Azimuthal Single-Spin Asymmetries on a Transversely Polarized Hydrogen Target at HERMES

G. Schnell

Tokyo Institute of Technology

gunar.schnell@desy.de

For the hermes Collaboration

Why worry about unintegrated distribution and fragmentation functions if we don't even understand the integrated ones?

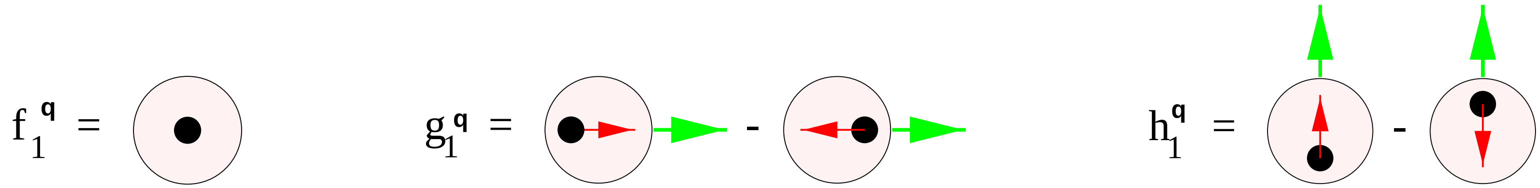
G. Schnell

Tokyo Institute of Technology

gunar.schnell@desy.de

For the hermes Collaboration

Leading Twist
Quark Distribution Functions

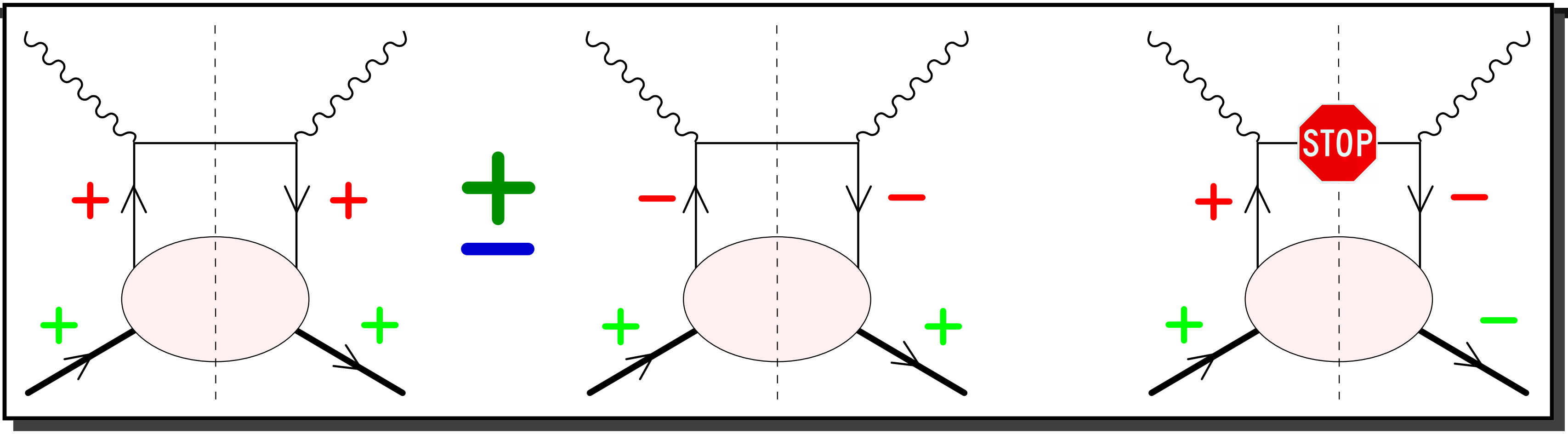


$\Downarrow$ $\Downarrow$ $\Downarrow$

Unpolarized quarks and nucleons	Longitudinally polarized quarks and nucleons	Transversely polarized quarks and nucleons
q(x): spin averaged (well known)	Δq(x): helicity difference (known)	δq(x): helicity flip (unmeasured!)
$\Rightarrow$ Vector Charge	$\Rightarrow$ Axial Charge	$\Rightarrow$ Tensor Charge

HERMES 1995-2000 HERMES 2002…

Leading Twist
Quark Distribution Functions



Unpolarized quarks and nucleons	Longitudinally polarized quarks and nucleons	Transversely polarized quarks and nucleons
$q(x)$: spin averaged (well known)	$\Delta q(x)$: helicity difference (known)	$\delta q(x)$: helicity flip (unmeasured!)
$\Rightarrow$ Vector Charge	$\Rightarrow$ Axial Charge	$\Rightarrow$ Tensor Charge
	HERMES 1995-2000	HERMES 2002…

Transversity Measurements

How can one measure transversity?

Need another chiral-odd object! $\Rightarrow$ Semi-Inclusive DIS

$$\sigma^{ep\rightarrow ehX} = \sum_q \delta q \otimes \sigma^{eq\rightarrow eq} \otimes FF^{q\rightarrow h}$$

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

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

DF and FF together: CHIRAL EVEN

Transversity Measurements

How can one measure transversity?

Need another chiral-odd object! $\Rightarrow$ Semi-Inclusive DIS

$$\sigma^{ep\rightarrow ehX} = \sum_q \delta q \otimes \sigma^{eq\rightarrow eq} \otimes FF^{q\rightarrow h}$$

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

CHIRAL EVEN

$\longrightarrow$ use Chiral-odd and T-odd **Collins FF**:

Correlation between $P_{h\perp}$ and transverse spin of nucleon

Transversity Measurements

How can one measure transversity?

Need another chiral-odd object! $\Rightarrow$ Semi-In… DIS

$$\sigma^{ep\rightarrow ehX} = \sum_q \delta q \otimes \sigma^{eq\rightarrow eq} \otimes \ldots$$

$\Downarrow$ $\Downarrow$

chiral-od… **chiral-odd**

D… FF

CHIRAL EVEN

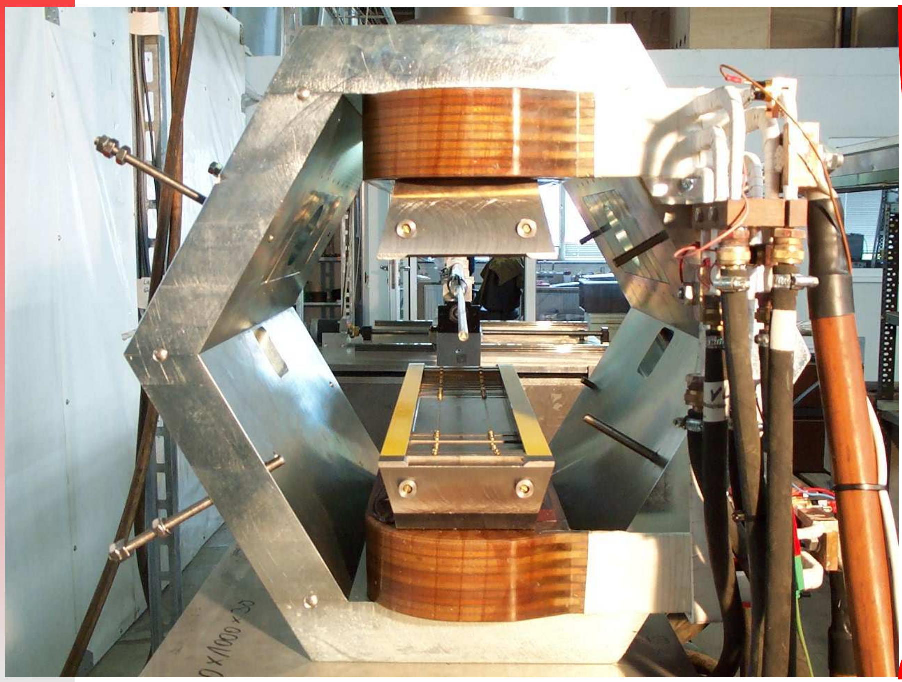
$\longrightarrow$ use Chi… and T-odd **Collins FF**:

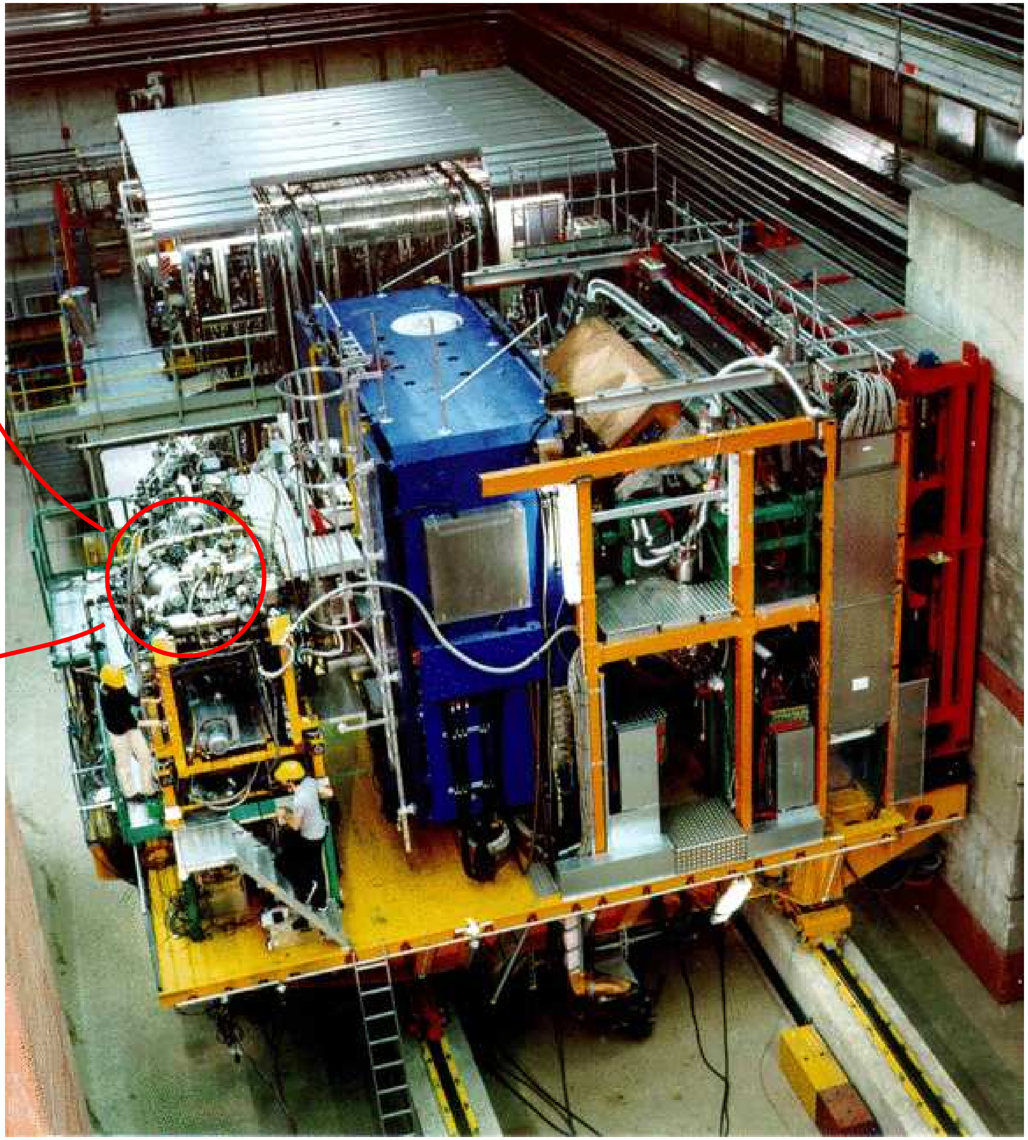
Correlati… ween $P_{h\perp}$ and transverse spin of nucleon

