Thermal dileptons as fireball thermometer and chronometer

Ralf Rapp and Hendrik van Hees

Thermal radiation of dileptons has long been recognized as an excellent messenger of the hot and dense QCD medium formed in high-energy heavy-ion collisions. At low invariant masses, M < 1GeV, the dilepton spectra are dominated by decays of thermally produced ρ(770) mesons, thus directly probing the in-medium modifications of the ρ-meson line shape. At intermediate masses, 1GeV < M < 3GeV, the radiation is continuum-like, and its slope characterizes the (early) temperatures of the fireball medium.

In our recent work [1] we have updated our calculations of thermal dilepton spectra by using a modern lattice-QCD (lQCD) based equation of state for the expanding fireball medium [2]. Thermal emission rates from the quark-gluon plasma (QGP), constrained by lQCD correlation functions [3], are combined with hadronic emission rates based in on an ρ in-medium spectral function calculated from hadronic many-body theory [4]. The predicted broadening and ultimate melting of the ρ-resonance around a pseudo-critical temperature of T_{pc} ~ 170MeV renders a smooth transition from the hadronic to the QGP emission rates. Convoluting these rates over the expanding fireball medium leads to the spectra shown in Fig. 1.

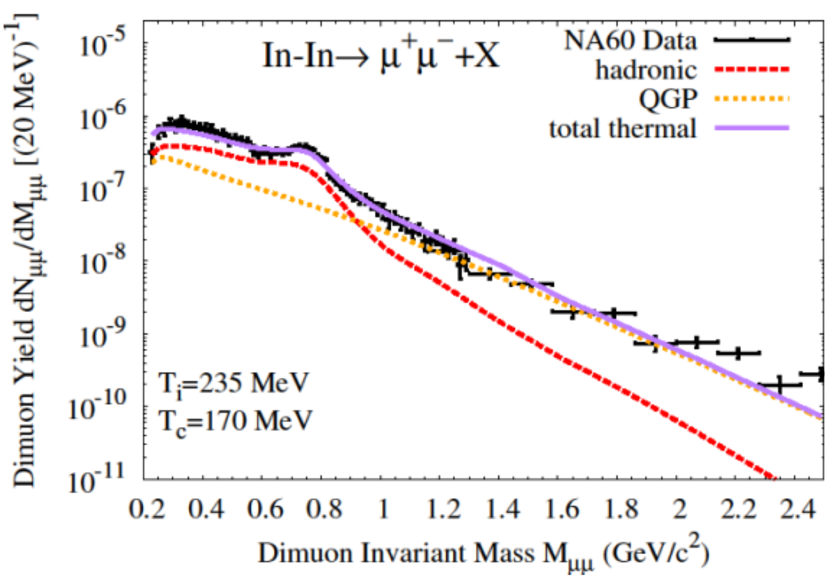

FIG. 1. Calculations of thermal dilepton spectra from the QGP (dotted line) and hadronic (dashed line) phases of an expanding fireball [1]. The sum (solid line) is compared to di-muon spectra measured by NA60 in In-In collisions at the SPS [5].

The agreement with the state-of-the-art NA60 dimuon data [5] in $\sqrt{s}$=17.3 GeV In-In collisions at the SPS allows for the following conclusions: (i) the spectral shape in the low-mass region confirms the melting of the ρ-meson and the total yield quantifies the fireball lifetime to be τ_{fb}=7±1fm/c; (ii) at intermediate masses the spectra are dominated by QGP radiation; its spectral slope (which is blue-shift free) directly yields an average temperature of T_{avg}~205±12MeV, corroborating emission from temperatures above T_{pc}~170 MeV.

The above framework has been extensively tested in heavy-ion collisions over a large range of energies; it describes all available dilepton data, from HADES at SIS-18 (√s~2.5GeV) [6] via CERES and NA60 at SPS (√s=8.8,17.3GeV) to STAR at RHIC in the beam-energy scan (√s=19.6,27,39,62.4,200GeV) [7], including the recently revised PHENIX data [8]. Based on this robust understanding, we have extracted the excitation function of the low-mass dilepton yields and the spectral slopes of the intermediate-mass dilepton spectra from our calculations [1], cf. Fig. 2.

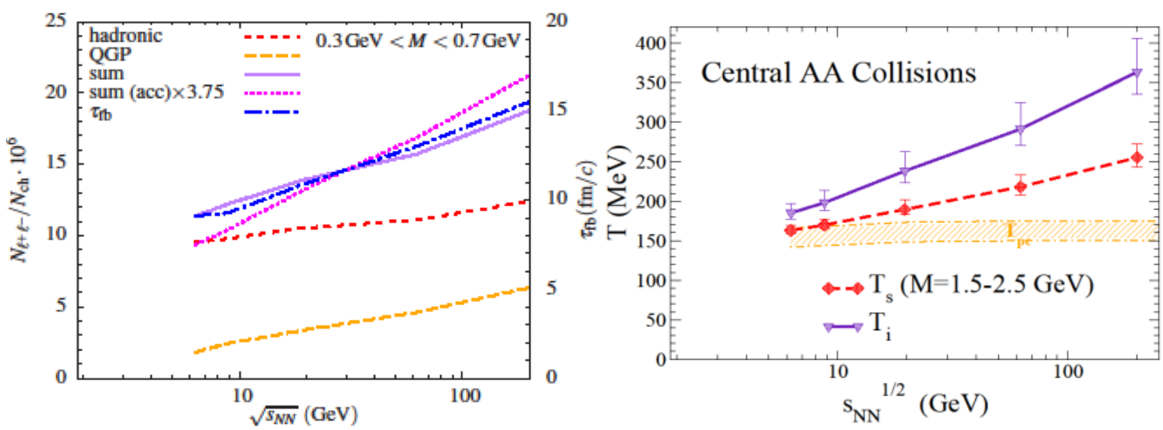

FIG. 2. Excitation functions of low-mass dilepton yields and corresponding fireball lifetime (left) and slope parameter, T_s, of intermediate-mass spectra compared to initial temperature, T_i, and T_{pc} (right).

We have found that the low-mass yields are an excellent measure of the fireball lifetime, while the intermediate-mass slopes reflect an average temperature of the QGP emission source. This temperature closely reflects the transition temperature for collision energies below √s=10GeV, and may thus serve to map out the transition region and a possible onset of a first-order transition via the emergence of a quasi-plateau. At the same time, non-monotonous variations in the fireball lifetime may signal the vicinity to a second-order endpoint.

[1] R. Rapp and H. van Hees, Phys. Lett. B **753**, 586 (2016).
[2] M. He, R.J. Fries, and R. Rapp, Phys. Rev. C **85**, 044911 (2012).
[3] R. Rapp, Adv. High Energy Phys. **2013**, 148253 (2013).
[4] R. Rapp and J. Wambach, Eur. Phys. J. A **6**, 415 (1999).
[5] H.J. Specht *et al*. (NA60 Collaboration) AIP Conf. Proc. **1322**, 1 (2010).
[6] S. Endres, H. van Hees, J. Weil, and M. Bleicher, Phys. Rev. C **92**, 014911 (2015).
[7] P. Huck *et al.* (STAR Collaboration), Nucl. Phys. **A931**, 659 (2014).
[8] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. C **93**, 014904 (2016).