Energy and rapidity dependence of pion production at relativistic energies using Tsallis statistics

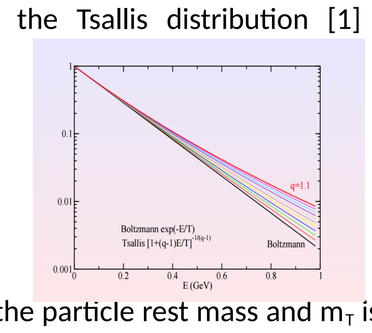
Oana RISTEA*, A. JIPA*, C. RISTEA*, , I. LAZANU*, M. CALIN*, T. ESANU*****

**University of Bucharest, Faculty of Physics, **Institute of Space Science, Magurele, ***IFIN-HH, Magurele*

Introduction

The transverse momentum spectra can be described by the Tsallis distribution [1] characterized by the nonextensivity parameter q and the temperature T:

$$\frac{d^2N}{p_T dp_T dy} = gV\frac{m_T\cosh(y)}{(2\pi)^2}\times \left[1+(q-1)\frac{m_T\cosh(y)-\mu}{T}\right]^{\frac{q}{1-q}}.$$



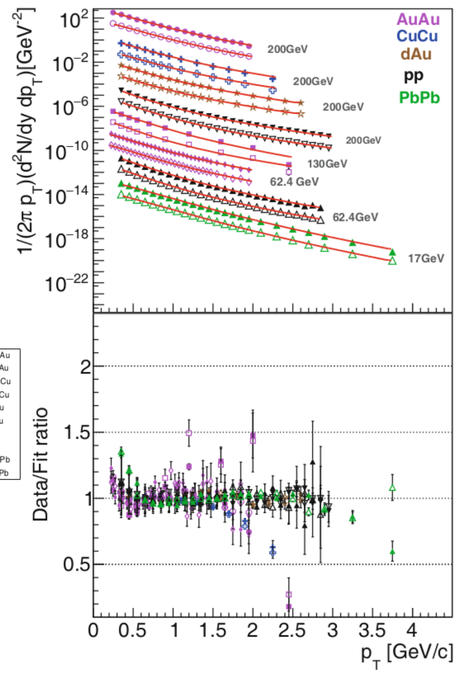
where g is the degeneracy factor, V is the volume, y is the rapidity, m is the particle rest mass and m_T is the transverse mass. The fit parameters are T, V and q. The T parameter can be interpreted as system temperature at the thermal freeze-out stage due to the similarity to the values obtained using the blast-wave model [2]. The non-extensivity parameter, q, which is always close to 1, is a measure of the deviation from the standard Boltzmann distribution. This parameter can be related to the non-equilibrium degree of the system and intrinsic fluctuations in the hadronic medium [3]. In the produced system temperature fluctuations could appear causing deviation of the system from the equilibrium state. Local temperature of the system T fluctuates in different parts of the system around a mean, equilibrium value, T_0: these fluctuations are due to possible energy transfer between the central, participant region and the spectator regions situated at forward rapidities.

Results – energy dependence

Transverse momentum spectra of charged pions produced at midrapidity in nuclear collisions at different energies were fitted using the Eq. 1.

The data are from Au+Au collisions (62.4 GeV, 130 GeV and 200 GeV), Cu+Cu and d+Au at 200 GeV, p+p collisions (62 GeV and 200 GeV) and Pb+Pb collisions at 17.3 GeV [4].

The Tsallis temperature, T parameter, is decreasing from top SPS energy to RHIC higher energies for heavy ion collisions, however no significant energy dependence of T was found between 62.4 GeV and 200 GeV.



