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DETERMINATION OF THE BRANCHING RATIO FOR THE DECAY OF RHO MESONS INTO MUON PAIRS*

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An experiment on photoproduction of muon pairs from carbon has been performed at the Cambridge Electron Accelerator using a 5.2-BeV bremsstrahlung beam. The data, when compared to Bethe-Heitler theory, exhibit an enhancement of muon pairs having an invariant mass corresponding to that of the ρ meson. These muons are interpreted as arising from leptonic decay of the ρ meson. This previously unreported experiment is an improved version of an earlier experiment.[1,2] It has more than 40 times the data of the earlier work and has reduced errors due to detector geometry and electronics.

The experiment utilized thick iron filters to separate pions from muons. Figure 1 schematically shows the experimental arrangement. A muon-pair trigger was generated when two charged particles, one on each side of the γ beam, traversed 4 ft 3 in. of iron. When a trigger was generated, 160 hodoscope detectors were observed in coincidence. The hodoscope counters measured the angles and range of each member of the pair. Polar angles from 4.2° to 10.9° were detected in nine equal intervals. Azimuthal angular intervals of 42°, centered about 180°, were observed on each side of the γ beam in 6° intervals. The angle-defining counters were placed behind 3 ft of iron. Ranges were measured for each muon corre-

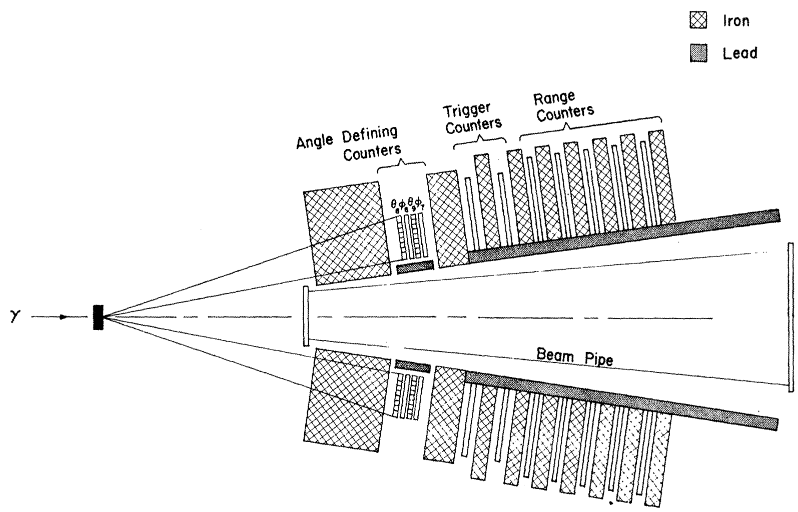

FIG. 1. Arrangement of apparatus for μ-pair experiment.

sponding to energies from 1.8 to 2.4 BeV in five intervals. The resulting invariant-mass resolution had a standard deviation of approximately 35 MeV.

The data were corrected for chance rates, target-out rates, dead-time losses, electronic and geometric trigger efficiencies, and Coulomb-scattering losses of particles in the iron preceding the trigger counters and the range counters. A correction was also made for π-meson pairs and their decay products which satisfied the trigger requirements. The pi-pair decay products gave rise to π, μ and μ, μ in addition to the $\pi\pi$ backgrounds. The backgrounds originating from π pairs were assumed to arise mainly from ρ production, as is indicated by previous measurements.[3-5] The background correction has uncertainties which will be considered in the latter part of this note.

