Measurement of the Σ^- Polarization in the Reaction $\pi^- + p \rightarrow \Sigma^- + K^+$†

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The average polarization of the Σ^- produced in the reaction $\pi^- + p \rightarrow \Sigma^- + K^+$ has been measured between center-of-mass angles 134° and 166° for an incident π^- momentum of 1145 MeV/c. A polarized proton target was used, and the Σ^- polarization was found by measuring the difference in the production rate of K^+ mesons for protons polarized along the production-plane normal and against it. Spark chambers were used to record the π^- and K^+ trajectories, and the π^- momentum was obtained from a magnetic spectrometer while the K^+ momentum was obtained from a range telescope. Each event was kinematically reconstructed in a one-constraint fit to help eliminate events produced from protons bound in heavy nuclei of the target. The Σ^- polarization was found to be -0.36 ± 0.46.

I. INTRODUCTION

BECAUSE of experimental difficulties, very few measurements have been made of the Σ^- polarization in the reaction $\pi^- + p \rightarrow \Sigma^- + K^+$.[1,2] The problem is that the Σ^- decays almost entirely through the mode $\Sigma^- \rightarrow n + \pi^-$, but since this process is almost pure S wave there is no decay asymmetry to reveal the polarization. If the angular distribution of the neutron is written as

$$dN/d\Omega = (1 + \alpha_- P \cos\theta),$$

the measured value of the asymmetry parameter (α_-) is only -0.104 ± 0.04.[3] There is some current interest in exploring the Σ^- polarization in $\pi^- + p \rightarrow \Sigma^- + K^+$ because this reaction could possibly serve as a source of polarized Σ^- for investigating the decay $\Sigma^- \rightarrow e^- + n + \nu$. Theories of weak interactions based on unitary symmetry predict an angular distribution in which the electron tends to come off in a direction opposite the spin of the Σ^- while the $V - A$ theory predicts an almost isotropic distribution.[4–6] If the measured electron asymmetry turns out to be small, knowledge of the Σ^- polarization is necessary to interpret the value found for the asymmetry.

We have measured the Σ^- polarization in $\pi^- + p \rightarrow \Sigma^- + K^+$ by using a polarized proton target and measuring the difference in the production rate of K^+ mesons for protons polarized along the production-plane normal ($\hat{k}_\pi \times \hat{k}_\Sigma$) and against the normal. If $I^+(\theta)$ and $I^-(\theta)$ are the number of events per unit of π^- flux, produced with the target protons polarized along the normal and against the normal, respectively, and P_T is the average target polarization, then the Σ^- polarization is given by

$$P_{\Sigma^-}(\theta) = \frac{1}{P_T} \frac{I^+(\theta) - I^-(\theta)}{I^+(\theta) + I^-(\theta)}.$$

The incident beam momentum was 1145 MeV/c with a momentum spread of $\pm 1.5\%$. Details of the construction and operation of the polarized target have been described elsewhere.[7] Average polarization of the target during the experiment was 37.5%. The Σ^- polarization was measured for Σ^- produced between center-of-mass angles 134° and 166° measured from the direction of the incoming π^-.

II. EXPERIMENTAL DETAILS

The arrangement of the spark chambers and counters used to detect K^+ mesons is shown in Fig. 1. The beam of π^- mesons passed through counter S_1 and D, and through a hole in veto-counter A_1 to strike the polarized target. Counter D was connected to a circuit $(\bar{D})_c$ which vetoed events in which two particles arrived in a period of 0.45 μsec in order to decrease the number of double tracks in the spark chambers. K^+ mesons produced in the target passed through scintillators S_2 and S_3, through water-filled Čerenkov counters C_1 and C_2, and stopped in the large water-filled Čerenkov counter T. The Čerenkov threshold for water is $\beta = 0.75$,

