Final HERMES Results on Single-Spin Asymmetries in Lepto-Production of Oppositely Charged Pion Pairs from the Transversely Polarized Hydrogen Target

Xiaorui Lu

(on behalf of HERMES Collaboration)

Tokyo Institute of Technology

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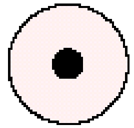
arXiv:0803.2367 [hep-ex]

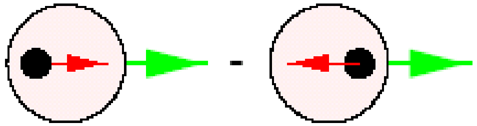
List of Contents:

Quark Structure of Nucleon

- **quark number density**:
  measures spin averaged distribution

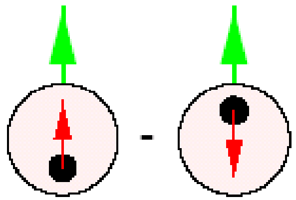
  $f_1^q =$  *well known!!!*

- **quark helicity distribution**:
  measures helicity difference

  $g_1^q =$  *known!*

  precise inclusive measurement: HERMES PRD75(2007)
  flavor-separated measurement: HERMES PRD71(2005)

- **transversity distribution**:
  measures helicity flip

  $h_1^q =$  *first glimpses!*

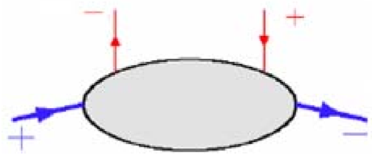
  first measurement: HERMES PRL94 (2005)

  - completes leading-twist picture of nucleon structure
  - no gluon transversity ➔ weaker Q^2 evolution than f_1 and g_1
  - related to relativistic effects inside the nucleon

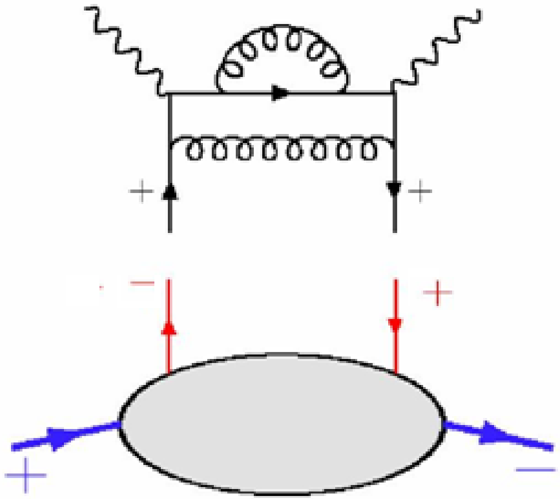
Measurement of Transversity Distribution

- **Chirality of the transversity distribution**

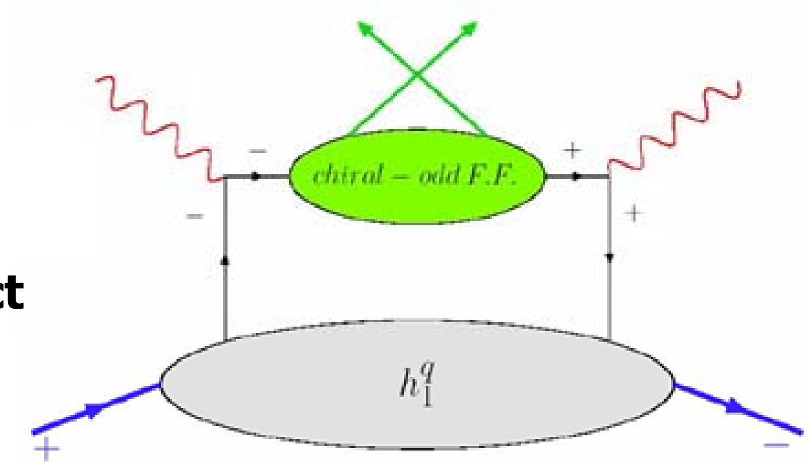
  chiral-odd quark Distribution Function (DF)



$\sim Im(A_{+-,-+})$



need another
chiral-odd object



cannot be determined in inclusive DIS

Semi-Inclusive DIS: coupled to a chiral-odd Fragmentation Function (FF)

