ELSEVIER

Nuclear Physics A715 (2003) 553c–556c

NUCLEAR PHYSICS A

www.elsevier.com/locate/npe

Towards strangeness saturation in central heavy-ion collisions at high energies

J. Cleymans,[a] B. Kämpfer,[b] S. Wheaton[a]

[a]University of Cape Town, Rondebosch 7701, Cape Town, South Africa

[b]Forschungszentrum Rossendorf, PF 510119, 01314 Dresden, Germany

Analyses of the centrality binned identified hadron multiplicities at SPS ($\sqrt{s}$ = 17 AGeV) and RHIC ($\sqrt{s}$ = 130 AGeV) within the statistical-thermal model point to strangeness saturation with increasing centrality and energy.

1. Introduction

It is now well established that particle abundances can be described by statistical-thermal models. In such a way, a large number of observables can be reproduced with a small number of parameters, namely the temperature, baryo-chemical potential and a factor measuring the degree of strangeness saturation. Here we focus on the centrality dependence of the hadron multiplicities and adjust the thermal parameters so as to reproduce the experimental data.

The recent study in [1] (cf. table III therein) impressively demonstrated that, with increasing system size at SPS energies, the strangeness saturation increases. In [2] we have shown that at a beam energy of 158 AGeV, in collisions of lead-on-lead nuclei, the strangeness saturation continuously increases with centrality. However, strangeness is well below saturation. A preliminary analysis [3] of the centrality dependence at RHIC energy of $\sqrt{s}_{NN}$ = 130 GeV points to a further increase of strangeness towards saturation for central collisions of gold nuclei. An independent analysis [4] confirms this finding.

In this paper, we compare the analyses of two data sets: (i) NA49 4π multiplicities of $\langle\pi\rangle$, $K^{\pm}$, ϕ, $N_{\rm part}$ (taken as the sum over all baryons) and $\bar{p}$ in 6 centrality bins in the reaction Pb (158 AGeV) + Pb [5,6] (our previous study [2] did not include the ϕ multiplicities). It should be emphasized that protons are not included in our analysis since, particularly in non-central collisions, there may be a large spectator component in the quoted experimental yields. (ii) PHENIX mid-rapidity densities of $\pi^{\pm}$, $K^{\pm}$ and $p^{\pm}$ in the reaction Au + Au at $\sqrt{s}$ = 130 AGeV in 5 centrality bins [7]. These yields were not corrected for weak decays. PHENIX estimates the probability for reconstructing protons from Λ decays as prompt protons at 32% at p_T = 1 GeV/c [7]. In the analysis of the PHENIX data, two fits were performed: with no feeding from weak decays, and with a 32% feed-down from Λ decay.

The use of 4π data at SPS energy is in the spirit of the fireball model, since many dynamical effects cancel out in ratios of fully-integrated hadron yields. In particular, effects

doi:10.1016/S0375-9474(02)01517-8

due to flow disappear if the freeze-out surface is characterized by a single temperature and chemical potential [8].

2. Analyses of Hadron Multiplicities

Hadron multiplicities can be described [9,10] by the grand-canonical partition function $\mathcal{Z}(V,T,\vec{\mu}_i) = \mathrm{Tr}\{\mathrm{e}^{-\frac{\hat{H}-\vec{\mu}_i\vec{Q}_i}{T}}\}$, where $\hat{H}$ is the statistical operator of the system, T denotes the temperature, and μ_i and Q_i represent the chemical potentials and corresponding conserved charges respectively. In the analysis of 4π data, the net-zero strangeness and the baryon-to-electric charge ratio of the colliding nuclei constrain the components of $\vec{\mu}_i = (\mu_B, \mu_S, \mu_Q)$. These constraints have to be relaxed when considering data in a limited rapidity window, increasing the number of free parameters. The particle numbers are given by

