Single Spin Asymmetries on proton at COMPASS

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on behalf of ***COMPASS collaboration***

Transversity 2008

Second Workshop on
Transverse Polarisation Phenomena in Hard Processes

Ferrara - May 28-31, 2008

Outline:

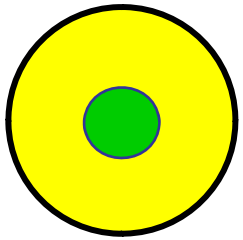
- Transverse spin physics
- The COMPASS experiment
- 2007 Transverse Proton run
- Data statistics
- Asymmetries extraction
- Results - Predictions

Transverse spin physics

For a complete description of momentum and spin distribution of the nucleon at leading-twist: 3 parton distribution functions (PDF)

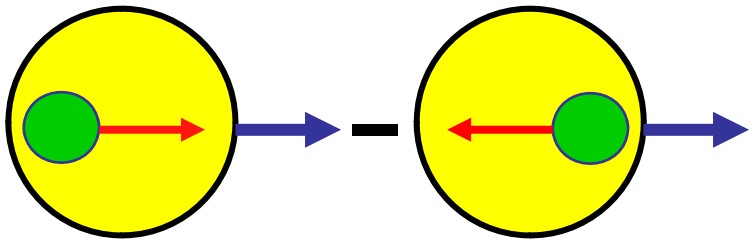
Unpolarised DF

$q(x)$



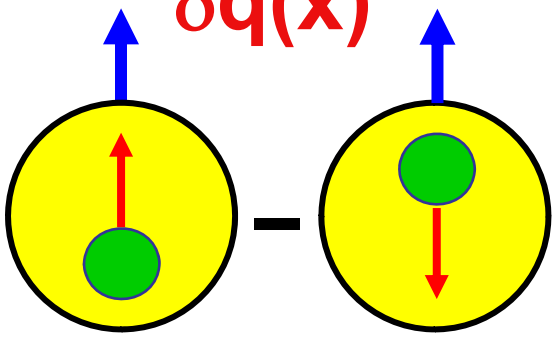
Helicity DF

$\Delta q(x)$



Transversity DF

$\delta q(x)$



$q(x)$

momentum distribution: describes the probability of finding a quark with a fraction x of the nucleon momentum;

$\Delta q(x)$

Helicity distribution: describes the probability, in a longitudinal polarized nucleon (w.r.t. the direction of motion), of finding a quark with spin parallel to the nucleon spin;

$\Delta_T q(x)$ transversity distribution: describes the probability, in a transversally polarized nucleon (w.r.t. the direction of motion), of finding a quark with spin parallel to the nucleon spin;

Transversity

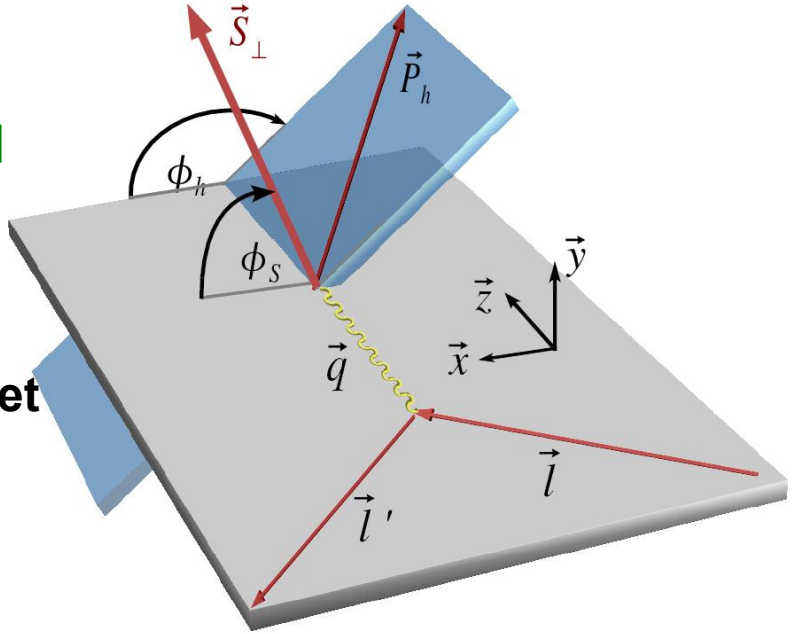
Transversity PDF is chiral-odd:

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

One way to measure the transversity PDF:

SIDIS reactions on a transversely polarized target

$\ell\, N^{\uparrow} \rightarrow \ell'\, h\, X$



ϕ_h azimuthal angle of the hadron
ϕ_s azimuthal angle of the transverse spin of the initial quark

The chiral-odd partner is the Collins Fragmentation Function

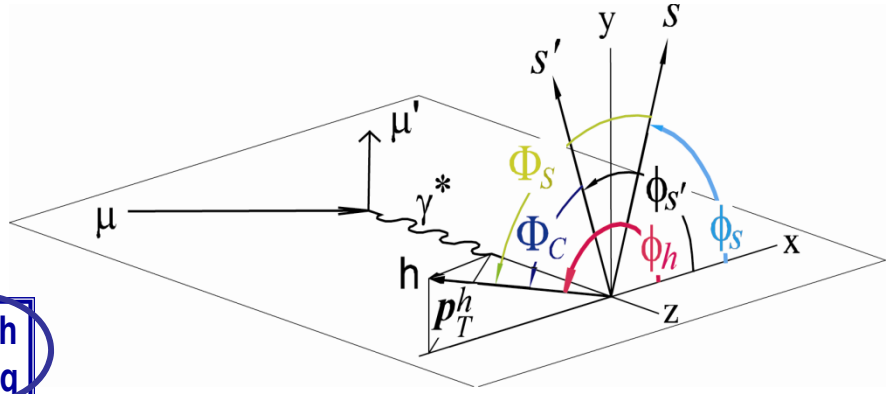
Collins effect

In the hadronization process from transversally polarized quarks, the produced hadrons show an azimuthal asymmetry

$\Phi_C = \phi_h - \phi_{s'}$ is the "Collins angle"

$$N_h^{\pm}(\Phi_C) = N_h^0 \cdot \{ 1 \pm A_C^h \cdot \sin\Phi_C \}$$

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



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

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

The measured Collins asymmetry gives access to the **transversity distribution function** convoluted **with Collins fragmentation function**

This is not the full story… different mechanisms can also produce azimuthal asymmetries in SIDIS

Sivers effect

Sivers effect is related to an asymmetry in the parton intrinsic transverse momentum distribution induced by the nucleon spin.

The number of produced hadrons can be written as:

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

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

Sivers DF

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

Independent from Collins angle; possible to measure both effects in the same data

$\sum_q$: sum on quarks

D_q^h : fragmentation function

q : unpolarized PDF

F dilution factor

P_T target polarization

D. W. Sivers, Phys. Rev. D **41**, 83 (1990)

More SIDIS azimuthal asymmetries

SIDIS cross-section in one-photon exchange approximation:
8 transverse target spin dependent azimuthal modulations

