SEARCH FOR RHO-MESON DECAY INTO MUONS*

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(Received 18 October 1965)

We report here a search for the mu-pair decay mode of the rho meson. Evidence for this decay mode was sought in the effective-mass distribution of muon pairs produced by a 4.85-BeV γ-ray bremsstrahlung beam incident on a carbon target at the Cambridge Electron Accelerator. In the mass region studied, muon-pair production is dominated by the Bethe-Heitler process. However, contributions from rho decays, if present in sufficient quantity, would appear as a peak, or excess above the Bethe-Heitler yield, in the effective-mass distribution of the muon pairs. The observed distribution does not show a significant difference from one calculated from the Bethe-Heitler pair-production process. Thus this experiment, together with a knowledge of the rho-photoproduction cross section,[1] determines an upper limit for the branching ratio R where $R=(\rho^0 \rightarrow 2\mu)/(\rho^0 \rightarrow 2\pi)$. We obtain, using the measured rho-production cross section[1] for carbon, an upper limit of $R<2\times10^{-4}$. The apparatus and the calculations are described below.

The apparatus used for muon-pair detection is shown schematically in Fig. 1. This is essentially the same apparatus used in a muon-photoproduction experiment previously reported,[2] except that wider angles were measured.

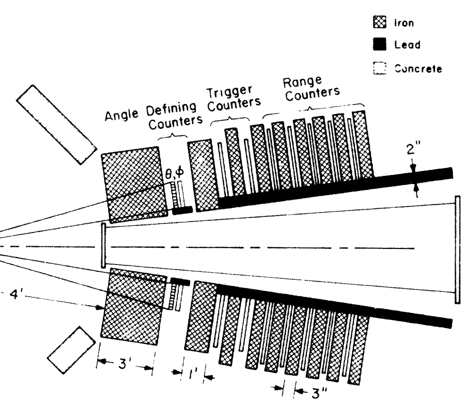

FIG. 1. Schematic of apparatus for wide-angle μ-pair experiment.

(However, the wider angle data discussed here were not previously reported.) It consisted of a 154-counter hodoscope[3] arranged in two similar arrays placed symmetrically on both sides of the γ-ray beam. The counters defined a range of polar angles for each particle from 6° to 14° in 1° intervals, while the azimuthal angle, measured in 6° intervals, was ±15°, on each side of the beam, centered about 180°. The range counters permitted determination of particle energies from 1.8 to 2.4 BeV in 120-MeV intervals.

A muon pair was identified by requiring a fast coincidence among the four trigger counters shown in Fig. 1. A pair of these counters were located behind four feet of iron on each side of the γ-ray beam. Three inches of iron was placed between the counters of each pair, and the pair was operated in coincidence as a charged-particle telescope. A coincidence between the two telescopes initiated the recording of a record on magnetic tape indicating which hodoscope counters had been struck by the triggering particles. Also additional information describing running conditions was recorded with each event.[3] The data recording could be initiated by either a prompt or delayed coincidence between the telescopes, and in this manner the chance backgrounds were directly measured along with the true events. The amount of iron preceding the trigger counters was sufficient to reduce the probability of pion pairs reaching the trigger counters to about 10^{-5} for each pion pair produced at the target. The probability of a trigger resulting from the decay in flight into muons of one or both members of a pion pair was also reduced to about 10^{-5} for each pion pair produced. The observed charged-particle rates were corrected for chance coincidences, nontarget-associated events, trigger-counter efficiency, dead-time losses, Coulomb-scattering losses, and background from π-pair production.

