Selected Recent hermes Results on Parton Distribution and Fragmentation Functions

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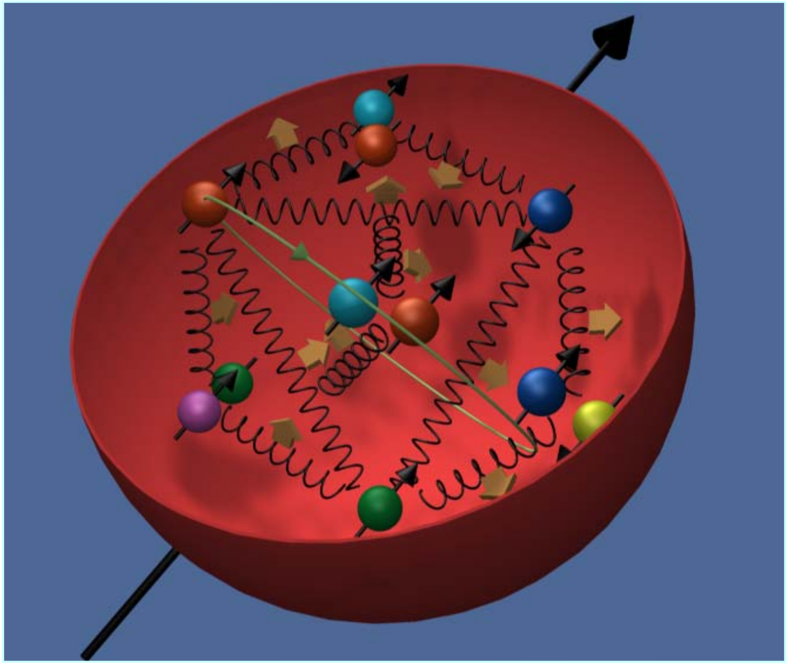
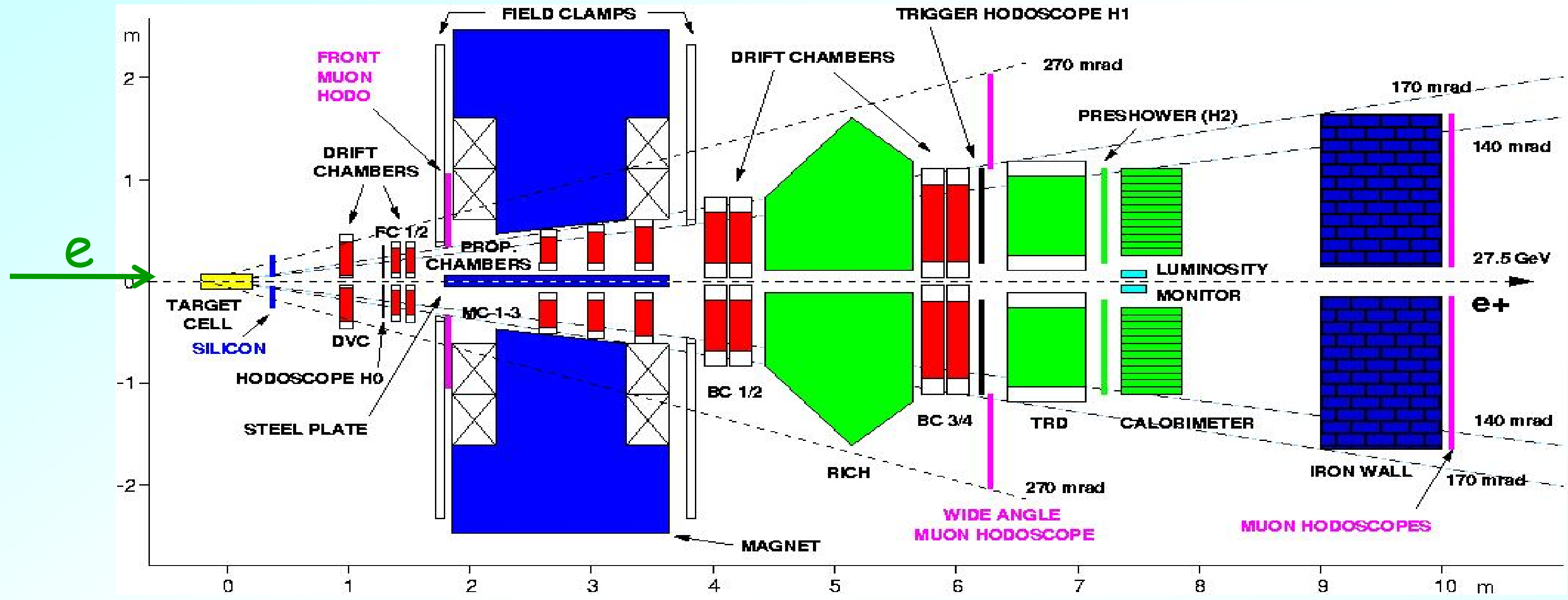


Main HERMES research topics:

- Origin of nucleon spin
- Details of nucleon structure

HERMES Spectrometer



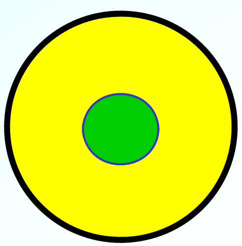
- HERA longitudinally polarized 27.6 GeV e+/e- beam
- Polarized and unpolarized internal gas target (spin flip every 90 s)
- Kinematics: $0.02<x<0.7$, $1.0\ GeV^2<Q^2<15\ GeV^2$
- Data taking: summer 1995 – June 30, 2007
- 1995-2000: longitudinal target polarization, 2002-2005: transverse target pol.
  2006-2007: unpolarized H, D targets + Recoil Detector

