SIDIS measurements at COMPASS

Anna Martin
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on behalf of the COMPASS Collaboration

IWHSS 2023

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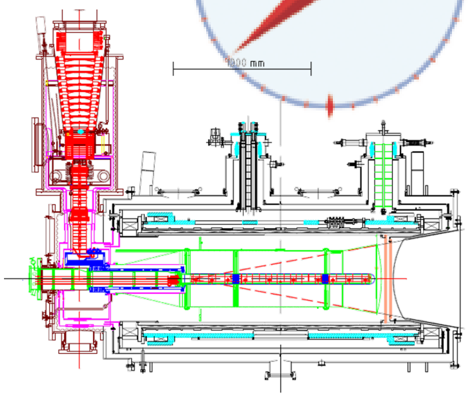
COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pecroscopy

fixed target experiment on the M2 beam line at CERN SPS
a facility, built by the COMPASS Collaboration, in the years 1997-2001

initially approved for 5 years of data taking,
the experiment took data from 2002 to 2022

and the spectrometer
is still there,
being used by the
AMBER Collaboration

the COMPASS spectrometer



designed to

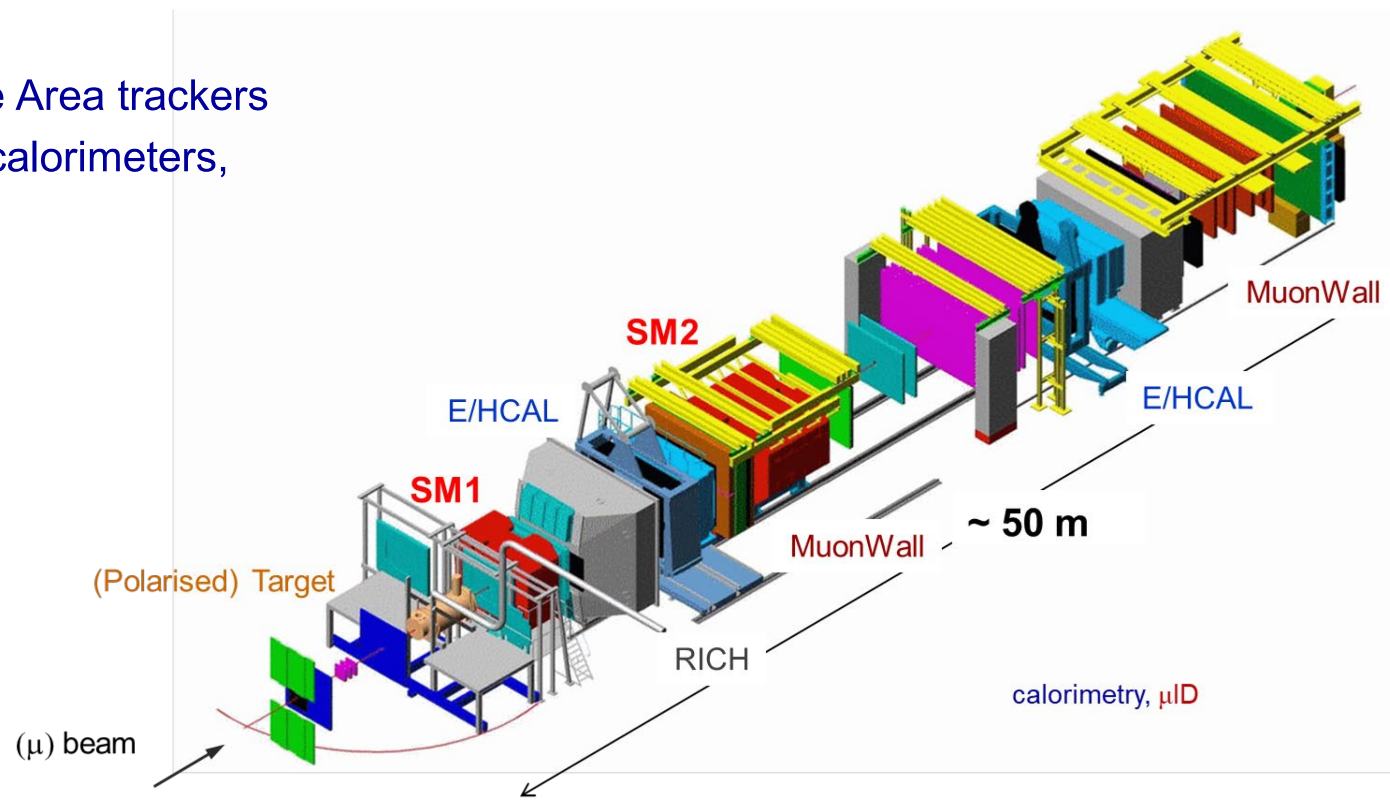
- use high energy muon and hadron beams, and different targets
- have large angular acceptance, as flat as possible
- cover a broad kinematical range

two stages spectrometer

Large Angle Spectrometer (SM1), Small Angle Spectrometer (SM2)

equipped with
Very Small, Small, Large Area trackers
RICH, muon detectors, calorimeters,
trigger hodoscopes

apart from 2005,
several upgrades
to fulfill the requirements of
the different measurements



15 years of data taking

2005, 2013, 2014, 2019, 2020, 2021 - CERN accelerators shut-down: no run or very short runs

dedicated to **spectroscopy** and **nucleon structure**

ΔG, SIDIS
160 GeV/c polarized μ^+ beam
L and T polarized d (^{6}LiD) target
2002-2004
L polarized d (^{6}LiD) target
2006

Hadron Spectroscopy and Primakof
hadron beams, LH and nuclear targets
2008, 2009
2012 (**)

→ *Philipp Haas*

SIDIS
L and T polarized p (NH_3) target
2007
2010 (*), 2011 (*)

COMPASS

Drell-Yan
190 GeV/c π^- beam
T polarized p (NH_3) target
2015, 2018 (**)

→ *Malgorzata R. Niemiec*

SIDIS
T polarized d (^{6}LiD) target
2022 (*)

DVCS / SIDIS
160 GeV/c polarized $\mu^\pm$ beams
LH target
(2012), 2016, 2017 (**)

→ *Karolina Lavickova*

(*) Addenda to the COMPASS Proposal
(**) COMPASS II Proposal

this talk

SIDIS off **unpolarised** and **transversely polarized p and d** targets

- review of some results on observables related to transversity and TMD PDFs, and plans

- news on the 2022 deuteron run

uncovered: longitudinally polarized targets, both “collinear” and TMD effects

SIDIS off unpolarised targets

SIDIS off unpolarised targets

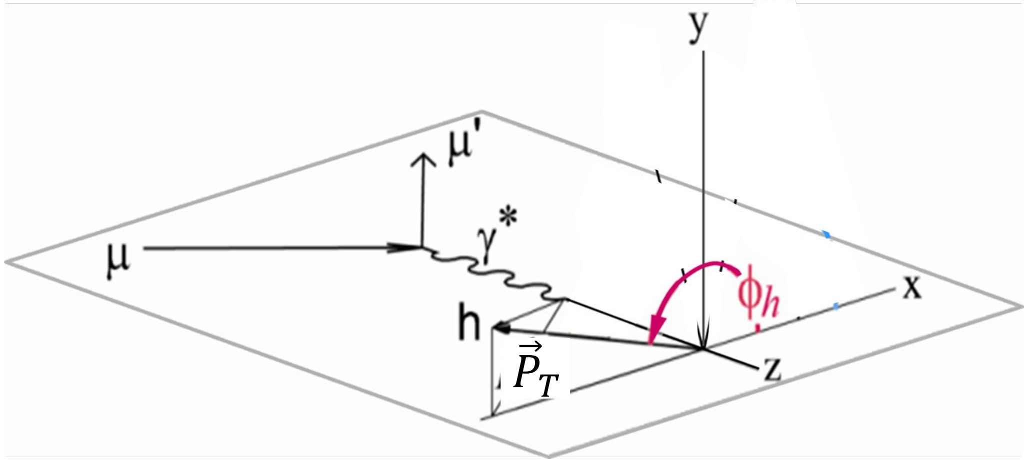
two sets of observables relevant for TMD studies

- $\boldsymbol{P_T}$ **distributions / multiplicities**

  distributions of the transverse momentum of the final state hadrons

- **azimuthal asymmetries**

  amplitudes of the modulations in the distributions of the azimuthal angle of the final state hadrons



P_T distributions

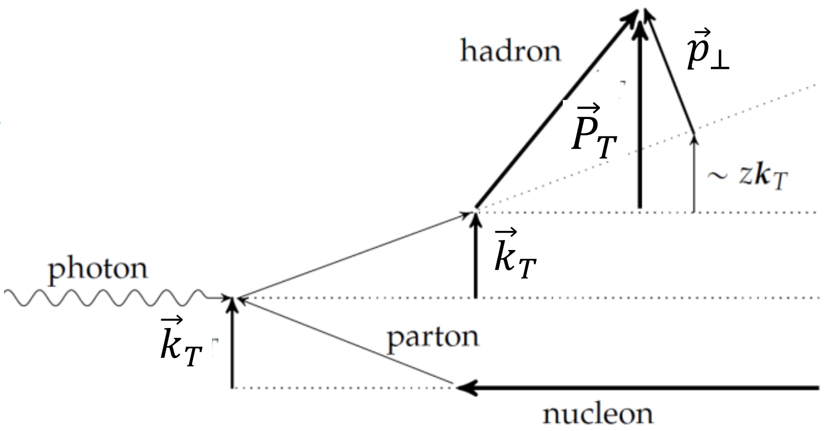
distributions of the transverse momentum of the final state hadrons

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_T^2} = \frac{\alpha_{em}^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

$$F_{UU,T} = \mathcal{C}[f_1 D_1]$$

$$\mathcal{C}[wfD] = x\sum_a e_a^2 \int d^2\vec{k}_T \int d^2\vec{p}_\perp \delta^2(\vec{P}_T - \vec{k}_T - \vec{p}_\perp) w(\vec{k}_T, \vec{p}_\perp) f^a$$

at LO $\vec{P}_T \simeq z\vec{k}_T + \vec{p}_\perp$



difficult disentangle $\vec{k}_T$ and $\vec{p}_\perp$ in SIDIS
independent information on $p_\perp$ from $e^+e^- \rightarrow hadrons$ data

P_T distributions

- first results from 2004 data, combined to cancel target spin effects

  160 GeV muons on $^6\mathrm{LiD}$

  in bins of x, Q^2, z *EPJ. C 73 (2013) 2531*

  ranges: $0.004 < x < 0.12 \quad 1 < Q^2 < 10\ \mathrm{GeV}^2 \quad 0.2 < z < 0.8$

- independent measurement from 2006 data

  transverse-momentum-dependent multiplicities of charged hadrons in DIS of

  160 GeV muons on $^6\mathrm{LiD}$

  in bins of x, Q^2, z *PRD 97 (2018) 032006*

  larger acceptance / kinematic range

  ranges: $0.003 < x < 0.40 \quad 1 < Q^2 < 81\ \mathrm{GeV}^2 \quad 0.2 < z < 0.8$

well known results

P_T distributions

SIDIS of 160 GeV muons on $^{6}\mathbf{LiD}$

PRD 97 (2018) 032006

- 8 x bins $0.003 < x < 0.40$
- 5 Q^2 bins $1 < Q^2 < 81\ \mathrm{GeV}^2$
- 4 z bins $0.2 < z < 0.8$

4918 data points

P_T distributions

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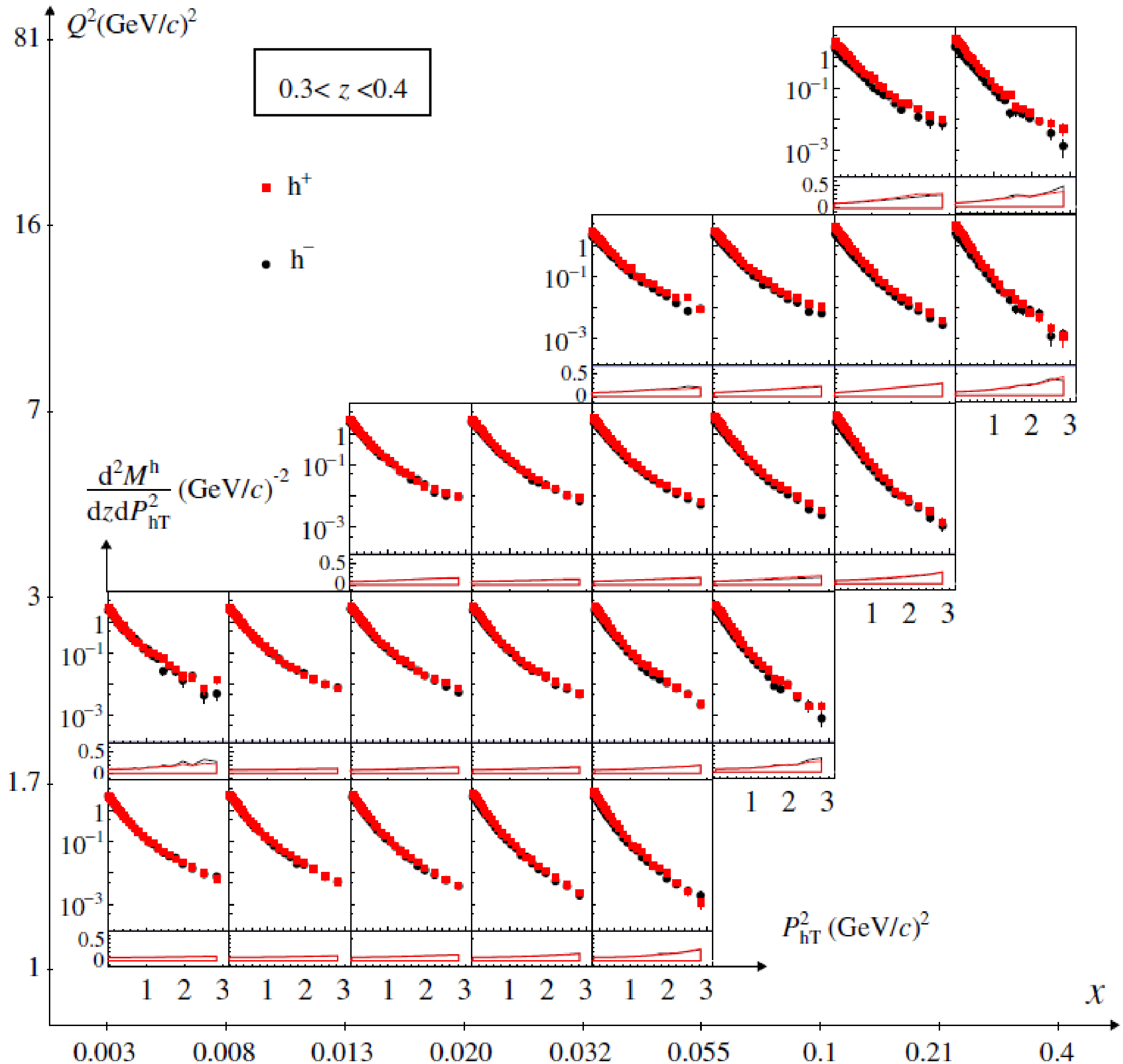

- strong z dependence
- strong x, Q^2, W dependence , not easy to disentangle
- similar shapes for h^+ and h^- (not normalization)

P_T distributions

- first results from 2004 data, combined to cancel target spin effects
  160 GeV muons on $^6\mathrm{LiD}$
  in bins of x, Q^2, z
  EPJ. C 73 (2013) 2531
  ranges: $0.004 < x < 0.12$ $\quad 1 < Q^2 < 10\ \mathrm{GeV}^2$ $\quad 0.2 < z < 0.8$

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  larger acceptance / kinematic range
  ranges: $0.003 < x < 0.40$ $\quad 1 < Q^2 < 81\ \mathrm{GeV}^2$ $\quad 0.2 < z < 0.8$

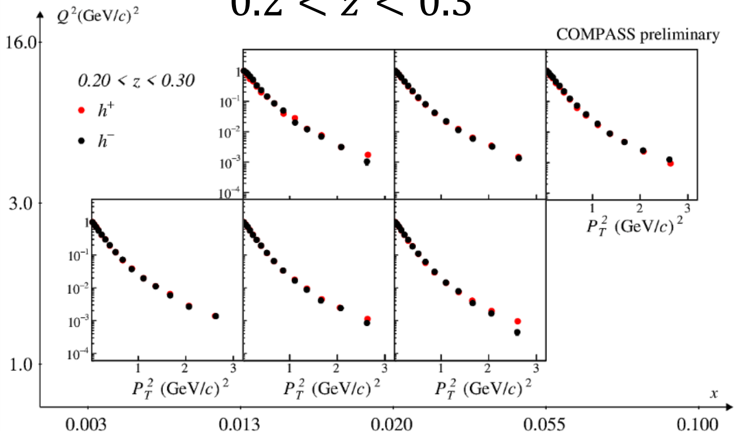
- recently, from 2016 data
  transverse momentum distributions of charged hadrons in DIS of
  160 GeV muons on LH
  ranges: $0.004 < x < 0.11$ $\quad 1 < Q^2 < 16\ \mathrm{GeV}^2$ $\quad 0.1 < z < 0.8$
  paper in preparation

P_T distributions

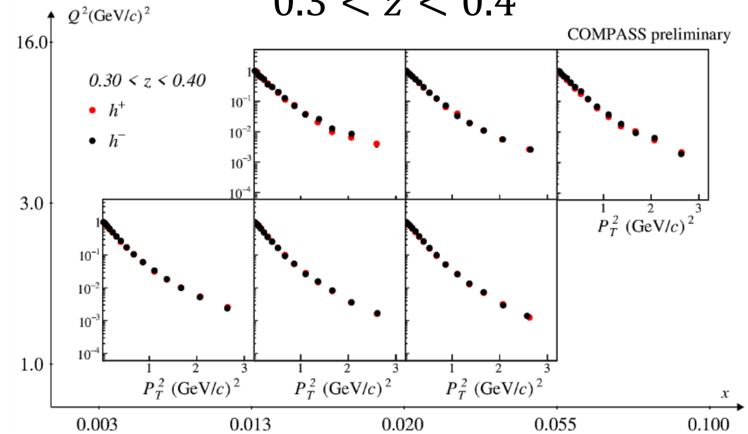
160 GeV muons, **LH**

$0.004 < x < 0.11 \quad 1 < Q^2 < 16\ \mathrm{GeV}^2 \quad 0.1 < z < 0.8$

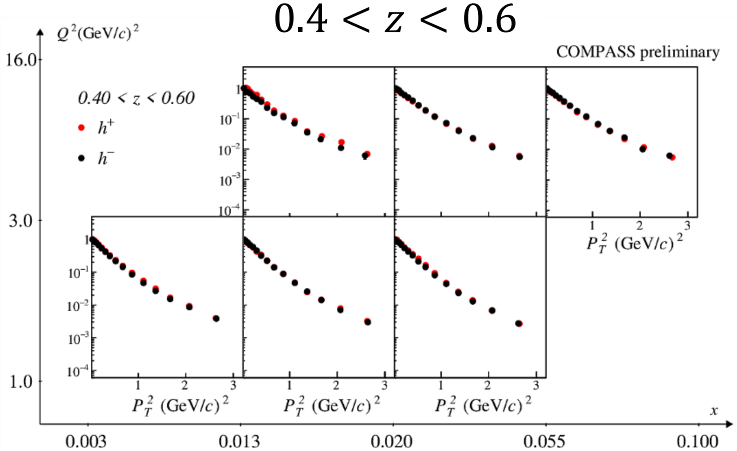
$0.2 < z < 0.3$



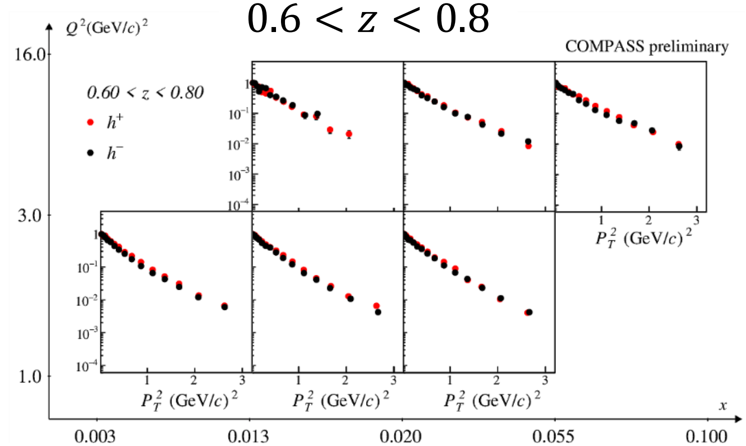
$0.3 < z < 0.4$



$0.4 < z < 0.6$



$0.6 < z < 0.8$



strong z dependence

strong x, Q^2 dependence

2 W bins

several interesting results

almost the same shapes for h^+ and h^- and in agreement with the deuteron results

good quality fits with one exponential up to $1\ (\mathrm{GeV}/c)^2$ and
with Tsallis functions and sum of two exponentials up to $3\ (\mathrm{GeV}/c)^2$

for other results see f.i.
J. Matousek [COMPASS], CPHI2020

P_T distributions

many SIDIS data from COMPASS, HERMES, Jlab exist
but only a small fraction is used in the most recent papers

theory: not easy describe the P_T distributions in terms of TMD PDFs over a wide range … evolution, factorisation, matching, ….

