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NEW RESULTS ON THE Υ-SYSTEM FROM DORIS

by

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ABSTRACT

Further studies of e^+e^- annihilations in the Υ region at the DESY storage ring DORIS have yielded improved results on the properties of the Υ mesons. For the Υ-meson the leptonic width Γ_{ee} and branching ratios $B_{\mu\mu}$ are found to be $\Gamma_{ee} = 1.29 \pm 0.07$ keV and $B_{\mu\mu} = 3.2 \pm 0.8$ %. This gives a total width of the Υ-meson of $\Gamma_{tot} = 40 ^{+13}_{-8}$ keV. The leptonic width of the Υ'meson was determined to $\Gamma_{ee}(\Upsilon') = 0.57 \pm 0.06$ keV.

The Υ mesons are by now well established[1-5]. They represent quarkonium states of the heavy quark b and its antiquark. From the leptonic width of the Υ mesons the charge of the b quark was found to be $e_b = -1/3$. The mass spectrum is well known up to the Υ''' mass just above the flavor threshold[6]. It has been shown that the Υ decay pattern can be understood by assuming that it consists mainly of decays into 3 gluons[7-9]. This implies that the width of the Υ meson should be rather small, comparable to that of the J/ψ particle which is 69 keV. Since up to now the upper limit for $\Gamma_{tot}(\Upsilon)$ amounted to some few MeV it was highly desirable to improve this situation. The main point of my talk is therefore to present an accurate value of this basic quantity.

The total width Γ_{tot} is given by

$$\Gamma_{tot} = \Gamma_{ee} / B_{\mu\mu} \qquad (1)$$

Is is mainly due to the fact that $B_{\mu\mu}$ has large errors[10,11] that Γ_{tot} is poorly known. Thus the experiments carried out at the DESY storage ring DORIS aimed for a better determination of $B_{\mu\mu}$ (Υ). Besides this result refined values for $\Gamma_{ee}(\Upsilon)$ and $\Gamma_{ee}(\Upsilon')$ will be given.

The DORIS machine was operating in a single-ring-single-bunch mode. It delivered a peak luminosity of 10^{30} cm^{-2} s^{-1} at beam currents of 18 mA. With a beam lifetime of about 4 hours and a refill time of few minutes the average luminosity amounted to 30 nb^{-1} day^{-1}. During the last months of 1979 and in the beginning of 1980 an integrated luminosity of about 1000 nb^{-1} was taken both in the Υ and Υ' region.

The experiments were carried out with the DASP detector (fig. 1) and the NaI-LG detector (fig. 2), which are well known for many years. The DASP-detector was operated by the DASP2-group and the NaI-LG-detector by the LENA-group

