First results on two-hadron interference fragmentation on a transversely polarized hydrogen target

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(on behalf of the HERMES collaboration)

Layout:

- Introduction
- Results on longitudinally polarized target
- Results on transversely polarized target
- Status of the analysis
- Conclusions & Outlook

Introduction - 1p fragmentation

h_1 couples to $H_1^{\perp}(z, z^2 \boldsymbol{k}_T^2)$

$$\mathcal{I}\left[\cdots\right] \equiv \int d^2 \boldsymbol{p}_T \, d^2 \boldsymbol{k}_T \, d(\boldsymbol{p}_T - \boldsymbol{k}_T - \frac{\boldsymbol{P}_{h\perp}}{z})\left[\cdots\right]$$

$$ds_{UT}^{Collins} \propto \sum_q e_q^2 \sin(f_h + f_S)\mathcal{I}\left[\frac{\boldsymbol{k}_T \cdot \widehat{\boldsymbol{P}}_{h\perp}}{M_h} h_1^q H_1^{\perp q}\right]$$

Difficulties:

- extraction of $h_1 H_1^{\perp}$ difficult, needs weighting with $P_h^{\perp}$
- Sivers & Collins entangled:

$$ds_{UT}^{Sivers} \propto \sum_q e_q^2 \sin(f_h - f_S)\mathcal{I}\left[\frac{\boldsymbol{p}_T \cdot \widehat{\boldsymbol{P}}_{h\perp}}{M_h} f_{1T}^{\perp q} D_1^q\right]$$

Introduction - 2π fragmentation

h_1 couples to:

$V \propto z_1/(z_1+z_2)$

$$H_1^{\perp}(z,V,M_h^2,\boldsymbol{k}_T^2,\boldsymbol{k}_T\cdot\boldsymbol{R}_T) \;\&\; H_1^{\sphericalangle\prime}(z,V,M_h^2,\boldsymbol{k}_T^2,\boldsymbol{k}_T\cdot\boldsymbol{R}_T)$$

Integrate over $P_h^{\perp}$:
left with only $H_1^{\sphericalangle}(z,V,M_h^2)$ $\Rightarrow$

$$\sigma_{UT} \propto \sum_q e_q^2 \sin(\phi_{R\perp}+\phi_S) h_1 H_1^{\sphericalangle}$$

Advantages:

- cross section asymmetry directly proportional to $h_1 H_1^{\sphericalangle}$ (no weigthing needed)
- No Collins/Sivers "entanglement"
- Completely independent from 1π analysis

Disadvantages:

- less statistics
- $H_1^{\sphericalangle}$ unknown (but can be measured at Belle & Babar)

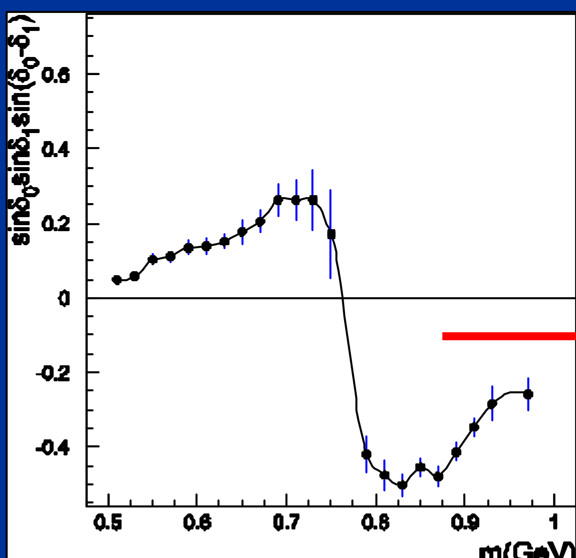
Interference FF

$$A_{UT} \sim \sin(\phi_{R\perp} + \phi_S)\sin\theta\, h_1 H_1^{\sphericalangle}$$

Expansion of $H_1^{\sphericalangle}$ in Legendre moments:

$$H_1^{\sphericalangle}(z,\cos\theta, M_{\pi\pi}^2) = H_1^{\sphericalangle,sp}\left(z, M_{\pi\pi}^2\right) + \cos\theta\, H_1^{\sphericalangle,pp}(z, M_{\pi\pi}^2)$$

describe interference between 2 pion pairs coming from different production channels