P_T distributions

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theory: not easy describe the P_T distributions in terms of TMD PDFs over a wide range … evolution, factorisation, matching, ….

data selection to guarantee TMD factorisation: from very recent papers

- "… The TMD factorization regime is fully consistent only for low values of q_T/Q and receives quadratic power corrections of order $(q_T/Q)^2$ …"
- "… The standard choice is to use the data with $\delta = P_T/zQ < 0.25$ and $Q^2 > 4\ GeV^2$ …"
- "… phenomenologically TMD factorization is valid for $\delta < 0.2 - 0.3$, and is strongly violated for large values of δ …"

> The values of χ^2/N_{pt} grow when $\delta > 0.25$. The same effect has been observed in ref. [19] for DY. Therefore, we conclude that our earlier estimation of the validity interval of TMD factorization as $\delta \lesssim 0.2 - 0.25$ holds also in the SIDIS case.

Scimemi, Vladimirov JHEP 06 (2020) 137

azimuthal asymmetries

complementary information on the transverse momentum structure of the nucleon

$$\frac{d\sigma}{dx\,dy\,dz\,d\phi_h\,dP_T^2} = \frac{\alpha_{em}^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)F_{UU}^{\cos 2\phi_h} + \lambda\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h F_{LU}^{\sin\phi_h}\Big\}$$

Cahn effect *Boer-Mulders term*

$$F_{UU}^{\cos\varphi_h} = \frac{2M}{Q}\mathcal{C}\left[-\frac{(\hat{h}\cdot\vec{k}_T)}{M}f_1D_1 - \frac{(\hat{h}\cdot\vec{p}_\perp)k_T^2}{zM^2M_h}h_1^\perp H_1^\perp + \cdots\right]$$

$$F_{UU}^{\cos 2\varphi_h} = \mathcal{C}\left[-\frac{2(\hat{h}\cdot\vec{k}_T)(\hat{h}\cdot\vec{p}_\perp) - \vec{k}_T\cdot\vec{p}_\perp}{zM\,M_h}h_1^\perp H_1^\perp\right]$$

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Boer-Mulders term

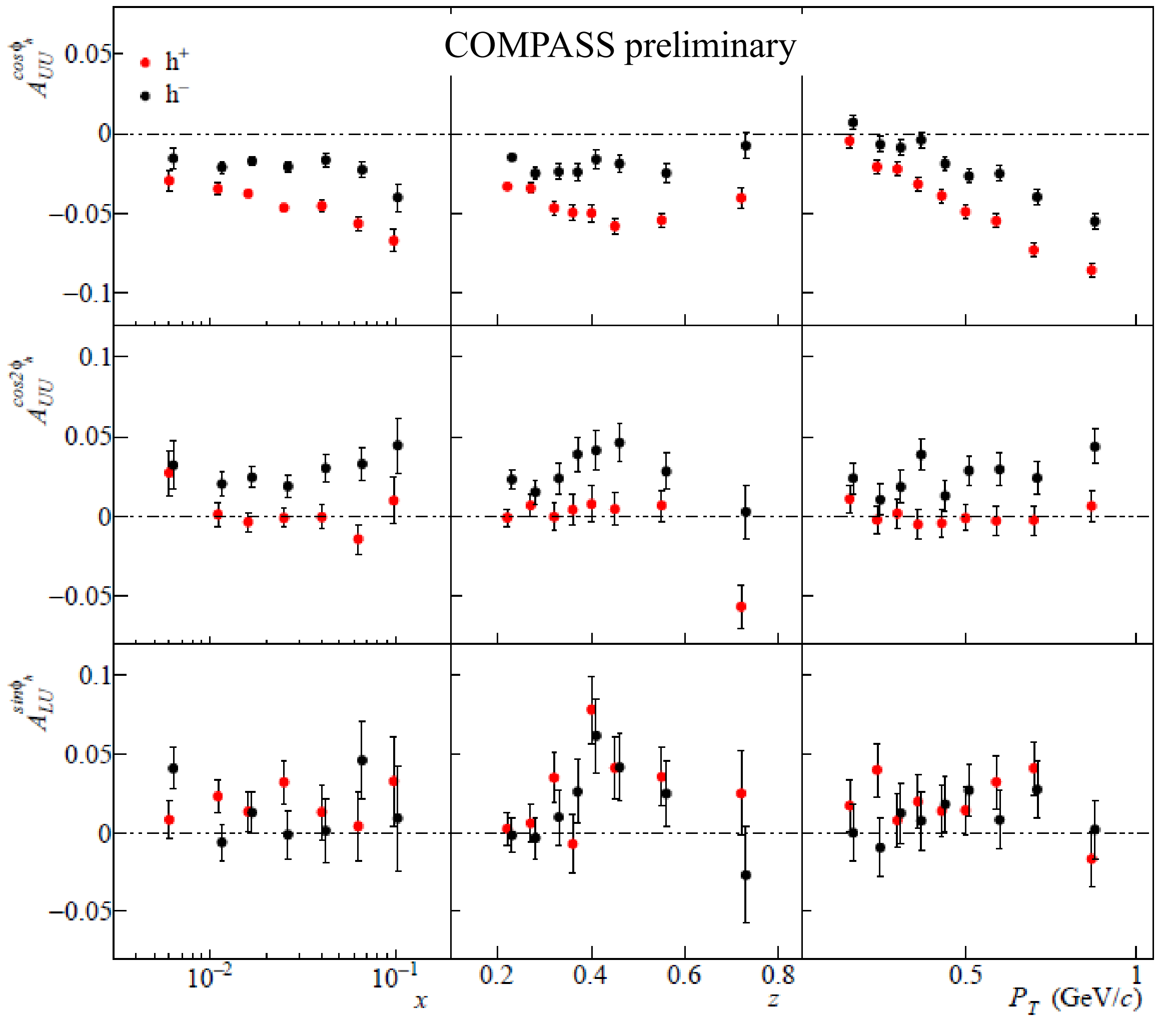
measured from the 2004 ^{6}LiD data NPB 886 (2014) 1046 NPB 956 (2020) 115039

measured from the 2016 LH data, in a limited kinematic range
more studies on kinematic dependence

with and without subtraction of the exclusive VM contribution

azimuthal asymmetries

proton data

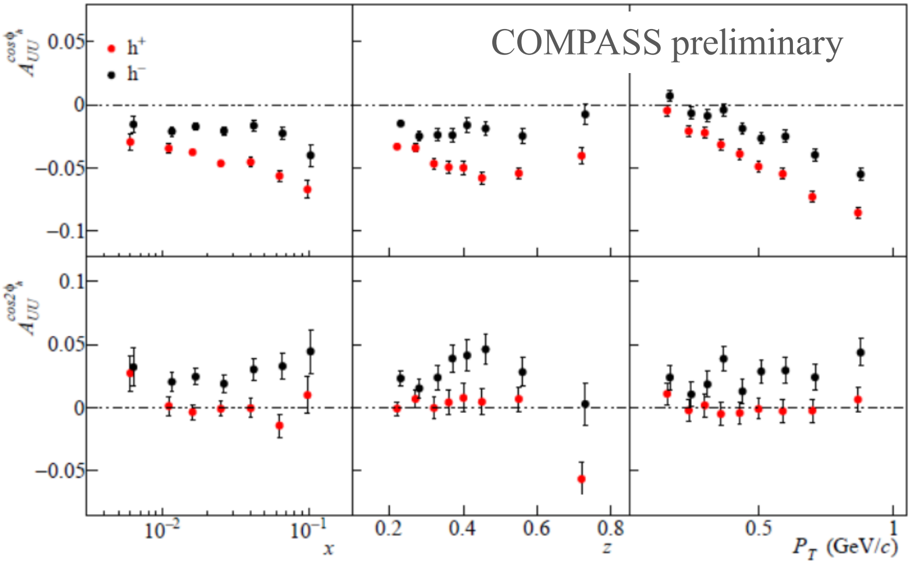


strong dependences on the kinematic variables

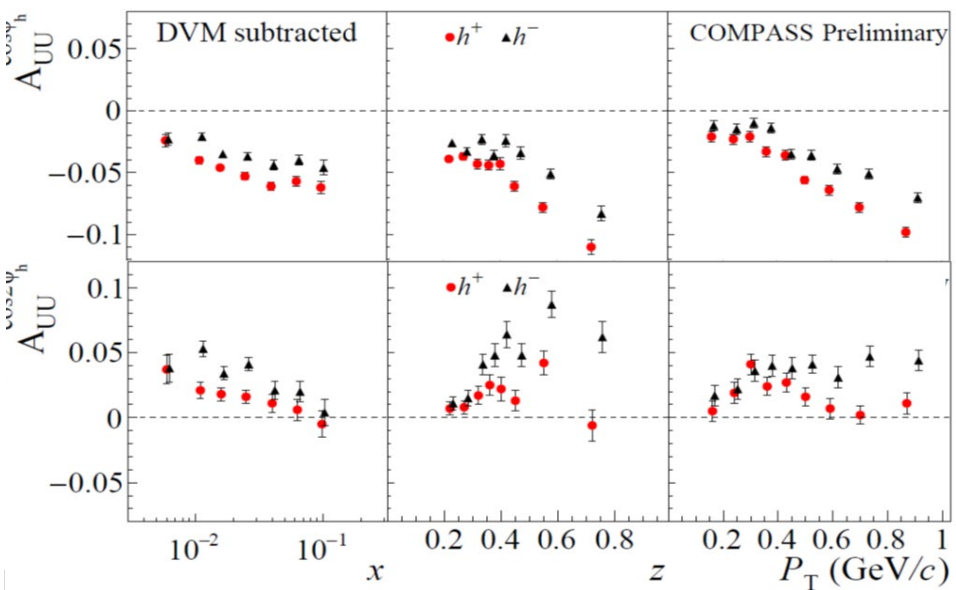
different for h^+ and h^-

azimuthal asymmetries

proton



deuteron



different for h^+ and h^-, and different for p and d, at variance with the P_T distributions

no clear interpretation in terms of the Cahn effect and the Boer-Mulders PDF, yet

data: several other interesting features

azimuthal asymmetries

proton data

COMPASS preliminary

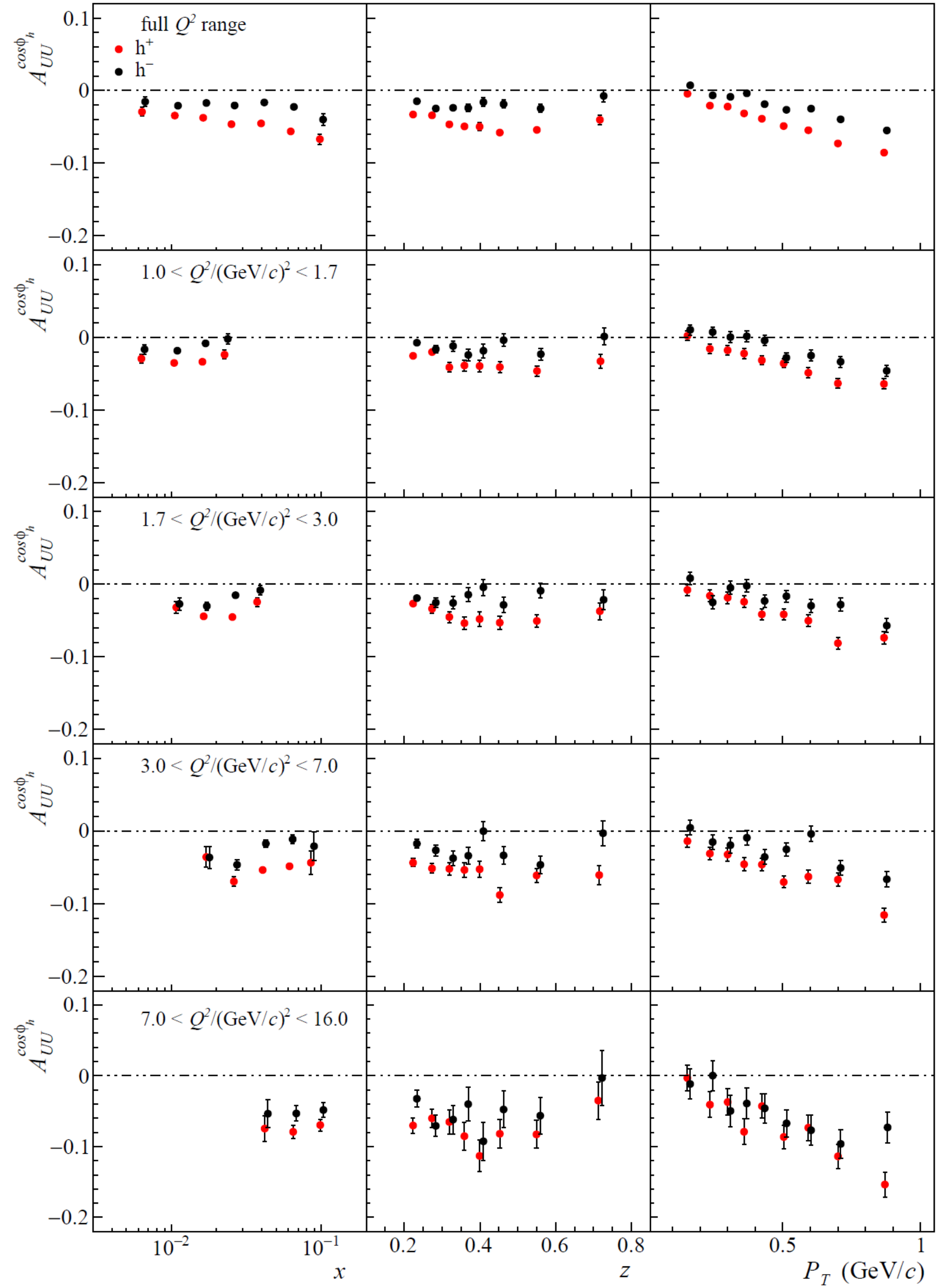
$$A_{UU|Cahn}^{\cos\phi_h} = -\frac{2zP_T\langle k_T^2\rangle}{Q\,\langle P_T^2\rangle}$$

4 Q^2 bins

other multiD results available

deuteron NPB 886 (2014) 1046 NPB 956 (2020) 115039

proton see f.i. A Moretti, Transvrsity 2022



SIDIS off unpolarised targets

plans

- finalise the measurements of the P_T distributions and azimuthal asymmetries from 2016/-2017 proton data

  evaluation of radiative effects corrections ongoing

  P_T cross-section measurements are also feasible

- same measurements using the 2022 deuteron data

  high statistics, larger kinematic coverage, flavor dependence

- measurement of the 2h multiplicities

  only "old" preliminary results exist

suggestions for kinematic cuts and binning, as well as indication for critical measurements to test theory are very welcome

SIDIS off
transversely polarised targets

SIDIS off transversely polarised targets

a long list of published / released results

d & p	Collins and Sivers asymmetries (1D)	several papers
d & p	di-hadron asymmetries (1D)	several papers hep-ex/2211.00093, acc PLB
d & p	other TSAs (1D)	conf
p	multiD measurements of TSAs (x, Q^2, z, P_T) $bins$	conf
p	interplay 1h -2h asymmetries	PLB 753 (2016) 406
p	Sivers (et al) asymmetry in Q^2 bins	PLB 770 (2017) 138
p	P_T - weighted Sivers asymmetries	NPB 940 (2019) 34
p	transversity induced $\Lambda/\bar{\Lambda}$ polarization	PLB 824 (2022) 136834
d & p	TSAs for high P_T pairs from PGF events	PLB 772 (2017) 85
p	J/Ψ Sivers asymmetry	conf
p	inclusive ρ^0 TSAs	hep-ex/2301.02013, acc PLB

d: deuteron 2002-2004
p: proton 2010 or 2007+2010 $\quad$ $160\ \mathrm{GeV}\ \mu^+$

SIDIS off transversely polarised targets

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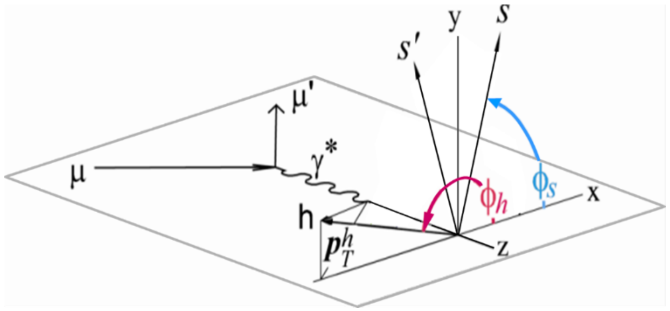
Collins and Sivers asymmetries

