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

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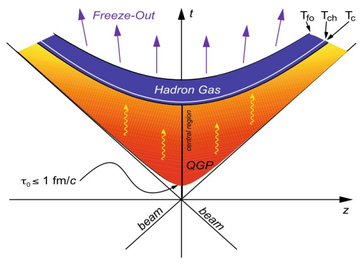
Presented at: International Conference on High Energy Physics-2020, Prague, Czech Republic

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 variabl 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.

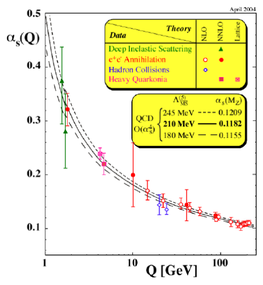


Quantum Chromo Dynamics (QCD)

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 statiatical 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.

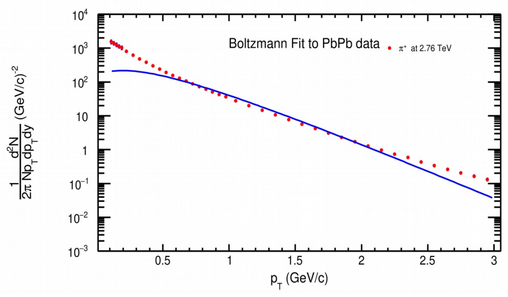


Boltzmann Distribution

- 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

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

- Graph represent a Boltzmann fit to most central π^+ particles
- produced in Pb-Pb collision at 2.76 TeV.
- Graph represent that the Boltzmann distribution is not a good
- explanation of p_T data.

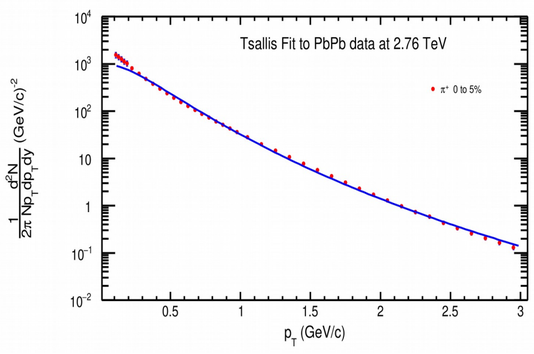


Tsallis Distribution

- 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.

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

- 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:

$$f(p_T) = \frac{1}{N}\frac{dN}{dp_T} = Ap_T\left(1+\frac{p_T}{p_0}\right)^{-n}$$

- 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:
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$$\frac{1}{p(x)}\frac{dp(x)}{dx} + \frac{a+x}{b_0+b_1x+b_2x^2} = 0$$

- Parameters a, b_0 , b_1, b_2 are related to first four moments of a distribution.
- Different condition on parameters a, b_0, b_1, b_2 or more generally different types of root of quadratic equation in the denominator will give different distribution functions.

- Solution of this differential equation will be of the form

$$p(x) = C(e+x)^f(g+x)^h$$

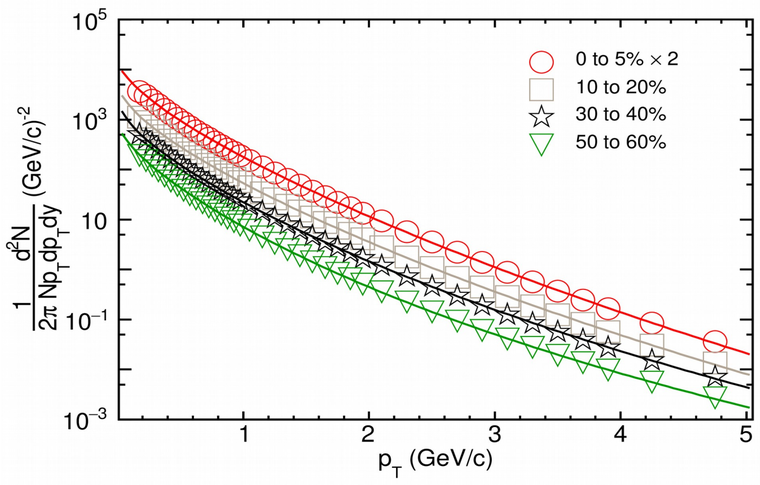
- We have modified this form of Pearson distribution by substituting physics parameters to give transverse momentum spectra [1]

$$\frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy} = B\left(1+\frac{p_T}{p_0}\right)^{-n}\left(1+(q-1)\frac{p_T}{T}\right)^{-\frac{q}{q-1}}$$

Hard-processes Soft-processes

- 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



Pearson Fit to p_T-spectra of charged hadrons produced in 2.76 TeV Pb-Pb collision [4] at four different centrality.

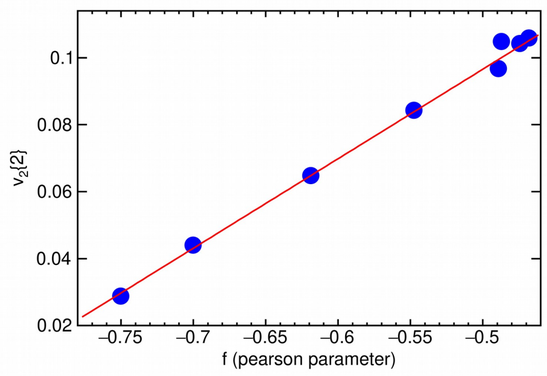
Flow Analysis

- Flow corresponds to the azimuthal anisotropy in distribution of particle produced in heavy ion collision.

$$E\frac{d^3N}{dp^3} = \frac{1}{p_T}\frac{d^2N}{dp_T dy}\frac{N}{2\pi}[1+2\sum_n v_n cos\{n(\phi-\psi)\}]$$

- Here, v_n is the nth order flow coefficient.

Initial geometry fluctuation → Final particle momentum anisotropies



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 distribudion 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

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