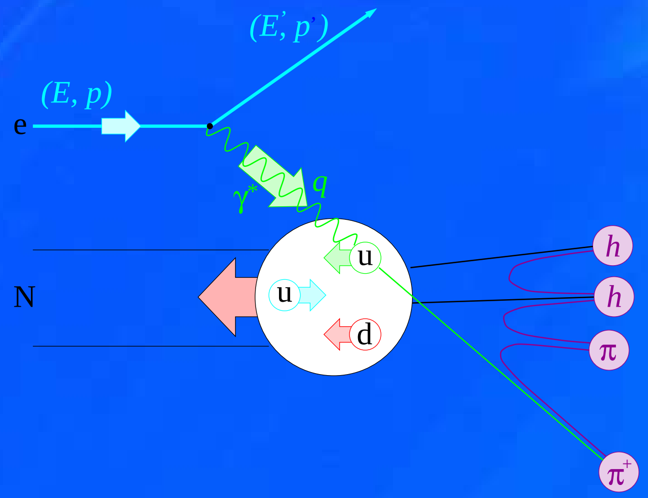
Latest News from HERMES

E.C. Aschenauer

DESY-ZEUTHEN

on behalf of the hermes Collaboration

Polarized Deep Inelastic Scattering



Important Variables:

$$Q^2 \stackrel{lab}{=} 4EE'\sin^2\left(\frac{\theta}{2}\right) \qquad \nu \stackrel{lab}{=} E - E'$$

$$x \stackrel{lab}{=} \frac{Q^2}{2m\nu} \qquad y \stackrel{lab}{=} \frac{\nu}{E} = \frac{p\cdot q}{p\cdot k}$$

$$z \stackrel{lab}{=} \frac{E_h}{\nu}$$

Cross Section: $$\frac{d^2\sigma}{d\Omega dE^2} = \frac{\alpha^2 E'}{Q^2 E} L_{\mu\nu} W^{\mu\nu}$$

$$L_{\mu\nu} = 2\left[k_\mu k'_\nu + k_\nu k'_\mu - \left(k\cdot k' - m_e^2\right) g_{\mu\nu} + i m_e \epsilon_{\mu\nu\alpha\beta} S^\alpha \left(k - k'\right)^\beta\right]$$

$$W^{\mu\nu} = -g^{\mu\nu} F_1\left(x, Q^2\right) + \frac{p^\mu p^\nu}{\nu} F_2\left(x, Q^2\right)$$

$$+ i\epsilon^{\mu\nu\lambda\sigma} \frac{q_\lambda}{\nu}\left(S_\sigma g_1\left(x, Q^2\right) + \frac{1}{\nu}\left(p\cdot q S_\sigma - S\cdot q p_\sigma\right) g_2\left(x, Q^2\right)\right)$$

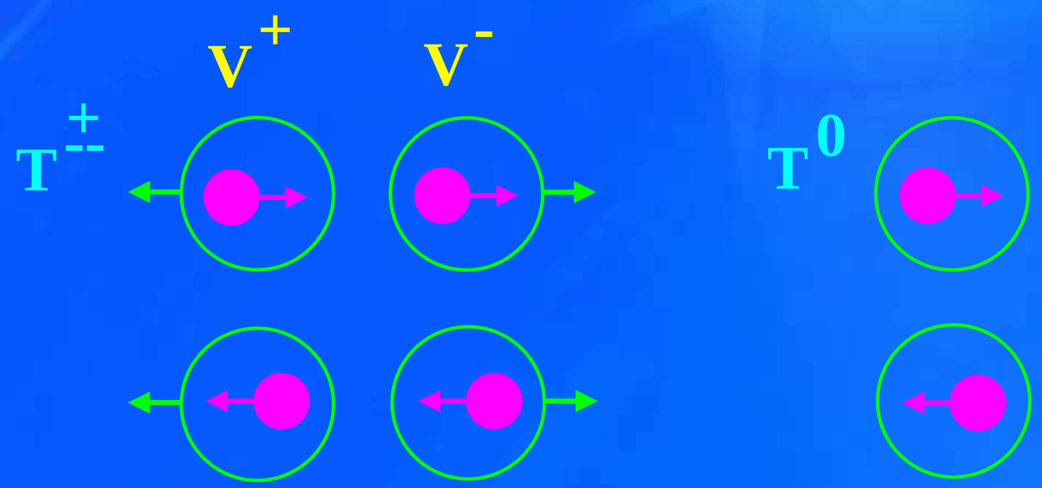
(for spin 1) $$-b_1\left(x, Q^2\right) r_{\mu\nu} + \frac{1}{6} b_2\left(x, Q^2\right)\left(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}\right)$$

$$+\frac{1}{2} b_3\left(x, Q^2\right)\left(s_{\mu\nu} - u_{\mu\nu}\right) + \frac{1}{2} b_4\left(x, Q^2\right)\left(s_{\mu\nu} - t_{\mu\nu}\right)$$

F_1,F_2 / g_1,g_2 $\Longrightarrow$ **Unpolarized / Polarized Structure Functions**

NO: relativistic effects , intrinsic k_T, quark masses and correlations

Deuterium - Tensor Polarization

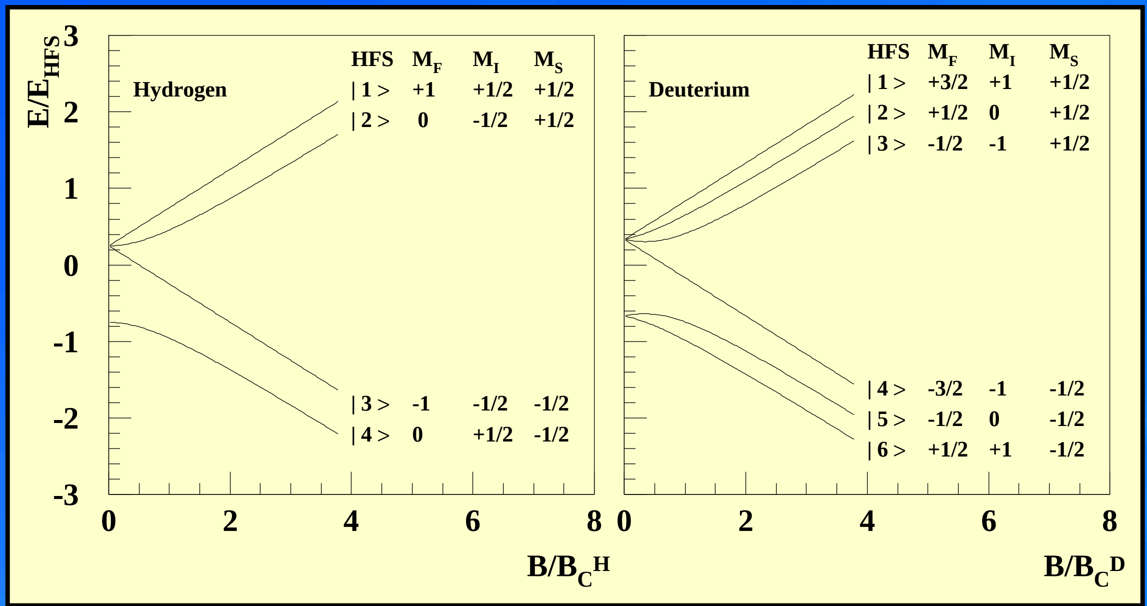


Tensor Polarization:

$$T = 1 - 3N^0$$

$$= \frac{N^+ + N^- - 2N^0}{N^+ + N^- + N^0}$$

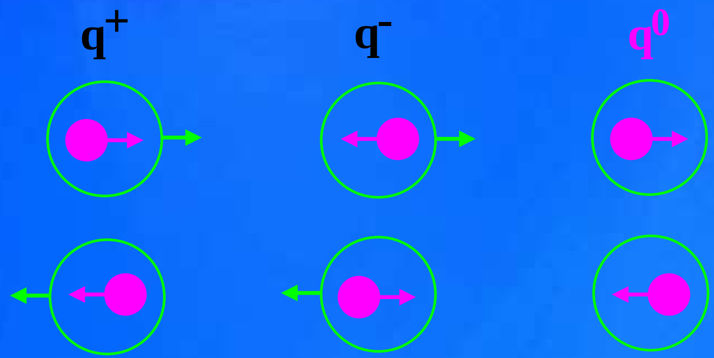
$$= \frac{N^\pm - 2N^0}{N^\pm + N^0}$$



State	Injected		V	T
Vector +	$\|1> + \|6>$	N^+	1	1
Vector -	$\|3> + \|4>$	N^-	-1	1
Tensor $\pm$	$\|3> + \|6>$	$N^\pm$	0	1
Tensor 0	$\|2> + \|5>$	N^0	0	-2

