



# New Results for Transverse Spin Effects at COMPASS

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# Agenda

- Short Introduction to
  - The Compass Experiment
  - Transverse Spin Effects at Compass
- New results from 2002-2004 data
  - Collins effect for  $K^0$
  - Transversity from Leading 2 Hadron Asymmetries
  - Sivers effect for  $K^0$

# Compass Experiment (2004)

- high energy beam
- large angular acceptance
- broad kinematical range

beam: 160 GeV/c

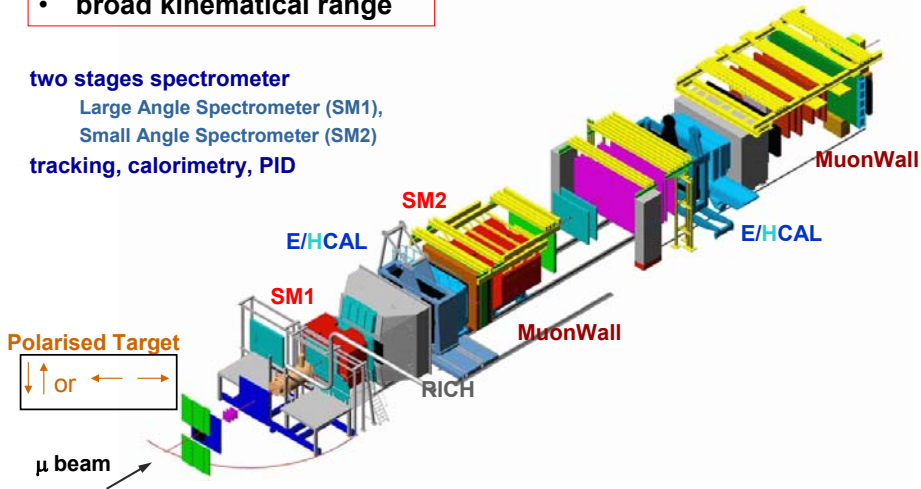
intensity  $2 \cdot 10^8 \mu^+/\text{spill}$  (4.8s/16.2s)

two stages spectrometer

Large Angle Spectrometer (SM1),

Small Angle Spectrometer (SM2)

tracking, calorimetry, PID

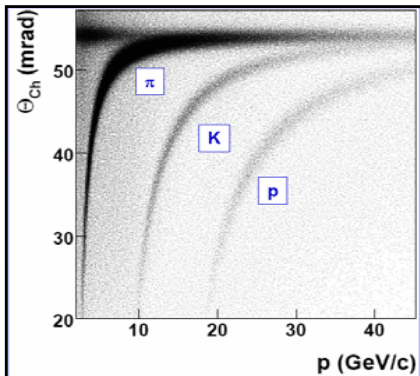
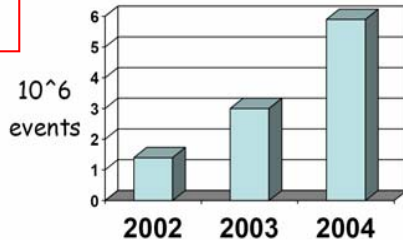


# Transverse Data taken 2002 - 2004

transversely polarized deuteron target  
~ 20% of the running time

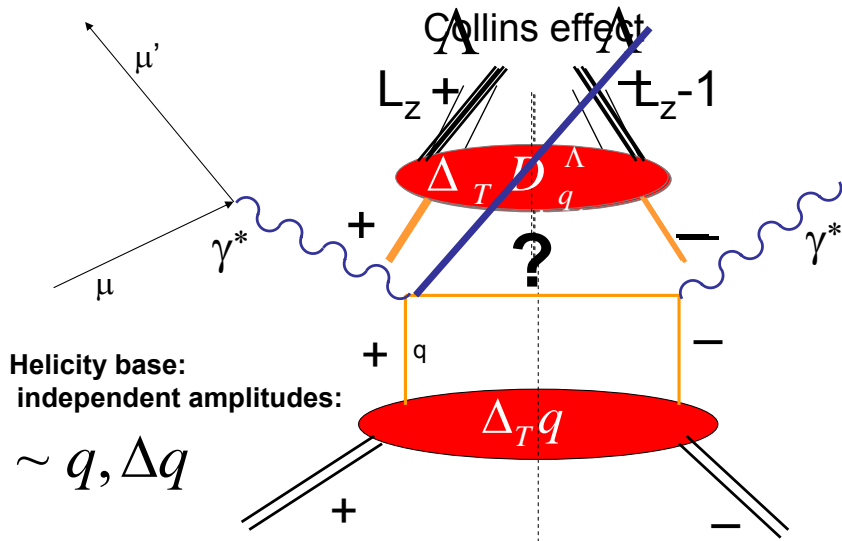
RICH PID starting 2003

10 Mill.  
DIS events



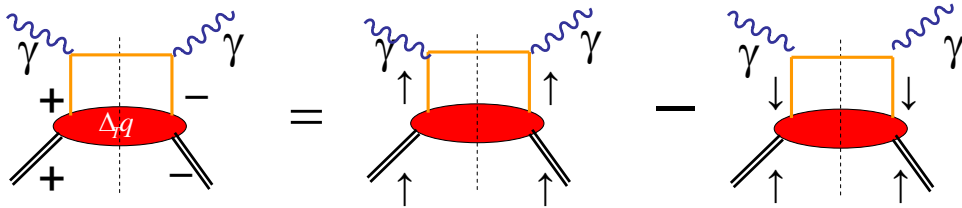
| Statistics<br>2003-2004: | positive | negative |
|--------------------------|----------|----------|
| $\pi$                    | 5.2M     | 4.5M     |
| K                        | 0.9M     | 0.6M     |

# Measuring Transversity in SIDIS



# Measuring Transversity

- Transversity base:
- Probabilistic interpretation

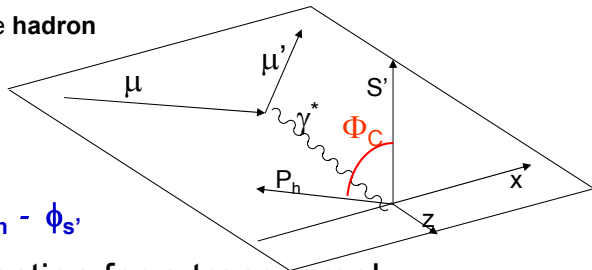


Difference in densities for  $\uparrow$ ,  $\downarrow$  quarks in  $\uparrow$  nucleon  
→ Azimuthal SSA on Transv. Pol. nucleon

