Study of Inclusive K_S^0, Λ, and $\overline{\Lambda}$ Production in Diffractive γp Interactions

S. Bhadra, J. A. Appel, D. F. Bartlett, B. H. Denby, J. Biel, D. Bintinger, V. K. Bharadwaj, D. E. Blodgett, S. B. Bracker, J. Bronstein, C. Daum, A. L. Duncan, A. M. Eisner, J. R. Elliott, P. Estabrooks, G. F. Hartner, G. R. Kalbfleisch, R. G. Kennett, B. R. Kumar, M. J. Losty, A. Lu, G. J. Luste, P. M. Mantsch, J. F. Martin, R. J. Morrison, T. Nash, U. Nauenberg, J. Pinfold, M. Robertson, W. Schmidke, K. K. Shahbazian, R. A. Sheperd, K. Sliwa, M. D. Sokoloff, W. J. Spalding, J. Stacey, K. C. Stanfield, M. Streetman, D. J. Summers, S. E. Willis, M. S. Witherell, S. J. Yellin, and C. J. Zorn

The University of Colorado, Boulder, Colorado 80309
The University of California at Santa Barbara, Santa Barbara, California 93106
Carleton University, Ottawa K1S 5B6, Canada
The Fermi National Accelerator Laboratory, Batavia, Illinois 60510
The National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada
The University of Oklahoma, Norman, Oklahoma 73019
The University of Toronto, Toronto M5S 1A7, Canada

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We have studied inclusive K_S, Λ, and $\overline{\Lambda}$ photoproduction over the ranges $40 < E_\gamma < 170$ GeV and forward produced mass $2 < M_F < 10$ GeV. We observe equal Λ and $\overline{\Lambda}$ production rates and spectra as expected in a diffractive process where the target proton remains unaltered. We show that the fraction of hadronic events with a strange particle produced in events with forward mass M_F agrees well with the same measurement in e^+e^- annihilation at a center-of-mass energy $E_{\rm c.m.} = M_F$. The $x = 2P/M_F$ distributions of these three particles in the forward-mass rest frame are compared with theoretical predictions.

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The inclusive production of K_S, Λ, and $\overline{\Lambda}$ in photon-initiated reactions and in e^+e^- annihilation can be used to compare the dynamics of strange-particle production in the two reactions. Any observed differences may indicate variations in the structure of the initial states or in the hadronization process in each reaction. In this experiment we show that the fraction of K_S, Λ, or $\overline{\Lambda}$ produced in diffractive photoproduction is very similar to that in e^+e^- annihilation. This comparison, which has never been possible before, is made by comparison of our measured photoproduction rates at a given forward mass, M_F, with the existing e^+e^- data at a center-of-mass energy $E_{\rm c.m.} = M_F$.

Our measurement of $\gamma + p \rightarrow K_S(\Lambda, \overline{\Lambda}) + X + p_{\rm recoil}$ used the Fermilab tagged-photon spectrometer (TPS). This detector consisted of a large-acceptance forward spectrometer and a highly segmented recoil detector with both tracking and dE/dx capabilities.[1,2] In addition, a tagging system gave a good measurement of the incident photon energy. The photon beam was generated by a 170-GeV electron beam impinging on a 0.2-radiation-length-thick Cu radiator. The photons then interacted in a 1.5-m liquid-hydrogen target. The error in the photon energy was $\sim 5\%$.

In this experiment the forward mass was calculated as a missing mass with use of the measurements of the recoil proton. A trigger processor[3] was used to select rapidly the events with single recoiling protons, was able to calculate the produced forward mass, and allowed us to record only events with a forward mass greater than 2 GeV. The error in the forward mass averaged 2.5%. In addition, the recoil detector determined not only that the recoil was a proton, but also that it was not associated with other particles present in the recoil detector. This allowed us to know whether the recoiling proton was the original target or whether it resulted from a recoiling N^* decay. The latter protons would give rise to a calculated forward (or missing) mass larger than the actual value.

The data presented in the report consist of a sample in which there was only one charged particle in the recoil detector, and it was identified as a proton. Hence we are studying particle production via the process generally described as "diffractive."

We made a detailed study of how often the forward mass was miscalculated because the proton was really a byproduct of a N^* decay where the associated pions were *not* observed in the recoil detector. This study was done with events in which the forward system of particles was fully reconstructed by the spectrometer.[4] The conclusion was that the average fraction of the herein-reported data with incorrectly determined mass values was about 8%. The maximum fraction, which occurred for $6 < M_F < 8$ GeV, was 12%.

The numbers of $K_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$, and $\overline{\Lambda} \rightarrow \overline{p}\pi^+$ events were determined from the size of the clear peak above background seen in the diparticle mass spectra. The background was effectively reduced

TABLE I. Number of events observed.