Leading-twist Parton Distributions

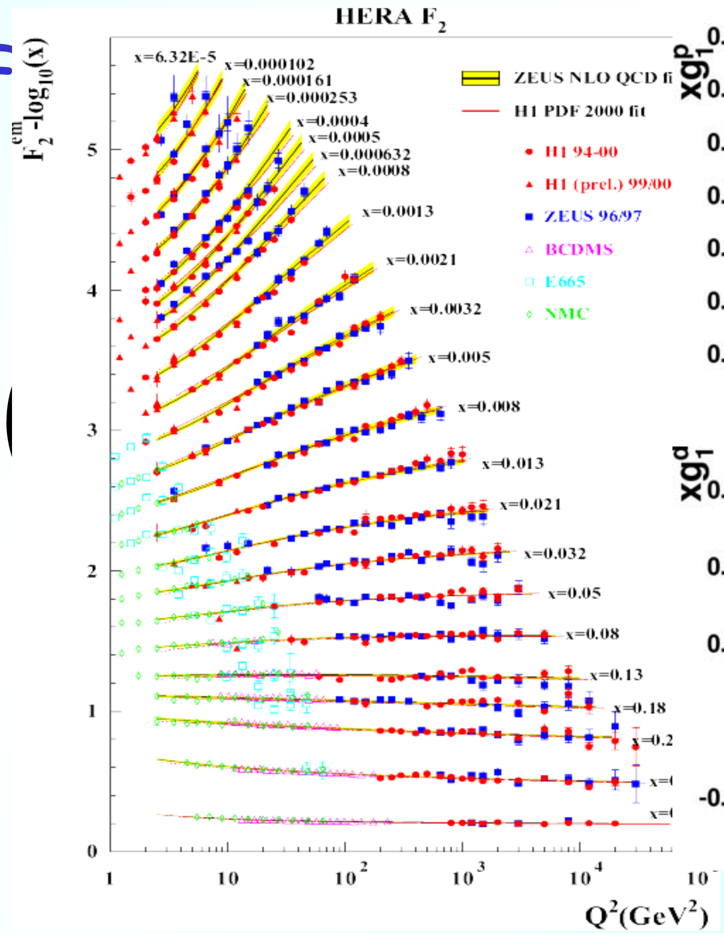
Complete description of nucleon by quark momentum and spin distributions at leading-twist: 3 k_T-integrated distribution functions (DF)

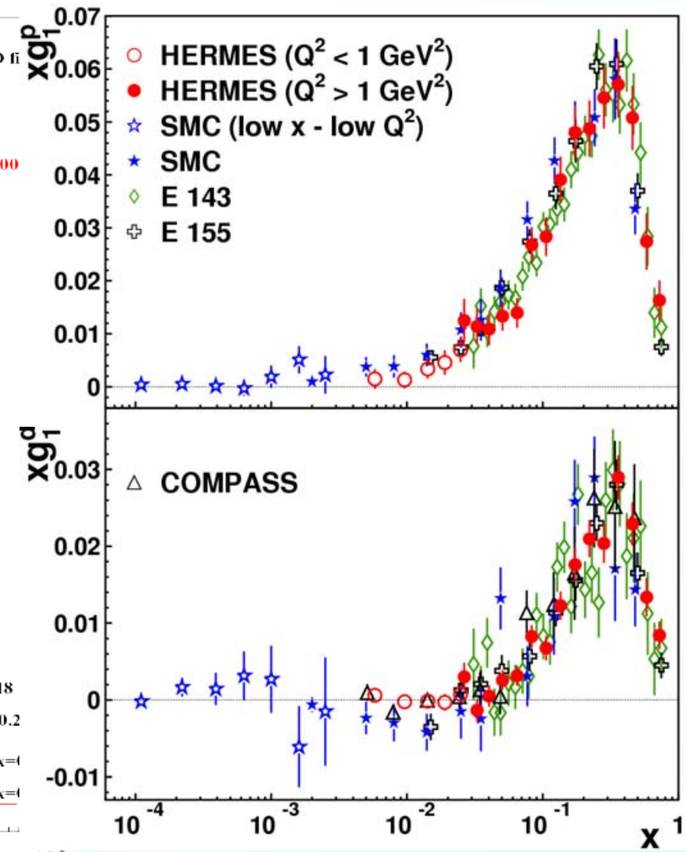
Unpolarised DF

$$q(x) \equiv f_1^q(x)$$



well known





HERMES 2002-2005

Transverse Momentum Dependent DFs

Quark distribution functions

		quark		
		U	L	T
nucleon	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

Boer-Mulders DF (chiral-odd) → $h_1^\perp$

Transversity DF (chiral-odd) → h_1

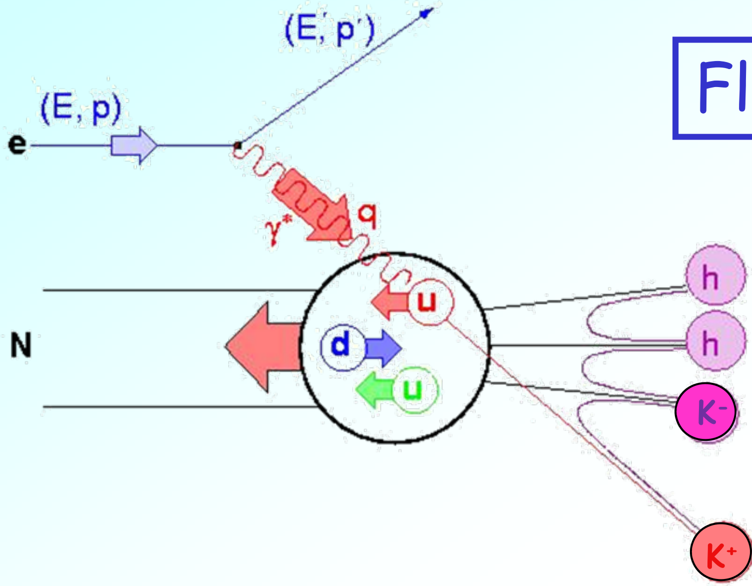
Sivers DF (T-odd) → $f_{1T}^\perp$

Fragmentation functions (FF)

$D_1 \equiv D_q^h$ = ‚normal' FF,

$H_1^\perp$ = spin-dependent Collins FF (chiral-odd)

Quark Distributions from SIDIS



Flavor tagging

$\nu = E - E'$, $Q^2 = -q^2 = -(l - l')^2$

$x = Q^2/(2M\nu)$ = fraction of nucleon's longitudinal momentum carried by struck quark

