# Updates on Transversity Experiments and Interpretations

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# Outline

- Recent results of SSA with transversely polarized targets from HERMES and COMPASS
  - What are the implications on the transversity, Collins fragmentation function, and Sivers quark distributions?
  - Can existing models explain the SSA data from HERMES for both the longitudinally polarized and the transversely polarized targets?
  - What are the implications for the Hall-A experiments?
  - What are the implications for polarized and unpolarized Drell-Yan experiments.

# Transversity distribution, Sivers distribution, and Collins fragmentation function in Semi-Inclusive DIS with transversely polarized target

$$d^6 = \frac{4^2 sx}{Q^4} \times ¿$$

Unpolarized

Transversity

Sivers

Polarized target

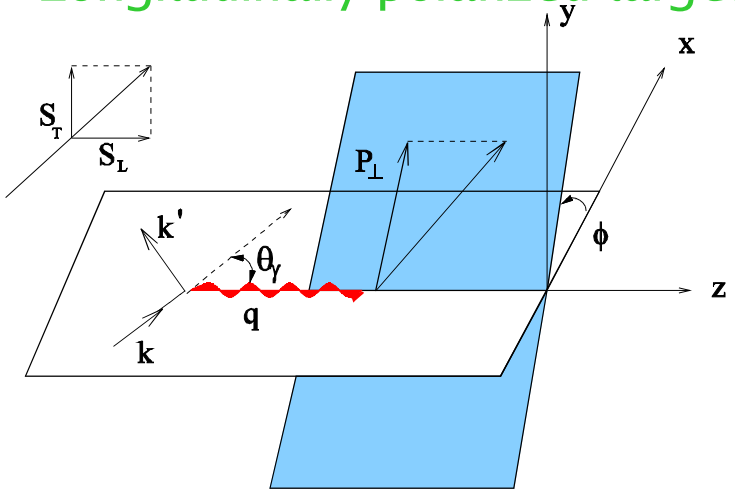
Polarzied beam and target

$S_L$ and $S_T$: Target Polarizations; $e$: Beam Polarization

# Observation of Single-Spin Azimuthal Asymmetry

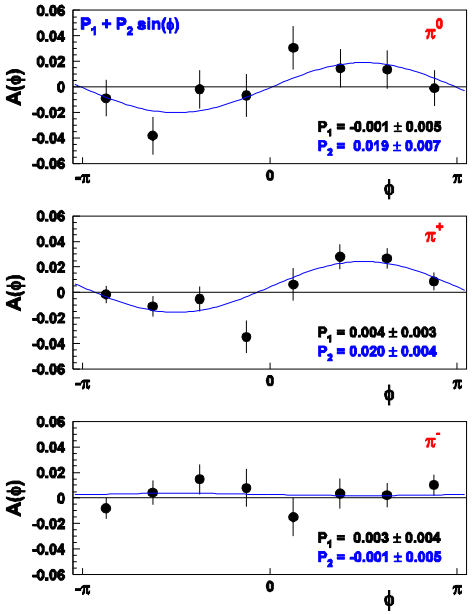
$ep \to e'X$

Longitudinally polarized target




$\langle S_T \rangle \sim 0.15$

HERMES




**Origins of the azimuthal asymmetry (correlation between the target nucleon transverse spin and the pion transverse momentum)?**

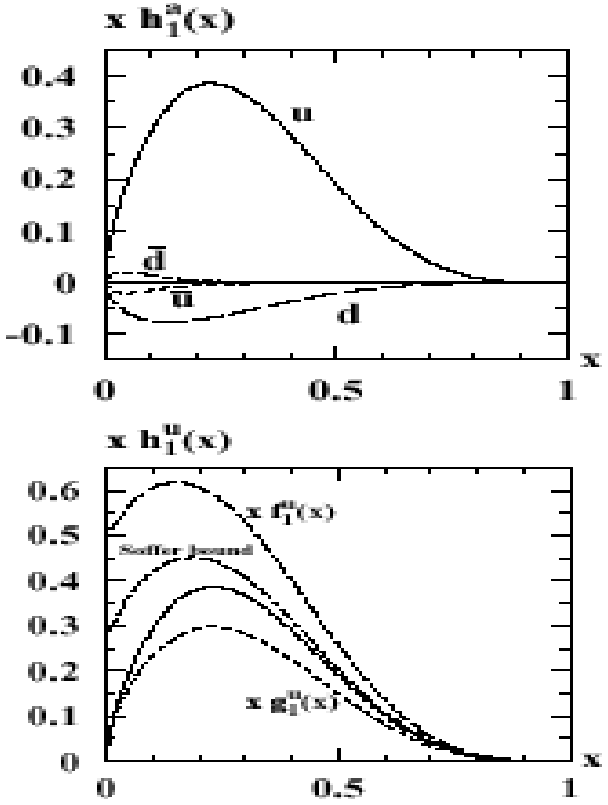
**Collins effect: Correlation between the quark's transverse spin with pion's $p_T$ in the fragmentation process.**

**Sivers effect: Correlation between the transverse spin of the proton with the quark's transverse momentum.**

**Other higher twist effects could also contribute.**

# Model prediction of transversity

Chiral-quark soliton model



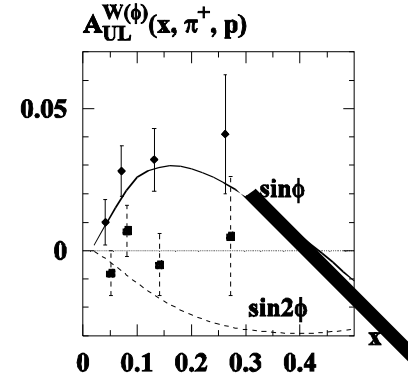

Similar to helicity distributions

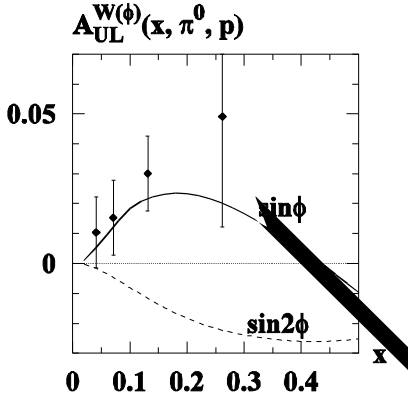
Chiral-quark soliton model predicts Sivers distribution is zero!

