every case our results are consistent with this prediction to within the experimental errors of about 10%.

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Measurements of $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, and $e^+e^- \to \gamma\gamma$ at Center-of-Mass Energies Close to 3105 MeV*

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Independent evidence is presented for the decay of the recently discovered particle $\psi(3105)$ into electron-positron pairs and new evidence is presented for the decay of this particle into muon pairs. Measurements of the rate of the reaction $e^+e^- \to \gamma\gamma$ at center-of-mass energies in the vicinity of 3105 MeV are also reported.

We report here independent evidence for the decay of the recently discovered particle[1-3] $\psi(3105)$ into electron-positron pairs and new evidence for the decay of this particle into muon pairs. We also report the results of a measurement of the reaction $e^+e^- \to \gamma\gamma$ at center-of-mass energies in the vicinity of 3105 MeV. These measurements were begun immediately following the discovery of the $\psi(3105)$ at SPEAR.[1] At that time an apparatus primarily designed for the study of quantum electrodynamics (QED) was operating in the second interaction region at SPEAR and was applied immediately thereafter to the study of the $\psi(3105)$. This apparatus is very similar to that described recently by Beron *et al.*,[4] and is capable of identifying the reactions $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, and $e^+e^- \to \gamma\gamma$. The detection apertures and procedures used to recognize each of these reactions are identical to those described by Beron *et al.*,[4] except that the detection aperture for the reaction $e^+e^- \to \mu^+\mu^-$ is larger by a factor of 2.6. All of the measurements reported in this Letter were made with the detection apparatus set to accept particles produced at angles θ close to 90° with respect to the colliding beams.

Figure 1 shows the observed event rate for the reaction $e^+e^- \to e^+e^-$ at center-of-mass energies in the vicinity of 3105 MeV.[5] A clear enhancement associated with the $\psi(3105)$ is observed with a width consistent with the upper limit of 1.9 MeV reported by Augustin *et al.*[1] and Abrams *et al.*[6] The event rates shown in Fig. 1, and those in the subsequent figures of this Letter, are normalized with respect to the observed rate of $e^+e^- \to e^+e^-$ events in an independent apparatus viewing the interaction region at angles close to 3.5°. This latter apparatus, or luminosity monitor, is a substitute at the present time for a precision monitor that is in preparation for later work. The statistical accuracy of the present monitor

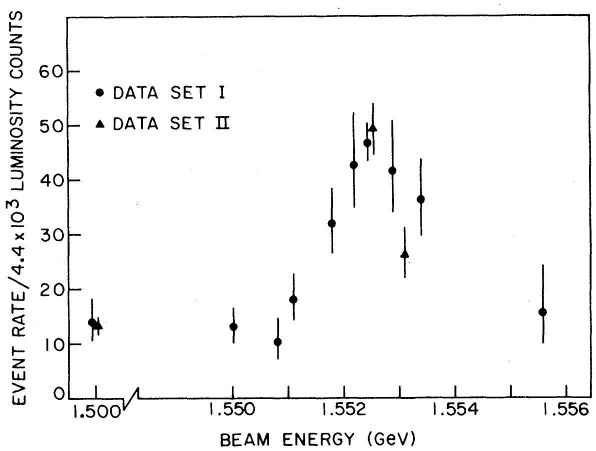

FIG. 1. The observed rate of $e^+e^- \to e^+e^-$ events for 4.4×10^3 luminosity counts as a function of beam energy. (4.4×10^3 luminosity counts are equivalent to an integrated luminosity of 2.6×10^{33} cm^{-2} at 1.5525 GeV.) The two data sets distinguished in this figure correspond to those identified in Fig. 2. The total event yield in this figure is 587. The error bars are purely statistical, as are those in Figs. 2 and 3.

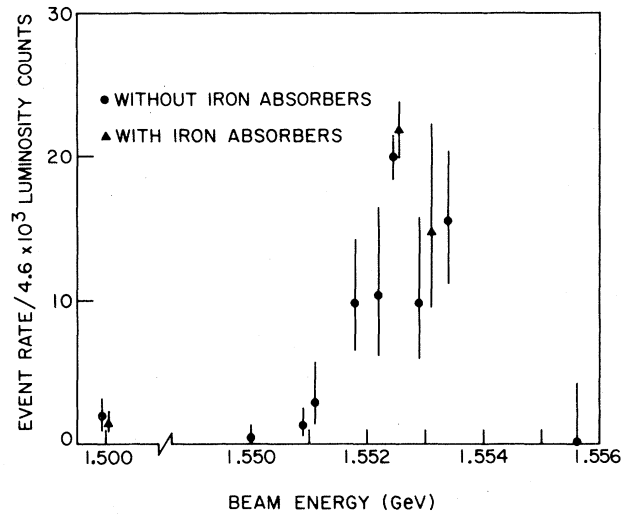

FIG. 2. The observed rate of $e^+e^- \to \mu^+\mu^-$ events for 4.6×10^3 luminosity counts as a function of beam energy. (4.6×10^3 luminosity counts are equivalent to an integrated luminosity of 2.7×10^{33} cm^{-2} at 1.5525 GeV.) The total event yield in this figure is 393.

is adequate, but the absolute calibration is subject to a systematic uncertainty of ±12%, principally due to uncertainties in counter geometry. To within this level of accuracy the event rates shown in Fig. 1 outside the peak are consistent with the expected event rate of 18.6 ± 2.3 from QED.

