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Previous attempts have been made to discover a strangeness +1 baryon (henceforth referred to as Z in this letter) as a resonance in the NK system. These experiments yielded negative results 1), but the possibility remains that such a particle could have a mass between that of the proton‡ and 1.43 GeV (the NK mass threshold). In this case it would decay by a weak strangeness-changing reaction to a nucleon and one or more pions, to a nucleon and a lepton pair, or to a nucleon and a γ ray.

Interest in such a possibility has recently been stimulated by several theoretical speculations. Thus it has been suggested that the Z may be the isosinglet member of the $\overline{10}$ representation of SU_3, the doublet and triplet perhaps being the $N^*_{1/2}$ (1510) and the Y^*_1(1660) 2). Then the equal-mass spacing rule predicts a Z^+ mass of 1.36 GeV 3). We might also expect that, apart from accidental cancellation of amplitudes, production cross sections should be similar for the reactions

$$\pi^- + p \to Z^+ + K^- \qquad (1)$$

and

$$\pi^- + p \to Y^* (1660) + K^0 , \qquad (2)$$

since these processes involve members of the same SU_3 representations, and both require K^*-type exchange processes. The cross section for reaction (2) at 2.2 GeV/c is ~ 60μb 4).

A Z^+ has also been predicted by Behrends and Landovitz 5), using the group G_2. They expect a mass of 1.09 GeV and a lifetime of the order of 10^{-7} sec.

Harari and Lipkin 6) point out that if the 35 representation of SU_3 is populated, a Z of isospin 2 would exist, but the mass of such a particle would probably be above the NK mass.

We have searched for reaction (1) in film taken in the course of a systematic study of 1.5- to 4.2-GeV/c $\pi^- p$ interactions in the Lawrence Radiation Laboratory's 72-in. hydrogen bubble chamber. The amount of film used in this analysis is shown for each incident momentum in Table 1. It is to be noted that the threshold for production of a Z^+ of mass 1.43 GeV (i.e., maximum mass for dominant weak decay) by reaction (1) is 1.5 GeV/c.

We find no evidence for the existence of a Z^+. The upper limit that we can set on its production depends on the process by which the Z^+ decays.

A. Fast decay** to $p\pi^0$ or $n\pi^+$

If the Z^+ decays before it can give a visible track, we would observe what appears to be a strangeness-violating process††

$$\pi^- + p \to p + \pi^0 + K^- \qquad (3)$$

or

$$\pi^- + p \to n + \pi^+ + K^- . \qquad (4)$$

We have searched for these reactions in the topology of 2-prong events where the negative track has measurable curvature and decays (topology T). Those events fitting the 2-body reaction

$$\pi^- + p \to \Sigma^- + K^+$$

where not analyzed further. The remaining events were fitted to reactions (3) and (4), with subsequent K^- decay

$$K^- \rightarrow \mu^- + \nu$$

or

$$K^- \rightarrow \pi^- + \pi^0 .$$

All events that gave satisfactory fits at production and decay were examined on the scanning table, and those that were obviously inconsistent (on the basis of track ionization) with the fitted hypothesis were rejected.‡‡ A histogram of the mass squared of the nucleon + pion system for the remaining events is shown in fig. 1. The mass resolution is shown on the histogram and is smaller than the bin size; so it seems that an upper limit on the number of events above background at any single mass value is about 3±2. This corresponds to a cross section of 8±5 μb.

B. Fast decay to $p\pi^+\pi^-$

Fast decay of the Z^+ to $p\pi^+\pi^-$ results in the final state $K^-p\pi^+\pi^-$. We have performed production and decay fits to all 4-prong events in which one of the negative tracks decays in the chamber. Of the 389 events of this category, three gave possible fits. However, these were also consistent with being $\Sigma^-K^+\pi^+\pi^-$, and indeed seemed more likely candidates for the Σ final state when examined on the scanning table.

