STUDIES OF THE NUCLEON AND HADRON STRUCTURE AT CERN

Project COMPASS-II, theme 02-0-1085-2009/2016, extension for 2017-2019, resubmission

Leader A.P. Nagaytsev
Deputy A.V.Guskov

COMPASS is a general institute project, 4 JINR laboratories, 49 physicists, engineers and PhD students.

The COMPASS-II proposal, suggested by the same Collaboration as continuation of COMPASS, has been approved in May 2010 and corresponding theme at JINR has been prolonged for 2014-2016.

Recommendations of PAC 46th meeting on COMPASS-II

The PAC appreciates the important role of the JINR group in data taking and detector maintenance as well as in the physics analysis, in particular the spin asymmetry studies and analyses related to hadron physics.

The PAC realizes the importance of JINR's participation in COMPASS and the potential synergy with future involvement in the NICA/SPD experiment.

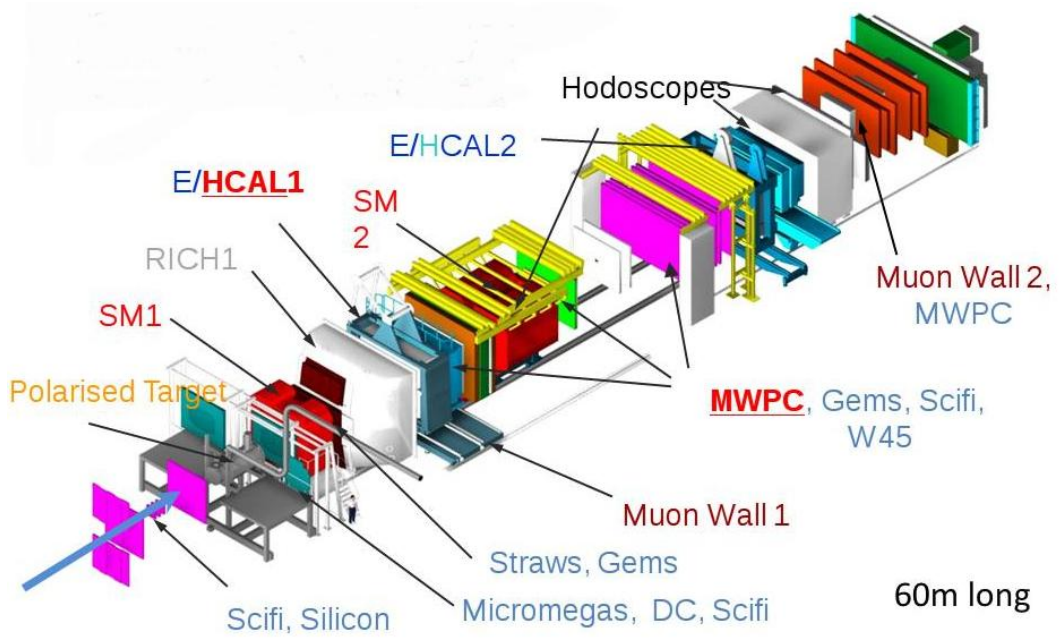
However, the PAC considers it unjustified to have two different JINR groups participating in the same experiment. Furthermore, the PAC is concerned by the mixing between the two proposals in terms of people involved, research interests and financial requests.

The PAC recommends that the two JINR groups resubmit one single proposal not later than the next PAC meeting, outlining the JINR strategy and goals for the next three years of the COMPASS II experiment. In the meantime the Laboratory directors should provide to the groups the minimal support that will allow them to continue fulfilling their obligations in COMPASS.

This proposal should include the following specific information: number of participants, COMPASS authors, PhD students, engineers, and a list of all the physics analyses they propose to carry out.

In addition, as far as the travel expenses are concerned, the group should provide justification for the large amount of about 200 k$ requested per year.

INTRODUCTION



COMPASS is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN in Geneva. The purpose of this experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.

Our reference : DG-DI-RCS-2017-041 Geneva, 18 April 2017

Notification to the COMPASS Funding Agencies

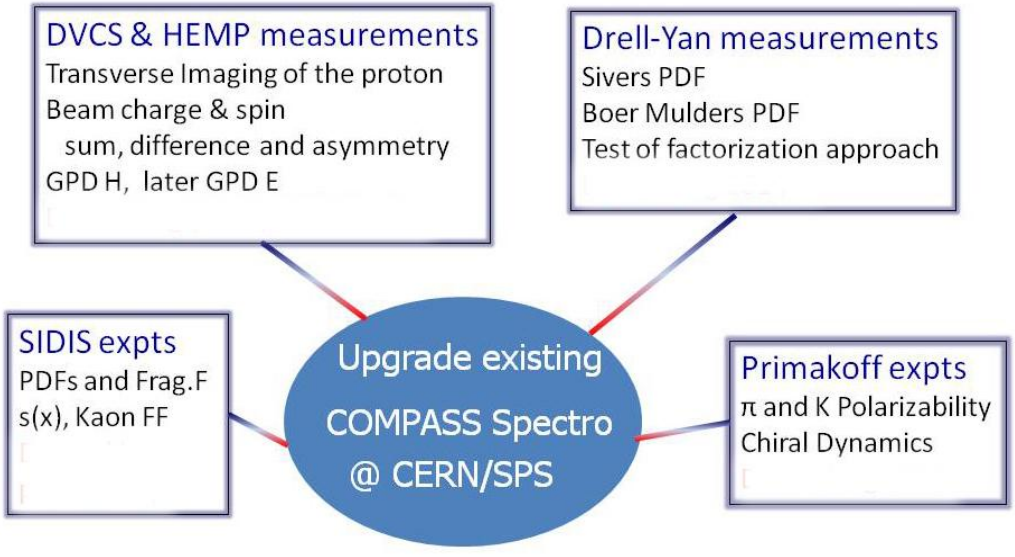
Following the decision taken at the last COMPASS Financial Review Committee (FRC) on 10. November 2016, I confirm the extension of the COMPASS Memorandum of Understanding until 31 December 2020. This decision is documented in the draft minutes of the FRC Meeting which will be approved at the next COMPASS FRC in November 2017."

Yours sincerely,

Eckhard Elsen

Extension of the COMPASS-II program has been approved by the CERN Directorate up to end of 2020.

