Measurements of Transverse Momentum and Transverse Spin Effects at COMPASS

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on behalf of the COMPASS Collaboration

Outlook

the COMPASS experiment

results from ^{6}LiD data

- unpolarised azimuthal asymmetries
- Collins asymmetry
- Sivers asymmetry
- other TMD asymmetries

NEW !

first results from NH_3 data

- Collins and Sivers asymmetries

NEW !

conclusions

COMPASS

**fixed target experiment
at the CERN SPS**

broad physics programme

data taking since 2002:

muon beam	deuteron (^{6}LiD) polarised target	2002 2003 2004	L/T target polarisation 4:1
		2006	L target polarisation only
	proton (NH_3) polarised target	2007	L /T target polarisation 1:1
hadron beam	LH target	2008	

muon beam: 160 GeV/c
longitudinal polarisation -80%
intensity $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)

COMPASS

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

two stages spectrometer

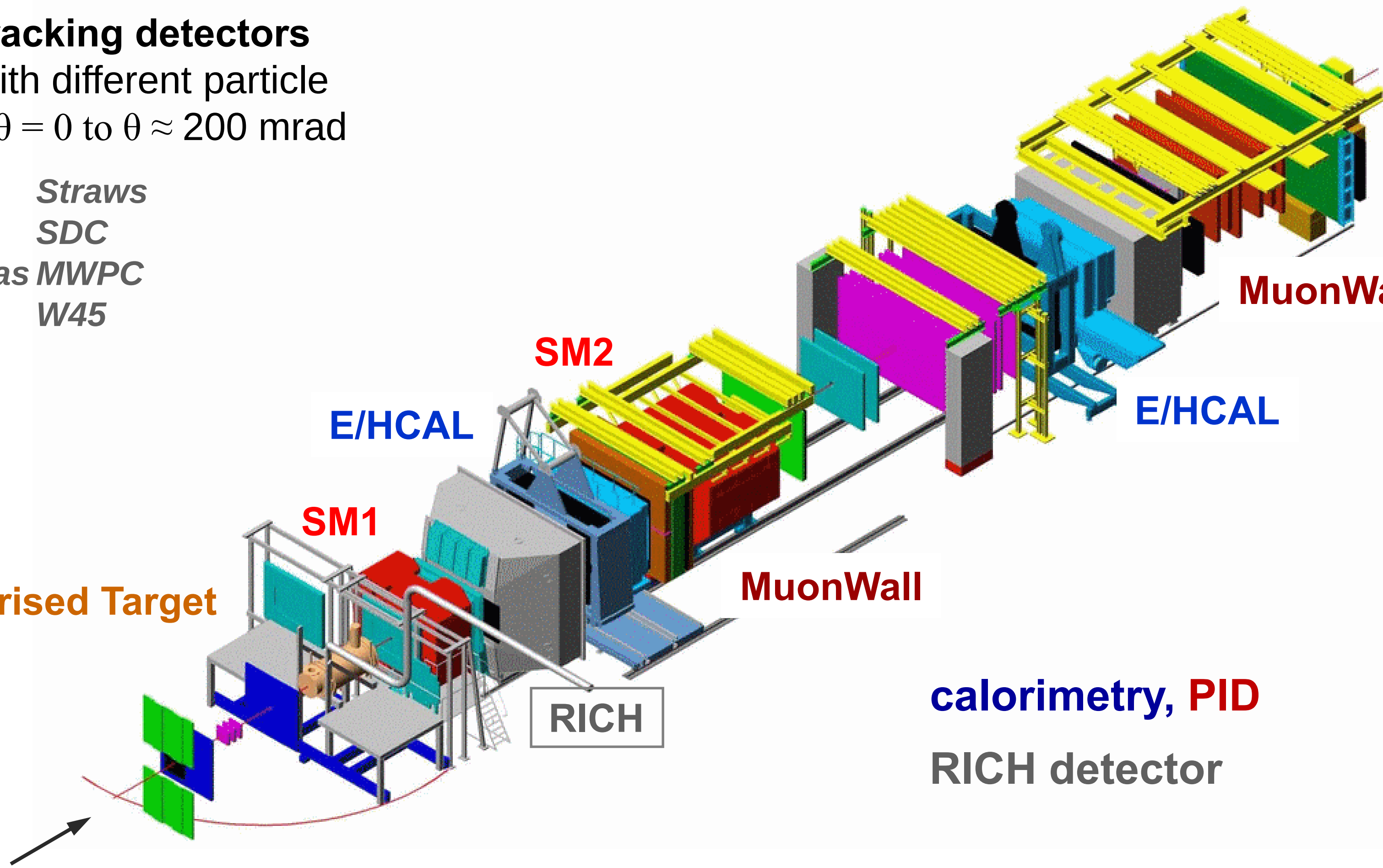
Large Angle Spectrometer (SM1)

Small Angle Spectrometer (SM2)

variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad

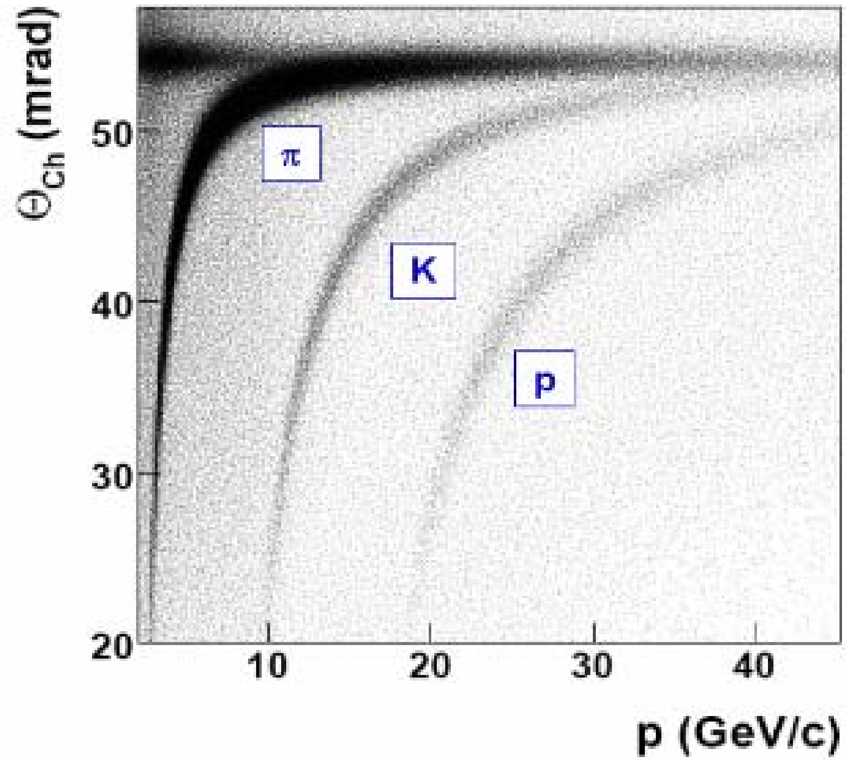
SciFi	*Straws*
Silicon	*SDC*
Micromegas	*MWPC*
GEMs	*W45*



calorimetry, PID

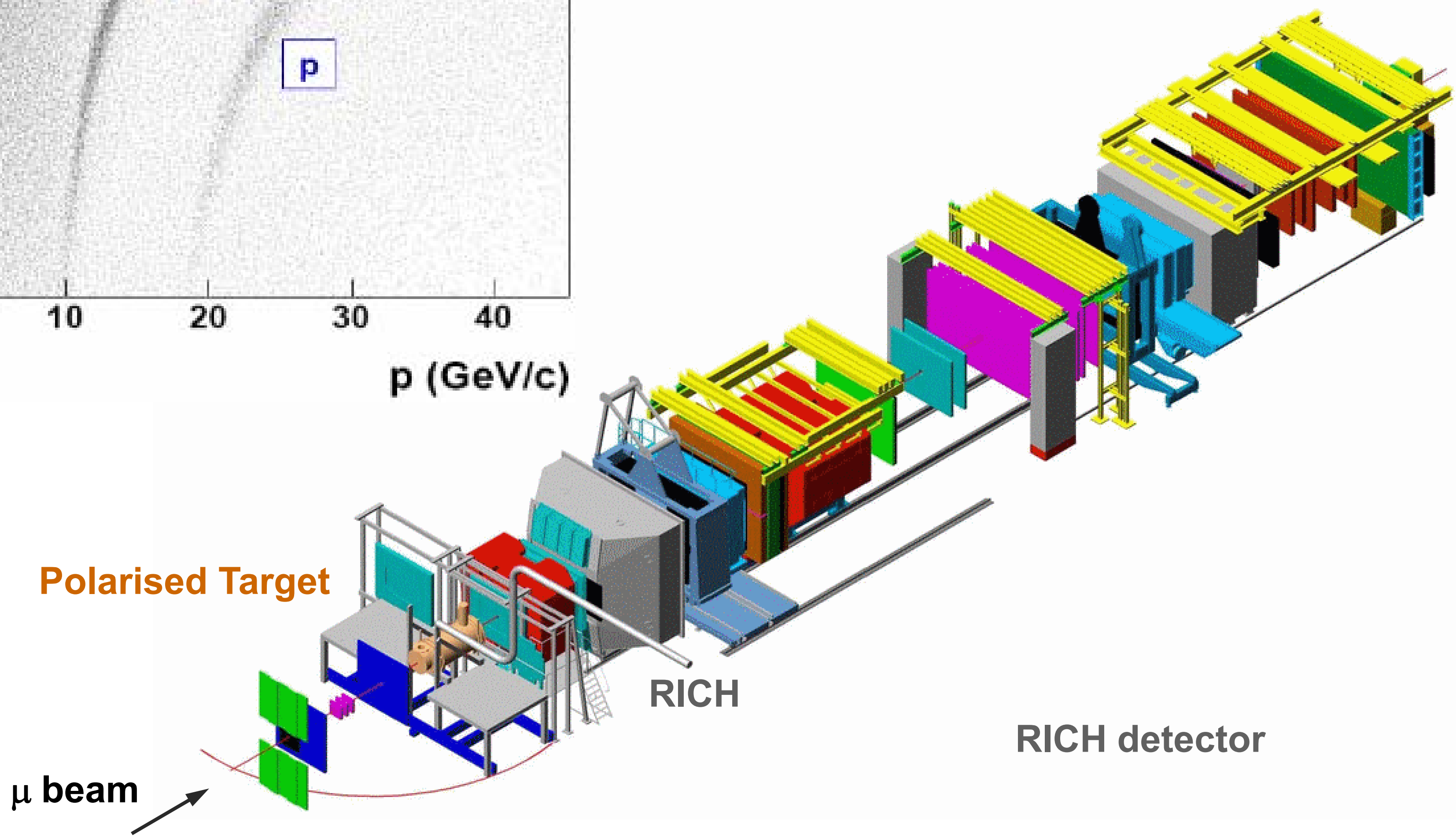
RICH detector

COMPASS



radiator C_4F_{10}

threshold: π ~2 GeV/c
K ~ 10 GeV/c

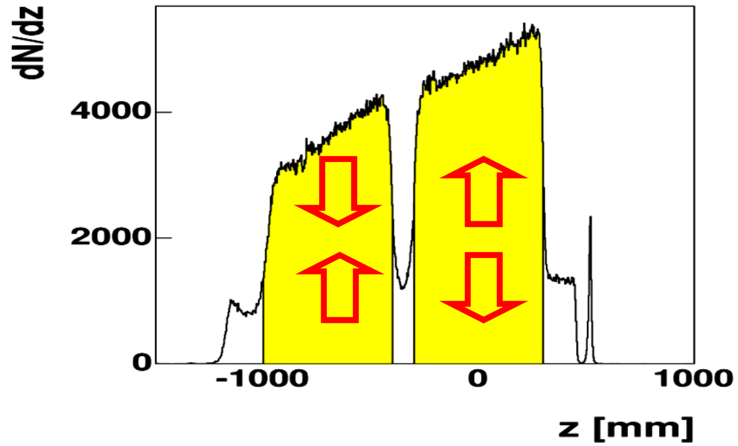


the target system

solid state target operated in frozen spin mode

2002-2004: ^{6}LiD (polarised deuteron)
dilution factor f = 0.38
polarization P_T = 50%

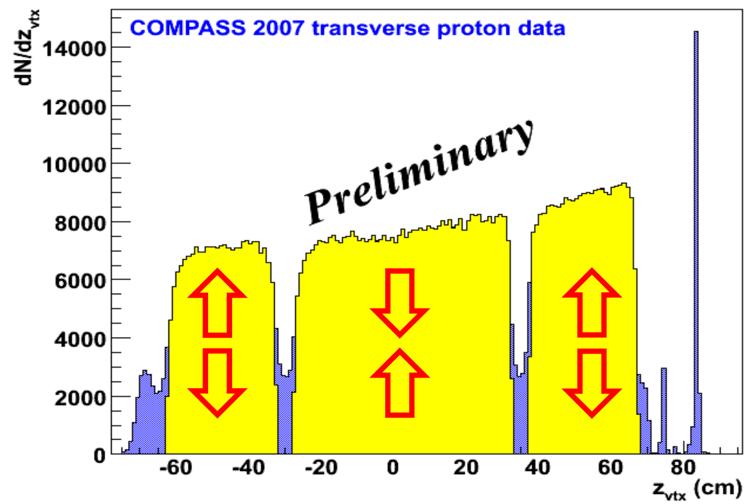
two 60 cm long cells
with opposite polarisation (systematics)



2006:

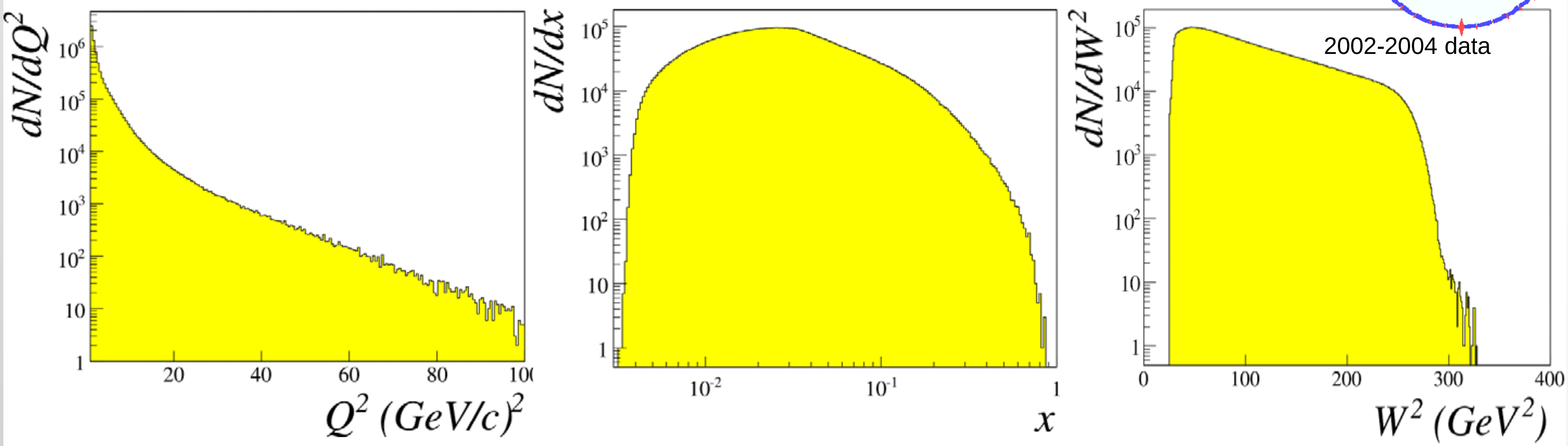
- PTM replaced with the large acceptance COMPASS magnet (180 mrad)
- 2 target cells ➔ 3 target cells

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

SIDIS event selection and kinematics

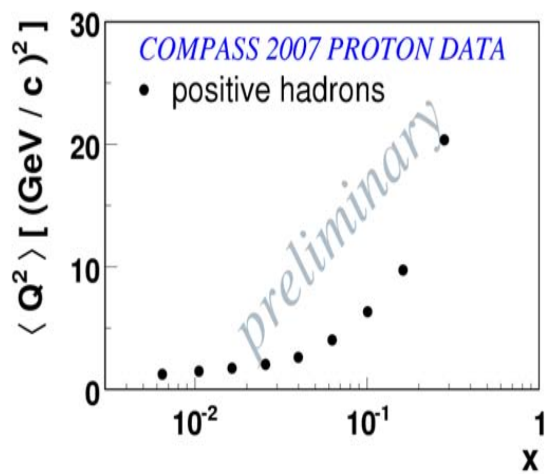


DIS cuts:

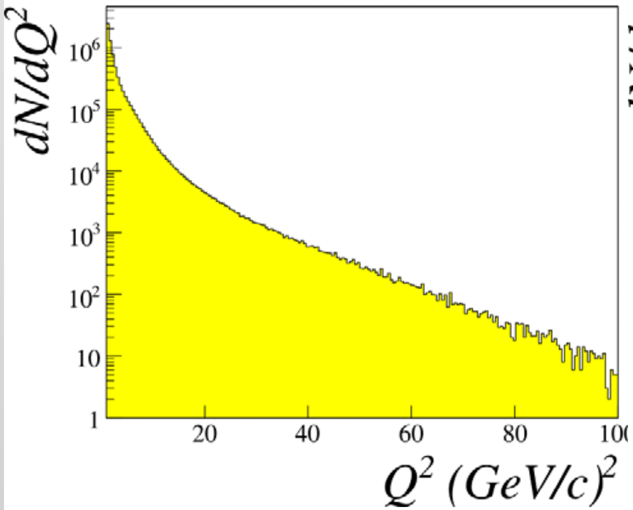
- $Q^2 > 1$ (GeV/c)^2
- $0.1 < y < 0.9$
- $W > 5$ GeV/c^2

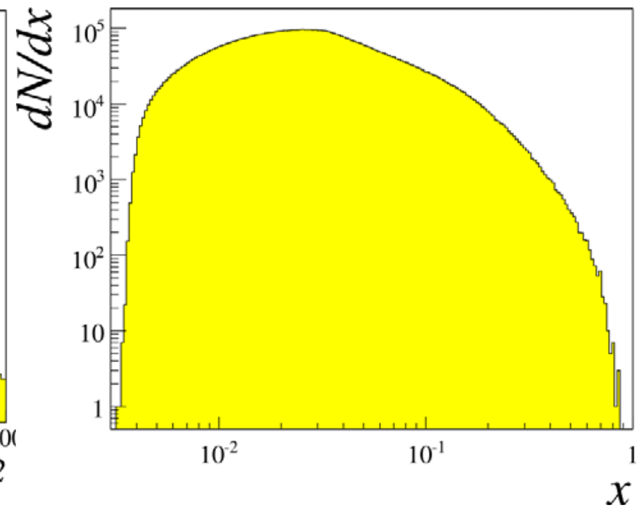
hadrons

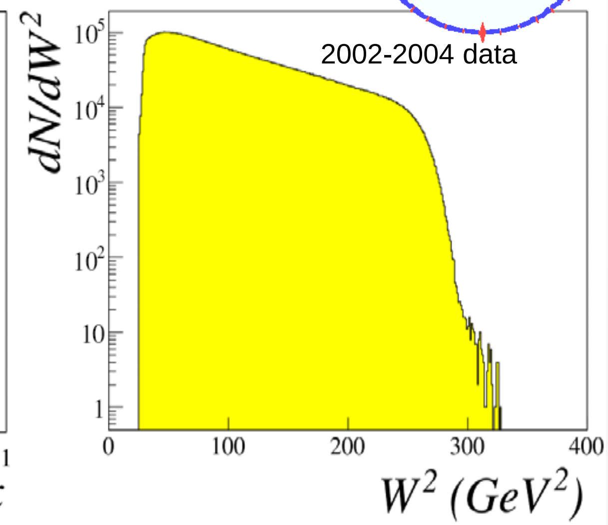
- energy deposit in HCALs>Thr. (~5 GeV)
- $p_T > 0.1$ GeV/c
- $z > 0.2$ (all), $z > 0.25$ (leading)



SIDIS event selection and kinematics







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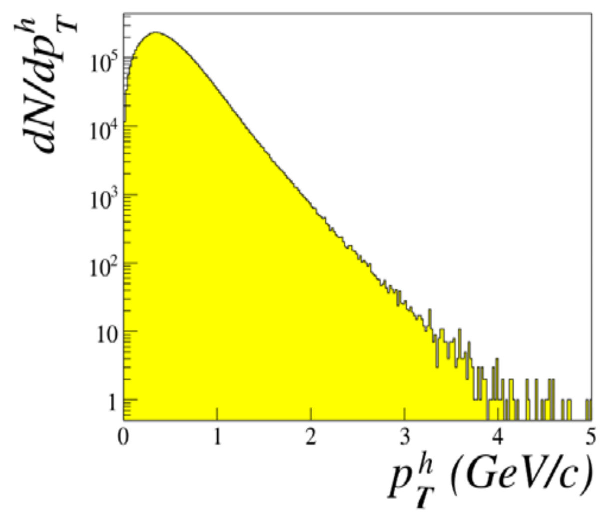

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unpolarised target SIDIS cross-section

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$
$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$
$$+\,\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

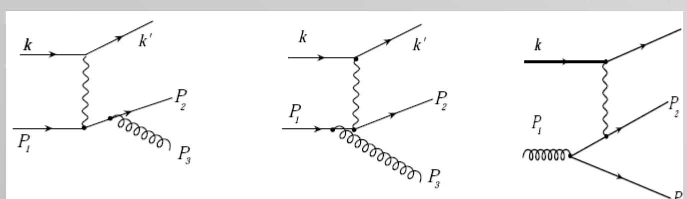
A Bacchetta, M Diehl, K Goeke, A Metz, P Mulders, M Schlegel (06)

3 independent azimuthal modulations

in ϕ_h , the hadron azimuthal angle in GNS

pQCD contributions

expected to be important at p_t > 1 GeV/c



O(α_s^1):
H. Georgi and H. D. Politzer. PRL 40 (1978) 3-6
A. Mendez. NP B145 (1978) 199-220.

O(α_s^2):
A. Daleo, D. de Florian, and R. Sassot. PR D71 (2005) 034013.

unpolarised target SIDIS cross-section

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

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

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

$$F_{LU}^{\sin\phi_h} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xe\,H_1^{\perp}+\frac{M_h}{M}\,f_1\frac{\tilde{G}^{\perp}}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xg^{\perp}D_1+\frac{M_h}{M}\,h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

“Amsterdam” notation

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

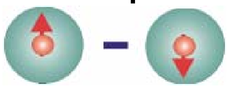
kinematical effect due to quark intrinsic momentum

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

Boer-Mulders DF

leading order DF

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



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

Cahn effect

\+ Boer-Mulders DF

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

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

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

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

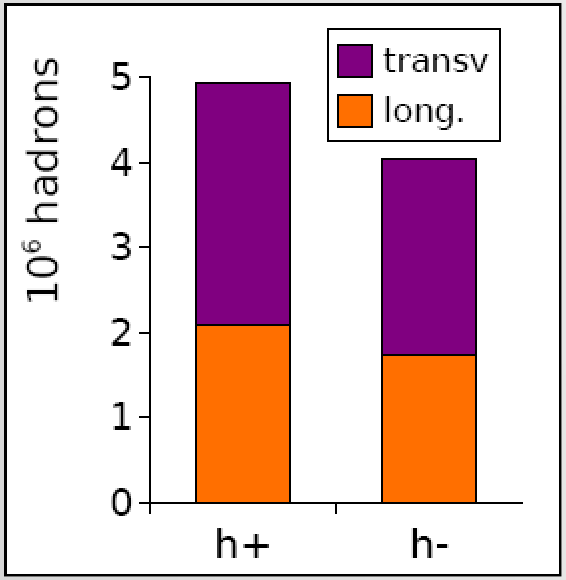
with both target orientation configurations to cancel possible polarisation effects

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:

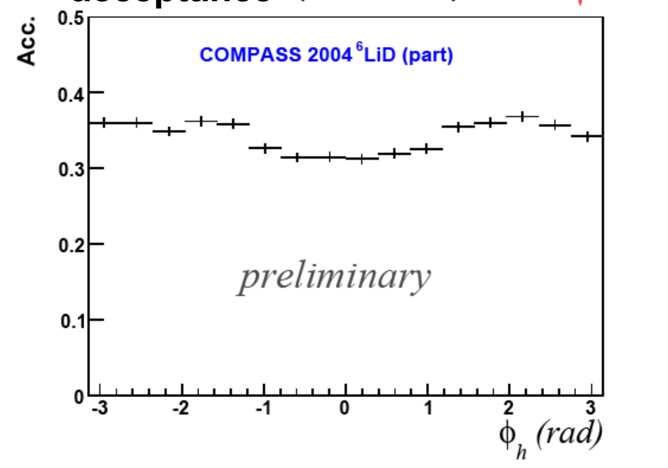


unpolarised target SIDIS cross-section

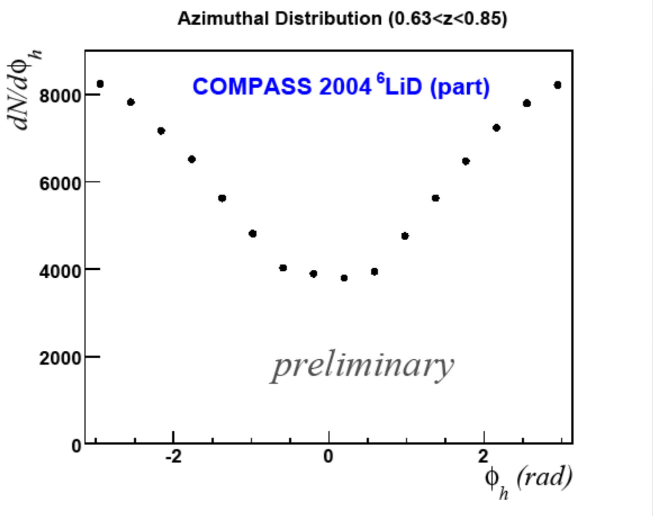
to extract the asymmetries

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

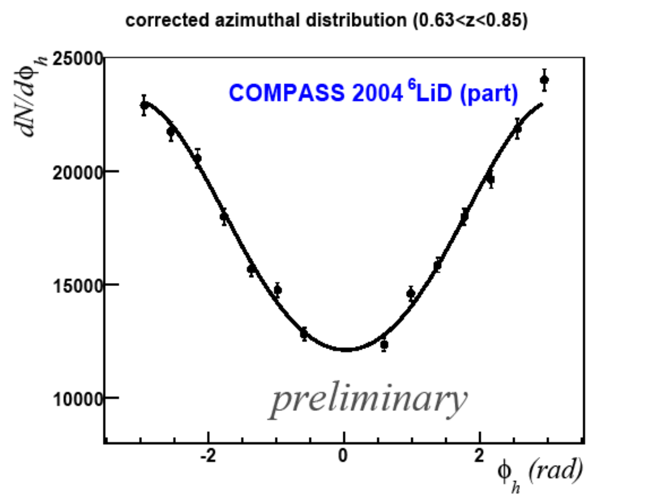
acceptance (0.63<z<0.85)