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ \quad \dots$$

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

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

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

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

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

Sivers

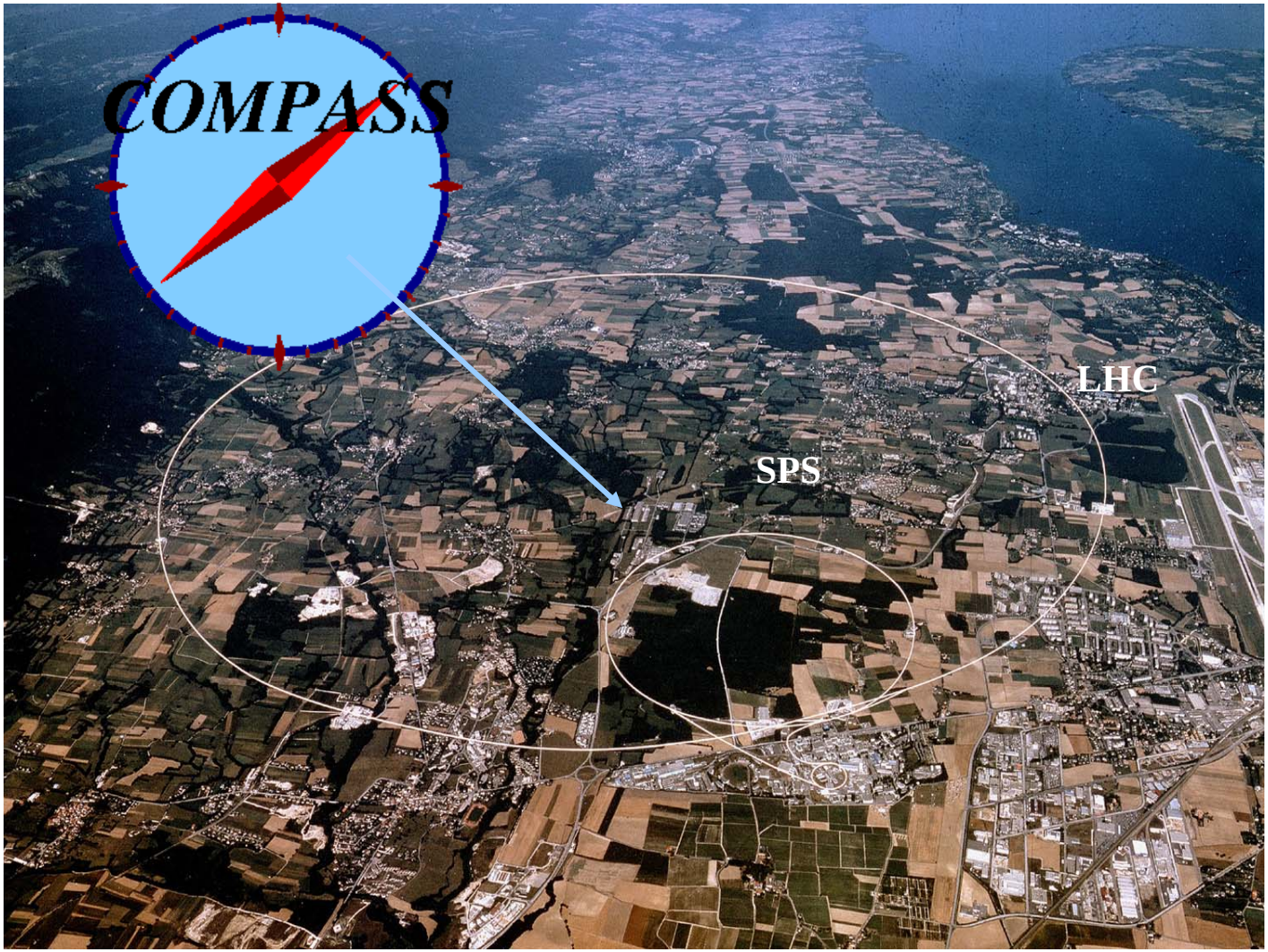
Collins

6 further modulations

M. Diehl, S. Sapeta, Eur.Phys.J C41 (2005) 515-533 hep-ph/0503023

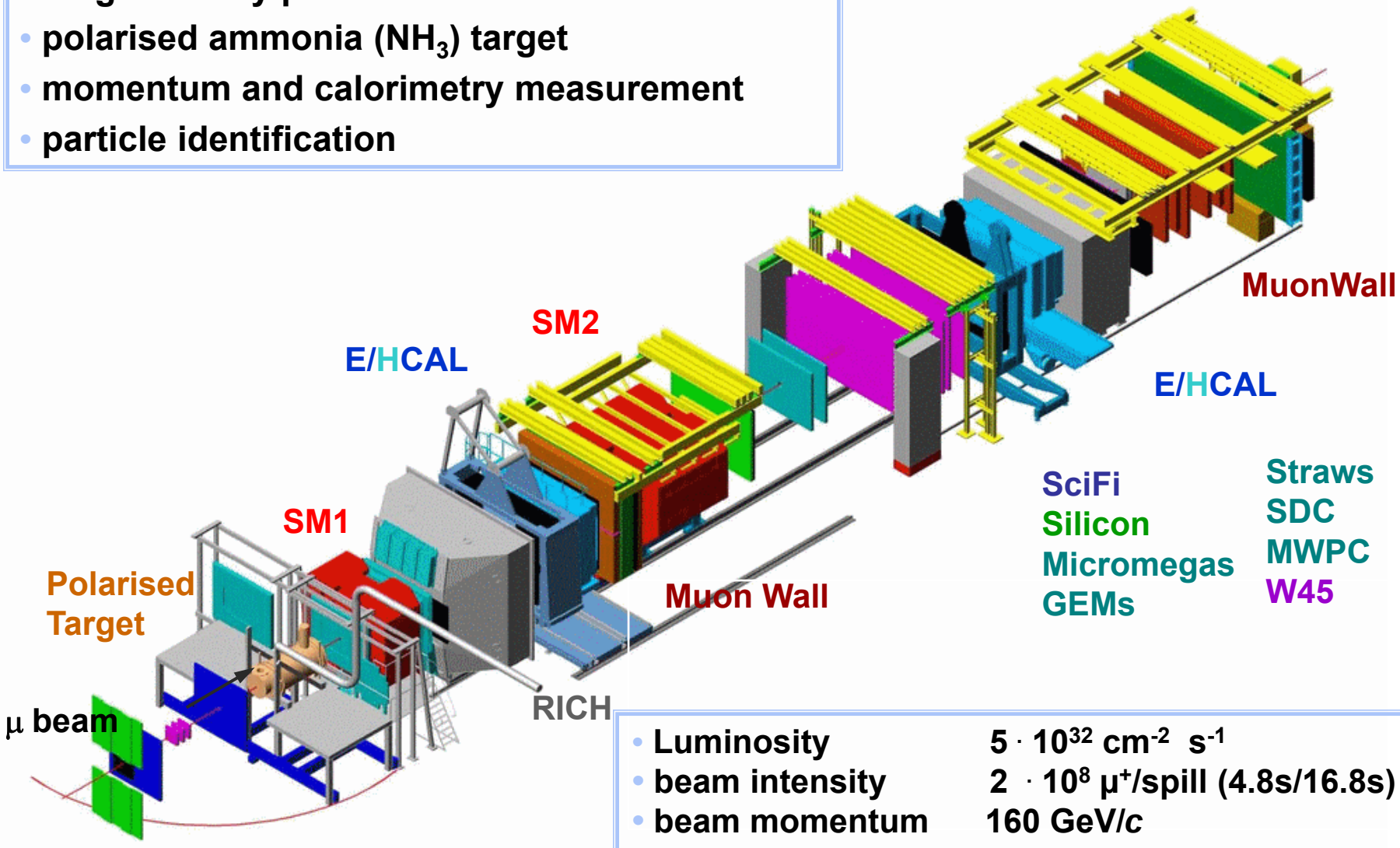
Our tool: the COMPASS spectrometer

COmmon Muon and Proton Apparatus for Structure and Spectroscopy



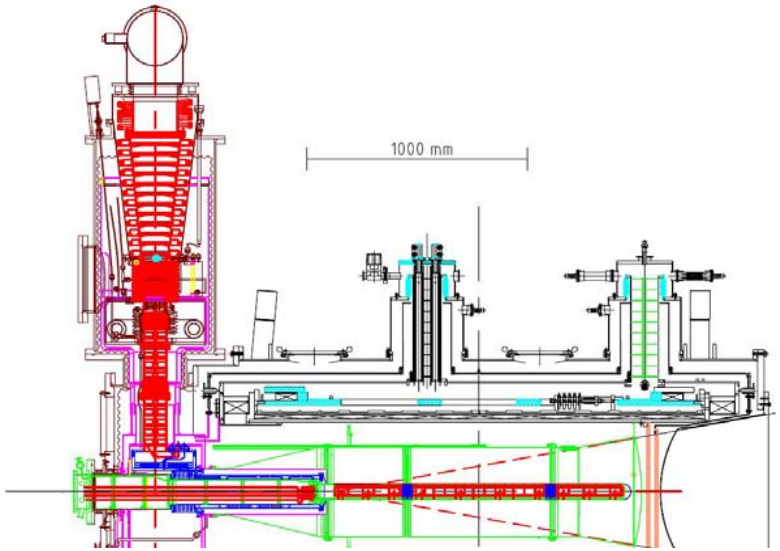
COMPASS spectrometer (2007 run)

- longitudinally polarised muon beam
- polarised ammonia (NH_3) target
- momentum and calorimetry measurement
- particle identification



- Luminosity $5 \cdot 10^{32}$ cm^{-2} s^{-1}
- beam intensity $2 \cdot 10^{8}$ μ^+/spill (4.8s/16.8s)
- beam momentum 160 GeV/*c*

Polarized target: 3 target cell configuration



New COMPASS target magnet:

→180 mrad geometrical acceptance

→excellent field homogeneity

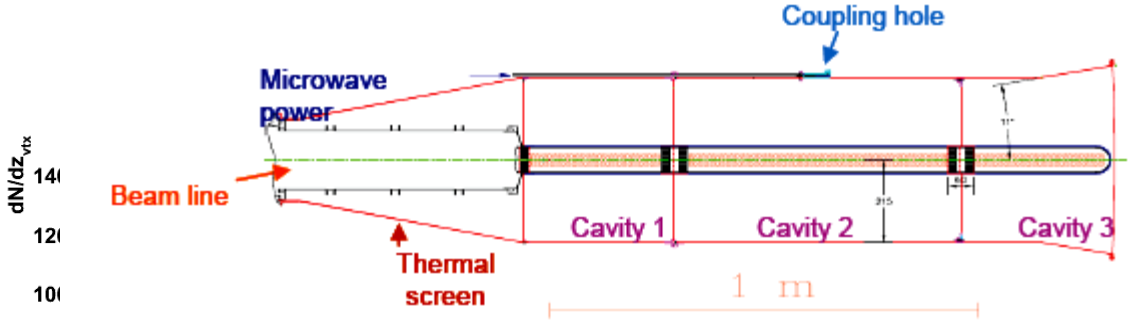
To match larger acceptance:

→new microwave cavity

→3 target cells: reduction of false asymmetries

Target material:

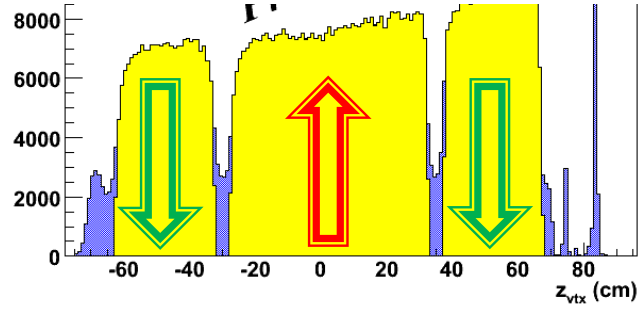
→NH_3

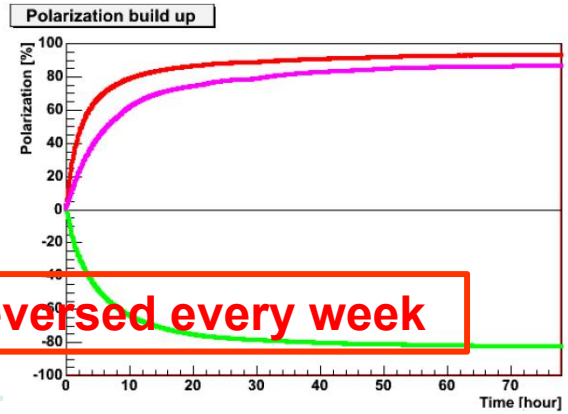


…on time (~ 4000 h)

