Is there more than one thermal source?

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Abstract. BRAHMS has the ability to study relativistic heavy ion collisions over a wide range of p_T and rapidity [1]. This allows us to test whether thermal models can be generalized to describe the rapidity dependence of particle ratios. This appears to work with the baryo-chemical potential changing more rapidly than the temperature. Using fits to BRAHMS data we are able to describe Ξ and Ω ratios from other experiments. This paper is dedicated to Julia Thompson who worked to bring South African teachers into physics.

1. Introduction

The purpose of RHIC is to map the phase structure of QCD. So far the community has concentrated on AuAu, dAu and pp collisions at $\sqrt{s_{NN}} = 200$ GeV in the hope of finding the quark gluon plasma. BRAHMS' special contribution has been to study the hadrons produced in these collisions over a broad range of p_T and rapidity The distribution of particles in rapidity and p_T may give information on the transverse and longitudinal flow while the mix of different kinds of particles may tell us about the "quark chemistry" of the system. It is on this aspect of the bulk behavior that we shall concentrate in this paper.

2. Particle Yields and Transverse Momenta

BRAHMS has measured particle spectra over a very wide range of rapidity and p_T. Our AuAu spectra are summarized in Fig. 1, which shows the rapidity densities, dN/dy, and the mean transverse momenta, $\langle p_T \rangle$, for π, K, p and $\bar{p}$ as a function of rapidity [2]. For π, k and $\bar{p}$ the yields peak at y=0 and drop significantly at higher rapidities. The π^+ and π^- yields are nearly equal while an excess of K^+ over K^- is observed that increases with rapidity.

The $\langle p_T \rangle$ for all particles decline slowly with rapidity. We have fitted the spectra themselves to the "blast wave" model in order to estimate the transverse flow and kinetic freeze-out temperature[6]. We find that the flow decreases with rapidity while the kinetic temperature tends to increase [7].

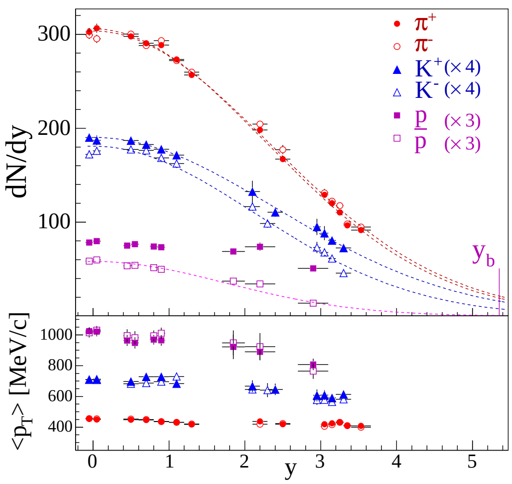

Figure 1. Rapidity densities (top) and mean transverse momentum (bottom) as a function of rapidity. The lines show Gaussian fits.

3. Rapidity Dependence of Chemical Freeze-out

Traditionally thermal analyses have assumed that there is only one source in heavy ion collisions and have used particle yields intergrated over all phase space as input.At RHIC several groups have shown that such models can give an excellent description of a large number of particle ratios at *mid-rapidity* The use of mid-rapidity ratios has been justified on the grounds that there is a boost invariant region near y=0. Such a hypothesis implies that there is a different source away from mid-rapidity. We have investigated this idea by fitting our particle yields at several different rapidities to a chemical model [3].

Figure 2 shows that as y increases both the baryo-chemical potential and (to a lesser extent) the chemical freeze-out temperature increase. This may suggest that the system has fewer degrees of freedom at higher rapidities. Figure 2 suggests that chemical freeze-out temperature changes more slowly with rapidity than the baryo-chemical potential. It is possible that this is also true as we change the collision energy. Figure 3 shows the correlation between k^-/k^+ and $\bar{p}/p$ ratios measured by BRAHMS for AuAu and pp collisions at several rapidities. Lower energy results are also shown. Both the AuAu and pp results can be described by a power law, $k^-/k^+ = (\bar{p}/p)^\alpha$ with $\alpha = 0.32 \pm 0.4$ for pp and 0.24 ± 0.02 for AuAu [2, 4]. Preliminary AuAu data from $\sqrt{s_{NN}} = 63$ GeV are also consistent with this fit [5].

Recasting the power law fit in terms of chemical potentials gives $\mu_s = (0.28\pm0.6)\cdot\mu_Q$ independent of temperature. If we take this seriously then we should be able to predict the correlation between other strange particle ratios and $\bar{p}/p = e^{-6\mu_q/T}$ just by counting

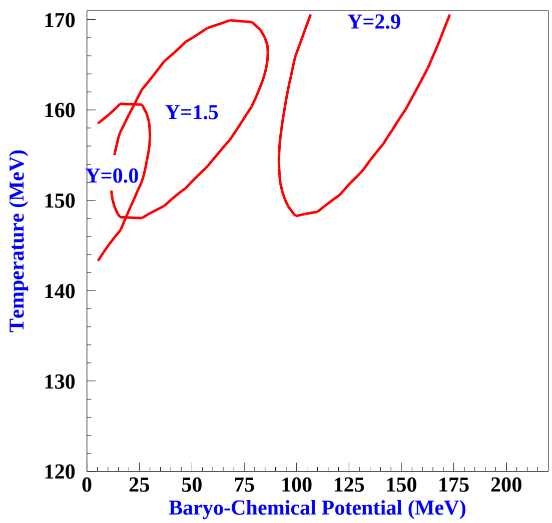

Figure 2. Preliminary thermal (right) fits to our data at various rapidities. The curves are the one sigma contours.

