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2013 J. Phys.: Conf. Ser. 420 012041

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Study of the freeze-out process in heavy ion collisions at relativistic energies

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Abstract. In this work, we investigate the freeze-out process in heavy ion collisions at different relativistic energies. We present a study of standard blast-wave fits and Tsallis blast-wave fits performed to the transverse momentum spectra obtained in Au+Au collisions at RHIC energies. In addition, comparisons with simulated heavy ion collisions data using the UrQMD code will be presented to provide more detailed insight into the properties of the space-time evolution such as collective dynamics of the dense matter.

1. Introduction

Ultra-relativistic heavy ions collisions are believed to produce initially hot and dense systems that cool down by expanding until they reach final thermal freeze-out stage when all particle interactions cease and the hadrons decouple from the systems. The produced particle spectra are fixed at this moment and carry information about the phase-space distribution in the final state of the fireball. An interesting phenomenon at this stage of the system evolution is the collective transverse expansion as it is entirely generated during the collision and therefore reflect the collision dynamics. The characteristics of the system at the thermal (kinetic) freeze-out, namely the transverse collective flow velocity and the thermal freeze-out temperature, can be studied using the so-called blast-wave model.

2. Blast-Wave

The blast-wave model is often used to describe the spectra of identified particles produced in relativistic heavy ion collisions [1, 2]. This model assumes that particles decouple from a system in local thermal equilibrium with temperature T , which expands both longitudinally and in the transverse direction; the longitudinal expansion is taken to be boost-invariant and the transverse expansion is defined in terms of a transverse flow profile. The transverse velocity profile, can be parameterized according to a power law: $\beta_T(r) = \beta_s(r/R)^\alpha$ where β_s is the maximum surface flow velocity and the α exponent describes the evolution of the flow velocity (flow profile) from any radius r to R ($r < R$), where R is the maximum radius of the expanding source at thermal freeze-out. The the particle spectra are written in the form

$$\frac{dN}{p_T dp_T} \sim \int_0^R r dr m_T I_0 \left(\frac{p_T \sinh \rho}{T} \right) K_1 \left(\frac{m_T \cosh \rho}{T} \right) \quad (1)$$

where $\rho = \tanh^{-1}\beta_T(r)$, K_1 and I_0 are the modified Bessel functions, m_T is the transverse mass and T is the thermal freeze-out temperature. The shape of each spectrum is determined by the freeze-out temperature, the velocity of the transverse expansion, the flow profile and the mass of the particle. The average transverse flow velocity is: $\langle \beta_T \rangle = \beta_s \cdot 2/(2 + \alpha)$.

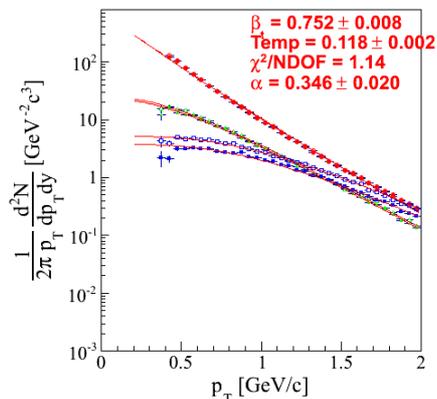


Figure 1. Transverse momentum spectra for identified charged particles produced in 0-10% most central Au+Au collisions at 200 GeV ($y=0$). Red points are for charged pions, green points are for charged kaons, blue open symbols are for protons and blue full symbols are for antiprotons. Data taken from [6]. Red lines represent the simultaneous blast wave fits to the spectra.

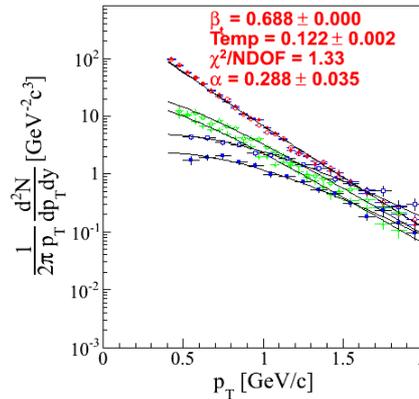


Figure 2. Transverse momentum spectra for identified charged particles produced in 0-10% most central Au+Au collisions at 62.4 GeV ($y=0$). Red points are for charged pions, green points are for charged kaons, blue open symbols are for protons and blue full symbols are for antiprotons. Data taken from [7, 8]. Red lines represent the simultaneous blast wave fits to the spectra.

