



# Transversity Signals in Two-Hadron Production at COMPASS



Christian Schill  
Universität Freiburg

On behalf of the COMPASS Collaboration

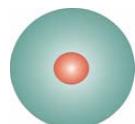
- Transverse spin physics at COMPASS
- Azimuthal asymmetries in two-hadron production
- Results for identified  $\pi\pi$ ,  $\pi K$  and  $K K$  pairs on the deuteron
- Discussion and Outlook

DIS 2007, Munich, April 18

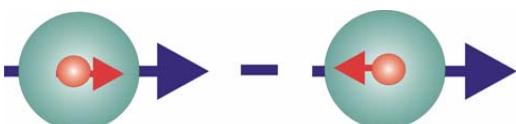
# Transverse Spin Physics

3 distribution functions are necessary to describe the spin structure of the nucleon at LO:

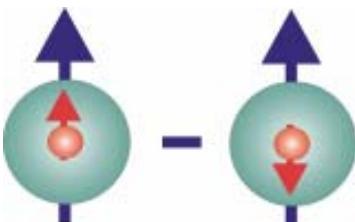
$$q(x)$$
  
 $f_1(x)$



$$\Delta q(x)$$
  
 $g_1(x)$



$$\Delta_T q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$$
  
 $h_1(x)$



**momentum distribution**  
well known - unpolarized DIS

**helicity distribution**  
known - polarized DIS

**transversity distribution**  
still unknown

$\Delta_T q(x)$  decouples from inclusive DIS:  
helicity flip of quark  
→ SIDIS experiment

# Transversity: How to measure it in SIDIS?

Transversity  $\Delta_T q(x)$  chiral odd: observable effect only in combination with chiral odd **fragmentation function**

## Suggested quark polarimeters in SIDIS:

- Azimuthal distribution of single hadrons  
**Collins fragmentation function**
- Azimuthal dependance of the plane containing a hadron pair  
**2-hadron interference fragmentation function**
- Measure transverse polarization of  $\Lambda$   
**fragmentation function  $q \rightarrow \Lambda$**

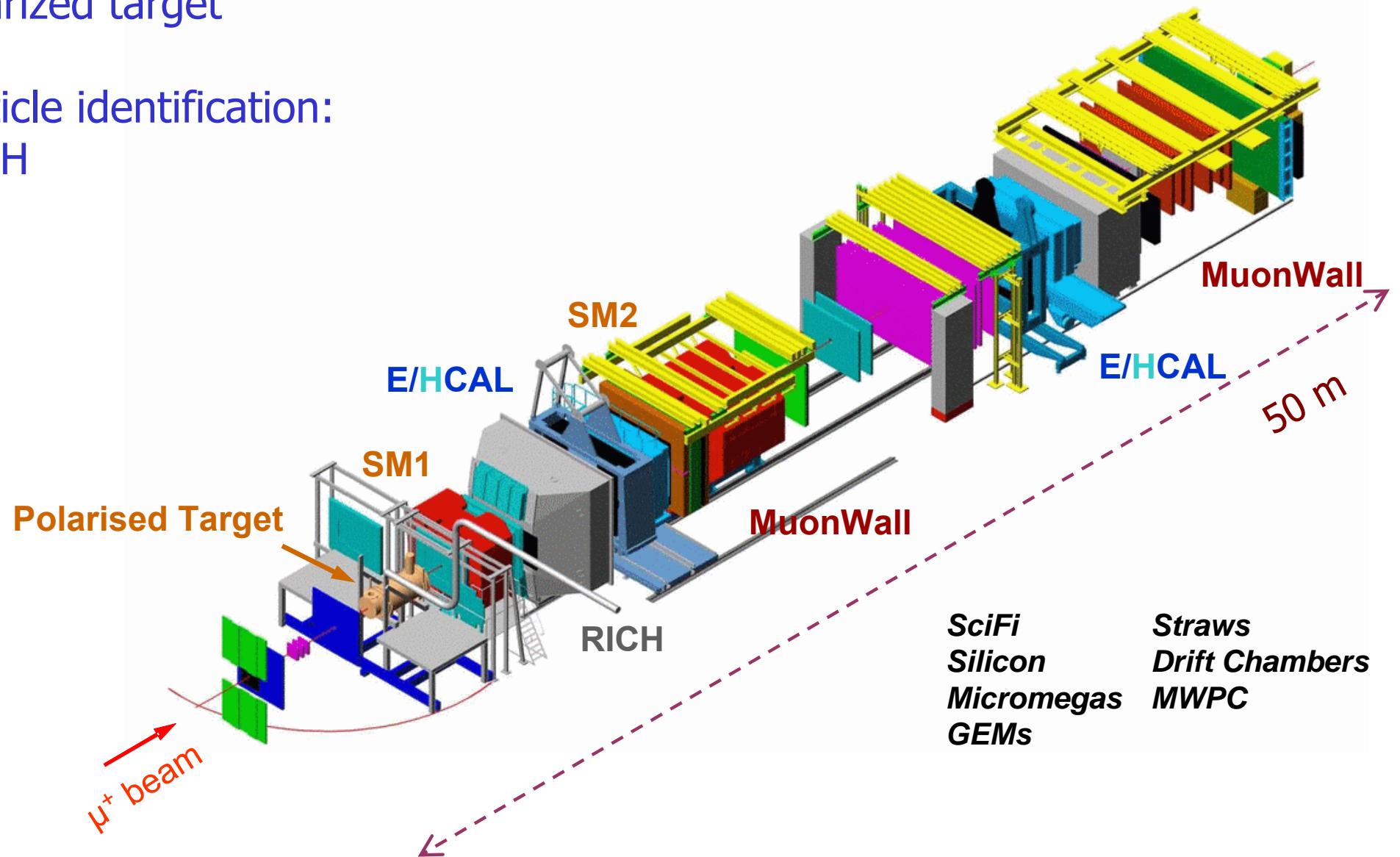
← COMPASS results  
Talk by A. Bressan

← This talk

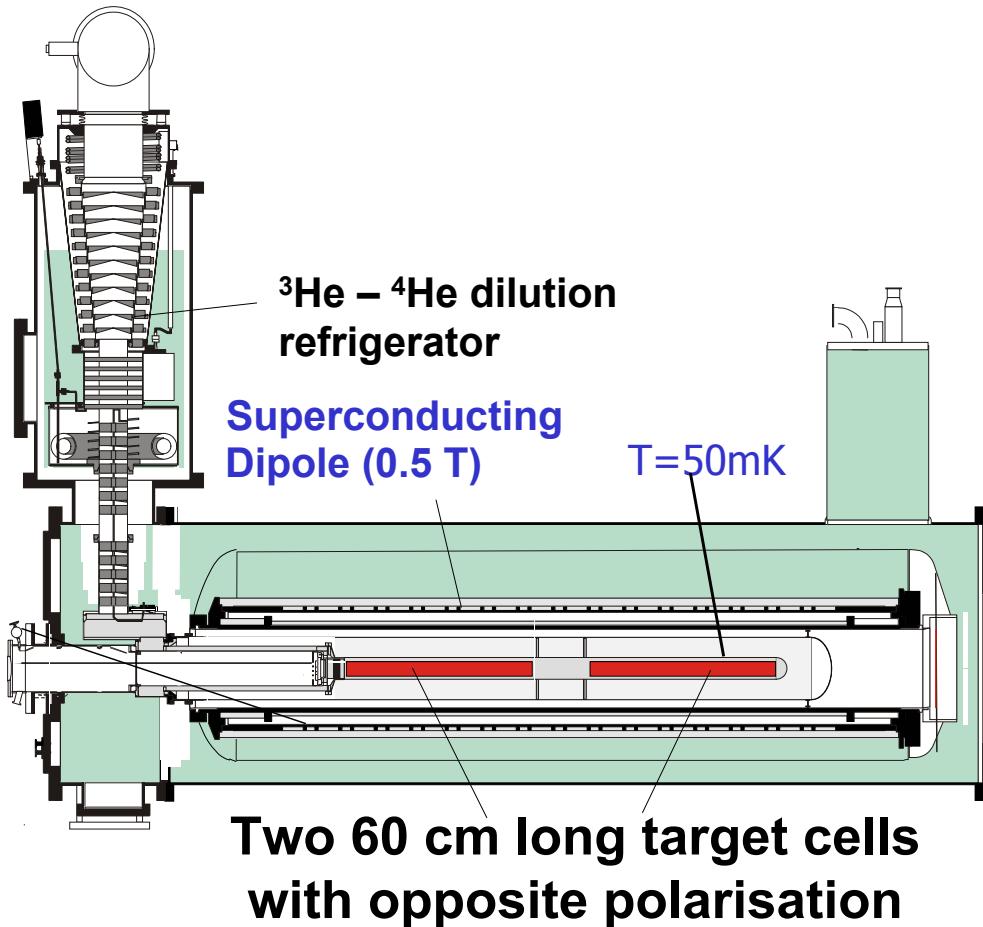
← COMPASS results

# The COMPASS Spectrometer at CERN

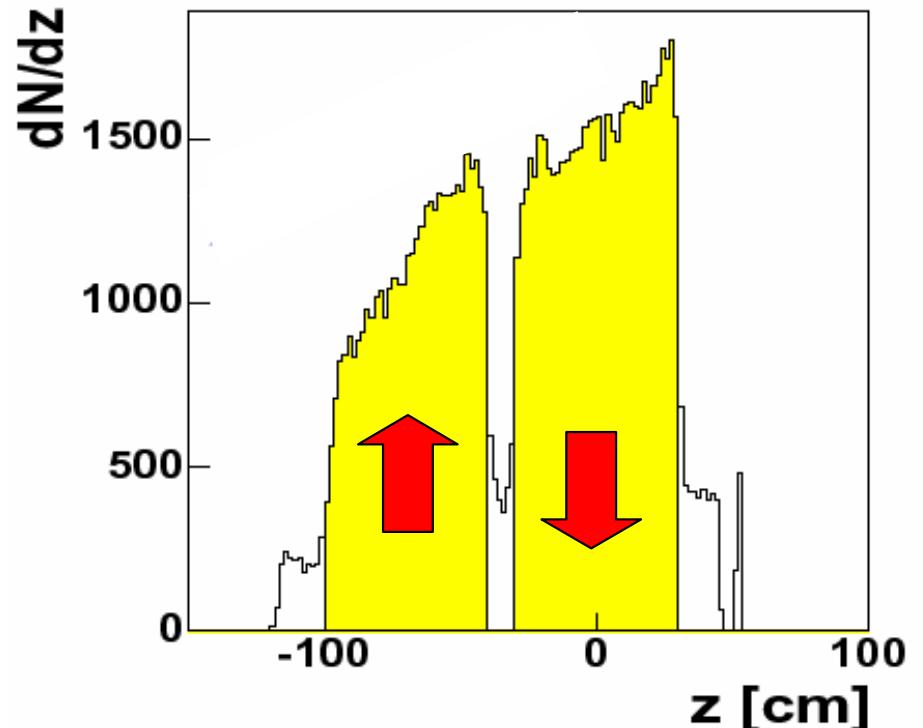
- Beam: 160 GeV  $\mu^+$  ( $2 \cdot 10^8 \mu^+$  / 5s spill)
- Polarized target
- Particle identification:  
RICH



