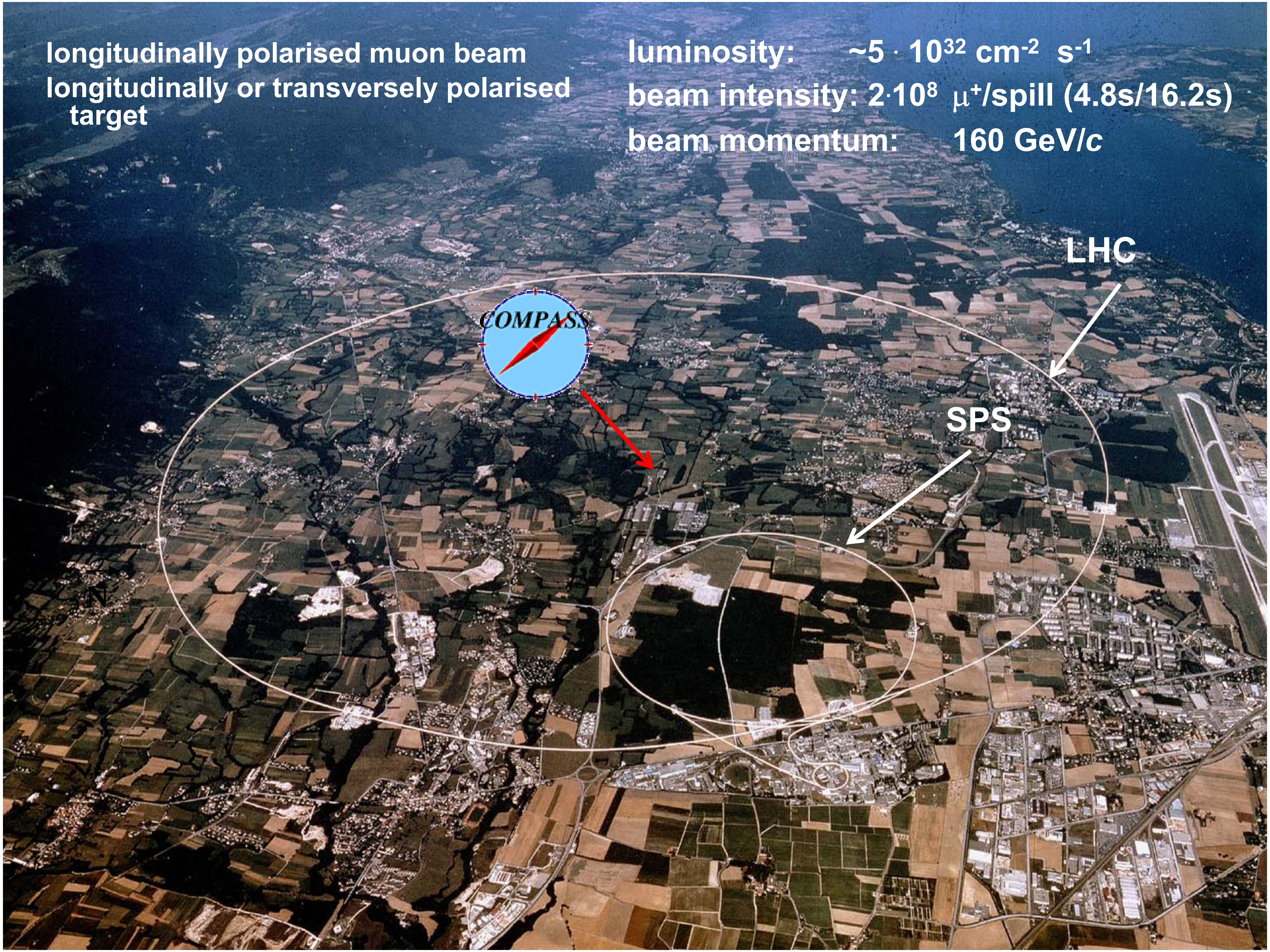
# Transverse Spin Structure of the Nucleon from COMPASS

**C. Schill (Universität Freiburg)**

*on behalf of the COMPASS collaboration*

- **The COMPASS experiment**
- **Results from $^6$LiD data:**
  - **Collins and Sivers asymmetry**
- **New results from $NH_3$ data:**
  - **Collins and Sivers asymmetry**

