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SEARCH FOR STRANGENESS ABUNDANT QUARK-GLUON PLASMA IN NUCLEUS-NUCLEUS COLLISIONS

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Strange particle production in nucleus-nucleus collisions is argued to be a useful tool to study high excited hadron matter. It is predicted as an effective probe for quark-gluon plasma formation in the stopping ("baryon-rich") regime* which could be obtained at rather low energies of nuclei (2÷10 A·GeV)[1-4].

The production of Λ-hyperons and K°_s-mesons has been investigated at JINR using a two-meter streamer spectrometer and a propane bubble chamber exposed to nuclear beams of the Dubna synchrophasotron at an energy of 3.3-3.7 A GeV[6-12]. It has been found in these earlier experiments that Λ-hyperons are emitted from CC collisions more and more uniformly (in the CM-system) with increasing the number (total energy) of projectile nucleons.

Additionally, the rise of averaged transverse momentum $< P_T >$ and temperature extracted from Boltzmann-like spectra has been observed as well. The temperature seems to stop rising when reaching the value $T_B \sim$ 150-160 MeV, besides near isotropic Λ-angular distributions and an enhancement for Λ's with unusually high P_T have been seen under these conditions.

Similar regularities have been revealed when K°_s-mesons have been used as a "thermometer"[13].

This chain of the found effects is predicted as signatures of the randomization (thermalization) and heating of hadron matter and of its transition into quark-gluon matter ("quagma"). It is of interest to analyse in more detail the Dubna data including some preliminary results on Λ-production in central MgMg-interactions[14]. On the other hand, it is important to compare the mentioned data with those obtained recently in BNL[15] and CERN[16] experiments in order to look for a further energy dependence of the observed effects. One might consider it to be a Nature's favour that the degree of thermalization (randomization) of hadron matter in AA-collisions could be easily estimated looking at the Λ-hyperon peculiarities in their angular distributions which are known to be for-

*This is likely not the case in the baryon-free regime [5] predicted to be realized at much higher energies (about 1 A TeV).

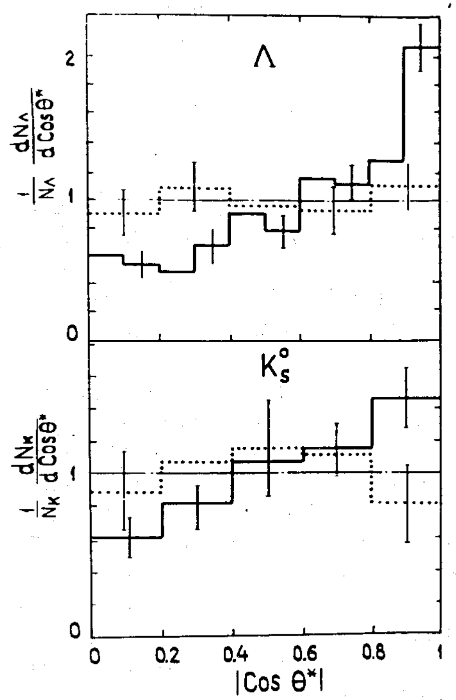

Fig.1. Angular distributions of Λ hyperons and K_s^o-mesons produced: in noncentral CC-collisions - solid lines, and in central ones - dashed lines.

ward (backward) peaked in the initial reaction NN → ΛNK due to the leading effect of the baryonic diquark.

Figure 1 illustrates the "folded" angular distributions ($dN_{\Lambda,K^o}/d\,Cos\Theta^*$) of $\Lambda(K_s^o)$-particles produced in central and noncentral CC-collisions which differ considerably in mean numbers of participant-nucleons of the projectile nucleus ($<Q>_c = 10$ and $<Q>_n = 5$, respectively). It could be seen from the comparison that the "centrally produced $\Lambda(K^o)$ particles are emitted near isotropically in contrast to the forward (backward) peaked emission from noncentral CC-collisions which reproduce the particular feature of initial NN-interactions. This difference in the angular distributions for noncentral and central CC-collisions can be characterized by asymmetry parameter $r = (N_1 - N_2)/(N_1 + N_2)$, where N_1 and N_2 are the numbers of particles in the intervals: $1 > |Cos\Theta^*| > 0.5$ and $0.5 > |Cos\Theta^*|$, respectively.

This asymmetry parameters are found to be: $r_n = 0.34 \pm 0.04$ and $r_c = -0.01 \pm 0.09$ - for Λ-hyperons, $r_n = 0.23 \pm 0.06$ and $r_c = 0.02 \pm 0.10$ - for K_s^o-mesons.

