pole model since we cannot simultaneously explain the $p+p$ and π^-+p results. It is possible that certain departures from simple Regge pole theory might in the future explain the data. It is difficult to see how agreement could be obtained without considerable complexity. However, if one allowed cuts, more poles, important spin effects, arbitrary distortions of Regge pole trajectories, it is probable some agreement could be obtained.

It appears safe, however, to conclude that Regge pole theory will not, as originally hoped, serve as a simple and definite prescription for this incident momentum range. Proposals would be further restricted by forthcoming results on π^++p, $K^\pm+p$ and $\bar{p}+p$ which we have also obtained but not finished processing yet. In any event one can, of course, always say that the energy is not high enough for asymptotic theorems. The striking difference in behavior of the πp and pp systems is, nevertheless, an interesting physical fact from any theoretical point of view.

The authors wish to thank the Alternating Gradient Synchrotron Department for valuable cooperation in providing desired beam characteristics, magnetic measurements, etc., throughout this project.

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[7]The electronic design was by W. Higinbotham and D. Potter and the unit was originally built for us in Brookhaven Instrumentation Division.

[8]A computer, similar to the Los Alamos Maniac II, built several years ago by the Brookhaven Instrumentation Division.

[9]S. J. Lindenbaum, W. A. Love, J. A. Niederer, S. Ozaki, J. J. Russell, and L. C. L. Yuan, Phys. Rev. Letters 7, 352 (1961).

[10]The errors shown are those referred to as "absolute errors" in Diddens et al., since the "relative errors within one momentum" also given are clearly inappropriate for drawing conclusions about shrinkage. The pattern of data and experimental errors do not seem to justify a definite conclusion on shrinkage for these data. The 18.6-GeV/c points are corrected as published later in an erratum, [Phys. Rev. Letters 10, 71(E) (1963)].

[11]The ρ has the right G-parity but its contribution must be small due to the small $(\pi^-+p)-(\pi^++p)$ and $pp-np$ total cross-section difference.

LEPTONIC DECAY OF THE Ξ^- HYPERON*

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We have analyzed 353 production events of the types

$$K^-+p\to\Xi^-+K^+, \quad (1a)$$

$$K^-+p\to\Xi^-+\pi^0+K^+, \quad (1b)$$

$$K^-+p\to\Xi^-+\pi^++\bar{K}^0, \quad (1c)$$

where in each case the decay kink of the Ξ^- was required to be present. In Reactions (1a) and (1b), the decay Λ was seen; in (1c), the decay Λ and/or the $\bar{K}^0$ was seen. These events were produced in an exposure of a 1.8-BeV/c and 1.95-BeV/c K^- beam in the Alvarez 72-inch hydrogen bubble chamber.

We wish to report here on an unambiguous example of leptonic decay via the mode

$$\Xi^-\to\Lambda+e^-+\bar{\nu}. \quad (2)$$

The event (Fig. 1 and Table I) fits the production Reaction (1c), and both the $\bar{K}^0$ and the Λ from the subsequent decay are visible. The χ^2 is 6.4 for four degrees of freedom. The miss-

