Измерение асимметрий Коллинза и Сиверса в эксперименте ГЕРМЕС

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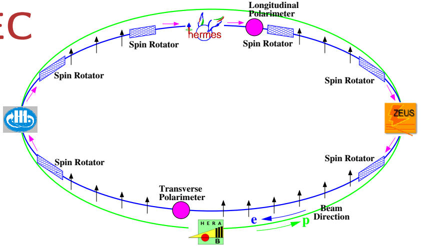
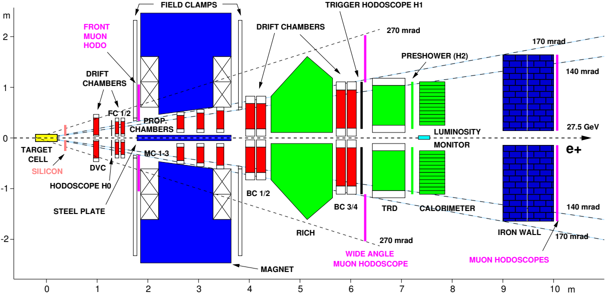
План

- Эксперимент ГЕРМЕС
- Мотивация измерений
- Азимутальные асимметрии в поуинклюзивном электророждении адронов
- Результаты
    - Измерение амплитуд асимметрии
    - Амплитуды Коллинза
    - Амплитуды Сиверса
    - Амплитуды в плоскости двух переменных
- Заключения

Эксперимент ГЕРМЕС

27.5 GeV polarized e^+/e^- beam of HERA





Internal gas Target:
polarized - $H^{\uparrow}$

Angular acceptance:
$40<\theta<220$ mrad

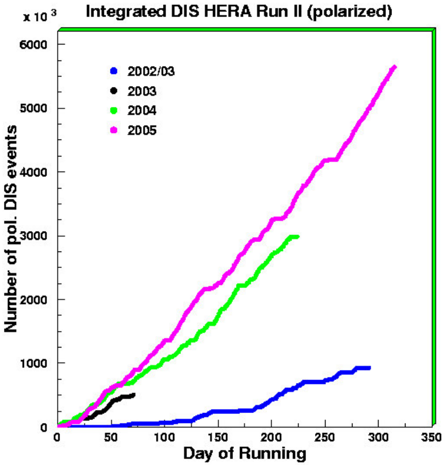
RICH: π / K / p

- e/h rejection: TRD, Preshower, Calorimeter, RICH
- magnetic spectrometer: $\Delta p/p < 2.5\%$ and $\Delta\theta < 0.6$ mrad

Эксперимент ГЕРМЕС

2002 – 2005 data taking years:

- transversely polarized atomic hydrogen ($P \sim 75\%$);
- flip of the polarisation direction every 90 sec in 0.5 sec;
- integrated luminosity about 170 pb^{-1}



Motivation: Transversity Distribution Function

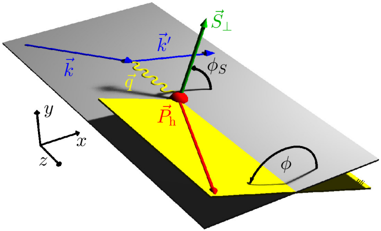
Leading Twist: three quark distribution functions.

Unpolarized DF	Helicity DF	Transversity DF
$q(x) = \overrightarrow{q}(x) + \overleftarrow{q}(x)$	$\Delta q(x) = \overrightarrow{q}(x) - \overleftarrow{q}(x)$	$\delta q(x) = q^{\uparrow}(x) - q^{\downarrow}(x)$
well known	known	unknown

- for non-relativistic quarks: $\delta q(x) = \Delta q(x)$.
- no gluon transversity for spin-1/2 nucleon
- $\delta q(x)$ doesn't contribute to inclusive DIS, $ep \to eX$, due to its chiral-odd nature.
- requires a combination with other chiral-odd object, e.g. Collins FF $\Longrightarrow$
  study of transverse target-spin asymmetries (TTSA) in SIDIS, $ep \to ehX$.

TTSA in SIDIS

- Collins FF $H_1^\perp$ describes an influence of the quark transverse polarization on the hadron transverse momentum $\vec{P}_{h\perp}$.
- Sivers DF $f_{1T}^\perp$ describes a correlation of struck quark p_T with target polarization.



