New measurements of transverse spin asymmetries at COMPASS

Federica Sozzi

INFN Trieste

On behalf of the COMPASS Collaboration

Rencontres de Moriond
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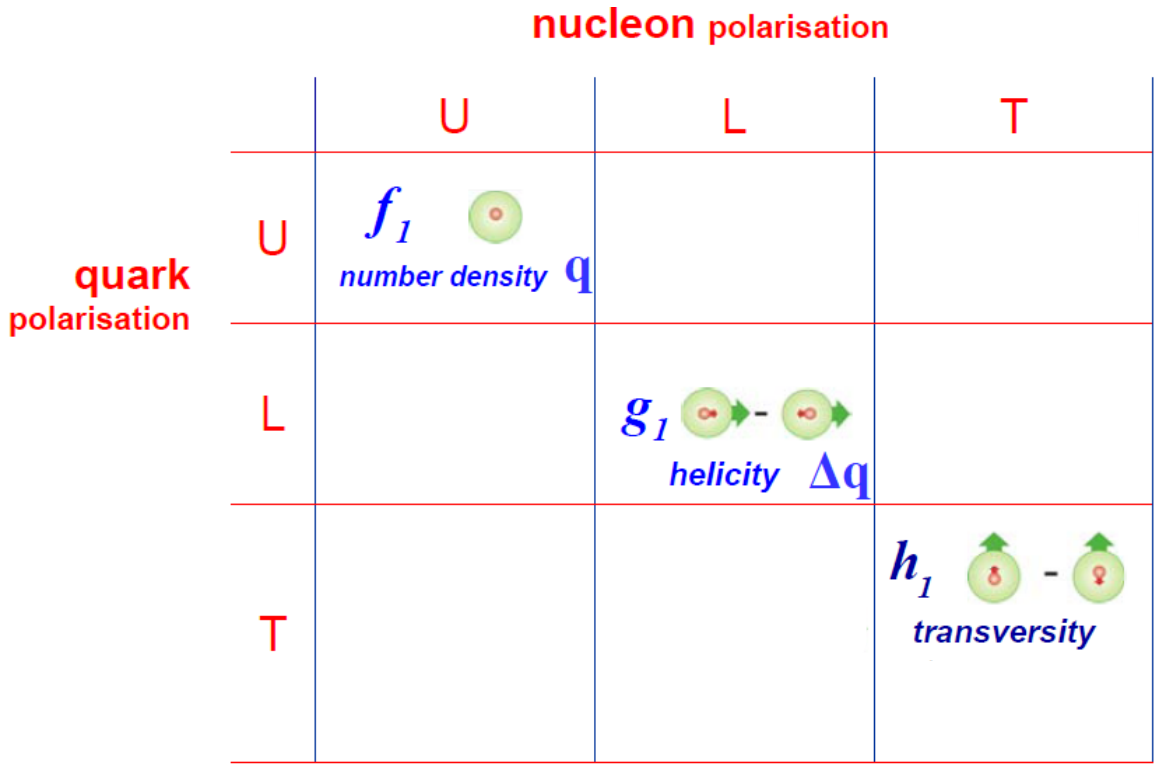
Outline

- Motivation
- COMPASS
- Results on Collins asymmetries
- Results on hadron pair asymmetries
- Conclusions

quark structure of the nucleon

At leading order, the inner structure of the nucleon can be described with three **Parton Distribution Function** (PDF):



helicity and transversity PDF:

probability of finding a quark with a momentum fraction x and spin parallel to that of the parent nucleon...

...in a longitudinally polarised nucleon

...in a transversely polarised nucleon

quark structure of the nucleon

Taking into account the intrinsic parton transverse momentum,
the nucleon structure description becomes more complex and needs 8
"Transverse Momentum Dependent" PDF.
TMDs describe the correlations between the spin and the momentum of quarks and of the parent nucleon

nucleon polarisation

quark polarisation	U	L	T
U	f_1 number density q		$f_{1T}^{\perp}$ Sivers
L		g_1 helicity Δq	g_{1T} Worm-gear
T	$h_1^{\perp}$ Boer Mulders	$h_{1L}^{\perp}$ Worm-gear	h_1 transversity; $h_{1T}^{\perp}$ pretzelosity

Assessing transversity: Collins effect

The transversity DF is chiral-odd: can be measured in Semi Inclusive DIS

on a transversely polarized target :

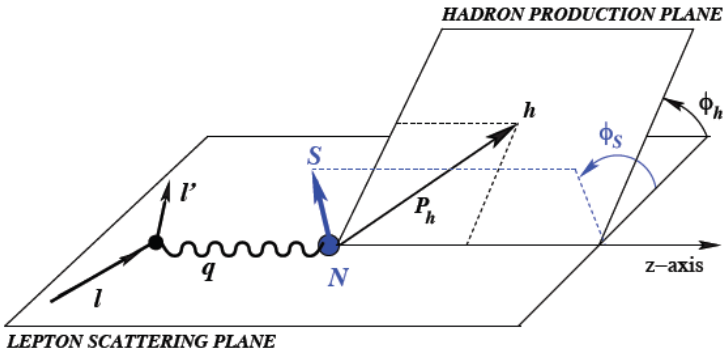
$l\, N^{\uparrow} \rightarrow l'\, h\, X$ 1 hadron production

coupled to another chiral-odd function: Collins fragmentation function

Describes the correlation between the fragmenting quark spin and the hadron momentum

→ Left right asymmetry

in the distribution of the hadron



$$N^{\pm}(\Phi_C) = N^0 \cdot (1 \pm A \sin \Phi_C)$$

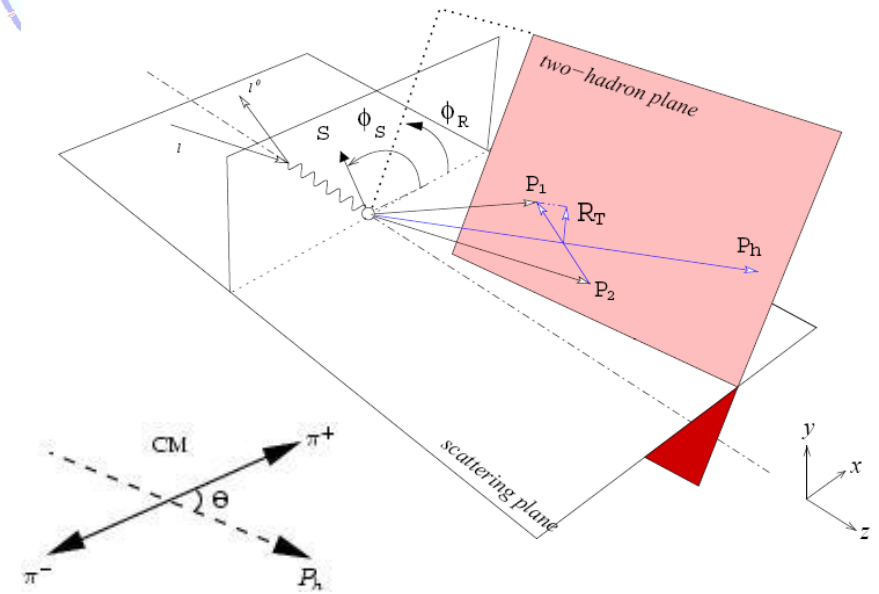
$\Phi_C = \phi_h + \phi_s$ is the "Collins angle"

Transversity PDF

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

Collins FF: accessible also in e^+e^-→hadrons [Belle, Babar]

Assessing transversity: hadron pair asymmetries



Another channel that can be used to assess transversity is the inclusive production of hadron pairs.