- **Semi-Inclusive DIS (SIDIS) Cross Section**

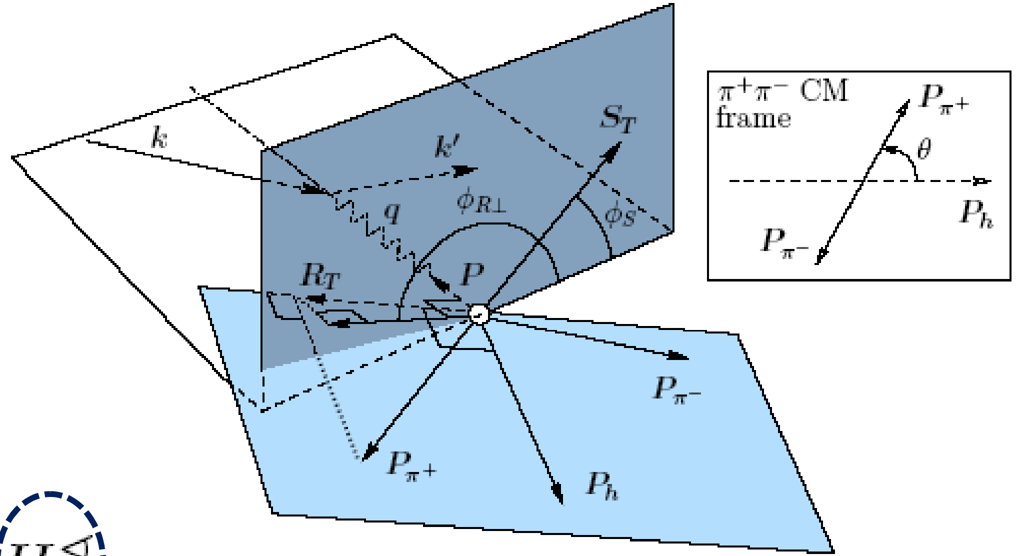
$$\sigma^{ep\to ehX} = \sum_q h_1^q \otimes \sigma^{eq\to eq} \otimes FF^{q\to h}$$

$\Downarrow$ **chiral-odd** DF $\Downarrow$ **chiral-odd** FF

Two-Pion SIDIS Production

semi-inclusive DIS on a transversely polarized hydrogen target

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



The target-spin asymmetry:

$$A_{U\perp} \equiv \frac{1}{|S_\perp|}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \sim \frac{\sigma_{UT}}{\sigma_{UU}}$$

$$\sigma_{UU} \sim f_1\, D_1$$

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

- The asymmetry is related to **transversity**
- It appears with an unknown **Dihadron FF** sensitive to quark transverse quark polarization
- Simpler probe of transversity than one-hadron SIDIS:
  - universal factorization and known Q^2 evolution

Dihadron Fragmentation Function

Dihadron FF $H_1^{\sphericalangle}$: transfer of the transverse spin of the fragmenting quark to the orientation of the hadron pair

Dihadron FFs can be expanded in terms of Legendre functions of cosθ:

$$D_1(\cos\theta) \simeq D_1 + D_1^{sp}\cos\theta + D_1^{pp}\,\frac{1}{4}(3\cos^2\theta - 1)$$

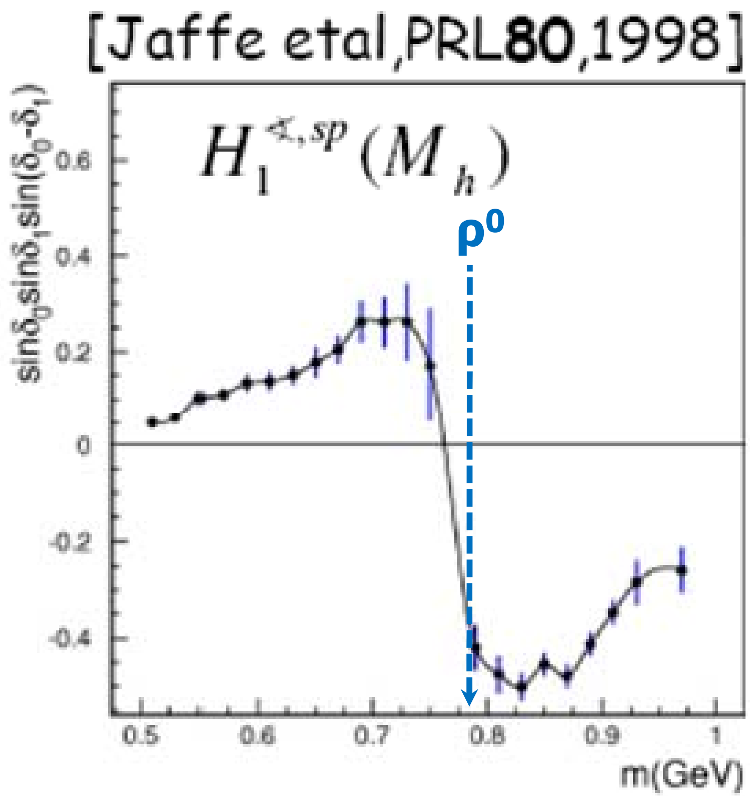
$$H_1^{\sphericalangle}\,(\cos\theta) \simeq H_1^{\sphericalangle,sp} + H_1^{\sphericalangle,pp}\cos\theta$$

