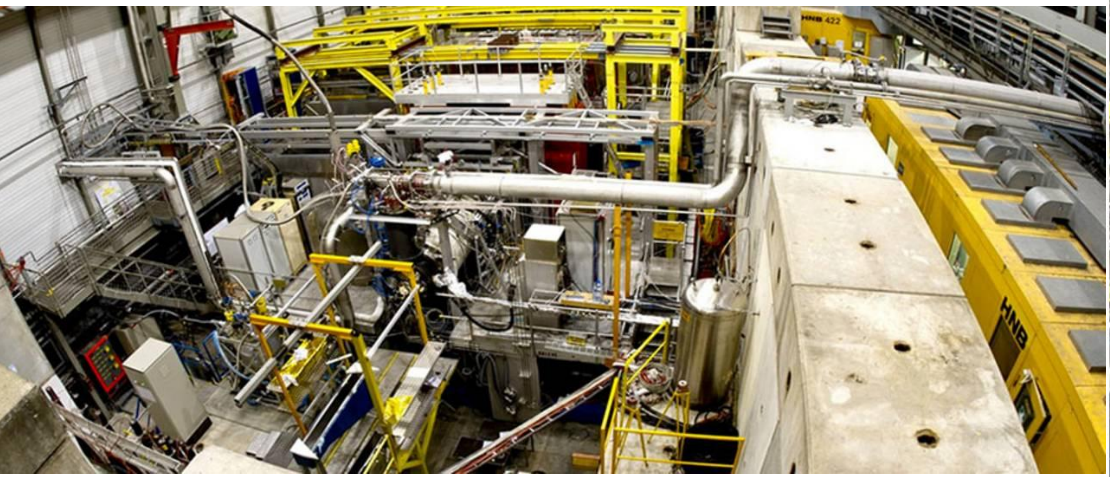
STUDIES OF THE NUCLEON AND HADRON STRUCTURE AT CERN
extension for 2021-2022

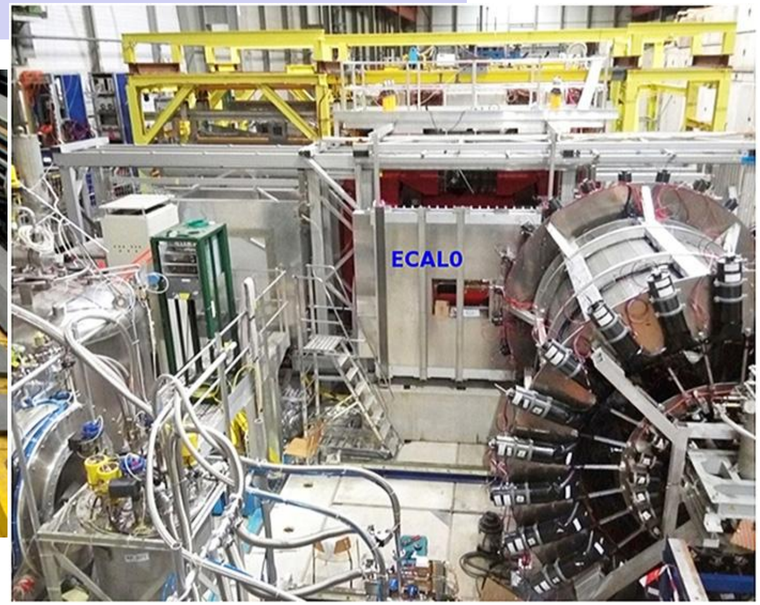
Leader **A.P. Nagaytsev**

LHEP participants(8):
Anosov V. A., Gavrishchuk O. P., Ivanov A. V., Kiselev Yu.F., Кouznetsov O. M., Nagaytsev A. P., Peshekhonov D. V., Savin I. A.

LNP participants(4):
Alexeev G. D., Guskov A. V., Frolov V. N., Olchevski A. G

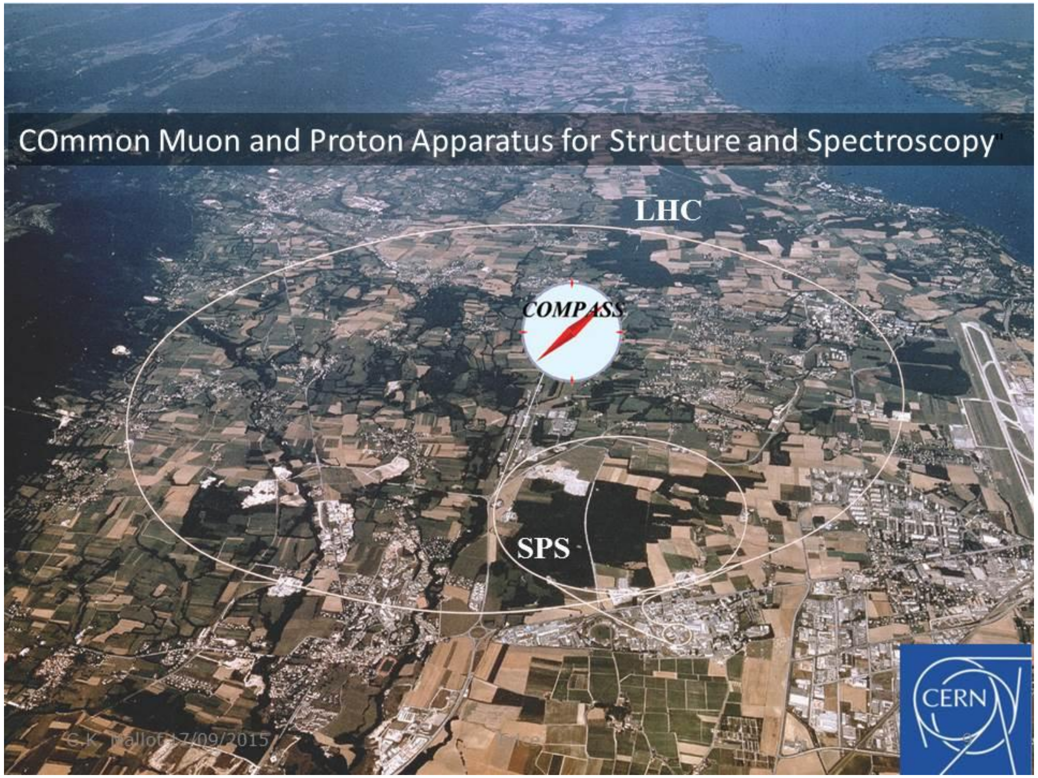
LTP participants (1) : Efremov A.V.





the materials of the COMPASS-II collaboration were used

INTRODUCTION

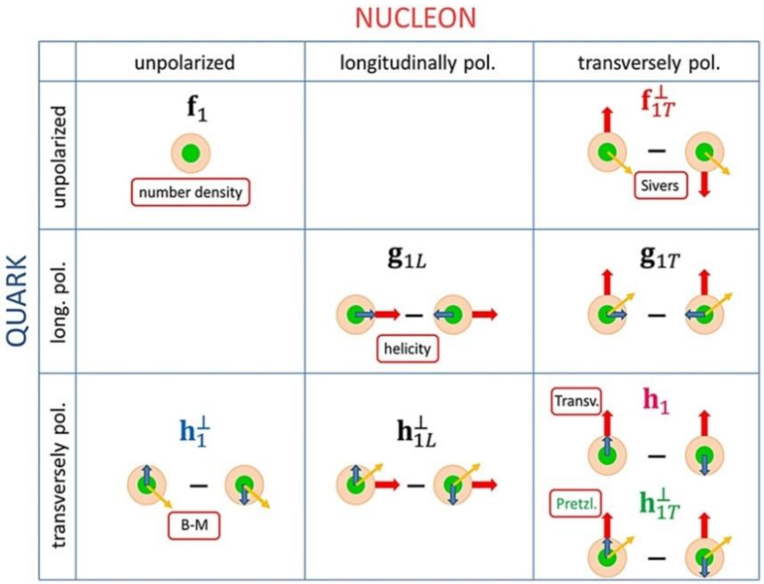


The COMPASS experiment has been proposed by the International Collaboration of 30 Institutions from 12 countries. The program of this experiment includes the nucleon spin structure studies in SIDIS of muons and studies of hadron structure in pion beams. It was approved at JINR and CERN in 1998.

The COMPASS-II proposal, suggested by the same Collaboration as continuation of COMPASS project, has been approved in May, 2010, and the corresponding theme at JINR was prolonged up to 2020. This stage of the Experiment is related to continuation the SIDIS measurements, particulary with studies of TMD PDFs, measurements of Generalized Parton Distributions (GPD) and Matveev-Muradyan-Tavkhelidze or Drell-Yan reactions. The COMPASS measurements will be finalized in 2021 (2022).

COMPASS-II MEASUREMENTS

Drell-Yan measurements



$f_{1T}^{\perp}(x,k_T^2)$: the Sivers TMD PDF describes the correlation of intrinsic transverse momentum of unpolarized quarks with nucleon transverse polarization.

$h_1^{\perp}(x,k_T^2)$: the Boer-Mulders TMD PDF describes the correlation between the transverse spin and the transverse momentum of a quark inside the unpolarized hadron.

$h_{1T}^{\perp}(x,k_T^2)$: the Pretzelosity TMD PDF describes quark transverse polarization along quark intrinsic transverse momentum in a transversely polarized nucleon.

$h_1(x)$: the Transversity PDF describes the correlation between the quarks and nucleon transverse spins.

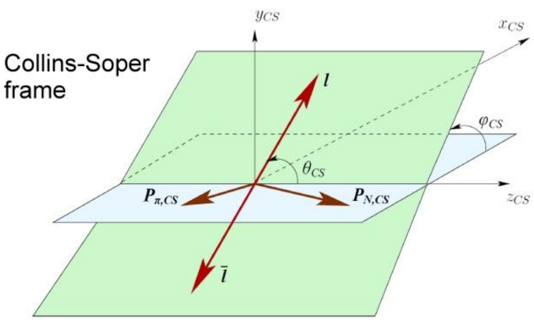
$A_U^{\cos 2\varphi_{CS}} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{\perp q}$ - gives access to the Boer-Mulders functions of the incoming hadron and target nucleon,

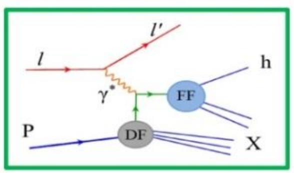
$A_T^{\sin\varphi_S} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$ - to the Sivers function of the target nucleon,

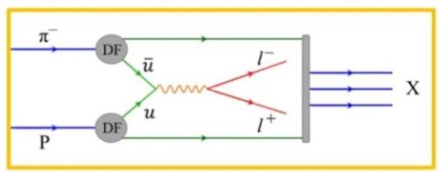
$A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,p}^{\perp q}$ - to the Boer-Mulders functions of the beam hadron and to the Pretzelosity function of the target nucleon,

$A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,p}^{q}$ - to the Boer-Mulders functions of the beam hadron and to the Transversity function of the target nucleon

Collins-Soper frame





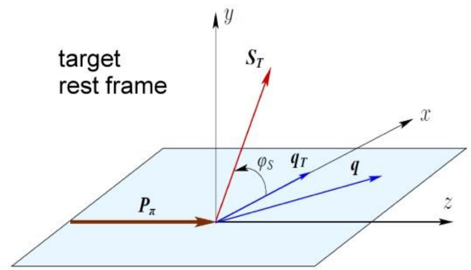


within *QCD TMD – framework:*

$h_1^{\perp q}$ & $f_{1T}^{\perp q}$ TMD PDFs are expected to undergo a sign change if (SIDIS ↔ DY)

h_1^{q} & $h_{1T}^{\perp q}$ TMD PDFs are expected to have no sign change under the (SIDIS ↔ DY)

target rest frame



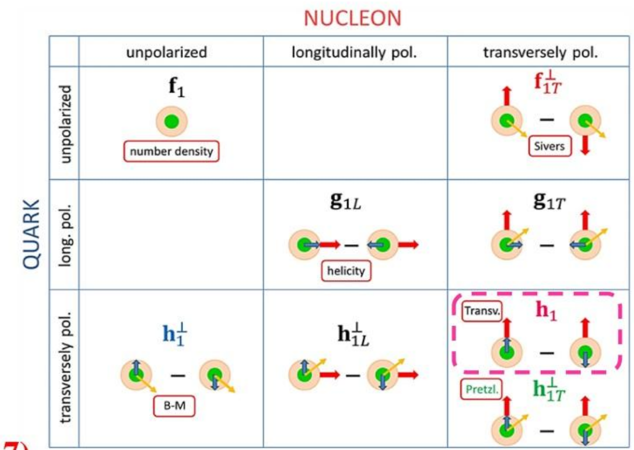
COMPASS-II MEASUREMENTS

Drell-Yan measurements

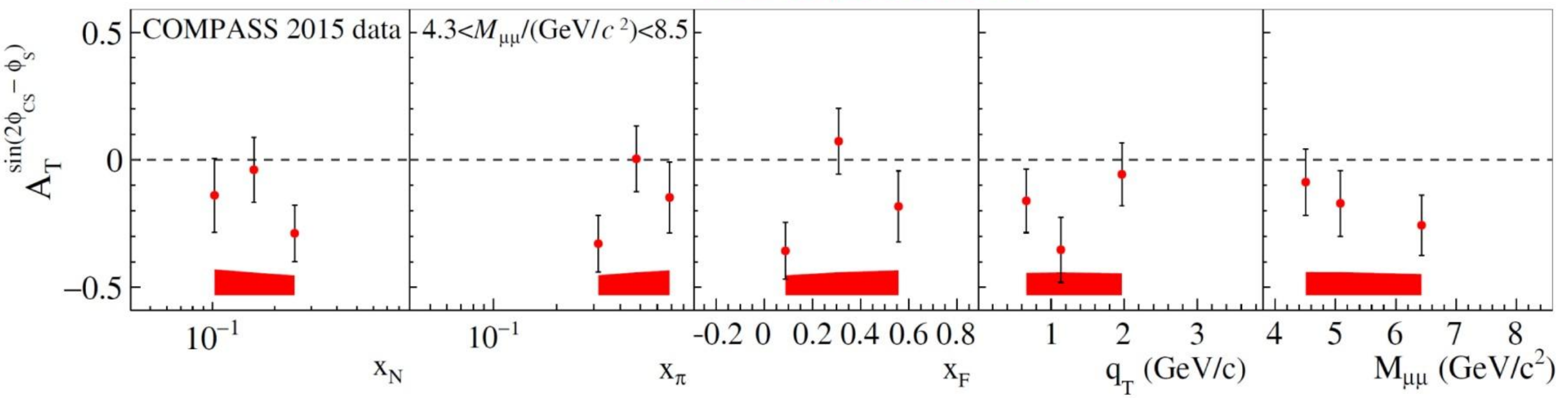
$$\frac{d\sigma}{d\Omega} \propto 1+\ldots+\ S_T\left[D_{[\sin^2\theta_{CS}]}\ A_T^{\sin(2\varphi_{CS}-\varphi_S)}\ \sin\left(2\varphi_{CS}-\varphi_S\right)+\ldots\right]$$

