Λ Hyperons Produced in Central Nucleus-Nucleus Interactions at 4.5 GeV/c Momentum per Incident Nucleon

M. Anikina, M. Gaździcki,[a] A. Golokhvastov, L. Goncharova, K. Iovchev, S. Khorozov, E. Kuznetzova, J. Lukstins, E. Okonov, T. Ostanievich, S. Sidorin, and G. Vardenga
Joint Institute of Nuclear Research, 101 000 Dubna, U.S.S.R.

and

O. Balea, N. Nikirovich, and T. Ponta
Central Institute of Physics, Bucharest, Romania

and

L. Chkhaidze, T. Dzobava, M. Despotashvili, and I. Tuliani
Institute of High Energy Physics, Tbilisi State University, 380 043 Tbilisi, U.S.S.R.

and

E. Khusaimov, N. Nurgozin, and B. Suleimenov
Institute of High Energy Physics, Kazakhs SSR Academy of Sciences, 480 082 Alma-Ata, U.S.S.R.

and

E. Skrzypczak and T. Tymieniecka
Institute of Experimental Physics, University of Warsaw, 00-681 Warsaw, Poland

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Transverse momenta and rapidities of Λ's produced in central nucleus-nucleus collisions at 4.5 GeV/c·u (C-C, . . . ,O-Pb) were studied and compared with those from inelastic He-Li interactions at the same incident momentum. Polarization of the Λ hyperons was found to be consistent with zero ($\alpha P = -0.06 \pm 0.11$ for Λ's from central collisions). An upper limit of the $\bar{\Lambda}/\Lambda$ production ratio was estimated to be less than 4.5×10^{-3}. The experiment was performed in a triggered streamer chamber.

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Data on strange-particle production in nucleus-nucleus collisions are expected to reveal effects due to highly excited nuclear matter. According to the existing theoretical considerations[1,2] one can expect in particular an enhancement of strange-particle production and an increase of the $\bar{\Lambda}/\Lambda$ production ratio; also kinematical characteristics (such as transverse momenta, p_T, and rapidities, Y) of strange particles might be influenced by exotic states of nuclear matter.

Published data on neutral strange-particle production in nuclear interactions were obtained for Λ's produced in Ar-KCl central collisions at 1.8 GeV/u,[3] for Λ hyperons and K^0 mesons produced in He-Li collisions at 4.5 GeV/c ·u,[4] and for Λ hyperons and K^0 mesons from d-Ta and C-Ta collisions at 4.2 GeV/c ·u.[5]

A search for "unusual" nuclear effects encounters the problem of "reference" data. The N-N data (if available at the same incident energy) have two main drawbacks: (i) The majority of the elementary data concern p-p interactions only, and (ii) the data on interactions of free nucleons do not include effects of Fermi motion of colliding nucleons.

An attempt to overcome these difficulties was undertaken when our first results on strange-particle production in central nuclear collisions were studied.[6] The data on Λ's produced in He-Li inelastic collisions[4] obtained at the same incident momentum were used in the analysis. In fact, He-Li inelastic collisions may be considered as a superposition of independent nucleon-nucleon interactions,[6,7] kinematical characteristics of the secondary particles being averaged over the charge of colliding nucleons and their Fermi motion. Other nuclear effects can be neglected in the first approach. Thus the He-Li data seem to be suitable for a comparison with data on strange particles produced in central collisions of heavier nuclei.

In this paper we present data on Λ hyperons produced in central collisions of ^{12}C and ^{16}O nuclei at 4.5 GeV/c ·u with pure nuclear targets: C, Ne, Cu, Zr, and Pb, and in inelastic inter-