…ation without polarisation loss

…H_3 in 2007:





Target Polarization reversed every week

Data: 2007 transverse run

2007 Transverse data taking statistics

- 2007 Compass Data taking

  Begin of run: 18 May 2007

  End of run: 11 November 2007

- Split between transverse and longitudinal target polarization:

  - μ on tape for transverse (40.0×10^{12})
  - μ on tape for longitudinal (41.5×10^{12})

- For the extraction of the asymmetries (*this analysis*) only a

Data taking Period	Target Polarization	Data taking Period	Target Polarization	Data taking Period	Target Polarization
Week 25	- + -	*Week 30*	+ - +	*Week 41*	- + -
Week 26	+ - +	*Week 31*	- + -	*Week 42a*	+ - +
Week 27	- + -	*Week 39*	+ - +	*Week 42a*	+ - +
Week 28	+ - +	*Week 40*	- + -	*Week 43*	- + -

Data quality checks

- Data taking stability is a required necessary condition:

  A dedicated set of quality checks have been developed and applied to fulfill this condition

Different and independent estimators have been taken into account:

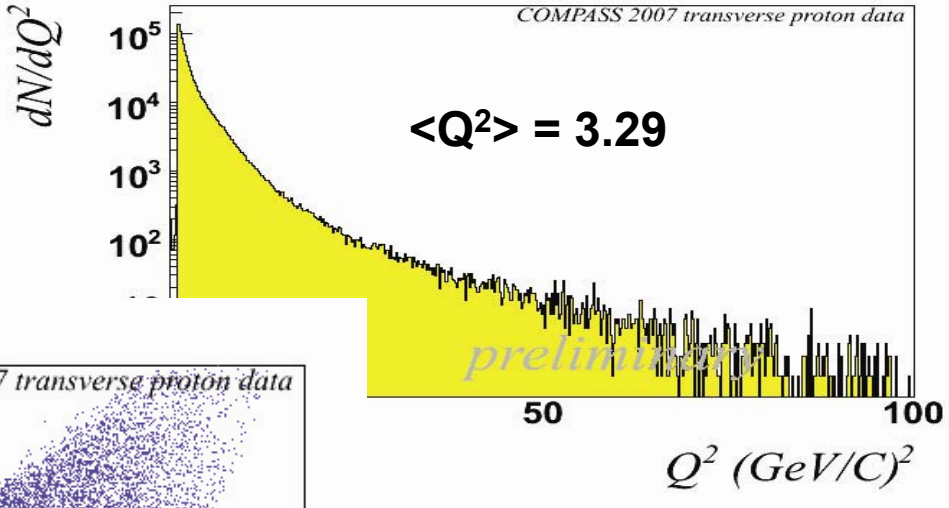
1. ***the detector profiles stability***
2. ***the number of primary vertexes per event***
3. ***the number of tracks per primary vertex***
4. ***beam particles per primary vertex***
5. ***the K_0 number per primary vertex***
6. ***the reconstructed mass of the K_0 meson***
7. ***stability of many kinematical variables:***

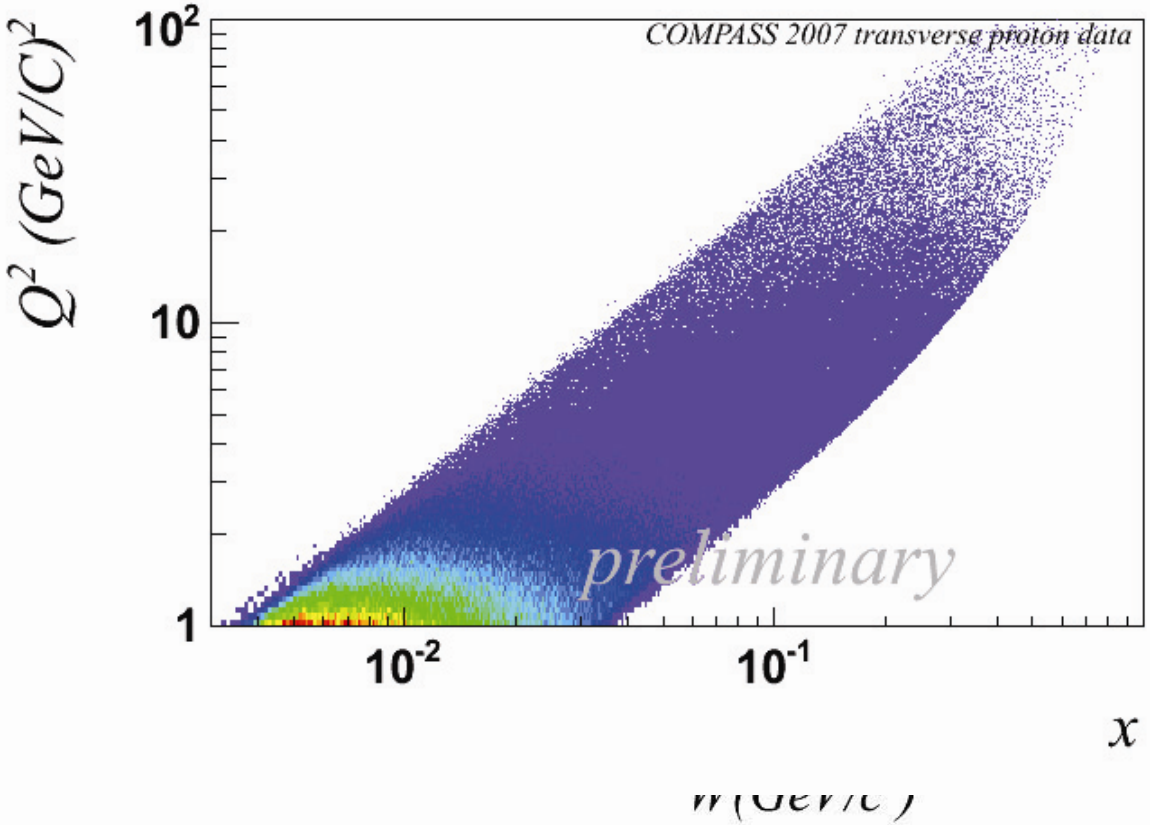
   (z_{vtx}, $E_{\mu'}$, $\phi_{\mu'}$, x_{Bj} Q^2,y, W, E_{had}, $\phi_{had_{Lab}}$, $\theta_{had_{Lab}}$, $\phi_{had_{GNS}}$, $\theta_{had_{GNS}}$, p_t)

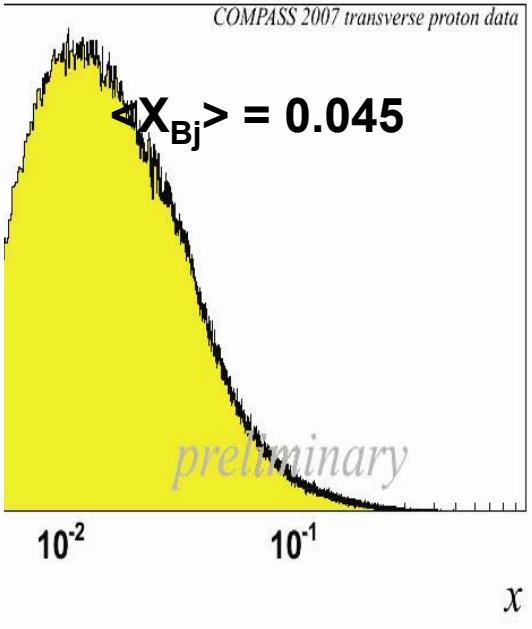
SIDIS Event Selection

DIS cuts:

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



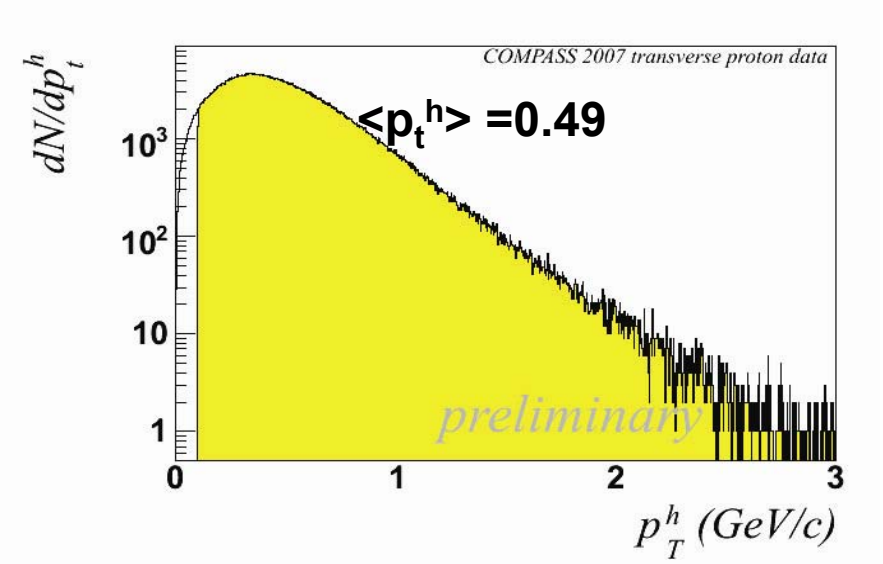


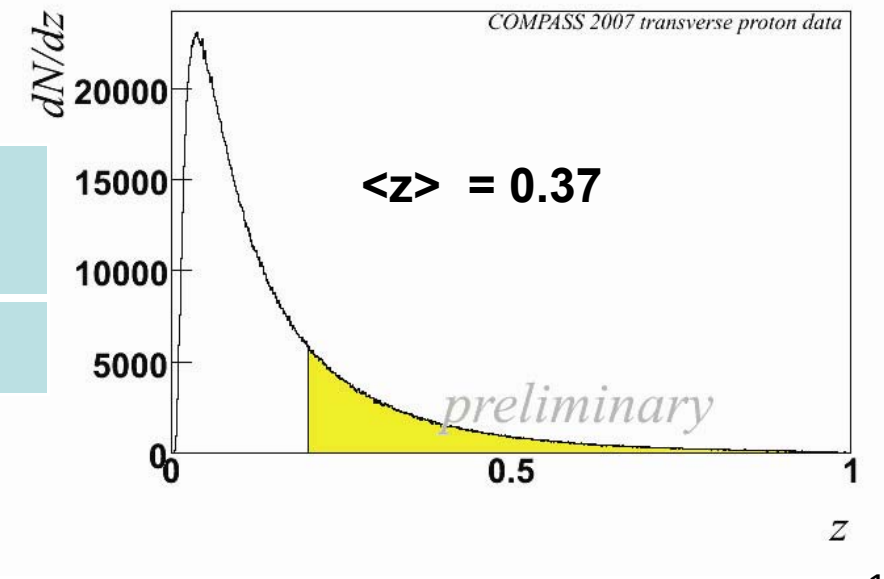


SIDIS Event Selection

All hadrons

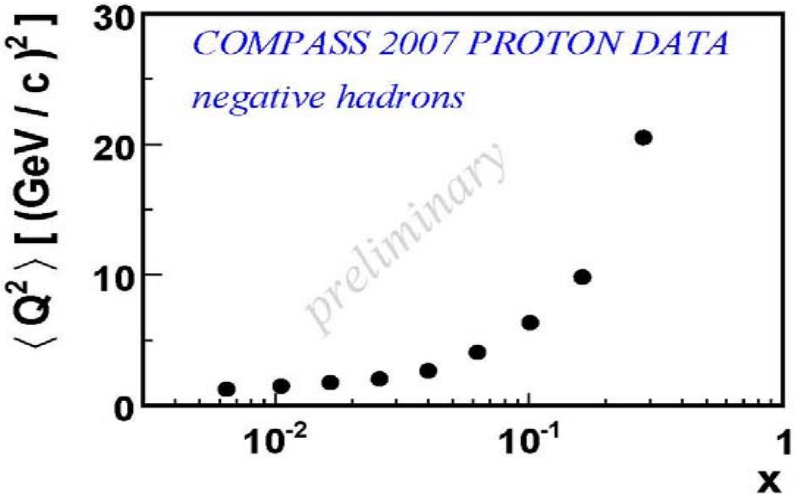
- Energy Deposit in HCALs>Thr. (~5 GeV)
- p_T>0.1 GeV/c
- z>0.2

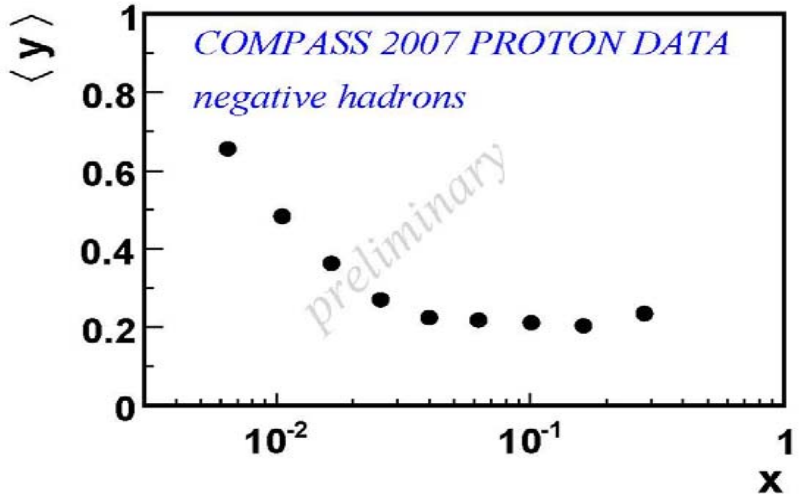


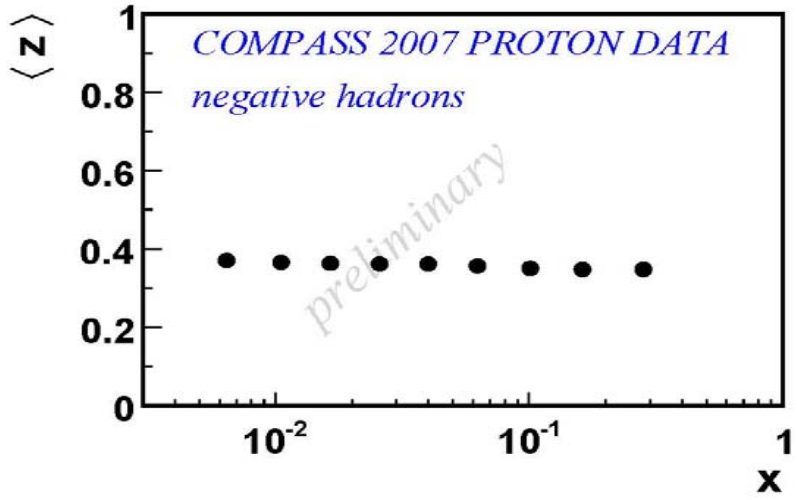


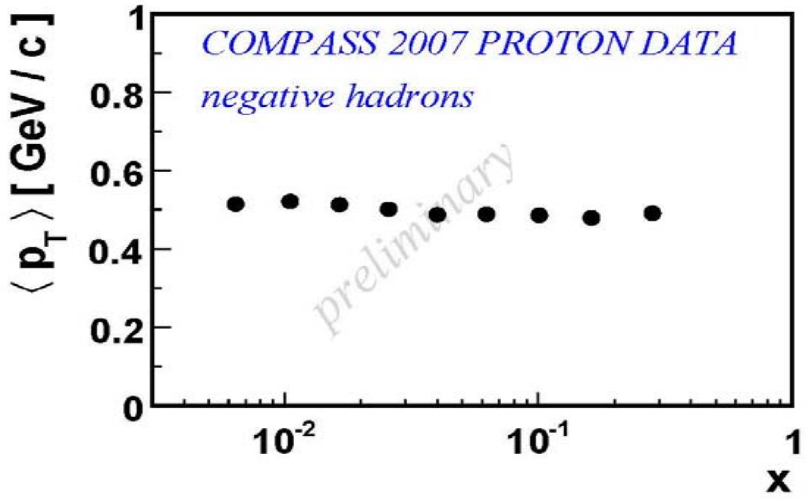
	Positive hadrons	Negative hadrons
Total statistic for this analysis	5703231	4505088

