into

$$g_V = G_V[F_Q + (\mu_p - \mu_n)F_M][1 + m_W^{-2}q^2]^{-1}$$

and

$$f_V = G_V(2m_n)^{-1}(\mu_p - \mu_n)F_M[1 + m_W^{-2}q^2]^{-1}. \qquad (13)$$

In such a case, the heavy-particle current that interacts with $W^\pm$ must be responsible for both Reactions (1) and (2), and Reactions (3) and (4). Therefore, if $\nu_e = \nu_\mu$, and if $W^\pm$ exists, the total number N_μ of $\mu^\pm$ produced must be the same as N_e (neglecting the mass difference between e and μ). This does not agree with the observed result.

Furthermore, information concerning g_A can now be obtained by using (6), (11), and (13). As an ad hoc assumption, we may take g_A to be of the form

$$g_A = -G_A[1 + \tfrac{1}{12}q^2b^2]^{-2}[1 + m_W^{-2}q^2]^{-1}, \qquad (14)$$

where $G_A \cong -1.25\,G_V$. Then, for example, we may calculate how many events would have been expected in the Brookhaven experiment for various choices of m_W and b. The results of this calculation are shown in Table I. The results are not to be taken as any more than an indication of the sensitivity of the procedure, inasmuch as the neutrino flux in the experiment is not known to better than 30%.

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*Work supported by the U. S. Atomic Energy Commission.

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STRUCTURE IN THE PION-PROTON TOTAL CROSS SECTION BETWEEN 2 AND 3 BeV†

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(Received 25 February 1963)

The total cross sections for $\pi^\pm$ on protons in the energy range from 1.5 to 6 BeV have been measured in a transmission experiment at the AGS. Many measurements have been made in the past at pion kinetic energies below 1.5 BeV,[1-3] and recently data in the energy range 5-20 BeV have become available.[4,5] However, in the intermediate range, the total cross section has been determined only at widely spaced points,[3,6,7] particularly in the case of $\pi^- - p$. It is the purpose of this Letter to report new data in this range, taken in smaller energy steps and with a statistical accuracy of about 1%. These results indicate two statistically significant and previously unreported pion-nucleon resonances, one in each of the two isotopic spin states.

The secondary beam was taken at an angle of -15° to the internal proton beam of the AGS. The particles, after collimation and magnetic analysis, were defined by 2-in. diameter scintillation counters S_1 and S_2. The pions were identified by means of a differential gas Cherenkov counter[8] taken in coincidence with S_1 and S_2 to form a pion telescope. Any pions interacting in the walls or gas of the Cherenkov counter were swept away by a second bending magnet. The flux in the telescope varied from 2×10^3 per pulse at the lowest momenta to 3×10^2 per pulse at 6 BeV, for an internal circulating beam of 3×10^{11} protons per pulse. The accepted beam, whose absolute momentum was known to $\pm1\frac{1}{2}$% and had a spread of $4\frac{1}{2}$% full width at half-height, was then incident upon a 48-in. long liquid hydrogen target, 6 in. in diameter, and with 0.007-in. Mylar walls. The pions which passed through the target were detected in four scintillation counters S_{3-6}, the outputs from which were separately placed in coincidence with the telescope and scaled.

Behind these transmission counters an iron absorber was placed, followed by scintillation counter S_7 which could be used in anticoincidence with the telescope to reject muons not resolved by the Cherenkov counter or arising from pion decay in flight.

In the energy range 1.5 to 3.5 BeV, 3 ft of iron absorber was used and S_3, S_4, S_5, S_6 subtended solid angles at the target of approximately 2, 4, 6, 8 millisteradians. For the range 2.5 to 6.0 BeV, the iron absorber was increased to a length of $3\frac{1}{2}$ ft and the counter solid angles were reduced by a factor of 2. The results obtained with the two systems in the overlapping region were in good agreement and have been averaged according to their statistical weights in obtaining the final values for the cross sections. The solid angles used were large enough to contain the multiple Coulomb scattering of the pions.

The partial total cross sections as measured by counters S_3-S_6 were linearly extrapolated to zero solid angle. At the lowest momenta a small deviation from a straight-line extrapolation was found for the smallest counter S_3, due to pions which decayed into muons at angles large enough so as to miss this counter. For these cases only the three larger counters were used in the extrapolation.

Above 2.0 BeV approximately one half of the data was obtained with S_7 in anticoincidence. To these data a small correction has been applied for the change in decay rate due to the pion energy loss in the liquid hydrogen target. The other half of the data above 2.0 BeV was taken without using S_7. In this case a correction had to be applied for the muon contamination of the beam at the hydrogen target. This correction was determined experimentally by placing S_7 in coincidence with the telescope and measuring the transmission of the beam through the iron, both with and without hydrogen in the target. The measured muon contamination varied between 3.5 and 5.0% and was in agreement with that calculated from the decay rate and geometry, plus an estimate of muons not rejected by the Cherenkov counter. The π-p total cross sections as determined by the two types of measurements agreed and have been averaged according to their statistical weights. Below 2.0 BeV not all the muons passed through the iron, and therefore in this energy range S_7 was not used and the muon correction was obtained by calculation.

