tials have smaller widths, but the smallest of these, that of the $L=4$ state in a square well, comes out greater than 1 GeV!

It is, of course, impossible to rigorously rule out a diabolically contrived mixture which produces nearly exact cancelations in η for both the $L=0$ and $L=2$ final states, but it seems extremely unlikely. There is also the possibility that recombination of the Ξ's to Ω's or final-state interactions may modify the values of the widths calculated. However, the unknown potential is unlikely to be so strongly repulsive as to diminish the overlap of the asymptotic states with the $\Xi\bar{\Xi}$ part of the ψ wave function by the many orders of magnitude required. I therefore conclude that, even from its own philosophical point of view, the $\Omega\bar{\Omega}$ picture of a ψ is untenable.

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Measurements of Selected $\psi(3684)$ Branching Ratios from a Study of Secondary Lepton Pairs*

E. Hilger,† B. L. Beron, R. L. Ford, R. Hofstadter, R. L. Howell, E. B. Hughes, A. D. Liberman, T. W. Martin, L. H. O'Neill, and J. W. Simpson

High Energy Physics Laboratory and Department of Physics, Stanford University, Stanford, California 94305

and

L. K. Resvanis

Department of Physics, University of Pennslyvania, Philadelphia, Pennslyvania 19174

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We determine the ratio of the partial decay width for $\psi(3684)\to\mu^+\mu^-$ to that for the cascade decay $\psi(3684)\to\psi(3095)+X$ to be $(1.4\pm0.3)\%$ and, by direct observation of associated charged particles and γ rays, find the ratio of the partial decay width for $\psi(3684)\to\psi(3095)+\pi^0\pi^0$ to that for $\psi(3684)\to\psi(3095)+\pi^+\pi^-$ to be 0.64 ± 0.15.

From a study of $\psi(3684)$ decays involving the emission of secondary e^+e^- or $\mu^+\mu^-$ pairs we are able to identify the cascade decay $\psi(3684)\to\psi(3095)+X$, determine the rate of the direct decay $\psi(3684)\to\mu^+\mu^-$, and estimate the ratio of the decay rates for $\psi(3684)\to\psi(3095)+\pi^0\pi^0$ and $\psi(3684)\to\psi(3095)+\pi^+\pi^-$. These measurements were made at the electron-positron storage ring (SPEAR) at the Stanford Linear Accelerator Center using an apparatus identical to that already used to detect lepton pairs from $\psi(3095)$ decay[1] and very similar to that described earlier by Beron *et al.*[2] It consists of two identical spectrometers mounted in a collinear configuration about the beam-interaction region. The energies of secondary electrons or positrons are measured with good resolution in large NaI(Tl) total-absorption detectors, while muons are identified by requiring them to penetrate 20 in. of NaI(Tl) and 16 in. of steel. In each spectrometer the NaI(Tl) detectors are preceded by three multiwire proportional chambers with space for an optional lead converter for γ-ray detection between the first two. 33% of the experiment was spent with converters 0.55 radiation lengths in thickness, 60% with converters 1.1 radiation lengths in thickness, and 7% with no converters at all.

The event rates reported in this Letter are normalized with respect to the observed rate of $e^+e^- \to e^+e^-$ events detected in an independent luminosity monitor viewing the interaction region at angles close to 3.5°. For the major portion (80%) of this experiment, luminosity measurements accurate to better than ±2% were provided by a precision luminosity monitor similar to that described by Crawford *et al.*[3] For the initial 20% of the experiment, luminosity measurements subject to a systematic uncertainty of ±12% were provided by a substitute monitor.

