Transverse Spin Physics at HERMES

- Azimuthal asymmetries in semi-inclusive deep inelastic scattering
- Disentangling of distribution and fragmentation function
- Results of the HERMES experiment
- Summary and Outlook

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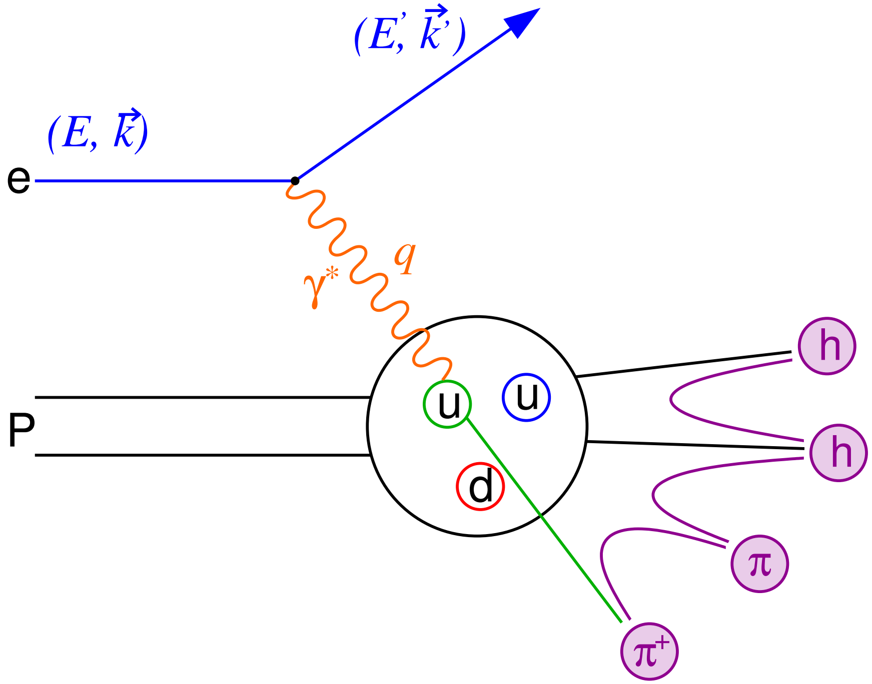
Recontres de Moriond
QCD and
High Energy Hadronic Interactions
April 1, 2004

Semi-inclusive Deep Inelastic Scattering



$$Q^2 = -q^2 = -(k - k')^2$$

$$\nu \overset{\text{Lab}}{=} E - E'$$

$$x = \frac{Q^2}{2M\nu}$$

$$z \overset{\text{Lab}}{=} \frac{E_{had}}{\nu}$$

evaluation of the cross section contains
quark distribution and fragmentation functions

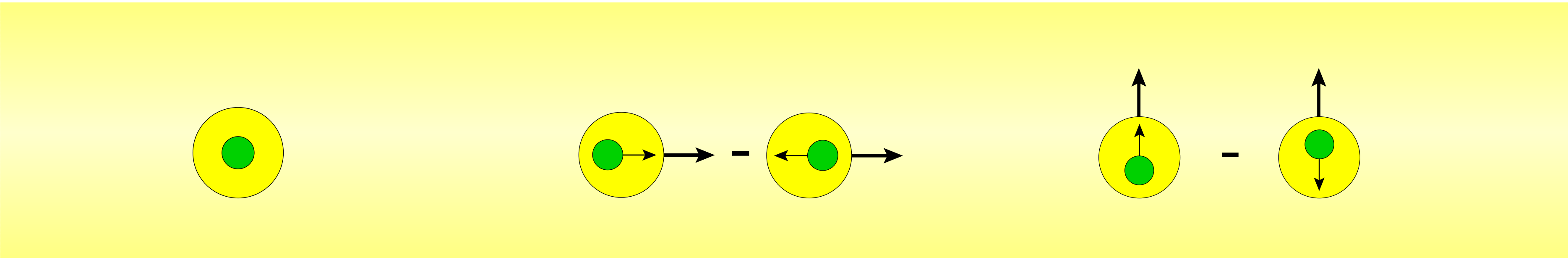
$$\sigma^{ep\to eh} \sim \sum_q DF^{p\to q} \otimes \sigma^{eq\to eq} \otimes FF^{q\to h}$$

Distribution Functions

Leading twist:

3 DFs survive the integration over transverse quark momenta

unpolarised DF $f_1(x)$	Helicity $g_1(x)$	Transversity $h_1(x)$

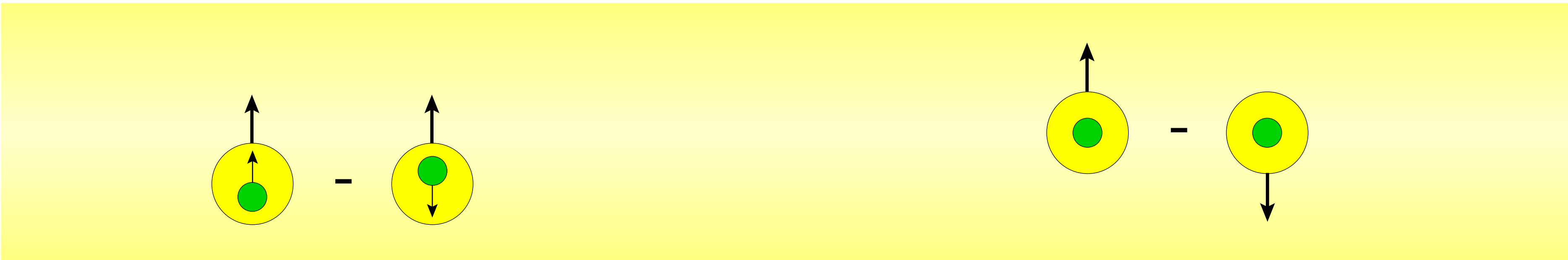


also $q(x)$	also $\Delta q(x)$	also $\delta q(x)$
well known	known	unknown
	HERMES 1996-2000	HERMES > 2002

