

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

h_1 couples to $H_1^\perp(z, z^2 k_T^2)$

$$\mathcal{I}[\dots] \equiv \int d^2 p_T d^2 k_T d(p_T - k_T - \frac{P_{h\perp}}{z})[\dots]$$

$$d\mathbf{S}_{UT}^{Collins} \propto \sum_q e_q^2 \sin(\mathbf{f}_h + \mathbf{f}_S) \mathcal{I} \left[\frac{\mathbf{k}_T \cdot \hat{\mathbf{P}}_{h\perp}}{M_h} h_1^q H_1^{\perp q} \right]$$

Difficulties:

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

$$d\mathbf{S}_{UT}^{Sivers} \propto \sum_q e_q^2 \sin(\mathbf{f}_h - \mathbf{f}_S) \mathcal{I} \left[\frac{\mathbf{p}_T \cdot \hat{\mathbf{P}}_{h\perp}}{M_h} f_{1T}^{\perp q} D_1^q \right]$$

h_1 couples to:

$$H_1^\perp(z, V, M_h^2, k_T^2, k_T \cdot R_T) \& H_1^{\leftarrow} (z, V, M_h^2, k_T^2, k_T \cdot R_T)$$

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

Integrate over P_h^\perp :

left with only $H_1^{\leftarrow} (z, V, M_h^2)$



$$s_{UT} \propto \sum_q e_q^2 \sin(\mathbf{f}_{R\perp} + \mathbf{f}_S) h_1 H_1^{\leftarrow}$$

Advantages:

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

Disadvantages:

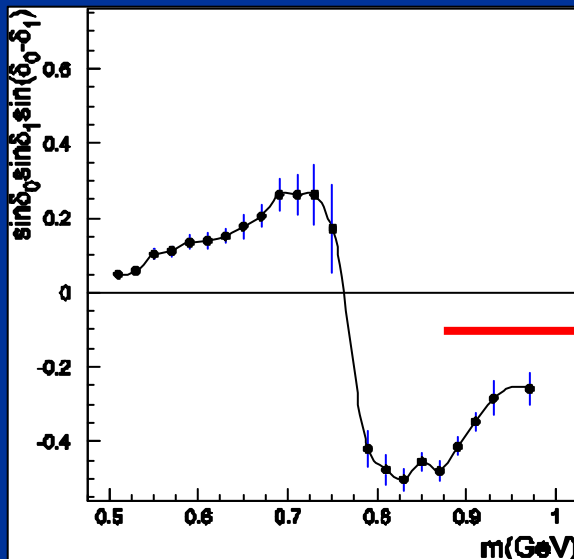
- less statistics
- H_1^{\leftarrow} unknown (but can be measured at Belle & Babar)

$$A_{UT} \sim \sin(\mathbf{f}_{R\perp} + \mathbf{f}_S) \sin q h_1 H_1^{\star}$$

Expansion of H_1^{\star} in Legendre moments:

$$H_1^{\star}(z, \cos \mathbf{q}, M_{pp}^2) = H_1^{\star, sp}(z, M_{pp}^2) + \cos \mathbf{q} H_1^{\star, pp}(z, M_{pp}^2)$$

describe interference between 2 pion pairs coming from different production channels



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

$$H_1^{\star, sp}(z, M_{pp}^2) = \sin d_0 \sin d_1 \sin(d_0 - d_1) H_1^{\star, sp'}(z, M_{pp}^2)$$

