Strangeness in Pb–Pb Collisions at 158 A GeV

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Abstract

We study relative strange particle abundances measured in Pb–Pb 158 A GeV interactions. The thermal and chemical source parameters of these particles are determined under reaction scenario hypothesis invoking confined and deconfined hadronic matter.

Introduction

The interest in the study of strange particles produced in relativistic nuclear collisions derives from the understanding that strangeness flavor arises most rapidly in the color deconfined phase. For reviews of the recent status of the field of strangeness as tool in study of dense forms of hadronic matter we refer to the proceedings of Strangeness’95 [1] and Strangeness’96 [2] meetings, and pertinent recent reviews [3, 4].

We recall here specifically that studies of Sulphur (S) induced reactions at 200 A GeV show that strangeness yield is considerably enhanced compared to appropriately scaled proton (p) induced reactions. Moreover, this effect is accompanied by anomalously high production of strange antibaryons. It has been suggested that these effects can arise when strangeness is formed by gluon fusion in high density deconfined phase, which disintegrates in a sudden hadronization process without reequilibration into final state hadrons. Detailed models were developed showing that [4, 5].

The possibility that strange particle anomalies seen in S-induced reactions are arising from the deconfined quark-gluon-plasma (QGP) phase has stimulated the continuation of this research program in the considerably more difficult, high particle multiplicity environment arising in Pb induced reactions, which are presently possible at 158 A GeV. Here we will attempt a first analysis of Pb–Pb data which became available in late Spring 1997. We advance an interpretation of these results in terms of the formation of a deconfined quark-gluon-plasma (QGP),

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and a confined hot hadronic gas (HG). Strategies for making this distinction with hadronic probes are considered.

This study addresses seven ratios of strange and anti strange baryons measured by the WA97–collaboration [6] and two such ratios measured by the NA49–collaboration [8, 9]. These ratios appear only on first sight to be much like the earlier S–W and S–S data of experiments WA85 and WA94 [10]. The NA49–collaboration has also presented the rapidity and transverse mass spectra of Λ, Λ and kaons [8]; the latter result are consistent with the central transverse mass spectra already reported by the NA44–collaboration [11]. First NA49 results about the production of φ = s¯s are also already available [12]. In the context of a thermal model interpretation of the data which we will pursue here, we note that the experiment NA49 reports a major change in the shape of rapidity spectra [8]: the Λ, Λ and kaon rapidity distributions are localized around mid-rapidity and are, in particular in case of Λ, narrower than previously seen in S-induced reactions, with a rapidity shape now quite similar to a directly radiating thermal source.

The WA97–collaboration stresses that at 95% confidence level there is at least a factor 2 enhancement in the Ω/Ξ ratio in Pb–Pb compared to p–Pb collisions:

\[
\frac{(\Omega + \bar{\Omega})/(\Xi + \bar{\Xi})|_{\text{Pb–Pb}}}{(\Omega + \bar{\Omega})/(\Xi + \bar{\Xi})|_{\text{p–Pb}}} \simeq 3 \ (> 2) .
\]

The significance of the last result is that hadronic cascades tend to attenuate the yield of multistrange hadrons in strangeness exchange reactions. This can be thus taken as evidence that direct emission from a hot fireball of deconfined matter is the prevailing reaction mechanism.

The NA49–collaboration stresses that there is no major change in total specific strangeness production, compared to the earlier study of S–S and S–Au interactions [13]. This is in rough agreement with our finding within the QGP reaction model [4], since the gluon fusion mechanism is sufficiently fast to nearly saturate the available phase space in the S and Pb induced reaction systems. For example, in Figs. 37 and 38 of Ref. [4], we have shown that the specific strangeness yield per baryon increases only by about 20% for central Pb induced reactions, compared to S-induced reactions.

