SEARCH FOR NARROW RESONANCES IN e^+e^- ANNIHILATION AT C.M. ENERGIES BETWEEN 29.90 AND 31.46 GeV

JADE Collaboration

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A search for narrow resonances in e^+e^- annihilation at c.m. energies between 29.90 and 31.46 GeV provides no evidence for the existence of such states. The 90% confidence upper limit on the integrated resonance cross section is 38 nb MeV, significantly below the value expected for the lowest $(t,\bar{t})$ bound state.

Previous experiments performed at PETRA at c.m. energies up to 31.6 GeV found no evidence for the production of mesons containing a new heavy quark [1]. An increase of more than 30% in $R = \sigma_{tot}(e^+e^- \to \text{hadrons})/\sigma_{\mu^+\mu^-}$ is expected above the production threshold for such mesons if the new quark has the same charge (2/3) as the proposed top quark. This increase is expected to be strongly enhanced if only

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events with a relatively wide angled hadron distribution are considered, since the low mass quarks are known to fragment mostly into narrow jet-like distributions at these energies. No such increase has been observed [1].

However, the first evidence for the existence of the quarks charm (c) and beauty (b) was obtained through the discovery of the narrow resonances J/ψ and Υ. Narrow vector meson bound states of heavy quarks $(Q\bar{Q})$ are predicted to exist below the threshold for the corresponding flavour production. Various models [2], which explain the observed $(c,\bar{c})$ and $(b,\bar{b})$ states reasonably well, predict for an assumed top meson mass of 15 GeV the lowest vector state to be 1 to 2 GeV below the $(Q\bar{Q})$ continuum. By looking for narrow resonances one is therefore sensitive to quark masses which exceed the beam energy by as much as 1 GeV.

In this letter we present the results of a search with the JADE detector for narrow resonances in the mass range 29.90 to 31.46 GeV. The cross section $\sigma_{\mathrm{tot}}(e^+e^- \to \text{hadrons})$ was measured in steps of 20 MeV in the c.m. energy W. This step size is matched to the rms resolution of W, which was also about 20 MeV at these energies. The integrated luminosity accumulated per point varied between 15 and 35 nb^{-1} and was on average 24 nb^{-1}. It was determined from small angle Bhabha scattering.

The JADE detector has already been described in ref. [3]. Charged particles and photons were detected over 90% and 97% of the full solid angle, respectively. The trigger conditions and the criteria for the selection of hadronic events were the same as applied previously [3] to measure σ_{tot}. The detection efficiency was calculated to be 82% by Monte Carlo simulation of the experiment based on a jet model including u, d, s, c, b quark production, and radiative corrections were applied according to ref. [4].

The results of the energy scan are shown in fig. 1a where the ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma_{\mu^+\mu^-}$ is plotted as a function of the c.m. energy. No significant structure is evident.

To obtain an upper limit on the production cross section of a hypothetical narrow resonance, we fit the data of fig. 1a to the sum of a resonance and a constant term

$$R(W) = R_0 + S \exp[-(W - M_{\mathrm{R}})^2/2\sigma_W^2] \,.$$

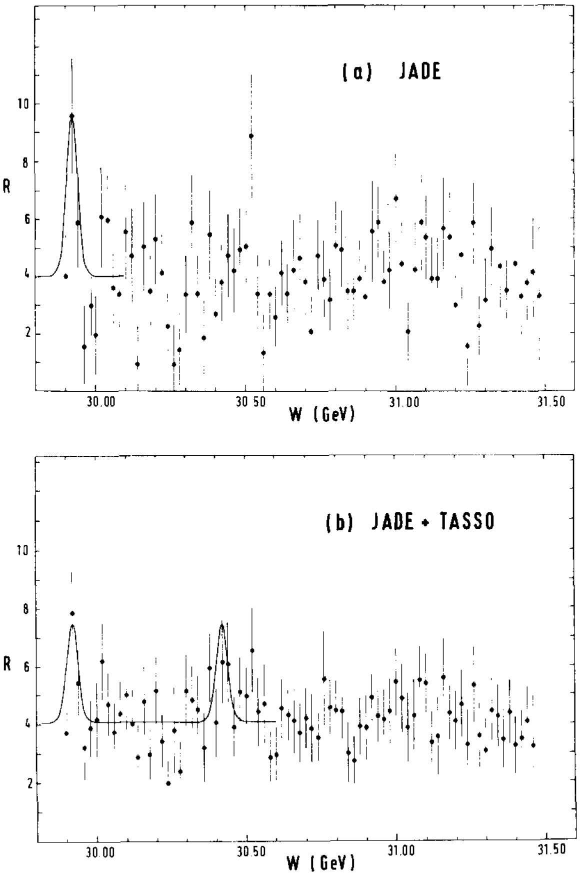

Fig. 1. The values of $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ versus the c.m. energy W. The results from JADE are shown in (a) and the sum of the JADE and TASSO data in (b). The curves represent the 90% confidence upper limits listed in table 1.

