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on behalf of the COMPASS Collaboration

Outline

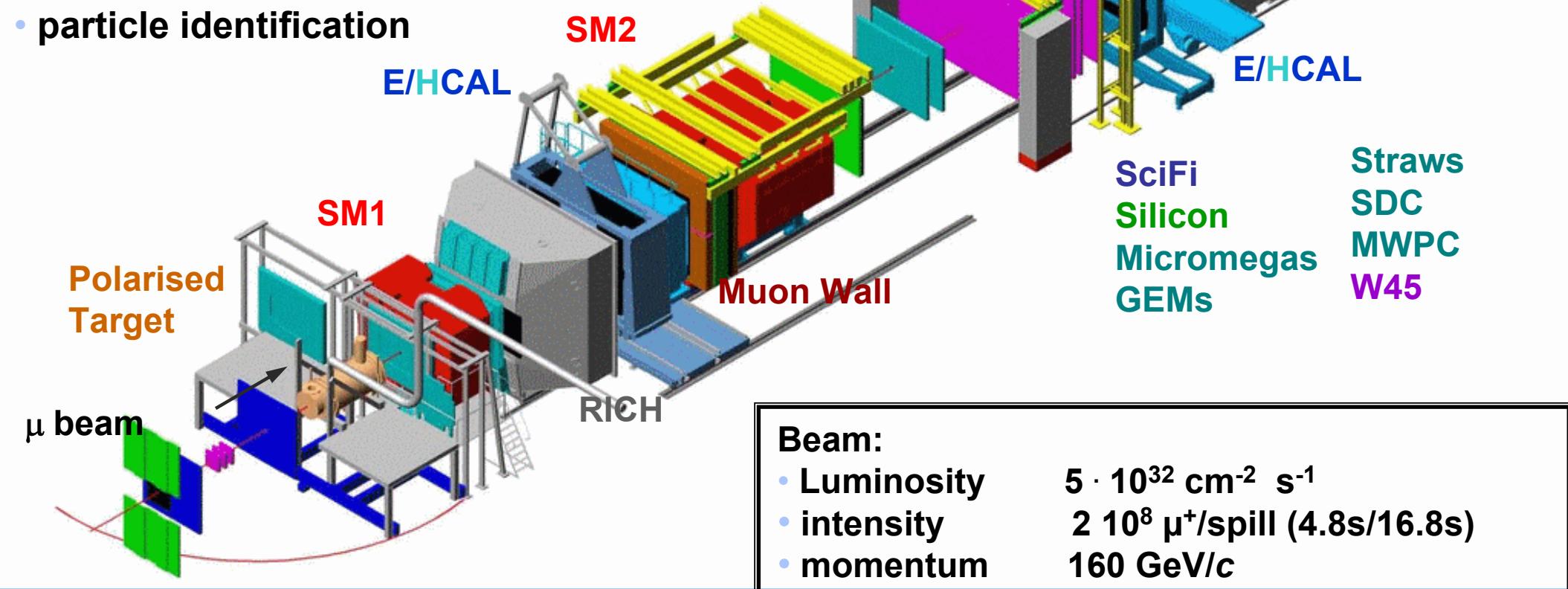
- The COMPASS experiment
- Results on:
 - Collins/Sivers asymmetries :
positive and negative hadrons
 π^\pm, K^\pm

For:

- Two hadron asymmetries: C.Shill on Thursday
- Beyond Collins/Sivers: A.Kotzinian on Thursday

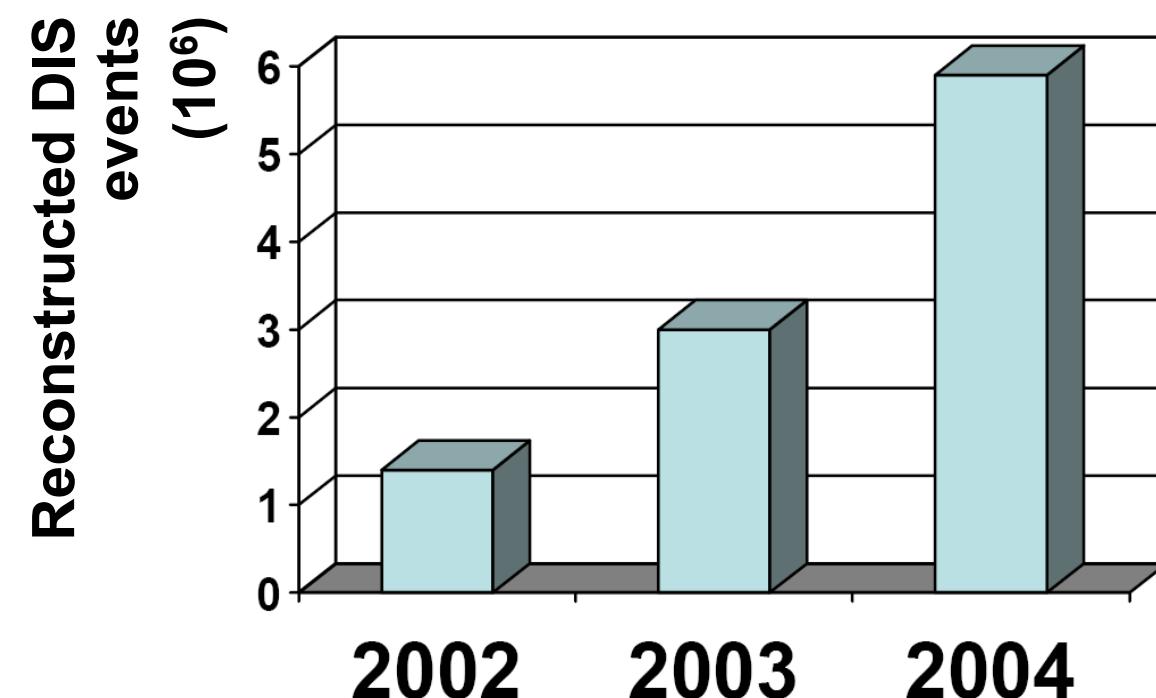
- high energy beam
- large angular acceptance
- broad kinematical range

- longitudinally polarised muon beam
- longitudinally or transversely polarised target
- momentum and calorimetry measurement
- particle identification

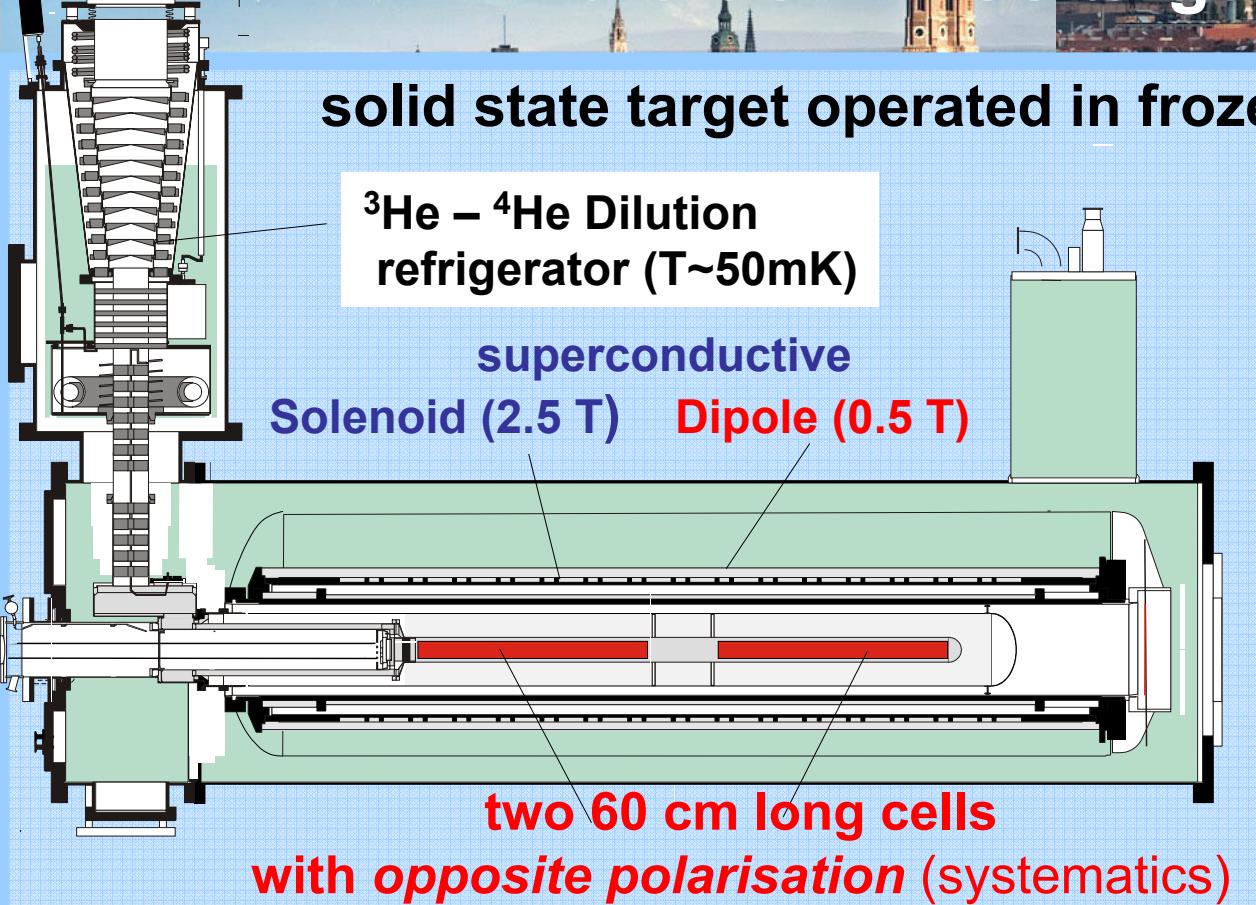


transversely polarised deuteron target (${}^6\text{LiD}$) ~ 20% of the running time

