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A NEUTRAL CASCADE HYPERON EVENT*

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The existence of a neutral cascade hyperon Ξ^0 has been predicted theoretically,[1] on the basis of the strangeness theory of Gell-Mann and Nishijima, as the neutral counterpart of the negative cascade hyperon,[2] Ξ^-, which decays by $\Xi^- \to \pi^- + \Lambda$.

In an attempt to establish the existence of this particle the Lawrence Radiation Laboratory 15-inch hydrogen bubble chamber was operated in a separated beam of 1.15 ± .02-Bev/c K^- mesons produced by the Bevatron. Two Cork-Wenzel-Lambertson parallel-plate spectrometers[3] were used to remove pions from the beam. Typical operating conditions gave $\approx 1.5\ K^-$, $\approx 0.2\ \pi^-$, and ≈ 4.5 beam μ^- mesons per picture.[4] The total number of K^- mesons through the chamber was about 10^5.

A large number of K^- interactions in hydrogen were observed; among them were some 500 single V^0 events, resulting from the reactions

$$K^- + p \to \bar{K}^0 + n, \qquad (1a)$$

$$\Lambda + \pi^0, \qquad (1b)$$

$$\Sigma^0 + \pi^0. \qquad (1c)$$

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In any of these, additional π^0 mesons may also have been produced.

On the other hand, only seven double V^0 events were observed. Since the reactions (1) lead only to single V^0's, whereas associated production by π^- mesons leads to double V^0's in about 20% of the interactions, the strikingly small ratio of double V^0 events to single V^0 events again shows that we are dealing principally with K^- interactions.

Six of the double V^0's were clear cases of associated production by π^-, five being

$$\pi^- + p \rightarrow \Lambda + K^0, \tag{2a}$$

and one

$$\pi^- + p \rightarrow \Sigma^0 + K^0, \quad \Sigma^0 \rightarrow \Lambda + \gamma. \tag{2b}$$

Most of these were produced by pions of somewhat less than the K^--beam momentum.

The remaining event is the one being reported here. A photograph and a diagram giving our interpretation of the event are shown in Fig. 1. The angles and momenta of the left-hand V^0 are consistent with K_1^0 decay, and are inconsistent with Λ decay. The K^0 momentum and angle of emission are consistent with the reaction $\pi^- + p \rightarrow \Sigma^0 + K^0$ of a beam-momentum pion.

The two charged tracks of the right-hand V^0 are consistent with Λ decay, giving $Q = 37.2 \pm 2.7$ Mev (accepted value 37.4 Mev). However, the decay is noncoplanar; i.e., the line connecting the end of the beam track and the vertex of the Λ fails by $7.0 \pm .7^\circ$ (see Fig. 2) to lie in the Λ decay plane. This line also fails to lie in the production plane defined by the K^0 path and the beam track by $2.5 \pm .7^\circ$. The latter discrepancy could be explained easily if the process were (2b), but to explain the lack of coplanarity of the Λ decay, using only well-established processes, we must invoke either: (a) Reaction (2b) followed by a β decay of the Λ, or (b) a scatter of the Λ in the hydrogen, or (c) an accidental coincidence of a K^0-meson production event with an unassociated Λ from the bubble chamber wall.[5]

Possibility (a) may be ruled out on kinematic grounds alone. Because of the large unbalance of transverse momentum, the electron and neutrino need more energy than would be available to them. The decay $\Lambda \rightarrow p + e^- + \nu$, for the most favorable Λ momentum, fails to balance energetically by 48 Mev, or 3.7 standard deviations; the error is mostly in angle measurements. For such large discrepancies, angle errors do not have Gaussian distributions, and this large a discrepancy is not possible. A decay via $\Lambda \rightarrow p + \mu^- + \nu$ fits even less well.

The second possibility, a Λ scattering, is likewise unsatisfactory. Choosing that initial Λ direction of motion for which the scattering angle would be smallest, one asks what the proton recoil range would be to account for the observed Λ. This turns out to be 4 mm, which would be clearly visible. To have a proton range small enough that there would be some doubt, namely 0.5 mm, requires stretching the errors by more than 5 standard deviations. Inelastic scatterings, double scatterings, scatterings on deuterium, or neutron reactions on deuterium that might look like Λ events are exceedingly unlikely.