Transversity DY TSA

$$A_T^{\sin(2\varphi_{CS}-\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1,\mathrm{p}}^{q}$$



COMPASS PRL 119, 112002 (2017)



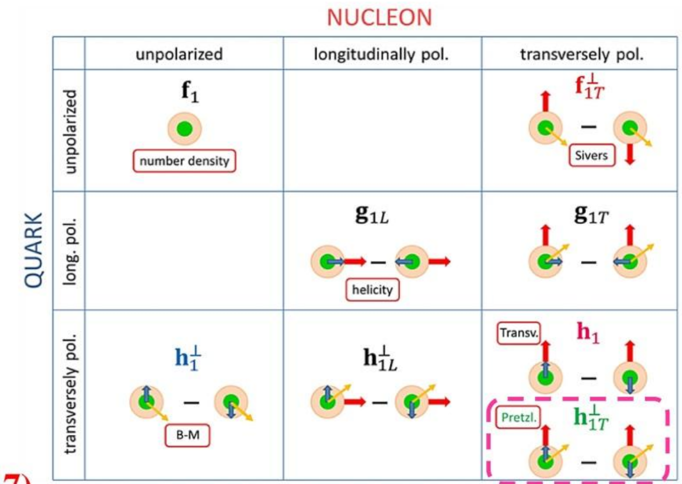
COMPASS-II MEASUREMENTS

Drell-Yan measurements

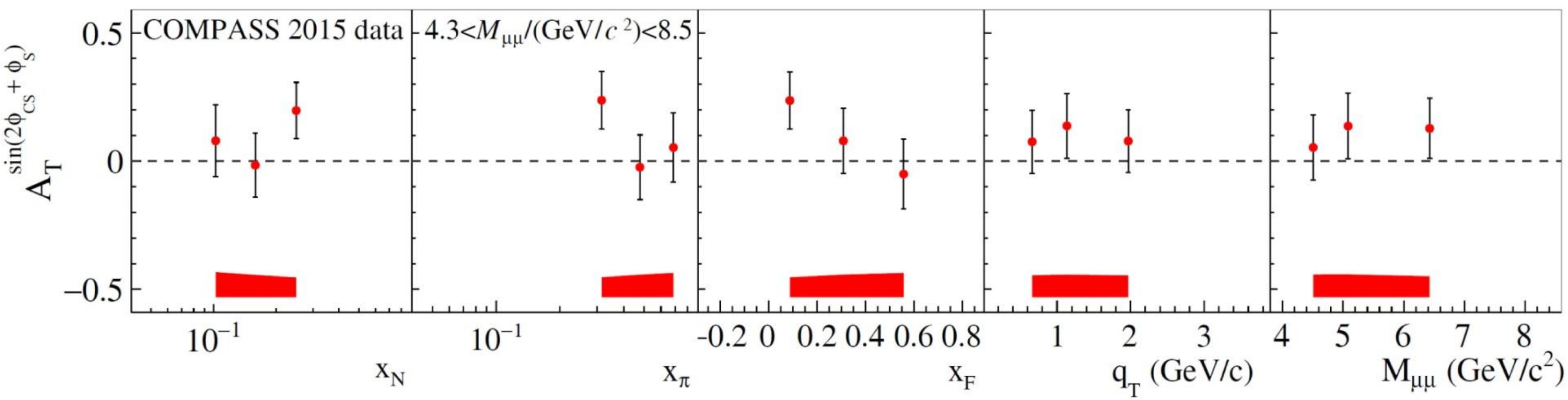
$$\frac{d\sigma}{d\Omega} \propto 1+\ldots+\ S_T\left[D_{[\sin^2\theta_{CS}]}\,A_T^{\sin(2\varphi_{CS}+\varphi_S)}\sin(2\varphi_{CS}-\varphi_S)+\ldots\right]$$

Pretzelosity DY TSA

$$A_T^{\sin(2\varphi_{CS}+\varphi_S)} \propto h_{1,\pi}^{\perp q} \otimes h_{1T,\mathrm{p}}^{\perp q}$$



COMPASS PRL 119, 112002 (2017)



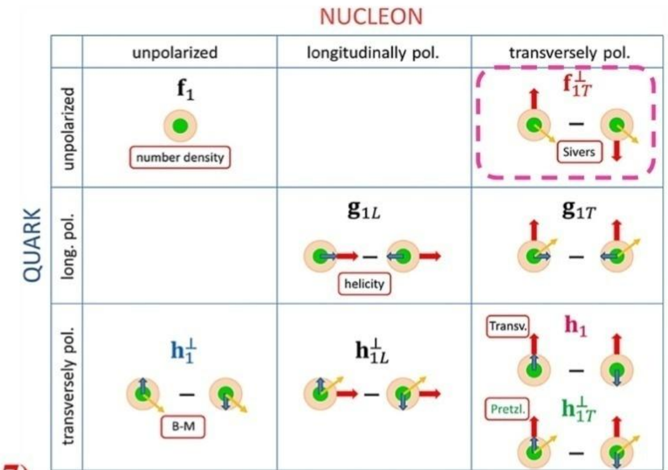
COMPASS-II MEASUREMENTS

Drell-Yan measurements

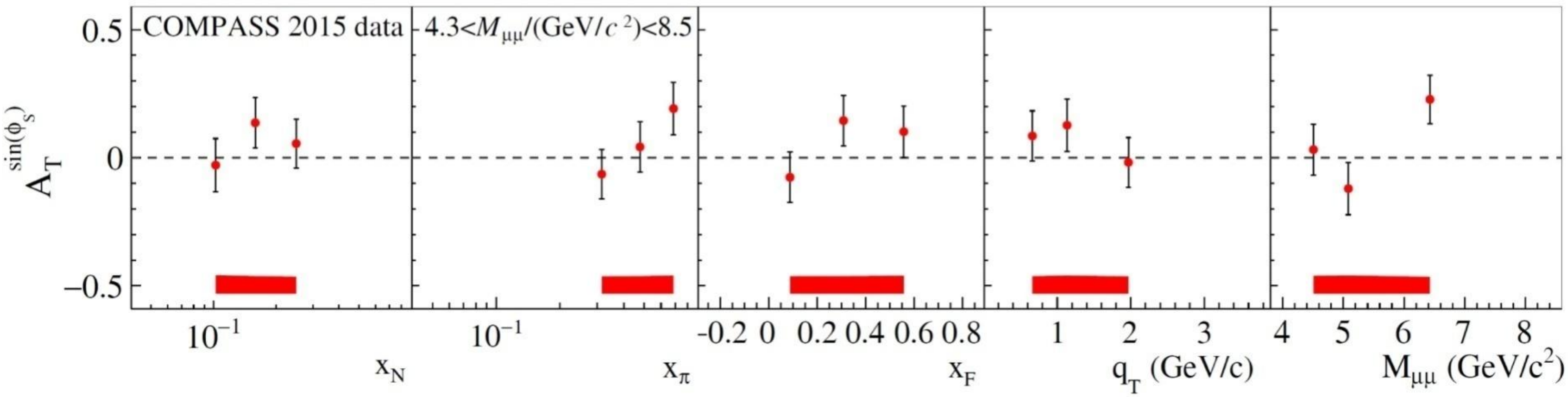
$$\frac{d\sigma}{d\Omega} \propto 1 + \ldots + S_T \left[A_T^{\sin\varphi_S} \sin\varphi_S + \ldots \right]$$

Sivers DY TSA

$$A_T^{\sin\varphi_S} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$$



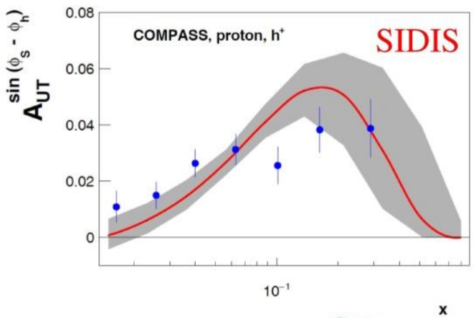
COMPASS PRL 119, 112002 (2017)



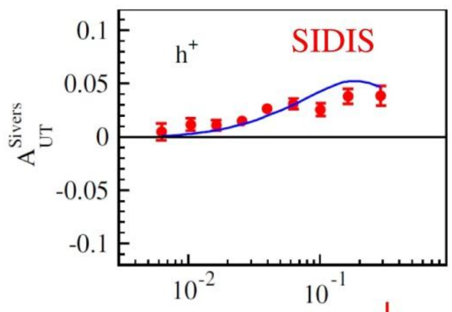
COMPASS-II MEASUREMENTS

Drell-Yan measurements

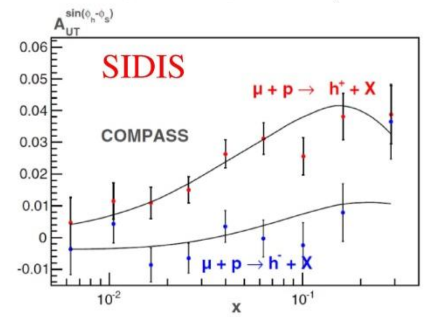
DGLAP (2016)
M. Anselmino et al., **JHEP 1704 (2017) 046**

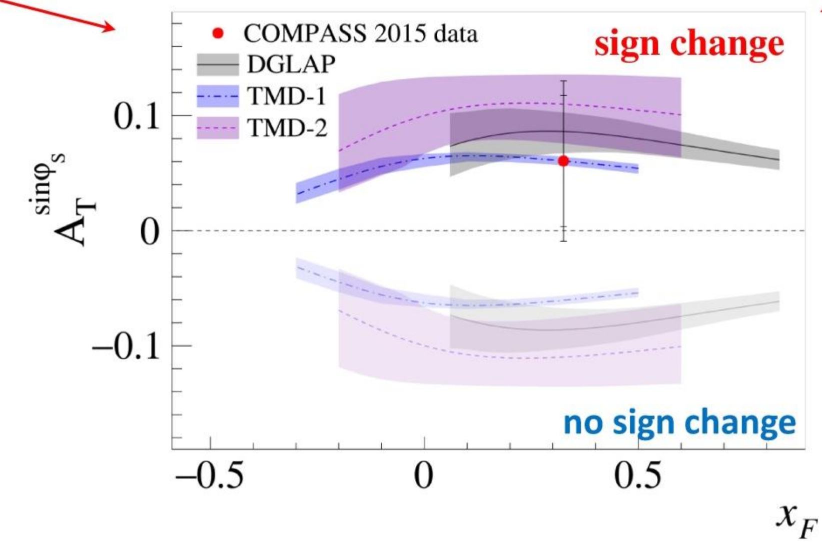


TMD-1 (2014)
M. G. Echevarria et al. **PRD89,074013**



TMD-2 (2013)
P. Sun, F. Yuan, **PRD88, 114012**





DY

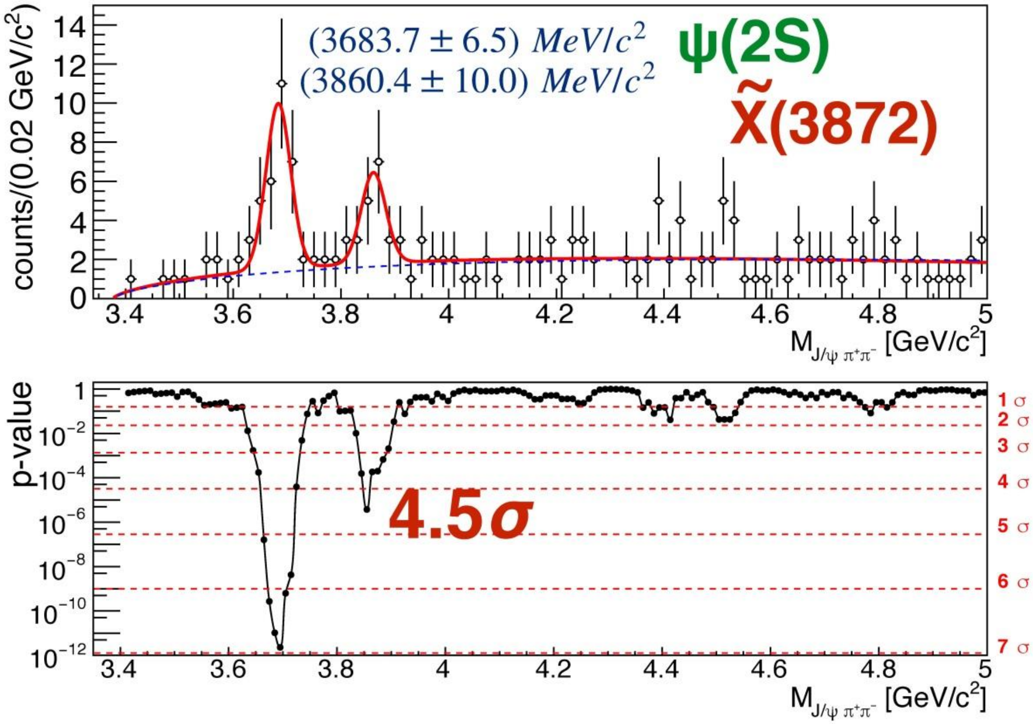
COMPASS
PRL 119, 112002 (2017)