# Collins Effect in SIDIS

$\mathbf{P}_h$  transverse momentum of the **hadron**

$\mathbf{S}'$  transverse spin of  
the **struck quark**



“Collins angle”  $\Phi_C = \phi_h - \phi_{s'}$

- Fragmentation Function for a transversely polarised quark into unpolarised hadron

$$+ \underbrace{\Delta_T^0 D_q^h}_{\text{spin dependent part}}$$

spin dependent part : “Collins fragmentation function”

Number of  
Events:

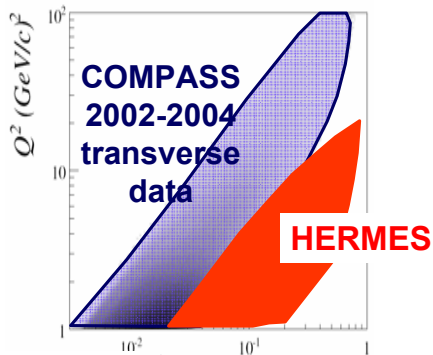
$$\mathbf{N}_h^\pm(\Phi_C) = \mathbf{N}_h^0 \cdot \{ 1 \pm \mathbf{A}_C^h \cdot \sin\Phi_C \}$$

$$\mathbf{A}_C^h \cong \frac{\sum_q e_q^2 \cdot \Delta_T \mathbf{q} \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot \mathbf{q} \cdot D_q^h}$$

# Selection of SIDIS Events

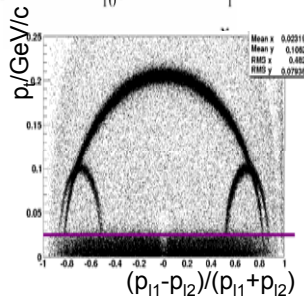
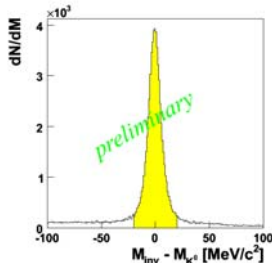
- DIS cuts:

- $Q^2 > 1 \text{ (GeV/c)}^2$
- $0.1 < y < 0.9$
- $W > 5 \text{ GeV/c}^2$



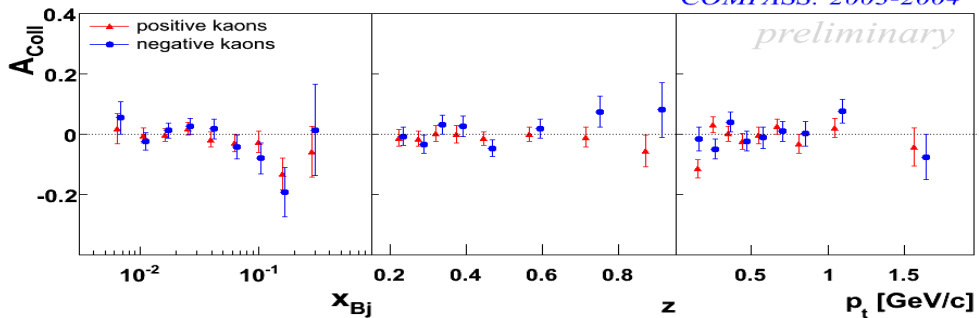
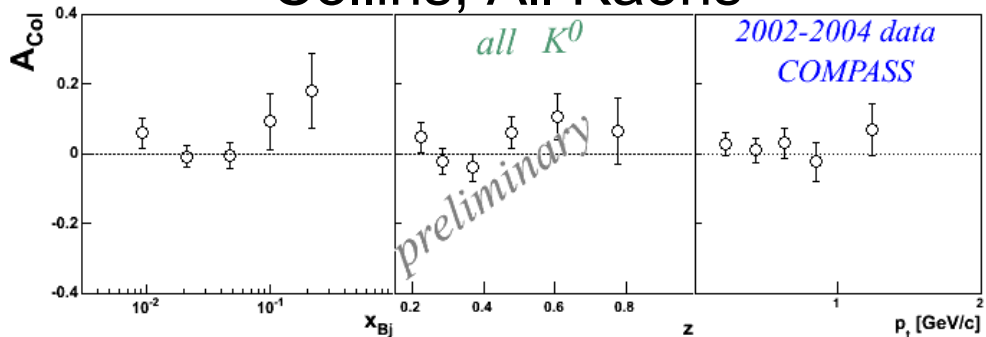
- $K^0$  selection

- 2 charged particles
- $-0.3 \text{ (GeV/c)}^2 < M_{\pi\pi} - M_{K^0} < 0.3 \text{ (GeV/c)}^2$
- $p_t$  rel. to  $p_1 + p_2 > 25 \text{ MeV/c}$  (Armenteros plot)
- $z > 0.2$



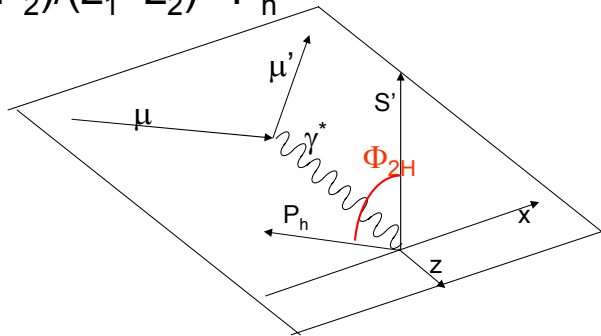


# Collins, All Kaons



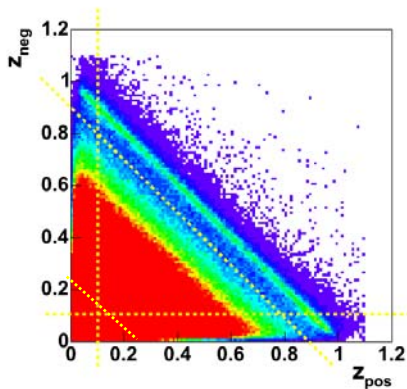
# Transversity signal in 2 Hadron Correlations

- Azimuthal Asymmetry measurement similar to Collins Asymmetry extraction
- $(z_2 P_1 + z_1 P_2) / (z_1 + z_2) = P_h$

