THE HADRONIC CROSS SECTION OF ELECTRON–POSITRON ANNIHILATION AT 9.5 GeV AND THE Υ AND Υ' RESONANCE PARAMETERS

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The reaction $e^+e^- \to$ hadrons has been measured in the Υ and Υ' region using the DASP detector at the DESY storage ring DORIS. The following final results are obtained: $R_{had}(9.5\ \text{GeV}) = 3.73 \pm 0.16 \pm 0.28$, $\Gamma_{ee}(\Upsilon) = (1.23 \pm 0.08 \pm 0.12)$ keV, $B_{\mu\mu}(\Upsilon) = (3.2 \pm 1.3 \pm 0.3)\%$, $\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}(\Upsilon') = (0.55 \pm 0.11 \pm 0.06)$ keV, and $M(\Upsilon') - M(\Upsilon) = (556 \pm 10)$ MeV.

The production of Υ- and Υ'-mesons in e^+e^- annihilations was first observed at the DESY storage ring DORIS in 1978 [1–4]. Here we report new results on the $\Upsilon'(10.02)$ meson and the hadronic R value at 9.5 GeV obtained with the DASP detector in a second run period in 1979/80. During this period data were also taken at the $\Upsilon(9.46)$ meson [5], and the results of a final analysis of this state are presented in this paper.

The double-arm spectrometer DASP has been described before [6]. Basically it consists of a non-magnetic inner detector accepting a solid angle of about 50% of 4π, and of two outer magnetic spectrometer arms covering about 5% of 4π. Both charged particles and photons are detected in either of the two components with good particle separation in the spectrometer arms.

DORIS was operated in a single ring, single bunch mode, as for the previous runs. We collected a total integrated luminosity of about 1600 nb^{-1}: 456 nb^{-1} on the Υ, 515 nb^{-1} on the Υ', and 602 nb^{-1} in the neighbouring continuum regions. In order to get the resonance curves for e^+e^- annihilation into hadrons, energy scans were performed in the regions $9.4 < \sqrt{s} < 9.6$ GeV and $9.9 < \sqrt{s} < 10.1$ GeV; $\sqrt{s}$ is the CM energy.

A clean sample of multi-hadron events in the inner detector was obtained only after a considerable reduc-

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tion of the recorded data. The trigger conditions and selection criteria are described in detail in refs. [7] and [8]. Cuts were applied to discriminate against background from beam–gas interactions, cosmic ray particles and synchrotron radiation, and against events from QED processes and two-photon interactions. In particular, the deposited energy had to be >800 MeV, and the number of reconstructed particles (charged or converted photons) was required to be $\geqslant 3$.

The efficiency of this data reduction procedure and the acceptance of the detector were determined by extensive Monte Carlo calculations. Events were generated both for the QED process $e^+e^- \to \ell^+\ell^-(\gamma)$ with $\ell = e, \mu, \tau$ [9], and for hadronic final states assumed to originate from the fragmentation of quark–antiquark pairs in the continuum, and of three-gluon states on the resonances. The fragmentation process was parametrized by the Field and Feynman jet model [10] and modifications thereof [11,12].

In the continuum, radiative corrections were incorporated into the Monte Carlo program by taking into account third order QED graphs in the event generation [9]. Thus the radiative corrections and the detector acceptance, including the data selection cuts, are calculated in a consistent way [8]. Fig. 1 shows the combined detector and reconstruction acceptance η, the radiative correction δ and the product $\eta(1+\delta)$ as a function of the energy of the radiated photon. Experimentally, the relevant quantity is $\eta(1+\delta)$ and this is insensitive to cuts in the photon energy. On the narrow resonances Υ and Υ', we used the method of Jackson and Scharre [13] to determine the radiative corrections in conjunction with the storage ring resolution.

The contribution from τ pair production was determined by the same acceptance and radiation calculations and was subtracted from the hadronic cross section. The product $\eta(1+\delta)$ for τ pairs was obtained to be $(22 \pm 1)\%$. Contributions from $\gamma\gamma$ processes to the hadronic cross section were estimated to be <1% and are therefore neglected.