Thus the difference in kaon angular distributions appears to be not so pronounced as in hyperon ones. This is likely due to the fact that anisotropy in the primary reaction NN → NΛK for kaon is substantially smaller for Λ-hyperon because the hyperon angular distributions are directly influenced by the leading effect of the baryonic diquark. Very similar regularities have been observed for the angular distributions of $\Lambda(K_s^o)$ particle energies in the CM-system: ($dF^*_{\Lambda,K}/d\,Cos\Theta^*$). The investigation of Λ-hyperon polarization (as well as the study of their angular distribution) appears to be another

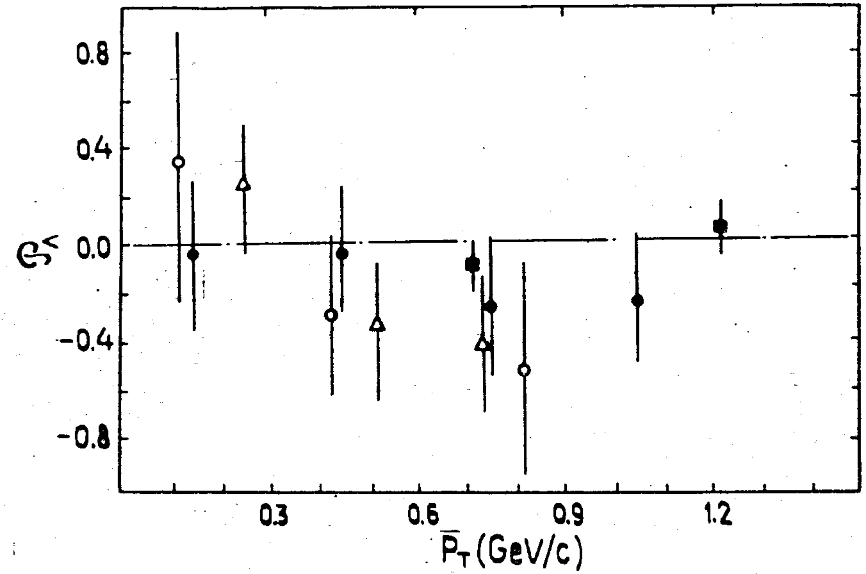

Fig.2. Polarization $\mathcal{P}_\Lambda$ as a function of averaged values of P_T for hyperons produced: - in HeLi collisions at 3.7 AGeV (ϕ)[11]; - in CC, CTa collisions at 3.3 AGeV (Δ)[12]; - in central collisions at 3.7 AGeV (ϕ)[11]; - in central SS collisions at 200 A·GeV (▪)[16].

tool for an examination of excited hadron matter. The polarization $\mathcal{P}_\Lambda$, which is likely also due to the leading di-quark effect, has been found to be rather large in pA-interactions for a high P_T-region. This parameter $\mathcal{P}_\Lambda$ is expected to vanish for Λ's from central AA-collisions with a formation randomized (thermalized) fireball*.

Figure 2 illustrates $\mathcal{P}_\Lambda$ for Λ's with different P_T. One could hardly see a hint for some increase of $\mathcal{P}_\Lambda$ (with possible change of sign) when increasing P_T of Λ's from noncentral collisions. As for centrally produced Λ's there is no polarization observed (within rather large errors, though). It is obvious that additional data are needed for more significant results.

The dependence of hadron matter excitation upun nuclear collision centrality has been studied by estimating parameters $< P_T >_{\Lambda,K}$ and temperatures T_B extracted from Boltzmann-like spectra and/or from the relation (see, e.g.,[18]):

*Such evidence ($\mathcal{P}_\Lambda = 0$) has been wrongfully considered to be a signature of the quagma[17], but it is very useful to examine conditions needed for phase transitions.

$$< P_T > = \left(\frac{\pi m T}{2}\right)^{1/2} K_{5/2}\left(\frac{m}{T}\right)/K_2\left(\frac{m}{T}\right),$$

where m is the mass of $\Lambda(K_s^\circ)$ and K_α is the so-called McDonald function. These two approaches give coinciding values of T_B (within the errors).

The search for a possible strangeness enhancement has been performed to look for relative yields ($< n_\Lambda >/< n_{\pi^-} >$) of cumulative Λ^k hyperons with $P^* > 1$ GeV/c what is beyond the kinematic limits of the reaction NN → Λ NK for 3.7 GeV. This cut, used to eliminate the Λ background from NN-interactions, has been recently supported by theoretical considerations which have argued in favour of the study of Λ´s with $P_T > 1$ GeV/c in order to search for the quagma.