Transversely Polarised Target

Transversity $\mathbf{h_1(x)}$

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



T-even

χ-odd

combined with χ-odd
fragmentation function $\mathrm{H}_1^{\perp}(\mathrm{z})$
(Collins function)

“naïve T-odd”

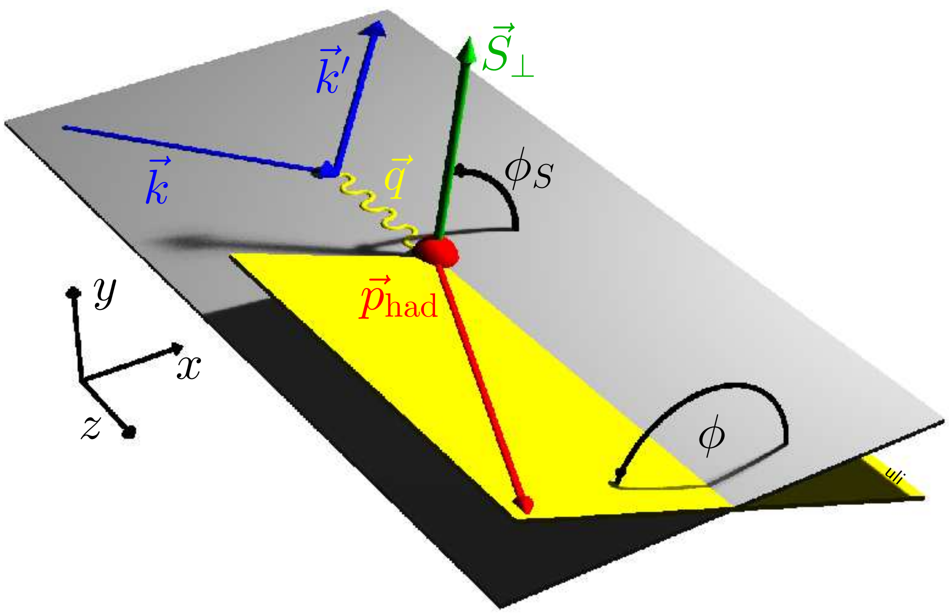
χ-even

$\neq$ 0 indicates
non-vanishing orbital angular
momentum of quarks

Azimuthal Asymmetries

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

$$\mathbf{A}(\phi,\phi_\mathbf{S}) \;=\; \frac{\mathbf{1}}{\mathbf{S}_\perp}\,\frac{\mathbf{N}^\uparrow(\phi,\phi_\mathbf{S}) - \mathbf{N}^\downarrow(\phi,\phi_\mathbf{S})}{\mathbf{N}^\uparrow(\phi,\phi_\mathbf{S}) + \mathbf{N}^\downarrow(\phi,\phi_\mathbf{S})}$$



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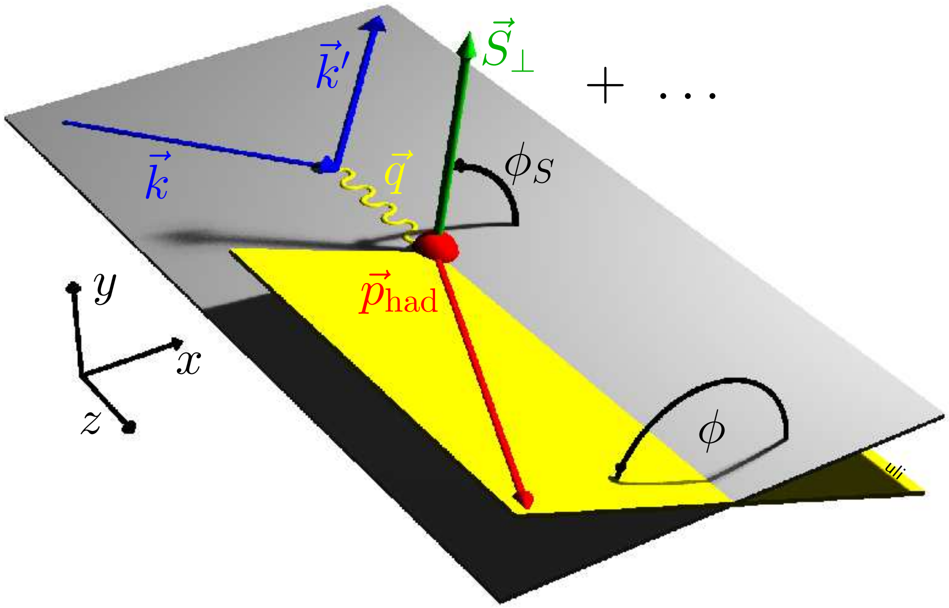
$$\sim \ldots \sin(\phi+\phi_\mathbf{S})\sum_\mathbf{q} \mathbf{e}_\mathbf{q}^\mathbf{2} \cdot \mathcal{I}\left[\ldots \mathbf{h}_\mathbf{1}^\mathbf{q}(\mathbf{x},\vec{\mathbf{p}}_\mathbf{T}^\mathbf{2}) \cdot \mathbf{H}_\mathbf{1}^{\perp\mathbf{q}}(\mathbf{z},\vec{\mathbf{k}}_\mathbf{T}^\mathbf{2})\right]$$

$$+ \ldots \sin(\phi-\phi_\mathbf{S})\sum_\mathbf{q} \mathbf{e}_\mathbf{q}^\mathbf{2} \cdot \mathcal{I}\left[\ldots \mathbf{f}_\mathbf{1T}^{\perp\mathbf{q}}(\mathbf{x},\vec{\mathbf{p}}_\mathbf{T}^\mathbf{2}) \cdot \mathbf{D}_\mathbf{1}^\mathbf{q}(\mathbf{z},\vec{\mathbf{k}}_\mathbf{T}^\mathbf{2})\right]$$

$$+ \ldots$$



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$$\sim \ \ldots\sin(\phi+\phi_\mathbf{S})\sum_\mathbf{q}\mathbf{e_q^2}\cdot\mathcal{I}\left[\ldots\ \mathbf{h_1^q}(\mathbf{x},\vec{\mathbf{p}}_\mathbf{T}^\mathbf{2})\cdot\mathbf{H}_\mathbf{1}^{\perp\mathbf{q}}(\mathbf{z},\vec{\mathbf{k}}_\mathbf{T}^\mathbf{2})\right]$$

$$+\ \ldots\sin(\phi-\phi_\mathbf{S})\sum_\mathbf{q}\mathbf{e_q^2}\cdot\mathcal{I}\left[\ldots\ \mathbf{f}_\mathbf{1T}^{\perp\mathbf{q}}(\mathbf{x},\vec{\mathbf{p}}_\mathbf{T}^\mathbf{2})\cdot\mathbf{D_1^q}(\mathbf{z},\vec{\mathbf{k}}_\mathbf{T}^\mathbf{2})\right]$$

