# OBSERVATION OF A HYPERON WITH STRANGENESS MINUS THREE*

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It has been pointed out[1] that among the multitude of resonances which have been discovered recently, the $N_{3/2}^*(1238)$, $Y_1^*(1385)$, and $\Xi_{1/2}^*(1532)$ can be arranged as a decuplet with one member still missing. Figure 1 illustrates the position of the nine known resonant states and the postulated tenth particle plotted as a function of mass and the third component of isotopic spin. As can be seen from Fig. 1, this particle (which we call $\Omega^-$, following Gell-Mann[1]) is predicted to be a negatively charged isotopic singlet with strangeness minus three.[2] The spin and parity should be the same as those of the $N_{3/2}^*$, namely, $3/2^+$. The 10-dimensional representation of the group $SU_3$ can be identified with just such a decuplet. Consequently, the existence of the $\Omega^-$ has been cited as a crucial test of the theory of unitary symmetry of strong interactions.[3,4] The mass is predicted[5] by the Gell-Mann–Okubo mass formula to be about 1680 MeV/$c^2$. We wish to report the observation of an event which we believe to be an example of the production and decay of such a particle.

The BNL 80-in. hydrogen bubble chamber was exposed to a mass-separated beam of 5.0-BeV/$c$ $K^-$ mesons at the Brookhaven AGS. About 100 000 pictures were taken containing a total $K^-$ track length of ~$10^6$ feet. These pictures have been partially analyzed to search for the more characteristic decay modes of the $\Omega^-$.

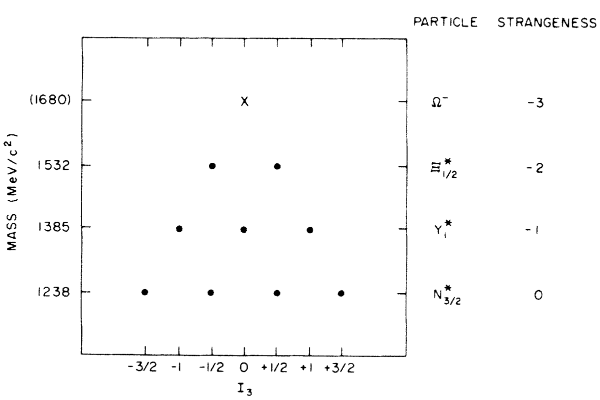


FIG. 1. Decuplet of $\frac{3}{2}^+$ particles plotted as a function of mass versus third component of isotopic spin.

The event in question is shown in Fig. 2, and the pertinent measured quantities are given in Table I. Our interpretation of this event is

$$\begin{array}{l} K^- + p \to \Omega^- + K^+ + K^0 \\ \quad \Omega^- \to \Xi^0 + \pi^- \\ \quad\quad \Xi^0 \to \Lambda^0 + \pi^0 \\ \quad\quad\quad \pi^0 \to \gamma_1 + \gamma_2 \\ \quad\quad\quad\quad \gamma_2 \to e^+ + e^- \\ \quad\quad\quad\quad \gamma_1 \to e^+ + e^- \\ \quad\quad\quad \Lambda^0 \to \pi^- + p. \end{array} \qquad (1)$$

From the momentum and gap length measurements, track 2 is identified as a $K^+$. (A bubble density of 1.9 times minimum was expected for this track while the measured value was 1.7 $\pm$0.2.) Tracks 5 and 6 are in good agreement with the decay of a $\Lambda^0$, but the $\Lambda^0$ cannot come from the primary interaction. The $\Lambda^0$ mass as calculated from the measured proton and $\pi^-$ kinematic quantities is $1116 \pm 2$ MeV/$c^2$. Since the bubble density from gap length measurement of track 6 is $1.52 \pm 0.17$, compared to 1.0 expected for a $\pi^+$ and 1.4 for a proton, the interpretation of the $V$ as a $K^0$ is unlikely. In any case, from kinematical considerations such a $K^0$ could not come from the production vertex. The $\Lambda^0$ appears six decay lengths from the wall of the bubble chamber, and there is no other visible origin in the chamber.

The event is unusual in that two gamma rays, apparently associated with it, convert to electron-positron pairs in the liquid hydrogen. From measurements of the electron momenta and angles, we determine that the effective mass of the two gamma rays is $135.1 \pm 1.5$ MeV/$c^2$, consistent with a $\pi^0$ decay. In a similar manner, we have used the calculated $\pi^0$ momentum and angles, and the values from the fitted $\Lambda^0$ to deter-

