Phenomenological extraction of Transversity

from COMPASS SIDIS and Belle e^+e^- data

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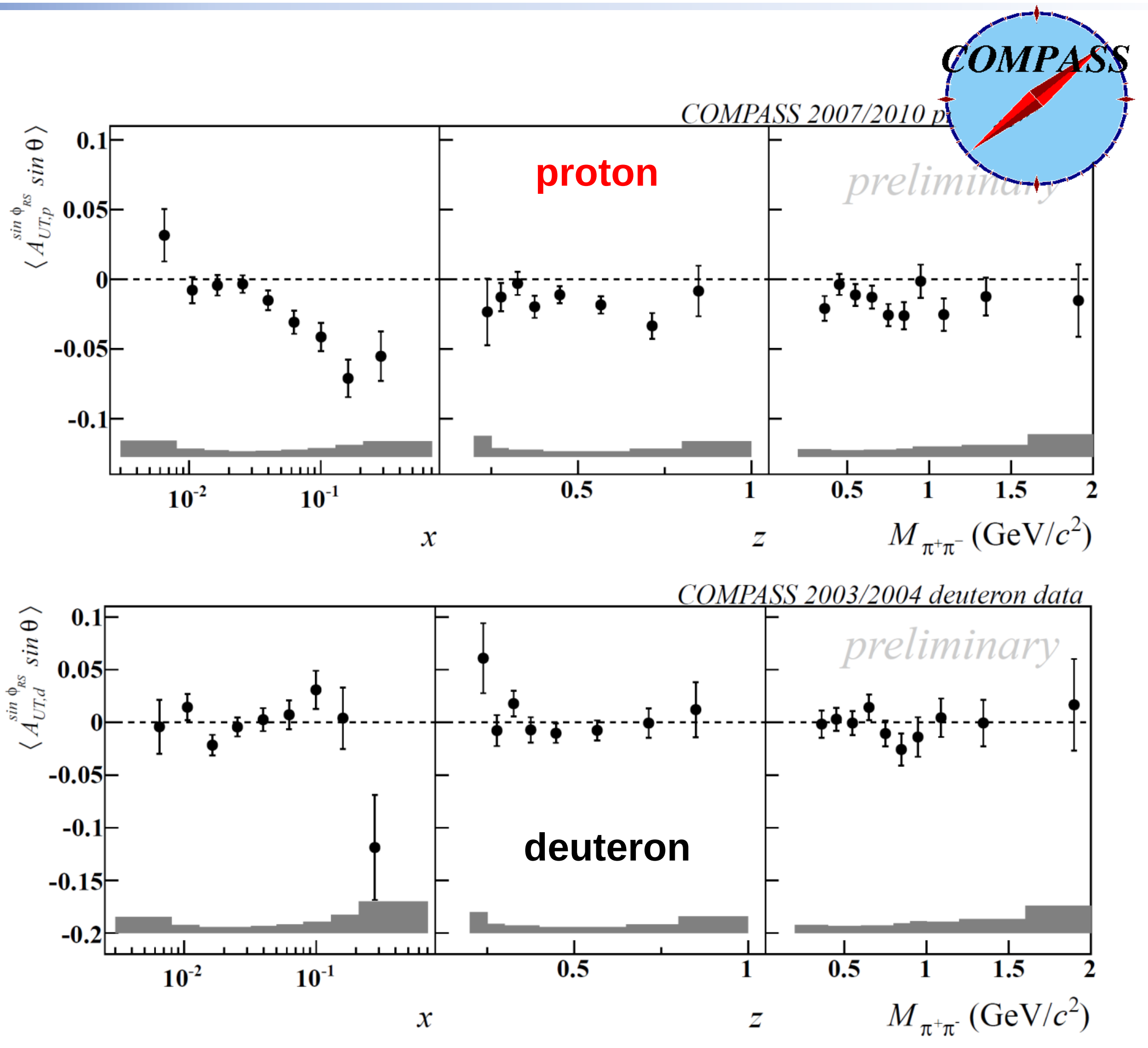
COMPASS results on dihadron asymmetry

Recent results

(DIS2014)

dihadron asymmetries

$\pi^+\pi^-$



COMPASS results on Collins asymmetry

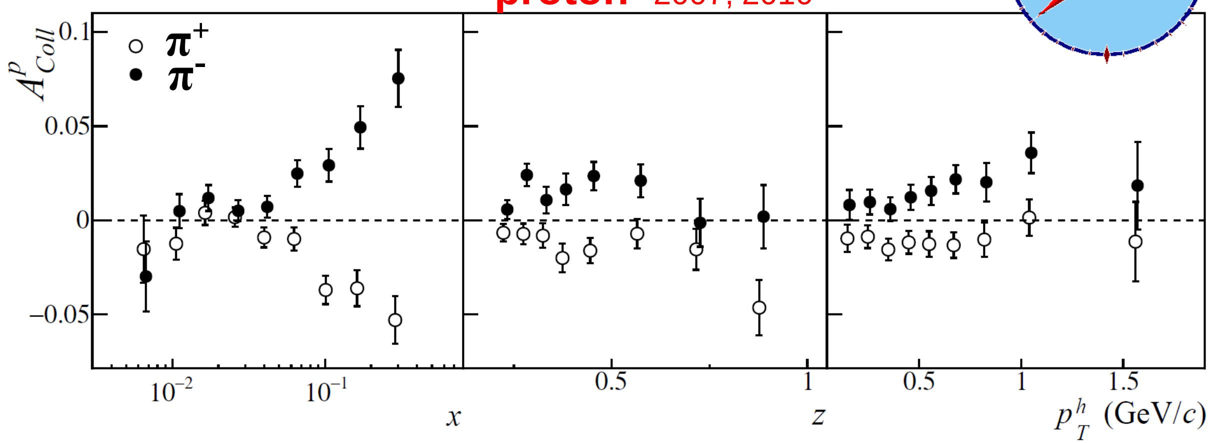
Recent results

(hep-ex/1408.4405)