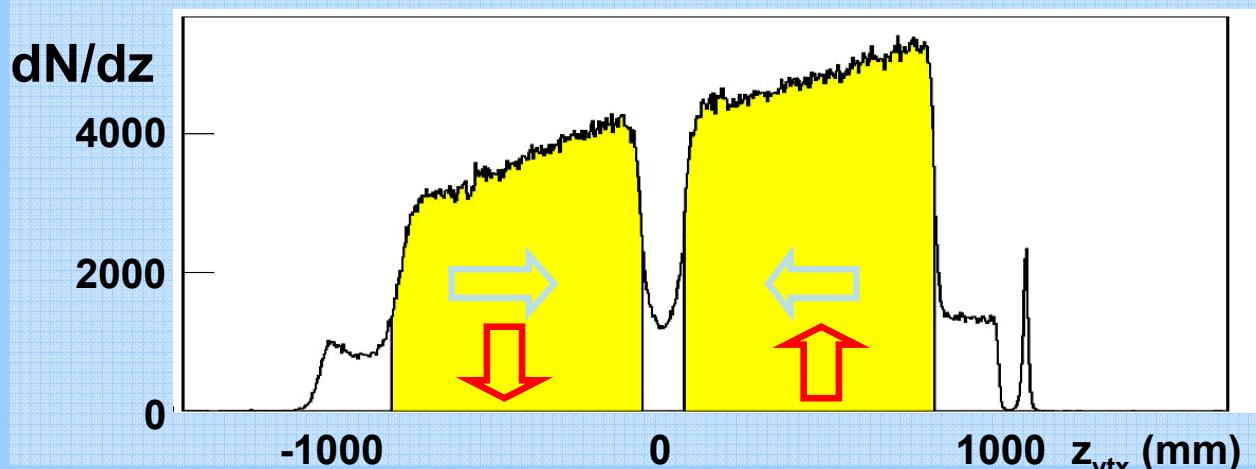
2002	11 days of data taking,	2 periods	trigger (large x , Q^2) DAQ, on line filter
2003	9 days of data taking,	1 period	
2004	14 days of data taking,	2 periods	



the COMPASS target system

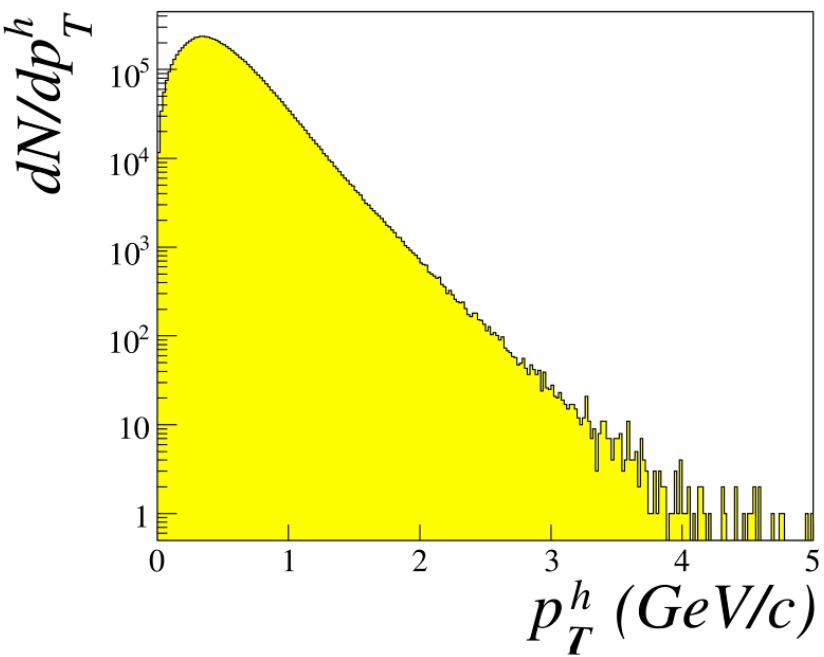
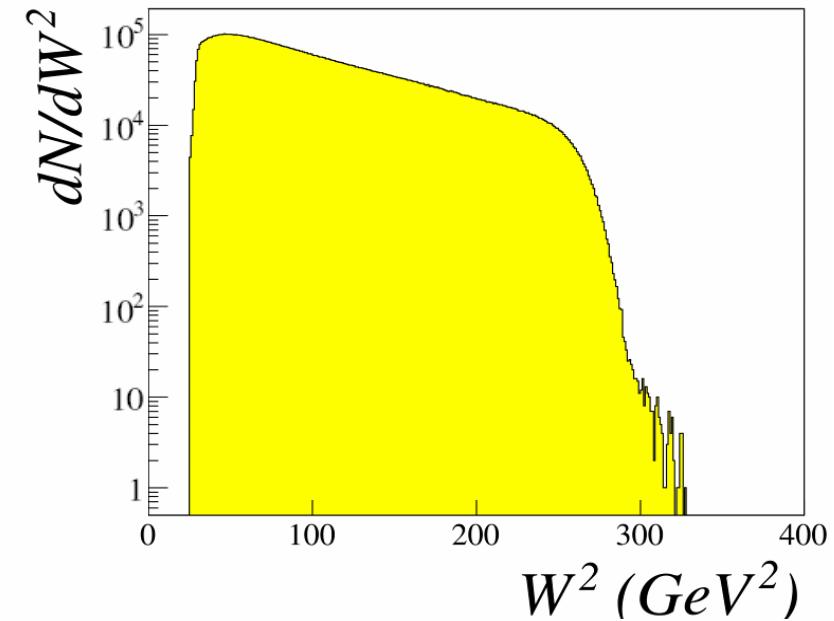
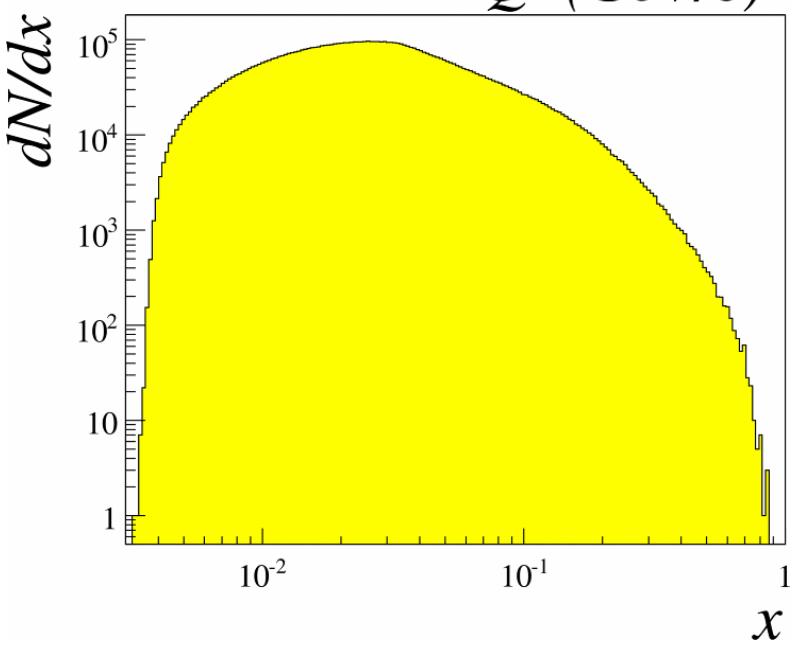
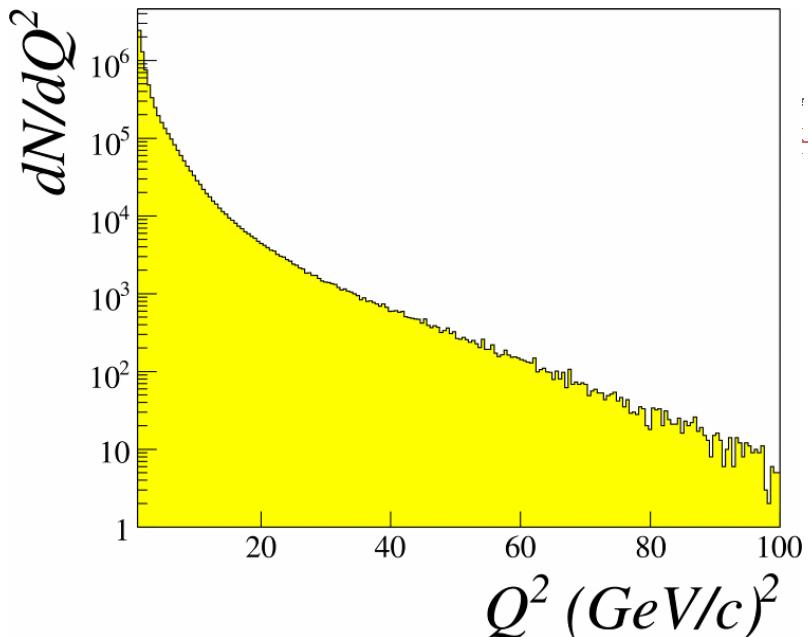