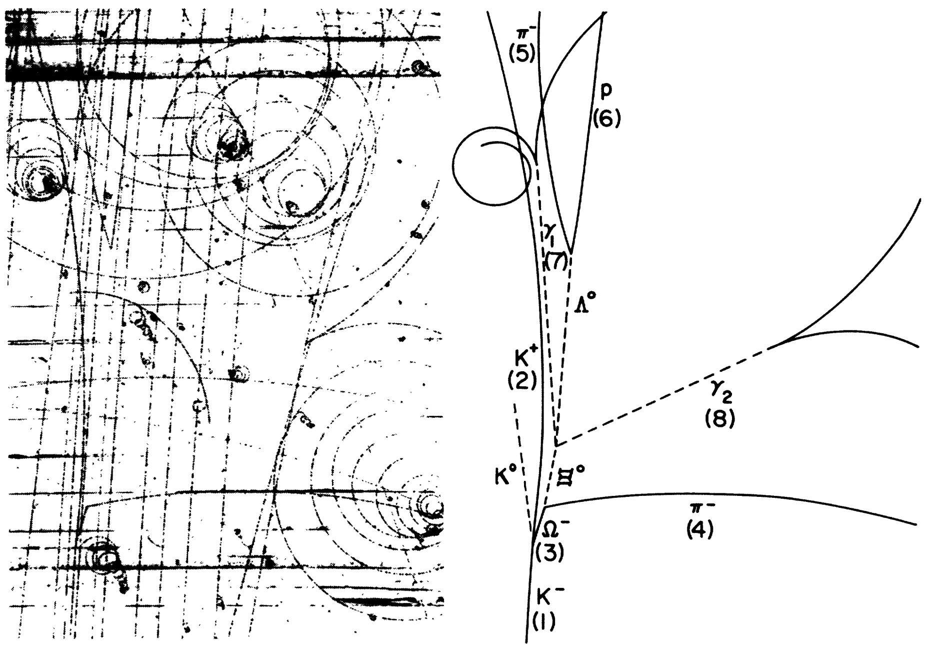


FIG. 2. Photograph and line diagram of event showing decay of $\Omega^-$.

mine the mass of the neutral decaying hyperon to be $1316 \pm 4$ MeV/$c^2$ in excellent agreement with that of the $\Xi^0$. The projections of the lines of flight of the two gammas and the $\Lambda^0$ onto the $XY$ plane (parallel to the film) intersect within 1 mm and in the $XZ$ plane within 3 mm. The calculated momentum vector of the $\Xi^0$ points back to the decay point of track 3 within 1 mm and misses the production vertex by 5 mm in the $XY$ plane. The length of the $\Xi^0$ flight path is 3 cm with a calculated momentum of $1906 \pm 20$ MeV/$c$. The transverse momenta of the $\Xi^0$ and of track 4 balance within the errors, indicating that no other particle is emitted in the decay of particle 3.

We will now discuss the decay of particle 3. From the momentum and gap length measurements on track 4, we conclude that its mass is less than that of a $K$. Using the $\Xi^0$ momentum and assuming particle 4 to be a $\pi^-$, the mass of particle 3 is computed to be $1686 \pm 12$ MeV/$c^2$ and its momentum to be $2015 \pm 20$ MeV/$c$. Note that the measured transverse momentum of track 4, $248 \pm 5$ MeV/$c$, is greater than the maximum momentum for the possible decay modes of the known particles (given in Table II), except for $\Xi^- \to e^- + n + \nu$. We reject this hypothesis not only because it involves $\Delta S = 2$, but also because it disregards the previously established associations of the $\Lambda$ and two gammas with the event.

Table I. Measured quantities.

| Track | Azimuth (deg) | Dip (deg) | Momentum (MeV/$c$) |
|---|---|---|---|
| 1 | 4.2 ± 0.1 | 1.1 ± 0.1 | 4890 ± 100 |
| 2 | 6.9 ± 0.1 | 3.3 ± 0.1 | 501 ± 5.5 |
| 3 | 14.5 ± 0.5 | -1.5 ± 0.6 | ··· |
| 4 | 79.5 ± 0.1 | -2.7 ± 0.1 | 281 ± 6 |
| 5 | 344.5 ± 0.1 | -12.0 ± 0.2 | 256 ± 3 |
| 6 | 9.6 ± 0.1 | -2.5 ± 0.1 | 1500 ± 15 |
| 7 | 357.0 ± 0.3 | 3.9 ± 0.4 | 82 ± 2 |
| 8 | 63.3 ± 0.3 | -2.4 ± 0.2 | 177 ± 2 |

Table II. Maximum transverse momentum of the negative decay product for various particle decays.

| Decay modes | Maximum transverse momentum (MeV/$c$) |
|---|---|
| $\pi^- \to \mu^- + \nu$ | 30 |
| $K^- \to \mu^- + \nu$ | 236 |
| $K^- \to \pi^- + \pi$ | 205 |
| $K^- \to e^- + \pi^0 + \nu$ | 229 |
| $\Sigma^- \to \pi^- + n$ | 192 |
| $\Sigma^- \to e^- + \Lambda^0 + \nu$ | 78 |
| $\Sigma^- \to e^- + n + \nu$ | 229 |
| $\Xi^- \to \pi^- + \Lambda^0$ | 139 |
| $\Xi^- \to e^- + \Lambda^0 + \nu$ | 190 |
| $\Xi^- \to e^- + n + \nu$ | 327 |

The proper lifetime of particle 3 was calculated to be $0.7\times10^{-10}$ sec; consequently we may assume that it decayed by a weak interaction with $\Delta S=1$ into a system with strangeness minus two. Since a particle with $S=-1$ would decay very rapidly into $Y+\pi$, we may conclude that particle 3 has strangeness minus three. The missing mass at the production vertex is calculated to be 500 $\pm$ 25 MeV/$c^2$, in good agreement with the $K^0$ assumed in Reaction (1). Production of the event by an incoming $\pi^-$ is excluded by the missing mass calculated at the production vertex, and would not alter the interpretation of the decay chain starting with track 3.