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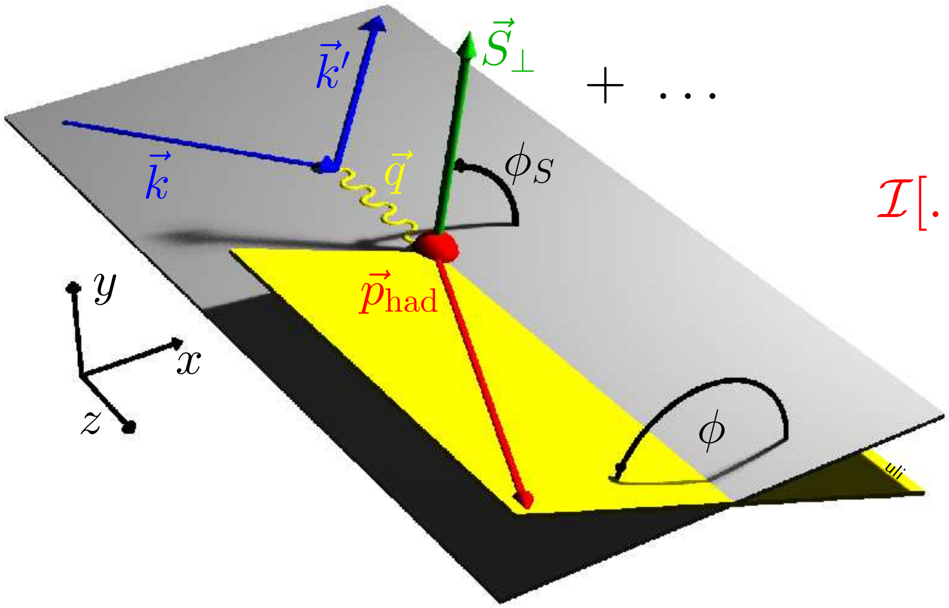

$\mathcal{I}[\ldots]$: convolution integral over initial ($\vec{\mathbf{p}}_\mathbf{T}$) and final ($\vec{\mathbf{k}}_\mathbf{T}$) quark transverse momenta

How to Disentangle . . .

. . . Distribution and Fragmentation Functions?

Weight the events with $P_{h\perp}$:

$$\frac{1}{\mathbf{S}_\perp} \frac{\sum_{\mathbf{i=1}}^{\mathbf{N}^\uparrow(\phi,\phi_\mathbf{S})} \mathbf{P}_{\mathbf{h}\perp\ \mathbf{i}} - \sum_{\mathbf{i=1}}^{\mathbf{N}^\downarrow(\phi,\phi_\mathbf{S})} \mathbf{P}_{\mathbf{h}\perp\ \mathbf{i}}}{\mathbf{N}^\uparrow(\phi,\phi_\mathbf{S}) + \mathbf{N}^\downarrow(\phi,\phi_\mathbf{S})}$$

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$$\sim \ \ldots \sin(\phi + \phi_S) \sum_q e_q^2 \cdot \ h_1^q(x) \ \cdot H_1^{\perp(1)q}(z)$$

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

(1): $\vec{p}_T^{\,2}$, $\vec{k}_T^{\,2}$ moment of distribution / fragmentation function

No assumption necessary!

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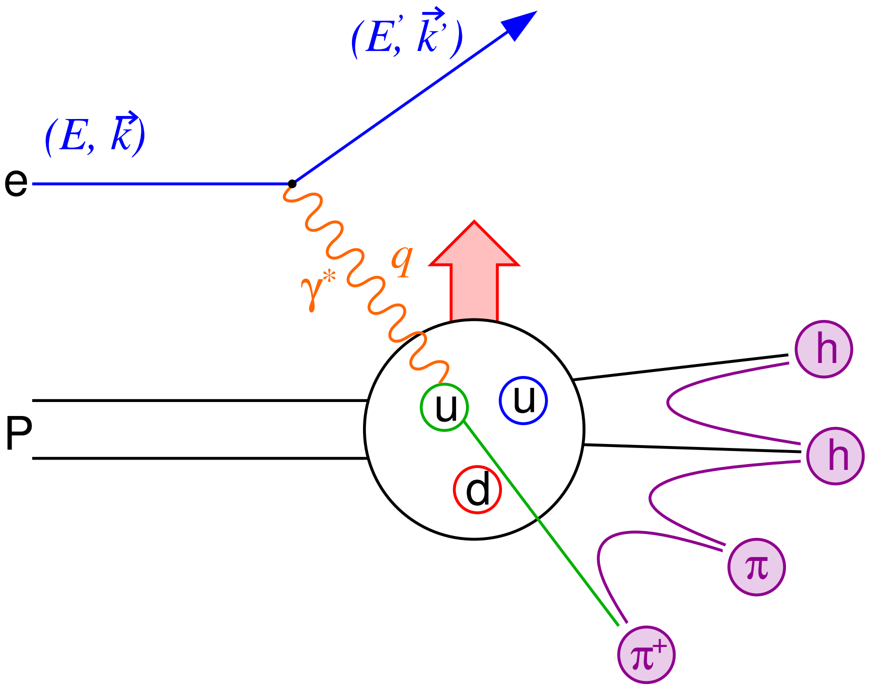
moments $A^{\sin(\phi+\phi_S)}$ and $A^{\sin(\phi-\phi_S)}$

