Single-spin asymmetries in two hadron production of polarized deep inelastic scattering at HERMES

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for the HERMES collaboration

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- The HERMES experiment
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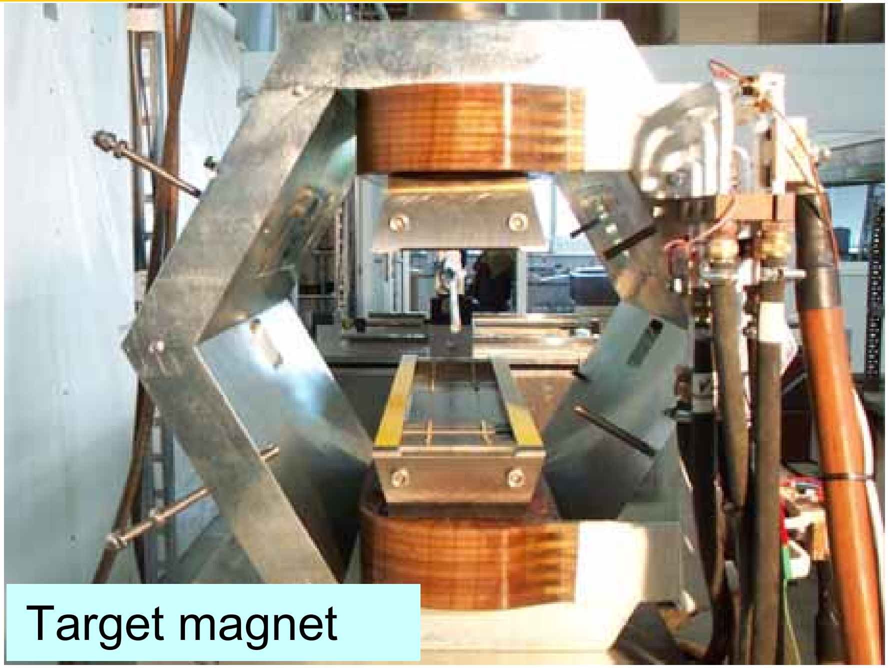
HERMES experiment at DESY



positron (electron) beam

27.6 [GeV]

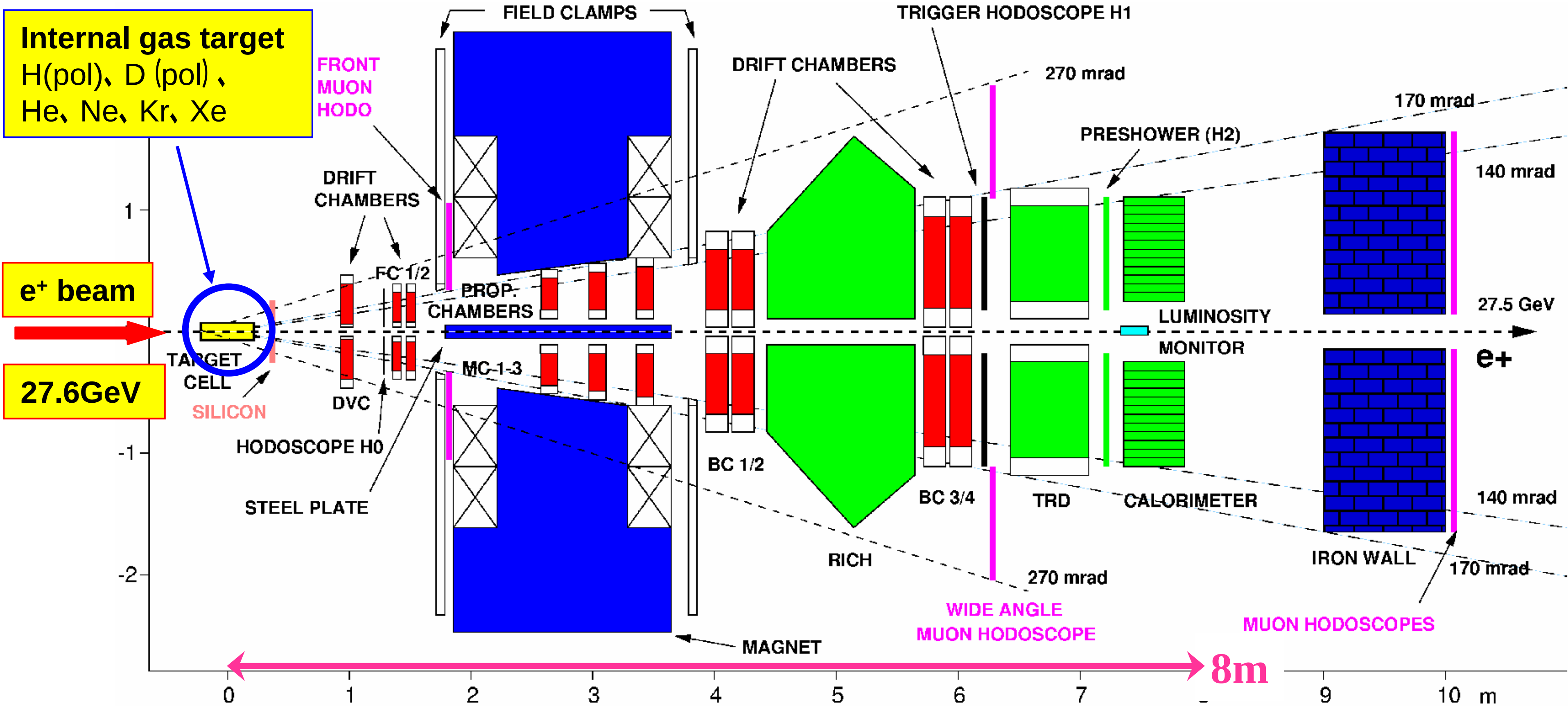
current ~ 30[mA]

Transversely polarized hydrogen target (2002~2005)

polarization ~ 75[%]

$$e + p^{\uparrow} \rightarrow e + \pi^{+} + \pi^{-} + X$$

HERMES Spectrometer



- acceptance : 40 mrad ≦Θ≦ 220 mrad
- Tracking resolution：δP/P = (0.7-1.3)%、δΘ = 0.6 mrad
- PID：Hodoscope、Calorimeter、TRD and RICH
  Lepton ID efficiency > **97%,** Hadron contamination < **1%**
  Hadron ID**(**π, K, P) at 2-15 GeV/c