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



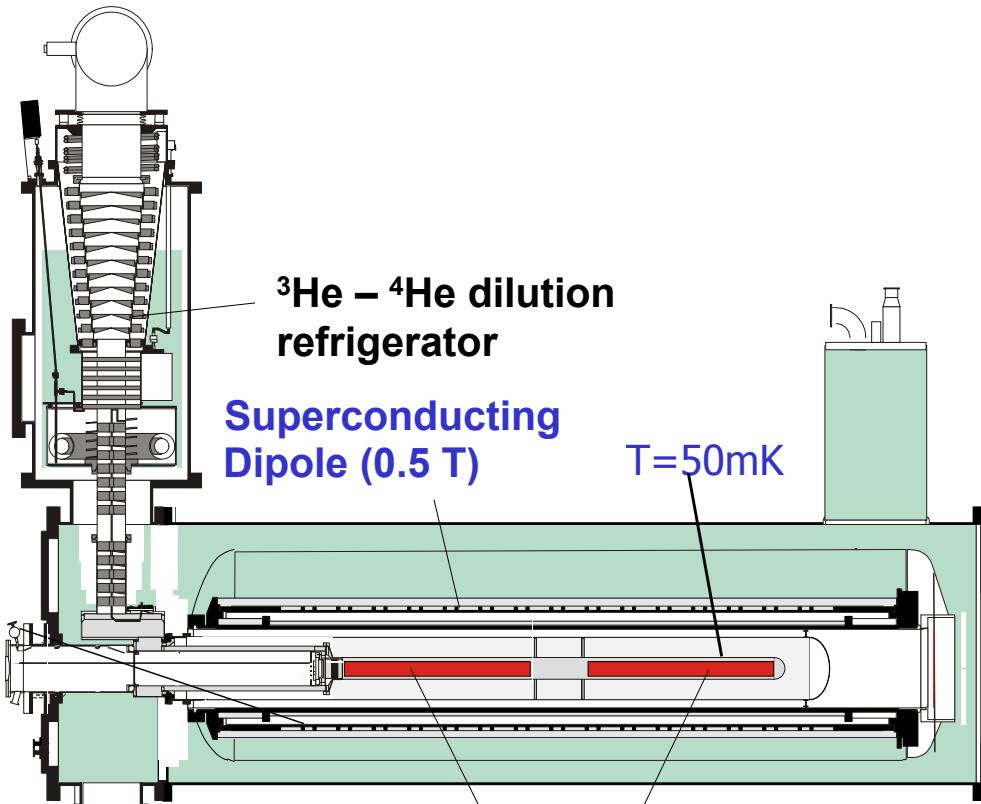
Vertex distribution:



**Transverse target polarization:  
Reversed one a week**

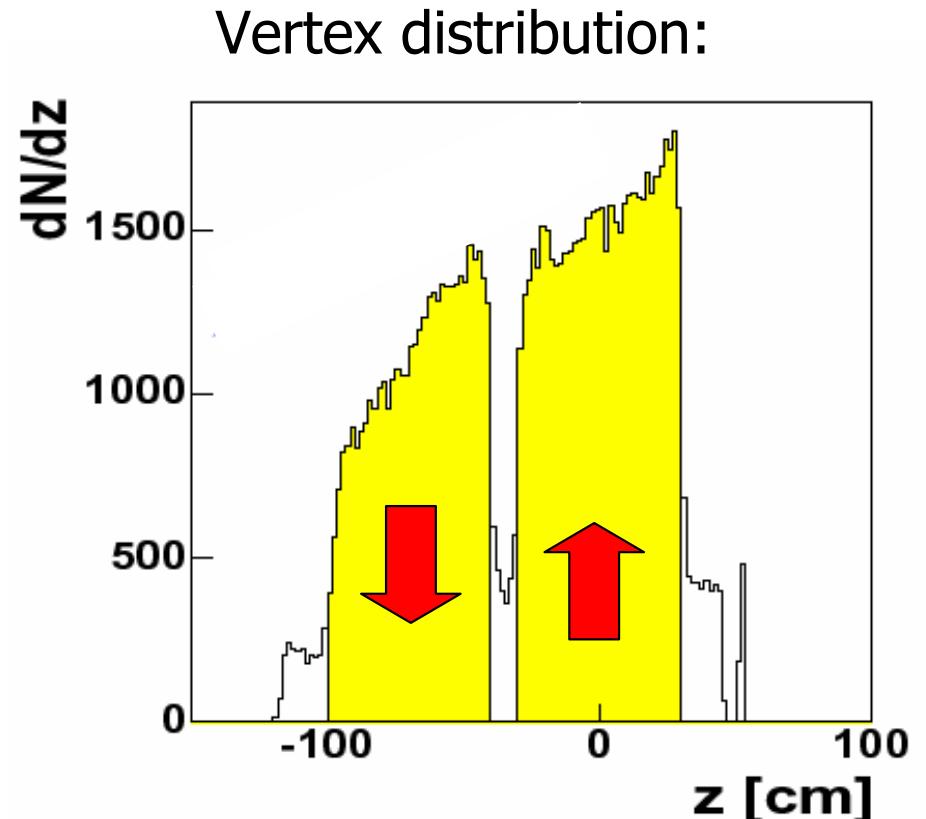
**Polarization: 50 %  
Dilution factor: 0.38**

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



Two 60 cm long target cells  
with opposite polarisation

**Transverse target polarization:**  
Reversed one a week



**Polarization: 50 %**  
**Dilution factor: 0.38**

# Ring Imaging Cherenkov Detector

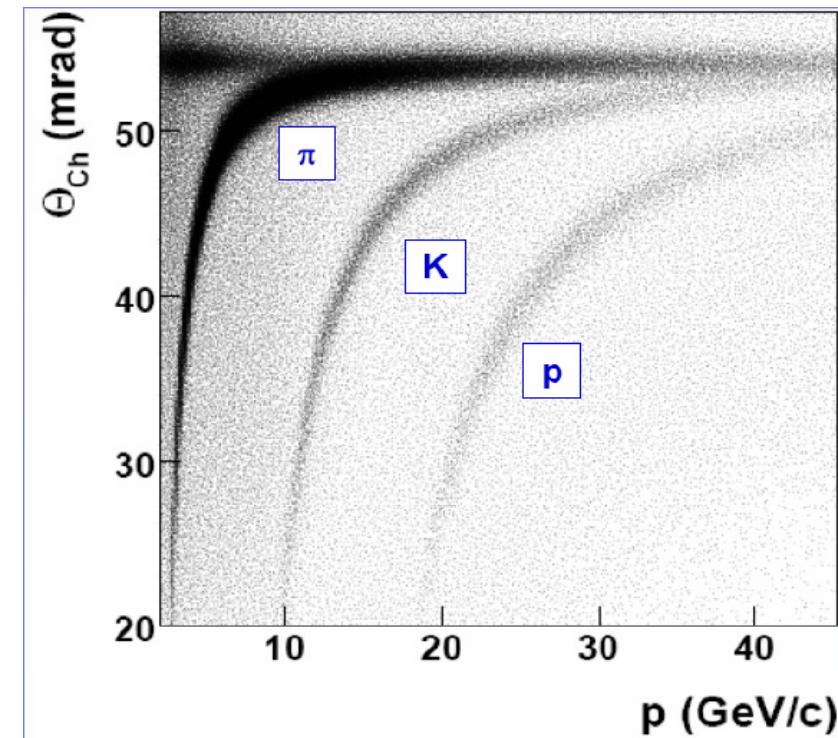
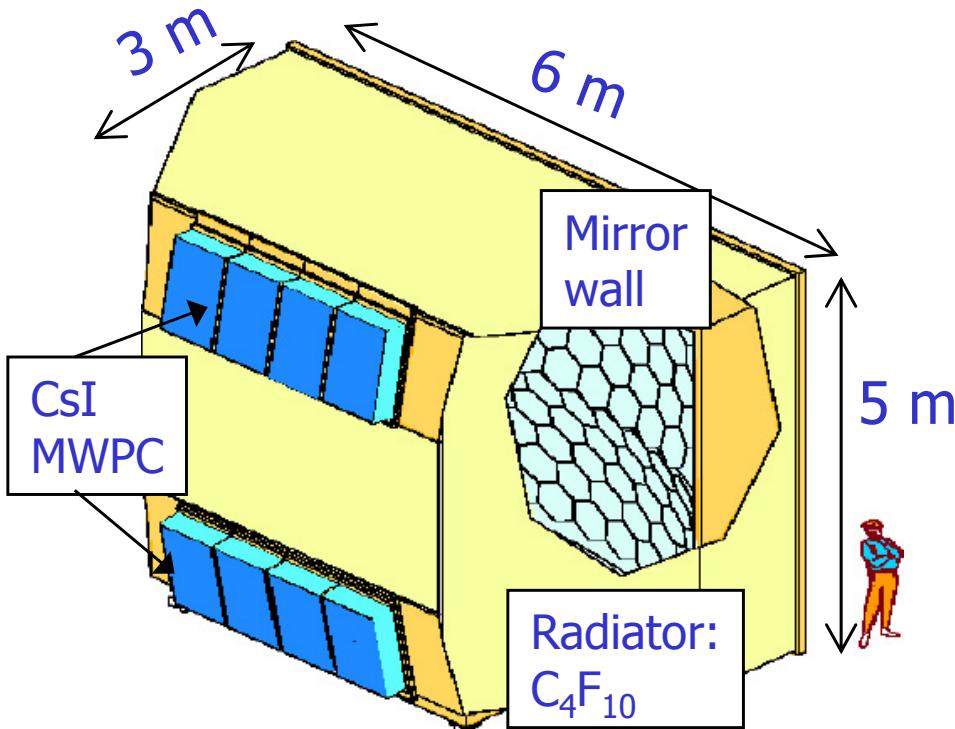
Identification of  $\pi$ , K and protons

Cherenkov thresholds:  $\pi \approx 3 \text{ GeV}/c$

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

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

$2\sigma \pi/K$  separation at  $43 \text{ GeV}/c$



# Transversity Data Sample

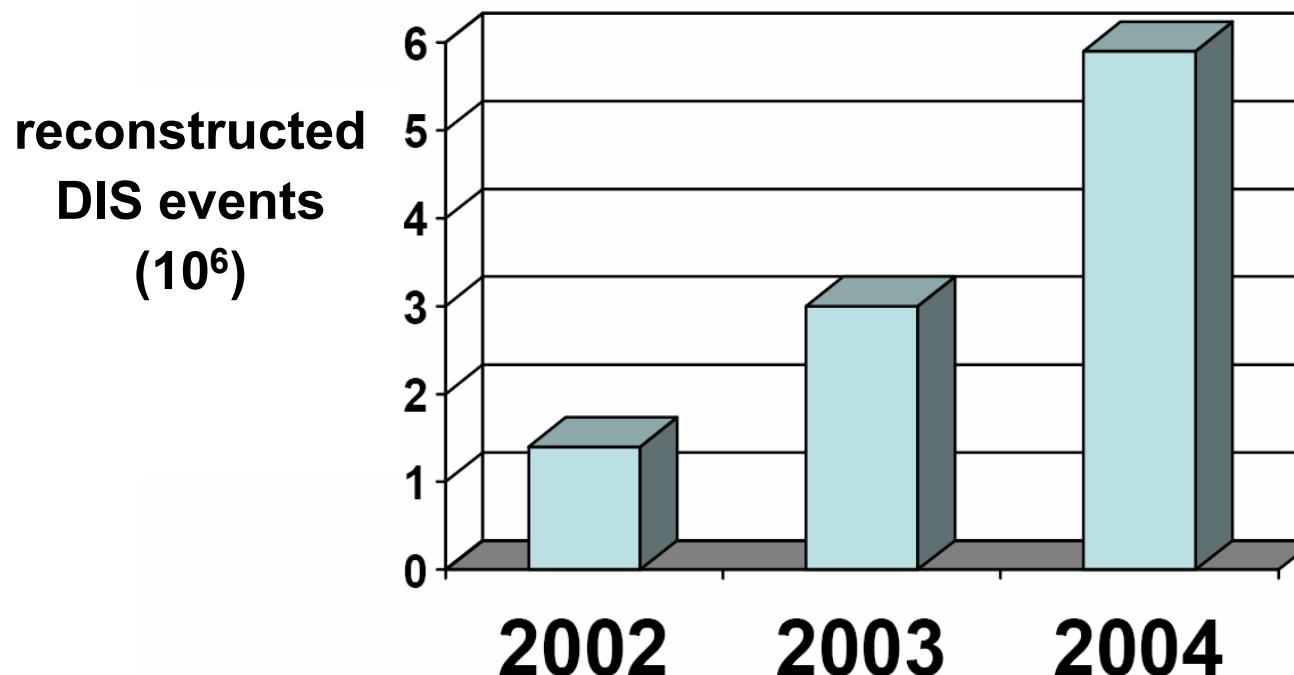
**transversely polarised deuteron target**  
**~ 20% of the running time**