QCD 08, Montpellier, 7. July 2008


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

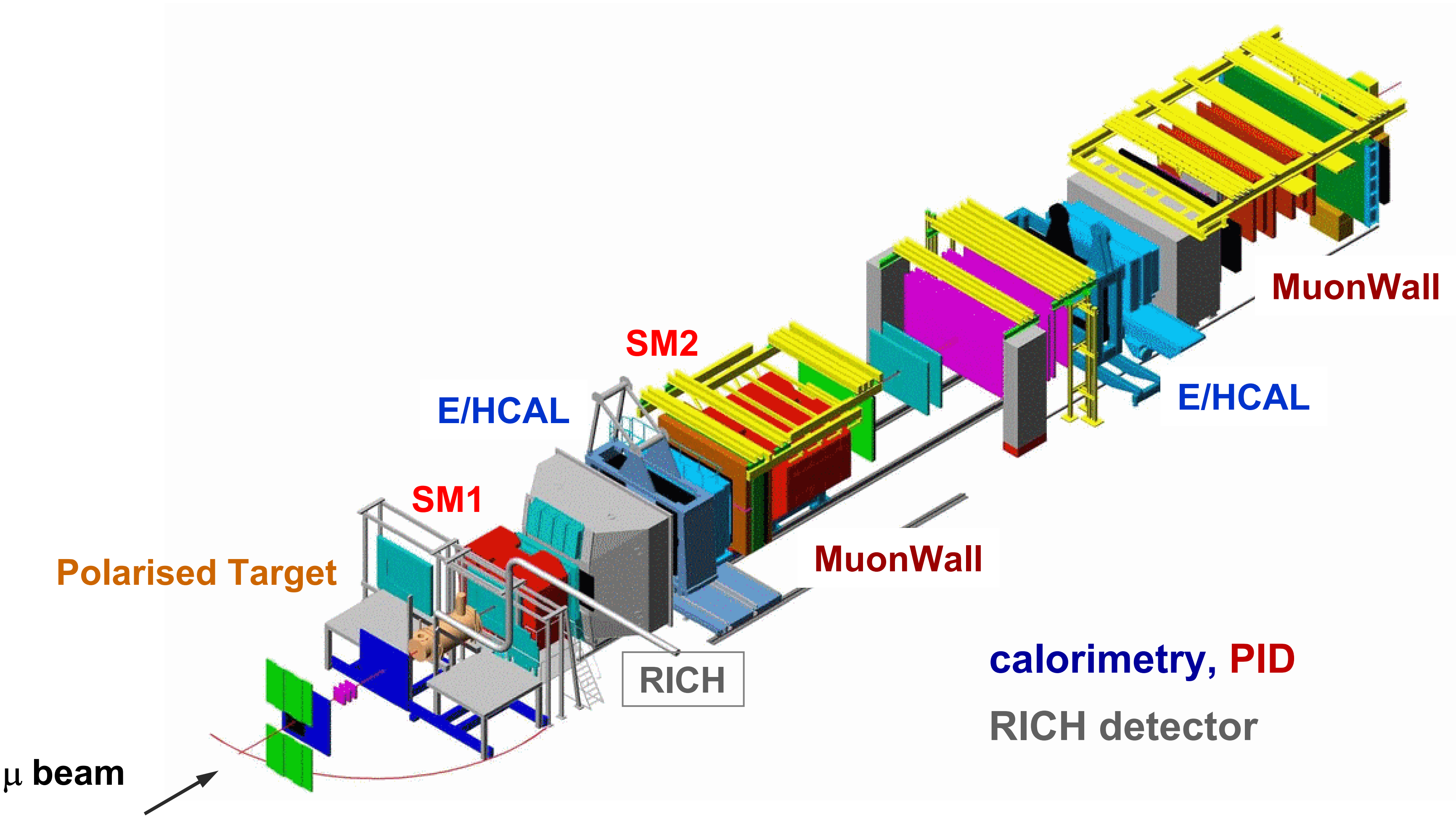
# COMPASS

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

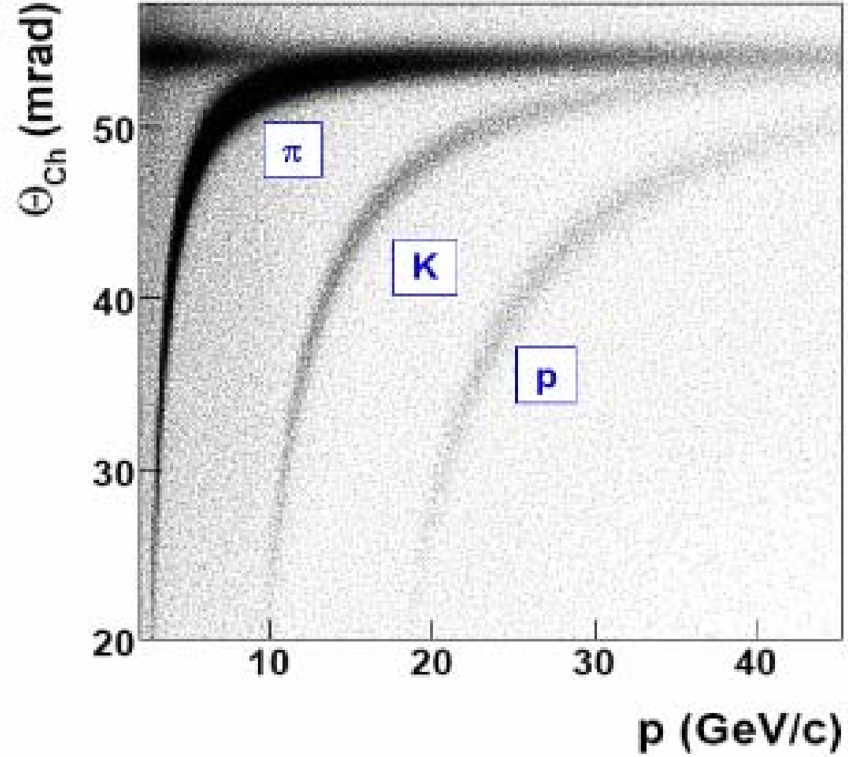
two stages spectrometer

Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

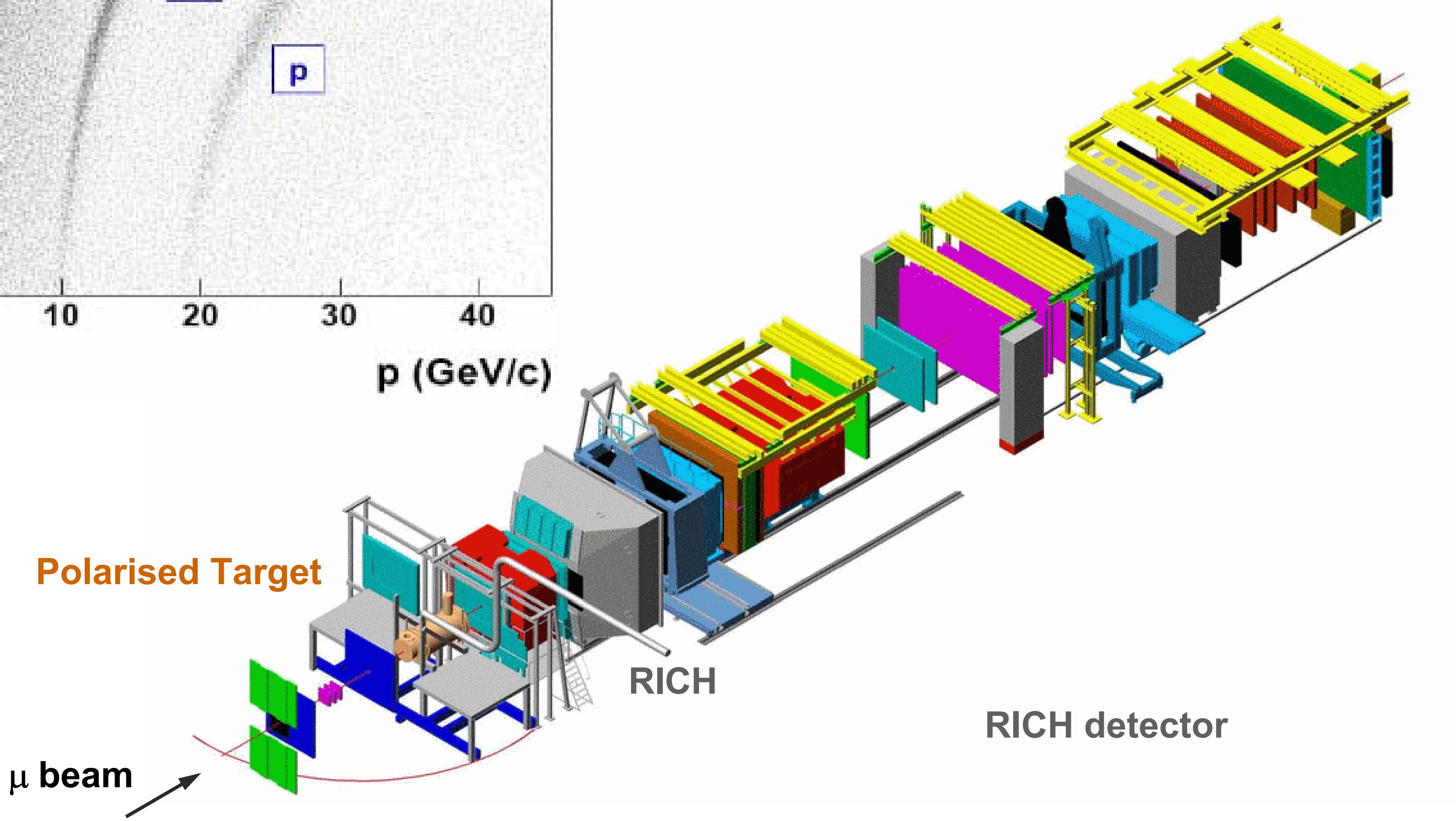


# COMPASS

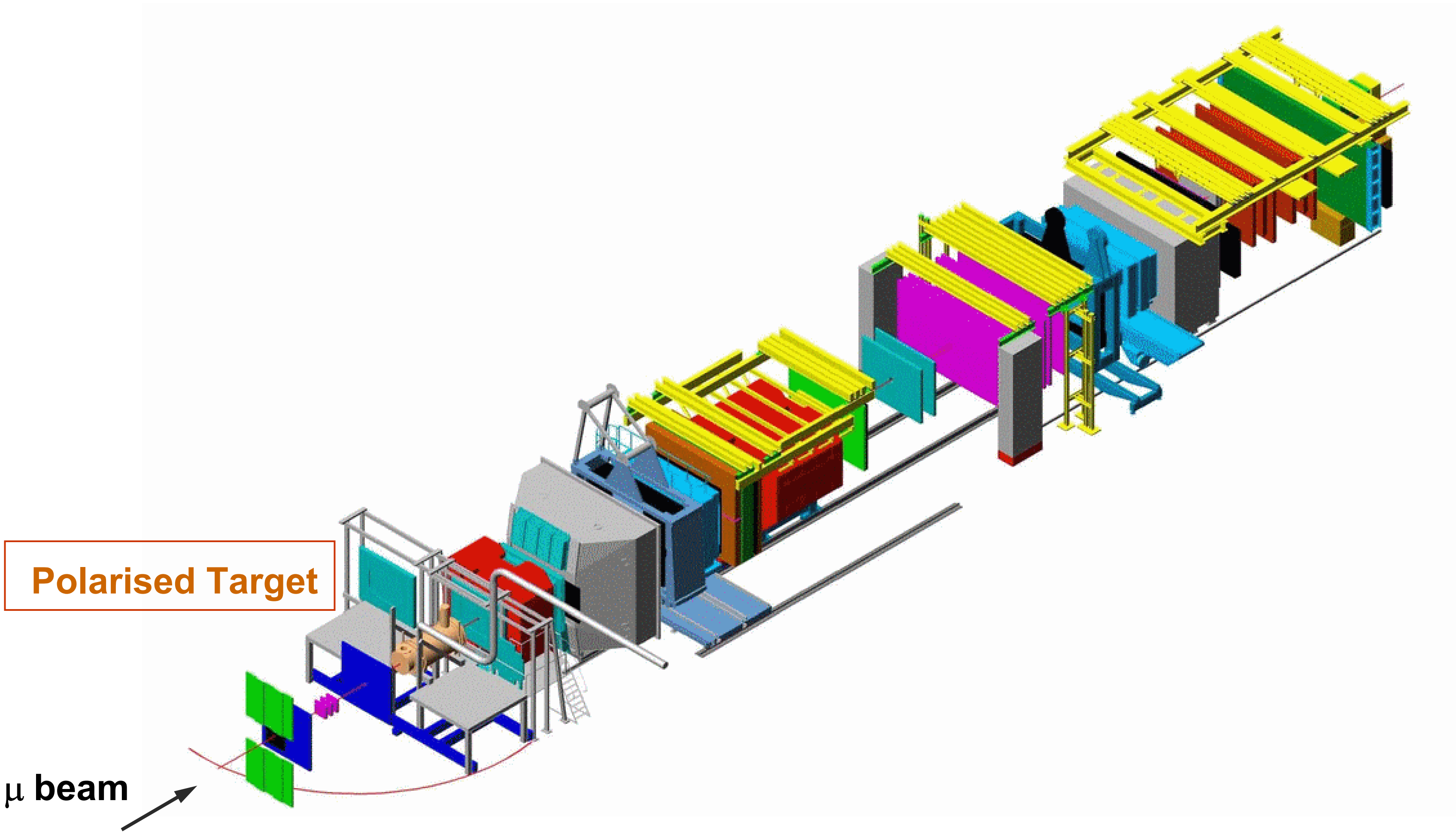



radiator $C_4F_{10}$

threshold: π ~2 GeV/c
K ~ 10 GeV/c



# COMPASS

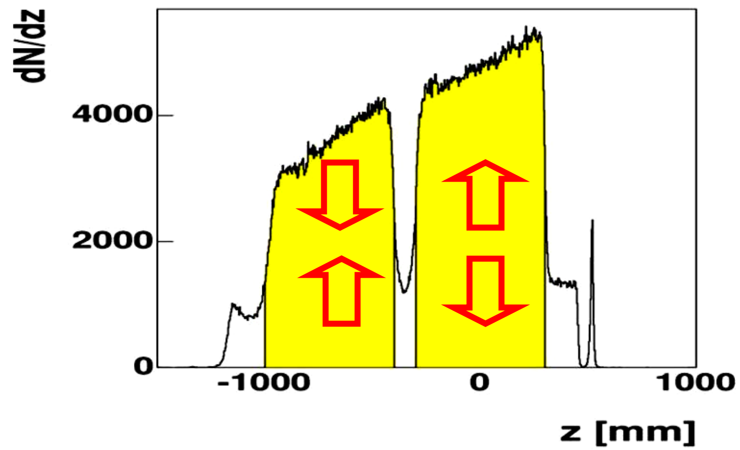


# The Target System

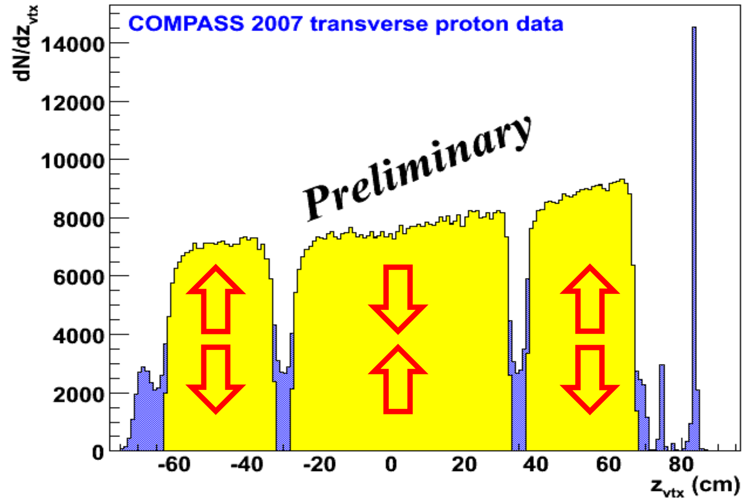
**solid state target operated in frozen spin mode**

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

**two 60 cm long cells**
**with opposite polarisation**




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

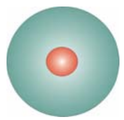



**during data taking with transverse polarisation,**
**polarisation reversal in the cells after ~ 4-5 days**

# Transverse Spin Physics

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

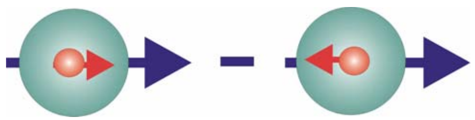
**$q(x)$**



**momentum distribution**

**well known - unpolarized DIS**

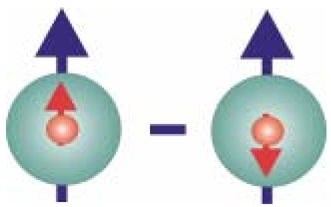
**$\Delta q(x)$**



**helicity distribution**

**known - polarized DIS**

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



**transversity distribution**

**still unknown**

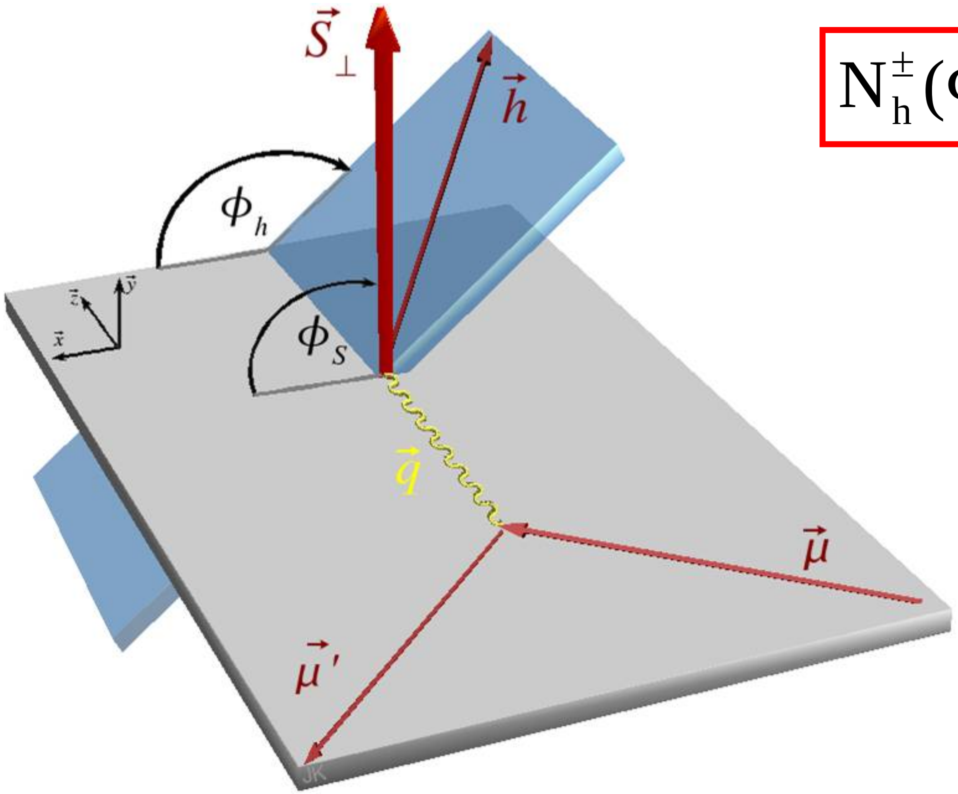
**$\Delta_T q(x)$ decouples from inclusive DIS: helicity flip of quark**

