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Rapidity Variation of Thermal Parameters at SPS and RHIC. *

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The rapidity dependence of the chemical freeze-out parameters T and μ_B is studied at the highest RHIC and SPS energies assuming that freeze-out occurs along a universal $T - \mu_B$ curve. The baryon chemical potential increases away from mid-rapidity and, correspondingly, T decreases.

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Data from the BRAHMS collaboration [1] show that antiparticle to particle ratios have a maximum at mid-rapidity and slowly decrease as the rapidity becomes larger. It was emphasized very eloquently by Röhrich [2] that the particle ratios at large rapidities are consistent with those measured at the SPS energies. This opens the possibility to compare measurements for e.g. the K^+/π^+ ratio at high rapidities and check them with the corresponding values measured in the energy scan at the SPS, thus complementing information about the rapid variation of this ratio as a function of beam energy. The sharp variation in this ratio with beam energy remains a mystery for most models and might indicate interesting dynamics possibly even linked to the appearance of the critical point at intermediate values of the baryon chemical potential in lattice quantum chromodynamics [3, 4].

A change in particle - anti-particle ratios with longitudinal momentum has been observed in many collisions, it was first discussed two decades ago in an analysis of $p-p$ and $p-N$ data [5].

The analysis of particle multiplicities in heavy ion collisions has shown strong evidence for chemical equilibrium in the final state. A summary as of 2007, combining the results from many different groups, is shown in Fig. 1. Except for particle multiplicities at RHIC energies, all data in

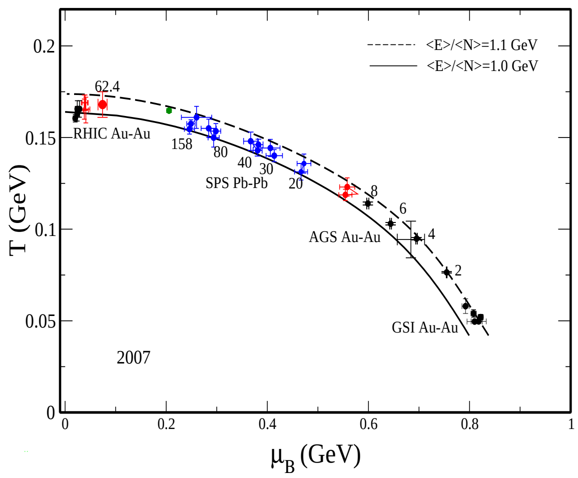

Figure 1: Temperature vs. μ_B as determined from heavy ion collisions at different beam energies. The lower AGS points are based on a preliminary analysis of 4π data. The RHIC point at 62.4 GeV was obtained by J. Takahashi [6]. See [7, 8] for more details.

Fig. 1 use integrated particle yields, the very systematic change of thermal parameters over the full range of beam energies is one of the most impressive features of relativistic ion collisions to date. It is now possible to use the thermal model to make reliable predictions for particle multiplicities at LHC energies [9] and to determine which beam energy will lead to the highest baryon density at freeze-out [10]. With chemical equilibrium thus firmly established, we focus on other properties, in particular, since the rapidity distributions of identified particles is now becoming available also at RHIC energies [1], it is now possible to determine the rapidity dependence of thermal parameters. A first analysis was done by Stiles and Murray [11] for the data obtained by the BRAHMS collaboration at 200 GeV [1]. This shows a clear dependence of the baryon chemical potential on rapidity due to the changing $\bar{p}/p$ ratio. A thorough analysis of the rapidity dependence was recently done in Ref. [12, 13] using a model based on a single freeze-out temperature. A first report of our results was presented elsewhere [14].

PoS(CPOD07)012

The general procedure is as follows: the rapidity axis is populated with fireballs following a gaussian distribution function given by $\rho(y_{FB})$ where y_{FB} is the rapidity of the fireball.

$$\rho(y_{FB}) = \frac{1}{\sqrt{2}\pi\sigma}\exp\left(-\frac{y_{FB}^2}{2\sigma^2}\right). \tag{1}$$

Particles will appear when the fireball freezes out and will follow a thermal distribution centered around the position of the fireball The momentum distribution of hadron i is then calculated from the distribution of fireballs as given by Eq. [1] along the rapidity axis as follows

$$E_i\frac{d^3N_i}{d^3p} = \int_{-\infty}^{\infty}\rho\,(y_{FB})\,E_i\frac{d^3N_1^i}{d^3p}(y-y_{FB})\,dy_{FB} \tag{2}$$

where $E_i\frac{d^3N_1^i}{d^3p}$ is the distribution of hadrons from a single fireball. The temperature T and the baryon chemical potential μ_B will depend on the rapidity of the fireball and are not assumed to be constant.

We have included resonance decays in the final distribution and assumed they decay isotropically.