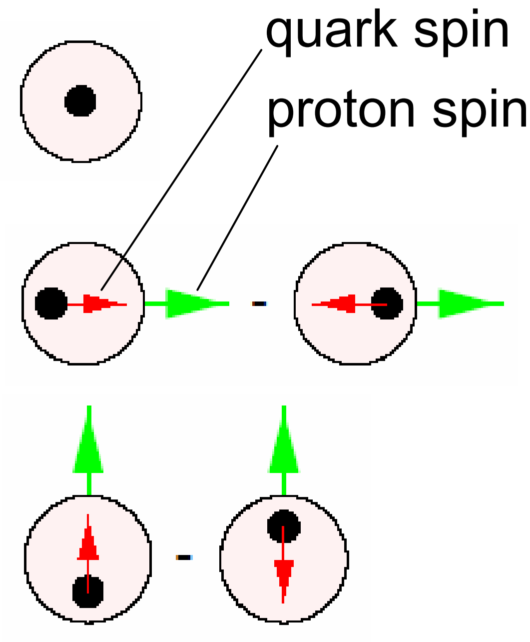
Quark distribution functions

At leading twist

Quark momentum distribution: $q(x) =$

Quark Helicity: $\Delta q(x) =$

Quark Transversity: $\delta q(x) =$



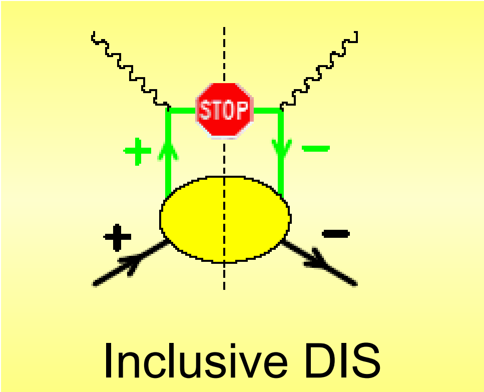
$\delta q(x)$: unknown
chiral odd

- quark's relativistic nature $\Rightarrow \delta q(x) \neq \Delta q(x)$
- positivity bound : $|\delta q(x)| \leq q(x)$

  Soffer bound : $|\delta q(x)| \leq \frac{1}{2}[q(x) + \Delta q(x)]$

Access to transversity

$\delta q(x)$: chiral odd $\Rightarrow$ Need another chiral odd objects.



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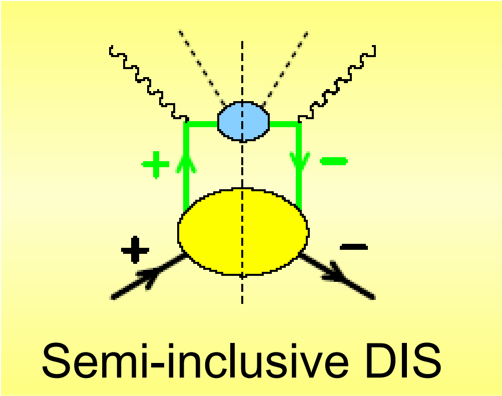


accessible

Transversity $\delta q(x)$ couples to …

- Collins fragmentation function (FF)
- 2-hadron interference FF
- Polarized Lambda FF
- Spin-1 FF

:

Single-spin asymmetry of 2-hadron production

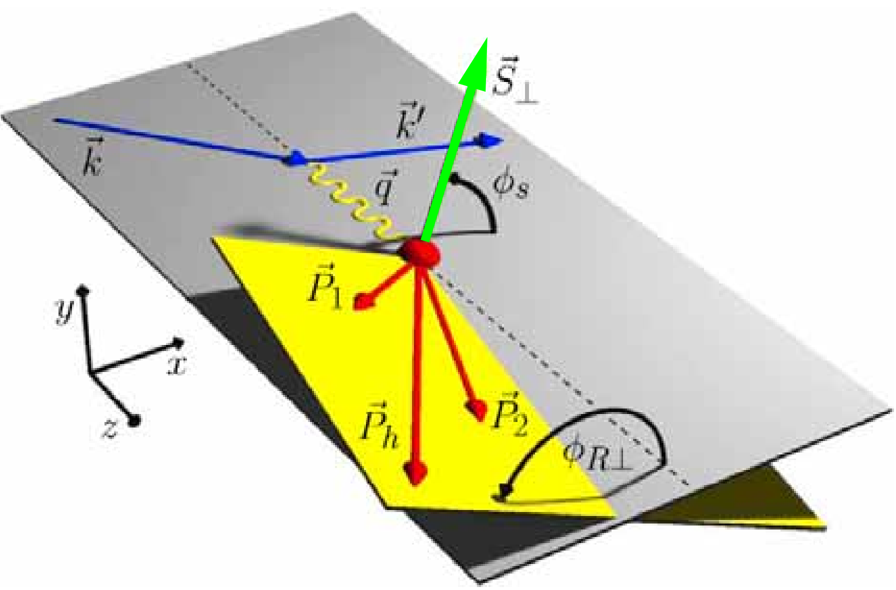
Azimuthal single-spin asymmetries (data taken in 2002…2004)

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

beam spin (U), target spin (T)

$$\sim \sin(\phi_{R\perp}+\phi_S)\sin\theta\ \delta q(x) H_1^{\sphericalangle}(z)$$

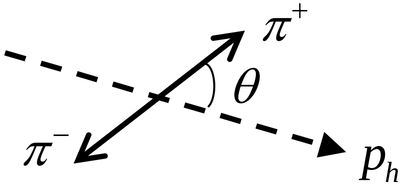
Transversity ($\delta q(x)$) Interference FF (chiral odd) ($H_1^{\sphericalangle}(z)$)



$$e(k)+p^{\uparrow} \rightarrow e(k')+\pi^{+}(P_1)+\pi^{-}(P_2)+X$$

$\delta q(x)$ can be extracted using $H_1^{\sphericalangle}(z)$ measured by $e^+ e^-$ collider, BELLE

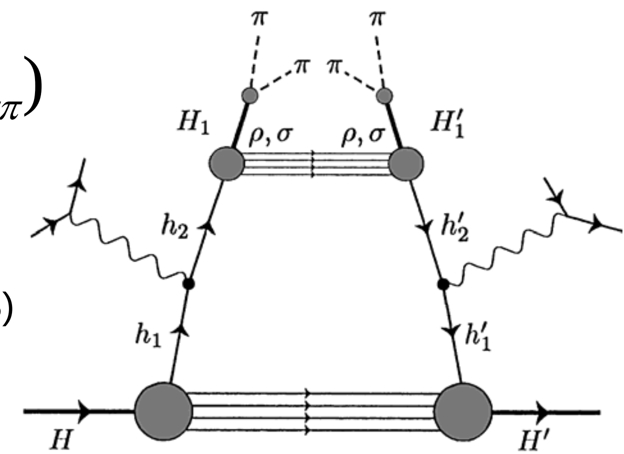
$H_1^{\sphericalangle}(z)$ describes interference between different production channels of pion pairs