INTRODUCTION

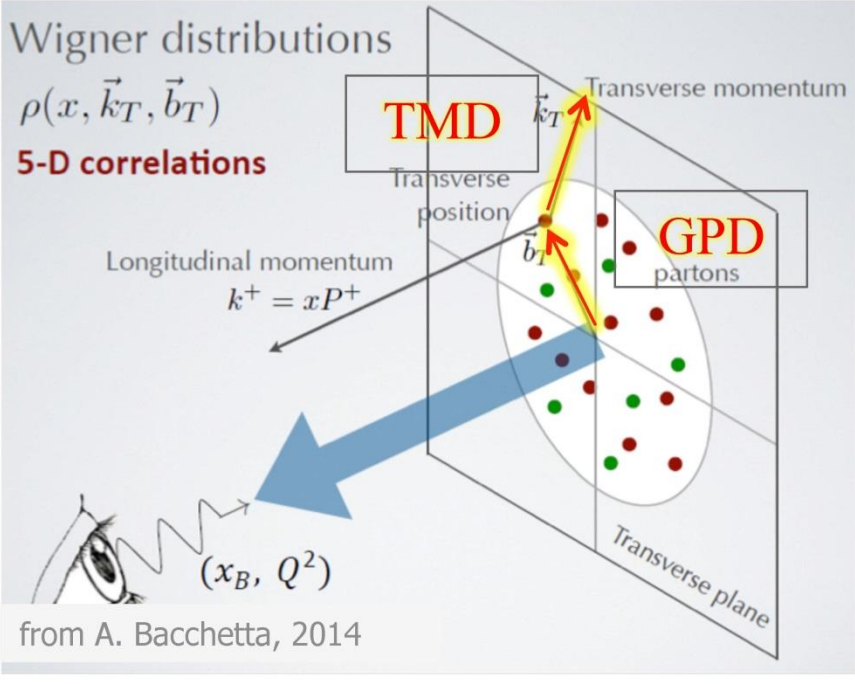


The COMPAS-II measurements have started in 2012 with a pion/kaon polarisability via Primakoff reactions and with GPD feasibility test using partially upgraded COMPASS-II spectrometer.

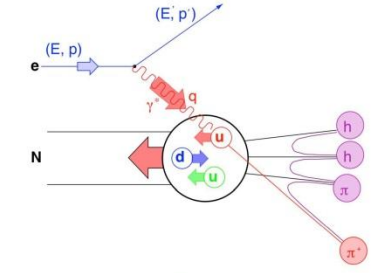
They will be focused on studies of transverse momentum dependent (TMD) distributions of partons in nucleons via Drell-Yan lepton pair production (running in 2014-2015, 2018) and measurements of Generalized Parton Distributions (GPDs) via hard exclusive meson production and DVCS (running in 2016-2017) .

In parallel with the GPD program, high statistic data for unpolarized SIDIS will be taken.

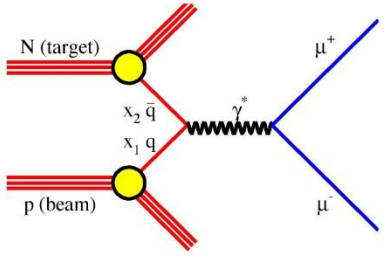
COMPASS-II MEASUREMENTS IN 2017-2019



Semi-Inclusive DIS



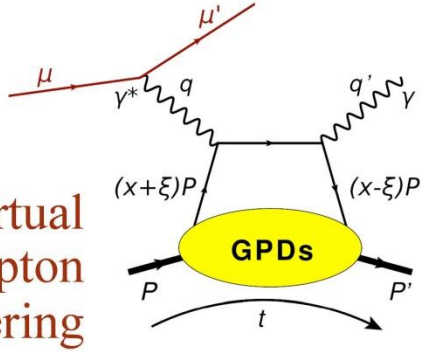
Drell-Yan process



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

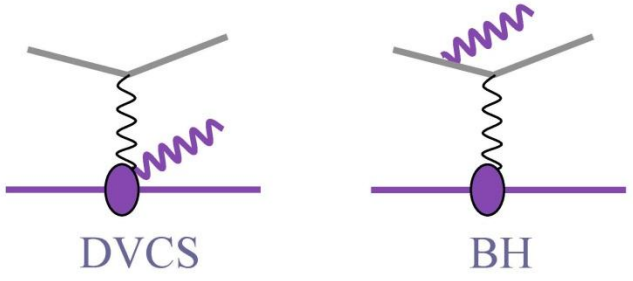
Deeply Virtual Compton Scattering



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

COMPASS-II MEASUREMENTS IN 2017-2019

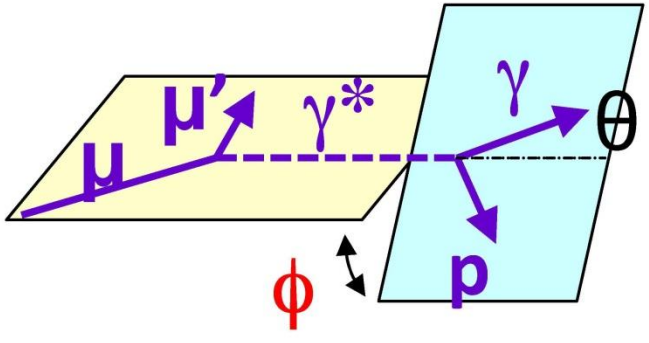
- Cross section for μp -> μpγ
  - DVCS and BH (known) processes:



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

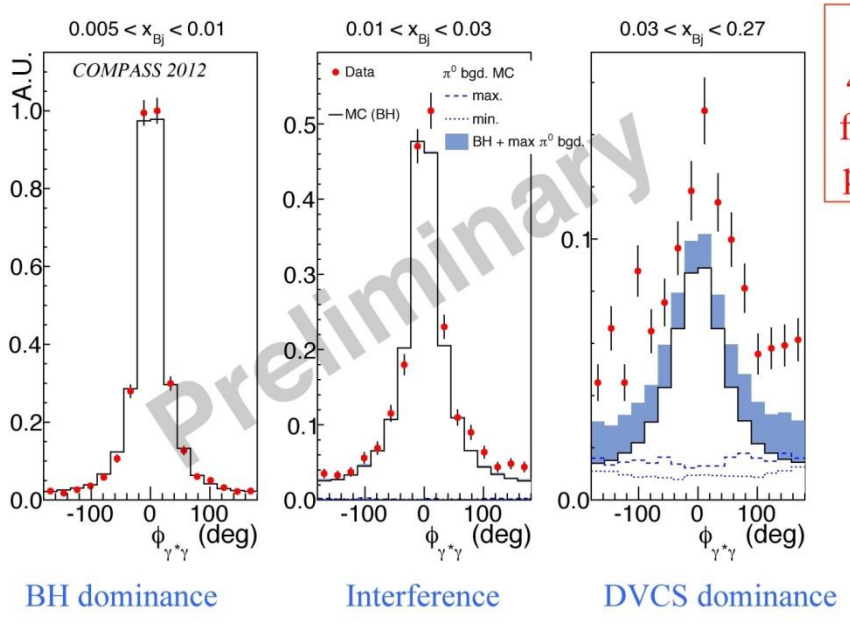
Beam polarization: P_μ beam charge: e_μ

- 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

COMPASS-II MEASUREMENTS IN 2017-2019

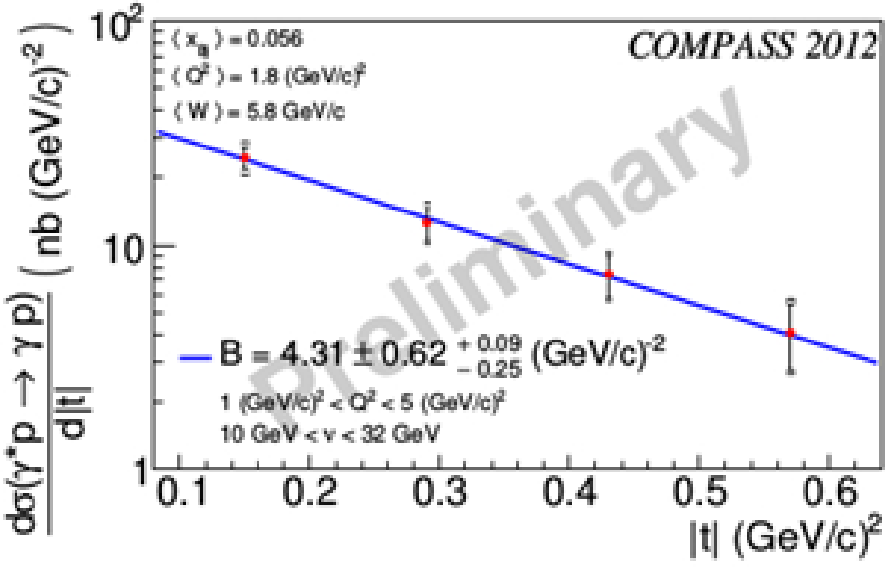


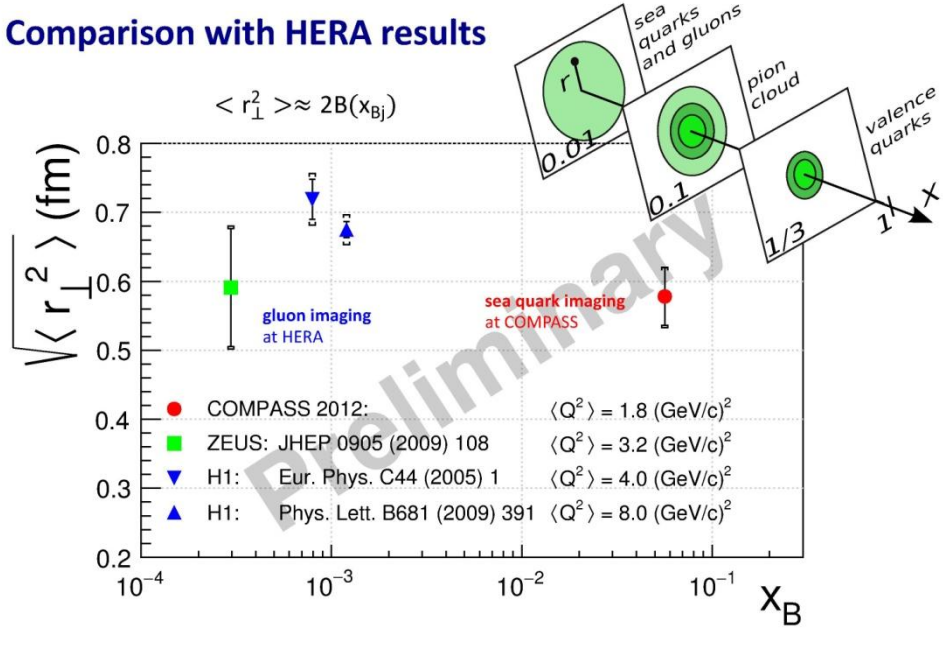
2012:
4 weeks
full scale
pilot run

The first proof of principle for the possibility to measure DVCS in COMPASS was brought by a 10-day long run test in 2009 with a reduced setup (40 cm liquid hydrogen target, short recoil proton calorimeter, no additional calorimetry).

A pilot run has been recorded in 2012, and the full DVCS run will be recorded in 2016-2017.

In 2012, a four-week long pilot run has been recorded, with a mostly complete DVCS setup (full scale recoil proton detector, full luminosity, partially equipped large angle calorimeter ECAL0).

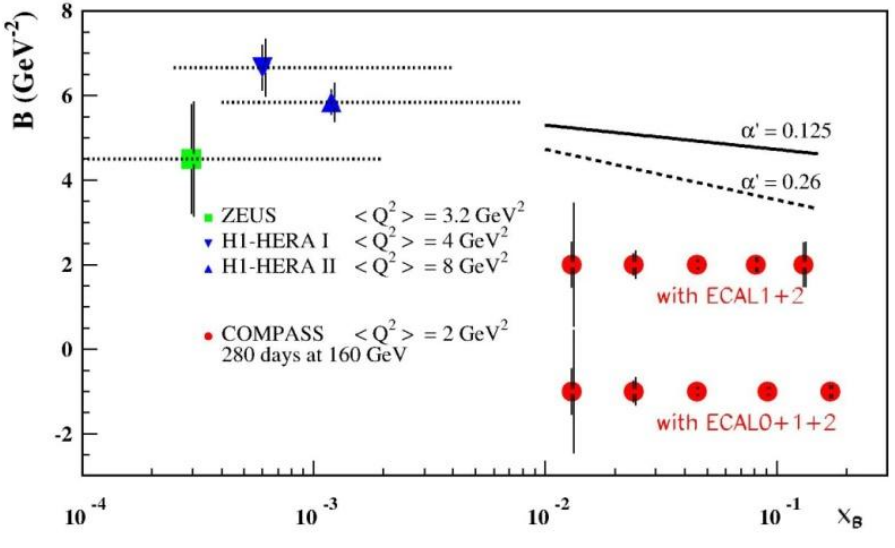


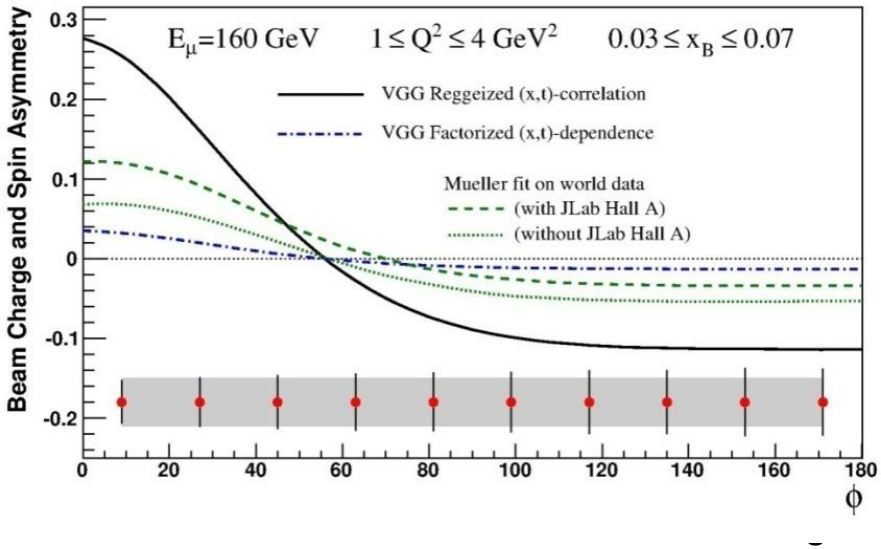


COMPASS-II MEASUREMENTS IN 2017-2019

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 ρ^0,ρ+,ω, φ (GPD H).**
- **Measurements of total contributions of π^0 (GPDs E and E_T).**



