Transverse Spin Effects at COMPASS

C. Schill (Universität Freiburg)

on behalf of the COMPASS collaboration

<u>Results on:</u>

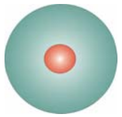
- **Transversity:**
  - **Collins asymmetry**
  - **2 hadron asymmetries**
- **Sivers asymmetries**
- **Unpolarized azimuthal asymmetries**

HS 09, Tatranska Strba, Aug. 31, 2009

Transverse Spin Physics

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

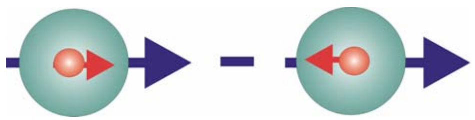
$q(x)$



momentum distribution

well known - unpolarized DIS

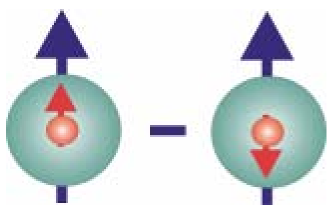
$\Delta q(x)$



helicity distribution

known - polarized DIS

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



transversity distribution

still poorly known

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

➔ SIDIS experiment

Transversity Distribution Function

is chiral-odd:

observable effects are given only by the product of $\Delta_T q\,(x)$ and an other 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" Fragmentation Function

$l\,N^{\uparrow} \rightarrow l'\,h\,h\,X$ **"two-hadron" asymmetry**

"Interference" Fragmentation Function

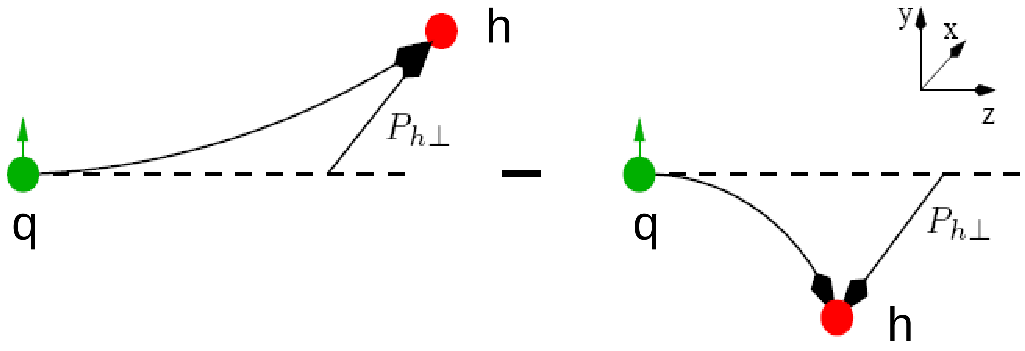
Collins-Effect

$$F_{UT}^{\sin(\phi_h+\phi_s-\pi)} \propto \Delta_T q(x) \otimes \Delta_T^0 D_q^h$$

The Collins FF $\Delta_T^0 D_q^h(z, p_T)$: correlates the

transverse spin of the fragmenting quark and the

transverse momentum $P_{h\perp}$ of produced hadron h



The measured asymmetry A_{Col} gives access to the transversity distribution times the Collins fragmentation function:

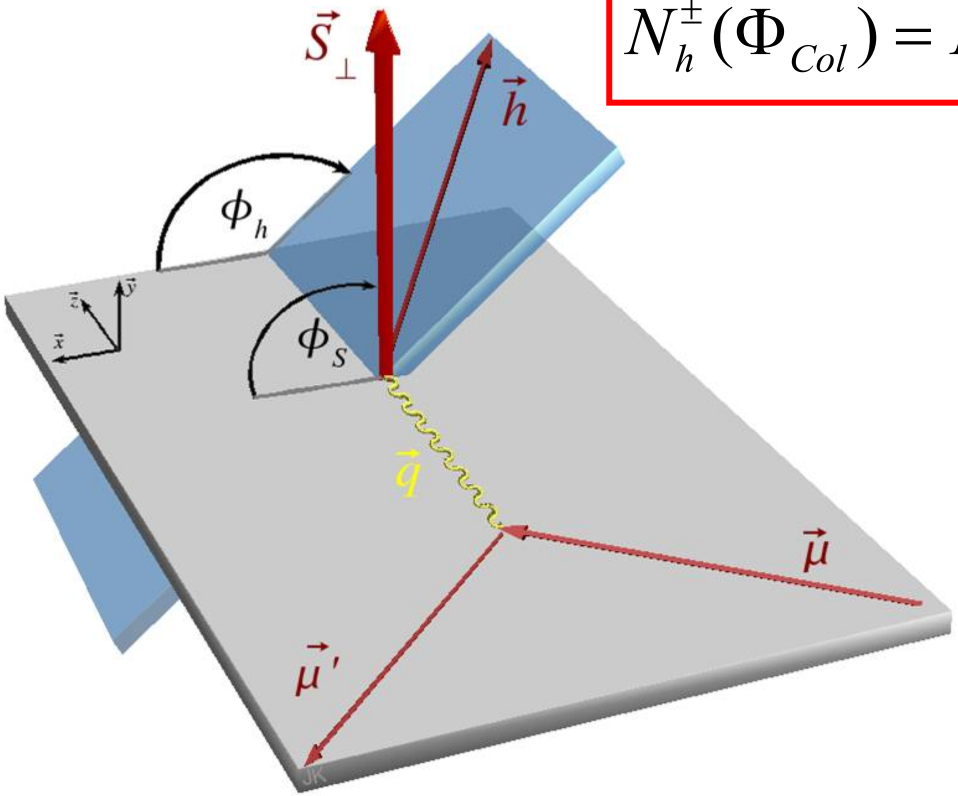
$$A_{\mathrm{Col}} \propto \frac{\sum_q e_q^2 \Delta_T q(x) \Delta_T^0 D_q^h}{\sum_q e_q^2 q(x) D_1}$$

Collins Asymmetry

SIDIS on a transversely polarized target: l $N^{\uparrow}$ → l´ h X

Fragmentation of a transversely polarized quarks into hadrons
→ azimuthal asymmetry:

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



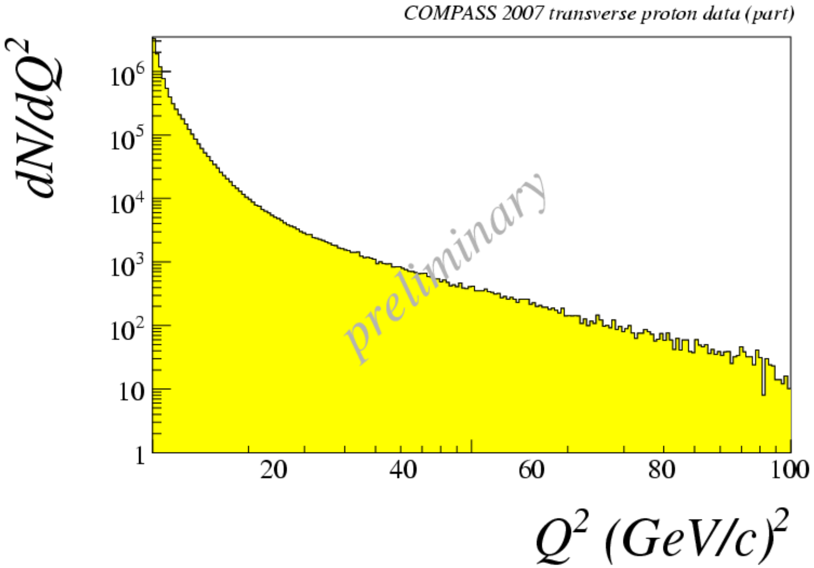
In SIDIS, the Collins angle Φ_{Coll} is defined as:

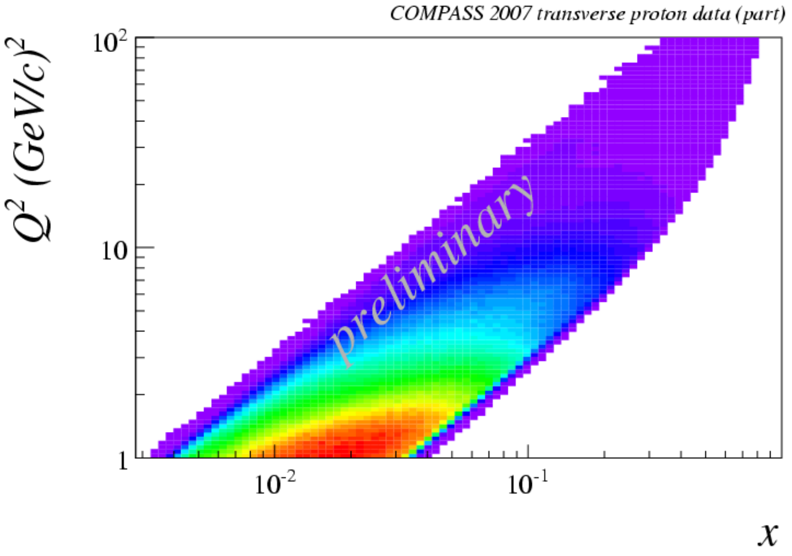
$$\Phi_{Col} = \phi_h + \phi_S - \pi$$

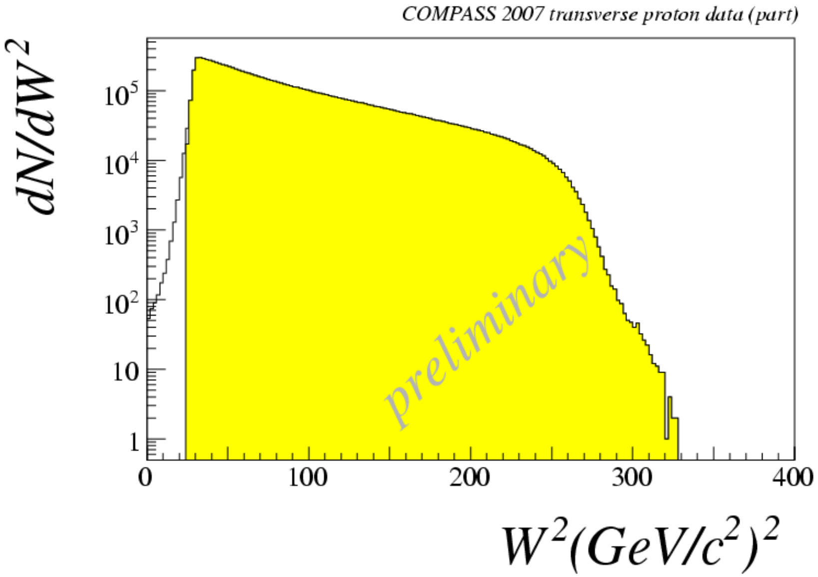
SIDIS Event Selection and Kinematics

DIS event selection:

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







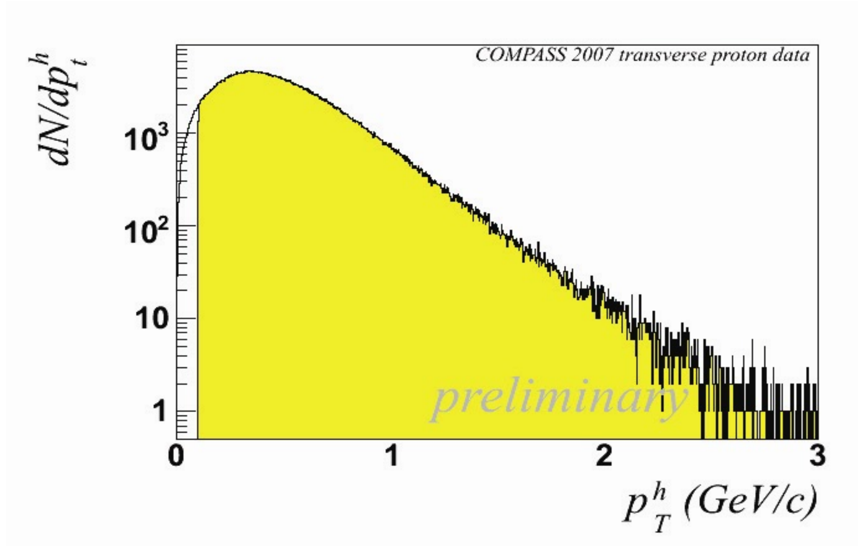
SIDIS Event Selection and Kinematics

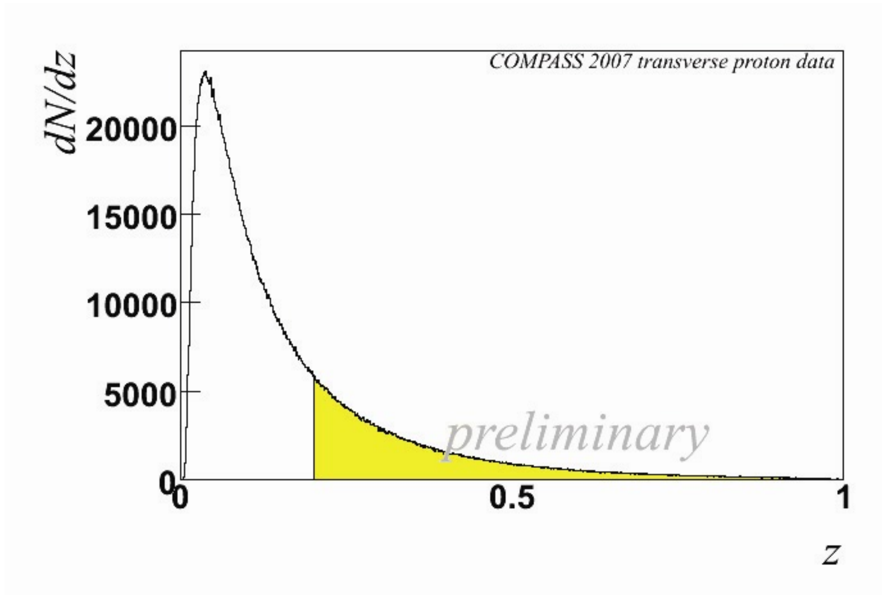
DIS event selection:

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

Hadron selection:

- $p_T>0.1\ GeV/c$
- $z>0.2$

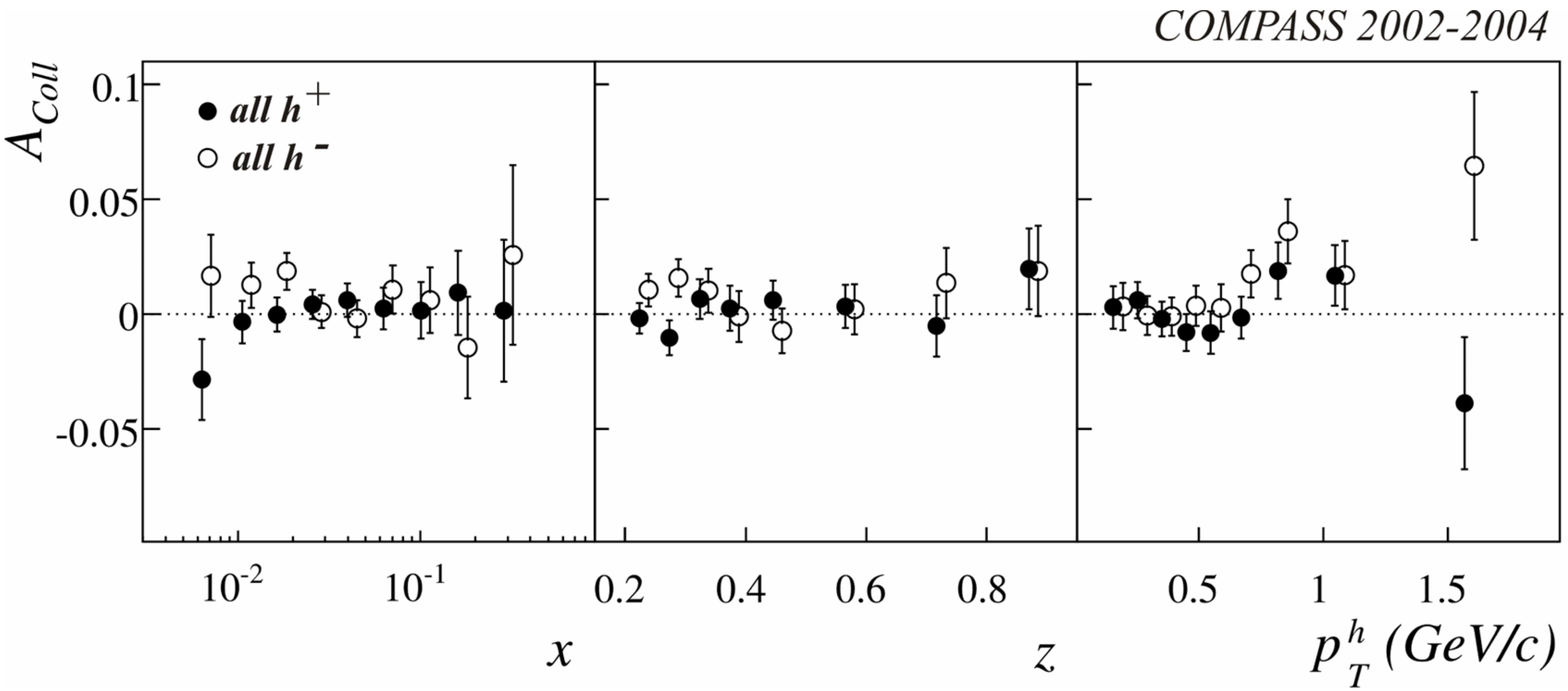




Collins Asymmetries - Deuteron data

charged hadrons

- 2004: first results from 2002 data [PRL94 (2005) 202002] confirmed in
- 2006: **final results from 2002-2004 data** [NPB765 (2007)31]

