Maximum Strangeness Content in Heavy Ion Collisions Around 30 A·GeV^{B,G}

J. Cleymans, University of Cape Town, South Africa
H. Oeschler, Technische Universität Darmstadt
K. Redlich, University of Wrocław, Poland and GSI, Darmstadt

Strangeness production in heavy ion collisions at relativistic energies provides one of the key information about the reaction mechanism and could indicate the onset of new phenomena.

The attempts to describe the measured particle ratios including strange hadrons at AGS and SPS and recently also at RHIC using a strangeness fugacity are very successful [1, 2, 3, 4, 5]. However, the usual grand-canonical treatment of strangeness conservation is not sufficient, if the number of strange particles is small [6]. This requires local strangeness conservation which is done in the statistical model using the canonical formulation of strangeness conservation [7].

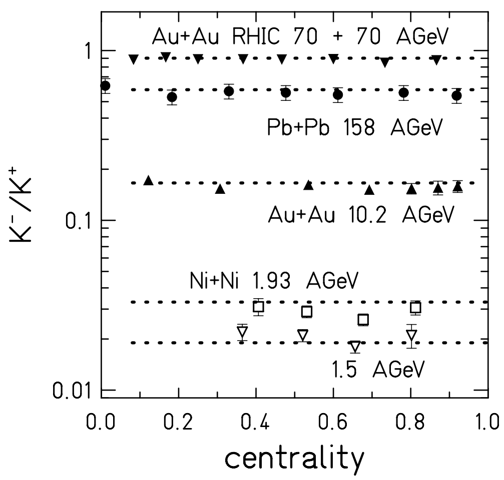

Figure 1: *K^+/K^- ratio is independent of the number of participating nucleons at incident energies from 1.5 A·GeV up to RHIC energies. The dashed lines show the values of the statistical model.*

The canonical approach describes the measured particle ratios at SIS energies and is able to explain the different excitation functions of K^+ and K^- in heavy ion collisions which – when plotted as a function of $\sqrt{s} - \sqrt{s}_{threshold}$ – cross around 1 A·GeV [8]. The canonical description also explains that $M(K^+)/A_{part}$ rises linearly with A_{part} as observed in Au+Au collisions at 1 A·GeV [7, 9] which is in contrast to the behavior of $M(\pi)/A_{part}$ which is independent of A_{part}. This difference is due to the volume term in the canonical description [7]

$$n_{K^+} \sim \exp\left(-\frac{E_{K^+}}{T}\right)\left[g_\Lambda V \int \frac{d^3p}{(2\pi)^3}\exp\left(-\frac{(E_\Lambda - \mu_B)}{T}\right)\right]$$

which takes care of the fact that strange particles are produced associately with another strange particle (e.g. a K^+ together with a Λ). The volume term V, however, drops out when studying the ratio of K^-/K^+ as for the production of K^- an analoguous formula holds

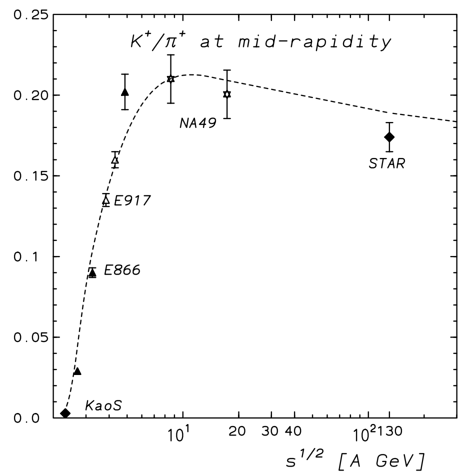

Figure 2: *K^+/π^+ ratio obtained around midrapidity as a function of $\sqrt{s}$ from the various experiments. The dashed line shows the calculation with the statistical model.*

$$n_{K^-} \sim \exp\left(-\frac{E_{K^-}}{T}\right)\left[g_{K^+} V \int \frac{d^3p}{(2\pi)^3}\exp\left(-\frac{E_{K^+}}{T}\right)\right].$$

Indeed, the measured ratios do not vary with the number of participating nucleons in Ni+Ni collisions [10]. This feature is found at all incident energies from 1.5 A·GeV up to RHIC energies as shown in fig. 1 [11, 12, 13]. The above result is especially interesting since between 1.5 and 2.5 A·GeV K^+ production is above while K^- production is below the corresponding NN thresholds.

The enhancement of multi-strange baryons from p+A to $A + A$ collisions might be explainable by a transition from canonical to grand-canonical description as demonstrated in [14].

Recently, the evolution of the K^+/π^+ ratio as a function of $\sqrt{s}$ has attracted great interest as a maximum seemed to appear around 40 A·GeV. Figure 2 shows this ratio obtained at midrapidity from SIS energies up to RHIC [12, 13, 15]. Indeed, a maximum around the data point obtained at 40 A·GeV is seen. In general, statistical-model calculations should be compared with 4π integrated results. Then the maximum is even more pronounced. The extrapolation to 4π is, however, in some cases not well established.

