Strange hadrons and their resonances: A diagnostic tool of quark-gluon plasma freeze-out dynamics

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We update our chemical analysis of (strange) hadrons produced at the SPS in Pb-Pb collisions at 158*A* GeV and discuss chemical analysis of RHIC results. We report that the shape of (anti)hyperon $m_\perp$ spectra in a thermal freeze-out analysis leads to freeze-out conditions found in chemical analysis, implying sudden strange-hyperon production. We discuss how a combined analysis of several strange-hadron resonances of differing lifespan can be used to understand the dynamical process present during chemical and thermal freeze-outs. In medium resonance quenching is considered.

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I. INTRODUCTION

The quark-gluon plasma (QGP) as we today call hot quark matter has been predicted many years ago to be a possible new state of hadronic matter. As the ideas about QGP formation in high-energy nuclear collisions matured, a challenge emerged how the locally deconfined state that exists 10^{-22} s can be distinguished from the gas of confined hadrons. This is also a matter of principle, since arguments were advanced that this may be impossible. A quark-gluon based description could be just a change of Hilbert space expansion basis. However, it is believed that a change in the structure of matter occurs at high temperature and QGP is qualitatively different compared to matter made of confined hadrons [1].

Clearly, these difficult questions can be settled by an experiment, if a probe of QGP operational on the collision time scale, can be devised. Several QGP observables were proposed and we address here our recent progress in the development of strangeness and strange-antibaryon production as an observable of QGP. Strangeness signature of QGP originates in the observation that when color bonds are broken, the chemically (abundance) equilibrated deconfined state has an unusually high abundance of strange quarks [2].

There was a possibility that the relatively small size of the plasma fireball would suppress strangeness yield. It was shown that when the system size is greater than about five elementary hadronic volumes [3] the physical properties of the hadronic system, including, in particular, strangeness abundance, are nearly as expected for an infinite system. Subsequently, kinetic study of the dynamical process of chemical equilibration has shown that the gluon component in the QGP is able to produce strangeness rapidly [4], allowing formation of (nearly) chemically equilibrated dense phase of deconfined, hot, strangeness-rich quark matter in relativistic nuclear collisions. Therefore, abundant strangeness production is today generally viewed to be related directly to presence of gluons in QGP.

The high density of strangeness in the reaction fireball favors the formation of multistrange hadrons [5], which are produced rarely if only individual hadrons collide [6,7]. The predicted systematics of strange-antibaryon production has in fact been observed, rising with strangeness content [8]. Moreover, there is now evidence that $\overline{\Xi}$ production shows a sudden onset when the number of participating (wounded) nucleons exceeds 50 [9]. Similar results were reported for the kaon yields by the NA52 Collaboration [10]. This threshold behavior arises for volumes that are large compared to the threshold found in Ref. [3], thus if the experimental results are trustworthy (and we have no reason to doubt them) they show that this effect is probably not a result of the smallness of the physical system (‘‘canonical suppression,’’ see Ref. [11]) but is more likely a result of the opening up of important reaction mechanisms, as is expected should QGP formation occur.

Definition of the baseline when determining yield enhancement is important. Indeed one observes for some strange particles already an enhancement comparing *pp* (proton-proton) to *pA* (proton-nucleus) interactions. There are several natural reasons to expect a change in production pattern when comparing *pA* with *pp* reactions, such as isospin selection rules, or (anti)shadowing of participating nucleons. This leads to ‘‘enhancements’’ in nonstrange particles along with strange particles [12]. For this reason the baseline for comparison of *AA* (nucleus-nucleus) results should be always the *NA* (nucleon-nucleus) collision system, and one should show that the value of *A* does not matter in *NA* reactions that establish the baseline (i.e., there is scaling of the yields with *A*).

