Evaporation of Neutral Strange Particles in $\bar{p}$-Ta at 4 GeV/c

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(Received 16 July 1984)

The reaction $\bar{p}+\mathrm{Ta}\rightarrow V^0+X$ ($V^0=\Lambda$, $\bar{\Lambda}$, or K_s^0) at 4 GeV/c has been studied by comparing with the results in $\bar{p}p$ interaction. Strong enhancement of Λ production was observed, while $\bar{\Lambda}$ production is suppressed. The $\bar{\Lambda}/\Lambda$ production ratio is obtained as $(2.0\pm1.0)\times10^{-2}$. Λ reveals evaporationlike behavior with a nuclear temperature of 97 MeV. Evaporationlike behavior with a temperature of 135 MeV, but via a short-range process, was observed also in K_s^0 production.

PACS numbers: 13.75.Cs, 25.40.Ve

Recently the effects of collective multinucleon processes[1] and phenomena of high nuclear temperature[2] have been deduced by the behavior of kaons produced in relativistic heavy-ion collisions. Λ production mechanisms are studied also in nucleus-nucleus collisions,[3,4] but their results contradict each other in the dominant production channel $NN\rightarrow\Lambda KN$. It has been emphasized that strange particles could be a better probe for a study of high-energy nuclear reaction dynamics.[5] Therefore, the strange-particle production mechanism has been theoretically studied from various points of view,[6-11] but details of the dynamics of the strange-particle production are still not clear.

In this report we present the result of an experiment in which we study the production mechanism of the neutral strange particles in $\bar{p}$-Ta collisions, and compare with the data of $\bar{p}p$ interaction.[12,13] We chose $\bar{p}$ as a projectile because of its large cross section for strange-particle productions in $\bar{p}p$ collisions. In addition, there has been only very scarce data of strange-particle production from $\bar{p}$-nucleus interactions.

The data come from an exposure of the KEK 1-m hydrogen bubble chamber to the beam of 4 GeV/c at the National Laboratory for High Energy Physics (KEK). Two 4.4-mm-thick Ta plates as a nuclear target are installed in the bubble chamber. The results presented here come from 107×10^3 pictures. Details of the experimental procedure will be described elsewhere.

Λ, $\bar{\Lambda}$, and K_s^0 are observed through their charged decay modes and corrections for the unseen modes are carried out. The V^0 events are analyzed by use of the program TVGP and are weighted with a correction factor (~1.3 on the average) for the limited detection volume of the bubble chamber. Corrections are made for scanning losses (3%) and for unidentified V^0 events (10%). The cross sections are corrected for absorption of V^0 by Ta plates by use of its longitudinal momentum spectra (16%).

The results are summarized in Table I, together with those in $\bar{p}p$ at 4 GeV/c.[12,13] The production cross section for Λ is much larger than that for $\bar{\Lambda}$ in $\bar{p}$-Ta, while those in $\bar{p}p$ are approximately equal to each other. If the strange particle is produced only at the primary collision of the $\bar{p}$, the cross section should be 32.0 ($A^{2/3}$, due to A dependence) times larger than that in $\bar{p}p$. The reason is that the inelastic cross section is just the same size as the geometrical cross section of the Ta nucleus. However, the measured cross sections are 364 ± 41 (Λ), 8.9 ± 4.2 ($\bar{\Lambda}$), and 43.2 ± 3.5 (K_s^0) times as large as the ones in $\bar{p}p$. The Λ production is surprisingly enhanced, while the $\bar{\Lambda}$ production is suppressed by the $\bar{\Lambda}N\rightarrow\bar{K}NN$, $\bar{N}N$, annihilation, . . . processes in the nucleus. The remarkable difference in these cross-section ratios is suggestive of different dynamics in

TABLE I. Summary of the cross sections.