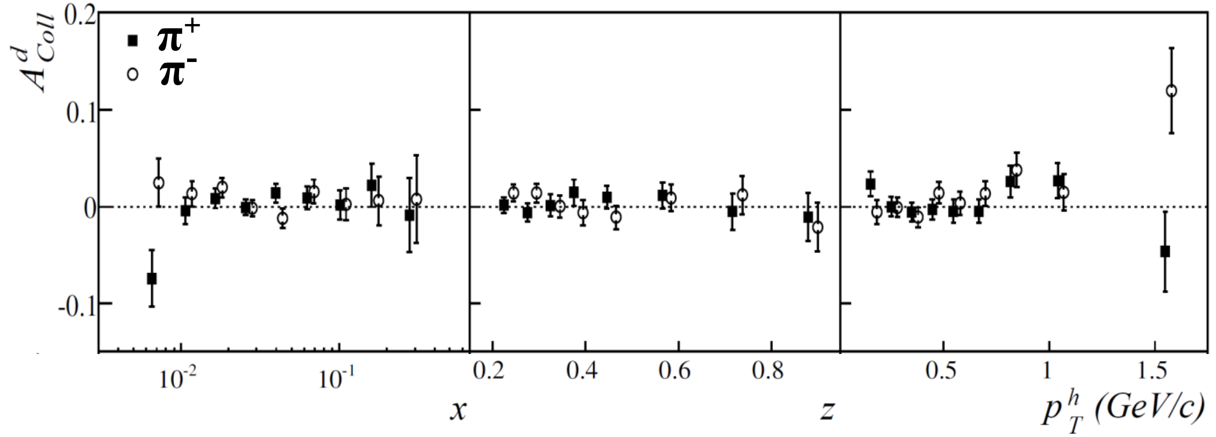
Collins asymmetries

$\pi^+ \pi^-$

proton 2007, 2010



deuteron 2003, 2004



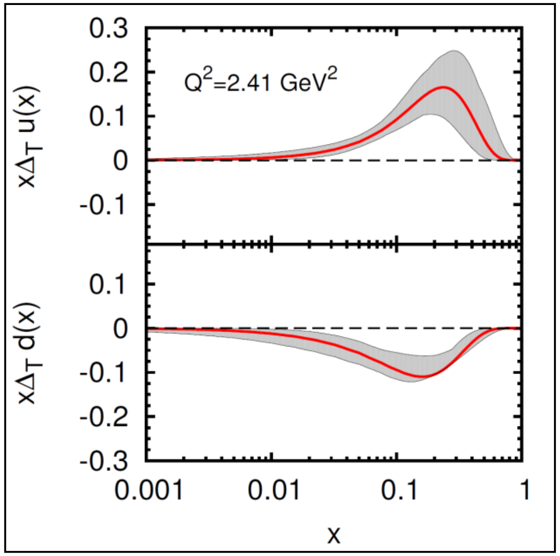
Transversity from COMPASS p and d results

COMPASS results already used to extract the transversity PDFs

- **Collins asymmetry ($\pi^+\pi^-$ COMPASS, HERMES, Belle)**
  Torino group

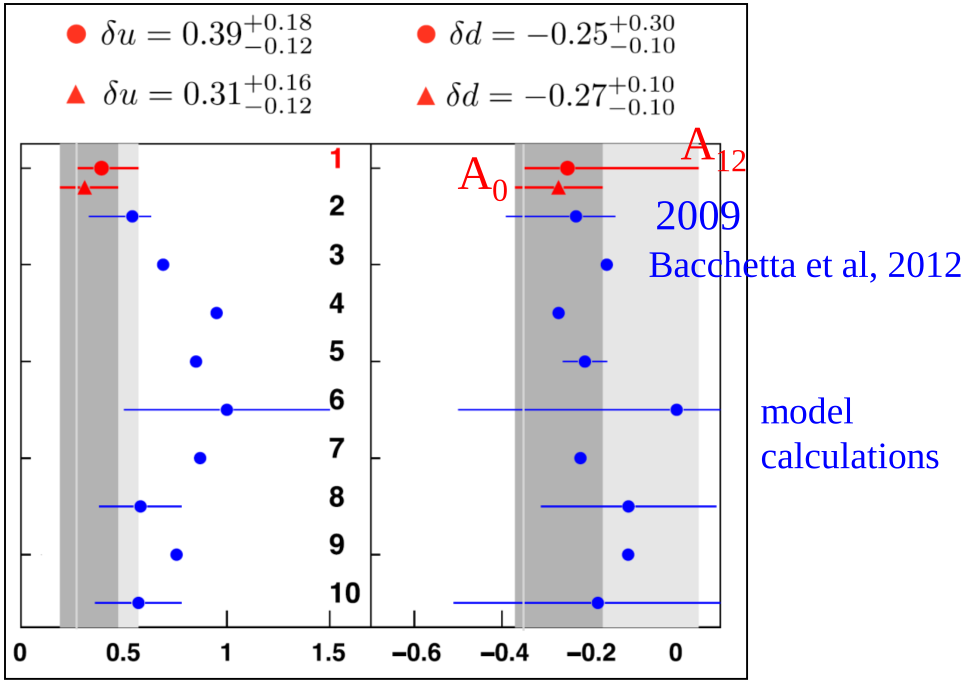
- **Dihadron asymmetry (COMPASS, HERMES, Belle)**
  Pavia group

Transversity from Collins asymmetry



$$\int_0^1 \mathrm{d}x[h_1^q(x) - \bar{h}_1^q(x)] = \delta q.$$

Anselmino et al., PRD87 2013
simultaneous fit of
HERMES p, COMPASS p & d, and Belle data
very good χ^2

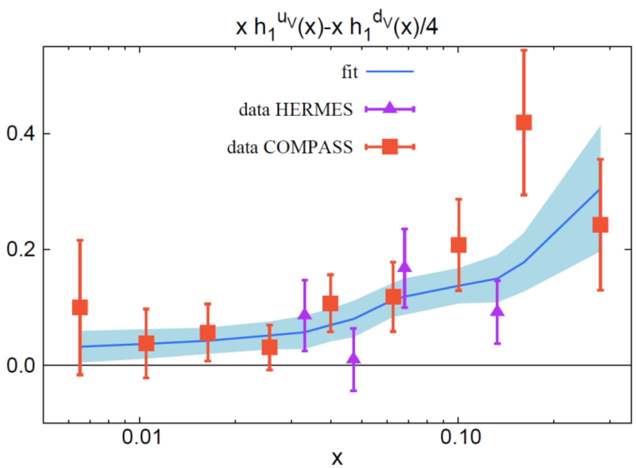


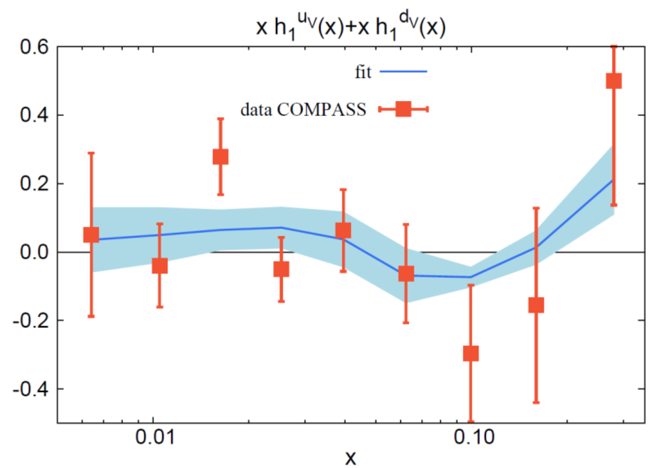
Transversity from dihadron asymmetry

D_q^{2h} from PYTHIA plus HERMES p, COMPASS p and d (2h), Belle data

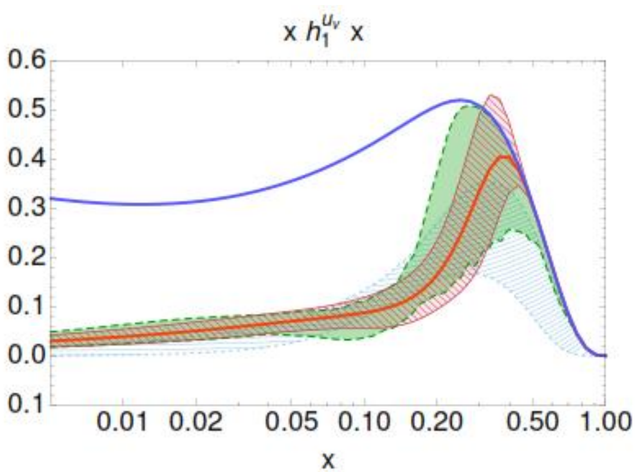
→ linear combinations of transversity for u and d valence quark