The data were then compared to theoretically predicted rates. These theoretical rates consisted of two terms, one arising from the Bethe-Heitler process, and the other a phenomenological description of muon pairs from rho mesons. The Bethe-Heitler calculation is very much like that described in an earlier Letter.[2]

The ρ-meson contribution to the mu-pair rate was calculated using a slight modification of the ρ-production cross section suggested by Lanzerotti et al.[3] We assume that the ρ-production cross section has the form

$$d^3\sigma/dkdmd\Omega = g(k)f(m)(e^{-At} + be^{-Dt}), \qquad (1)$$

which results in a yield of

$$\text{Yield} = nQB\int\left[C\left(\frac{k}{4.4}\right)^2(e^{-At}+be^{-Dt})d\varphi d\cos\theta\right]$$
$$\times\left[\frac{0.9dk}{k}\right][f(m)dm]\left[\frac{1}{2\pi}d\bar{\varphi}d\cos\bar{\theta}\right]. \qquad (2)$$

In these equations, n is the target thickness in nuclei per cm^2, Q is the number of equivalent quanta striking the target, k is the photon energy in BeV, and t is the square of the four-momentum transferred to the nucleus in (BeV/c)^2. The terms e^{-At} and be^{-Dt} represent coherent and noncoherent ρ production from the carbon nucleus. The constant b is chosen to be 0.098 in order to fit the data[6] for large t. A and D are taken, respectively, to be 45 and 10 to fit the carbon and nucleon form factors. $C(e^{-45t}+0.098e^{-10t})$ is the value of $d\sigma/d\Omega$ for $E_\gamma = 4.4$ BeV. Reference 3 gives a value of $d\sigma/d\Omega \approx 95$ mb/sr for ρ production from carbon at 4.4 BeV, for $t=0$. Hence $1.098C = 95 \times 10^{-27}$ cm^2/sr. θ is the ρ-production angle with respect to the γ direction. The term $0.9dk/k$ represents the bremsstrahlung spectrum in the region of interest. The invariant mass of the μ pair is m, and $f(m)$ is a normalized Breit-Wigner resonance shape with $m_0 = 740$ MeV and a full width at half-maximum of 150 MeV.[3] $\bar{\theta}$ is the angle of one of the μ's in the center of mass of the ρ, taken with respect to the ρ direction of motion in the laboratory system. The ρ meson is in a 1^- state, and can decay into a $^3S_1$ or a $^3D_1$ state of muons.

We have assumed that the S wave dominates. Finally, B is the branching ratio of the ρ decay into two muons compared to ρ decay into two pions.

The yield in terms of the above variables was transformed to the yield in terms of the laboratory variables by the appropriate transformation equations and a 6×6 Jacobian. The integration indicated in Eq. (2) was performed over the various laboratory acceptance intervals. The yields resulting from Eq. (2) were folded with a Molière distribution function to account for the effects of Coulomb scattering.

The interference terms between the Bethe-Heitler amplitudes and the ρ amplitude, in our experiment, are zero if charge conjugation is a good quantum number.[7] On this assumption we simply add the Bethe-Heitler cross section to that calculated for the ρ in order to get the theoretical muon-pair rate which we compare to experiment.

It is convenient to express both the theory and the experimental yields as ratios R, to Bethe-Heitler theory. Thus $R_{\text{theory}}=1+B\times(\text{yield}_\rho/\text{yield}_{\text{BH}})$. In order to allow for a normalization error in the experiment we include an adjustable normalization constant A. Furthermore, since many classes of systematic errors give a slope to R when m^2 is taken as the independent variable, we include an adjustable slope $dR/dm^2=\alpha$. The theory we use for a best fit to the data is then of the form

$$R_{\text{theory}}=A(1+\alpha m^2+BY_\rho/Y_{\text{BH}}). \quad (3)$$

It is not our purpose in this note to test the Bethe-Heitler theory by setting limits on α, but rather to use conservative extremes of α to set limits on B. The spread in α arises primarily from the uncertainties in the background subtractions of π pairs and their decay products. We include as an error in B the effect of these uncertainties.

