HERMES *measurements of Collins and Sivers asymmetries from a transversely polarised hydrogen target*

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on behalf of the hermes collaboration

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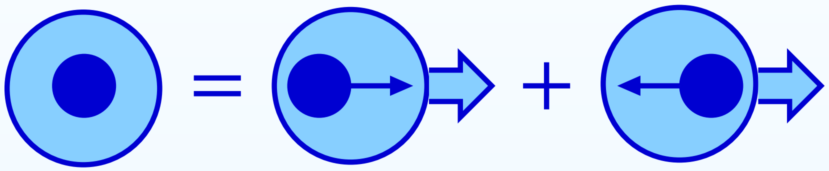
The spin structure of the nucleon:

momentum distribution $q\,(x)$:

measures spin average

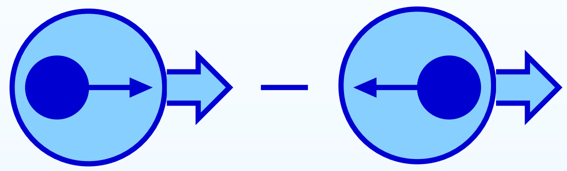


(in helicity basis)

$$F_1(x) = \frac{1}{2}\sum e_q^2\,(q(x) + \bar{q}(x))$$

helicity distribution $\Delta q\,(x)$**:**

measures helicity difference



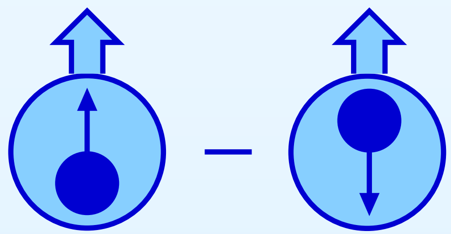
(in helicity basis)

$$g_1(x) = \frac{1}{2}\sum e_q^2\,(\Delta q(x) + \Delta\bar{q}(x))$$

transversity distribution $\delta q\,(x)$**:**

probabilistic interpretation:

- experimentally unknown
- helicity flip amplitude
- no gluon transversity at nucleon target



(in basis of transverse spin eigenstates)

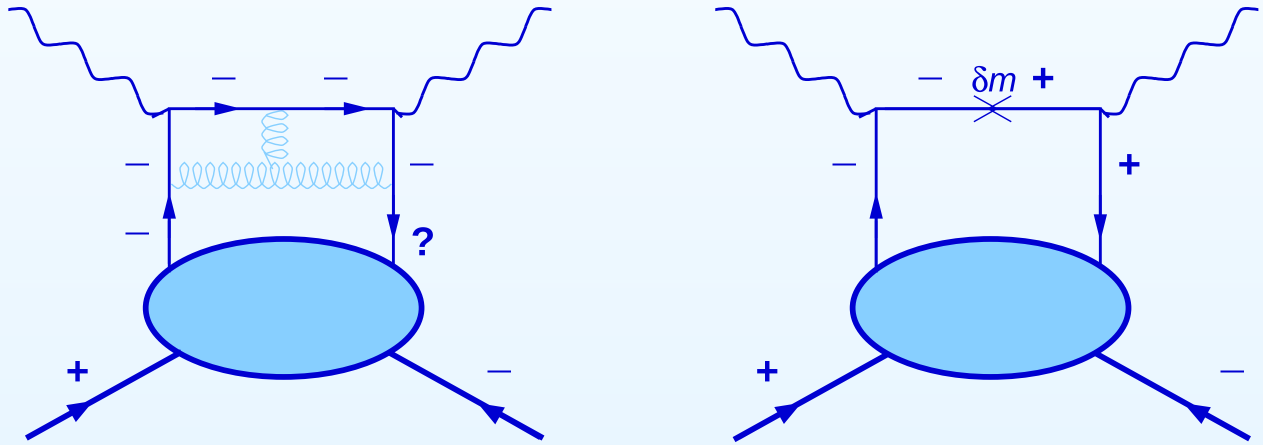
non-relativistic quarks: $\delta q\,(x) = \Delta q\,(x)$

Measurement of the transversity distribution:

- **Chirality of the transversity distribution**
  - transversity distribution measures helicity flip

$$N^{\Uparrow} q^{\downarrow} \longrightarrow N^{\Downarrow} q^{\uparrow}$$

  - **chiral-odd** quark distribution:

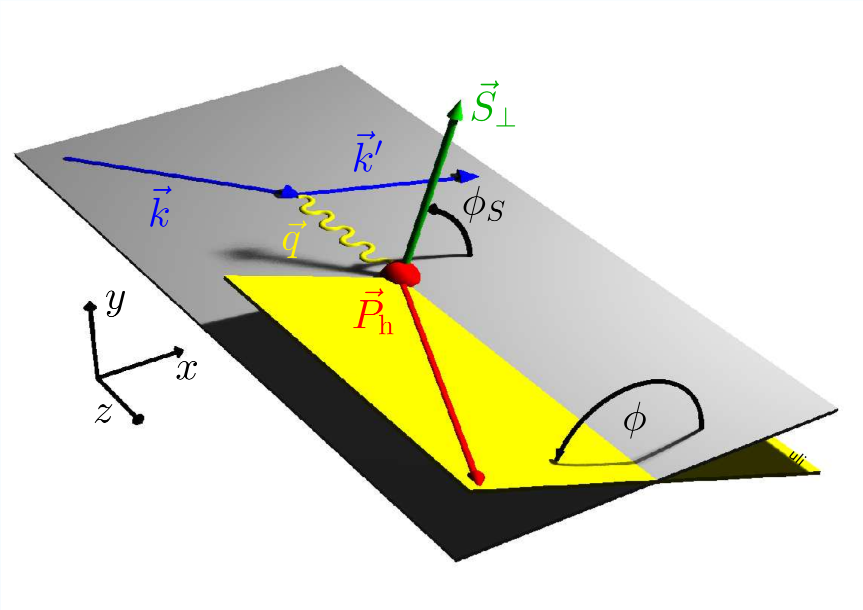


cannot be determined in inclusive DIS | another chiral-odd function is needed

- **Measurement at HERMES:** semi-inclusive DIS on a transversely polarised hydrogen target, chiral-odd fragmentation function

Azimuthal single-spin asymmetries:

- **Kinematics on a transversely polarised hydrogen target**:

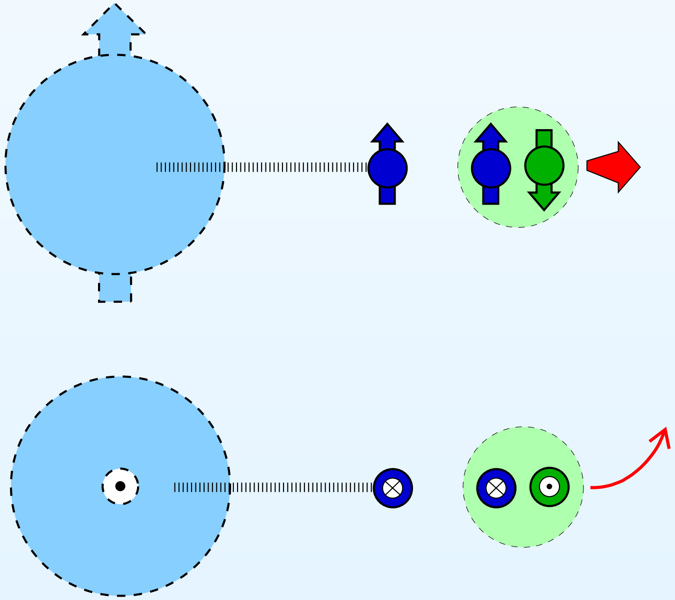


- **Azimuthal single-spin asymmetries (SSA):**
  - azimuthal asymmetry in the momentum distribution of the produced hadrons (transverse to the nucleon spin)
  - non-vanishing $\boldsymbol{P}_{\mathrm{h}\perp}$ is caused by intrinsic transverse momenta $\boldsymbol{p}_\perp$ (distribution part) and $\boldsymbol{k}_\perp$ (fragmentation part)

$\Leftrightarrow$ **Collins and Sivers mechanisms**

The Collins mechanism:

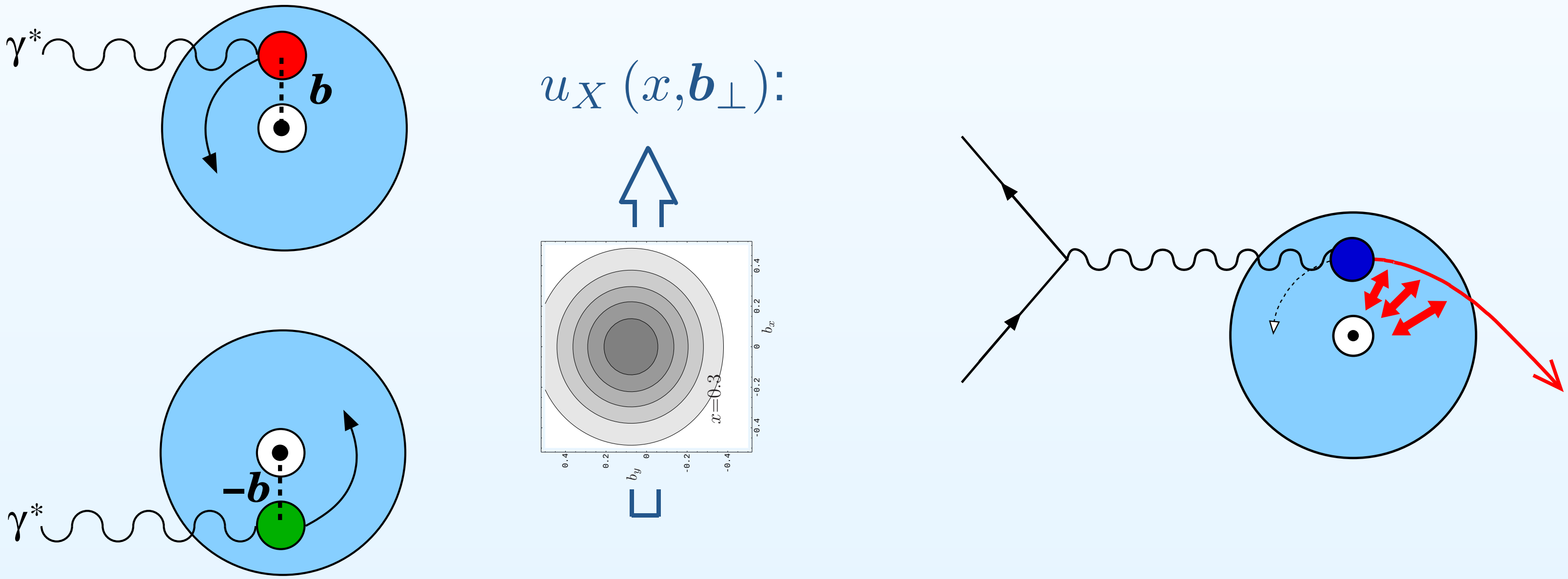
- **Collins fragmentation function $H_1^{\perp q}$**
- **chiral-odd** partner for the transversity measurement
- correlation between the transverse polarisation of the fragmenting quark and the transverse momentum $P_{h\perp}$ of the produced (unpolarised) hadron



