First measurement of interference fragmentation on a transversely polarized hydrogen target at HERMES

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On behalf of the HERMES collaboration

Layout:

h_1

Introduction - 1π fragmentation

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

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

$$d\sigma_{UT}^{\text{Collins}} \propto \sum_q e_q^2 \sin(\phi_h + \phi_S)\mathcal{I}\left[\frac{\boldsymbol{k}_T \cdot \hat{\boldsymbol{P}}_{h\perp}}{M_h} h_1^q H_1^{\perp q}\right]$$

Difficulties:

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

$$d\sigma_{UT}^{\text{Sivers}} \propto \sum_q e_q^2 \sin(\phi_h - \phi_S)\mathcal{I}\left[\frac{\boldsymbol{p}_T \cdot \hat{\boldsymbol{P}}_{h\perp}}{M} f_{1T}^{\perp q} D_1^q\right]$$

Introduction - 2π fragmentation

h_1 couples to:

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

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

Integrate over $\boldsymbol{P}_{h\perp}$:

left with only $H_1^{\sphericalangle}(z,\zeta,M_h^2)$ $\Longrightarrow$ $\sigma_{UT} \propto \sum_q e_q^2 \sin(\phi_{R\perp}+\phi_S) h_1 H_1^{\sphericalangle}$

Advantages:

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

Disadvantages:

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

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Interference FF

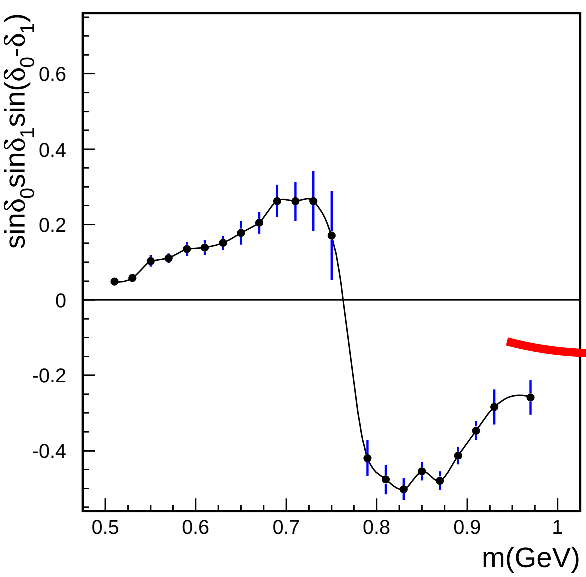
$$A_{UT} \sim \sin(\phi_{R\perp} + \phi_S) \sin\theta h_1 H_1^{\sphericalangle}$$

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

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

describe interference between 2 pion pairs coming from different production channels.

about $H_1^{\sphericalangle, sp}$:



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

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

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

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

$\Longrightarrow A_{UL}^{\sin\phi_{R\perp}}$ might depend stongly on $M_{\pi\pi}$

Interference FF

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

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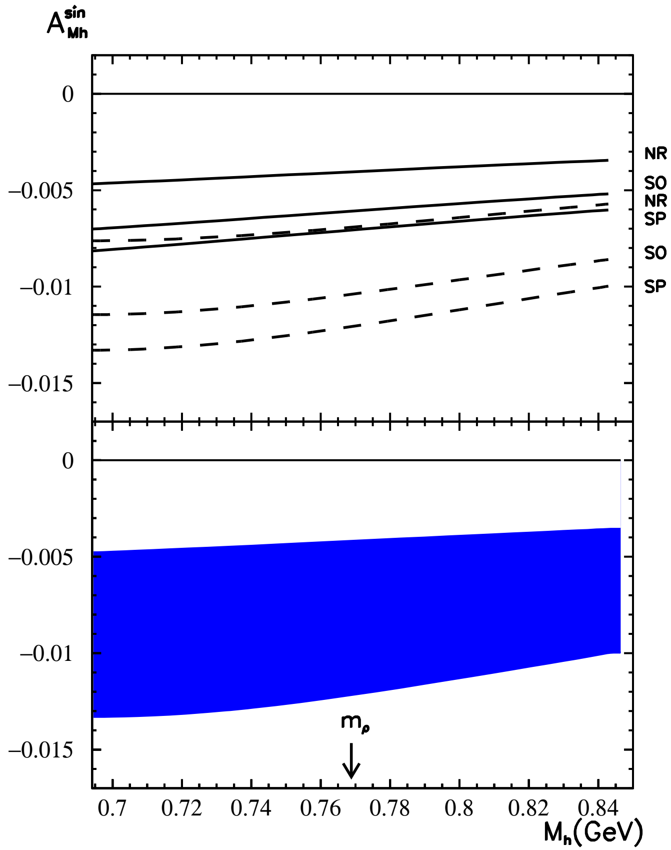

