TRANSVERSE SPIN EFFECTS AT COMPASS

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on behalf of the COMPASS Collaboration

TRANSVERSE SPIN EFFECTS AT COMPASS

the nucleon spin structure

- the COMPASS experiment
- the COMPASS physics program
- spin structure of the nucleon
- study of the transverse spin effects

  Collins and Sivers asymmetries
- conclusions and future plans

Anna Martin, February 12, 2009

fixed target
experiment
at the CERN SPS

COMPASS Collaboration:

Czech Republic, Finland, France, Germany, India,
Israel, Italy, Japan, Poland, Portugal, Russia

28 Institutions, 240 physicists

fixed target
experiment
at the CERN SPS

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Anna Martin, February 12, 2009

Physics programme

- **with hadron beams**
  - Pion and Kaon polarizabilities
  - Diffractive production of exotic states
  - Search for glueballs
  - Light meson spectroscopy
  - Production of double charmed baryons

- **with muon beam**
  - ΔG/G
  - g_1
  - Flavor decomposition of spin distribution functions
  - Transverse spin effects
  - Vector meson production
  - Spin transfer in Λ-hyperon production

DATA TAKING started in 2002

muon beam 160 GeV/c intensity $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s) P ~ -0.80	deuteron (^{6}LiD) polarised target	2002, 2003, 2004	L and T target polarisation
		2006	L target polarisation
	proton (NH_3) pol target	2007	L and T target polarisation
hadron beam	**LH target**	**2008**	
		2009	

~400 TB/year

COMPASS apparatus

- high energy/intensity beams
- large angular acceptance
- broad kinematical range

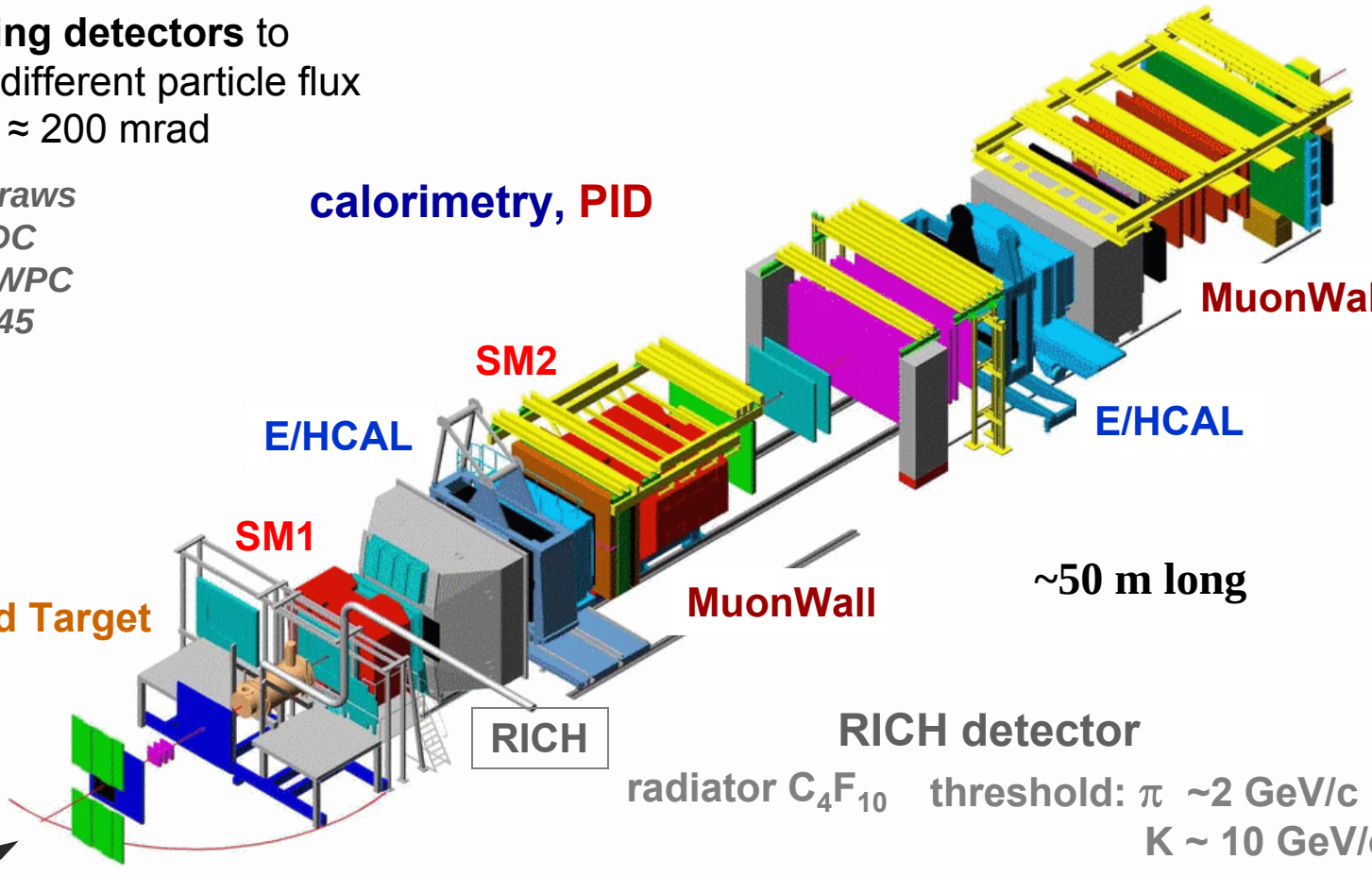
two stages spectrometer

Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors to cope with the different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

