[5]For data at 13, 18, 21, 24 and 28.5 GeV/c, see D. B. Smith, thesis, Berkeley, UCRL Report No. UCRL-20632 (unpublished); E. L. Berger, B. Y. Oh, and G. A. Smith, Phys. Rev. Lett. 29, 675 (1972). I am grateful to B. Oh and G. Smith (Michigan State University) for providing me with prong cross sections corrected to include strange particle topologies.

[6]Data at 50 and 70 GeV/c, Mirabelle French-Soviet Collaboration results presented by H. Blumenfeld, in Proceedings of the Fourth International Conference on High Energy Collisions, Oxford, England 1972 (unpublished).

[7]E. L. Berger, M. Jacob, and R. Slansky, Phys. Rev. D (to be published).

[8]G. H. Thomas and D. Sivers, ANL Report No. ANL/HEP 7218 (to be published); L. Van Hove, Rev. Mod. Phys. 36, 655 (1964).

[9]L. W. Jones *et al.* (Echo Lake Collaboration), Nucl. Phys. B43, 477 (1972).

[10]ISR data: G. Neuhofer *et al.*, Phys. Lett. 37B, 438 (1971), and 38B, 51 (1972); M. Breidenbach *et al.*, Phys. Lett. 39B, 654 (1972), and in Proceedings of the Fourth International Conference on High Energy Collisions, Oxford, England, 1972 (unpublished).

[11]In this fit, the ISR and Echo Lake points are excluded. ISR points may have large systematic errors because they are estimated from an integral over the single-particle inclusive distribution, which has not yet been measured over the full 4π kinematic region at ISR. Cosmic-ray Echo Lake points are obviously inconsistent with accelerator data.

[12]E. L. Berger and A. Krzywicki, Phys. Lett. 36B, 380 (1971).

[13]Cf. Frazer *et al.*, Ref. 4, Sec. II-E.4.

[14]British-Scandinavian ISR Collaboration results reported by E. Lillethun, in Proceedings of the Fourth International Conference on High Energy Collisions, Oxford, England, 1972 (unpublished).

[15]N. F. Bali *et al.*, Phys. Rev. Lett. 25, 557 (1970); M. S. Chen *et al.*, Phys. Rev. Lett. 26, 280, 598(E) (1971).

[16]This point was emphasized by M. Jacob, private communication.

[17]Wilson, Ref. 3; R. Arnold, Phys. Rev. D 5, 1724 (1972).

[18]W. Burdett *et al.*, unpublished.

Search for Narrow Resonances in the *R* Region

D. Bowen, D. Earles, W. Faissler, D. Garelick, M. Gettner, M. Glaubman, B. Gottschalk, G. Lutz, J. Moromisato,* E. I. Shibata, Y. W. Tang, E. von Goeler, and R. Weinstein
Northeastern University at Boston, Boston, Massachusetts 02115†

and

H. R. Blieden,‡ G. Finocchiaro, J. Kirz,§ and R. Thun
State University of New York at Stony Brook, Stony Brook, New York 11790‖
(Received 12 July 1972)

We report on a measurement of the missing-mass, $(\mathrm{mm})^-$, spectrum from the reaction $\pi^- + p \rightarrow (\mathrm{mm})^- + p$ at 8 GeV. The data contain 6500 events in the R peak ($M^2 = 2.72 \pm 0.02$ GeV^2, $\Gamma = 139 \pm 31$ MeV). The R shape is consistent with either a single Breit-Wigner or several wide resonances, as suggested by bubble-chamber experiments, but inconsistent with the series of narrow resonances reported by the CERN missing-mass group.