The integrated luminosity at each energy was determined by measuring the reactions $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ in the inner detector, and independently by a luminosity monitoring system using small angle Bhabha scattering measured by four identical counter arms.

The determination of $R = \sigma(e^+e^- \to \text{hadrons})/$

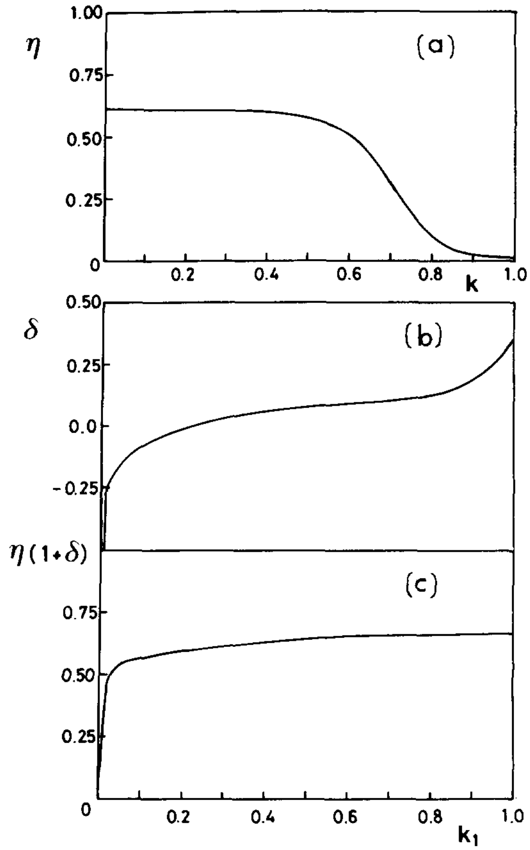

Fig. 1. Monte Carlo calculations of (a) the acceptance of $q\bar{q}\gamma$ events following Field–Feynman fragmentation [10] and Berends–Kleiss radiation [9] for fixed values of k, where $k = 2E_\gamma/\sqrt{s}$, (b) the radiative correction δ defined by $\sigma(e^+e^- \to \text{hadrons} + \gamma \text{ with } k < k_1) = (1+\delta)\cdot\sigma_0(e^+e^- \to \text{hadrons}, k = 0)$, and (c) the experimentally relevant product $\eta(1+\delta)$.

$\sigma(e^+e^- \to \mu^+\mu^-)$ is based on 730 reconstructed events in the energy ranges 9.40–9.44 and 9.49–9.60 GeV. The second region has been corrected for the radiative tail of the Υ resonance following ref. [13]. The mean energy value is 9.51 GeV. We find

$$R = 3.73 \pm 0.16 \pm 0.28 ,$$

where the first error is statistical and the second is systematic. The systematic error contains 5% for the luminosity determination, 5% for the uncertainty on $\eta(1+\delta)$, 1% for τ subtraction, 2% for subtraction of other background sources and 1% for the Υ radiative tail.

The hadronic cross sections around the resonances are shown in fig. 2. The curves are the results of fitting

