Lifetime of the Λ^0 Hyperon*

M. M. BLOCK, R. GESSAROLI,† AND S. RATTI‡
Northwestern University, Evanston, Illinois

L. GRIMELLINI, T. KIKUCHI,§ L. LENDINARA, AND L. MONARI
University of Bologna, Bologna, Italy

E. HARTH AND W. BECKER
Syracuse University, Syracuse, New York

AND

W. M. BUGG, AND H. COHN
Oak Ridge National Laboratory, Oak Ridge, Tennessee

(Received 3 December 1962)

A precision measurement of the Λ^0 lifetime has been made in a helium bubble chamber. An exposure to a stopping K^- beam yielded 2239 Λ^0's, with a mean momentum of $\sim$250 MeV/c, which satisfied rigorous selection criteria designed to minimize biases. The mean lifetime was found to be $\tau=(2.36\pm0.06)\times10^{-10}$ sec.

1. INTRODUCTION

THE mean lifetime of the Λ^0 particle is not yet well known. The latest summary on the subject[1] shows essentially two groups of experiments in considerable disagreement, the first leading to $\tau\cong2.4\times10^{-10}$ sec, the other to $\tau\cong2.8\times10^{-10}$ sec. This indicated the necessity of a careful measurement of the Λ^0 lifetime with increased statistical accuracy and with particular attention paid to possible sources of bias and background contamination.

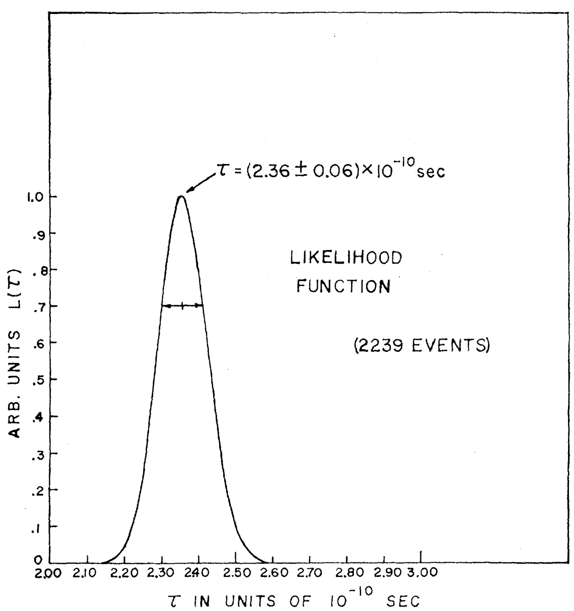

FIG. 1. The likelihood function, in arbitrary units, as a function of the lifetime τ.

A beam of stopping K^- mesons in the helium bubble chamber ($10\times12.5\times20$ cm^3 operated in a 14 000 G magnetic field) provided a copious source of low momentum Λ^0 hyperons with a mean momentum of about 250 MeV/c. Because of the low average momentum, the mean potential time is about 5 times the lifetime and the corresponding corrections are small.

A carefully selected sample of 2239 Λ^0 decays yielded a mean lifetime $\tau=(2.36\pm0.06)\times10^{-10}$ sec.

2. EXPERIMENTAL PROCEDURE

All Λ^0 events found in about 5000 pictures ($\approx$4000 candidates), independent of the type of production reaction and of length of the secondaries, were accepted for analysis. The events were analyzed with a new kinematic program (LIBRARY I) developed at Northwestern University for the 709 computer. The event was first made coplanar in the ORGY step and then an energy-momentum balance in that plane was performed to find the Λ^0 momentum in the PORGY step. The accepted input data were the dip and projected angles with errors; the proton and pion momenta at the decay vertex, with symmetrized errors; the hyperon length; and the coordinates of its origin.

As we assume we measure projected momenta and projected length, these quantities were corrected back for the change of the dip angles due to the optimization process in the ORGY step.