The mass spectrum produced in the reaction $\pi^- + p \rightarrow (\mathrm{mm})^- + p$ has been investigated in the region of the R enhancement (mass ~ 1700 MeV) using the missing-mass technique. The data were obtained with the Northeastern–Stony Brook double-arm spectrometer at the Brookhaven alternating gradient synchrotron at a beam momentum of 8 GeV.[1] A description of the method and the apparatus is given in earlier publications and reports.[2,3]

Previously, the CERN missing-mass spectrometer group, CMMS, established the presence of the R enhancement in the missing-mass spectrum.[4] Later publications of the CMMS group[5] reported three narrow resonances in this region, called R_1, R_2, and R_3, with masses of 1632, 1700, and 1748 MeV, and widths with upper limits of 21, 30, and 38 MeV for the R_1, R_2, and R_3, respectively. These widths were consistent with zero. Bubble-chamber groups report mainly wide ($\Gamma \gtrsim 100$ MeV) resonances.[6] A combination of such wide resonances would be expected to show up as a single broad enhancement in a missing-mass experiment. Our data, compared to the CMMS data, have 6.5 times as many R events above background, were taken with better resolution, and are fitted well by a single wide ($\Gamma \sim 140$ MeV)

TABLE I. Mass resolution δM ($M = 1700$ MeV).

	Resolution (FWHM)	Contribution to δM (FWHM)
Proton angle	11.0 ± 0.5 mr	19.9 ± 0.9 MeV
Proton energy	4.5 ± 1.0 MeV	5.0 ± 1.1 MeV
Beam energy	60 ± 15 MeV	6.8 ± 1.7 MeV
Total		21.6 ± 1.0 MeV

resonance. Fits to the CMMS three-meson hypothesis have large values of χ^2, for widths less than 30 MeV.

Our data were obtained at two different spectrometer angle settings, 48.5° and 47.0°, and were checked for consistency and then combined. To approximate the CMMS kinematic conditions, we have restricted the range of t, the four-momentum transfer squared, to $0.2 \leq |t| \leq 0.3$ GeV^2. The data have been corrected for geometrical detection efficiency, the nuclear absorption of protons in the recoil spectrometer, and beam absorption in the target.[1]

The mass scale, its stability, and the missing-mass resolution were determined by using the double-arm spectrometer system to measure $\pi^- p$ elastic scattering.[1-3] The results are shown in Table I which lists the contributions to the missing-mass resolution.

Our missing-mass resolution at 1700 MeV is measured to be 21.6 ± 1.0-MeV full width at half-maximum (FWHM),[7] compared to the CMMS resolution of 30 ± 3 MeV FWHM.[5]

The mass-squared spectrum at 8 GeV for $0.2 \leq |t| \leq 0.3$ GeV^2 is shown in Fig. 1. The data are presented in mass squared because the resolution is nearly constant in mass squared and because the background (by which we mean the nonresonant part of the spectrum) is approximately linear in mass squared. The average acceptance is indicated as a broken line below the data. There are about 250 000 detected events represented. Evident in the data are an A_2 peak at 1.7 GeV^2 and an enhancement at ~2.7 GeV^2, all above a nearly linear background.

The mass-squared region 1.75 to 3.5 GeV^2 was fitted with an A_2 signal, a background term (linear or quadratic in M^2), and various hypotheses for the R. The experimental resolution is included in all fits. Relativistic S-wave Breit-Wigner shapes with constant widths were used for the resonances.[8] The A_2 Breit-Wigner shape had M_0^2 fixed at 1.7 GeV^2 and width fixed at 100 MeV. Fits with linear or quadratic backgrounds give essentially the same results.

The hypothesis that there is no R meson is rejected since it gives a confidence level of less than 10^{-4}. A one-Breit-Wigner R signal gives a good fit in the region M^2 from 1.75 to 3.5 GeV^2, a χ^2 of 69 for 64 degrees of freedom. The fitted parameters are $M^2 = 2.72 \pm 0.02$ GeV^2 ($M = 1648 \pm 6.5$ MeV), $\Gamma = 139 \pm 31$ MeV. This fit is shown in Fig. 1. The CMMS R mass for a single Breit-Wigner shape is 43 MeV higher, 1691 ± 15 MeV. The widths for the R are the same within errors.

From our single Breit-Wigner fit to the R region, we obtain an average differential cross section of 95 ± 23 μb/GeV^2 in the t range $0.2 \leq |t| \leq 0.3$ GeV^2. From an analysis of elastic scattering data and other checks, the additional normalization error is estimated to be less than ± 25%.

The CMMS group's R_1, R_2, R_3 hypothesis was tried, keeping the mass spacing and the cross-section ratios fixed to the CMMS values, but al-

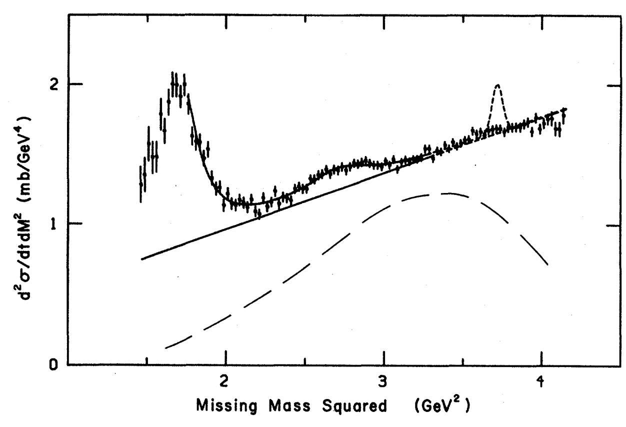

FIG. 1. Mass-squared spectrum at 8 GeV. Solid line, fit to the data using a single Breit-Wigner shape for the R, as described in the text. Dashed line through the high-mass data, expected shape in the S region, assuming the CMMS parameters and cross section. Because of the difference in beam momenta, we would expect to see an even larger S signal, but we have not scaled the cross section up in the figure. The broken line below the data shows the spectrometer acceptance; the data have been corrected for the acceptance.

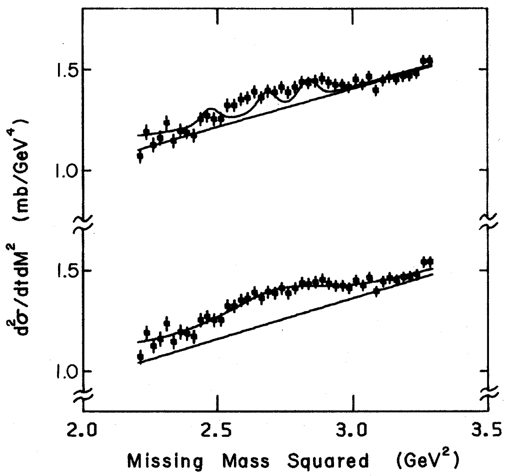

FIG. 2. The 8-GeV data in the R region, fitted by a single Breit-Wigner shape (lower curve) and by the CMMS group split-R hypothesis with three zero-width peaks, allowing the CMMS mass scale to shift (upper curve). The fits are described in the text.

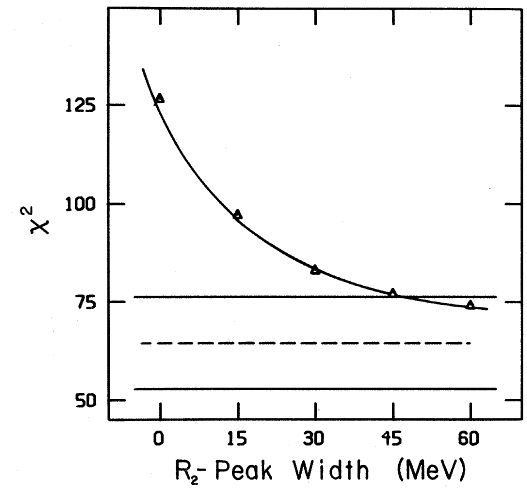

FIG. 3. χ^2 from fits to the CMMS-group split-R hypothesis, as a function of the assumed width of the R_2 peak. Dashed line, expected χ^2; solid lines, χ^2 for a 17% confidence level (upper line) and 83% confidence level (lower line). The R-peak widths were constrained to the ratio of CMMS upper-limit widths, $\Gamma_1:\Gamma_2:\Gamma_3 = 21:30:38$. The curve through the points is drawn to guide the eye.

lowing their mass scale to shift. The best-fit mass-scale shift agrees with the single-Breit-Wigner mass-scale shift, about 45 MeV. For zero-width resonances, the three-meson hypothesis is rejected since it gives a confidence level of less than 10^{-4} ($\chi^2 = 126$ for 65 degrees of freedom). This fit is shown in Fig. 2, along with the single-Breit-Wigner fit. As the widths of the individual resonances are allowed to increase, better fits are obtained. The χ^2 decreases smoothly to an acceptable value with no evidence for a "best" width, as shown in Fig. 3.

The CMMS group quotes a confidence level of 0.8% on a one-Breit-Wigner fit to their data.[5] This means that the split R was a 2.5-standard-deviation effect. Our data, with significantly better statistics and resolution, have a smooth mass spectrum, well described by a single Breit-Wigner shape. Our data also strongly reject the split-R hypothesis, for individual widths less than 15 MeV.

Several wide resonances, such as the g, A_3, and $\rho(1710)$, which have masses of 1659, 1640, and 1712 MeV, respectively, have been observed by bubble-chamber groups.[6] Since the widths ($\gtrsim 100$ MeV) of these resonances are large compared with their separation, a missing-mass experiment would not be expected to resolve them, without further information about the decay products. Our data are consistent with almost any combination, expect pure $\rho(1710)$.

The CMMS group also observed an S meson at a beam momentum of 12 GeV[5] having a mass of 1.93 GeV ($M^2 = 3.72$ GeV^2), and width consistent with zero, with an average differential cross section of 35 ± 12 μb/GeV^2 in the range $0.22 \leq |t| \leq 0.36$ GeV^2. Shown in Fig. 1 is the yield expected from an S meson with those properties. No effect of that magnitude is evident in our data; in fact, the data in the mass-squared range $3.1 \leq M^2 \leq 4.2$ GeV^2 are consistent with a linear background. Our data yield an average differential cross section of 1.9 ± 1.5 μb/GeV^2 for a zero-width resonance, and 5.2 ± 3.0 μb/GeV^2 for a width of 35 MeV, the CMMS upper-limit width. We might expect to measure an even larger cross section than the CMMS group did, both because our $|t|$ range extends to lower values, and because of our lower beam momentum, but we have not made any corrections for these effects.

We gratefully acknowledge the cooperation and assistance of many people, in particular, W. Armstrong, C. Boyer, B. Cairns, and the staffs of the Brookhaven National Laboratory alternating gradient synchrotron and on-line data facility and the Northeastern University computing centers. The loan of equipment to us by the Carnegie-Mellon University (Professor R. Edelstein), Cornell University (Professor J. Orear), and the Brookhaven Physics Department (Dr. G. Collins and Dr. S. Lindenbaum) is also gratefully acknowl-

edged.

*Work supported in part by a Ford Foundation Fellowship. Present address: University of San Marcos, Lima, Peru.

†Work supported in part by the National Science Foundation under Grants No. GP9217 and No. GP25307.

‡On leave of absence with the Advanced Technology Application Division of the RANN Program, National Science Foundation, Washington, D. C.

§Alfred P. Sloan Foundation Fellow.

‖Work supported in part by the U. S. Atomic Energy Commission, and by the National Science Foundation under Grant No. GP32952.

[1]A preliminary analysis of these data is given in J. Moromisato, Ph. D. thesis, Northeastern University, 1971 (unpublished).

[2]D. Bowen *et al.*, Phys. Rev. Lett. 26, 1663 (1971); D. Bowen *et al.*, in *Phenomenology in Particle Physics*, edited by C. B. Chiu, G. C. Fox, and A. J. G. Hey (California Institute of Technology Press, Pasadena, Calif., 1971).

[3]Y. W. Tang, Ph. D. thesis, Northeastern University, 1971 (unpublished).

[4]J. Seguinot *et al.*, Phys. Lett. 19, 712 (1966). This paper contains references to earlier work on the *R*.

[5]M. N. Focacci *et al.*, Phys. Rev. Lett. 17, 890 (1966). See also B. Levrat *et al.*, Phys. Lett. 22, 714 (1966); L. Dubal *et al.*, Nucl. Phys. B3, 435 (1967).

[6]A. Rittenberg *et al.*, Rev. Mod. Phys. 43, S1 (1971).

[7]The hydrogen target used to obtain our 8-GeV data contained more scattering material than the target used for the data described in Refs. 1 and 2 above. This accounts for the larger proton angular resolution reported here than that given in Ref. 1.

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