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PECULIARITIES OF Λ HYPERON AND π MESON PRODUCTION IN NUCLEUS-NUCLEUS COLLISIONS AT HIGH ENERGIES

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Theoretical models treating a nucleus-nucleus (A_P-A_T) collision as a superposition of successive quasi-independend hadron-hadron interactions (intranuclear cascade models) are widely used in attempts to reproduce experimental data on A_P-A_T collisions [1-3]. Within the framework of such models, "trivial" nuclear effects are taken into account: binding energies of participant and spectator nucleons, their Fermi momenta and spatial correlations of incident and target nucleus.

Main features of experimental data at Berkeley and Dubna energies (a few GeV region of incident energy per nucleon) are satisfactorily reproduced by cascade models [1,2]. A quantitative comparison of model predictions with details of experimental data is, however, not quite reliable due to the lack of full "input" data on hadron-hadron collisions required for a wide range of particles and their energies. Moreover, "technical" features of advanced intranuclear cascade models lead to discrepancies between detailed predictions of various models of this type [4].

It seems therefore especially desirable to look for phenomena, whose influence on nucleus-nucleus data would be qualitatively non-explicable within the cascade approach.

An example of such a phenomenon is the recently observed effect of the nuclear matter flow from the interaction region of colliding nuclei [5].

Other effects which seem to be incompatible with the cascade model approach were observed in our previous study of nucleus-nucleus collisions [6,7]:

- a comparison of kinematical features of Λ hyperons and π^--mesons produced in nucleon-nucleon and central nucleus-nucleus collisions revealed a change of Λ characteristics in contrast to the stable behaviour of π^--meson characteristics (see fig. 1);
- a study of π^- mesons accompanying Λ's produced within and beyond nucleon-nucleon (N-N) kinematical limits revealed differences in pion kinematical characteristics.

In this paper we present a more detailed analysis of these effects. The experimental data were obtained in a streamer chamber experiment, in which inelastic ^{4}He-Li interactions and central ^{12}C-C, ^{12}C-Ne and ^{16}O-Ne collisions were studied at 4.5 A GeV/c [6,8], and in a propane bubble chamber experiment, in which inelastic ^{12}C-p and ^{12}C-C collisions were studied at 4.2 A GeV/c [9].

Figures 1 and 2 present $\cos\theta^*$ distributions of Λ hyperons

Fig.1. The $\cos\theta^*$ distributions for π^- mesons and Λ hyperons produced in hadron-hadron ^{4}He-Li inelastic and A_P-A_T central collisions; θ^* - the emission angle calculated in the N-N c.m.system.

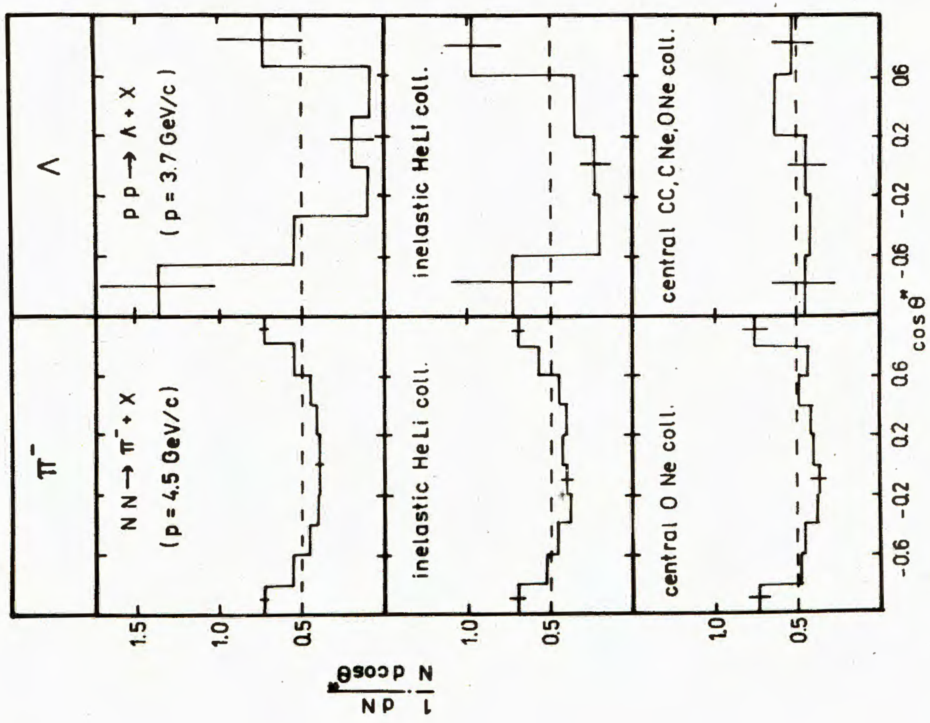
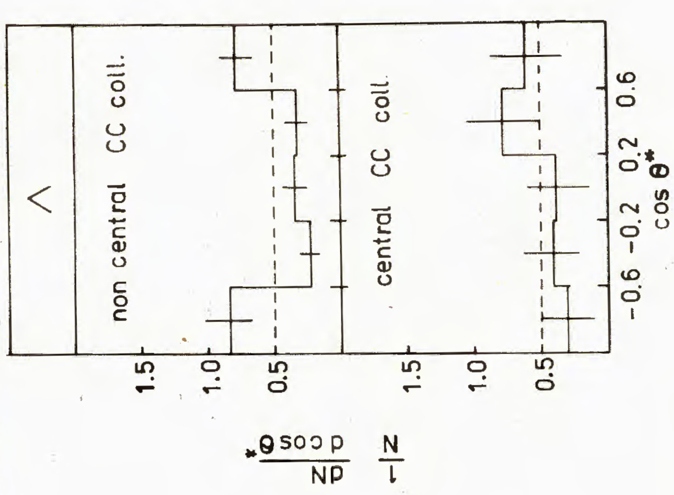


