COMPASS future

transverse spin and transverse momentum phenomena in SIDIS

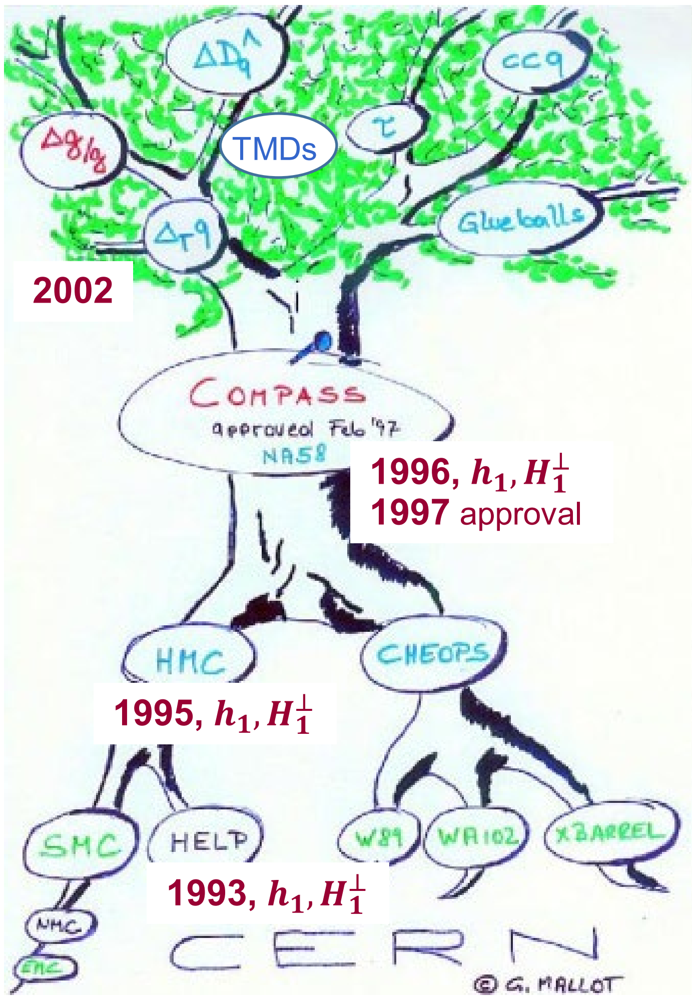
Anna Martin
Trieste University and INFN, sezione di Trieste

Opportunities with JLab
Energy and Luminosity Upgrade
26 September 2022 — 30 September 2022
ECT*, Trento

Outlook

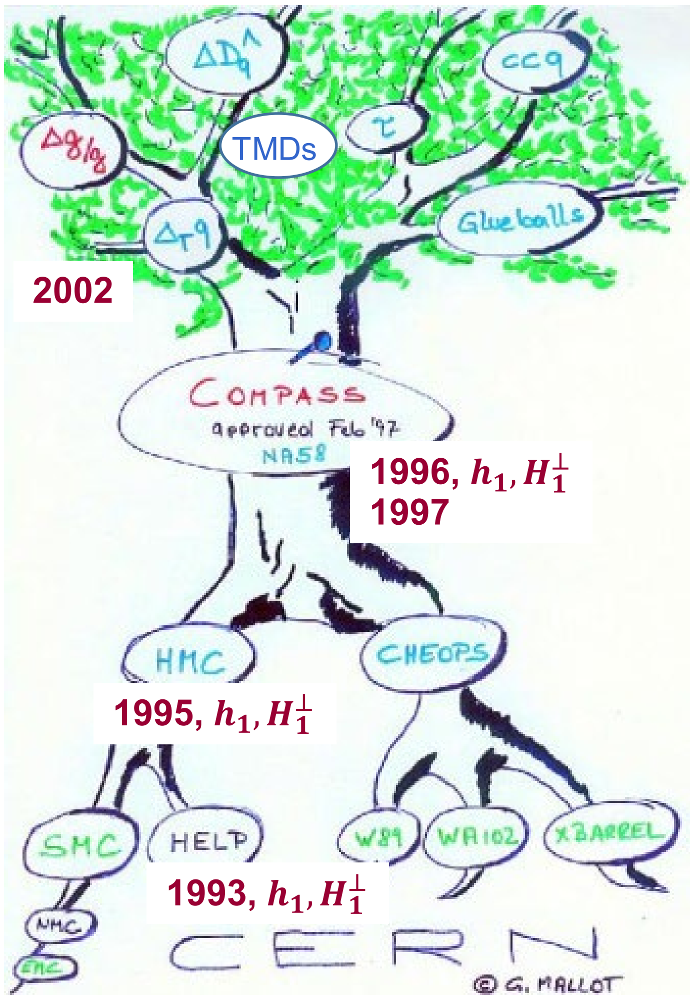
- some history
- the TSAs in SIDIS
    - a few selected results and perspectives
- the unpolarised SIDIS
    - open questions
- possible future directions

some history



some history

2022: **20** years of data taking



,	beam	target	
2002 **2003** **2004**	μ,160 GeV	**P deuteron** (^{6}LiD)	80% L polarisation **20% T** → **U**
2005			acc. shut down / upgrade
2006	μ,160 GeV	**P deuteron**	100% L → **U**
2007	μ,160 GeV	**P proton** (NH_3)	50% L **50% T**
2008/09	hadron	LH_2	spectroscopy, Primakoff
2010	μ,160 GeV	**P proton**	**100% T**
2011	μ, 200 GeV	P proton	100% L
2012	hadron	Ni target	Primakoff & pilot DVCS
2013			acc. shut down
2014	π	proton	pilot Drell-Yan
2015	π	P proton	100% T, Drell-Yan
2016/17	μ , 160 GeV	**LH_2**	DVCS, **unpol. SIDIS**
2018	pion beam	P proton	100% T, Drell-Yan
2019/20			acc. shut down
2021	μ,160 GeV	deuteron	running in, SIDIS
2022	μ,160 GeV	**P deuteron**	**100% T** → ***U***

some history

SIDIS off transversely polarized deuteron and proton targets

	beam	target	
2002 **2003** **2004**	μ,160 GeV	**P deuteron** (^{6}LiD)	**20% T**
2005			acc. shut down / upgrade
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2010	μ,160 GeV	**P proton**	**100% T**
2022	μ,160 GeV	**P deuteron**	**100% T**

some history

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2010	μ,160 GeV	**P proton**	**100% T**
2022	μ,160 GeV	**P deuteron**	**100% T**

results published in 2005-2009

results published in 2010-2012

results published in 2012-….

data collected with
- the same beam energy (as in SMC for inclusive DIS)
- the same large acceptance, after the 2005 upgrade
- the same binning in the kinematic variables

in order to make easier the comparison between data collected wiith different targets

data taking ongoing

some history

SIDIS off unpolarised deuteron and proton targets

	beam	target		
2004	μ,160 GeV	**P deuteron** (^{6}LiD)	80% L polarisation **20% T**	→ **U**
2005			acc. shut down / upgrade	
2006	μ,160 GeV	**P deuteron**	100% L	→ **U**
2016/17	μ , 160 GeV	**LH_2**	DVCS, **unpol. SIDIS**	
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some history

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2016/17	μ , 160 GeV	**LH_2**	DVCS, **unpol. SIDIS**	
2022	μ,160 GeV	**P deuteron**	**100% T**	→ ***U***

results published in 2013 2014

results published in 2018

no dedicated data taking:
“parasitic” measurements

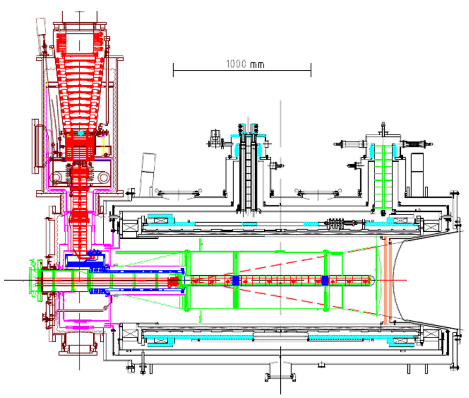
first results, paper in preparation

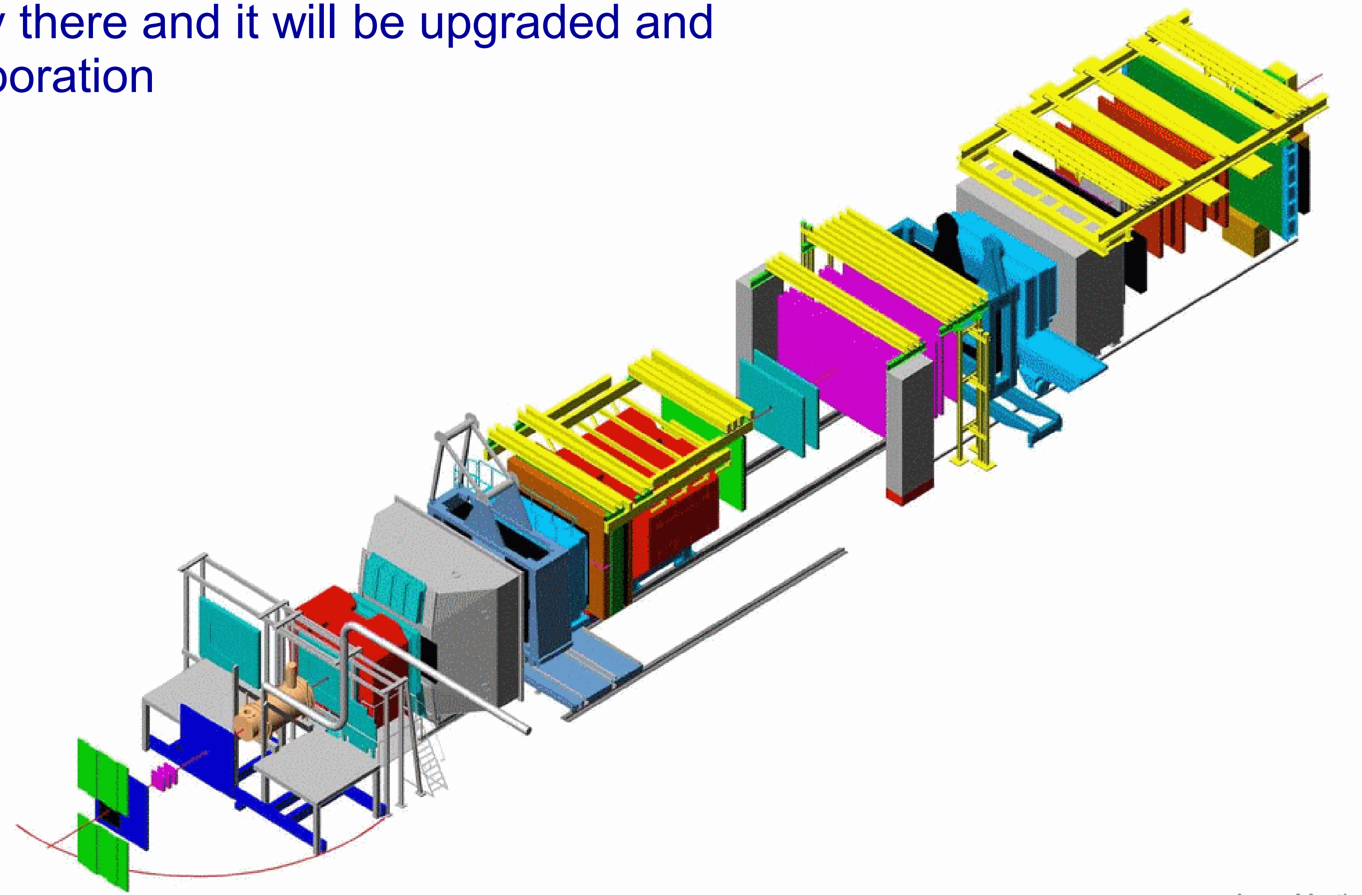
some history

the 2022 data taking is the last run of the COMPASS experiment, and the last of the exploratory study of the nucleon structure

at CERN, COMPASS will change from “**data taking**” to “**data analysis**” and will continue for several years

the spectrometer will stay there and it will be upgraded and run by the AMBER Collaboration





Transverse Spin Asymmetries in SIDIS off transversely polarised targets

a few selected results

more results → Bakur Parsamyan

COMPASS

TSA in SIDIS

a long list of measurements

d & p	Collins and Sivers asymmetries (1D)	several papers
d & p	di-hadron asymmetries	several papers
d & p	other TSAs	
p	multiD measurements of TSAs (x, Q^2, z, P_T) $bins$	
p	Sivers 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	
p	inclusive ρ^0 TSAs	paper ready

all to be done again using the 2022 data

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Collins asymmetry

SIDIS cross-section

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

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

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

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

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

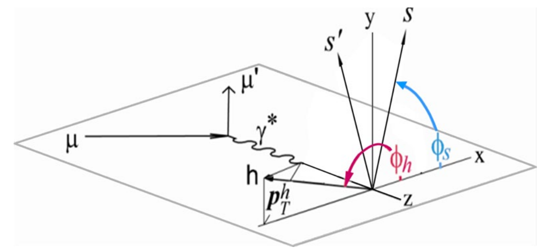
$$+\,|\boldsymbol{S}_{\perp}|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

