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The Horn and the Thermal Model.

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Abstract. The recently discovered sharp peak in the K^+/π^+ ratio in relativistic heavy-ion collisions is discussed in the framework of the thermal model. In this model a rapid change is expected as the hadronic gas undergoes a transition from a baryon-dominated to a meson-dominated gas. The transition occurs at a temperature $T = 140$ MeV and baryon chemical potential $\mu_B = 410$ MeV corresponding to an incident energy of $\sqrt{s_{NN}} = 8.2$ GeV.

The thermal model has been extremely successful in bringing order to a very large number of experimental results on particle yields in relativistic heavy-ion collisions. The results for the temperature and baryon chemical potential have been found to be consistent with having $E/N = 1$ GeV from the lowest beam energies up to the highest ones. This is illustrated in Fig. 1 which combines results from SIS up to RHIC.
The NA49 Collaboration has recently performed a series of measurements of Pb-Pb collisions at 20, 30, 40, 80 and 158 AGeV beam energies. When these results are combined with measurements at lower beam energies from the AGS and SIS they reveal an unusually sharp variation with beam energy in the $\Lambda/\langle\pi\rangle$, with $\langle\pi\rangle \equiv 3/2(\pi^+ + \pi^-)$, and in the K^+/π^+ ratios. Such a strong variation with energy does not occur in pp collisions and therefore indicates a major difference in heavy-ion collisions. This transition has been referred to in Ref. [1] as the "horn". A strong variation with energy of the $\Lambda/\langle\pi\rangle$ ratio has been predicted on the basis of arguments put forward in [2]. In [3] another, less spectacular, possibility for the origin of the sharp maximum, namely as being due to the transition from a baryon-dominated to a meson-dominated hadronic gas has been suggested; the distinction being based on whether the entropy of the hadronic gas is dominated by baryons or by mesons. For this purpose various quantities along the freeze-out curve [4] as a function of $\sqrt{s_{NN}}$ have been studied in [3].

In the thermal model a steep rise at low energies and a subsequent flattening off leading to a mild maximum in the K^+/π^+ ratio, was predicted many years ago [6, 5, 8]. The sharpness of the observed peak therefore comes as a surprise. On the other hand, a sharp peak in the $\Lambda/\langle\pi\rangle$ ratio was predicted by the thermal model [8] and is in good agreement with the data. While the thermal model cannot explain the sharpness of the peak in the K^+/π^+ ratio, there are nevertheless several phenomena, giving rise to the rapid change, which warrant a closer look at the model. To get a better estimate of the thermal parameters we have analyzed the entropy density as a function of beam energy following the freeze-out curve given in [4] (see Fig. 2). There is a clear transition from a meson to a baryon-dominated hadronic gas at $\sqrt{s_{NN}}$ = 8.2 GeV. Above this value the entropy is carried mainly by mesonic degrees of freedom. It is remarkable that the entropy density divided by T^3 is constant over the entire freeze-out

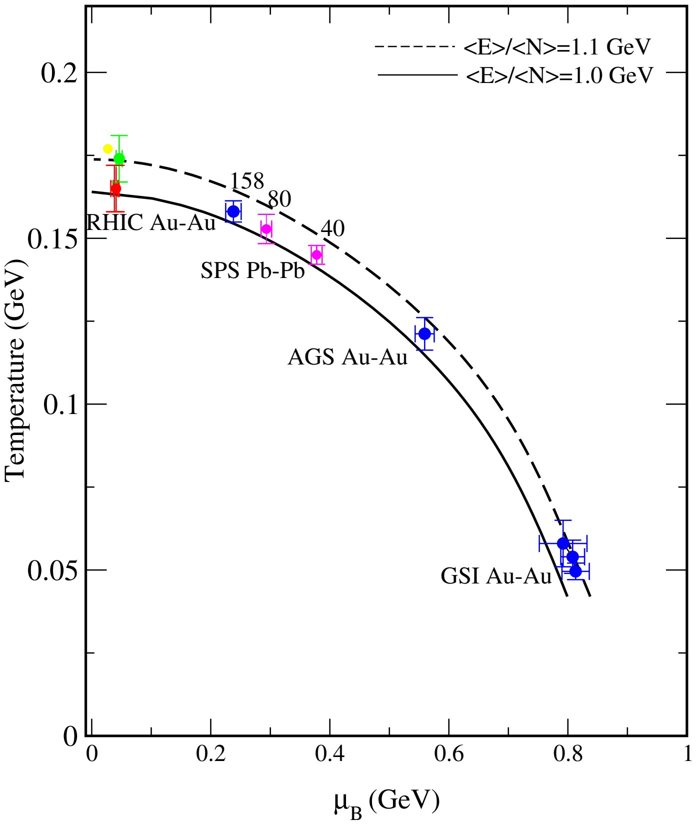

Figure 1. The chemical freeze-out points together with curves at fixed values of E/N.

curve, except for the low-energy, SIS, energy region. The line denoting the transition from a baryon-dominated to a meson-dominated hadron gas is shown in Fig. 2. This line crosses the freeze-out curve at a temperature of T = 140 MeV, when the baryon chemical potential equals μ_B = 410 MeV. The corresponding invariant energy is $\sqrt{s_{NN}}$ = 8.2 GeV. The strong decrease in the net baryon density is due to the fact that low energies are characterized by a very low multiplicity of mesons and, correspondingly, a very large baryon-to-meson ratio. As a consequence, the baryon chemical potential is also very large. As the beam energy is increased, meson production increases and the baryon chemical potential decreases. The number of strange baryons produced in heavy-ion collisions at different collision energies will follow the net baryon density since a large baryon chemical potential will also enhance the number of hyperons. As is well-known [9, 10], the thermal model description leads to a mild maximum in the K^+/π^+ ratio which does not reproduce the so-called “horn” observed by the NA49 collaboration [1]. The observed deviations at the highest SPS energy have been interpreted as a lack of full chemical equilibrium in the strangeness sector, leading to a strangeness suppression factor, γ_s, deviating from its equilibrium value by about thirty percent. Detailed fits using the thermal model in the region of the “horn” show rapid variations in γ_s [10] which do not lend themselves to any interpretation. There is no corresponding peak in the K^-/π^- ratio because the production of K^- is not tied to that of baryons. As the relative number of baryons decreases with increasing energy, there is no corresponding decrease in the number of K^- as is the case with K^+ as these