Channel	Number of events	Cross section (mb)	Cross section in $\bar{p}p$ (mb)
Total inelastic	...	1628 ±30	...
K_s^0+X	445	82.0 ±6.0	1.90 ±0.07
$\Lambda+X$	929	193 ±12	0.53 ±0.05
$\bar{\Lambda}+X$	21	3.8 ±2.0	0.44 ±0.05

strange-particle productions. The $\bar{\Lambda}/\Lambda$ production ratio is obtained as $(2.0 \pm 1.0)\times 10^{-2}$. The value is larger than an upper limit of the $\bar{\Lambda}/\Lambda$ production ratio (4.5×10^{-3}) in nucleus-nucleus collision at 4.5A GeV/c.[4] This is reasonable because the projectile is an antiparticle, $\bar{p}$, in the present experiment, while in Ref. 4, $\bar{\Lambda}$ cannot be produced by elementary process because of the lack of incident energy. Further studies are needed to determine the $\bar{\Lambda}$ production mechanism. In this paper we restrict ourselves to the analyses on Λ and K_s^0 because of insufficient statistics in the $\bar{\Lambda}$ data.

Figure 1 shows rapidity distributions of Λ and K_s^0 from $\bar{p}$-Ta in the laboratory system. The rapidity distribution of K_s^0 is symmetric. Its peak lies at $y=0.6$ and the peak goes to $y^*=0$ if one assumes the $\bar{p}$-3N c.m. frame, i.e., that the incident $\bar{p}$ collides with an effective target of three-nucleon mass in the center-of-mass system. The frame is moving with $\beta=0.54$ in the laboratory system. The rapidity distribution of Λ is roughly symmetric but has an asymmetric tail on the higher-rapidity side. The tail lies just in the rapidity region of the Λ's from the $\bar{p}p$ interaction.[13] The peak of the rapidity distribution of Λ goes to $y^*=0$ if one assumes the $\bar{p}$-13N c.m. frame, moving with $\beta=0.24$.

In order to explore the source of the asymmetric distribution of Λ, a scatter plot of momentum p^* versus rapidity y^* of Λ's from $\bar{p}$-Ta is shown in Fig. 2. Momentum p^* and rapidity y^* are defined in the $\bar{p}$-13N c.m. frame. In Fig. 2 the absence of data points around $y^*=-0.35$ is due to the Ta target plates. A dashed curve is drawn in order to show a shape of the distribution of Λ from $\bar{p}p$ in the moving system with $\beta=0.24$. The data points concentrate almost symmetrically in the region of $p^*\lesssim 0.8$ GeV/c and $|y^*|\lesssim 0.8$ (assigned as a region S, shown by a solid curve). Data points outside of the region S overlap well with the distribution expected from the $\bar{p}p$ interactions, which is shown with a dashed curve. This means that these events come from elementary $\bar{p}N$ interactions and could be separated from the main symmetric region S. It is also worthwhile to notice that the number of these events and the angular distribution correspond to

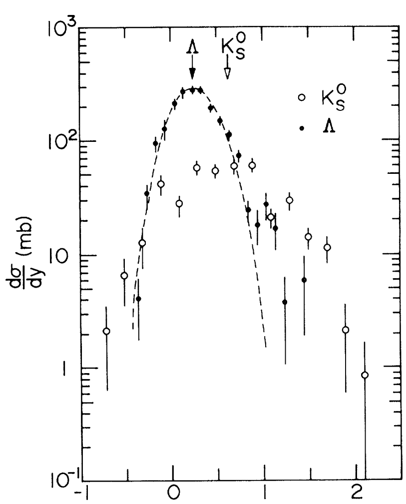

FIG. 1. Rapidity spectra of K_s^0 and Λ. The dashed curve shows a symmetric curve for the Λ distribution. The centers of the distributions of K_s^0 and Λ are indicated by arrows.

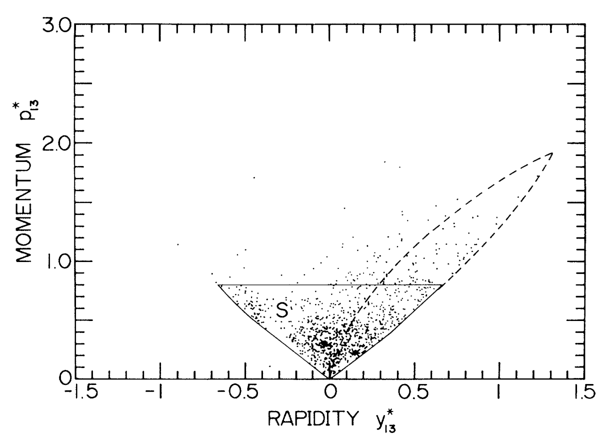

FIG. 2. Scatter plot of momentum p^* vs rapidity y^* which are defined in the $\bar{p}$-13N c.m. frame. A dashed curve shows the shape of the distribution of Λ's in $\bar{p}p$ collisions.

those expected from the elementary $\bar{p}p$ cross section [see Fig. 3(b)].

