Probing Quark Distributions in Semi-Inclusive Single Spin Asymmetries

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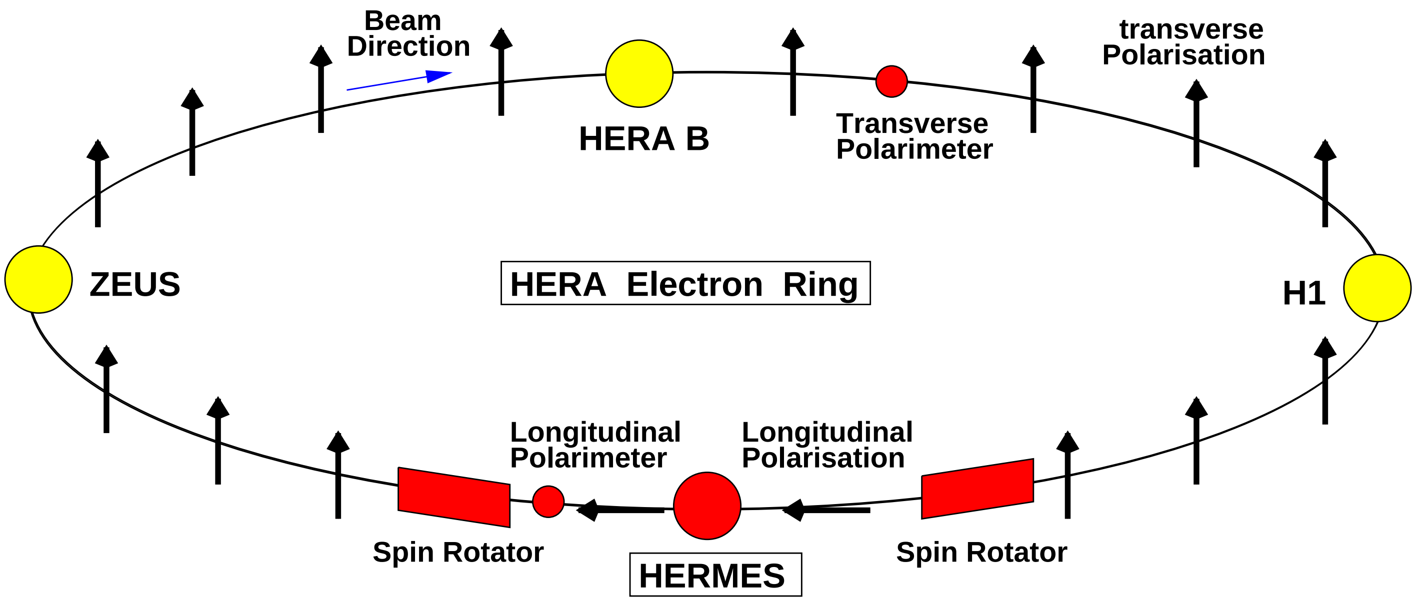
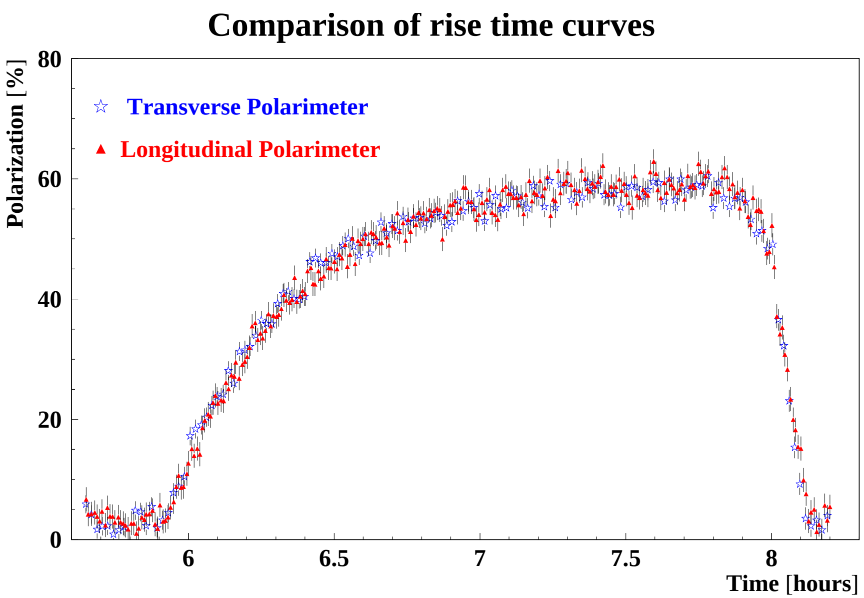
DESY - Zeuthen