Jaffe et al. [hep-ph/9709322]:

$$H_1^{\sphericalangle,sp}\left(z, M_{\pi\pi}^2\right) = \sin\delta_0 \sin\delta_1 \sin(\delta_0 - \delta_1) H_1^{\sphericalangle,sp'}\left(z, M_{\pi\pi}^2\right)$$

(δ_0 (δ_1) $\rightarrow$ S(P)-wave phase shift)

$$= \mathcal{P}(M_{\pi\pi}^2) H_1^{\sphericalangle,sp'}(z, M_{\pi\pi}^2)$$

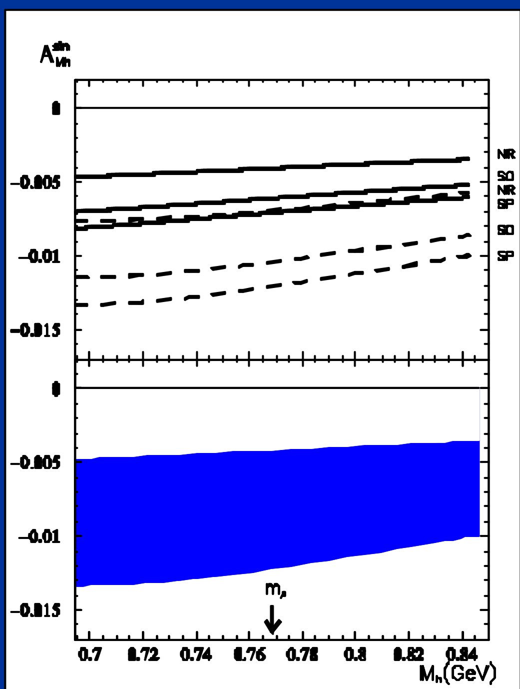
$\Longrightarrow$ $A_{UT}^{\sin\phi_{R\perp}}$ might depend strongly on $M_{\pi\pi}$!!

Interference FF

$$A_{UT} \sim \sin(f_{R\perp} + f_S)\sin q\, h_1 H_1^{\sphericalangle}$$

Expansion of $H_1^{\sphericalangle}$ in Legendre moments:

$$H_1^{\sphericalangle}(z, \cos q, M_{pp}^2) = H_1^{\sphericalangle, sp}\left(z, M_{pp}^2\right) + \cos q\, H_1^{\sphericalangle, pp}(z, M_{pp}^2)$$



Radici et al. [hep-ph/0110252]:

complety different model, not predicting a sign change of the asymmetry around the r_0

The polarized cross sections

The A_{UL} & A_{UT} asymmetries are related to these polarized cross sections (subleading twist, Bacchetta et al.):

$$s_{UL} \sim \sum_q e_q^2 \sin f_{R\perp} \sin \boldsymbol{q} \left[K_1 \,|\, \boldsymbol{S}_\parallel \,|\, h_L - K_2 \,|\, \boldsymbol{S}_\perp \,|\, h_1 \right] \left(H_1^{\sphericalangle, sp} + H_1^{\sphericalangle, pp} \cos \boldsymbol{q} \right)$$

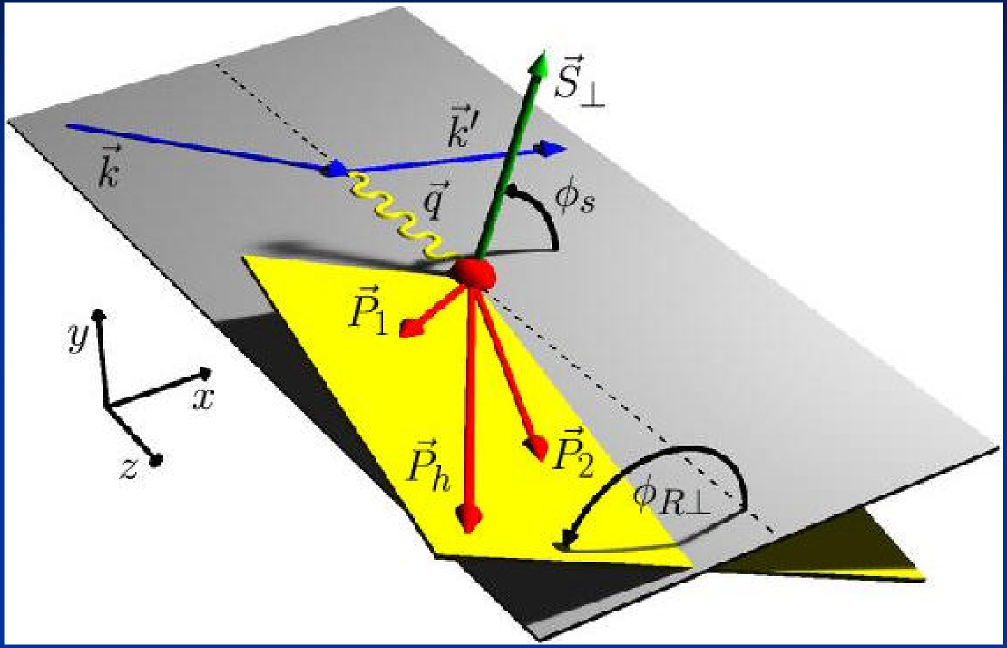
$$s_{UT} \sim \sum_q e_q^2 \,|\, \boldsymbol{S}_\perp \,|\, \sin\left(f_{R\perp} + f_S \right) \sin q \, K_3 h_1 \left(H_1^{\sphericalangle, sp} + H_1^{\sphericalangle, pp} \cos q \right)$$
$$+ K_4 \sin f_S (\ldots)$$