two dimensional fit of $A(\phi, \phi_S)$

The HERMES Experiment at HERA



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HERA positron beam 27.5 GeV

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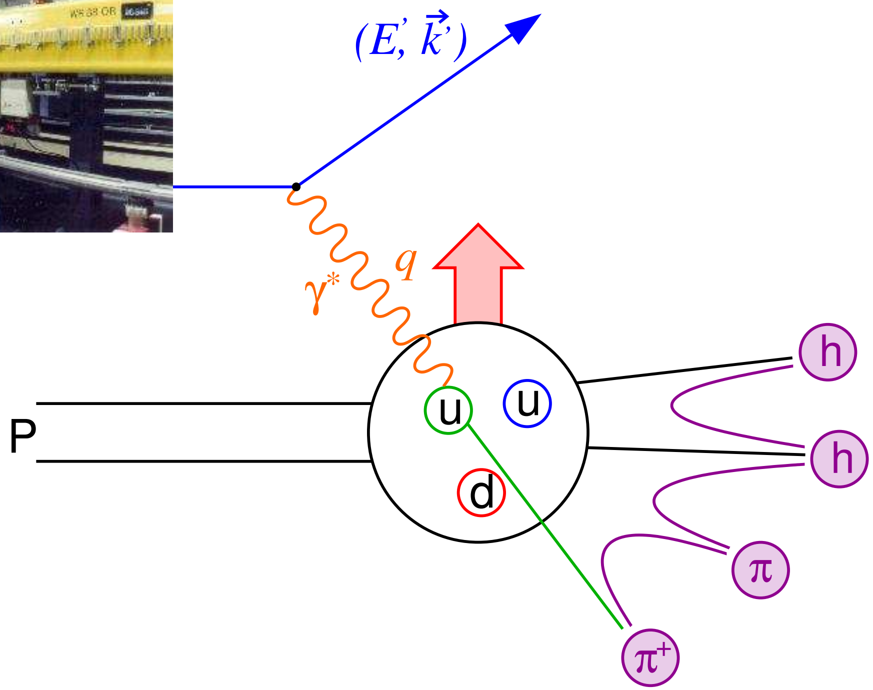

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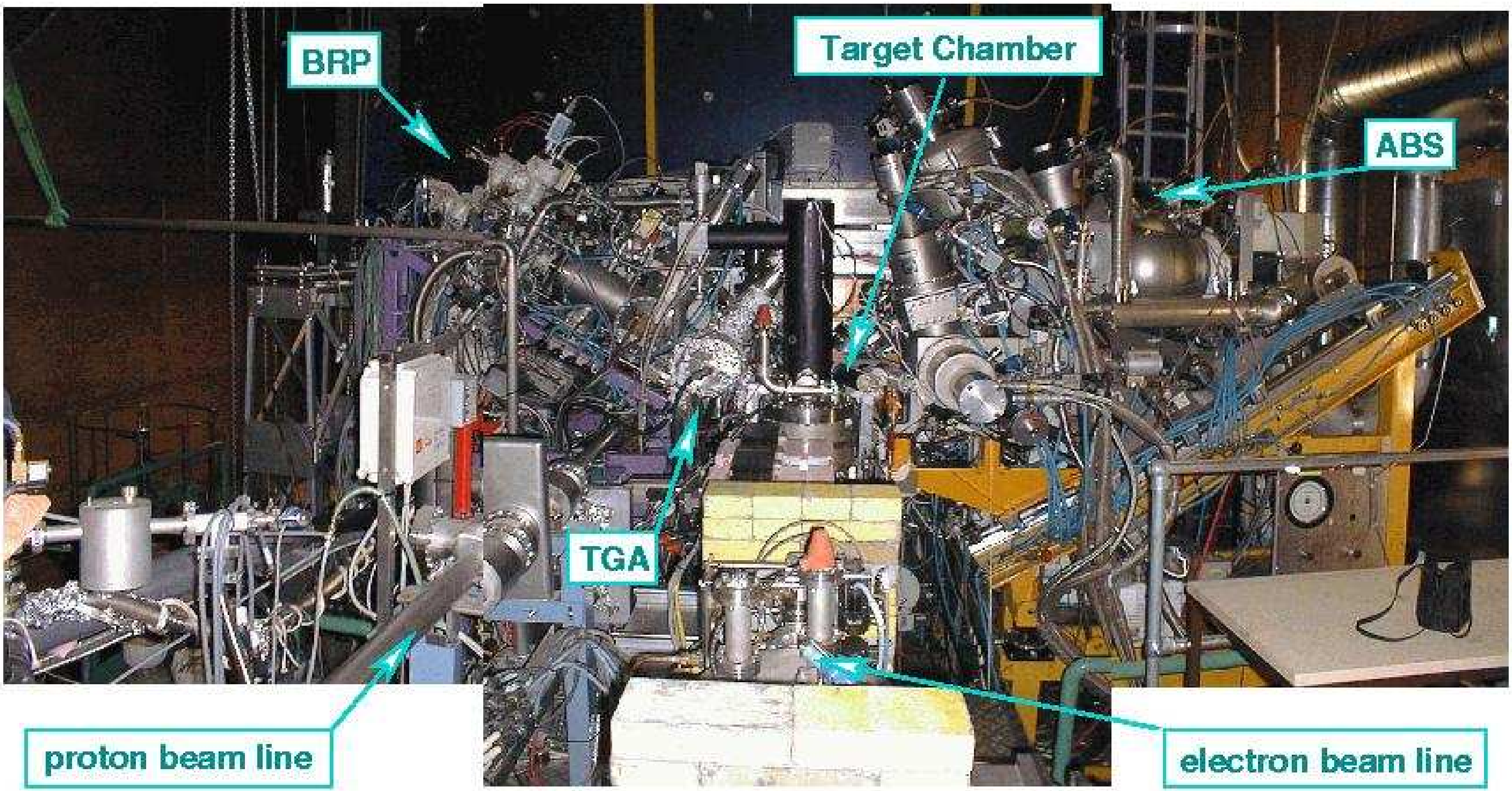

