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Λ^0 production from low energy antiproton annihilations in complex nuclei

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Low energy antiproton absorptions in complex nuclei were found to produce Λ^0 hyperons with a frequency of 1.9 ±0.4%.

Recently, considerable interest has been attached to the effects resulting from the deposition of a large amount of energy within a complex nucleus.[1] The most interesting possibility is that, under appropriate conditions, a collection of nucleons could be transformed into a quark-gluon plasma. One of the signals for such a process is expected to be an enhanced strange particle production. In this regard Λ^0 hyperon production has recently been reported for a variety of energetic heavy ion collisions.[2] Another process which deposits considerable energy (and negligible momentum) into a nucleus is the absorption of a low energy antiproton. Aside from deuterium experiments, the study of neutral strange annihilation products from slow $\bar{p}$ absorptions by complex nuclei has been effected only in an early, low statistics propane bubble chamber experiment.[3] Here, the observation of two definite Λ^0 events from ~ 400 carbon annihilations does little more than confirm the existence of such a process. With a deuterium target, Bizzarri *et al.*[4] find a Λ^0 emission probability of $\sim \frac{1}{300}$ for stopping $\bar{p}$ interactions. More recently, Mandelkern *et al.*[5] have studied Λ^0 production in $\bar{p}d$ interactions at $\bar{p}$ momenta between 300 and 900 MeV/*c*. The purpose of our experiment is to extend the measurements on Λ^0 production from low energy $\bar{p}$ annihilations to complex nuclei ($A \geq 12$).

Our experimental data were obtained from an exposure of the BNL 76-cm hydrogen bubble chamber into which were placed four thin plates of carbon, titanium, tantalum, and lead. The thicknesses of the plates were 0.85, 0.56, 0.22, and 0.35 cm, respectively, each of which is sufficient to just stop an antiproton of momentum 290 MeV/*c*. Random measurements of the $\bar{p}$'s at their entrance to the plates indicated a momentum range for the incident $\bar{p}$'s between zero and 450 MeV/*c*. Although the beam was contaminated by a muon background, the separation between μ^- and $\bar{p}$ was trivial because of their different ionizations at these momenta. The beam was totally free of K^- contamination. This observation is based on the fact that of $\sim 20\,000$ interacting heavily ionizing tracks in the hydrogen liquid, not a single example of Λ^0 production or of collinear $\Sigma^\pm\pi^\mp$ production was observed. Since these final states constitute over half the products of slow K^-p interactions, and are forbidden in low energy $\bar{p}p$ interactions, we take this as evidence that our sample of $\bar{p}$ interactions is completely free of any K^- contamination and that no systematic error results from this cause.

The experiment consists of searching about each $\bar{p}$ interaction in any of the elemental plates for any neutral "Vee" particle decay which could be characteristic of the $p\pi^-$ decay mode of a Λ^0. Each event which had a prospective Λ^0 was measured and processed by means of the kinematic reconstruction program TVGP. For an event to be accepted as a Λ^0, the resulting measurements were required to be consistent with a one-constraint fit for which the direction of the Λ passed within 1 cm of the reconstructed interaction point in the plates. For events for which no other tracks emerged from the $\bar{p}$ annihilation, the one-constraint Λ^0 fit was required to intersect the extension of the $\bar{p}$ track in the plate volume. Similar measurements from a sample of the same film where the beam track was a K^- indicated that 12 ±3% of the definite Λ^0 were rejected by this procedure. A rescan of ~ half the film resulted in the observation of one additional Λ^0 not observed in the initial scan. This suggests a scanning efficiency of ~0.98. However, when consideration is given to the occasional near