SIDIS cross-section



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

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

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

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

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

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

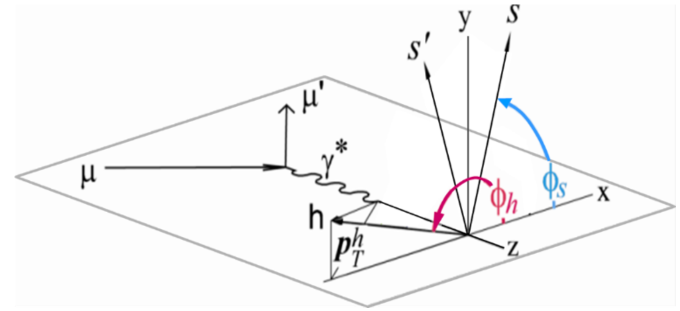
$$+\,\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)} + \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

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

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

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

SIDIS cross-section



$$
\begin{aligned}
\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \\
\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{ & F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
& +\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
& +S_{\|}\Big[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\Big] \\
& +S_{\|}\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big] \\
& +|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) \\
& \quad+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
& \quad+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] \\
& +|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
& \quad+\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},
\end{aligned}
$$

in the parton model

Sivers asymmetry

$$A_{Siv} \sim \frac{\sum_q e_q^2\, f_{1T}^{\perp\, q} \otimes D_{1q}}{\sum_q e_q^2\, f_1^q \otimes D_{1q}}$$

Collins asymmetry

$$A_{Coll} \sim \frac{\sum_q e_q^2\, h_1^q \otimes H_{1q}^{\perp}}{\sum_q e_q^2\, f_1^q \otimes D_{1q}}$$

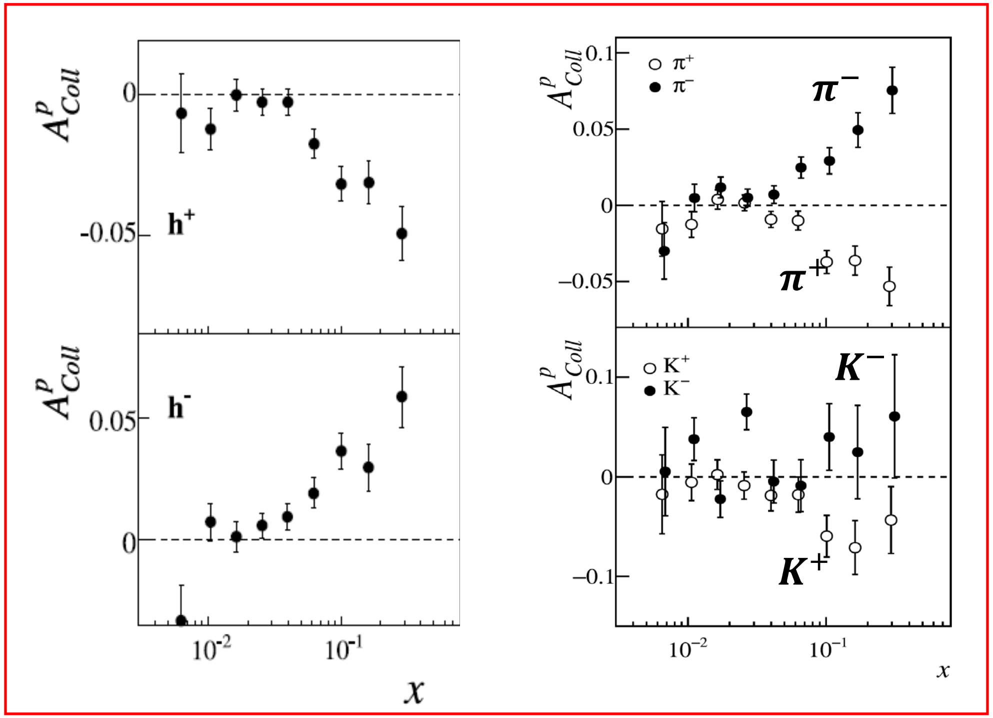
Collins asymmetry

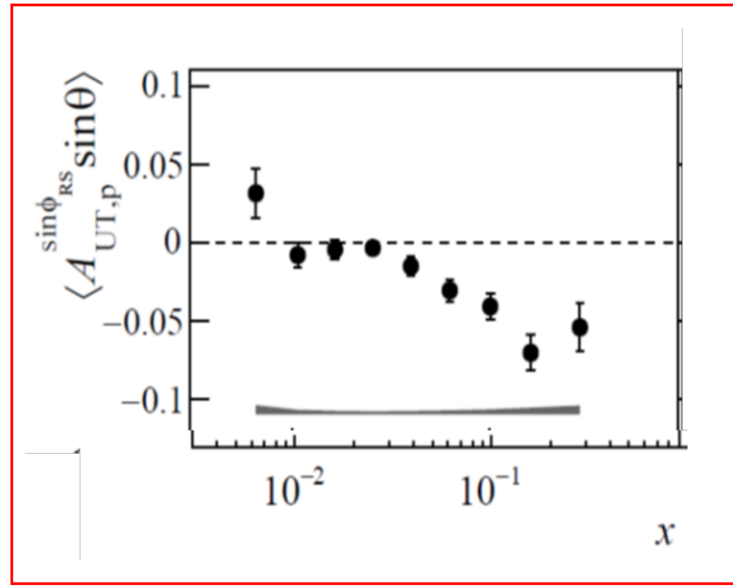
Collins asymmetry

proton target results

2010 data PLB 717 (2012) 376

2007 and 2010 data PLB 744 (2015) 250





very clear signal in the valence region

opposite sign for h^+ and h^-

specular symmetry vs x

in agreement with the HERMES results, in spite of the different energies

similar to the di-hadron asymmetry

Anna Martin

Collins asymmetry

proton target results

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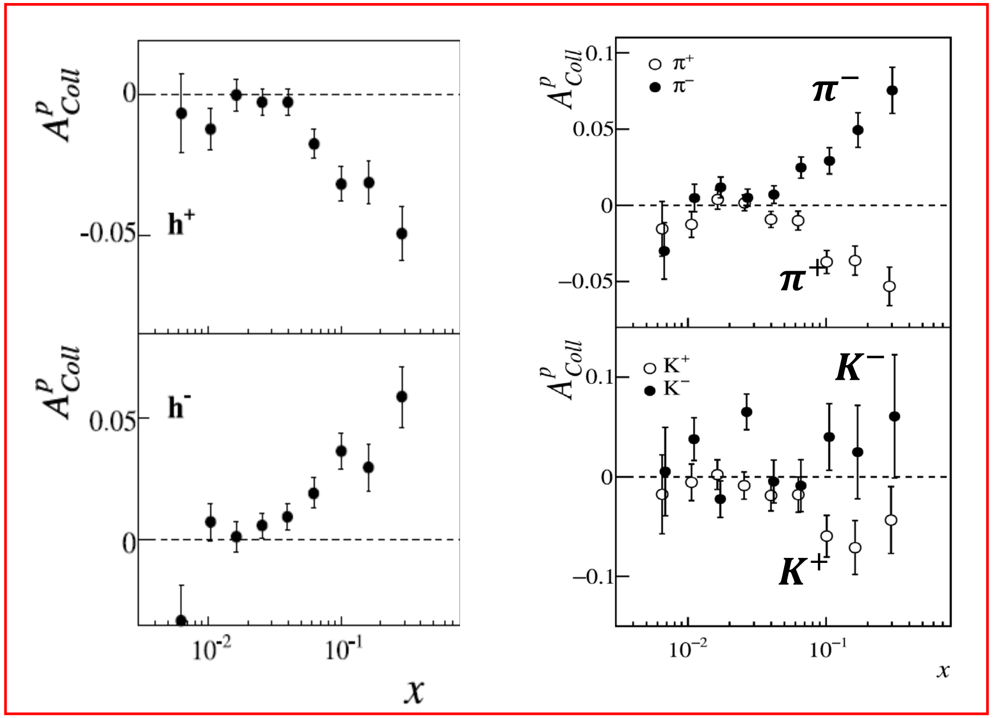
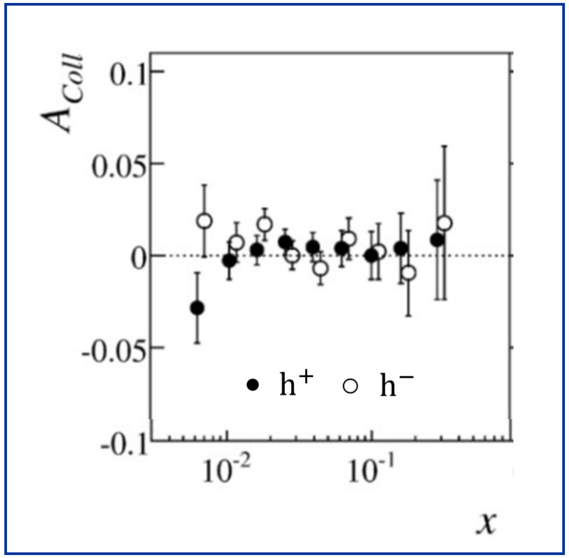


very clear signal in the valence region
opposite sign for h^+ and h^-
specular symmetry vs x

in agreement with the HERMES results, in spite of the different energies

deuteron target results

all 2002-2004 data NPB765 (2007) 31



compatible with zero

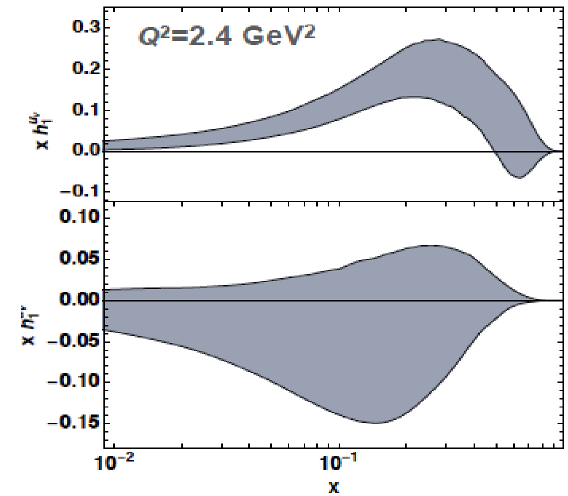
interpreted as cancellation between u and d quark contributions

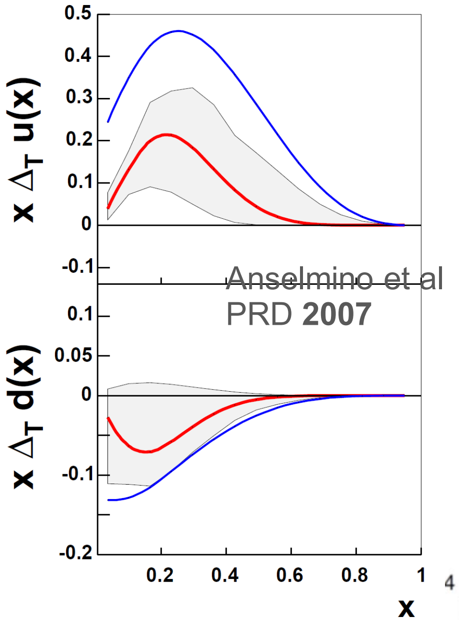
large statistical errors, as compared to the proton data

the **only existing d results**
(low statistics He3 measurement at JLab)

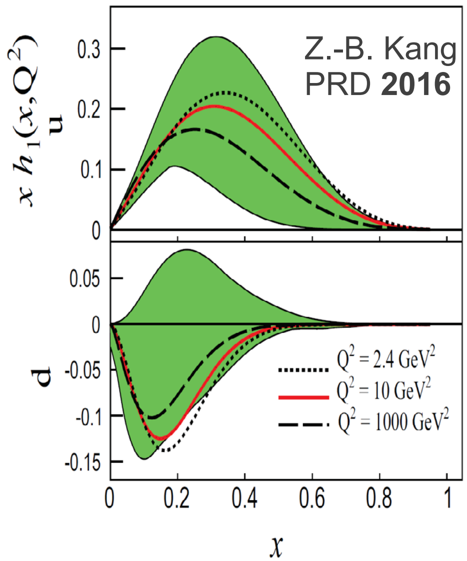
accessing transversity

Radici Bacchetta PRL **2018**

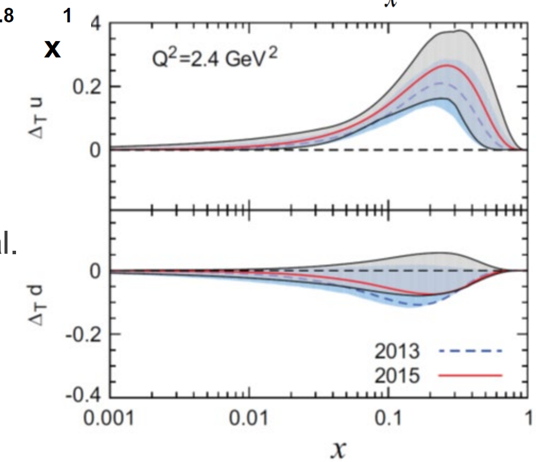




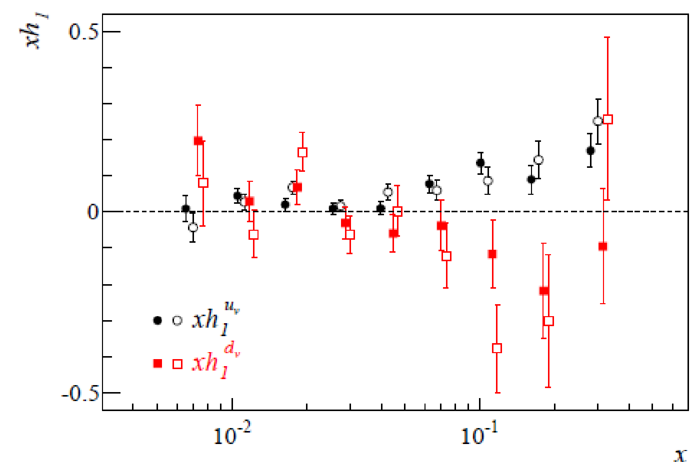
Anselmino et al
PRD **2007**



Z.-B. Kang et al.
PRD **2016**



M. Anselmino et al.
PRD 2015



A.M., V. B. F.B
PRD 2015

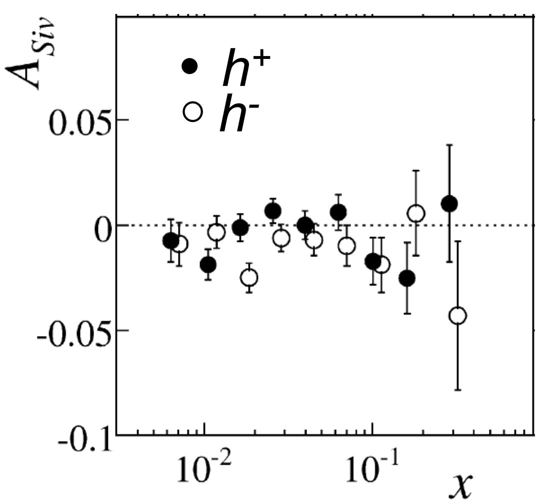
SIDIS and
e^+e^- data
only

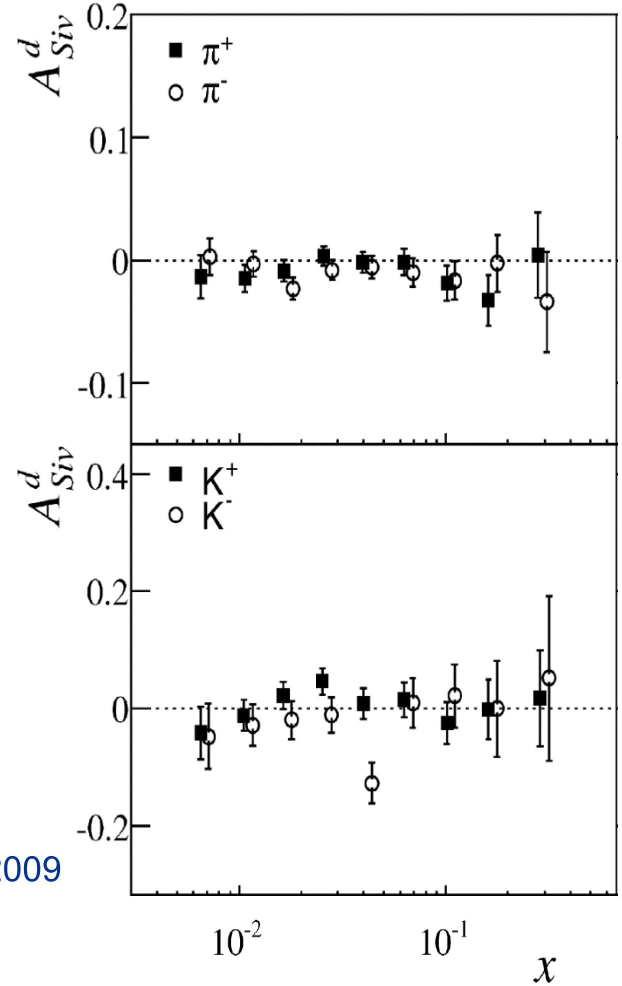
- indication of opposite sign u- and d-quark transversity PDFs have opposite sign
- d-quark PDF much worse determined than u-quark PDF because of the scarcity of deuteron (neutron) data
  → *2022 COMPASS run*