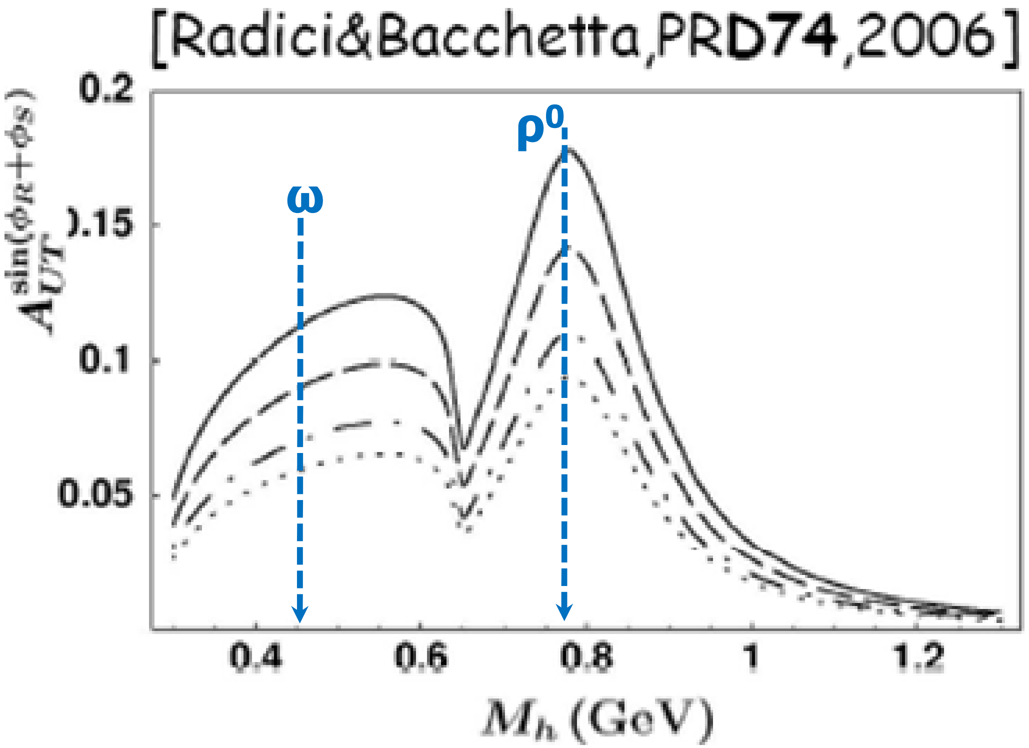
sp : interference between *s*- and *p*-wave components of the hadron pair

The transverse target-spin asymmetry becomes

$$A_{U\perp} \sim \sin(\phi_{R\perp} + \phi_S)\; h_1\; \frac{H_1^{\sphericalangle,sp}\sin\theta + \frac{1}{2}H_1^{\sphericalangle,pp}\sin(2\theta)}{f_1\big(D_1 + \cos\theta D_1^{sp} + \frac{1}{4}(3\cos^2\theta - 1)D_1^{pp}\big)}$$