- **naive time reversal odd** $\Leftrightarrow$ final state interactions
  $\Rightarrow$ **single-spin asymmetry**

The Sivers mechanism:

- non-zero **Sivers distribution** $f_{1T}^{\perp}$ involves non-zero Compton amplitude $N^{\Uparrow}q^{\uparrow} \rightarrow N^{\Downarrow}q^{\uparrow}$
- **orbital angular momentum of quarks:**
  (M. Burkardt, *Physical Review*, **D66**, 114005 (2002))



- **final state interactions:**
  left-right asymmetry of quark distribution
  $\Rightarrow$ left-right asymmetry of momentum distribution of produced hadron

SSA amplitudes:

Single-spin asymmetry $\boldsymbol{A^h_{\mathsf{UT}}}$ for hadron type h, unpolarised lepton beam (U) and transversely polarised target (T):

$$A^h_{\mathsf{UT}} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}}$$

Collins amplitude

$$\propto 2\,|\boldsymbol{S}_T|\, \sin(\phi + \phi_S) \frac{\sum_q e_q^2\, \boldsymbol{\delta q(x)\, H_1^{\perp q}(z)}}{\sum_q e_q^2\, q(x)\, D_1^q(z)}$$

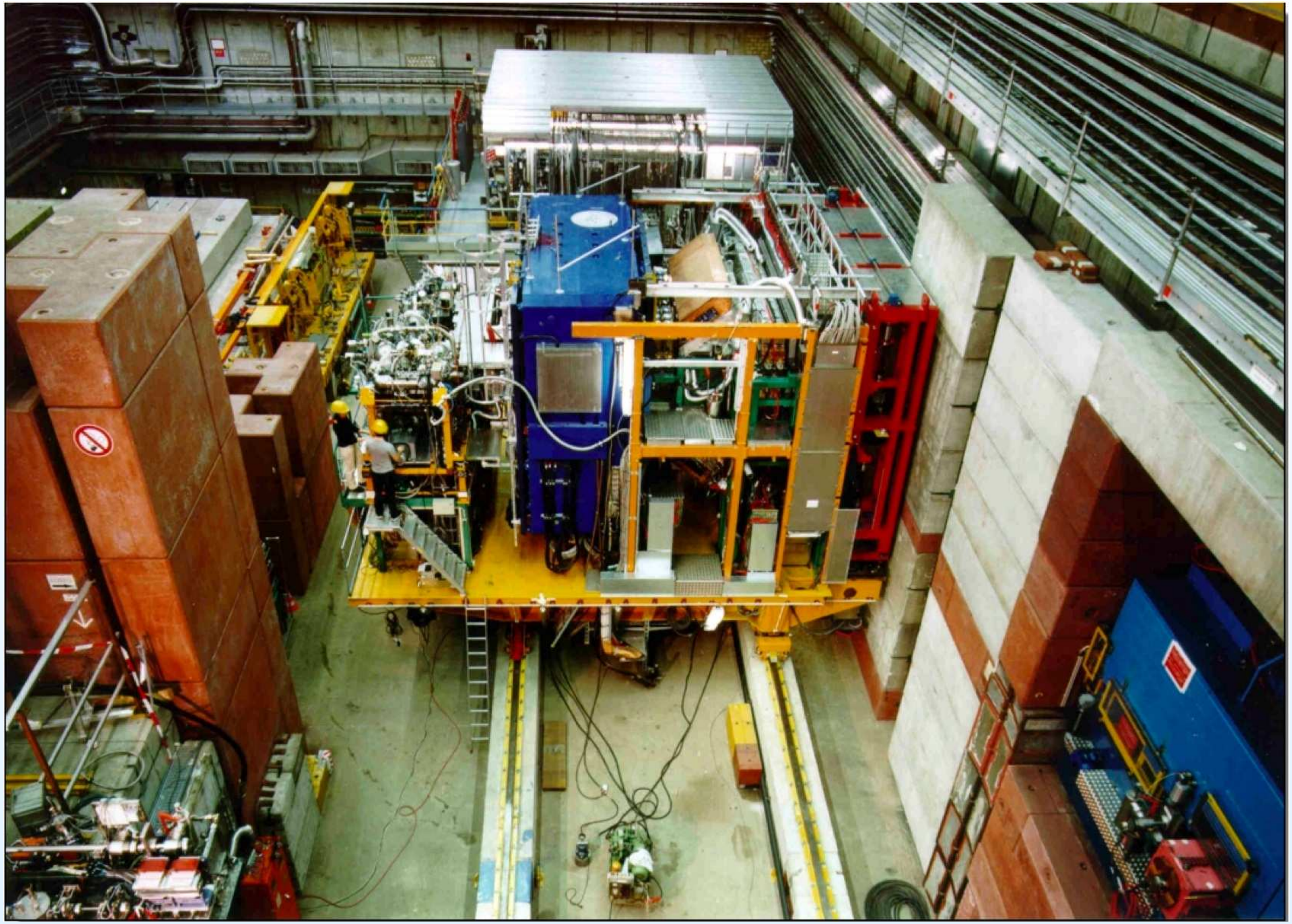
↑
distinguishable

Sivers amplitude

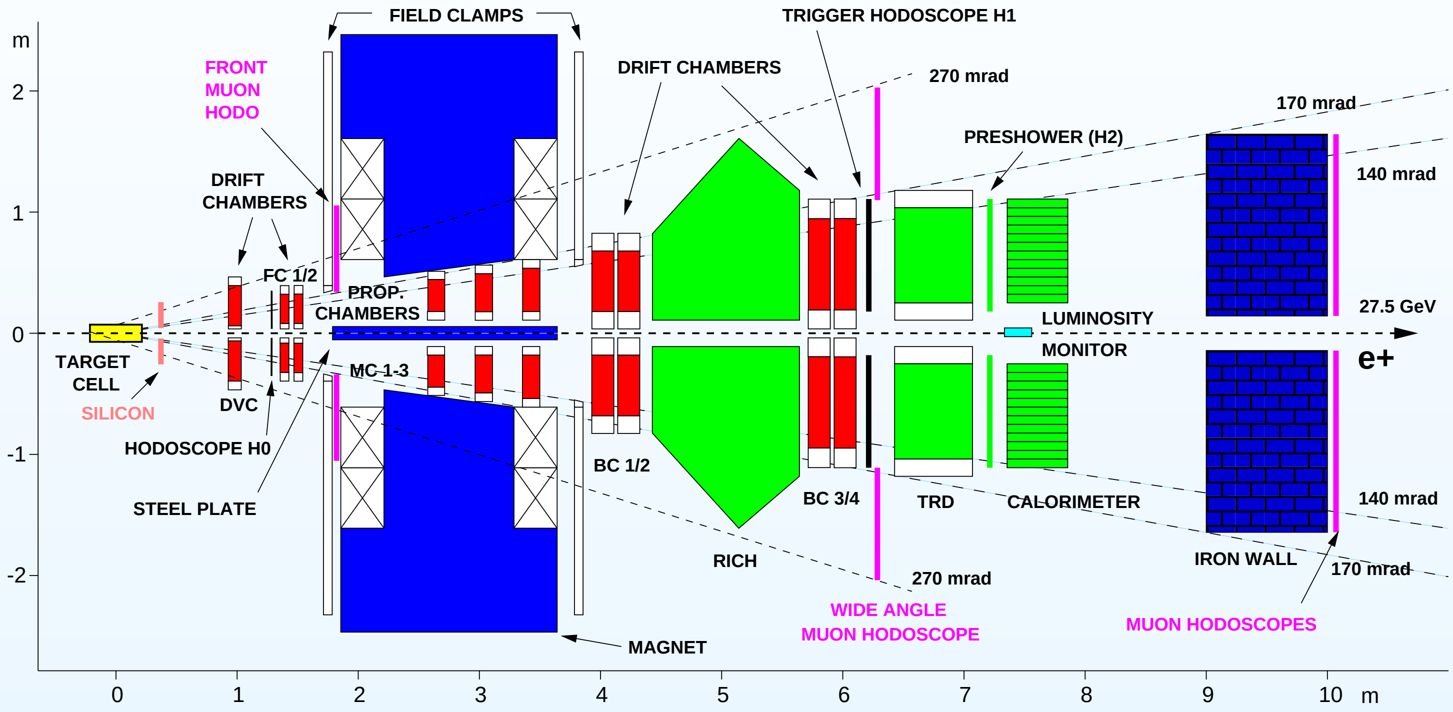
Signature
↓

$$- 2\,|\boldsymbol{S}_T|\, \sin(\phi - \phi_S) \frac{\sum_q e_q^2\, \boldsymbol{f_{1T}^{\perp q}(x)\, D_1^q(z)}}{\sum_q e_q^2 q(x)\, D_1^q(z)}$$

The HERMES measurement of SSA amplitudes:



The HERMES spectrometer:



- large momentum and angle acceptance: $\theta_{\text{hor.}} \leqslant 175\,\mathtt{mrad}$, $40\,\mathtt{mrad} \leqslant \theta_{\text{vert.}} \leqslant 140\,\mathtt{mrad}$
- good momentum resolution: $\Delta p/p = 0{,}7 - 1{,}3\%$
- and angle resolution: $\Delta\theta \leqslant 0{,}6\,\mathtt{mrad}$
- very clean lepton-hadron separation, hadron identification with RICH

Extraction of SSA amplitudes:

- maximum likelihood fits are used for π-mesons and charged K-mesons:

$$\mathrm{F}\left(2\left\langle\sin\left(\phi\pm\phi_S\right)\right\rangle_{UT}^{h},\ldots,\phi,\phi_S\right)=$$

$$\frac{1}{2}\Big(1+P_\alpha^z\Big(2\left\langle\sin\left(\phi+\phi_S\right)\right\rangle_{UT}^{h}\cdot\sin\left(\phi+\phi_S\right)+$$

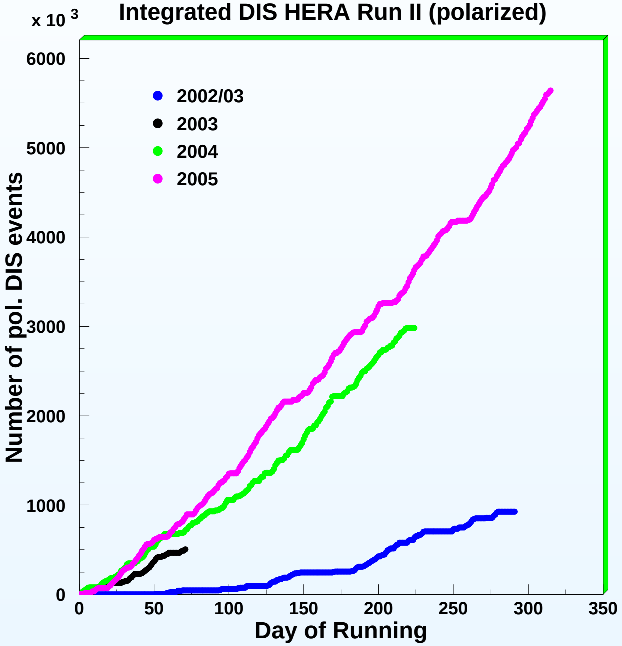
$$2\left\langle\sin\left(\phi-\phi_S\right)\right\rangle_{UT}^{h}\cdot\sin\left(\phi-\phi_S\right)+$$

$$2\left\langle\sin\left(3\phi-\phi_S\right)\right\rangle_{UT}^{h}\cdot\sin\left(3\phi-\phi_S\right)+$$

$$2\left\langle\sin\left(2\phi-\phi_S\right)\right\rangle_{UT}^{h}\cdot\sin\left(2\phi-\phi_S\right)+$$

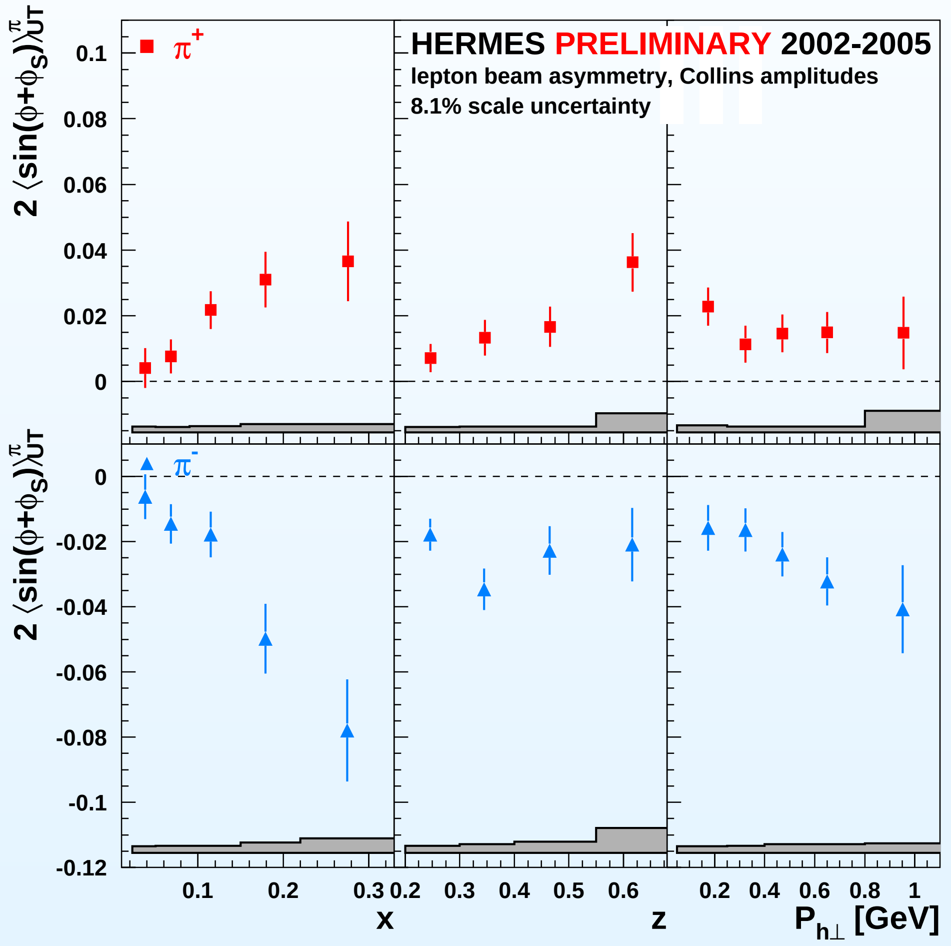
$$2\left\langle\sin\phi_S\right\rangle_{UT}^{h}\cdot\sin\phi_S\Big)\Big)$$