The data accumulated without γ-ray converters, all of which were obtained at center-of-mass energies within 1.0 MeV of 3684 MeV, were examined for electron-positron pairs. Events were accepted as candidates provided that one and only one track entered each crystal, that each track intersected the crystal face within an aperture diameter of 16 in., and that a minimum energy of 1100 MeV was observed in each crystal. Figure 1 shows the correlation between the energies deposited in the two crystals for such events. Also identified in this plot are those events with

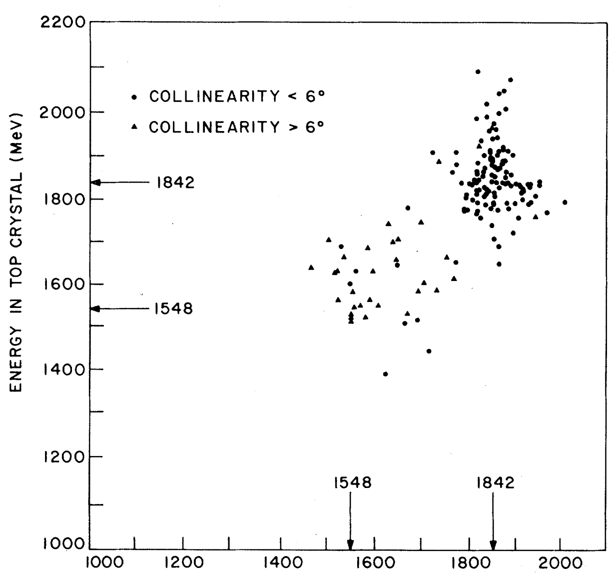

FIG. 1. A scatter plot for 158 electron-positron-pair events showing the energy deposited in one crystal versus the energy deposited in the other. Also identified are those events with collinearities larger than 6°. The average detected energy of the events associated with $\psi(3095)$ decay exceeds 3095 MeV primarily because of the simultaneous detection of γ rays from π^0 decay, which happens with a probability of about 35%.

acollinearities larger than 6°. Two types of events are clearly revealed in this plot. First, a group of events with energies around 1842 MeV in each crystal, mostly with acollinearities smaller than 6°, and second, a group of events with energies around 1548 MeV, mostly with acollinearities larger than 6°. The former are elastic $e^+e^- \to e^+e^-$, while the latter, obviously associated with $\psi(3095)$ decay, come from the cascade decay $\psi(3684) \to \psi(3095) + X$ and are clearly distinguishable from the elastic events from the energy information alone. The numbers of electron-positron pairs in Fig. 1 from elastic and cascade decays are 120 and 38, respectively. A correction (3.5 events) is necessary to the raw number of cascade events because of the small probability that elastic events are included. This correction is obtained from the distribution of events observed earlier for $\psi(3095) \to e^+e^-$ decay.[1]

Cascade decays also occur with the production of muon pairs from the decay $\psi(3095) \to \mu^+\mu^-$, but, in the absence of muon-energy information, the identification of these events must be based on a measurement of the muon acollinearity. All of the data in the present experiment were examined for muon pairs from SPEAR. Such events are recognized by reconstructing their point of origin within the interaction region and by measuring their apparent time of flight through the apparatus, in addition to the range requirement. Figure 2 shows the observed rate of events as a function of center-of-mass energy in the vicinity

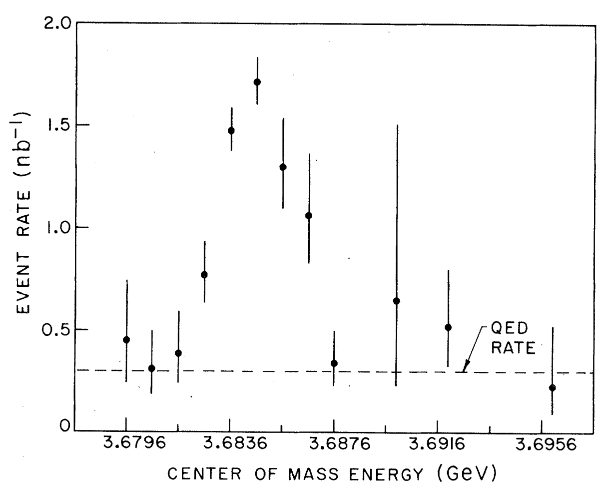

FIG. 2. The observed rate of muon-pair events as a function of center-of-mass energy in the vicinity of 3684 MeV. The total event yield in this figure is 603. The error bars are statistical and the dashed line indicates the expected rate of events from QED.

