Brief Reports

Brief Reports are short papers which report on completed research which, while meeting the usual **Physical Review** *standards of scientific quality, does not warrant a regular article. (Addenda to papers previously published in the* **Physical Review** *by the same authors are included in Brief Reports.) A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Diffractive production of $K_S^0 K_S^0 \pi^-$ in $\pi^- N$ interactions at 200 GeV/c

T. Y. Chen,* E. W. Jenkins, K. J. Johnson,† K. W. Lai,
J. Le Britton, Y. C. Lin,‡ and A. E. Pifer
University of Arizona, Tucson, Arizona 85721

H. C. Fenker§ and D. R. Green
Fermilab, Batavia, Illinois 60510

J. R. Albright, R. N. Diamond, J. H. Goldman, S. L. Hagopian,
J. E. Lannutti, and J. E. Piper
Florida State University, Tallahassee, Florida 32306

C. C. Chang, T. C. Davis, and J. A. Poirier
University of Notre Dame, Notre Dame, Indiana 46556

A. Napier
Tufts University, Medford, Massachusetts 02155

J. M. Marraffino, C. E. Roos, J. W. Waters,
M. S. Webster, and E. G. H. Williams
Vanderbilt University, Nashville, Tennessee 37235

G. B. Collins, J. R. Ficenec, and W. P. Trower
Virginia Polytechnic Institute and State University,
Blacksburg, Virginia 24061

(Received 29 March 1983; revised manuscript received 27 July 1983)

The reaction $\pi^- N \rightarrow K_S^0 K_S^0 \pi^- N'$ at 200 GeV/c has been observed with a sensitivity of 450 ± 150 events/μb. The $K_S^0 K_S^0 \pi^-$ system exhibits substantial $K^{*-}(890)K^0$ production. Also produced are $f^0(1270)\pi^-$, $f'(1515)\pi^-$, and $K^{*-}(1430)K^0$ final states. These resonances occur predominantly at threshold. The diffractive $K_S^0 K_S^0 \pi^-$ cross section is 3.4 ± 1.1 μb. An enhancement near the A_3^- (1680) is observed in the $K_S^0 K_S^0 \pi^-$ invariant-mass distribution.

Although diffraction dissociation has been widely observed in high-energy hadroproduction experiments,[1–3] relatively little information[2] is available on the flavor dependence of this process. This paper presents the latest, highest-energy results on the diffraction dissociation of a 200-GeV/c π^- beam into $K_S^0 K_S^0 \pi^-$.

The experiment (E-580) was carried out in a 200-GeV/c π^- beam in the M6W line using the Fermilab Multiparticle Spectrometer.[4] A 20-element 13-cm-long scintillator target which provided longitudinal primary-vertex location was followed by a 2-m helium-filled decay region where neutral strange particles (V^0's) materialized into charged tracks. A bending magnet, which imparted a 697-MeV/c transverse-momentum change to each charged particle, was followed by a 30-cell atmospheric Cherenkov counter and by 24 large spark-chamber planes. A proportional-wire-chamber (PWC) system with 10^4 wires measured the incident beam, as well as primary and decay charged-particle trajectories before and after the magnet, and provided fast trigger information.

The experiment was designed to trigger with good acceptance in mass and momentum transfer on events in which two neutral strange particles were produced. The $V^0 V^0$ trigger required a charged-particle-multiplicity increase of 4 ± 1 in the decay volume by sampling two PWC's before and five PWC's after the decay volume. In addition, the primary charged multiplicity, measured before the decay volume, was less than 6. The incident beam rate of 6×10^5 π^- per sec yielded 1.2×10^6 triggers.

All triggers were processed through pattern recognition and geometry programs which performed three-dimensional fits to all track parameters using a detailed magnetic-field map. The K^0 effective mass has a full width at half maximum (FWHM) of 14 MeV/c^2 and the Λ a FWHM of 5 MeV/c^2. Constrained fits were made to the V^0 mass, V^0 decay vertex, and V^0-V^0-beam primary vertex. Approximately 70 500 events with fit probabilities greater than 10^{-5}, 3×10^{-3}, and 3×10^{-3}, respectively, were accepted, of which 62% were $K_S^0K_S^0$, 16% $K_S^0\Lambda$, 13% $K_S^0\bar{\Lambda}$, 8% $\Lambda\bar{\Lambda}$, and 1% $\Lambda\Lambda$ or $\bar{\Lambda}\bar{\Lambda}$.

