OBSERVATION OF A NARROW RESONANCE AT 10.02 GeV IN e^+e^- ANNIHILATIONS

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Received 5 September 1978

The Υ' state has been observed as a narrow resonance at $M(\Upsilon') = 10.02 \pm 0.02$ GeV in e^+e^- annihilations, using a NaI and lead-glass detector in the DORIS storage ring at DESY. The ratio $\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}$ of electronic, hadronic, and total widths has been measured to be 0.32 ± 0.13 keV. The parameters of the Υ particle have also been determined to be $M(\Upsilon) = 9.46 \pm 0.01$ and $\Gamma_{ee}\Gamma_{had}/\Gamma_{tot} = 1.04 \pm 0.28$ keV. The mass difference is $M(\Upsilon') - M(\Upsilon) = 0.56 \pm 0.01$ GeV.

The two massive particles $\Upsilon(9.4)$ and $\Upsilon'(10.0)$ discovered by Herb et al. [1] were produced in 400 GeV proton nucleus collisions and were observed in their $\mu^+\mu^-$ decay with a mass resolution of about 200 MeV (rms). It was thought that they could be bound states of a quark–antiquark pair in analogy to the $J/\Psi(3.1)$ and $\Psi'(3.7)$ states, but composed of a new type of quark. In this context it is essential to establish a narrow width, and to measure the mass difference accurately. In the framework of such quarkonium models [2], the charge of the new quark is related to the electronic partial widths Γ_{ee} which are, therefore, of considerable interest. These quantities can most conveniently be determined if the Υ resonances are formed in e^+e^- annihilations, a process expected to occur since they decayed into $\mu^+\mu^-$.

This had prompted the efforts of the DORIS machine group to extend the energy range of the storage ring beyond its original limits. DORIS was modified to operate as a single-ring single-bunch machine, and in April 1978 it had reached energies up to 9.6 GeV. Using this modified machine the existence of the Υ resonance was confirmed by the PLUTO [3] and DASP II [4] groups. The mass of the resonance was found to be 9.46 ± 0.01 GeV, and $\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}$ was measured to be 1.3 ± 0.4 keV. In July 1978 additional cavities were installed in the DORIS ring, which allowed a search for the Υ' resonance expected above 10 GeV.

Here we present the results of measurements performed with the DESY–Heidelberg NaI and lead-glass detector in June and August 1978. During the first period the Υ resonance was measured, whereas during the second period the 10 GeV region was scanned and the Υ' resonance observed.

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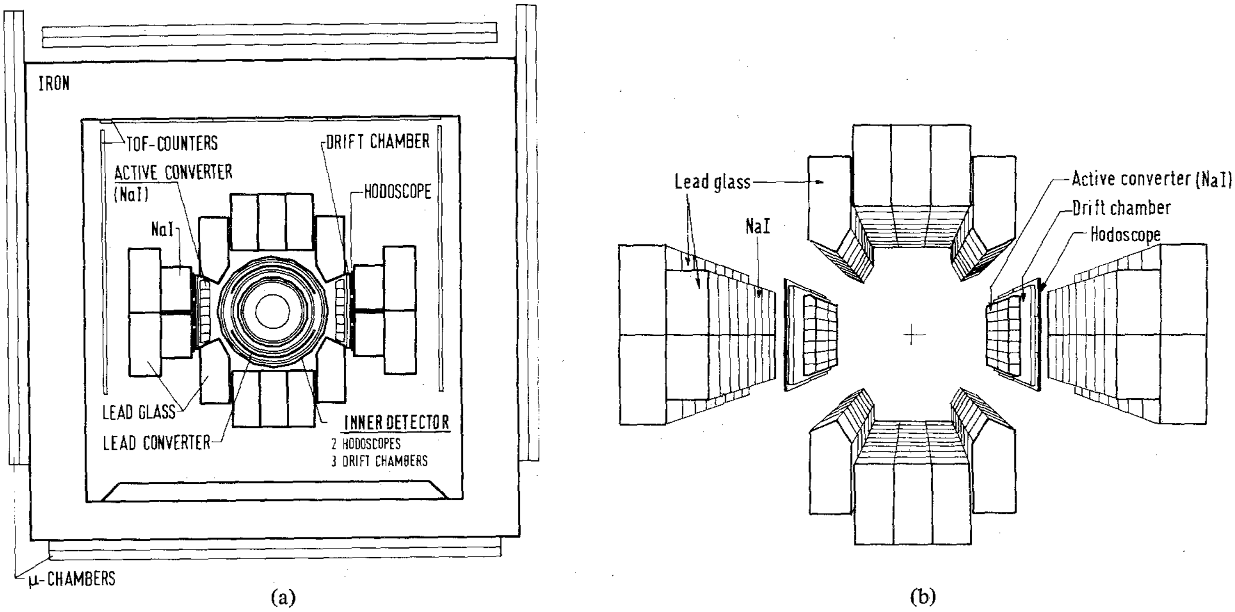