Mean Values negative hadrons

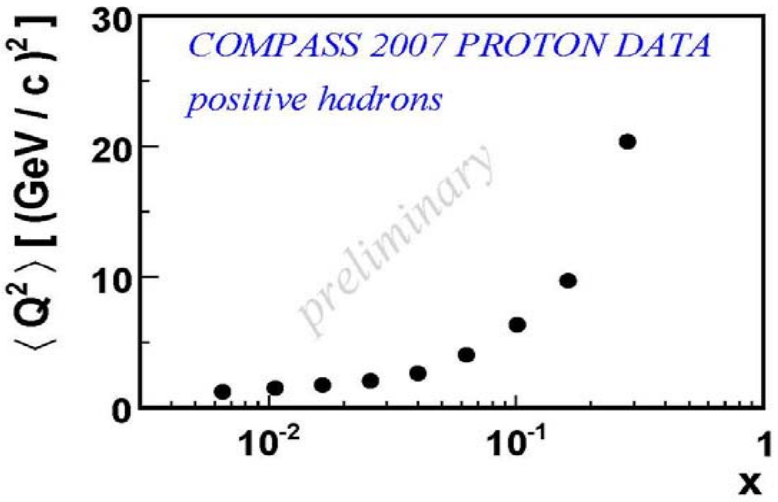


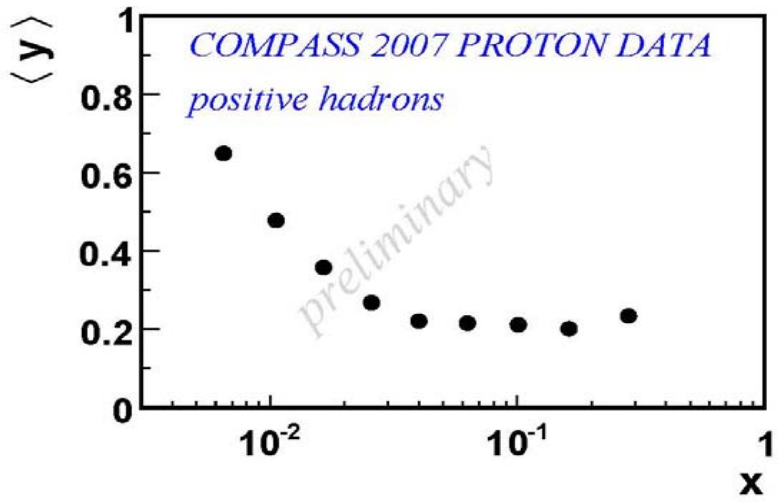


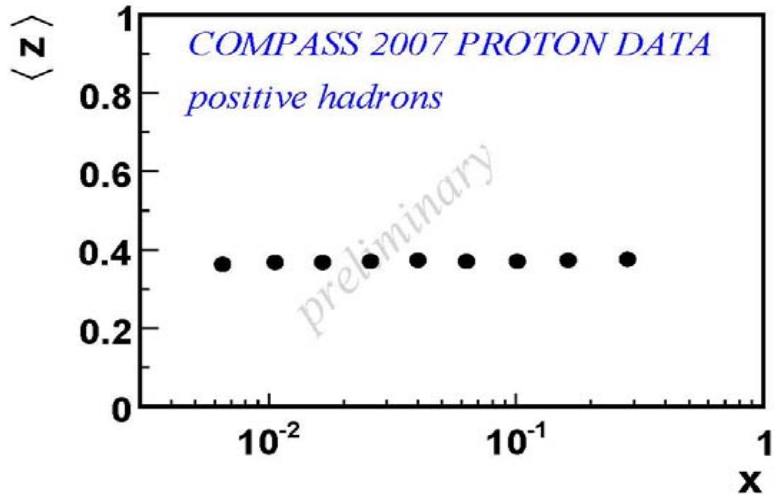


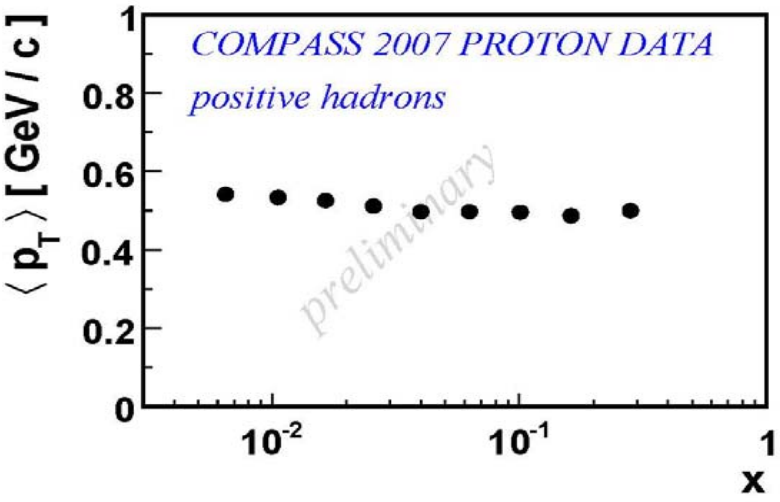


Mean Values, positive hadrons





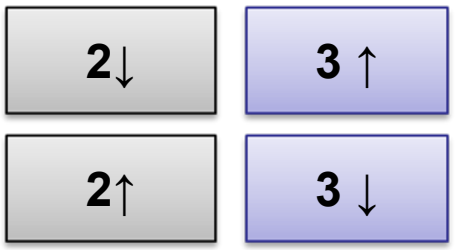


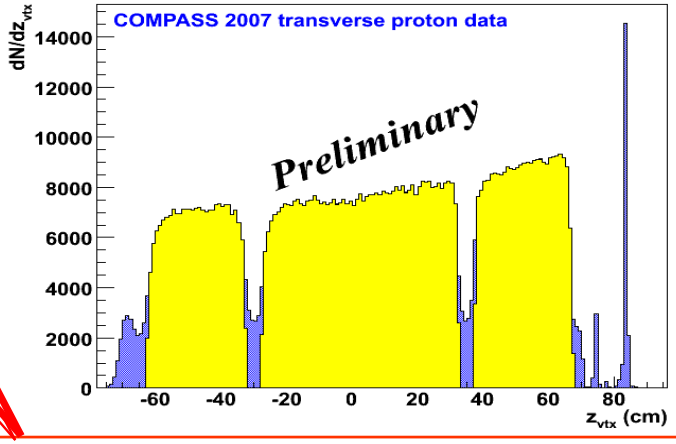


Asymmetries

Asymmetry extraction, target configurations

Taking advantage from the new three target cell configuration





Two consecutive data taking weeks with opposite polarization for the same target cells

Extract two independent values of the asymmetries
(one for each split part of the target)
→ the values have been averaged.

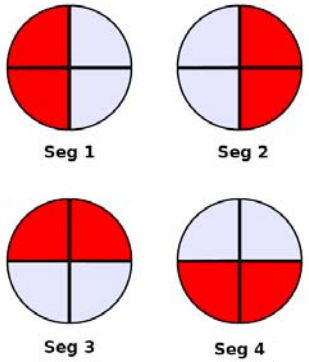
Asymmetries extraction via 2D binned maximum likelihood method
All possible azimuthal modulations have been taken into account.

Systematic Studies

Several systematics tests have been performed:

Splitting of the target into sectors:

1. Left right
2. Up down

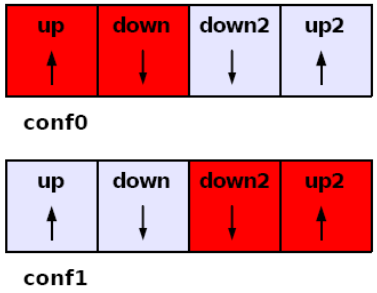


False asymmetries test:

1. Combining cells with the same polarization

Target split: different target sectors

1. Combining half upstream target cells (conf 0)
2. Combining half downstream target cells (conf 1)

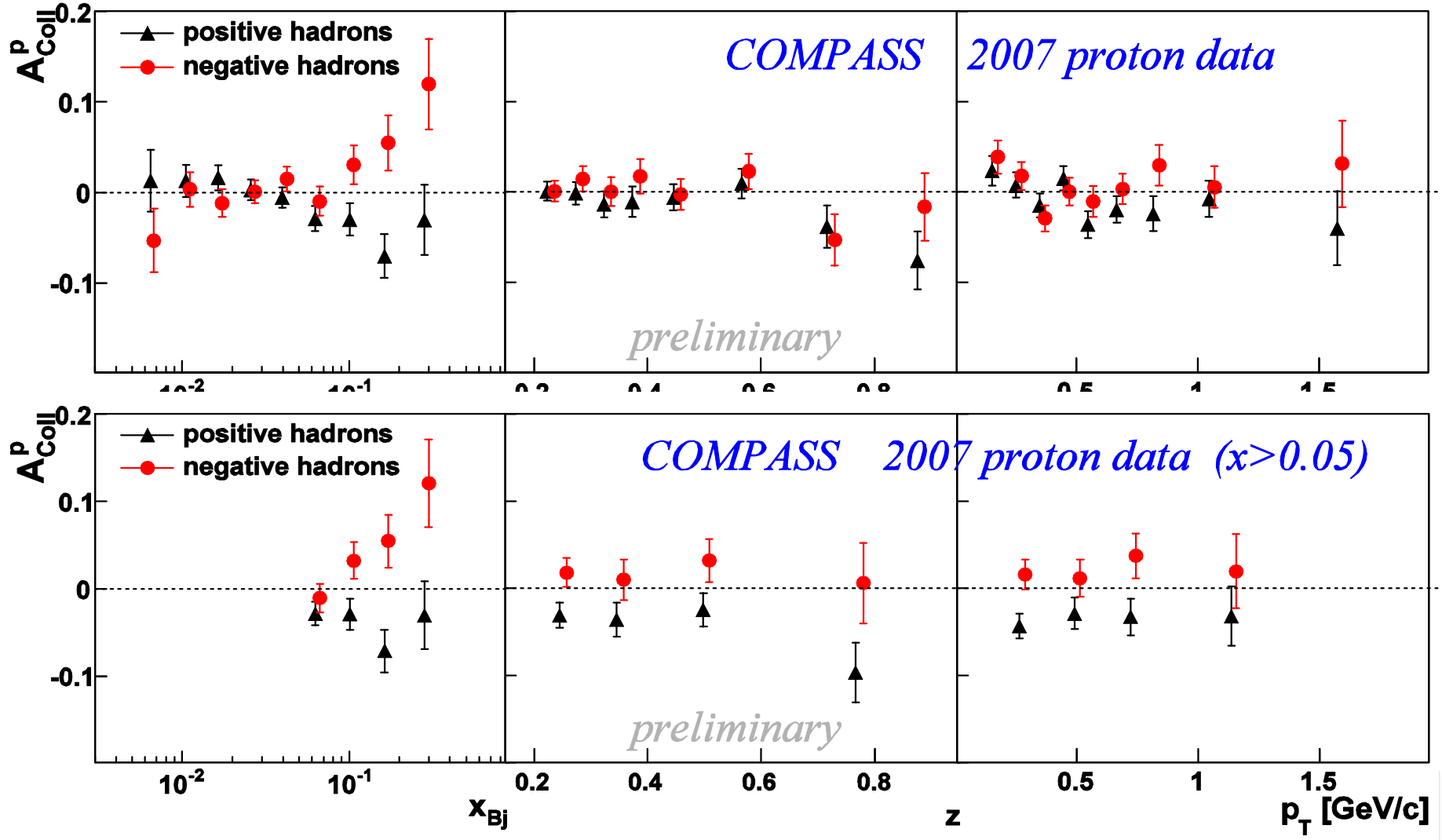


Different methods for asymmetry extraction

1. 5 different methods

Overall systematic error has been evaluated to be 0.3 and 0.5 statistical error for Collins and Sivers respectively for this analysis.