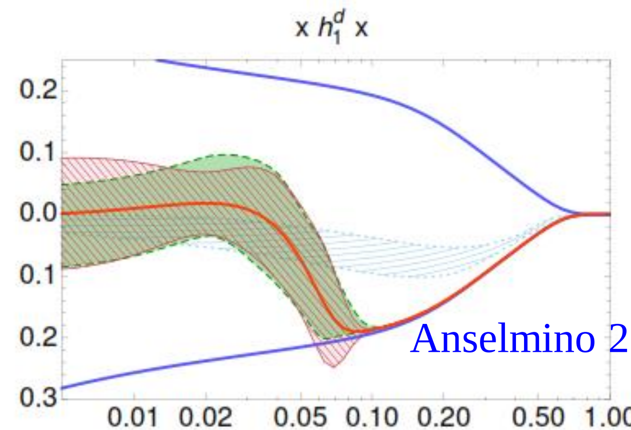
fit with parametrisations → transversity PDFs





flexible





Anselmino 2013

Transversity from COMPASS p and d results

new:

COMPASS result on transversity
measured in each x bin from pion-pair asymmetry on p and d
using results of the Pavia group analysis for the FFs

C. Braun, DIS2014 (PhD Thesis)
G. Sbrizzai, this Symposium

Transversity from COMPASS p and d results

this work [F. B., Anna Martin, Vincenzo Barone]

published COMPASS results for the dihadron asimmetries on p and d
A_p^{2h} **and** A_d^{2h} **as function of** x

directly use the Belle data to evaluate the analyzing power
following Bacchetta et al., PRL107(2011)012001

numerical values for $4xh_1^{u_v} - xh_1^{d_v}$ **and** $xh_1^{u_v} + xh_1^{d_v}$
in each x **bin**

numerical values for $xh_1^{u_v}$ **and** $xh_1^{d_v}$ **in each** x **bin**

and follow a similar procedure for the Collins asymmetries,
without using parametrisations for Collins FFs and transversity PDFs

first shown @ QCD Evolution 2014

dihadron asymmetries

dihadron asymmetry – COMPASS data

$$A^{2h} = \frac{R}{M_{2h}} \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q}$$

measured as function of x, z, M

$$H_q(z, M_{2h}) = \sin\theta_q \cdot R/M_{2h} \cdot H_q^{\angle}(z, M_{2h})$$

dihadron asymmetry – COMPASS data

$$A^{2h} = \frac{R}{M_{2h}} \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q}$$

measured as function of x, z, M

$$H_q(z, M_{2h}) = \sin\theta_q \cdot R/M_{2h} \cdot H_q^{\angle}(z, M_{2h})$$

with reasonable assumptions on the FFs

Bacchetta et al. PRL107(2011)012001

$$H_q = -H_{\bar{q}}, \quad H_u = -H_d, \quad H_s = H_c = 0$$

$$D_u = D_d = D_{\bar{u}} = D_{\bar{d}}, \quad D_s = D_{\bar{s}}, \quad D_c = D_{\bar{c}} \qquad D_s \simeq D_c \simeq 0.5 D_u \quad ,$$

neglecting s and c quark contributions, and integrating over z, M :

$$A_p^{2h}(x) \simeq \frac{4xh_1^{u_v} - xh_1^{d_v}}{4xf_1^{*u} + xf_1^{*d}} \frac{< H_u >}{< D_u >} \qquad A_d^{2h}(x) \simeq \frac{3}{5} \frac{xh_1^{u_v} + xh_1^{d_v}}{xf_1^{*u} + xf_1^{*d}} \frac{< H_u >}{< D_u >}$$

$f_1^{*q} = f_1^q + f^{\bar{q}}$ from CTEQ

from Belle data

dihadron asymmetry – COMPASS data

$$A^{2h} = \frac{R}{M_{2h}} \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q}$$

measured as function of x, z, M

$$H_q(z, M_{2h}) = \sin\theta_q \cdot R/M_{2h} \cdot H_q^{\angle}(z, M_{2h})$$

with reasonable assumptions on the FFs

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$$H_q = -H_{\bar{q}}, \quad H_u = -H_d, \quad H_s = H_c = 0$$

$$D_u = D_d = D_{\bar{u}} = D_{\bar{d}}, \quad D_s = D_{\bar{s}}, \quad D_c = D_{\bar{c}} \qquad D_s \simeq D_c \simeq 0.5 D_u \;,$$

neglecting s and c quark contributions, and integrating over *z*, *M* :

$$A_p^{2h}(x) \simeq \frac{4xh_1^{u_v} - xh_1^{d_v}}{4xf_1^{*u} + xf_1^{*d}} \frac{< H_u >}{< D_u >} \qquad A_d^{2h}(x) \simeq \frac{3}{5} \frac{xh_1^{u_v} + xh_1^{d_v}}{xf_1^{*u} + xf_1^{*d}} \frac{< H_u >}{< D_u >}$$

only unknowns

dihadron asymmetry – Belle data

$$a_{12} = \frac{s^2}{1+c^2} \frac{\sum_q e_q^2 H_q H_{\bar{q}}}{\sum_q e_q^2 D_q D_{\bar{q}}}$$

measured as function of z_1, z_2, M_1, M_2

$$s^2 = \sin^2\theta,\ c^2 = \cos^2\theta$$

$$H_q(z, M_{2h}) = \sin\theta_q \cdot R/M_{2h} \cdot H_q^{\angle}(z, M_{2h})$$

with the previous assumptions on the FFs

and D_c fixed in order to reproduce the charm yield,

the fully integrated a_{12} asymmetry given by Belle is

$$a_{12}^I \simeq -\frac{5}{8}\frac{s^2}{1+c^2}\left(\frac{< H_u >}{< D_u >}\right)^2$$