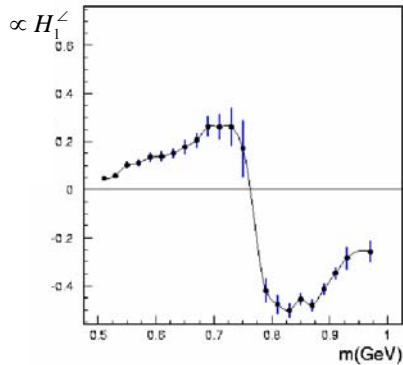


# Event Selection **Leading 2 Hadron**

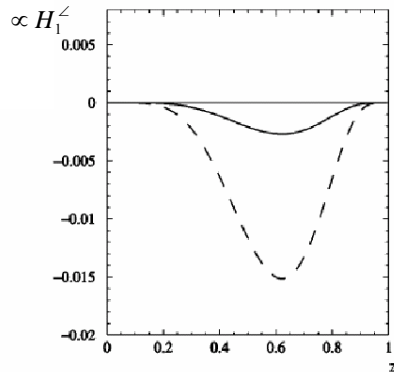
- $Q^2 > 1$
- $0.1 < y < 0.9$
- $W > 5 \text{ GeV}/c^2$
- Leading 2h
  - $h_1$  leading,  $h_2$  subleading in event
  - $z_{1,2} > 0.1$  (current fragmentation region)
  - $x_{F1,2} > 0.1$
  - $0.25 < z_1 + z_2 < 0.9$  (no exclusive events)



# Predictions for $H_1^\zeta$



R. L. Jaffe, X. Jin and J. Tang,  
Phys. Rev. Lett. 80, 1166 (1998)



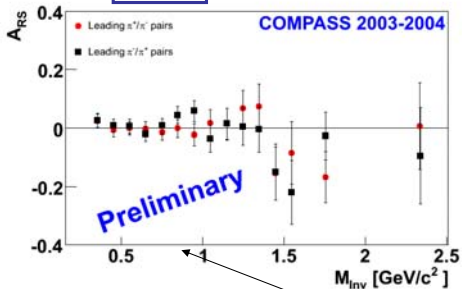
Radici, Jakob, Bianconi, PRD 65, 074031

Expecting Signal around  $\rho$ -Mass

# Compass Results

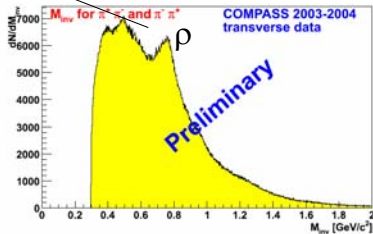
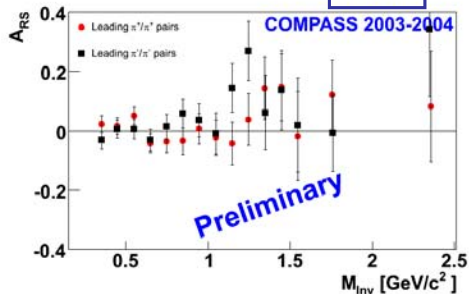
$\pi^+ \pi^-$

$\pi^- \pi^+$

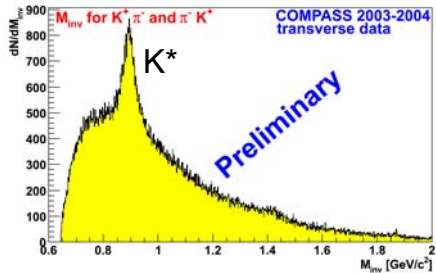
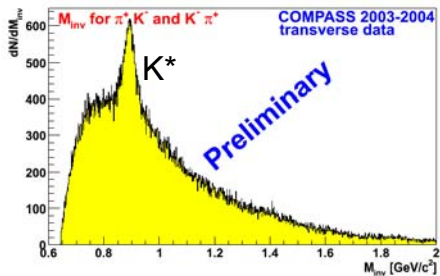
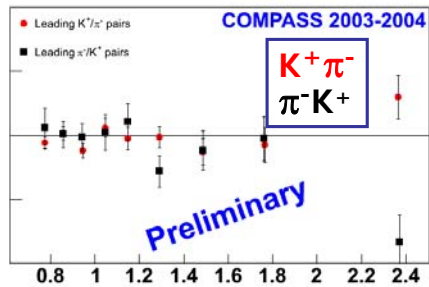
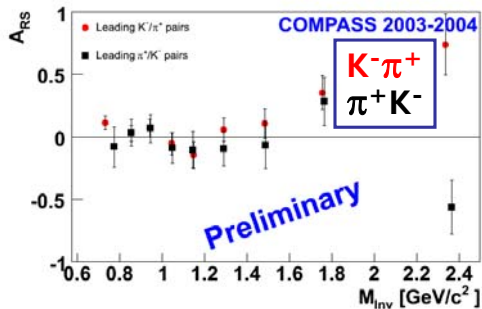


$\pi^+ \pi^+$

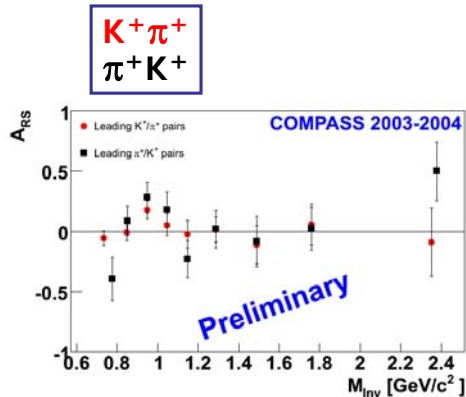
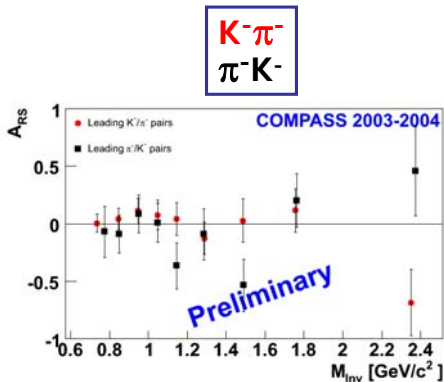
$\pi^- \pi^-$