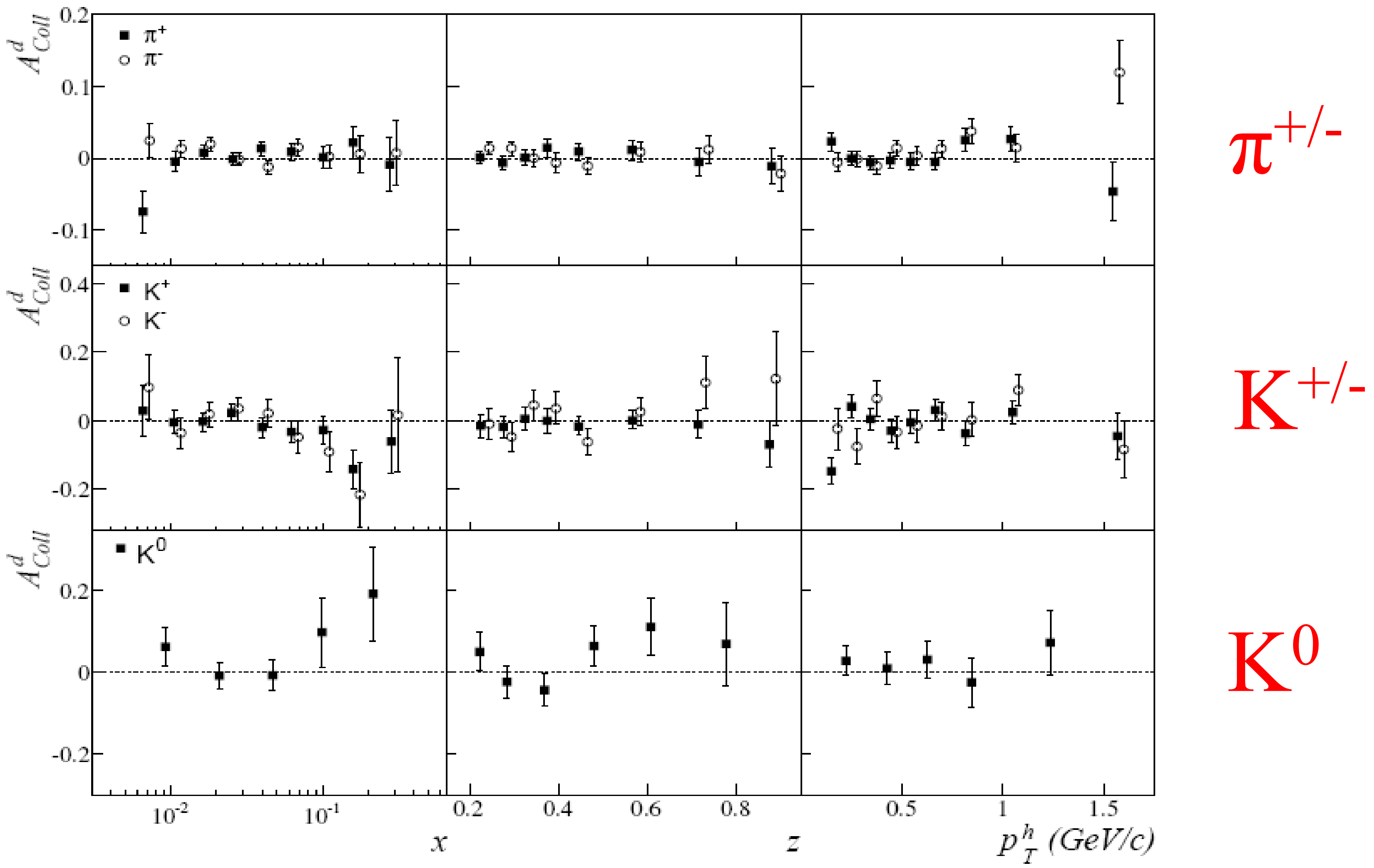


Asymmetries compatible with 0 within statistical errors
(systematical errors considerably smaller)

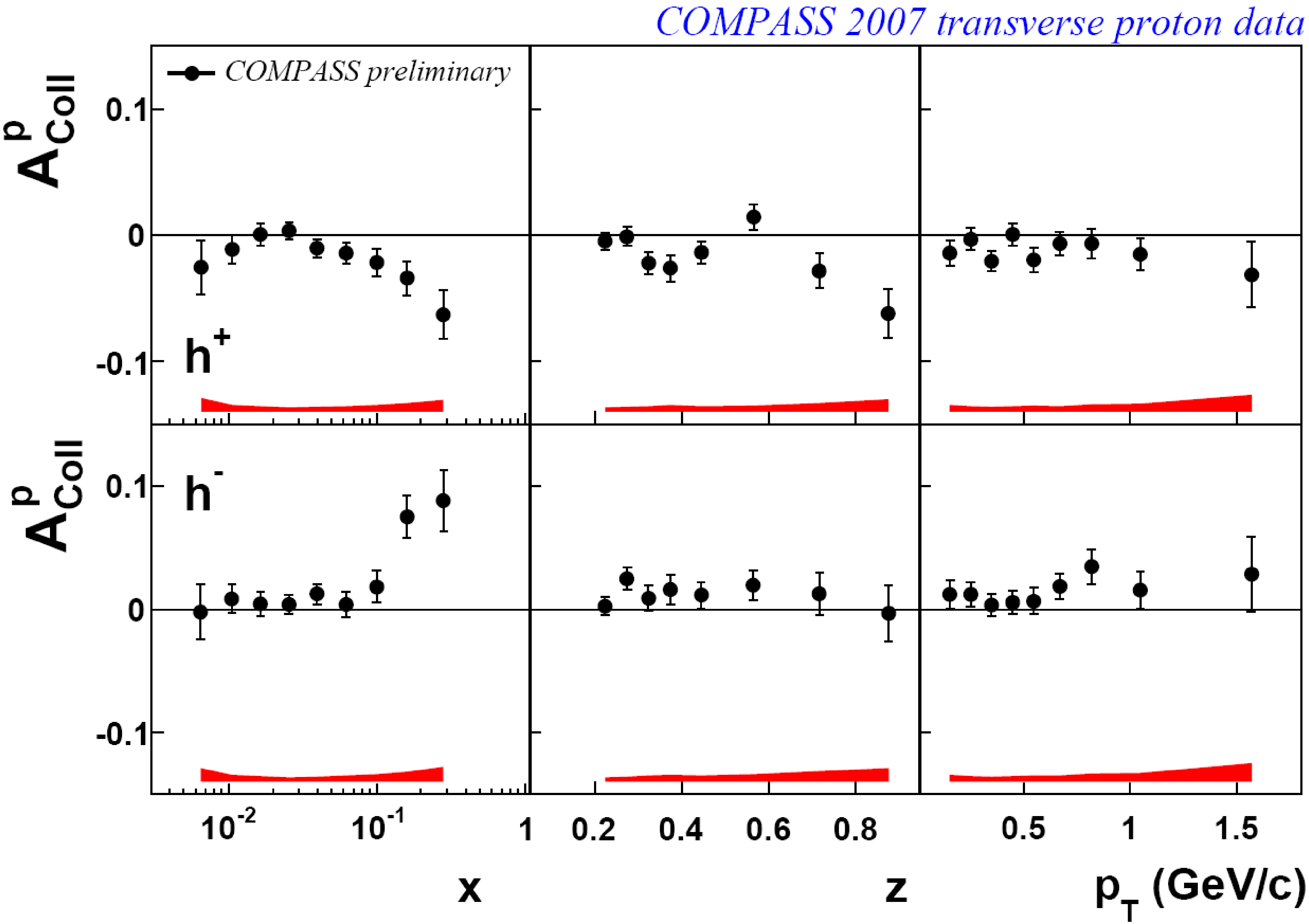
Collins Asymmetries - Deuteron data

identified hadrons

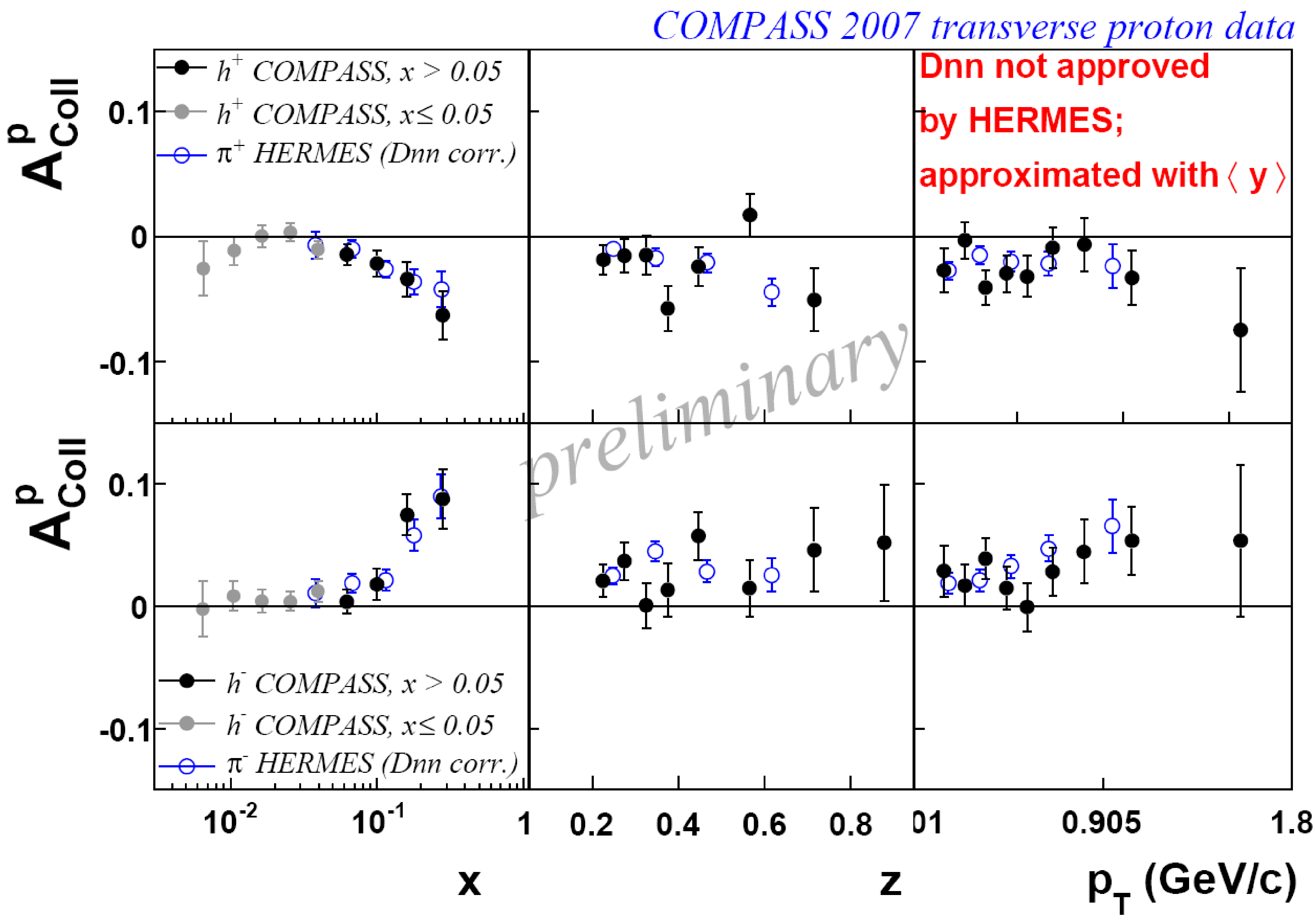
- 2007: **final results from 2002-2004 data** [PLB 673 (2009) 127]