We also see in the experimental data we address here that particles of very different properties are produced by the same mechanism since they are appearing with identical or similar $m_\perp$ spectra [13]. The symmetry between strange baryon and antibaryon spectra is strongly suggesting that the same reaction mechanism produces Λ and $\overline{\Lambda}$ and Ξ and $\overline{\Xi}$. This is understood readily if a dense fireball of deconfined matter formed in heavy-ion reactions expands explosively, super cools, and in the end encounters a mechanical instability that facilitates sudden breakup into hadrons [14].

Another evidence for this sudden reaction mechanism arises if there is coincidence of chemical (particle yield) and thermal (spectral shape) freeze-out. By definition at thermal freeze-out condition the momentum distributions of final-state particles stop evolving after expansion dilution of dense-matter fireball reduces frequency of elastic and inelastic collisions. Inelastic reactions occur more rarely, and they change hadron abundances. Thus, in general, chemical freeze-out naturally occurs earlier than the thermal freeze-out. Simultaneous chemical and thermal freeze-out require nonequilibrium evolution of the fireball as has been discussed recently [14].

We study the chemical freeze-out conditions reached at highest SPS energy in Sec. II A. In Sec. II B we show that the first RHIC run data does not allow to determine the temperature of particle production. Turning back to SPS results, we discuss in Sec. II C the results of thermal freeze-out analysis [15]. These results show that for the four collision centralities of the experiment WA97 with participant number greater than 100, the thermal and chemical freeze-out conditions (described in Sec. II A) are practically the same. This offers an excellent confirmation of the sudden QGP breakup hypothesis [14].

In Sec. III, we consider the production of strange-hadron resonances as a method to study the dynamics of QGP hadronization. The idea is to use abundance of unstable resonances that have varying width and to determine fraction that becomes unobservable in consideration of the rescattering effects: once resonance products rescatter one cannot ''see'' the resonance by reconstruction [16]. We expand this idea here allowing for the phenomenon that in dense matter a resonance that is ''unnaturally'' narrow could be ''quenched'' in collisional processes and decay much faster, which would give a greater opportunity for the rescattering to occur.

II. CHEMICAL AND THERMAL FREEZE-OUT

A. Global chemical freeze-out condition at SPS

After a recent update of some experimental results [17], we have updated our earlier chemical analysis [18]. Our strategy is to maximize the precision of the description of the final multiparticle hadron state employing statistical methods. In our present chemical freeze-out analysis there are a few theoretical refinements such as use of Fermi-Bose statistics throughout, more extensive resonance cascading. In the experimental input data compared to earlier work we omit the NA49 $\overline{\Lambda}/\overline{p}$ ratio and update the NA49 ϕ yields. The total $\chi^2_{\rm T}$, the number of measurements used N, the number of parameters being varied p, and the number of restrictions on data points r are shown in the heading of Table I. The values imply that our model of the hadronic phase space has a very high confidence level.

In the upper section of Table I, we show statistical model parameters that best describe the experimental results for Pb-Pb data. We show in turn chemical freeze-out temperature, T (MeV), expansion velocity v, the light and strange quark fugacities λ_q,λ_s and light quark phase space occupancy γ_q and the strange to light quark ratio γ_s/γ_q. We fix γ_q at the point of maximum pion entropy density $\gamma_q^c = e^{m_\pi/2T_f}$ [18], since this is the natural value to which the fit converges once the Bose distribution for pions is used.

TABLE I. Physical properties of Pb-Pb 158A GeV fireball, left column with and right column without imposed strangeness balance. We do not include $\Omega+\overline{\Omega}$ yields in this analysis, see end of Sec. II C. For more details see text.