For the hermes Collaboration

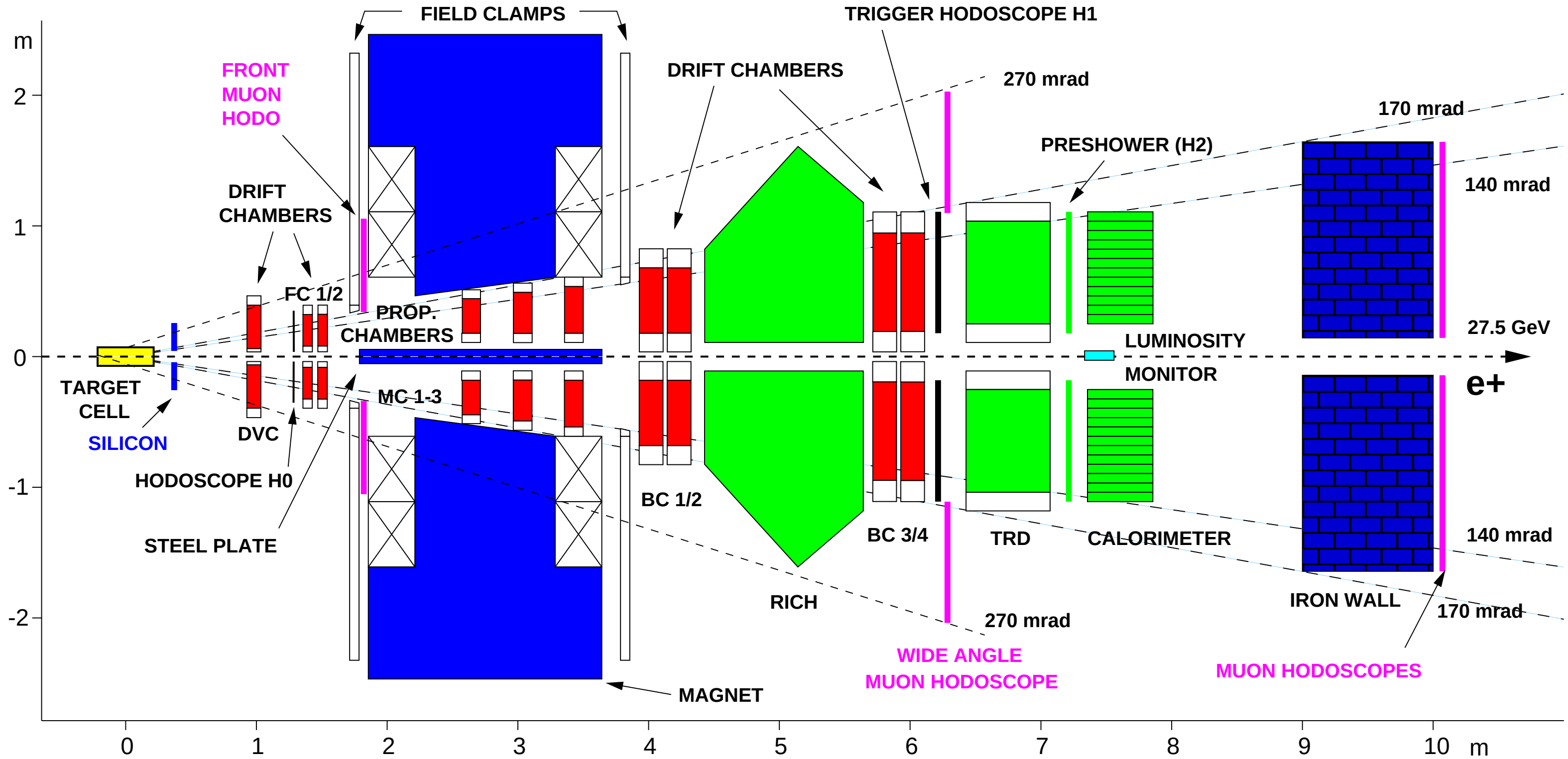
Polarized Beam at HERA





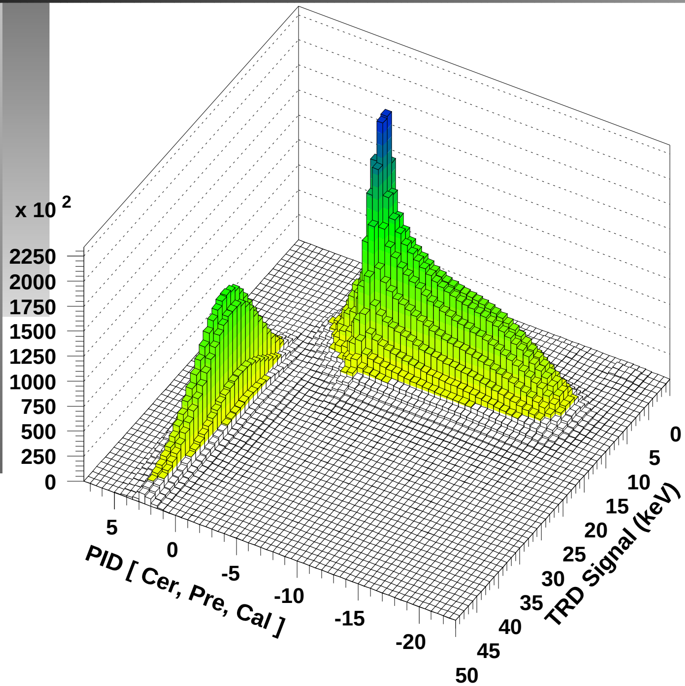
- 27.5 GeV e^+/e^- beam
- Self-polarizing through Sokolov-Ternov-Effect
- Average beam polarization of about 55%

The HERMES Experiment



- Internal storage cell: pure gas target
- Forward acceptance spectrometer: 40 mrad $\leq \Theta \leq$ 220 mrad
- Tracking: 57 tracking planes: $\delta P/P = (0.7 - 1.3)\%$, $\delta\Theta \leq 0.6$ mrad
- PID: Cherenkov (RICH after 1997), TRD, Preshower, Calorimeter

Particle Identification

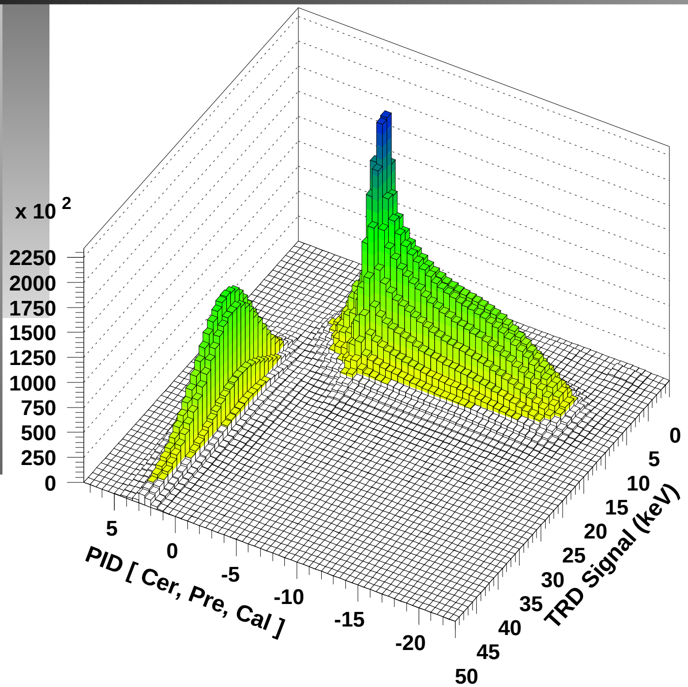


Excellent e^{+}/e^{-} identification:

- Efficiency $\geq 99\%$
- Hadron contamination $\leq 1\%$

Until 1997 only used Threshold Cherenkov

Particle Identification



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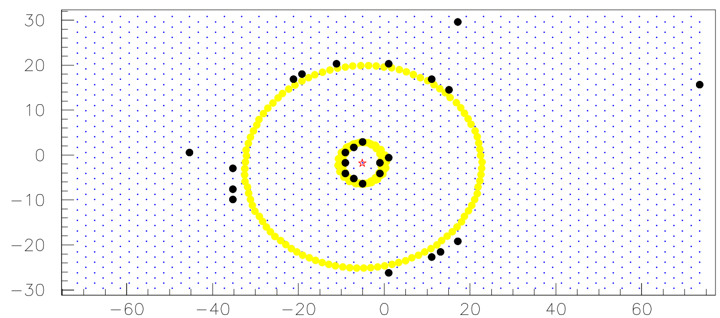
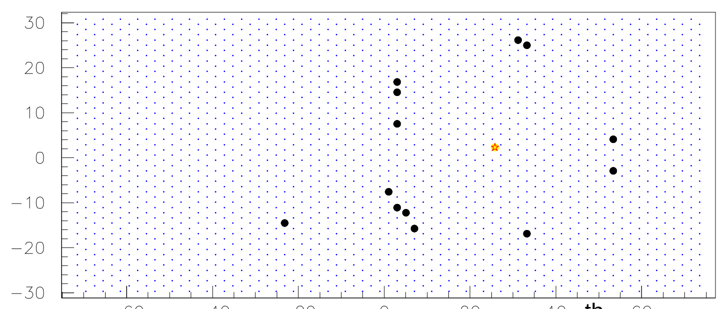
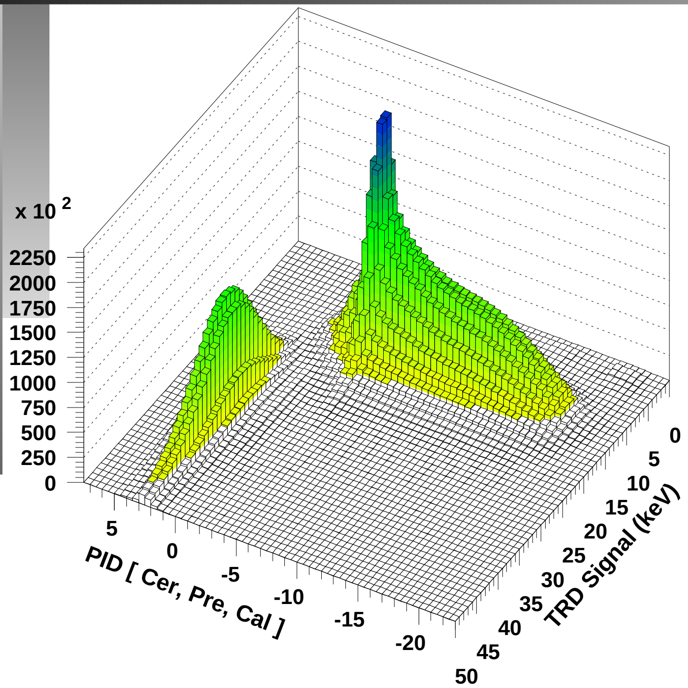


After 1997 use dual radiator
Ring Imaging CHerenkov



Particle Identification



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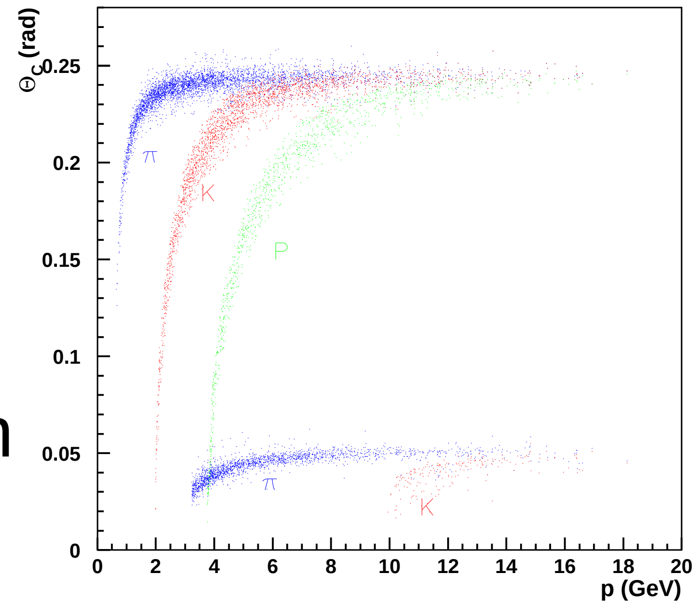
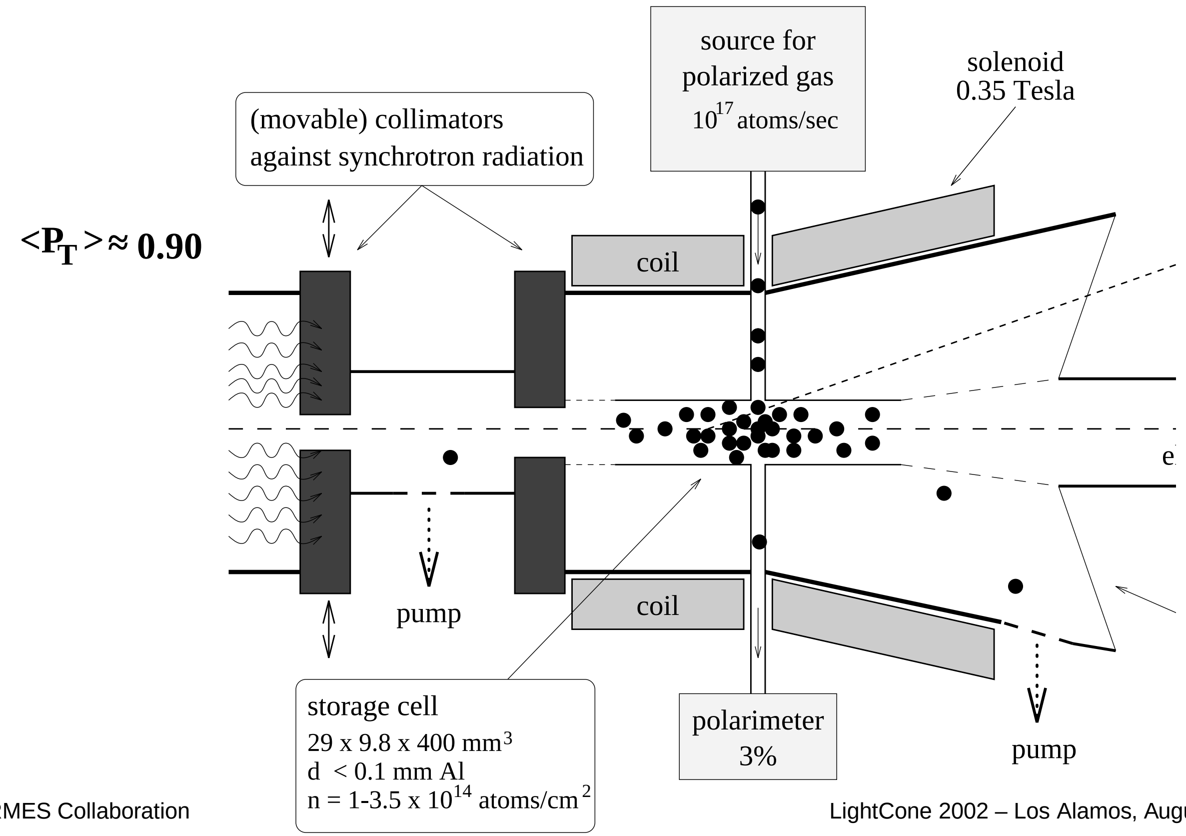