initial azimuthal distribution



final azimuthal distribution



unpolarised target SIDIS cross-section

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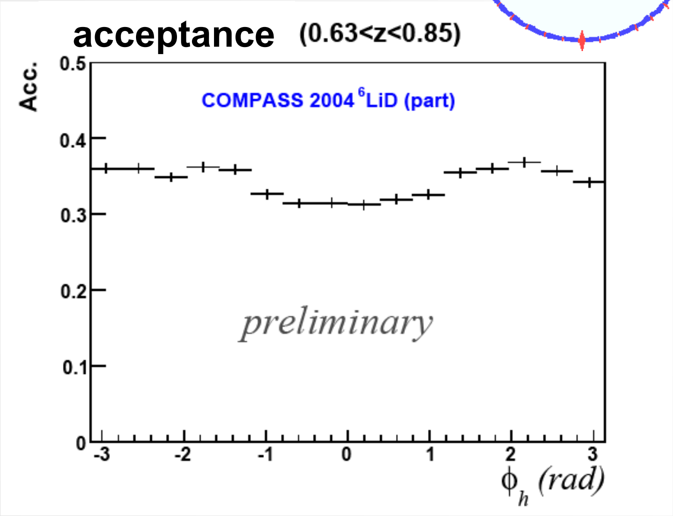
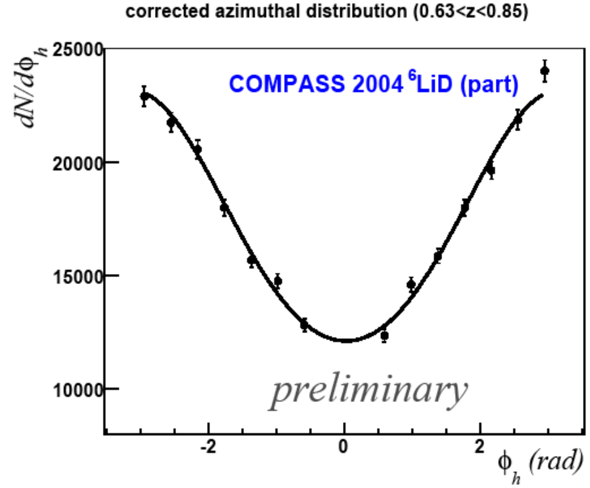


final azimuthal distribution



the final azimuthal distributions are fitted with the function:

$$N_{corr}(\phi_h) = N_0(1 + A_{\sin\phi_h}\sin\phi_h + A_{\cos\phi_h}\cos\phi_h + A_{\cos2\phi_h}\cos2\phi_h)$$

unpolarised target SIDIS cross-section

systematic errors evaluated from:

- **compatibility of results with L and T target polarization**
  (different experimental conditions, different MCs)

- **comparison of results obtained using two MCs with different settings for each data set**
  (LEPTO default, standard COMPASS high p_t; ~extreme cases)

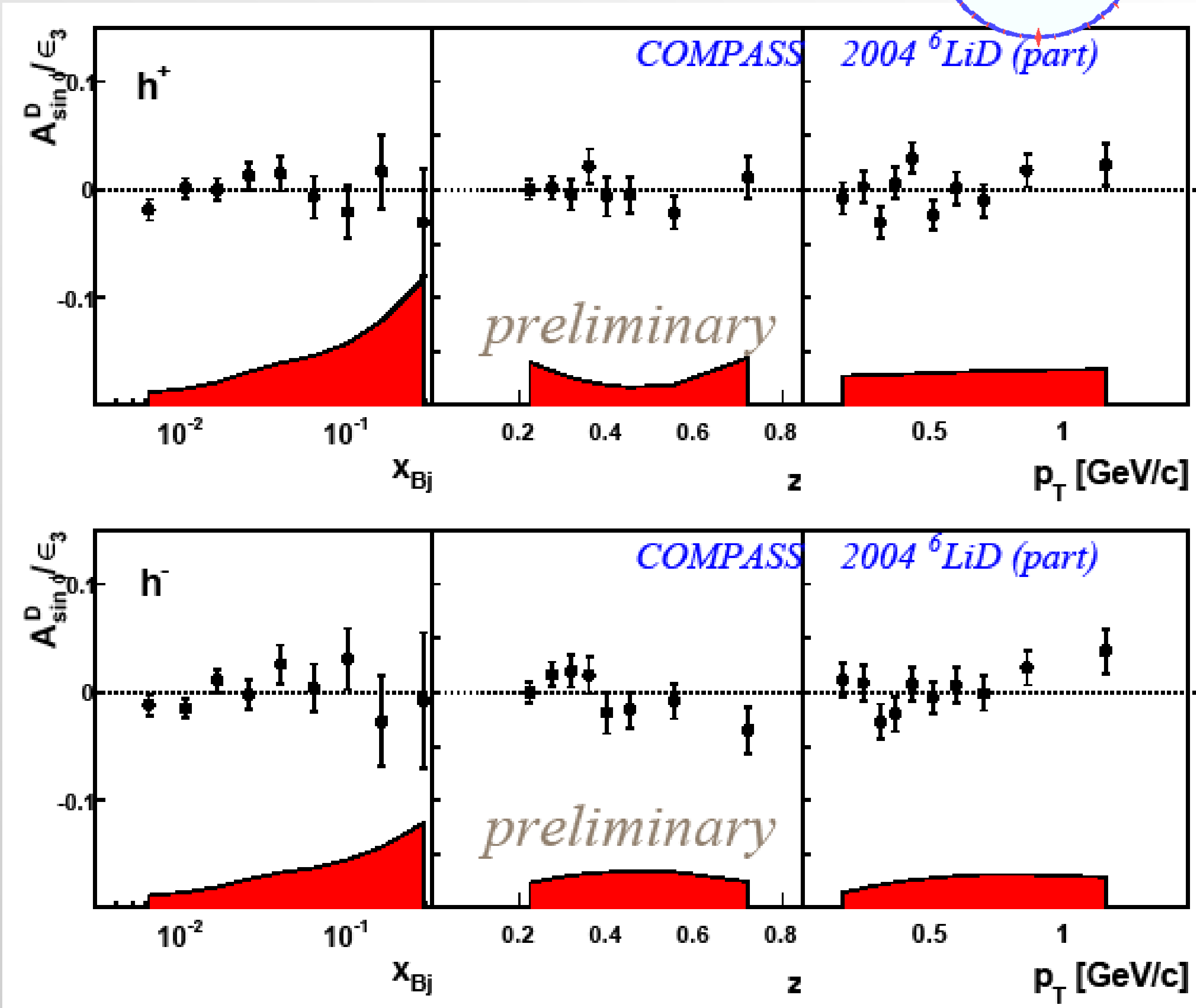
  most important contribution

- **compatibility of results from subsamples corresponding to**
  - different periods
  - different target polarisations
  - different geometrical regions for the scattered muon

results: sinϕ modulation

$$A_{\sin\phi} / \varepsilon_s$$

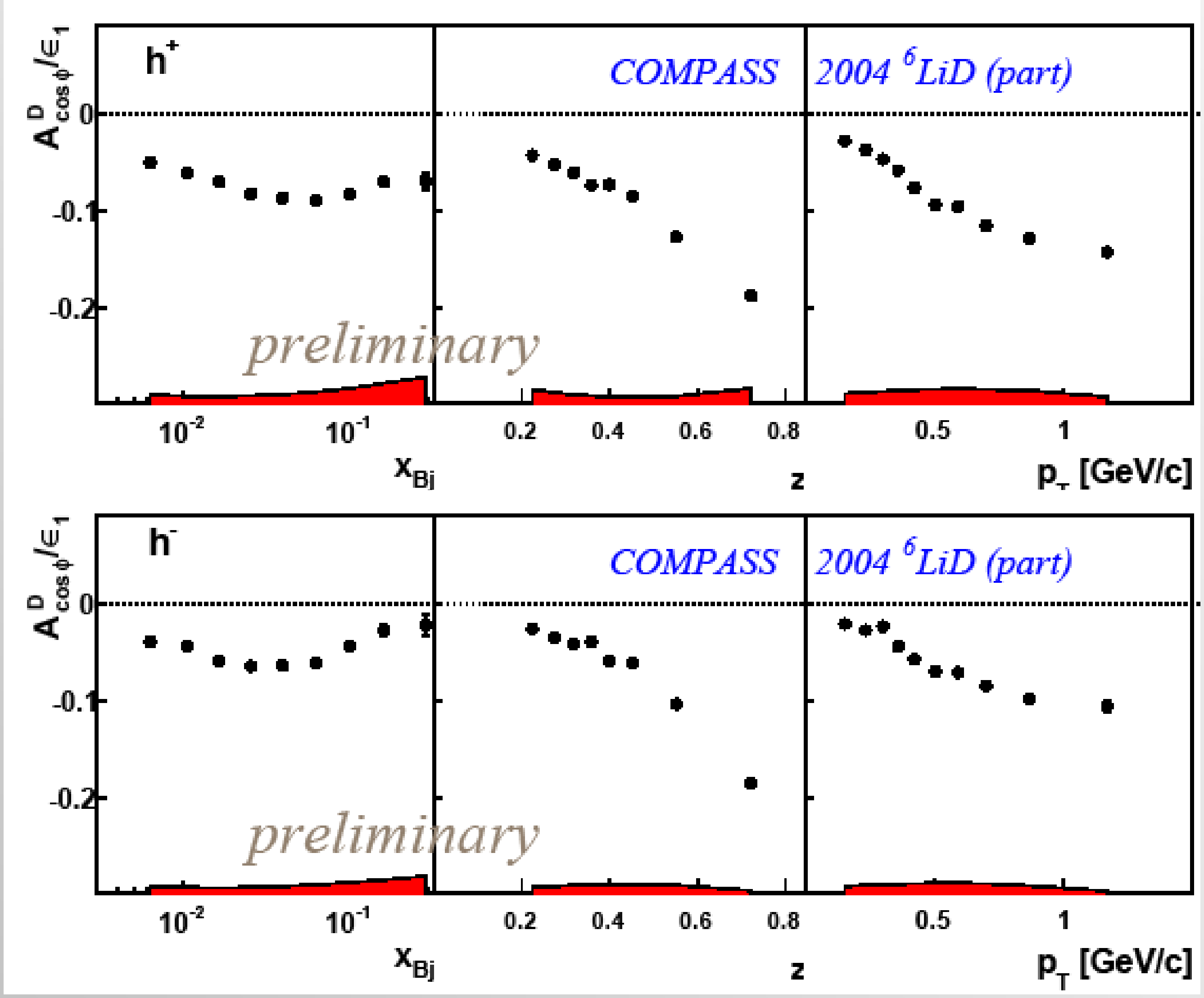
$$\varepsilon_s = \frac{2y\sqrt{1-y}}{1+(1-y)^2}$$