	$\mathrm{Pb}\vert_v^{s,\gamma_q}$	$\mathrm{Pb}\vert_v^{\gamma_q}$
$\chi^2_{\rm T};N;p;r$	2.25; 10; 3; 2	1.36; 10; 4; 2
T (MeV)	150 ± 3	145 ± 3.5
v	0.57 ± 0.04	0.52 ± 0.055
λ_q	1.616 ± 0.025	1.625 ± 0.025
λ_s	1.105*	1.095 ± 0.02
γ_q	$\gamma_q^c{*}=e^{m_\pi/2T_f}=1.61$	$\gamma_q^c{*}=e^{m_\pi/2T_f}=1.59$
γ_s/γ_q	1.02 ± 0.06	1.02 ± 0.06
E_f^{in}/S_f	0.163 ± 0.01	0.158 ± 0.01
s_f/b	0.68 ± 0.05	0.69 ± 0.05
$(\overline{s}_f-s_f)/b$	0*	0.05 ± 0.05

It is interesting that in the Pb-Pb collisions γ_s/γ_q is so close to unity, the often tacitly assumed value. In this detail the revised analysis differs by more than 2 standard deviations (s.d.) from our earlier results [18]. The only other notable new finding is the prediction for $\overline{\Lambda}/\overline{p}\simeq 0.6$ (not shown in table).

In the bottom section of Table I, we show physical properties of the fireball derived from the properties of the hadronic phase space: E_f^{in}/S_f, the specific energy per entropy of the hadronizing volume element in local rest frame; s_f/b specific strangeness per baryon; $(\overline{s}_f-s_f)/b$ net strangeness of the full-hadron phase space characterized by these statistical parameters. The relevance of this results is that E_f^{in}/S_f characterizes in a model independent way the breakup point. Strangeness is nearly (within error) balanced.

In the first column of Table I we see that imposing exact strangeness balance increases the chemical freeze-out temperature T slightly from 145 to 150 MeV. Insisting on exact balance is an improper procedure since the WA97 central rapidity data, which are an important input into this analysis, are only known at central rapidity. It is likely that the longitudinal flow of light quark content contributes to some mild s-$\overline{s}$-quark separation in rapidity. For this reason we normally consider the results presented in right column of Table I to be more representative of the freeze-out dynamics in Pb-Pb interactions at central rapidity at $\sqrt{s_{NN}}=17.2$ GeV.

B. RHIC freeze-out

There is now first hadronic particle and strangeness data from RHIC $\sqrt{s_{NN}}=130$ GeV, presented at QM2001 by the STAR Collaboration [19]. We draw the following conclusions from these results, which in part agree with concluding remarks by Nu Xu made at QM2001 [20]:

(1) From $\overline{p}/p=0.6\pm0.02=\lambda_q^{-6}$ it follows $\lambda_q=1.09$.

(2) Hence $\mu_B=38$ MeV (18% of SPS value) at $T=150$ MeV. If a hadronization at $T=175$ MeV applies, this value rises to $\mu_B=44$ MeV.

(3) The ratios $\overline{\Lambda}/\Lambda=0.73\pm0.03=\lambda_s^{-2}\lambda_q^{-4}$ and $\overline{\Xi}/\Xi$

$\overline{\Xi}/\Xi = 0.82 \pm 0.08 = \lambda_s^{-4}\lambda_q^{-2}$ are consistent within 1.5% with $\lambda_s = 1$, value expected for sudden hadronization.

(4) $K^-/K^+ = 0.88 \pm 0.06$ is also consistent within error with $\lambda_q = 1.09$.

(5) On the other hand, the ratio $K^*/\overline{K^*} \simeq 1$ differs from $K/\overline{K}$ significantly. This suggests that $K^*, \overline{K^*}$ yields are influenced at the level of 10% by ''in hadronization'' decay product rescattering in an asymmetric way.

(6) Thus $K^*, \overline{K^*}$ should not be used to fix T using the ratios K^*/h^- and $\overline{K^*}/h^-$.

(7) The ratio $\overline{p}/\pi = 8\%$ cannot be used to fix T since the $\overline{p}$ yield contains undetermined hyperon feed [21].

(8) The ratio K^-/π^- does not suffice to fix the temperature: we need at least three reliable yield ratios as we must also fix γ_q, γ_s: $K^-/\pi^- = 15\% = f(T)\gamma_s/\gamma_d$.

