transferred energies in the region of 3 GeV. This is in contradiction to some of the cosmic-ray experiments which reported deviation from the Bhabha cross section. Our results for the scattering of positive muons on electrons up to transferred energies in the region of 1.5 GeV also show agreement with Bhabha cross section. This is in contradiction to some extent to the charge-asymmetry results of Kotzer and Neddermeyer.[4]

Thus we believe that to the best of our knowledge this is the first muon-beam experiment in nuclear emulsion in which a systematical study was made for the pure knock-on process. We are checking the results at 5-GeV/c negative muon momenta and also extending our observations to a 10.1-GeV/c positive-muon beam.

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SEARCH FOR MESONS SUGGESTED BY THE VENEZIANO MODEL*

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Recent Regge-pole models have predicted the existence of particles of well-defined mass lying on daughter trajectories of such known particles as the ρ. A search for the coherent photoproduction of these mesons from carbon has been made. None was found. We conclude that in the mass range 1.0–1.8 GeV such mesons are coupled to the photon or the nucleus, at least two orders of magnitude more weakly than is the ρ.

A common feature of various Regge-pole models is the existence of daughter trajectories.[1] In particular, the Veneziano[2] model leads to families of particles lying on parallel, linearly rising trajectories. Thus, each particle on the ρ trajectory is degenerate in mass with particles of lower spin lying on daughter trajectories. We report here a search for the 1^- daughters of the 2^+ and 3^- mesons of the ρ trajectory. Henceforth, we shall refer to these 1^- mesons as the ρ' and ρ'', respectively. Shapiro,[3] applying the Veneziano model to $\pi\pi$ scattering, obtains the following values for the masses and 2π decay widths of the ρ' and ρ'': $m_{\rho'} = 1300$ MeV and

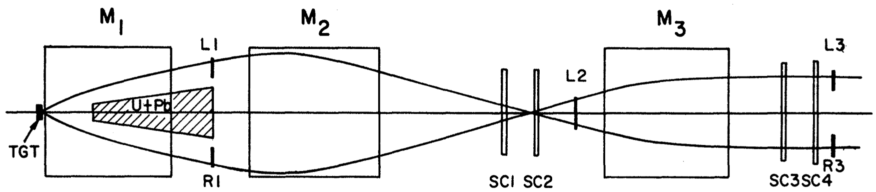

FIG. 1. Experimental apparatus.

$\Gamma_{\rho'\to\pi\pi} = 112$ MeV, $m_{\rho''} = 1670$ MeV and $\Gamma_{\rho''\to\pi\pi} = 14$ MeV.

We have looked for the coherent photoproduction of these particles from carbon and their subsequent decay into $\pi^+\pi^-$. At finite energy coherent production is reduced due to the longitudinal momentum transferred to the carbon nucleus. The reduction factor at 0° is approximately $\exp(-40m_{\pi\pi}^4/4k^2)$, where $m_{\pi\pi}$ is the meson mass and k the photon energy. At our highest energy, 10 GeV, this factor becomes $1/e$ for $m_{\pi\pi} = 1.7$ GeV.

The apparatus is shown in Fig. 1. The bremsstrahlung beam of the Cornell 10-GeV synchrotron passes through a carbon target and is buried in the uranium and lead beam stop. The beam is monitored by a calibrated thin ion chamber upstream of the target. Pairs of oppositely charged particles produced in the target pass through the uniform field magnets M_1, M_2, and M_3. A fivefold coincidence between counters L_1, L_2, L_3, R_1, and R_3 triggers the four optical spark chambers SC1, etc. from which the particle trajectories are determined. Assuming the particles to be pions, we compute their invariant mass. The mass resolution is $\Delta m_{\pi\pi} = \pm 8$ MeV. At a single magnet setting the counters define a mass acceptance of approximately $\Delta m_{\pi\pi}/m_{\pi\pi} = \pm 0.05$. To scan the mass range 500-1800 MeV the three magnets were scaled together. As a result the photon energy and $m_{\pi\pi}$ are very nearly proportional to each other. Care was taken to vary the magnets in small steps ($\Delta m_{\pi\pi} = 25$ MeV) and to vary smoothly the running time at each point, from a short time at the low end to a long time at the high end. This permits all the events, after precision spark-chamber analysis, to be lumped in a single mass distribution.[4] This procedure reduces the danger of introducing spurious structure due to errors in efficiency calculations.

