# The NA60+ experiment at the CERN SPS

*Sabyasachi* Siddhanta[1,*] for the NA60+ Collaboration

[1]Istituto Nazionale di Fisica Nucleare (INFN), Cagliari, Italy

**Abstract.** NA60+ is a new experiment designed to study the phase diagram of the strongly interacting matter at high baryochemical potential from 200 to 550 MeV at the CERN SPS. It is focused on precision studies of thermal dimuons, heavy quark and strangeness production in Pb–Pb collisions at center of mass energies ranging from 6 to 17 GeV. This contribution is focussing on the experimental apparatus, including the technical aspects and the R&D status, as well as the physics program and its competitiveness and complementarity to other experiments.

## 1 Introduction

Heavy ion collisions at low energies in the range 6 to 17 GeV is a tool to investigate the QCD phase diagram at large baryo-chemical potential ($\mu_B$). This is in contrast to studies at top RHIC energies and at the LHC which are characterised by a high initial temperature and close to zero $\mu_B$. The low energy studies could give insights to open questions at large $\mu_B$ like a first order phase transition with the presence of a critical point separating the hadronic phase with the QGP [1]. The low energy range is available at the CERN SPS and we propose a new fixed target experiment, presently denoted as the NA60+.

A rich physics program is foreseen, which includes the search for chiral symmetry restoration effects through the $\rho - a_1$ mixing, the study of the order of the phase transition at large baryochemical potential through the measurement of a caloric curve, the onset of the deconfinement through the measurement of $J/\psi$ suppression. The measurement of the transport properties of the medium via open charm states and the study of hadrochemistry via detection of strange hadrons and hypernuclei are also part of the physics program.

## 2 Experimental apparatus

The proposed NA60+ apparatus, as shown in Figure 1, is inspired by the former NA60 apparatus[3]. It is composed of a muon spectrometer with six tracking stations, a large-acceptance toroidal magnet and a two-stage absorber system to filter out muons. This is complemented by a vertex telescope located close to the target and sitting before the absorber for precise measurement of muon kinematics. For the beam energy scan, the z-position can be adjusted to cover roughly one unit of rapidity in the forward direction at all energies.

The vertex telescope will be hosted inside a dipole magnet, a few centimeters after a lead target system comprising of five 1.5 mm thick Pb disks (bottom right image of Figure 2). An

*e-mail: sabyasahi.siddhanta@cern.ch

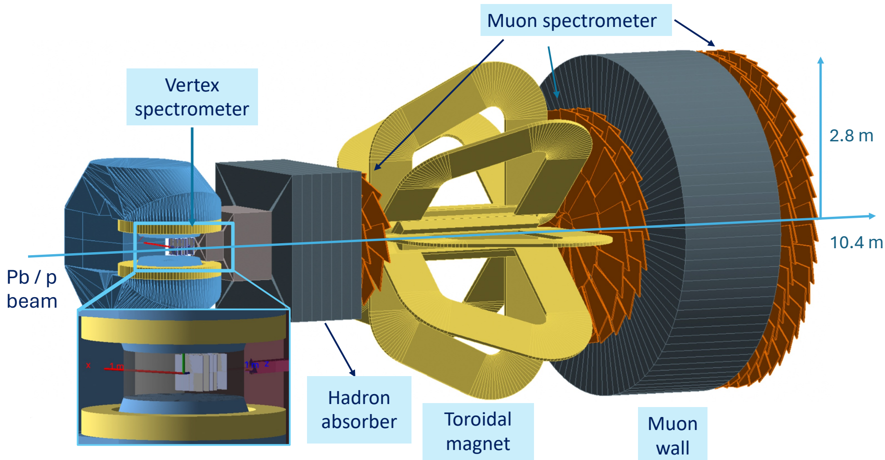


**Figure 1.** The NA60+ apparatus.

existing magnet - MEP48 which is stored at CERN is proposed. It provides 1.5 T over a 40 cm gap. The vertex telescope will consist of several planes of ultra-thin, large area Monolithic Active Pixel sensors (MAPS). For proton runs, which is needed to provide a reference to Pb-Pb runs, several target species from beryllium to tungsten will be exposed to the beam.