**Strange (Anti)Baryon Ratios from QGP**

The experiment WA97 [6] has reported several specific strange baryon and antibaryon ratios from Pb–Pb collisions at 158 A GeV, comprising 30% of inelastic interactions. All ratios are obtained in an overlapping kinematic window corresponding effectively to transverse momentum \(p_\perp > 0.7\) GeV, within the central rapidity region \(y \in y_{cm} \pm 0.5\). They have been corrected for weak interactions cascading decays. The experimental values are:

\[
R_\Lambda = \frac{\bar{\Lambda}}{\Lambda} = 0.14 \pm 0.03 , \quad R_\Xi = \frac{\Xi}{\bar{\Xi}} = 0.27 \pm 0.05 , \quad R_\Omega = \frac{\bar{\Omega}}{\Omega} = 0.42 \pm 0.12 , \quad (1)
\]

\[
R_\bar{\Lambda}^p = \frac{\bar{\Lambda}}{\Lambda} = 0.14 \pm 0.02 , \quad R_\bar{\Xi}^p = \frac{\Xi}{\bar{\Xi}} = 0.26 \pm 0.05 , \quad (2)
\]

\[
R_\bar{\Omega}^p = \frac{\bar{\Omega}}{\Omega} = 0.19 \pm 0.04 , \quad R_\bar{\Xi}^p = \frac{\Xi}{\bar{\Xi}} = 0.30 \pm 0.09 . \quad (3)
\]
Here, the lower index $s$, resp. $\bar{s}$ reminds us that the ratio measures the density of strange, resp. antistrange quarks and upper index $p$ that it is done within a common interval of transverse momenta (and not common transverse mass). We should keep in mind that only 6 different particle yields were measured and thus only 5 ratios are independent of each other. One easily finds the two definition constraints:

$$\frac{R_{\Xi}}{R_{\Lambda}} = \frac{R_{\bar{s}}}{R_{s}}, \quad \frac{R_{\Omega}}{R_{\Xi}} = \frac{R_{\bar{s}p}}{R_{sp}}.$$  

(4)

However, in our fit to these data, we shall retain all seven ratios as presented and the error $\xi^2$ will correspond to sum of seven relative square errors. On the other hand we keep in mind that in this experiment alone there is only 5 independent data points.

There is agreement between WA97 and NA49 on the value of $R_{\Lambda}$, even though the data sample of NA49 is taken for more central trigger, constrained to as few as 4% of most central collisions. The cuts in $p_{\perp}$ and $y$ are nearly identical in both experiments. From Fig. 3 in [3] we obtain the value $R_{\Lambda} = 0.17 \pm 0.03$, which we shall combine with the value given by WA97 and we thus take in our data fit:

$$R_{\Lambda} = \frac{\Lambda}{\bar{\Lambda}} = 0.155 \pm 0.04.$$  

(5)

The experiment NA49 also reported [4]:

$$\frac{\Xi + \Xi}{\Lambda + \bar{\Lambda}} = 0.13 \pm 0.03.$$  

(6)

While this ratio can be expressed in terms of the three other ratios

$$\frac{\Xi + \Xi}{\Lambda + \bar{\Lambda}} = R_{sp} \frac{1 + R_{\Xi}}{1 + R_{\Lambda}},$$  

(7)

it is again a separate measurement which thus can be fitted independently.

We next introduce all the model parameters used in the fit of the particle ratios, not all will be required in different discussions of the experimental data. For more details about the thermo-chemical parameters we refer to the extensive discussion in the earlier study of S–S and S–W data [1, 4, 13, 14]:

1. $T_f$ is the formation/emission/freeze-out temperature, depending on the reaction model. $T_f$ enters in the fit of abundance ratios of unlike particles presented within a fixed $p_{\perp}$ interval. The temperature $T_f$ can in first approximation be related to the observed high-$m_{\perp}$ slope $T_{\perp}$ by:

$$T_{\perp} \approx T_f \frac{1 + v_{\perp}}{\sqrt{1 - v_{\perp}^2 - v_{\parallel}^2}}.$$  

(8)

In the central rapidity region the longitudinal flow $v_{\parallel} \simeq 0$, in order to assure symmetry between projectile and target. Thus as long as $T_f < T_{\perp}$, we shall use Eq. (8) setting $v_{\parallel} = 0$ to estimate the transverse flow velocity $v_{\perp}$ of the source.