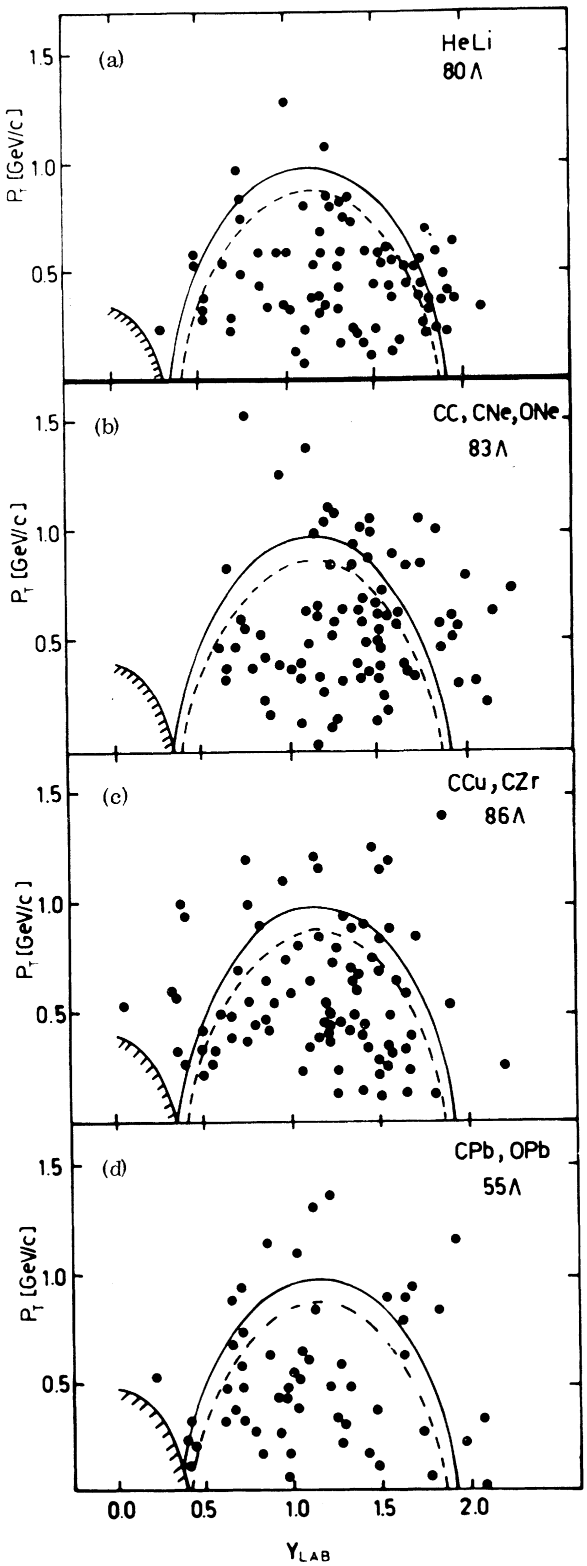

FIG. 1. Transverse momentum vs rapidity for Λ's produced (a) in He-Li inelastic collisions and in central collisions of (b) C-C, C-Ne, O-Ne; (c) C-Cu, C-Zr; (d) C-Pb, O-Pb nuclei. Phase-space limits for $NN \to N\Lambda K$ and $NN \to N\Lambda K\pi$ production channels are shown as solid-line and dashed-line contours, respectively. Hatched lines show regions of Λ's with momenta $p < M_\Lambda R/5.5c\tau_\Lambda$ [R = (a) 13 cm, (b) 15 cm, (c) 15 cm, and (d) 18 cm].

actions of He nuclei with a Li target at the same momentum.

Both the interactions of beam nuclei with target nuclei and the strange-particle decays (V^0 events) were registered in the 2-m streamer chamber[7] triggered for the inelastic collisions in the case of He-Li data and for central collisions of the other nuclear pairs. In the latter case the triggering system included anticoincidence counters of charged fragments of the projectile (and of the spectator neutrons) emitted at angles less than 2°-3°.[8]

The sample of V^0 events was selected out of double-scanned films. V^0 events were measured and subsequently analyzed by the V^0 pointing fit of kinematical equations. The analysis of χ^2 distributions and various kinematical characteristics for Λ, K^0, γ, and $\bar{\Lambda}$ hypotheses permitted identification of Λ hyperon decays. A cut on the proper time equal to 5.5 units of the Λ lifetime, τ_Λ, was introduced. The contamination of the Λ sample due to the K^0 mesons and electron pairs was less than 4%.

The Λ mass distribution gives $M_\Lambda^{\text{expt}} = 1117 \pm 0.4$ MeV/c^2 with a dispersion $D = 7.7 \pm 0.3$ MeV/c^2. The errors are statistical only; the M_Λ^{expt} value yields an estimate of systematical errors in the measurements (roughly 4% in momentum determination) of the decay secondaries. These systematical errors can be neglected when considering data presented in the paper (Figs. 1 and 2).