$(d_0(d_1) \rightarrow S(P)\text{-wave phase shift})$

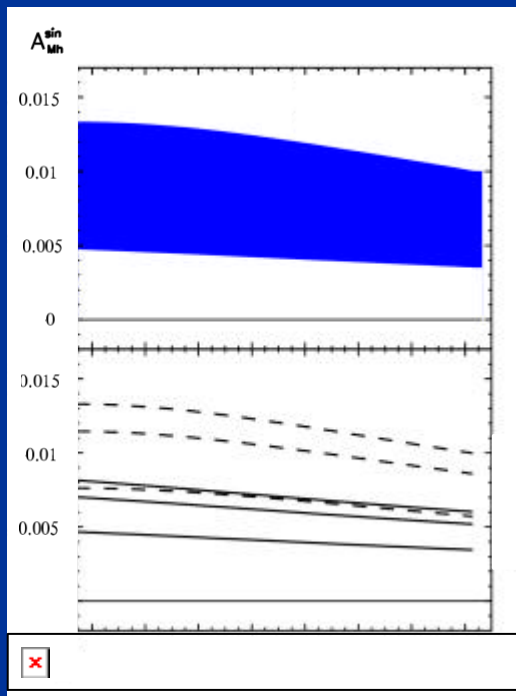
$$= \mathcal{P}(M_{pp}^2) H_1^{\star, sp'}(z, M_{pp}^2)$$

$\rightarrow A_{UT}^{\sin \mathbf{f}_{R\perp}}$ might depend strongly on M_{pp} !!

$$A_{UT} \sim \sin(\mathbf{f}_{R\perp} + \mathbf{f}_S) \sin q h_1 H_1^{\star}$$

Expansion of H_1^{\star} in Legendre moments:

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

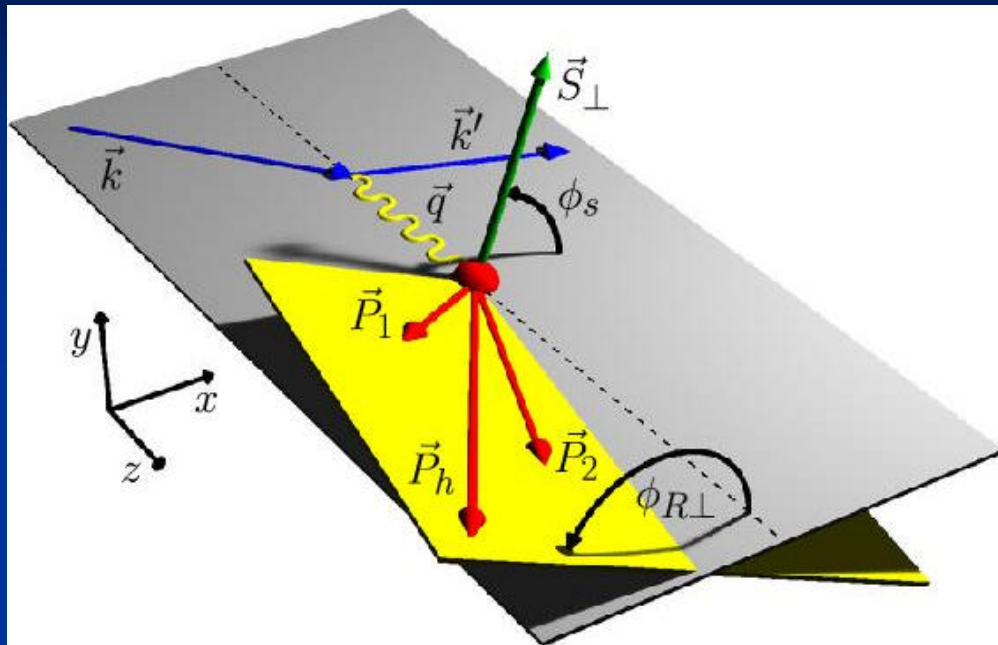
completely different model, not predicting a sign change of the asymmetry around the r_0 (times -1 \rightarrow trento conventions) based on the spectator model

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

$$\mathbf{s}_{UL} \sim \sum_q e_q^2 \sin \mathbf{f}_{R\perp} \sin \mathbf{q} \left[K_1 |S_{\parallel}| h_L - K_2 |S_{\perp}| h_1 \right] \left(H_1^{\langle,sp} + H_1^{\langle,pp} \cos \mathbf{q} \right)$$