$q(x)$ = quark number density

Leading hadron originates with large probability from struck quark

$D_q^h(z)$:= Fragmentation function (FF) $z = E_h/\nu$

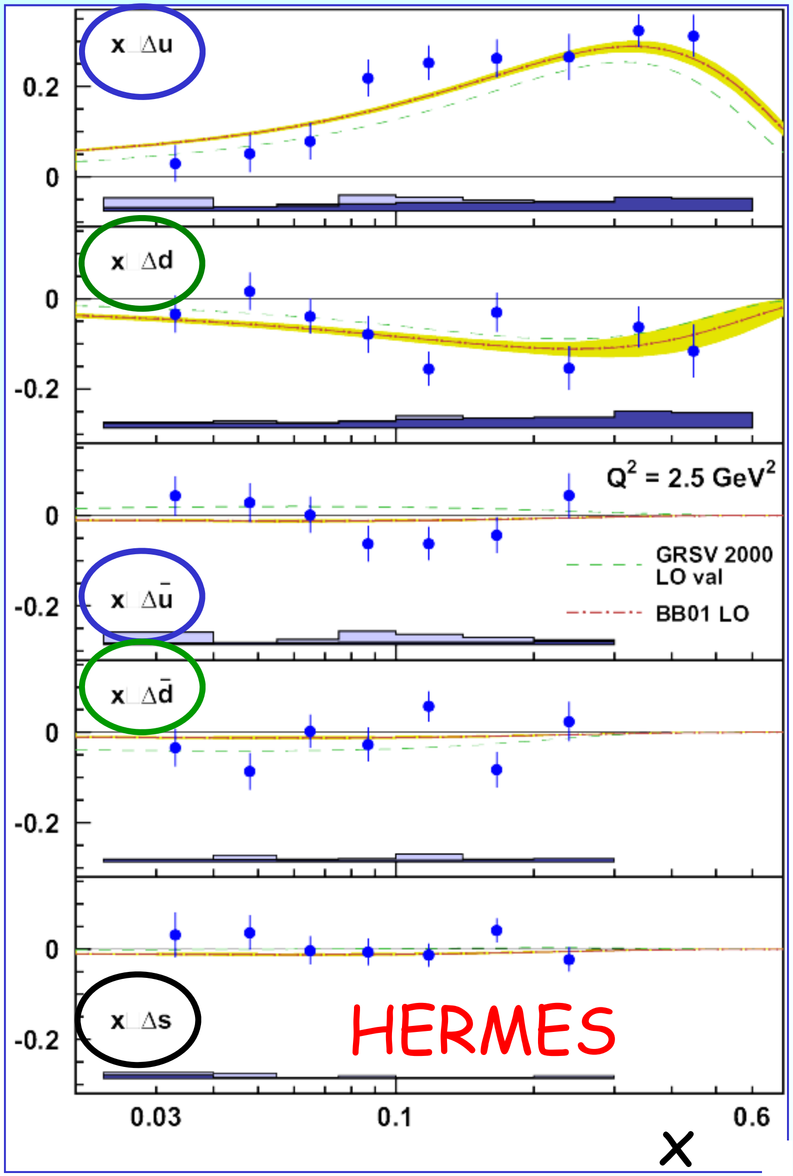
Measure hadron asymmetries

$$A_{LL}(x,z) \cong \frac{\sum_q z_q^2 \Delta q(x) D_q^h(z)}{\sum_q z_q^2 q(x) D_q^h(z)}$$

Targets: $\vec{H}$, $\vec{D}$; $h = \pi^\pm, K^\pm, p$ (identified with RICH)

Quark Helicity Distributions $\Delta q(x)$

PRD 71 (2005) 012003



- u quarks: large positive polarisation
- d quarks: negative polarisation

  $\Delta d(x) \cong - 0.4\ \Delta u(x)$

- Sea quarks ($\bar{u}$, $\bar{d}$, s): polarisation compatible with 0.

The Strange Sea: S(x), ΔS(x)

Inputs:

- Multiplicities for K+ and K- from unpolarized deuteron

$d^2N_D^{DIS}/dxdQ^2 = K_U(x,Q^2)[5\,Q(x) + 2S(x)]$

where $Q(x) = u(x)+\bar{u}(x)+d(x)+\bar{d}(x)$ and $S(x) = s(x) + \bar{s}(x)$

$d^2N_D^{K\pm}/dxdQ^2 = K_U(x,Q^2)[Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz]$

where $D_Q^K(z) = 4D_u^K(z)+D_d^K(z)$ and $D_S^K(z) = 2D_s^K(z)$

- Inclusive and K+, K- asymmetries from polarized deuteron

$A_{1,D}\, d^2N^{DIS}/dxdQ^2 = K_{LL}(x,Q^2)[5\Delta Q(x) + 2\Delta S(x)]$

$A_{1,D}^{K\pm} d^2N^{K\pm}/dxdQ^2 = K_{LL}(x,Q^2)[\Delta Q(x)\int D_Q^K(z)dz + \Delta S(x)\int D_S^K(z)dz]$

S(x) from Kaon Multiplicities

$$\frac{dN^{K\pm}}{dN^{DIS}} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5\,Q(x) + 2\,S(x)} \xrightarrow{x>0.3} \frac{\int D_Q^K(z)dz}{5}$$

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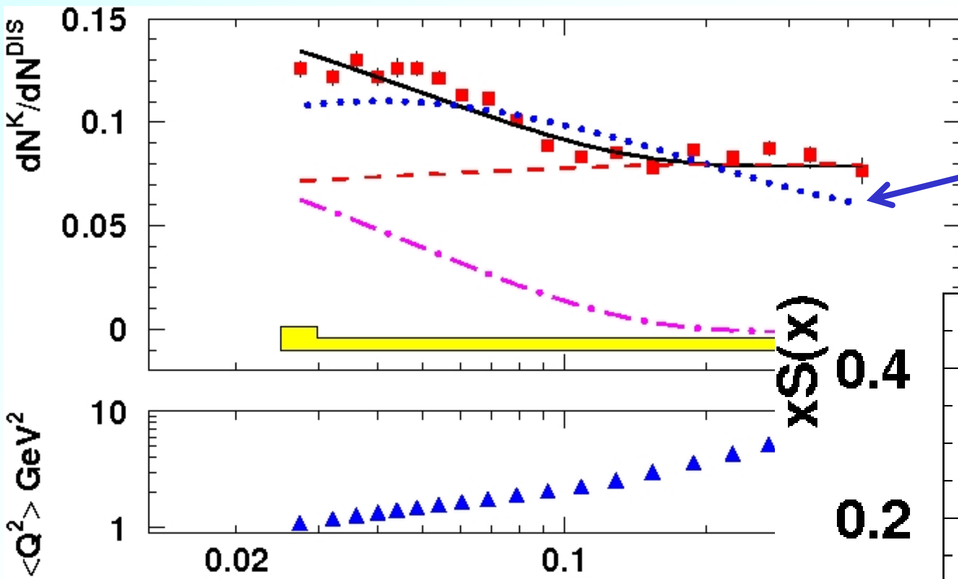
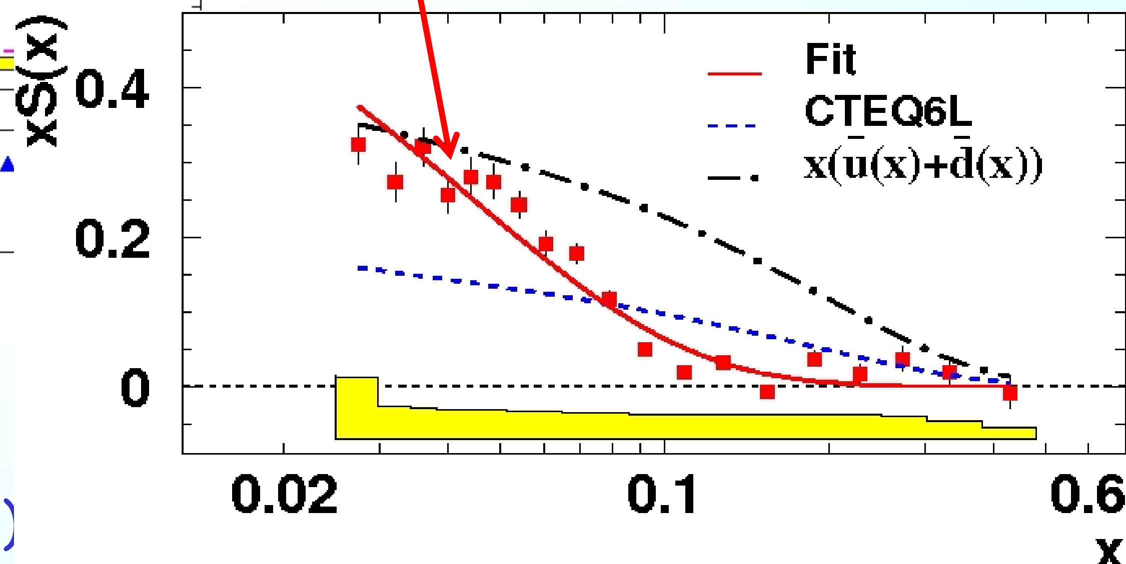