The calculation of the expected yield from Bethe-Heitler type processes (Fig. 2) was based

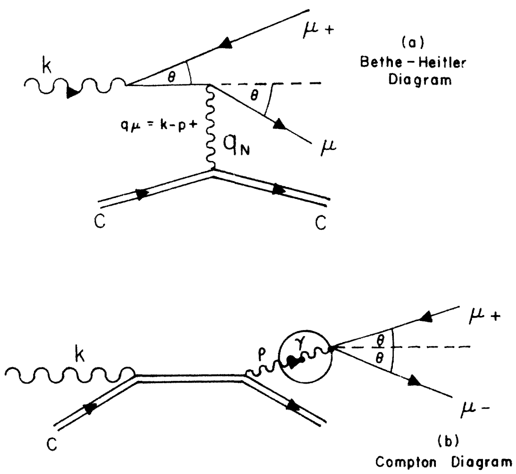

FIG. 2. Electromagnetic pair-production diagrams.

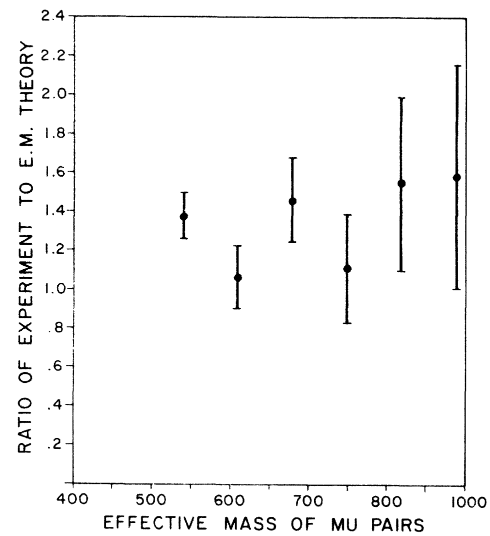

FIG. 3. Ratio of experiment to electromagnetic theory.

on a relativistic first Born approximation of the cross section for electromagnetic muon-pair production.[4] The calculation included the measured elastic form factor of the carbon,[5] an integration over counter acceptances, and a folding with a Coulomb-scattering distribution function to account for the scattering in the three feet of iron preceding the angle defining counters. The yield also included contributions from inelastic production. Further details of the yield calculation for the Bethe-Heitler type processes can be found in reference 2. This yield constitutes the background in the present experiment. The corrected data and the calculated Bethe-Heitler yields were sorted into 70-MeV $\mu^+\mu^-$ effective-mass bins. This bin width corresponds to the resolution due to the angular acceptance of the counters and the uncertainty in the particle energy. The effective-mass distribution is shown in Fig. 3 and includes only those events for which the nuclear momentum transfer was less than 0.66 F^{-1}. With this restriction, the inelastic contributions were calculated to be less than 10% of the elastic yield. The measured and calculated yields are given in Table I. The ratio of experiment to theory was calculated for each value of effective mass and is shown in Fig. 3. The error in this ratio is dominated by the statistical uncertainty in the number of observed events.

A comparison of the theoretical Bethe-Heitler yield with the measured value (Fig. 3) shows no significant deviation between theory and experiment as a function of the effective mass of the muon pair, but shows an average ratio of experiment to theory (for the data given in Table I) of 1.30 ± 0.15. We conclude from this

Table I. Summary of observed and calculated yields. The yields given have been normalized to 0.01 C of charge collected by Quantameter.

Mass	Calculated electromagnetic yield	Renormalized calculated yield	Observed yields	Calculated rho-decay muon yield $R = 10^{-4}$
540	408	522 ± 80	567 ± 47	4.9
610	293	375 ± 57	310 ± 46	15
680	166	212 ± 33	243 ± 35	36
750	78	100 ± 15	86 ± 20	45
820	40	51 ± 8	62 ± 18	31
890	17	24 ± 5	27 ± 10	11

that muons from rho decays are not present in the data in statistically significant numbers. This normalization discrepancy cannot be attributed to the rho decay into two muons, since these muons would not contribute equally to all mass bins, and thus could not result in a yield differing from Bethe-Heitler theory by a constant amount. We attribute the over-all normalization of 1.30 ± 0.15 to systematic error in determining the absolute normalization.

