MEASUREMENT OF THE RATIO OF Σ^0 TO Λ^0 INCLUSIVE PRODUCTION BY 28.5 GeV/c PROTONS ON BERYLLIUM

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The ratio of the cross section for Σ^0 inclusive production to the cross section for Λ^0 inclusive production has been measured with 28.5 GeV/c protons incident on a beryllium target at an average laboratory production angle of 4°. This ratio was measured to be 0.278 ± 0.011 ± 0.05 where the uncertainties are statistical and systematic in that order. The ratio does not depend strongly on the momentum of the produced particle between 10 and 24 GeV/c. The effect of Σ^0 contamination on previous determinations of the polarization of inclusively produced Λ^0's is discussed.

Measurements of the inclusive production of Λ^0 hyperons by protons [1–4] on various targets have not distinguished between Λ^0's produced directly and Λ^0's arising from the decay $\Sigma^0 \to \Lambda^0 + \gamma$. Comparisons with theoretical models [‡1] [6] of Λ^0 polarization in inclusive production by protons are compromised somewhat due to the Σ^0 contribution to the Λ^0 sample. In K–p interactions, the Σ^0 contribution was found [7] to be substantial – almost 30% at 8.25 GeV/c. In this paper, the first measurement with incident protons of the ratio of the cross section for Σ^0 inclusive production to the cross section for Λ^0 inclusive production is reported. The effect on previous determinations of Λ^0 polarization is presented.

The experiment was performed at the AGS at Brookhaven National Laboratory, using 28.5 GeV/c protons on a 15 cm beryllium target. A neutral beam, 3 msr in solid angle, was defined at a 4° angle from the incident proton beam by a collimator embedded in a 37.1 kGm sweeping magnet. A decay region following the collimator was filled with helium at atmospheric pressure. Λ^0's were detected by the decay $\Lambda^0 \to p + \pi^-(\Lambda_{p\pi})$ and Σ^0's by the decay $\Sigma^0 \to \Lambda^0 + \gamma$. The two charged tracks of the Λ^0 decay were detected in a spectrometer which has been described in detail elsewhere [1]. There were two analyzing magnets, D6 set at 3.24 kGm for momentum analysis of the pion and D7 at 27.2 kGm for momentum analysis of the proton. A two track trigger was formed from scintillator hodoscope elements in the front, middle, and rear sections of the spectrometer and a veto counter before the decay region. The tracks were recorded in three banks of spark chambers. Further details of the

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[‡1] For a more detailed discussion of the analysis procedures, see ref. [5].

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charged track measurement can be found in refs. [1,2, 5].

A lead glass array, consisting of 84 elements, was added to the spectrometer to provide 3.8 msr of photon detection capability. Each element consisted of a block of SF-2 lead glass, 6.35 × 6.35 cm in cross section and 58.4 cm long. Each element was calibrated in an electron test beam with 1.5 and 2.5 GeV/c electrons. A photon trigger was satisfied when a linear sum of the energy deposited in the array was greater than 500 MeV. A veto counter in front of the array insured that the array was not triggered by charged particles. The pulse height in each element was recorded for every event. Two track triggers prescaled by 64 (2T) and two tracks in coincidence with a photon (2T γ) were taken concurrently. The data presented were obtained from approximately 4×10^5 2T triggers and 1.25×10^6 2T γ triggers.

The data were processed through a track finding reconstruction program and subjected to a number of cuts to identify $\Lambda_{p\pi}$ decays [5]. The tracks in the spectrometer were required to be of opposite sign, to pass within the various detector apertures, to intersect hodoscope elements consistent with the trigger, and to extrapolate to a vertex within the decay region. All cuts were consistent with chamber resolutions and multiple scattering in the spectrometer. Finally, the vector sum of the momenta of the two particles was required to point back to the target. The $p\pi^-$ invariant mass distribution for events satisfying those cuts yields a Λ^0 peak (rms width 2 MeV/c^2) with negligible background. A Λ^0 was defined as any event with invariant mass within ±8 MeV/c^2 of the central value of 1.1156 GeV/c^2.

The $\Lambda^0\gamma$ invariant mass was calculated for those 2Tγ triggers having a $\Lambda_{p\pi}$ decay satisfying the same cuts as the Λ^0's above. The photon energy was determined from the sum of the energies in the nine blocks centered on the block with the maximum energy in the array. Showers centered in blocks at the edges of the array were rejected. The photon direction was taken as the line between the Λ^0 origin in the target and the nine block energy centroid. The $\Lambda^0\gamma$ invariant mass distribution is shown in fig. 1a. In order to improve the signal to noise, the original calibration of each lead glass element was adjusted according to a least square fit to the Σ^0 mass, resulting in an average energy resolution of 6% (rms) for photon energies between 0.8 and 3.8 GeV. The $\Lambda\gamma$ invariant mass distribution after the fit is shown in fig. 1b. In both figures, a Σ^0 peak is apparent, centered around 1.19 GeV/c^2.

The data were examined both as a function of p, the magnitude of the momentum of the produced particle, and as function of p_T, the momentum of the particle transverse to the incident proton beam. In each case, the data were binned in the appropriate variable (p or p_T) and the following analysis procedure was used to extract the ratio of production cross sections.

The number of Λ^0 events observed in each bin, N_Λ, is given by the number of 2T triggers passing the cuts described above minus the estimated background under the peak, typically 1.5%. The number of Σ^0 events in each bin, N_Σ, was found by fitting the $\Lambda\gamma$ invariant mass histogram, above 1.15 GeV/c^2, with a gaussian

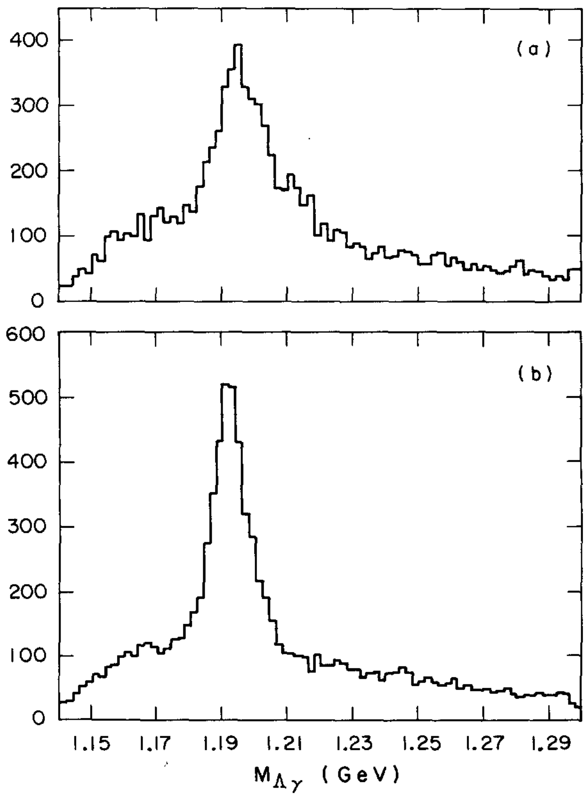

Fig. 1. Invariant $\Lambda^0\gamma$ mass distribution (a) using calibrations for lead glass blocks from test beam studies (b) using adjusted calibrations – see text. A Σ^0 peak is evident.

signal plus an exponential background. The average χ^2 for these fits was 80 for 70 degrees of freedom. The fitted background function was subtracted from the data to give N_Σ. Several systematic corrections were applied to N_Σ. These included an estimate of the number of photons lost due to early conversion in the target or spectrometer (13 ± 1)%; lifetime corrections for 2Tγ triggers (< 1%); and effects due to photon reconstruction and the energy calibration procedure (< 3%).

The relative acceptance for Λ^0 and Σ^0 events, A_Λ/A_Σ, was calculated using a Monte Carlo program. Acceptances were determined by passing Monte Carlo generated events through the same reconstruction and analysis procedures used for the data and taking the ratio of observed to generated events in each p or p_T bin. The Monte Carlo program included such effects as multiple Coulomb scattering, measured chamber resolutions, hodoscope efficiencies, and $\pi \to \mu\nu$ decays in flight. The effects of both Λ^0 and Σ^0 polarization on the acceptance were also investigated. The Λ^0 polarization was taken from ref. [2], which measured the Λ^0 polarization in this beam. The Σ^0 polarization was taken to be equal and opposite to that of the Λ^0, as suggested by recent data on Σ^- and Σ^+ [6,8]. Monte Carlo calculations assuming unpolarized Λ^0's and Σ^0's were made for comparison. The acceptance for these extremes was found to be the same within statistics. The acceptance ratio A_Λ/A_Σ decreased with increasing momentum, with an average value on the order of 50.

The ratio of the cross section for Σ^0 inclusive production to the cross section for Λ^0 inclusive production, R_1, was determined in each bin as follows:

$$R_1 = (N_\Sigma/N_\Lambda)(A_\Lambda/A_\Sigma)(1/\text{Prescale})\ \text{BR}\,,$$

where the prescale is 64 and BR is the ratio of the decay branching ratios for the two particles. Since the branching ratio for $\Sigma^0 \to \Lambda\gamma$ is ~100%, BR is 1. In fig. 2, the solid circles show R_1 plotted against p and p_T. R_1 does not depend strongly on either p or p_T over the range observed. The weighted average for R_1 is 0.278 ± 0.011 ± 0.05. The first uncertainty is statistical and the second is an estimate of systematic uncertainties.

It should be noted that this result includes all sources for Λ^0 production. The major contributions are "directly produced" Λ^0's (including resonance

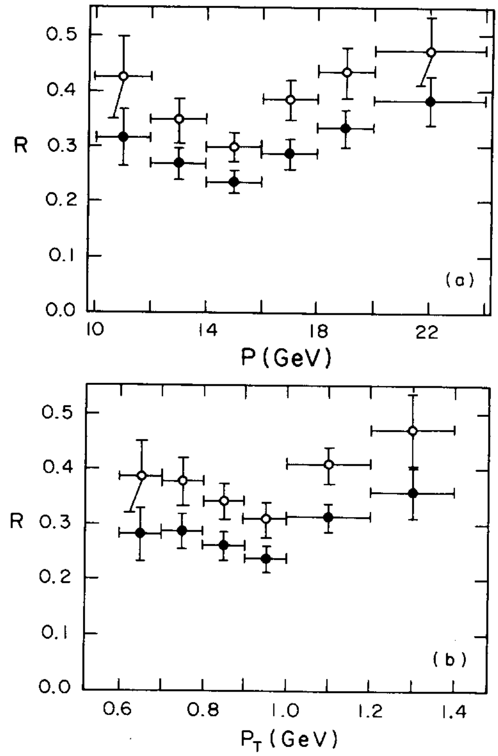

Fig. 2. R_1, the ratio of Σ^0 inclusive production to Λ^0 inclusive production, is shown with solid circles versus (a) p, the momentum of the produced particle and (b) p_T, the transverse momentum of the produced particle. R_2, the ratio of Σ^0 inclusive production to directly produced Λ^0 production, is shown with open circles versus (a) p and (b) p_T. In both cases, the errors are statistical only.

production), Λ^0's from Σ^0 decay and Λ^0's from Ξ^0 decay. The contribution from Ξ^0 decay is estimated to be less than one percent since production is only a few percent of Λ^0 production [9] and the spectrometer acceptance for the $\Xi^0 \to \Lambda^0 + \pi^0$ decay with the requirement that the Λ^0 point back to the target is quite small.

Assuming that there are only two contributions (prompt Λ^0's and Σ^0 decay Λ^0's) a value for R_2, the ratio of the cross section for Σ^0 inclusive production to the cross section for prompt Λ^0 production can be extracted. The data analyzed were to measure r, the ratio of Σ^0 decay Λ^0's to the total Λ^0 production. Then R_2 is obtained with the relation $R_2 = R_1/(1-r)$. In fig. 2, the open circles show R_2 plotted versus p and p_T. In the range under investigation, Σ^0 production is

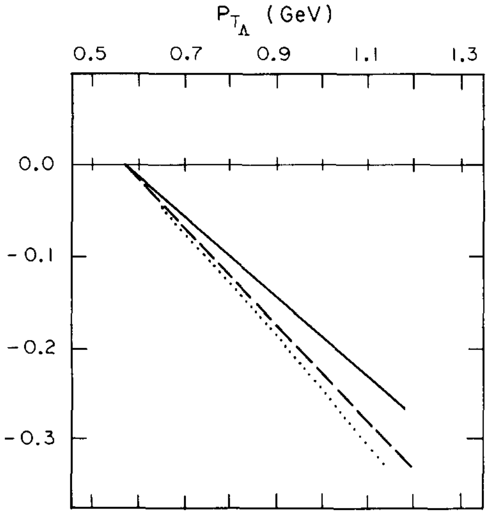

Fig. 3. The effect of this measurement on a previous Λ^0 polarization experiment. The solid line is the fit to the polarization data determined in ref. [2]. The dashed line results if Σ^0 polarization is equal and opposite to that of the observed Λ^0 polarization. The dotted line results if the Σ^0 are produced unpolarized.

approximately 36% of prompt Λ^0 production.

Previous determinations of Λ^0 polarization in inclusive processes should be re-examined. Not only does Σ^0 production represent a large contribution to Λ^0 production but also on the average, Λ^0's from Σ^0 decay retain $-1/3$ of the Σ^0 polarization. For example, data from this experiment may be used to estimate the effect of Σ^0 contamination on the Λ^0 polarization measurement in ref. [2]. Ref. [2] presents Λ^0 polarization as a function of p_T, the transverse momentum of the Λ^0. To determine the contamination from Σ^0's as a function of the Λ^0 transverse momentum, the data were re-analyzed binning in that variable. The Λ^0 polarization measured in ref. [2] was then corrected under two different assumptions regarding Σ^0 polarization. In fig. 3, the solid line is the fit to the polarization data obtained in ref. [2]. The dashed line results if Σ^0 polarization is equal and opposite to that of the observed Λ^0 polarization; the dotted line results if the Σ^0's are produced unpolarized. In each case the effect is significant.

We note that this result is the first measurement using protons of the Σ^0/Λ^0 inclusive production ratio in this energy range. Although it is similar in magnitude to that found in K^-p interactions [7], it does not agree with any of the predictions for this ratio. For example, a calculation [10] based on SU(6) formalism and polarization measurements predicts 0.11. It is amusing that the result obtained in this experiment is consistent with the simple argument that Σ and Λ productions should be equal. Since there are three Σ's, Σ^0/Λ^0 should be roughly one-third.

It is important to note that there are other sources of Λ^0's which are not directly produced such as baryon resonance production [7,11] (Σ(1385)). It therefore behooves any theoretical model of the the hyperon polarization phenomenon to account for these non-direct contributions. Models without such effects may be slightly naive and it is entirely likely that the agreement between theory and experiment has been fortuitous.

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