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Radici et al. [**hep-ph/0110252**]:

- completely different model, not predicting a sign change of the asymmetry

before integration over $P_{h\perp}$

Bacchetta et al. [hep-ph/0212300]

$$
\begin{aligned}
d^9\sigma_{OT} \;=\; & \sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y}\,|\vec S_T|\,A(y)\left\{\frac{|\vec R_T|}{M_h}\,\sin(\phi_R-\phi_S)\,\mathcal{I}\left[\frac{\vec p_T\cdot\vec k_T}{2MM_h} g_{1T}\,G_1^{\perp}\right]\right.\\
& -\frac{|\vec R_T|}{M_h}\,\cos(\phi_R-\phi_S)\,\mathcal{I}\left[\frac{(\vec p_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec k_T)-(\vec k_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec p_T)}{2MM_h} g_{1T}\,G_1^{\perp}\right]\\
& -\frac{|\vec R_T|}{M_h}\,\sin(2\phi_h-\phi_R-\phi_S)\,\mathcal{I}\left[\frac{2(\vec p_T\cdot\hat P_{h\perp})(\vec k_T\cdot\hat P_{h\perp})-\vec p_T\cdot\vec k_T}{2MM_h}\,g_{1T}\,G_1^{\perp}\right]\\
& -\frac{|\vec R_T|}{M_h}\,\cos(2\phi_h-\phi_R-\phi_S)\,\mathcal{I}\left[\frac{(\vec p_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec k_T)+(\vec k_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec p_T)}{2MM_h}\,g_{1T}\,G_1^{\perp}\right]\\
& \left.+\sin(\phi_h-\phi_S)\,\mathcal{I}\left[\frac{\vec p_T\cdot\hat P_{h\perp}}{M}\,f_{1T}^{\perp}\,D_1\right]+\cos(\phi_h-\phi_S)\,\mathcal{I}\left[\frac{\hat P_{h\perp}\wedge\vec p_T}{M}\,f_{1T}^{\perp}\,D_1\right]\right\}\\
& +\sum_a \frac{\alpha^2 e_a^2}{2\pi Q^2 y}\,|\vec S_T|\,B(y)\left\{\sin(\phi_h+\phi_S)\,\mathcal{I}\left[\frac{\vec k_T\cdot\hat P_{h\perp}}{M_h}\,h_1\,H_1^{\perp}\right]\right.\\
& +\cos(\phi_h+\phi_S)\,\mathcal{I}\left[\frac{\hat P_{h\perp}\wedge\vec k_T}{M_h}\,h_1\,H_1^{\perp}\right]+\boxed{\frac{|\vec R_T|}{M_h}\,\sin(\phi_R+\phi_S)\,\mathcal{I}\left[h_1\,\bar H_1^{\triangleleft}\right]}+\sin(3\phi_h-\phi_S)\\
& \times\mathcal{I}\left[\frac{4(\vec p_T\cdot\hat P_{h\perp})^2(\vec k_T\cdot\hat P_{h\perp})-2(\vec p_T\cdot\hat P_{h\perp})(\vec p_T\cdot\vec k_T)-\vec p_T^{\,2}(\vec k_T\cdot\hat P_{h\perp})}{2M^2M_h}\,h_{1T}^{\perp}\,H_1^{\perp}\right]\\
& +\cos(3\phi_h-\phi_S)\,\mathcal{I}\left[\left(\frac{2(\vec p_T\cdot\hat P_{h\perp})^2(\hat P_{h\perp}\wedge\vec k_T)+2(\vec k_T\cdot\hat P_{h\perp})(\vec p_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec p_T)}{2M^2M_h}\right.\right.\\
& \left.\left.-\frac{\vec p_T^{\,2}(\hat P_{h\perp}\wedge\vec k_T)}{2M^2M_h}\right)h_{1T}^{\perp}\,H_1^{\perp}\right]+\frac{|\vec R_T|}{M_h}\,\sin(2\phi_h+\phi_R-\phi_S)\,\mathcal{I}\left[\frac{2(\vec p_T\cdot\hat P_{h\perp})^2-\vec p_T^{\,2}}{2M^2}\,h_{1T}^{\perp}\,\bar H_1^{\triangleleft}\right]\\
& \left.+\frac{|\vec R_T|}{M_h}\,\cos(2\phi_h+\phi_R-\phi_S)\,\mathcal{I}\left[\frac{(\vec p_T\cdot\hat P_{h\perp})(\hat P_{h\perp}\wedge\vec p_T)}{2M^2}\,h_{1T}^{\perp}\,\bar H_1^{\triangleleft}\right]\right\}
\end{aligned}
$$

