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LEPTONIC DECAYS OF HYPERONS

Results of a Search in 1.05-to 1.75-BeV/c K^- Interactions in Hydrogen

Part I. Muonic Λ Decays

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ABSTRACT

Examples of the decay mode

$$\Lambda \rightarrow p + \mu^- + \bar{\nu}$$

were searched for in a sample of K^-p interactions in the 72-inch hydrogen bubble chamber. Among 30,000 events of the type "two-prong + V," one unambiguous and three possible examples of this decay mode were found. Other possible interpretations of these events are examined. It is concluded that the decay branching ratio is about 1.2×10^{-4}.

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The rate for the electronic Λ decay

$$\Lambda \rightarrow e^- + p + \bar{\nu} \qquad (1)$$

has recently been measured.[1] Of the muonic decay mode,

$$\Lambda \rightarrow \mu^- + p + \bar{\nu}, \qquad (2)$$

only two examples have been reported[2] to date.

We searched for examples of the muonic mode (2) in the Lawrence Radiation Laboratory 72-inch hydrogen bubble chamber. Our sample of events was so selected that the Λ momentum could be determined from the production fit alone. This insured a kinematic check on Λ-decay fits. These events are examples of the reaction

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^-, \qquad (3)$$

$$K^- + p \rightarrow \Sigma^0 + \pi^+ + \pi^-, \qquad (4)$$

or

$$K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0, \qquad (5)$$

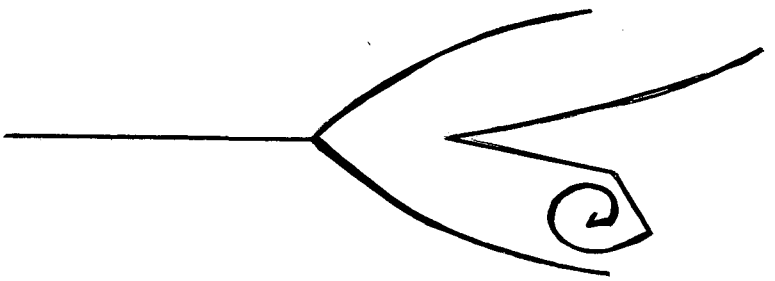
each of which appears as a "two-prong + V" in the bubble chamber if the Λ decays through the charged mode. Our sample consists of 30,000 such events.

Scanners were asked to check the negative prong of the V, and make a list of those that had at least one obvious kink or decay. The bulk of the events listed (there were almost 1000 of them) had two kinks and were due to

the sequence

$$\Lambda \rightarrow p + \pi^-, \qquad \pi^- \rightarrow \mu^- + \bar{\nu}, \qquad \text{and} \qquad \mu^- \rightarrow e^- + \nu + \bar{\nu}. \tag{6}$$

These events looked like this:



The only events given further consideration were those for which the following conditions were satisfied:

- Only one kink was visible,
- the decaying negative track had a curvature resembling that of a stopping μ and was heavily ionizing, or
- the decay product was minimum-ionizing.

This reduced the sample to 32 events. These events were then measured on the Franckenstein and processed by using the on-line kinematic-fitting program QUEST.[3] First, the Λ momentum was determined from the production fit [Reaction (3), (4), or (5)]; then the Λ-decay hypotheses,

$$\Lambda \rightarrow \mu^- + p + \bar{\nu} \qquad (\mu^- \text{ stops}) \tag{7}$$

and

$$\Lambda \rightarrow \pi^- + p \qquad (\pi^- \text{ does not necessarily stop}) \tag{8}$$

were considered. Only four events gave acceptable fits to hypothesis (7); the rest were discarded. [Most of these discarded events fitted hypothesis (8) and were examples of chain (6) for which the $\pi^- \rightarrow \mu^-$ decay resulted in a very small kink in the track.]

The remaining four events were fitted to one additional hypothesis. We assumed that in chain (6) the π^- decayed close

to its origin and was therefore of "zero length." A summary of the results for these four events is given in Table I.