The measurement is based on an azimuthal asymmetry in the angle $\phi_{RS} = \phi_{R\perp} + \phi_S$ in which $\phi_{R\perp}$ is the angle of the plane containing the two hadrons

$$N^{\pm}(\Phi_{RS}) = N^0 \cdot (1 \pm A \sin \Phi_{RS})$$

$$A_{RS} = \frac{\sum_q e_q^2 \cdot \Delta_T q(x) \cdot H_q^{\angle}(z, M_h^2)}{\sum_q e_q^2 \cdot q(x) \cdot D_q^h(z, M_h^2)}$$

Transversity PDF

Di-hadron fragmentation function:
Correlation between the transverse polarization of the fragmenting quark and the azimuthal angle of the plane containing the hadron pair

A. Bacchetta, M. Radici, hep-ph/0407345
X. Artru, hep-ph/0207309

Accessible also in e^+e^-→hadrons [Belle, Babar]

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Fixed target experiment
at CERN SPS
Data taking since 2002

Nucleon spin structure

with high energy muon beams
on longitudinally polarized targets:

- **-gluon polarization**
- **-helicity PDF**

Transversely polarized targets:

- **transversity PDF**
- **TMDs**

Meson and baryon spectroscopy
with high energy hadron beam

The COMPASS spectrometer

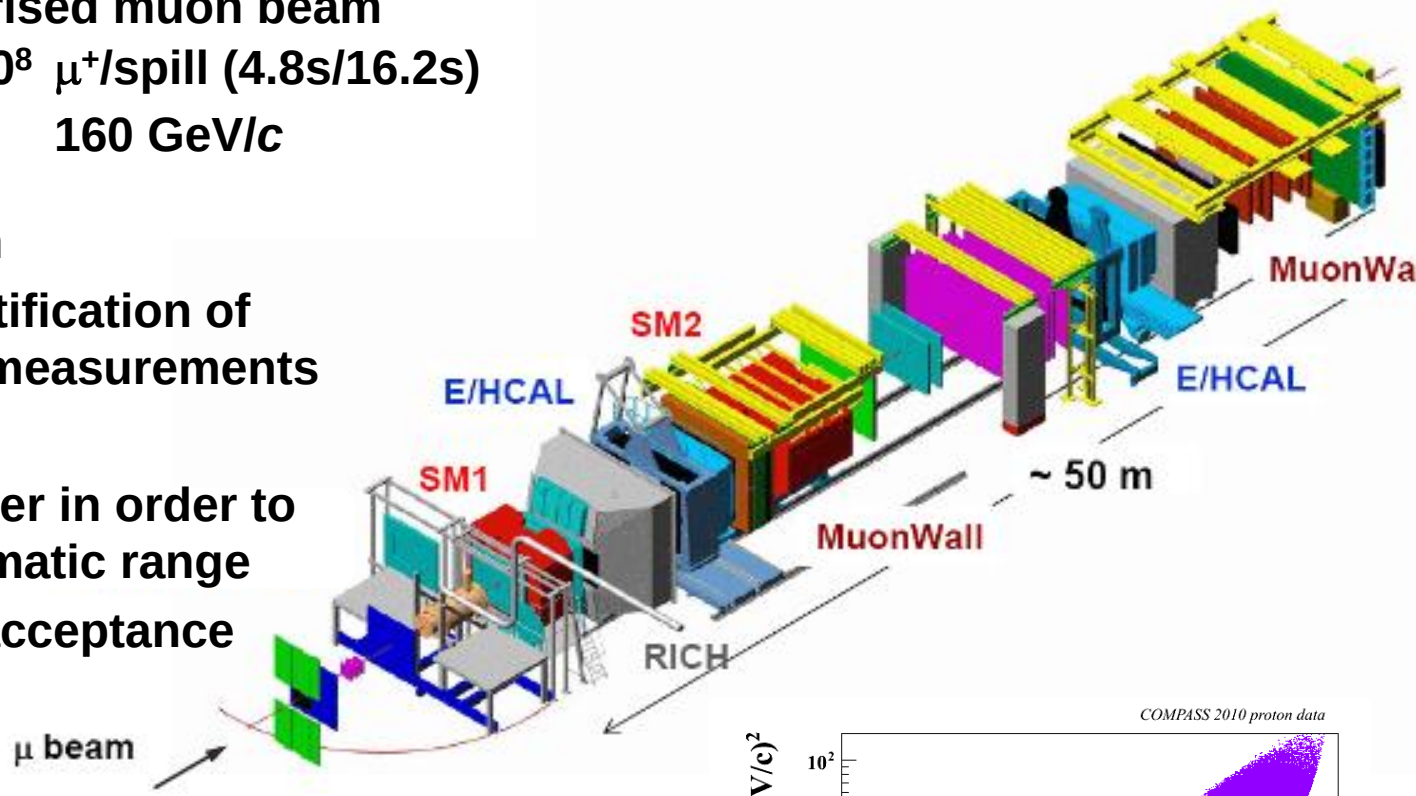
longitudinally polarised muon beam
beam intensity: $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)
beam momentum: 160 GeV/*c*

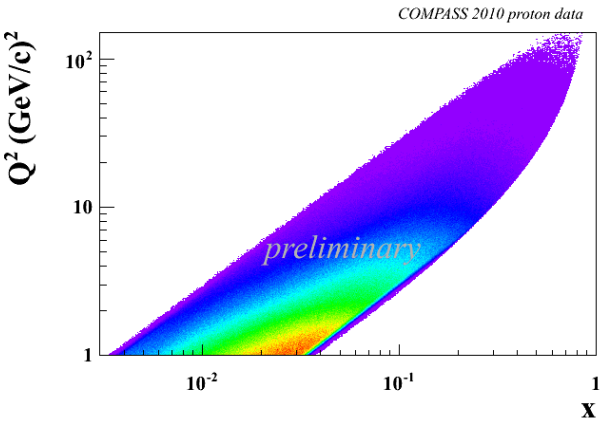
Muon identification

Detection and identification of hadrons for SIDIS measurements

2 stage spectrometer in order to cover a large kinematic range

180 mrad angular acceptance





COMPASS transverse data taking

2002-4: ^{6}LiD target, 20% time transverse data taking.

pT ~ 50% ; f ~ 0.38

PRL 94(2005)202002
PLB 673(2009)127-135
NP B 675 (2007) 31-70

2007: NH_3 target, 50% time transverse data taking;

pT ~ 90% ; f ~ 0.15

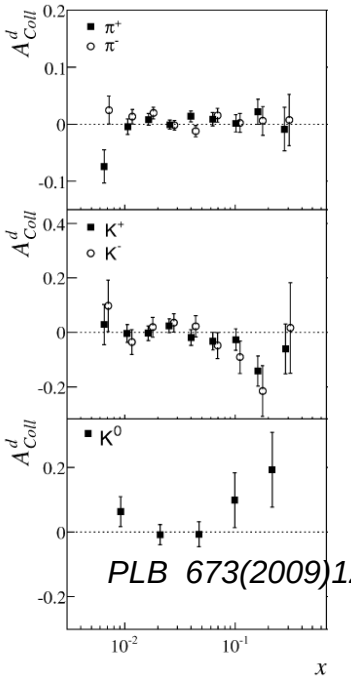
PLB 692 (2010) 240

2010: NH_3 target, full time to transverse data taking:
preliminary results on Collins asymmetries,
hadron pair asymmetries

Assessing transversity from Collins asymmetries

2005 First information

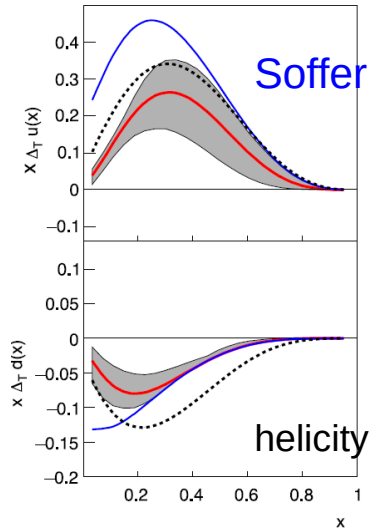
Sizeable asymmetries on proton target
→First evidence that transversity PDF and Collins FF are different from zero



