Measurement of Transversity at HERMES

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HERMES

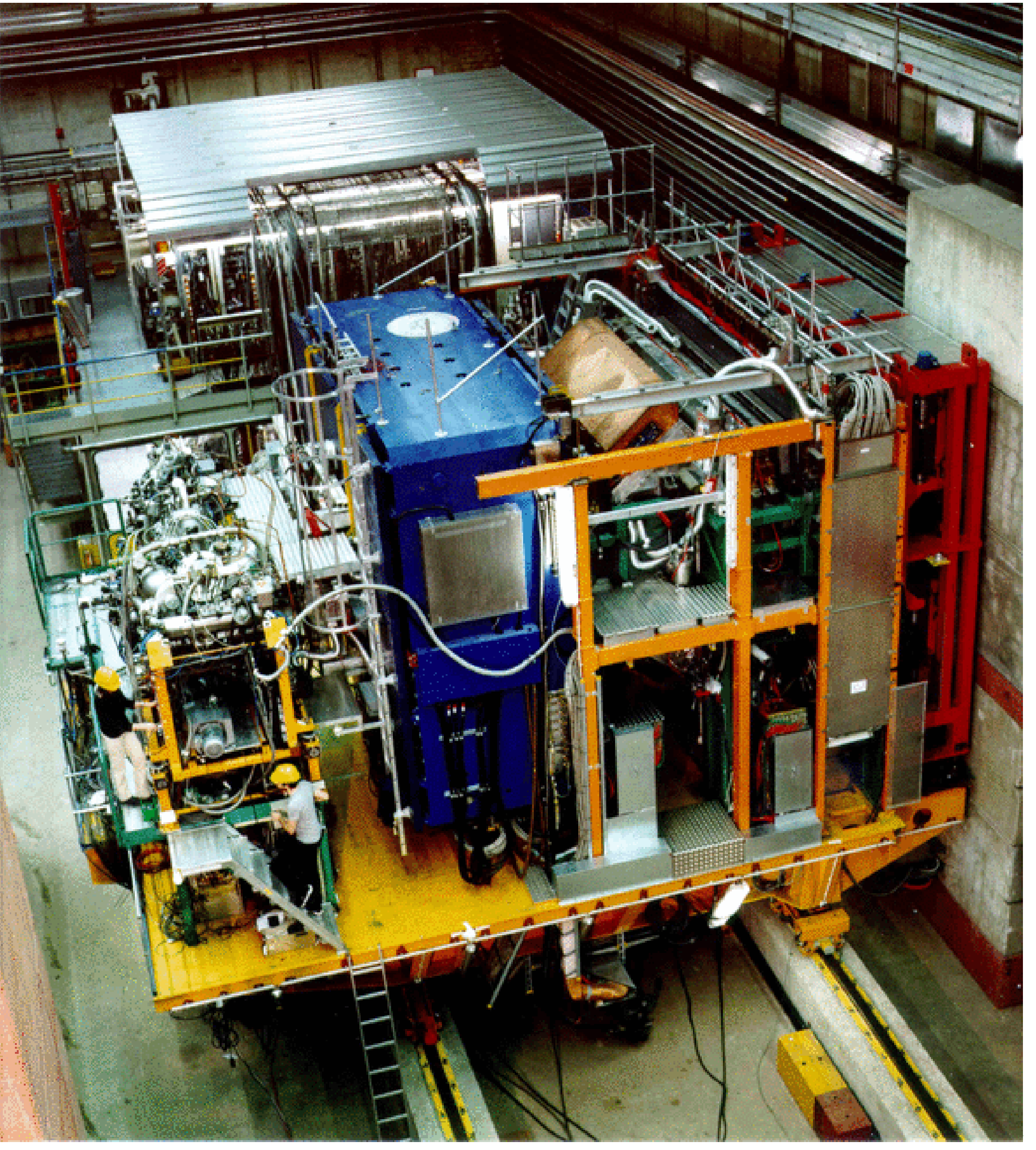
Großgeräte der physikalischen Grundlagenforschung

Štrbské Pleso

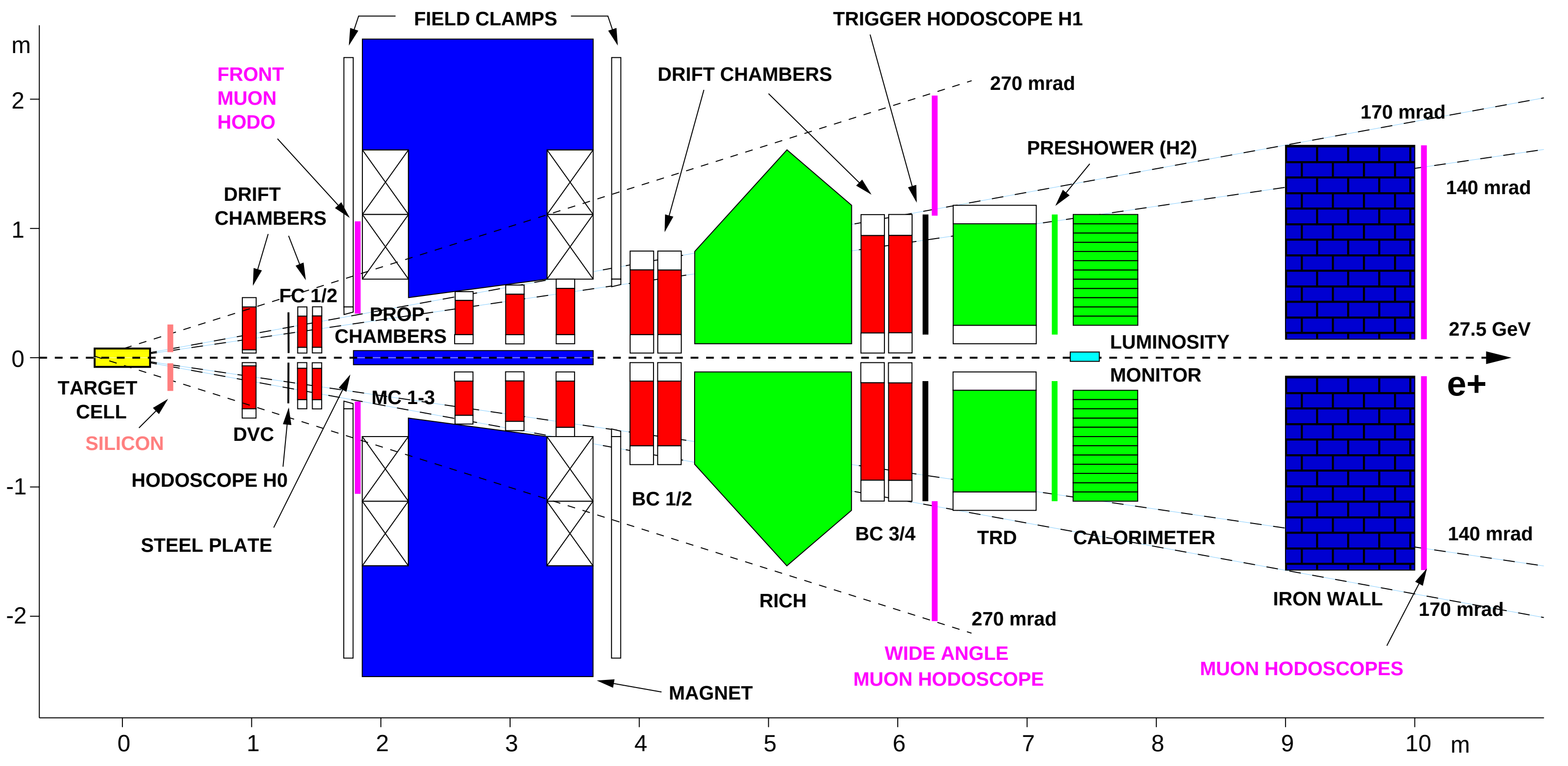
April 15, 2004

- Motivation
- The HERMES Experiment at HERA
- Azimuthal Asymmetries:
  - Transverse momentum dep. DFs and FFs
  - Distribution Functions in SIDIS $\rightarrow$ SSAs
  - Single Spin Asymmetries (SSAs)
  - MC-Studies
  - First transverse Asymmetries
  - Interpretations
- Summary and outlook

The HERMES Experiment at HERA

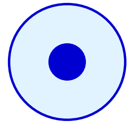


The HERMES Spectrometer



- Kinematic range: $0.02 \leq x \leq 0.8$ for $Q^2 > 1$ GeV^2 and $W > 2$ GeV
- Resolution: $\Delta p/p = 1.4 \ldots 2.5\%$, $\Delta\Theta \lesssim 1$ mrad
- Particle Identification: TRD, Preshower, Calorimeter, additionally:
  $\rightarrow$ 1997: Threshold-Čerenkov Counter
  1998 $\rightarrow$: RICH

Motivation: Transversity

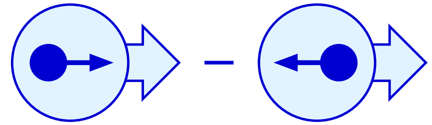
f_1^q = 

Unpolarized
Quarks and Nucleons

Vector-charge:

$$\langle PS|\bar{\psi}\gamma^{\mu}\psi|PS\rangle = \int_0^1 dx\,(q(x) - \bar{q}(x))$$