The mass combinations $p\pi^+\pi^-$, $p\pi^+$, and $p\pi^-$ were calculated for the three passing events. No two of these nine mass values agreed within their errors. We thus set a limit of 2.7±2.7 μb on the cross section for

$$\pi^-+p \rightarrow K^-+Z^+ \qquad Z^+ \rightarrow p+\pi^++\pi^- .$$

as well as for the reactions

$$\pi^-+p \rightarrow K^-+\pi^++Z^0 \qquad Z^0 \rightarrow p+\pi^-$$

and

$$\pi^-+p \rightarrow K^-+\pi^-+Z^{++} \qquad Z^{++} \rightarrow p+\pi^+ .$$

We also looked for the reaction

$$\pi^- + p \rightarrow Z^+ + \pi^- + \bar{K}^0$$

followed by the $p\pi^+\pi^-$ decay mode. This would result in the final state $p\pi^+\pi^-\pi^-\bar{K}^0$. A search among those events consisting of four prongs and a V produced no event fitting this final state. Here, one event would correspond to a cross section of 0.4 μb, which is the limit we set on the following possibilities:

$$\pi^- + p \rightarrow \bar{K}^0 + \pi^- + Z^+ \qquad Z^+ \rightarrow p + \pi^+ + \pi^-$$

$$\pi^- + p \rightarrow \bar{K}^0 + \pi^+ + Z^- \qquad Z^- \rightarrow p + \pi^- + \pi^-$$

$$\pi^- + p \rightarrow \bar{K}^0 + \pi^- + \pi^- + Z^{++} \qquad Z^{++} \rightarrow p + \pi^+$$

$$\pi^- + p \rightarrow \bar{K}^0 + \pi^- + \pi^+ + Z^0 \qquad Z^0 \rightarrow p + \pi^- .$$

C. Fast decay to three particles including two neutrals

The more obvious three-particle decay modes that include two neutral particles are:

$$Z^+ \rightarrow p + \pi^0 + \pi^0$$

$$Z^+ \rightarrow n + \pi^+ + \pi^0$$

$$Z^+ \rightarrow n + e^+ + \nu$$

$$Z^+ \rightarrow n + \mu^+ + \nu .$$

However, from experience of other strange-particle decays, we might expect the last two modes to be relatively unlikely, unless the mass of the Z^+ were below the $N\pi$ mass threshold.

It is difficult in a hydrogen bubble chamber to identify the above modes of decay, but we can set an approximate upper limit on the pionic decays as follows. We examined those events of topology T that are inconsistent with the 2-body reaction $\pi^- + p \rightarrow \Sigma^- + K^+$, where the decaying track is consistent with being a K^-, and where the missing mass (MM) in the reaction

$$\pi^- + p \to K^- + p + MM_1$$

or

$$\pi^- + p \to K^- + \pi^+ + MM_2$$

is in the range 0.028 to 0.425 or 1.04 to 1.41 GeV, respectively. These two ranges include a large fraction of the available phase space for the $p\pi^0\pi^0$ and $n\pi^+\pi^0$ decay modes; allowance for the rejected part has been made in calculating the cross sections below.

Those events giving a mass squared below 2.2 GeV^2 for either the proton + MM_1 or the π^+ + MM_2 were examined on the scanning table, and those that were obviously inconsistent on the basis of track ionization were rejected. A histogram of the mass squared of the $p + MM_1$ or $\pi^+ + MM_2$ for the remaining events is shown in fig. 2. The resolution on the Z^+ mass is worse than for the fitted events of category A; a typical mass error is approximately 40 MeV. There are at most 3±2 events above background at any one mass value. This corresponds to an upper limit of 15±10 μb.

We do not set a limit on the cross section if the main decay is via leptonic modes. We feel that a considerable fraction of these events would have been detected by the above method, but the exact proportion requires a detailed calculation of the e^+ and μ^+ spectra expected from Z^+ decay, and also depends on the production angular distribution of the Z^+.

D. Medium-rate decay

We attempted to fit all 2-prong events with a decaying positive track to the production reaction

$$\pi^- + p \to K^- + Z^+ ,$$

using values of 1.33, 1.36, and 1.39 GeV for the Z^+ mass. A parabola was then fitted through the three values of χ^2 for each event, to determine the value of the Z^+ mass at which χ^2 is a minimum, and the error in this mass.

From the widths of these parabolae, we estimate that we would obtain a satisfactory fit provided the Z^+ mass is greater than 1.15 GeV. The decay was also fitted as

$$Z^+ \to p + \pi^0$$

or

$$Z^+ \to n + \pi^+$$

for the same three values of the Z^+ mass.

The events giving a satisfactory fit were examined on the scanning table. Five events were not inconsistent with the required track ionization. These all had different mass values for the Z^+, and none gave satisfactory decay fits. We set a limit of 0.1±0.1 μb on the production cross section for all decay modes. Note that there is a scanning loss for small-angle Z^+ decays. We have not allowed for this in the above cross-section estimate since the evaluation of this correction depends on the details of the production and decay kinematics of the Z^+ for the particular decay mode considered.