Only possible with a gas target

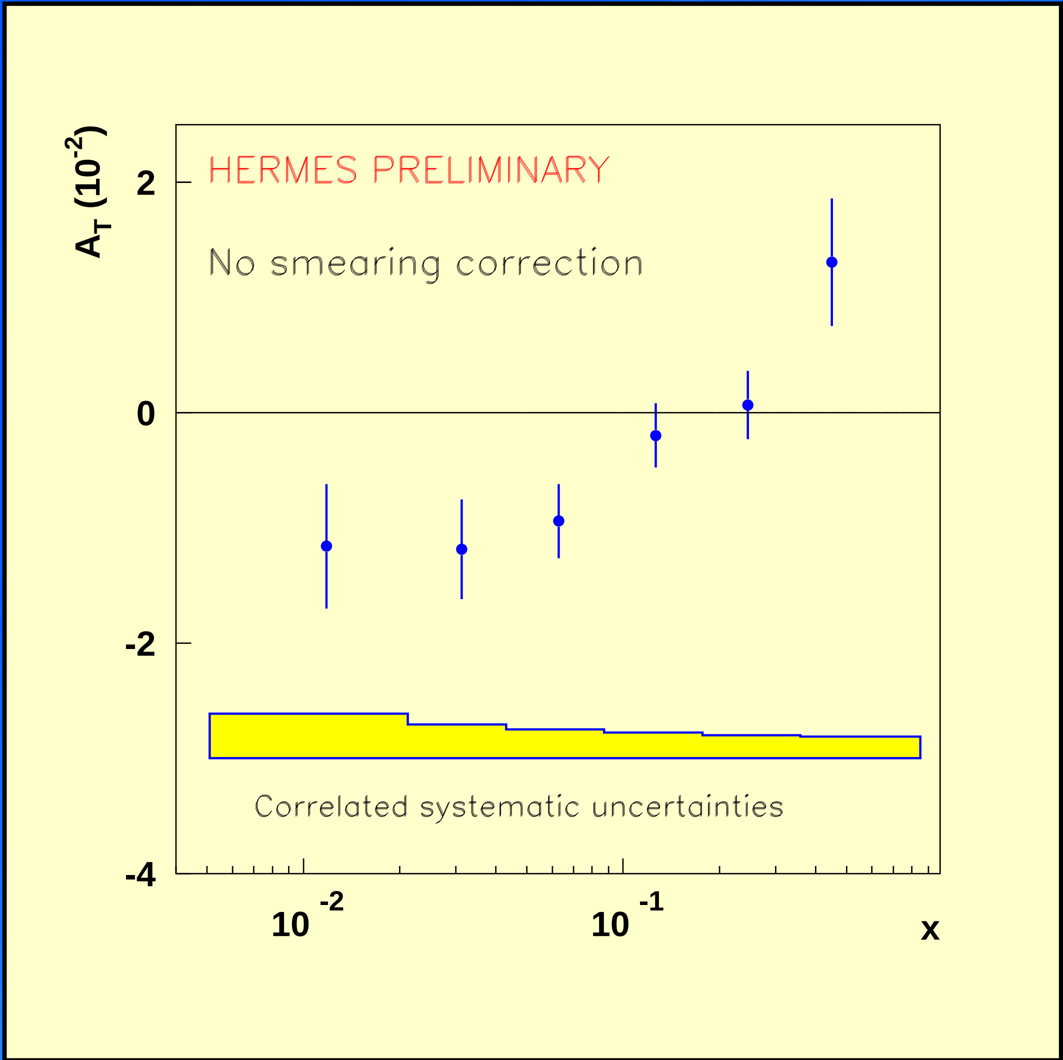
The Tensor Polarized Structure Function b_1^d



	Proton	Deuteron
$\mathbf{F_1(x)}$:	$\frac{1}{2}\sum_i e_i^2(q_i^+(x) + q_i^-(x))$	$\frac{1}{3}\sum_i e_i^2(q_i^+(x) + q_i^-(x) + q_i^0(x))$
$\mathbf{g_1(x)}$:	$\frac{1}{2}\sum_i e_i^2(q_i^+(x) - q_i^-(x))$	$\frac{1}{2}\sum_i e_i^2(q_i^+(x) - q_i^-(x))$
$\mathbf{b_1(x)}$:		$\frac{1}{2}\sum_i e_i^2(2q_i^0(x) - (q_i^+(x) + q_i^-(x)))$

In the parton model b_1^d measures the difference in the quark momentum distributions of helicity 1 and 0 targets

Tensor Asymmetry



$\mathbf{b_1^d}$

enters in the symmetric part of $W^{\mu\nu}$

$\longrightarrow$ **not sensitive to** $\mathbf{P_B}$

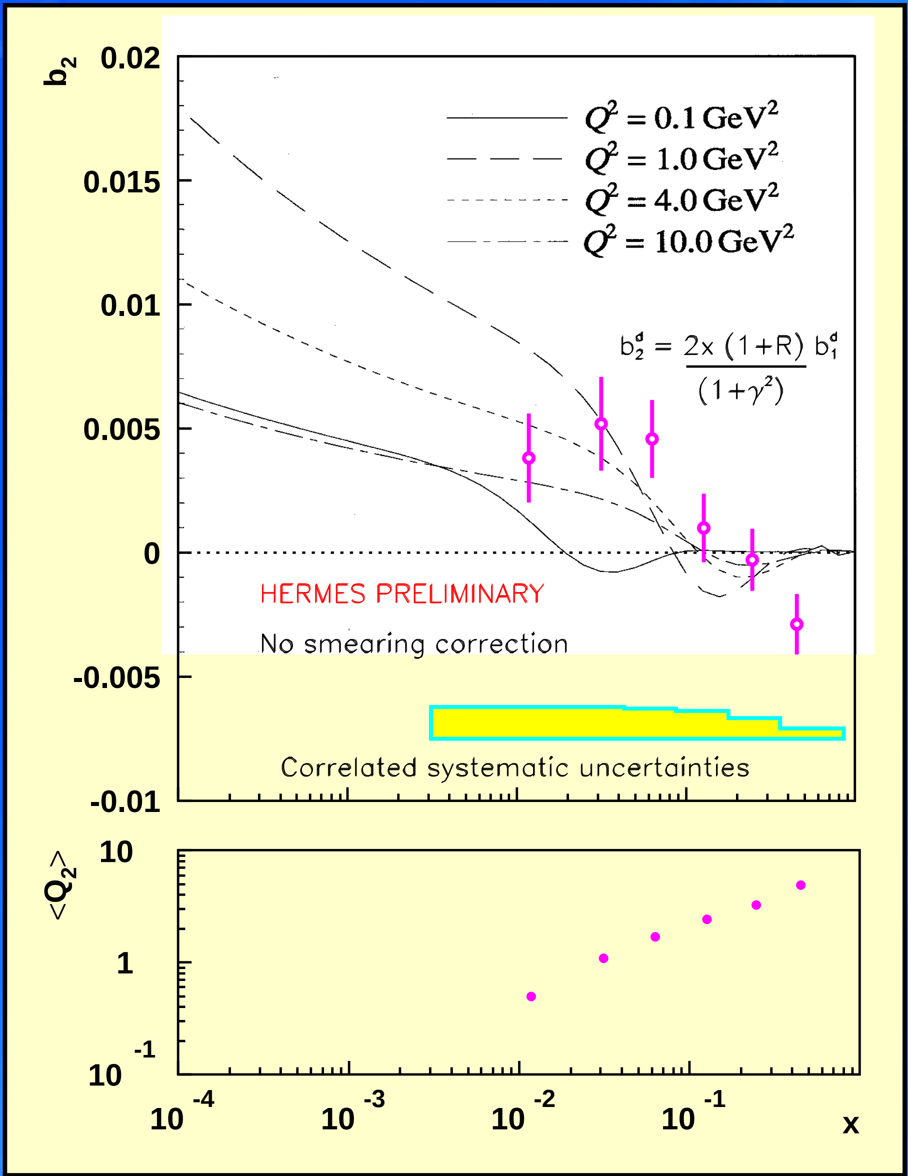
$$\mathbf{A_T} = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{\sigma^+ + \sigma^- + \sigma^0}$$