This paper is based on a sample of 4257 $K_S^0K_S^0$ events which had one and only one negatively charged primary track passing through the spectrometer. The estimated Λ, $\bar{\Lambda}$ contamination in this sample is 2%. The angular acceptance of the spectrometer magnet was ±84 mrad horizontally and ±50 mrad vertically. The geometrical acceptance was calculated by producing, for each observed event, 100 identical events rotated about the beam axis and tracing each particle through the aperture of the magnet and tracking chambers while avoiding a beam veto counter. The mean efficiency for events with recoiling mass squared (MM^2) less than 16 (GeV/c^2)^2 (see next paragraph) is $(91.8\pm0.1)\%$, where the error is purely statistical. This acceptance, which is reduced to 16.7% when the K_S^0 decay probabilities are included, is flat for $K_S^0K_S^0$ masses up to 3 GeV/c^2 and for t up to 2 (GeV/c)^2. We are, however, biased against very small t because of a fast pretrigger requirement of a greater-than-minimum pulse height from at least one quadrant of the active target. This trigger requirement loses events with $t<0.009$ (GeV/c)^2 for production from nucleons or with $t<0.1$ (GeV/c)^2 for production from carbon. Trigger and track-reconstruction inefficiencies lead to systematic uncertainties in the cross section. If we normalize our data by parametrizing the inclusive $(K_S^0K_S^0)$ data of Ref. 5 by e^{-6x}, where $x=2P_L^{\text{c.m.}}/\sqrt{s}$, taking our x-dependent acceptance from Monte Carlo, we find an average sensitivity for diffractive $K_S^0K_S^0$ events to be 450 ± 150 events/μb.

To isolate the diffractive component in our $K_S^0K_S^0\pi^-$ data, we plot the recoiling mass squared (MM^2) in Fig. 1(a) assuming a nucleon target. We observe a prominent low-mass peak whose FWHM is only slightly greater than the calculated spectrometer resolution of 14.0 (GeV/c^2)^2 FWHM. The curve in Fig. 1(a) is the result of a fit using a logarithmic-normal distribution,[6] plus polynomial background. The shape of the peak indicates the presence of diffractively excited nucleon states which we are unable to resolve from an unexcited nucleon. This double diffraction, whose $1/M^2$ behavior[7] is reproduced by our fitted distribution, is estimated to be $\sim\frac{1}{3}$ of the MM^2 peak.[8] In all of the discussions that follow we require MM$^2<16$ (GeV/c^2)^2 in order to minimize the background from inelastic processes. This background is still $(25\pm2)\%$, while double diffraction is $\sim7\%$ of the 992 surviving events. Removing this background implies a single-diffractive $\pi^-\to K_S^0K_S^0\pi^-$ cross section of 3.4 ± 1.1 μb. When compared with lower-energy results,[9] these data indicate a weak $(P_{\text{lab}}^{-0.3\pm0.15})$ energy dependence.

In Fig. 1(b) we plot the variable t', defined as $t'=|t-t_{\min}|$, where t is the square of the four-momentum transfer from the beam to the $K_S^0K_S^0\pi^-$ system. A fit to the distribution of the form $dN/dt'=Ae^{-Bt'}+Ce^{-Dt'}$ yields $A=127.0\pm14.8$ events/0.04 (GeV/c)^2, $B=9.6\pm1.9$ (GeV/c)$^{-2}$, $C=48.1\pm9.9$ events/0.04 (GeV/c)^2, and