# Kaon-Pion Combinations

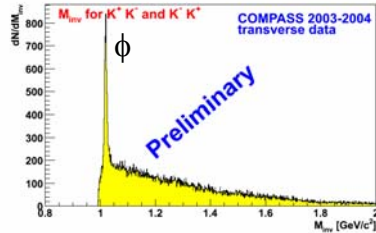


# Like Sign Kaon Combinations



# Kaon-Kaon Combinations

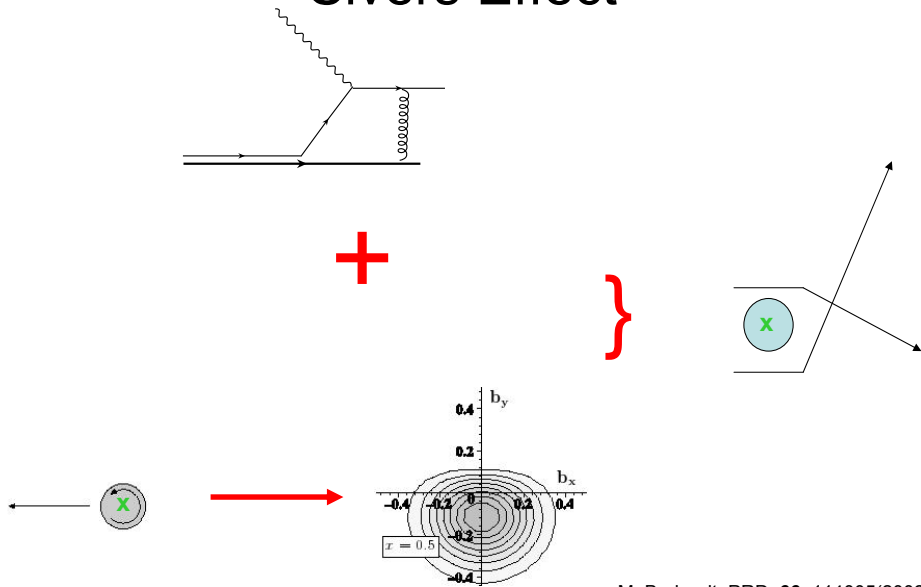
- $K^+/K^-$ :  $0.0273 \pm 0.0552$
- $K^-/K^+$ :  $-0.0890 \pm 0.0583$



- $K^+/K^+$ :  $0.2482 \pm 0.1390$
- $K^-/K^-$ :  $0.4257 \pm 0.1798$



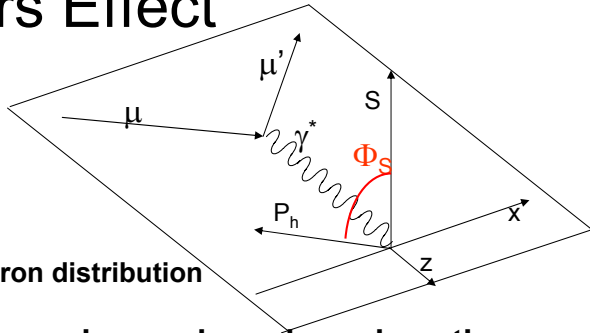
# Sivers Effect



# Sivers Effect

“Sivers angle”  $\Phi_S = \phi_h - \phi_s$

$$\Phi_C = \phi_h - \phi_{s'} = \phi_h + \phi_s - \pi$$



Modulation in  $\Phi_S$  of the hadron distribution

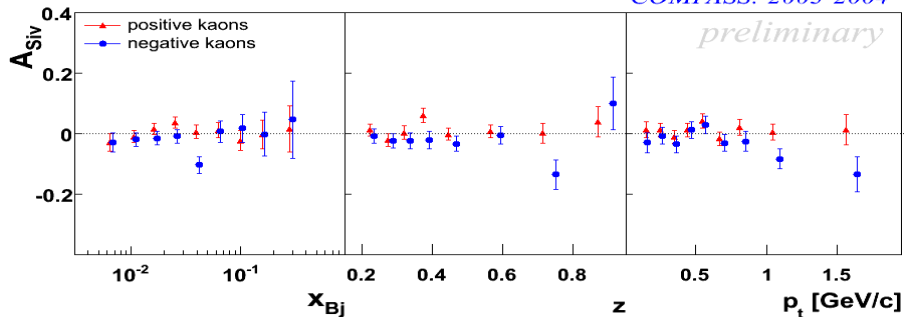
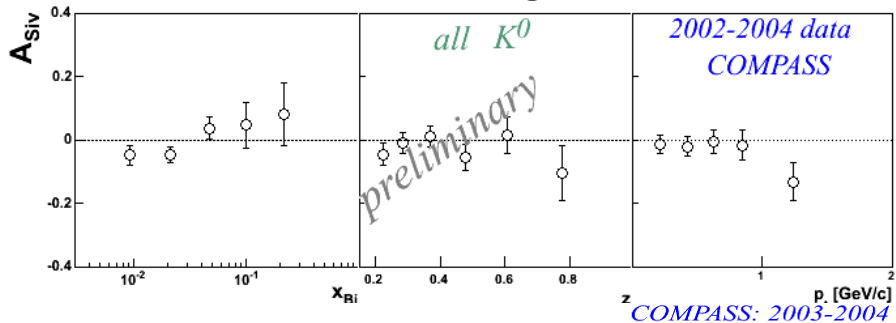
Correlation between the nucleon spin and quark motion

Sivers effect  $\neq 0$   $\square$  Quark angular momentum  $\neq 0$

modulation in  $\Phi_S$  of the hadron distribution

$$N_h^\pm(\Phi_S) = N_h^0 \cdot \left\{ 1 \pm \mathbf{A}_S^h \cdot \sin\Phi_S \right\} \quad \mathbf{A}_S \cong \frac{\sum_q e_q^2 \cdot \Delta_0^T \mathbf{q} \cdot \mathbf{D}_q^h}{\sum_q e_q^2 \cdot \mathbf{q} \cdot \mathbf{D}_q^h}$$

# All $K^0$ s



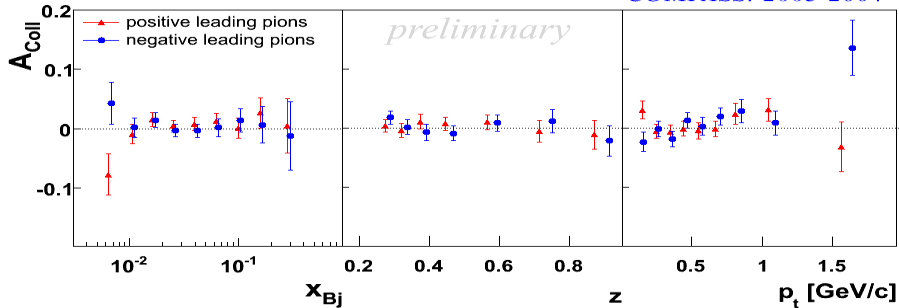
# Summary/Outlook for transverse spin physics at COMPASS

