Collins and Sivers asymmetries on the deuteron from the COMPASS data

The physics case

The final results from run 2002

The COMPASS perspectives

Paolo Pagano (INFN - Trieste)

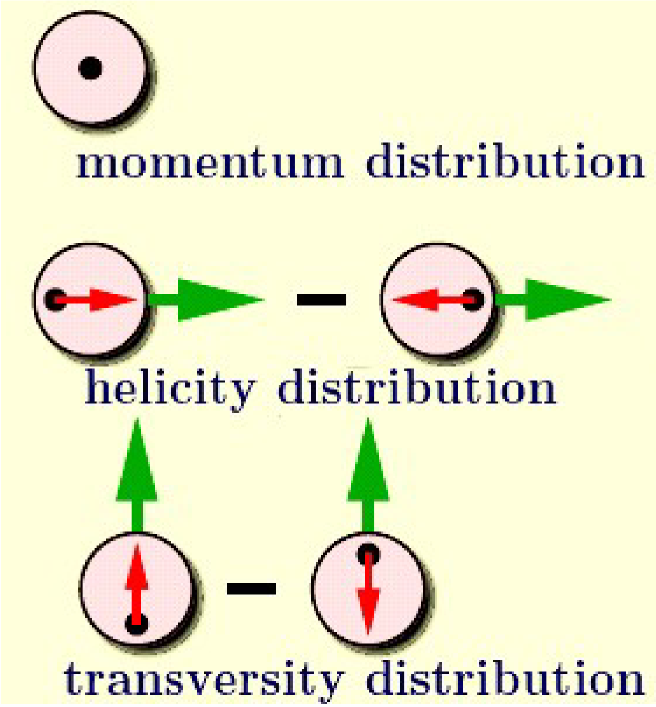
Spin structure functions

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

$q(x)$

$\Delta q(x)$

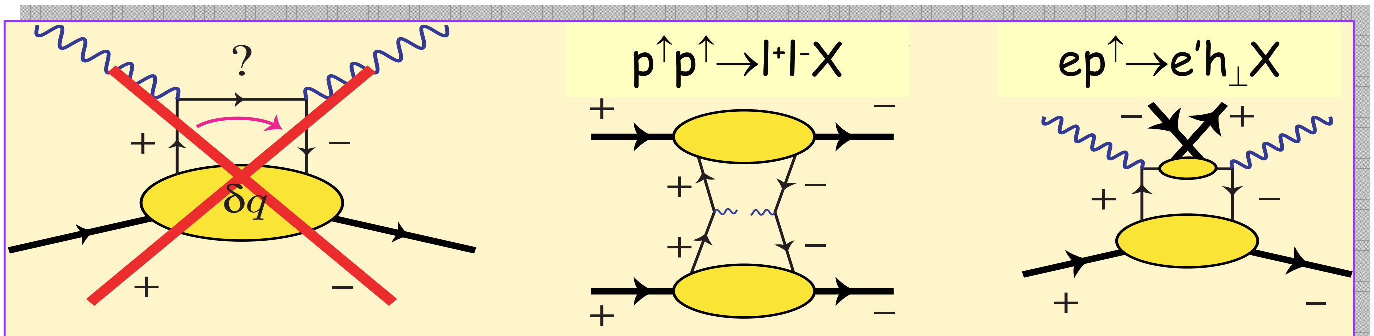
$\Delta_T q(x)$



All of equal importance!

Measuring $\Delta_T q(x)$

Chiral-odd: requires another chiral-odd partner



Impossible in DIS

Direct Measurement

Convolution with still unknown fragment. func.

Also:

Interference in fragmentation of 2 hadrons, see R. Joosten's talk

How to access it:

SIDIS (e.g. COMPASS and HERMES)	$\Delta_T q(x) \otimes FF$

Hard scattering NN **(e.g. RHIC)**	**Hard scattering** $N\overline{N}$ **(e.g. GSI)**
– **Drell-Yan** $\Delta_T q \cdot \Delta_T \bar{q}$	– **Drell-Yan** $\Delta_T q \cdot \Delta_T q$
– **Single Spin Asym (e.g.** $p^\uparrow p \rightarrow \pi X$**)**	

Transversity

In the last ten years:

- Great development in the theory of transversity;
- Remarkable role of $\Delta_T q(x)$, notably complementary to $\Delta q(x)$.

In the last couple of years:

- Role of the k_T structure functions clarified (Cahn and Sivers effects, …).

Key features of transversity:

- Probes relativistic nature of quarks
- No gluon analog for spin-1/2 nucleon
- Different Q^2 evolution and sum rule than $\Delta q(x)$
- Sensitive to valence quark polarization

- Tensor charge ('91 – '92):

$$g_T = \int dx \left[\Delta_T q(x) - \Delta_T \bar{q}(x) \right]$$

in analogy with:

$$g_A = \int dx \left[\Delta q(x) + \Delta \bar{q}(x) \right]$$

- Soffer inequality (95):

$$\Delta_T q(x) \leq \frac{1}{2} \left(\Delta_T q(x) + q(x) \right)$$

- Leader sum rule (04):

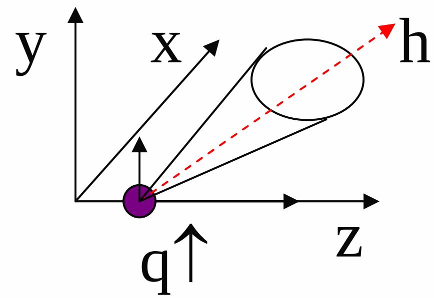
$$\frac{1}{2} = \frac{1}{2} \sum_{q,\bar{q}} \int dx \cdot \Delta_T q(x) + \sum_{q,\bar{q},g} \langle L_z \rangle$$

in analogy with:

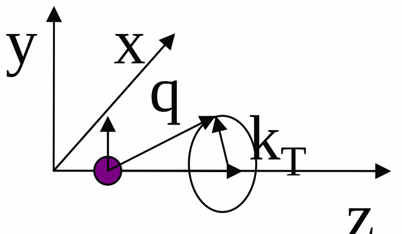
$$S_z = \frac{1}{2} \Delta\Sigma + \Delta G + \langle L_z \rangle$$