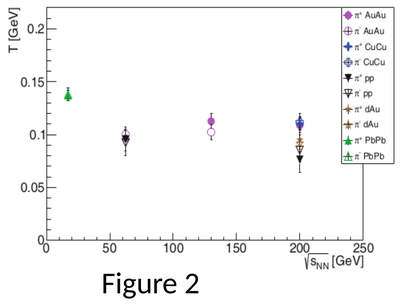


Figure 2

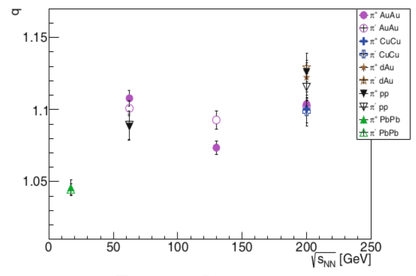


Figure 3

The dependence of nonextensivity parameter on center-of-mass energy per nucleon pair is presented in Figure 3. The symbols represent q parameter extracted from fits to pT spectra of positive and negative pions in different collisions listed above and shown in the figure legend. The q parameter increases with energy and this behaviour was already observed in p+p collisions in Refs. \cite{1401.5639,cleymans_en}. The q values are very close to 1, however a slight larger q seems to be observed for RHIC energies as compared to the top SPS energy.

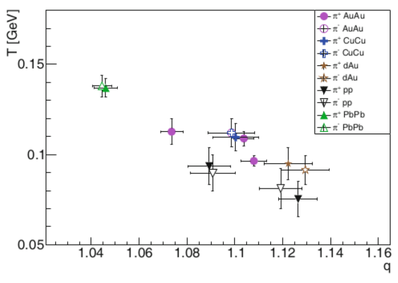


Figure 4

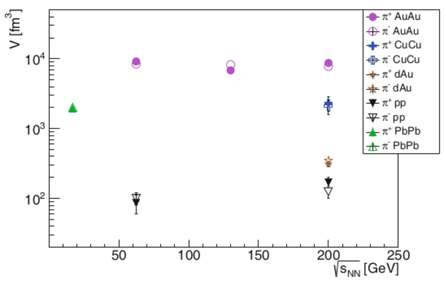


Figure 5

Fig. 4 shows the correlation between the two Tsallis parameters, T and q.

Fig. 5 shows the energy dependence of the Tsallis volume.

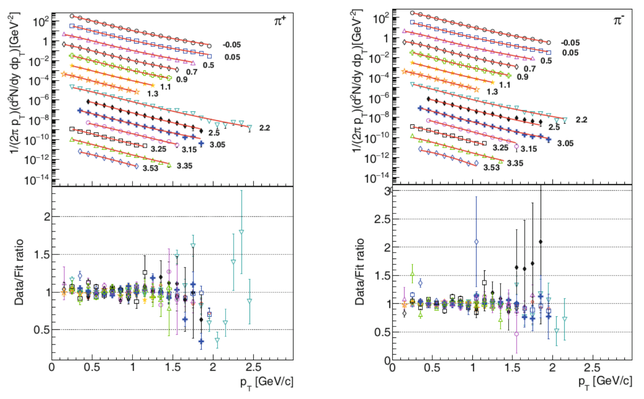
These two parameters are anticorrelated, when T is increasing q is decreasing. The same behaviour was observed in Ref. [6], although in Ref.[6], the parameters were obtained from centrality dependence of Au+Au collisions at 200 GeV. In our analysis, the Tsallis fit parameters are obtained for the most central collisions at different energies. The p+p results are slightly lower than A+A and d+Au results and could suggest that the energy transfer between the central region and the rest of the system in p+p collisions is reduced as compared with the other studied collisions.

For the same colliding nuclei, Au+Au, we observe no energy dependence from 62.4 GeV to 200 GeV, but there is a decrease in Tsallis volume at Pb+Pb at 17.3 GeV as compared with the Au+Au volumes at RHIC energies. Decreasing the collision energy, the density of the produced hot matter is decreasing and the number of produced particles is lower. For the same energy, 200 GeV, the Tsallis volume presents a clear dependence on the system size, increasing from p+p, d+Au to Au+Au.