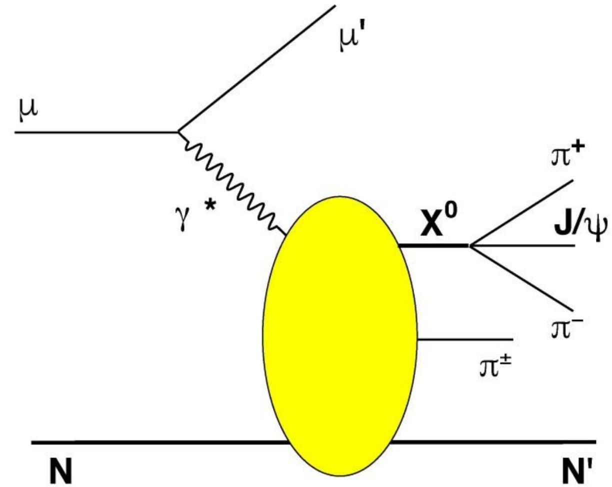
Sign Change is favored

In 2018 – 2nd round of polarized DY measurements at COMPASS

COMPASS-II MEASUREMENTS

Exotic charmonia



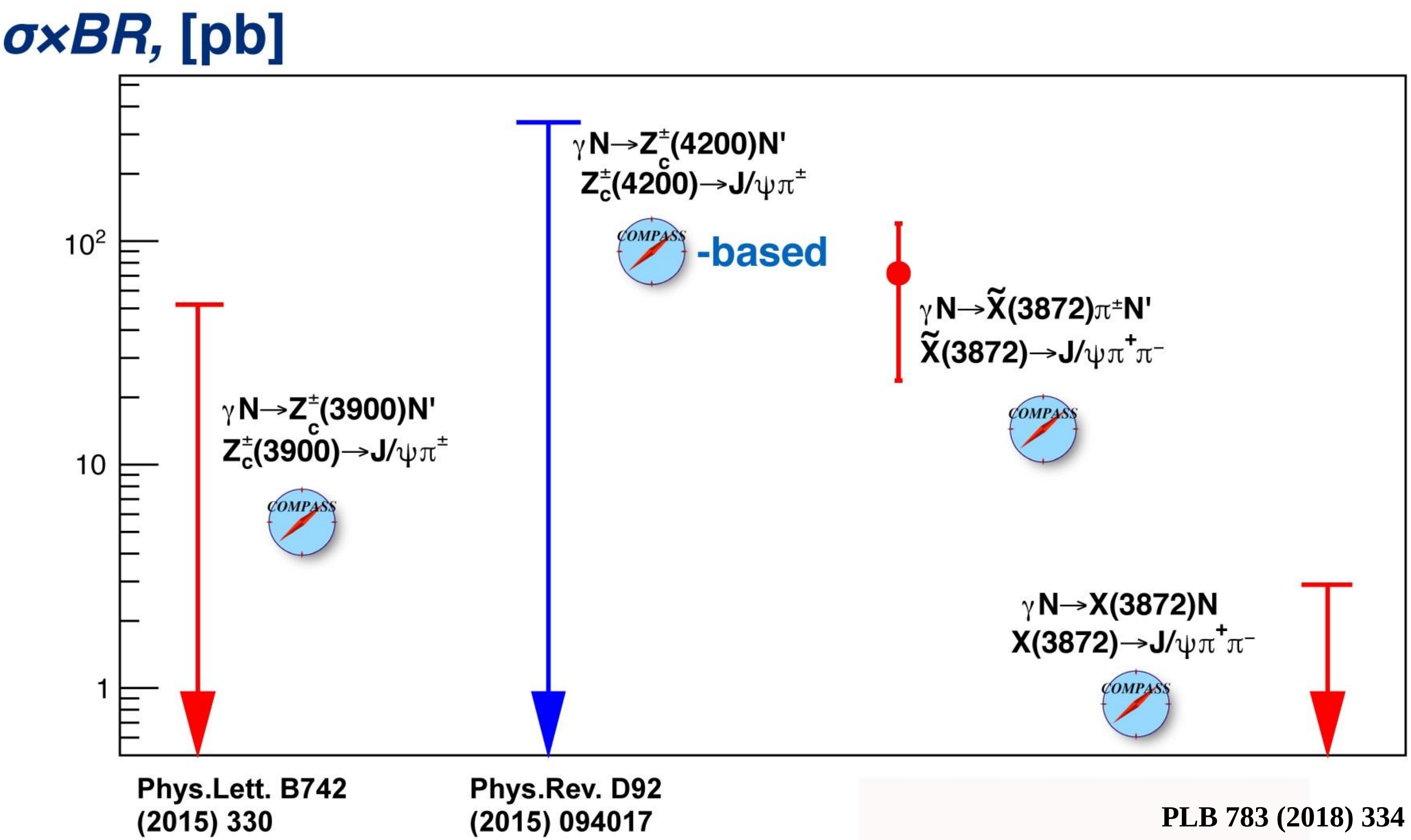


σ_M=(22.8±6.9) MeV/c^2 $N_{(\tilde{X}3872)}$=(13.2±5.2) events

COMPASS-II MEASUREMENTS

Exotic charmonia

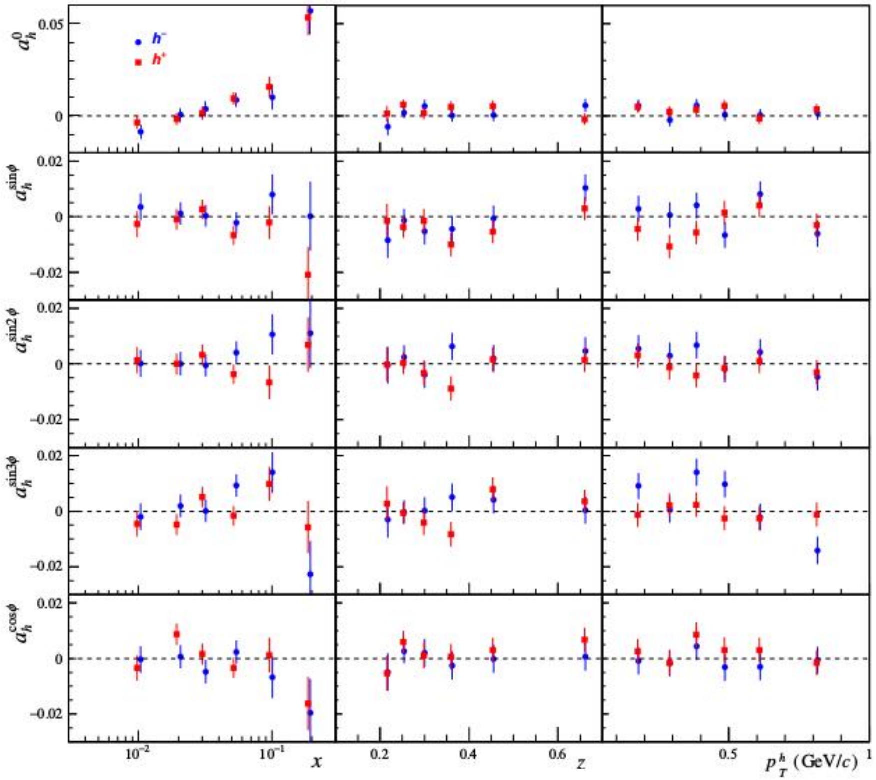
$$\sigma_{\gamma N \to \tilde{X}(3872)\pi N'} \times \mathcal{B}_{\tilde{X}(3872)\to J/\psi\pi\pi} = 71 \pm 28(\mathrm{stat}) \pm 39(\mathrm{syst})\ \mathrm{pb}.$$
$$\sigma_{\gamma N \to X(3872) N'} \times \mathcal{B}_{X(3872)\to J/\psi\pi\pi} < 2.9\ \mathrm{pb}\ (\mathrm{CL} = 90\%).$$

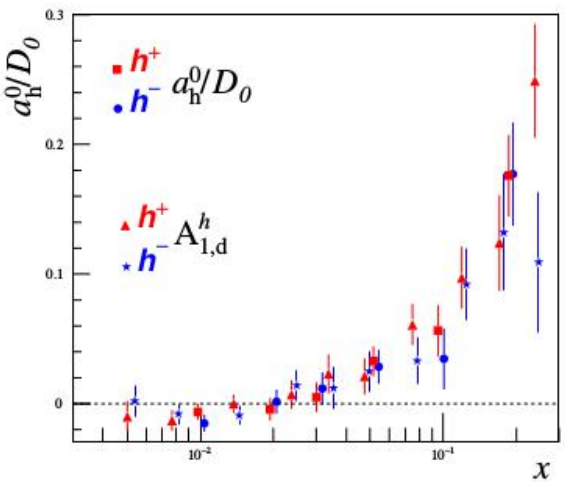


PLB 783 (2018) 334

COMPASS-II MEASUREMENTS

Azimuthal asymmetries of charged hadrons produced in high-energy muon scattering off longitudinally polarised deuterons





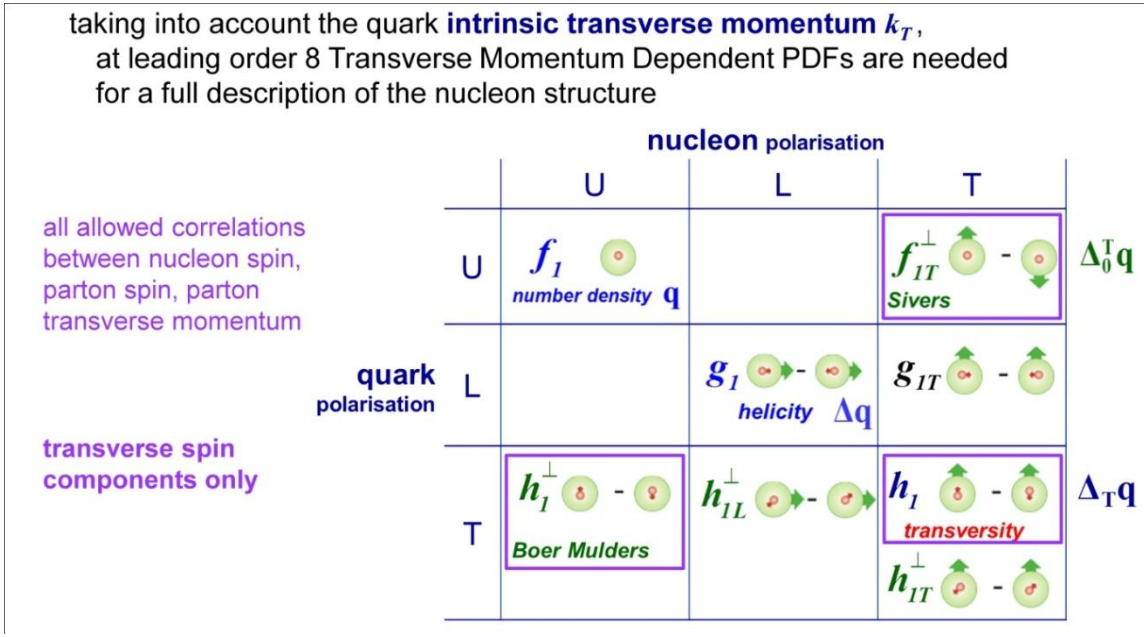
Single hadron azimuthal asymmetries in the cross sections of positive and negative hadron production in muon semi-inclusive deep inelastic scattering off longitudinally polarised deuterons.

The dependence of the azimuthal asymmetry on the hadron azimuthal angle φ is obtained by means of a five-parameter fitting function that besides a φ -independent term includes four modulations predicted by theory: sin φ , sin 2φ , sin 3φ and cos φ .

The amplitudes of the five terms have been first extracted for the data integrated over all kinematic variables.

Except the φ -independent term, all the modulation amplitudes are very small, and no clear kinematic dependence could be observed within experimental uncertainties.

COMPASS-II MEASUREMENT IN 2021



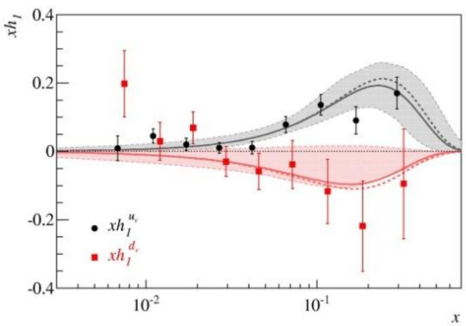
In QCD, for the leading twist, the nucleon structure is described by eight parton distributions that depend on the parton's transverse proper momentum (TMDS):
$f_1(x, k^2_T)$, $g_1(x, k^2_T)$,
$h_1(x, k^2_T)$, $g_{1T}(x, k^2_T)$,
$h_{1T}^{\perp}(x, k^2_T)$, $h_{1L}^{\perp}(x, k^2_T)$,
$h_1^{\perp}(x, k^2_T)$, $f_{1T}^{\perp}(x, k^2_T)$.

