inconsistent $[P(\chi^2) < 0.01]$ with a pure high-Z composition ($Z \geq 15$). This latter conclusion is quite insensitive either to the model of EAS or to the method of generating the burst patterns. (3) The BASJE data are adequately described by a composition similar to that at $\sim 10^{11}$ eV.

These results indicate that any rigidity cutoff which exists for the galactic component of cosmic rays has not yet become important at 10^{15} eV.

We express our gratitude to the entire participating staff of the BASJE. In particular we thank Dr. K. Suga for his role in the design and installation of the shielded detectors, and Dr. K. Kamata and Dr. M. LaPointe for making the data reported herein available to us.

*This work was supported in part by the U.S. Air Force Office of Scientific Research under Contract No. F-44-620-67-C-0020 and the U.S. Atomic Energy Commission under Contract No. AT(30-1)2098.

[1]H. V. Bradt and S. Rappaport, Phys. Rev. 164, 1567 (1967).

[2]V. I. Ginzburg and S. I. Syrovatsky, in The Origin of Cosmic Rays, translated by H. S. W. Massey and edited by D. ter Haar (The MacMillan Company, New York, 1964). The low-energy composition quoted here was determined under the assumption of a logarithmic slope of −1.5 for the primary integral energy spectrum near 10^{11} eV.

[3]N. L. Grigorov, V. E. Nesterov, I. D. Rapoport, I. A. Savenko, G. A. Skuridin, and A. F. Titenkov, Kosmich. Issled., Akad. Nauk SSSR 5, 395 (1967).

[4]A. Krieger and H. V. Bradt, to be published.

[5]J. Linsley and L. Scarsi, Phys. Rev. Letters 9, 123 (1962).

[6]C. B. A. McCusker, L. S. Peak, and M. H. Rathgeber, Phys. Rev. 177, 1902 (1969).

[7]N. M. Nesterova and S. I. Nikolsky, Zh. Eksperim. i Teor. Fiz. 46, 1908 (1964) [translation: Soviet Phys. −JETP 19, 1285 (1964)].

[8]K. J. Orford and K. E. Turver, Nature 219, 706 (1968).

[9]Y. Toyoda, K. Suga, K. Murakami, H. Hasegawa, S. Shibata, V. Domingo, I. Escobar, K. Kamata, H. Bradt, G. Clark, and M. LaPointe, in Proceedings of the Ninth International Conference on Cosmic Rays, London, England, 1965, edited by A. C. Stickland (The Institute of Physics and The Physical Society, London, England, 1966), Vol. 2, p. 708.

[10]I. W. Rogers, M. G. Thompson, M. J. Turner, and A. W. Wolfendale, to be published.

[11]K. Suga, I. Escobar, G. Clark, W. Hazen, A. Hendel, and K. Murakami, J. Phys. Soc. Japan Suppl. 17, 128 (1962).

[12]B. K. Chatterjee, G. T. Murthy, S. Naranan, B. V. Sreekantan, M. V. Srinivasa Rao, and S. C. Tonwar, in Proceedings of the Ninth International Conference on Cosmic Rays, London, England, 1965, edited by A. C. Stickland (The Institute of Physics and The Physical Society, London, England, 1966), Vol. 2, p. 802.

[13]T. Kameda, T. Maeda, H. Oda, and T. Sugihara, in Proceedings of the Ninth International Conference on Cosmic Rays, London, England, 1965, edited by A. C. Stickland (The Institute of Physics and The Physical Society, London, England, 1966), Vol. 2, p. 681.

LAMBDA POLARIZATION IN $K^- n \rightarrow \Lambda\pi^-$ AT 4.5 GeV/c *

W. L. Yen,‡ A. C. Ammann, D. D. Carmony, R. L. Eisner,§ A. F. Garfinkel, L. J. Gutay, R. V. Lakshmi, D. H. Miller, and G. W. Tautfest†
Department of Physics, Purdue University, Lafayette, Indiana 47907
(Received 13 January 1969)

An analysis is given of 236 events (102 ± 15 μb) of the reaction $K^- n \rightarrow \Lambda\pi^-$ at an incident momentum of 4.5 GeV/c. The lambda polarization is large and positive up to a squared four-momentum transfer of -2.0 (GeV/c)^2. The differential cross section has a dip near $-t = 0.4$ (GeV/c)^2. The differential cross section for 87 events of the reaction $K^- n \rightarrow \Sigma^0\pi^-$ is also shown corresponding to a total cross section of 39 ± 10 μb.