error bars:
statistical errors

bands:
systematical errors

results: $\cos\phi$ modulation

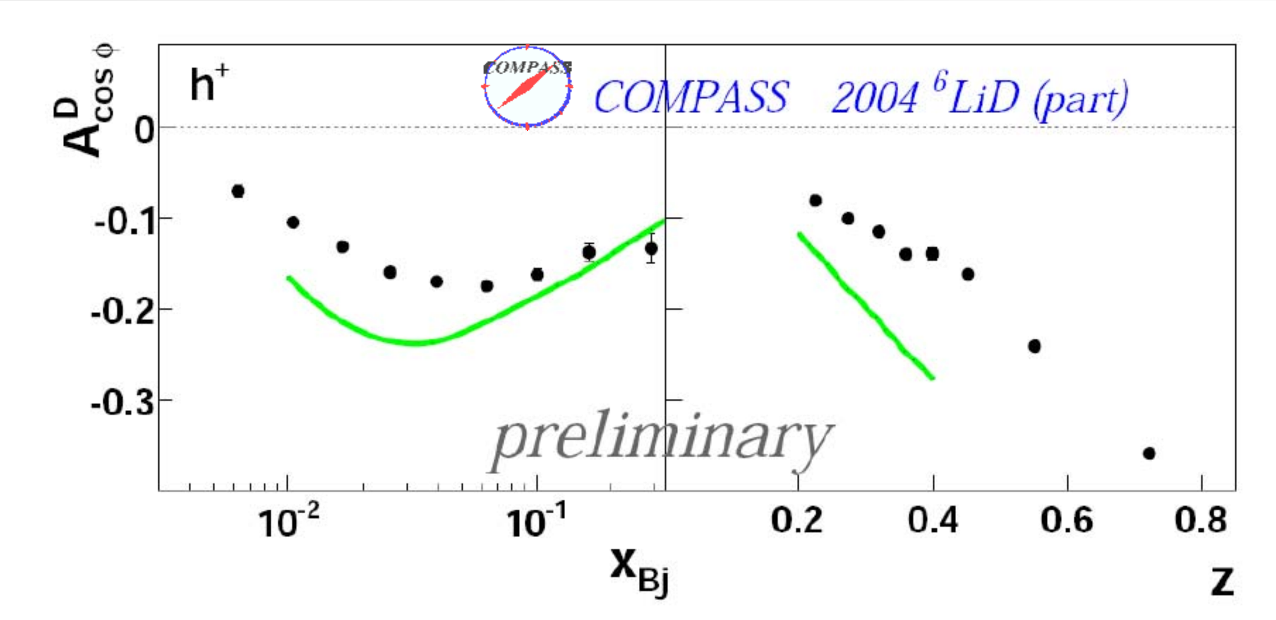


$$A_{\cos\phi} / \varepsilon_c$$

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

results: $\cos\phi$ modulation

comparison with theory

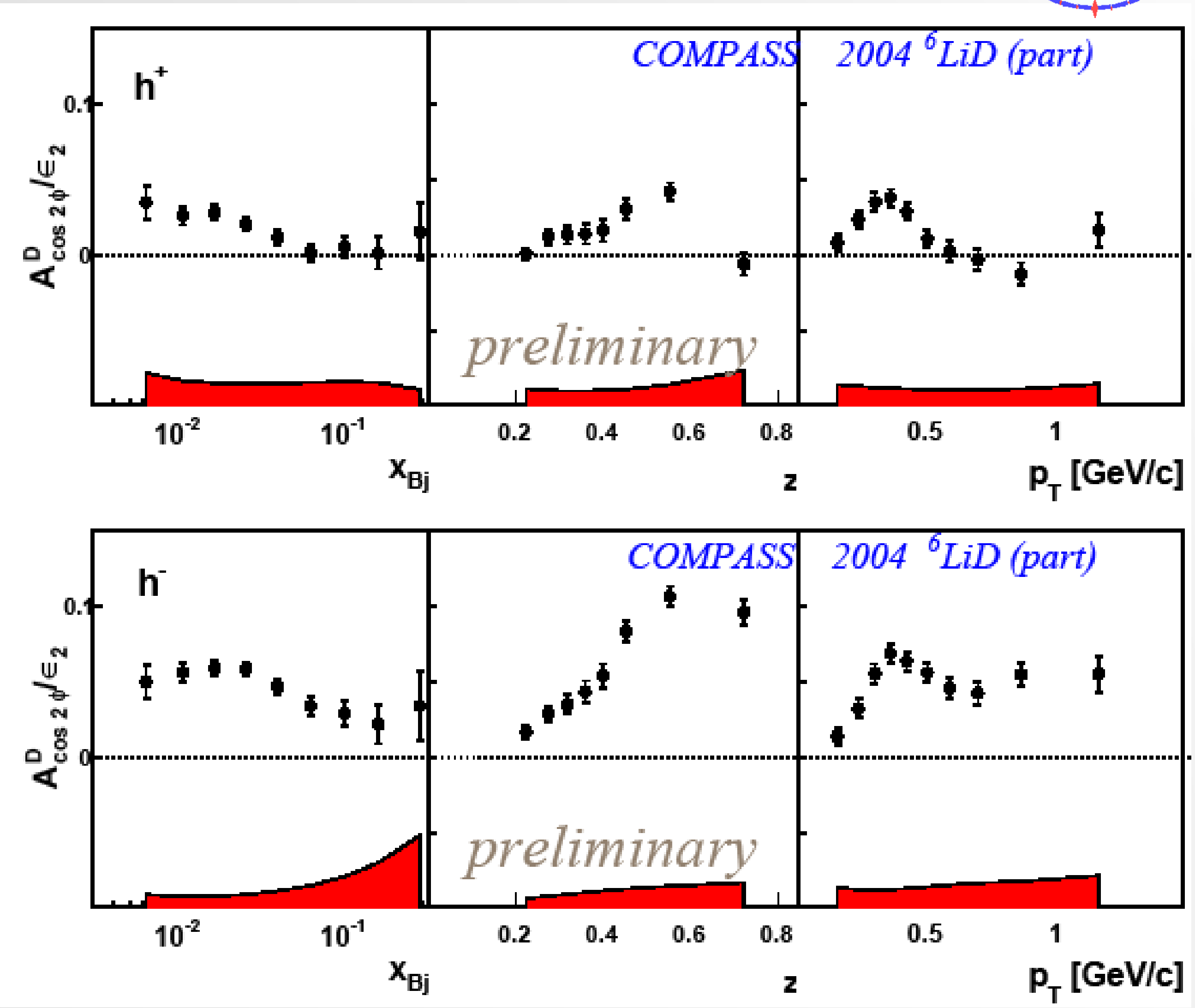


M. Anselmino, M. Boglione, A. Prokudin, C. Türk
Eur. Phys. J. A 31, 373-381 (2007)
does not include Boer – Mulders contribution

results: cos 2ϕ modulation

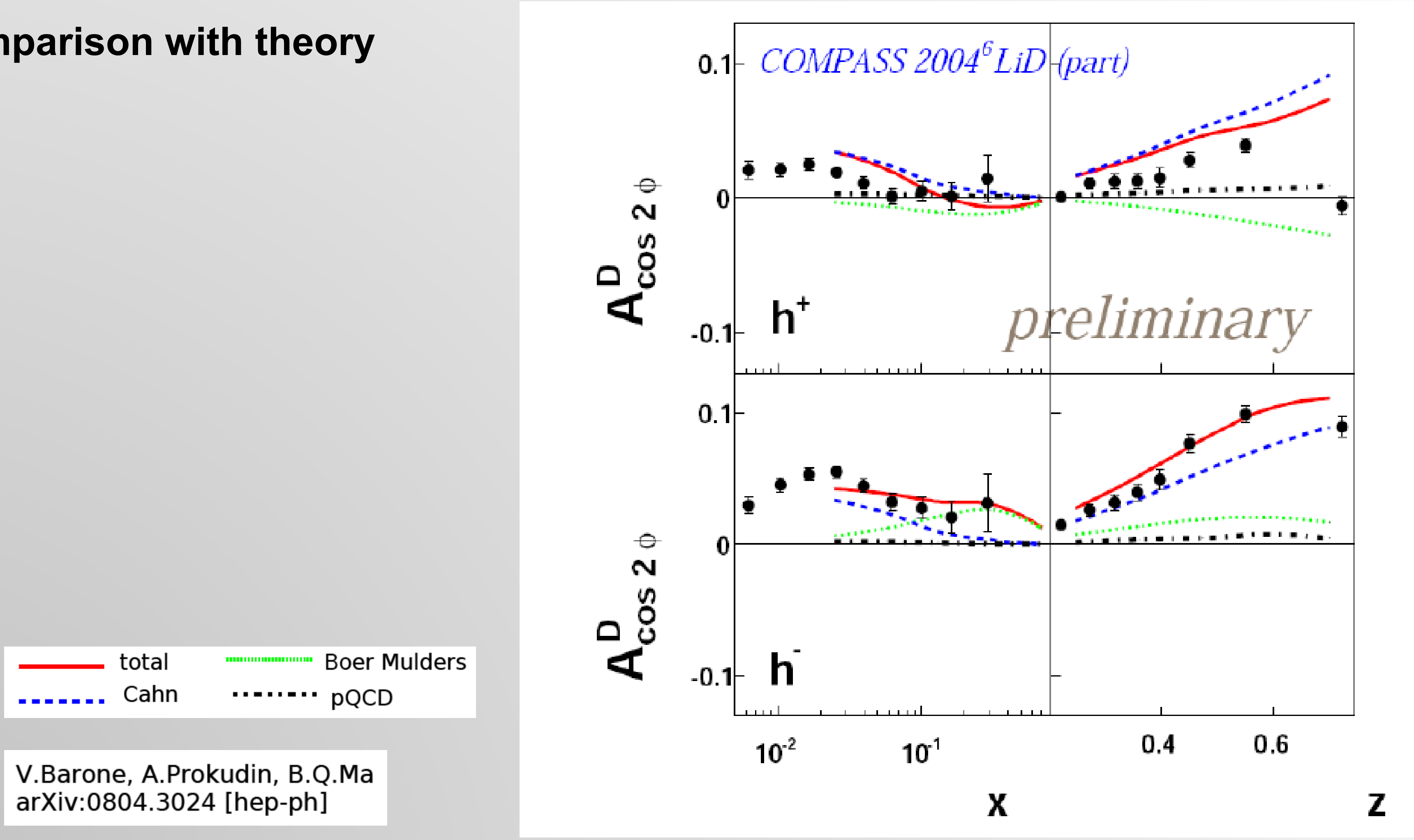
$$A_{\cos 2\phi} / \varepsilon_{c2}$$

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



results: cos 2ϕ modulation

comparison with theory



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

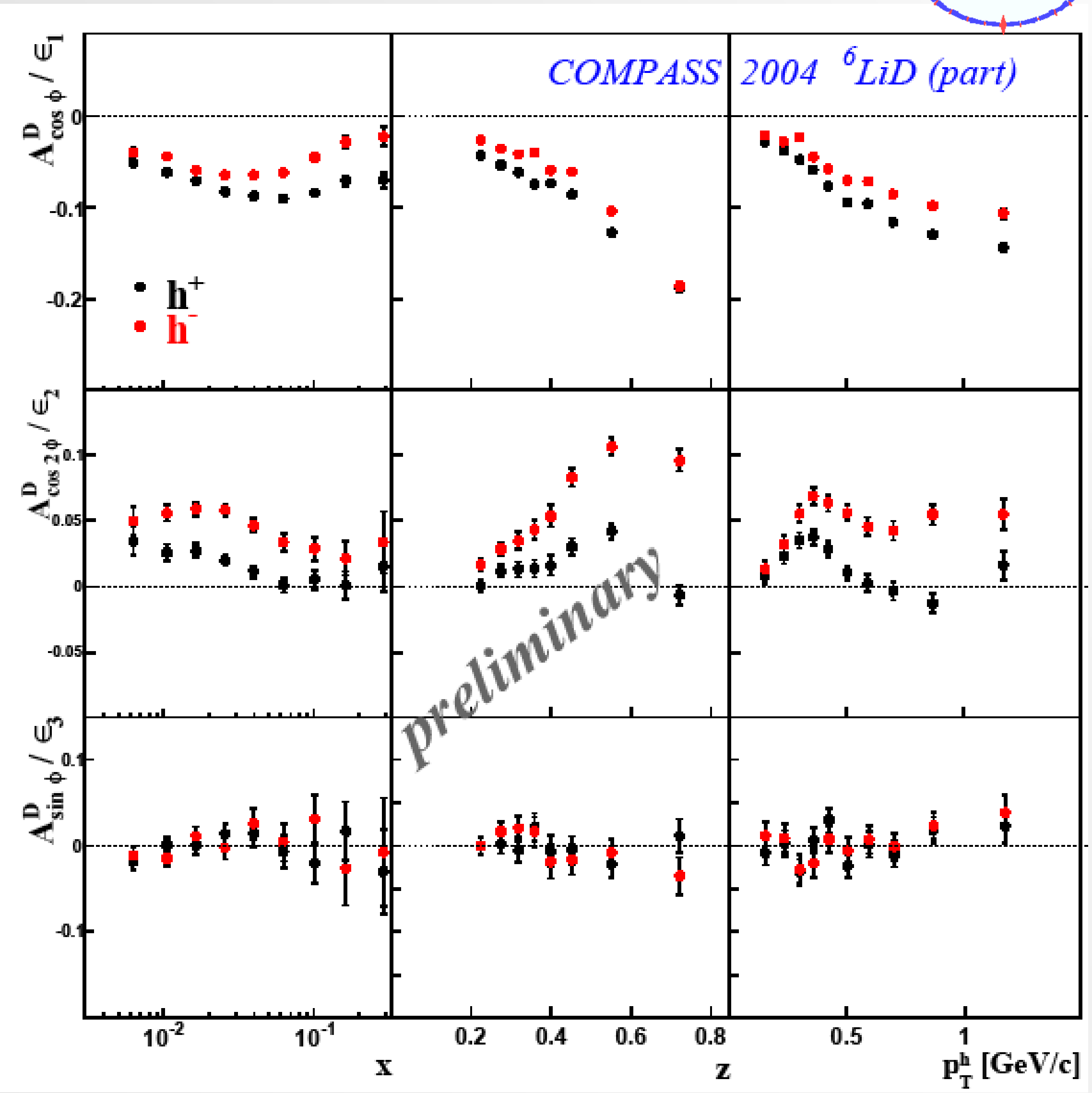
results

summary

positive hadrons

negative hadrons

error bars:
statistical errors
only



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- unpolarised azimuthal asymmetries
- **Collins asymmetry**
- Sivers asymmetry
- other TMD asymmetries

first results from NH_3 data

- Collins and Sivers asymmetries

conclusions

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

all explored in COMPASS

I will concentrate on the first

Collins asymmetry

Collins effect

→ azimuthal distribution of the hadrons produced in $l\, N^{\uparrow} \rightarrow l'\, h^{\pm}\, X$

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

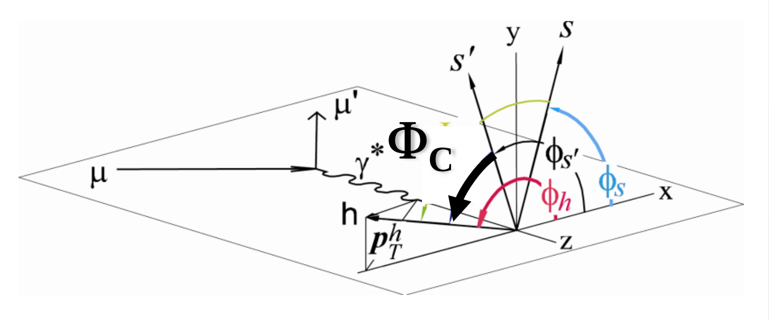
refer to the opposite orientation of the transverse spin of the nucleon

P_T is the target polarisation; D_{NN} is the transverse spin transfer coefficient initial → struck quark

"Collins angle"

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

$\phi_{h,s',S}$ azimuthal angles of hadron momentum, of the spin of the fragmenting quark and of the nucleon in the GNS



from the azimuthal distribution of the hadrons one measures the "Collins Asymmetry"

