Total Width and Leptonic Branching Ratio of the Υ(9.46)

B. Niczyporuk and T. Zełudziewicz
Institute of Nuclear Physics, Cracow, 31-342 Cracow, Poland

and

K. W. Chen and R. Hartung
Department of Physics, Michigan State University, East Lansing, Michigan 48824

and

H. Vogel[(a)] and H. Wegener
Physikalisches Institut der Universität Erlangen-Nürnberg, D-8520 Erlangen, Germany

and

J. K. Bienlein, R. Graumann, J. Krüger, M. Leissner, C. Rippich,[(b)] and M. Schmitz
Deutsches Elektronen-Synchrotron, D-2000 Hamburg 52, Germany

and

E. Filos, F. H. Heimlich, R. Nernst, A. Schwarz, U. Strohbusch, and P. Zschorsch
I. Institut für Experimentalphysik der Universität Hamburg, D-2000 Hamburg, Germany

and

A. Engler, R. W. Kraemer, F. Messing, T. Ridge, B. J. Stacey, and S. Youssef
Department of Physics, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

and

A. Fridman
Département de Physique des Particules Elémentaires, Centre d'Etudes Nucléaires de Saclay, F-91190 Gif-sur-Yvette, France

and

G. Alexander,[(c)] A. Av-Shalom, G. Bella, Y. Gnat, and J. Grunhaus
Department of Physics and Astronomy, Tel-Aviv University, Ramat Aviv, Israel

and

E. Hörber,[(d)] W. Langguth,[(c)] and M. Scheer
Physikalisches Institut der Universität Würzburg, D-8700 Würzburg, Germany
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With use of the LENA detector at the DORIS e^+e^- storage ring, the hadronic cross section and the μ-pair decay branching ratio of the Υ(9.46) resonance have been measured. $\Gamma_{ee} = 1.23 \pm 0.10$ (± 0.14) keV, $B_{\mu\mu} = [3.5 \pm 1.4$ (± 0.4)]%, and $\Gamma_{tot} = 35^{+25}_{-10}$ ($^{+9}_{-7}$) keV have been obtained. The first set of errors gives the statistical uncertainty. The numbers in parentheses represent systematic errors arising from the uncertainty in the total hadronic cross section.

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The discovery of Υ(9.46) in proton-nucleus reactions[1] and its subsequent confirmation in e^+e^- annihilations[2,3] opened the study of a new family of particles. The properties of the members of this family provide a testing ground for the many models which have been used to describe the J/ψ family. Of particular interest are the electronic and total widths (Γ_{ee} and Γ_{tot}) for the Υ which can be obtained from the Υ hadronic cross section $\sigma_h(\Upsilon)$ and the leptonic branching ratio $B_{\mu\mu}$. We present a measurement of $B_{\mu\mu}$ which differs from zero by more than 2 standard deviations.

The data were taken with the LENA (lead-glass–NaI) detector (Fig. 1) at the DORIS e^+e^- storage ring. The LENA detector was constructed by the Deutsches Elektronen-Synchrotron (DESY)–Heidel-

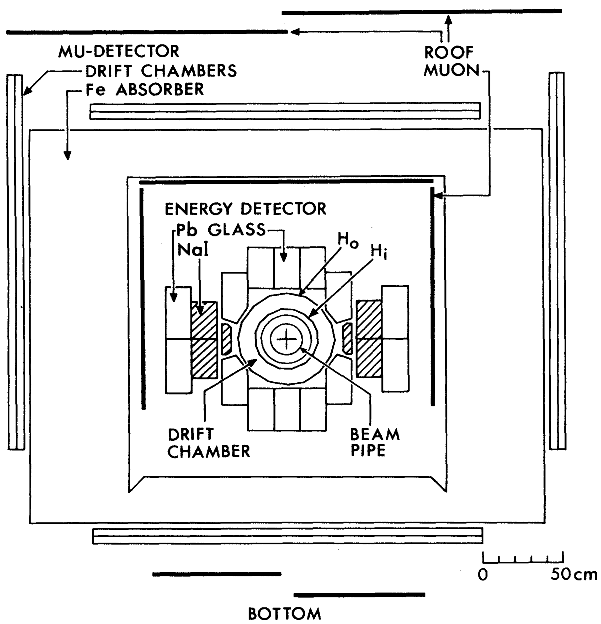

FIG. 1. The LENA detector seen along the beam direction.