Sivers asymmetry

Sivers asymmetry

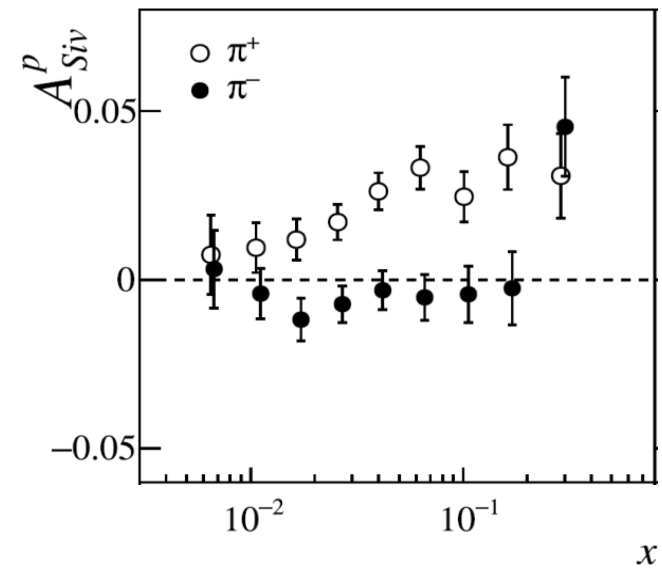
deuteron





2002-2004 data
NPB765 2007, PLB673 2009

proton

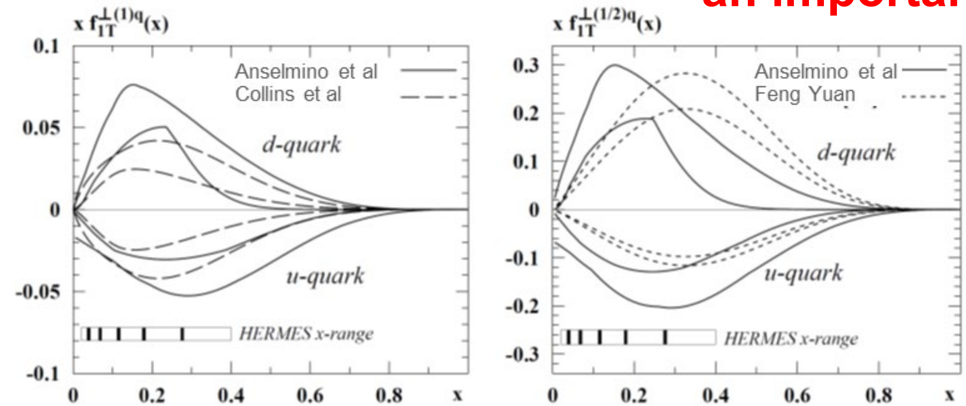


clearly positive for π^+
down to $x \sim 10^{-2}$
slightly lower than
HERMES results

Sivers function

the first extractions of the **Sivers PDFs** from these p and d Sivers asymmetries **in the TMD framework** came very soon, in 2005, after the publication of the first HERMES p results and COMPASS d results

an important step forward !!



proceedings of
Transversity 2005

from SIDIS data only

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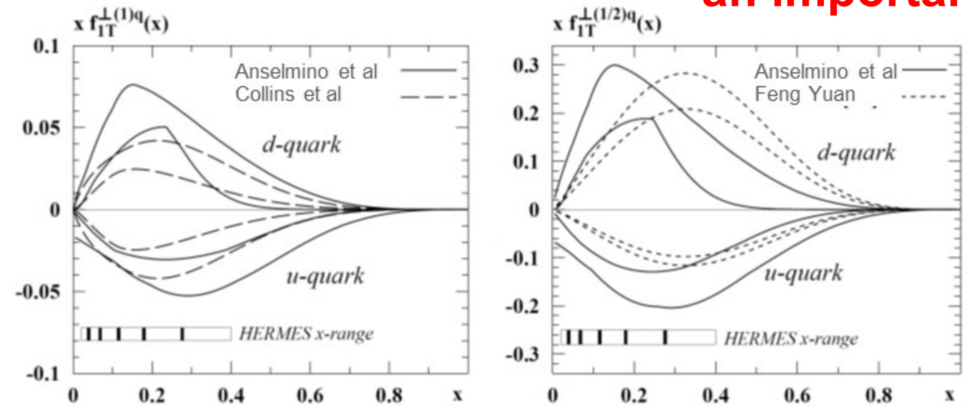
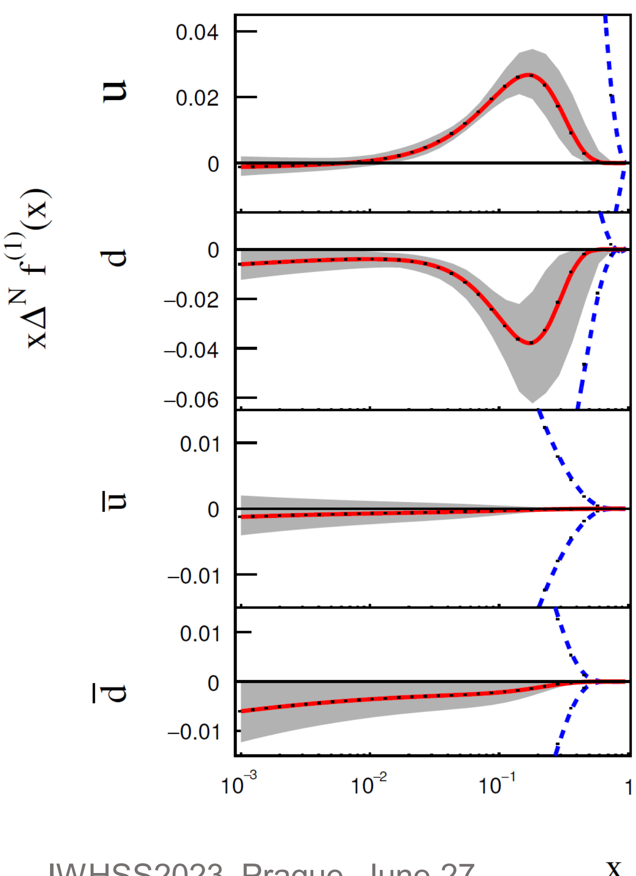
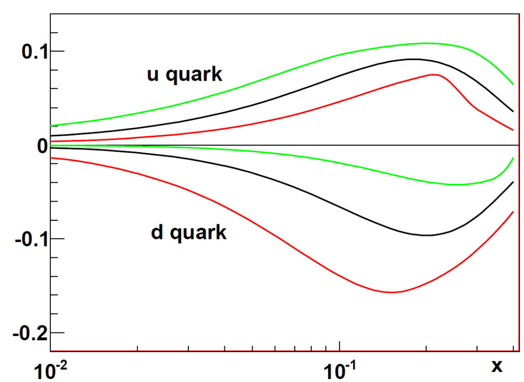


proceedings of ***Transversity 2005***

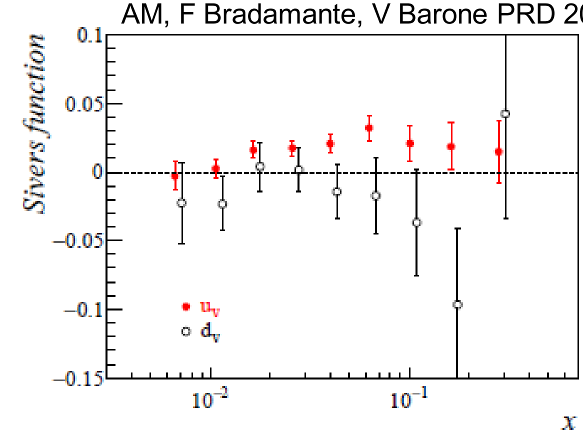
Anselmino et al., JHEP04 **2017**



Sun and Yuan PRD88 **2013**



AM, F Bradamante, V Barone PRD 2017



from SIDIS data only

P_T weighted Sivers asymmetry

P_T weighted Sivers asymmetry

$$A_{Siv} \propto \frac{\sum_q e_q^2 \cdot f_{1T}^{\perp q} \otimes D_{1q}^h}{\sum_q e_q^2 \cdot f_1^q \cdot D_{1q}^h}$$

convolution

→ non negligible uncertainties in extractions

$\vec{k}_T$, parametrisations…

a possible way out: use of the P_T weighted asymmetries

obtained by weighting the spin dependent part of the cross-section

$$w = P_T/zM$$

$$A_{Siv}^w = \frac{\sigma_S^w}{\sigma_U} = 2\frac{\sum_q e_q^2 \cdot f_{1T}^{\perp(1)q} \cdot D_{1q}^h}{\sum_q e_q^2 \cdot f_1^q \cdot D_{1q}^h}$$

easier to extract $f_{1T}^{\perp(1)q}$

proposed a long time ago …

A. Kotzinian and P. J. Mulders, PLB 406 (1997) 373
D. Boer and P. J. Mulders, PRD 57 (1998) 5780
J. C. Collins et al. PRD 73 (2006) 014021

Zhong-Bo Kang et al., Phys.Rev. D87 (2013)
….

preliminary results by HERMES in 2005

measured by COMPASS using the 2010 proton data

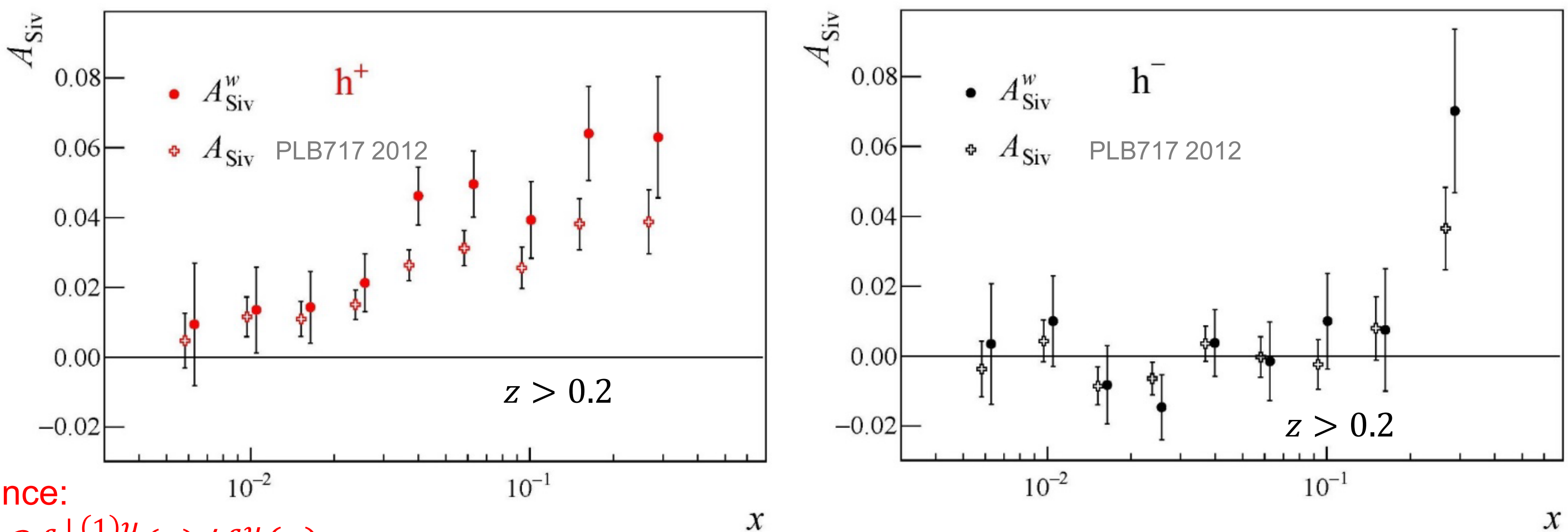
P_T weighted Sivers asymmetry

COMPASS

results

$$A^{w}_{Siv}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^q}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^q} \qquad \widetilde{D}_1^q = \int_{z_{min}}^{z_{max}} dz D_1^q(z)$$

NPB 940 (2019) 34



u-dominance:
$A^{w}_{Siv} \sim 2 f_{1T}^{\perp(1)u}(x)/f_1^u(x)$

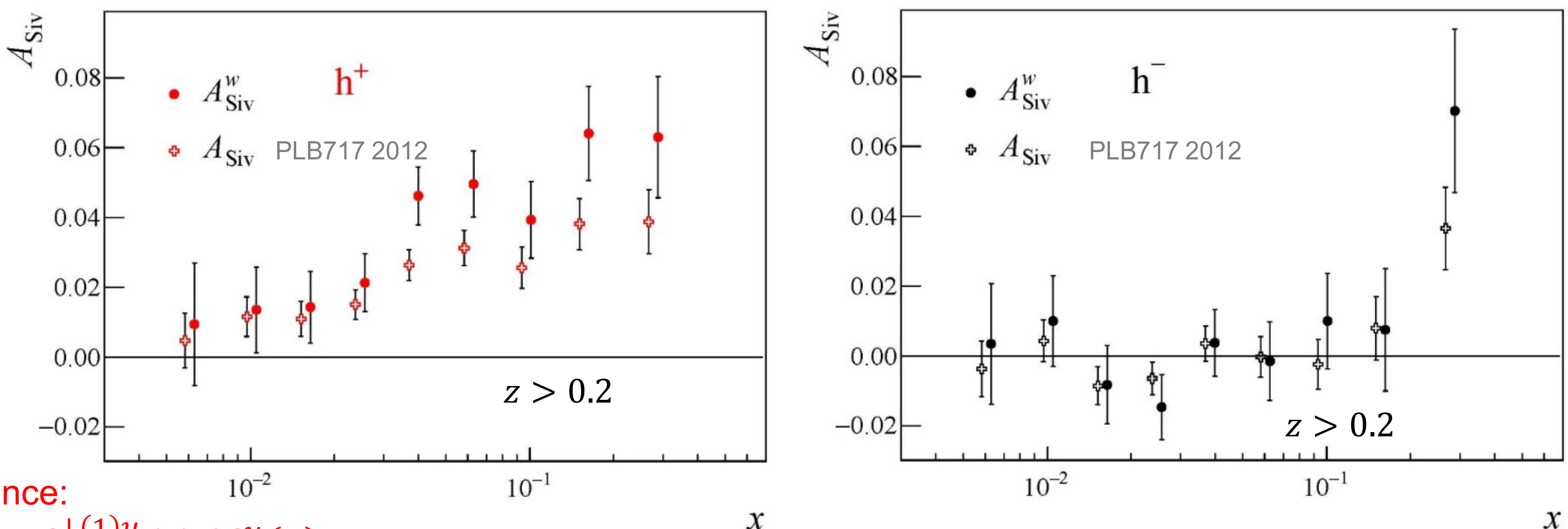
similar x dependence of the weighted and unweighted asymmetries, in agreement with the expectation

$$\frac{A^{w\prime}_{Siv}(x,z)}{A_{Siv,G}(x,z)} = \frac{4\langle P_T\rangle}{\pi M}$$

P_T weighted Sivers asymmetry

NPB 940 (2019) 34

results $$A^w_{Siv}(x) = 2\frac{\sum_q e_q^2 x f_{1T}^{\perp(1)q}(x)\widetilde{D}_1^q}{\sum_q e_q^2 x f_1^q(x)\widetilde{D}_1^q} \qquad \widetilde{D}_1^q = \int_{z_{min}}^{z_{max}} dz D_1^q(z)$$



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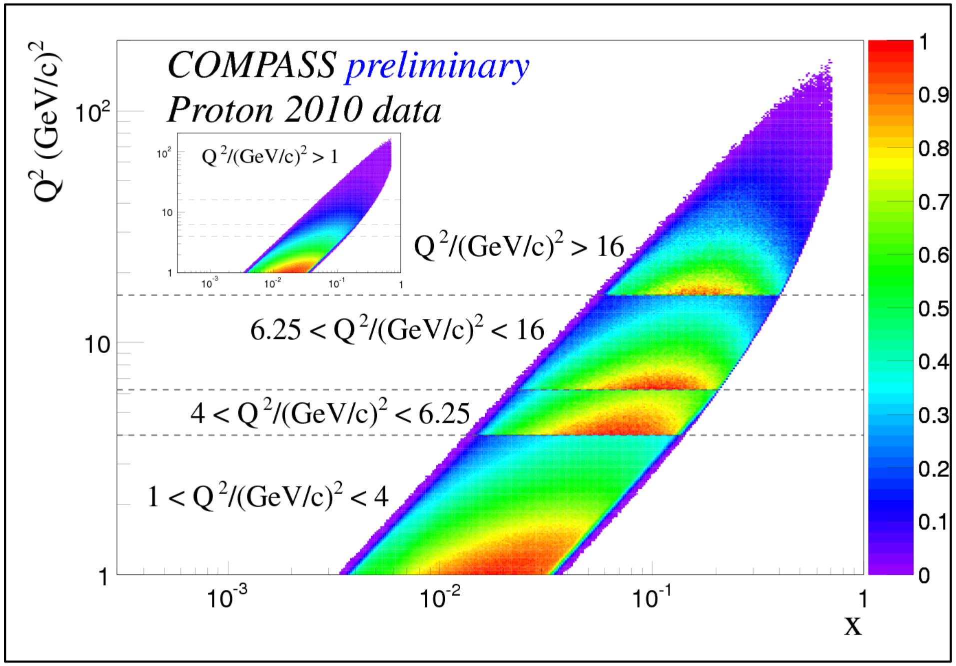
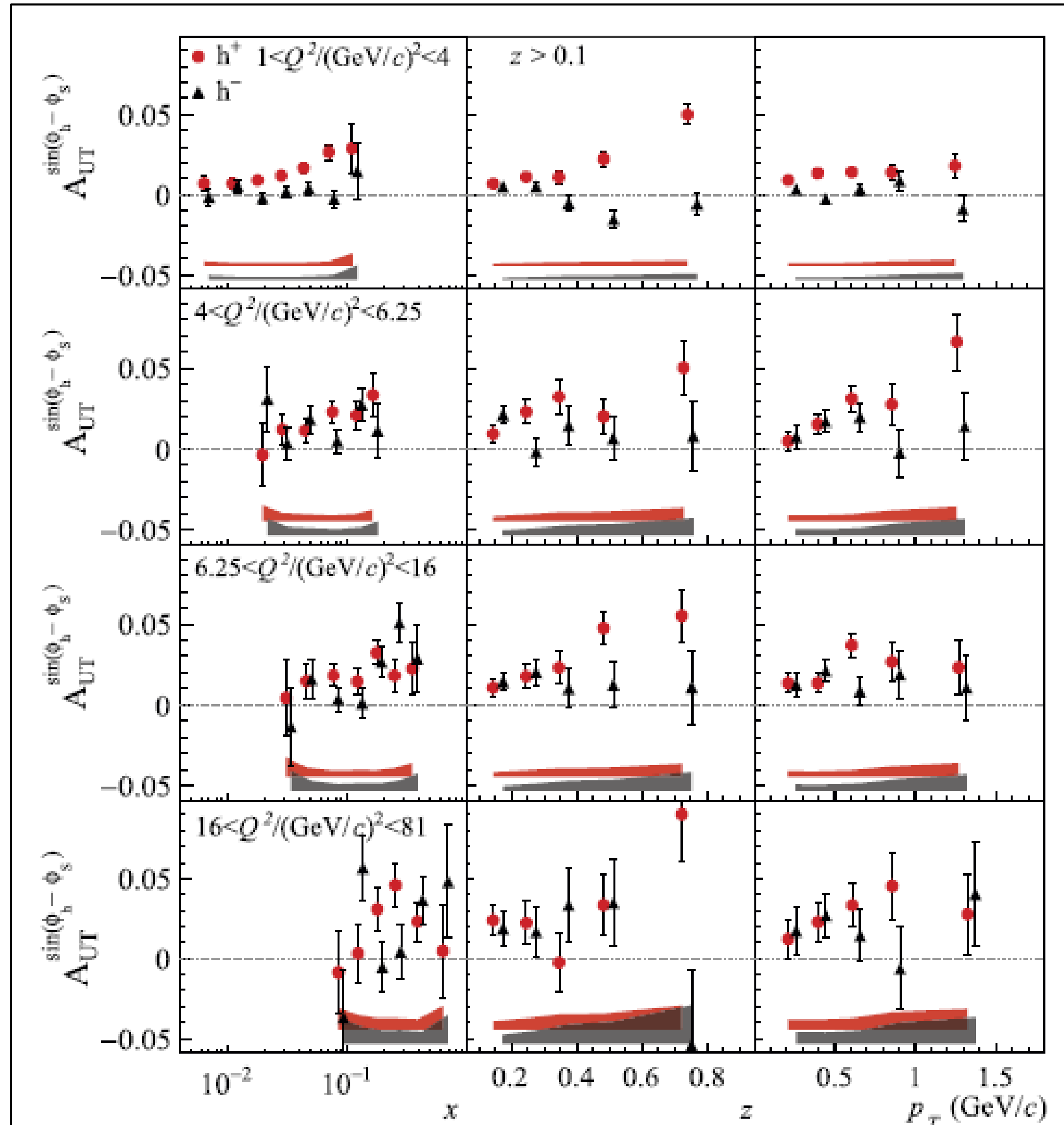
in the paper, several other results, also the point-by-point extraction of $f_{1T}^{\perp(1)}(x)$ neglecting the sea-quark contribution - in agreement with extraction from standard asymmetries

nothing at variance with expectations

TSAs – multiD results

proton data only – bins in Q^2
motivated by the comparison of the Sivers asymmetry in SIDIS and Drell-Yan