HERMES with Transverse Target

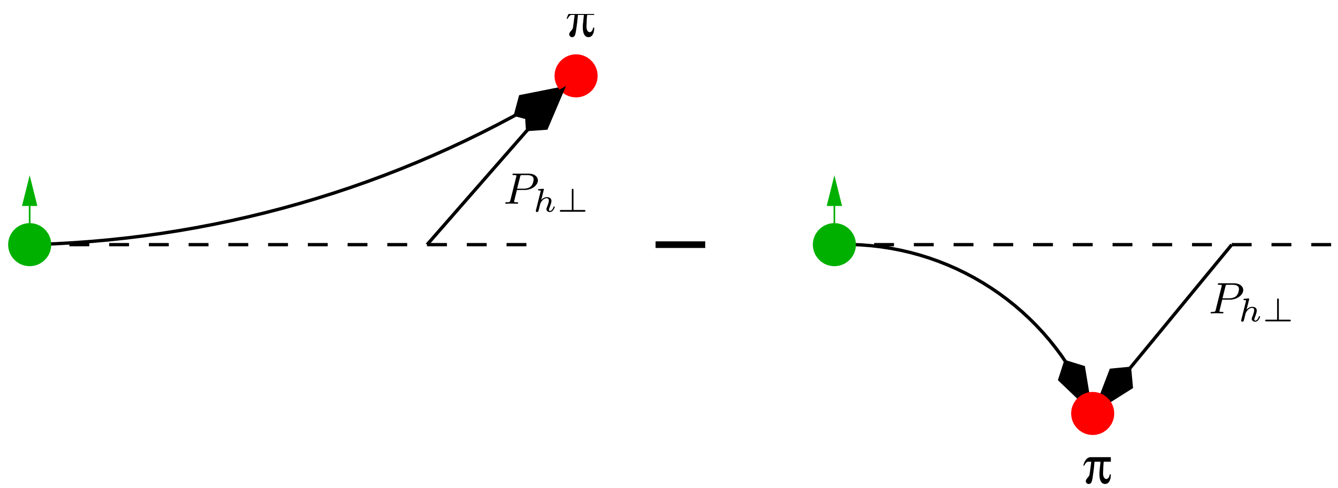
HERMES at DESY

HERMES at DESY





Collins Fragmentation Function



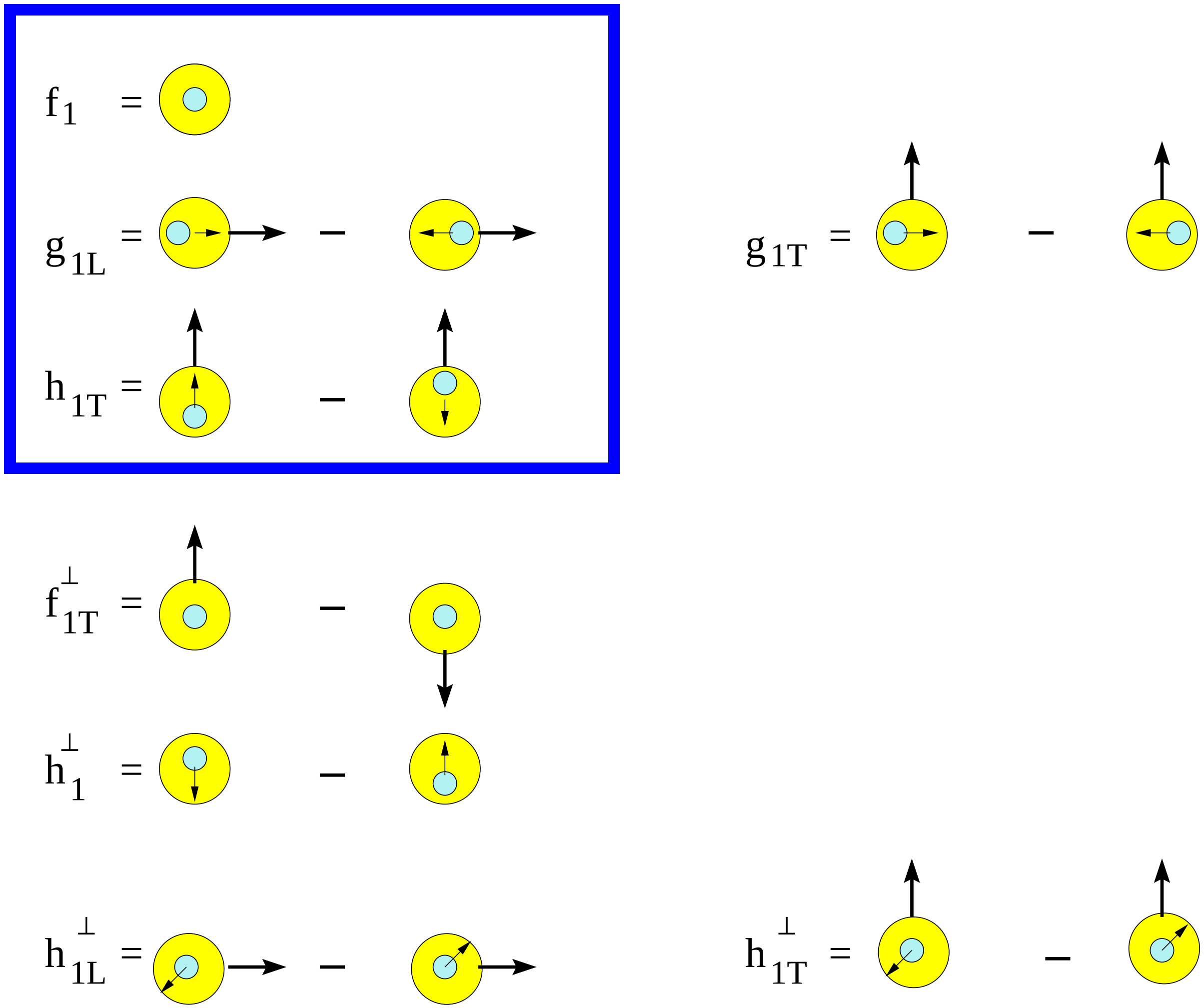
- Collins function $H_1^\perp$ describes left-right asymmetry in the direction of outgoing hadron
- Originally proposed by Collins (1993)
- T-odd $\Rightarrow$ need interference of amplitudes
- basically unknown (estimates from DELPHI data and model calculations exist)

Caution!

Other Spin-Momentum-Correlations exist!

