[5] D. M. Brink and G. R. Satchler, *Angular Momentum* (Oxford U. Press, Oxford, England, 1962).

[6] V. Singh, private communication.

[7] P. O. Löwdin, Rev. Mod. Phys. 36, 966 (1964).

[8] W. S. Burnside and A. W. Panton, *The Theory of Equations* (Dover, New York, 1960), Vol. II.

Search for Structure in the Nucleon Isobar Mass Spectrum from 1100 to 1800 MeV*

W. E. Ellis,† B. Maglić, J. Norem,‡ F. Sannes, and M. Silverman
Rutgers—The State University, New Brunswick, New Jersey 08903

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A new high-resolution (±5 MeV) missing-mass spectrometer was used to search for minor peaks and structure in the N^* spectrum with $\sim 10^5$ events per 2-MeV mass bin. All the widths were found to be narrower than widths obtained from πp phase-shift analyses. For example, our result for $N^*(1512)$ is $\Gamma = 88 \pm 2$ MeV as compared with the "table value" of 105 – 155 MeV. No narrow structure greater than 5% of the cross section for the known peaks was observed.

A high-resolution baryon spectrometer[1] was used at the Princeton-Pennsylvania accelerator to measure the missing-mass (MM) spectrum of protons from the reaction

$$p_1 + p_2 \rightarrow p_3 + \mathrm{MM} \qquad (1)$$

in the region from 1.1 to 1.8 GeV at squared four-momentum transfer $-t$ from 0.11 to 0.44 $(\mathrm{GeV}/c)^2$. The present experiment differs from previous investigations[2,3] of Reaction (1) in two respects: (1) The average mass resolution was ± 5 MeV. The recoil protons, emitted backwards in the center-of-mass system, were detected in the region of the Jacobian peak,[4] where the mass resolution was independent, to first order, of the recoil momentum; therefore, a precise measurement of only the recoil angle was necessary. (2) The absence of magnets and wire spark planes permitted the use of high incident beam intensities and a large solid angle of acceptance resulting in a data rate of 10^3/sec and a total of 5×10^7 events after processing.

The experimental apparatus consisted of a sixty-element hodoscope and five trigger counters (Fig. 1). A 3.7-GeV/c proton beam of intensity 2×10^{11}/sec was incident on a 2-cm liquid-hydrogen target. Momentum selection of the recoil protons was achieved by two aluminum absorbers: a thick absorber which determined the threshold momentum p_3 and a thin absorber, used in conjunction with a veto counter behind it, which determined the momentum bite Δp_3, the trigger logic being $C_1C_2C_3C_4\overline{C}_5$. Recoil momenta were selected in the range 340 MeV/c $< p_3 <$ 700 MeV/c with typically 10% dispersion. The spectrometer scanned continuously the region $25° < \theta_3 < 75°$ in the laboratory, the angular bite at one setting being 10°. The position of an event in the hodoscope together with the position of the "point" target determined the recoil angle θ_3 to within ± 2.2 mrad. The hodoscope information was reduced by a diode matrix to a six-bit binary number and stored in a pulse height analyzer which served as a memory. Since the missing mass was proportional to the recoil angle, the mass spectra appeared directly on the analyzer display.

The missing-mass spectra for five recoil momenta p_3 are displayed in Fig. 2; the errors shown are statistical only. Each spectrum at fixed p_3 is the normalized sum of several overlapping spectrometer settings at different θ_3. For a given p_3 the Jacobian peak occurs at a unique angle and missing mass.[1] For $p_3 = 400$ MeV/c the Jacobian occurs near a missing mass of 1.25 GeV and for $p_3 = 700$ MeV/c it occurs near 1.65 GeV.

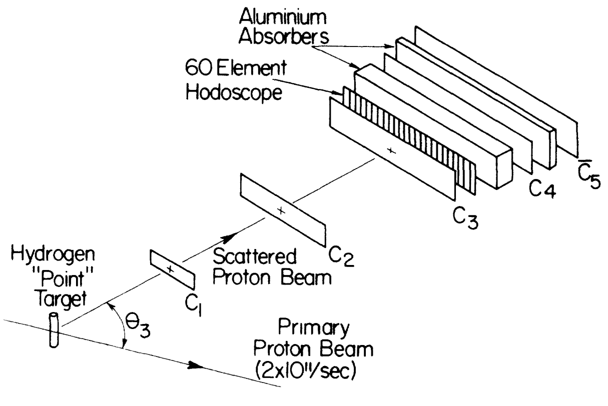

FIG. 1. Missing-mass spectrometer experimental setup (not to scale). Each hodoscope element is $\frac{1}{2}$ in. wide and 4 in. high. The distance from target to last counter is 16 ft.

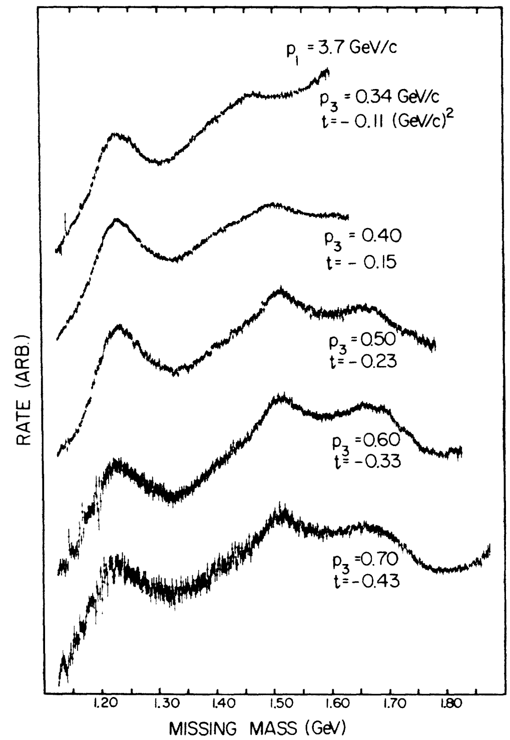

FIG. 2. Missing-mass spectra from $-t = 0.11$ to 0.43 $(\mathrm{GeV}/c)^2$.

While most of the data were taken in the region of the Jacobian peak, data were also taken off the Jacobian peak, with poorer resolution, in order to determine the shape of the nonresonant background. The experimental mass resolution was inferred from the shape of the measured elastic peak. In the region of the Jacobian peak the mass resolution was ± 4 and ± 7 MeV for $p_3 = 700$ and 400 MeV/c, respectively. Below 400 MeV/c the angular resolution, and hence also the mass resolution, deteriorated rapidly due to multiple Coulomb scattering.

Referring to Fig. 2, we note the following features of the missing-mass spectra: (1) A clear peak occurs at a mass of 1.23 GeV at all momentum transfers. (2) The peaks at 1.51 and 1.67 GeV are clearly seen at fixed masses only at the highest three momentum transfers, $|t| = 0.23$, 0.33, and 0.43 $(\mathrm{GeV}/c)^2$. (3) At the lowest momentum transfer, $|t| = 0.11$ $(\mathrm{GeV}/c)^2$, there is a dip rather than a peak at 1.51 GeV. However, a broad peak centered at 1.45 GeV is observed as well as an enhancement at 1.40 GeV compatible with the Roper resonances. (4) At the next highest momentum transfer, $|t| = 0.15$ $(\mathrm{GeV}/c)^2$, the broad structure at 1.40 GeV is still present while the peak previously at 1.45 GeV has either disappeared or shifted to a mass of 1.50 GeV, near, but still 10 MeV below the 1.51-GeV peak. (5) No other structure is observed. The upper limit of one standard deviation for the production of new peaks narrower than 30 MeV is 5% of the cross section for the known peaks at 1.23, 1.51, and 1.67 GeV which are dominant in the mass region investigated.

The widths and masses of the various peaks were extracted from the missing-mass distributions through a least-squares fitting program. Before the raw data were fitted the following corrections were applied: The empty-target signal, which was about 25% that of the full-target and contained no discernible structure, was subtracted from the full target signal; the tail of the elastic peak was extrapolated and subtracted from the data; and the mass axis was shifted by 1.5% so that the elastic peak had the correct mass.

A relativistic Breit-Wigner formula with a mass-dependent width[5] was used to fit the peaks. The experimental resolution was folded into the Breit-Wigner formula before the fits were made. The background was accounted for by 1π, 2π, and 3π phase-space functions, all with adjustable amplitudes, together with a first-order polynomial in mass. The χ^2 did not improve significantly when higher order phase-space functions were used.

Of the three fitted isobars, the best determina-

TABLE I. Comparison of isobar widths and masses obtained in this experiment with those of previous experiments.

Reference	Type of measurement	Mass (MeV)	Full width (MeV)	Mass (MeV)	Full width (MeV)	Mass (MeV)	Full width (MeV)
This experiment	$pp \to p + \mathrm{MM}$	1227 ± 7	105 ± 7	1512 ± 2	88 ± 2	1672 ± 4	102 ± 9
Ref. 2	$pp \to p + \mathrm{MM}$	1240 ± 6	102 ± 4	1508 ± 2	92 ± 3	1683 ± 3	110 ± 4
Ref. 6	$\pi p \to \pi + \mathrm{MM}$	1217 ± 8	92 ± 12	1503 ± 6	105 ± 9	1691 ± 4	119 ± 9
Ref. 7	πp phase shifts	1236 ± 0.6	120 ± 2	1510 − 1540	105 − 150	1680 − 1692	105 − 180

tion of the mass and width was that of the 1.51-GeV isobar since it lies on a relatively slowly varying background. The 1.23-GeV isobar lies on top of the rapidly rising 1π and 2π nonresonant background and the 1.67-GeV isobar lies near the limit of the instrumental acceptance. These factors introduce uncertainties in fitting the background under these peaks and hence also in their masses and widths.

In Table I the results of the present experiment are compared with the most recent preceding pp missing-mass experiment,[3] a recent πp missing-mass experiment,[6] and the results of πp phase-shift analyses.[7] The three missing-mass experiments are in good agreement, demonstrating that widths obtained in missing-mass experiments are narrower than widths obtained from πp phase-shift analyses.

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†Present address: Mississippi State University, State College, Miss. 39762.

‡Present address: Daresbury Nuclear Physics Laboratory, Daresbury, England.

[1] F. Sannes, W. E. Ellis, J. Norem, M. Silverman, and B. Maglić, Nucl. Instrum. Methods 92, 345 (1971).

[2] G. Cocconi, E. Lillethun, J. P. Scanlon, C. A. Stahlbrandt, C. C. Ting, J. Walters, and A. M. Wetherell, Phys. Lett. 8, 134 (1964); E. W. Anderson, E. J. Bleser, G. B. Collins, T. Fujii, J. Menes, F. Turkot, R. A. Carrigan, Jr., R. M. Edelstein, N. C. Hien, T. J. McMahon, and I. Nadelhaft, Phys. Rev. Lett. 16, 855 (1966); I. M. Blair, A. E. Taylor, W. S. Chapman, P. I. P. Kalmus, J. Litt, M. C. Miller, D. B. Scott, H. J. Sherman, A. Astbury, and T. G. Walker, Phys. Rev. Lett. 17, 789 (1966).

[3] C. M. Ankenbrandt, A. R. Clark, B. Cork, T. Elioff, L. T. Kerth, and W. A. Wenzel, Phys. Rev. 170, 1223 (1968).

[4] B. Maglić and G. Costa, Phys. Lett. 18, 185 (1965).

[5] J. D. Jackson, Nuovo Cimento 34, 1644 (1964).

[6] E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick, J. Menes, F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon, J. F. Mucci, and J. S. Russ, Phys. Rev. Lett. 25, 699 (1970).

[7] A. Barbaro-Galtieri, S. E. Devenzo, L. R. Price, A. Rittenberg, A. Rosenfeld, N. Barash-Schmidt, C. Brickman, M. Roos, P. Söding, and C. G. Wohl, Rev. Mod. Phys. 42, 87 (1970).

Determination of the Photoproduction Phase of ϕ Mesons*

H. Alvensleben, U. Becker, W. Busza, M. Chen, K. J. Cohen, R. T. Edwards, P. M. Mantsch,
R. Marshall, T. Nash, M. Rohde, H. F. W. Sadrozinski, G. H. Sanders, H. Schubel,
Samuel C. C. Ting, and Sau-Lan Wu
Department of Physics and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge,
Massachusetts 02139, and Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
(Received 28 May 1971)

We have measured wide-angle electron-positron pairs from the reaction $\gamma+\mathrm{C}\rightarrow\mathrm{C}+e^{+}+e^{-}$ in the invariant-mass region $920<m<1080$ MeV/c^2 for incident photon energy $6<k<7.4$ GeV. The photoproduction amplitude of the ϕ meson was found to deviate from pure imaginary by 25° ± 15° corresponding to a ratio of the real to imaginary part of the ϕ-nucleon amplitude of $\beta=-0.48^{+0.33}_{-0.45}$. The forward photoproduction cross section $[d\sigma(\gamma+C\rightarrow C+\phi(\phi\rightarrow e^{+}e^{-}))dt]_{t=0}$ was found to be 96 ± 14 nb/(GeV/c)^2.

We determine the ratio of the real to imaginary part of the ϕ-nucleon amplitude, β, and the quantity $C_{\phi}=[d\sigma(\gamma+\mathrm{C}\rightarrow\mathrm{C}+\phi(\phi\rightarrow ee))/dt]_{t=0}$ by studying the $e^{+}e^{-}$ yields from the reaction

$$\gamma+\mathrm{C}\rightarrow\mathrm{C}+e^{+}+e^{-} \qquad (1)$$

in the energy region 6.0–7.4 GeV and $e^{+}e^{-}$ invariant-mass range $920<m<1080$ MeV/c^2. The motivation for measuring β and C_{ϕ} is as follows:

(1) The phase of the ϕN scattering amplitude, or the ratio of the real to the imaginary part of the amplitude β, has been of considerable theoretical interest. On the one hand, since the ϕN system does not couple to any of the known high-lying trajectories other than the Pomeranchukon,[1] one will expect the ϕN amplitude to be purely imaginary. On the other hand, according to the quark model[2] the ϕN amplitude is related to the $K^{\pm}N$, $\pi^{\pm}N$ amplitudes. Using the existing data on the $K^{\pm}N$, $\pi^{\pm}N$ amplitudes, various quark models[2]