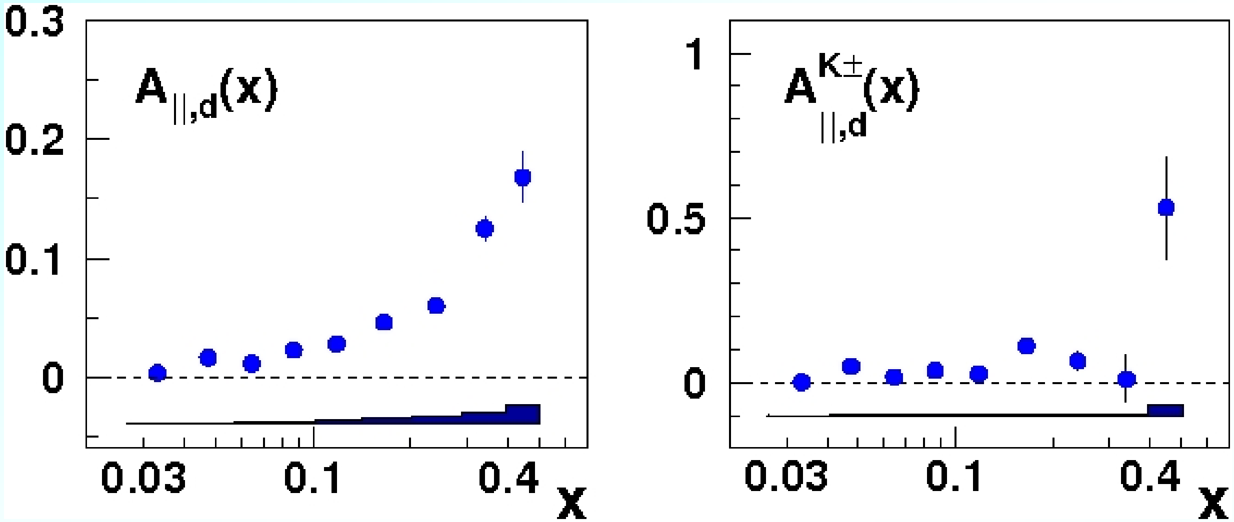
- $S(x)$ from CTEQ6L with $\int D_Q^K(z)dz$ & $\int D_S^K(z)dz$ as free parameters (dotted) does not fit the data



- $S(x)$ much softer than assumed by current PDFs (mainly based on $\overset{(-)}{\nu}N \rightarrow \mu^+\mu^-X$)

Take $\int D_S^K(z)dz = 1.27 \pm 0.13$ from de Florian et al.

ΔS(x) from Kaon Asymmetries



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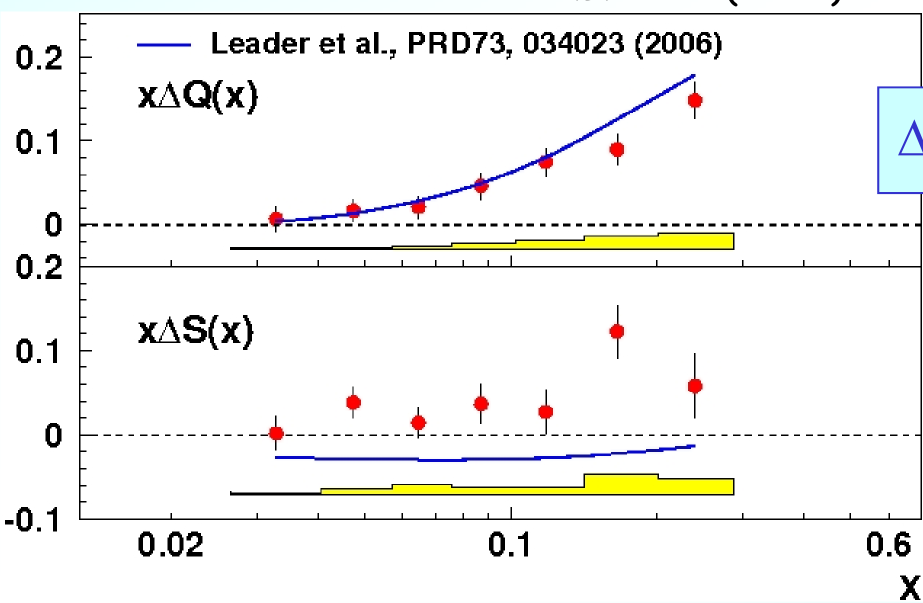


$\Delta S = 0.037 \pm 0.019(\text{stat.}) \pm 0.027(\text{syst.})$

compared to

$\Delta S = -\,0.085 \pm 0.013(\text{stat.}) \pm 0.012(\text{syst.})$
from inclusive data and SU(3)

Large negative contribution
from low x?