before integration over $P_{h\perp}$

$$
\begin{aligned}
d^9 s_{UT} = {} & \sum_a \frac{a^2 e_a^2}{2p Q^2 y} |\vec{S}_T| A(y) \{ \frac{\vec{R}_T}{M_h} \sin(j_R - j_S) \mathcal{I} [\frac{\vec{p}_T \cdot \vec{k}_T}{2MM_h} g_{1T} G_1^{\perp}] \\
& - \frac{|\vec{R}_T|}{M_h} \cos(j_R - j_S) \mathcal{I} [\frac{(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{k}_T) - (\vec{k}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{p}_T)}{2MM_h} g_{1T} G_1^{\perp}] \\
& - \frac{|\vec{R}_T|}{M_h} \sin(2j_h - j_R - j_S) \mathcal{I} [\frac{2(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{k}_T \cdot \vec{P}_{h\perp}) - \vec{p}_T \cdot \vec{k}_T}{2MM_h} g_{1T} G_1^{\perp}] \\
& - \frac{|\vec{R}_T|}{M_h} \cos(2j_h - j_R - j_S) \mathcal{I} [\frac{(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{k}_T) + (\vec{k}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{p}_T)}{2MM_h} g_{1T} G_1^{\perp}] \\
& + \sin(j_h - j_S) \mathcal{I} [\frac{(\vec{p}_T \cdot \vec{P}_{h\perp})}{M} f_{1T}^{\perp} D_1] + \cos(j_h - j_S) \mathcal{I} [\frac{(\vec{P}_{h\perp} \times \vec{p}_T)}{M} f_{1T}^{\perp} D_1]] \} \\
& + \sum_a \frac{a^2 e_a^2}{2p Q^2 y} |\vec{S}_T| B(y) \{ \sin(j_h + j_S) \mathcal{I} [\frac{(\vec{k}_T \cdot \vec{P}_{h\perp})}{M_h} h_1 H_1^{\perp}] \\
& + \cos(j_h + j_S) \mathcal{I} [\frac{(\vec{P}_{h\perp} \times \vec{k}_T)}{M_h} h_1 H_1^{\perp}] + \frac{|\vec{R}_T|}{M_h} \sin(j_R + j_S) \mathcal{I} [h_1 \overline{H}_1^{\sphericalangle}] + 3\sin(3f_h - f_S) \\
& \times \mathcal{I} [\frac{4(\vec{p}_T \cdot \vec{P}_{h\perp})^2 (\vec{k}_T \cdot \vec{P}_{h\perp}) - 2(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{p}_T \cdot \vec{k}_T) - \vec{p}_T^{\,2} (\vec{k}_T \cdot \vec{P}_{h\perp})}{2M^2 M_h} h_{1T}^{\perp} H_1^{\perp}] \\
& + \cos(3j_h - j_S) \mathcal{I} [(\frac{2(\vec{p}_T \cdot \vec{P}_{h\perp})^2 (\vec{P}_{h\perp} \times \vec{k}_T) + 2(\vec{k}_T \cdot \vec{P}_{h\perp})(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{p}_T)}{2M^2 M_h} \\
& - \frac{\vec{p}_T^{\,2} (\vec{P}_{h\perp} \times \vec{k}_T)}{2M^2 M_h}) h_{1T}^{\perp} H_1^{\perp}] + \frac{|\vec{R}_T|}{M_h} \sin(2j_h + j_R - j_S) \mathcal{I} [\frac{2(\vec{p}_T \cdot \vec{P}_{h\perp})^2 - \vec{p}_T^{\,2}}{2M^2} h_{1T}^{\perp} \overline{H}_1^{\sphericalangle}] \\
& + \frac{|\vec{R}_T|}{M_h} \cos(2j_h + j_R - j_S) \mathcal{I} [\frac{(\vec{p}_T \cdot \vec{P}_{h\perp})(\vec{P}_{h\perp} \times \vec{p}_T)}{2M^2} h_{1T}^{\perp} \overline{H}_1^{\sphericalangle}]] \}
\end{aligned}
$$