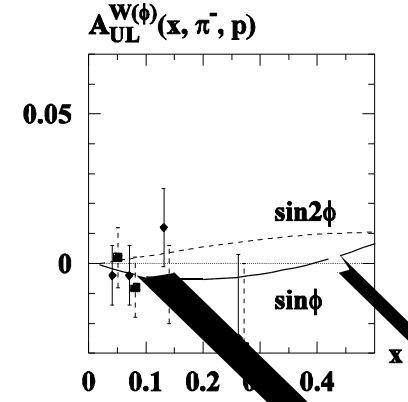
# Comparison with HERMES longitudinal SSA data

Proton data

Deuteron data



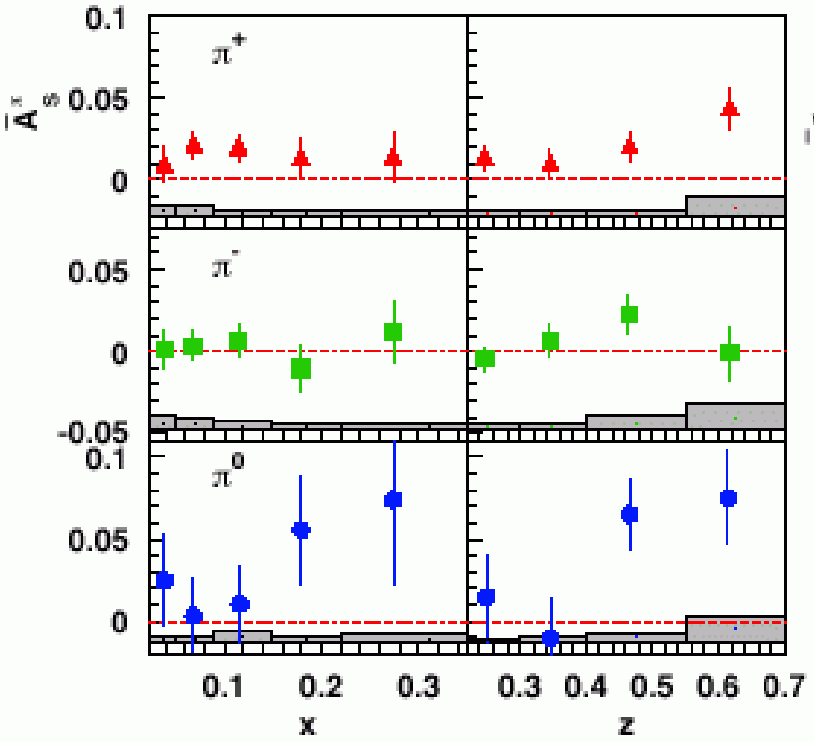




Chiral-quark soliton model can describe the SSA data very well (by including only the transversity term)

# First Results from HERMES Run 2: H↑ Target

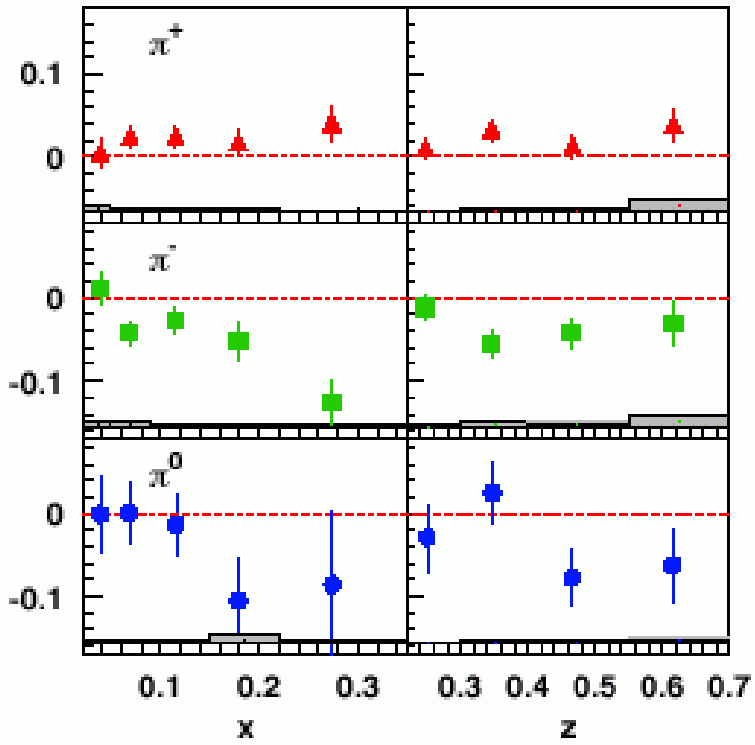
## Sivers Moments for $\pi^+$ $\pi^-$ $\pi^0$




