ENERGY SCAN FOR NARROW STATES IN e^+e^- ANNIHILATION AT C.M. ENERGIES BETWEEN 29.90 AND 31.46 GeV

TASSO Collaboration

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A fine energy scan has been performed to search for narrow states in e^+e^- annihilation at c.m. energies between 29.90 and 31.46 GeV. No such state has been observed. The 90% confidence upper limit on the leptonic decay width times the hadronic decay branching ratio is $\Gamma_{ee}B_h < 1.6$ keV.

The experiments conducted at PETRA up to the presently highest available energy of 31.6 GeV did not reveal any evidence for the existence of a new heavy quark [1,2]. These experiments were sensitive to a possible $Q\bar{Q}$ continuum contribution provided the charge of the Q is 2/3 (as for the hypothetical top quark); the production of a new heavy quark of charge 1/3 appeared also unlikely [2]. These conclusions were arrived at by studying (a) the ratio R of the total cross section σ_T for annihilation into hadrons to the μ pair cross section, $4\pi\alpha^2/3s$, (b) the sphericity and thrust distributions [1,2], and (c) by searching for noncollinear nonplanar events [2] at certain discrete energies between 13 and 31.6 GeV. Models of heavy quarkonia predict the first $Q\bar{Q}$ vector bound state, V_Q, to lie approximately 2 GeV below the threshold for the $Q\bar{Q}$ continuum [3]. Thus, by an energy scan sensitive to narrow states up to the highest energy we extend the mass range searched for $Q\bar{Q}$ states by ~2 GeV.

We report in this letter the results from an energy scan performed at PETRA between 29.90 and 31.46 GeV with the TASSO detector. In this scan the c.m. energy W was increased in steps of 20 MeV. The step size is close to the c.m. energy spread produced by quantum fluctuations in the beams,

$$\sigma_W\,(\text{GeV}) = 2.2 \times 10^{-5}\, W^2\,(\text{GeV}^2)\,,$$

or $\sigma_W = 20$ MeV for $W = 30$ GeV. Data were accumulated for an integrated luminosity of ~24 nb^{-1} per point. The luminosity delivered by PETRA was typically about 100 nb^{-1} per day. The beam energy was monitored by the current in the bending magnets of the storage ring, and by a nuclear resonance probe situated in a magnet identical to the bending magnets of the ring and powered in series with them. The latter method provided a monitor of the beam energy to ~10^{-4} or ~3 MeV in W. The absolute value of the PETRA energy was known with an accuracy of 10^{-3}.

The properties of the TASSO detector have been described previously [2,4]. The event selection and the procedure to determine σ_T were the same as applied previously to measure σ_T at energies of 27.6, 30 and 31.6 GeV [2]. Events from e^+e^- annihilation into hadrons were identified by observing five or more charged particles in the central detector with the total sum of momenta, Σp_t, larger than 8 GeV. The detection efficiency as determined from a Monte Carlo study was 80%. The luminosity was determined by measuring small-angle Bhabha scattering in the forward detector. Radiative corrections lead to a reduction of the cross section by 10%. The overall systematic uncertainty of the absolute normalization was estimated to be ± 10%.

Fig. 1a shows R measured as a function of the c.m. energy in 20 MeV steps between 29.90 and 31.46 GeV as obtained from a total of 640 accepted hadron events. On the average, there are 8 hadronic events per data point. No statistically significant structure is observed. The R value averaged over the full energy range is 4.1 ± 0.2 with a systematic error of ± 0.4.

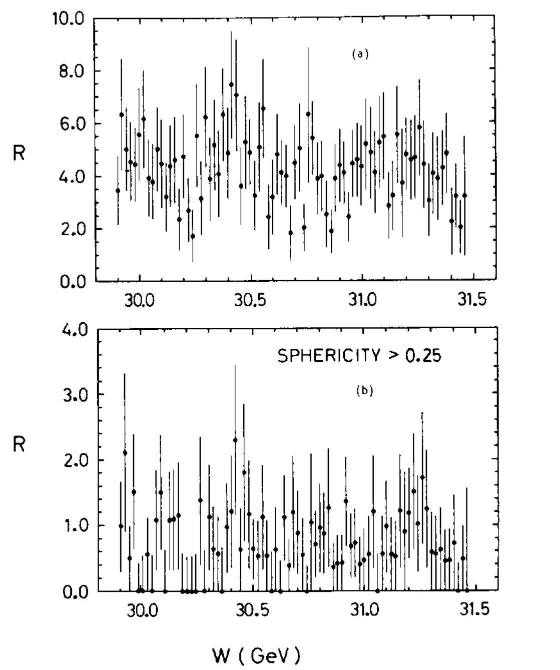

Fig. 1. The ratio R of the cross section σ_T for $e^+e^- \to$ hadrons to the μ pair cross section as a function of the c.m. energy W. (a) For all events. (b) For events with a sphericity $S > 0.25$.