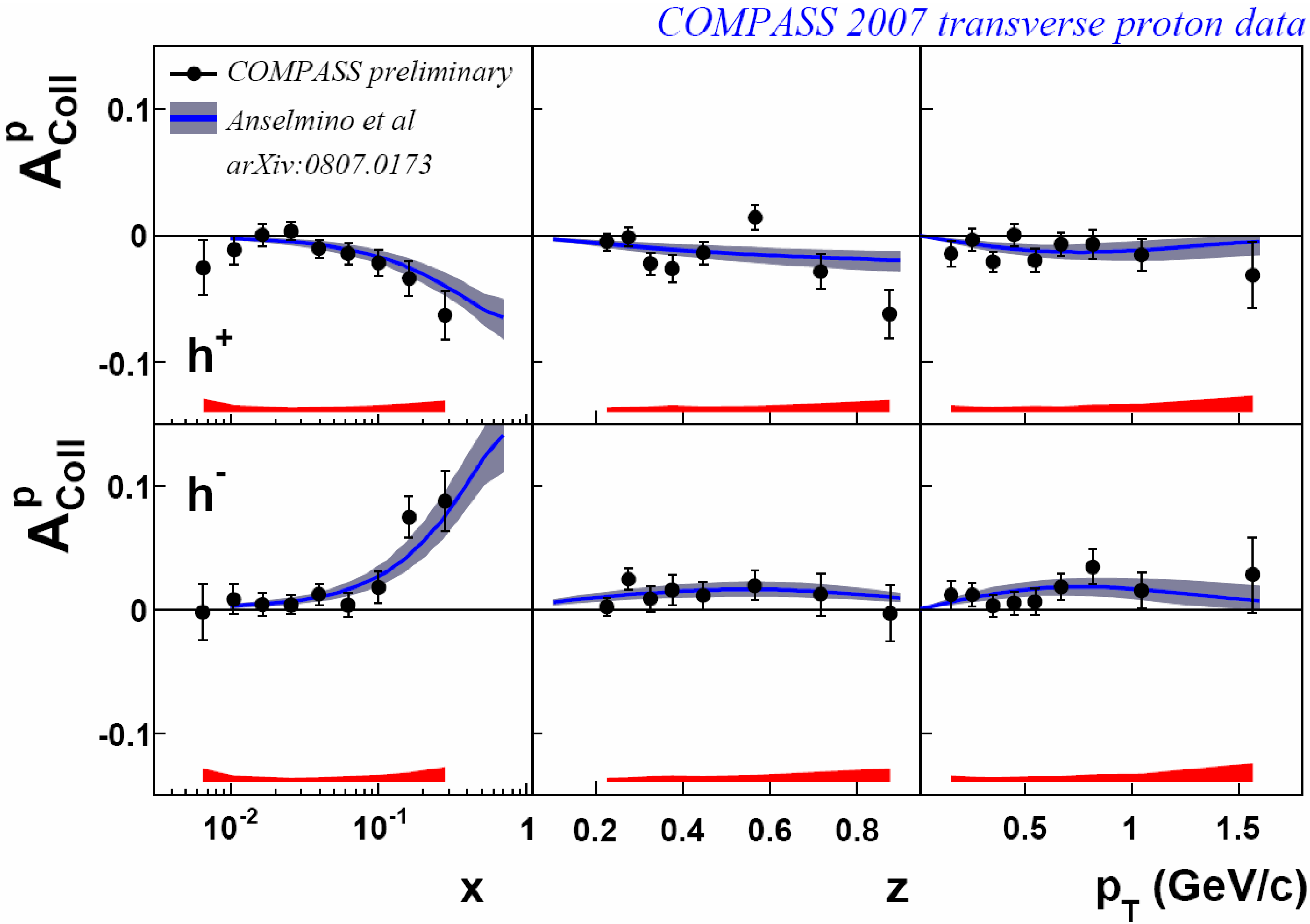
Collins Asymmetry – Proton data



Collins Asymmetry – comparison with HERMES data

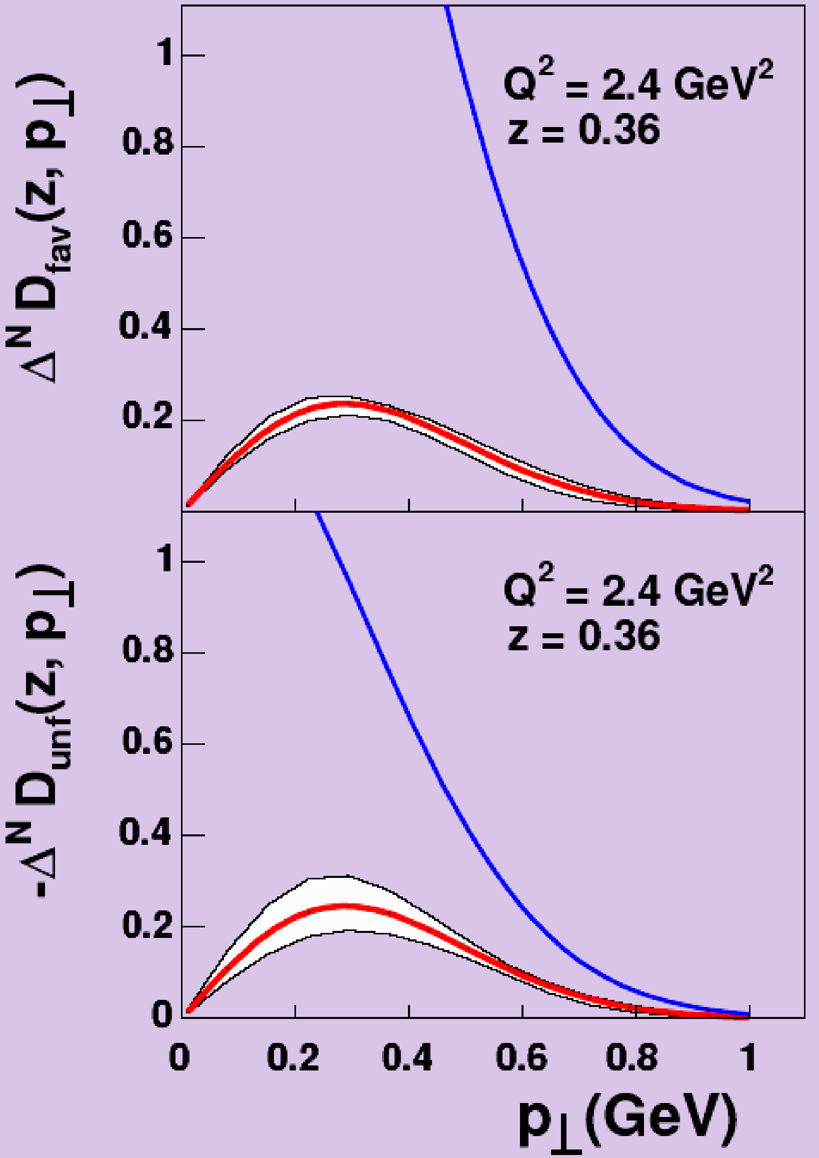


Collins-Asymmetry – Predictions



Collins Fragmentation function – Fits to Data

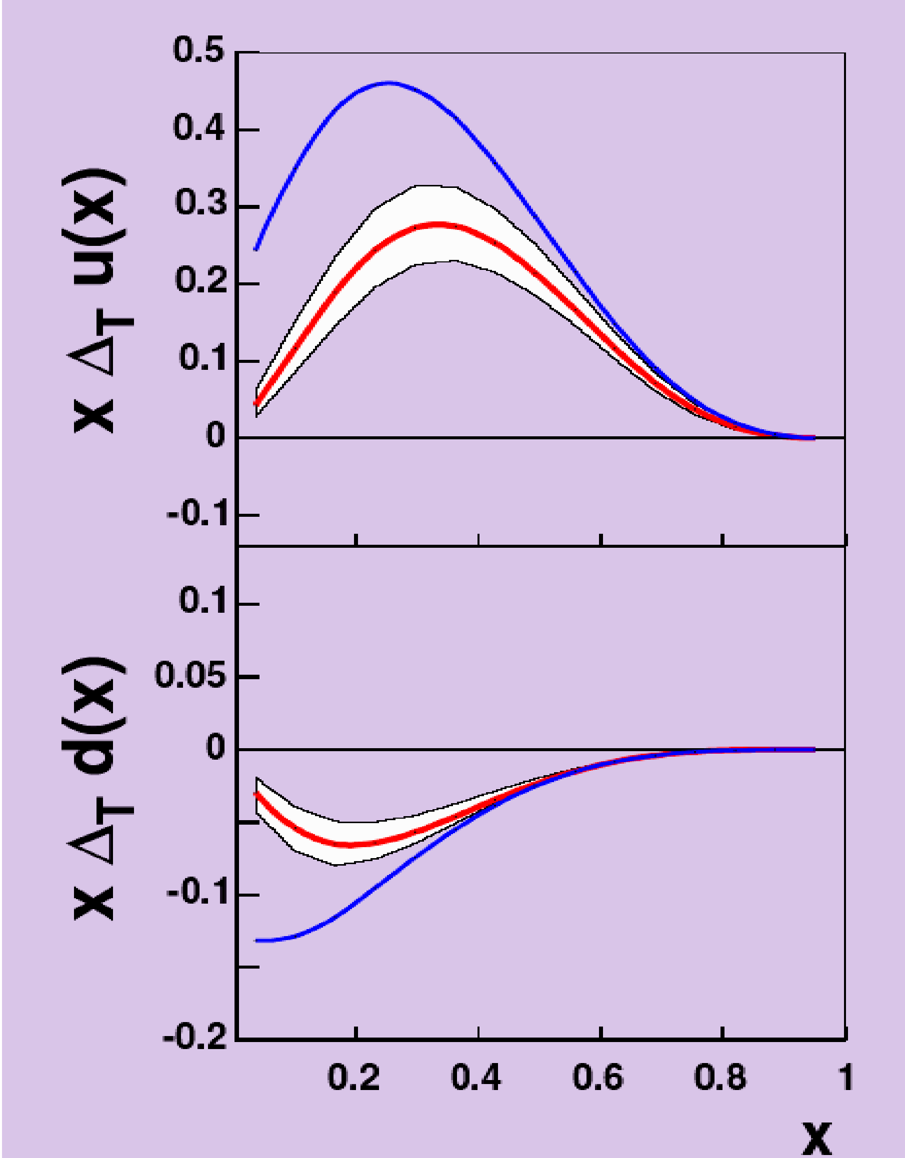
new results using HERMES (p) and COMPASS (d) pion data, and BELLE data



A. Prokudin et al., Transversity ´08 Ferrara, Mai ´08

Transversity – Fits to Data

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

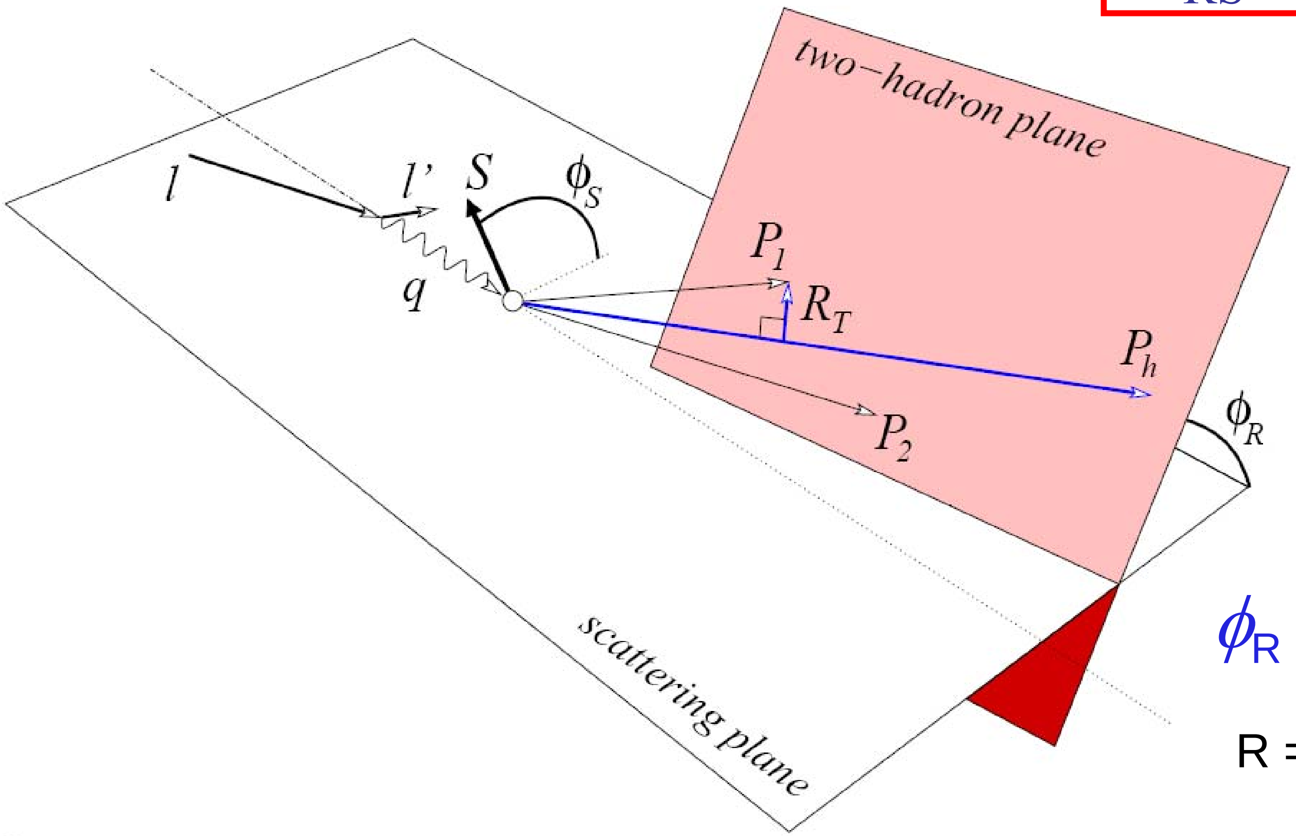


A. Prokudin et al. Ferrara ´08

Transversity in hadron pair production

Collins-Angle replaced by:

$$\Phi_{RS} = \phi_R + \phi_S - \pi$$



ϕ_R defined by:

R = (z_1**p_2** – z_2**p_1**)/(z_1+z_2)

(X. Artru, hep-ph/0207309)

Transversity in hadron pair production

The measured asymmetry A_{RS} is a product of Transversity and the „Interference Fragmentation Function“ $H_1^{\sphericalangle}$

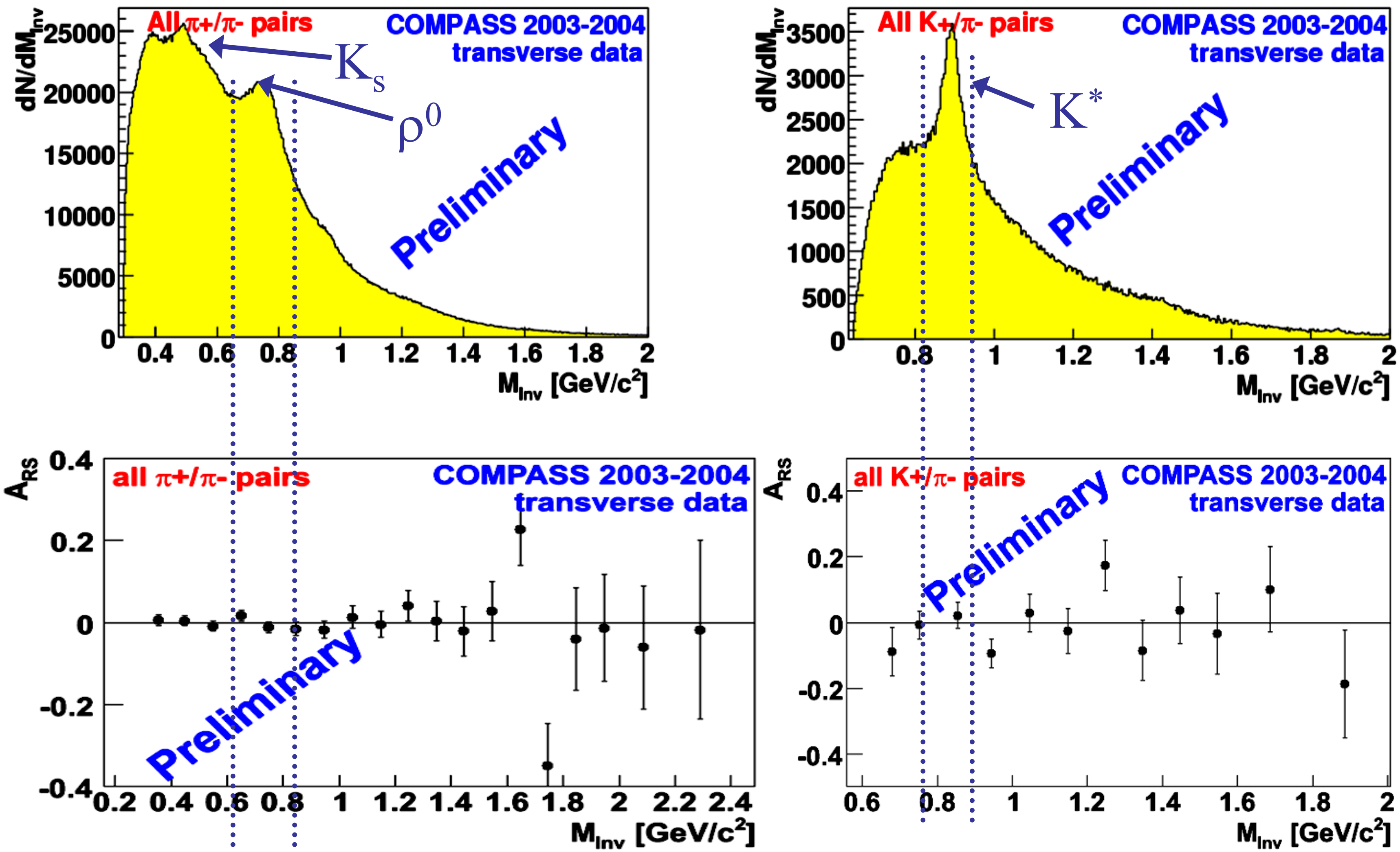
$$A_{RS} = \frac{A}{f P_T D_{nn}} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_1^{\sphericalangle}(z, M_{inv}^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_1(z, M_{inv}^2)}$$