$q(x)$: Spin averaged
well known

g_1^q = 

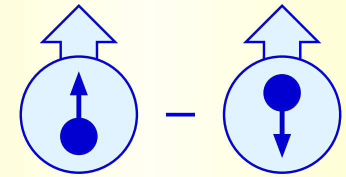
Longitudinally polarized
Quarks and Nucleons

Axial charge:

$$\langle PS|\bar{\psi}\gamma^{\mu}\gamma_5\psi|PS\rangle = \int_0^1 dx\,(\Delta q(x) + \Delta\bar{q}(x))$$

$\Delta q(x)$: Helicity difference
known

HERMES: 1995 - 2000

h_1^q = 

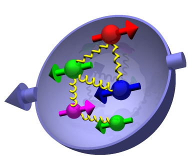
Transversely polarized
Quarks and Nucleons

Tensor-charge:

$$\langle PS|\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi|PS\rangle = \int_0^1 dx\,(\delta q(x) - \delta\bar{q}(x))$$

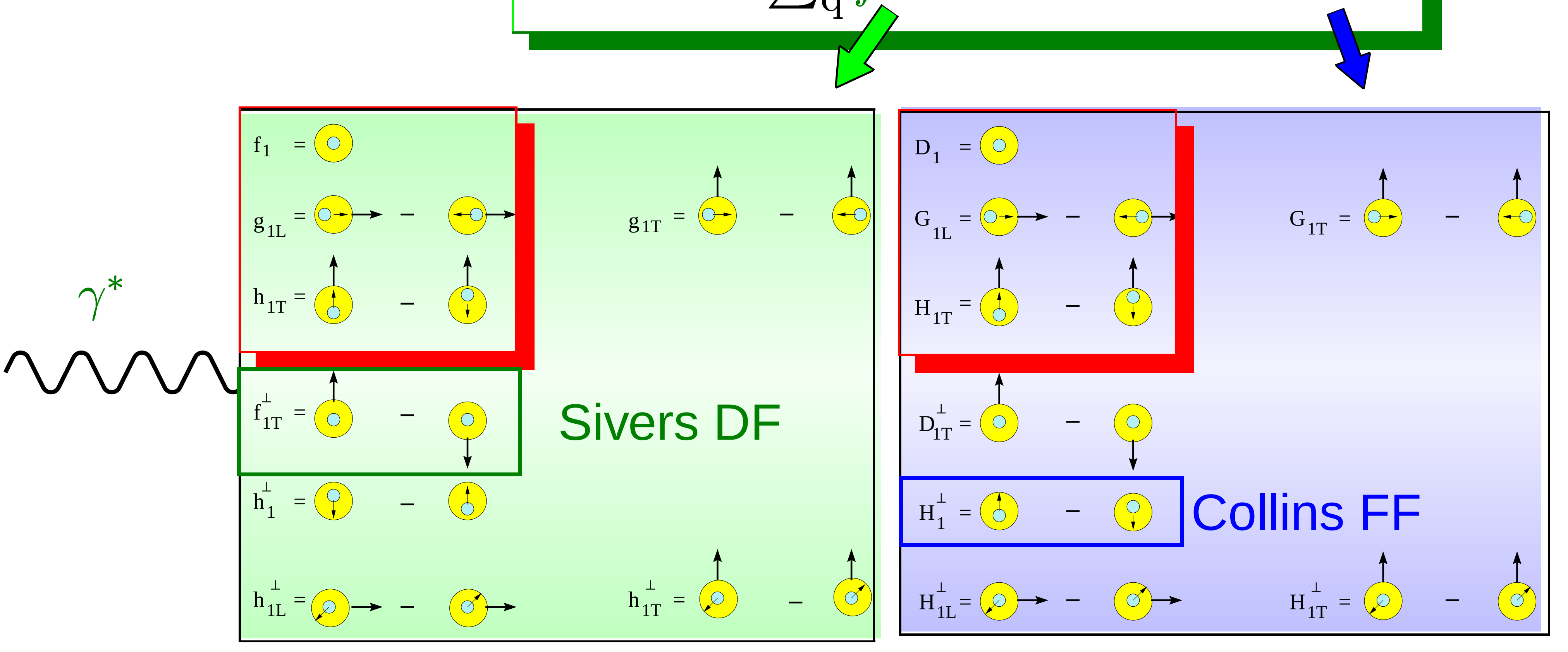
$\delta q(x)$: Helicity flip
chiral odd!
unknown

HERMES: 2002...



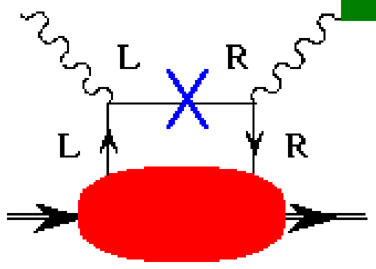
Transverse momentum dependent DFs and FFs

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



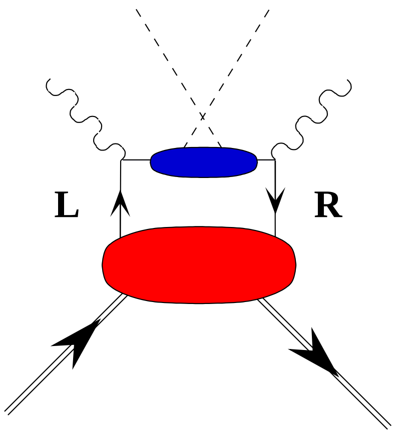
- "survive" integration over p_T(quarks) or k_T (fragmentation)
- T-odd and T-even functions
- chiral-odd and chiral-even functions

T-odd → SSAs



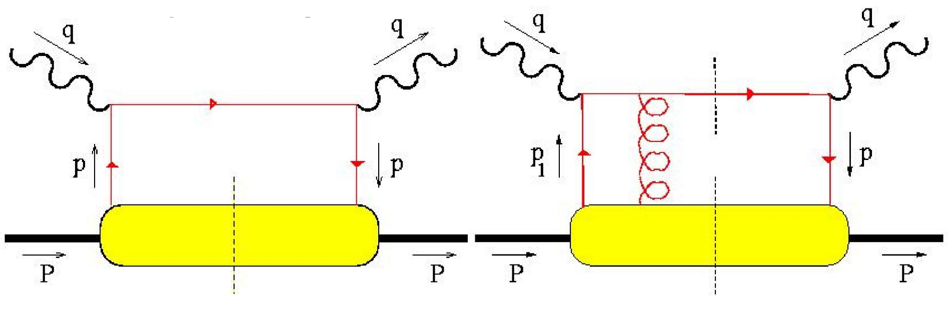
Transversity: $h_1(x)$

- does not couple to gluons
- Transversity is chiral-odd
- ...and (nearly) massless quarks conserve chirality
- a 2nd chiral-odd object necessary
- Collins Fragmentation Function (FF)
- Interference of diagrams $\Rightarrow$ naive time-reversal odd

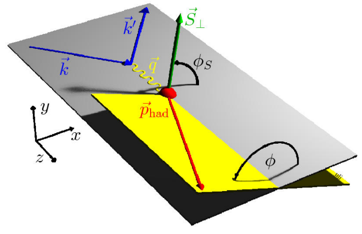


Sivers: $f_{1T}^{\perp}(x)$

- chiral even
- measurable with unpolarized Fragmentation Function
- Interference of diagrams $\Rightarrow$ naive time-reversal odd
- nonzero orbital momentum



$\Rightarrow$ Single Spin Asymmetries

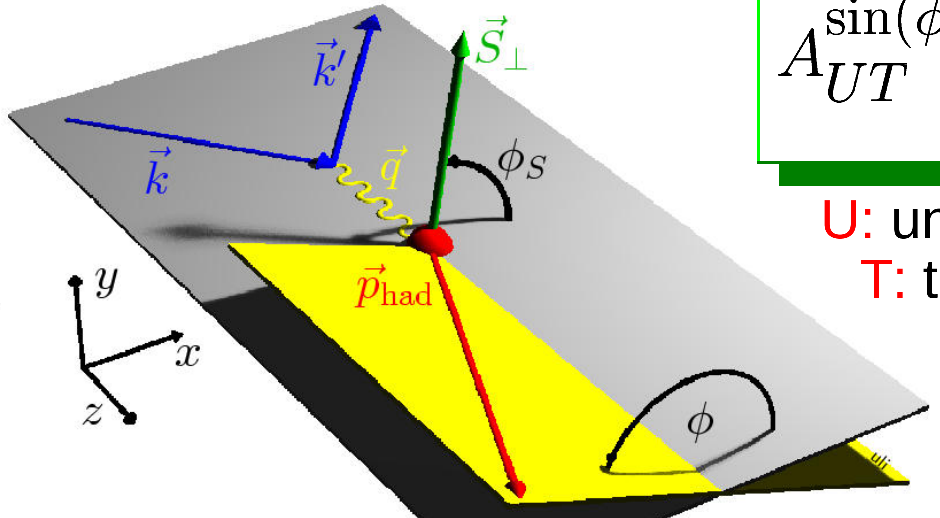


Why a transverse target?