$$= \frac{1}{T} \cdot \frac{\frac{N^+}{L^+} + \frac{N^-}{L^-} - 2\frac{N^0}{L^0}}{\frac{N^+}{L^+} + \frac{N^-}{L^-} + \frac{N^0}{L^0}}$$

T: target polarization $< T >= 0.83 \pm 0.03$

$\mathbf{L^{+/-/0}}$**: dead-time corrected luminosities**

Results on b_1^d



$$\mathbf{b_1} = -\frac{3}{2} \cdot \mathbf{A_T} \cdot \mathbf{F_1^d}$$

$$\mathbf{b_1} = \frac{1+\gamma^2}{2 \cdot x(1+R)} \cdot \mathbf{b_2}$$

with:

- $\mathbf{F_1^d} = \frac{1+\gamma^2}{2 \cdot x(1+R)} \cdot \mathbf{F_2^d}$

  $\mathbf{F_2^d} = \mathbf{F_2^p}(1 + \frac{F_2^n}{F_2^p})$
- $\frac{F_2^n}{F_2^p}$: **NMC, Nucl. Phys. B371 (1992) 3**

  $\mathbf{F_2^p}$: **ALLM97 (hep-ph 9712415)**

  R: **Phys. Lett. B250 (1990) 193**
- **no higher twist effects (b_3, b_4 = 0)**

K.Bora & R.L. Jaffe Phys.Rev.D57 (1998) 6906

DVCS azimuthal asymmetries

$$d\sigma \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + (\mathcal{T}^*_{BH}\mathcal{T}_{DVCS} + \mathcal{T}^*_{DVCS}\mathcal{T}_{BH})$$

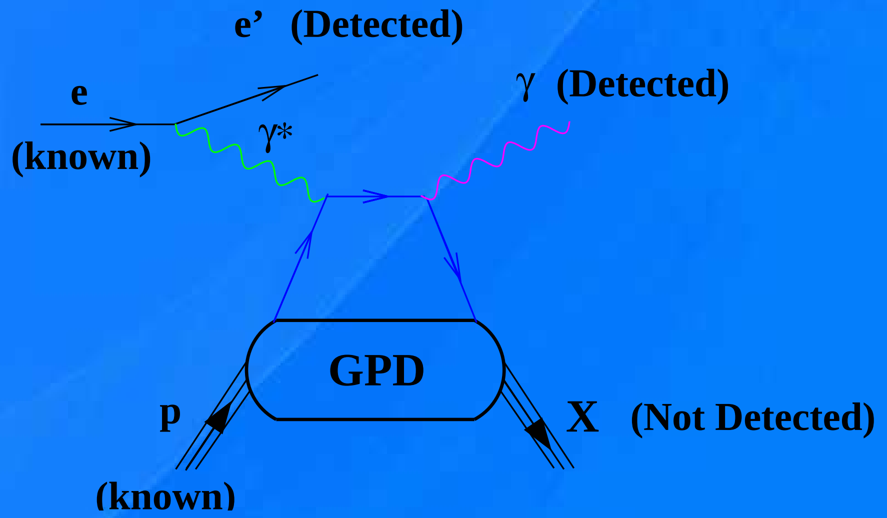
isolate BH-DVCS interference term:

- **imaginary part $\propto$ beam helicity asymmetry:**

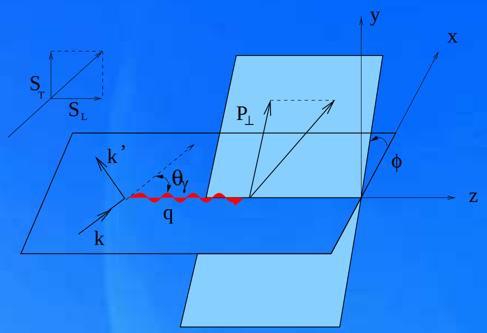
$$d\sigma_{\overleftarrow{e^+}} - d\sigma_{\overrightarrow{e^+}} \propto \mathrm{Im}(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \propto \sin\phi$$

- **real part $\propto$ beam charge asymmetry:**

$$d\sigma_{e^+} - d\sigma_{e^-} \propto \mathrm{Re}(\mathcal{T}_{BH}\mathcal{T}_{DVCS}) \propto \cos\phi$$