polarised H target:



- the logarithm of the likelihood function $\mathcal{L}=\prod\left(\mathrm{F_i}\right)^{w_i}$ is maximised with respect to the SSA amplitudes

The Collins amplitudes for charged pions:



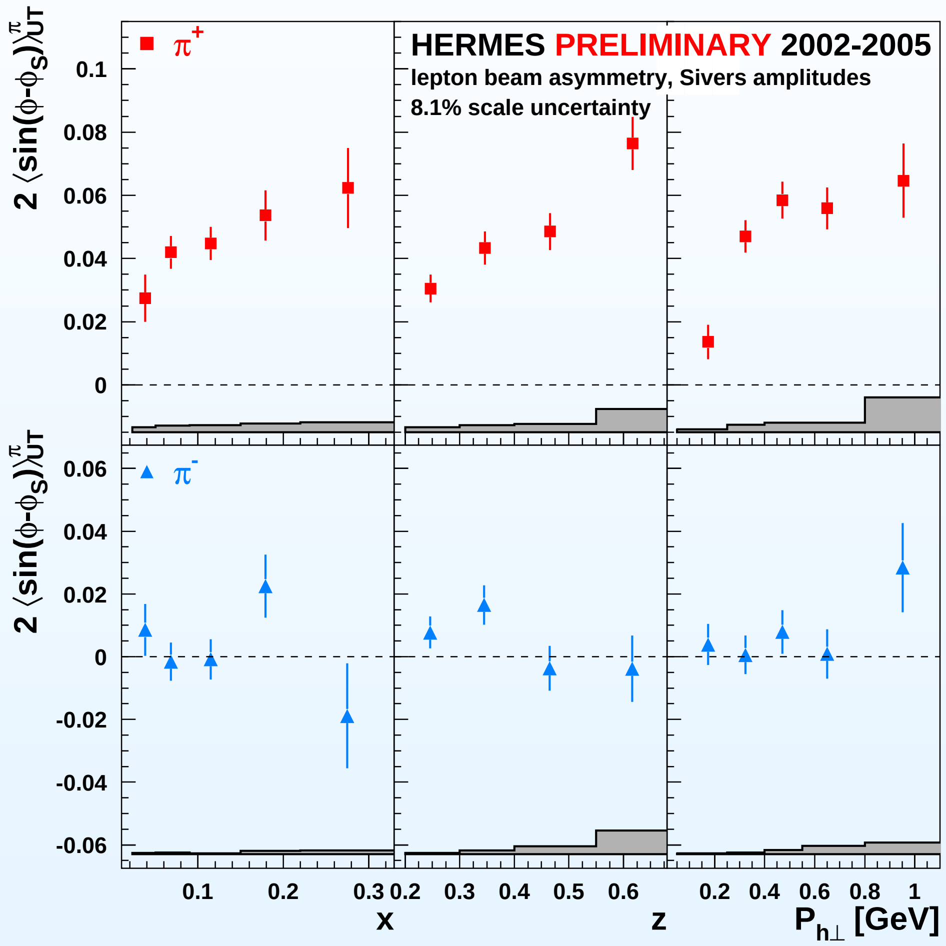
Results of the Collins amplitude:

$$\delta q(x) \otimes H_1^{\perp q}(z)$$

from 2002–2005 data:

- positive amplitudes for π^+
- negative amplitudes for π^-
- large negative π^-amplitudes is unexpected
- $H_1^{\perp,\text{unfav}}(z) \approx -H_1^{\perp,\text{fav}}(z)$
- information from another process on the Collins fragmentation function (BELLE) permits **extraction of transversity** (e.g. Anselmino et al, *Physical Review*, **D75**, 054032 (2007))

The Sivers amplitudes for charged pions:



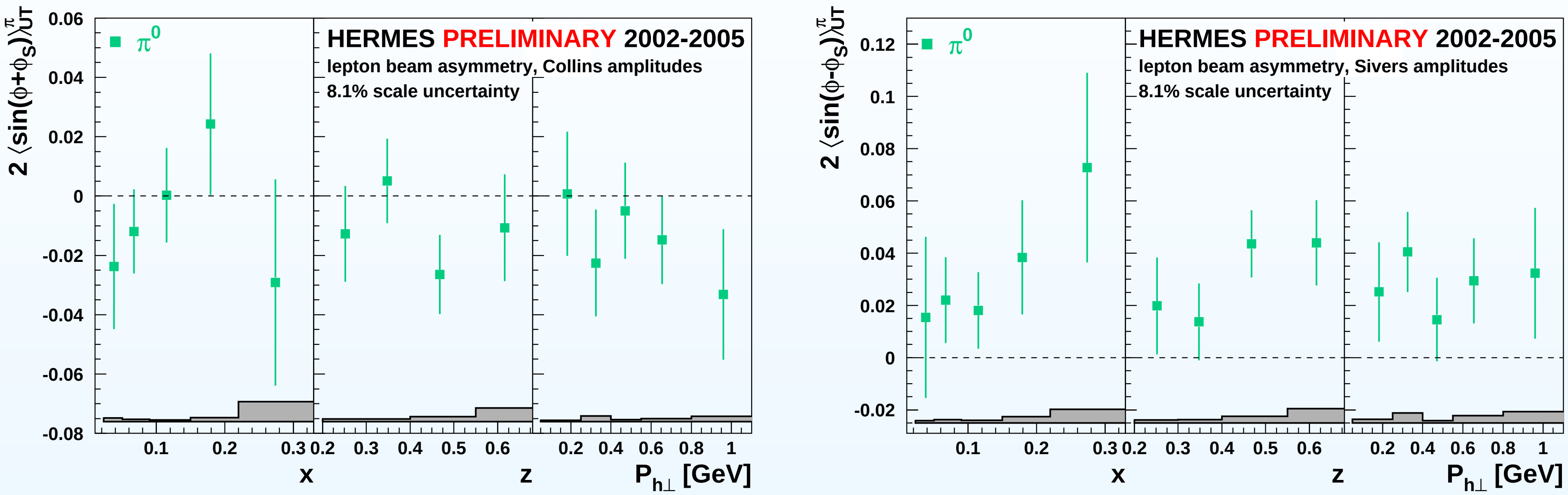
Results of the Sivers amplitude:

$$f_{1T}^{\perp q}(x) \otimes D_1^q(z).$$

from 2002–2005 data:

- significantly positive for π^+
- implies non-zero L_z^q
- π^- amplitude consistent with zero
- **extraction of the Sivers function** is possible as spin-independent fragmentation function $D_1^q(z)$ is known

SSA amplitudes for neutral pions:

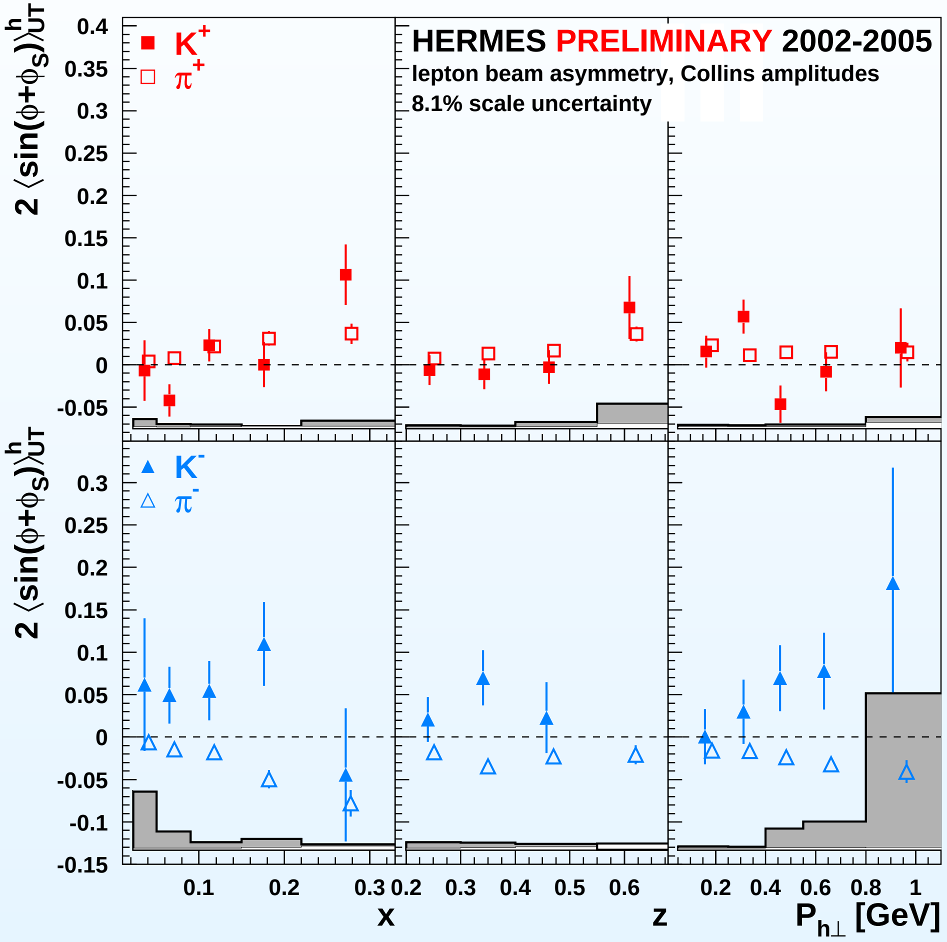


- the isospin triplet of π-mesons is reflected in a relation for any SSA and DSA amplitudes in semi-inclusive DIS ($C = \sigma^{\pi^-}/\sigma^{\pi^+}$):