In order to study the dynamical characteristics of Λ's inside the region S, we have to know how much contribution is made from the Λ's produced in the elementary $\bar{p}N$ interactions. This contribution is estimated to be 8% from the $\bar{p}p$ data.[13] Therefore, it is negligible for further analysis, such as angular distributions. Figure 3(a) shows the angular distribution of Λ's inside the symmetric region S in the $\bar{p}$-13N c.m. frame. The fact that the distribution is clearly isotropic indicates an evaporation character of the process. The difference of the Λ production processes is clear when one compares the angular distribution with the one in Fig. 3(b), that is, for the events outside the region S. The angular distribution of K_s^0 is also almost flat in the $\bar{p}$-3N c.m. frame, as seen in Fig. 3(c). The fact suggests a similar evaporation character of the K_s^0 production process.

The inverse slopes of kinetic-energy spectra $[(1/p^*)d\sigma/dT^*]$ are analyzed for K_s^0 and Λ inside the region S and obtained as 135 MeV for K_s^0 in the $\bar{p}$-3N c.m. and 97 MeV for Λ in the $\bar{p}$-13N c.m. frame, respectively. The value of 135 MeV for K_s^0 is comparable with the experimental and theoretical ones for K^+ production in the nucleus-nucleus collisions.[2,10] These temperatures may not be high enough to induce a phase transition to quark-gluon plasma, which requires a higher temperature, of the order of 200 MeV.[14] K_s^0 is emitted through an evaporationlike process from the hot cluster consisting of three or four nucleons. This indicates a short-range correlation of K_s^0. The main fraction of the Λ's, which is responsible for the enhancement of Λ production, appears to be leaving from the hot $\bar{p}$-13N cluster through the evaporation mechanism. This cluster may break up during the traversal of the nucleus because of its high internal energy, $\frac{1}{3}$ of the kinetic energy of the cluster. An average Λ polarization was also measured to be consistent with zero ($P=0.02\pm0.09$), which is in agreement with the results in nucleus-nucleus collisions.[3,4] The polarization of the Λ also indicates the evaporationlike behavior.

In summary, we have seen a very large Λ production cross section and have observed evaporationlike Λ's from a hot cluster with $\beta=0.24$ and $T=97$ MeV. A similar observation is made also for the evaporation process of K_s^0 from a moving system with $\beta=0.54$ and $T=135$ MeV.

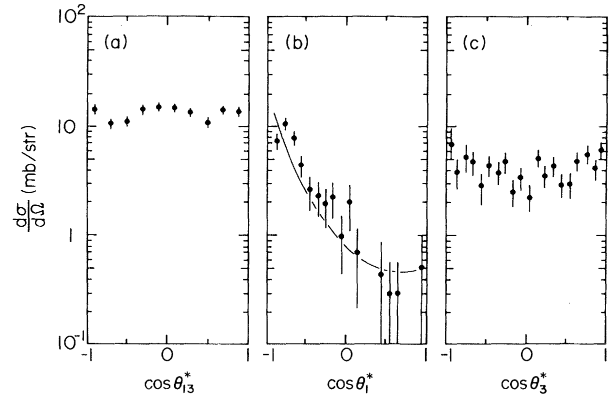

FIG. 3. Angular distributions of Λ and K_s^0. (a) Λ's inside the region S in the $\bar{p}$-13N c.m. frame. (b) Λ's outside of the region S, which is the angular distribution in the $\bar{p}p$ c.m. system; the solid curve shows the angular distribution of Λ's in the $\bar{p}p$ interaction, but multiplied by 32.0 ($=A^{2/3}$). (c) K_s^0 in the $\bar{p}$-3N c.m. frame.

The authors wish to express their thanks to the crews of the KEK 1-m hydrogen bubble chamber, beam channel, and 12-GeV synchrotron. They thank Professor A. Kusumegi for his continuous interest and useful discussions regarding this experiment. They also thank Professor T. Nishikawa, Professor S. Ozaki, and Professor S. Suwa for their continuous interest and support.

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