- Collins and Sivers effect not distinguishable with longitudinally polarized target
- higher twist effects kinematically favored with long. target
- with transversely polarized target, 2 azimuthal angles exist
- Collins and Sivers effect distinguishable:

$$A_{UT}^{\sin(\phi+\phi_S)} \propto S_\perp \frac{\sum_{a,\bar{a}} e_a^2 h_1^a(x)\; H_1^\perp(z)}{\sum_{a,\bar{a}} e_a^2 f_1^a(x)\; D_1(z)}$$

$$A_{UT}^{\sin(\phi-\phi_S)} \propto S_\perp \frac{\sum_{a,\bar{a}} e_a^2 f_{1T}^{\perp,a}(x) \cdot D_1(z)}{\sum_{a,\bar{a}} e_a^2 f_1^a(x)\; D_1(z)}$$

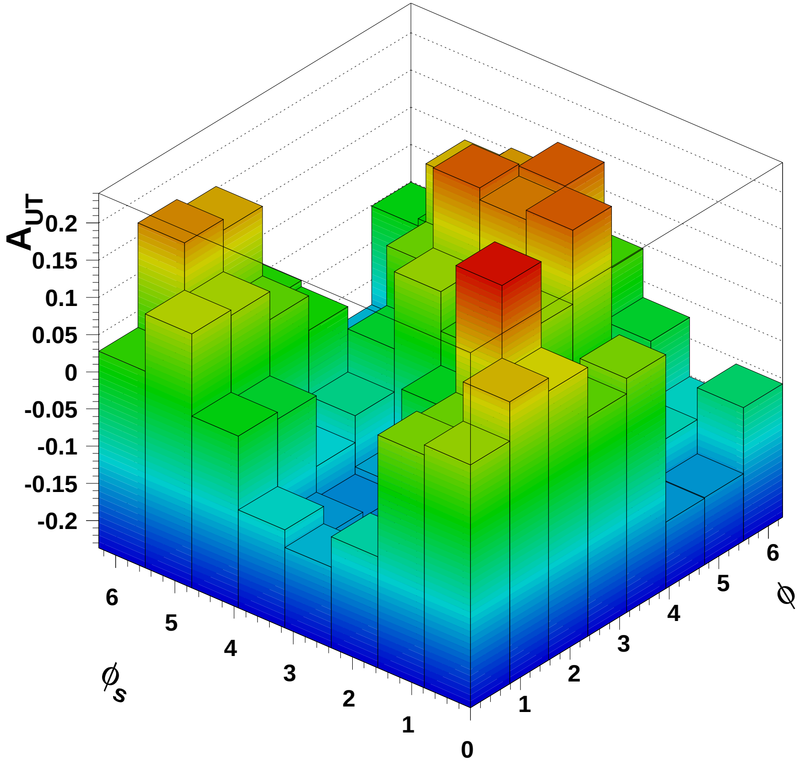


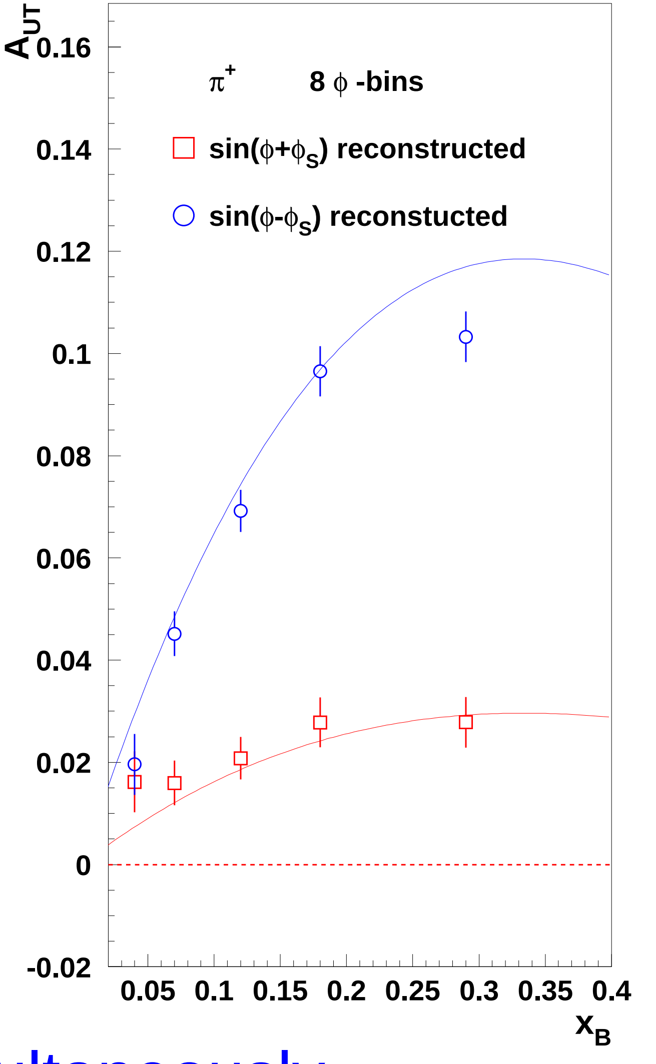
U: unpolarized e^+-beam
T: transversely polarized target