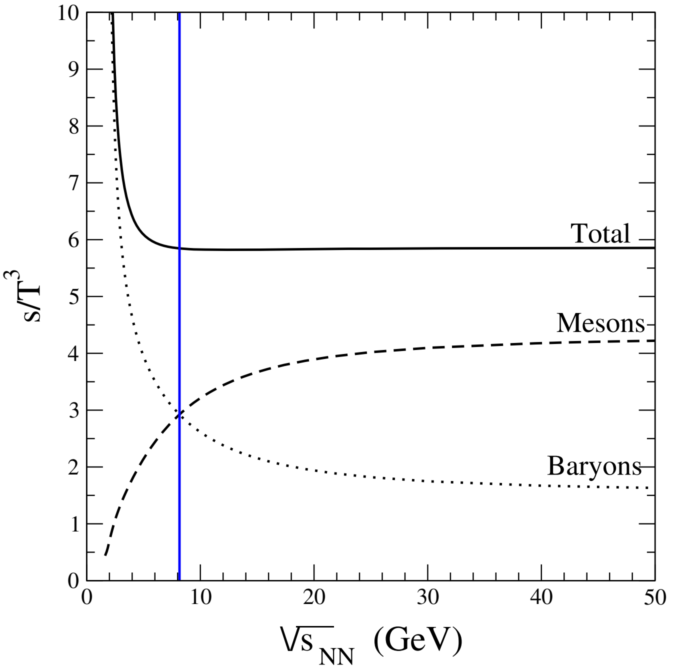

Figure 2. The entropy density normalised to T^3 as a function of the beam energy as calculated in the thermal model using THERMUS [7].

must be balanced by strange baryons.

It is worth noting that the maxima in the ratios for multi-strange baryons occur at ever higher beam energies. The higher the strangeness content of the baryon, the higher in energy is the maximum. This behavior is due to a combination of the facts that strangeness has to be balanced, the baryon chemical potential decreases rapidly and the multi-strange baryons have successively higher thresholds. The dependence of the baryon chemical potential on the beam energy is shown in Fig. 3. It is to be expected that if these maxima do not all occur at the same temperature, i.e. at the same beam energy, then the case for a phase transition is not very strong.

In conclusion, while the thermal model cannot explain the sharpness of the peak in the K^+/π^+ ratio, its position corresponds precisely to a transition from a baryon-dominated to a meson-dominated hadronic gas. This transition occurs at a temperature $T = 140$ MeV, a baryon chemical potential $\mu_B = 410$ MeV and an energy $\sqrt{s_{NN}} = 8.2$ GeV. In the thermal model this transition leads to a sharp peak in the $\Lambda/\langle\pi\rangle$ ratio, and to moderate peaks in the K^+/π^+, Ξ^-/π^+ and Ω^-/π^+ ratios. Furthermore, these peaks are at different energies in the thermal model. The thermal model predicts that the maxima in the $\Lambda/\langle\pi\rangle$, Ξ^-/π^+ and Ω^-/π^+ occur at increasing beam energies.

If the change in properties of the above excitation functions were associated with a genuine

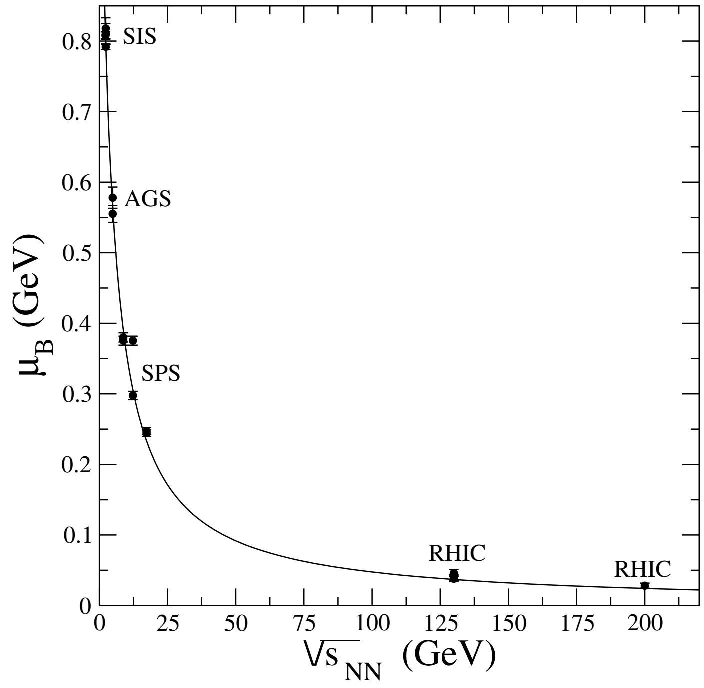

Figure 3. The energy dependence of the baryon chemical potential at freeze-out.

deconfinement phase transition one would expect these changes to occur at the same beam energy. It is clear that more data are needed to clarify the precise nature of the sharp variation observed by the NA49 collaboration.

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