berg collaboration and has been described elsewhere.[4] Briefly, the inner detector consists of three double layers of cylindrical drift chambers and two cylindrical hodoscopes (H_i, H_0) each with 32 elements. The outer-hodoscope counters H_0 are used as time-of-flight (TOF) counters. Surrounding the inner detector is the energy detector consisting of 178 blocks of lead-glass and NaI. The inner detector covers a solid angle of 86% of 4π sr and the energy detector provides more than 10 radiation lengths of absorber over 70% of 4π sr. Surrounding the energy detector are additional TOF counters, steel absorber, and muon drift chambers. The TOF counters are labeled "muon," "roof," and "bottom" in the drawing and are at minimum distances of 1.0, 1.9, and 1.5 m, respectively, from the intersection region. The steel absorber is 60 cm thick on the sides and 30 cm thick on the top and bottom.

The experiment was triggered by a coincidence between tracks in the inner detector and pulse height in the energy detector. Multiple coincidences were defined between elements of H_i and H_0 corresponding to tracks leaving the beam pipe radially. For three tracks or more, the energy threshold was roughly 250 MeV. For two (one) tracks, the threshold was 300 (800) MeV. For the purpose of finding μ pairs, an additional muon trigger was provided which formed a coincidence between elements of H_0 and the muon hodoscope and required exactly two tracks. For the muon trigger the energy threshold was 200 MeV, which corresponds to one minimum-ionizing track in the energy detector.

The luminosity was measured in two independent ways. A luminosity monitor measured small-angle Bhabha (SAB) events at a scattering angle of 130 mrad. Large-angle Bhabha (LAB) events ($|\cos\theta| < 0.8$) were identified in the drift chambers and energy detector. The ratio of the measurements is $L(\text{SAB})/L(\text{LAB}) = 1.03 \pm 0.01$ before radiative corrections (statistical error only).

For the measurement of the hadronic cross section the following conditions were required: (i) The event was within ±12 ns of the bunch crossing; (ii) $\geqslant 3$ tracks were in the inner detector; (iii) $\geqslant 1.8$ GeV was in the energy detector; and (iv) not all the energy was deposited in one-half of the detector.

These computer-selected events were all visually scanned by physicists to remove any remaining beam-gas, Bhabha-scattering, or cosmic-ray events. The final data consist of 7713 hadronic events accumulated in an energy scan over the Υ resonance. The integrated luminosity was 1158 nb^{-1}, half of which was accumulated at the peak of the resonance. The visible cross section in the continuum was corrected for acceptance and efficiency by normalizing to $R = \sigma_h/\sigma_{\mu\mu} = 3.7 \pm 0.4$.[5] Here σ_h and $\sigma_{\mu\mu}$ are the hadronic and μ-pair cross sections in the continuum. The correction corresponded to an efficiency of $\epsilon_h = 65\%$ in the continuum. This efficiency is in agreement with a two-quark Monte Carlo prediction of $(70 \pm 10)\%$. Since the Υ is expected to decay primarily via three gluons, while the continuum events are primarily two-quark jets, a different efficiency ϵ_R was applied to the resonance. A Monte Carlo calculation gives $\epsilon_R/\epsilon_h = 1.17$. This ratio is insensitive to the energy calibration of the detector for hadrons. After making an estimate for hadronic decays of τ pairs (20%), their contribution was subtracted from the observed hadronic cross section. The resulting hadronic cross section is shown in Fig. 2, where the errors shown are statistical only. A systematic error arising from the 10% error in R can affect only the normalization. We have fitted the hadronic cross section to a continuum plus a convolution of a radiatively corrected Breit-Wigner cross section and a Gaussian machine-energy distribution with variable width[6] and find $\tilde{\Gamma}_{ee} \equiv \Gamma_{ee}\Gamma_h/\Gamma_{\text{tot}} = 1.10 \pm 0.07 \pm 0.11$ keV and $M_\Upsilon = 9461.6 \pm 0.6 \pm 10$ MeV.[7]

For $B_{\mu\mu}$ we used the data taken with the muon

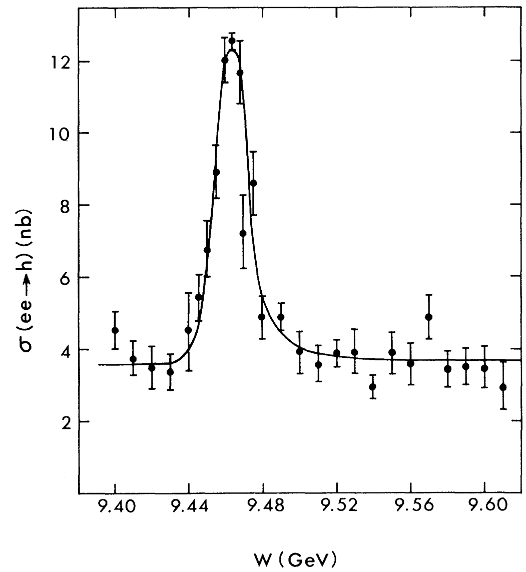

FIG. 2. The hadronic cross section $\sigma_h(e^+e^- \to h)$. The full line shown is the result of the fit described in the text.