After 1997 use dual radiator
Ring Imaging CHerenkov
$\hookrightarrow$ very good hadron identification in the range $2\ GeV \leq P_h \leq 15\ GeV$

HERMES Internal Gas Target

- Storage cell with atomic beam source
- Pure target (NO dilution)
- Polarized or unpolarized targets possible
- Different gas targets available (H, D, He, N, Kr ...)

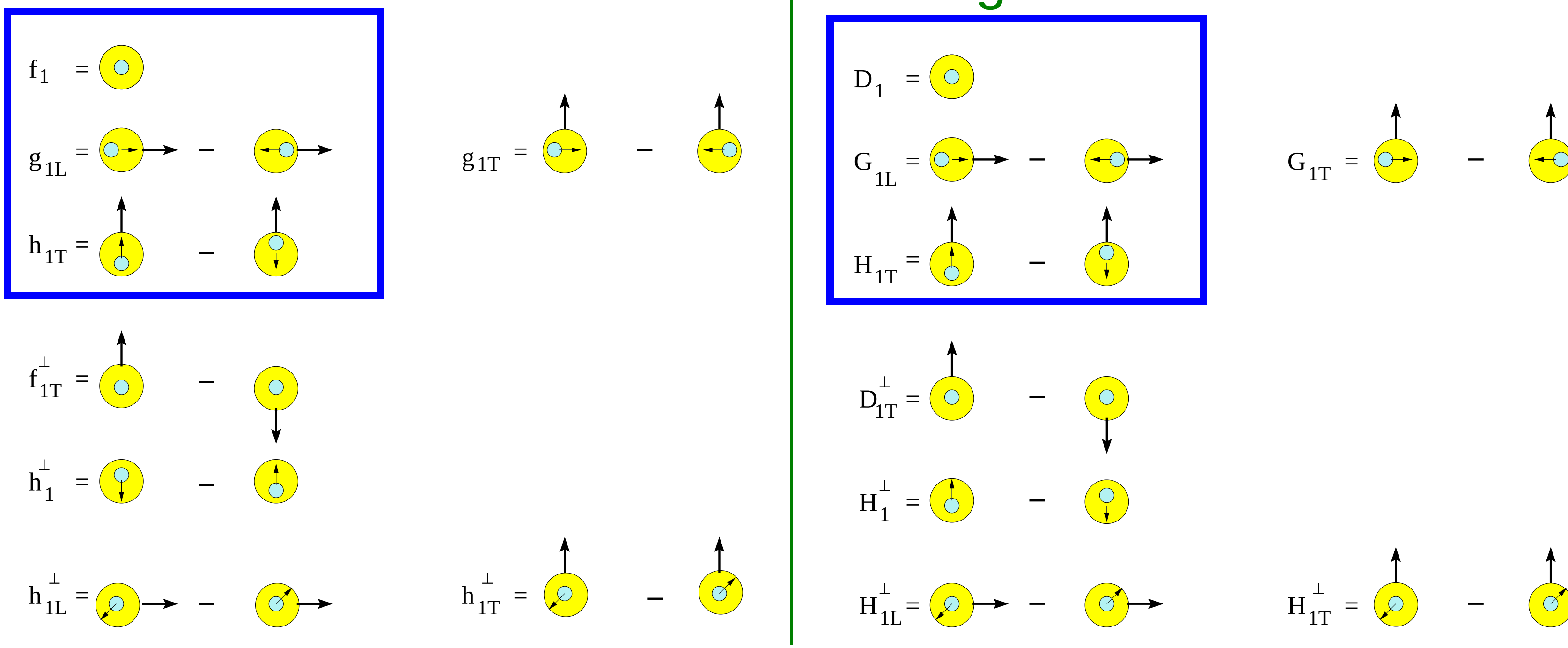


Twist-2 Quark Distribution Functions

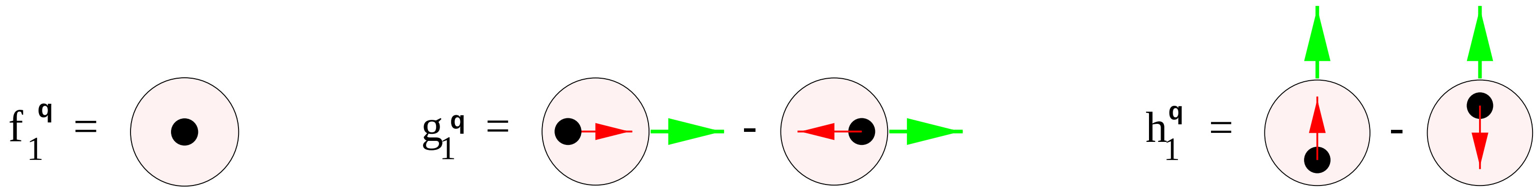
Functions Surviving on Integration over Transverse Momenta

- The others are sensitive to intrisic $< k_t >$ in the nucleon & in the fragmentation process