- So far
  - Precise COMPASS data, identified hadrons with deuteron target available
  - Collins and Sivers from All and Leading  $\pi^+$ ,  $\pi^-$ ,  $K^+$ ,  $K^-$ ,  $K^0$
  - 2 Hadron Correlations from Pions and Kaons
  - Each Combination gives new constraints on Distribution and Fragmentation functions
  - 6 more transverse Spin dependent Asymmetries in TMD SIDIS XSection
- COMPASS currently measures with proton target!
- Flavor separation

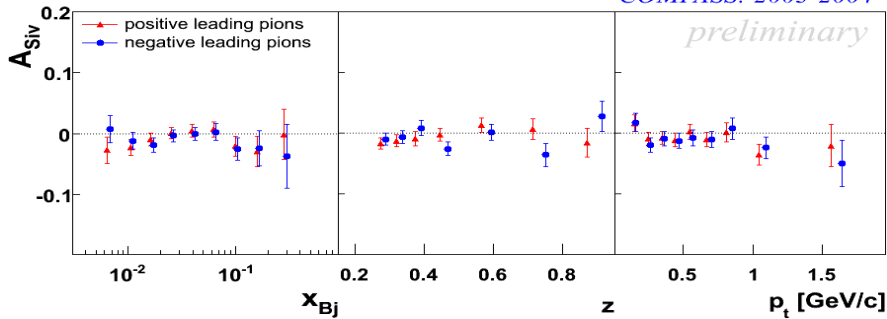
Backup

# Single Hadron Collins, Sivers

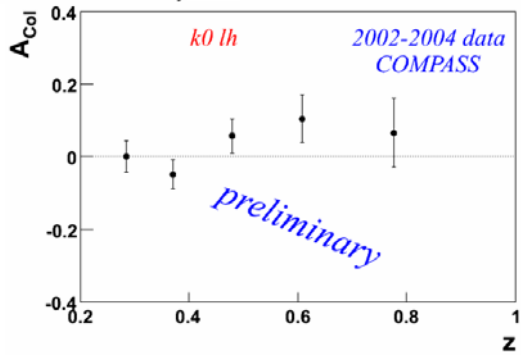
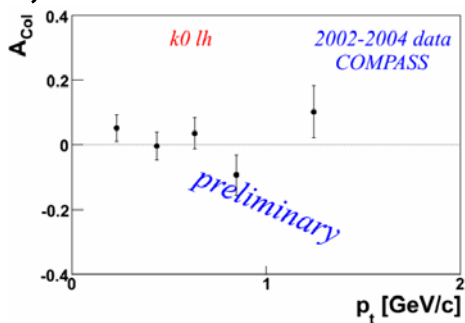
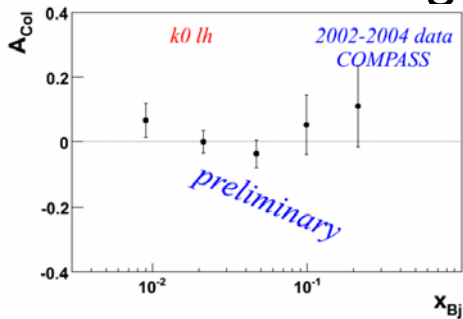
COMPASS: 2003-2004



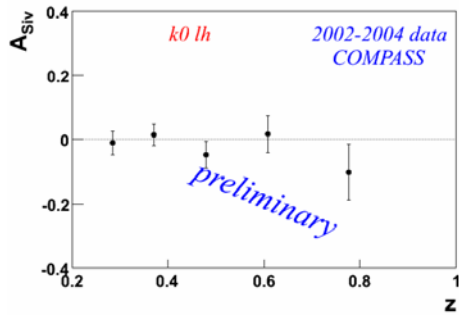
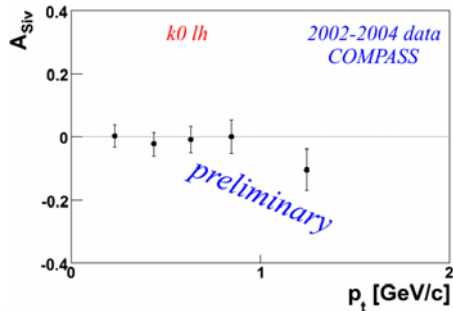
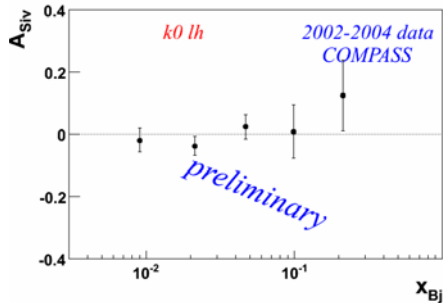
COMPASS: 2003-2004



# Leading $K^0$ , Collins

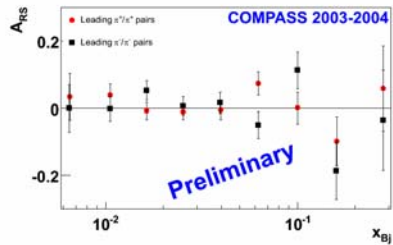
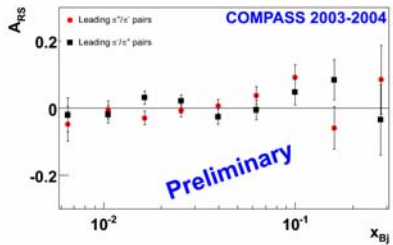


