New COMPASS results on Transverse Spin Asymmetries in Hadron Pair Production in DIS

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on behalf of the COMPASS Collaboration

22/10/2014 spin2014 Beijing

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

Collaboration
~ 250 physicists
28 institutions
12 countries

fixed target experiment at the CERN SPS

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

wide physics program carried on using both **muon** and hadron beam

luminosity: ~5 · 10^{32} cm^{-2} s^{-1}

beam intensity: $2 \cdot 10^8$ μ^+/spill (4.8s/16.2s)

beam momentum: 160 GeV/*c*

longitudinally polarized muon beam

deuteron (^{6}LID) polarized target	2002	L/T
	2003	L/T
	2004	L/T
	2006	L
proton (NH_3) polarized target	2007	L/T
	2010	T
	2011	L
H_2 target	2012	

hadron beam

nuclear targets	2004
LH target	2008
	2009
	2012

the COMPASS spectrometer

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

two stages spectrometer

Large Angle Spectrometer (SM1)

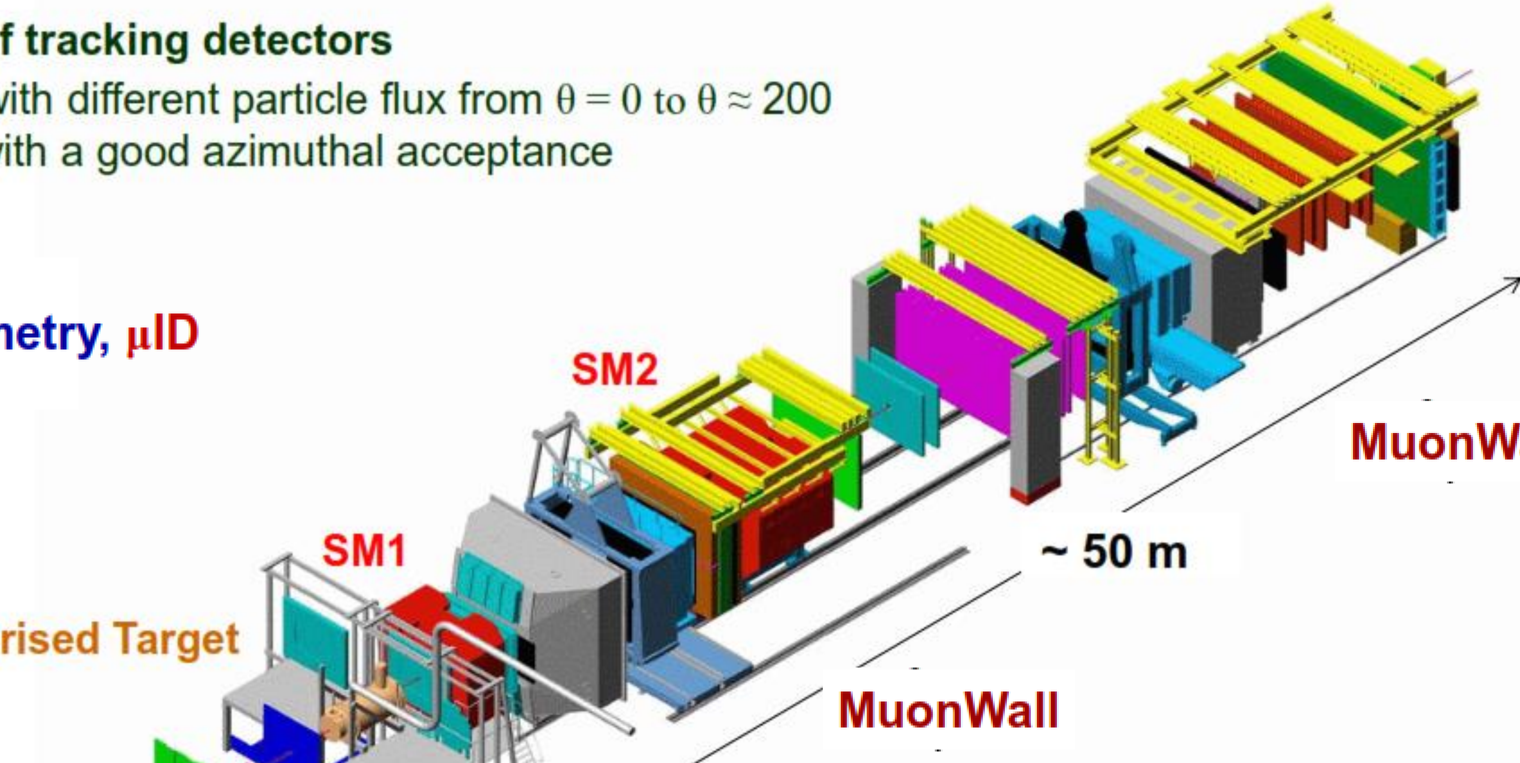
Small Angle Spectrometer (SM2)

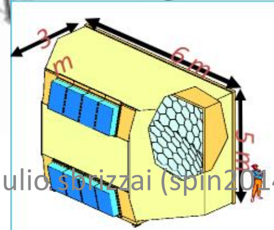
variety of tracking detectors

to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance

calorimetry, μID

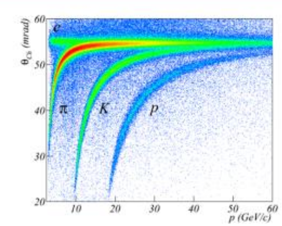
RICH





Hadron identification: $\pi^{\pm}$ $K^{\pm}$

based on RICH-1 response (likelihood algorithm)



Cherenkov thresholds

π ~ 3 GeV/c

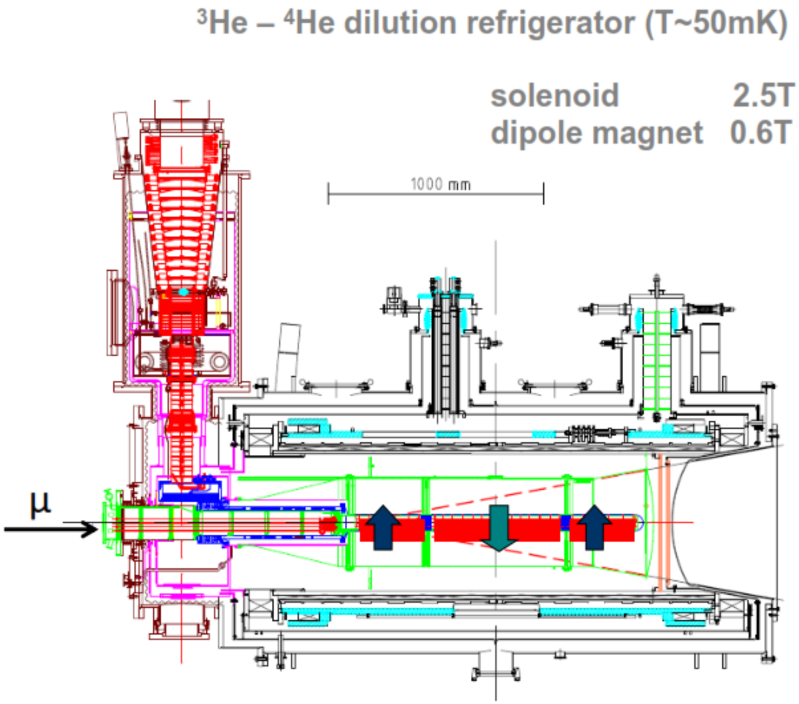
K ~ 9 GeV/c

p ~ 18 GeV/c

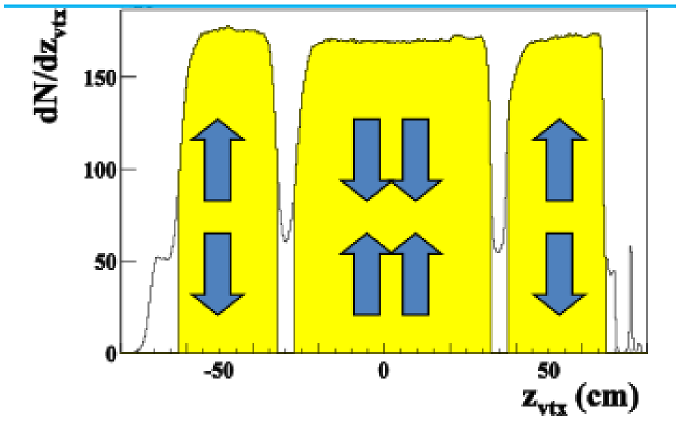
polarized target system (>2005)

solid state target operating in frozen spin mode

	d (^6LiD)	p (NH_3)
polarization	**50%**	**90%**
diliution factor	**40%**	**16%**



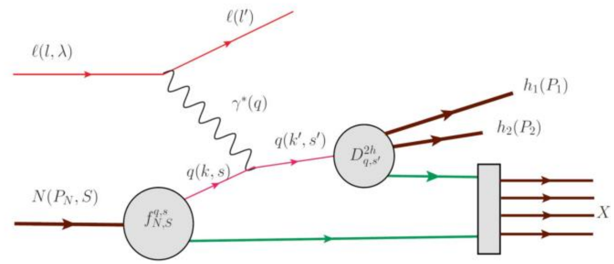
3 cells target with opposite polarizations