Distribution Functions | Fragmentation Functions



... surviving $k_\perp$ integration



$\downarrow$ Unpolarized quarks and nucleons

q(x): spin averaged (well known)

$\downarrow$ Longitudinally polarized quarks and nucleons

Δq(x): helicity difference (known)

HERMES 1995-2000

$\downarrow$ Transversely polarized quarks and nucleons

δq(x): helicity flip (unmeasured)

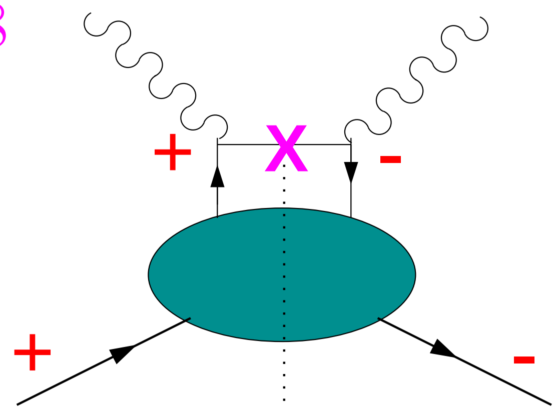
HERMES 2002. . .

Transversity

- Non-relativistic quarks: $\Delta q(x) = \delta q(x)$
  $\Rightarrow \delta q$ probes relativistic nature of quarks
- obvious bound: $|\delta q(x)| \leq q(x)$
- Soffer bound: $|\delta q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)]$

- Sum Rule: first moment $\rightarrow$ tensor charge reliably calculable in lattice QCD (i.e. at $Q^2 = 2GeV^2$):

$$\delta\Sigma = \sum_f \int_0^1 dx(\delta q_f - \delta\bar{q}_f) = 0.562 \pm 0.088$$



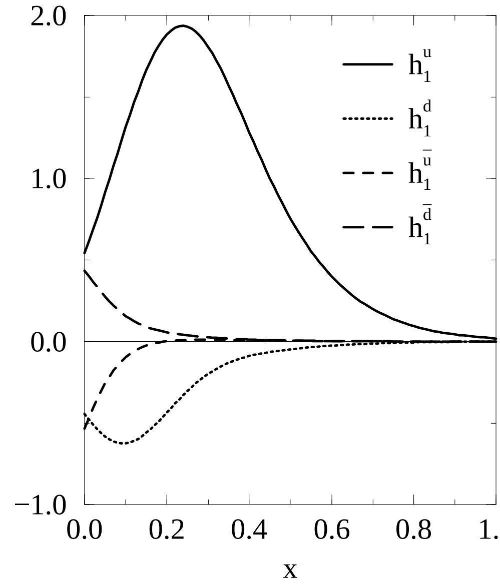
- transversity distribution CHIRAL ODD

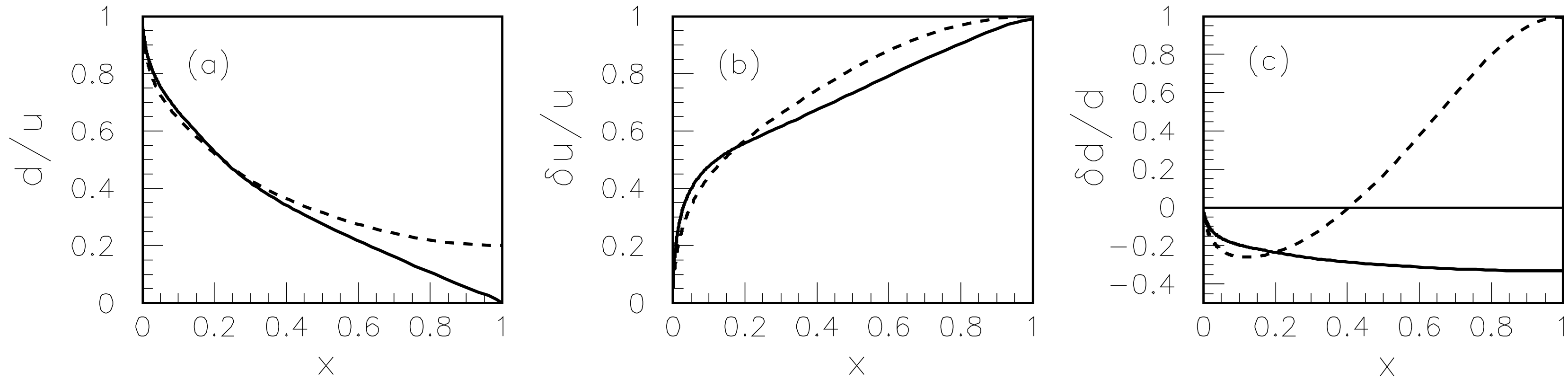
$\hookrightarrow$ No Access In Inclusive DIS

Transversity Phenomenology

- $\exists$ a number of model calculation (facing a lack of experimental data)
- h_1 must satisfy Soffer inequality
- in common: h_1 behaves more valence-like

χQSM (A.V. Efremov et a





Quark-Diquark (solid), pQCD based model (dashed) (B.Q. Ma et al)

Transversity Measurements

How can one measure transversity?

Need another chiral-odd object!

Semi-Inclusive DIS $\longrightarrow$ HERMES with transversely polarized target

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

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

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

Candidates for Fragmentation

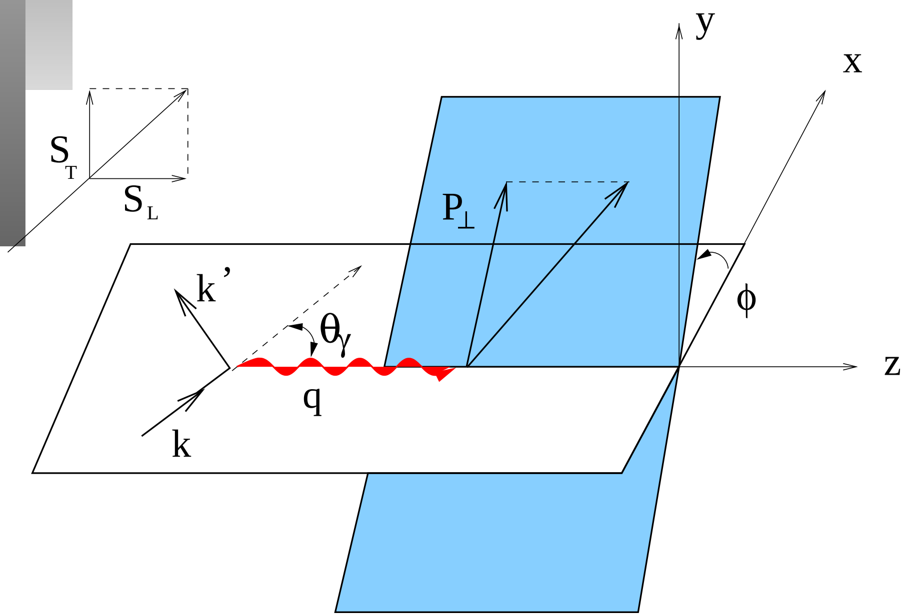
Want to measure polarization of outgoing quark various “polarimeters” proposed in the literature possible at HERMES:

1. $ep^{\uparrow} \longrightarrow e'\pi(k_\perp)X$ $\Leftarrow$ Favoured Process $\Rightarrow$ Signature: Single-Spin Azimuthal Asymmetry
2. $ep^{\uparrow} \longrightarrow e'\Lambda^{\uparrow}X$
3. $ep^{\uparrow} \longrightarrow e'\pi\pi X$

1. Collins,93, Kotzinian,95, Mulders et al,96
2. Baldracchini,82, Jaffe,96
3. Jaffe et al,97

Single Spin Asymmetries

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



study azimuthal distribution of π's:

$$A^{\sin\Phi} \propto \frac{\sum_{i=1}^{N^+} \sin\Phi_i - \sum_{i=1}^{N^-} \sin\Phi_i}{\frac{1}{2}(N^+ + N^-)}$$

with transversely polarized target:

$$A_T^{\sin\Phi} \propto \frac{\sum_q e_q^2 \delta q(x) H_1^{\perp,q}(z)}{\sum_q e_q^2 q(x) D_1^q(z)}$$

$\Phi = \phi + \phi_s^l$ Collins angle

$\phi_s^l \ldots$ angle between target spin vector and scattering plane

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

(T-odd, chiral odd)

Single Spin Asymmetries at HERMES

HERMES 1996/97: longitudinal polarized proton target

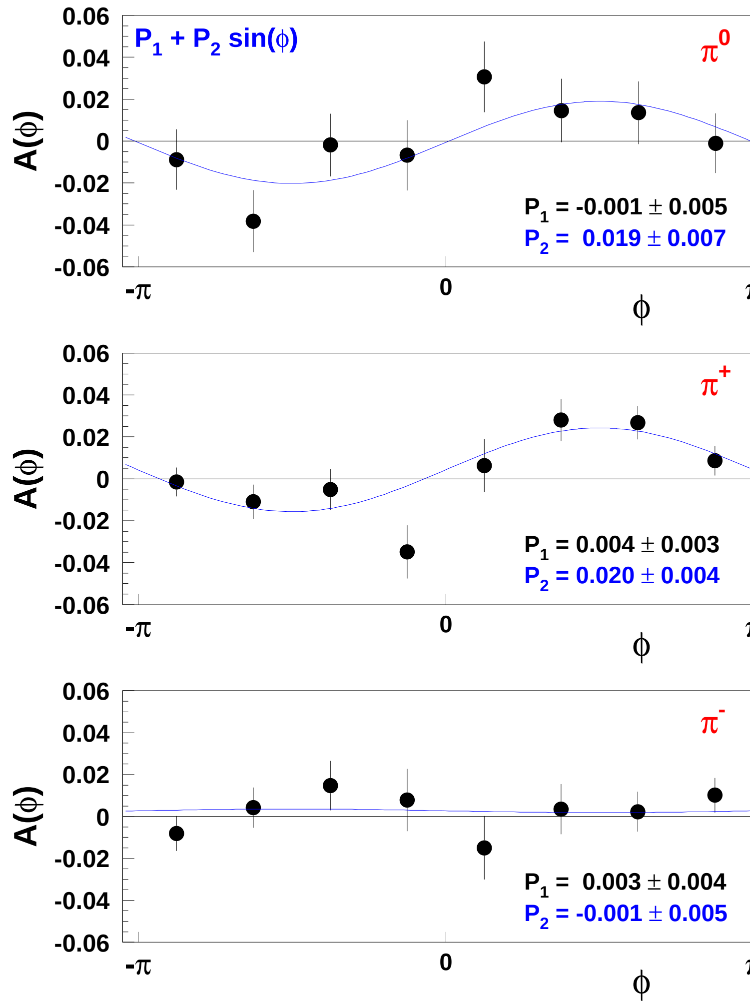
transverse component S_T
of target spin (w.r.t. virtual photon):

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

$\Rightarrow$ glimpse on transversity?!

