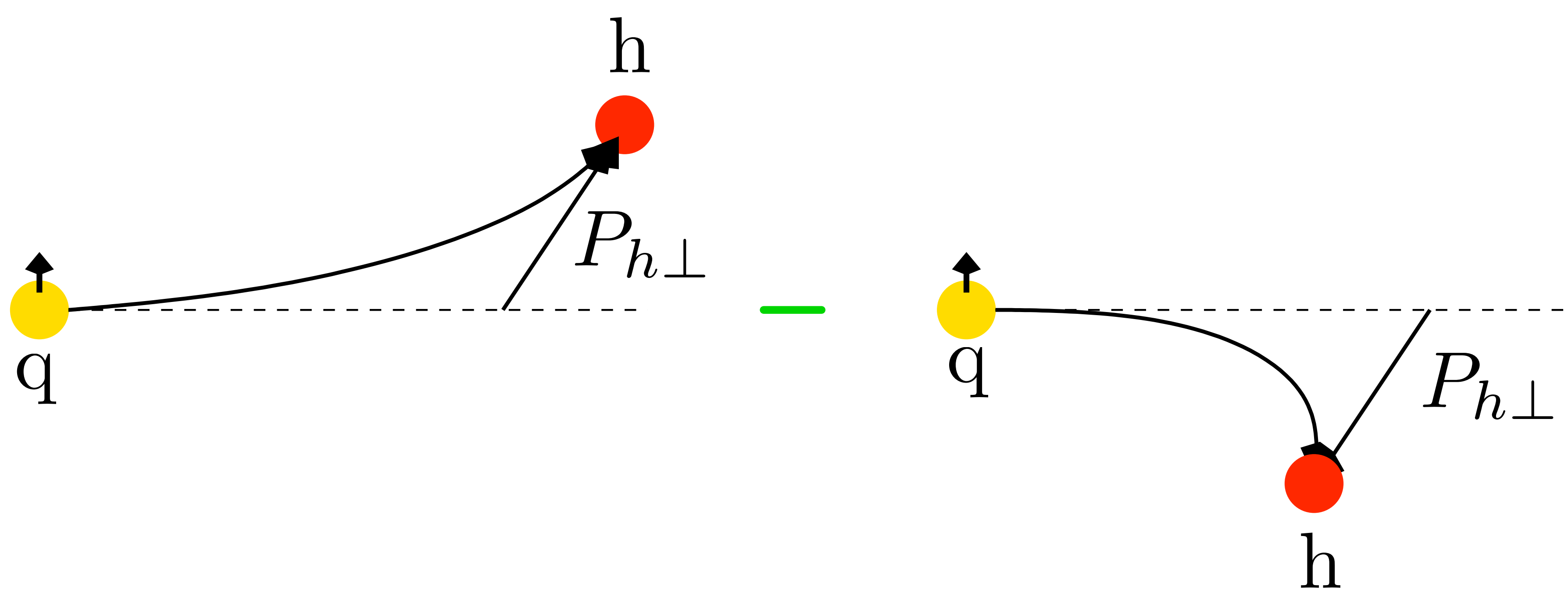


- access to δq in combination with another chiral odd object
  ⇒ Collins-FF $H_1^\perp$

Collins Effect

- Collins fragmentation function $H_1^{\perp}$
- naive time reversal odd $\Longleftrightarrow$ final state interactions
  $\Rightarrow$ azimuthal single-spin asymmetries
- describes correlation between transverse polarisation of fragmenting quark and the transverse momentum $P_{h\perp}$ of the produced (unpolarised) hadron



Azimuthal Asymmetries

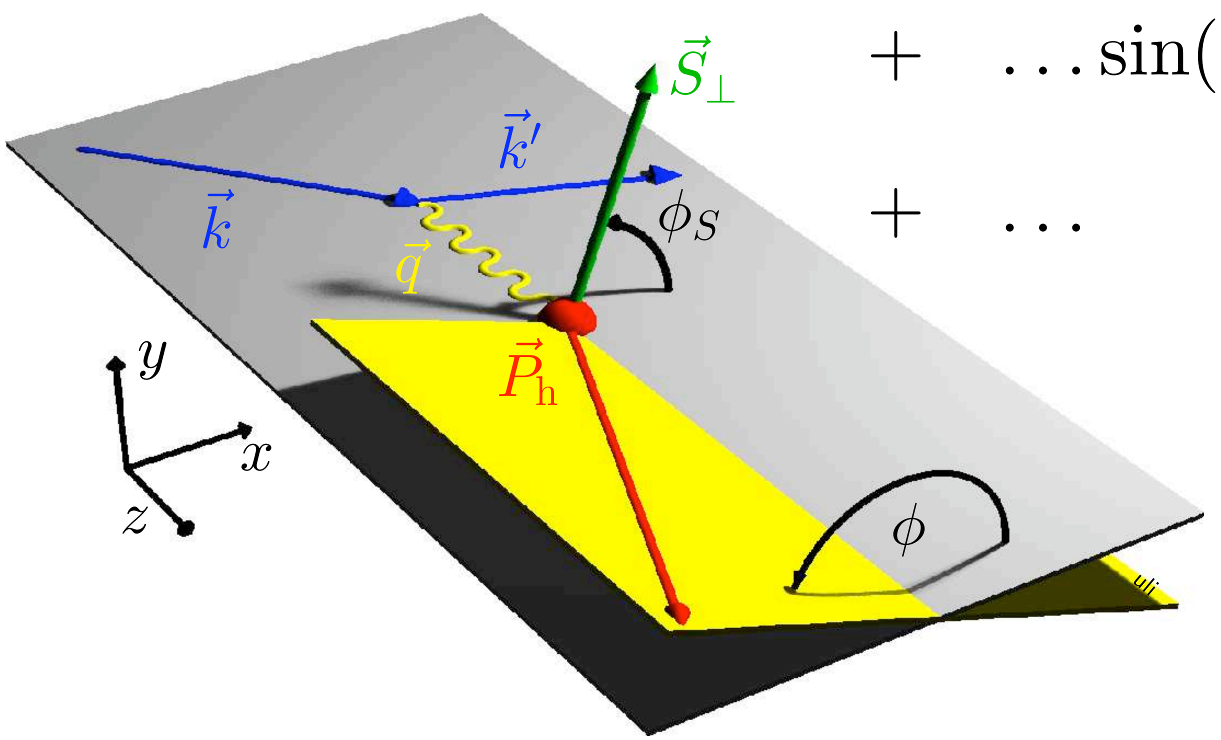
Measurement of cross-section asymmetries depending on the azimuthal angles ϕ and ϕ_S

$$A_{UT}(\phi, \phi_S, \ldots) = \frac{1}{S_\perp} \frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

$$\sim \ldots \sin(\phi + \phi_S) \frac{\sum_q e_q^2 \, \mathcal{I}\left[\ldots \delta q(x, \vec{p}_T^{\,2}) \cdot H_1^{\perp q}(z, \vec{k}_T^{\,2})\right]}{\sum_q e_q^2 \, q(x) \cdot D_1^q(z)}$$

$$+ \ldots \sin(\phi - \phi_S) \frac{\sum_q e_q^2 \, \mathcal{I}\left[\ldots f_{1T}^{\perp q}(x, \vec{p}_T^{\,2}) \cdot D_1^q(z, \vec{k}_T^{\,2})\right]}{\sum_q e_q^2 \, q(x) \cdot D_1^q(z)}$$

$$+ \ldots$$



$\mathcal{I}[\ldots]$: convolution integral over initial (p_T) and final (k_T) quark transverse momenta