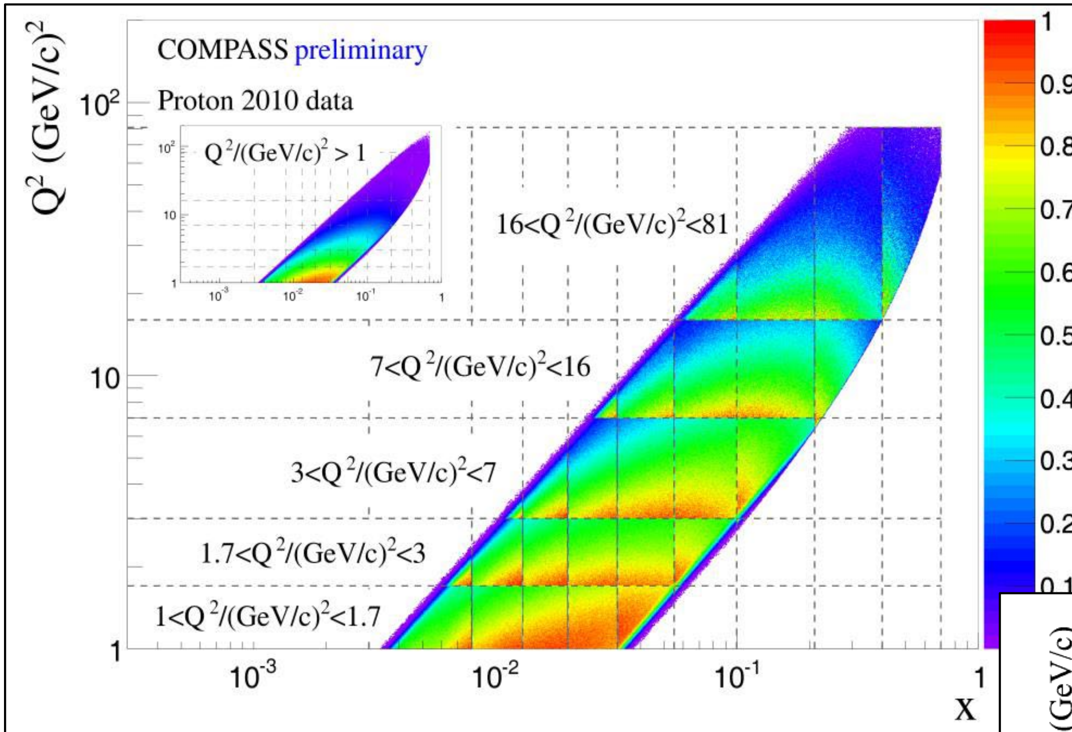


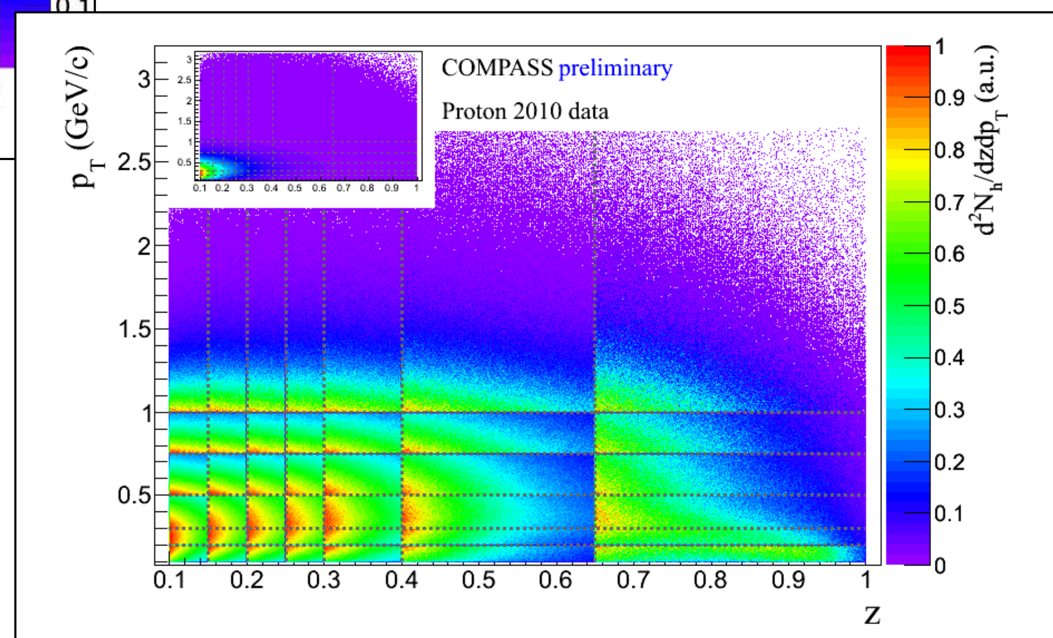
results for all 8 TSAs

PBL 770 (2017) 138

TSAs – multiD results

proton data only – preliminary results, all 8 TSAs

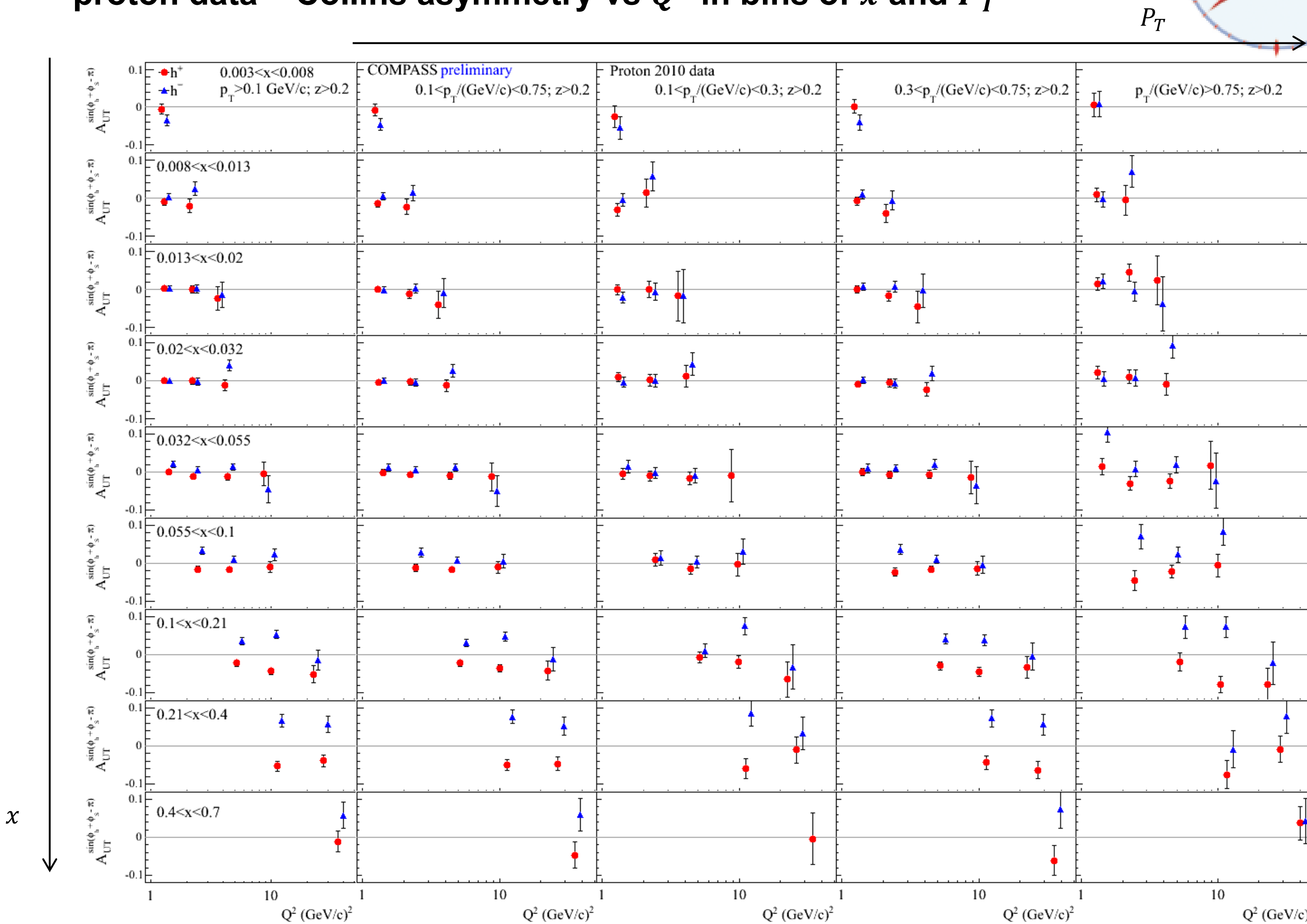




SPIN2014

TSAs – multiD results

proton data – Collins asymmetry vs Q^2 in bins of x and P_T



the 2022 run

the 2022 run

request to CERN (2017):
one year of data taking with the transversely polarized deuteron (^{6}LiD) **target** in the same conditions of the 2010 proton run
aim:
balance the proton and deuteron statistics to improve, in particular, the knowledge of the **d-quark transversity** and of the tensor charge, in a unique $x - Q^2$ range

CERN-SPSC-2017-034
SPSC-P-340-ADD-1

approved by CERN in 2018, the run took place in **2022**

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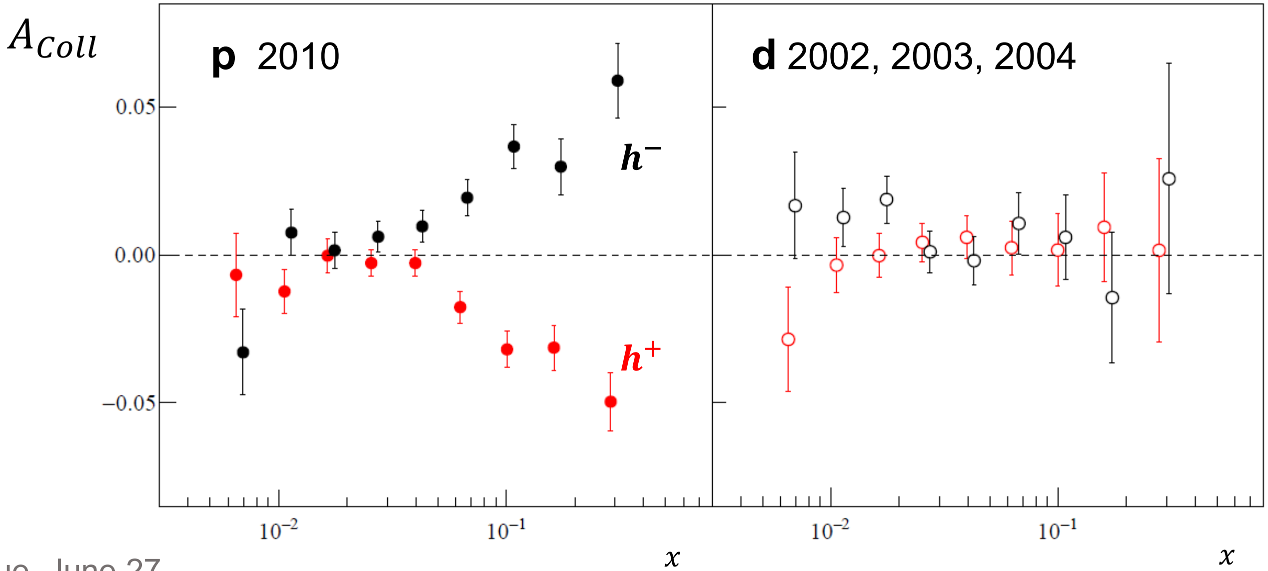
expected statistical uncertainties $\boldsymbol{\sigma^d_{2022} \simeq 0.6 \cdot \sigma^p_{2010}}$ for all the TSAs

expected impact on the **Collins asymmetry**



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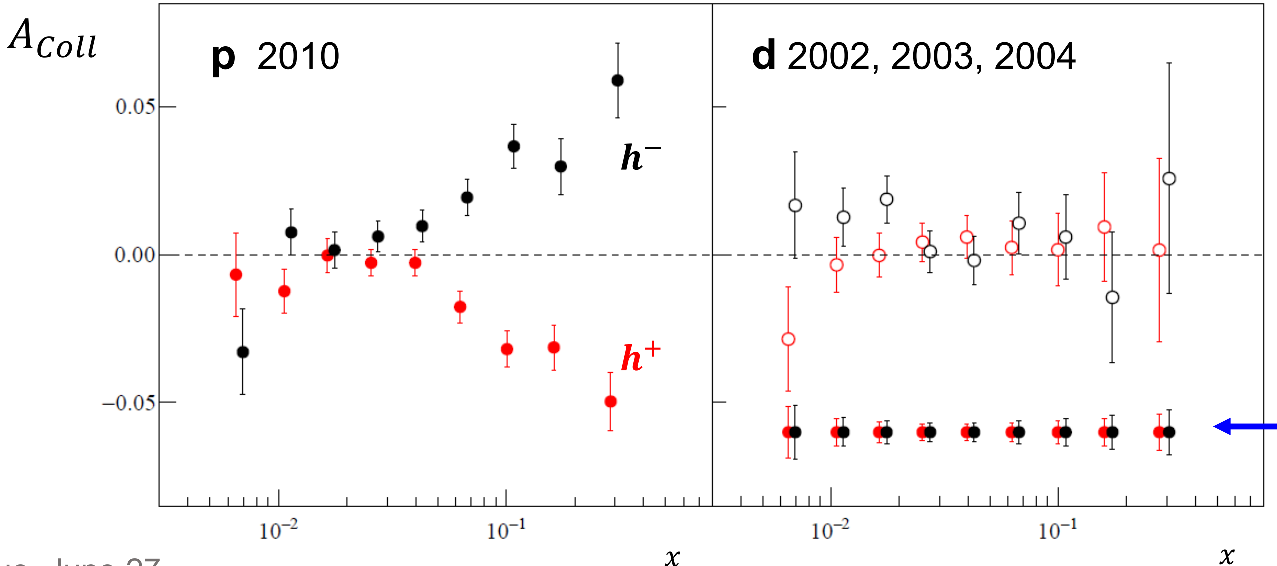
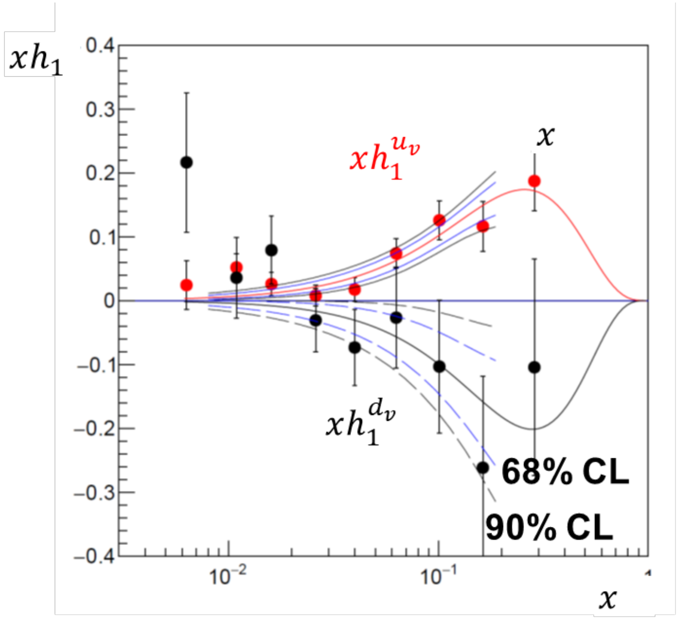


expected 2022 uncertainties:
factor 2 to 5 smaller than 2002-2004

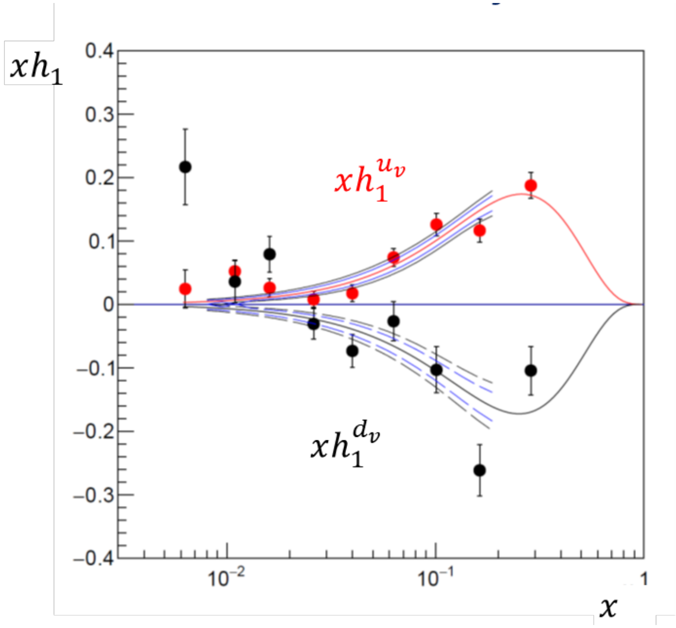
the 2022 run

expected impact on **transversity** quantified using the point by point extraction

present: all p and d data



projected: all p and 2022 d data



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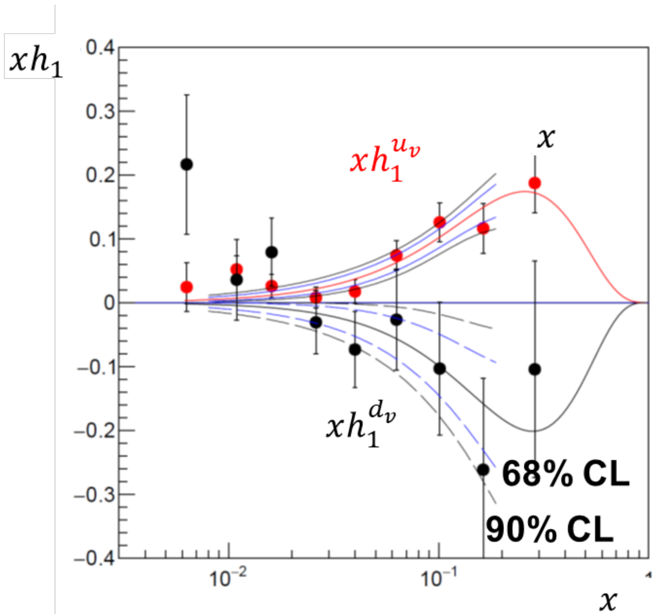

