Nuclear Modification factor of heavy flavours using Tsallis Statistics

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Introduction

The search for a possible deconfined state of quarks and gluons (QGP) is one of the major goals of heavy ion collisions. The bulk properties of QGP are governed by light quarks whereas the heavy flavour quarks act as probes for QGP properties as they witness the entire plasma evolution. Heavy quarks can retain the entire interaction history as the time scale of thermalization of heavy quarks is longer than that of light quarks. The energy loss is more for high-p_T heavy quark flavours due to interaction with the medium. Finally they appear as constituents of hadrons. The nuclear modification factor, R_{AA} is a measure of medium modification of particle yield/spectra. It can be represented as

$$R_{AA} = \frac{f_{fin}}{f_{in}}, \tag{1}$$

where f_{in} is the distribution of the highly energetic particles immediately after their formation and f_{fin} is the distribution of the particles after the interaction with the medium.

In this work the initial distribution is represented with the help of Tsallis distribution. We plug the initial distribution (f_{in}) in Boltzmann Transport Equation (BTE) and solve it with the help of Relaxation Time Approximation (RTA) of the collision term to find out f_{fin}.

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R_{AA} in Relaxation Time Approximation

The evolution of the particle distribution due to its interaction with the medium is studied through BTE,

$$\frac{df(x,p,t)}{dt} = \frac{\partial f}{\partial t} + \vec{v}.\nabla_x f + \vec{F}.\nabla_p f = C[f], \tag{2}$$

where $f(x,p,t)$ is the distribution of particles which depends on position, momentum and time. v is the velocity and F is the external force. $C[f]$ is the collision term which encodes the interaction of the probe particles with the medium. Assuming homogeneity of the system and absence of external force, the second and third term of the above equation become zero.

In RTA, the collision term is expressed as,

$$C[f] = -\frac{f - f_{eq}}{\tau}, \tag{3}$$

where f_{eq} is Boltzmann distribution characterized by a temperature T_{eq} and τ is the relaxation time. Solving Eq. 2, the nuclear modification factor is expressed as,

$$R_{AA} = \frac{f_{fin}}{f_{in}} = \frac{f_{eq}}{f_{in}} + \left(1 - \frac{f_{eq}}{f_{in}}\right) e^{\frac{-t_F}{\tau}}, \tag{4}$$

where t_F is the freeze-out time.

A thermodynamically consistent non-extensive Tsallis distribution, which is used as the initial distribution, is given by,

$$f_{in} = \frac{gV}{(2\pi)^2} p_T m_T \left[1 + (q-1)\frac{m_T}{T}\right]^{-\frac{q}{q-1}}. \tag{5}$$

And, the equilibrium Boltzmann distribution is given by,

$$f_{eq} = \frac{gV}{(2\pi)^2} p_T m_T e^{-\frac{m_T}{T_{eq}}} \tag{6}$$

Here, V is the system volume, $m_{\rm T}$ is the transverse mass and q is the non-extensive parameter, which measures the degree of deviation from equilibrium. Using Eqs. 5 and 6 nuclear modification factor is expressed as,

$$R_{AA} = \frac{e^{-\frac{m_T}{T}}}{(1+(q-1)\frac{m_T}{T})^{-\frac{q}{q-1}}} + \left[1 - \frac{e^{-\frac{m_T}{T}}}{(1+(q-1)\frac{m_T}{T})^{-\frac{q}{q-1}}}\right] e^{-\frac{t_F}{\tau}} \quad (7)$$

Results and Discussion

From Eq.7, it is observed that for higher values of q, R_{AA} decreases for all the values of p_T. This suggests that when the initial distribution remains closer to equilibrium, the suppression becomes less.

We fit the R_{AA} spectra using TMinuit class available in ROOT library to get a convergent solution by keeping all the parameters free except the the equilibrium temperature T_{eq} which is fixed at 160 MeV. The convergent solutions are obtained for T, q and t_F/τ by χ^2 minimization technique in the present analysis.

In Fig. 1 we fit the experimental data for D^0 meson in most central Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV (triangles) and for (30-50)% central Pb+Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV (dots). Fig. 2 shows the fitting of the experimental data for J/ψ in most central Pb+Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV (triangles) and $\sqrt{s_{NN}}$= 5.02 TeV (dots). The model fits the experimental data of D^0 and J/ψ for all p_T ranges.

Also, mass dependence of the parameter t_F/τ is studied. It is observed that heavy particles have more relaxation time compared to lighter particles.

A detailed description of the formalism and its application to study the R_{AA} of light and heavy flavoured particles at different energies are discussed in Ref. [1]

Acknowledgments

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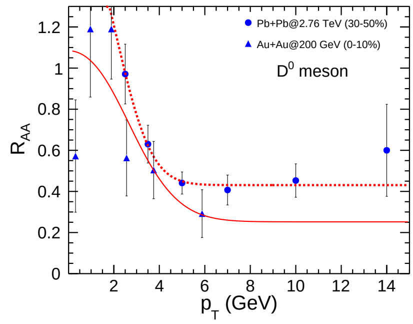

FIG. 1: Fitting of experimental data with the proposed model (Eq.7) for D^0 meson in most central Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV (triangles) and for (30-50)% central Pb+Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV (dots).

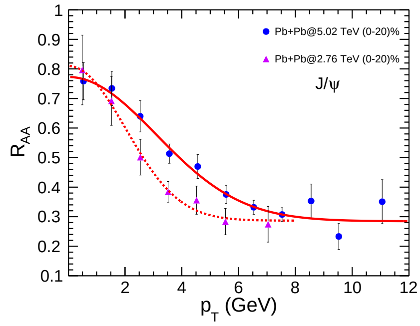

FIG. 2: Fitting of experimental data with the proposed model (Eq.7) for J/ψ in most central Pb+Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV (triangles) and $\sqrt{s_{NN}}$= 5.02 TeV [2] (dots).

References

[1] S. Tripathy, T. Bhattacharyya, P. Garg, P. Kumar, R. Sahoo and J. Cleymans, arXiv:1606.06898 [nucl-th], [Eur. Phys. J A (2016) (in press)]

[2] J. Adam *et al.* [ALICE Collaboration], arXiv:1606.08197 [nucl-ex].