Azimuthal Asymmetries

Measurement of cross-section asymmetries depending on the azimuthal angles Φ and Φ_S

$$A_{UT}(\phi, \phi_S, \ldots) = \frac{1}{S_\perp} \frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

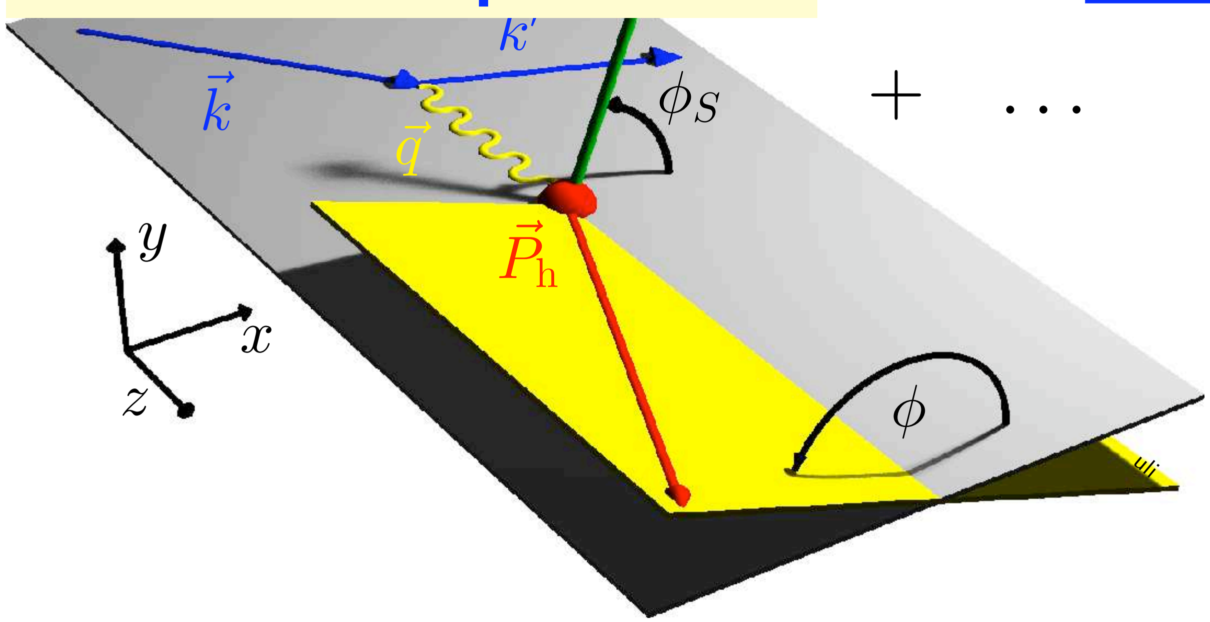
Collins Amplitude

$$\sim \ldots \sin(\phi + \phi_S) \frac{\sum_q e_q^2 \, \mathcal{I}\left[\ldots \delta q(x, \vec{p}_T^{\,2}) \cdot H_1^{\perp q}(z, \vec{k}_T^{\,2})\right]}{\sum_q e_q^2 \, q(x) \cdot D_1^q(z)}$$

Sivers Amplitude

$$+ \ldots \sin(\phi - \phi_S) \frac{\sum_q e_q^2 \, \mathcal{I}\left[\ldots f_{1T}^{\perp q}(x, \vec{p}_T^{\,2}) \cdot D_1^q(z, \vec{k}_T^{\,2})\right]}{\sum_q e_q^2 \, q(x) \cdot D_1^q(z)}$$

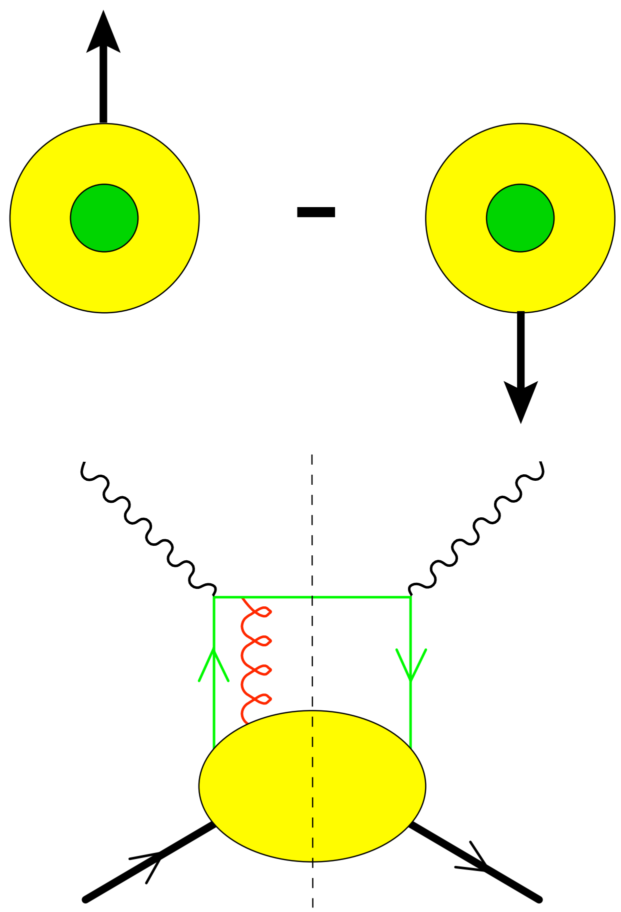
$$+ \ldots$$



$\mathcal{I}[\ldots]$: convolution integral over initial (p_T) and final (k_T) quark transverse momenta