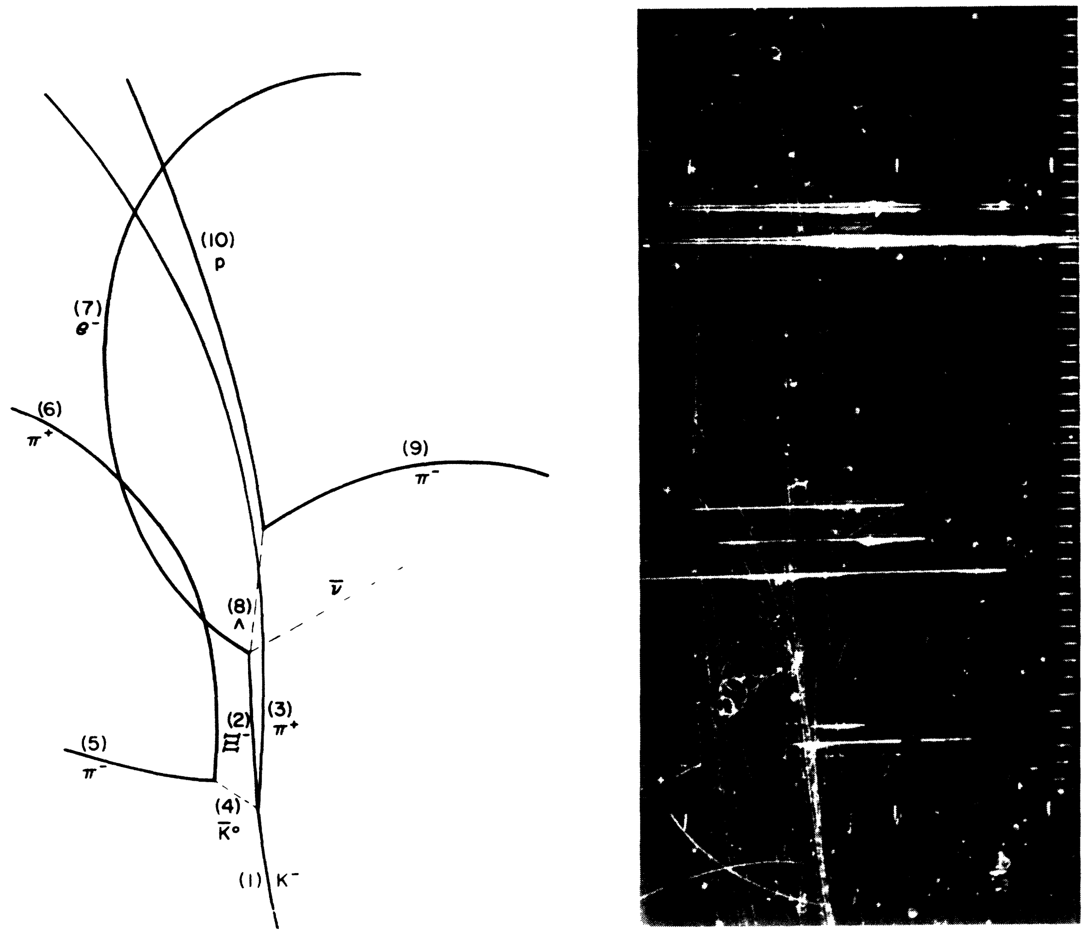

FIG. 1. Decay of negative cascade into a lambda, electron and neutrino.

ing mass (MM) in the reaction $K^- + p \to \pi^+ + \bar{K}^0 + MM$ is 1307 ± 25 MeV in agreement with the Ξ^- mass. Utilizing the Ξ momentum as determined by the production reaction and the lambda fitted as emitted from the decay vertex, we find that the missing mass in $\Xi^- \to \Lambda + MM$ is 176 ± 2 MeV.

Table I. Measured quantities.

Track No.	Particle	P (MeV/c)	Φ (azimuth)	λ (dip angle)
1	π^-, K^-	1930 ± 140	98.4 ± 0.1	0.2 ± 0.3
2 prod.	Σ^-, Ξ^-	1049 ± 70	93.0 ± 0.1	5.6 ± 0.3
2 decay	Σ^-, Ξ^-	1037 ± 60	88.4 ± 0.1	5.7 ± 0.3
3	π^+, K^+	546 ± 5	82.7 ± 0.1	-1.4 ± 0.2
5	π^-	436 ± 44	176.2 ± 0.4	-18.0 ± 0.5
6	π^+	202 ± 2	79.6 ± 0.2	3.5 ± 0.3
7	e^-, μ^-, π^-	181 ± 2	141.0 ± 0.2	-9.2 ± 0.4
9	π^-	170 ± 35	47.3 ± 0.2	19.4 ± 0.4
10	p	941 ± 10	89.5 ± 0.1	4.5 ± 0.2

The χ^2 for the decay (2) is 0.02 for one degree of freedom, and the effective mass of the electron-neutrino system as calculated from the fitted electron and neutrino momenta is 176 ± 1.6 MeV. Other possible interpretations for the production reaction are

$$K^- + p \to \Sigma^- + \bar{K}^0 + K^+ \qquad (4)$$

and, from the small pionic background,

$$\pi^- + p \to \Sigma^- + \bar{K}^0 + \pi^+ + \text{possible } \pi^0, \qquad (5)$$

both followed by the decay $\Sigma^- \to \Lambda + e^- + \bar{\nu}$. Reaction (4) is ruled out because the maximum kinematically allowed laboratory angle of the K mesons with respect to the beam direction is 16°. The measured angle of the $\bar{K}^0$ is 48°, and track 3 is not a K^+ since it is minimum ionizing.

