Study of hard and electromagnetic processes at the CERN SPS: an investigation of the high-$\mu_{\rm B}$ region of the QCD phase diagram with NA60+

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The exploration of the phase diagram of Quantum ChromoDynamics (QCD) is carried out by studying ultrarelativistic heavy-ion collisions. The energy range covered by the CERN SPS ($\sqrt{s_{\rm NN}} \sim$ 5–17 GeV) is ideal for the investigation of the region of the phase diagram corresponding to finite baryochemical potential ($\mu_{\rm B}$), and has been little explored up to now. In this paper we describe a new experiment, NA60+, that would address several observables which are fundamental for investigating the possible existence of a first phase transition between hadronic matter and a Quark–Gluon Plasma (QGP) at finite $\mu_{\rm B}$. In particular, we propose to study the production of thermal dimuons in Pb-Pb collisions at different energies, from which one would obtain a caloric curve of the QCD phase diagram that is sensitive to the order of the phase transition. In addition, the measurement of the ρ–$\rm a_1$ chiral mixing would provide crucial insight into the restoration of the chiral symmetry of QCD. In parallel, studies of heavy quark and quarkonium production would also be carried out, providing sensitivity for transport properties of the QGP and the investigation of the onset of the deconfinement transition. Results of physics performance studies for most observables accessible by NA60+ are discussed, showing that the results of the experiment would lead to a significant advance of our understanding of (non-perturbative) strong interaction physics.

KEYWORDS: Quark-gluon plasma, QCD phase transition, chiral symmetry restoration

1. Exploring the QCD phase diagram at high μ_B with NA60+

QCD has a rich phase structure. While asymptotic freedom allows it to completely define the degrees of freedom in terms of quarks and gluons, hadrons become the relevant degrees of freedom when confinement sets in. The phase diagram, shown in Fig. 1 left, is described in terms of temperature (T) and baryochemical potential (μ_B) . Our knowledge of the QCD phase diagram is largely restricted to the region of low μ_B. Here, lattice QCD ([1] and references therein) provides evidence for a cross-over phase transition at a critical temperature $T_c \sim 155$ MeV (Fig. 1 right). The experiments carried out by colliding (ultra)relativistic heavy ions at the CERN-SPS, BNL-RHIC and CERN-LHC accelerators have so far mostly explored the low $\mu_{\rm B}$ region. The results demonstrated that a deconfined state of matter is produced in such collisions, with properties consistent with lattice QCD predictions.
For moderate temperatures and high baryon densities the existence of a first-order phase