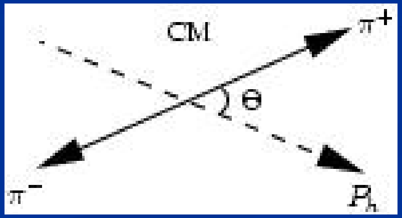
Bacchetta et al. [hep-ph/0212300]

Single Spin Asymmetry



transversely polarized hydrogen target

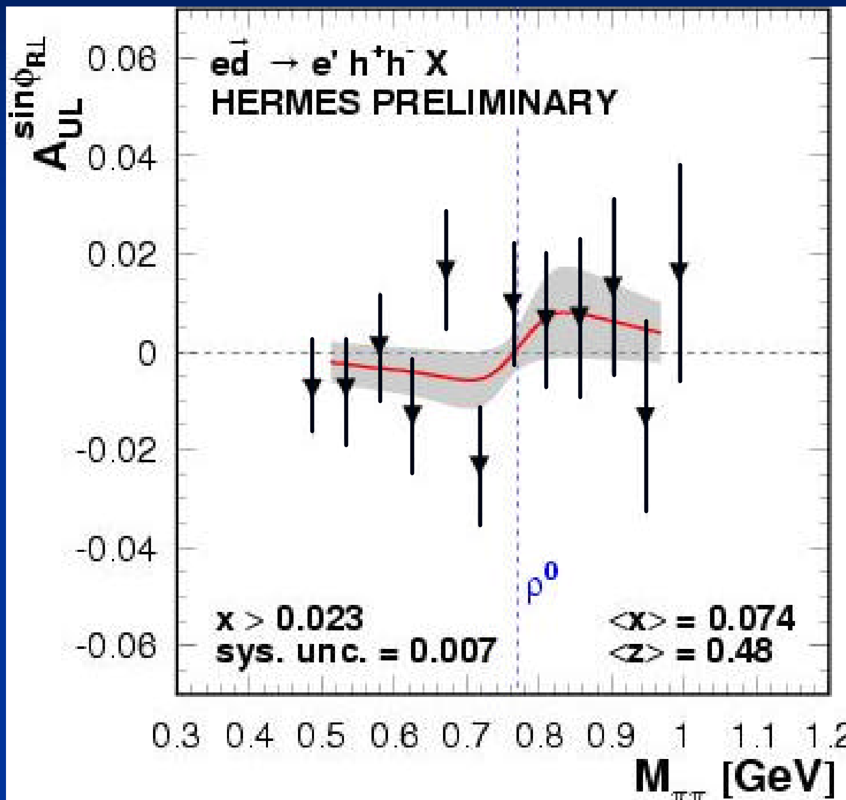
$$\overrightarrow{P}_h \equiv \overrightarrow{P}_1 + \overrightarrow{P}_2$$



What is measured:

$$A_{UT}(f_{R\perp}, f_S, q) = \frac{1}{S_T}\frac{N^{\uparrow}(f_{R\perp}, f_S, q)/N^{\uparrow}_{\text{DIS}} - N^{\downarrow}(f_{R\perp}, f_S, q)/N^{\downarrow}_{\text{DIS}}}{N^{\uparrow}(f_{R\perp}, f_S, q)/N^{\uparrow}_{\text{DIS}} + N^{\downarrow}(f_{R\perp}, f_S, q)/N^{\downarrow}_{\text{DIS}}}$$