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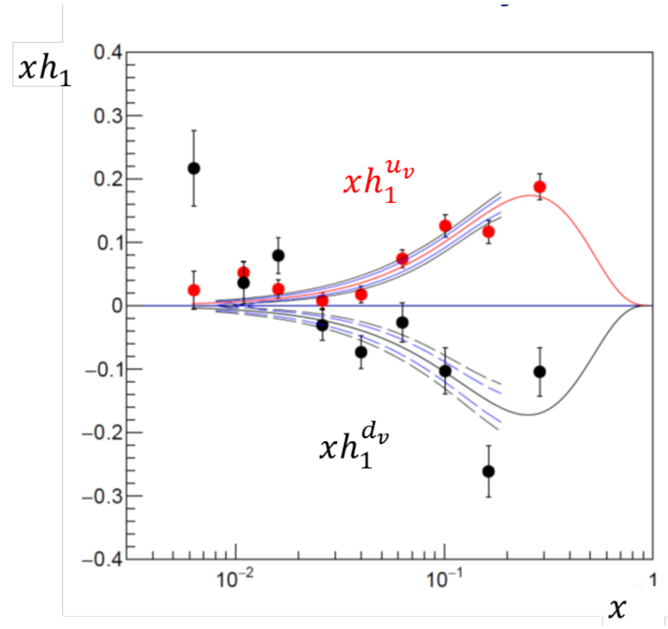
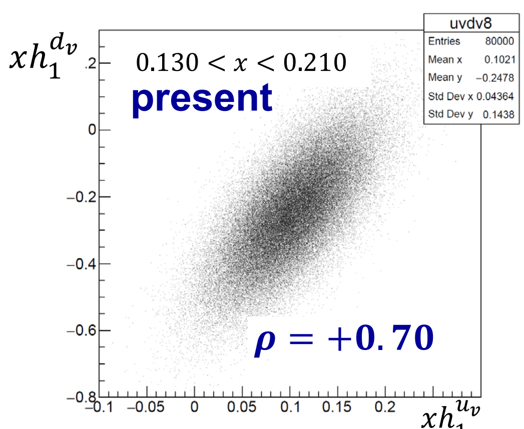
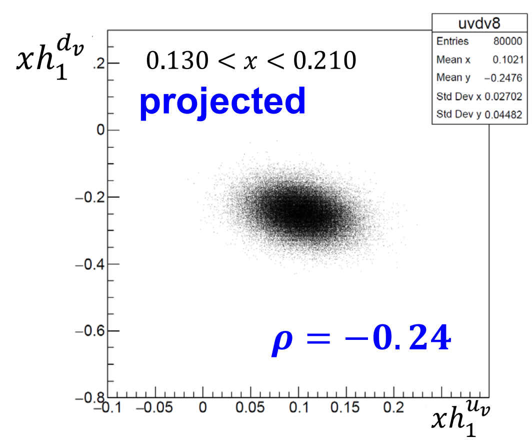




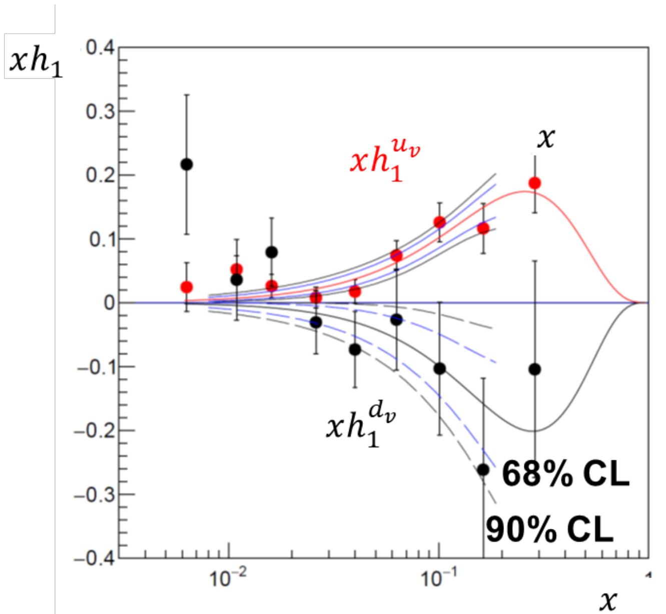


replicas

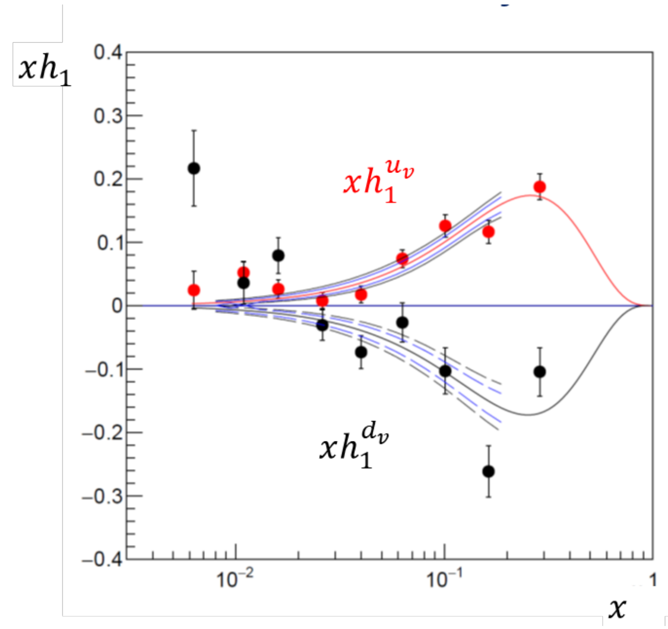
the 2022 run

expected impact on **transversity** quantified using the point by point extraction

present: all p and d data



projected: all p and 2022 d data



and on the **tensor charge**

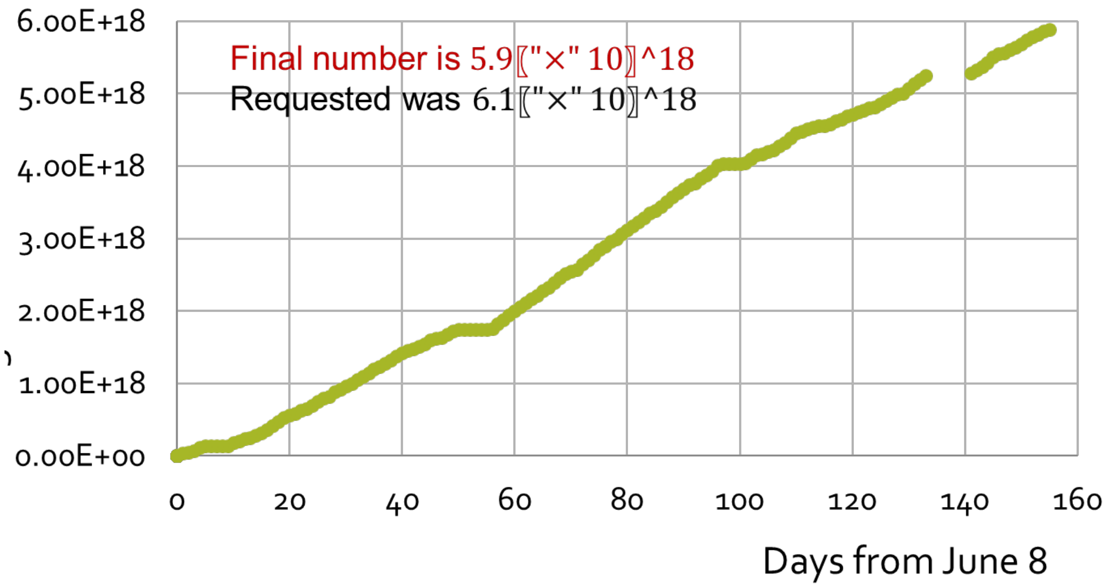
$\Omega_x: 0.008 \div 0.210$

	$\delta_u = \int_{\Omega_x} dx h_1^{u_v}(x)$	$\delta_d = \int_{\Omega_x} dx h_1^{d}(x)$	$g_T = \delta_u - \delta_d$
present	$0.201 \pm \mathbf{0.032}$	$-0.189 \pm \mathbf{0.108}$	$0.390 \pm \mathbf{0.087}$
projected	$0.201 \pm \mathbf{0.019}$	$-0.189 \pm \mathbf{0.040}$	$0.390 \pm \mathbf{0.044}$

the 2022 run

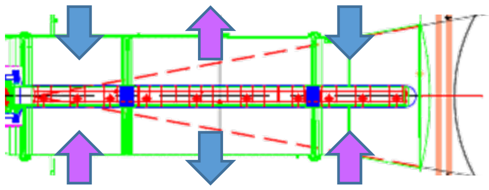
data taking from June 8 to November 9, 2022, with some short break

integrated number of protons delivered on the muon production target



in total 10 data taking periods,

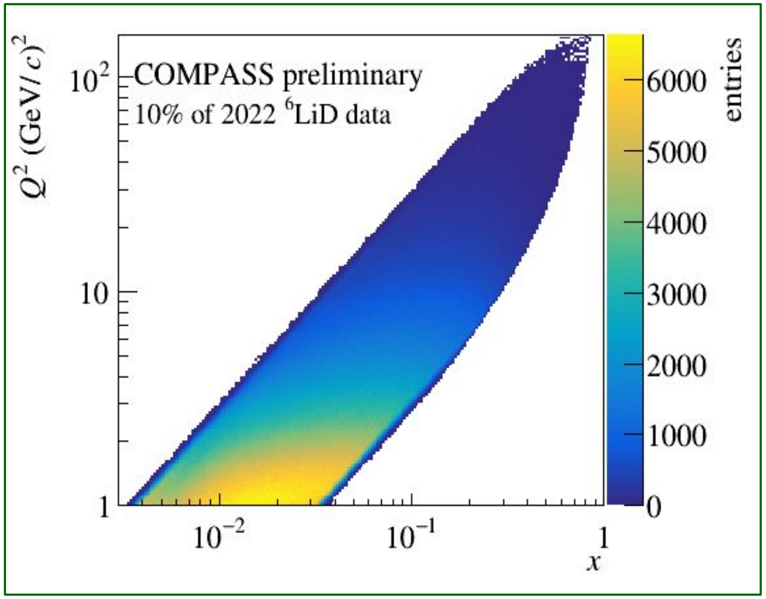
each divided in 2 sub periods
with opposite polarization in the target cells
to minimize possible systematic effects

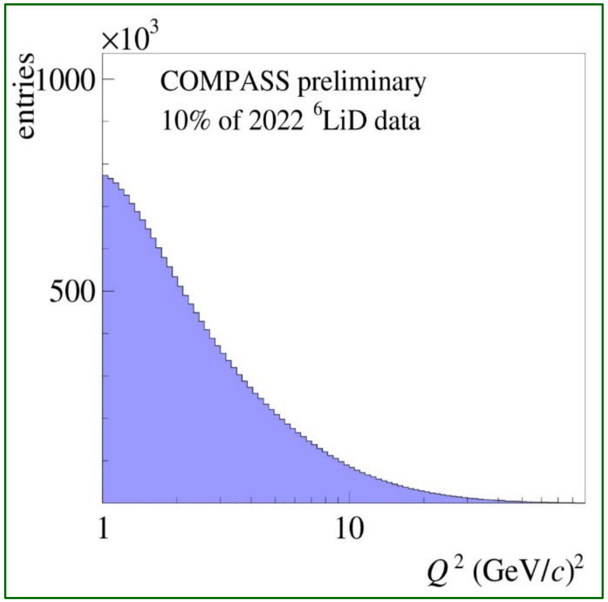


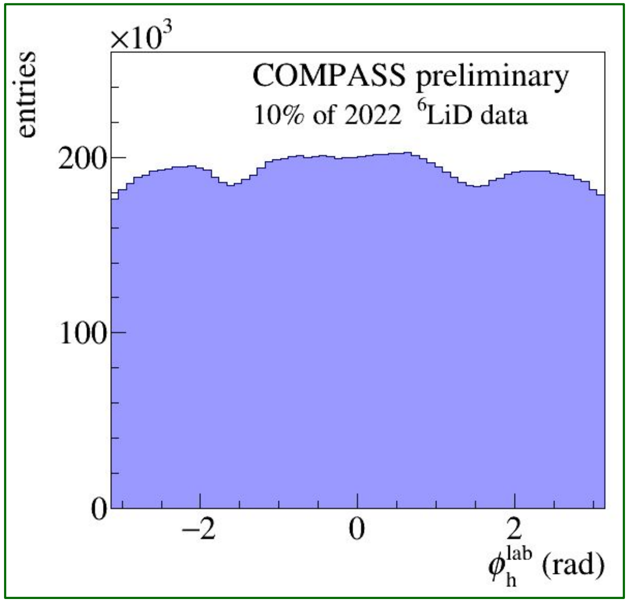
data analysis started during data taking, and is going on as expected

the 2022 run

some distribution







the 2022 run

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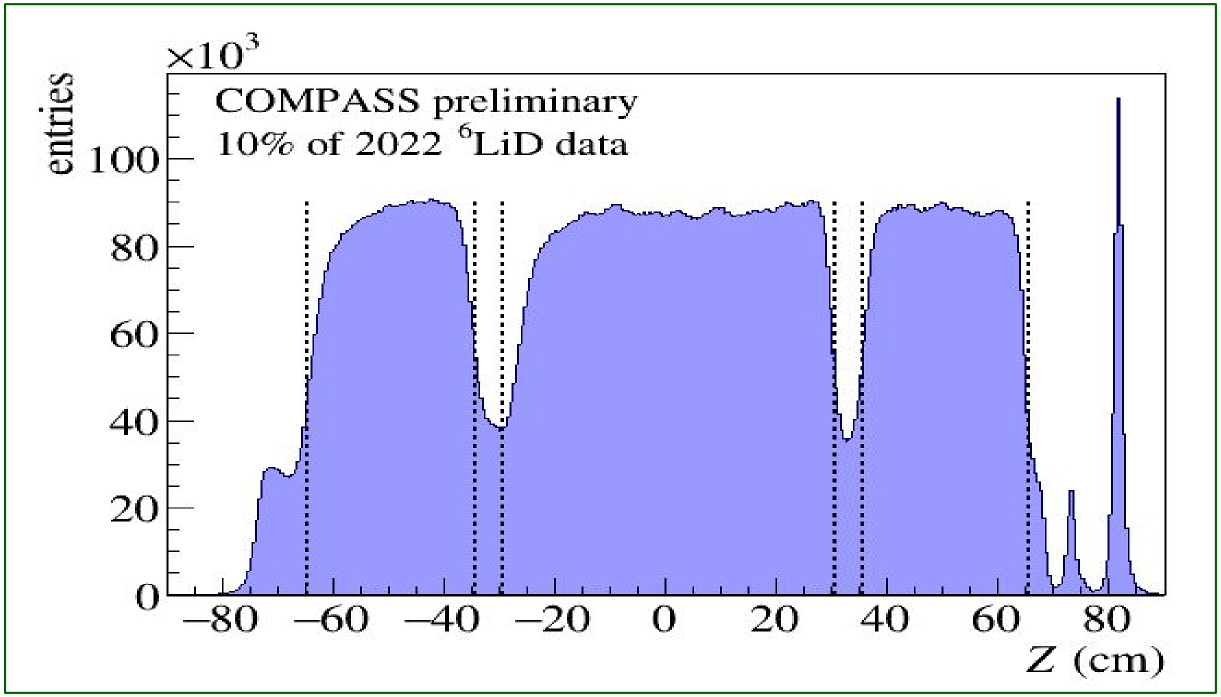