For the pixel sensor we plan to use large area stitched sensors, based on the R&D carried out by ALICE for ITS3[2], which has the same timeline for the installation as NA60+. The sensor is based on 25 mm sub-units called Repeated Sub-Units (RSU), which are replicated up to 14 cm for NA60+ through a stitching technology provided by the foundry. These 14 cm strips are then replicated vertically in the silicon wafer to obtain 14x14 $cm^2$ sensors. Each plane will be formed by four of such sensors, covering approximately an area of 28x28 $cm^2$ as shown in the top right image in Figure 2. The material budget will be less than 0.1 % $X_0$ and the spatial resolution better than 5 $\mu m$. A dedicated R&D for mechanics and cooling, based on airflow and water, is presently ongoing

The muon spectrometer will utilize large area gaseous detectors for muon tracking and a large-acceptance toroidal magnet based on a new light-weight and general-purpose concept. The tracking is based on six stations, with increasing size, with a modular structure exploiting a trapezoidal unit, arranged in concentric rings. An absorber comprising a BeO and a graphite section will be placed after the vertex telescope to reduce the background in the muon spectrometer. A second absorber will be placed before the last two stations to stop the residual background. The warm toroidal magnet with low material budget in the acceptance area will be placed between the second and third station to measure the muon momentum. The overall scheme is shown in the left image of Figure 2. The muon spectrometer will be placed on rails, so as to adjust its length to better cover the mid-rapidity region at different energies. For higher energies, the graphite secion of the first absorber will be extended. The rates after the absorber, evaluated with dedicated Fluka simulations, do not exceed few $kHz/cm^2$ for $10^6$ Pb ions per second. This would mean that both Multi Wire Proportional Chambers (MWPC) and/or Gas Electron Multiplier (GEM) detectors can match the requirements.

First MWPC prototypes have been built and beam tests were performed in 2023. It is based on double strip readout providing a spatial resolution around 100 $\mu m$. There are on-

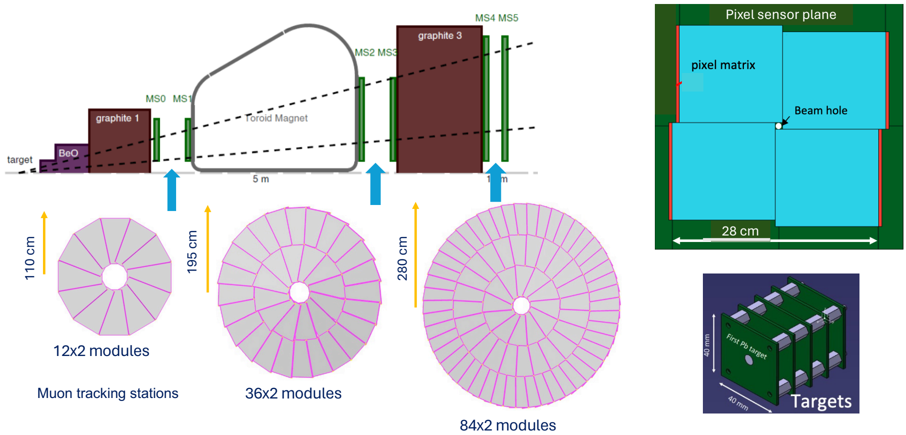


**Figure 2.** Left: Schematic layout of the muon spectrometer. The setup is adapted for a beam energy of $\sqrt{s_{NN}}$ = 6.3 GeV. For higher beam energies, the graphite absorber will be extended. Right (top): One plane of the vertex telescope consisting of four large area (14 x 14 $cm^2$) MAPS sensors. Right (bottom): Sketch of the NA60+ target system (Pb–Pb collisions set-up).

going discussions for the final setup, with the possibility to use GEMs for the first two stations, and MWPC for the most downstream stations. Discussions for the overall readout electronics are also ongoing.

A complete feasibility study has been performed to install NA60+ in the EHN1-PP138 area, where CERES-NA45 was previously installed. This includes rails needed to shift the spectrometer longitudinally, a floor excavation to cope with the vertical position of the beam line and a rather massive shielding needed for complying with radio-protection safety rules.