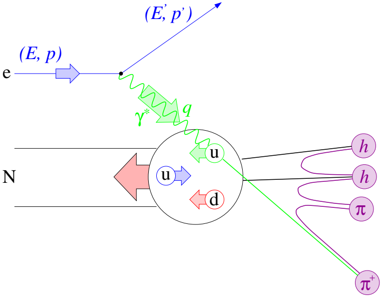
$$A_{UT}^h(\phi, \phi_S) = \frac{1}{|S_T|} \frac{N_h^\uparrow(\phi,\phi_S) - N_h^\downarrow(\phi,\phi_S)}{N_h^\uparrow(\phi,\phi_S) + N_h^\downarrow(\phi,\phi_S)}$$

$$A_{UT}^h \propto \sin(\phi+\phi_S) \sum_q e_q^2 \cdot \mathcal{I}[h_{1T}^q(x, P_T^2) \cdot H_1^{\perp q}(z, k_T^2)] \quad \text{— “Collins”}$$

$$A_{UT}^h \propto \sin(\phi-\phi_S) \sum_q e_q^2 \cdot \mathcal{I}[f_{1T}^{\perp q}(x, P_T^2) \cdot D_1^q(z, k_T^2)] \quad \text{— “Sivers”}$$

$\mathcal{I}[\dots]$ - convolution integral over initial (P_T^2) and final (k_T^2) quark transverse momenta.

SIDIS Kinematics



$e(k) + P(P) \longrightarrow e'(k') + h(P_h) + X(P_X)$

$Q^2 = -q^2 = -(k-k')^2,\ x_B = \frac{Q^2}{2P\cdot q},\ y = \frac{P\cdot q}{P\cdot k},\ W^2 = (P+q)^2,\ z = \frac{P\cdot P_h}{P\cdot q}$

$W^2 > 10\ \text{GeV}^2, \quad 0.1 < y < 0.85, \quad Q^2 > 1\ \text{GeV}^2, \quad 0.2 < z < 0.7$

$< Q^2 >= 2.4\ \text{GeV}^2, < x >= 0.09, < y >= 0.54, < z >= 0.36,$
$P_{h\perp} = 0.41\ \text{GeV}^2$

Extraction of TTSA Amplitudes

- Unbinned maximum likelihood (ML) fits are used to extract simultaneously the Collins and Sivers amplitudes.

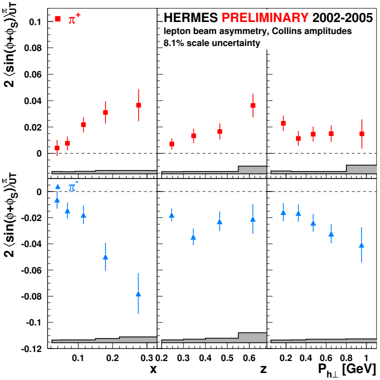
- Probability density function is defined as:

$$F(2 < \sin(\phi + \phi_S) >^h_{UT},\ 2 < \sin(\phi - \phi_S) >^h_{UT},\ \ldots,\ P,\ \phi,\ \phi_S) =$$

$$\frac{1}{2}\Bigg(1 + P \cdot \Big(2 < \sin(\phi + \phi_S) >^h_{UT} \cdot \sin(\phi + \phi_S) + 2 < \sin(\phi - \phi_S) >^h_{UT} \cdot \sin(\phi - \phi_S) + 2 < \sin(3\phi - \phi_S) >^h_{UT} \cdot \sin(3\phi - \phi_S) + 2 < \sin(2\phi - \phi_S) >^h_{UT} \cdot \sin(2\phi - \phi_S) + 2 < \sin(\phi_S) >^h_{UT} \cdot \sin(\phi_S)\Big)\Bigg)$$

- The logarithm of the likelihood function $\mathcal{L} = \prod_i F_i^{w_i}$ is maximized wrt the TTSA amplitudes.

