Particle Ratios at CERN, BNL and GSI : Unified description of Freeze-Out Parameters.*

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It is shown that the chemical freeze-out parameters obtained at CERN/SPS, BNL/AGS and GSI/SIS energies all correspond to a unique value of 1 GeV for the average energy per hadron.

1. Particle Ratios : General Remarks

Information about the chemical freeze-out parameters, the temperature, T_{ch}, and baryon chemical potential μ_B^{ch} can be obtained from ratios of integrated particle yields [1,2]. This is because various effects like transverse flow or particle production from a superposition of fireballs cancel out in such ratios provided the freeze-out parameters are unique. We will discuss in succession particle ratios at GSI/SIS, BNL/AGS and SPS/CERN. We will then discuss common properties, in particular, the observation that all of them correspond to an average energy of 1 GeV per hadron independent of the beam energy [3].

2. Particle ratios at GSI/SIS

A systematic study of the particle ratios measured at GSI/SIS energies has been done recently [4,5]. In figure 1 we show the results obtained in [5] for Ni-Ni at 1.0 AGeV. The particle ratios are consistent with the interpretation that the hadronic composition of the final state is fixed at a unique temperature and baryon chemical potential. Since the temperature is low, the number of particles created is small and it is therefore necessary to take into account the exact conservation of strangeness because strange particles are always produced in pairs and it is more difficult to create two particles in a small cold system than it is to create one particle. There is no necessity to introduce any other parameters and a good fit can be achieved with full chemical equilibrium including strange particles, i.e. with $\gamma_s = 1$. In view of the fact that kaons are produced below threshold at SIS this is remarkable.

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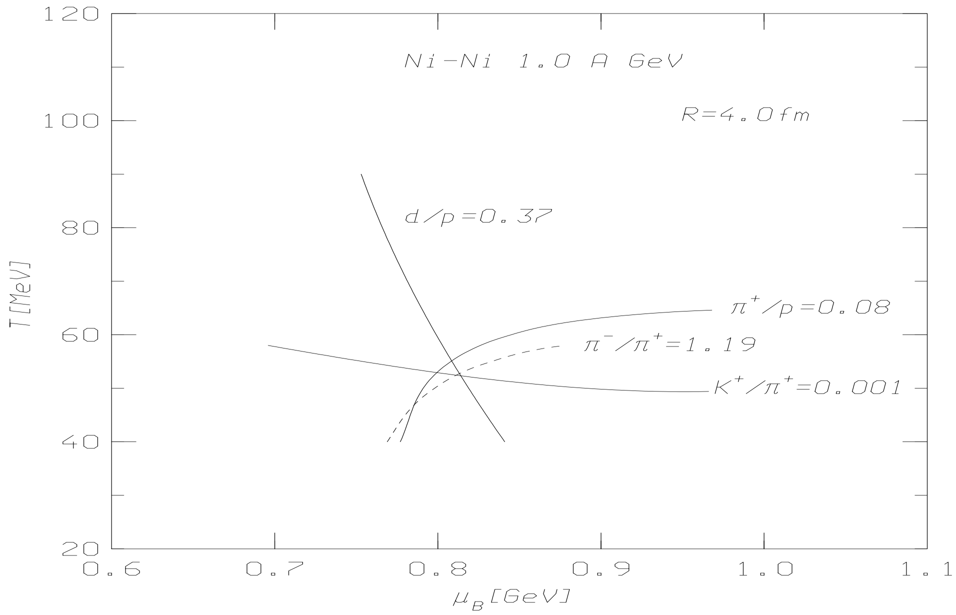

Figure 1. Particle ratios for Ni-Ni at 1.0 A GeV at SIS [5].

3. Particle ratios at BNL/AGS

Particle ratios at BNL/AGS have been reanalyzed recently in references [6] and [7]. The results are consistent with those obtained previously, e.g. ref. [6] obtains $T_{ch} = 118.4 \pm 11.6$ MeV and $\mu_B^{ch} \approx 522$ MeV. The ratios together with error bands are shown in figure 2 [8]. This temperature is about double the one extracted from SIS results, the baryon chemical potential is clearly much smaller. Because of the higher temperature, it is no longer necessary to treat strangeness in a special way and corrections from the more exact canonical treatment are negligible. There is agreement that a good fit can be achieved with $\gamma_s = 1$ and the data are again consistent with chemical equilibrium.