Theoretical Predictions



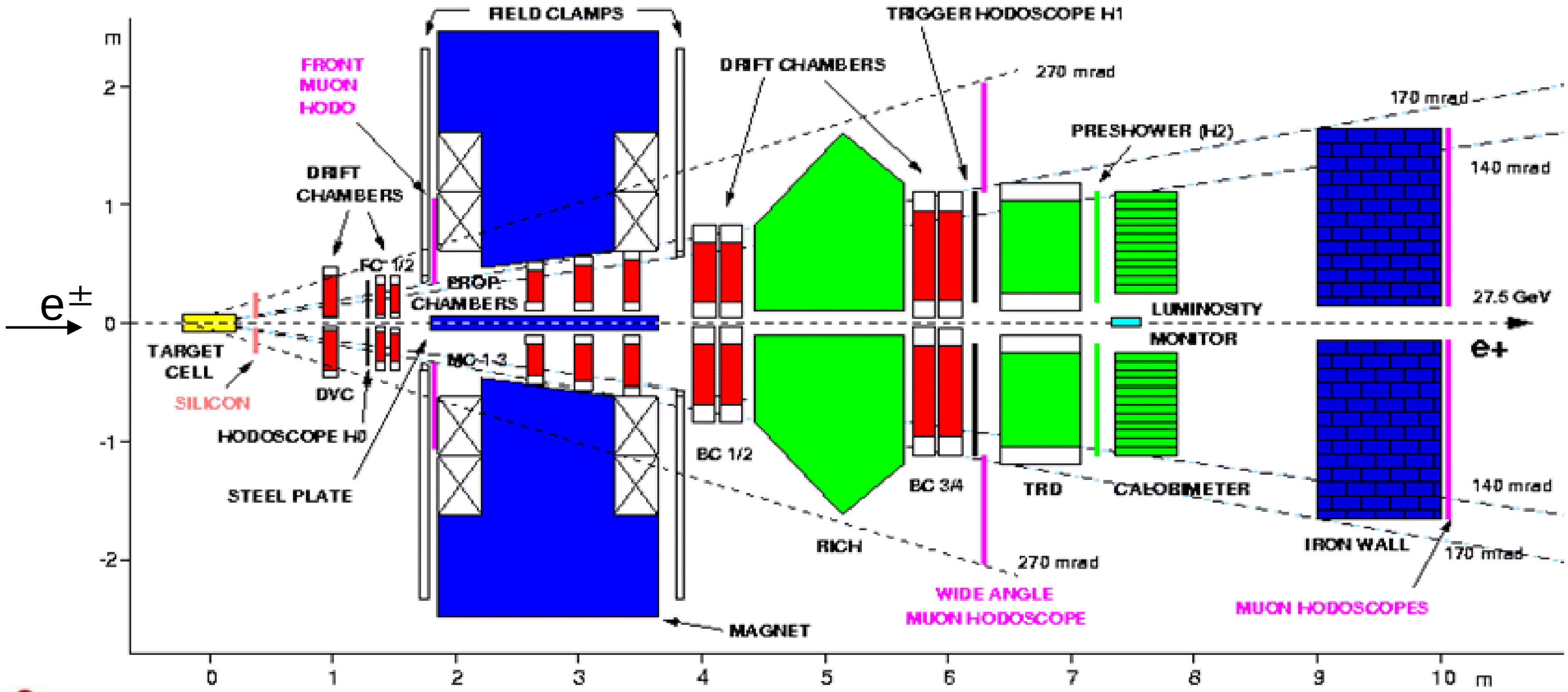


Sign Change ~ ρ^0(770)

No Sign Change ~ ρ^0(770) but Maximal Asymmetry

Dominance of real (Jaffe) vs. imaginary (Radici) part of ρ^0 decay amplitude.

HERMES Spectrometer



- **Reconstruction: Δp/p < 2%, Δθ < 0.6 mrad**
- **Positron/Hadron separation efficiency: > 99%**
- **Hadron Identification: dual radiator RICH Detector:**

  π , K and p identification at 2 – 15 GeV/c
- **Atomic hydrogen target** with transversely polarization ~75%
  - atomic pure gas target ➔ no dilution
  - flipping time ~90s ➔ small systematic errors

Extracting Asymmetry Amplitude

Two-dimensional fit binned to $(\phi_{R\perp} + \phi_S)$ and $\theta' \equiv ||\theta - \pi/2| - \pi/2|$:

$$A_{U\perp}(\phi_{R\perp} + \phi_S, \theta') = \sin(\phi_{R\perp} + \phi_S) \frac{a \sin\theta'}{1 + b\frac{1}{4}(3\cos^2\theta' - 1)}$$

where $a \equiv A_{U\perp}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} \sim \frac{h_1 H_1^{\sphericalangle,sp}}{f_1 D_1}$

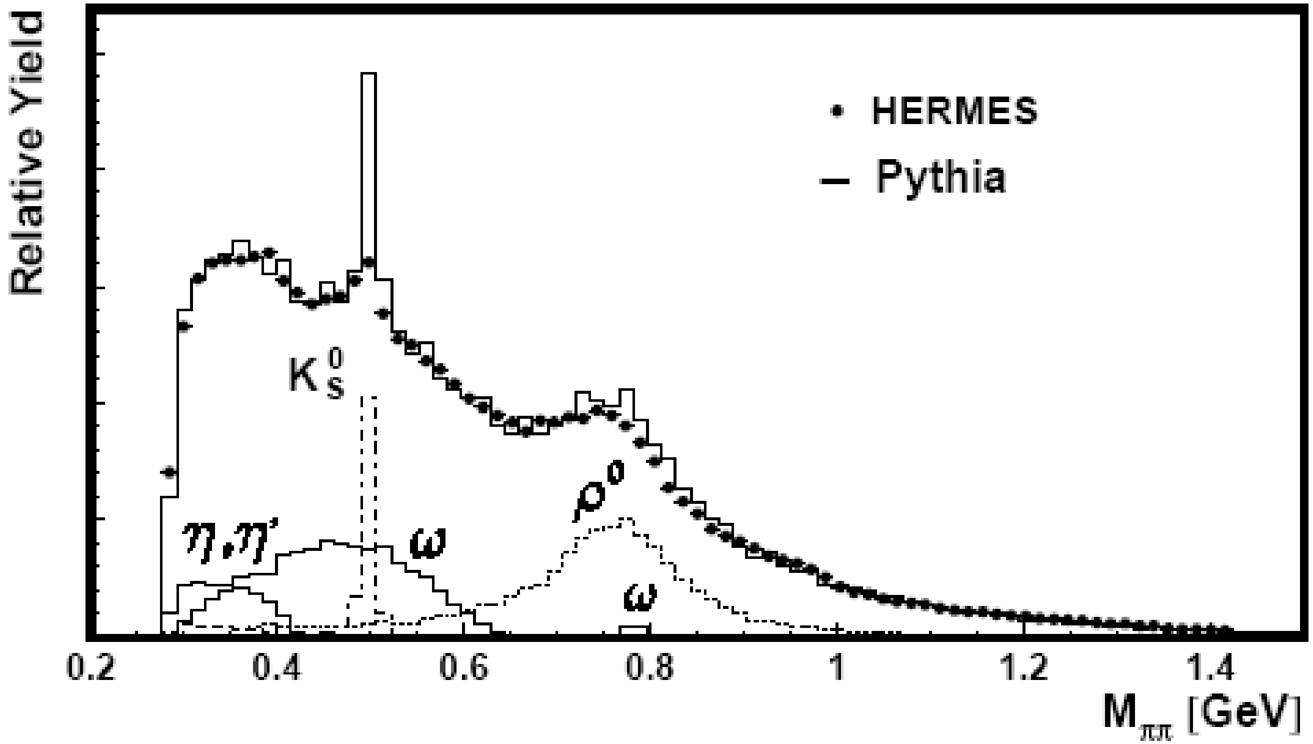
varying b within positivity limits:

$$-\frac{3D_1^p(z, M_{\pi\pi})}{2D_1(z, M_{\pi\pi})} \le b \le \frac{3D_1^p(z, M_{\pi\pi})}{D_1(z, M_{\pi\pi})}$$

- limits estimated by PYTHIA6 Monte Carlo
- take the center value in the range of ***a*** as asymmetry amplitude, the standard deviation as systematic uncertainty (doing a ***b-scan***).