SIDIS off transversely polarized target

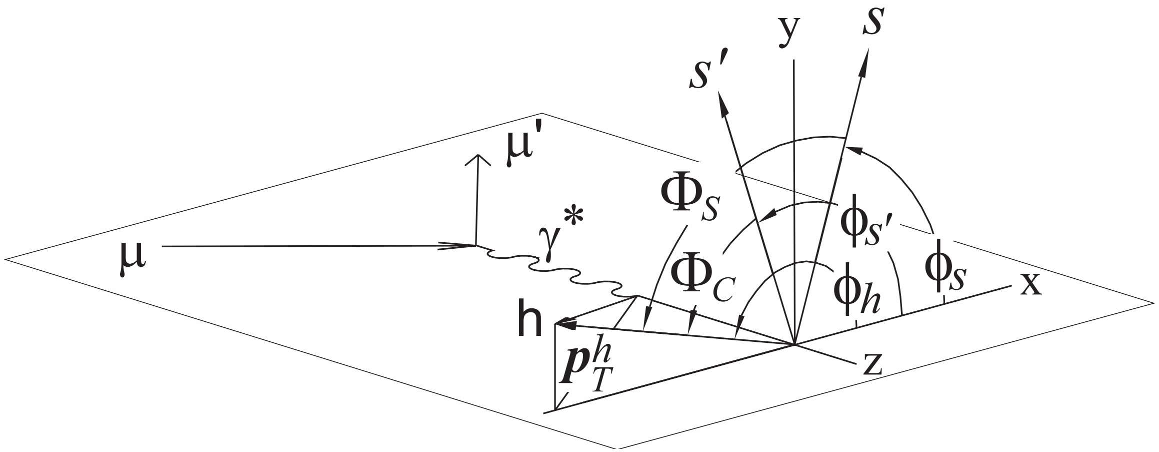
- Collins effect predicts an azimuthal asymmetry in the quark fragmentation



- The quark prefers to fragment in one direction;
- Look at leading hadron (it comes from the struck quark);
- The larger is “z” (fraction of the available energy carried by the hadron), the stronger is the signal ;
- But an azimuthal asymmetry can also come from the un-polarised quarks; namely from an azimuthal modulation of quark transverse momentum for a transversely polarized nucleon (Sivers effect)



Collins and Sivers asym's

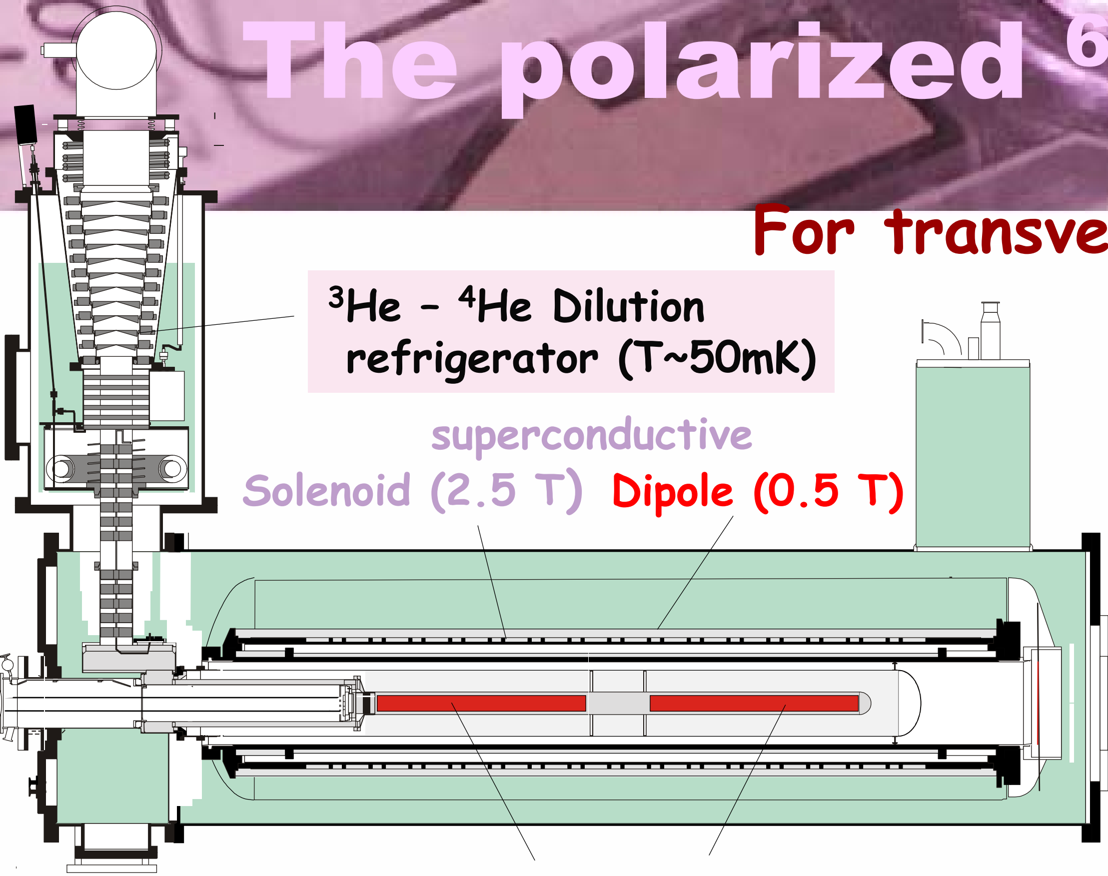


Calculated as function of x, z and p_t and for "Leading Hadrons" and for "All Hadrons"

$$A_{Coll}^{\sin\Phi_{Coll}} = \frac{\sum_q e_q^2 \cdot \Delta_T q \cdot \Delta_T^0 D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

$$A_{Siv}^{\sin\Phi_{Siv}} = \frac{\sum_q e_q^2 \cdot \Delta_0^T q \cdot D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^h}$$

