QGP formation and strange antibaryons

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Abstract

We analyze current experimental results and explore, as function of the collision energy and stopping in relativistic nuclear collisions, the production yields of strange antibaryons, assuming formation of a deconfined thermal QGP-fireball which undergoes a sudden hadronisation.
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It is believed that a new phase of hadronic matter, the so-called quark-gluon plasma (QGP) can be formed in relativistic nuclear (A–A) collisions. Because of its rather limited (nuclear size) volume and hence very short lifespan of about 5 fm/c at currently accessible energies $\sqrt{s} \leq 10$A GeV, the search for this transient phase is today a formidable experimental task and considerable effort is devoted to the theoretical study of possible experimental observables.

In this paper we develop the method that involves as observable the strange antibaryons [1, 2, 3]. The expected and confirmed high production rate of multiply strange antibaryons in A–A reactions, and the central (in rapidity) spectral distribution, are indicative of a 'collective' formation mechanism: in the QGP reaction picture it is the ready made high density of (anti) strange quarks which leads to highly anomalous yields of multiply strange particles. We note that no alternative model to the here developed rapidly hadronising QGP has been proposed which could generate both strangeness abundance and multi-strange antibaryon enhancement. The contributions from the conventional mechanisms are small since the required multi-step processes occur relatively rarely in p–p interactions. In other approaches, e.g. in the dual parton model DPM [4], several parameters help enhance strangeness and some strange antibaryon abundances, but one finds a considerably smaller relative abundance $\overline{\Omega}/\overline{\Xi}$.

Several studies addressed recently the question [3, 5, 6, 7, 8] how the current data can distinguish between the formation of a central fireball consisting of a dense and very hot hadron (resonance) gas and the creation of a transient deconfined state such as the quark-gluon plasma (QGP) which subsequently hadronise — note that even if this final state hadronisation involves

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a full re-equilibration, then the memory of the QGP should not be completely lost, since the deconfined state is often richer in entropy than the confined state [5, 9, 11], which becomes visible as particle excess in the final state.

In our approach we assumes the formation in the collision of a thermal baryon-rich fireball in the central rapidity region, an assumption supported by the pattern of diverse particle production processes even in 200A GeV collisions. For example, the rapidity distribution of Λ and $\overline{\Lambda}$ as measured by the NA35 experiment [12] affirms such a picture of the A–A reactions. These results show that the S–Ag/W/Pb and even the S–S collisions at 200A GeV are far from the limit of baryon-transparency in which the valence quarks of projectile and target are presumed to leave the central rapidity region. This picture of hadronic processes implies a rapid thermalization of the relevant degrees of freedom on the prevailing time scale of the interaction. We can expect that the leading particle and flow effects diminish in their significance as the size of the interaction region increase.

The different (cooling) stages of the evolution of such a central fireball are characterized by the following temperatures:
$T_{\rm th}$ temperature of initial thermal equilibrium,
$T_{\rm ch}$ temperature of chemical equilibrium for non-strange quarks and gluons,
T_0 temperature of maximal chemical equilibrium ('visible' emission temperature),
$T_{\rm f}$ temperature at freeze-out.

In the transverse mass spectra of strange (anti)baryons a temperature $T_\perp$ is found. If the final state particles emerge directly without re-equilibration from the fireball [2, 13], this observed temperature ($T_\perp = 232 \pm 5$ in S–A collisions at 200A GeV) in the particle spectra would be closely related to the full chemical equilibration temperature T_0 : subsequent to the establishment of the conditions at T_0 we have either directly the emission of particles and thus we have $T_\perp \leq T_0$, or there is collective, (so called transverse) radial flow in the hot matter, in which fraction of the thermal energy is converted into the flow energy. When the final state particles emerge from the flowing surface, they are blue-shifted by the flow velocity. This Doppler shift effect restores the high apparent T_0 in high $m_\perp$ particle spectra [14]. In either case the uncertainty in the value of the temperature T_0 as derived from the value of $T_\perp$ is not large.