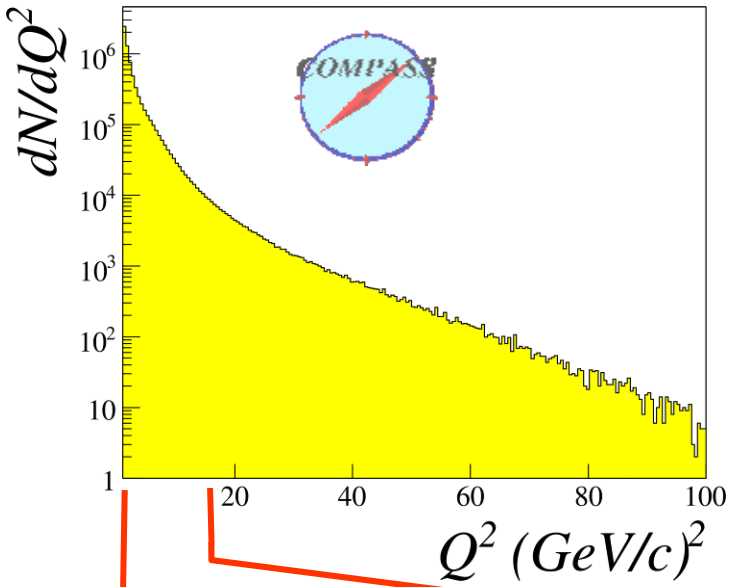
Results: Collins asymmetry

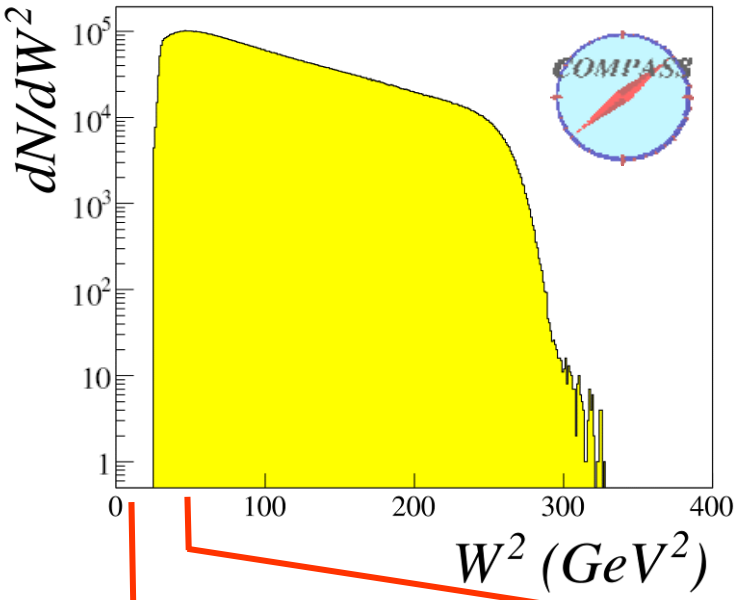


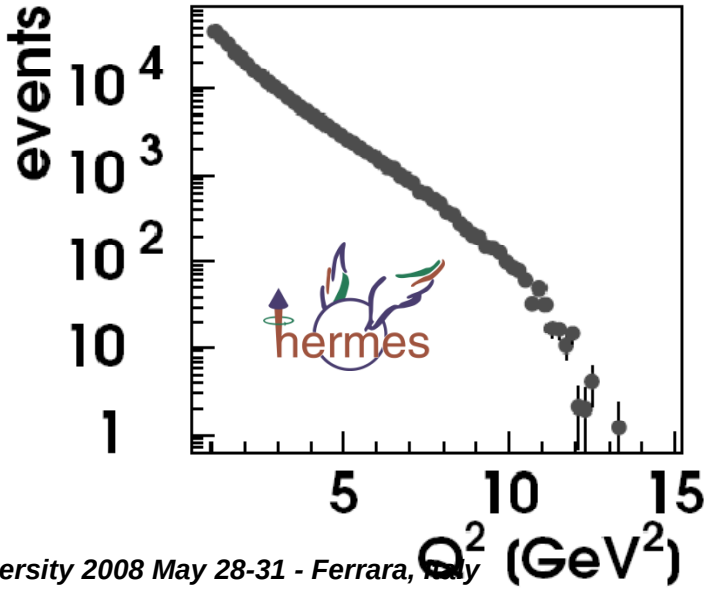
SIDIS kinematics

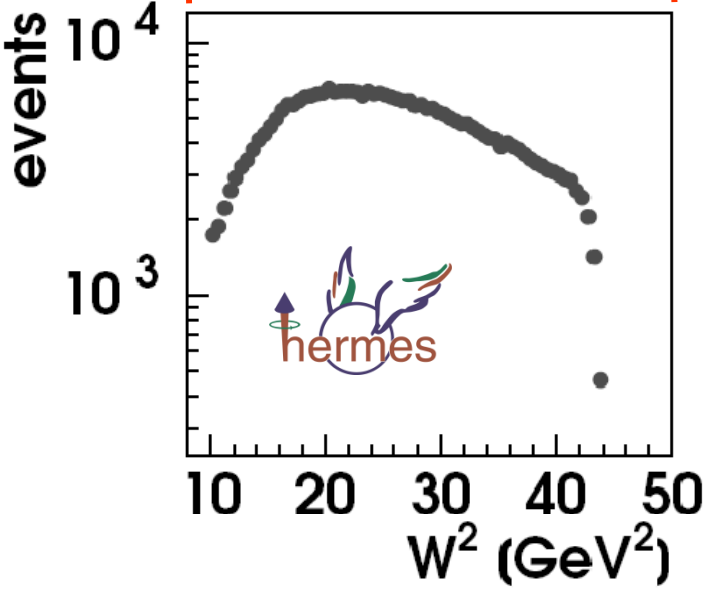
F. Bradamante

International Erice School/Workshop on Nuclear Physics - Sept. 16-24, 2007, Erice, Italy

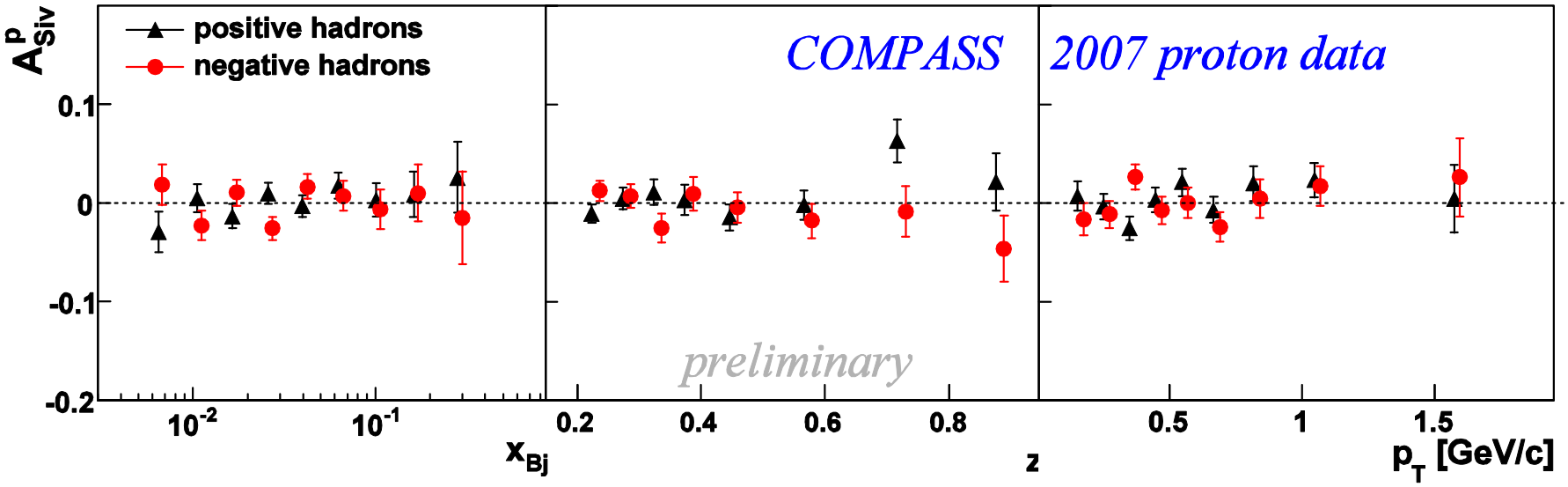








Results: Sivers asymmetry



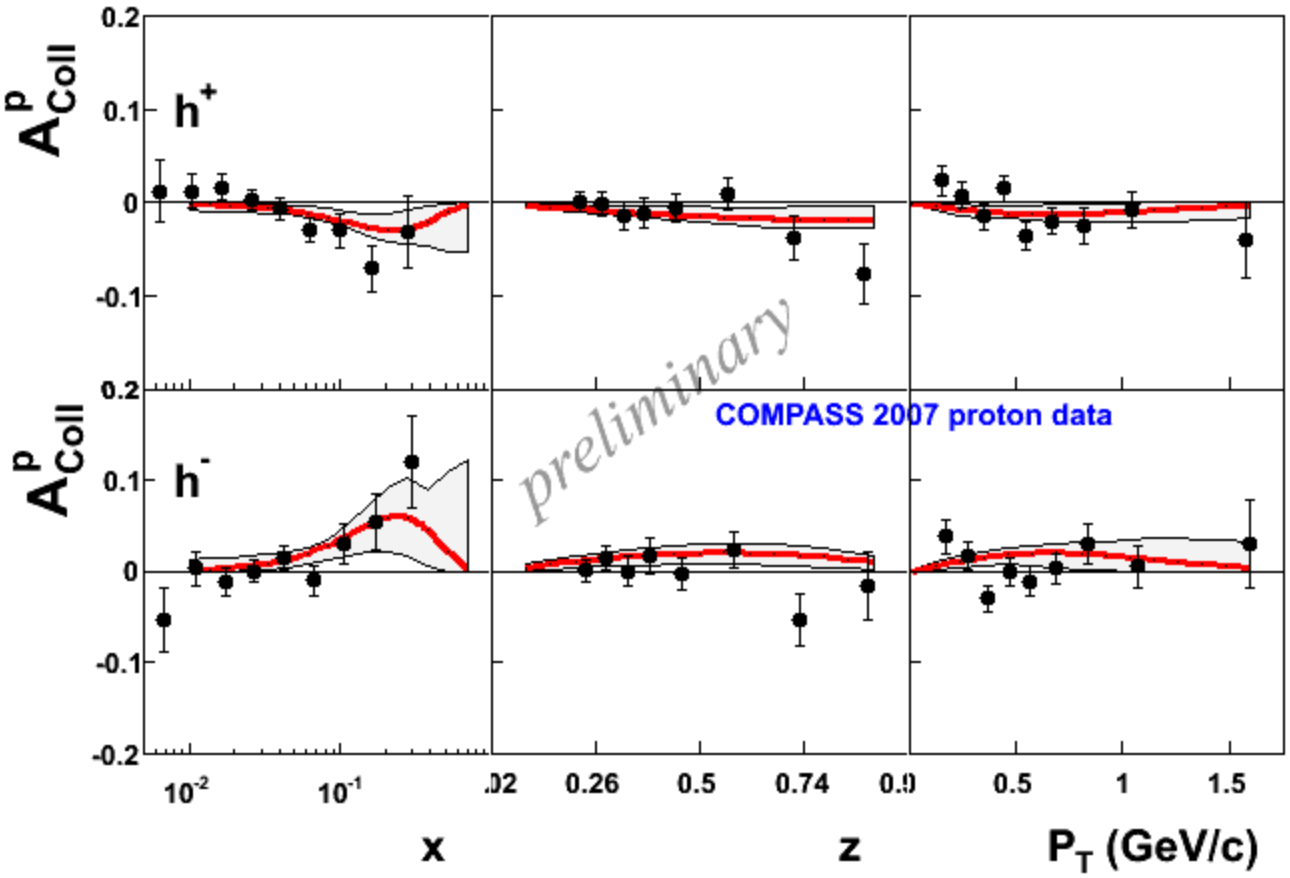
Asymmetry small, compatible with zero within present statistical errors

