Annotation of the project

# Hadron physics in the COMPASS experiment

COMPASS is a modern fixed-target experiment at a secondary beam of the SPS accelerator at CERN. The purpose of this experiment is the study of hadron structure and hadron spectroscopy with muon and hadron beams of high intensity. The experiment has an intensive physics programme which includes the next topics:

- study of the nucleon spin structure (measurement of the spin-dependent parton distribution functions) in the deep inelastic scattering (DIS) and the Drell-Yan (DY) processes, measurement of generalized parton distributions in the reactions of deeply-virtual Compton scattering (DVCS) and deeply-virtual meson production (DVMP) (**not a part of this project**);
- test of the chiral theory predictions in Primakoff reactions with a pion beam;
- hadron spectroscopy: study of the hadron production mechanisms, search for exotic hadron states including multiquark states, glueballs and hybrids using pion, proton and muon beams;
- nuclear modification of the nucleon structure (EMC-effect).

At the moment the second phase of the COMPASS experiment, approved at CERN for the period 2012-2018, is under realization.

The COMPASS setup is a universal spectrometer based on two spectrometric magnets. It can be notionally divided into three parts along the beam axis: the beam part, responsible for the reconstruction and identification of beam particles, the Large Angle Spectrometer (LAS) and the Small Angle Spectrometer (SAS). Each of the spectrometers includes in addition to tracking detectors, electromagnetic and hadron calorimeters and a muon identification system. The LAS aslo includes a Ring Image Cherenkov detector (RICH) which provides identification of secondary hadrons. The third electromagnetic calorimeter ECAL0 was introduced in 2016 and is situated just downstream the target.

Different targets have been used in the different physics programmes: polarized $^6$LiD, $NH_3$ (DIS, DY), liquid hydrogen (DVCS, hadron spectroscopy) and nuclear targets, such as C, Ni, Pb, W (hadron spectroscopy, Primakoff reactions), surrounded by proton recoil detector. In addition, the tungsten absorber used in the Drell-Yan programme can be treated as an additional target for study of the EMC-effect. Positive (160 GeV/c and 200 GeV/c) and negative (190 GeV/c) muon beams and hadron beams of 190 GeV/c, positive (~75% of protons, ~24% of pions) and negative (~97% of pions and ~2% of kaons) have been used for the different physics programmes. The large set of the "beam-target" combinations provides unique possibility to solve a wide class of problems related to the properties of hadrons, hadronic interactions and hadron spectroscopy. Information about main data samples collected in 2002-2016 is presented in table below.

| Year | Target | Beam particle | Beam momentum, GeV/c |
|---|---|---|---|
| 2002 | $^{6}$LiD | $\mu^+$ | 160 |
| 2003 | $^{6}$LiD | $\mu^+$ | 160 |
| 2004 | $^{6}$LiD | $\mu^+$ | 160 |
| 2006 | $^{6}$LiD | $\mu^+$ | 160 |
| 2007 | $NH_3$ | $\mu^+$ | 160 |
| 2008 | Liquid $H_2$ | $\pi^-$, $K^-$ | 190 |
| 2009 | Liquid $H_2$, Ni, W, Pb | $\pi^-$, $K^-$, $\mu^-$ | 190 |
| 2010 | $NH_3$ | $\mu^+$ | 160 |
| 2011 | $NH_3$ | $\mu^+$ | 200 |
| 2012 | Ni, C, W, Pb | $\pi^-$, $K^-$, $\mu^-$ | 190 |
| 2014 | $NH_3$, W, Al | $\pi^-$ | 190 |
| 2015 | $NH_3$, W, Al | $\pi^-$ | 190 |
| 2016 | Liquid $H_2$ | $\mu^\pm$ | 160 |
| 2017 | Liquid $H_2$ | $\mu^\pm$ | 160 (planned) |

## JINR group plans for 2017-2019

The first priority for the JINR group participating in the COMPASS experiment within this project in 2017-2019 is analysis of physics data collected in 2002-2018, participation in preparation of the physics program with a hadron beam for the next stage of the experiment (2020+) and preparation of the proposal for the coresponding upgrade of the COMPASS setup.

1) **Precise measurement of electric and magnetic polarizabilities of the charged pion**

In 2015 the COMPASS collaboration published the result for the measurement of the charged pion polarizabilities $\alpha_\pi$ and $\beta_\pi$ extracted under the assumption $\alpha_\pi+\beta_\pi=0$ based on the analysis of 2009 data. At the moment the obtained result is the most precise dedicated measurement of this quantity. Analysis of the experimental data collected in 2012 will provide possibility to increase the accuracy of such kind of measurements and decrease both the statistical and the systematic uncertainties. In addition, larger statistics for the reaction $\pi Z \rightarrow \pi Z \gamma$ and an extended kinematic range will help us to perform independent measurements of $\alpha_\pi$ and $\beta_\pi$. Contamination of kaons in the hadron beam provides possibility to perform the first observation of the Compton scattering of a virtual photon off a charged kaon $K Z \rightarrow K Z \gamma$ and the first measurement of the kaon polarizabilities. The results for the pion and kaon polarizabilities are fundamentally important as a crucial test of the prediction power of the lowenergetic phenomenological QCD models such as the Chiral Perturbation Theory (ChPT).

