Phenomenological extraction of Transversity

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

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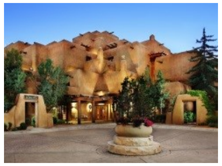


QCD Evolution 2014

Santa Fe

COMPASS SIDIS results on TMD observables

with the logitudinally polarised 160 GeV μ^+ beam and

- **unpolarised d target**
  - **- $h^\pm$ multiplicities vs p_t^2**
  - **- $h^\pm$ azimuthal asymmetries**

- **longitudinally polarised d target**
  - **- $h^\pm$ azimuthal asymmetries**

- **transversely polarised d and p target**
  - **- Collins and Sivers asymmetries for $h^\pm$, $\pi^\pm$, $K^\pm$, K^0**
  - **- the other 6 transverse spin asymmetries for $h^\pm$**
  - **- dihadron asymmetry for h^+h^-, $\pi^+\pi^-$, K^+K^-, π^+K^-, π^-K^+**

and other results will come soon

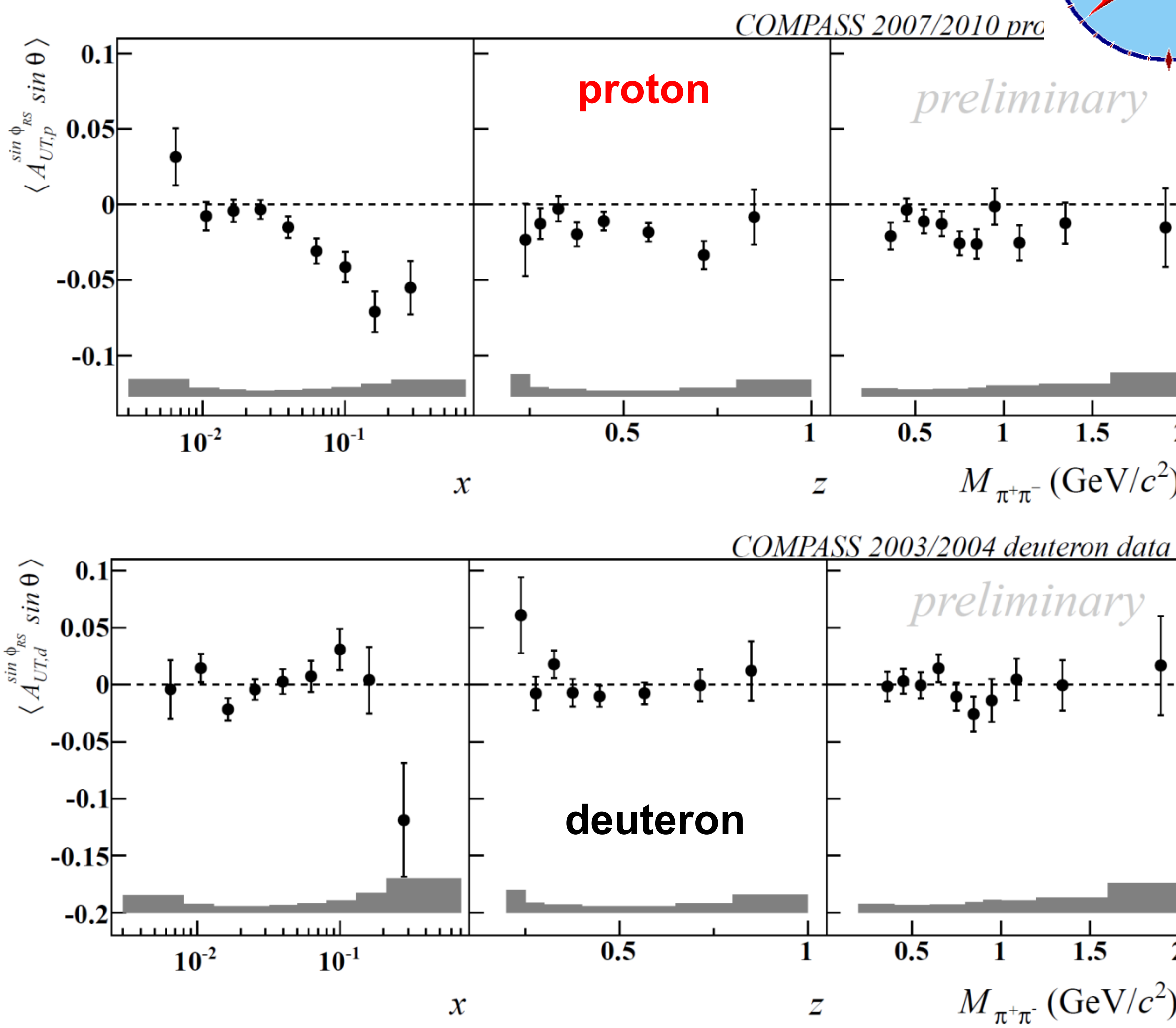
multidimensional analysis of TSA

COMPASS SIDIS results on TMD observables