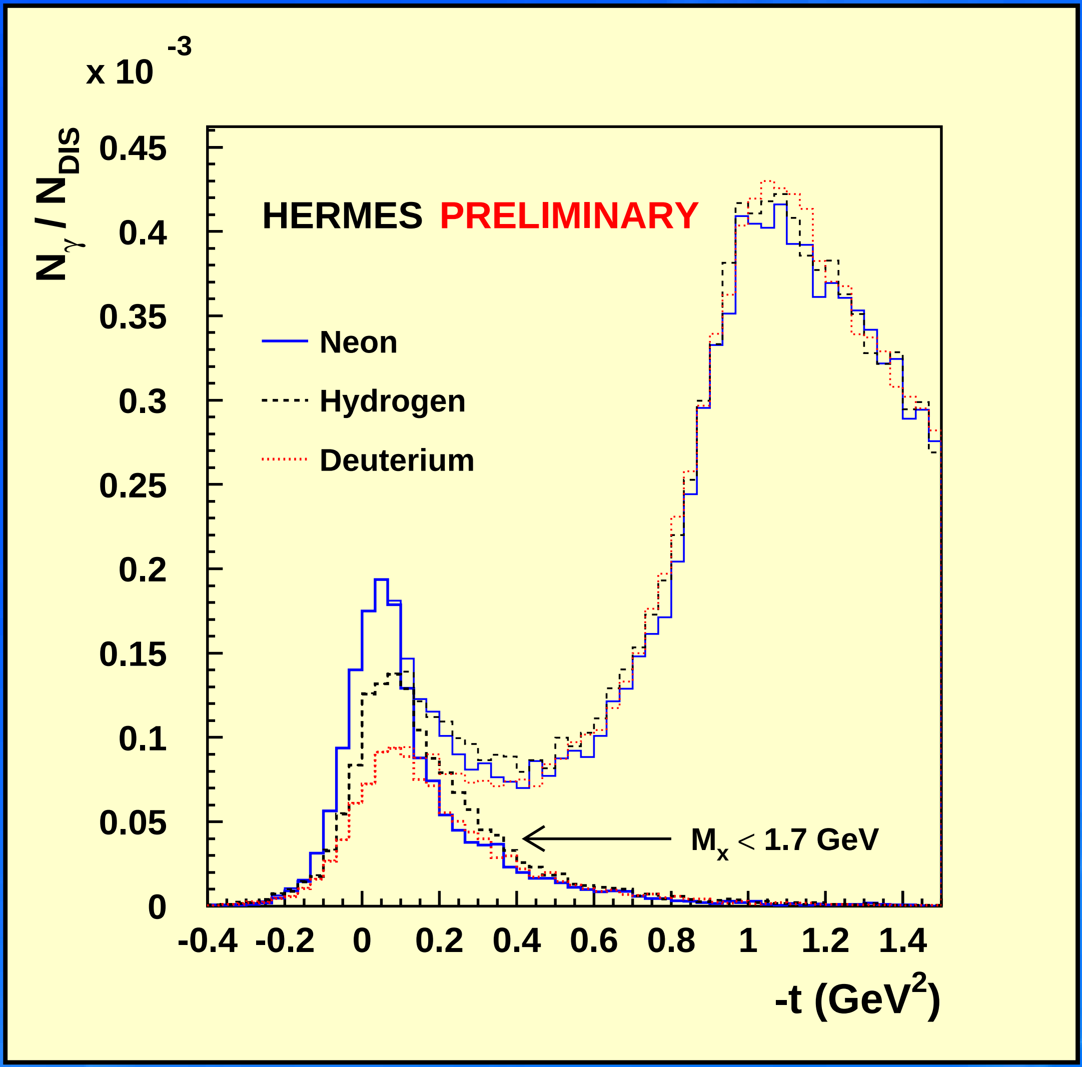


$\Rightarrow$ **both asymmetries measured by HERMES**



ϕ: azimuthal angle between lepton scattering plane and the $\gamma^*\gamma$ - plane

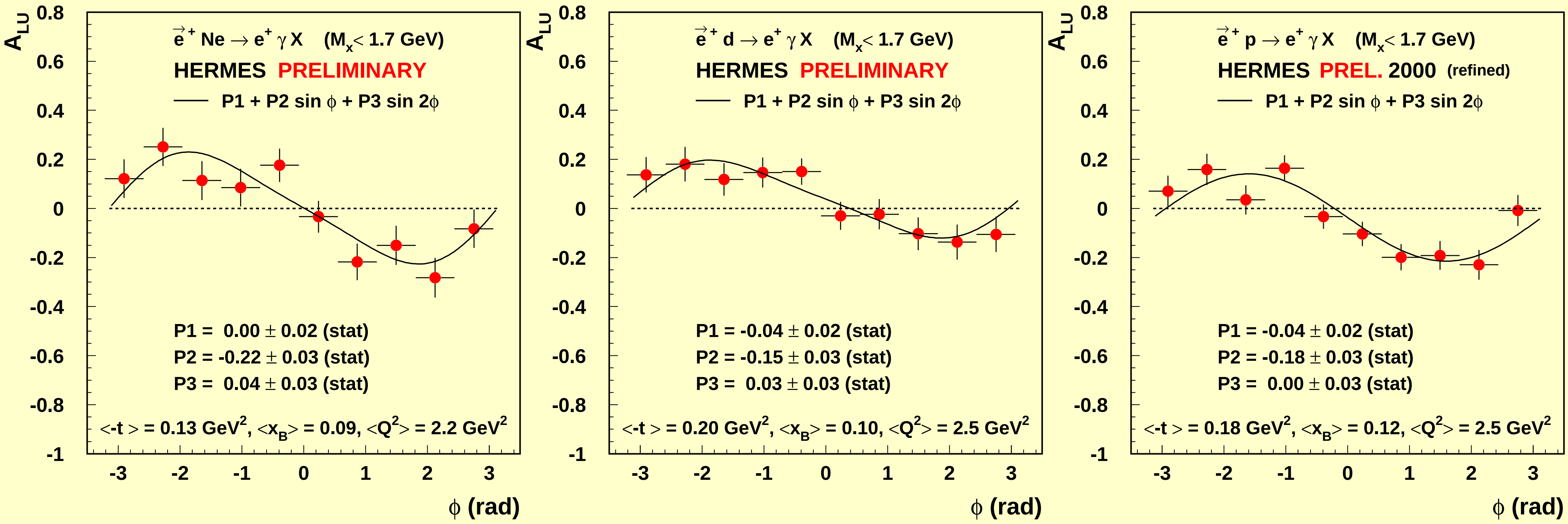
DVCS on Nuclear Targets



Proportional to :

- **Charge of the Nucleus**
- **Formfactor of the Nucleus**

DVCS SSA on Nuclear Targets



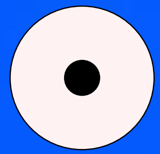
Predictions by A.V. Belitsky et al. (hep-ph/0112108):

Deuterium: $\mathbf{A_{LU} \sim -0.13 \cdot \sin(\Phi)}$ **at** $\mathbf{Q^2 = 4GeV^2 x = 0.1, t = -0.3GeV^2}$

Hydrogen: $\mathbf{A_{LU} \sim -0.16 \cdot \sin(\Phi)}$

First Hint for coherent scattering on the nucleus.

The 3rd Twist-2 Structure function

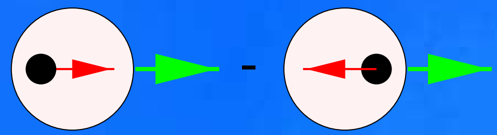
$f_1^q =$ 

Unpolarized
quarks and nucleons

vector charge:

$$< PS|\bar{\psi}\gamma^{\mu}\psi|PS >=$$
$$\int_0^1 dx q(x) - \bar{q}(x)$$

q(x): spin averaged
well known

$g_1^q =$ 

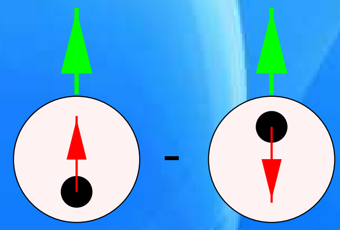
Longitudinally polarized
quarks and nucleons

axial charge:

$$< PS|\bar{\psi}\gamma^{\mu}\gamma_5\psi|PS >=$$
$$\int_0^1 dx \Delta q(x) + \Delta\bar{q}(x)$$

Δq(x): helicity difference
known

HERMES 1995-2000

$h_1^q =$ 

Transversely polarized
quarks and nucleons

tensor charge :

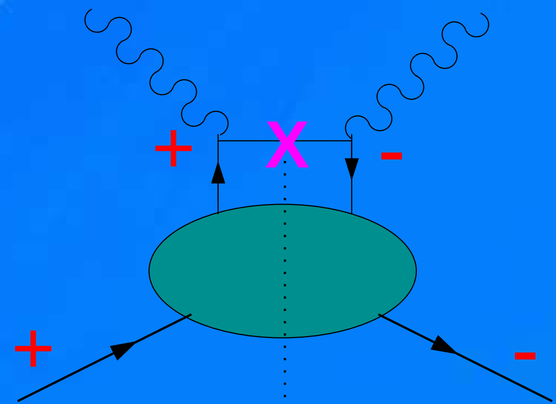
$$< PS|\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi|PS >=$$
$$\int_0^1 dx \delta q(x) - \delta\bar{q}(x)$$

δq(x): helicity flip
unmeasured

HERMES 2002. . .

Characteristics of Transversity

- **Non-relativistic quarks:** $\Delta q(x) = \delta q(x)$
  $\Rightarrow$ δq **probes relativistic nature of quarks**
- **Angular momentum conservation**
  $\Rightarrow$ **Transversity has no gluon component**
  $\Rightarrow$ **different** Q^2 **evolution than** $\Delta q(x)$
- q **and** $\bar{q}$ **contribute with opposite sign to** $\delta q(x)$
  $\Rightarrow$ **predominantly sensitive to valence quark polarization**
- **Bounds:**
  $\Rightarrow$ $|\delta q(x)| \leq q(x)$
  $\Rightarrow$ **Soffer bound:** $|\delta q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)]$



- **Transversity distribution CHIRAL ODD**

$\Rightarrow$ **No Access In Inclusive DIS**

How can one measure Transversity?

Need another chiral-odd object!