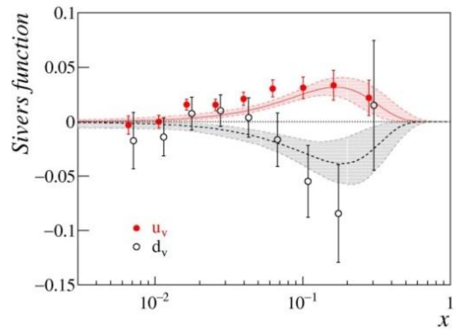
One of the main methods for investigating the above-mentioned parton distributions is to measure semi-inclusive deep-inelastic scattering processes of polarized leptons on polarized nuclear targets. Such measurements are the most important point of the physical program of the COMPASS and COMPASS-II experiments. The data taking periods for this topic were performed in 2002-2004, 2007, and 2010 with polarized targets. To continue research of TMDs COMPASS-II prepared a proposal to extend SIDIS measurements in 2021. This proposal was approved by CERN SPSC in 2018.

The main experimental aims of such measurements are the following:

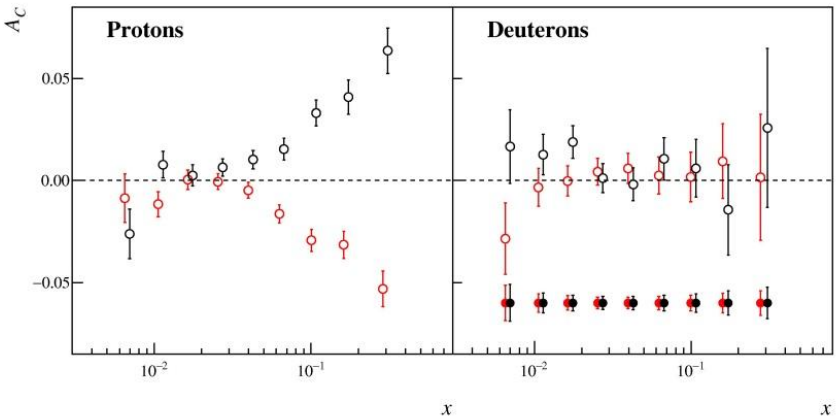
- measurement of the Collins and Sivers assymmetires;
- getting data on the parton distribution of h_1 (transversity);
- measurement of the tensor charge;
- getting new data on the g_2 structure function;
- measurement of asymmetries in processes with the two hadrons production;

COMPASS-II MEASUREMENT IN 2021



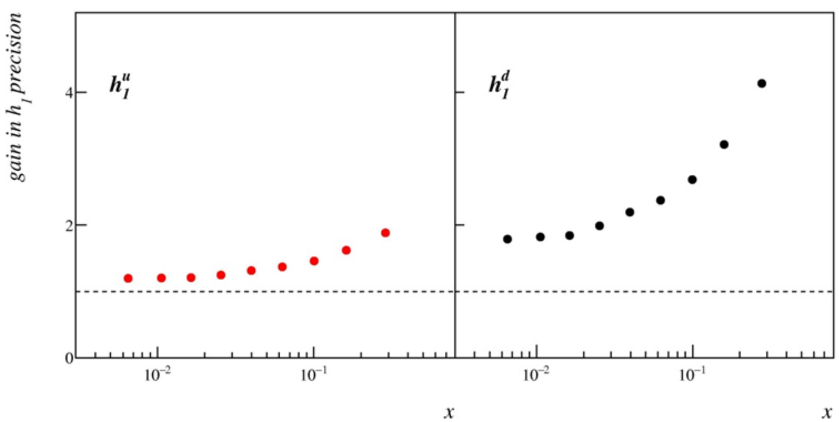


- The Sivers function $f^{\perp}_{1T}$: in a nucleon that is polarised transversely to its momentum the quark distribution is not left-right symmetric with respect to the plane defined by the directions of the nucleon spin and momentum. This asymmetry of the distribution function is called the Sivers effect, and the asymmetric function is known as the Sivers PDF.



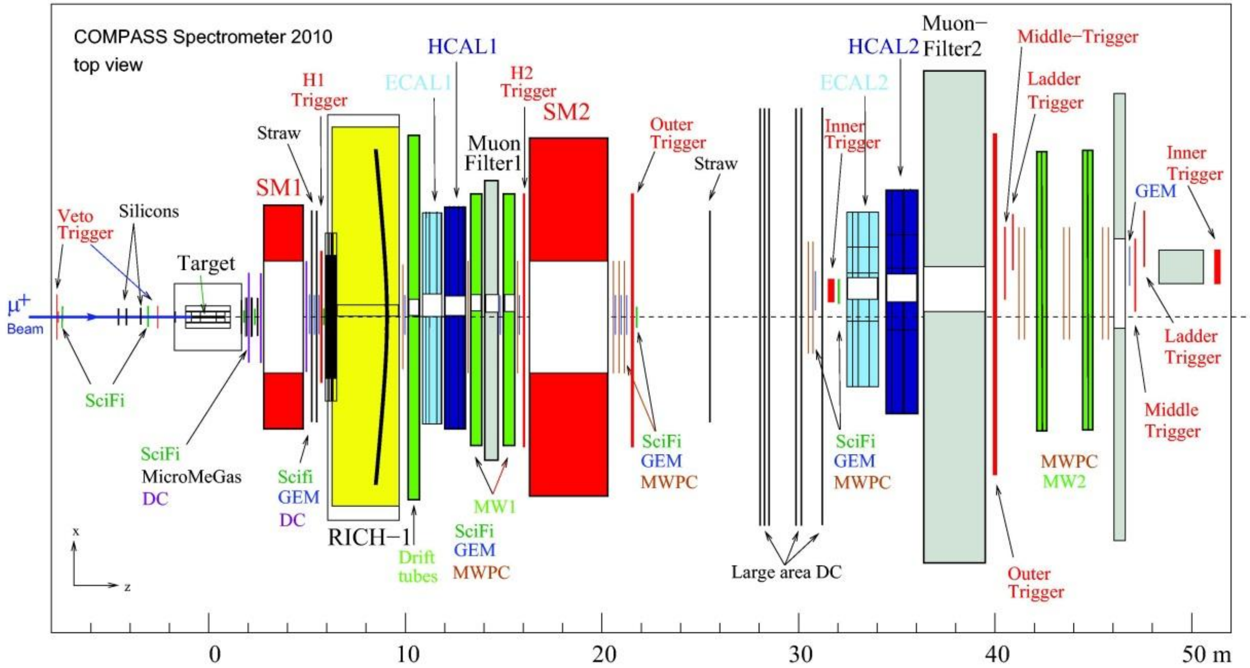
- The transversity distribution function h_1: the quarks in a transversely polarized nucleon are transversely polarised. Their polarisation is described by the h_1 PDFs which a priori are different and have

- The Collins function $H^{\perp}_1$: the hadronization of a transversely polarised quark is not left-right symmetric with respect to the plane defined by the direction of the quark momentum and the quark spin.



The impact of the proposed measurement is quantified in Figure (left) , which gives the ratio, at each x value, of the present and projected errors on the extracted transversity PDFs. The gain in precision for the d-quark ranges from a factor of 2 at small x to more than a factor of 4 at large x, and is also important for the u-quark.

COMPASS-II MEASUREMENT IN 2021



COMPASS-II proposes to perform a standard one-year (150 days) measurement, scattering the M2 muon beam with 160 GeV/c momentum on a transversely polarised deuteron target.

The apparatus to be used for the deuteron run is basically the COMPASS Spectrometer as it was used in the 2010 muon run. The polarised target will be housed in the large acceptance COMPASS PT magnet, and the target material will be the same which was used in the years 2002, 2003, 2004 and 2006, namely ^{6}LiD. For a better usage of the muon beam, the target cells diameter will be increased from 3 to 4 cm. The average polarisation of the target is expected to be the same as in the past deuteron runs (about 50%). The beam request is the same as for the 2010 proton run, namely 2.5×10^{13} protons delivered to the T6 target of the M2 beam line every 40.8 s. With an accelerator chain efficiency of 90% and a running time of 150 days a total of 6.1×10^{18} protons at T6 is expected.

Two detectors supported by JINR group have to be used in 2021data taking: MW1 and HCAL1

MOU and TIME LINES

Notification to the COMPASS Funding Agencies

Following the decision taken at the COMPASS Financial Review Committee (FRC) on 24 October 2019, I confirm the extension of the COMPASS Memorandum of Understanding (MoU) for the experimental run in 2021, which will terminate the experimental programme of COMPASS and the financial obligations of the Funding Agencies for Maintenance and Operation.

Beyond 2021 the MoU will remain valid in the part which does not regard hardware obligations until the end of the analysis campaign which is currently scheduled for 31 December 2025.

Eckhard Elsen

According to the COMPASS-II Memorandum of understanding (MoU), JINR's responsibilities are technical support for the installation's detectors (HCAL1, ECAL0, MW1), participation in polarized target work, support for the engineering structure of the experimental hall, data collection systems, and processing and analysis of experimental data.

The extension of this Memorandum until the end of 2025 was approved by the FRC and SPS committees at CERN, without obligations for detectors beyond 2021.

In period of 2021-2022 COMPASS-II collaboration is going to take the experimental data with muon (2021) and continue the analysis of the experimental data taken in previous years.

2021:
- **Participation in COMPASS data taking;**
- **Maintenance of MW1, HCAL1 during running ;**
- **Development/support of MW1/HCAL1software;**
- **Analysis of COMPASS experimental data;**

2022:
- **Completion of work with MW1, HCAL1 and ECAL0 detectors for the COMPASS-II project (utilization, export to JINR or transfer to another experiment);**
- **Analysis of COMPASS experimental data;**

MANPOWER AND ACTIVITIES

No.	Name	Status	Activity	FTE	Laboratory
1	Abazov V.	tech	MW1	0,3	DLNP
2	Alexeev G.	scient	MW1	0,3	DLNP
3	Anfimov N.	scient	HCAL1,ECAL0	0,1	DLNP
4	Anosov V.	tech	Hall Engeneering	0,8	LHEP
5	Gavrishchuk O.	scient	HCAL1, ECAL0	0,2	LHEP
6	Golovanov G.	tech	MW1	0,3	DLNP
7	Gridin A.	PhD st	Data analysis	0,7	DLNP
8	Guskov A.	scient	ECAL0, Data analysis	0,3	DLNP
9	Gushterski R.	scient	Data analysis	1,0	LHEP
10	Denisenko I.	PhD st	Data analysis	0,5	DLNP
11	Efremov A.	scient	Theory	0,5	LTP
12	Jouravlev N.	scient	MW1	0,3	DLNP
13	Ivanov A.	scient	Data analysis	0,4	LHEP
14	Ivanshin Yu.	scient	Data analysis	1,0	LHEP
15	Kisselev Yu.	scient	Polarised target	1,0	LHEP
16	Kouznetsov O.	scient	Data analysis	1,0	LHEP
17	Maltsev A.	Dip.st	Data analysis	0,7	DLNP
18	Meshcheryakov G.	scient	HCAL1, ECAL0	0,5	LHEP
19	Mitrofanov Ye.	PhD st	Data analysis	0,7	DLNP
20	Nagaytsev A.	scient	Team leader,ECAL0	1,0	LHEP
21	Olchevski A.	scient	ECAL0, data analysis	0,1	DLNP
22	Peshekhonov D.	scient	Data taking	0,3	LHEP
23	Piskun A.	tech	MW1	0,3	DLNP
24	Rymbekova A.	PhD st	Data analysis	0,3	DLNP
25	Savin I.	scient	Data analysis	1,0	LHEP
26	Selyunin A.	PhD st	HCAL1, ECAL0	0,1	DLNP
27	Tokmenin V.	tech	MW1	0,3	DLNP
28	Frolov V.	scient	DAQ, ECAL0	0,5	DLNP

Spokespersons:	Oleg DENISOV and Fulvio TESSAROTTO
Chair of the Collaboration Board:	Eva-Maria KABUSS
Resource Coordinator:	Gerhard MALLOT
Technical Coordinator:	Stefano LEVORATO
Analysis Coordinator:	Vincent ANDRIEUX
Chair of Publication Committee:	Bakur PARSAMYAN
Run Coordinator:	TBA
Secretary:	Anne LISSAJOUX
Engineer:	Vladimir ANOSOV
Technician:	Cyril COT

Contact persons for Subdetectors & Slow Control

GLIMOS:	Stefano LEVORATO
BMS:	Rainer JOOSTEN
Scintillating Fibres D:	Rainer JOOSTEN
Silicon Trackers:	Jan FRIEDRICH
Polarized Target:	Jaakko KOIVUNIEMI
Liquid Hydrogen Target:	Norihiro DOSHITA
CAMERA:	Andrea FERRERO
DY Absorber:	Daniele PANZIERI
DY Vertex Detector:	Rainer JOOSTEN
Micromegas:	Damien NEYRET
Saclay Drift Chambers:	Stephane PLATCHKOV
ECAL0:	Alexander NAGAYTSEV
UIUC Drift Chambers:	Caroline RIEDL
GEM Trackers:	Bernhard KETZER
Straw Drift Chambers:	Robert HEITZ
RICH:	Silvia DALLA TORRE
RICH-WALL:	Daniele PANZIERI
Multi Wire Proportional Chambers:	Daniele PANZIERI
ECAL1-2:	Sergey DONSKOV
HCAL1:	Oleg GAVRISHCHUK
HCAL2:	Sergey DONSKOV
Muon Trigger:	Friedrich KLEIN and Eva-Maria KABUSS
Muon Walls:	Yuri KHOKHLOV and Gennady ALEXEEV
W45:	Carlos AZEVEDO
Frontend Electronics:	Maxim ALEKSEEV
DAQ:	Vladimir FROLOV
DCS:	Catarina QUINTANS

FTE profile: for LNP - 5.8 for LHEP - 8.2 for LTP - 0.5
The total sum of FTE is 14.5

TIMELINES AND FINANCIAL PROFILE

JINR's total expenses on the project (theme 1085) for the period 2018-2020 amounted to about $ 624 thousand. Scientific trips – $ 374 thousand, materials and equipment - $ 250 thousand.
CERN has allocated about $ 30,000 (NA 58, COMPASS-II) to support JINR experts at CERN.