The third possibility, a chance coincidence, can be shown to be most improbable on statistical grounds. Since the argument hinges on how well the event fits the production and decay of a Ξ^0 hyperon, let us now turn to this hypothesis. If we assume the K^0 meson to be produced in association with a heavy unstable particle, the incident particle being a beam K^- meson, then the extra energy available in the center of mass in the $K^- + p$ system (compared with the $\pi^- + p$ system) requires the heavy particle to be much heavier than a Σ^0. If this particle travels a distance of 3.7 cm and decays into a Λ and a π^0, then the presence of an associated Λ can be explained, as well as its apparent noncoplanarity.

The mass of the particle may then be deduced in two ways, i.e., from its production and from its decay. First, if we take the production process to be a two-body reaction, the heavy particle must lie in the plane formed by the beam track and the line of flight of the K^0 meson. Further, the direction of the heavy particle in this plane is fixed by the requirement that its path intersect that of the Λ. Then, using the production angles and the measured K^0 momentum, we can calculate the heavy-particle mass as well as the momentum of the incident K^- meson. The calculated momentum of the incident K^- is $1.13 \pm .06$ Bev/c, which agrees well with the nominal beam momentum. (This serves as a first check on our hypothesis.) The heavy-particle mass is 1303 ± 28 Mev.

Second, if the heavy-particle velocity as determined in the above calculation is taken in conjunction with the observed Λ momentum and angle, a second mass determination is possible. The heavy-particle mass resulting from this calculation, based on the assumption of decay into a π^0 and a Λ, is 1349 ± 30 Mev. This value is insensitive to the heavy-particle velocity, and therefore the two determinations are nearly independent.

Combining the two mass determinations,[7] we obtain

$$M = 1326 \pm 20 \text{ Mev}.$$

The closeness of this result to the accepted Ξ^- mass of 1321 ± 3.5 Mev[8] is remarkable.

One might put the arguments the other way and ask to what extent the agreement (within errors) with the Ξ^- mass restricts the position, momentum, and angle of the decay Λ. In order for the Ξ^0 mass, as determined by its production, to vary by 30 Mev, the Λ need be moved (transversely) only 0.4 mm. Similarly, in order for the Ξ^0 mass, as determined by its decay, to vary by 30 Mev, the Λ momentum must be changed by 50 Mev/c (at fixed angle), or the angle by 2° (at fixed momentum).

These restrictions form a strong argument against the possibility of accidental coincidence. A careful estimate shows that the probability of getting one such accidental event in the entire experiment is of the order of 10^{-5}. We have not been able to think of any more likely possibilities. Therefore, we believe that this event represents the production and decay of a Ξ^0, i.e. a hyperon of strangeness-2 and mass comparable to that of the Ξ^-.[9]

The measured dynamical variables of the event are:

K^0: Momentum, 277.5 ± 5.0 Mev/c;

Production angle (laboratory system), 38.8 ± .9°.

Λ: Momentum, 920 ± 50 Mev/c;

Angle (laboratory system) between Λ and Ξ^0, 9.5 ± .7°.

Ξ^0: Production angle (laboratory system), 10.8 ± .7°.

The incident K^- momentum agrees so well with the independently determined beam momentum, 1.15 ± .02 Bev/c, that it is highly probable that our K^- is one of the beam K^-'s. On this basis we can determine the mass much more precisely:

M_{Ξ^0} = 1308 ± 8 Mev at production. This gives $\chi^2 = 0.077$ ($\langle\chi^2\rangle = 1$) .

If we consider all the information given by the production, the beam momentum, and the decay (assuming $\Xi^0 \rightarrow \pi^0 + \Lambda$), we find for the most probable mass M_{Ξ^0} = 1311 ± 8 Mev. For this we find $\chi^2 = 1.45$ ($\langle\chi^2\rangle = 2$). The event cannot be used for a check of the decay mode; for instance, if we assume $\Xi^0 \rightarrow \gamma + \Lambda$, we find an even better fit ($\chi^2 = 0.247$).