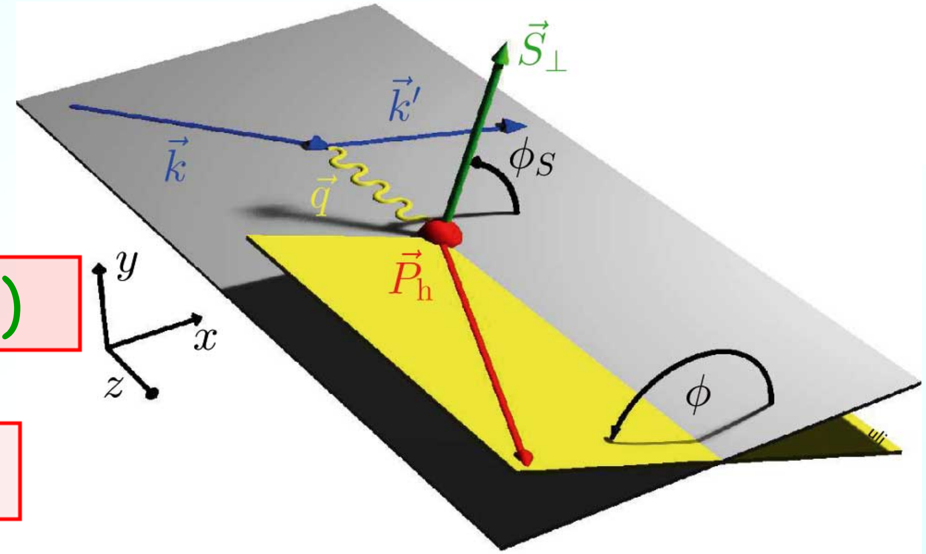
Transverse Azimuthal Angular Asymmetries

Amplitude has 2 components:

Transversity DF

$2\langle \sin(\phi + \phi_S)\rangle^h_{UT} \sim h_1^q(x) \otimes H_1^{\perp q}(z)$

Collins FF



U: unpol. e±-beam
T: transv. pol. Target
$z = E_h/\nu$

Unpolarised FF

$2\langle \sin(\phi - \phi_S)\rangle^h_{UT} \sim f_{1T}^{\perp q}(x) \otimes D_1^q(z)$

Sivers DF

(Requires non-vanishing orbital angular momenta L_q of quarks)

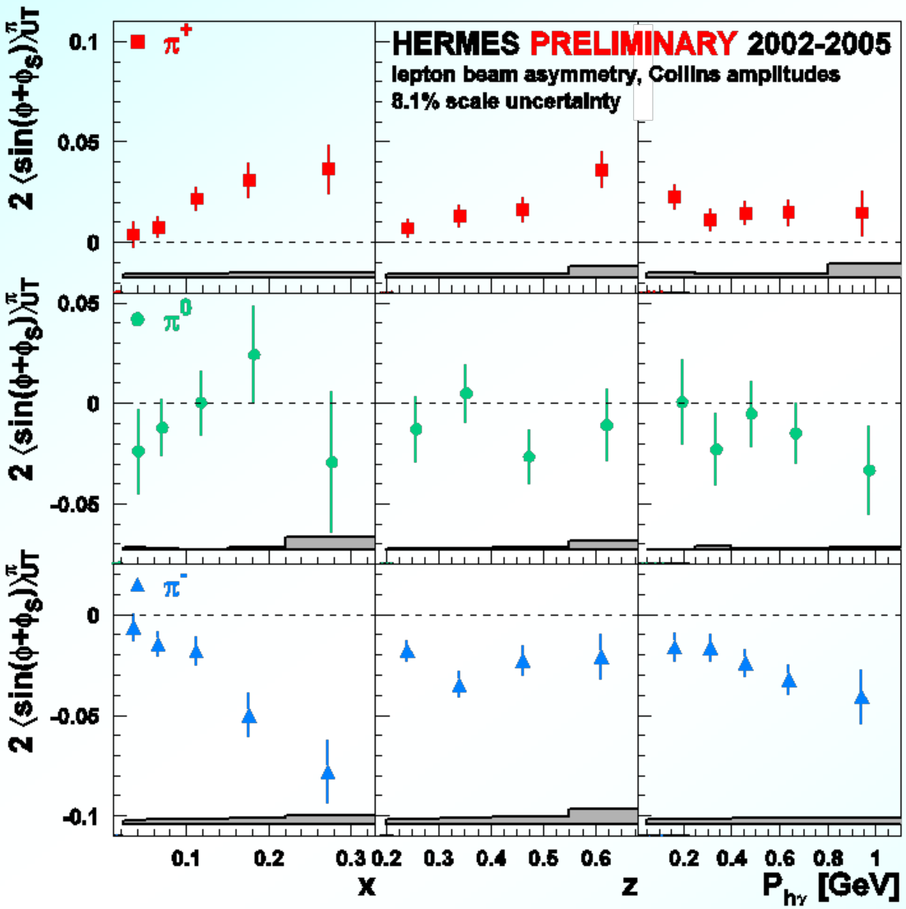
Collins Amplitudes

Transversity DF

$2\langle\sin(\phi + \phi_S)\rangle^h_{UT} \sim h_1^q(x) \otimes H_1^{\perp q}(z)$

Collins FF

N/q	U	L	T	
U	f_1		$h_1^\perp$	
L		g_1	$h_{1L}^\perp$	
T	$f_{1T}^\perp$	g_{1T}	h_1	$h_{1T}^\perp$



- First measurement of non-zero Collins effect
- Both Collins fragmentation function and transversity distribution function are sizeable
- Surprisingly large π^- asymmetry
- Possible source: large contribution (with opposite sign) from unfavored fragmentation, i.e. $u \rightarrow \pi^-$