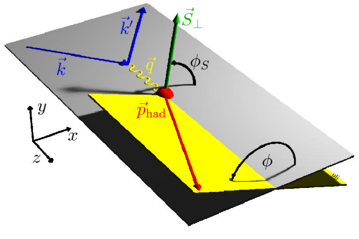
MC: Asymmetry reconstruction

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

$$= A_{UT}^{Collins}\sin(\phi+\phi_S) + A_{UT}^{Sivers}\sin(\phi-\phi_S)\cdots$$



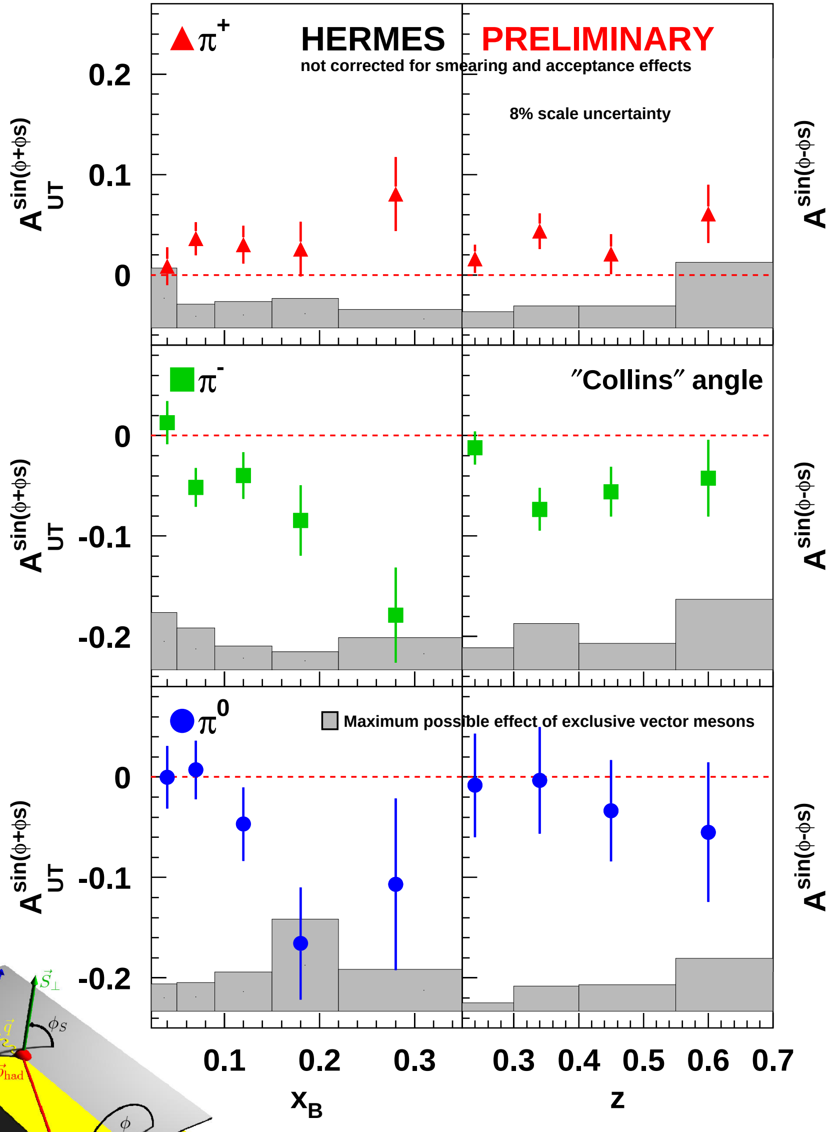




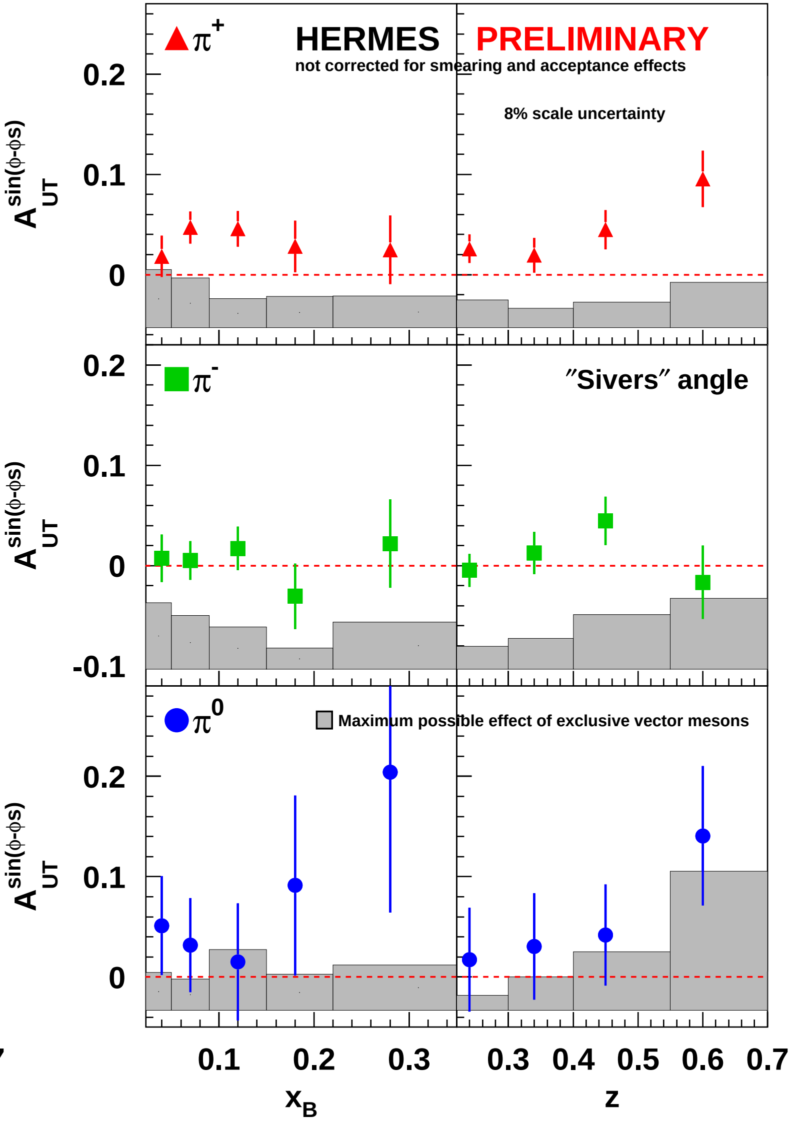
fit both asymmetries simultaneously

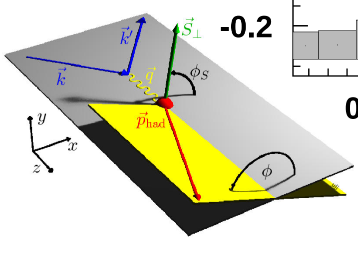
First Measurements of transverse SSAs

'Collins' Moments



'Sivers' Moments





Weighted asymmetries

transverse cross section contains convolution integrals over intrinsic transverse momenta:

$$d^6\sigma_{UT} \approx |S_T| \sum_q e_q^2 \left(B(y) \sin(\phi+\phi_S) \mathcal{I}\left[\frac{\mathbf{k}_T \cdot \hat{P}_{h\perp}}{M_h} h_1^q H_1^{\perp,q}\right] + A(y) \sin(\phi-\phi_S) \mathcal{I}\left[\frac{\mathbf{p}_T \cdot \hat{P}_{h\perp}}{M_N} f_{1T}^{\perp,q} D_1^q\right] + \cdots \right)$$

$\frac{P_{h\perp}}{M}$ weighted moments decouple integrals:

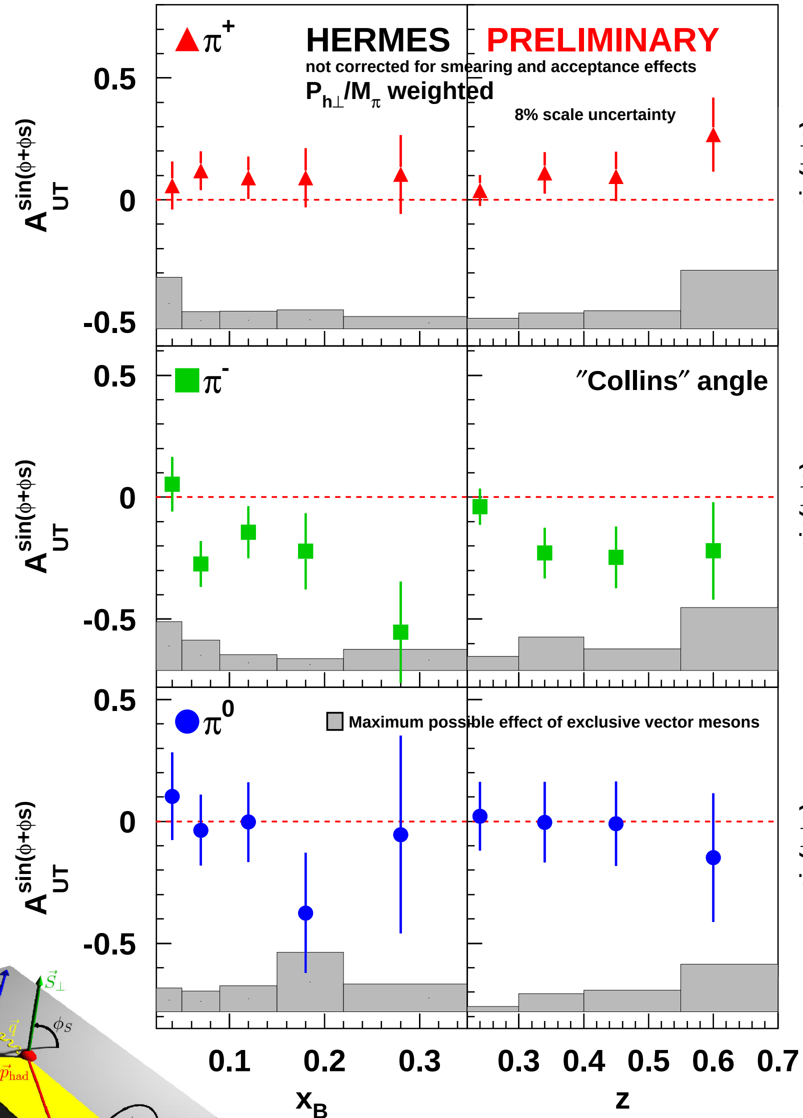
$$A_{UT}^{Collins,wt} \approx |S_T| \frac{\sum_q e_q^2 h_1^q H_1^{\perp(1),q}}{\sum_q e_q^2 f_1^q D_1^q}$$

$$A_{UT}^{Sivers,wt} \approx |S_T| \frac{\sum_q e_q^2 f_{1T}^{\perp(1),q} D_1^q}{\sum_q e_q^2 f_1^q D_1^q}$$

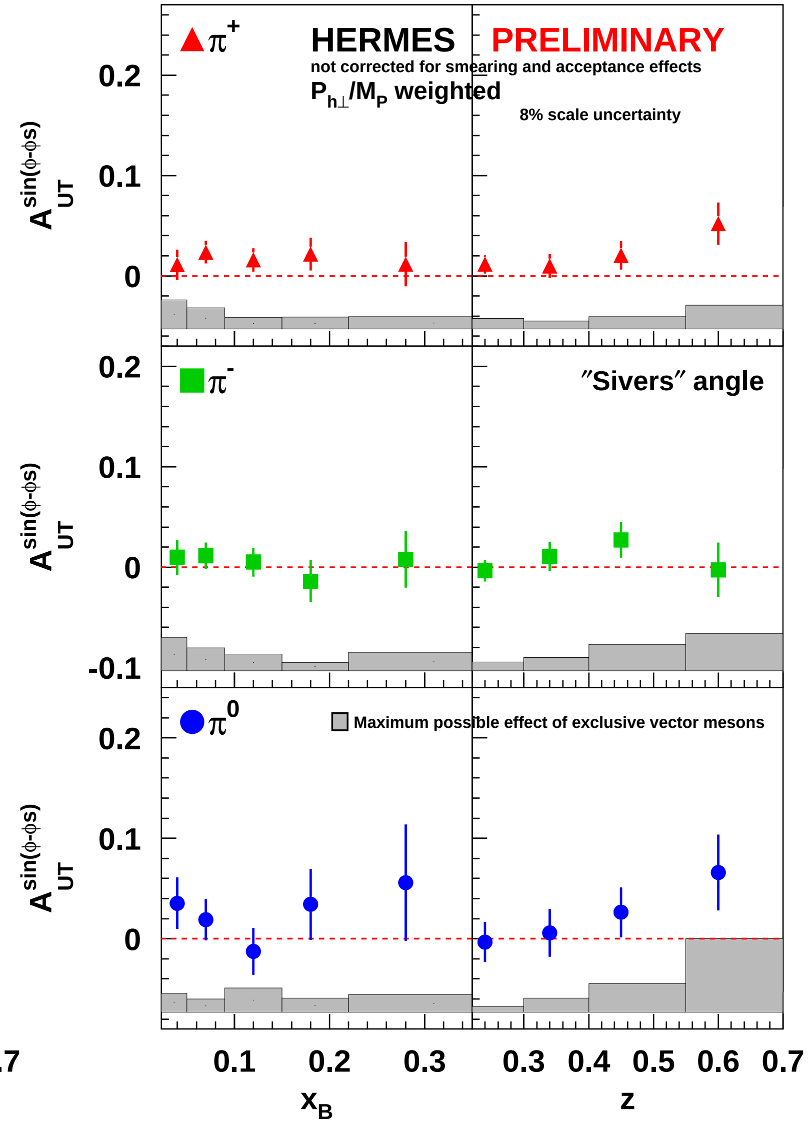
...while unweighted asymmetries can only be decoupled by making assumptions about tranv. momentum dependencies