The electron contamination of the identified pion beam was negligible. Accidental coincidences between the telescope and a transmission counter were continuously monitored and gave a correction of about 0.1 mb. The correction made for the residual gas in the target-empty runs amounted to $1.5 \pm 1\%$, the uncertainty being due to a lack of accurate knowledge of the temperature of the gas in the target. This error, which applies uniformly to all the data, is the largest known systematic error in the final results. In the calculation of the cross sections, the hydrogen density was assumed to be 0.0708 g/cm^3.

The total cross sections are tabulated in Table I and plotted in Fig. 1. Figure 1(a) shows the measured π^--p values together with the results of previous experiments. It is seen that the new results agree well with other measurements[1,2,4-6] at all energies. However, they show a pronounced maximum of about 2 mb at a laboratory pion kinetic energy of 1.95 BeV. The π^+-p results, shown in Fig. 1(b), again agree with previous experiments at both the low-energy[1-3] and high-energy[4] ends. There is some disagreement, however, with the results of Longo and Moyer[3] and Vovenko *et al.*[7] between 2 and 4 BeV. Our results show a well-defined peak of 2 mb occurring at a pion kinetic

Table I. The pion-proton total cross sections.

Kinetic energy (BeV)	$\sigma(\pi^+ - p)$ (mb)	$\sigma(\pi^- - p)$ (mb)
1.51	34.90 ±0.47	34.06 ±0.36
1.59	⋯	34.67 ±0.47
1.69	30.62 ±0.47	34.38 ±0.40
1.80	⋯	35.38 ±0.42
1.85	29.23 ±0.44	⋯
1.90	29.31 ±0.43	35.94 ±0.37
2.00	29.07 ±0.30	35.73 ±0.25
2.11	30.01 ±0.29	35.63 ±0.23
2.21	30.89 ±0.27	34.63 ±0.29
2.32	31.10 ±0.26	34.01 ±0.37
2.42	30.55 ±0.27	⋯
2.52	30.89 ±0.27	33.37 ±0.32
2.63	29.99 ±0.27	⋯
2.73	29.87 ±0.26	32.85 ±0.32
2.83	29.49 ±0.23	⋯
2.93	28.96 ±0.35	32.29 ±0.28
3.03	28.84 ±0.22	⋯
3.14	28.38 ±0.27	31.90 ±0.19
3.34	28.43 ±0.22	⋯
3.55	27.99 ±0.16	31.35 ±0.22
3.76	27.70 ±0.23	⋯
3.97	27.37 ±0.26	30.27 ±0.22
4.18	27.84 ±0.23	⋯
4.39	27.22 ±0.23	29.92 ±0.22
5.79	⋯	28.16 ±0.21

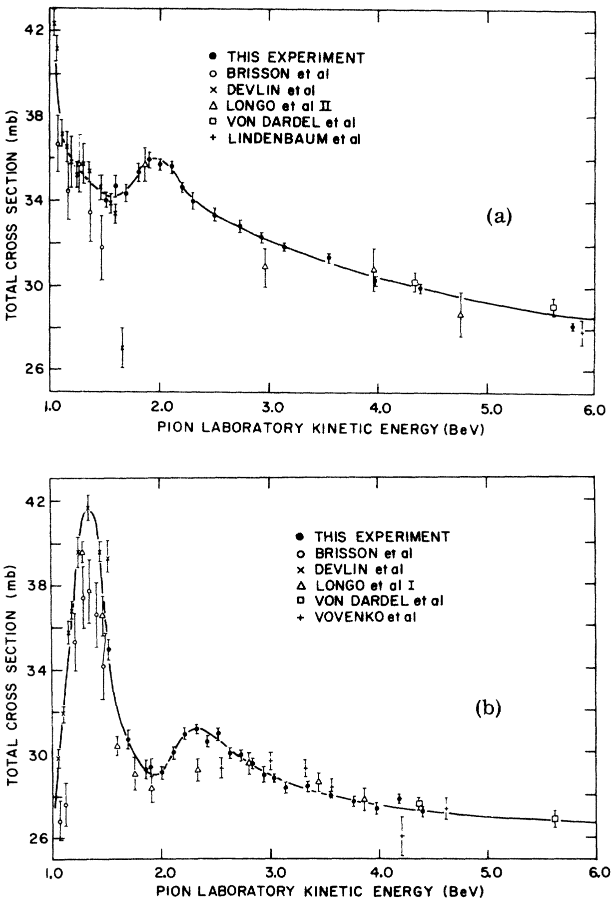

FIG. 1. The pion-proton total cross sections. (a) π^-p; (b) π^+p.

energy of 2.37 BeV.