Fig.2. The $\cos\theta^*$ distributions for Λ hyperons in noncentral (upper diagram) C-C collisions.



and of π^- mesons (θ^* is the emission angle calculated in the N-N c.m. system). The upper part of fig.1 shows the distributions obtained from nucleon-nucleon data at close energies /11,12/. The middle part of the figure shows the distributions for Λ's and negative pions produced in ^{4}He-Li inelastic collisions. It is seen that the $\cos\theta^*$ distributions for N-N and ^{4}He-Li are consistent with each other. The observation shows that the Fermi motion of nucleons does not influence significantly the angular distribution of secondaries. The lower part of fig.1 shows the change of the $\cos\theta^*$ distribution for Λ's produced in central collisions, whereas the $\cos\theta^*$ distribution for pions is similar (back and forward peaked) to those observed in N-N and ^{4}He-Li collisions. An additional illustration of the effect observed for Λ-hyperons is shown in fig.2 where $\cos\theta^*$ distributions for noncentral and central ^{12}C-C collisions are presented.

The observations described above deserve a more quantitative study. For a further analysis we define the quantity α, which makes it possible to compare the behaviour of symmetrical distributions such as angular distributions of secondaries produced in collisions of nuclei with close mass numebrs ($A_P \simeq A_T$). The value of characterizing $\cos\theta^*$ distribution, is given by

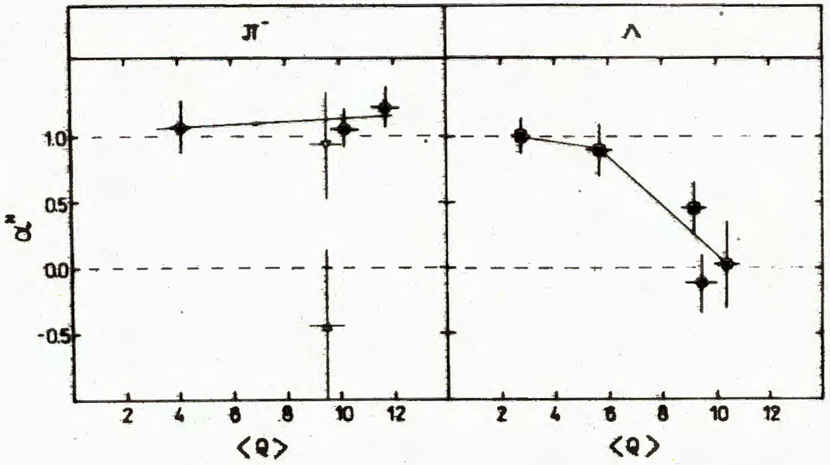
$$\alpha^N = \frac{D - D_0}{D_{HeLi} - D_0},$$

where D is the dispersion of the distribution, D_0 is the dispersion of a flat distribution ($D_0 = 0.577$), D_{He-Li} is the dispersion observed for particles emitted from the inelastic He-Li collisions which can be considered as essentially NN collisions averaged over the charge of nucleons and their Fermi momenta. According to the above definition, $\alpha^N = 0$ corresponds to an isotopical distribution of the particles studied, and $\alpha^N = 1$ corresponds to a distribution with the dispersion equal to that observed for inelastic He-Li collisions.