Three groups can be delineated:

A. Event (1) is definitely a muonic decay of the Λ. It is described in some detail in the appendix.

B. Events (2) and (3) could have a "zero length" pion at the decay vertex.

C. Events (3) and (4) could have a visibly long π with a $\pi^- \rightarrow \mu^-$ decay of fortuitous kinematics: the π^- may decay into an invisibly short-range "zero length" μ^- near the end of its range.

The possibility of $\pi^- \rightarrow e^- + \bar{\nu}$ was also investigated, and an additional event of this type was found. The momentum of the decay electron provides clear identification of such events.

Using the known Λ momentum distribution and the π^- lifetime, we calculated the expected number of "zero length" pions. Such events always fit the $\Lambda \rightarrow p + \mu^- + \bar{\nu}$ hypothesis. Also calculated were the expected number of "zero length" μ^-. About 50% of these fit the $\Lambda \rightarrow p + \mu^- + \bar{\nu}$ hypothesis.[4] Table II summarizes the results. The number of observed events of classes B and C is in good agreement with the expected number of "zero length" π and μ, respectively.

The expected efficiency of our method for finding muonic decay was calculated by use of the curve given by Humphrey et al.[5] Their curve includes the probability that the μ^- stop in the chamber, and that the event will not be compatible with a $\Lambda \rightarrow p + \pi^-$ decay, irrespective of whether the π^- is assumed to go a finite distance. For our Λ-momentum spectrum the method is about 23% efficient. We still have to multiply this figure by the scanning efficiency for listing $\mu^- \rightarrow e^-$ decays, which we estimate is 80%.

The branching ratio based on the one event that fits the hypothesis of muonic decay only is

$$F = \frac{1}{3/2 \times 0.23 \times 0.80 \times 30{,}000} = \frac{1}{8300} = 1.2 \times 10^{-4},$$

in which the factor 3/2 corrects for the neutral decay mode of the Λ.

This result follows the trend of other $\Delta s = 1$, $\Delta s/\Delta Q = +1$ leptonic decays,[1,5,6] inasmuch as it is about 1/25 of the Feynman-Gell-Mann[7] predictions. Also, the ratio of electronic and muonic rates is not inconsistent with the predictions based on the relative phase space available.

Many members of the Alvarez group have contributed to the experiment at one state or another, and their help is gratefully acknowledged. We would like to especially thank Professor Luis W. Alvarez for his interest and support. Mr. Darrell O. Huwe, Dr. Joseph J. Murray, and Dr. Janice B. Shafer had more than 10,000 events of this sample measured and processed, and aided us generously with the information so obtained. Discussions with Dr. William E. Humphrey, Dr. George R. Kalbfleisch, and Professor Arthur H. Rosenfeld were invaluable.

APPENDIX

Details about the $\Lambda \rightarrow p + \mu^- + \bar{\nu}$ event (Serial number 3276-308)

The event is shown in Fig. 1; the track numbering is shown in Fig. 2. Results of three measurements are listed in Table III. The three measurements were made by using slightly different positions for the production vertex; thus, somewhat different Λ directions resulted. The table also shows the one-constraint fit to muonic Λ decay.

The following alternative hypotheses were tried and ruled out:

1. Normal $\Lambda \rightarrow \pi^- + p$ decay followed by $\pi^- \rightarrow \mu^-$ decay at any point along the track. The necessary π^- (as determined by using the Λ and the p parameters only) has 54 ± 2 MeV/c momentum, and its direction is $105 \pm 7°$ from that of the observed μ^-. Although the errors are appreciable because of uncertainties in the Λ momentum and direction, the required π^- cannot give rise to the observed μ^-.

2. Other sources of V production

   a. There is no other possible origin for the Λ on the picture.

   b. The decay cannot be that of a K^0 because track 5 is identified as a proton by ionization.

   c. When only the π^+ and π^- (tracks 2 and 3) are considered from the final state, energy and momentum conservation require a neutral system of effective mass 1265 ± 18 MeV to escape with momentum 648 ± 15 MeV/c. This in itself strongly suggests the production reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + \pi^0$, and puts narrow limits on the allowed Λ directions and momenta.