An important parameter is the width of the distribution. For the RHIC data at 200 GeV this was determined from the π^+'s as these are very sensitive to the value of σ and less to variations in the baryon chemical potential. The width of the distribution $\sigma = 2.183$ is compatible with the values quoted by the BRAHMS collaboration [1], e.g. $\sigma_{\pi^+} = 2.25\pm0.02$ and $\sigma_{\pi^-} = 2.29\pm0.02$. The hadrons described by Eq. [2] are mainly hadronic resonances. Only a fraction of these are stable under strong interactions and most of them decay into stable hadrons at chemical freeze-out, hence the need to implement multi-particle decays.

We assume that the temperature T and the chemical potential μ_B are always related via the freeze-out curve as given in Fig. [1]; if the temperature varies along the rapidity axis, then also the chemical potential will vary. Thus a decrease in the temperature of the fireball will be accompanied by an increase in the baryon chemical potential. In other words, we assume a universality of the chemical freeze-out condition. This relationship between temperature and baryon chemical potential is very reasonable since all particle abundances measured so far follow it. Once the width of the distribution of fireballs has been fixed, we assume a parabolic dependence of the baryon chemical potential on the rapidity of the fireball. This is the minimal assumption consistent with the evidence that μ_B increases from mid-rapidity to large rapidity (as is clear from the $\bar{p}/p$ ratio) and use the general formula:

$$\mu_B = \mu_B^0 + a\,y_{FB}^2. \tag{3}$$

Particularly, for RHIC, we find that $\mu_B^0 = 0.025$ GeV and $a = 0.011$ GeV. This is shown graphically in Fig. [2].

A comparison of the resulting antiproton to proton ratio with RHIC data at 200 GeV is shown in Fig. [3].

The variation of the temperature along the rapidity axis is shown in Fig. [4]. The temperature is maximal at mid-rapidity and gradually decreases towards higher (absolute) values of the rapidity. Note that the temperature varies less than 2 MeV over the rapidity interval.

The situation at the highest SPS energy is more difficult to describe because the changes of the thermal variables with rapidity are much larger. First of all we need the distribution of fireballs at

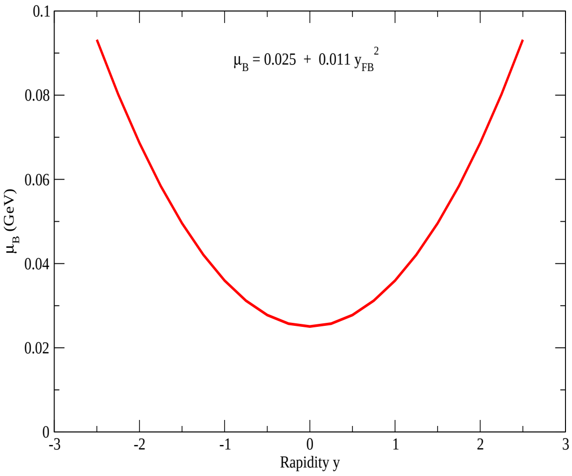

Figure 2: Values of the baryon chemical potential as a function of rapidity at the highest RHIC energy.

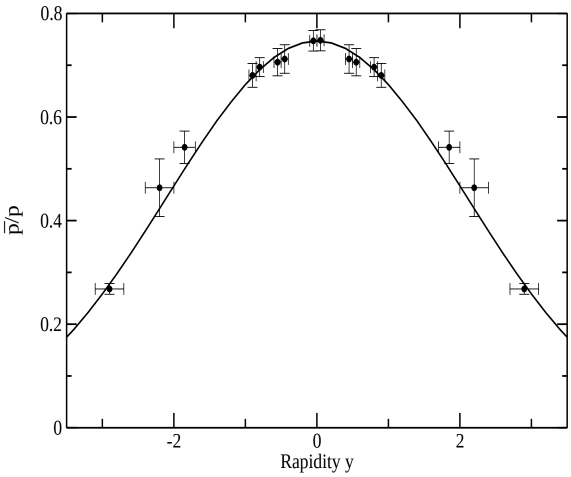

Figure 3: The $\bar{p}/p$ ratio as a function of rapidity.

SPS energies. This is determined by the variable σ appearing in Eq. (1) which we fixed using the distribution of pions. The baryon chemical potential can approximately be described by:

$$\mu_B = 0.237 + 0.011\, y_{FB}^2. \tag{4}$$

This is shown graphically in Fig. [5]. The corresponding change in the temperature as a function of rapidity is shown in Fig. [6]. Whereas there is almost no change in the temperature in the rapidity interval under consideration (the change is less than 2 MeV at RHIC), at the highest SPS energy the change in temperature is much larger and ranges from about 160 MeV down to about 120 MeV. In summary, the rapidity dependence of the thermal parameters T and μ_B has been determined over a wide range of rapidities and show a systematic behavior towards an increase in μ_B as the rapidity is increased.