some examples

dihadron asymmetries

$\pi^+\pi^-$

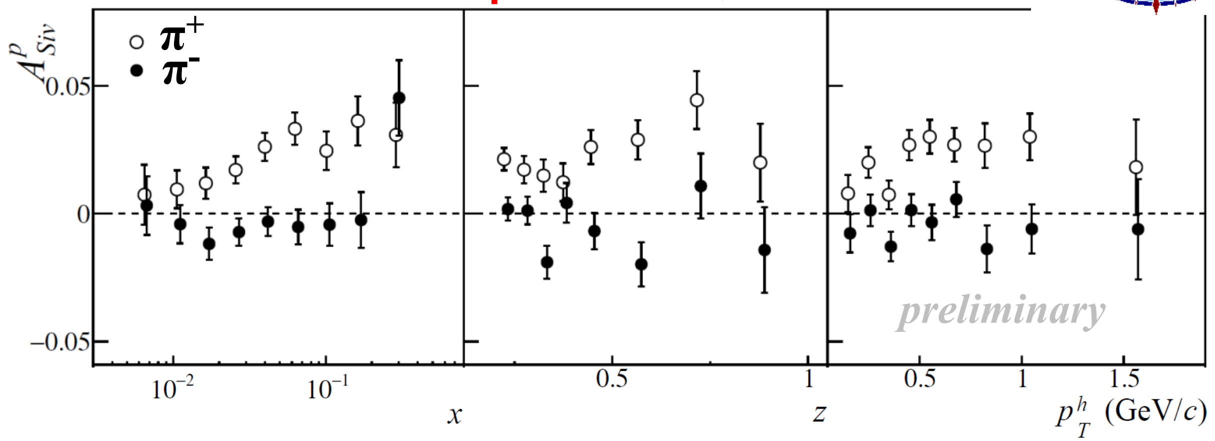


COMPASS SIDIS results on TMD observables

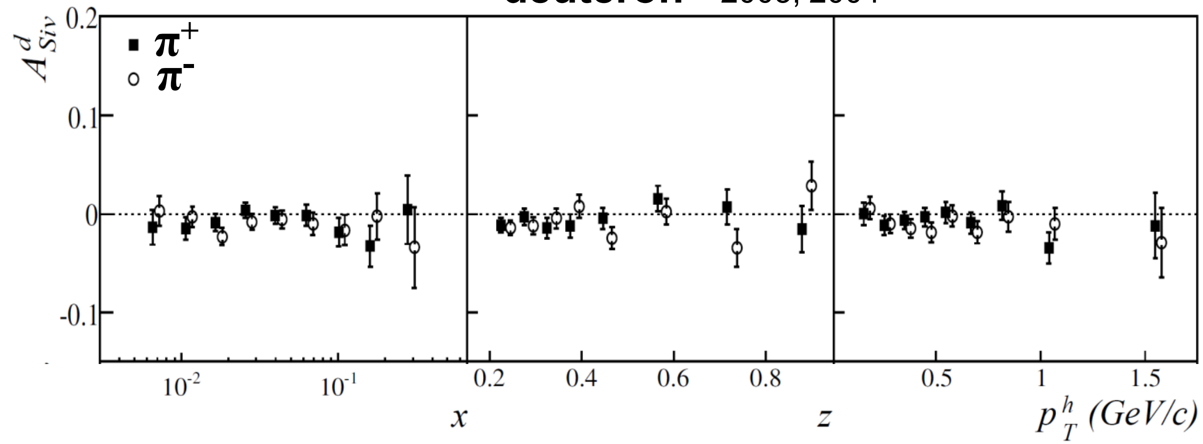
some examples

Sivers asymmetry

proton 2007, 2010



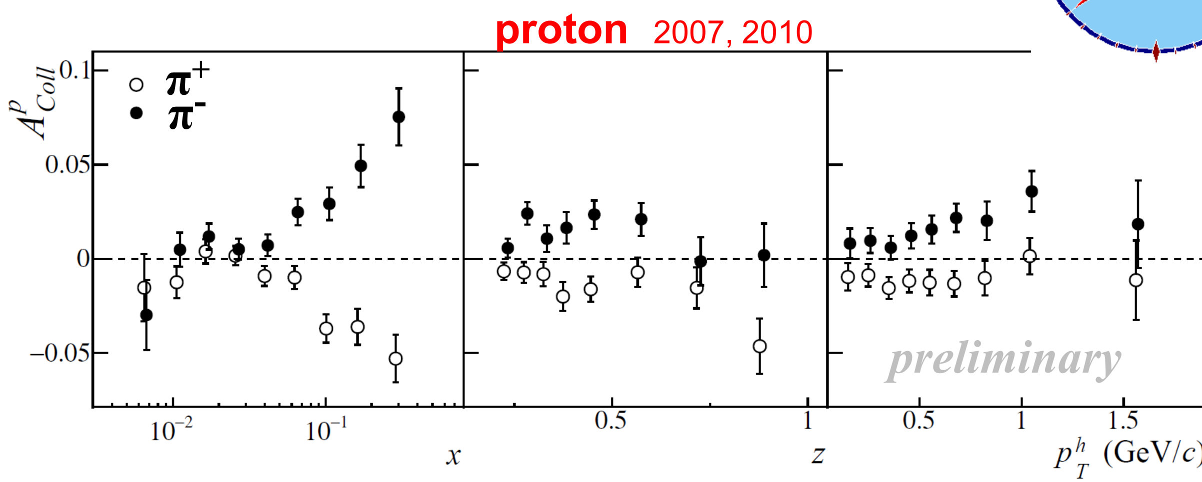
deuteron 2003, 2004

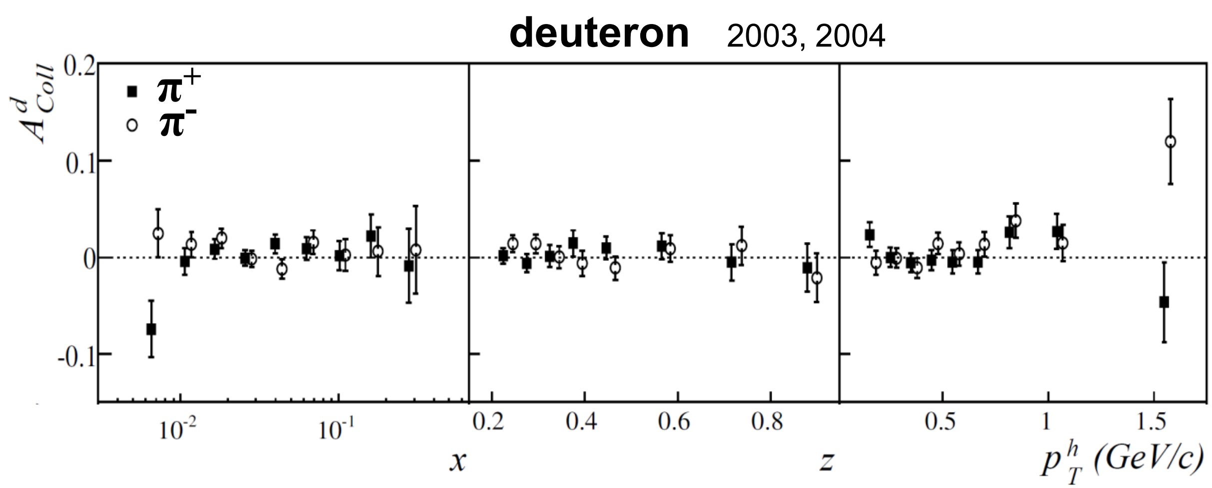


COMPASS SIDIS results on TMD observables

some examples

Collins asymmetry



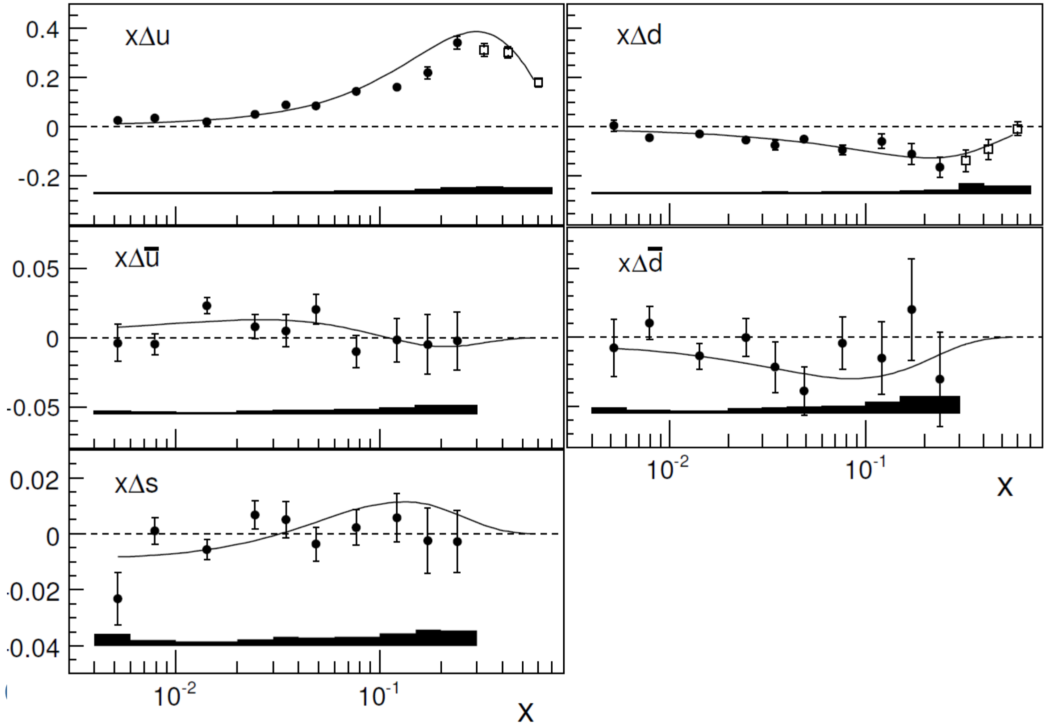


COMPASS SIDIS results on TMD observables

measurements on p and d
at the same beam momentum
with the same x binning → same $< x >$, $< Q^2 >$ in each bin

this allows to combine p and d asymmetries to perform
flavour separation and point-to-point extraction of PDFs

as done in the case of longitudinal spin asymmetries using the DSS FFs



COMPASS Collaboration,
PLB 693 (2010) 227

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)