The mass distribution obtained in this way at zero degrees from carbon is shown in Fig. 2 where $d^2\sigma/d\Omega dm_{\pi\pi}$ is plotted against $m_{\pi\pi}$. So little time was spent at the low end that the bump at 600 MeV is statistically insignificant. Of course, the ρ dominates the plot. Qualitatively the data show a rather smooth decrease for $m_{\pi\pi} > m_\rho$. Above 1100 MeV, the data are also shown expanded by a factor of 40. The smooth curves are two possible Breit-Wigner forms normalized at the ρ peak,[5] modified to include the form factor due to the longitudinal momentum transfer and the k^2 dependence due to the diffractive nature of the process. We attach no particular significance to the detailed comparison of the data with the curves, but only comment that, superficially, all or most of the events could belong to the tail of the ρ. We will make that statement more quantitative in what follows.

There is nothing significant at $m_{\pi\pi} = 1300$ MeV (ρ') and there is a suggestion of an effect at $m_{\pi\pi} = 1670$ MeV (ρ''). The most significant "bump" occurs at $m_{\pi\pi} = 1400$ MeV. We consider first the

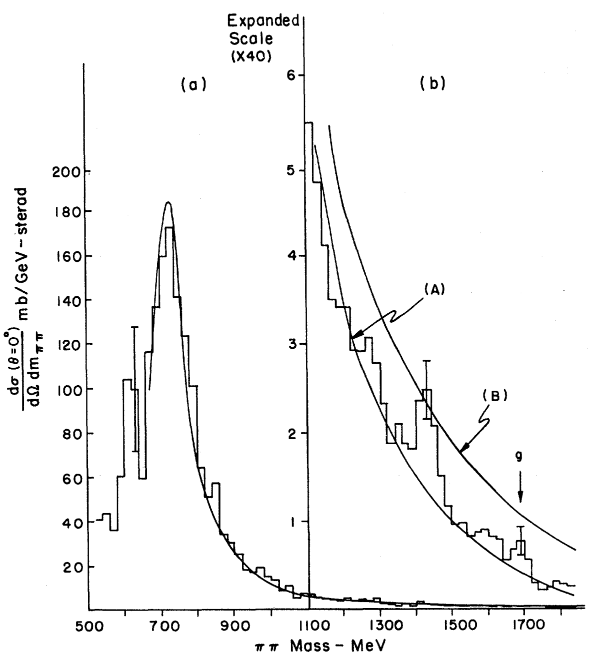

FIG. 2. Mass distribution of pion pairs observed from carbon. $m_{\pi\pi}$ is proportional to the photon energy k_γ and is 2 GeV when $k_\gamma = 10$ GeV. See text for explanation of and comments on the solid curves shown.

1670-MeV region and estimate the upper limit for producing a 1^- meson of this mass by assuming the following: (a) At 1670 MeV the measured value of $d^2\sigma/d\Omega dm_{\pi\pi}$ is due entirely to production of the ρ''. (b) In analogy to ρ dominance the meson is directly coupled to the photon with a coupling constant $f_{\gamma\rho''} = em_{\rho''}^2/2\gamma_{\rho''}$. We will concentrate on the unknown $\gamma_{\rho''}$ in quoting our upper limit, or rather, since our data included the ρ, we will quote $\gamma_{\rho''}^2/\gamma_\rho^2$. This is inferred from the ratio of the rate at the ρ'' mass to that at the ρ. Recall that $\gamma_\rho^2/4\pi$ is known to be approximately 0.5 or 1. (c) The cross section for the coherent production on carbon is given by a formula analogous to that assumed for ρ production:

$$\frac{d\sigma}{dt}(t=0) = \frac{\alpha}{4}\frac{4\pi}{\gamma_{\rho''}^2}\frac{1}{16\pi}\sigma_T^2(\rho'', C),$$

where $\sigma_T(\rho'', C)$ is the total cross section of the ρ'' on carbon. We assume that $\sigma_T(\rho'', C) = \sigma_T(\rho, C)$.

