NA61/SHINE plans beyond the approved program

By the NA61 Collaboration
http://na61.web.cern.ch

Abstract

This document reports on plans of the NA61/SHINE experiment at the CERN SPS beyond the approved and currently performed measurements within the ion, neutrino and cosmic-ray programs.

In particular, data taking on Pb+Pb collisions and for the Fermilab and CERN neutrino experiments is proposed as an important extension of the ion and neutrino programs.
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1 Introduction

This document briefly presents plans of the NA61/SHINE Collaboration beyond the approved and currently executed program of measurements. First, a possible extension of the NA61/SHINE ion program is discussed by measurements of Pb+Pb collisions. Second, data taking for the Fermilab and CERN neutrino experiments is suggested.

The NA61/SHINE (SPS Heavy Ion and Neutrino Experiment) experiment [1] at the CERN Super Proton Synchrotron (SPS) is pursuing a rich physics program in various fields: from precise hadron production measurements for the T2K long-baseline neutrino oscillation experiment [2] and more reliable simulations of cosmic-ray air showers for the Pierre Auger and KASCADE experiments [3, 4], to the study of the properties of the onset of deconfinement [5] and search for the critical point of strongly interacting matter with measurements of p+p, p+Pb and nucleus+nucleus collisions at the SPS energies.

The NA61 detector consists of a large acceptance hadron spectrometer with excellent capabilities in charged particle momentum measurements and identification by a set of five Time Projection Chambers as well as Time-of-Flight detectors. The high resolution forward calorimeter, the Projectile Spectator Detector, measures energy flow around the beam direction. An array of beam detectors identifies beam particles, secondary hadrons and ions as well as primary ions, and measures precisely their trajectories. NA61 greatly profits from the long development of the CERN particle sources and the accelerator chain as well as the H2 beam line of the CERN North Area. The latter has recently been modified to also serve as a fragment separator as needed to produce the Be beam for NA61. Numerous components of the NA61/SHINE set-up were inherited from its predecessors, in particular, the last one, the NA49 experiment.

This document briefly presents plans of the NA61/SHINE Collaboration beyond the approved and currently executed program of measurements. First, a possible extension of the NA61/SHINE ion program by measurements of Pb+Pb collisions is discussed. Second, further data taking for particle production measurements required by the Fermilab and CERN neutrino experiments are proposed.

2 Possible extension of the NA61/SHINE ion program

Since 2009 NA61/SHINE performs a comprehensive scan in two dimensional parameter space: size of colliding nuclei (p+p, p+Pb, Be+Be, Ar+Ca, Xe+La) versus collision energy (13A, 20A, 30A, 40A, 80A, 158A GeV/c). In the program both secondary (p, Be) and primary beams (Ar, Xe) are used. This assures compatibility with the LHC schedule. The energy scan with p+p interactions is completed and the scan with Be+Be collisions will be completed in 2012. The energy scans with Ar+Ca and Xe+La collisions are planned to be performed in 2014 and 2015, respectively. A detailed data taking schedule is presented in Fig. 1.
Figure 1: The NA61/SHINE data taking schedule for the ion program and its proposed extension for the period 2016-2019 (in red).

The main goals of this program [1] are:

1. study of the properties of the onset of deconfinement, and, in particular establishing the system size dependence of its signals and

2. search for the critical point of strongly interacting matter by study of the system size and collision energy dependence of hadron fluctuations and correlations.

The second goal has the potential for an important discovery – the experimental observation of the critical point of strongly interacting matter.

The NA61/SHINE ion program was motivated by the NA49 discovery of the onset of deconfinement [6] which was based on data from central Pb+Pb collisions at 20A, 30A, 40A, 80A, 158A GeV/c. Recently the NA49 results and their interpretation were confirmed [7] by data from the RHIC Beam Energy Scan (BES) Program and the LHC Ion Program, respectively. These data serve as an excellent basic reference for the NA61/SHINE results on collisions of lighter nuclei. However, the typical event statistics per reaction recorded by NA49 was only about 4·10^5. The RHIC BES data suffer from a limited acceptance in
rapidity and transverse momentum as well as from the impossibility of an unbiased selection of central events. Data below 30\(A\) GeV/c could not be registered due to insufficient quality of the Au beam. In conclusion, it is now evident that the NA61/SHINE measurements should also include Pb+Pb collisions.