The contribution to σ_T of a vector state V_Q of mass M, total width Γ, leptonic and hadronic decay widths Γ_{ee} and Γ_h, respectively, for W close to M is given by

$$\sigma_V(W) = \frac{3\pi}{W^2} \frac{\Gamma_{ee}\Gamma_h}{(W-M)^2 + \Gamma^2/4}.$$

For a narrow resonance, where narrow means that its width is small compared to the energy resolution, $\Gamma \ll \sigma_W$, we consider instead of σ_V the cross section integrated over the resonance,

$$\Sigma_V = \int \sigma_V \, dW = \frac{6\pi^2}{M^2} B_h \Gamma_{ee},$$

where $B_h = \Gamma_h/\Gamma$ is the branching ratio into hadrons. The quantity Σ_V is independent of σ_W. From the measurements of R given in fig. 1a the following 90% upper limits on Σ_V are obtained:

$$\text{for } \Gamma < 10 \text{ MeV:} \quad \Sigma_V < 40 \text{ nb MeV}$$

$$\text{or} \quad \Gamma_{ee} B_h < 1.6 \text{ keV}.$$

These numbers were determined by fits of the form $a + b \exp[-(W-M)^2/2\sigma_W^2]$, which were made for the gaussian centered at each energy measured. The largest value of b, obtained at 30.42 GeV, was used to determine the upper limit. The numbers given include radiative corrections.

The sensitivity for a $Q\bar{Q}$ bound state can be increased by studying the distribution of the sphericity

$$S = \frac{3}{2} \sum p_{Ti}^2 \Big/ \sum p_i^2,$$

where p_i is the momentum of the charged hadron i, and p_{Ti} its transverse momentum relative to the axis which minimizes Σp_{Ti}^2 (= jet axis). In the continuum region the dominant process at high energies is two-jet formation, leading [2] to small sphericity values $\langle S \rangle \approx 0.15$ at $W = 30$ GeV. By contrast, the final states from the direct decay of a $Q\bar{Q}$ bound state are expected to resemble phase space with an average sphericity around 0.5 as observed for J/ψ and Υ [5]. Thus, the signal-to-background ratio can be improved by rejecting low-sphericity events. In fig. 1b R is shown for events with $S > 0.25$. This cut removes about 80% of the two-jet continuum events [2] while roughly 10% of the direct decays of the hypothetical $Q\bar{Q}$ vector state will be lost. Again, no statistically significant structure is seen. The average value for $R(S > 0.25)$ is 0.75, which is consistent with the size expected for the nonresonant contribution to σ_T [2].

The R values measured for large sphericities (fig. 1b) can also be used to place an upper limit on a narrow vector state contribution. It should be noted, however, that essentially only the direct decays of V_Q ($\Gamma_{dir} = \Gamma_h - R\Gamma_{ee}$) will contribute in this case. This is because the decay via a single virtual photon (second-order electromagnetic) leads to final states indistinguishable from those of the continuum. From the fits to the $R(S > 0.25)$ values shown in fig. 1b the following 90% confidence upper limits were found using the worst case at 31.25 GeV:

$$\text{for } \Gamma < 10 \text{ MeV:} \quad \Sigma_V^{dir} < 14 \text{ nb MeV}$$

$$\text{or} \quad \Gamma_{ee} B_h^{dir} < 0.56 \text{ keV}.$$

Assuming $B_h = 0.7$ and $\Gamma_{dir} = 0.5\,\Gamma_h$, the 90% confidence upper limit is $\Gamma_{ee} < 1.6$ keV.

The upper limit on $\Gamma_{ee} B_h$ given may be compared to what is expected for the $t\bar{t}$ vector ground state, namely $\Gamma_{ee} \approx 5$ keV (as for the J/ψ) which seems to be a conservative estimate, and $B_h \approx 0.7$.

Within three consecutive bins the values of $\Gamma_{ee} = 5$ keV and $B_h = 0.7$ imply 40 events from the resonances to which 20 events have to be added for the continuum. These 60 events have to be compared with 32 events observed. In the case of high-sphericity events (fig. 1b), assuming $\Gamma_{dir} = 0.5\Gamma_h$, 18 events were expected from the resonance and 4 events from the continuum. These 22 events should be compared to 7 events observed.

Instead of the hypothetical $t\bar{t}$ system we may consider a vector bound state of a new heavy quark of charge 1/3. In this case the value expected for Γ_{ee} is 1.3 keV, namely one quarter of the $t\bar{t}$ value. The data do not exclude this possibility.

In conclusion, we have scanned the energy region from 29.90 to 31.46 GeV for narrow resonances. We place an upper limit of $\Gamma_{ee} B_h = 1.6$ keV on such states.

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