# Leading $K^0$

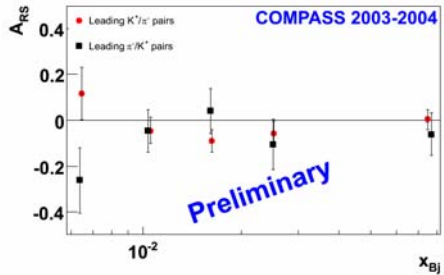
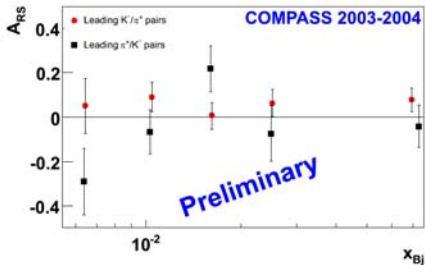
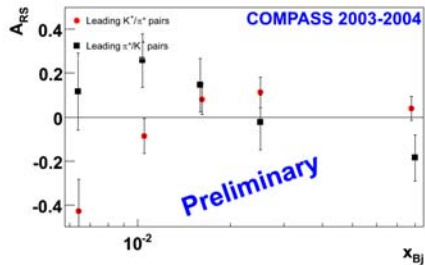
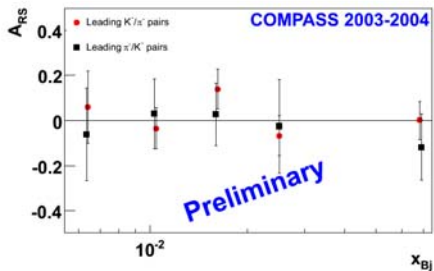




# $X_{Bj}$ Binning

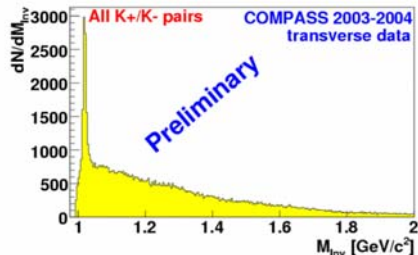
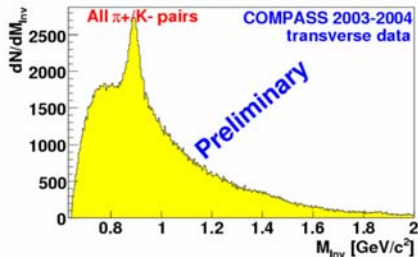
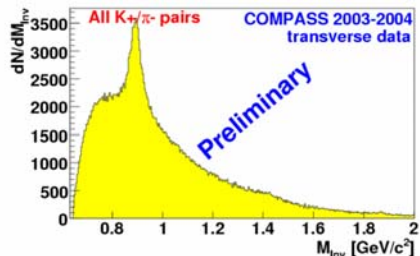
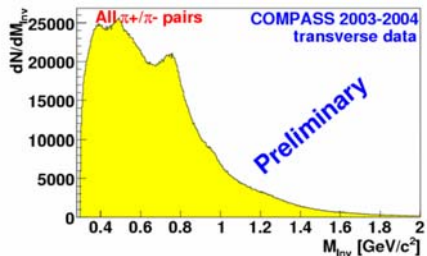


# $X_{Bj}$ Binning

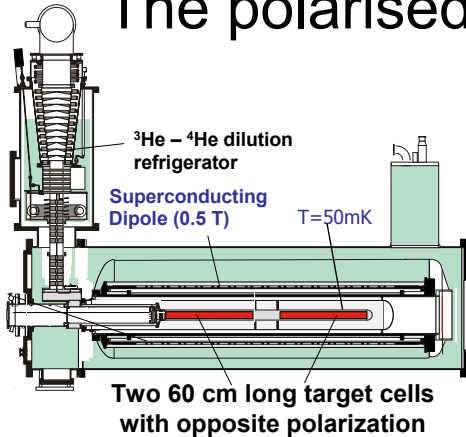


# Hadron Pairs Invariant Mass

all hadron pairs: 5.3 M Spectra

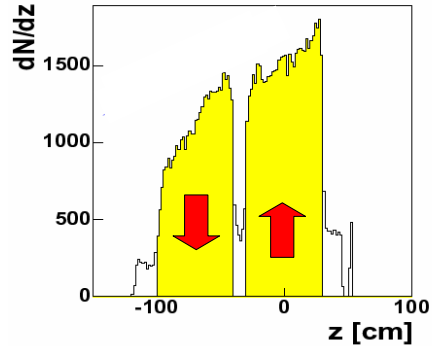


# The polarised ${}^6\text{LiD}$ -Target



Transverse target polarization:  
Reversed one a week

Vertex distribution:



Polarization: 50 %  
Dilution factor: 0.38

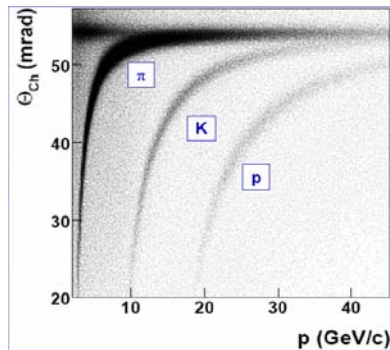
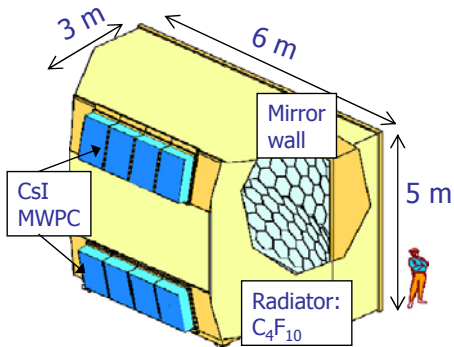
# Ring Imaging Cherenkov

Identification of  $\pi$ , K and protons

Cherenkov thresholds:  $\pi \approx 3 \text{ GeV}/c$   $2\sigma$   $\pi/K$  separation at  $43 \text{ GeV}/c$