E. Slow decay

Events of topology T were used, the positive track being interpreted as the Z^+. Again events consistent with the two-body reaction $\pi^- + p \to \Sigma^- + K^+$ were not analysed further.

The K^- decay was first fitted as $K_{\mu 2}$ or $K_{\pi 2}$, and then production fits were made for Z^+ mass values of 1.06, 1.09, and 1.12 GeV as well as 1.33, 1.36, and 1.39 GeV. The parabolic fitting technique was again used to determine the best Z^+ mass for each event. Here we estimate that we are sensitive to the whole of the mass range for which the Z^+ would decay via a weak interaction.

The 10 successful events were examined on the scanning table. Only one of these could not obviously be rejected on the basis of track ionization. We are thus able to set an upper limit of 5 μb on the production of a long-lived Z^+ of any mass.

Thus we find no evidence for the existence of a strangeness +1 baryon in the mass region below the NK threshold. The limits that we set on its production cross section are summarized in Table 2. In particular it seems that if there exists a Z^+ as predicted by Sakurai or by Behrends and Landovitz, then it is produced more weakly than considerations discussed above would lead one to expect.

We wish to thank Prof. L. W. Alvarez for his continued interest and encouragement. Miss Pam Starr was responsible for the careful scanning of possible Z^+ events, and Mr. W. Koellner for the efficient processing of the data. L. L. wishes to thank Prof. Alvarez and his group for their hospitality during his stay in Berkeley, and Drs. G. and S. Goldhaber for several interesting discussions.

Table 1

Film used in search for Z^{+}

Beam Momentum (GeV/c)	Quantity of Film: Rolls	Events/μb	Events with identified K^{-} decay/μb*
1.65	15	690	32
1.8	13	600	23
1.9	45	2070	70
2.0	158	7250	225
2.15	13	600	17
Total	244	10810	367

*The numbers in the last column allow for the following factors:

1. Only a fraction of the K^{-}'s decay within the chamber. To obtain an upper limit on the production cross section, we assumed the K^{-}'s to be produced in the forward direction, when they have their maximum momenta.
2. Only 85% of K^{-} mesons decay by the $K_{\mu 2}$ or $K_{\pi 2}$ modes.
3. There is a scanning loss of 20% for one-prong decays of K mesons at these momenta[7].
4. 10% of the events failed to pass the geometry programs.

To check our estimate of the efficiency of observing K^{-} decays, we have calculated, from the observed number of $K^{-}K^{0}p$ events in which the K^{-} gives a visible decay within the chamber, that 30±4 events of this final state should appear in topology T. The observed number is 33±6.

Table 2

Summary of results of search for a Z particle

Production	Lifetime	Decay Mode	Limit on cross section* (μb)
K^-Z^+	short	$p\pi^0$ $n\pi^+$	8±5
	short	$p\pi^+\pi^-$	2.7±2.7
	short	$p\pi^0\pi^0$ $n\pi^+\pi^0$	15 ±10
	medium	all	0.1±0.1†
	long	all	5
$K^-\pi^-Z^{++}$	short	$p\pi^+$	2.7±2.7
$\overline{K}^0\pi^-Z^+$	short	$p\pi^+\pi^-$	0.4
$K^-\pi^+Z^0$	short	$p\pi^-$	2.7±2.7
$\overline{K}^0\pi^+Z^-$	short	$p\pi^-\pi^-$	0.4
$\overline{K}^0\pi^-\pi^-Z^{++}$	short	$p\pi^+$	0.4
$\overline{K}^0\pi^+\pi^-Z^0$	short	$p\pi^-$	0.4

*The values quoted here are for any Z mass value within the physical range. The limit on a particular Z mass is usually more stringent.

†This applies only for a Z mass above 1.15 GeV, and does not include a factor to allow for the scanning efficiency for detecting small-angle Z^+ decays.

References

1) J. Fisk, H. K. Ticho, D. H. Stork, W. Chinowsky, G. Goldhaber, S. Goldhaber, and T. F. Stubbs, in *Proceedings of the 1962 International Conference on High Energy Physics at CERN* (CERN Scientific Information Service, Geneva, 1962), p. 358; G. Goldhaber, in *Proceedings of the Athens Topical Conference on Recently Discovered Resonant Particles, Athens, Ohio, 1963* (University of Ohio, Athens, Ohio, 1963), p. 80; K. F. Riley, ibid, p. 90.