The amount of necessary funding for 2021-2022 is $ 310 thousand from the JINR budget. The main part of these expenses is required for participation of JINR physicists in data collection, for maintenance of detectors and online software systems for monitoring their operation, as well as for contributions to the Common Fund of the collaboration in accordance with the obligations under the Memorandum of understanding.

#	Expenditure items	Full cost	2021	2022
	Direct expenses for the Project			
1.	Materials and equipments	30k$	20 k$	10 k$
2.	Collab common fund	90 k$	50 k$	40 k$
3.	Travels, including · outside RUSSIA · inside RUSSIA	 180 k$ 10 k$	 115 k$ 5 k$	 65 k$ 5 k$
	TOTAL DIRECT EXPENSES	310 k$	190 k$	120 k$

We ask to approve JINR participation in COMPASS-II (last term) for 2021-2022.

This extension of the COMPASS-II project is the last one, in the future, the project is planned to close and continue the analysis of COMPASS-II data within the JINR theme activity.

BACKUP SLIDES

INTRODUCTION

Muon beam	deuteron (^{6}LiD) PT	2002 2003 2004	80% L/20% T target polarisation
		2006	L target polarisation
	proton (NH_3) PT	2007	50% L /50% T target polarisation
Hadron	LH target	2008 2009	
Muon beam	proton (NH_3) PT	2010	T target polarisation
		2011	L target polarisation
Hadron	Ni target	2012	Primakoff
Muon beam	LH_2 target	2012	Pilot DVCS & unpol. SIDIS
Hadron	Proton (NH_3) DT PT	2014 2015	Pilot DY run DY run
Muon beam	LH_2 target	2016 2017	DVCS & unpol. SIDIS
Hadron	Proton (NH_3) PT	2018	DY run

RUN IN 2021 WITH MUON BEAM AND TRANSVERSALY POLARIZED DEUTERON TARGET

COMPASS-II MEASUREMENTS

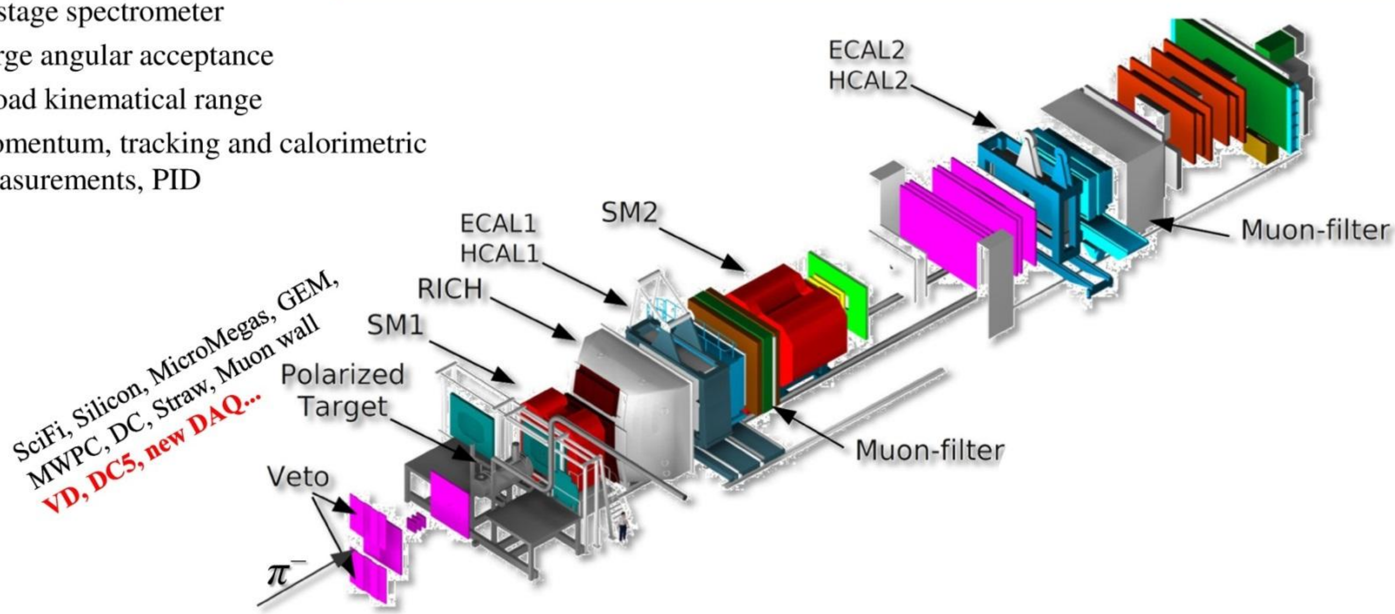
COMPASS-II continued the data taking - TMD in DY processes with a pion beam at energy of 160 GeV and with a polarized target.
Participation of JINR physicists and engineers: maintenance of the hadron calorimeter (HCAL1), coordinate detector systems (MW1), support for the polarized target, support for the data acquisition system (DAQ), the engineering structure of the experimental hall, and analysis of the experimental data.

During the reporting period, the collaboration prepared and published 10 articles. Three articles were prepared with significant contributions from JINR physicists.

Drell-Yan measurements

Two-stage spectrometer

- Large angular acceptance
- Broad kinematical range
- Momentum, tracking and calorimetric measurements, PID



Data-taking years: 2014 (test) 2015 and 2018
High energy π^- beam:
Energy: 190 GeV/c, Intensity: 10^8 π/s

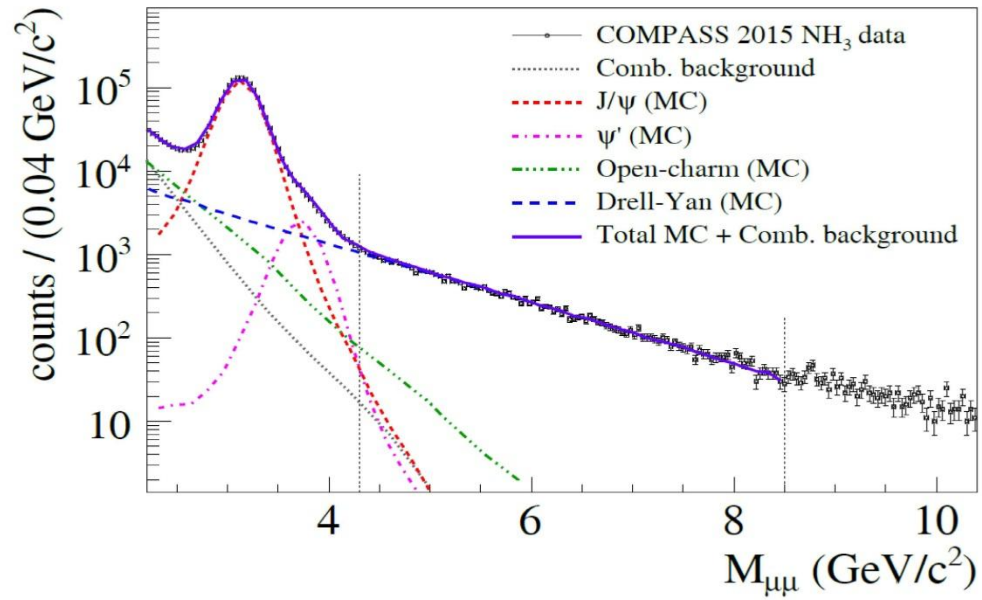
Target: Solid state

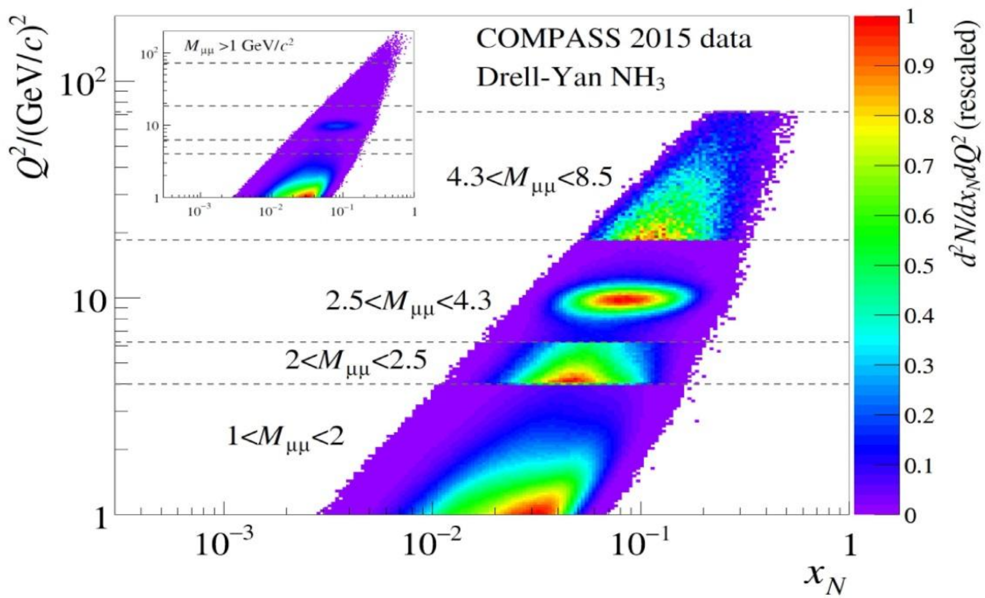
- NH_3 2-cell configuration. Polarization T ~ 73%, f ~ 0.18
- Data is collected simultaneously with both target spin orientations
  Periodic polarization reversal to minimize systematic effects

COMPASS-II MEASUREMENTS

Drell-Yan measurements

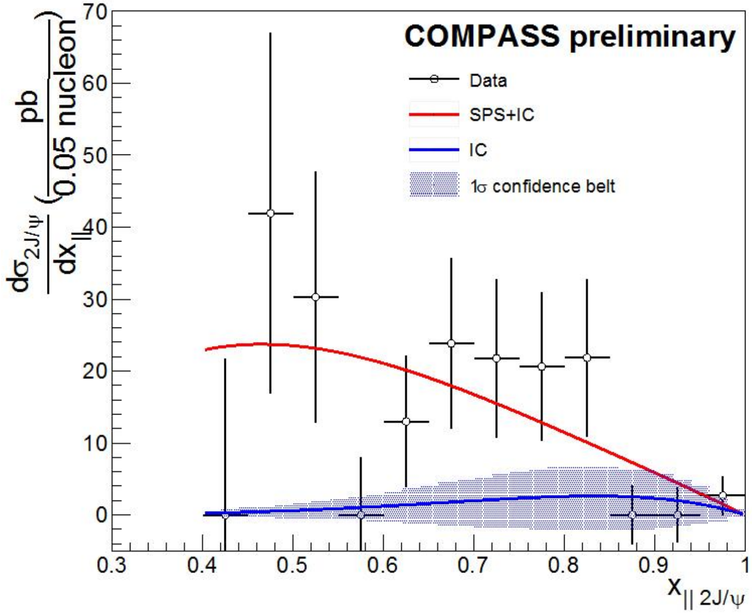
- $1.0 < M_{\mu\mu}/(\text{GeV}/c^2) < 2.0$ "Low mass"
  - Large background contamination, combinatorial, Open-charm (B) $D\bar{D}$, $B\bar{B}$, π, K decays
- $2.0 < M_{\mu\mu}/(\text{GeV}/c^2) < 2.5$ "Intermediate mass"
  - High DY-cross section
  - Still low DY-signal/background ratio
- $2.5 < M_{\mu\mu}/(\text{GeV}/c^2) < 4.3$ "Charmonia mass"
  - Strong J/ψ-signal → study of J/ψ physics
  - Good signal/background
- $4.3 < M_{\mu\mu}/(\text{GeV}/c^2) < 8.5$ "High mass"
  - Low DY cross-section
  - Beyond charmonium region, background < 3%
  - Valence region → largest asymmetries





COMPASS-II MEASUREMENTS

Search for pion-induced double J/ψ production



Ongoing interest to the production J/ψ pair in hadronic interaction of is caused by a general problem of understanding of charmonia production mechanisms and possibility to form a tetraquark that decays into a J/ψ pair.

COMPASS observed pion-induced double J/ψ production off nuclear targets and determined the cross sections of the reaction.

The obtained result for the differential cross section is fully consistent with the SPS production mechanism (see Figure).

An upper limit of the relative contribution of the intrinsic charm production mechanism could be estimated. No evidence of any resonant states decaying into the two J/ψ final state was found.

JINR COMPASS-II Talks

QCD 17 (parallel)
E. Zemlyanichkina, Final COMPASS SIDIS results on charged hadron, pion and kaon multiplicities

LomCon 2017 (parallel)
A. Gridin, Search for exotic charmonium-like states at COMPASS

DSPIN2017(parallel -both)
A. Ivanov, Longitudinal target spin-dependent azimuthal asymmetries in semi-inclusive reactions at COMPASS
N. Mitrofanov, The results of measured mulfiplicities of charged-kaons, charged-pions and charged-hadrons at the COMPASS experiment.

HADRON2017 (plenar)
A. Guskov, Muoproduction of exotic charmonia at COMPASS

AYSS17(parallel -both)
E. Mitrofanov, EMC-effect in Drell-Yan process
N. Mitrofanov, The results of measured mulfiplicities of charged-kaons, charged-pions and charged-hadrons at the COMPASS experiment.