**➔ SIDIS experiment**

# Collins Asymmetry

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

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




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

In SIDIS, the Collins angle $\Phi_{Coll}$ is defined as:

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

# Collins Asymmetry

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

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

f: Dilution factor

$D_{nn}$: Depolarization factor

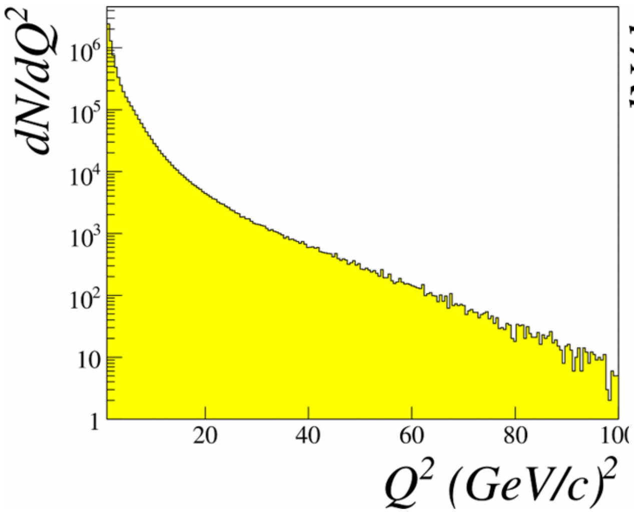
$D_{nn}=2(1-y)/(1+(1-y)^2)$

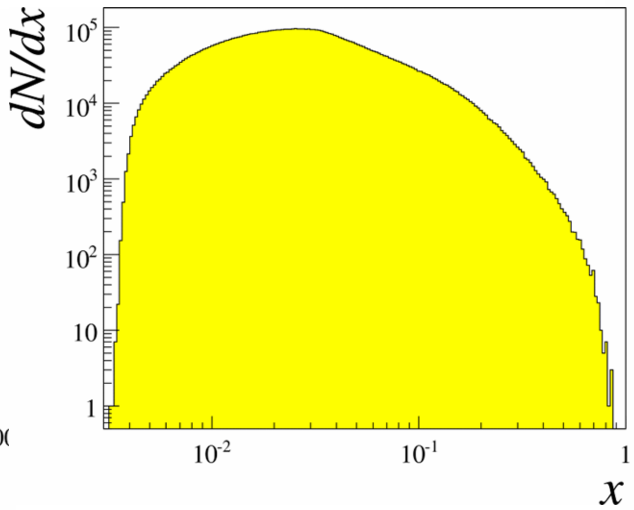
$P_T$: Target polarisation

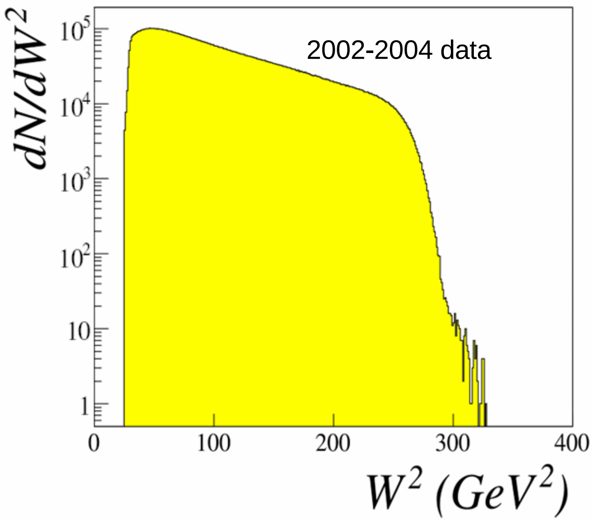
$\Delta_T q(x)$: Transversity distribution

$\Delta_T^0 D_q^h$: Collins fragmentation function (measured in $e^+e^-$ at BELLE)

# SIDIS Event Selection and Kinematics

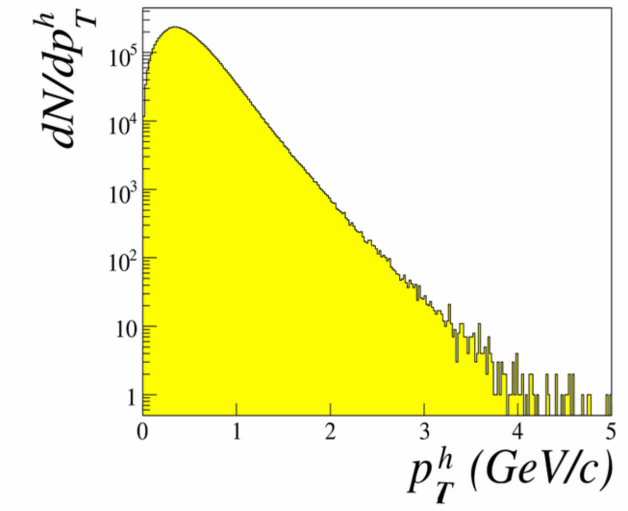



DIS cuts:

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

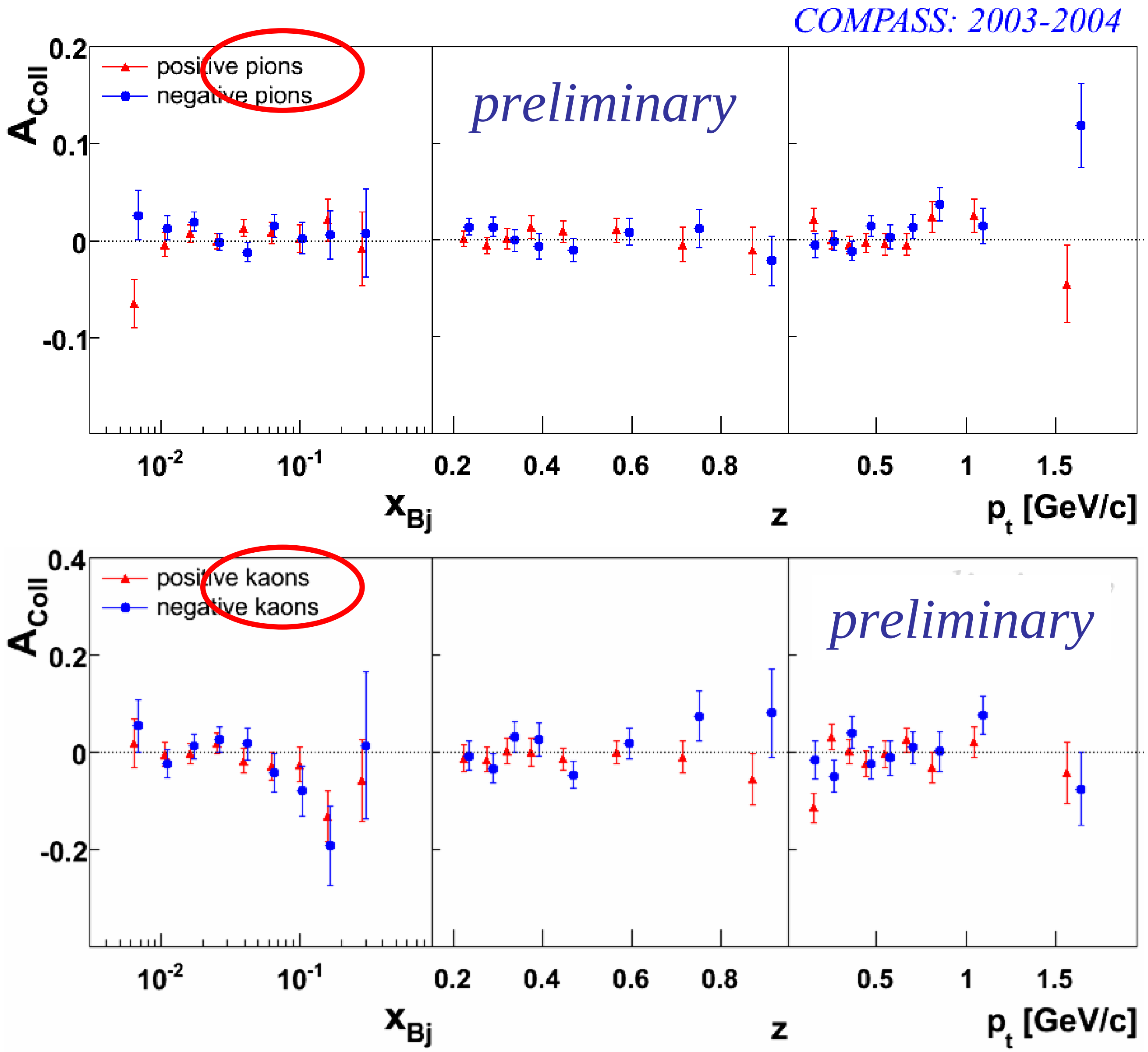



hadrons

- energy deposit in HCALs>Thr. ( ~5 GeV )
- $p_T>0.1$ GeV/c
- $z>0.2$

# COMPASS Results: Collins Effect

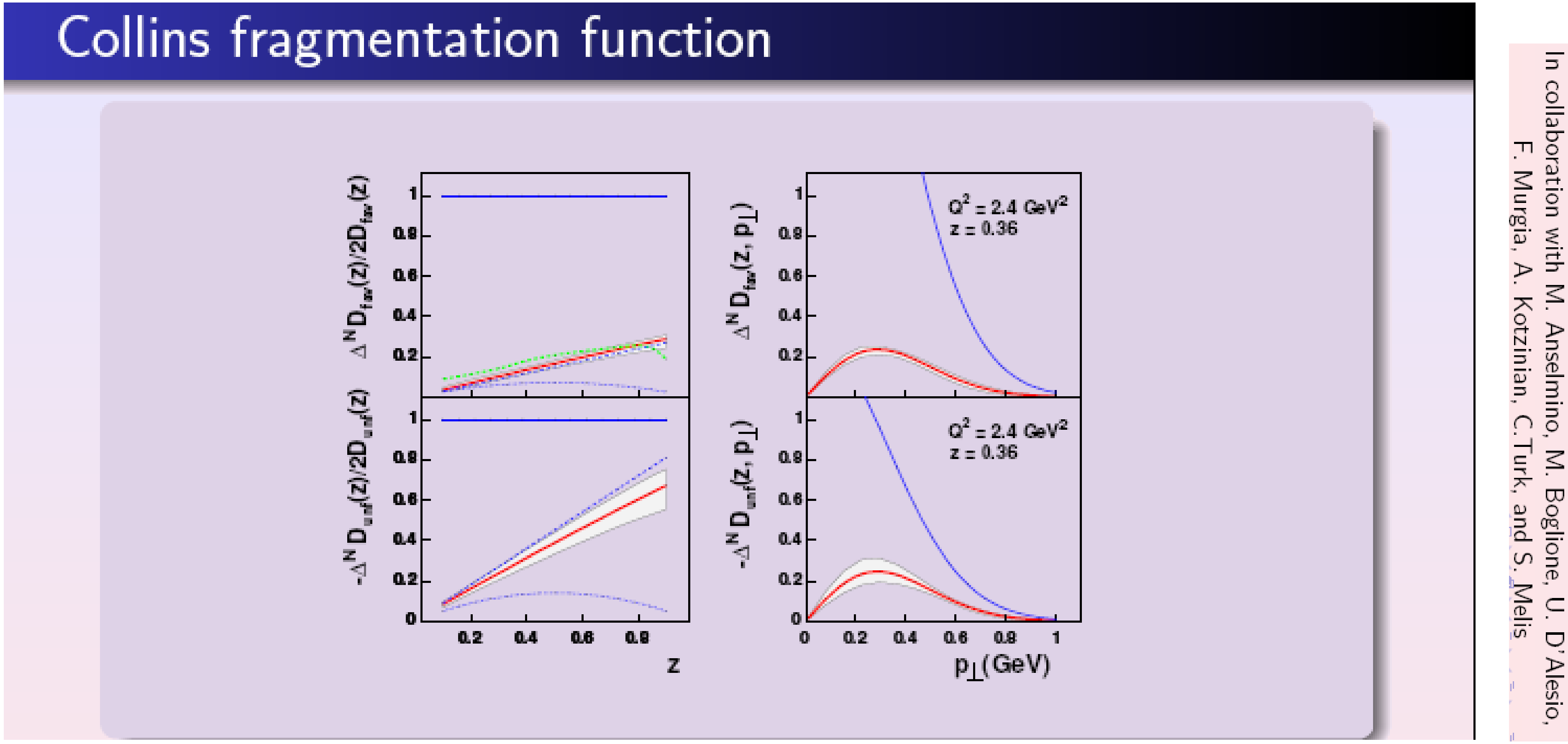
Deuteron target




only statistical errors shown (systematical errors considerably smaller)