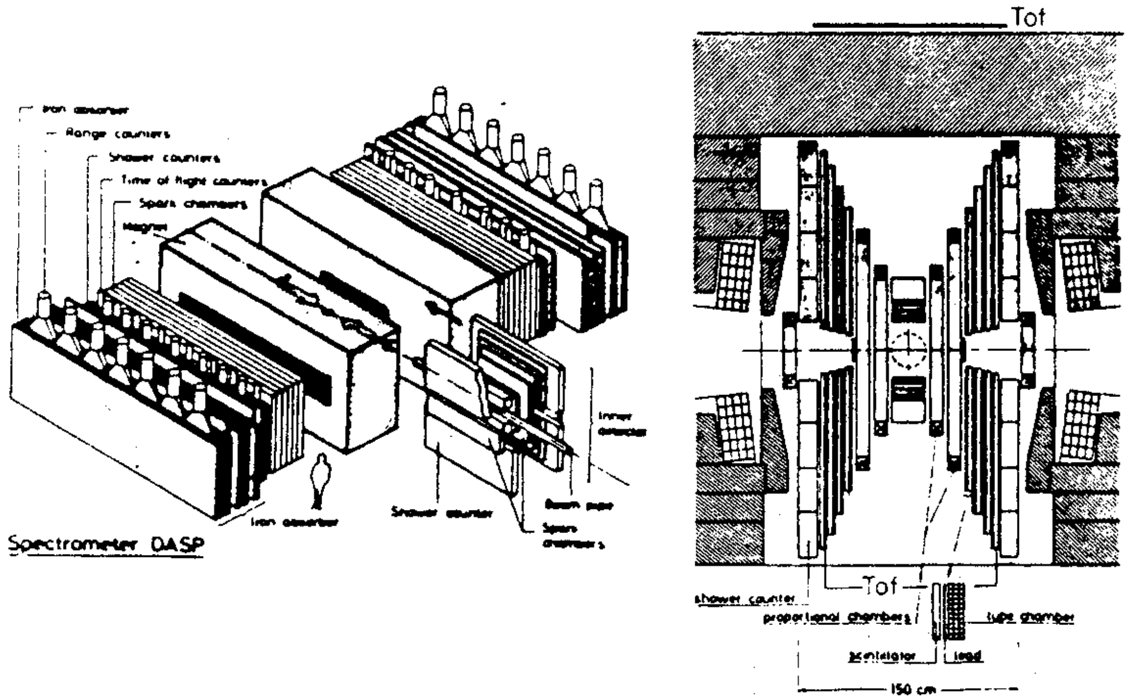

Fig. 1
DASP - detector

(a) spectrometer (b) inner detector

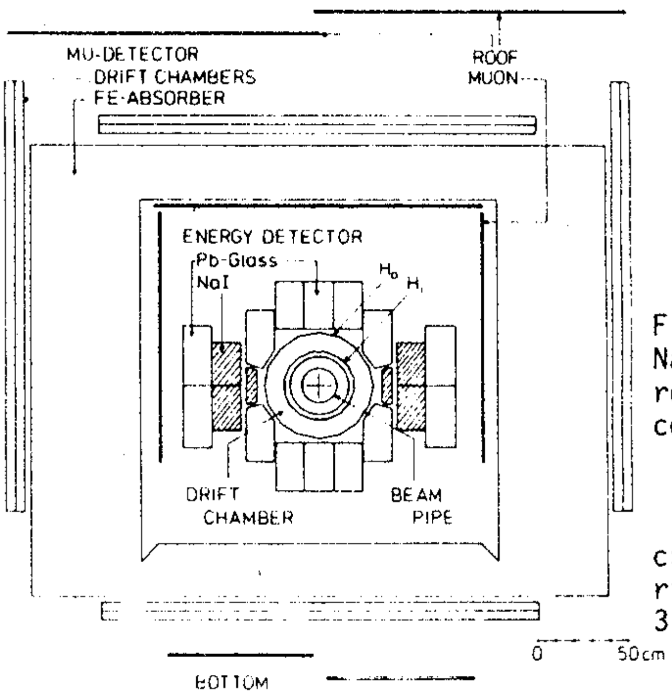

Fig. 2
NaI-Lead Glass detector with roof and bottom-time-of-flight counters

The measured hadronic cross section for each experiment is displayed in figs. 3 and 4.

