The physics program of the NA60+ experiment

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Abstract.
The NA60+ experiment, which has been proposed as a fixed target experiment at the CERN SPS, is designed to study the phase diagram of the strongly interacting matter at high baryochemical potential by performing precision studies of thermal dimuons, heavy quark and strangeness production in Pb-Pb collisions at center-of-mass energies ranging from 5 to 17 GeV. The progress of the R&D and the key points of the NA60+ physics program will be described.

1 Introduction

One of the key points in the understanding of the QCD under extreme conditions is the exploration of its phase diagram. Lattice QCD calculations predict a cross-over transition from the hadronic matter to the Quark-Gluon Plasma (QGP) at vanishing baryochemical potential μ_B around a critical temperature $T_c \approx 155$ MeV, while at large μ_B values a first order phase transition is expected. A strong experimental program is being carried out since two decades at the CERN-SPS, BNL-RHIC and CERN-LHC at top energies to characterize the region around $\mu_B \sim 0$, showing that a deconfined state of matter is formed, with properties consistent to the predictions from lattice QCD. More recently, interest in the experimental study of the large μ_B region increased. The search of a critical point in the phase diagram, the order of the phase transition and of the properties of the medium at large μ_B, the chiral symmetry restoration effects and the temperature at which the onset of the deconfinement takes place constitute fundamental issues in the understanding of the phase diagram properties.

The target of the NA60+ experiment is to study electromagnetic and hard probes in the range $200 < \mu_B < 400$ MeV via an energy scan at the SPS in the range $6 < \sqrt{s} < 17$ GeV. Electromagnetic probes, and in particular dileptons, will allow to determine the temperature of the system via a measurement of the thermal dimuon mass spectrum. Also chiral symmetry restoration effects related to the modification spectral function of the ρ and its chiral partner a_1 can be investigated. Hard probes bring information on the onset of deconfinement via the measurement of J/ψ suppression versus CM energy, while the production of open charm hadrons can provide information on the transport properties of the QGP.

2 The experimental apparatus

The detector concept of NA60+ is based on the design of NA60. The layout of the experiment is shown in figure 1. The two main components of the apparatus are a muon spectrometer

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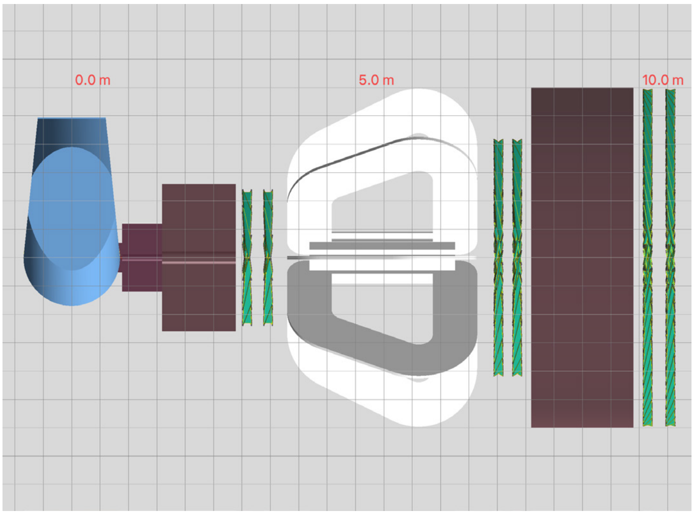

Figure 1. Conceptual design of the NA60+ experimental apparatus. The figure represents the set-up adapted to low-energy collisions, with a thinner hadron absorber and the muon spectrometer relatively closer to the target.

(MS) and a vertex spectrometer (VS), separated by a thick hadron absorber made of BeO and graphite, which acts as a muon filter.

The MS is composed of a set of six tracking stations (plotted as green boxes in the figure) and a large aperture toroidal magnet. Two tracking stations are located upstream the magnet, which is followed by two other tracking stations. A thick graphite wall (brown rectangle in the figure) filters out possible residual hadrons. Finally, a set of two more tracking stations is placed downstream of the graphite wall. The relatively low rates after the hadron absorber, $\sim$ 2 kHz for a Pb beam rate of 10^{-6} s^{-1}, allows to adopt the GEM or MWPC technologies for the tracking stations. A prototype of trapezoidal MWPC is currently being constructed and will be tested at the CERN SPS in autumn 2022. The prototype detector constitutes a module that would be replicated several times and arranged in such a way to cover the designed geometry in each tracking station. As an alternative option, triple GEM modules will also be studied. The toroidal magnet, which is being designed for NA60+, is foreseen to provide a magnetic field of 0.5 T over a volume of 120 m^3. A small-scale prototype (1:5) was constructed and tested. The simulations of the magnetic field were found to be in agreement with the results of the tests within 3%.

The MS can be moved on rails, to cover the midrapidity region at different collision energies. At top SPS energies, the absorber thickness will be increased.

The hadron absorber, while providing muon identification, deteriorates the muon momentum resolution, due to multiple scattering and fluctuations in the energy loss. This loss in resolution is recovered by matching the tracks measured in the MS with those reconstructed in the VS, both in coordinates and momentum space.

The VS (figure 2) consists of a set of five to ten planes of ultra-thin, large area Monolithic Active Pixel Sensors (MAPS) for tracking, embedded in the gap of a dipole magnet. MAPS sensors are composed of 25 mm long units, which are replicated through a stitching technique to cover an area of 15×15 cm^2. Each plane contains four MAPS sensors. The sensor thickness is of about 0.1% X_0, reducing the effect of multiple scattering in the VS. The spatial resolution is expected to be 5 μm or better, with an improvement of a factor of two with respect to the hybrid technology. The magnet considered for the VS is the CERN MEP48 dipole, that provides a field up to $B = 1.47$ T.