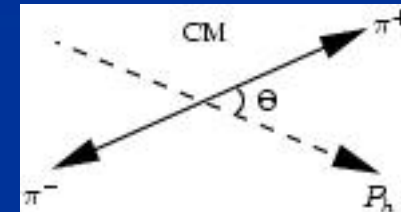
$$\begin{aligned} \mathbf{s}_{UT} \sim & \sum_q e_q^2 |S_{\perp}| \sin(\mathbf{f}_{R\perp} + \mathbf{f}_S) \sin \mathbf{q} K_3 h_1 \left(H_1^{\langle,sp} + H_1^{\langle,pp} \cos \mathbf{q} \right) \\ & + K_4 \sin \mathbf{f}_S (\dots) \end{aligned}$$

$$\begin{aligned}
 d^9 \mathbf{s}_{UT} = & \sum_a \frac{\mathbf{a}^2 e_a^2}{2pQ^2 y} |\bar{S}_T| A(y) \left\{ \frac{|\bar{R}_T|}{M_h} \sin(\mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{\bar{p}_T \cdot \bar{k}_T}{2MM_h} g_{1T} G_1^\perp \right] \right. \\
 & - \frac{|\bar{R}_T|}{M_h} \cos(\mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{k}_T) - (\bar{k}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{p}_T)}{2MM_h} g_{1T} G_1^\perp \right] \\
 & - \frac{|\bar{R}_T|}{M_h} \sin(2\mathbf{j}_h - \mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{2(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{k}_T \cdot \bar{P}_{h\perp}) - \bar{p}_T \cdot \bar{k}_T}{2MM_h} g_{1T} G_1^\perp \right] \\
 & - \frac{|\bar{R}_T|}{M_h} \cos(2\mathbf{j}_h - \mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{k}_T) + (\bar{k}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{p}_T)}{2MM_h} g_{1T} G_1^\perp \right] \\
 & + \sin(\mathbf{j}_h - \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{p}_T \cdot \bar{P}_{h\perp})}{M} f_{1T}^\perp D_1 \right] + \cos(\mathbf{j}_h - \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{P}_{h\perp} \times \bar{p}_T)}{M} f_{1T}^\perp D_1 \right] \left. \right\} \\
 & + \sum_a \frac{\mathbf{a}^2 e_a^2}{2pQ^2 y} |\bar{S}_T| B(y) \left\{ \sin(\mathbf{j}_h + \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{k}_T \cdot \bar{P}_{h\perp})}{M_h} h_1 H_1^\perp \right] \right. \\
 & + \cos(\mathbf{j}_h + \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{P}_{h\perp} \times \bar{k}_T)}{M_h} h_1 H_1^\perp \right] + \frac{|\bar{R}_T|}{M_h} \sin(\mathbf{j}_R + \mathbf{j}_S) \mathcal{I} \left[h_1 \bar{H}_1^\perp \right] + 3 \sin(3\mathbf{f}_h - \mathbf{f}_S) \\
 & \times \mathcal{I} \left[\frac{4(\bar{p}_T \cdot \bar{P}_{h\perp})^2 (\bar{k}_T \cdot \bar{P}_{h\perp}) - 2(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{p}_T \cdot \bar{k}_T) - \bar{p}_T^2 (\bar{k}_T \cdot \bar{P}_{h\perp})}{2M^2 M_h} h_{1T}^\perp H_1^\perp \right] \\
 & + \cos(3\mathbf{j}_h - \mathbf{j}_S) \mathcal{I} \left[\frac{2(\bar{p}_T \cdot \bar{P}_{h\perp})^2 (\bar{P}_{h\perp} \times \bar{k}_T) + 2(\bar{k}_T \cdot \bar{P}_{h\perp})(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{p}_T)}{2M^2 M_h} \right. \\
 & \left. - \frac{\bar{p}_T^2 (\bar{P}_{h\perp} \times \bar{k}_T)}{2M^2 M_h} \right] h_{1T}^\perp H_1^\perp + \frac{|\bar{R}_T|}{M_h} \sin(2\mathbf{j}_h + \mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{2(\bar{p}_T \cdot \bar{P}_{h\perp})^2 - \bar{p}_T^2}{2M^2} h_{1T}^\perp \bar{H}_1^\perp \right] \\
 & \left. + \frac{|\bar{R}_T|}{M_h} \cos(2\mathbf{j}_h + \mathbf{j}_R - \mathbf{j}_S) \mathcal{I} \left[\frac{(\bar{p}_T \cdot \bar{P}_{h\perp})(\bar{P}_{h\perp} \times \bar{p}_T)}{2M^2} h_{1T}^\perp \bar{H}_1^\perp \right] \right\}
 \end{aligned}$$