2002-2004: ${}^6\text{LiD}$
dilution factor $f = 0.38$
polarization $P_T = 50\%$
 $\sim 20\%$ of the time
transversely polarised



during data taking with transverse polarization

- dipole field always \uparrow
- polarization reversal in the 2 cells after ~ 5 days

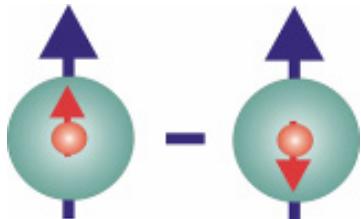


$$\Delta_T q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$$

$$h_1^q(x),$$

$$\delta q(x),$$

$$\delta_T q(x)$$



$q = u_v, d_v, q_{sea}$

quark with **spin** parallel to the nucleon spin in a transversely polarised nucleon

Properties:

- probes the relativistic nature of quark dynamics
- no contribution from the gluons \rightarrow simple Q^2 evolution
- Positivity: Soffer bound..... $2|\Delta_T q| \leq q + \Delta q$
Soffer, PRL 74 (1995)
- first moments: tensor charge..... $\Delta_T q \equiv \int dx \Delta_T q(x)$
- sum rule for transverse spin
in Parton Model framework..... $\frac{1}{2} = \frac{1}{2} \sum \Delta_T q + L_q + L_g$
Bakker, Leader, Trueman, PRD 70 (04)
- it is related to GPD's
- is chiral-odd: decouples from inclusive DIS

the Transversity DF is chiral-odd:

☞ survives only by the product with another chiral-odd function

can be measured in SIDIS on a transversely polarised target via “quark polarimetry”

$L N^{\uparrow} \rightarrow l' h X$	Collins Asymmetry (Collins FF)
$L N^{\uparrow} \rightarrow l' \Lambda X$	Λ polarization (FF of $q^{\uparrow} \rightarrow \Lambda$) [from COMPASS]
$L N^{\uparrow} \rightarrow l' hh X$	Two hadrons asymmetry (Interference FF) (see talk of C.Shill on Thursday)

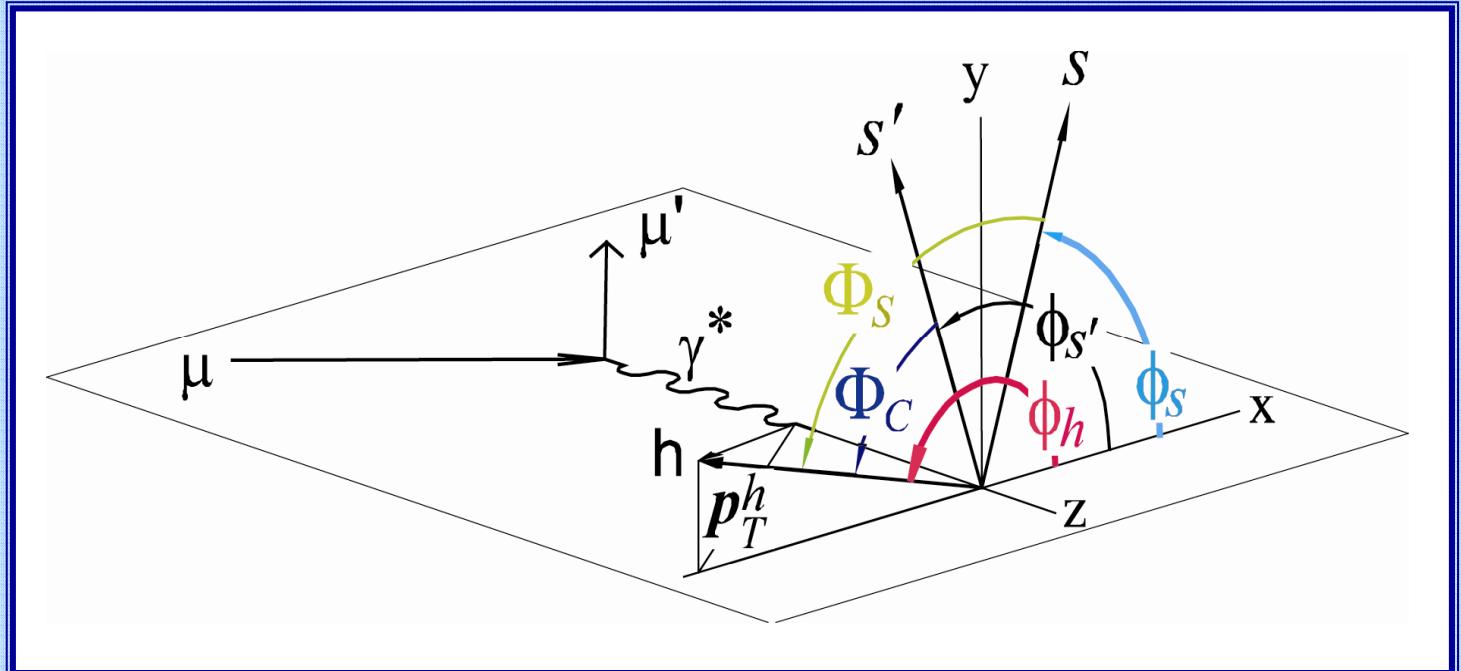
Collins and Sivers terms in SIDIS cross sections depend on different combination of angles:

$$\Phi_C = \phi_h - \phi_{s'}$$

Collins angle

$$\Phi_S = \phi_h - \phi_s$$

Sivers angle



ϕ_h azimuthal angle of the hadron

ϕ_s azimuthal angle of the transverse spin of the initial quark

$\phi_{s'}$, azimuthal angle of the transverse spin of the fragmenting quark

$$\phi_{s'} = \pi - \phi_s \text{ (*spin flip*)}$$

Collins effect:

a quark with an upward (downward) polarization, perpendicular to the motion, prefers to emit the leading meson to the left (right) side with respect to the quark direction

i.e.

the fragmentation function of a transversely polarized quark has a spin dependent part

$$D_q^h(z, \vec{p}_T^h) = D_q^h(z, p_T^h) + \Delta_T^0 D_q^h(z, p_T^h) \times \sin(\varphi_h - \varphi_s)$$

And the resulting measured asymmetry

$$N_h^\pm(\Phi_C) = N_h^0 \cdot \left\{ 1 \pm A_C^h \cdot \sin \Phi_C \right\} \quad \Phi_C = \phi_h + \phi_s - \pi$$

$$A_{\text{Coll}} = \frac{A_C^h}{f \cdot P_T \cdot D_{nn}} = \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

event selection

DIS cuts:

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

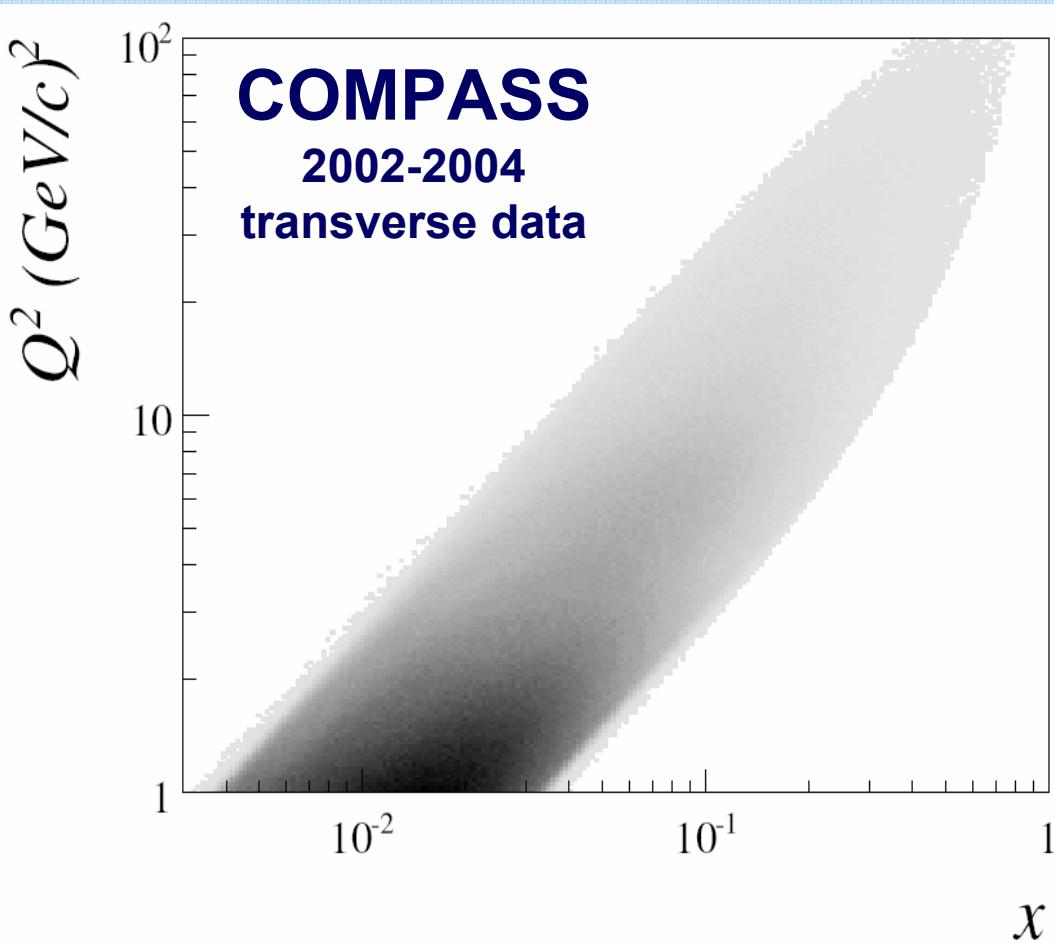
All hadron selection:

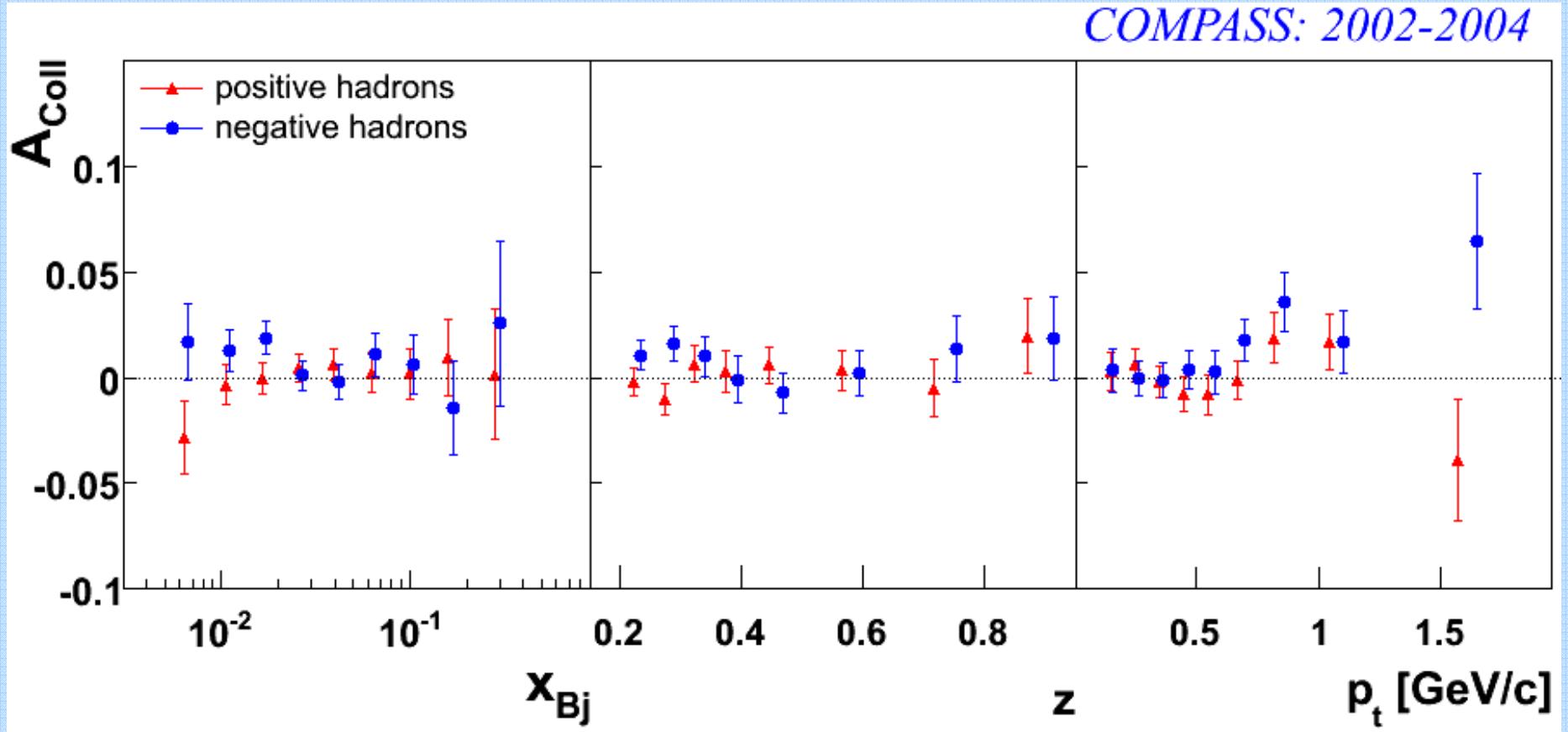
- $z > 0.20$
- $p_t > 0.1$

Plus for leading hadron:

- $z_l > 0.25$
- No signals in the CALOs from neutral particles with $z > z_l$

Statistics 2002 - 2004:
 $8.5 * 10^6$ positive hadrons
 $7.0 * 10^6$ negative hadrons



