Transversity Measurements at HERMES

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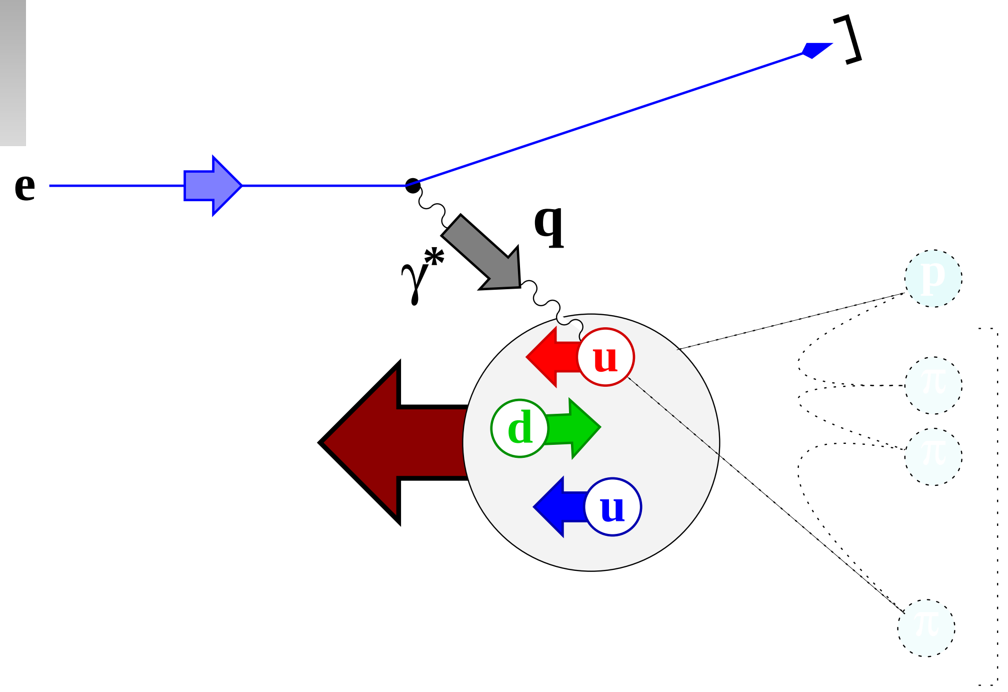
For the hermes Collaboration

Deep Inelastic Scattering

use well-known probe to study hadronic structure



$$Q^2 \stackrel{\text{lab}}{=} 4EE' \sin^2(\frac{\Theta}{2})$$

$$\nu \stackrel{\text{lab}}{=} E - E'$$

$$W^2 \stackrel{\text{lab}}{=} M^2 + 2M\nu - Q^2$$

$$y \stackrel{\text{lab}}{=} \frac{\nu}{E}$$

$$x \stackrel{\text{lab}}{=} \frac{Q^2}{2M\nu}$$

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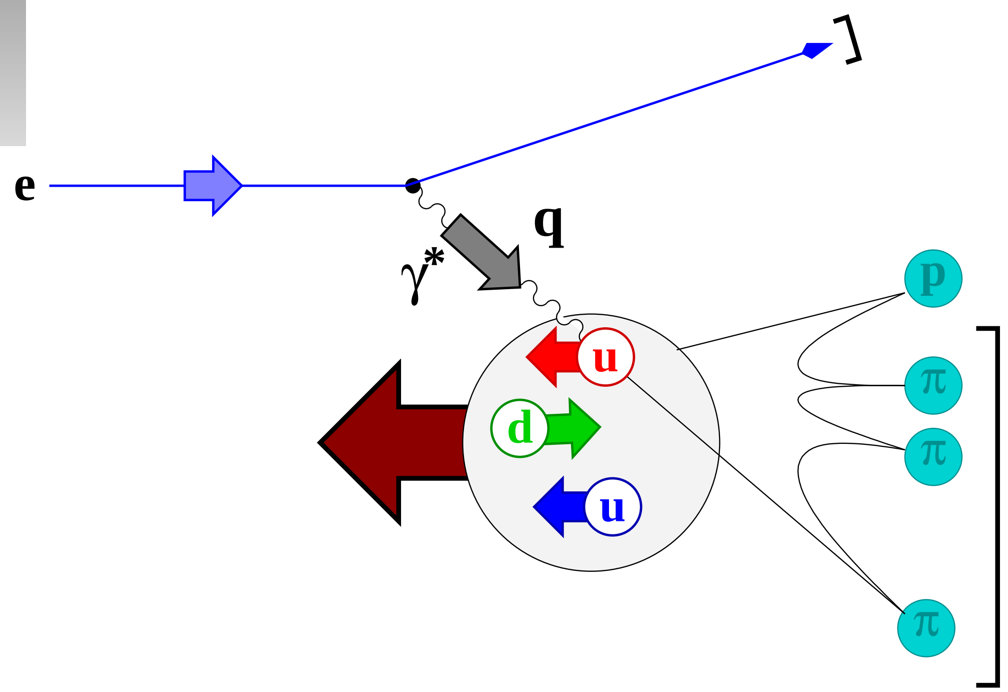

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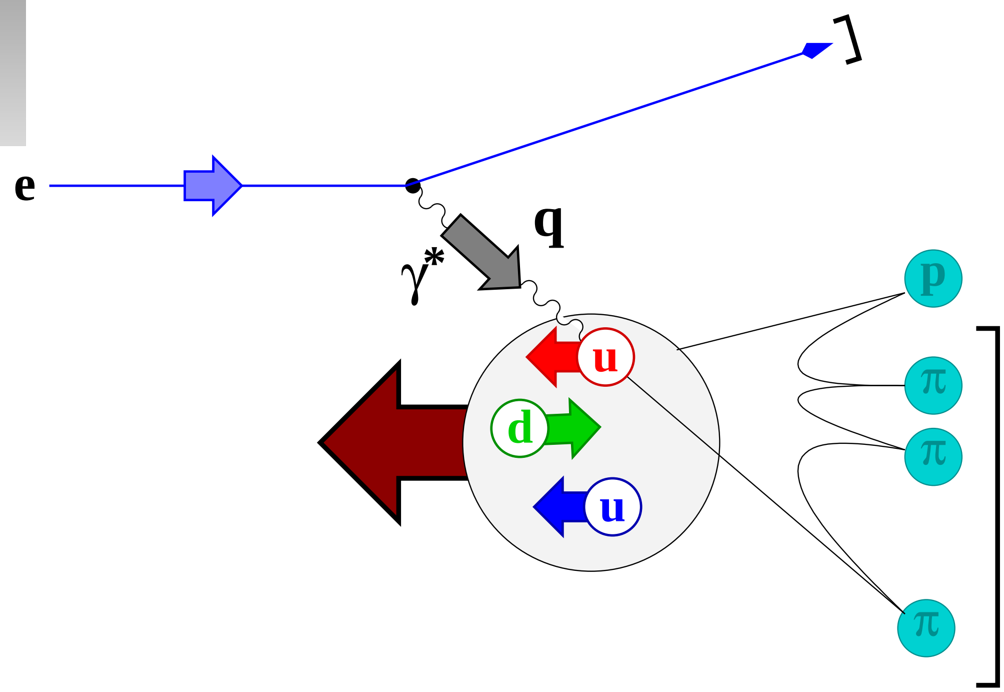

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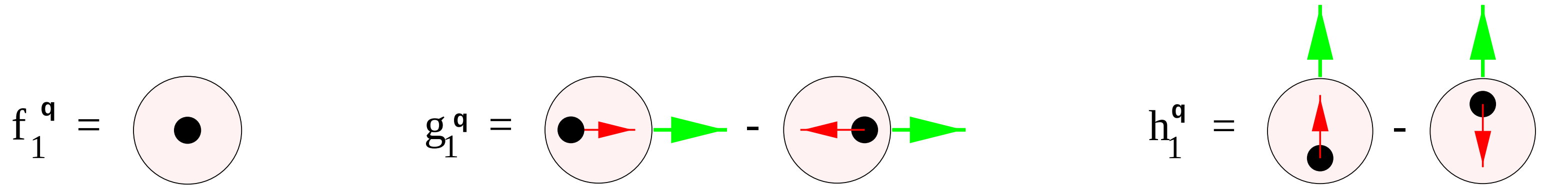
Factorization $\Rightarrow \sigma^{ep \to ehX} = \sum_q f^{p \to q} \otimes \sigma^{eq \to eq} \otimes D^{q \to h}$

Quark Distribution Functions



$\Downarrow$

Unpolarized quarks and nucleons

q(x): spin averaged (well known)

$\Rightarrow$ Vector Charge

$\Downarrow$

Longitudinally polarized quarks and nucleons

Δq(x): helicity difference (known)

$\Rightarrow$ Axial Charge

$\Downarrow$

Transversely polarized quarks and nucleons

δq(x): helicity flip (unmeasured!)

$\Rightarrow$ Tensor Charge

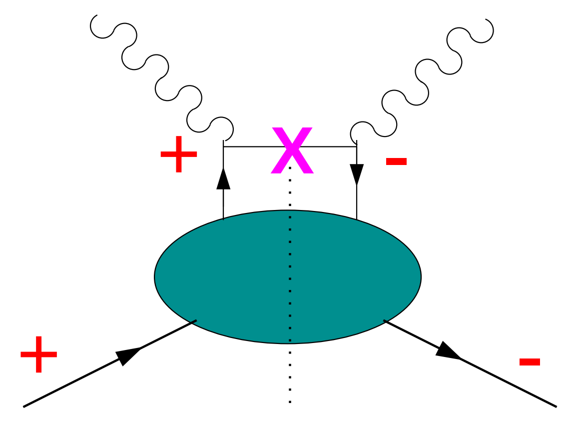
HERMES 1995-2000   HERMES 2002. . .