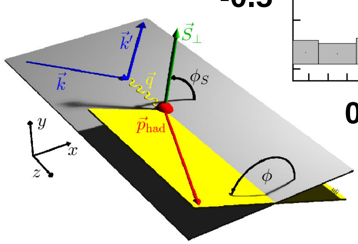
$P_{h\perp}/M_h$ weighted asymmetries

'Collins' Moments

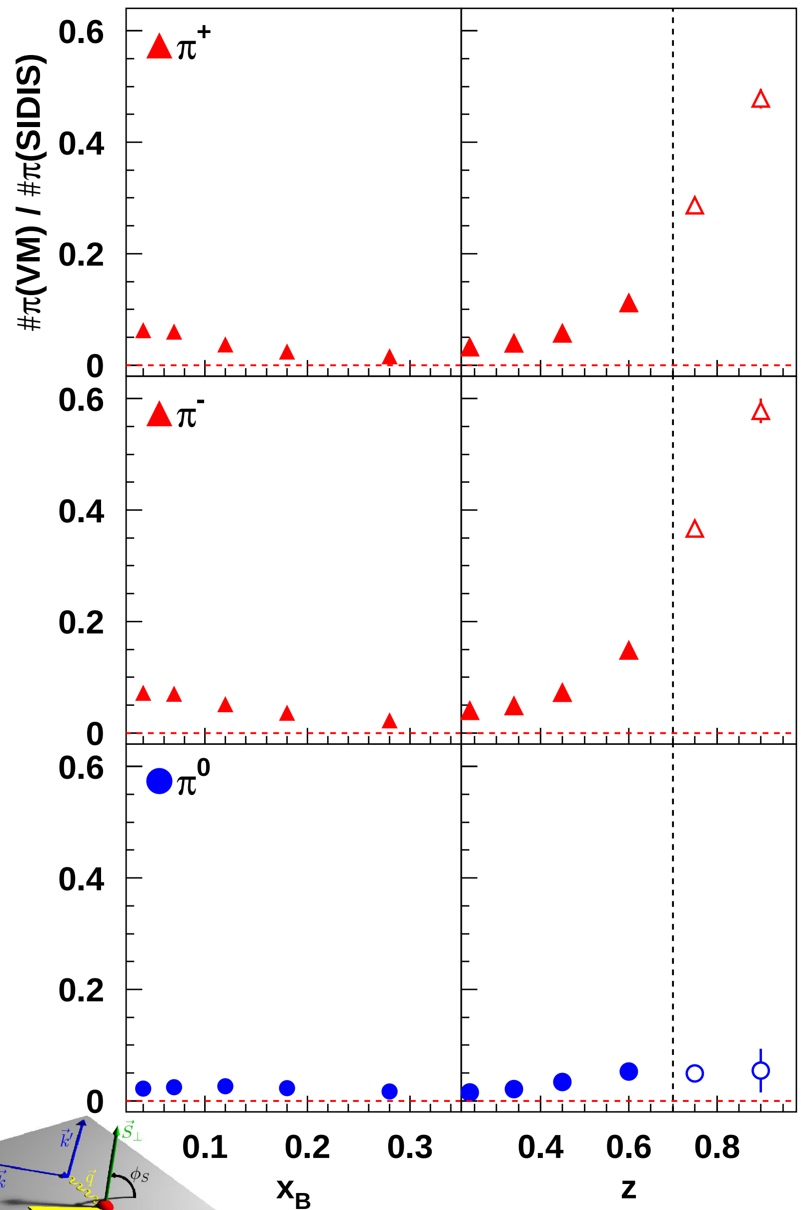


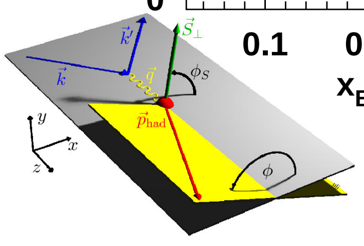
'Sivers' Moments





Interpretative uncertainties by diffractive VM





- decay pions of excl. ρ, ω in data sample
- dilutions not negligible
- conservative approach: calculate transfer for maximal ρ asymmetries: $A_{UT}^{Collins,\rho}$ and $A_{UT}^{Sivers,\rho} = \pm 1$
- Positivity limits reduce uncertainties
  ➡ $\sigma(A_{UT}^{Collins,\rho})$ and $\sigma(A_{UT}^{Sivers,\rho}) = \frac{1}{\sqrt{6}}$

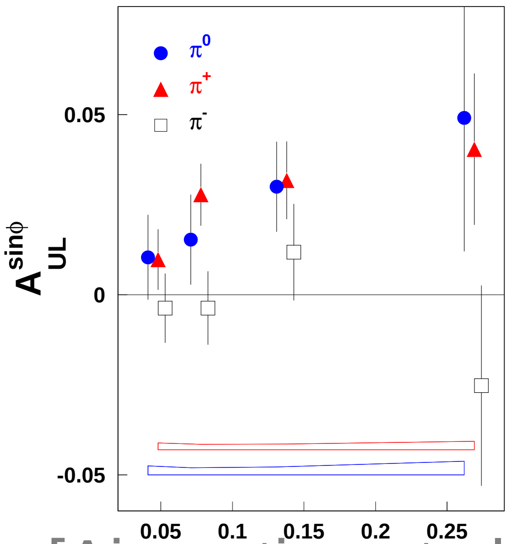
Interpretation of Collins results

The Collins results for π^+,π^- and π^0 show an unexpected behavior...
Expectation: u-quark dominance in Quark distributions

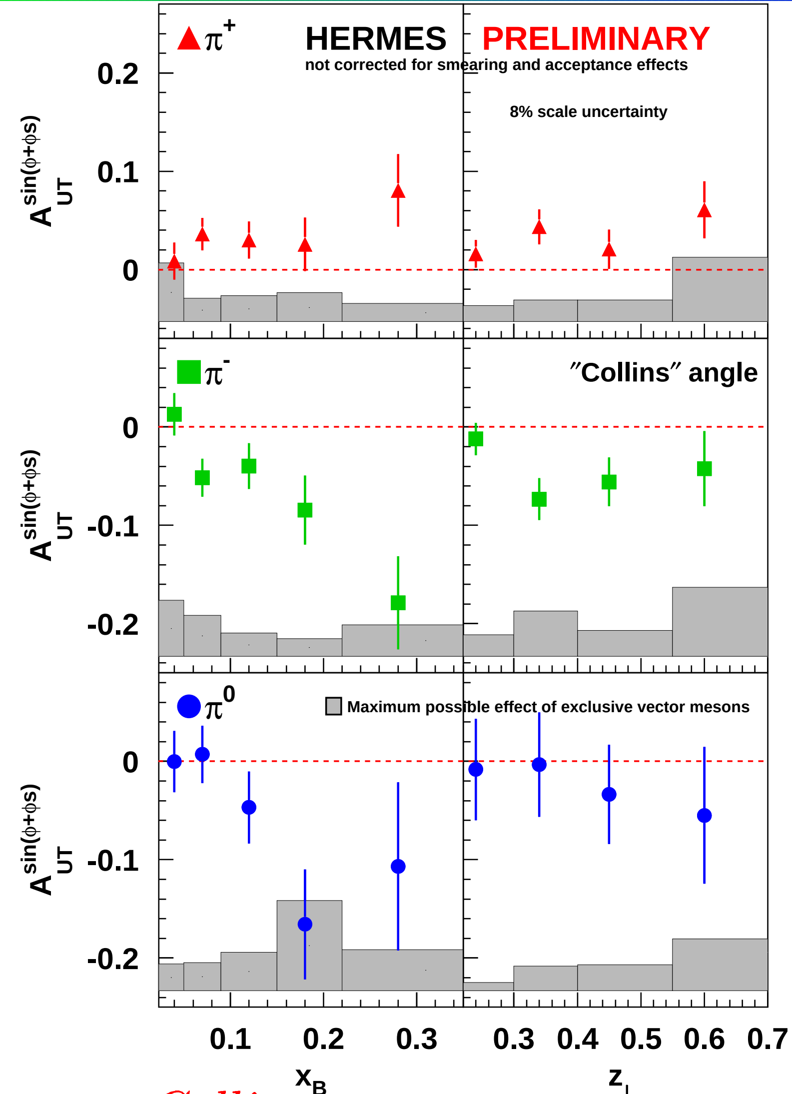
$\delta u > 0, \delta d < 0 \Rightarrow A^{\pi^+} > A^{\pi^0} > 0$

and $A^{\pi^-} \leq 0$ and $|A^{\pi^-}| < |A^{\pi^+}|$

A_{UL} from Proton



[Airapetian et al., PRL 84(2000) 4047]