2. $\lambda_q$, the light quark fugacity. We initially used in our fits both $u, d$-flavor fugacities $\lambda_u$ and $\lambda_d$, but we determined that the results were represented without allowing for up-down quark asymmetry by the geometric average $\lambda_q = \sqrt{\lambda_u \lambda_d}$; moreover the fitted up-down quark fugacity asymmetry was found as expected in our earlier analytical studies [14].
Table 1: Values of fitted statistical parameters within thermal model, see text for their meaning. Superscript star '*': a fixed input value for equilibrium hadronic gas; subscript '|c': value is result of the imposed strangeness conservation constraint. $\chi^2$ is the total relative square error of the fit for all data points used. First line: Direct emission QGP model, no meson ratio fit. Second line: same, but with strangeness conservation yielding $\lambda_s$ and $R_C$ variable. Line three: as in line two, with meson ratio fitted. Line four: hadronic gas fit.

| $T_i[MeV]$ | $\lambda_q$ | $\lambda_s$ | $\gamma_s$ | $R_C^s$ | $\chi^2$ |
|------------|-------------|-------------|------------|----------|----------|
| 272 ± 74   | 1.50 ± 0.07 | 1.14 ± 0.04 | 0.63 ± 0.10 | —        | 1.0      |
| 272 ± 74   | 1.50 ± 0.08 | 1.14|_c | 0.63 ± 0.10 | 4.21± 1.88 | 1.0      |
| 151 ± 10   | 1.54 ± 0.08 | 1.13|_c | 0.91± 0.09 | 0.85± 0.22 | 1.5      |
| 155 ± 7    | 1.56 ± 0.09 | 1.14|_c | 1*       | 1*       | 7.6      |

3. $\lambda_s$, the strange quark fugacity. A source in which the carriers of $s$ and $\bar{s}$ quarks are symmetric this parameter should have the value $\lambda_s \approx 1$, in general in a re-equilibrated hadronic matter the value of $\lambda_s$ can be determined requiring strangeness conservation.

4. $\gamma_s$, the strange phase space occupancy. Due to rapid evolution of dense hadronic matter it is in general highly unlikely that the total abundance of strangeness can follow the rapid change in the conditions of the source, and thus in general the phase space will not be showing an overall abundance equilibrium corresponding to the momentary conditions.

5. We also show when appropriate in table II the parameter $R_C^s$ describing the relative off-equilibrium abundance of strange mesons and baryons, using thermal equilibrium abundance as reference. This parameter is needed, when we have constraint on the strangeness abundance and/or when we address the abundance of mesons since there is no a priori assurance that production/emission of strange mesons and baryons should proceed according to relative strength expected from thermal equilibrium. Moreover, it is obvious that even if reequilibration of particles in hadronic gas should occur, this parameter will not easily find its equilibrium value $R_C^s = 1$. However, due to reactions connecting strange with non-strange particles we obtain $R_C^s = R_C$, where $R_C$ is the same ratio for non-strange mesons and baryons, using thermal abundance as reference. The value of $R_C > 1$ implies meson excess abundance per baryon, and thus excess specific entropy production, also expected due to color deconfinement [16].