Particle yields from a fireball are further characterized by particle fugacities, which allow to conserve flavor quantum numbers. It is sufficient to combine the light quarks into one fugacity $\lambda_{\rm q}^2 \equiv \lambda_{\rm d}\lambda_{\rm u}$. The fugacity of each hadronic particle species is the product of the valence quark fugacities, thus, for example, the hyperons have the fugacity $\lambda_{\rm Y} = \lambda_{\rm u}\lambda_{\rm d}\lambda_{\rm s}$. Fugacities are related to the chemical potentials μ_i by:

$$\lambda_i = e^{\mu_i/T}\,, \quad \lambda_{\bar{i}} = \lambda_i^{-1} \qquad i = u,\, d,\, s\,. \tag{1}$$

The chemical potentials for particles and antiparticles are opposite to each other, provided that there is complete chemical equilibrium, and if not, that the deviation from the full phase space occupancy is accounted for by introducing a non-equilibrium chemical parameters $\gamma_i(t)$, which accounts for the fact that the production of particles within the fireball is a considerably slower process than elastic collisions of the constituents, and thus even though we assume a thermal equilibrium scheme, we should not expect the chemical equilibrium to be present.

In addition, we differentiate the relative and absolute chemical equilibria. In the former, only the particle abundances are in relative equilibrium with each other, in the latter the total particle yields are completely filling the available phase space — relative chemical equilibrium is clearly easier to attain. Calculations [15, 16] of the complete chemical relaxation constant show that in general strangeness will not fully saturated the available phase-space. Therefore, we consider the associated off-equilibrium parameter $\gamma_{\rm s}$. Since the thermal equilibrium is believed here to be established within a considerably shorter time scale than the (absolute) chemical equilibration of strangeness, we can characterize the saturation of the strangeness phase space by an average over the momentum distribution:

$$\gamma_{\rm s}(t) \equiv \frac{\int d^3p\, d^3x\, n_{\rm s}(\vec{p}, \vec{x}; t)}{\int d^3p\, d^3x n_{\rm s}^{\infty}(\vec{p}, \vec{x})}\ , \tag{2}$$

where $n_{\rm s}^{\infty}$ is the equilibrium particle density. The factor $\gamma_{\rm s}$ thus enters the (Boltzmann) phase space momentum distribution as a multiplicative factor. Unexpectedly, it is rather straightforward to extract from the strange antibaryon experimental particle yields [3, 8, 13, 17] the value of $\gamma_{\rm s}$. Roughly speaking, $\gamma_{\rm s}$ makes its appearance in all particle ratios in which we compare the abundances involving different strangeness content.

We now consider the conditions reached in the collision fireball: an important constraint arises from the energy per baryon content in the fireball. The energy of colliding nuclei determines the energy per baryon content in the fireball E/B:

$$\frac{E}{B} = \frac{\eta_{\rm E} E_{\rm CM}}{\eta_{\rm B} A_{\rm part}} \simeq \frac{E_{\rm CM}}{A_{\rm part}}, \tag{3}$$

where $A_{\rm part}$ is the number of nucleons participating in the reaction. The last equality follows when the stopping fractions $\eta_{\rm E}$ of energy and $\eta_{\rm B}$ of baryon number in the central fireball are equal. When the projectile is smaller than the target we assume a collision with the geometric target tube of matter and obtain the following kinematic energy content:

$E/B = 2.3$ GeV for Au–Au at 10.5A GeV,
$E/B = 2.6$ GeV for Si–Au at 14.6A GeV,
$E/B = 4.3$ GeV for A–A at 40A GeV,
$E/B = 8.6$ GeV for Pb–Pb at 158A GeV,
$E/B = 8.8$ GeV for S–W/Pb at 200A GeV,
$E/B = 9.6$ GeV for S–S at 200A GeV.

This specific energy content E/B, given QGP equations of state (EoS), establishes a constraint [18] between the statistical parameters T and $\lambda_{\rm q}$. Choosing $\alpha_s = 0.6$ for the QCD coupling, the temperatures seen in transverse mass spectra are consistent with these kinematic requirements [19]. We next use the intuitive idea that the statistical conditions reached in the central fireball arise from the equilibrium between the fireball internal thermal and external compression pressure. The thermal pressure follows in usual way from the EoS, the pressure due to kinetic motion can be directly inferred from the pressure tensor and is given by $P_{\rm dyn} = \eta_{\rm p}\rho_0 p_{\rm CM}^2/E_{\rm CM}$ [20]. Here it is understood that the energy $E_{\rm CM}$ and the momentum $p_{\rm CM}$ are given in the nucleon–nucleon CM frame and $\eta_{\rm p}$ is the momentum stopping fraction — only this fraction $0 \leq \eta_{\rm p} \leq 1$ of the incident CM momentum can be used by a particle incident on the central fireball in order to exert dynamical pressure.