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 $Q^2 = 2GeV^2$):
  $$\delta\Sigma = \sum_f \int_0^1 dx(\delta q_f - \delta\bar{q}_f) = 0.562 \pm 0.088$$
- no “gluon transversity”
- transversity distribution CHIRAL ODD

$\hookrightarrow$ No Access In Inclusive DIS



Transversity Measurements

How can one measure transversity?
Need another chiral-odd object!

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

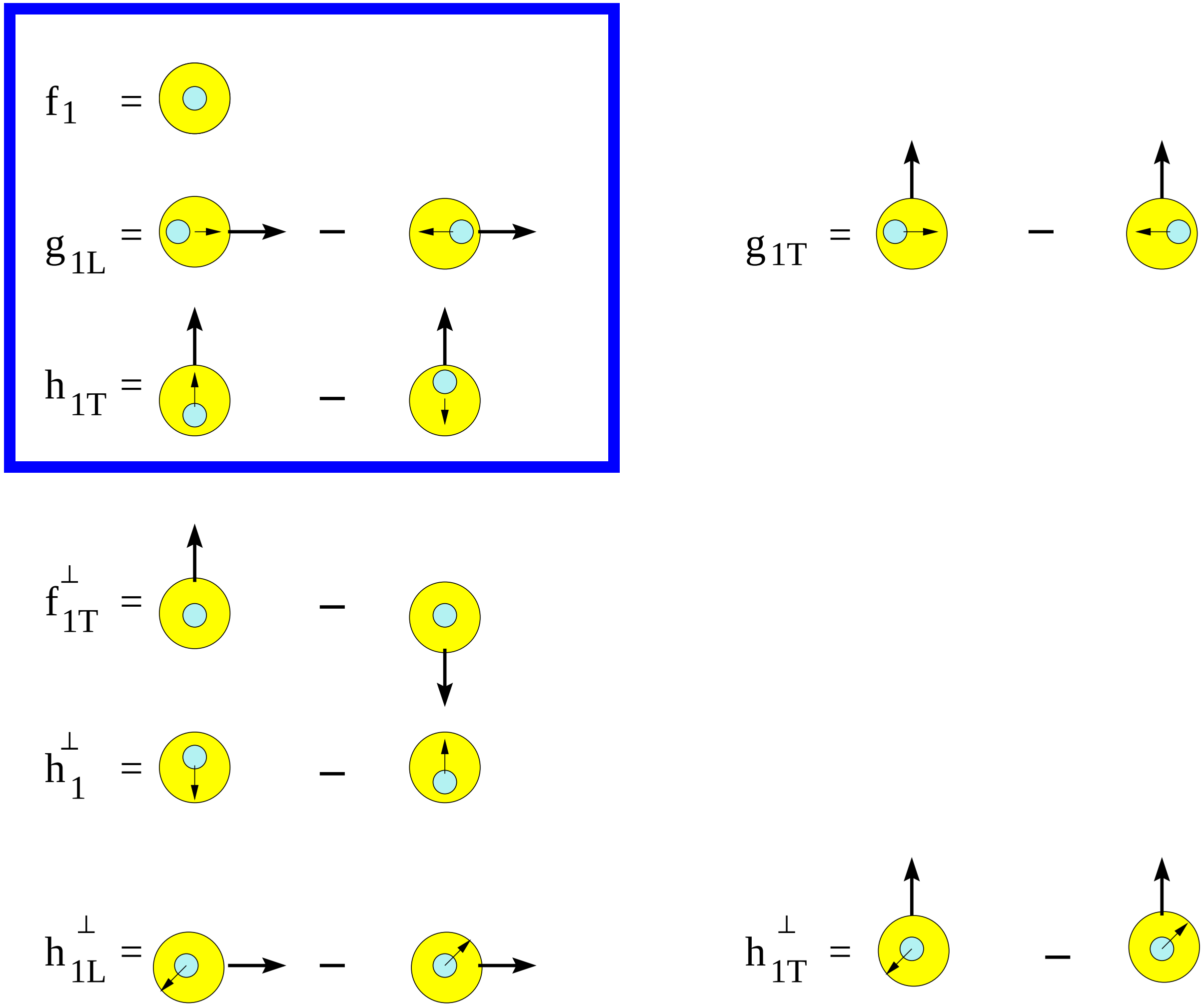
$$\sigma^{ep\rightarrow ehX} = \sum_q f^{H\rightarrow q} \otimes \sigma^{eq\rightarrow eq} \otimes D^{q\rightarrow h}$$

$\Downarrow$ **chiral-odd** DF

$\Downarrow$ **chiral-odd** FF

Twist-2 Quark Distribution Functions

Functions surviving integration over intrinsic transverse momentum



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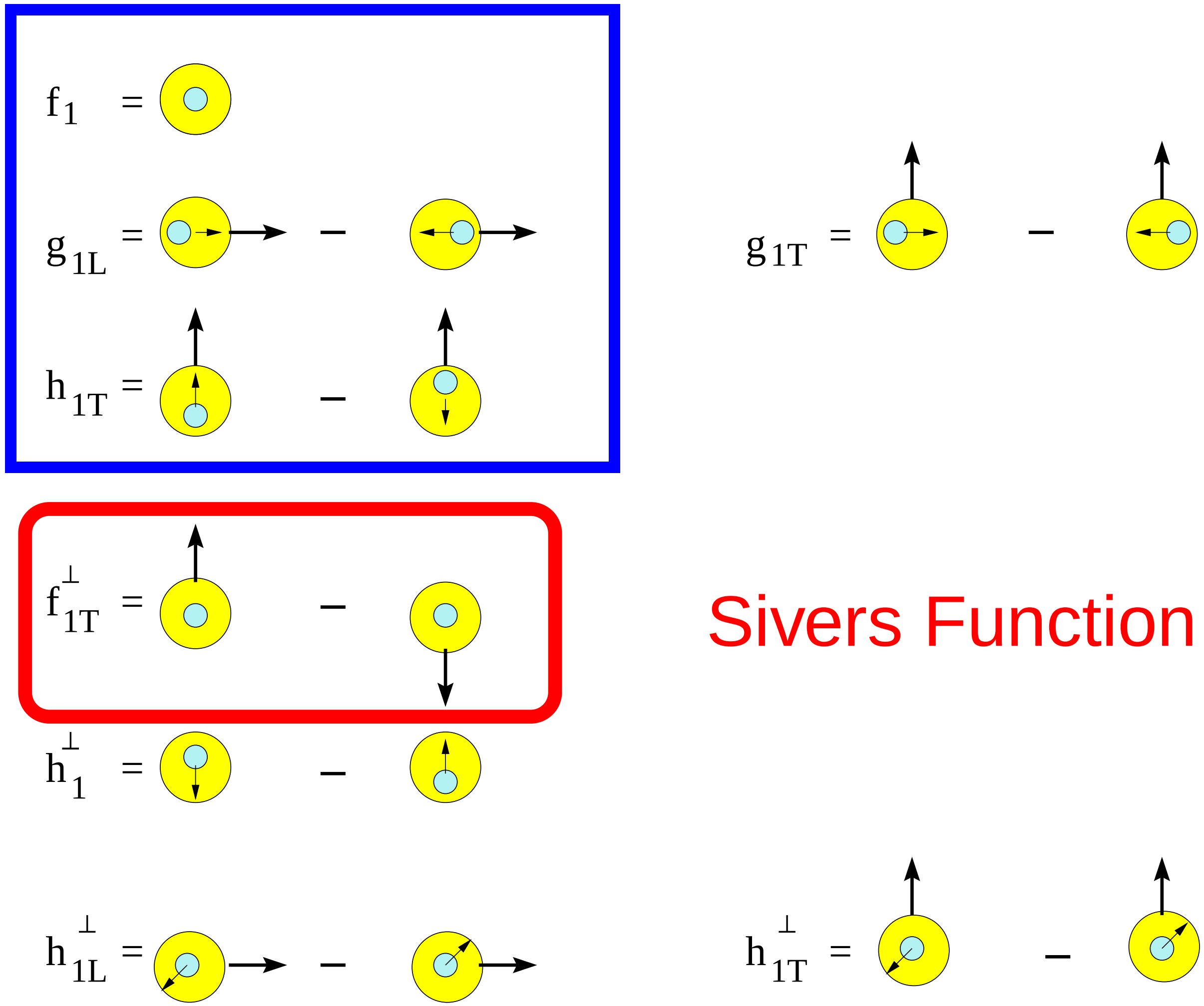