The relative number of particles of same type emitted at a given instance by a hot source is obtained by noting that the probability to find all the $j$-components contained within the $i$-th emitted particle is

$$N_i \propto \gamma_s^k \prod_{j \in i} \lambda_j e^{-E_j/T},$$

and we note that the total energy and fugacity of the particle is:

$$E_i = \sum_{j \in i} E_j, \quad \lambda_i = \prod_{j \in i} \lambda_j.$$
The strangeness occupancy $\gamma_s$ enters Eq. (8) with power $k$, which equals the number of strange and antistrange quarks in the hadron $i$. With $E_i = \sqrt{m_i^2 + p_i^2} = \sqrt{m_i^2 + p_{i\perp}^2 \cosh y}$ we integrate over the transverse momentum range as given by the experiment (here $p_{i\perp} > 0.6$ GeV taking central rapidity region $y \simeq 0$ to obtain the relative strengths of particles produced. We then allow all hadronic resonances to disintegrate in order to obtain the final multiplicity of ‘stable’ particles we require to form the observed ratios. This approach allows to compute the relative strengths of strange (anti)baryons both in case of surface emission and equilibrium disintegration of a particle gas since the phase space occupancies are in both cases properly accounted for by Eq. (8). The transverse flow phenomena enter in a similar fashion into particles of comparable mass and cannot impact particle ratios. On the other hand, the abundance comparison between different kinds of particles (mesons and baryons) is unreliable in case of emission from unequilibrated source and we will only consider this ratio for the case of a disintegrating equilibrated gas. Finally, particles that are easily influenced by the medium, such as $\phi$, require a greater effort than such a simple model, and are also not explored in depth here.

We obtain the least square fit for the eight above discussed (anti)baryon ratios. Our first approach is motivated by the reaction picture consisting of direct emission from the QGP deconfined fireball. The value of statistical parameters controlling the abundances are thus free of constraints arising in an equilibrated hadronic gas (HG) state [14]. The fitted thermal parameters are presented in the first line of table 1 along with the total $\chi^2$ for the eight ratios. The fit is quite good, the error shown corresponds to the total accumulated error from 8 measurements; even if one argues that it involves 4 parameters to describe 5 truly independent quantities, the statistical significance is considerable, considering that 8 different measurements are included. We compare the experimental and fitted values in second and third column of table 2.

The errors seen in table 1 on the statistical parameters arise in part from strong correlations among them. In particular the very large error in $T_f$ arise from the 80% anti-correlation with $\gamma_s$. However, some further information about the relation of $T_f$ and $\gamma_s$ may be garnered from theoretical considerations. We evaluate using our dynamical strangeness evolution model in QGP [4] how the value of $\gamma_s$ depends on the temperature of particle production $T_f$. The most important parameter in such a theoretical evaluation is the initial temperature at which the deconfined phase is created. We estimated this temperature at $T_{in} = 320$ MeV [5]. Further uncertainty of the calculation arises from the strange quark mass taken here to be $m_s(1$ GeV$) = 200$ MeV (the strength of the production rate is now sufficiently constrained by the measurement of $\alpha_s(M_Z))$. We choose a geometric size which comprises a baryon number $B = 300$ at $\lambda_q \simeq 1.5$, and have verified that our result will be little dependent on small variations in $B$. We show in Fig. 1 how the computed $\gamma_s$ depends on formation temperature $T_f$. The cross to the right shows our fitted value from line 1 in table 1. It is consistent with the theoretical expectation for early formation of the strange (anti)baryons, and implies that the central fitted values of $T_f$ and $\gamma_s$ can be trusted, if such a model is presumed. The relatively high value of temperature $T_f$ we obtained calls for a closer inspection of the experimental inverse $m_{\perp}$ slopes. In the common $p_{\perp}$ range of WA97 and NA49 experiments the transverse mass spectrum of $\Lambda$ and $\bar{\Lambda}$ obtained by NA49 is exponential [8]. A thermal model motivated fit the inverse slope (temperature) yields $T_\Lambda^{\perp} = 284 \pm 15$ MeV and $T_{\bar{\Lambda}}^{\perp} = 282 \pm 20$ MeV. This is consistent with the mid-rapidity proton and antiproton slope of the NA44 experiment: $T_p = 289 \pm 7$ MeV and $T_{\bar{p}} = 278 \pm 9$ MeV. For $\Xi + \bar{\Xi}$ a consistent value $T_{\Xi} = 290$ MeV is also quoted by NA49–collaboration [9]. We note that because the baryon masses are large, all these slopes are at relatively high $m_{\perp} > 1.3$ GeV.
Table 2: Particle ratios: experimental results and different fits; column $|c|$ refers to strangeness constrain imposed in hot QGP, (the QGP and $|c|$ columns are practically the same); ‘cold’ column refers to late particle formation from QGP with last given ratio also fitted. HG fit is for fully equilibrated hadronic gas thermal model.