New data for $A_{UT}^{Collins}$ shows $A^{\pi^+} > 0$

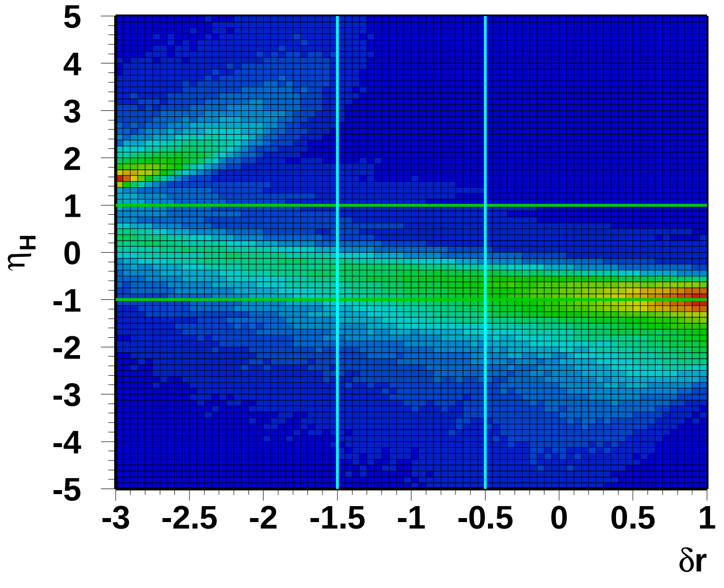
but $A^{\pi^0} \simeq A^{\pi^-} < 0$ and $|A^{\pi^-}| > |A^{\pi^+}|$

Interpretation der Collins results

- **consistency equation**: weighted and unweighted Asymmetries within 1σ of stat. error ➡ Data is consistent

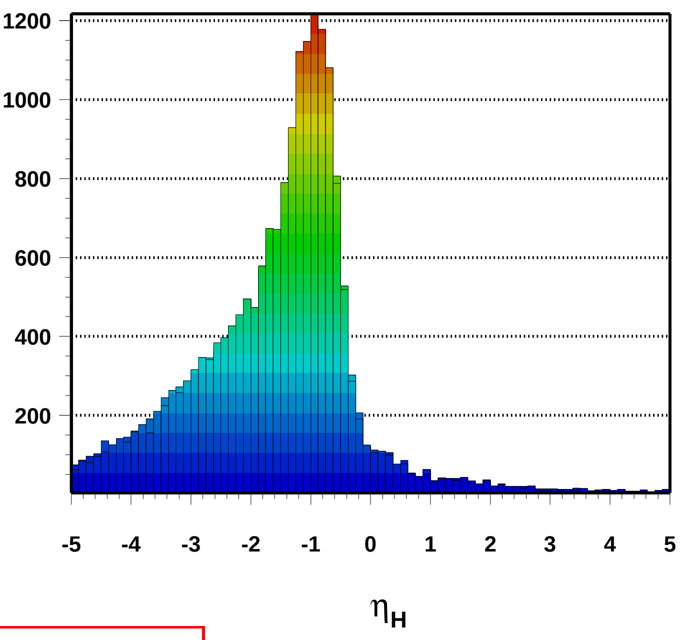
- **solution space** for $\delta r = \frac{\delta d + 4\delta\bar{u}}{\delta u + 1/4\delta\bar{d}}$ vs. $\eta_H = H_{dis}/H_{fav}$

solution space populated acc. to stat. errors



η_H solution at $\delta r = -0.93$

χQSM value of Wakamatsu



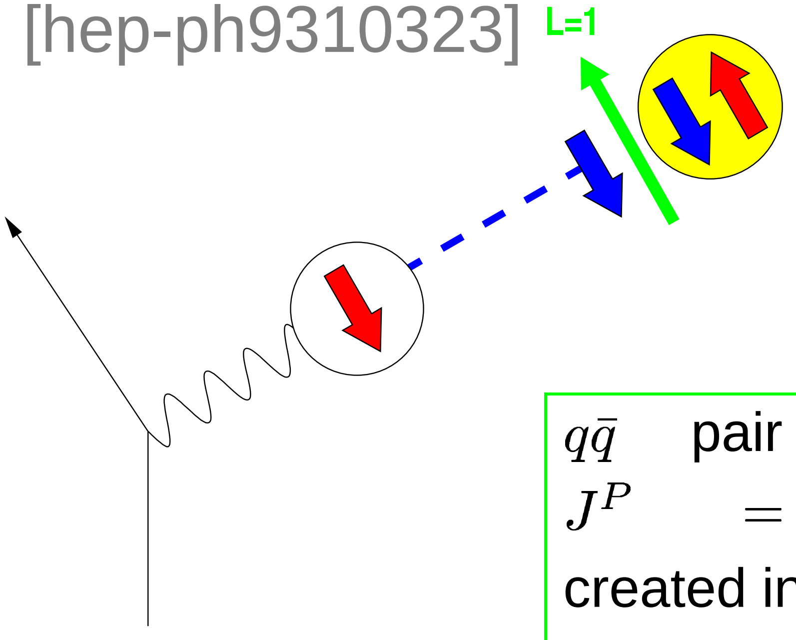
a hint to $H_{\rm disf} \approx -H_{\rm fav}$?

Interpretation of Collins results

Possible explanation: $H_{\rm disf} \approx -H_{\rm fav}$?

Artru model

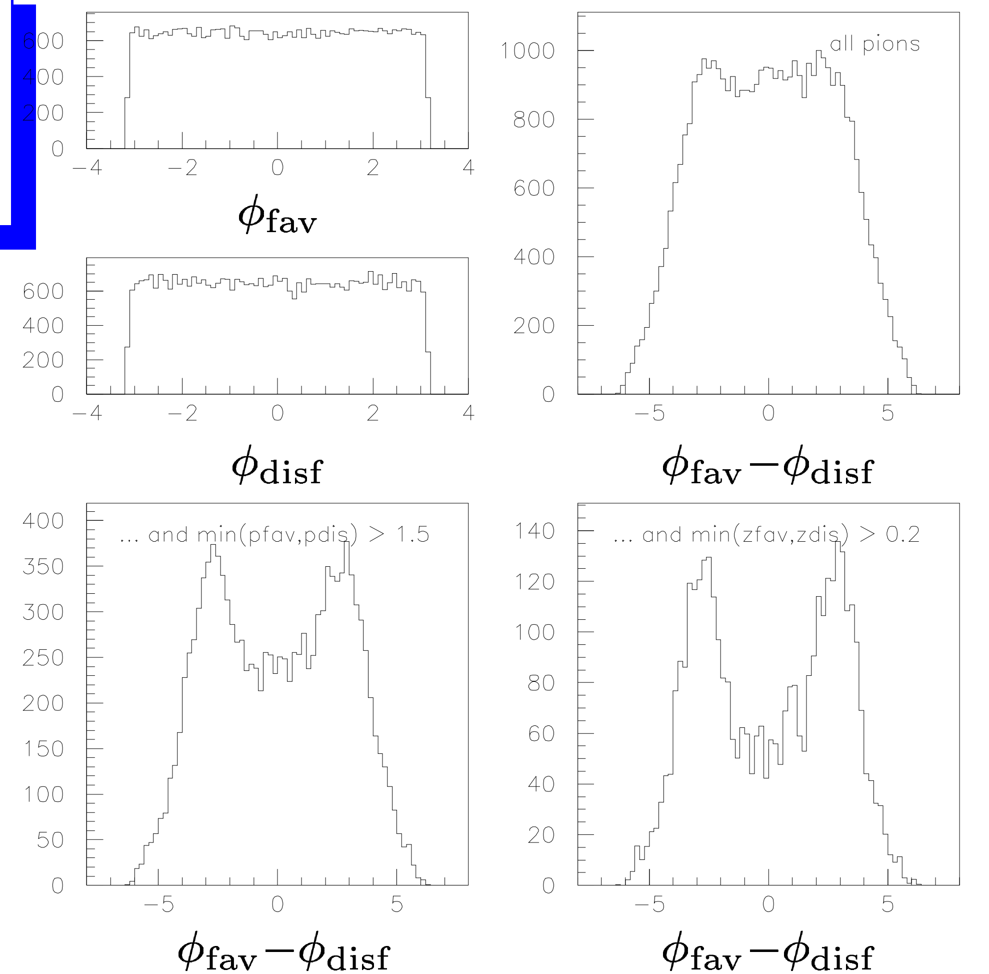
[hep-ph9310323]



leading π into plane

$q\bar{q}$ pair with $J^P = 0^+$ created in string breaking

unpol. Lund MC



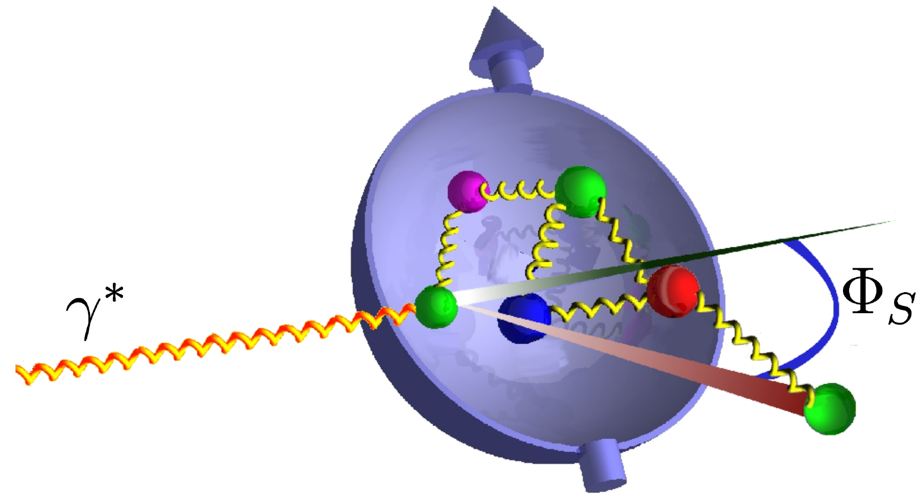
How to understand the Sivers effect?