An analogous definition of the α parameter (α^E) is used for presenting the data on $\cos\theta^*$ distributions of the energy carried by the secondaries.

In figs. 3 and 4 α^N and α^E values for Λ hyperons and negative pions are plotted against $\langle Q \rangle$, the average number of protons participating in the interaction /9,13/. The $\langle Q \rangle$ value, as a measure of the quantity of nuclear matter involved in the interaction, is correlated with the degree of the collision centrality. It is seen that the α^N and α^E values for Λ hyperons decrease from $\alpha = 1$ for noncentral collisions down to $\alpha = 0$ for central ones, whereas in the case of pions the α values remain close to unity independently of collision centrality.

Another difference in the behaviour of the Λ and pion kinematical features is seen in fig.5, where average transverse mo-



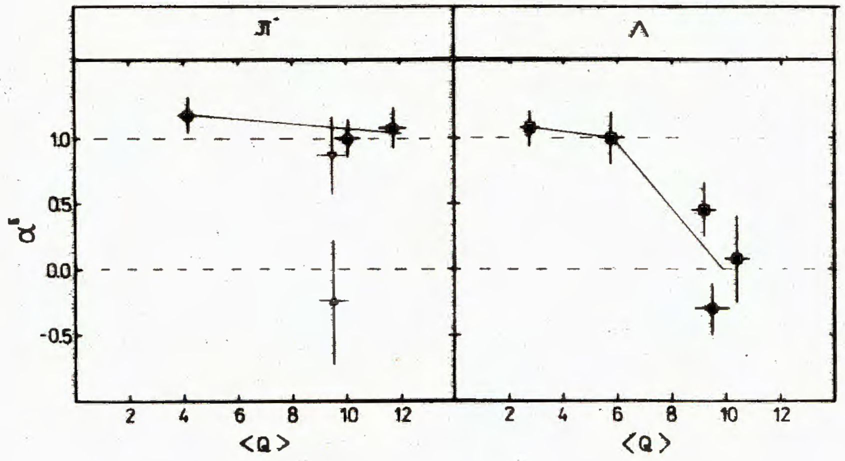


Fig.3,4. The α^N (fig.3) and α^E (fig.4) values (for definition see text) versus $\langle Q\rangle$, the average number of participant protons for π^- mesons and Λ hyperons. The dashed lines show the values corresponding to the flat $\cos\theta^*$ distribution and to the $\cos\theta^*$ distribution observed in inelastic HeLi collisions. Circles - data obtained in the streamer chamber experiment; squares - data obtained in the propane bubble chamber experiment; triangles - data corresponding to "Λ in" (∇) "Λ out" (Δ) pions. The solid lines are drawn to guide the eye only.

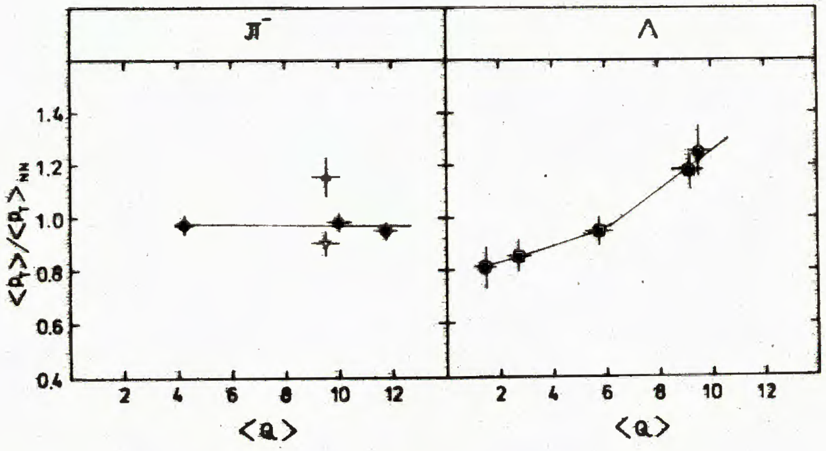


Fig.5. The ratio of the average transverse momenta ($\langle p_t\rangle$) to the average $\langle p_t\rangle$ observed in inelastic HeLi collisions plotted against $\langle Q\rangle$, the average number of participant protons. The circles, squares and triangles correspond to the samples listed in the caption to figs.3 and 4.

menta, $\langle p_t\rangle$, normalized to the average momentum observed in the inelastic He-Li collisions. The ratio $\langle p_t\rangle / \langle p_t\rangle_{HeLi}$ for pions is independent of $\langle Q\rangle$, whereas the ratio for Λ hyperons increases with $\langle Q\rangle$.