# Collins Asymmetry – Fits to Data

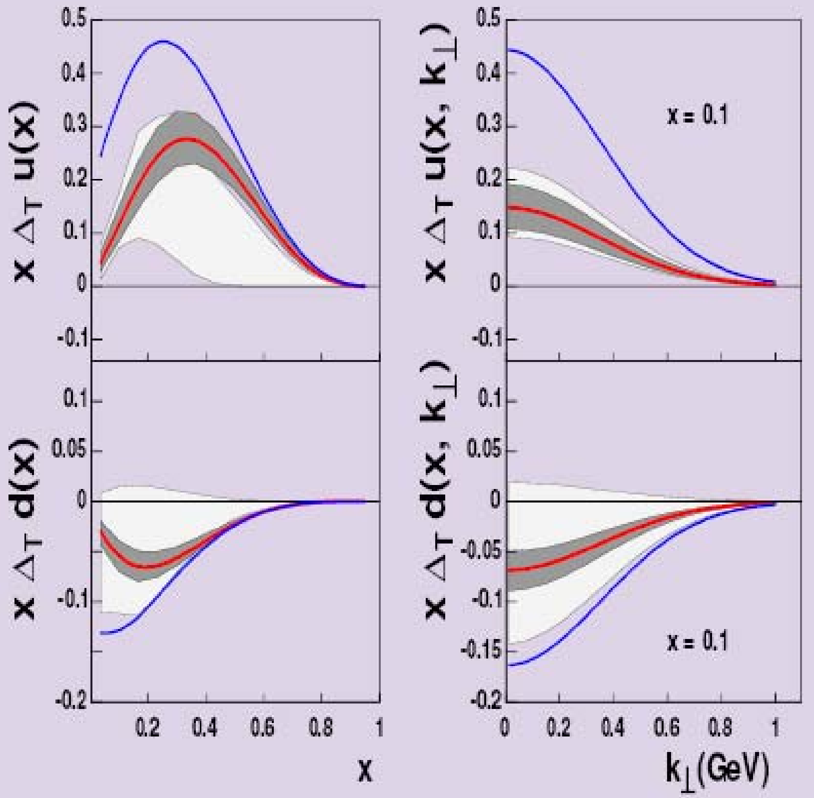
**new results using last HERMES and COMPASS [arXiv:0802.2160] pion data, and BELLE data**




A. Prokudin: Transversity 08, Ferrara

# Transversity – Fits to Data

**HERMES, COMPASS, BELLE**




- 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.

A. Prokudin: Transversity 08, Ferrara

# Sivers Effect

- Intrinsic transverse momentum of unpolarized quarks in a transversely polarized nucleon → azimuthal asymmetry

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

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

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

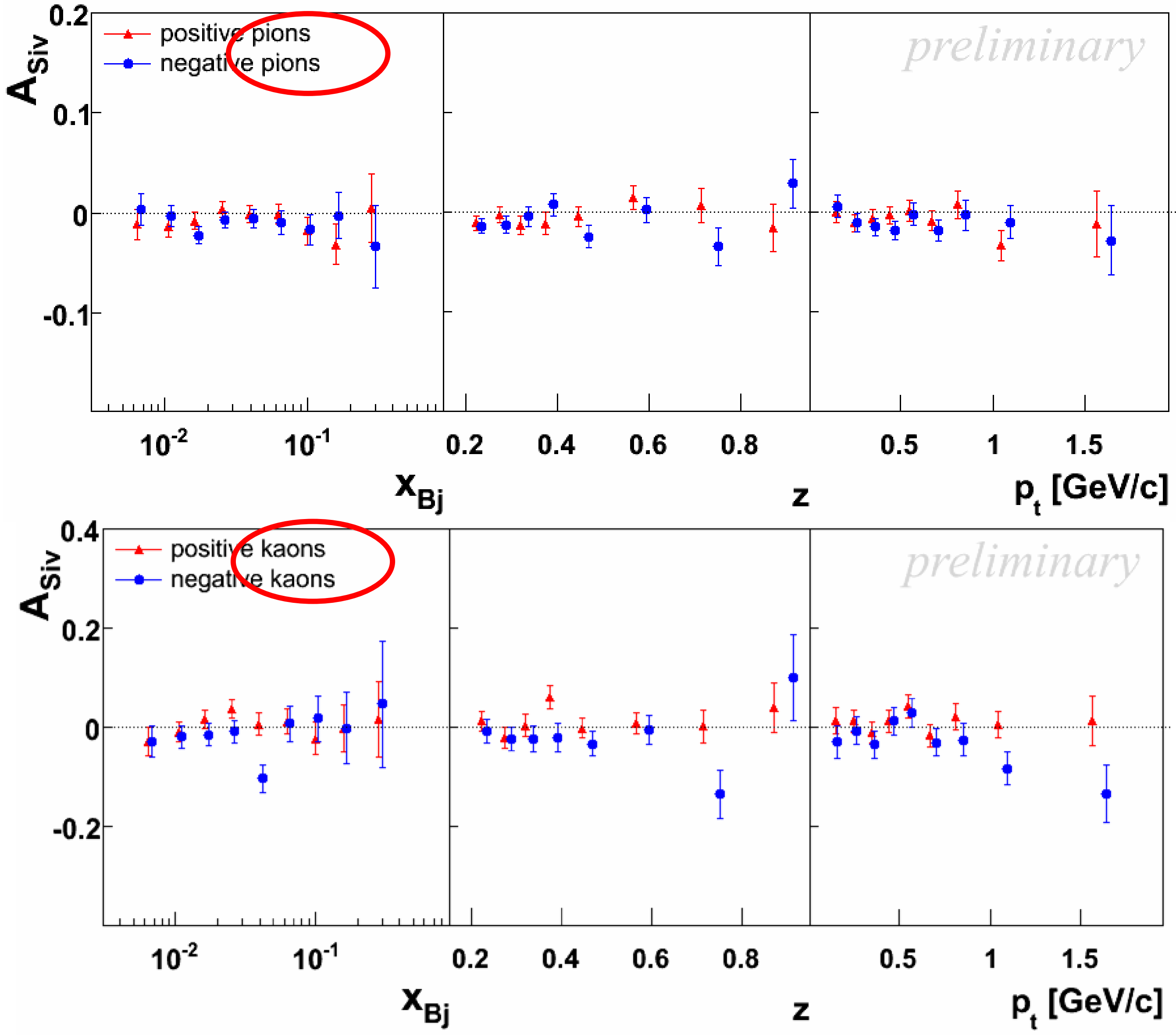
The Sivers asymmetry:

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

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

# COMPASS Results: Sivers effect

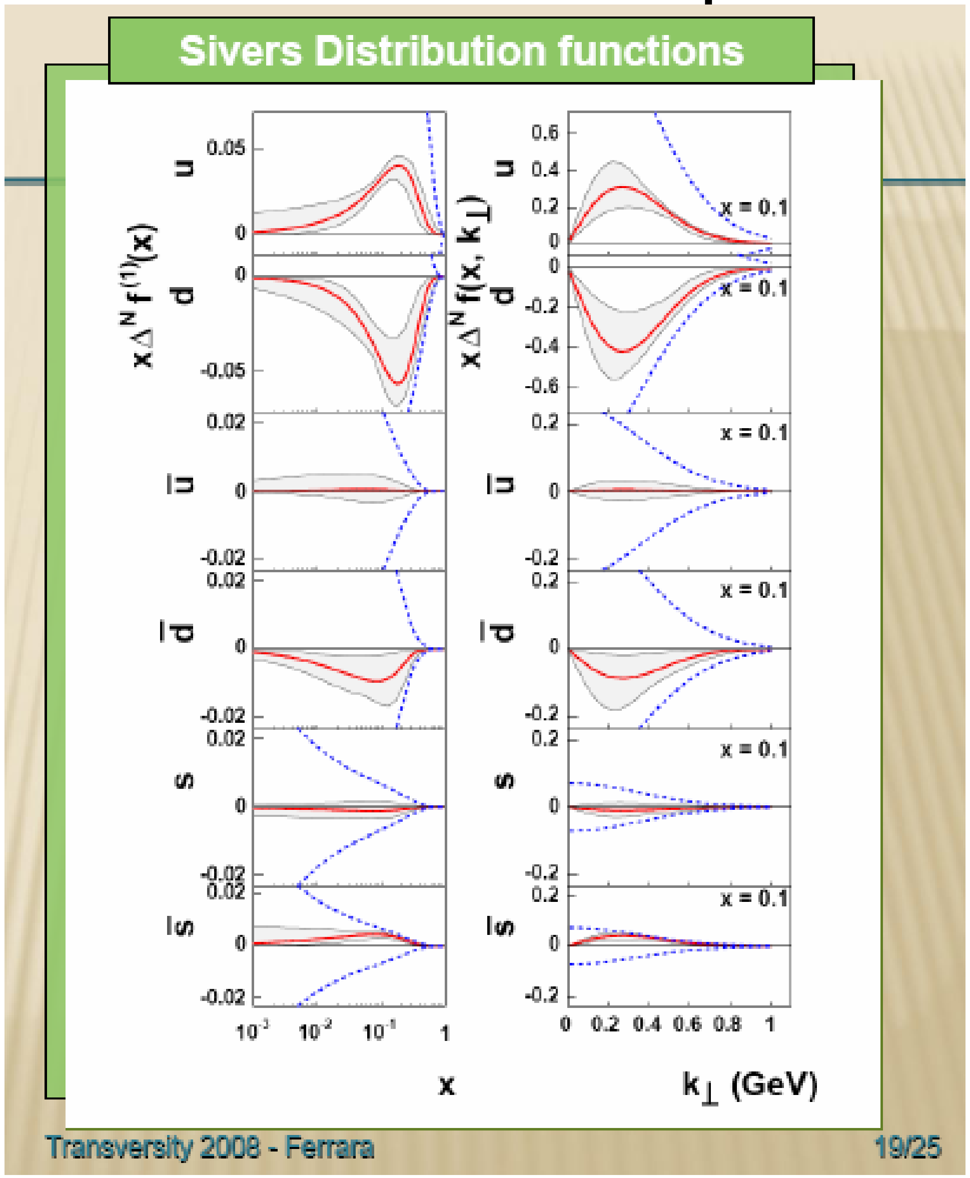
Deuteron target




only statistical errors shown (systematical errors considerably smaller)

# Sivers Asymmetries - Fits to Data

new results using HERMES and COMPASS pion and kaon data




**M. Boglione**

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

# 2007 Transverse Data Statistics

**2007 run: May to November**
**equally shared between transverse and longitudinal**

**Transverse polarization data taking:**

| Period | "Weeks" | Target Polarization |
|---|---|---|
| 1 | 25 / 26 | - + - / + - + |
| 2 | 27 / 28 | - + - / + - + |
| 3 | 30 / 31 | + - + / - + - |
| 4 | 39 / 40 | + - + / - + - |
| 5 | 41 / 42a | - + - / + - + |
| 6 | 42b / 43 | + - + / - + - |

