Υ'(10.01) RESONANCE PARAMETERS

LENA Collaboration

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The resonance parameters of the Υ'(10.01) were measured using the LENA detector at the DORIS e^+e^- storage ring. We obtained a mass of $M(\Upsilon') = (10\,013.6 \pm 1.2 \pm 10.0)$ MeV and an electronic width of $\Gamma_{ee}(\Upsilon') = (0.53 \pm 0.07^{+0.09}_{-0.05})$ keV. The upper limit set to the μ-pair branching ratio is 3.8% which implies a lower limit on the total Υ' width of 14 keV. Together with our previous measurement of the Υ parameters we obtain a mass difference $M(\Upsilon') - M(\Upsilon) = (552.0 \pm 1.3 \pm 10.0)$ MeV and $\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon) = 0.43 \pm 0.07^{+0.05}_{-0.00}$.

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The $\Upsilon'(10.01)$ which is accepted to be the second member of the Υ family was discovered together with the $\Upsilon(9.46)$ in proton nucleus reactions [1]. Additional information about this resonance was obtained when it was first seen at DORIS in e^+e^- annihilations [2,3]. However, the amount of data then accumulated was rather small, and hence the $\Gamma_{ee}(\Upsilon')$ value was only measured to a significance of 4 s.d. from zero. Consequently it was even not possible to get an upper limit on $B_{\mu\mu}$, the μ-pair branching ratio. In view of the interest in Γ_{ee} and $B_{\mu\mu}$ for the understanding of the bound $b\bar{b}$ system, it was desirable to improve these measurements. Furthermore, increased statistics allows a study of the Υ' decay final states [4].

The data presented here were taken with the non-magnetic LENA (*Le*ad glass *Na*I) detector (fig. 1) at the DORIS e^+e^- storage ring. The LENA detector was constructed initially by the DESY–Heidelberg collaboration. The inner detector consists of three double layers of cylindrical drift chambers and two cylindrical hodoscopes (H_i, H_o), one of which (H_o) is also used for time of flight measurements. Surrounding the inner detector is the energy detector consisting of 178 blocks of lead glass and NaI. The energy detector is in turn surrounded by additional time of flight counters, steel absorber, and muon drift chambers. A detailed description of the detector has been presented elsewhere [5,6].

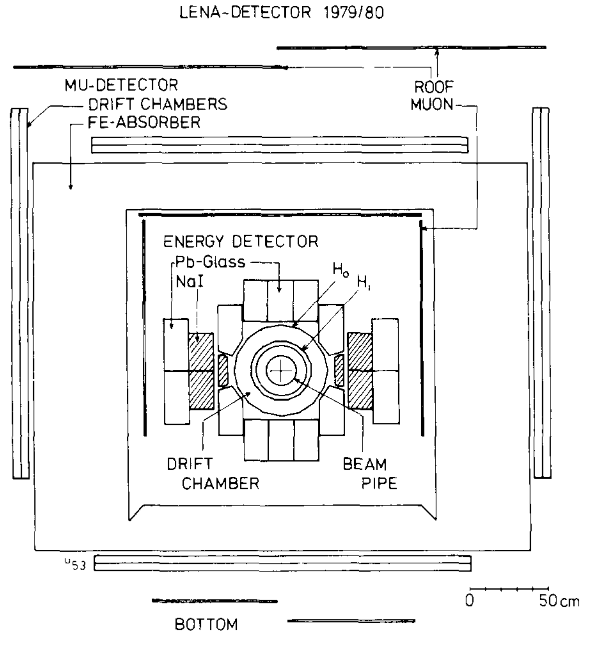

Fig. 1. The LENA detector shown along the beam direction.

The detector was triggered by a coincidence between radial tracks in the inner detector as recognized by the cylindrical hodoscopes and pulse height in the energy detector. A total integrated luminosity of 1257 nb^{-1} was measured by large angle Bhabha events within the detector and by small angle (≈130 mrad) Bhabha events in a separate luminosity monitor. The two methods, used to determine the luminosity without applying radiative corrections, agree within the statistical error of 1%. The amount of luminosity accumulated on the Υ' resonance was ≈650 nb^{-1}.