2002 11 days of data taking

2003 9 days of data taking

2004 14 days of data taking

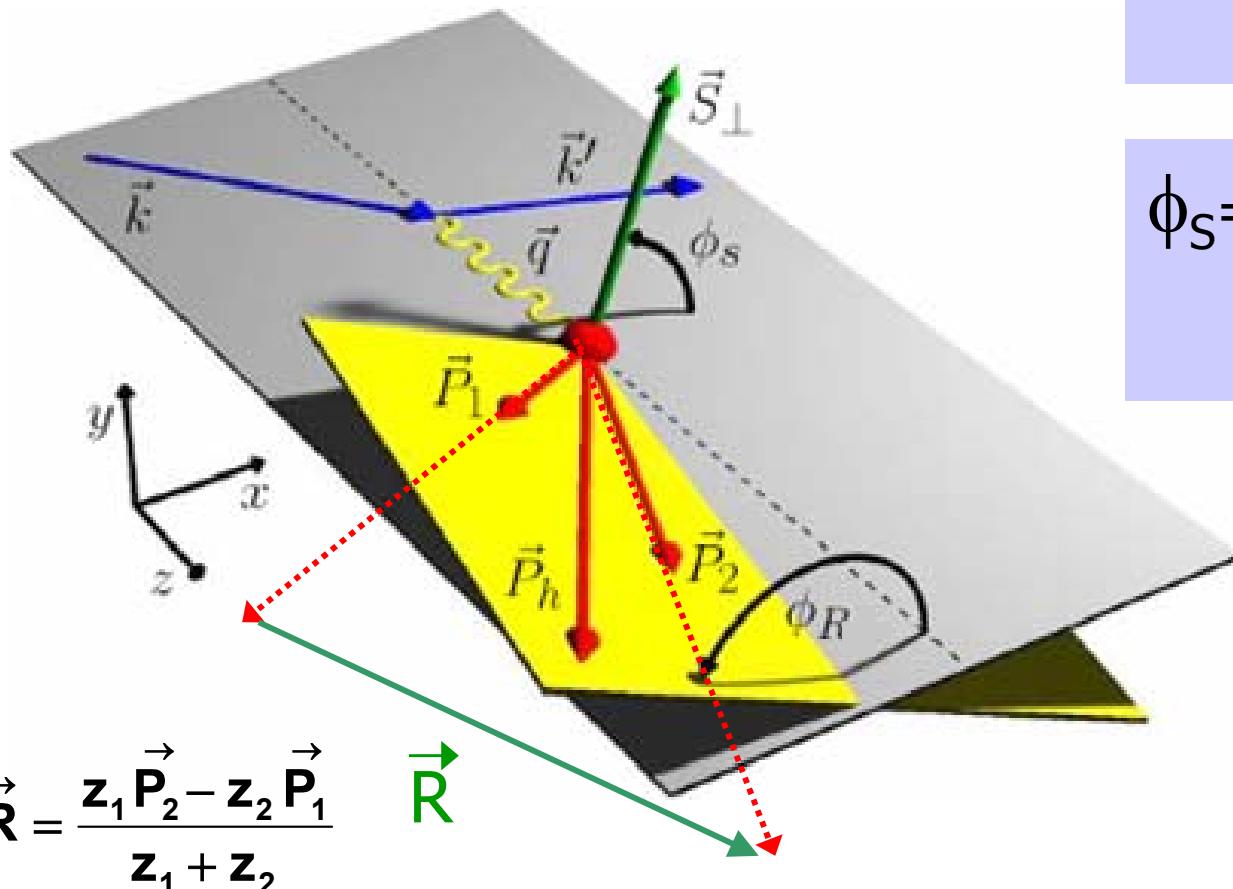
trigger (large  $x$ ,  $Q^2$ )  
+ PID (ECAL, RICH)



# The Coordinate System

z-axis = virtual photon direction

x-z plane = lepton scattering plane



$\phi_R$  = angle between lepton scattering plane and two-hadron plane

$\phi_S$  = azimuthal angle of initial quark versus lepton scattering plane

$\phi_{S'} = \pi - \phi_S$   
(fragmenting quark)

$$\begin{aligned}\phi_{RS} &= \phi_R - \phi_{S'} \\ &= \phi_R + \phi_S - \pi\end{aligned}$$

(A. Bacchetta, M. Radici, hep-ph/0407345)

(X. Artru, hep-ph/0207309)

# Azimuthal asymmetry for two-hadron production

Target single spin asymmetry  $A_{RS}(x, z, M_h^2)$ :

$$z = z_1 + z_2$$

$$N^\pm(\Phi_{RS}) = N_0 \left\{ 1 \pm A_{UT}^{\sin\phi_{RS}} \sin\Phi_{RS} \right\}$$

and

$$A_{RS} = \frac{1}{f P_T D} A_{UT}^{\sin\phi_{RS}}$$

$N^\pm(\phi_{RS})$ : Number of events for target spin up (+) and down (-)

$f$ : Dilution factor  $\approx 0.38$

$D$ : Depolarisation factor

$$D = (1-y)/(1-y+y^2/2)$$

$P_T$ : Target polarisation  $\approx 0.5$

$$A_{RS}(x, z, M_h^2) = \frac{\sum_q e_q^2 \Delta_T q(x) H_q^{ch}(z, M_h^2)}{\sum_q e_q^2 q(x) D_q^h(z, M_h^2)}$$

$$D_q^h, H_q^{ch}$$
  
 $\downarrow$

presently unknown  
can be measured  
in  $e^+e^-$  (BELLE)

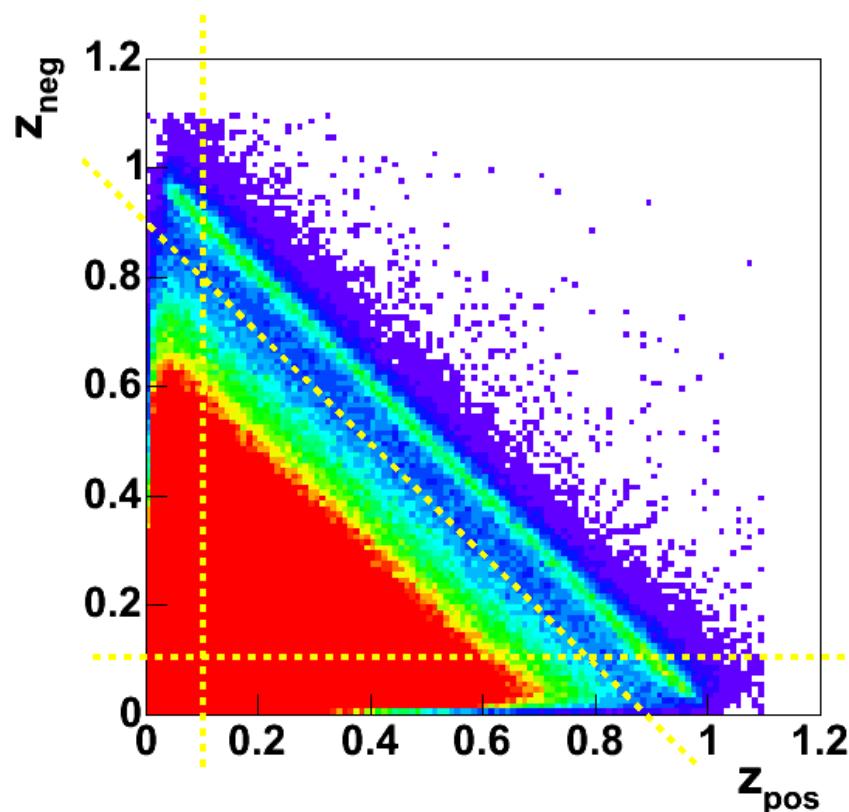
expected to depend on the hadron pair invariant mass

(X. Artru, hep-ph/0207309)

# Event selection

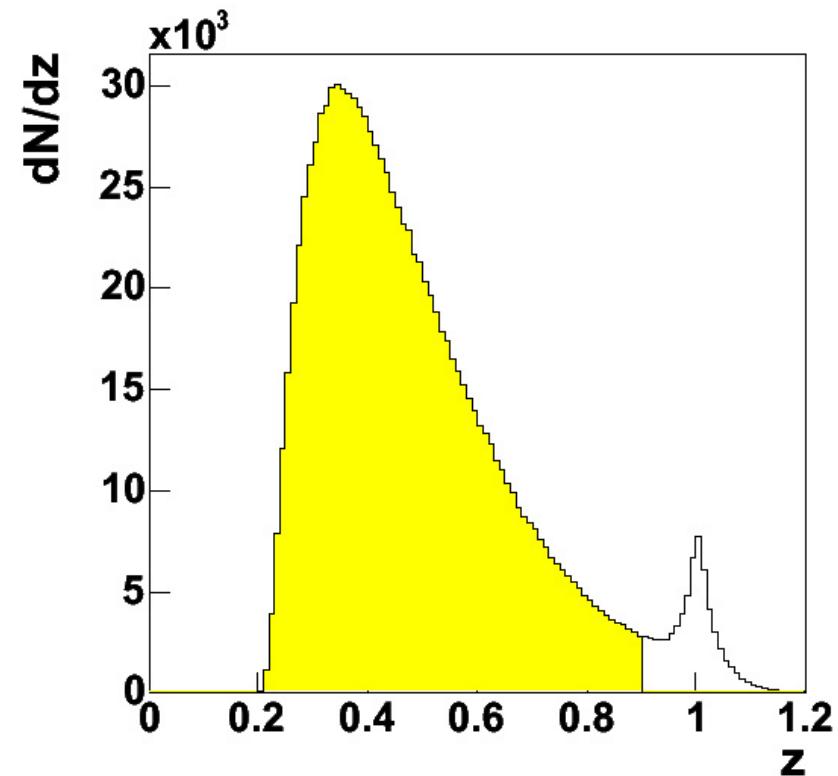
## DIS cuts:

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



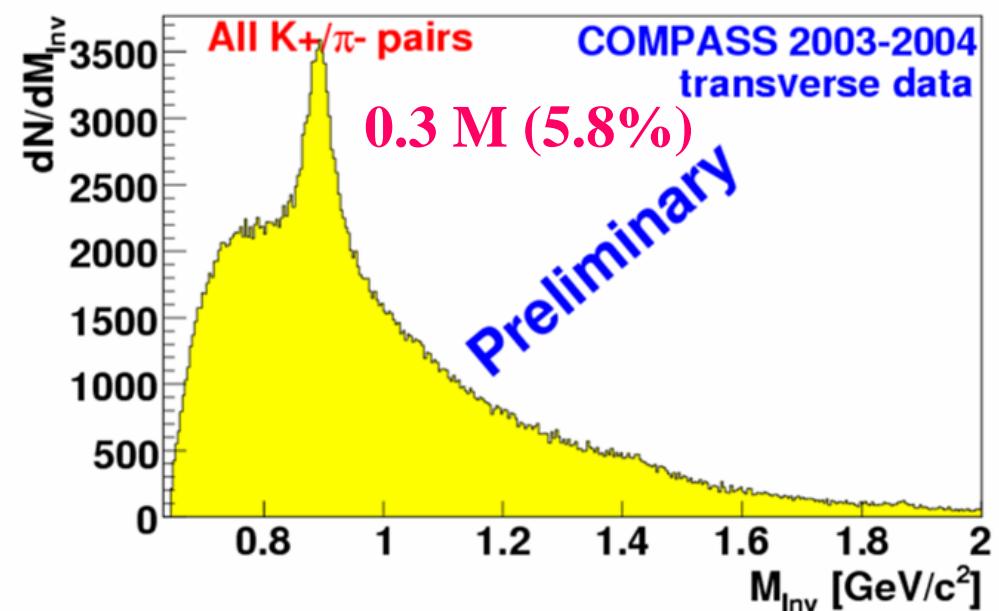
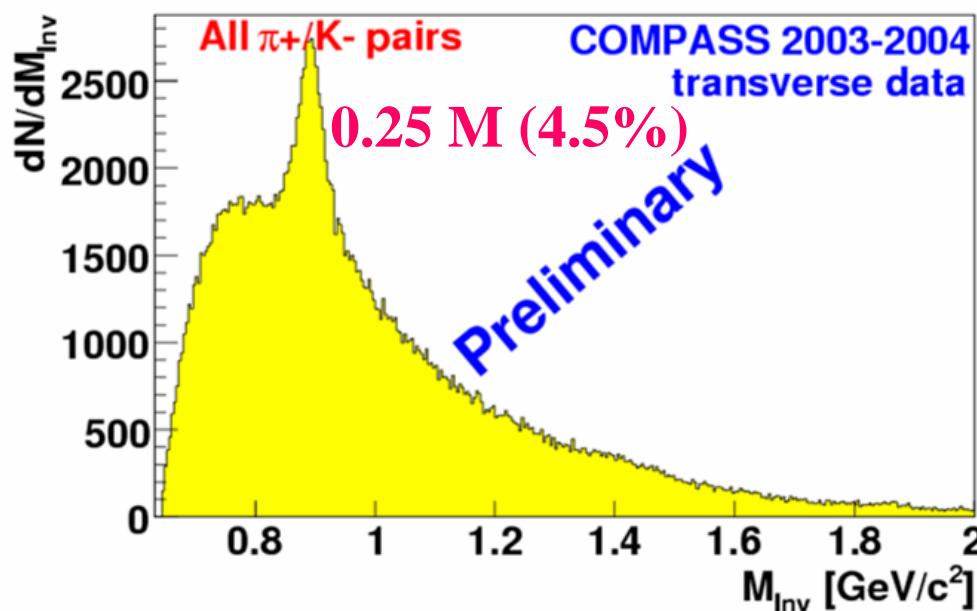
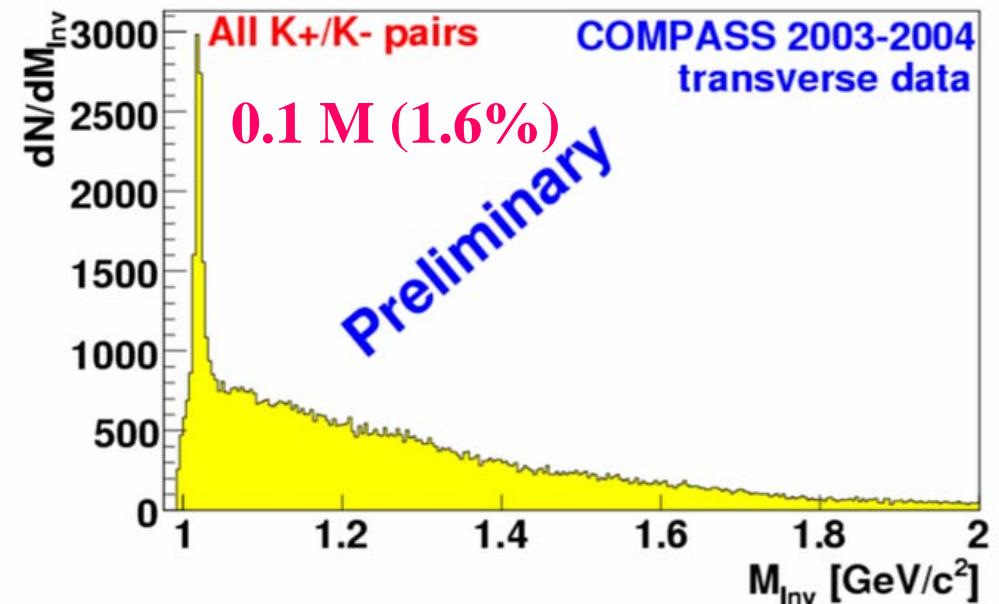
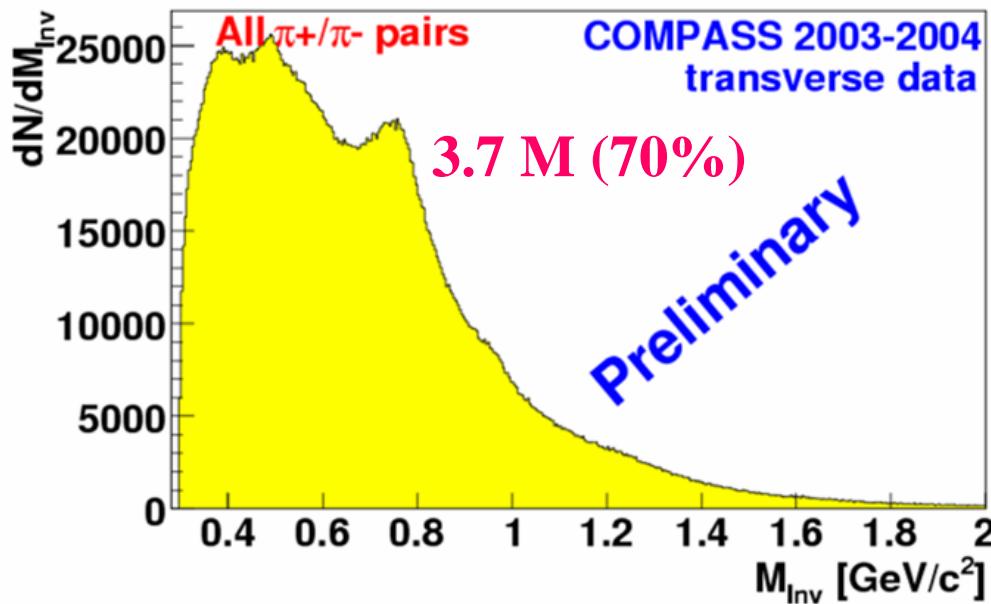
## Hadron selection:

- $z_{1,2} > 0.1$  (current fragmentation)
- $x_{F1,2} > 0.1$
- $z_1 + z_2 < 0.9$  (exclusive rho)
- RICH identification of  $\pi, K$

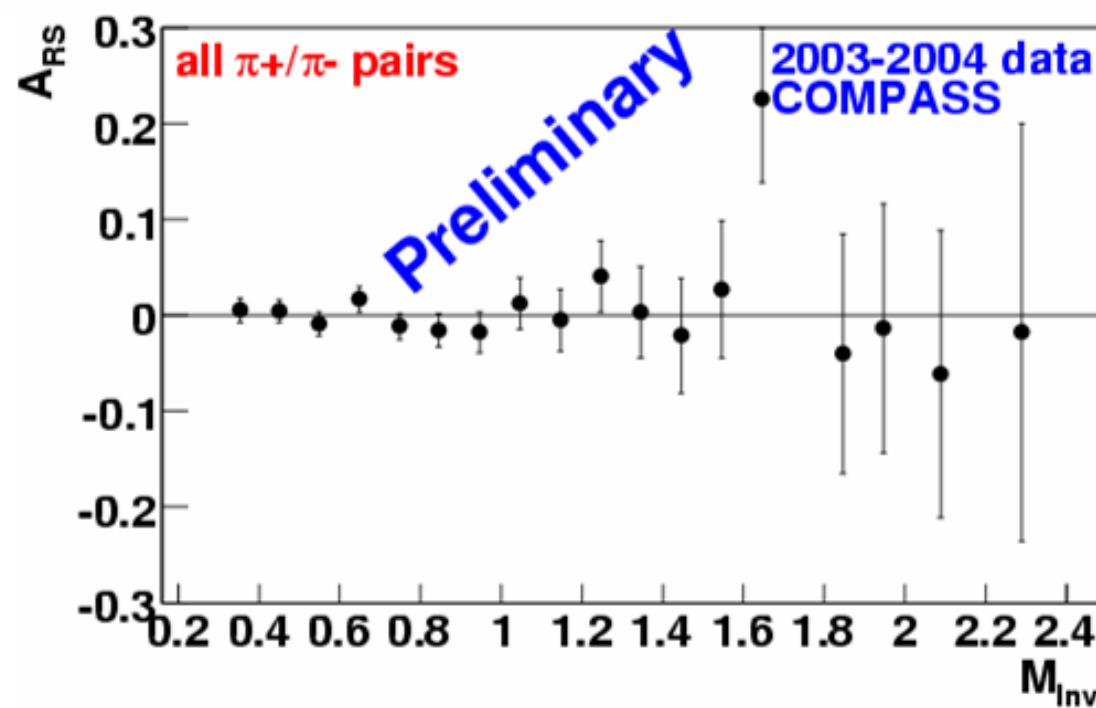
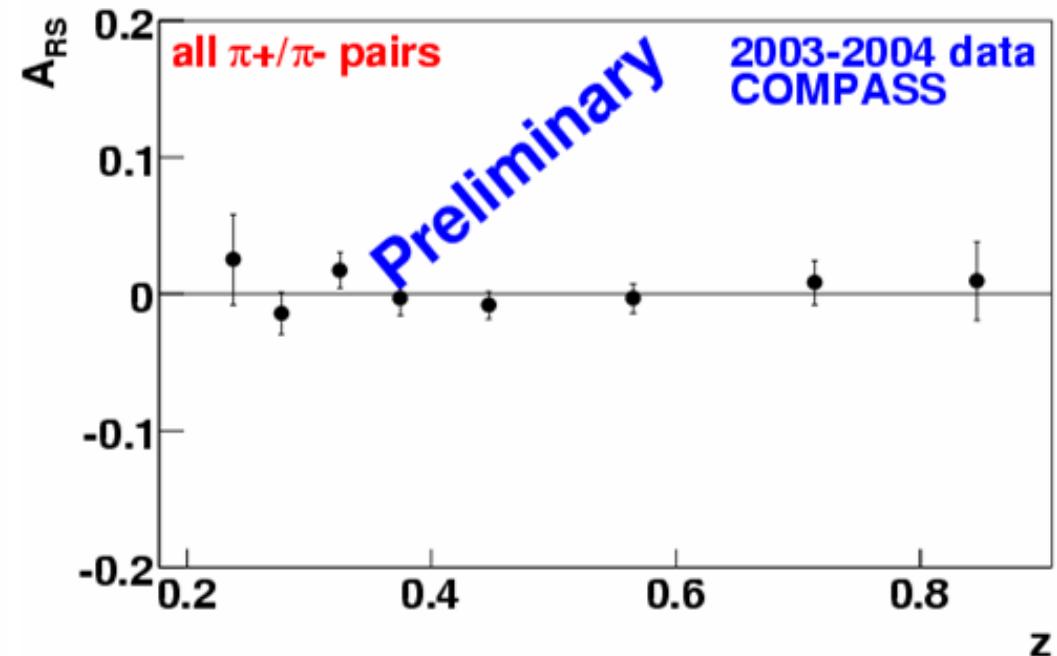
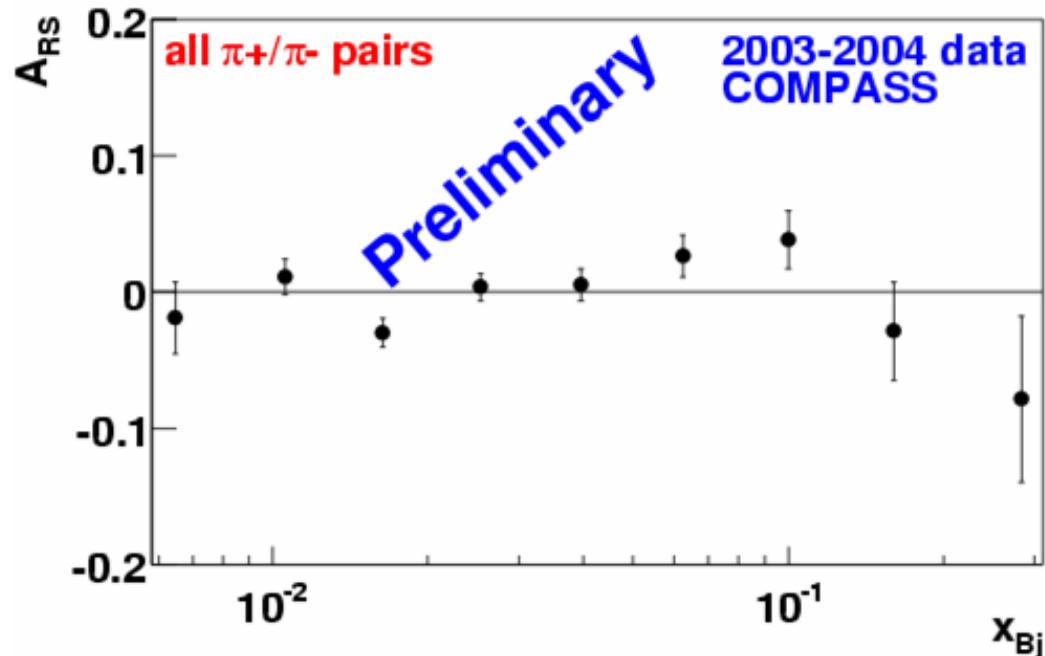


