Studies of the nucleon and hadron structure at CERN
(Project COMPASS-II, theme 02-0-1085-2017/2019)
extention of the theme for next 3 years

ABSTRACT

COMPASS is a high-energy physics experiment at the Super Proton Synchrotron (SPS) at CERN, Geneva, Switzerland. The purpose of this experiment is to study the nucleon structure and hadron spectroscopy by means of high intensity muon and hadron beams.

In February , 1997, the experiment was conditionally approved at CERN and the final Memorandum of Understanding was signed in September 1998. The spectrometer was installed in 1999 - 2000 and commissioned during the technical run in 2001. The data taking for styding of the nucleon structure started in the summer of 2002 and continued till the autumn of 2004 using 160 GeV muon beam and polarised ^{6}LiD («deuterium») target. After one-year shutdown in 2005, COMPASS resumed data taking with the muon beam in 2006. The years 2008 and 2009 were dedicated to the COMPASS hadron spectroscopy program with pion and proton beam. In 2007 and 2011 nucleon structure function measurements with a NH_3 polarized («proton») target were performed.

In 2010 Research Board approved the extension of the COMPASS program. The COMPASS-II program included a set of measurements to study the Generalized Parton Distribution (GPD) in nucleons via Deep Virtual Compton Scattering (DVCS) and Hard Exclusive Meson Production (HEMP), Transverse Momentum Dependent Parton Distribution Funstion (TMD PDFs) in SIDIS and TMD PDFs in polarized Drell-Yan processes. Further investigations in the field of hadron spectroscopy were envisaged as well. In January 2013, a new Memorandum of Understanding was signed, in order to fulfill this program. In 2012 the data to study the Primakoff reaction were taken. The first (pilot) run for the DVCS measurement was also conducted. The first polarised Drell-Yan measurement with the beam of negative pions and a polarised proton target was performed in 2015. The experimental set-up is modified for the GPD runs in 2016 and 2017 with a liquid hydrogen target and the muon beam.

The JINR group made a essential contribution towards receiving new results in spin asymmetry of A_1^p and the longitudinal structure function g_1^p. These results were obtained by the COMPASS collaboration using polarised 200 GeV muons that were scattered off the longitudinally polarised target. The data were collected in 2011 and complement those collected in 2007 at 160 GeV, in particular at lower x values. They improved the statistical precision of g^1 (x) by about the factor of two in the region $x < 0.02$. A next-to-leading order QCD fit to the g^1 world data is performed. It lead to a new determination of the quark spin contribution to the nucleon spin, $\Delta\Sigma$, ranging from 0.26 to 0.36, and to a re-evaluation of the first moment of g^1 . The uncertainty of $\Delta\Sigma$ is mostly due to the large uncertainty of the present determinations of the gluon helicity distribution $\Delta g/g = 0.113 \pm 0.038$ (stat.) $\pm$ 0.036 (syst.). A new evaluation of the Bjorken sum rule based on the COMPASS results for the non-singlet structure function $g_1^{NS}(x,Q^2)$ yields ratio of the axial to vector coupling constants $|g_A/g_V| = 1.22 \pm 0.05$ (stat.) $\pm$ 0.10 (syst.), which validates the sum rule with accuracy of about 9%.

One of the results published by COMPASS is the measurement of pion polarisability confirming prediction of the chiral theory of strong interaction. Chiral Perturbation Theory (ChPT) predicts the following values for charged pion values $\alpha_\pi = (2.9\pm0.5)\times10^{-4}$ fm^3 и $\beta_\pi = (-2.8\pm0.5)\times$10-4 fm^3 correspondinaly. From the analysed 63 000 events, the electric pion polarisability is determined to be $\alpha_\pi = (2.0 \pm 0.6$ stat ± 0.7 syst$) \times 10^{-4}$ fm^3 under the

assumption $\alpha_\pi = -\beta_\pi$ that links the electric and magnetic dipole polarisabilities. The values of these polarizabilities can be directly extracted from the data on differential sections of Compton scattering.

As a part of the proposal in 2017-2019, COMPASS-II will study generalized parton distributions (GPDs) using scattering of the polarized muons off the liquid-hydrogen target surrounded by a recoil detector (RPD) and new electro-magnetic calorimeter ECAL0.