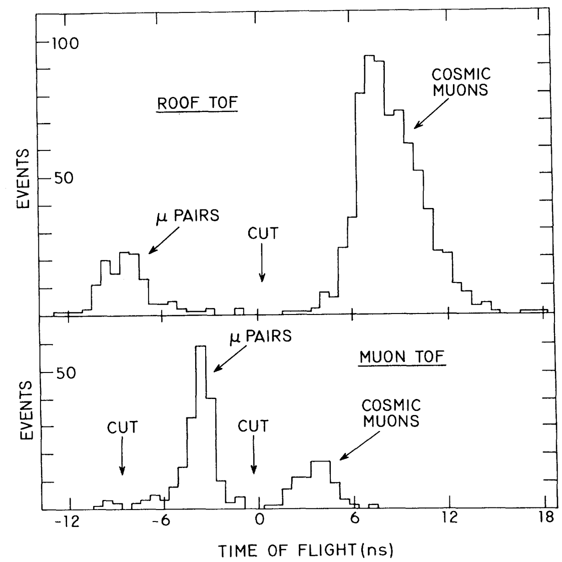

FIG. 3. Time-of-flight distributions for the "roof" and "muon" sidewall counters.

trigger. To separate muon events from hadron events, we made the following cuts: (i) two collinear tracks in the inner detector, and (ii) detected energy $\leqslant 1200$ MeV. The drift chambers independently determined $\cot\theta$ (where θ is the polar angle of a track with respect to the positron-beam direction) and the azimuthal angle φ. From cosmic-ray muons, we found our rms resolutions to be $\delta\varphi = 0.015$ and $\delta\cot\theta = 0.070$. We defined for each event a normalized acollinearity $\delta^2 = (\Delta\varphi/0.015)^2 + (\Delta\cot\theta/0.070)^2$ where $\Delta\varphi$ and $\Delta\cot\theta$ were the measured acollinearities of the two tracks. Two tracks were classified as collinear if $\delta^2 \leqslant 25$.

Most cosmic-ray muons were removed by requiring the event to occur within ±5 ns of the bunch crossing and within a cylindrical region ±60 mm long and having a radius of 6 mm. The final selection was made with use of the TOF counters. For each event the TOF for the track above the horizon was measured between the counters farthest from and nearest to the intersection region. Figure 3 shows the resulting TOF distributions obtained for the roof and muon counters. The signals resulting from cosmic-ray muons and muon pairs from e^+e^- annihilation are clearly separated. Cuts were made at the positions indicated. The residual background consists of at most a few events and resulted from drifts in the TOF timings. This was verified independently by running without beam in DORIS and by shifting the bunch-crossing cut by ±10 ns away from the true crossing time.

We expect a small amount of hadron background in our muon sample. An estimate was obtained with use of four-prong hadron events which have tracks pointing to the muon chambers. For these events, we measured the average hadron punch-through plus accidentals to be $(6.8 \pm 0.8)\%$ per track. A direct measure of the residual hadron background was obtained with use of a subsample of muon events which have both tracks pointing at the muon drift chambers. Within this sample we found that $(14 \pm 2)\%$ of the events have at least one track which does not record a hit in a chamber. Since the muon chamber efficiency, as determined from cosmic-ray muons, is nearly 100%, these must be background events. Tightening the δ^2 cut to 12 reduces this hadron background to 8%. Therefore, to purify the sample, we rejected any event having a track which points at a muon chamber but does not record a hit. For those events in which neither track points at a muon chamber, we cut at $\delta^2 = 12$. Our final sample consists of 451 events with 359 events having at least one track recorded in a muon chamber. The residual hadron background of $(0.08) \times 92/451 = 1.6\%$ is energy independent. Outside the resonance region[8] the μ-pair cross section is given by $\sigma_{\rm QED}(e^+e^- \to \mu^+\mu^-) = (86.8 \text{ nb GeV}^2)/W^2$. Here we observe 102 μ-pair events for an integrated luminosity of 330 nb^{-1}. From these

TABLE I. Compilation of the Γ_{ee} and $B_{\mu\mu}$ results of $\Upsilon(9.46)$.