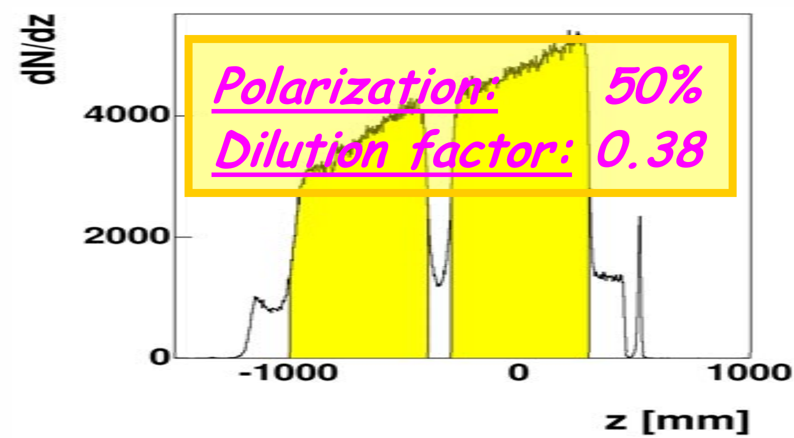
The polarized ^{6}LiD-Target



For transversity:

1	↑	↓
2	↓	↑

reversed once a week

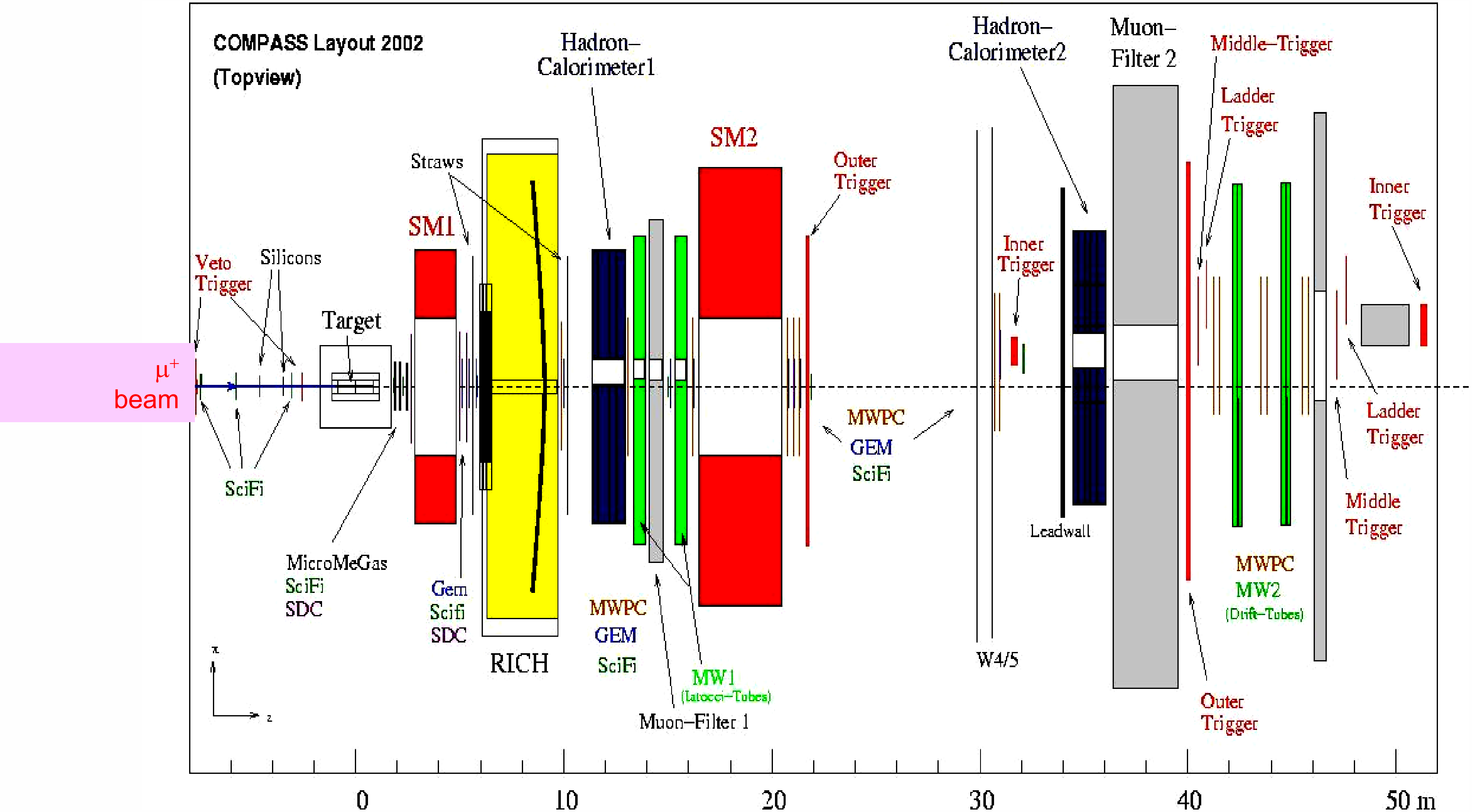


two 60 cm long Target-Containers
with opposite polarization

During data taking for transversity
dipole field always ↑

Relaxing time > 2000 hrs

The COMPASS Experiment in 2002



COMPASS data sample

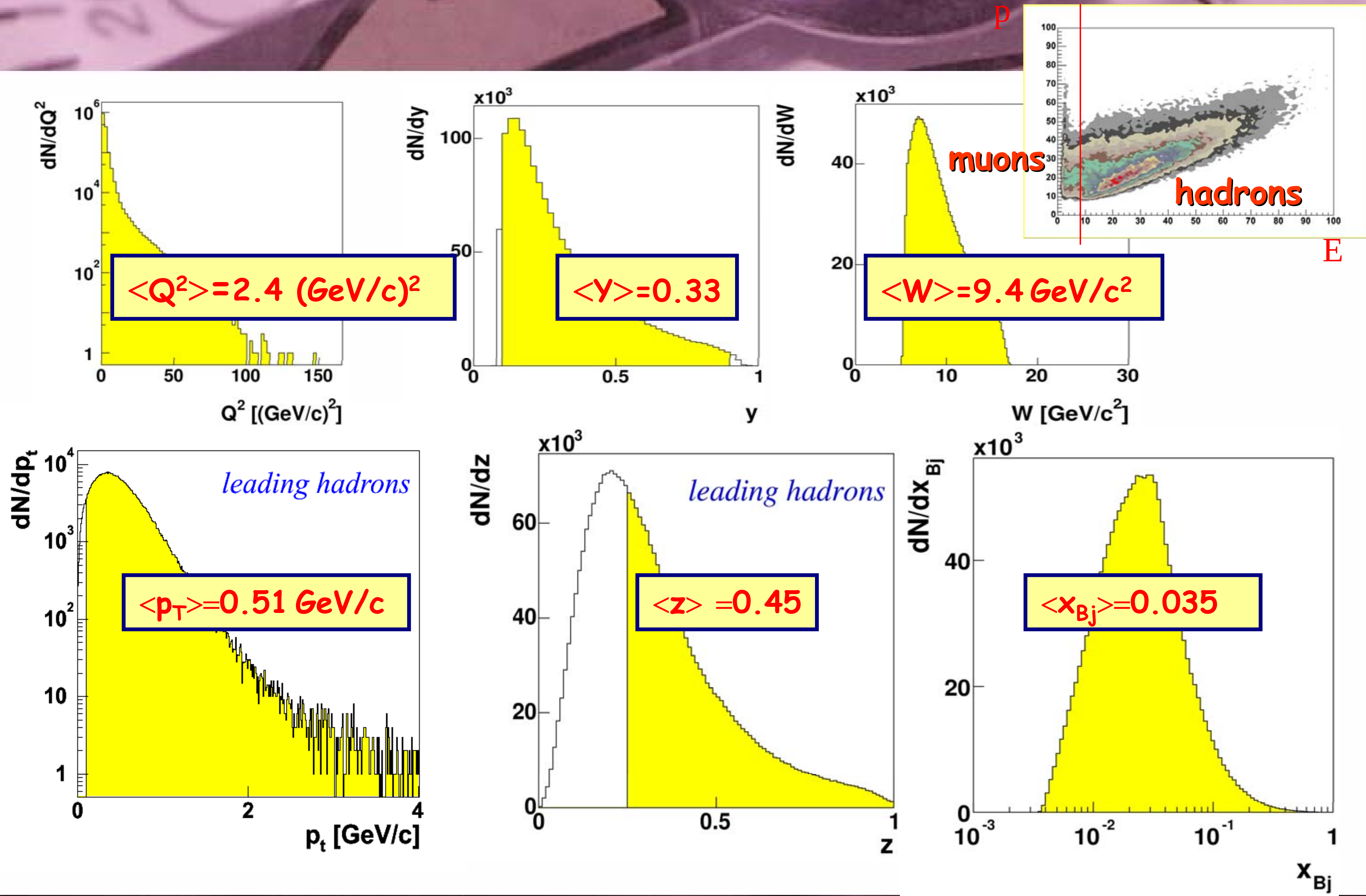
- In so far (3 years)
  - only DIS off ^{6}LiD
  - only runs with transverse polarized target being analyzed

	runs	good runs	used events in the analysis
2002	475	453 (100 SPS spills)	$1.6 \cdot 10^{6}$
2003	479	429 (100 SPS spills)	~4•(2002)
2004	496	470 (200 SPS spills)	~2•(2003)

RICH PID (2003, 2004)

E-Calorimetry (2004)

Kinematical distributions



Extraction of Collins (Sivers) asymmetries

- Evaluating the population as a function of Φ, independently in both target cells;

$$N_j(\Phi_j) = Fn\sigma \cdot a_j(\Phi_j)\cdot(1 \pm \varepsilon_j \sin\Phi_j)$$

$$\varepsilon_C = f \cdot |P_T| \cdot D_{NN} \cdot A_{Coll}$$

$$\varepsilon_S = f \cdot |P_T| \cdot A_{Siv}$$

j = C, S, (Φ_j calculated always with spin = ↑) and F is the muon flux, n the number of target particles, σ the spin averaged cross-section, and a_j the product of angular acceptance and efficiency of the spectrometer;

- Extracting 2 asymmetries and calculating the weighted mean;

$$A_j^m(\Phi_j) = \frac{N_j^{\uparrow}(\Phi_j) - r\cdot N_j^{\downarrow}(\Phi_j)}{N_j^{\uparrow}(\Phi_j) + r\cdot N_j^{\downarrow}(\Phi_j)} = \varepsilon_j^1 \cdot \sin\Phi_j$$

⇔

$$\frac{a_j^{\uparrow}(\Phi_j)}{a_j^{\downarrow}(\Phi_j)} = \text{const}$$

Evaluation of systematics

- **Stability of the asymmetries**:
  i) in time;
  ii) in two halves of the target cells;
  iii) according to the hadron momentum.

- **Evaluated 3 different estimators** and check the compatibility with the standard one.