First, a detailed energy scan with Pb+Pb collisions, namely, data taking at 13\(A\), 20\(A\), 30\(A\), 40\(A\), 80\(A\), 158\(A\) GeV/c, should be performed in 2016. Within a single data taking period (42 days) data at all energies can be recorded with a typical event statistics of about 10 times the one of the NA49 data. This, together with the important detector upgrades, will allow to significantly decrease statistical and systematic uncertainties of results on Pb+Pb collisions by replacing the NA49 by new NA61/SHINE measurements. This in turn will allow to reach significantly higher precision in establishing the system size dependence of hadron production properties, which is relevant for both the search for the critical point and the study of the onset of deconfinement. Study of particle fluctuations and long–range correlations will profit from the new data significantly because of a high precision centrality determination and low background reached thanks to the Projectile Spectator Detector and the He beam pipes. Moreover, measurements at 13\(A\) GeV/c and for minimum bias collisions (with exception of 40\(A\) and 158\(A\) GeV/c) were not performed by NA49 and should be completed by NA61/SHINE.

Figure 2: The combinatorial invariant mass spectra of kaon and pion pairs (black line) in the NA61 acceptance before (left) and after (right) applying background rejection cuts. The magenta histograms show the component of \(D^0 + \overline{D^0}\) signal. The simulation was performed for central Pb+Pb collisions at 158\(A\) GeV/c.

Second, high statistics measurements of Pb+Pb collisions at three energies are necessary to establish the energy dependence of rare processes, in particular, production of D mesons and multi–strange hyperons. Moreover, these data will allow to extend transverse momentum spectra of identified hadrons from about 4.5 GeV/c [8] up to about 7 GeV/c. D meson production in heavy ion collisions has not been measured in the SPS energy
range. Relevance of these measurements for physics is discussed in detail in Ref. [9]. Only sparse results on spectra of multi–strange hyperons in Pb+Pb collisions are available [10].

For open charm measurements an upgrade of the NA61/SHINE facility by adding a vertex detector is necessary. The upgrade will also significantly improve the performance for measurements of multi–strange hyperons. Figure 2 illustrates results of a simulation performed for future NA61/SHINE measurements of $D^0$ and $\bar{D}^0$ meson production. The plots show invariant mass spectra of kaon and pion pairs in the NA61 acceptance before (left) and after (right) background rejection cuts which are essentially based on the information from the new vertex detector. The presented simulation results were obtained for 100k central Pb+Pb collisions at 158A GeV/c assuming a yield of $D^0$ and $\bar{D}^0$ mesons as predicted by the HSD model [9]. A vertex detector consisting of 3 planes of pixel detectors with a single point resolution of 10 \( \mu \)m positioned at 5, 10 and 15 cm from the Pb target was assumed in the simulation. In a 60 day-long data taking period NA61 can register up to 50M events which would result in 48k $D^0$ and $\bar{D}^0$ mesons reconstructed with a signal to background ratio of about 4.5 and signal significance of about 200 standard deviations.

The proposed high statistics measurements of Pb+Pb collisions at 20A, 40A and 158A GeV/c could be performed in the period 2017-2019, see Fig. 1 for details. The physics test of the vertex detector would then have to be scheduled in 2016.

![Figure 3: Global plans for data taking on high energy nucleus–nucleus collisions. In near future NA61/SHINE may remain the only large acceptance hadron spectrometer at the non–LHC energies.](image-url)

In parallel to the extension of the NA61/SHINE program to Pb+Pb collisions a new dedicated experiment on the energy dependence of di–lepton production in Pb+Pb col-
collisions could be constructed and executed (by another collaboration). This experiment should establish the energy dependence of $J/\psi$ meson production and the in-medium modification of vector meson properties. Both require long data-taking periods at several SPS energies.