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**

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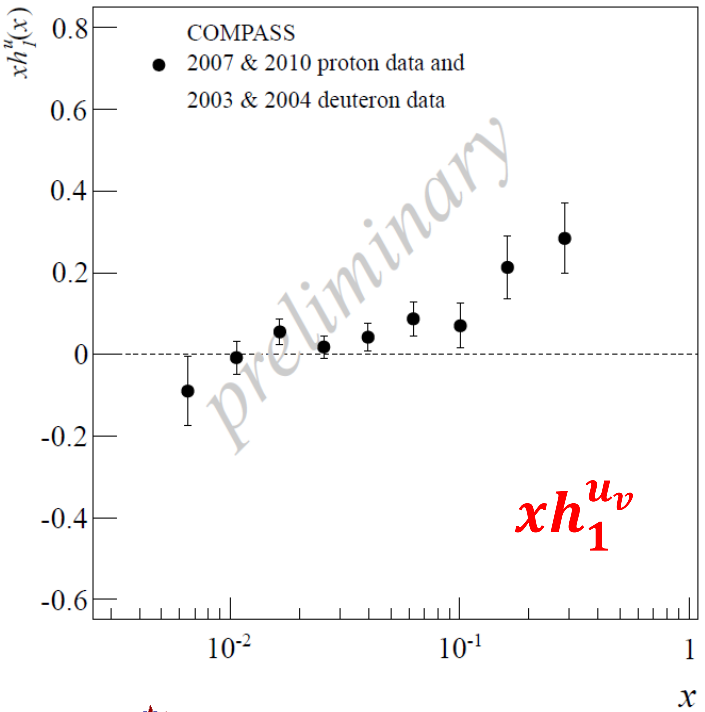
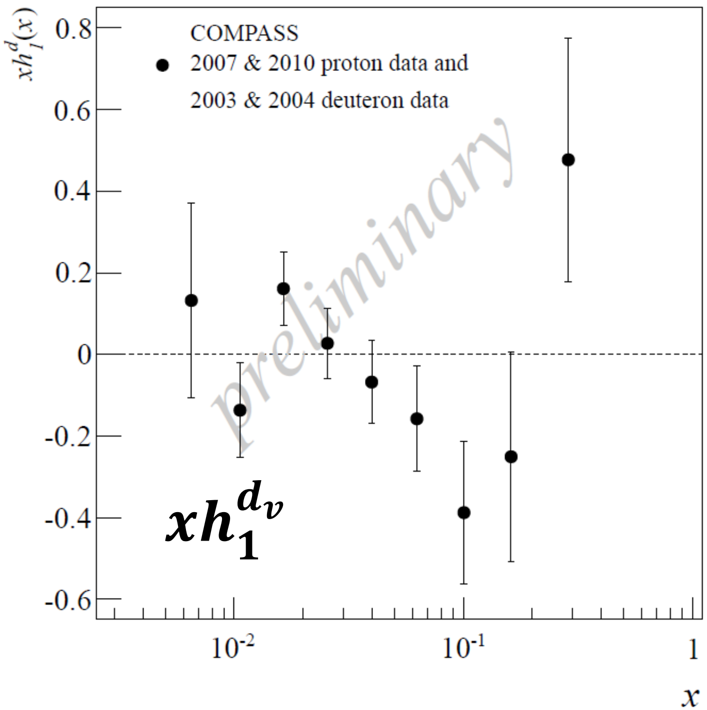
Transversity from COMPASS p and d results

results:





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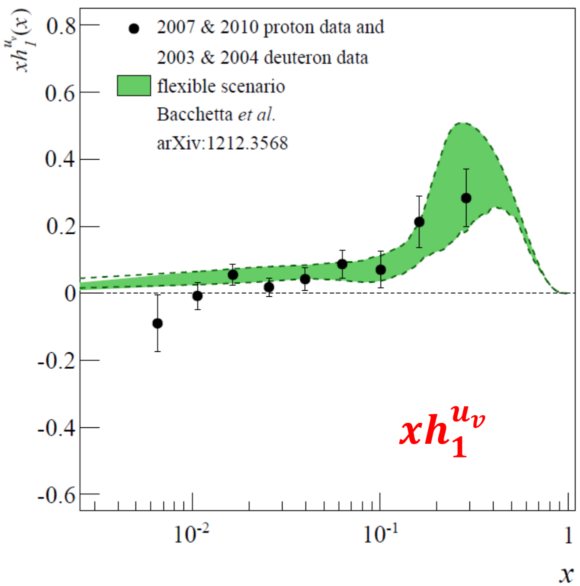
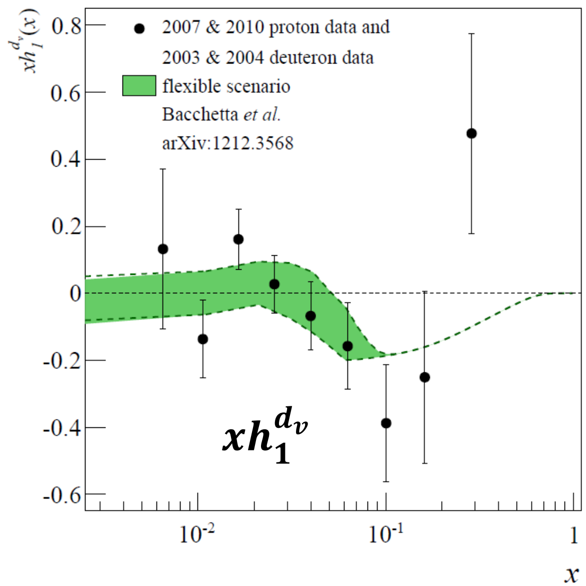
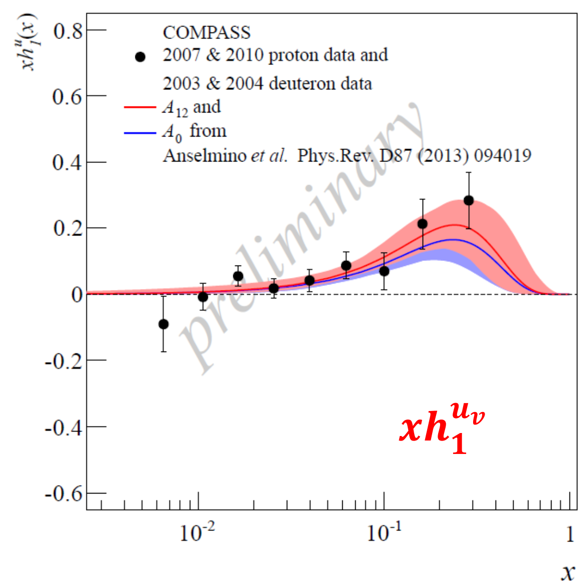
Transversity from COMPASS p and d results