In this Letter we present data on the reactions

$$K^- d \rightarrow p_s \pi^- \Lambda, \qquad (1)$$

and

$$K^- d \rightarrow p_s \pi^- \Sigma^0 \qquad (2)$$

at an incident momentum of 4.48 GeV/c. The data were obtained from a 370 000-picture exposure in the Argonne National Laboratory 30-in. deuterium bubble chamber.[1,2] We have obtained 236 events of Reaction (1) and 87 events of Reaction (2) corresponding to cross sections of 102 ± 15 and 39 ± 10 μb.

The film was scanned for events of the types two-prong plus vee and one-prong plus vee. In the case of the two-prong events it was demanded that the positive particle be a proton with a momentum less than 300 MeV/c. This was to ensure that the events were predominately K^--neutron interactions with the proton being merely a spectator (p_S). In the impulse approximation[3] 98% of all spectator protons have a momentum less than 300 MeV/c.

All events of these topologies were measured and kinematically fitted using SQUAW. Events were then selected having a confidence level of at least 1% for Reaction (1) or Reaction (2). In this sample all Λ^0 and K^0 ambiguities were removed on the basis of χ^2 and ionization. In all 271 events had an acceptable fit to Reaction (1) but 212 of these also had an acceptable fit for Reaction (2) (i.e., a probability >1%). The events were assigned to the two final states on the basis of the ratio of the probabilities of the two fits. The validity of this technique was checked by examining the angular distribution of the photon from the Σ^0 decay with respect to the production plane.[4] We estimate 5±3% of the events assigned to Reaction (1) are in reality events from Reaction (2).

The Hulthén momentum distribution[3] was normalized to those events with visible spectators. The fitted spectator momentum distribution of the events measured with an invisible spectator agreed in both magnitude and shape with the normalized curve.[5] The number of events was corrected for unseen decays and detection efficiencies.[6] Total cross sections of 102±15 μb for Reaction (1) and 39±10 μb for Reaction (2) were then obtained.

The production angular distribution of the hyperon is shown in Figs. 1(a) and 1(b), and the differential cross section as a function of $-t$ (the squared four-momentum transfer between the incident K^- and the outgoing π^-) is shown in Figs. 2(a) and 2(b). A peripheral peak is observed for both reactions. A small number of events are produced at $\cos\theta^*$ greater than zero (where θ^* is the angle in the $Y\pi^-$ center of mass between the incident K^- and the outgoing hyperon). These events could have been produced either by nucleon exchange or by the decay of an s-channel resonance.[7] The partial cross sections for $\cos\theta^* > 0$ are 9±3 μb and 3±1 μb for Reactions (1) and (2), respectively.

The peripheral peaks have been fitted to the form $d\sigma/dt = Ae^{B(t-t_0)}$ (where t_0 is the maximum allowable four-momentum transfer squared); the results obtained are

$$A = 340 \pm 50\ \mu\text{b}/(\text{GeV}/c)^2,$$

$$B = 4.1 \pm 0.8\ (\text{GeV}/c)^{-2} \text{ for Reaction (1)};$$

$$A = 155 \pm 60\ \mu\text{b}/(\text{GeV}/c)^2,$$

$$B = 5.1 \pm 2.0\ (\text{GeV}/c)^{-2} \text{ for Reaction (2)}.$$

The experimental distributions start to deviate from this form above $-(t-t_0) = 0.5\ (\text{GeV}/c)^2$. At this point a shoulder is apparent in the differential cross section for Reaction (1). These slopes are consistent with meson exchange although they are somewhat smaller than those found in other hypercharge-exchange reactions.[8-11] If the process is mediated by the exchange of a single meson or trajectory, then the polarization of the lambda will be zero. This is because one-meson-exchange models even with absorption[12] have purely real amplitudes, while in the case of a single Regge trajectory the helicity flip and non-