transversely polarised atomic Hydrogen $\langle P \rangle \approx 80\ \%$

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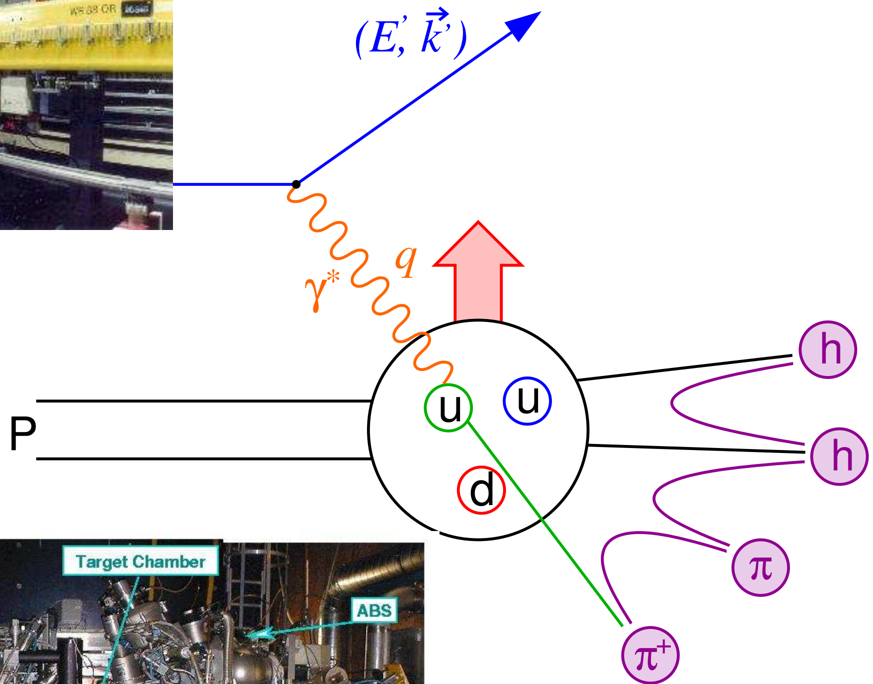

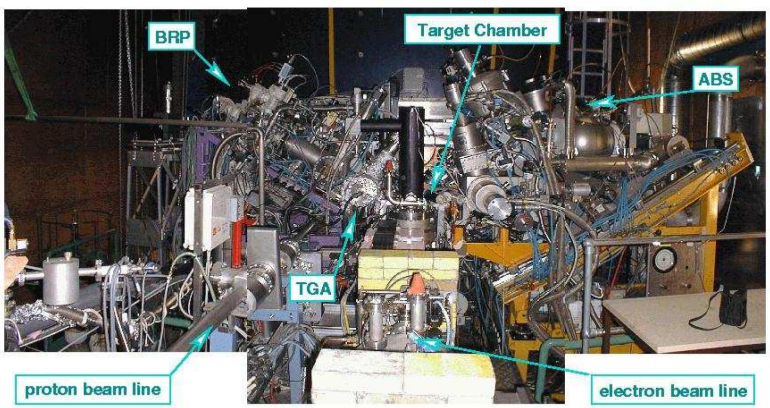

since 2002

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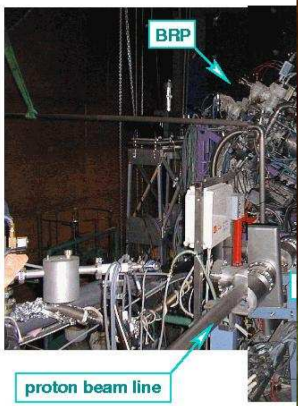
The HERMES Experiment at HERA

HERA posit



transverse

The HERMES Experiment at HERA

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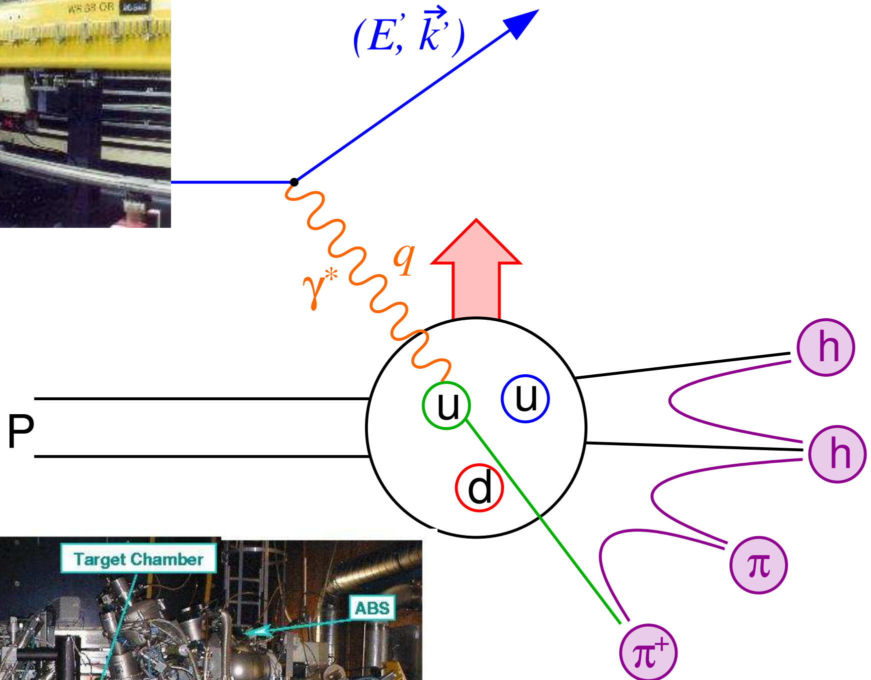
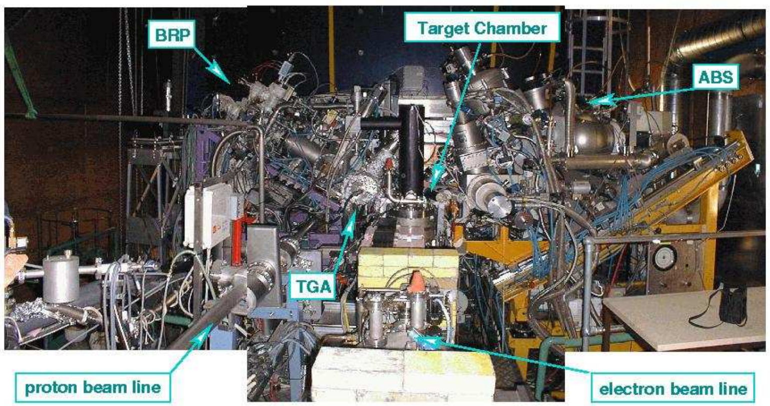