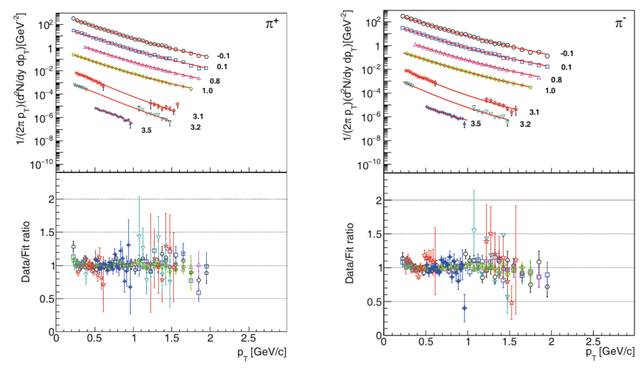
Bibliography:

1. C. Tsallis, J. Statist. Phys. 52 (1988) 479.
2. B. Abelev et al. (STAR Collaboration) Phys.Rev. C 79, (2009) 034909; B. Abelev et al. (ALICE Collaboration) Phys. Rev. C 88, (2013) 044910 (2013)
3. G. Wilk and Z. Wlodarczyk, Phys. Rev. Lett. 84, (2000) 2770; G. Wilk and Z. Wlodarczyk, Eur. Phys. J. A 48, (2012) 161;
4. I. Arsene et al. (BRAHMS Collaboration), Phys. Lett. B 687, (2010) 36; K. Adcox et al. (PHENIX Collaboration), Phys. Rev. C 69, (2004) 024904; I. Arsene et al. (BRAHMS Collaboration), Phys. Rev. Lett. 94, (2005) 162301; I. Arsene et al. (BRAHMS Collaboration), Phys. Rev. C 94, (2016) 014907; S.S. Adler et al. (PHENIX Collaboration), Phys. Rev. C 74, (2006) 024904; A. Adare et al. (PHENIX Collaboration), Phys. Rev. C 83, (2011) 064903; C. Alt et al. (NA49 Collaboration), Phys. Rev. C 77, (2008) 034906; I. Arsene et al. (BRAHMS Collaboration), Phys. Rev. Lett. 98, (2007) 252001
5. M. Rybczynski, Z. Wlodarczyk, Eur. Phys. J. C 74, (2014) 2785; J. Cleymans et al, Phys.Lett. B 723, (2013) 351
6. G. Wilk, Z. Wlodarczyk, Phys.Rev. C79 (2009) 054903

Results –rapidity dependence



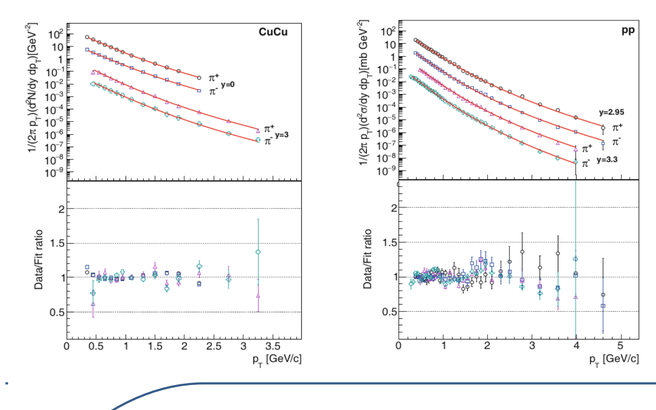
pT spectra of charged pions produced in AuAu collisions at 200 GeV were fitted with Eq (1) (assuming a chemical potential =0).
The 200 GeV Au+Au experimental data are for rapidities y = -0.05, 0.05, 0.5, 0.7, 0.9, 1.1, 1.3, 2.2, 2.5, 3.05, 3.15, 3.25, 3.35, 3.53.