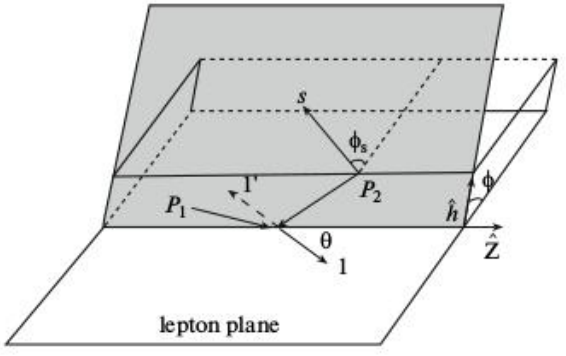


COMPASS-II MEASUREMENTS IN 2017-2019

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

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

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

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

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

- Factorization and gauge invariance:

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

  - TMDs (unlike PDFs) can be process dependent ("non-universality")
  - Opposite sign in SIDIS and DY processes for T-odd TMDs:

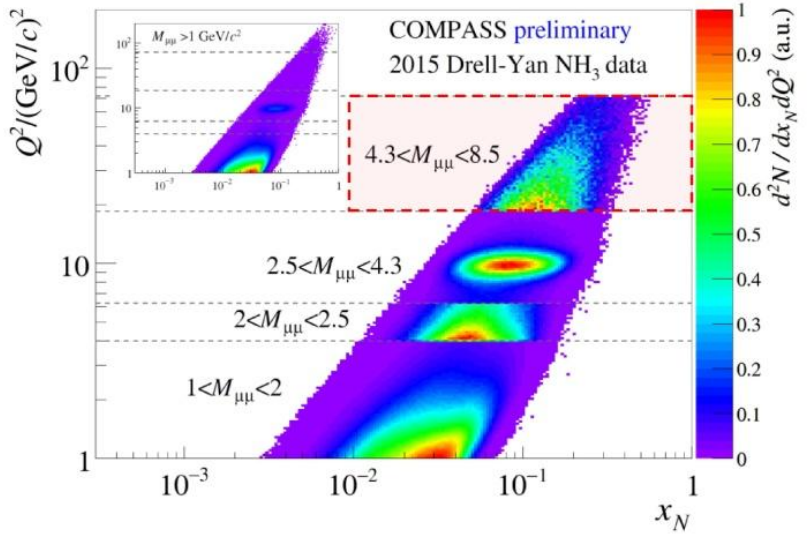
Sivers:
$$f_{1T}^{\perp}(SIDIS) = -f_{1T}^{\perp}(DY)$$

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

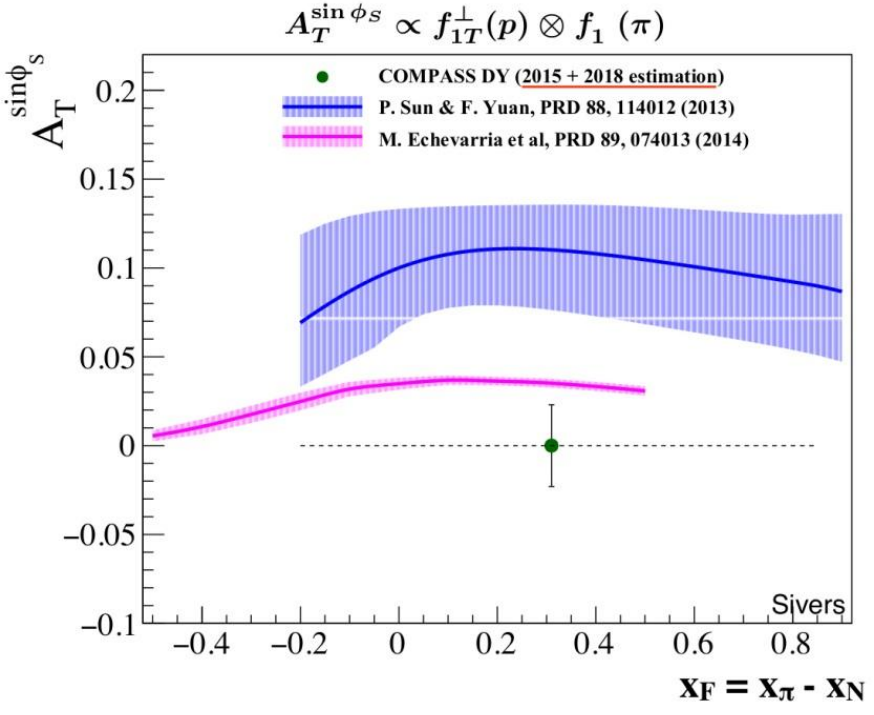
COMPASS-II MEASUREMENTS IN 2017-2019

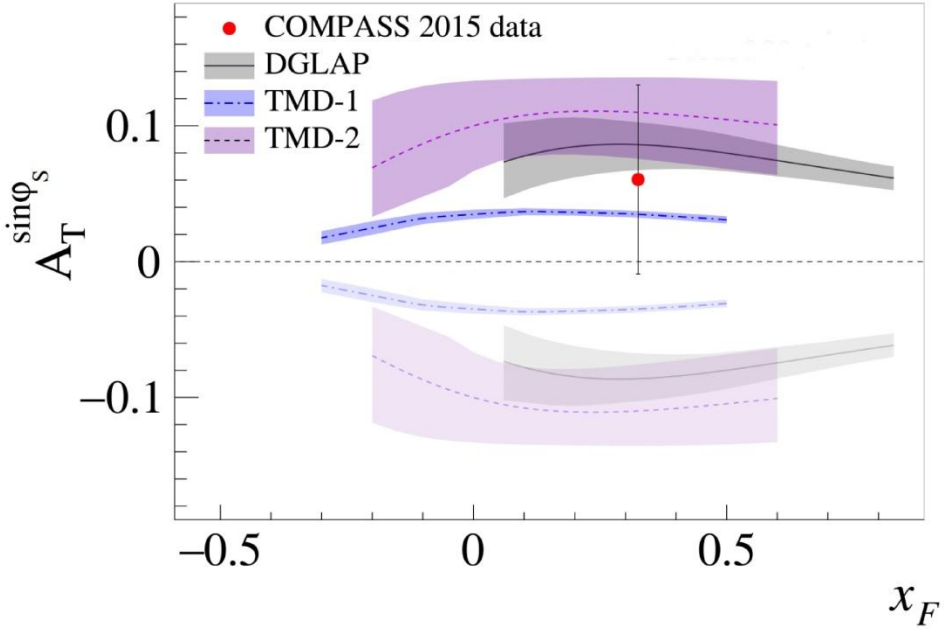


The Drell-Yan data taking has started in 2014 with pilot run: about 7K DY events and 200 K J/Ψ events.