$H_1^{\sphericalangle}$: s-p wave interference in $\pi\ \pi$ scattering theory

Partial wave expansion

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

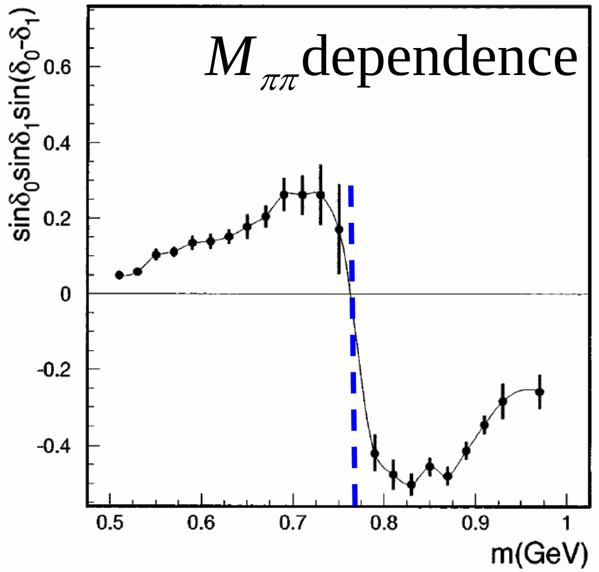


$M_{\pi\pi}$ dependence of Interference FF

R. L. Jaffe, Xuemin Jin, and Jian Tan, Phys. Rev. Lett. 80, 1166 (1998)

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

$\pi\pi$ phase shift analysis using $\pi^- p\rightarrow\pi^-\pi^+ n$ scattering



P. Estabrooks and A. D. Martin, Nucl. Phys. B79, 301 (1974)

Sign of the phase shift changes at $M_{\pi\pi}=M_{\rho 0}$

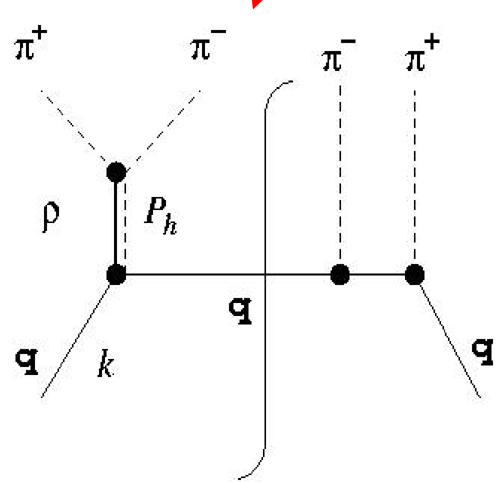
⇓

A_{UT} might depend strongly on $M_{\pi\pi}$

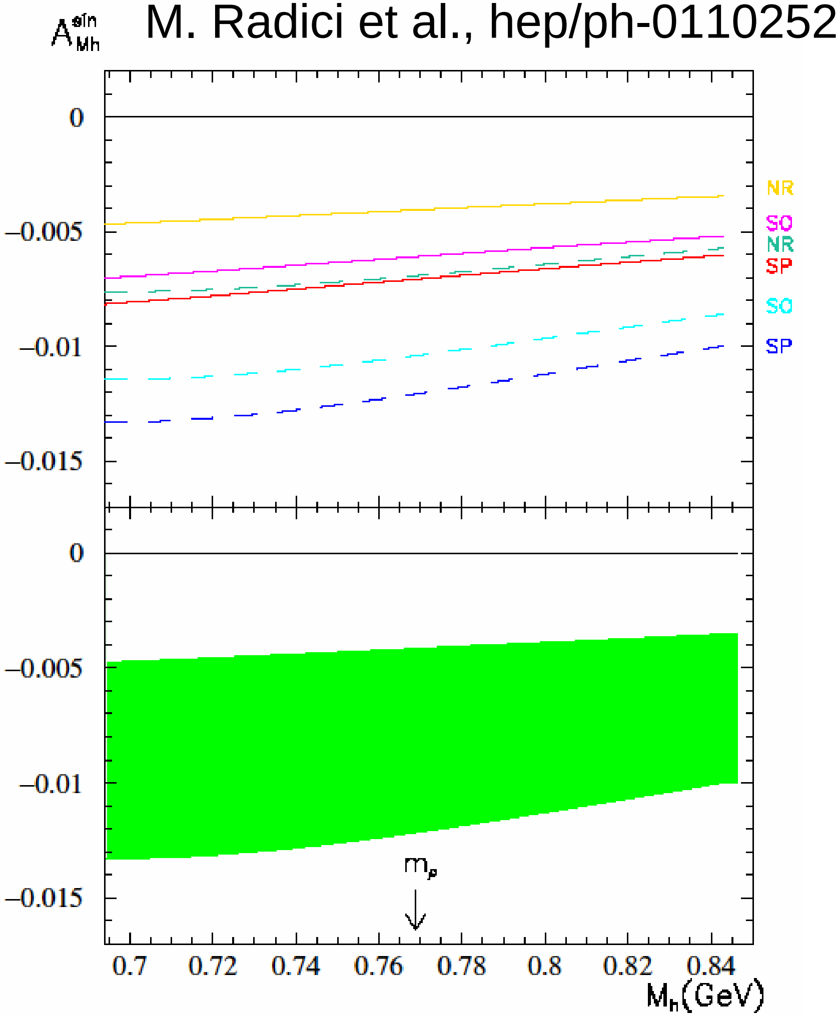
Spectator model for $\pi^+\pi^-$ fragmentation

Partial wave expansion

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



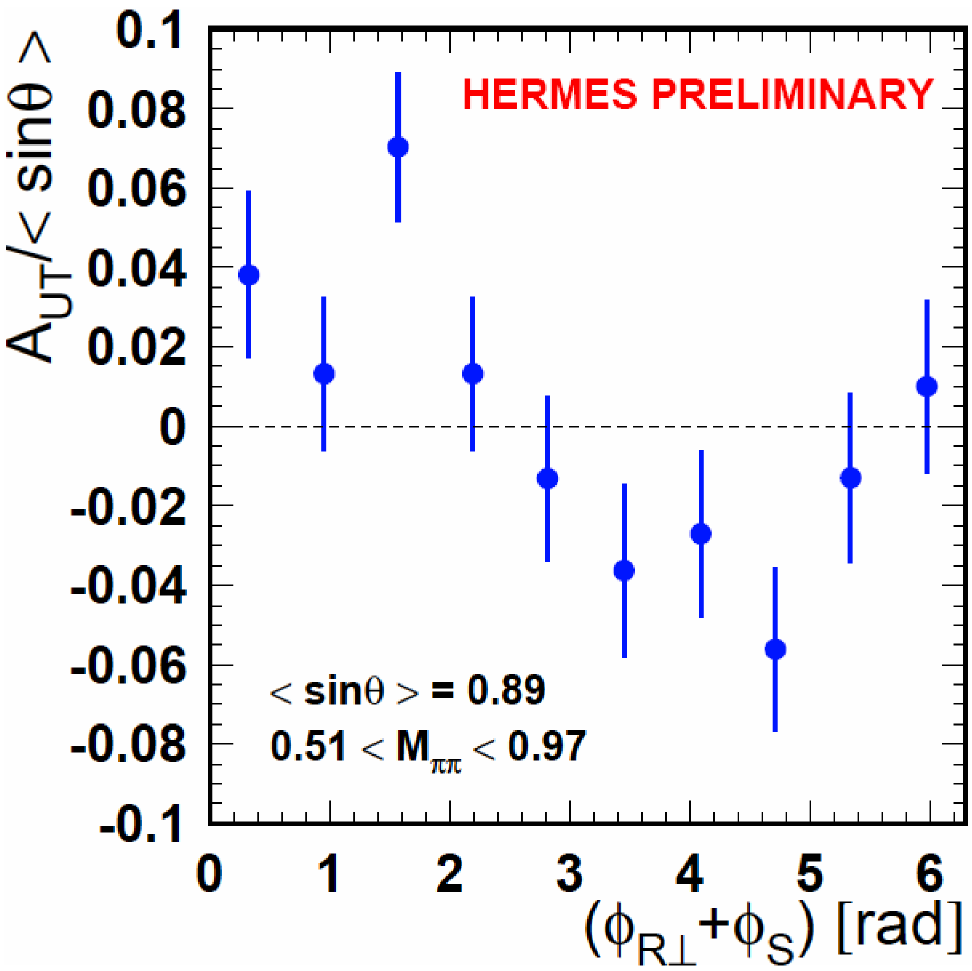
M. Radici et al., hep/ph-0110252



No strong $M_{\pi\pi}$ dependence.