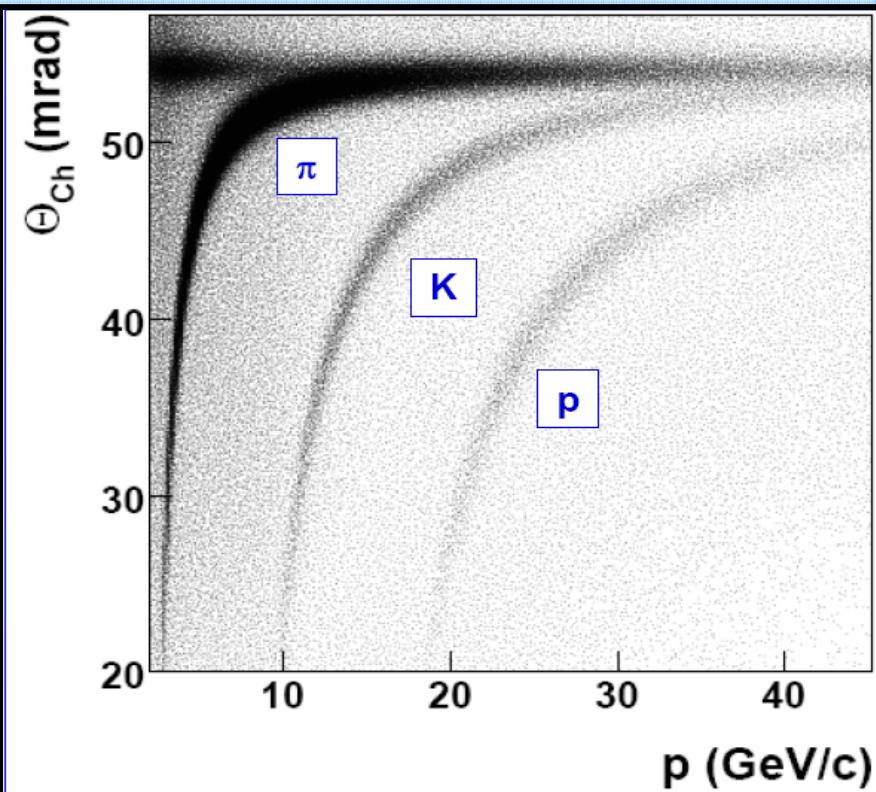


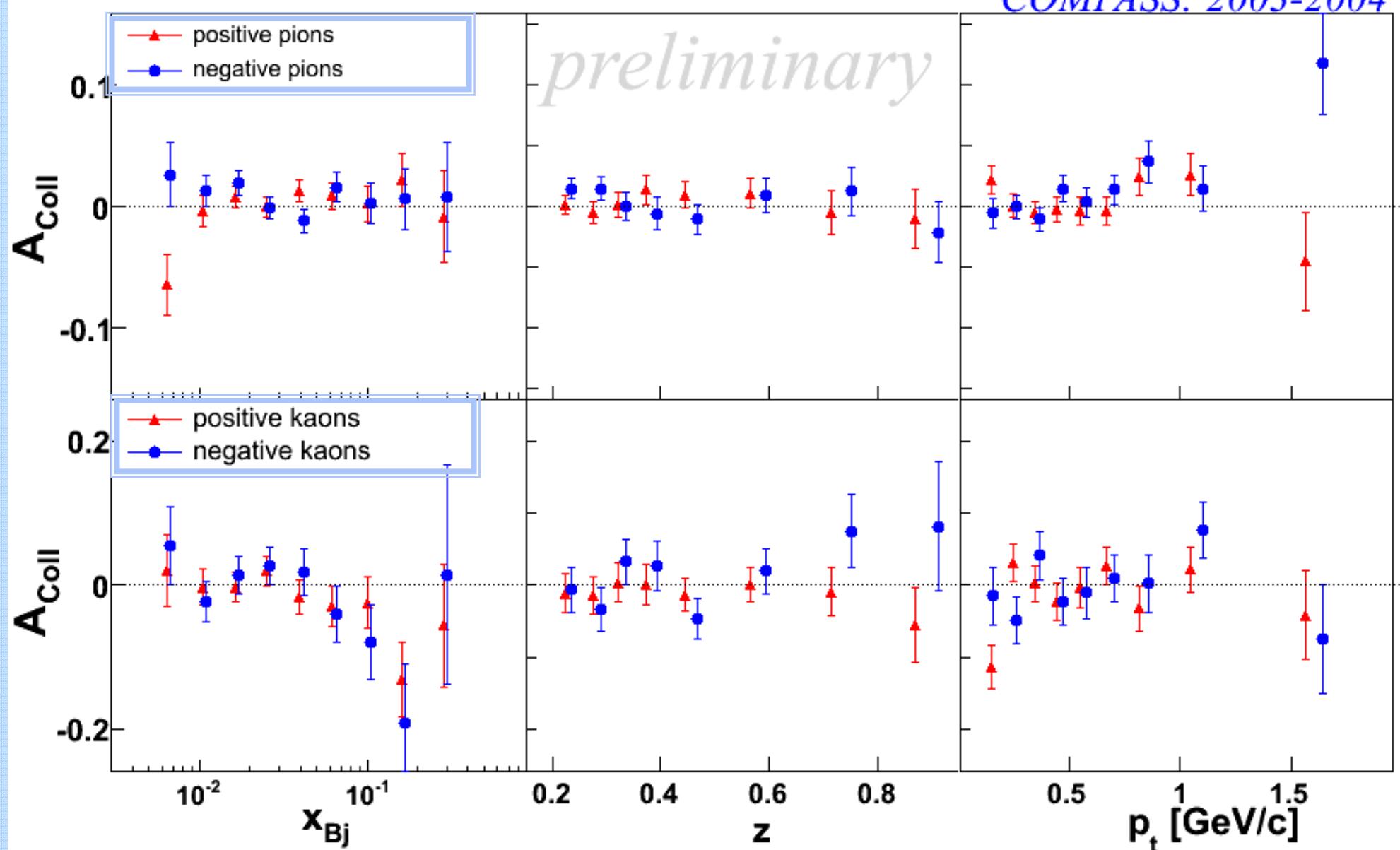
- only statistical errors shown (~1%), systematic errors considerably smaller
- small asymmetries compatible with 0 for both + and – hadrons

[NP B765 (2007) 31-70]

- 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 GeV/c
- In the leading hadron sample:
~76% pions
~12% kaons

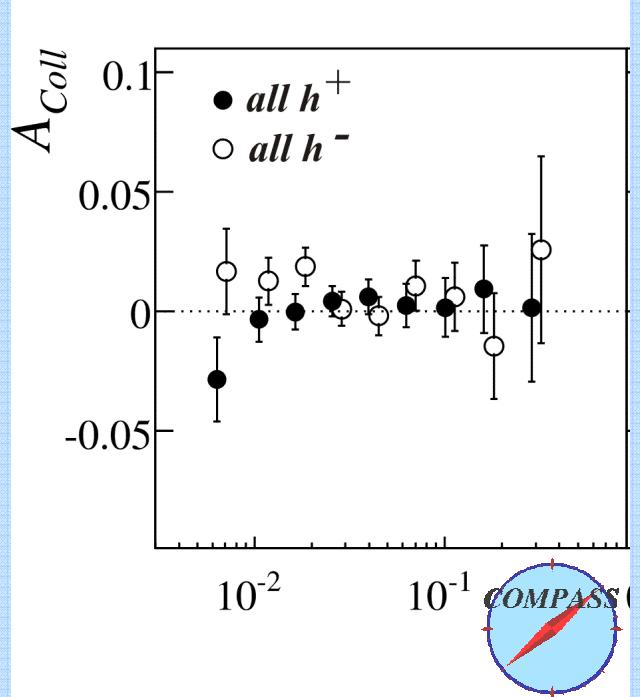
	positive	negative
leading π	3.4M	2.8M
leading K	0.7M	0.4M





naïve interpretation

- deuteron data



(parton model, valence region)

$$A_{Coll}^{d,\pi^+} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{4\Delta_T^0 D_1 + \Delta_T^0 D_2}{4D_1 + D_2}$$

$$A_{Coll}^{d,\pi^-} \simeq \frac{\Delta_T u_v + \Delta_T d_v}{u_v + d_v} \frac{\Delta_T^0 D_1 + 4\Delta_T^0 D_2}{D_1 + 4D_2}$$

- Cancellation between $\Delta_T u(x)$ and $\Delta_T d(x)$
- Deuteron data give access to $\Delta_T d(x)$

(for a global analysis of Hermes, Belle and Compass data see D'Alesio talk, but also the works of Vogelsang and Yuan, Efremov and coworkers)

- from proton and e+e- data

→ unfavored Collins FF ~ – favored Collins FF

$$\Delta_T^0 D_2 \approx -\Delta_T^0 D_1 \quad \text{at variance with unpol case}$$

from proton: u quark dominance (d quark DF ~ unconstrained)

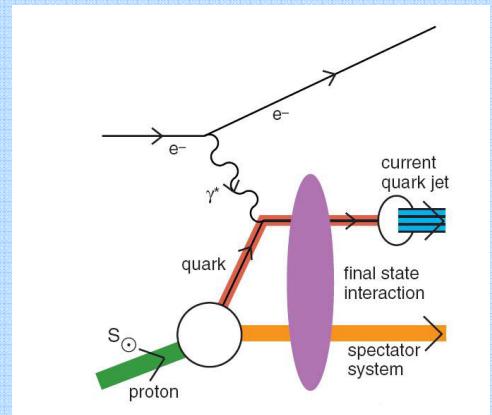
- The Sivers DF $\Delta_0^T q$ is probably the most famous between TMDs...
- gives a measure of the correlation between the transverse momentum and the transverse spin
- Requires final/initial state interactions of the struck quark with the spectator system and the interference between different helicity Fock states to survive time-reversal invariance
- Time-reversal invariance implies:

$$\Delta_0^T q(x, k_T^2)_{SIDIS} = -\Delta_0^T q(x, k_T^2)_{DY}$$

...to be checked

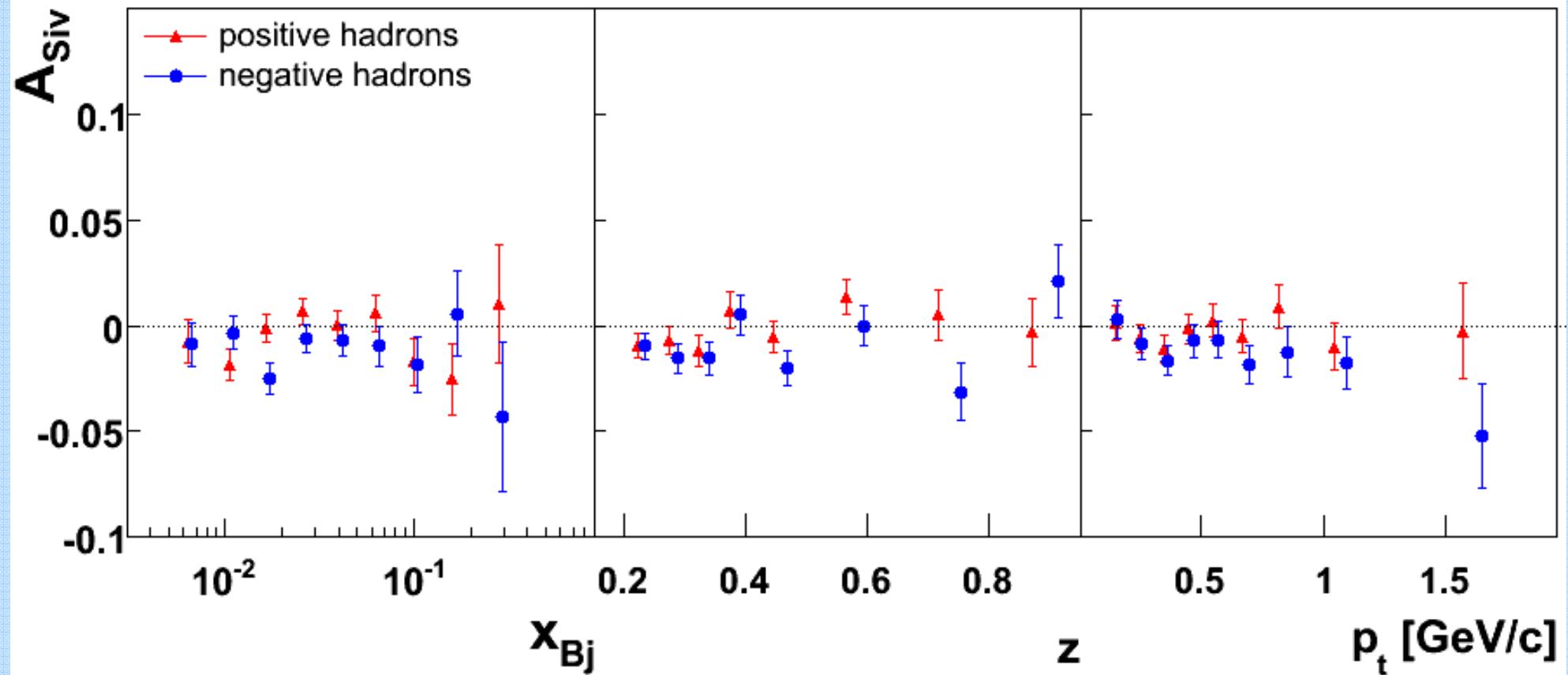
- In SIDIS:

$$N_h^\pm(\Phi_s) = N_h^0 \cdot \left\{ 1 \pm A_s^h \cdot \sin \Phi_s \right\}$$



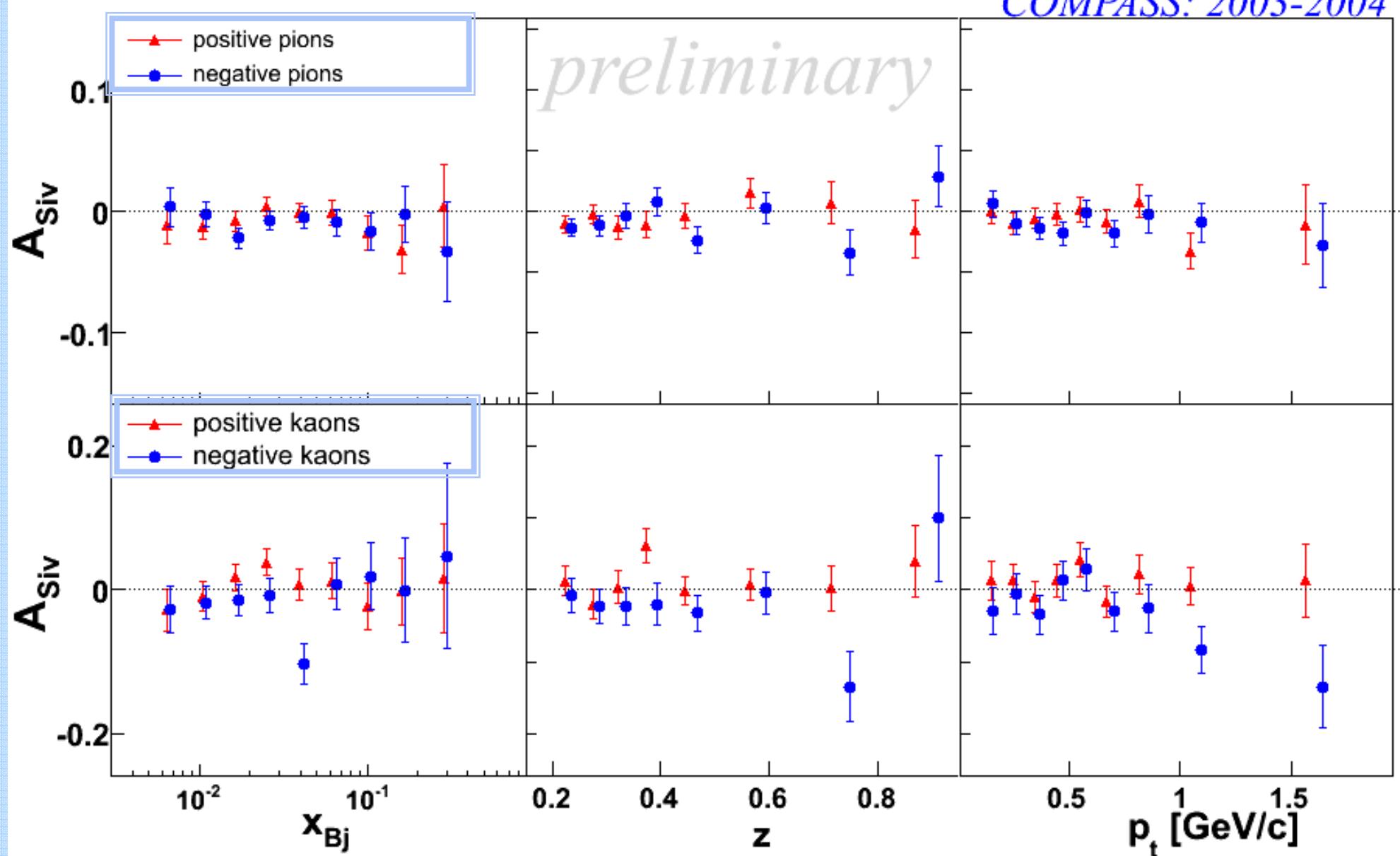
$$A_{Siv} = \frac{A_s^h}{f \cdot P_T} = \frac{\sum_q e_q^2 \Delta_0^T q \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

COMPASS: 2002-2004

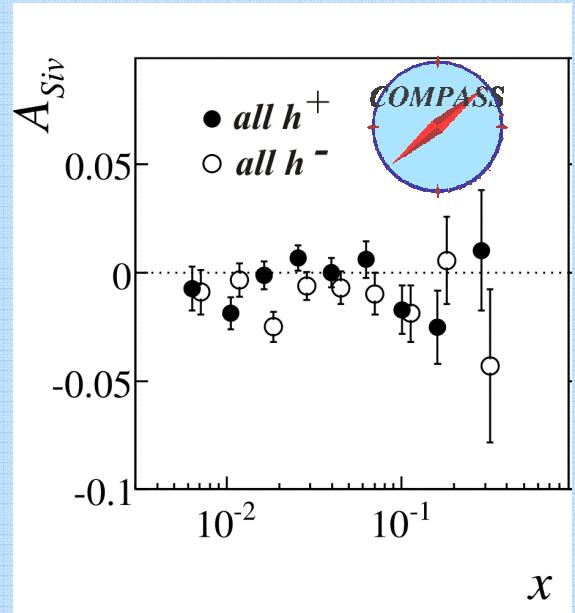


- only statistical errors shown ($\sim 1\%$), systematic errors considerably smaller
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[NP B765 (2007) 31-70]



- deuteron data



$$A_{Siv}^{d,\pi^+} \simeq A_{Siv}^{d,\pi^-} \simeq \frac{\Delta_0^T u_v + \Delta_0^T d_v}{u_v + d_v}$$

the measured asymmetries
compatible with zero suggest

$$\Delta_0^T d_v \simeq -\Delta_0^T u_v$$

- proton data

$$A_{Siv}^{p,\pi^+} \simeq \frac{4\Delta_0^T u_v D_1 + \Delta_0^T d_v D_2}{4u_v D_1 + d_v D_2}$$

$$A_{Siv}^{p,\pi^-} \simeq \frac{4\Delta_0^T u_v D_2 + \Delta_0^T d_v D_1}{4u_v D_2 + d_v D_1}$$

asymmetry for $\pi^+ > 0$, asymmetry for $\pi^- \approx 0$

→ **Sivers DF for d-quark ≈ -2 Sivers DF for u-quark**

$$\Delta_0^T d_v \simeq -2 \Delta_0^T u_v$$

the measured asymmetry on deuteron compatible with zero has been interpreted as

Evidence for the Absence of Gluon Orbital Angular Momentum in the Nucleon

S.J. Brodsky and S. Gardner, PLB643 (2006) 22

The approximate cancellation of the SSA measured on a deuterium target suggests that the gluon mechanism, and thus the orbital angular momentums carried by gluons in the nucleon, is small.

summary and outlook

precise deuteron data from COMPASS are now available

Collins and Sivers asymmetries h^\pm, π^\pm, K^\pm

all the measured deuteron asymmetries are very small, and compatible with zero

COMPASS data on deuteron allows to determine the d-quark contribution

[for two hadron asymmetries → C.Shill]

[for all transverse momentum dependent SSA azimuthal asymmetries → A.Kotzinian]

present phenomenological studies can describe at the same time the BELLE (FF), the HERMES (proton) and COMPASS (deuteron)...and have allowed a first extraction of the transversity distribution $\Delta_T q$

At the same way COMPASS and HERMES data have allowed a first extraction of the Sivers DF

(work ongoing)



in the near future COMPASS will complete the analysis of the recorded deuteron data:

- K^0 asymmetries
- exclusive ρ production on transversely polarised target

A little further in time...