Fig. 1. Layout of the NaI lead-glass detector: (a) cross section perpendicular to the e^+e^- beam directions; (b) "exploded view" of the arrangement of energy detectors.

The layout of the apparatus is shown in fig. 1. This non-magnetic detector was described in detail in ref. [5]. For the measurements presented here, use has been made of the following parts: an inner detector measures the directions of charged particles; it has three cylindrical double-drift chambers and two scintillation hodoscopes. An outer box of energy counters (NaI and lead glass) determines the energy and direction of photons and electrons originating from the interaction point. The side walls have a total thickness of 15.2 X_0 (radiation lengths). The lead glass at top and bottom has 12.7 X_0. The lead converter between the second and third drift chamber of the inner detector has a thickness of 1 X_0. Minimum ionizing particles deposit about 200 MeV energy. The inner detector, as well as the energy counters, cover a solid angle of 86% of 4π.

The trigger consisted of several combinations of charged track multiplicities and a minimum total deposited energy as described in ref. [5]. An on-line filter eliminated beam–gas interactions that were easily recognized by their oblique incidence in the chambers. In the data reduction the following cuts were applied in order to isolate events of the type $e^+e^- \rightarrow$ hadrons: more than 1.8 GeV seen in the energy detector; at least three charged tracks recognized; at least 10% of the energy seen in the energy detector correlated with charged tracks. In a hand-scan, all events were eliminated which had drift chamber timing information inconsistent with the geometry of beam-beam interactions. Table 1 shows the breakdown of the events as they pass through the filtering procedure.

The "visible cross section" σ_{vis} was obtained by dividing the number of observed hadronic events by the time-integrated luminosity measured with the large-angle ($\alpha > 36°$) Bhabha events in the same apparatus for each energy point. The luminosity was also measured in a set of four counter telescopes for Bhabha scattering under 7°. Both measurements agreed within ±10%.

Fig. 2 shows how σ_{vis} depends on the centre-of-mass energy $\sqrt{s}$. The Υ is seen near 9.46 GeV above a

Table 1
Number of events in the filtering procedure and luminosity.

	Υ region	Υ' region
Triggers	3.4×10^6	5.1×10^6
Left after on-line filter	4.6×10^5	9.1×10^5
Left after off-line filter	2500	770
Left after hand-scan	1200	420
Integrated luminosity (nb^{-1})	173	120

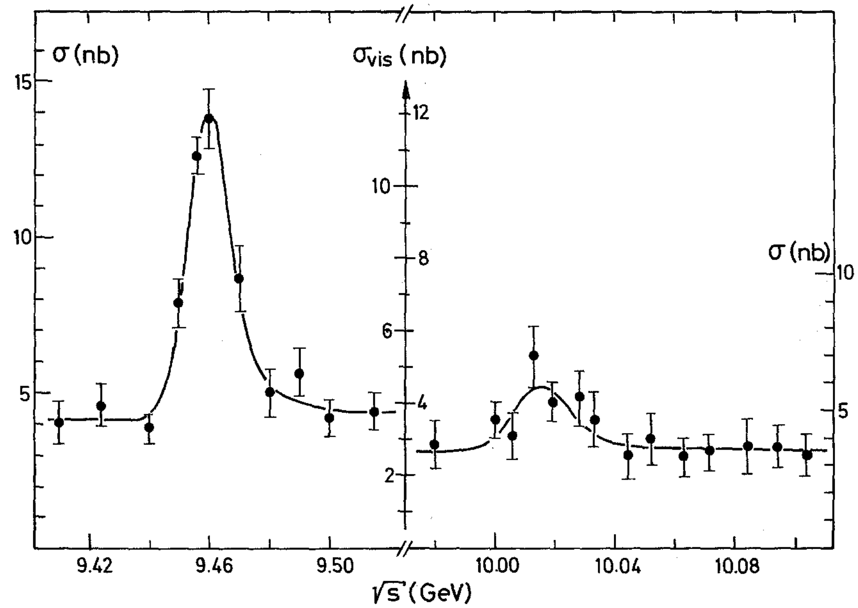

Fig. 2. Observed cross section $\sigma_{vis}(e^+e^- \to$ hadrons) in the Υ and Υ' regions (centre scale common to both measurements). The two outer scales represent the data after normalization to the expected level of continuum based on $R = 4.7$ (see text). The two outer scales are different by $\approx 10\%$, reflecting the systematic errors between the independent normalizations of the two measurements.