Single-spin asymmetry in 2-hadron production

Single-spin asymmetries



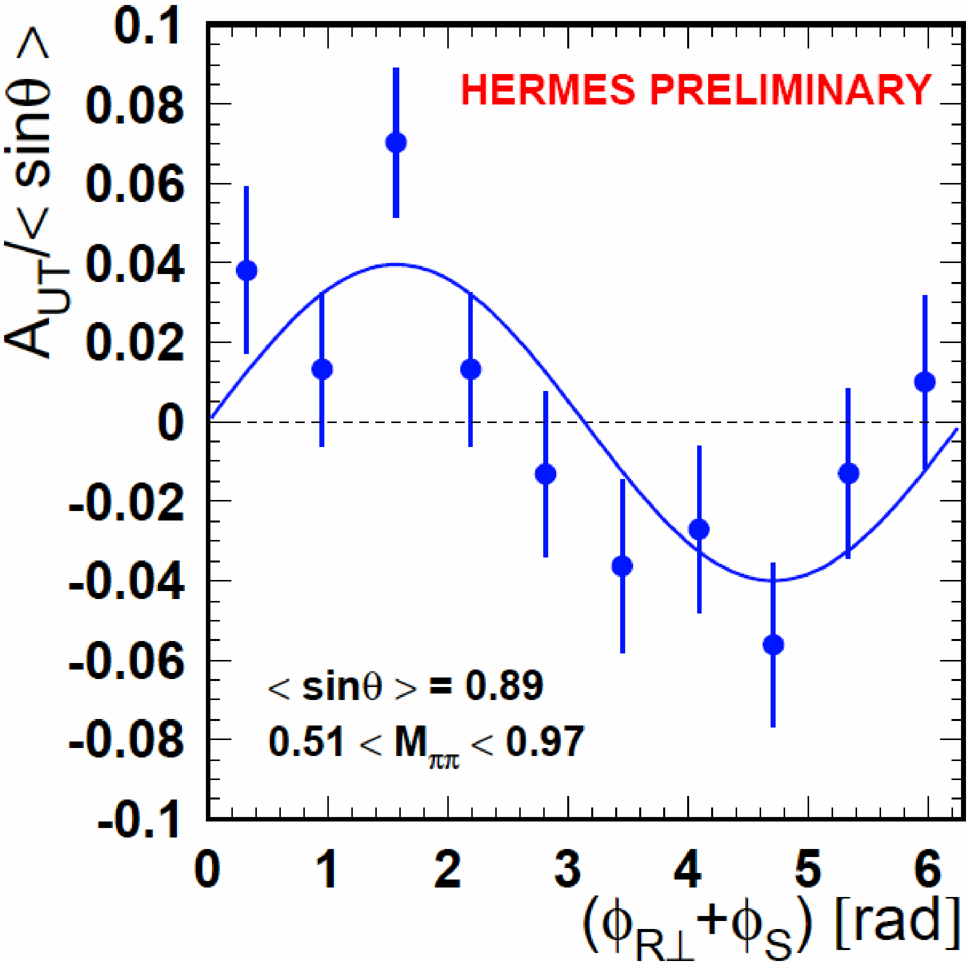
$$A_{UT} \sim \sin(\phi_{R\perp} + \phi_S)\langle \sin\theta \rangle \delta q H_1^{\sphericalangle}$$

(no θ binning)

First observation of transverse asymmetries in interference process

Single-spin asymmetry in 2-hadron production

Single-spin asymmetries



Fit $\frac{A_{UT}}{\langle \sin\theta \rangle} \sim \sin(\phi_{R\perp} + \phi_S)\delta q H_1^{\sphericalangle}$

with $a_0 + a_1 \sin(\phi_{R\perp} + \phi_S)$

$$a_0 = 0.000 \pm 0.006$$

$$a_1 = 0.040 \pm 0.009$$

⇓

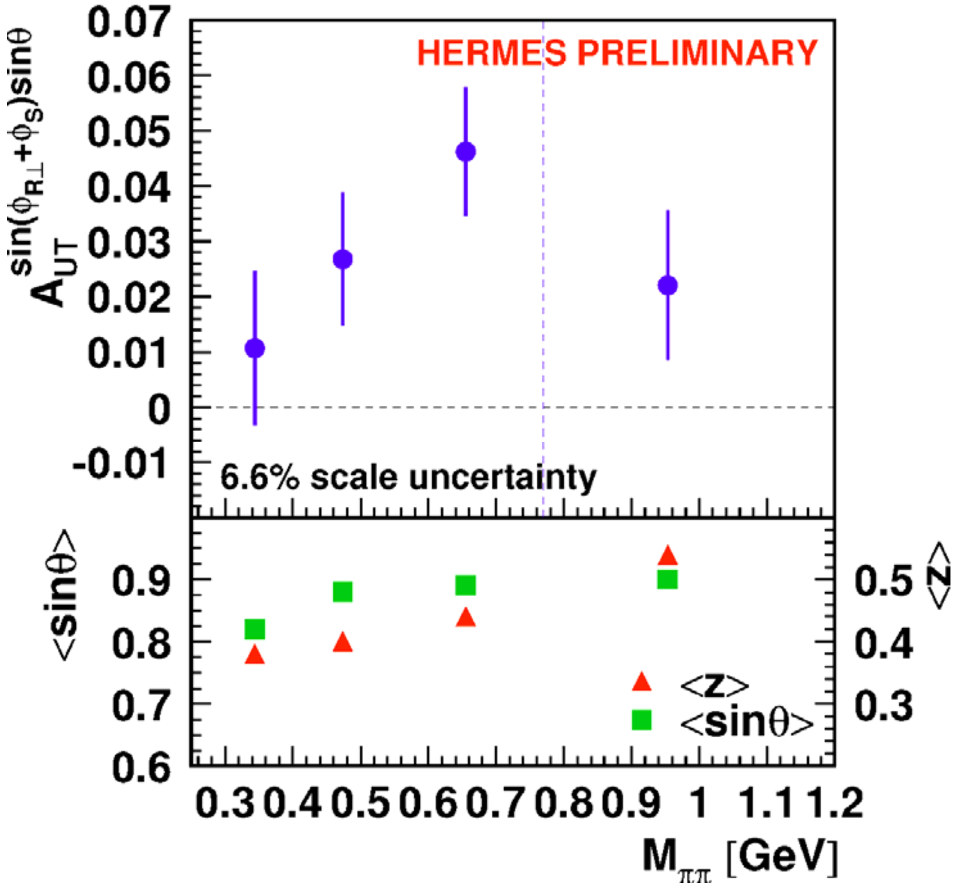
Amplitude of the asymmetry modulation

$$a_1 = 0.040 \pm 0.009_{\text{Stat}} \pm 0.003_{\text{Syst}}$$

$$\delta q \cdot H_1^{\sphericalangle} \neq 0$$

Single-spin asymmetry in 2-hadron production

If we look at $M_{\pi\pi}$ dependence, ($M_{\pi\pi}$: invariant mass of pion pair)