longitudinally polarized deuterium

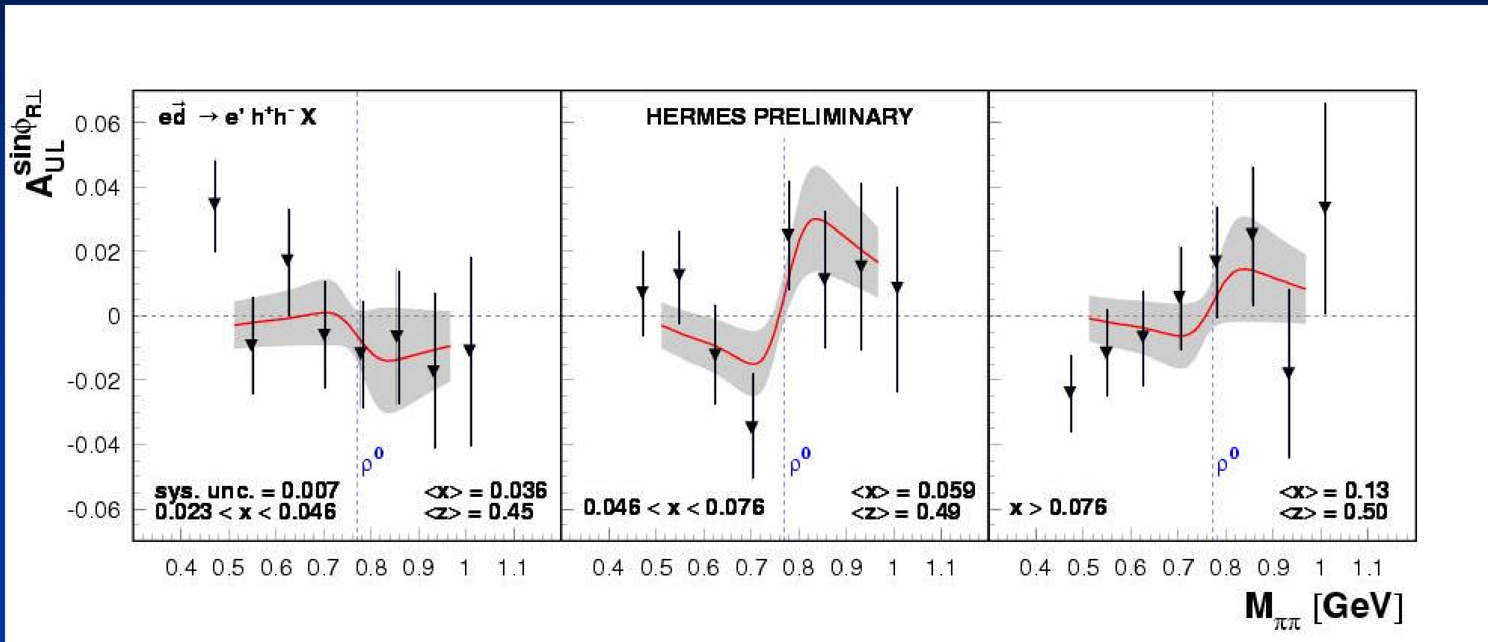


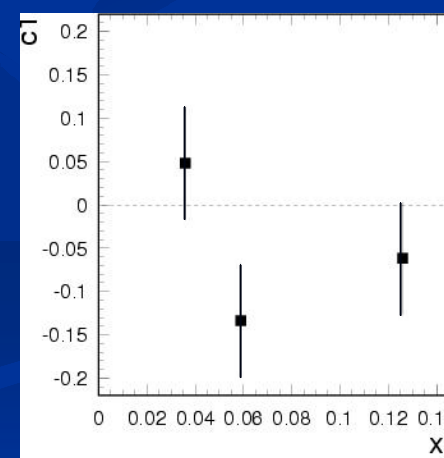
$$c_1 = -0.040 \pm 0.036$$
$$c_2 = -0.001 \pm 0.004$$

$$g(M_{pp}^2) \simeq c_1 \mathcal{P}(M_{pp}^2) + c_2$$

Hint of a sign change
at the ρ^0 mass!