References

[1] I.G. Bearden for the BRAHMS collaboration, J. Phys. G 34, (2007) S207.

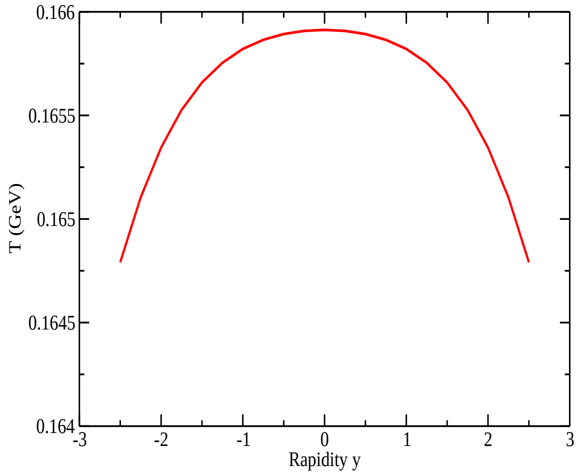

Figure 4: Values of the chemical freeze-out temperature function of rapidity at the highest RHIC energy.

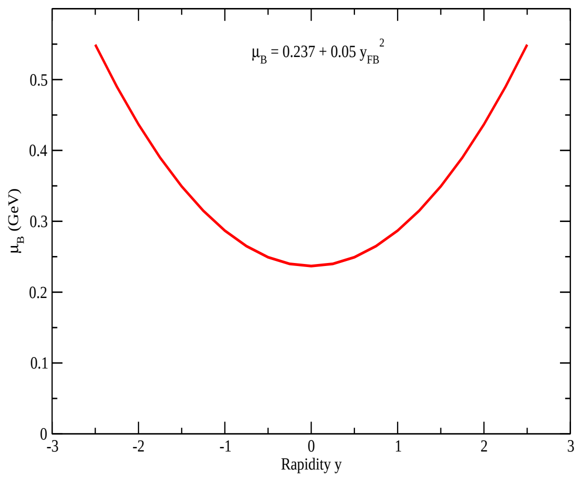

Figure 5: Values of the baryon chemical potential as a function of rapidity at the highest SPS energy.

[2] D. Röhrich, talks presented at “Critical Point and Onset of Deconfinement”, Florence, July, 2006 and SQM2007, Levoca, Slovakia, June 2007.

[3] F. Karsch, talk presented at “Critical Point and Onset of Deconfinement”, July 2007.

[4] Z. Fodor, talk presented at “Critical Point and Onset of Deconfinement”, July 2007.

[5] W. Greiner, P. Koch and J. Rafelski, Phys. 145 (1984) 142.

[6] J. Takahashi, Talk presented at SQM2007, Levoca, Slovakia, June 2007.

[7] J. Cleymans, H. Oeschler, K. Redlich, S. Wheaton, Phys. Rev. C73, 034905 (2006).

[8] J. Manninen, F. Becattini and M. Gaździcki, Phys. Rev. C73 (2006) 044905.

[9] J. Cleymans, I. Kraus, H. Oeschler, K. Redlich and S. Wheaton, hep-ph/0604237.

[10] J. Randrup and J. Cleymans, Phys. Rev. C74 (2006) 047901.

[11] L.A. Stiles and M. Murray,nucl-ex/0601039, unpublished.

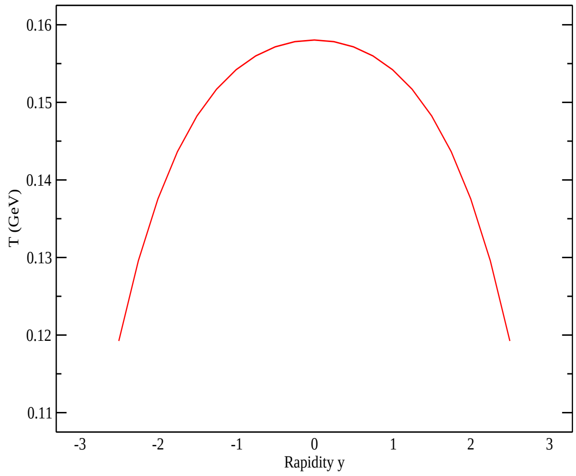

Figure 6: Values of the chemical freeze-out temperature as a function of rapidity at the highest SPS energy.

[12] B. Biedron and W. Broniowski, Phys. Rev. C75 (2007) 054905.

[13] W. Broniowski and B. Biedron, nucl-th/0709.0126.

[14] F. Becattini and J. Cleymans, J. Phys. G 34 S959 (2006).