δq(x) accessible in semi-inclusive DIS

$$\sigma^{ep \rightarrow ehX} = \sum_q f^{H \rightarrow q} \otimes \sigma^{eq \rightarrow eq} \otimes D^{q \rightarrow h}$$

$\Downarrow$ **chiral-odd DF** (for $f^{H \rightarrow q}$)

$\Downarrow$ **chiral-odd FF** (for $D^{q \rightarrow h}$)

Study SSA with a transversely polarized target at HERMES

1. $ep^{\uparrow} \longrightarrow e'\pi X$ $\Leftarrow$ **Favorite Process**
   Collins,93, Kotzinian,95, Mulders et al,96
2. $ep^{\uparrow} \longrightarrow e'\Lambda^{\uparrow} X$ **Baldracchini,82, Jaffe,96**
3. $ep^{\uparrow} \longrightarrow e'\pi\pi X$ **Jaffe et al,97**

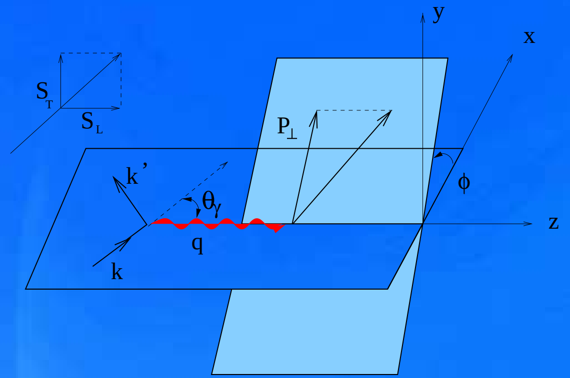
First glimpse on Transversity ?!

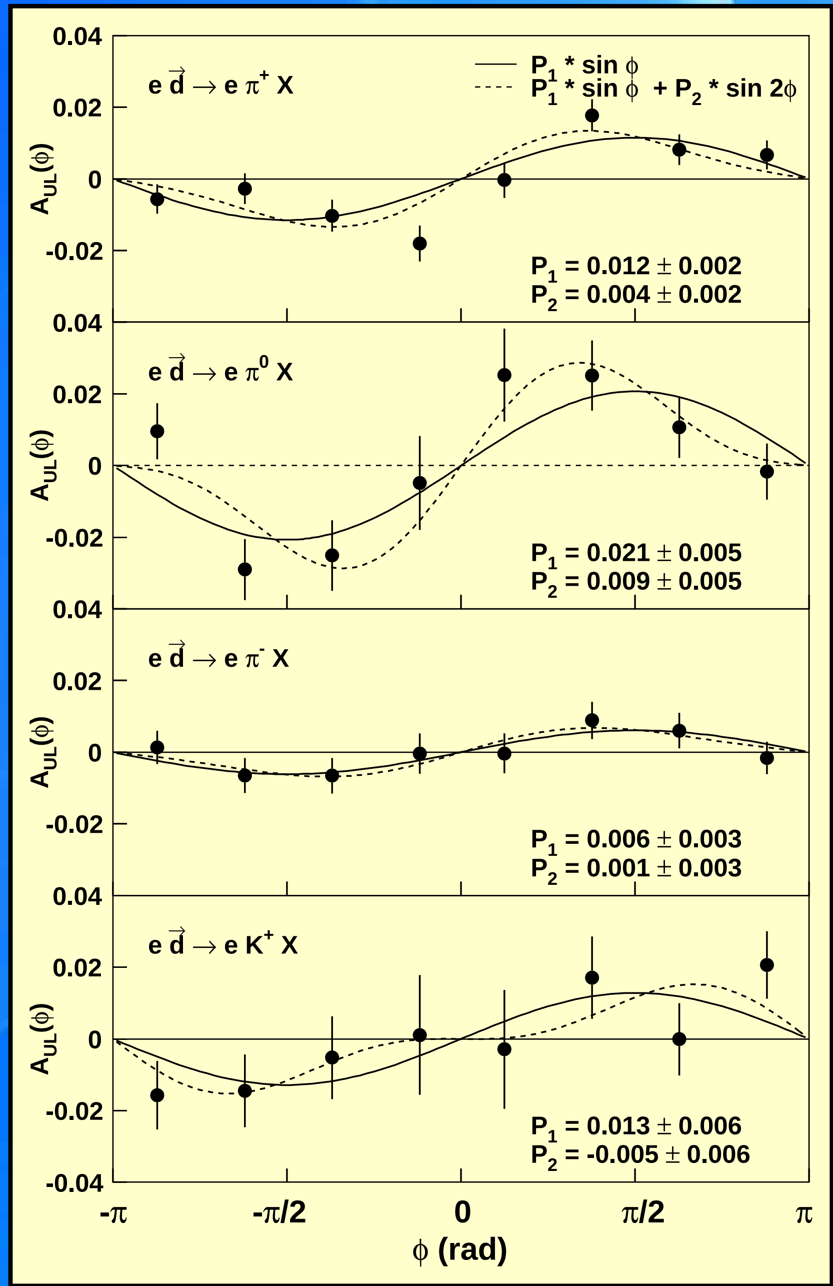
Longitudinal polarized deuteron target

$$A_{UL}(\phi) = \frac{1}{\langle P \rangle} \cdot \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

S_T transverse component of target spin w.r.t. virtual photon:

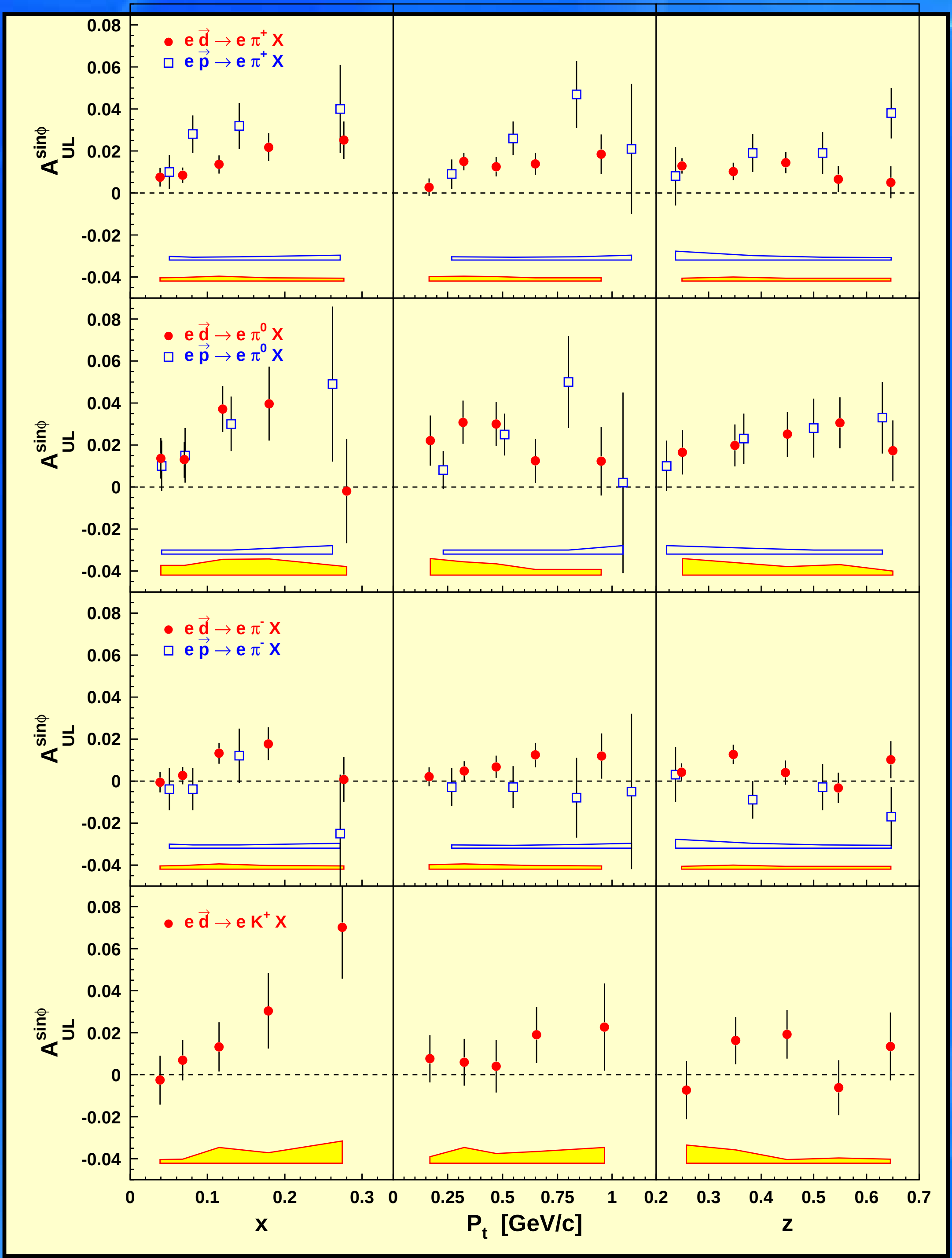
$$S_T \propto \sin\Theta_\gamma \simeq \frac{2Mx}{Q}\sqrt{1-y} \sim \mathbf{0.15}$$