| Ratios            | Experiment | QGP  | $|c|$  | cold | HG  |
|-------------------|------------|------|-------|------|-----|
| $\Xi/\Lambda$     | 0.14 ± 0.02| 0.136| 0.136 | 0.142| 0.158|
| $\bar{\Xi}/\bar{\Lambda}$ | 0.26 ± 0.05| 0.232| 0.232 | 0.260| 0.292|
| $\Omega/\Xi$      | 0.19 ± 0.04| 0.185| 0.184 | 0.123| 0.141|
| $\bar{\Omega}/\bar{\Xi}$ | 0.30 ± 0.09| 0.320| 0.320 | 0.228| 0.262|
| $\Lambda/\Lambda$ | 0.155 ± 0.04| 0.153| 0.153 | 0.141| 0.131|
| $\bar{\Xi}/\Xi$   | 0.27 ± 0.05| 0.261| 0.260 | 0.259| 0.242|
| $\bar{\Omega}/\Omega$ | 0.42 ± 0.12| 0.451| 0.451 | 0.480| 0.450|
| $(\Xi + \bar{\Xi})/(\Lambda + \bar{\Lambda})$ | 0.13 ± 0.03| 0.151| 0.151 | 0.166| 0.184|
| $\Lambda/K_s^0|_{m_{\perp}}$ | 6.2 ± 1.5 | —    | —     | 5.6  | 5   |

Figure 1: QGP stranginess occupancy $\gamma_s$ as function of temperature $T_f$ at time of particle production, for initial temperature $T_{in} = 320$ MeV, with $\gamma_s(T_{in}) = 0.1$. See [4] for details of the model.
(for nucleons, in NA44, $m_\perp > 1$ GeV). Systematically smaller inverse-transverse slopes are seen at smaller $m_\perp$, for Kaons $T_{\perp}^K \simeq 213–224$ MeV for $0.7 < m_\perp < 1.6$ GeV in NA49 \[8\] and $T_{\perp}^{K^+} = 234 \pm 6$, $T_{\perp}^{K^-} = 235 \pm 7$ MeV in NA44 \[11\]; and 155–185 MeV for $\pi$, \[8, 11\], depending on the range of $p_\perp$, but here we have to remember that pions arise primarily from resonance decays. An increase of $T$ with $m_\perp$ is most naturally associated with the effects of transverse flow of the source. In any case we are led to the conclusion that $200 < T_f < 290$ MeV and that as far as the fitted temperatures and slopes are concerned it is possible that the high $m_\perp$ strange (anti)baryons we have described could have been emitted directly from a primordial (deconfined) phase before it evolves into final state hadrons.

Is this hypothesis also consistent with the chemical fugacities we have obtained? The chemical condition is fixed to about 5% precision, and there is 40% anti-correlation between the two fugacities $\lambda_q$ and $\lambda_s$. The information that $\lambda_s \neq 1$ is contained in at least two particle abundances; arbitrary manipulation of the reported yields of one particle abundance did not reduce the value $\lambda_s$ to unity. Since $\lambda_s \neq 1$ by 4 s.d. it is highly unlikely that $\lambda_s = 1$ is found after more data is studied. While one naively expects $\lambda_s^{QGP} = 1$, to assure the strangeness balance $\langle s - \bar{s} \rangle = 0$, there must be a small deviations from this value, even if the emitted particles were to reach asymptotic distances without any further interactions: in presence of baryon density the deconfined state is not fully symmetric under interchange of particles with antiparticles. A possible mechanism to distinguish the strange and anti-strange quarks arises akin to the effect considered for the $K^-/K^+$ asymmetry in baryonic matter \[17, 18\]: there is asymmetric scattering strength on baryon density $\nu_b$ which causes presence of a mean effective vector potential $W$. Similarly, strange quark interaction with baryon density would lead to a dispersion relation