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

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

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

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



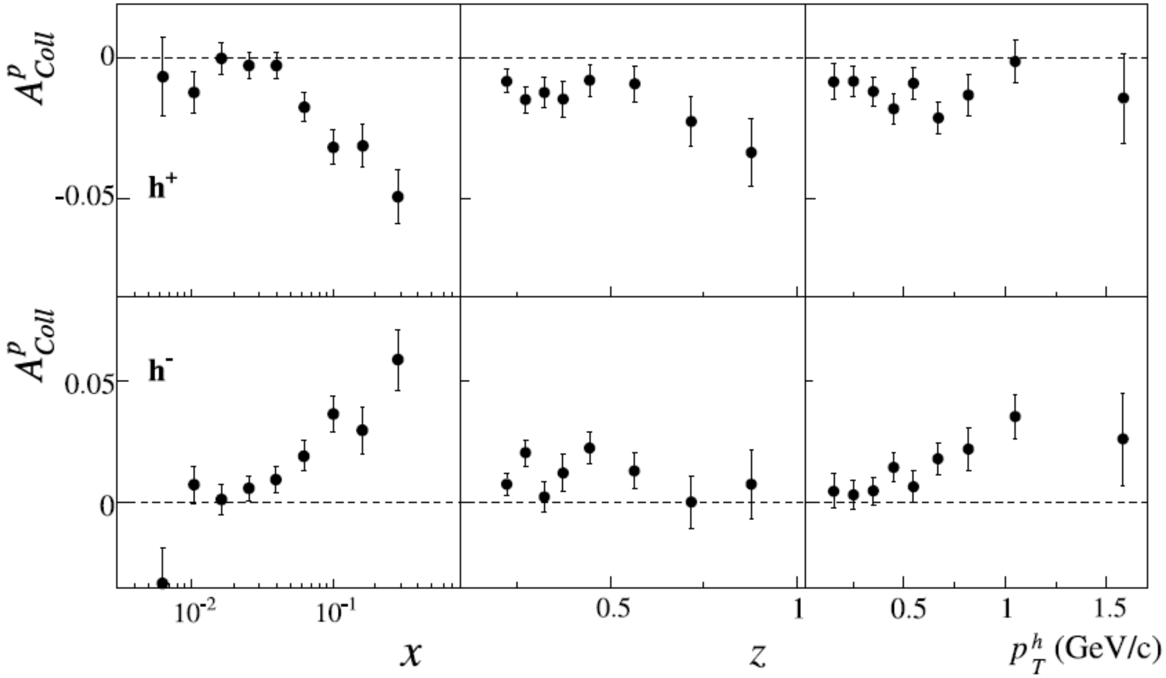
in the parton model

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

Collins asymmetry

proton target - results

2010 data PLB 717 (2012) 376



very clear signal
in the valence region

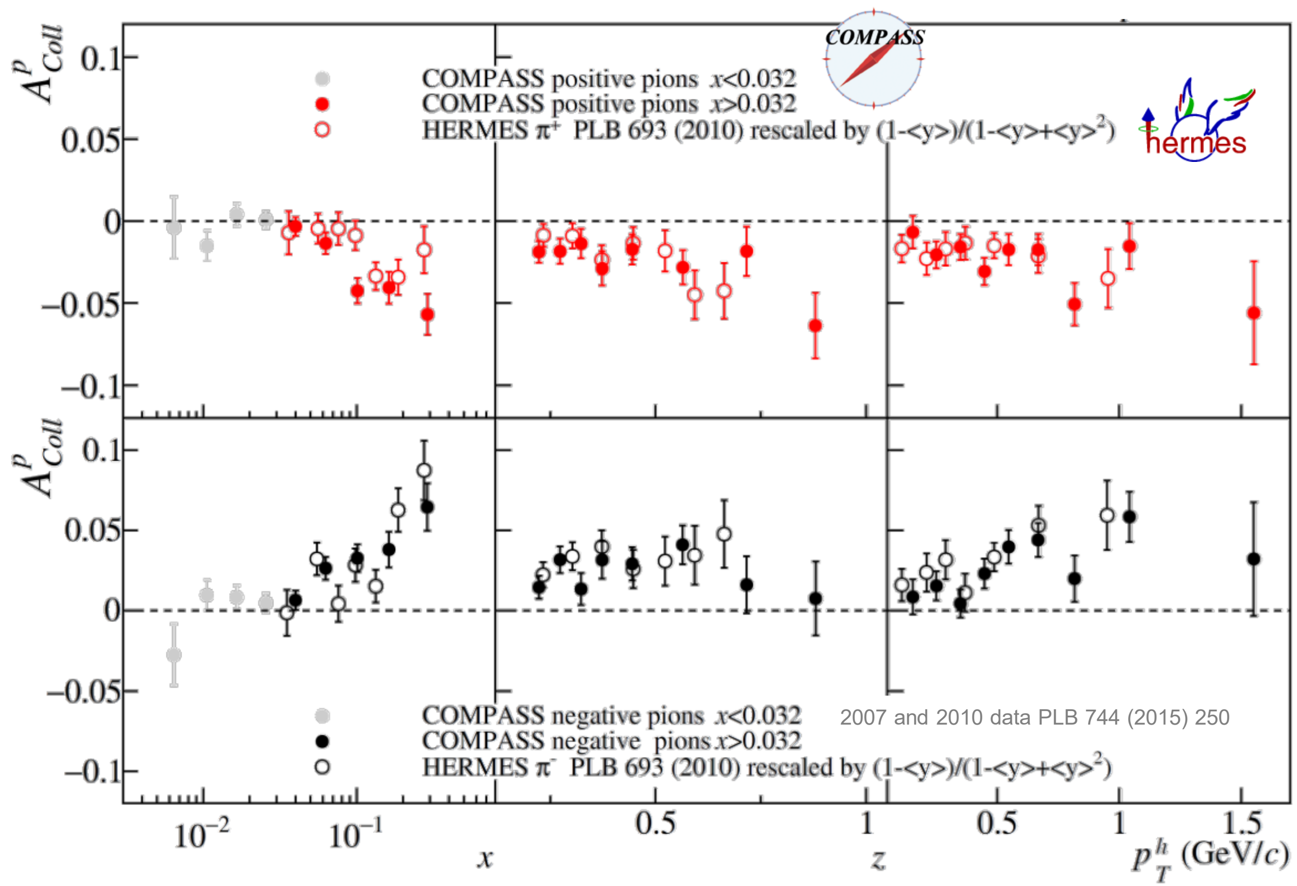
opposite sign for h^+ and h^-
mirror symmetry vs x

interesting z and P_T^h dependence

Collins asymmetry

proton target - results

very good agreement with the 2010 **HERMES** results



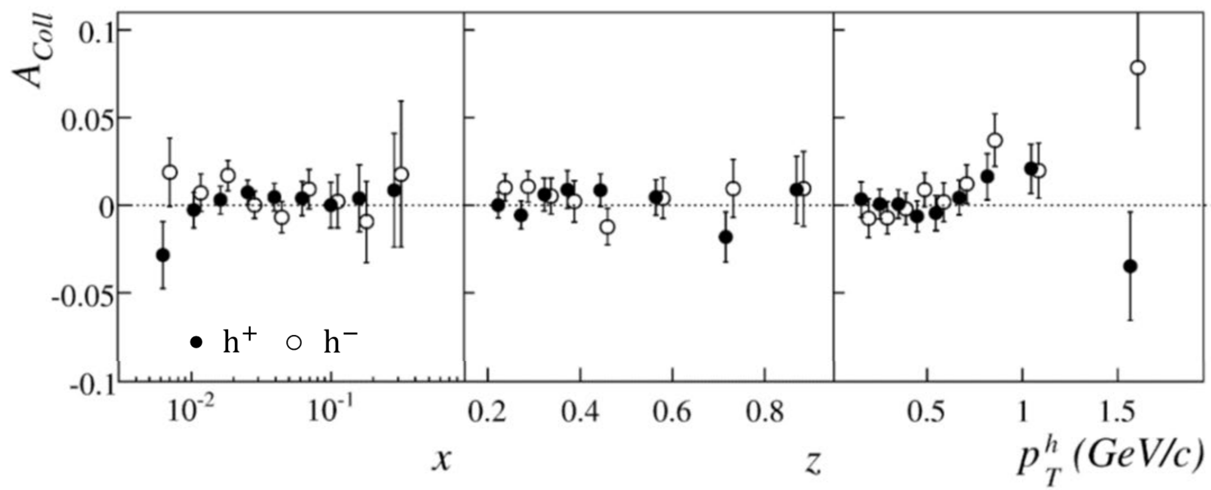
Collins asymmetry

deuteron target - results

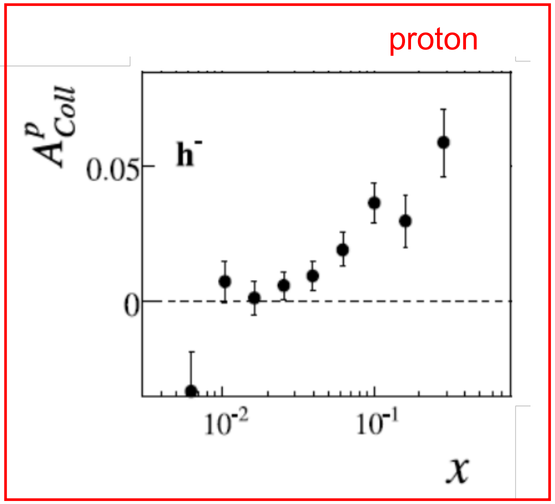
compatible with zero

some signal at $P_T^h \simeq 1$ GeV/c ?

all deuteron 2002-2004 data NPB765 (2007) 31



interpreted as cancellation between u and d quark contributions



Collins asymmetry

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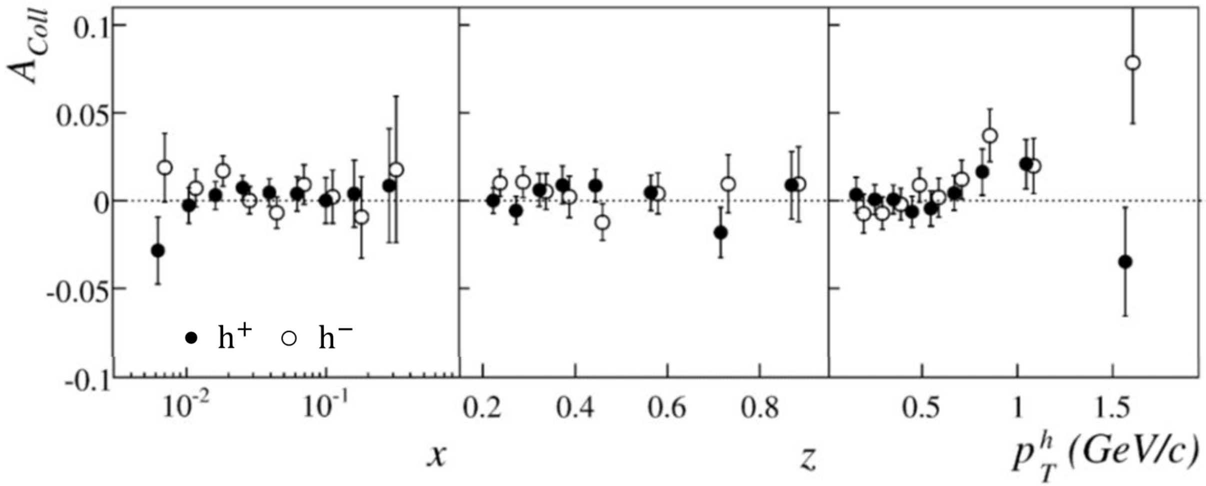

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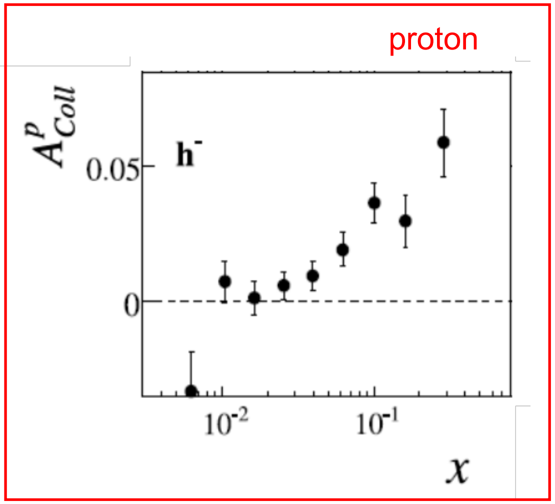


large statistical errors, as compared to the proton data

only existing d data

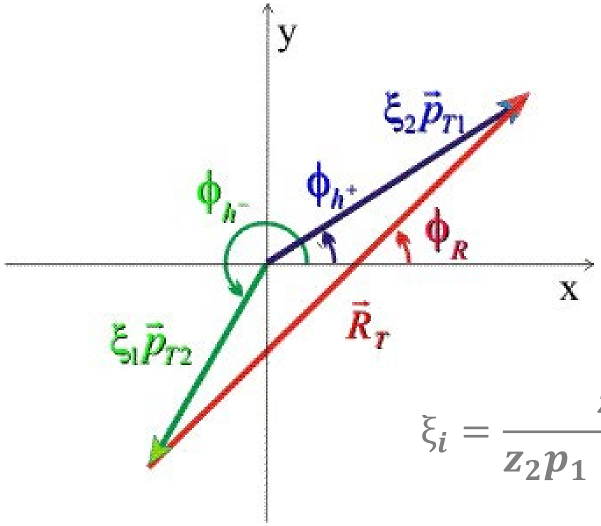
(low statistics He3 measurement at Jlab)

motivation for the 2022 COMPASS run

di-hadron asymmetry

$$A_{hh} \sim \frac{\sum_q e_q^2\, h_1^q \cdot H_{1q}^{\angle}}{\sum_q e_q^2\, f_1^q \cdot D_{1q}}$$

amplitude of the sin modulation
in the distribution
of the azimuthal angle $(\phi_R + \phi_S)$



