Search for Narrow Resonances in e^+e^- Annihilation in the Mass Region 3.2 to 5.9 GeV*

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We have searched the mass region 3.2 to 5.9 GeV for evidence of narrow resonances in $e^+e^- \rightarrow$ hadrons. We find no evidence for any such resonances other than the $\psi(3695)$ in this region with a sensitivity ranging from about 12 to 45% of the integrated cross section of the $\psi(3695)$. The more stringent bounds apply to resonances of a few MeV width, while the looser bounds apply to resonances of up to 20 MeV width.

After the discovery of the $\psi(3105)$,[1,2] we began a systematic search for other narrow resonances in e^+e^- annihilation. In the first run of this search, which extended from 3.60 to 3.71 GeV, the $\psi(3695)$ was discovered.[3] The search has been continued and now covers the mass region 3.2 to 5.9 GeV. No evidence for other narrow resonances has been found.

The search, performed at the Stanford Linear Accelerator Center e^+e^- colliding-beam facility SPEAR, used the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory solenoidal magnetic detector. The properties of this detector have been described previously.[4] Events from the process $e^+e^- \rightarrow$ hadrons are identified in the detector by the observation of three or more charged tracks or two charged tracks acoplanar with the incident beams by more than 20°. The detection efficiency for hadronic events varies from about 50 to 70% over the energy range of the search. The luminosity is determined by the measurement of e^+e^- scattering at 20 mrad. Details of the determination of the detection efficiency, backgrounds, and other corrections to the measurement of total hadronic cross sections are discussed elsewhere.[5]

The mass resolution is determined by the energy spread in the colliding beams which arises mainly from quantum fluctuations in the synchrotron radiation emitted by the beams. The resolution varies as the square of the energy and ranges from 2.0 to 6.9 MeV (full width at half-maximum) as the center-of-mass energy ($E_{\rm c.m.}$) increases from 3.2 to 5.9 GeV.[6]

The search was conducted by automatically increasing the center-of-mass energy (twice the beam energy) by 1.88 MeV every few minutes. Data taken during each step were analyzed in real time and the relative cross sections were computed at the end of each step. The data were also written on magnetic tape for later reanalysis. After each fill of the rings, the starting energy was normally set to overlap the previous scan by a few steps. A few mass regions were scanned more than once.

Figure 1 shows the relative cross sections for $e^+e^- \rightarrow$ hadrons in 1.88-MeV steps in $E_{\rm c.m.}$. The

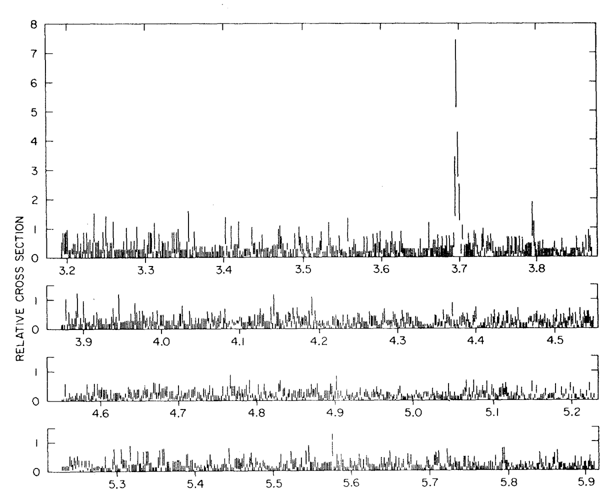

FIG. 1. Relative cross sections for $e^+e^- \rightarrow$ hadrons.

TABLE I. Upper limits at the 90% confidence level for the radiatively corrected integrated cross section of a possible resonance. The units are nb MeV.

Mass range (GeV)	Resonance width (full width at half-maximum in MeV) 0 [a]	10	20
3.200 to 3.500	970	1750	2230
3.500 to 3.690	780	1090	1540
3.720 to 4.000	1470 [b]	1530	1860
4.000 to 4.400	620	1260	1820
4.400 to 4.900	580	1080	1310
4.900 to 5.400	780	1100	1720
5.400 to 5.900	800	1120	1470

[a]Width less than the mass resolution.
[b]See Ref. 8.

ψ(3695) is clearly visible, but no other structure is evident. Multiple measurements at the same energy step have been combined, but the region around the ψ(3695) represents a single scan of average luminosity and time span. The average time spent at each step was 2.7 min at an average luminosity of 1.1×10^{30} cm^{-2} sec^{-1}.

We have set upper limits on the integrated cross sections for the production of narrow resonances in this mass region. The integrated cross section is defined as

$$\Sigma = \int \sigma(E_{c.m.}) dE_{c.m.},$$

where σ is the resonant cross section and is assumed to have a Breit-Wigner line shape. We quote limits in terms of Σ since it is the only resolution-independent parameter we can measure if the resonance width is less than the mass resolution. It is also directly related to the partial decay width of the resonance into electron pairs, Γ_{ee}: If the resonance has spin 1,

$$\Gamma_{ee} = (m^2/6\pi^2)\Sigma/B,$$

where m is the mass of the resonance and B is the branching ratio into hadrons.

The limits were set by hypothesizing the existence of resonances at each energy and comparing the expected yield with the observed yield by using Poisson statistics. We made a conservative background subtraction of 16 nb for $E_{c.m.} \leq 5.0$ GeV and 12 nb for $E_{c.m.} > 5.0$ GeV for nonresonant hadron production.[5] The limits for radiatively corrected[7] integrated cross sections at the 90% confidence level are given in Table I. For comparison, the integrated cross section of the ψ(3695) is of order 5000 nb MeV. Thus, the upper limits range from 12 to 45% of the integrated cross section of the ψ(3695), with sensitivity decreasing as the resonance width increases.

We plan to continue to search for narrow resonances at higher masses.

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[1]J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974).

[2]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).

[3]G. S. Abrams *et al.*, Phys. Rev. Lett. 33, 1453 (1974).

[4]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 233 (1975).

[5]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 764 (1975) (this issue).

[6]The resolutions given are those arising from quantum fluctuations in the synchrotron radiation emitted by the circulating beams. This energy spread has a Gaussian distribution. There can also be a contribution to the spread from instabilities in high-peak-current beams. By measuring the peak cross sections of the ψ (3105) and ψ(3695) as a function of circulating-beam current we have determined that for the currents used in this experiment the increased energy spread was less than 50% at 3.1 GeV and less than 25% at 3.7 GeV. This effect is expected to decrease rapidly with increasing energy.

[7]D. R. Yennie, Phys. Rev. Lett. 34, 239 (1975); Y. S. Tsai and D. R. Yennie, private communications.

[8]The largest fluctuation is centered at 3.795 GeV, where 8 events were detected for 2 expected. There is an independent reason for considering this a fluctuation rather than a signal. A narrow resonance with an integrated cross section of 1470 nb MeV located at 3.795 GeV would yield a radiative tail of about 13 nb at 3.800 GeV (see Ref. 7). We have previously taken extensive data at 3.800 GeV and these data cannot reasonably support the existence of a radiative tail of that size (see Ref. 5). If this fluctuation is excluded, then the limit on a narrow resonance in the region 3.720 to 4.000 GeV changes from 1470 to 850 nb MeV.