# RICH hadron identification

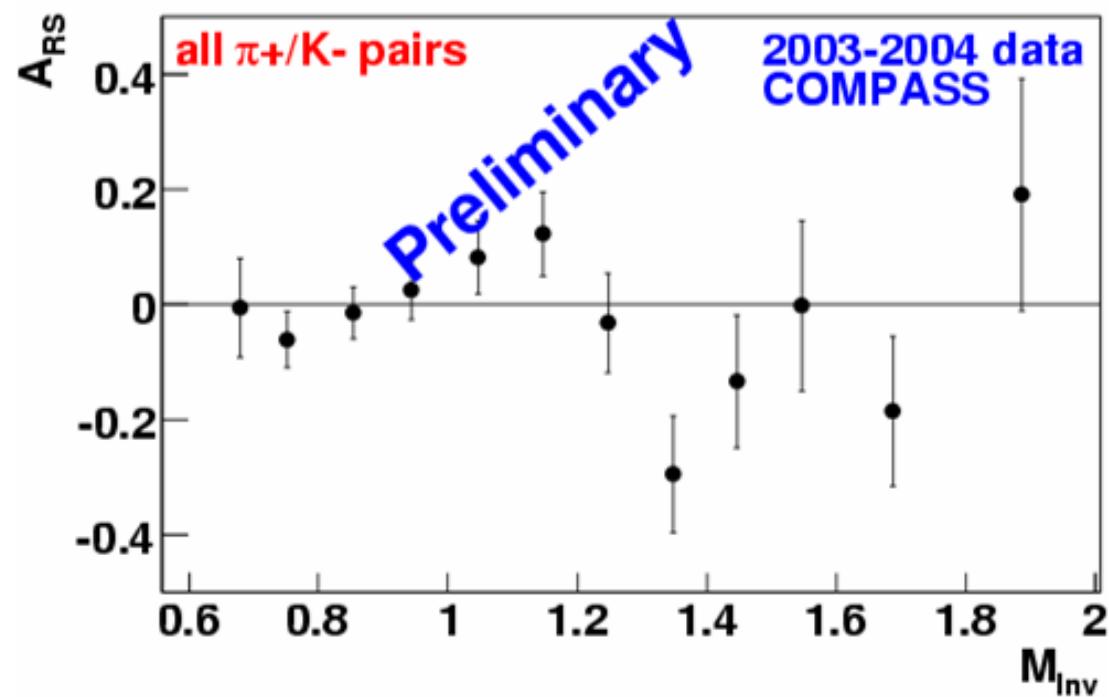
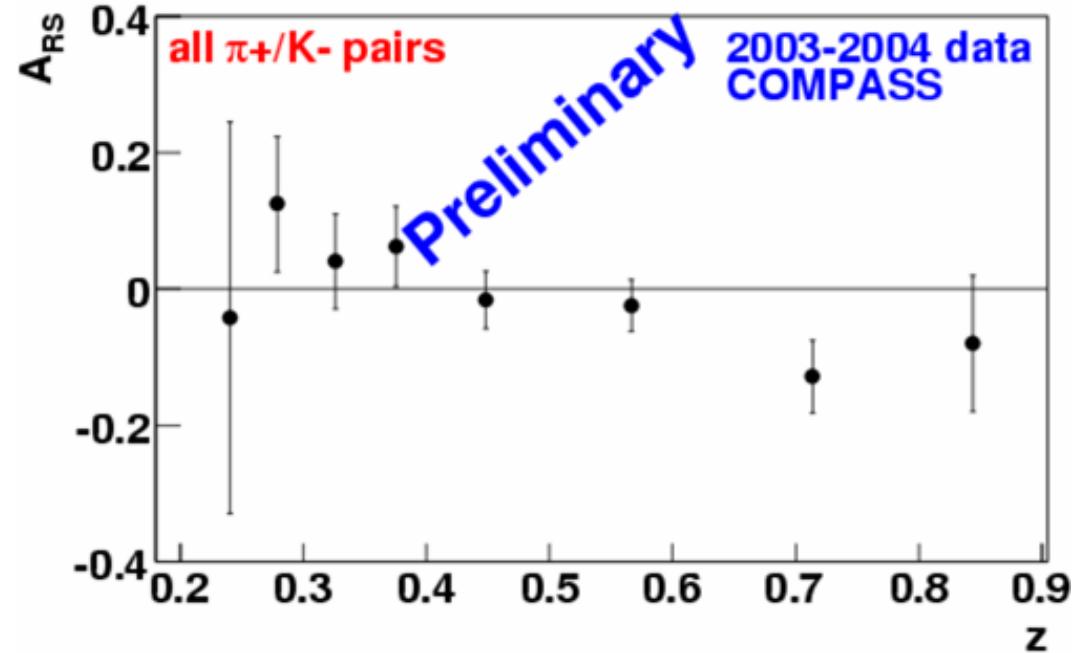
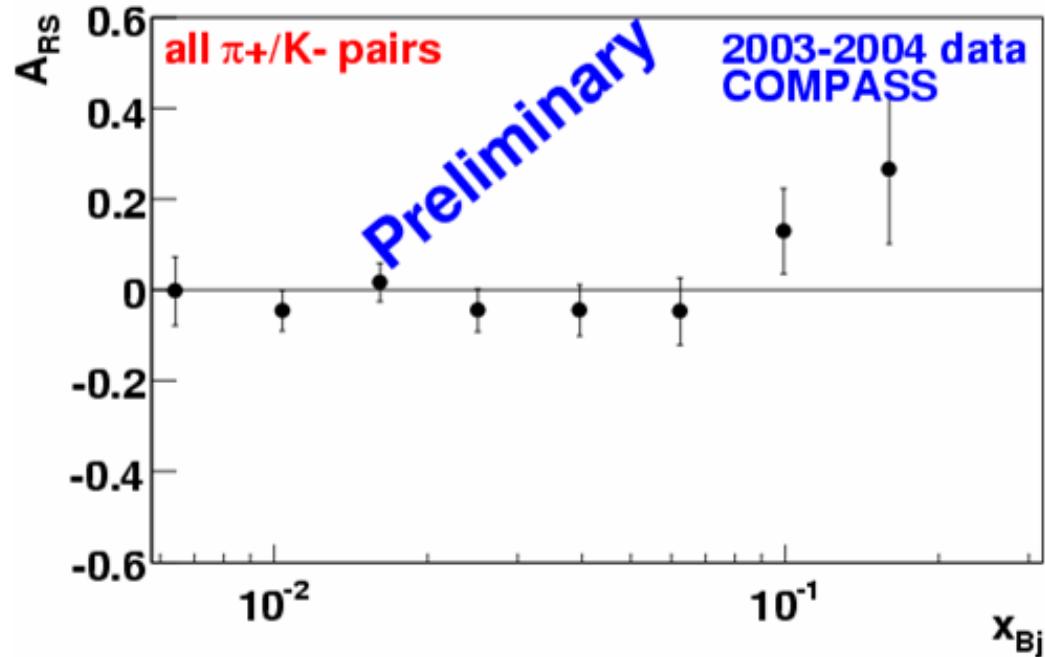
all hadron pairs: 5.3 M



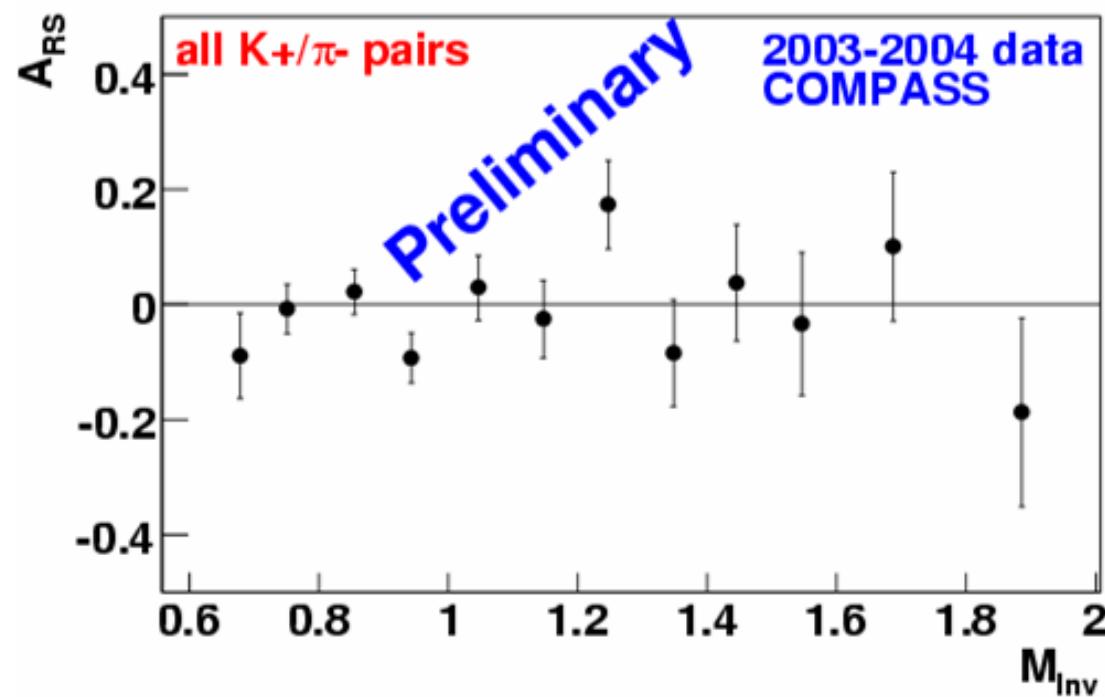
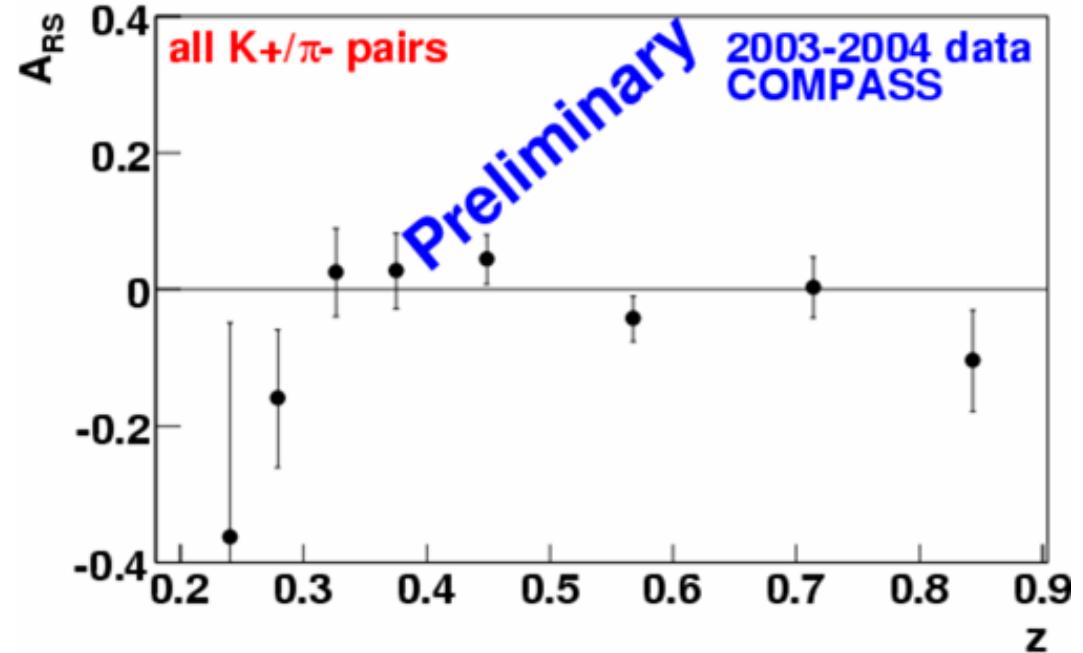
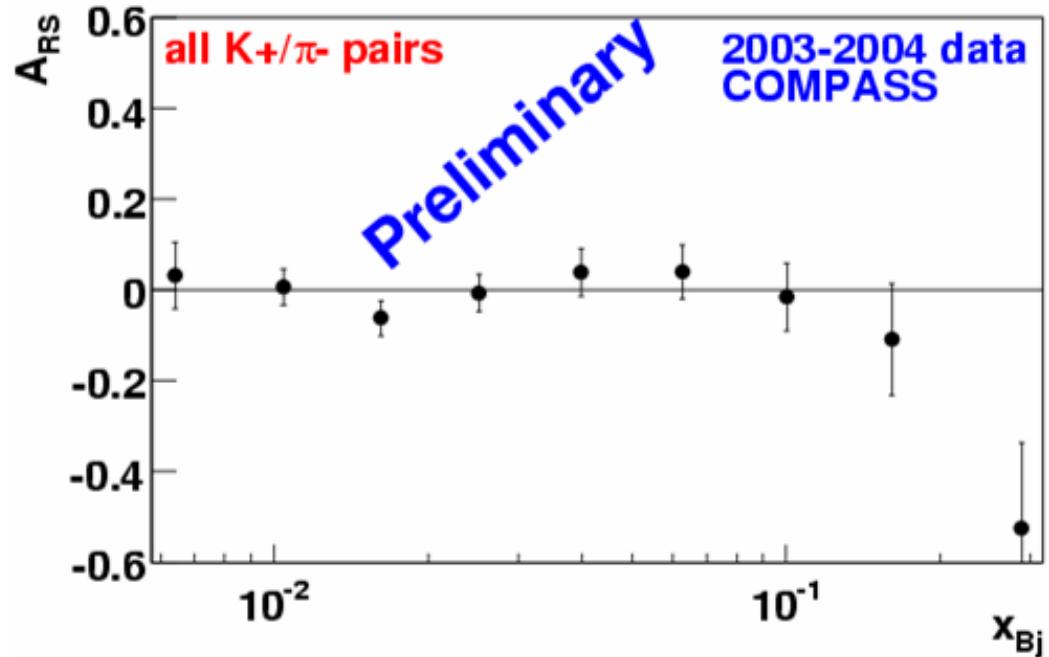
# Results for $\pi^+ \pi^-$ pairs