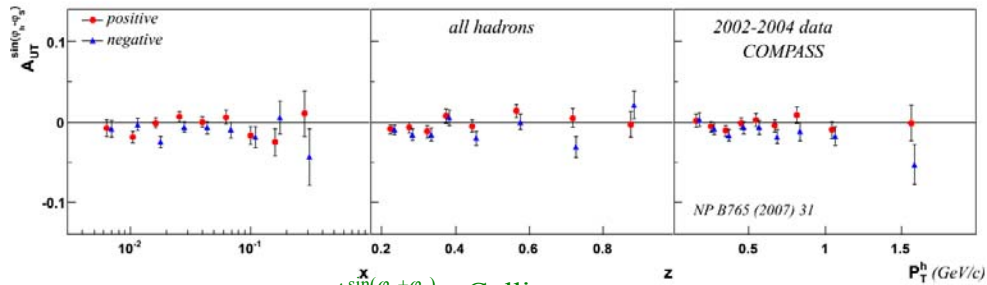
$K \approx 9 \text{ GeV}/c$

$p \approx 17 \text{ GeV}/c$

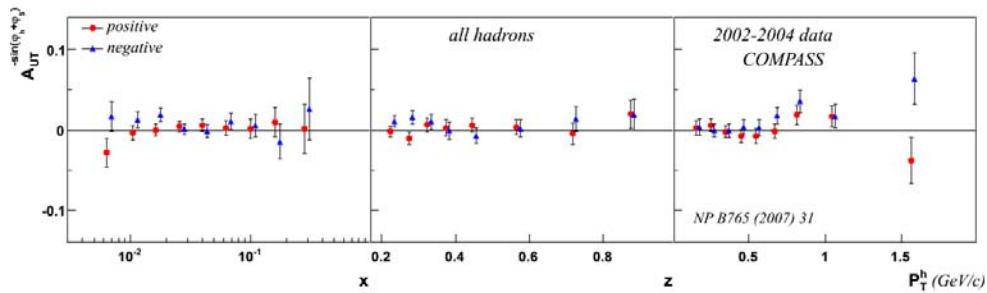


# Results for all hadrons

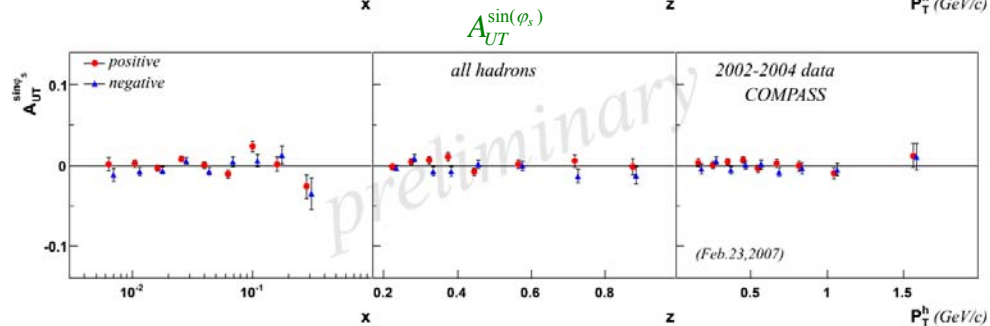
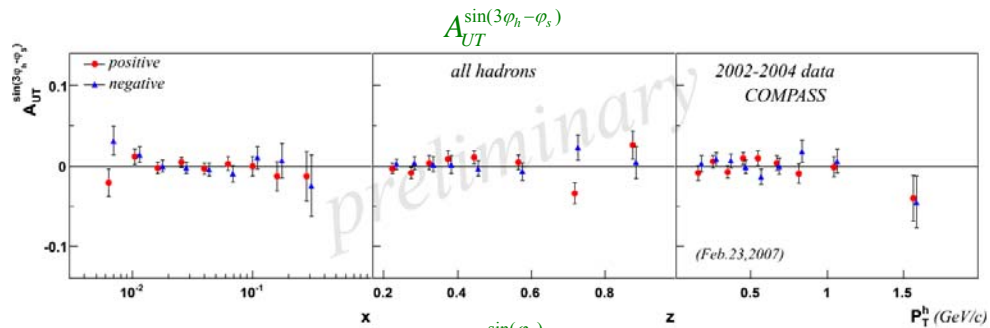
$A_{UT}^{\sin(\varphi_h - \varphi_s)}$  - Sivers asymmetry



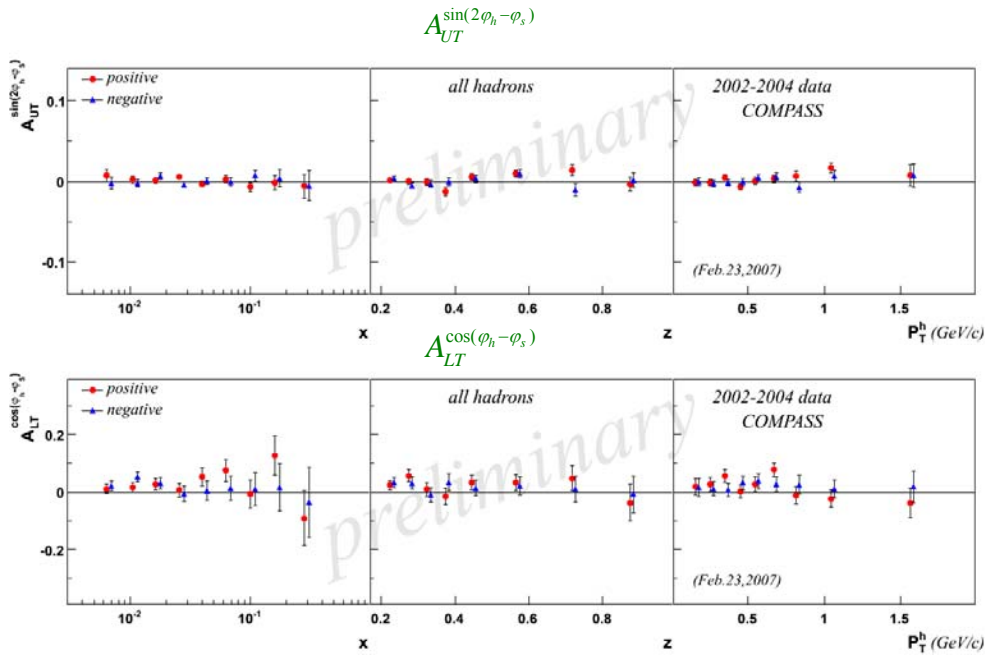
$-A_{UT}^{\sin(\varphi_h + \varphi_s)}$  - Collins asymmetry