LASNPA17(plenar)
A. Guskov, COMPASS Experiment at CERN

ECT workshop 2017 (plenar)
A. Guskov, Direct Photon Production with Meson Beams

BLOIS2018 (parallel)
E. Mitrofanov, EMC effect in the Drell-Yan process at COMPASS

BEACH2018 (plenar)
A. Guskov, Search for muoproduction of X(3872) at COMPASS

Lomonosov 2019 (plenar)
A. Guskov, The COMPASS experiment at CERN

CPHI2020 (parallel)
I. Denisenko, Physics with charmonia at the SPD and AMBER experiments

COMPASS-II PAPERS

1. COMPASS Collaboration, “First measurement of transverse-spin-dependent azimuthal asymmetries in the Drell-Yan process”, PRL 119 (2017) 112002

2. COMPASS collaboration, “Search for muon production of X(3872) at COMPASS and indication of a new state $X^{\sim}(3872)$”, PLB 783 (2018) 334

3. COMPASS Collaboration, “New analysis of ηπ tensor resonances measured at the COMPASS experiment”, PLB 779 (2018) 464

4. COMPASS collaboration, “Transverse extension of partons in the proton probed by deeply virtual compton scattering”, PRD 97 (2018) 032006

5. COMPASS collaboration, “Longitudinal double-spin asymmetry A_1^p and spin dependent structure function g_1^p of the proton at small values of x and Q^2”, PLB 781 (2018) 464

6. COMPASS collaboration,” K− over K+ multiplicity ratio for kaons produced in DIS with a large fraction of the virtual-photon energy”, PLB 786 (2018) 390

7. COMPASS Collaboration, “Light isovector resonances in $\pi^- p \rightarrow \pi^-\pi^-\pi^+ p$ at 190 GeV/c”, PRD 98 (2018) 092003

8. COMPASS Collaboration, “Measurement of P_T-weighted Sivers asymmetries in leptoproduction of hadrons”, NPB 940 (2019) 34

9. COMPASS Collaboration, “Azimuthal asymmetries of charged hadrons produced in high-energy muon scattering off longitudinally polarised deuterons”, EPC 78 (2018) 952

10. COMPASS Collaboration, “Measurement of the cross section for hard exclusive π^0 leptoproduction”, sub PLB, CERN-EP/2019-049

11. COMPASS Collaboration, “Contribution of exclusive diffractive processes to the measured azimuthal asymmetries in SIDIS”, sub NPB, CERN-EP/2019-286

for the proposal we have evaluated the expected precision on

- **the Collins asymmetry**
- **the transversity PDF**
- **the tensor charge**

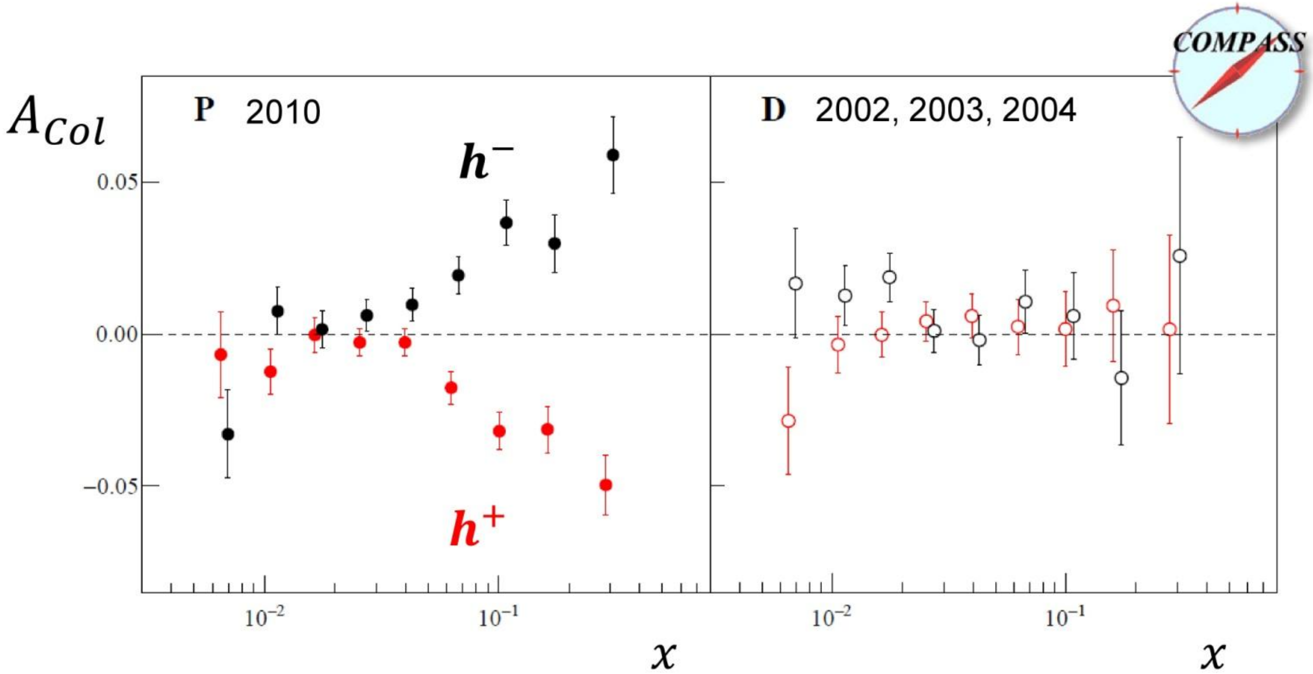
starting from the experience of the successful 2010 proton run

we assumed one year of data taking
with ^{6}LiD as in 2002 - 2004,
with the **same muon beam integrated intensity as in 2010** and
the **same spectrometer performances**

$$N_{d,h}^{1y} = N_{p,h} = 80 \cdot 10^6$$

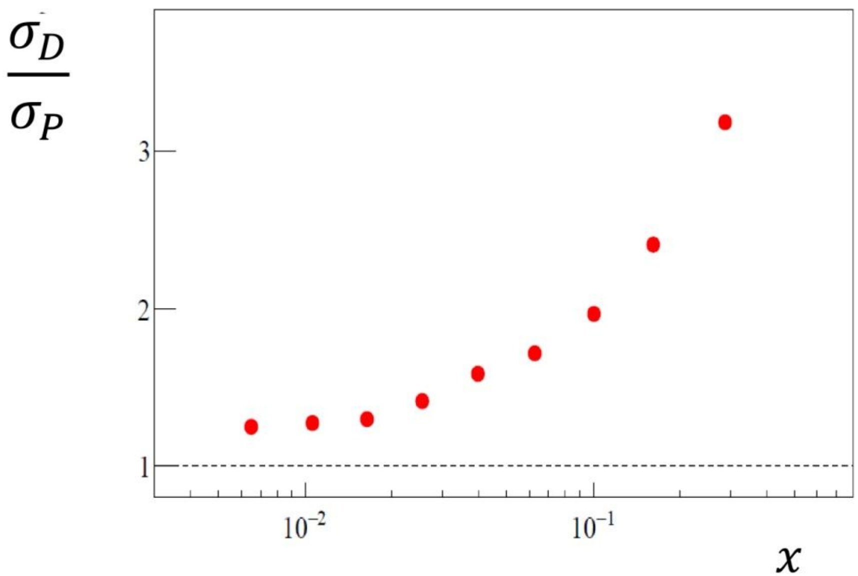
$$\sigma_A \approx \frac{1}{fP}\frac{1}{\sqrt{N}} = \frac{1}{FOM}\frac{1}{\sqrt{N}}$$

$$\frac{\sigma_{A_d}^{1y}}{\sigma_{A_p}^{2010}} = \frac{FOM_p}{FOM_d} = 0.62$$



present

P 2007 data
non used here



three effects:

1. **running time**
2. **FoM**
3. **acceptance**

difference asymmetries – results

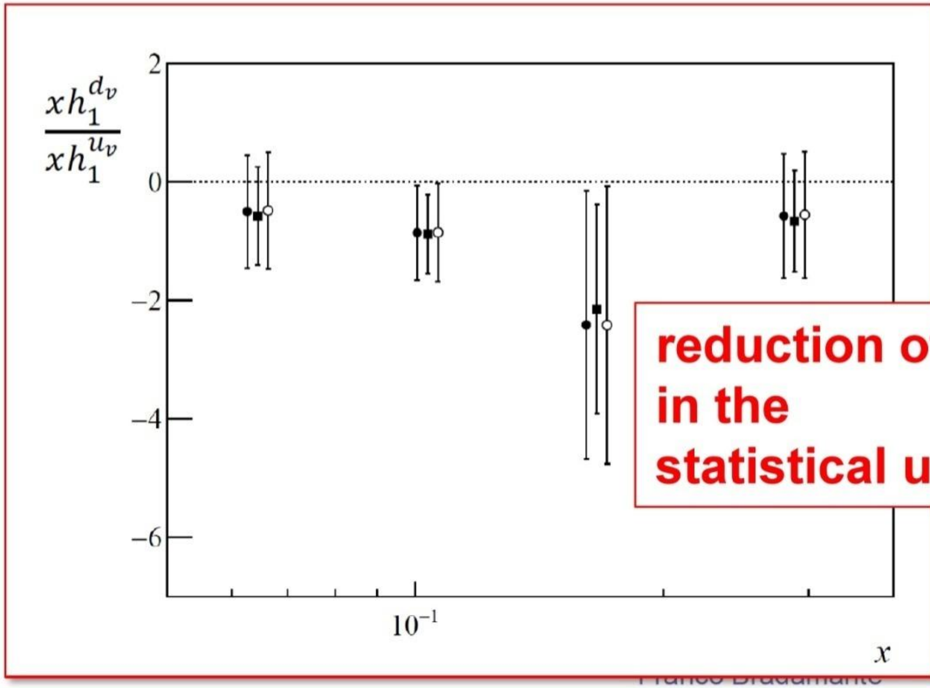
$$\frac{A_{D,d}}{A_{D,p}} = 3\,\frac{\sigma^{+}_{0,p} + \sigma^{-}_{0,p}}{\sigma^{+}_{0,d} + \sigma^{-}_{0,d}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}$$

$$\frac{A'_{D,d}}{A'_{D,p}} = \frac{4f_1^{u_v} - f_1^{d_v}}{f_1^{u_v} + f_1^{d_v}}\,\frac{h_1^{u_v} + h_1^{d_v}}{4h_1^{u_v} - h_1^{d_v}}$$

$\rightarrow$ $\dfrac{h_1^{d_v}}{h_1^{u_v}}$

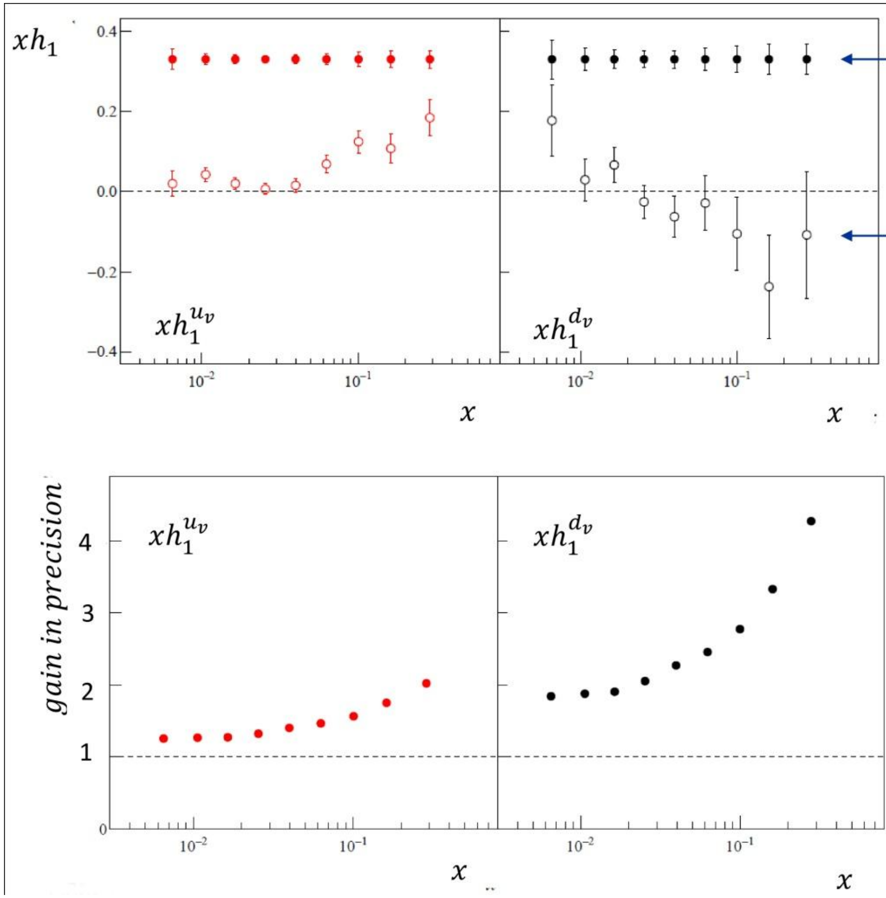
- ● from A_D
- ■ from A'_D
- ○ from $xh_1^{d_v}$ and $xh_1^{u_v}$