f target dilution factor

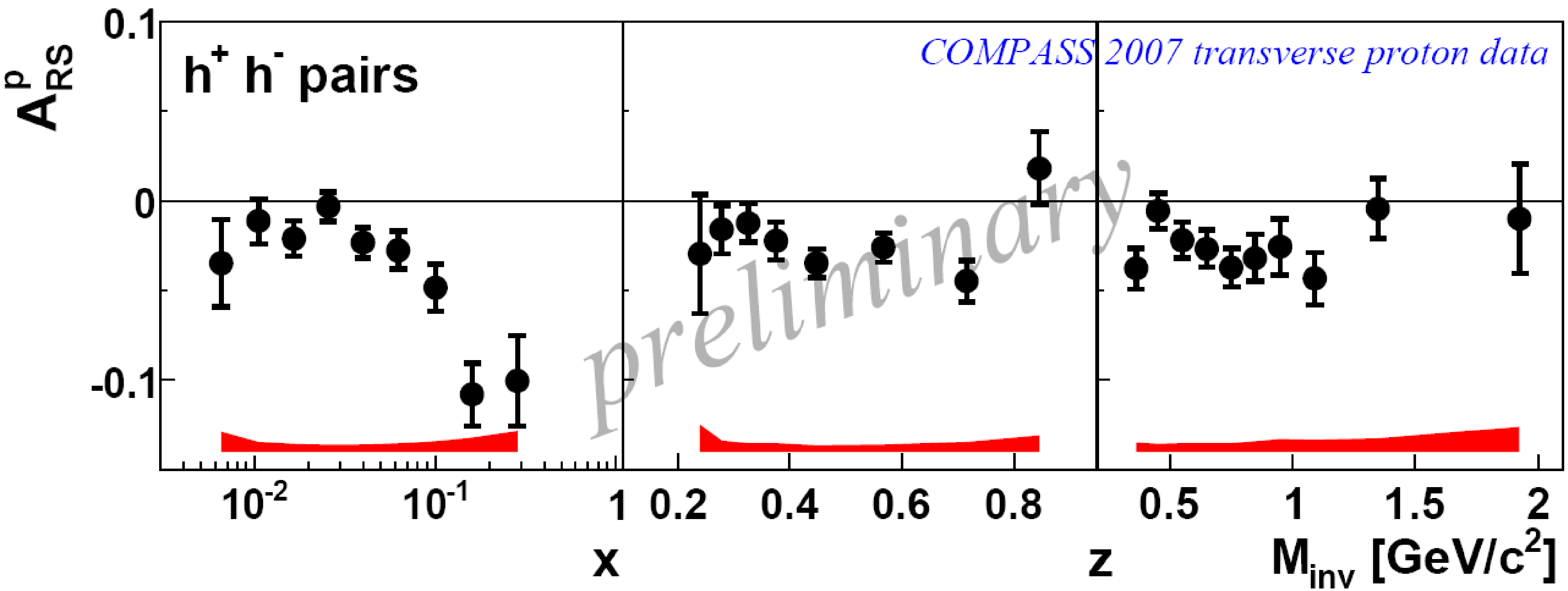
P_T target polarization

$D_{nn} = \frac{1-y}{1-y+y^2/2}$ depolarization factor

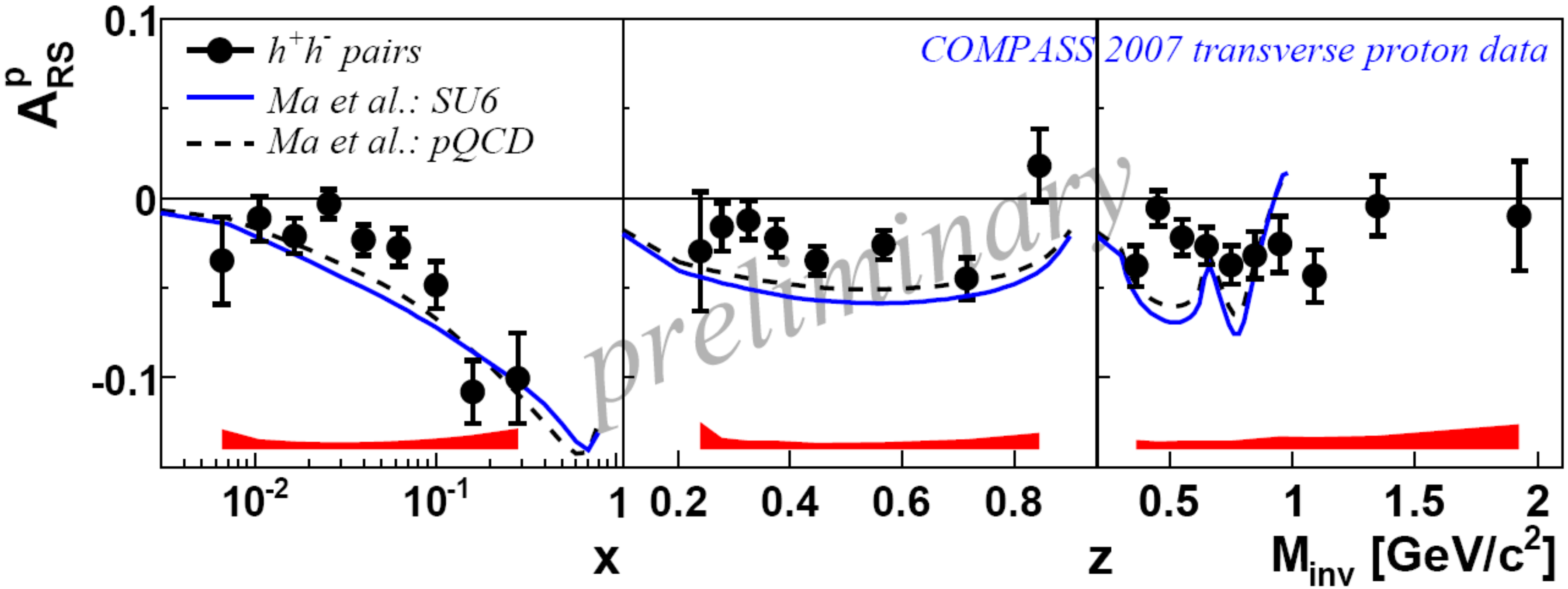
Hadron Pairs – Deuteron Data



Hadron pairs – Proton data

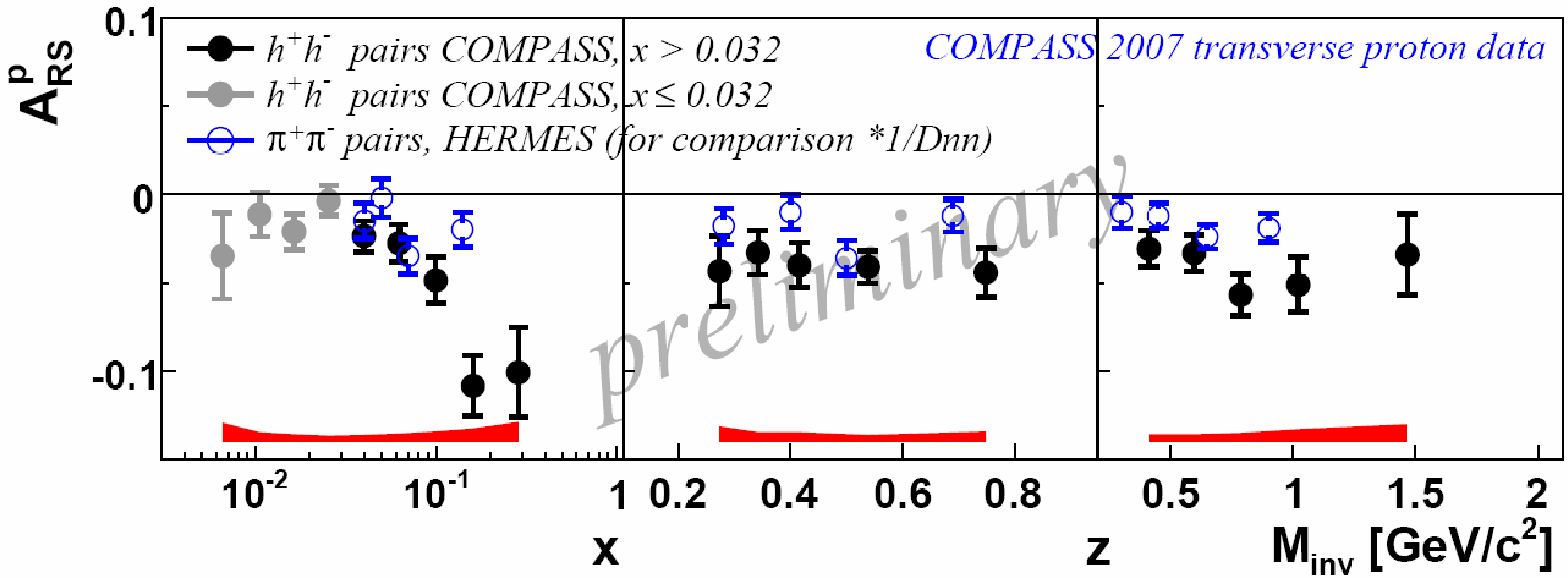


Hadron pairs – Proton data

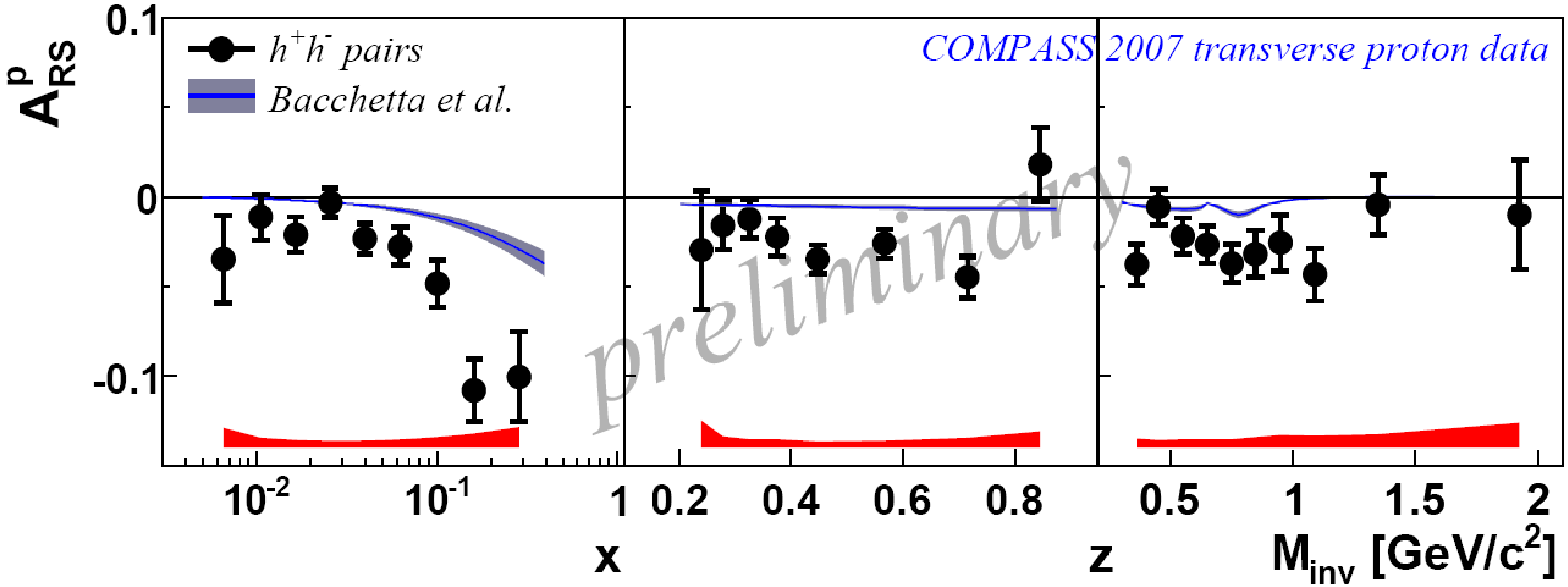


Calculation by Ma et al. , TPSH09, Armenia, June 2009.

Hadron pairs – Comparison with HERMES



Hadron pairs – Proton data



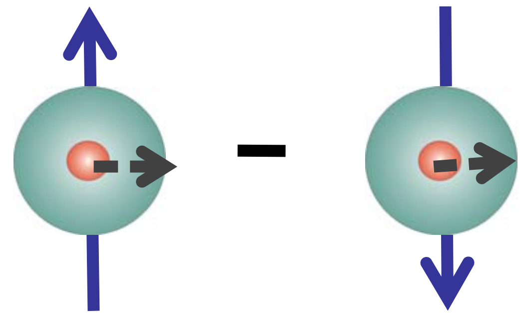
Prediction by Bacchetta, Radici, hep-ph/0608037
(Interference Fragmentation function scaled down to fit HERMES data)

still waiting for extraction of Interference FF by BELLE

Sivers Effect

$$F_{UT}^{\sin(\phi_h+\phi_s)} \propto \Delta_0^T q(x) \otimes D_1$$

Distribution of unpolarized quarks with transverse momentum k_T in a transversely polarized nucleon



The presence of spin can distort the distribution of quarks (needs orbital angular momentum of quarks)

A distortion in the distribution of quarks in transverse space can give rise to a nonzero Sivers function

Sivers Effect

$$N_h^{\pm}(\Phi_{Siv}) = N_h^0 \{1 \pm A_S^h \cdot \sin \Phi_{Siv}\}$$

$\Phi_{Siv} = \phi_h - \phi_s$

Sivers angle independent
of Collins angle:
measure both in the same data

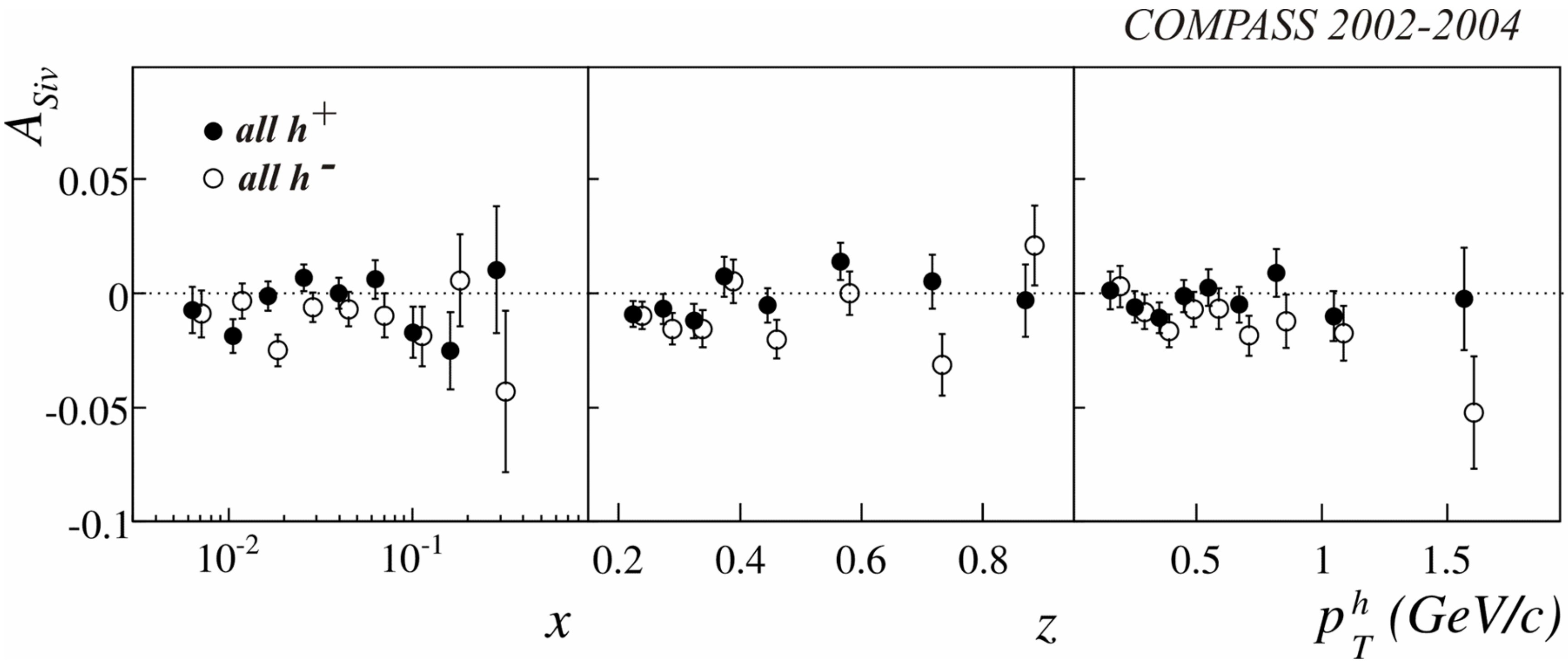
The Sivers asymmetry:

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

$\Delta_0^T q(x)$: Sivers function

Sivers asymmetry - deuteron data

- 2004: first results from 2002 data [PRL94 (2005) 202002] confirmed in
- 2006: **final results from 2002-2004 data** [NPB765 (2007)31]



asymmetries compatible with zero within the statistical errors

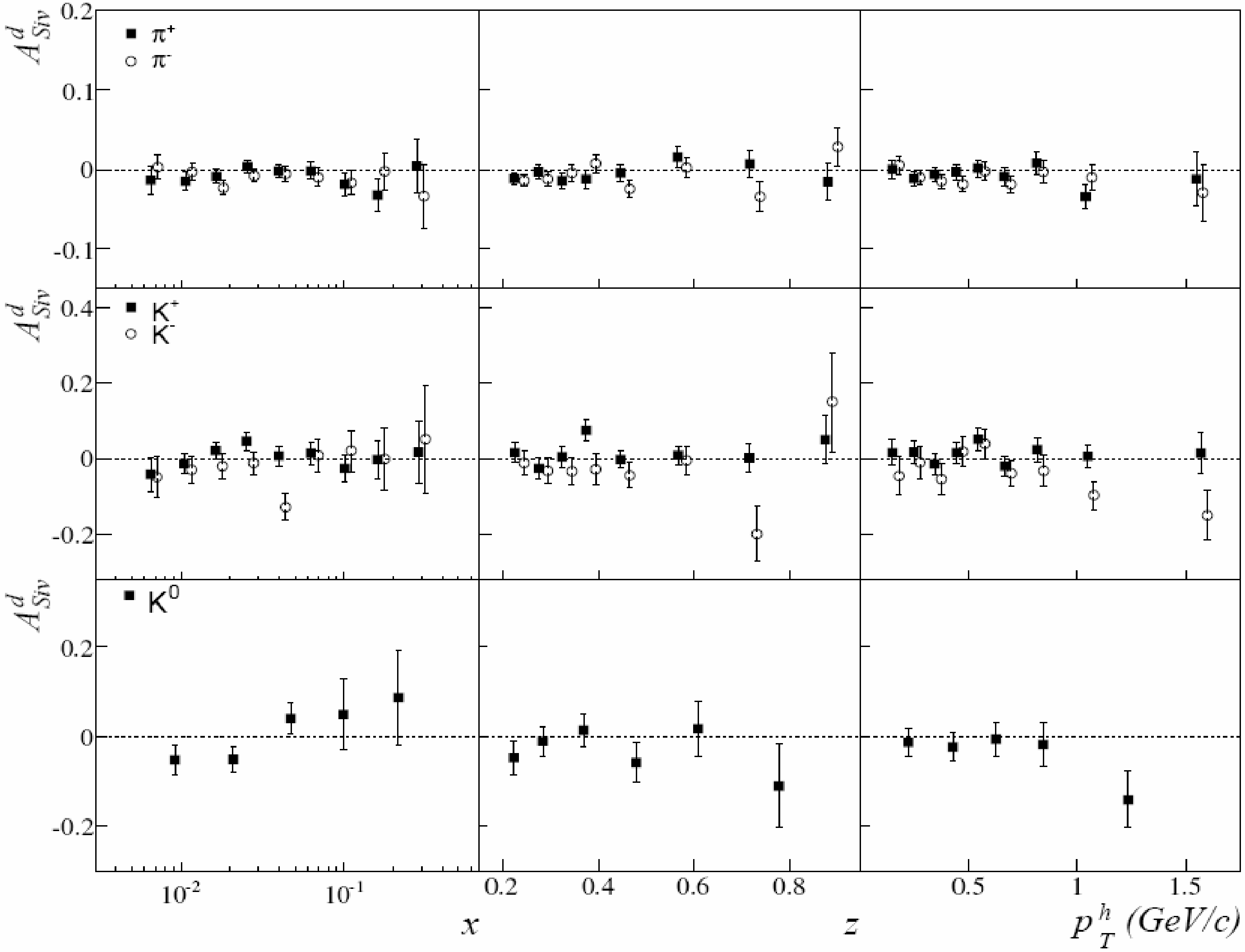
(systematic errors much smaller)

