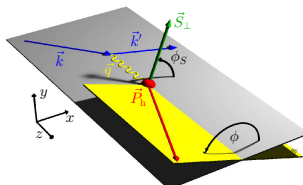


Transverse spin physics at HERMES

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Outline

HERMES

Transverse spin physics at HERMES

Transversity distribution δq

Sivers function f_{1T}^\perp

Azimuthal single-spin asymmetries

Results from a transversely polarised target

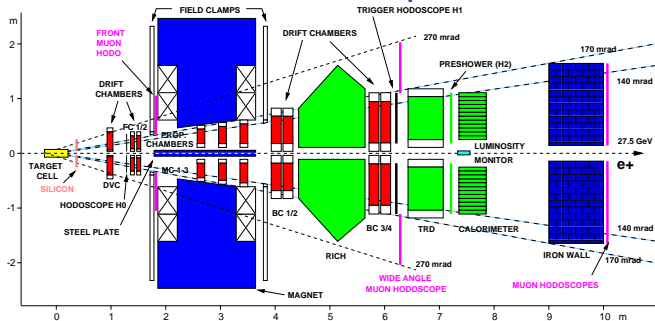
Collins moments

Sivers moments

Summary and Outlook



The HERMES Experiment



- HERA e^+ beam:

$$E = 27.6 \text{ GeV}$$

- transv. pol. H target

$$\langle P \rangle \approx 80\%$$

- Forward spectrometer:

$$40 \text{ mrad} \leq \theta \leq 220 \text{ mrad}$$

- Resolution:

$$\delta p/p \leq 2.6\%$$

$$\delta \theta \leq 1 \text{ mrad}$$

- PID:

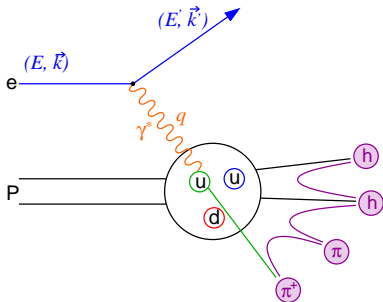
lepton-hadron separation: $> 98\%$

Hadron-ID:

$$\pi : 98\%, K : 88\%, P : 85\%$$



Semi-inclusive Deep-inelastic Scattering



$$\begin{aligned}
 Q^2 &= -q^2 = -(k - k')^2 \\
 \nu &\stackrel{\text{lab}}{=} E - E' \\
 x &= \frac{Q^2}{2M\nu} \\
 z &\stackrel{\text{lab}}{=} \frac{E_{\text{had}}}{\nu}
 \end{aligned}$$

Cross section contains **Distribution Functions** and **Fragmentation Functions**:

$$\sigma^{ep \rightarrow eh} \sim \sum_q \text{DF}^{p \rightarrow q} \otimes \sigma^{eq \rightarrow eq} \otimes \text{FF}^{q \rightarrow h}$$

DF: distribution of quarks in the nucleon

FF: fragmentation of (struck) quark into hadronic final state

Distribution Functions

Leading twist:

3 DFs survive the integration over transverse quark momenta

unpolarised DF

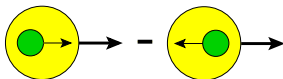
$$q(x, Q^2)$$



well known

Helicity

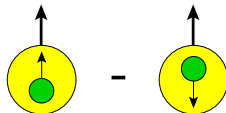
$$\Delta q(x, Q^2)$$



known

Transversity

$$\delta q(x, Q^2)$$



unkown

HERMES 1996-2000

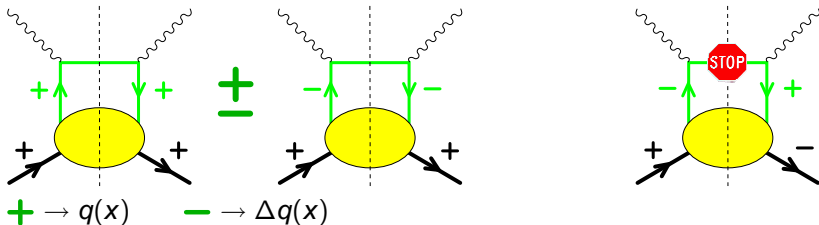
HERMES 2002-2005

⇒ All 3 DFs needed for complete description of the nucleon!



