The NA60+/DiCE experiment at the CERN SPS

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Abstract. NA60+/DiCE (Dilepton and Charm Experiment) is a new experiment designed to study the phase diagram of the strongly interacting matter at CERN SPS energies, where the values of the baryochemical potential μ_B approximately range between 220 and 480 MeV. It is focused on precision studies of thermal dimuons, heavy quarks, and strangeness production in Pb–Pb collisions at centre-of-mass energies ranging from 6 to 17 GeV per nucleon pair. This paper will discuss the apparatus concept and the physics reach.

1 Introduction

The QCD phase diagram at high baryochemical potential (μ_B) remains largely unexplored. At low μ_B, a transition from hadronic matter to the Quark–Gluon Plasma (QGP) has been established at temperatures of about 155 MeV [1]. At larger μ_B, theoretical models predict a richer structure, including a possible first-order phase transition terminating at a critical point [2, 3]. However, precise measurements of dileptons and charm production in this region are still missing.

NA60+/DiCE will address this gap by exploring the range $220 < \mu_B < 480$ MeV through an energy scan with Pb beams at the SPS, covering $6 < \sqrt{s_{NN}} < 17$ GeV [4]. Its ambitious physics program includes: the search for chiral-symmetry restoration via ρ–a_1 mixing, the study of the phase transition order through a caloric curve reconstructed from thermal dileptons, and the investigation of the onset of deconfinement via J/ψ suppression. In addition, NA60+/DiCE will probe the transport properties of the medium using open-charm measurements and explore hadrochemistry through the detection of strange hadrons and hypernuclei.

2 Experimental apparatus

The NA60+/DiCE experimental setup is shown in Figure 1. Behind the target, the vertex spectrometer (VS) will consist of five layers of large-area Monolithic Active Pixel Sensors (MAPS) based on TPSCo 65nm imaging technology [5]. Each plane will host four large-area stitched MAPS (13.6×13.7 cm^2), obtained by stitching 19.6×21.7 mm^2 units, with a central hole left for the beam passage. Pixel size is 20.8×22.8 μm^2, corresponding to a spatial resolution of about 5 μm. The sensors are 50 μm thick and mounted on 400 μm carbon-fibre planes for efficient heat dissipation, with a low material budget of 0.2% X_0 per plane. The vertex spectrometer will be embedded in a 1.47 T dipole field from the MEP48 magnet. A sketch of the VS is shown in Fig. 2.

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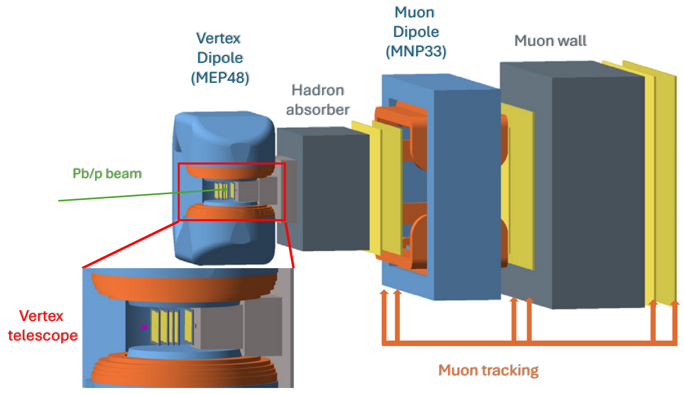

Figure 1. View of the NA60+/DiCE experimental apparatus.

A BeO–graphite absorber follows the vertex spectrometer to reduce muon background, corresponding to 14.4-26.1 interaction lengths depending on beam energy (20–150 GeV). The muon spectrometer comprises six modular stations (Fig. 2). FLUKA simulations indicate maximum rates of ~2 kHz in the first station at 10^6 Pb ions/s, compatible with MWPC and GEM detectors. Prototypes have been built and tested, achieving a 120 μm resolution, well within the experiment requirements. The magnetic field for muon momentum measurement will be provided by the NA62 MNP33 dipole magnet, which will become available during LHC Long Shutdown 3. A second absorber (muon wall) will be placed upstream of the last two stations to stop residual background. The muon spectrometer will be mounted on rails to adjust its length and optimise mid-rapidity coverage at different energies.

