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DECAY $\Xi^- \to \Lambda^0 e^- \bar{\nu}$ †*

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In the course of a search for leptonic decays of the Ξ hyperon, we have observed two unambiguous examples of

$$\Xi^- \to \Lambda^0 e^- \bar{\nu} \tag{1}$$

and obtain a branching fraction of 1.0×10^{-3} for this mode. The Ξ^- were produced in a 27-event/μb exposure of the Lawrence Radiation Laboratory 72-in. hydrogen bubble chamber to an incident K^- beam with momentum 1.7, 2.1, and 2.40 to 2.75 GeV/c. We have considered production events of the types

$$K^-p \to \Xi^- K^+, \tag{2a}$$
$$\to \Xi^- K^+\pi^0, \tag{2b}$$
$$\to \Xi^- K^0\pi^+, \tag{2c}$$
$$\to \Xi^- K^+\pi^+\pi^-, \tag{2d}$$
$$\to \Xi^- K^0\pi^+\pi^0, \tag{2e}$$

where the decay kink of the Ξ^- and the decay Λ^0 were observed. Some 2823 events fitted one of Reactions (2a)-(2e) as well as the normal decay sequence

$$\Xi^- \to \Lambda^0\pi^-, \tag{3a}$$
$$\Lambda^0 \to p\pi^-, \tag{3b}$$

with confidence level $\gtrsim$0.5% for each of the three one-vertex fits.

Candidates for the beta-decay mode (1) satisfied the following criteria: (a) Lambda decay (3b) fits with confidence level $\gtrsim$0.5%. (b) Normal Ξ^- decay (3a) does not fit; confidence level $\lesssim$0.5%. (c) A two-vertex fit to one of Reactions (2a)-(2e) followed by the decay (1) is obtained with confidence level $\gtrsim$0.5%. Only nine events of the topologies giving rise to Reactions (2a)-(2e) satisfied the criteria (a), (b), and (c). Of these, three events have negative tracks from the Ξ^- decay which are nearly flat in the chamber, have measured laboratory-system momenta less than 200 MeV/c, but are clearly darker than minimum ionizing. A pion of 200 MeV/c or less has bubble density >1.5 times that for the minimum-ionizing beam tracks, a difference distinguishable in our pictures for any but steeply dipping tracks. Another four events have charged Ξ^- decay tracks with momenta greater than 200 MeV/c. We have imposed the additional requirement that this momentum be less than 200 MeV/c for an event to be a candidate for (1). The remaining two events are shown in Fig. 1.

Each of the events in Fig. 1 is an unambiguous example of the decay (1). Event A fits $K^-p \to \Xi^-K^+$ with subsequent $\Xi^- \to \Lambda e^-\bar{\nu}$ decay with a four-constraint $\chi^2 = 1.45$. Event B fits the same production-decay sequence with $\chi^2 = 0.34$. Neither event fits muonic decay $\Xi^- \to \Lambda\mu^-\bar{\nu}$, although four of the seven rejected events do fit this mode. None of these four events has been unambiguously identified as an example of Ξ muonic decay. In each of events A and B the electron tracks are nearly flat in the chamber, with measured momenta 100.3 $\pm$ 1.2 and 134.6 $\pm$ 1.8 MeV/c, respectively. If the negative decay tracks were pions, their relative ionizations would be 2.6 and 2.0, respectively (as muons, 2.0 and 1.6); therefore,