The sample of Λ events was divided into four groups of Λ's produced in (i) He-Li, (ii) C-C, (iii) C-Cu and C-Zr, and (iv) C-Pb and O-Pb interactions.

An analysis of the scanning losses in the region of high track density in the vicinity of the parent interaction was performed by means of the maximum-likelihood approach (Bartlett method). The analysis permitted us to estimate for each group of events the radius R of the region in which the V^0 events were either undetected or detected with a low and momentum-dependent efficiency. The R value depends on the target nucleus mass number and it ranges from 13 up to 18 cm.

In Fig. 1 p_T values are plotted against Y

values for all identified Λ hyperons. The obvious "nonexotic" processes responsible for the Λ production in the nucleus-nucleus central collisions are nucleon-nucleon interactions, $NN \to N\Lambda K$ and $NN \to N\Lambda K\pi$. Phase-space limits for the two channels are shown in Fig. 1 as solid-line and dashed-line contours, respectively. It is seen that the majority of our Λ hyperons are produced within the kinematical limits both in inelastic He-Li and the neutral nucleus-nucleus collisions. As mentioned above, the scanning losses lead to a bias against Λ's decaying at a short distance from the parent interaction. Low-momentum Λ hyperons are most sensitive to this bias. An illustration of this effect is shown in Fig. 1, where the areas under the hatched curves correspond to the Λ's emitted with momenta lower than $p_{\min} = MR/5.5c\tau_\Lambda$ (R ranging from 13 to 18 cm). No experimental points were found in the hatched areas. Also beyond these areas the scanning bias leads to depletion of the density of experimental points; the most serious effect is expected in the plot regions close to the hatched areas.

The authors of Ref. 3 have found that most of the Λ hyperons (from central Ar-KCl collisions at 1.8 GeV/c ·u) are produced beyond the phase-space limits in contradistinction to our result. It should be noted that the effects of the Fermi motion of colliding nucleons are much less essential at our energy than in the case of the near-threshold production of Ref. 3.

The data on Λ's produced in an inelastic d-Ta and C-Ta collisions presented in Ref. 5 show that about 40% of Λ's are beyond the phase-space limits; almost all "outer" Λ's are in the region corresponding to low laboratory momenta. These Λ hyperons observed in heavy nuclei might result from the process $\pi N \to \Lambda K$,[9] sufficiently energetic pions being abundantly produced at this energy,[7] and from secondary processes such as Λ scattering within nuclear matter. Low-momentum Λ hyperons are detected with a poor efficiency in our experiment, whereas in the propane bubble chamber[5] low-momentum Λ's can be detected without a serious bias.

In order to reduce the momentum-dependent bias in the transverse momentum and rapidity distributions, a cutoff value $R = 18$ cm was used. Thus Λ hyperons with momenta less than $p_{\min} = 463$ MeV/c were excluded from further analysis. Appropriate corrections for Λ's ($p > p_{\min}$) decaying at distances less than 18 cm or beyond the fiducial volume of the chamber were introduced. Average value of the weighting factors is $\langle w \rangle = 4.4$. Momentum dependence of other losses of Λ hyperons was found to be negligible.

Figure 2(a) presents an intercomparison of average transverse momentum values, $\langle p_T \rangle$, for four samples of Λ hyperons analyzed in this work. Similar data on average rapidity values, $\langle Y \rangle$, are shown in Fig. 2(b). It is seen that $\langle p_T \rangle$ values for all four samples of Λ hyperons are consistent with each other. An intercomparison of $\langle Y \rangle$ values does not reveal any significant difference between Λ's from inelastic He-Li interactions and Λ's from central collisions of C and O with intermediate-mass target nuclei (C, Ne, Cu, Zr). On the other hand average rapidity of Λ's from central C-Pb and O-Pb collisions is significantly lower than $\langle Y \rangle$ values for other samples of nuclear collisions. These observations can be qualitatively explained as due to the secondary processes inside a heavy nucleus, namely to the contribution of the $\pi N \to \Lambda K$ channel of the Λ production and to the Λ rescattering.