*Sivers* $\langle A^{\pi^+} \rangle$ *= 0.034 ± 0.008*

*⇒ 3σ away from zero*

## Collins Moments for $\pi^+$ $\pi^-$ $\pi^0$

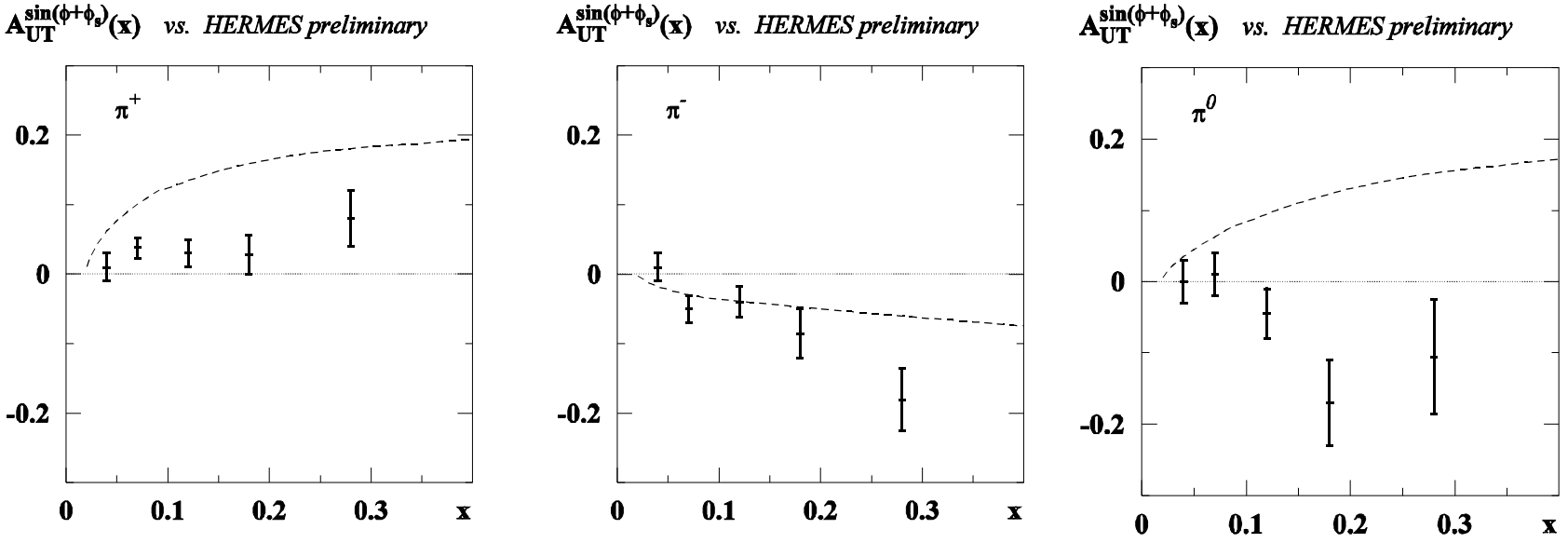



*Collins asym large for* $\pi^-$*, small for* $\pi^+$

Makins DNP04 talk

# Comparison between the HERMES transversely polarized target SSA data with Chiral-quark soliton model

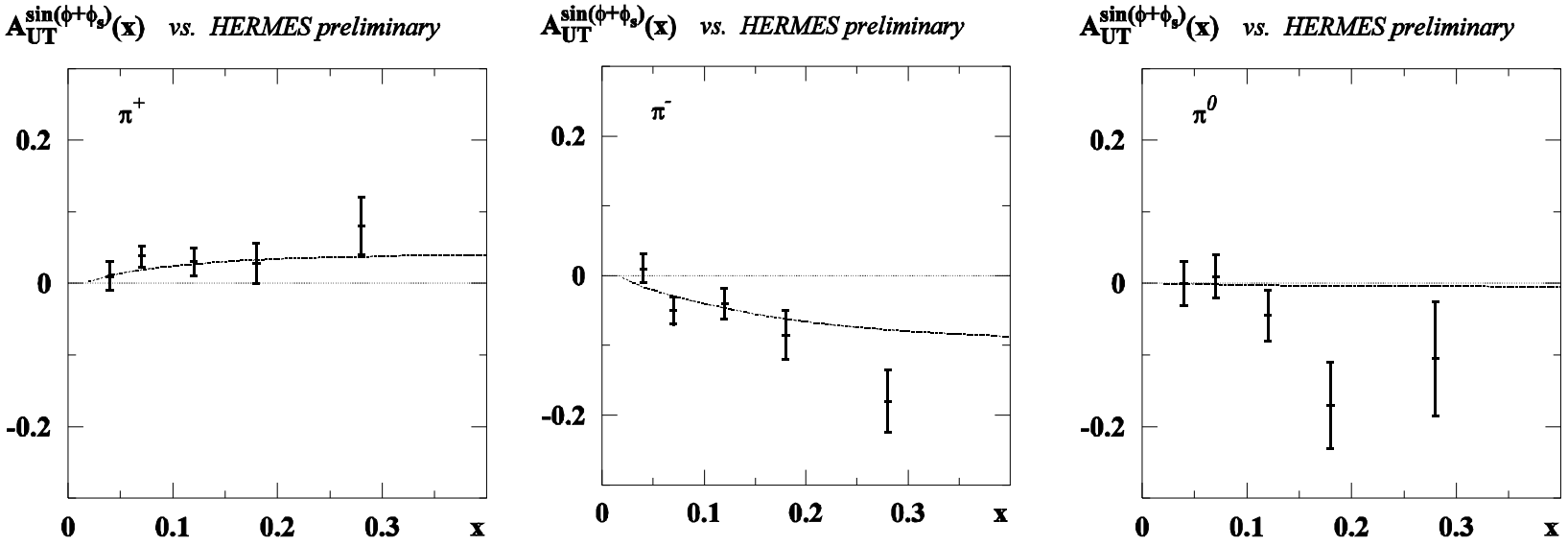
hep-ex/0412420




Disfavored Collins function = 0

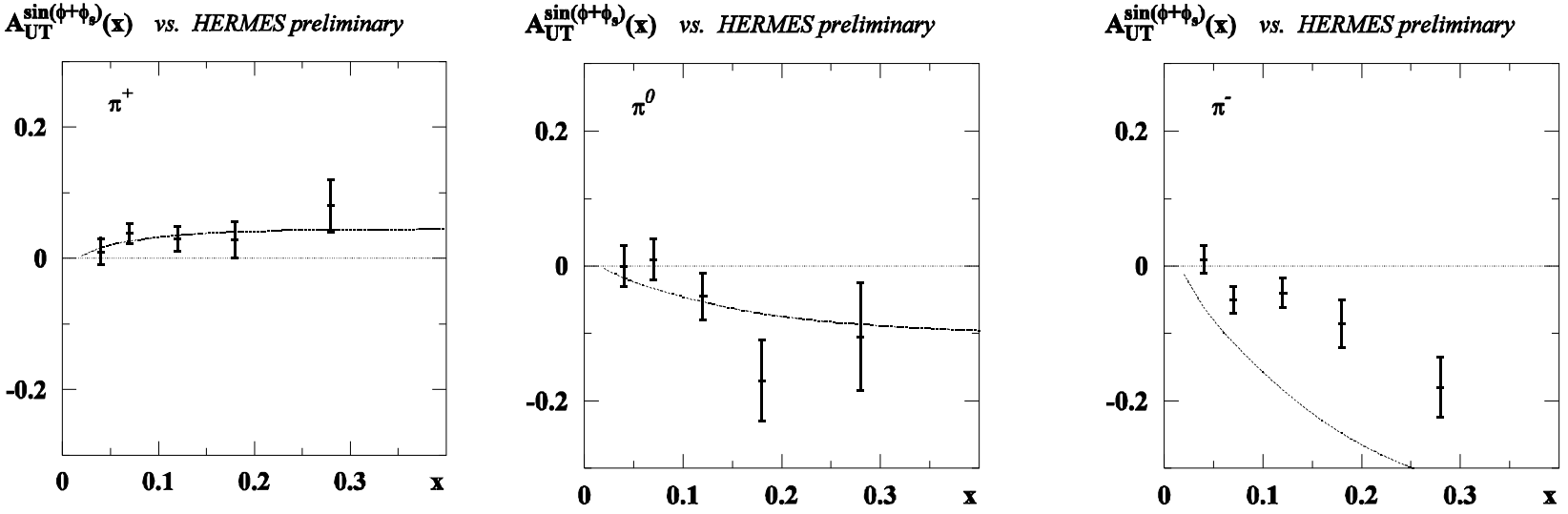
$$H_1^{\perp \mathrm{dis}}(z) = 0$$

# Comparison between the HERMES transversely polarized target data with the Chiral-quark soliton model




$$H_1^{\perp \text{disf}}(z) = -1.2 H_1^{\perp \text{fav}}(z)$$