SciFi	*Straws*
Silicon	*SDC*
Micromegas	*MWPC*
GEMs	*W45*

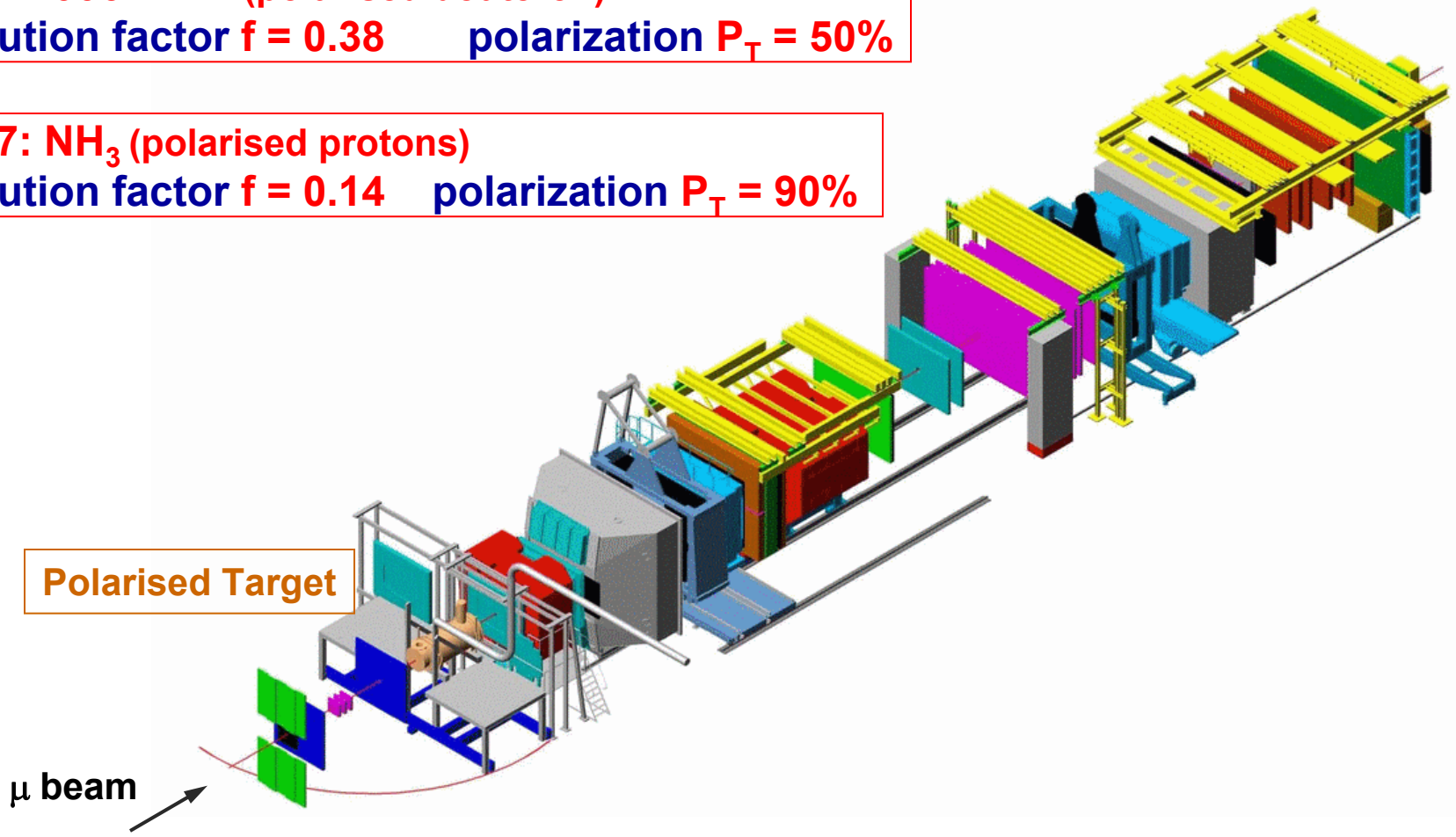


COMPASS apparatus

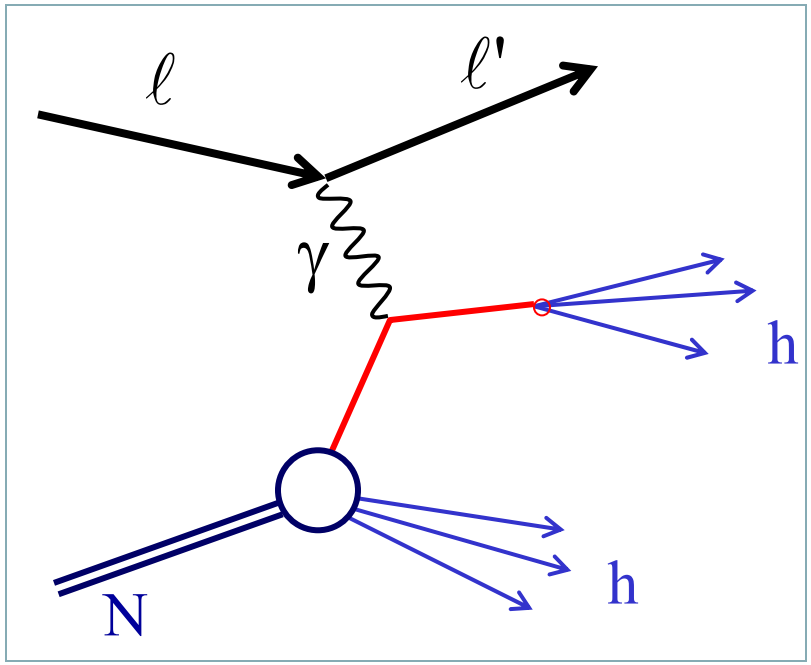
solid state target operated in frozen spin mode
total length 120 cm
2 (or 3) cells **with opposite polarisation** (systematics),
both L and T

2002-2006: ^{6}LiD (polarised deuteron)
dilution factor **f = 0.38** polarization **P_T = 50%**

2007: NH_3 (polarised protons)
dilution factor **f = 0.14** polarization **P_T = 90%**



Deep Inelastic Scattering



$$Q^2 = -q^2 > 0 \qquad \nu = E - E'$$

$$x = Q^2/2M\nu \qquad y = \nu/E$$

$$\gamma = \sqrt{Q^2}/\nu$$

$Q^2 >> M^2$

$W^2=(P+q)^2 >> M^2$

Inclusive DIS: only the incident and scattered leptons are measured

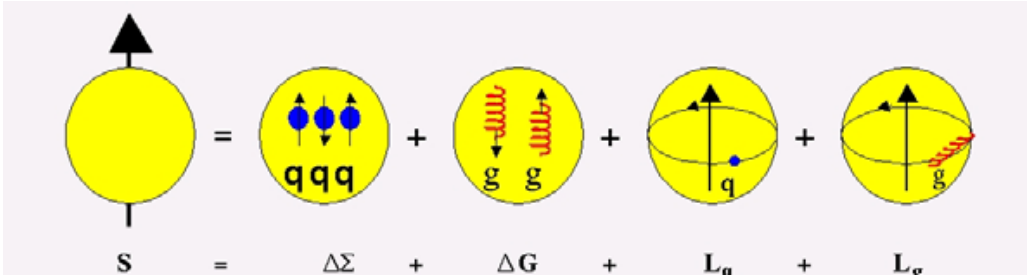
Semi-Inclusive DIS: the incident and scattered leptons, and at least one final state hadron are measured

$$z = E_h/\nu$$

$$\sigma^{\ell N \to \ell h X} \propto \sum_q \sigma^{\ell q \to \ell q} \otimes q(x) \otimes D_q^h(z)$$

longitudinal spin case

the “spin crisis”: ways out



$$S_N = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$$

experiments:

- **measurement of Δu, Δd, …** SIDIS with longitudinally polarised targets / beam
- **measurements of ΔG** open charm, high p_T pairs, …

a large effort: COMPASS, HERMES and JLab (SIDIS), RHIC (pp)

first results: ΔG is SMALL

→ interest in orbital angular momentum

Generalised Parton Distributions

HERMES, JLab, *COMPASS*

transverse spin case

since many years intriguing evidence of large transverse spin effects at high energy

- **hyperon polarization**
- **asymmetries in hadron production**
- **…**

confirmed at RHIC

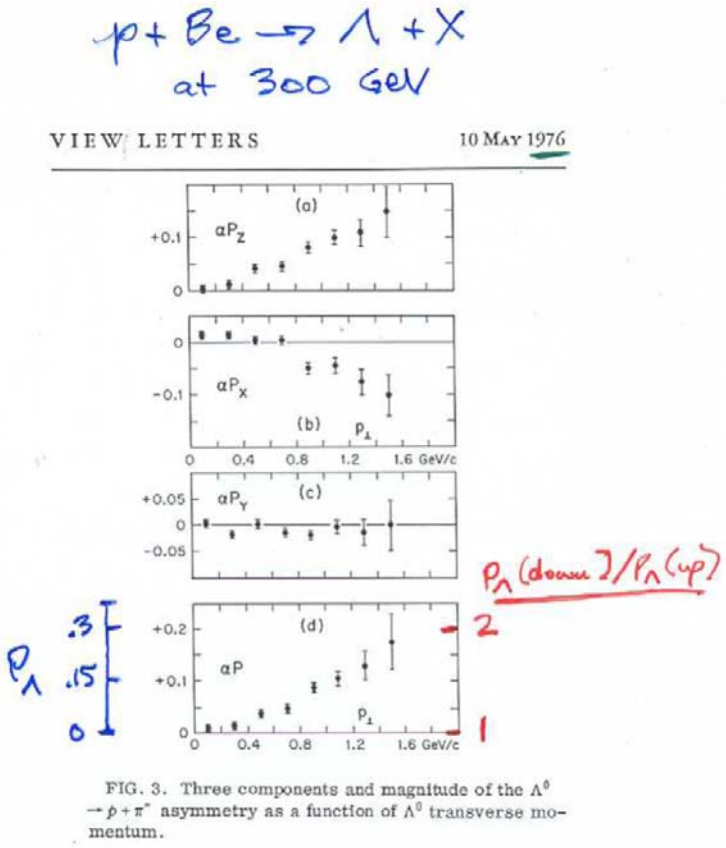
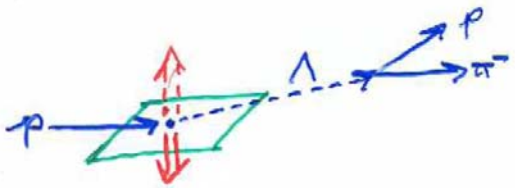


FIG. 3. Three components and magnitude of the $\Lambda^0 \to p + \pi^-$ asymmetry as a function of Λ^0 transverse momentum.



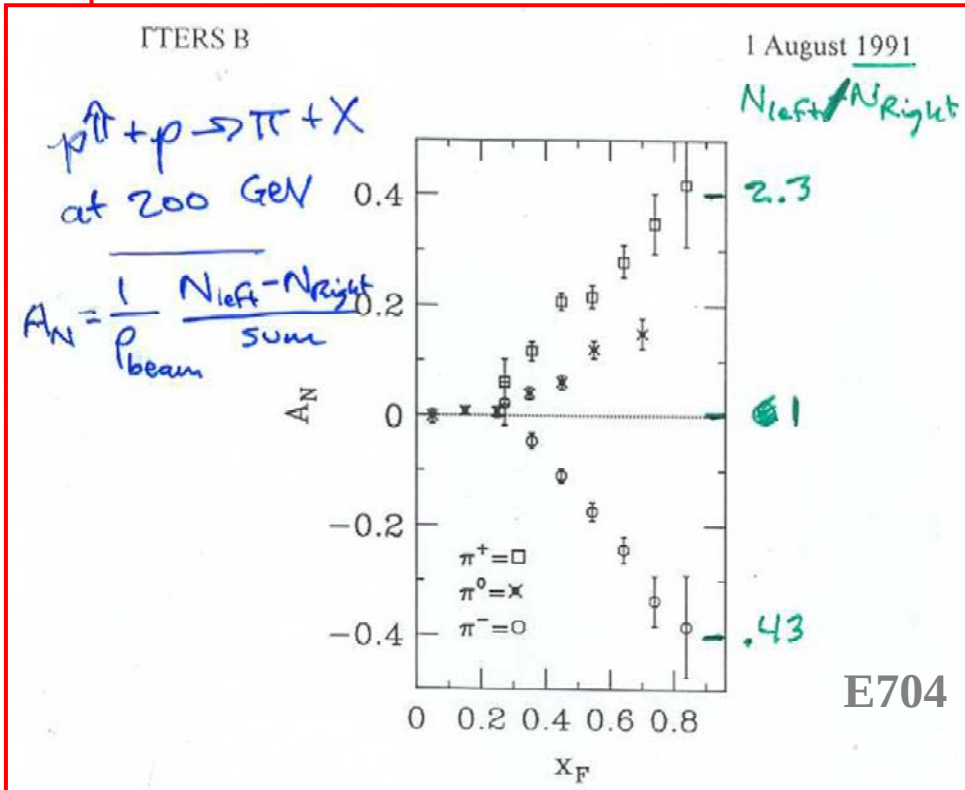


Fig. 4. A_N versus x_F for π^+, π^- and π^0 data.