possible cancellation between u and d quark contributions in the deuteron

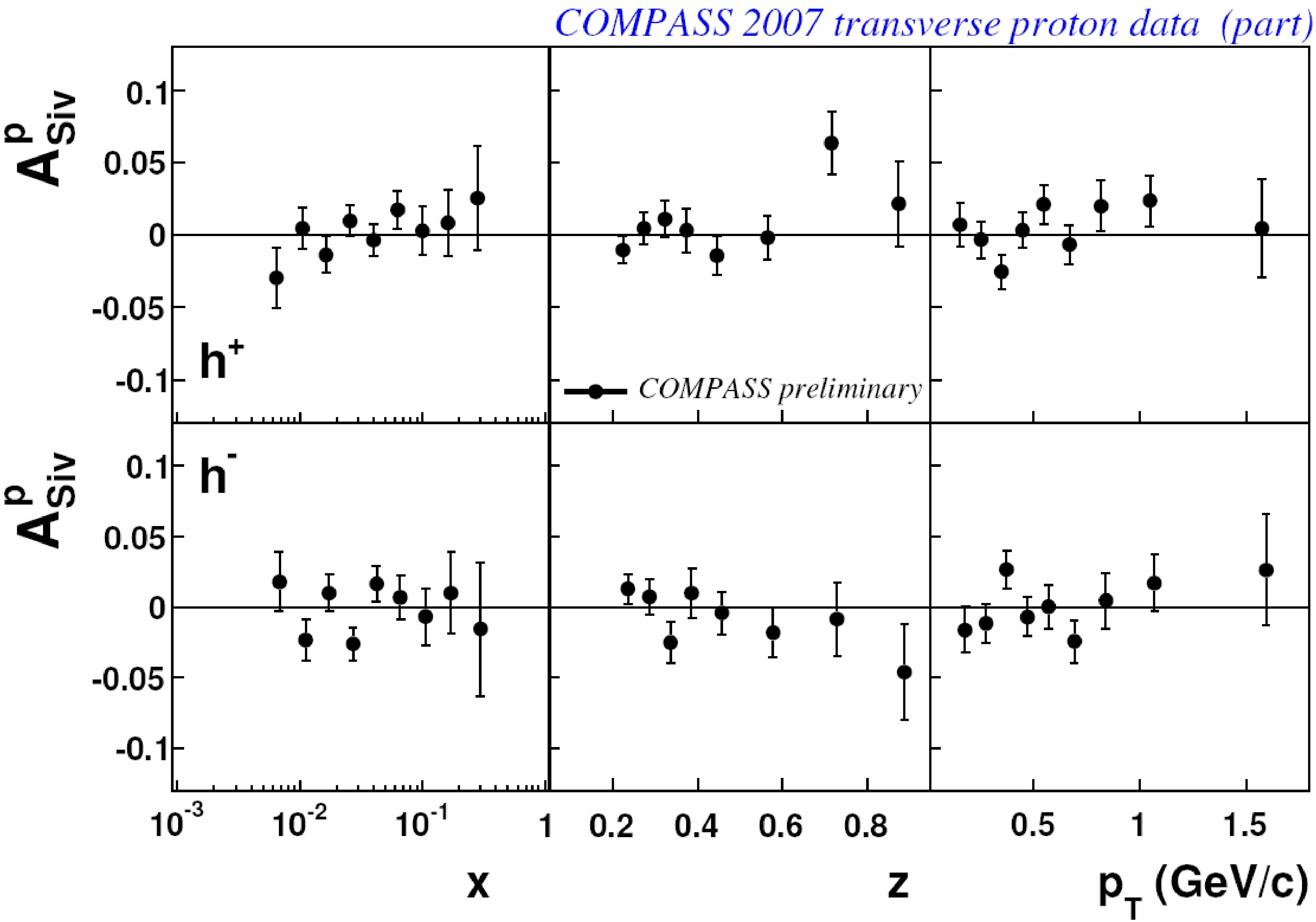
Sivers asymmetry - deuteron data

identified hadrons

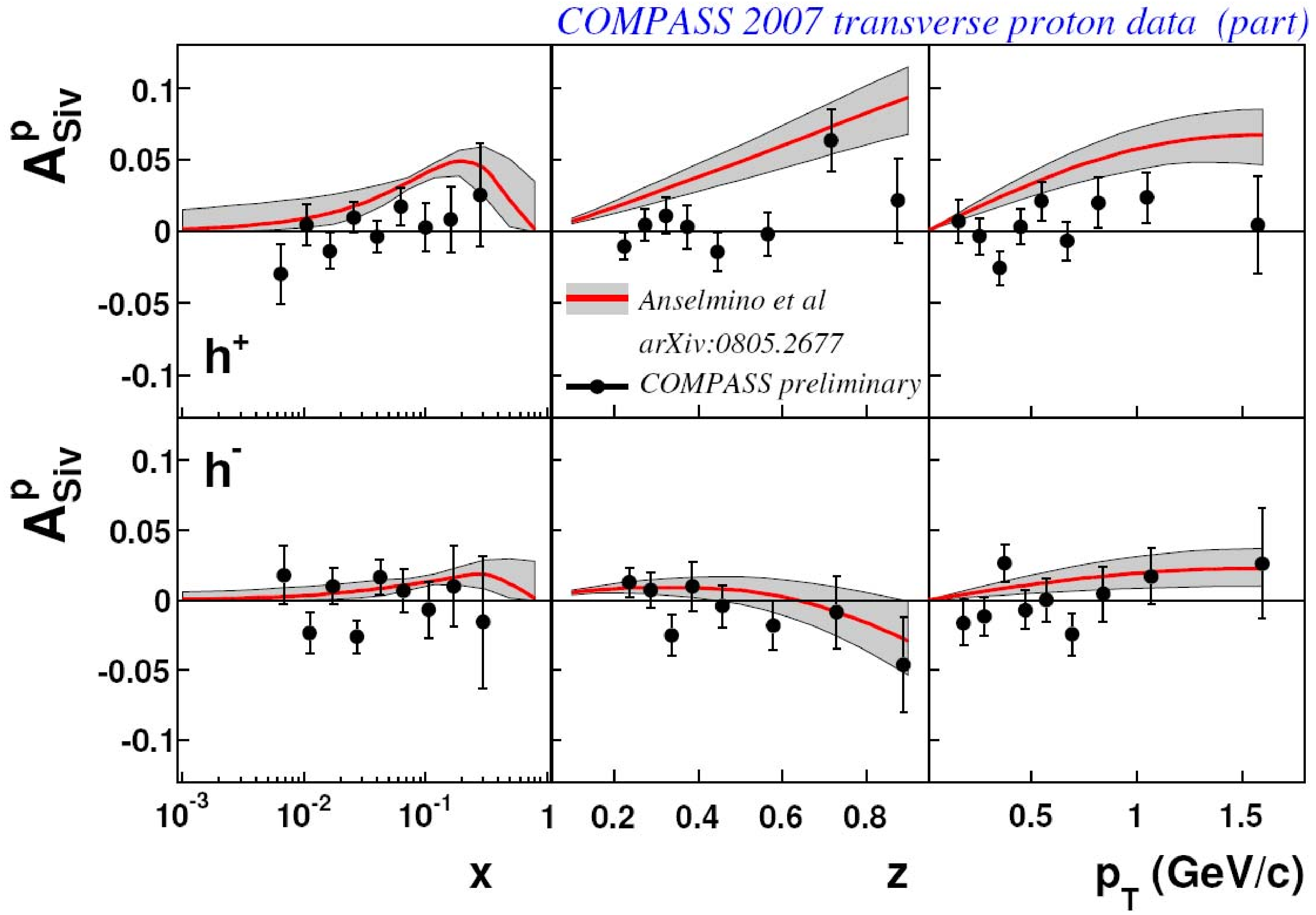
- 2007: **final results from 2002-2004 data** [PLB 673 (2009) 127]



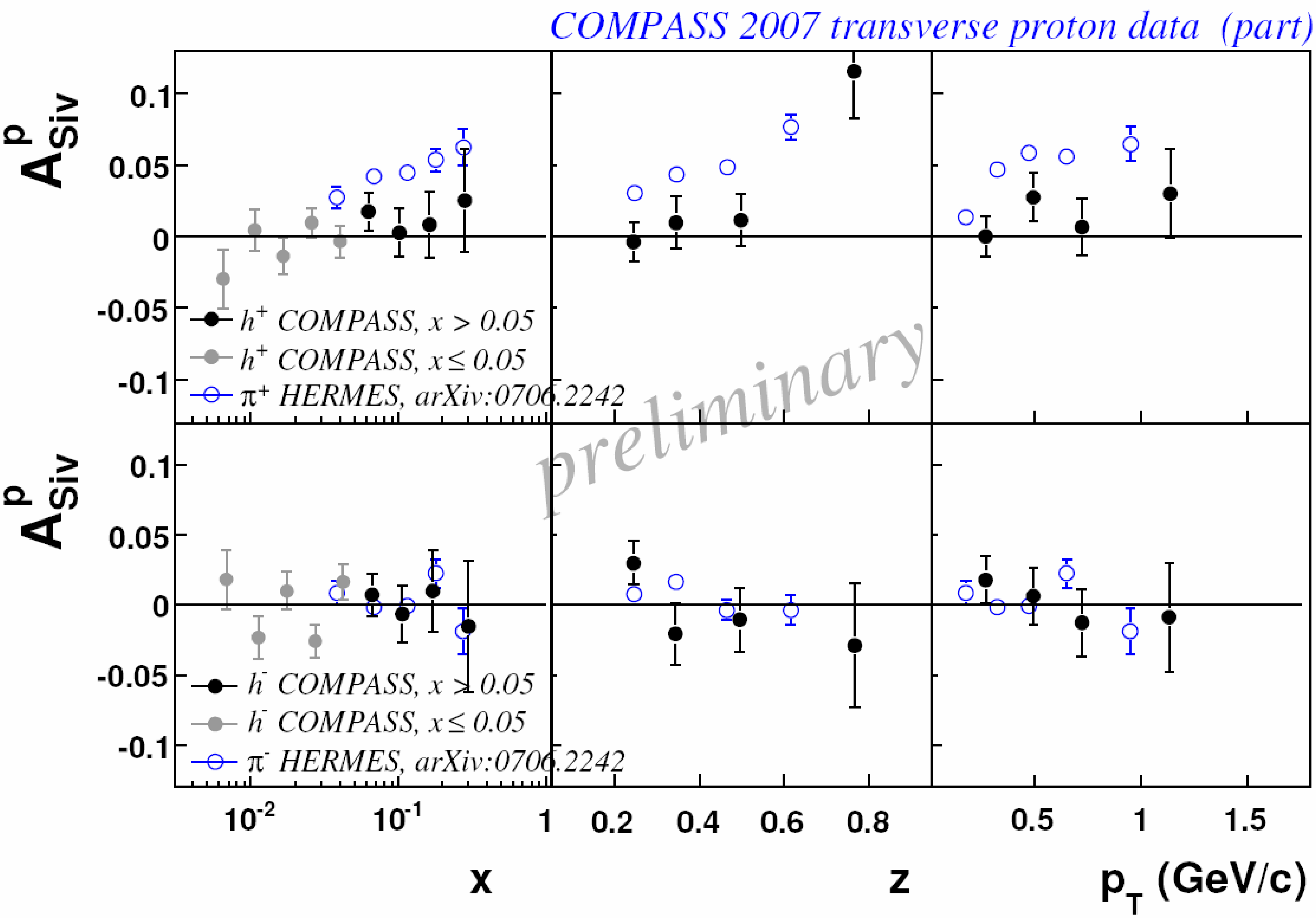
Sivers Asymmetry – Proton Data



Sivers Asymmetry– Proton Data



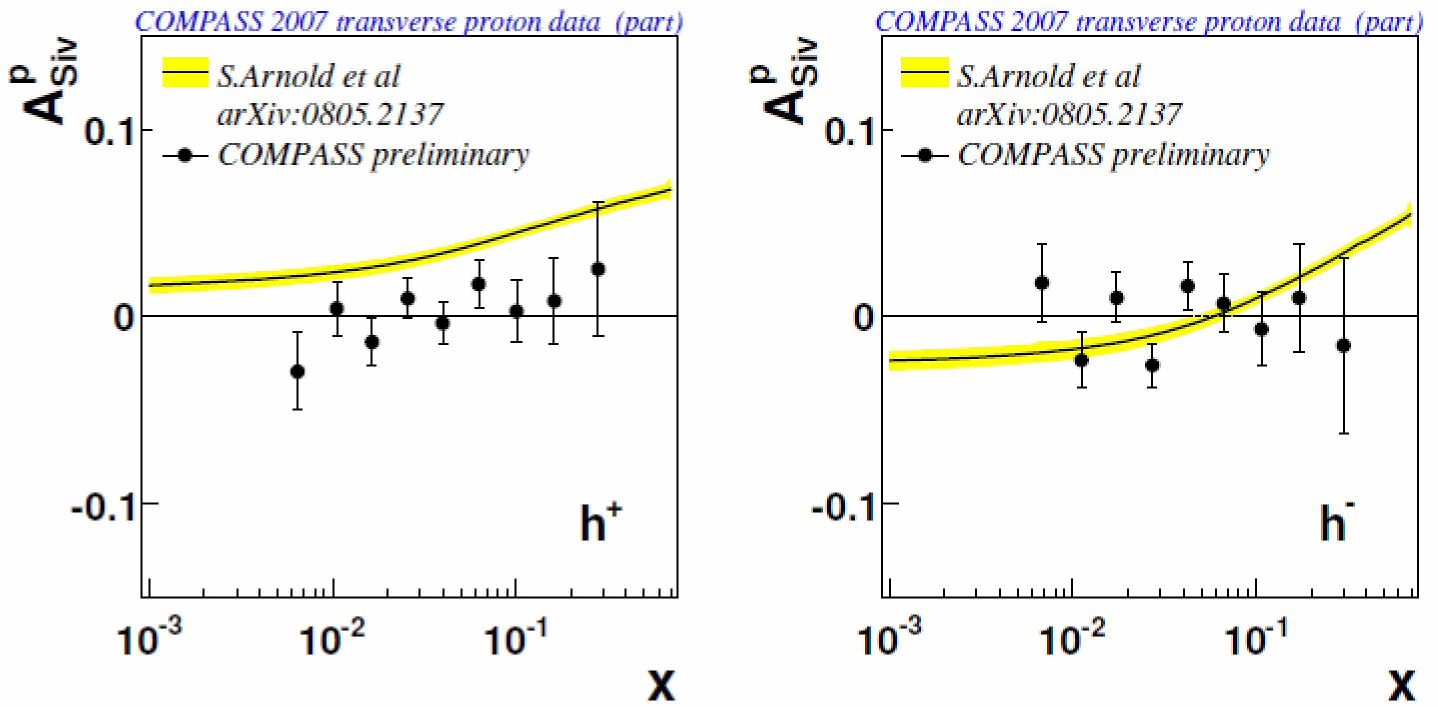
Sivers Asymmetry: Comparison with HERMES



Results: Sivers Asymmetry

comparison with predictions from

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

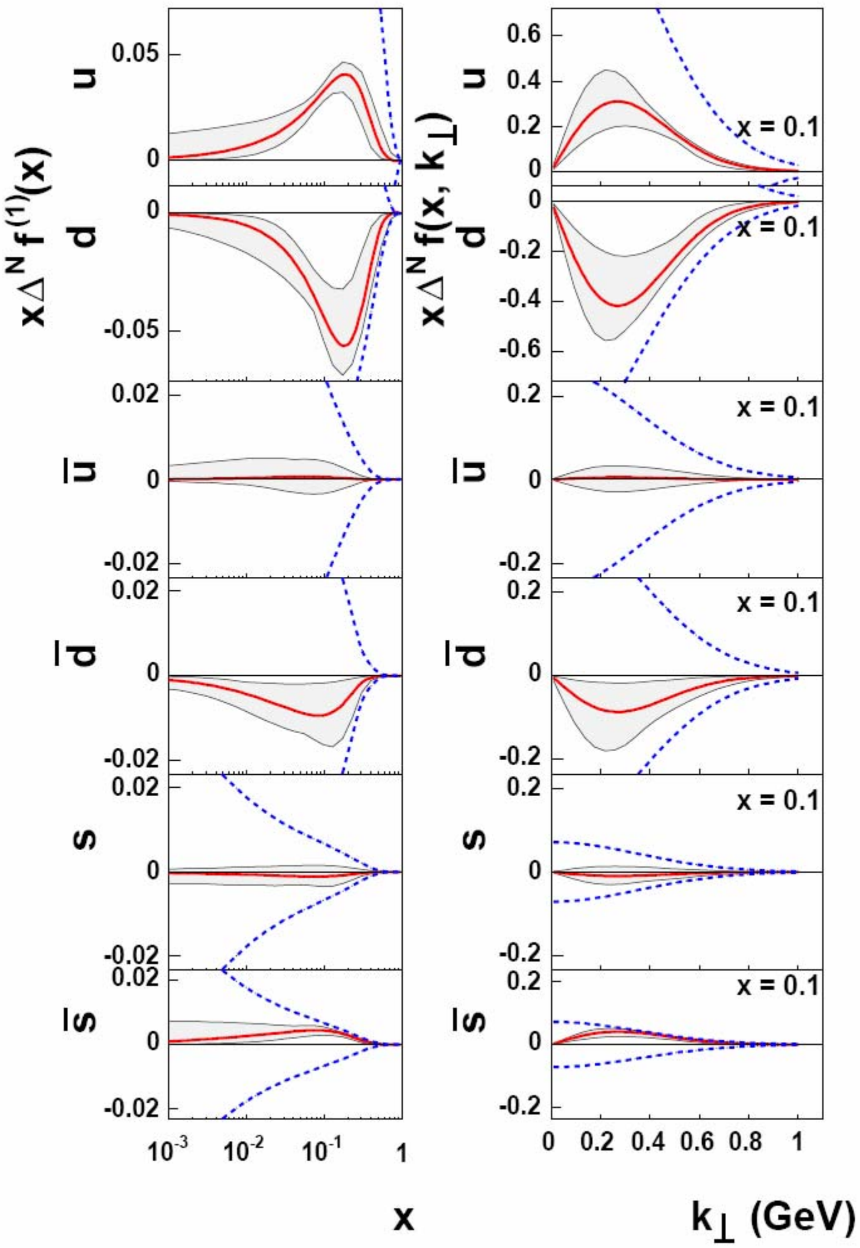


$$A_{UT\,\mathrm{measured}}^{\sin(\phi-\phi_S)} = \Big\{\text{'twist-2 Sivers effect' in Eqs. (11, 15)}\Big\} + C(Q)\,\frac{M_N^2}{Q^2}$$

Maybe such corrections are irrelevant for $Q^2 > 1\,\mathrm{GeV}^2$ which is typically used as DIS-cut. In any case, a careful comparison of all (present and future) data from COMPASS, HERMES and JLab will shed light on the possible size of power corrections.