In view of the properties of charge ($Q=-1$), strangeness ($S=-3$), and mass ($M=1686\pm12$ MeV/$c^2$) established for particle 3, we feel justified in identifying it with the sought-for $\Omega^-$. Of course, it is expected that the $\Omega^-$ will have other observable decay modes, and we are continuing to search for them. We defer a detailed discussion of the mass of the $\Omega^-$ until we have analyzed further examples and have a better understanding of the systematic errors.

The observation of a particle with this mass and strangeness eliminates the possibility which has been put forward[6] that interactions with $\Delta S=4$ proceed with the rates typical of the strong interactions, since in that case the $\Omega^-$ would decay very rapidly into $n+K^0+\pi^-$.

We wish to acknowledge the excellent cooperation of the staff of the AGS and the untiring efforts of the 80-in. bubble chamber and scanning and programming staffs.

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[4]See, however, R. J. Oakes and C. N. Yang, Phys. Rev. Letters 11, 174 (1963).

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# REGGE-POLE MODEL FOR HIGH-ENERGY $pp$ AND $\bar{p}p$ SCATTERING*

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Recent experiments at high energies have indicated that the width of the diffraction peak in the elastic cross section is considerably smaller in $\bar{p}p$ scattering than in $pp$ scattering.[1,2] On the other hand, the total cross section for $\bar{p}p$ is greater than that for $pp$.[3] We have then the qualitative feature that the larger total cross section is associated with the narrower diffraction peak. The purpose of this Letter is to investigate whether this feature may be understood in terms of a Regge-pole model for high-energy scattering. We find that, because all Regge exchanges give a positive coefficient for the residue function in the contribution to the imaginary part of the $\bar{p}p$ amplitude, this feature can be understood only if some residue functions are allowed to be negative. We therefore conclude that the simple Regge-pole model of high-energy scattering cannot be valid for the data of reference 1 unless residue functions may be negative.

(I) We consider first the three-pole model of Hadjioannou, Phillips, and Rarita in which only helicity-nonflip amplitudes are considered[4]:

$$A_{\bar{p}p}=\mathrm{P}+\mathrm{P}'-\omega,$$

$$A_{pp}=\mathrm{P}+\mathrm{P}'+\omega,$$

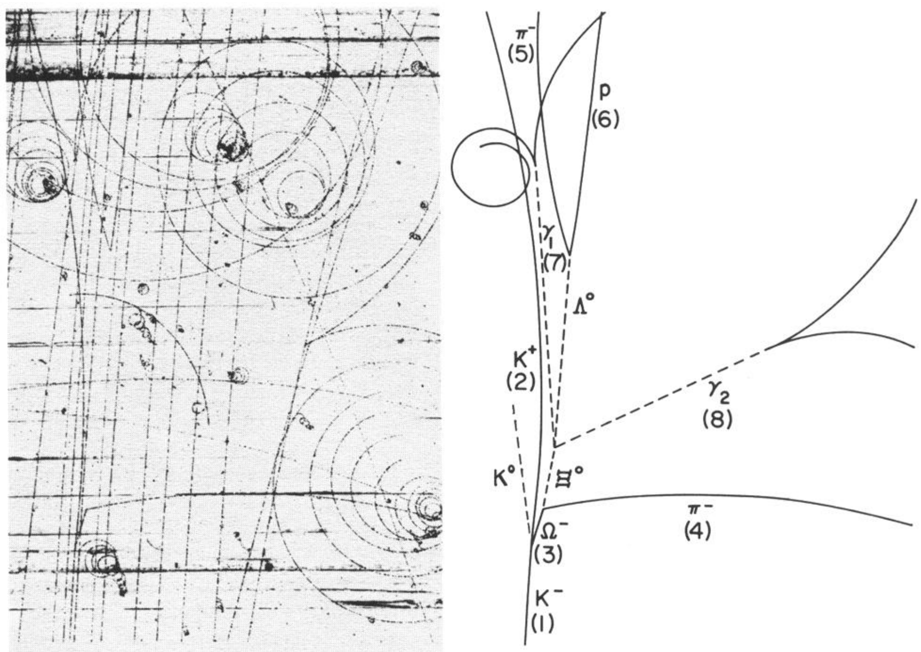


FIG. 2. Photograph and line diagram of event showing decay of $\Omega^-$.