The cross section, based on this one event, is $\sigma_{\Xi^0 K^0} \approx 50$ μb. We have not seen any examples of $K^- + p \rightarrow \Xi^- + K^+$; this sets a diffuse upper limit, $\sigma_{\Xi^- K^+} \lesssim 17$ μb. (No correction for lifetime is made here. If the lifetime of either Ξ is long compared with 5×10^{-10} sec, many would escape from the chamber.) Our one Ξ^0 lived 1.5×10^{-10} sec.

It is interesting to compare the above cross sections with those for the similar reactions

$$\pi^- + p \rightarrow \Sigma^- + K^+,$$
$$\Sigma^0 + K^0$$

at the same outgoing c.m. momentum (190 Mev/c):[10]

$$\sigma_{\Sigma^- K^+} \approx 200\ \mu b,$$

$$\sigma_{\Sigma^0 K^0} \approx 400\ \mu b.$$

At present the search for production of cascade hyperons in the 1.15-Bev/c K^- beam is being continued in collaboration with the Lawrence Radiation Laboratory 30-inch propane bubble chamber group.

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2. Armenteros, Barker, Butler, Cachon, and York, Phil. Mag. 43, 597 (1952); C. Franzinetti and G. Morpurgo, Supplemento 2 Nuovo cimento 6, 565 (1957).
3. Coombes, Cork, Galbraith, Lambertson, and Wenzel, Phys. Rev. 112, 1303 (1958).
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5. Extension of the beam track by postulating missing bubbles at its end does not reduce the noncoplanarity of the Λ, but instead spoils the coplanarity of the K^0.
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7. We used 497.9 Mev for the K^0 mass; F. S. Crawford et al. and A. H. Rosenfeld et al., Phys. Rev. Letters (to be published).
8. M. Gell-Mann and A. H. Rosenfeld, Ann. Rev. Nuclear Sci. 7, 410 (1957).
9. A picture of a possible Ξ^0 was submitted by the Pic du Midi group to the 1958 Geneva Conference.
10. Proceedings of the 1958 Annual International Conference on High Energy Physics at CERN, p. 148.

Figure Captions

Fig. 1a. Picture of Ξ^0 event.

Fig. 1b. Sketch of Ξ^0 event.

Fig. 2. Stereographic projection (Wulff Plot) of the event.