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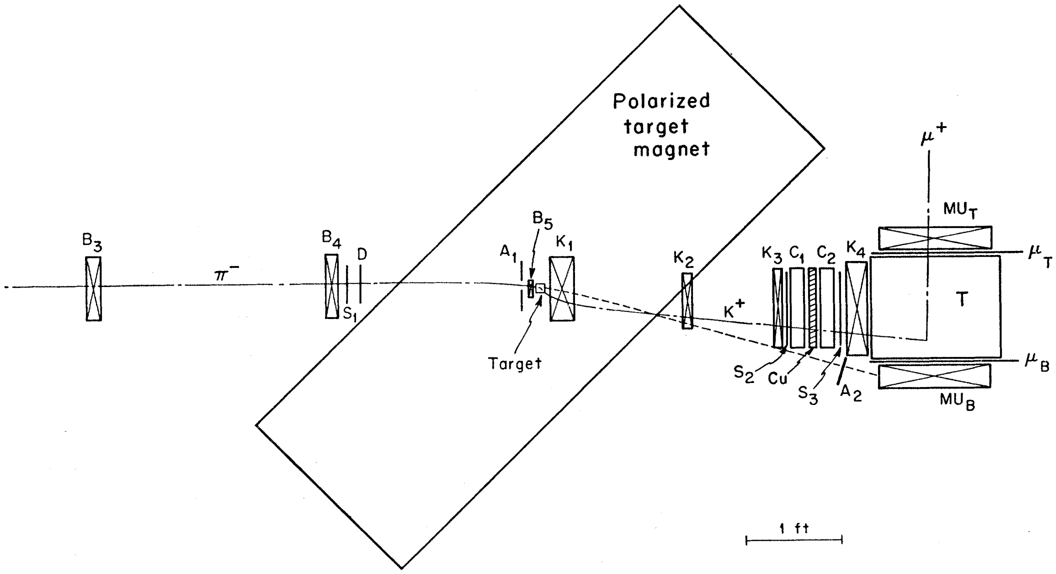

FIG. 1. Elevation diagram of the counter and spark-chamber arrangement.

so the K^+ mesons ($0.7 \leq \beta \leq 0.75$) did not trigger veto-counters C_1 and C_2, but elastically scattered π^- and protons did. The 1.33-in. copper block degraded the momentum of the K^+ mesons so that they would stop in T. Once in T, a K^+ meson decaying by either $K_{\pi 2}$ or $K_{\mu 2}$ decay produced a charged particle with β high enough to trigger T. If the particle passed through a side of T covered by one of the four μ counters it would also trigger a μ counter. The T signal and the sum of the μ-counter signals (μ_{sum}) were required to be delayed by more than 6 nsec from a "prompt" signal to further favor triggering on K^+ mesons. Veto-counter A_2 prevented triggering on events in which there was an unscattered beam particle. The master trigger can thus be written as

$$S_1S_2S_3\bar{D}_c\bar{A}_1\bar{C}_1\bar{C}_2\bar{A}_2\,(T\mu_{\text{sum}})_{\text{delayed}}.$$

Once triggered, spark chambers K_1 through K_4 recorded the K^+ trajectory, while the μ chambers recorded the trajectories of the K^+ charged decay products. Chambers B_3, B_4, and B_5 recorded the trajectory of the incoming π^-. Not shown in Fig. 1 are spark chambers B_1 and B_2 and a bending magnet which in conjunction with spark chambers B_3 and B_4 made a magnetic spectrometer measuring the π^- momentum. Counter signals were photographed on a four-beam oscilloscope, and the delay-time distribution between any μ-counter signal and the S_3 signal was checked for consistency with the K^+ lifetime.

III. DATA ANALYSIS AND RESULTS

In the particular target used in this experiment only 3% by weight of the target constituted free hydrogen and therefore Σ^- hyperons were produced from protons bound in heavy nuclei in the target as well as from free protons. A large percentage of these quasielastic events were eliminated by reconstructing each event kinematically and discarding those events where a large momentum (Fermi momentum) of the initial proton was indicated. Kinematic variables measured in this experiment were the momenta of the incoming π^- ($\mathbf{k}_{\pi^-}$) and the outgoing K^+ ($\mathbf{k}_{K^+}$); the Σ^- was not measured because it usually decayed before reaching the spark chamber which could have detected it. However, it is very probable that most of the detected K^+ corresponded to the production of a Σ^-, since for a two-body final state, one final particle being a K^+ and the other a Λ, Σ^+, or Σ^0, production by a π^- incident on a nucleon is forbidden by charge conservation. However, more complicated interactions in heavy nuclei, such as $\pi^- + p + p \rightarrow K^+ + \Lambda + N$, or the production of extra particles in the final state, constituted part of the quasi-elastic background which had to be subtracted. The magnitude of the K^+ momentum was found from its range in counter T.

Momentum determined from the range measurement was compared with the momentum measured from the particle's bending in the polarized target's magnetic field. This comparison made it possible to eliminate the background of π^- mesons and protons which had triggered the system in spite of the bias against these particles by the electronic logic. From $\mathbf{k}_\pi$ and $\mathbf{k}_K$ the mass of the unseen Σ^- was calculated from the formula

$$M_\Sigma^2 = E_\Sigma^2 - P_\Sigma^2 = (E_\pi + m_p - E_K)^2 - (\mathbf{k}_K - \mathbf{k}_\pi)^2,$$

where E_π and E_K are total energies of the π^- and K^+, respectively, and m_p is the mass of the proton. If the event was from a free proton the missing mass of the unseen particle would be 1197.2 (the mass of the Σ^-),