In considering the ratio of ρ'' to ρ it is still necessary to include the total widths $\Gamma_\rho = 120$ MeV and $\Gamma_{\rho''}$ as well as the partial width $\Gamma_{\rho''\to\pi\pi}$. We then obtain

$$\frac{\gamma_{\rho''}^2}{\gamma_\rho^2} > 250\frac{\Gamma_{\rho''\to\pi\pi}\Gamma_\rho}{\Gamma_{\rho''}^2}.$$

If we take $\Gamma_{\rho''} = 50$ MeV, as suggested by the data of Fig. 2(b), and $\Gamma_{\rho''}(2\pi) = 14$ MeV, as computed by Shapiro, we obtain $\gamma_{\rho''}^2/\gamma_\rho^2 > 190$.

We will now optimistically attempt to interpret the bump at 1400 MeV as being Shapiro's meson. First consider the statistical significance. In the mass range 1390-1440 MeV there are 142 events, while there are 98 background counts as obtained by comparison with the rates above and below this range. Had the energy at which we observe the bump been predicted this would have been an excess of some 3 standard deviations and hence of some significance. But the probability of our having seen a bump at least this large, somewhere in our energy range, is 10 or 20%. Hence our data cannot be taken as self-contained evidence for a new particle.

We can, however, make an analysis for this ρ' meson similar to the above ρ'' analysis. We assume that $d^2\sigma/d\Omega dm_{\pi\pi}$ is half due to the ρ' at 1400 MeV and we take $\Gamma_{\rho'} = \Gamma_{\rho'\to\pi\pi} = 100$ MeV as a compromise between Shapiro's value of 110 MeV and the somewhat smaller value of $\Gamma_{\rho'}$ suggested by our data. This yields $\gamma_{\rho'}^2/\gamma_\rho^2 > 240$.

We conclude that any 1^- meson in the mass range 1.0-1.8 GeV is coupled much more weakly to either the photon or to the nucleon than is the ρ meson.

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[5]The two smooth curves A and B used in Fig. 2 are calculated as follows:

$$A,\ \frac{d^2\sigma(m_{\pi\pi})}{d\Omega dm_{\pi\pi}} = \frac{d^2\sigma(m_{\pi\pi}=m_\rho)}{d\Omega dm_{\pi\pi}} \times \frac{(m_\rho^2\Gamma_0/\pi)F(m_{\pi\pi})}{(m_{\pi\pi}^2-m_\rho^2)^2+m_\rho^2(\Gamma_0/2)^2},$$

$$B,\ \frac{d^2\sigma(m_{\pi\pi})}{d\Omega dm_{\pi\pi}} = \frac{d^2\sigma(m_{\pi\pi}=m_\rho)}{d\Omega dm_{\pi\pi}} \times \frac{(\Gamma_0/\pi)F(m_{\pi\pi})}{(m_{\pi\pi}^2-m_\rho^2)+(\Gamma_0/2)^2},$$

where $m_\rho = 760$ MeV, $\Gamma_0 = 120$ MeV, and from our data $d^2\sigma(m_\rho)/d\Omega dm_{\pi\pi} = 182$ mb/GeV sr. Also $F(m_{\pi\pi}) = e^{-40|t_{\min}|} \times k^2(m_{\pi\pi})/k^2(m_\rho)$; $|t_{\min}| = m_{\pi\pi}^4/4k^2(m_{\pi\pi})$; $k(m_{\pi\pi}) = 5m_{\pi\pi}$. We emphasize that these curves are shown for qualitative comparison with the data and are not in any way "fits" to the spectrum.