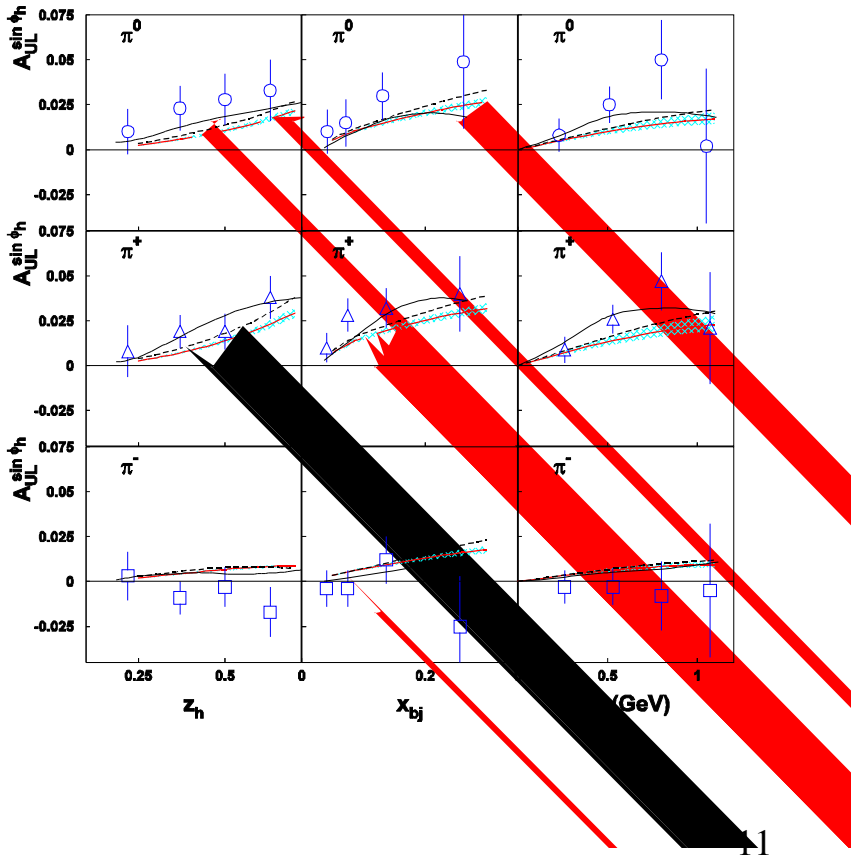
# Comparison between the HERMES transversely polarized data with the Chiral-quark soliton model




$$H_1^{\perp \text{disf}}(z) = -5H_1^{\perp \text{fav}}(z)$$

# Implications of the HERMES SSA data with transversely polarized target

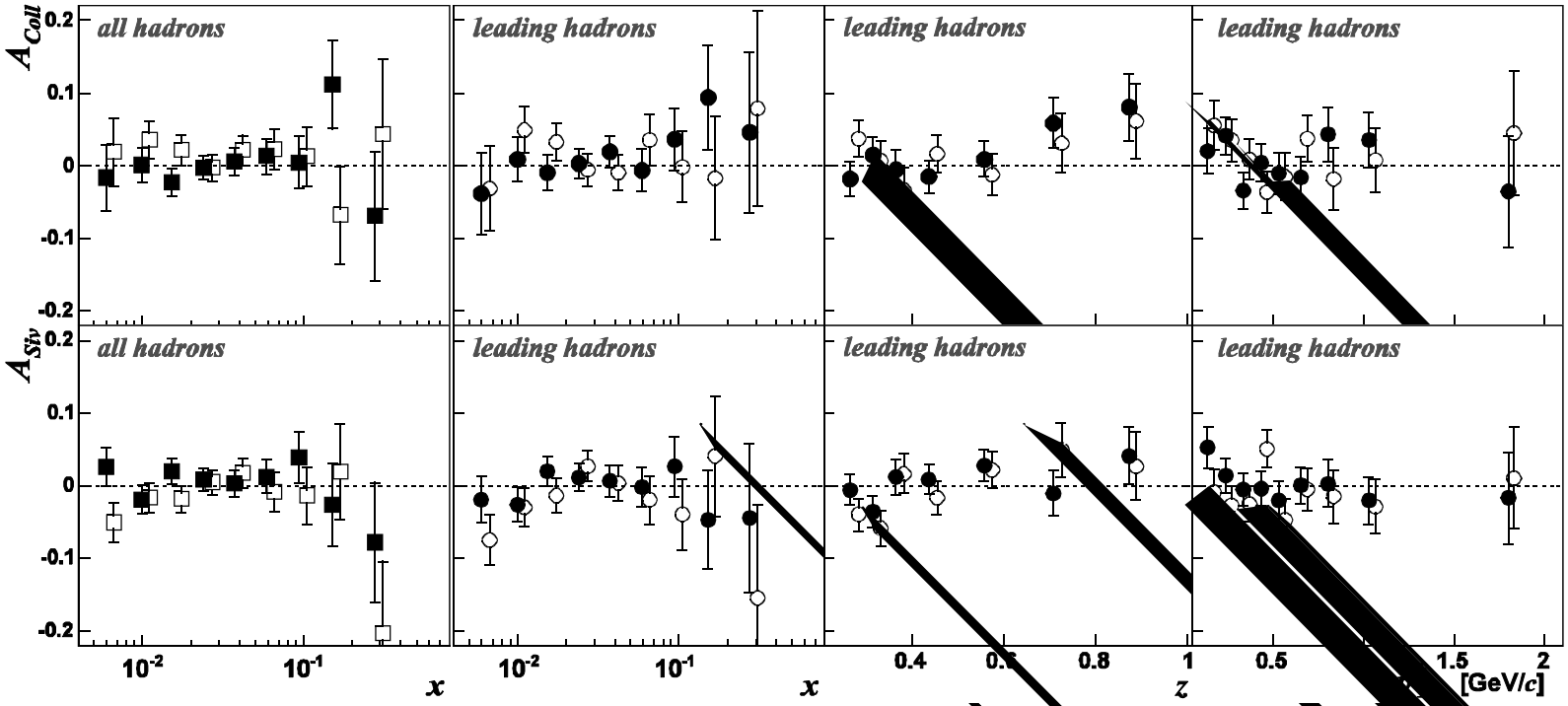
- Anselmino et al. showed that the Hermes SSA data for longitudinally polarized data can be explained by Sivers effect alone (without the transversity/Collins effect).
- However, the extracted Sivers function is much larger (and of opposite sign) compare to the HERMES SSA data with transversely polarized data.