Asymmetry is fitted with

$$a_0 + a_1 \sin(\phi_{R\perp} + \phi_S)\sin\theta$$

⇩

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = a_1$$

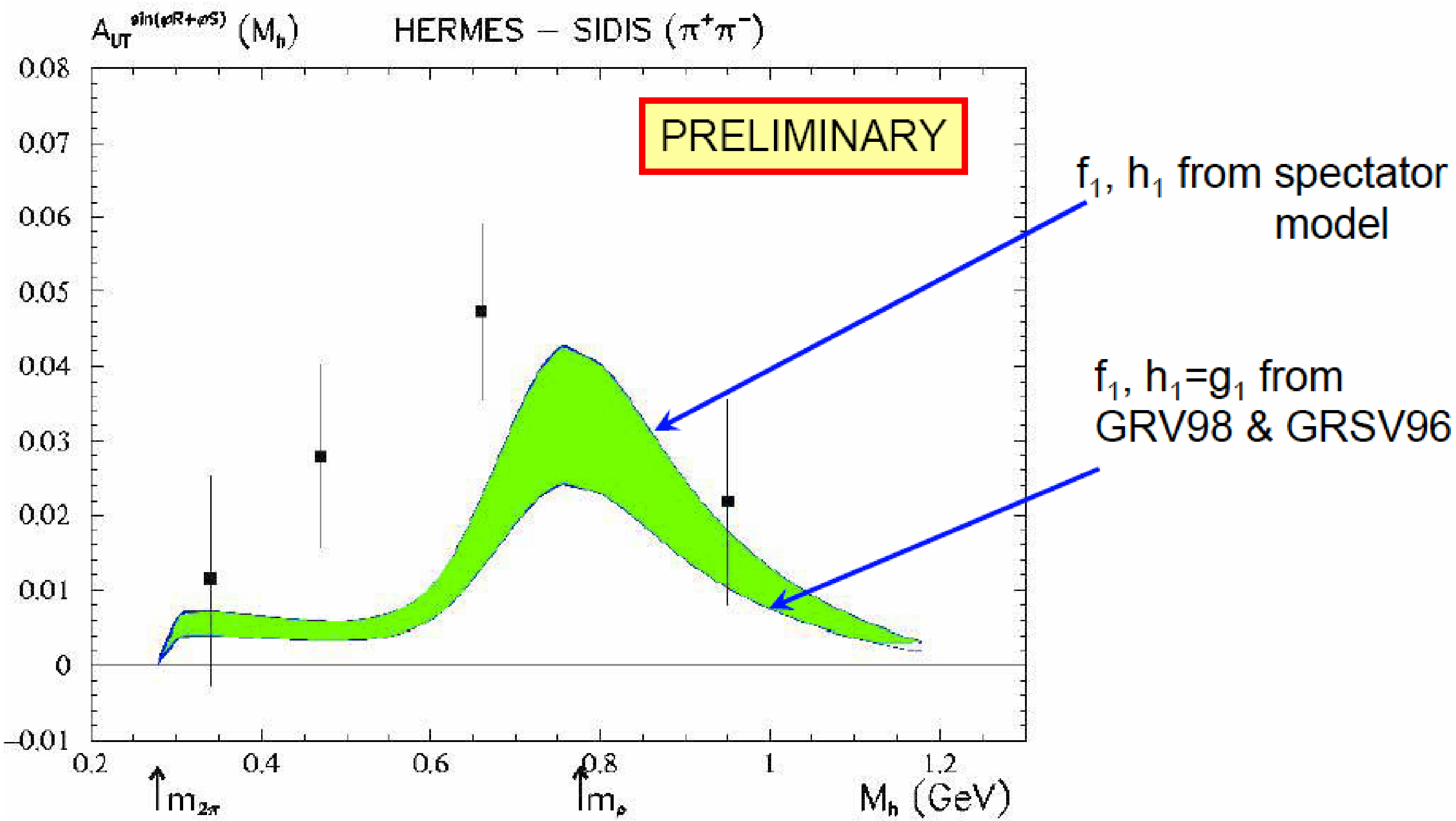
Positive asymmetry is observed around $M_{\pi\pi} = M_{\rho 0}$

Spectator model for $\pi^+\pi^-$ fragmentation

Partial wave expansion

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

Marco Radici at Como, 7 - 10 Sept 2005



Conclusion

Conclusion

- Single-spin asymmetry in π^+, π^- production is measured with transversely polarized hydrogen target at HERMES.
- This is the first observation of transverse target spin asymmetry in interference process.
- $\sin(\phi_{R\perp} + \phi_S)$ modulation of A_{UT} is observed at 4 sigma level.

$$\frac{A_{UT}^{\sin(\phi_{R\perp}+\phi_S)}}{\langle \sin\theta \rangle} = 0.040 \pm 0.009_{\text{Stat}} \pm 0.003_{\text{Syst}}$$

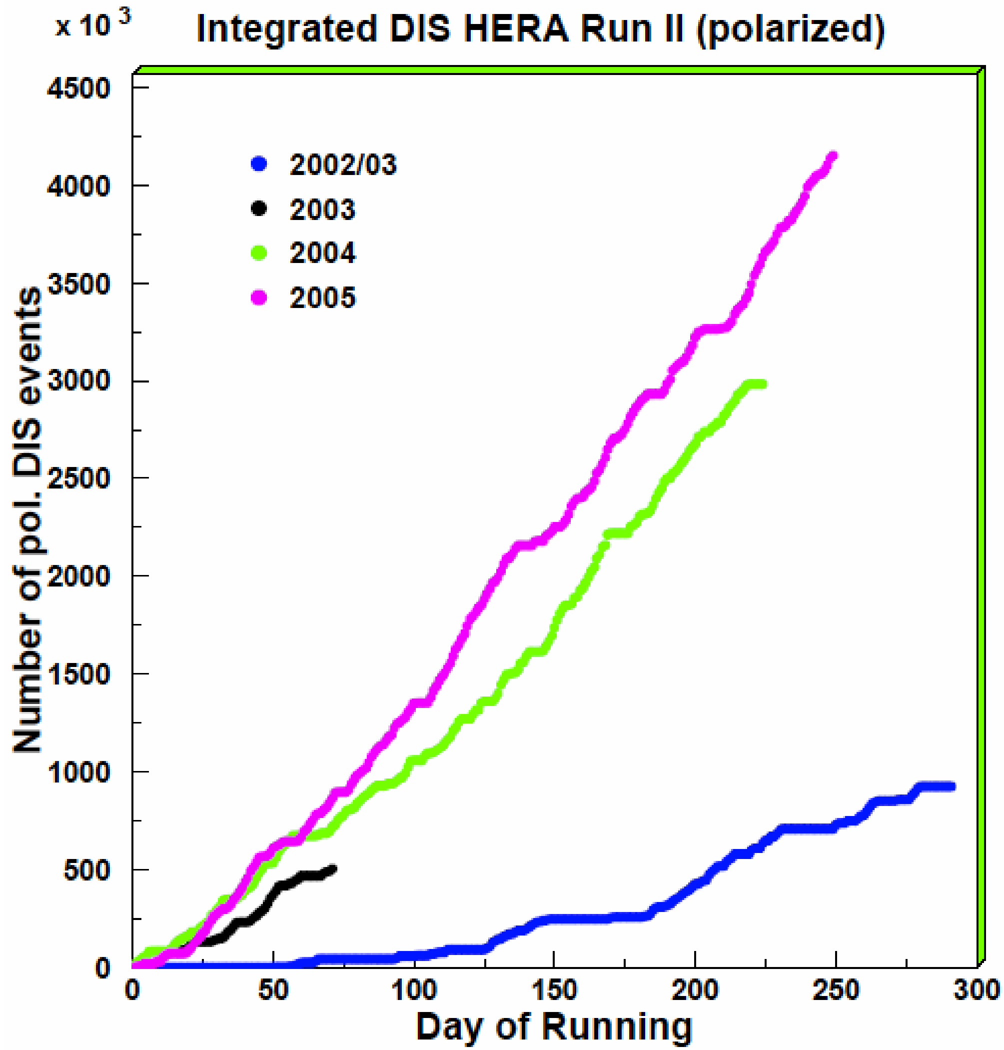
- Positive asymmetry is observed for measured π^+, π^- invariant mass range. ($M_{\pi\pi}$ =0.25 - 2.0 [GeV/c^2])