Monte Carlo Simulation

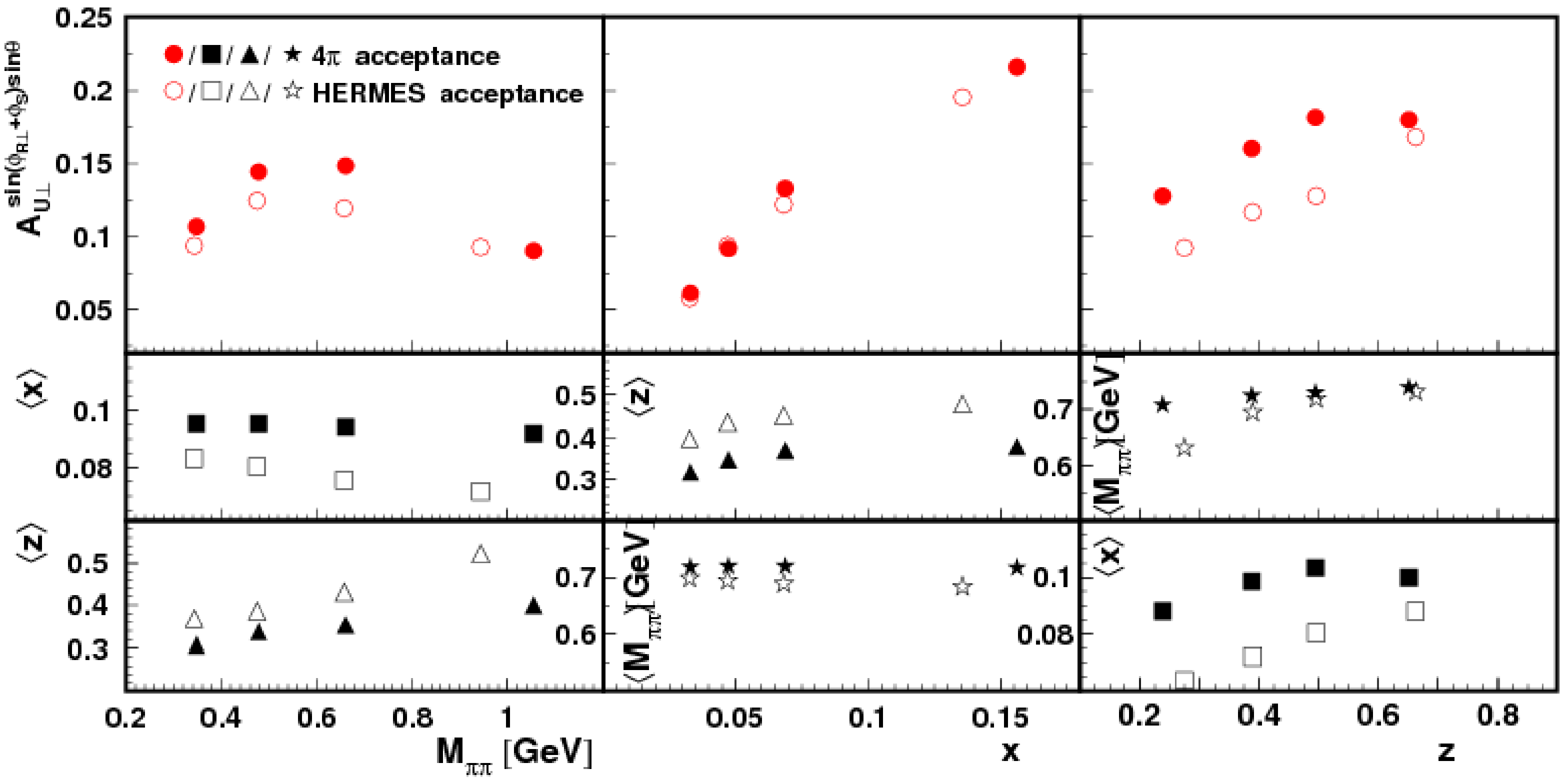
Tuned to HERMES single-hadron multiplicities



- MC describes two-hadron spectrum well
- ρ^0 and ω resonances contribute strongly to the spectrum
- $H_1^{\sphericalangle,sp}$ is predicted to be maximal near $\rho^0(770)$ by theory