2) This has been suggested by many people. The only published article, however, is by J. J. Sakurai [Phys. Letters 10, 132 (1964)] who discusses the possibility that the spin-parities for both the $N^*(1510)$ and $Y^*(1660)$ are the same.

3) Also predicted is a $\Xi^*_{3/2}$ of mass 1.81 GeV. It seems unlikely that this is to be identified with the isospin -1/2 Ξ^* recently reported by G. Smith, J. S. Lindsey, J. J. Murray, J. Button-Shafer, A. Barbaro-Galtieri, O. I. Dahl, P. Eberhard, W. B. Humphrey, G. R. Kalbfleisch, R. R. Ross, F. T. Shively, and R. D. Tripp in Lawrence Radiation Laboratory Report UCRL-11456, May 19, 1964.

4) G. A. Smith, in *Proceedings of the Athens Topical Conference on Recently Discovered Resonant Particles, Athens, Ohio, 1963* (University of Ohio, Athens, Ohio, 1963), p. 67.

5) R. E. Behrends and L. F. Landovitz, Phys. Rev. Letters 11, 296 (1963).

6) H. Harari and H. J. Lipkin (private communication).

7) This is derived from data provided by R. Hubbard (private communication) on one-prong and τ decays of 1.2- to 1.7-GeV/c K mesons.

Footnotes

[*] Work sponsored by the U. S. Atomic Energy Commission.

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[‡] The mass cannot be below the proton mass, since otherwise the proton would be unstable.

[**] By short, medium, or long lifetime we mean that the Z will typically decay before it leaves a visible track, will decay after having left a visible track, or will decay out side the chamber, respectively.

[‡‡] It is possible to hypothesize other weakly decaying particles with lifetimes such that they do not leave a visible track in the bubble chamber, and thus give rise to events that do not appear to conserve strangeness. Apart from the Z, the only such particle that might merit looking for at present is a strangeness +2 boson, L. This could be produced in reactions such as $K^{+}+n\rightarrow\Lambda+L^{+}$, $K^{+}+p\rightarrow\Sigma^{+}+L^{+}$, or $\pi^{-}+p\rightarrow\Xi^{-}+L^{+}$ or, if the isospin of the L is 1, $K^{+}+p\rightarrow\Lambda+L^{++}$, etc. Then the L would decay into $K+\pi$, $K+2\pi$, K + a lepton pair, $K+\gamma$. Such an L could not be heavier than 1 GeV, since it would then decay strongly or electromagnetically into two kaons, nor could it be much lighter than a K, since otherwise there would be appreciable decay of the K into it. An L with a mass towards the lower end of this range could be long-lived (compare our disussion of Z-decay and lifetime in the text).

[††] These fits are probably all spurious. Certainly those events that give a mass for the Z^{+} above the NK threshold cannot be genuine, since such a particle would decay almost entirely by strong interactions.

Legends

Fig. 1. Histogram of mass squared of pion plus nucleon from events consistent with $\pi^-+p\to K^-+p+\pi^0$; or $\pi^-+p\to K^-+n+\pi^+$. The width of the resolution function is shown above the histogram for mass squared values of 1.6 and 2.3 GeV^2.

Fig. 2. Histogram of mass squared of $p+MM_1$ or π^++MM_2 for events consistent with $\pi^-+p\to K^-+p+MM_1$ or $\pi^-+p\to K^-+\pi^++MM_2$. The width of the resolution function is approximately 0.05 to 0.10 GeV.^{2}

