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

The experiment NA61/SHINE at the CERN SPS accelerator (**S**PS **H**eavy **I**on and **N**eutrino **E**xperiment) received its name due to the dual experimental program.

The research program devoted to strong interactions in NA61/SHINE is based on scanning with beams of light and intermediate nuclei (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La, Pb+Pb) with energies in a range of 13A – 158A GeV.

Note that it is this energy range that corresponds to the transition energy region to be studied at the constructed JINR accelerator complex NICA.

Precise measurements of the processes necessary for experiments with cosmic rays and neutrinos are performed in the framework of this experiment. During many years, the NA61/SHINE collaboration has been pursuing the program of hadron production measurements for experiments with neutrino oscillations with long base at J-PARC and Fermilab. These measurements contribute to our knowledge of neutrino flux formed with accelerated particle beams. NA61/SHINE is also engaged in measurement of hadron production required for interpretation of data on extensive atmospheric showers at ultrahigh energies, as well as measurement of cross sections of production and fragmentation for understanding the data on galactic cosmic rays.

It should specially be noted that NA61/SHINE is the only world facility for investigations in the field of relativistic nuclear physics in the abovementioned energy range that possesses the set of detectors (TPC+TOF) ensuring precision measurement of angular and energy characteristics of secondary particles in the conditions of their identification.

The JINR research group has been actively participating in the creation of the detector base for NA61/SHINE for a long time. The NA61/SHINE collaboration performed an extensive work on the facility upgrade 2019-2022. The engineers and physicists of the Laboratory of High Energy Physics created a new time-of-flight registration system based on MRPC detectors, which is the key detector for charged particle identification. The system consists of two walls. The first wall has already been installed in the facility and demonstrated reliable operation in the accelerator runs during 2023. At present, the second wall of the detector is being installed and put in operation. The new system ensures a substantially better time resolution (50 ps) than the previous one based on scintillation counters (70 ps).

A large amount of experimental data on p+p, Be+Be, Ar+Sc, Xe+La, and Pb+Pb collisions was acquired by the NA61/SHINE collaboration in 2009-2018 in the framework of the accepted research program. After the upgrade the data acquisition rate increased substantially (by approximately a factor of 15).

Measurements of observable variables sensitive to the considered effects in nucleus-nucleus collisions should be performed upon scanning the phase diagram. Such observables are the multiplicity of charged particles, their transverse momenta, and spectral characteristics of secondary hadrons, including strange baryons and antibaryons.

Initially, the research program of the NA61/SHINE experiment included measurements of the yields of charged particles in p+p collisions and central collisions of ^{7}Be + ^{9}Be, Ar+ Sc,p+ Pb, and Xe + La nuclei at momenta of 13, 19, 30, 40, 75, 150/158 AGeV/c per nucleon. Then the research program of NA61/SHINE was extended. Now it includes the investigation of collective flows in nucleus-nucleus collisions in the same energy range, as well as investigation of hyperon and hyper-nuclei production. Hyper-nuclei are unique objects which can serve for enhancement of our knowledge on interaction of strange particles with nuclei in a multiparticle medium under the controllable conditions.

The program on investigation of charmed particle production in collisions of relativistic heavy ions is also very important. Some researchers assume that the specific feature of charmed particle production in collisions of heavy ions may serve as an indication of QGP formation, in

particular, this is related to suppression of J/ψ-meson yield. Such data are lacking yet, and it is planned to perform such analysis in the framework of the NA61/SHINE experiment.

It should be underlined that the experimental results inspired certain theoretical studies, especially those on the proof of the beginning of deconfinement at SPS at a decreased energy. It is planned to continue these studies. Moreover, this activity stimulated the measurements at low energies in the experiments STAR and PHENIX at RHIC (Brookhaven National Laboratory, USA) and implementation of first-priority projects in the framework of the NICA/MPD scientific program at JINR and CBM at GSI.

The JINR researchers made a substantial contribution in the measurement and analysis of the processes of light nuclei production. This part of the experiment was completely carried out by the LHEP team, starting from data acquisition, to data analysis, and publication of obtained physical results. The collaboration in the framework of NA61/SHINE is extremely efficient and fruitful for both organizations: CERN and JINR. Several PhD and Dr.Sci. Theses were defended based on the results obtained in the NA49/NA61SHINE experiment.

The extension of this collaboration will contribute to deeper understanding of the properties of nuclear matter at relativistic energies. The analysis of experimental data acquired at NA61/SHINE is definitely extremely valuable for preparation of experiments at the JINR accelerator complex NICA. The participation of JINR in the NA61/SHINE experiment is also of great importance for training JINR young scientists for the upcoming research within the NICA project, the physical program of this project containing the tasks close to those addressed at NA61/SHINE. The experience of the JINR group in design, development, and maintenance of various detectors for SPS accelerated ion beams at CERN and their participation in processing and analysis of experimental data cannot be overestimated for further relativistic nuclear physics research at JINR.

It follows from the above said that the participation of the JINR group in the NA61 experiment is undoubtedly fruitful. The required finances are completely justified by the excellent physical results serving to the benefit of high scientific reputation of our institute. I believe that the anticipated results will certainly be considered a substantial contribution to the development of the long-term research programs in the field of relativistic heavy ion physics at JINR. I recommend to approve extension of the JINR participation in the experiment NA61 in 2025-2029 with the first priority in the framework of the requested funding.

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