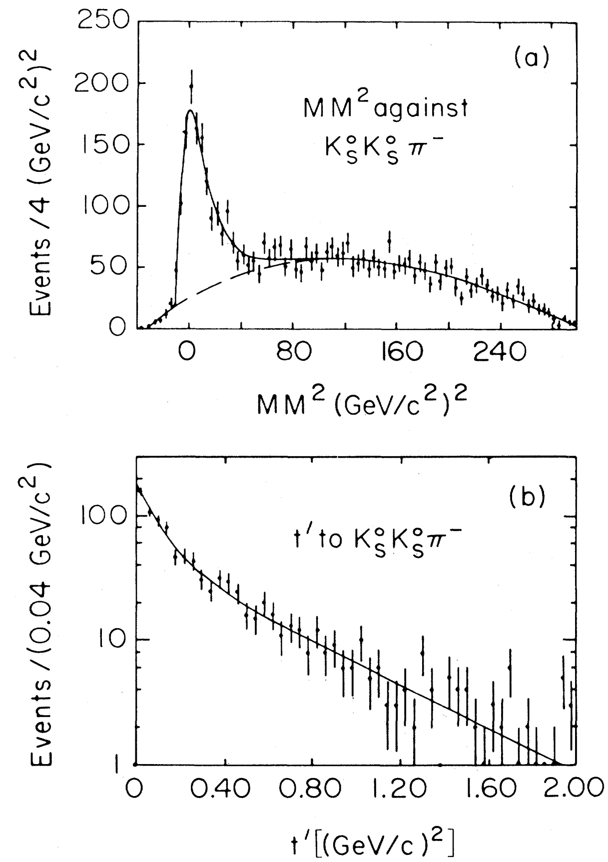

FIG. 1. (a) Missing mass squared for all $K_S^0K_S^0\pi^-$ final-state events. (b) t' for the sample of events with MM$^2(KK\pi)\leq16$ (GeV/c^2)^2. The curves are explained in the text.

$D=2.0\pm0.2$ (GeV/c)$^{-2}$. The value of the slope parameter B is consistent with values found at lower energies,[10] with that found for 3π diffractive production,[3] and with values for pion-nucleon elastic scattering.[11] The value of the slope parameter D is consistent with that obtained in fitting the t' distribution for events with MM$^2>16$ (GeV/c^2)^2. Our t' resolution ($\sigma\sim0.023$ GeV^2/c^2 at low t') is such that coherent production from carbon in our target would appear in the first bin of Fig. 1(b) were it not for the trigger bias previously described. The t'-slope parameter B decreases with $K_S^0K_S^0\pi^-$ mass in a manner characteristic of diffractive processes.[1,3]

We display in Fig. 2 the $K_S^0K_S^0\pi^-$ mass distribution and note an excess of events at a mass ~1.7 GeV/c^2. This peak is in the region of the A_3^- (1680), but is at slightly too high a mass and is narrower than the A_3^- reported by Daum *et al.*[3] Because of the large background of unknown shape, the A_3^- content of this mass region is difficult to determine.

The $K_S^0K_S^0$ mass distribution for our 992 event sample is shown in Fig. 3(a). The curve representing the background has the form $e^{-cm}m'^a(1-m')^b$, where $m'=(m-m_{\min})/(m_{\max}-m_{\min})$. The choice of background parametrization is arbitrary. Ordinary phase space is not a good representation of the background, because a resonance in one channel will through energy conservation distort the background mass

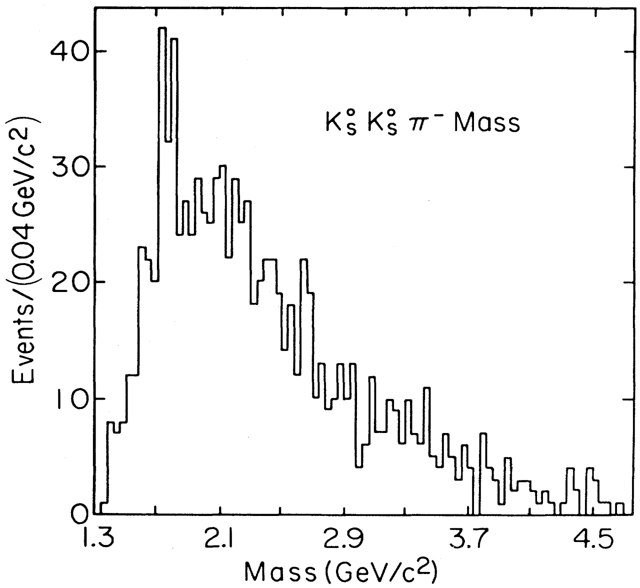

FIG. 2. For the sample with $MM^2 < 16$ GeV/c^2, the $K_S^0K_S^0\pi^-$ effective-mass distribution.