PLB 673(2009)127-135

Asymmetries on deuteron target compatible with zero on the whole x range

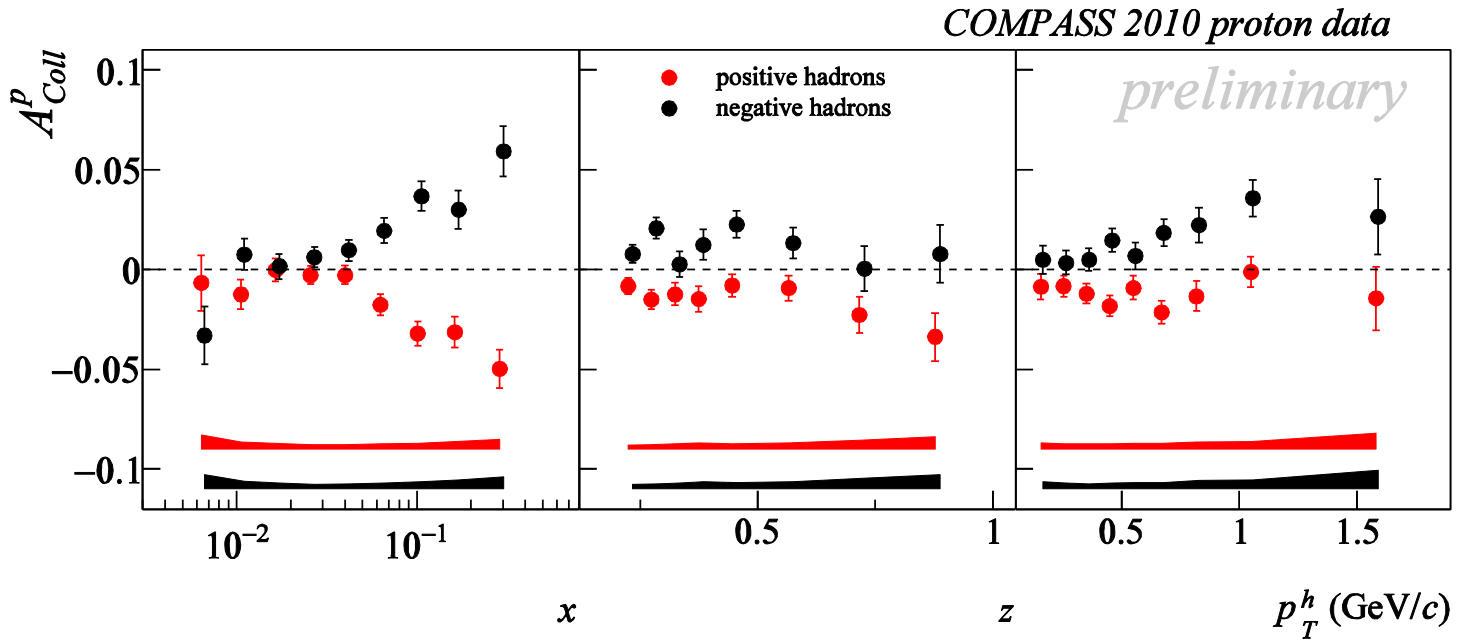
These data, together with Belle e+e- are well described with a global fit
→first extraction of the Collins FFs and the transversity PDFs



M. Anselmino et al.,
Nucl.Phys.Proc.Suppl. 191 (2009) 98

→COMPASS results interpreted as cancellation between u and d contributions due to the isoscalar target

Collins asymmetries: results from 2010 run

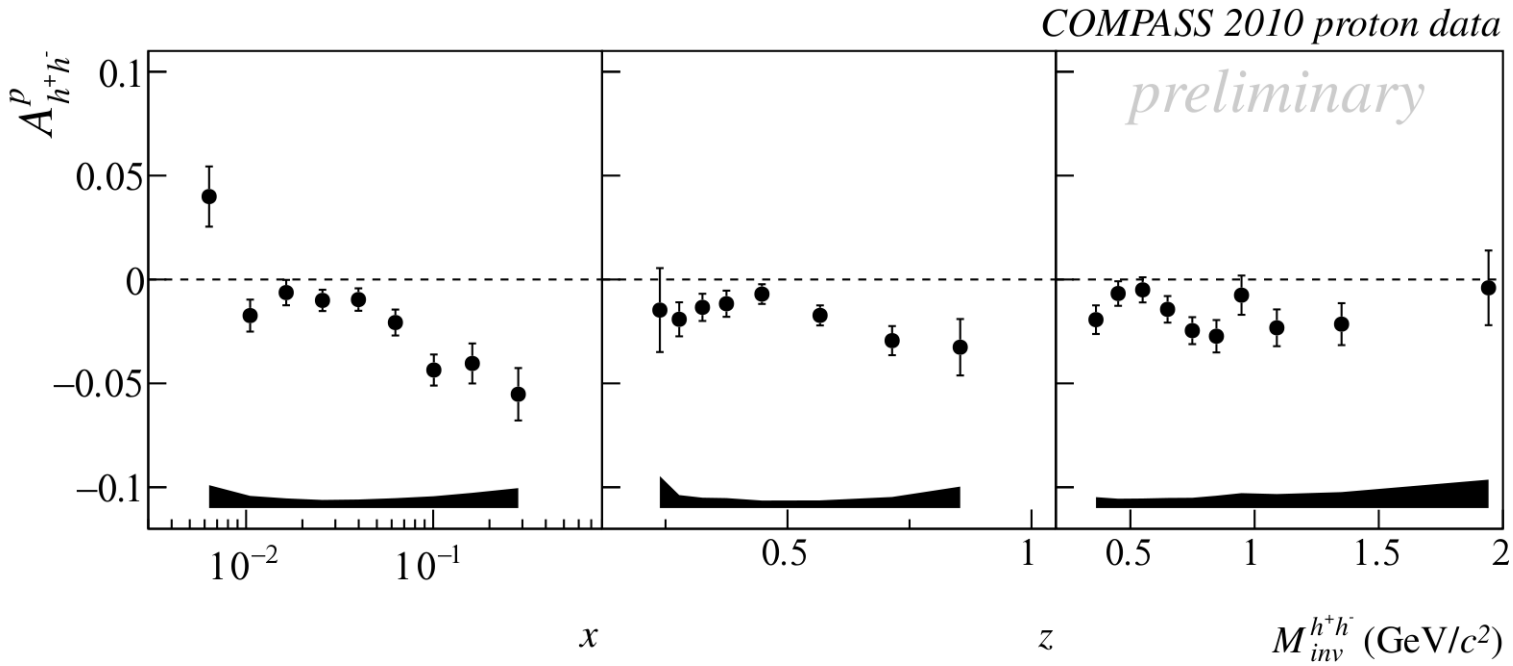


Confirm the results from 2007 with improved statistical uncertainties, factor ~2

- At small x (range not covered by Hermes) asymmetries compatible with zero
- agreement with Hermes results in the overlap region→ not obvious result, implies a negligible Q2 dependence for the Collins effect
- Valence region: large signal of opposite sign for positive and negative hadrons, (Dunf~-Dfav)

New important input for global fit

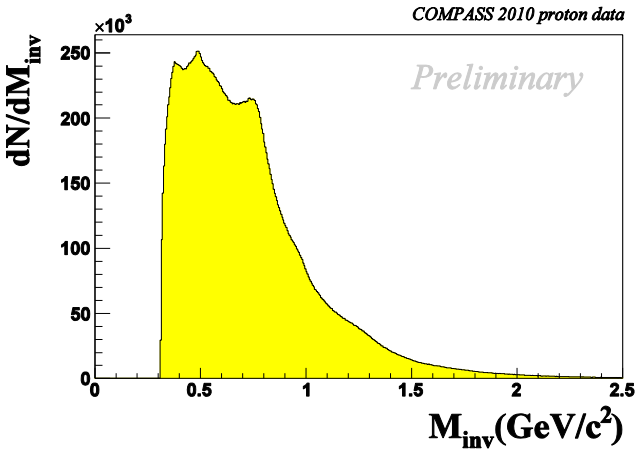
Hadron pair asymmetries: results from 2010 run