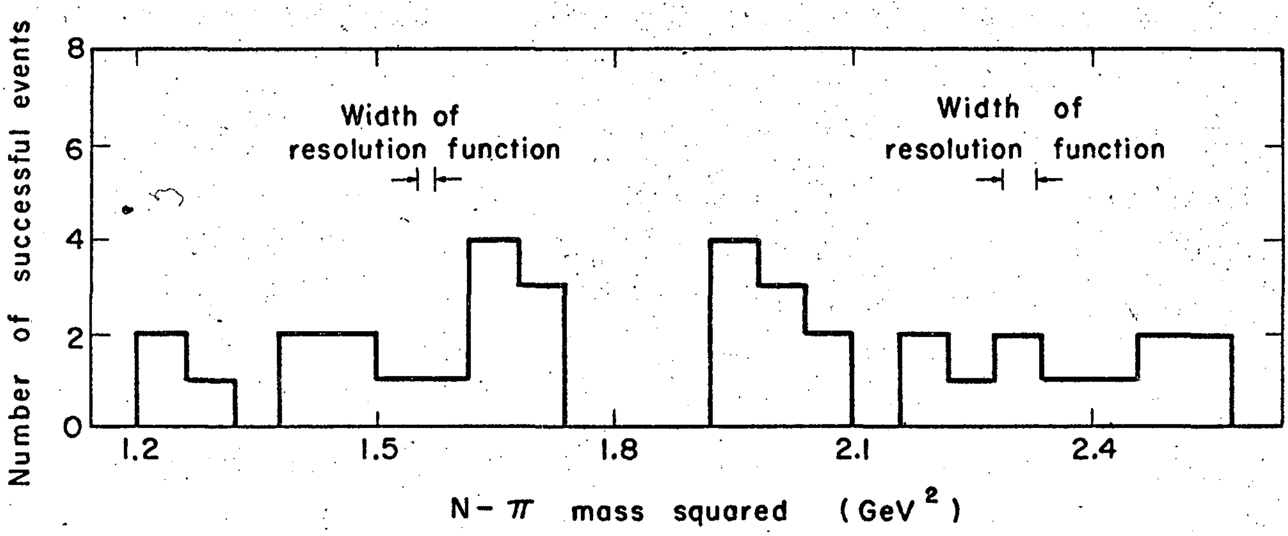

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Fig. 1

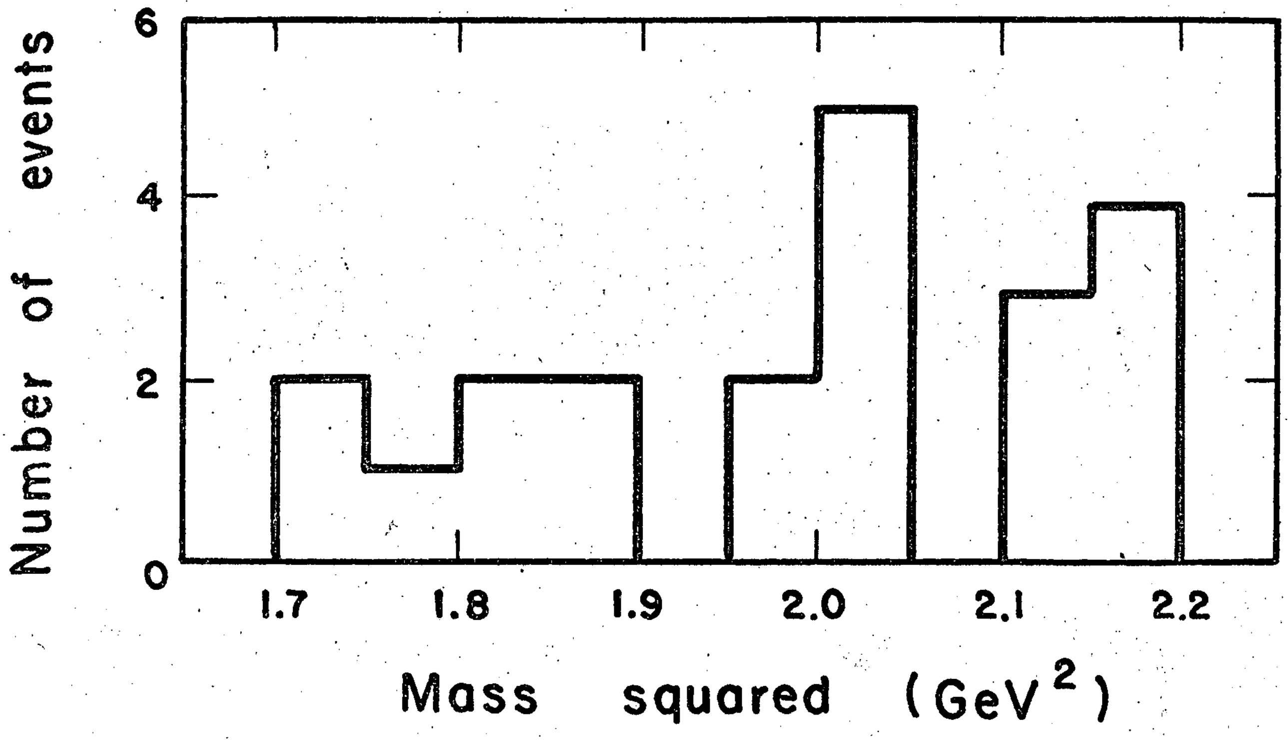

Fig. 2

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