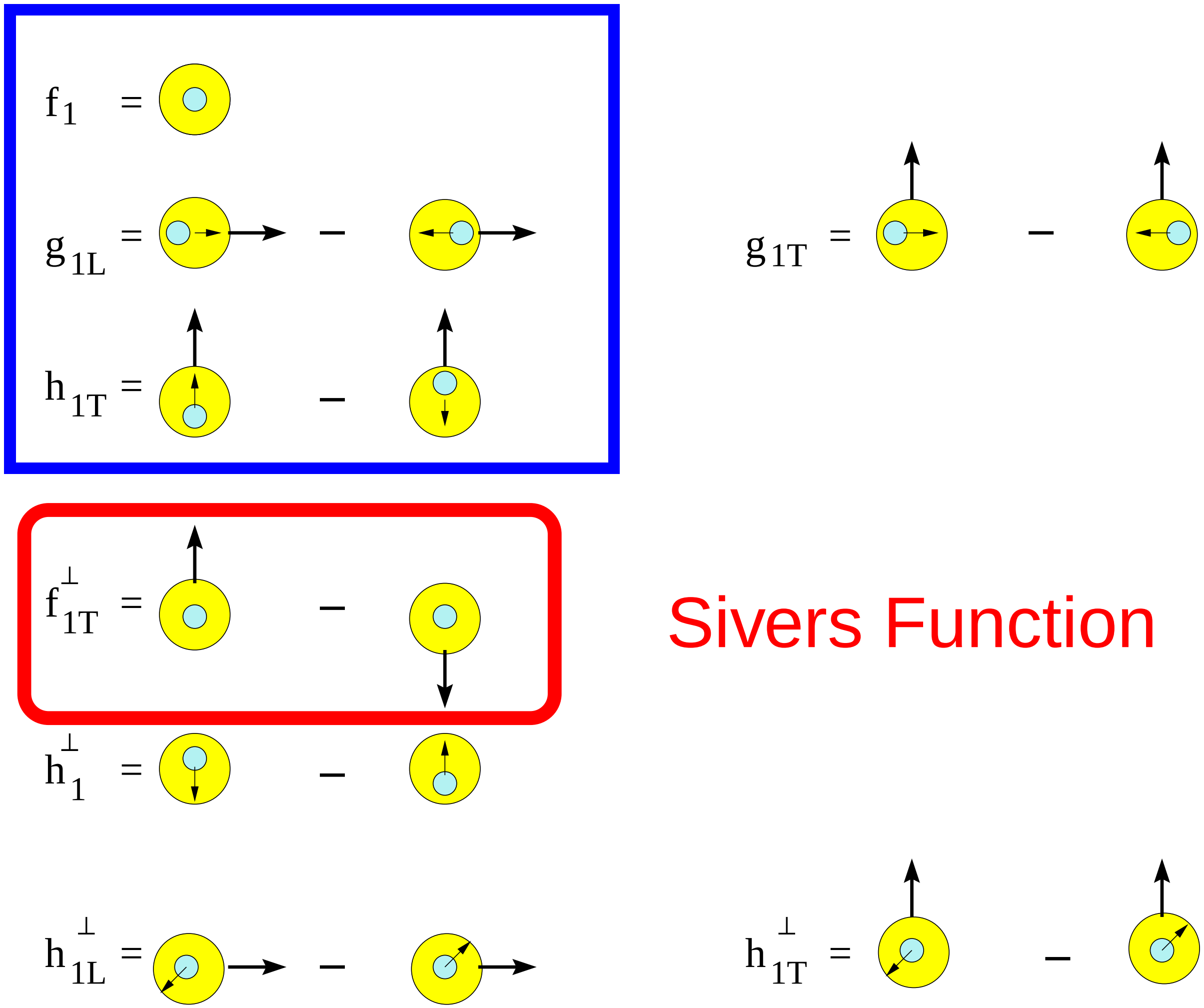
Unintegrated ***Quark Distributions***

Functions surviving integration over intrinsic transverse momentum

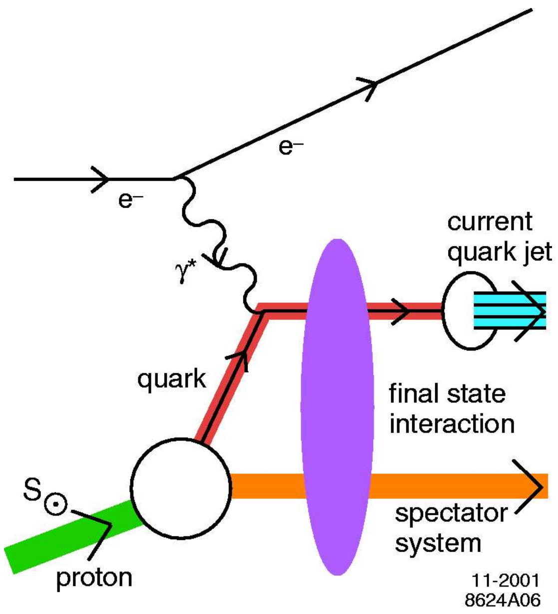


Unintegrated ***Quark Distributions***

Functions surviving integration over intrinsic transverse momentum



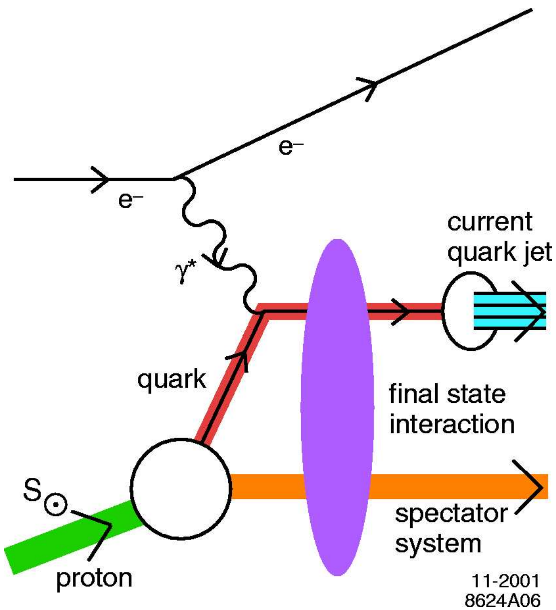
Some words about Sivers Effect



Thanks to Brodsky, Hwang, Schmidt:

- quark rescattering via soft gluon exchange
- correlates transverse spin with direction of outgoing hadron
- requires L_z of quarks

Some words about Sivers Effect



Thanks to Brodsky, Hwang, Schmidt:

- quark rescattering via soft gluon exchange
- correlates transverse spin with direction of outgoing hadron
- requires L_z of quarks

Thanks to Collins, Ji, Yuan, Belitzky ...:

- Soft gluon is model for gauge link needed for gauge invariance
- Gauge links provide necessary complex phase for interference
- T-Symmetry of QCD requires opposite sign of Sivers function in DIS and DY
- slightly different approach by Burkardt using impact parameter dependent PDF's ("chromodynamic lensing")

Azimuthal Single-Spin Asymmetries

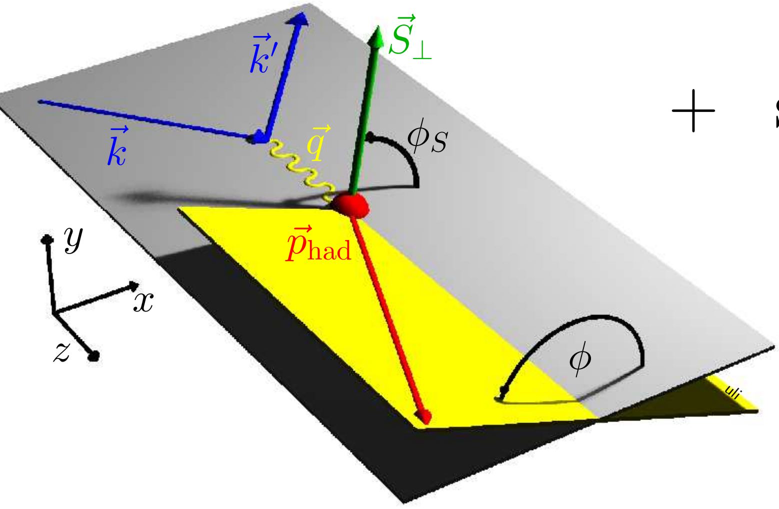
$ep \rightarrow e'hX$ – study azimuthal distribution of hadrons:
(Unpolarized beam & Transversely polarized target)

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

$$\sim \sin(\phi+\phi_S) \sum_q e_q^2 \, \mathcal{I}\left[h_{1T}^q(x,p_T^2) H_1^{\perp,q}(z,k_T^2)\right]$$

$$+ \sin(\phi-\phi_S) \sum_q e_q^2 \, \mathcal{I}\left[f_{1T}^{\perp,q}(x,q_T^2) D_1^q(z,k_T^2)\right]$$

$$+ \quad \ldots$$

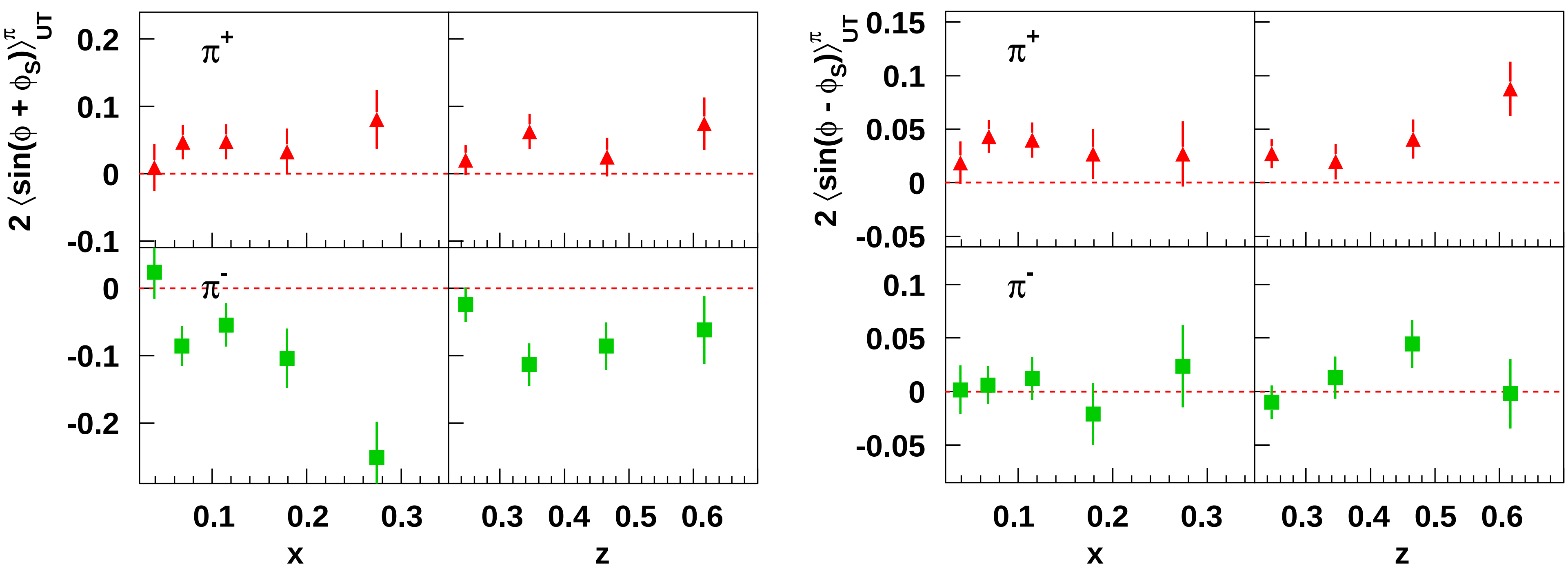


$\mathcal{I}[\ldots]$: convolution integral over initial (p_T) and final (k_T) quark transverse momenta

