Thermal di-muon from QGP source at FAIR energy

R. P. Adak[1], S. Chattopadhyay[2], S. Das[1],
S. K. Ghosh[1], R. Ray[1], and S. Samanta[1*]
[1] *Center for Astroparticle Physics and Space Science, Bose Institute, India and*
[2] *Variable Energy Cyclotron Centre, Kolkata, India*

Introduction

The leptons are electromagnetically interacting particles. The mean free path of the leptons exceed the size of the system formed after the heavy ion collisions and hence the leptons come out of the system undisturbed after their production, carrying the information about the initial state of the system. In heavy-ion collisions, the dilepton sources are (1) Drell-Yan process during initial $q\bar{q}$ collisions, (2) heavy quarkanium decay, (3) thermal radiation resulting from interaction between secondary partons or even in a locally thermalized QGP. The dilepton yields from thermal radiation is expected to serve as a probe to the QGP. Here we have studied the thermal contribution to the dilepton continuum relevent for the MUCH physics simulation in the CBM experiment at FAIR, Germany.

1. Thermal dilepton production

We assume that, due to heavy-ion collisions, initial temperature T_i and chemical potential μ_i become so large that the system form quark-gluon plasma (QGP). The system then evolves in space and time and cools from an initial temperature T_i to the critical temperature T_c at time τ_c via a first order phase transition. In QGP phase, dileptons are produced dominantly from quark-antiquark annihilation process. In this process, a quark interact with an antiquark to form a virtual photon which subsequently decays into a lepton pair. In case of massless quark and antiquark, the number of dileptons produced per unit dilepton invariant mass squared M^2, per unit four-volume,

*Electronic address: samanta@jcbose.ac.in

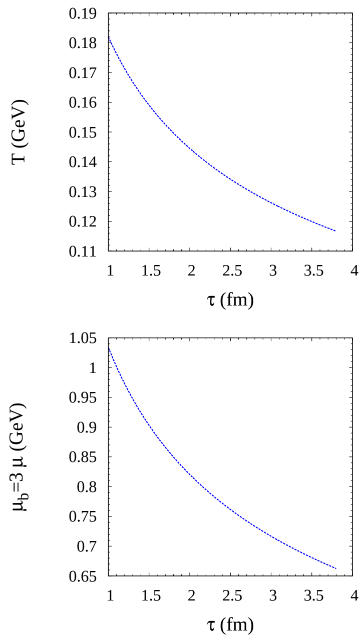

FIG. 1: Evolution of temperature and chemical potential in one dimensional Bjorken expansion.

is given by

$$\frac{dN_{l^+l^-}}{dM^2 d^4x} = N_c N_s^2 \sum_{f=1}^{N_f} (\frac{e_f}{e})^2 \frac{\sigma(M)}{2(2\pi)^4} M^2 \times f_1(\epsilon) F_2(\frac{M^2}{4\epsilon})(\frac{2\pi}{w(\epsilon)})^{1/2}, \quad (1)$$

where N_c, N_s are color and spin degeneracy factors respectively, N_f is the number of flavour, e_f is the electric charge of a quark with flavour f, $\sigma(M) = \frac{4\pi}{3}\frac{\alpha^2}{M^2}\sqrt{(1-\frac{4m_l^2}{M^2})}(1+\frac{2m_l^2}{M^2})$, α is the fine structure constant, m_l is

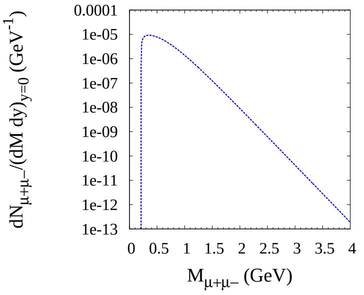

FIG. 2: Dimuon invariant mass distribution.

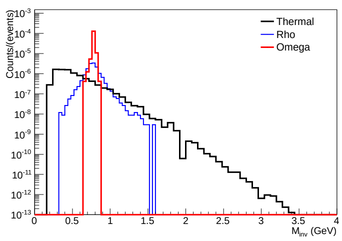

FIG. 3: Reconstructed invariant mass of di-muons.

the mass of the lepton (in our present analysis m_l is the mass of muons), $F_2(E) = -\int_{\infty}^{E} f_2(E')dE'$, f_1 (f_2) is the quark (anti-quark) distribution function, $\epsilon(M)$ is the root of the equation $\frac{d}{dE}[lnf_1(E)+lnF_2(\frac{M^2}{4E})]_{E=\epsilon} = 0$, $w(\epsilon) = -[\frac{d^2}{dE^2}(lnf_1(E)+lnF_2(\frac{M^2}{4E}))]_{E=\epsilon}$.

For simplicity we assume one dimensional Bjorken expansion for which $d^4x = \pi R_A^2 \tau d\tau dy$, where R_A is the radii of the colliding nuclei, y is the fluid rapidity and τ is proper time.

So,

$$\frac{dN_{l^+l^-}}{dMdy} = \int 2M(N_c N_s^2 \sum_{f=1}^{N_f} (\frac{e_f}{e})^2 \frac{\sigma(M)}{2(2\pi)^4} M^2 \times f_1(\varepsilon) F_2(\frac{M^2}{4\varepsilon})(\frac{2\pi}{w(\varepsilon)})^{1/2})\pi R_A^2 \tau d\tau. \quad (2)$$

To calculate the above quantity we have to know the initial time of the expansion of the fireball as well as the dependency of temperature and chemical potential of the system with time for which we have to know the equation of state of the system. For Au+Au collisions at $\sqrt{s} = 8$ GeV, initial time of the thermalized fireball is taken as $1fm$. Using the available experimental data of heavy ion collision ($R \sim 6.3fm$) near $\sqrt{s} = 8$ GeV, we have estimated T_i and μ_{b_i} as 181 MeV and 1034 MeV respectively. The temperature and chemical potential of the system at a particular time can be calculated using the relations $n_b\tau = (n_b\tau)_i$ and $\varepsilon\tau^{1+c_s^2} = (\varepsilon\tau^{1+c_s^2})_i$ and using the information of initial conditions T_i and μ_i. In Fig. 1 we have shown variation of temperature and baryonic chemical potential with time. Here we have assumed that the system is in QGP phase till $\varepsilon = 0.6GeV/fm^3$ which corresponds to four times the nuclear density ($150MeV/fm^3$). In Fig. 2 we have shown dimuon invariant mass distribution. This thermal dimuon produces a continuum in invariant mass distribution. Now we will discuss about application of these calculations in simulation for CBM experiment at FAIR. For CBM experiment, muonic detector system consists of segmented absorbers with tracking chamber triplets placed in between the absorber segments. Using those theoretical calculations we have generated four-momentum of μ^+ and μ^- and used them in simulation in CBMROOT. To use this we have used FairAsciiGenerator as our primary event-generator. Geometry which is used in this simulation is SIS300. After passing through absorbers and detectors, we have reconstructed the invariant-mass of muon pairs. We have used several cuts like hits in MUCH detectors $\geq$ 14, hits in STS detectors $\geq$ 4 and $\chi^2 < 3$. We have compared reconstructed invariant-mass of muon pairs coming from low mass vector mesons ρ and ω. For ρ and ω, we have used pluto event generator. In Fig. 3 we have shown the reconstructed invariant mass of di-muons. It can be seen that, in low mass region thermal part is buried inside low-mass vector mesons. However, they are important in the intermediate mass region.