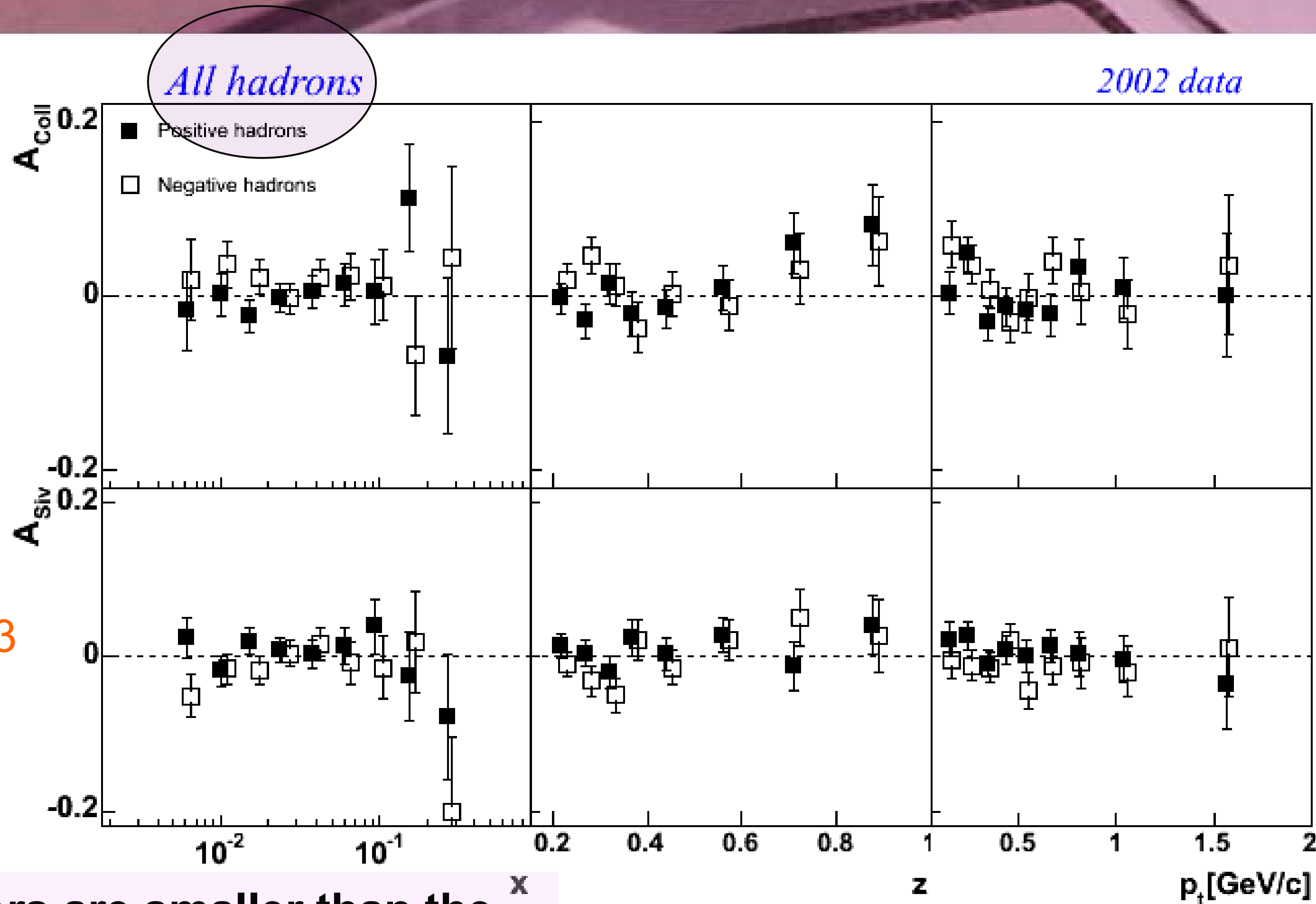
- Look at the paper:

“First Measurement of the Transverse Spin Asymmetries of the Deuteron in Semi-Inclusive Deep Inelastic Scattering”
(The COMPASS Collaboration)

CERN-PH-EP/2005-003
hep-ex/0503002
(accepted by PRL)

Collins and Sivers effects (1)

- Asymmetries as a function of x, z, p_t
- Only statistical errors shown

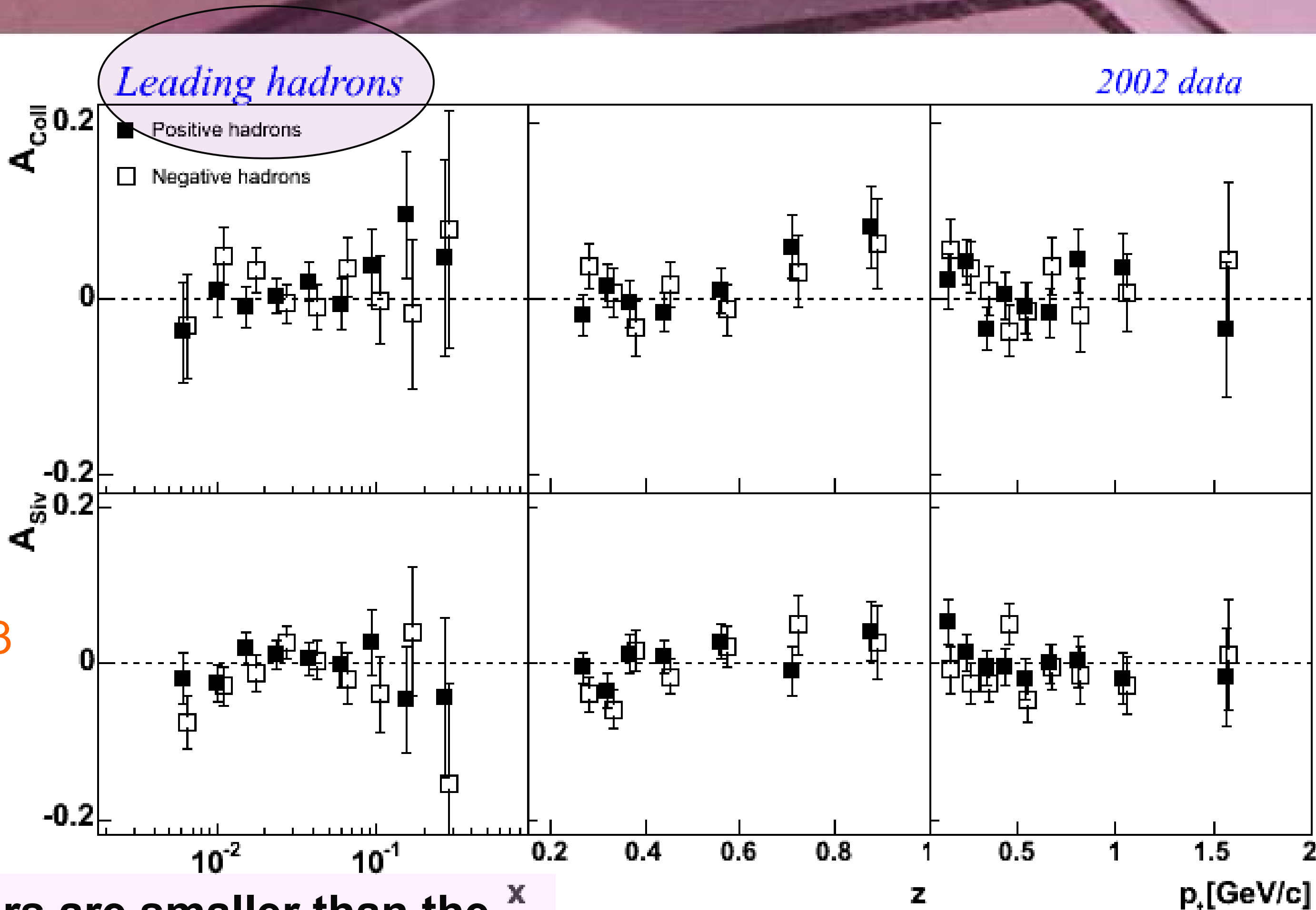


CERN-PH-EP/2005-003
hep-ex/0503002

Systematic errors are smaller than the quoted statistical errors.