# Results beyond Collins and Sivers

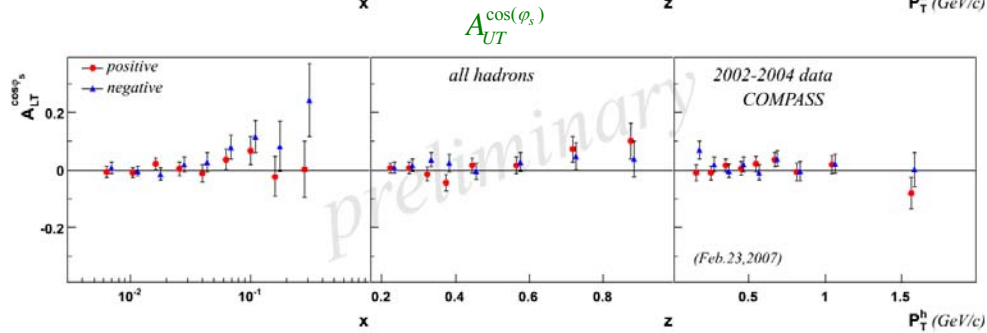
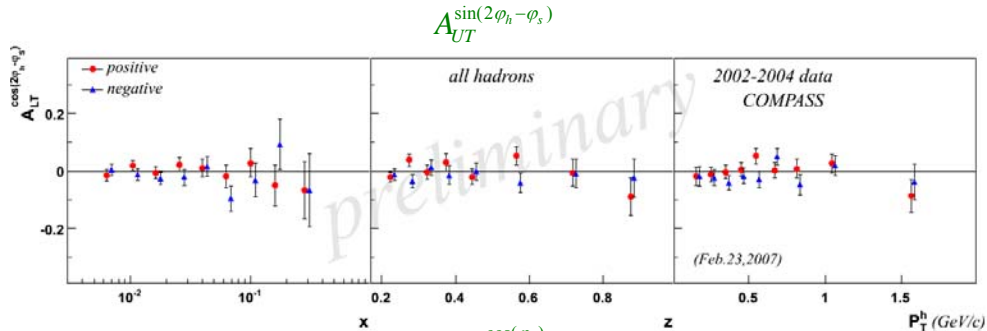


# Results beyond Collins and Sivers





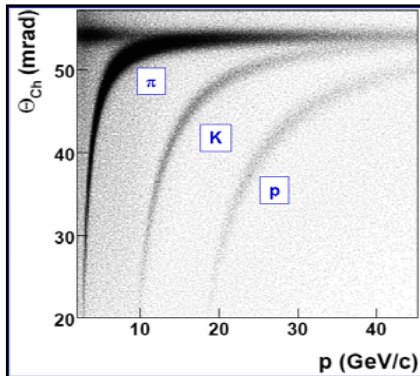
# Results beyond Collins and Sivers



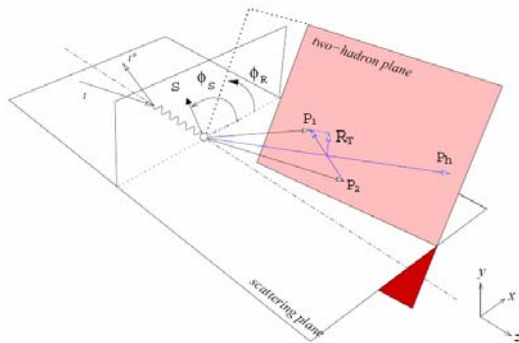
# Particle ID in 2003-2004 Data

- Hadron identification is based on RICH response: several studies performed on the stability in time of the detector.
- Cherenkov thresholds:  $\pi \sim 3 \text{ GeV}/c$   
 $K \sim 9 \text{ GeV}/c$   
 $p \sim 17 \text{ GeV}/c$
- $2 \sigma$   $\pi/K$  separation at  $43 \text{ GeV}/c$
- In the hadron sample:

| Statistics<br>2003-2004: | positive | negative |
|--------------------------|----------|----------|
| $\pi$                    | 5.2M     | 4.5M     |
| K                        | 0.9M     | 0.6M     |



# Frame independent definition of



A. Bacchetta,  
hep-ph/0608037

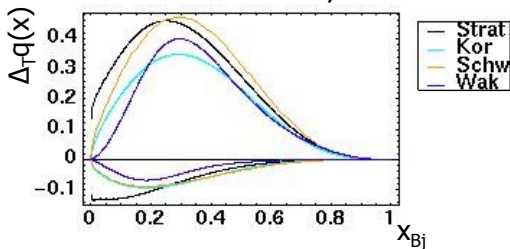
with: 
$$R_T = \frac{z_2 P_{1T} - z_1 P_{2T}}{z_1 + z_2}$$
 where  $P_{1T}$  and  $P_{2T}$  are the transverse components of the hadron momenta

we define: 
$$\cos \phi_R = \frac{(\mathbf{q} \times \mathbf{l}) \cdot (\mathbf{q} \times \mathbf{R}_T)}{|\mathbf{q} \times \mathbf{l}| |\mathbf{q} \times \mathbf{R}_T|} \quad \sin \phi_R = \frac{(\mathbf{l} \times \mathbf{R}_T) \cdot \mathbf{q}}{|\mathbf{q} \times \mathbf{l}| |\mathbf{q} \times \mathbf{R}_T|}$$

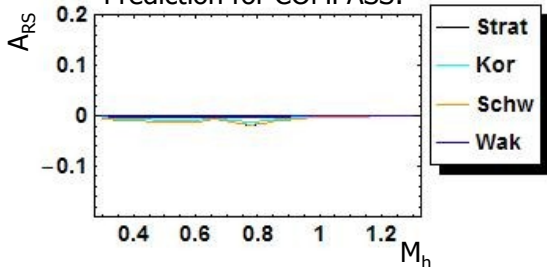
# Comparison with Theory

Model calculations for COMPASS kinematics (M. Radici, QCDN 06, hep-ph/0608037):

Model for transversity:



Prediction for COMPASS:

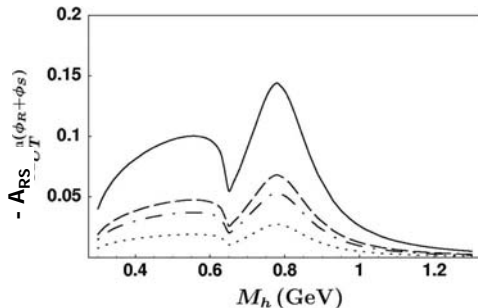


- Soffer, Stratmann, Vogelsang, P.R. D65 (02) 114024
- Korotkov, Nowak, Oganessian, E.P.J. C18 (01) 639
- Schweitzer et al., P.R. D64 (01) 034013
- Wakamatsu P.L. B509 (01) 59

→ small asymmetries on the deuteron

# Predictions for Asymmetries on the Proton

Predictions for two-hadrons asymmetries on the **proton** at COMPASS:



- Soffer, Stratmann, Vogelsang, P.R. D65 (02) 114024
- Korotkov, Nowak, Oganessian, E.P.J. C18 (01) 639
- Wakamatsu P.L. B509 (01) 59

(M. Radici, hep-ex/0608037)