It has been noted[4] that in experiments over symmetric intervals such as this, Compton-type diagrams such as Fig. 2(b) do not interfere with Bethe-Heitler-type diagrams such as Fig. 2(a). This is also true, in general, as long as charge-conjugation invariance holds and the muon charges are not measured. Hence the upper limit of the number of muon pairs from ρ^0's can be directly related to the ρ^0 production cross section without concern about interference terms between Bethe-Heitler and Compton diagrams.

The calculation of muon-pair yield from rho decay was based on the measured pion-pair photoproduction cross section for the carbon nucleus.[1] These measurements indicated that the dominant mode of pion-pair production in the region of interest in this experiment arises from the photoproduction of rho mesons. In order to extrapolate these data to a prediction of the desired yield, the rho-production cross section was assumed to have the following form:

$$d^3\sigma/dkdmd\Omega = f(k)e^{-\alpha t}\Gamma(m),$$

where $f(k)$ is a function of photon energy k, $\Gamma(m)$ is the Breit-Wigner distribution function, t is the square of the nuclear four-momentum transfer, α is a constant, and $d^3\sigma/dkdmd\Omega$ is the cross section for production of a rho of mass m into solid angle $d\Omega$, by an incident photon of energy k. This production cross section was then multiplied by the probability that the produced rho would decay into a pion pair at a given angle in the c.m. system of the rho. This probability was calculated assuming that angular distribution of the pions (in c.m. system of the rho) was a $\sin^2\theta^*$ distribution where θ^* is measured with respect to the rho direction. Thus the number of pion pairs produced at a given angle in the center-of-mass system of the rho would be proportional to

$$N(k)f(k)e^{-\alpha t}\Gamma(m)\sin^2\theta^* dmdkd\Omega d\Omega^*,$$

where $N(k)$ is the number of photons at energy k, and $d\Omega^*$ is the solid angle of the pion pairs in the rho c.m. system.

In order to obtain the expected pion yields, the above expression must be written in terms of the pion parameters measured in this experiment, namely their energies E_1, E_2, and their polar and azimuthal angles θ_1, θ_2, and φ_1, φ_2, respectively. This was done by expressing the six quantities[6] k, m, θ, φ, θ^*, and φ^* in terms of the six measured parameters and replacing $dmdkd\Omega d\Omega^*$ by $JdE_1dE_2d\theta_1d\theta_2d\varphi_1d\varphi_2$, where J is the appropriate 6×6 Jacobian.

With the yield in this form, the function $f(k)$ and the constant α were chosen to fit the pion yields measured by Lanzerotti et al.[1] The expected yields for the muon decay mode of the rho for any assumed branching ratio R was then determined for the apparatus and the conditions of this experiment. The expected yield for a branching ratio of 10^{-4} is given in Table I. The systematic uncertainty in this yield arising from the intercomparison of two experiments as described above is estimated to be less than 50%.

The branching-ratio upper limit was calculated on the assumption that the observed rate is consistent with Bethe-Heitler muon-pair production insofar as the ratio of experiment to electromagnetic theory as a function of the effective mass of the lepton pair is consistent with a straight line of zero slope. To establish this upper limit, the maximum number of muons from rho decays which might be present in the data was calculated. To obtain this number, the measured yields in all the mass bins excluding the 680-, 750-, and 820-MeV bins was used to determine the proper normalization. Using this normalization, the expected yields were calculated for the excluded bins. The difference between these yields and the measured value was then assumed to be due to the muon-pair decay of the rho meson. In this manner, the number of muon pairs due to this process obtained was 28 ± 57. This number, because of its large statistical error, is consistent with a branching ratio of zero. However, an upper limit on the branching ratio can be set using the uncertainty of 50 counts and the calculated expected muon-pair yield from rho decays. This yield, given in Table I, for the three mass bins in the vicinity of the rho mass was about $1.1\times 10^6 R$ where R is the branching ratio. Thus with a 95% confidence, the upper limit on the branching ratio is $R<(28+2\times 57)/1.1\times 10^6=1.3\times 10^{-4}$. However, as mentioned above a maximum systematic error of 50% in the yield was estimated as possibly resulting from the comparison of two experiments.[1] Including this possible systematic error results in an upper limit of 2.0×10^{-4}.