Collins and Sivers effects (2)

- Asymmetries as a function of x, z, p_t
- Only statistical errors shown



CERN-PH-EP/2005-003
hep-ex/0503002

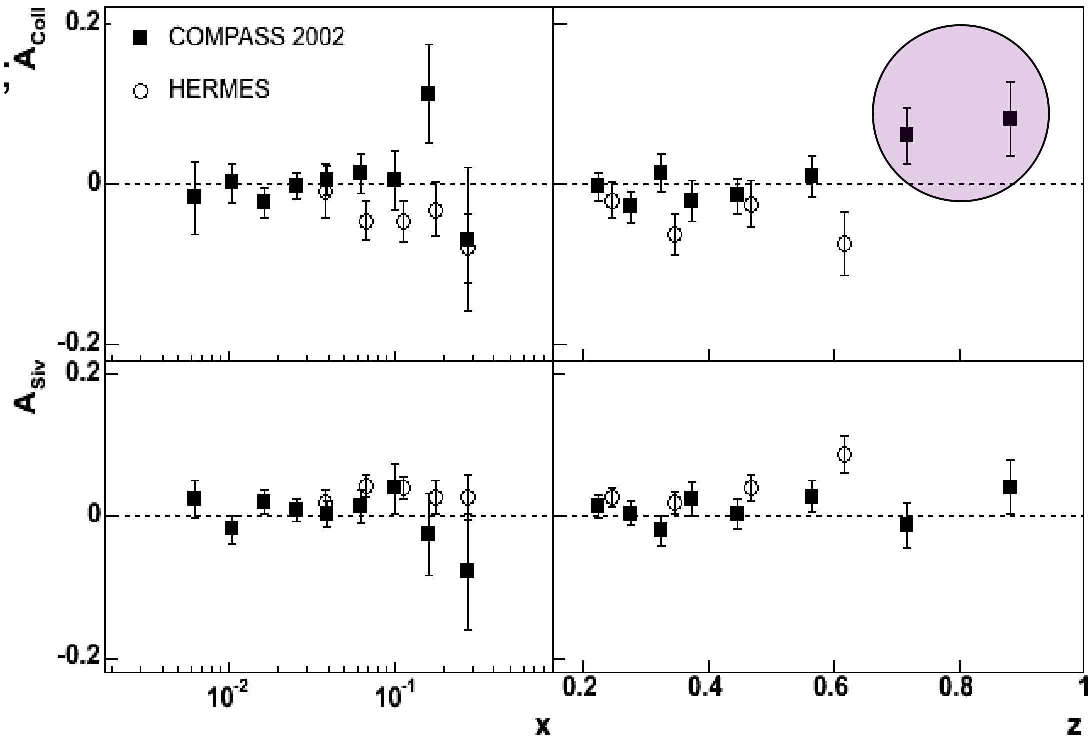
Systematic errors are smaller than the quoted statistical errors.

COMPASS (deut.) vs. HERMES (protons) Positive hadrons

- In Hermes:
  - Negative Collins asymmetries;
  - Positive Sivers asymmetries.

Pay attention at the phase of π in the definition of Φ_C between HERMES and COMPASS !

- In COMPASS:
  - No sizeable effect apart…
  - Possible cancellations in iso-scalar target?



Statistical accuracy:

COMPASS accesses low x but (for 2002 data) has larger errors at high x.

HERMES data points from:
A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002[DC53] (hep-ex/0408013)

COMPASS (deut.) vs. HERMES (protons) Negative hadrons

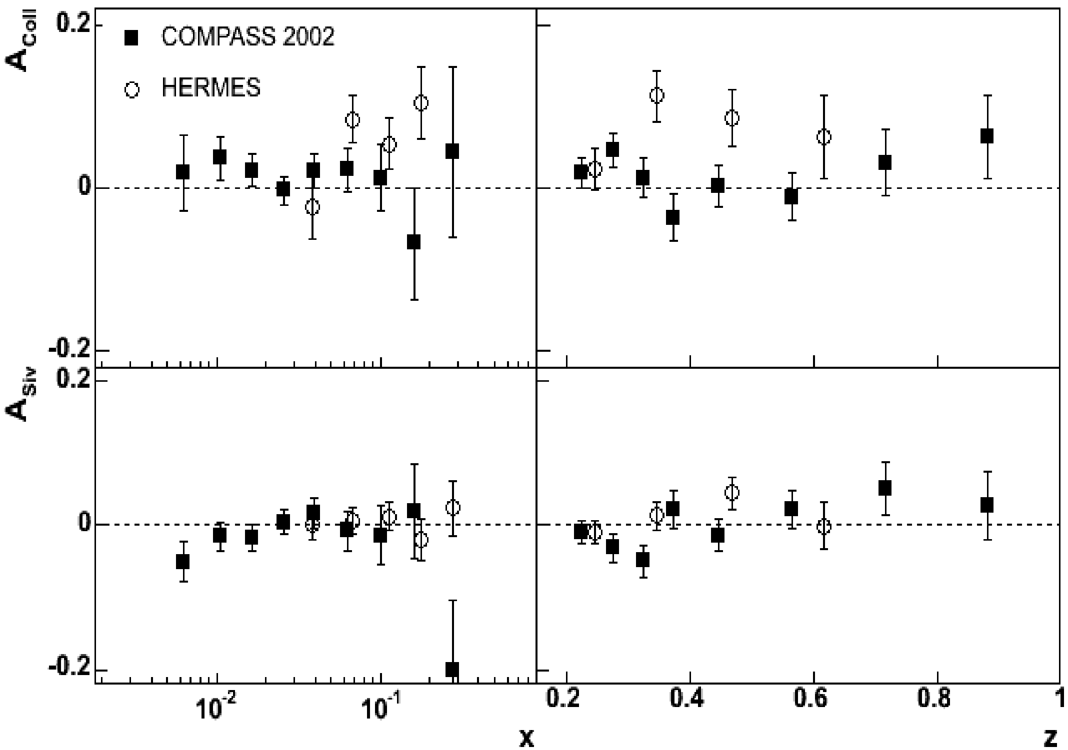
- In Hermes:
  - Large Positive Collins asymmetries;
  - No Sivers effect.