The hadronic events were selected off-line applying the same criteria used in our Υ study [6]. These criteria included cuts on: (i) event timing within ± 12 ns of the bunch crossing; (ii) $\geqslant 3$ tracks recognized by the drift chambers; (iii) $\geqslant 1.8$ GeV deposited in the energy detector and not all the energy in one half of the detector. All the computer selected events were further scanned by physicists to remove any remaining events due to beam gas interactions, Bhabha scattering or cosmic rays.

The final accepted hadronic sample consisted of 4720 events accumulated in an energy scan over the Υ' resonance between 9900 and 10 080 MeV. The visible cross section in the continuum was normalized to the R value of $R = \sigma_h/\sigma_{\mu\mu} = (3.7 \pm 0.4)$ [7]. The difference in acceptance on resonance and on the continuum was determined by Monte Carlo methods. The resulting hadronic cross section is shown in fig. 2, where the errors are statistical only. The systematic errors are due to the 10% uncertainty in R which can only change the overall normalization.

The cross section data were fitted to a continuum plus a convolution of a radiatively corrected Breit–Wigner cross section and a gaussian beam energy distribution [8] (solid curve in fig. 2). The fit yielded the following values [‡1]

$$\tilde{\Gamma}_{ee} \equiv \Gamma_{ee}\Gamma_h/\Gamma_{tot} = (0.53 \pm 0.07 \pm 0.05)\ \mathrm{keV},$$

$$M = (10\,013.6 \pm 1.2 \pm 10.0)\ \mathrm{MeV}.$$

For the determination of the leptonic branching

[‡1] Here and in the following results the first error is statistical and the second error is systematic.

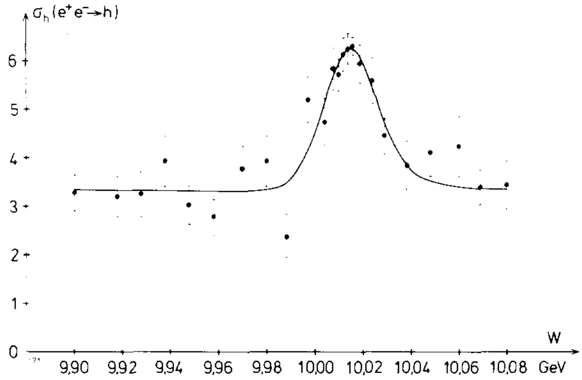

Fig. 2. The hadronic cross section $\sigma(e^+e^- \to h)$ in the Υ' energy region. The data have been corrected for acceptance and the τ-contribution has been subtracted. The errors shown are only statistical. The full line shown is the fit described in the text.

ratio $B_{\mu\mu}$ the criteria applied for the selection of the μ-pairs was the same as that used in our study of the Υ resonance [6]. Briefly, we demanded two collinear tracks in the inner detector with an energy deposition of less than 1200 MeV. Fig. 3 shows the acollinearity distribution of the μ-pair sample in cot θ and ϕ. Here θ and ϕ are, respectively, the polar and azimuthal angles with respect to the e$^+$ beam direction. From cosmic ray muons we found our rms resolution to be $\delta\phi = 0.015$ and $\delta(\cot\theta) = 0.070$. We defined for each event a normalized acollinearity

$$\delta^2 = \left(\frac{\Delta\phi}{0.015}\right)^2 + \left(\frac{\Delta\cot\theta}{0.070}\right)^2 ,$$

where $\Delta\phi$ and $\Delta\cot\theta$ were the measured acollinearities between the two tracks. Two tracks were classified collinear if $\delta^2 \leqslant 25$. A clean separation of μ-pair events from cosmic rays was achieved by applying cuts on the position of the interaction point and on the time of flight [6]. The residual hadronic background was found to be 3% from a study of tracks pointing at the muon drift chambers [6]. This hadronic background has a uniform acollinearity distribution in the plane defined in fig. 3. The final accepted μ-pair sample consisted of 380 events. The cross section $\sigma(e^+e^- \to \mu^+\mu^-)$ deduced from these data shows no enhancement at the position of the Υ'. This sets an upper limit for the μ-pair branching ratio of:

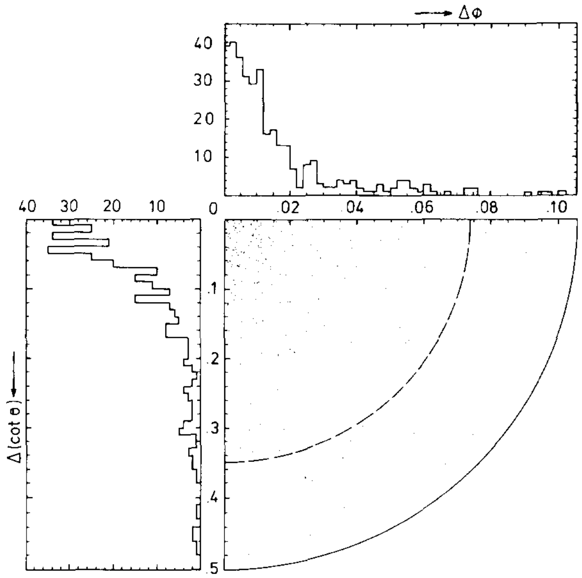

Fig. 3. Two-dimensional acollinearity distribution in cot θ and ϕ, for μ-pairs. Here θ is the polar angle of the track with respect to the positron beam direction and ϕ is the azimuthal angle. The dashed curve represents the cut applied to the data. Projections on the cot θ and ϕ axes are also shown.

$$B_{\mu\mu} < 3.8\% \quad \text{(90\% confidence level)} .$$

The upper limit established for $B_{\mu\mu}$ should be compared to various theoretical predictions which give (1.2–1.7)% [9].

The leptonic branching ratio Γ_{ee} can be obtained from the measured quantities by

$$\Gamma_{ee} = \widetilde{\Gamma}_{ee}\Gamma_{tot}/\Gamma_h = \widetilde{\Gamma}_{ee}/(1 - 3B_{\mu\mu}) .$$

As we have only an upper limit for $B_{\mu\mu}(\Upsilon')$ we can approximate

$$\Gamma_{ee} \approx \widetilde{\Gamma}_{ee} = (0.53 \pm 0.07^{+0.09}_{-0.05})\ \text{keV} .$$

The systematic error comes partly from the 10% error in R and partly from the range given by our upper limit on $B_{\mu\mu}$. If we use for $B_{\mu\mu}$ the weighted average of the positive range ($B_{\mu\mu} = 1.7\%$) we find $\Gamma_{ee} = (0.56 \pm 0.07 \pm 0.06)$ keV. The first part of the systematic error cancels out when considering the ratio between the leptonic widths of the Υ and Υ' resonances. Using our Υ result [6] we obtain:

$$\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon) = 0.43 \pm 0.07^{+0.05}_{-0.00} .$$

Table 1
Experimental results on the Υ' (10.01) resonance parameters.