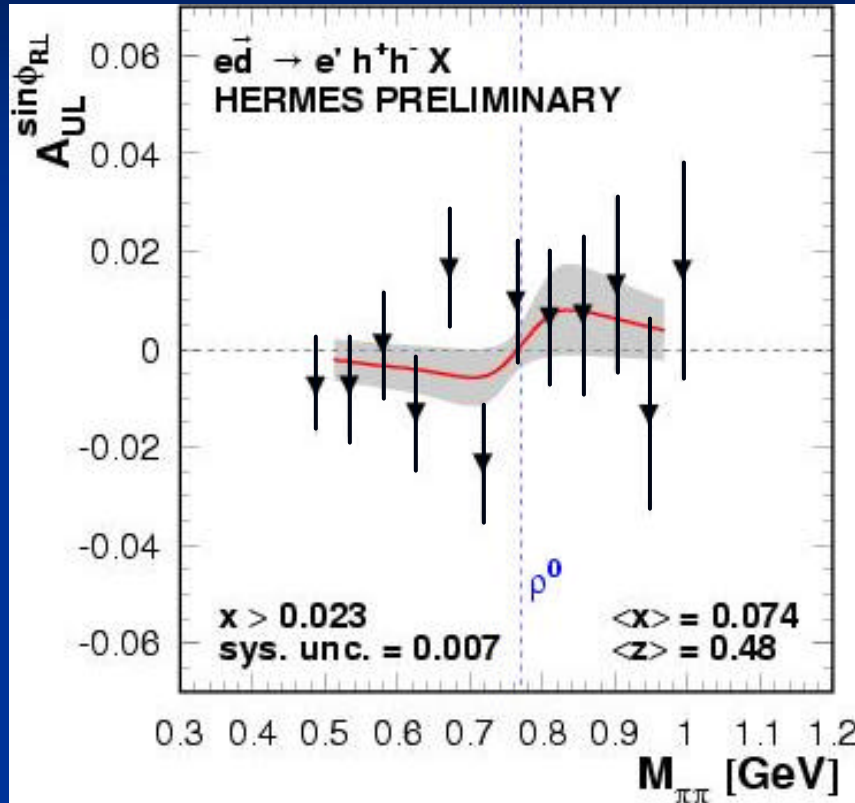
transversely polarized hydrogen target

$$\vec{P}_{||} \equiv \vec{P}_1 + \vec{P}_2$$



What is measured:

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

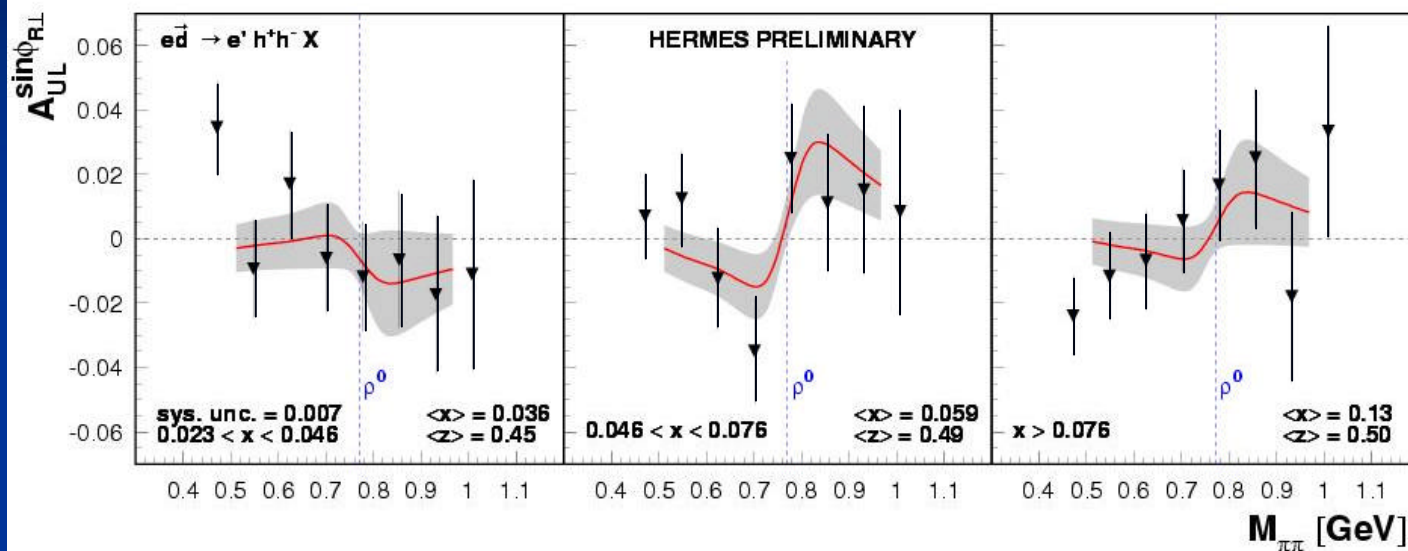


$$c_1 = -0.040 \pm 0.036$$

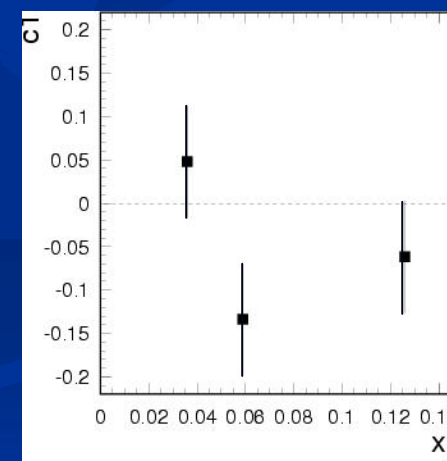
$$c_2 = -0.001 \pm 0.004$$

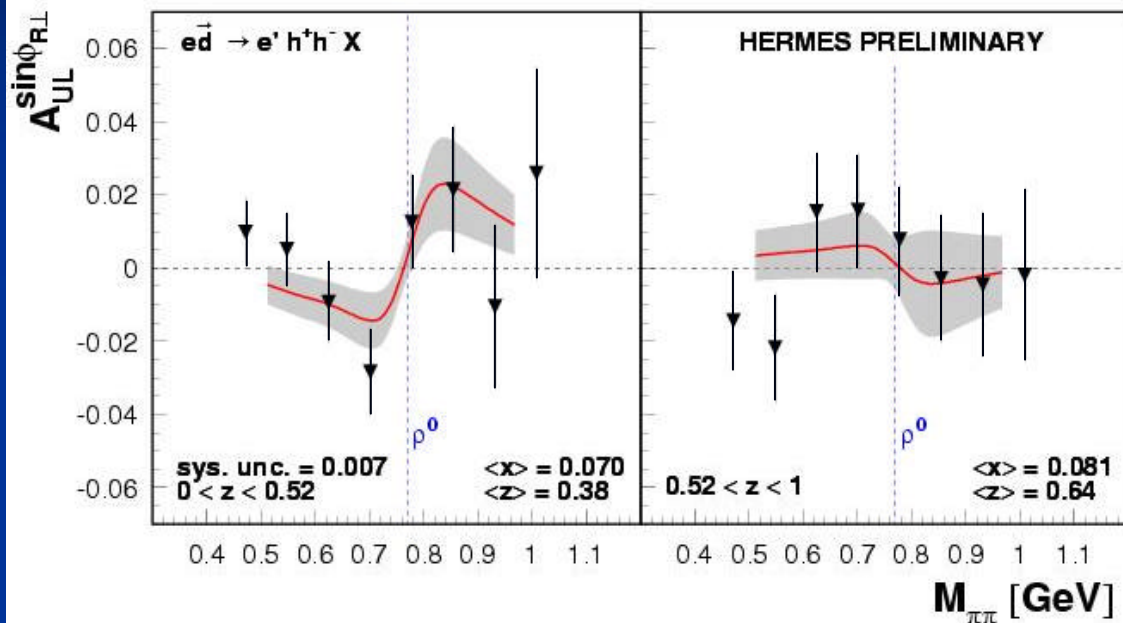
$$g(M_{pp}^2) \approx c_1 \mathcal{P}(M_{pp}^2) + c_2$$