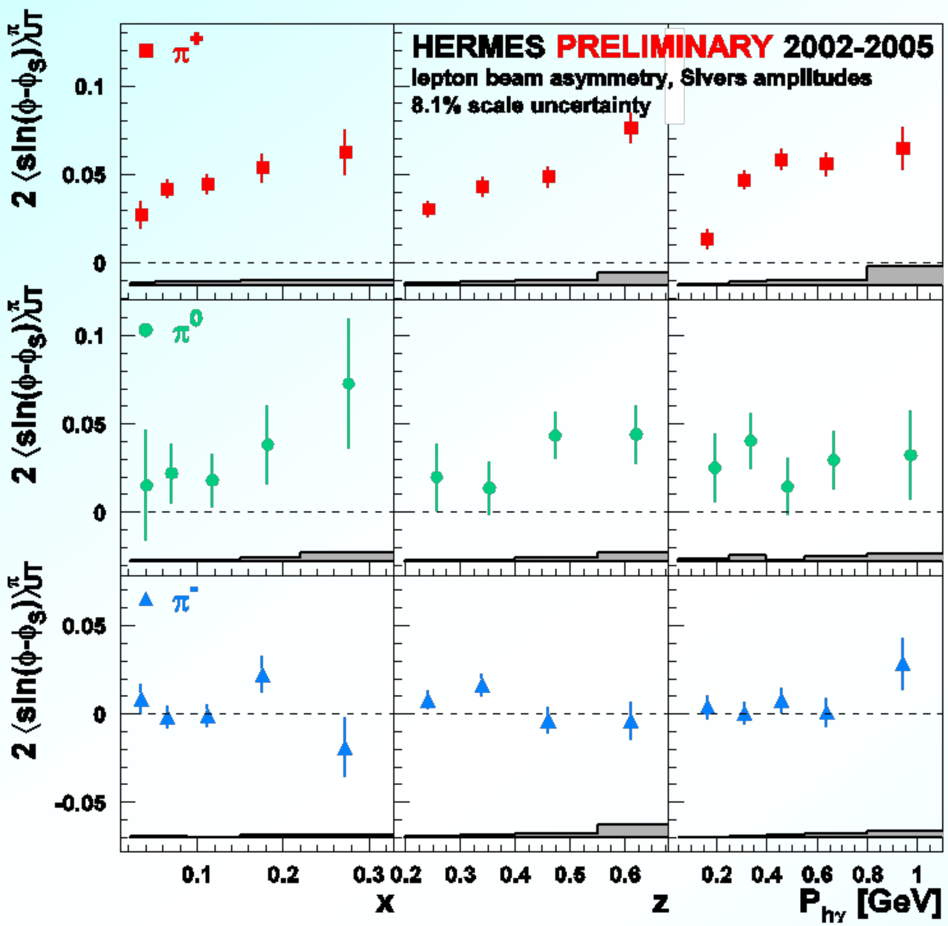
$H_1^{\perp}{}_{,disf} \approx - H_1^{\perp}{}_{,fav}$

Sivers Amplitudes

Sivers DF

$$2\langle\sin(\phi - \phi_S)\rangle^h_{UT} \sim f_{1T}^{\perp q}(x) \otimes D_1^q(z)$$

N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

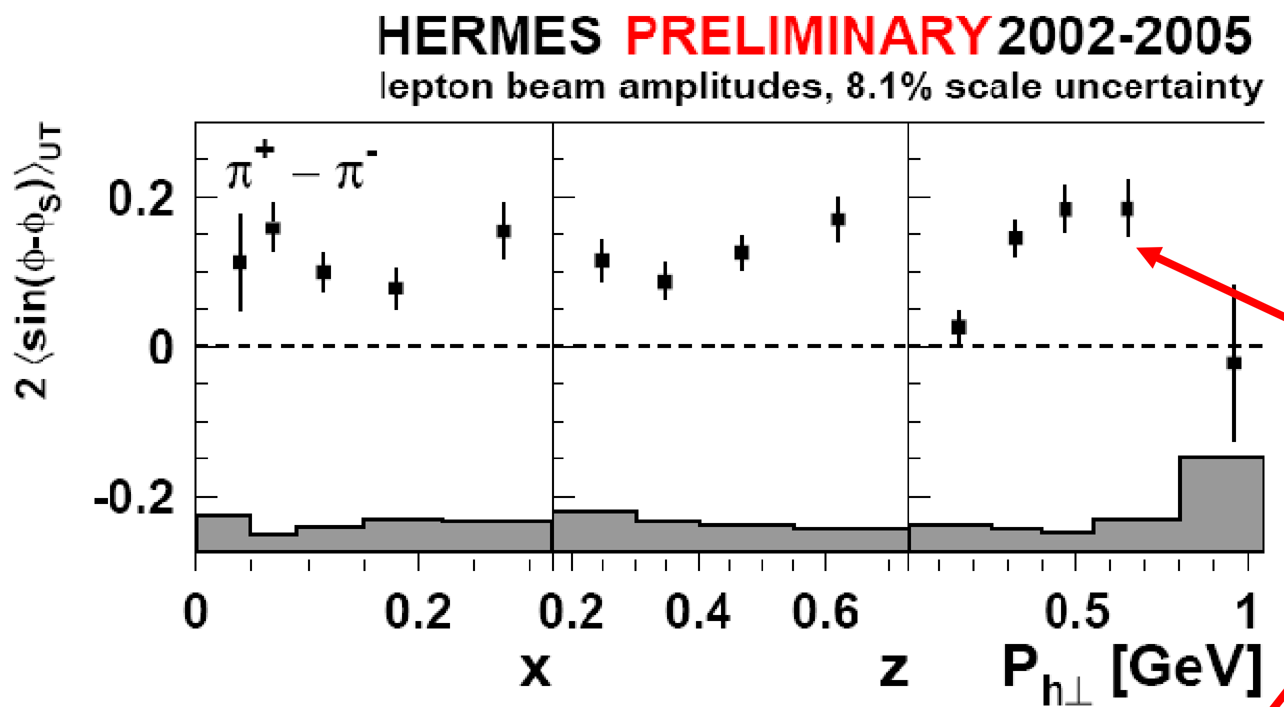


- First observation of non-zero Sivers distribution function in DIS

➡ Experimental evidence for orbital angular momentum L_q of quarks

But: Quantitative contribution of L_q to nucleon spin still unclear

Transverse SSA for $\pi^+ - \pi^-$

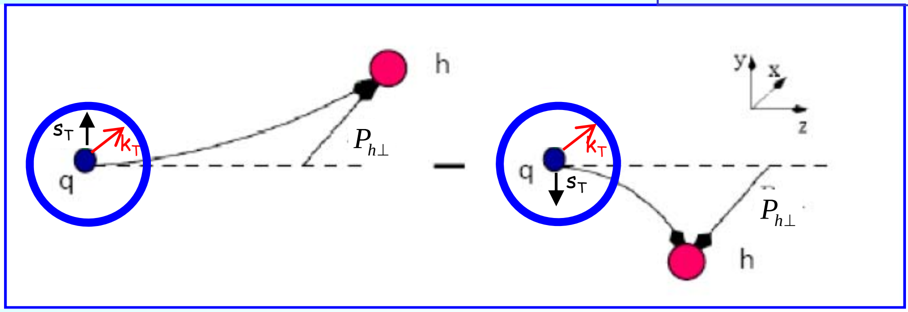


access to Sivers valence distribution

$$2\left\langle \sin(\phi-\phi_S)\right\rangle_{UT}^{\pi^+-\pi^-} = -2\,\frac{4\,f_{1T}^{\perp,u_v} - f_{1T}^{\perp,d_v}}{4\,f_1^{\perp,u_v} - f_1^{\perp,d_v}}$$