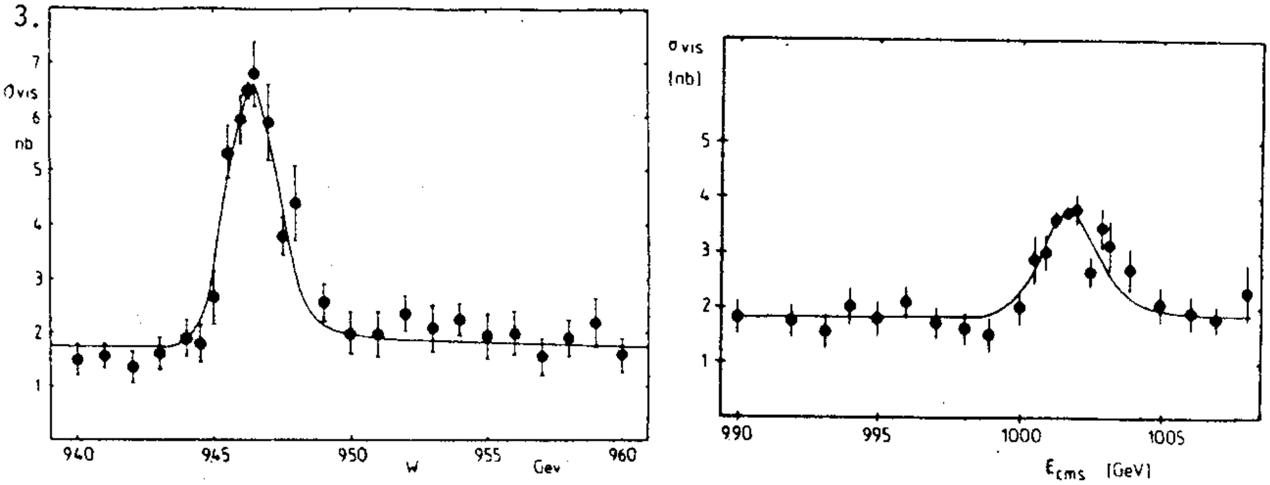

Fig. 3
$\sigma(e^+e^- \to \text{hadrons})$ with DASP[14]

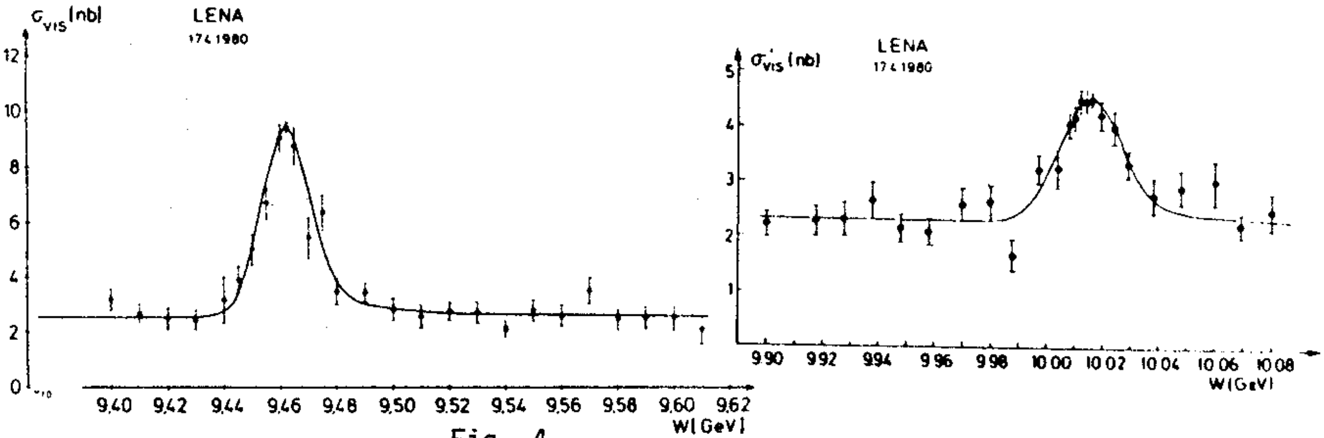

Fig. 4
$\sigma(e^+e^- \to \text{hadrons})$ with LENA

It was expressed in terms of a continuum contribution and a Breit-Wigner function

$$\sigma_{had} = \frac{3\pi}{s}\left(\frac{4\alpha^2}{9}\cdot R_{had}\cdot \eta_1 + \frac{\Gamma_{ee}\ \Gamma_{had}}{(M-\sqrt{s})^2+\Gamma^2/2}\cdot \eta_2\right) \quad (2)$$

This expression was folded with the gaussian energy resolution of the machine and radiative corrections were applied. Knowing the efficiencies η_1 for two-jet events and η_2 for mainly 3-jet-events the following quantities could be extracted (table I):

TABLE I: Υ and Υ' resonance parameters*

	DASP2	LENA	AVERAGE	
M (Υ)	9463.1 ± 0.7±10	9461.6 ± 0.6±10	9462.4 ± 0.5±10	MeV
M (Υ')	10016.8 ± 1.5±10	10014.2 ± 0.9±10	10014.9 ± 0.8±10	MeV
M (Υ')-M(Υ)	553.7 ± 1.7±10	552.6 ± 1.0±10	553.1 ±0.06±10	MeV
$\Gamma_{ee}(1-3B_{\mu\mu})(\Upsilon)$	1.23± 0.09±0.2	1.10 ± 0.07±0.11	1.15±0.06	keV
$\Gamma_{ee}(1-3B_{\mu\mu})(\Upsilon')$	0.61± 0.11±0.11	0.55 ± 0.07±0.06	0.57±0.06	keV

* The first error is the statistical error whereas the second one is the systematic error.