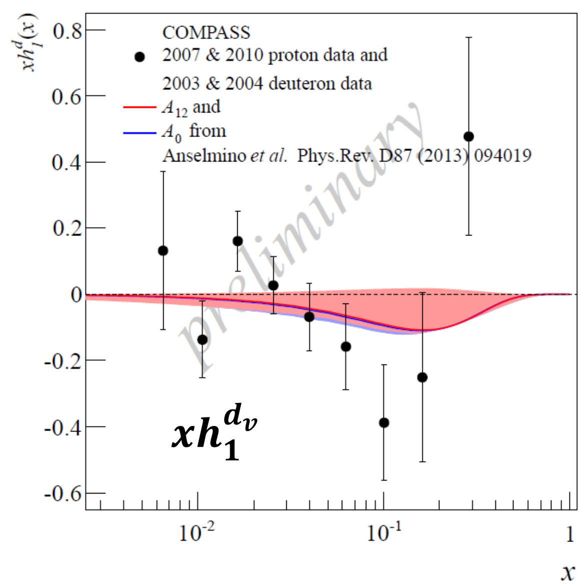




Pavia

Torino





DIS2014

Transversity from COMPASS p and d results

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

COMPASS results for A_d^{2h} **and** A_p^{2h} **as function of** x

directly use the Belle data
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

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 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

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

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

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 :

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

$f_1^{*q} = f_1^q + f^{\bar{q}}$ 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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$$H_q = -H_{\bar{q}}, \quad H_u = -H_d, \quad H_s = H_c = 0$$

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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

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

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

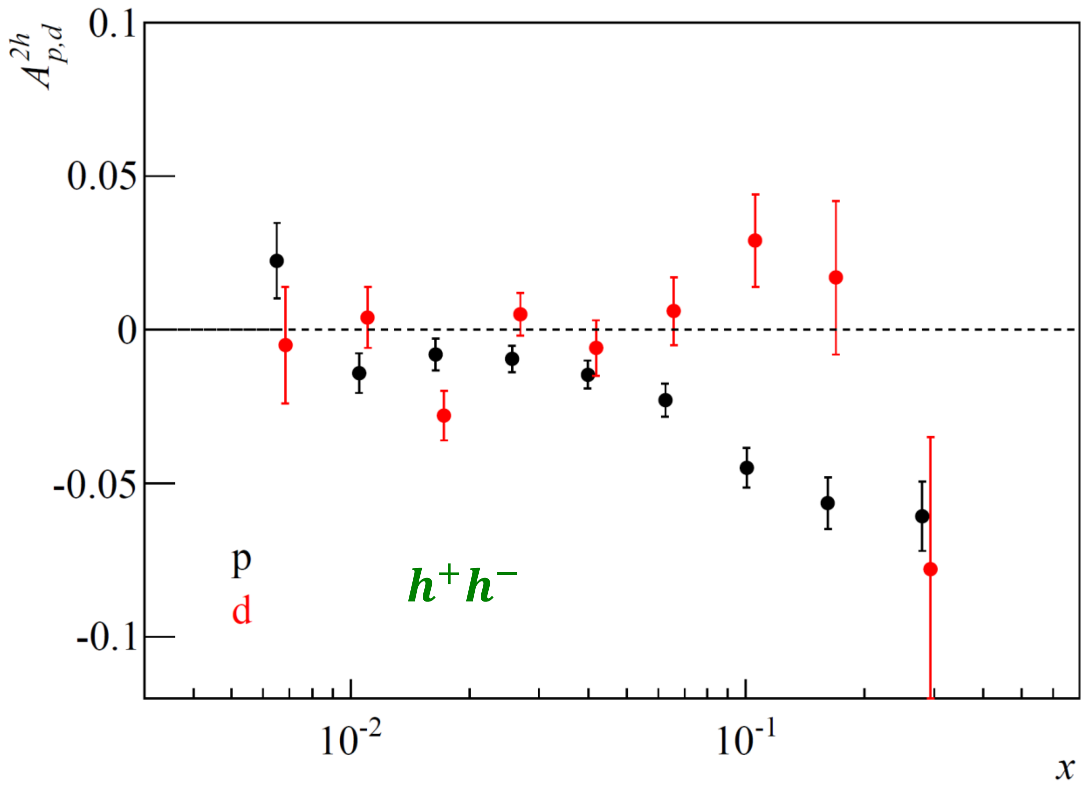
and the anaysing power is

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

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

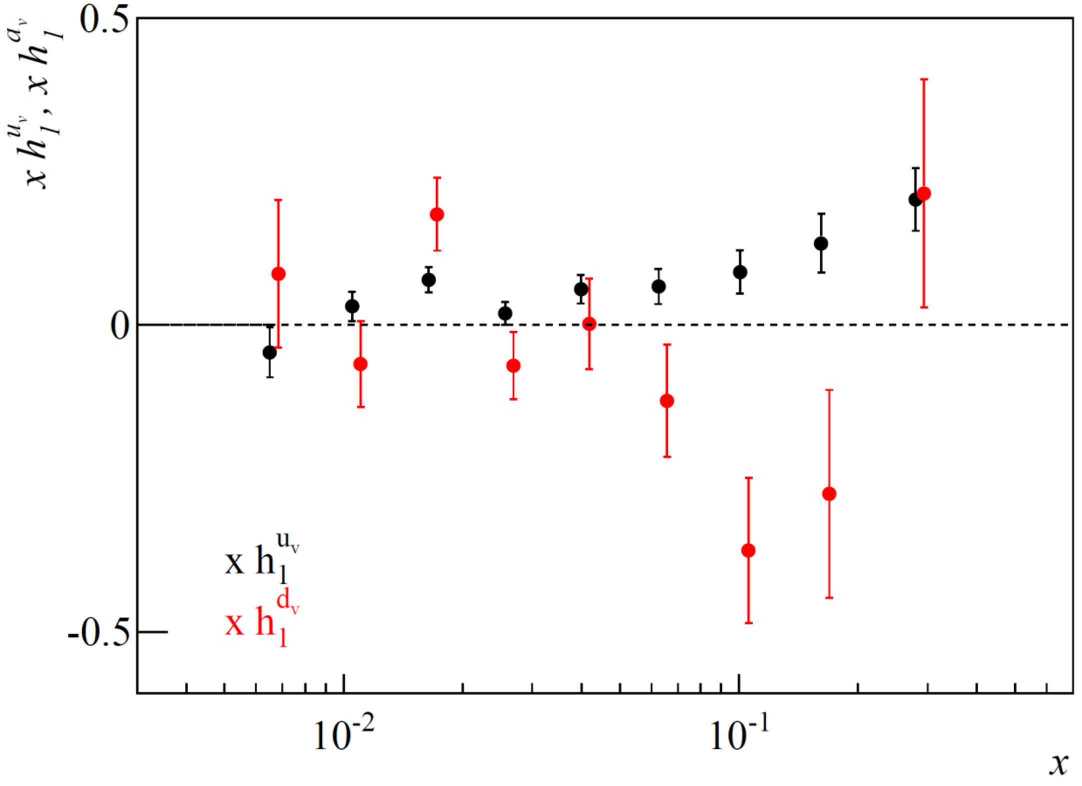
effect evaluated by the Pavia group: ~ -8%