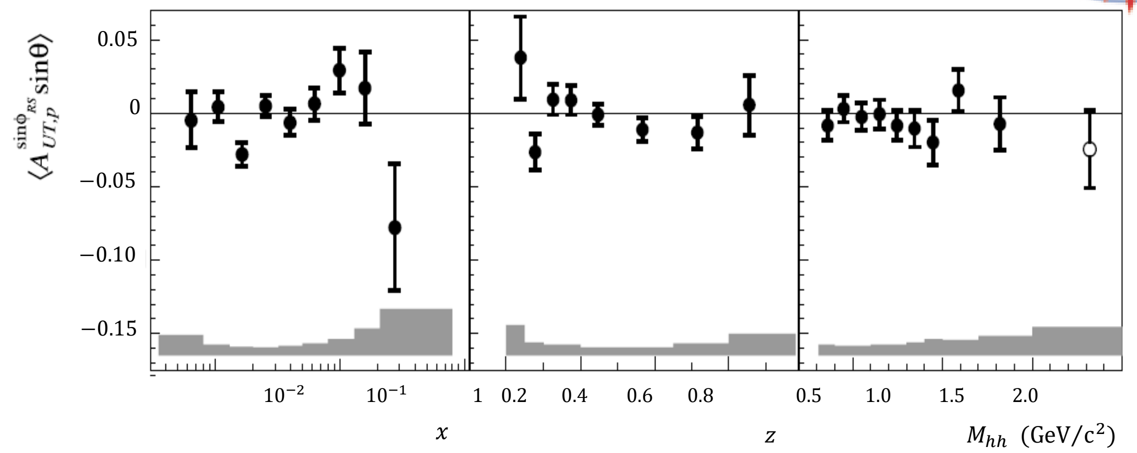
$$\xi_i = \frac{z_i}{z_2 p_1 + z_1 p_2}$$

di-hadron asymmetry

$$A_{hh} \sim \frac{\sum_q e_q^2\, h_1^q \cdot H_{1q}^{\angle}}{\sum_q e_q^2\, f_1^q \cdot D_{1q}}$$

deuteron

PLB 713 (2012) 10



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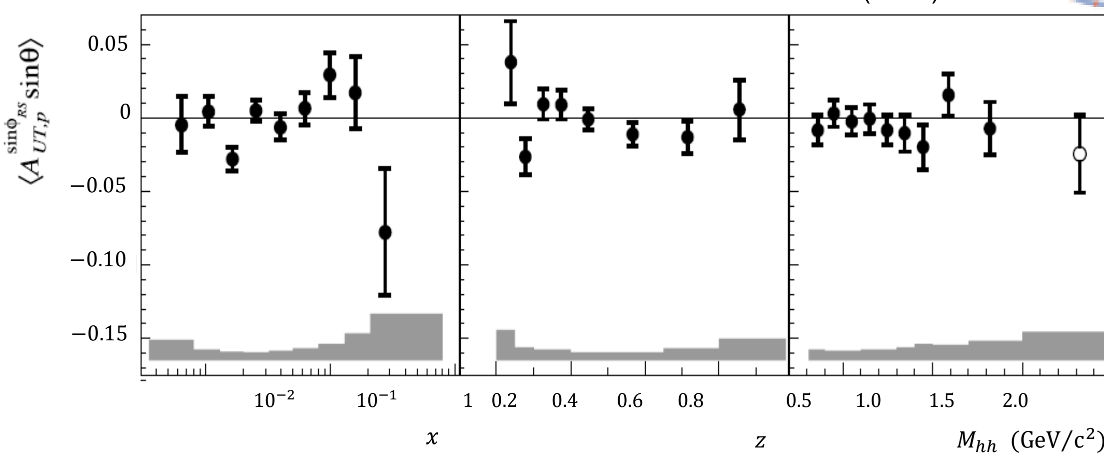
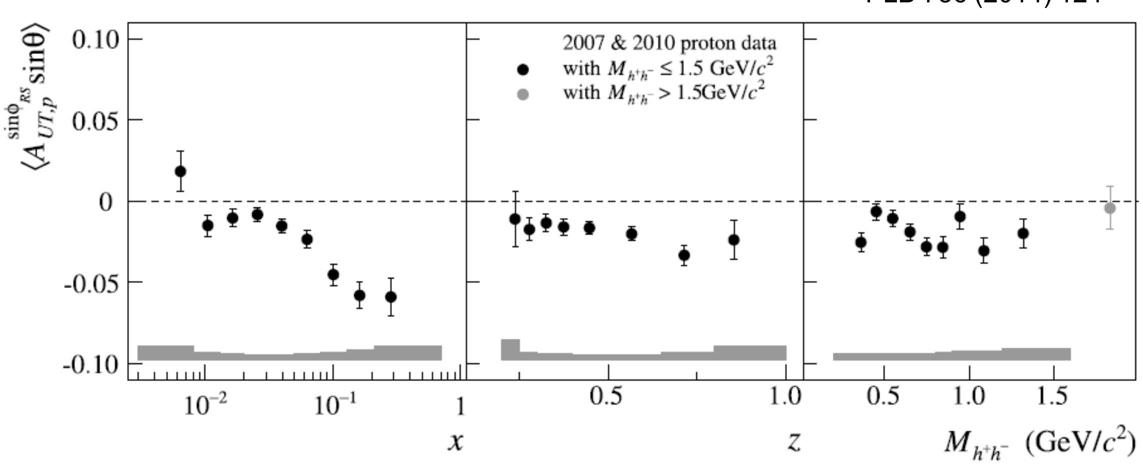
PLB 713 (2012) 10

deuteron

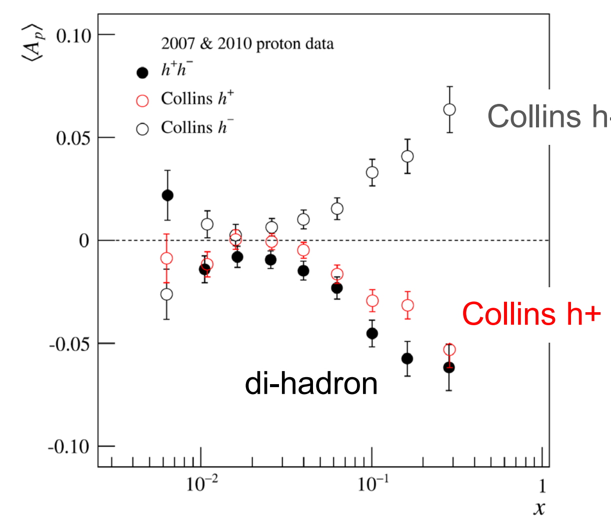


proton

PLB 736 (2014) 124



interplay
PLB 736 (2014) 124



accessing transversity

all the p and d HERMES and COMPASS SIDIS data, and the $e^+e^- \rightarrow hadrons$ Belle data, could be fitted to extract the transversity PDF and the corresponding spin-dependent FFs

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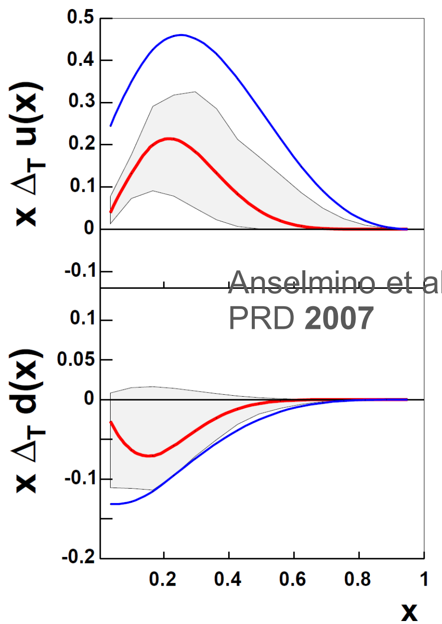
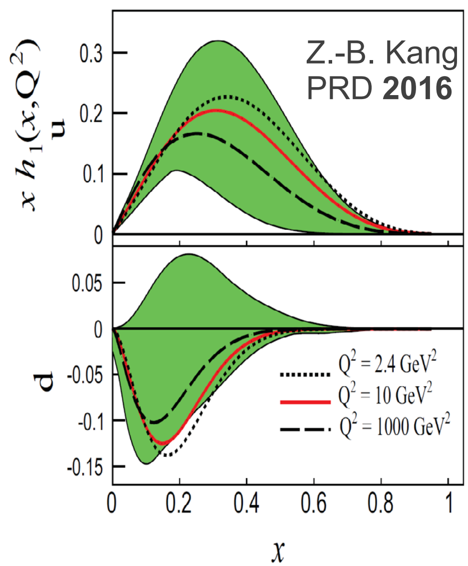
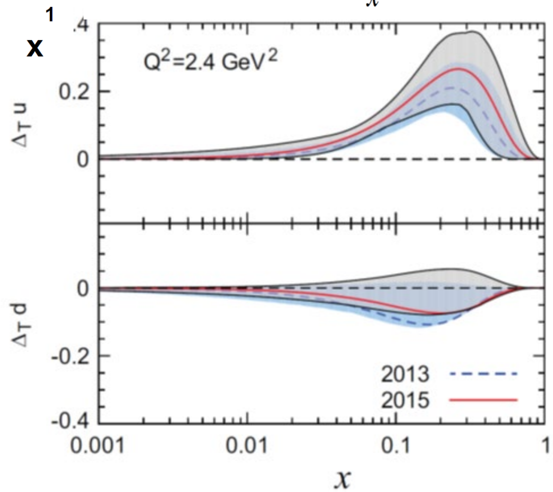
fits of **Collins asymmetries**



Anselmino et al
PRD **2007**



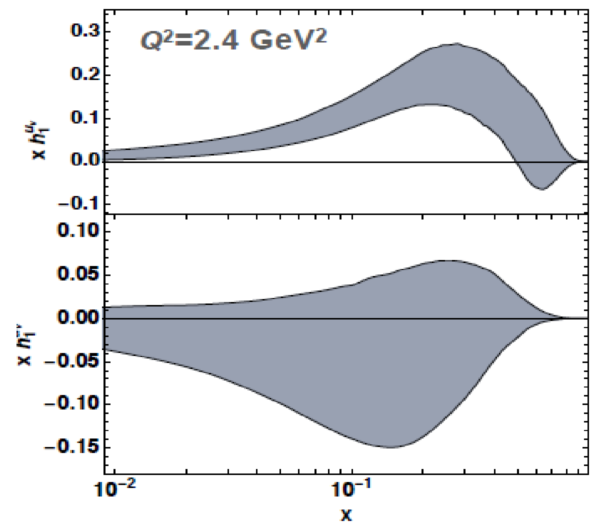
Z.-B. Kang et al.
PRD **2016**



M. Anselmino et al.
PRD **2015**

fits of **di-hadron asymmetries**

Radici Bacchetta PRL **2018**



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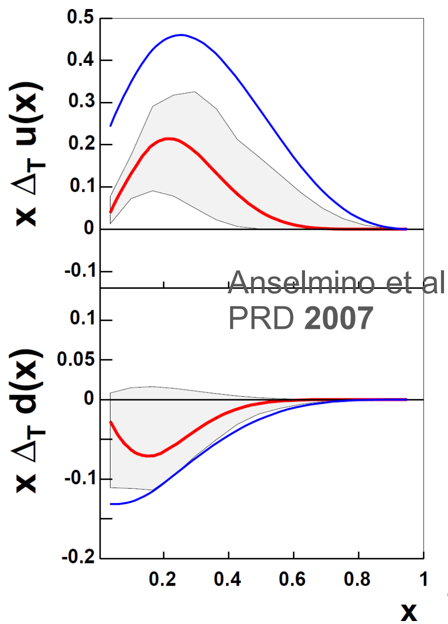

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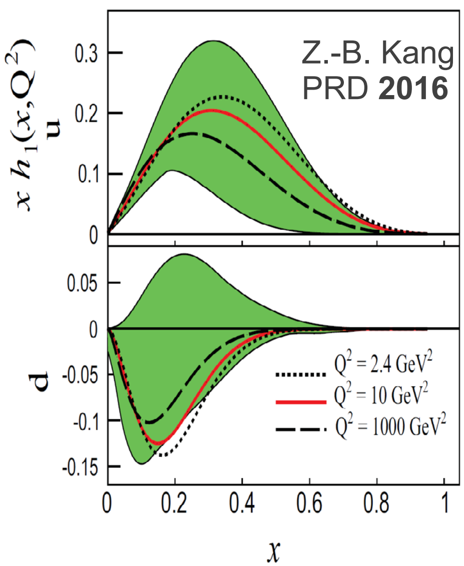