We find that the first RHIC results allow us to understand the magnitude of chemical potentials ($\mu_s = 0$, $\mu_b = 38$ MeV), but T and γ_q, γ_s cannot yet be fixed. Given the rescattering phenomena of resonances, see Sec. III, one cannot do a global analysis without stable strange hadron yields, akin to the situation we have at the SPS energy range. Thus the final analysis must await the time these results become available. On the other hand, the strong presence of observable resonances in the hadronic final state reported by the STAR experiment, implies that hadronization has occurred in a sudden fashion, as has been seen at SPS. Other RHIC results, such as particle correlation analysis, are also strongly suggestive of sudden breakup/hadronization.

The most interesting departure at RHIC from SPS physics is the great strangeness density. We note that

$$\left.\frac{dN_{K^+}}{dy}\right|_{y=0} = 35 \pm 3.5, \quad \left.\frac{dN_{K^-}}{dy}\right|_{y=0} = 30 \pm 3.$$

Total strangeness ($\overline{s}$) yield depends on unmeasured hyperons. Model calculations suggest more than 20%. Hence,

$$\left.\frac{d\overline{s}}{dy}\right|_{y=0} > 85 \pm 9.$$

Compare this to

$$\frac{d\pi^+}{dy} \simeq \frac{d\pi^-}{dy} \simeq 235.$$

Under these conditions, calculations suggest that $\overline{s}/b \simeq 8$ (11–12 times greater as compared to 17A GeV SPS Pb-Pb).

Given this strangeness rapidity yield, it is very difficult to imagine that among three (anti)quarks that coalesce to make a (anti)baryon there is no (anti)strange quark. Hence, we found in a statistical model study that most baryons and antibaryons produced will carry strangeness [21]. Thus currently observed nonstrange nucleons and antinucleons are strongly contaminated by hyperon decay feed, and at this time the reported nucleon RHIC results cannot be used in order to characterize freeze-out conditions. Corrections as large as factor 2–3 in relative yields must be expected. The influence of this effect on, e.g., antiproton-$m_\perp$ spectra has so far not been quantitatively explored.

C. Strange-hyperon $m_\perp$ spectra

About a year ago the experiment WA97 determined the relative normalization of $m_\perp$-distribution for strange particles Λ, $\overline{\Lambda}$, Ξ, $\overline{\Xi}$, $\Omega + \overline{\Omega}$, $K_s = (K^0 + \overline{K^0})/2$ in four centrality bins [13]. We have since obtained a simultaneous description of the absolute yield (chemical freeze-out) and shape (thermal freeze-out) of these results [15]. Our strategy has been to maximize the precision of the description of the final multiparticle hadron state employing statistical methods.

This requires that we introduce parameters that characterize possible chemical nonequilibria, and velocities of matter evolution. Our analysis employed two velocities: a local flow velocity v of the fireball volume element where from particles emerge, and hadronization surface (breakup) velocity, which we refer to as $v_f^{-1} \equiv dt_f/dx_f$.

We have found, as is generally believed and expected, that all hadron $m_\perp$ spectra are strongly influenced by resonance decays. In the spectral analysis we assume that decay products of resonances do not reequilibrate in rescattering, i.e., there is a tacit assumption that the freeze-out is sudden, and thus we can only test for consistency of this approach. The final particle distribution is composed of directly produced particles and nonrescattered first-generation decay products, as no other contributing decays are known for hyperons, and hard kaons.

Since resonance contributions are important, the correct combination of the direct and decay contributions influences the detailed shape of the spectra, and thus one can determine the freeze-out temperature alone from the study of the single particle $m_\perp$ spectra, once these are very precisely known. This approach fixes a best temperature and velocity of expansion and hadronization without any additional input, such as is two particle intensity interferometry, commonly used in this context.

Our procedure to determine the combined spectrum was based on Refs. [22,23]. The best statistical parameters that minimize the total relative error χ^2_{T} at a given centrality are then determined fitting all available spectral data points keeping the different collision centrality apart.