$$a_{12}^I = -0.0196 \pm 0.0002 \pm 0.0022$$

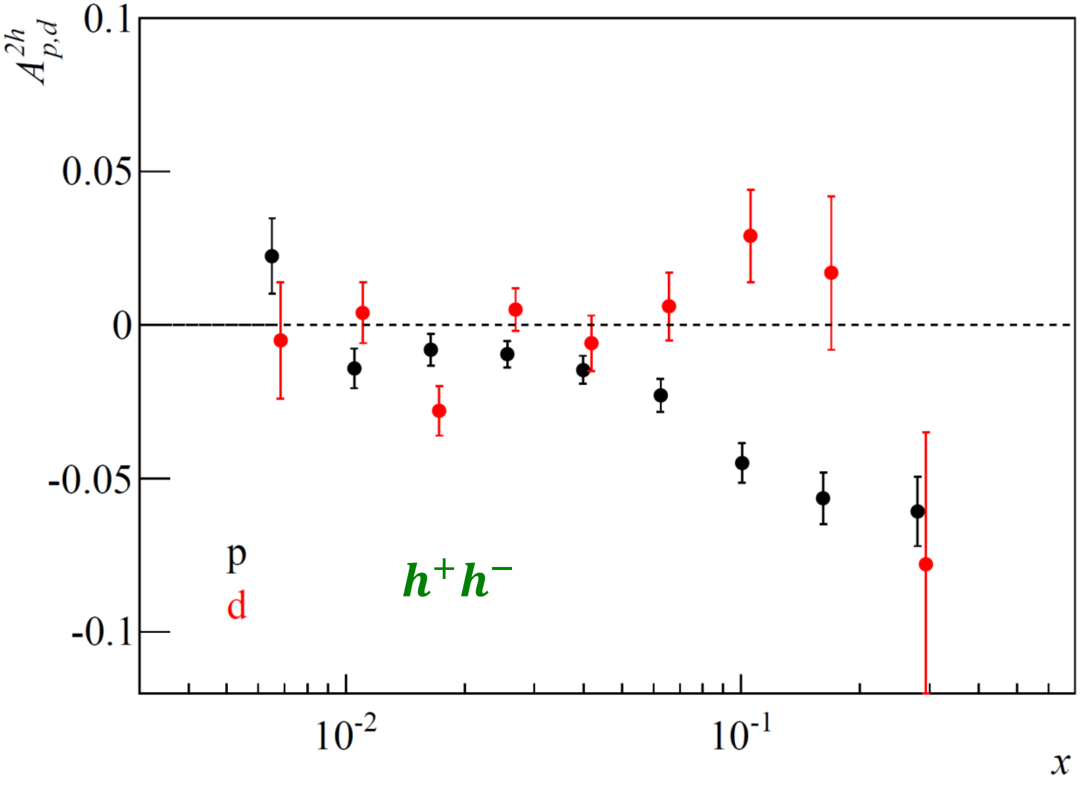
and the anaysing power is

$$< a_P > = \frac{< H_u >}{< D_u >} = 0.203$$

here we have used this value at all COMPASS Q^2, neglecting evolution

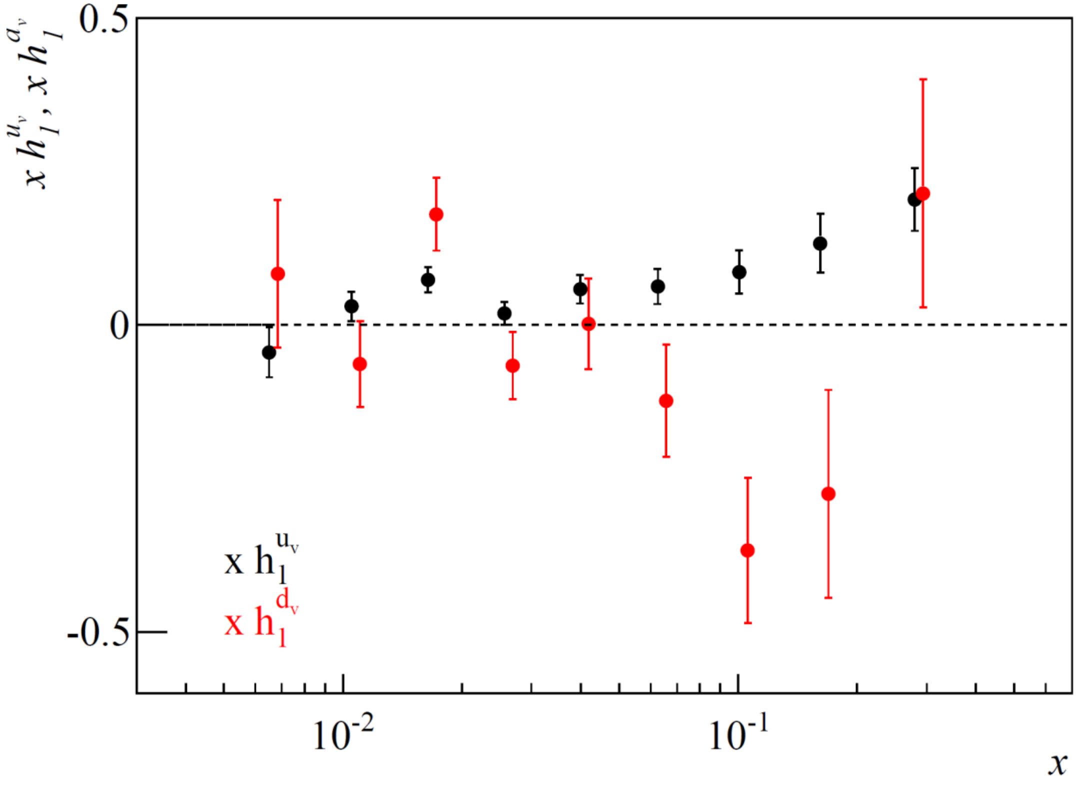
effect evaluated by the Pavia group: ~ -8%

dihadron asymmetry – COMPASS data



dihadron asymmetry – transversity

present result



Collins asymmetries

Collins asymmetries

in this case, from the Belle data one has to calculate the analysing power

$$< a_{P,C} > = \frac{<H^{fav}>}{<D^{fav}>}$$

Collins asymmetry – Belle data

we have used the asymmetry (corrected for charm contribution)

$$A_{12}^{UL}(z_1, z_2) = \frac{< s^2 >}{< 1 + c^2 >} \left[P_U(z_1, z_2) - P_L(z_1, z_2) \right]$$

integrated over M_1, M_2

where

$$P_U(z_1, z_2) = \frac{\sum_q e_q^2 [H_{1q}^{+}(z_1) H_{1\bar{q}}^{-}(z_2) + H_{1q}^{-}(z_1) H_{1\bar{q}}^{+}(z_2)]}{\sum_q e_q^2 [D_{1q}^{+}(z_1) D_{1\bar{q}}^{-}(z_2) + D_{1q}^{-}(z_1) D_{1\bar{q}}^{+}(z_2)]}$$

$$P_L(z_1, z_2) = \frac{\sum_q e_q^2 [H_{1q}^{+}(z_1) H_{1\bar{q}}^{+}(z_2) + H_{1q}^{-}(z_1) H_{1\bar{q}}^{-}(z_2)]}{\sum_q e_q^2 [D_{1q}^{+}(z_1) D_{1\bar{q}}^{+}(z_2) + D_{1q}^{-}(z_1) D_{1\bar{q}}^{-}(z_2)]}$$

$$H_{1q}^{\pm} = H_{1\,(q\to\pi^{\pm})}^{\perp\,(1/2)}, \quad D_{1q}^{\pm} = D_{1\,(q\to\pi^{\pm})}$$