2 configurations:
polarisation reversed each week
to minimize possible systematic errors

results on 2 charged hadron production in DIS on transversely polarised target

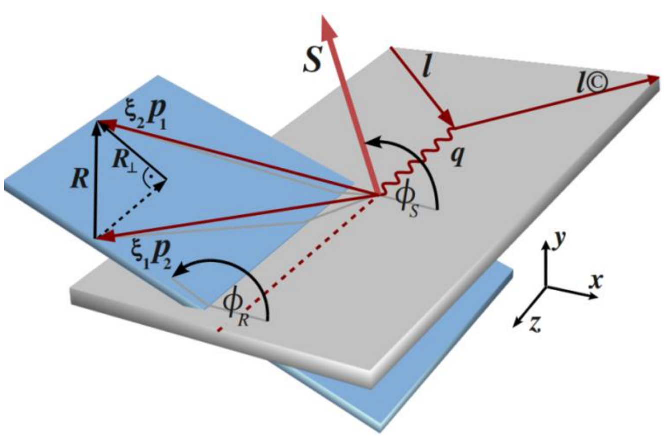
$$\ell(k) + N(P) \rightarrow \ell(k') + H_1(P_1) + H_2(P_2) + X$$



we measure

$$N_{h^+h^-} \propto \sigma_{UU} \left(1 + f(x,y)\, P_T\, D_{nn}(y)\, A_{UT}^{\sin\phi_{RS}} \sin\theta \sin\phi_{RS}\right)$$

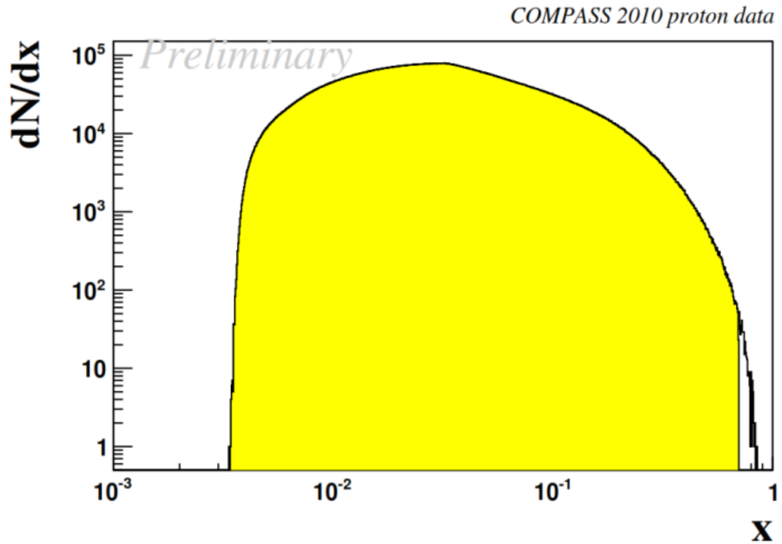
*on **oppositely charged hadrons pairs***

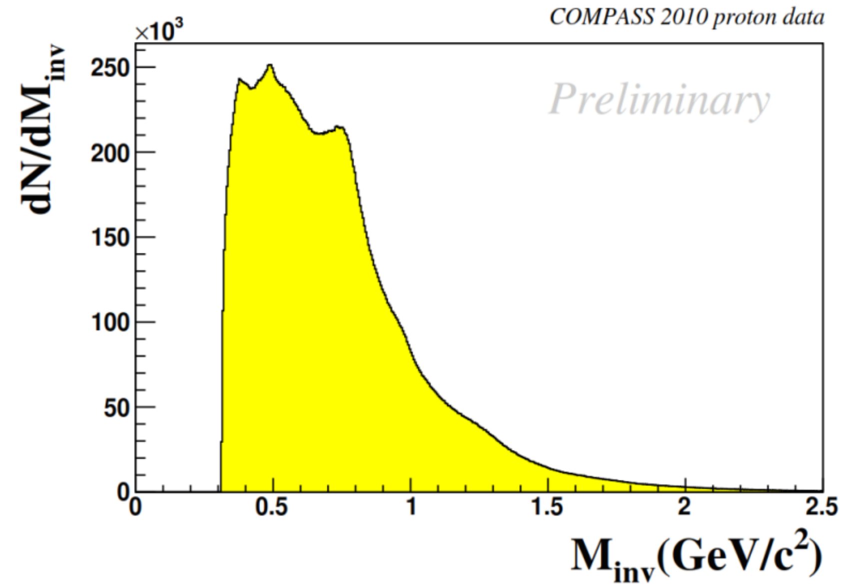


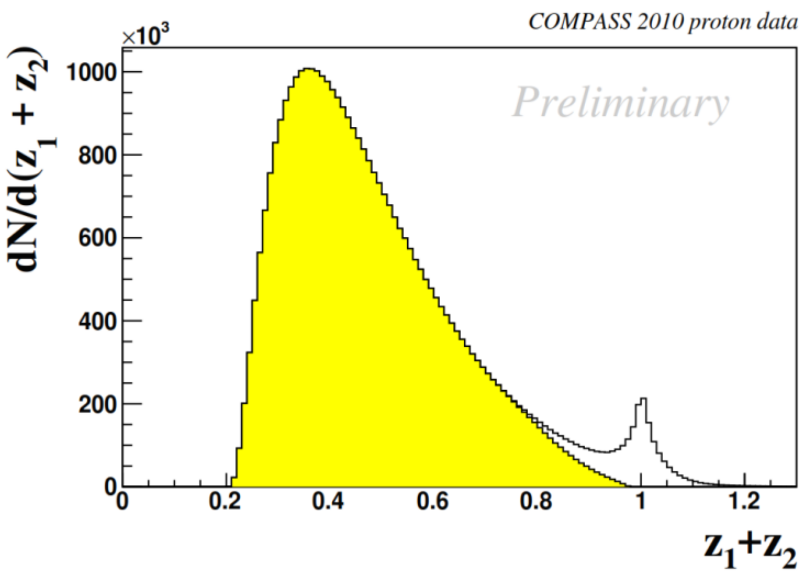
the azimuthal distribution of the hadrons pairs shows a modulation in the azimuthal angle:

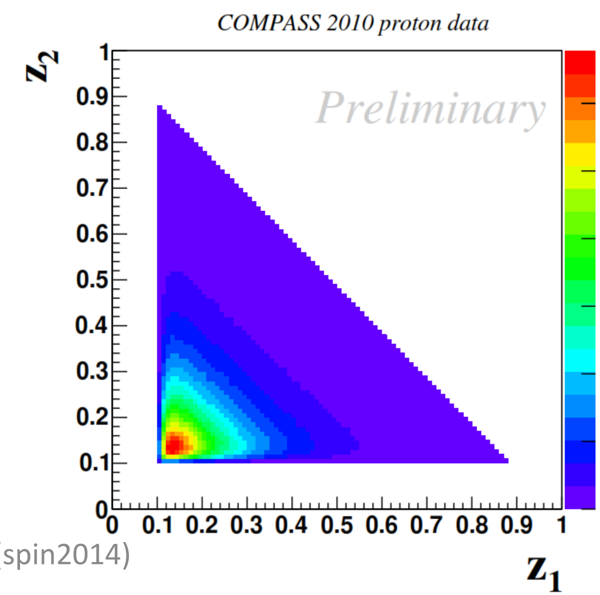
$$\phi_{RS} = \phi_R + \phi_S - \pi$$

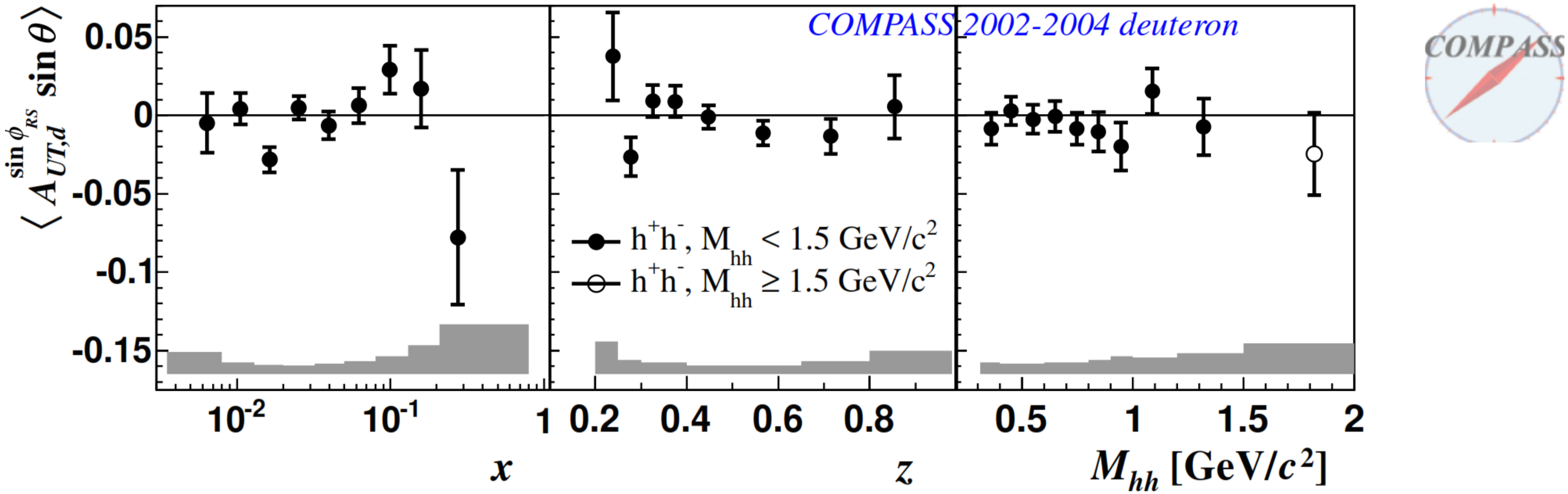
$A_{UT}^{\sin\phi_{RS}}(x,z,M)$ **asymmetries** measured as function of x, z=z1 + z2, M_{inv}

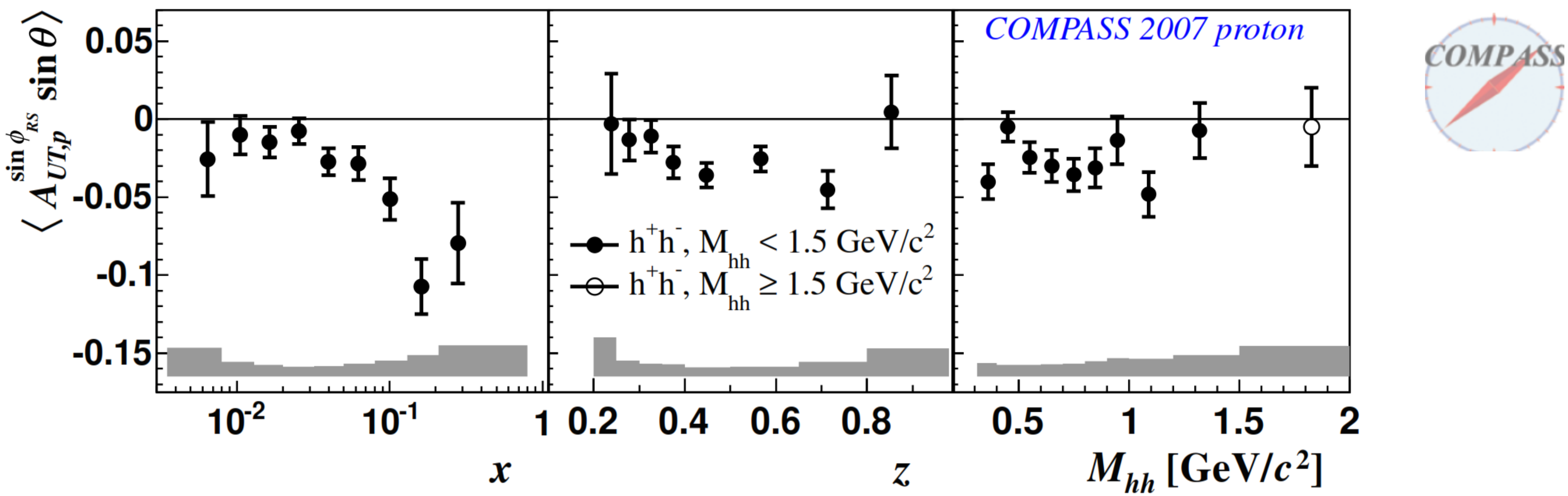












2002-2004 deuteron + 2007 proton data published in 2012

PLB 713 (2012) 10

these data were used in JHEP03(2013)119 (Bacchetta, Courtoy, Radici):
extraction of the **tranversity PDF** *(collinear mechanism)*

$$A_{UT}^{\sin\phi_{RS}}(x,z,M) = \frac{\sum_q e_q^2 \cdot h_1^q(x) \cdot H_q^{2h}(z,M)}{\sum_q e_q^2 \cdot f_1^q(x) \cdot D_q^{2h}(z,M)}$$

→ 2h interference fragmentation function IFF

using:

$$D_1^u = D_1^{\bar{u}}\,, \quad D_1^d = D_1^{\bar{d}}\,, \quad D_1^s = D_1^{\bar{s}}\,,$$
$$H_1^{\sphericalangle u} = -H_1^{\sphericalangle d} = -H_1^{\sphericalangle \bar{u}} = H_1^{\sphericalangle \bar{d}}\,, \quad H_1^{\sphericalangle s} = -H_1^{\sphericalangle \bar{s}} = 0\,.$$

- H calculated using model tuned on belle data
- D from model, tuned on MC generator
- f well known from PDF tables

asymmetries measured as function of x (integrated over z and M) are then:

calculated

$$A_{UT,p}^{\sin\phi_{RS}}(x) = c_p \cdot (x h_1^{u_v} - x h_1^{d_v} / 4)$$

proton target

$$A_{UT,d}^{\sin\phi_{RS}}(x) = c_d \cdot (x h_1^{u_v} + x h_1^{d_v})$$

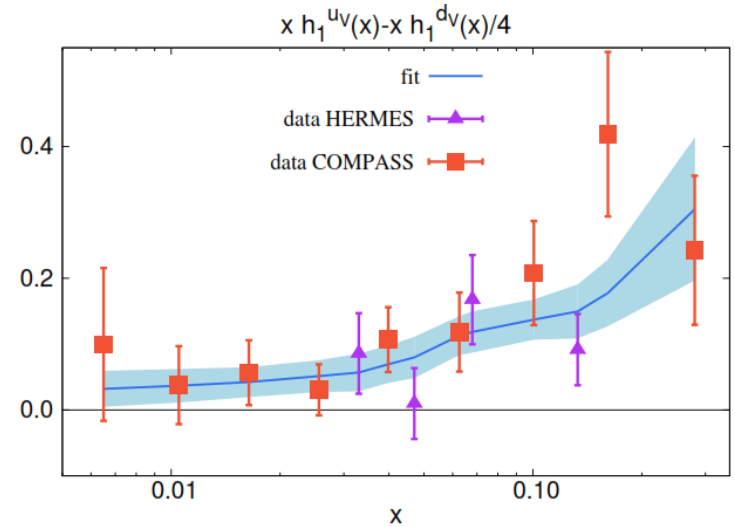
deuteron target

using some functional form for the valence transversity distribution:

extract from proton data $xh_1^{u_v} - xh_1^{d_v}/4$

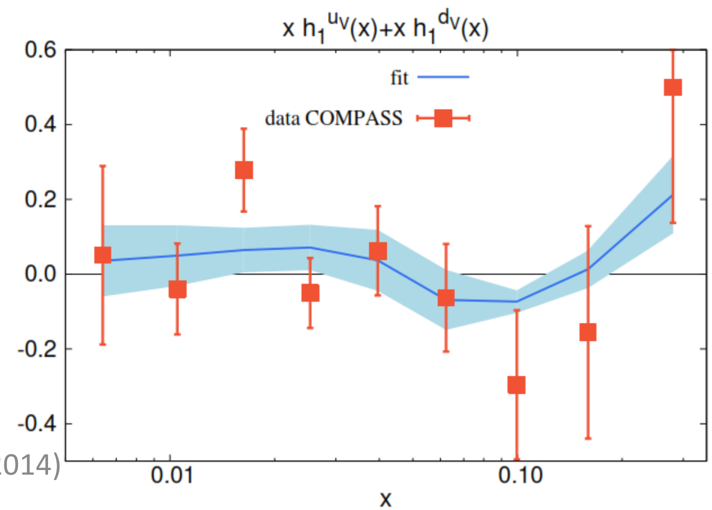
HERMES		data		
x	y	$Q^2[\text{GeV}^2]$	A_{SIDIS}	$h_1^{u_v} - h_1^{d_v}/4$
0.033	0.734	1.232	0.015 ± 0.010	0.086 ± 0.061
0.047	0.659	1.604	0.002 ± 0.011	0.010 ± 0.054
0.068	0.630	2.214	0.035 ± 0.011	0.167 ± 0.069
0.133	0.592	4.031	0.020 ± 0.010	0.092 ± 0.054

COMPASS	proton	data	
x	$Q^2[\text{GeV}^2]$	A_{SIDIS}	$h_1^{u_v} - h_1^{d_v}/4$
0.0065	1.232	0.026 ± 0.030	0.10 ± 0.12
0.0105	1.476	0.010 ± 0.016	0.038 ± 0.059
0.0164	1.744	0.015 ± 0.013	0.057 ± 0.049
0.1330	2.094	0.008 ± 0.010	0.031 ± 0.039
0.0398	2.802	0.027 ± 0.011	0.107 ± 0.049
0.0626	4.342	0.029 ± 0.014	0.118 ± 0.060
0.1006	6.854	0.051 ± 0.016	0.208 ± 0.079
0.1613	10.72	0.108 ± 0.023	0.42 ± 0.12
0.2801	21.98	0.080 ± 0.033	0.24 ± 0.11

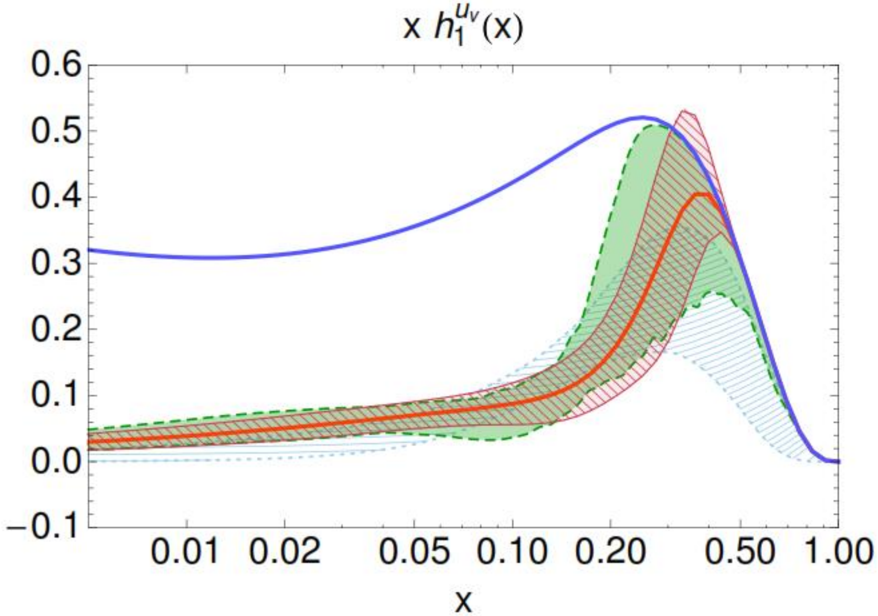


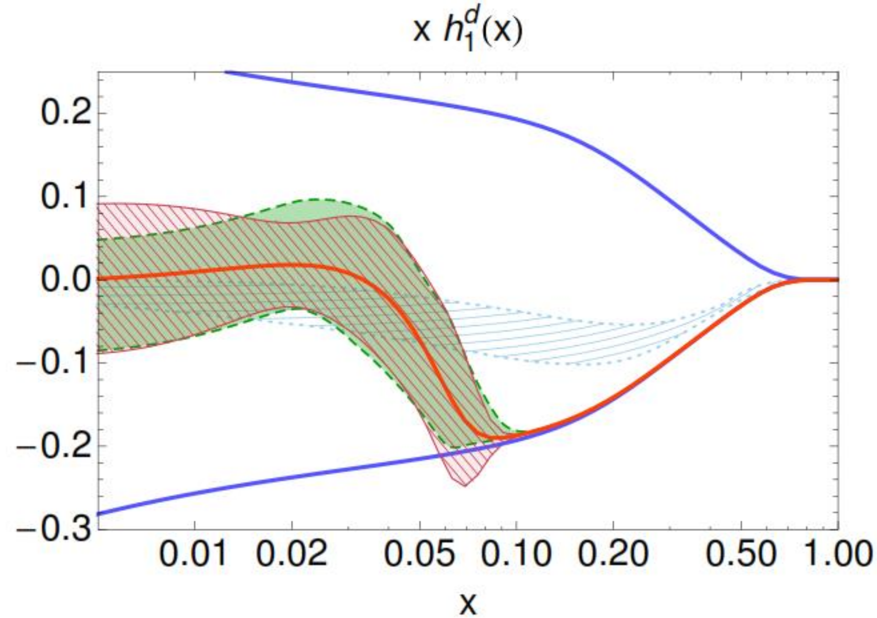
extract from deuteron data $xh_1^{u_v} + xh_1^{d_v}$

COMPASS	deuteron	data	
x	$Q^2[\text{GeV}^2]$	A_{SIDIS}	$h_1^{u_v} + h_1^{d_v}$
0.0064	1.253	0.005 ± 0.024	0.05 ± 0.24
0.0105	1.508	-0.004 ± 0.012	-0.04 ± 0.12
0.0163	1.792	0.028 ± 0.010	0.28 ± 0.11
0.0253	2.266	-0.005 ± 0.009	-0.051 ± 0.094
0.0396	3.350	0.006 ± 0.011	0.06 ± 0.12
0.0623	5.406	-0.006 ± 0.014	-0.06 ± 0.14
0.0996	8.890	-0.029 ± 0.019	-0.30 ± 0.20
0.1597	15.65	-0.017 ± 0.030	-0.16 ± 0.28
0.2801	33.22	0.078 ± 0.054	0.50 ± 0.36