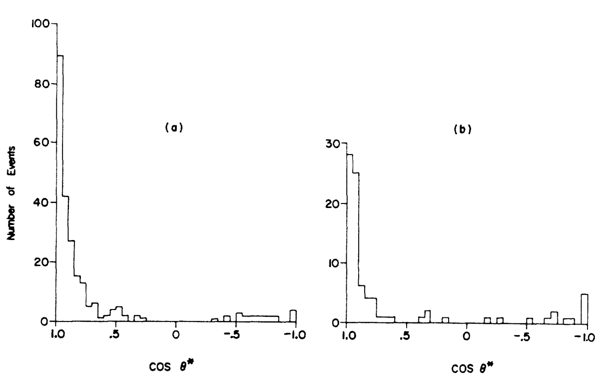

FIG. 1. (a) Production angular distribution of the lambda in the center-of-mass system for Reaction (1). (b) Production angular distribution of the Σ^0 in the center-of-mass system for Reaction (2).

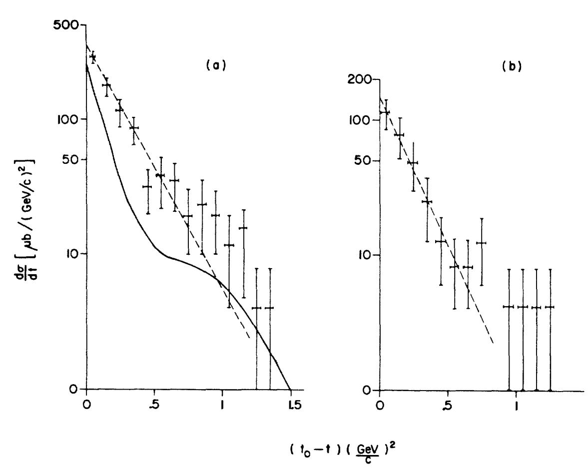

FIG. 2. (a) Differential cross section as a function of $-t$ for Reaction (1). The solid line is the prediction from D. D. Reeder and K. V. L. Sarma, Phys. Rev. 172, 1566 (1968). (b) Differential cross section as a function of $-t$ for Reaction (2). The dashed lines indicate the results of the fits to $d\sigma/dt = Ae^{B(t-t_0)}$.

flip amplitudes are in phase. The polarization of the lambda is given by

$$P=\frac{3}{\alpha N}\left[\sum_{i=1}^{N}(\hat{q}\cdot\hat{n})_i \pm\left(\sum_{i=1}^{N}(\hat{q}\cdot\hat{n})_i^2\right)^{1/2}\right], \qquad (3)$$

where $\alpha=0.647$ is the Λ asymmetry parameter[13] and N is the number of events in the chosen t interval. The unit vector q is along the decay proton direction in the hyperon center-of-mass system and $\hat{n}=\hat{P}_K\times\hat{P}_\pi/|\hat{P}_K\times\hat{P}_\pi|$ is a unit vector normal to the production plane. The polarization of the Λ as a function of $-t$ is shown in Fig. 3 for Reaction (1). No striking variation as a function of $-t$ is seen, the polarization remaining large and positive. This is in contrast to results on hypercharge-exchange reactions at neighboring energies,[9,14,15] where a change in sign is observed in the region of the dip in the differential-cross-section distribution. The presence of polarization indicates that more than one Regge trajectory is exchanged. We have compared our data with a double Regge model of Reeder and Sarma[16] who use $K^*(890)$ and $K^*(1420)$ exchanges to fit hypercharge-exchange reactions. These exchanges are denoted as q and Q exchange, and the predictions from their model are shown by the solid lines in Figs. 2 and 3.

Using their notation and parametrization, the trajectory functions α_q and α_Q and the crossover factor $(1+t/t_Q)$ vanish at $t=-0.4$, -0.35, and -0.53 $(\mathrm{GeV}/c)^2$, respectively. Thus a minimum in $d\sigma/dt$ should occur near $t=-0.4$ $(\mathrm{GeV}/c)^2$ where the trajectories pass through $\alpha(t)=0$. A dip occurs in the experimental differential cross section near $-t=0.4$ $(\mathrm{GeV}/c)^2$ indicating the passage of one or more of the trajectories through $\alpha(t)=0$ in this region. The model predicts a change in sign of polarization in this region coming from the crossover factor in the Q helicity nonflip amplitude. This change in sign is not observed experimentally. The crossover factor was used successfully to account for the change in sign of polarization in the reaction $\pi^+p\rightarrow\Sigma^+K^+$ at 3.23 GeV/c.[14] The shape of the experimental differential cross section agrees with that predicted by the model although it is somewhat larger in magnitude. Our data appear to indicate that the current adopted parameters of the $K^*(890)$ and $K^*(1420)$ trajectories are not sufficient to account for the properties of hypercharge exchange reactions as a function of energy.