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

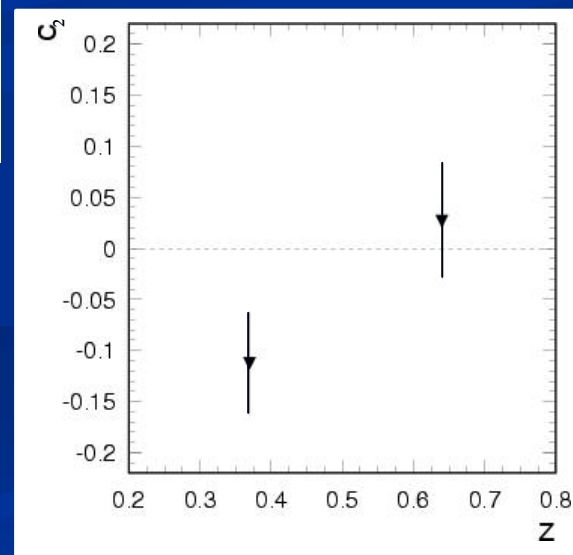


- higher x : hint of sign change at ρ^0 mass according to Jaffe's model
- $c_1(x) \propto h_1(x)$?

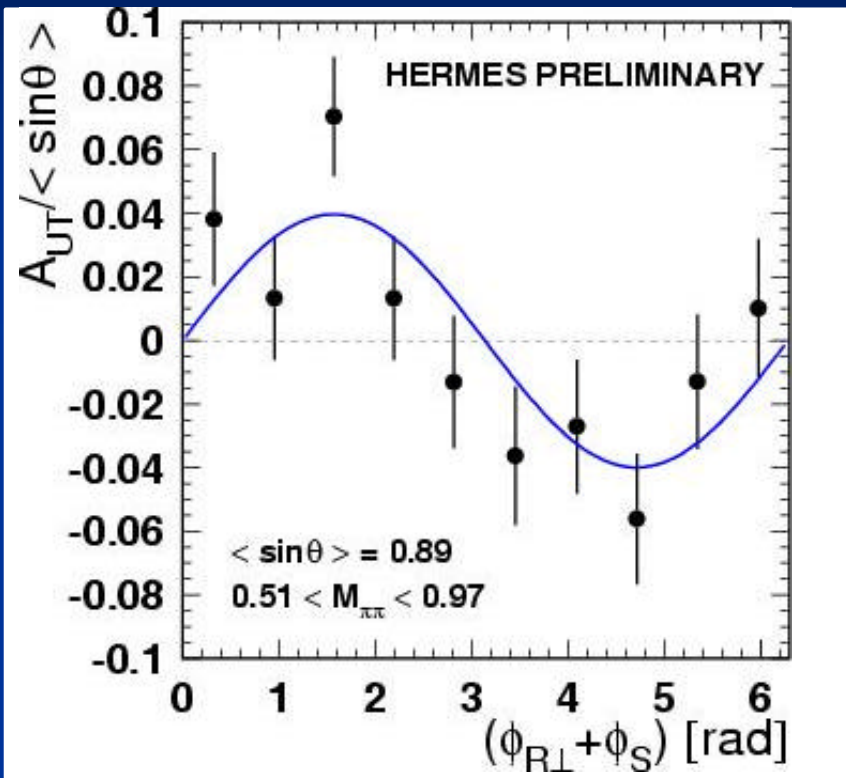




- sign change at ρ^0 according to Jaffe's model for low z
- $c_2(z) \propto H_1^{\chi, sp}(z, M_{pp})$