Collins amplitudes for charged pions

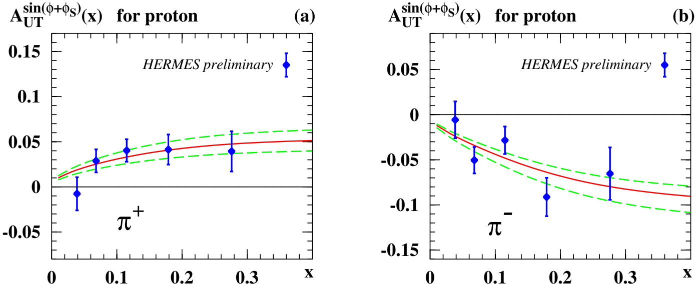


- all data (02 - 05) are used (PRL, 94 (2005) 012002)
- positive amplitudes for π^+
- negative amplitudes for π^-
- large negative amplitudes for π^- were unexpected
- $H_1^{\perp,unf}(z) \approx -H_1^{\perp,fav}(z)$

- $H_1^{fav} = H_1^{u\to\pi^+} = H_1^{d\to\pi^-} = H_1^{\bar{u}\to\pi^-} = H_1^{\bar{d}\to\pi^+}$
- $H_1^{unf} = H_1^{u\to\pi^-} = H_1^{d\to\pi^+} = H_1^{\bar{u}\to\pi^+} = H_1^{\bar{d}\to\pi^-}$

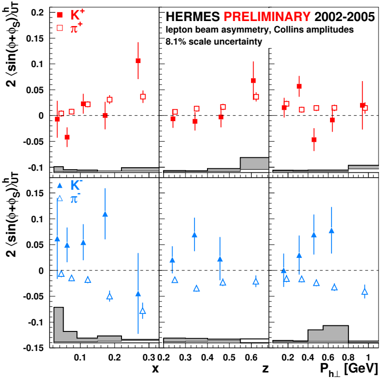
Collins amplitudes for charged pions

Efremov, Goeke, Schweitzer (Phys.Rev.D73,094025,2006)
Preliminary HERMES data 2002 - 2004.



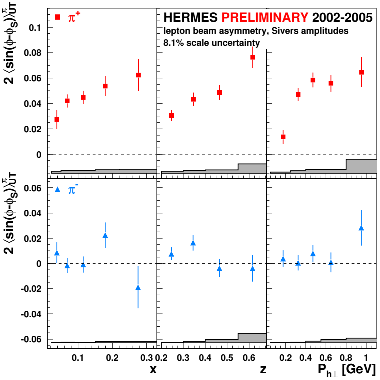
$$\langle 2B_{\rm Gauss} H_1^{\perp(1/2)\rm fav}\rangle = \quad (3.5 \pm 0.8)\%$$
$$\langle 2B_{\rm Gauss} H_1^{\perp(1/2)\rm unf}\rangle = -(3.8 \pm 0.7)\%$$

Collins amplitudes for charged kaons



- K^+ amplitudes are consistent with π^+
- K^- may have the opposite sign from π^-

Sivers amplitudes for charged pions

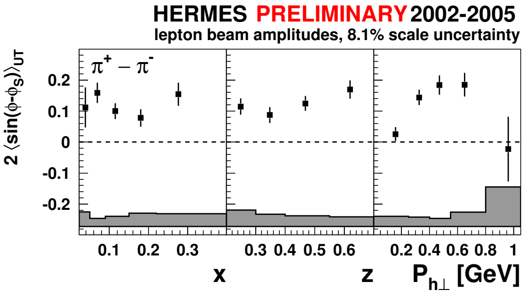


- significantly positive for π^+
- a signiture of non-zero quark orbital angular momentum
- π^- amplitudes consistent with zero

Sivers Valence Quark Distributions

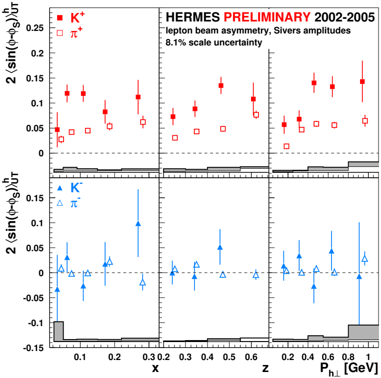
$$A_{UT}^{\pi^+-\pi^-}(\phi,\phi_S) = \frac{1}{|S_T|}\frac{(\sigma_\uparrow^{\pi^+}-\sigma_\uparrow^{\pi^-})-(\sigma_\downarrow^{\pi^+}-\sigma_\downarrow^{\pi^-})}{(\sigma_\uparrow^{\pi^+}-\sigma_\uparrow^{\pi^-})+(\sigma_\downarrow^{\pi^+}-\sigma_\downarrow^{\pi^-})}$$

$$2 < \sin(\phi-\phi_S) >_{UT}^{\pi^+-\pi^-} = -\frac{4f_{1T}^{\perp,u_v} - f_{1T}^{\perp,d_v}}{4f_1^{u_v} - f_1^{d_v}}$$