Azimuthal Asymmetries in Unpolarised SIDIS

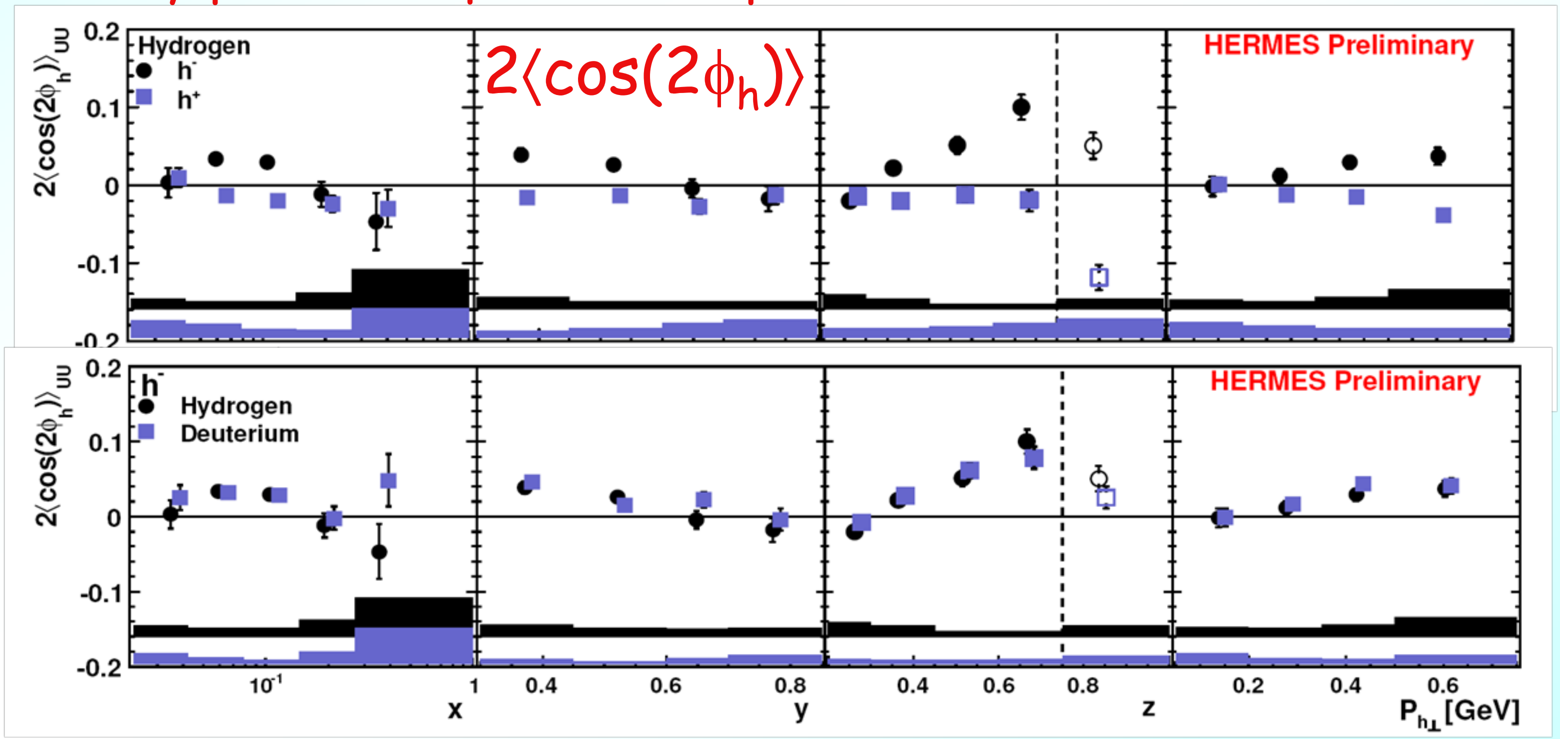
Boer-Mulders DF



N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

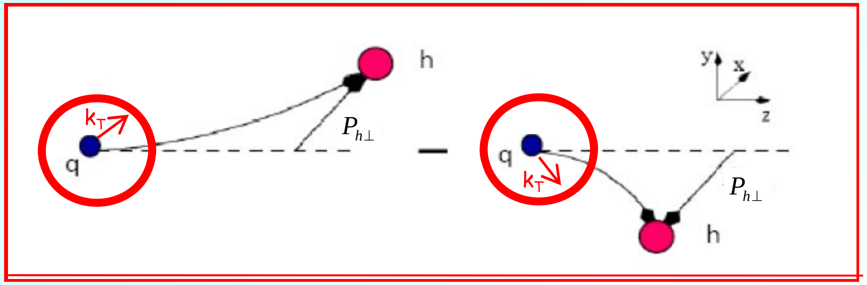
$$F_{UU}^{\cos 2\phi} = C\left[-\frac{2(\hat{h}\cdot\vec{k}_T)(\hat{h}\cdot\vec{p}_T) - \vec{k}_T\cdot\vec{p}_T}{MM_h} h_1^\perp H_1^\perp \right]$$