In 2015 COMPASS has taken about 35K ($4.3<M_{\mu\mu}<8.5$ GeV) DY events and 1200 K J/Ψ events in 4.5 months of stable data taking.

The first indication was obtained on change of sign via measurement of the DY Sivers asymmetry. The result is consistent with the predicted change of sign for the Sivers function.





MAIN COMPASS-II RESULTS. JINR Contribution.

The list of papers with JINR contribution:

«Measurement of the charged-pion polarisability» **PRL 114 (2015) 062002**

«Search for exclusive photoproduction of $Z^{\pm}_{c}$ (3900) at COMPASS», **PLB 742 (2015) 330**

«Multiplicities of charged pions and unidentified charged hadrons from deep-inelastic scattering of muons off an isoscalar target», **PLB 764 (2017)**

«Multiplicities of charged kaons from deep-inelastic muon scattering off an isoscalar target», **PLB 767 (2017)**

«Azimuthal asymmetries of charged hadrons produced in high-energy muon scattering off longitudinally polarised deuterons», **submitted to EPJC**

«The COMPASS setup for physics with hadron beams», **NIMA 779 (2015) 69**

«The spin structure function g_1^p of the proton and a test of the Bjorken sum rule», **PLB 753 (2016).**

«Final COMPASS results on the deuteron spin-dependent structure function g1d and the Bjorken sum rule», **PLB 769 (2017).**

New electromagnetic calorimmeter (ECAL0) was developed, produced and installed in COMPASS setup.

For details – COMPASS-II and Hadron Physics, 46th meeting of the PAC for Particle Physics

MANPOWER AND MAIN ACTIVITIES

The total number of JINR participants are equal to 49,
one consists of 25 scientists, 11 PhD students,
one diploma student and 12 technicians and engineers.

The number of COMPASS author is equal to
18 scientists and 6 PhD students.

1.SIDIS,
Zemlyanichkina E., Mitrofanov N., Ivanshin Yu.,
Efremov A., Savin I.,

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

«Multiplicities of charged pions and kaons»,
«Longitudinal spin dependent single-hadron asymmetries»

2. GPD asymmetries,
Kouznetsov O., Akhunzyanov R., Gushterski R.

3. Pion polarizability
A.Guskov, Maltsev A., Mitrofanov Ye., Rymbekova A.

The sum of FTE for LNP is equal to 15.5,
for LHEP -12.1, for LTP - 0.6.

The total sum of FTE is 28.2.

5. Pion electromagnetic reactions with pions in the final state,
A.Guskov, Gridin A., Denisenko I., Maltsev A.,
Mitrofanov Ye., Rymbekova A.

6. EMC effect in the pion-induced Drell-Yan process
Guskov A., Gridin A., Denisenko I., Maltsev A.,
Mitrofanov Ye., Rymbekova A.

7. Exotic charmonia
Guskov A., Gridin A., Denisenko I.

8. Data production and alignment
Zemlyanichkina E.

The technical maintenance of three detectors is a one of the main tasks during data taking.

The calorimetry group, which support two calorimeters(HCAL1 and ECAL0), consists of
Anfimov N., Antoshkin A., Gavrishchuk O.,
Meshcheryakov G., Selyunin A., Rezinko T.,
Rybnikov A., Chirikov-Zorin I., Yukaev A.

The second hardware group from LNP,
supporting MW1, are as follows:
Abazov V.A., Alexeev G., Jouravlev N.,
Piskun A., Tokmenin V., Golovanov A.

For details – COMPASS-II and Hadron Physics, 46th meeting of the PAC for Particle Physics

TIMELINES

2017:

- Participation in COMPASS data taking;
- Maintenance during running of MW1, HCAL1 and ECAL0;
- Development/support of MW1/HCAL1/ECAL0 software;
- Temporary decommissioning of ECAL0;
- Analysis of COMPASS experimental data;

2018:

- Participation in COMPASS data taking;
- Maintenance during running of MW1, HCAL1;
- Development/support of MW1/HCAL1 software;
- Analysis of COMPASS experimental data;

2019:

- Temporary decommissioning of MW1/HCAL1;
- Analysis of COMPASS experimental data;

TIMELINES AND FINANCIAL PROFILE

#	Item	Total	2017	2018	2019
1.	Materials	**45**	**20**	**15**	**10**
2.	Equipment	**75**	**25**	**25**	**25**
3.	Subcontracts (collab. common fund)	**222**	**72**	**75**	**75**
4.	Travels, including outside RUSSIA inside RUSSIA	 **376** **15**	 **150** **5**	 **130** **5**	 **96** **5**
	Total , K$	**733**	**272**	**250**	**211**

		Year											
№	Item	2017				2018				2019			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Data taking		■	■	■		■	■	■				
2	ECAL0 preparation	■	■										
3	HCAL1 preparation	■	■			■	■						
3	ECAL0 maintenance		■	■	■								
4	HCAL1 maintenance		■	■	■		■	■	■	■	■		
5	MW1 preparation	■	■			■	■						
6	MW1 maintenance		■	■	■		■	■	■	■	■		
7	MW1/HCAL1 software	■	■	■	■	■	■	■	■				
8	ECAL0 software	■	■	■	■	■	■	■	■				
9	Data analysis	■	■	■	■	■	■	■	■	■	■	■	■

BACKUP SLIDES

COMPASS-II for PAC PP

	Prolongation for 2011-2013 34 PAC PP	Prolongation for 2014-2016 39 PAC PP	Proposal for 2017-2019 46 PAC PP	Resubmission for 2017-2019 47 PAC PP
Total budget, K$	860	1050	842+206	733
Travel expenses, K$	345	460	420+140	376
No. participants	49	47	45+17	49
No. authors	27	22	20	18
Activities in data analysis	DIS,SIDIS, ΔG/G, Λ polarizations , Primakoff	DIS,SIDIS, Λ polarizations , Primakoff	SIDIS, DY ,GPD, Exotic, Primakoff	SIDIS, DY , GPD, Exotic, Primakoff
Detectors	HCAL1, MW1, ECAL0*	HCAL1, MW1, ECAL0*	HCAL1, MW1, ECAL0	HCAL1, M,W1, ECAL0
Recommendations	approval with first priority until the end of 2013.	It recommends continuation of this project and theme until the end of 2016.	resubmit one single proposal not later than the next PAC meeting	

Travel budget is reduced by factor 1.5 (560/376 ~ 1.5)

* - developing and production

DATA TAKING

The data taking is planned to be executed in 2017 and 2018. Every year duration of a data taking is about 7 months. Every day the data taking is divided into 3 shifts, on 2 physics in each shift.