Twist-2 Fragmentation Functions

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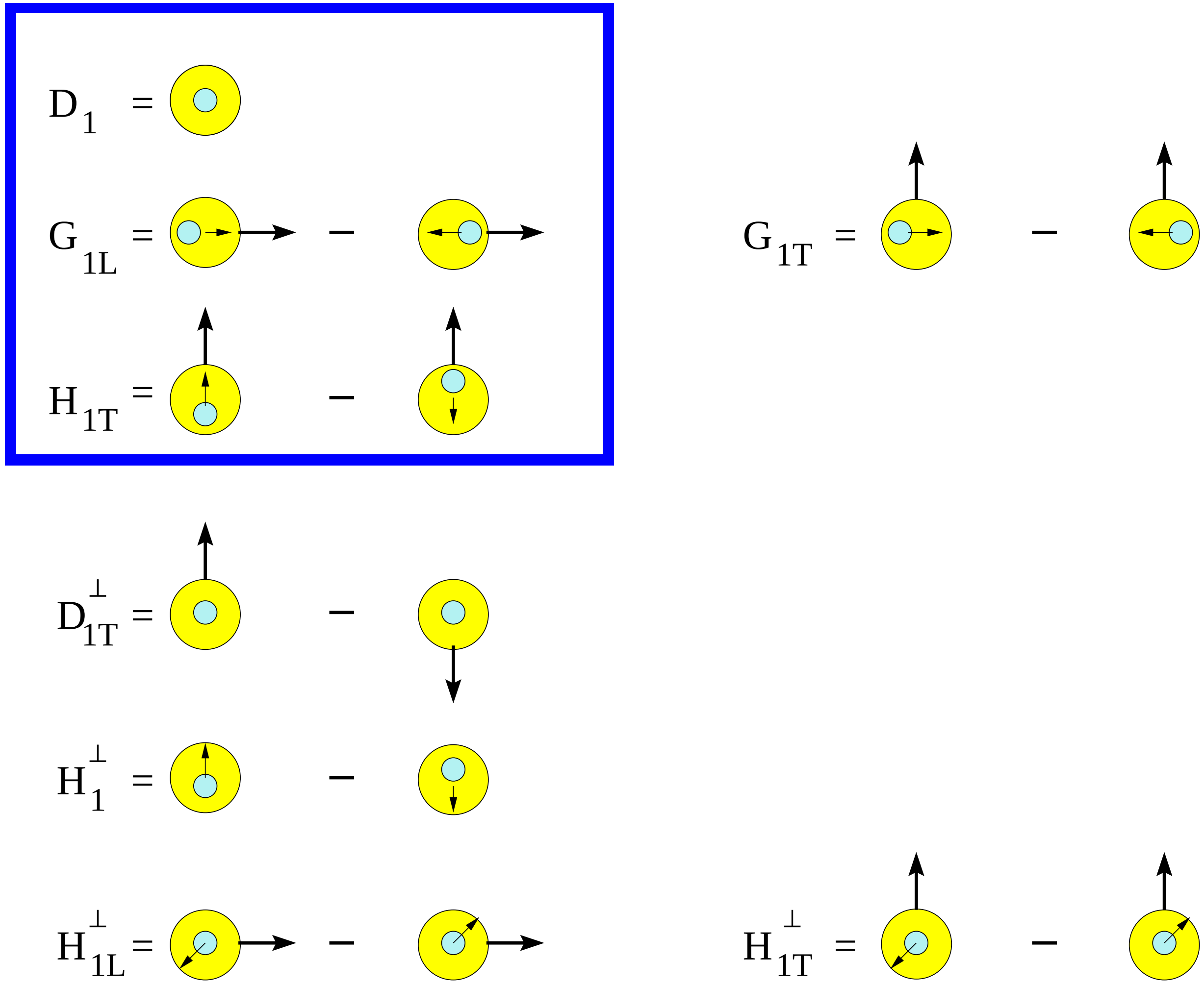

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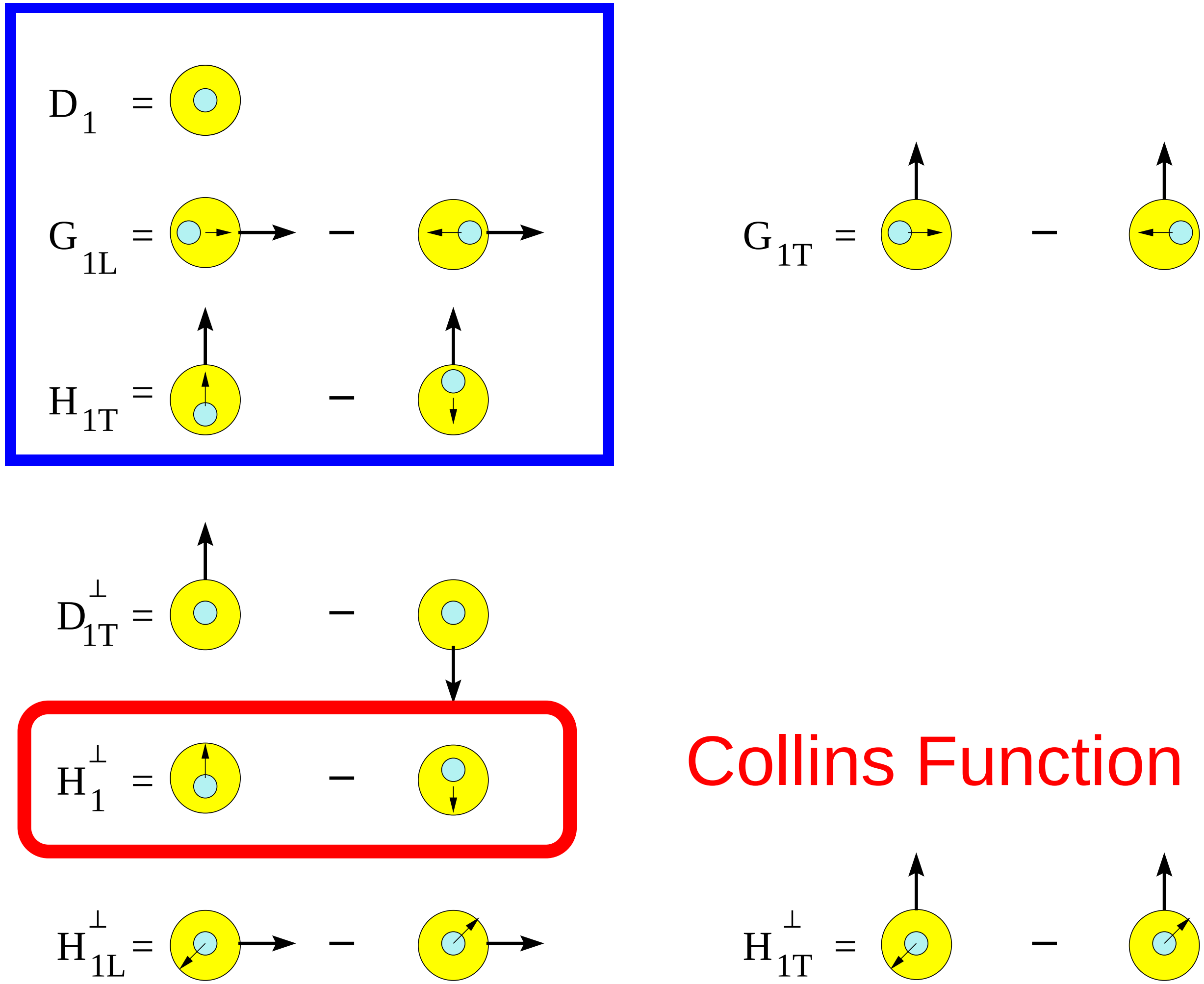


hermes

The Need for Semi-Inclusive Measurements

- h_1 chiral odd
  - $\Rightarrow$ not accessible in inclusive DIS
  - $\Rightarrow$ need some sort of quark polarimetry
    - $\Rightarrow$ Collins Effect: transverse spin of quark $\leadsto$ transverse motion of produced hadron
- $k_\perp$-dependent distribution functions (besides f_1, g_1, h_1)
  - $\Rightarrow$ vanish when integrating over $k_\perp$ (i.e. inclusive DIS)
  - $\Rightarrow$ need to access $k_\perp$-dependence

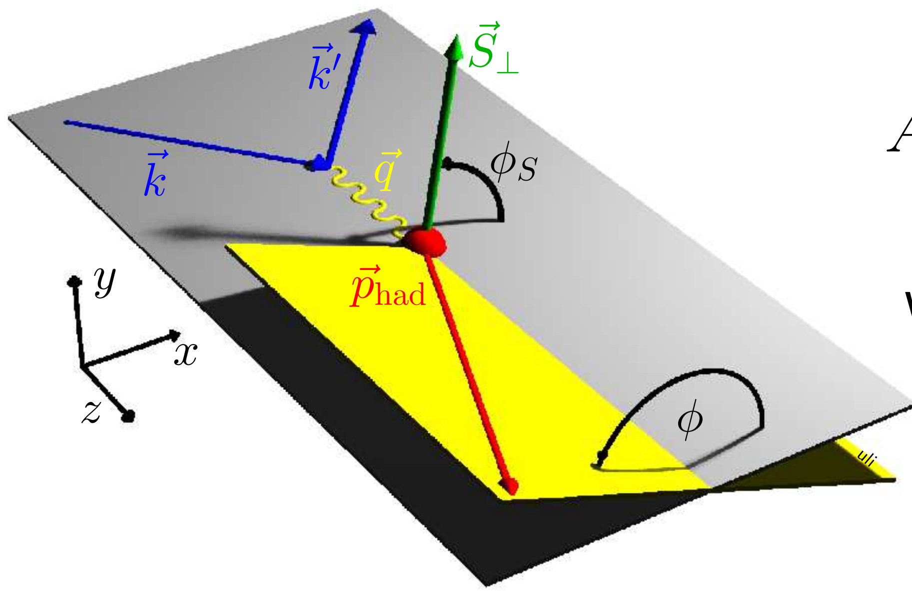
Azimuthal Single Spin Asymmetries in Semi-Inclusive DIS

Single Spin Asymmetries

$$ep \longrightarrow e'\pi X$$

study azimuthal distribution of π's:

$$A(\Phi) = \frac{1}{\langle P \rangle} \cdot \frac{N^+(\Phi) - N^-(\Phi)}{N^+(\Phi) + N^-(\Phi)}$$



with transversely polarized target:
(unpolarized beam)

$\Phi = \phi + \phi_S$ Collins angle

$$A_{UT}^{\sin\Phi} \propto \frac{\sum_q e_q^2 h_1^q(x) H_1^{\perp,q}(z)}{\sum_q e_q^2 f_1^q(x) D_1^q(z)}$$