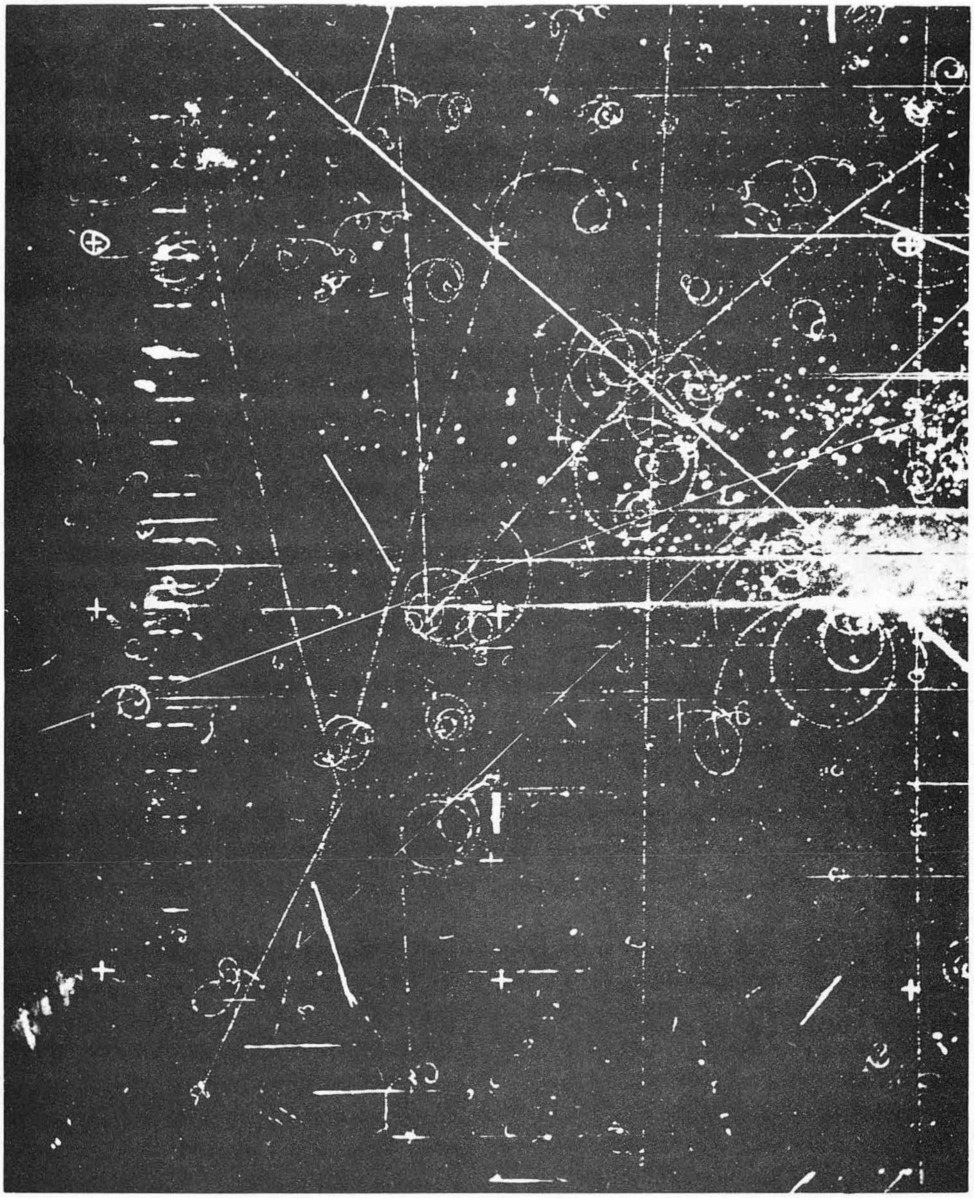
Observed tracks:

1. Beam K^-
2. Line connecting end of beam track to vertex of Λ
3. Line connecting end of beam track to vertex of K^0
4. π^-
5. π^+
6. π^-
7. p

Inferred "tracks":

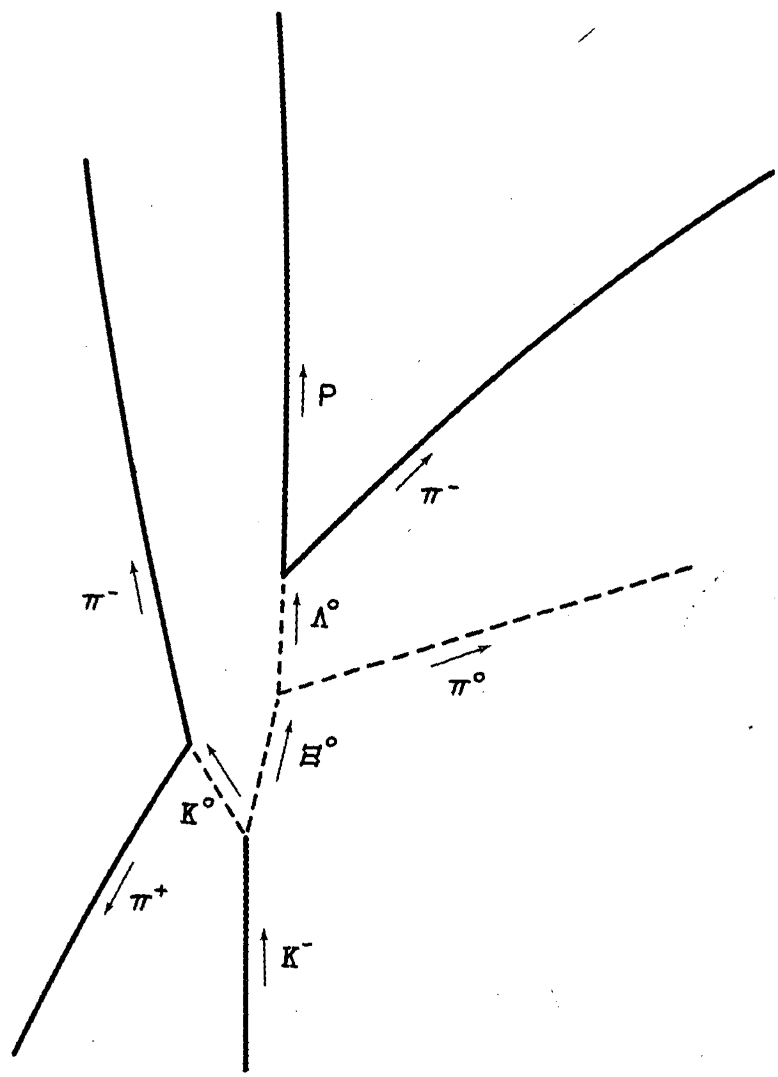
Λ : obtained by balancing transverse momentum on Tracks 6 and 7.