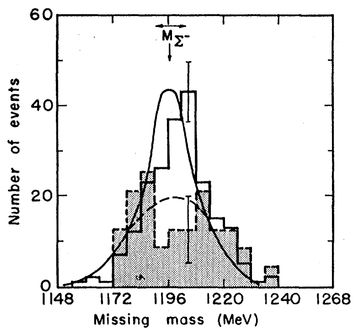

FIG. 2. Missing mass for dummy target (shaded) and crystal target data normalized to the π^- flux. The smooth continuous curve is a Monte Carlo calculation of the crystal target data, and the smooth dashed curve shows what part is due to events from protons bound in heavy elements of the target. Normalization of the Monte Carlo calculation is to the number of events in the crystal target data. The calculated resolution in missing mass is illustrated by an interval which should contain 68% of the events from free hydrogen in the crystal target.

but if it was from a bound proton the Fermi momentum would usually make the missing mass some other value. Of course some of the quasielastic events exactly simulate events from free protons, and this background was measured by means of a dummy target similar to the crystal target but lacking free hydrogen.

Figure 2 shows the distributions in missing mass for the final sample of K^+ events. The unshaded histogram contains positive and negative target polarization data added together and the shaded histogram contains the dummy target data. In order to normalize the dummy target distribution to the polarized target distribution according to the number of incident π^- mesons, the dummy target data have been multiplied by a factor 4.2. This is the ratio of the number of incident π^- for polarized target data to the number of incident π^- for dummy target data. The smooth curve is a Monte Carlo calculation of the missing-mass distribution for the crystal target normalized to the actual number of events, while the dashed lines show what part is due to quasielastic events. Included in the Monte Carlo

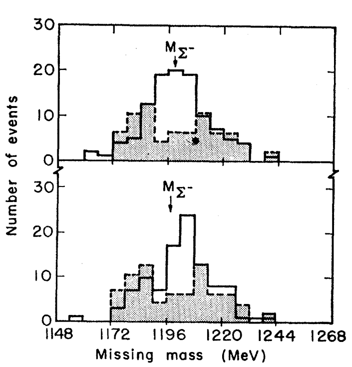

FIG. 3. Missing mass plotted separately for positive and negative target polarization. Shaded histograms indicate dummy target data normalized to the crystal target data. The top graph corresponds to the target polarized opposite the production-plane normal.

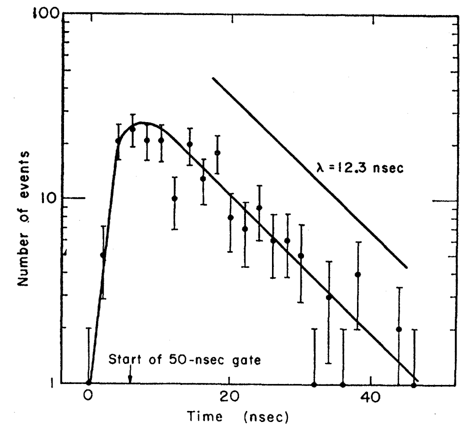

FIG. 4. Decay-time distribution of K^+ mesons for summed polarized target and dummy target data. A line with a slope corresponding to the K^+ lifetime of 12.3 nsec is shown for comparison.

calculation is the estimated resolution of the experiment in missing mass which is taken as a Gaussian with $\sigma=6$ MeV. Resolution in missing mass is calculated from the effect of Coulomb scattering in counter T on $\mathbf{k}_K$, and the effect of Coulomb scattering in the polarized target and of inaccuracy in measuring spark-chamber tracks on $\mathbf{k}_\pi$ and $\mathbf{k}_K$. Events in the mass interval $1184\leq$ missing mass ≤ 1210 MeV will be taken to be in the "elastic" peak, which means that two standard deviations are taken on each side of the mass of the Σ^-, assuming a 6-MeV resolution. After subtracting the dummy target distribution (representing events from bound protons) from the crystal target data, there is a total of 72 events from free hydrogen.

Figure 3 shows data for positive and negative target polarizations plotted separately. The upper graph corresponds to negative target polarization; the shaded histograms are normalized dummy target data.

Figure 4 shows the decay-time distribution of all events from crystal or dummy target which were accepted as K^+ mesons. Agreement with the K^+ lifetime is seen to be satisfactory. The final value found for the polarization was $\bar{P}_\Sigma=-0.36\pm0.46$.