The event does fit Reaction (5) at production with no missing neutrals ($\chi^2 = 12.8$ for 4 constraints). The fitted sigma momentum adjusted to the decay vertex, however, is 1084 ± 4 MeV/c. The decay lambda has a momentum of 1052 ± 10 MeV/c, and the momentum of the negative decay product is $p' = 181 \pm 2$ MeV/c. Thus the energy requirement for the sigma interpretation,

$$E_\Sigma \geq E_\Lambda + E' > E_\Lambda + p', \tag{6}$$

is not satisfied ($E_\Sigma = 1612 \pm 3$ MeV and $E_\Lambda + p' = 1714 \pm 7$ MeV).

Other possible interpretations for the Ξ decay are

$$\Xi^- \rightarrow \Lambda + \pi^- \tag{7}$$

and

$$\Xi^- \rightarrow \Lambda + \mu^- + \bar{\nu}. \tag{8}$$

The event, however, has $\chi^2 = 215$ for the four-constraint interpretation (7) and $\chi^2 = 58$ for the one-constraint interpretation (8). We have also ruled out interpretations (7) and (8) by means of gap length measurements. We find that for the flat, minimum ionizing ($\beta = 0.97$) beam track, $50.0 \pm 4.7\%$ of the gaps are longer than $d = 0.0275$ mm on the film. Track 6, which is a 202-MeV/c pion ($\beta = 0.82$, dip angle 3.5°) and which has $26.6 \pm 3.6\%$ of its gaps longer than d, would be slightly more "gappy" than track 7 if track 7 were a pion (181 ± 2 MeV/c, dip angle 9.2°). We find, however, that $55.6 \pm 6.3\%$ of the gaps on track 7 are greater than d. This is more than 4.5 standard deviation evidence that track 7 is lighter in mass than a pion. Furthermore, we calculate that $38 \pm 6\%$ of the gaps would exceed d if track 7 is a muon. Thus, from ionization measurements alone, we have 3 standard deviation evidence that track 7 is an electron.

The large missing mass in the decay rules out the interpretation of the event as a normal pionic decay followed by a $\pi \rightarrow e$ or a $\pi \rightarrow \mu \rightarrow e$ decay near the vertex. We thus conclude that this event is an unambiguous example of leptonic decay.[1] There exists only one published event which may be of this type.[2]

In order to determine an upper limit for the branching ratio for the decay (2), we have selected within a restricted fiducial volume a sample of 194 events of the type (1a) and (1c) with the added requirement in (1c) that both the Λ and the $\bar{K}^0$ be visible. Although all of the events except the one described in the first part of this report fit the four-constraint pionic decay with a normal χ^2 distribution, kinematic ambiguities allow 164 of these events to fit the leptonic decay (2) with a χ^2 probability of 1% or greater. We therefore regard these 164 events as potential leptonic decay candidates. Figure 2(a) shows the neutrino momentum spectrum for these candidates and also the spectrum expected from phase space.

Figure 2(b) shows the angular distribution $dN/d(\cos\theta)$ where θ is then the angle between the neutrino momentum in the cascade rest frame and the cascade direction of flight. Conservation of parity in the production process forbids any correlation between these directions; therefore the interval $|\cos\theta| < 0.8$ should contain 80% of