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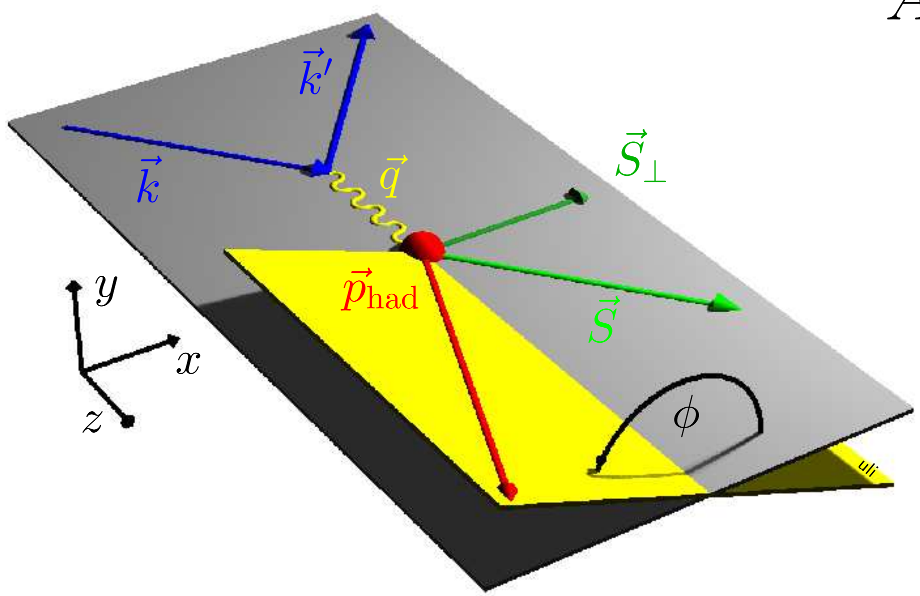

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with longitudinally polarized target:

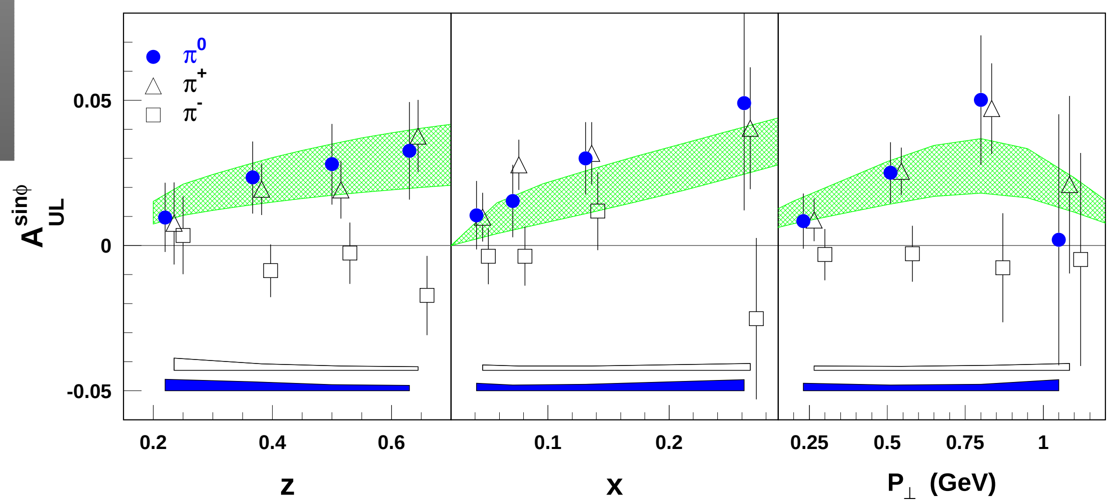
$$A_{UL}^{\sin\Phi} \propto \ldots$$

Single Spin Asymmetries at HERMES

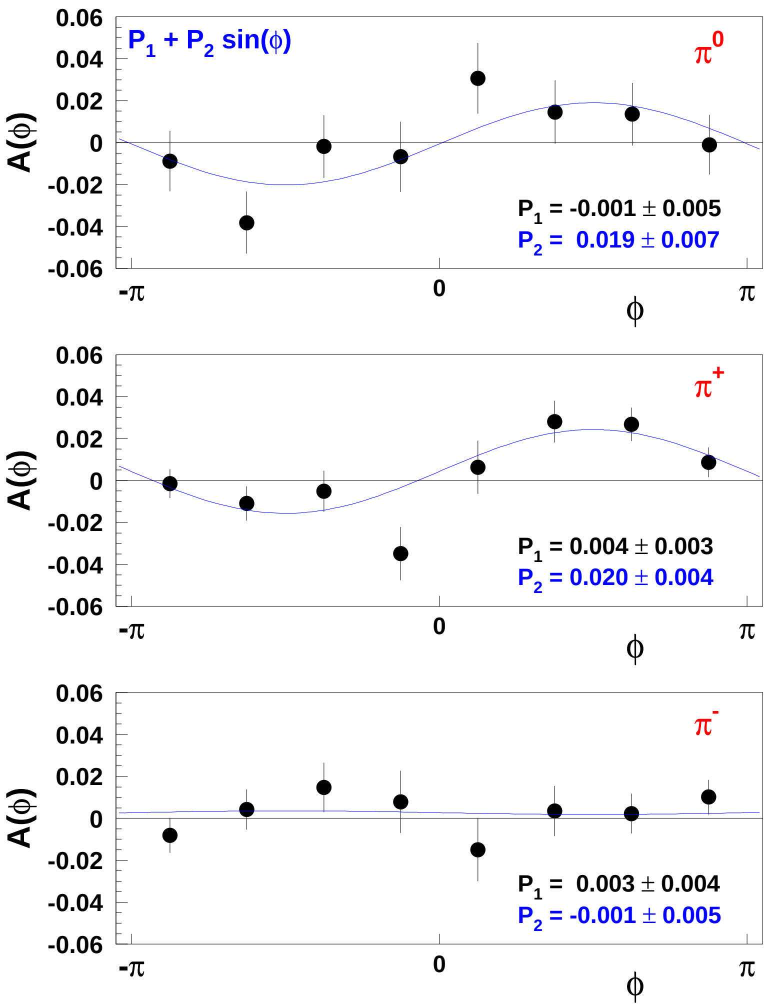
HERMES 1996/97: longitudinally polarized proton target

Longitudinal target SSA:

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

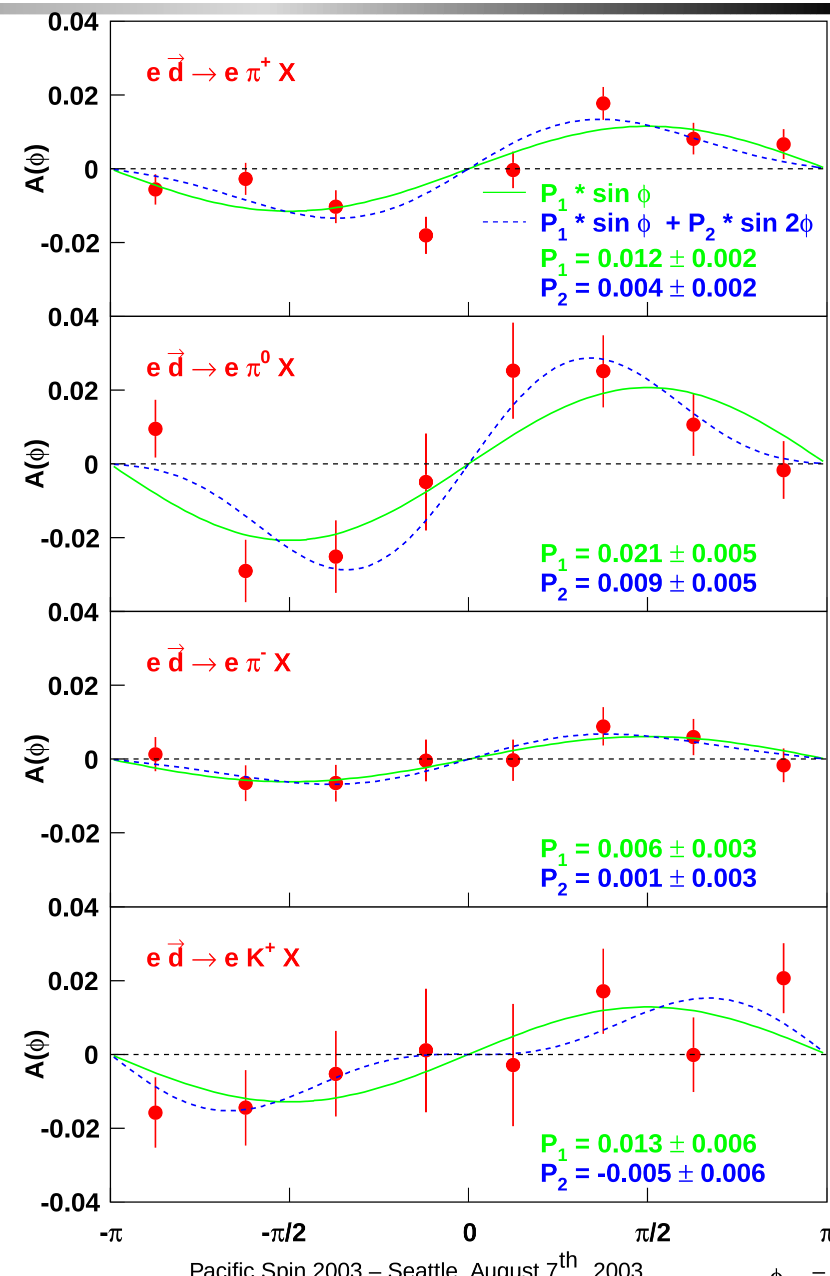


(green band: model calculation)



HERMES Results on Deuteron Target

- HERMES 1998-2000: longitudinally polarized deuteron target
- High statistics: ∼8 Million DIS
- Good hadron identifi cation due to RICH
- First measurement of Kaon SSA