Data used for these results

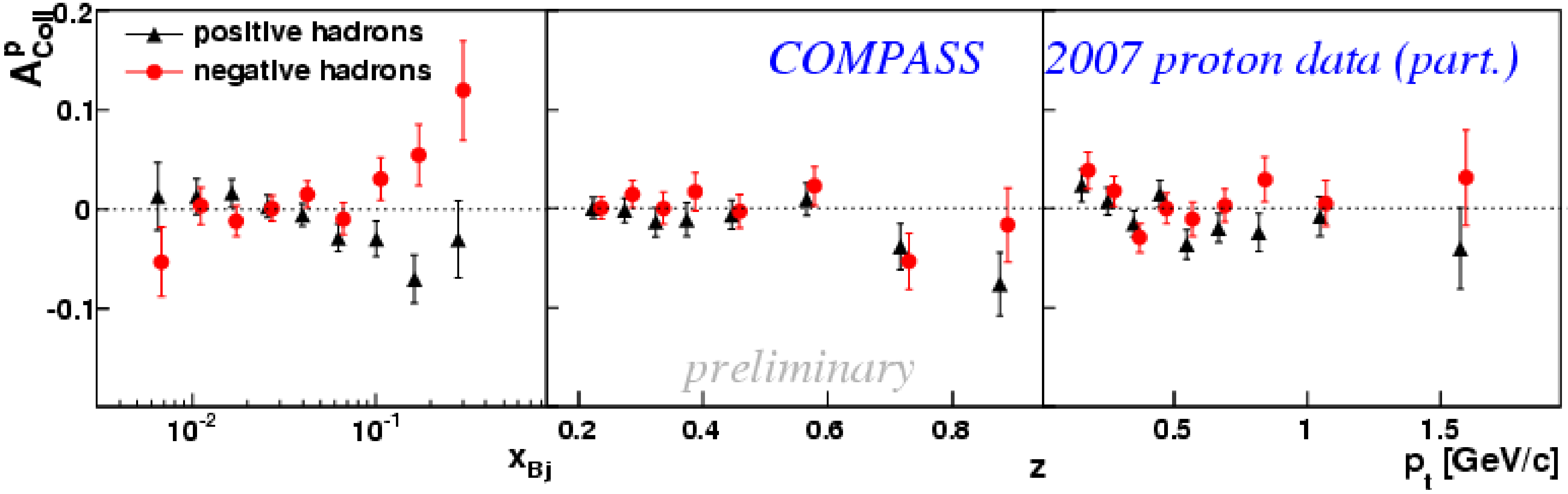
**several stability tests have been performed**

- detectors and triggers performances
- event reconstruction
- $K_0$ reconstruction
- distributions of kinematical variables:

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

**~20% of the total collected data has been used for this analysis**

# Collins Asymmetry – Proton Data

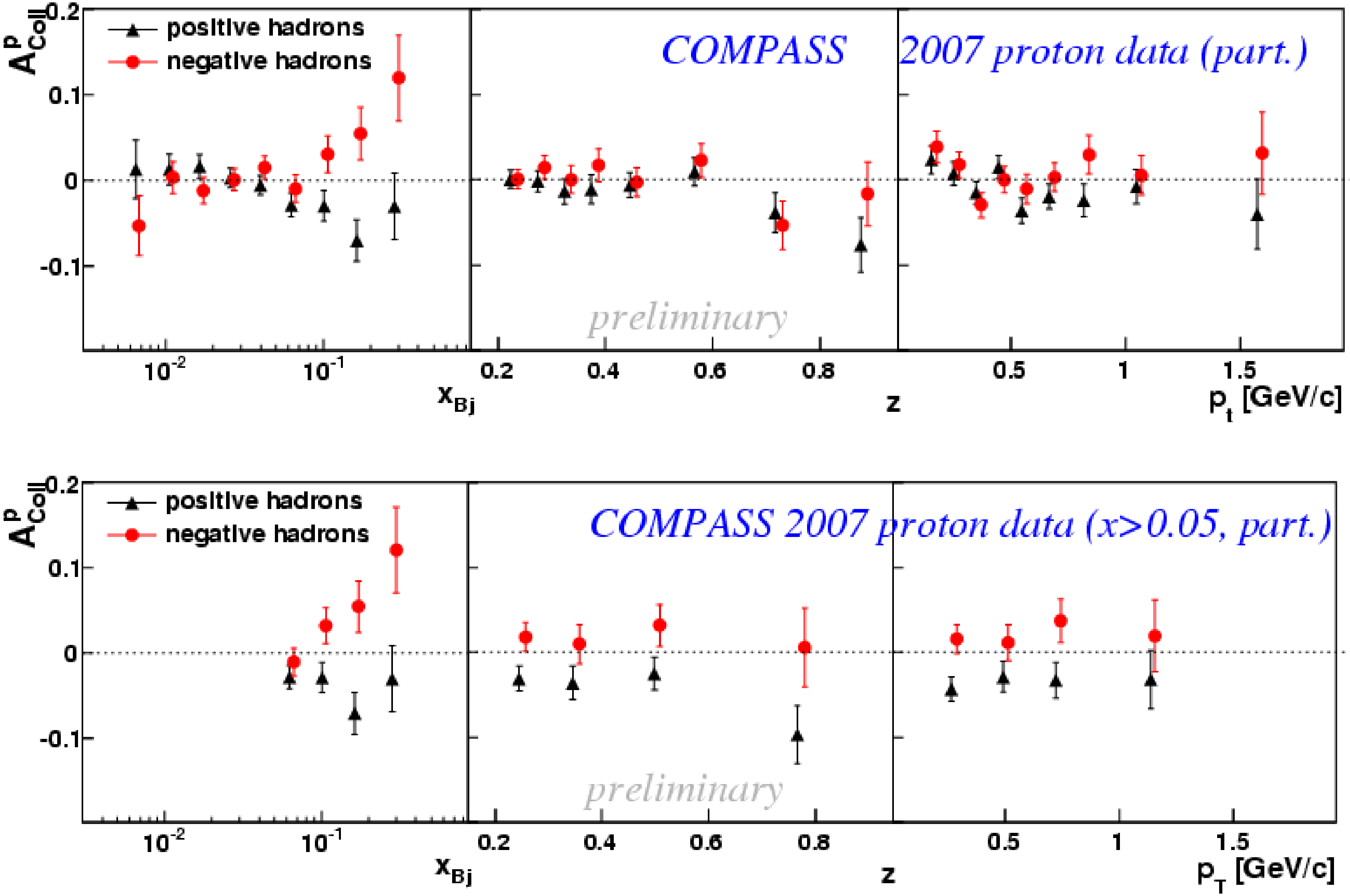



integrated over x and z

**statistical errors only; systematic errors ~ 0.3 $\sigma_{stat}$**

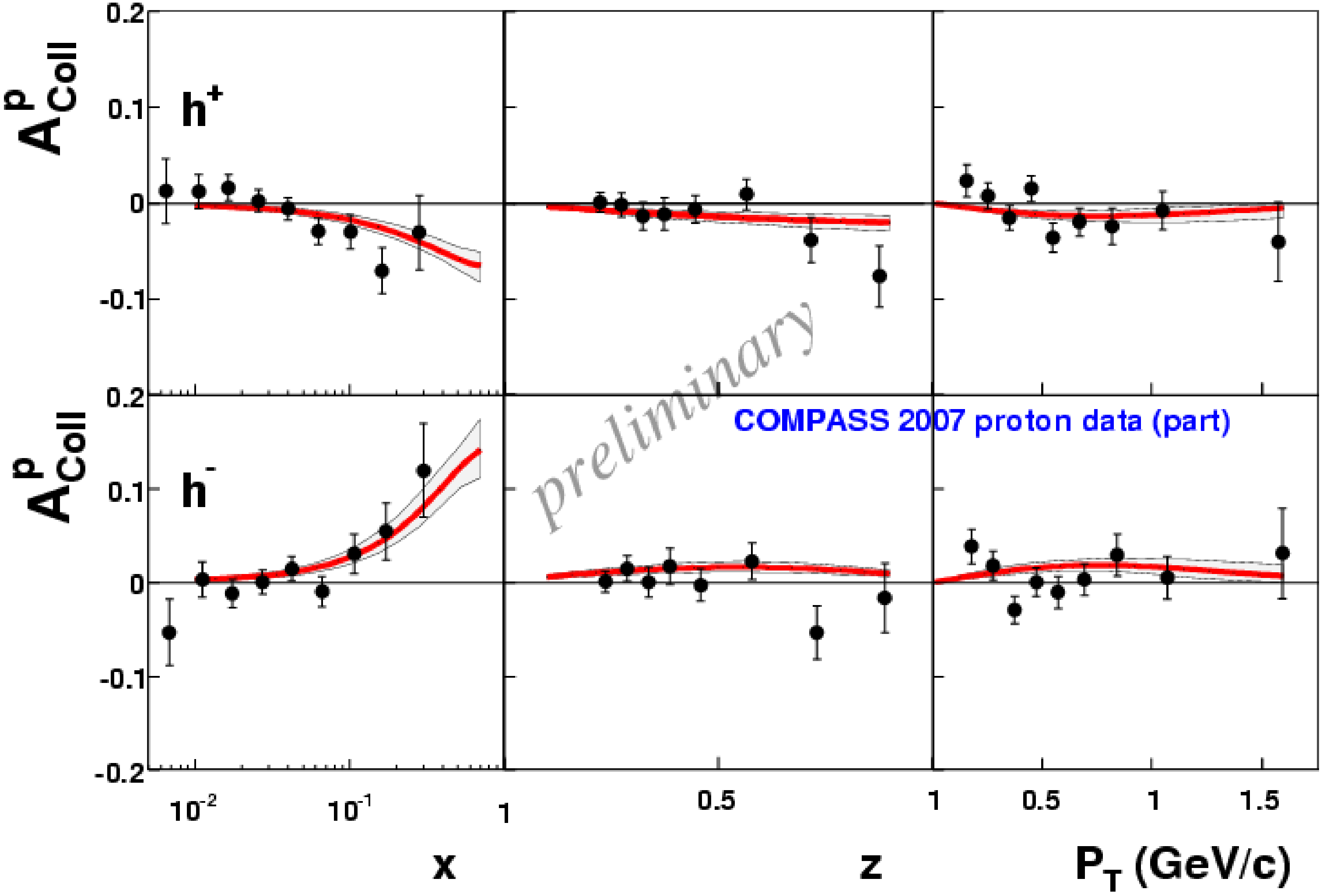
**at small x, the asymmetries are compatible with zero**
**in the valence region the asymmetries are different from zero,**
**of opposite sign for positive and negative hadrons,**
**and have the same strength and sign as HERMES**