The ECAL0 calorimeter, suggested and developed at JINR, is a unique device of the "shashlyk"-type (scintillator, lead), in which the most advanced photodetectors – Micro-pixel Avalanche Photo Diodes (MAPD) with ultra-high pixel density (up to 15 thousand pixels / mm2) were used, instead of the traditional photomultiplier tubes.

In March-April 2016 the ECAL0 was fully assembled, tested, installed in the COMPASS setup, and currently it is successfully used for data taking. The main features of the new calorimeter may be formulated as follows: ECAL0 effectively registers direct photons of from the DVSC and DVMP reactions in the wide energy range (0.2-40 GeV). Together with ECAL1 (Figure 1), ECAL0 effectively registers π^0, which can significantly reduce the photons background, which produced by π^0. These properties significantly expand the kinematic range measuring with minimal systematic uncertainties.

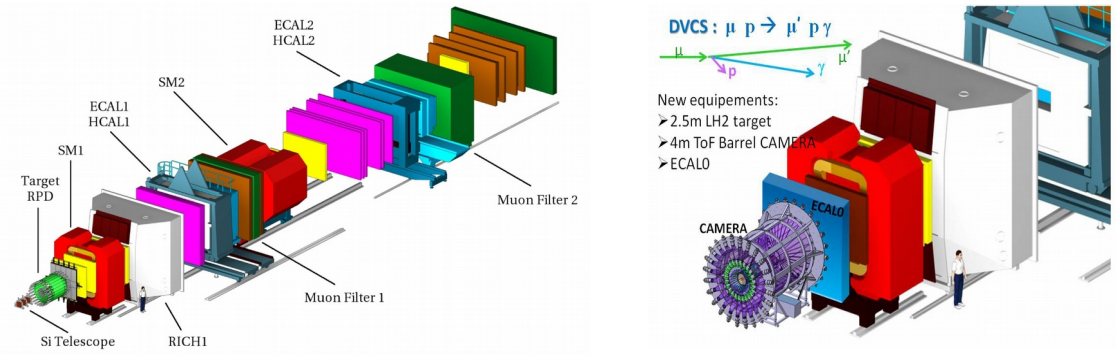

Figure 1: Experimental COMPASS setup (left) and the in front part of the spectrometer.

COMPASS collaboration highly appreciated stable work of the calorimeter. It is important to mention that groups from Russia, Germany (Munich), Poland (Warsaw) and Chech Republic (Prague) participated in the construction of ECAL0.

As another part of the COMPASS-II proposal, the Collaboraton performed studies of the nucleon structure of DY lepton pairs production by pions off at the polarized protons target to access transverse-momentum-dependent parton distributions and compare them with the same measured in SIDIS. Among the distributions to be studied are the Sivers, Boer-Mulders and "pretzelosity". The data taking on Drell-Yan program will be possibly be continued in 2018.

In 2016 the preparation of COMPASS-III proposal has been started. In March, the first workshop “COMPASS beyond 2020» took place at CERN. The goal of this workshop was to explore opportunities for fix-target COMPASS-like experiment at CERN beyond 2020. The scientific program comprises of reviews the various physics domains (TMDs, GPDs, spectroscopy, exotics, tests of ChPT, astrophysics), and reviews of the results expected in the next 10 years from labs around world. More then 100 physicists have participated in this workshop. The main outcomes of the workshop are as follows:

- Existing muon and hadron beam allows to extend current COMPASS program by doing unique measurements of exclusive processes using the muon (SIDIS) and pion (Drell-Yan) mechanisms of TMD PDFs studies;

- RF Separated antiproton/kaon beam, if available, would provide a unique opportunity for future fixed target COMPASS-like program at CERN.

The future GPD and DY programs require new recoil detector which is to be inserted in the COMPASS polarised target magnet. JINR group has started the preparation the R&D tests of such detector. This upgrade of the COMPASS polarised target allows to get access to GPD E via two processes to be measured with muon beam: DVCS ($\mu p \rightarrow \mu p \gamma$) and DVMP ($\mu p \rightarrow \mu \rho (\omega) \gamma$).