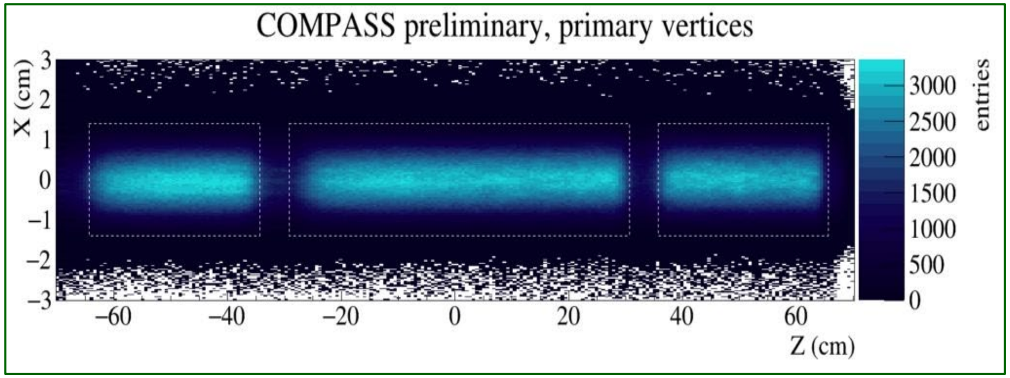

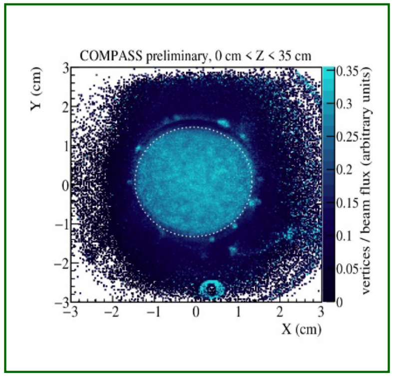

the 2022 run

NEW

recently we completed the processing of all the collected data

several more tests could be performed

- on data quality and stability inside the periods and among periods
- tuning of the cuts, systematic effects

work in progress but
we already have a **solid estimate of the final statistical uncertainties**
which are in **very good agreement with the expectations** of the proposal

the 2022 run

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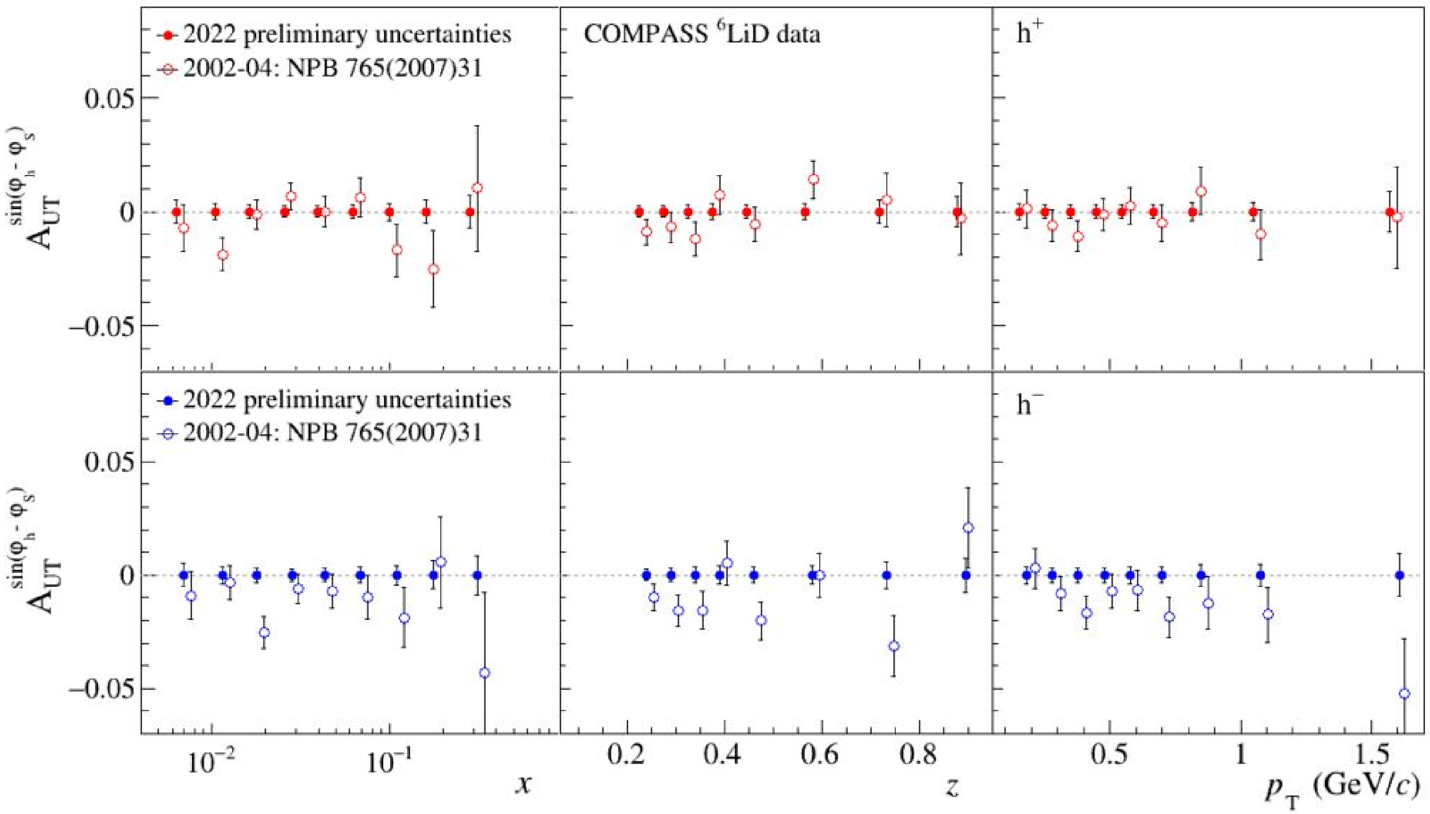

Sivers asymmetry from 2002-2004 data and statistical errors form 2022 data

same reduction in the uncertainties of all the TSAs

the 2022 run

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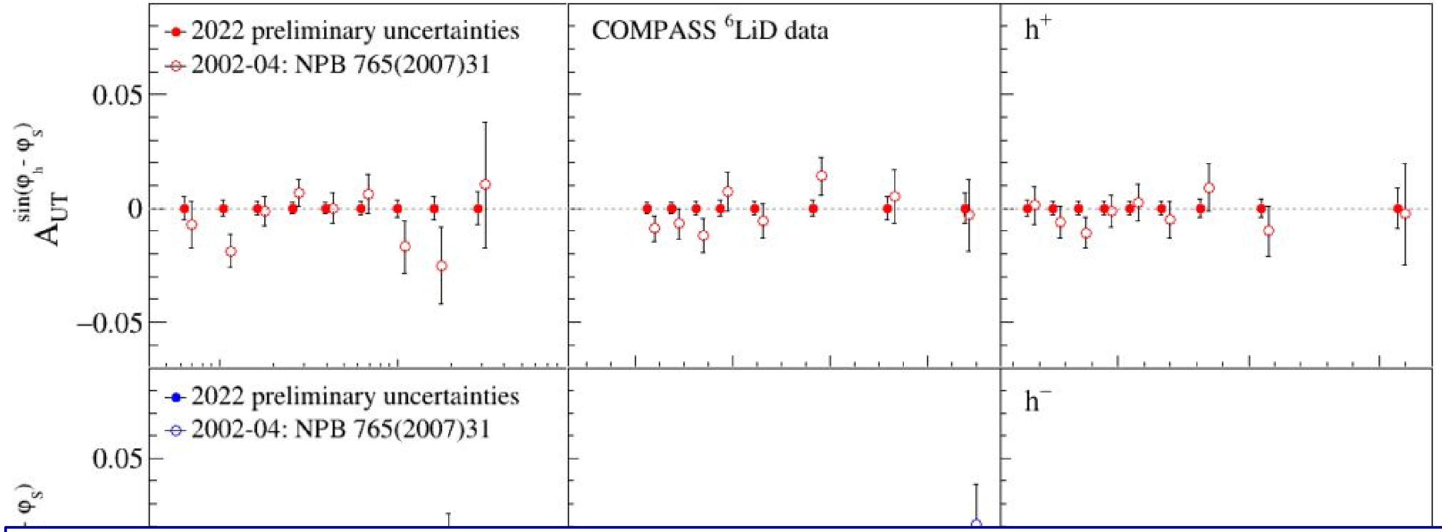


Sivers asymmetry from 2002-2004 data and statistical errors form 2022 data

same reduction in the uncertainties of all the TSAs

the 2022 run has been successful

- the data are there
- the analysis is progressing fast
- the statistics is as expected

we plan to have the first results soon, in time for SPIN2023

summary

COMPASS has produced many relevant SIDIS measurements

in the near future more results will come on
SIDIS off

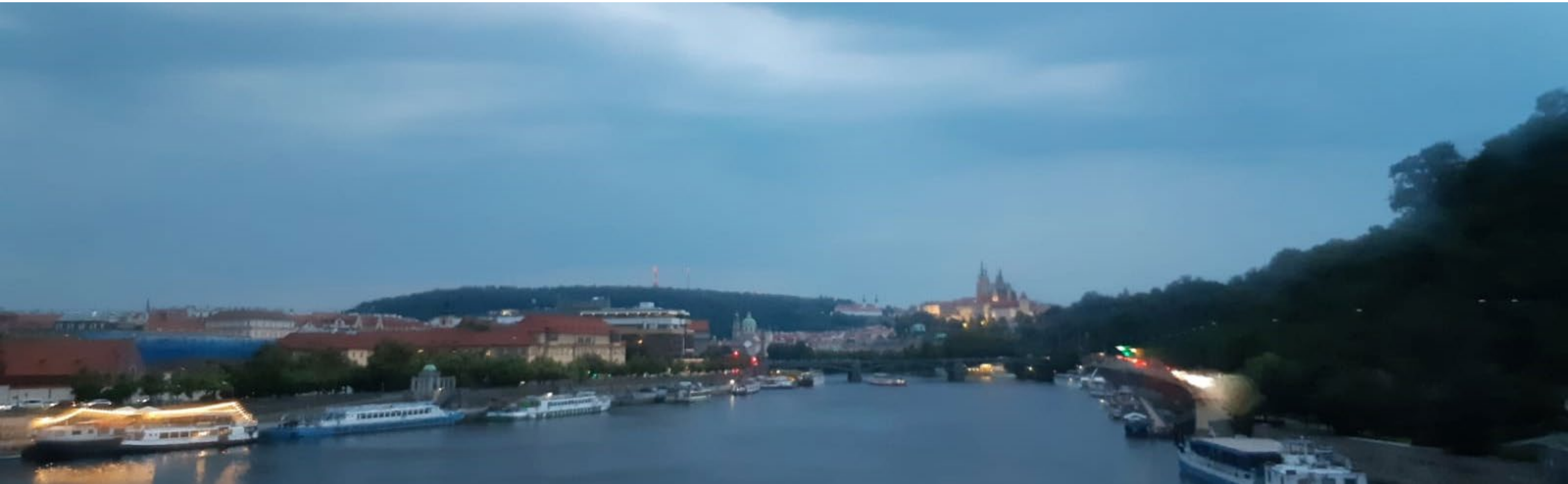
- **unpolarised protons** using the 2016-2017 data and
  unpolarised deuterons using the 2022 data
- **transversely polarized deuterons using the 2022 data**

these data will stay unique for several years

we have a long list of measurements aimed to put
constrains on the transversity function, the tensor charge,
and much more

- a lot of space for new people interested in these analyses
- we look forward at a closer collaboration with the theory groups

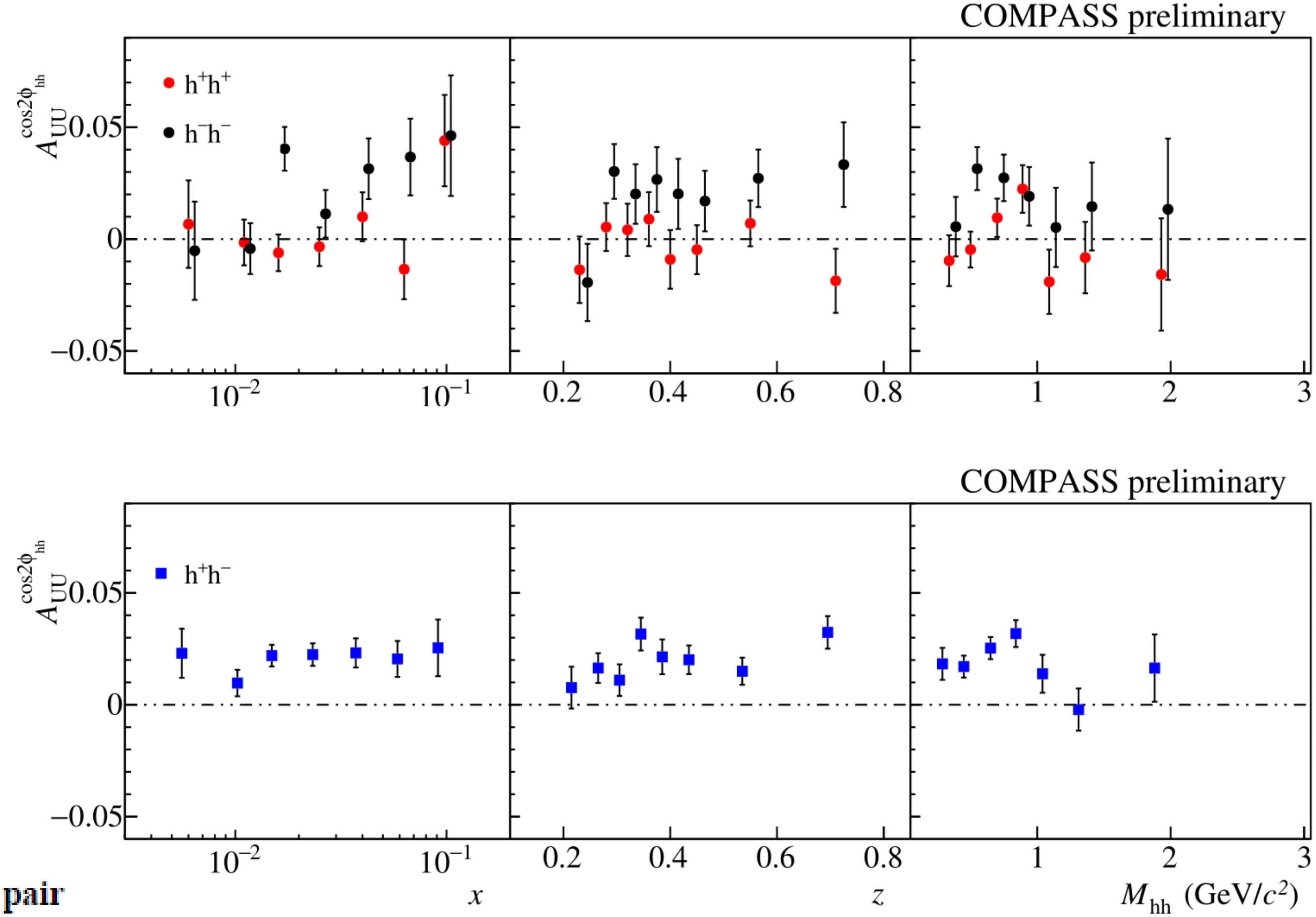
thank you!



azimuthal asymmetries

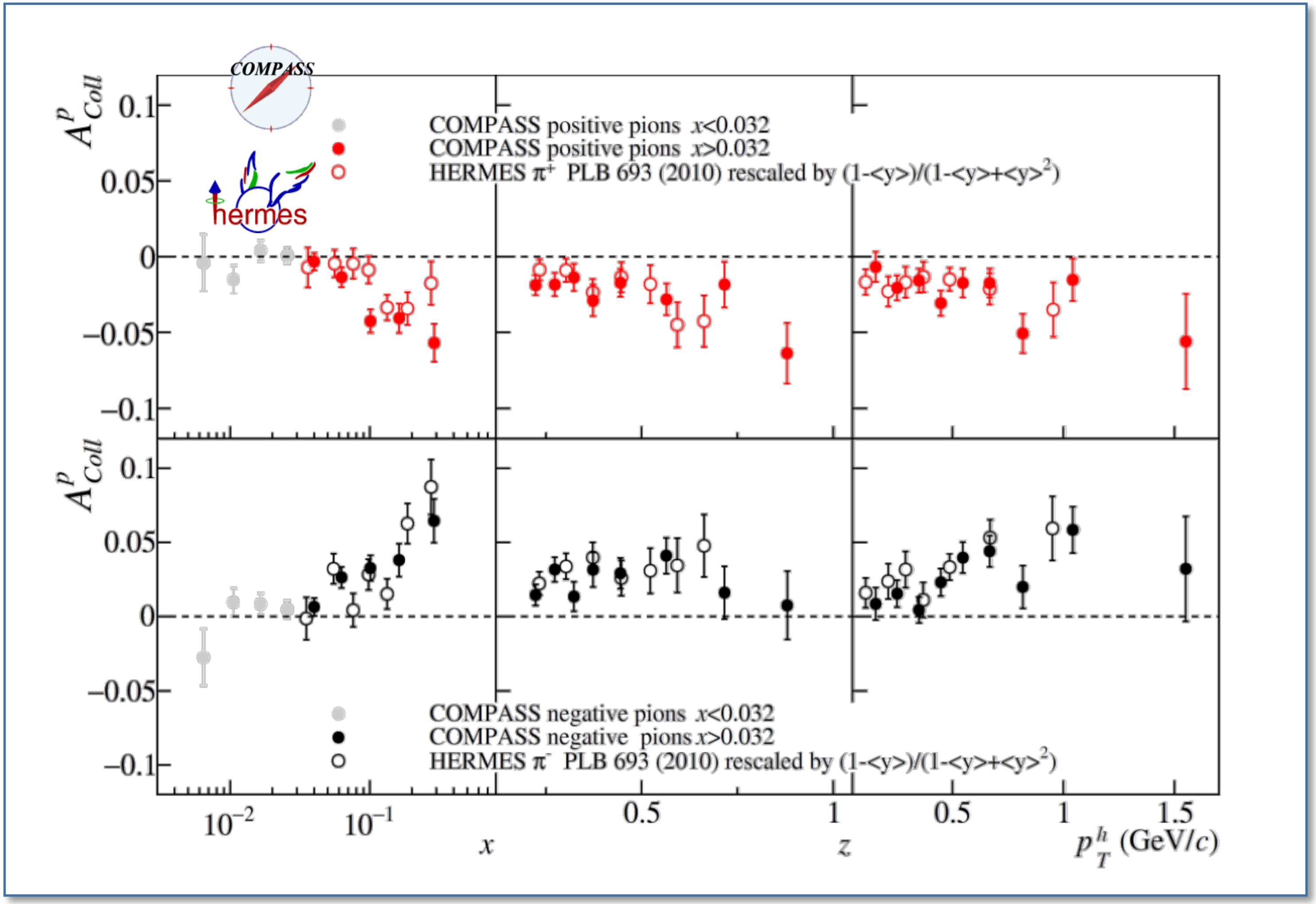
finally, exploratory measurements of di-hadron asymmetries have been performed

