Invariant mass spectra of dimuons from In+In collision at $\sqrt{s_{NN}}$=17.3 GeV

Jajati K. Nayak,* Jan-e Alam, T. Hirano[1], Sourav Sarkar, and B. Sinha
Theoretical Physics Division, Variable Energy Cyclotron Centre, Kolkata - 700064, INDIA and
[1]Physics Department, The University of Tokyo, Tokyo 113-0033, Japan

In relativistic heavy ion collisions charged particles are produced either in hadronic or in quark gluon plasma (QGP) phase depending on the beam energy. Interactions among the charged particles will inevitably produce photons and dileptons which are regarded as very efficient tool in discriminating the phases of the matter produced in the collisions of nuclei at high energies. Because of their nature of interactions they escape out of the system retaining undistorted informations of the source point. Between the real photon and lepton pair the later has the advantage of having an additional kinematic variable M, the invariant mass which can help in making the diagnosis of the state of the matter better. In other words, the transverse momentum (p_T) spectra are available as only observable in case of real photons whereas both the p_T and the M spectra are available for dileptons.

We perform a theoretical analysis of the high precision dimuon data made available by the NA60 collaborations for In+In collision at $\sqrt{s_{NN}}$=17.3 GeV [1] for different p_T and M windows. The results of the detailed analysis will be presented in the symposium.

Thermal dilepton production per unit space-time volume per unit four momentum is given by[2]

$$\frac{dR}{d^4p} = -\frac{\alpha^2}{6\pi^3 q^2} L(M^2) f_{\rm BE}(q_0) W^\mu_\mu(q_0,\vec{q}) \quad (1)$$

where $\alpha(= 1/137)$ is the electromagnetic coupling, W^μ_μ represents the electromagnetic current-current correlator and $f_{\rm BE}(E,T)$ is the phase space factor for thermal bosons. The factor

$$L(M^2) = \left(1 + 2\frac{m^2}{M^2}\right)\sqrt{1 - 4\frac{m^2}{M^2}} \quad (2)$$

arises from the final state leptonic current involving Dirac spinors of mass m (in this case muon) and $p^2(= p_\mu p^\mu) = M^2$ is the invariant mass square of the lepton pair. Using vector meson dominance model Eq. 1 can be written as:

$$\frac{dR}{dM^2 q_T dq_T dy} = \frac{\alpha^2}{\pi^2 M^2} L(M^2) f_{\rm BE}(q_0) \sum_{V=\rho,\omega,\phi} A_V(q_0,\vec{q}) \quad (3)$$

for hadronic matter. In Eq.3 A_v is the spectral function of the vector mesons which consists of a pole and continuum term,

$$A_V = A_V^{\rm pole} + A_V^{\rm cont} \quad (4)$$

For thermal dilepton productions from hadronic matter we considered the decays of thermal ρ, ω and ϕ vector. Thermal effects on the spectral functions of ρ and ω have been taken into account [3]. A large enhancement in the lepton pair production below ρ mass has been observed due to the broadening of the ρ.

In the QGP phase the annihilation of quark-antiquark pairs is the major source of dilepton production ($q\bar{q} \to l^+l^-$). In the present work we consider two flavor QGP. QCD corrections of order $\mathbf{O}(\alpha^2\alpha_s)$ has been included in the production process.

The contributions from ρ-decays at the freeze-out point has been included since this contribution has not been subtracted out from the data. The static dilepton spectra $(dR/d^2M_T dM^2 dy)$ have been convoluted with

*Electronic address: `jajati-quark@vecc.gov.in`

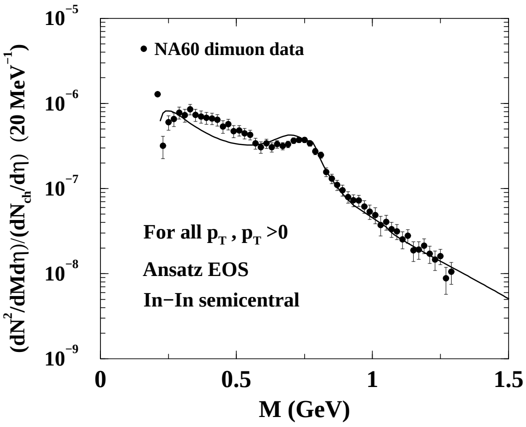

FIG. 1: Invariant mass spectra of dimuon measured by NA60 collaboration at $\sqrt{s_{NN}}$=17.3 GeV for $p_T > 0$ (GeV).

the space-time evolution to evaluate the invariant yield which can be compared with experimental data. Ideal relativistic hydrodynamics has been used for the space-time description of the matter. The invariant mass spectra are obtained as:

$$\frac{dN}{dMdy} = \sum_{phases} \int \left(\frac{dR}{d^2p_T dy dM^2} \right)_{phase} \times d^2p_T d^4x \quad (5)$$

where d^4x is the four dimensional volume element. The limits for integration for p_T can be fixed from the experimental measurements.

The initial temperature(T_i) and thermalization time (τ_i) are constrained by the following relation for an isentropic expansion:

$$T_i^3 \tau_i \approx \frac{2\pi^4}{45\xi(3)} \frac{1}{4a_{\rm eff}} \frac{1}{\pi R_A^2} \frac{dN}{dy}. \quad (6)$$

where, dN/dy= hadron multiplicity, R_A is the effective radius of the system, $\xi(3)$ is the Riemann zeta function and $a = \pi^2 g/90$ ($g = 32$ taken as the effective degeneracy in the QGP phase). We take the initial thermalization time τ_i=0.6 fm, $T_i = 238$ MeV and $T_c = 175$ MeV. The initial radial velocity, $v_r(\tau_i, r)$ and energy density, $\epsilon(\tau_i, r)$ profiles are taken as in [4]. In a quark gluon plasma to hadronic transition scenario - we use the bag model EOS for the QGP phase and for the hadronic EOS all the resonances with mass $\leq$ 2.5 GeV have been considered. The transition region has been parametrized as follows:

$$s = f(T)s_q + (1 - f(T))s_h \quad (7)$$

where s_q (s_h) is the entropy density of the quark (hadronic) phase at T_c and $f(T) = \frac{1}{2}(1 + \tanh(\frac{T-T_c}{\Gamma}))$. The value of the parameter Γ can be varied to make the transition strong first order or continuous.

With all the above ingredients we have evaluated the invariant mass spectra of dimuons for semicentral In+In collision at $\sqrt{s_{NN}}$ = 17.3 GeV. The result for the invariant mass spectra for 0< p_T (GeV)<2.4 is displayed in fig. 1. At low M region ($< m_\rho$) the observed enhancement of the lepton pairs is well reproduced by the theoretical calculations. Invariant mass spectra for other p_T windows and the transverse mass spectra for different M windows are also explained using same initial conditions.

References

[1] R. Arnaldi et al for the NA60 collaboration, Phys. Rev. Lett. **100** 022302 (2008); Eur. Phys. J. C **61**, 711 (2009).

[2] L. D. McLerran and T. Toimela, Phys. Rev. D **31**, 545 (1985).

[3] S. Ghosh, S. Sarkar and J. Alam, Eur. Phys. J. C, **71**, 1760(2011).

[4] J. K. Nayak *et al.*arxiv:0902.0446[nucl-th].