Mass (GeV)	Hadronic events	$K_S \to \pi^+\pi^-$	$\Lambda \to p\pi^-$	$\bar{\Lambda} \to \bar{p}\pi^+$
2–4	371 198	8192 ± 229	584 ± 56	505 ± 154
4–6	388 683	$10\,814 \pm 344$	1399 ± 115	1279 ± 124
6–8	368 202	$10\,309 \pm 337$	1492 ± 118	1509 ± 132
8–10	209 248	5736 ± 269	1032 ± 97	923 ± 111

by cuts in the distance of closest approach (<1 cm) between the charged tracks and by the requirement that the Cherenkov counter within the spectrometer identify the tracks as pions or protons in the appropriate cases. While the background was reduced by a factor of 3 for K_S and 9 for $\Lambda, \bar{\Lambda}$ decays, the loss of signal was no more than 15%. These factors were reproduced by our Monte Carlo program which included a detector simulation. The number of events observed is shown in Table I. The signal-to-background ratio for $\Lambda, \bar{\Lambda}$ and for K_S was 1 to 4.0 and 1 to 2.5, respectively. These totals were corrected for decay branching ratios, losses due to detector inefficiencies, and decays outside the active region of the detector.

The photoproduction data were analyzed as a function of both the center-of-mass energy and the forward mass. In Fig. 1 we show the number of K_S, Λ, $\bar{\Lambda}$ per hadronic event as a function of the forward mass for various incident photon energies. The data indicate that the production of these particles does not depend on the incident energy for a given forward mass, while it does depend on the forward mass for a given photon energy. Hence we conclude that the forward mass is the more relevant variable in this problem. This is similar to the behavior in hadronic spectra.[5]

Hadronic reactions have not generally been analyzed in terms of the forward mass, but in terms of the available energy ($E_{\text{avail}} = E_{\text{c.m.}} - \sum M_{\text{initial}}$). We show, for completeness, in Fig. 2, a comparison of K_S production for various comparable photon[6] and hadronic reactions[7] in terms of this variable. Our data points, because we only triggered on $M_F > 2$ GeV, have been corrected for that part of the K_S and hadronic cross section with $M_F < 2$ GeV.[9] This leads to a reduction in the fraction of K_S by the factor 0.70 ± 0.07. The similarity between photon-induced and pion-induced

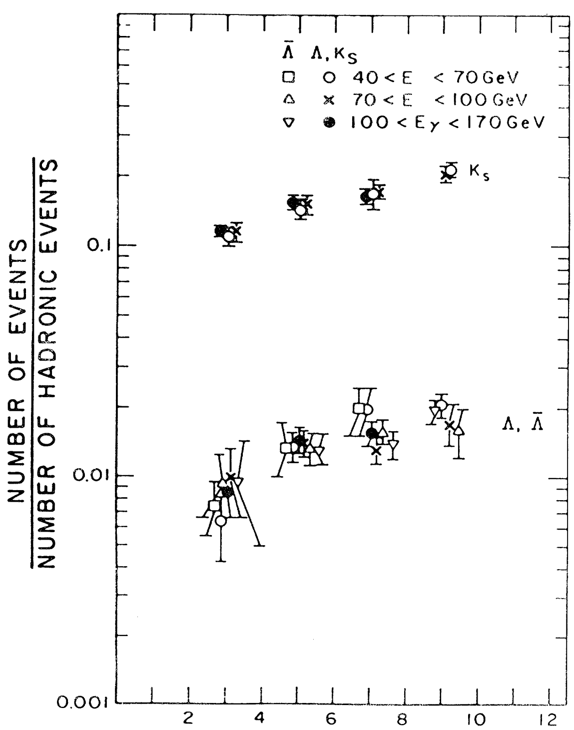

FIG. 1. Fraction of hadronic events with a K_S, Λ, or $\bar{\Lambda}$ in the final state as a function of the forward mass for various incident photon energies.