Efremov et al., PRD73 (2006)
Bacchetta et al., PLB659 (2008)
Anselmino et al., PRD75 (2007)
Seidl et al., PRD78 (2008)

Collins asymmetry – Belle data

for the FFs we have made the assumptions

$$H_1^{fav} = H_{1u}^{+} = H_{1d}^{-} = H_{1\bar{u}}^{-} = H_{1\bar{d}}^{+}$$
$$H_1^{dis} = H_{1u}^{-} = H_{1d}^{+} = H_{1\bar{u}}^{+} = H_{1\bar{d}}^{-}$$

(same for D)

ignoring the c and s quark contributions, in the case $z_1 = z_2 = z$ it is

$$A_{12}^{UL}(z) = \frac{< s^2 >}{< 1 + c^2 >} \left[\frac{H_1^{fav}(z)}{D_1^{fav}(z)} \right]^2 B(z)$$

where $B(z) = \frac{b(z)[1 + a^2(z)] - [1 + b^2(z)]a(z)}{b(z)[1 + b^2(z)]}$ $\quad a(z) = \frac{H_1^{dis}(z)}{H_1^{fav}(z)}$ $\quad b(z) = \frac{D_1^{dis}(z)}{D_1^{fav}(z)}$

not so simple as in the 2h case →

Collins asymmetry – Belle data

we have done 2 alternative assumptions

a1 $H_1^{fav}(z) = -\, H_1^{dis}(z) \quad i.e. \quad a(z) = -1$

a2 $\dfrac{H_1^{fav}(z)}{D_1^{fav}(z)} = -\dfrac{H_1^{dis}(z)}{D_1^{dis}(z)} \quad i.e. \quad a(z) = -b(z)$

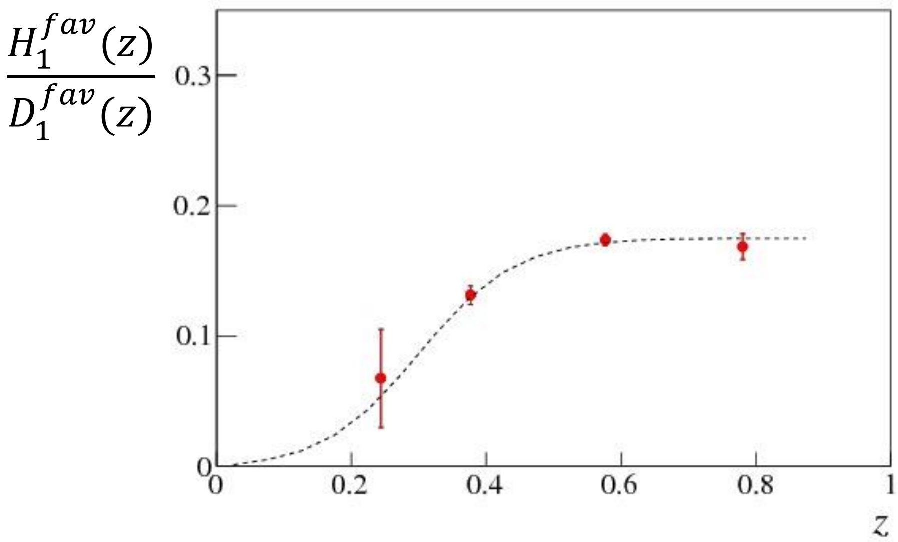
both in agreement with the considerations on the “interplay between the Collins and the dihadron FFs”

and already used / suggested / found as a result of global fits

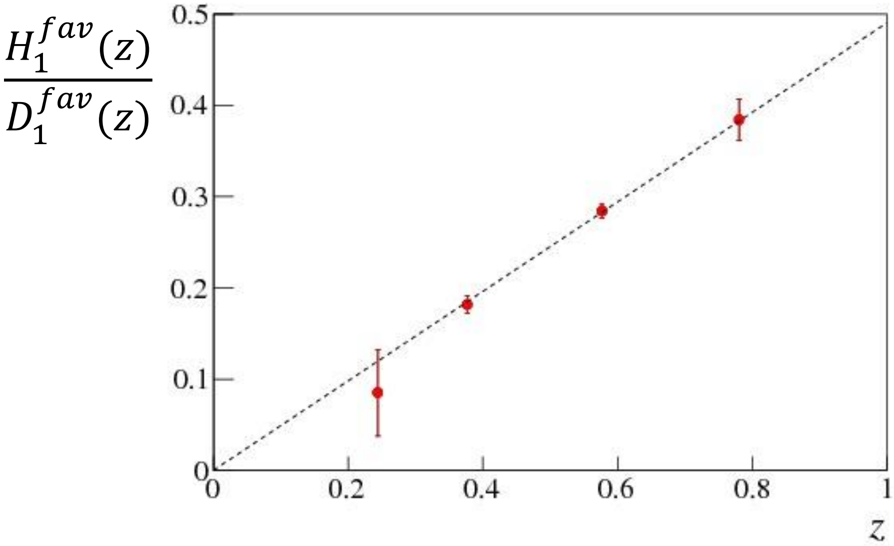
- **these assumptions allow to evaluate** $\dfrac{H_1^{fav}(z)}{D_1^{fav}(z)}$ **in the four** z **bins**
- **the values are then fitted with a function of** z

Collins asymmetry – Belle data

a1



a2



to obtain the analysing power
the functions are integrated over z

Collins asymmetry – Belle data

finally :

a1 $$\frac{< H_1^{fav} >}{< D_1^{fav} >} \sim 0.10$$

a2 $$\frac{< H_1^{fav} >}{< D_1^{fav} >} \sim 0.18$$

if the evolution of H_1^{fav} is negligible;

if the evolution of H_1^{fav} is the same as that of D_1^{fav}
the analysing powers decrease by ~ 10%

Collins asymmetry – COMPASS data

$$A^{\pm}_{Coll}(x,z) = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) \otimes H_{1q}^{\pm}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) \otimes D_{1q}^{\pm}(z)}$$

“gaussian ansatz”:

$$A^{\pm}_{Coll}(x,z) = C_G \cdot \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) H_{1q}^{\pm}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) D_{1q}^{\pm}(z)}$$

$$C_G = \frac{1}{\sqrt{1 + z^2 < p_{h_1}^2 > / < p_{H_1}^2 >}}$$

Efremov et al., PRD73 (2006)

we have assumed

- $C_G = 1$
- **the previous relations among the FFs**
- **the s and c quark contributions to be negligible**