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

Collins asymmetry

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

unique feature of SIDIS

has been measured by the HERMES experiment on p

different from zero for charged particles

of opposite signe for positive and negative charge particles

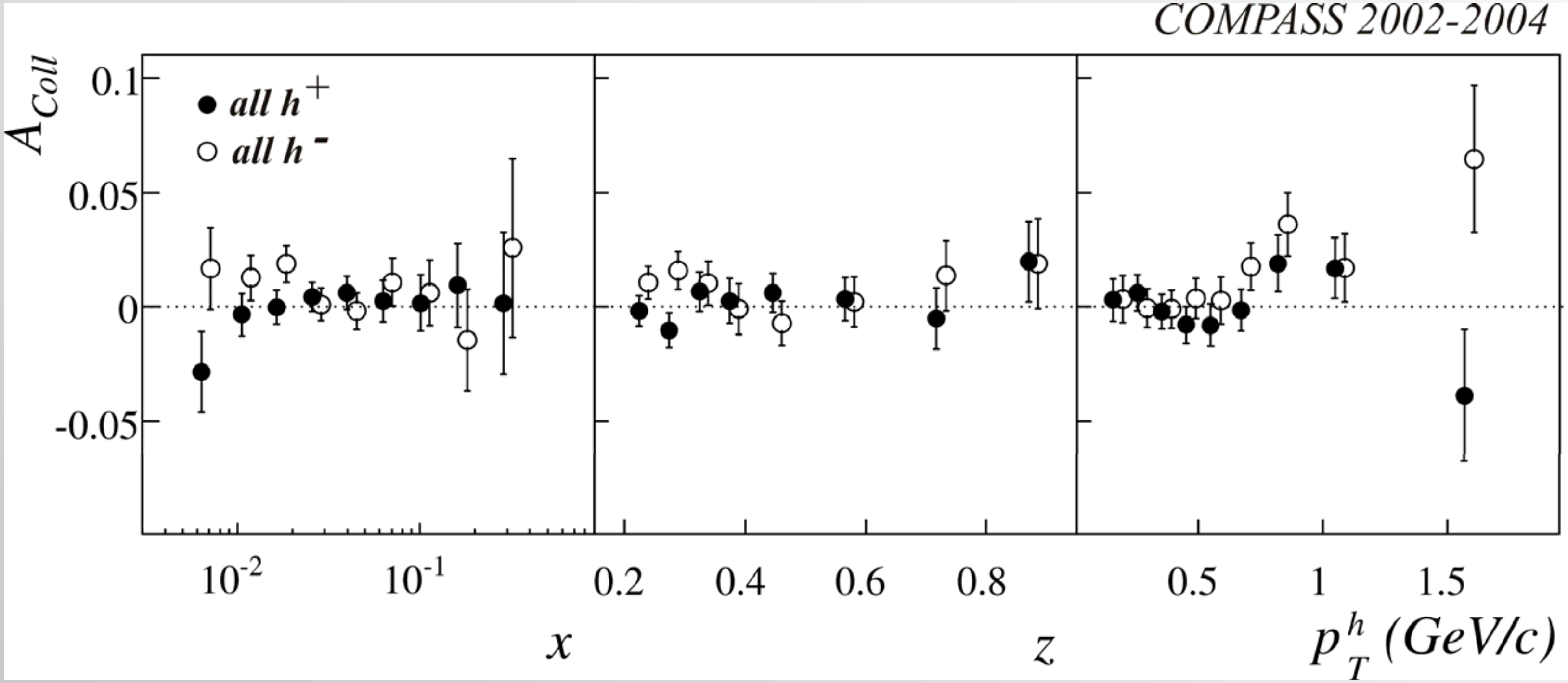
from the azimuthal distribution of the hadrons one measures the "Collins Asymmetry"

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

Collins asymmetry – deuteron data

charged hadrons (mostly pions)

- 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
(syst. errors much smaller)

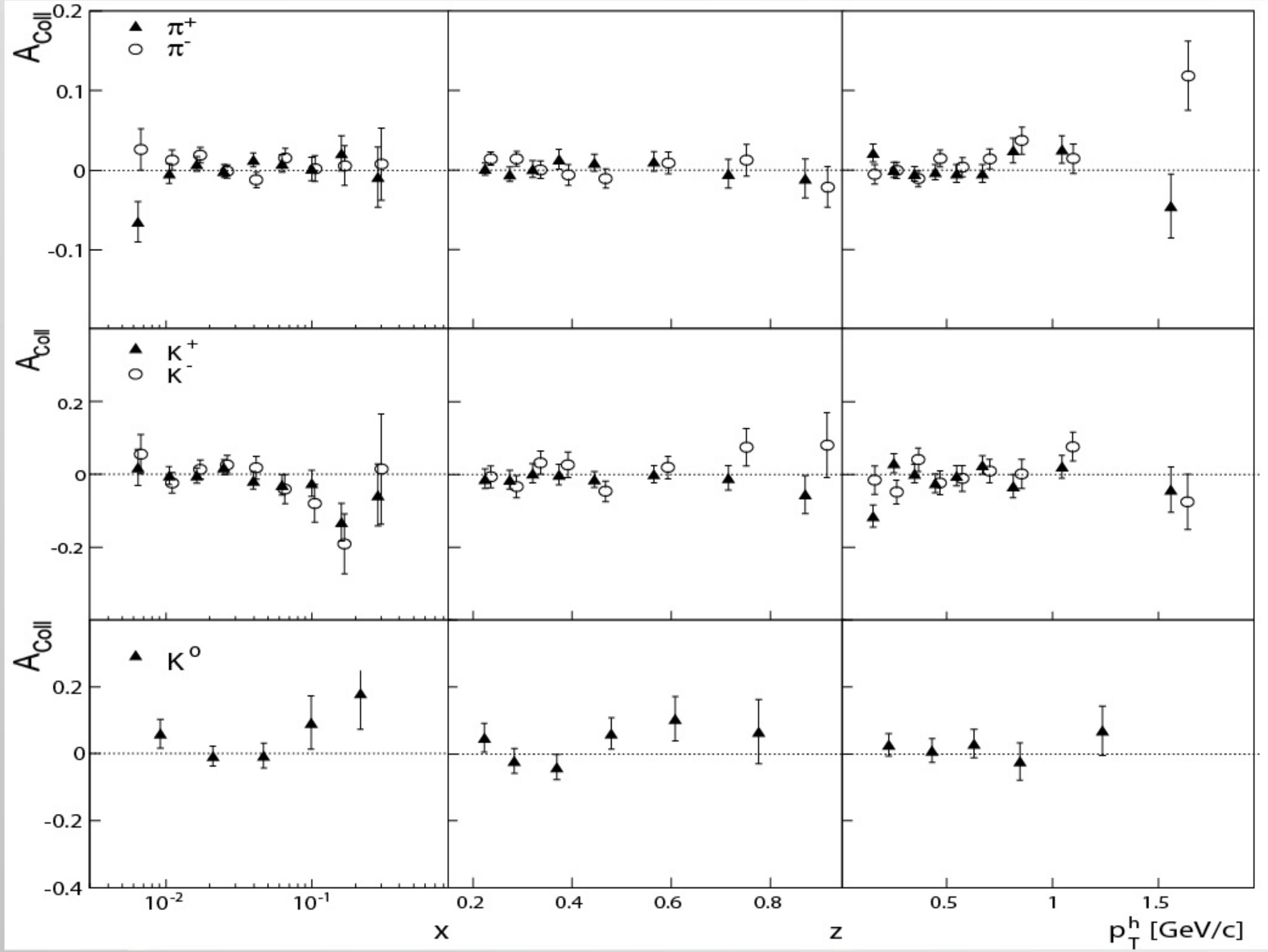
the same with leading h

with HERMES results, cancellation between u and d quark contributions

Collins asymmetry – deuteron data

identified hadrons

- 2007: **final results from 2002-2004 data** [arXiv:0802.2160]

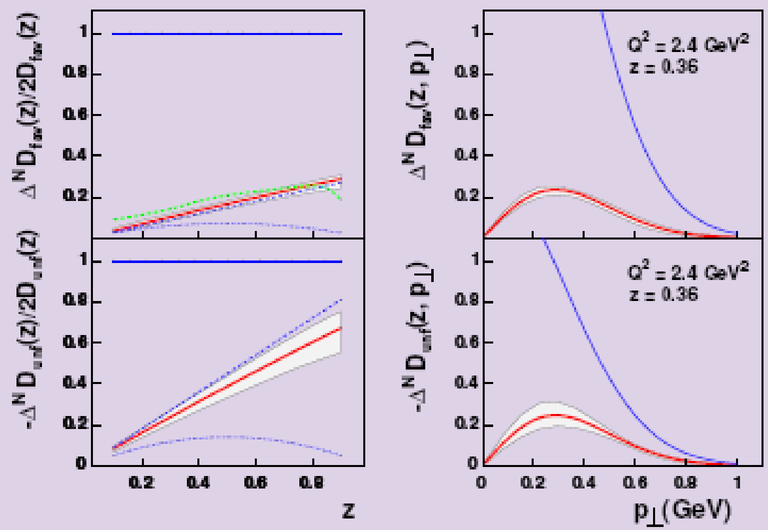


again, difficult to see a signal …

Collins asymmetry – fits to data

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

Collins fragmentation function



compared to Ref. [1] (dashed line), Ref. [2] (dotted line), and Ref. [3] (dashed green line)

[1] A. V. Efremov, K. Goeke, and P. Schweitzer, Phys. Rev. D73, 094025 (2006).

[2] W. Vogelsang and F. Yuan, Phys. Rev. D72, 054028 (2005).

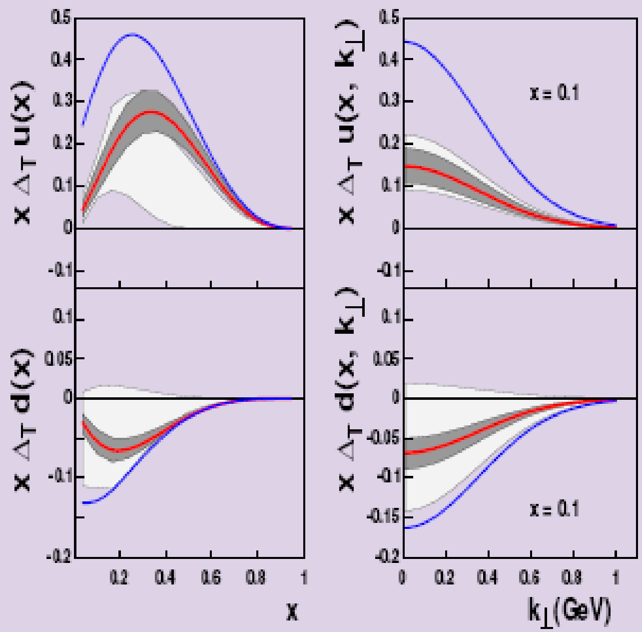
[3] A. Bacchetta, L. Gamberg, G. R. Goldstein, A. Mukherjee PLB659:234-243,2008.

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

Collins asymmetry – fits to data

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

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

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Sivers asymmetry

appears in SIDIS as a modulation in the "Sivers angle" $\Phi_S = \phi_h - \phi_S$

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

ϕ_h azimuthal angle of hadron momentum
ϕ_S azimuthal angle of the spin of the nucleon

the "Sivers angle" Φ_S and the "Collins angle" Φ_C are independent

→ the Collins and Sivers asymmetries can be disentangled and extracted from the same data in SIDIS on a transversely polarised target

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

the "Sivers DF"

the most famous of the TMD parton DF

the Sivers asymmetry

has been measured by the HERMES experiment on p

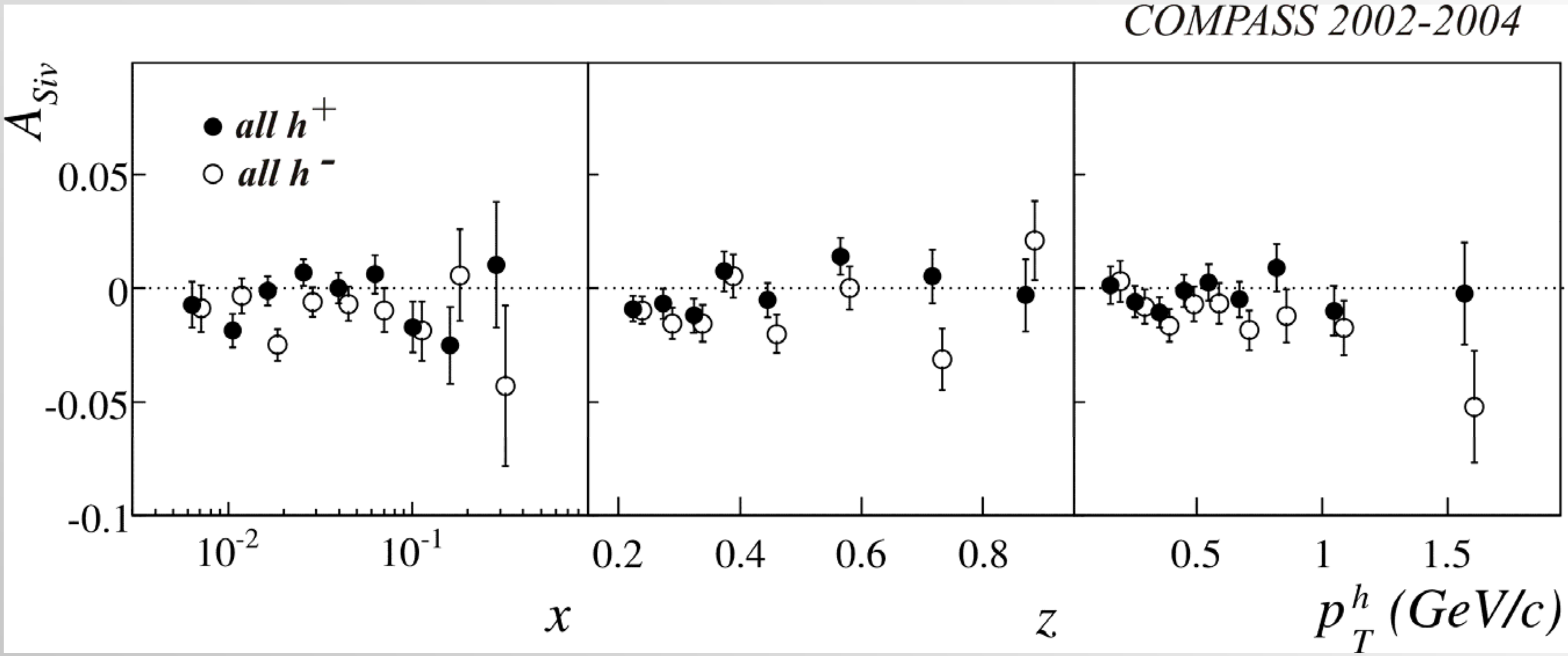
different from zero for positive charge particles

compatible with zero for negative charge particles

Sivers asymmetry – deuteron data

charged hadrons (mostly pions)