Transversity Distribution Function

three quark Distribution Functions are necessary to describe the structure of the nucleon at leading order

R.L. Jaffe and X. Ji, Phys. Rev. Lett. **67** (1991) 552

q(x)

$f_1^q(x)$

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

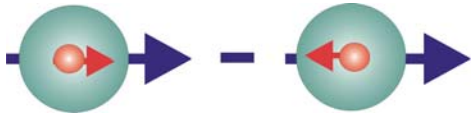
unpolarised DF

quark with momentum *xP* in a nucleon

well known – unpolarised DIS

Δq(x)

$g_1^q(x)$



helicity DF

quark with spin parallel to the nucleon spin in a longitudinally polarised nucleon

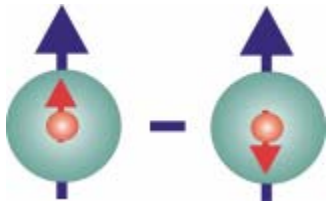
known – polarised (SI)DIS

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

$h_1^q(x)$,

$\delta q(x)$,

$\delta_T q(x)$



transversity DF

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

almost unknown …

ALL 3 OF EQUAL IMPORTANCE

Transversity Distribution Function

$\Delta_T q(x)$ contribution of the quarks to the transverse spin of the nucleon

properties:

- probes the relativistic nature of quark dinamics
- no contribution from the gluons → simple Q^2 evolution
- positivity (Soffer) bound $2|\Delta_T q| \leq q + \Delta q$
- first moments: **tensor charge** $\Delta_T q \equiv \int dx\, \Delta_T q(x)$
- sum rule for transverse spin $\frac{1}{2} = \frac{1}{2}\sum \Delta_T q + L_q + L_g$

Bakker, Leader, Trueman, PRD 70 (04)

- **is chiral-odd: decouples from incl DIS because helicity of quark must flip**

observable effects are given only by the product of $\Delta_T q(x)$ and an other chiral-odd function

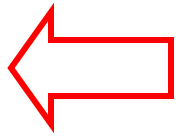
Transversity Distribution Function

$\Delta_T q(x)$

can be measured in SIDIS on a transversely polarised target

via "quark polarimetry"

$l\, N^{\uparrow} \rightarrow l'\, h\, X$ **"Collins" asymmetry**
"Collins" Fragmentation Function



$l\, N^{\uparrow} \rightarrow l'\, h\, h\, X$ **hadron-pair asymmetry**
"Interference" Fragmentation Function

$l\, N^{\uparrow} \rightarrow l'\, \Lambda\, X$ **Λ polarisation**
Fragmentation Function of $q^{\uparrow} \rightarrow \Lambda$

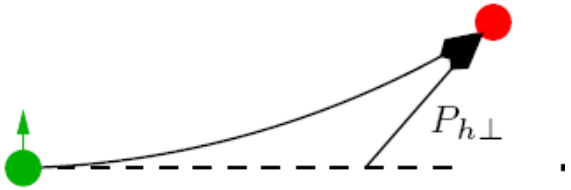
....

all measured in COMPASS

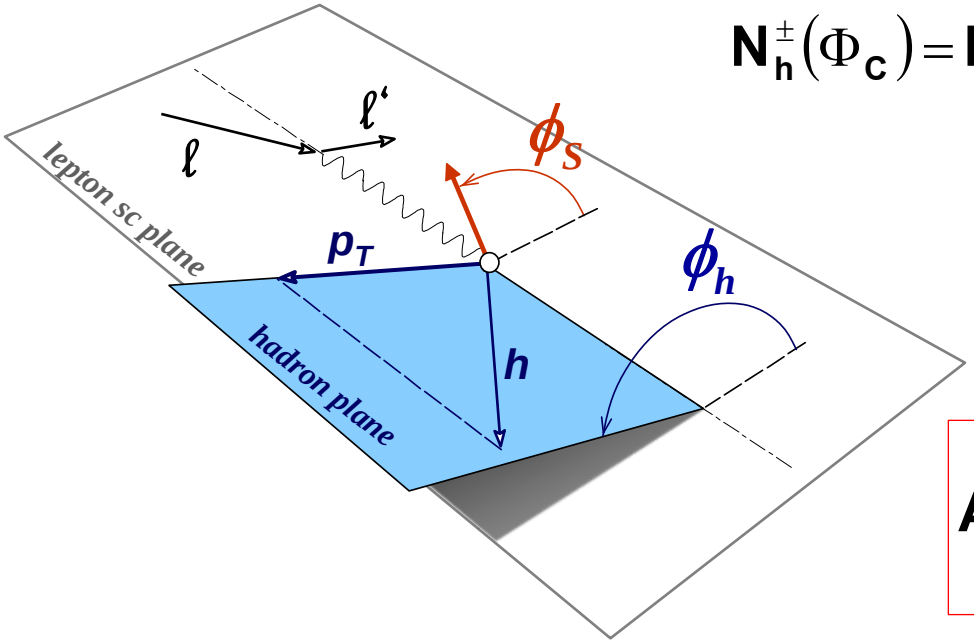
the Collins asymmetry

"Collins Effect"

a quark moving "horizontally" and polarized "upwards" would emit the leading meson preferentially on the "left" side of the jet ("Collins FF")



→ **modulation in the azimuthal distribution of the final state hadrons**



$$N_h^{\pm}(\Phi_C) = N_h^0 \cdot \left[1 \pm P_T \cdot D_{NN} \cdot A_{Coll} \cdot \sin\Phi_C\right]$$

"Collins angle"

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

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

the Collins asymmetry

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

using different targets (p, d, n) and identifying the final hadron one can perform flavour separation

i.e. measure transversity DF x Collins FF for each quark flavor

transversity DF and Collins FF were unknown …

since 2004:

- **HERMES** (28 GeV/c e beam) **has measured the Collins asymmetry on proton** ***different from zero for h^+ and h^-***
- **BELLE has measured asymmetries related to the Collins FF in $e^+e^- \rightarrow$ h's** ***different from zero***