hep-ph/0412316

# First results from COMPASS transversely polarized $^6$LiD

hep-ex/0503002

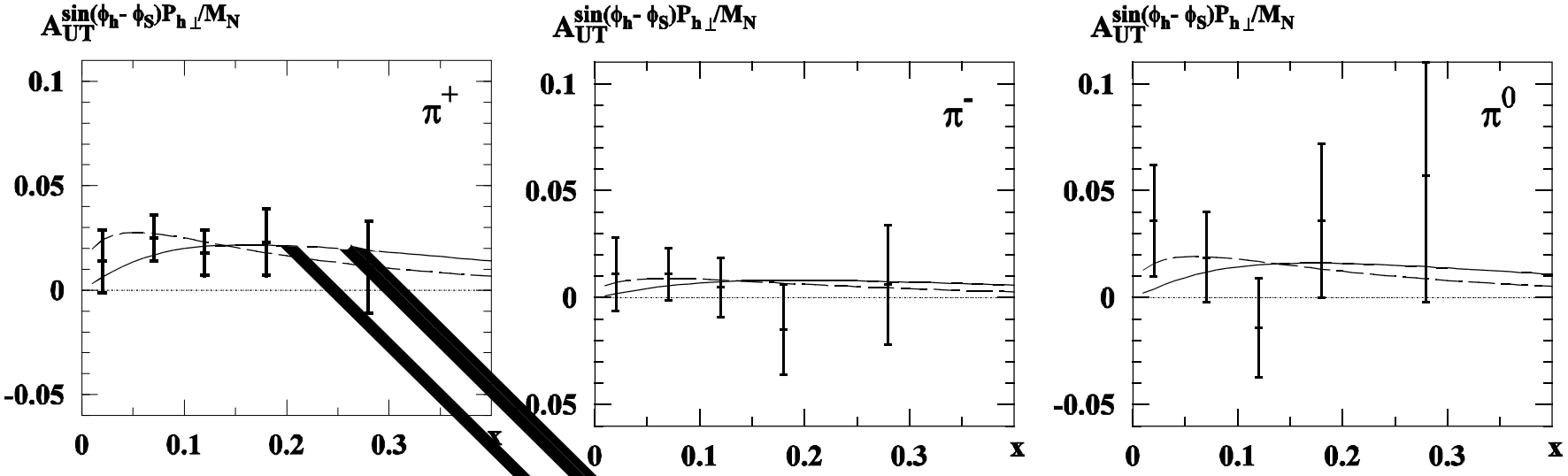



- Effects are expected to be small at small x
- Some cancellations between proton and neutron are expected

# Extraction of the Sivers distribution

## Fits to the HERMES data on Sivers moments

(hep-ph/0412353)




Solid curve: $xf_{1T}^{\perp(1)u}(x) = -0.4\,x(1-x)^5$

Dashed curve: $xf_{1T}^{\perp(1)u}(x) = -0.1\,x^{0.3}(1-x)^5$

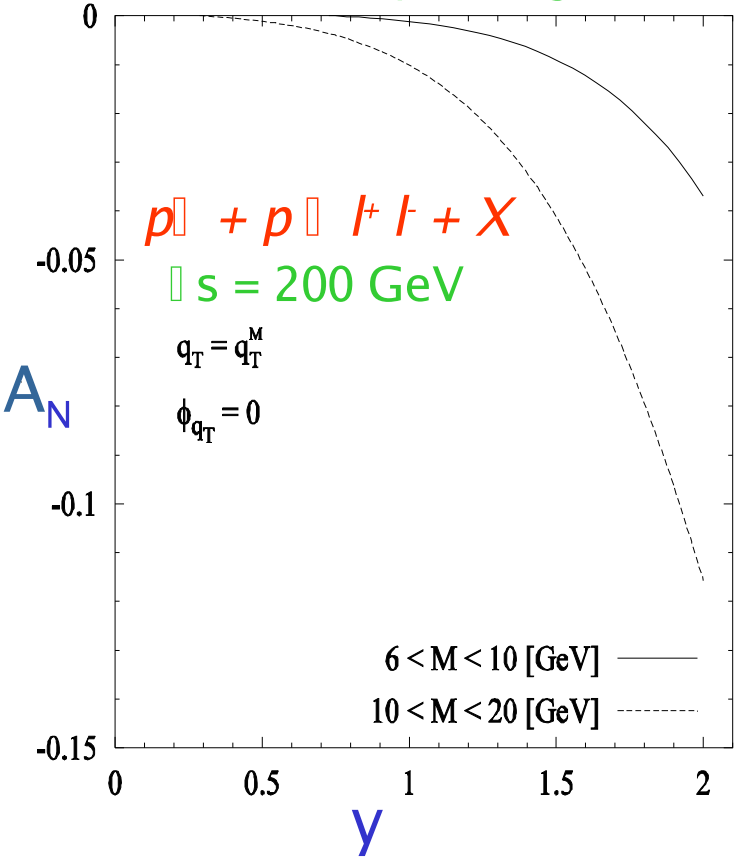
# SSA with Transversely Polarized Drell-Yan

## Analysing power ($A_N$) is sensitive to Sivers function

$$A_{N\,DY} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp}(x_q) f_{-}(x_{-})}{\sum_q e_q^2 f_q(x_q) f_{-}(x_{-})}$$

Sivers function in Drell-Yan is expected to have a sign opposite to that in DIS!

(Brodsky, Hwang, Schmidt, hep-ph/0206259; Collins, hep-ph/0204004)