The experiment will be installed in the PPE138 area of the CERN EHN1 hall, on the H8 beamline. Dedicated installation studies have been carried out, including shielding design and beam property investigations [6]. In NA60+/DiCE, a narrow Pb beam spot is required to allow the non-interacting Pb ions pass through the hole of the pixel planes. Measurements, performed in ad-hoc test beams, have confirmed that a Pb beam spot of $200 \times 100\ \mu\text{m}^2$ at 150 AGeV can indeed be achieved at the high intensities required by the experiment.

3 Physics performance

NA60+/DiCE will measure the thermal dimuon spectrum up to 2.5–3 GeV/c^2, reconstructing roughly 6×10^6 dimuons in central Pb–Pb collision at each energy point. Fitting the mass spectra for $M_{\mu\mu} > 1.5$ GeV/c^2 with $dN/dM_{\mu\mu} \propto M_{\mu\mu}^{-3/2} \exp(-M_{\mu\mu}/T_{\text{slope}})$ will yield the slope parameter, related to the medium temperature, with a few-percent precision, providing a caloric curve versus $\sqrt{s_{NN}}$. Figure 3 (left) shows the expected thermal dimuon distributions. Full ρ–a_1 chiral mixing would enhance dilepton yields by 20–30% in $0.8 < M_{\mu\mu} < 1.5$ GeV/c^2 [7]. As shown in Fig. 3 (right), NA60+/DiCE will measure this region with sufficient precision to detect a signal of chiral symmetry restoration. NA60+/DiCE will perform the first measurement of dimuon elliptic flow below RHIC energies.

NA60+/DiCE will also look for the onset of charmonium suppression, measuring the J/ψ production down to $\sqrt{s_{NN}} = 9.8$ GeV, and $\psi(2S)$ down to ~15 GeV. Cold nuclear matter effects will be calibrated with dedicated p–A runs. Figure 4 shows the expected performance for the J/ψ nuclear modification factor at $\sqrt{s_{NN}} = 9.8$ GeV.

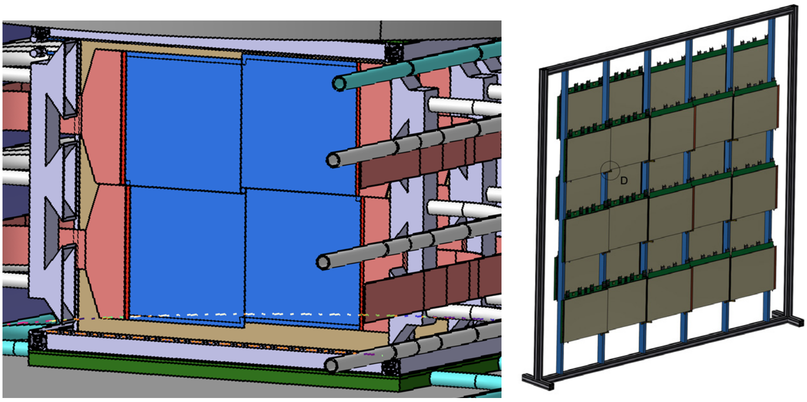

Figure 2. Left: view of the vertex spectrometer inside MEP48. Right: sketch of one of the stations of the muon spectrometer.

Open charm will be reconstructed by exploiting displaced decay vertices ($c\tau \sim$ 60–300 μm). Figure 4 shows the expected $\Lambda_c^+ \rightarrow pK\pi$ invariant mass distribution at $\sqrt{s_{NN}}$ = 16.8 GeV in the centrality class 0-5%. NA60+/DiCE will reach a few per cent precision in terms of statistical uncertainties. Differential studies of D^0, D^+, D_s^+, yield and v_2 vs p_T, rapidity, and centrality will be possible. A similar approach allows multi-differential studies of strange particles and hypernuclei. Hypernuclei production at low $\sqrt{s_{NN}}$ is more abundant than at LHC, enabling high-precision measurements of ${}^3_\Lambda$H, ${}^4_\Lambda$He, ${}^5_\Lambda$He, and the possible discovery of Ξ and Σ hypernuclei.

