In-medium ρ mesons, dilepton spectra and flow in heavy ion collisions

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It is well known that dileptons are excellent probes to study the local properties of the transient form of matter produced in nuclear collisions at ultra-relativistic energies as they leave the system almost unscathed after production. In the low invariant mass region, which we study in this work, the rate of dilepton production is controlled by the spectral functions of the vector mesons, specially the ρ and hence the modification of the ρ spectral function determines the yield of lepton pairs in this region. We have studied dilepton production using a spectral function with in-medium self energies evaluated in the real time formulation of thermal field theory with the interaction vertices taken from chiral perturbation theory which is the low energy effective theory of QCD. We show in Fig. 1, upper panel, the dilepton emission rate indicating the relative contributions from the cuts in the $\pi-h$ loops keeping only one of them at a time. The unitary and Landau cuts for the π, ω, h_1 and a_1 are seen to contribute with different magnitudes for different values of the energy and three momenta of the off-shell ρ. In the time-like region, in the vicinity of the (bare) rho mass the imaginary part of the self energy from a particular loop receives dominant contribution from only one of the cuts. The $\pi-\pi$ loop for example, has only the unitary cut and this contributes most significantly to dilepton emission near the ρ pole. In contrast, the Landau cut contribution from the $\pi-\omega$ loop is dominant up to about 400 MeV. In the bottom panel we show the cumulative contribution to the lepton pair yield from the $\pi-\pi$ and the $\pi-h$ loops in the region below the bare ρ pole.

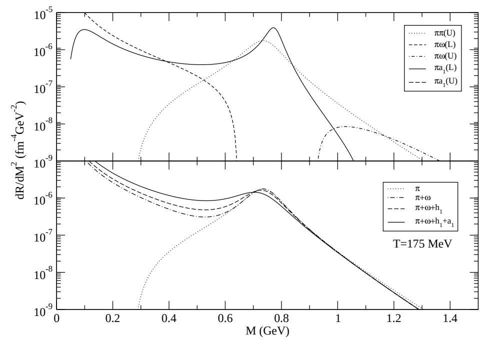

FIG. 1: Upper panel shows contributions from the discontinuities of the self-energy graphs to the dilepton emission rate at $T = 175$ MeV. L and U denote the Landau and unitary cut contribution. Lower panel shows contributions from the different mesons in the loop.

We intend to investigate the radial flow of the produced matter through lepton pair spectra at RHIC and LHC energies. The convolution of the static rates with the space-time profile is performed using relativistic hydrodynamics. To simulate a realistic situation we have considered an equation of state obtained from lattice calculations. Since the invariant mass spectra is invariant under flow we use the $M_T (= \sqrt{p_T^2 + M_{\rm av}^2})$ spectra to study this aspect. In Fig. 2 the M_T spectra is shown at RHIC energies where the differential yield is integrated over small bins of the pair invariant mass (from M_1 to M_2) and plotted against $M_T - M_{av}$ which is actually a measure of the kinetic energy (KE) of the pair, M_{av} being the average mass ($= [M_1 + M_2]/2$) of the bin. In Fig. 3 we have plotted the effective temperature versus M_{av} for various mass windows of the lepton pairs at RHIC energies, evaluated with the in-medium spectral function of the vector mesons. Also shown by a filled square is the value of T_{eff} for the vacuum case in the

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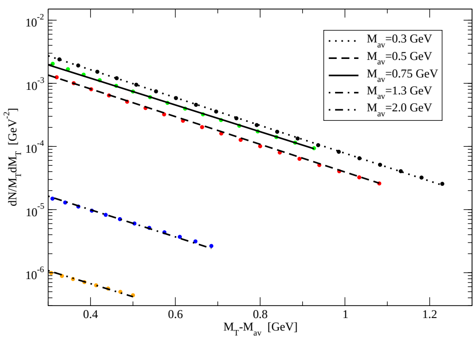

FIG. 2: The dilepton yield plotted against $M_T - M_{av}$ for different M windows for RHIC initial conditions.

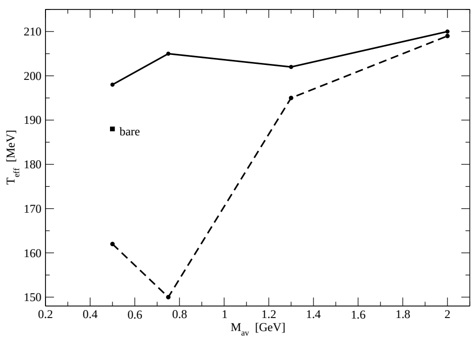

FIG. 3: T_{eff} for different values of the M-bins for RHIC energy. The dashed line is obtained by setting $v_T = 0$.

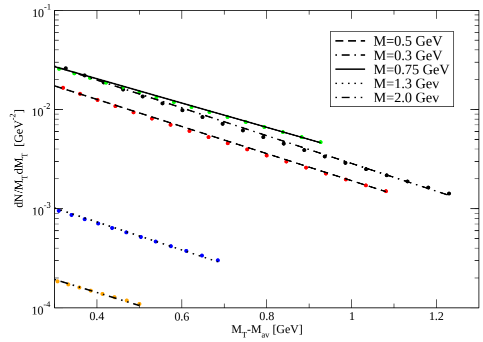

FIG. 4: The dilepton yield plotted against $M_T - M_{av}$ for different M windows for LHC initial condition.

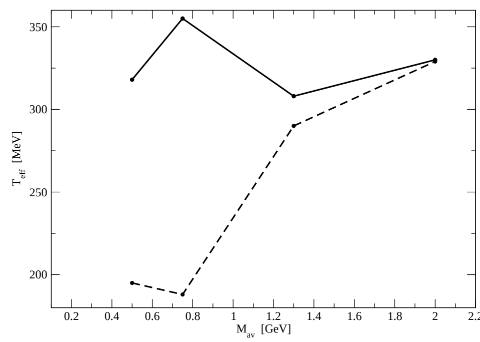

FIG. 5: T_{eff} for different values of the M-bins for LHC conditions. The dashed line is obtained by setting $v_T = 0$.

window $0.4 \leq M \leq 0.6$ where there is substantial difference between the yields in free and medium cases. The slope of these curves measure the average temperature and the flow of the matter. The transverse momentum spectra of lepton pairs is displayed for LHC initial conditions in Fig. 4 where the yield is larger primarily because of the large initial temperature. The variation of inverse slope of the M_T distributions with $M_{\rm av}$ for LHC is depicted in Fig. 5. The values of T_{eff} for various M-bins are larger than RHIC because of the combined effects of large initial temperature and flow. In fact the value of v_T for $0.5 <$ M(GeV)$<$ 0.77 is ~ 0.52. The radial flow in the system is responsible for the rise and fall of $T_{\rm eff}$ with $M_{\rm av}$ (solid line) in the mass region (0.5 $<$ M(GeV)$<$ 1.3) because for $v_T = 0$ (dashed line) a completely different behaviour is obtained. This type of non-monotonic variation of $T_{\rm eff}$ (or v_T) can not be obtained with a single dilepton source. Therefore, such non-monotonic variation of the inverse slope deduced from the transverse mass distribution of lepton pairs with average invariant mass is an indication of the presence of two different phases during the evolution of the system. Thus, such variation may be treated as a signal of QGP formation in heavy ion collisions.

References

[1] S. Ghosh, S. Sarkar and J. Alam [arXiv:1009.1260]