4. Particle ratios at CERN/SPS

Several papers have appeared recently analyzing the particle ratios measured in Pb-Pb collisions at CERN [9–11]. In reference [10] it is found that a strangeness suppression factor $\gamma_s = 0.55$ is needed to describe the data while in reference [9] it is argued that a good description is possible using $\gamma_s = 1$. Despite this serious difference both papers arrive at very similar results : $T_{ch} = 165$ MeV in [10] vs $T_{ch} = 170$ MeV in [9], i.e. the difference is less than 3 percent. The disagreement over the value of γ_s will be settled when more precise data become available, indications from this conference are that a value below 1 is necessary but a full analysis is still outstanding.

The analysis of reference [11] introduces new parameters and is not directly comparable to the one discussed here.

5. Particle Ratios : Common Properties at SPS, AGS and SIS

The results from GSI, BNL and CERN show a striking systematic behavior (see figure 3) : the GSI/SIS results have the lowest temperature and the highest baryon chemical

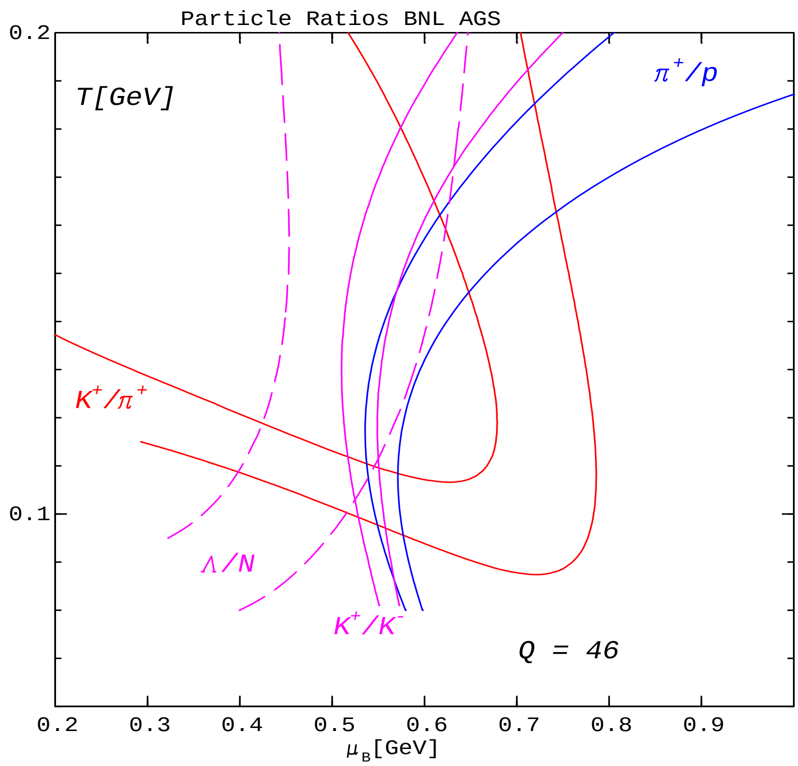

Figure 2. Particle ratios for Si-Au at 11.0 A GeV at AGS [8].

potential, as the beam energy is increased a clear shift towards higher temperatures and lower baryon chemical potentials occurs. The points have in common that the average energy per hadron is approximately 1 GeV [3]. Chemical freeze-out is thus reached when the energy per particle drops below 1 GeV per hadron. When this value is reached inelastic collisions are no longer important and the abundances of the various hadronic species are fixed. The consequences of this are discussed in detail in reference [12]. Recent results from E895 collaboration presented at this conference [13] are compatible with the above result.

6. Conclusions

Bringing together results obtained at very different beam energies shows that the hadronic abundances seen in the final state of relativistic heavy ion collisions are fixed once the average energy per hadron drops below 1 GeV. We expect the results from the SPS beams at 40 and 80 GeV to follow this observation. It will be interesting to see how the results from RHIC will relate to this observation.