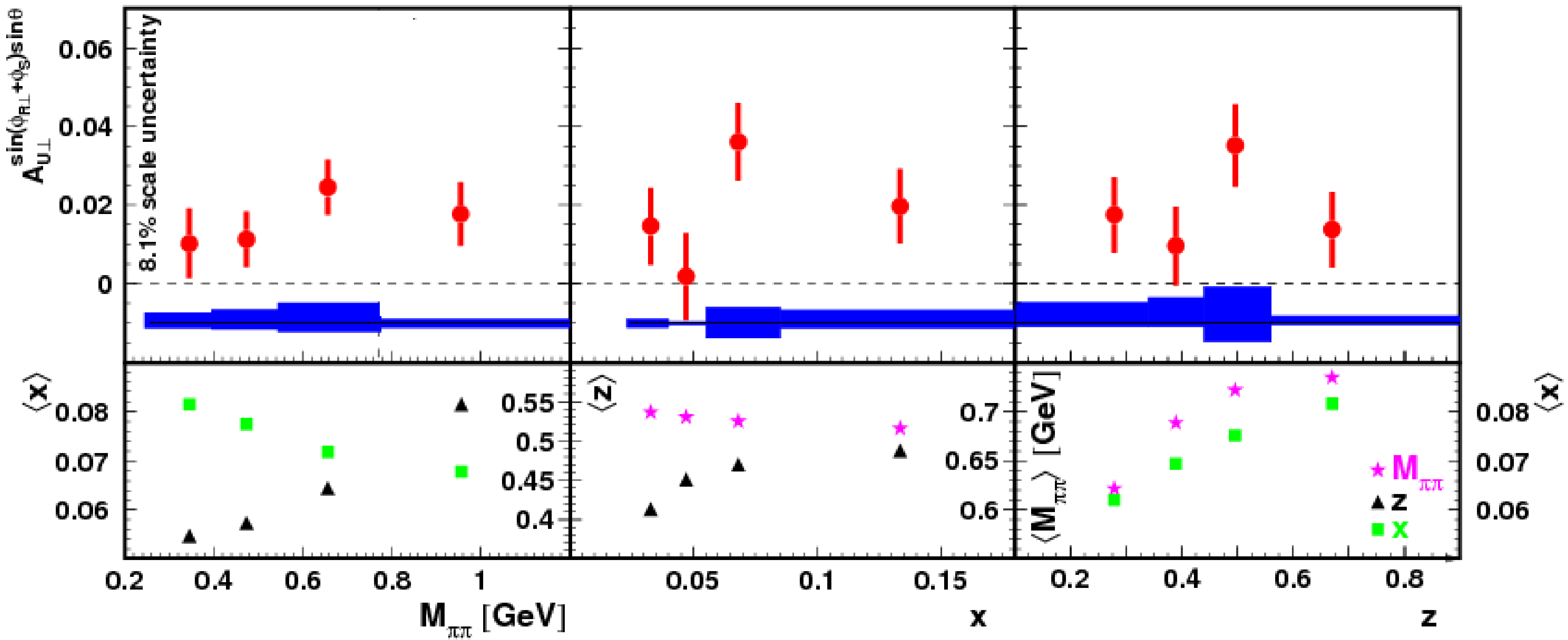
Estimate of Acceptance Effects

- Introduce target-spin dependence to the MC
- Combine models for Dihadron FF(*Bacchetta&Radici[PRD74:114007,2006]*), h_1(*Schweitzer et al.[PRD64:034013,2001];*) and f_1(*Gluck et al. [EPJC5:461,1998]*)
- Compare the asymmetry amplitudes in 4π and HERMES acceptance.



- **Fractional acceptance effect taken as systematic uncertainty**

Extracted Asymmetry Amplitudes



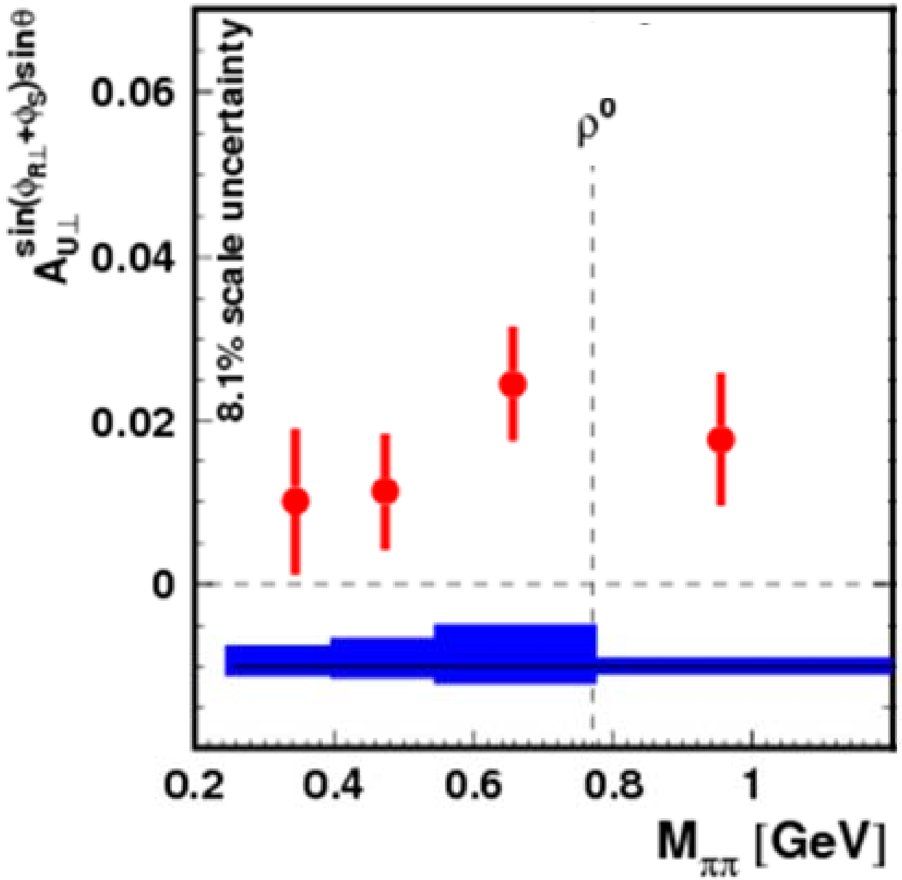
✓average amplitude positive :