Figure 2 shows the observed event rate for the reaction $e^+e^- \to \mu^+\mu^-$, which also has a strong enhancement centered at 3105 MeV. Outside this peak the event rate is again consistent with the expected event rate of 0.9 ± 0.1 from QED. The detected particles in these events, in addition to geometrical and timing criteria, are required to penetrate a minimum of 20 in. of NaI(Tl) (1.4 pion absorption units) and to deposit energies in these crystals consistent with 1.5-GeV muons. For 42% of the data included in Fig. 2 the detected particles were also required to penetrate an additional 16 in. of steel (2.4 pion absorption lengths). The rate of events observed at 3105 MeV is not significantly changed by this additional range requirement, which confirms the identity of the detected particles as muons. Quantitatively, this result also implies that the admixture of collinear charged hadron pairs in the measured rate without the steel absorbers cannot exceed 11% of the rate of muon pairs (with 95% confidence).

Although the peak event rates shown in Figs. 1 and 2 are influenced both by radiative corrections and by the energy spread in the colliding beams,[7] the ratio of these event rates, after subtraction of the measured QED background, can be used to estimate the ratio of the $\psi(3105)$ decay rates into electron-positron and muon pairs. If the $\psi(3105)$ is a resonance with unit spin and odd parity, the peak event rates, minus the QED background, are not affected by interference with the QED amplitudes and both decays are expected to occur with an angular dependence proportional to $1+\cos^2\theta$. When this angular dependence is used to normalize the observed rates to the same detection aperture, which is approximately 2.0 times larger in the present apparatus for $e^+e^- \to e^+e^-$ than for $e^+e^- \to \mu^+\mu^-$, the ratio of the decay rates $\Gamma(e^+e^- \to e^+e^-)/\Gamma(e^+e^- \to \mu^+\mu^-)$ has the value of 0.93 ± 0.10. In addition, if the resonance profile for the reaction $e^+e^- \to e^+e^-$ is integrated over energy and also over the unobserved angular range, an estimate of the ratio Γ_{ee}/Γ^2 can be obtained, where Γ_{ee} is the partial decay width of the $\psi(3105)$ into electron-positron pairs and Γ is the total decay width. Such an analysis, including a radiative correction, leads to the value of 0.36 ± 0.10 keV for this ratio.

Figure 3 summarizes the observed event rates for the reaction $e^+e^- \to \gamma\gamma$ at center-of-mass energies close to 3105 MeV. The available data are combined to show the average rates observed at center-of-mass energies in the ranges 3000–

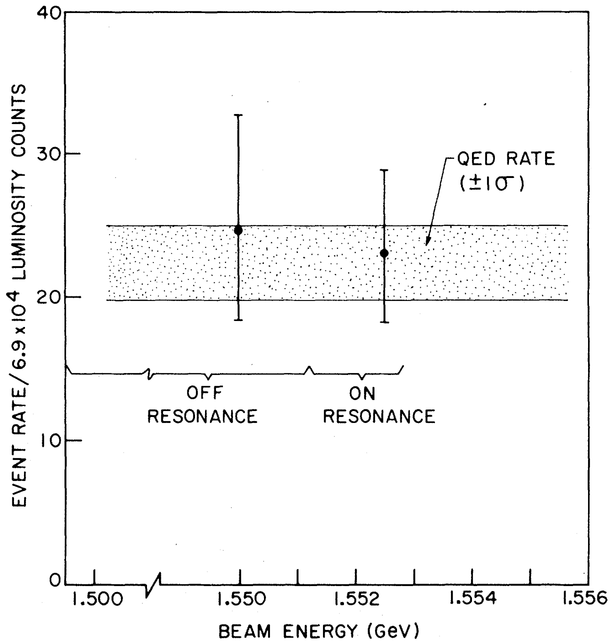

FIG. 3. The observed rate of $e^+e^- \rightarrow \gamma\gamma$ events for 6.9×10^4 luminosity counts as a function of beam energy. (6.9×10^4 luminosity counts are equivalent to an integrated luminosity of 4.1×10^{34} cm^{-2} at 1.5525 GeV.)

3102 MeV and 3102–3107 MeV. Fifteen events and 23 events are observed within these two ranges, respectively. When these event numbers are normalized to the same luminosity, both are consistent with the number expected from QED, which is also indicated in Fig. 3.

We conclude from this initial study of the ψ(3105) that this particle, if its spin and parity assignment is 1^-, decays with approximately equal probability into electron-positron and muon pairs and that to within the precision of the present data the rate of the reaction $e^+e^- \rightarrow \gamma\gamma$ at center-of-mass energies close to 3105 MeV is consistent with that expected from QED.

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[5]The absolute beam energies used in this experiment were provided to us by the SPEAR operations group and are subject to correction should this group announce a recalibration of the energy scale.

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[7]The energy spread in the colliding beams at SPEAR has also been found to depend upon the stored currents (B. Richter, private communication). In principle it is therefore necessary that comparisons of peak event rates, such as that of the muon-pair rate with and without the additional iron absorbers, be normalized with respect to simultaneous measurements of the rate of electron-positron pairs. This was done for only 38% of the muon-pair data reported here. However, no significant changes were observed in the peak event rates of either electron-positron pairs or muon pairs throughout this experiment. This is not unexpected because the average stored currents were essentially unchanged. We therefore assume that a continuous normalization with respect to electron-positron pairs is not necessary.