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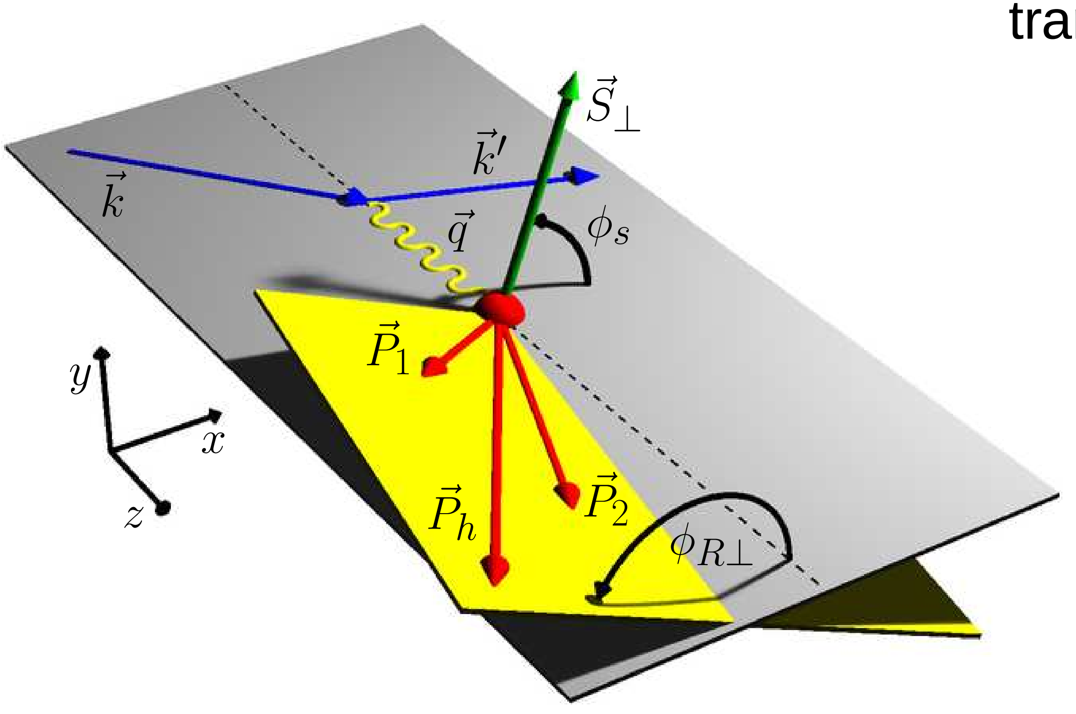
The polarized cross sections

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

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

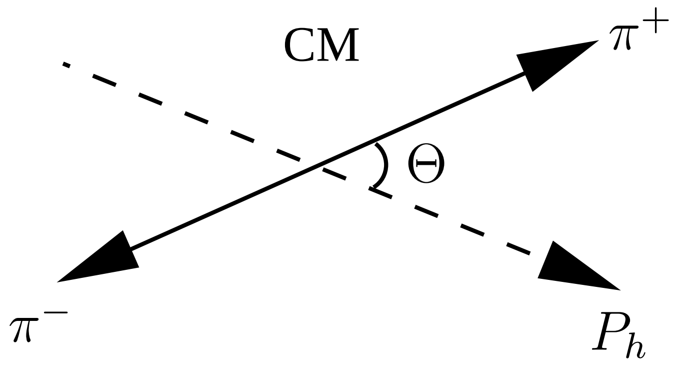
$$\sigma_{UT} \sim \sum_q e_q^2 |\boldsymbol{S}_\perp| \sin(\phi_{R\perp} + \phi_S) \sin\theta K_3 h_1 \left(H_1^{\sphericalangle,sp} + H_1^{\sphericalangle,pp} \cos\theta\right)$$
$$+ K_4 \sin\phi_S (\dots)$$