$$A_{U\perp}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = 0.018 \pm 0.005_{\rm stat} \pm 0.002_{\rm b-scan} + 0.004_{\rm acc}$$

✓8.1% scale systematic uncertainty contribution from target polarization

✓ the asymmetric error band combines ***b-scan*** effect and acceptance effect

Discussion of the Results



- ✓ Non-zero asymmetry amplitudes
- ✓ World first evidence of the Dihadron FF $H_1^{\sphericalangle}$
- ✓ Positive amplitudes in the whole range of the invariant mass
  - rule out the sign change predicted by Jaffe
  - shape consistent with later model by Radici & Bacchetta
- ✓ Big contribution from *s*-*p* wave interference around $\rho^0(770)$
- ✓ Asymmetry results sensitive to transversity

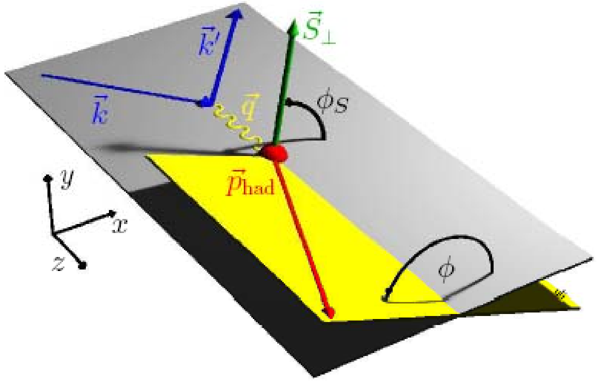
Summary

- **Semi-Inclusive two-hadron production from a transversely polarized hydrogen measured at HERMES; Full data analyzed**
- **First evidence for a spin-dependent Dihadron FF**
- **Transversity can thus be accessed in two-pion SIDIS**
- **No evidence of a sign change of the asymmetry amplitudes around ρ^0(770): Jaffe's model not favored**
- **An analogous mechanism can be studied in pp collisions at RHIC and SIDIS at COMPASS**
- **Dihadron FF can be extracted from e^+e^- data at BELLE, which can be combined with SIDIS and pp collisions data to extract transversity**

Backup Slides

Semi-Inclusive DIS Cross Section

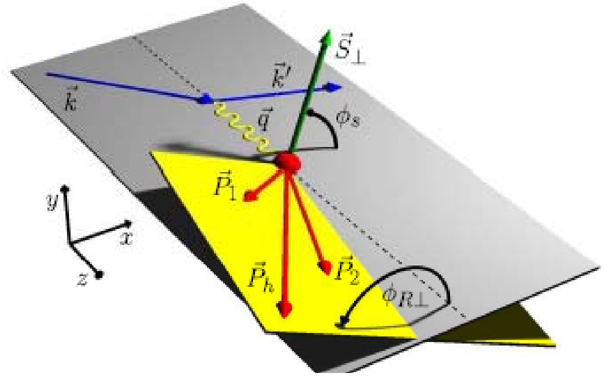
One-Hadron Production



$$\sigma_{UT} \sim \sin(\phi+\phi_S)\sum_q e_q^2\, \mathcal{I}\left[\frac{k_T \hat{P}_{h\perp}}{M_h} h_1^q H_1^{\perp,q}\right]$$

- Convolution integral over intrinsic quark transverse momenta
- To extract $h_1 H_1^{\perp}$, need to de-convolve transverse momentum integral
- Competition with Sivers Effect
  - ➔Well distinguished via Fourier component

Two-Hadron Production



$$\sigma_{UT} \sim \sin(\phi_{R\perp}+\phi_S)\sum e_q^2\, h_1^q\, H_1^{\sphericalangle}$$

- Only relative momentum of two-hadron survives the integral over $\vec{H}_{h\perp}$
- Directly proportional to $h_1 H_1^{\sphericalangle}$
- Independent measurement of transversity from one-hadron case

But:

- Lower statistics
- More kinematic dependence ($d^9\sigma$)
- No 2-hadron FF measured sofar (can be measure by BELLE)

Spectrometer Acceptance Effect

The fully differential asymmetry depends on 9 kinematic variables:

$$x,\ y,\ z,\ \phi_{R\perp},\ \phi_S,\ \text{and}\ \theta,\ M_{\pi\pi},\ \text{and}\ \boldsymbol{P_{h\perp}}\ (\mathrm{d}^2\boldsymbol{P_{h\perp}} = |\boldsymbol{P_{h\perp}}|\,\mathrm{d}|\boldsymbol{P_{h\perp}}|\,\mathrm{d}\phi_h).$$

Measured number of events convoluted with the experimental acceptance:

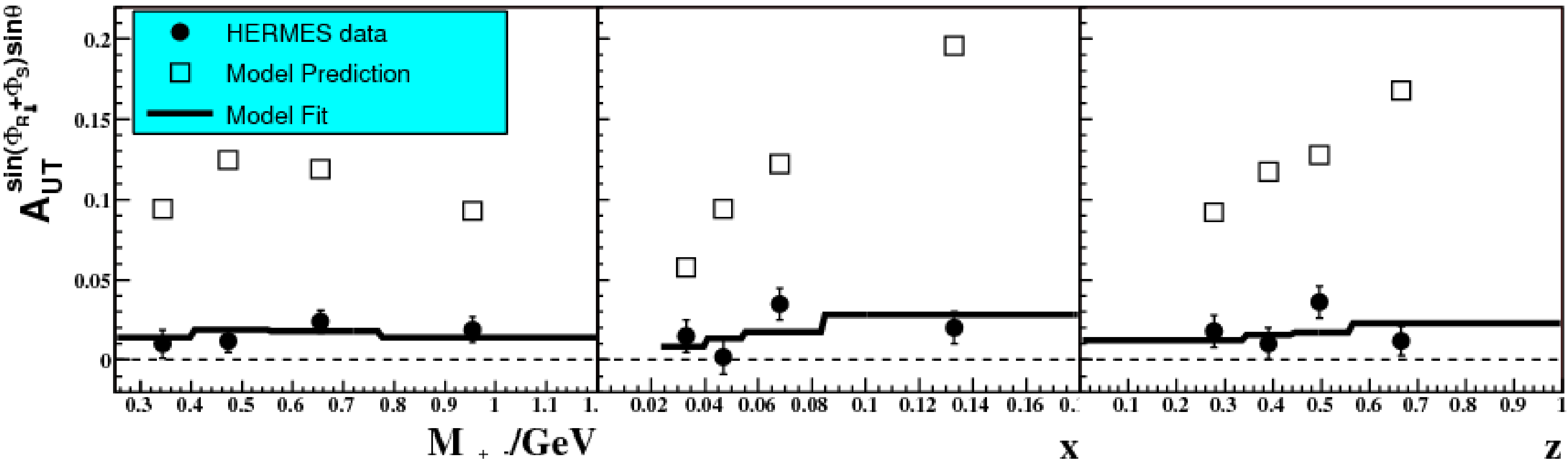
$$N^{\uparrow(\downarrow)}(\phi_{R\perp},\phi_S,\theta,M_{\pi\pi}) \propto \int \mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z\,\mathrm{d}^2\boldsymbol{P_{h\perp}}\,\epsilon(x,y,z,\boldsymbol{P_{h\perp}},\phi_{R\perp},\phi_S,\theta,M_{\pi\pi}) \times \sigma_{U\uparrow(\downarrow)}(x,y,z,\boldsymbol{P_{h\perp}},\phi_{R\perp},\phi_S,\theta,M_{\pi\pi}),$$

To study the acceptance effect, the single target-spin asymmetry was introduced to the HERMES-tuned PYTHIA6 Monte Carlo simulation based on the theoretical model:

$$A_{UT}(x,y,z,M_{\pi\pi},|\boldsymbol{P_{h\perp}}|,\phi_{R\perp},\phi_S,\phi_h,\theta) = -\sin(\phi_{R\perp}+\phi_S)\frac{B(y)}{A(y)}\sqrt{1-4\left(\frac{M_\pi}{M_{\pi\pi}}\right)^2}\frac{\sum_q e_q^2 h_1^q(x) H_{1,q}^{\sphericalangle,sp}(M_{\pi\pi},z)}{\sum_q e_q^2 f_1^q(x) D_{1,q}(M_{\pi\pi},z)}$$

- $H_{1,q}^{\sphericalangle,sp}(z,M_{\pi\pi})$ and $D_{1,q}(z,M_{\pi\pi})$ from A. Bacchetta and M. Radici (hep-ph/0608037)
- $h_1^q(x)$ at $Q^2 = 2.5\mathrm{GeV}^2$ from P.Schweitzer et al.(hep-ph/0101300)
- $f_1^q(x)$ at $Q^2 = 2.5\mathrm{GeV}^2$ from GRV (M. Glueck, E. Reya, A. Vogt (hep-ph/9806404)

Theoretical and Extracted Amplitudes



Overestimated asymmetry from theory!