$$N_i^{\mathrm{prim}} = V(2J_i+1)\int \frac{d^3p}{(2\pi)^3}\,dm_i\,\frac{1}{\gamma_s^{-|S_i|}\mathrm{e}^{\frac{E_i-\vec{\mu}_i\vec{Q}_i}{T}} \pm 1}\mathrm{BW}(m_i), \tag{1}$$

where we include phenomenologically a strangeness saturation factor γ_s with $|S_i|$ the number of valence strange quarks and anti-quarks in species i [11] (e.g. γ_s suppression for the kaons and γ_s^2 for ϕ) to account for incomplete equilibration in this sector, $E_i = \sqrt{\vec{p}^2 + m_i^2}$, and BW is the Breit-Wigner distribution. The particle numbers to be compared with experiment are $N_i = N_i^{\mathrm{prim}} + \sum_j \mathrm{Br}^{j\to i} N_j^{\mathrm{prim}}$, due to decays of unstable particles with branching ratios $\mathrm{Br}^{j\to i}$.

The results of our fits are displayed in figs. 1 and 2. The inclusion of weak decays in the PHENIX analysis lowers the temperature but does not appreciably affect either γ_s or μ_B. Both at SPS and RHIC, the number of kaons and antikaons increase with centrality relative to the charged pion and antiproton multiplicities. This is responsible for the increase of the strangeness saturation factor γ_s. At RHIC energy the temperature also appears to increase with centrality, as shown in fig. 1.

The findings for central collisions at RHIC agree fairly well with the results in [9], as do our extracted values of T and μ_B in central collisions at SPS energy. In contrast to [9], however, we find a pronounced strangeness under-saturation, as in [1] at SPS energy (cf. also [10] for other analyses with $\gamma_s < 1$ at SPS). What is striking is the increase of γ_s with energy and centrality, and the tendency to approach full strangeness saturation at RHIC, i.e. $\gamma_s \to 1$. The observed increase of γ_s with increasing centrality is in agreement with parton kinetics as described in [12], for example.

The baryo-chemical potential is fairly constant at both SPS and RHIC, as shown in fig. 2. The apparent centrality independence of the temperature and baryo-chemical potential at SPS leads to the model prediction that the ratio ϕ/K^+ should increase like γ_s with centrality. This, however, does not agree with the experimentally observed centrality independence of this ratio. The trend can be reproduced by the model if the ϕ is suppressed by a factor of γ_s (instead of γ_s^2), but this leads to higher values of χ^2 in all but the most peripheral bin. This is shown quantitatively in fig. 2 where the ϕ/K^+ ratio is plotted against the number of participants. As can be seen, if the ϕ mesons are suppressed only by a factor γ_s, one overestimates their number but the dependence as a

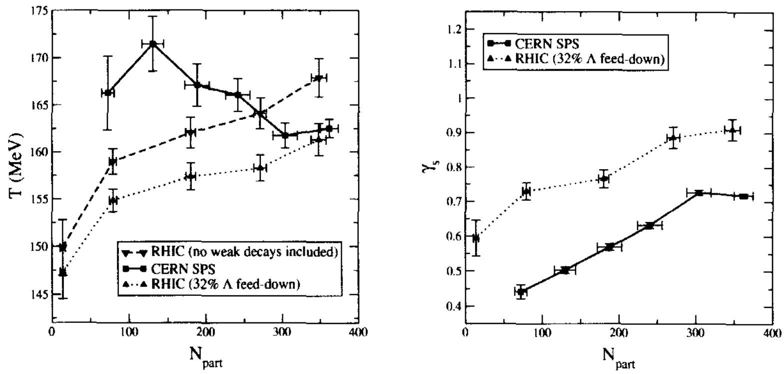

Figure 1. Temperature T (left panel) and the strangeness suppression factor γ_s (right panel) as a function of N_{part}. Squares (triangles) are for the full phase-space NA49 data [5,6] (mid-rapidity PHENIX [7]). Two sets of results are shown for the RHIC data in the temperature plot: with no weak decay contributions (triangle down) and with a 32% feed-down from Λ decay (triangle up).

function of N_{part} can be reproduced. If however, the ϕ has a quadratic suppression factor, γ_s^2, then the normalization is reproduced, at least in the three most central bins, but the shape of the curve does not match the observed dependence. It would be of interest to establish this point more clearly, since it touches on the precise way in which strangeness suppression occurs. A more accurate determination of the ϕ yield for small values of N_{part}, especially for 150 - 200 participants, would be extremely useful. Also at AGS energies, the ϕ/K^+ ratio is centrality independent [13]. The situation of the ϕ yield as a function of N_{part} remains inconclusive.

