Nuclear modification factor of light hadrons in an anisotropic *Quark-Gluon-Plasma*

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We calculate the nuclear modification factor (R_{AA}) of light hadrons by taking into account the initial state momentum anisotropy of the quark gluon plasma (QGP).A phenomenological model for the space time evolution of the anisotropic QGP is used to obtain the time dependence of the anisotropy parameter ξ and the hard momentum scale, $p_{\rm hard}$. The result is then compared with the PHENIX experimental data to constrain the isotropization time scale, $\tau_{\rm iso}$ for fixed initial conditions (FIC).It is shown that the extracted value of $\tau_{\rm iso}$ lies in the range $0.5 \leq \tau_{\rm iso} \leq 1.5$.The present calculation is also extended to contrast with the recent measurement of nuclear modification factor by ALICE collaboration at $\sqrt{s} = 2.76$ TeV. It is argued that in the present approach, the extraction of $\tau_{\rm iso}$ at this energy is uncertain and, therefore, refinement of the model is necessary. The sensitivity of the results on the initial conditions has been discussed. We also present the nuclear modification factor at LHC energies with $\sqrt{s} = 5.5$ TeV.

1. Introduction

The partonic energy loss can be probed by measuring the high p_T hadrons emanating from ultra-relativistic heavy ion collisions. This idea was first proposed by Bjorken [1] where 'ionization loss' of the quarks and gluons in a QCD plasma was estimated. In QCD medium, the partons can dissipate energy in two ways, *viz.*, by two body collisions or *via* the bremsstrahlung emission of gluons, commonly referred to as collisional and radiative loss respectively. The possibility of QGP formation at RHIC experiment, with initial density of 5 GeV/fm^3 is supported by the observation of high p_T hadron suppression (jet-quenching) in the central Au-Au collisions compared to the binary-scaled hadron-hadron collisions [1, 2].

However, many properties of QGP are still poorly understood. The most debated question is whether the matter formed in the relativistic heavy ion collisions is in thermal equilibrium or not. Recent hydrodynamical studies [3] have shown that due to the poor knowledge of the initial conditions there is a sizable amount of uncertainty in the estimate of thermalization or isotropization time. It is suggested that (momentum) anisotropy driven plasma instabilities may speed up the process of isotropization [4], in that case one is allowed to use hydrodynamics for the evolution of the matter.

The rapid expansion of the matter along the beam direction causes faster cooling in the longitudinal direction than in the transverse direction [5]. As a result, the system becomes anisotropic with $\langle {p_L}^2\rangle << \langle {p_T}^2\rangle$ in the local rest frame. At some later time when the effect of parton interaction rate overcomes the plasma expansion rate, the system returns to the isotropic state again and remains isotropic for the rest of the period. Thus, during the early stage the plasma remains anisotropic and any calculation of energy loss should, in principle, include this aspect. The collisional energy loss in anisotropic media for heavy fermions has been calculated in Refs. [6, 7]. For a parton propagating in the direction of anisotropy it is found that that the fractional energy loss increases by a factor of 1.5 - 2 depending upon the anisotropy parameter ξ. In the present work, we shall apply this formalism to calculate the nuclear modification factor for light hadrons. A phenomenological model for the space-time evolution will be used for the time evolution of ξ and $p_{\rm hard}$.

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2. p_T spectrum

The differential cross-section for hadron production is [8],

$$E\frac{d\sigma}{d^3p}(AB \to \text{jet} + X) = K\sum_{abcd} \int dx_a dx_b G_{a/h_A}(x_a, Q^2)\, G_{b/h_B}(x_b, Q^2) \frac{\hat{s}}{\pi}\frac{d\sigma}{d\hat{t}}(ab \to cd)\delta(s + \hat{t} + u), \quad (1)$$

It should be noted that to obtain single particle inclusive invariant cross-section in hadron-hadron collisions, the fragmentation function $D_{h/c}(z, Q^2)$ must be included. Multiplying the result by the nuclear overlap function for a given centrality one can obtain the p_T distribution of hadrons in $A - A$ collisions.

Now in order to obtain the hadronic p_T spectrum in $A - A$ collisions we modify the fragmentation function to obtain an effective fragmentation function as follows:

$$D_{h/c}(z, Q^2) = \frac{z^*}{z} D_{h/c}(z^*, Q^2) \quad (2)$$

where, $z^* = z/(1-\Delta E/E)$ is the modified momentum fraction. Also in order to take into account the jet production geometry we assume that all the jets are not produced at the same point and the path length traversed by these partons before fragmentation are not the same. It is also assumed that the jet initially produced at (r, ϕ) leaves the plasma after a proper time (t_L) or equivalently after traversing a distance L (for light quarks $t_L \sim L$) given by $L(r, \phi) = \sqrt{R_T^2 - r^2 \sin\phi^2} - R_T \cos\phi$, where R_T is the transverse dimension of the system. The number of jets produced at $\vec{r}$ is proportional to the number of binary collisions, the probability is proportional to the product of thickness functions :

$$\mathcal{P}(\vec{r}) \propto T_A(\vec{r})\, T_B(\vec{r}) \quad (3)$$

we obtain the p_T spectra of hadrons as follows:

$$\frac{dN^{\pi^0(\eta)}}{d^2p_T dy} = \sum_f \int d^2r \mathcal{P}(r) \int_{t_i}^{t_L} \frac{dt}{t_L - t_i} \int \frac{dz}{z^2} \times D_{\pi^0(\eta)/f}(z, Q^2)|_{z = p_T/p_T^f}\, E\frac{dN}{d^3p^f} (4)$$

The quantity $E\frac{dN}{d^3p^f}$ is the initial momentum distribution of jets and can be computed using LO-pQCD.For the fragmentation function Eq.(2) has been used. We use the average value of distance traversed by the partons, $\langle L \rangle$ given by [9]

$$\langle L \rangle = \frac{\int_0^{R_T} rdr \int_0^{2\pi} L(\phi, r) T_{AA}(r, b = 0) d\phi}{\int_0^{R_T} rdr \int_0^{2\pi} T_{AA}(r, b = 0) d\phi} \quad (5)$$

The nuclear modification factor, R_{AA} is defined as

$$R_{AA}(p_T) = \frac{\frac{dN_{AA}^{\pi^0(\eta)}}{d^2p_T dy}}{\left[\frac{dN_{AA}^{\pi^0(\eta)}}{d^2p_T dy}\right]_0} \quad (6)$$

where the suffix '0' in the denominator indicates that energy loss has not been considered while evaluating the expression.

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