# Collins Asymmetry – Proton Data

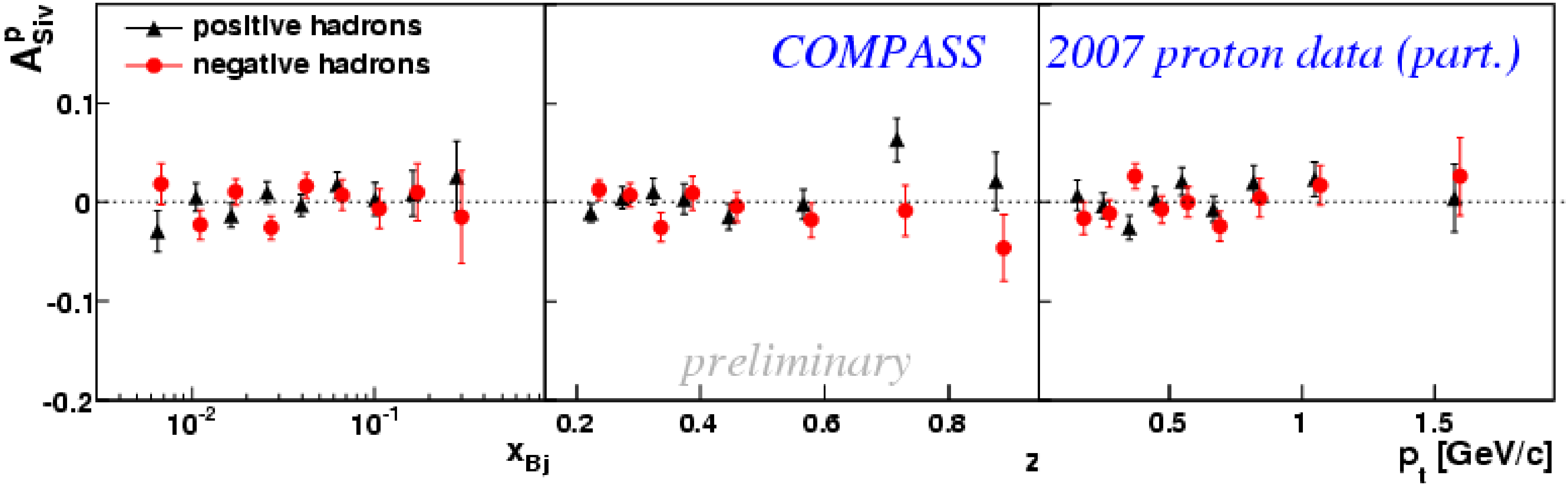


# Collins Asymmetry – Proton Data

**comparison with M. Anselmino et al. predictions**



# Sivers Asymmetry – Proton Data




integrated over x and z

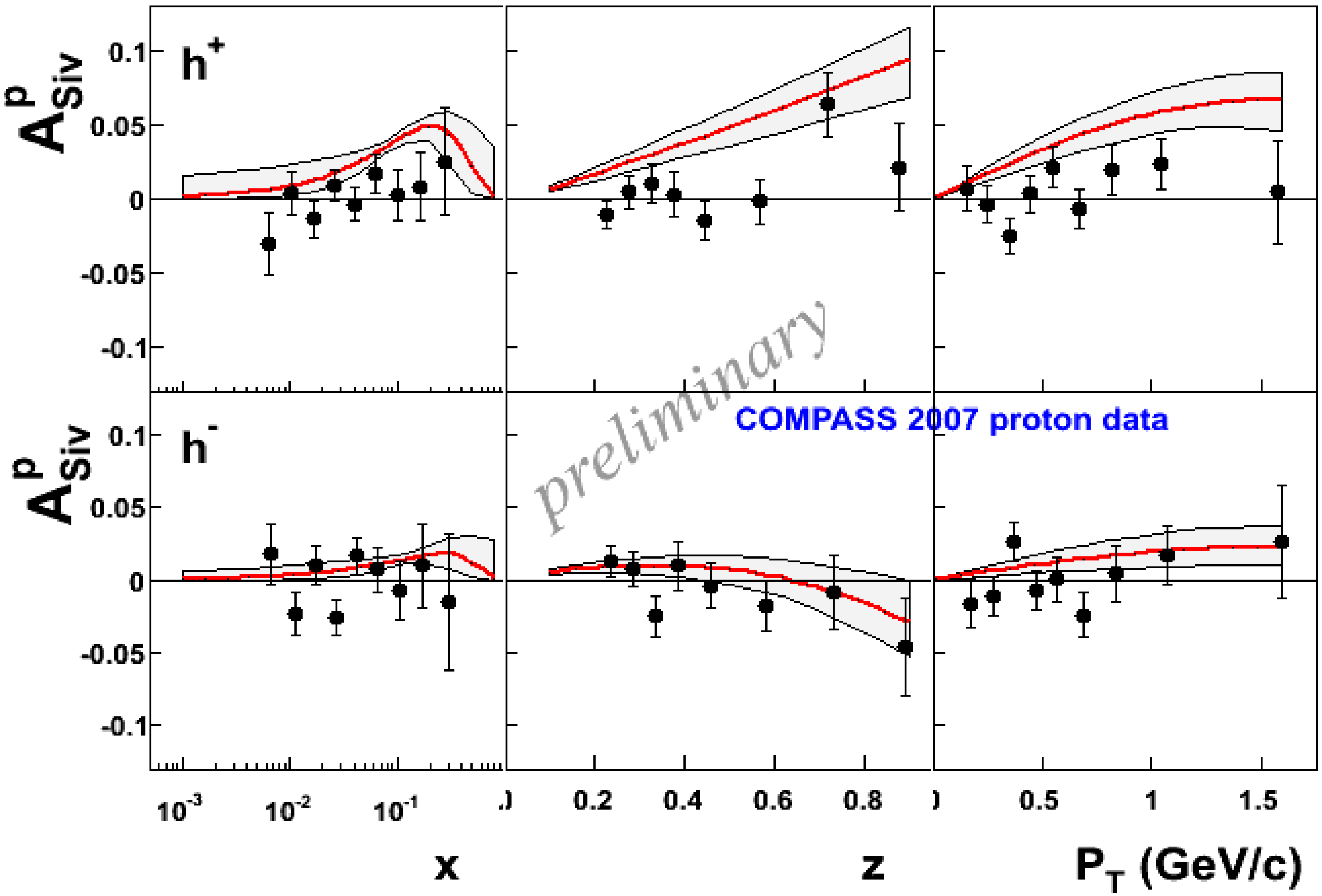
**statistical errors only; systematic errors ~ 0.5 $\sigma_{stat}$**

**the measured symmetries are small, compatible with zero**

# Sivers Asymmetry– Proton Data

**comparison with the most recent predictions from M. Anselmino et al.**

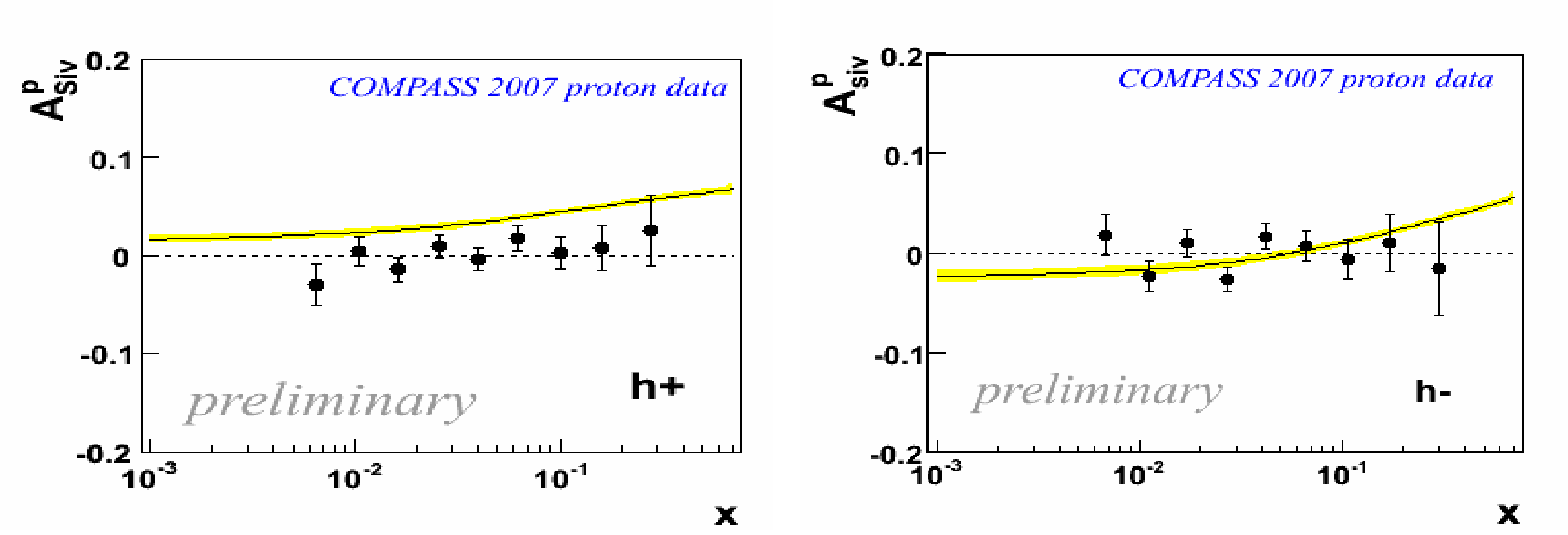
arXiv:0805.2677



# Results: Sivers Asymmetry

**comparison with predictions from**

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



# Conclusions

**COMPASS preliminary results on**

- **Collins and Sivers asymmetries on protons**
  - **Collins asymmetry different from zero**
    **the effect is there at COMPASS energies**
  - **Sivers asymmetry: smaller, compatible with zero**
    **to be understood**

**near future: analysis of the whole 2007 proton data sample**

**longer term:**
**transverse spin physics is one of the items in the future COMPASS program**

**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!

# Unpolarised Target SIDIS Cross-section

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

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

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

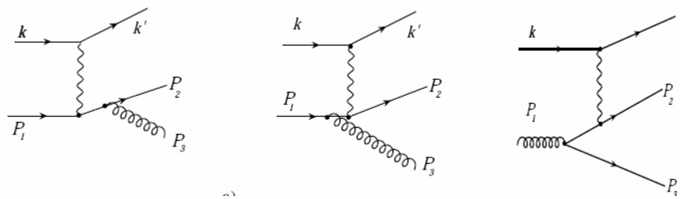
A Bacchetta, M Diehl, K Goeke, A Metz, P Mulders, M Schlegel (06)

**3 independent azimuthal modulations**

in $\phi_h$, the hadron azimuthal angle in GNS

**pQCD contributions**

**expected to be important at $p_t$ > 1 GeV/c**




$O(\alpha_s^1)$:

H. Georgi and H. D. Politzer. PRL 40 (1978) 3-6
A. Mendez. NP B145 (1978) 199-220.

$O(\alpha_s^2)$:

A. Daleo, D. de Florian, and R. Sassot. PR D71 (2005) 034013.

# Unpolarised Target SIDIS Cross-section

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

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

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

$$F_{UU}^{\cos\phi_h}=\frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xh\,H_1^{\perp}+\frac{M_h}{M}\,f_1\frac{\tilde{D}^{\perp}}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xf^{\perp}D_1+\frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{H}}{z}\right)\right]$$

**Cahn effect**

\+ Boer-Mulders DF

$$xh = x\tilde{h}+\frac{p_T^2}{M^2}\,h_1^{\perp}$$

$$F_{UU}^{\cos\phi_h}\approx\frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\,f_1 D_1\right]$$

$$F_{UU}^{\cos 2\phi_h}=\mathcal{C}\left[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)-\boldsymbol{k}_T\cdot\boldsymbol{p}_T}{M\,M_h}\,h_1^{\perp}H_1^{\perp}\right]$$

**Boer-Mulders DF** x Collins FF

\+ Cahn effect

# Unpolarised Target SIDIS Cross-section

**Cahn effect**

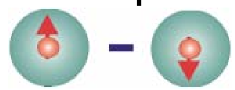
kinematical effect due to quark intrinsic momentum

$$\frac{d\sigma}{d\phi_h} \propto 1 - 4\frac{\langle k_t^2\rangle z P_t}{Q\langle P_t^2\rangle} D_{\cos\phi_h}(y)\cos\phi_h + \dots$$

**Boer-Mulders DF**

leading order DF

quark with spin parallel to the nucleon spin in an unpolarised nucleon



$$F_{UU}^{\cos\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(xh\,H_1^\perp + \frac{M_h}{M}\,f_1\frac{\tilde{D}^\perp}{z}\right) - \frac{\hat{h}\cdot p_T}{M}\left(xf^\perp D_1 + \frac{M_h}{M}\,h_1^\perp\frac{\tilde{H}}{z}\right)\right]$$

**Cahn effect**

\+ Boer-Mulders DF

$$xh = x\tilde{h} + \frac{p_T^2}{M^2}h_1^\perp \qquad F_{UU}^{\cos\phi_h} \approx \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot p_T}{M}\,f_1 D_1\right]$$

$$F_{UU}^{\cos 2\phi_h} = \mathcal{C}\left[-\frac{2\left(\hat{h}\cdot k_T\right)\left(\hat{h}\cdot p_T\right) - k_T\cdot p_T}{M M_h}h_1^\perp H_1^\perp\right]$$