This result is approximately an order of magnitude improvement over previous measurements of the muon branching ratio.[7] The upper limit of the muon branching ratio set by these data is approximately equal to the upper limit on the electron branching ratio of the ρ set by other recent work.[8] Further work on an improved design of this experiment is now in progress.

We wish to thank the authors of reference 2 and the staff of the Cambridge Electron Accelerator for their aid and cooperation in obtaining data used in this experiment. We wish also to acknowledge the valuable assistance of the research group of reference 1, and most especially of John Russel who provided many experimental details needed to compare the two experiments. One of us (M.G.) acknowledges the many helpful discussions with Dr. von Goeler of Northeastern University concerning this work.

*Work supported in part by the National Science Foundation under Grants No. NSFG-17419 and No. GP625, and in part by the U. S. Atomic Energy Commission under Contract No. AT(30-1)2098.

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[2]J. K. de Pagter, A. Boyarski, G. Glass, J. I. Friedman, H. W. Kendall, M. Gettner, J. F. Larrabee, and R. Weinstein, Phys. Rev. Letters 12, 739 (1964). To accept wider angles, the only change necessary in the apparatus was to move the carbon target two feet closer to the iron shielding.

[3]A complete description of the apparatus, hodoscopes, and recording techniques used will be published soon.

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$\pi^- + p$ ELASTIC SCATTERING FROM 2.5 TO 6 GeV/c*

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(Received 22 October 1965)

We have measured the differential elastic-scattering cross section for $\pi^- + p$ collisions at four incident pion momenta: 2.5, 3.0, 4.0, and 6.0 GeV/c. The emphasis in this experiment has been placed on scattering at relatively large momentum transfers—in particular, on the structure in the differential cross section near the backward direction and in the region of the secondary maximum at $-t=1.2$ which has been seen by other experimenters[1,2] at lower energies.

The experiment was carried out in the 17° beam of the zero-gradient synchroton (ZGS) at Argonne National Laboratory with the apparatus shown in Fig. 1. A liquid-hydrogen target one foot long and 1.5 inches in diameter is completely surrounded by a coplanar array

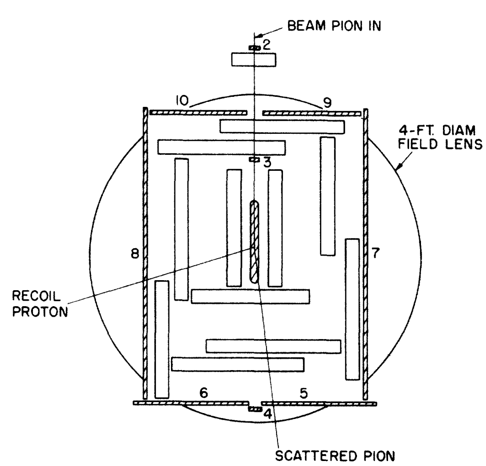

FIG. 1. Plan view of experiment.

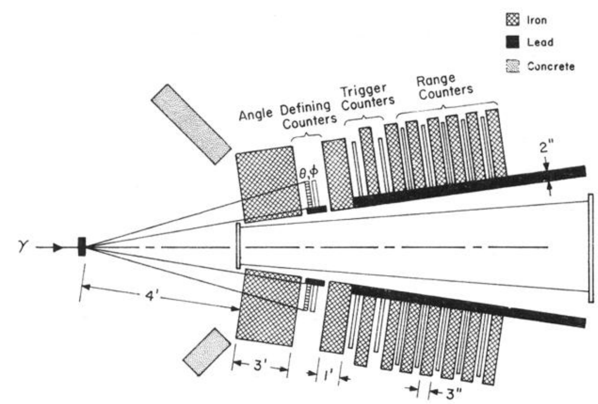

FIG. 1. Schematic of apparatus for wide-angle μ-pair experiment.