According to safety rules for CERN, presence of participants of shifts in the Control room of COMPASS is obligatory. It is explained by existence in the setup of a liquid hydrogen target, RICH detector and some other systems which demand permanent operating control.

The number of shifts per year for each group is defined by number of authors and PhD students. The JINR fraction of authors and PhD students is about 1/6 from all authors and PhD students of collaboration. Thus, total number of shifts for our group in a year - about 200.

In 2017 COMPASS will take data on the program of GPD measurements. According MoU, the JINR group is obliged to support 3 detectors: hadron calorimeter HCAL1, coordinate system MW1 and new electromagnetic calorimeter ECAL0. One needs presence of oncall experts for all time of a data taking. Constantly 2 oncall experts from our group participate in data taking, one - for MW1, the second – for HCAL1 and ECAL0. These experts also take the shifts, usually – about half of total number of shifts for our group per year. Rest part of shifts covers by JINR group members which are involved in the data analysis, combining work in shifts with reports at various meetings of collaboration and other activities.

In 2018 COMPASS will collect data on the Drell-Yan program. For these measurements only two from three above mentioned detectors will be used – HCAL1 and MW1. The number of authors from the JINR group will be reduced, the smaller number of shifts is expected.

2014-2016 talks

In 2014-2016 17 CM talks :
A.Nagaytsev -8 , A.Guskov -4,
A.Efremov -2, V.Anosov-2, I.Savin-1

12 TB talks,
20 conference talks (including ECAL0 talks)
22 AM talks

The annual international workshop on hadron structure and spectroscopy took place in town Suzdal on 18th-20th of May 2015. COMPASS and JINR group were organizers of the event.

<u>COMPASS CM in 2017:</u>
Feb 9/10, <u>Apr 6/7, Jun 29/30,</u>
Sep 6/7, Nov 16/17

RUN 2017: May 8 – Oct 23

TRAVEL FINANCE PROFILE FOR 2017-2019

N	Activity	#man-months	Appox. Expenses, K$
1	Preparation for data taking (3 detectors)	3	14
2	Maintenance of detectors during data taking	14	63
3	Temporary decommissioning of ECAL0	2	9
3	International conferences and workshops	3	14
4	Participation in Collaboration meetings	3	13
5	Support of works on target maintenance, hall engineering, DAQ, data production and alignment	2	10
6	Participation in group meeting: analysis meeting, technical board, drafting committees and collaboration board	6	27

N	Activity	#man-months	Appox. Expenses, K$
1	Preparation for data taking (2 detectors)	3	14
2	Maintenance of detectors during data taking	12	54
3	International conferences and workshops	3	14
4	Participation in Collaboration meetings	2	10
5	Support of works on target maintenance, hall engineering, DAQ, data production and alignment	2	10
6	Participation in group meeting: analysis meeting, technical board, drafting committees and collaboration board	6	28

N	Activity	#man-months	Appox. Expenses, K$
1	Preparation for data taking (2 detectors)	3	14
2	Maintenance of detectors during data taking	12	54
3	International conferences and workshops	3	14
4	Participation in Collaboration meetings	2	10
5	Support of works on target maintenance, hall engineering, DAQ, data production and alignment	2	10
6	Participation in group meeting: analysis meeting, technical board, drafting committees and collaboration board	6	28

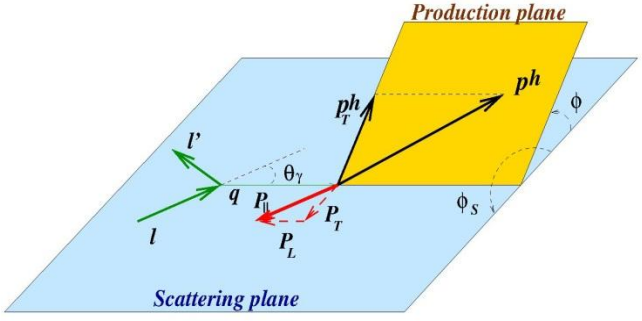
MANPOWER AND MAIN ACTIVITIES

No.	Name	Status	Activity	FTE	Laboratory
1	Abazov V.	scient	MW1	0,5	LNP
2	Arbuzov A.	scient	Data analysis	0,1	LTP
3	**Alexeev G.**	scient	MW1	0,5	LNP
4	**Anfimov N.**	scient	ECAL0	0,5	LNP
5	**Anosov V.**	tech	Hall Engeneering	1,0	LHEP
6	**Antoshkin A.**	PhD st	ECAL0	0,5	LNP
7	Astakhov V.	tech	ECAL0 electronics	0,1	LHEP
8	**Akhunzyanov R.**	PhD st	Data analysis	1,0	LHEP
9	Batozskaya V.	PhD st	Data analysis	1,0	LHEP*
10	**Gavrishchuk O.**	scient	HCAL1, ECAL0	0,4	LHEP
11	Gridin A.	PhD st	Data analysis	0,5	LNP
12	Gromov V.	tech	ECAL0, Slow control	0,5	LNP
13	**Guskov A.**	scient	ECAL0, Data analysis	0,5	LNP
14	Gushterski R.	scient	Data analysis	1,0	LHEP
15	Denisenko I.	PhD st	Data analysis	0,5	LNP
16	**Efremov A.**	scient	Data analysis, Theory	0,5	LTP
17	**Jouravlev N.**	scient	MW1	0,5	LNP
18	**Zemlyanichkina E.**	scient	Data analysis	1,0	LHEP
19	Ivanov A.	scient	Data analysis	1,0	LHEP*
20	**Ivanshin Yu.**	scient	Data analysis	1,0	LHEP
21	**Kisselev Yu.**	scient	Polarised target	1,0	LHEP
22	**Kouznetsov O.**	scient	Data analysis	1,0	LHEP
23	Maltsev A.	Dip.student	Data analysis	0,5	LNP
24	Golovanov A.	tech	MW1	0,5	LNP
25	**Meshcheryakov G.**	scient	HCAL1, ECAL0	1,0	LHEP
26	**Mitrofanov Ye.**	PhD st	Data analysis	1,0	LNP
27	**Mitrofanov N.**	PhD st	Data analysis	1,0	LHEP
28	**Nagaytsev A.**	scient	Team leader,ECAL0	1,0	LHEP
29	Nikitin M.	tech	ECAL0	0,5	LNP
30	**Olchevski A.**	scient	ECAL0, data analysis	0,1	LNP
31	**Peshekhonov D.**	scient	Data taking	0,5	LHEP
32	Piskun A.	tech	MW1	0,5	LNP
33	Rezinko T.	tech	ECAL0	0,5	LNP
34	Rogacheva N.	scient	Data analysis	1.0	LHEP*
35	**Rybnikov A.**	PhD st	ECAL0	0,5	LNP
36	Rymbekova A.	PhD st	Data analysis	0,1	LNP
37	**Savin I.**	scient	Scien. team leader, data analysis	0,5	LHEP
38	Salmina E.	PhD st	Data analysis	1,0	LHEP*
39	Samartsev A.	tech	designer	0,5	LNP
40	**Selyunin A.**	PhD st	HCAL1, ECAL0	0,5	LNP
41	**Slunechka M.**	scient	Data taking	1,0	LNP
42	Smirnov G.	scient	Data analysis	0,1	LHEP
43	Tokmenin V.	tech	MW1	0,5	LNP
44	Fedoseev D.	tech	ECAL0	0,5	LNP
45	**Frolov V.**	scient	DAQ, ECAL0	1,0	LNP
46	Tchalyshev V.	tech	ECAL0	0,5	LNP
47	Chirikov-Zorin I.	scient	ECAL0	0,8	LNP
48	Yukaev A.	tech	HCAL1	0,5	LHEP
49	Janata A.	scient	Data taking	1,0	LNP