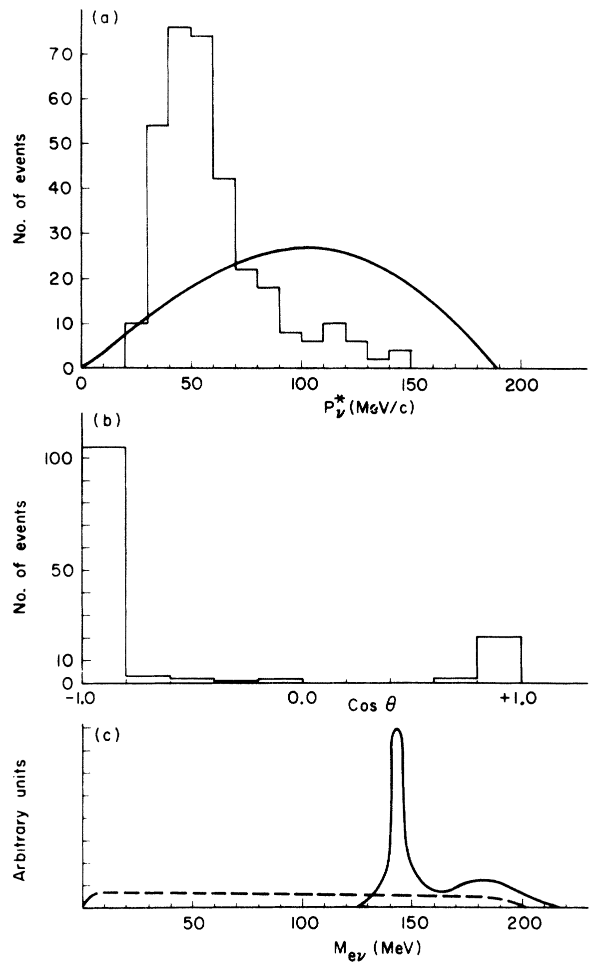

FIG. 2. Figure 2(a) is a histogram of p_ν^*, the momentum of the neutrino in cascade rest frame, in 10-MeV/c intervals. Also shown is the normalized phase-space prediction. Figure 2(b) is a histogram of $\cos\theta$, where θ is the angle between the direction of flight of the cascade in the laboratory and the neutrino in the cascade rest frame in 0.2 intervals. Figure 2(c) shows the phase-space prediction (dashed curve) for the electron-neutrino system and to the same normalization the Gaussian ideogram of the missing mass, $\Xi^- \rightarrow \Lambda + MM$, of four candidates for the leptonic decay.

the leptonic decay candidates. There are ten events in this interval. These ten candidates were reduced to five by visual comparison of the ionization of the negative decay particle with other tracks in the event and, in one case, by the detection of a charge exchange. Of these five remaining candidates, one is the established leptonic decay discussed earlier.

Figure 2(c) shows the phase-space prediction for the mass of the electron-neutrino system contrasted with a Gaussian ideogram of the missing mass in the reaction $\Xi^- \rightarrow \Lambda + MM$ for the four events. In all four cases the missing mass is consistent with that of a pion. These four events are thus most likely normal decays. We conclude that the most probable value of the branching ratio for the decay (2) is

$$R_{\Xi} = 1/(0.8)(194) = 0.6\,\%. \quad (9)$$

In conclusion, if all $\Delta Q/\Delta S = +1$ decays have the same matrix element, the fraction of decays via mode (2), R_{Ξ}, is related to the fraction of lambda decays, R_Λ, via the mode $\Lambda \rightarrow p + e^- + \bar{\nu}$ by

$$R_{\Xi} = R_\Lambda (Q_{\Xi}/Q_\Lambda)^5 \tau_{\Xi}/\tau_\Lambda, \quad (10)$$

where Q is the Q value and τ is the mean life of the respective particles. Experiment yields $R_\Lambda = 0.2\,\%$,[3] and thus from Eq. (10), $R_{\Xi} = 0.3$, in agreement with our upper limit. As is well known, if one assumes that the strangeness-nonconserving Fermi interaction takes place with the same coupling constant as strangeness-conserving weak interactions, then R_Λ is predicted to be $1.6\,\%$[4] and hence $R_{\Xi} = 2.4\,\%$. Since the probability of observing one or zero leptonic decays in our sample would be 11% if $R_{\Xi} = 2.4\,\%$, our experiment gives some further evidence that the coupling constant for $\Delta Q/\Delta S = +1$ weak decays is smaller than the coupling constant for strangeness-conserving decays.

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[1]Since the missing mass in the reaction $\Xi^- \rightarrow \Lambda + e^- + MM$ is 2 ± 10 MeV, the lepton-nonconserving decay $\Xi^- \rightarrow \Lambda + \pi^0 + e^-$ is ruled out. The decay $\Xi^- \rightarrow \Sigma^0 e^- \bar{\nu} \rightarrow \Lambda e^- \gamma \bar{\nu}$ can not be ruled out, but it is unlikely that the effective mass of the gamma and neutrino would be zero.