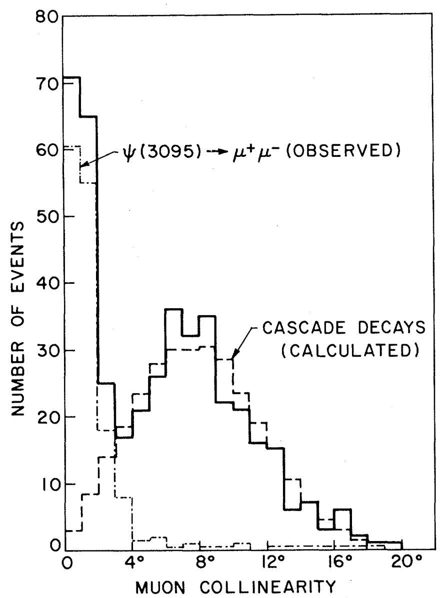

FIG. 3. The muon collinearity distribution for the 444 events observed at center-of-mass energies in the range 3683–3685 MeV. The expected collinearity distribution for elastic events and that computed for cascade events are normalized to the total number of events observed of each kind.

of 3684 MeV. A clear enhancement associated with the $\psi(3684)$ is observed. Figure 3 shows the collinearity distribution for those muon pairs detected at center-of-mass energies within 0.5 MeV of the resonance energy. Also shown in this figure, with suitable normalization, is the collinearity distribution observed earlier for $\psi(3095) \to \mu^+\mu^-$ decay[1] and that expected from the cascade decay $\psi(3684) \to \psi(3095) + \pi\pi$, $\psi(3095) \to \mu^+\mu^-$. The latter was obtained by a Monte Carlo simulation of the detection process in which the mass distribution of the two-pion system was adjusted in order to optimize the fit. The best fit was obtained using an invariant phase-space mass distribution weighted by a Breit-Wigner function with a mass peak at 0.55 ± 0.15 GeV and a full width of 0.65 ± 0.15 GeV. The total numbers of detected elastic and cascade events are estimated from Fig. 3 to be 146 ± 25 and 299 ± 25, respectively.

From both the detected numbers of electron-positron and muon-pair cascade events, and the known branching ratio for $\psi(3095)$ decay into lepton pairs,[4] we have estimated the partial cross section

$$\sigma(e^+e^- \to \psi(3684)) \frac{\Gamma(\psi(3684) \to \psi(3095) + X)}{\Gamma(\psi(3684) \to \text{all})}.$$

We obtain 335 ± 85 nb[5] and 340 ± 60 nb from the respective electron-positron and muon-pair data. The error on the former number is primarily statistical but only 20% of the error on the latter number is due to statistics. While this partial cross section depends upon the energy spread in the colliding beams, the agreement between the measured values deduced from the two data sets demonstrates a consistency between the two different experimental techniques used to identify the cascade events.[6]

The expected rate of muon pairs from quantum electrodynamics (QED) is included in Fig. 2 and agrees well with the measured rates away from the resonance energy. The number of direct decays $\psi(3684) \to \mu^+\mu^-$ can be determined by subtracting the expected number of QED events from the number of elastic events in Fig. 3. When this is done we obtain for the ratio $\Gamma(\psi(3684) \to \mu^+\mu^-)/\Gamma(\psi(3684) \to \psi(3095) + X)$ the value 0.014 ± 0.003, assuming the $\psi(3684)$ to be a resonance with unit spin and odd parity. The statistical and systematic contributions to the error on this ratio are of approximately equal size and are simply added to obtain the assigned error. Since 90% of the data used to obtain this result was accumulated at center-of-mass energies within 0.3 MeV of the peak, and the remaining 10% within 0.5 MeV, the possible error due to interference between the direct leptonic decay and the QED amplitude is minimized. If we use the published value[7] of 0.57 ± 0.08 for the branching ratio for $\psi(3684)$ decay via the cascade mode, we obtain the value 0.008 ± 0.003 for the branching ratio for the decay $\psi(3684) \to \mu^+\mu^-$.[8]