A. Martin, F.B., V. Barone
PRD91 2015



reduction of a factor ~4 in the statistical uncertainties

SIDIS 2021



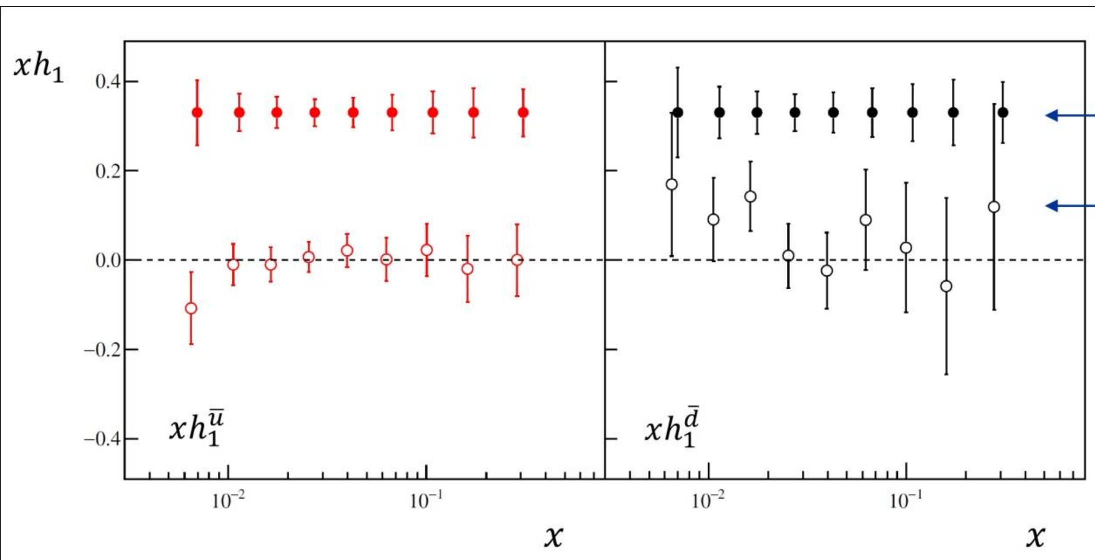
projected

present

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

we have followed the method in for all the transversity extraction

valence



projected

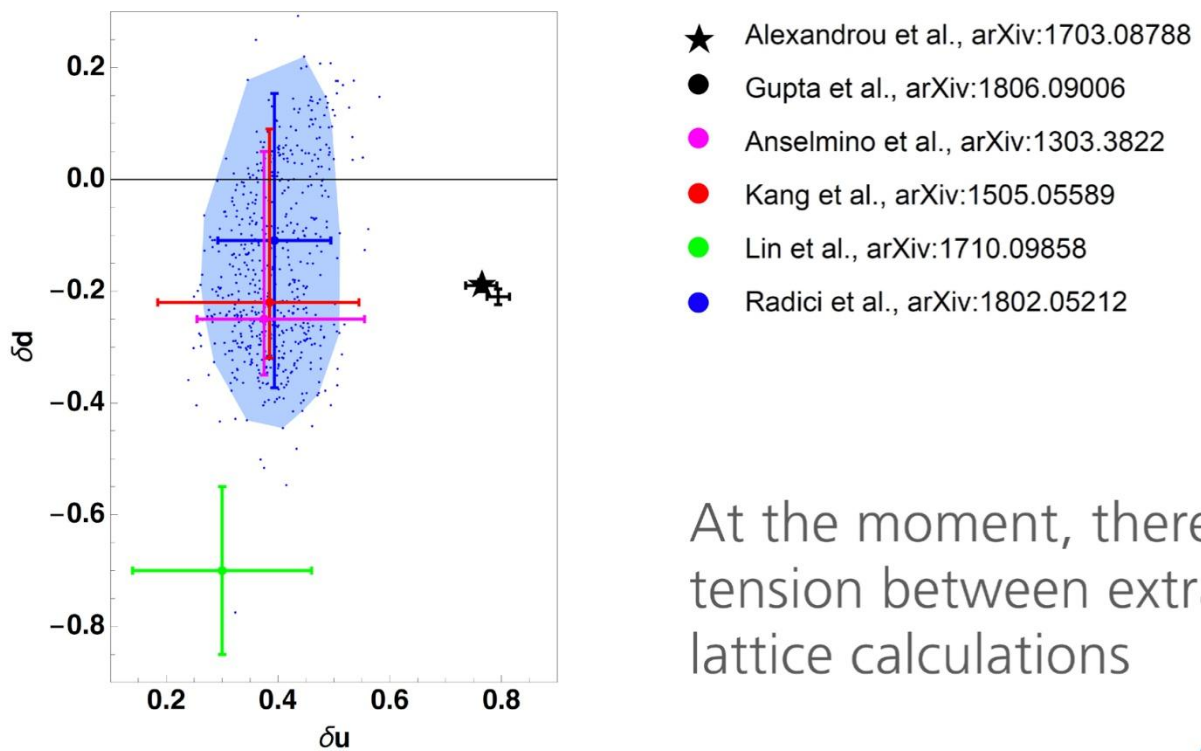
present

SIDIS 2021- tenzor charge

$$g_T = \delta u - \delta d$$

A. Bacchetta, M. Radici
plenary, WG6

Tensor charge $\quad \delta q \equiv g_T^q = \int_0^1 dx \ \left[h_1^q(x,Q^2) - h_1^{\bar{q}}(x,Q^2)\right]$



At the moment, there is a clear tension between extractions and lattice calculations

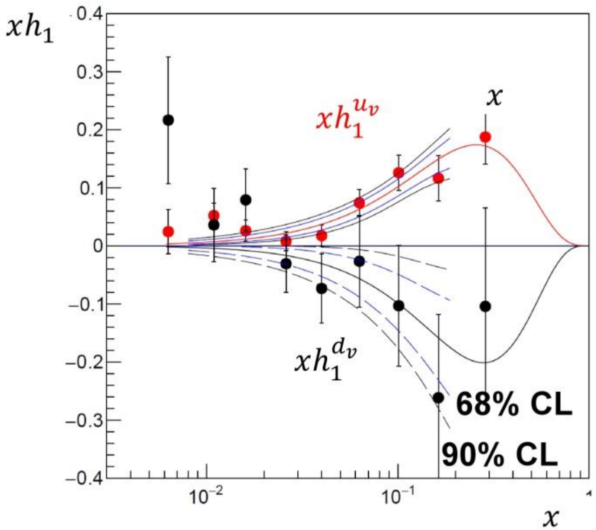
A. Bacchetta

SIDIS 2021-tenzor charge

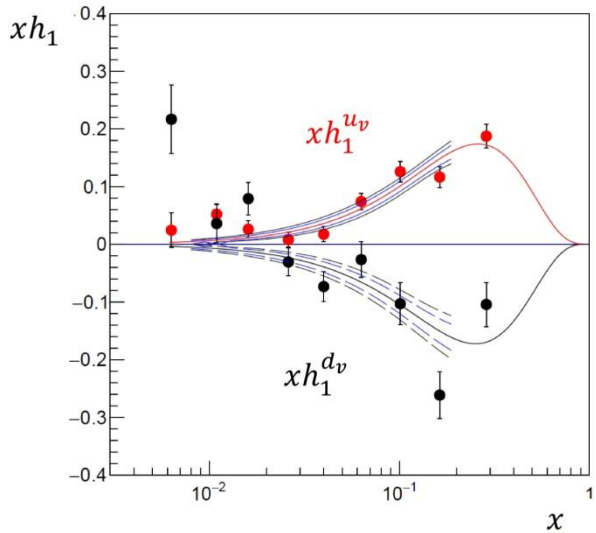
using all the existing proton data
COMPASS 2010 and 2007 plus HERMES ("P all")

using a simple parametrisation we have calculated the Confidence Levels from replicas

present
P all, **D 2002-2004**



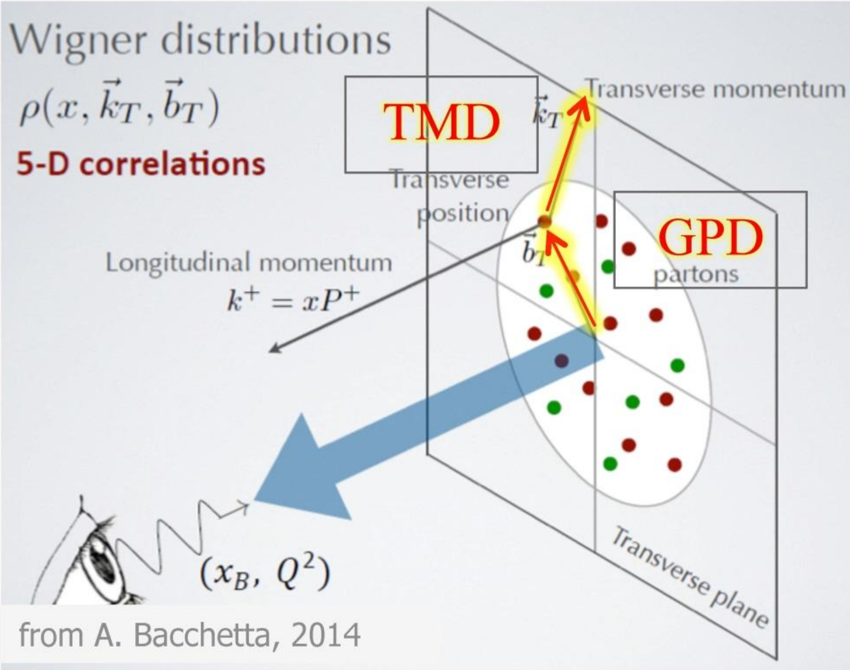
projected
P all, **D 2021 only**



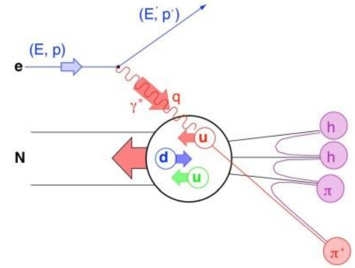
$\Omega_x: 0.008 \div 0.210$

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

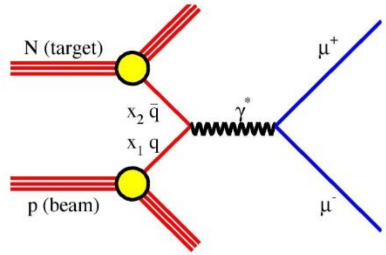
COMPASS-II MEASUREMENTS IN 2017-2019



Semi-Inclusive DIS



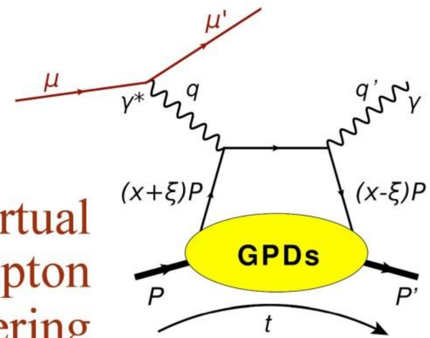
Drell-Yan process



Transversity Momentum Distributions: TMD (x,k_T):
probe the transverse parton momentum dependence

Generalized Parton Distributions : GPD (x,b_T):
probe the transverse parton distance dependence

Deeply Virtual Compton Scattering



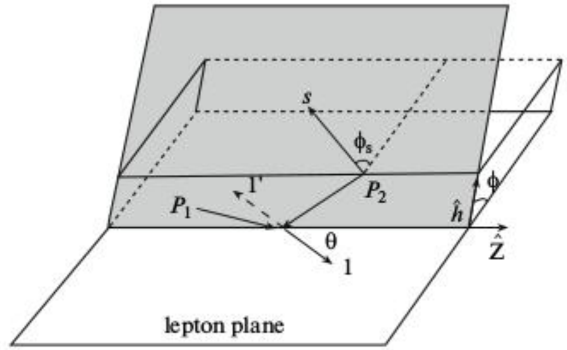
COMPASS explores the multi-dimensional structure of the nucleon - both in momentum and in configuration space

COMPASS-II MEASUREMENTS IN 2017-2019

Drell-Yan measurements

- Full formalism for two spin ½ hadrons
- COMPASS: access 4 TMDs:
  - Boer-Mulders, Sivers, Pretzelosity, Transversi

Arnold, Metz and Schlegel, Phys. Rev. D79 (2009) 034005.



- Access 4 TMDs – asymmetry modulations:

Boer-Mulders	$A_U^{\cos 2\phi} \propto 1 + \bar{h}_1^{\perp} \otimes h_1^{\perp} \cos 2\phi$
Sivers	$A_T^{\sin\phi} \propto S_T \left[\bar{f}_1 \otimes f_{1T}^{\perp} \sin\phi_s) \right]$
Pretzelosity	$A_T^{\sin(2\phi+\phi_s)} \propto S_T \left[\bar{h}_1^{\perp} \otimes h_{1T}^{\perp} \sin(2\phi+\phi_s) \right]$
Transversity	$A_T^{\sin(2\phi-\phi_s)} \propto S_T \left[\bar{h}_1^{\perp} \otimes h_1 \sin(2\phi-\phi_s) \right]$
Worm-Gear	Not possible: needs double polarization

All four TMDs are also measured in SIDIS

COMPASS-II MEASUREMENTS IN 2017-2019

Drell-Yan measurements

- SIDIS vs TMD
  - SIDIS: TMD and FF
  - Drell-Yan: two TMDs

$$\sigma^{SIDIS} \propto TMD_p(x, k_T) \otimes D_f^h(z, Q^2)$$

$$\sigma^{DY} \propto TMD_\pi \otimes TMD_p$$

Collins, Soper, Sterman,
Adv. Ser. High En Phys. 5, 1988.