	Result	Group	Ref.
Γ_{ee} (keV)	1.33 ± 0.14 [a]	PLUTO	b
	1.5 ± 0.4	DASP-II	c
	1.04 ± 0.28 [a]	NaI–Pb-glass	d
	1.35 ± 0.11 (± 0.22)	DASP-II	e
	1.23 ± 0.10 (± 0.14)	LENA	f
$B_{\mu\mu}$ (%)	2.2 ± 2.0	PLUTO	b
	5.1 ± 3.0	PLUTO	g
	2.5 ± 2.1	DASP-II	c
	$1.0^{+3.4}_{-1.0}$	NaI–Pb-glass	h
	3.1 ± 1.6	DASP-II	e
	$3.5 \pm 1.4 \pm 0.4$	LENA	f

[a] Value given is $\Gamma_{ee}\Gamma_h/\Gamma_{tot}$.
[b] Ch. Berger *et al.*, Z. Phys. C 1, 343 (1979).
[c] C. W. Darden *et al.*, Phys. Lett. 80B, 419 (1979).
[d] J. K. Bienlein *et al.*, Phys. Lett. 78B, 360 (1978).
[e] H. Albrecht *et al.*, DESY Report No. 80/30 (unpublished).
[f] This experiment.
[g] Ch. Berger *et al.*, DESY Report No. 80/15 (unpublished).
[h] G. Flügge, in *Proceedings of the Nineteenth International Conference on High Energy Physics, Tokyo, 1978*, edited by S. Homma, M. Kawaguchi, and H. Miyazawa (Physical Society of Japan, Tokyo, 1979), p. 802.

we obtain the muon efficiency $\epsilon_\mu = 0.32 \pm 0.03$. Note that in addition to geometric acceptance ϵ_μ includes trigger inefficiencies and systematic errors in luminosity measurements which are not calculable by Monte Carlo methods. We obtain $\tilde{B}_{\mu\mu} = \Gamma_{ee}/\Gamma_h$ by fitting the measured μ-pair cross section in the resonance region to the form $\sigma(e^+e^- \to \mu^+\mu^-) = \epsilon_\mu[\sigma_{QED} + \tilde{B}_{\mu\mu}\sigma_h(T)]$, where $\sigma_h(T)$ is taken from our fit to the hadronic cross section with the continuum subtracted. We find $\tilde{B}_{\mu\mu} = (3.9 \pm 1.7 \pm 0.5)\%$. When e-μ-τ universality is assumed, $\Gamma_{tot} = \Gamma_h + 3\Gamma_{ee}$. Then $B_{\mu\mu} = \tilde{B}_{\mu\mu}/(1+3\tilde{B}_{\mu\mu})$ and we find $B_{\mu\mu} = (3.5 \pm 1.4 \pm 0.4)\%$. The radiative corrections are small compared to our statistical errors and have been neglected.

Again using lepton universality, we obtain

$$\Gamma_{ee} = \tilde{\Gamma}_{ee}/(1 - 3B_{\mu\mu}) = 1.23 \pm 0.10\ (\pm 0.14)\ \text{keV}$$

and

$$\Gamma_{tot} = \Gamma_{ee}/B_{\mu\mu} = 35^{+25}_{-10}\ (^{+9}_{-7})\ \text{keV},$$

where the first set of errors gives the statistical uncertainty and the numbers in parentheses represent systematic errors arising from the uncertainty in the total hadronic cross section. Our results are listed in Table I together with other known measurements.

We use our Υ results to extract (to lowest order of quantum chromodynamics[9]) the strong-coupling constant, α_s, and find $\alpha_s = 0.16^{+0.04}_{-0.02}$ (± 0.01). The corresponding value of the J/Ψ mass is $\alpha_s = 0.19 \pm 0.01$.[10]

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(a) Present address: Max-Planck-Institute, Munich, Germany.
(b) Present address: Physics Department, Carnegie-Mellon University, Pittsburgh, Pa. 15213.
(c) Present address: Deutsches Electronen-Synchrotron, D-2000 Hamburg 52, Germany.
(d) Present address: Messerschmidt Bölkow Blohm, Munich, Germany.

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[6] J. D. Jackson and D. L. Scharre, Nucl. Instrum. Methods 128, 13 (1975).
[7] For all results quoted in this Letter, the first error is statistical and the second (enclosed in parentheses) is systematic.
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[10] C. Bricman *et al.* (Particle Data Group), Phys. Lett. 75B, 1 (1978).