$$E_{s/\bar{s}} = \sqrt{m_s^2 + p^2} \pm W,$$

and this requires in the statistical approach that the Fermi distribution for strange and antistrange quarks acquires a compensating fugacity $\lambda_{s,\bar{s}} = e^{\pm W/T}$ to assure strangeness balance in the deconfined phase. In linear response approach $W \propto \nu_b$ consistent with both $W$ and baryon density $\nu_b = (n_q - n_{\bar{q}})/3$, being fourth component of a Lorenz-vector. It is clear for intuitive reasons, as well as given experimental observations, that the baryon stopping and thus density increases considerably comparing the S and Pb induced reactions in the energy domain here considered. We also recall that in S–W reactions $\lambda_s^S \simeq 1.03 \pm 0.05$ \[17\]. Should in the dense matter fireball the baryon density $\nu_b$ grow by factor 2–4 as the projectile changes from S to Pb, this alone would consistently explain the appearance of the value $\lambda_s = 1.14 \pm 0.04$. It is worth noting that the value $W \simeq 38$ MeV suffices here. Note that the Coulomb potential effect on the charge of the strange quarks is of opposite magnitude and about 1/5–1/6 of the here required strength.

In order to estimate what would be implied by strangeness conservation constraint by the presence of the value $\lambda_s \neq 1$ we present in table \[7\] the result of a fit assuming that the value of $\lambda_s$ is result of the conservation constraint $\langle s - \bar{s} \rangle = 0$, and introducing $R_c \neq 1$. The result implies that considerably more strange mesons would be produced if they were emitted along with baryons in a sudden and early QGP disintegration. The statistical error is found practically the same as in line 1. We note that the third raw in table \[2\] (under heading $|c|$ for constrain) is presenting the resulting particle ratios for this fit. It is hardly changed from the second raw, as the fit converges practically to the same point in this approach.
Late Emission Interpretation

If particle formation from QGP occurs late in the evolution of the dense hadronic matter we must preserve the strangeness conservation criterion in our fit. It will be of some considerable importance for this alternative study to have a measure of the relative abundance of kaons and hyperons. The issue is that all open-strangeness hadronic particles are now produced at the same time in the evolution of the fireball and thus should definitively add up to give \( \langle s - \bar{s} \rangle \approx 0 \). This is here a very strong constraint as it in principle establishes a consistency between different otherwise seemingly unrelated particle abundances. An experimental measure of the relative abundance strength is so far not given. However, we note that the NA49 spectra \[^8\] of kaons and hyperons have a slightly overlapping domain of \( m_\perp \). We recall that the slopes are different, thus all we can do is to try to combine the two shapes, assuming continuity consistent with flow, and to estimate the relative normalization of both that would place all experimental points on a common curve. We have carried out this procedure and obtained:

\[
\frac{\Lambda}{K_0^0} \bigg|_{m_\perp} \approx 6.2 \pm 1.5. \tag{12}
\]