Our experimental ratio of $\sigma(\Lambda\pi^-)/\sigma(\Sigma^0\pi^-)$ is in agreement with the predicted value of 3 from SU(3) and the independent quark model.[17] In addition the cross section for $K^-n\rightarrow\pi^-\Sigma^0$ is approximately half the quoted cross section[8] for $K^-p\rightarrow\pi^-\Sigma^+$ in agreement with Ref. 17. The forward cross section for $K^-n\rightarrow\Lambda\pi^-$ is not in agreement with the predicted ratio[17,18]

$$\left(\frac{d\sigma}{dt}\right)_0\left[\frac{K^-n\rightarrow\Lambda\pi^-}{K^-p\rightarrow\pi^-\Sigma^+}\right]=\tfrac{3}{2}, \qquad (4)$$

which we find experimentally to be 0.6 ± 0.2.

We would like to express our appreciation to the staff of the accelerator and bubble chamber at Argonne National Laboratory, Argonne, Illinois.

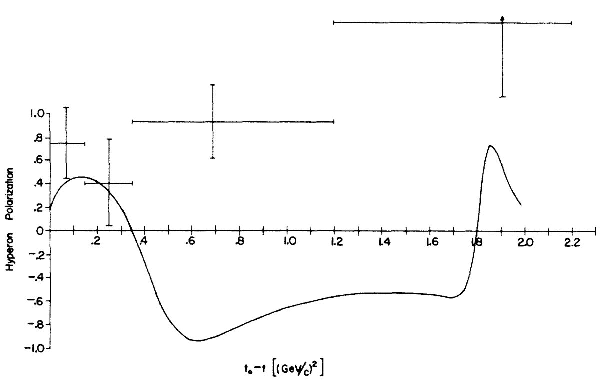

FIG. 3. Polarization of the lambda for Reaction (1) as a function of the square of the four-momentum transfer. The solid line is the prediction from D. D. Reeder and K. V. L. Sarma, Phys. Rev. 172, 1566 (1968).

*Work supported in part by the U. S. Atomic Energy Commission.

‡Now at Purdue University, Indianapolis, Ind.

§Now at Brookhaven National Laboratory, Upton, N. Y.

†Deceased.

[1]For further details of this experiment: R. L. Eisner, thesis, Purdue University, 1968 (unpublished).

[2]Reaction (1) and details of other final states containing a lambda can be found in W. L. Yen, thesis, Purdue University, 1968 (unpublished).

[3]L. Hulthén and M. Sugawara, in Handbuch der Physik, edited by S. Flugge (Springer-Verlag, Berlin, Germany, 1957), Vol. 39, p.1.

[4]The angular distribution of the γ ray from a Σ^0 decay with respect to the normal to the production plane should be isotropic for true Σ^0 events. Experimentally we find this is so for those events having a probability three times greater than that for the seven-constraint reaction (1). The other ambiguous events when interpreted as Reaction (2) show an extremely anisotropic distribution and were assigned to Reaction (1).

[5]The events with seen spectator proton are seven-con-

straint fits. In the case of invisible spectator protons, before entering the fitting procedure a momentum of zero was assigned to the spectator. The momentum had errors $P_x = P_y = 30$ MeV/c and $P_z = 40$ MeV/c. Once again the fit is a seven-constraint fit, this technique being the accepted one for reproducing the expected momentum distribution using the Fourier transform of the Hulthén wave function. The resolution for the invisible spectator events is only slightly worse than for the seen spectator events and does not affect the analysis.

[6]Our detection efficiency for events with unseen spectator was slightly less than for the seen spectator. This was so particularly for those events with small laboratory angle between the K^- and the π^-. A 4% correction was made to account for the screening effect.

[7]Our center-of mass energy E^* of the K^-n system covers the range $2.7 \lesssim E^* \lesssim 3.3$ because of the Fermi motion of the neutron. The backward hyperon events did not seem to come from any narrow resonance in this energy region.