Recently Au+Au collisions at SPS energies were also studied at RHIC. The considered upgrade of RHIC to electron-ion interactions is expected to stop data taking on nucleus-nucleus collisions within a few years. The SIS-100 accelerator at the FAIR facility is planned to be constructed by 2018. Its maximum energy is about 10.4 GeV, significantly below the energy of the onset of deconfinement and below the energy domain in which the critical point should be searched for. The planned NICA ion collider at the JINR Dubna will not start operation before 2017. Its maximum energy converted to the fixed target equivalent is about 80.4 GeV. Measurements in the collider mode at NICA would provide important results complementary to the measurements at the SPS. The present world plans for data taking on high energy nucleus-nucleus collisions are summarized in Fig. 3.

3 Possible extension of the NA61/SHINE neutrino program

It is now widely recognized that hadron production experiments have already significantly contributed to recent advances in neutrino physics. Moreover, hadroproduction studies are crucial for future precision neutrino experiments. There is no doubt that the NA61/SHINE set-up is currently the best experimental facility in the world for such hadron production measurements at SPS energies.

NA61/SHINE has already performed measurements for the T2K neutrino oscillation experiment at J-PARC. First results on charged pion and kaon spectra in $p+C$ interactions at 31 GeV/c were published [11, 12, 13]. These data are of significant importance for a precise prediction of the J-PARC neutrino beam and have already been used for the first analysis of the T2K data [14, 15, 16].

An order of magnitude larger event samples for T2K were already collected during the 2009 and 2010 NA61/SHINE runs with both thin (4% of a nuclear interaction length) and replica targets. After full analysis of these data the required precision of 5% on the absolute neutrino flux predictions in the near and far detectors should be achieved. An even higher precision is needed for future accelerator neutrino experiments.

We are currently studying the possibility to use the existing NA61/SHINE set-up (eventually after minor upgrades) for hadroproduction studies required for the future long baseline neutrino oscillation experiment in Europe, LAGUNA-LBNO [17]. The aim is to achieve the best possible precision on prediction of un–oscillated neutrino fluxes. Preliminary acceptance studies for charged particles produced in $p+C$ interactions at 400 GeV/c are presented in Fig. 4. In the maximum magnetic field configuration of 9 Tm the detector provides a good coverage of the $\{p, \theta\}$ phase space of interest for the LBNO project.
Figure 4: Top: NA61/SHINE acceptance in laboratory momentum, $p$, polar angle, $\theta$, for different track topologies, so-called right-side tracks (RST) and wrong-side tracks (WST). Bottom: $\{p, \theta\}$ distributions of positively charged pions weighted by the probability that their decay produces a neutrino passing through the LBNO far detector. The distributions are given for the target placed at the nominal position (left) and 70 cm inside the first focusing horn (right).

Furthermore the NA61/SHINE experiment is expected to benefit the upcoming accelerator neutrino programs based in the United States. Over a period of 4–5 years, the plan is to perform measurements of hadron yields with proton beam momenta ranging from 9 GeV/c to 120 GeV/c on a number of target materials. The data would be relevant for MINERvA [18], MINOS, MINOS+ [19], NOvA [20] and the future Long Baseline Neutrino Experiment (LBNE) [21]. A number of US based institutes are in the process of joining the NA61/SHINE collaboration. Dedicated measurements in p+C interactions at 120 GeV/c are expected to take place this summer as an initial phase.

Acknowledgements: This work was supported by the Hungarian Scientific Research Fund (grants OTKA 68506 and 71989), the Polish Ministry of Science and Higher Education (grants 667/N-CERN/2010/0 and N N202 484339), the Federal Agency of Education of
the Ministry of Education and Science of the Russian Federation (grant RNP 2.2.2.2.1547), the Russian Academy of Science and the Russian Foundation for Basic Research (grants 08-02-00018 and 09-02-00664), the Ministry of Education, Culture, Sports, Science and Technology, Japan, Grant-in-Aid for Scientific Research (grants 18071005, 19034011, 19740162, 20740160 and 20039012), the German Research Foundation (grant GA 1480/2-1), Bulgarian National Scientific Foundation (grant DENVU 02/19/2010), Ministry of Education and Science of the Republic of Serbia (grant OI171002), Swiss Nationalfonds Foundation (grant 200020-117913/1) and ETH Research Grant TH-01 07-3.

References


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