dihadron asymmetry – COMPASS data



dihadron asymmetry – transversity

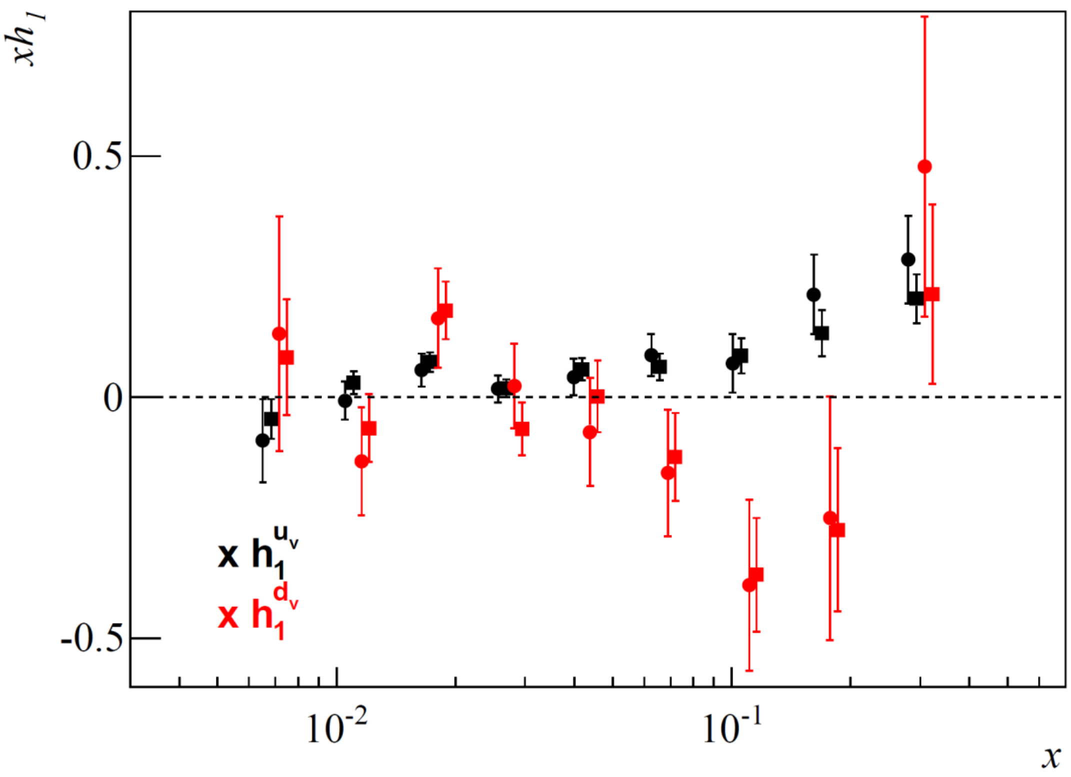
present result



dihadron asymmetry – transversity

present result ■ u ■ d h^+h^-

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



Collins asymmetries

interlude

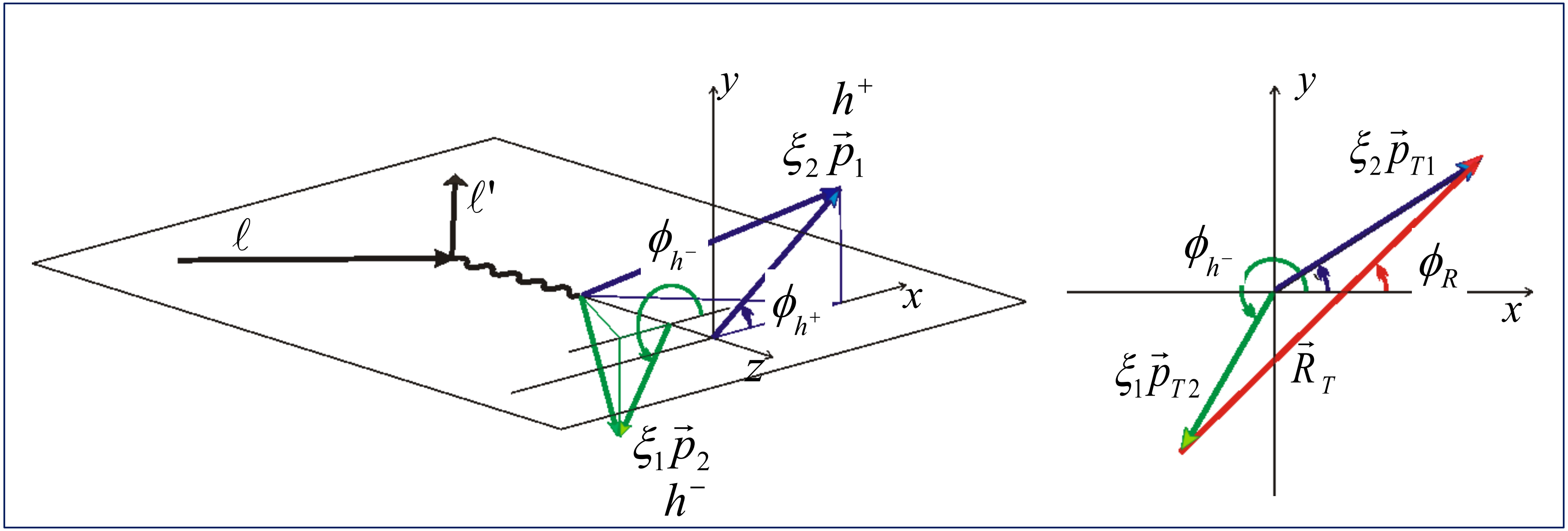
some thoughts on the
interplay between the Collins and the dihadron FFs

see FB, Structure of Nucleons and Nuclei, Como,10-14 June 2013,
FB, Dspin-13, Dubna, October 8-12 2013,
C. Adolph et al. [COMPASS Collaboration], hep-ex/1401.7873

interlude - dihadron and Collins asymmetries

$$N_{2h}^{\pm}\left(\phi_{RS}\right) = N_{2h}^{0} \cdot \left\{ 1 \pm A \cdot \sin\, \phi_{RS} \right\}$$