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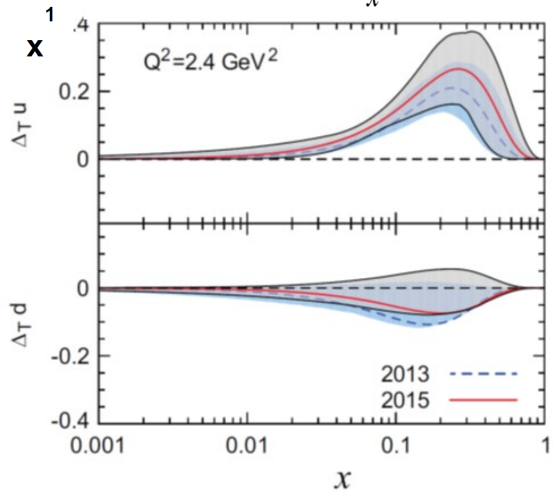

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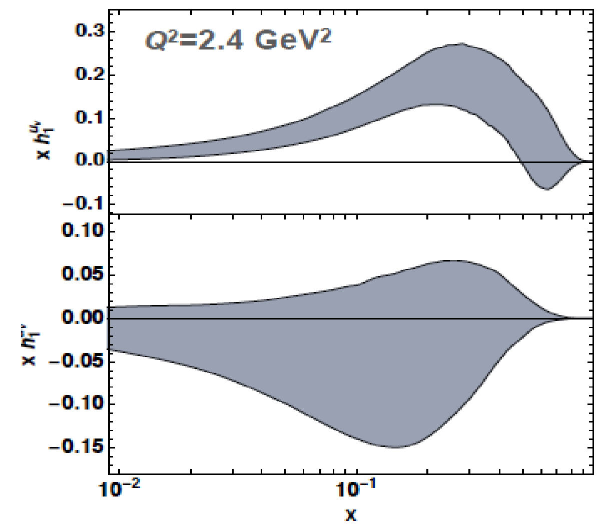

very important results:
the TMD framework allows to well describe all the existing SIDIS and e^+e^- data

work ongoing, adding the new pp data …

accessing transversity

alternative extraction: taking advantage of the fact that the COMPASS Collins asymmetries on p and d are measured in the same kinematic region with the same x binning, one can measure the **transversity PDF in each x bin**, using COMPASS and BELLE results

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

using the Gaussian Ansatz for the TM distributions, analytical solution:

$$xh_1^{u_v} = \frac{1}{5}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha})}\left[(xf_p^+ A_p^+ - xf_p^- A_p^-) + \frac{1}{3}(xf_d^+ A_d^+ - xf_d^- A_d^-)\right]$$

$$xh_1^{d_v} = \frac{1}{5}\frac{1}{\tilde{a}_P^h(1-\tilde{\alpha})}\left[\frac{4}{3}(xf_d^+ A_d^+ - xf_d^- A_d^-) - (xf_p^+ A_p^+ - xf_p^- A_p^-)\right]$$

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combinations of unpolarised PDFs and FFs, known

accessing transversity

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combinations of unpolarised PDFs and FFs, known

$$\tilde{a}_P^h(Q^2) = \frac{\tilde{H}_{1,\mathrm{fav}}^{\perp(1/2)}(Q^2)}{\tilde{D}_{1,\mathrm{fav}}(Q^2)}$$

$$\tilde{\alpha}(Q^2) = \frac{\tilde{H}_{1,\mathrm{unf}}^{\perp(1/2)}(Q^2)}{\tilde{H}_{1,\mathrm{fav}}^{\perp(1/2)}(Q^2)}$$

from BELLE results

assuming either $H_{1,\mathrm{fav}}^{\perp(1/2)}(z,Q^2) = -H_{1,\mathrm{unf}}^{\perp(1/2)}(z,Q^2)$

or $\dfrac{H_{1,\mathrm{unf}}^{\perp(1/2)}(z,Q^2)}{H_{1,\mathrm{fav}}^{\perp(1/2)}(z,Q^2)} = -\dfrac{D_{1,\mathrm{unf}}(z,Q^2)}{D_{1,\mathrm{fav}}(z,Q^2)}$

and that the Collins function evolves in Q^2 as the unpolarised FF or that it is constant

→ *very close results in the 4 cases*

accessing transversity

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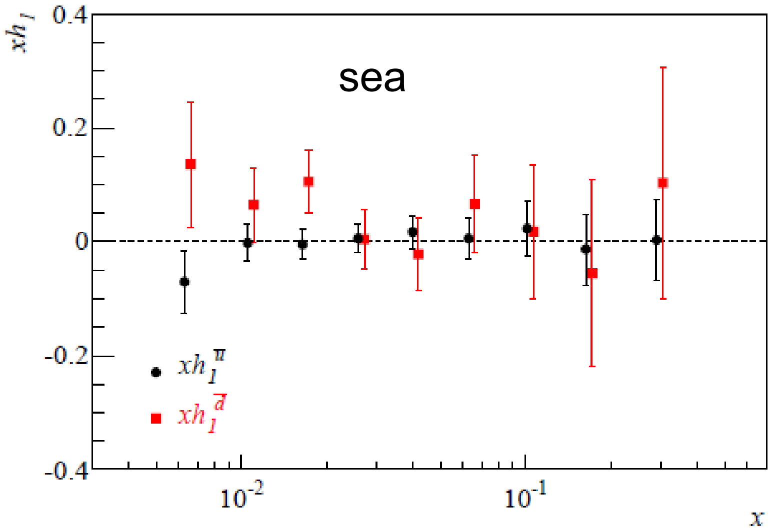
$$xh_1^{\bar{u}} = \frac{1}{15}\frac{1}{\widetilde{a}_P^h(1-\widetilde{\alpha}^2)}\left[(1-4\widetilde{\alpha})\,xf_p^+A_p^+ + (4-\widetilde{\alpha})\,xf_p^-A_p^- - xf_d^+A_d^+ + \widetilde{\alpha}\,xf_d^-A_d^-\right],$$

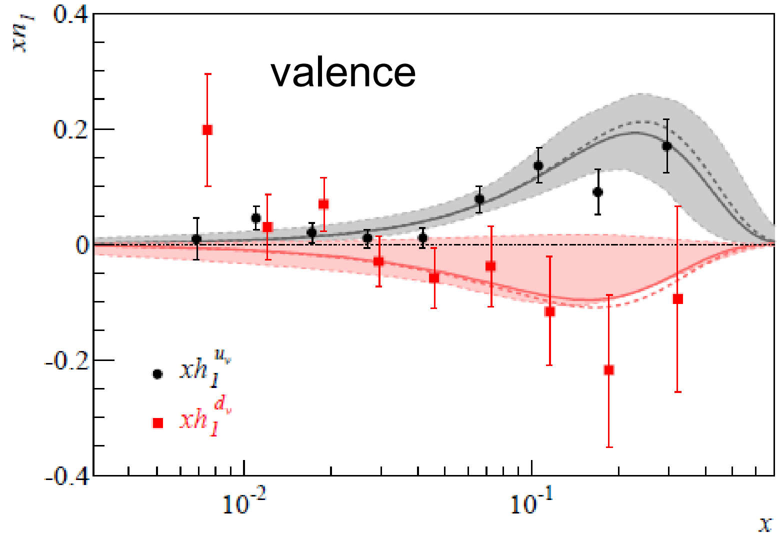
$$xh_1^{\bar{d}} = \frac{1}{15}\frac{1}{\widetilde{a}_P^h(1-\widetilde{\alpha}^2)}\left[(4\widetilde{\alpha}-1)\,xf_p^+A_p^+ - (4-\widetilde{\alpha})\,xf_p^-A_p^- - 4\widetilde{\alpha}\,xf_d^+A_d^+ + 4\,xf_d^-A_d^-\right]$$

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.

accessing transversity

alternative extraction: results

A.M., V. Barone, F. Bradamante
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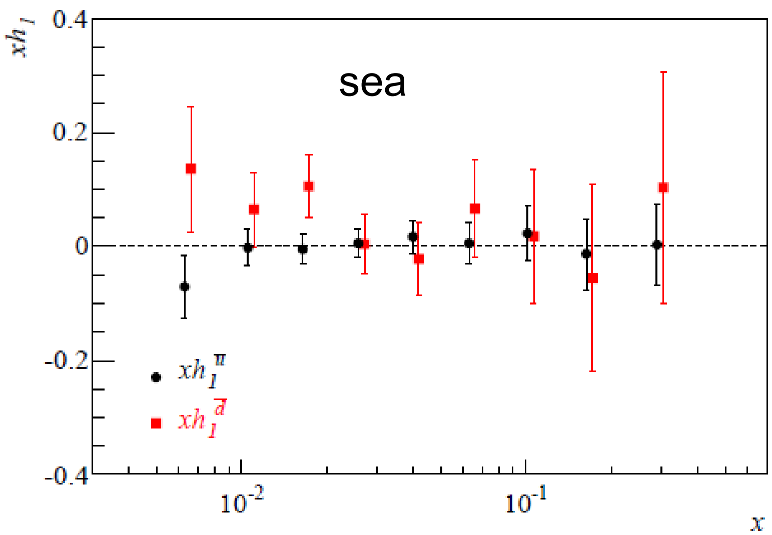

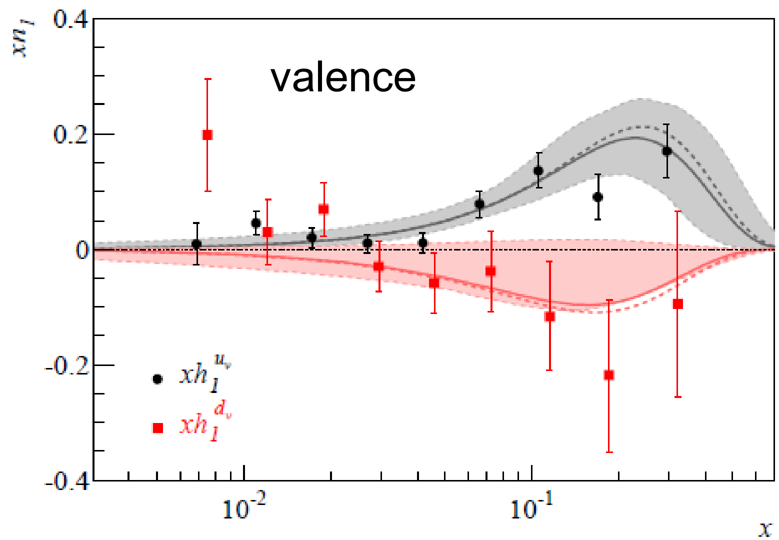

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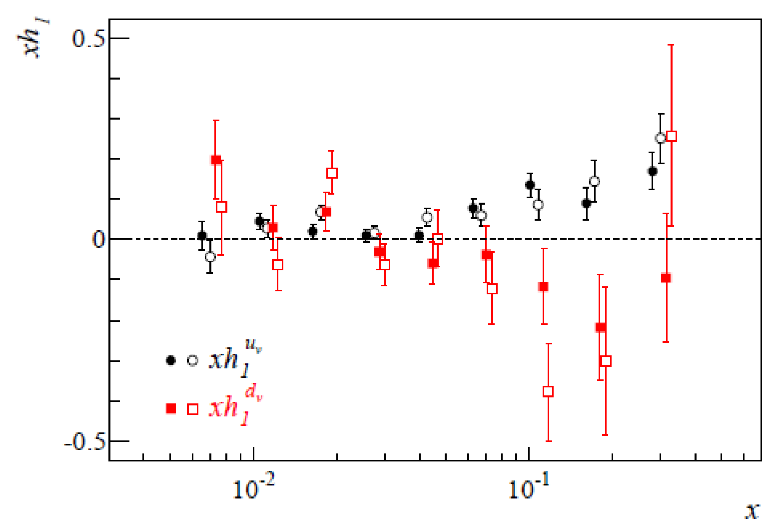
similar procedure for the di-hadron asymmetries
(no Gaussian Ansatz)