$$\delta q \cdot H_1 \neq 0$$

Outlook

Outlook

- 4~5 M more DIS events are expected in 2005, compared to 3.5 M DIS events in 2002~2004.



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Event selection

Data set : 2002~2004

SIDIS events with at least pion pair(π^+, π^-) appeared were analyzed.

$$ep^{\uparrow} \rightarrow e'\pi^+\pi^- X$$

Kinematic cuts :

$Q^2 \geq 1$ GeV^2

$W^2 \geq 4$ GeV^2

$x \geq 0.023$

$0.1 < y < 0.85$

$p_{\text{track}} > 2.5$ GeV (for DIS lepton)

$p_{\text{track}} > 1$ GeV (for Hadron)

To cut exclusive channel.

$\Delta E > 2$ GeV, where $\Delta E = \dfrac{M_x^2 - M_p^2}{2M_p}$

Evaluate A_{UT}

What is measured

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

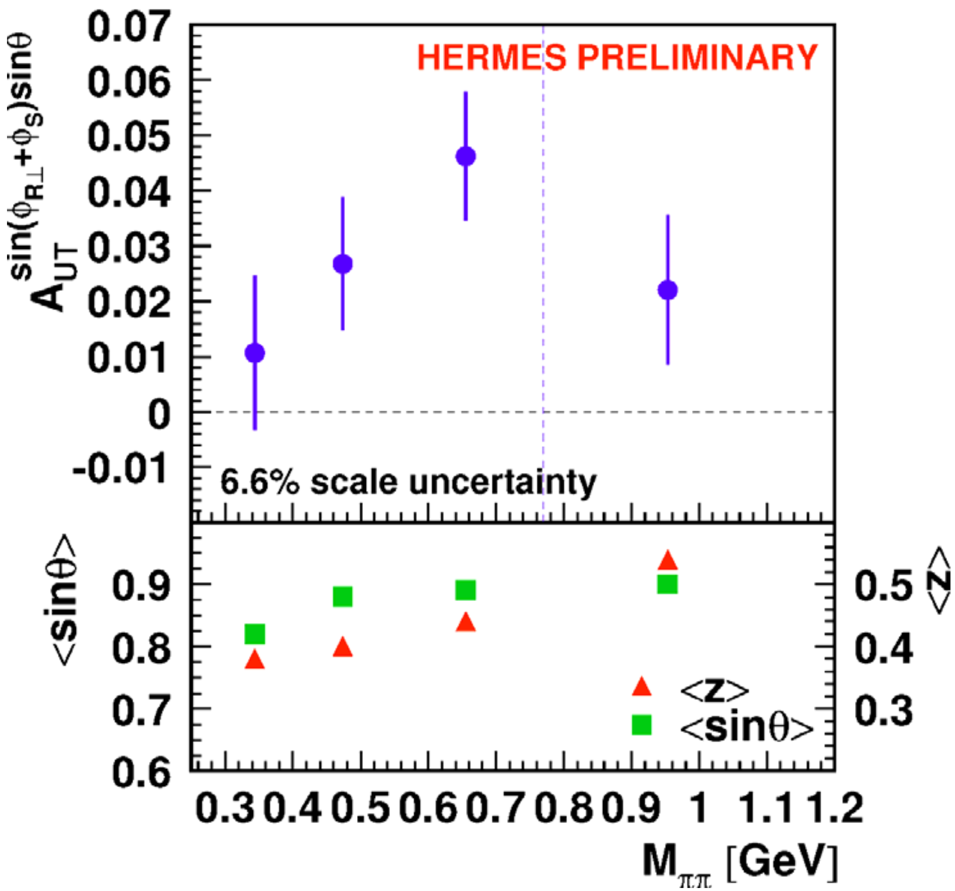
$$\sim \sin(\phi_{R\perp}+\phi_S)\sin\theta\ h_1 H_1^{\measuredangle}+\ldots\ ,$$

where $|S_T|$ is the average target polarization. ($|S_T| = 75.4 \pm 5.0$)

Single-spin asymmetry in 2-hadron production

$M_{\pi\pi}$ dependence of $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$