The data taken with γ-ray converters in place and at center-of-mass energies within 1 MeV of the resonance energy were scanned for evidence of either charged particles or converted γ rays accompanying the detected muon pairs. 126 events were found with one or two additional charged tracks and 69 with an additional one or more converted γ rays.[9] If we assume that these events are cascade decays of the type $\psi(3684) \to \psi(3095) + \pi^+\pi^-$ and $\psi(3684) \to \psi(3095) + \pi^0\pi^0$, respectively, we obtain, with the aid of a Monte Carlo simulation of our detection process, the value of 0.64 ± 0.15 for the ratio $\Gamma(\psi(3684) \to \psi(3095) + \pi^0\pi^0)/\Gamma(\psi(3684) \to \psi(3095) + \pi^+\pi^-)$, where the error is a simple addition of approximately equal parts due to statistics and systematics. If the two-pion system is in a state of definite isospin, this result confirms the isospin assignment $I = 0$ suggested by Abrams *et al.*[7] The assignment

$I=1$ is forbidden, and the assignment $I=2$ would require the value of 2 for the above ratio.

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†Visitor from Physikalisches Institut, Universität Bonn, Bonn, Germany.

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[5]This result assumes that the two pions accompanying the cascade decay are emitted in a state of isospin zero. This information is necessary because electron-positron pairs are not accepted if a charged pion also enters either NaI(Tl) crystal.

[6]The partial cross section obtained from this experiment can be compared with a concurrent measurement of total cross section for $\psi(3684)$ production made available to us by B. Richter of the SLAC/LBL Magnetic Detector Group at SPEAR (660 nb) to obtain the value of 0.52 ± 0.11 for the branching ratio $\Gamma(\psi(3684) \to \psi(3095)+X)/\Gamma(\psi(3684) \to \mathrm{all})$. This number is in good agreement with that reported in G. S. Abrams *et al.*, Phys. Rev. Lett. 34, 1181 (1975).

[7]Abrams *et al.*, Ref. 6.

[8]The number of elastic electron-positron-pair events observed in Fig. 1 is insufficient to determine the branching ratio for the direct decay $\psi(3684) \to e^+e^-$ because of the large QED background, but can be used to place an upper limit on this number of 4.4% (with 95% confidence).

[9]For 66 events in which two charged tracks were observed, we have reconstructed the invariant mass of the two-pion system with the constraint that the mass of the muon pair be equal to that of the $\psi(3095)$. The mass distribution for these events is in agreement with that obtained by Monte Carlo calculation using the mass distribution deduced earlier from the muon collinearity data.

Are Heavy Leptons Found?*

A. De Rújula, Howard Georgi,† and S. L. Glashow
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138

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Recently reported observations suggest the existence of a new particle without strong interactions. We interpret it as a massive neutral lepton L^0 produced by decays of a new charged lepton $L^{\pm}$ which in turn is pair-produced electromagnetically by cosmic rays. The mass of $L^{\pm}$ must be ~ 2 GeV; the lifetime of L^0 must be $\sim 10^{-5}$ sec. Possible gauge models incorporating the new leptons are discussed, as are other experimental consequences.

Astonishing results are reported from a cosmic-ray experiment designed to detect neutrino-induced interactions underground.[1,2] In ten years, twenty candidates for such interactions were found. Only a small fraction of neutrino-induced interactions should involve more than one detected track, because neutrinos generally produce a single muon together with hadrons, and only the muon is very penetrating. However, 40% of the observed events involve several tracks. Four or five of the events probably originate in the air within the cave as if they were particle decays. Many of the particles seen in these events seem to be muons, and no showers or nuclear interactions are observed. Krishnaswamy *et al.* conclude that the anomalous events are likely to be decays of new massive long-lived particles.

Krishnaswamy *et al.*[1] suggest that the new particle is produced by interactions of the neutrino flux in rock, has a mass from 2 to 5 GeV, and has a lifetime $\geqslant 10^{-9}$ sec. We find this explanation implausible. If the new particle has weak couplings to muon neutrinos of conventional strength—indicated by its allegedly copious production by underground neutrinos—it should have a short lifetime: 10^{-11} to 10^{-14} sec in the stated