accessing transversity

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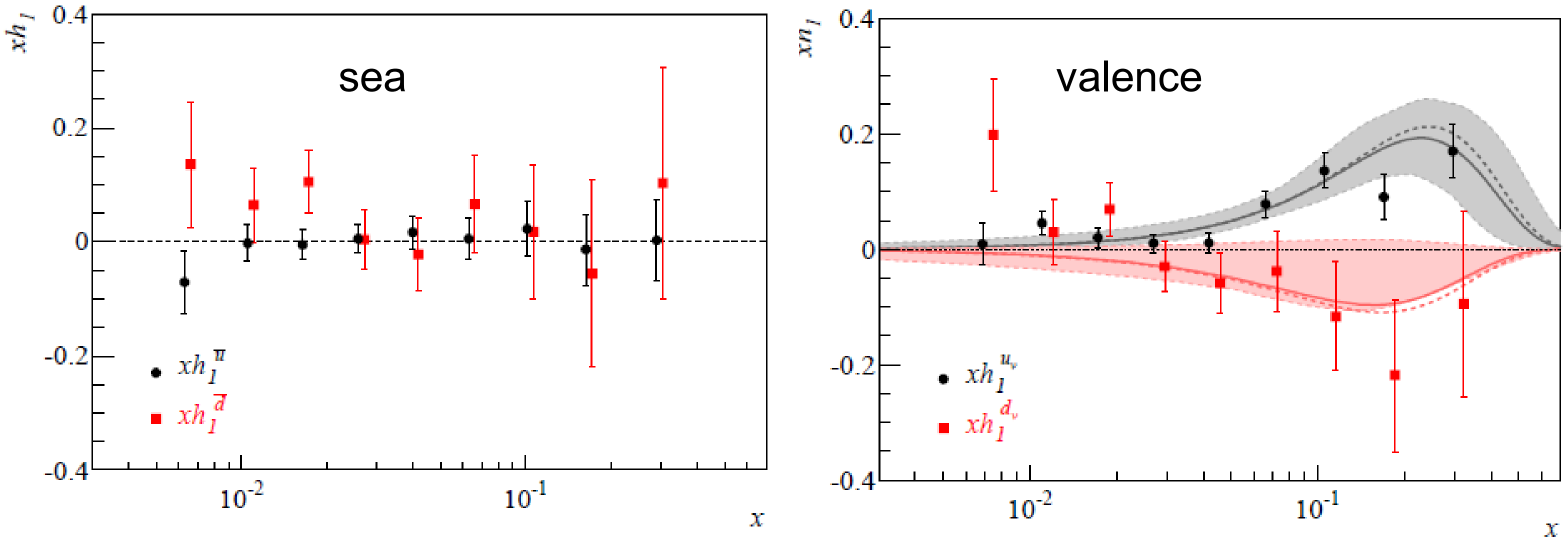
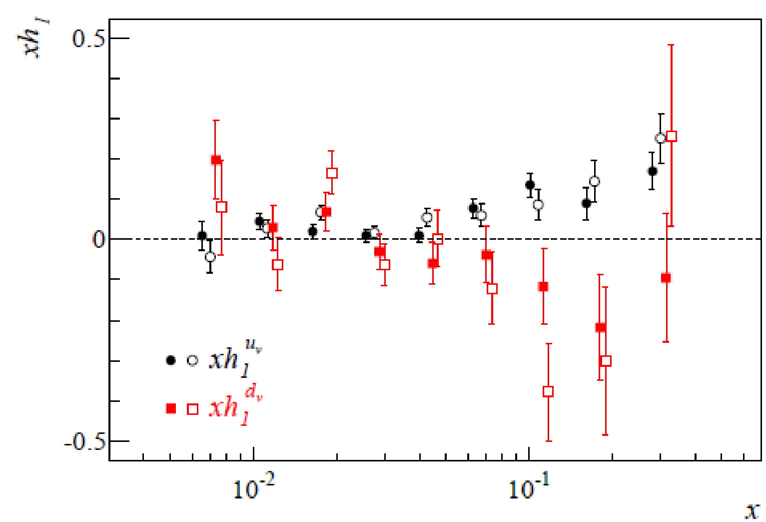
A.M., V. Barone, F. Bradamante
PRD 91 (2015) 1, 014034



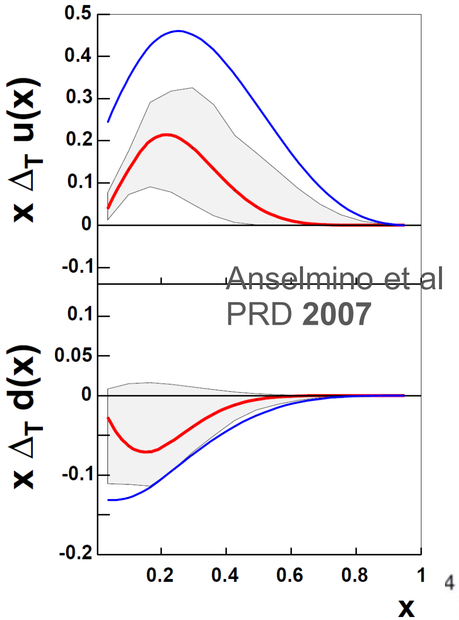
curves:
M. Anselmino ett al
PRD 87, 094019 (2013)
Soffer bound.

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

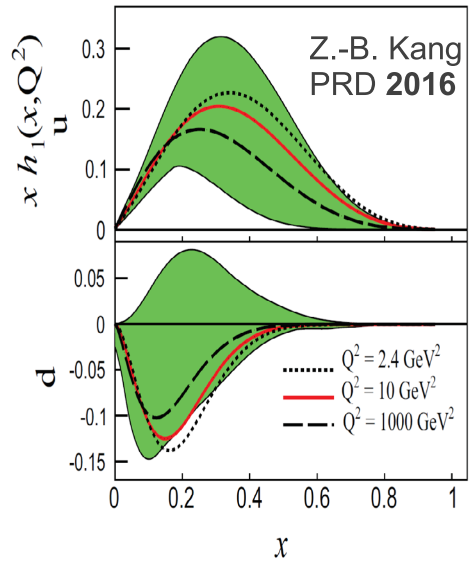
simple and direct model-independent extraction
possible thanks to the fact of having SIDIS p and d data in the same kinematics:
to be considered in the future experiments!



accessing transversity

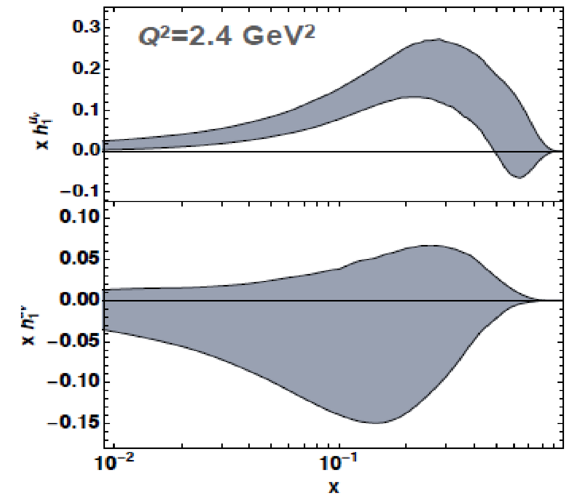


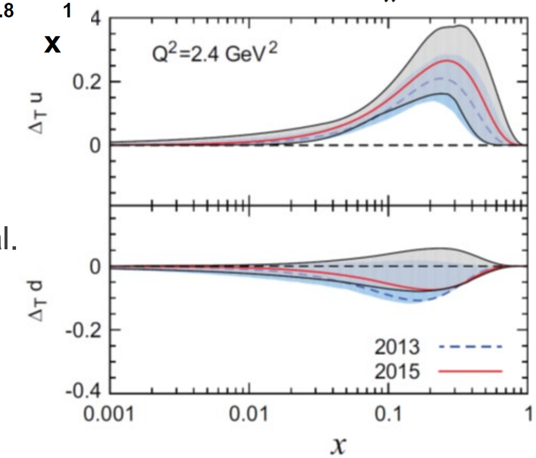
Anselmino et al
PRD **2007**



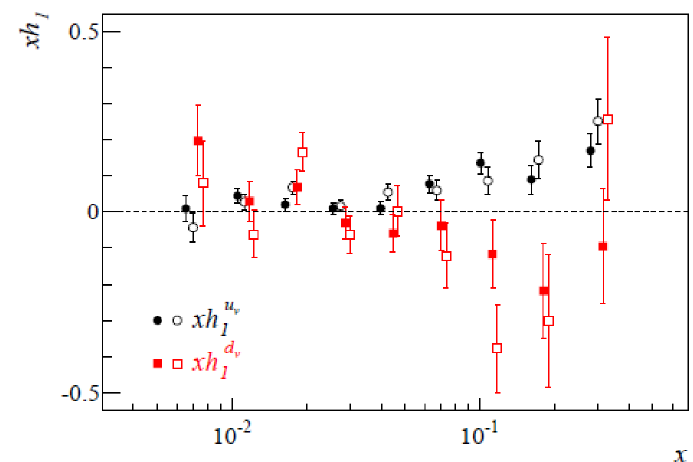
Z.-B. Kang et al.
PRD **2016**

Radici Bacchetta PRL **2018**





M. Anselmino et al.
PRD 2015



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

from the existing SIDIS data, it is clear that

- 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

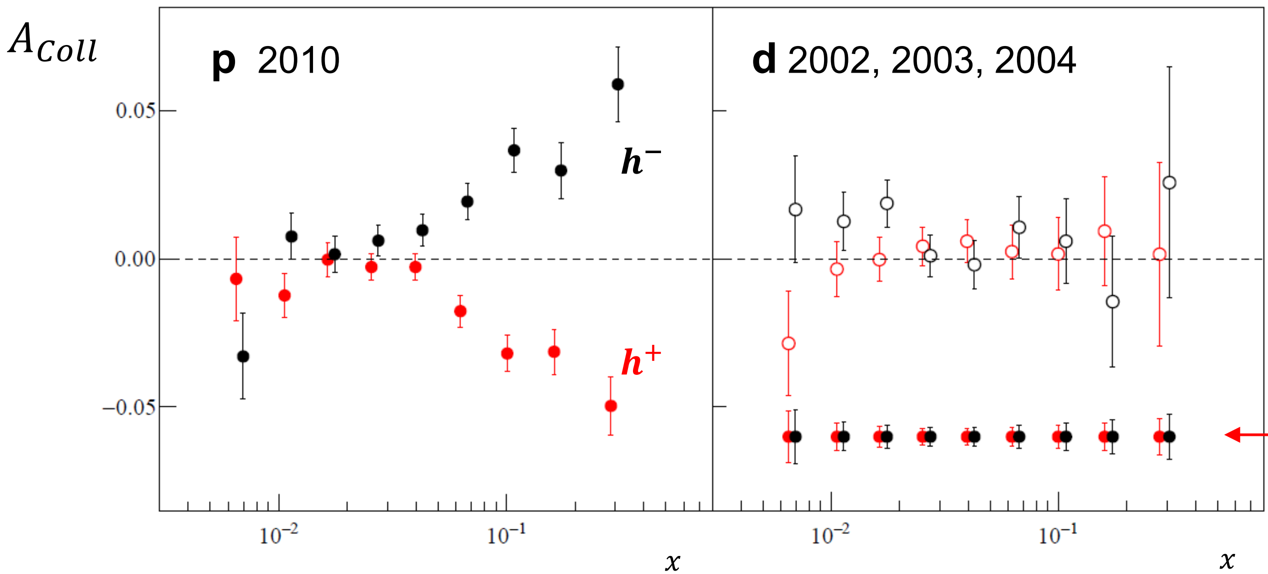
→ *2022 COMPASS run*

the 2022 COMPASS run

approved: one year of data taking with the transversely polarized deuteron (^{6}LiD) target in the same conditions of the 2010 proton run

ongoing: beginning of June – mid November 2022

impact on the Collins asymmetry



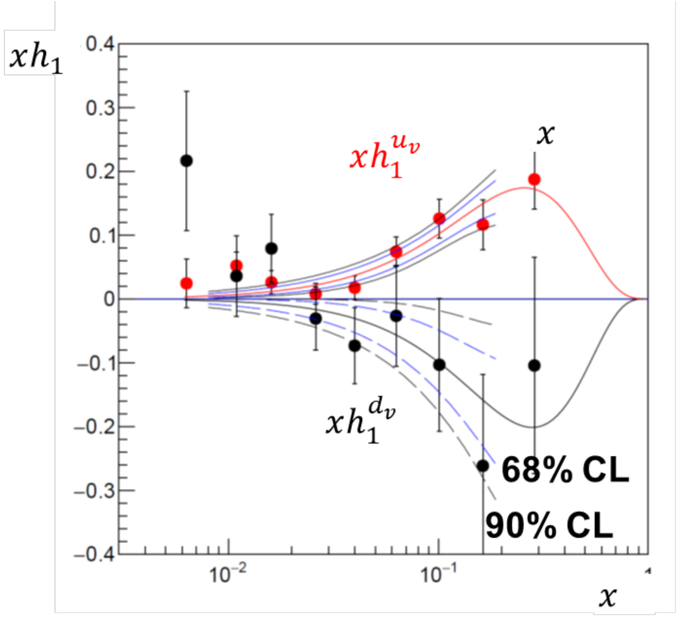
expected 2022 uncertainties: factor 2 to 5 smaller