Pay attention at the phase of π in the definition of Φ_C between HERMES and COMPASS !

- In COMPASS:
  - No sizeable effect.
  - Possible cancellations in iso-scalar target?

Statistical accuracy:

COMPASS accesses low x but (for 2002 data) has larger errors at high x.



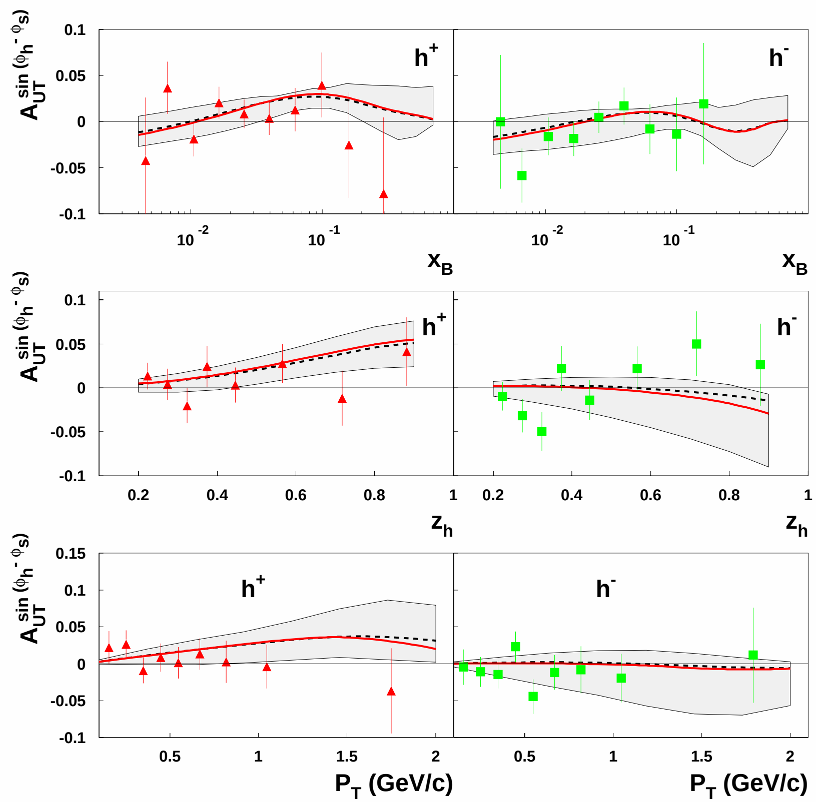
HERMES data points from:
A. Airapetian et al, Phys. Rev. Lett. 94 (2005) 012002[DC53]
(hep-ex/0408013)

Theoretical work on the subject

- **“The role of Cahn and Sivers effects in DIS”**

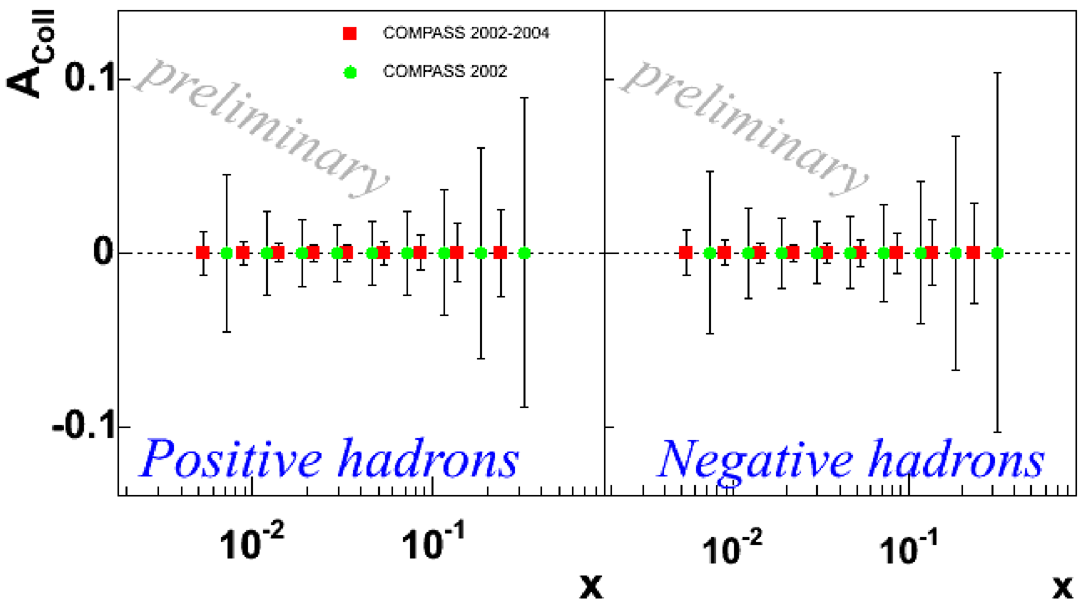
  M. Anselmino et al. (hep-ph/0501196)

  - **Phenomelogical model whose parameters are constrained by HERMES proton measurements;**
  - **COMPASS preliminary results for Sivers effect (shown at SPIN04) are in agreement with the model.**



- Interpretation of Collins effect in progress.