- g_2
- transverse effects from longitudinal data
- Cahn and Boer-Mulders effect

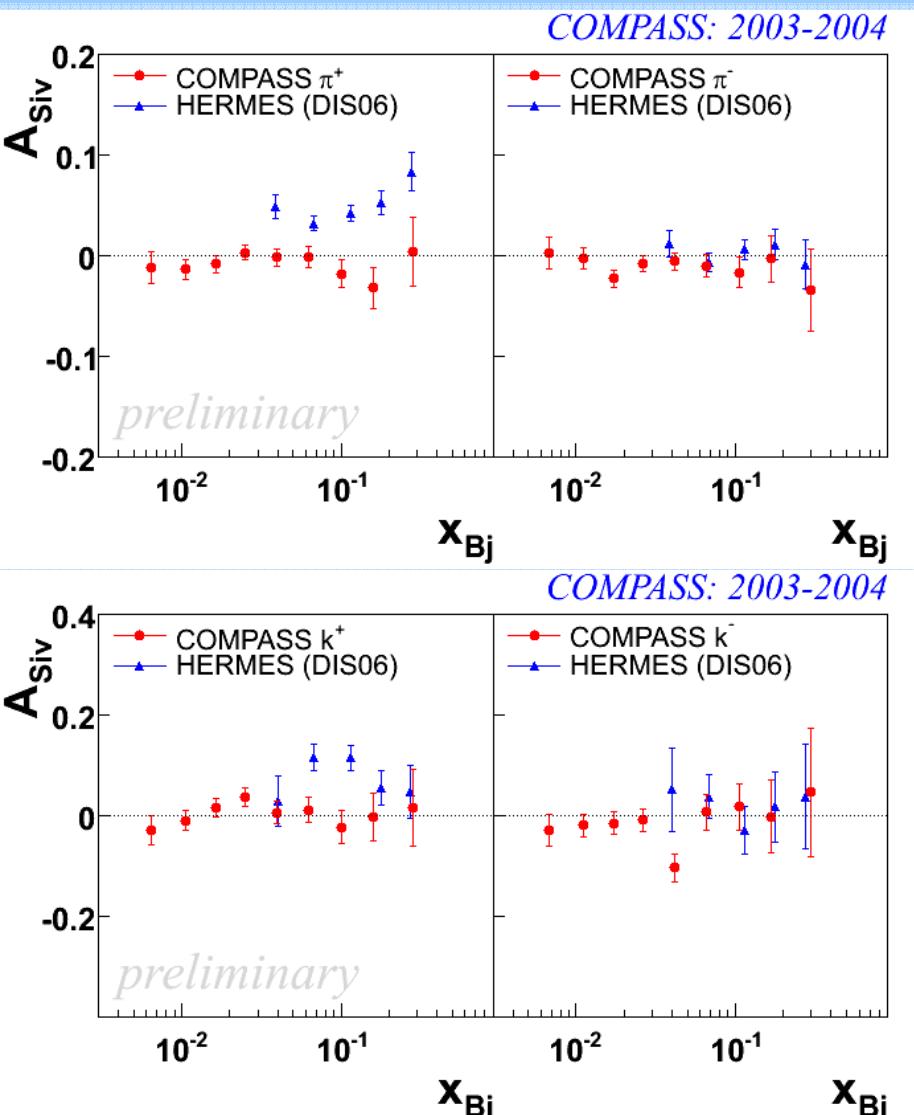
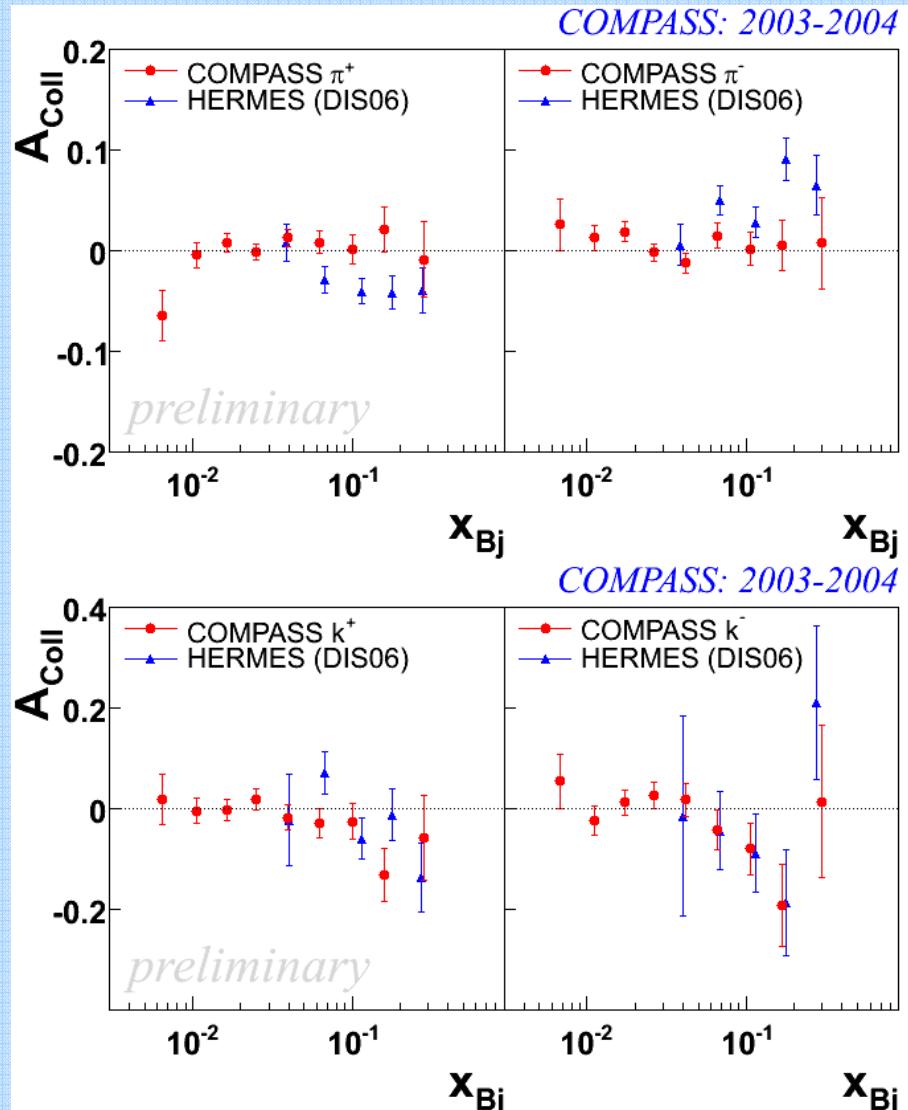
in 2007 COMPASS will take data with a
transversely polarised proton target (NH_3)

(with 50 days running, precision ~ deuteron at small x , better at “large” x for the new PT magnet)

On a longer time scale, good perspective for a measurement of Drell-Yan pairs in COMPASS and further measurements of transverse spin effects in SIDIS



Just in Case



HERMES data from 'Transversity results from HERMES', L.Pappalardo et al., to appear in the proceedings of the XIV International Workshop on Deep Inelastic Scattering, Tosukuba city, Japan, April 20-24, 2006.,
courtesy of the HERMES Collaboration