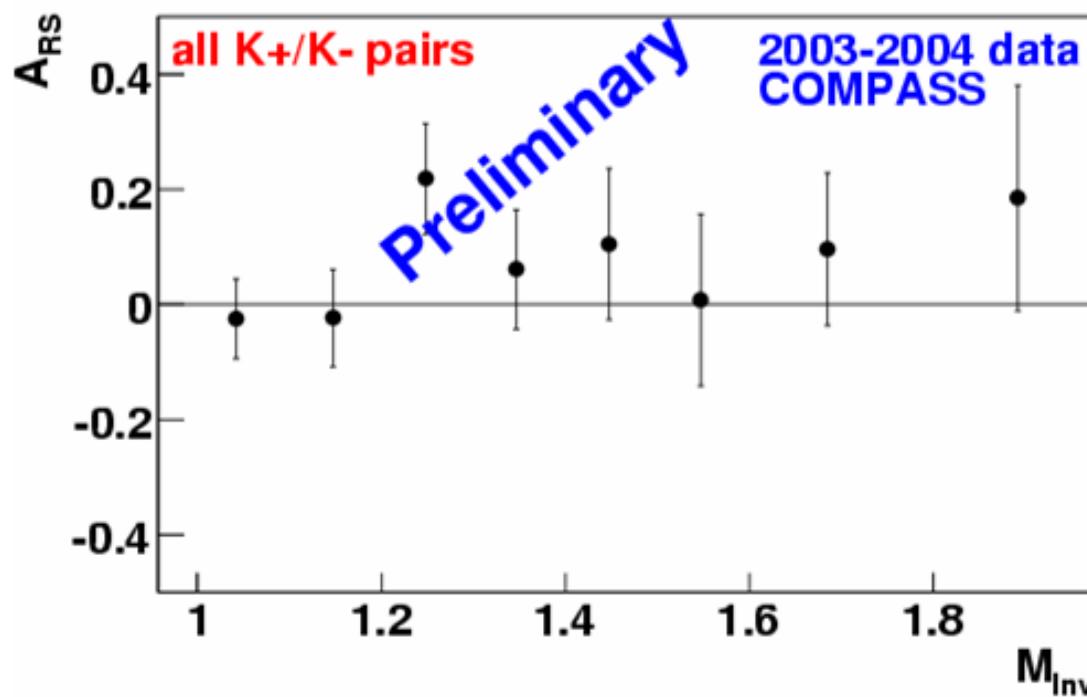
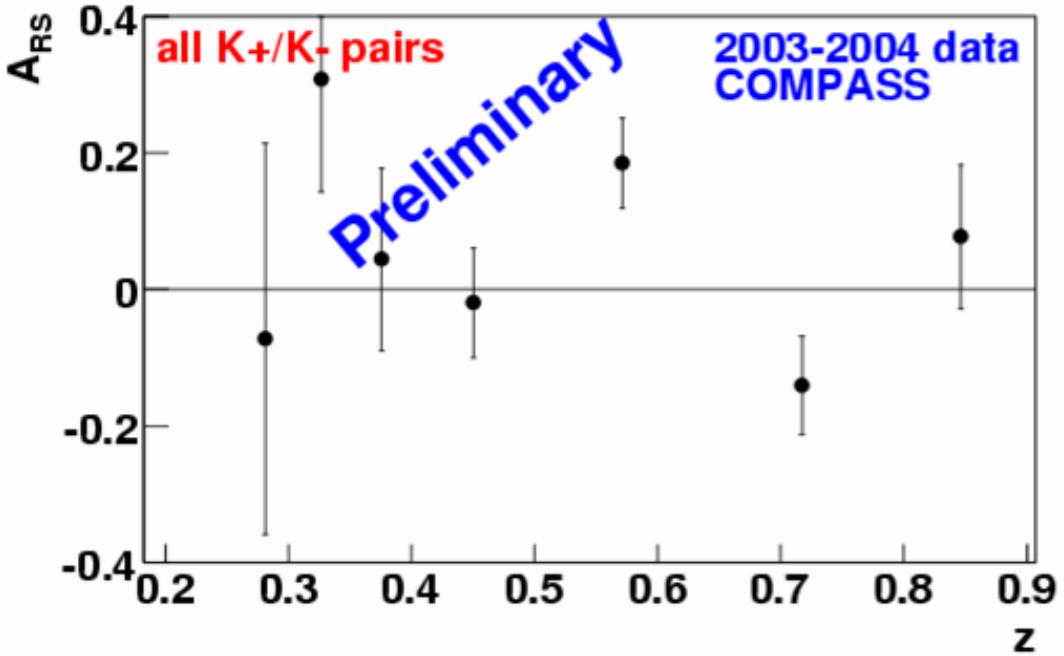
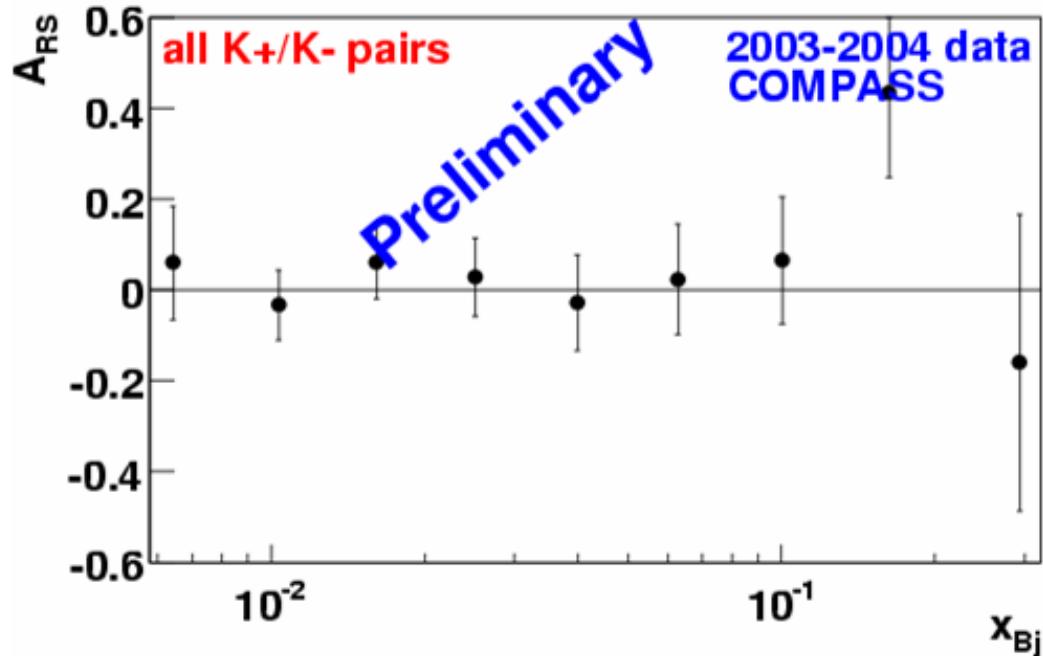
# Results for $\pi^+ K^-$ pairs



# Results for $K^+ \pi^-$ pairs



# Results for K<sup>+</sup> K<sup>-</sup> pairs

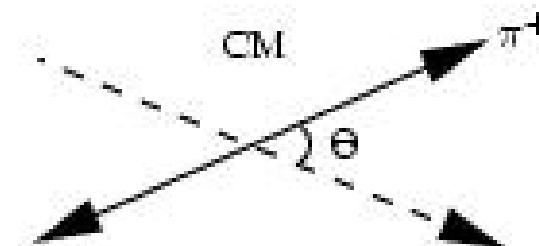


# $\sin\theta$ Dependence

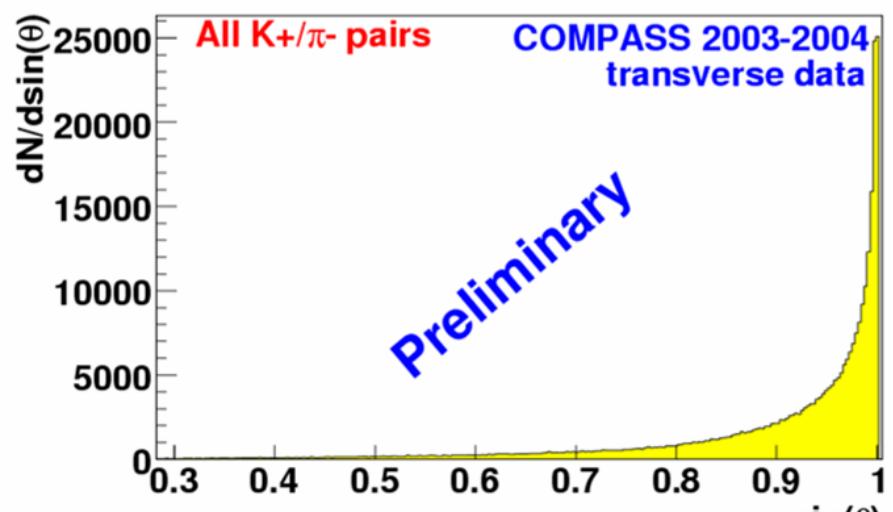
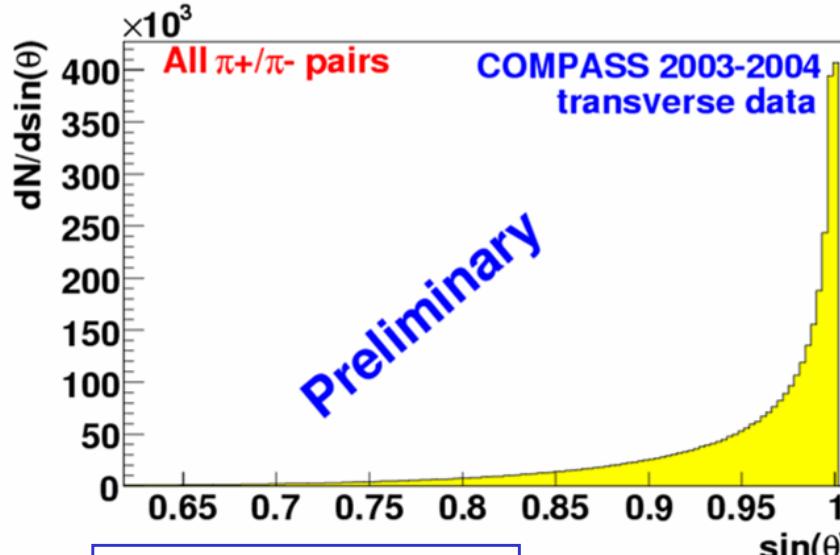
Cross section  $\sigma_{UT}$  for two- $\pi$  fragmentation depends on  $\sin\theta$ :  
(Interference of s- and p-wave of the  $2\pi$ -state)

$$\sigma_{UT} \propto \sum_q e_q^2 |S_T| \sin\theta \sin\phi_{RS} \Delta_T q(x) H_q^{ch}(z, M_h^2)$$

(A. Bacchetta and M. Radici,  
hep-ph/0212300)



$\theta$  : Angle of  $h_1$  in the two-hadron CMS  
to the direction of  $P_h = P_{h1} + P_{h2}$