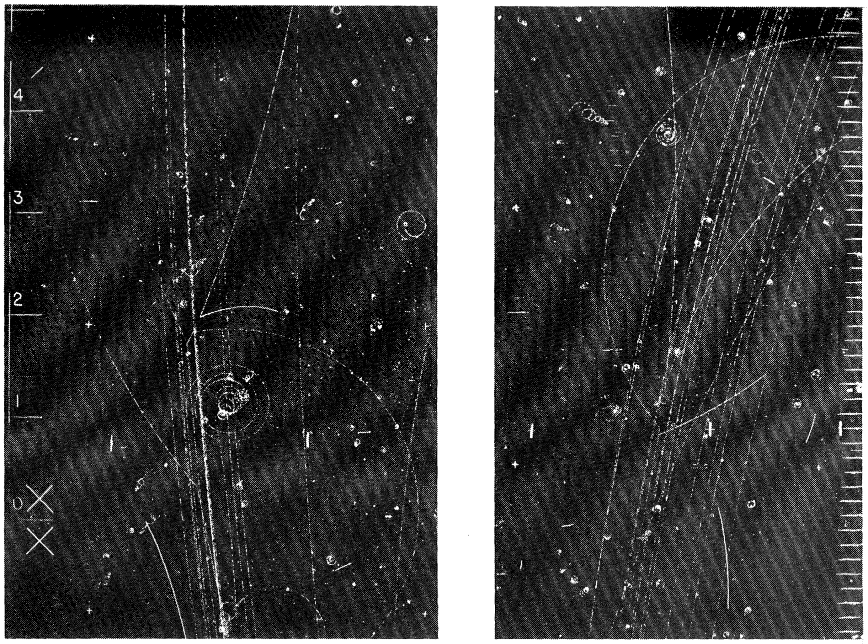

FIG. 1. Two examples of $K^-p\to\Xi^-K^+$ followed by the decay $\Xi^-\to\Lambda e^-\bar{\nu}$; on the left-hand side, event *A* and on the right-hand side, event *B*.

their identification is unambiguous by ionization alone. In addition, event *B* has an 8-MeV "delta ray" on the negative decay track which also requires the track to be an electron. Neither event is a candidate for Σ^- production and decay via $\Sigma^-\to\Lambda e^-\bar{\nu}$. The measured transverse electron momenta (component of momentum of the decay track perpendicular to the Ξ direction) in each event—82.4 ± 1.3 MeV/c for event *A* and 86.9 ± 1.6 MeV/c for event *B* —are greater than the maximum of 79 MeV/c for $\Sigma^-\to\Lambda$ decay. An attempt was nevertheless made to fit event *A*, in particular, to $\Sigma^-\to\Lambda$ decay with production via both K^-p and π^-p interactions (the beam at 2.6 GeV/c included $13\pm3\%$ π^-). No such fits were obtained. The relevant quantities in the identification of the events are summarized in Table I.

In order to calculate a branching fraction for the decay (1) based on our sample of two events, we need only know the number of events (2823) fitting Reactions (2a)-(2e), and the efficiency for detecting $\Xi^-\to\Lambda e^-\bar{\nu}$ with our selection criteria. The most important effect is the requirement which we impose that the electron momentum be less than 200 MeV/c. This eliminates about 25% of the events, according to a sample of the decay (1) Monte Carlo-generated by using a realistic Ξ^- momentum distribution and phase space for the electron momentum distribution in the Ξ^- rest frame. Only 6% of the Monte Carlo events fitted the normal decay hypothesis (3a). Neglecting possible small differences in the scanning efficiency for normal and leptonic Ξ^- decays, we arrive at an over-all detection efficiency of 0.7 ± 0.1 for the decay (1). Thus we obtain for the branching fraction

$$\frac{\Xi^-\to\Lambda e^-\bar{\nu}}{\text{all }\Xi^-}=\frac{2}{1976}=(1.0^{+1.3}_{-0.65})\times10^{-3}.$$

For such small numbers of events, the usual $N^{1/2}$ approximation for the error is inappropriate, so we have used the Poisson distribution directly. The quoted errors correspond to fractions for which the observed number of events would represent a one-standard-deviation fluctuation from the true branching fraction.

Previous knowledge of the branching fraction for Ξ^- beta decay was based on one certain event found at University of California, Los Angeles (UCLA)[1] and one unambiguous plus one ambiguous event found at Brookhaven.[2] A compilation[3] based on the two unambiguous events and including several other experiments in which no leptonic Ξ^- decays were found yielded 790 events as an effective denominator. An additional sample of events at UCLA[4] with incident

Table I. Fitted quantities[a] for $\Xi^- B^-$ decay events.