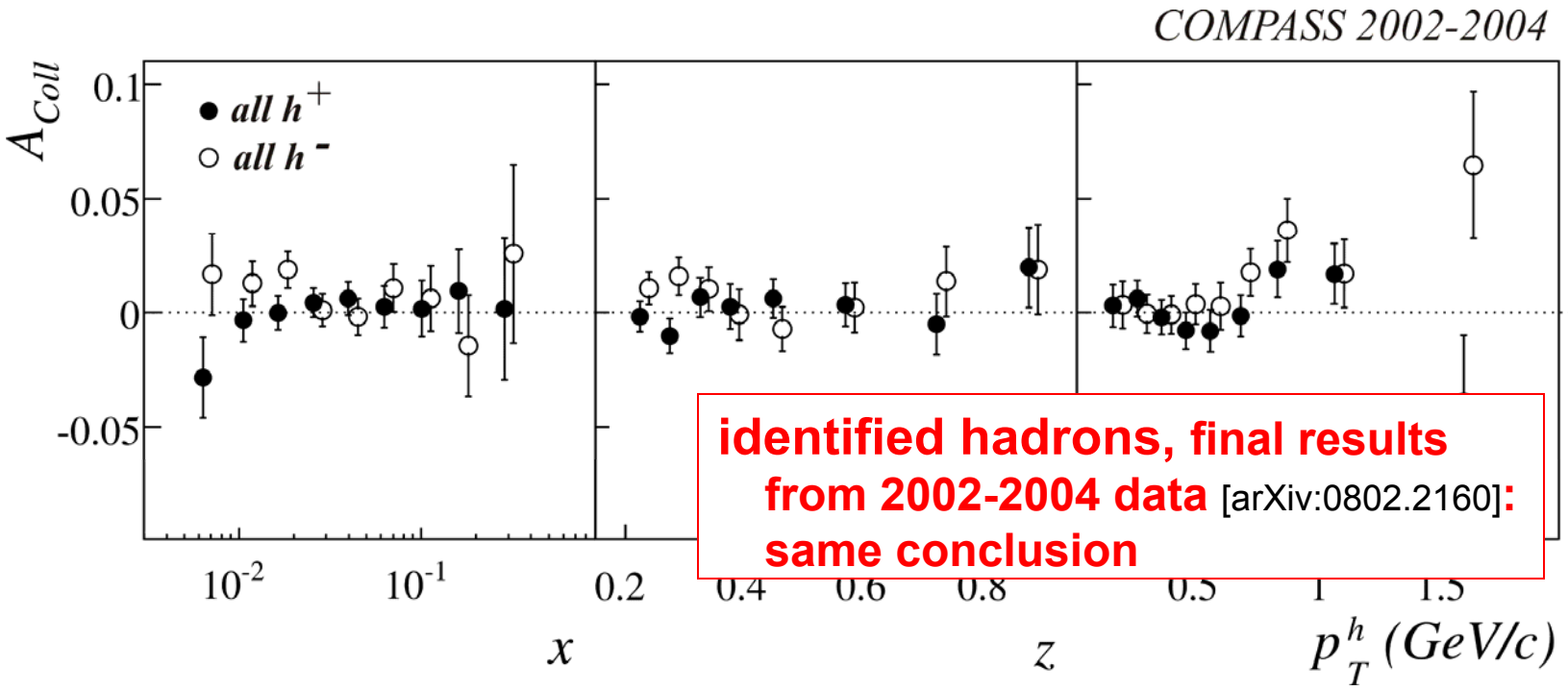
both transversity and Collins FF are different from zero!

- **COMPASS** (160 GeV/c μ beam) **has measured the Collins asymmetry on deuteron**

the Collins asymmetry – COMPASS d data

charged hadrons (mostly pions)

- **final results from 2002-2004 data** [PRL94 (2005) 202002 NPB765 (2007)31]



identified hadrons, final results from 2002-2004 data [arXiv:0802.2160]**: same conclusion**

asymmetries compatible with zero within the statistical errors
(syst. errors much smaller)

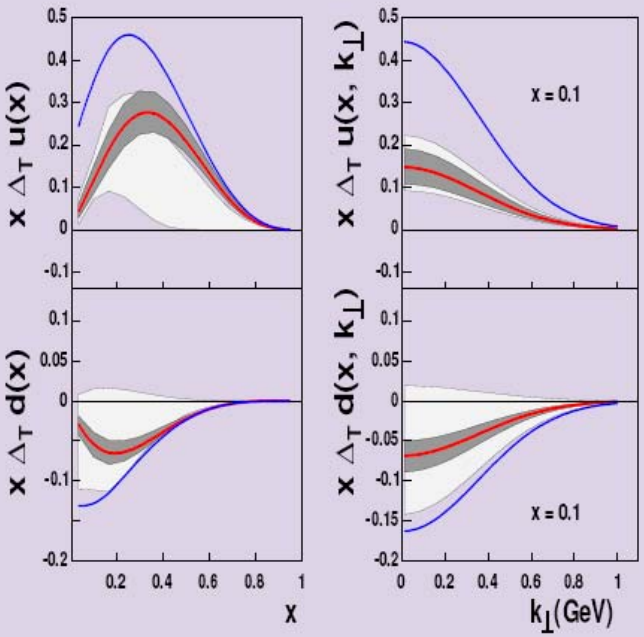
with HERMES results,
cancellation between u and d quark contributions in the d

