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Probing the QCD Phase Structure with Dileptons from SIS to LHC Energies

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We explore the properties of strongly interacting matter at finite temperature and baryon chemical potential as created in relativistic heavy-ion collisions, focusing on the QCD phase structure probed via dilepton observables. The equilibrium description of the non-perturbative quark–gluon plasma (QGP) is realized within the Dynamical QuasiParticle Model (DQPM), which reproduces lattice QCD results for the equation-of-state (EoS) above the deconfinement temperature. Using this framework, we evaluate transport coefficients at finite baryon chemical potential, including the specific shear viscosity and the ratios of electric, baryon, and strange conductivities to temperature, as well as the thermal rates incorporating both elastic and inelastic (for the first time within quasiparticle model) partonic processes.

The dynamical, non-equilibrium evolution of strongly interacting matter is described within the off-shell transport approach Parton–Hadron–String Dynamics (PHSD), which consistently propagates partonic and hadronic degrees-of-freedom and their interactions based on Kadanoff–Baym theory. This allows for a microscopic realization of the QCD phase transition while maintaining energy–momentum and quantum number conservation. Chiral symmetry restoration effects are included, leading to in-medium modifications of hadronic spectral functions and strange hadron properties.

We present results for the space–time evolution of heavy-ion collisions across a wide energy range, demonstrating that a deconfined QGP core can emerge (in a small volume) even at low invariant energies of $\sqrt{s_{NN}} \simeq 3.5$ GeV. Dileptons serve as penetrating probes of the QCD medium, providing insight into its thermal and transport properties. For the first time, we report on the baryon-chemical-potential dependence of QGP thermal radiation calculated within PHSD, showing that its influence increases with decreasing collision energy. The excitation function of thermal QGP dileptons, accounting for μ_B-dependent quasiparticle masses, widths, and interactions, reveals that QGP radiation surpasses the dilepton yiels from the correlated charm decays in central Au+Au collisions at $\sqrt{s_{NN}} \leq 25 - 30$ GeV, accessible at RHIC–BES and future FAIR experiments. Furthermore, we find an increasing QGP contribution to dilepton spectra in proton–proton reactions toward LHC energies. Our results suggest that, after careful subtraction of dilepton contributions from correlated heavy-flavor and Drell–Yan sources, direct observation of QGP thermal radiation may be achieved. which demonstrates that dileptons provide a sensitive electromagnetic probe of the QCD phase structure over a broad range of temperatures and baryon densities.

References:
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