A substantial change of the Λ^k properties had been revealed when analysing the influence of the degree of collision centrality upun the P_T distributions (see Fig.3)/23/.Two distin-

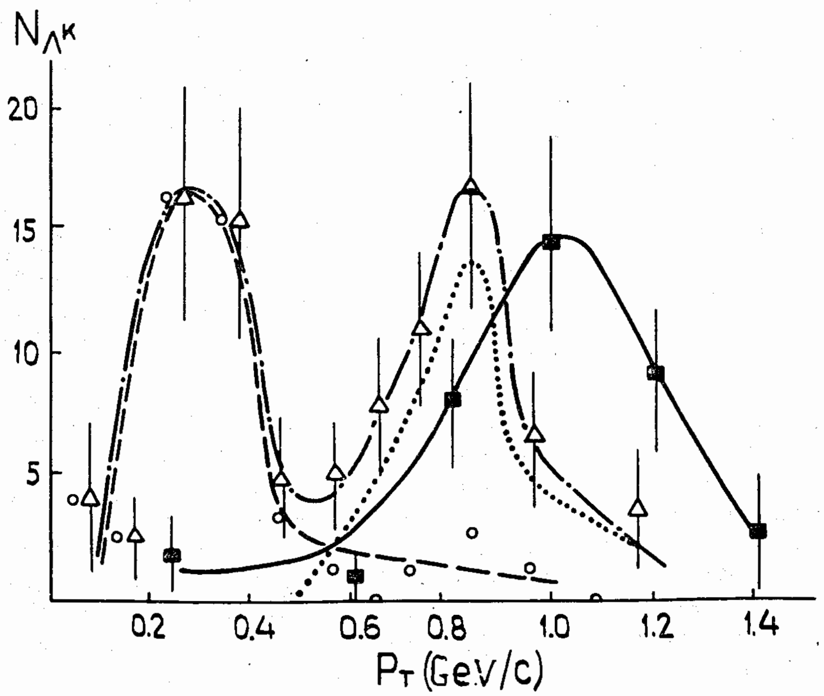

Fig.3. The P_T spectra of cumulative Λ^k-hyperons produced in central CC-collisions (———) and in noncentral ones (—•—•—) including two samples in different rapidity regions: 0.4 > y > 1.8 (-----) and 0.4 < y < 1.8 (·······).

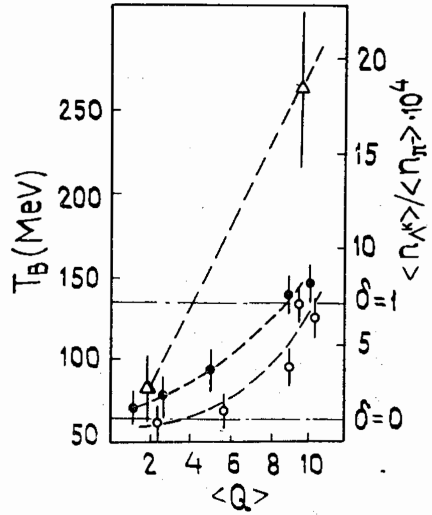

Fig.4. A dependence upon collision centrality (i.e. upon < Q > - average number of projectile nucleons-participants) of the following parameters: - the degree of flattening δ which is opposite in its meaning to asymmetry parameter r, used above: δ = 0 for the peaked distribution from pp → $\Lambda K^+ p$ and δ = 1 for the isotropic distribution (open circles); - the Boltzmann temperature T_B (black circles); - the relative yield ($< n_\Lambda >/< n_{\pi^-} >$) of Λ^k hyperons with $P_T > 1$ GeV/c (triangles).

guished samples could be seen for noncentral collisions without such a feature for central ones. A more detailed analysis has shown that two mentioned Λ^k-samples differ not only in their P_T-parameters but also in rapidities: the first one (with $< P_T > = 0.36 \pm 0.01$) consists of Λ´s emitted mostly from the target/projectile fragmentation region (y < 0.4 and y>1.8), another ($< P_T > = 0.78 \pm 0.02$), with Λ^k-emission in midrapidities (0.4 < y < 1.8). The Λ^k hyperons from fragmentation regions are very likely due to secondary processes whereas the Λ^k sample with greater $< P_T >$ could be emitted from a fireball formed in the central rapidity region.

On the contrary, the corresponding distribution for centrally produced Λ^k hyperons demonstrates the single midrapidity enhancement with $< P_T > = 0.91 \pm 0.06$ which could be due to a highly excited fireball.

Most of the effects found in Dubna experiments are summarized in the Table, and Fig.4 illustrates the dependence of the main obtained parameters upon collision centrality, i.e. upon averaged numbers of projectile nucleons involved in AA interaction (< Q >).