The resulting best fit is shown in Fig. 2 together with the data. For convenience, the data and theory are shown on a linear mass scale. Figure 2 displays about $\frac{1}{4}$ of our data. The data include events in which each charged particle stops in one of the last three of our five observed energy intervals. This preselection of data was made in order to reduce the effect of backgrounds due to pi pairs and their decay products and thereby reduce the uncertainties in α. The value of B given by the best fit is $B=(0.33\pm0.04)\times10^{-4}$, where the error is due to statistics alone. This value of B is, however, quite sensitive to the correction for background due to pion pairs and their decay products. In order to allow for this sensitivity, we have computed values of B for a subtraction of 0.8 and 1.2 times our best estimate of this background. We have also computed values of

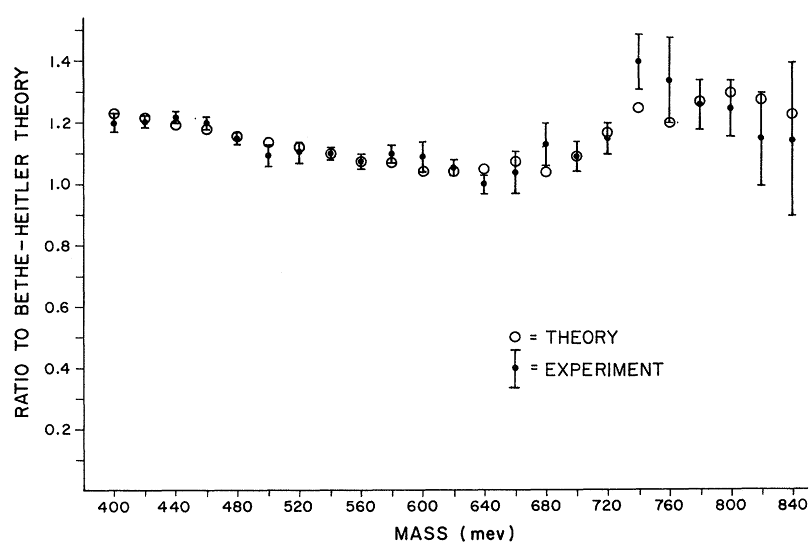

FIG. 2. Invariant-mass spectrum of μ pairs. Both experiment and theory are normalized to Bethe-Heitler theory. The fluctuations in the theoretical predictions reflect the differences in the number of counter combinations corresponding to various kinematic intervals. The theoretical fit is to Eq. (3) with $A=1.4$, $\alpha=-0.74$, and $B=(0.331\pm0.040)\times10^{-4}$.

B for various methods of normalizing the π backgrounds. The resulting minimum and maximum values of B are 0.28×10^{-4} and 0.49×10^{-4}. We consider this variation in B to be our last estimate of the expected error due to the uncertainties in background subtractions. In addition, since B is inversely proportional to the cross section for the photoproduction of ρ mesons measured in Ref. 3, the error in B must include the error in that measurement, which is about ±15% or $\pm0.05\times10^{-4}$. Thus our best estimate of B and the expected error, including all known sources, is $B=(0.33_{-0.07}^{+0.16})\times10^{-4}$. A more complete description of our procedures, analysis, and results than is possible in this brief communication is in preparation.

In assigning the observed mu-pair excess to the decay of the ρ meson we are of course assuming that all of the di-pion resonant mass structure observed in Ref. 3 is due to the ρ meson. We further assume that the contribution due to muon-pair decay of the ω meson is negligible. This assumption is based upon the small value of the ω-photoproduction cross section in hydrogen observed at the Cambridge Electron Accelerator[4] and at the Deutsches Elektronen Synchrotron,[5] and upon a reasonable upper limit on the diffraction mechanism contribution to this process. However, the validity of the assumption depends on the branching ratio for ω decay into two muons. If this branching ratio is more than five times that of the ρ, our value of B may have to be revised downward by more than the quoted error. Binnie et al.[8] have reported a branching ratio of the ω meson into electrons which lies between 0.5×10^{-4} and 6×10^{-4}.

Our results for B are to be compared to the recent upper limit of 2×10^{-4} on the muon branching set by Boyarski et al.,[1] and to the electron branching ratio reported by Zdanis et al. (for an assumed ω-φ mixing angle of 38 degrees) to be $(0.5_{-0.3}^{+0.6})\times10^{-4}$.[9]

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