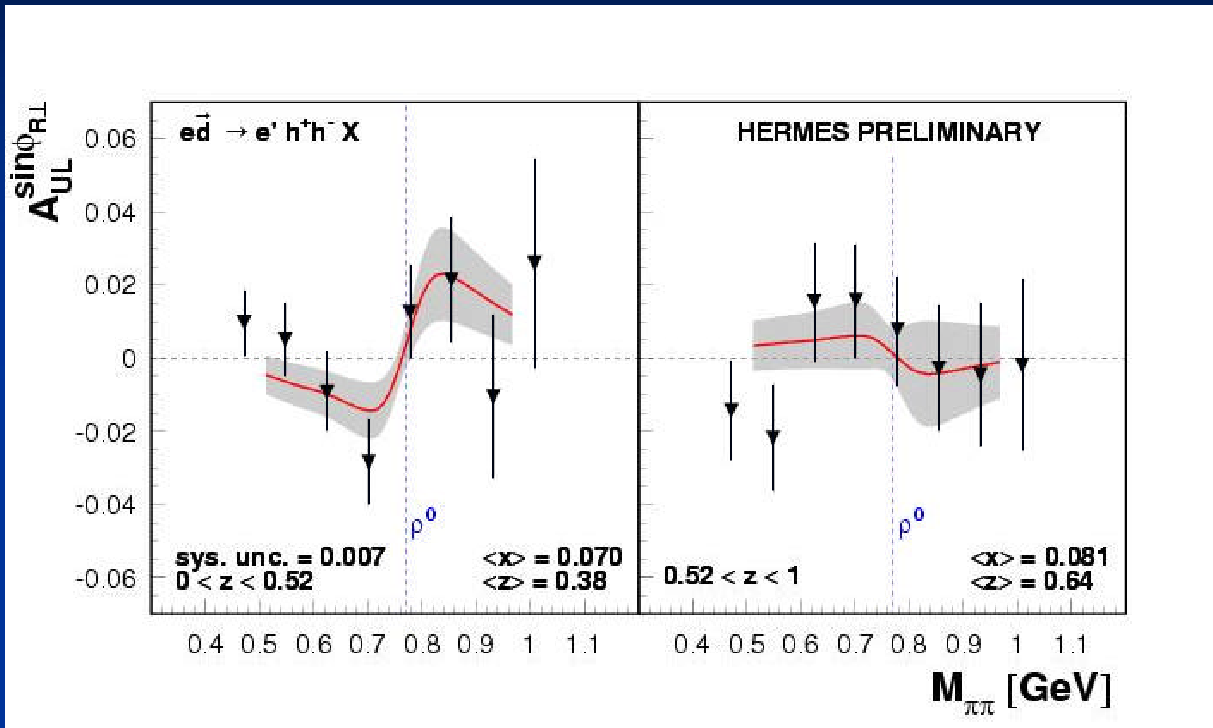
long. pol. deuterium, x-dependence

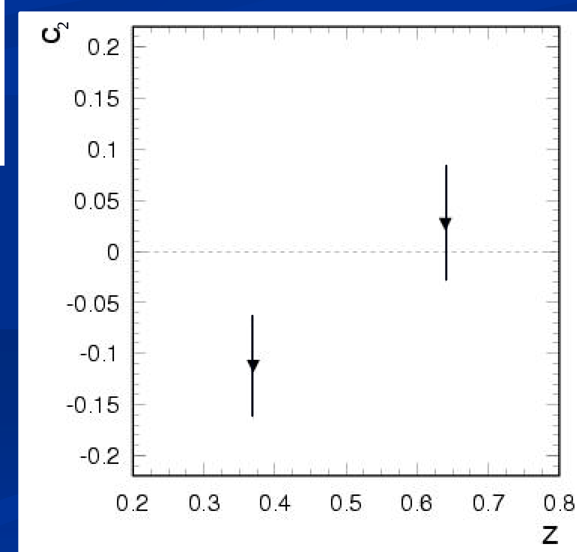




- higher x: hint of sign change at ρ^0 mass according to Jaffe's model
- $c_1(x) \propto h_1(x)$?

