The Transverse Spin Structure of the Nucleon: overview and perspectives of COMPASS SIDIS measurements

Franco Bradamante
INFN, sezione di Trieste
on behalf of the COMPASS Collaboration

23–27 May 2022, Almo Collegio Borromeo, Pavia, Italy

COMPASS

COmmon
Muon and
Proton
Apparatus for
Structure and
Spectroscopy

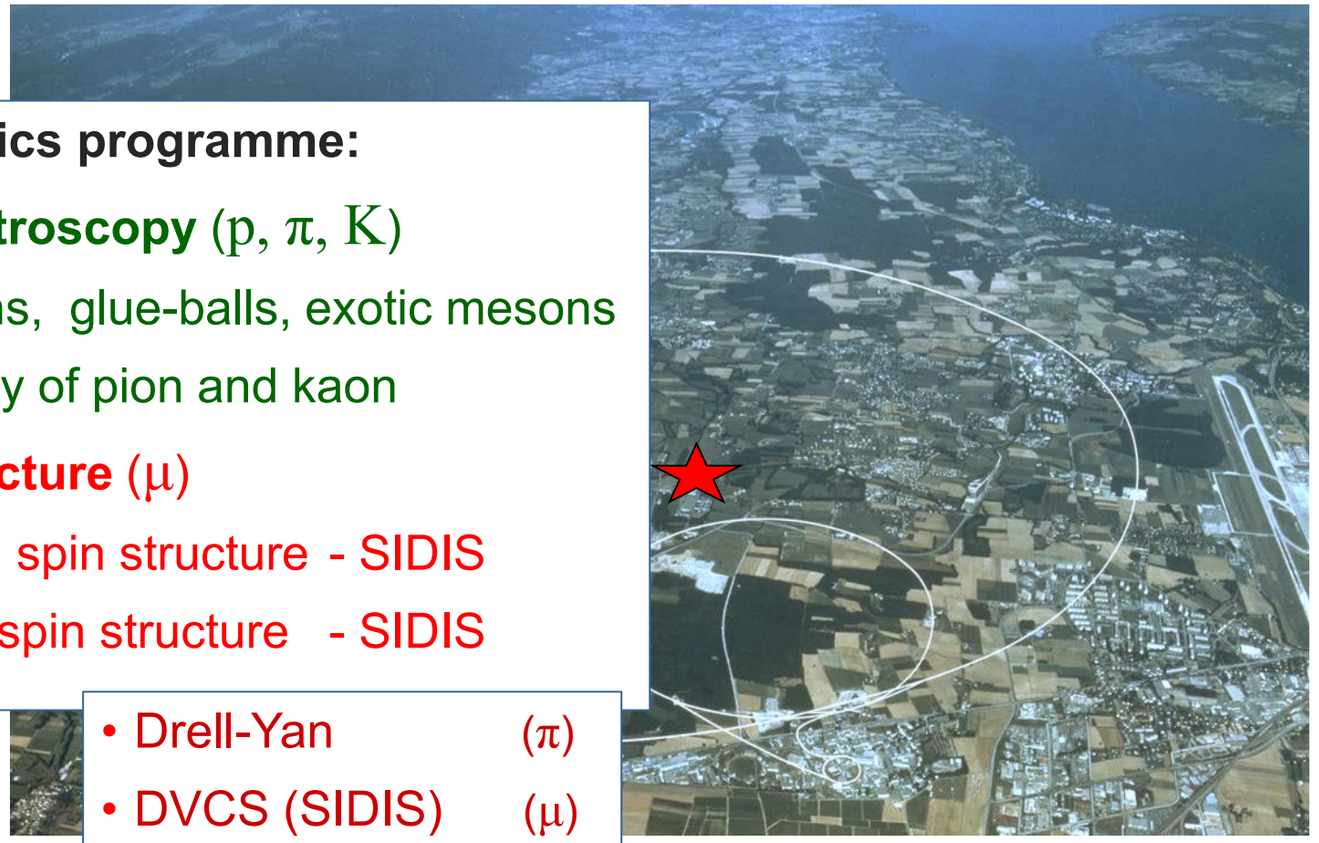
fixed target experiment at the CERN SPS

COMPASS

fixed target experiment at the CERN SPS

PROPOSAL	**March ’96**
RECOMMANDED	**September ’96**
APPROVED	**February ’97**
TAKING DATA	**since 2002**

fixed target experiment at the CERN SPS



proposed physics programme:

hadron spectroscopy (p, π, K)

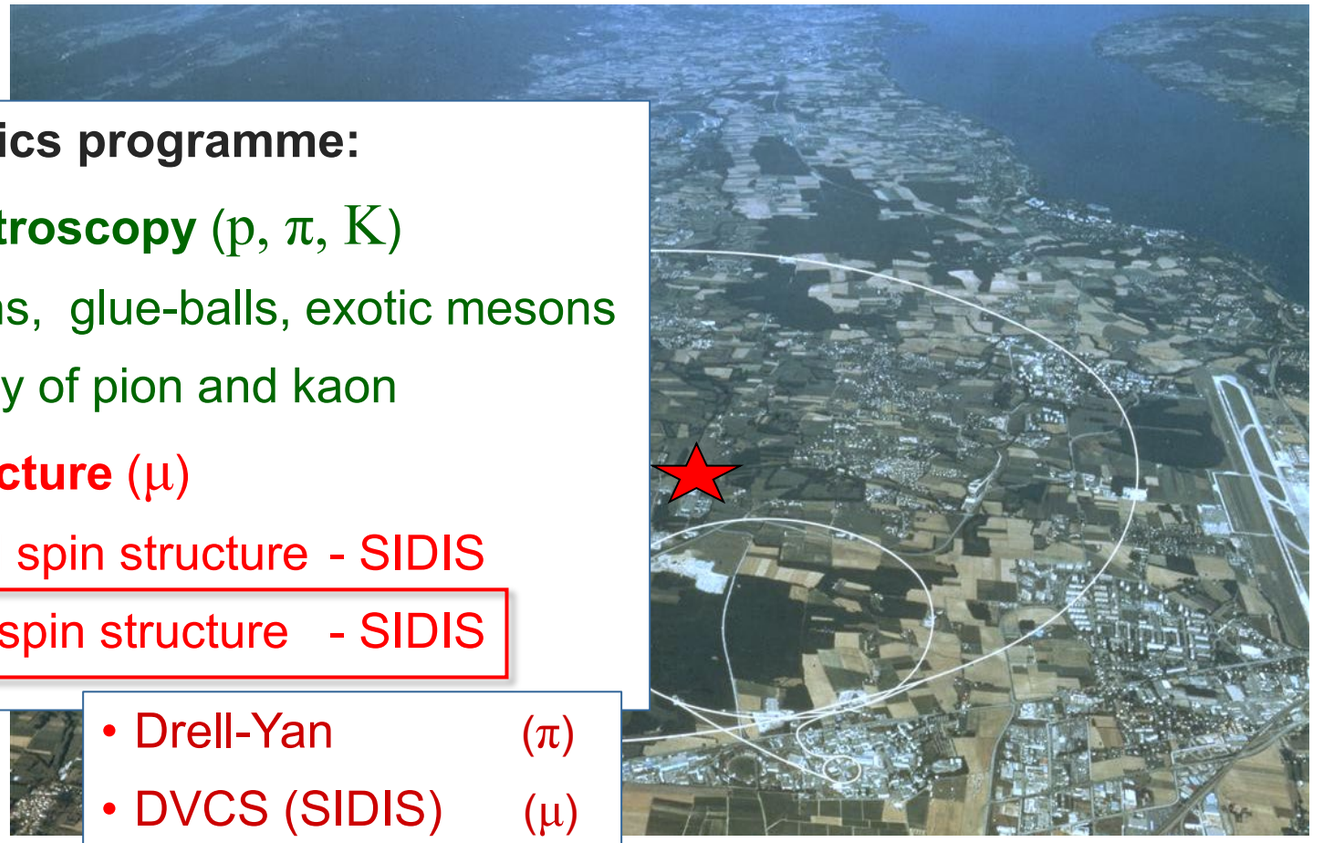
- light mesons, glue-balls, exotic mesons
- polarisability of pion and kaon

nucleon structure (μ)

- longitudinal spin structure - SIDIS
- transverse spin structure - SIDIS

- Drell-Yan (π)
- DVCS (SIDIS) (μ)

fixed target experiment at the CERN SPS



proposed physics programme:

hadron spectroscopy (p, π, K)

- light mesons, glue-balls, exotic mesons
- polarisability of pion and kaon

nucleon structure (μ)

- longitudinal spin structure - SIDIS
- transverse spin structure - SIDIS

- Drell-Yan (π)
- DVCS (SIDIS) (μ)

TRANSVERSITY IN COMPASS actually is tightly coupled to the

Inter-University project "Measurement of the Nucleon Transversity“,
financed by MIUR, PRIN2003

proposed in 2002, 20 YEARS AGO

which is the father of the six Transversity workshops organized in Italy

THE STRUCTURE OF THE NUCLEON

taking into account the quark intrinsic transverse momentum k_T, at leading order
8 TMD PDFs are needed for a full description of the nucleon structure

correlations between parton transverse momentum, parton spin and nucleon spin

nucleon polarisation

quark polarisation	U	L	T
U	f_1		$f_{1T}^{\perp}$
L		g_1	g_{1T}
T	$h_1^{\perp}$	$h_{1L}^{\perp}$	h_1 $h_{1T}^{\perp}$

SIDIS gives access to all of them

THE STRUCTURE OF THE NUCLEON

taking into account the quark intrinsic transverse momentum k_T, at leading order
8 TMD PDFs are needed for a full description of the nucleon structure

correlations between parton transverse momentum, parton spin and nucleon spin

nucleon polarisation

quark polarisation	U	L	T
U	f_1		$f_{1T}^{\perp}$
L		g_1	g_{1T}
T	$h_1^{\perp}$	$h_{1L}^{\perp}$	h_1 $h_{1T}^{\perp}$

SIDIS gives access to all of them

h_1 **Transversity**

$f_{1T}^{\perp}$ **Sivers**

$h_{1T}^{\perp}$ pretzelosity

g_{1T} worm-gear T
Kotzinian- Mulders

SEMI-INCLUSIVE DEEP INELASTIC SCATTERING

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

SEMI-INCLUSIVE DEEP INELASTIC SCATTERING

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

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

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

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

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

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

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

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

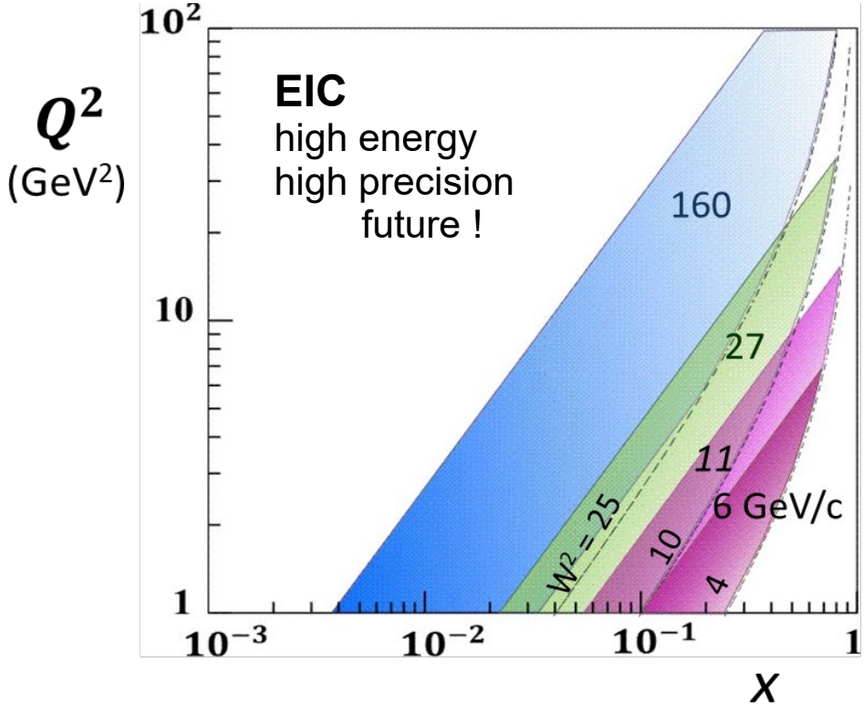
$$\left.+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\right]\Big\},$$

8 independent azimuthal modulations

leading twist amplitudes
→ convolutions of transversity and TMD PDFs and FFs

A BIG EXPERIMENTAL EFFORT

SIDIS



COMPASS ongoing

hermes over
results still coming

Jefferson Lab 6 GeV over
11 GeV: to be started
high precision data
24 GeV future

$e^+e^- \rightarrow hadrons$

Fragmentation Functions Collins, DiHadron, ….

BELLE BABAR BESIII

polarized DY

pp -> jets

THE COMPASS SPECTROMETER – SIDIS with polarized targets

designed to
- use high energy beams
- have large angular acceptance
- cover a broad kinematical range

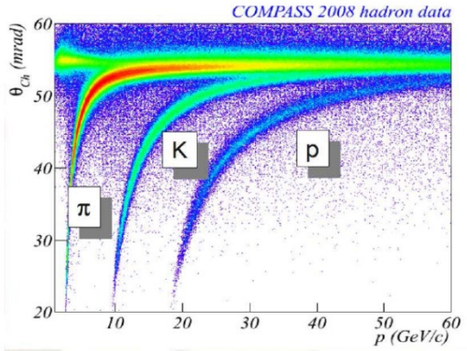
two stages spectrometer
- Large Angle Spectrometer (SM1)
- Small Angle Spectrometer (SM2)

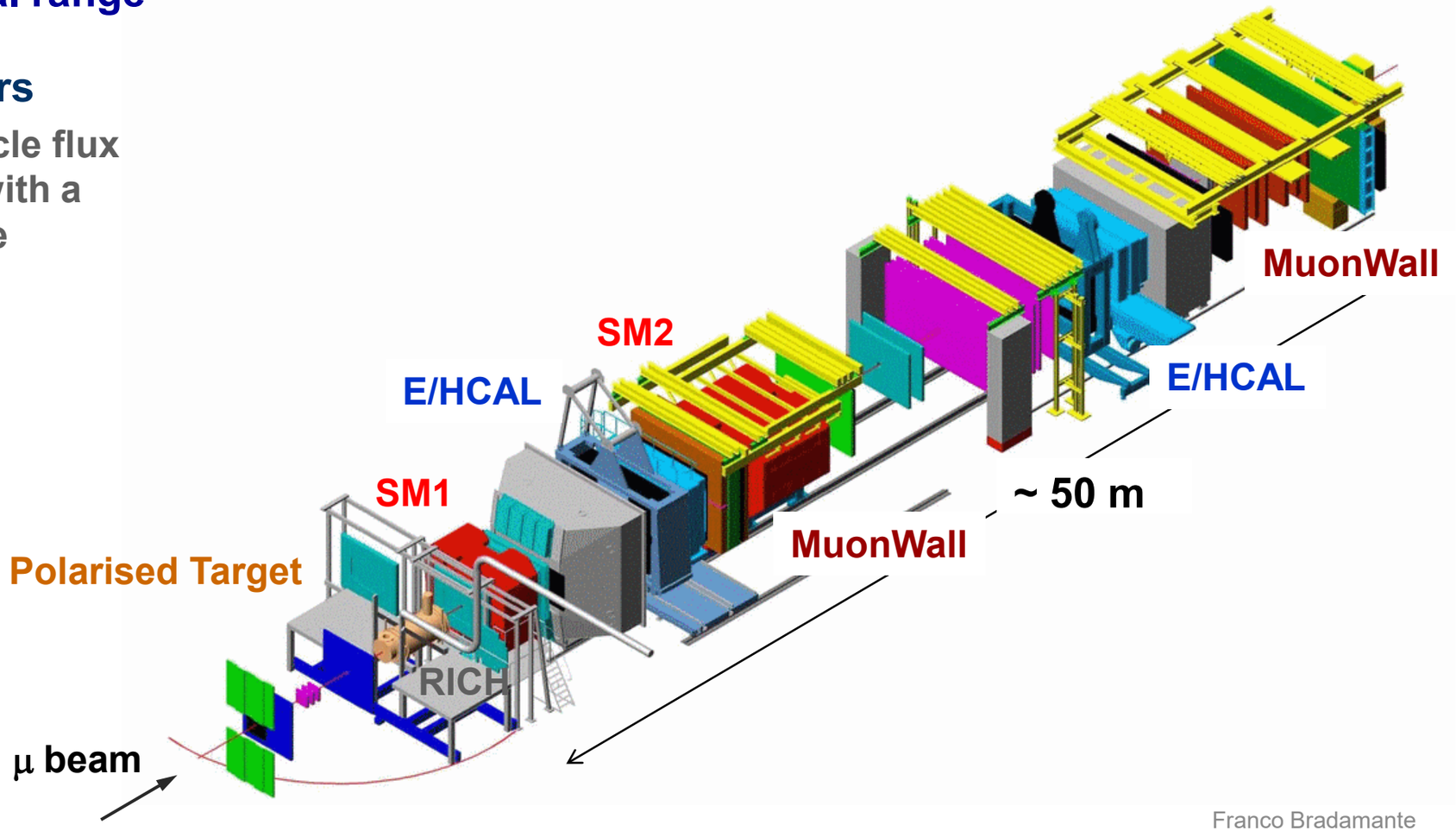
variety of tracking detectors

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

calorimetry, μID

RICH detector





results on
Transverse Spin Asymmetries

17 years after the first publication

- **a review of well known results**
- **a few less known results**
- **expected results**

THE DEUTERON DATA

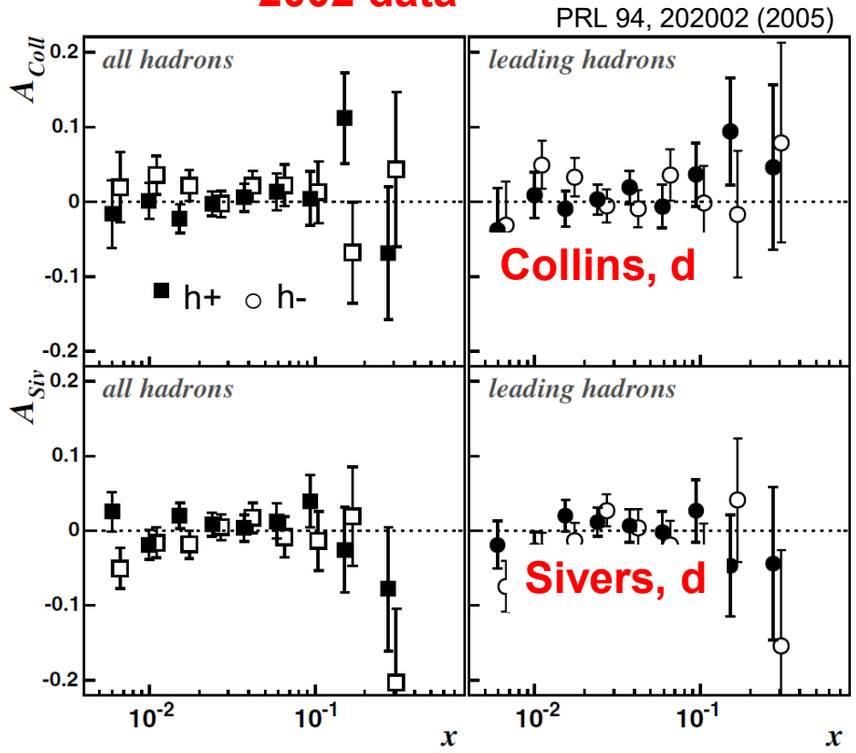
the first SIDIS data with a transversely polarized target in COMPASS were collected in **2002**: 0.5 effective weeks of data taking
in 2004 first results for the **Collins asymmetry** and for the **Sivers asymmetries**

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

first publication in 2005

2002 data

PRL 94, 202002 (2005)



large statistical uncertainties, compatible with zero

?

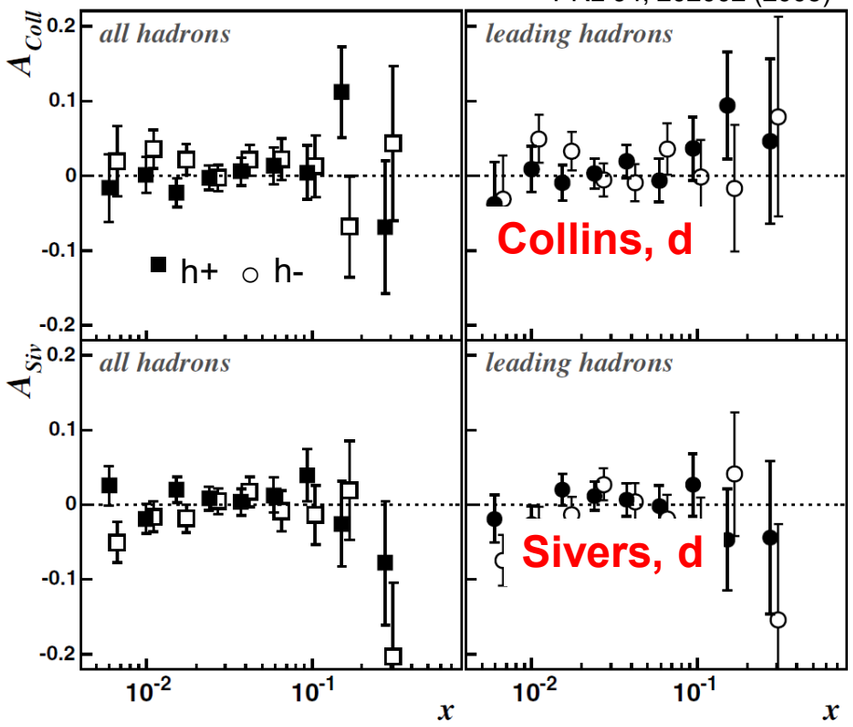
THE DEUTERON DATA

the first SIDIS data with a transversely polarized target in COMPASS were collected in **2002**: 0.5 effective weeks of data taking
in 2004 first results for the **Collins asymmetry** and for the **Sivers asymmetries**

first publication in 2005

2002 data

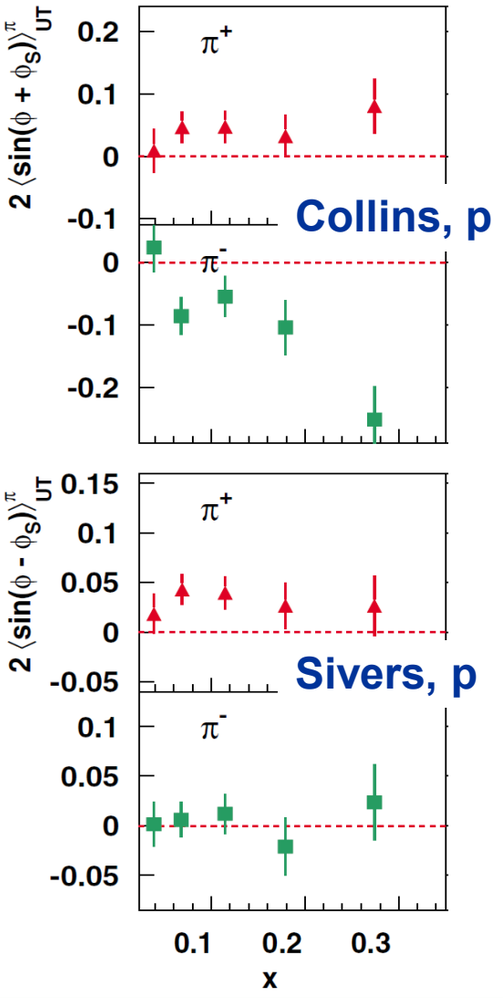
PRL 94, 202002 (2005)



in the mean time, HERMES measurements with a proton target

for the first time clear signals: real effects !

hep-ex/0408013

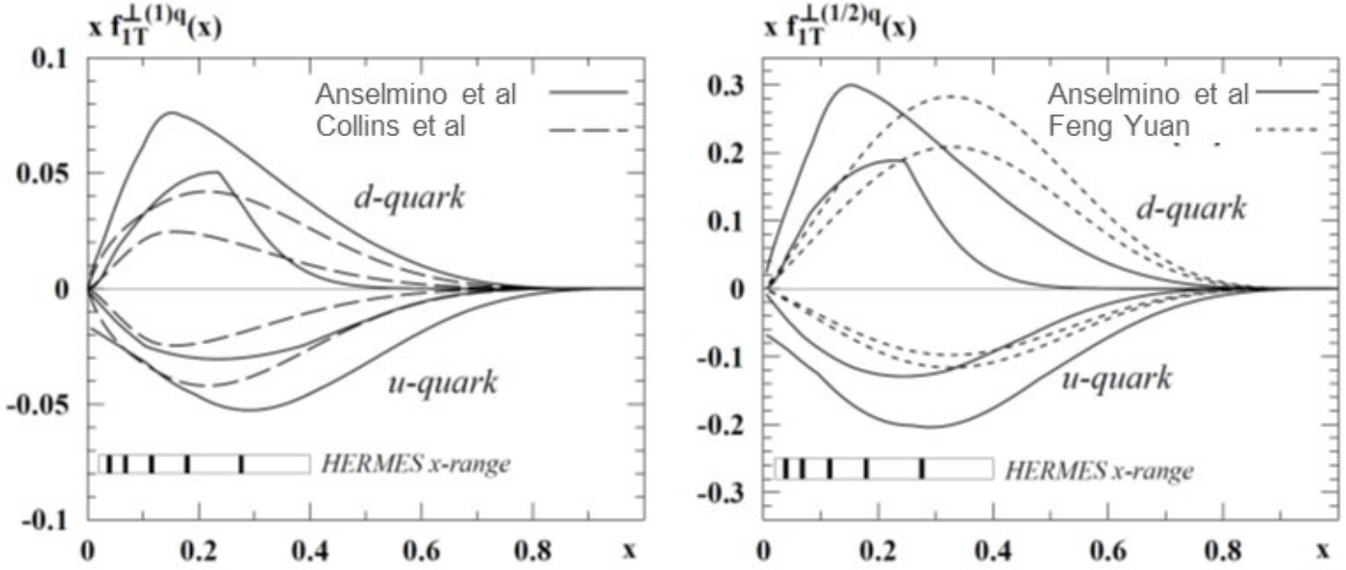


FIRST EXTRACTIONS OF THE NEW PDFs

the first extractions of the Sivers PDFs from the p and d Sivers asymmetries came very soon

proceedings of
Transversity 2005

the HERMES and COMPASS data could be well described



confirmation that the COMPASS results could be due to u d quark cancellation

FIRST EXTRACTIONS OF THE NEW PDFs

the first extractions of the Sivers PDFs from the p and d Sivers asymmetries came very soon

proceedings of
Transversity 2005

the extraction of the transversity PDFs took some more time

the Collins FF was the missing piece
it was qualitatively described by the Artru $^3P_0$ model

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

FIRST EXTRACTIONS OF THE NEW PDFs

the first extractions of the Sivers PDFs from the p and d Sivers asymmetries came very soon

proceedings of
Transversity 2005

the extraction of the transversity PDFs took some more time

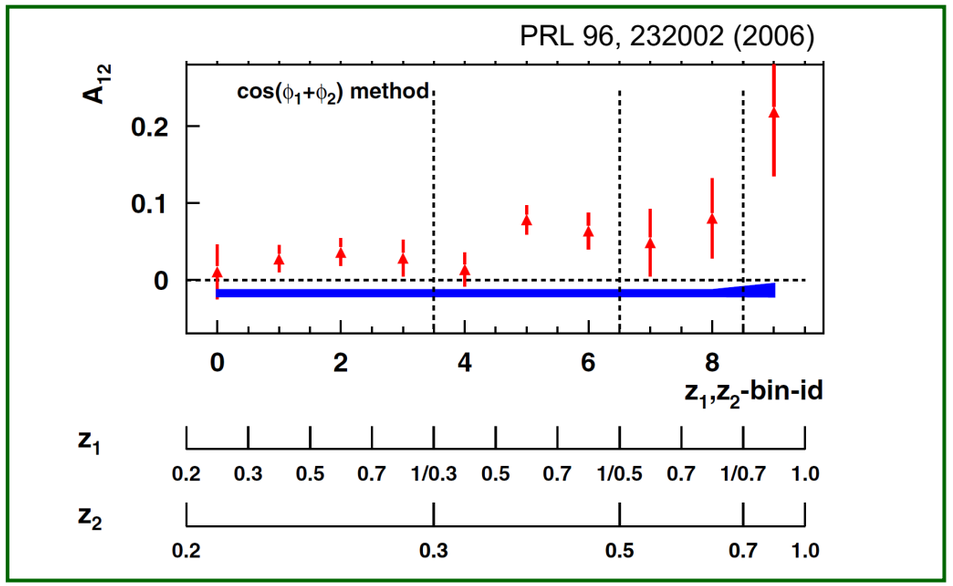
the Collins FF was the missing piece
it was qualitatively described by the Artru $^3P_0$ model

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

first measurements the Collins- like asymmetry
in $e^+e^- \rightarrow hadrons$ at BELLE

clear independent indication of
non-zero Collins FFs

again indication that the COMPASS results could be due to u d cancellation



FIRST EXTRACTIONS OF THE NEW PDFs

the first extractions of the Sivers PDFs from the p and d Sivers asymmetries came very soon

proceedings of
Transversity 2005

the extraction of the transversity PDFs took some more time

the Collins FF was the missing piece
it was qualitatively described by the Artru $^3P_0$ model

first measurements the Collins- like asymmetry
in $e^+e^- \rightarrow hadrons$ at BELLE

to summarize:

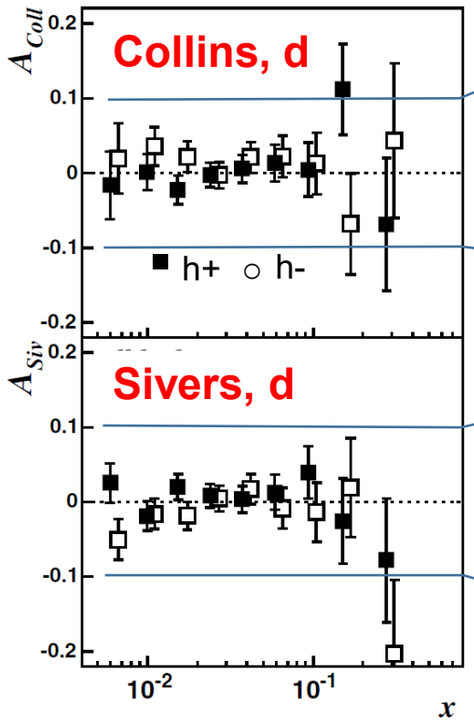
- **clear signals of the new transverse spin effects seen at HERMES and Belle**
- **a consistent picture of transverse spin effects was coming out, which could explain both the HERMES proton and the COMPASS deuteron data**

THE DEUTERON DATA

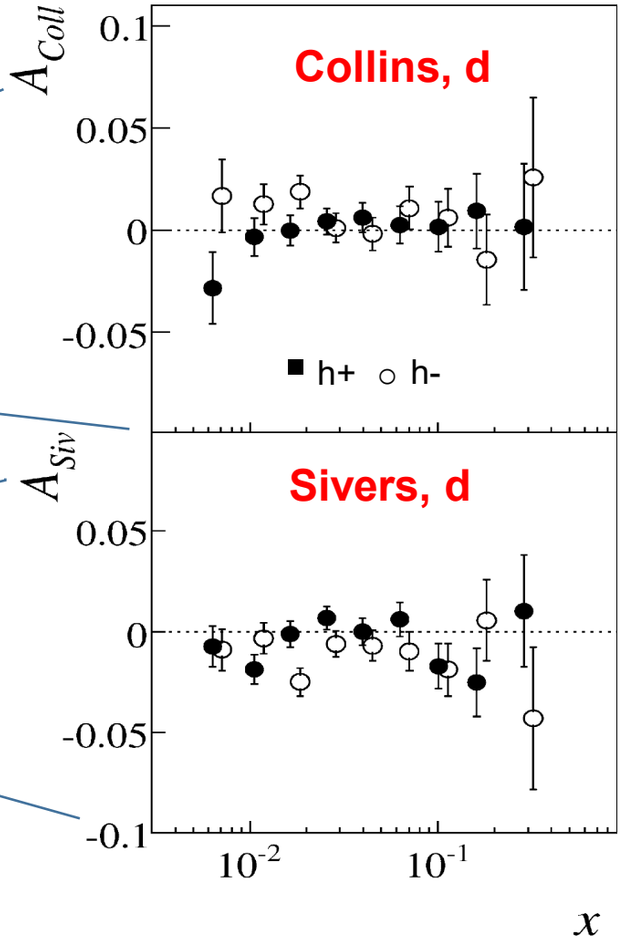
first publication in 2005 from 2002 data

2002: ~0.5 effective weeks of data taking
2003: 2 weeks of data taking
2004: 2 weeks of data taking

2002 data



2002-2004 data



final results for deuteron
NPB 765 (**2007**) 31

a more precise measurements of zero

still, large statistical uncertainties

today, these are the only existing deuteron data

JLab6: He3, statistically limited

THE PROTON DATA

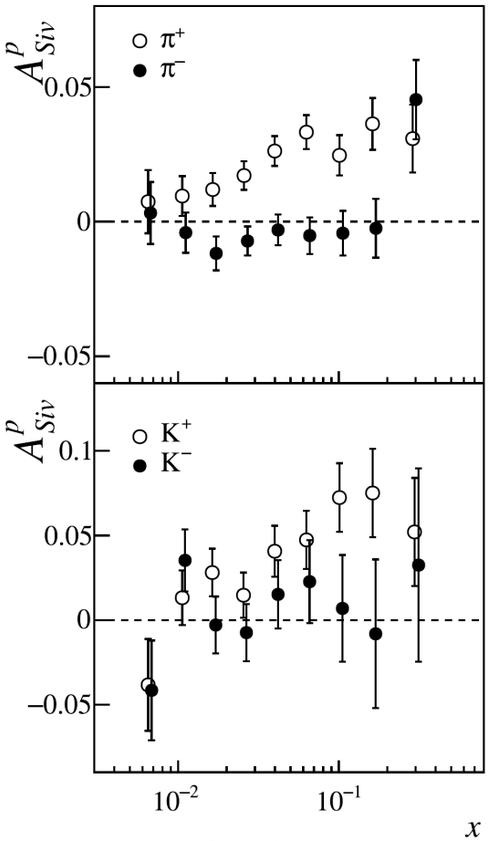
2007 half year, **2010** one year of data taking - the signals are there!

THE PROTON DATA

2007 half year, **2010** one year of data taking - the signals are there!

Sivers asymmetry

all COMPASS proton data



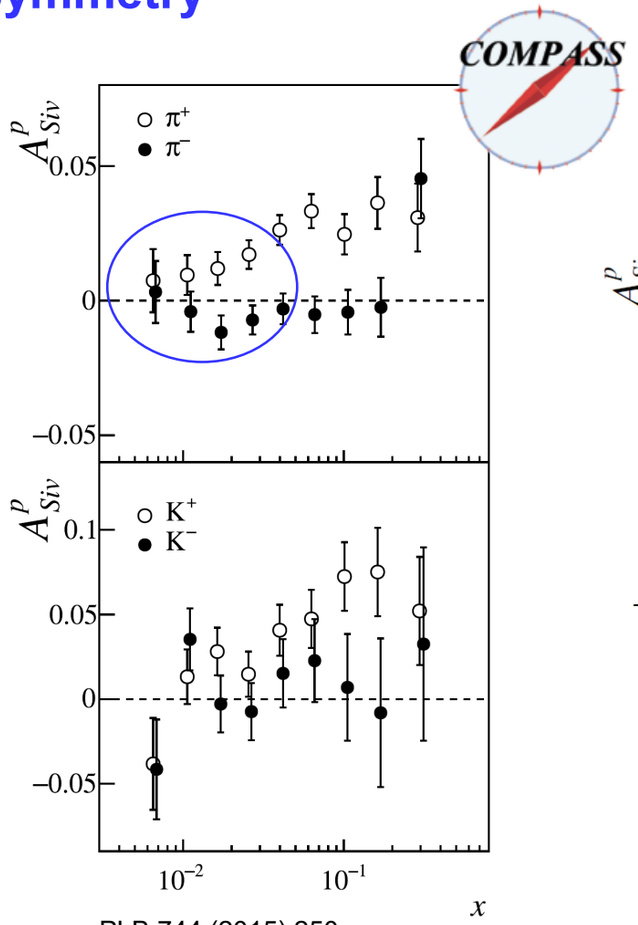
PLB 744 (2015) 250
PLB 717 (2012) 383

THE PROTON DATA

2007 half year, **2010** one year of data taking - the signals are there!

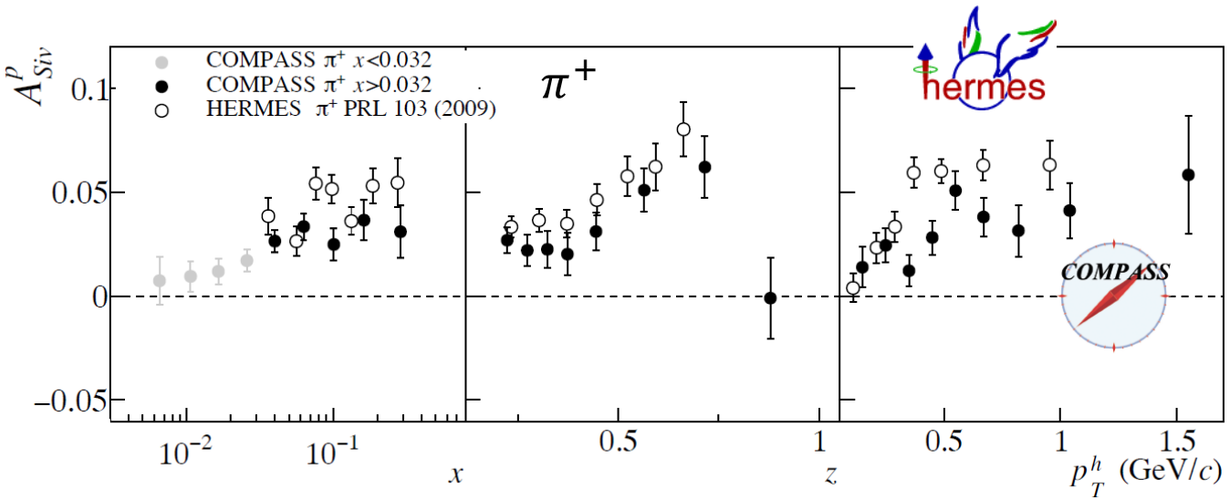
Sivers asymmetry

all COMPASS proton data



PLB 744 (2015) 250
PLB 717 (2012) 383

comparison with HERMES



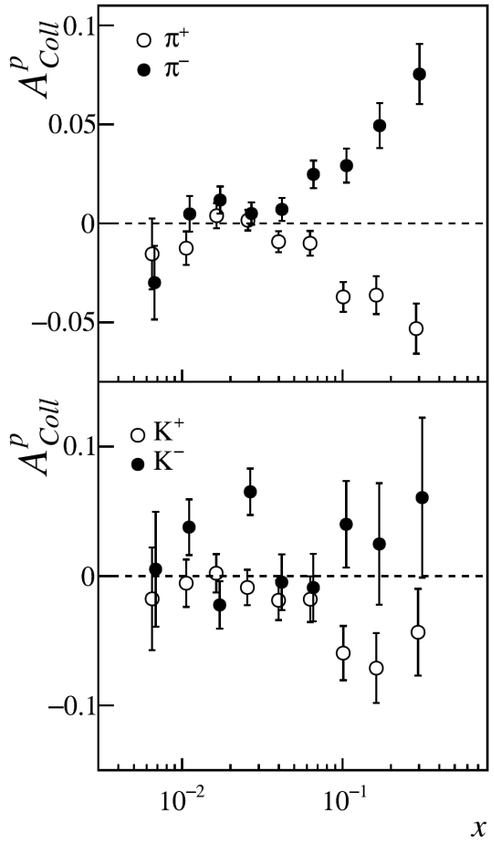
smaller values at COMPASS:
TMD evolution …

THE PROTON DATA

2007 half year, **2010** one year of data taking - the signals are there!

Collins asymmetry

all COMPASS proton data



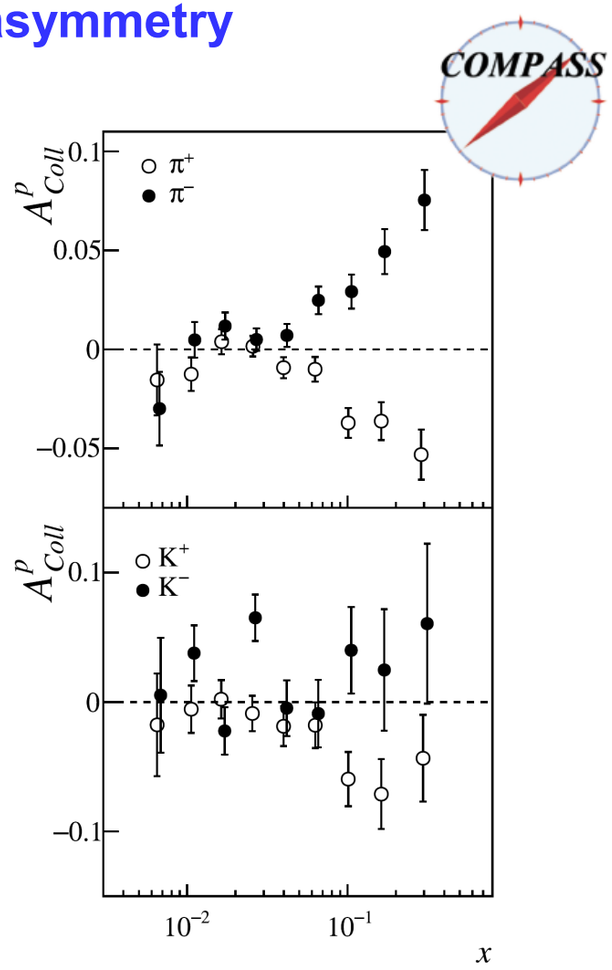
PLB 744 (2015) 250
PLB 717 (2012) 376

THE PROTON DATA

2007 half year, **2010** one year of data taking - the signals are there!

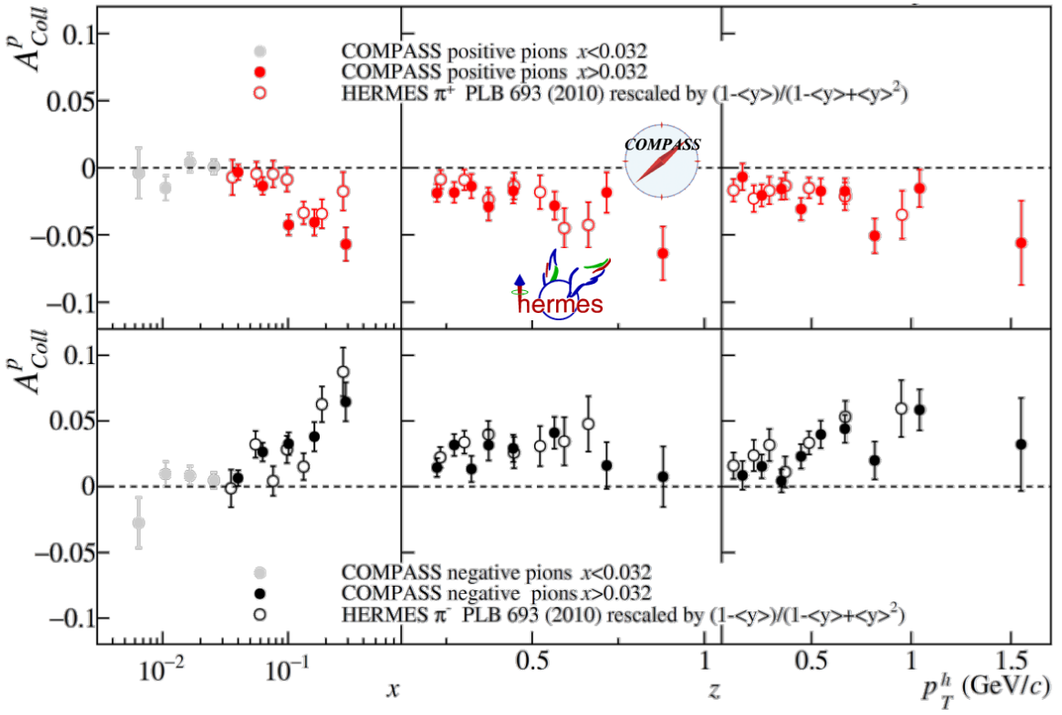
Collins asymmetry

all COMPASS proton data



PLB 744 (2015) 250
PLB 717 (2012) 376

comparison with HERMES



π^+

π^-

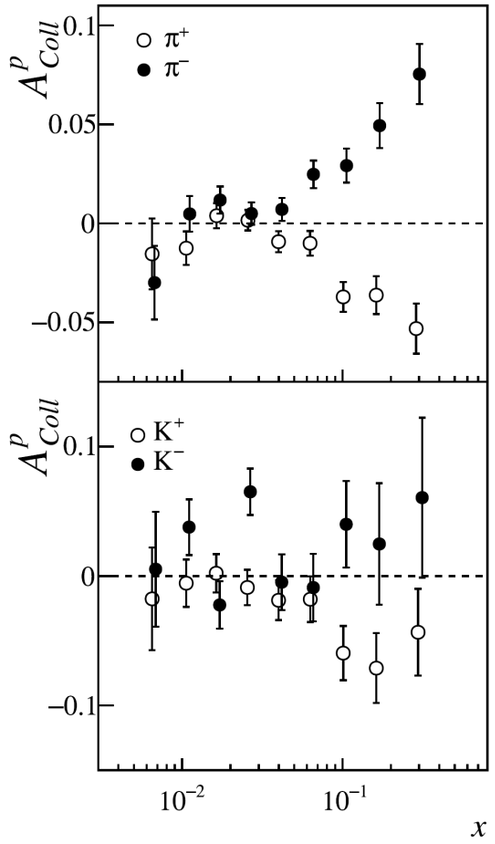
very good agreement !

THE PROTON DATA

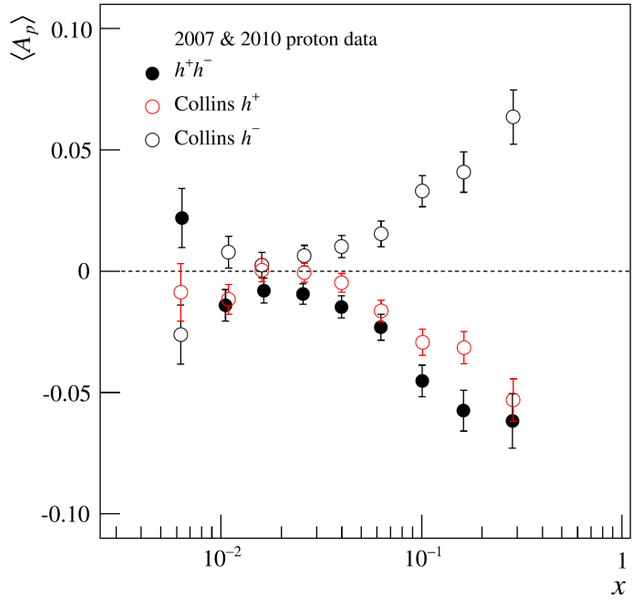
2007 half year, **2010** one year of data taking - the signals are there!

Collins asymmetry

all COMPASS proton data



PLB 744 (2015) 250
PLB 717 (2012) 376



- **di-hadron asymmetry**

PLB 736 (2014) 124

study of the interplay between Collins and di-hadron asymmetries – not independent

COMPASS, PLB 753 (2016) 406

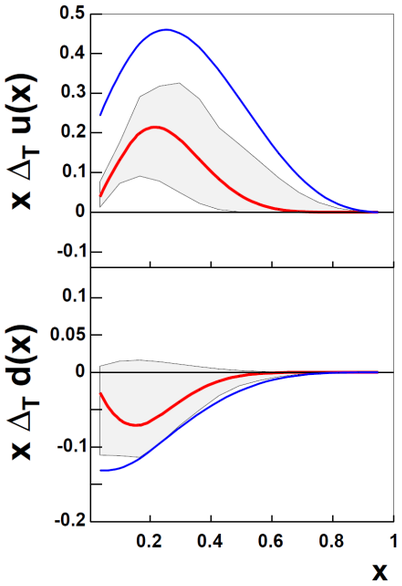
well reproduced by the $^3P_0$ model

A. Kerbizi et al. PRD97 (2018) no.7, 074010

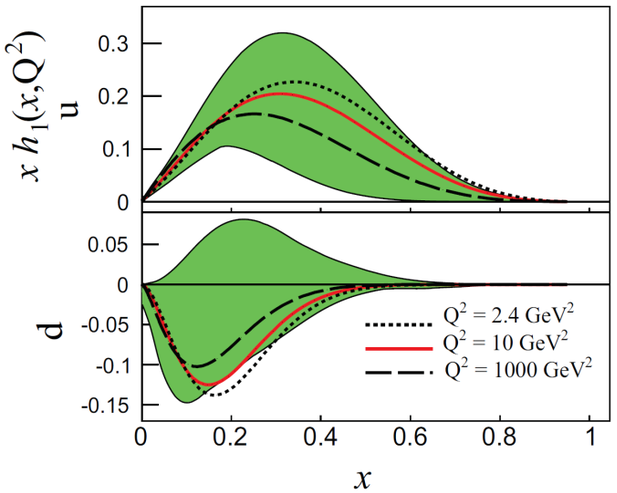
EXTRACTIONS OF TRANSVERSITY

fits of **Collins asymmetries** SIDIS off p and d, and e^+e^- data

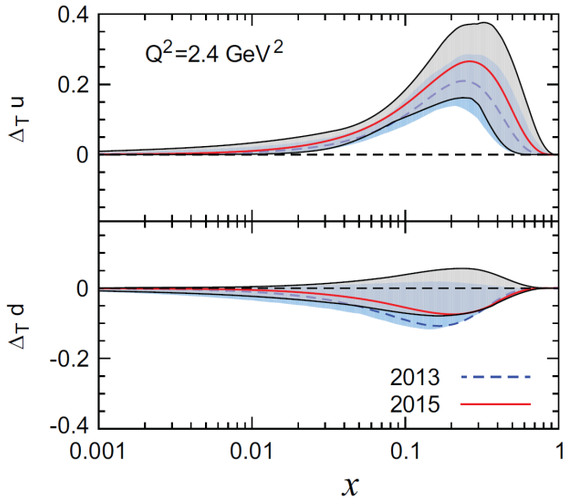
Anselmino et al PRD **2007**



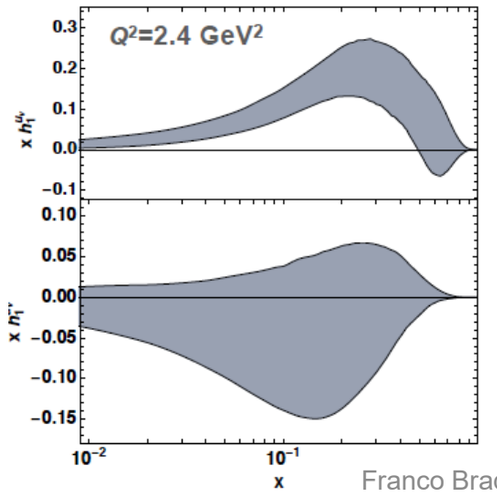
Z.-B. Kang et al. PRD **2016**



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



Radici Bacchetta PRL **2018**

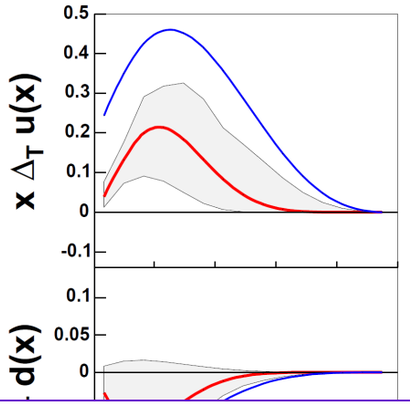


fits of **di-hadron asymmetries** SIDIS off p and d , e^+e^-, and pp data

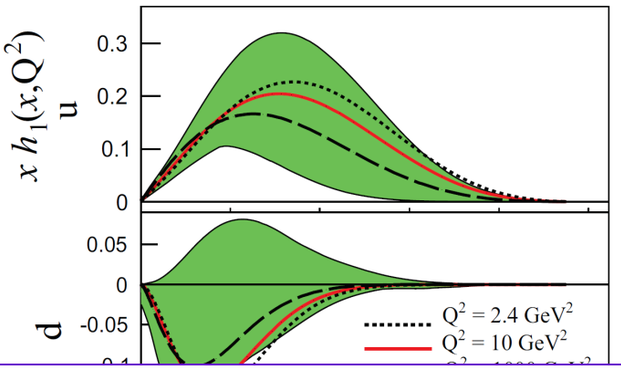
EXTRACTIONS OF TRANSVERSITY

fits of **Collins asymmetries** SIDIS off p and d, and e^+e^- data

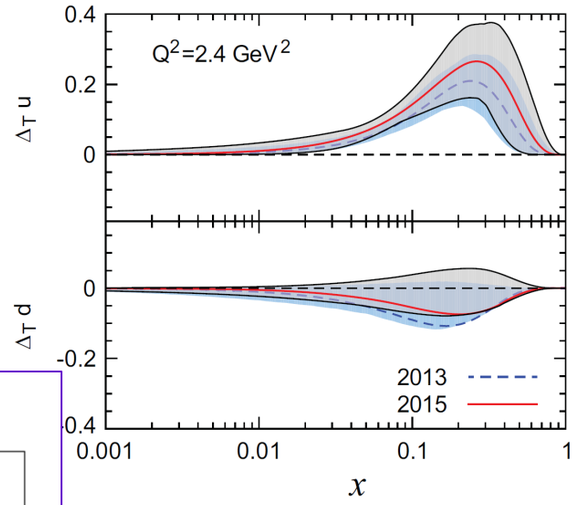
Anselmino et al PRD **2007**



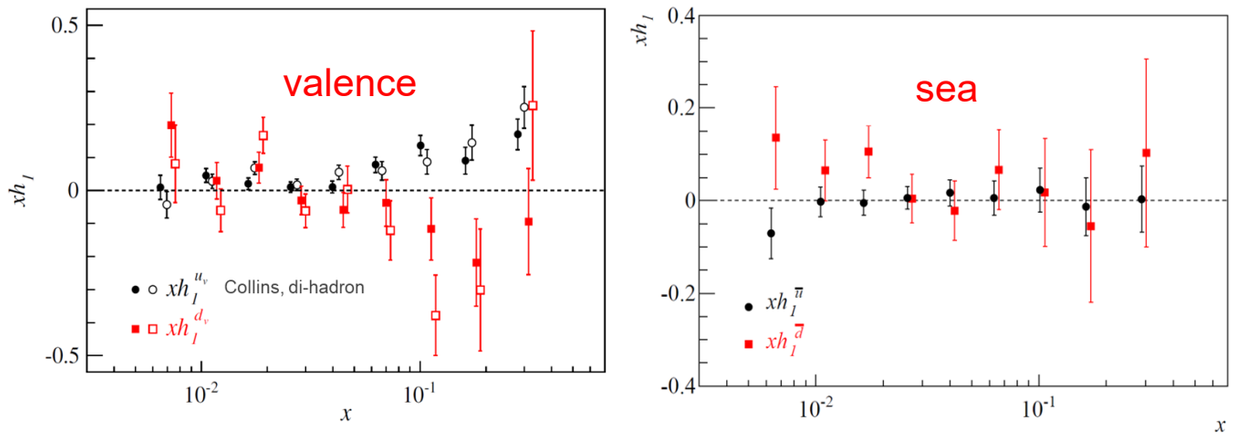
Z.-B. Kang et al. PRD **2016**



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



A. Martin, F. B., V. Barone PRD 2015



point by point extraction

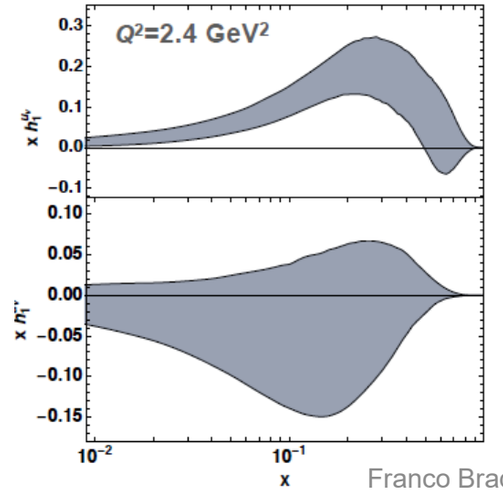
using COMPASS p and d asymmetries, and e^+e^- data

no Soffer bound; no Monte Carlo nor parametrisations needed

ymmetries

e⁺e⁻, and pp data

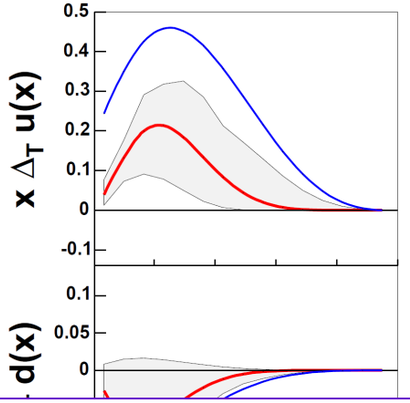
Radici Bacchetta PRL **2018**



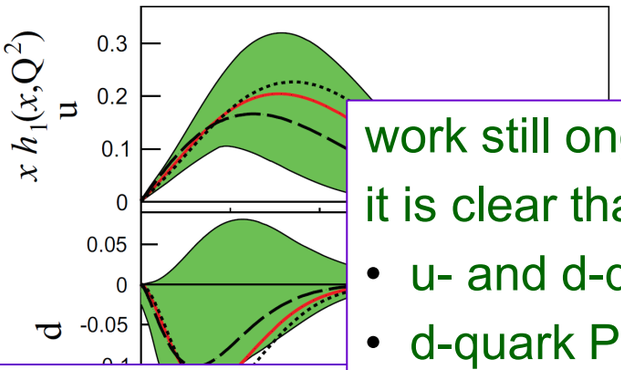
EXTRACTIONS OF TRANSVERSITY

fits of **Collins asymmetries** SIDIS off p and d, and e^+e^- data

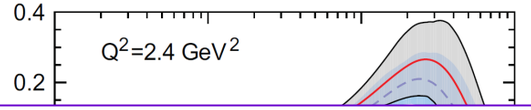
Anselmino et al PRD **2007**



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



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

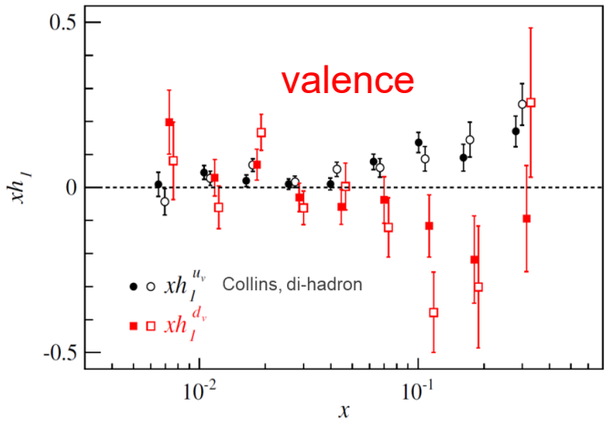


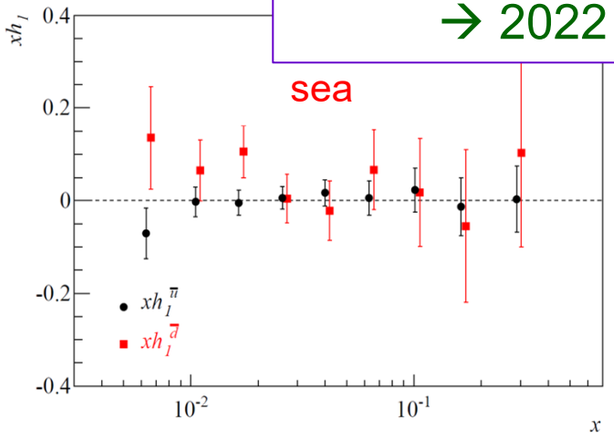
work still ongoing …

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

A. Martin, F. B.





point by point extraction

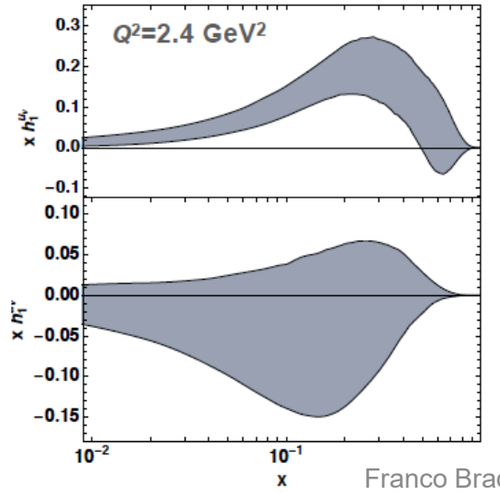
using COMPASS p and d asymmetries, and e^+e^- data

no Soffer bound; no Monte Carlo nor parametrisations needed

ymmetries

e^+e^-, and pp data

Radici Bacchetta PRL **2018**



THE PROTON DATA

several other measurements have been performed

THE PROTON DATA

several other measurements have been performed

- **other TSAs**

$A_{UT}^{\sin\phi_s}$

subleading twist
similar to HERMES results

$A_{UT}^{\sin(3\phi_h-\phi_s)}$

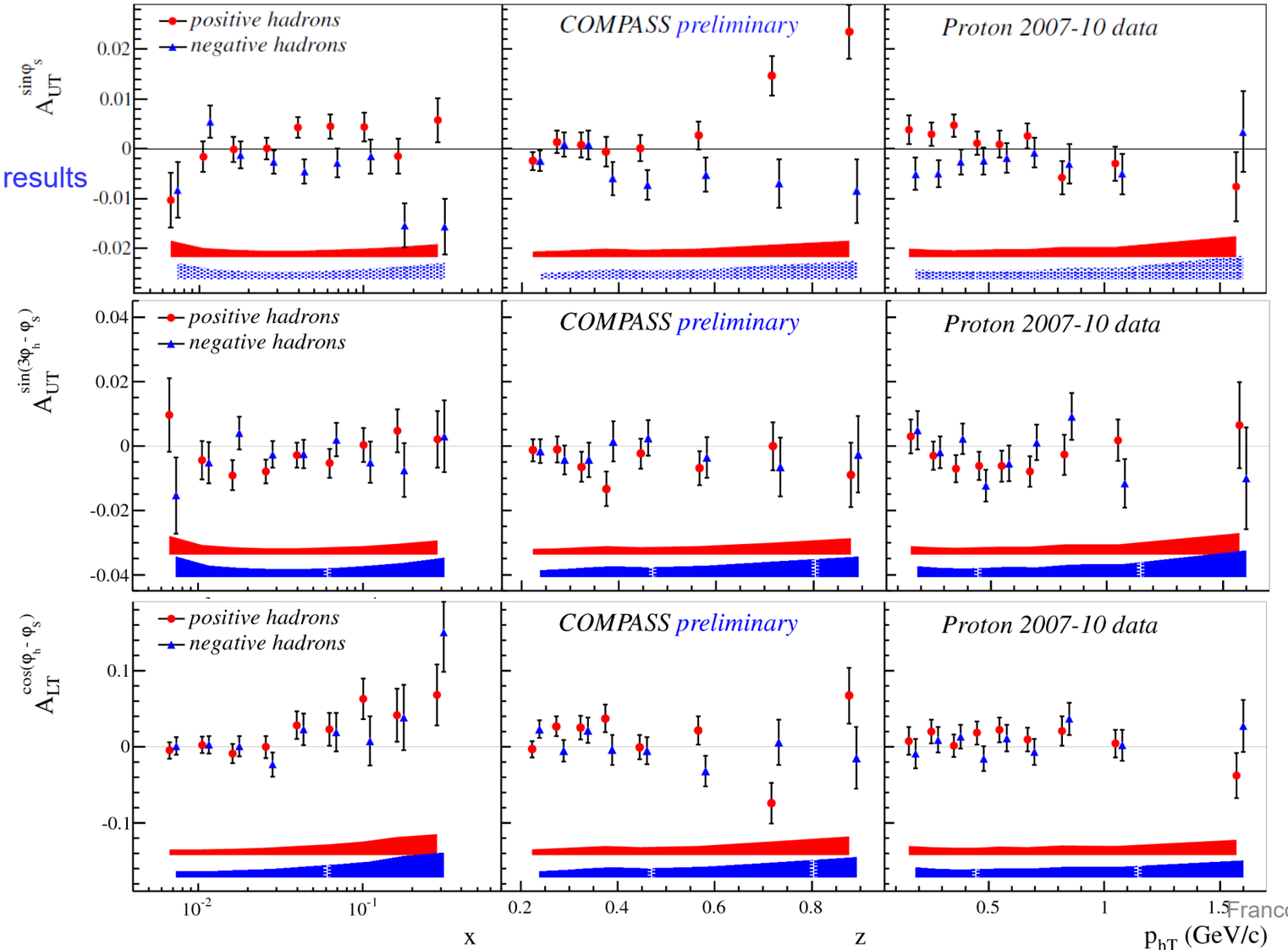
$h_{1T}^{\perp} \otimes H_1^{\perp}$

pretzelosity

$A_{UT}^{\cos(\phi_h-\phi_s)}$

$g_{1T} \otimes D_1$

worm-gear T
Kotzinian- Mulders



THE PROTON DATA

several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins

  in particular for the COMPASS Drell-Yan measurement PBL 770 (2017) 138
- P_T - weighted Sivers asymmetries

  no convolution, important tests, extraction of the Sivers function NPB 940 (2019) 34

THE PROTON DATA

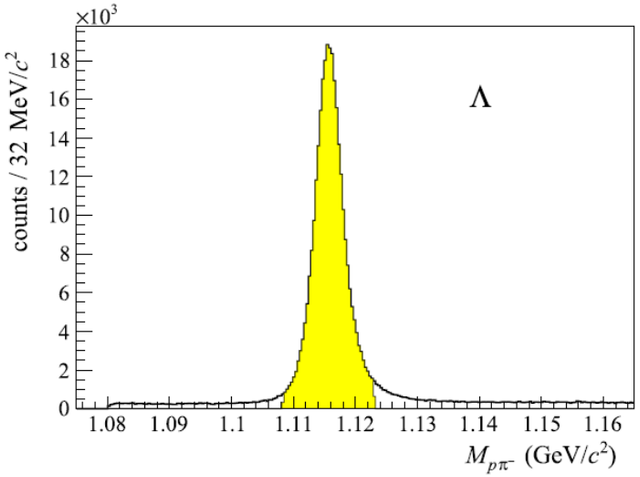
several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins

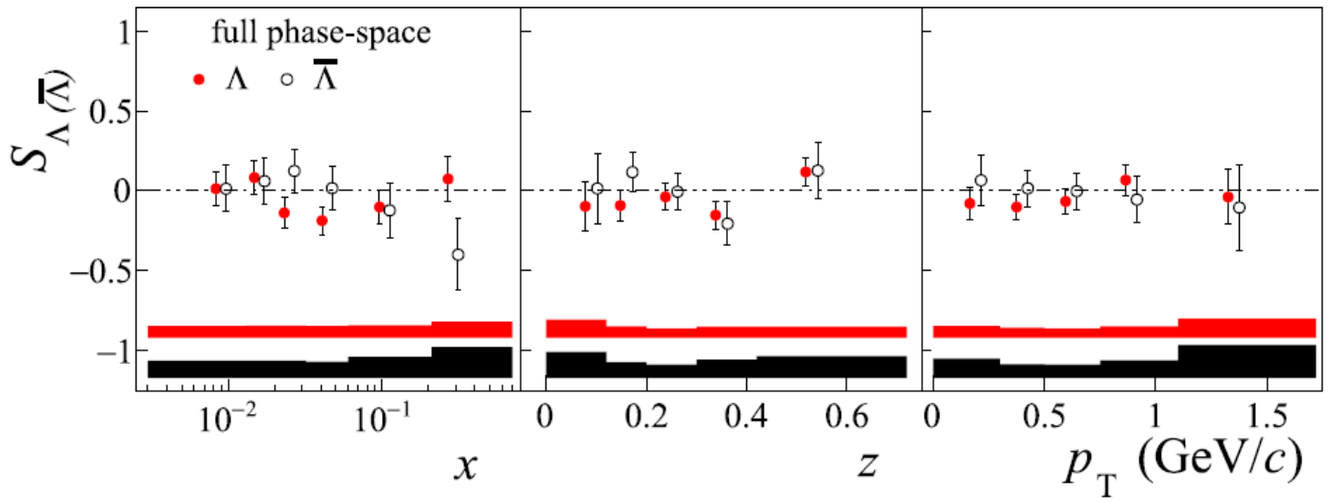
  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries

  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- **transversity induced $\Lambda/\bar{\Lambda}$ polarization** — PLB 824 (2022) 136834

$$S_{\Lambda(\bar{\Lambda})} = \frac{\sum_q e_q^2 h_1^q H_{1,q}^{\Lambda(\bar{\Lambda})}}{\sum_q e_q^2 f_1^q D_{1,q}^{\Lambda(\bar{\Lambda})}}$$



~ 305 000 Λs, 154000 $\bar{\Lambda}$s.

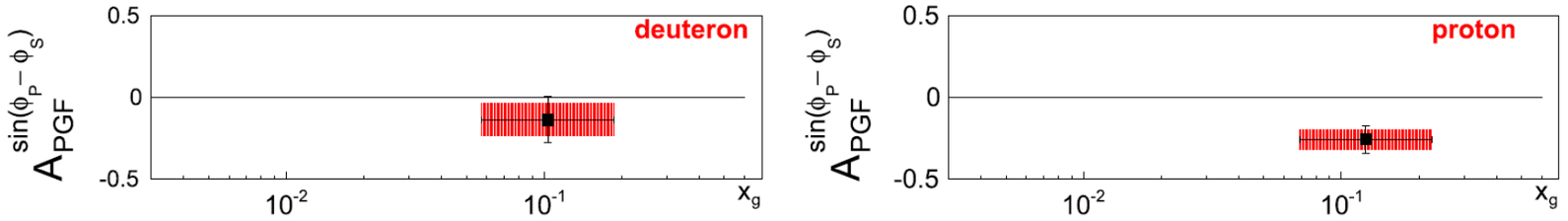


THE PROTON DATA

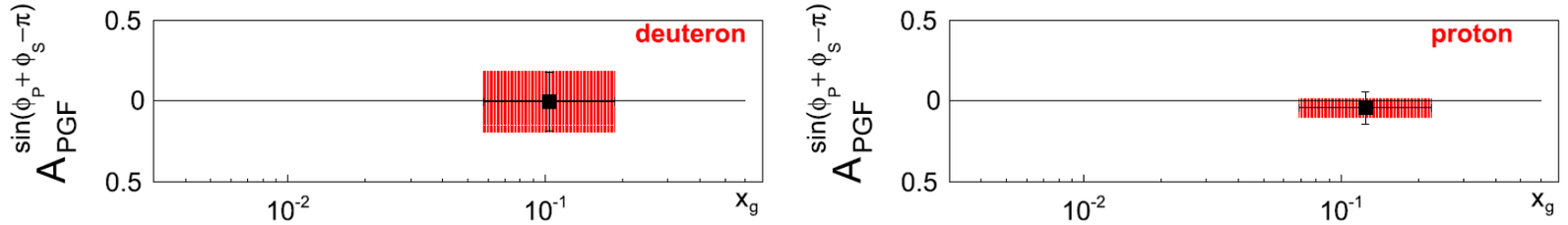
several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins
  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries
  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- *transversity induced* $\Lambda / \bar{\Lambda}$ *polarization* — PLB 824 (2022) 136834
- **TSAs for high P_T pairs from PGF events** — PLB 772 (2017) 854

Sivers-like



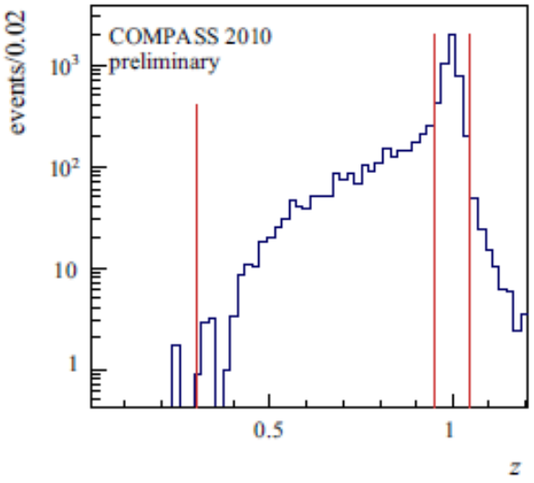
Collins-like

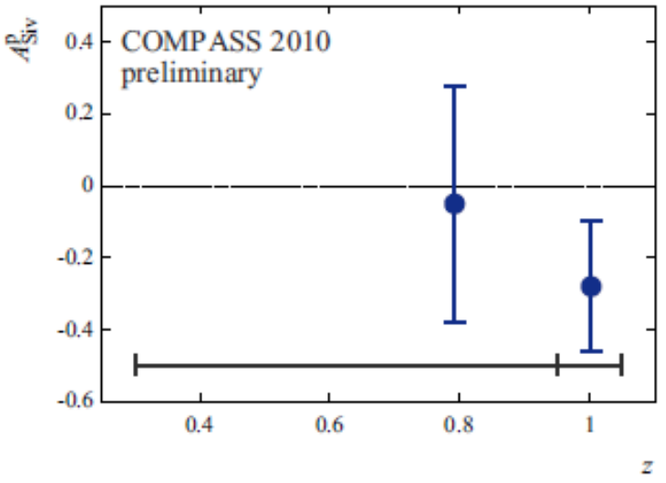


THE PROTON DATA

several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs (x, Q^2, z, P_T) *bins*
- Sivers asymmetry in Q^2 bins
  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries
  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- *transversity induced* $\Lambda / \bar{\Lambda}$ *polarization* — PLB 824 (2022) 136834
- *TSAs for high* P_T *pairs from PGF events* — PLB 772 (2017) 854
- **J/Ψ Sivers asymmetry**





THE PROTON DATA

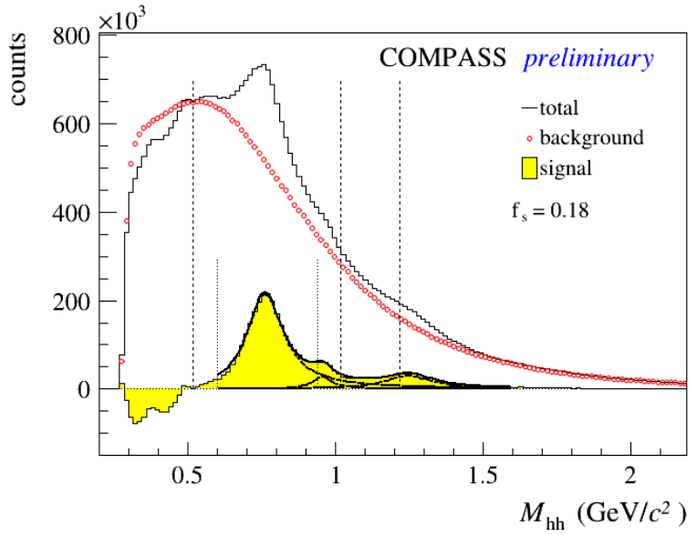
several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins
  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries
  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- transversity induced $\Lambda / \bar{\Lambda}$ polarization — PLB 824 (2022) 136834
- TSAs for high P_T pairs from PGF events — PLB 772 (2017) 854
- J/Ψ *Sivers asymmetry*

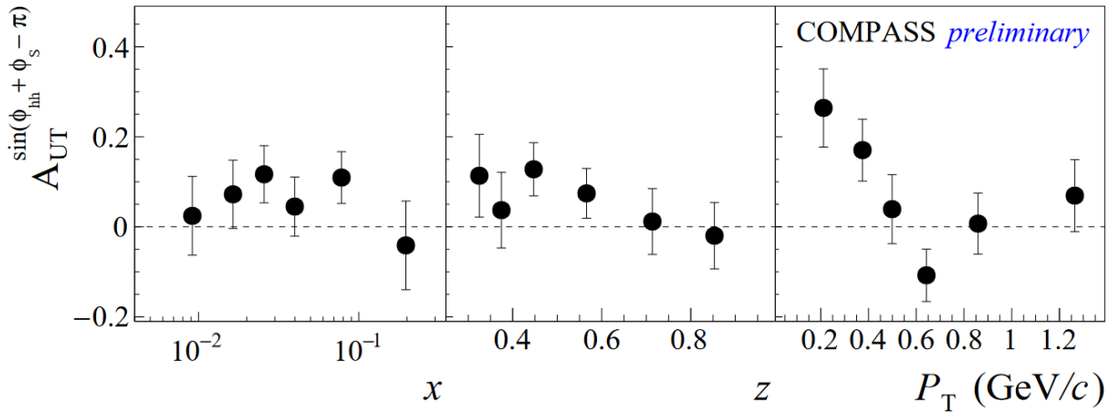
- **ρ^0 TSAs - new!**

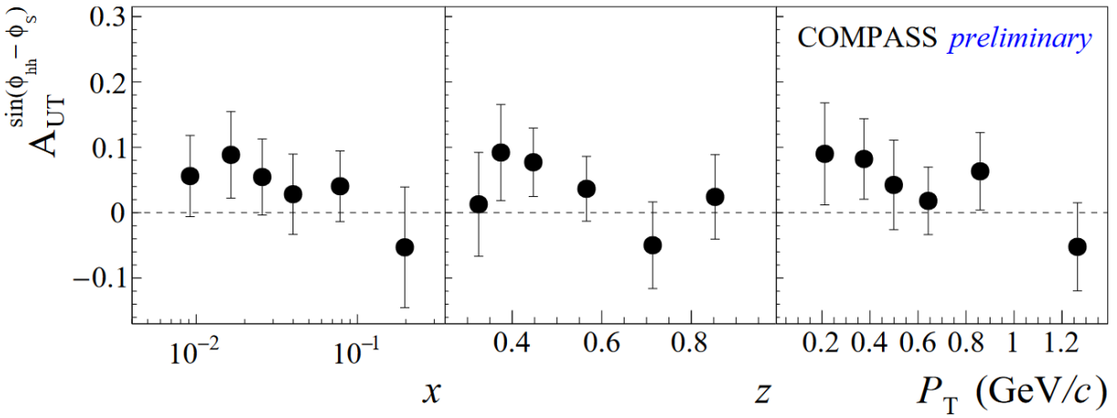
THE PROTON DATA

ρ^0 TSAs



paper in preparation





COLLINS ASYMMETRY

- indication for positive asymmetry
  opposite to π^+ as expected
- large at small P_T

SIVERS ASYMMETRY

- indication for positive asymmetry
  similarly to π^0 as expected

only statistical uncertainties
$\sigma_{syst} = 0.3\sigma_{stat}$

THE PROTON DATA

several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins

  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries

  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- *transversity induced $\Lambda / \bar{\Lambda}$ polarization* — *PLB 824 (2022) 136834*
- *TSAs for high P_T pairs from PGF events* — *PLB 772 (2017) 854*
- *J/Ψ Sivers asymmetry*
- *ρ^0 TSAs*

and there are ideas for new measurements

- measurement of the g_2 structure function – ongoing
- ….

THE PROTON DATA

several other measurements have been performed

- *other TSA*
- multidimensional measurements of TSAs $(x, Q^2, z, P_T)\ bins$
- Sivers asymmetry in Q^2 bins
  in particular for the COMPASS Drell-Yan measurement — PLB 770 (2017) 138
- P_T - weighted Sivers asymmetries
  no convolution, important tests, extraction of the Sivers function — NPB 940 (2019) 34
- *transversity induced $\Lambda / \bar{\Lambda}$ polarization* — *PLB 824 (2022) 136834*
- *TSAs for high P_T pairs from PGF events* — *PLB 772 (2017) 854*
- *J/Ψ Sivers asymmetry*
- *ρ^0 TSAs*

and there are ideas for new measurements

- measurement of the g_2 structure function – ongoing
- ….

all these measurements will be repeated with the new deuteron data, which will hopefully be collected this year

SUMMARY

COMPASS has given a relevant contribution to the study of the transverse structure of the nucleons with the Transverse Spin Asymmetries in SIDIS

the 2022 deuteron run COMPASS will allow to complete the exploratory study of the transverse spin structure of the nucleon

→ improved measurement of the tensor charge

these new data will allow to fully use the existing proton data and will be unique in the relatively short future

thank you !

TARGET LONGITUDINAL SPIN ASYMMETRIES

$$\frac{d\sigma}{dxdydzdp_T^2 d\phi_h d\phi_S} \propto \left(F_{UU,T} + \varepsilon F_{UU,L}\right)\Big\{ \quad 1 + \ldots$$

$$+ \; S_L \begin{bmatrix} \sqrt{2\varepsilon(1+\varepsilon)}\, A_{UL}^{\sin\phi_h} \sin\phi_h \\ +\varepsilon\, A_{UL}^{\sin 2\phi_h} \sin 2\phi_h \end{bmatrix}$$

$$+ \; S_L \lambda \begin{bmatrix} \sqrt{1-\varepsilon^2}\, A_{LL} \\ +\sqrt{2\varepsilon(1-\varepsilon)}\, A_{LL}^{\cos\phi_h} \cos\phi_h \end{bmatrix} \Big\}$$

measured with unprecedented precision

$A_{UL}^{\sin\phi_h}$

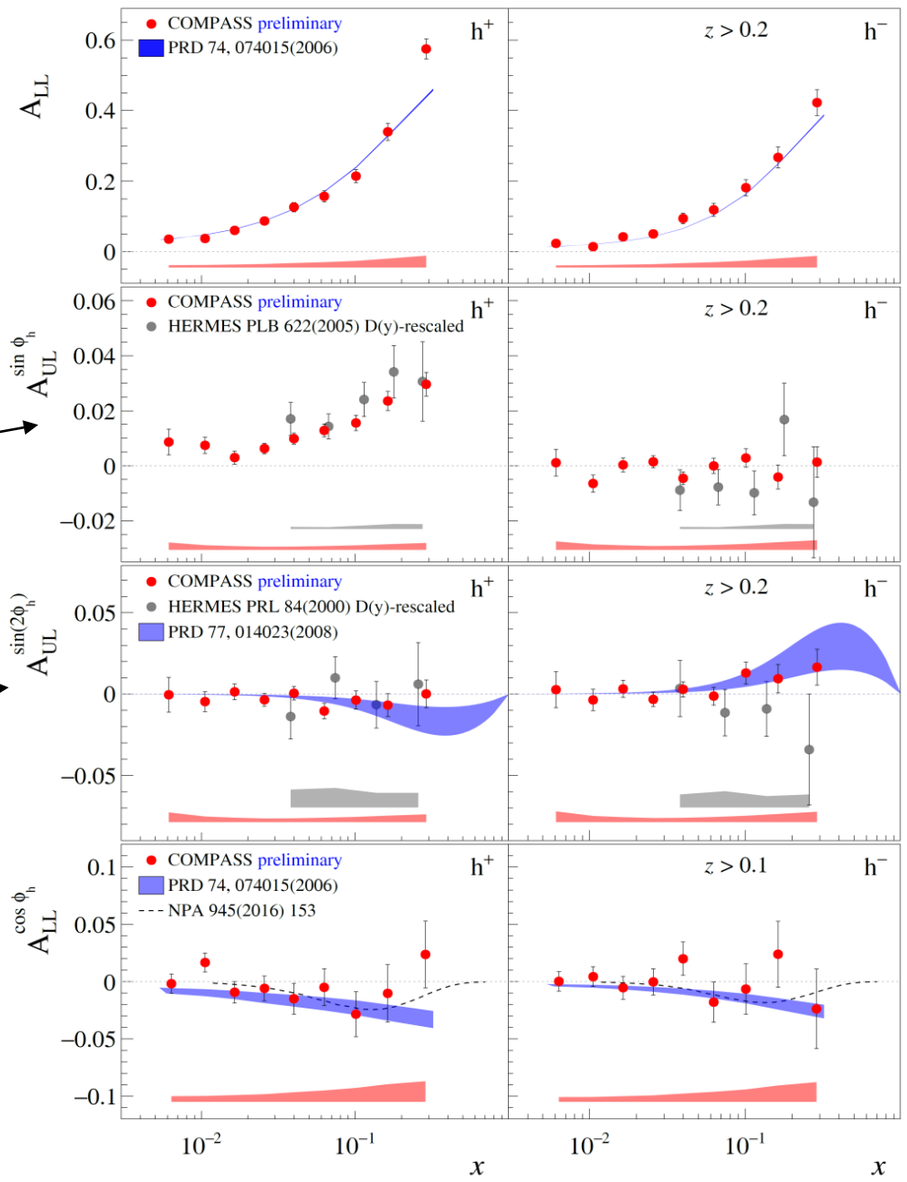
- Q-suppression, different “twist” contributions
- **significant h^+ asymmetry**

$A_{UL}^{\sin 2\phi_h}$ $\quad h_{1L}^{\perp} \otimes H_1^{\perp}$

- only “twist-2” ingredients, additional p_T-suppression
- **compatible with zero**, in agreement with models

$A_{LL}^{\cos\phi_h}$

- Q-suppression, different “twist” contributions
- **compatible with zero**, in agreement with models



B. Parsamyan, COMPASS Coll arXiv:1801.01488

THE DEUTERON DATA

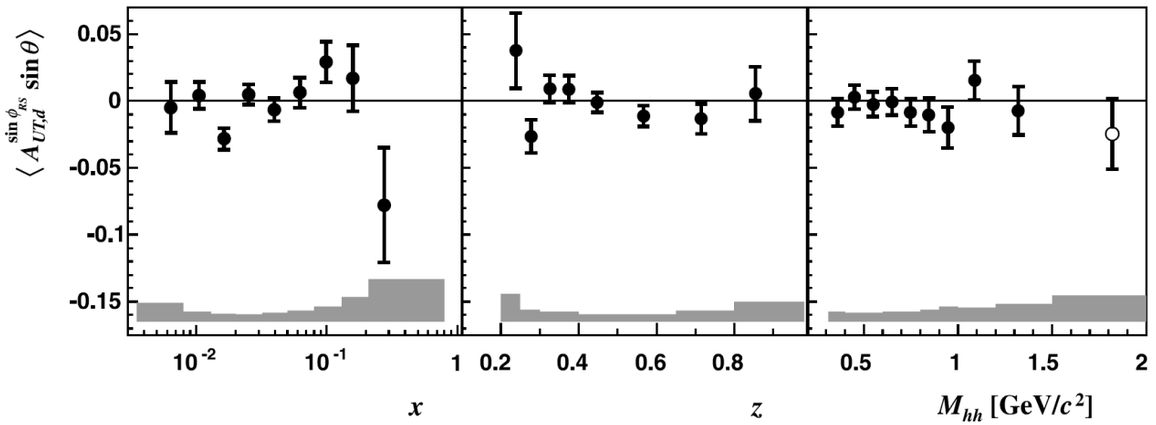
looking for a signal

di-hadron asymmetries:
a different approach to transversity

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

Belle

2002-2004 deuteron data
$all\ h^+h^-\ pairs$



PLB713 (2012) 10

many tests measurements:

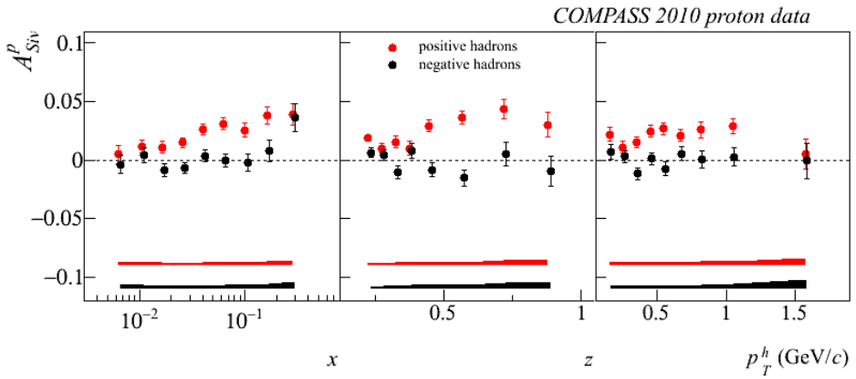
- z ordering, leading + or - with subleading like or unlike sign
- particle identification
- ….

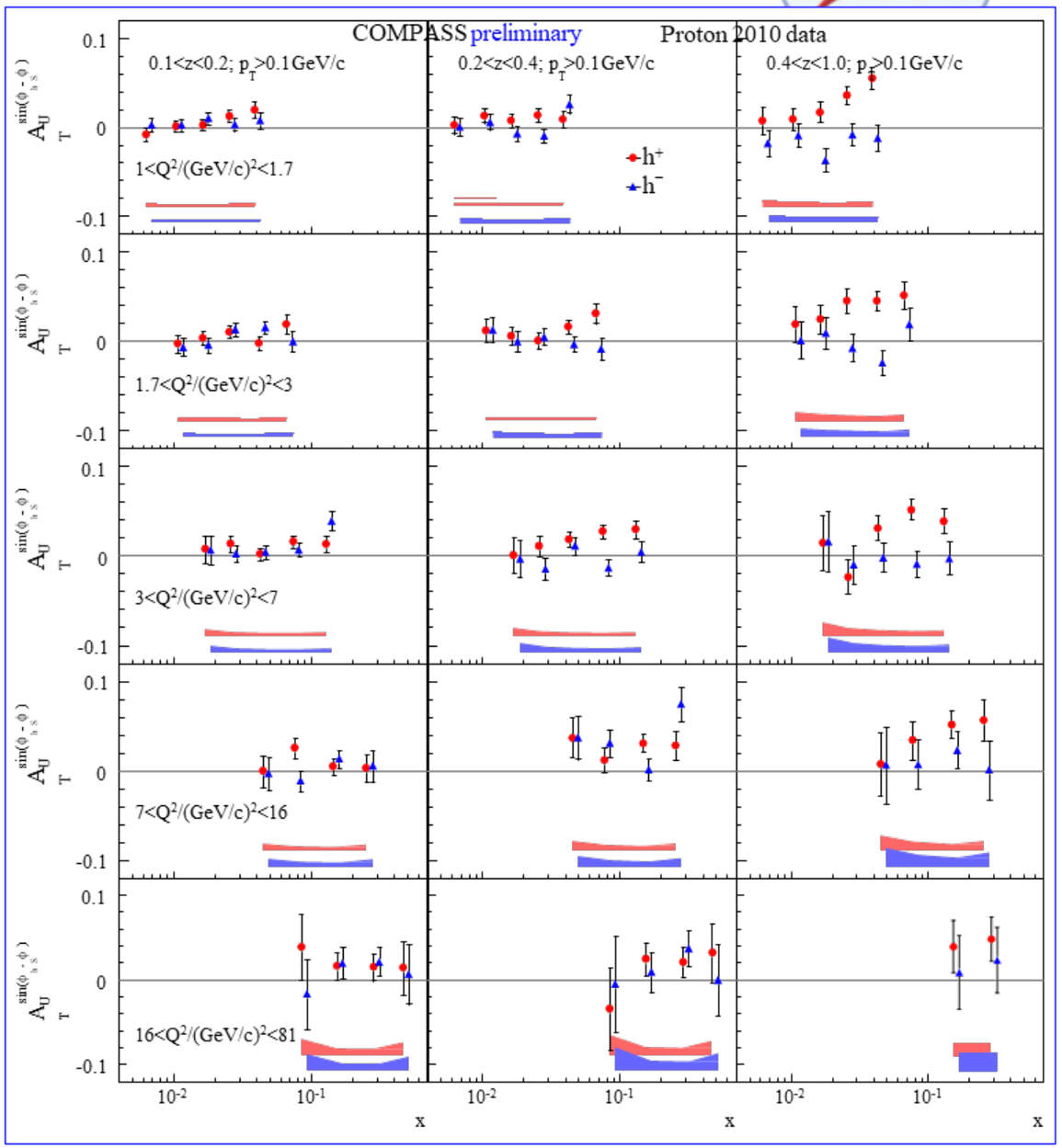
a lot of expectation for the COMPASS proton results (higher energy)

THE PROTON DATA

multidimensional measurements of TSAs
(x, Q^2, z, P_T) *bins*

Sivers asymmetry

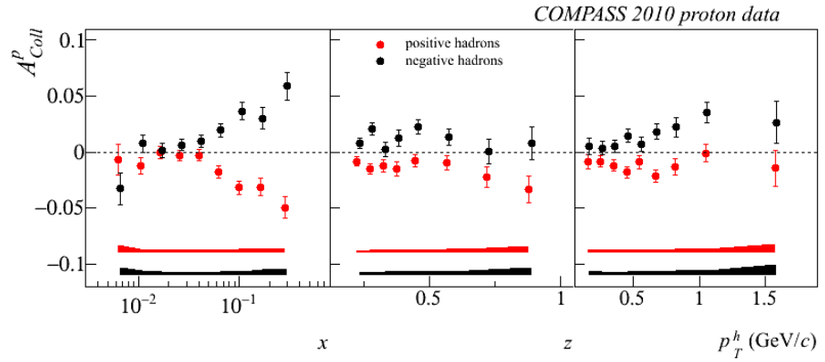


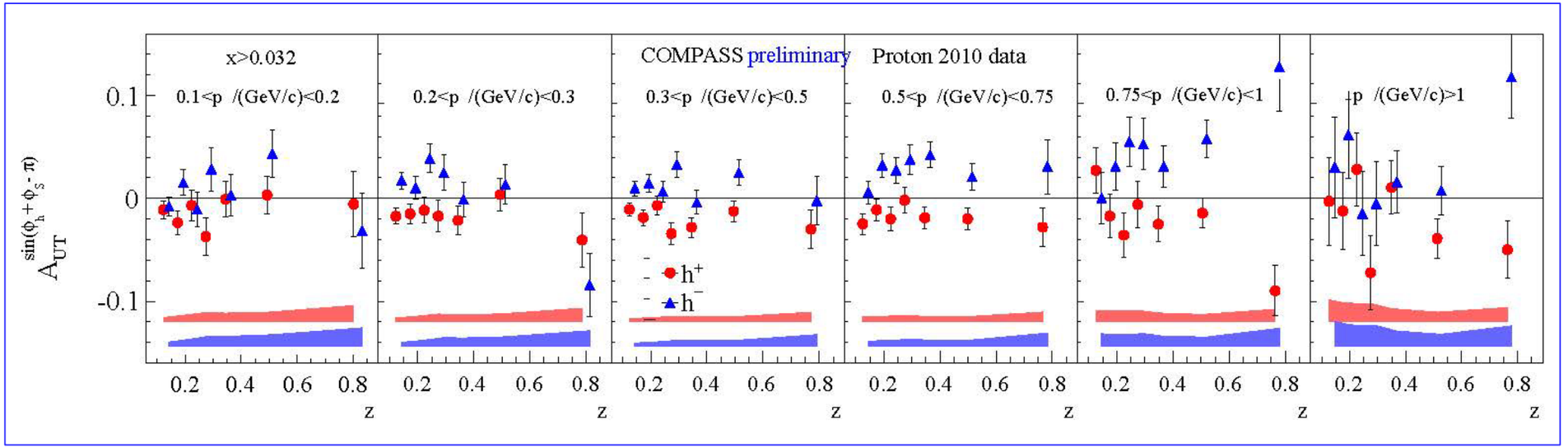


THE PROTON DATA

multidimensional measurements of TSAs
(x, Q^2, z, P_T) *bins*

Collins asymmetry





THE 2022 RUN – TRANSVERSELY POLARISED DEUTERON

the missing measurement to complete the exploratory study of transverse spin effects in SIDIS, and the COMPASS programme

in a kinematic range that only COMPASS can cover, as long as EIC will not start, complementary to JLab

approved in 2018

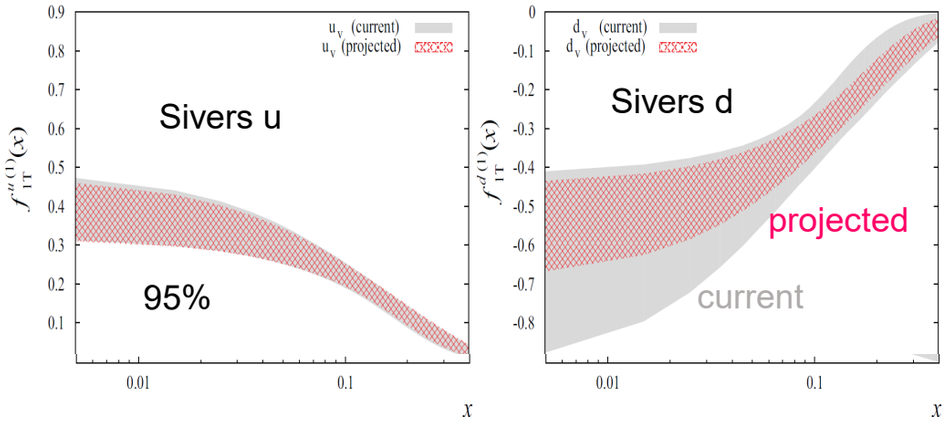
one year of run with 160 GeV muons to measure SIDIS off transversely polarised d

collecting the same statistics as in 2010, the deuteron asymmetries will have a statistical uncertainty

$$\sigma_d \cong 0.6\,\sigma_p^{2010}$$

- important impact on the knowledge of TMD PDFs

Sivers functions from global fits
M. E. Boglione and J. O. Gonzalez

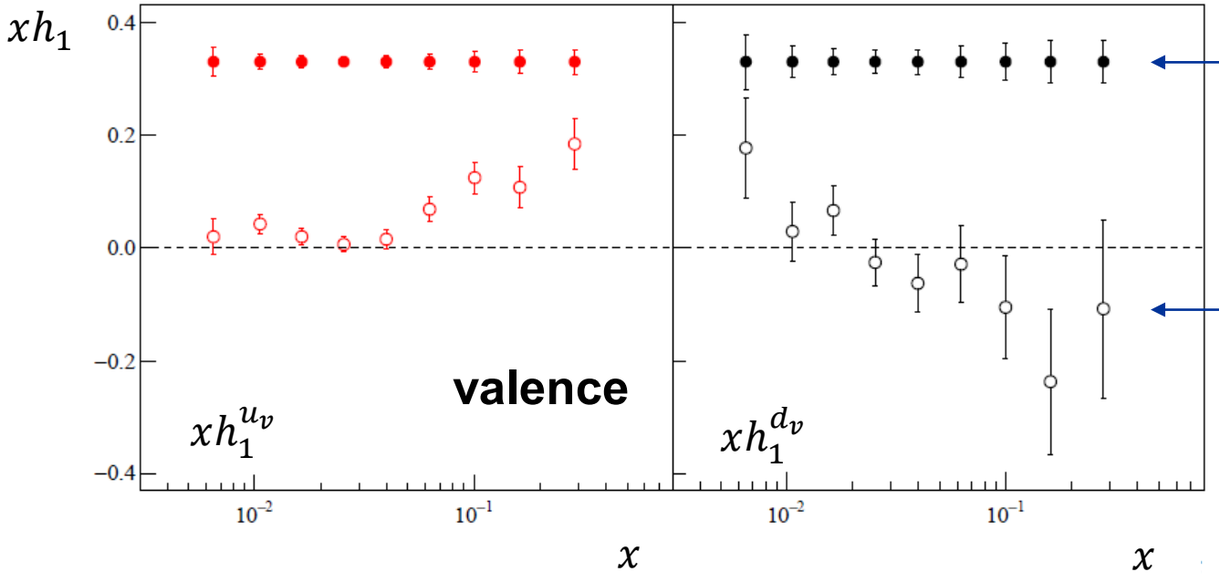


and in particular

- transversity and tensor charge $g_T = \delta_u - \delta_d$

$$\delta_q = \int_0^1 dx h_1^{q_v}(x)$$

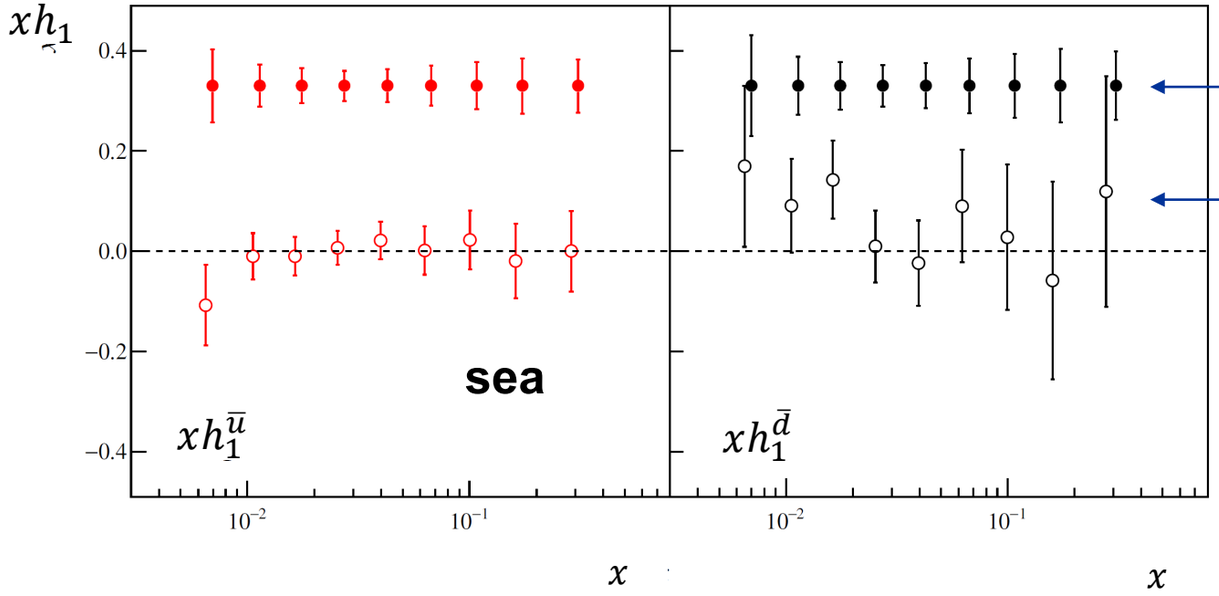
THE 2022 RUN: IMPACT ON THE TRANSVERSITY FUNCTIONS



projected
gain 1.2 to 2.0 for u
1.8 to 4.0 for d

present

PRD 91(2015) 014034
from COMPASS p, d
and e+e- data



projected

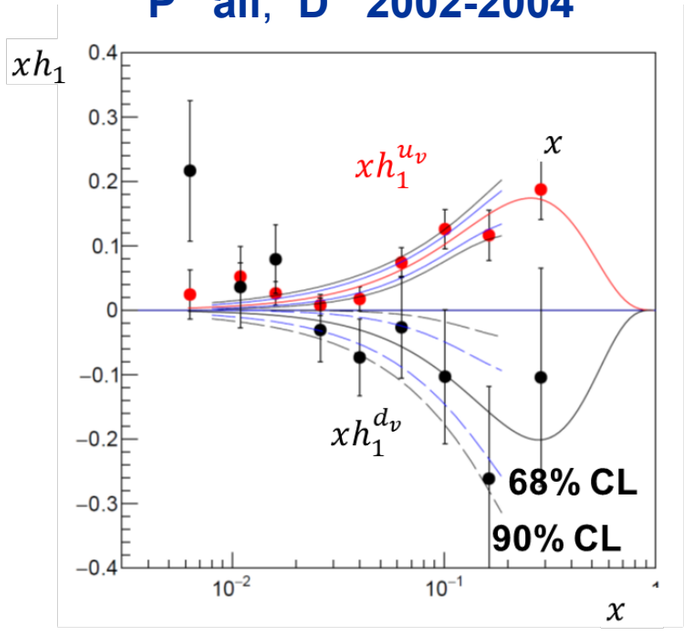
present

COMPASS

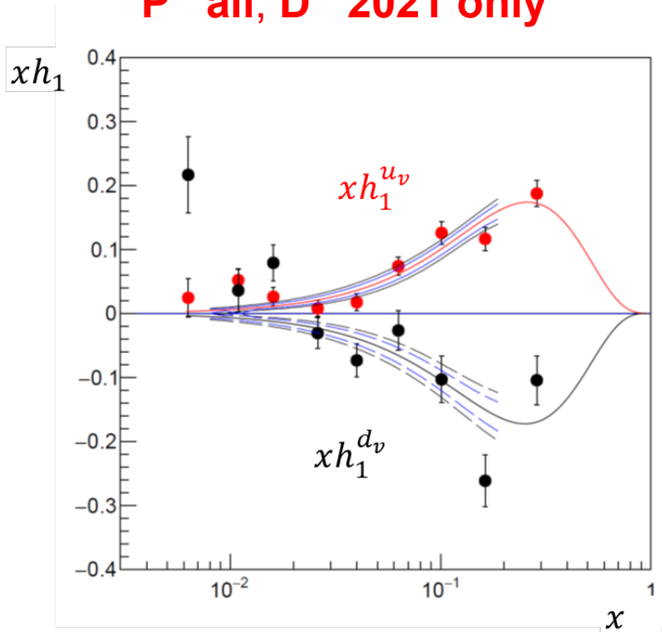
THE 2022 RUN: IMPACT ON THE TRANSVERSITY FUNCTIONS

for the proposal, we have evaluated the tensor charge in the measured x range

present
P all, D 2002-2004



projected
P all, D 2021 only



$\Omega_x: 0.008 \div 0.210$

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

complementarity with the future JLab results

- we have assumed that from SoLid data one extract 50 values of $xh_1^{d_v}$ in the range $0.1 < x < 0.6$ with a statistical uncertainty of 0.013
- we have used two possible x dependences:
  A. $xh_1^{d_v} = -2.5\, x^{1.5}\,(1-x)^4$ B. $xh_1^{d_v} = -8\, x^{1.5}\,(1-x)^8$
  and generated the data accordingly
- we have looked for reasonable different parametrisations still in agreement with SoLid simulated data (p-value >0.10) finding the curves 1 and 2

Z. Ye et al.
PLB767 (2017) 91