The results of the thermal analysis are in excellent agreement with the chemical analysis. In all centrality bins we find that the thermal freeze-out temperature T is in agreement with the chemical freeze-out condition. There is no indication of a significant or systematic change of T with centrality. This is consistent with the belief that the formation of the new state of matter at CERN is occurring in all centrality bins explored by the experiment WA97. It will be interesting to see if the low centrality fifth bin now studied by experiment NA57 will show different characteristics [9].

The magnitude of the collective expansion velocity v is also found to be in excellent agreement with the chemical freeze-out analysis. Though within the experimental error, there is found a systematic increase in transverse flow velocity v with centrality and thus size of the system. This is expected, since the more central events comprise greater volume of matter, which allows more time for development of the flow.

The chemical analysis has not been sensitive to the breakup (hadronization) speed parameter v_f, which was for the first time determined in the thermal analysis. The value of v_f found is near to velocity of light, which is consistent with the picture of a sudden breakup of the fireball.

The strange particle $m_\perp$ spectra of $\Lambda,\overline{\Lambda},\Xi,\overline{\Xi},K_s=(K^0+\overline{K^0})/2)$ are reproduced in great precision and without systematic variations, but $\Omega+\overline{\Omega}$ [15]. Although in the purely chemical fit discussed in Sec. II A we excluded the $\Omega,\overline{\Omega}$ yields due to their anomalous production pattern, we did include their spectra in the thermal analysis. In all four centrality bins for the sum $\Omega+\overline{\Omega}$ we systematically underpredict the two lowest $m_\perp$ data points. This low-$m_\perp$ excess also explains why the inverse $m_\perp$ slopes for $\Omega,\overline{\Omega}$ are reported to be smaller than the values seen in all other strange (anti)hyperons.

The 1.5 s.d. low $p_\perp$ deviations when summed over all bins of the $\Omega+\overline{\Omega}$ spectrum translates into 3 s.d. deviations from the prediction of the statistical model chemical analysis. It has been proposed that this excess is evidence, but not proof, that $\Omega,\overline{\Omega}$ are produced as topological defects arising from the formation of disoriented chiral condensates with an average domain size of about 2 fm [24]. However, an excess above statistical yield is also expected due to in source (anti)strange quark correlations [5], visible in the hadron of smallest statistical yield, such as is $\Omega,\overline{\Omega}$. For details of the thermal fit the reader should consult Ref. [15].

III. RESONANCES AND FREEZE-OUT DYNAMICS

We explore here if it is possible to experimentally determine the period of time a fireball particle is in touch with matter after formation and before it is free-streaming, using strange-hadron resonances [16]. At this time $\Lambda(1520)$ of width $\Gamma_{\Lambda(1520)}=15.6$ MeV has been observed in heavy-ion reactions at SPS energies [25,26]. Both SPS [26] and RHIC experiments [19] report measurement of the $K^*(892)$ signal, which has a much greater width, $\Gamma_{K^*(892)}=50$ MeV.

The $\Lambda(1520)$ abundance yield is found about two times smaller than expectations based on the yield extrapolated from nucleon-nucleon reactions, scaled with hadron yield. This is to be compared with an increased production by factor 2.5 of Λ. A possible explanation for this relative suppression by a factor 5 is that the decay products (π,Λ) have rescattered and thus their momenta did not allow to reconstruct this state in an invariant mass analysis. However, the observation of a strong K^*-yield signal contradicts this point of view, since this is a faster decaying resonance: a back-of-envelope calculation based on exponential population attenuation and assuming that all decays in matter become unobservable suggests that if the observable yield of $\Lambda(1520)$ is reduced by factor 5, the observable yield of $K^*(892)$ should be suppressed by a factor 15. This is clearly not the case, as the $K^*(892)$ yield is significant.

