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Search for Narrow Structure in the *S, T, U* Region

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We report a measurement of the missing mass (MM) spectra from the reaction $\pi^- + p \rightarrow (MM)^- + p$ at 11, 13.4, and 16 GeV, in the region of the $S(1930)$, $T(2200)$, and $U(2375)$ mesons. Our mass spectra exhibit no narrow enhancements in this region with $\langle d\sigma/dt \rangle \gtrsim 10\ \mu\text{b/GeV}^2$.

The $S(1930)$, $T(2200)$, and $U(2375)$ mesons were first reported by the CERN Missing Mass Spectrometer Group (CMMS)[1-3] and, to date, the CMMS results remain the strongest evidence for the existence of narrow resonances in this region. CMMS observed these mesons in the missing-mass (MM) spectrum from the reaction

$$\pi^- + p \rightarrow (MM)^- + p \tag{1}$$

at 12 GeV. The experimental arrangements were similar to ours except that the CMMS apparatus included a hodoscope to measure the final-state charge multiplicity. The S and T resonances were observed to decay only into three charged particles. We report here measurements of the MM spectra from Reaction (1) at incident momenta of 11, 13.4, and 16 GeV with $0.2 < |t| < 0.3$ GeV^2. Our data have comparable mass resolution and improved statistics (in the S region: 200, 50, and 100 events/MeV, signal plus background, at 11, 13.4, and 16 GeV, respectively, compared to 60 events/MeV in all charge modes for the CMMS data). Our mass spectra are adequately described by smooth background curves only, and do not support the existence of narrow resonances in this region.

The data were obtained with the Northeastern–Stony Brook double-arm spectrometer system at the Brookhaven National Laboratory alternating-gradient synchrotron. Descriptions of the apparatus, data collection techniques, methods of calibration and checks, and measurements of the mass resolutions may be found in previous reports.[4-8] For each incident momentum, Table I summarizes the kinematic regions studied, the number of events histogrammed, and the mass-squared (M^2) resolutions. After correcting for geometrical detection efficiency, nuclear absorption of the proton in the recoil spectrometer, and beam absorption in the target, data at the

TABLE I. Data summary and mass-squared resolutions for $0.2 < |t| < 0.3$ GeV^2.

Beam momentum (GeV)	Proton spectrometer angle setting	Mass-squared range (GeV^2)	Number of unweighted events histogrammed	FWHM mass-squared resolution (GeV^2)
11	55°	1.0–5.0	120 000	0.11
13.4	58°	0.8–5.9	24 000	0.11
13.4	47.5°	2.9–7.1	75 000	0.11
16	63.5°	0.0–6.1	40 000	0.17
16	55°	1.4–7.4	110 000	0.17

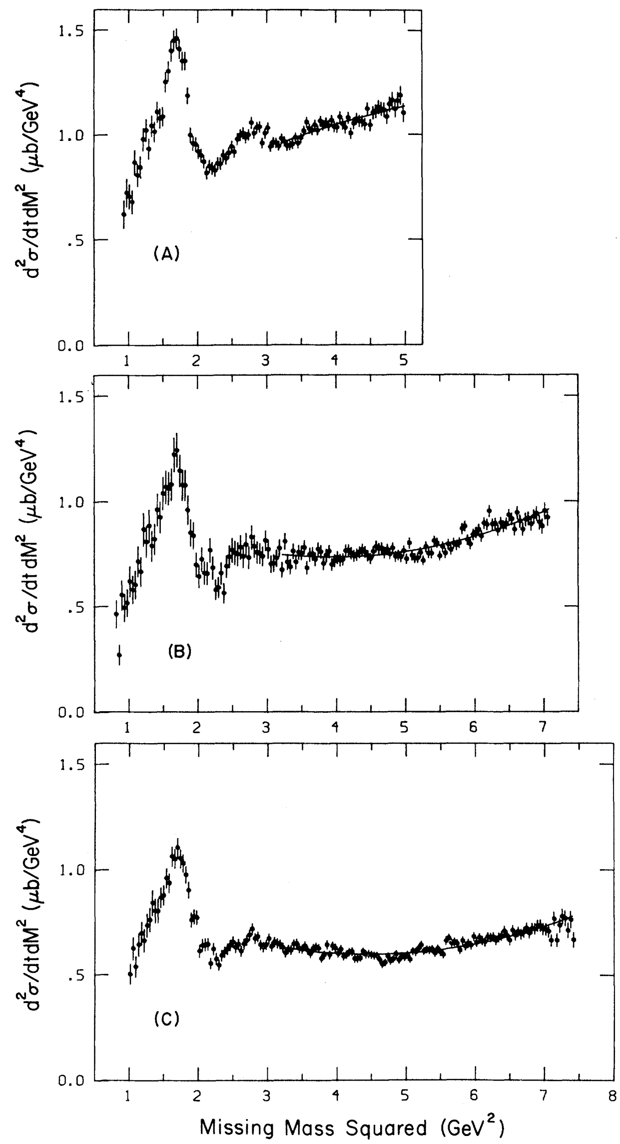

FIG. 1. (a)–(c) Missing-mass spectrum for $\pi^- + p \rightarrow (MM)^- + p$ at 11, 13.4, and 16 GeV, respectively, for $0.2 \leq |t| \leq 0.3$ GeV^2. The quadratic background fits are shown. For details, see text.

same beam energy but different spectrometer angles were checked for consistency and then combined in order to cover a broader mass bite.

Figure 1 shows the mass-squared spectra at 11, 13.4, and 16 GeV. Apparent in these spectra are the A_2 ($M^2 \cong 1.7$ GeV^2, $\Gamma \cong 0.1$ GeV) and the R ($M^2 \cong 2.75$ GeV^2, $\Gamma \cong 0.15$ GeV), the masses and widths of which we find to be consistent at the three beam energies. Above the R region the spectra show no narrow structure. In the 11-GeV data there is a hint of a broad bump in the 3.25–4.0-GeV^2 region. We fitted the region $2.76 \leq M^2 \leq 4.48$ GeV^2 with the sum of an R enhancement and a linear background with (and without) a resonant peak, obtaining a χ^2 per degree of freedom of 38/37 (and 69/40). The fitted parameters for this broad bump are $M^2 = 3.74 \pm 0.05$ GeV^2, $\Gamma = 0.133 \pm 0.070$ GeV, and $\langle d\sigma/dt \rangle \cong 56 \pm 37$ μb/GeV^2 for $0.2 \leq |t| \leq 0.3$ GeV^2. Because of the limited statistical significance of this broad bump and the uncertainty in the background shape, we feel there is no compelling need for a broad resonance to fit the data satisfactorily.[9]

Our data show no statistically significant narrow structure in the S, T, U region. This region is adequately described with just a quadratic background (smooth solid curves through the data shown in the figure) with χ^2 per degree of freedom of 47/42, 130/94, and 125/102 for the 11-, 13.4-, and 16-GeV data, respectively. The χ^2 values for these fits differ from the expected values by 0.6 standard deviations at 11 GeV, 2.4 s.d. at 13.4 GeV, and 1.6 s.d. at 16 GeV. This indicates that any S, T, or U effects in our data will be of limited statistical significance. To determine upper limits for cross sections and for comparisons with CMMS results, we have fitted our data, in the mass region $3.2 \leq M^2 \leq 6.1$ GeV^2 ($M^2 < 5.0$ at 11 GeV), with a quadratic background plus resonances with masses at the CMMS values but with resonance amplitudes determined by the fits. These fits were done for both zero-width resonances and for resonances with widths given by the CMMS upper-limit widths ($\Gamma_S = 35$, $\Gamma_T = 13$, $\Gamma_U = 30$ MeV.[1,2] The resulting cross sections are given in Table II. As suggested by the acceptable χ^2 values for smooth backgrounds without resonances, these fitted cross sections are consistent with zero. The central values are generally a factor of 6 below the originally published CMMS cross sections,[1,2] but consistent with their latest revised ones,[3] which are a factor of ~4 lower than the original ones. The revised CMMS cross sections are also given in Table II. There is no significant disagreement between our results and the revised CMMS cross sections. However, our data, while statistically superior, yield cross sections consistent with zero.

To minimize normalization discrepancies[10] further we have also calculated the signal-to-background ratios for our cross-section estimates. The ratios are presented in Table III. Our ratios for the S and T are not directly comparable with the CMMS ratios, which are quoted

TABLE II. S, T, and U cross sections.

Beam momentum (GeV)	S	$\langle d\sigma/dt\rangle^a$ (μb/GeV^2) T	U	Assumed width	Mass interval (GeV^2)	χ^2	Degrees of freedom
11	3.2 ±2.1	4.3 ±3.8		0	3.2–5.0	43	40
13.4	2.2 ±2.7	1.2 ±2.1	−2.6 ±2.0	0	3.2–6.1	86	66
16	1.1 ±2.2	−4.2 ±1.8	4.9 ±2.1	0	3.2–6.1	68	66
11	11.6 ±4.5	5.2 ±5.9		b	3.2–5.0	38	40
13.4	3.6 ±5.4	1.5 ±3.0	−6.4 ±4.5	b	3.2–6.1	86	66
16	2.9 ±3.8	−6.3 ±2.4	7.0 ±3.9	b	3.2–6.1	68	66
12	8.8 ±2.5[c]	7.3 ±2.5[c]	10.5 ±2.5[c]				

[a]For t interval $0.2 \leq |t| \leq 0.3$ GeV^2. Errors shown are statistical only. For a discussion of possible systematic errors, see footnote 10.
[b]$\Gamma_S = 35$, $\Gamma_T = 13$, $\Gamma_U = 30$ MeV.
[c]CMMS results. For the CMMS experiment, for the S and T, $0.22 \leq |t| \leq 0.36$ GeV^2; and for the U, $0.28 \leq |t| \leq 0.36$ GeV^2. These are the renormalized cross sections. See Ref. 3. The normalization factor of ~4 is only given approximately in Ref. 3, and no errors are attached. We have used a factor of 4.0 here.

for a three-charged-particle (3-ch) background [ratio = (signal height)/(3-ch background)]. Using the charge-selected mass spectra given in Ref. 2, we have converted the CMMS ratios to correspond to an unselected background, multiplying each ratio by a factor [3-ch/(1-ch + 3-ch + >3-ch)]. These adjusted ratios are also presented in Table III. Our ratios, as expected, are compatible with zero signal. They are also a factor of $\gtrsim 2$ lower than the CMMS ratios, but the discrepancies are below the 2-standard-deviation level, except for the U meson, where the disagreement is 6 s.d. at 13.4 GeV and 3 s.d. at 16 GeV.

In addition, the weighted average of our ratios at 11, 13.4, and 16 GeV for the S, T, and U individually are shown in Table III. We have assumed here that the ratio is independent of beam energy. Assuming a P_{beam}^{-1} dependence changes the results by less than $\frac{1}{2}$ the quoted error. Our averaged ratios disagree with the CMMS ratios by 1.6 standard deviations for the S, but between 3 and 4 s.d. for the T and U. Not only are our data consistent with no S, T, or U, but there is significant disagreement, independent of normalization, between our data and the CMMS results. Our data do not support the existence of the S, T, and U mesons.

In view of these results, we see no compelling evidence for a simple linear relationship between meson peak numbers and the corresponding masses squared, as suggested in Ref. 1. Furthermore, if such a relationship does not exist, the concept of linear, indefinitely rising, ex-

TABLE III. Peak signal-to-background ratios.

	Beam momentum (GeV)	S	T	U
NU/SUNY[a]	11	0.057 ± 0.022	0.036 ± 0.040	···
	13.4	0.026 ± 0.039	0.015 ± 0.030	− 0.046 ± 0.032
	16	0.020 ± 0.026	− 0.050 ± 0.020	0.048 ± 0.029
	Average	0.039 ± 0.015	− 0.020 ± 0.015	0.010 ± 0.021
CMMS[b]	12	0.08 ± 0.02	0.08 ± 0.02	0.16 ± 0.03

[a]Ratios are for maximum-width cross-section estimates ($\Gamma_S = 35$, $\Gamma_T = 13$, $\Gamma_U = 30$ MeV).
[b]We have assigned an error based on the cross section accuracy. The errors in Ref. 1 may include normalization errors as well as statistical accuracy, and thus overestimate the errors in the ratios. These ratios are adjusted to an all-charged background. See text.

change-degenerate, boson trajectories[11] will have to be re-examined.

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Study of the Reaction $\nu p \to \mu^- \pi^+ p$†

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We present an analysis of 153 events of the reaction $\nu p \to \mu^- \pi^+ p$ at an average neutrino energy of 1 GeV. The results were obtained using the Argonne 12-ft hydrogen bubble chamber. The reaction is dominated by $\mu^- \Delta^{++}(1236)$ production for which the total cross section rises from threshold to a value of $(0.74 \pm 0.18) \times 10^{-38}$ cm^2 at $E_\nu \gtrsim 1.0$ GeV. The production and decay angular distributions of the Δ^{++} are given. There is no evidence for hadron-lepton mass enhancements.

We present results on the reaction $\nu p \to \mu^- \pi^+ p$ observed in the 12-ft chamber exposed to the neutrino beam at the zero-gradient synchrotron (ZGS). These data, which were obtained from an analysis of 361 000 pictures taken with an H_2 fill of the chamber and 145 000 pictures with a D_2 fill, represent the first experimental study of neutrino interactions in pure hydrogen and deuterium.

The full circulating beam of the ZGS was resonantly extracted with an efficiency of 65% and a spill time of ~20 μsec. On the average, 1.2