## 3 Physics performance studies

Several new and unique measurements are foreseen with NA60+ in the energy range 6 - 17 GeV related to thermal dimuons, quarkonia, open heavy flavor and strangeness. The NA60+ physics program includes, among others, the measurement of a caloric curve of temperature vs. collision energy, investigation of chiral symmetry restoration close to the phase boundary, charmonium melting in the QGP and open heavy flavor to extract QGP transport coefficients and investigate hadronization [4].

Detailed performance studies were carried out with different observables for the 5% most central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 6.3, 8.8 and 17.3 GeV[4].

The left plot of Figure 3 shows the NA60+ performance on the measurement of a caloric curve which displays the temperature evolution as a function of collision energy. Thermal dileptons provide a precise thermometer by measuring the invariant mass slope in the mass region 1.5 - 2.5 GeV. This slope is an average temperature of the early stage of the system. There are only two precision measurements of the temperature till date, done by NA60 and HADES as shown in Figure 3, which also shows the evolution of $T_{slope}$ vs $\sqrt{s_{NN}}$ from theory. In the energy range covered by SPS, NA60+ would extract information in the region close to the deconfinement temperature, with a possible signal of a first order phase transition.

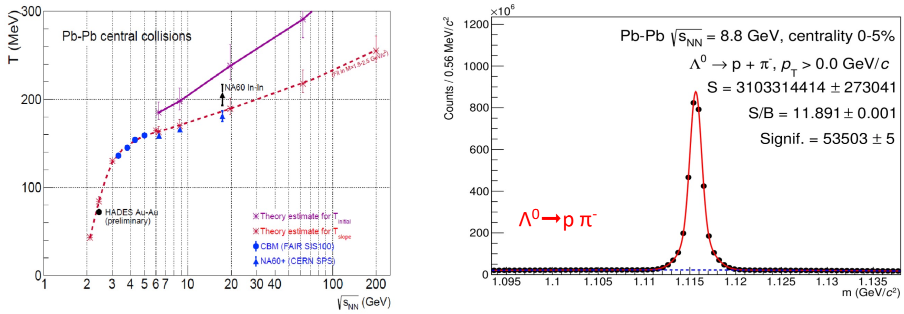


**Figure 3.** Left: Caloric curve - medium temperature evolution vs $\sqrt{s_{NN}}$ in central Pb–Pb collisions. Blue triangles are the expected performance from NA60+. Right: Projection for the invariant-mass distribution of $\Lambda^0$ candidates (right).

The hadronic decays of strange hadrons can be studied with the Vertex Telescope of the NA60+ apparatus. Several decal channels involving hadronic decays of $\Lambda, \Xi, \Omega, K_s^0$ and $\phi$ were studied. For example, the right plot of Figure 3 shows the projection for the invariant-mass distribution of $\Lambda^0$ candidates. The analysis was performed on $10^7$ simulated Pb-Pb collisions in the 0-5% centrality class at $\sqrt{s_{NN}} = 8.8$ GeV.

## 4 Conclusion and outlook

The Letter of Intent for the NA60+ experiment[4] was submitted to the SPS Committee (SPSC) in 2022 and was discussed in February 2023 with a favorable feedback. The project is mentioned in US 2023 Long Range Plan for Nuclear Science and in the NUPECC Long Range Plan 2024. Significant progress was made in the detector and toroidal magnet R&D and beam optics studies in 2023 and 2024. Presently, preparation and consolidation work is ongoing for the Technical Proposal which will be submitted to the SPSC in early 2025.

NA60+ is planned to be commissioned during the Long Shutdown 3 (LS3) of the LHC (2026-28). The data taking will start from 2029 and will continue over a period of seven years. Data taking for one energy point will be performed including one month of Pb-Pb and a few weeks of p-A runs each year.

## References


[1] K. Fukushima and T. Hatsuda, The phase diagram of dense QCD. Reports on Progress in Physics **74.1** (2010): 014001

[2] ALICE Collaboration, Technical Design Report for the ALICE Inner Tracking System 3 - ITS3. CERN-LHCC-2024-003/ALICE-TDR-021

[3] NA60 Collaboration, Study of prompt dimuon and charm production with proton and heavy ion beams at the CERN SPS. CERN-SPSC-2000-010

[4] NA60+ Collaboration, Letter of Intent: the NA60+ experiment. CERN-SPSC-2022-036; SPSC-I-259