Large signal up to 5-10% in the valence region

Statistical uncertainties improved of a factor ~2 wrt 2007 run

agreement with Hermes results



Assessing transversity from hadron pair asymmetries

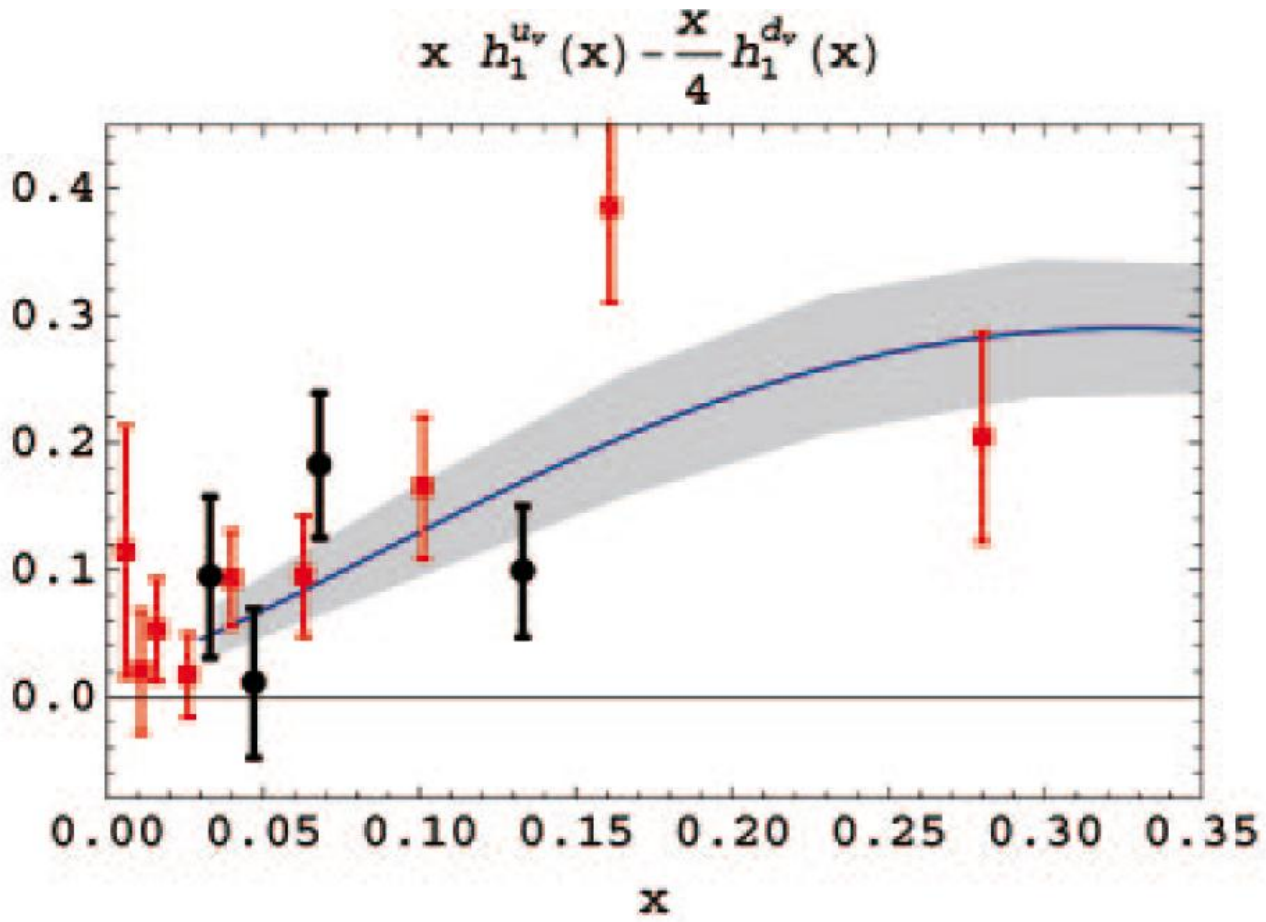
Extract information on the di hadrons fragmentation functions using Belle data
PRL 107 (2011) 072004

and:

HERMES proton data (black points)
C JHEP 0806 017 (2008)

COMPASS 2007 proton data (red points)

→Using the new 2010 data the extraction can be improved



Radici, Transversity 2011
Bacchetta, Courtoy, Radici, PRL 107:012001,2011

Conclusions

A lot of results have been produced by COMPASS from 2005:

-using a **deuterium target in 2002-2004;**
-using a **proton target in 2007 and 2010;**

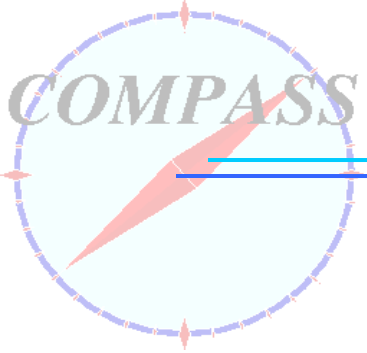
The most recent results from the 2010 data taking have been shown:

- They confirm 2007 results with improved statistical uncertainties
- both Collins and hadron pair asymmetries are different from zero and can be used to extract transversity PDFs

Not shown here…more, interesting results on other TMD PDFs (Sivers, Boer-Mulders)