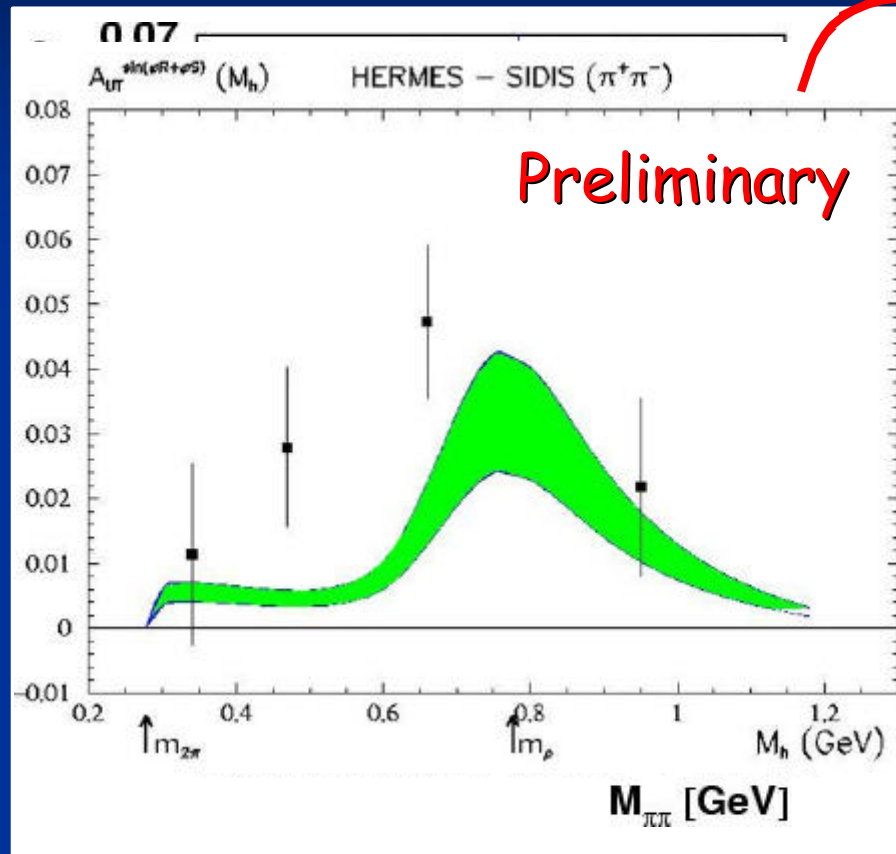


The A_{UT} asymmetry



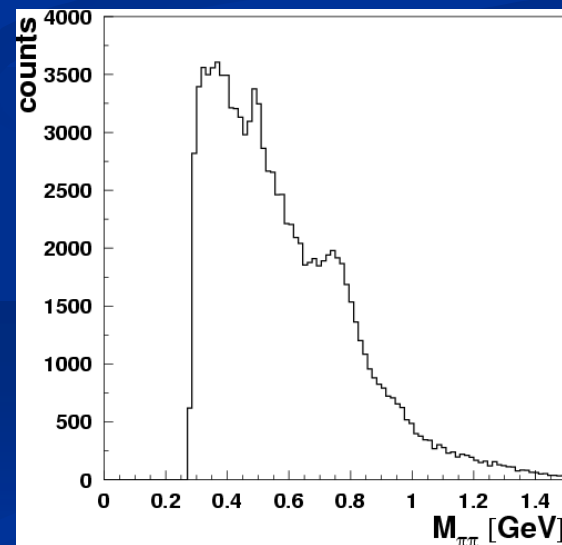
Significant $\sin(\mathbf{f}_R + \mathbf{f}_S)$ behavior!

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



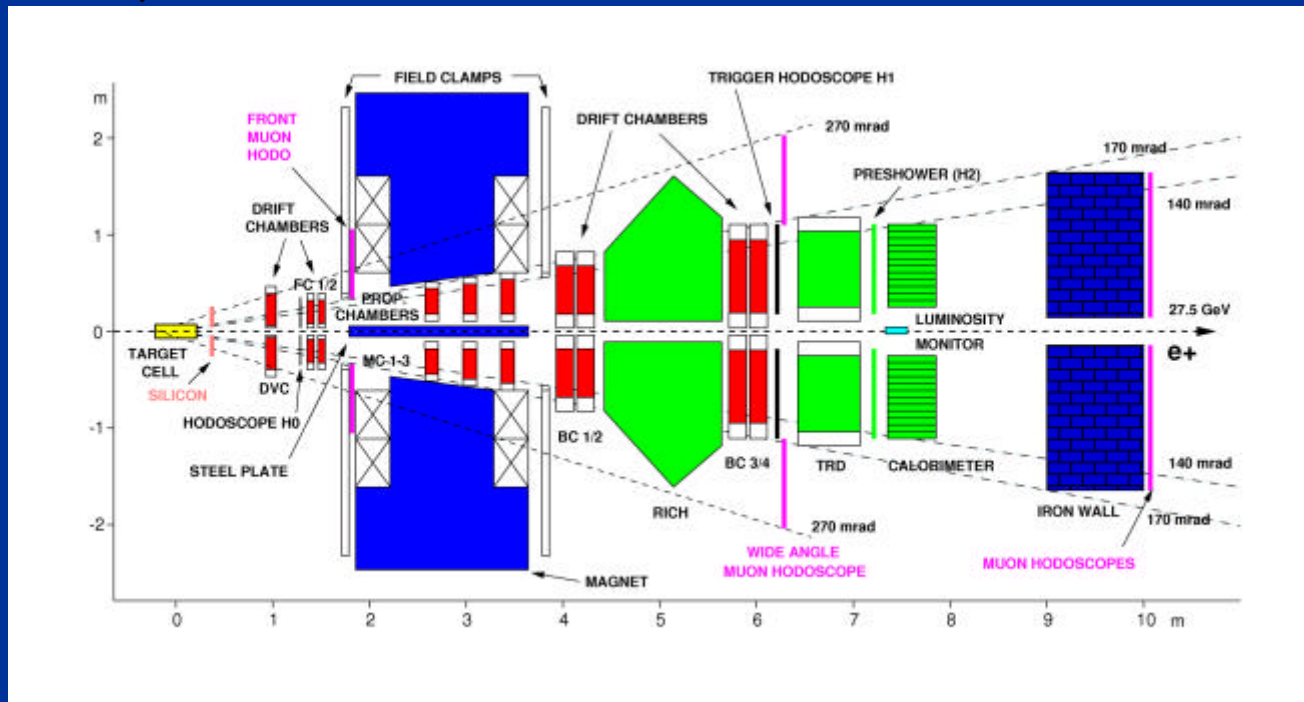
see f.i. M. Radici, hep-ph/0510165

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



Dealing with low statistics:

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



tion of the
fit

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 $H_1^{\langle,PP}$
- Extract quantitative information on $h_1H_1^{\langle}$