same improvement for all the other TSA

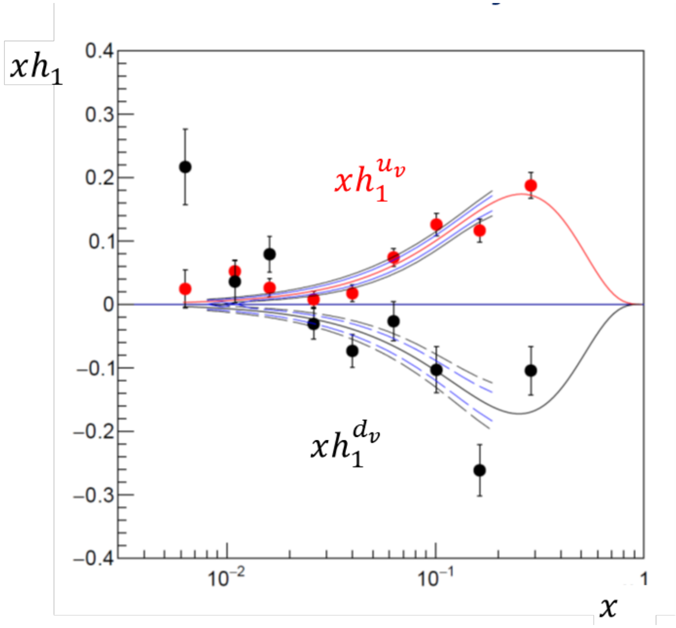
the 2022 COMPASS run

impact on **transversity**

present: all p and d data

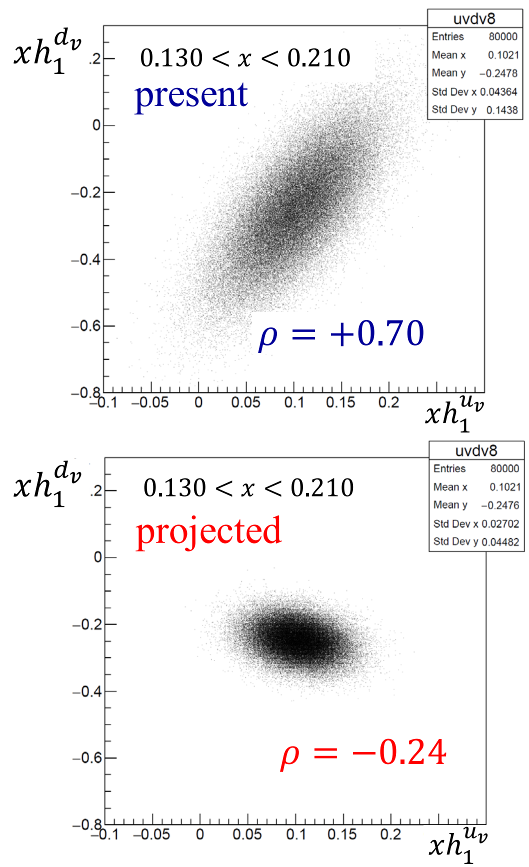


projected: all p and 2022 d data



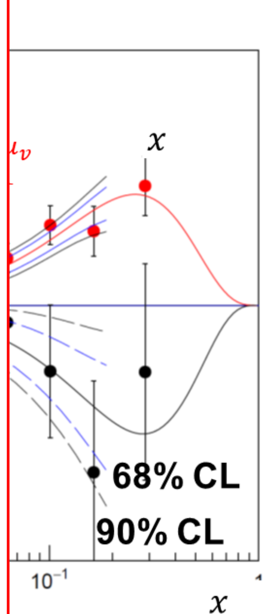
the 2022 COMPASS run

impact on **transversity**

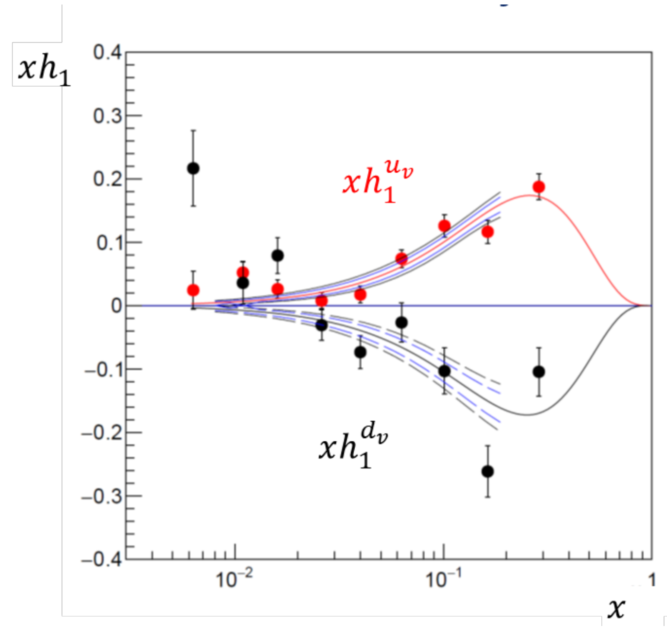


replicas

and d data



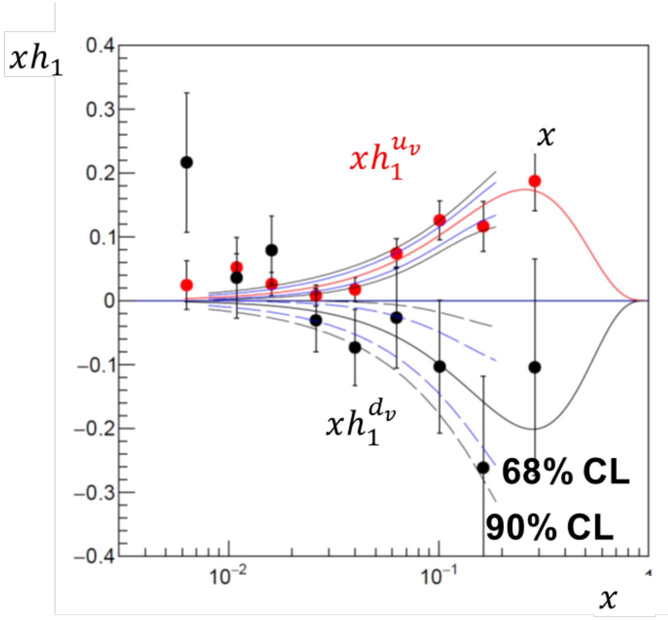
projected: all p and 2022 d data



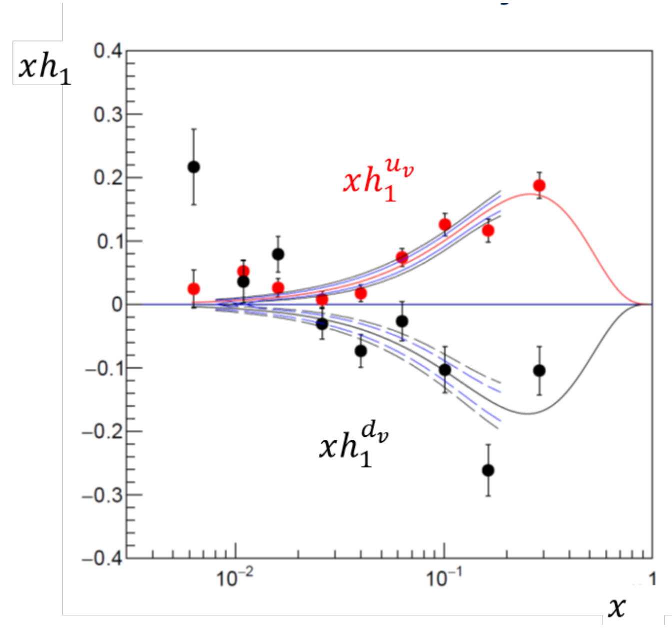
the 2022 COMPASS run

impact on **transversity**

present: all p and d data



projected: all p and 2022 d data



and **tensor charge**

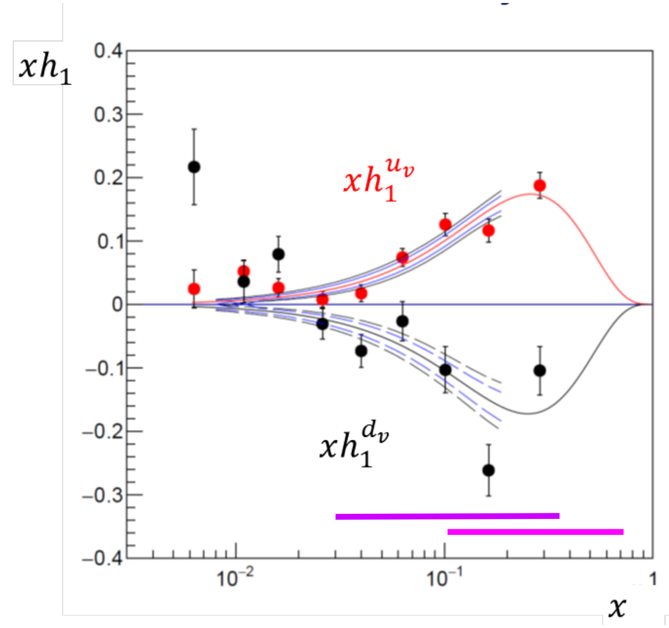
$\Omega_x: 0.008 \div 0.210$

	$\boldsymbol{\delta_u} = \int_{\Omega_x} dx h_1^{u_v}(x)$	$\boldsymbol{\delta_d} = \int_{\Omega_x} dx h_1^{d}(x)$	$\boldsymbol{g_T = \delta_u - \delta_d}$
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 COMPASS run

impact on **transversity**

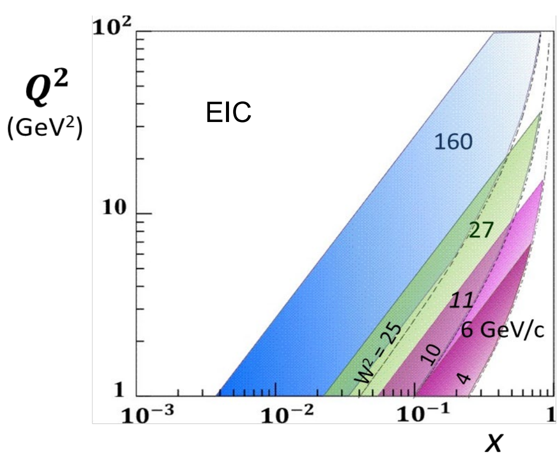
projected: all p and 2022 d data



the work will not be over with
the COMPASS measurements !

precise measurements are needed
asap, in particular at larger x

measurements at Jlab 12 and 20+
are complementary for a more
precise measurement of the
tensor charge