Statistical error in the polarization amounted to ±0.41, but in addition there were two principal sources of systematic error. One error was a 10% uncertainty in measuring target polarization. The other systematic error came about from the manner in which the dummy target background was normalized to the crystal target data. Because the dummy target was only 0.75 as dense as the crystals, fewer events occurred per unit area with a given incident flux of π^- mesons; but because the dummy target was larger it intercepted more of the beam, which tended to equalize production rates of events from bound protons in dummy and crystal targets. What is usually done in polarized target experiments to get the correct background normalization is to take the shape of the dummy target data and normalize it to the quasielastic tails of the crystal data in whatever manner it is plotted. In this experiment the number of events in the inelastic tails of the dummy target was only 20 events which is too small to be useful. Another possibility would be to ignore the dummy target data and use the Monte Carlo calculation to estimate the quasielastic background. Agreement of the flux-normalized background with the Monte Carlo calculated background is certainly encouraging; but there are large uncertainties in the calculation too, as a result of the oversimplified nuclear model used. The procedure finally adopted was to calculate the polarization as if the flux normalization was correct but increase the error to take account of the possibility of an incorrect normalization. From considerations of the maximum possible error in the normalization, this systematic error in the value of the Σ^- polarization is estimated to be ± 0.2 which, when combined with the other errors, all taken in quadrature, yields the stated error $\Delta P_{\Sigma^-} = \pm 0.46$.

Although this measurement of Σ^- polarization is lacking in statistical accuracy, it does serve the purpose of concretely demonstrating the feasibility of the method used. Enlarged K^+ detectors and longer experiments for greater statistics will make polarized target experiments very practical for investigating Σ^- polarization in the reaction $\pi^- + p \rightarrow \Sigma^- K^+$.

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Properties of the Ξ^- and the $\Xi^*(1817)$ from K^-p Interactions above 1.7 BeV/c*

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A sample of 2529 Ξ^- hyperons, produced in Ξ^-K^+, $\Xi^-K^{+,0}\pi^{0,+}$, and $\Xi^-K^{+,0}\pi^{-,0}\pi^+$ final states by K^- (in hydrogen) at incident momenta from 1.7 to 2.7 BeV/c, has been analyzed. The data are from an exposure of 26 events/μb ("K-63" run) in the Alvarez 72-in. bubble chamber; approximately 85% of the Ξ^- events with visible Λ decay have been analyzed. A maximum-likelihood fit (with $\alpha_\Lambda = 0.656 \pm 0.055$ and with the Ξ spin $= \frac{1}{2}$) yields the following values of Ξ^- decay parameters: $\alpha_{\Xi^-} = -0.375 \pm 0.051$; $\Phi_{\Xi^-} \equiv \tan^{-1}(\beta_{\Xi^-}/\gamma_{\Xi^-}) = 9.8° \pm 11.6°$. Spin analysis of the 3278 Ξ^- decays from the K-63 and K-72 (K^-p at 1.2–1.7 BeV/c) experiments gives likelihood results which favor $J_\Xi = \frac{1}{2}$ over $J_\Xi = \frac{3}{2}$ by the equivalent of approximately 2.5 standard deviations. Analysis of the $\Xi^*(1817) \rightarrow \Xi^*(1530) + \pi$ decay mode indicates that the hypotheses $J^P = \frac{1}{2}^+$, $\frac{1}{2}^-$, $\frac{3}{2}^-$, $\frac{5}{2}^+$, $\frac{7}{2}^-$, etc. are favored; but results are inconclusive because of high background as well as poor statistics. Analysis of the $\Xi^*(1817) \rightarrow \Lambda + \bar{K}$ provides no spin or parity discrimination. The K-63 beam channel is briefly bescribed.

I. INTRODUCTION

PRIOR to this experiment, approximately 2600 Ξ^- had been analyzed to determine the Ξ^- decay parameters α_{Ξ^-} and $\Phi_{\Xi^-} \equiv \tan^{-1}(\beta_{\Xi^-}/\gamma_{\Xi^-})$.[1–6] The largest single sample previously analyzed consisted of 1004 events from the K-72 experiment[1] (K^-p at 1.2–1.7 BeV/c), for which the values $\alpha_{\Xi^-} = -0.368 \pm 0.057$ and $\Phi_{\Xi^-} = 0.5° \pm 10.7°$ (with $\alpha_\Lambda = 0.641 \pm 0.056$ and with the Ξ spin assumed to be $\frac{1}{2}$) were reported. In this paper we describe the analysis of 2529 Ξ^- events in the K-63 experiment (K^-p at 1.7–2.7 BeV/c), including 224 Ξ^-K^+ events previously analyzed.[6,7] From K-63 data we obtain values $\alpha_{\Xi^-} = -0.375 \pm 0.051$ and $\Phi_{\Xi^-} = 9.8° \pm 11.6°$ (with $J_{\Xi^-} = \frac{1}{2}$ and $\alpha_\Lambda = 0.656 \pm 0.055$), in good agreement with previously reported values. Combining

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