the Collins asymmetry – fits to data

using HERMES (p) and COMPASS (d) pion data, and BELLE data

first extractions of the transversity DF

Transversity

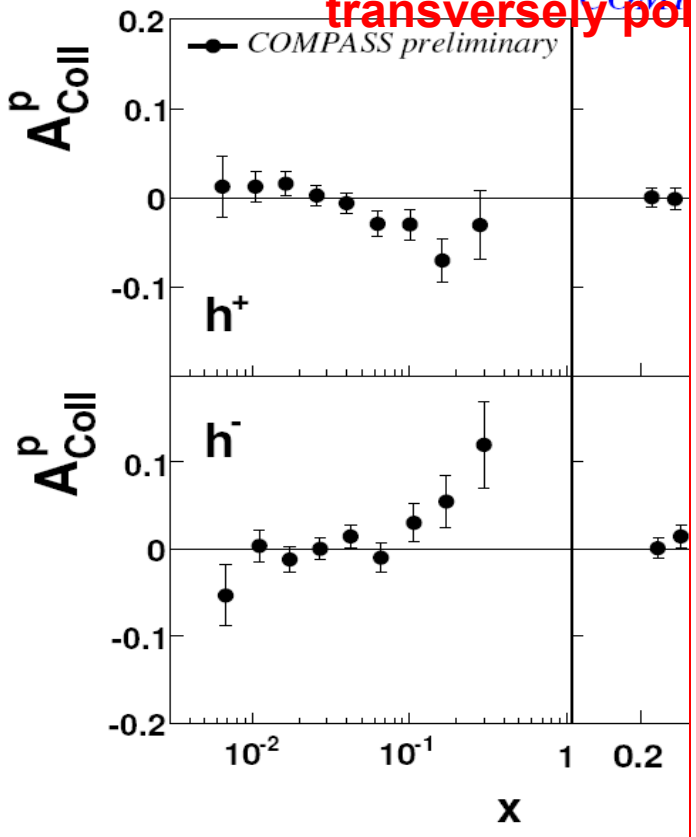


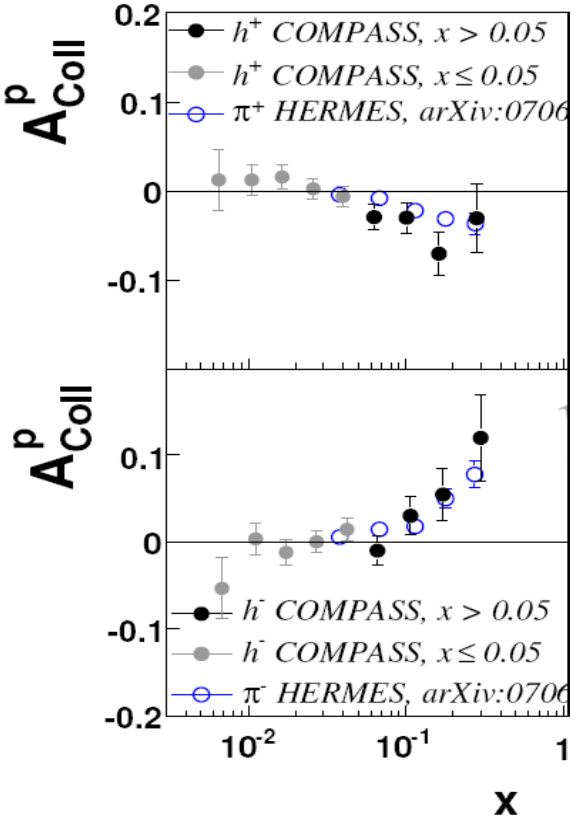
- This is the extraction of transversity from new experimental data.
- Compared to previous extraction PRD75:054032,2007
- $\Delta_T u(x) > 0$ and $\Delta_T d(x) < 0$ The errors are diminished significantly.
- $\Delta_T u(x)$ became larger than that of the previous fit.

In collaboration with M. Anselmino, M. Boglione, U. D'Alesio, F. Murgia, A. Kotzinian, C.Turk, and S. Melis

the Collins asymmetry – COMPASS p data

2007: COMPASS (160 GeV/c μ bea **transversely pol**





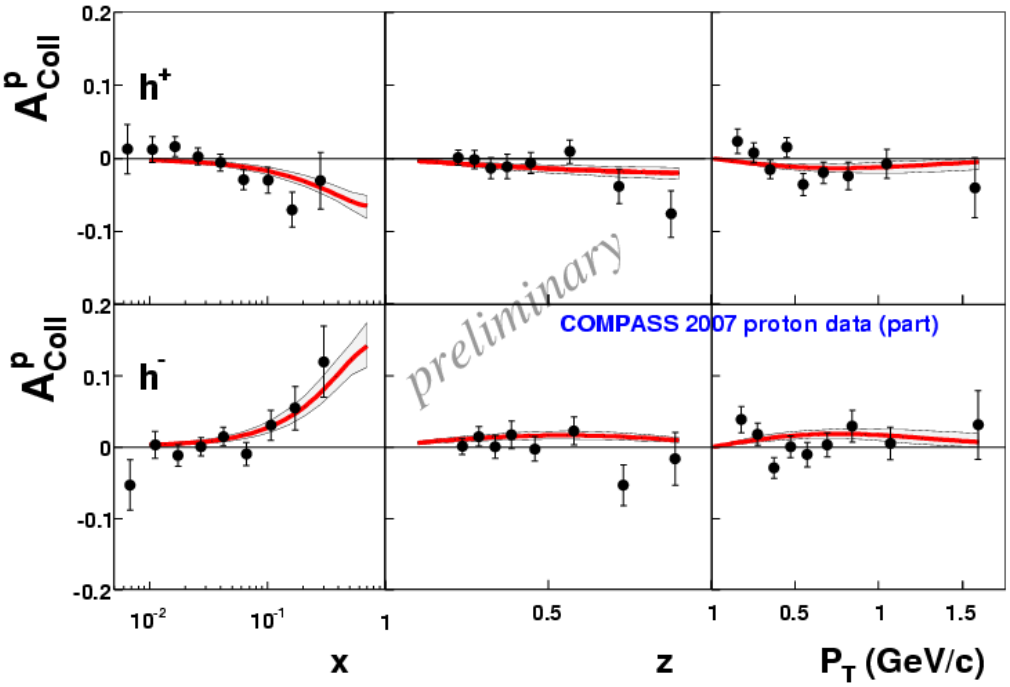
2002-2005

statistical errors only; systematic errors ~ 0.3 σ_{stat}

at small x, the asymmetries are compatible with zero
in the valence region the asymmetries are different from **zero**

the Collins asymmetry – COMPASS p data

comparison with M. Anselmino et al. predictions



- the Collins asymmetry on p is different from zero
  also at COMPASS energies
- it is not a high twist effect

- more statistics is needed to better study its properties

the Sivers asymmetry

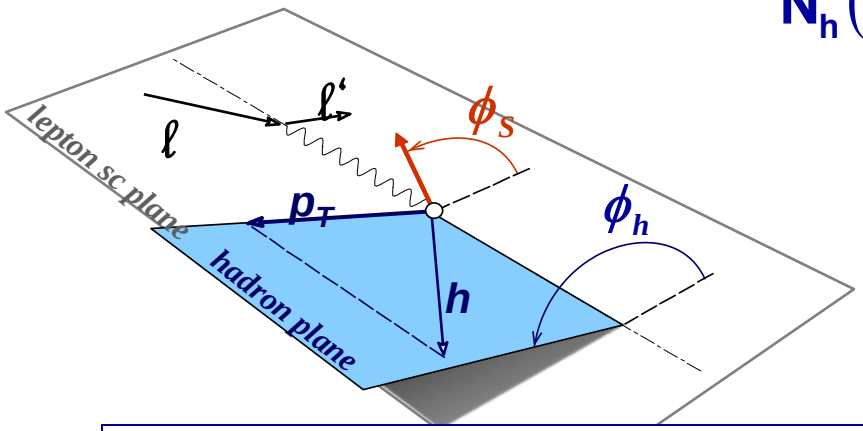
another effect can give an azimutahl modulation in the SIDIS hadron distribution

the "Sivers function" $\Delta_0^T q$

- **the most famous of the TMD parton DF**
- **describes the correlation between the nucleon spin and the quark transverse momentum**

→ modulation in the azimuthal distribution of the final state hadrons

$$N_h^{\pm}(\Phi_S) = N_h^0 \cdot \left[1 \pm P_T \cdot A_{Siv} \cdot \sin\Phi_S \right]$$