Figure 2 summarizes the present knowledge of pion-nucleon resonances in both $I=\frac{3}{2}$ and $I=\frac{1}{2}$ isotopic spin states. The two new resonances found in this experiment are also shown on an expanded scale.

Table II summarizes some of the characteristics of these two new resonances.

If one makes the assumption that particular spin states are responsible for these two phenomena, then it is not possible to rule out any values of

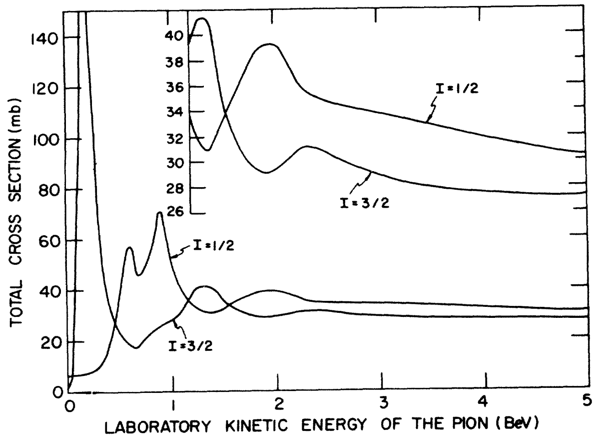

FIG. 2. The pion-nucleon total cross section in the two isotopic spin states. For pion kinetic energies greater than 1.2 BeV, the cross section is also shown magnified 10 times.

the spin by means of a comparison between $4\pi\lambda\!\!\!^{-2}$ and the heights of the resonances.[9]

In the inelastic channels some effects are worth noting. In the $I=\frac{1}{2}$ state there is a relatively abundant production of $Y_0^*(1405)+K$ and $Y_0^*(1520)+K$ at 1.89 and 2.09 BeV/c; at 2.16 and 2.24 BeV/c, however, production in these channels has disappeared.[10] In addition, the $K^*(888)$, $Y_1^*(1385)$, and $K^*(730)$ production appear to change around this energy.

The π^--p and π^+-p differential elastic cross section has been measured[11] in the energy region being considered, but not as yet accurately enough to allow a partial-wave analysis. The total elastic cross section is known from these experiments, and within the errors (±15%) it does not show any structure but seems to fall off smoothly.

One has repeatedly remarked on the correlation between the threshold for the production of resonant meson states and the energy at which a peak in the π-p total cross section appears. A similar situation may exist here. In the $I=\frac{1}{2}$ state, the threshold for the production of the 1.25-BeV

Table II. Some parameters of the two new resonances.

Isotopic spin	Kinetic energy (BeV) lab	Momentum (BeV/c) lab	Momentum (F^{-1}) c.m.	$4\pi\lambda\!\!\!^{-2}$ (mb) c.m.	Total energy (BeV) c.m.	Full width (BeV) c.m.
$\frac{1}{2}$	1.95	2.08	4.52	6.14	2.19	0.2
$\frac{3}{2}$	2.37	2.51	5.04	4.95	2.36	0.2

f_0[12,13] is 1.93 BeV (kinetic energy). For the $I=\frac{3}{2}$ state, where one has to produce $f_0+\pi$, because of isotopic spin conservation, the threshold is 2.26 BeV.

The energies of the two new resonances are such that they fit well into a Regge plot[14] of Reα versus the square of the center-of-mass energy. A straight-line extrapolation through the nucleon pole and the $N^*(f_{5/2}$, 900 MeV) pole passes accurately through $h_{9/2}$ at the squared mass of the new $I=\frac{1}{2}$ resonance. Similarly, the $N^*(p_{3/2}$, 190 MeV), the $N^*(?_{7/2}$, 1350 MeV),[15] and the new $I=\frac{3}{2}$ resonance can reasonably well be connected by a straight line of the same slope, making the latter resonance an $h_{11/2}$ state. However, this could be purely coincidental, since Regge trajectories do not have to be straight lines, and since their slopes do not have to be "standard."[14] Indeed, a trajectory through the $N^*(d_{3/2}$, 600 MeV) and the new $I=\frac{1}{2}$ resonance at $g_{7/2}$ has a slope which is not too different from "standard." Similarly, the new $I=\frac{3}{2}$ resonance can be connected to the shoulder at approximately 850 MeV in the $I=\frac{3}{2}$ state. This latter picture would then result in four trajectories for the πN system, each with two poles.

We wish to acknowledge the invaluable cooperation of the AGS staff, in particular, M. H. Blewett. We also wish to thank Dr. Longo for showing us his results prior to publication. His π^- point at 2 BeV/c was largely responsible for the undertaking of the present experiment. The technical assistance of George Munoz, Frank Seier, and Oscar Thomas is greatly appreciated.

[†] Work performed under the auspices of the U. S. Atomic Energy Commission.

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