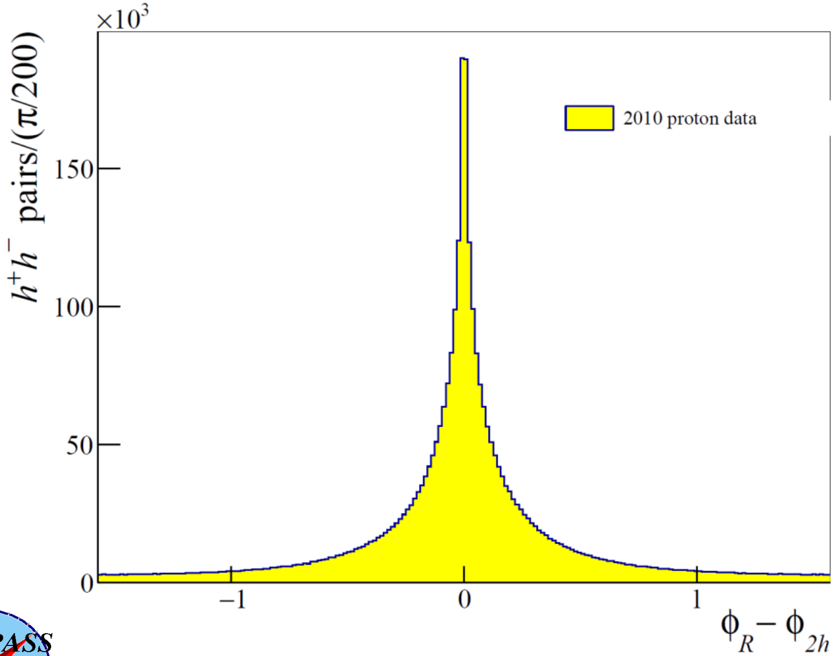
$$\phi_{RS} = \phi_R + \phi_S - \pi$$



$$\phi_R \longrightarrow \phi_{2h} = \frac{1}{2}\left[\, \phi_{h^+} + (\phi_{h^-} - \pi) \,\right]$$

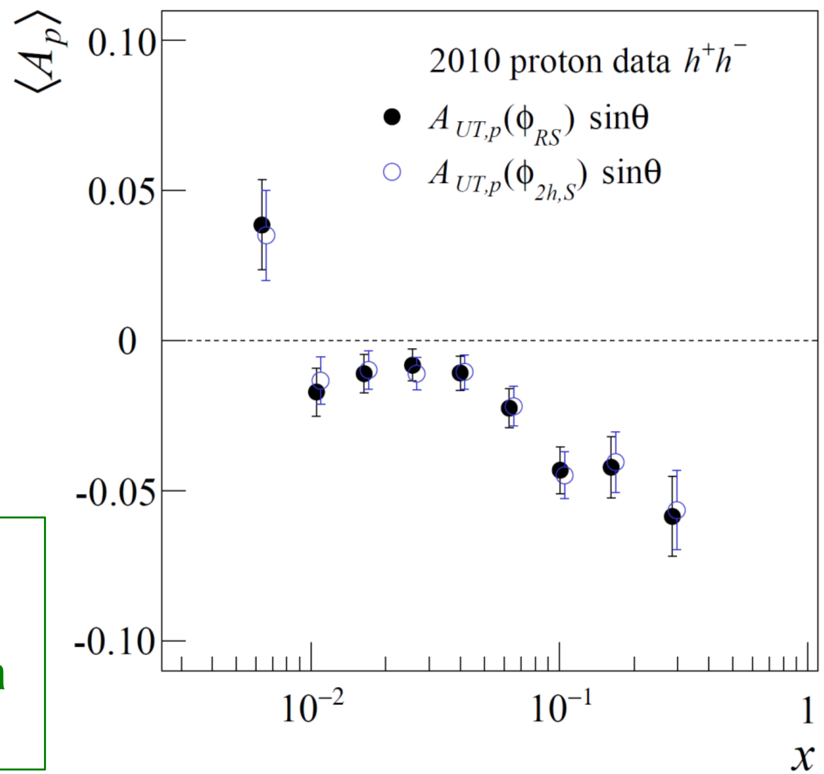
mod 2π

interlude - dihadron and Collins asymmetries



hep-ex/1401.7873

$$\phi_R \longrightarrow \phi_{2h} = \frac{1}{2}\left[\, \phi_{h^+} + (\phi_{h^-} - \pi) \,\right]$$



… Due to local compensation of transverse momentum, the one-particle Collins effect generates a two-particle effect, and viceversa
(X. Artru, arXiv:hep-ph/0207309)

Collins asymmetries

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

$$A_P = \frac{<H^{fav}>}{<D^{fav}>}$$

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

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

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

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

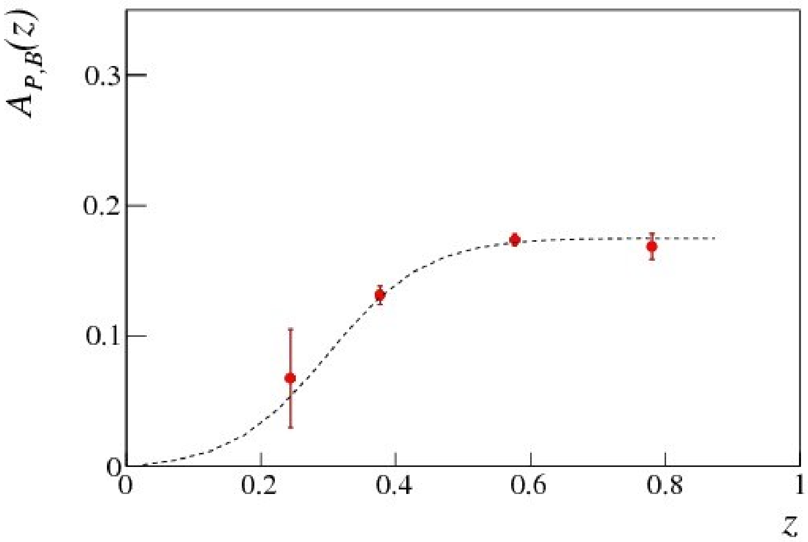
both in agreement with the considerations on the "interplay between the Collins and the dihadron FFs"

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

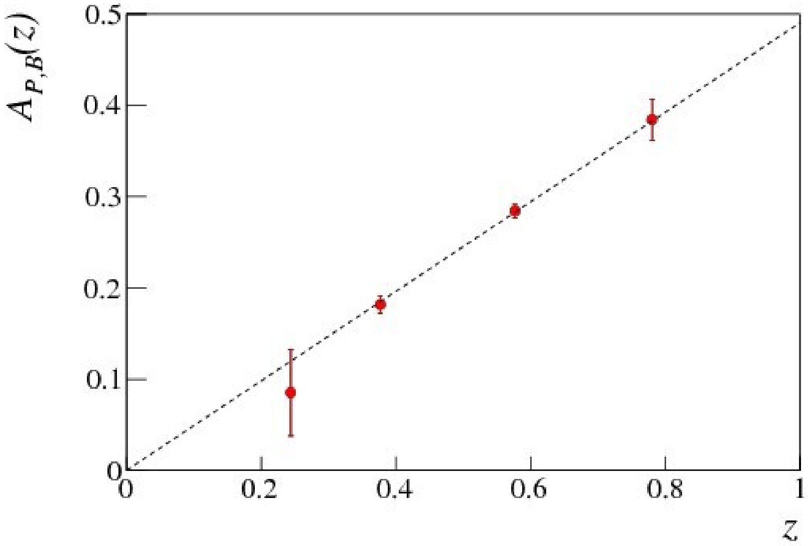
- **these assumptions allow to evaluate** $\dfrac{H_1^{fav}(z)}{D_1^{fav}(z)}$ **in the four** z **bins**
- **the values are then fitted with a function of** z