$M_{\pi\pi}$: invariant mass of pion pair



Asymmetry is fitted with

$$a_0 + a_1 \sin(\phi_{R\perp} + \phi_S)\sin\theta$$

⇓

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = a_1$$

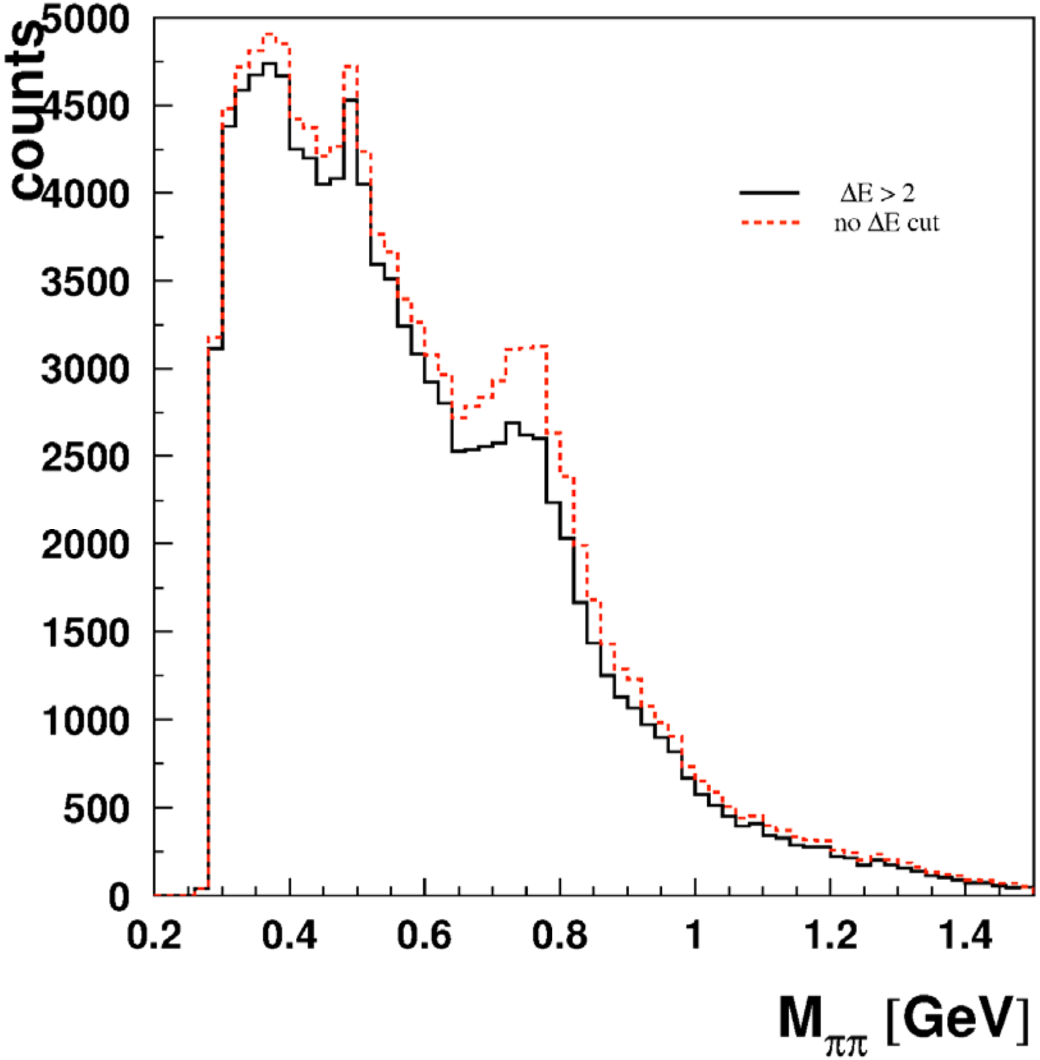
$M_{\pi\pi}$ binning :0.25, 0.40, 0.55, 0.77, 2.0 [GeV]

Positive asymmetry is observed around $M_{\pi\pi} = M_{\rho 0}$

$M_{\pi\pi}$ spectrum

With or without $\Delta E > 0.2[\mathrm{GeV}]$ cut

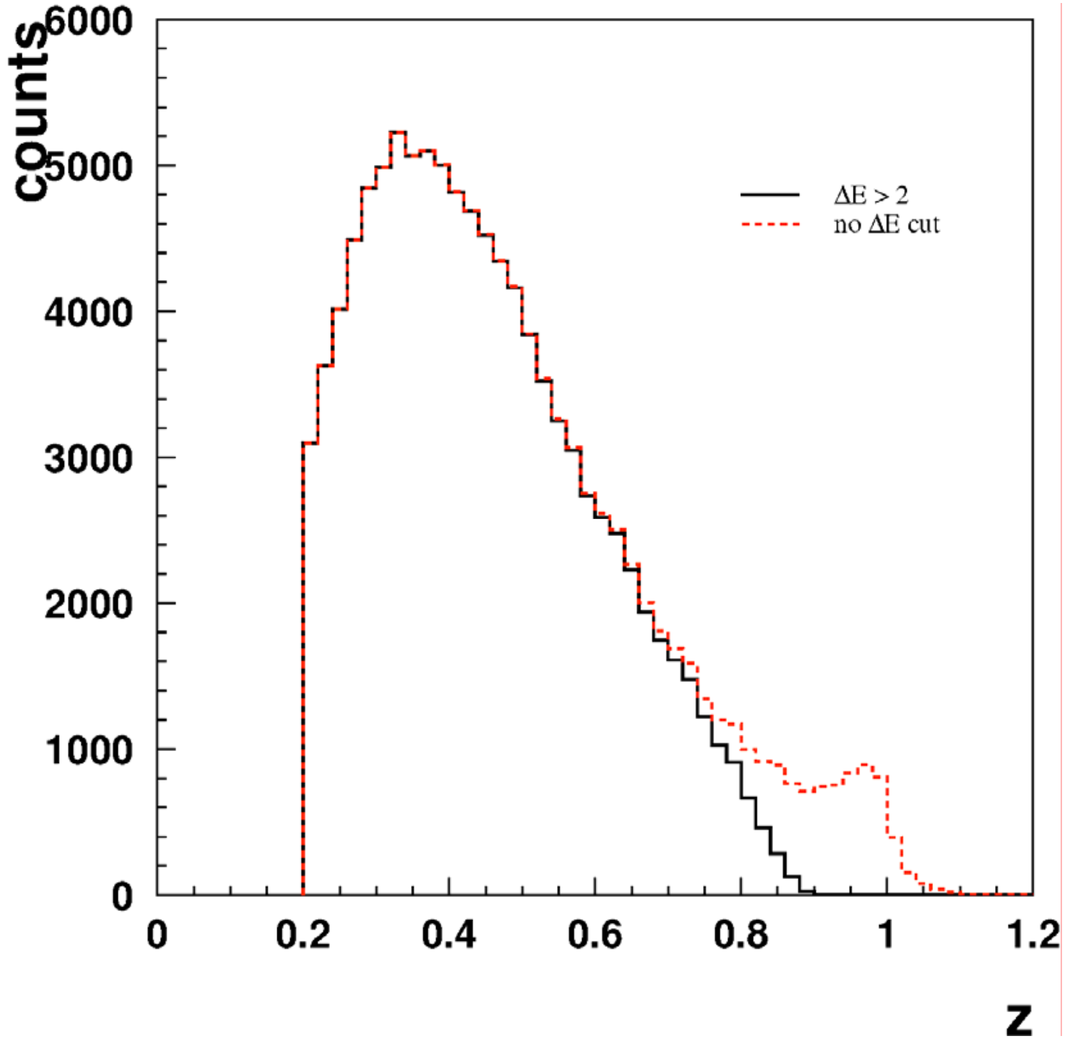
$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p}$$



