# An Overview of Differential freezeout and Radial flow in *pp*-collisions at $\sqrt{s} = 7$ TeV at the LHC

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## Introduction

It has been always a matter of interest to study *pp*-collisions at the relativistic energies. In this order, transverse momentum ($p_T$)-spectra has been analysed as a function of charged-particle multiplicity at midrapidity ($|y| < 0.5$) for various identified non-strange, strange and multistrange hadrons in *pp*-collisions at $\sqrt{s} = 7$ TeV. For this, we have made use of Boltzmann-Gibbs Blast Wave (BGBW) model and thermodynamically consistent Tsallis distribution function. The kinetic freezout temperature ($T_{kin}$) and radial flow ($\beta$) has been extracted by BGBW model while non-extensive parameter ($q$) by the Tsallis distribution function. The expression for invariant yield in BGBW model is given by

$$\frac{d^2N}{dp_T dy}\mid_{y=0} = D\int_0^{R_0} r\ drK_1\left(\frac{m_T cosh\rho}{T_{kin}}\right) I_0\left(p_T\frac{sinh\rho}{T_{kin}}\right), \quad (1)$$

where $D$ is normalisation constant, $m_T = \sqrt{p_{\rm T}^2 + m^2}$ is transverse mass. The average transverse velocity by BGBW model is given by

$$\langle\beta\rangle = \frac{\int \beta_s\xi^n d\xi}{\int \xi\ d\xi} = \left(\frac{2}{2+n}\right)\beta_s, \quad (2)$$

where $\rho = \tan^{-1}\ \beta$ and $\beta = \beta_s(\xi)^n$ is radial flow. $\beta_s$ is maximum surface velocity and $\xi = (r/R_0)$ where r is radial distance.

On the other hand, thermodynamically consistant non-extensive Tsallis distribution function is given by

$$\frac{1}{p_T}\frac{d^2N}{dp_T dy}\Big|_{y=0} = \frac{gVm_T}{2\pi^2}\left[1+(q-1)\frac{m_T}{T}\right]^{-\frac{q}{q-1}} \quad (3)$$

where $q$ is a measure of degree of deviation from equilibrium.

## Results and Discussions

We have observed a dependence of kinetic-freezeout temperature ($T_{kin}$) on the charge multiplicity ($dN_{ch}/d\eta$). The study reveals a clear mass ordering regarding the temperature *i.e.* heavier particles freeze out at a higher temperature than the lighter particles. This observation supports the well-known idea of differential freezeout hypersurface because it is assumed that heavier particles freeze out from inner hypersurface relatively at a higher temperature.

The reasonable answer to this behavior lies in the lower cross-section of heavier particles, which is responsible for less scattering and leads to an earlier freezeout than the lighter particles (See FIG. 1). Another interesting observation is regarding the non-extensive parameter ($q$), which represents the degree of non-extensivity, tends towards the unity at the higher multiplicity. This observation forwards to heavy-ion like behavior in *pp*-collisions. To explain this behavior, the concept of thermal

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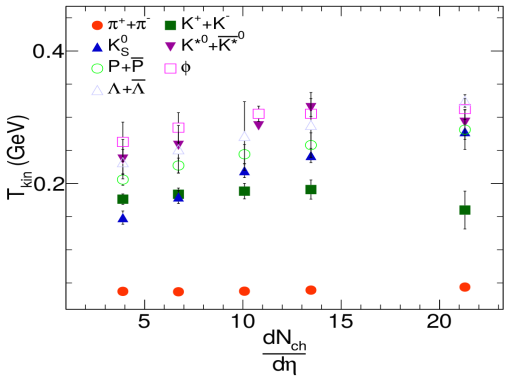


FIG. 1: (Color online) Multiplicity dependence of $T_{\rm kin}$ for *pp*-collisions at $\sqrt{s} = 7$TeV using BGBW model

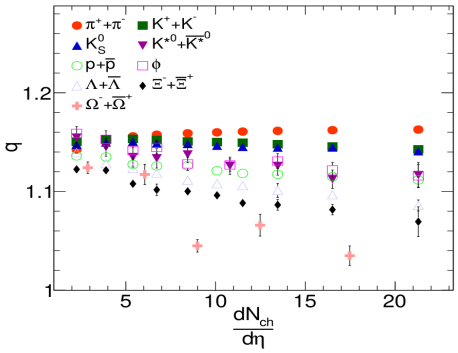


FIG. 2: (Color online) Multiplicity dependence of $q$-parameter for *pp*-collisions at $\sqrt{s} = 7$TeV using Tsallis distribution statistics model

equilibrium can be applied. In the higher multiplicity, the interactions among the particles increase so it can be assumed that it leads towards the thermal equilibrium. It is obvious from Eq. 3, if $q \to 1$ then the equation reduces to Boltzmann equation, which signifies a system in thermal equilibrium (See FIG. 2).

Another observation of interest lies in radial flow ($\beta$) extraction. A mass ordering has been observed with respect to charge multiplicity where lighter particles *i.e.* $\pi^{\pm}$ get relatively higher boost (higher magnitude of $\beta$) while

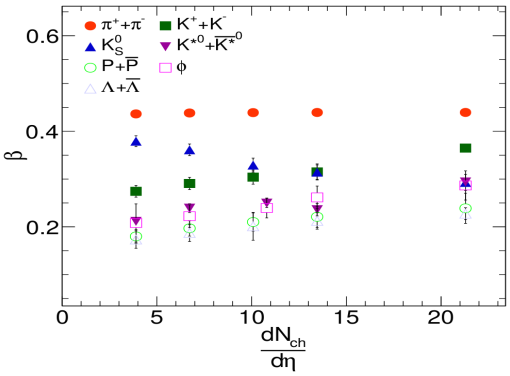


FIG. 3: (Color online) Multiplicity dependence of $\beta$ for *pp*-collisions at $\sqrt{s} = 7$TeV using BGBW model

heavier one *i.e.* $p + \bar{p}$ finds lower boost than lighter particles. This observation supports the heavy-ion like behavior (See FIG. 3).

Conclusively, kinetic-freezeout temperature ($T_{kin}$) has been extracted for identified hadrons using the BGBW model, which are different for strange and non-strange hadrons. This observations assists the idea of differential-freezeout in *pp*-collisions at the LHC. On the other hand, study of the $q$-parameter at higher multiplicities using Tsallis distribution function, supports the idea of thermal equilibrium in the produced system in *pp*-collisions. In the observation of radial-flow ($\beta$), an expected mass-ordering has been noticed for identified hadrons and can be recognized as a hydrodynamic behavior of the system.

## References

[1] A. Khuntia, H. Sharma, S. K. Tiwari, R. Sahoo and J. Cleymans, arXiv:1808.02383 [hep-ph].