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

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

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

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

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

$$\alpha = \frac{< H_1^{dis} >}{< H_1^{fav} >} = \begin{cases} -1 & \text{A1} \\ \dfrac{< D_1^{dis} >}{< D_1^{fav} >} & \text{A2} \end{cases}$$

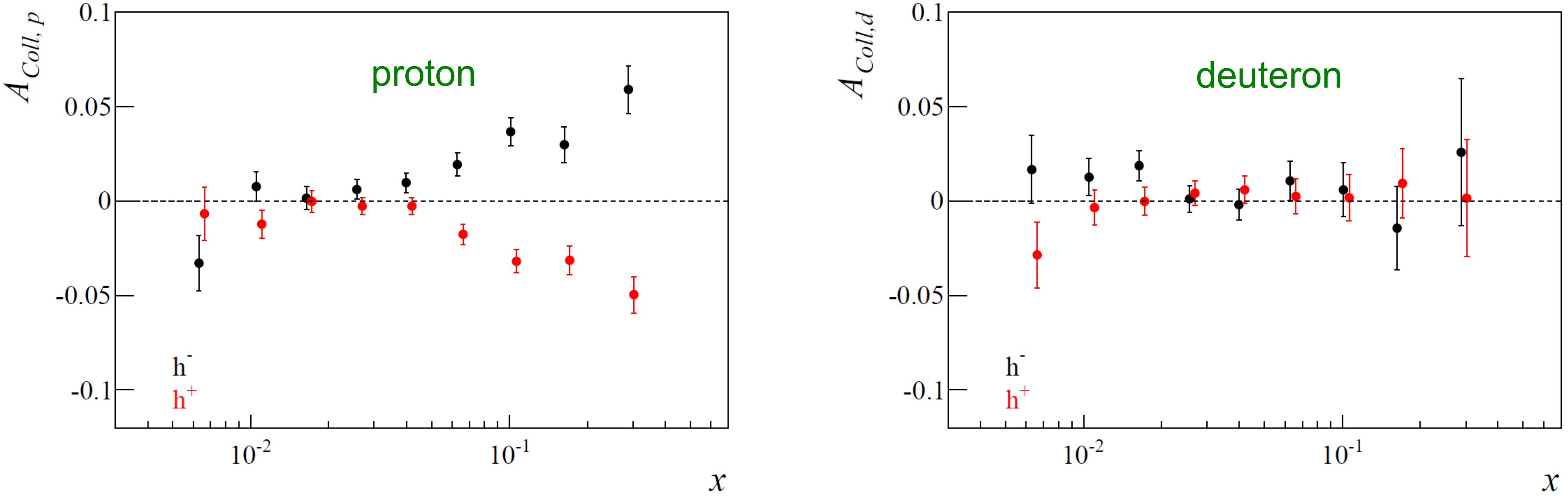
corresponding quantities with unpol PDFs and FFs