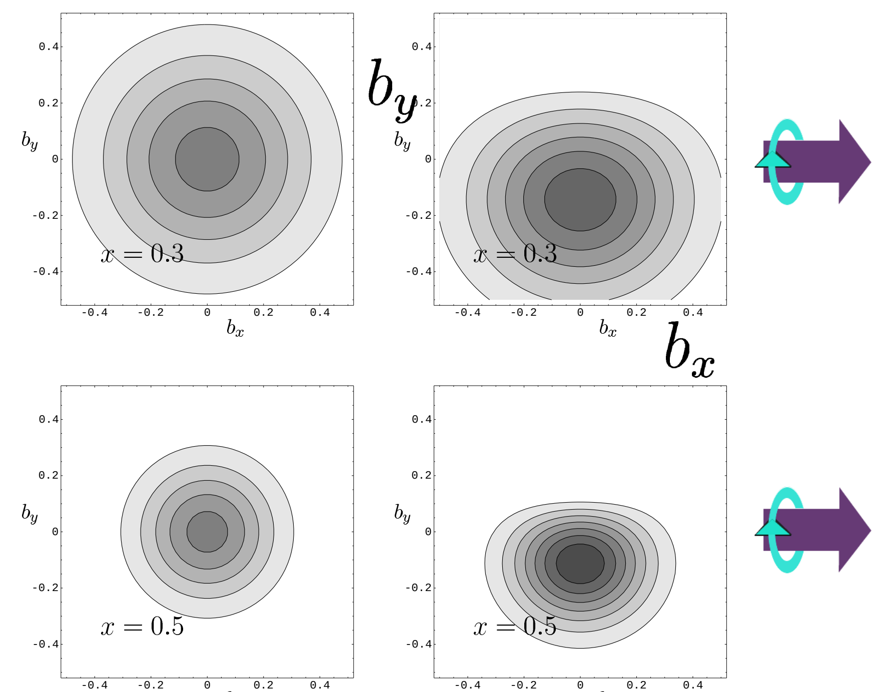
Sivers effect

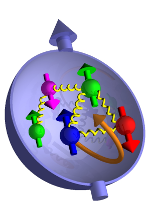
- rescattering of hit quark by gluon
- M.Burkardt (hep-ph0309269) - impact parameter (b_x, b_y) formalism
- Orbital angular momentum at finite impact parameter $\rightarrow$ observed and true x_B differ

$$x_{B,obs} = x_{B,true} \pm \Delta x_B$$

- higher possibility to find quarks on one side ($q(x)$ is not flat!)







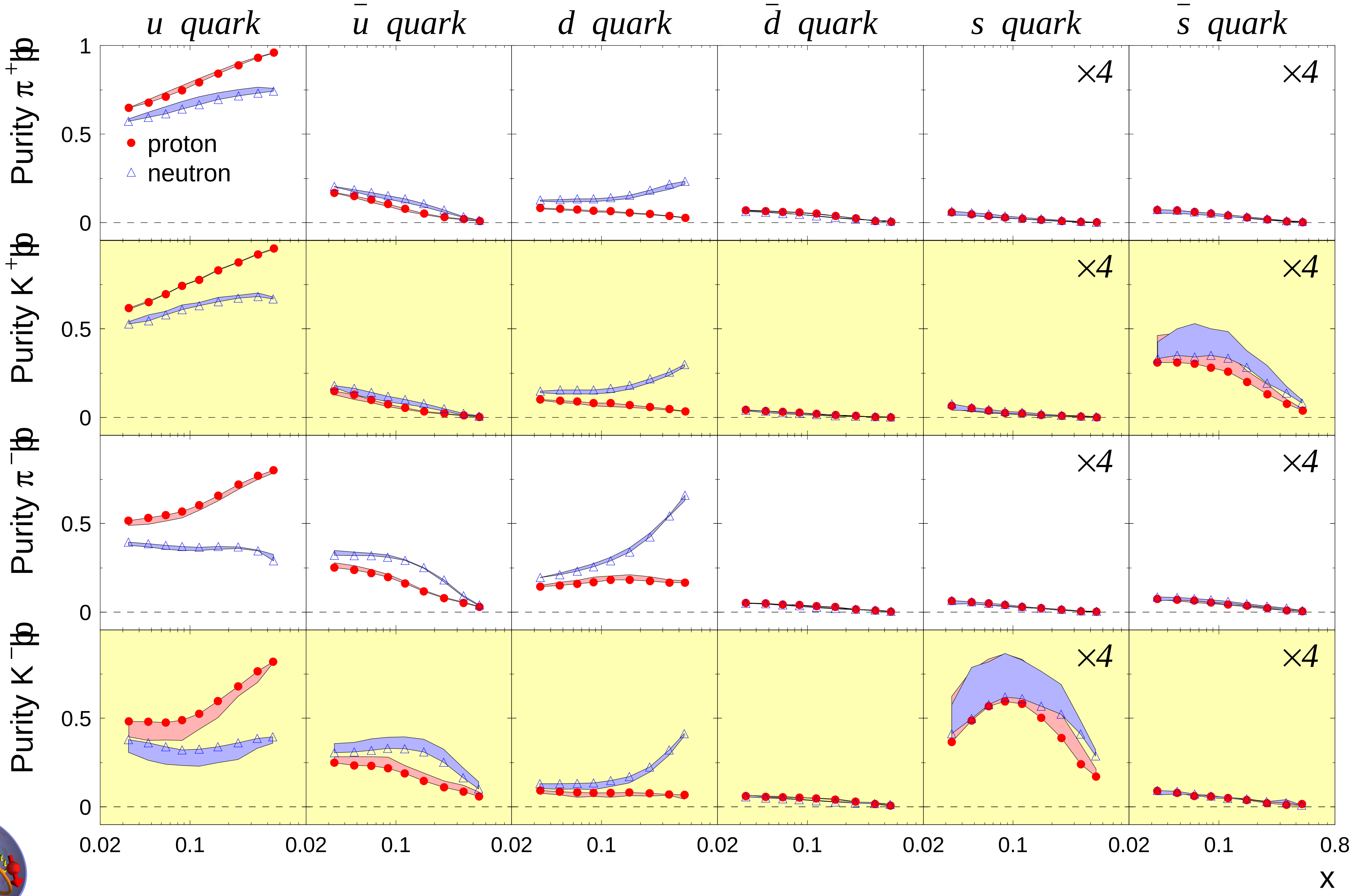
Extraction of quark polarizations

$$A_{UT}^{\sin\phi,h}(x_i) \approx \frac{\sum_f e_f^2 \delta q_f(x_i) \cdot \int dz H_{1,f}^{h}(z,Q^2) \mathcal{A}(x_i,Q^2,z)}{\sum_{f'} e_{f'}^2 q_{f'}(x_i) \cdot \int dz D_{1,f'}^{h}(z,Q^2) \mathcal{A}(x_i,Q^2,z)}$$

$$= \sum_f \underbrace{\frac{e_f^2 q_f(x_i) \cdot \mathcal{H}_{1,f}^{h}(z,Q^2,x_i)}{\sum_{f'} e_{f'}^2 q_{f'}(x_i) \cdot \mathcal{D}_{1,f'}^{h}(z,Q^2,x_i)}}_{P_{f'}^{h}(x_i)} \cdot \frac{\delta q_f}{q_f}(x_i)$$

- for Transversity extraction Collins FF has to be known
  $\Rightarrow$ BELLE e^+e^- Collins Analysis!
- for Sivers extraction everything to generate Purities is known (Analysis ongoing)