Transversity δq

- non-relativistic quarks \rightarrow transversity=helicity

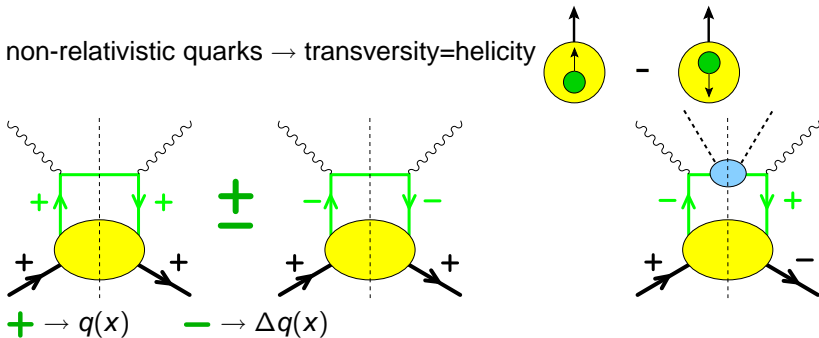


- chiral-odd \rightarrow helicity flip



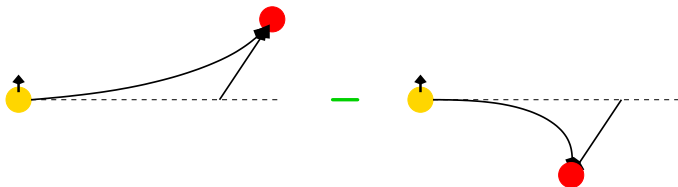
Transversity δq

- non-relativistic quarks \rightarrow transversity=helicity



- chiral-odd \rightarrow helicity flip
- access to δq in combination with another chiral-odd object
 \rightarrow Collins-FF H_1^\perp

Collins Effect

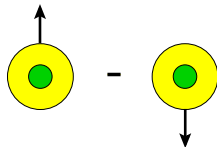


- Collins function H_1^\perp describes left–right asymmetry in the direction of the outgoing hadron.
- Originally proposed by Collins in 1993 → Collins effect
- basically unknown
 - estimations from DELPHI
 - model calculations
 - first measurements from BELLE which are sensitive to H_1^\perp



Sivers Function f_{1T}^\perp

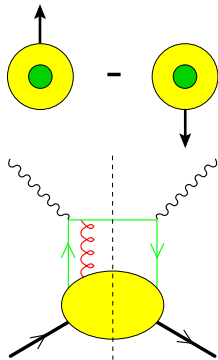
- describes **correlation** between **intrinsic transverse quark momentum** \vec{p}_T and **transverse nucleon spin**
- Chiral-even function
- T-odd \rightarrow **forbids its existence?**





Sivers Function f_{1T}^\perp

- describes **correlation** between **intrinsic transverse quark momentum** \vec{p}_T and **transverse nucleon spin**
- Chiral-even function
- T-odd functions allowed due to **final state interactions (FSI)**:
quark rescattering via a soft gluon
time-reversal invariance condition change
→ **naive** T-odd
- non-zero Sivers function requires **non-vanishing orbital angular momentum** in the nucleon wave function (can contribute to nucleon spin!)





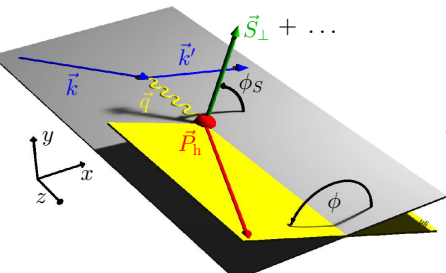
Azimuthal Asymmetries

Measurement of cross-section asymmetries depending on the azimuthal angles ϕ and ϕ_S

$$A_{UT}(\phi, \phi_S) = \frac{1}{S_{\perp}} \frac{N^{\uparrow}(\phi, \phi_S) - N^{\downarrow}(\phi, \phi_S)}{N^{\uparrow}(\phi, \phi_S) + N^{\downarrow}(\phi, \phi_S)}$$

$$\sim \dots \sin(\phi + \phi_S) \frac{\sum_q e_q^2 \mathcal{I} \left[\dots \delta q(x, \vec{p}_T^2) \cdot H_1^{\perp q}(z, \vec{k}_T^2) \right]}{\sum_q e_q^2 q(x) \cdot D_1^q(z)}$$