To examine a further dependence of hadron matter excitation upon the total released energy, the study has been performed with an analysis of the P_T-spectrum for Λ hyperons produced in central MgMg-interactions which involve a twofold number of nucleons (i.e. with twice as great released energy) than central CC-collisions. The value of $T_B = 137 \pm 9$ MeV has been found in the mentioned analysis which does not differ within the errors from $T_B = 150 \pm 10$ MeV obtained for central CC-col-

Table

The effects observed	Predicted signature of....	Experim. significance*
<u>for Λ from central CC-collisions</u> (compared with noncentral ones)		
- flattening in dN/dCosΘ*	randomization	+
- flattening in dE*/dCosΘ*	randomization	+
- on polarization ($\mathcal{P}_\Lambda$<0.1-0.2)**	randomization	+
- Boltzmann like spectrum	thermalization	+
- increase of T_B from 80 to 150 MeV	heating	+
<u>for K° from central CC-collisions</u> (compared with noncentral ones)		
- flattening in dN/dCosΘ*	randomization	+
- flattening in dE*/dCosΘ*	randomization	+
- increase of T_B from 80 to 160 MeV	heating	+
<u>for Λ^k from central CC-collisions</u> (compared with noncentral ones)		
- increase of N_Λ/N_{π^-} at P* >1 GeV/c - (by a factor of ~2)	QGP formation	+
- increase of N_Λ/N_{π^-} at P_T >1 GeV/c** (by a factor of ~10)	QGP formation	+
- increase of dN_Λ/dy at $y=y_0\pm0.5$** (by a factor of ~4)	QGP formation	+
<u>for Λ from central MgMg-collisions</u> (compared with CC central ones)		
- less flat dN/dCoSΘ*	less degree of	+
- less flat dE*/dCoSΘ*	randomization	+
- stop of increasing of T_B (approach to a plateau)**	first order phase transition	+

*The signs (in partial circles) denote symbolically the data/predictions compatibility (its statistical significance).
**Supported by recent BNL and CERN data [15,16].

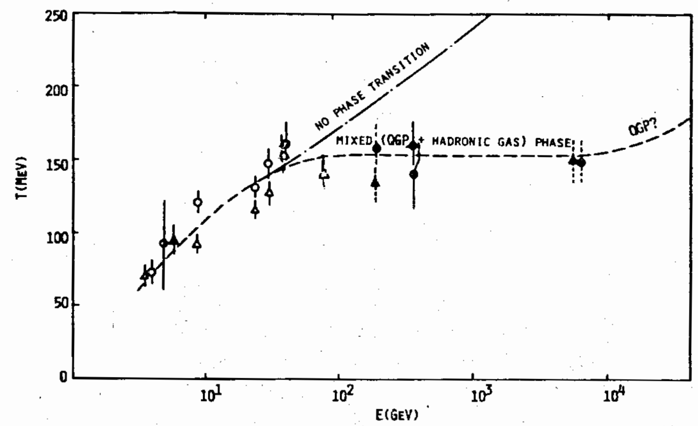

Fig.5. Boltzmann temperatures versus E = < Q > E_p: ϕ, ϕ K^o_S, Λ - JINR data; ϕ, ϕ $K^\pm$ BNL data [15]; ϕ, ϕ K^o_S, Λ - CERN data [16] (obtained from slope parameter $T_o \simeq 1.3\ T_B$). Theoretical predictions: without phase transition (— • — • —), with mixed phase formation (- - -).

lisions. This gives evidence for that the temperature stops rising in the considered energy region and seems to go to a plateau*.

The recent data of the experiments at BNL (SiAu at 14 AGeV)[15] and at CERN (^{32}S•S at 200 AGeV)[16] supported the indication of such a plateau extending to much higher energy (at least up to E = E_p·< Q > ~ 6000 GeV as could be seen from Fig.5).

Moreover, in these experiments strangeness enhancements have been also observed in central AA-collisions, and not only for a relative yield of Λ´s but also for those of $K^\pm$, K° and Λ (with different cuts: P_T > 0.4÷0.5 GeV/c).

All these above results taken together correspond to QCD thermodynamics predictions for first order phase transition with the formation of the mixed (quagma + hadron gas) strangeness abundant phase, although statistically richer investiga-

*At the same time some distinction from isotropy was observed in $dN_\Lambda/dCos\Theta^*$ and $dE^*_\Lambda/dCos\Theta^*$ distributions with forward/backward enhancements about 2 standard deviations what might mean that smaller parts of Mg-nuclei could be involved in randomization (thermalization) than in the case of central CC-collisions.

tions are desirable with adequate comparisons of data obtained in wide energy ranges*. On the other hand, theorists are challenged to propose any alternative interpretations (besides quagma formation) for the observed effects.

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*It is noteworthy that similar regularities have been also observed in $\bar{p}p$-interactions (see e.g. /22/) at CERN and FERMILAB-colliders providing very high available energies (up to $\sqrt{s} \sim 1.8$ TeV).