

Referee report on the NA61/SHINE project (JINR participation)

The presented project is a continuation of the successful participation of a group of employees of the Veksler and Baldin Laboratory of High Energy Physics and the Dzhelepov Laboratory of Nuclear Problems of JINR in the NA61/SHINE experiment at the CERN Super Proton Synchrotron (SPS).

NA61/SHINE is a multi-purpose spectrometer to study the hadron-proton, hadron-nuclear and nuclear-nuclear collisions. The wide momentum range of the beam particles, from pions to lead nuclei, together with the high acceptance and high resolutions of the NA61/SHINE detector provides a unique opportunity to perform the necessary measurements. The experimental program includes the tasks of searching for a hypothetical critical point in the phase diagram of nuclear matter, studying the properties of the onset of deconfinement and the formation of the open charm. Precise measurements of the processes necessary for experiments with cosmic rays and neutrinos are also carried out.

The data analysis will continue in the following directions:

- formation of light nuclei during nuclear interactions;
- production of hyperons in Be+Be, Ar+Sc, Xe+La, Pb+Pb interactions;
- formation of antimatter in nuclear-nuclear interactions;
- open and hidden charm production in heavy ion interaction.

In addition, the joint modeling work is underway for the NICA and NA61/SHINE projects, based on experimental data obtained in the NA61/SHINE experiment.

The NA61/SHINE collaboration has done a lot of work to modernize the setup in 2019-2022. JINR group members, within the framework of the collaboration, have fulfilled obligations both for physical data analysis and simulation to implement the NA61/SHINE setup upgrade program, namely, to develop and install a new time-of-flight system based on MRPC detectors. The installed left arm of the ToF was fully integrated into the setup and successfully worked during the data runs in 2023. The right shoulder of the ToF is expected to be installed in 2024, which will cover the entire acceptance of the set-up.

The project provides an overview of the program of physical research on relativistic interactions of nuclei and describes the unique experimental results obtained over the past three years with the active participation of JINR staff in the NA61/SHINE project. The work plans for the experiment for the period of 2025-2029 are also given.

It is necessary to analyze a huge amount of collected data and ensure the operation of the upgraded setup on SPS beams.

The experiment provides a comprehensive and consistent study of hadron interactions, starting with elementary nucleon-nucleon processes and ending with collisions of heavy ions with different atomic numbers and beam energies (20 AGeV-158 AGeV).

The project participants are co-authors of numerous publications and presentations on this topic, which are widely cited in the world literature.

JINR physicists have also performed original research using the approach to study relativistic nuclear interactions in the four-dimensional velocity space, which was previously proposed by Academician A.M. Baldin. The introduction of the similarity parameter proved to be very fruitful in the study of nuclear interactions at high energies. The modified approach has been successfully applied to describe the inclusive spectra of generated pions and kaons in the central region of rapidity in pp and AA interactions. The essence of the modification of this approach is to include quark-gluon dynamics in the generation of hadrons in the nucleon-nucleon interaction in the central region of velocities ($y = 0$). The calculations have shown a fairly successful description of the ratio of the yields of kaons and pions in a wide range of initial energies, up to the LHC energies.

Further participation in the NA61/SHINE experiment will allow physicists to continue the systematic study of nuclear interactions from light nuclei till the heavy ones, including

medium-sized nuclei. For this program, the research at the NA6/SHINE facility is extremely valuable and still out of competition due to the unique installation parameters and the presence of nuclear beams at the SPS at CERN. In particular, after the upgrade, the data taking run speed was increased by about 15 times.

It is important to emphasize that the beam momentum range provided by SPS for NA61/SHINE is very important for heavy ion, neutrino and cosmic ray communities. The efforts are being made worldwide to construct new installations providing ion and hadron beams in the momentum range of the CERN SPS beam. These are fixed-target setups at FAIR, Germany, as well as the NICA collider installation, Russia. They will start working after the main results of the project are received, which are extremely necessary for planning future experiments.

JINR group's participation in the NA61/SHINE experiment is necessary as part of training young specialists for the NICA project. Several doctoral dissertations have already been defended in physics close to the NICA program within the framework of the NA61/SHINE project. In the near future, it is planned to prepare two PhD and doctoral dissertations using the results of the NA61/SHINE experiment and modeling for the NICA project. Experienced employees who have defended their doctoral and PhD theses based on the results of the NA61 experiment are currently successfully working on the NICA project.

Financial requests are fully justified in order to obtain significant physical results, which will become a significant contribution to the JINR research program. It should be emphasized that JINR's participation in the NA61/SHINE experiment is very important, since the research program of this experiment lies in the main stream of the long-term program in the field of relativistic nuclear physics at JINR. It complements the research conducted at the Nuclotron (JINR), RHIC (BNL), and the experimental results obtained are necessary for planning research at the NICA accelerator complex. The unique experience of working in the international collaboration will allow its participants to apply their acquired skills in the implementation of the NICA megaproject at JINR.

Thus, the participation of the JINR group in the analysis of the experimental data of the NA61/SHINE project and in new measurements at this facility is fruitful and its extension for the next 5 years should be recommended with the first priority.

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15.03.2024