transversely polarised quarks in unpolarised nucleon



Azimuthal Asymmetries in Unpolarised SIDIS

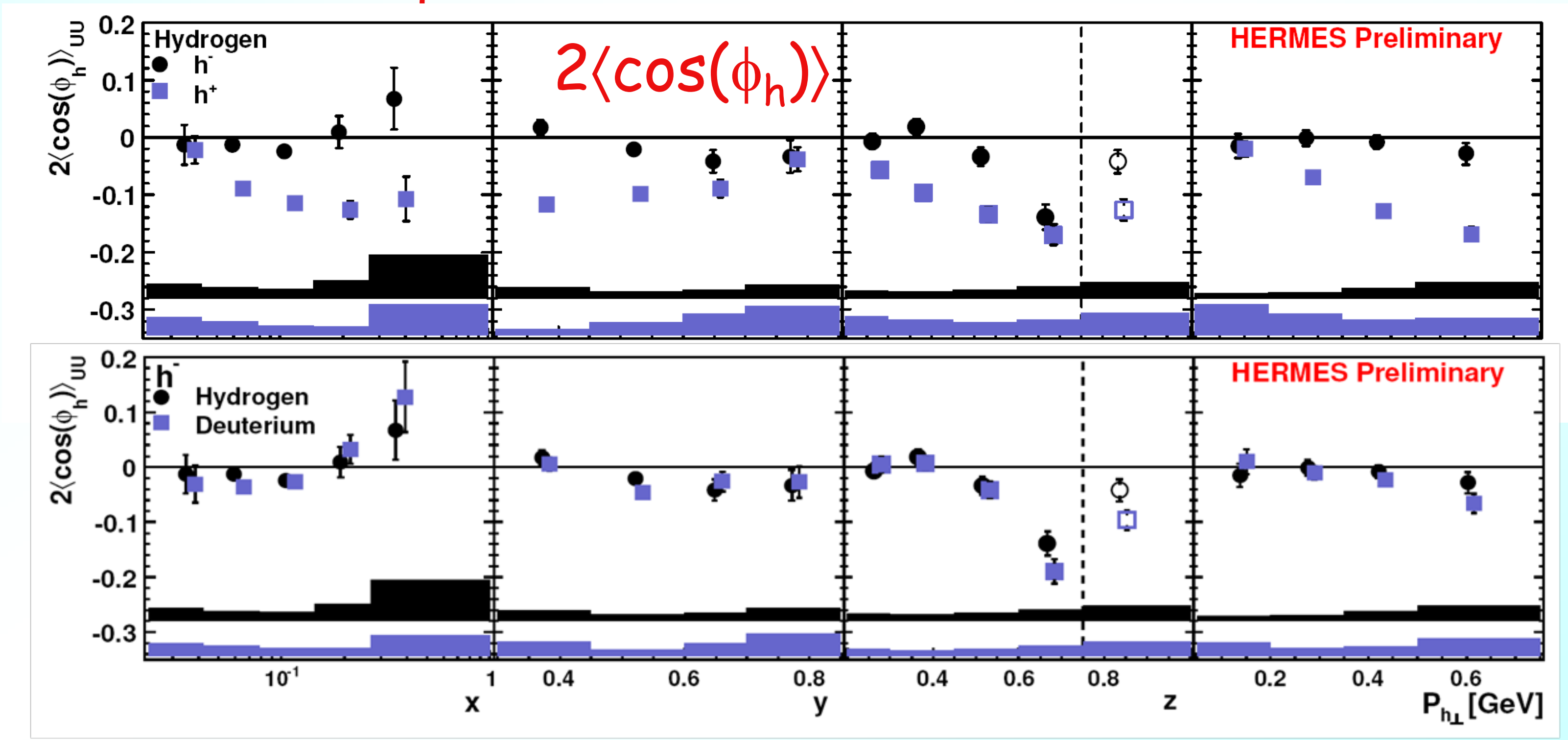
Cahn effect



N/q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

$$F_{UU}^{\cos\phi} = \frac{2M}{Q} C\left[-\frac{\hat{h}\cdot\vec{p}_T}{M_h} x h_1^\perp H_1^\perp - \frac{\hat{h}\cdot\vec{k}_T}{M} x f_1 D_1 \right]$$

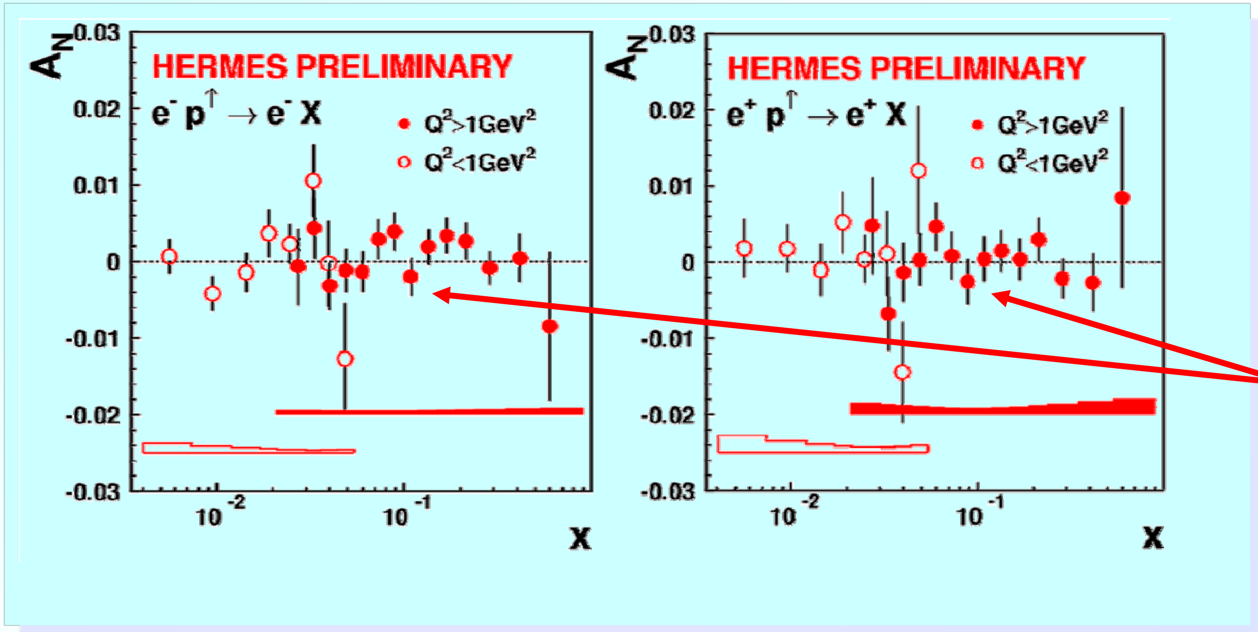
Intrinsic transverse quark momentum



Transverse Azimuthal Asymmetry in DIS

1-photon exchange approximation: TAA forbidden

(Spin-flip every 90 s)



$A_N \neq 0$: Signature of

2-photon exchange

$A_N = O(10^{-3})$

Compatible
with zero !

Conclusions

- HERMES provides new constraints for S(x) at low Q^2

- HERMES made a first glimpse at various Transverse Momentum dependent parton Distribution functions

- TMDs offer a large amount of new information on the nucleon structure They need to be explored in detail by the next generation of experiments at future high-luminosity e-N facilities