Single Spin Asymmetry



transversely polarized hydrogen target

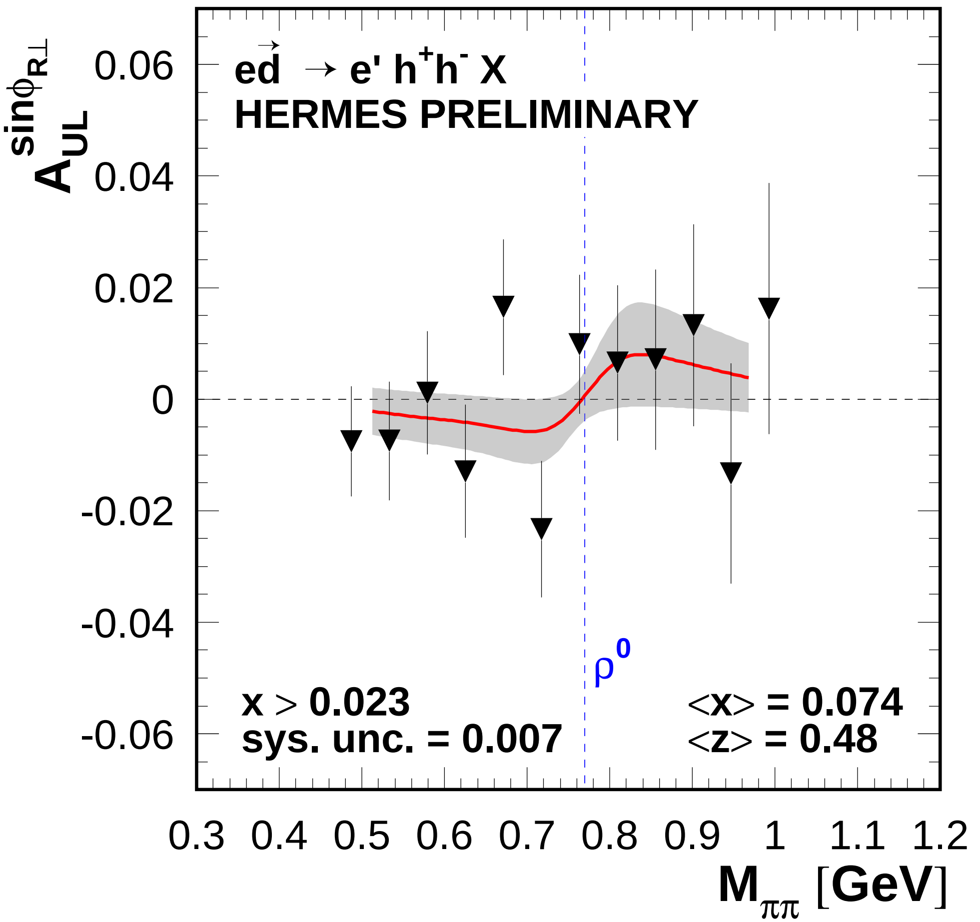
$$\vec{P}_h \equiv \vec{P}_1 + \vec{P}_2$$



What is measured:

$$A_{UT}(\phi_{R\perp}, \phi_S, \theta) = \frac{1}{|S_T|} \frac{N^\uparrow(\phi_{R\perp}, \phi_S, \theta)/N^\uparrow_{\mathrm{DIS}} - N^\downarrow(\phi_{R\perp}, \phi_S, \theta)/N^\downarrow_{\mathrm{DIS}}}{N^\uparrow(\phi_{R\perp}, \phi_S, \theta)/N^\uparrow_{\mathrm{DIS}} + N^\downarrow(\phi_{R\perp}, \phi_S, \theta)/N^\downarrow_{\mathrm{DIS}}}$$