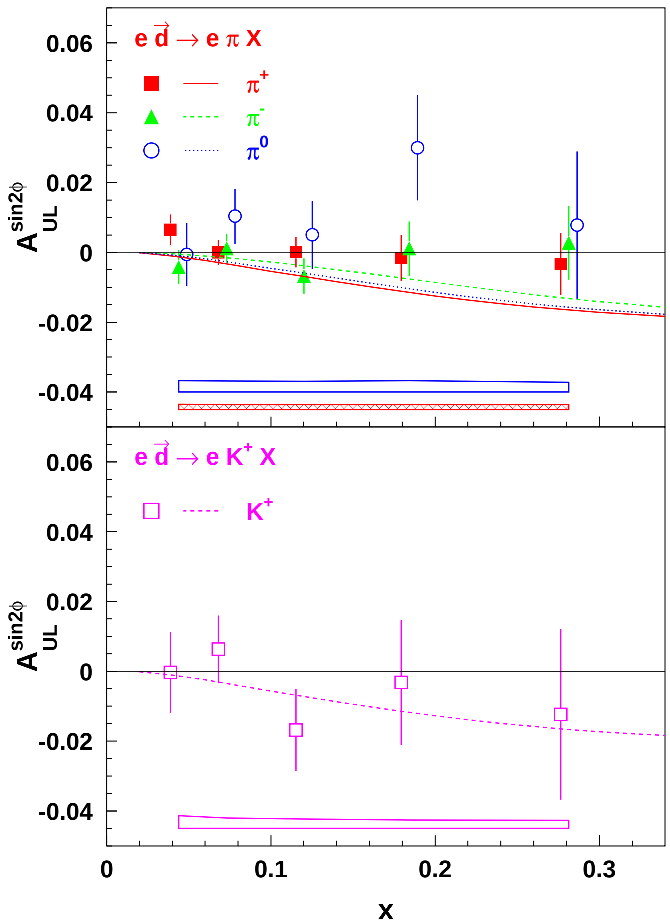


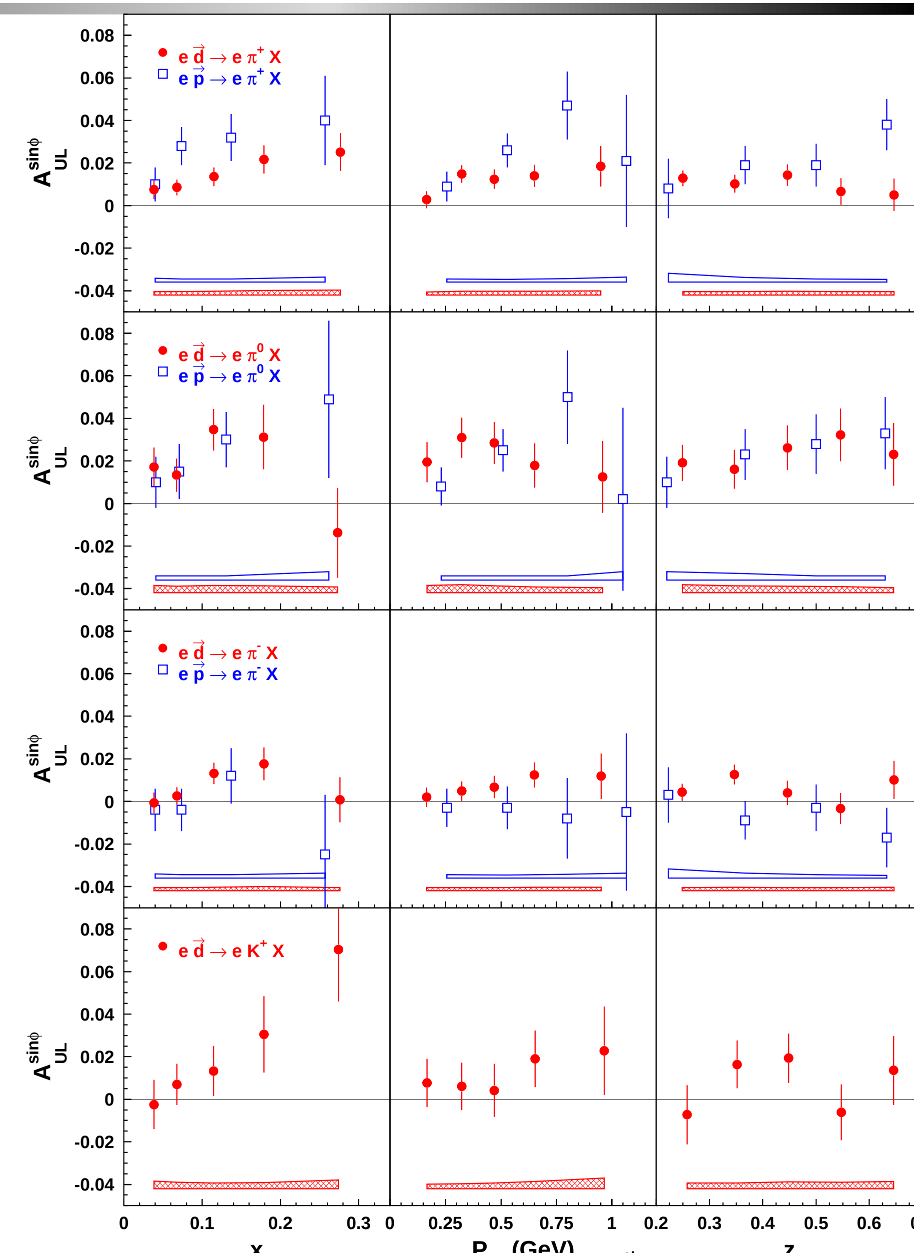
HERMES Results on Longitudinally Polarized Deuteron

$\sin(\phi)$-moment $\Rightarrow$

$\sin(2\phi)$-moment $\sim h_{1L}^{\perp} H_1^{\perp}$

$\Downarrow$





Longitudinally Polarized Target

transverse component $\mathbf{S_T}$ of target spin (w.r.t. virtual photon):

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

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

Longitudinally polarized in experiment **(along beam direction)**

L/T polarized in theory **(along virtual gamma direction)**

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

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

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

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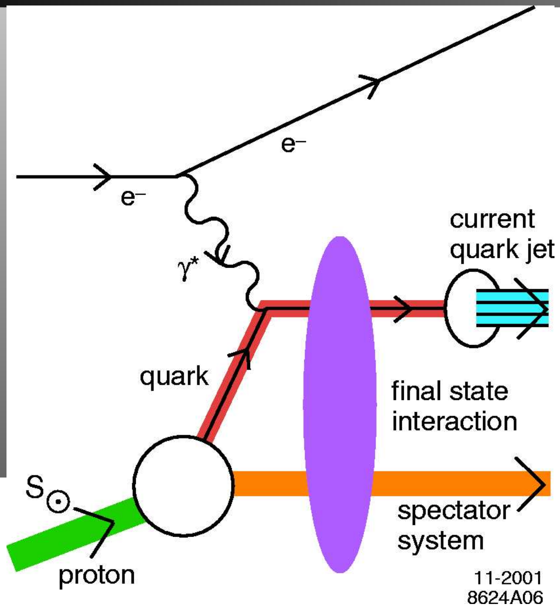
$$\langle \sin\phi \rangle_{UT} \sim \sum_q e_q^2 h_1^q(x) H_1^{\perp(1),q}(z)$$ Collins

$$\langle \sin\phi \rangle_{UT} \sim \sum_q e_q^2 f_{1T}^{\perp(1),q} D_1^q(z)$$ Sivers

Contributions to $A_{UL}^{\sin\phi}$ hard to disentangle

Some words about Sivers Effect



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- quark rescattering
- can generate SSA
- leading twist effect
- requires L_z of quarks

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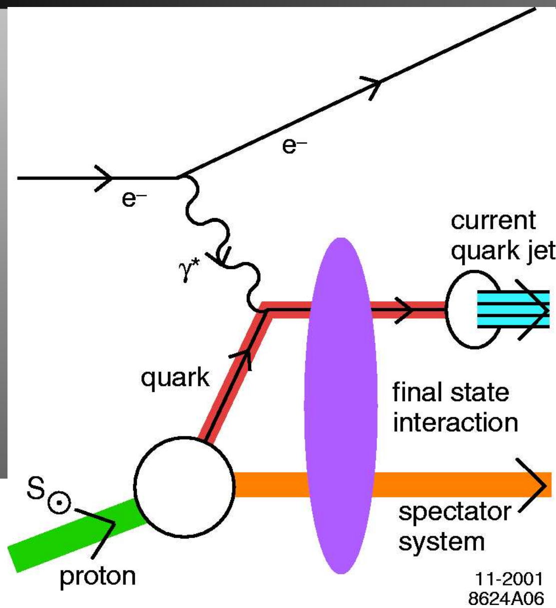

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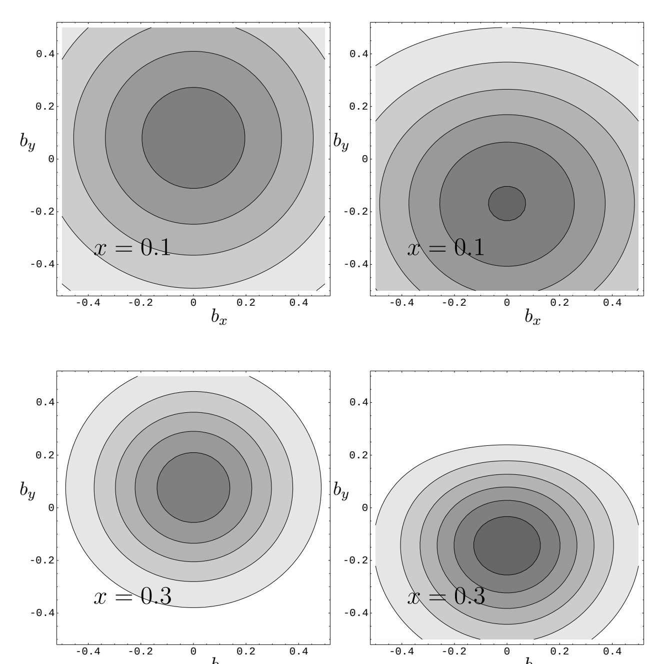
different approach by Burkardt:

spatial distortion of q-distribution

(consequence of anom. magn. moments

& impact parameter dependent PDFs)