To determine the properties of the fireball we make the plausible hypothesis that when the collision has terminated (at about 1.5 fm/c in the CM frame), the u, d quarks and gluons have reached their chemical equilibrium, $\gamma_{\rm q} \to 1$, $\gamma_{\rm G} \to 1$, but the strange flavor is still far from equilibrium and we choose $\gamma_{\rm s} \simeq 0.15$ appropriate for strange quark relaxation time [16]. Because the QGP phase is strangeness neutral we have $\lambda_{\rm s} = 1$. The remaining statistical parameters $T_{\rm ch}$

Table 1: Properties of different collision fireballs.

Phase space occupancy	$<s-\bar{s}>=0$ $\lambda_s\equiv 1$	E/B [GeV]				
		2.6 $\eta=1$ Au–Au	4.3 $\eta=1$ Pb–Pb	8.8 $\eta=0.5$ S–Pb	8.6 $\eta=0.75$ Pb–Pb	8.6 $\eta=1$ Pb–Pb
	T_{ch} [GeV]	0.212	0.263	0.280	0.304	0.324
$\gamma_q=1$	λ_q	4.14	2.36	1.49	1.56	1.61
	n_g/B	0.56	1.08	2.50	2.24	2.08
	n_q/B	3.11	3.51	5.16	4.81	4.62
$\gamma_g=1$	$n_{\bar{q}}/B$	0.11	0.51	2.16	1.81	1.62
	$n_{\bar{s}}/B$	0.05	0.11	0.25	0.22	0.21
	P_{ch} [GeV/fm^3]	0.46	0.76	0.79	1.12	1.46
$\gamma_s=0.15$	$\rho_{\rm B}$	3.35	3.31	1.80	2.45	3.19
	S/B	12.3	19.7	41.8	37.4	34.9
	γ_s	1	1	0.8	1	1
$\gamma_q=1$	T_0 [GeV]	0.184	0.215	0.233	0.239	0.255
$\gamma_g=1$	λ_q	4.14	2.36	1.49	1.56	1.61
	$n_{\bar{s}}/B$	0.34	0.68	1.27	1.43	1.33
$\gamma_s=0.8$	P_0 [GeV/fm^3]	0.30	0.41	0.47	0.54	0.71
or	$\rho_{\rm B}$	2.17	1.80	1.05	1.19	1.56
$\gamma_s=1$	S/B	14.5	24.0	49.5	46.5	43.4

and $\lambda_{\rm q}$ are now fixed by the EoS and are shown with other interesting properties of the fireball (number of gluons per baryon, number of light quarks and antiquarks per baryon, number of anti-strange quarks per baryon, the pressure in the fireball, baryon density and the entropy per baryon) in the top section of the table 1. The columns of table 1 correspond to the cases of specific experimental interest, in turn: Au–Au collisions at AGS, possible future Pb–Pb collisions at SPS with 40A GeV, S–Pb at 200A GeV, and for the Pb–Pb collisions at 158A GeV, we considered two possible values of stopping which impacts proportionally the pressure in the fireball, $\eta=0.75$ and $\eta=1$.

At the end of QGP evolution, $t\le 5$ fm/c, well after the collision has ended, thus for times $t\ge 1$ fm/c the strange quarks are very near equilibrium abundance and the temperature dropped from $T_{\rm ch}$ to the value T_0 as shown in the bottom portion of the table: full chemical equilibrium ($\gamma_s=1$) is here assumed (with exception of the S–W case for which experimental results imply $\gamma_s=0.8$ [3, 19]). During the formation of the strangeness flavor the fireball has already expanded outside of the collision region and we allow for this by keeping $\lambda_{\rm q}=$ Const. This effectively freezes the entropy content of gluons and light quarks, allowing for significant drop in pressure and some cooling due to conversion of energy into strangeness.