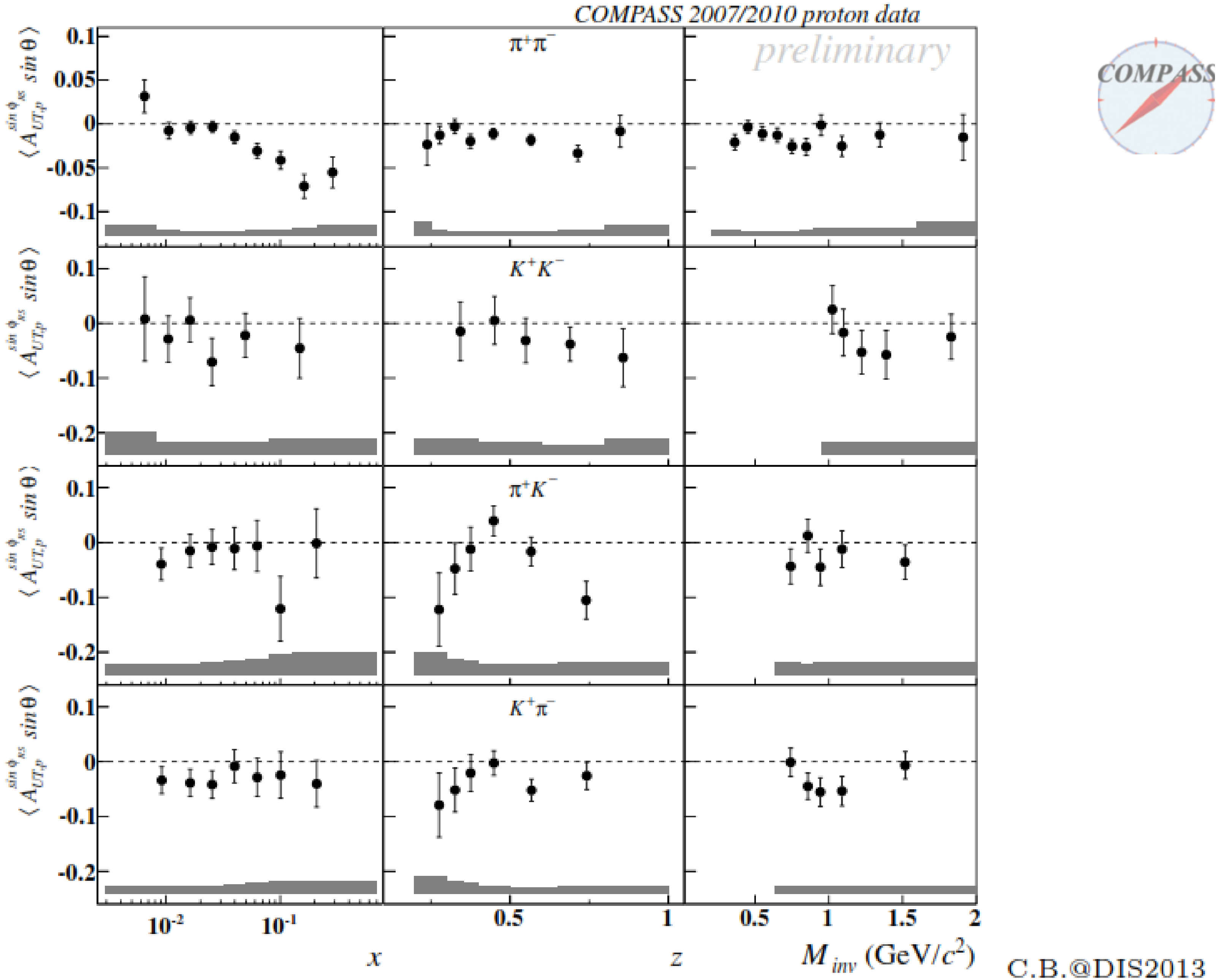
transversity for u and d valence quarks obtained from the *flexible scenario*





the COMPASS data used in this analysis are the
2002-2004 deuteron and the 2007 proton data
the results are on unidentified hadrons
(assumed to be all pions in the calculations)

- **identified hadrons** on transversity polarised **deuteron and proton**


COMPASS 2007/2010 proton data
preliminary
COMPASS
$\pi^+\pi^-$
K^+K^-
π^+K^-
$K^+\pi^-$
$\langle A_{UT,p}^{\sin\phi_{RS}} \sin\theta \rangle$
x
z
M_{inv} (GeV/c^2)
C.B.@DIS2013

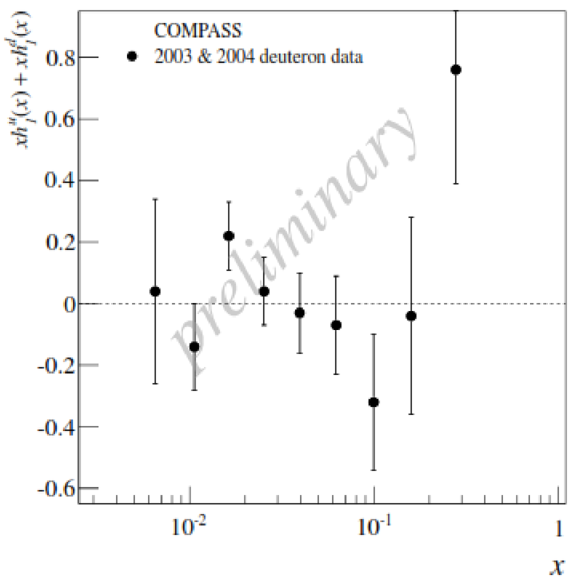
recent work by compass (carmine elia, christopher braun)

use the COMPASS results on identified hadrons to re-evaluate transversity using the c_p and c_d calculated in *Bacchetta et al.*

$$A_{UT,d}^{\sin\phi_{RS}}(x)/c_d \qquad\qquad A_{UT,p}^{\sin\phi_{RS}}(x)/c_p$$

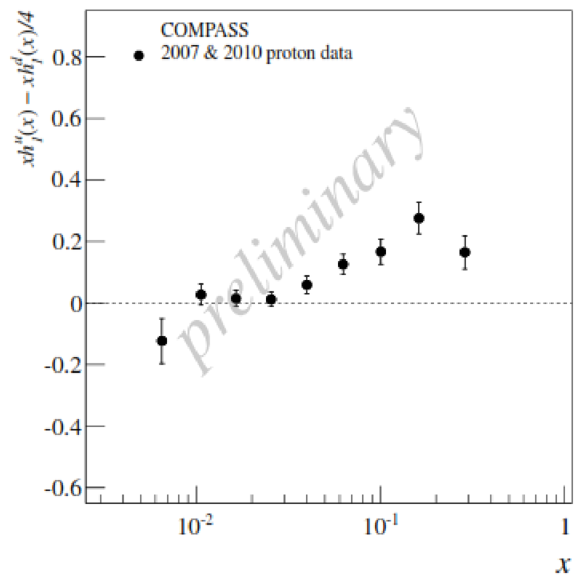
$$xh_{1,d} = xh_1^u(x;Q^2) + xh_1^d(x;Q^2)$$

from deuteron data:



$$xh_{1,p} = xh_1^u(x;Q^2) - \frac{1}{4}xh_1^d(x;Q^2)$$

from proton data:

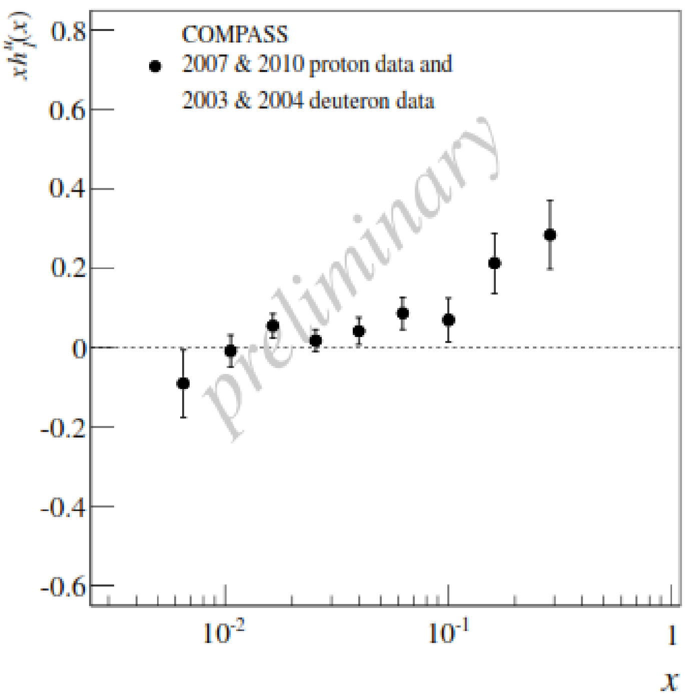


C.B.@DIS2014

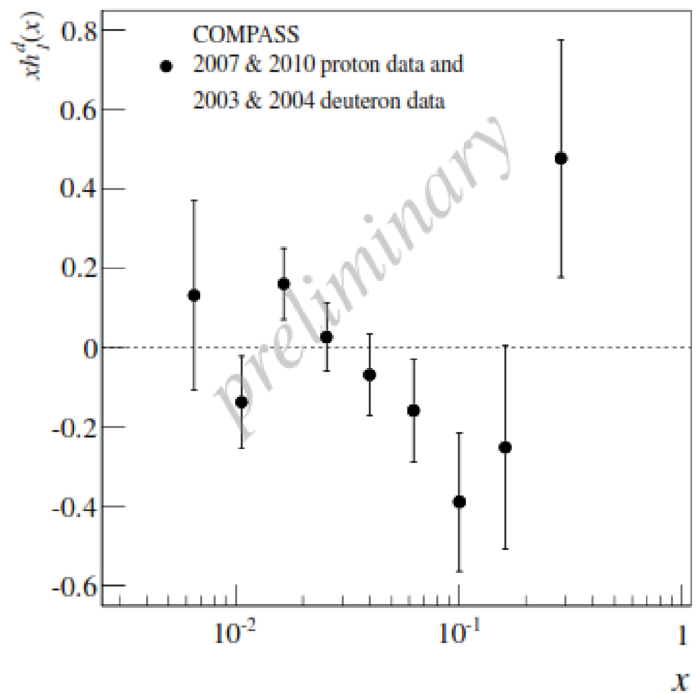
extraction of the transversity bin by bin (no use of functional parametrisation)

xh_1^u and xh_1^d are obtained by solving the system of equations:

$xh_1^u(x; Q^2)$



$xh_1^d(x; Q^2)$



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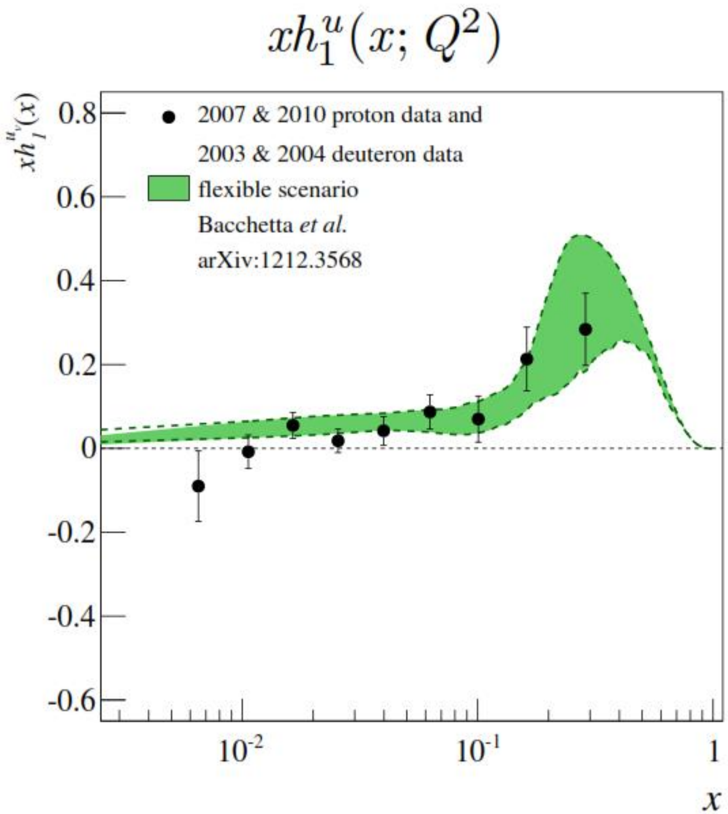
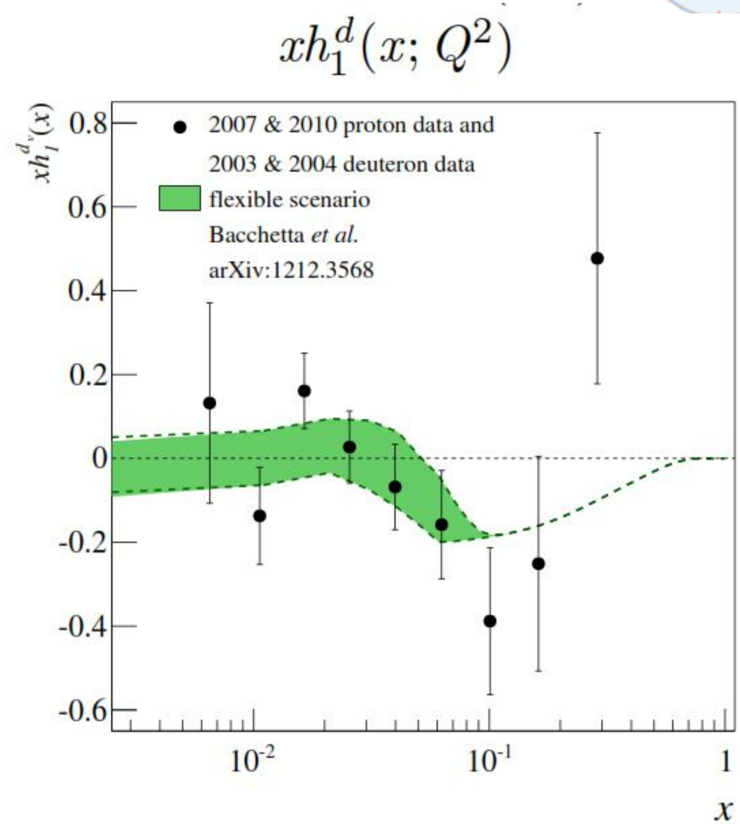
compared with the results of *Bacchetta et al.*





also: transversity extraction using only COMPASS and BELLE results, no models

⟶ *see talk by Franco Bradamante*

another ***interesting quantity*** can be ***measured*** by combining COMPASS and BELLE results on the 2h asymmetries

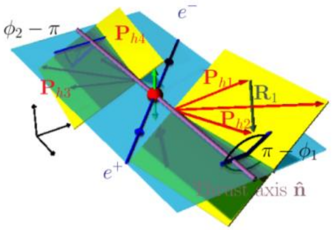
$$\int_{\Omega_x} (4xh_1^{u_v} - xh_1^{d_v})dx$$

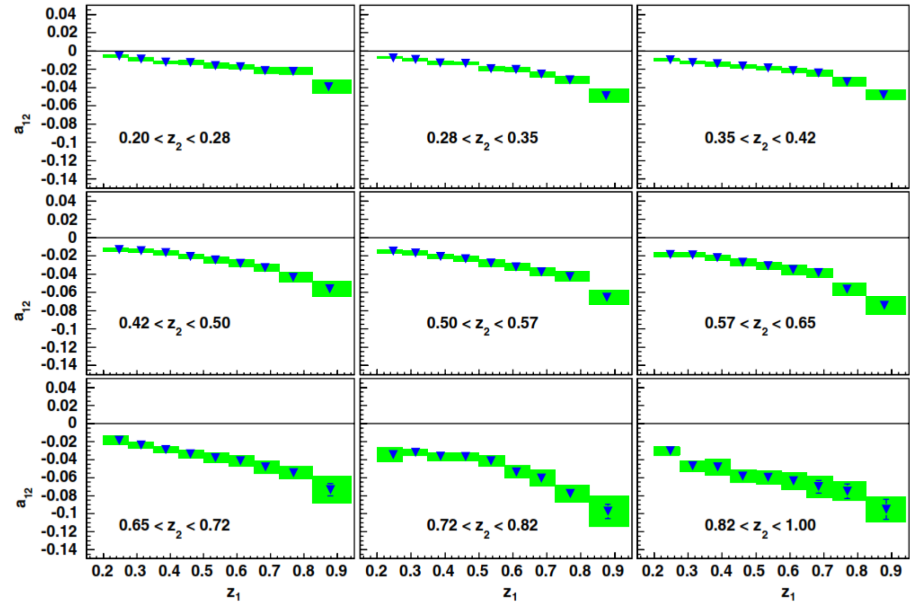
work by
Franco Bradamante
Andrea Bressan
Anna Martin
GS

and which can be compared with theoretical calculations *belle asymmetries*

$$a_{12}(z_1,z_2,M_1,M_2) \approx -\frac{5}{8}\frac{s^2}{1+c^2}\left(\frac{H_u}{D_u}\right)^2$$

e+e- ⟶ back to back jets





multi dimensional extraction (z_1,z_2) (z_1,M_1), … and a_{12}^{I} which is the asymmetry integrated over the whole kinematic range

compass asymmetries

$$\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta\rangle(x,z,M) \approx \frac{4xh_1^{u_v} - xh_1^{d_v}}{4xf_1^{u} + xf_1^{d}} \cdot \frac{H_u}{D_u}$$

comparison

- neglecting possible different Q2 evolution of the spin dependent and spin independent terms (small effect)
- the kinematic values (z,M) explored by the two experiments are similar (differences have been neglected)

comparing asymmetries as function of z:

$$\langle a_I \rangle = \frac{\int_{\Omega z_2} dz_2 \int_{\Omega M_2} dM_2 \, H_u(z_2, M_2)}{\int_{\Omega z_2} dz_2 \int_{\Omega M_2} dM_2 \, D_u(z_2, M_2)}$$