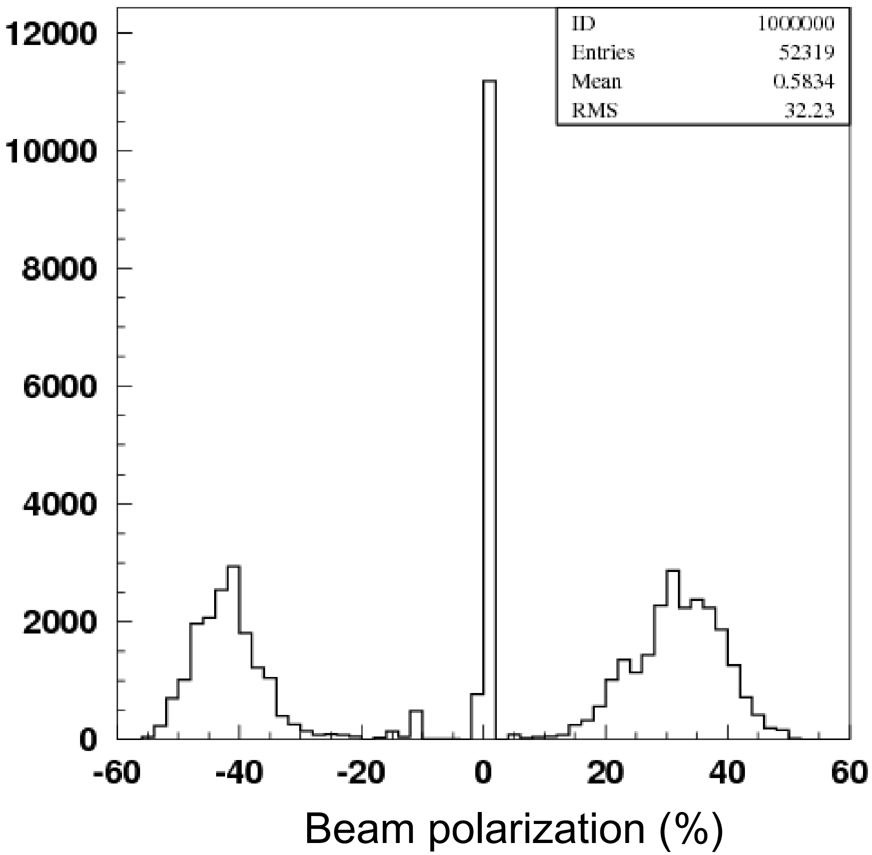
z spectrum

With or without $\Delta E > 0.2[\mathrm{GeV}]$ cut

$$\Delta E = \frac{M_x^2 - M_p^2}{2M_p}$$



double spin asymmetry



Fit

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

for both beam polarization.

$$A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = b$$

$$= 0.041 \pm 0.011 \text{ for } \mathrm{P_{beam}} \geq 0$$

$$= 0.040 \pm 0.012 \text{ for } \mathrm{P_{beam}} \leq 0$$

No double spin asymmetry

$$a + b\sin(\phi_{R\perp} + \phi_S)\sin\theta + c\sin(\phi_{R\perp} - \phi_S)\sin\theta$$

	a	b	c	< pol >
pol >= 0	0.002 ± 0.007	0.041 ± 0.011	0.020 ± 0.012	21.49
pol <= 0	0.002 ± 0.008	0.040 ± 0.012	0.017 ± 0.013	-23.97

Beam polarization don't affect to the asymmetry

Polarized cross section for 2 hadron SIDIS

2 hadron semi-inclusive DIS

$$d\sigma_{UL} \propto \sum_q e_q^2 \sin\phi_{R\perp} (h_L^q H_1^{\sphericalangle\, q} + A g_1^q \tilde{G}^{\sphericalangle\, q})$$

$$d\sigma_{UT} \propto \sum_q e_q^2 \sin(\phi_R + \phi_S) h_1^q H_1^{\sphericalangle\, q} + B \sin\phi_S (\ldots)$$

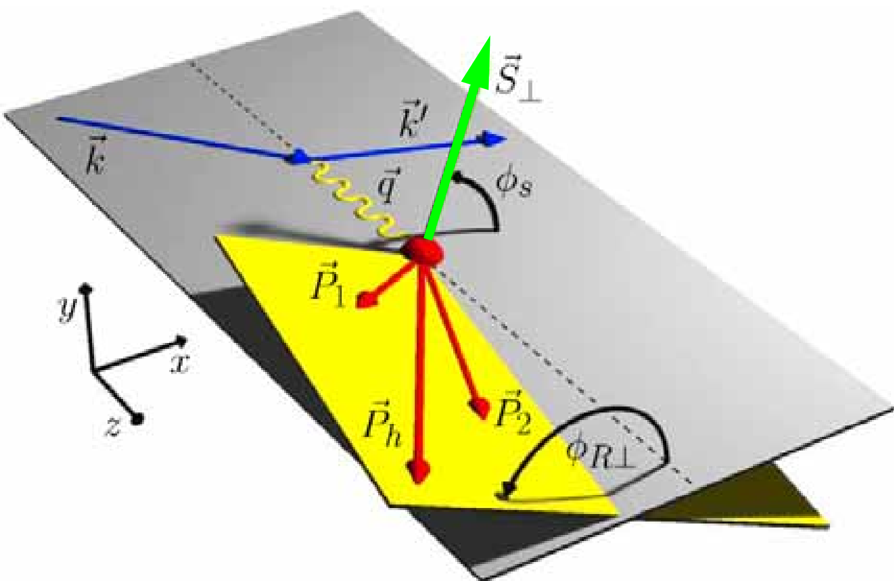
$$d\sigma_{LU} \propto \sum_q e_q^2 \sin\phi_{R\perp} \left[e^q H_1^{\sphericalangle\, q} + C f_1^q \tilde{G}_1^{\sphericalangle\, q} \right]$$

Single spin asymmetries

$$A_{UL}^{\sin\phi_{R\perp}} \propto h_L H_1^{\sphericalangle} + A g_1 \tilde{G}^{\sphericalangle}$$

$$A_{UT}^{\sin(\phi_R + \phi_S)} \propto h_1 H_1^{\sphericalangle}$$

$$A_{LU}^{\sin\phi_{R\perp}} \propto e H_1^{\sphericalangle} + C f_1 \tilde{G}^{\sphericalangle}$$



Polarized cross section for 2 hadron SIDIS

2 hadron semi-inclusive DIS

$$A(y) = 1 - y + \frac{y^2}{2}$$
$$B(y) = 1 - y$$
$$V(y) = 2(2-y)\sqrt{1-y}$$
$$W(y) = 2y\sqrt{1-y}$$

$$d\sigma_{UU} \propto \sum_q e_q^2 \left\{ A(y) f_1 D_1 - V(y)\cos\phi_R \sin\theta \frac{|R|}{Q}\left[\frac{f_1}{z}\tilde{D}^{\sphericalangle} + \frac{M_x}{M_h} h H_1^{\sphericalangle}\right]\right\}$$

$$d\sigma_{UL} \propto \sum_q e_q^2 \sin\phi_R \left\{ |S_L| V(y) \sin\theta \frac{|R|}{Q}\left[\frac{M_x}{M_h} h_L H_1^{\sphericalangle} + \frac{1}{z} g_1 \tilde{G}^{\sphericalangle}\right]\right\}$$

$$d\sigma_{UT} \propto \sum_q e_q^2 |S_\perp| \left\{ \begin{array}{l} B(y)\sin(\phi_R + \phi_S)\sin\theta \frac{|R|}{M_h} h_1 H_1^{\sphericalangle} \\ +V(y)\sin\phi_S \frac{M_h}{Q}\left[h_1 \left(\frac{1}{z}\tilde{H} + \sin^2\theta \frac{|R|^2}{M_h^2} H_1^{\sphericalangle\, o(1)}\right) - \frac{M}{M_h} x f_T D_1 \right] \end{array} \right\}$$

$$d\sigma_{LU} \propto \sum_q e_q^2 \lambda_e W(y) \sin\phi_R \sin\theta \frac{|R|}{Q}\left[\frac{M_x}{M_h} e H_1^{\sphericalangle} + \frac{1}{z} f_1 \tilde{G}^{\sphericalangle}\right]$$

In Wandzura-Wilzcek approx., function with tilde vanish.