Sivers Distribution Function

new results using COMPASS
pion and kaon data
on deuteron
and HERMES proton data
(but not COMPASS
proton data)



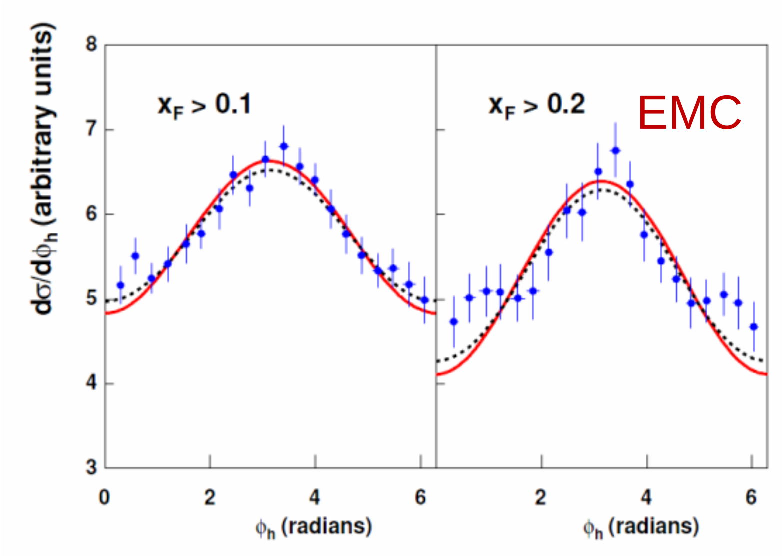
M. Boglione
in collaboration with
M. Anselmino, U. D'Alesio,
A. Kotzinian, S. Melis,
F. Murgia, A. Prokudin, C. Turk

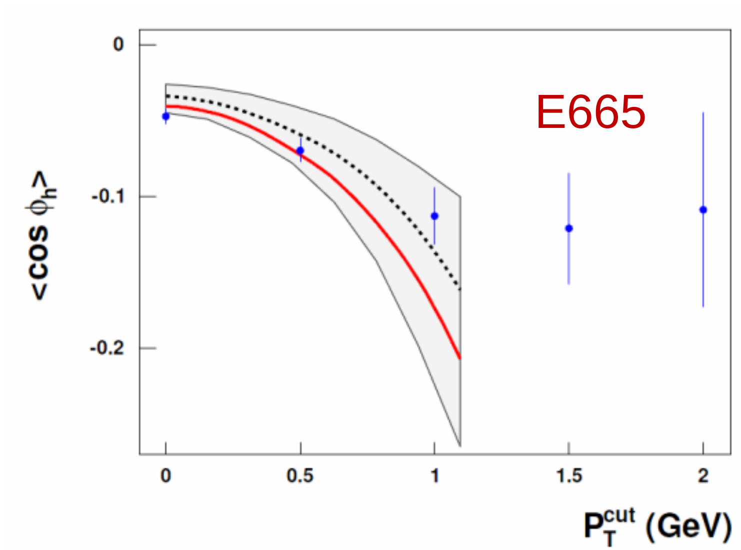
Azimuthal asymmetries in unpolarized SIDIS

- Cahn effect
- Boer-Mulders distribution function

Experimental status

- Azimuthal modulations in $lp \rightarrow l'hX$ measured by





Fits from M. Anselmino, V. Barone, E. Boglione,U. D'Alesio, F. Murgia, A. Prokudin, A. Kotzinian, and C. Turk

Large modulations up to 40% for $\cos\phi$, while $\cos 2\phi \sim$ 5%

Since last year, new data from COMPASS and HERMES

Cahn effect

The unpolarized SIDIS cross section is:

$$d\sigma^{lp\to l'hX} = \sum_q f_q\left(x,Q^2\right) \otimes d\sigma^{lp\to l'q} \otimes D_q^h\left(z,Q^2\right)$$

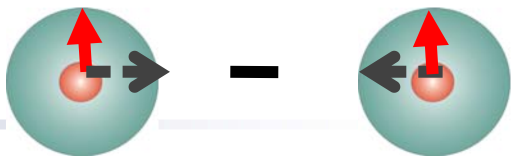
The elementary Cross-Section:

$$d\sigma^{lp\to l'q} \propto \hat{s}^2 + \hat{u}^2$$

Taking into account the quark transverse momentum:

$$\hat{s} = sx\left[1 - \frac{2k_T}{Q}\sqrt{1-y}\cdot\cos\phi\right] + O\left(\frac{k_T^2}{Q}\right)$$

Boer-Mulders Effect



$$F_{UU}^{\cos\phi}, F_{UU}^{\cos 2\phi} \propto h_1^{\perp} \otimes H_1^{\perp}$$

Side view

Front view

Convoluted with Collins function

Contributes to cos ϕ_h and cos $2\phi_h$ moments

COMPASS data

data sample:

part of the 2004 data collected with L and T target polarization

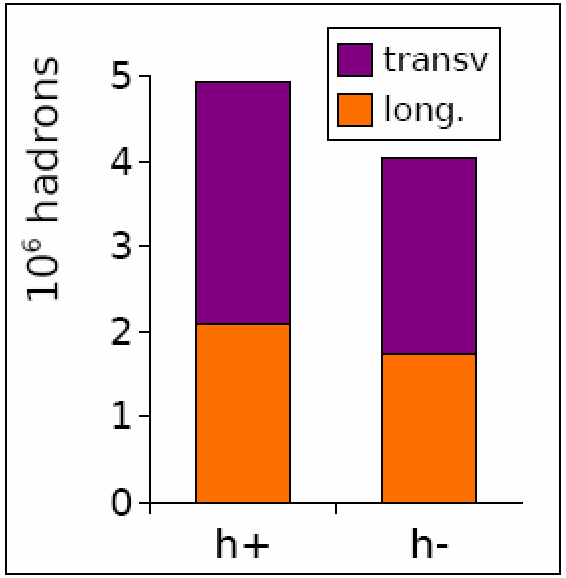
with both target orientation configurations to cancel possible polarization effects

event selection:

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

- $0.2 < z < 0.85$
- $0.1 < p_T < 1.5\ GeV/c$

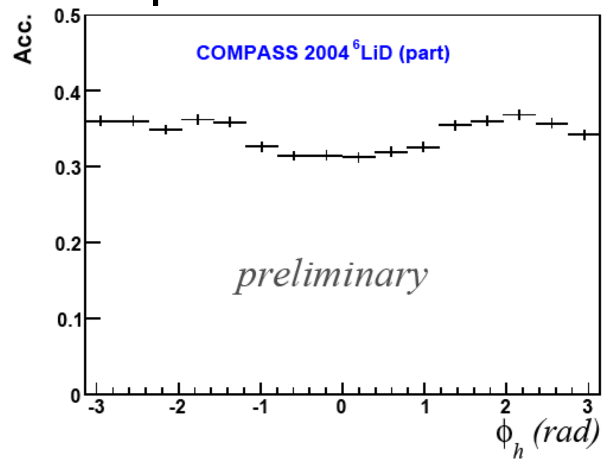
final statistics:



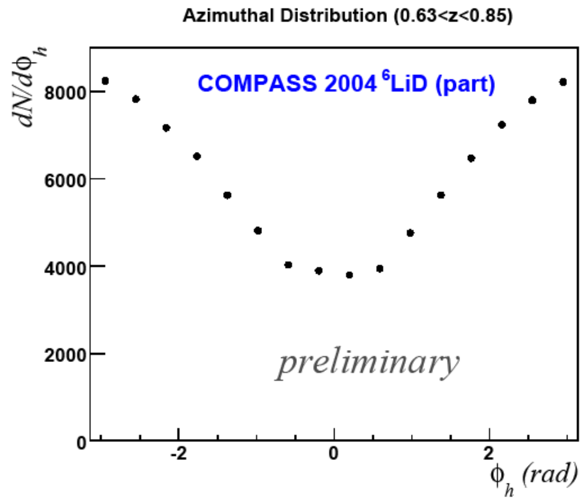
Unpolarized Cross-section

the azimuthal distributions have been corrected by the acceptance of the experiment
→ MC simulations
for L and T target polarization data

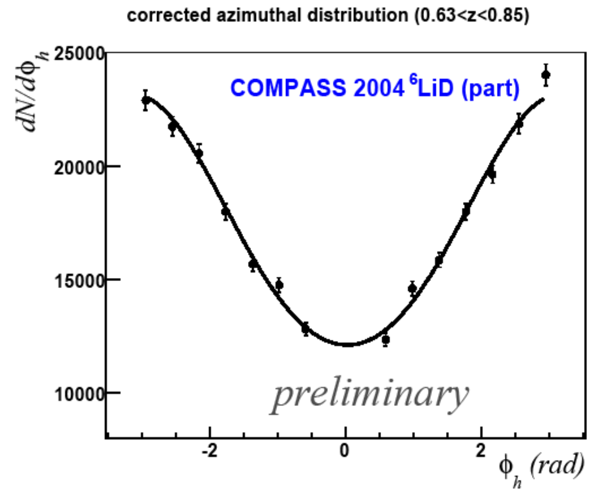
acceptance (0.63<z<0.85)



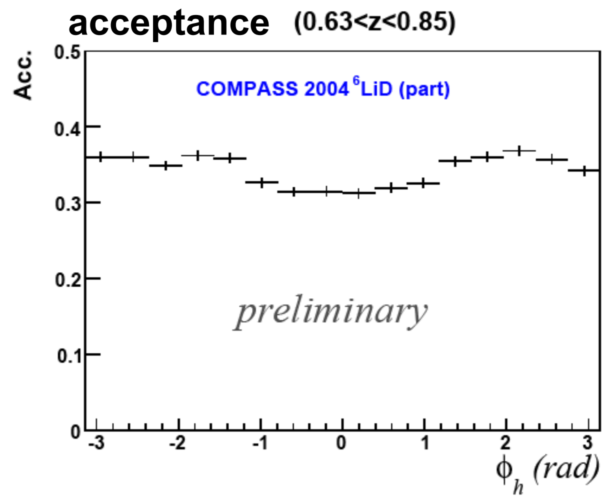
initial azimuthal distribution



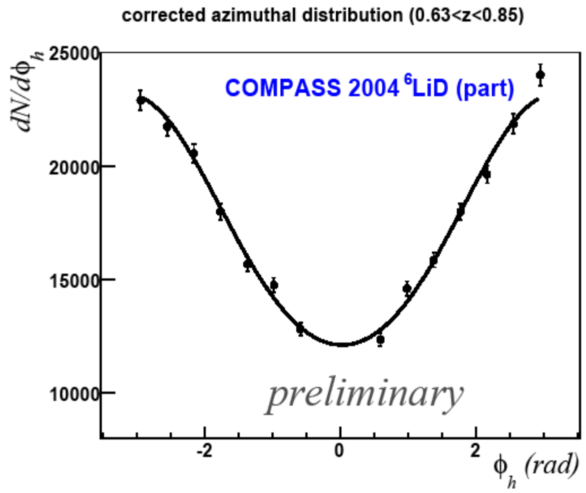
final azimuthal distribution



Unpolarized Cross-section



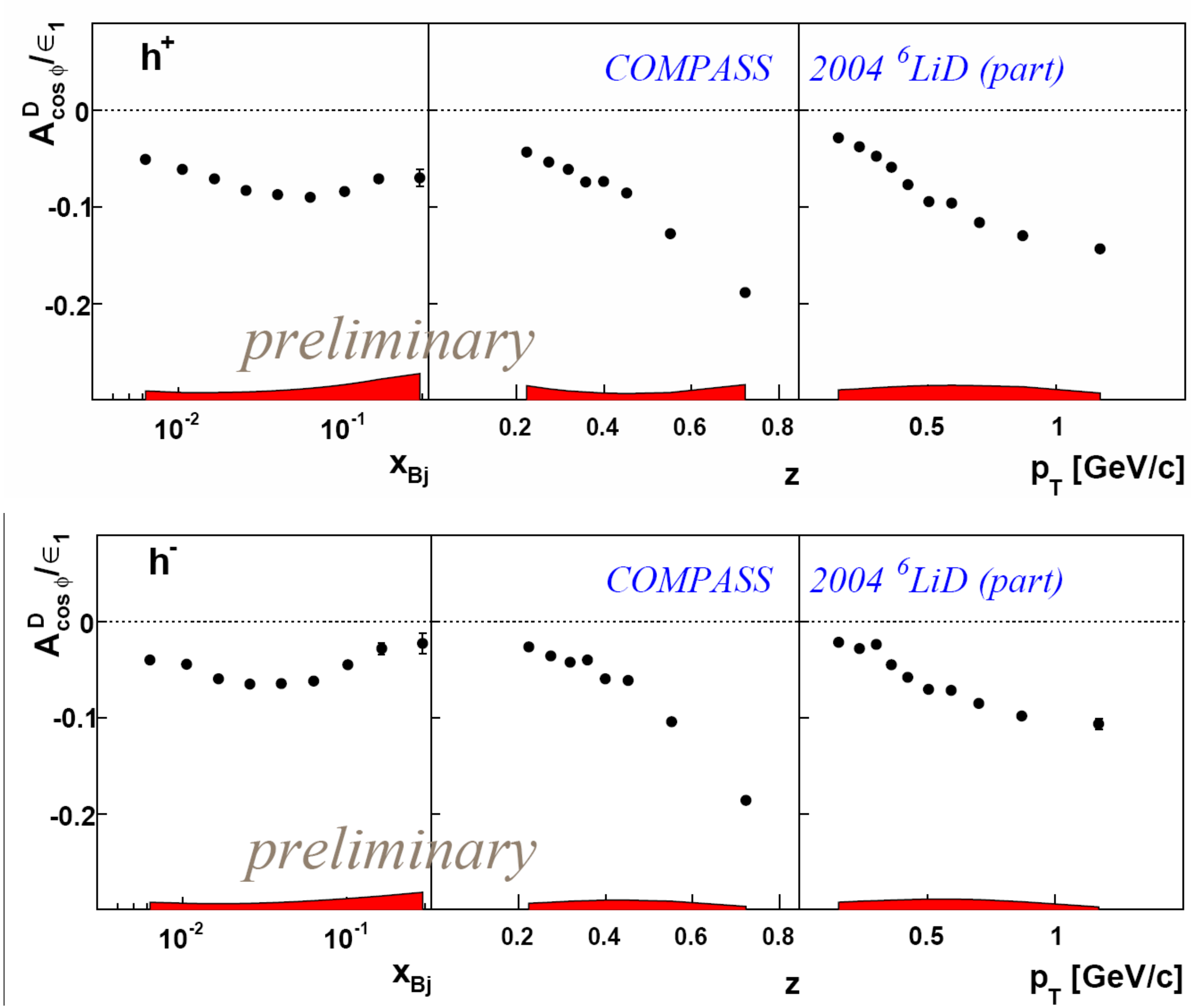
final azimuthal distribution



the final azimuthal distributions are fitted with the function:

$$N_{corr}(\phi_h) = N_0(1 + A_{\sin\phi_h}\sin\phi_h + A_{\cos\phi_h}\cos\phi_h + A_{\cos 2\phi_h}\cos 2\phi_h)$$