Sine Moments of Countrate Asymmetries

Fit $A(\phi, \phi_S) = A_C \frac{B(<y>)}{A(<x>,<y>)} \sin(\phi + \phi_S) + A_S \sin(\phi - \phi_S)$

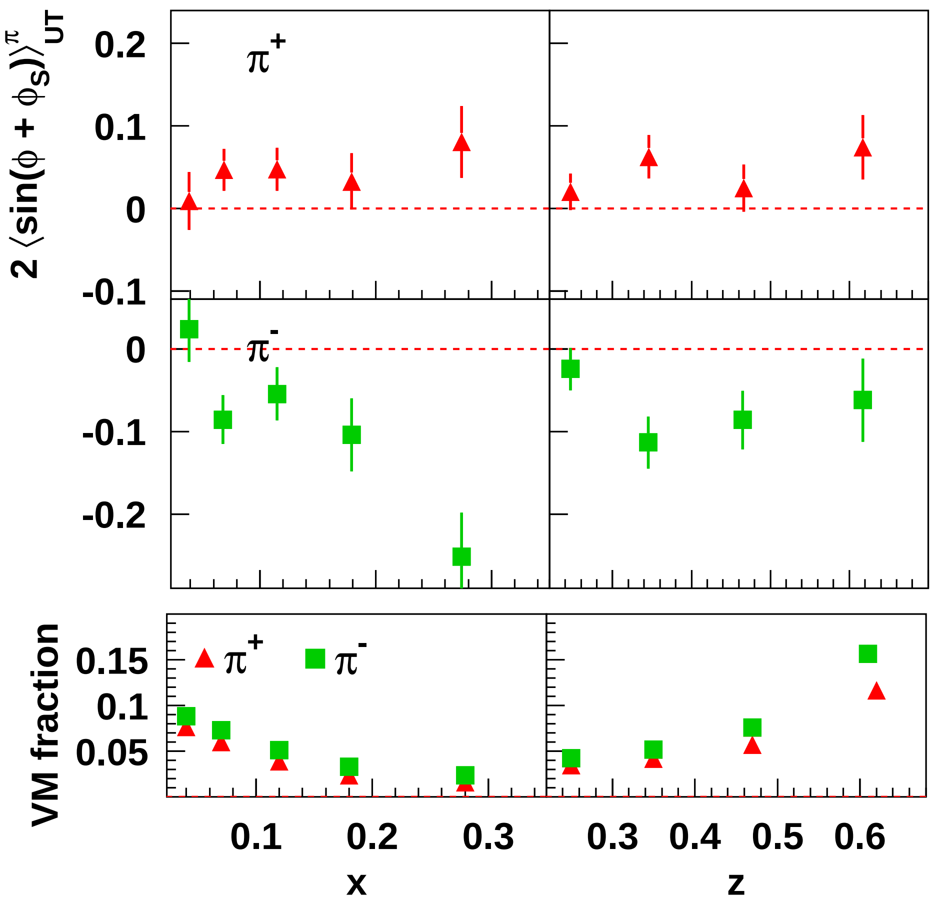
(Virtual Photon Asymmetries)



A. Airapetian et al, **hep-ex/0408013** (submitted to PRL)

Sine Moments of Countrate Asymmetries

Collins Asymmetry: $A_C \propto -h_1(x, p_T^2) H_1^\perp(z, z^2 k_T^2)$

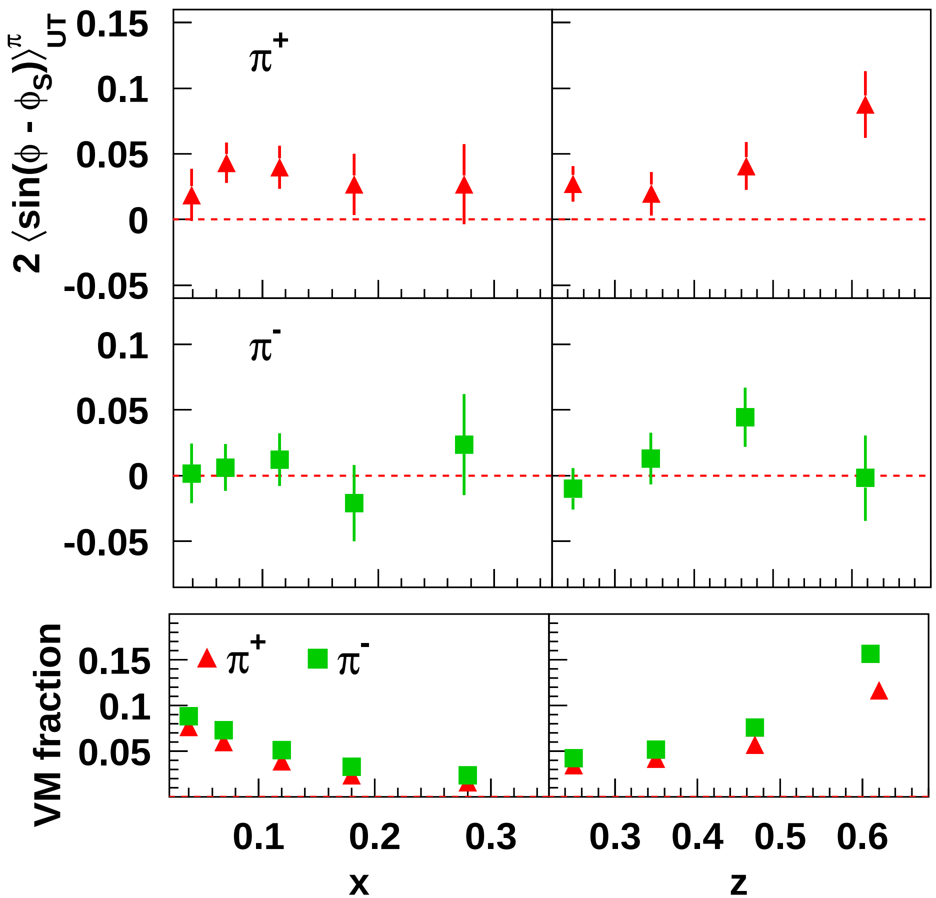


- positive for π^+ and negative for π^- as maybe expected (expectation for transversity gives positive δu and negative δd)
- unexpected large π^- asymmetry
- averaged over acceptance: $A_C^{\pi^+} = 0.042 \pm 0.014$ and $A_C^{\pi^-} = -0.076 \pm 0.016$
- overall scale uncertainty of 8%
- contribution to pion sample from exclusively produced vector mesons (VM) (from PYTHIA MC)

Sine Moments of Countrate Asymmetries

Sivers Asymmetry: $A_S \propto -f_{1T}^{\perp}(x, p_T^2) D_1(z, z^2 k_T^2)$

- significantly positive for π^+
- first hint of T-odd distribution function from DIS
- π^- asymmetry consistent with zero
- averaged over acceptance:
  $A_S^{\pi^+} = 0.034 \pm 0.008$ and
  $A_S^{\pi^-} = 0.004 \pm 0.010$
- overall scale uncertainty of 8%
- systematic error due to VM contribution unknown because VM asymmetry itself unknown



Resolving the Convolution Integral

Weight with transverse hadron momentum $P_{h\perp}$ to resolve convolution:

$$\tilde{A}_{UT}(\phi,\phi_S) = \frac{1}{\langle S_\perp \rangle} \frac{\sum_{i=1}^{N^+} P_{h\perp,i} - \sum_{i=1}^{N^-} P_{h\perp,i}}{N^+ + N^-}$$

$$\sim \sin(\phi+\phi_C)\cdot \sum_q e_q^2\, \delta q(x)\, z\, H_1^{\perp(1),q}(z)$$

$$- \sin(\phi-\phi_S)\cdot \sum_q e_q^2\, f_{1T}^{\perp(1),q}(x)\, z\, D_1^q(z)$$

$$+ \ldots$$

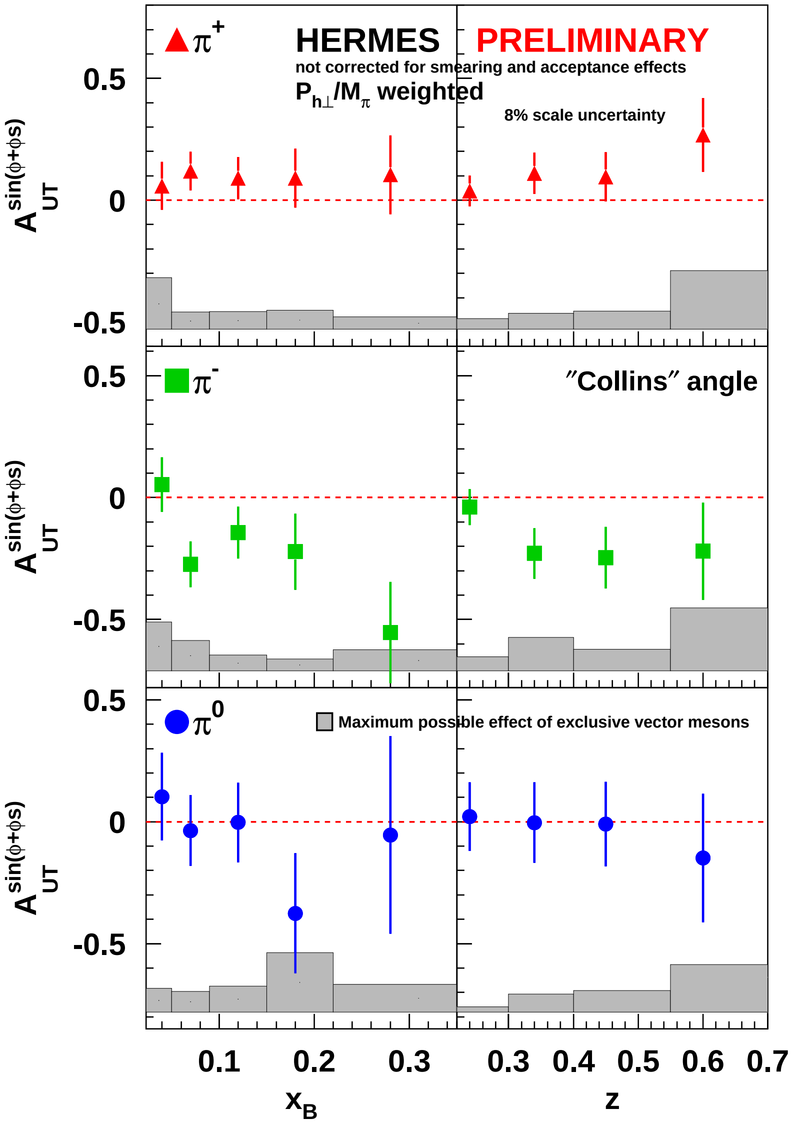
(1): p_T^2-/k_T^2-moment of distribution / fragmentation function