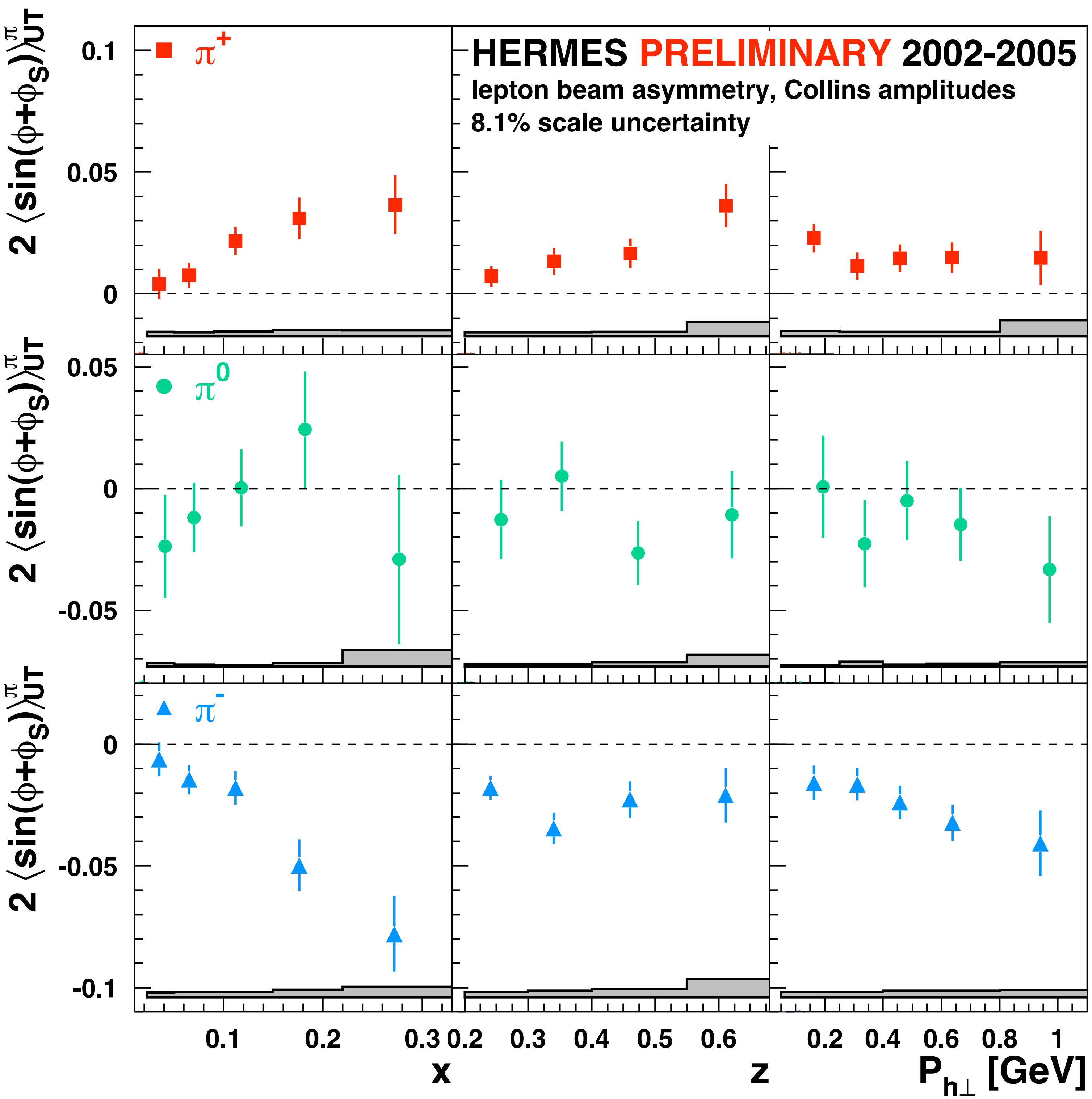
Sivers function

- describes correlation between intrinsic transverse quark momentum (p_T) and transverse nucleon spin
- Chiral-even function
- T-odd functions allowed due to final state interactions (FSI):
  quark rescattering via a soft gluon
  ➡ time-reversal invariance condition changes
  ➡ naive T-odd



- non-zero Sivers function requires non-vanishing orbital angular momentum in the nucleon wave function (can contribute to nucleon spin!)

Collins Amplitudes for Pions



$$A_C \propto \delta q \otimes H_1^{\perp}$$

- positive amplitudes for π^+
- large negative π^- amplitude

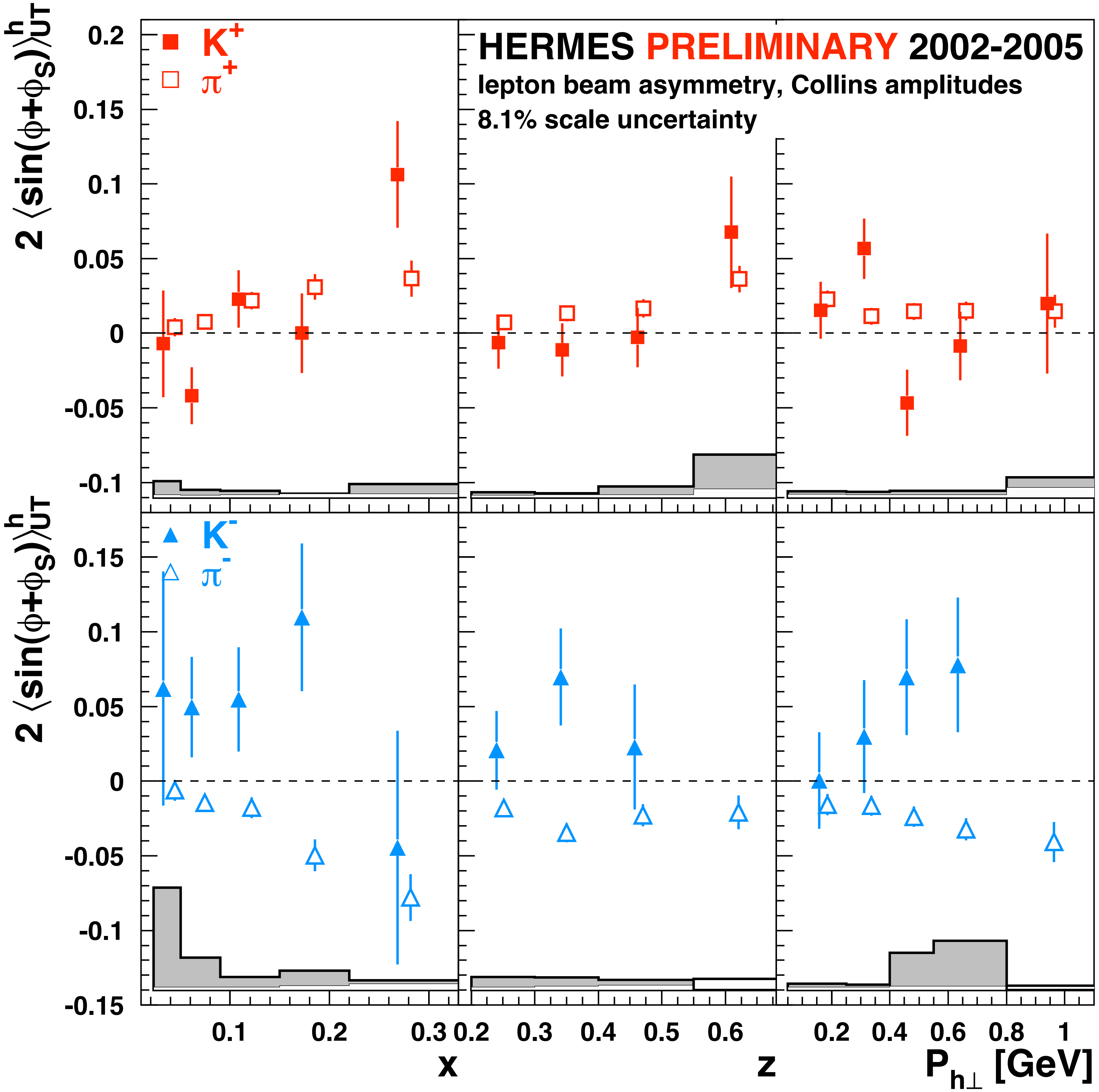
$$u \rightarrow \pi^+ \quad \Rightarrow \quad H_1^{\perp,\mathrm{fav}}$$

$$u \rightarrow \pi^- \quad \Rightarrow \quad H_1^{\perp,\mathrm{unfav}}$$

$$\Rightarrow \quad H_1^{\perp,\mathrm{fav}} \approx -H_1^{\perp,\mathrm{unfav}}$$