MAIN COMPASS-II RESULTS

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

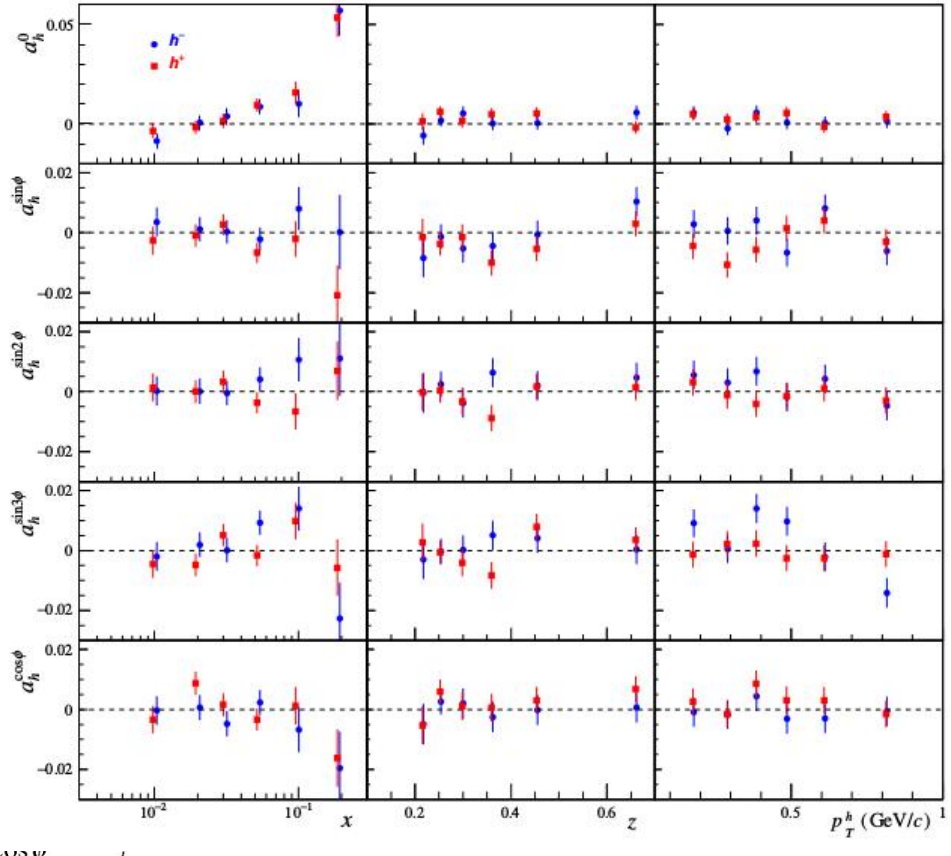
CERN-EP/2016-245, submitted to EPJC



$$a_{h^\pm}(\phi) \equiv \frac{d\sigma^{\leftarrow\Rightarrow} - d\sigma^{\leftarrow\Leftarrow}}{|P_L|(d\sigma^{\leftarrow\Rightarrow} + d\sigma^{\leftarrow\Leftarrow})} = \cdot$$

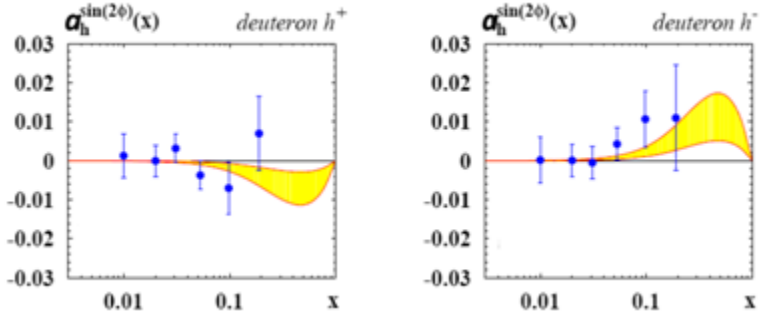
$$- \frac{d\sigma_{0L} + P_\mu d\sigma_{LL} - \tan\theta_\gamma \left(d\sigma_{0T} + P_\mu d\sigma_{LT}\right)}{d\sigma_{00} + P_\mu d\sigma_{L0}}$$

Possible contributions of PDFs to the cross sections and their azimuthal modulations are given in
Eur.Phys.J C70 (2010) 39



$$a_{h^\pm}(\phi) = a^0_{h^\pm} + a^{\sin\phi}_{h^\pm} \sin\phi + a^{\sin 2\phi}_{h^\pm} \sin 2\phi + a^{\sin 3\phi}_{h^\pm} \sin 3\phi + a^{\cos\phi}_{h^\pm} \cos\phi$$

Modulation amplitudes	Amplitudes in 10^{-3} units h^+	h^-
a^0	2.81 ± 0.96	2.01 ± 0.98
$a^{\sin\phi}$	-1.93 ± 1.31	-0.74 ± 1.41
$a^{\sin 2\phi}$	-0.29 ± 1.33	-0.74 ± 1.41
$a^{\sin 3\phi}$	0.34 ± 1.36	-0.10 ± 1.42
$a^{\cos\phi}$	1.52 ± 1.32	0.66 ± 1.42



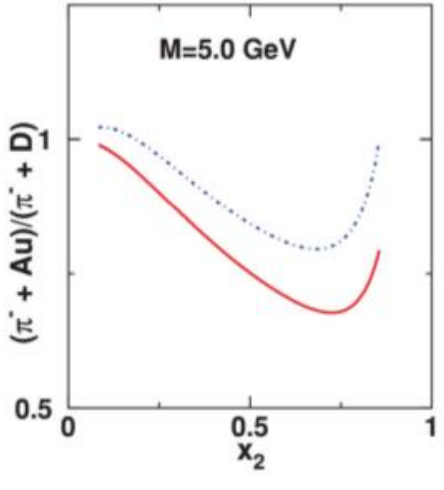
COMPASS-II ANALYSIS IN 2017-2019

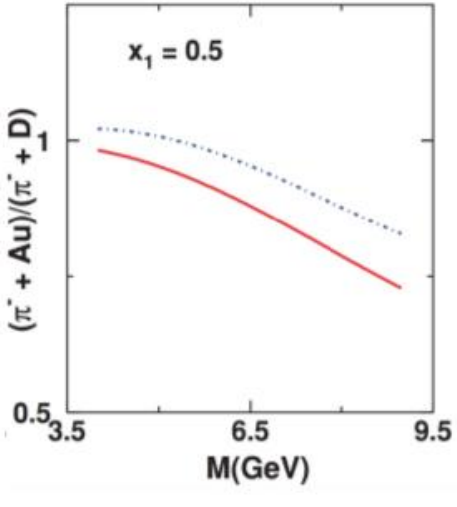
Study of the EMC effect in the pion-induced Drell-Yan process.