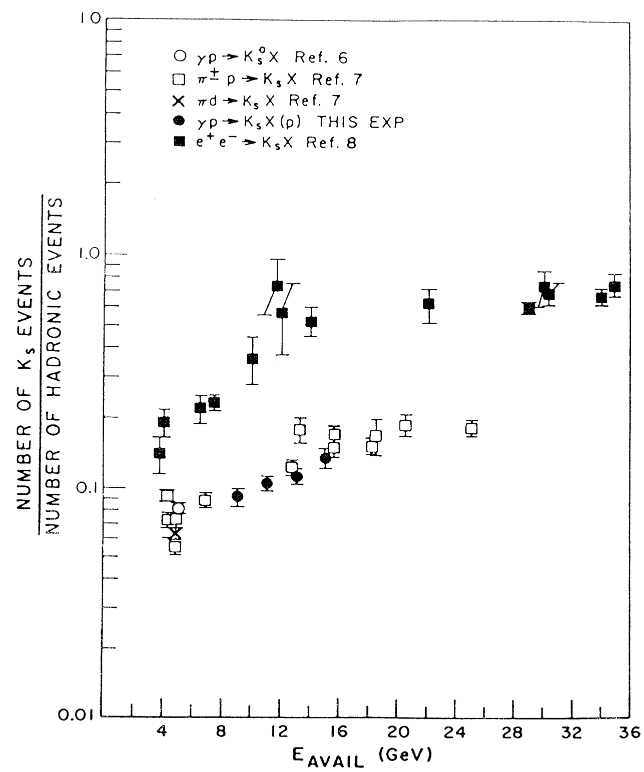

FIG. 2. Fraction of hadronic events with a K_S in the final state as a function of the available energy ($E_{\text{avail}} = E_{\text{c.m.}} - \sum M_{\text{initial}}$). The comparison data are from Refs. 6–8. The errors on the data points of this experiment do not include an overall normalization error of $\pm 10\%$ due to the correction for low-mass events.

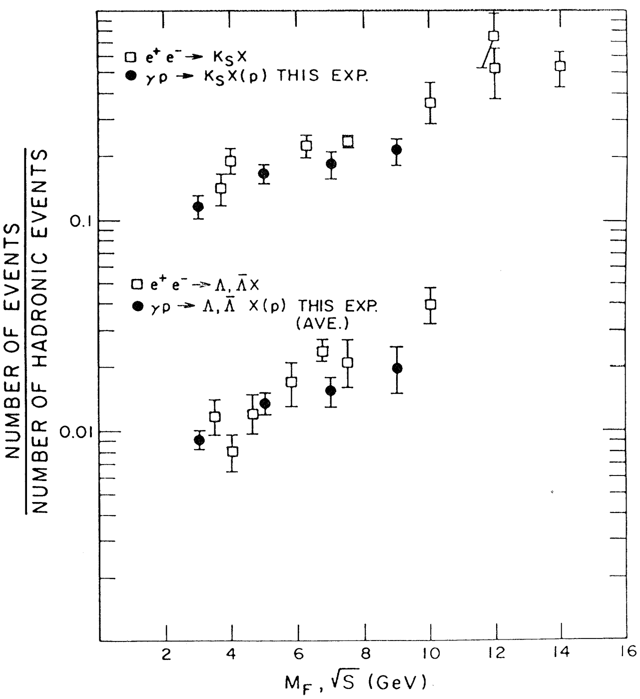

FIG. 3. Fraction of hadronic events with a K_s, Λ, or $\overline{\Lambda}$ in the final state as a function of the forward mass for this experiment and as a function of $E_{\text{c.m.}}$ for e^+e^- annihilation for $E_{\text{c.m.}} < 14$ GeV. The comparison data are from Ref. 8.

reactions is clear, as is the discrepancy between these and e^+e^- annihilation[8] when plotted in this variable. A similar comparison in the case of Λ and $\overline{\Lambda}$ production yields the same conclusions.

In Fig. 3 we compare our results on K_S, Λ, and $\overline{\Lambda}$ production as a function of the forward mass M_F with those in e^+e^- annihilation[8] at the center-of-mass energy $E_{\text{c.m.}} = M_F$. The $\Lambda, \overline{\Lambda}$ data are averaged since they are equal. The agreement between these two reactions is striking. The only discrepancy is at high mass, where the production in e^+e^- annihilation may be slightly larger than in photoproduction. Hence we are led to the main conclusion of this study: The photon-initiated diffractive production of strange particles in mass sytems >2 GeV cannot be clearly distinguished with present-day measurements from that of an e^+e^- annihilation state with the same mass.

We have also measured the distribution in Feynman $x_F = 2P/M_F$ of the K_S, Λ, and $\overline{\Lambda}$. The data for $x_F\, d\sigma/dx_F$ were fitted by the form $A(1-x_F)^\alpha$. The values of α which we obtained were $\alpha = 1.8 \pm 0.4$ for K_S and 3.04 ± 0.87 for $\Lambda + \overline{\Lambda}$. These results are in marginal agreement with predictions of photon fragmentation models ($\alpha = 1$ for K_S, $\alpha = 2$ for $\Lambda, \overline{\Lambda}$).[10] Finally, we have also observed $\Xi^-, \overline{\Xi}^-$ production. The ratio of Ξ to Λ production is 0.07 ± 0.015. This result is in good agreement with the same ratio in e^+e^- annihilation.[11]

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