**Boer-Mulders DF** x Collins FF

\+ Cahn effect

# Unpolarised Target SIDIS Cross-section

**data sample:**

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

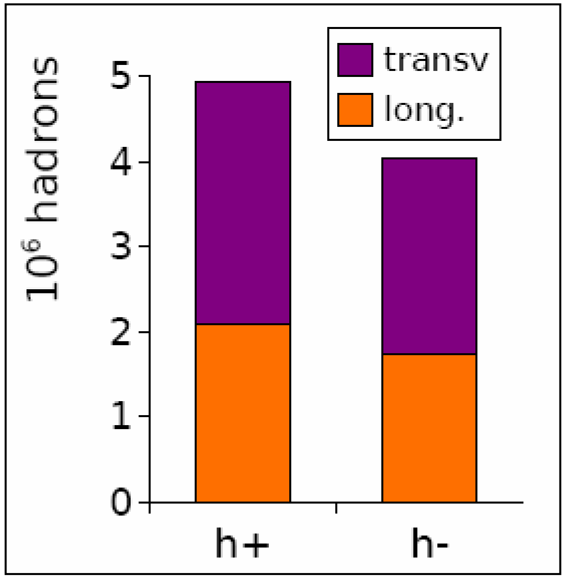
with both target orientation configurations to cancel possible polarisation effects

**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:**

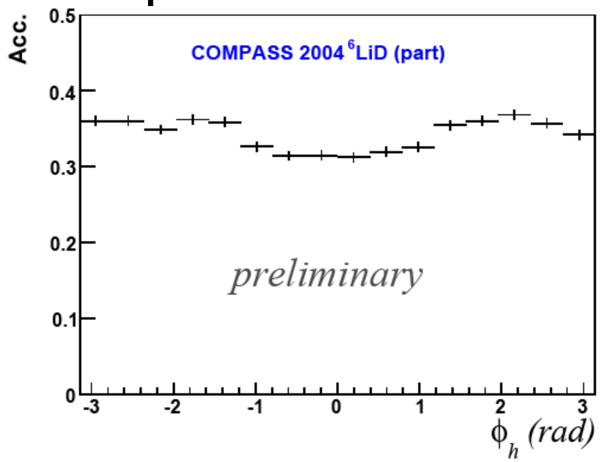


# Unpolarised Target SIDIS Cross-section

**to extract the asymmetries**

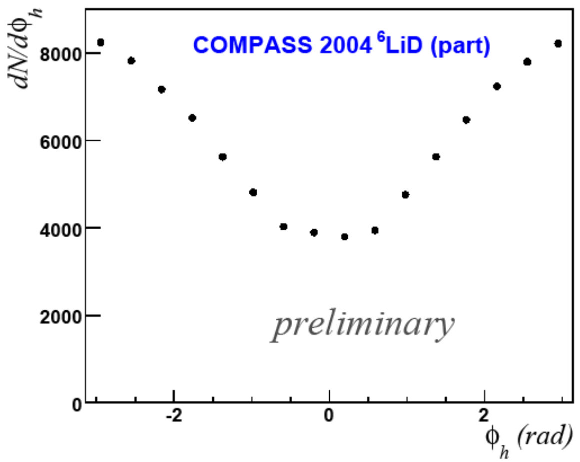
**the azimuthal distributions have to be corrected by the apparatus acceptance**
**→ dedicated MC simulations for L and T target polarisation data**

**acceptance** (0.63<z<0.85)



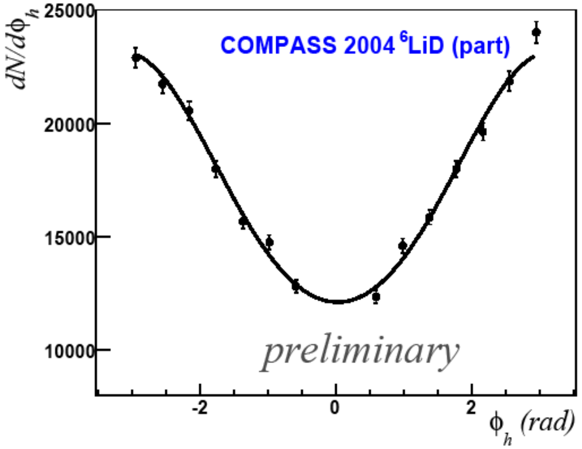

**initial azimuthal distribution**

Azimuthal Distribution (0.63<z<0.85)




**final azimuthal distribution**

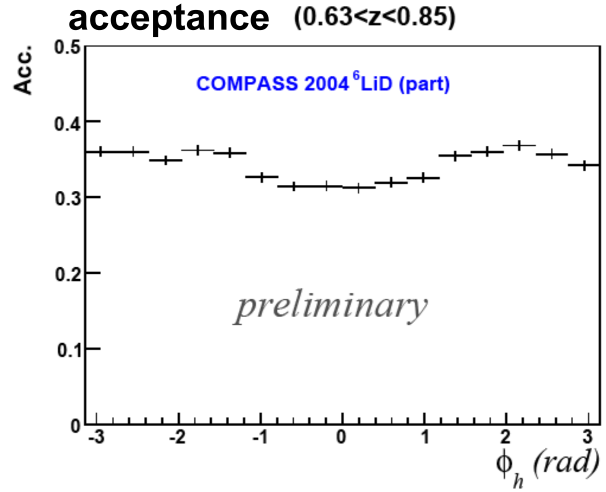
corrected azimuthal distribution (0.63<z<0.85)



# Unpolarised Target SIDIS Cross-section

**to extract the asymmetries**

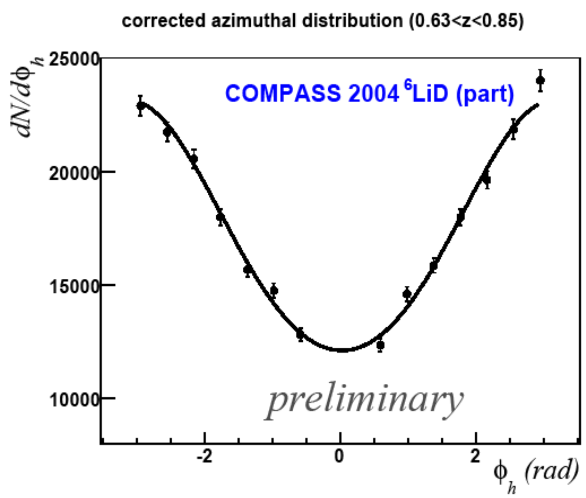
**the azimuthal distributions have to be corrected by the apparatus acceptance**
**→ dedicated MC simulations for L and T target polarisation data**