longitudinal polarized hydrogen target

π^0: **hep-ex/0104005,** $\pi^{\pm}$: **hep-ex/9910062**



$\sin\phi$ *Moments*

Original predictions by Collins:

- **Proton Target**
  Larger for π^+, π^0 than for π^-
  (u-quark dominance)
- **Raise with x$_{bj}$**
  (valence quark dominance)
- **Grow with $p_\perp$, peak around 1 GeV**
  ($\frac{H_1^\perp}{D_1} \propto \frac{M_c M_h}{M_c^2+p_\perp^2}$ with $M_c \simeq$1 GeV)
- **First SSA for Kaons**

Attempt of Interpretation

- **observe non-vanishing $\langle \sin\phi \rangle$-moments**
- **$\langle \sin 2\phi \rangle$-moment small (consistent with zero)**

Attribute asymmetry to Collins fragmentation and Transversity:

$$A_{UL}^{\sin\phi} \sim S_L \langle \sin\phi \rangle_{UL} - S_T \langle \sin\phi \rangle_{UT}$$

Longitudinally polarized in experiment (along beam direction)

L/T polarized in theory (along γ^* direction)

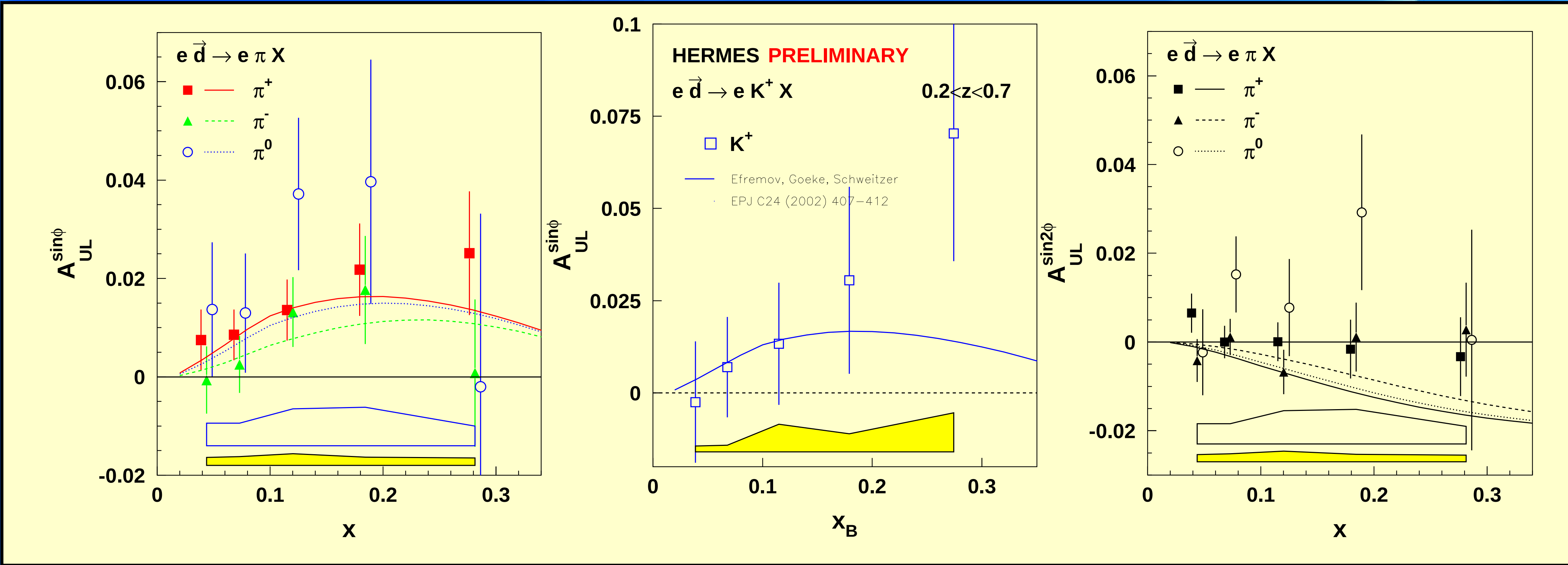
$$\langle \sin\phi \rangle_{UL} \sim \frac{1}{Q} \sum_q e_q^2 \left(h_L^q(x) H_1^{\perp(1),q}(z) - \frac{1}{z} h_{1L}^{\perp(1),q}(x) \tilde{H}(z) \right)$$

$$\langle \sin\phi \rangle_{UT} \sim \sum_q e_q^2 x h_1^q(x) H_1^{\perp(1),q}(z)$$

but $S_T \sim \frac{1}{Q}$ like twist-3

$$\langle \sin 2\phi \rangle_{UL} \sim \sum_q e_q^2 x h_{1L}^{\perp(1),q}(x) H_1^{\perp(1),q}(z)$$

Data - Theory



- h_1 from χQSM (Efremov et al. Eur.Phys.J. C24 (2002) 407)
- assume reduced twist-3 $\longrightarrow \tilde{h}_L = 0$
- $H_1^\perp$: Collins function parametrisation to fit HERMES proton data

  "optimistic" result from DELPHI $e^+e^- \rightarrow 2$jets: $\frac{\langle H_1^{\perp(1)} \rangle}{\langle D_1 \rangle} = (12.5 \pm 1.4)\%$

Challenges in Interpretation

Attribute asymmetry to Sivers effect:

- **Final state interactions (Brodsky et al.)**
- **Sivers function (Sivers, Mulders et al)** $\langle \sin\phi \rangle_{\mathbf{UL}} \sim \mathbf{f_{1T}^{\perp(1)} D_1}$

longitudinally polarized target

$\Rightarrow$ **Sivers and Collins effect indistinguishable**

Transversely polarized target

- $\langle \sin\phi \rangle_{UT}$ **becomes dominant**
- **Sivers and Collins distinguishable**