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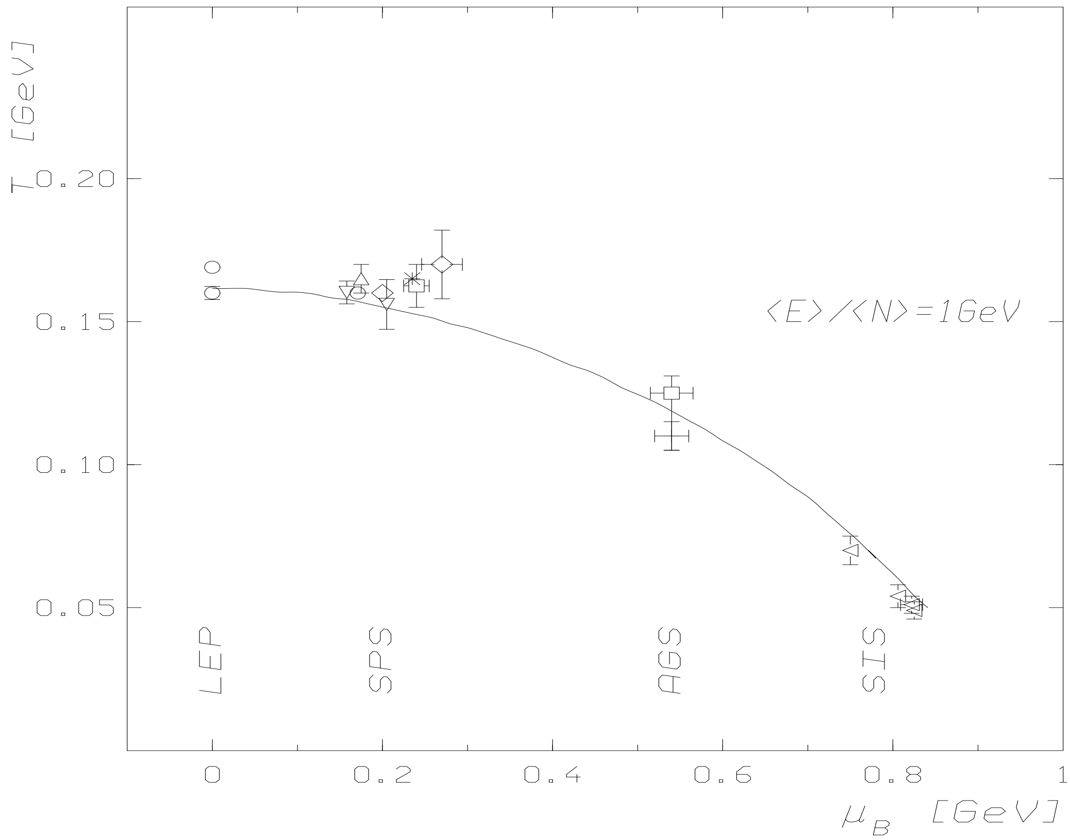

Figure 3. Freeze-out values obtained from ratios of hadronic abundances. The smooth curve corresponds to a fixed energy per hadron of 1 GeV in the hadronic gas model.

REFERENCES

1. U. Heinz, J. Phys. G **25**, 263 (1999).
2. J. Cleymans, H. Oeschler and K. Redlich, J. Phys. G **25** 281 (1999).
3. J. Cleymans and K. Redlich, Phys. Rev. Lett. **81** 5284 (1998).
4. J. Cleymans, D. Elliott, A. Keränen and E. Suhonen, Phys. Rev. C**57** 319 (1998).
5. J. Cleymans, H. Oeschler and K. Redlich, Phys. Rev. C**59** 3319 (1999).
6. F. Becattini, J. Phys. G **25** 287 (1999).
7. J. Stachel, private communication and I. Heppe, Diplomarbeit, University of Heidelberg, 1998.
8. J. Cleymans, D. Elliott, R.L. Thews and H. Satz, Z. Phys. **74** 319 (1997).
9. P. Braun-Munzinger, I. Heppe and J. Stachel, nucl-th/9904058.
10. G.D. Yen and M. Gorenstein, Phys. Rev. C**59** 2788 (1999).
11. J. Rafelski and J. Letessier, nucl-th/9903018.
12. J. Cleymans and K. Redlich, nucl-th/9903063.
13. G. Rai, contribution to this conference.