- isospin symmetry of π-mesons is fulfilled
- information from another process on Collins FF (BELLE) allows extraction of δq (eg Anselmino et al Phys.Rev.D75:054032,2007)

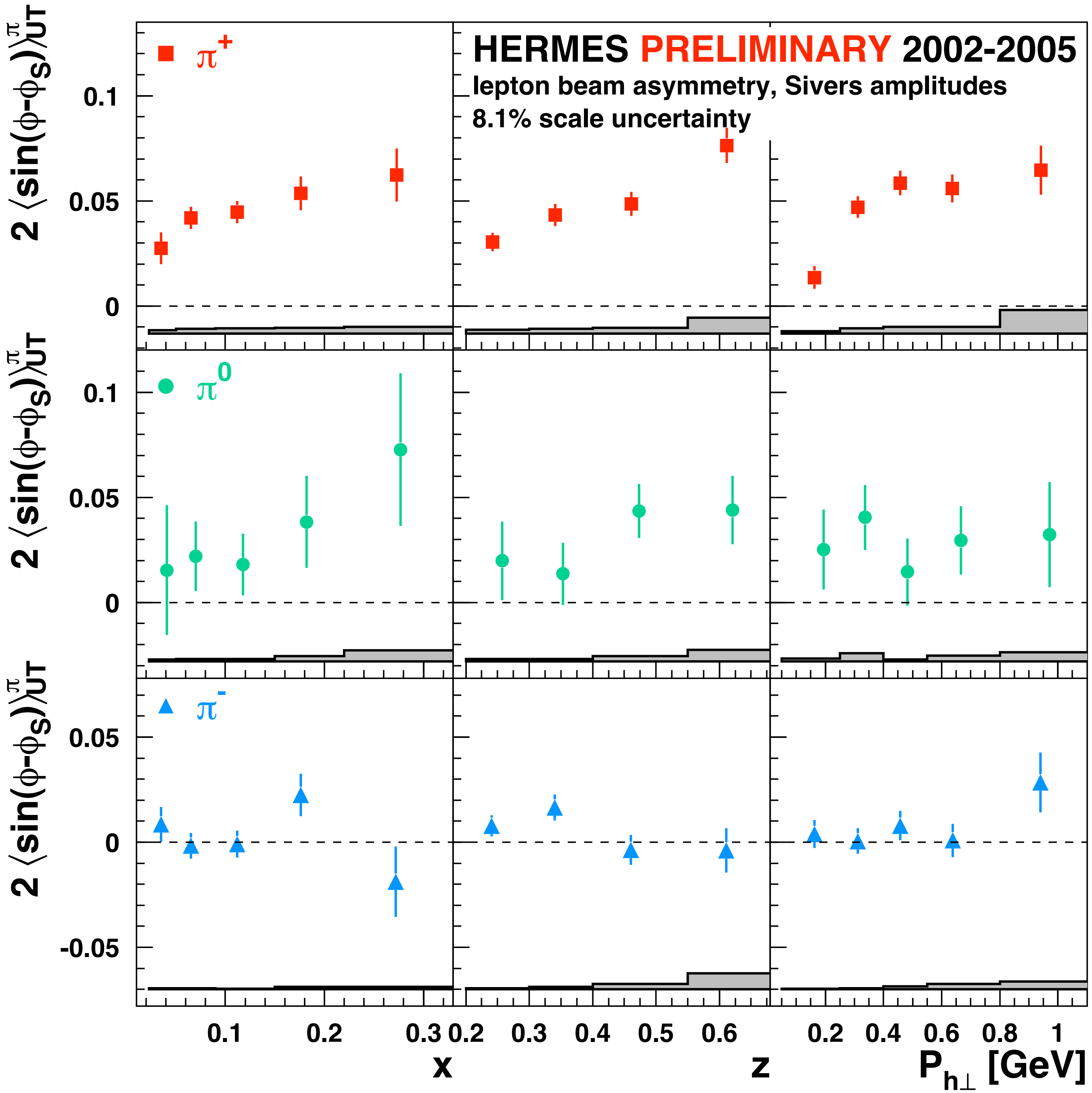
Collins Amplitudes for Kaons



$$A_C \propto \delta q \otimes H_1^{\perp}$$

- no significant non-zero Collins amplitudes for both K^+ and K^-
- Collins amplitudes for K^+ are within statistical accuracy consistent with π^+