"Sivers angle" $\Phi_S = \phi_h - \phi_S$

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

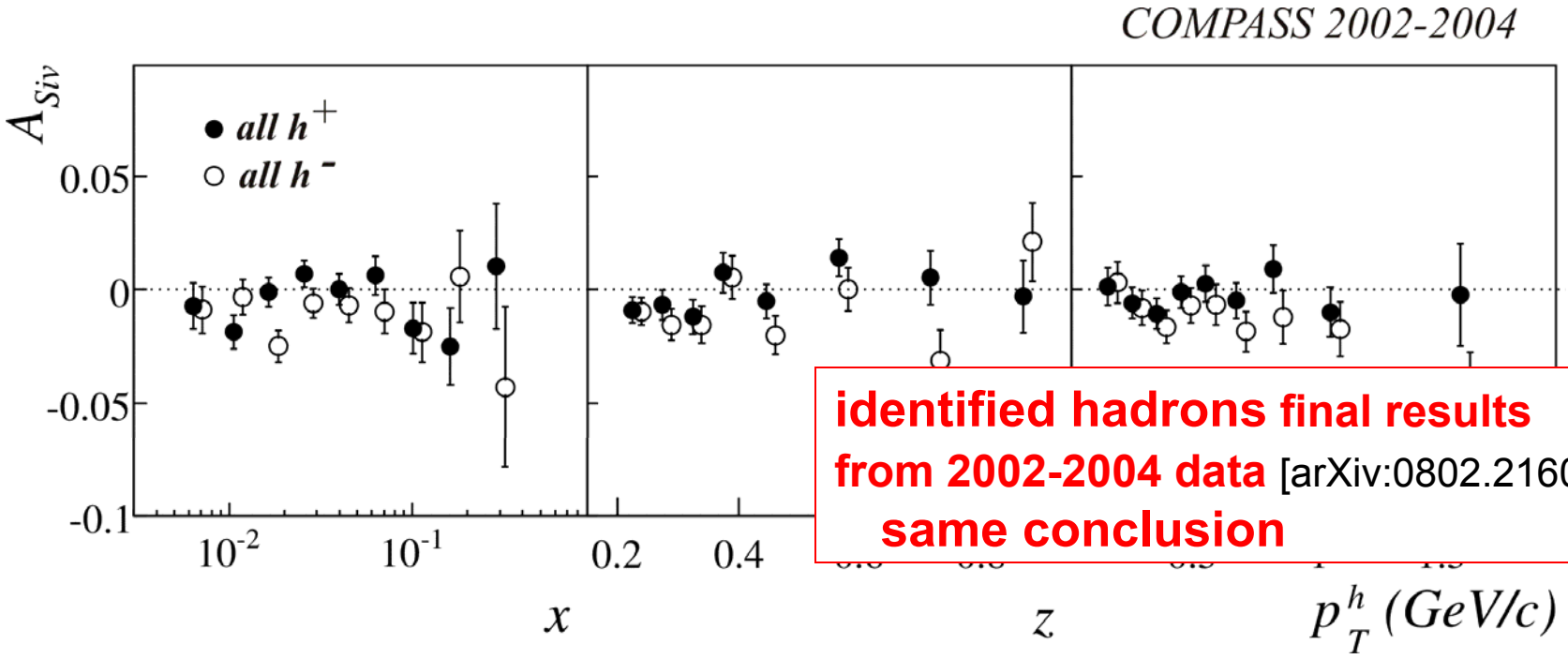
2004:

- **HERMES has measured the Sivers asymmetry on proton**
  different from zero for h^+
- **COMPASS has measured the Sivers asymmetry on deuteron**

the Sivers asymmetry – COMPASS d data

charged hadrons (mostly pions)

final results from 2002-2004 data [PRL94 (2005) 202002, NPB765 (2007)31]



identified hadrons final results from 2002-2004 data [arXiv:0802.2160]**: same conclusion**

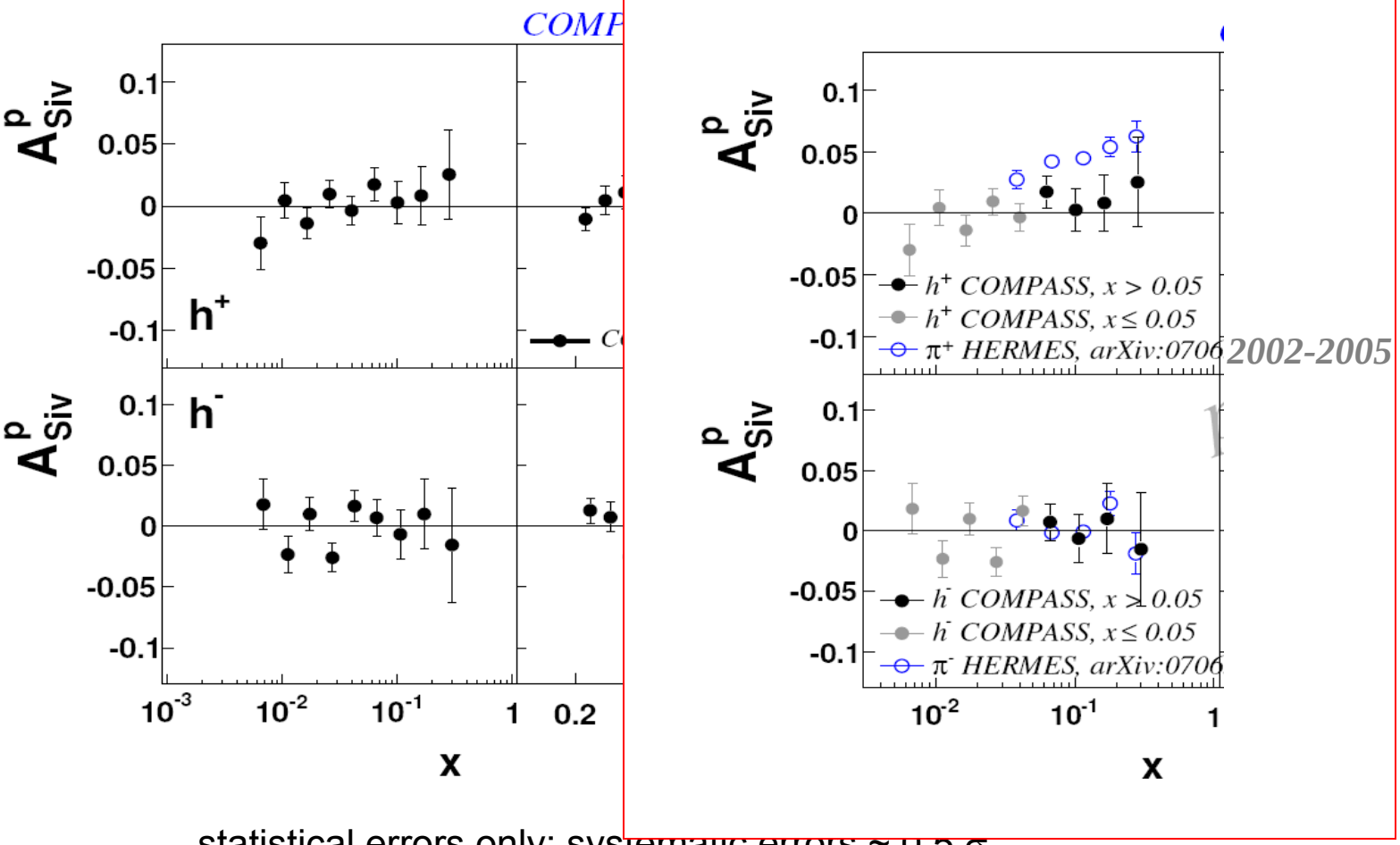
asymmetries compatible with zero within the statistical errors