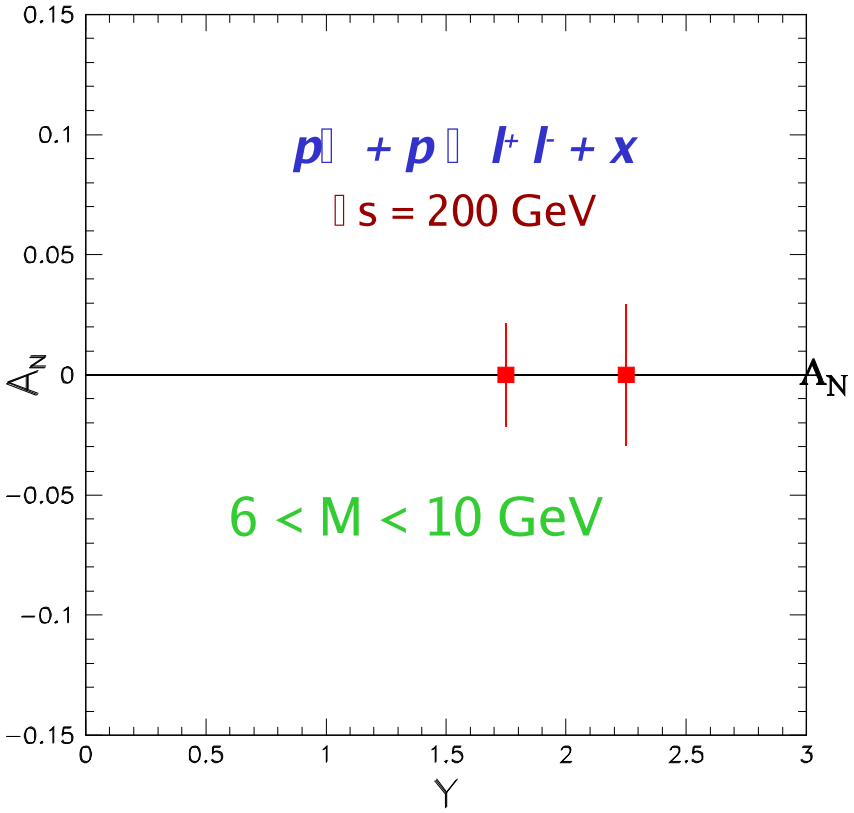


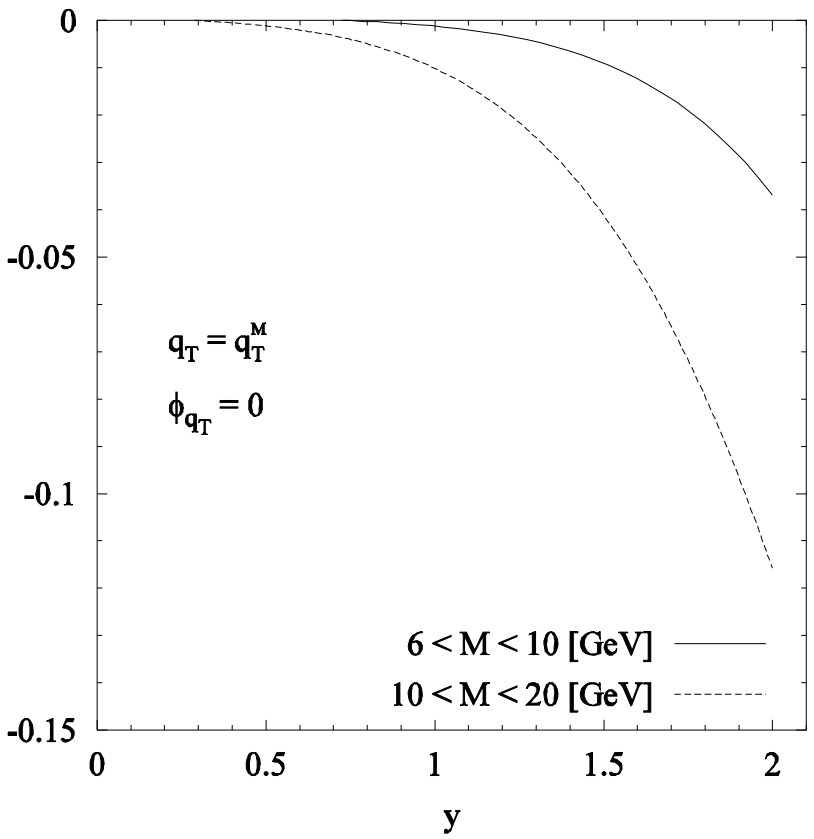

- Prediction by Anselmino, D'Alesio, Murgia (hep-ph/0210371) for a negative $A_N$.
- $|A_N|$ increases with rapidity, y, and with dilepton mass, M.

Is this measurement feasible at RHIC?

# Expected statistical sensitivity for Drell-Yan $A_N$

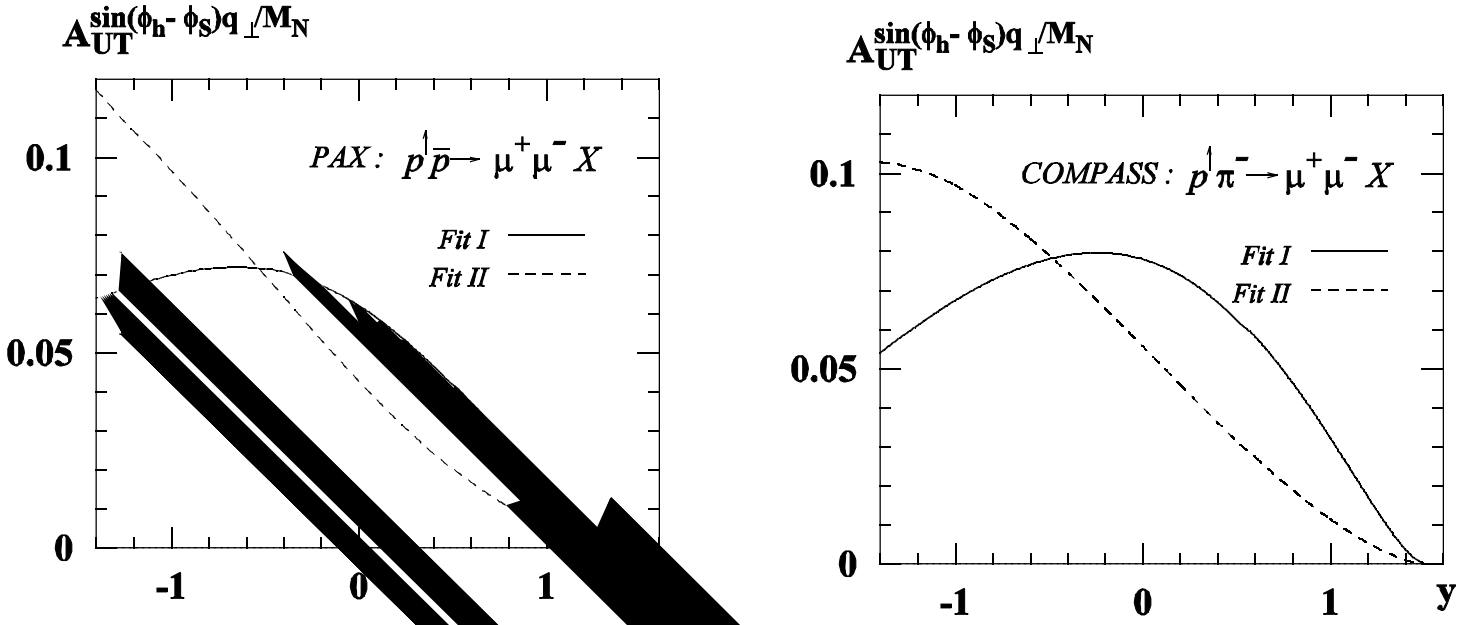
## Assuming 400 $pb^{-1}$ 50% polarization




- Might be feasible to determine the sign of the Sivers function at RHIC
- Should consider fixed-target polarized Drell-Yan too

# Sivers functions from SSA in polarized Drell-Yan







Solid curve: $xf_{1T}^{\perp(1)u}(x) = -0.4\,x(1-x)^5$

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# Cos2□ Dependence in Unpolarized Drell-Yan

Large cos2□ dependences have been observed in □ – induced Drell-Yan

This azimuthal dependence could arise from a product of $K_T$-dependent distribution function $h_1^{\perp}$

( Boer, hep-ph/9902255; Boer, Brodsky, Hwang, hep-ph/0211110)