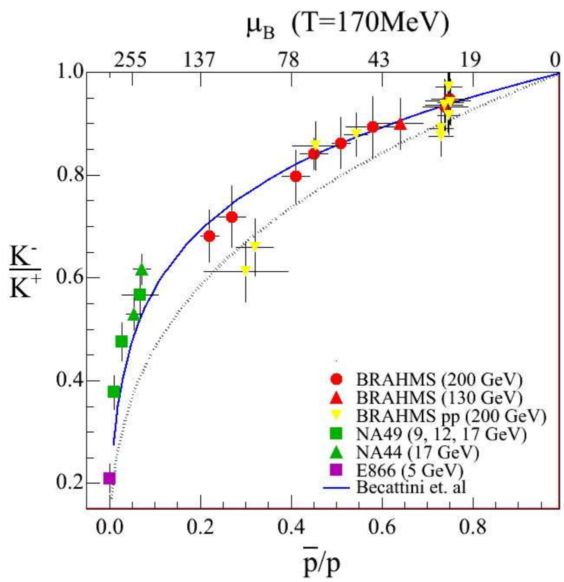

Figure 3. Correlation between k^-/k^+ and $\bar{p}/p$ ratios for central AuAu and pp collisions. The NA44 and NA49 the results are for central PbPb collisions.

the number of strange and non-strange quarks. For example

$$\frac{\bar{\Omega}}{\Omega} = e^{-6\mu_s/T} = e^{-0.28 \cdot 6\mu_q/T} = \left(\frac{\bar{p}}{p}\right)^{0.28} \qquad (1)$$

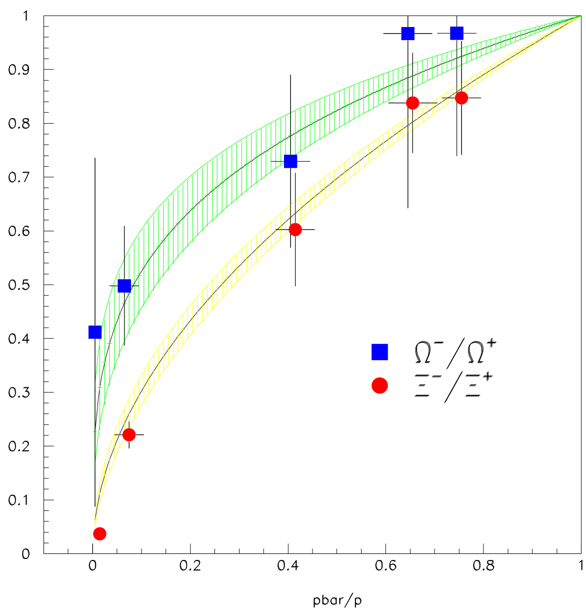

Figure 4. Preliminary $\bar{\Omega}/\Omega$ and $\bar{\Xi}/\Xi$ ratios from STAR and NA57 versus predictions Eqns [1] and [2]. The $\bar{p}/p$ ratios have been displaced slightly for clarity. The bands represent the error on the determination of μ_s from the BRAHMS data.

and

$$\frac{\bar{\Xi}}{\Xi} = e^{-(4\mu_s+2\mu_q)/T} = e^{-(1.12+2)\cdot\mu_q/T} = \left(\frac{\bar{p}}{p}\right)^{0.52}. \qquad (2)$$

Figure 4 shows the predictions of Equations (1) and (2) as well as preliminary Ξ and Ω ratios from STAR and NA57. The agreement between the prediction and data is very good. Note that our ignorance of the temperature T does not effect the shape of these curves.

4. Summary and Conclusions

Thermal descriptions are a powerful way to describe AuAu collisions. Chemical analysis of our particle yields hint that both the baryo-chemical potential and the chemical freeze-out temperature increase with rapidity. One could interpret this in terms of the system becoming less partonic (with consequently fewer degrees of freedom) at higher rapidities. At this stage however the data are also consistent with a constant temperature at different rapidities. The baryo-chemical seems to dominate the rapidity (and energy) dependence of the particle ratios. However the correlation between k^-/k^+ and $\bar{p}/p$ is different for pp and heavy ion collisions. This may be an effect of the small size of the pp system. For central AuAu (PbPb) collisions the relationship $\mu_s = (0.28 \pm 0.6) \cdot \mu_Q$ derived from BRAHMS data gives a good description of hyperon ratios.

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