- Factorization and gauge invariance:
  - TMDs (unlike PDFs) can be process dependent (“non-universality”)
  - Opposite sign in SIDIS and DY processes for T-odd TMDs:

Sivers:

$$f_{1T}^{\perp}(SIDIS) = -f_{1T}^{\perp}(DY)$$

Boer-Mulders:

$$h_1^{\perp}(SIDIS) = -h_1^{\perp}(DY)$$

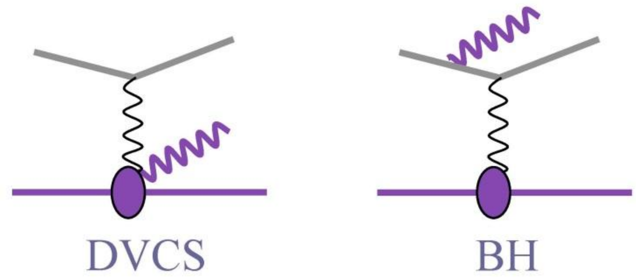
Crucial test of the QCD factorization approach

NB: Recent results of TSA for W/Z prod:
STAR@RHIC: arXiv: 1511.06003

COMPASS-II MEASUREMENTS IN 2017-2019

GPD measurements

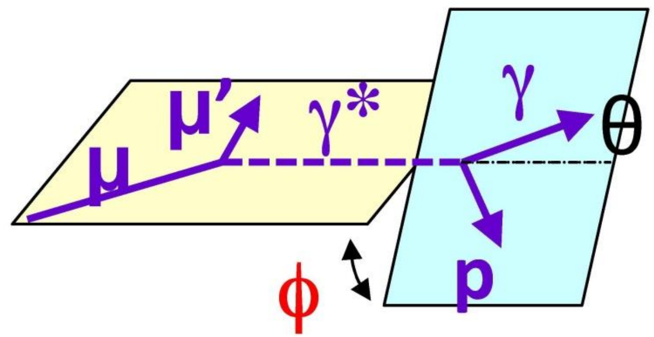
- Cross section for μp -> μpγ
  - DVCS and BH (known) processes:



$$d\sigma = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu \, d\sigma^{DVCS}_{pol} + e_\mu a^{BH} \mathrm{Re}\, A^{DVCS} + e_\mu P_\mu a^{BH} \mathrm{Im}\, A^{DVCS}$$

Beam polarization: P_μ beam charge: e_μ

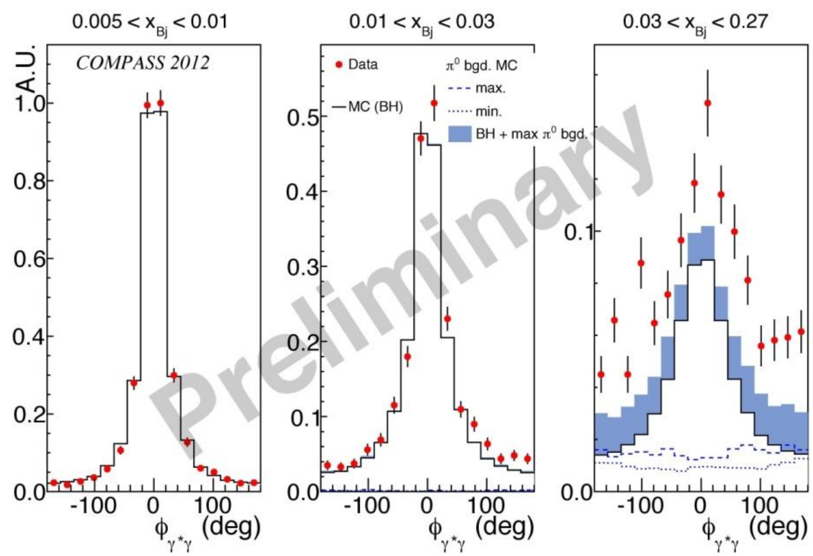
- COMPASS beams: opposite charge/spin
  - Charge-and-Spin Sum
  - Charge-and-Spin Difference



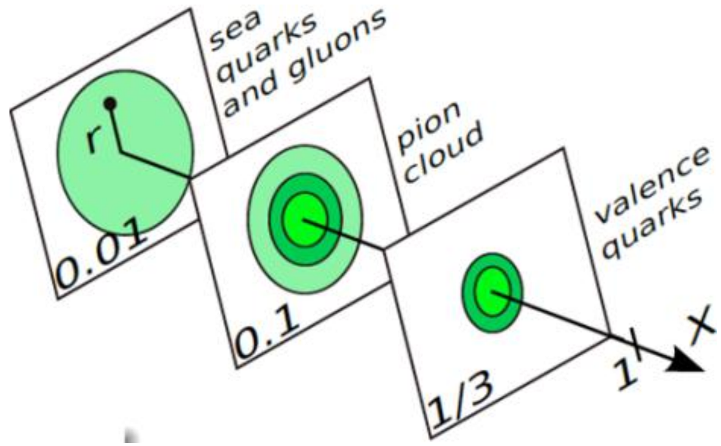
Access both Re(*H*) and Im(*H*) by measuring the Sum and the Difference

4. COMPASS-II MEASUREMENTS IN 2017-2019

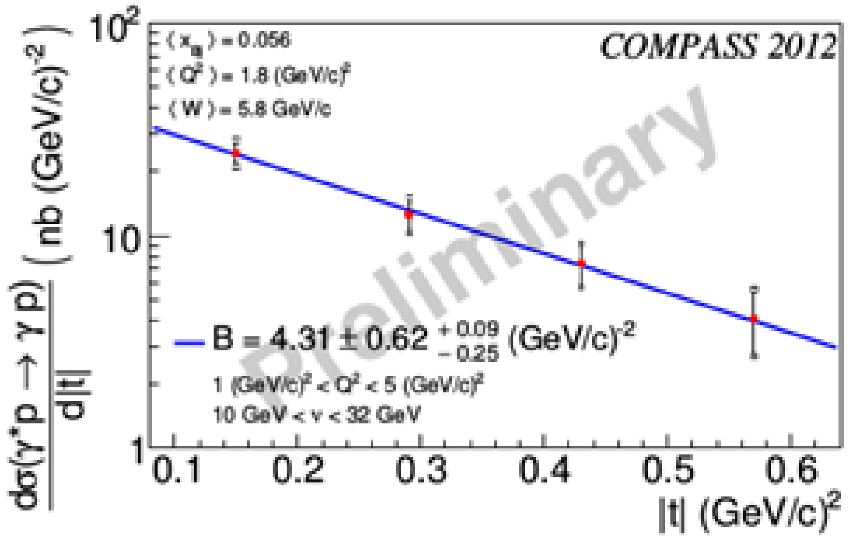
GPD measurements

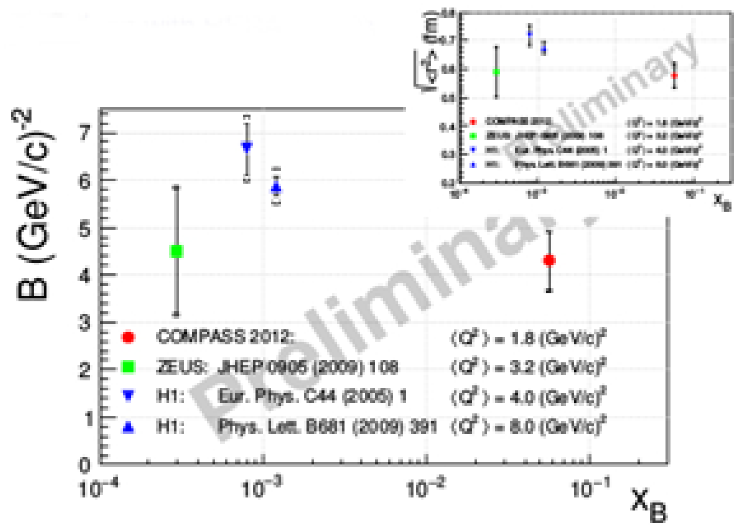


2012:
4 weeks
full scale
pilot run



BH dominance | Interference | DVCS dominance





COMPASS-II ANALYSIS IN 2017-2019

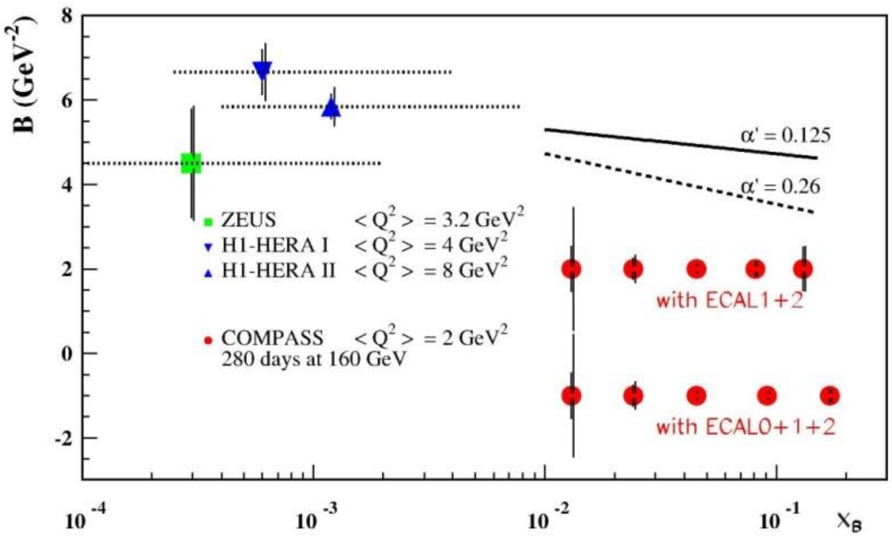
GPD studies

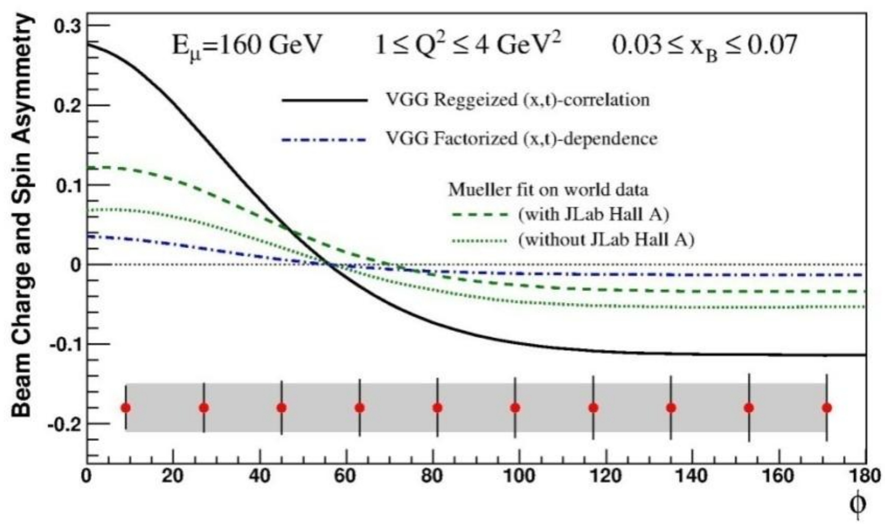
The GPD run has started in 2016 and will be continued in 2017. The main tasks of GPDs investigations with Hard Exclusive Photon and Meson Production are as follows.

- Measurements of the t-slope of the DVCS and HEMP cross section (transverse distribution of partons).
- Studies of the beam-charge-and-spin sum and difference of amplitudes (Re TDVCS and Im TDVCS for the GPD H determination).

-Measurements of longitudinal contribution of Vector Mesons ρ^0,ρ+,ω, φ (GPD H).

-Measurements of total contributions of π^0 (GPDs E and E_T).





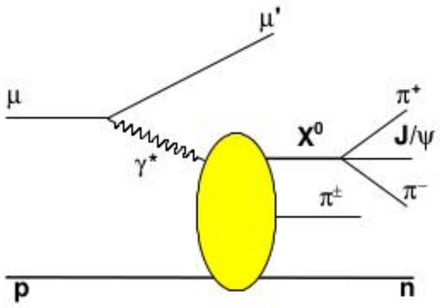
COMPASS-II MEASUREMENTS IN 2017-2019

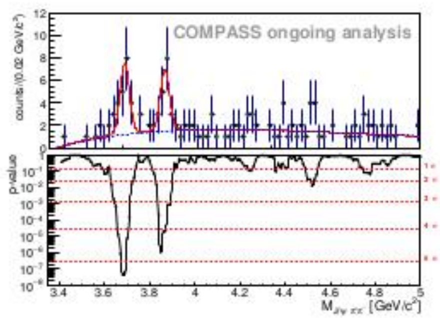
Exotic charmonia

The first glimpse of the X(3872) lepto-production at COMPASS is observed in the exclusive reaction

$$\mu^+ N \to \mu^+ X^0 \pi^\pm N' \to \mu^+ (J/\psi \pi^+ \pi^-) \pi^\pm N' \to \mu^+ (\mu^+ \mu^- \pi^+ \pi^-) \pi^\pm N',$$

where X^0 is the well-known charmonium ψ(2S) or the exotic state X(3872).





Measurement of absolute production rate of X(3872) in the above mentioned reaction could provide important input for clarification of its nature. Search for another exotic charmonia in $J/\psi\varphi$, $J/\psi\pi^+\pi^-\pi^\pm$, $\psi(2S)\pi^\pm$, $\psi(2S)\pi^+\pi^-$ final states is ongoing.

The dominant contribution to the cross section of this reaction is the diffractive process, which can be accounted by the Pomeron exchange in the t-channel, while the excitation of $P_c^+(4380)$ and $P_c^+(4450)$ can occur mainly via the s-channel. The exclusive leptoproduction of the states $P_c^+(4380)$ and $P_c^+(4450)$ potentially can be searched for in the future COMPASS muon runs in the reaction:

$$\mu^+ p \to \mu^+ P_c \to \mu^+ J/\psi p \to \mu^+ \mu^+ \mu^- p.$$

The $Z_c^\pm(3900)$ can be produced by interaction of a high-energy pion beam with the Coulomb field of a nucleus:

$$\pi^-(A,Z) \to Z_c^-(3900)(A,Z) \to J/\psi \pi^-(A,Z).$$