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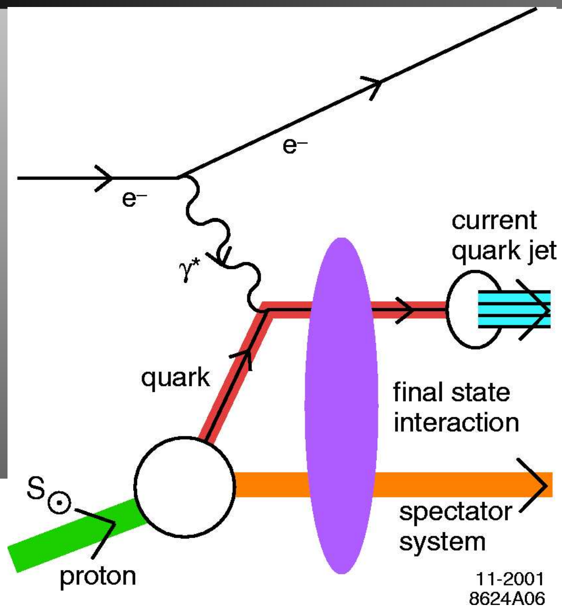

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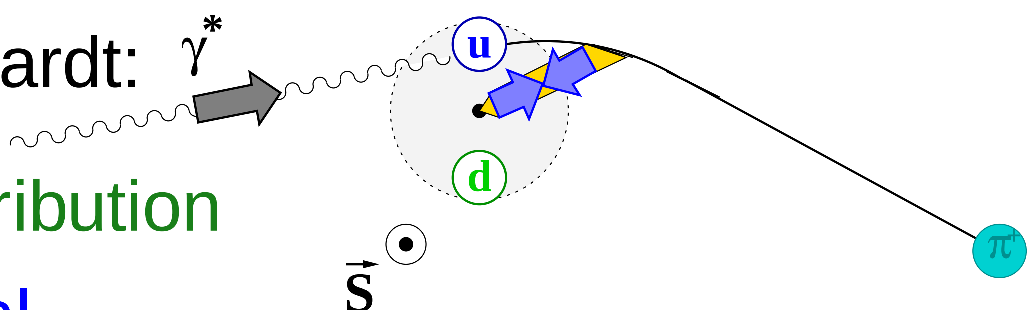

spatial distortion of q-distribution

+ attractive QCD potential

(gluon exchange)

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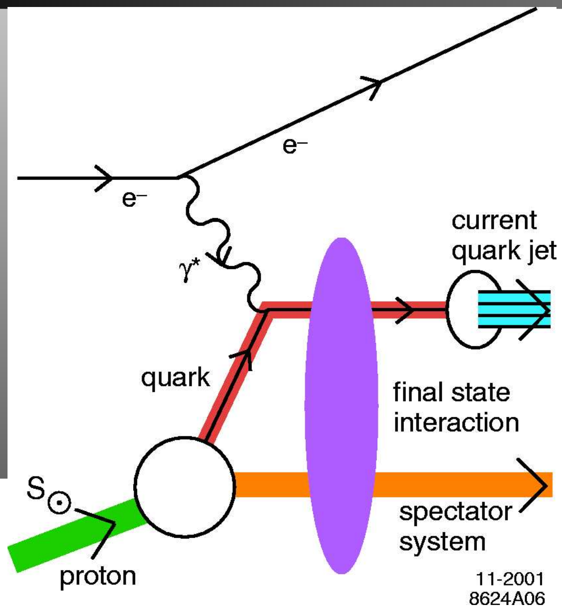

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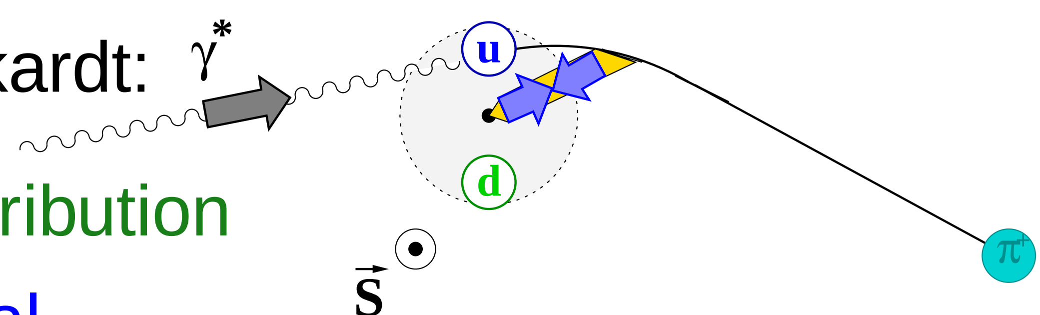

spatial distortion of q-distribution

+ attractive QCD potential

$\Rightarrow$ transverse asymmetries

How to do better?

Longitudinally polarized target $\Rightarrow$ Sivers and Collins effects indistinguishable

Transversely polarized target

$\swarrow$ $\searrow$

Sivers	Collins
$\langle \sin(\phi - \phi_s) \rangle$ moment	$\langle \sin(\phi + \phi_s) \rangle$ moment
$\downarrow$	$\downarrow$
$f_{1T}^{\perp}(x)$	$h_1(x)$, $H_1^{\perp}(z)$

Additionally: $\langle \sin(3\phi - \phi_s) \rangle$ moment $\Rightarrow h_{1T}^{\perp}(x)$, $H_1^{\perp}(z)$ and others

What do theorists expect?

Not much is known about the Collins FF:

$$\left|\frac{<H_1^\perp>}{<D_1>}\right| = 6.3\%$$

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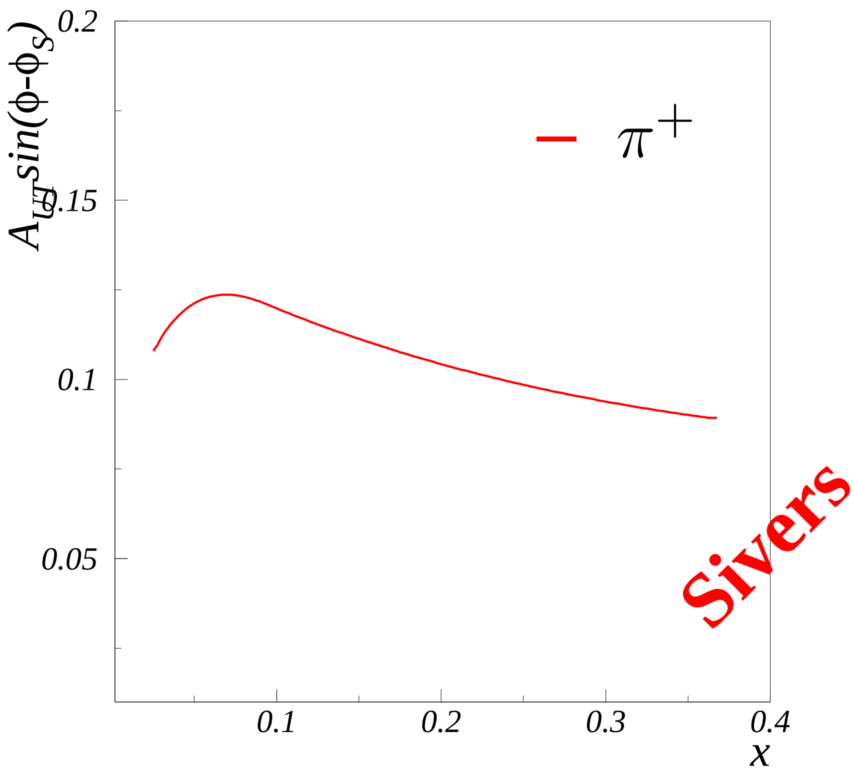
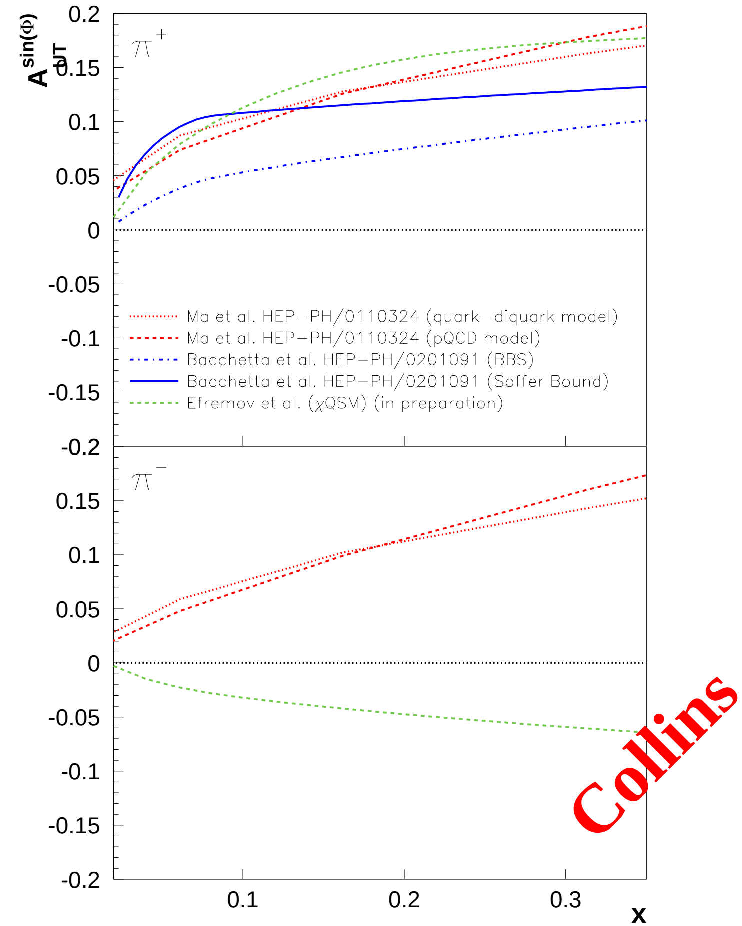
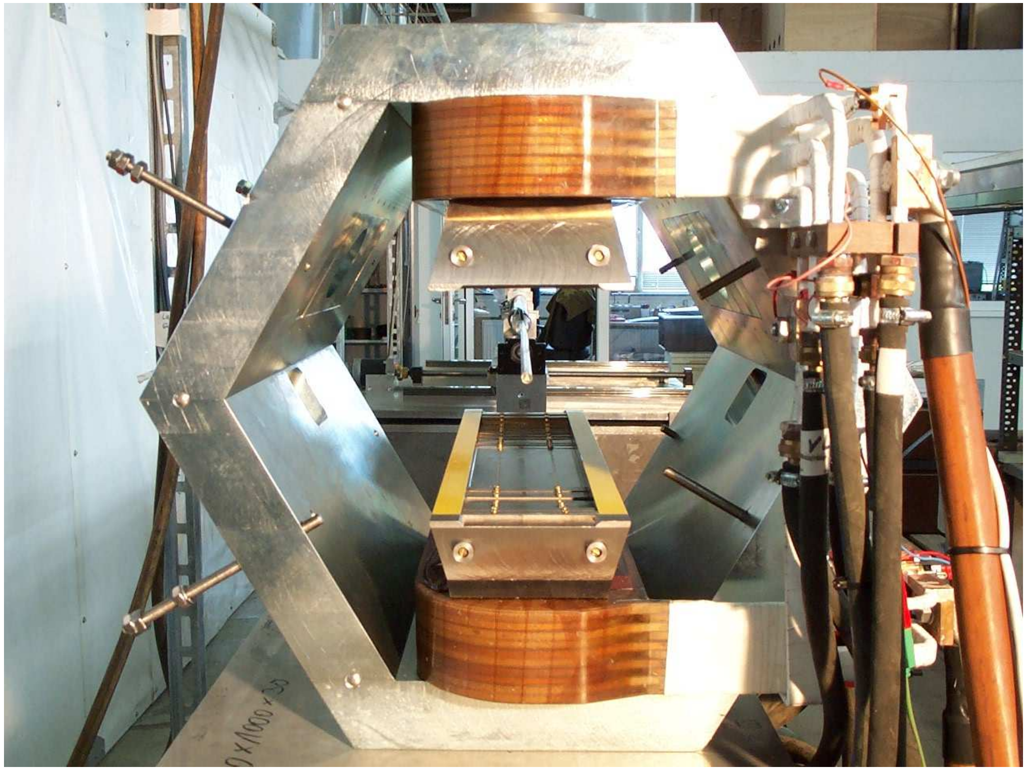


Gamberg et al. HEP-PH/0301018

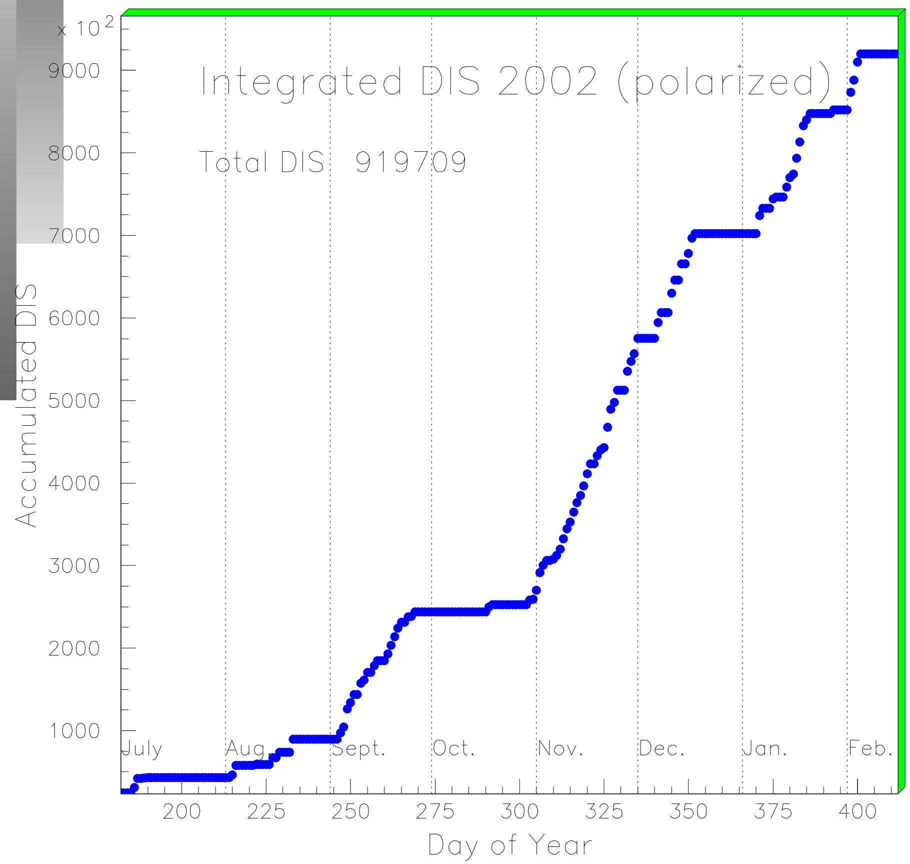


New Transverse Target HERMES



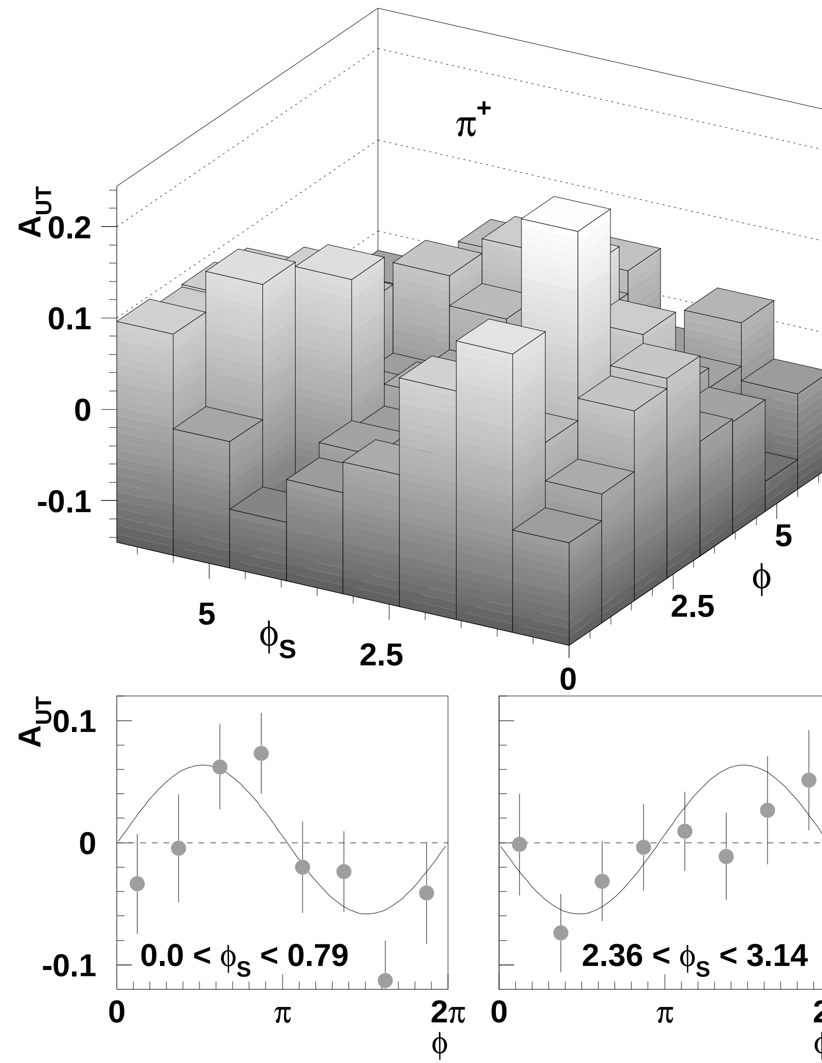
- **Transverse target magnet (**$B = 0.295T$**)**
- **High uniformity along beam direction:** $\Delta B \leq 4.5 \cdot 10^{-5} T$
- **Transversely polarized hydrogen**
- **Target polarization around 75%**

Data Taking in 2002/03



Integrated Luminosity 2002/03

(before data quality cuts)