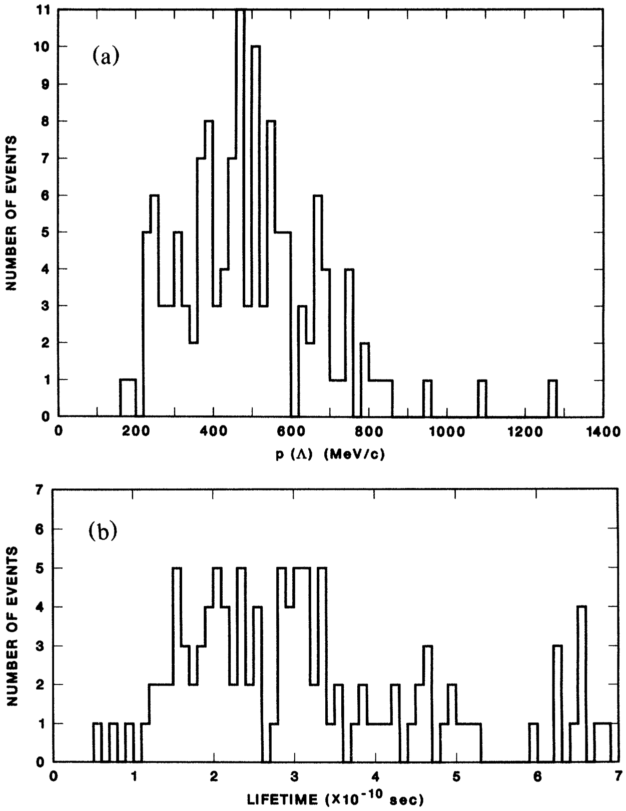

FIG. 1. (a) Λ^0 momentum spectrum from $\bar{p}$ annihilations. (b) Λ^0 lifetime (24 events had a lifetime exceeding the upper limit on the figure.)

TABLE I. Λ^0 production from $\bar{p}$ annihilations.

Element	No. of $\bar{p}$	Observed Λ^0	Corrected No. of Λ^0	Background Λ^0 due to K^- interactions	$\Lambda^0/\bar{p}$
C	8.300	33	207 ±48	14 ±5	0.023 ±0.006
Ti	6.050	46	138 ±38	12 ±4	0.021 ±0.007
Ta	7.800	31	105 ±31	16 ±5	0.013 ±0.004
Pb	2.550	22	74 ±25	5 ±2	0.027 ±0.011

juxtaposition of several annihilating antiprotons in the plates and to the invidious nature of some Λ^0 decays [small (p,π^-) opening angle, zero length protons, etc.] we consider a more realistic estimate of our scanning efficiency to be 0.90 ±0.05. The principal loss occurs for those Λ^0's which are created by a $\bar{p}$ annihilation and which subsequently decay either in the plates themselves or in their shadows which extend the invisible width of all of the plates to $\gtrsim 1$ cm. Figures 1(a) and 1(b) show the momentum spectrum for those Λ^0's satisfying the above criteria as well as the lifetime of each one-constraint Λ^0.

We can get a reasonable estimate of the total number of Λ^0's which are implied by the data of Fig. 1 by assuming that all of the decays, with individual lifetimes greater than the Λ^0 lifetime, except for a 5% solid angle correction, occur exterior to the region occluded from observation by the plates. After account is taken of the all neutral Λ decay mode, this number becomes 467 ±100 Λ^0's. If the lifetime cut were made at $2\tau_{\Lambda^0}$, this estimate would rise to 505 ±145 Λ^0 events.