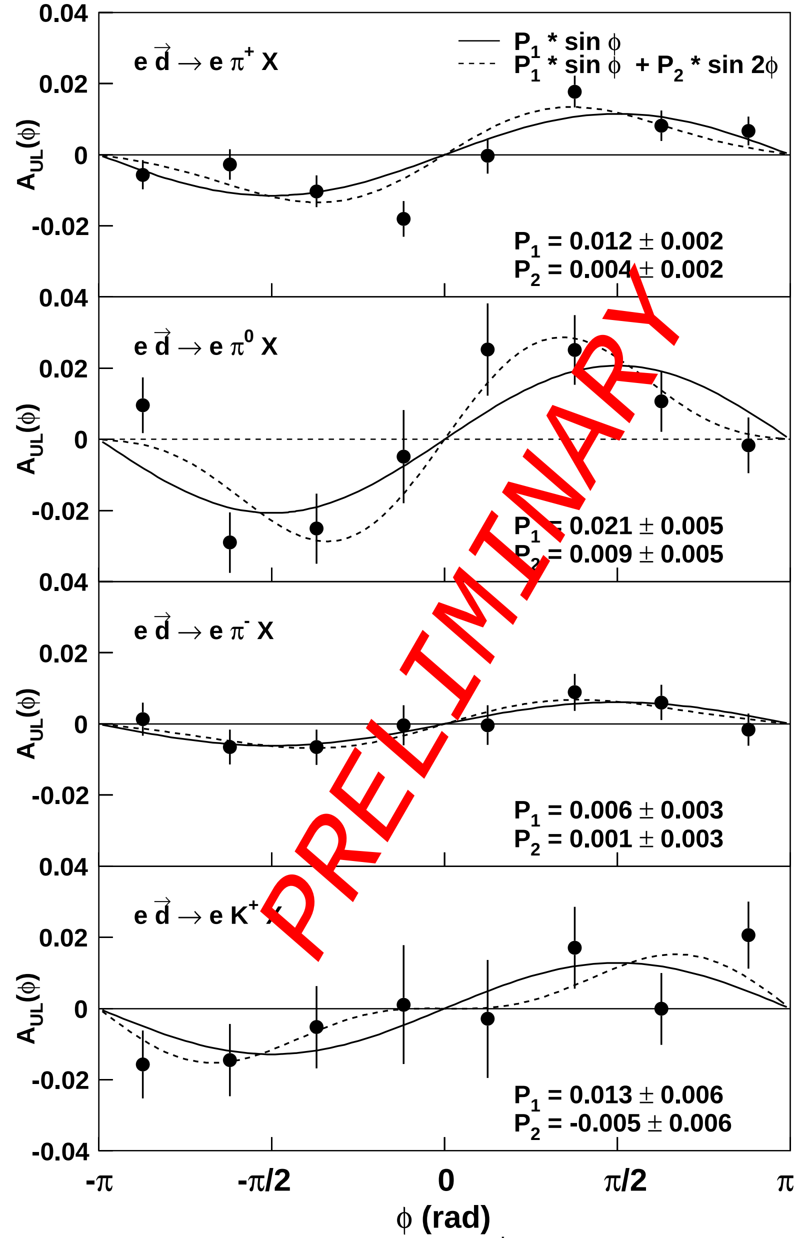
Longitudinal target SSA:

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



HERMES Results on Deuteron Target

- HERMES 1998-2000: longitudinal polarized deuteron target
- High statistics: ~8 Million DIS
- Very good hadron identifi cation due to RICH
- First measurement of Kaon SSA



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 virtual gamma direction)

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

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

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

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

What about Twist-3?

distribution functions are related:

$$h_L(x) = \frac{m_q}{M}\frac{h_1(x)}{x} - \frac{2}{x}h_{1L}^{\perp(1)}(x) + \tilde{h}_L(x)$$

Lorentz covariance $\Rightarrow h_L(x) = h_1(x) - \frac{d}{dx}h_{1L}^{\perp(1)}(x)$

$$\hookrightarrow \quad h_L(x) = \tilde{h}_L(x) + 2x\int_x^1 \frac{dy}{y^2}\left[h_1(y) - \tilde{h}_L(y)\right]$$

set $\tilde{h}_L = 0$

$$\Rightarrow h_L(x) = -\frac{2}{x}h_{1L}^{\perp(1)}(x) = 2x\int_x^1 \frac{dy}{y^2}h_1(y)$$

"Reduced Twist-3"

Attempt of Interpretation II

Attribute asymmetry to Sivers effect:

- **Final state interactions (Brodsky et al.)**
- **Sivers function (Sivers, Mulders et al)**

$$\langle \sin\phi \rangle_{UL} \sim f_{1T}^{\perp(1)} D_1$$

longitudinally polarized target $\Rightarrow$ Sivers effect indistinguishable from Collins effect

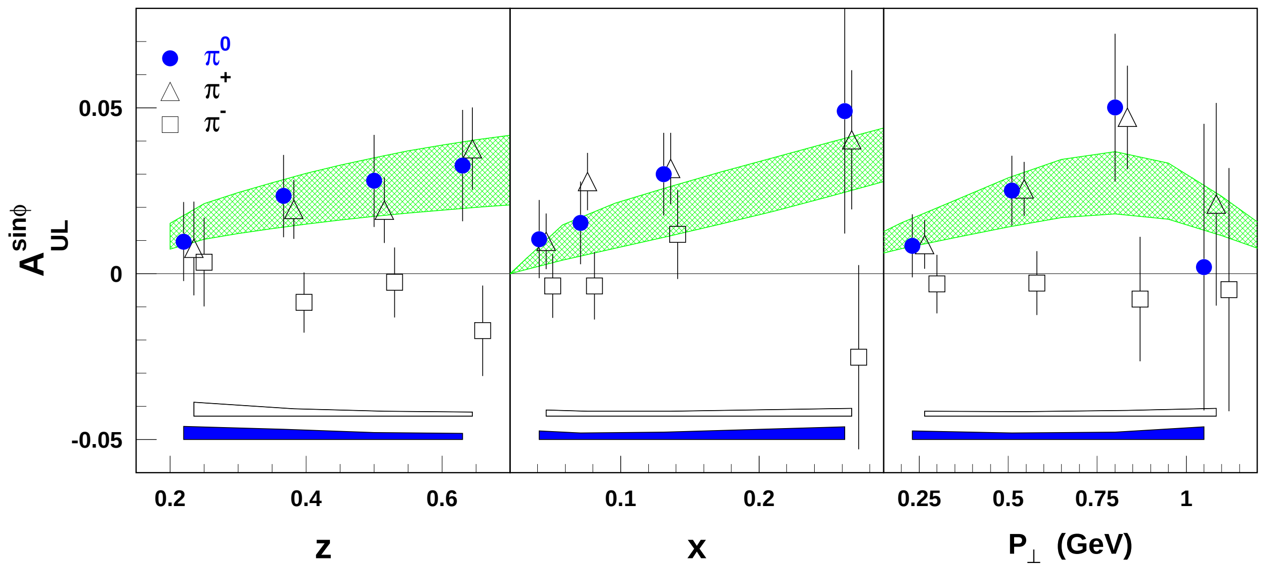
Transversely polarized target

$\swarrow$ $\searrow$

Sivers | Collins

$\langle \sin(\phi_h^l - \phi_s^l) \rangle$ moment | $\langle \sin(\phi_h^l + \phi_s^l) \rangle$ moment