In an attempt to understand the observed effects within the framework of cascade models we considered two nuclear effects which might be responsible for the observed dependence of the Λ and π kinematical features on the collision centrality:
- rescattering of the produced particles and
- production of the particles in secondary interactions.

These effects are not expected to play an essential role in the case of collisions of light nuclei, but their influence, if observable in angular and $\langle p_t\rangle$-data, would be probably more strongly manifested in high $\langle Q\rangle$ events than in the low $\langle Q\rangle$ ones.

The influence of the rescattering is expected to be more pronounced for pions than for Λ's due to the fact that cross section values for pions are higher than those for Λ's produced in collisions at our energy ($\sigma_{\pi N} > \sigma_{\Lambda N}$) /14,15/.

The $\cos\theta^*$ distributions for Λ's from $\pi N \to K\Lambda$ collisions are expected to be more strongly back-and-forward peaked than for Λ's produced in primary N-N collisions /12/ if they are both studied in the N-N c.m. system. The rescattering and particle production in secondary collisions would result in some decrease of <p >values for both Λ's and π^- mesons. These effects are expected within the cascade approach and they are, in fact, observed in our experimental data for heavier target nuclei [4,6,10] in which secondary processes should play an essential role. We observe, however, an opposite behaviour - the flattenning of the $\cos\theta^*$ distributions and some increase of $<p_t>$ values for Λ hyperons in events with a higher degree of centrality (figs.3, 4 and 5), in which secondary processes are expected to be more pronounced.

We conclude therefore that within the framework of the cascade approach one expects that the pion characteristics should be more sensitive to the collision centrality than the Λ hyperon ones, and, moreover, the expected dependence on the centrality for Λ's would be opposite to that observed in the experiment.

Another effect observed in the particle production concerns the analysis of π^- mesons emitted from nuclear (A_P-A_T) collisions, in which a Λ hyperon has been produced within ("Λ in") and beyond ("Λ out") kinematical limits [7].

The values of a^N , a^E and $<p_t>/<p_t>$ HeLi for "Λ in" pions and "Λ out" pions are plotted in figs.3, 4 and 5. The data for "Λ out" pions seem to be inconsistent with those for "average" pions and "Λ in" pions as well. The poor statistics did not allow us to study the "Λ in" and "Λ out" pions in more detail, in particular for collisions with various degrees of centrality. Qualitative considerations, similar to those presented above, do not allow one to explain the observed effect within the framework of the cascade model approach.

The flat angular distributions observed for Λ's produced in the most central collisions and for "Λ out" pions seem to suggest that these particles are emitted isotropically from sources being at rest in the N-N c.m. system. The Boltzman shape of the kinematic energy (T^*) distribution, observed for these samples of particles (fig.6) may suggest that the thermal equilibrium has been reached in the sources from which the particles are emitted. The source temperature, T_0, can be obtained from the slope of the diagram shown in fig.6 or equivalenty from the $<p_t>$ value [16]. The latter way allows one to estimate the average temperature also in the case when a single thermalized source has not been formed. Thus, the calculated T_0 values are plotted against <Q> in fig.7. The T_0 values for Λ's emitted from central collisions and for "Λ out" pions approach the temperature values predicted by the thermodynamical model of Hagedorn [16] and calculated under the assumption that the nuclear matter involved in the collision has been fully stopped and thermalized in the N-N c.m. system.

We conclude that the presented effects, observed in the hy-

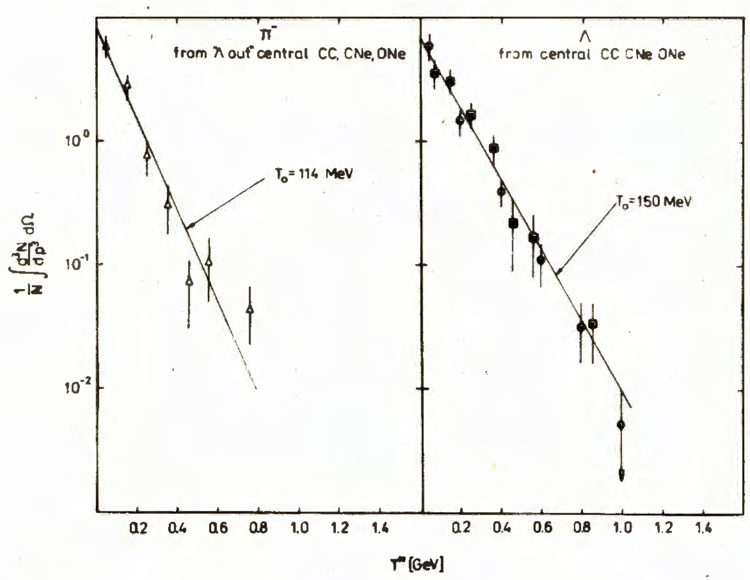


Fig.6. The spectrum of the kinetic energy T^* *calculated in the N-N c.m.system for "Λout" pions and Λ hyperons produced in central collisions of nuclei* ($A_P=A_T$). T_0 *- the temperature parameter.*

