A generalized approach to study low as well as high pT regime of transverse momentum spectra

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Presented at: SLAC Summer Institute-2020

Motivation

Studying the QCD matter produced under extreme condition of temperature and density called Quark Gluon Plasma (QGP) is among the important goal of heavy-ion collision experiments. QGP state is being created for a very short interval of time (~10^{-22} s) so we cannot directly probe this state. Hence we utilize kinematic data of final state particles produced in heavy-ion collision in order to study the dynamics of QGP. Transverse momentum (p_{T}) spectra is one such kinematic variable that gives us information about the thermodynamical as well as hydrodynamical properties of the system produced in heavy-ion collision. We have developed a unified formalism to study full range of p_{T} spectra including both soft as well as hard part using a single distribution function.

Quantum Chromo Dynamics (QCD)

QCD is the field theoretical framework which governs the strong interaction between quarks and gluons.

Theoretical models for p_{T} spectra

- Due to the asymptotic freedom and very nature of QCD coupling constant, it is difficult to apply perturbative QCD at low energy because of high coupling strength.
- To overcome this issue, we resort to phenomenological models with most common being the statistical approach to explain low-p_{T} part of the spectra whereas we have a well defined perturbative QCD based power-law form of distribution function for high-p_{T} region corresponding to particles produced in hard processes.

Conventional Approach to study p_{T} spectra

- Considering the particles produced in heavy-ion collision to be of thermal origin. Most natural choice to explain energy spectra is Boltzmann distribution.
- For Boltzmann distribution, p_{T} spectra is given as

\[ \frac{1}{2\pi p_T} \frac{d^3N}{dp_T dy} = \frac{g T^3}{(2\pi)^3} \exp \left( \frac{-m_T}{T}\right) \]

- Here m_{T} is the transverse mass given as

\[ m_T = \sqrt{p_T^2 + m^2} \]

- In the graph above, we have fitted p_{T} spectra of positive pions produced in 2.76 TeV Pb-Pb collision with the Boltzmann distribution function.
- We observe that Boltzmann distribution deviates significantly from data beyond certain p_{T} range.
- In order to overcome this problem, Tsallis statistics have been introduced in high energy physics.

- Tsallis statistics [2] is a generalised Boltzmann-Gibbs statistics which also takes into account non-extensivity in the system.
- Non-extensivity can arise in strongly coupled system.

\[ \frac{1}{2\pi p_T} \frac{d^3N}{dp_T dy} = \frac{g T^3}{(2\pi)^3} \left[ 1 + \left( q - 1 \right) \frac{m_T}{T} \right] ^{-\frac{1}{q-1}} \]

- Non-extensivity parameter "q" takes care of deviation from thermal equilibrium.
- Tsallis distribution deviates from data at high p_{T} region corresponding to hard scattering.

Pearson Distribution

- Hard scattering part of p_{T} spectra is governed by power law form:

\[ f(p_T) = C (1 + \frac{p_T}{p_0})^{-\alpha} \]

- Pearson distribution [3] is a generalised form of many probability distribution functions like gaussian, exponential, gamma distributions etc.
- It is given in form of differential equation:

\[ \frac{1}{p(x)} \frac{dp(x)}{dx} + b_2 p(x) - b_1 \frac{x}{p(x)} = 0 \]

- Parameters a, b_1, b_2, b_3 are related to first four moments of a distribution.
- We have modified solution of this distribution function by substituting physics parameters to give transverse momentum spectra [1].

\[ \frac{1}{2\pi p_T} \frac{d^3N}{dp_T dy} = \beta \left( \frac{1 + \frac{p_T}{p_0}}{\alpha} \right)^{-\alpha} \left[ 1 + \left( q - 1 \right) \frac{m_T}{T} \right] ^{-\frac{1}{q-1}} \]

Here parameter values are such that the "soft" part decay very quickly and hence giving way for dominance of "hard" part after certain p_{T} value.

Results

Plots of p_{T}-spectra of charged hadrons produced in 2.76 TeV Pb-Pb collision [4] at four different centrality fitted with different distribution function.

Flow Analysis

- Flow corresponds to the azimuthal anisotropy in distribution of particle produced in heavy ion collision.
- Here v_{n} is the nth order flow coefficient.

Final state momentum anisotropy v_{n} is correlated to initial spatial eccentricity \( \varepsilon_{n} \)

We observed a linear relationship between one of the pearson fit parameter with elliptic flow coefficient v_{2}[2] obtained from Ref [5].

Summary

- Tsallis distribution deviates from data as we move towards higher p_{T} region.
- We developed a generalized approach to study both low as well as high p_{T} regions of the spectra.
- We also observe that there is a linear relationship between one of the fitted parameters and elliptic flow coefficient.

Acknowledgement

We would like to acknowledge the financial support provided by CSIR through fellowship number 09/947 (0067) 2015-EMR-1.

References