Year of experiment	Collaboration	Refs.	$\Gamma_{ee}(\Upsilon')$ a) (keV)	$\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon)$	$M(\Upsilon')$ (MeV)	$M(\Upsilon') - M(\Upsilon)$ (MeV)	$B_{\mu\mu}(\Upsilon')$
1978	D–HH–HD–M b)	2, 7	0.37 ± 0.16	0.34 ± 0.10 c)	10 020 ± 20	560 ± 10	
1978	DASP II	3, 17	0.35 ± 0.14	0.23 ± 0.11	10 012 ± 20	555 ± 11	
1979/80	CLEO	18	0.468 ± 0.04 ± 0.07	0.51 ± 0.05 ± 0.05 d)	9 994.4 ± 0.4 ± 30	560.8 ± 0.4 ± 3.0	
1979/80	CUSB	11	0.39 ± 0.06 d)	0.39 ± 0.06 d)		559 ± 1 ± 3	
1979/80	DASP II	19	0.61 ± 0.11 ± 0.11	0.45 ± 0.09 ± 0.05	10 016.8 ± 1.5 ± 10.0	553.7 ± 1.7 ± 10.0	
1979/80	LENA	this work	0.53 ± 0.07 ± 0.06	$0.43 \pm 0.07^{+0.05}_{-0.00}$	10 013.6 ± 1.2 ± 10.0	552.0 ± 1.3 ± 10.0	<3.8%

a) All experiments use $\Gamma_{ee}\Gamma_h/\Gamma_{tot}$ for the Υ' extent of Γ_{ee}.
b) D–HH–HD–M: DESY–Hamburg (I. Inst. Exp. Physik)–Heidelberg–MPI München.
c) This value was not given in the original publication, but was calculated from $\Gamma_{ee}(\Upsilon')$ and $\Gamma_{ee}(\Upsilon)$ by us.
d) The ratio given uses $\Gamma_{ee}\Gamma_h/\Gamma_{tot}$ for the Υ instead of Γ_{ee}.

This ratio is in good agreement with the values measured at CESR and at DORIS (see table 1). Theoretical predictions for this ratio are more reliable than the predictions for $\Gamma_{ee}(\Upsilon)$ and $\Gamma_{ee}(\Upsilon')$ separately since it is independent of higher order corrections which may not be negligible [12,15]. This ratio depends only on the masses and wave functions of the $b\bar{b}$ system for the Υ and Υ' states [14]:

$$\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon) = (|\Psi_{\Upsilon'}(0)|^2/M_{\Upsilon'}{}^2)/(|\Psi_{\Upsilon}(0)|^2/M_{\Upsilon}^2)\,,$$

where $|\Psi(0)|^2$ depends on the assumed potential model. A range of values between 0.41 and 0.45 have been calculated by several authors [13–16] which agree with our measurement.

Using our value for Γ_{ee} and our established upper limit for $B_{\mu\mu}$ one obtains a lower limit for the total width:

$$\Gamma_{tot} > 14 \text{ keV}\,.$$

The mass obtained for the Υ' is in agreement with the values measured at DORIS in 1978 by this detector [2], namely (10 020 ± 20) MeV, and by the DASP 2 detector [3]: (10 012 ± 10) MeV. We have determined the mass difference between the Υ' and the Υ to be

$$\Delta M = M(\Upsilon') - M(\Upsilon) = (552.0 \pm 1.3 \pm 10.0) \text{ MeV}\,.$$

This value is in agreement with the CESR values of (560.7 ± 0.8 ± 3.0) MeV [10] and (559 ± 1 ± 3) MeV [11]. This mass difference can be described by potential models and the values predicted range between 555 MeV [14,16] and 566 [13] – in agreement with experiment.

In conclusion, we have measured the mass and electronic width of the Υ'(10.01) resonance and obtained an upper limit for the μ-pair branching ratio. These values agree well with the predictions of potential models which have been formulated to describe the quarkonium states. This agreement supports the idea that both the Υ and Υ' are bound states of the bottom–anti-bottom quark system.

This experiment was made possible thanks to the efforts of Dr. K. Wille and the DORIS machine group. The help of all the DESY services is greatly appreciated. Our thanks are due to the DESY–Heidelberg group which built the detector and has allowed us to use their data analysis programs. Furthermore we thank our technicians and summer students. The non-DESY members of the collaboration thank the DESY directorate for their hospitality. A.A., B.N., F.M., and T.Z. would like to thank the DESY directorate for financial support.

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