longitudinally polarized deuterium



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

- hint of a sign change at the ρ^0 mass

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

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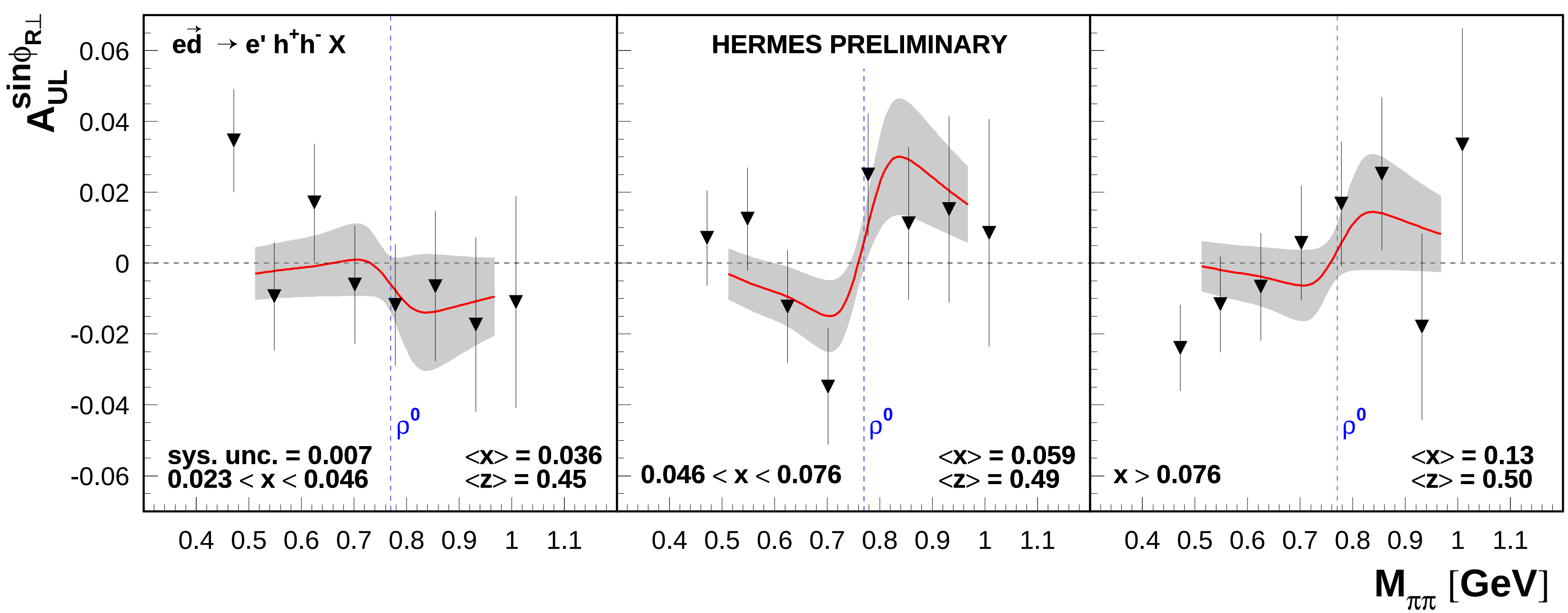
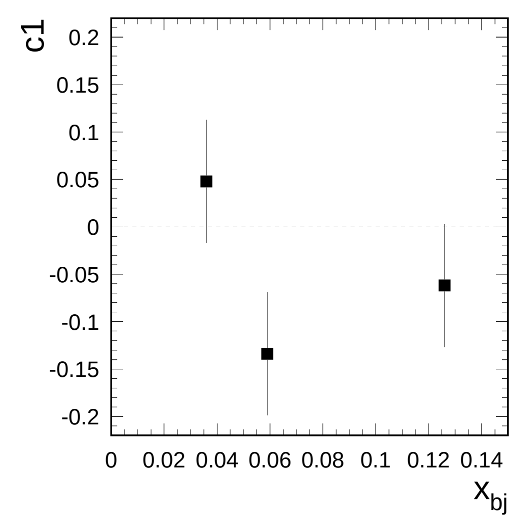
long. pol. deuterium, x-dependence