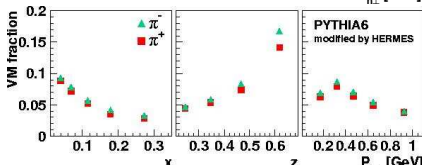
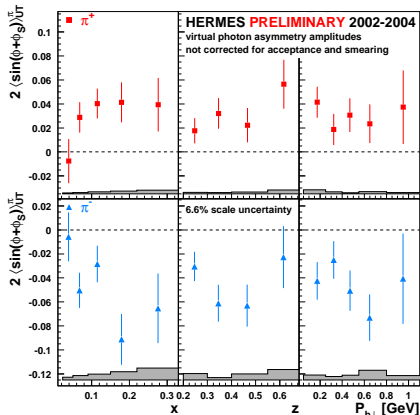
$$+ \dots \sin(\phi - \phi_S) \frac{\sum_q e_q^2 \mathcal{I} \left[\dots f_{1T}^{\perp q}(x, \vec{p}_T^2) \cdot D_1^q(z, \vec{k}_T^2) \right]}{\sum_q e_q^2 q(x) \cdot D_1^q(z)}$$



$\mathcal{I}[\dots]$: convolution integral over initial (\vec{p}_T) and final (\vec{k}_T) quark transverse momenta



Collins Amplitudes $A_C \propto \delta q \cdot H_1^\perp$

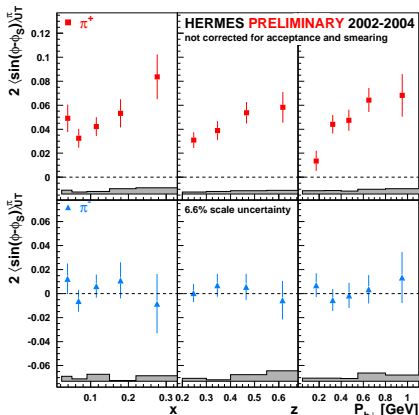


Results of 2002–2004 data

- Collins amplitude **positive** for π^+ and **negative** for π^- .
- **First evidence for non-vanishing Collins FF**
- large negative π^- moment unexpected
→ important role of unfavoured FF (eg same size, opposite sign)
- Extraction of δq : additional information on H_1^\perp needed
- BELLE data are analysed, extraction of FF in progress
- Contribution from exclusive elastic vector mesons
→ uncertainty in interpretation

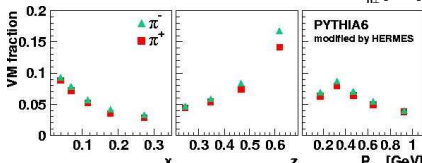


Sivers Amplitudes $A_S \propto f_{1T}^\perp \cdot D_1^q$



Results of 2002–2004 data:

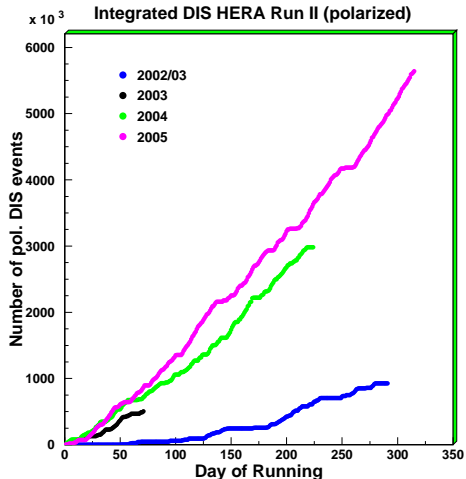
- Sivers moment **significantly positive** for π^+
- **First evidence for T-odd DF**
- Possible link to orbital angular momentum of quarks
(Theorists are working hard)
- Sivers moment for π^- consistent with zero
- spin independent fragmentation function known
⇒ Extraction of Sivers function possible
- QCD prediction:
 $f_{1T}^\perp(\text{Drell - Yan}) = -f_{1T}^\perp(\text{DIS})$
⇒ Await measurements from pp -scattering
- Contribution from exclusive elastic vector mesons
→ uncertainty in interpretation





HERMES Transverse Data Set

Statistics on transversely polarised hydrogen target



Prospects

- 2005 more than doubled statistics
- results on K^\pm and π^0
→ flavor decomposition
- Collins moment: extract $\delta q(x)$ using FF from BELLE
- Sivers moment: We are ready to extract the Sivers function



Conclusions

- Transverse spin physics fast evolving field
- First evidence for T-odd Collins and Sivers functions
- different methods to access transversity δq
here discussed: Collins mechanism
but also: 2 hadron production (HERMES results exist)
Drell-Yan (RHIC...)
- Sivers potentially an alternative access to L_q
- more results on Collins and Sivers soon from HERMES
- results from other experiments: BELLE, COMPASS and RHIC