$\Rightarrow$ 2D-fit of $\tilde{A}_{UT}$ to get Collins and Sivers asymmetries:

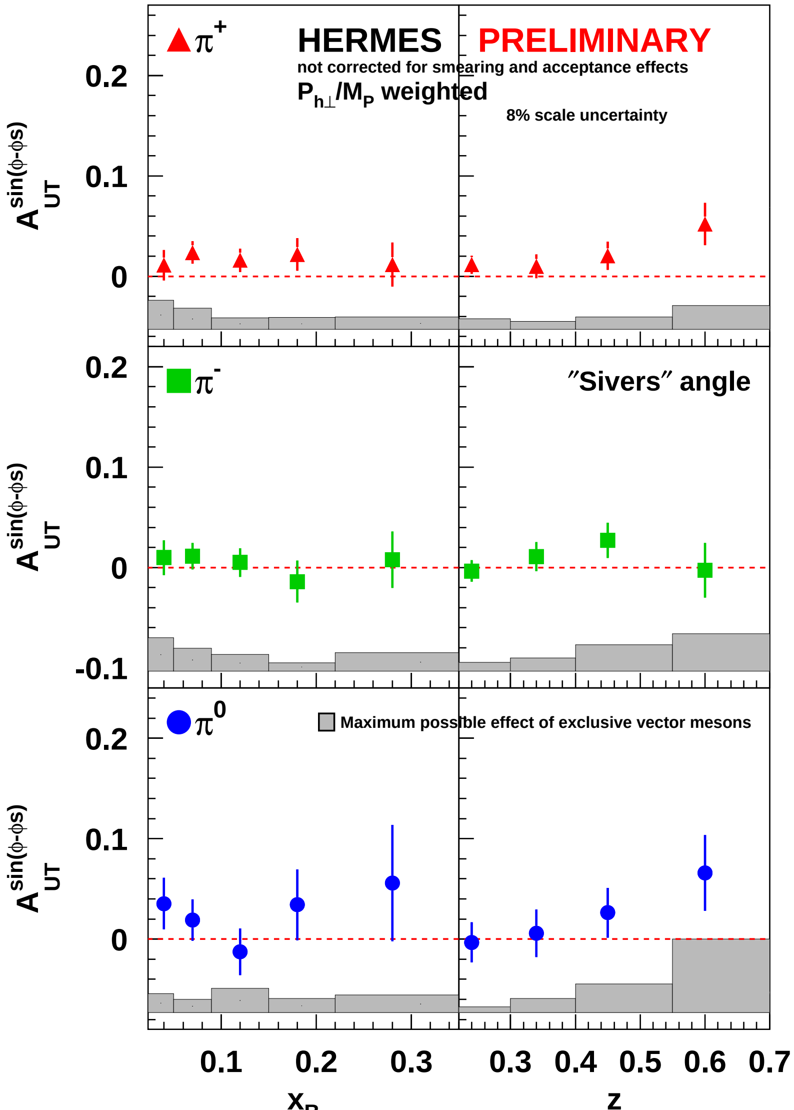
$$\tilde{A}_{UT}(\phi,\phi_S) = M_\pi \tilde{A}_C(x,z)\sin(\phi+\phi_s) + M_p \tilde{A}_S(x,z)\sin(\phi-\phi_s)$$

Preliminary Results ($P_{h\perp}$ weighted)

$$\tilde{A}_{UT}^{\sin\Phi} \propto \delta q(x) \cdot z\, H_1^{\perp(1)}(z)$$



$$\tilde{A}_{UT}^{\sin\Phi} \propto -f_{1T}^{\perp(1)}(x) \cdot z\, D_1(z)$$



A Closer Look at Collins Asymmetries I

rewrite asymmetries in terms of favored and disfavored fragmentation:

- use $P_{h\perp}$ weighted asymmetries
- neglect strange quarks
- employ symmetry among fragmentation functions, i.e.

$$\begin{aligned} D_f &\equiv D(u \to \pi^+) \simeq D(d \to \pi^-) \simeq D(\bar{d} \to \pi^+) \simeq D(\bar{u} \to \pi^-) \\ D_d &\equiv D(d \to \pi^+) \simeq D(u \to \pi^-) \simeq D(\bar{u} \to \pi^+) \simeq D(\bar{d} \to \pi^-) \\ \frac{1}{2}(D_f + D_d) &\simeq D(u \to \pi^0) \simeq D(d \to \pi^0) \simeq D(\bar{d} \to \pi^0) \simeq D(\bar{u} \to \pi^0) \end{aligned}$$

$$\hookrightarrow \tilde{A}_C^{\pi^+/\pi^-}(x,z) \propto \frac{(4\delta u + \delta\bar{d})H_{f/d} + (4\delta\bar{u} + \delta d)H_{d/f}}{(4u + \bar{d})D_{f/d} + (4\bar{u} + d)D_{d/f}}$$

$$\tilde{A}_C^{\pi^0}(x,z) \propto \frac{\left[4(\delta u + \delta\bar{u}) + \delta d + \delta\bar{d}\right](H_f + H_d)}{\left[4(u + \bar{u}) + d + \bar{d}\right](D_f + D_d)}$$

A Closer Look at Collins Asymmetries II

express asymmetries in terms of flavor ratios:

$$\tilde{A}_C^{\pi^+} = \mathcal{K}(x,z)\frac{4+\delta r\mathcal{H}}{4+r\mathcal{D}}$$

$$\tilde{A}_C^{\pi^-} = \mathcal{K}(x,z)\frac{4\mathcal{H}+\delta r}{4\mathcal{D}+r}$$

$$\tilde{A}_C^{\pi^0} = \mathcal{K}(x,z)\frac{(4+\delta r)(1+\mathcal{H})}{(4+r)(1+\mathcal{D})}$$

Polarized Objects

$$\mathcal{H} = \frac{H_d}{H_f}$$

$$\delta r = \frac{\delta d + 4\delta\bar{u}}{\delta u + \frac{1}{4}\delta\bar{d}}$$

Unpolarized Objects

$$\mathcal{D} = \frac{D_d}{D_f}$$

$$r = \frac{d+4\bar{u}}{u+\frac{1}{4}\bar{d}}$$

Mixed

$$\mathcal{K} = \frac{(\delta u + \frac{1}{4}\delta\bar{d}) z H_f}{(u+\frac{1}{4}\bar{d}) D_f}$$

i.e. CTEQ6,R1990 and Kretzer et al.

$\Rightarrow$ 3 constraints and 3 unknowns!

A Closer Look at Collins Asymmetries II

express asymmetries in terms of flavor ratios:

$$\tilde{A}_C^{\pi^+} = \mathcal{K}(x,z)\frac{4+\delta r\mathcal{H}}{4+r\mathcal{D}}$$

$$\tilde{A}_C^{\pi^-} = \mathcal{K}(x,z)\frac{4\mathcal{H}+\delta r}{4\mathcal{D}+r}$$

$$\tilde{A}_C^{\pi^0} = \mathcal{K}(x,z)\frac{(4+\delta r)(1+\mathcal{H})}{(4+r)(1+\mathcal{D})}$$

The three asymmetries are not independent ($C(x,z) \equiv \frac{r(x)+4\mathcal{D}(z)}{r(x)\mathcal{D}(z)+4}$):

$$\tilde{A}_C^{\pi^+}(x,z) + C(x,z)\tilde{A}_C^{\pi^-}(x,z) - (1+C(x,z))\tilde{A}_C^{\pi^0}(x,z) = 0$$

for measured asymmetries: 0.17 ± 0.36 (stat.)

$\Rightarrow$ 3 constraints and 3 unknowns!

A Closer Look at Collins Asymmetries II

express asymmetries in terms of flavor ratios:

$$\tilde{A}_C^{\pi^+} = \mathcal{K}(x,z)\frac{4+\delta r\mathcal{H}}{4+r\mathcal{D}}$$

$$\tilde{A}_C^{\pi^-} = \mathcal{K}(x,z)\frac{4\mathcal{H}+\delta r}{4\mathcal{D}+r}$$

$$\tilde{A}_C^{\pi^0} = \mathcal{K}(x,z)\frac{(4+\delta r)(1+\mathcal{H})}{(4+r)(1+\mathcal{D})}$$

Polarized Objects

$$\mathcal{H} = \frac{H_d}{H_f}$$

$$\delta r = \frac{\delta d + 4\delta\bar{u}}{\delta u + \frac{1}{4}\delta\bar{d}}$$

Unpolarized Objects

$$\mathcal{D} = \frac{D_d}{D_f}$$

$$r = \frac{d+4\bar{u}}{u+\frac{1}{4}\bar{d}}$$

Mixed

$$\mathcal{K} = \frac{(\delta u + \frac{1}{4}\delta\bar{d})zH_f}{(u+\frac{1}{4}\bar{d})D_f}$$

i.e. CTEQ6,R1990 and Kretzer et al.