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



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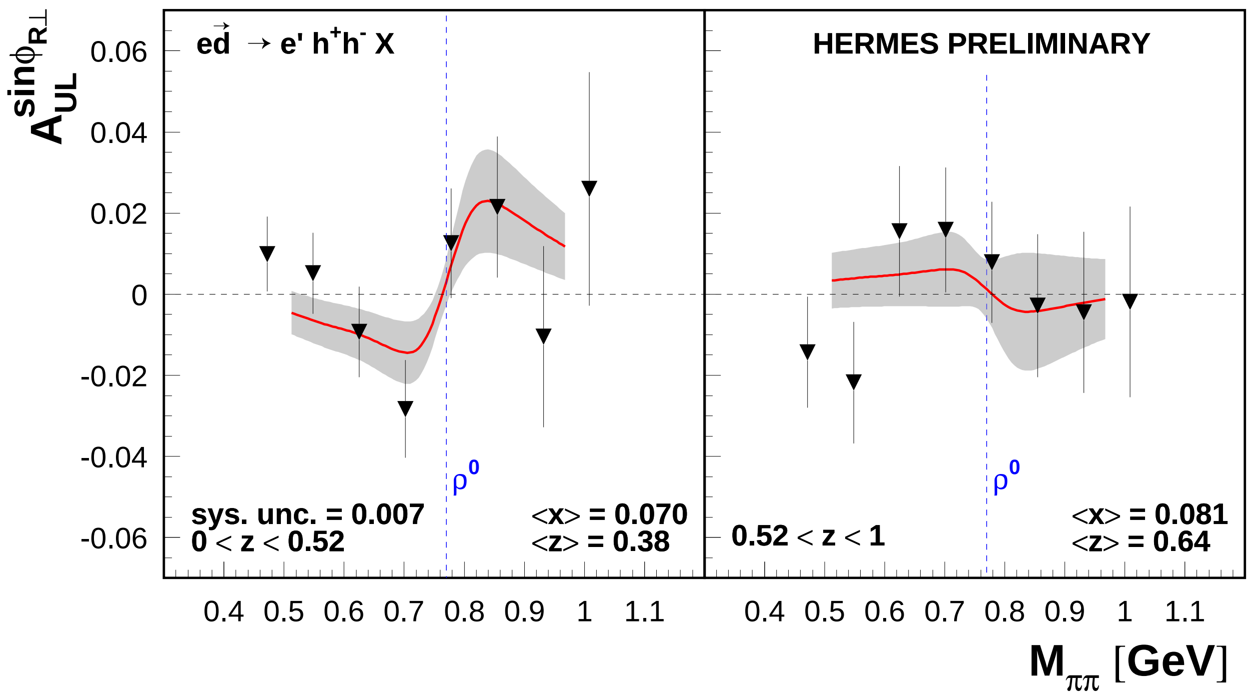
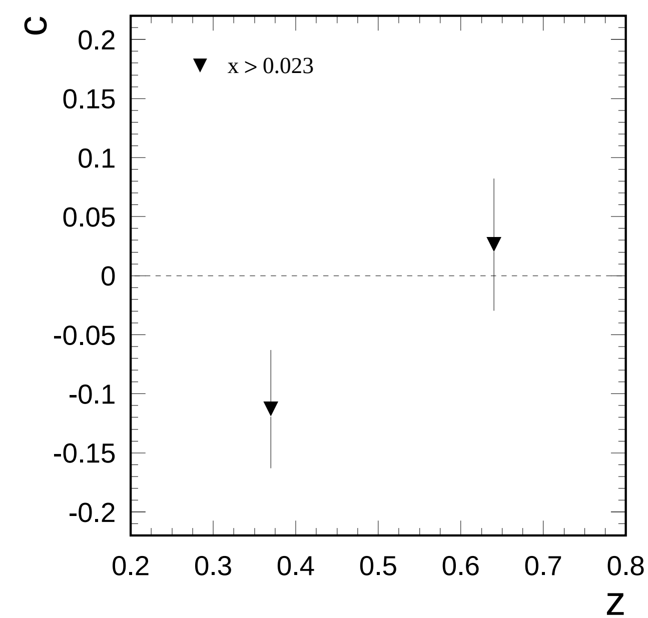
long. pol. deuterium, z-dependence



- sign change at ρ^0 according to Jaffe's model for low z
- $c_1(z) \propto H_1^{\sphericalangle,sp}(z, M_{\pi\pi})$?