The freeze-out properties of the fireball created at RHIC energies have been extensively studied in the last years. The identified particle spectra at RHIC are well described by the blast-wave model[3, 4].

The BRAHMS [5] transverse momentum distributions for identified particles produced in 0-10% most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [6] and $\sqrt{s_{NN}} = 62.4$ GeV [7, 8] were fitted simultaneously using the standard blast-wave model. Results of the fit parameters: the thermal freeze-out temperature, T , the average transverse collective flow velocity, $\langle \beta_T \rangle$, the surface collective flow velocity, β_s and the flow profile, α , for Au+Au collisions are shown in the Fig. 1 and Fig. 2 and listed in Table 1.

Table 1. Blast-Wave fit parameters obtained for Au+Au collisions at 200 GeV and 62.4 GeV.

$\sqrt{s_{NN}}$ [GeV]	T [MeV]	$\langle \beta_T \rangle$	β_s	α
62.4	122 ± 2	0.601 ± 0.022	0.688 ± 0.010	0.288 ± 0.035
200	118 ± 2	0.641 ± 0.015	0.752 ± 0.008	0.346 ± 0.020

At midrapidity ($y=0$), for the most central 0-10% Au+Au collisions at 200 GeV, the BW model reproduces the measured spectra well and suggests that the fireball is thermalized and expands explosively with an average velocity over half the speed of light and finally decouples when the temperature has dropped to about 118 MeV. For the 62.4 GeV Au+Au collisions, the freeze-out temperature is slightly higher, but the average transverse radial flow velocity $\langle \beta_T \rangle$ decreases with decreasing energy. This may suggest that a higher initial energy density results in a larger particle multiplicity and longer expansion time for the system, yielding a larger flow velocity and lower kinetic freeze-out temperature.

Table 2. Blast-Wave fit parameters obtained for the simulated Au+Au collisions at different energies using UrQMD code.

$\sqrt{s_{NN}}$ [GeV]	$T^{0-10\%}$ [MeV]	$\beta_s^{0-10\%}$	$T^{40-60\%}$ [MeV]	$\beta_s^{40-60\%}$
3.34	140 ± 3	0.448 ± 0.013	159 ± 5	0.327 ± 0.019
4.53	148 ± 2	0.486 ± 0.015	169 ± 4	0.381 ± 0.018
7	149 ± 2	0.531 ± 0.011	168 ± 5	0.442 ± 0.015
200	131 ± 3	0.653 ± 0.012	168 ± 5	0.505 ± 0.016

The thermal freeze-out parameters are investigated in the framework of Ultra-Relativistic Quantum Molecular Dynamics approach (UrQMD model) for Au+Au collisions at different energies in the future CBM-FAIR energy range ($\sqrt{s_{NN}} = 3.3, 4.5, 7$ GeV) and at top RHIC energy ($\sqrt{s_{NN}} = 200$ GeV). The UrQMD model is a microscopic many body approach to pp, pA and AA interactions at relativistic energies[9]. The centrality and energy dependence of simulated transverse collective flow and thermal freeze-out temperature are presented in Table 2. It is found that the collective flow increases as a function of collision energy and centrality for all studied energies. For top RHIC energy we find that β_s is lower than experimental data, indicating that the emission in the model is less explosive than observed in the data.

3. Tsallis Blast-Wave

One of the main assumptions of the BW model is that the produced system is in local thermal equilibrium and it is unclear whether this is the case because immediately after the collision the system starts to expand both longitudinal and transverse direction. Recently, many authors have used Tsallis statistics to characterize the particle production in high energy nuclear collisions [10]. This statistics is appropriate for the study of complex systems with a certain degree of non-equilibrium as can be the case with these nuclear collisions.