There were three possible cases: (a) No secondary momenta were measurable; (b) only one momentum was measurable; and (c) both momenta were measurable.

The momentum of a track was defined as measurable if either it stopped or if its projected length was greater than 3 cm. This last condition was necessary in order

* This work was supported by the Office of Naval Research and the Atomic Energy Commission.
† Present Address: University of Bologna, Bologna, Italy.
‡ On leave of absence from the University of Milan, Milan, Italy. N.A.T.O. Science Fellowship.
§ Now at Department of Physics, Northwestern University, Evanston, Illinois.
[1] *Proceedings of the 1960 Annual International Conference on High-Energy Physics at Rochester* (Interscience Publishers, Inc., New York, 1960), p. 879; also see *Proceedings of the 1962 International Conference on High-Energy Physics at CERN* (CERN, Scientific Information Service, Geneva, 1962), p. 839.

to insure reasonable momentum accuracy. In the actual sample, about 62% of events were of type (c), 30% were of type (b), and only 8% were of type (a).

The following selection criteria were applied: (1) The Λ^0 had to decay outside of a hypothetical 2-mm sphere circumscribed about the production vertex. (2) Both the production vertex and the decay vertex must lie inside a fiducial volume whose external dimensions were 1 cm from the physical chamber walls. (3) χ^2 in the ORGY step must be <10.00 for all types (a), (b), and (c). (4) χ^2 in the PORGY step must be <6.5 for case (c); <4.5 for case (b). For case (a), the Λ^0 momentum was measured from the angular correlation of the decay particles (θ^+ and θ^-). (5) The measured momentum of the Λ^0 hyperon must lie in the range 100–500 MeV/c. In this way we felt that biases such as scanning, measuring, etc., would be minimized. In order to be sure that the cutoffs do not introduce a geometry dependent bias, the χ^2 acceptance band in the ORGY step was chosen sufficiently large ($\chi^2<10$, when $\langle\chi^2\rangle=0.98$ for the distribution truncated at 10) that within our statistical accuracy the ratio between the accepted events and the rejected events was independent of the length of the hyperon, i.e., of its time of flight. In essence, over 99% of the Λ^0's are accepted in the ORGY χ^2 band. However, the background events (neutron stars, $\mu-e$ decays, $K-\pi$ decays, etc.) are still severely discriminated against on the basis of the ORGY and PORGY tests. Thus, the background can come mainly from the 8% of events of type (a) in which we had no momentum information. From the analysis of all the rejected events, our best estimate is that about 1 event in the retained sample could be spurious.

On the average, the Λ^0 momenta were measured to an accuracy of about 8%. For the accepted events the average χ^2 were: $\langle\chi^2\rangle=0.98\pm0.05$ in the ORGY step ($\langle\chi^2\rangle_{\text{expected}}=0.98$); $\langle\chi^2\rangle=1.25\pm0.08$ in the PORGY step ($\langle\chi^2\rangle_{\text{expected}}=1.40$[2]).