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



asymmetries compatible with zero within the statistical errors

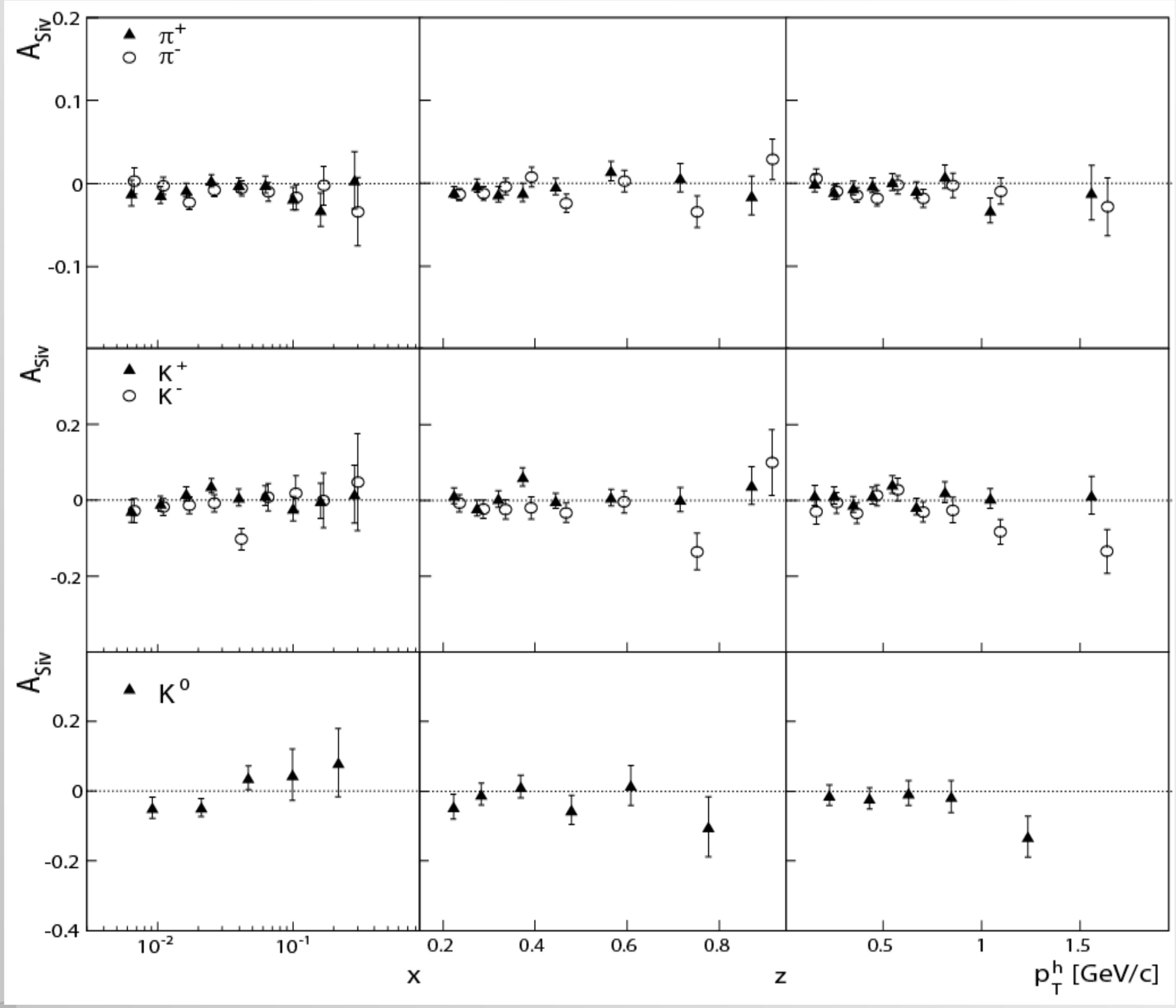
(systematic errors much smaller)

cancellation between u and d quark contributions in the dueteron

Sivers asymmetry – deuteron data

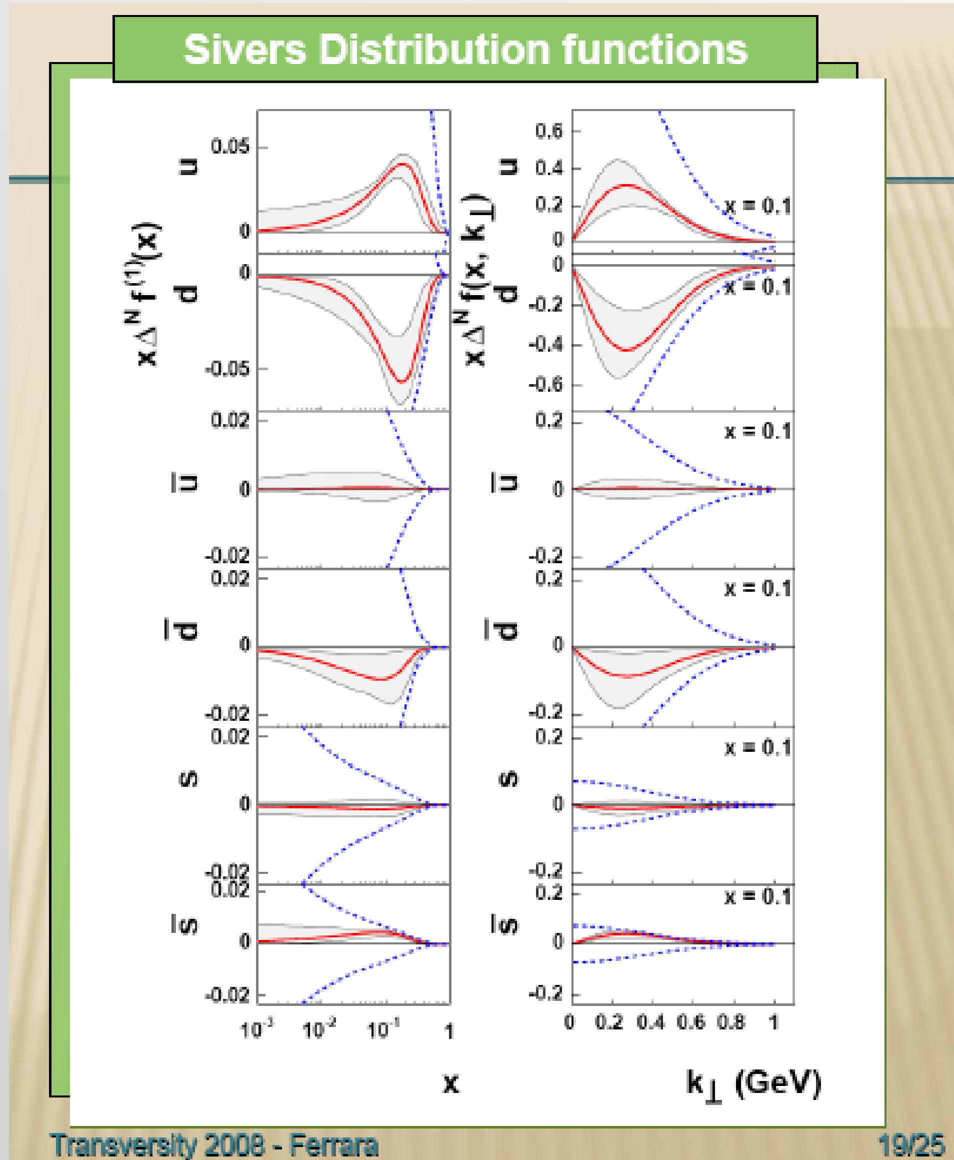
identified hadrons

- 2007: **final results from 2002-2004 data** [arXiv:0802.2160]



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

Outlook

the COMPASS experiment

results from ^{6}LiD data

- unpolarised azimuthal asymmetries
- Collins asymmetry
- Sivers asymmetry
- other TMD asymmetries

first results from NH_3 data

- Collins and Sivers asymmetries

conclusions

semi-inclusive cross-section

18 structure functions

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

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

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

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

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

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

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

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

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

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

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

semi-inclusive cross-section

8 tgt transverse spin dependent asymmetries, 4 LO

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

$f_{1T}^{\perp q} \otimes D_{1q}^h$ **Sivers**

$h_1^q \otimes H_{1q}^{\perp h}$ **Collins**

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

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

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

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

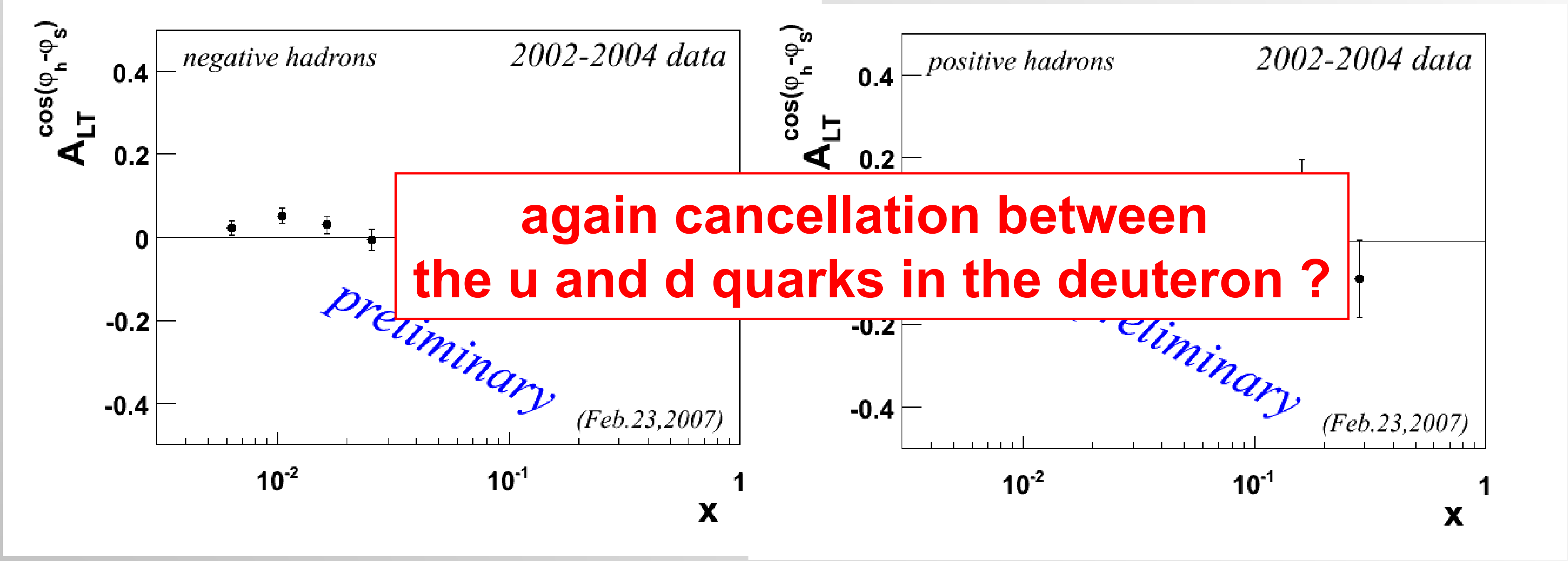
$$+ \sqrt{2\,\varepsilon(1-\varepsilon)}\, \cos(2\phi_h - \phi_S)\, F_{LT}^{\cos(2\phi_h-\phi_S)} \Big] \Big\},$$

all measured by COMPASS on deuteron

target transverse spin dependent asymmetries (LO)

$$F_{LT}^{\cos(\phi_h - \phi_s)} \propto g_{1T}^q \otimes D_{1q}^h$$

g_{1T} is the only parton DF which is chiral-even, T-even, leading twist in addition to the unpolarised DF and to the helicity DF



again cancellation between the u and d quarks in the deuteron ?

all these asymmetries are compatible with zero
the same result for charged pions and kaons

conclusions from COMPASS deuteron data

- the unpolarised azimuthal asymmetries are different from zero and different for positive and negative hadrons
- all the transverse spin asymmetries have been measured to be compatible with zero

HERMES, COMPASS, BELLE data:

consistent picture

first fits, extractions of the new DFs, and predictions for other experiments

conclusions from COMPASS deuteron data

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HERMES, COMPASS, BELLE data:

consistent picture

first fits, extractions of the new DFs, and predictions for other experiments

- still, a lot of expectation for the higher energy COMPASS proton data

PHYSICAL REVIEW D **72**, 054028 (2005)

Single-transverse-spin asymmetries: From deep inelastic scattering to hadronic collisions

Werner Vogelsang[1,2,*] and Feng Yuan[2,†]

It will be very interesting to check these predictions with future COMPASS data for a proton target. Thanks to the higher Q^2, such data would also help in confirming the leading-twist nature of the Sivers and Collins asymmetries.