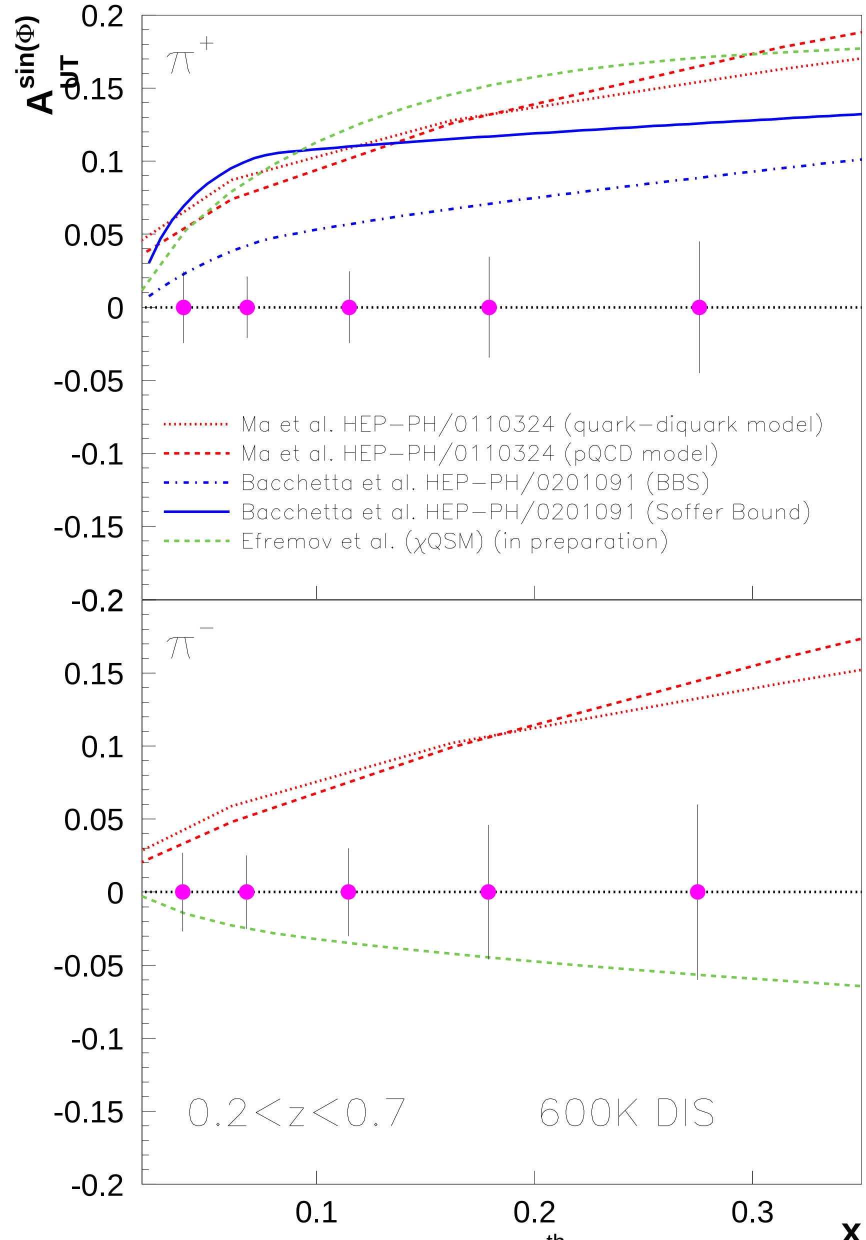


Transverse Asymmetry $A_{UT}(\phi, \phi_S)$

Data Taking in 2002/03

Expected precision in comparison with model calculations for Collins Asymmetry

- After data quality: $\sim$ 600K DIS events
- charged and neutral π asymmetries
- statistics good enough to (dis)favour various model calculation



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Future Data Taking

- additional data taking starting fall of 2003
- detector upgrade (Λ-Wheels)

$\Rightarrow$ additional statistics allows analysis of different channels to access transversity:

  - 2-Meson-Correlations $\Rightarrow$ Interference FF

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    (transverse Λ polarization)

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  - Spin-1 Fragmentation
  - Spin-1/2 Fragmentation (transverse Λ polarization)

- polarized beam $\Rightarrow A_{LT}$ in π production (measurement of twist-3 fragmentation function and transversity)

Extracting Quark Distributions – Purity Formalism

$$A_{UT}^{\sin(\phi-\phi_S),h}(x) = \frac{\int dy S_T \frac{1+(1-y)^2}{2}}{\int dy \frac{1+(1-y)^2}{2}} \frac{\sum_q e_q^2 \, f_{1T}^{\perp,q}(x) \int dz \, D_1^{q,h}(z) \mathcal{A}(x,z)}{\sum_{q'} e_{q'}^2 \, f_1^{q'}(x) \int dz \, D_1^{q',h}(z) \mathcal{A}(x,z)}$$

$$= \mathcal{C} \cdot \sum_q \frac{e_q^2 \, f_1^q(x) \, \mathcal{D}_1^{q,h}(x)}{\sum_{q'} e_{q'}^2 \, f_1^{q'}(x) \, \mathcal{D}_1^{q',h}(x)} \cdot \frac{f_{1T}^{\perp,q}}{f_1^q}(x)$$

$$= \mathcal{C} \cdot \sum_q \mathcal{P}_q^h(x) \cdot \frac{f_{1T}^{\perp,q}}{f_1^q}(x)$$

- purities are completely unpolarized objects $\rightarrow$ present Monte Carlo-tunes can be used
- probabilistic interpretation of purities possible
- “easy”: Sivers $\leftarrow$ fragmentation function (D_1) known

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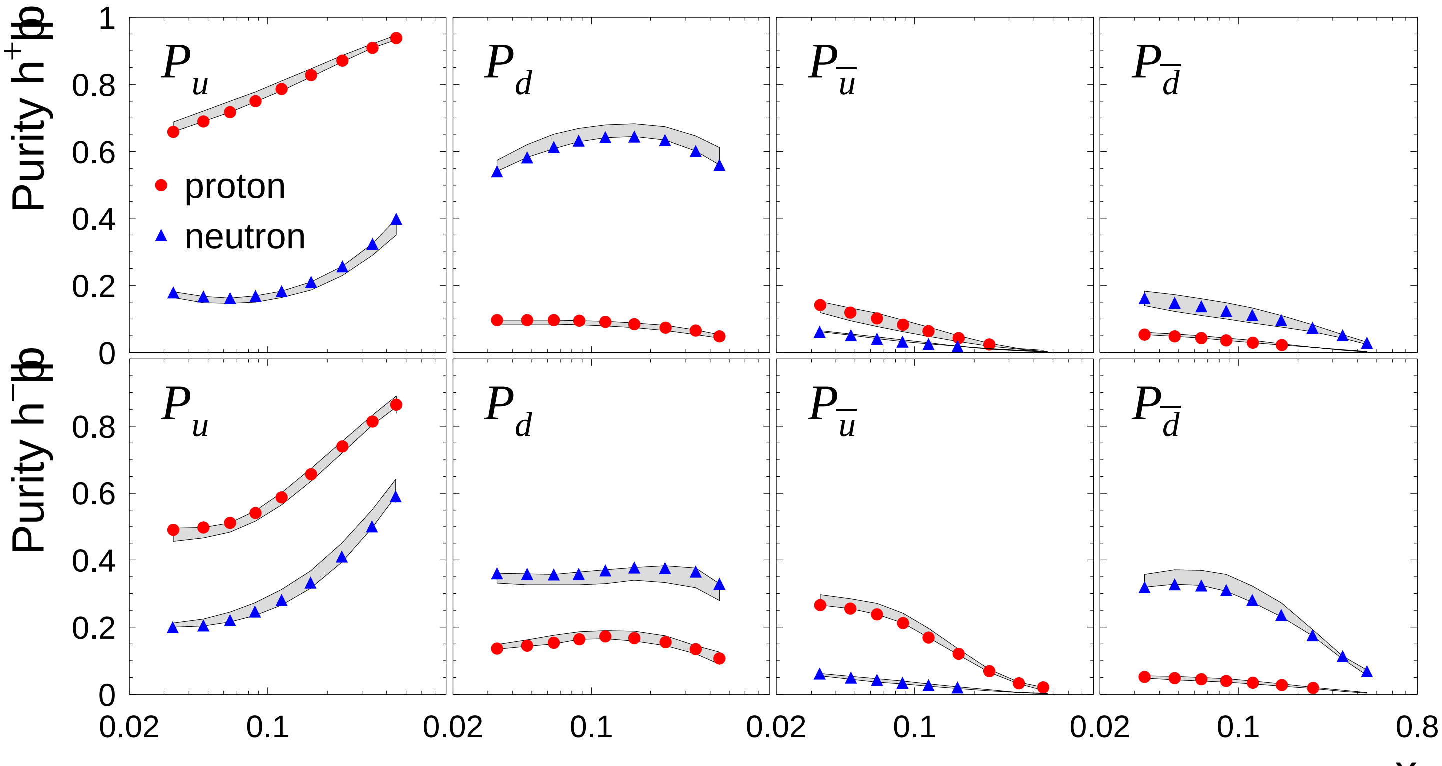

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$$= \mathcal{C} \cdot \sum_q \frac{e_q^2\, f_1^q(x)\, \mathcal{H}_1^{\perp q,h}(x)}{\sum_{q'} e_{q'}^2\, f_1^{q'}(x)\, \mathcal{D}_1^{q',h}(x)} \cdot \frac{h_1^q}{f_1^q}(x)$$

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- probabilistic interpretation of purities possible
- “easy”: Sivers ← fragmentation function (D_1) known
- Collins: these purities still depend on parametrization of Collins FF function

hermes

Summary

- HERMES measured SSA on longitudinally polarized hydrogen and deuterium targets
- HERMES has taken data with a transversely polarized hydrogen target
- Presently more than 600k DIS events after data quality cuts
- Transverse Asymmetries $\Rightarrow$ disentangle Sivers and Collins contributions
- Purity formalism $\Rightarrow$ extraction of quark distributions $f_{1T}^{\perp,q}$ and h_1^q ($q = u, d$)
- IFF on longitudinal/transversely polarized target
- ...