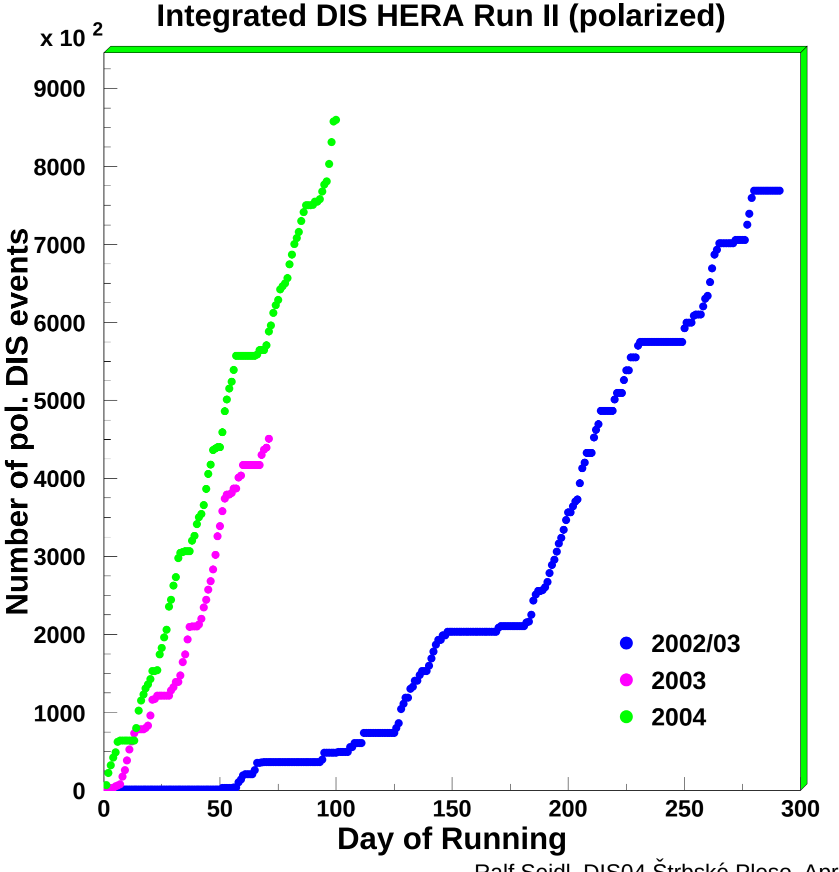
Generated Purities



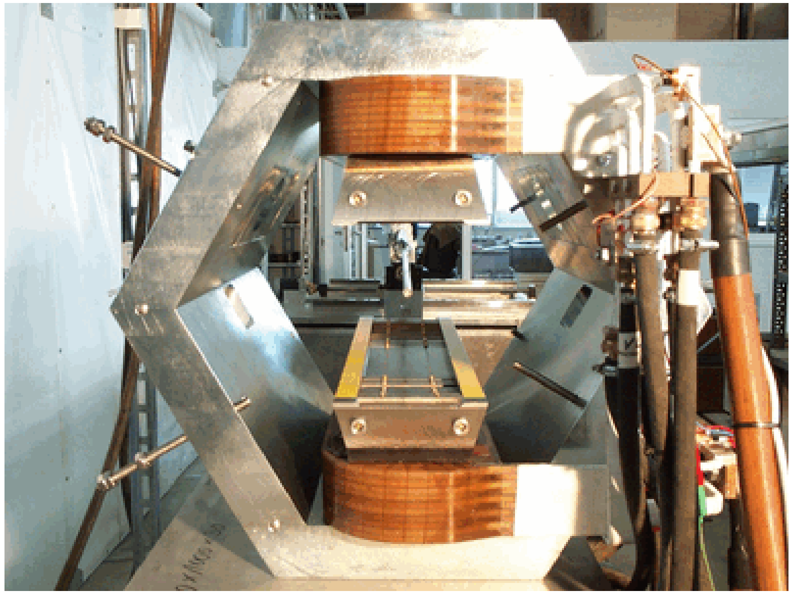
Summary and Outlook

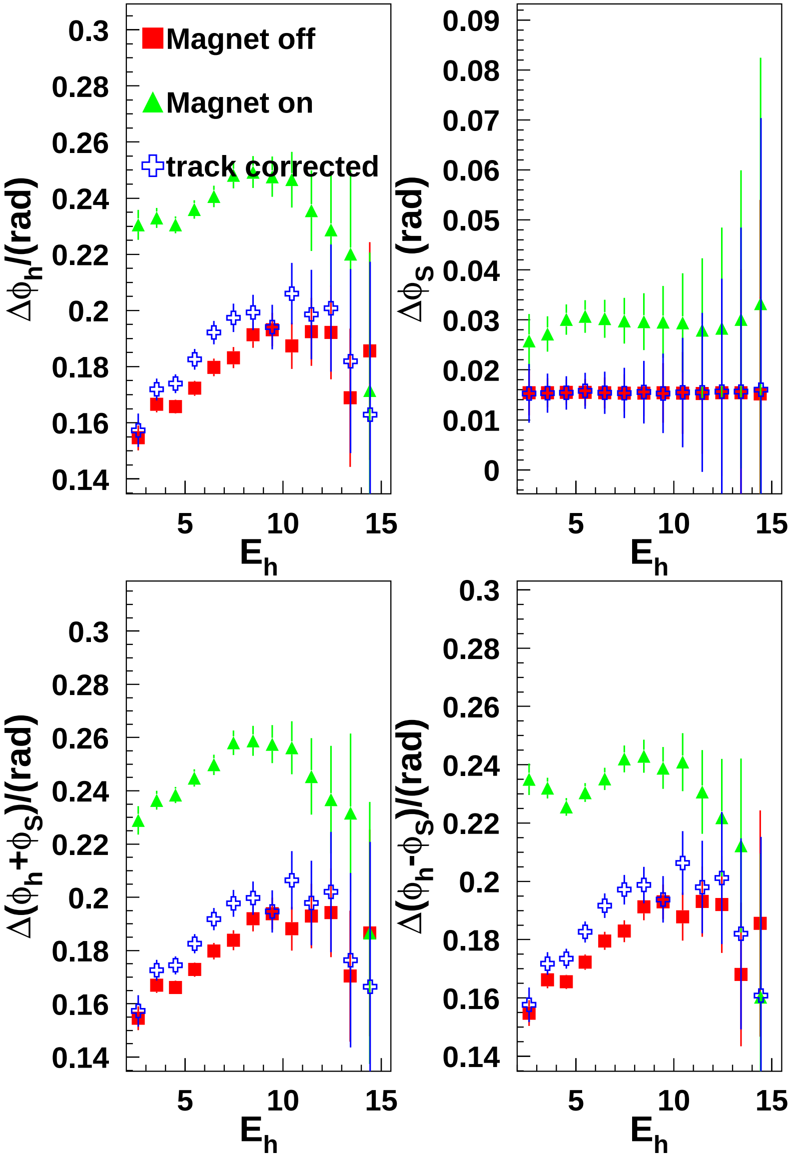
- first measurements of asymmetries directly related to Transversity
- Sivers function nonzero $\rightarrow$Orbital angular momentum
- first direct Collins asymmetries measured
- indication that disfavored Collins Fragmentations Function with opposite sign and same magnitude as favored Collins FF

- Sivers and Transversity flavor separation in progress
- with additional statistics further analysis (IFF, 2 hadron Collins FF, Λ) possible



MC-studies: resolutions





way below bin widths

Interpretation of Collins results

Minimal assumptions

- $A_{UT}^{Collins}$ is **leading Twist**
- Collins FF follows **favoured/disfavoured** symmetry

$$H_{fav} \equiv H_{1,\perp}^{u\to\pi^+} = H_{1,\perp}^{d\to\pi^-} \cdots$$
$$H_{dis} \equiv H_{1,\perp}^{u\to\pi^-} = H_{1,\perp}^{d\to\pi^+} \cdots$$

$$A^{\pi^+} = k\frac{(4\delta u+\delta\bar{d})H_{fav}+(\delta d+4\delta\bar{u})H_{dis}}{(4u+\bar{d})D_{fav}+(d+4\bar{u})D_{dis}},$$

$A^{\pi^-} = k\frac{\cdots}{\cdots}$,etc

$$r \equiv \frac{d+4\bar{u}}{u+\bar{d}/4} \qquad \eta \equiv \frac{D_{dis}}{D_{fav}}$$
$$\delta r \equiv \frac{\delta d+4\delta\bar{u}}{\delta u+\delta\bar{d}/4} \qquad \eta_H \equiv \frac{H_{dis}}{H_{fav}}$$

back back

Asymmetry ratios $\alpha^- \equiv A^{\pi^-}/A^{\pi^+}$ and $\alpha^0 \equiv A^{\pi^0}/A^{\pi^+}$ $\Rightarrow$ Consistency equation with only unpol. quantities

$$\alpha^- C = \alpha^0(1+C) - 1$$

with $C \equiv \frac{4\eta+r}{4+\eta r}$ $\Rightarrow$ solution space in η_H vs δr can be determined:

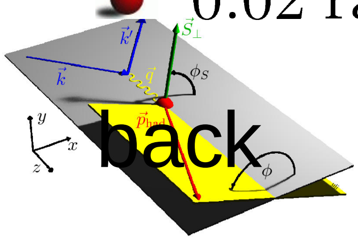
$$\eta_H = \frac{\delta r - 4(\alpha^- C)}{(\alpha^- C)\delta r - 4}$$

$$\eta_H = \frac{\delta r - 4(\alpha^0(1+C)-1)}{(\alpha^0(1+C)-1)\delta r - 4}$$

SIDIS cuts

- vertex and acceptance cuts
- $0.1 \leq y < 0.85$
- $0.023 < x < 0.4$
- $W^2 > 10\ \mathrm{GeV}^2$
- $Q^2 > 1\ \mathrm{GeV}^2$
- $2\ \mathrm{GeV} < p_{\mathrm{track}} < 15\ \mathrm{GeV}$
- $4\ \mathrm{GeV} < p_{\mathrm{track}} < 13.8\ \mathrm{GeV}$ (A_{UL}^p)
- π^0 :$0.1\ \mathrm{GeV} < M_{\gamma\gamma} < 0.17\ \mathrm{GeV}$
- $0.2 < z < 0.7$
- $0.02\ \mathrm{rad} < \theta_{\gamma,\mathrm{had}}$

year	target gas	orientation	# pol. DIS
96-97	p	L	2.4M
98-00	d	L	8.9M
02-	p	T	1.5M



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