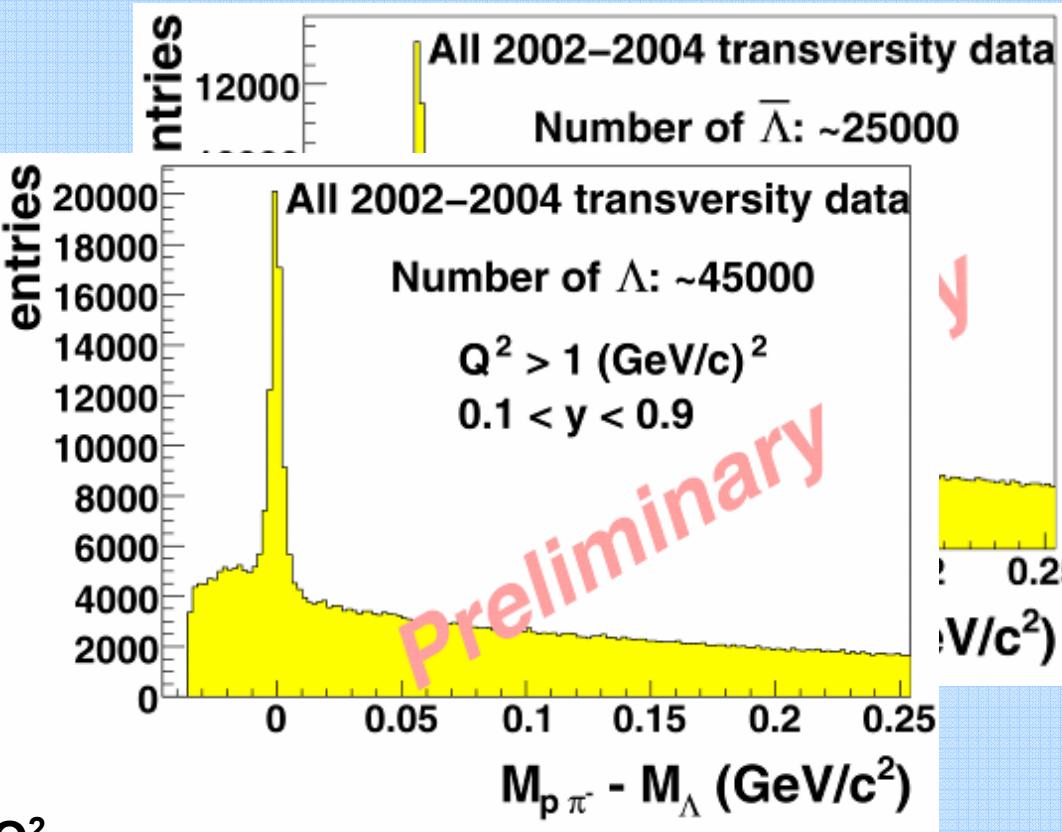
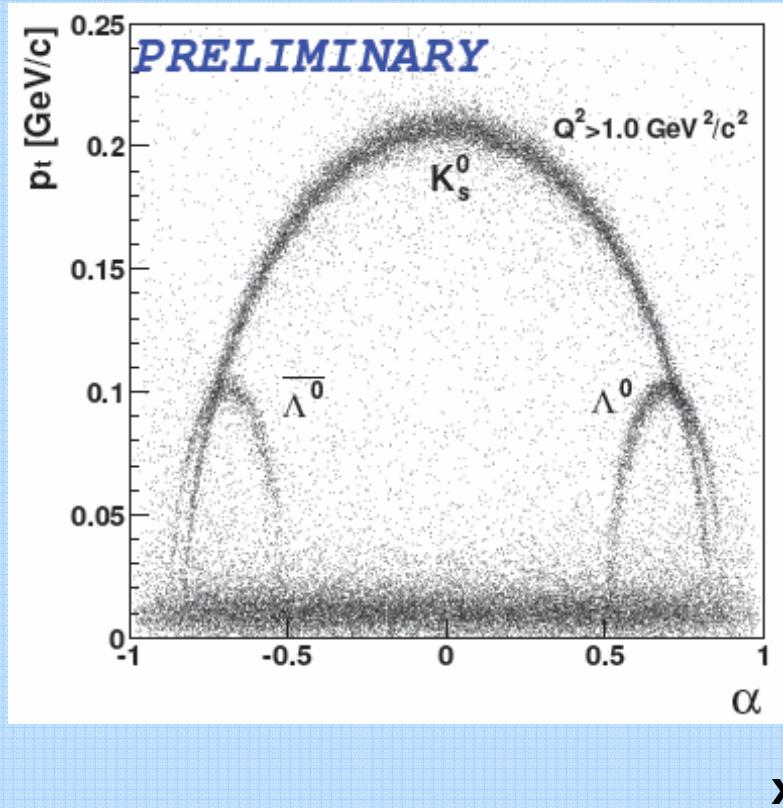
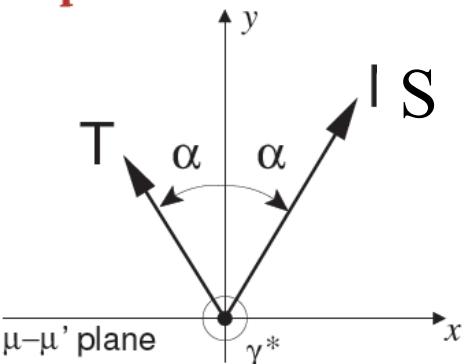
transversity from Λ polarimetry

$$P_{T,exp}^{\Lambda} = \frac{d\sigma^{\mu N^{\uparrow} \rightarrow \mu' \Lambda^{\uparrow} X} - d\sigma^{\mu N^{\downarrow} \rightarrow \mu' \Lambda^{\uparrow} X}}{d\sigma^{\mu N^{\uparrow} \rightarrow \mu' \Lambda^{\uparrow} X} + d\sigma^{\mu N^{\downarrow} \rightarrow \mu' \Lambda^{\uparrow} X}}$$

$$= \sum_q e_q^2 \Delta_T q(x) \Delta_T D_{\Lambda/q}(z)$$

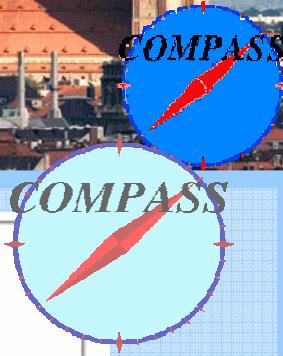
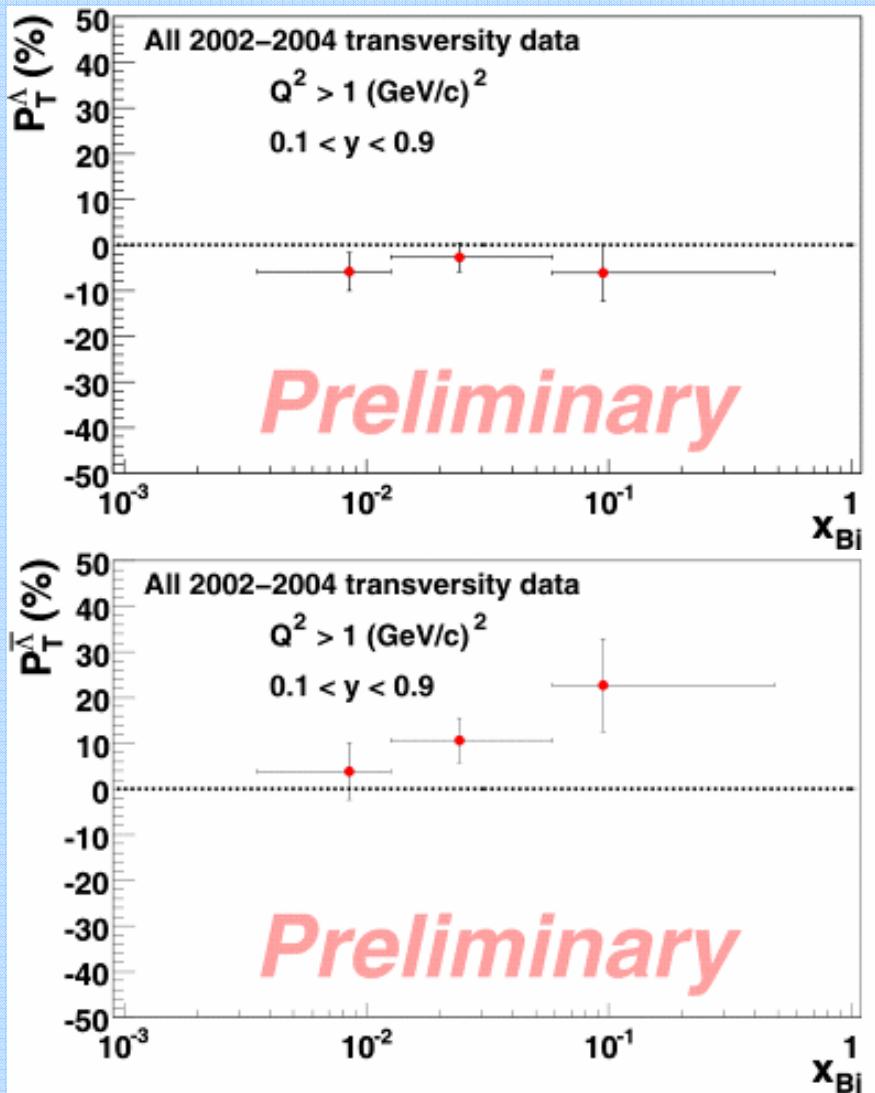
$$= f P_N D(y) \frac{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}{\sum_q e_q^2 q(x) D_{\Lambda/q}(z)}$$

Λ polarization axis



Λ polarimetry

COMPASS



systematic errors not larger than statistical errors