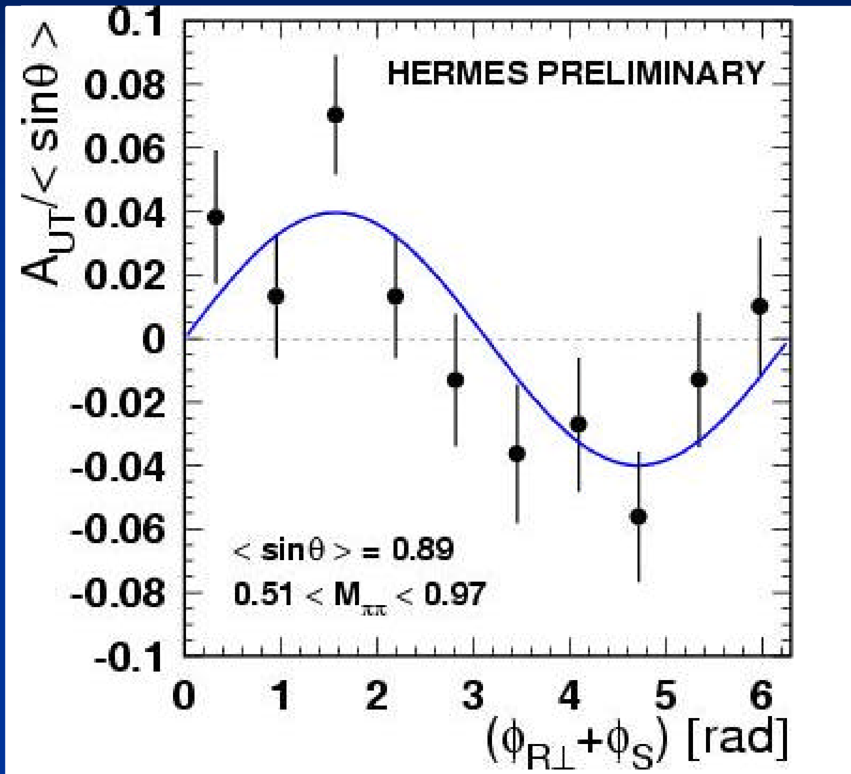
long. pol. deuterium, z-dependence





- sign change at ρ^0 according to Jaffe's model for low z
- $c_2(z) \propto H_1^{\sphericalangle,sp}(z, M_{pp})$

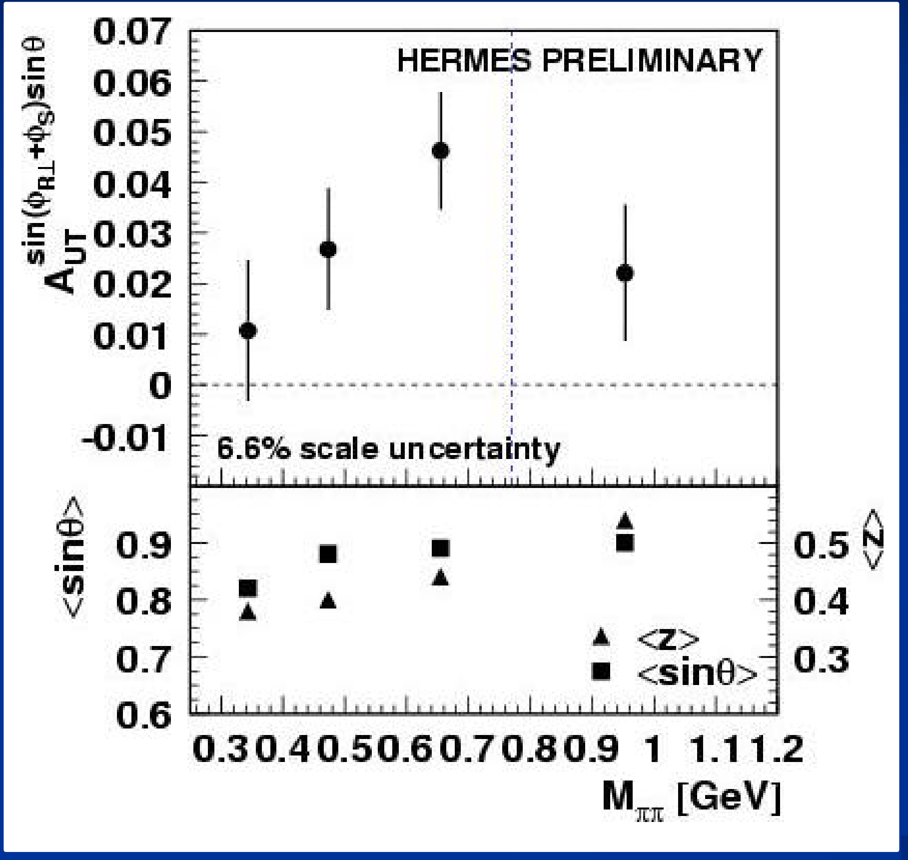
The A_{UT} asymmetry



Significant $\sin(f_R + f_S)$ behavior!

$$A_{UT}^{\sin(f_R+f_R)\sin q} = 0.040 \pm 0.009\ (\text{stat})\ \pm 0.003\ (\text{syst})$$

Invariant mass dependence



- positive asymmetry moments for all invariant mass bins
- result rules out predicted sign change at the ρ^0 mass (Jaffe et al.)