→ small contribution in the kinematic region of COMPASS

# Discussion

---

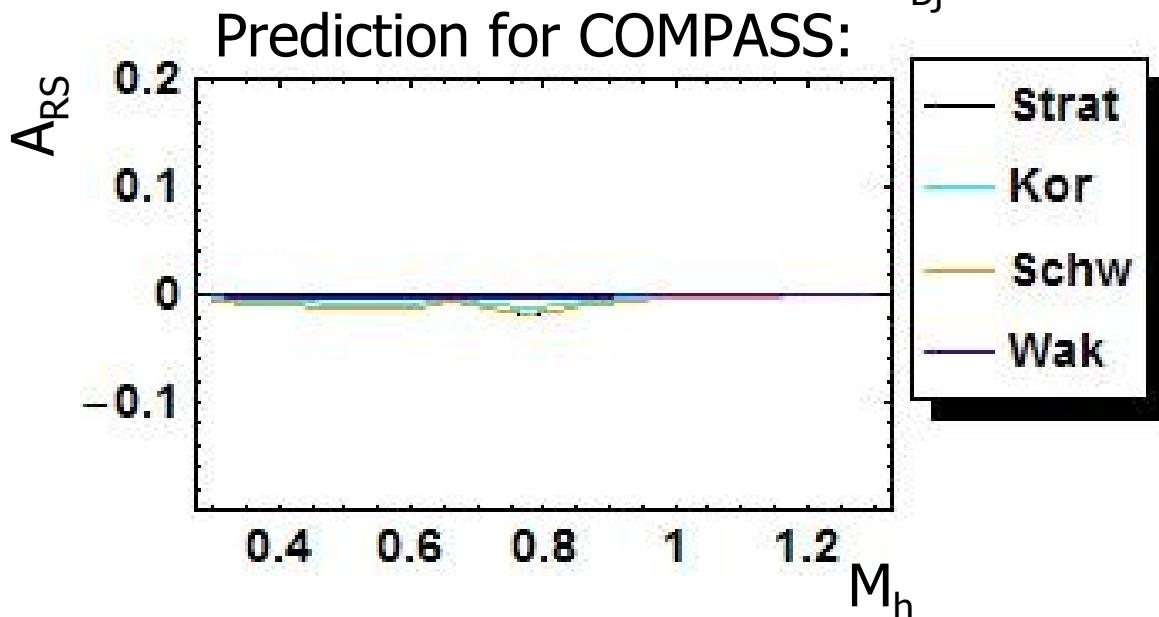
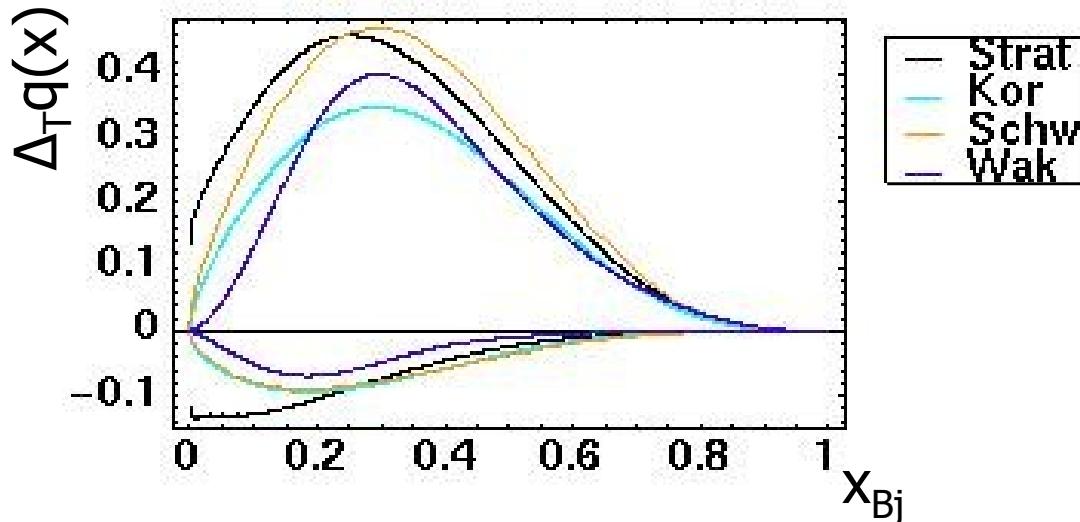
- First results for two identified hadron pair asymmetries
- Asymmetries are small for all hadron pairs  $\pi\pi$ ,  $\pi K$ , and  $KK$
- Systematic effects are considerably smaller than the statistical error

Comparison with theoretical models →

# Comparison with Theory

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

Model for transversity:



- 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

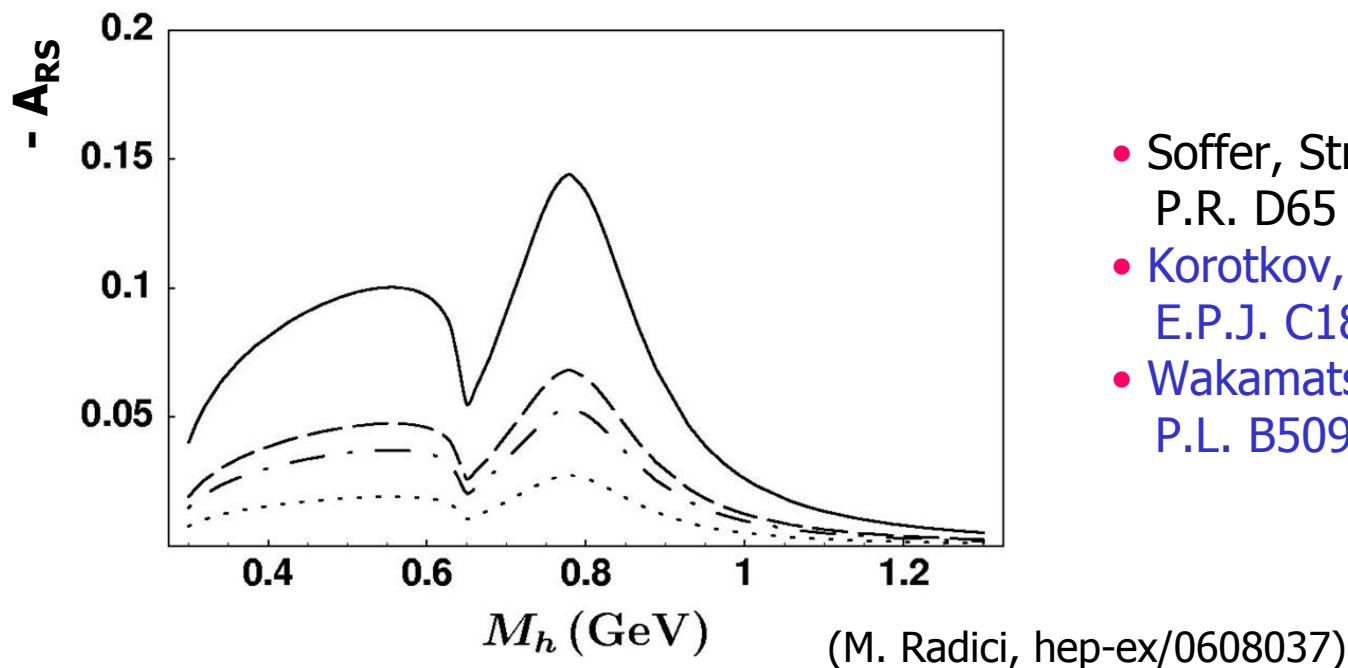
→ small asymmetries on the deuteron

combination of isospin-symmetric target and properties of dihadron-fragmentation function  $H_q^{\angle h}(z)$

# Outlook

- Complementary measurements with **proton** target planned this year
- Data (of comparable statistics) will be collected on a transversely polarized proton target ( $\text{NH}_3$ ) and will allow flavour separation

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



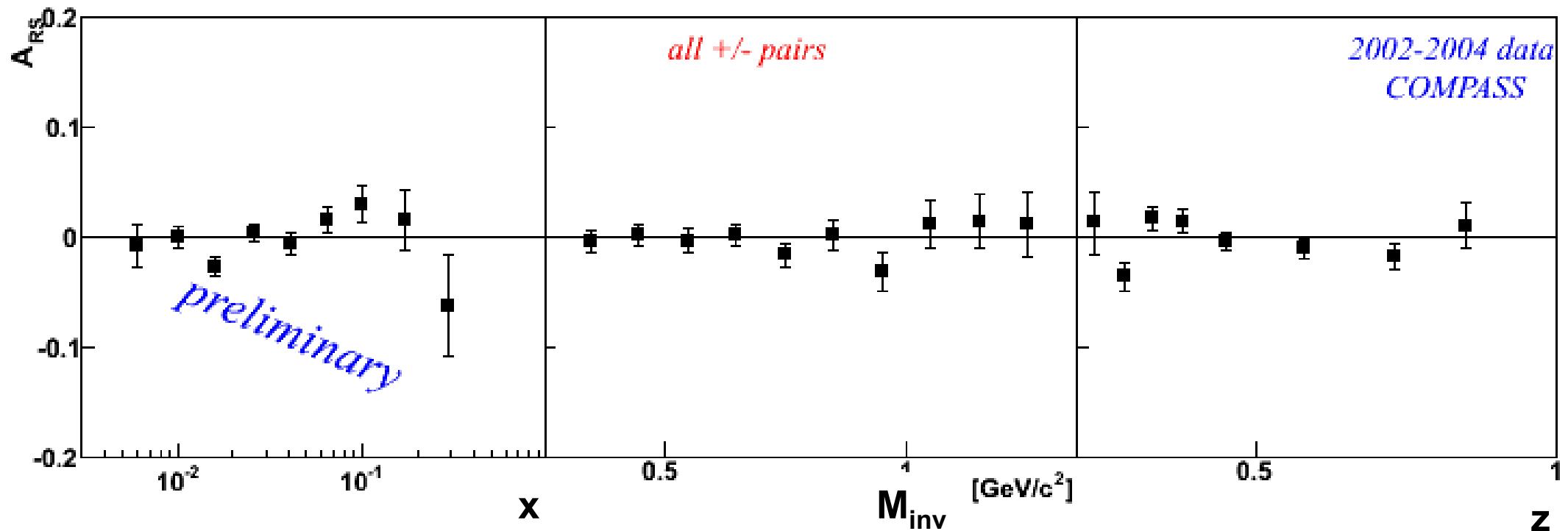
- Soffer, Stratmann, Vogelsang,  
P.R. D65 (02) 114024
- Korotkov, Nowak, Oganessian,  
E.P.J. C18 (01) 639
- Wakamatsu  
P.L. B509 (01) 59

---

Thank you!