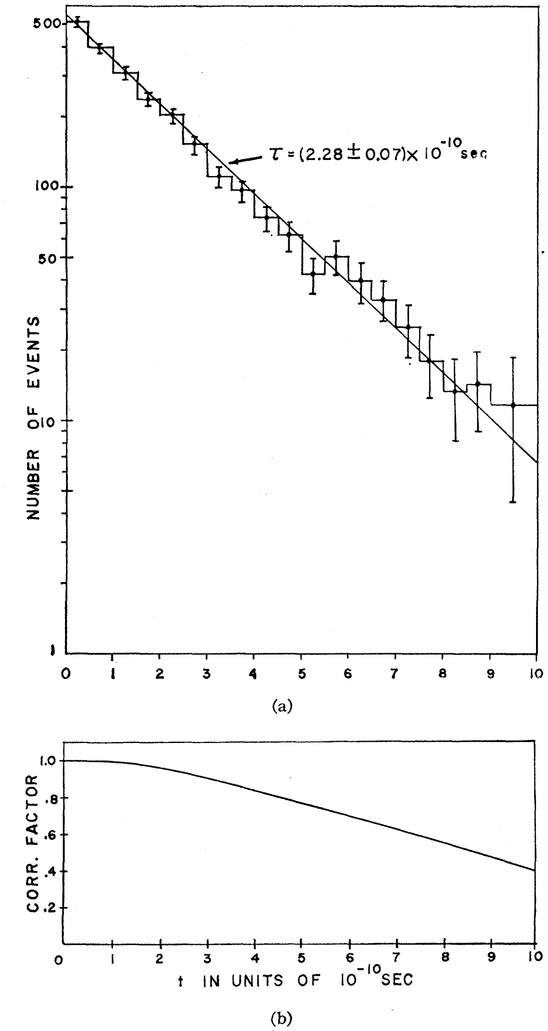

FIG. 2. (a) Corrected decay distribution. The straight line corresponds to a best least-square fit $\tau=(2.28\pm0.07)\times10^{-10}$ sec. [$\langle\chi^2\rangle_{\text{expected}}=38$; $\langle\chi^2\rangle_{\text{observed}}=28$; the least-squares fit and the χ^2 calculation were done using time intervals $\Delta t=0.25\times10^{-10}$ sec]. (b) The correction factor, defined as the percentage of events having potential time T greater than t, as a function of the time t.

3. SYSTEMATIC ERRORS

Since we assumed symmetrized errors in the momenta at the decay vertex, we checked whether or not this fact introduces a systematic error in the measurement of the Λ^0 momentum.

We analyzed about a hundred events with a different program which fits the angles and the sagittae at the same time (HEGUTS program). The result was $\langle P_{\text{HEGUTS}}-P_{\text{LIBRARY 1}}\rangle=(-1\pm4)$ MeV/c. We feel that no significant systematic error is introduced by this procedure.

Furthermore, as both measurement of length and momentum are involved in the calculation of the times of flight, possible systematic errors can come from (a) uncertainty in the knowledge of the magnification factor, (b) uncertainty in the knowledge of the liquid helium density, and (c) uncertainty in the knowledge of the magnetic field. These systematic errors were studied in detail in a previous paper.[3]

Taking into account all the possible sources mentioned, our best estimate of the systematic error in the time measurement is $\approx0.7\%$.

4. MEAN LIFETIME CALCULATION

The likelihood function,

$$L(\tau)=\prod_{i=1}^{N}\left[e^{-t_i/\tau}/\tau(1-e^{-T_i/\tau})\right] \quad (1)$$

[2] The expected χ^2 was calculated by adding 67% of expected χ^2 for a 2 constraint class distribution truncated at 6.5 and 33% of expected χ^2 for a 1 constraint class distribution truncated at 4.5.

[3] M. M. Block, E. Fiorini, T. Kikuchi, G. Giacomelli, and S. Ratti, Nuovo Cimento **23**, 1114 (1962).

TABLE I. Lifetime results for the subdivision of our data in different subsamples, including changing geometric boundaries, and breaking up into high- and low-momentum intervals. The quoted errors are statistical.[a]

	1-cm boundary	2-cm boundary	$P_\Lambda < 250$ MeV/c 1-cm boundary	$P_\Lambda > 250$ MeV/c 1-cm boundary
2-mm sphere	2.36 ± 0.05 $\times 10^{-10}$ sec	2.35 ± 0.06 $\times 10^{-10}$ sec	2.40 ± 0.08 $\times 10^{-10}$ sec	2.33 ± 0.09 $\times 10^{-10}$ sec
3-mm sphere	2.36 ± 0.05	2.35 ± 0.06	2.39 ± 0.08	2.34 ± 0.09

[a] The number of events in the different subsamples are:

1-cm boundary	2-mm sphere	2239
1-cm boundary	3-mm sphere	2072
1-cm boundary High Mom.	2-mm sphere	1084
1-cm boundary High Mom.	3-mm sphere	1015
1-cm boundary Low Mom.	2-mm sphere	1103
1-cm boundary Low Mom.	3-mm sphere	1006
2-cm boundary	2-mm sphere	1978
2-cm boundary	3-mm sphere	1825

(where t_i is the actual time of flight, T_i is the potential time, and τ is the mean lifetime to be determined), for 2239 accepted events, is shown in Fig. 1.