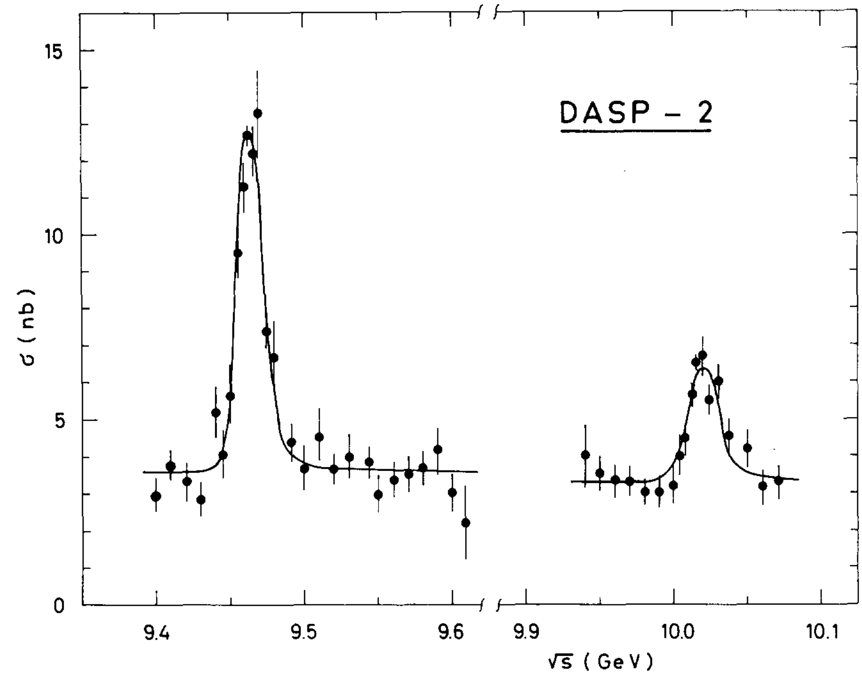

Fig. 2. Cross sections of the reaction $e^+e^- \to$ hadrons for the Υ and Υ' region as a function of the CM energy $\sqrt{s}$. The cross sections are corrected for the detector acceptance and in the continuum for radiation effects. The curves are the results of fitting a narrow resonance with gaussian resolution and radiative corrections according to ref. [13].

to the data an incoherent sum of a continuum curve varying like $1/s$ and a Breit–Wigner resonance function folded with gaussian machine resolution and radiation [13]. The resulting fit parameters are given in the columns two and three of table 1. The large systematic errors for the resonance masses reflect mainly the uncertainties of the energy calibration of DORIS. The mass values found in the first run period in 1978 [2,4,14] were about 6 MeV below the present values both for Υ and Υ', whereas the mass difference stayed constant. The rms widths of the resonances agree with the energy resolution of DORIS (~9 MeV). Also given in table 1 are bounds and values for the muon-pair branching ratio $B_{\mu\mu}$, the electronic width Γ_{ee} and the total width Γ_{tot}. The results for Υ are consistent with the values previously published [5], whereas $\Gamma_{had}\Gamma_{ee}/\Gamma_{tot}$ for the Υ' is nearly two standard deviations higher than our preliminary result [4].

The muonic branching ratio $B_{\mu\mu}$ on the resonances was determined by comparing the numbers of μ-pair events on and off resonance [7]. This was done independently for the inner and outer detector, and the results have been averaged. The value quoted in table 1 for the Υ meson, $B_{\mu\mu} = (3.2 \pm 1.3 \pm 0.3)\%$, is the final DASP-2 result, since it is the average over the two run periods.

Table 1
Resonance parameters.

	M (MeV)	$\Gamma_{had}\Gamma_{ee}/\Gamma_{tot}$ (keV)	$\Delta M(\Upsilon', \Upsilon)$ (MeV)	$B_{\mu\mu}$	Γ_{ee} (keV)	Γ_{tot} (keV)
Υ'	10018 ± 1.5 ± 20	0.55 ± 0.11 ± 0.06	556 ± 10	< 6% (95% CL)		> 9 (95% CL)
Υ	9462 ± 0.6 ± 10	1.12 ± 0.07 ± 0.04	556 ± 10	(3.2 ± 1.3 ± 0.3)%	1.23 ± 0.08 ± 0.12	38^{+27}_{-11}

The systematic errors on R are still too large for extracting a value of α_s from first order QCD corrections. On the other hand, $B_{\mu\mu}$ is now so well known that its value may be used to determine α_s with the help of QCD calculations for $\Upsilon \to ggg + gggg$ obtained by Mackenzie and Lepage [15]. Our value of the leptonic branching ratio of the Υ, combined with results from other experiments [16], leads to a world average of $B_{\mu\mu}(\Upsilon) = (3.3 \pm 0.5)\%$. From this value, Mackenzie and Lepage obtain $\alpha_s(M_\Upsilon) = 0.14 \pm 0.01$ and $\Lambda = (100^{+34}_{-25})$ MeV, where Λ is the QCD parameter in the $\overline{\mathrm{MS}}$ renormalization scheme.

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