Outlook

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conclusions

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

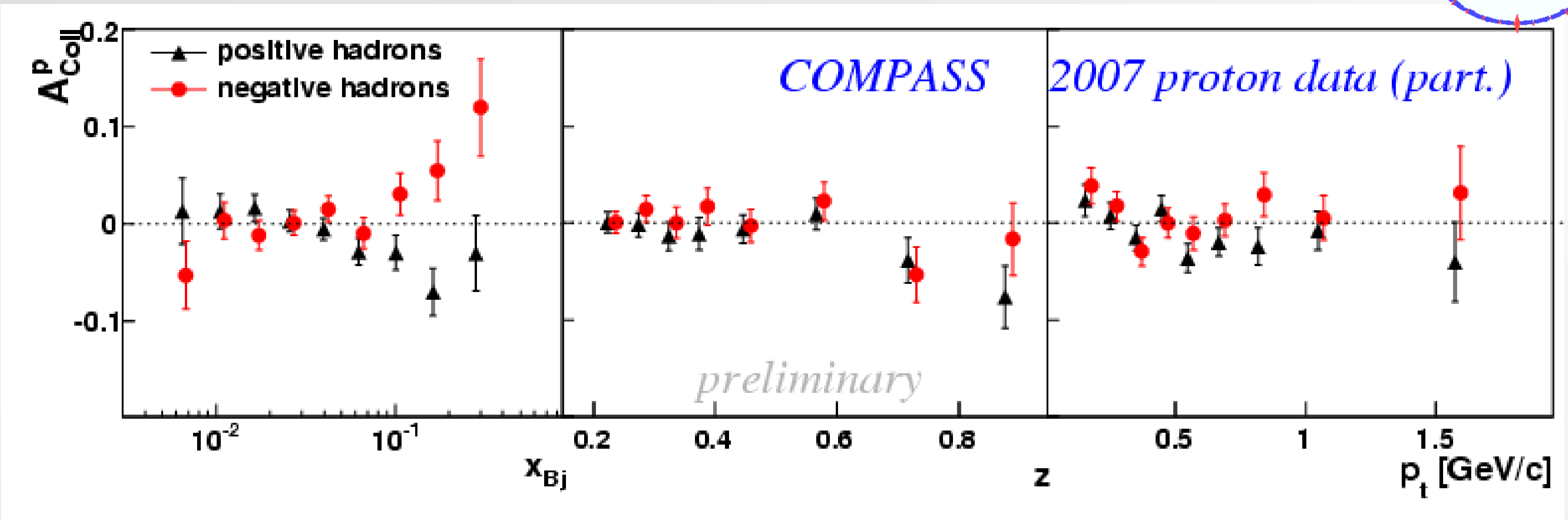
several stability tests have been performed

- 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

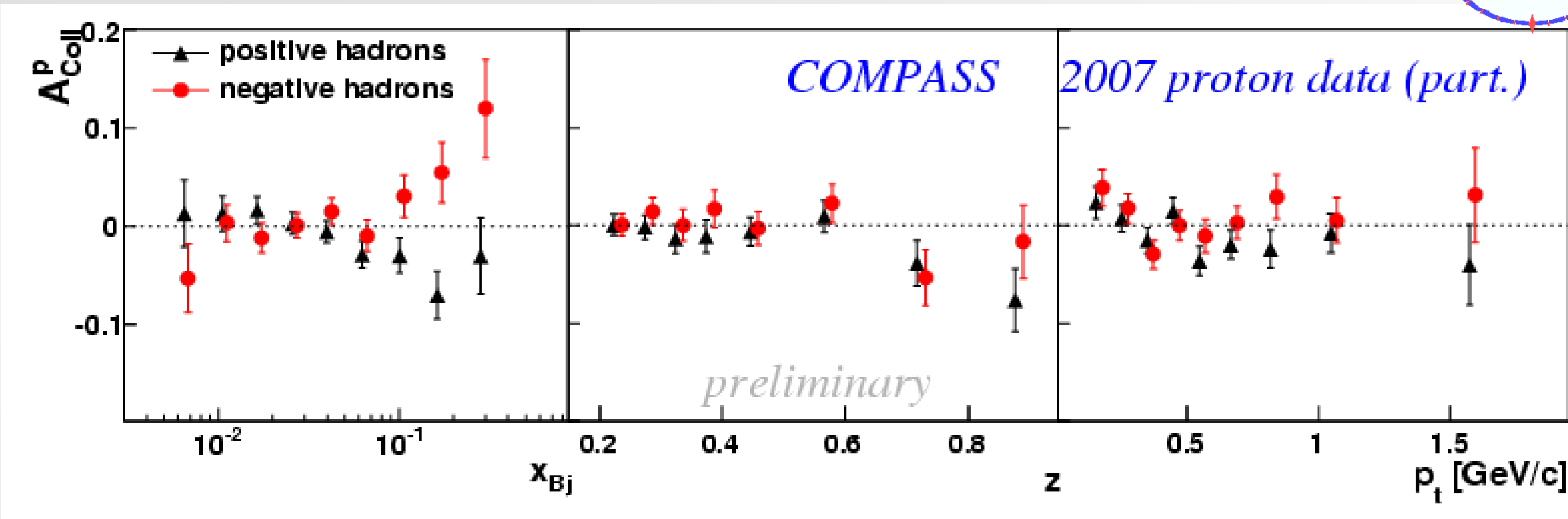


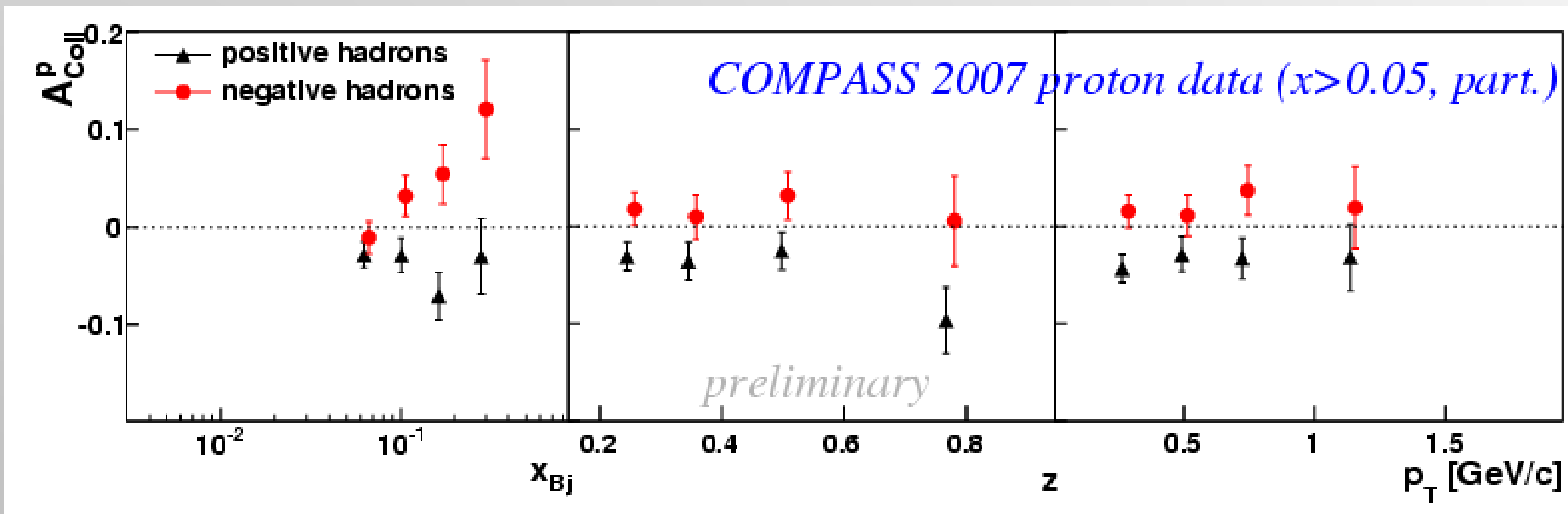
integrated over x and z

statistical errors only; systematic errors ~ 0.3 σ_{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