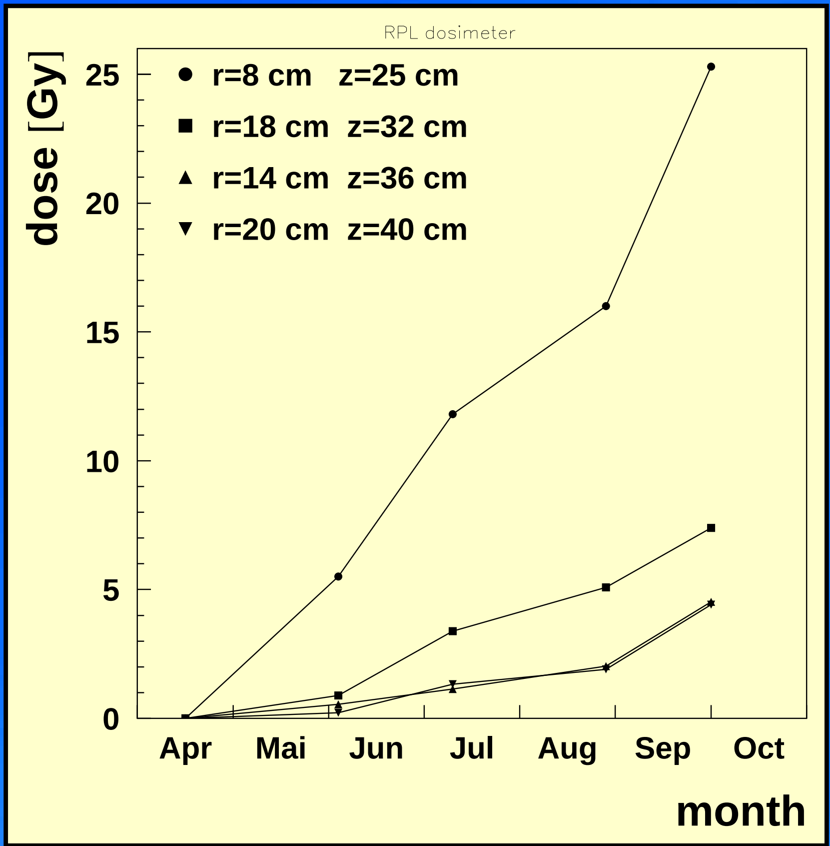
$\swarrow$ $\searrow$

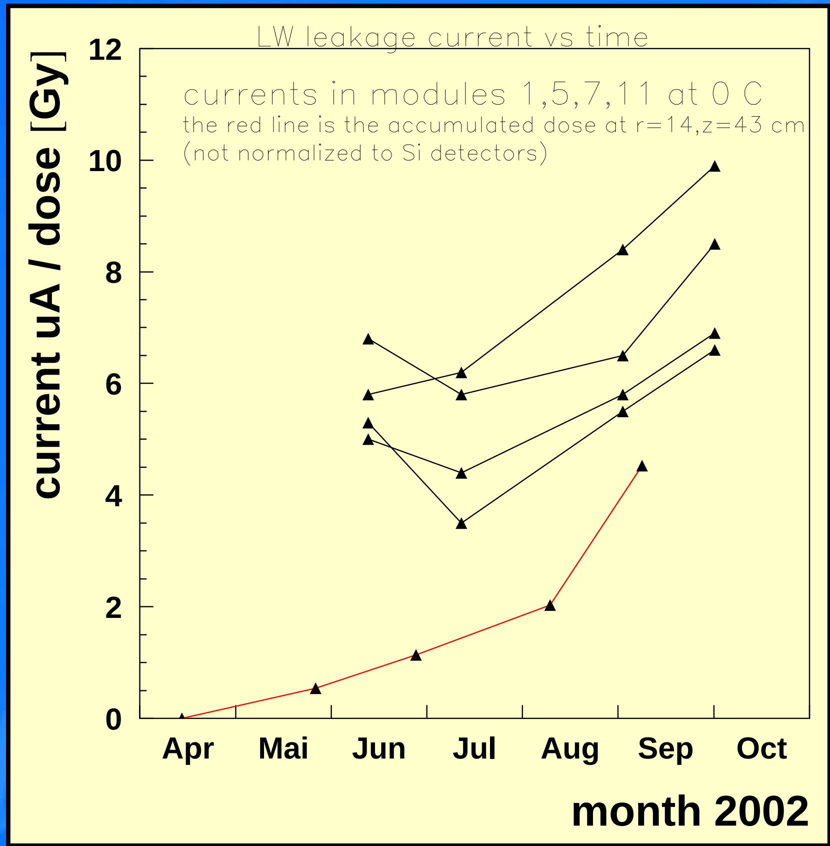
$\langle \sin(\phi_{\mathbf{h}}^{\mathbf{l}} - \phi_{\mathbf{s}}^{\mathbf{l}}) \rangle$ **moment** $\langle \sin(\phi_{\mathbf{h}}^{\mathbf{l}} + \phi_{\mathbf{s}}^{\mathbf{l}}) \rangle$ **moment**