$\Rightarrow$ ~~3~~ 2 constraints and 3 unknowns!

A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

$\Rightarrow$ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

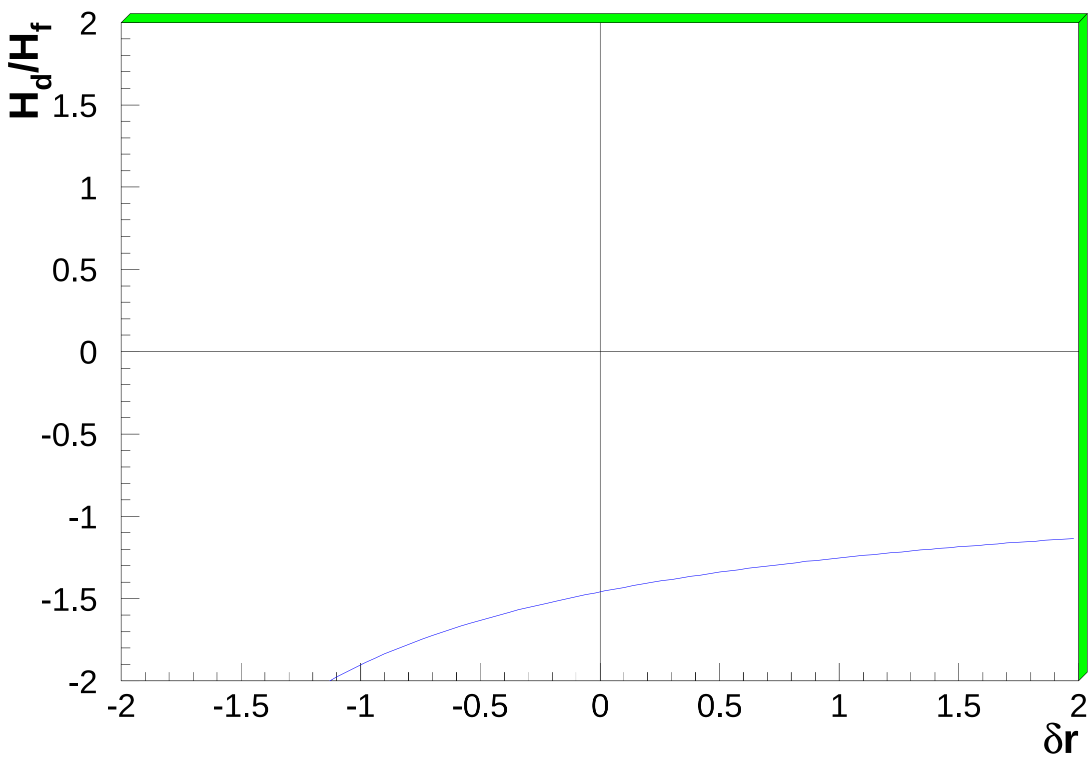
(around measured values according to statistical uncertainty)

A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

$\Rightarrow$ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

(around measured values according to statistical uncertainty)

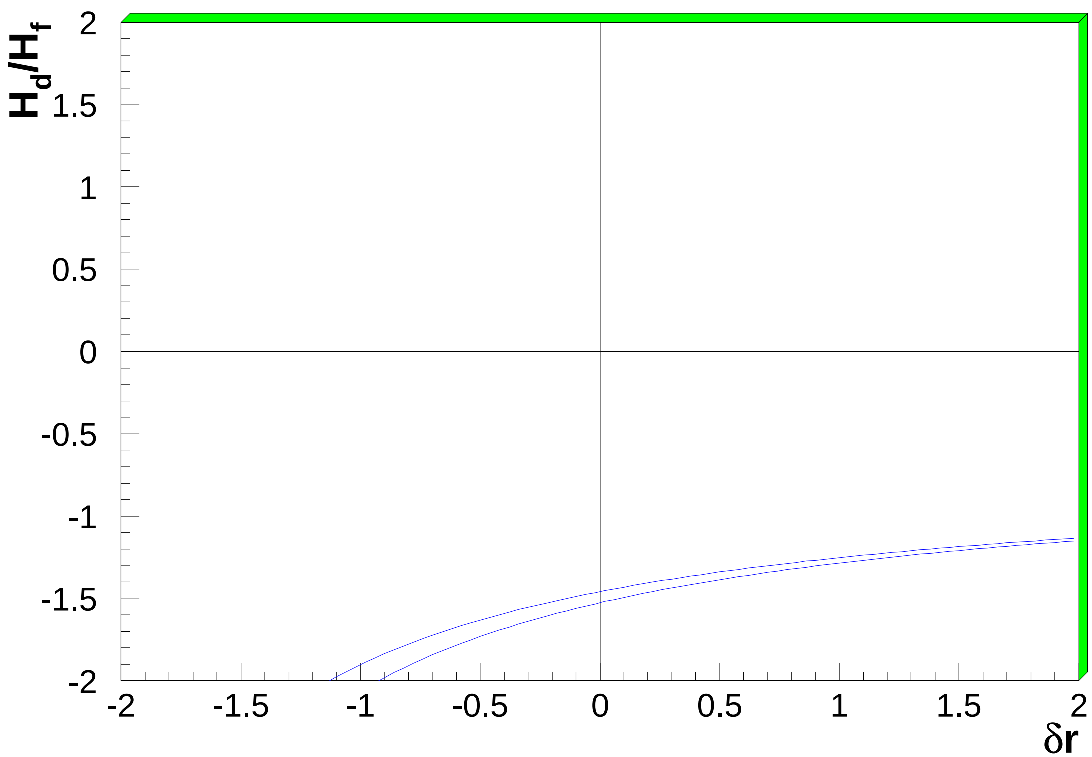


A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

⇒ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

(around measured values according to statistical uncertainty)

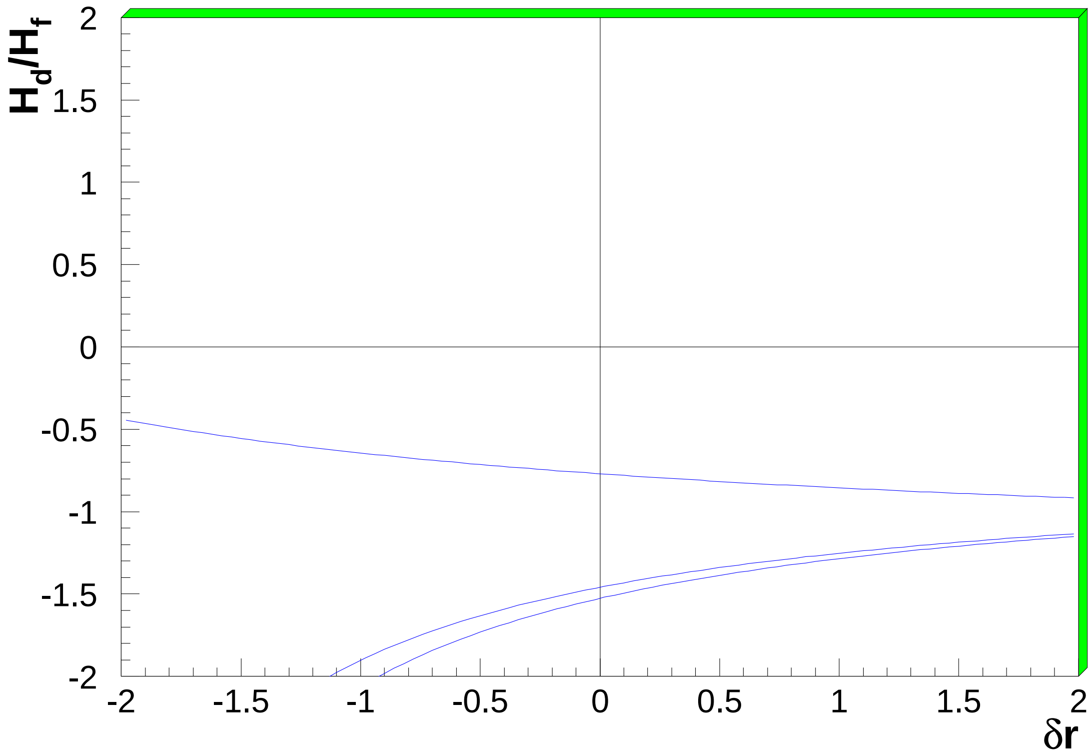


A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

$\Rightarrow$ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

(around measured values according to statistical uncertainty)

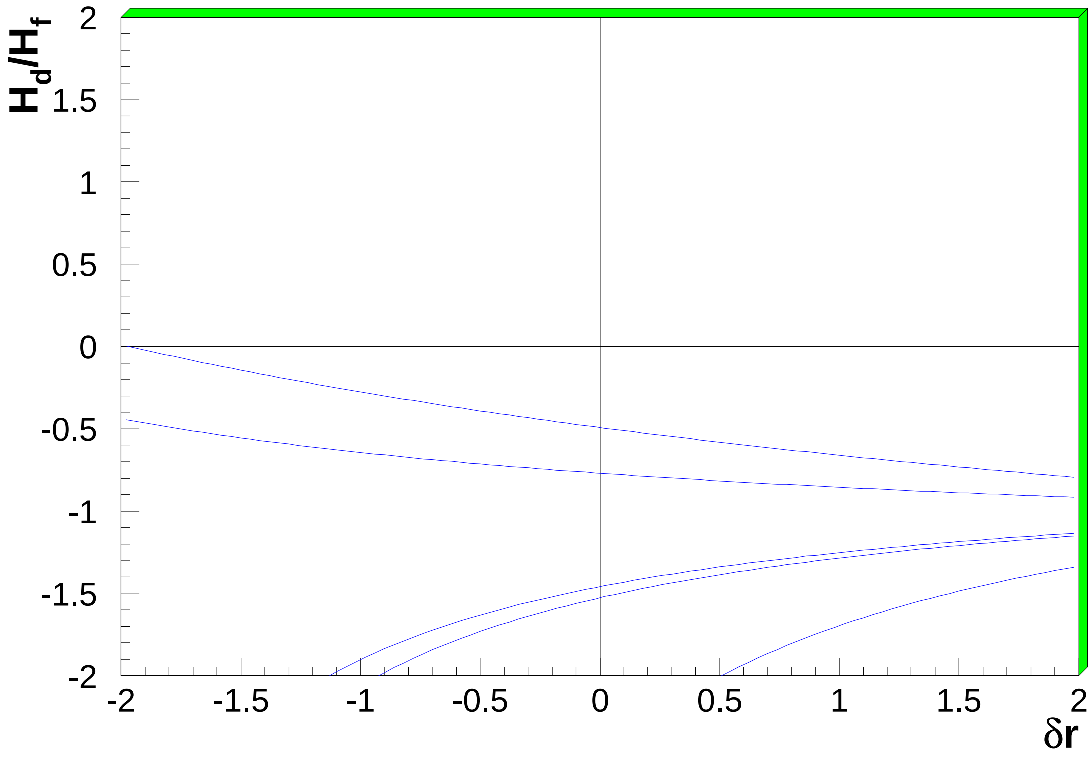


A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

$\Rightarrow$ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

(around measured values according to statistical uncertainty)