Despite the DIS being the main instrument to study the EMC-effect, the effect has also been experimentally verified in the time-like region using both the pion- and the proton-induced Drell-Yan reactions in the E772, E866, NA3, and NA10.

The pion-induced Drell-Yan process is complementary to the DIS process and can provide another experimental tool that is sensitive to flavor-dependent effects in the nuclear quark distributions (since in the DIS contributions of u and d quarks are mixed). Keeping only the dominant terms in the cross section, one readily obtains

Data taking for the Drell-Yan process study with a negative pion beam of 190 GeV/c ($\sqrt{s}$=18.9 GeV) was performed at COMPASS in 2014 (pilot run) and 2015.





$$\frac{\sigma_{DY}^{\pi^- A}}{\sigma_{DY}^{\pi^- D}} \approx \frac{u_A(x_2)}{4u_D(x_2)},$$

Study of nuclear effects in charmonia production could also be performed at COMPASS. Since the gluon fusion gg → J/ψ is a significant part of the J/ψ production mechanism in hadron collisions, comparison of the cross sections of J/ψ production for ammonia, aluminium and tungsten provides access to the EMC effect for gluons.

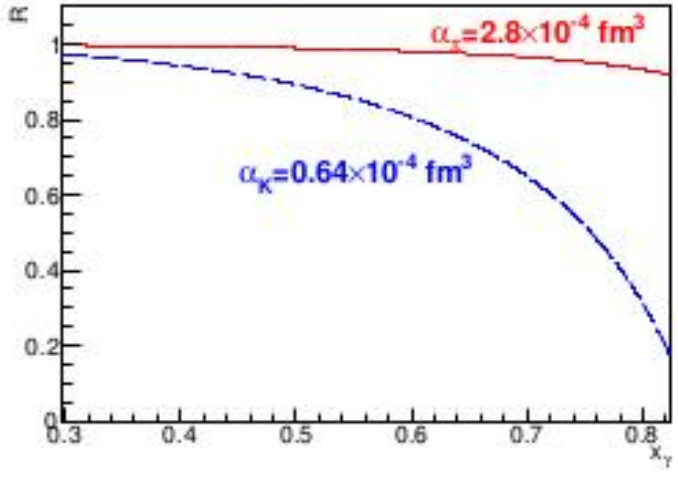
COMPASS-II ANALYSIS IN 2017-2019

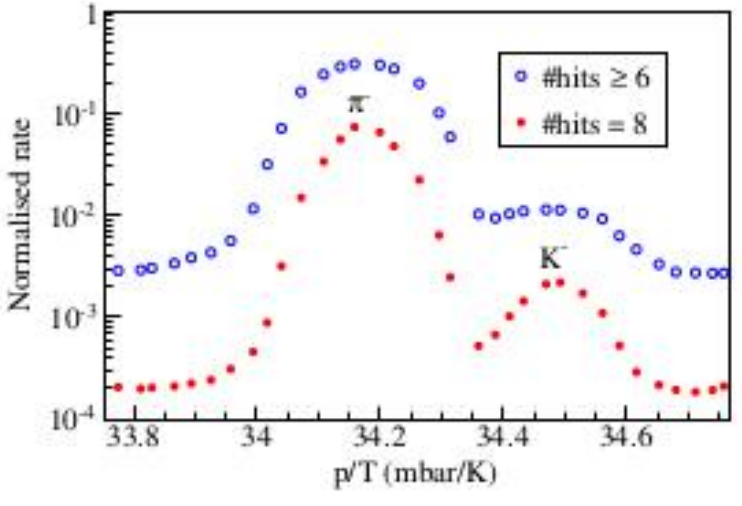
Pion and kaon polarizabilities

The prediction of the chiral perturbation states that, for the charged kaon, the polarizability is $\alpha_K=(0.64\pm0.10)\times10^{-4}$ fm^3 under assumption that $\alpha_K+\beta_K=0$. While the prediction of the quark confinement model is rather different: $\alpha_K=2.3\times10^{-4}$ fm^3, $\alpha_K+\beta_K=1.0\times10^{-4}$fm^3 . As for the experimental results, only the upper limit $\alpha_K<200\times10^{-}4$ fm^3 (CL=90%) has been established from the analysis of X-rays spectra of kaonic atoms. The reaction

$$K^-(A, Z) \rightarrow K^-(A, Z)\gamma.$$

can be used to determine the kaon polarizability. The expected ratio R for the kaon with polarizability $\alpha_K=0.6\times10^{-4}$ fm^3 and for the pion with polarizability $\alpha_\pi=2.8\times10^{-4}$ fm^3 as a function of x_γ is depicted in Figure below (left).





Ratio R of the differential cross sections for the pion with polarizability $\alpha_\pi=2.8\times10^{-4}$ fm^3 and the kaon with polarizability $\alpha_K=0.64\times10^{-4}$ fm^3 to the corresponding cross sections for the point-like pion and kaon (left).
π/K identification by the CEDARs in the COMPASS negative hadron beam (right).

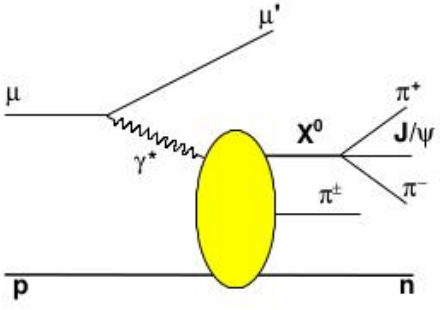
COMPASS-II ANALYSIS IN 2017-2019

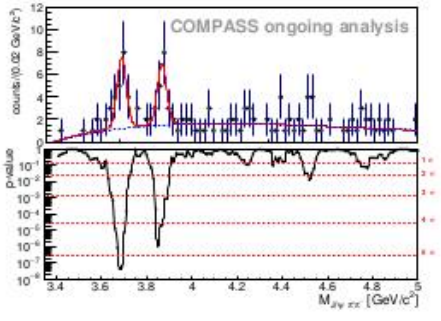
Exotic charmonia

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 $\psi(2S)$ 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.

Upgrade of the COMPASS setup for the GPD programme (2016-2017) provides new opportunities for searching for leptoproduction of exotic charmonium-like states. Searching for the production of exotic charmonia decaying into the final states with π0 , η and χc -mesons, which decays into J/ψγ, could also be possible.

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:

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