BELLE asymmetries as function of z_1 (integrated over M_1, z_2, M_2)

$$\langle a_{12}(z_1) \rangle = -\frac{5}{8} \frac{s^2}{1+c^2} \frac{\int_{\Omega M_1} dM_1 \, H_u(z_1, M_1)}{\int_{\Omega M_1} dM_1 \, D_u(z_1, M_1)} \cdot \langle a_I \rangle$$

measured angular quantities

calculated from the **measured** integrated asymmetry

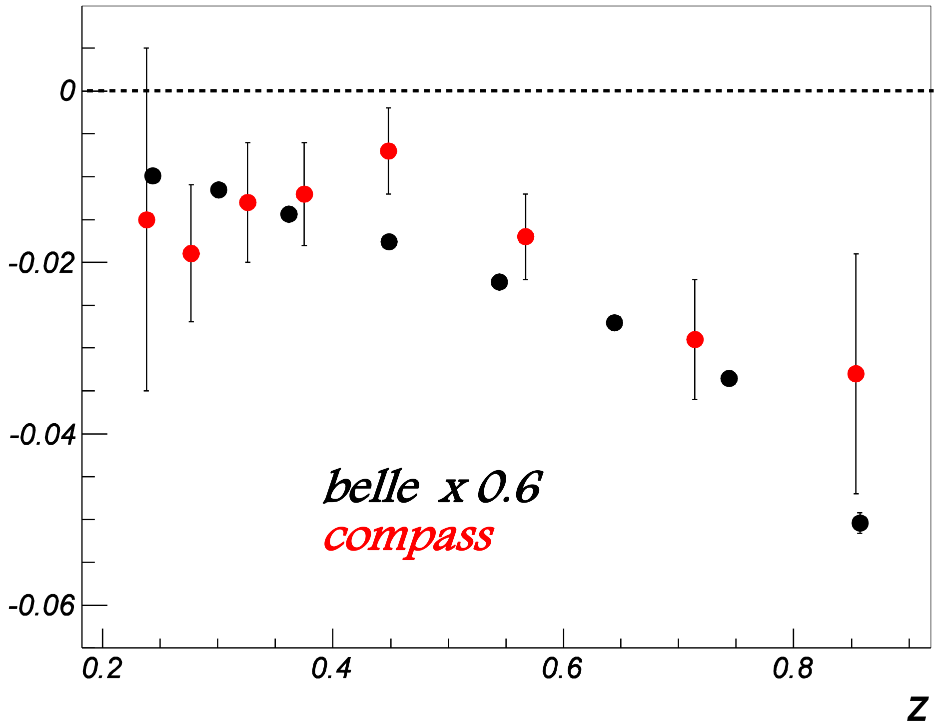
measured quantities !

same term over the same kinematic range !

$$\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta \rangle(z) = \frac{\int_{\Omega x} dx (4x h_1^{u_v} - x h_1^{d_v})}{\int_{\Omega x} dx (4x f_1^{u} + x f_1^{d})} \cdot \frac{\int_{\Omega M} dM \, H_u(z, M)}{\int_{\Omega M} dM \, D_u(z, M)}$$

COMPASS 2h asymmetries as function of z

comparing asymmetries as function of z:



same z trend suggested by the data

$$\langle a_{12}(z_1)\rangle$$

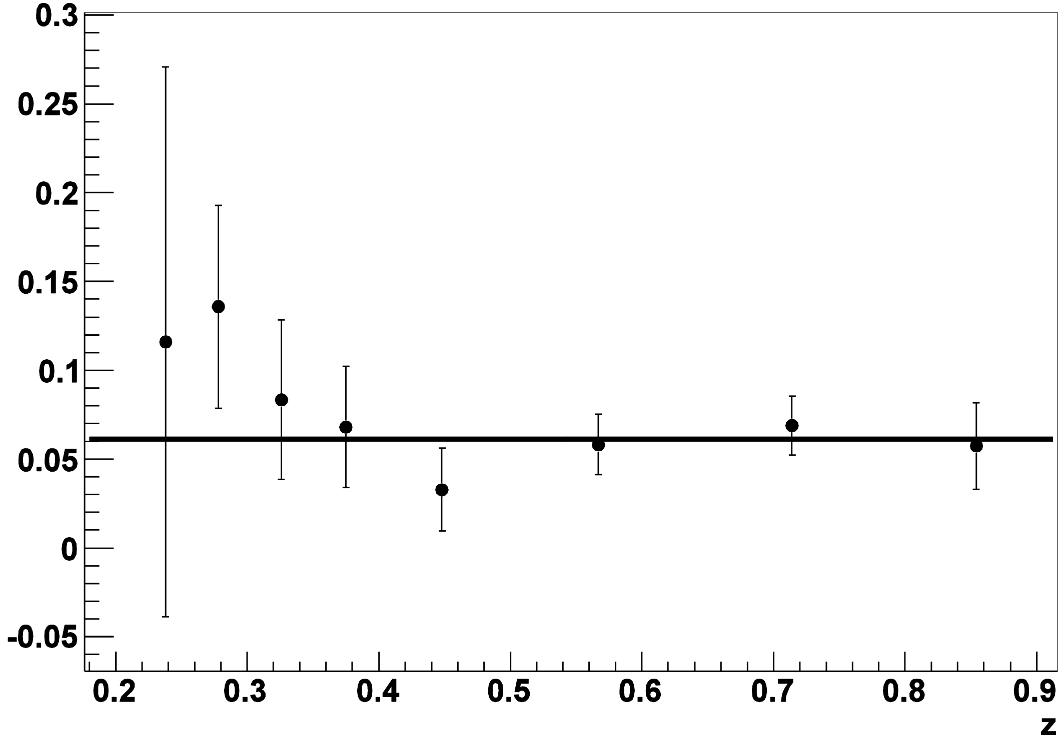
$$\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta\rangle(z)$$

$$\frac{\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta\rangle(z)}{\langle a_p(z_1)\rangle} = \frac{\int_{\Omega x} dx(4xh_1^{u_v} - xh_1^{d_v})}{C}$$

$$\langle a_p(z_1)\rangle = \frac{\langle a_{12}(z_1)\rangle}{\langle a_I\rangle} \cdot \frac{-8}{5} \cdot \frac{1+c^2}{s^2}$$