Another explanation is that in matter $\Lambda(1520)$ decays faster and there is much more opportunity for the rescattering of decay products, and fewer observable resonances. The width of $\Lambda(1520)$ can be quenched in collisions such as

$$\pi+\Lambda(1520)\rightarrow\Sigma^*\rightarrow\pi+\Lambda,$$

since $\Gamma_{\Lambda(1520)}$ is small due to need for angular $L=2$ partial wave in its decay. Collisional widening of a metastable state is a familiar phenomenon explored in several areas of physics [27]. The decay of the $\phi(s\bar{s})$ has been the "usual suspect" in search for such a quenching, given the proximity of the KK mass threshold [28–30]. It should be noted that the experimentally observed width will always be the natural width, since in-matter-decay products are not allowing $\Lambda(1520)$ reconstruction (see below).

The observable yield of resonances is thus controlled by several physical properties, such as the freeze-out temperature T, the decay width in matter Γ, and the time spent in the hadron phase after freeze-out τ. The suppressed yield can mean either a low-temperature chemical freeze-out, or a long interacting phase with substantial rescattering. We have formulated a simple model based on the width of the resonances in question and the decay products reaction cross sections within an expanding fireball of nuclear matter. For more details we refer to Ref. [16].

We found that the observable resonance yields are very sensitive to the interaction period in the hadron phase, but not to the magnitude of interaction cross sections used. It turns out that practically all resonances that decay inside matter become unobservable, the medium is opaque as it scatters effectively even at realtaively small cross sections the decay products. The observable resonance yield can be derived from original T-controlled yield followed by a comparison of the lifespan of the hadron phase and decay lifespan of the resonance in medium.

For $\Lambda(1520)/(\text{all}\,\Lambda)$ we show the result in Fig. 1: the bottom portion is for the natural width $\Gamma_{\Lambda(1520)}=15.6$ MeV, and the top portion of the figure is for a width quenched to 150 MeV. We recall that in the just completed study of NA49 experiment [25] it has been found that $\Lambda(1520)/(\text{all}\,\Lambda)=0.025\pm0.008$, which is barely if at all compatible with the unquenched result, since it implies an extremely long hadronization time of about 20 ± 5 fm/c (depending on freeze-out temperature), which is incompatible with other experimental results. On the other hand, we see in the top portion of Fig. 1 that after introduction of a quenched resonance width the experimental result is compatible for all freeze-out temperatures with a sudden hadronization model—the magnitude of the freeze-out time (1 fm/c) is a consequence of the assumed quenched width, suggested by the phase space size of the decay, once angular momentum selection rule in the decay is overcome. This value of the width can be a factor 2 different without altering the physical conclusion.

This finding tells us that a study of several resonances with considerably different physical properties must be used in an investigation of freeze-out dynamics of QGP. Among strange-particle resonances, the $\Sigma^*(1385)$, with $\Gamma_{\Sigma^*(1385)}=35$ MeV is in our opinion most interesting. This state that decays primarily into Λ is on theoretical grounds produced