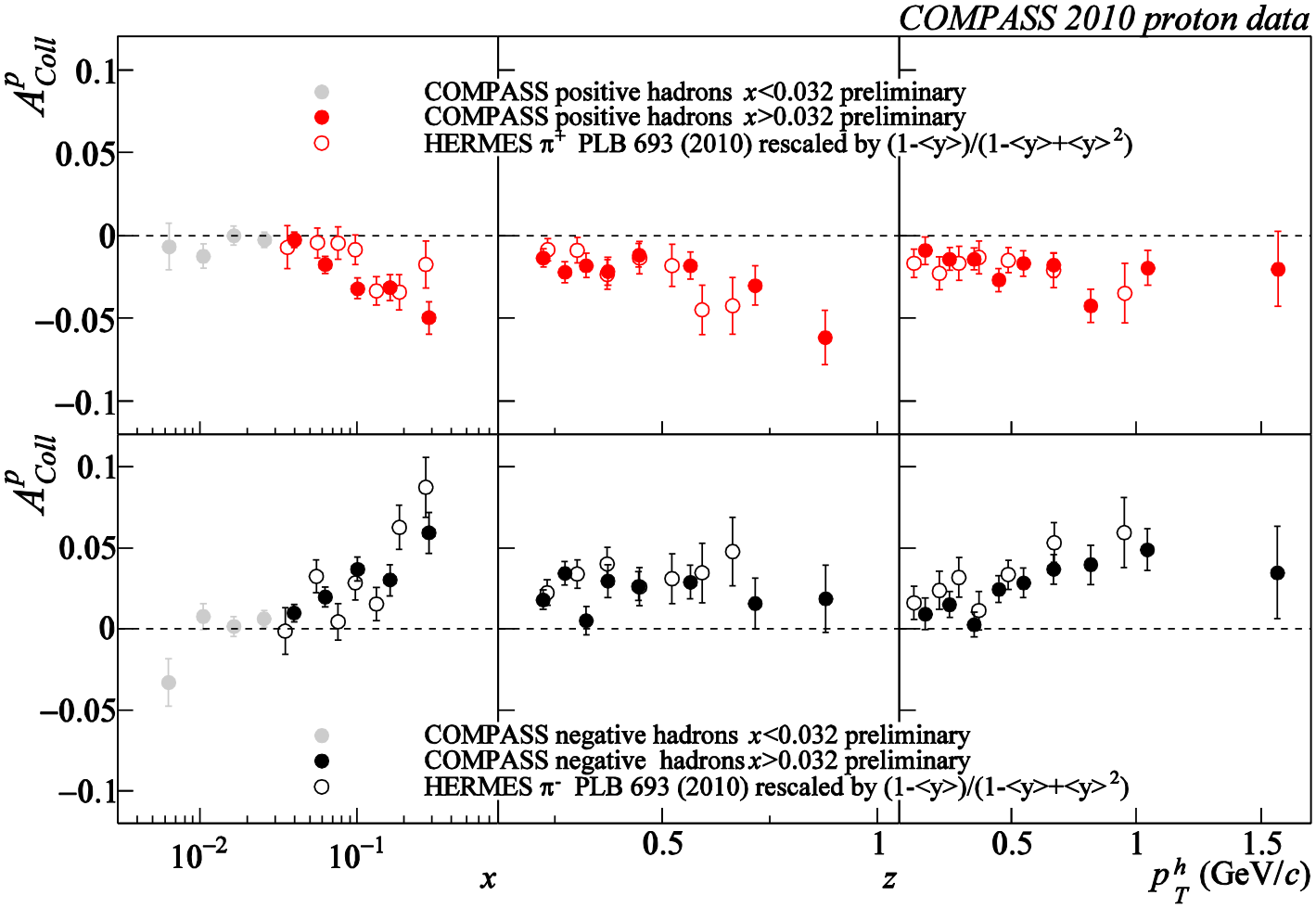
Next future

- Extract the asymmetries for kaons
- Investigation of kinematical dependence of the asymmetries in multidimensional analysis, thanks to the high statistics collected in the 2010 run



backup

Collins asymmetries from 2010 data comparison with Hermes results



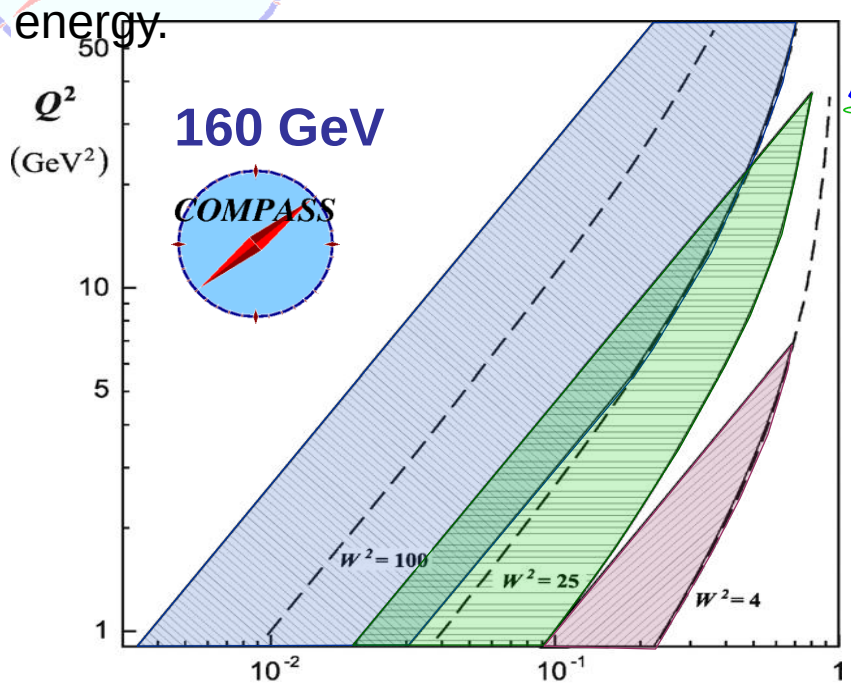
x>0.032

Region where the signal is different from zero, overlap with Hermes range

- agreement with Hermes results → not obvious result, since the kinematical range covered by the two experiments is different, implies a negligible Q2 dependence for the Collins effect

Phase space of different experiments

Strong dependence of x, Q2 and W, depending on the lepton beam energy.



hermes

27.5 GeV

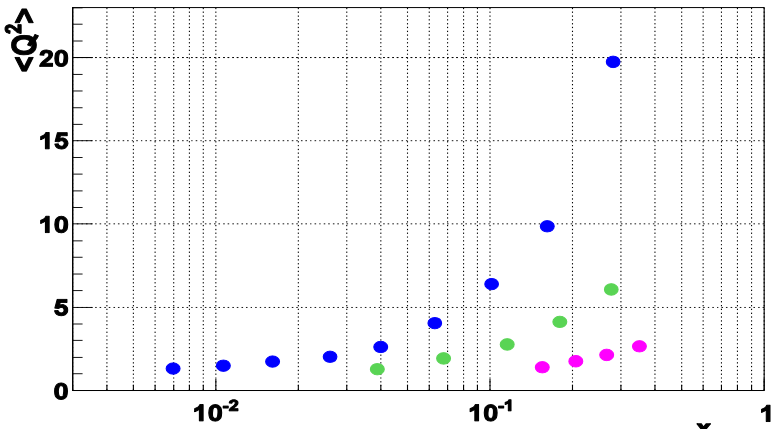
$0.004 < x < 0.3$, $25 < W^2 < 200\ \text{GeV}^2$

$0.023 < x < 0.4$, $10 < W^2 < 50$

$0.14 < x < 0.34$, $4 < W^2 < 10$

(0.48)

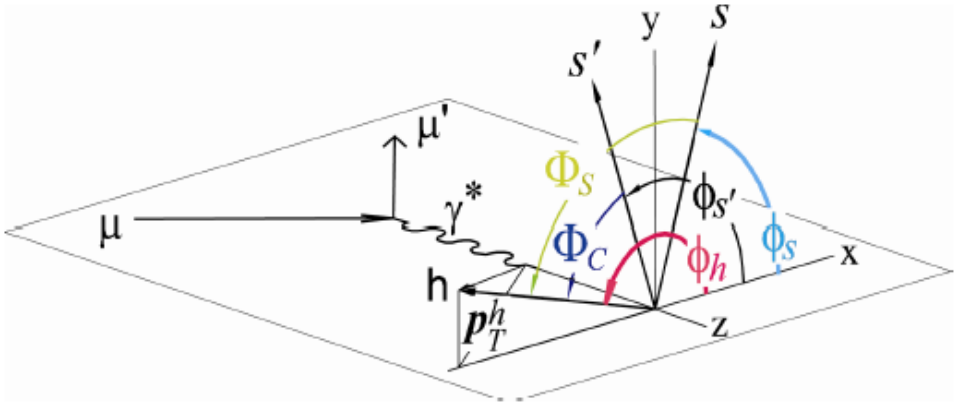
JLab 6 GeV



The Sivers modulation

Sivers function $f_{1T}^{\perp}(x,k_T)$: Correlation between the transverse spin of a nucleon and the intrinsic transverse momentum of unpolarized quarks

$$A_{Siv} = \frac{A_S^h}{f \cdot P_T} = \frac{\sum_q e_q^2 \cdot f_{1Tq}^{\perp} D_q^h}{\sum_q e_q^2 \cdot f_{1q} \cdot D_q^h}$$