3. Summary

In summary, we have shown that the analyses of full phase-space multiplicities at SPS energy and mid-rapidity densities at RHIC energy point to strangeness saturation in central collisions at still higher energies.

REFERENCES

1. I.G. Bearden et al. (NA44 collaboration), nucl-ex/0202019.
2. J. Cleymans, B. Kämpfer, S. Wheaton, Phys. Rev. C 65 (2002) 027901.
3. B. Kämpfer, J. Cleymans, K. Gallmeister, S. Wheaton, hep-ph/0202134, hep-ph/0204227.
4. N. Xu and M. Kaneta, presentations at QM2002, Nantes, France.
5. F. Sikler (NA49 collaboration), Nucl. Phys. A 661 (1999) 45c.

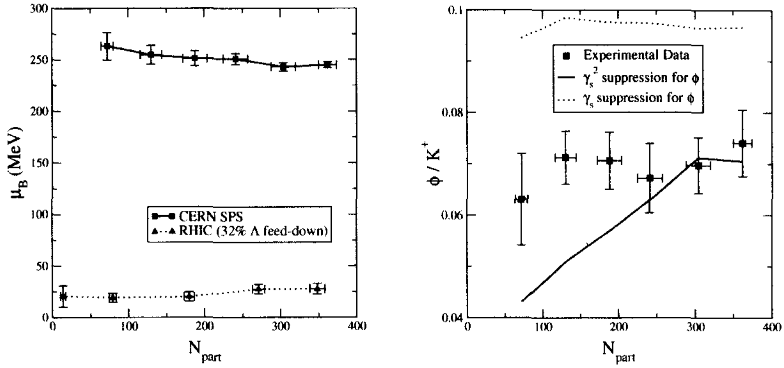

Figure 2. Left panel: The baryo-chemical potential μ_B as a function of $N_{\rm part}$. Squares (triangles) are for the full phase-space NA49 data [5,6] (mid-rapidity PHENIX [7]). Right panel: The ϕ/K^+ ratio at SPS as a function of the number of participants. The dotted line corresponds to predictions of the model using a linear γ_s suppression factor for ϕ mesons, while the solid line is obtained using γ_s^2.

6. V. Friese et al. (NA49 collaboration), Nucl. Phys. A 698 (2002) 487c.
7. K. Adcox et al. (PHENIX collaboration), Phys. Rev. Lett. 88 (2002) 242301.
8. J. Cleymans, K. Redlich, Phys. Rev. C 60 (1999) 054908.
9. P. Braun-Munzinger et al., Phys. Lett. B 344 (1995) 43, B 365 (1996) 1, B 465 (1999) 15, B 518 (2001) 41.
10. F. Becattini, J. Cleymans, A. Keränen, E. Suhonen, K. Redlich, Phys. Rev. C 64 (2001) 024901.
11. J. Letessier, J. Rafelski and A. Tounsi, Phys. Rev. C 50 (1994) 406; C. Slotta, J. Sollfrank and U. Heinz, in *Proceedings of Strangeness in Hadronic Matter*, Tucson, edited by J. Rafelski, AIP Conf. Proc. No. 340 (AIP, Woodbury, 1995), p. 462.
12. D. Pal, A. Sen, M.G. Mustafa, D.K. Srivastava, Phys. Rev. C 65 (2002) 034901.
13. B.B. Back et al. (E917 Collaboration), Nucl. Phys. A 698 (2002) 643c, nucl-th/0108048.