An alternate method of quantifying the true number of Λ^0 in our sample evolves from a comparison of our $\bar{p}$ data with the Λ^0 emission frequencies following slow K^- captures in our plates. Vander Velde-Wilquet *et al.*[6] have reported that the Λ^0 emission rate ($p\pi^-$ decay mode only) from stopping K^- interactions in carbon, in a propane bubble chamber, is 0.47 ±0.02. In a separate run of our experiment, the beam employed was K^- mesons with their incident momentum adjusted so that the film was rich in stopping K^- interactions with the nuclei in the various plates. The rate of visible Λ^0 decays from these K^- carbon interactions was determined to be 0.125 ±0.008. Thus a comparison of our K^- data with the data of Ref. 6 indicates a geometric correction factor of 3.75 ±0.33 for these Λ^0 events in carbon. A further correction of 0.90 ±0.02 is required for the Λ^0 events from $\bar{p}$ annihilations since the average observed momenta for Λ^0's from $\bar{p}$ annihilations exceeds that for Λ's from K^- interactions. A smaller correction (~ 2.0) rather than 3.75 is required for the other plates since boiling about the carbon plate was more severe and since Λ^0 trapping[7] in the nucleus where a K^- interacts increases strongly with A. Our raw data together with the effects of these corrections (column 4) are given in Table I.

The entries in column 4 of Table I must undergo an additional correction (as must our preliminary estimates) to account for those Λ^0 whose origin is a $\bar{K}^0$ or K^- interaction with a neighboring nucleus contained within the visible volume of the plates. The rate of $\bar{K}K$ production[8] from $\bar{p}p$ and $\bar{p}d$ annihilations can be taken as 6 ±1%. The subsequent $K^-,\bar{K}^0$ will produce Λ^0 hyperons from in-flight annihilations near the interaction site. Further, any K^- that is reduced to rest within the plate volume has a finite chance of creating a Λ^0. By assuming a K^- absorption cross section in the various elements of $10A^{2/3}$ mb, and a Λ^0 emission probability from the various elements consistent with the Λ^0 trapping data,[7] we find ~ 8 Λ^0 to result from in-flight K^- interactions in the plates. The number of K^- produced by $\bar{p}$ annihilations which stop within 1 cm of the $\bar{p}$ annihilation star is computed by assuming that 45% of the strange particle production[9] yields $K^-(K^+)$ and by using the kaon momentum spectra in Refs. 9. Averaged over our different materials, this yields 40 ±16 Λ^0 due to nearby at-rest K^- interactions. These numbers of Λ^0's are given in the fifth column of Table I.

It is clear that the data in column 5 of Table I, with the large associated errors, do not permit any distinction as regards to the Λ^0 emission rate in our various materials. We therefore eschew the effort to segregate the data and treat all of the complex nuclei as a single specie. Our conclusion therefore is that 24 700 $\bar{p}$ annihilations in complex nuclei yield 477 ±90 Λ^0 hyperons which give a final fraction of 0.019 ±0.004 Λ^0 per $\bar{p}$ annihilation. This should be regarded as a lower limit since we have ignored 12 Λ^0 events for which no one-constraint fit could be achieved and which could, for example, represent Λ^0 scattering within the plates.

The Λ^0 emission frequency from $\bar{p}$ absorptions by complex nuclei is thus about five times that from deuterium. This increase is suggestive of the case of at-rest K^- interactions where the multinucleon (nonmesonic) capture probability rises from $\sim 1\%$ in deuterium[10] to 10–30% for complex nuclei[11] (Λ^0 production from slow $\bar{p}$ absorption also requires the involvement of at least two nucleons). Alternatively, one can consider Λ^0 production as being due to a final state $K^-,\bar{K}^0$ interaction in the annihilation nucleus. This would yield an average $\bar{K}$ reabsorption probability, in the parent nucleus, of at least 30 ±10%. That this is a lower limit follows since all inelastic $\bar{K}N$ interactions do not result in a Λ^0 and because Λ^0 trapping is a significant feature, especially in heavy nuclei, following Λ^0 production by at-rest K^- interactions.[7] Further, since the $\bar{p}$ is captured quite peripherally[12] where the nucleon density is less than 10% of its central value, the Λ^0 created by a secondary $\bar{K}$ interaction will, on the average, be created in a more central region of the nucleus, which will enhance the probability of its being trapped in the parent nucleus. Both of these effects indicate the above $\bar{K}$ reabsorption probability to be a lower limit.

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