- $f_{1T}^{\perp,d_v} > f_{1T}^{\perp,u_v}$
- $f_{1T}^{\perp,u_v} < 0$

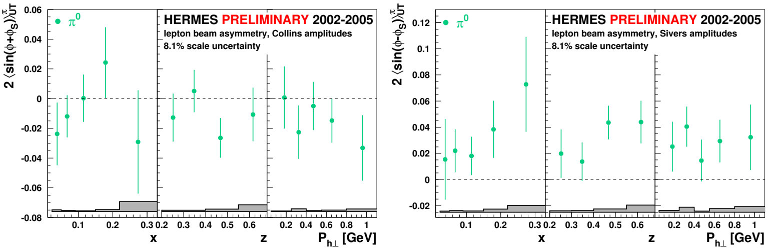
Sivers amplitudes for charged kaons



- significantly positive for K^+
- K^- amplitudes consistent with zero
- K^+ amplitude is 2.3 ± 0.3 times larger than for π^+

- $K^- = s\bar{u},\ \pi^- = d\bar{u}$ same antiquark
- $K^+ = u\bar{s},\ \pi^+ = u\bar{d}$ different antiquarks
- May suggest significant antiquark Sivers functions and strongly flavor-dependent.

Amplitudes for neutral pions



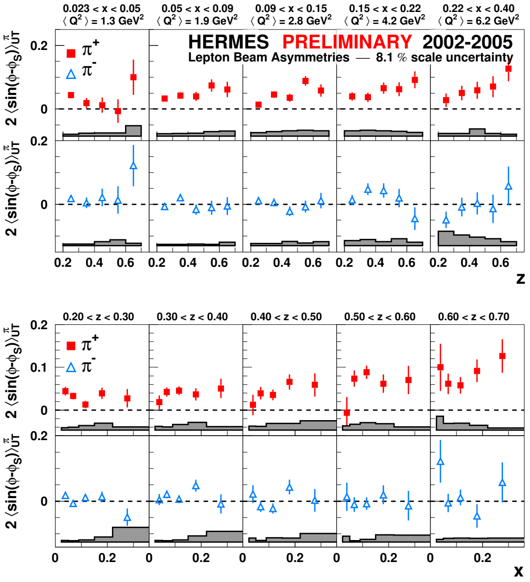
Using charge conjugation and isospin symmetry of the Collins FF π^+, π^-, and π^0 amplitudes can be related:

$$< \sin(\phi \pm \phi_S) >_{UT}^{\pi^+} + C \cdot < \sin(\phi \pm \phi_S) >_{UT}^{\pi^-} + (1 - C) \cdot < \sin(\phi \pm \phi_S) >_{UT}^{\pi^0} = 0$$

Here, $C = \sigma_{UU}^{\pi^+} / \sigma_{UU}^{\pi^-}$

Hermes results for the extracted TTSA amplitudes fulfill the isospin symmetry relation.

2-Dimensional Binning



- high statistics of pion data allows 2-dimensional binning
- amplitudes still non-zero at higher Q^2
- additional combination of variables available, e.g. for fitting models

Заключения

- Фрагментационная функция Коллинза существенно отлична от нуля. Амплитуда асимметрии Коллинза для π^- имеет противоположный знак по отношению к амплитуде для π^+.
  Объяснение: $H_1^{\perp,unf}(z) \approx -H_1^{\perp,fav}(z)$
- ГЕРМЕС впервые показал что функция распределения Сиверса отлична от нуля.
- Амплитуда Сиверса для K^+ больше амплитуды для π^+ фактором 2.3 ± 0.3.
  Существенную роль играют морские кварки?
- Амплитуды Коллинза и Сиверса измерены в плоскости двух переменных: ($x - z$), ($x - P_{h\perp}$), ($z - P_{h\perp}$).