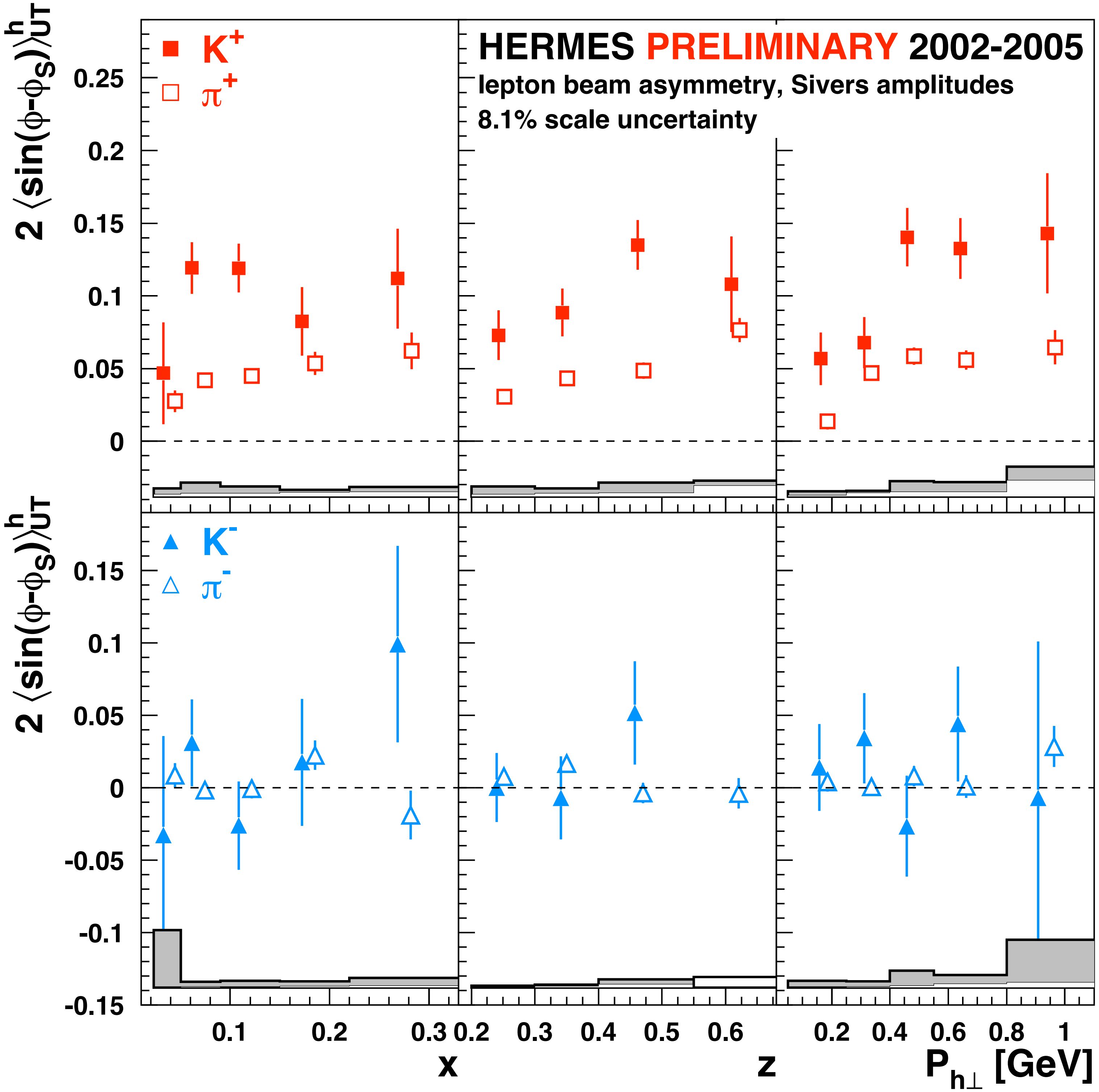
Sivers Amplitudes for Pions



$$A_S \propto f_{1T}^{\perp} \otimes D_1^q$$

- significantly positive for π^+
- implies non-zero angular momentum of quarks
- consistent with zero for π^-
- isospin symmetry of π-mesons fulfilled

Sivers Amplitudes for Kaons



$$A_S \propto f_{1T}^{\perp} \otimes D_1^q$$

- significantly positive for K^+
- implies non-zero angular momentum of quarks
- consistent with zero for K^-
- K^+ amplitude larger than π^+ amplitude

strange contribution to Sivers mechanism may be important

$$\pi^+ = |u\bar{d}\rangle \quad K^+ = |u\bar{s}\rangle$$

Strangeness in the nucleon

Strange PDFs with isoscalar target

Assumptions:
- isospin symmetry between proton and neutron
- charge conjugation invariance in fragmentation

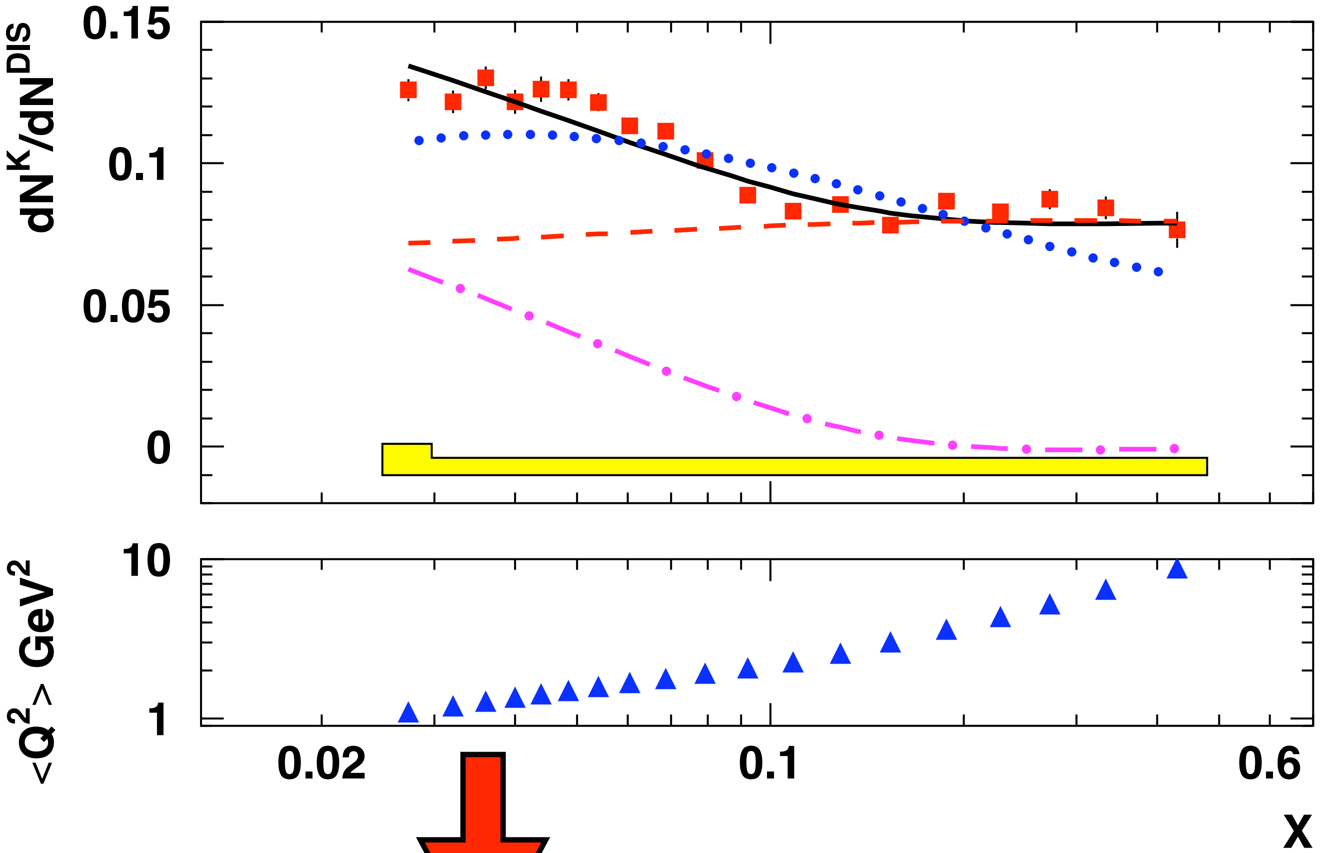
- strange quarks carry no isospin ⇒ $s(x)_{\text{Proton}} = s(x)_{\text{Neutron}}$
- deuteron target (isoscalar!): fragmentation process in DIS can be described by isospin independent FFs
- Charged kaon multiplicity in LO:

$$\frac{dN^{\mathrm{K}}(x)}{dN^{\mathrm{DIS}}(x)} = \frac{Q(x)\int D_Q^{\mathrm{K}}(z)dz + S(x)\int D_S^{\mathrm{K}}(z)dz}{5Q(x)+2S(x)}$$

$$Q(x) \equiv u(x) + \bar{u}(x) + d(x) + \bar{d}(x) \qquad D_Q^{\mathrm{K}} \equiv 4D_u^{\mathrm{K}}(z) + D_d^{\mathrm{K}}(z)$$

$$S(x) \equiv s(x) + \bar{s}(x) \qquad D_S^{K}(z) \equiv 2D_s^{\mathrm{K}}(z)$$

Fitting $dN^K(x)/dN^{DIS}(x)$



Assuming S(x)=0 for x>0.15:

$$\int_{0.2}^{0.8} D_Q^K(z)dz = 0.398 \pm 0.010$$

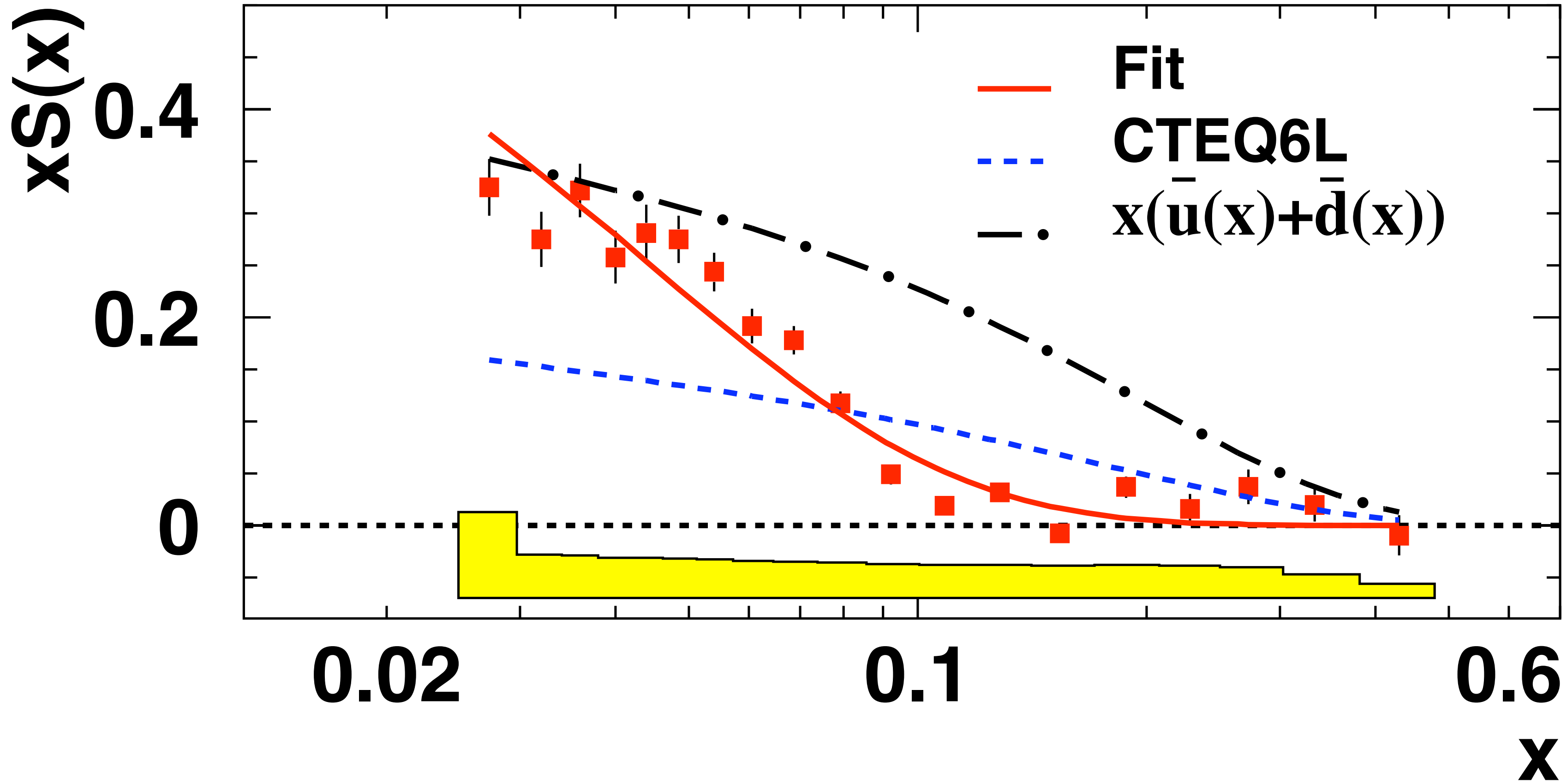
de Florian et al., PRD75, 114010 (2007):

$$\int_{0.2}^{0.8} D_Q^K(z)dz = 0.435 \pm 0.044$$

$$\frac{dN^K(x)}{dN^{DIS}(x)} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x) + 2S(x)}$$

CTEQ6L

S(x) at Q^2_0=2.5 GeV^2



- xS(x) obtained by evolution of data to Q^2_0=2.5 GeV^2 using

$$\int_{0.2}^{0.8} D_S^{\mathrm{K}}(z)dz = 1.27 \pm 0.13$$

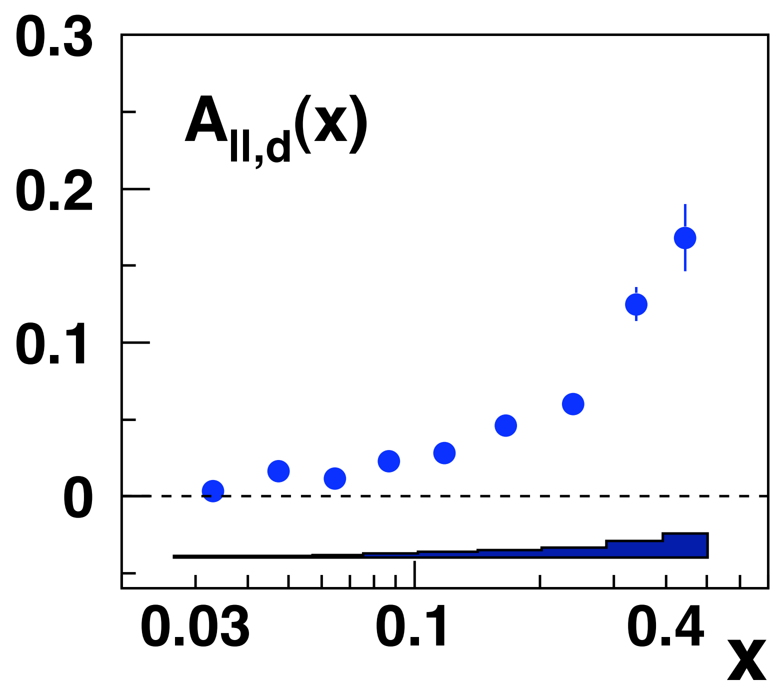
de Florian et al., PRD75, 114010 (2007)

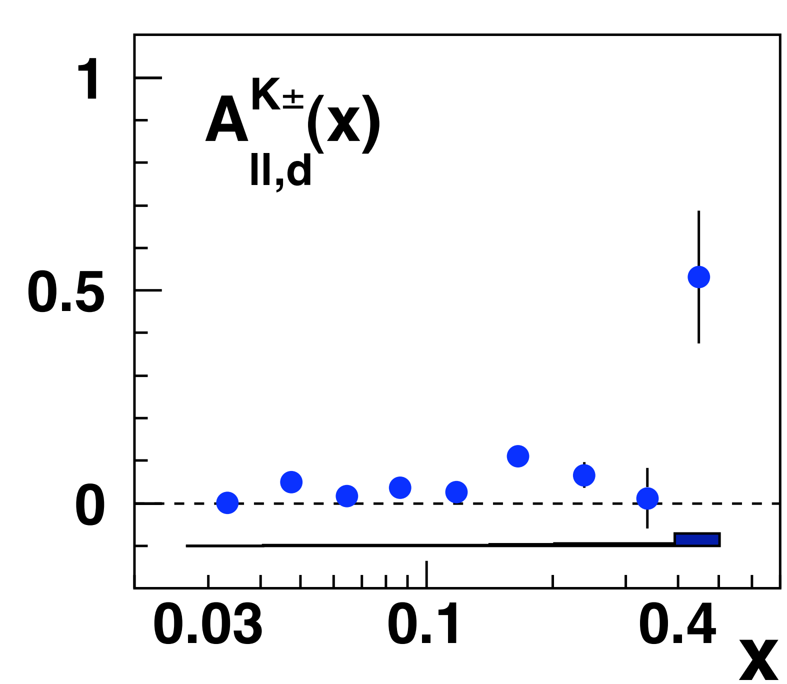
- Shape incompatible with CTEQ6L and with average of the isoscalar nonstrange sea