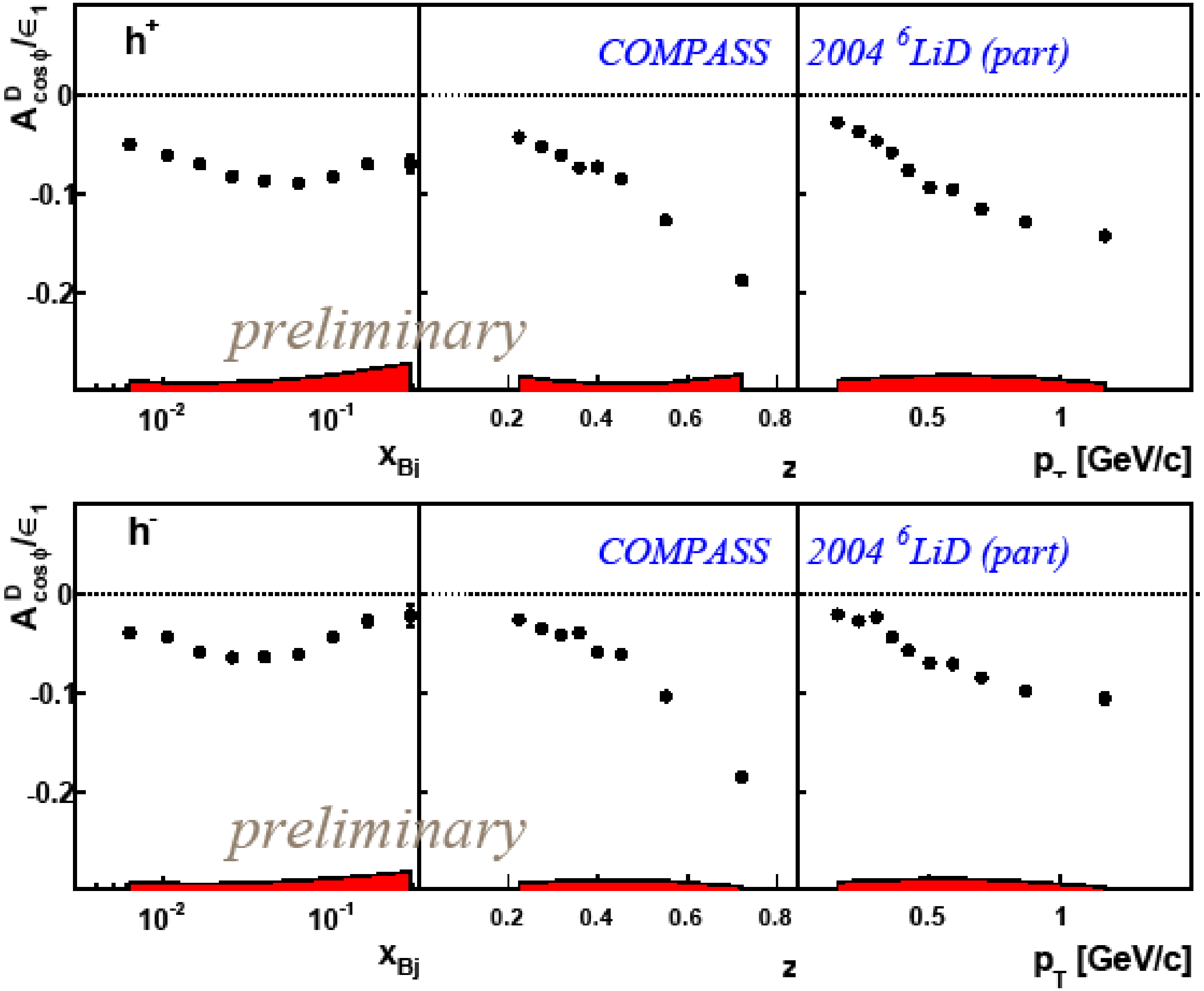

**the final azimuthal distributions are fitted with the function:**

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

**final azimuthal distribution**



# Results: cos$\phi$ Modulation

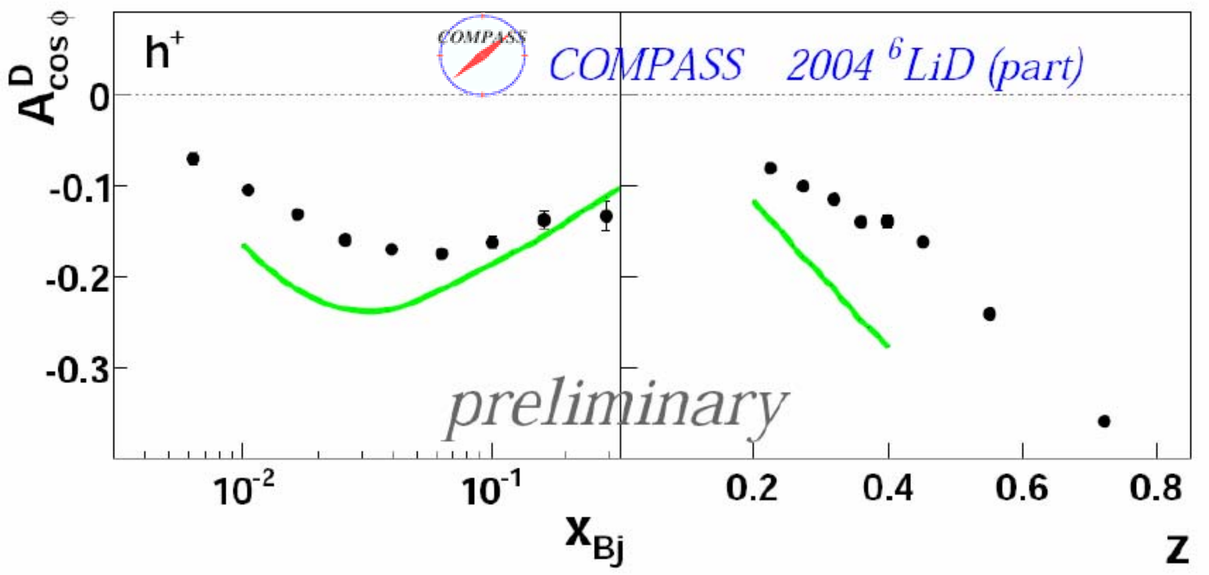



$$A_{\cos\phi} / \varepsilon_c$$

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

# Results: $\cos\phi$ Modulation

**comparison with theory**

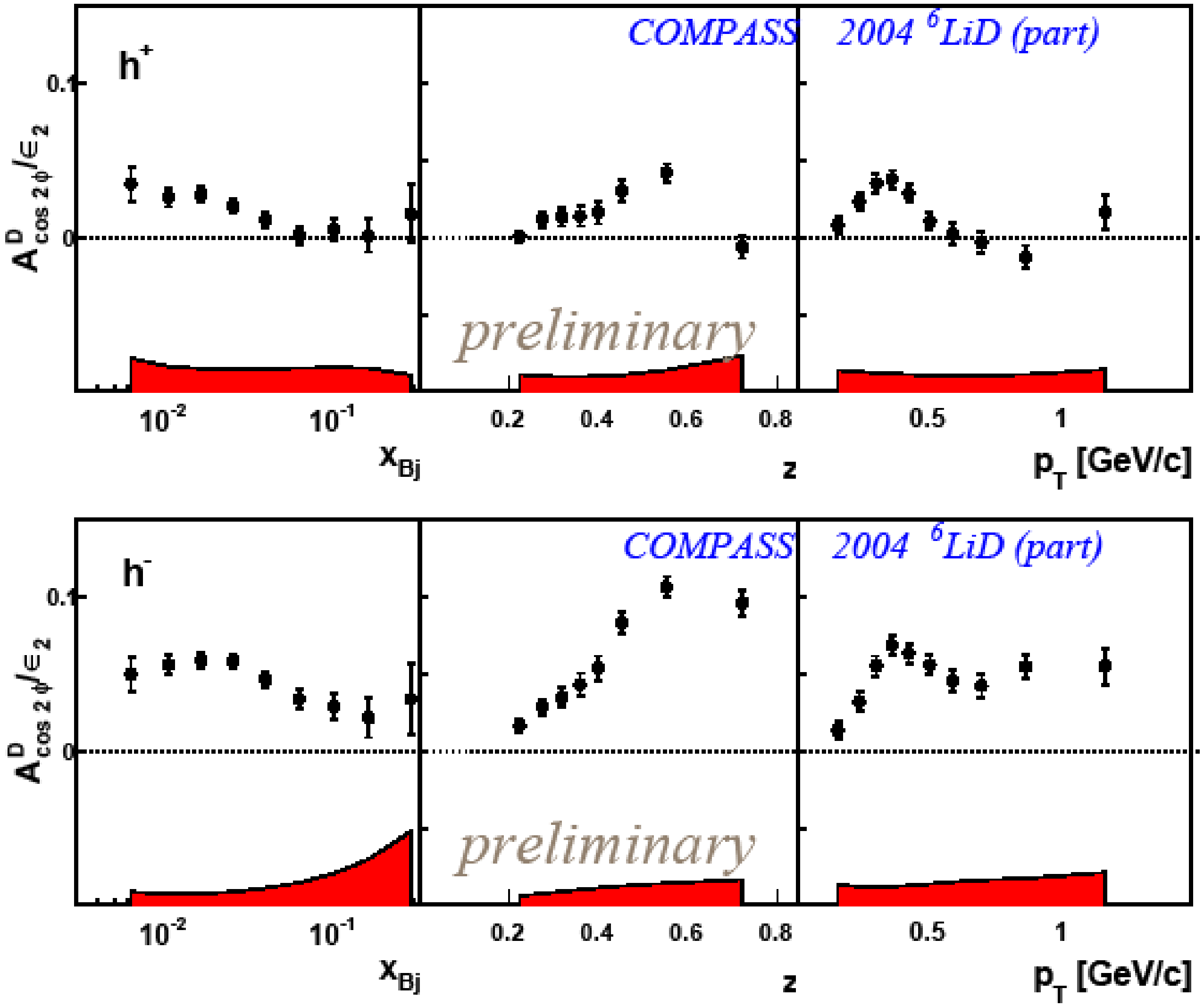



M. Anselmino, M. Boglione, A. Prokudin, C. Türk
Eur. Phys. J. A 31, 373-381 (2007)
does not include Boer – Mulders contribution

# Results: cos $2\phi$ Modulation

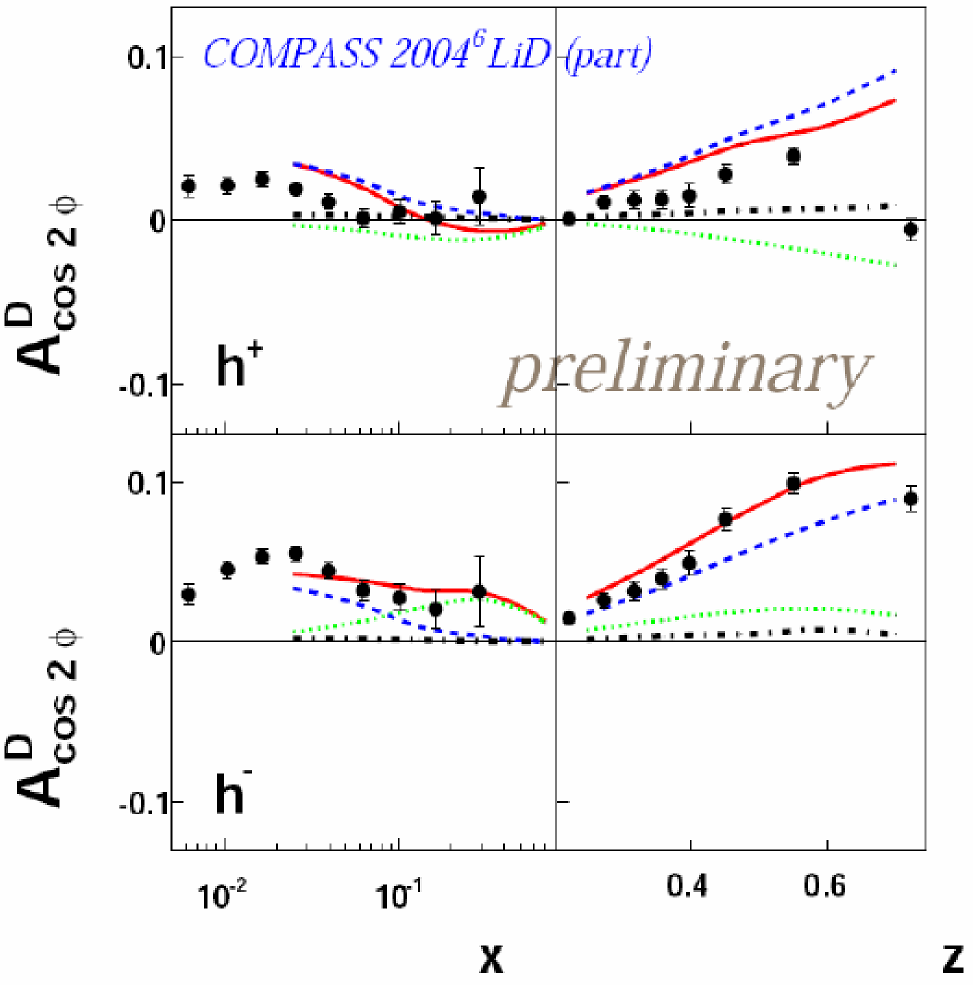
$$A_{\cos 2\phi} / \varepsilon_{c2}$$

$$\varepsilon_{c2} = \frac{2(2-y)}{1+(1-y)^2}$$



# Results: cos 2$\phi$ Modulation

**comparison with theory**





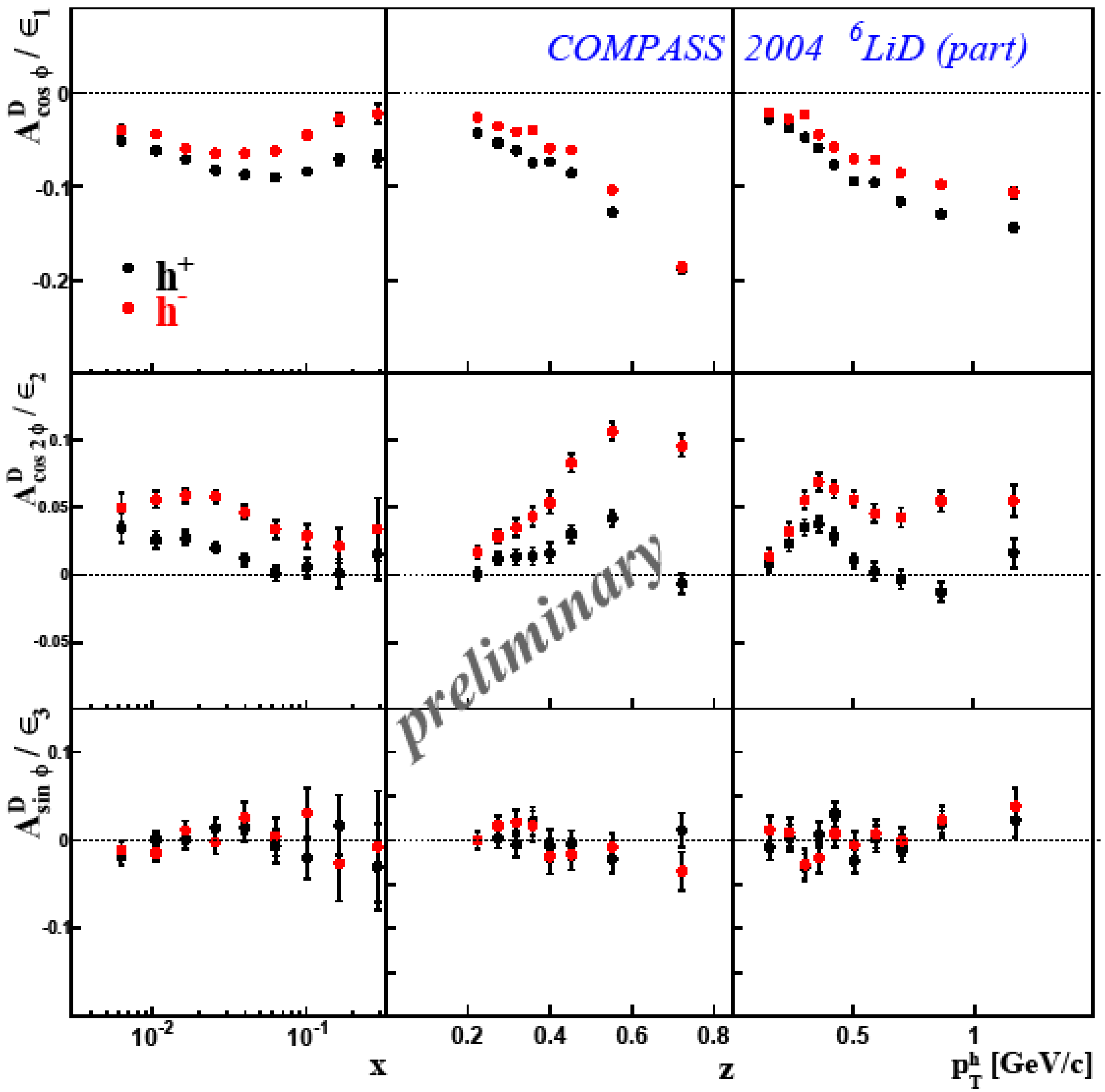
V.Barone, A.Prokudin, B.Q.Ma
arXiv:0804.3024 [hep-ph]

# Results

**summary**

**positive hadrons**

**negative hadrons**




**error bars:**
**statistical errors only**