Let's assume Collins

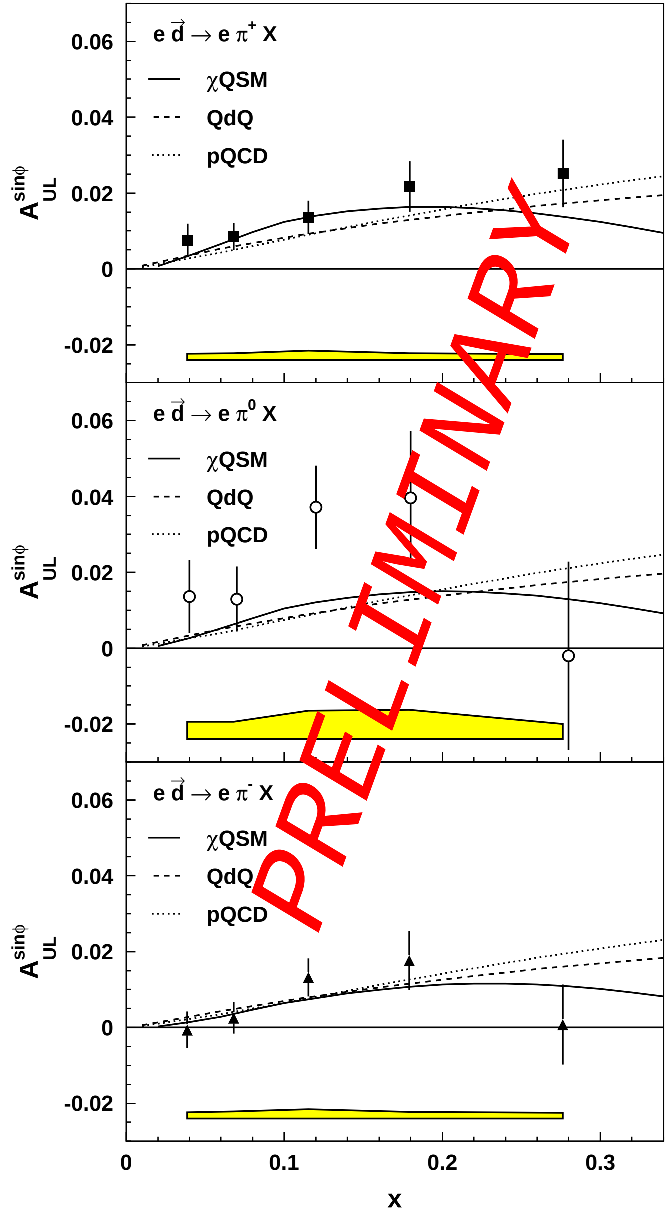


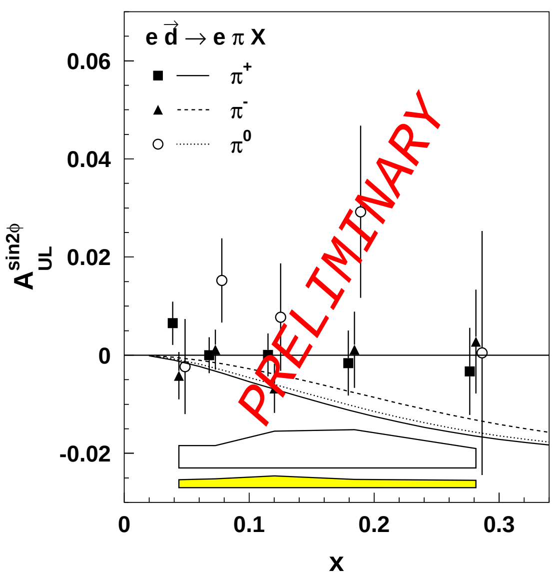
Original predictions by Collins (here: proton target):

- **Larger for π^+, π^0 than for π^- (u-quark dominance in case of proton target)**
- **Peak around $x = 0.3$ (valence quark dominance)**
- **Grow with $p_\perp$ and 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)**

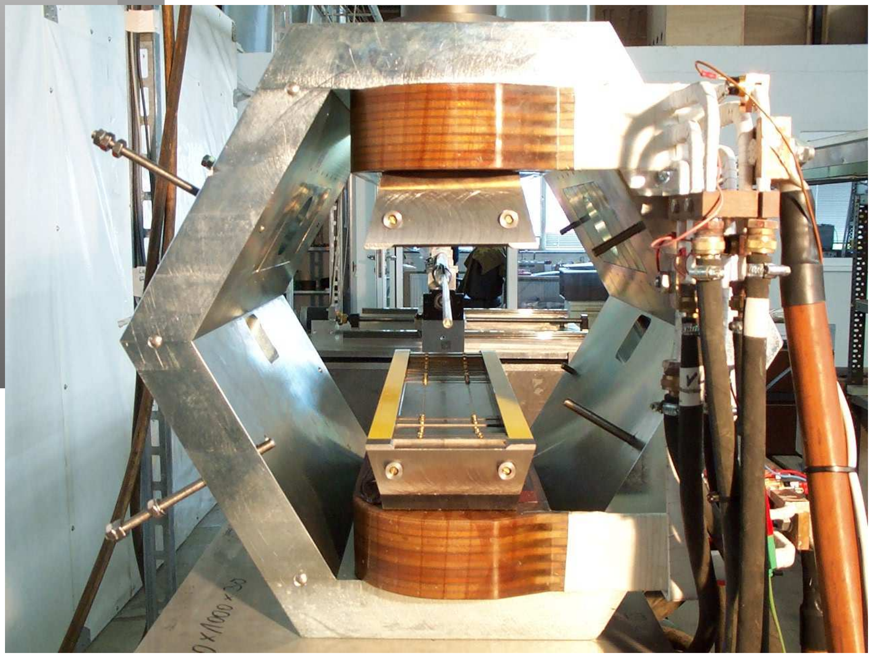
Model Predictions for Deuteron

- deuteron target
- h_1 from χQSM, quark-diquark and pQCD model
- assume reduced twist-3
- $H_1^\perp$: Collins Ansatz or fit to DELPHI data
- $\sin 2\phi$ using χQSM model





Outlook



New Target Magnet for HERMES

- **Transverse target ($B = 0.295T$)**
- **High uniformity along beam direction:** $\Delta B \leq 4.5 \cdot 10^{-5}T$
- **Transversely polarized hydrogen**
- **Target polarization above 80%**

- $\langle \sin\phi \rangle_{UT}$ becomes dominant
- Sivers and Collins distinguishable
  $\hookrightarrow h_1$ and $H_1^\perp$ as well as $f_{1T}^\perp$ accessible