### 2) Measurement of the constant $F_{3\pi}$ for the reaction $\pi Z \rightarrow \pi Z \pi^0$

The constant $F_{3\pi}$ of the reaction $\pi Z \rightarrow \pi Z \pi^0$, as well as the constant of the neutral pion decay is related to the hypothesis of the chiral anomaly. A precise measurement of this value can be the test of the chiral theory (ChPT) prediction. The accuracy of the measurements performed more than 30 years ago in the experiments FRAMM (CERN) and SIGMA (Protvino), at the moment is not good enough for such tests. The statistics for this reaction collected at COMPASS in 2009 and 2012 is more than one order of magnitude larger than the statistics of the previous experiments. Moreover, the new methods, proposed recently, give possibility to use for determination of the constant not only the data near the threshold but aslo the data in the mass range of the $\pi^-\pi^0$ system corresponding to the production and decay of the ρ-meson. Large statistics for the similar process $\pi Z \rightarrow \pi Z \eta$ gives opportunity to improve the result for the constant $F_{\pi\pi\eta}$, measured for the first time in the VES experiment in Protvino.

Measurement of the cross section dynamics for the Primakoff reactions with a larger number of charged and neutral pions in the final state is also interesting for the chiral theory.

The expected results are important for all phenomenological models of QCD in the low energy region.

### 3) Search and study of exclusive lepto(photo)production of exotic charmonia

More than ten charmonium-like states with mass above 3.8 GeV were discovered during the last 15 years but their nature is still unknown. Several interpretations of such states do exist: tetraquarks, mesonic molecules etc. Till the moment all of them are observed either in decays of heavier particles, in e+e− annihilation or produced inclusively in hadronic interactions. Huge statistics for muon-nucleon scattering collected by COMPASS provides possibility to study the exclusive lepto(photo)production of such particles, that could be an important source of the information about their nature. The JINR group is the initiator of such kind of studies. In 2015 the COMPASS collaboration published the result for search for exclusive photoproduction of the charged hadron $Z_c(3900)$. At the moment the exclusive photoproduction of the charmonium-like state X(3872) is under investigation. The study of photoproduction of heavier charged and neutral XYZ states is planned for the future. It is worth to mention the potential possibility to search for the exclusive photoproduction of the pentaquarks $P_c^+$, discovered by the LHCb collaboration in 2015, in the reaction $\mu p \rightarrow \mu P_c^+ \rightarrow \mu p J/\psi$ (s-channel).

### 4) Observation of the EMC-effect in the Drell-Yan process

The dependence of the parton distribution functions of the nucleon on the atomic number of the nucleus containing the nucleon, so-called the EMC-effect, is well-studied in the reaction of the deep inelastic scattering. Nevertheless, the origin of the effect is still not fully understood. The peculiarity of the EMC-effect in the negative pion-induced Drell-Yan process is that the dominating contribution is made by the parton distribution for u-quark while for the deep inelastic scattering the contributions of u- and d- quarks are comparable. The EMC-effect in the production of the J/ψ-meson is also interesting since in this case not only the process q qbar $\rightarrow J/\phi$ but also the process gg $\rightarrow J/\phi$ contributes. In this way indirect information about nuclear modification of the gluon distributions in the nucleon could be obtained.

Since COMPASS has the world's largest statistics of DY-events among the fixed-target experiments, the measurements mentioned above are unique.

**5) Preparation of the proposals for the new physics program and modification of the setup for the next phase of the experiment.**

At the moment the COMPASS collaboration discuss actively the physics program of the experiment for the period after 2020 and possible related modifications of the setup. Possibility to use RF-separated kaon and antiproton beams is under consideration. Study of kaon-induced Primakoff reactions could become an important step to test phenomenological QCD models in the low energy region.

The system of three electromagnetic calorimeters provides a unique possibility to study rare processes with photons in the final state such as production of prompt photons. Study of the prompt photon production with hadron beams could provide an important information about the gluon structure of nucleons, pions and kaons (for kaons such experimental information is almost absent).

In the course of this project our proposals for the future physics program of the experiment will be presented to the collaboration.

Expected modification of the COMPASS setup could be related both with installation of new detectors and with an upgrade of the existing systems. The coordinate detectors, produced at JINR, based on the mini drift tubes (MDT) which operate in the muon identification system MW1 have spent a major part of their resource. For operation within the possible future COMPASS program they should be upgraded. They could also be replaced by new detectors of another type (RPC, Micromegas, GEMs etc.).

Within this project the required R&D will be performed and suggestions concerning modification of the corresponding subsystems of the COMPASS setup will be presented.