Background conditions as in 2000

Ready for production data taking

Radiation Doses relevant for the Si-Detector

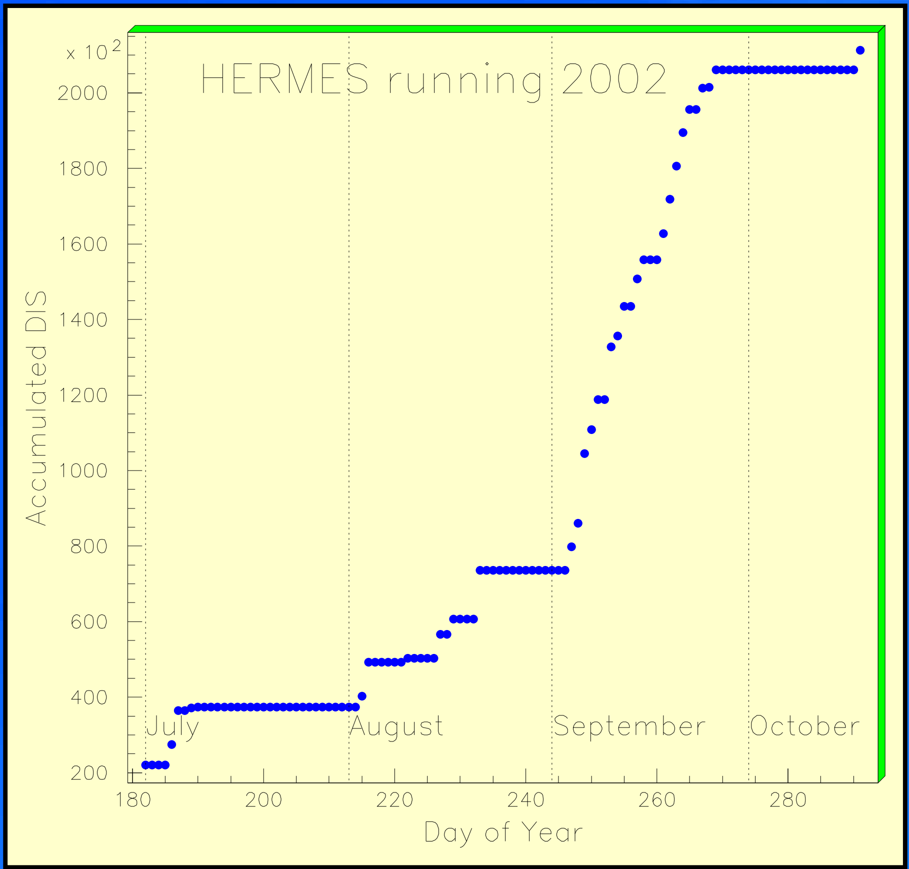


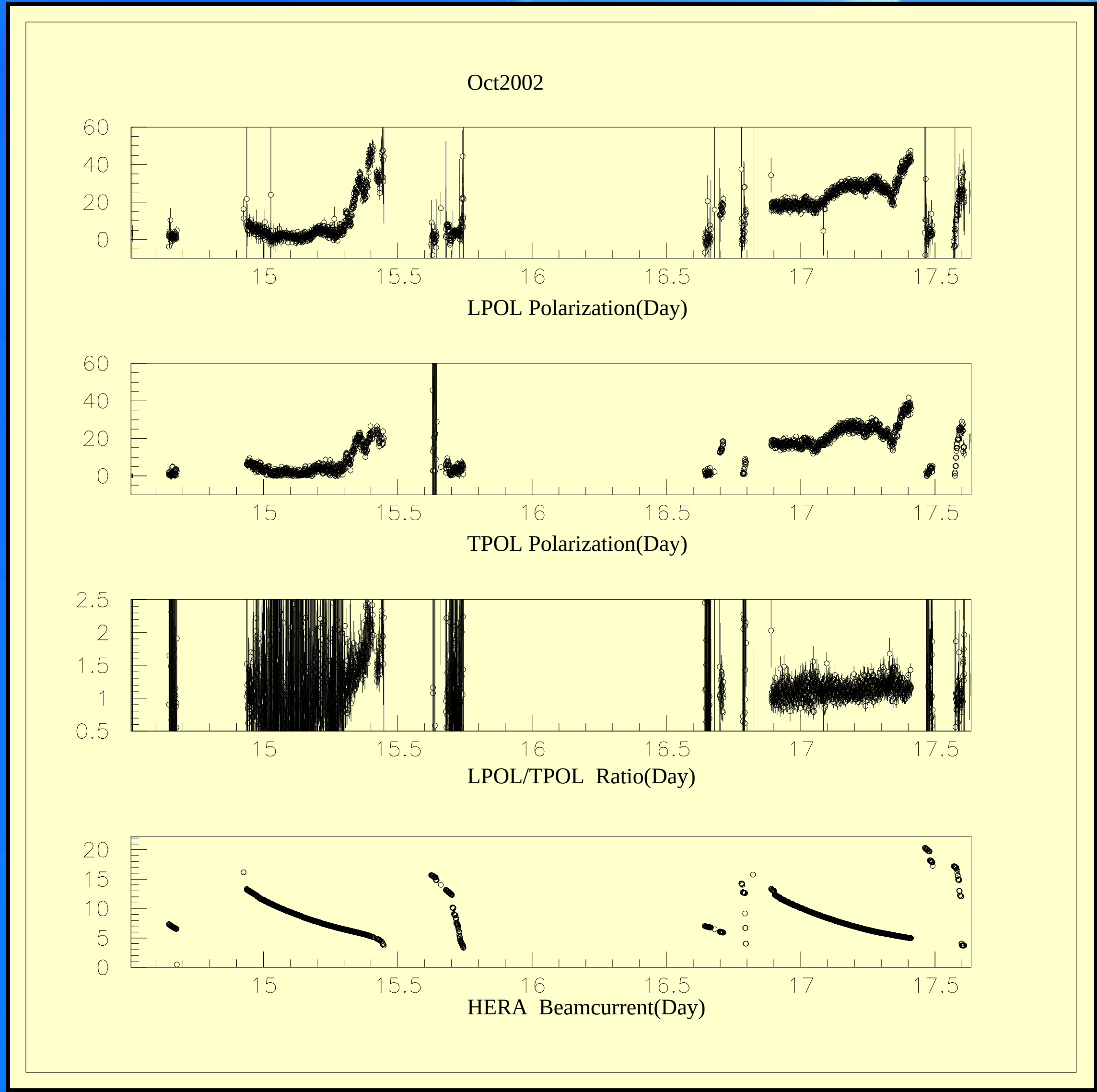


Lethal Dose HELIX: 2-5 kGy **Lethal Dose SI: 20 kGy**

No big damage

2002 Data Taking (II)





Need **1.4 Million DIS**
Data rate:
70 DIS / mA h ⟶ 20 Ah

Both polarimeters worked
stable and reliable

Single Spin Asymmetries in 2002

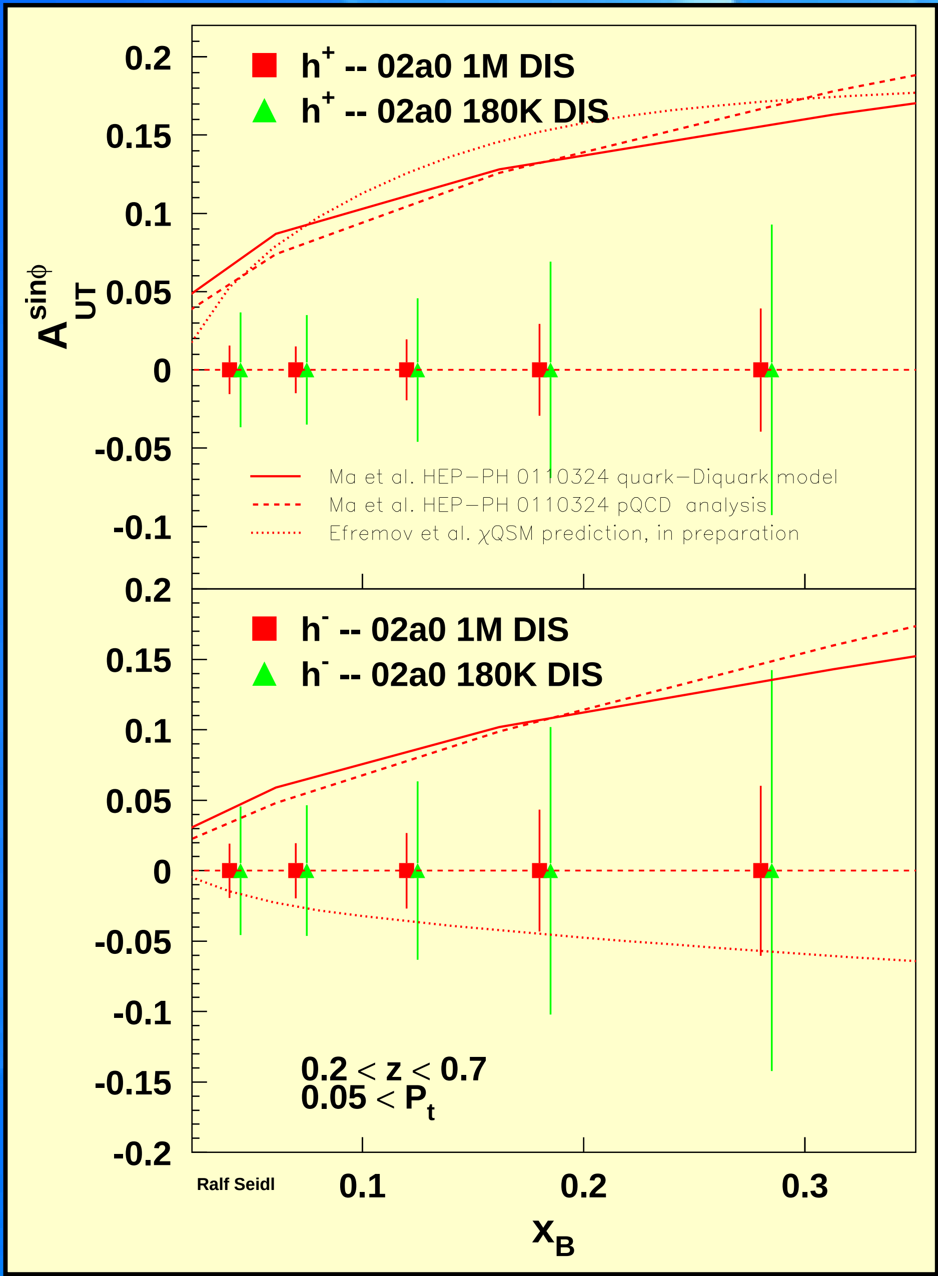
$$ep^{\uparrow} \longrightarrow e'\pi X$$

HERMES is ready to measure $\delta \mathbf{q}(\mathbf{x})$

with its transversely polarized target:

$$A_{UT}^{\sin(\phi_h^l+\phi_s^l)} \propto \frac{\sum_q e_q^2 \delta q(x) H_1^{\perp,q}(z)}{\sum_q e_q^2 q(x) D_1^q(z)}$$

$H_1^{\perp}(z)$ **Collins fragmentation function**



Summary

- **Inclusive**
  - **first measurement of b$_1$(x)**
- **DVCS**
  - **First Hint for coherent scattering on the nucleus**
- **Transversity**
  - **first results with a transversely polarized target coming soon**