Results: $\cos\phi$ Modulation

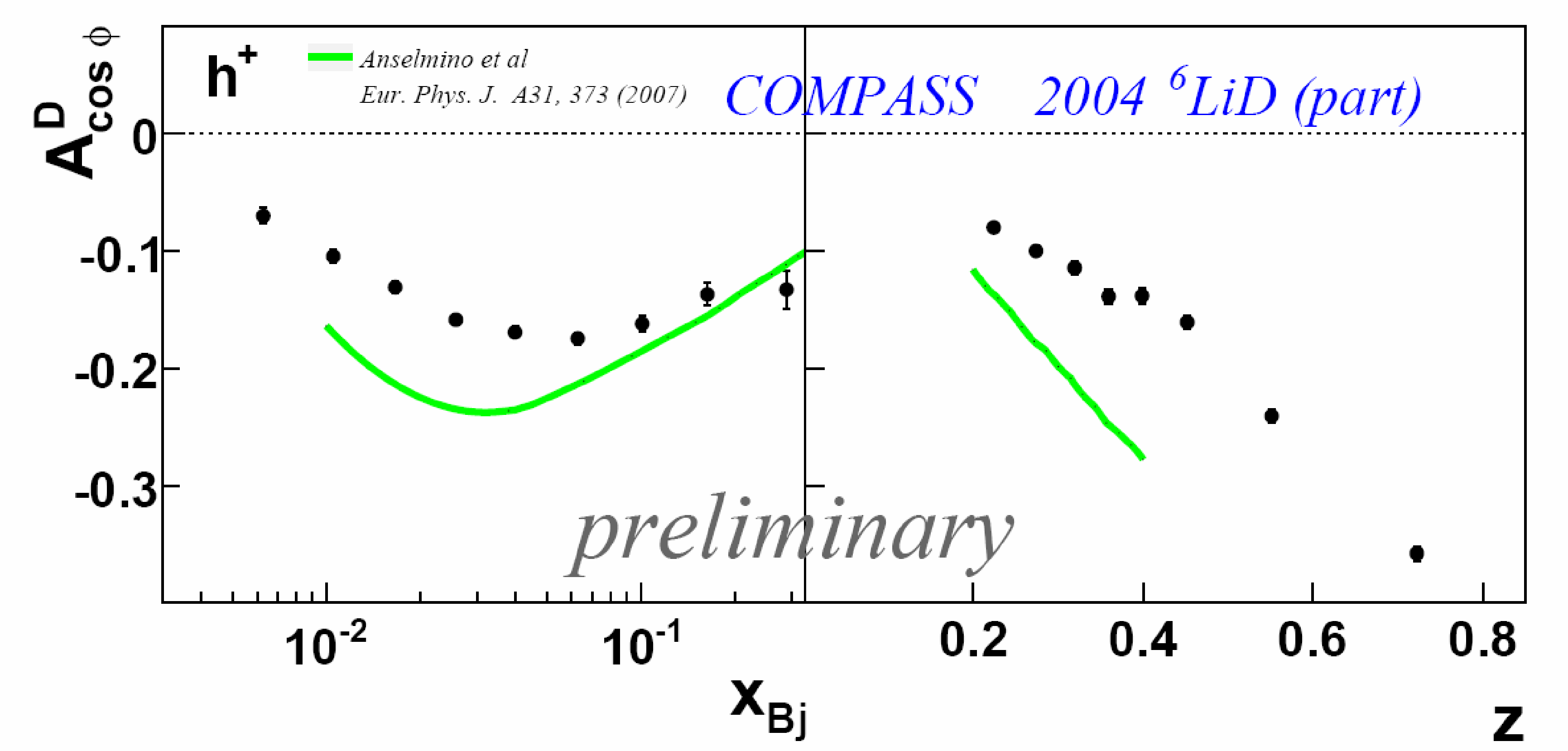


$$A_{\cos\phi} / \varepsilon_1$$

$$\varepsilon_1 = \frac{2(2-y)\sqrt{1-y}}{1+(1-y)^2}$$

Results: cosϕ Modulation

comparison with theory

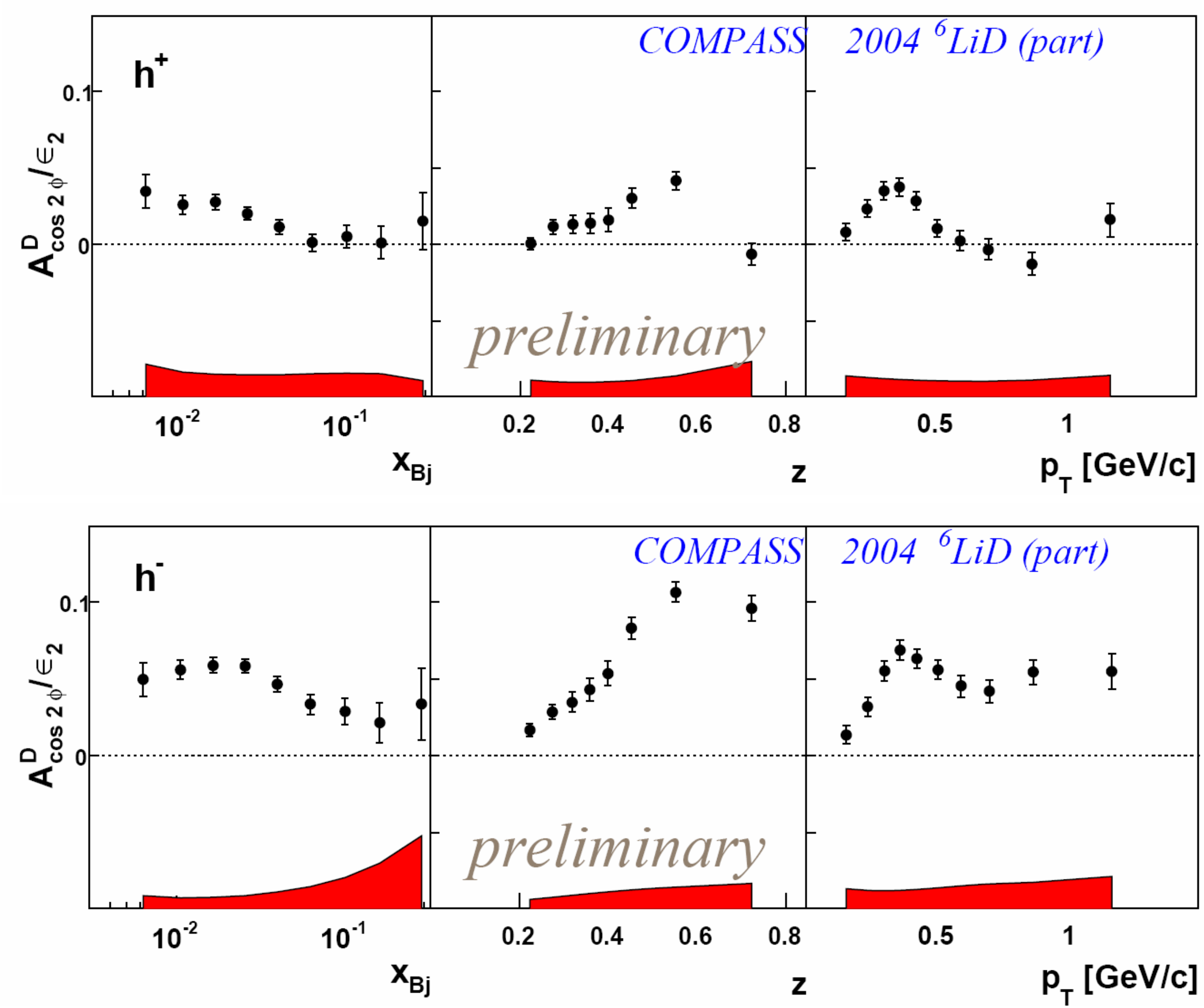


M. Anselmino, M. Boglione, A. Prokudin, C. Türk
Eur. Phys. J. A 31, 373-381 (2007)
does not include Boer – Mulders contribution

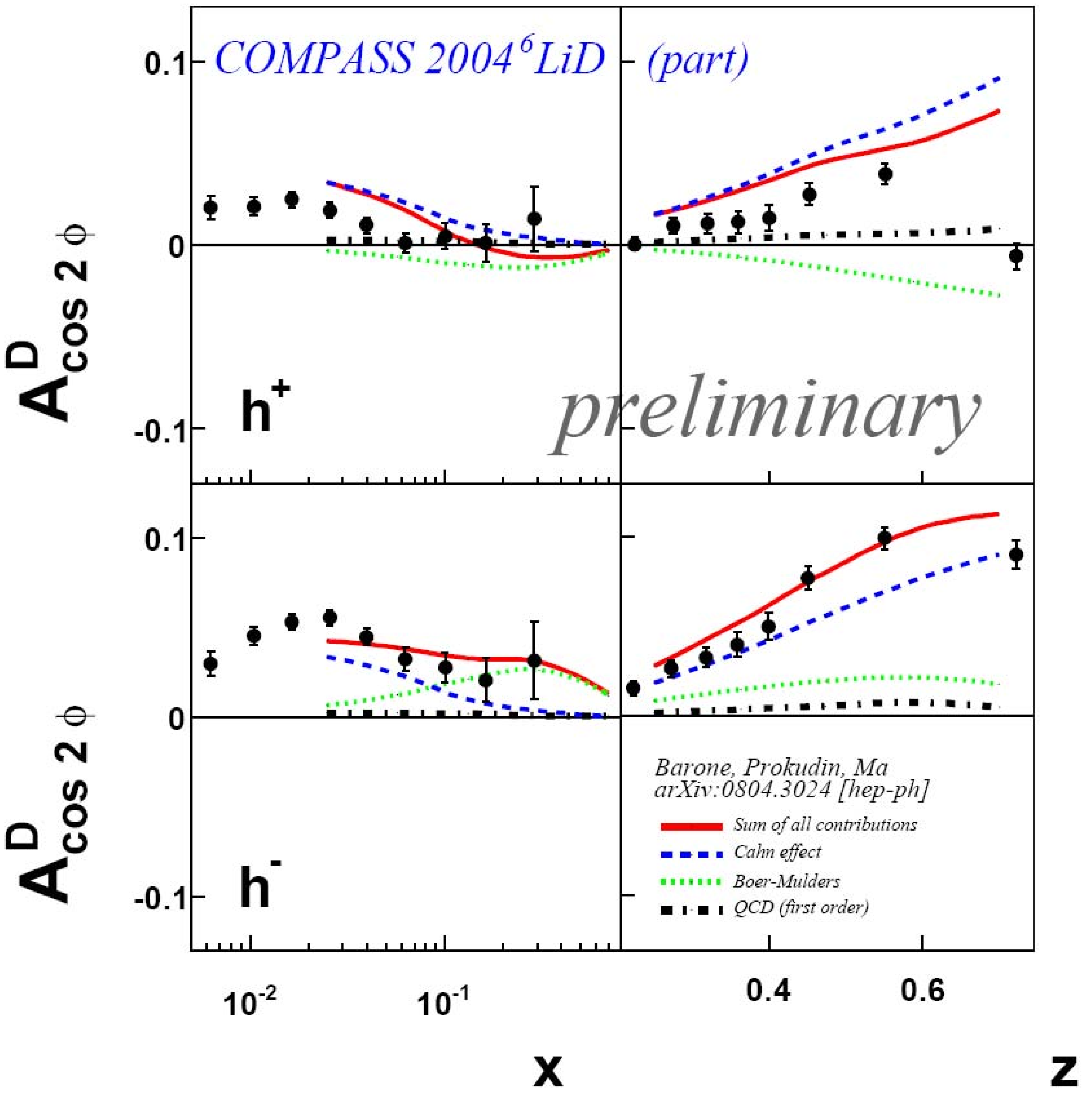
Results: cos 2ϕ Modulation

$$A_{\cos 2\phi} / \varepsilon_2$$

$$\varepsilon_2 = \frac{2(2-y)}{1+(1-y)^2}$$



Results: cos 2ϕ Modulation



Conclusions

interesting COMPASS results for:

- **large unpolarized hadron asymmetries on deuteron for positive and negative hadrons**
- **Collins and Sivers asymmetries on protons and deuterons**
- **Two hadron asymmetries**

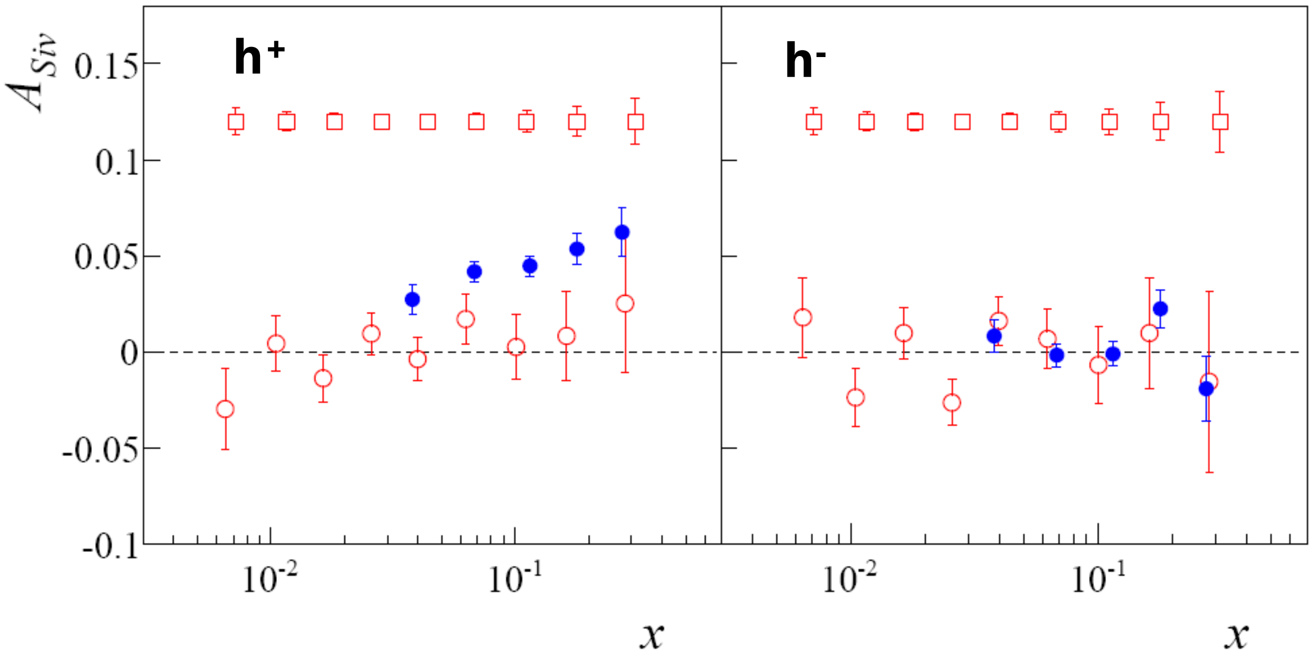
near future:

- **identified hadron asymmetries on proton**
- **all TMD asymmetries on the proton**

Outlook

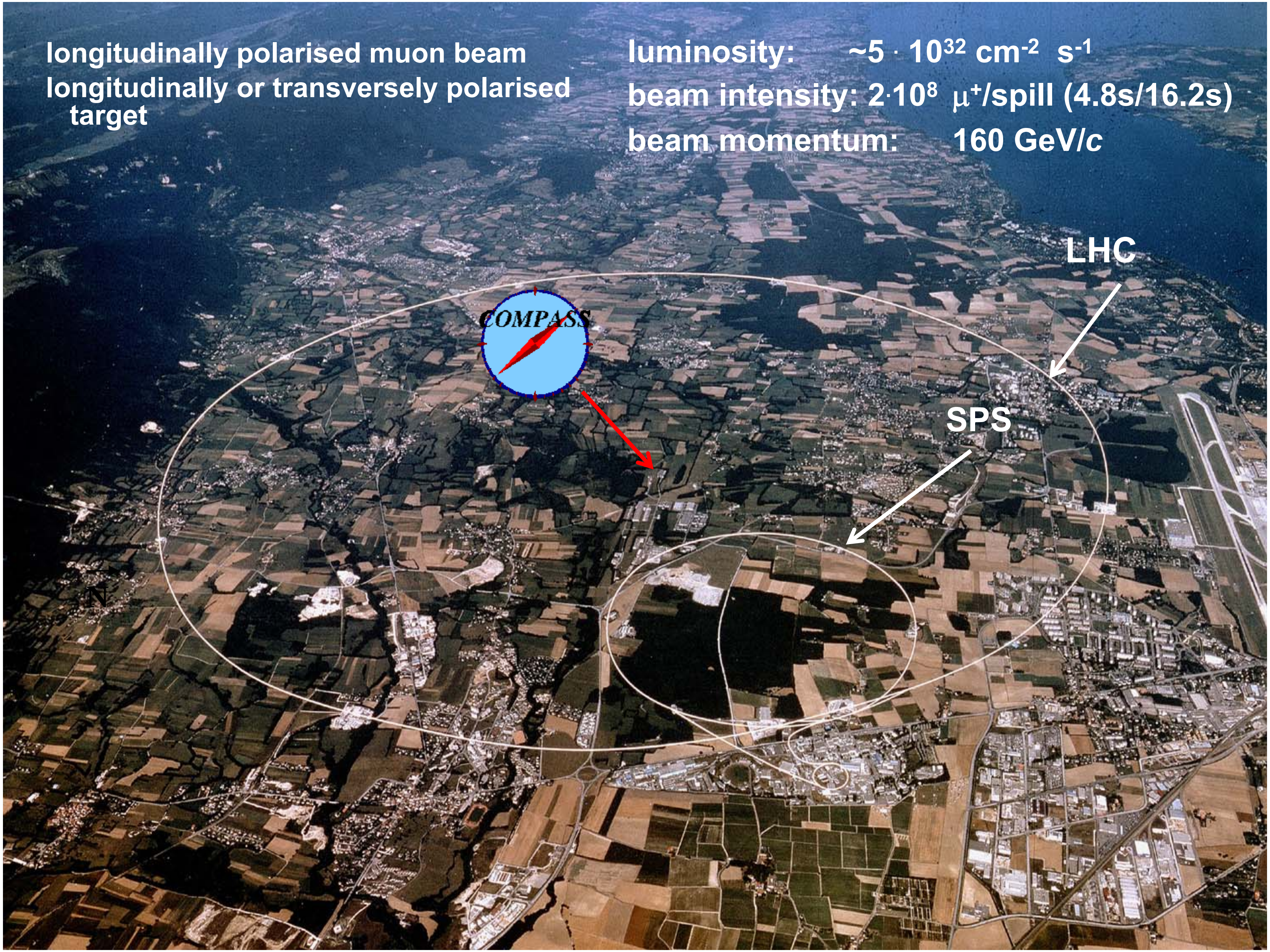
one full year of transverse data taking in 2010