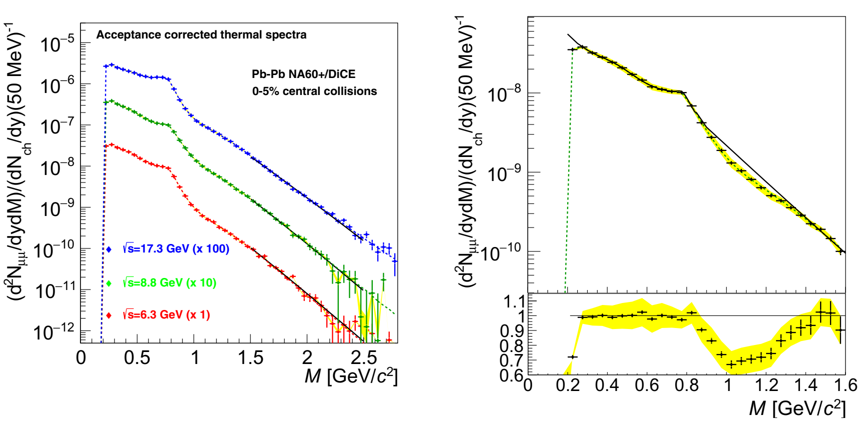

Figure 3. Left: the expected invariant mass distribution of thermal dileptons corrected by the efficiency and acceptance in central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 6.3, 8.8, and 17.3 GeV. Right: the thermal dileptons invariant mass distribution at $\sqrt{s_{NN}}$ = 8.8 GeV in the case of no-chiral mixing compared with full chiral mixing (black line).

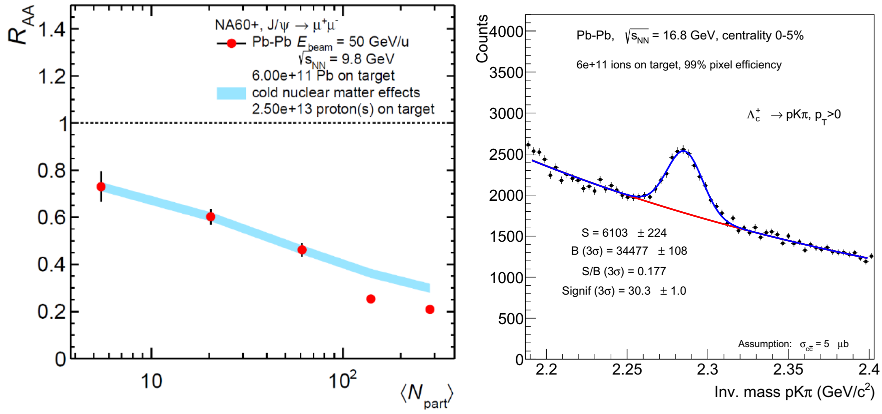

Figure 4. Nuclear modification factor of the J/ψ production in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 9.8 GeV as a function of the average number of participants in the collision (left). The expected invariant mass distribution for the $\Lambda_c^+ \rightarrow pK\pi$ in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 16.8 GeV in the centrality class 0-5% (right).

4 Conclusion

State-of-the-art detector technology and the high-intensity SPS beam will enable precision measurements of electromagnetic probes, charmed hadrons, strange particles, and hypernuclei. The proposal was submitted to the CERN SPSC in May 2025 [4], with construction starting in 2026 and expected to last ∼3 years, in time for 2029/2030 data taking. The experiment will collect data for 7 years, with one energy point per year. Reference runs with a proton beam will also be taken. NA60+/DiCE will thus provide a unique and comprehensive exploration of the QCD phase diagram in the region of high baryochemical potential.

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