Because of the choice of the QGP-EoS ($\alpha_s=0.6$) and stopping ($\eta=0.5$) we find for the case of $E/B=8.6$ GeV remarkably agreeable values of temperature $T_0=233$ (which corresponds to the reported inverse slopes of the WA85 results [21]) and $\lambda_{\rm q}=1.49$ (in agreement with the results of our previous data analysis [3]). Our ability to describe the experiment at 200A GeV well with the canonical choices of the parameters α_s, η implies that at least in qualitative terms the temporal evolution of the fireball is properly represented in our model. This encourages us to explore in systematic fashion the variation of the statistical fireball properties with the energy content of the fireball. In Fig. 1 we show, as function of the specific energy content E/B, the expected behavior of temperature T_0, the light quark fugacity $\lambda_{\rm q}$ and entropy per baryon S/B at the time of full chemical equilibration in the QGP fireball. The range of the possible values as function of η is indicated by showing results, for $\eta = 1$ (solid line), 0.5 (dot-dashed line) and 0.25 (dashed line). The experimental bars on the right hand side of the Fig. 1 show for high (8.8 GeV) energy the result of analysis [3] of the WA85 data [21]. The experimental bars on the left hand side of the Fig. 1 (2.6 GeV) are taken from our analysis of the BNL-AGS data [22], but note that in this case we had found $\lambda_{\rm s} = 1.7$ and not $\lambda_{\rm s} = 1$ as would be needed for the QGP interpretation at this low energy. For the BNL-AGS range of energies $E/B = 2.3$–2.6 GeV, we expect $\eta \simeq 0.9$–1, and this is indeed in good agreement with the QGP-based evaluation of the experimental results ($T = 180 \pm 30$ MeV, $\lambda_{\rm q} = 4.8 \pm 0.4$ and $S/B = 13 \pm 1$) [22]. We also looked in this analysis at the case of S–S collisions, which have a lot of flow [17, 23]: we take at $E/B = 9.6$ GeV a stopping fraction $\eta \simeq 0.3 \pm 0.1$ and obtain $T_0 \simeq 196 \pm 13$ MeV, in agreement with the experimental results for the inverse slope [24]. The value of $\lambda_{\rm q}$ which traces the baryon density cannot be so easily estimated in this case, we refer here to a study with flow made recently [23].

Among the features shown in the Fig. 1, we note that, in qualitative terms, the drop in temperature with decreasing energy and stopping is intuitively as expected, and the value of $\lambda_{\rm q}$ is relatively insensitive to the stopping power, and also varies little when the energy changes by $\pm 15\%$. This implies that even when different trigger conditions lead to different stopping fractions η_i, the resulting value of $\lambda_{\rm q}$ which is determining the strange particle (baryon/antibaryon) ratios, is rather independent of different trigger conditions. Our analysis shows that $\lambda_{\rm q}$ *decreases while E/B increases.* This behavior can be argued for by noting that baryon density is higher in the QGP at lower energies. However, note that this intuitive insight was really arising from our believe that the stopping of baryon number decreases as energy of the collision increases, while the result here found occurs irrespective of the change in baryon stopping, provided it follows energy stopping closely. Another important result is the (rapid) rise of specific entropy with the energy content: while at the BNL-AGS energies we find similar entropy contents in the confined and deconfined phases of hadronic matter, at CERN-SPS energies we encounter twice as much entropy in the deconfined phase, which leads to a noticeable excess in particle abundances. We note that a computation of the confined hadronic gas entropy [3] at the same statistical conditions of the fireball yields only 50% of the QGP-fireball specific entropy value, and thus suggests in view of the observed particle multiplicities that the fireball could not have been just an assembly of confined hadrons.

The abundance of particles emerging in explosive disintegration or radiated is determined by the normalization constant:

$$N_j = V \prod_i n_i\,, \qquad n_i = g_i \lambda_i \gamma_i, \tag{4}$$

where it is assumed that the final state particle of type j contains the quark valence components of type i and these are counted using their statistical degeneracy g_i, fugacity $\lambda_i = \exp(\mu_i/T)$ and the chemical equilibration factor γ_i. V is the emission source volume. Fragmentation of gluons could contribute to the abundance of the valence quarks and has been considered previously [2]. Because it enhances the number of all quarks and the effect is weighted in a similar way