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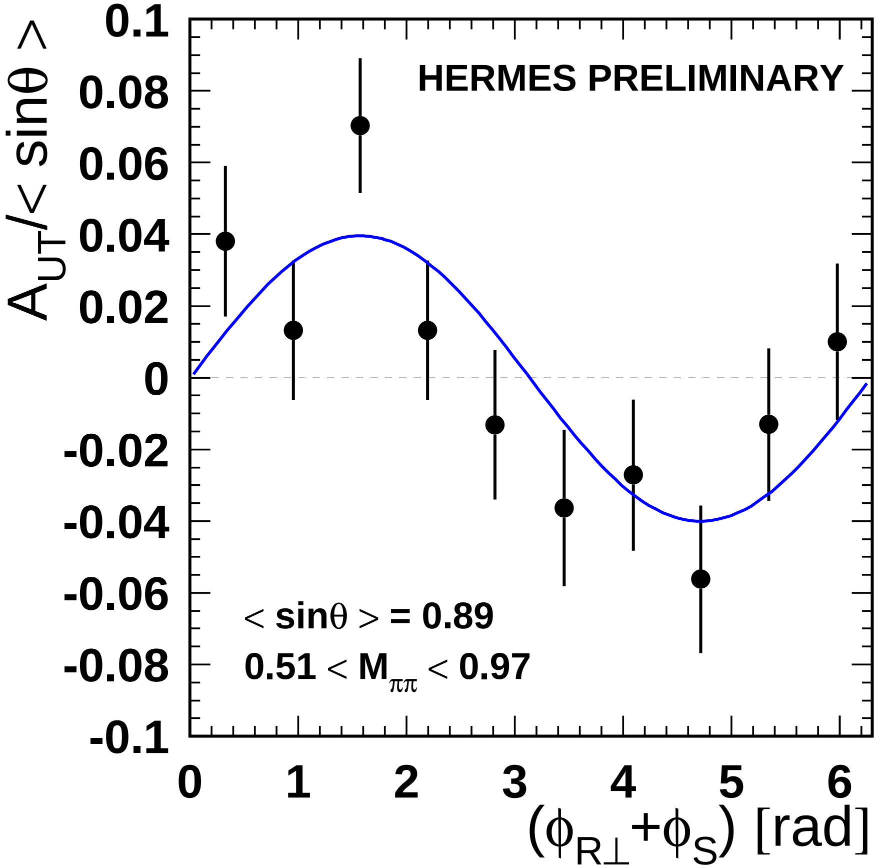
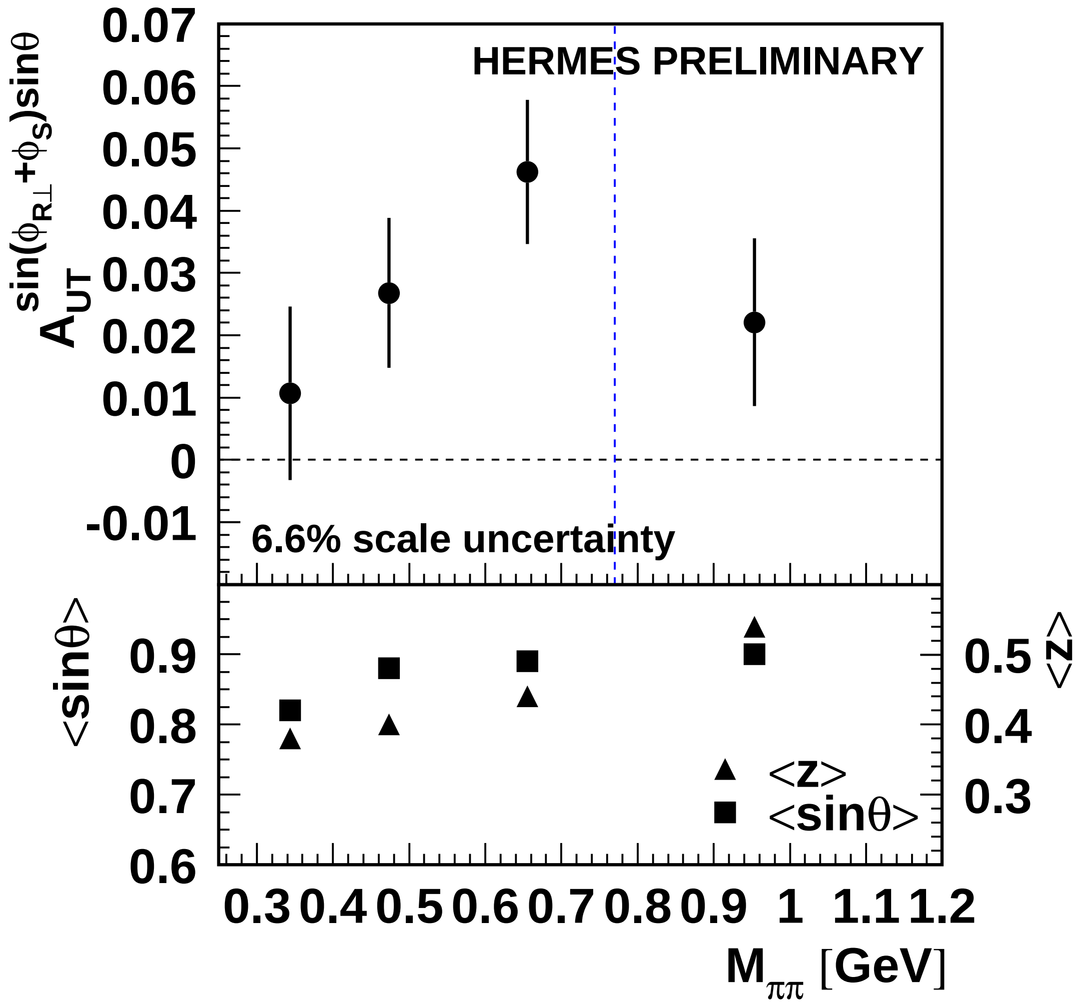
The A_{UT} asymmetry