According to the COMPASS-II MoU, JINR is obligated to support of the HCAL1, MW1, and new electromagnetic calorimeter ECAL0. The MoU for COMPASS-II contains the following provisions:

- The COMPASS collaboration which is based on 1998 MoU and consists of the group of collaborating institutions from CERN Member and non-Member States as well as CERN, have proposed to expand the original program and carry out a set of measurements to study the structure of the nucleon structure in Deep Virtual Compton Scattering (DVCS), Hard Exclusive Meson Production (HEMP) and SIDIS and Polarized Drell-Yan as well as study of the hadron spectroscopy and Primakoff reactions.
- At the end of each year a provisional budget for the next year is established, based on the foreseen running costs and contingencies. It should to be approved by the FRC (Financial Resources Committie). To cover the running costs, maintenasnce and operation (M&O) fund, with contributions from all the Collaborating Institutions, is setup. The contribution to M&O, is due to by each Collaborating Institution for the following year. It is calculated “Per Capita” by July 1st according to the number of members carrying a financial contribution.

The main activities on data analysis in framework of COMPASS-II project will be focused on GPD and SIDIS analysis. The Drell-Yan and Primakoff studies mainly will be performed in the framework of new project proposed by LNP.

The MoU entered into force on January 1, 2013 and will be valid until December 31, 2017. Extensions of this MoU for three year without changes will be approved by the FRC basing on recommendations from SPSC (SPS and PS experiments Committie).

In 2017-2019 the COMPASS collaboration is going to plan to take the experimental data with muons (in 2017 and possibly in 2018) and with pions (possibly in 2018). The analysis of the experimental data will be continued and work on preparation of the proposal of the new physical program after 2020 is started. The detailed plan of works is presented below.

2017:
- Participation in COMPASS data taking ;
- Maintenance during running of MW1, HCAL1 and ECAL0 during running;
- Development/support of MW1/HCAL1/ECAL0 software;
- Analysis of COMPASS experimental data;
- Preparation of COMPASS-III project.

2018:
- Participation in COMPASS data taking;
- Maintenance of MW1, HCAL1 and ECAL0 during running;
- Development/support of MW1/HCAL1/ECAL0 software;
- Analysis of COMPASS experimental data;
- Preparation of COMPASS-III project.

2019:
- Analysis of COMPASS experimental data;
- Preparation of detectors for COMPASS-III project;
- Detector's upgrade for COMPASS-III.

The common JINR expenses on the project during a stage of 2014-2016 on the project (theme 1085) was equal to about $770 thousand. About $130 thousand have been allocated by CERN for support of experts from JINR at CERN in 2014-2016. The collaboration of NA58 allocates also 40 thousand Swiss francs per year for payment of the common works performed by JINR engineers in CERN during preparation and support of the experiment for a data taking. In last three years about $25 thousand were received from Czech Republic grants. Also funds from LHEP themes were spent for support Workshops in Suzdal (May 2015).

Expences form JINR badget for 2017 - 2019 equal to $852 thousand from the JINR budget. The main part of these expenses are required for participation of JINR physicists in data taking, for maintenance of detectors at JINR responsibility and also for payment of contributions to the common fund according to obligations from MoU. The resources that are necessary for realization this stage of the project (2017-2019) are given below.

TABLE: JINR FINANCE PROFILE FOR 2017-2019 (IN K$)

#	Item	Total	2017	2018	2019
1.	design bureau (man-h)	300	100	100	100
2.	workshops (man-h)	700	500	100	100
3.	Materials	**110**	**40**	**35**	**35**
4.	Equipment	**75**	**25**	**25**	**25**
5.	Subcontracts (collab common fund)	**222**	**72**	**75**	**75**
6.	Travels, including outside RUSSIA inside RUSSIA	 **420** **15**	 **150** **5**	 **150** **5**	 **120** **5**
	Total K$ (man-h)	**842** 1000	**292** 600	**290** 200	**260** 200

		Year											
№	Item	***2017***				***2018***				***2019***			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
1	Data taking												
2	ECAL0 maintenance												
3	Monitoring system and repair of ECAL0/HCAL1												
4	HCAL1 maintenance												
5	MW1 maintenance												
6	Low voltage system of MW1												
7	MW1/HCAL1/ECAL0 software												
8	Data analysis												
9	Detector remote control system												
10	COMPASS-II preparationI												
11	Detectpr's upgrade for COMPASS-III												