(systematic errors much smaller)

cancellation between u and d quark contributions in the deuteron

→ first extractions of the Sivers function for u and d quarks

the Sivers asymmetry – COMPASS p data



statistical errors only; systematic errors ~ 0.5 σ_{stat}

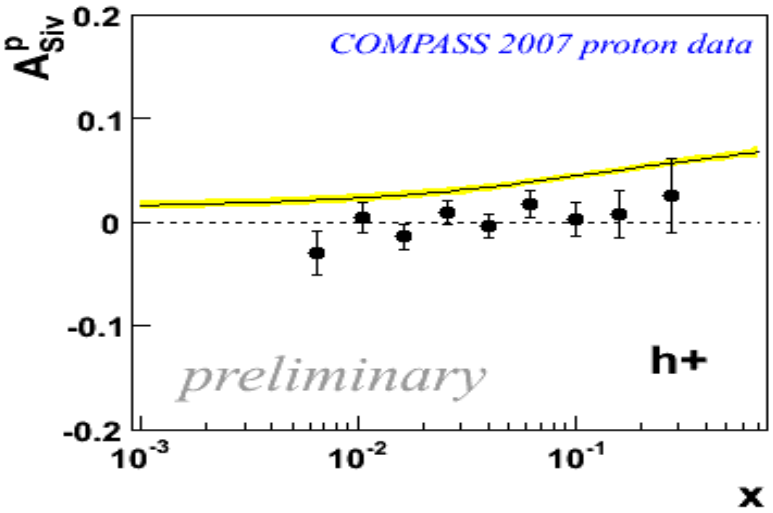
the measured symmetries are small, compatible with zero

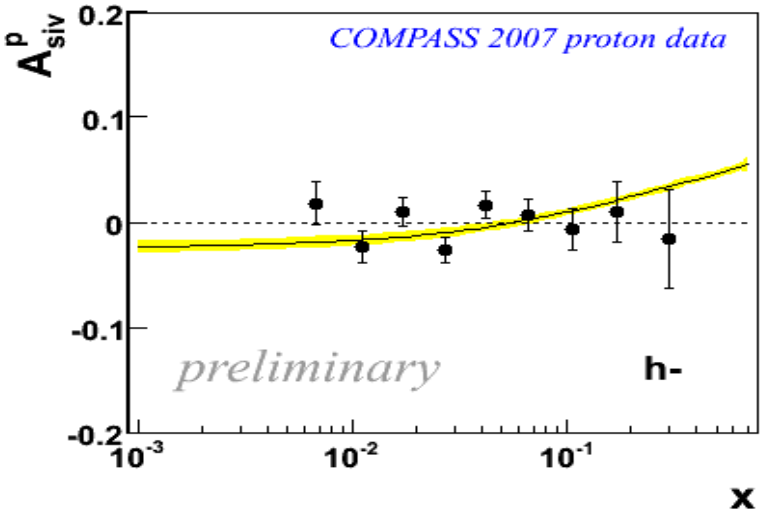
the Sivers asymmetry – COMPASS p data

unexpected result

comparison with predictions
based on HERMES p and COMPASS d data

S.Arnold, A.V.Efremov, K.Goeke, M.Schlegel and P.Schweitzer, arXiv:0805.2137





to be understood!

more statistic on p is needed …

TMD's in SIDIS

- **Sivers is not the only TMD parton distribution funcion**
- **in SIDIS cross-section 18 structure functions, 3 unpolarised, 8 transverse transverse spin dependent**
- **preliminary results on deuteron from COMPASS for all the transverse spin dependent** (no signal) **and the unpolarised modulations**
- **still, measurements in different channels are needed**
  - **proton-proton data from RHIC**
  - **future: Drell-Yan in antiproton-proton, pion-proton**

SIDIS cross-section

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+\,S_\parallel\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

$$+\,|\boldsymbol{S}_\perp|\left[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)\right.$$

$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$\left.+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\right]$$

$$+\,|\boldsymbol{S}_\perp|\lambda_e\left[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}\right.$$

$$\left.\left.+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\right]\right\},$$

18 structure functions

Sivers

Collins

8 modulations (4 LO)

all measured by COMPASS on deuteron

A Bacchetta, M Diehl, K Goeke, A Metz, P Mulders, M Schlegel (06)

transverse spin effects: summary

- in the last few years, remarkable progress on the transverse spin and transverse momentum structure of the nucleon
- properties of transversity and relevance of intrinsic quark momentum and TMD well establishes
- first experimental evidence that the new PDF are different from zero
- first extractions using HERMES proton and COMPASS deuteron data
- COMPASS proton results vs HERMES results
  - Collins asymmetries in good agreement
  - Sivers asymmetries smaller

- more data are needed for detailed studies
- COMPASS offers unique opportunity for precision studies at high energy

  covers a large x-range (0.003 – 0.3), high Q^2

  → new measurements

new COMPASS proposal

new proposal from the COMPASS Collaboration

LoI: "COMPASS Medium and Long Term Plans"

CERN-SPSC-2009-003 / SPSC-I-238 / 21 January 2009

Proposal in preparation, open to new groups

proposed measurements:

- further measurements of **transverse spin effects in SIDIS**
  one year of running (2010?) with muon beam and polarised p target
- precision measurements of the **longitudinal spin structure of the proton**
  one year of running with muon beam and polarised p target
- **Generalised Parton Distribution** functions (DVCS)
  with muon beam and LH / polarised p target (L)
- **Drell-Yan** measurements
  with pion beam and polarised p target (TMDs)

transverse spin effects: future

- **more results will come soon from HERMES and COMPASS using the collected data**
- **new proposal from the COMPASS Collaboration**
  further measurements of transverse spin effects in **SIDIS**
  and

SIDIS:

- **complementary precise measurements** at lower energy (6→12 GeV beam) coming soon from **JLab**
- **new ep Collider** at GSI, eRHIC, … (far future)
- **pp collisions:** transverse spin measurements at **RHIC** (pp)
  ongoing
- **Drell-Yan** measurements at **COMPASS** (pion-proton)
- **Drell-Yan** measurements at **GSI** (antip-p) **…**

a very active and promising field …!