The fact that the statistical model based on the general freeze-out curve [16] (dashed line in Fig. 2 exhibits a maximum, too, might appear surprising. Intuitively, one expects that the fraction of strange particles increases with increasing incident energy. So, the question arises whether the maximum is caused by the distribution of strange quarks among the hadrons at freeze out or whether

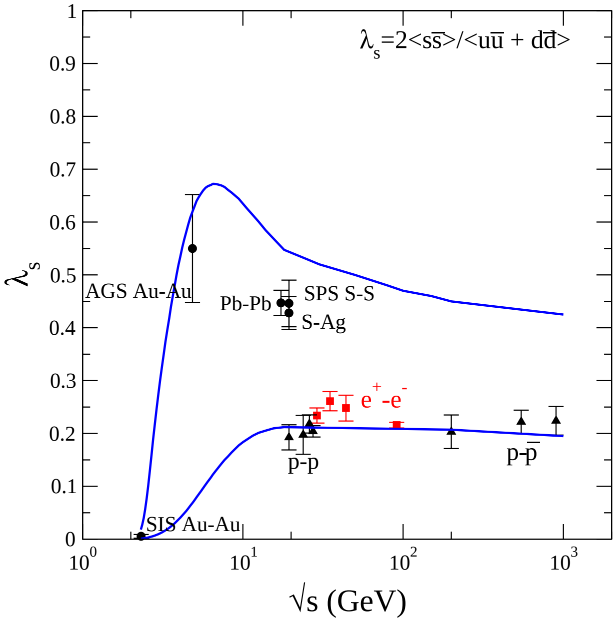

Figure 3: *The Wroblewski ratio λ_S as a function of $\sqrt{s}$. The points refer to measured values (not measured particles species with generally rather small cross sections are added according to the statistical model). The solid lines shows the statistical model results for PbPb and pp collisions.*

less strange quarks are produced in total above a certain incident energy.

To clarify this point, we study next the Wroblewski ratio [17], which is a measure of the strangeness content produced in the collisions. It is defined as

$$\lambda_S = \frac{2N(s\bar{s})}{N(u\bar{u}) + N(d\bar{d})}$$

where $N(q\bar{q})$ is the number of produced quark-antiquark pairs of the given species. The Wroblewski ratio varies from 0 at low incident energies, where no strange particle are produced to a upper limit of 1 for infinite temperature where the difference in masses can be neglected.

Figure 3 shows the values of λ_S extracted from the experimental data. The solid lines in Fig. 3 are the results of the statistical model based on the general freeze-out curve [16]. The results for pp, p$\bar{\text{p}}$, e^+e^- are also included. The lower values of λ_S in elementary compared to AA collisions are due to canonical suppression [18]. From Fig. 3 we conclude that around 30 A·GeV the strangeness content in heavy ion collisions reaches a maximum and decreases slightly towards higher incident energies. This is evidenced in Fig. 4 which shows contour lines of constant λ_S in the $T - \mu_B$ plane. As expected λ_S rises with increasing T. With decreasing μ_B, μ_S decreases and hence λ_S. Following the general freeze-out curve, shown as full line in Fig. 4, λ_S rises quickly at SIS and AGS energies, reaches then a maximum around 30 A·GeV.

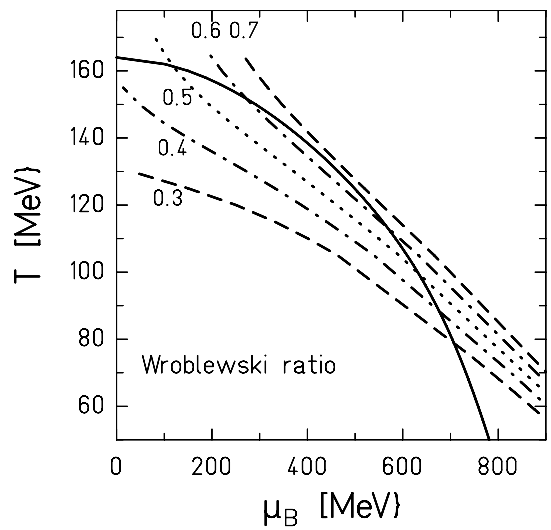

Figure 4: *Lines of constant strangeness content λ_S in the $T - \mu_B$ plane together with the general freeze-out curve (full line) [16].*

References

[1] J. Cleymans and H. Satz, Z. Phys. **C57** (1993) 135.

[2] P. Braun-Munzinger, J. Stachel, J.P. Wessels and N. Xu, Phys. Lett. **B344** (1995) 43.

[3] J. Sollfrank, J. Phys. G: Nucl. Part. Phys. **23** (1997) 1903.

[4] P. Braun-Munzinger, I. Heppe, J. Stachel, Phys. Lett. **B465** (1999) 15.

[5] V.D. Toneev et al., submitted to J. Phys. G: Nucl. Part. Phys.

[6] R. Hagedorn and K. Redlich, Z. Phys. **A27** (1985) 541.

[7] J. Cleymans, H. Oeschler and K. Redlich, Phys. Rev. **C59** (1999) 1663.

[8] J. Cleymans, H. Oeschler and K. Redlich, Phys. Lett. **B485** (2000) 27.

[9] M. Mang, Dissertation, University of Frankfurt, (KaoS Collaboration), 1997.

[10] M. Menzel, Dissertation, U. Marburg, (KaoS Collaboration), 2000.

[11] L. Ahle et al., (E802 Collaboration), Phys. Rev. **C60** (1999) 044904.

[12] C. Blume, (NA49 Collaboration), Conference on "Quark Matter 2001", Stony Brook, Jan. 2001....

[13] J. Harris, (STAR Collaboration), idem.

[14] S. Hamieh, K. Redlich, A. Tounsi, Phys.Lett. **B486** (2000) 61.

[15] L. Ahle et al., (E866/E917 Collaboration), Phys. Lett. B476 (2000) 1.

[16] J. Cleymans and K. Redlich, Phys. Rev. Lett. **81** (1998) 5284; Phys. Rev. **C60** (1999) 054908.

[17] A. Wroblewski, Acta Physica Polonica **B16** (1985) 379.

[18] F. Becattini et al., hep-ph/0002267.