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REGGE POLES IN RENORMALIZABLE FIELD THEORIES

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Recently, the Regge behavior of the scattering amplitudes at high energy was obtained also from field theoretical models[1] or from perturbative calculation in field theory.[2] Further, this behavior has been obtained by the use of the renormalization group.[3] We will discuss this point and show that the group can give a necessary condition for the existence of Regge type solutions in renormalizable theories.

Let us suppose that we have a renormalizable theory of interacting fields defined by a (renormalized) coupling constant e_0, and two physical masses m_1 and m_2.[4] Let M' be a renormalizable quantity for such a process; we put

$$M'(s,t,m_1^2,m_2^2,e^2) = M_0(s,t,m_1^2,m_2^2,e_0^2)M(s,t,m_1^2,m_2^2,e_0^2), \quad (1)$$

where M_0 represents the corresponding first Born

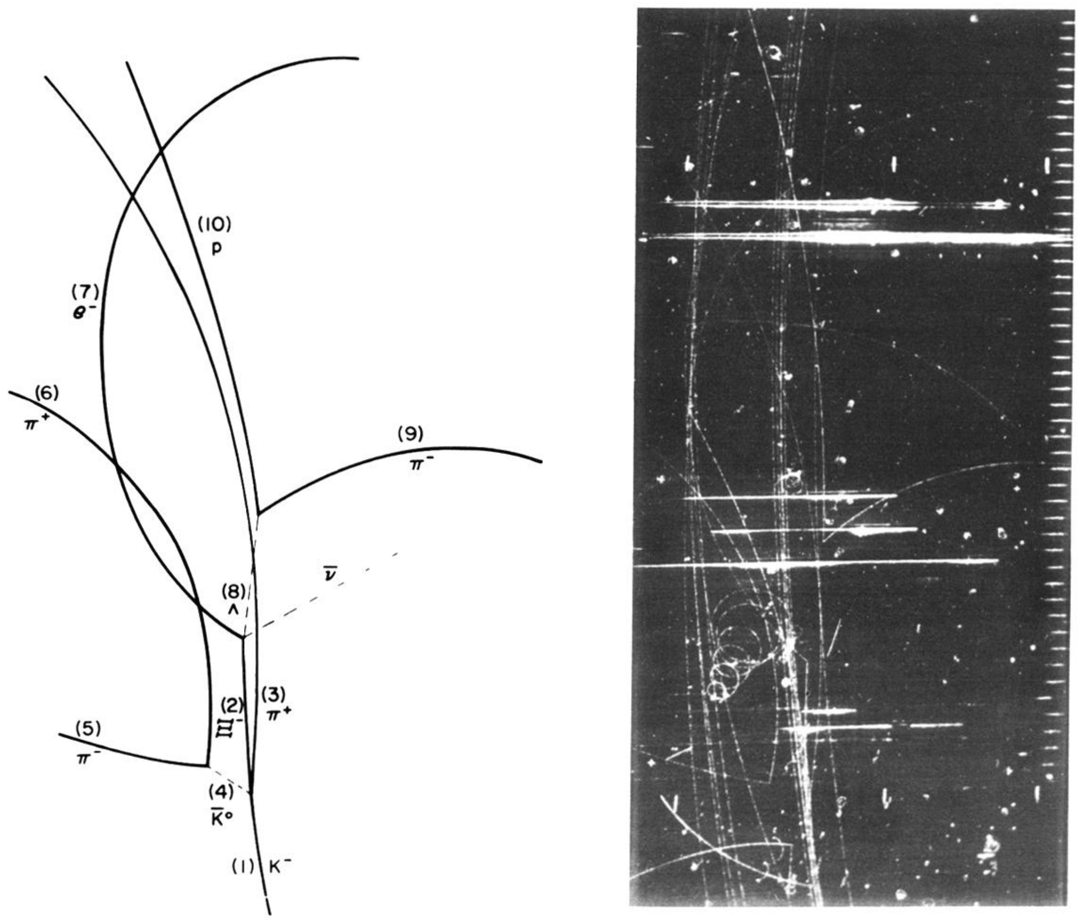

FIG. 1. Decay of negative cascade into a lambda, electron and neutrino.