In quark-diquark model, $h_1^{\perp}$ is identical to Sivers function

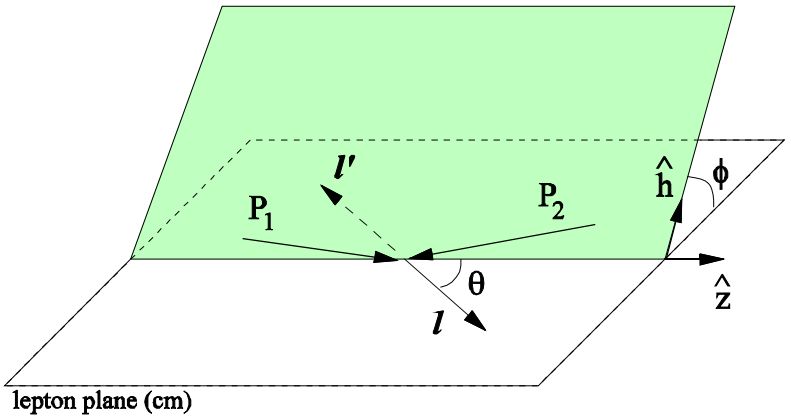
No Cos2□ depenence for unpolarized p-p Drell-Yan has been reported yet (The effect from $h_1^{\perp}$ is expected to be smaller)

- RHIC would provide unpolarized p-p Drell-Yan data too
- Fixed-target unpolarized p-p Drell-Yan data also exist

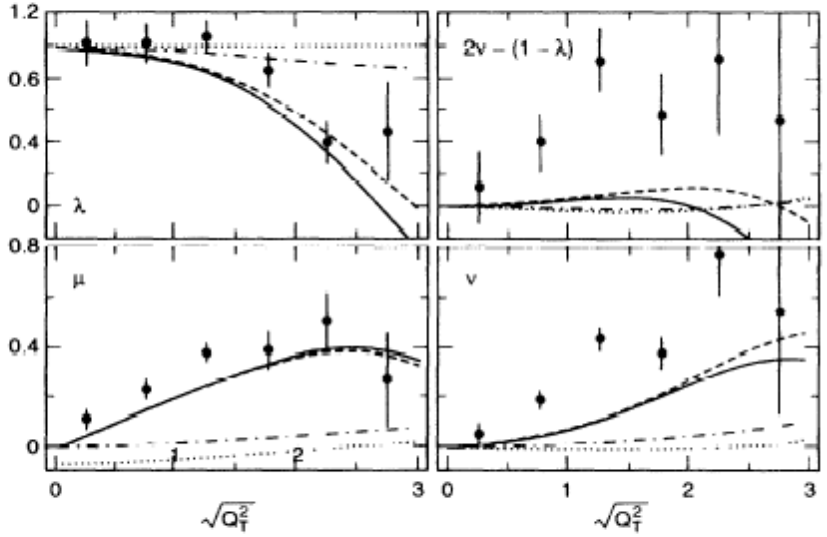
$$h + N \to \gamma^* + X \to \mu^+ + \mu^- + X$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} : \; 1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\phi + \frac{\nu}{2}\sin^2\theta \cos 2\phi$$

Lam-Tung sum rule : $1 - \lambda - 2\nu = 0$




252 GeV $\pi^-$ + W (Conway et al.)



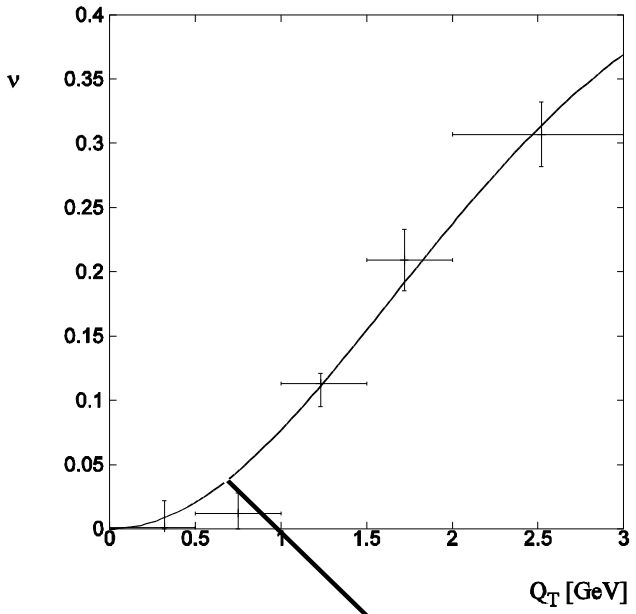

Lam-Tung rule is violated and can not be explained by pion bound state effect

## Brandenburg, Nachtmann and Mirkes proposed correlation between quark $k_T$ and its transverse spin

$$1-\lambda-2\nu \approx -4\kappa \qquad \kappa = \kappa_0 \frac{Q_T^4}{Q_T^4 + m_T^4}$$

$\kappa$ is a measure of the correlation between the transverse spins of the $q\bar{q}$