Collins asymmetry – COMPASS data

the measured asymmetries as function of *x* can be written as

$$A^{+}_{Coll,p} = \frac{< H_1^{fav} >}{< D_1^{fav} >} \frac{4(xh_1^u + \alpha x h_1^{\bar{u}}) + (\alpha x h_1^d + x h_1^{\bar{d}})}{d_p^+}$$

$$A^{-}_{Coll,p} = \frac{< H_1^{fav} >}{< D_1^{fav} >} \frac{4(\alpha xh_1^u + x h_1^{\bar{u}}) + (x h_1^d + \alpha x h_1^{\bar{d}})}{d_p^-}$$

$$A^{+}_{Coll,d} = \frac{< H_1^{fav} >}{< D_1^{fav} >} \frac{(xh_1^u + x h_1^d)(4+\alpha) + (x h_1^{\bar{u}} + x h_1^{\bar{d}})(1+4\alpha)}{d_d^+}$$

$$A^{-}_{Coll,d} = \frac{< H_1^{fav} >}{< D_1^{fav} >} \frac{(xh_1^u + x h_1^d)(4\alpha+1) + (x h_1^{\bar{u}} + x h_1^{\bar{d}})(4+\alpha)}{d_d^-}$$

$$\alpha = \frac{<H_1^{dis}>}{<H_1^{fav}>} = \begin{cases} -1 & \text{a1} \\ \dfrac{< D_1^{dis} >}{< D_1^{fav} >} & \text{a2} \end{cases}$$

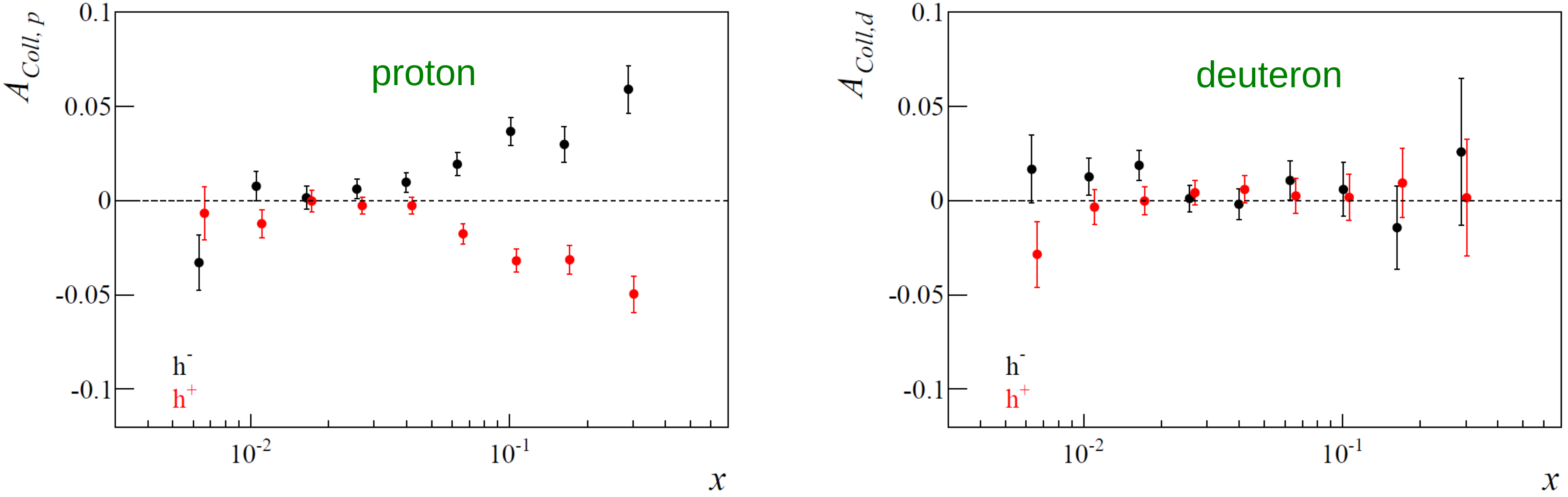
corresponding quantities with unpol PDFs and FFs