HERMES spectrometer



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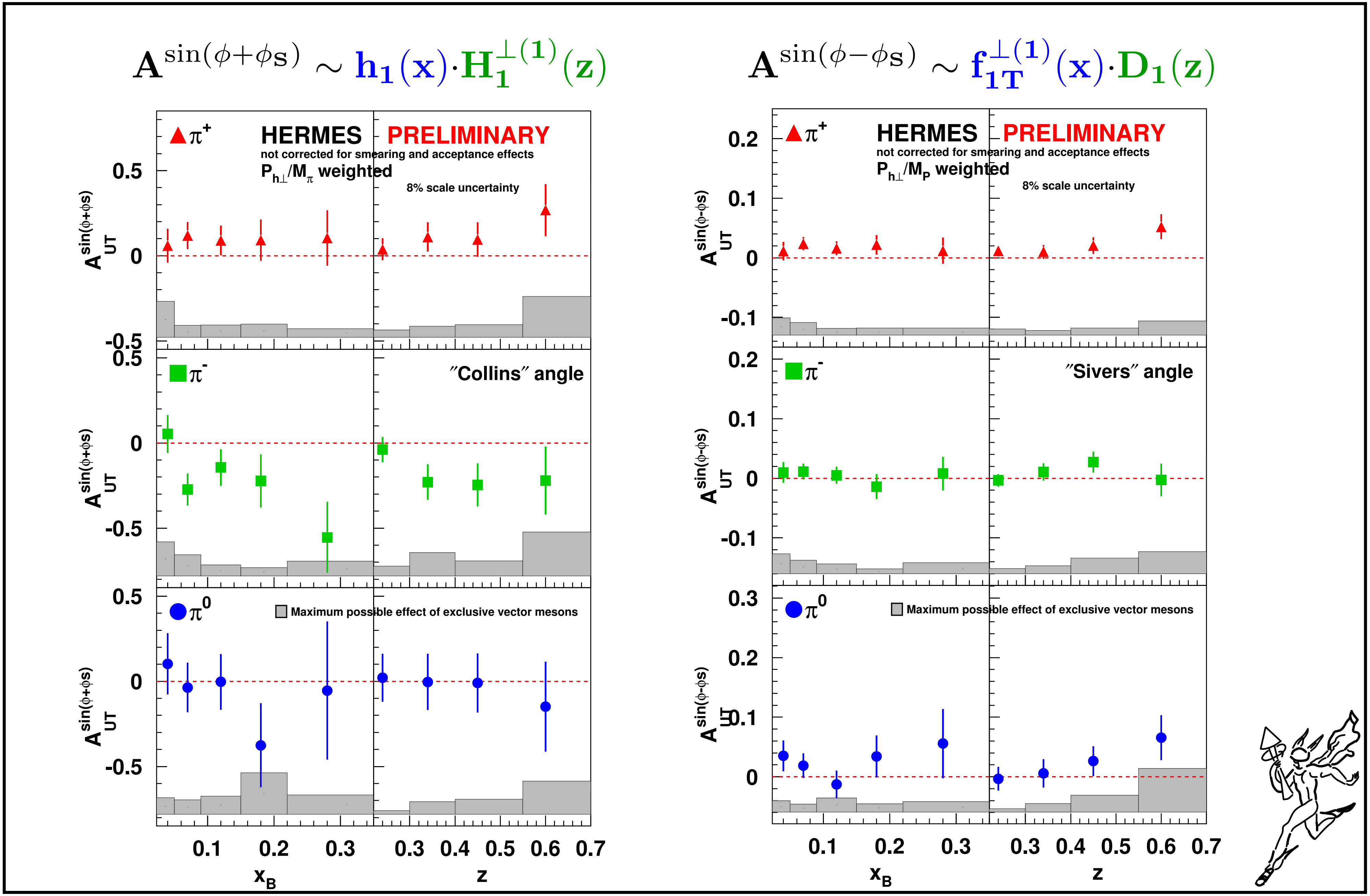
Results for the $P_{h\perp}$ Weighted Asymmetries



Extraction of the Distribution Functions

$$\sum_{\mathbf{q}} \mathsf{DF}^{\mathbf{q}}(\mathbf{x}) \cdot \mathsf{FF}^{\mathbf{q}}(\mathbf{z})$$

- measure $\mathbf{A}^{\sin(\phi \pm \phi_\mathbf{S})}$ in many $(\mathbf{x}, \mathbf{z})$ bins
  ➜ large statistics necessary
- information about fragmentation functions