Status of the analysis

Dealing with low statistics:

- forced to integrate the asymmetry over many variables. combined with the HERMES acceptance: watch out for acceptance effects!

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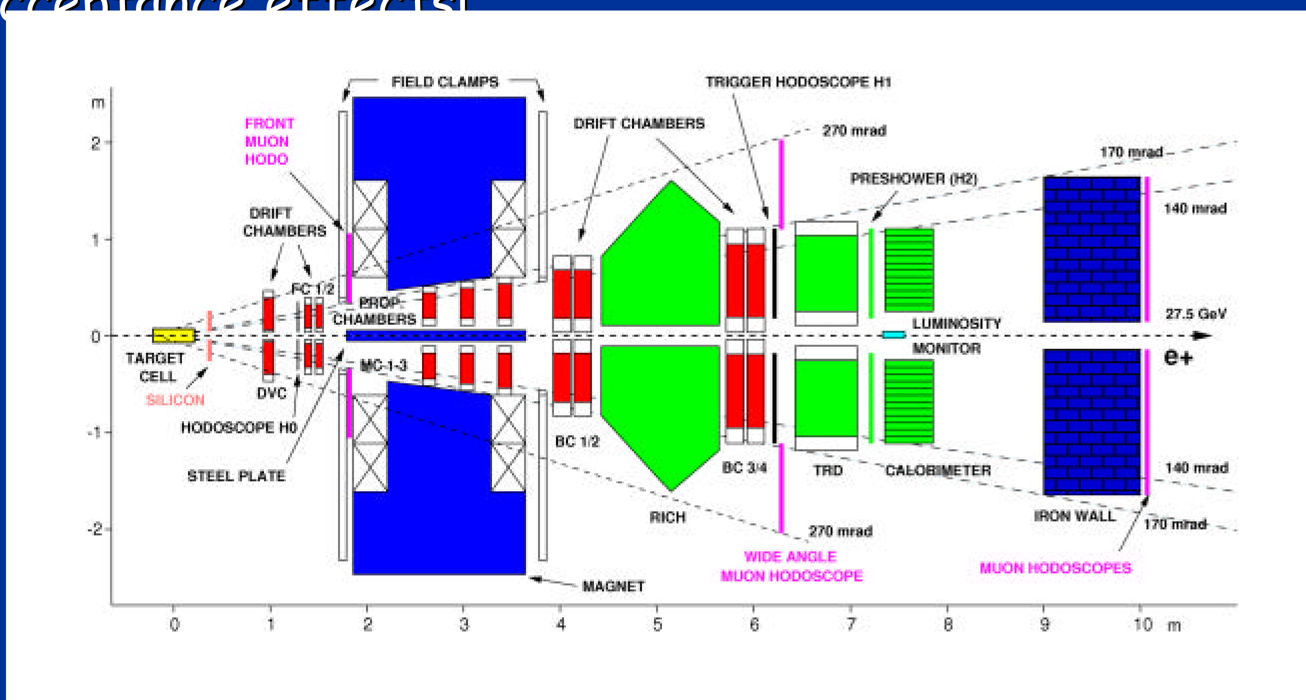

Status of the analysis

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- forced to integrate the asymmetry over many variables combined with the HERMES acceptance: watch out for acceptance effects!

  being studied using pythia MC data

- comparing different fitting methods for the extraction of the azimuthal moments:
  normal binned χ^2 fit versus unbinned max. likelihood fit

Conclusions & Outlook

Conclusions:

- A (significantly) non-zero asymmetry-moment has been measured providing evidence for a non-zero interference fragmentation function.
- This also implies that interference fragmentation can be used to study transversity!
- The new results using a transversely polarized hydrogen target rule out the invariant mass behavior as predicted by R. Jaffe.

Outlook:

- Increase the statistics using the 2005 data
- Extract asymmetry moment relating to $H_1^{\sphericalangle, pp}$
- Extract quantitative information on $h_1 H_1^{\sphericalangle}$