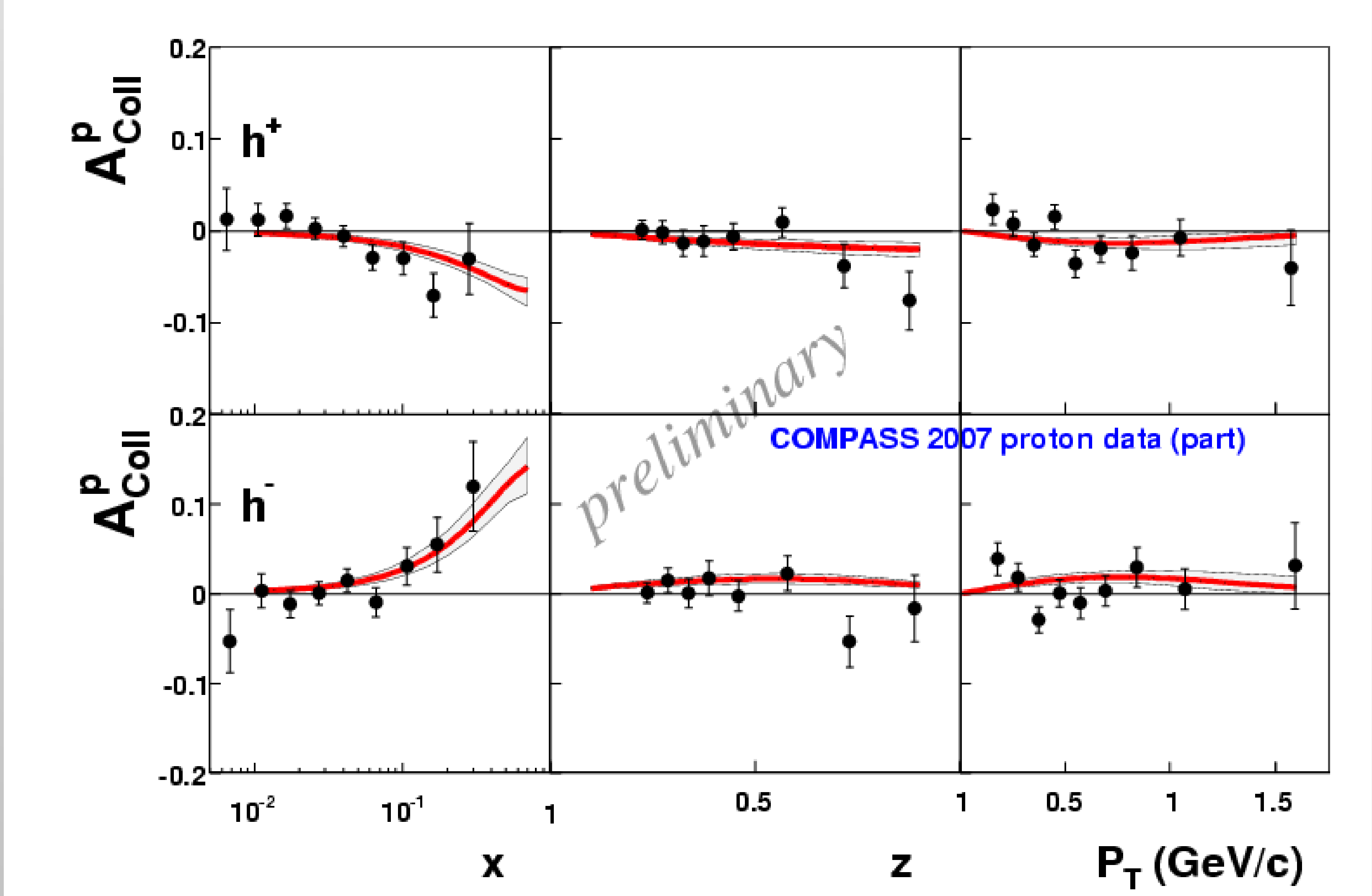
Collins asymmetry – proton data



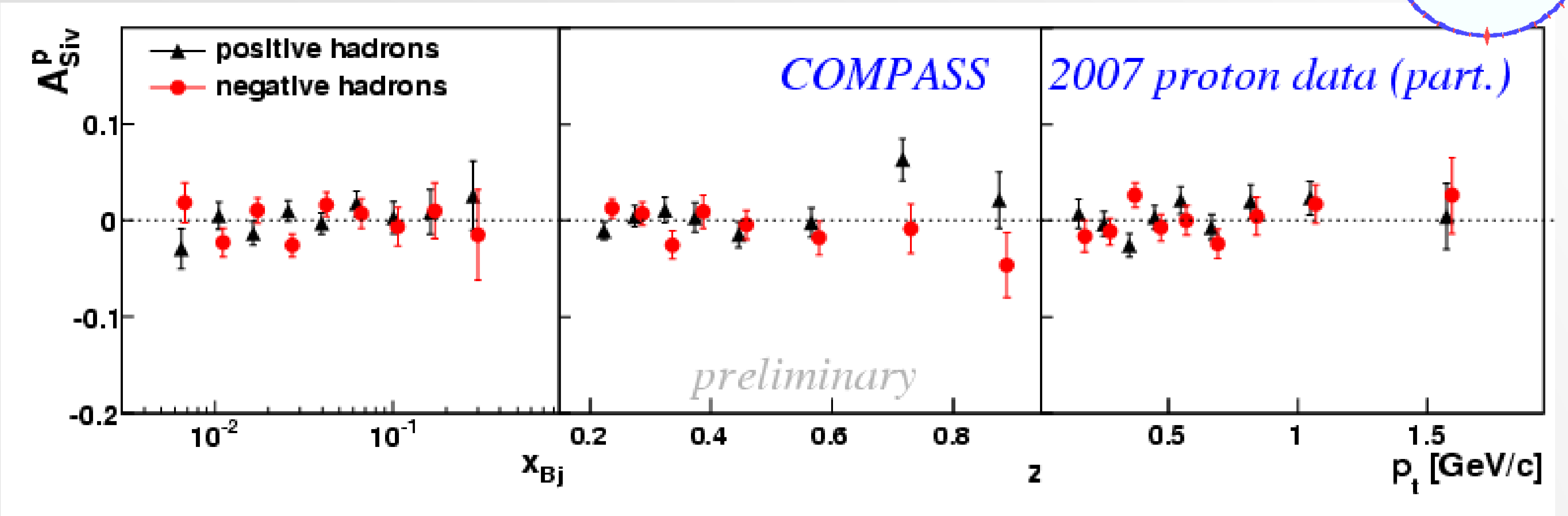


Collins asymmetry – proton data

comparison with M. Anselmino et al. predictions



Sivers asymmetry – proton data

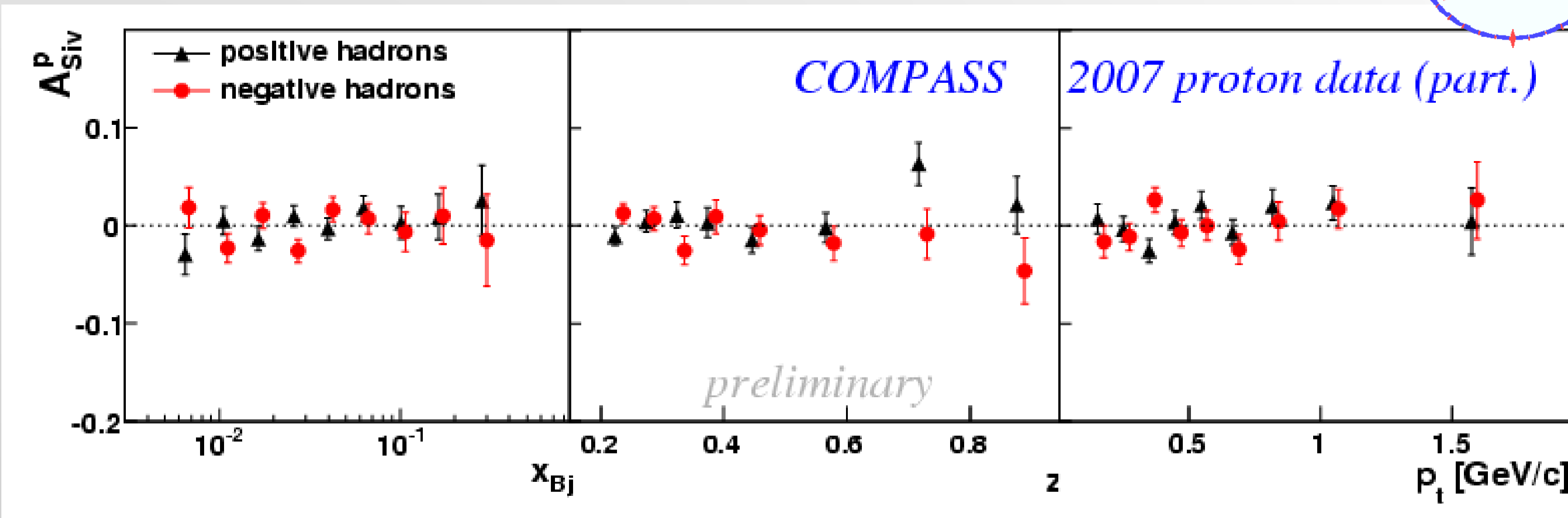


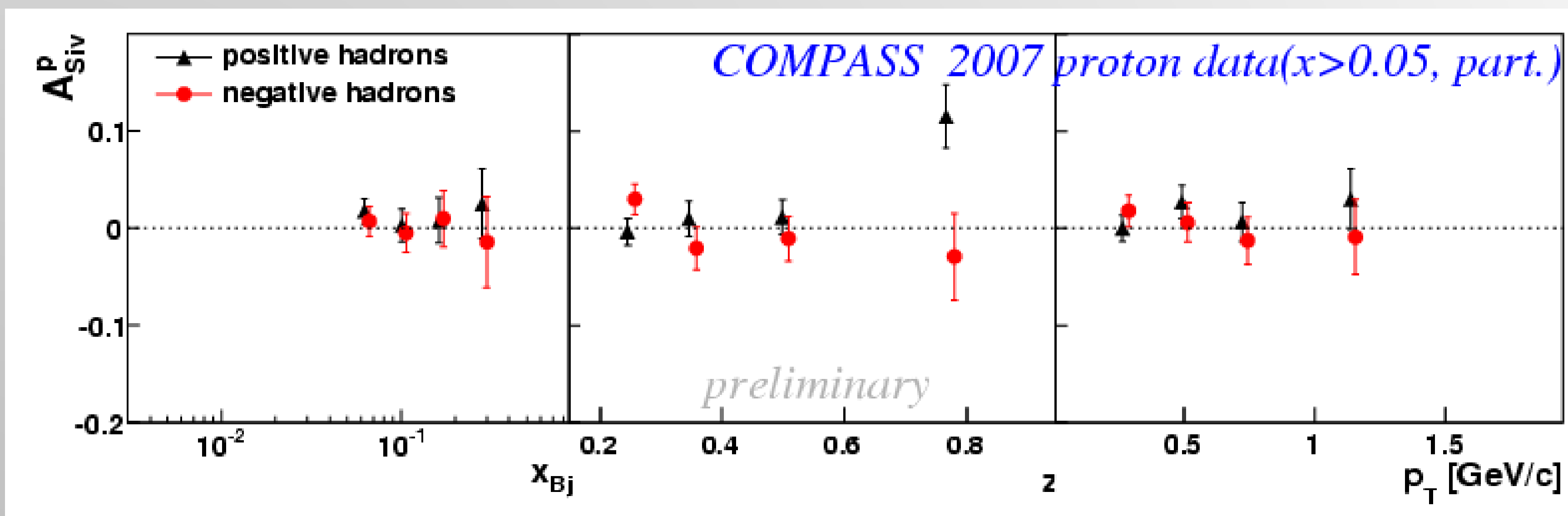
integrated over x and z

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

the measured symmetries are small, compatible with zero

Sivers asymmetry – proton data

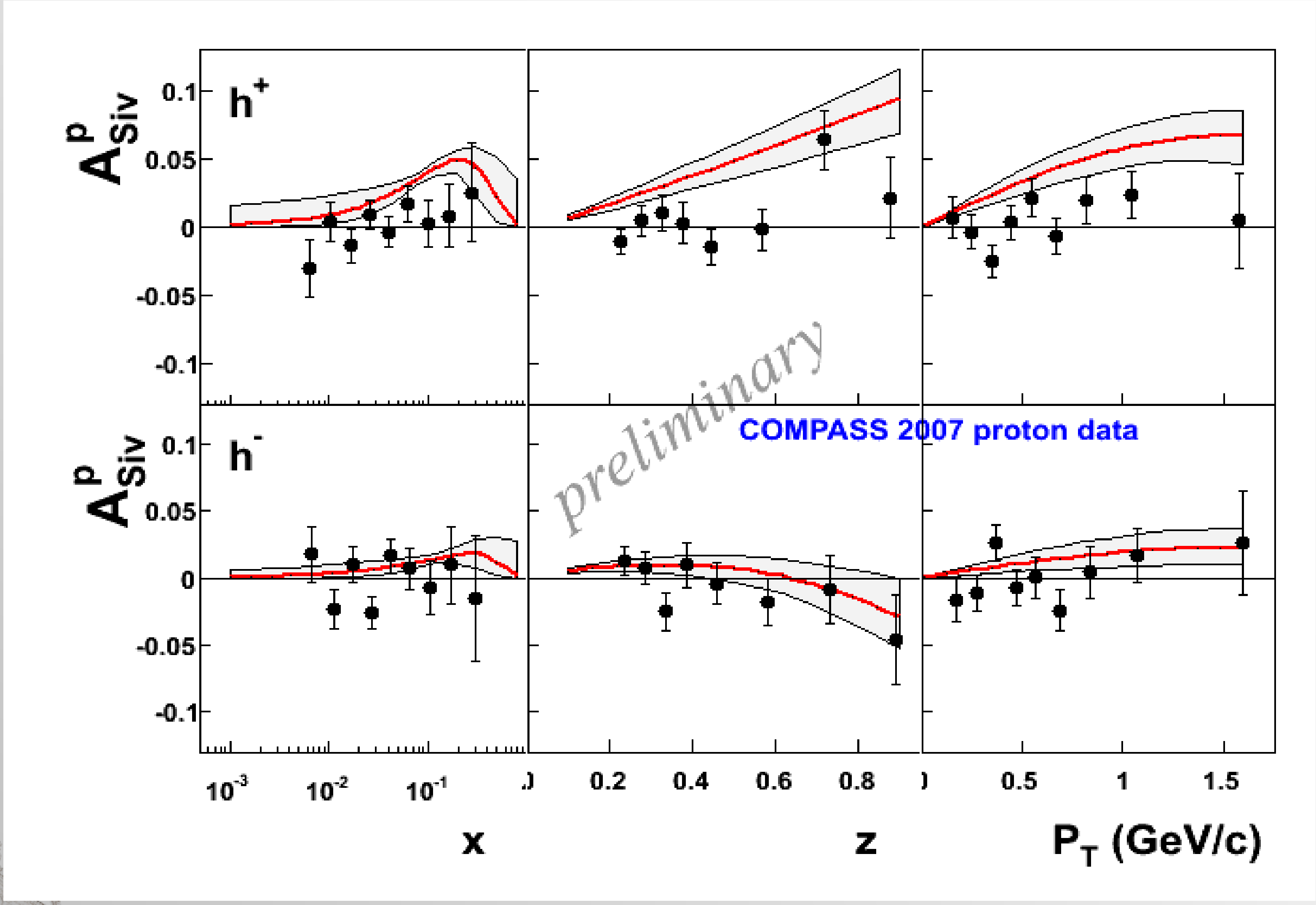




Sivers asymmetry– proton data

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

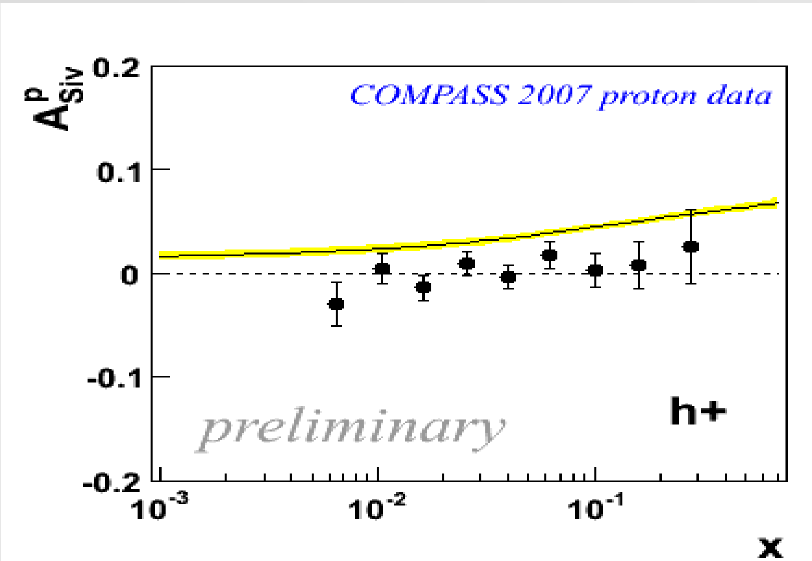
arXiv:0805.2677

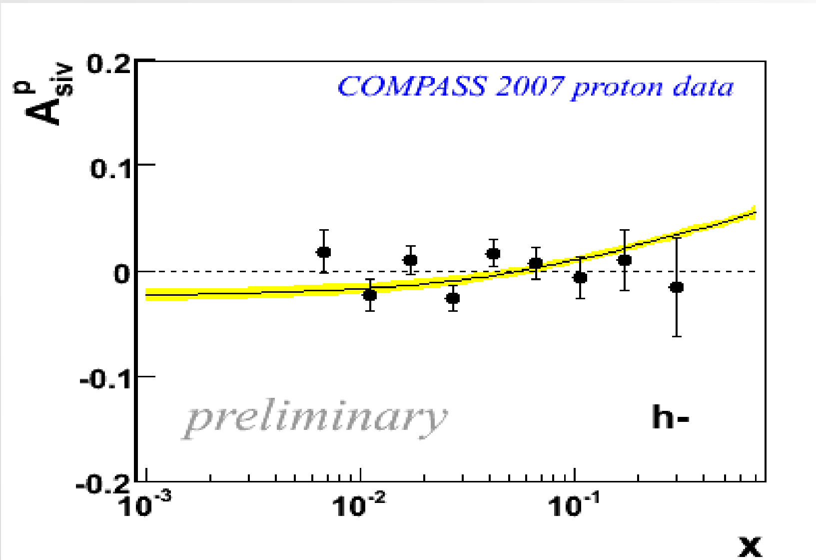


Results: Sivers asymmetry

comparison with predictions from

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





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

Maybe such corrections are irrelevant for $Q^2 > 1\,\text{GeV}^2$ 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.

conclusions

COMPASS preliminary results on

- unpolarised hadron asymmetries on deuteron
  for positive and negative hadrons

- 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 being spelled out for 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

Results: Sivers asymmetry