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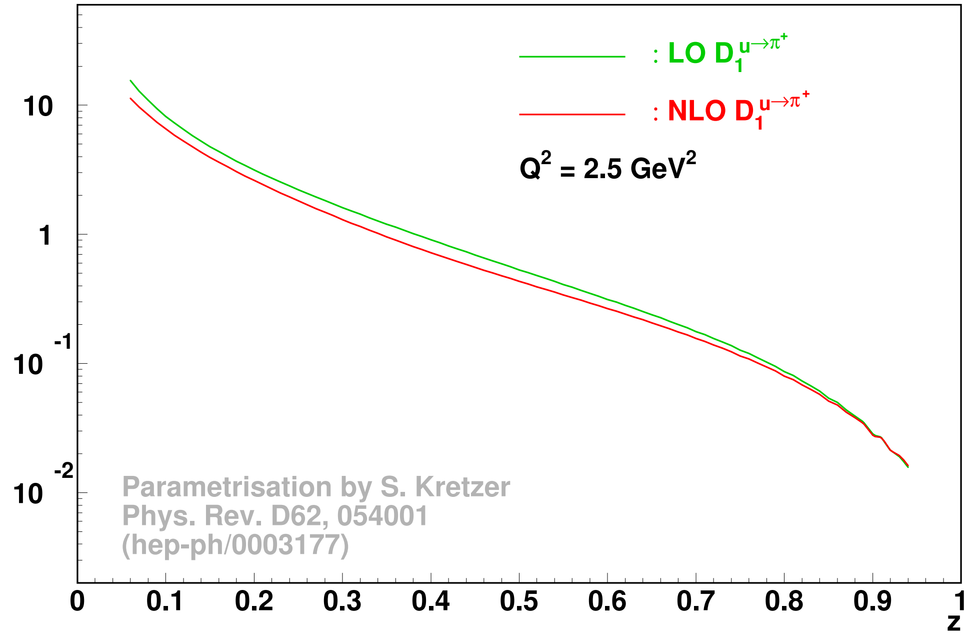
  - $D_1^{q \to h}(z)$ for some hadrons h sufficiently known



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$$\sum_{q} h_1^q(x) \cdot H_1^{\perp q}(z)$$

  - $\mathbf{H}_{\mathbf{1}}^{\perp \mathbf{q} \to \mathbf{h}}(\mathbf{z})$: results of different asymmetries from other experiments,
    for example $\mathbf{e}^+\mathbf{e}^-$ annihilation: BABAR, BELLE
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$\mathrm{DF}^q(x)$

combination of $A^{\sin(\phi \pm \phi_S)}$ of various hadrons
➜ quark flavour decomposition

First Glimpse of Transversity and Collins Function

- neglect contributions of strange sea quarks

$$\mathbf{s(x) = \bar{s}(x) = h_1^s(x) = h_1^{\bar{s}}(x) = 0}$$

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$$\mathbf{D_f \equiv D_1^{u\to\pi^+} \approx D_1^{d\to\pi^-} \approx D_1^{\bar{d}\to\pi^+} \approx D_1^{\bar{u}\to\pi^-}}$$ favoured

$$\mathbf{D_d \equiv D_1^{u\to\pi^-} \approx D_1^{d\to\pi^+} \approx D_1^{\bar{d}\to\pi^-} \approx D_1^{\bar{u}\to\pi^+}}$$ disfavoured

➜ $\mathbf{\frac{1}{2}(D_f + D_d) \approx D_1^{u\to\pi^0} \approx D_1^{d\to\pi^0} \approx D_1^{\bar{d}\to\pi^0} \approx D_1^{\bar{u}\to\pi^0}}$

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➜ $\mathbf{\frac{1}{2}(D_f + D_d) \approx D_1^{u\to\pi^0} \approx D_1^{d\to\pi^0} \approx D_1^{\bar{d}\to\pi^0} \approx D_1^{\bar{u}\to\pi^0}}$

➜ QPM expressions for $\mathbf{A_{\pi^+}^{\sin(\phi+\phi_S)}}$, $\mathbf{A_{\pi^-}^{\sin(\phi+\phi_S)}}$, $\mathbf{A_{\pi^0}^{\sin(\phi+\phi_S)}}$ simplify

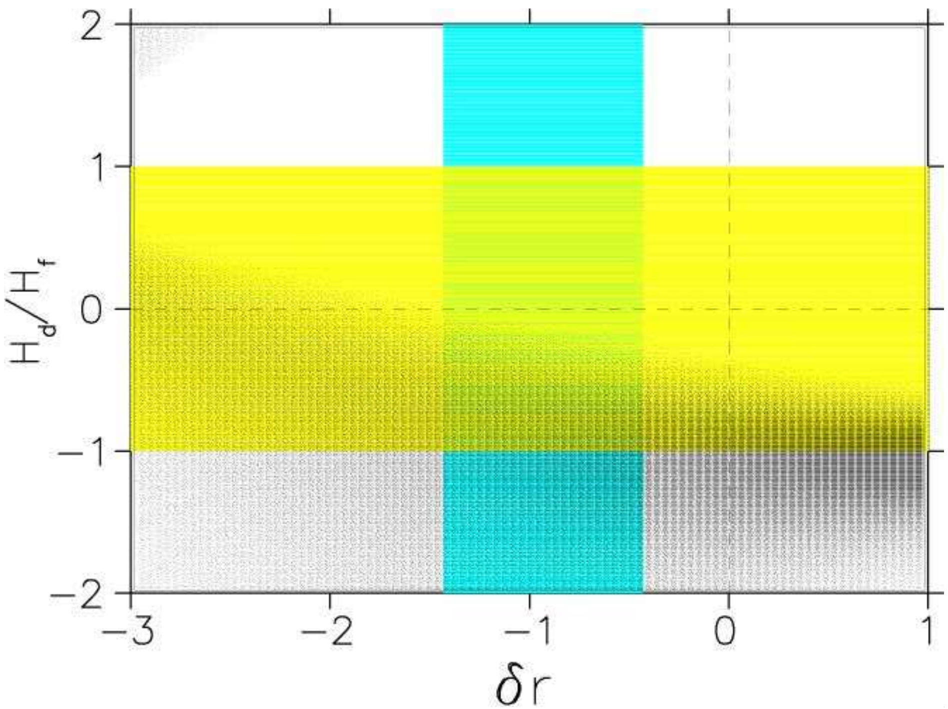
$$\mathbf{\frac{H_d}{H_f} = f\left(\delta r, A_{\pi^+}^{\sin(\phi+\phi_S)}, A_{\pi^-}^{\sin(\phi+\phi_S)}, A_{\pi^0}^{\sin(\phi+\phi_S)}\right)}$$