We obtained a mean lifetime $\tau = (2.36 \pm 0.06) \times 10^{-10}$ sec, where the error includes both statistical and systematic effects. As a check on the hypothesis of the exponential law, i.e., a check on possible biases, we plotted the corrected decay distribution up to $t = 10^{-9}$ sec, in Fig. 2(a). The correction factor, the fraction of events having potential time T greater than the proper time t, is shown in Fig. 2(b). The best straight line fit, $\tau = (2.28 \pm 0.07) \times 10^{-10}$ sec, gives substantial agreement with the maximum likelihood method. We adopt the maximum likelihood result because we feel that it utilizes the data in the most efficient statistical fashion.

In order to further check the reliability of the experiment, we tested the data in the following subdivisions: (1) division between the four laboratories, (2) division into high and low momenta of the Λ^0 hyperon, (3) the sphere around the production vertex changed to 3-mm radius, (4) the fiducial volume constrained to be at least 2 cm from the physical chamber walls.

The checks (2), (3), and (4) are by far the most indicative tests on the presence of possible biases. In Table I the values of the mean lifetimes for these different subsamples are listed.

A further check on possible configuration-dependent biases can be made by looking at the angular distribution of the decay pion in the Λ^0 rest frame. If parity is conserved in the strong interactions, the distribution of the pion angle in the Λ^0 rest frame has to be isotropic. In Fig. 3 such a distribution is shown for 2404 events (the accepted events plus those with length between 1 and 2 mm), yielding an asymmetry parameter $a = (0.01 \pm 0.03)$, in excellent agreement with the isotropy hypothesis.

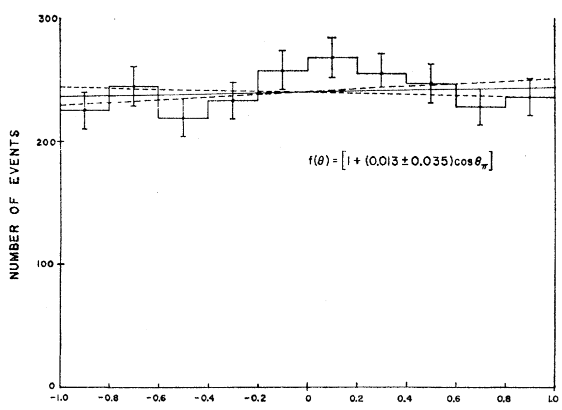

FIG. 3. The center-of-mass angular distribution of the π^- from the decay $\Lambda^0 \to p + \pi^-$ of 2404 events. The straight lines represent the best fit of the type $1 + a \cos\theta$, where $a = 0.01 \pm 0.03$.

5. CONCLUSIONS

None of our tests indicate any significant bias. Thus, we conclude that the Λ^0 mean lifetime is $\tau = (2.36 \pm 0.06) \times 10^{-10}$ sec.

ACKNOWLEDGMENTS

The cooperation of the Bevatron staff of the Lawrence Radiation Laboratory, whose effort made this experiment possible, is gratefully acknowledged.

We would like to thank Mrs. Joan Capps and Michael Carlitz of Northwestern University for their invaluable aid in the programming and computing, and the Northwestern University Computing Center, for its cooperation.

One of us (S.R.) wishes to thank the NATO Science Program and the Italian Consiglio Nazionale della Ricerca for a Fellowship.