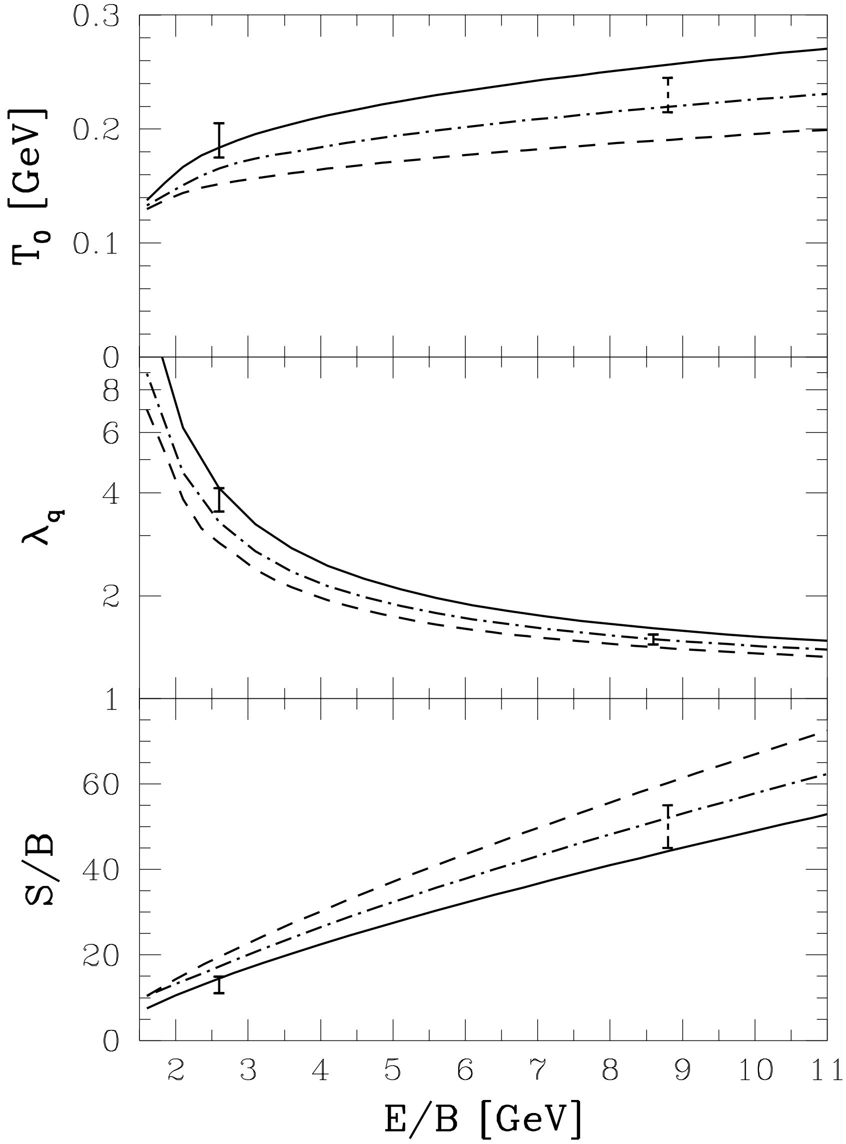

Figure 1: Temperature T_0, light quark fugacity $\lambda_{\rm q}$ and entropy per baryon S/B at the time of full chemical equilibration as function of the QGP-fireball energy content E/B. Results for momentum stopping $\eta = 1$ (solid line), 0.5 (dot-dashed line) and 0.25 (dashed line) are shown. See text for comparison with analysis results.

for all flavors, and further, since in the ratio of particle abundances a partial cancelation of this effect occurs, this effect is apparently of lesser importance.

There is a strong constraint between the two fugacities $\lambda_{\rm q}$, and $\lambda_{\rm s}$ arising from the requirement of strangeness conservation which was discussed at length recently [3]. These non-trivial relations between the parameters characterizing the final state are in general difficult to satisfy and the resulting particle distributions are constrained in a way which differs considerably between different reaction scenarios which we have considered in detail: the rapidly disintegrating QGP or the equilibrated HG phase. These two scenarios differ in particular by the value of the strange quark chemical potential $\mu_{\rm s}$:

1. In a strangeness neutral QGP fireball μ_s is always exactly zero, independent of the prevailing temperature and baryon density, since both s and $\bar{s}$ quarks have the same phase-space size.

2. In any state consisting of locally confined hadronic clusters, μ_s is generally different from zero at finite baryon density, in order to correct the asymmetry introduced in the phase-space size by a finite baryon content.

At non-zero baryon density, that is for $\mu_B \equiv 3\mu_q \neq 0$, there is just one (or perhaps at most a few) special value $\mu_B^0(T)$ for which $\langle s \rangle = \langle \bar{s} \rangle$ at $\mu_s^{HG} = 0$, which result mimics the QGP condition. However, the two different collision systems analyzed at 200A GeV (S–W and S–S) lead to [3, 8, 17, 23] $\lambda_s = 1$ $(\mu_s = 0)$, but to different $T_\perp$. A natural explanation of this behavior is that the particle source is a rapidly dissociating deconfined phase. Of course it is far from certain that QGP is formed already in the nuclear collisions at presently accessible energies below $\sqrt{s} = 10$A GeV. A crucial confirmation of such a reaction picture would arise if the changes observed in the chemical equilibration of strangeness would be attainable when the energy content in collision is varied. Importantly, this could be done at the maximum volume available, thus assuring that unwanted dynamical variations such as changes in longitudinal flow (transparency) with changes in impact parameter were minimal, while the highest accessible particle and energy density is explored in each case. For the strange antibaryon signature this approach is much preferred, as the abundance of particles produced, and their centrality remains assured.