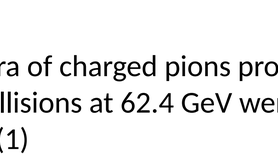
pT spectra of charged pions produced in AuAu collisions at 62.4 GeV were fitted with Eq (1)

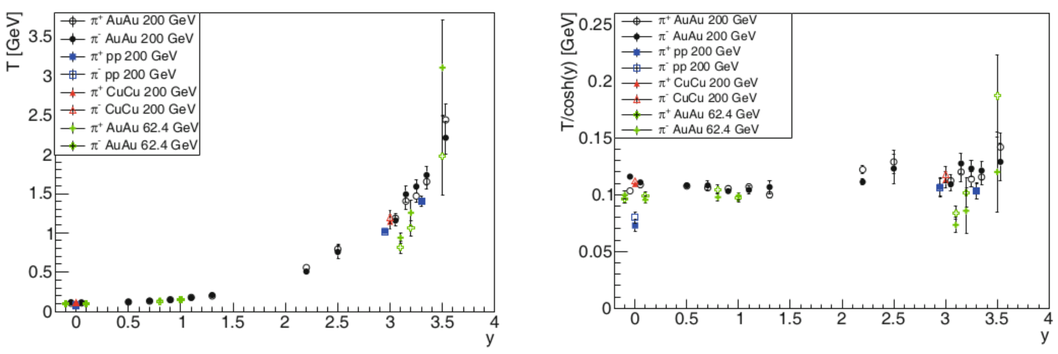
Figures show the experimental data together with the Tsallis fit function. The symbols represent BRAHMS experimental data and the solid curves are the fits of the experimental data using the Tsallis distribution function given in Eq. 1.

The Tsallis fit parameters have been obtained for the most central heavy ion collisions, 0-5% centrality for Au+Au collisions at 200 GeV and 0-10% centrality for Au+Au collisions at 62.4 GeV and Cu+Cu collisions at 200 GeV.

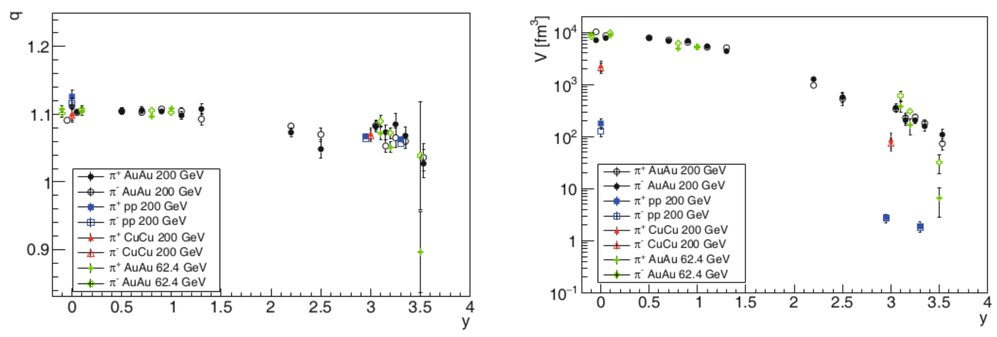


The values of the temperature parameter, T, as a function of rapidity obtained from fits to the charged pion transverse momentum distributions.





The right figure shows the temperatures T/cosh(y). The rapidity dependence of temperatures obtained for Au+Au collisions can be parametrized as $T = T_0 \cosh(y)$, with T_0 as the mean temperature in the system. For Au+Au collisions we found a value for T_0 = 0.107 +/- 0.001 GeV, while for Au+Au collisions at 62.4 GeV we obtained T_0 = 0.098 +/- 0.001 GeV suggesting that the system temperature is slowly increasing with the beam energy.



The q parameter shows a very weak rapidity dependence. The Tsallis volume is decreasing from midrapidity to forward rapidity for all the analyzed systems. The volumes for most central Au+Au collisions are similar for both energies. For the same rapidity, both for central rapidity region and forward rapidities, the Tsallis volume increases with the system size.

Conclusions:

- For charged pions, T is decreases with the beam energy and with the size of the system
- Non-extensivity parameter, q and Tsallis volume, V increase with energy
- T and q are correlated ➔ informations about the energy transfer between the central region and suroundings.
- T depends on rapidity, it increases at forward rapidities, but T/cosh(y) ratio is constant as a function of rapidity
- The non-extensivity parameter, q shows a very weak rapidity dependence in A+A and p+p collisions at 200 GeV

Acknowledgements: **This work was supported by F09/30.06.2014 and F09/2016 grants.**