significant $\sin(\phi_{R\perp} + \phi_S)$ behavior!

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = 0.040 \pm 0.009 \text{ (stat)} \pm 0.003 \text{ (syst)}$$

Invariant Mass Dependence



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

Where the following binning was used: 0.25 - 0.40 - 0.55 - 0.77 - 2.0

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Conlusions:

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

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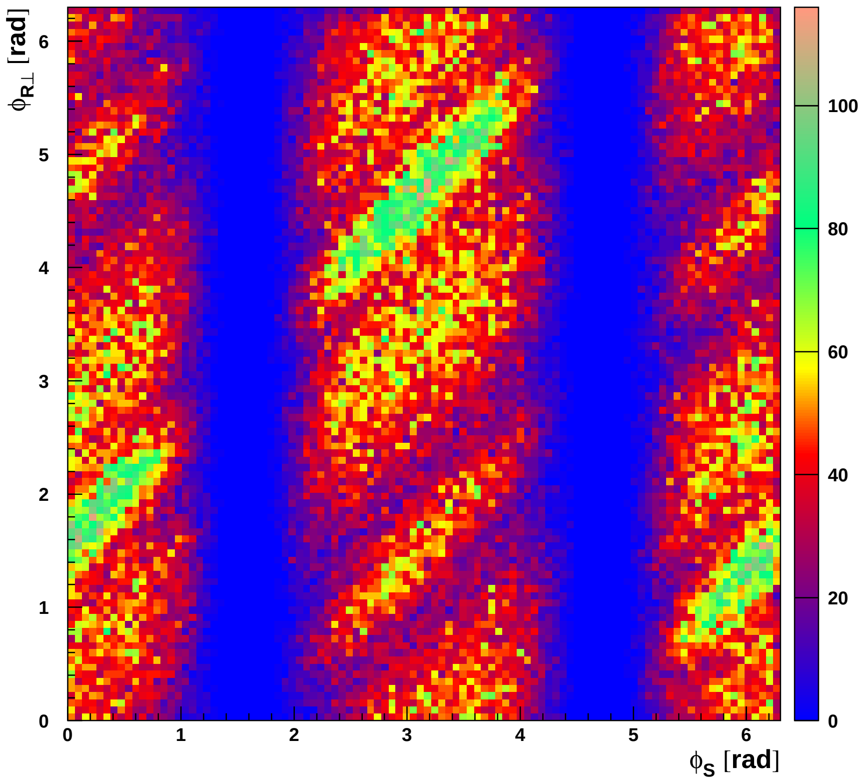
Angle Distribution - $(\phi_{R\perp}, \phi_S)$



Correlation in the $(\phi_{R\perp}, \phi_S)$ distribution due to HERMES acceptance & spectrometer magnet fi eld

Monte Carlo studies show: no fake asymmetries due to these correlations