We now study as function of energy the production of strange baryons and antibaryons. We include here ratios involving $\bar{p}$. The ratios of (strange) antibaryons to strange baryons *of same particle type*: $R_N = \bar{p}/p$, $R_\Lambda = \overline{\Lambda}/\Lambda$, $R_\Xi = \overline{\Xi}/\Xi$ and $R_\Omega = \overline{\Omega}/\Omega$, are in our approach simple functions of the quark fugacities [3, 13]. The behavior of these ratios is shown in Fig. 2**a** as function of energy. It is obtained using the results for λ_q shown in Fig. 1, and taking the QGP value $\lambda_s = 1$. We have to remember that $R_\Omega = \lambda_s^{-6} = 1$, but since some re-equilibration is to be expected towards the HG behavior $\lambda_s > 1$, we expect $\lambda_s = 1 + \epsilon$, with ϵ small, and thus for this ratio $R_\Omega = 1 - 6\epsilon < 1$. A further non negligible correction which has been discussed in Ref. [3] is due to the isospin asymmetry: in the heavy Pb–Pb collisions it will be necessary to account for d–u asymmetry which is as large as 15%, and which favors the abundance of particles with d-quark content over those with u-quark content. This impacts here in particular the ratio R_Ξ, since there are no light quarks contributing to R_Ω and the ratio R_Λ is u-d symmetric.

In order to assess, as function of collision energy the magnitude of the strange antibaryon yields per particle multiplicity formed in the collision, we need to establish the excitation function of the individual particle (antibaryon) yields. Considerable uncertainty is arising from the off-equilibrium nature of the hadronisation process, which in particular makes it hard to estimate how the different heavy particle resonances are populated. Some of this uncertainties are eliminated when we normalize the yields in Fig. 2**b** at an energy, which we take here to be the value $E/B = 2.6$ GeV (we assume freeze-out temperature $T = 150$ MeV, $\gamma_s = 1$, $\eta_p = 0.5$ and absence of any re-equilibration after particle production). These yields are rising in qualitatively similar systematic fashion with energy, as would be expected from the microscopic considerations, but the rise of more strange antibaryons is less pronounced, unlike what we would naively have expected.

The quantitative point to note is that at BNL-AGS ($E/B = 2.6$ GeV) the yield from a disintegrating QGP-fireball is a factor 100–400 smaller compared to yields at $E/B = 9$ GeV. Since