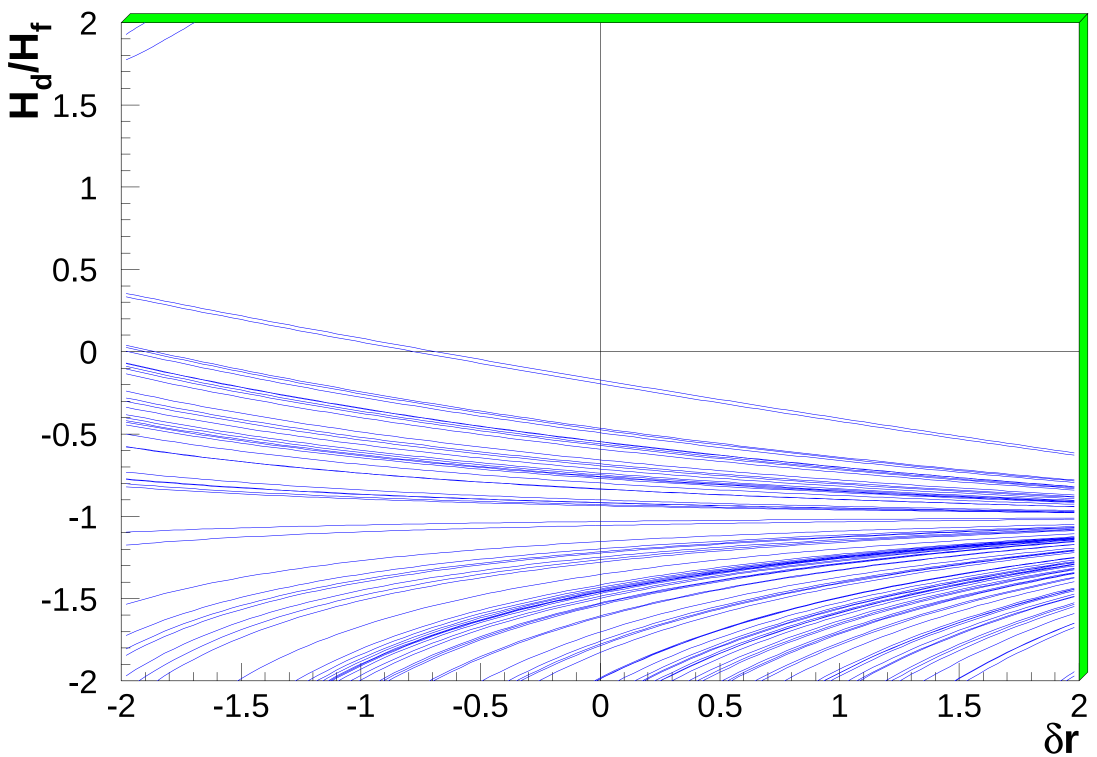


A Closer Look at Collins Asymmetries III

elminate $\mathcal{K}$ and relate $\mathcal{H}$ to δr

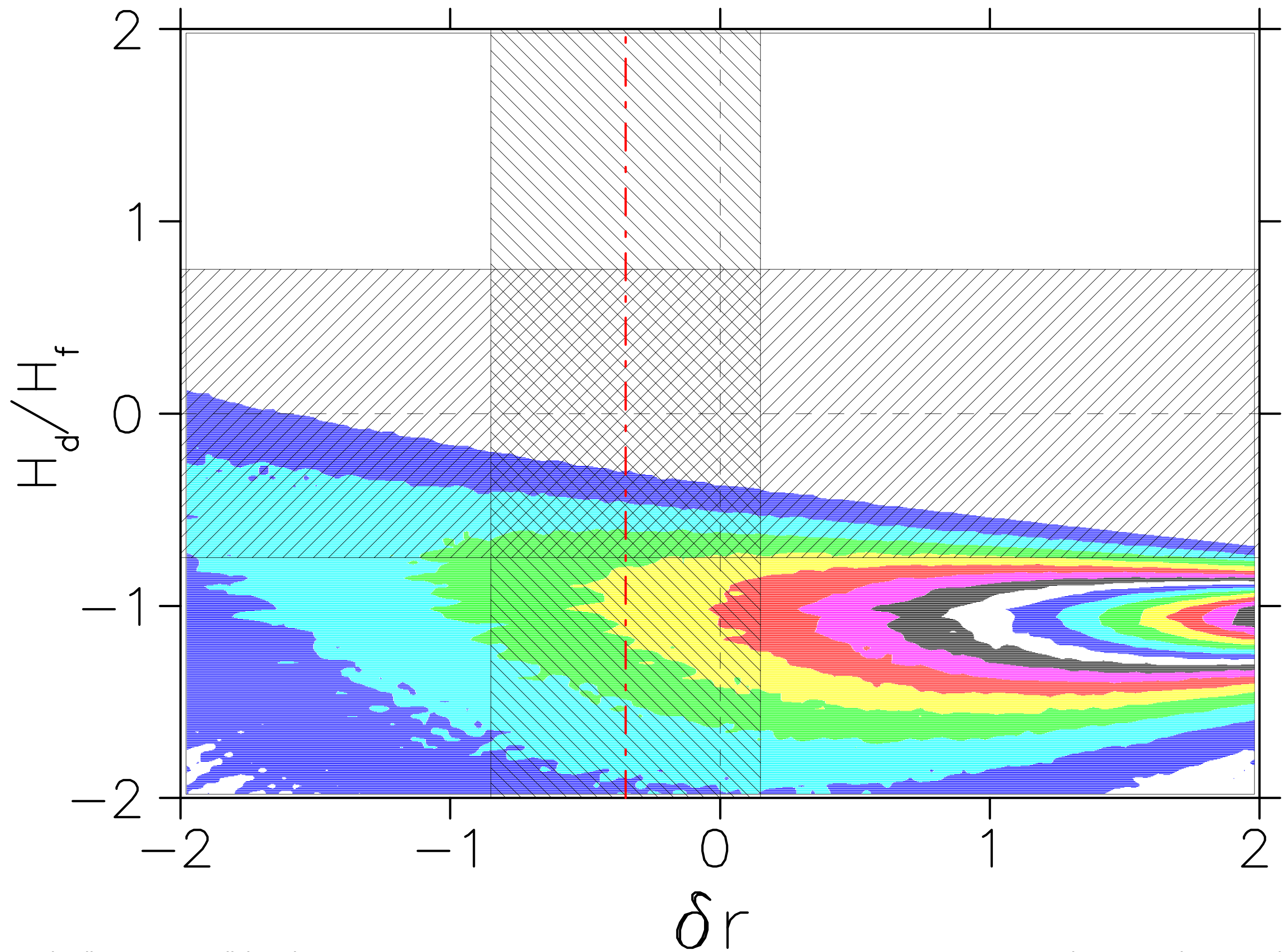
$\Rightarrow$ scan solution space for $\mathcal{H}$ and δr by sampling set of $(\tilde{A}_C^{\pi^+}, \tilde{A}_C^{\pi^-}, \tilde{A}_C^{\pi^0})$

(around measured values according to statistical uncertainty)