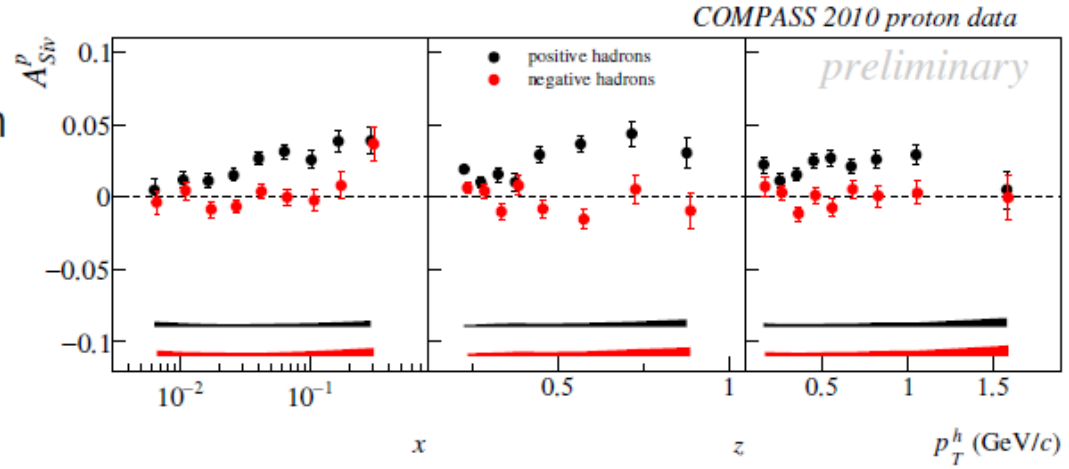


Azimuthal distribution of the produced hadrons:

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

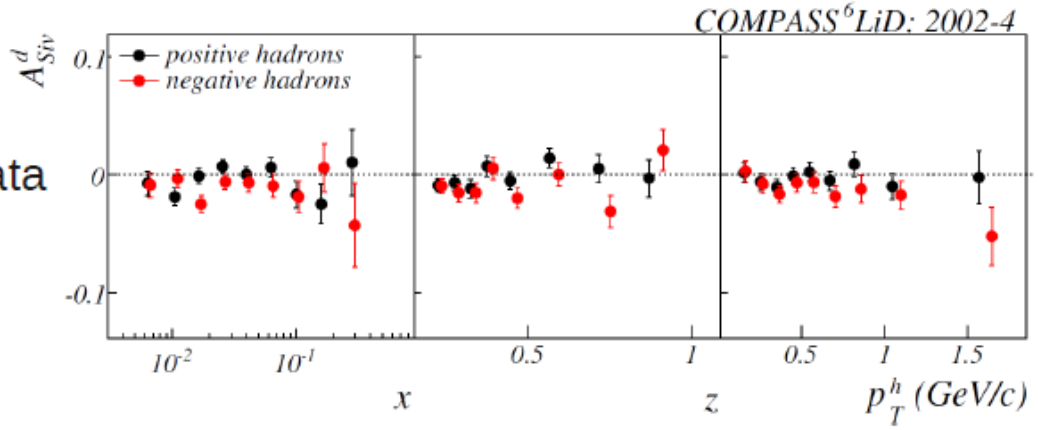
with $\Phi_S = \phi_h - \phi_s$

2010 proton data



positive signal for positive hadrons

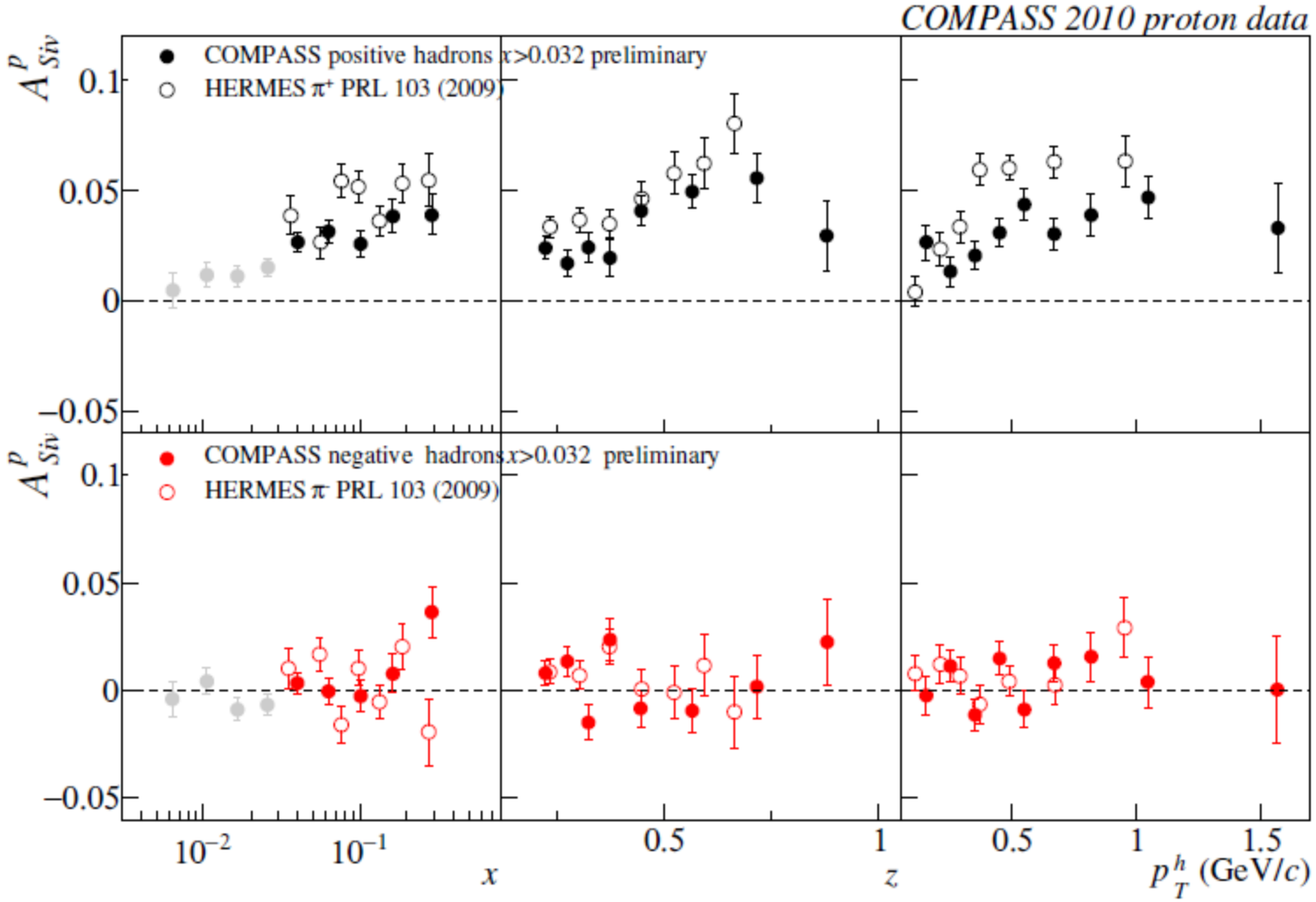
2002-04 deuteron data



Asymmetries compatible with zero

NPB 765 (2007)

Comparison to Hermes data for x > 0.032



difference between COMPASS and HERMES results, but same trend

DIS cuts:

$Q^2 > 1\ GeV/c^2$

$0.1 < y < 0.9$

$W > 5\ GeV/c^2$

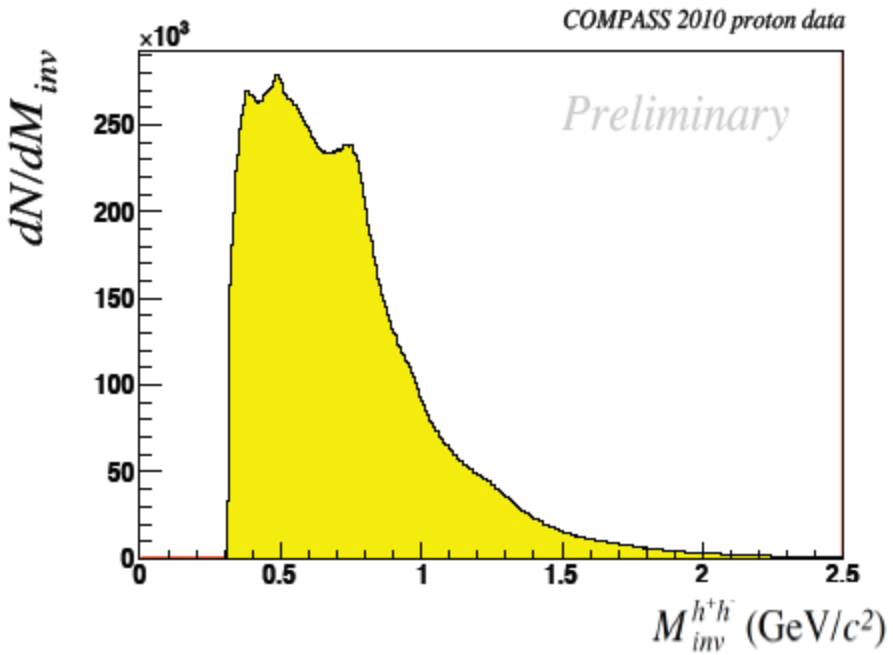
hadron pair selection:

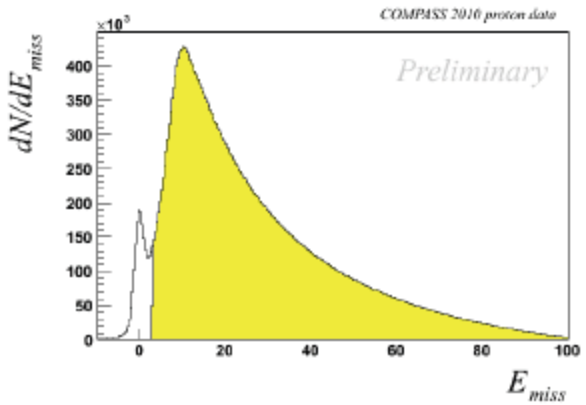
$z_i > 0.1$

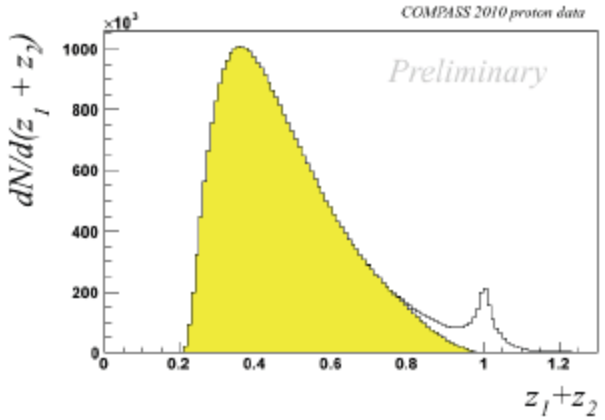
$x_{iF} > 0.1$

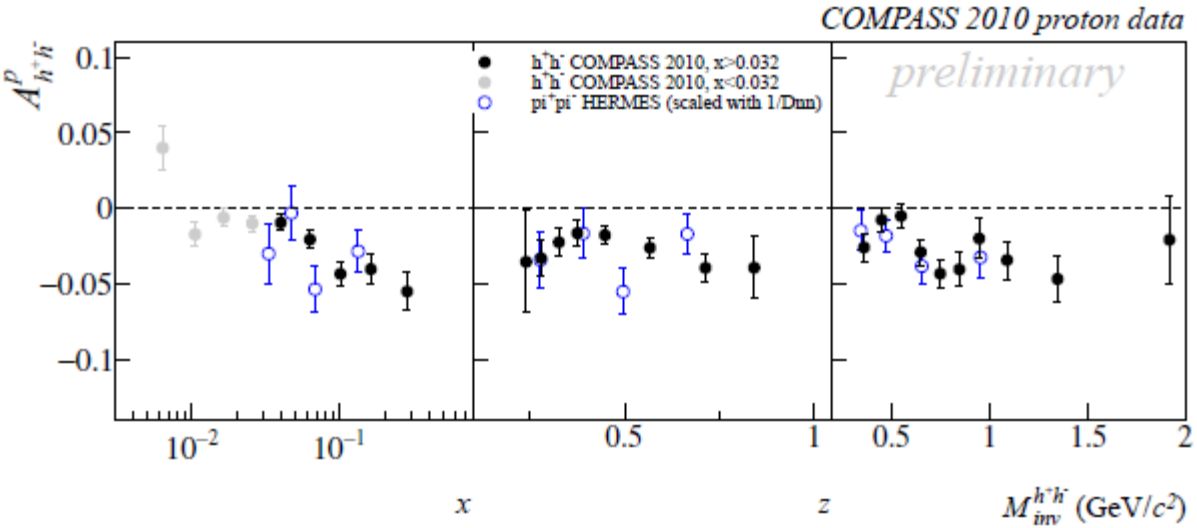
$R_T > 0.07\ GeV$

$E_{miss} > 3\ GeV$

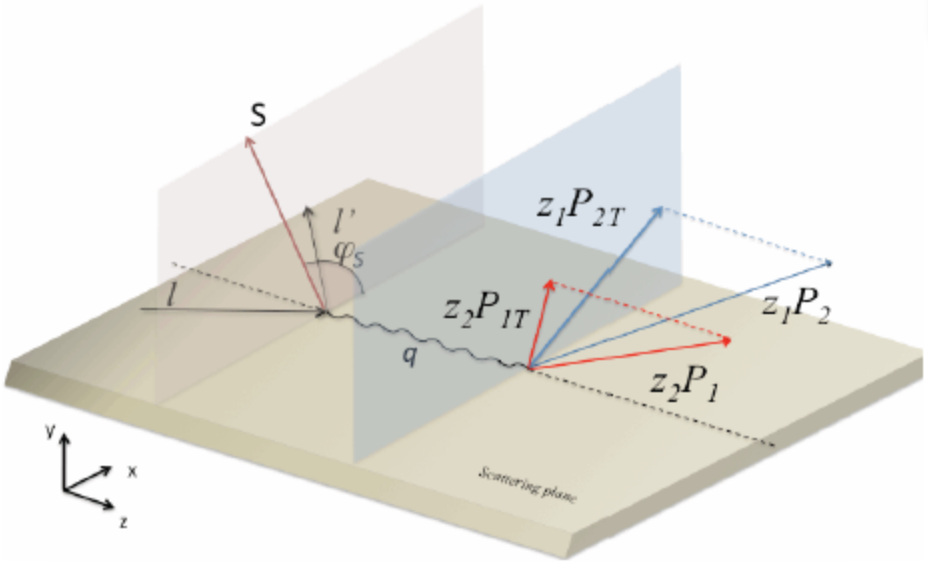


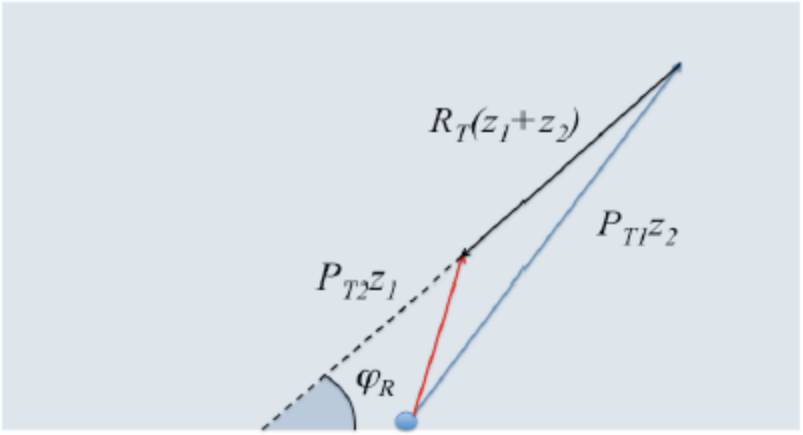





COMPASS 2010 proton data
preliminary
h+h- COMPASS 2010, x>0.032
h+h- COMPASS 2010, x<0.032
pi+pi- HERMES (scaled with 1/Dnn)
$A^p_{h^+h^-}$
0.1
0.05
0
−0.05
−0.1
10^{-2}
10^{-1}
0.5
1
0.5
1
1.5
2
x
z
$M^{h^+h^-}_{inv}$ (GeV/c^2)