The polarization of Λ hyperons analyzed in this experiment was calculated according to the

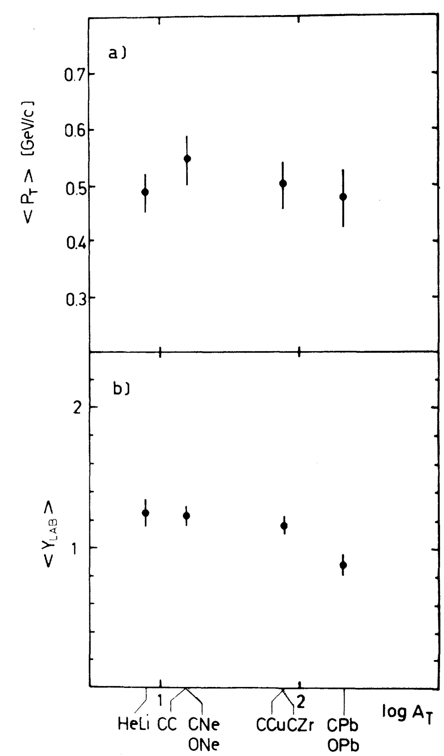

FIG. 2. A comparison of (a) average transverse momenta, $\langle p_T \rangle$, and (b) average rapidities, $\langle Y \rangle$, for samples resulting from inelastic He-Li interactions and from central collisions of heavier nuclei.

known formula: $\alpha P = \langle\cos\theta\rangle/\langle\cos^2\theta\rangle$, where θ is the angle (in the Λ c.m. system) between the vector normal to the production plane and the direction of the decay proton. No cutoff on the decay distance and no weighting factors were used in this analysis. The αP values, obtained for each pair of the colliding nuclei, were found to be consistent with zero within statistical errors. For the whole sample of Λ hyperons emitted from central nuclear collisions, $\alpha P = -0.06 \pm 0.11$, and for Λ's from He-Li inelastic collisions, $\alpha P = -0.12 \pm 0.17$. The αP value obtained for 224 Λ events from central nuclear collisions is consistent with that obtained in Ref. 3 for 80 Λ's produced in central Ar-KCl collisions ($\alpha P = 0.06 \pm 0.03$).

Particular attention was paid to all V^0 events in the course of their identification from the point of view of the $\bar{\Lambda}$ hypothesis. In less than 1% of the total V^0 sample the $\bar{\Lambda}$ hypothesis passed the fitting procedure, but in each case it was accompanied by an acceptable (within our criteria) Λ, K^0, or γ identification. We conclude therefore that no $\bar{\Lambda}$ decay has been uniquely identified. An estimation of the upper limit of the relative contribution of the underthreshold production of $\bar{\Lambda}$ is therefore

$$\sigma(\bar{\Lambda})/\sigma(\Lambda) \lesssim 1/224 \approx 4.5\times10^{-3}$$

for central nuclear collisions at our energy.

The above-presented results on the Λ hyperons produced in the nucleus-nucleus collisions are summarized as follows: (i) The p_T-Y plots show that the majority of Λ hyperons are contained within kinematical limits of the phase space for $NN \to N\Lambda K$ production channel. (ii) The average transverse momentum, $\langle p_T\rangle$, of Λ hyperons does not reveal any significant difference between Λ's produced in inelastic He-Li interactions and in central collisions of pairs of heavier nuclei. (iii) The average rapidity, $\langle Y\rangle$, for Λ's produced in C-Pb and O-Pb collisions is lower than that for Λ's from interactions of other pairs of nuclei. (iv) The polarization of Λ hyperons observed in this experiment ($\alpha P = -0.06 \pm 0.11$) is found to be consistent with zero. (v) A search for an underthreshold production of antilambda hyperons yielded an upper limit for the ratio of the production cross sections

$$\sigma(\bar{\Lambda})/\sigma(\Lambda) \lesssim 4.5\times10^{-3}.$$

No striking effects were revealed when passing from inelastic He-Li interactions to central collisions of heavier nuclei.

The experimental results presented in this work can be qualitatively explained in terms of "ordinary" nuclear effects at the present stage of the analysis.

[a] On leave from the Institute of Experimental Physics, University of Warsaw, 00-681 Warsaw, Poland.

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