$$2\left\langle\sin\left(\phi\pm\phi_S\right)\right\rangle_{UT}^{\pi^+} + C\cdot 2\left\langle\sin\left(\phi\pm\phi_S\right)\right\rangle_{UT}^{\pi^-} - (1+C)\cdot 2\left\langle\sin\left(\phi\pm\phi_S\right)\right\rangle_{UT}^{\pi^0} = 0$$

  assuming isospin symmetry of the Collins fragmentation function
- isospin symmetry of π-mesons is fulfilled for the extracted SSA amplitudes

The Collins amplitudes for charged kaons:



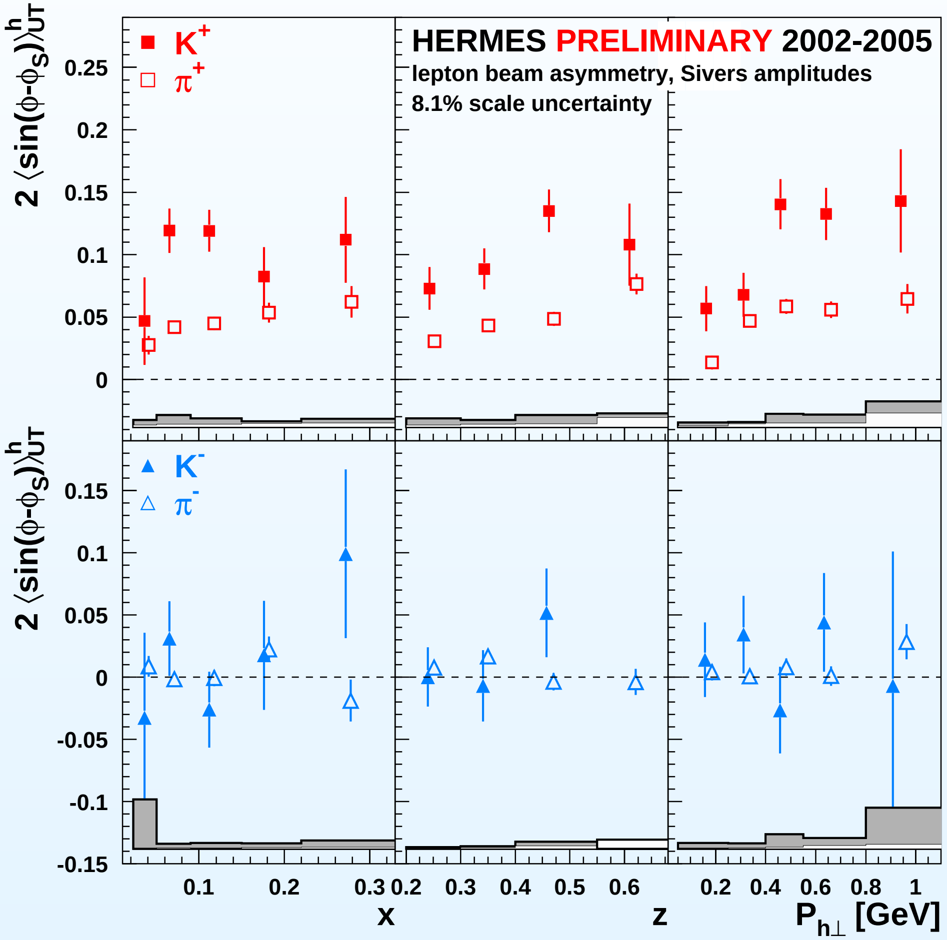
Results of the Collins amplitude:

$$\delta q\,(x) \otimes H_1^{\perp q}\,(z)$$

from 2002–2005 data:

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

The Sivers amplitude for charged kaons:



Results of the Sivers amplitude:

$$f_{1T}^{\perp q}(x) \otimes D_1^{\perp q}(z).$$

from 2002–2005 data:

- significantly positive for K^+
- implies non-zero L_z^q
- K^-amplitude consistent with zero
- K^+ amplitude larger than π^+ amplitude
  $\Rightarrow$ sea quark contribution to Sivers mechanism may be important:
  $K^+ = |u\bar{s}\rangle \quad \pi^+ = |u\bar{d}\rangle$

The beginning is not the end:

- most precise data on a transversely polarised hydrogen target
- significant Collins amplitudes for π-mesons
  $\longrightarrow$ enables first extraction of transversity distribution
- significant Sivers amplitudes for $\pi^+$and K^+
  $\longrightarrow$ clear evidence of a naive time reversal odd parton distribution

(by courtesy of Alessandro Bacchetta (DESY))

Backup slide

Contribution from exclusivly produced vector mesons:

- possible contribution from diffractive vector meson production and decay is unknown
- simulated fraction of mesons originating from this process: