COMPASS legacy: transverse spin phenomena

(as seen from the back stage)

Franco Bradamante
INFN, sezione di Trieste
Common Muon and Proton Apparatus for Structure and Spectroscopy

fixed target experiment at the CERN SPS
fixed target experiment at the CERN SPS

PROPOSAL
March ’96

RECOMMENDED
September ’96

APPROVED
February ’97

TAKING DATA
since 2002

25 YEARS
our jubilee

August 29, 2022
Franco Bradamante
THE STRUCTURE OF THE NUCLEON

Collinear description  leading twist

<table>
<thead>
<tr>
<th>nucleon polarisation</th>
<th>U</th>
<th>L</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>$f_1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td>$g_1$</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td>$h_1$</td>
</tr>
</tbody>
</table>

- **number density** $f_1(q)$
  - very well known
- **helicity distribution** $g_1(\Delta q)$
  - well known
- **transversity distribution** $h_1(\Delta T q)$

- first experimental evidence in 2005
- correlation between the transverse polarisation of the nucleon and the transverse polarisation of the quark
- related to **tensor charge**
- a chirally-odd distribution, not observable in DIS, accessible in SIDIS
SEMI-INCLUSIVE DEEP INELASTIC SCATTERING

hard interaction of a lepton with a nucleon via virtual photon exchange

\[ \sigma_{lN \rightarrow lhX} \sim \sum_q \sigma_{lq \rightarrow lq} \otimes f(x) \otimes D_q^h(z) \]

\[ p_T^h, \phi_h \]

\[ \begin{align*}
  x & = \frac{Q^2}{2P \cdot q} \\
  y & = \frac{P \cdot q}{P \cdot \ell} =_{LAB} \frac{E - E'}{E} \\
  Q^2 & = -q^2 \\
  W^2 & = (P + q)^2 \\
  z & = \frac{P \cdot P_h}{P \cdot q} =_{LAB} \frac{E_h}{E - E'}
\end{align*} \]
SIDIS – THE COLLINS ASYMMETRY

Collins effect

→ azimuthal distribution of the hadrons produced in \( LN^\uparrow \rightarrow l'hX \)

\[
N_h^\pm(\Phi_C) = N_h^0 \cdot \left[ 1 \pm P_T \cdot D_{NN} \cdot A_{Coll} \cdot \sin \Phi_C \right]
\]

\( \pm \) refer to the opposite orientation of the transverse spin of the nucleon

\( P_T \) is the target polarisation; \( D_{NN} \) is the transverse spin transfer coefficient initial \( \rightarrow \) struck quark

“Collins angle”

\[
\Phi_C = \phi_h - \phi_S', = \phi_h + \phi_S - \pi
\]

\( \phi_{h,S'},S \) azimuthal angles of hadron momentum, of the spin of the fragmenting quark and of the nucleon in the GNS

from the azimuthal distribution of the hadrons one measures the “Collins Asymmetry”

\[
A_{Coll} \propto \sum_q e_q^2 \frac{\Delta_T q \cdot \Delta_T D_q^h}{\sum_q e_q^2 \cdot q \cdot D_q^n}
\]

\( \Delta_T q \leftrightarrow h_1^q \)

\( \Delta_T D_q^h \leftrightarrow H_{1}^{1h} \) Collins function

from the azimuthal distribution of the hadrons one measures the “Collins Asymmetry”
HELP proposal (L. Dick, B. Vuaridel, R. Hess, 1993) rejected by CERN: regarded as black magic

Our Collaboration accepted as a compromise to dedicate 20% of the running time with muon beam to measurements with transversely polarized nucleon targets
HELP proposal (L. Dick, B. Vuaridel, R. Hess, 1993) rejected by CERN: regarded as black magic

Our Collaboration accepted as a compromise to dedicate 20% of the running time with muon beam to measurements with transversely polarized nucleon targets

**Transversity is different from zero**
and has been extracted from COMPASS and $e^+e^-$ data and with “global” fits of COMPASS, HERMES, $e^+e^-$, ...data

A. Martin, F.B., V. Barone, Phys.Rev.D 91, 2015 curves from Anselmino et al., PRD87 2013
in parallel, the Sivers function story

a long debate

• 1992 introduced by D. Sivers
• 1993 J. Collins demonstrate that it must vanish
• 2002 S. Brodsky et al.: it can be $\neq 0$ because of FSI
• 2002 J. Collins: process dependent, change of sign  SIDIS $\leftrightarrow$ DY
  ....
in parallel, the Sivers function story

a long debate

- 1992 introduced by D. Sivers
- 1993 J. Collins demonstrate that it must vanish
- 2002 S. Brodsky et al.: it can be $\neq 0$ because of FSI
- 2002 J. Collins: process dependent, change of sign $\text{SIDIS} \leftrightarrow \text{DY}$

1996: not in our Proposal

IT IS ALSO DIFFERENT FROM ZERO
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.

<table>
<thead>
<tr>
<th>Quark Polarisation</th>
<th>Nucleon Polarisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>$f_1$</td>
</tr>
<tr>
<td>L</td>
<td>$g_1$</td>
</tr>
<tr>
<td>T</td>
<td>$h_1^\perp$</td>
</tr>
<tr>
<td></td>
<td>$h_{1L}$</td>
</tr>
<tr>
<td></td>
<td>$h_{1T}$</td>
</tr>
</tbody>
</table>

$h_1$ Transversity  \[ h_{1T} \] Pretzelosity
$f_{1T}^\perp$ Sivers PDF  \[ g_{1T} \] Worm-gear T Kotzinian-Mulders
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

<table>
<thead>
<tr>
<th>Quark Polarisation</th>
<th>U</th>
<th>L</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>$f_1$</td>
<td></td>
<td>$f_{1T}^\perp$</td>
</tr>
<tr>
<td>L</td>
<td>$g_1$</td>
<td></td>
<td>$g_{1T}$</td>
</tr>
<tr>
<td>T</td>
<td>$h_1^\perp$</td>
<td>$h_{1L}^\perp$</td>
<td>$h_1$ $h_{1T}^\perp$</td>
</tr>
</tbody>
</table>

SIDIS gives access to all of them!

$h_1$ Transversity $h_{1T}^\perp$ pretzelosity

$f_{1T}^\perp$ Sivers PDF $g_{1T}$ worm-gear T Kotzinian- Mulders
\[ \frac{d\sigma}{dx dy d\psi dz d\phi_h dP^2_{h\perp}} = \]
\[ \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1 - \varepsilon)} \left( 1 + \frac{\gamma^2}{2x} \right) \left\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1 - \varepsilon)} \cos \phi_h F_{UU}^{\cos \phi_h} \right. \]
\[ + \varepsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_\varepsilon \sqrt{2\varepsilon(1 - \varepsilon)} \sin \phi_h F_{LU}^{\sin \phi_h} \]
\[ + S_\parallel \left[ \sqrt{2\varepsilon(1 + \varepsilon)} \sin \phi_h F_{UL}^{\sin \phi_h} + \varepsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right] + S_\parallel \lambda_\varepsilon \left[ \sqrt{1 - \varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1 - \varepsilon)} \cos \phi_h F_{LL}^{\cos \phi_h} \right] \]
\[ + |S_\perp| \left[ \sin(\phi_h - \phi_S) \left( F_{UT,T}^{\sin(\phi_h - \phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h - \phi_S)} \right) \right. \]
\[ + \varepsilon \sin(\phi_h + \phi_S) F_{UT}^{\sin(\phi_h + \phi_S)} + \varepsilon \sin(2\phi_h - \phi_S) F_{UT}^{\sin(2\phi_h - \phi_S)} \]
\[ + \sqrt{2\varepsilon(1 + \varepsilon)} \sin \phi_S F_{UT}^{\sin \phi_S} + \sqrt{2\varepsilon(1 + \varepsilon)} \sin(2\phi_h - \phi_S) F_{UT}^{\sin(2\phi_h - \phi_S)} \]
\[ + |S_\perp| \lambda_\varepsilon \left[ \sqrt{1 - \varepsilon^2} \cos(\phi_h - \phi_S) F_{LT}^{\cos(\phi_h - \phi_S)} + \sqrt{2\varepsilon(1 - \varepsilon)} \cos \phi_S F_{LT}^{\cos \phi_S} \right. \]
\[ + \sqrt{2\varepsilon(1 - \varepsilon)} \cos(2\phi_h - \phi_S) F_{LT}^{\cos(2\phi_h - \phi_S)} \right\}, \]
\[
\frac{d\sigma}{dx \ dy \ d\psi \ dz \ d\phi_h \ d\rho_{h,\perp}^2} = \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\varepsilon)} \left[ (1 + \frac{y^2}{2x}) \left( F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1-\xi)} \cos \phi_h F_{UU}^{\cos \phi_h} \right) 
\right. \\
+ \varepsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_\varepsilon \sqrt{2\varepsilon(1-\xi)} \sin \phi_h F_{LU}^{\sin \phi_h} \\
+ \left. S_{\parallel} \left[ \sqrt{2\varepsilon(1+\xi)} \sin \phi_h F_{UL}^{\sin \phi_h} + \varepsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right] + S_{\parallel} \lambda_\varepsilon \left[ \sqrt{1-\varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1-\xi)} \cos \phi_h F_{LL}^{\cos \phi_h} \right] \right]
\]
\[ \frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP^2_{h\perp}} = \frac{\alpha^2}{xyQ^2} \left( 1 + \frac{\gamma^2}{2x} \right) \left\{ F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1 + \varepsilon)} \cos \phi_h F_{UU}^{\cos \phi_h} h^+_T H^+_T \right. \\
+ \left. \varepsilon \cos(2\phi_h) F_{UU}^{\cos 2\phi_h} + \lambda_\varepsilon \sqrt{2\varepsilon(1 - \varepsilon)} \sin \phi_h F_{LU}^{\sin \phi_h} h^+_T \right. \\
+ S_\parallel \left[ \sqrt{2\varepsilon(1 + \varepsilon)} \sin \phi_h F_{UL}^{\sin \phi_h} + \varepsilon \sin(2\phi_h) F_{UL}^{\sin 2\phi_h} \right] + S_\parallel \lambda_\varepsilon \left[ \sqrt{1 - \varepsilon^2} F_{LL} + \sqrt{2\varepsilon(1 - \varepsilon)} \cos \phi_h F_{LL}^{\cos \phi_h} \right] \]

8 independent azimuthal modulations
leading twist amplitudes → convolutions of transversity and TMD PDFs and FFs
TRANSVERSE SPIN EFFECTS – A BIG EXPERIMENTAL EFFORT

SIDIS

\[ Q^2 (\text{GeV}^2) \]

- **EIC**
  - high energy
  - high precision
  - future!

- **COMPASS**
  - ongoing

- **hermes**
  - over
  - results still coming

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

\[ e^+ e^- \rightarrow \text{hadrons} \]

**Fragmentation Functions**
- Collins, DiHadron, …

**BELLE BABAR BESIII**

**polarized DY**

**pp \rightarrow jets**
THE COMPASS SPECTROMETER – SIDIS with polarized targets

August 29, 2022

Franco Bradamante
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, $\mu$ID
RICH detector

and MOST IMPORTANT the polarized target
The COMPASS polarized target system – SIDIS >2005

3He – 4He dilution refrigerator (T~50mK)

solenoid 2.5T
dipole magnet 0.6T

Acceptance > ±180 mrad

3 target cells
30, 60, and 30 cm long

Opposite polarisation

Dilution factor

No evidence for relevant nuclear effects (160 GeV)

MANY THANKS TO ALAIN

Franco Bradamante
results on Transverse Spin Asymmetries

25 years after the proposal

• a review of well known results
• less known and new results
• expected results
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 asymmetry

first publication in 2005

PRL 94, 202002 (2005)

large statistical uncertainties, compatible with zero

\[ A_{Coll} \sim \frac{\sum_q e_q^2 h_1^q \otimes H_{1q}^q}{\sum_q e_q^2 f_1^q \cdot D_{1q}} \]

\[ A_{Siv} \sim \frac{\sum_q e_q^2 f_{11q}^{1q} \otimes D_{1q}}{\sum_q e_q^2 f_1^q \cdot D_{1q}} \]
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 asymmetry

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!

Collins, p

Sivers, p

hep-ex/0408013

August 29, 2022
FIRST EXTRACTIONS OF THE NEW PDFs

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

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 these p and d Sivers asymmetries came very soon

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

\[
A_{Coll} \sim \frac{\sum_q e_q^2 h_1^q \otimes H_{1q}^1}{\sum_q e_q^2 f_1^q \cdot D_{1q}}
\]

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 these 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

$$A_{Coll} \sim \frac{\sum_q e_q^2 h^q_1 \otimes H^1_{1q}}{\sum_q e_q^2 f^q_{1} \cdot D_{1q}}$$

collinear

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
in 2004 first results for the **Collins asymmetry** and for the **Sivers asymmetries**

**first publications in 2005**

**EXPERIMENTAL SITUATION IN 2005**

- PRL 94, 202002 (2005)

- **h+** Collins, **d** Sivers, **o** h-

- 2002 data

- **HERMES** had no deuteron data

- **COMPASS** had no proton data

- more data were needed!
THE DEUTERON DATA

2002: ~0.5 effective weeks of data taking, published in 2005
2003: 2 weeks of data taking
2004: 2 weeks of data taking

2002-2004 data

final results for deuteron published in 2007 NPB 765 (2007) 31

a more precise measurement of zero; still, large statistical uncertainties
THE DEUTERON DATA

2002: ~0.5 effective weeks of data taking, published in 2005
2003: 2 weeks of data taking
2004: 2 weeks of data taking

2002 data

Collins

2003: 2 weeks of data taking

2004: 2 weeks of data taking

Collins

final results for deuteron published in 2007 NPB 765 (2007) 31

a more precise measurement of zero; still, large statistical uncertainties

the only existing deuteron data

→ run 2022 ongoing!

JLab6: He3, statistically limited
in 2007 first (short) COMPASS run with transversely polarized protons (NH3) preliminary results (half of the data): Transversity 2008

COLLINS ASYMMETRY different from zero and COMPATIBLE WITH HERMES!
THE 2007 PROTON DATA

in 2007 first (short) COMPASS run with transversely polarized protons (NH3)
preliminary results (half of the data): Transversity 2008

COLLINS ASYMMETRY
different from zero and
COMPATIBLE WITH HERMES!

SIVERS ASYMMETRY
compatible with zero, also for positive hadrons
AT VARIANCE WITH HERMES

UNEXPECTED RESULT

no panic but NIGHTMARES
A_2 splitting
S meson
superluminal neutrinos
Close scrutiny of the collected data revealed some systematics
"fairly long and sometimes difficult analysis"


**Collins asymmetry:** preliminary result confirmed $\sigma_{syst} \approx 0.5 \sigma_{stat}$

**Sivers asymmetry:**
positive hadrons exhibit an average asymmetry of 0.03 somewhat smaller than HERMES but
definitely non zero

$\sigma^{+}_{syst} \approx 0.8 \sigma^{+}_{stat} \pm 0.01$

→ necessity of a longer and better data taking
Necessity of a longer and better data taking:
request for 1 year of data taking with transversely polarized p

“Transverse spin structure and Drell-Yan measurements at COMPASS”
FB talk at New opportunities in the physics landscape at CERN, May 2009

Addendum 2 to the COMPASS Proposal
CERN-SPSC-2009-025 SPSC-M-769
SPSLC-P-297 Add. 2, 21 June 2009
Necessity of a longer and better data taking:
request for 1 year of data taking with transversely polarized p

“Transverse spin structure and Drell-Yan measurements at COMPASS”
FB talk at New opportunities in the physics landscape at CERN,
May 2009

Addendum 2 to the COMPASS Proposal
CERN-SPSC-2009-025 SPSC-M-769
SPSLC-P-297 Add. 2, 21 June 2009

Many thanks to Elke

Year 2010 entirely dedicated to proton running
and the 2010 run was quite successful

Preliminary results shown at Transversity 2011 in Losini
First results published in 2012
THE PROTON DATA – Sivers asymmetry

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

Franco Bradamante
THE PROTON DATA – Sivers asymmetry

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

Sivers asymmetry
all COMPASS proton data

comparison with HERMES

smaller values at COMPASS:
TMD evolution …
Sivers function extractions from SIDIS data (COMPASS, HERMES, Jlab)

→ u and d: clearly different from zero

M. Anselmino et al
Sivers function extractions from SIDIS data (COMPASS, HERMES, Jlab)

→ u and d: clearly different from zero


proposal to measure it in pion-induced Drell-Yan muon pair production at COMPASS

CERN-SPSC-2010-014
SPSC-P-340
to make easier the comparison with DY, avoiding $Q^2$ evolution problems, we have measured the Sivers asymmetry in $Q^2$ bins

COMPASS DY run 2015 + 2018
new results at DIS2022
→ Jan Matousek
THE PROTON DATA – Collins asymmetry

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

Collins asymmetry
all COMPASS proton data

$A_{\text{Coll}}^p$

$\pi^+$
$\pi^-$
$K^+$
$K^-$

PLB 744 (2015) 250
PLB 717 (2012) 376
THE PROTON DATA – Collins asymmetry

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

Collins asymmetry
all COMPASS proton data

comparison with HERMES

very good agreement!
THE PROTON DATA – Collins asymmetry

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

Collins asymmetry all COMPASS proton data

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

well reproduced by the $^3P_0$ model

COMPASS, PLB 753 (2016) 406

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

A. Kerbizi et al. PRD97 (2018) no.7, 074010
fits of **Collins asymmetries** in SIDIS off p and d, and e^+e^- data

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

**TRANSVERSITY**

point by point extraction using COMPASS p and d asymmetries, and e⁺e⁻ data

no Soffer bound; no Monte Carlo nor parametrisations needed
fits of **Collins asymmetries** in SIDIS off p and d, and e^+e^- data

work still ongoing …

it is clear the

- 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

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

no Soffer bound; no Monte Carlo nor parametrisations needed

**TRANSVERSITY**
THE DEUTERON DATA

run 2022 - expectation

CERN{SPSC}{2017}{034
SPSC-P-340-ADD-1
April 5, 2018

many thanks to Gunar and Daniel
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
  - \(P_T\) - weighted Sivers asymmetries
    - no convolution, important tests, extraction of the Sivers function
- transversity induced \(\Lambda/\bar{\Lambda}\) polarization
- TSAs for high \(P_T\) pairs from PGF events
- \(J/\Psi\) Sivers asymmetry

- \(\rho^0\) TSAs - new
THE PROTON DATA

$\rho^0$ TSAs

\[ \text{COMPASS preliminary} \]

- indication for positive asymmetry similarly to $\pi^0$ as expected
- large at small $P_T$

COLLINS ASYMMETRY

SIVERS ASYMMETRY

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

August 29, 2022
Franco Bradamante
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
- \(P_T\) - weighted Sivers asymmetries
  no convolution, important tests, extraction of the Sivers function
- *transversity induced \(\Lambda/\bar{\Lambda}\) polarization*
- TSAs for high \(P_T\) pairs from PGF events
- \(J/\Psi\) Sivers asymmetry
- \(\rho^0\) TSAs

and other new measurements are ongoing

- the \(g_2\) structure function
- ....

all these measurements will be repeated with the new deuteron data, which we are collecting this year
COMPASS has given a relevant contribution to the study of the transverse structure of the nucleons with the Transverse Spin Asymmetries in SIDIS.

It has not been easy to make these measurements, but for sure it has been a lot of fun.
COMPASS has given a relevant contribution to the study of the transverse structure of the nucleons with the Transverse Spin Asymmetries in SIDIS

It has not been easy to make these measurements, but for sure it has been a lot of fun

The results have come and are coming, they have been very interesting, sometimes unexpected and anyway NEW

Our 2022 deuteron run will conclude the exploratory phase of these transverse spin phenomena carried out by HERMES and COMPASS

Much more will surely come from the next generation facilities

SOLID
EIC
....
thank you!
THE PROTON DATA

- other TSAs

\[ A_{UT}^{\sin \phi_s} \]
subleading twist
similar to HERMES results

\[ A_{UT}^{\sin(3\phi_h - \phi_s)} \]
\[ h_{1T}^+ \otimes H_1^\perp \]
pretzelosity

\[ A_{UT}^{\cos(\phi_h - \phi_s)} \]
\[ g_{1T} \otimes D_1 \]
worm-gear T
Kotzinian-Mulders

August 29, 2022
• transversity induced $\Lambda/\bar{\Lambda}$ polarization

\[ S_{\Lambda(\bar{\Lambda})} = \frac{\sum_q e_q^2 h_q^q H_{1,q}^{\Lambda(\bar{\Lambda})}}{\sum_q e_q^2 f_1^q D_{1,q}^{\Lambda(\bar{\Lambda})}} \]
THE PROTON DATA

• TSAs for high $P_T$ pairs from PGF events
THE PROTON DATA

• $J/\Psi$ Sivers asymmetry