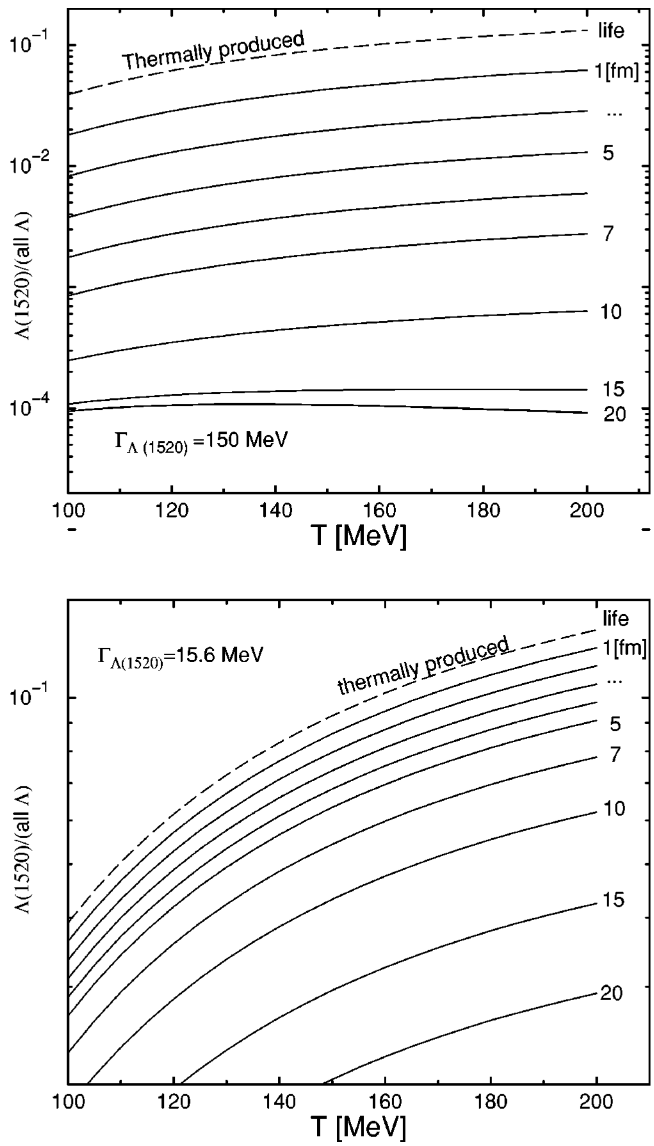

FIG. 1. Relative $\Lambda(1520)/(\text{all}\,\Lambda)$ yield as function of freeze-out temperature T. Dashed line, thermal yield; solid lines, observable yield for evolution lasting the time shown (1–20 fm) in an opaque medium. Bottom: natural resonance width $\Gamma_{\Lambda(1520)}=15.6$ MeV; top: quenched $\Gamma_{\Lambda(1520)}=150$ MeV.

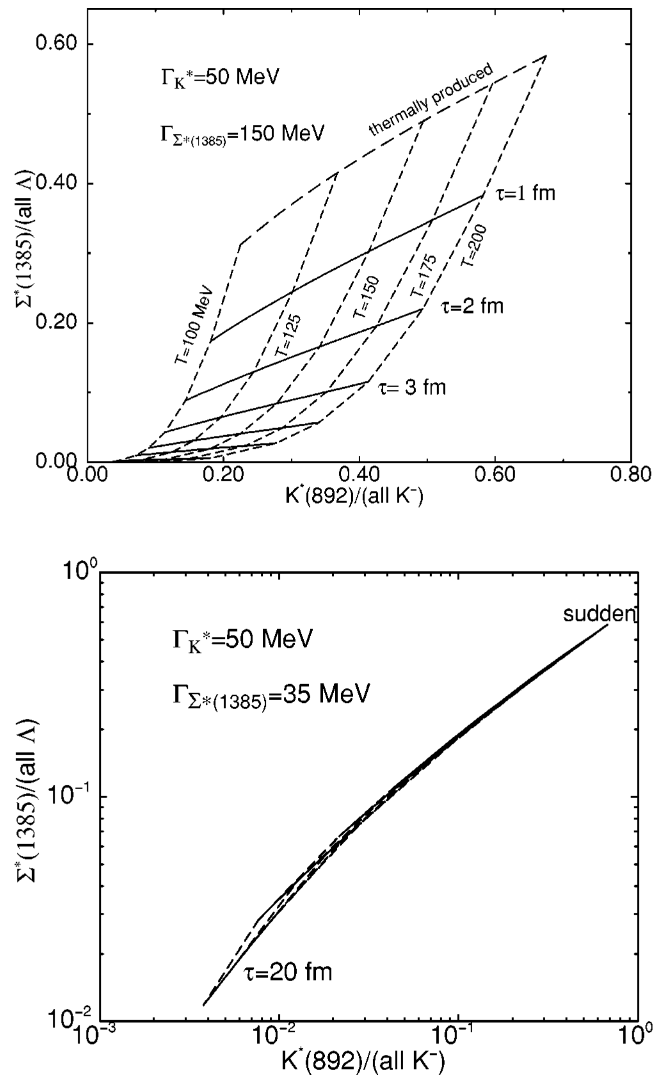

FIG. 2. Dependence of the combined $\Sigma^*/(\text{all}\ \Lambda)$ with $K^*(892)/(\text{all K})$ signals on the chemical freeze-out temperature and interacting phase lifetime. Top: quenched $\Gamma_{\Sigma^*}=150$ MeV; bottom: natural widths.

an order of magnitude more abundantly than is $\Lambda(1520)$, due to a high degeneracy factor and smaller mass. Without in-medium quenching, the Σ^* signal is more strongly influenced by final state interactions than that of $\Lambda(1520)$, but not as strong as $K^*(892)$.