COMPASS

hermes

Jefferson Lab

Sivers asymmetry

SIDIS cross-section

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

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

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

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

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

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

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

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

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

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

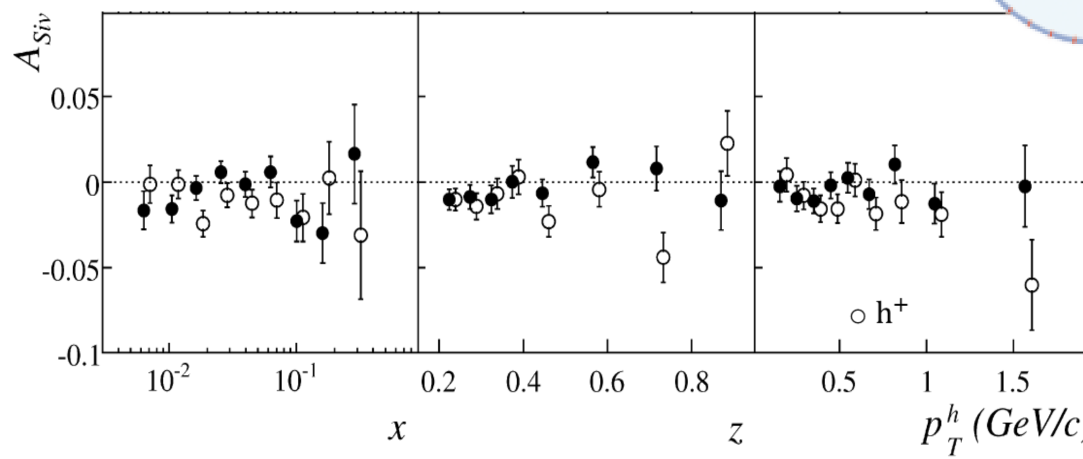
in the parton model

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

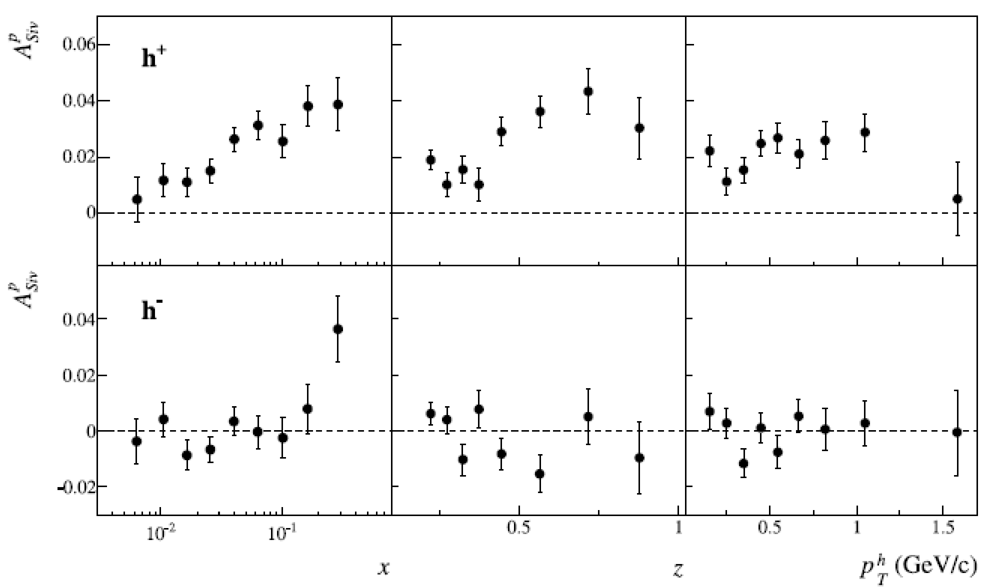
Sivers asymmetry

deuteron results

close to zero
with large statistical uncertainties



all 2002-2004 data
NPB765 (2007) 31



proton results

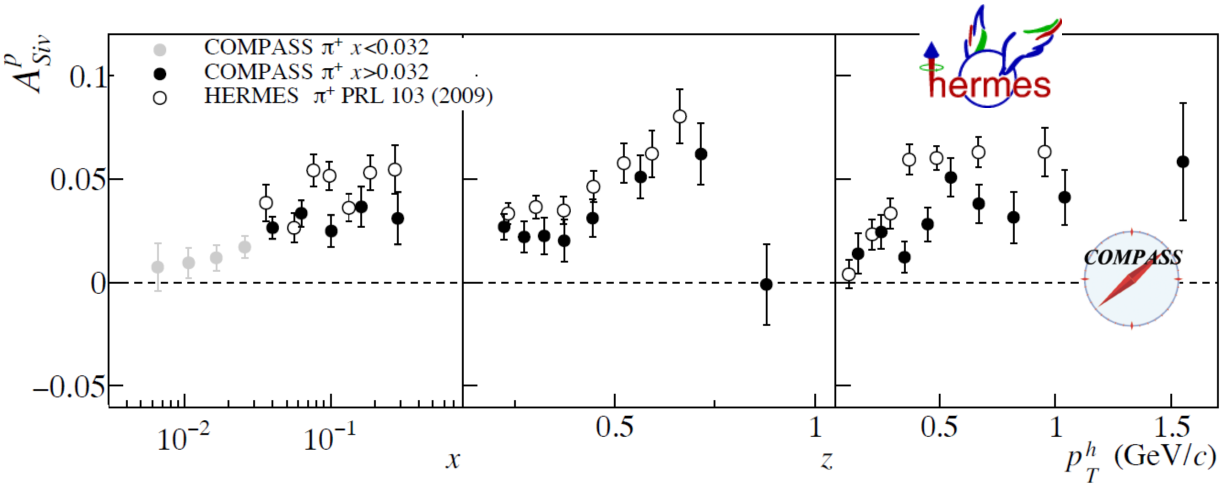
clearly positive for h^+
compatible with zero (but last x point) for h^-

2010 data
PLB 717 (2012) 383

Sivers asymmetry

comparison with HERMES

smaller values at COMPASS:
TMD evolution …



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

both the HERMES and COMPASS data could be well described

Sivers asymmetry

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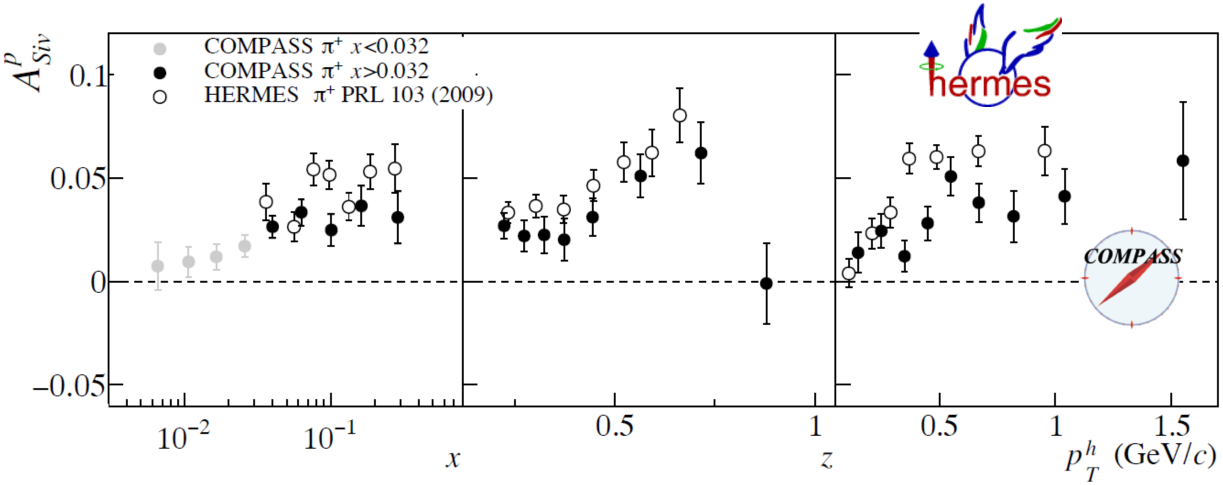
TMD evolution …



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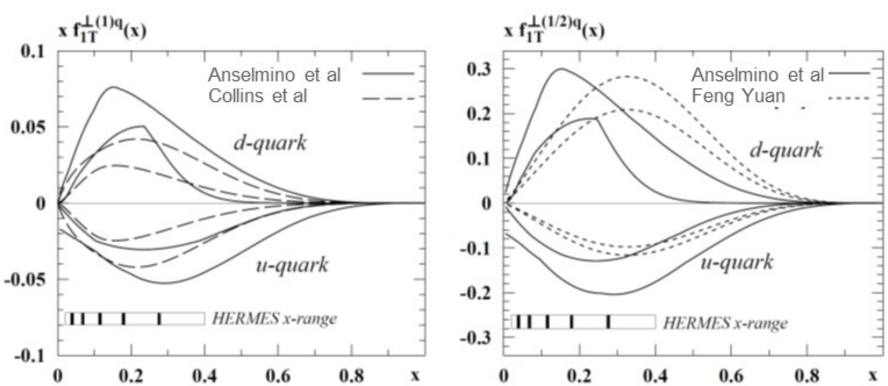

proceedings of ***Transversity 2005***

an important step forward !!

a big success of the new TMD framework

P_T weighted Sivers asymmetry

an interesting measurement from several points of view

at leading twist and leading order in QCD it is

$$A_{Siv}(x,z,P_T) = \frac{\sum_q e_q^2 x C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_\perp^2)\right]}{\sum_q e_q^2 x C\left[f_1^q(x,k_T^2)\, D_1^q(z,p_T^2)\right]}$$

$\boldsymbol{P_T}$ final state hadron in the GNS $\boldsymbol{k_T}$ intrinsic transverse momentum
$\boldsymbol{p}_\perp$ transverse momentumof the hadron with respect to the struck quark

the convolution cannot be analytically evaluated in the general case:
to disentangle $f_{1T}^{\perp}$ and D_1 , and **extract the Sivers function** assumptions for the transverse-momentum dependence of the distribution and fragmentation functions are needed

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the convolution cannot be analytically evaluated in the general case:
to disentangle $f_{1T}^{\perp}$ and D_1 , and extract the Sivers function **assumptions** for the transverse-momentum dependence of the distribution and fragmentation functions are needed

when assuming the usual Gaussian dependence and integrating over $\boldsymbol{P_T}$:

$$A_{Siv,G}(x,z) = \frac{a_G \sum_q e_q^2\, x f_{1T}^{\perp(1)q}(x)\, zD_1^q(z)}{\sum_q e_q^2\, x f_1^q(x)\, D_1^q(z)}$$

$$a_G = \frac{\sqrt{\pi}M}{\sqrt{\langle p_T^2\rangle + z^2\langle k_T^2\rangle_S}} \simeq \frac{\pi M}{2\langle P_T\rangle}$$

($a_G \cong 1$ for the Collins asymmetry)

$$f_{1T}^{\perp(1)q}(x) = \int d^2\boldsymbol{k}_T \frac{k_T^2}{2M^2} f_{1T}^{\perp q}(x,k_T^2)$$

but the assumption can introduce a bias into the extraction of the Sivers function

P_T weighted Sivers asymmetry

the problem can be avoided measuring the P_T −weighted asymmetries:

$$w = P_T/zM \qquad A_{Siv}^{w}(x,z) = \frac{\sum_q e_q^2 x \quad \int d^2\boldsymbol{P_T}\, \frac{P_T}{zM}\, C\left[\frac{\boldsymbol{P_T}\cdot\boldsymbol{k}_T}{MP_T} f_{1T}^{\perp q}(x,k_T^2)\, D_1^q(z,p_T^2)\right]}{\sum_q e_q^2\, x f_1^q(x)\, D_1^q(z)}$$

$$= 2\frac{\sum_q e_q^2\, x f_{1T}^{\perp(1)q}(x)\, D_1^q(z)}{\sum_q e_q^2\, x f_1^q(x)\, D_1^q(z)}$$

$$w' = P_T/M \qquad A_{Siv}^{w\prime}(x,z) = 2\frac{\sum_q e_q^2\, x f_{1T}^{\perp(1)q}(x)\, zD_1^q(z)}{\sum_q e_q^2\, x f_1^q(x)\, D_1^q(z)}$$

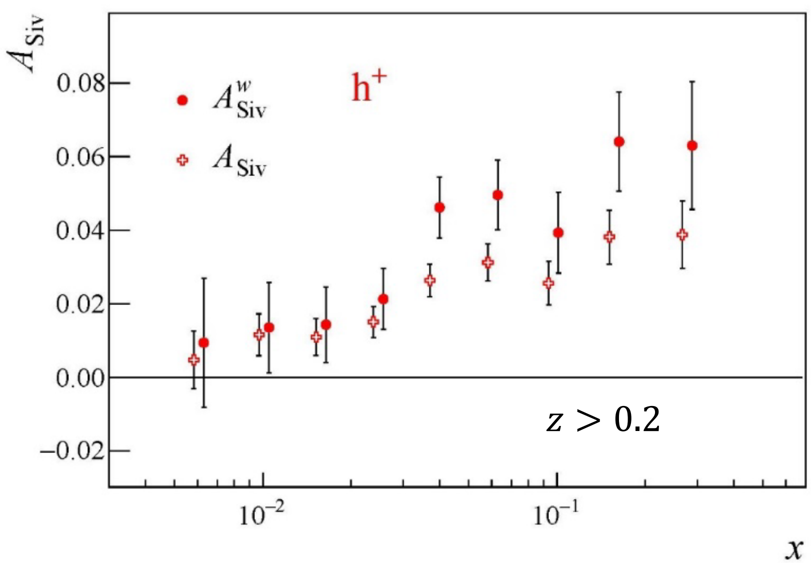
$$\frac{A_{Siv}^{w\prime}(x,z)}{A_{Siv,G}(x,z)} = \frac{4\langle P_T\rangle}{\pi M}$$

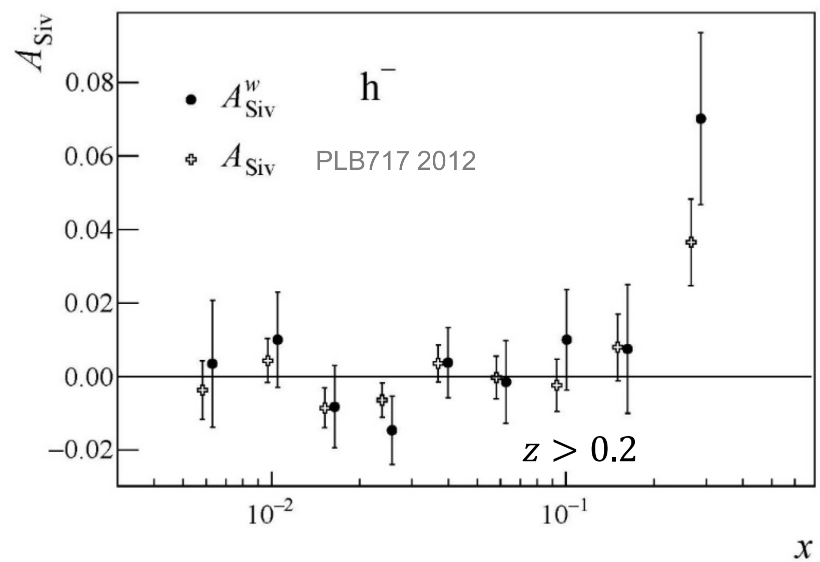
P_T weighted Sivers asymmetry

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

$w = P_T/zM$

from 2010 proton data NPB 940 (2019) 34





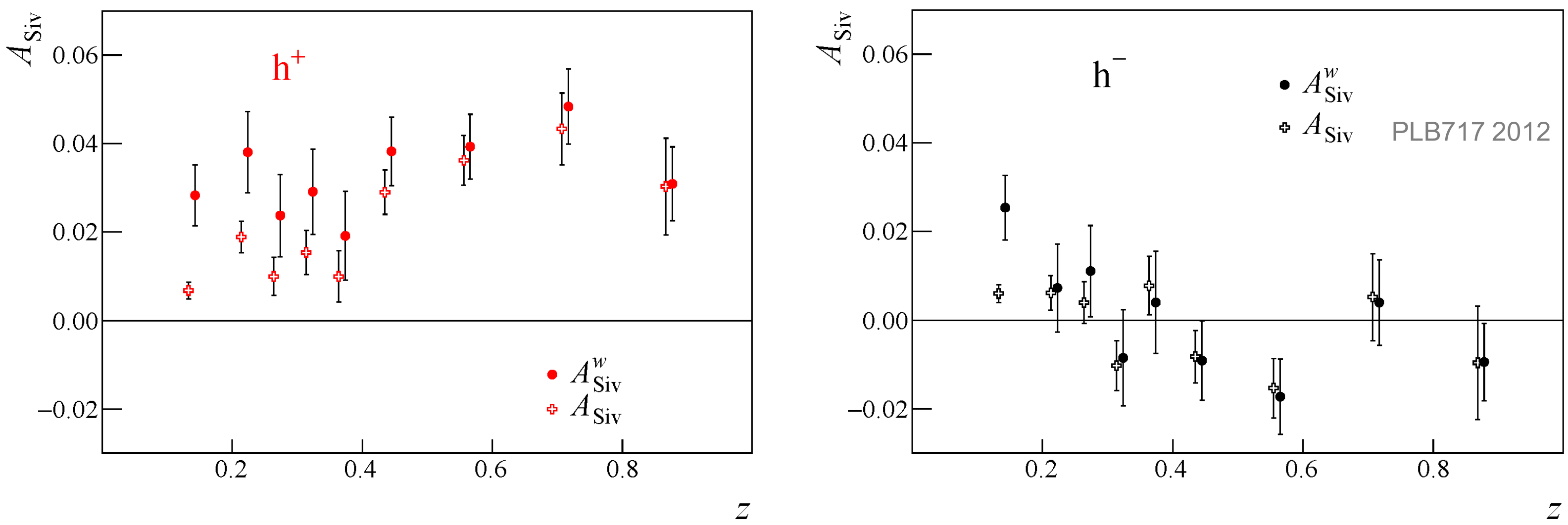
the trends of the weighted and unweighted asymmetries are similar both for positive and negative hadrons