The muonic branching ratio is given by

$$B = \frac{\sigma(e^+e^- \to T \to \mu^+\mu^-)}{\sigma(e^+e^- \to T \to \text{had}) + 3 \cdot \sigma(e^+e^- \to T \to \mu^+\mu^-)} \qquad (3)$$

The muonic resonance cross section is determined by measuring the muon cross section in the resonance and subtracting the QED-contribution from the continuum. Due to a lack of statistics only the $B_{\mu\mu}$ for the T meson could be determined.

Muon pairs are required to be collinear. They are recognized by their ability to penetrate large amounts of material without interacting (see figs. 1 and 2) and by time-of-flight (TOF) measurements in order to separate them from cosmic rays. This discrimination is illustrated fro the DASP inner detector in fig. 5 where the bunch crossing time is plotted versus the TOF difference between two opposite TOF counters. Muon pairs from the e^+e^- annihilation should be correlated with the bunch crossing at 16 ns and should have a zero TOF difference (see arrows in fig. 5). Cosmic rays are not correlated with the bunch signal and have a TOF difference of -6 ns. In fig. 5 one clearly sees an enhancement for muon pairs in

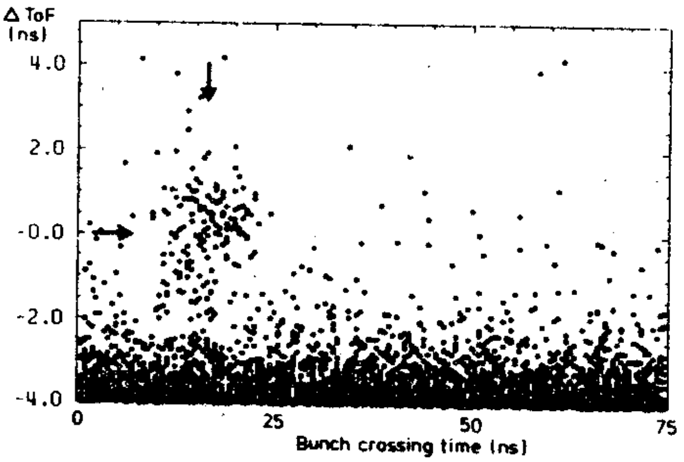

Fig. 5
Bunch crossing time versus TOF-difference between two opposite counters

the right region. Fig. 6 shows a projection onto the TOF axis for muon pairs correlated (a) and uncorrelated with bunch crossing (b). The subtraction of both spectra yields the spectrum in fig. 6 c which exhibits a clear μ-pair signal. The angular distribution of these μ pairs shows the expected $(1 + \cos^2\Theta)$ distribution (fig. 7).

