Comprehensive Interpretation of Thermal Dileptons at the SPS

Hendrik van Hees and Ralf Rapp

Electromagnetic (e.m.) probes, i.e., leptons and photons, are especially valuable for the investigation of strongly interacting matter as created in ultrarelativistic heavy-ion collisions (URHICs) since they are emitted at all stages of the collision and penetrate the medium with negligible final-state interactions [1]. Here we investigate medium modifications of the hadronic e.m. current correlator in the context of dimuon spectra as recently measured in 158 *A*GeV In-In collisions by the NA60 collaboration at the CERN Super Proton Synchrotron (SPS) [2].

At low invariant mass (M≤1 GeV), the e.m. current correlator is saturated by the light vector mesons ρ, ω, and φ. Since the dominant contribution is from the ρ-meson, its medium modifications have been studied in great detail [1]. Here, we employ hadronic many-body theory (HMBT) to evaluate the spectral properties of the ρ-meson, including modifications of its pion cloud by baryon-hole excitations and thermal Bose factors, as well as direct interactions with thermal mesons (π, *K*, ρ) and baryons (nucleons, Δ's, hyperons etc.) [3]. The coupling constants and form factors have been fixed by hadronic and radiative decay branchings, photoabsorption data on nucleons and nuclei, and $\pi N \to \rho N$ scattering. When averaged over a typical space-time evolution of URHICs at SPS, its spectral width amounts to ~350 MeV (compared to about 150 MeV in vacuum). The ω-meson is evaluated in the same HMBT framework as the ρ, leading to an average width of about 100 MeV [4]. For the φ meson-gas effects are expected to generate a broadening of ~20 MeV at T=150 MeV [5], while the dressing of the kaon cloud in nuclear matter induces an increase of the width by ~25 MeV at saturation density [6] (recent nuclear photoproduction data suggest an even larger value [7]). Since there is no comprehensive study of medium effects on the φ-meson in hot and dense matter currently available, we here assume an average width of 80 MeV.

In the intermediate-mass region (1 GeV≤M≤1.5 GeV) we use model-independent predictions based on chiral symmetry in connection with a (leading order) virial expansion. One finds that thermal pions induce a mixing of the vacuum isovector-vector (V) and –axialvector (A) current correlators [8],

$$\Pi_{V,A}(s) = (1-\varepsilon)\,\Pi^{vac}_{V,A}(s) + \varepsilon\,\Pi^{vac}_{A,V}(s)\,.$$

The mixing parameter ε, following from thermal tadpole diagrams, is evaluated for finite pion mass and pion-chemical potential as $\varepsilon = 1/2 \;\; I(T,\mu_\pi)/I(T_c,0)$ with

$$I(T,\mu_\pi) = \int \frac{d^3k}{(2\pi)^3} \frac{f^\pi(\omega_\pi)}{\omega_k}$$

(f^π: Bose distribution, ω_π: pion energy) [9], where, as an upper estimate, we enforced V-A degeneracy at T=T_c, a direct signature of chiral-symmetry restoration. The vacuum V and A correlators are fitted to τ-decays into even and odd numbers of pions, respectively, as measured by the ALEPH collaboration [10].

Dilepton emission from the Quark-Gluon Plasma (QGP) is calculated using the leading-order hard-thermal-loop improved perturbative QCD expression for quark-antiquark annihilation [11]. The corresponding dilepton rate resembles the HMBT results around the critical temperature, being suggestive for chiral restoration via a "quark-hadron duality".

Dilepton spectra are calculated by convoluting the thermal rates over an expanding thermal fireball assuming isentropic expansion and utilizing ideal QGP and hadronic resonance-gas equations of state to infer the temperature and baryon-density evolution. Initial and final temperatures for central In(158*A*GeV)-In are 197 MeV and 120 MeV, respectively.

The comparison with NA60 data [2] (Fig.1) confirms the prevalence of the ρ-meson at low-mass in connection with its substantial broadening as predicted by HMBT. At intermediate masses 4-pion contributions in the e.m. correlator take over, resulting in good agreement with experiment, especially if chiral mixing effects are included [2]. Current experimental uncertainties in the cocktail subtraction (late hadron decays) do not yet allow to draw any conclusions about possible medium effects on ω- and φ-mesons. While the fireball model implies theoretical uncertainties in the overall (absolute) normalization of 20-30% (without impact on the spectral shape), we emphasize that the relative strength of all thermal sources as calculated here is essentially fixed. The overall agreement of our approach with the data thus suggests that the medium produced in URHICs at the SPS is in indeed close to chiral-symmetry restoration. To further corroborate this finding, a detailed study of a manifestly chirally symmetric model, including baryons, is mandatory.

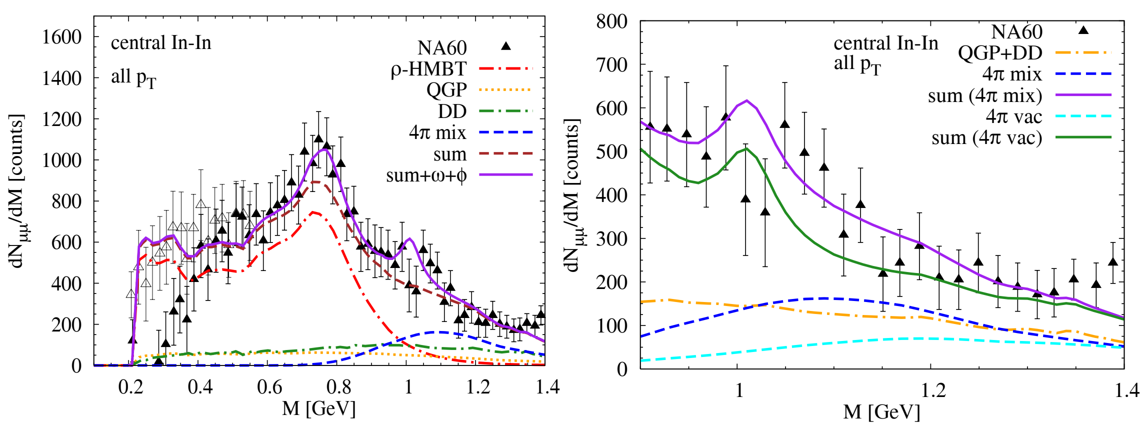

Figure 1. (Left panel) NA60 excess dimuon spectrum [2] in central In(158*A*GeV)-In collisions compared to thermal dimuon radiation using an in-medium e.m. current correlator evaluated using HMBT for the ρ-meson (dash-dotted red line), 4-pion contributions with chiral V-A mixing (dashed blue line), QGP (dotted orange line) and correlated open charm (dash-dotted green line); the upper dashed line is the sum of these contributions, and the solid purple line additionally includes in-medium ω– and ϕ–meson decays. (Right panel) NA60 data at intermediate mass compared to thermal dimuon spectra with different implementations of the 4-pion contribution, using either its vacuum form (lower dashed line) or with chiral mixing (upper dashed line). The corresponding total spectra are given by the lower and upper solid line, respectively.

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