in agreement with the expectation

P_T weighted Sivers asymmetry

results for $A^{w}_{Siv}(z) = 2\frac{\sum_q e_q^2 D_{1q}(z) \int C(x) f_{1T}^{\perp(1)q}(x)\, dx}{\sum_q e_q^2 D_{1q}(z) \int C(x) f_1^q(x) dx}$

from 2010 proton data NPB 940 (2019) 34



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

negative hadrons: at small z the asymmetry increases

and several other results:
nothing at variance with expectations

extraction of $f_{1T}^{\perp(1)}(x)$

P_T/zM weighted asymmetries for positive e negative hadrons:

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

$f_1^q, \widetilde{D}_1^{q,\pm}$ from parametrisations (CTEQ5D and DSS)

having only the proton data, we had to neglect the **sea-quark** Sivers distributions, it is

$$A_{Siv}^{w,\pm} = 2\frac{4x f_{1T}^{\perp(1)u_v}\widetilde{D}_1^{u,\pm} + x f_{1T}^{\perp(1)d_v}\widetilde{D}_1^{d,\pm}}{\delta^\pm} \qquad \delta^\pm = 9\sum_q e_q^2 x f_1^q \widetilde{D}_1^q$$

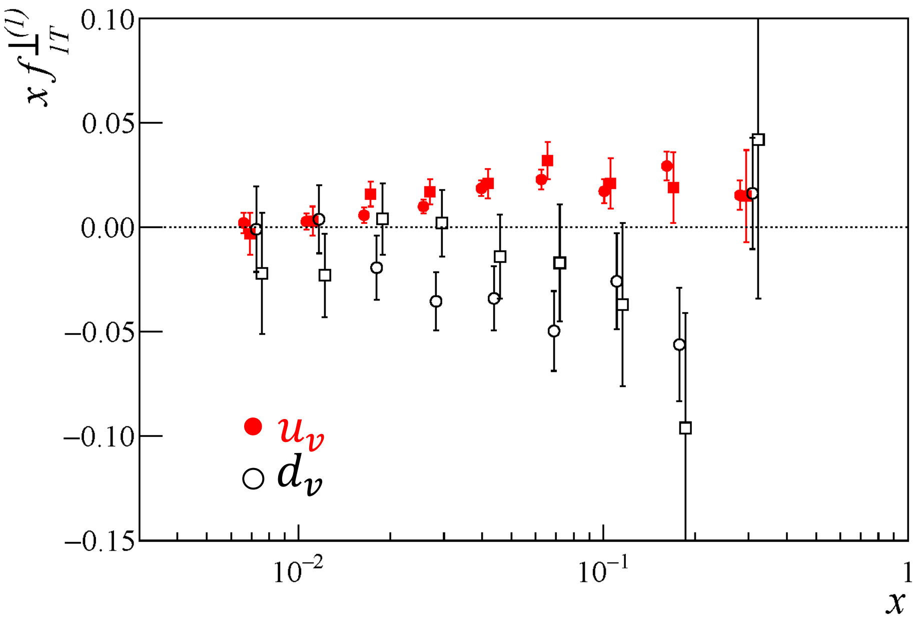
and

$$x f_{1T}^{\perp(1)u_v} = \frac{1}{8}\frac{\delta^+ A_{Siv}^{w,+}\widetilde{D}_1^{d,-} - \delta^- A_{Siv}^{w,-}\widetilde{D}_1^{d,+}}{\widetilde{D}_1^{u,+}\widetilde{D}_1^{d,-} - \widetilde{D}_1^{d,+}\widetilde{D}_1^{u,-}}$$

$$x f_{1T}^{\perp(1)d_v} = \frac{1}{2}\frac{\delta^- A_{Siv}^{w,-}\widetilde{D}_1^{u,+} - \delta^+ A_{Siv}^{w,+}\widetilde{D}_1^{u,-}}{\widetilde{D}_1^{u,+}\widetilde{D}_1^{d,-} - \widetilde{D}_1^{d,+}\widetilde{D}_1^{u,-}}$$

extraction of $f_{1T}^{\perp(1)}(x)$

NPB 940 (2019) 34



all in all
no new / unforseen effect

why?

previous point-by-point extraction [A.M., F.Bradamante, V.Barone, PRD95, 2017]

using pion Sivers asymmetries from the COMPASS p and d data, ■ ❑

(no assumptions on the Sivers function of the sea quarks, Gaussian ansatz)

slightly different trend for $f_{1T}^{\perp(1)d_v}$

we checked that the difference is only due to the fact that here we had to neglect the sea-quark contribution

using the p data only and imposing the sea-quark Sivers functions to be zero, both the central values and the uncertainties become very similar to the present ones

unpolarised SIDIS

COMPASS *results → Andrea Moretti talk*

unpolarised SIDIS - P_T^2 distributions

they give access to k_T distributions, a hot topic

COMPASS measurements using

- 2004 and 2006 deuteron data - published EPJC 73 (2013) 2531 PRD 97 (2018) 032006
- 2016 proton data - paper in preparation

→ smooth dependencies on the kinematic variables,

other recent SIDIS measurements
by HERMES and JLab experiments

→ similar observation

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→ similar observation

presently, phenomenological analysis
can descibe only a limited kinematic region

… no clear indications on how SIDIS experiments can further contribute

unpolarised SIDIS – azimuthal asymmetries

they give access to $\langle k_T^2 \rangle$, Boer-Mulders function, higher twist

COMPASS measurements using

- 2004 deuteron data - published NPB 886 (2014) 1046 NPB 956 (2020) 115039
- 2016 proton data - preliminary results, work ongoing

→ strong dependencies on the kinematic variables, sometimes at variance with naive expectations

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→ strong dependencies on the kinematic variables,
sometimes at variance with naive expectations

other recent SIDIS measurements
by HERMES and JLab experiments

→ similar observation

quite difficult to interpret

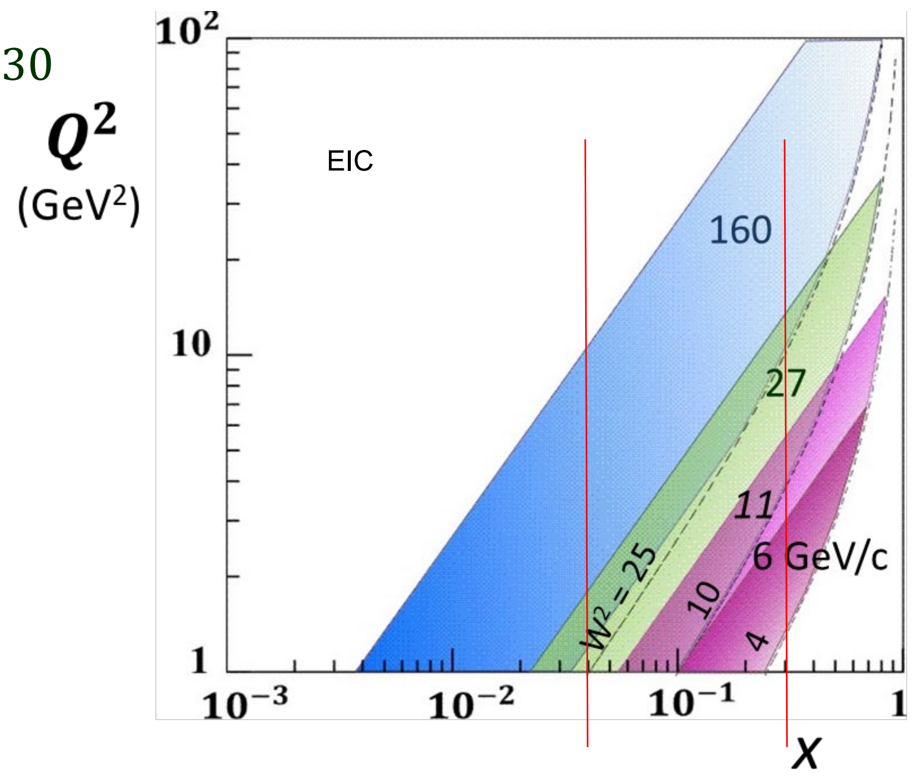
only a few attempts of phenomenological analyses

→ Boer-Mulders function still unknown

unpolarised SIDIS – azimuthal asymmetries

insight should come from a direct comparinon of the results at COMPASS, HERMES, JLab12 … and, in future, JLab20+

eg Q^2 dependence in
the region $0.05 < x < 0.30$



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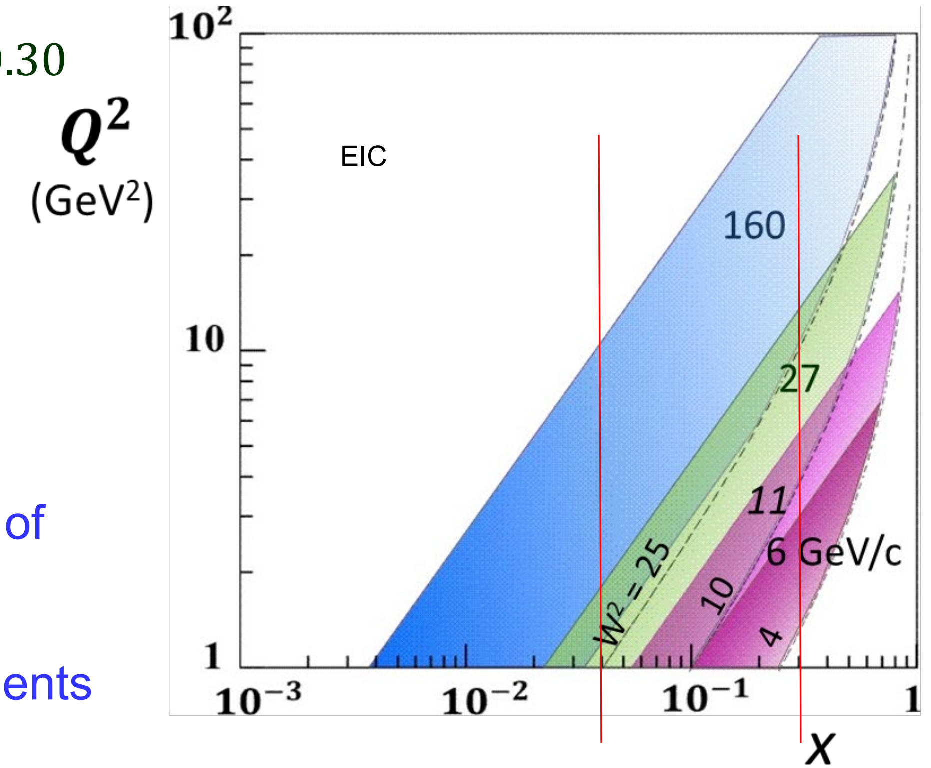

presently not easy, because of the different binning and event/hadron selection used in the different experiments

main motivation for the proposal of a new project

unpolarised SIDIS

Progetti di Riecra di Interesse Nazionale (PRIN) 2022

ECOS 2022 (Experimental COllaboration for the study of the nucleon Structure)

Trieste, Frascati, Ferrara, Genova

submitted March 31, 2022

Aim build a collaboration among the Italian groups involved in different experiments in order to perform coherent measurements and studies of key observables in SIDIS off unpolarised targets over the entire kinematic region accessed by the existing data.

The project is **focused on the azimuthal asymmetries**, with the goal of

- revising the measurements and the related analyses as well as the extraction methods, and
- performing multidimensional measurements by choosing common kinematic variables, selections and binning, to direct compare the results over the full kinematic range.

unpolarised SIDIS

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- performing multidimensional measurements by choosing common kinematic variables, selections and binning, to direct compare the results over the full kinematic range.

not an easy project: it requires (partial) data sharing
but we are convinced that it could be the way out for the azimuthal asymmetries, and the starting point of new and wider projects

is it the direction where to go in the future, in order to fully exploit complementarity?

thank you !