The resonance width Γ is assumed to be much smaller than the c.m. energy resolution $\sigma_W = 2.2 \times 10^{-5}\, W^2$ (GeV) (W in GeV). Separate fits were made with M_{R} varying from 29.90 to 31.46 GeV in steps of 10 MeV. The highest value $S = 3.6 \pm 1.3$ was obtained for $M_{\mathrm{R}} = 29.92$ GeV. From this we obtain an upper limit $S < 5.3$ (90% confidence). The curve corresponding to this upper limit is indicated in fig. 1a.

The integrated cross section of a narrow $J^P = 1^-$ Breit–Wigner resonance is

$$\Sigma = \int \sigma_{\mathrm{R}}(W)\, \mathrm{d}W = (6\pi^2/M_{\mathrm{R}}^2)\Gamma_{\mathrm{ee}}\Gamma_{\mathrm{h}}/\Gamma \,,$$

where Γ_{ee} and Γ_{h} are the leptonic and hadronic decay

Table 1
Upper limits (90% confidence) of the integrated production cross section Σ for a narrow resonance ($\Gamma < 10$ MeV) and the product of the leptonic width Γ_{ee} and the hadronic branching ratio.

	Σ (nb MeV)	$\Gamma_{ee}\Gamma_h/\Gamma$ (keV)
JADE	<38	<1.5
TASSO	<40	<1.6
JADE + TASSO	<24	<1.0

widths, respectively. From the upper limit of S we obtain, taking radiative corrections [5] into account, an upper limit for the production of a narrow ($\Gamma \ll 20$ MeV) resonance $\Sigma < 38$ nb MeV or $\Gamma_{e^+e^-} \times \Gamma_h/\Gamma < 1.5$ keV.

Similar results have been obtained by the TASSO collaboration [6] whose 90% confidence upper limits are listed in table 1 together with the results of this experiment. The sum of the JADE and TASSO data is shown in fig. 1b. Applying the above fitting procedure to the data of fig. 1b one obtains values of S up to 2.0 ± 1.0 at $M_R = 29.92$ GeV and at $M_R = 30.42$ GeV. The corresponding upper limits, which are also listed in table 1, amount to about 2/3 of those from the individual experiments; as expected from the increased statistics.

The lowest ($t\bar{t}$) vector bound state is expected to have a leptonic width Γ_{ee} of about 5 keV, similar to the J/ψ resonance. This value is considerably above the observed upper limits, even if Γ_h/Γ is pessimistically assumed to be 0.5. A bound state of charge 1/3 quarks however, which is expected to have a four times smaller leptonic width, cannot be excluded by the present data.

There is also no evidence of any broader structure in the JADE data. Averaging the data in fig. 1a within different energy intervals yields the same values of $\langle R \rangle$ within the statistical uncertainties. The overall average is $\langle R \rangle = 4.1 \pm 0.2 \pm 0.4$, where ±0.4 is a conservative estimate of our present systematic uncertainties. The hypothesis $R = 4.1$ yields a reasonable χ^2 of 107 for 78 degrees of freedom. The average $\langle R \rangle$ is also in good agreement with our previous measurement [3] of R between 22 and 31.6 GeV.

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References

[1] JADE Collab., W. Bartel et al., Phys. Lett. 89 B (1979) 136;
Mark J Collab., D.P. Barber et al., Phys. Lett. 85B (1979) 463;
PLUTO Collab., Ch. Berger et al., DESY 79/56;
TASSO Collab., R. Brandelik et al., DESY 79/74.

[2] C. Quigg and J.C. Rosner, Phys. Lett. 72B (1978) 462;
H. Krasemann and S. Ono, DESY 79/09.

[3] JADE Collab., W. Bartel et al., Phys. Lett. 88B (1979) 171.

[4] G. Bonneau and F. Martin, Nucl. Phys. B27 (1971) 381.

[5] J.D. Jackson and D.L. Scharre, Nucl. Instrum. Methods 128 (1975) 13.

[6] TASSO Collab., R. Brandelik et al., Phys. Lett. 88B (1979) 199.