The Tsallis Blast-Wave (TBW) [11, 12] modify the standard Blast-Wave model to utilize Tsallis statistics instead of the conventional Boltzmann-Gibbs statistics (the authors changed sources of particle emission from a Boltzmann distribution to a Tsallis distribution)

$$\frac{dN}{p_T dp_T} \sim m_T \int_{-Y}^{+Y} \cosh(y) dy \int_{-\pi}^{\pi} d\phi \times \int_0^R r dr \left(1 + \frac{q-1}{T} (m_T \cosh(y) \cosh(\rho) - p_T \sinh(\rho) \cos(\phi)) \right)^{-1/(q-1)} \quad (2)$$

where the left-hand side is invariant differential particle yield, q is the parameter characterizing the degree of non-equilibrium of the produced system, and ρ is the flow profile along the transverse radial direction (r), growing from zero at the center of the collision to β_s at the

hard-spherical edge (R). Maximum flow velocity is $\beta_s = \langle \beta_T \rangle (1 + n/2)$, where $n=1$ and $\langle \beta_T \rangle$ is the average flow velocity.

The physical interpretation of the q parameter is that it is a measure of some intrinsic fluctuations characteristic for the hadronizing systems. For $q > 1$ and in the transverse momentum space it could be fluctuations of the system temperature (the temperature is fluctuating from point to point around some equilibrium value). The system produced in a nucleus-nucleus collision has many hot spots and these hot spots are dissipated into creating more particles, producing collective flow and modifying temperature [13, 14]. For $q \rightarrow 1$ one recovers the usual Boltzmann-Gibbs statistics.

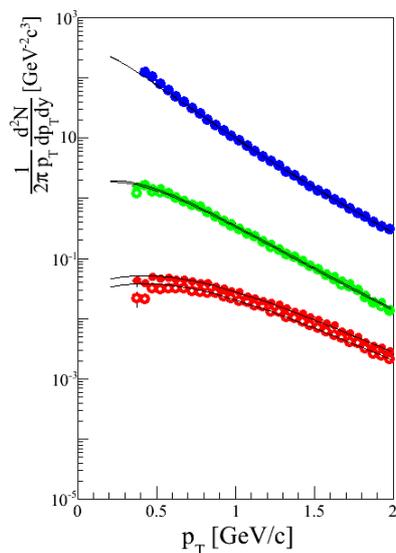


Figure 3. Identified particle p_T spectra in 0-10% Au+Au collisions at 200 GeV. The curves represents the TBW fits.

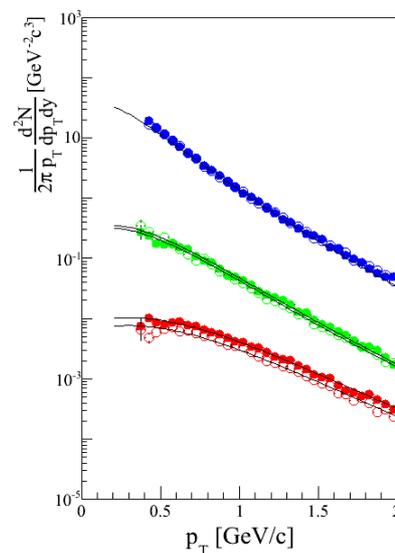


Figure 4. Identified particle p_T spectra in 40-60% Au+Au collisions at 200 GeV. The curves represents the TBW fits.

For Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, we obtain the thermal freeze-out parameters by fitting the p_T spectra for different types of particles detected by the BRAHMS experiment at midrapidity ($y = 0$) with the Tsallis Blast-Wave expression above. The obtained values for two centrality classes (0-10% and 40-60%) are listed in Table 3. Fig. 3 and 4 show the simultaneous Tsallis Blast-Wave fits to the identified p_T spectra of particle species produced in 200 GeV Au+Au collisions.

We observe no centrality dependence of the freeze-out temperature from TBW fits. This trend is in contrast to the conventional BW, where an increase of temperature was observed with collision centrality.

The non-equilibrium parameter $q - 1$ is small in central 0-10% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV suggesting that produced particles approach thermal equilibrium. In 40-60% peripheral Au+Au collisions, $(q - 1)$ increases by a factor of ~ 3 from 0.022 to 0.068 indicating large deviation from Boltzmann statistics and a very non-equilibrated system. The centrality dependence of the $(q - 1)$ parameter suggests an evolution from a very non-equilibrated system in peripheral Au+Au collisions towards an almost thermalized system in central Au+Au collisions.

