Nuclear Modification Factor using Tsallis Blast Wave Description in Boltzmann Transport Equation at LHC Energies

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Introduction

Understanding the properties and behaviour of quark-gluon plasma (QGP) is a central challenge in the field of heavy-ion collision physics. It requires probing the fleeting moments when QGP forms and evolves within the ultra-hot and dense medium created during such collisions at Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC). The nuclear modification factor R_{AA} is a key observable in the study of high-energy heavy-ion collisions. R_{AA} is calculated by dividing the actual yield of the particles observed in heavy-ion collisions by the yield expected from a scaled proton-proton collision, taking into account the number of binary collisions, N_{coll} in the heavy-ion collision.

In the present work, we have employed the Boltzmann Transport Equation (BTE) in relaxation time approximation (RTA) to characterize the R_{AA} spectra and R_{pPb}. We have utilized the Tsallis statistics as the initial distribution function and Tsallis Blast Wave (TBW) model as an equilibrium distribution function, which are parameterized by two key factors: q_{pp}, q_{AA} and the temperatures.

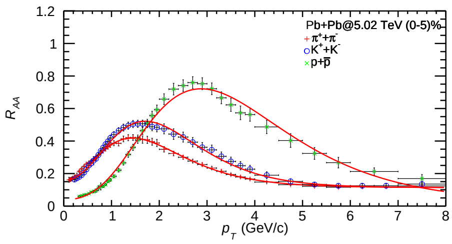

FIG. 1: R_{AA} vs. p_T of $(\pi^+ + \pi^-)$, $(K^+ + K^-)$ and $(p + \bar{p})$ at (0-5)% for Pb-Pb collisions.[2]

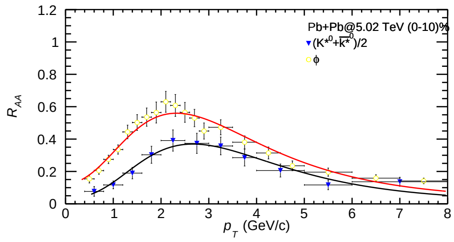

FIG. 2: R_{AA} vs. p_T of $(K^{*0} + \bar{K}^{*0})/2$ and ϕ for Pb-Pb collisions for the (0-10)% centrality[3]

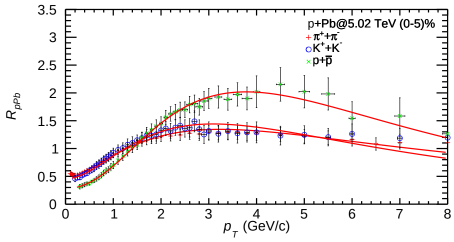

FIG. 3: R_{pPb} vs. p_T of $(\pi^+ + \pi^-)$, $(K^+ + K^-)$ and $(p + \bar{p})$ in (0-5)% centrality for p-Pb collisions.[4]

Formulation

We have used BTE with RTA and we get the final distribution function as follows [1]:

$$f_{fin} = f_{eq} + (f_{in} - f_{eq})e^{\frac{-t_f}{\tau}} \quad (1)$$

The nuclear modification factor can be ex-

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pressed as

$$R_{AA} = \frac{f_{fin}}{f_{in}} = \frac{f_{eq}}{f_{in}} + \left(1 - \frac{f_{eq}}{f_{in}}\right) e^{\frac{-t_f}{\tau}} \quad (2)$$

Using Tsallis Blast wave and Tsallis power law as equilibrium and initial distribution function, respectively R_{AA} can be written as:

$$R_{AA} = \frac{f_{fin}}{f_{in}} = C \frac{\int_{-\pi}^{+\pi} d\phi \times \int_0^R r\, dr \left[1 + \frac{(q_{AA}-1)}{T}\left[m_T \cosh(\rho) - p_T \sinh(\rho)\cos(\phi)\right]\right]^{\frac{-1}{q_{AA}-1}}}{\left[1 + (q_{pp}-1)\frac{m_T}{T_{ts}}\right]^{\frac{-q_{pp}}{q_{pp}-1}}} + \left(1 - C \frac{\int_{-\pi}^{+\pi} d\phi \times \int_0^R r\, dr \left[1 + \frac{(q_{AA}-1)}{T}\left[m_T \cosh(\rho) - p_T \sinh(\rho)\cos(\phi)\right]\right]^{\frac{-1}{q_{AA}-1}}}{\left[1 + (q_{pp}-1)\frac{m_T}{T_{ts}}\right]^{\frac{-q_{pp}}{q_{pp}-1}}}\right) e^{\frac{-t_f}{\tau}} \quad (3)$$

where $C= D/D'$, here D and D' are the normalisation constants of Tsallis blast wave and tsallis power law distribution, respectively.

Results and Discussions

In Figures 1 and 2, we show the fitted R_{AA} spectra encompassing pions, kaons, protons, $(K^{*0} + \bar{K}^{*0})/2$, and ϕ mesons obtained from Pb-Pb collisions at a central collision configuration with a center-of-mass energy of $\sqrt{s_{NN}}$ = 5.02 TeV. Additionally, Figure 3 provides a visualization of the fitted R_{AA} spectra for pions, kaons, and protons arising from the most central p-Pb collision at the center-of-mass energy, $\sqrt{s_{NN}}$ = 5.02 TeV. We have generated the data of R_{pPb} by using the input of the experimental yields of hadrons in $p-Pb$ collisions. Our presently employed model, as described in equation 3, adeptly captures these R_{AA} spectra within the range of transverse momenta p_T up to approximately 8 GeV/c, showcasing a commendably low χ^2/ndf ratio.

We observe that the extracted average transverse velocity denoted as $< \beta_r >$ decreases as the particle mass increases aligning the hydrodynamic properties of heavy-ion collision. This may be due to heavier particles tend to exhibit less radial expansion because they are less affected by the pressure gradients in the transverse direction. This reduced expansion leads to lower transverse velocities.

Moreover, we observe a consistent rise in the ratio t_f/τ as particle mass increases in heavy ion collisions. This phenomenon can be attributed to the fact that heavier particles, characterized by their greater inertia, exhibit reduced sensitivity to the collective flow effects, allowing them to persist within the medium for an extended period before undergoing freeze-out.

References

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