D. Boer pointed out that $h_1^{\perp}$ provides such correlation



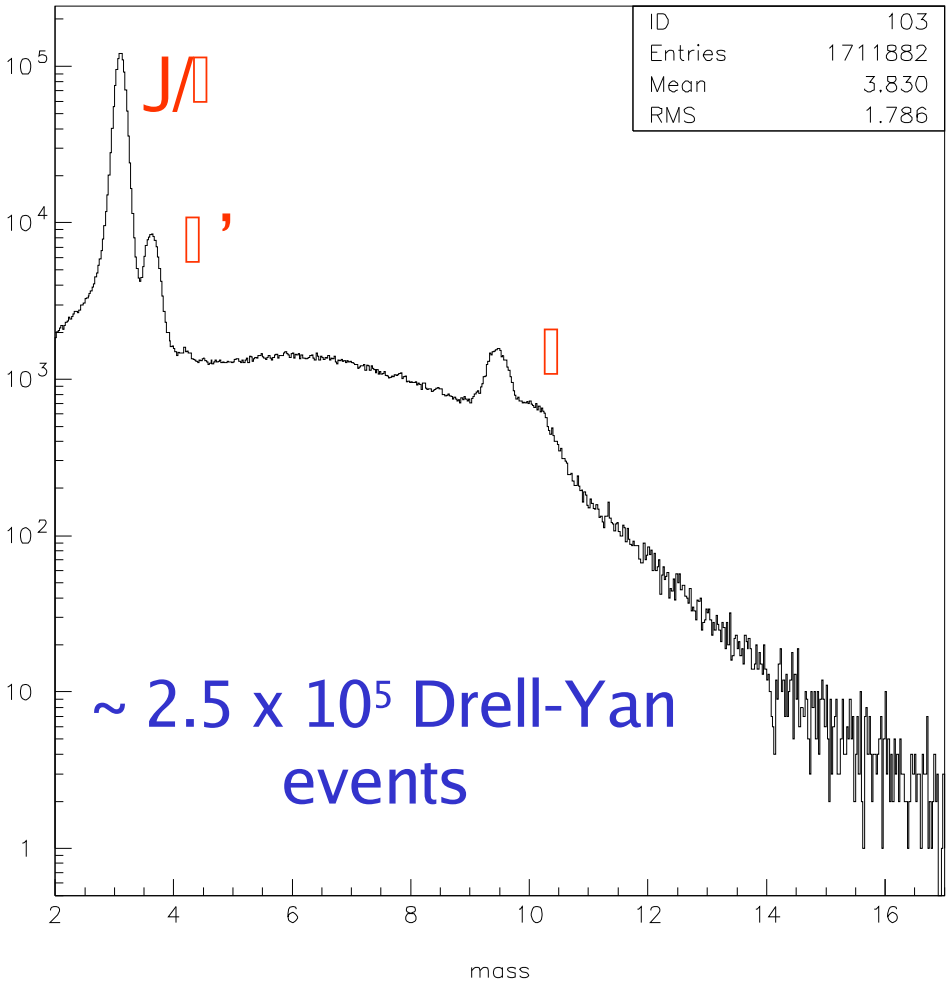

$$h_1^{\perp}(x,k_T^2) = \frac{\alpha_T}{\pi} c_H \frac{M_C M_H}{k_T^2 + M_C^2} e^{-\alpha_T k_T^2} f_1(x)$$

$$M_C = 2.3\,\text{GeV},$$

$$C_H = 1,\ \alpha_T = 1\,\text{GeV}^{-2}$$

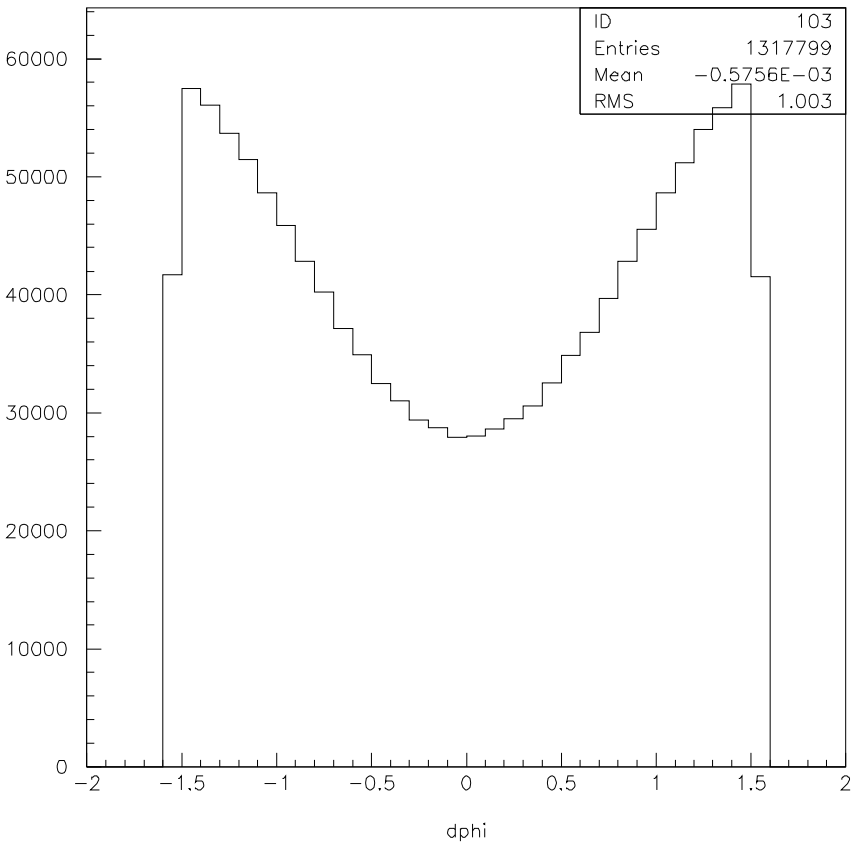
# Unpolarized p-p and p-d dimuon production

Fermilab E866, $\sqrt{s}$ = 38.8 GeV

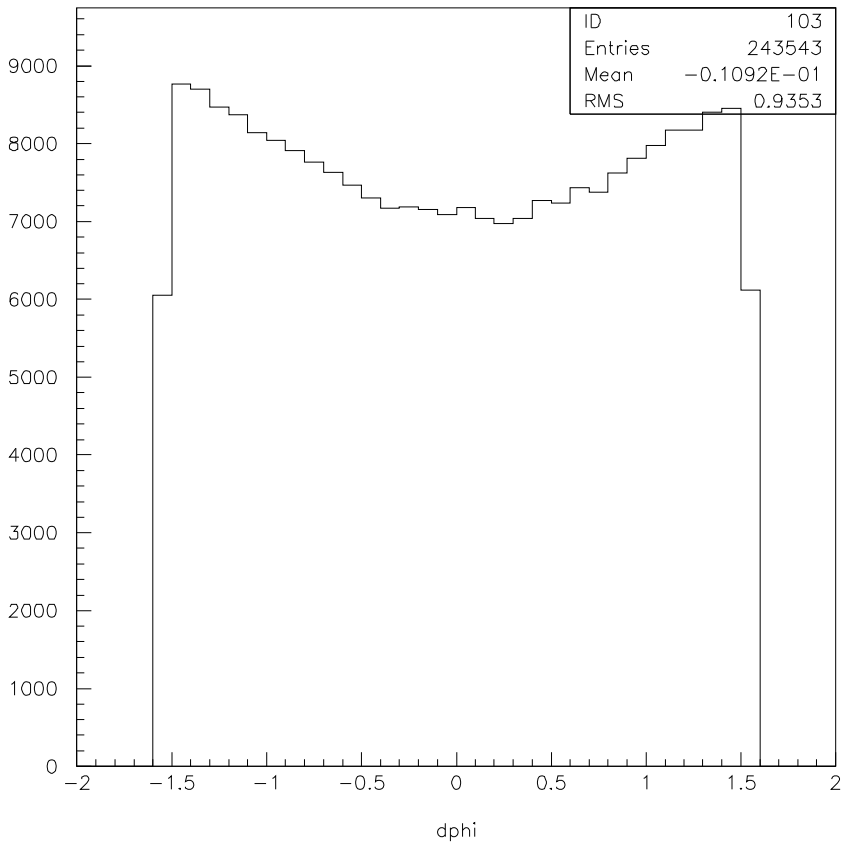


# – coverage of the E866 dimuon data

J/ events




Drell-Yan events




Not corrected for acceptance yet

# Summary

- Transversity distribution remains an interesting frontier in understanding spin structure in nucleon.
- Study of the T-odd Sivers structure function and the Collins fragmentation function are important for their own sake, and for extracting information on transversity.
- First results of SSA using transversely polarized p and d targets are intriguing. The proposed Hall-A measurement on $^3$He should provide very useful new information.
- New Semi-Inclusive DIS experiments at JLab will continue to probe the flavor structure of unpolarized and polarized parton distributions.