The average flow velocity decreases from 0.46c in central to 0.31c in 40-60% peripheral Au+Au collisions. The TBW $\langle \beta_T \rangle$ for produced hadrons (π^\pm , K^\pm , p and \bar{p}) in most central Au+Au

Table 3. Tsallis Blast-Wave fit parameters obtained for Au+Au collisions.

Centrality	T [MeV]	$\langle \beta_T \rangle$	β_s	q-1
0-10%	93 ± 2	0.46 ± 0.01	0.69 ± 0.01	0.022 ± 0.004
40-60%	90 ± 3	0.31 ± 0.01	0.46 ± 0.04	0.068 ± 0.005

collisions is much smaller than the obtained value from the standard BW ($\sim 0.64c$). It seems that the hadron scattering doesn't produce a similar collective radial flow and is not sufficient to maintain the system in thermal equilibrium. This results in a non-zero ($q - 1$) value for the system without increasing the radial flow at the level obtained from standard BW.

4. Conclusions

We have presented the single particle inclusive spectra for charged pions, kaons, protons and antiprotons from Au+Au collisions which can be characterized by two parameters, i.e. the thermal freeze-out temperature and the transverse collective flow velocity. We have shown that the experimental freeze-out temperatures extracted from the standard blast-wave parametrization are similar for the two studied energies, while the collective flow velocity increases as the energy increases.

The data studied in the framework of modified Tsallis blast-wave parametrization revealed that the non-equilibrium parameter changes from 0.068 ± 0.005 for 40-60% centrality to 0.022 ± 0.004 for 0-10% centrality, indicating an evolution from a non-equilibrated system in peripheral Au+Au collisions to an almost thermalized system in most central Au+Au collisions.

Acknowledgments

The work of Oana Ristea and Catalin Ristea was supported by the strategic grant POSDRU/89/1.5/S/58852, Project Postdoctoral programme for training scientific researchers, co-financed by the European Social Found within the Sectorial Operational Program Human Resources Development 2007-2013. This work was partially supported by PN-II-ID-PCE-IDEI 34/05.10.2011 grant.

References

- [1] Schnederman E *et al* 1993 *Phys. Rev. C* **48** 2462
- [2] Schnederman E *et al* 1994 *Phys. Rev. C* **50** 1675
- [3] Adams J *et al* (STAR Collaboration) 2004 *Phys. Rev. Lett.* **92** 112301
- [4] Abelev B *et al* (STAR Collaboration) 2009 *Phys. Rev. C* **79** 034909
- [5] Adamczyk M *et al* (BRAHMS Collaboration) 2003 *Nucl. Inst. Meth. A* 499 437
- [6] Arsene I *et al* (BRAHMS Collaboration) 2005 *Phys. Rev. C* **72** 014908
- [7] Arsene I *et al* (BRAHMS Collaboration) 2009 *Phys. Lett. B* **677** 267-271
- [8] Arsene I *et al* (BRAHMS Collaboration) 2010 *Phys. Lett. B* **687** 36-41
- [9] Bass S A *et al* 1998 *Prog. Part. Nucl. Phys.* **41** 225; Bleicher M *et al* 1999 *J. Phys. G* **25** 1859.
- [10] Biro T S and Muller B 2004 *Phys. Lett. B* **578** 78; Alberico W M, Lavagno A and Quarati P 2000 *Eur. Phys. J. C* **12** 499; Osada T and Wilk G 2008 *Phys. Rev. C* **77** 044903
- [11] Tang Z, Xu Y, Ruan L, Van Buren G, Wang F and Xu Z 2009 *Phys. Rev. C* **79** 051901(R)
- [12] Shao M, Yi L, Tang Z, Chen H, Li C and Xu Z 2010 *J.Phys. G* **37** 085104
- [13] Wilk G and Wlodarczyk Z 2009 *Eur. Phys. J. A* **40** 299
- [14] Wilk G and Wlodarczyk Z 2009 *Phys. Rev. C* **79** 054903