We can express our finding representing one resonance yield (normalized ratio) against the other, as is seen in Fig. 2. As indicated from top to bottom in the grid, the lifespan in fireball increases, while from left to right the temperature of chemical particle freeze-out increases. The medium is effectively opaque, all resonances that decay in medium become unobservable. A remarkable result is found for unquenched resonances $\Sigma^*/(\text{all}\,\Lambda)$ with $K^*(892)/(\text{all K})$, seen in bottom of Fig. 2. This projection results in a nearly unique line in the two-dimensional plane, and thus any deviation from this result constitutes a firm evidence for resonance quenching. This is seen in the top portion of Fig. 2 obtained with a quenched $\Gamma_{\Sigma^*}=150$.

IV. SUMMARY AND CONCLUSIONS

We updated our chemical freeze-out analysis and have compared with the hyperon thermal freeze-out analysis in Sec. II. Our results confirm that CERN-SPS results originate in interesting and important physics phenomenon, and are consistent with the reaction picture of a suddenly hadronizing QGP fireball [14], since both chemical and thermal freeze-out coincide. We were able to determine the thermal freeze-out alone from a single-particle spectra since the spectrum includes heavier resonance contribution. A similar analysis of the $m_\perp$ spectra for high-energy collisions has been carried out recently [31]. This work reaches for elementary high-energy processes similar conclusions as we have presented regarding the identity of chemical and thermal freeze-out. The higher freeze-out temperature found in elementary interactions is also consistent with our results, considering that only in nuclear collisions significant super cooling is expected [14]. In our view the large nuclear collision (quark-gluon?) fireball is driven to rapid expansion by internal pressure, and ultimately a sudden breakup (hadronization) into final state particles occurs that reach detectors without much, if any, further rescattering. The required sudden fireball breakup arises since as the fireball supercools, and in this state encounters a strong mechanical instability [14]. Note that deep supercooling requires a first-order phase transition.

We have presented in Sec. III results on strange-hadron resonance production that allow to study the dynamics of thermal and chemical freeze-out. A comparison of several resonances with considerably different physical properties must be used in a study of freeze-out dynamics of QGP. Strange resonances are easier to explore, since their decay involve rarer strange hadrons and thus the backgrounds are smaller. Moreover, the detectability of the naturally wide nonstrange resonances is always relatively small, except if (very) sudden hadronization applies. For this reason it will be quite interesting to see if $\Delta(1230)$ can be observed at all, as this would be only possible if chemical and thermal freeze-out conditions are truly coincident.

The observability of several strange-hadron resonances depends if these decay in matter or outside. The more short lived a resonance is, the more likely it is to decay within the confined hadron matter period of fireball evolution. Suitably comparing yields of several resonances we can hope to resolve the question how sudden hadronization of QGP in fact is. We studied the suppression of observability of three strange resonances $\Lambda(1520), K^*(892), \Sigma^*(1385)$ as a tool capable of estimating conditions at particle freeze-out. Our objective was to quantify how temperature, lifespan and the (quenched) width T, τ, Γ_i for the resonance i influence the observable yield. Γ_i in matter may significantly differ from natural width.

This discussion of how resonances help to understand the hadronization dynamics is a beginning of a complex analysis that will occur in interaction with experimental results. We saw that observable strange resonance yields can vary widely depending on conditions that should allow a detailed study of QGP freeze-out dynamics. We believe considering $\Lambda(1520)$ result that in-matter resonance lifetime quenching is significant.

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