could give access to the Boer-Mulders PDF

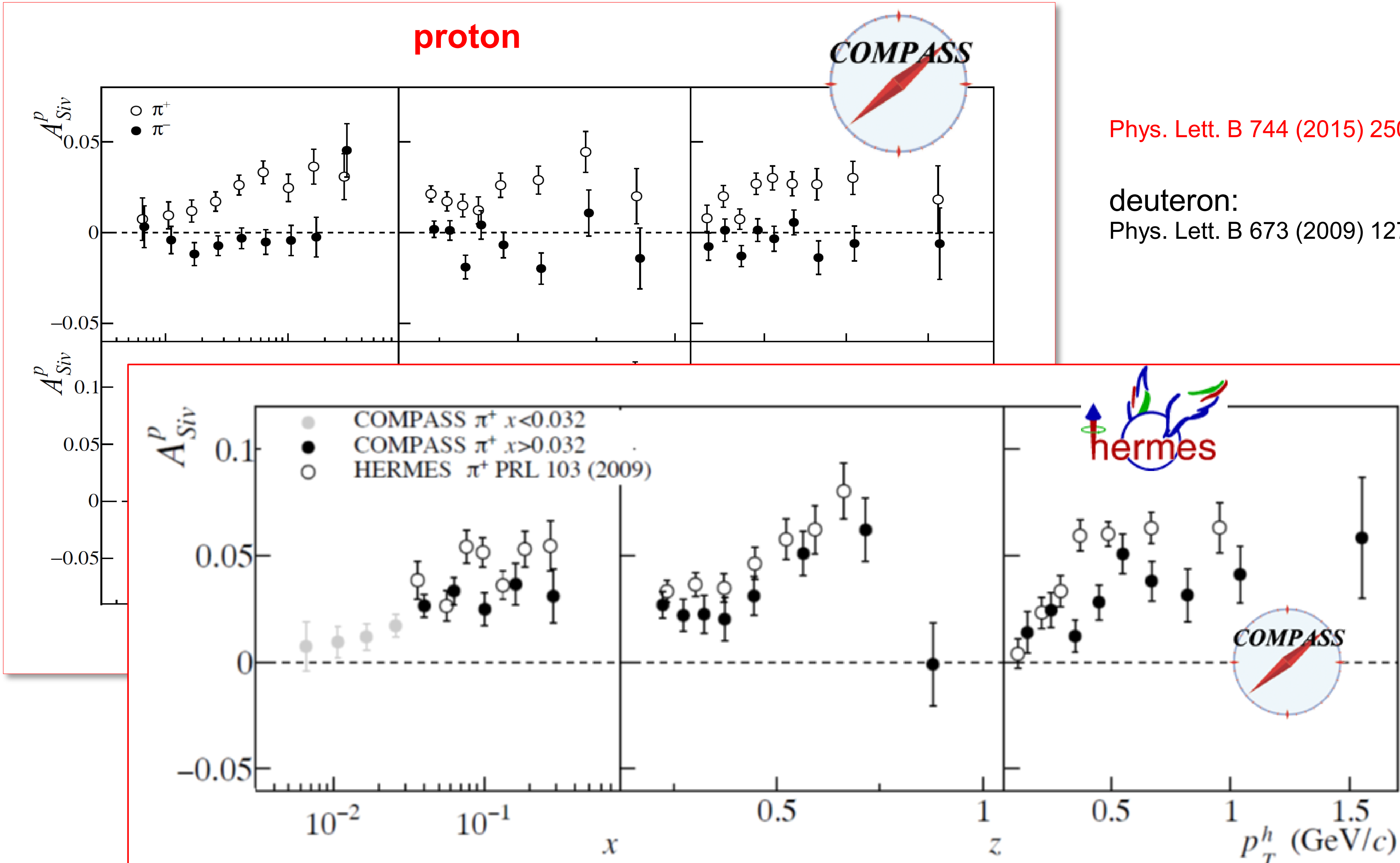


- ϕ_{hh}: azimuthal angle of the pair

Collins asymmetry



Sivers asymmetry

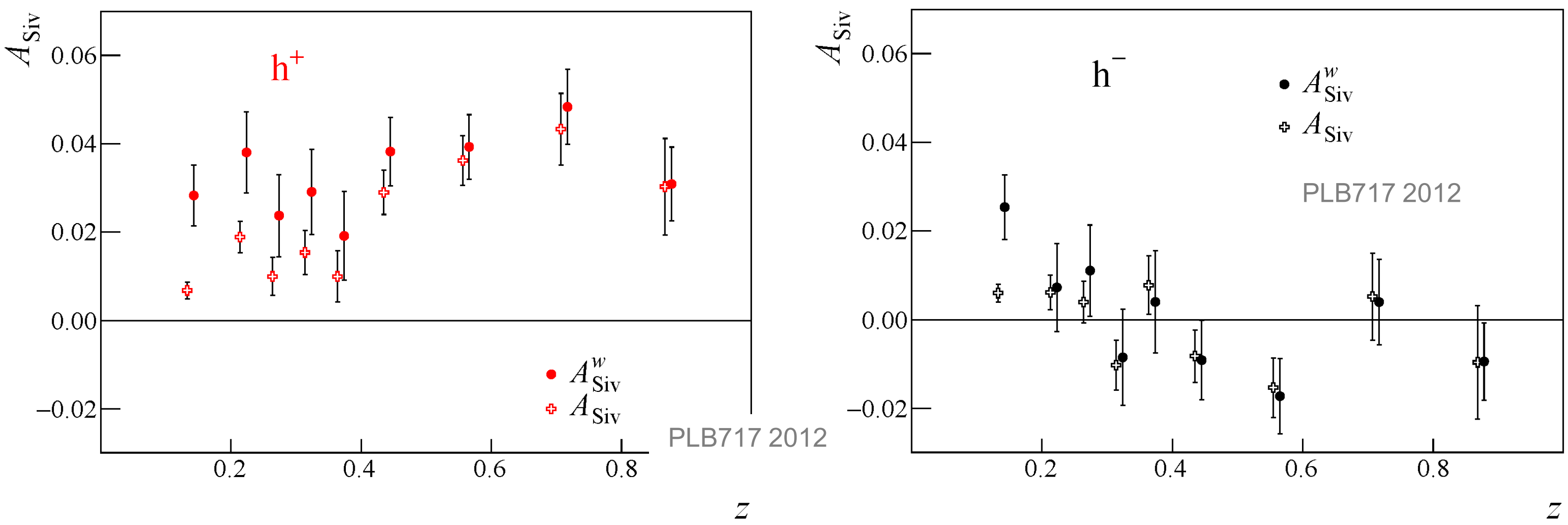


Phys. Lett. B 744 (2015) 250

deuteron:
Phys. Lett. B 673 (2009) 127

P_T weighted Sivers asymmetry

results: $A^{w}_{Siv}(z)$



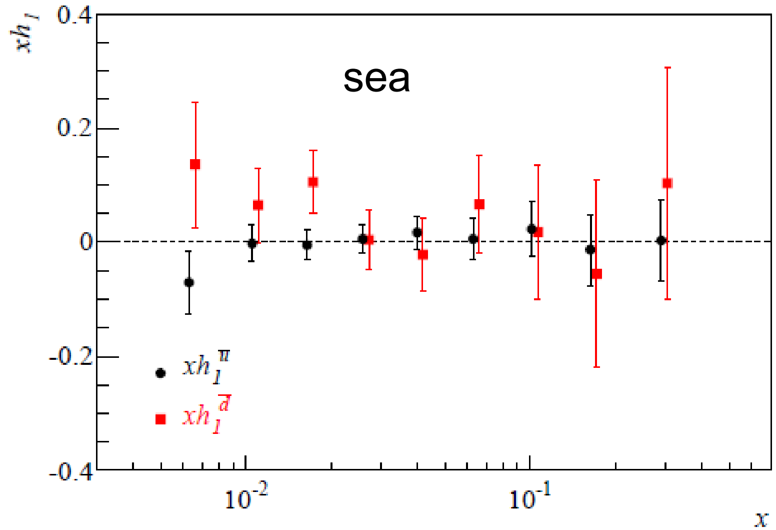
positive hadrons: almost constant values vs z -- u-quark dominance
supports the idea that factorisation works at small z in our kinematic range

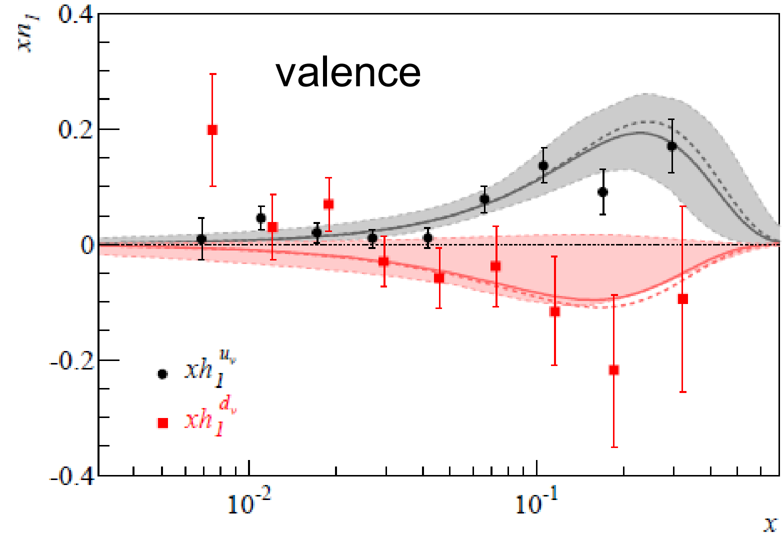
negative hadrons: at small z the asymmetry increases, as already seen

accessing transversity

alternative extraction: results

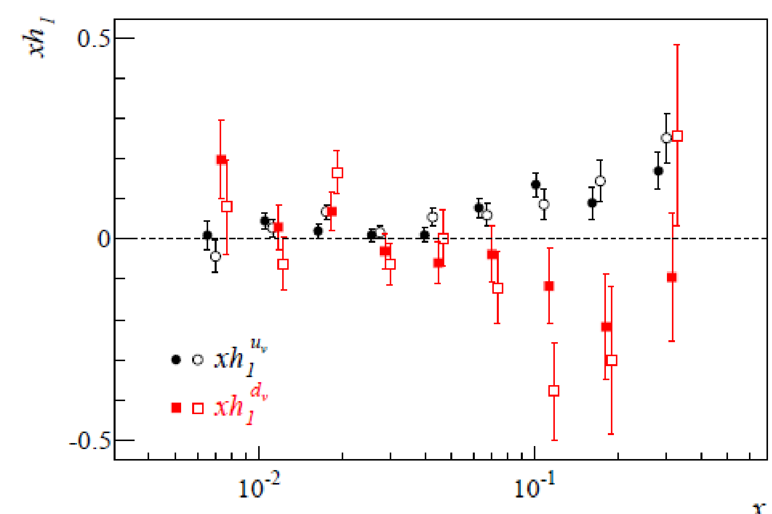
A.M., V. Barone, F. Bradamante
PRD 91 (2015) 1, 014034





curves:
M. Anselmino ett al
PRD 87, 094019 (2013)
Soffer bound.

similar procedure for the di-hadron asymmetries
(no Gaussian Ansatz)



simple and direct model-independent extraction
possible thanks to the fact of having SIDIS p and d data in the same kinematics:
to be considered in the future experiments!

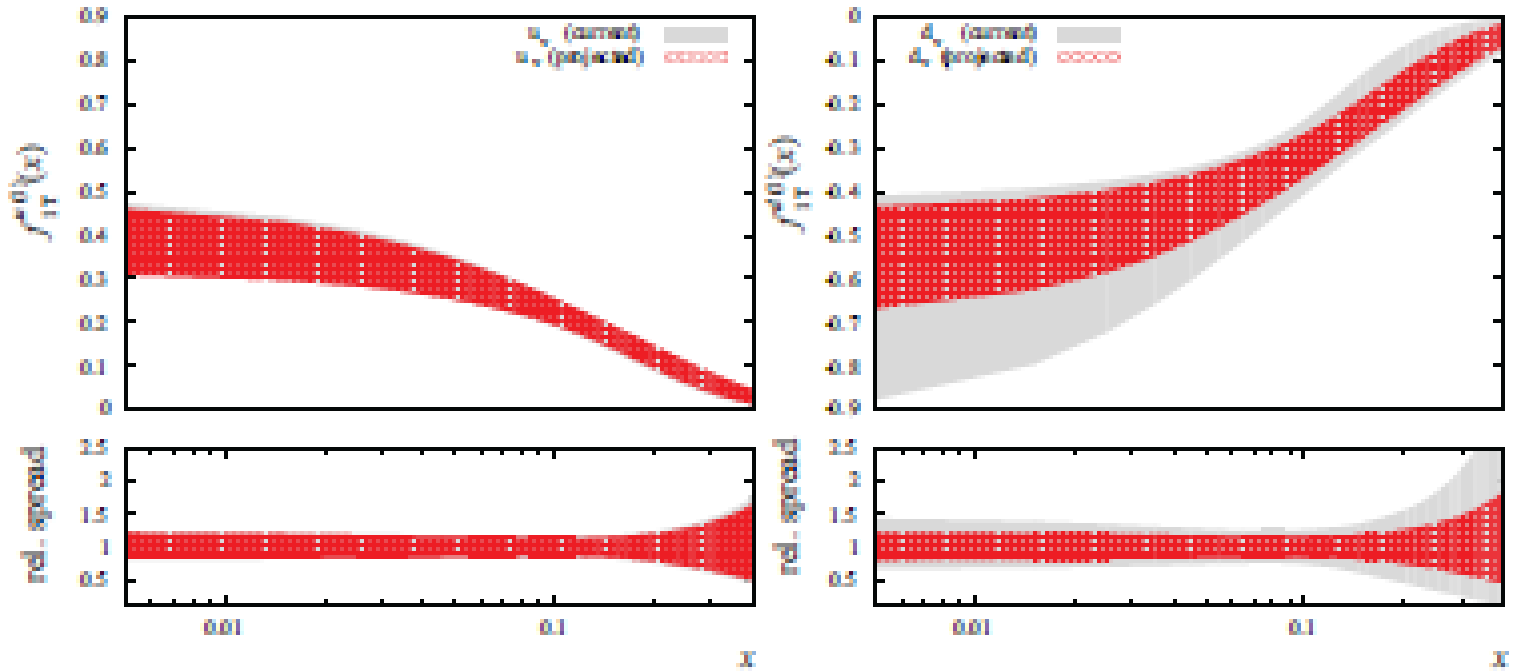


Figure 5: The first moment of the Sivers function from the fit of the Torino Group (private communication), which uses all the HERMES [14], COMPASS [16, 12, 15] and JLab [17, 18] data. The bands correspond to the "current" and "projected" uncertainties for the deuteron asymmetries. Also shown (lower raw) are the relative spreds of the results (see text).

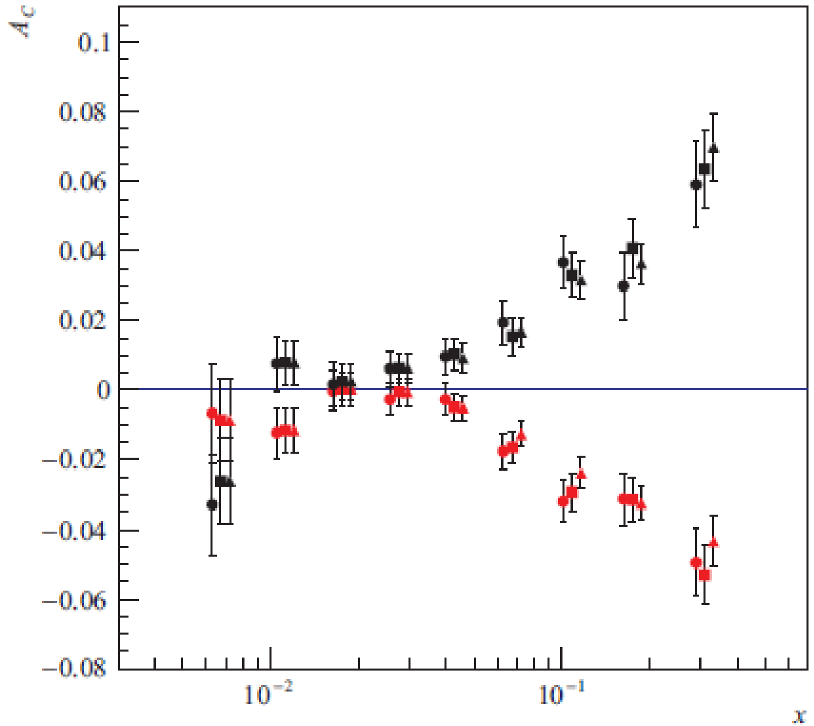


Figure 13: The Collins asymmetry for positive (red) and negative (black) hadrons from the existing proton data. In each x bin, the first point (left to right) is from the 2010 COMPASS run, the second point is from the combined 2007 and 2010 COMPASS data, the third is obtained by adding also the HERMES data.

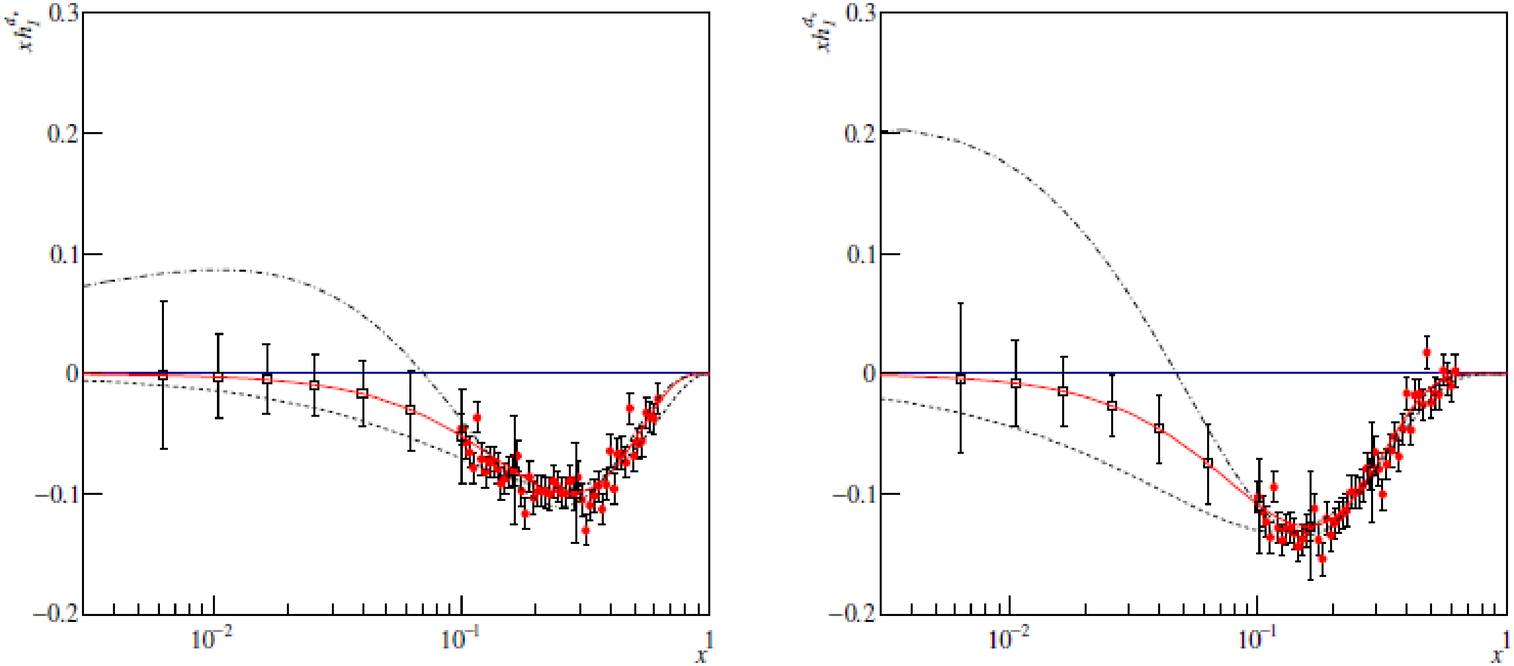


Figure 16