Extraction of ΔQ(x) and ΔS(x)

Double spin asymmetries from long. pol. deuteron target

$$A_{||}^{(h)} = \frac{\sigma^{\overrightarrow{\Leftarrow},(h)} - \sigma^{\overrightarrow{\Rightarrow},(h)}}{\sigma^{\overrightarrow{\Leftarrow},(h)} + \sigma^{\overrightarrow{\Rightarrow},(h)}}$$





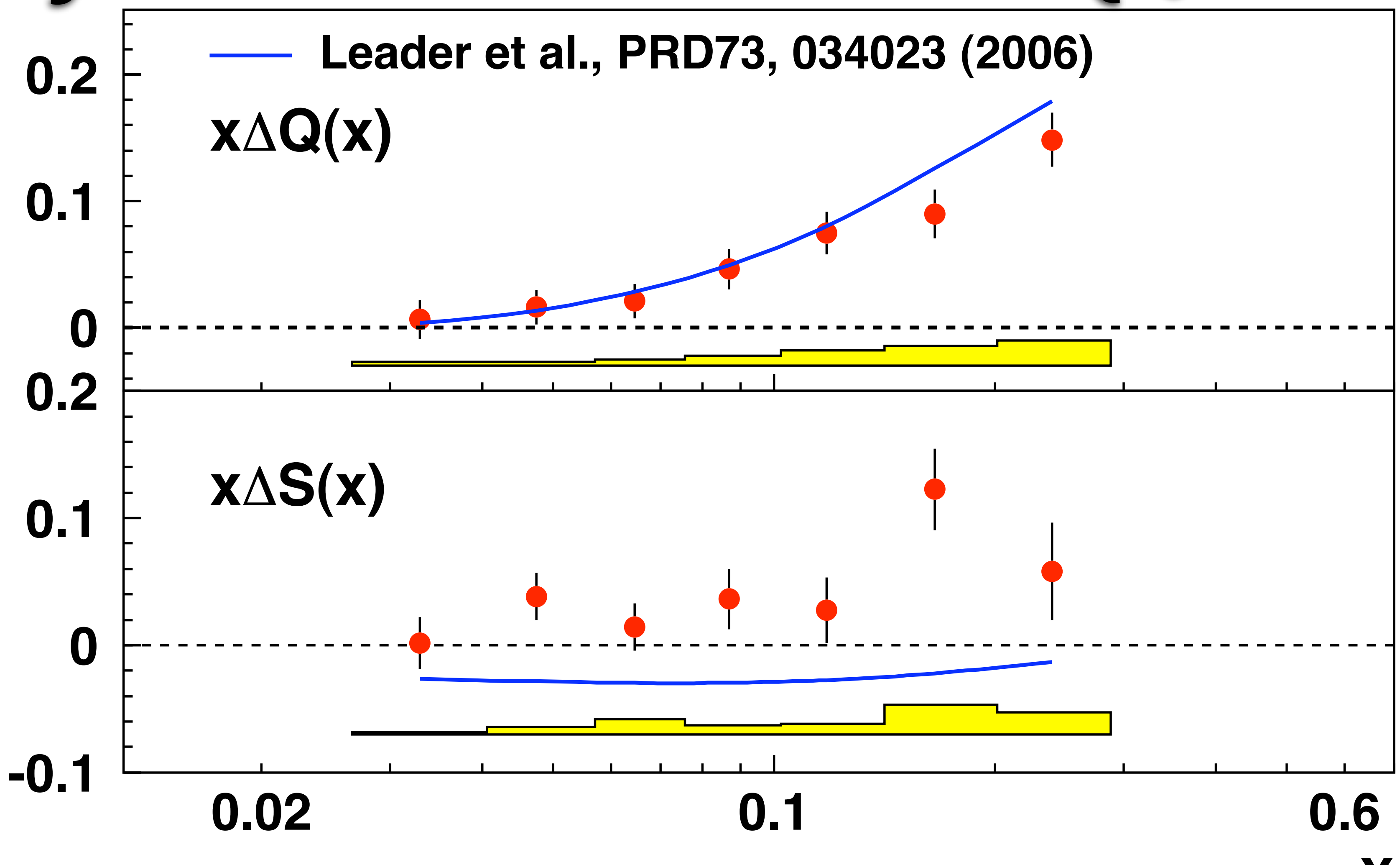
$$A_{||,d}(x)\frac{d^2N^{\mathrm{DIS}}(x)}{dxdQ^2} = \mathcal{K}_{LL}(x,Q^2)\left[5\Delta Q(x) + 2\Delta S(x)\right]$$

$$A^{\mathrm{K}}_{||,d}(x)\frac{d^2N^{\mathrm{K}}(x)}{dxdQ^2} = \mathcal{K}_{LL}(x,Q^2)\left[\Delta Q(x)\int D_Q^{\mathrm{K}}(z)dz + \Delta S(x)\int D_S^{\mathrm{K}}(z)dz\right]$$

$$\Delta Q(x) = \Delta u(x) + \Delta\bar{u}(x) + \Delta d(x) + \Delta\bar{d}(x)$$

$$\Delta S(x) = \Delta s(x) + \Delta\bar{s}(x)$$

Helicity distributions at Q^2_0=2.5 GeV^2



- $0.02 < x_{Bj} < 0.6$
- $\Delta q_8 = \Delta Q - 2\Delta S$
- from hyperon decay constants (assuming SU(3) symmetry):