FOOTNOTES AND REFERENCES

* Work done under the auspices of the U. S. Atomic Energy Commission.

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2. M. L. Good and V. G. Lind, Phys. Rev. Letters 9, 518 (1962); F. Eisler, J. M. Gaillard, J. Keren, M. Schwartz, and S. Wolf, Phys. Rev. Letters 7, 136 (1961).

3. M. H. Alston, J. E. Braley, and P. White, Rev. Sci. Instr. 34, 64 (1963).

4. To find what fraction of "zero length" μ events would fit the $\Lambda \rightarrow \mu^-$ hypothesis (2), we measured a sample of normal $\Lambda \rightarrow p + \pi^-$ decays for which the π^- stopped in the chamber. Half of these gave acceptable fits to $\Lambda \rightarrow \mu$ decay.

5. W. E. Humphrey, J. Kirz, A. H. Rosenfeld, and J. Leitner, in Proceedings of International Conference on High Energy Physics, CERN, July 1962. (CERN, Geneva, 1962), p. 442.

6. W. J. Willis, R. Adair, H. Courant, H. Filthuth, P. Franzini, R. G. Glasser, A. Minguzzi, A. Segar, R. Burnstein, T. B. Day, F. Herz, B. Kehoe, M. Sakitt, N. Seeman, B. Sechi-Zorn, and G. A. Snow, Bull. Am. Phys. Soc. 8, 349 (1963).

7. R. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

Table I. Kinematic decay fits to the four "possible" events.

	Serial number	χ^2 for the hypothesis/expected value $\Lambda^0 \to \mu^- + p + \bar{\nu}$	$\Lambda^0 \to \pi^- + p$	"Zero length" π	Production reaction
1.	3276-308	0.37/1	460.7 /4	500.8 /2	$K^- + p \to \Lambda^0 \pi^+ \pi^- \pi^0$
2.	3438-315	1.99/1	62.05/4	2.12/2	$K^- + p \to \Lambda^0 \pi^+ \pi^- \pi^0$
3.	3977-209	0.04/1	3.51/3	2.04/2	$K^- + p \to \Lambda^0 \pi^+ \pi^- \pi^0$
4.	3415-097	0.12/1	8.23/4	43.81/2	$K^- + p \to \Lambda^0 \pi^+ \pi^- \pi^0$

Table II. Expected number of spurious events.

	Fraction	In 30,000 decays	Observed
Expected "zero length π"[a]	0.53×10^{-4}	1.6	1 or 2[c]
Expected "zero length μ"[a,b]	$1/2 \times 1.11 \times 10^{-4}$	$1/2 \times 3.3$	1 or 2[c]
Total		3.3	3

[a] We define "less than 1 mm in space" to be "zero length."

[b] The factor 1/2 accounts for the probability that these events simulate $\Lambda^0 \to \mu^- + \bar{\nu} + p$ (see reference 4).

[c] Event 3 in Table I could be in either category.

Table III. Kinematics of the event 3276-308. Three sets of measurements and one fit are shown.

TN[a,d]	PA[e]	Momentum				Azimuth				Dip			
		Measurement				Measurement				Measurement			
		I	II	III	Fit[b]	I	II	III	Fit[b]	I	II	III	Fit[b]
1	K^-	1498±15	1495±15	1501±15	1498±10	80.7±0.1	80.7±0.1	80.7±0.1	80.7± 0.1	1.7±0.3	1.9±0.3	1.8 ±0.3	1.9±0.3
2	π^-	407± 9	417± 8	406± 4	415± 9	86.5±0.2	86.4±0.2	86.5±0.2	86.4± 0.2	19.2±0.3	19.1±0.3	19.2 ±0.3	19.1±0.3
3	π^+	678±19	640±19	687±13	635±16	106.7±0.1	106.4±0.1	106.6±0.1	106.4± 0.1	-19.4±0.3	-19.3±0.3	-19.6 ±0.3	-19.3±0.3
4	μ^-	53.1±0.6[c]	53.6±0.6[c]	53.4±0.6[c]	53.0±0.6	36.9±1.8	37.0±1.9	37.1±1.8	36.8± 1.8	43.2±1.8	44.1±1.8	43.5 ±1.8	42.9±1.8
5	P	577±17	573±17	568±11	570± 9	51.5±0.2	51.4±0.2	51.3±0.2	51.4± 0.2	17.2±0.3	17.1±0.3	17.0 ±0.3	17.2±0.3
6	e^-	49.7± 1	---	---	---	---	---	---	---	---	---	---	---
7	Λ	---	---	---	602±52[f]	47.5±0.1	46.6±0.1	45.7±0.1	47.5± 0.1[f]	14.6±0.5	13.4±0.6	16.06±0.5	14.5±0.4[f]
8	$\bar{\nu}$	---	---	---	61± 4	---	---	---	350.5±11.1	---	---	---	-52.2± 3.4
9	π^0	---	---	---	86±21	---	---	---	95.5±27.2	---	---	---	-18.0±5.0