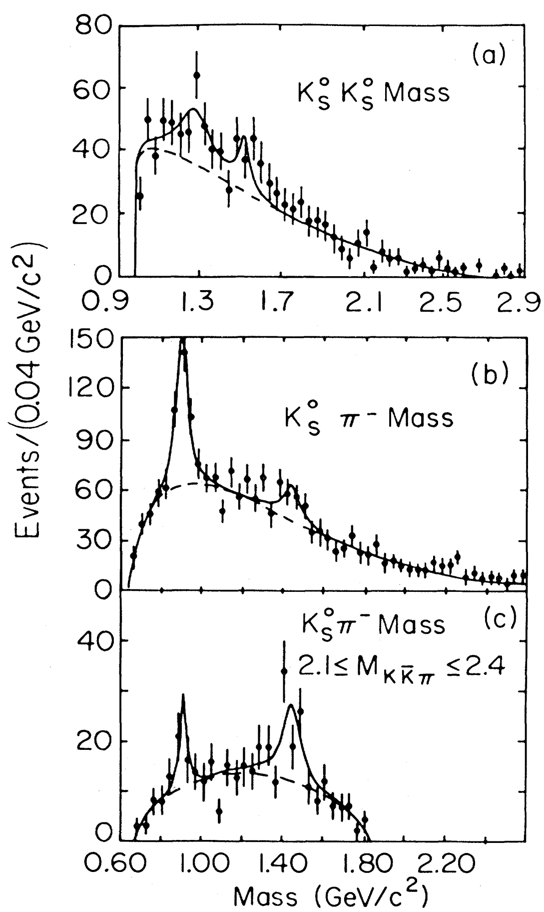

FIG. 3. For the sample with $MM^2(KK\pi) \le 16$ (GeV/c^2)^2: (a) the $K_S^0K_S^0$ effective-mass distribution, (b) the $K_S^0\pi^-$ effective-mass distribution, and (c) the $K_S^0\pi^-$ effective-mass distribution, with the $K_S^0K_S^0\pi^-$ mass between 2.1 and 2.4 (GeV/c^2). The curves are explained in the text.

spectrum in another channel. In particular, three-body phase space does not reproduce the large $K_S^0K_S^0$ signal just above threshold. Breit-Wigner resonance forms with the mass and width for the f^0 and f' fixed at the Particle Data Group values[12] added to the background are respectively found to constitute $(8 \pm 4)\%$ and $(6 \pm 2)\%$ of the $K_S^0K_S^0$ data. The fit was obtained by χ^2 minimization of the background plus resonance forms to the histogram. The contributions of the resonances were constrained to be positive and estimated by integration over an interval of three resonance widths. As the χ^2 probability for the fit in Fig. 3(a) is only slightly better with the inclusion of the resonance forms than without, the significance of the f^0 and f' signals is marginal.

In Fig. 3(b) we show the $K_S^0\pi^-$ mass distribution (two combinations/event) and estimate the amount of $K^{*-}(890)$ to be $(21 \pm 3)\%$ of the data. We have added Breit-Wigner resonance forms for the higher-mass K^*'s, but although the χ^2 probability for the fit improves by a factor of 2, the evidence in Fig. 3(b) for $K^{*-}(1430)$, for example, is not compelling.

When we look at the $K_S^0K_S^0$ and $K_S^0\pi^-$ mass distributions for eight intervals of $K_S^0K_S^0\pi^-$ mass, chosen so as to provide roughly equal statistics, the underlying resonance structure becomes clearer. As an example, in Fig. 3(c) we show the $K_S^0\pi^-$ mass when we require the $K_S^0K_S^0\pi^-$ mass to lie between 2.1 and 2.4 GeV/c^2. We note the significant $K^{*-}(1430)$ signal. In each of the $K_S^0K_S^0\pi^-$ mass intervals the number of events for each known $K_S^0K_S^0$ or $K_S^0\pi^-$ resonance was determined by fitting a Breit-Wigner resonance form plus background to the mass spectrum. The χ^2 probability for the fit in Fig. 3(c) is an order of magnitude greater with the $K^{*-}(1430)$ resonance included than when it is omitted.

We summarize our results in Fig. 4. In Figs. 4(a) and 4(b) we plot the number of f^0 and f' events and in Figs.

