Dileptons in heavy-ion collisions in a coarse-grained transport approach

S. Endres[1,2], H. van Hees[1,2], J. Weil[1,2], and M. Bleicher[1,2]

[1]Institute for Theoretical Physics, Goethe University Frankfurt; [2]Frankfurt Institute of Advanced Studies (FIAS)

Lepton-antilepton pairs (dileptons) and photons provide valuable observables for the properties of strongly interacting hot and dense matter, created in heavy-ion collisions. Due to their penetrating nature they leave the hot and dense fireball nearly unaffected from final-state interactions, enabling insight into the spectral properties of the electromagnetic current-correlation function with relations to the (chiral) phase structure of strongly interacting matter.

In this work, for the description of the bulk-medium evolution the UrQMD transport simulation has been used. A fundamental challenge is the implementation of reliable dilepton and photon production rates from a hot and dense partonic (Quark Gluon Plasma, QGP) and hadronic (Hadron Resonance Gas, HRG) medium. Here, one relies on the application of equilibrium quantum-many body theory to describe the in-medium electromagnetic current-correlation function. In [1] we have followed the strategy to use a coarse-graining approach to make the detailed equilibrium dilepton-production rates of [2], based on hadronic many-body theory, as well as an extrapolation of recent lattice results on the dilepton-production rates to finite momenta [3] applicable within a detailed transport description of bulk-medium dynamics: UrQMD has been run several times for a given heavy-ion collision to provide an ensemble, which samples the bulk-medium evolution on a space-time grid, providing average values for the local energy-momentum and baryon-number density ("coarse graining"). Using a lattice-QCD inspired equation of state, extrapolated to finite baryon-chemical potential, describing the cross-over phase transition from a deconfined QGP to a hot and dense HRG phase of the evolving fireball, local temperatures and chemical potentials (baryon- and pion-chemical potential to take chemical off-equilibrium after chemical freeze-out into account) have been fitted in the local Eckart frame, where the net-baryon-number flow vanishes. In the early phases the fit to an anisotropic hydrodynamical flow pattern has been used.

In Fig. 1 this calculation is compared to the high-precision invariant-mass excess spectrum measured by the NA60 collaboration in $158A$GeV In-In collisions at the CERN SPS. The excellent description of the data demonstrates the feasibility of the coarse-graining method to implement detailed equilibrium many-body calculations of the dilepton rates into realistic bulk-evolution transport descriptions. This shows that the medium modifications of the light vector mesons leading to substantial spectral broadening with small mass shifts describe the low-mass enhancement below the ρ-peak region around $M \simeq 170$ MeV. In the intermediate-mass region, $M \gtrsim 1$ GeV,

multi-pion processes and $q\bar{q}$ processes become the prevalent production mechanism. The slope of the mass spectrum in this region directly reflects the space-time weighted average of an invariant temperature (without impact of Doppler blue-shift effects due to radial flow), which is clearly above the critical temperature, $T_{M-\text{slope}} \simeq 205$-$230$ GeV.

Applications of this method to dilepton (and photon) production in heavy-ion collisions over a larger range of collision energies (RHIC beam-energy scan, GSI HADES, and future CBM experiment at FAIR) are in preparation.
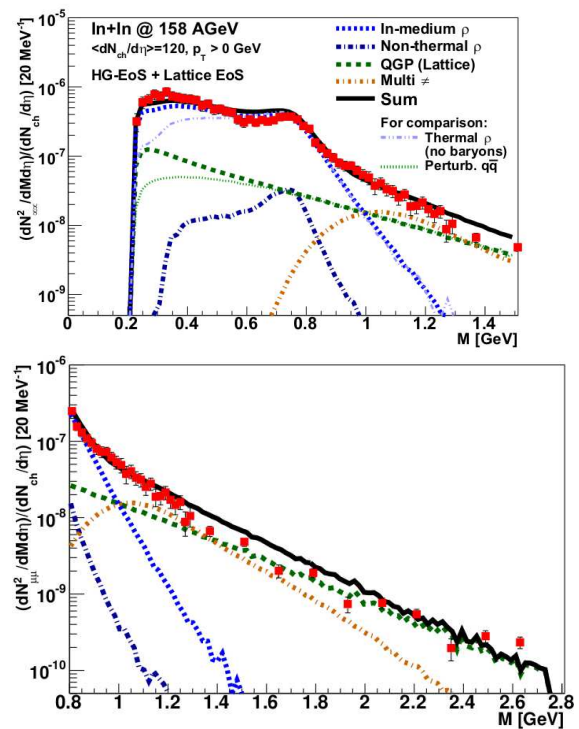

Figure 1: The dimuon invariant-mass spectrum in $158A$GeV In-In collisions at the CERN SPS, compared to the data from the NA60 collaboration [4].

References

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