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



the study of transverse spin effects needs further precise measurements and the COMPASS facility is the only place where SIDIS can be measured at high energy

Thank you!


longitudinally polarised muon beam
longitudinally or transversely polarised target
luminosity: ~5 · 10^{32} cm^{-2} s^{-1}
beam intensity: 2·10^{8} μ^+/spill (4.8s/16.2s)
beam momentum: 160 GeV/c
COMPASS
LHC
SPS
N

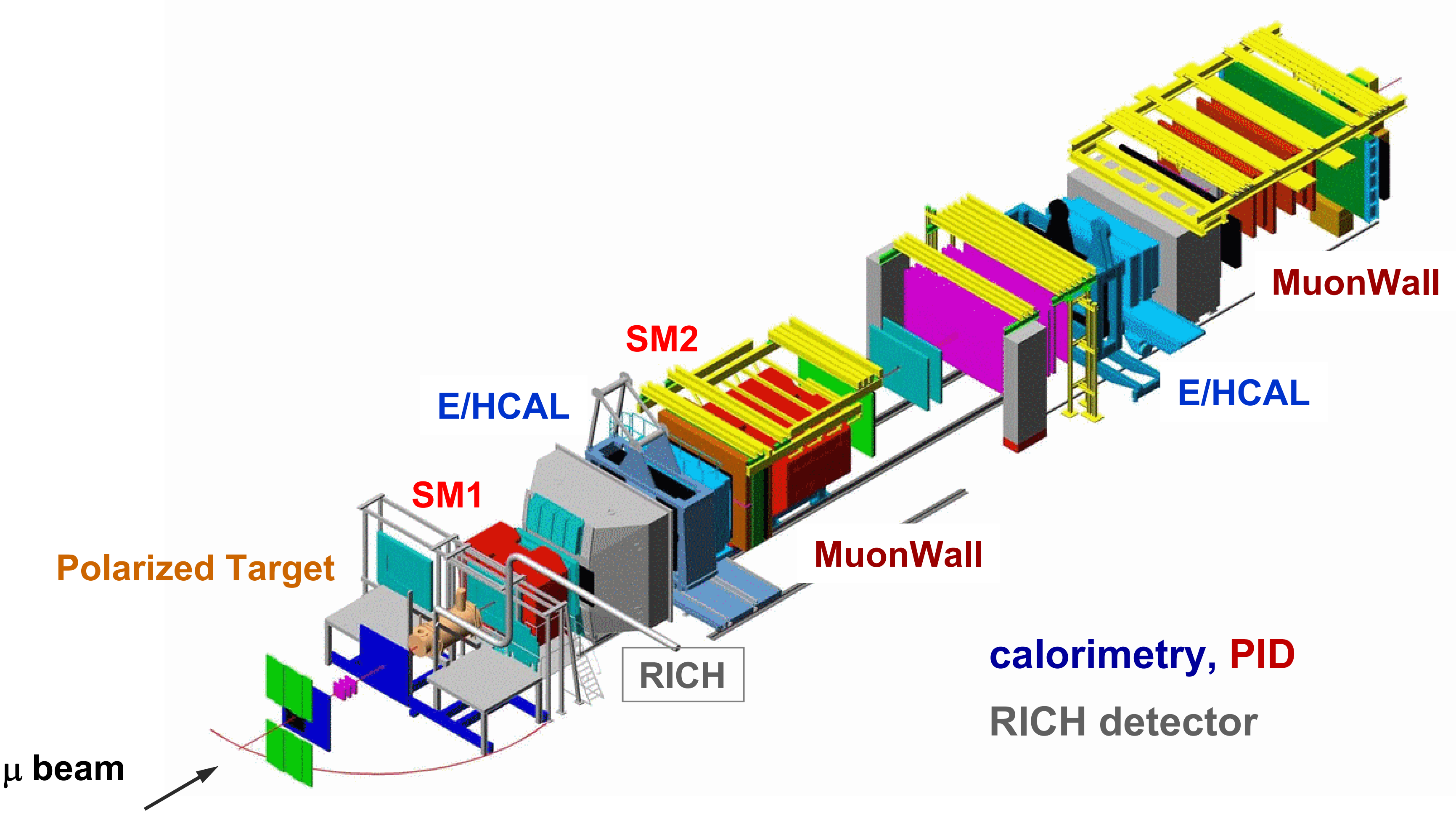
COMPASS

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

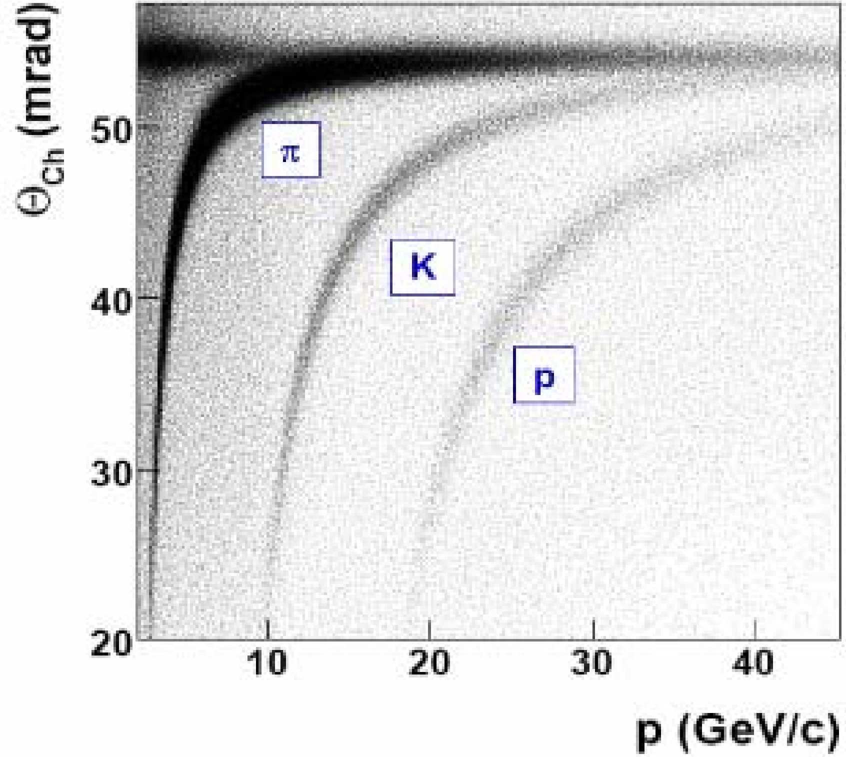
two stages spectrometer

Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

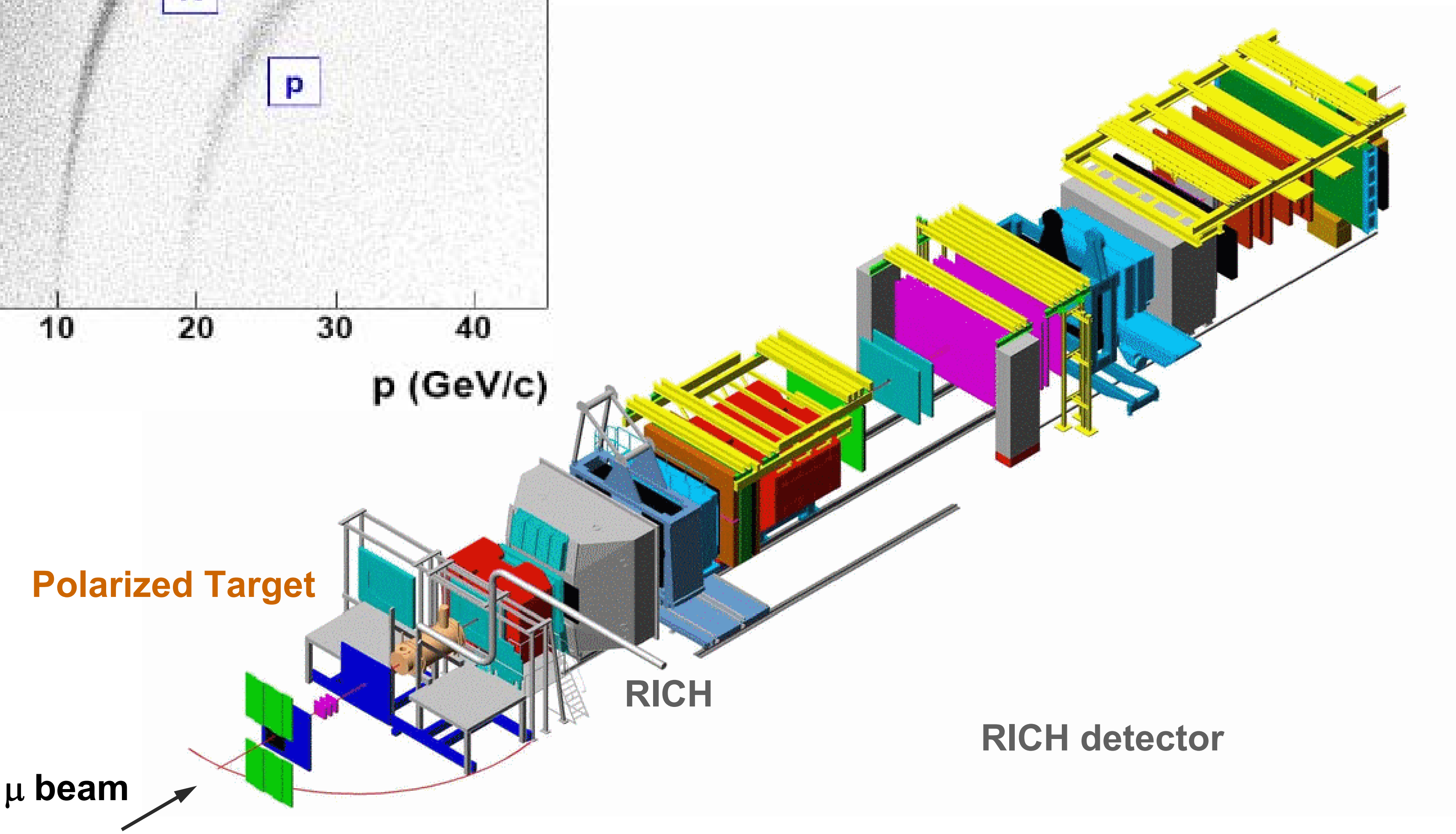


COMPASS

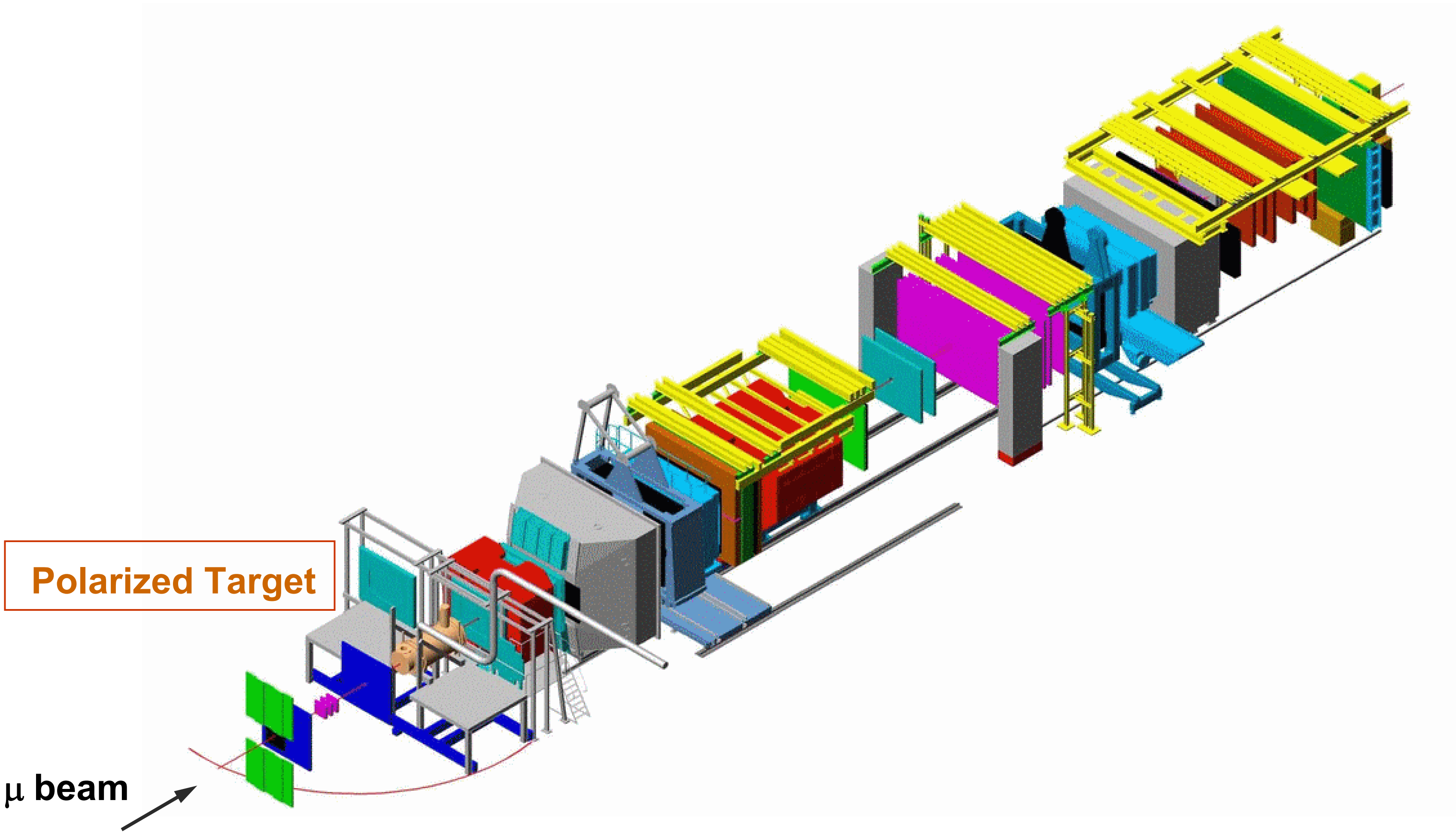


radiator C_4F_{10}

threshold: π ~2 GeV/c
K ~ 10 GeV/c



COMPASS

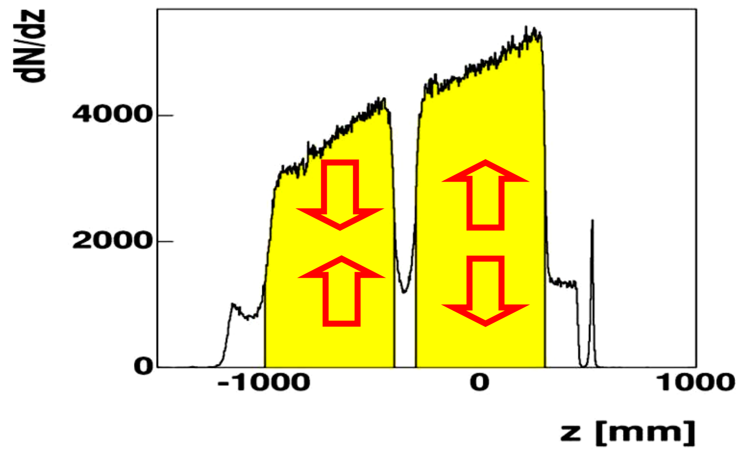


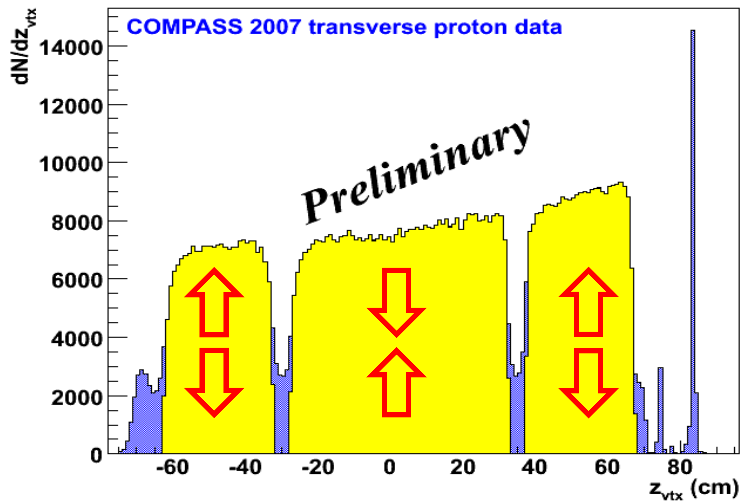
The Target System

solid state target operated in frozen spin mode

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

two 60 cm long cells
with opposite polarization





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

during data taking with transverse polarization,
polarization reversal in the cells after ~ 4-5 days