Expected accuracy for transversity

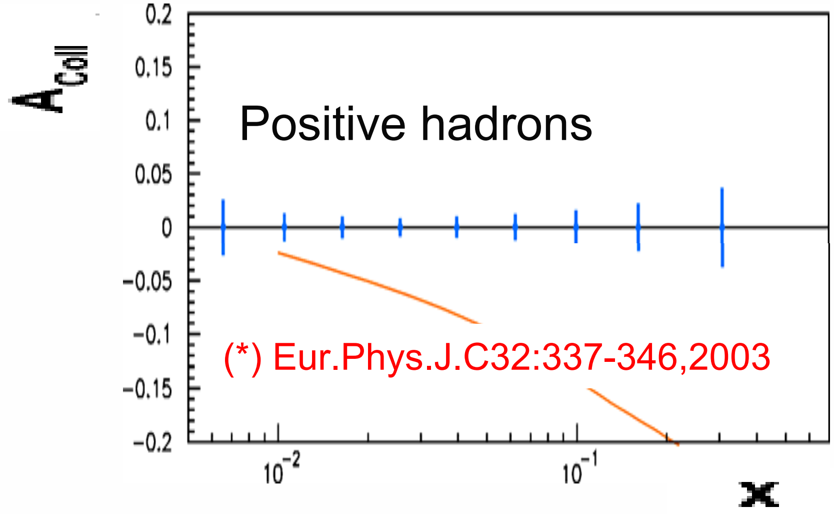


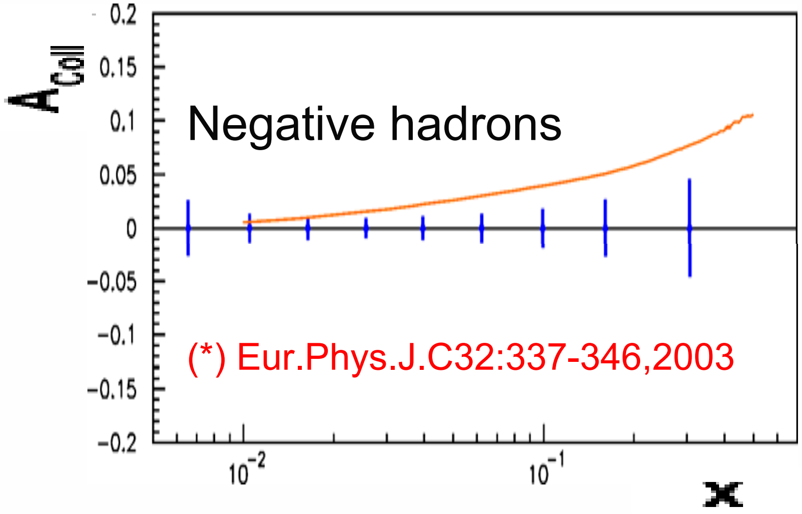
A_{Coll} statistical errrors:	
Positive hadrons (to the left): 2002 - Green; 2002 – 2004 Red.	Negative hadrons (to the right): 2002 - Green; 2002 – 2004 Red.

- **Statistical accuracy increased in years 2003/4:**
  - trigger system upgraded;
  - DAQ upgraded;
  - 2004 longer run.
- 2003 data analyzed (systematics evaluation in progress)
- 2004 data production over (analysis in progress)

COMPASS proton run

- Projections for 30 days of data taking with NH_3 target (theoretical predictions by A. Efremov et al.(*) superimposed):
  - Taking into account:
    - Variation of statistical errors: $$\sigma(A_{NH_3}) \cong 1.34 \cdot \sigma(A_{^6LiD})$$
    - taking into account the variation of: $$P_T \cdot f$$





Outlook

- COMPASS has a multi-purpose spectrometer which will take data at least until 2010;
- Collins and Sivers SSA calculated from 2002 data (first measurements on a deuteron target) submitted for publication (PRL);
- The asymmetries are small and compatible with zero at variance from HERMES measurements on a proton target:
  - Cancellation between proton and neutron?
  - Too small Collins mechanism?
- Finalization (in progress) of the analysis of the deuteron data: the total collected statistics allows to increase by a factor of 3 the accuracy of the measurement of 2002;
- Complementary data (of comparable statistics) will be collected on a transversely polarized proton target (NH_3).

Save slides

Estimators

$$\frac{N^{\uparrow}_{j,u}(\Phi_j)}{N^{\downarrow}_{j,u}(\Phi_j+\pi)} \cdot \frac{N^{\uparrow}_{j,d}(\Phi_j)}{N^{\downarrow}_{j,d}(\Phi_j+\pi)} = \mathrm{cost} \cdot (1 + 4\varepsilon_j^2 \sin\Phi_j)$$

Weaker assumptions on acceptance effects

less sensitive to distorsions set by Cahn effects

$$\frac{\sqrt{N^{\uparrow}_j(\Phi_j)\cdot N^{\downarrow}_j(\Phi_j)} - \sqrt{N^{\downarrow}_j(\Phi_j+\pi)\cdot N^{\uparrow}_j(\Phi_j+\pi)}}{\sqrt{N^{\uparrow}_j(\Phi_j)\cdot N^{\downarrow}_j(\Phi_j)} + \sqrt{N^{\downarrow}_j(\Phi_j+\pi)\cdot N^{\uparrow}_j(\Phi_j+\pi)}} = \varepsilon_j^3 \cdot \sin\Phi_j$$

Reconstruction time
independent in the solid angle

Flavor decomposition

Flavour decomposition of $\Delta_T q$:

$$D_1 = D_u^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} = D_{\bar{d}}^{\pi^+} \qquad D_2 = D_u^{\pi^-} = D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-}$$

1. proton target, combining π+ and π-

$$A_1^{p1} = f_p \cdot P_T^p \cdot D \cdot \frac{4\Delta_T u + \Delta_T \bar{d} + 4\Delta_T \bar{u} + \Delta_T d}{4u + \bar{d} + 4\bar{u} + d} \cdot \frac{\Delta D_1 + \Delta D_2}{D_1 + D_2}$$

$$A_1^{p2} = f_p \cdot P_T^p \cdot D \cdot \frac{4\Delta_T u_v - \Delta_T d_v}{4u + \bar{d} + 4\bar{u} + d} \cdot \frac{\Delta D_1 - \Delta D_2}{D_1 + D_2}$$

2. deuterium target:

$$A_1^{d1} = f_d \cdot P_T^d \cdot D \cdot \frac{\Delta_T u + \Delta_T \bar{d} + \Delta_T \bar{u} + \Delta_T d}{u + \bar{d} + \bar{u} + d} \cdot \frac{\Delta D_1 + \Delta D_2}{D_1 + D_2}$$

$$A_1^{d2} = f_d \cdot P_T^d \cdot D \cdot \frac{3(\Delta_T u_v + \Delta_T d_v)}{5(u + \bar{d} + \bar{u} + d)} \cdot \frac{\Delta D_1 - \Delta D_2}{D_1 + D_2}$$