Note that there is a tacit presumption in our approach that a similar effective \( \Delta y \) interval was used in both spectra. We recall that this ratio was \( 4.5 \pm 0.2 \) in the S-W data \[^9\]. We will now fit altogether 9 data points: the 8 baryonic ratios and our above estimate. We show the resulting fitted statistical parameters in the third line of table \[^1\], and note that this cold-QGP alternative has a very comparable statistical significance as the hot-QGP. The computed flow velocity at freeze-out is \( v_f = 0.51c \). This is just below the relativistic sound velocity \( v_s = 1/\sqrt{3} = 0.58 \) which we have assumed in the calculation shown in Fig.\[^4\]. In that figure, the cross to the left shows the result of the fit; allowing for potentially smaller expansion velocity and all the above discussed uncertainties in the computation, this result must also be seen as a very good agreement between the result of data fit and the theoretical calculation. This also means that we cannot distinguish in the present data between early formation of strange antibaryons and an expansion model followed by direct global hadronization. However, we note that in table \[^2\] the resulting particle ratios shown in column four, under heading ‘cold’ are quite different from the other QGP fits and thus we should be able to distinguish the scenarios with better experimental data.

We will finally consider the possibility that the strange particle abundances could be explained within a simple thermal model of confined, equilibrated particles, commonly called hadronic gas (HG) emanating at a late stage of fire evolution. We can now employ a minimal set of parameters since assuming fully equilibrated hadronic gas we have \( \gamma_s = 1, R_c = 1 \), and we use strangeness conservation to evaluate the strangeness fugacity \( \lambda_s \). We show the result of the fit in the last line of table \[^4\] and in particular we note:

\[
T_f = 156 \pm 8.7 \text{ MeV}, \quad v_\perp \simeq 0.5 \simeq v_s; \\
\lambda_q = 1.56 \pm 0.07, \quad \lambda_s = 1.14; \\
\chi^2/9 = 0.84, \quad \text{C.L.} > 60\%. \tag{13}
\]

We recall that the baryochemical potential is given in terms of \( T \) and \( \lambda_q, \mu_b = 3T \ln \lambda_q \), and we find \( \mu_b = 205 \pm 10 \) MeV in this hadronic gas condition. We note that while the quality of the fit has degraded, it still has considerable statistical significance. The resulting particle ratios is
shown in last column in table 4. Looking at it, we see that it is very hard with ‘naked’ eye to give preference to any of the fits to the data, though this last one is definitively less statistically significant than the other three.

Concluding Remarks

Clearly, the remarkable effect that we see in the data is that within factor 1.4 all available Pb–Pb results can be explained in terms of fully thermally and chemically equilibrated hadronic gas. If this is born out by more precise data, we will have a considerable interpretation problem to solve: a back of envelope calculation shows that equilibration constants on HG are far too slow to explain this effect, and thus either we err significantly in our estimates about the evolution of HG or there is some chemical equilibration mechanism, such as QGP formation. If we apply QGP model to the data, we find a more statistically significant fit, but cannot distinguish at present the type of fireball evolution that is occurring. All this shows that we really need to have better data to make progress, and these should include not only ratios of strange particles but also reflect on the global strangeness enhancement, and a measure of specific entropy per baryon which, as we did stress previously [16] provides additional evidence for the color bond breaking of hadrons as deconfinement sets in.

Our quite successful fits to the data show that the freeze-out properties of strange baryons and antibaryons point to a well localized, confined, thermally and nearly chemically equilibrated source, undergoing possibly a transverse expansion nearly with the velocity of sound of relativistic matter. Some preference of the data points towards the QGP picture of the reaction, but assumption of an equilibrated HG also explains the present day Pb–Pb data, and more and better data is needed to resolve the issue. However, we have been able to obtain here a rather specific information on the chemical conditions in the dense matter fireball formed in central Pb–Pb collisions; this information is of considerable relevance for study of other phenomena. We determined that quark fugacity is $\lambda_q \approx 1.53$ corresponding to $\lambda_b = \lambda_q^3 \approx 3.6$ (and thus baryochemical potential $\mu_b = T \log \lambda_b = 200$ MeV for ‘cold’ QGP or HG freeze-out condition), and a strange quark fugacity $\lambda_s \approx 1.14$.

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