Quantity	Event A	Event B
Beam K^- momentum (MeV/c)	2633±24	1718±13
Ξ^- momentum	1209±10	1666±13
K^+ momentum	1758±18	341±5
e^- momentum	100± 1	135±2
Transverse e^- momentum (unfitted)	82.4±1.3	86.9±1.6
e^- dip	-4±1°	11±1°
χ^2 (3C) $\Lambda \to p\pi^-$	1.65	1.89
χ^2 (4C) $K^-p \to \Xi^-K^+$, $\hookrightarrow \Lambda e^-\bar{\nu}$	1.45	0.34
$\hookrightarrow \Lambda \mu^-\bar{\nu}$	162.40	69.20
χ^2 (7C) 3 vertex fit to $K^-p \to \Xi^-K^+$, $\hookrightarrow \Lambda e^-\bar{\nu}$, $\hookrightarrow p\pi^-$	3.86	2.54
Overall confidence level	80%	92%
χ^2 (3C) $\Xi^- \to \Lambda\pi^-$	380.38	314.38

[a]The fitted momenta and angles are insignificantly different from the measured, or unfitted, quantities except for the momentum of the short Ξ^-, which is essentially undetermined without fitting.

K^- momentum 2.0 GeV/c has yielded no leptonic Ξ^- events, with an effective denominator of 717. If the available data are combined, there are four events in an effective sample of 3483 Ξ^-, which results in a fraction of $(1.15^{+0.90}_{-0.55}) \times 10^{-3}$. This value is probably a slight overestimate of the true fraction because experimenters with small samples and no leptonic events tend not to report their results. In addition, one should consider that an event with sufficiently low electron momentum might be detected in some experiments, including this one, despite the fact that it failed to satisfy all the criteria used to calculate the effective denominator. Such events have not been reported; this suggests that the true branching fraction is still lower than that obtained above. A value of 1.0×10^{-3} is probably realistic for the world average.

Our result for $(\Xi^- \to \Lambda e^-\bar{\nu})/(\text{all } \Xi^-)$ may be compared with the prediction of the Cabibbo theory of leptonic decays.[5] Fits to the theory for baryonic decays are tightly constrained by the data on Λ and Σ^- decay; the predicted branching fraction for Ξ^- leptonic decay is only slightly affected by an input value for this fraction with a large uncertainty. Willis et al.,[6] using $(2.4 \pm 1.4) \times 10^{-3}$ as input for the leptonic Ξ^- decay fraction, obtained two solutions in a fit to Cabibbo's theory. Solution A predicted 0.66×10^{-3} for this fraction; solution B gave 1.06×10^{-3}. Since then, solution B has been essentially eliminated by new data[7] on the decay branching fraction for $\Sigma^- \to \Lambda e^-\bar{\nu}$. Several fits that closely correspond to solution A have been published; new data on leptonic baryon decay and modified versions of the theory were used. Brene et al.[8] use a parametrization in terms of two angles θ_V and θ_A for the vector and axial-vector baryon currents, respectively, instead of Cabibbo's one angle θ. With an input fraction for $\Xi^- \to \Lambda e^-\bar{\nu}$ of $(1.2 \pm 0.8) \times 10^{-10}$ they obtain $(0.43 \pm 0.03) \times 10^{-3}$ for the predicted fraction. Carlson,[9] using a one-angle theory, momentum-dependent form factors, and no input $\Xi^- \to \Lambda$ fraction, predicts

0.56×10^{-3}. Finally, a fit has been obtained,[10] including the $\Sigma^- \rightarrow \Lambda e^-\bar{\nu}$ data of Barash et al.[7] which were not used in the earlier fits; this fit predicts 0.62×10^{-3} for the $\Xi^- \rightarrow \Lambda$ fraction, again using no input value.