Hadron pair angle definition





Definitions

$$z_i = \frac{E_i}{E_{Tot}}$$

$$z = z_1 + z_2$$

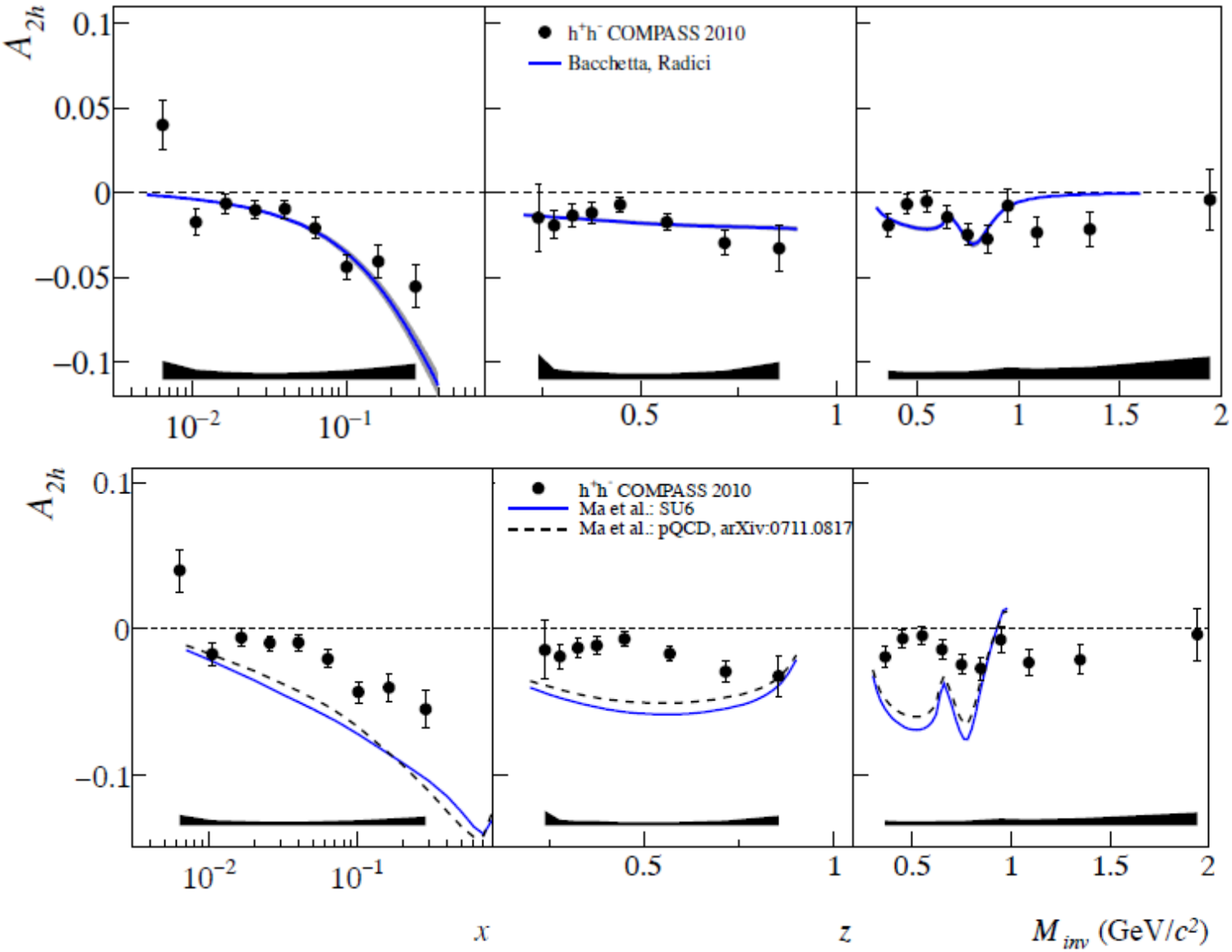
$$\xi = \frac{z_1}{z}$$

$$R_T = \frac{z_1 P_{2T} - z_2 P_{1T}}{z_1 + z_2}$$

φ_S = azimuthal angle of the spin of the nucleon

φ_R = azimuthal angle of R_T

$$\varphi_{RS} = \varphi_R + \varphi_S - \pi$$


A_{2h}
0.1
0.05
0
−0.05
−0.1
h⁺h⁻ COMPASS 2010
Bacchetta, Radici
10^{-2}
10^{-1}
0.5
1
0.5
1
1.5
2
A_{2h}
0.1
0
−0.1
h⁺h⁻ COMPASS 2010
Ma et al.: SU6
Ma et al.: pQCD, arXiv:0711.0817
10^{-2}
10^{-1}
0.5
1
0.5
1
1.5
2
x
z
M_{inv} (GeV/c^2)

Accessing transversity from two-hadron asymmetries

A Bacchetta, A. Courtoy, M Radici Phys.Rev.Lett.107:012001,2011

$$\boxed{x h_1^{u_v}(x) - \frac{1}{4} x h_1^{d_v}(x)}$$

$$= A_{2h} \frac{n_u(Q^2)}{n_u^{\uparrow}(Q^2)} x\left(f_1^u(x) + f_1^{\overline{u}}(x) + \frac{1}{4}\left(f_1^d(x) + f_1^{\overline{d}}(x) + f_1^s(x) + f_1^{\overline{s}}(x)\right)\right)$$

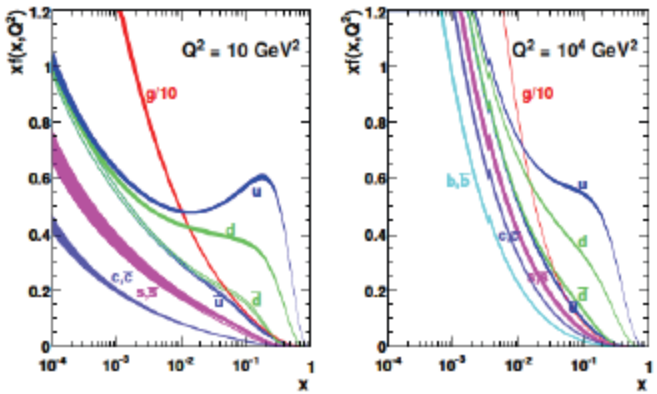
$n^{\uparrow q}(Q^2)/n_q(Q^2)$

at Belle scale (100 GeV²) $= -0.273 \pm 0.007_{ex} \pm 0.009_{th}$

at HERMES scale (2.5 GeV²) $= -0.251 \pm 0.006_{ex} \pm 0.023_{th}$

A_{2h} HERMES data

$f_1^q(x)$ MSTW08LO PDF set



Transversity Distribution Function

$\Delta_T q(x)$, $h_1^q(x)$, $\delta q(x)$, $\delta_T q(x)$, $q=u_v, d_v, q_{sea}$

recently much interest !

properties:

- $\Delta_T q(x) \neq \Delta q(x)$
- **probes the relativistic nature of quark dynamics**
- **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 in Parton Model framework**

$$\frac{1}{2} = \frac{1}{2}\sum \Delta_T q + L_q + L_g$$

Bakker, Leader, Trueman, PRD 70 (04)

- **it is related to GPD's**
- **is chiral-odd: decouples from inclusive DIS**