[a] See Fig. 2.

[b] The fit is based on measurement I.

[c] μ^- momentum and error calculated from range.

[d] Track number.

[e] Particle assignment.

[f] The fitted values shown come from the production fit. The decay gives p = 622±4 MeV/c; azimuth 47.4±0.1°; dip 14.6±0.5°.

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FIGURE CAPTIONS

Fig. 1. Photograph of the event 3276-308, showing production and muonic decay of Λ.

Fig. 2. Sketch of the event shown in Fig. 1.

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Fig. 1.

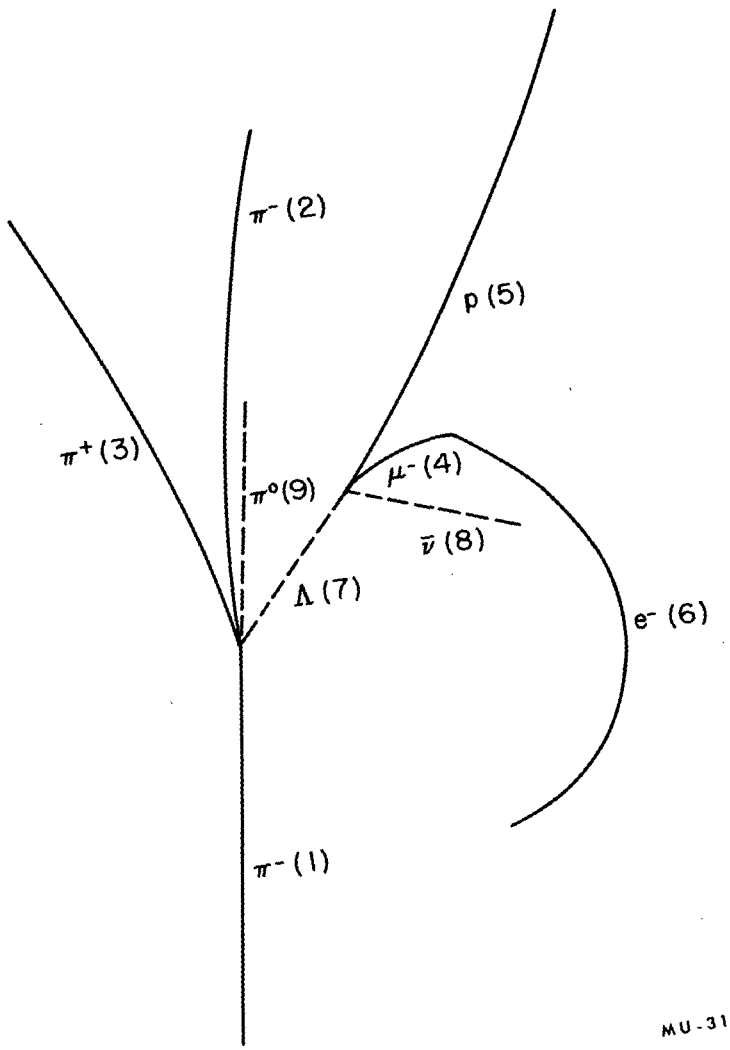

Fig. 2.