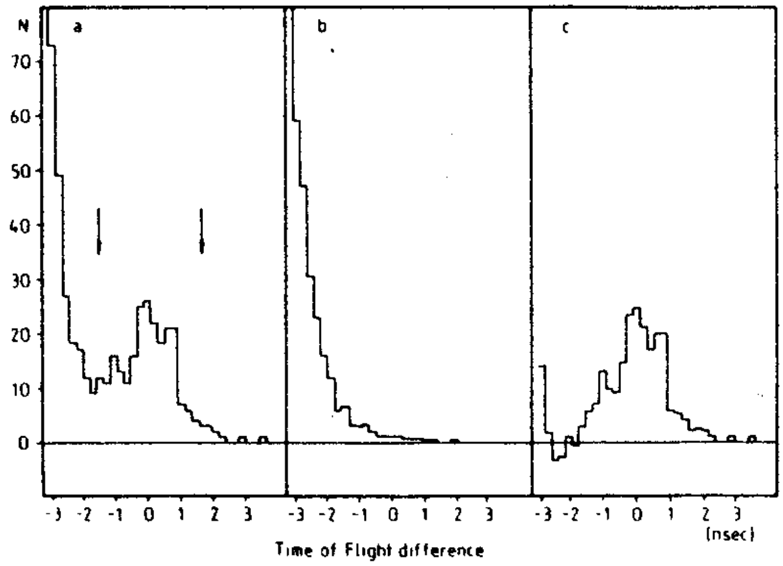

Fig. 6
TOF-difference for collinear, non showering particles

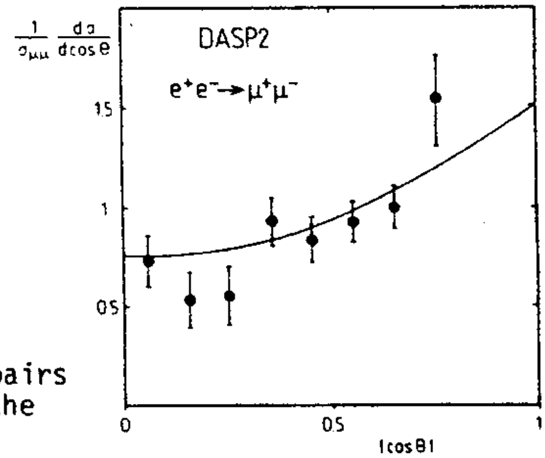

Fig. 7
Angular distribution of μ-pairs from e^+e^- annihilation at the Υ-resonance energy

The resonance cross section for μ-pair production is then given by:

$$\sigma(e^+e^- \to \Upsilon \to \mu^+\mu^-) = \sigma_{\mu\mu}^{QED} \left(\frac{N_{\mu\mu}^{on}}{N_{\mu\mu}^{cont}} \frac{L_{cont}}{L_{on}} - 1 \right) \quad (4)$$

where $N_{\mu\mu}$ are the number of μ - pairs on the peak of the resonance and in the continuum and the L's the corresponding luminosities. $\sigma_{\mu\mu}^{QED}$ is the QED cross section $\sigma(e^+e^- \to \mu^+\mu^-)$ at the resonance energy.

From the measured numbers one then gets for the DASP inner detector:

$$B_{\mu\mu}(\Upsilon) = 2.5 \pm 1.8\ \%$$

and for the LENA detector

$$B_{\mu\mu}^{LENA}(\Upsilon) = 3.5 \pm 1.4 \pm 0.5\ \%$$

In the analysis of the DASP outer detector, which has an acceptance of only 5 % of 4π but an excellent particle discrimination, the number of μ-pairs coming from the decay of the Υ-meson is determined in the following way: There are 24 μ-pairs at the resonance energy whereas from 135 e^+e^- pairs in the outer detector one would expect only 14.3 ± 2 from the QED process.This excess of about 10 μ-pairs leads to a branching ratio of

$$B_{\mu\mu} = 5.6 \pm 3.3\ \%.$$

Averaging the DASP2 values including the result from 1978[10] of $B_{\mu\mu} = 2.5 \pm 2.1$ % yields

$$B_{\mu\mu}^{DASP2}(\Upsilon) = 2.9 \pm 1.3 \pm 0.5\ \%$$

where the first error is statistical and the second one is systematic.