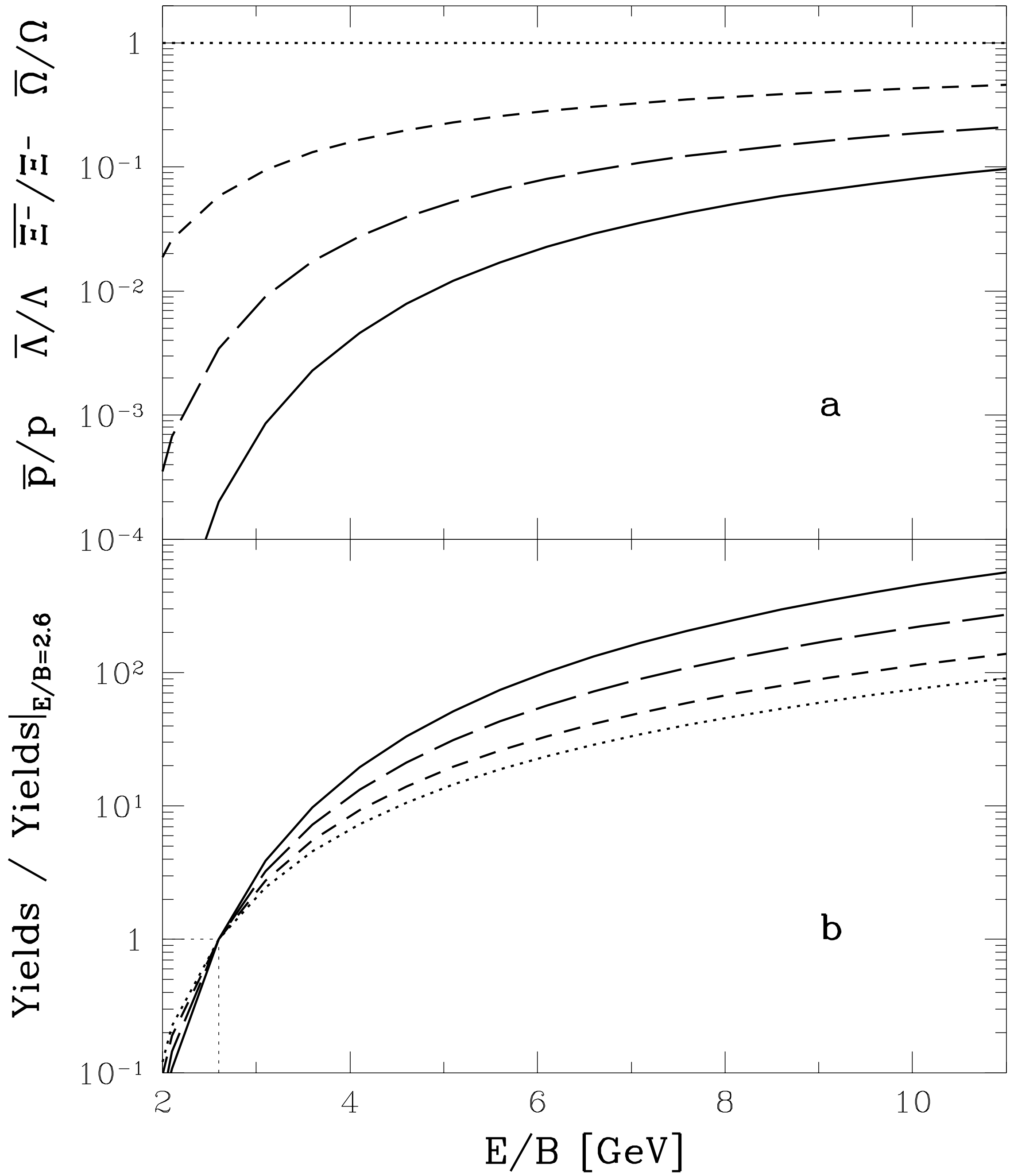

Figure 2: **a)** Antibaryon to baryon abundance ratios as function of energy per baryon E/B in a QGP-fireball: $R_{\rm N} = \bar{p}/p$ (solid line), $R_\Lambda = \overline{\Lambda}/\Lambda$ (long-dashed line), $R_\Xi = \overline{\Xi}/\Xi$ (short-dashed line) and $R_\Omega = \overline{\Omega}/\Omega$ (dotted line). **b)** Relative antibaryon yields as function of E/B in a QGP-fireball. $\overline{p}$ (solid line), $\overline{\Lambda}$ (long-dashed line) $\overline{\Xi^-}$ (short-dashed line) and $\overline{\Omega}$ (dotted line), all normalized to their respective yields at $E/B = 2.6$ GeV.

the particle density dN/dy is not that much smaller at the lower energies (recall that the specific entropy, see table 1, drops only by factor 3.5, implying a reduction in specific multiplicity by a factor 5), it is considerably more difficult at the lower energies to search for antibaryons than it is at higher energies. We should remember that the results presented in Fig. 2**b** are obtained assuming formation of the QGP-fireball and same freeze-out and hadronisation conditions for