$$C = \int_{\Omega x} dx(4xf_1^u + xf_1^d) = 1.801$$

calculated using CTEQ PDF

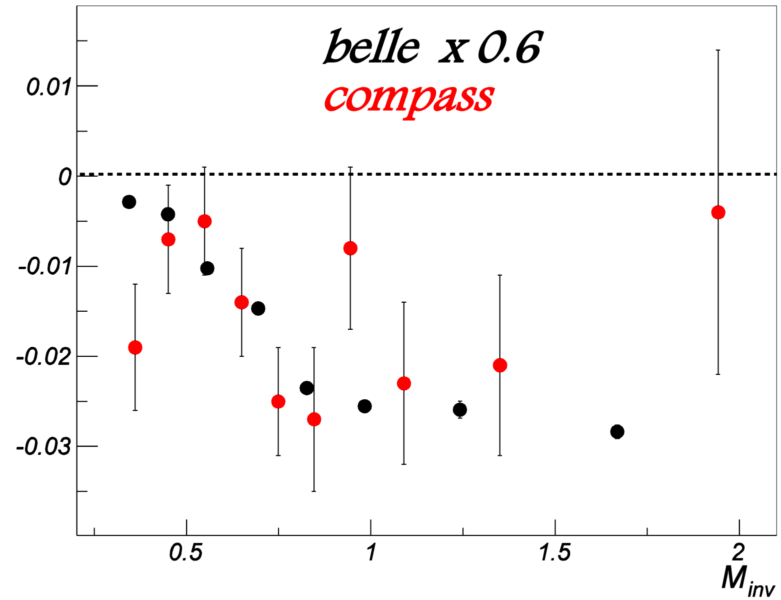


$$\frac{\int_{\Omega x} dx(4xh_1^{u_v} - xh_1^{d_v})}{C} = $$

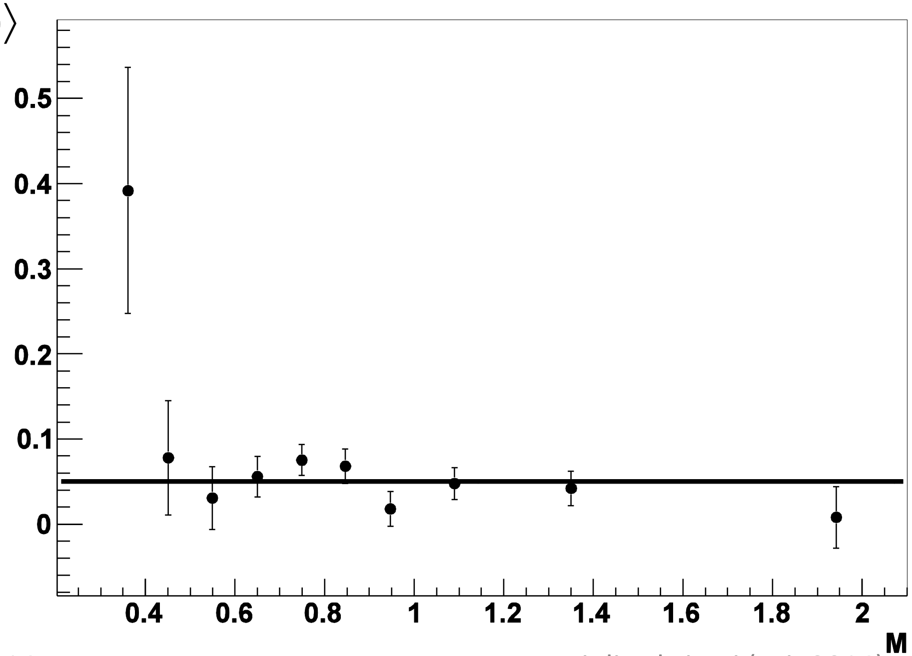
$$= 0.061 \pm 0.009$$

same quantity calculated from
asymmetries as functions of M

$$\frac{\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta\rangle(M)}{\langle a_p(M_1)\rangle} = \frac{\int_{\Omega x} dx(4xh_1^{u_v} - xh_1^{d_v})}{C}$$



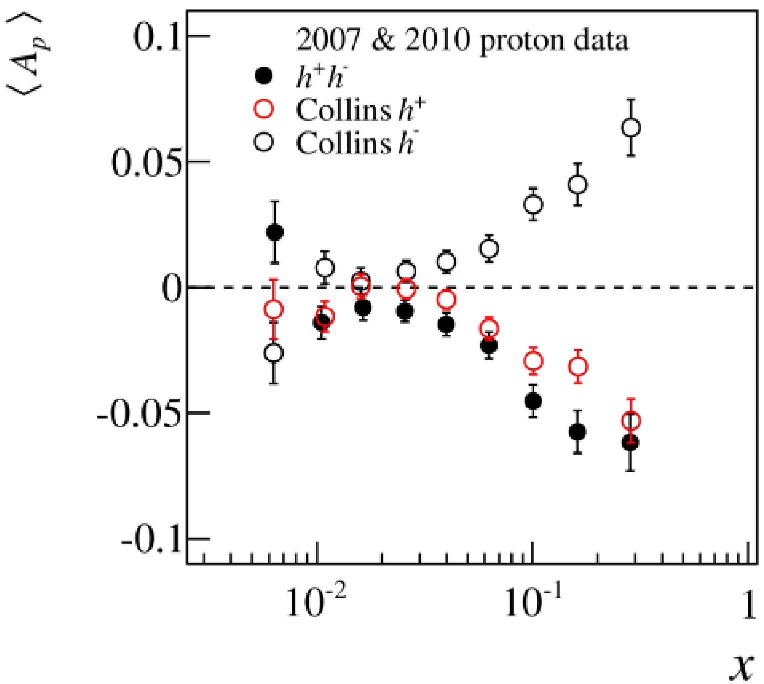
$$\frac{\langle A_{UT,p}^{\sin\phi_{RS}} \sin\vartheta\rangle(M)}{\langle a_p(M_1)\rangle}$$



$$\frac{\int_{\Omega x} dx(4xh_1^{u_v} - xh_1^{d_v})}{C} =$$

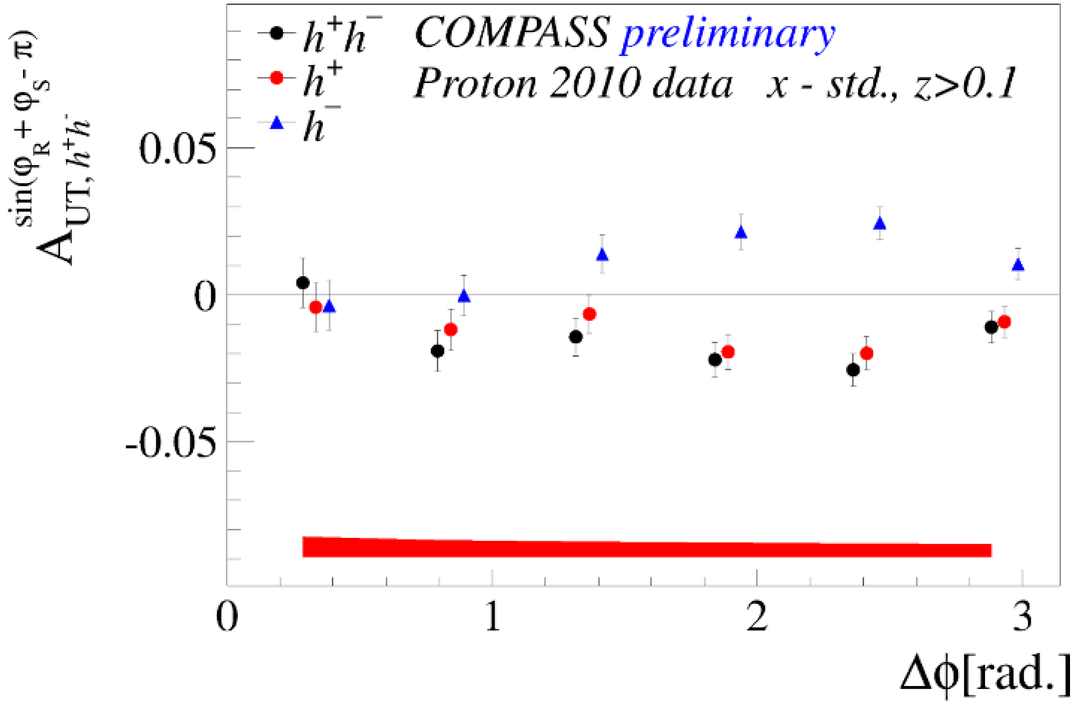
$$= 0.050 \pm 0.008$$

another interesting topic recently studied by COMPASS
and still ongoing ….



1. Observation of almost equal shape and strength of the Collins asymmetry of h^+ and the dihadron h^+h^- asymmetry.

Collins vs. dihadron asymmetries ▶ ΔΦ dependence



these results were presented at transversity 2014 *(by Christopher Braun)*

more results in *Franco Bradamante’s talk on Friday* end

backup