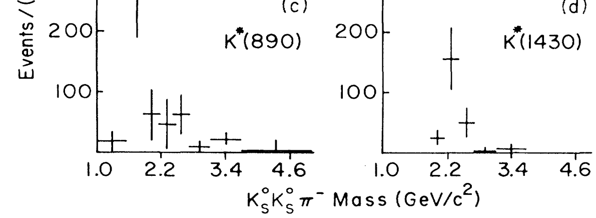

FIG. 4. For the sample with $MM^2 < 16$ (GeV/c^2)^2: (a) and (b), respectively, the number of $[f^0(1270)\pi^- \rightarrow K_S^0K_S^0\pi^-]$ events and $[f'(1515)\pi^- \rightarrow K_S^0K_S^0\pi^-]$ events per GeV/c^2 of $K_S^0K_S^0\pi^-$ mass; (c) and (d), respectively, the number of $[K^{*-}(890)K_S^0 \rightarrow K_S^0\pi^-K_S^0]$ and $[K^{*-}(1430)K_S^0 \rightarrow K_S^0\pi^-K_S^0]$ per GeV/c^2 of $K_S^0K_S^0\pi^-$ mass.

4(c) and 4(d) the number of K^* events per GeV/c^2 of $K_S^0 K_S^0 \pi^-$ mass. One can clearly see in Figs. 4(c) and 4(d) the $K^{*-}(890)$ and $K^{*-}(1430)$ being produced once their thresholds are crossed. The f^0 and f' in Figs. 4(a) and 4(b) are also most prominent at threshold.

In summary, we have observed a clear signal for the diffractive dissociation of π^- into $K_S^0 K_S^0 \pi^-$. In the low-mass region of the $K_S^0 K_S^0 \pi^-$ spectrum we have found some evidence for the A_3^- (1680). We have noted strong resonance production in the $K_S^0 \pi^-$ substate but less significant resonance production in the $K_S^0 K_S^0$ substate. The production of $f^0(1270)$, $f'(1515)$, $K^{*-}(890)$, and $K^{*-}(1430)$ appears to be most prominent at threshold.[13]

We thank the Fermilab staff, especially S. Hansen and R. Cantel, for their valuable help during the experiment. Z. Ma and C. Young provided helpful support. We wish to acknowledge J. Owens for valuable discsussions. This work was supported in part by Department of Energy contracts (Arizona, Florida State, Tufts) and National Science Foundation grants (Arizona, Notre Dame, Vanderbilt, and Virginia Tech).

---

*Present address: Department of Physics, Nanking University, Nanking, People's Republic of China.

†Present address: University of Notre Dame, Notre Dame, Indiana 46556.

‡Present address: 1782 Calle Yucca, Thousand Oaks, California 91360.

§Former address: Florida State University, Tallahassee, Florida 32306.

[1]See, for example, R. L. Cool *et al.*, Phys. Rev. Lett. 47, 701 (1981), and references therein. See also A. B. Kaidalov, Phys. Rep. 50, 157 (1979), and references cited there.

[2]G. Otter *et al.*, Nucl. Phys. B96, 365 (1975); R. Diamond *et al.*, Phys. Rev. D 7, 1977 (1973).

[3]C. Daum *et al.*, Nucl. Phys. B182, 269 (1981).

[4]C. Bromberg *et al.*, Nucl. Phys. B134, 189 (1978). For the present layout see J. Poirier *et al.*, in *Multiparticle Dynamics 1981*, proceedings of the XIIth International Symposium, Notre Dame, Indiana, edited by W. D. Shephard and V. P. Kenney (World Scientific, Singapore, 1982), p. 153.

[5]D. Bogert *et al.*, Phys. Rev. D 16, 2098 (1977).

[6]W. T. Eadie *et al.*, *Statistical Methods in Experimental Physics* (North-Holland, Amsterdam, 1973).

[7]R. G. Roberts, in *Phenomonology of Particles at High Energy*, proceedings of the Fourteenth Scottish Universities Summer School, 1973, edited by R. L. Crawford and R. Jennings (Academic, New York, 1974), p. 201; D. P. Roy and R. G. Roberts, Nucl. Phys. B77, 240 (1974).

[8]M. G. Albrow *et al.*, Nucl. Phys. B108, 1 (1976); J. W. Lamsa *et al.*, Phys. Rev. D 18, 3933 (1978); A. Givernaud *et al.*, Nucl. Phys. B152, 189 (1979).

[9]P. Bosetti *et al.*, Nucl. Phys. B128, 205 (1977).

[10]Y. M. Antipov *et al.*, Nucl. Phys. B57, 333 (1973), and references cited there.

[11]J. Whitmore, Phys. Rep. 10, 273 (1974).

[12]Particle Data Group, Phys. Lett. 111B, 1 (1982).

[13]E. P. Pietilainen and K. E. Lassila, Phys. Rev. D 16, 2803 (1977).