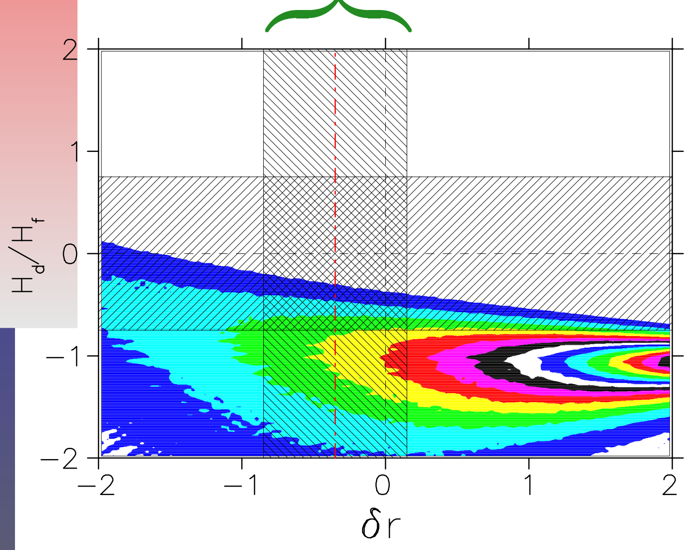
Limits on Transversity and Collins FF

probability distribution for H_d/H_f vs. δr

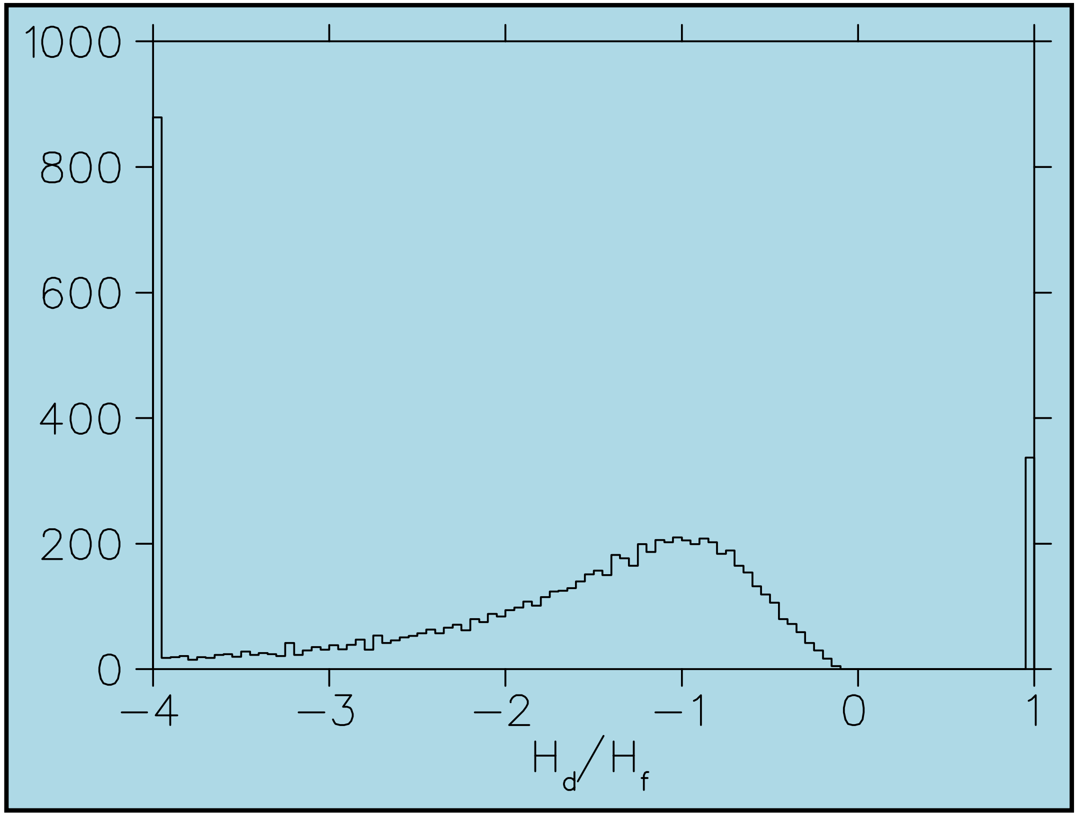


Limits on Transversity and Collins FF

$\delta r \approx \delta d/\delta u$ from χQSM



look at slice of distribution in δr:



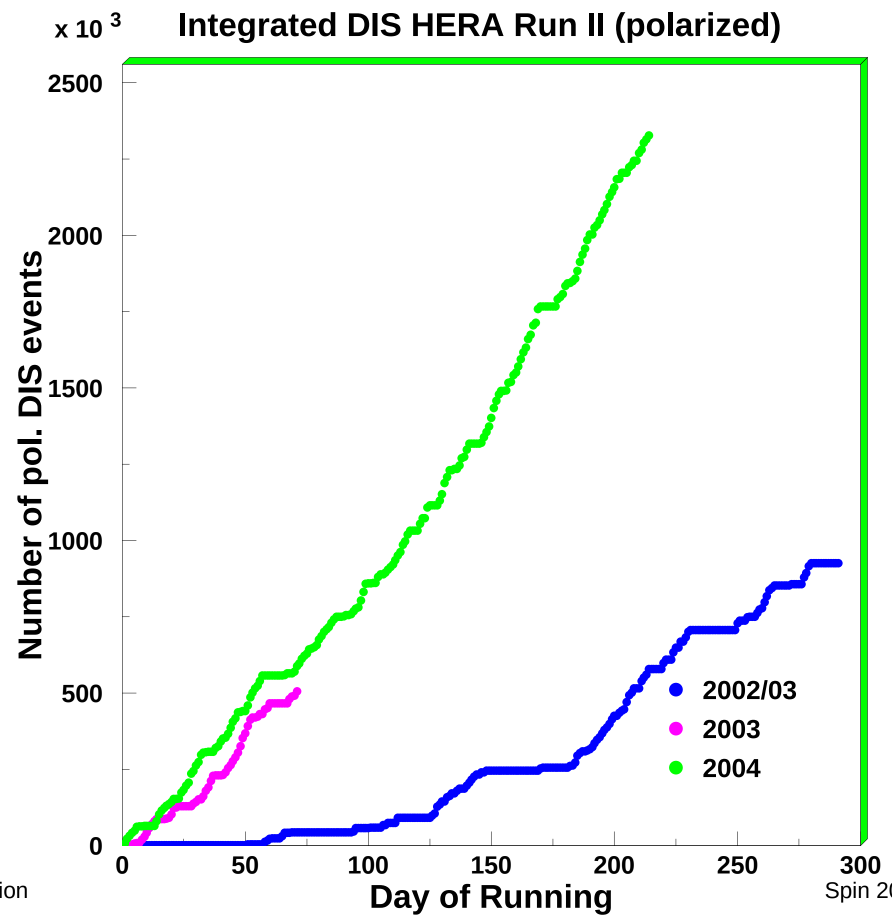
strong hint for H_d/H_f negative

Summary and Outlook

- Non-zero Collins effect observed with $H_d/H_f < 0$
- First evidence of T-odd Sivers distribution in DIS?

Summary and Outlook

- Non-zero Collins effect observed with $H_d/H_f < 0$
- First evidence of T-odd Sivers distribution in DIS?
- More data taking since fall of 2003



Summary and Outlook

- Non-zero Collins effect observed with $H_d/H_f < 0$
- First evidence of T-odd Sivers distribution in DIS?
- More data taking since fall of 2003

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

- 2-Meson-Correlations $\Rightarrow$ Interference FF
- Spin-1 Fragmentation
- Spin-1/2 Fragmentation (transverse Λ polarization)

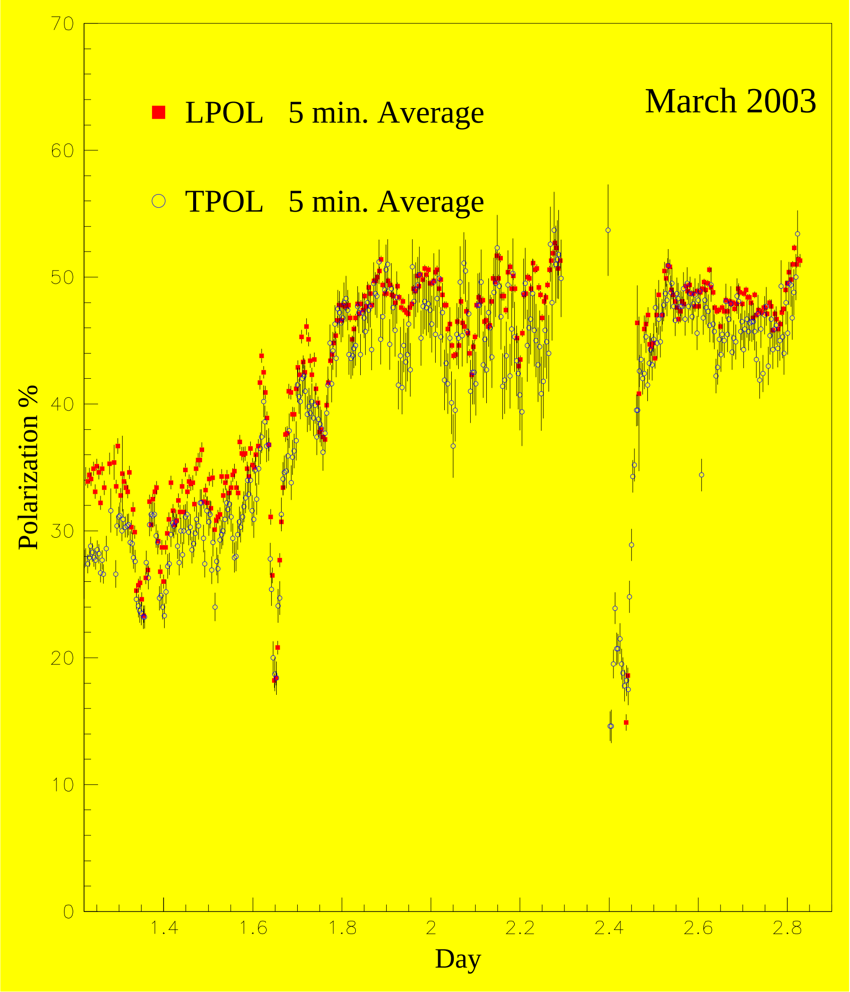
Summary and Outlook

- Non-zero Collins effect observed with $H_d/H_f < 0$
- First evidence of T-od
- More data taking sinc

⇒ Additional statistics a
channels to access tr

  - 2-Meson-Correlati
  - Spin-1 Fragmenta
  - Spin-1/2 Fragmen
    (transverse Λ pola

- polarized beam



Summary and Outlook

- Non-zero Collins effect observed with $H_d/H_f < 0$
- First evidence of T-odd Sivers distribution in DIS?
- More data taking since fall of 2003

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

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

Kinematic Cuts

- $0.023 < x < 0.4 \quad \Rightarrow \langle x \rangle = 0.09$
- $0.2 < z < .7 \quad \Rightarrow \langle z \rangle = 0.36$
- $0.1 < y < 0.85 \quad \Rightarrow \langle y \rangle = 0.54$
- $Q^2 > 1$ GeV^2 $\quad \Rightarrow \langle Q^2 \rangle = 2.41$ GeV^2
- $W^2 > 10$ GeV^2
- $\theta_{\gamma^* h} > 0.02$rad $\quad \Rightarrow \langle P_{h\perp} \rangle = 0.41$ GeV