The PLUTO group has evaluated the Bhabha cross section from the first Υ-measurement at DORIS in 1978[15]. From the excess of e^+e^- pairs compared to the Bhabha cross section at backward angles (fig. 8) a branching ratio

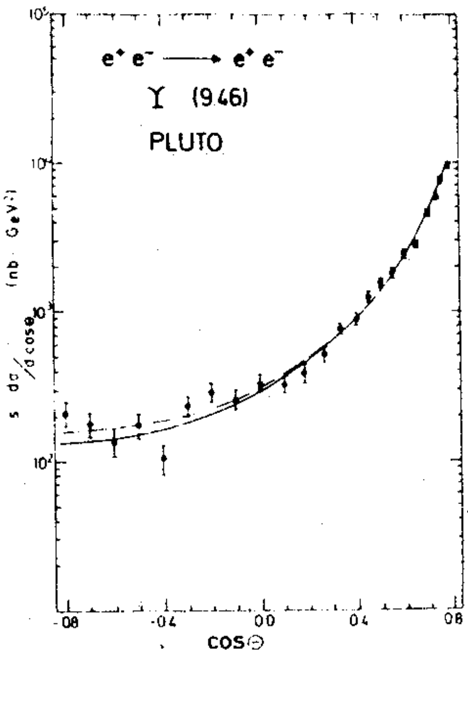

Fig. 8

Angular distribution of Bhabha pairs at the Υ - resonance energy

$$B_{ee} = (5.1 \pm 3.0)\ \%$$

is deduced. Averaging this number with the already published value of $B_{\mu\mu}$ [11] yields

$$B_{ee}^{PLUTO}(\Upsilon) = 3.1 \pm 1.7.$$

In Table II the final results are summarized.

TABLE II: DORIS results on $B_{\mu\mu}$ and Γ_{ee} of the Υ-mesons

	DASP2	LENA	PLUTO 78	AVERAGE ***
$B_{\mu\mu}(\Upsilon)(\%)$	$2.9 \pm 1.3 \pm 0.5$	$3.5 \pm 1.4 \pm 0.4$	3.1 ± 1.7	3.2 ± 0.8
$\Gamma_{ee}(\Upsilon)$ (keV)	$1.35 \pm 0.11 \pm 0.22$	$1.23 \pm 0.13 \pm 0.14$ (1.04 ± 0.28)*	1.33 ± 0.14	1.29 ± 0.07
$\Gamma_{ee}(\Upsilon')$(keV) **	$0.61\,^{+0.12}_{-0.11} \pm 0.11$	$0.55 \pm 0.07 \pm 0.06$		0.57 ± 0.06
$\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon)$	$0.45 \pm 0.09 \pm 0.05$	$0.45 \pm 0.06 \pm 0.02$		0.45 ± 0.05

* Result from the DESY-Hamburg-Heidelberg-München-group[5]

** $B_{\mu\mu}(\Upsilon') \lesssim 2$ % assumed

*** Only statistical errors quoted

By using relation (1) one can now deduce the total width of the meson:

$$\Gamma_{tot}(\Upsilon) = 40\,^{+13}_{-8}\ \text{keV}.$$

This value is very close to that of the J/ψ particle suggesting that their nature is very similar. In both cases one expects that the direct hadronic decay into 3 gluons is the dominant decay mode. This decay width can be calculated using the following relation:

$$\Gamma_{dir} = \Gamma_{tot} - (R + N)\,\Gamma_{ee} \qquad (5)$$

where N is the number of leptonic decay modes and R takes into account the decay into a $q\bar{q}$ pair also through a virtual photon. In lowest order QCD the direct hadronic decay width is given by[16]:

$$\Gamma_{dir} = \Gamma_{3g} = \frac{10(\pi^2 - 9)\,\alpha_s^3}{81\pi \quad e_Q^2\,\alpha^2} \cdot \Gamma_{ee} \qquad (6)$$

and thus is a measure of the strong coupling constant α_s.

Neglecting for the moment the possible corrections to (6) one gets the following results (see Table III):

TABLE III:

	$\Upsilon(9.46)$	J/ψ
Γ_{tot} (keV)	$40\,^{+13}_{-8}$	67 ± 12
Γ_{3g} (keV)	$31\,^{+13}_{-8}$	48 ± 12
α_s	0.16 ± 0.02	0.19 ± 0.02

This result shows that as expected α_s is indeed small. Furthermore, both values show that α_s is only a very weak function of energy. A comparison with the values of α_s deduced from gluon bremsstrahlung events shows also a remarkable agreement[17]. If this is not just an accident then it strongly suggests that the corrections to (6) are not substantial.

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