[8]J. S. Loos, V. E. Kruse, and E. L. Goldwasser, Phys. Rev. 173, 1330 (1968).

[9]O. I. Dahl, L. M. Hardy, R. L. Hess, J. Kirz, D. H. Miller, and J. A. Schwartz, Phys. Rev. 163, 1430 (1968).

[10]D. J. Crennell, G. R. Kalbfleisch, K. W. Lai, J. M. Scarr, T. G. Schumann, I. O. Skillicorn, and M. S. Webster, Phys. Rev. Letters 18, 86 (1967).

[11]The reaction $\pi^- p \rightarrow \Lambda^0 K^0$ has $B = 7.5 \pm 2.0$ at 5 GeV/c. J. Weisbach, Purdue University, private communication.

[12]J. D. Jackson, Rev. Mod. Phys. 37, 484 (1965; J. D. Jackson, J. T. Donohue, K. Gottfried, R. Keyser, and B. E. Y. Svensson, Phys. Rev. 139, B428 (1965).

[13]A. H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and W. J. Willis, Rev. Mod. Phys. 40, 77 (1968).

[14]R. R. Kofler, R. W. Hartung, and D. D. Reeder, Phys. Rev. 163, 1479 (1967).

[15]The polarization in the reaction $\pi^- p \rightarrow \Lambda^0 K^0$ changes sign at $-t \sim 0.5$ (GeV/c)^2 at an incident momentum near 4 GeV/c (Ref. 9). There is evidence that this is still so at 5 GeV/c (Ref. 11), but at 6 GeV/c the polarization is consistent with zero for $-t < 0.5$ (Ref. 10).

[16]D. D. Reeder and K. V. L. Sarma, Phys. Rev. 172, 1566 (1968).

[17]M. P. Locher and H. Romer, Phys. Letters 23, 496 (1966).

[18]R. C. Arnold, Phys. Rev. 153, 1506 (1967).

PRODUCTION OF $K_2{}^0$ MESONS AND NEUTRONS BY 10- AND 16-GeV ELECTRONS ON BERYLLIUM*

A. D. Brody, W. B. Johnson, D. W. G. S. Leith, G. Loew, J. S. Loos, G. Luste, R. Miller, K. Moriyasu, B. C. Shen, W. M. Smart, and R. Yamartino
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 13 March 1969)

We have measured the $K_2{}^0$ yields for electron energies of 10 and 16 GeV and at production angles of 2° and 4°, using a 40-in. hydrogen bubble chamber as a $K_2{}^0$ detector. The observed yields are compared with the predictions of a model involving the intermediate photoproduction of $\varphi(1020)$ mesons. In addition, we have measured the relative neutron-to-$K_2{}^0$ ratio as a function of the secondary beam momentum.

The yields of strongly interacting charged particles produced in electron-Be collisions have been measured recently at the Stanford Linear Accelerator Center (SLAC) by several groups[1-4] and confirm the general features of the calculations made by Tsai[5] and others. We report here a measurement of the $K_2{}^0$ yields from Be for electron energies of 10 and 16 GeV and production angles of 2° and 4°. The SLAC 40-in. hydrogen bubble chamber was used as the $K_2{}^0$ decay detector. The observed $K_2{}^0$ yields are consistent with the average of K^+ and K^- yields reported previously.[1,2,4] A comparison with the $K_2{}^0$ yields expected from the photoproduction of $\varphi(1020)$ mesons indicates that this process alone cannot explain either the observed magnitude or the angular dependence of the data. A preliminary measurement of the intensity and momentum spectrum of neutrons at the chamber indicates that favorable $K_2{}^0$-to-neutron ratios may be obtained for secondary beam momenta above 2 GeV/c.

The primary electron beam from the accelerator was focused on a Be target which was mounted downstream of a vertical bending magnet. This magnet allowed variation of the production angle of the neutral beam within the range 1.5°-5°. The intensity of the electron beam was measured by use of a toroid charge integrator. The position and focus of the electron beam at the target were continuously monitored by a closed circuit television display of a ruled ZnS sheet attached to the upstream end of the Be target. The neutral beam passed through a sweeping magnet to clear out charged particles, a γ-ray