The experimental branching fraction for $\Xi^- \rightarrow \Lambda e^-\bar{\nu}$ is therefore consistent with the Cabibbo theory and with data for other baryon leptonic decays.

Improved upper limits for other unusual decay modes of Ξ^- and Ξ^0 will be presented in a later paper along with a detailed analysis of the normal $\Xi \rightarrow \Lambda\pi$ decay.

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NEUTRON-PROTON AND NEUTRON-DEUTERON TOTAL CROSS SECTIONS FROM 14 TO 27 GeV/c*

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The first direct measurements of neutron-proton and neutron-deuteron total cross sections in the momentum range 14 to 27 GeV/c are presented. The np total cross section apparently becomes less than the pp total cross section in this momentum region. Our results show no evidence for a rapid vanishing of the Glauber screening correction as predicted by Abers et al. on the basis of Regge theory.

In this Letter we present the results of the first direct measurements of neutron total cross sections in the 14 to 27 GeV/c region. Previous measurements[1,2] in this momentum region have been obtained by means of a comparison of pd and pp cross sections with the use of the Glauber corrections.[3] Direct measurements of neutron cross sections through a good geometry attenuation experiment with a neutron beam affords an opportunity to check the validity of the Glauber correction in the nucleon-nucleon system, to obtain the cross sections without the uncertainties such a correction introduces, and to investigate more directly the momentum dependence of $\sigma_T(np)-\sigma_T(pp)$. The data presented here also extend to somewhat higher momenta than previous measurements.

The experiment was performed at the Brookhaven alternating-gradient synchrotron (AGS) following an experiment to measure np elastic-scattering differential cross sections. A neutral beam was taken off at an angle of 1° from a beryllium target in the circulating beam of the AGS. Charged particles were removed by sweeping magnets. The beam was collimated by a series of collimators; the defining colli-

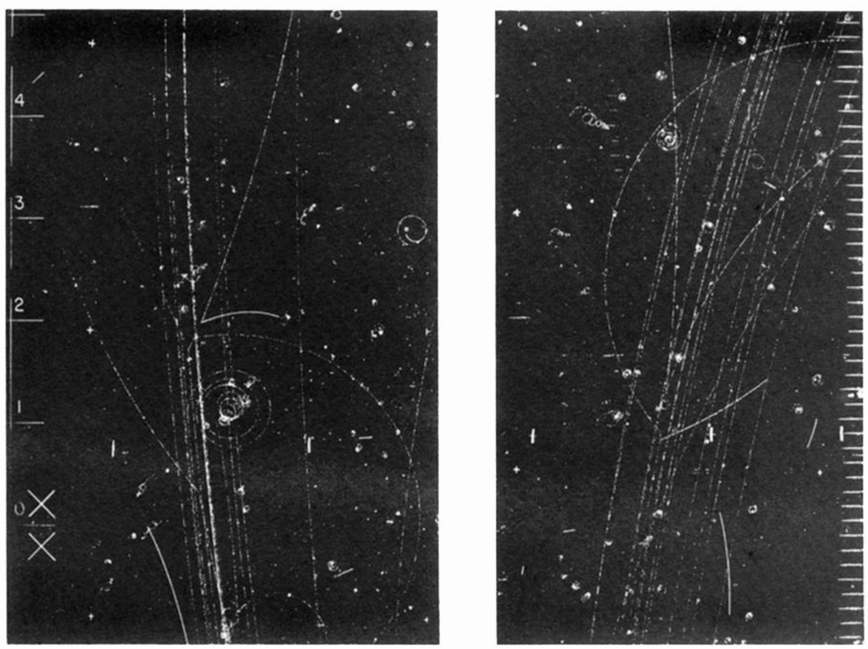

FIG. 1. Two examples of $K^- p \to \Xi^- K^+$ followed by the decay $\Xi^- \to \Lambda e^- \bar{\nu}$; on the left-hand side, event A and on the right-hand side, event B.