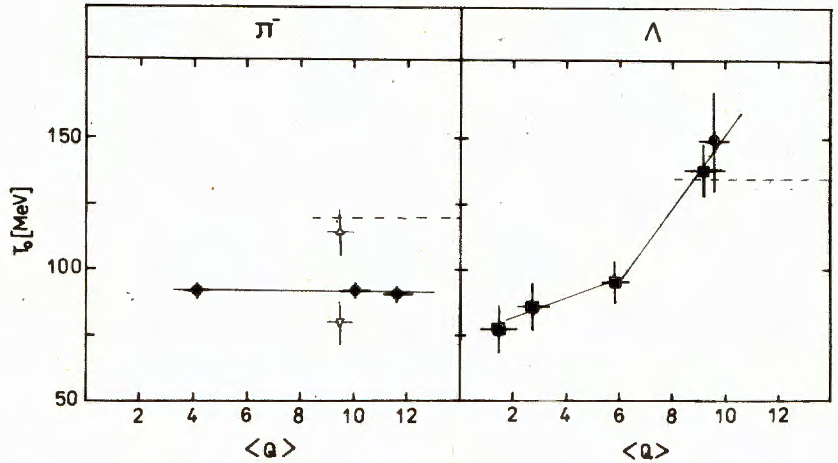


Fig.7. The temperature parameter, T_0*, plotted against* <Q>*, the average number of participant protons. The dashed lines show the* T_0 *values predicted by the thermodynamical model of Hagedorn* [16].

peron and pion production in central nuclear collisions, could not readily be understood within the cascade model approach.

The production of Λ hyperons in central nuclear collisions (high local excitation of the nuclear matter) and especially the production of Λ's beyond N-N kinematical limits (still higher excitation) with cross sections $\sigma \lesssim 5\cdot 10^{-3}\sigma_{inel}$ and $\sigma \leq 5\cdot 10^{-4}\sigma_{inel}$, respectively, may be considered as signatures of the formation of a fully stopped and thermalized hot sources within the nuclear matter. It should be noted that an increase in the relative yield of "Λ^{out}"-events ($\langle n_{\Lambda^{out}}\rangle / \langle n_{\pi^-}\rangle$) with Q was observed (by a factor of 5÷10) /6/ which was predicted as a signature of quark-gluon plasma formation. However, to draw a final conclusion, all possible alternative explanations of this effect must be considered.

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It should be stressed that due to the contribution of pions from Δ decays the temperature parameter T_0 derived from the pion data is expected to be lower than that one derived from the Λ data (see dotted lines in fig.7).

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Особенности образования Λ-гиперонов и π-мезонов в ядро-ядерных столкновениях при высоких энергиях

Приводится анализ экспериментальных данных о процессе рождения Λ-гиперонов и π^--мезонов в HeLi-, CC-, CNe- и ONe-взаимодействиях при 4,5 ГэВ/с на нуклон и C-C взаимодействиях при 4,2 ГэВ/с на нуклон. Показано, что кинематические характеристики Λ зависят от степени центральности взаимодействия, в противоположность стабильному поведению π-характеристик. Наблюдалась корреляция характеристик Λ-гиперонов с характеристиками сопровождающих их пионов. Наблюденные эффекты, по-видимому, не согласуются с внутриядерным каскадным подходом. Данные указывают на образование полностью заторможенного термализованного горячего источника в центральных ядро-ядерных взаимодействий.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Peculiarities of Λ Hyperon and π Meson Production in Nucleus-Nucleus Collisions at High Energies

The analysis of data on the production of Λ hyperons and π^- mesons in He-Li, C-C, C-Ne and O-Ne at 4.5 A GeV/c and C-C collisions at 4.2 A GeV/c is presented. Kinematical features of Λ's are shown to depend on the collision centrality in contrast to the stable behaviour of the pion characteristics. The correlation between the characteristics of Λ's and accompanying pions is observed. The effects seem to be incompatible with the intranuclear cascade approach. The data suggest the formation of a fully stopped and thermalized hot source in central nucleus-nucleus collisions in which Λ hyperons are produced.

The investigation has been performed at the Laboratory of High Energies, JINR.

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