- ✓ **Unexpected result**
- ✓ **Of paramount importance**

Overall systematic error has been evaluated to be 0.5 σ_{stat} for Sivers asymmetry for this analysis.

Predictions from the global analysis: Collins

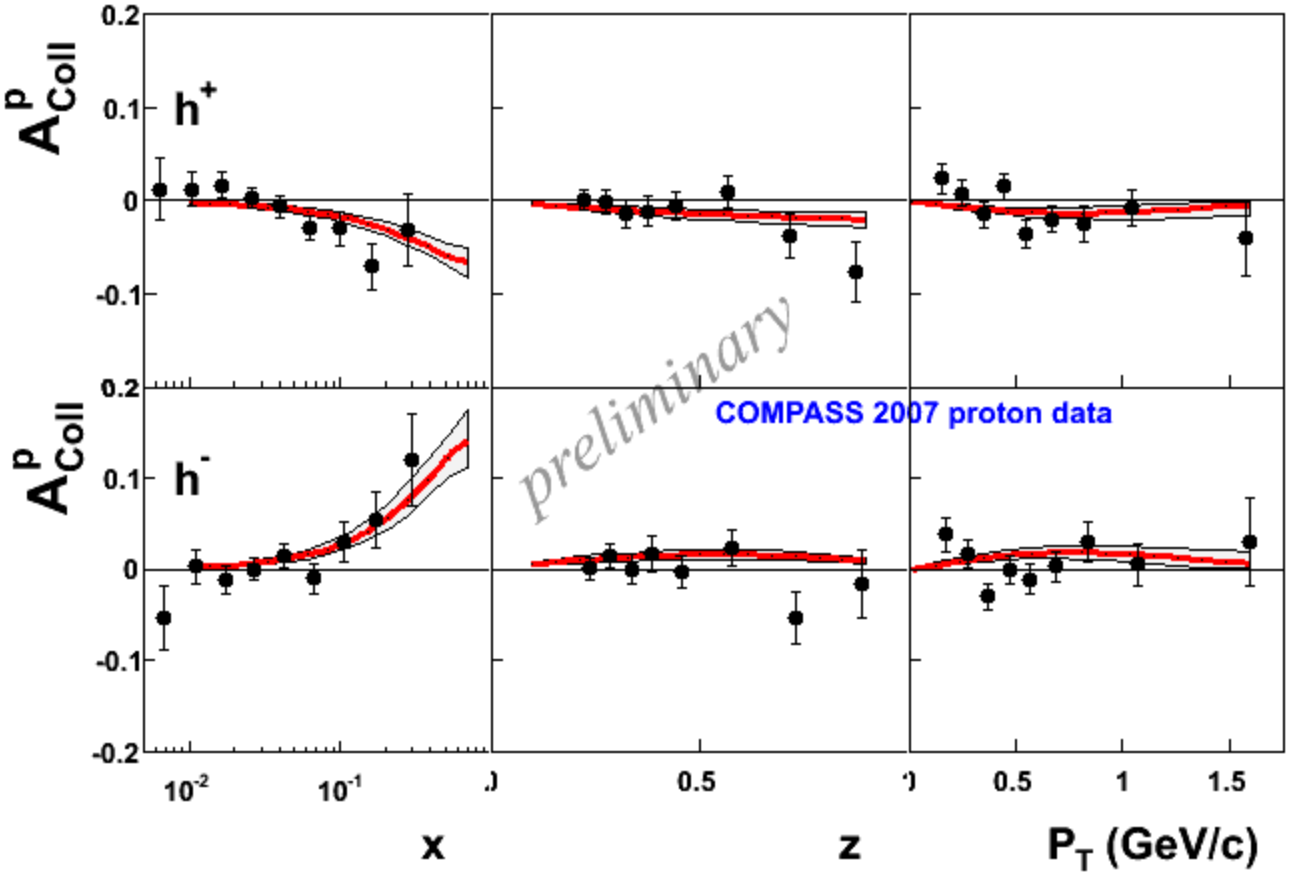
COMPASS Deuteron, HERMES Proton, BELLE $e^+ e^-$ data



COMPASS proton data for h+ and h-,
with the **predictions from the global analysis of Anselmino et Al.**
Phys. Rev. D 75 (2007) 054032

Predictions from the global analysis, Collins

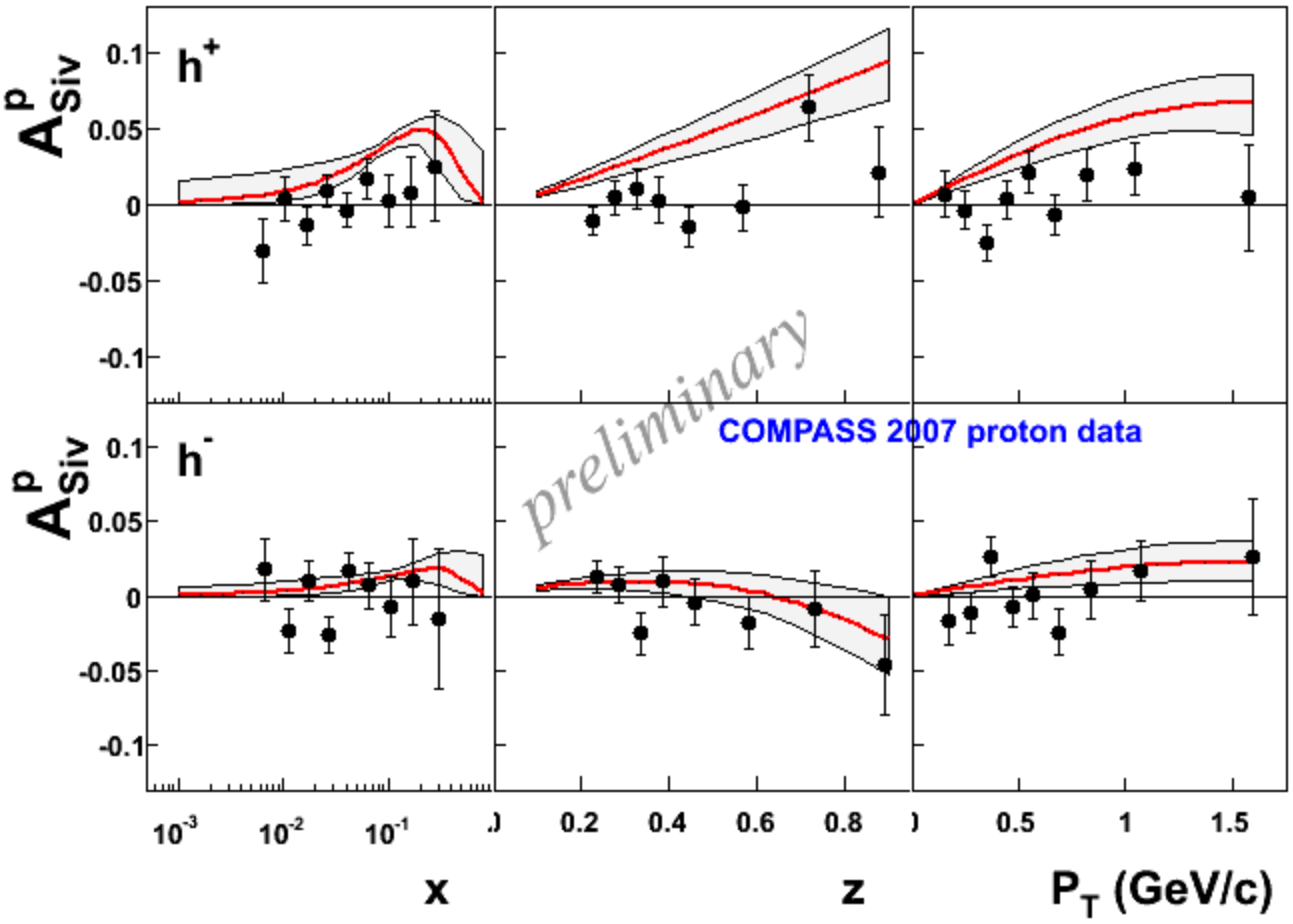
Update of the analysis with the most recent
***COMPASS Deuteron*, *HERMES Proton*, *BELLE e^+ e^-* data**



COMPASS proton data for h+ and h-, with the *very last* predictions of Anselmino et al. *(DIS08 by A.Prokudin.)*

Predictions: Sivers

Latest prediction of Anselmino et al.