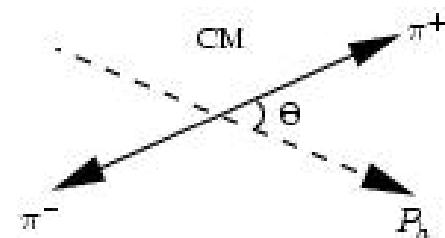
# Results for two unidentified hadrons

**all combinations  
of +ve (h1) and -ve (h2)  
hadrons**



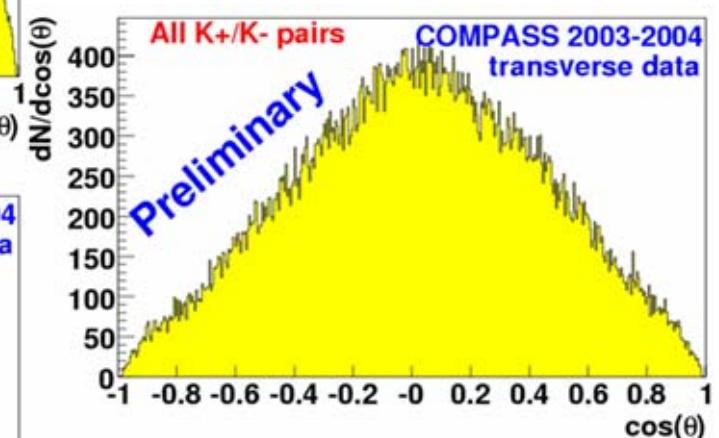
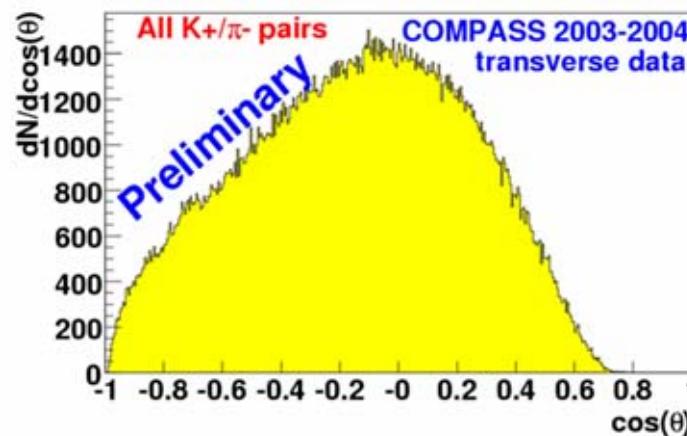
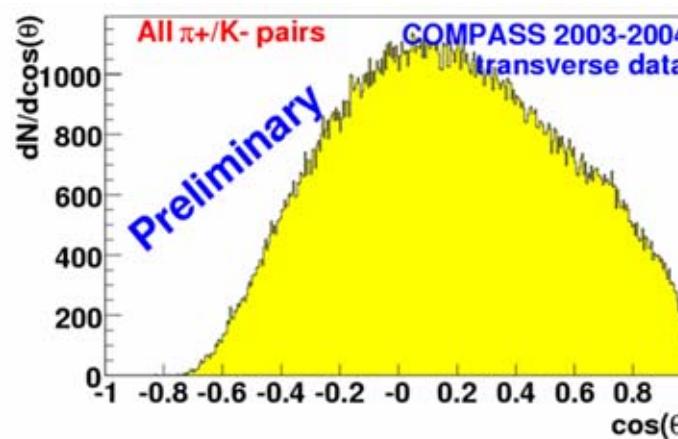
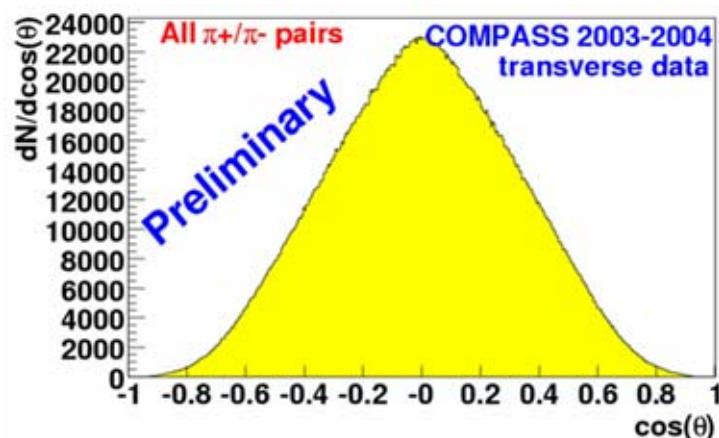
# Partial wave expansion of $H_q^{\angle h}(z)$

$$H_q^{\angle h}(z, \cos\theta, M_h^2) = H_{q,0t}^{\angle h}(z, M_h^2) + H_{q,lt}^{\angle h}(z, M_h^2) \cos\theta$$

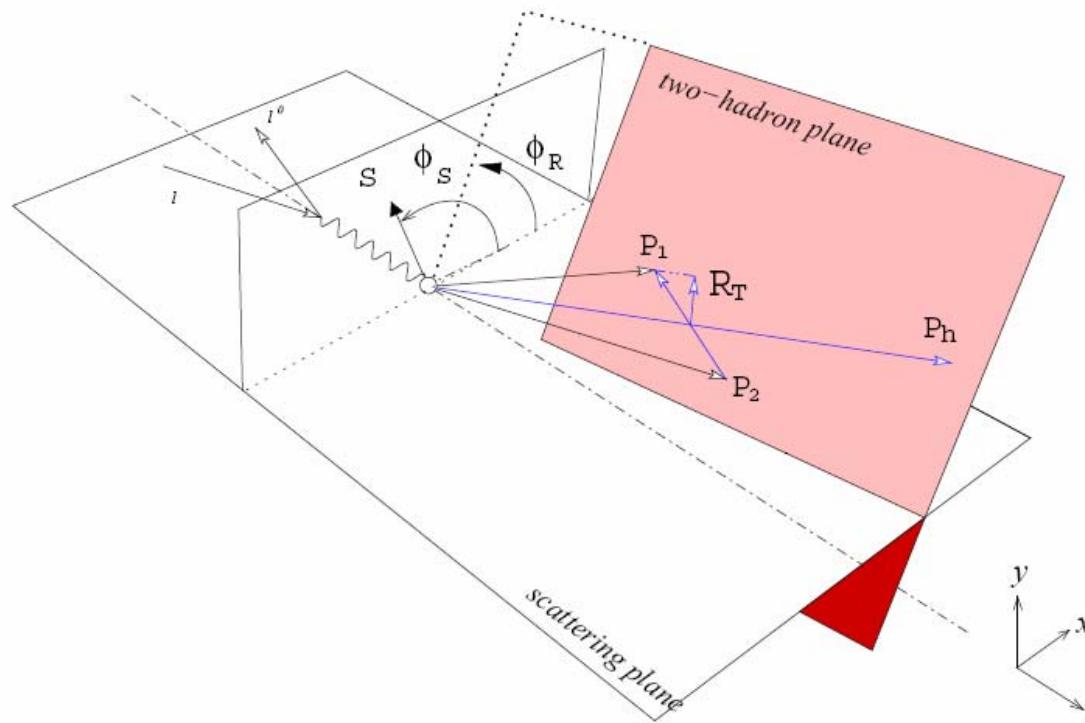


A. Baccetta, hep-ph/0708037

cosθ-Distributions  
of our data:



# Frame independant definition of $\Phi_R$



A. Baccetta,  
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:

$$\cos\phi_R = \frac{(q \times l)}{|q \times l|} \cdot \frac{(q \times R_T)}{|q \times R_T|}$$

$$\sin\phi_R = \frac{(l \times R_T) \cdot q}{|q \times l| |q \times R_T|}$$

# Double Ratio Method

double ratio:

$$F(\phi_{RS}) = \frac{N_{up}^{\uparrow}(\phi_{RS}) \cdot N_{down}^{\uparrow}(\phi_{RS})}{N_{up}^{\downarrow}(\phi_{RS}) \cdot N_{down}^{\downarrow}(\phi_{RS})}$$

$N_{up/down}$ : upstream / downstream target cell

$N^{\uparrow\downarrow}$ : target polarization vector pointing up / down

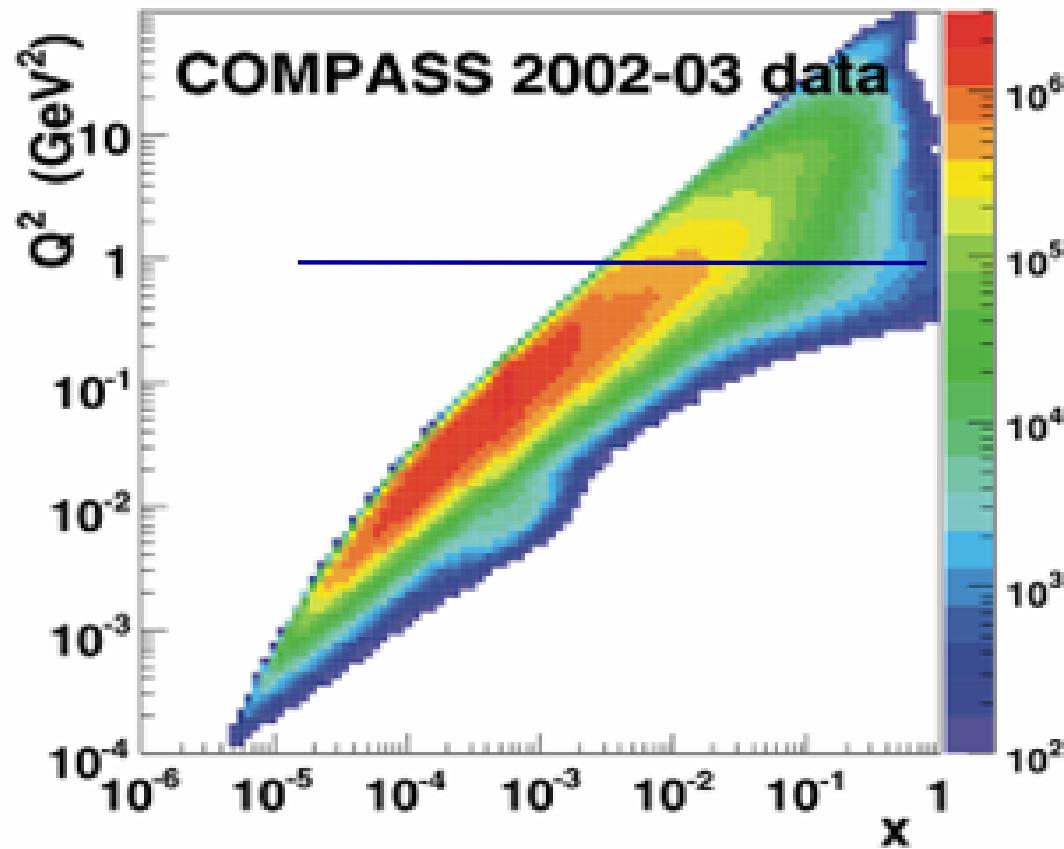
fit function:

$$F(\phi_{RS}) = \text{const} \cdot (1 + 4 \cdot A_{UT}^{\sin \phi_{RS}} \sin \phi_{RS})$$

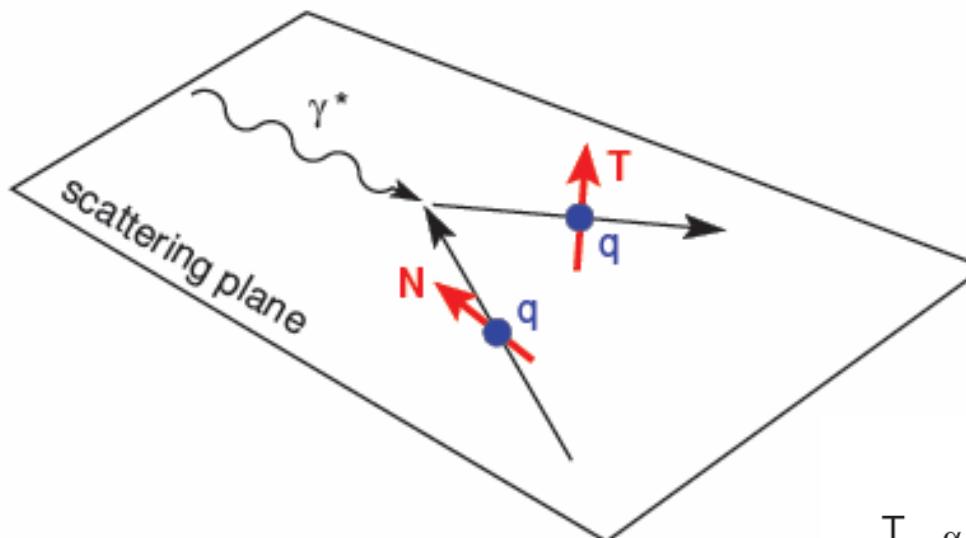
final asymmetry:

$$A_{RS} = \frac{1}{f P_T D} A_{UT}^{\sin \phi_{RS}}$$

# COMPASS kinematic region

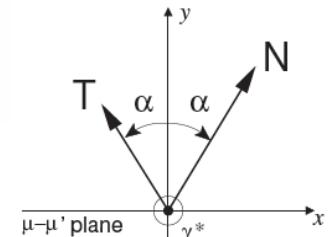


# Transverse $\Lambda$ Polarization



**N:** component of target spin perpendicular to  $p_{\gamma^*}$

**T:** symmetric of N wrt. the normal to the scattering plane



$$P_{T,exp}^\Lambda = \frac{d\sigma^{\mu N^\dagger \rightarrow \mu' \Lambda^\dagger X}}{d\sigma^{\mu N^\dagger \rightarrow \mu' \Lambda^\dagger X}} - \frac{d\sigma^{\mu N^\dagger \rightarrow \mu' \Lambda^\dagger X}}{d\sigma^{\mu N^\dagger \rightarrow \mu' \Lambda^\dagger X}} = f P_N D(y) \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T D_{\Lambda/q}(z)}{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}$$

$f$  = target dilution factor,  $P_N$  = target polarization,

$D(y)$  = virtual photon depolarization factor

$$\Delta_T D_{\Lambda/q}(z) = D_{\Lambda^\dagger/q^\dagger}(z) - D_{\Lambda^\dagger/q^\dagger}(z)$$

# Transverse $\Lambda$ Polarization

