Brief Reports

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Search for Λp states in the baryon-exchange reaction $pp \to \Lambda p K^+$ at 11.75 GeV/c

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We have obtained 1400 events of the baryon-exchange reaction $pp \to \Lambda p K^+$ using the ANL Zero Gradient Synchrotron 11.75-GeV/c polarized proton beam and the effective-mass spectrometer. A search for enhancements in the Λp mass spectrum has been made. No enhancements are observed; in particular, the narrow Λp enhancement at 2.13 GeV seen in $K^- d \to \Lambda p \pi^-$ is not observed. We establish limits on the production of narrow states of ~ 10 nb. Also, 100 000 events of the forward reaction $pp \to \Lambda K^+ p$ were examined and no narrow Λp enhancements are seen.

The subject of dibaryon resonances has received much attention recently. In the case of states with strangeness -1 there has long been experimental evidence for a narrow enhancement in the Λp effective-mass distribution at 2.13 GeV in the reaction $K^- d \to \Lambda p \pi^-$.[1] The fact that the enhancement is very close to the threshold for Σ production has complicated its interpretation. Several authors[2] have analyzed this reaction assuming the mechanism to be Σ production off one nucleon followed by $\Sigma N \to \Lambda p$ scattering off the other nucleon. These analyses claim evidence for a deuteronlike state in the $\Sigma N \to \Lambda p$ amplitude. If, on the other hand, the Λp enhancement is an ordinary resonance, one might expect to observe it in the baryon-exchange reaction $pp \to \Lambda p K^+$, where the K^+ is slow in the laboratory and the Λp system is produced fast and forward. We have obtained 1400 events of this reaction at 11.75 GeV/c during an experiment primarily designed to study the exclusive forward production of the ΛK^+ system with high statistics. We report here a search for Λp enhancements using this data sample.

This experiment used the polarized proton beam from the ANL Zero Gradient Synchrotron and the effective-mass spectrometer. The apparatus and analysis procedures have been described in detail elsewhere[3,4] and here we give only a brief description with emphasis on changes in the apparatus required for this experiment. The 11.75-GeV/c proton beam was measured by four sets of multiwire proportional chambers upstream of the 25-cm target which was filled alternately with liquid hydrogen and liquid deuterium. The forward-produced proton, and the proton and π^- from the decay of the Λ, were momentum analyzed using the large-aperture magnet surrounded by sets of magnetostrictive-readout wire spark chambers.[4] The recoil K^+ was detected in the recoil detector[5] consisting of two cylindrical multiwire proportional chambers coaxial with the target. For this experiment the target and recoil detector were moved 30 cm upstream from their usual position[5] to provide a longer decay space for the Λ's.

In addition to basic trigger conditions requiring a good beam track and no count in a 2.5-cm-square beam-veto counter just downstream of the spectrometer magnet, the trigger selected the final state ΛX^+ by requiring a single charged particle to emerge near the forward direction from the target, and three charged particles further downstream following a 65-cm fiducial volume for the Λ decay. The requirement of only one charged particle from the target was imposed by a cut on the pulse height of a counter (called $dE\,dX$) just downstream of the target. The three-particle requirement was imposed by a pulse-height cut on a large counter 65 cm downstream from $dE\,dX$, combined with a requirement of exactly three hits in the 40-scintillator hodoscope downstream of the magnet. In addition, no count was allowed in the large threshold Cherenkov counter at the downstream end of the apparatus; this counter was filled with CO_2 at 51 psi for a π threshold of 2.6 GeV/c. The performance of the pulse-height counters was continuously monitored with random beam triggers and unbiased three-particle triggers (i.e., three particles in the hodoscope with no pulse-height requirements).

After corrections for accidentals the beam flux of the experiment gives a cross-section sensitivity (for 100% acceptance) of 15.0 events/nb for the hydrogen-target data and 33.8 events/nb for the deuterium-target data.

After track reconstruction we first searched for Λ's in those events with two positive and one negative track. The distribution of invariant mass of the π^- with one of the positive tracks showed a Λ peak with full width at half maximum of about 5 MeV on top of a small background. About 450 000 events with $\pi^- p$ mass within ± 5 MeV of the Λ mass were selected for further analysis. The events of the reactions $pp \to \Lambda K^+ p_r$ and $pp \to \Lambda p K_r^+$ (where the subscript r denotes the recoil particle) were selected using the three available kinematic constraints (since all kinematic quantities are measured except the magnitude of the recoil particle's momentum). The three constraints used were the square of the missing mass recoiling against the forward particles and the differences between the measured azimuthal angle and cotangent of the polar angle of the recoil and the values predicted by the kinematics. Figure 1(a) shows the difference $\Delta m_X{}^2$ in missing mass squared and the proton mass squared for the proton-recoil hypothesis for events satisfying cuts on $\Delta\phi$ and $\Delta \cot\theta$ for the hydrogen-target data. Figure 1(b) shows for the same data the $\Delta \cot\theta$ distribution after cuts on $\Delta m_X{}^2$ and $\Delta\phi$. Figures 1(c) and 1(d) show the same distribution for the deuterium-target data. Clear signals are seen, the resolution for the deuterium data, of course, being broader.

Figure 2 shows the same quantities as Fig. 1, but now for the K^+-recoil hypothesis. In this figure an additional cut has also been made excluding events that give good fits to the proton-recoil hyptothesis. Signals for the K^+-recoil events are evident in Fig. 2 although clearly there is more background contamination under the deuterium-target data due to the worse resolution. The hydrogen data show a signal-to-background ratio of about 2:1 while the deuterium data have a ratio of about 1:2. The final event sample was selected using cuts on $\Delta m_X{}^2$, $\Delta\phi$, and $\Delta \cot\theta$ of 0.5 GeV^2, 0.1 rad, and 0.1, respectively, for the hydrogen-target data and 0.5 GeV^2, 0.18 rad, and 0.18 for the deuterium-target data.

The acceptance was calculated by a Monte Carlo program. Events were generated with flat angular distributions for the angles describing the decay of the Λp system and $\Lambda \to p\pi^-$ decay. The four-momentum-transfer u distribution was generated to agree approximately with that seen in the raw data. A number of constant corrections were also made; these included reconstruction inefficiency [$(9\pm 6)\%$], interactions of the forward particles (5%), inefficiency of the recoil detector (7%), and inefficiency induced by the $dE\,dX$ counter vetoing good events (20%). Correcting for the branching fraction of $\Lambda \to p\pi^-$ we obtain a cross section for $pp \to \Lambda p K^+$ in the Λp mass range from threshold to 3.0 GeV and u from $u_{\max}$ to -1.0 GeV^2 of 550 ± 50 nb.

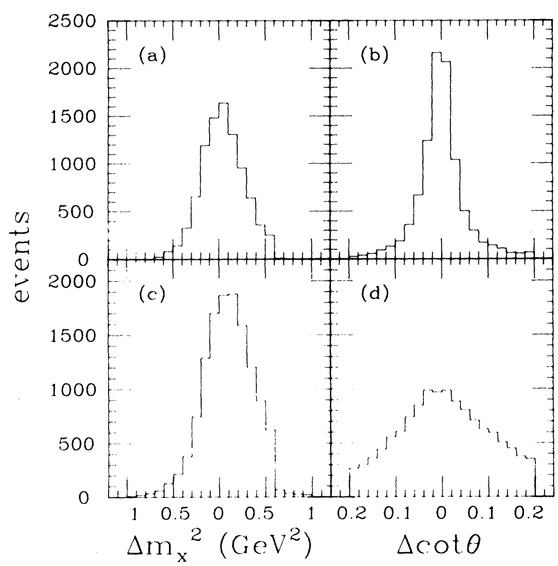

FIG. 1. (a) Distribution of the difference of the missing mass squared and the proton mass squared for the reaction $pp \to \Lambda K^+ p$, after the cuts on $\Delta\phi$ and $\Delta\cot\theta$ described in the text. (b) $\Delta\cot\theta$ after cuts on $\Delta m_X{}^2$ and $\Delta\phi$. (a) and (b) are for events using the hydrogen target; (c) and (d) are the same quantities for events using the deuterium target.

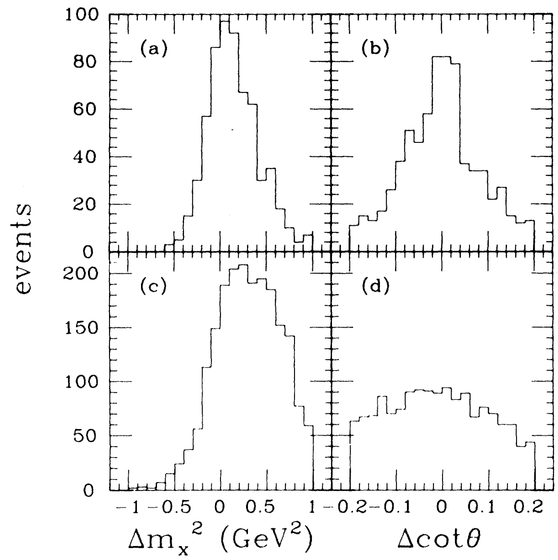

FIG. 2. (a)–(d) Same as Fig. 1 except for the hypothesis $pp \to \Lambda p K_r{}^+$, where r denotes the recoil particle. Here $\Delta m_X{}^2$ is the difference relative to the K^+ mass squared.

It is possible that some of the events with recoil K^+ are in fact diffractivelike $\Lambda K^+ p$ events with very backward decays of the ΛK^+ system. A Monte Carlo simulation using the $pp \to \Lambda K^+ p$ cross section measured in a 12-GeV/c bubble-chamber experiment[6] indicates that at most about 500 events could come from this source. These events contribute to the Λp mass distribution only at high masses.

Figure 3 shows the distribution of the data in Λp mass for events with $-u$ less than 1.0 GeV^2. No evidence is seen for any enhancements. The Λp mass resolution is about 4

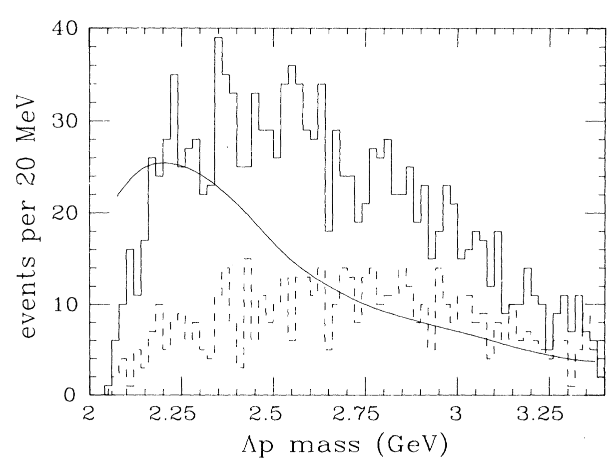

FIG. 3. Distribution of the Λp mass in $pp \to \Lambda p K^+$ for all events with $|u| \leq 1.0$ GeV^2. The dashed histogram shows the hydrogen-target data alone. The solid curve shows the geometric acceptance (with the vertical scale being interpreted as percent).

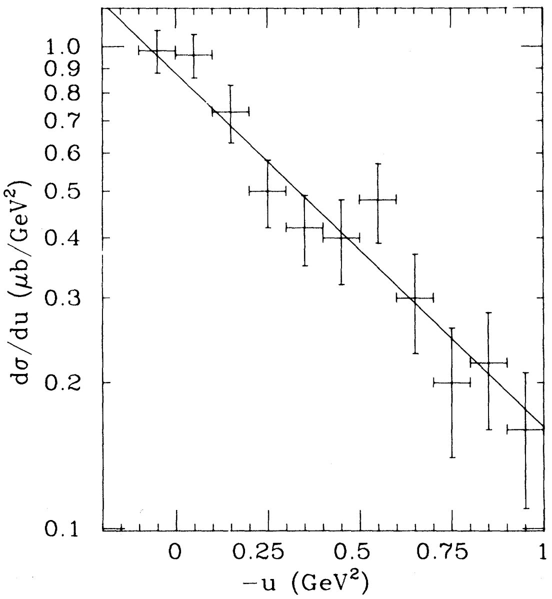

FIG. 4. Differential cross section $d\sigma/du$ for $pp \to \Lambda p K^+$ with Λp mass less than 3.4 GeV/c. Only the hydrogen-target data were used to determine this cross section. The acceptance was calculated assuming isotropic decay angular distributions. The line is a fit to the form Ae^{Bu} with $B = 1.7 \pm 0.2$ GeV^{-2}.

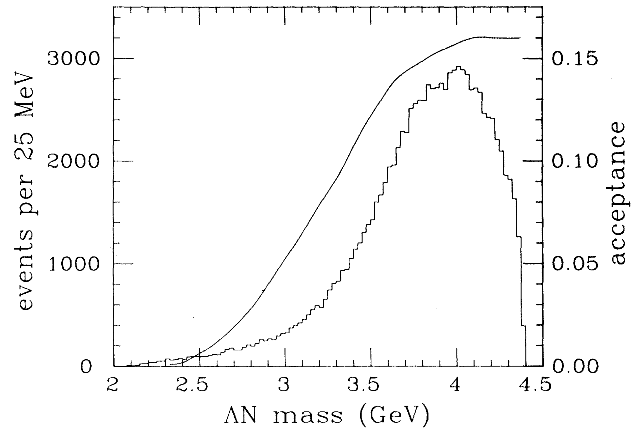

FIG. 5. Distribution of the ΛN mass in $pN \to \Lambda K^+ N$. The solid curve (right scale) shows the geometric acceptance.

MeV. The geometric acceptance is shown by the solid line in Fig. 3. We have calculated 5-standard-deviation upper limits on the production of a Λp state of width 20 MeV and obtain values in the range 6 to 20 nb for Λp masses between 2.1 and 3.0 GeV. We know of no theoretical expectation for the cross section for baryon-exchange production of a dibaryon resonance; however, cross sections for hyperon-exchange production of meson and baryon resonances are on the order of 100 nb at this energy.[7]

Figure 4 shows the cross section versus the four-momentum transfer u. Only the hydrogen-target data were used for this plot in order to obtain answers relatively free of background contamination. The distribution is well described by the form e^{Bu} with $B = 1.7 \pm 0.2$ GeV^{-2}.

We have also examined the ΛN mass distribution of the much larger sample of forward-produced events, shown in Fig. 5. This plot contains $\sim 100\,000$ events. An earlier bubble-chamber experiment obtained ~ 100 events at 12 and 24 GeV/c.[6] Previous counter experiments have had samples of 10 000 events at 10 GeV/c (Ref. 8) and 20 000 events at 50 GeV/c.[9] The forward events were selected by a cut of ± 0.4 GeV^2 on $\Delta m_X{}^2$ only. The signal-to-background ratio of these data is about 1.6 to 1. The acceptance, calculated by Monte Carlo, is shown as the smooth curve in Fig. 5. Five-standard-deviation upper limits for a 25-MeV-wide resonance are about 60 nb, independent of Λp mass in the region above ~ 3.0 GeV. The limit at 2.7 GeV is 130 nb and at 2.5 is 200 nb.

In conclusion, we have obtained 1400 events of the baryon-exchange reaction $pp \to \Lambda p K^+$ at 11.75 GeV/c. The cross section is 550 ± 50 nb (including possibly ~ 200 nb of contamination from diffractivelike events). The u distribution of the reaction is $e^{(1.7 \pm 0.2)u}$. No evidence is seen for Λp mass enhancements; in particular, there is no enhancement near 2.13 GeV, and limits in the range 6 to 20 nb have been established for narrow structures. A very-high-statistics sample of the forward reaction $pp \to \Lambda K^+ p$ has also been examined and no narrow Λp enhancements are seen, with upper limits of about 60 nb.

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