from Belle

neglecting qbar transversity,

in each *x* bin, the only unknowns are the u and d quark transversity PDFs

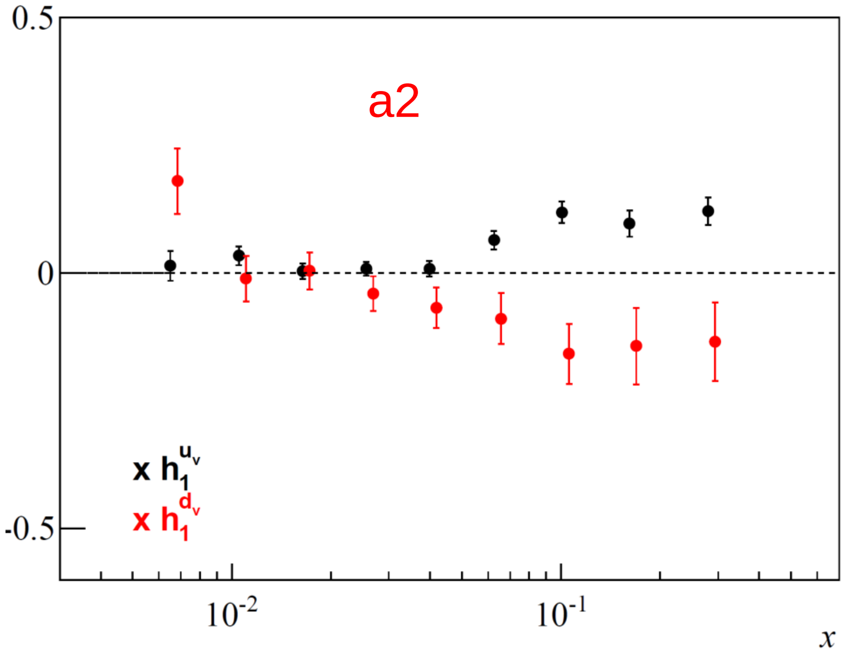
Collins asymmetry – COMPASS data

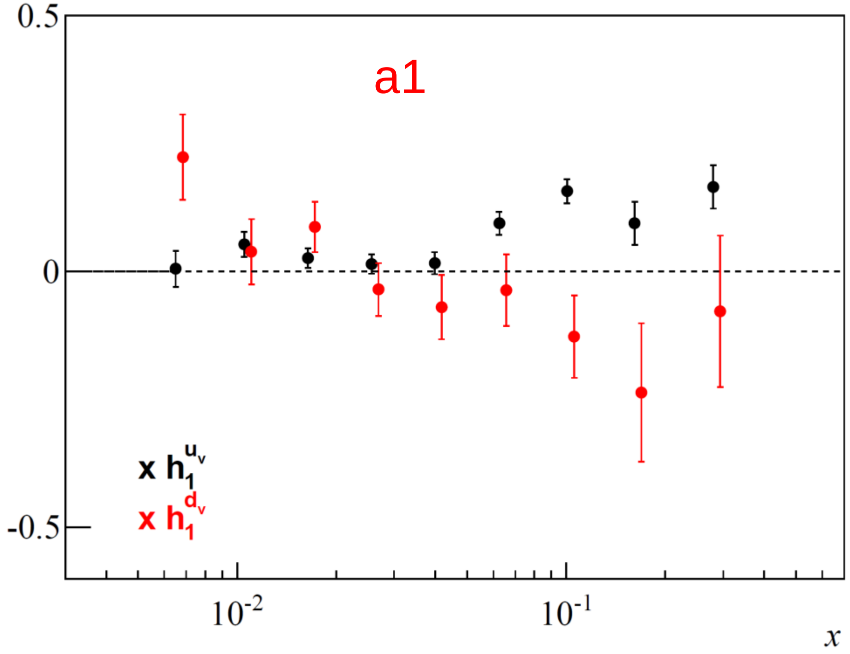


un-identified hadrons

Collins asymmetry – transversity

results

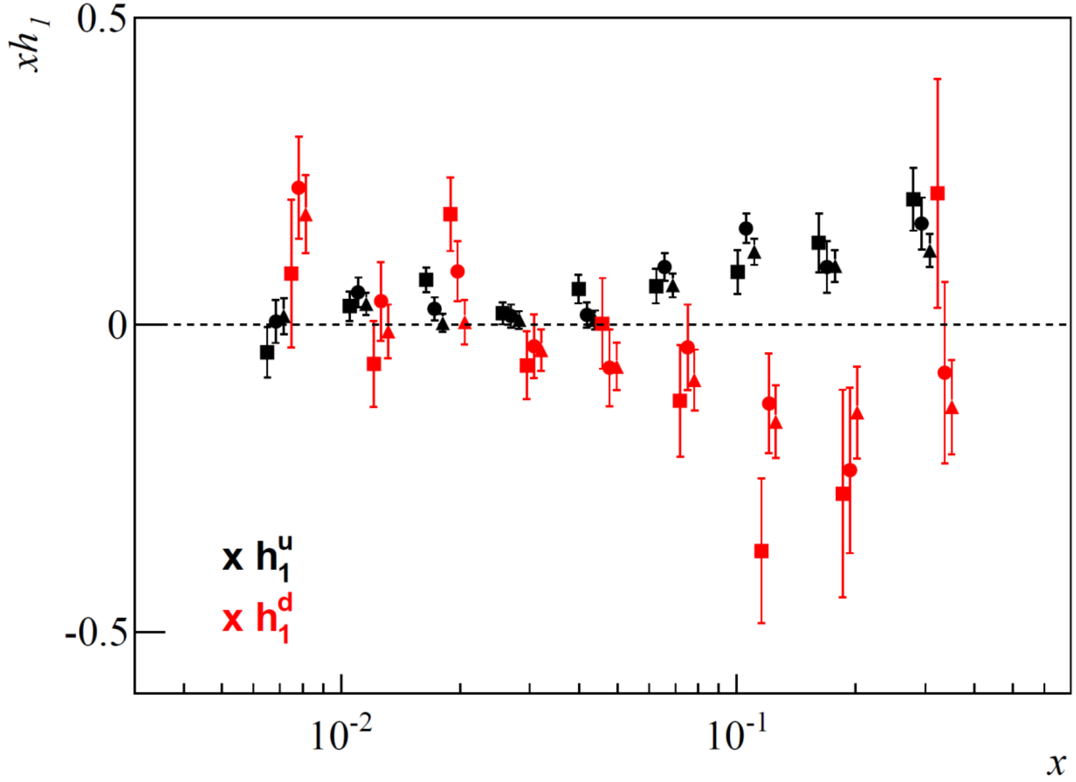




Franco Bradamante

Transversity from COMPASS and Belle data

results of the present work



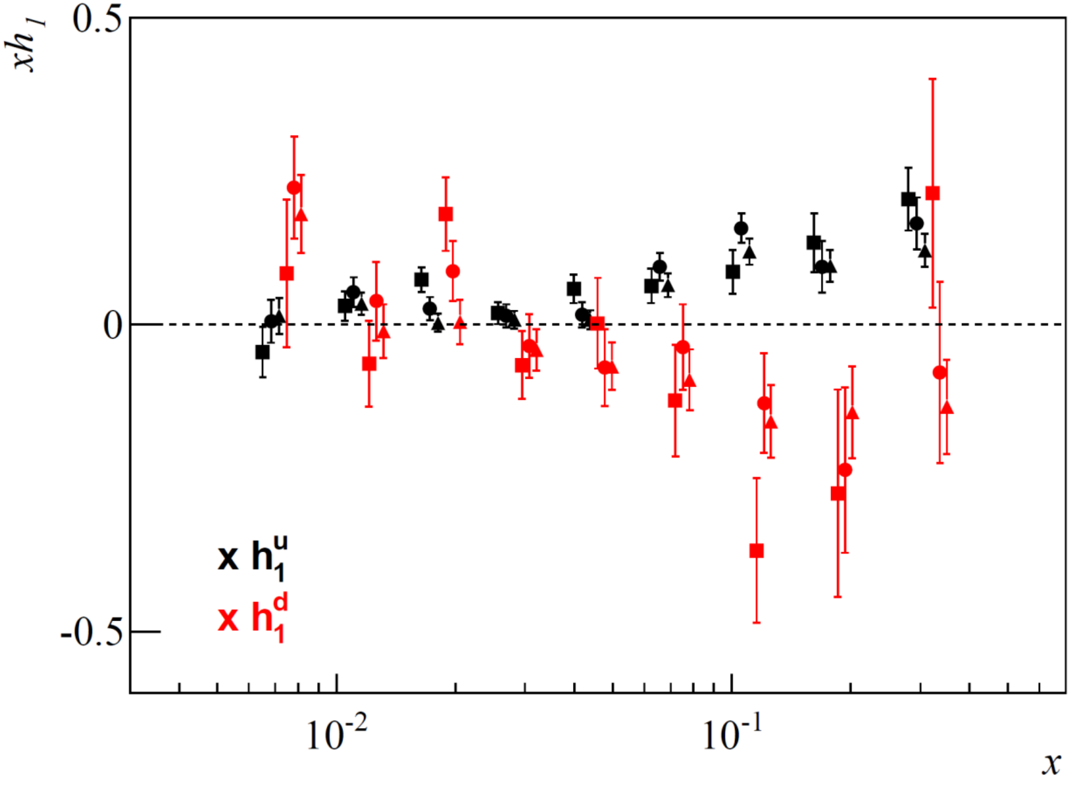
■ dihadron

● Collins A1

▲ Collins A2

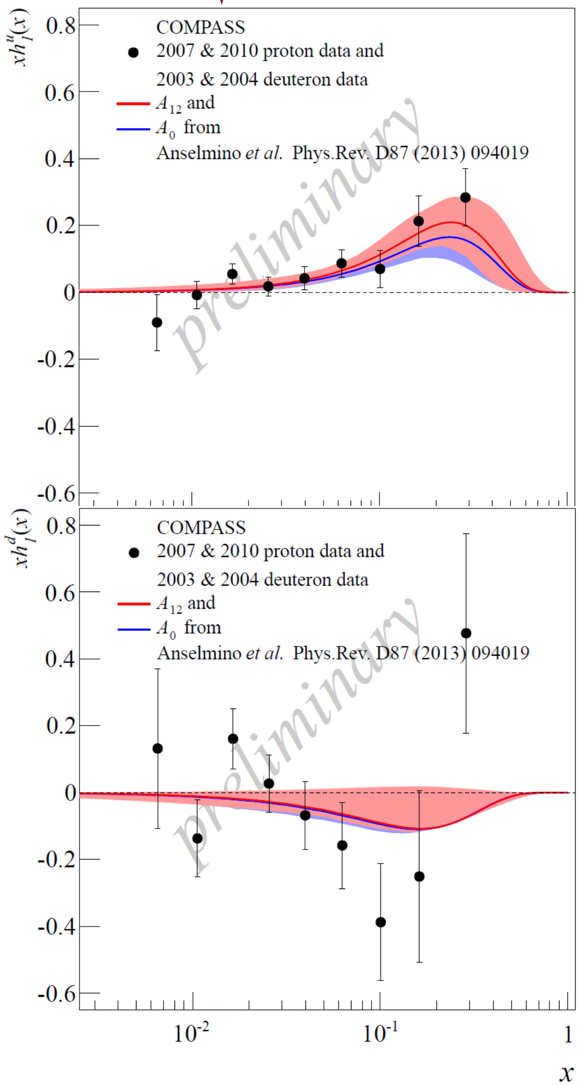
Transversity from COMPASS and Belle data

results of the present work



■ dihadron
● Collins A1
▲ Collins A2

COMPASS
DIS2014



Transversity from COMPASS and Belle data

summary

- **promising results**
- **the physics is simple**

The work is almost over

The same method used for the Collins asymmetry could be used for the point-to-point extraction of the Boer-Mulders PDF and, even simpler, of the Sivers function

Transversity from COMPASS p and d results

method:

COMPASS results for $A_d^{2\pi}$ and $A_p^{2\pi}$ as function of x

⇓

use the same coefficients evaluated by A. Bacchetta et al. from Belle data [JHEP1303 (2013)119]

numerical values for in each x bin $4xh_1^{u_v} - xh_1^{d_v}$ **and** $xh_1^{u_v} + xh_1^{d_v}$

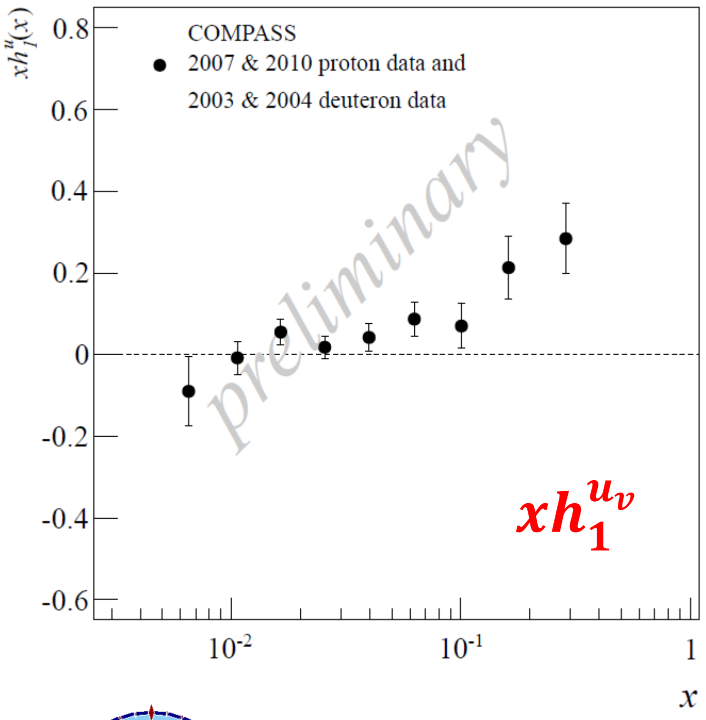
⇓

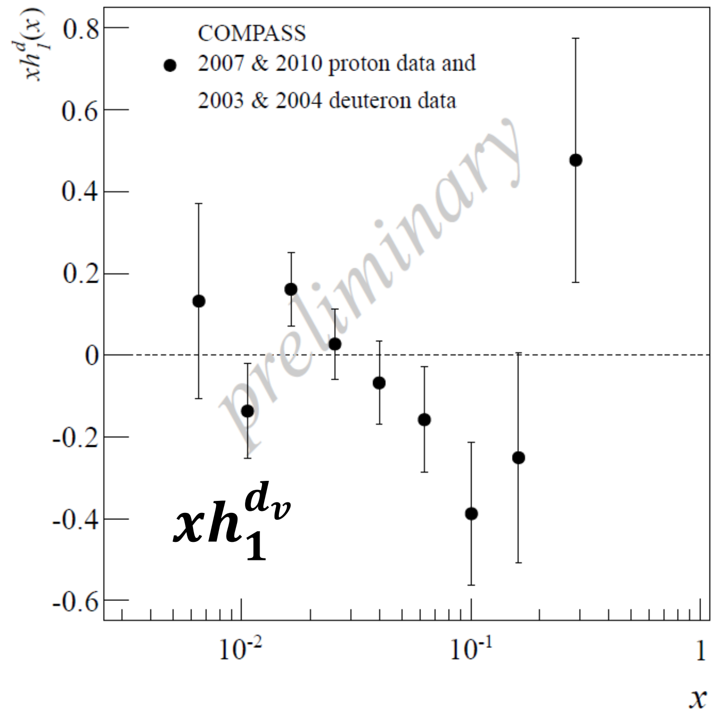
numerical values for $xh_1^{u_v}$ **and** $xh_1^{d_v}$ **in each x bin**

DIS2014

Transversity from COMPASS p and d results

results:





DIS2014

Transversity from COMPASS and Belle data

results obtained using

- **Belle results for pion and pion-pair asymmetries**

  PRL 107(2011)072004, PRD78(2008)032011 / 86(2012)039905

- **COMPASS results on**
  - **p and d dihadron asymmetries vs x** (integrated over z, M)
  - **p and d Collins asymmetry vs x** (integrated over z, p_T)

  h^+ and h^- assuming that all hadrons are pions

- **unpolarised PDFs and FFs parametrisations**
  - **PDFs: CTEQ5D**
  - **FFs: DSS LO**

dihadron asymmetry – transversity

present result ■ u ■ d h^+h^-

compared with DIS2014 ● u ● d $\pi^+\pi^-$