nearly constant continuum of 3.7 nb, and the Υ' resonance is seen for the first time to be formed in e^+e^- annihilations, above a continuum of 2.7 nb. We note that the Υ' signal is also very clearly visible in the event sample defined by the off-line filter.

The energy dependence of σ_{vis} was fitted around each resonance by a radiatively corrected gaussian resolution function (according to ref. [6]) over a background proportional to $1/s$. At the present time we are not able to calculate the exact amount of losses of hadronic events due to our filtering procedure. They are probably between 10% and 30% and are roughly independent of s. The visible cross section was normalized to 4.16 nb at 9.4 GeV and to 3.68 nb at 10.0 GeV to correspond to a value of $R = \sigma_{had}/\sigma_{\mu\mu}$ of 4.2 derived from $R(\sqrt{s} = 5\text{ GeV}) = 4.7$ [7] minus 0.5 units for undetected heavy-lepton decays due to our event selection. R was assumed to be energy independent between 5 and 10 GeV.

We foudn the resonances at masses of $M(\Upsilon) = 9.46 \pm 0.01$ GeV, $M(\Upsilon') = 10.02 \pm 0.02$ GeV; $\Delta M = 0.56 \pm 0.01$ GeV where the errors are from the machine [8]. The mass difference is only 29 ± 10 MeV less than the one between J/Ψ and Ψ', contrary to expectations based on universal potentials, "Coulomb + linear" [2], for the charmed and the new quarks.

The observed widths were found to be $\sigma(\Upsilon) = (7.1 \pm 0.8)$ MeV and $\sigma(\Upsilon') = (12 \pm 4)$ MeV. These are consistent with the energy resolution of the storage ring calculated to be $\sigma(9.5) = (7.8 \pm 0.8)$ MeV at the Υ and $\sigma(10.0) = (8.7 \pm 0.9)$ MeV at the Υ'. The machine value was used in the following determination of the area under the Υ'.

The areas under the normalized resonance curves were $A(\Upsilon) = 208 \pm 25$ MeV nb and $A(\Upsilon') = 59 \pm 15$ MeV nb, which turned into $A_0(\Upsilon) = 267 \pm 32$ MeV nb and $A_0(\Upsilon') = 74 \pm 19$ MeV nb after radiative corrections. We assume the Υ and Υ' are $J^P = 1^-$ objects, for which the ratio of electronic, hadronic, and total widths is

$$\Gamma_{ee}\Gamma_{had}/\Gamma_{tot} = (E_{res}^2/6\pi^2)A_0 \approx \Gamma_{ee}.$$

We obtained:

$$\Gamma_{ee}\Gamma_{had}/\Gamma_{tot} = (1.04 \pm 0.28)\text{ keV for the } \Upsilon,$$

$$(0.32 \pm 0.13)\text{ keV for the } \Upsilon',$$

thus confirming the earlier measurement of the Υ [3,4], whereas the Υ'-value is new. The errors contain a statistical contribution of ± 0.13 keV (Υ) and ± 0.08 keV (Υ'), and a common systematic contribution of $\pm 15\%$. The ratio 0.32/1.04 is, therefore, known with a precision of $\pm 28\%$. In the quarkonium picture [2] such values of Γ_{ee} favour the assignment of charge 1/3 to the new quark. Our small $\Gamma_{ee}(\Upsilon')$ seems to exclude a charge of 2/3 [9].

This work would not have been possible without the successful operation of the DORIS storage ring, which the machine group was able to run far beyond its original specifications. We are very grateful to the old DESY–Heidelberg group, who built the experiment and let us use their software. We are indebted to all the service groups who supported the experiment, i.e. the computer centre, the synchrotron staff, and the vacuum group as well as our technicians. The non-DESY members of our collaboration want to thank the DESY directorate for their hospitality.

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