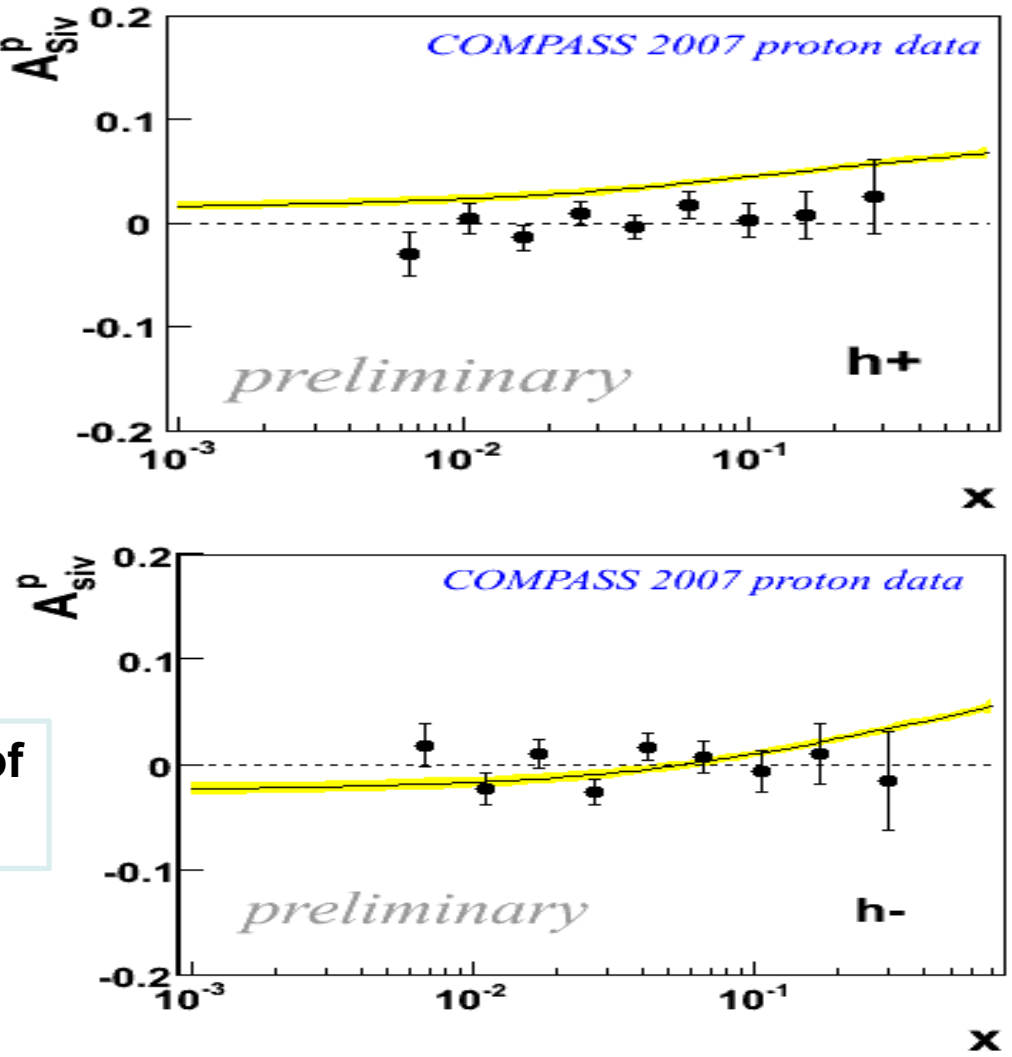
COMPASS proton data for h+ and h-, with the latest prediction of Anselmino et al.

M. Anselmino et al. ``Sivers Effect for Pion and Kaon Production in Semi-Inclusive Deep Inelastic Scattering,'' arXiv:0805.2677 [hep-ph].

Sivers comparison with prediction

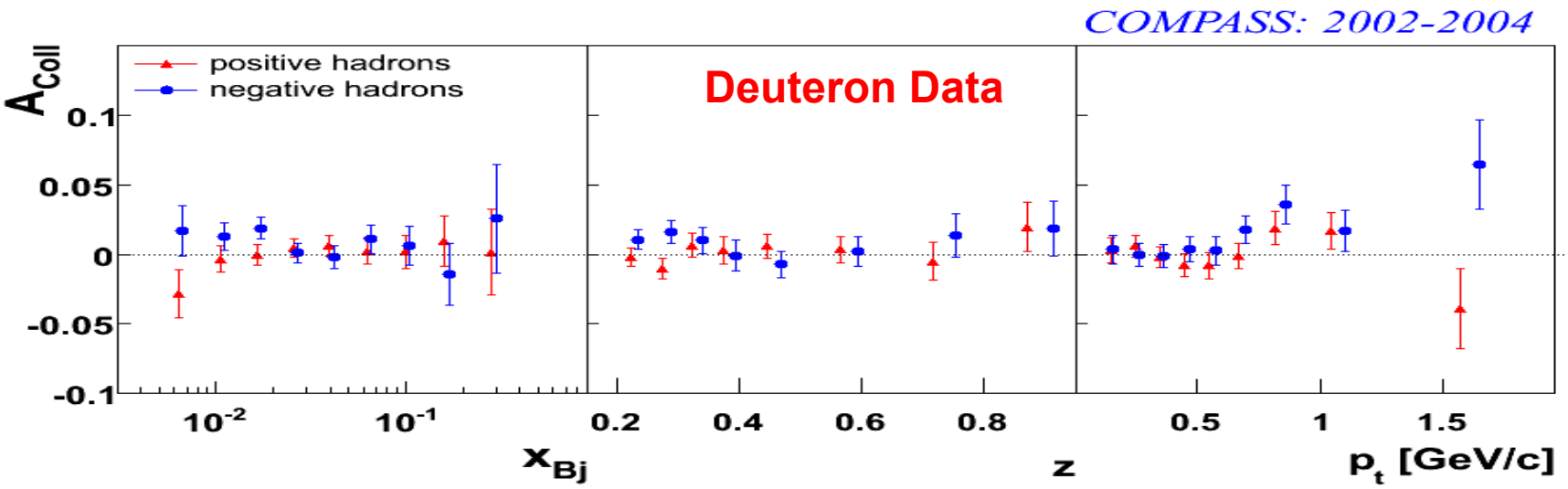
COMPASS proton data for h+ and h-, with the prediction of the group of Efremov et al.

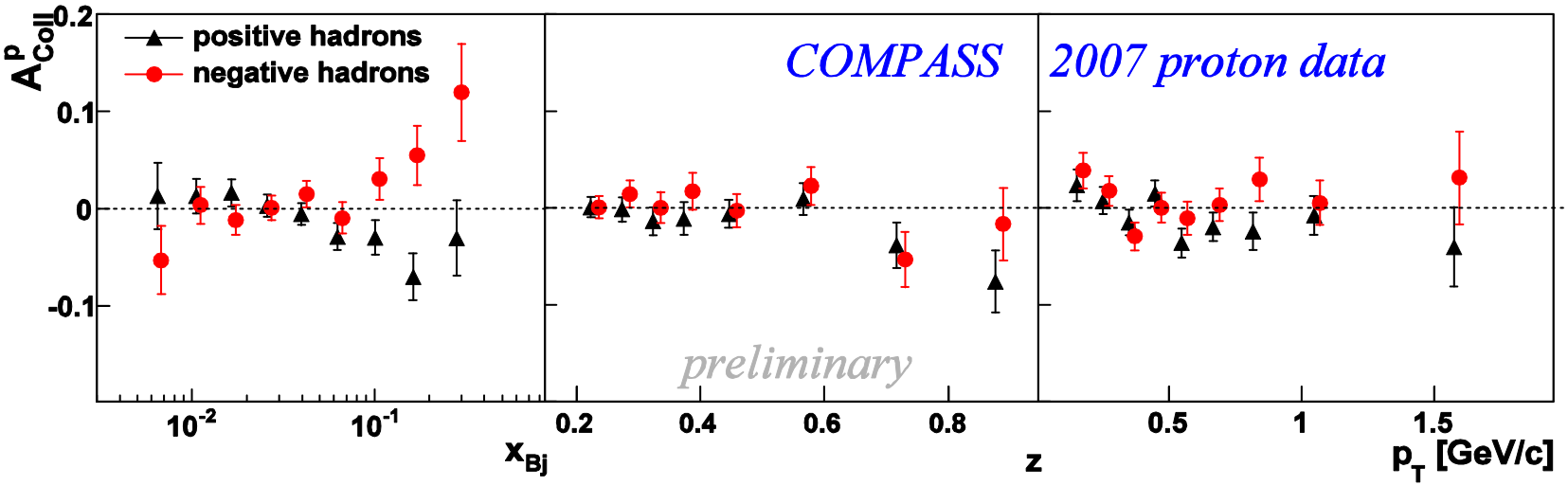
Private communication of P.Schweitzer



S.Arnold, A.V.Efremov, K.Goeke, M.Schlegel and P.Schweitzer, "Sivers effect at HERMES, COMPASS and CLAS12", arXiv:0805.2137 [hep-ph]

Compass Deuteron Data - Proton Data





Global analysis from COMPASS Deuteron and Proton Data possible!!

Summary

- ✓ First result of ***COMPASS 2007 proton transverse*** run have been presented;
- ✓ ***Collins*** Asymmetry different from zero;
  - ✓ Comparable strength of HERMES asymmetry;
  - ✓ Agreement with Anselmino et al predictions;
- ✓ ***Sivers*** Asymmetry statistically compatible with zero within present statistical error;
  - ✓ Contribute to reduce the uncertainty band of predictions.
- ✓ Full data statistics yet to come → reduce the statistical error on the extracted asymmetries up to a factor 2.
- ✓ Compass proton data can now be used in global analysis.

Thank you