Ξ^0 : obtained by intersection of production plane (containing Tracks 1 and 3) with the plane containing Track 2 and the Λ.



ZN-2118

Fig. 1A



MU-16643

Fig. 1B

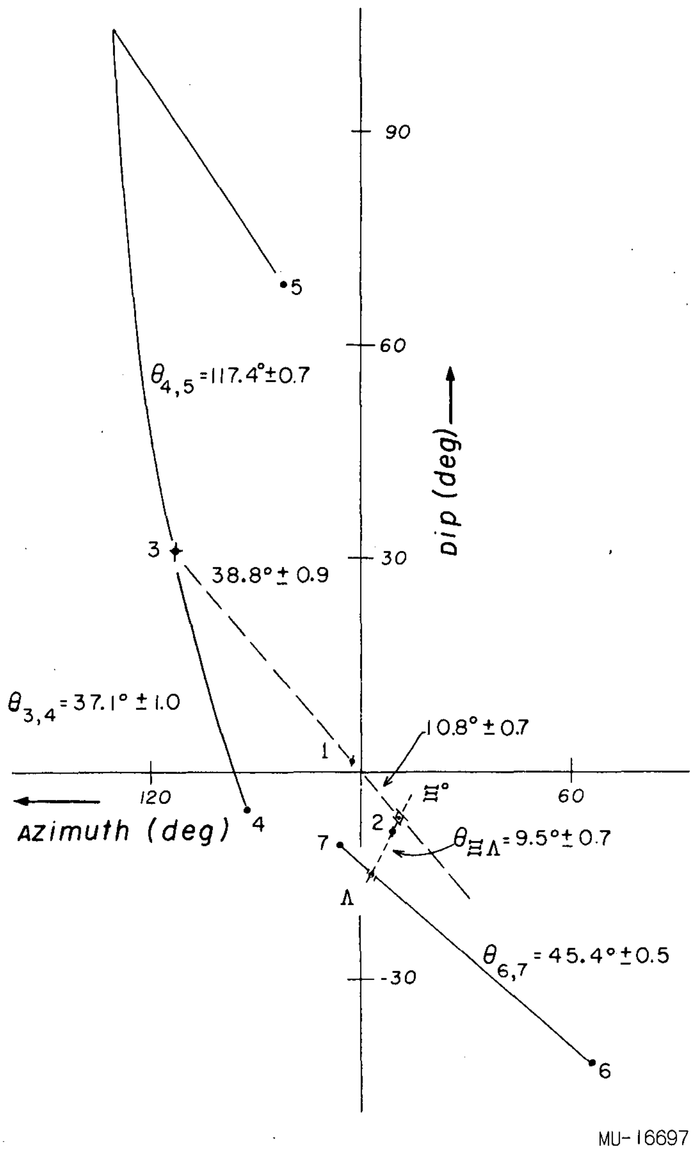

90
60
30
-30
120
60
Dip (deg)
Azimuth (deg)
5
3
1
2
4
7
6
Λ
Ξ°
θ4,5 =117.4°±0.7
38.8°± 0.9
θ3,4 = 37.1° ± 1.0
10.8° ± 0.7
θΞΛ = 9.5°± 0.7
θ6,7 = 45.4°±0.5
MU-16697

Fig. 2