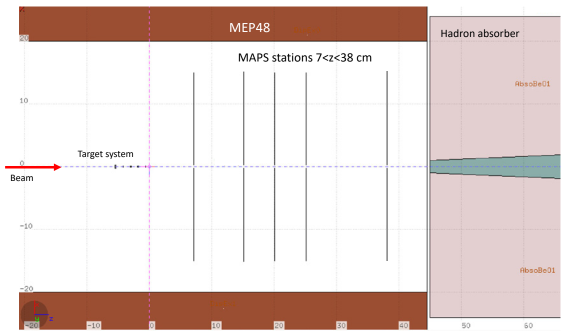

Figure 2. Schematic layout of the silicon planes inside MEP48.

3 Physics performances

The physics performances of NA60+ were studied executing fast simulations of the signals with semi-analytical tracking based on the Kalman filter, while the simulation of the background was performed with FLUKA. The obtained opposite sign dimuon mass spectrum is shown in figure 3 (left). The combinatorial background and the fake matches contribution can be evaluated using event mixing techniques and subtracted to the opposite sign mass spectrum. The signal mass spectrum resulting after background subtraction is dominated by the hadronic cocktail for $M < 1.5$ GeV/c^2. In this region, a precision measurement of the ρ spectral function can be performed, complementing the NA60 measurement in In-In at top SPS energy with results at lower energy.

In the region $1 < M < 1.5$ GeV/c^2, a dimuon enhancement due to the chiral mixing between the ρ and its chiral partner a_1 via 4π states can be observed [1]. With the foreseen accuracy of the measurement, a 20-30% enhancement, expected in case of full mixing, can be detected by NA60+.

A study of the thermal dimuon mass spectrum can be performed for $M > 2$ GeV/c^2. A fit with the form $dN/dM \propto M^{-3/2} \exp(-M/T_S)$ allows to extract the parameter T_S, which represents a space-time average of the thermal temperature over the fireball evolution and can be determined with a precision of the order of 10 MeV. The determination of the evolution of T_S vs CM energy for $\sqrt{s_{NN}} < 10$ GeV may allow to discover a plateau in the caloric curve (fig. 3, right) that would be present in case of a phase transition of the first order [2].

Charmonium suppression in Pb-Pb collisions was extensively studied at the top SPS energy by the NA50 collaboration [3]. NA60+ aims to extend the measurements at lower energies, down to $E_{\rm lab}/A = 40$ GeV, in order to search for the onset of the deconfinement. A statistics ranging from 10^4 to 10^5 reconstructed J/ψ, depending on the beam energy, can be collected at the foreseen Pb beam intensity, allowing for a precise measurement of the suppression. Also data taking with p-A collisions is foreseen, in order to determine precisely cold nuclear matter effects.

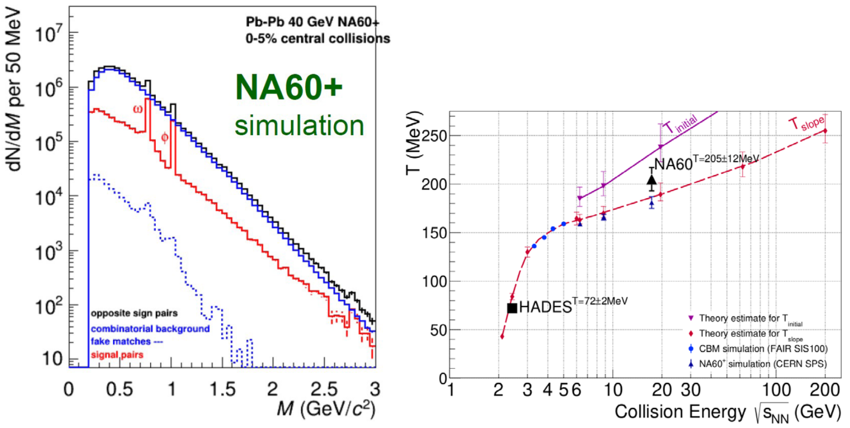

Figure 3. Left: simulated dimuon mass spectrum in central Pb-Pb collisions at $E = 40$ GeV per nucleon. Right: medium temperature evolution vs $\sqrt{s_{NN}}$ in central Pb-Pb collisions.

Open charm measurements will be performed using the vertex telescope as a stand-alone detector, reconstructing the decays of charmed hadrons into two or three charged hadrons. The huge combinatorial background can be reduced by applying geometrical selections on the displaced decay vertex topology. The MAPS technology can provide a signal to background ratio ~ 10 times higher than the corresponding value obtainable with hybrid pixel sensors. No open charm measurement are currently available below the top SPS energy. In one month data taking, a measurement of the D^0 yield in central Pb-Pb collisions with a statistical precision much better than 1% can be obtained, allowing for a precise determination of the yield and v_2 as a function of p_T, rapidity and centrality. At $\sqrt{s_{NN}} = 10.6$ GeV due to the lower production cross section, a reduction of the statistics by an order of magnitude is expected. Still, the measurement will be feasible with a statistical precision at the level of the percent.

Finally, strangeness measurements in the hadronic decay channels will allow to explore the low multiplicity region to have a complete view of strangeness enhancement with multiplicity. A large statistics is expected, allowing for a high p_T-reach, studies in narrow centrality bins and an extension to multistrange hadrons of the elliptic flow measurements.

4 Timeline

The EoI [4] was submitted in 2019 at the CERN SPSC. A Letter of Intent is being prepared and will be submitted at the end of 2022. If the experiment will be approved, the goal is to have the detector ready for data taking after the LHC Long Shutdown 3 and run for at least 5-6 years, with $\sim$ one month data taking for each Pb beam incident energy, complemented by a few weeks of data taking with proton beams for cold nuclear matter studies.

References

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