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[1]See summary by R. H. Dalitz, in Proceedings of the Thirteenth International Conference on High-Energy Physics, 1967 (University of California Press, Berkeley, Calif., 1967) and reference given therein.

[2]Here we are referring to the orbital excitation model discussed in Ref. 1.

[3]For possible exceptions, see the resonancelike structure observed in the K^+-nucleon total-cross-section measurements of R. L. Cool et al., Phys. Rev. Letters 17, 102 (1966), and the $\pi^-\rho^-$ effect discussed in R. Vanderhagen et al., Phys. Letters 24B, 493 (1967).

[4]H. J. Lipkin and S. Meshkov, Phys. Rev. Letters 14, 670 (1965); D. Horn, J. J. Coyne, S. Meshkov, and J. C. Carter, Phys. Rev. 147, 980 (1966). Also see references to previous work given in these articles.

[5]D. Horn, H. J. Lipkin, and S. Meshkov, Phys. Rev. Letters 17, 1200 (1966).

[6]It is worth noting that these reactions have never been studied before. Furthermore, the analogous reactions in the π^+p incoming channel are either difficult to separate from the background ($\pi^+p\to n\pi^+\pi^+\pi^+\pi^-$) or are kinematically underconstrained ($\pi^+p\to n\pi^+\pi^+\pi^+\pi^-\pi^0$).

[7]These multimeson $I=2$ resonances can be produced peripherally through A_2- or B-exchange mechanisms. There are no clear $SU(6)_W$ selection rules forbidding such processes, and calculations are presently in progress regarding these couplings (S. Meshkov and J. Coyne, private communication).

[8]By heavily ionizing we mean having an ionization of at least twice minimum. This means that we have a momentum cutoff on the protons of ~1 GeV/c. For the five-pronged events we assume that the missing track is that of the low-momentum spectator proton.

[9]We have used the "Maryland version" of the TVGP-SQUAW programs in our analysis [see T. B. Day, University of Maryland Report No. 649, 1966 (unpublished)]. This version of the programs contains the zero-momentum approximation for the spectator proton which we used for the five-pronged events [see O. Dahl, Alvarez Group Note P-104, 1964 (unpublished)]. We thank O. Dahl, T. Day, and F. Solmitz for many helpful conversations and clarifications of these programs. For more details regarding our experimental-analysis procedures, see W. Katz et al., University of Rochester Report No. UR-875-249, 1968 (unpublished).

[10]The typical mass resolution (1 standard deviation) in Fig. 1(a) for the unfitted data is 100 MeV for the five-pronged events and 30 MeV for the six-prongs.

[11]Differential production cross sections for the two-body reactions $\pi^\pm p\to R^\pm p$, where $R^\pm$ represents resonances such as the B, A_2, $\rho(760)$, $\rho(1700)$, or $\pi(1640)$, are highly peripheral; the total cross sections for these processes are typically in the 50- to 150-μb range. See, for example, summary given by T. Ferbel in Proceedings of the Pennsylvania Conference on Meson Spectroscopy, 1968 (to be published), and references cited therein.

SEARCH FOR RESONANCE FORMATION IN ANTIPROTON-PROTON ELASTIC SCATTERING FROM 1.6 TO 2.2 GeV/c*

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We have measured the antiproton-proton elastic differential cross section in the center-of-mass angular range $\cos\theta = -0.985$ to $+0.40$ at six momenta between 1.6 and 2.2 GeV/c in a bubble-chamber experiment. We use the data to look for evidence of direct-channel boson resonances.

We have measured the antiproton-proton elastic-scattering differential cross section outside of the large diffraction peak at six momenta between 1.6 and 2.2 GeV/c. We use the data to look for evidence of direct-channel boson resonances. We find no conclusive evidence for any such bosons, but an energy-varying backward peak strongly suggests resonance formation.

The experiment was performed in the Argonne National Laboratory 30-in. hydrogen bubble chamber, with approximately 320 000 incident antiprotons at each momentum. The six momenta, in GeV/c (invariant mass in MeV) were 1.62 (2296), 1.77 (2350), 1.83 (2370), 1.89 (2391), 1.95 (2412), and 2.20 (2500). A momentum spread of ±1% meant that the four central momenta just overlapped.

Previous measurements on antiproton-proton elastic scattering near our momenta have been reported at 1.0, 1.5, 2.0, and 2.5 GeV/c (all folded about 90° in the center of mass),[1] 2.7,[2] 1.6,[3] and 1.2-1.6 GeV/c (backward hemisphere).[4]

An important aim of the experiment was the search for boson resonances. Abrams et al.[5] have reported enhancements in the nucleon-antinucleon total cross section, at 2345 MeV ($I=1$) and 2380 MeV ($I=0$), which could be due to broad resonances (widths ~140 MeV). The narrow U meson[6] also has a mass within our energy region, but apparently is not seen in the total cross-section measurements.

The film was scanned twice, with scan rules designed to reject two-prong events that were clearly not elastic scatters or that were small-angle elastic scatters. At all momenta, all elastic scatters with center-of-mass scattering angle $\cos\theta < 0.40$ were included by the scan rules. (The actual limit for full-scan-rule efficiency varied with momentum from $\cos\theta \approx 0.50$ at 1.6 GeV/c to $\cos\theta \approx 0.60$ at 2.2 GeV/c.) Because of the low efficiency found for scanners to see very backward elastic scatters ($\cos\theta \lesssim -0.90$), with an antiproton annihilating in the chamber, and because simple models suggest that this region could be rather sensitive to a direct-channel resonance, a second double scan was performed for just these events.

Approximately 16 000 events were found by the scanners, measured on conventional machines, and processed through the programs CAST-TVGP-SQUAW.

Events were classed as elastic scatters if the four-constraint hypothesis had a χ^2 less than 36. Less than 0.1% of these events also satisfied the $\bar{p}p\pi^0$ final-state hypothesis, and an ionization study of a sample showed that contamination by final states other than $\bar{p}p\pi^0$ was less than 0.3%.

The combined-scan efficiency was greater than 95% for elastic scatters in all angular intervals in the range $\cos\theta = +0.40$ to -0.975. The numbers of events show no significant dependence upon the scattering-plane orientation, except in the very last bin ($\cos\theta = -0.975$ to -0.985), where we used only events in the more favorable half of scattering-plane angles. Events beyond $\cos\theta = -0.985$ are lost owing to the short range of the antiproton; at $\cos\theta = -0.985$ this range is 0.5 cm for 1.6-GeV/c incident momentum, 1.0 cm for 2.2 GeV/c.

Figures 1(a)-1(f) show the elastic-scattering angular distributions at the six momenta. In Figs. 2(a)-2(d) the cross sections for various $\cos\theta$ intervals are plotted as a function of the invariant mass. We believe that we have taken into account all necessary corrections in arriving at the absolute cross sections. However, since the data at all momenta are treated in the same way, a small systematic error in the absolute normalization should not affect the comparisons made in Fig. 2. We estimate an absolute normalization error of ±3%.

The heights of the two enhancements in the total cross section measurements[5] give values for $(2J+1)\kappa$ of 1.2 and 0.8, respectively, where J is the spin and κ the elasticity of the assumed resonance (of a definite isospin). Clearly the heights, and so $(2J+1)\kappa$, depend somewhat on where one draws the background curve under the enhancements.

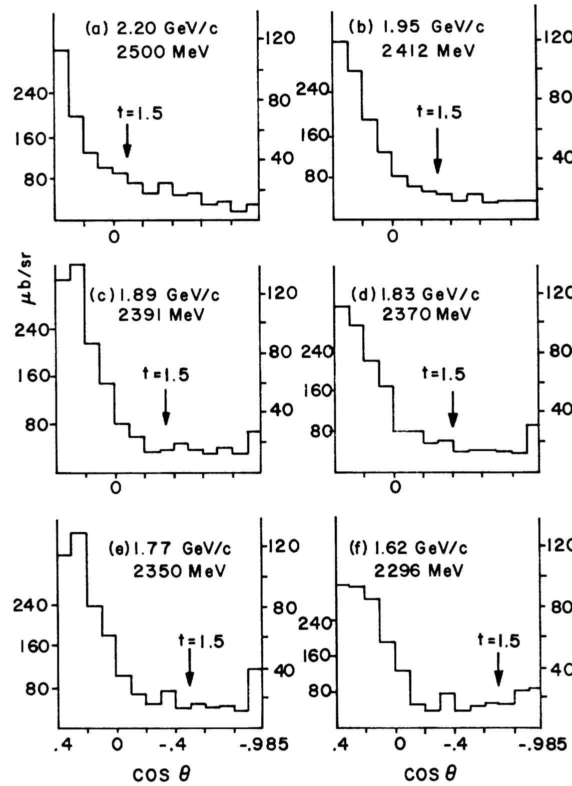

FIG. 1. The antiproton-proton elastic differential cross section at six momenta.

For a resonance with $(2J+1)\kappa = 1.0$, we would expect an enhancement in the total elastic cross section, decreasing with spin J, from 120 μb at $J=2$ to 46 μb at $J=6$, where we have used the formula

$$\sigma_E = [(2J+1)\kappa]^2 \pi \lambda\!\!\!^{-2}/4(2J+1), \qquad (1)$$

where an isospin factor of $\frac{1}{4}$ is included, and $\lambda\!\!\!^{-}$ is the center-of-mass de Broglie wavelength, divided by 2π ($\lambda\!\!\!^{-} = \hbar/p^*$), and σ_E is the elastic-cross-section enhancement. This equation assumes that there is no background (i.e., nonresonating) elastic scattering amplitude with the same quantum numbers J, P, C, as the resonance. In fact, the large (~30 mb) elastic cross section, and the high partial waves needed to fit it,[3] indicate that it is reasonable to expect such a background, of larger amplitude than that of the resonance. This background would usually increase the size of the elastic cross-section enhancement at the

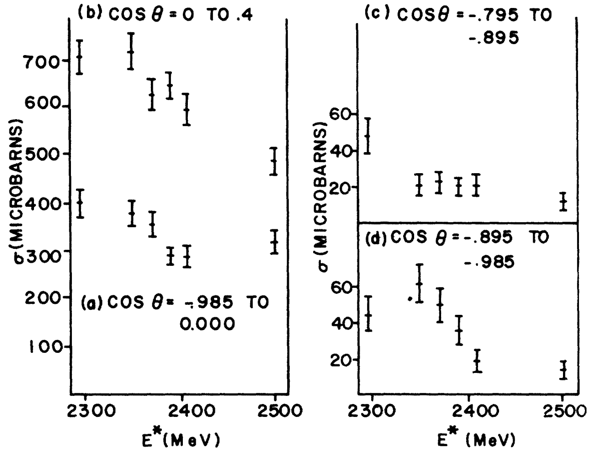

FIG. 2. The antiproton-proton elastic scattering cross section in four angular intervals versus invariant mass. (Errors are statistical.)

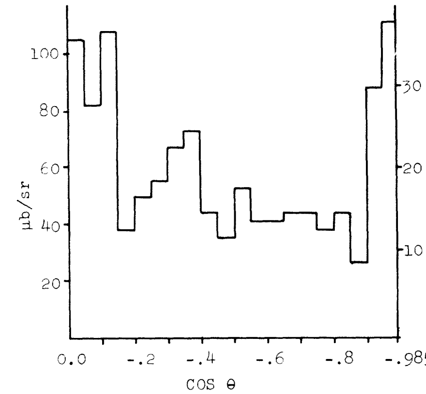

FIG. 3. The backward elastic differential cross section, 1.77- and 1.83-GeV/c data combined.

resonance.[7] Thus the values of 120 and 46 μb just mentioned are really lower limits. However, for the backward hemisphere we might expect just one-half of the 120 μb or 46 μb.

From the absence of any 3-standard-deviation peak in our plot of the elastic cross section for $\cos\theta < 0.0$ [Fig. 2(a)], and by making use of Eq. (1), we can say the following for each of the two enhancements of Abrams et al.: It cannot be due to a single resonance with spin less than 3 and with at least one-half of its elastic scattering enhancement in the backward hemisphere (we assume that the widths and heights given by Abrams et al. are approximately correct).

The most striking feature of Fig. 1 is the very backward peak that appears at 1.77, 1.83, and 1.89 GeV/c. This does not appear to be a fixed-t-value phenomenon (t is the four-momentum transfer) as are, for example, the diffraction peak and first minimum,[1,8] since no corresponding enhancement occurs in the two highest momenta. The rapid energy dependence and lack of a suitable dibaryon also argue against a dibaryon-exchange interpretation. It is suggestive of resonance formation, and Fig. 2(d) suggests a possible peak at around 2345 MeV for the $\cos\theta < -0.90$ cross section. [Note that any loss of events at $\cos\theta \sim -0.98$ due to scanners missing very short antiproton tracks should affect points in Fig. 2(d) at low invariant mass more than at high mass. We have no evidence for such a loss.] If the 1.77- and 1.83-GeV/c data are combined and plotted in finer bins, we see that the backward peak rises abruptly at $\cos\theta \approx -0.90$ (see Fig. 3). We do not see any significant structure at these momenta in other $\cos\theta$ intervals.

Structure in the elastic differential cross section on passing through a resonance would result from a pure resonance term plus an interference between the resonant amplitude and the background amplitude (of the same helicity). The sign and magnitude of the interference term depend on the relative phase, of which we have no knowledge. A reasonable estimate of the background amplitude for $\cos\theta < 0.0$ (from the differential cross section; we do not know the sizes of the different helicity contributions) indicates that the two terms might be of comparable average magnitude [taking $(2J+1)\kappa \approx 1.0$ for the resonance].

For these reasons, and because of meager statistics, quantitative conclusions from our data concerning resonance formation are difficult to make. However, the energy dependence of our backward peak [Figs. 1(c)-1(e), 2(d)] is consistent with being due to some background plus a resonance with mass, width, and $(2J+1)\kappa$ values quoted by Abrams et al. for their $I=1$ (2345-MeV) enhancement. The angular width of the backward peak (Fig. 3) indicates a spin J from 3 to 5.

Our evidence that the backward peak disappears above 2400 MeV is certainly stronger than our evidence that it goes through a maximum at 2350 MeV [see Fig. 2(d)]. Thus we may be on the trailing edge of a very broad resonance centered below 2300 MeV. Such a resonance could also explain our data on $\bar{p}p \to \pi^+\pi^-$ from this same exposure. This channel has a rapidly decreasing cross section through our energy region[9,10] and an angular distribution which may indicate the presence of a $J=4$ resonance.[10]

In conclusion, there is some interesting structure in the elastic scattering in our momentum region, which should be investigated further. The lack of a significant enhancement in our total backward-hemisphere cross section argues against a $J \leq 2$ resonance interpretation of the data of Abrams et al. On the other hand, there appears to be a significant backward peak in our data which could be due to a resonance with $J = 3$-5.

We are indebted to Dr. F. Schweingruber for invaluable assistance with the antiproton beam, and to Dr. L. Voyvodic and the crew of the 30-in. bubble chamber at Argonne. Professor Tom Day was of great help in our initial use of the programs TVGP and SQUAW. Mr. M. Church made valuable programming contributions to the experiment. We appreciate the excellent work of our scanners and measurers. Finally we thank Professor D. Sinclair and Professor M. Ross for their suggestions and interest.

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EVIDENCE FOR Ξ^* RESONANCE WITH MASS 1930 MeV*

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Evidence is presented for the existence of a baryon with a strangeness $S=-2$, mass $M=1930\pm20$ MeV, and width $\Gamma=80\pm40$ MeV. It is speculated that this resonance completes a $J^P=\frac{5}{2}^-$ octet. An SU(3) analysis of the conjectured $\frac{5}{2}^-$ octet gives a reasonable overall description of the partial widths of the member states.

In this Letter we present positive evidence for the existence of a Ξ^* resonance with mass $M = 1930$ MeV and width $\Gamma = 80$ MeV. The existence of such a state has been reported in two previous experiments.[1,2] The earlier data, although suggestive, were far from convincing because of limited statistics and difficulties with interference effects. The inconclusive nature of the old data is also indicated in the latest compilation by Rosenfeld et al.[3] To date, the confirmed baryon states with strangeness $S=-2$ are those with masses 1320, 1530, and with less confidence, 1815 MeV.[1,2,4] This is to be contrasted with the larger number of baryon states with $S=0$ and $S=-1$. The difference is in part due to the ability to perform both formation and production experiments in the $S=0,-1$ cases while only production experiments can be utilized to investigate $S=-2$ resonances. As a result, the number of established SU(3) baryon families is still limited to the $J^P=\frac{1}{2}^+$ octet and $\frac{3}{2}^+$ decuplet. At the conclusion of this Letter, we speculate on the possible existence of a second baryon octet with $J^P=\frac{5}{2}^-$.

The data for this report come from the continu-