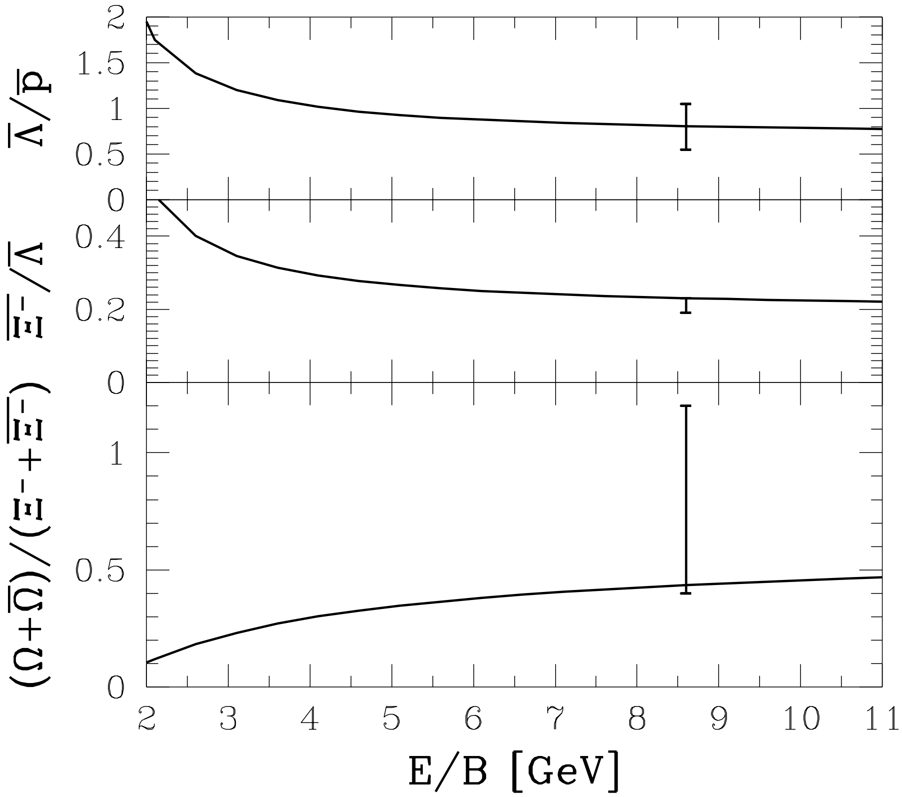

Figure 3: Strange antibaryon ratios for S–W/Pb collisions as function of E/B in a QGP-fireball: $\overline{\Lambda}/\bar{p}$ (full phase space), $\overline{\Xi^-}/\overline{\Lambda}$ for $p_\perp > 1.2$ GeV and $(\overline{\Omega}+\Omega)/(\overline{\Xi^-}+\Xi^-)$ for $p_\perp > 1.6$ GeV; experimental results shown are from experiments NA35, WA85.

all energies shown, which as discussed should not apply at AGS-energies.

We finally consider in Fig. 3 the key experimental results obtained at $\sqrt{s} = 8.6$A GeV, compared to our theoretical results obtained with same phase space cuts on the range of $p_\perp$ as in the experiments and presented here as function of energy. The $\overline{\Lambda}/\bar{p} \simeq 0.8 \pm 0.25$ ratio of the NA35 collaboration [26] was obtained for the S–Au system at 200A GeV for full phase space; WA85 precise value of $\overline{\Xi^-}/\overline{\Lambda} = 0.21 \pm 0.02$ for $p_\perp > 1.2$ GeV, which result determines our choice $\gamma_{\rm s} = 0.70$ and $\eta_{\rm p} = 0.5$; and WA85 [25] $(\Omega+\overline{\Omega})/(\Xi^-+\overline{\Xi^-}) = 0.8 \pm 0.4$ for $p_\perp > 1.6$ GeV. The fact that the two ratios $\overline{\Lambda}/\bar{p}$ (NA35) and $(\Omega+\overline{\Omega})/(\Xi^-+\overline{\Xi^-})$ (WA85) are satisfactorily explained, provides a very nice confirmation of the consistency of the thermal fireball model. We also draw attention to the remarkable behavior of the $\overline{\Xi^-}/\overline{\Lambda}$ ratio, which rises rapidly as the energy decreases: this result shown in Fig. 3 at fixed $p_\perp$ is even more pronounced when $m_\perp$ is fixed.

In view of the results we have presented here, we firmly believe that strange antibaryons provide the best hadronic signatures, and diagnostic tools, of the deconfined matter. We have shown in Fig. 3 the large $\overline{\Xi}/\overline{\Lambda}$ ratios obtained in our QGP-fireball reaction picture, which we find even at relatively small energies. We think that this is in great contrast to microscopic models and near to $\overline{\Xi}$ production threshold in p–p interaction, where this ratio is very small. This lets us expect that there will be a peak in the relative $\overline{\Xi}/\overline{\Lambda}$ yield as function of collision energy which will provide an interesting possibility to identify the energy at which collective production of strange antibaryons is first encountered. At this energy we should also encounter for the first time the other features of the QGP phase: strangeness production enhancement, strange phase space saturation ($\gamma_{\rm s} \to 1$), entropy enhancement (particle multiplicity enhancement), pattern of strange antibaryon flow showing $\lambda_{\rm s} = 1$, which allow to differentiate between confined and deconfined hadronic phases.

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