from Belle

neglecting qbar transversity,

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

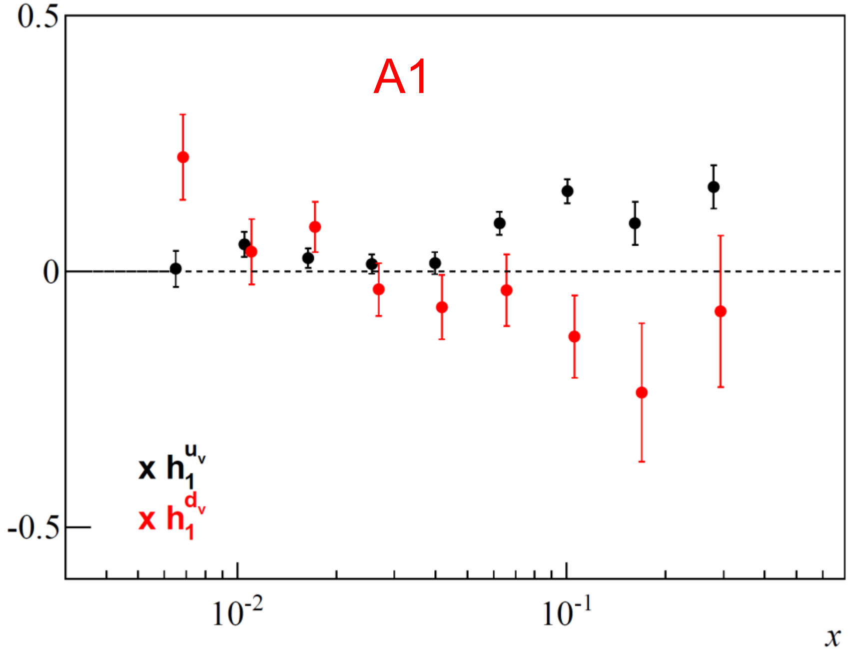
Collins asymmetry – COMPASS data

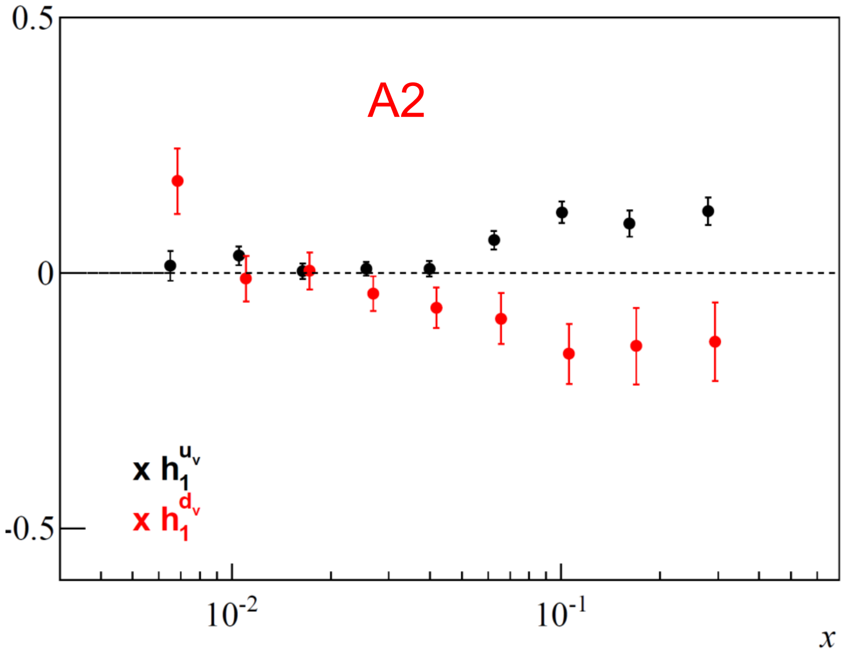


un-identified hadrons

Collins asymmetry – transversity

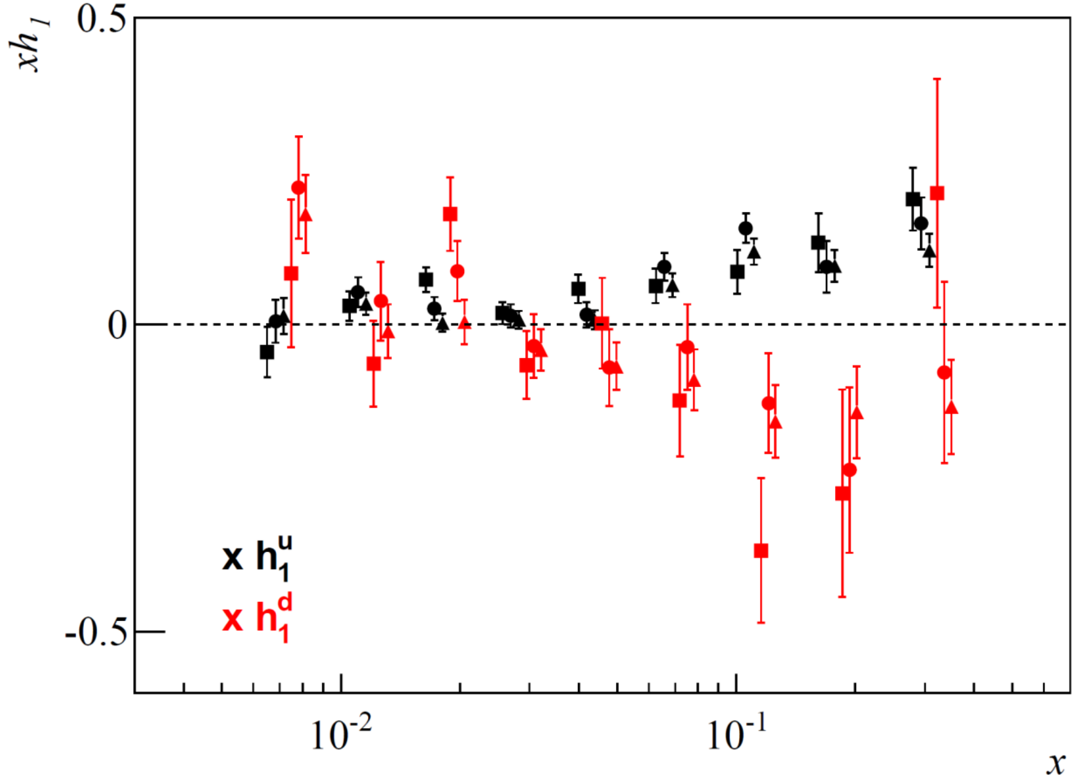
results





Transversity from COMPASS and Belle data

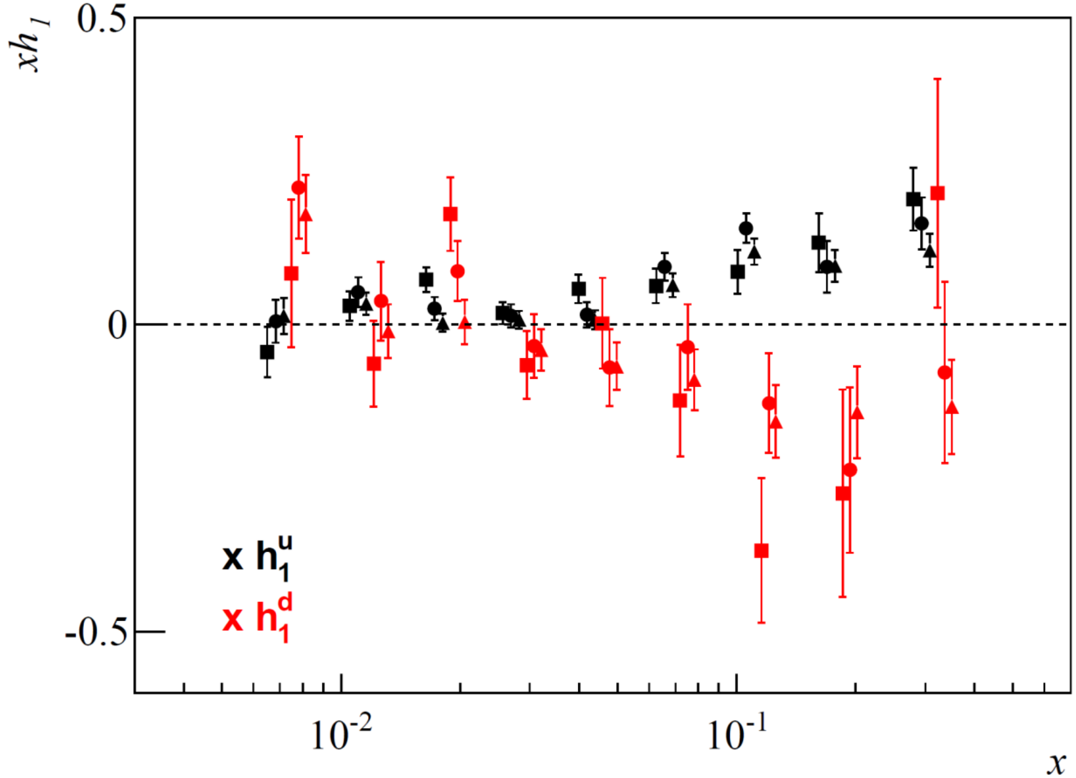
results of the present work



■ dihadron
● Collins A1
▲ Collins A2

Transversity from COMPASS and Belle data

results of the present work



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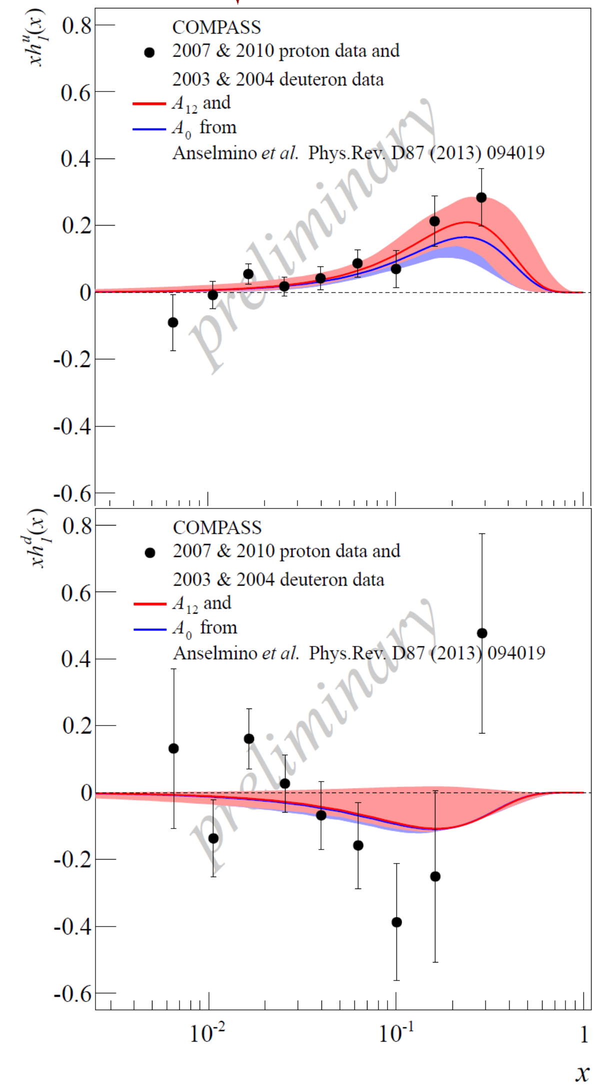
DIS2014



Transversity from COMPASS and Belle data

summary

- promising results
- the physics is simple

- refinements are needed

Transversity from COMPASS and Belle data

summary

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and Q^2 evolution is needed !