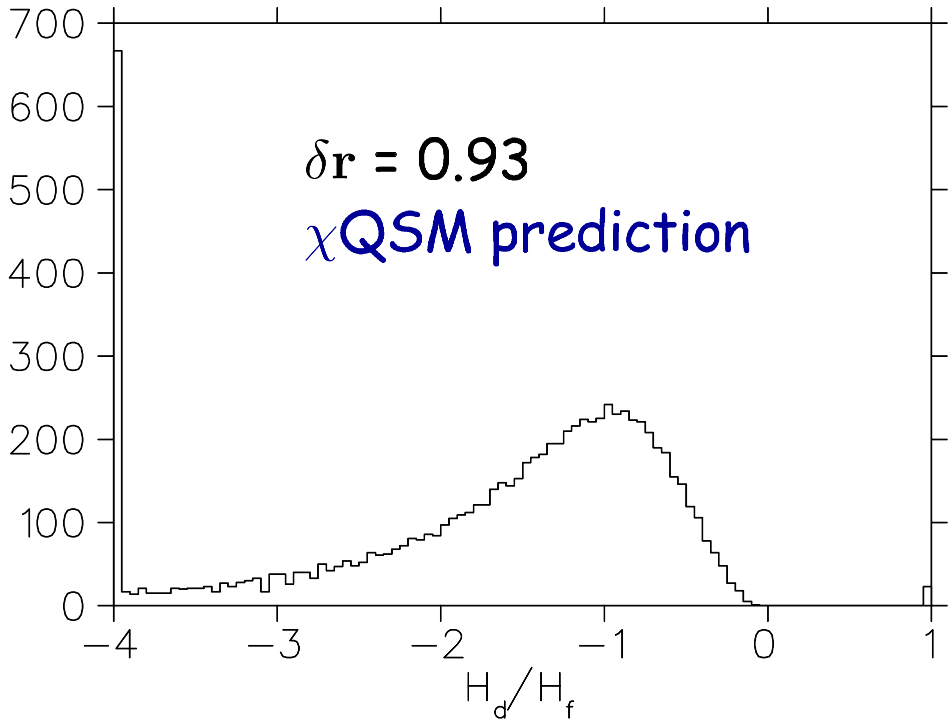
with $$\mathbf{\delta r = \frac{h_1^d(x) + 4h_1^{\bar{u}}(x)}{h_1^u(x) + \frac{1}{4}h_1^{\bar{d}}(x)}}$$

First Glimpse of Transversity and Collins Function

sample $\mathbf{A}^{\sin(\phi+\phi_S)}_{\pi^\pm,0}$ about measured values according to statistical variances

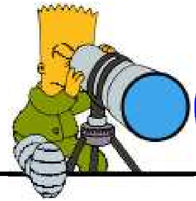
➜ likelihood distribution:



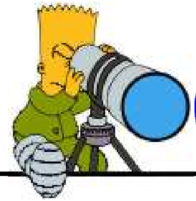


- Data do not constrain Transversity ($\delta\mathbf{r}$).
- In plausible range of $\delta\mathbf{r}$: $\frac{\mathbf{H_d}}{\mathbf{H_f}} < 0$
  ➜ disfavoured Collins function has opposite sign, probably significant magnitude

$$\delta\mathbf{r} = \frac{\mathbf{h_1^d(x) + 4h_1^{\bar{u}}(x)}}{\mathbf{h_1^u(x) + \frac{1}{4}h_1^{\bar{d}}(x)}}$$

Summary and utlook

- First measurement of transverse target spin asymmetries in DIS.
- First evidence for non-zero Sivers function.
- Disfavoured Collins function appears to be of opposite sign and similar magnitude to favoured function.

Summary and  utlook

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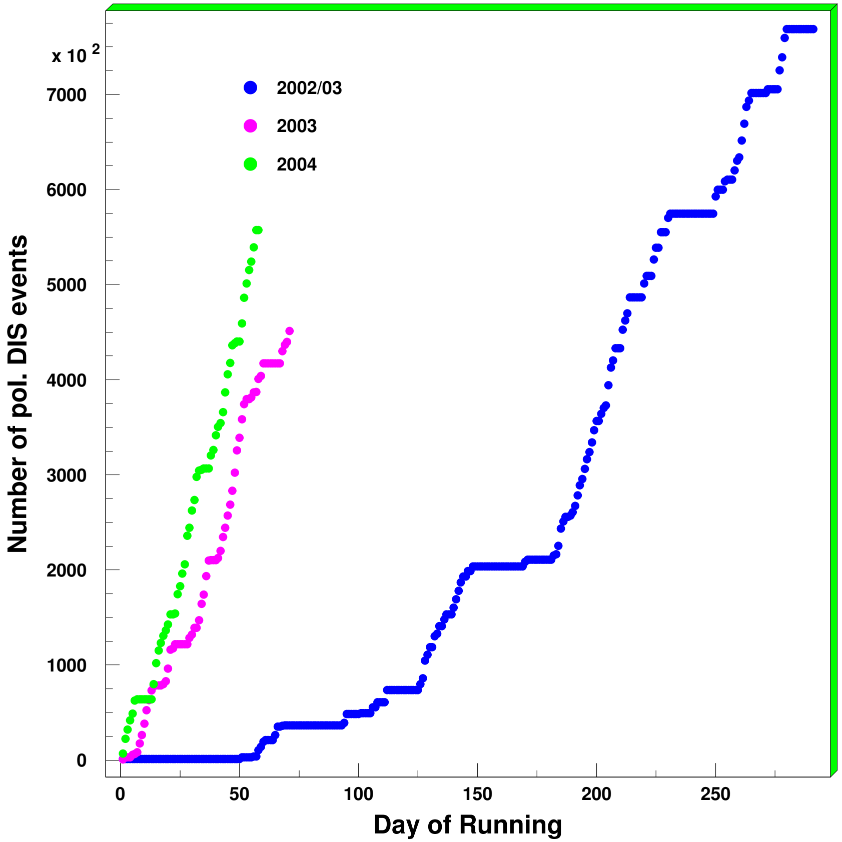

- Number of DIS events doubled, HERMES continues data taking.
- Sivers function extraction possible ➜ work in progress.

Results for the Unweighted Asymmetries

$A^{\sin(\phi+\phi_S)} \sim h_1(x) \cdot H_1^{\perp(1/2)}(z)$ $\qquad$ $A^{\sin(\phi-\phi_S)} \sim f_{1T}^{\perp(1/2)}(x) \cdot D_1(z)$