$$\Delta q_8 = \int_0^1 \Delta q_8(x) dx = 0.586 \pm 0.031$$

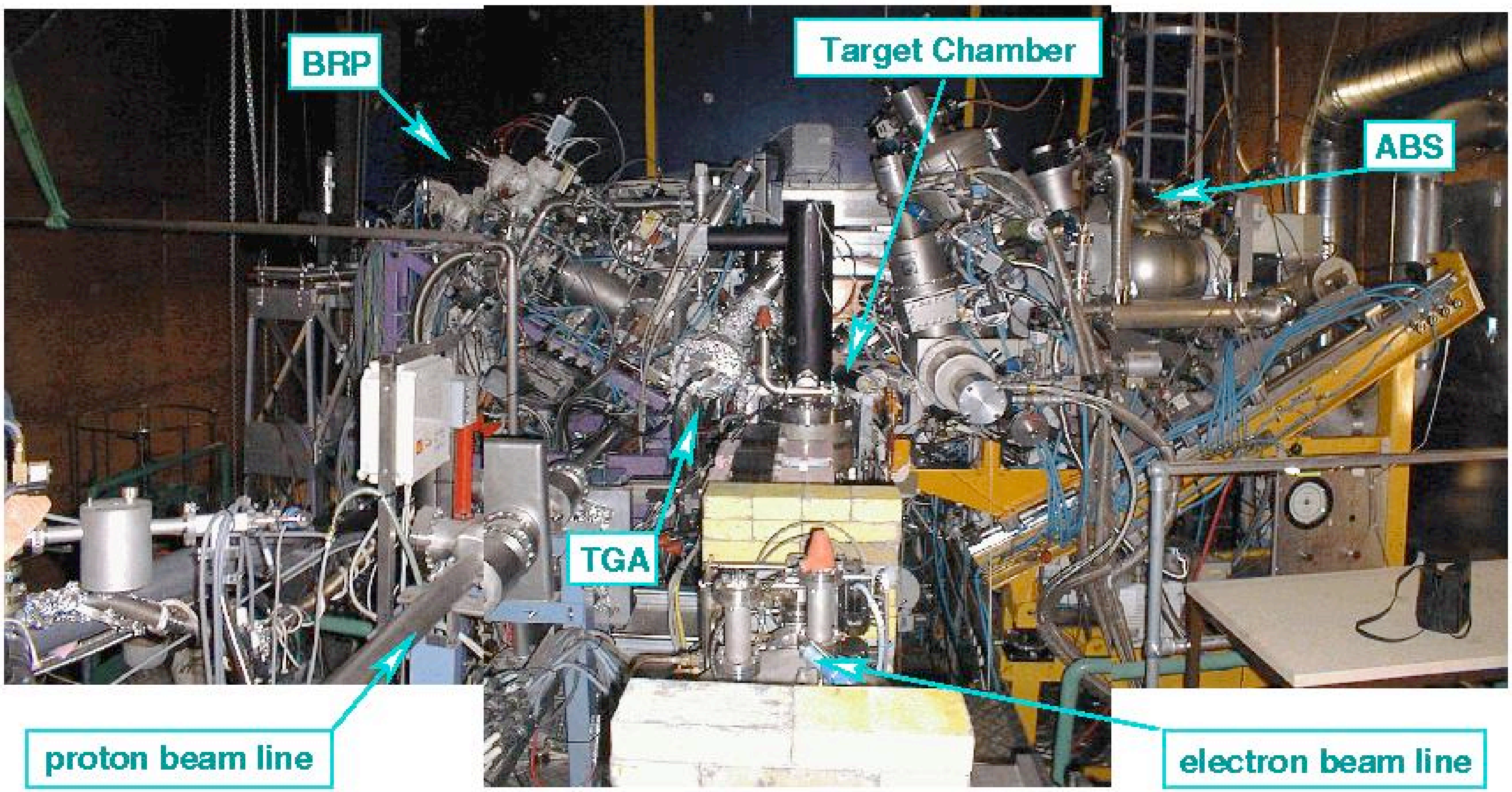
	Moments in measured range
ΔQ	$0.359 \pm 0.026(\text{stat.}) \pm 0.018(\text{sys.})$
ΔS	$0.037 \pm 0.019(\text{stat.}) \pm 0.027(\text{sys.})$
Δq_8	$0.285 \pm 0.046(\text{stat.}) \pm 0.057(\text{sys.})$

Conclusions

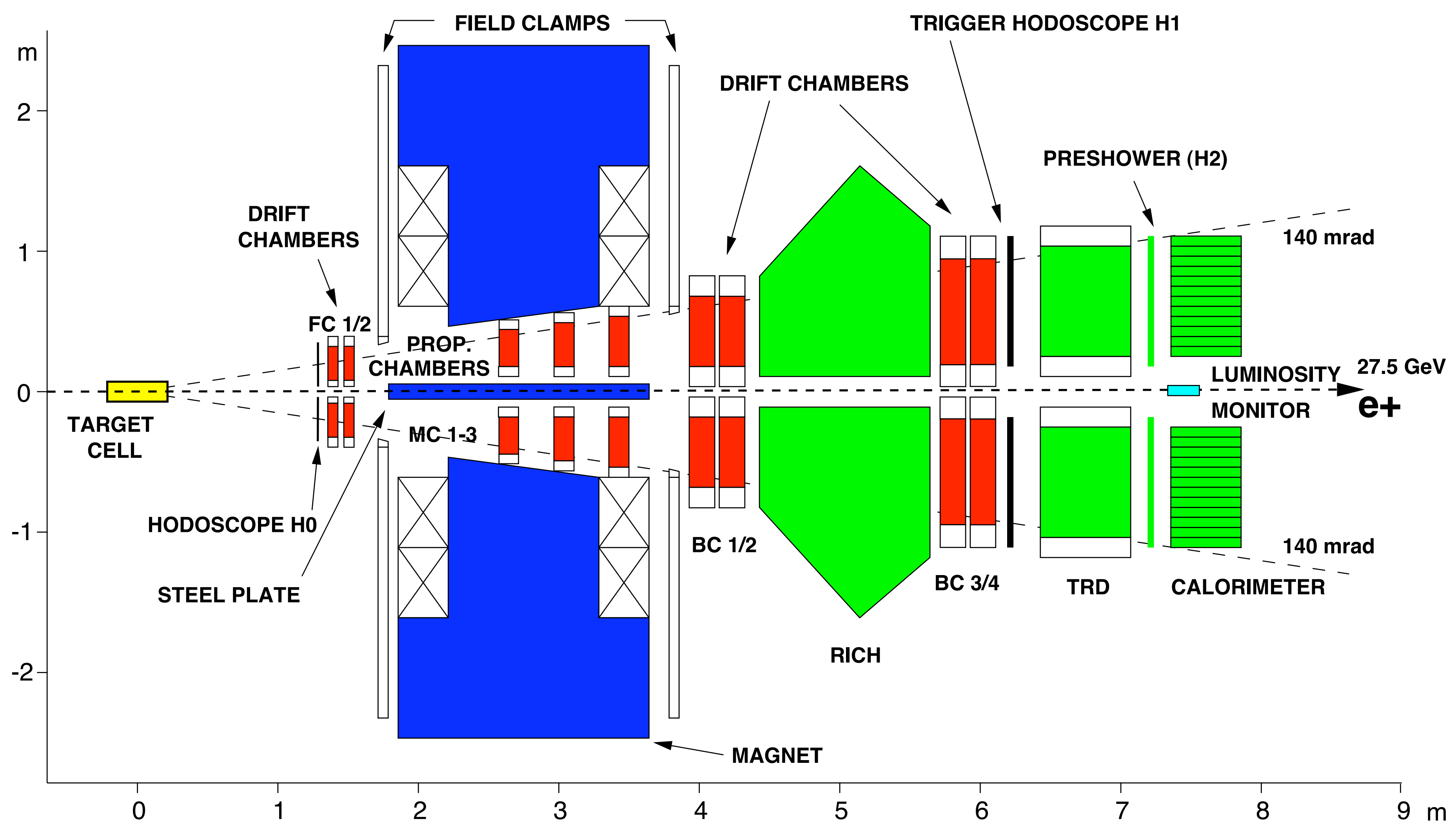
- (most) precise data on a transversely polarized hydrogen target
- significant Collins amplitudes for π-mesons
  ⇒ enables quantitative extraction of transversity distribution
- significant Sivers amplitudes for π^+ and K^+
  ⇒ clear (and first) evidence of naive-T-odd parton distribution
  ⇒ enables quantitative extraction of the Sivers function
- Shape of S(x) is much softer than the isoscalar sea
- SU(3) symmetry seems to be violated by strange quark PDFs
- s quark helicity densities consistent with 0

Additional slides

The transversely pol target



The HERMES Experiment



Internal gas target: pol. : He, H, D

unpol: H_2, D_2, He, N_2, Ne, Kr, Xe

Particle ID: TRD, Preshower, Calorimeter, Cerenkov (until 1997), RICH (since 1998)

Reconstruction: $\Delta p/p < 2\%$, $\Delta\Theta < 1$ mrad