Z. Phys. C – Particles and Fields 28, 45–50 (1985)

Zeitschrift für Physik C Particles and Fields

A Determination of the Muon Pair Branching Ratio of the Υ' Meson

ARGUS Collaboration

H. Albrecht, U. Binder, G. Harder, H. Hasemann, A. Philipp, W. Schmidt-Parzefall, H. Schröder, H.D. Schulz, R. Wurth

DESY, D-2000 Hamburg, Federal Republic of Germany

A. Drescher, B. Gräwe, U. Matthiesen, H. Scheck, J. Spengler, D. Wegener

Institut für Physik, Universität, D-4600 Dortmund [1], Federal Republic of Germany

R. Heller [2], K.R. Schubert, J. Stiewe, R. Waldi, S. Weseler

Institut für Hochenergiephysik, Universität, D-6900 Heidelberg [1], Federal Republic of Germany

N.N. Brown [3], K.W. Edwards [4], W.R. Frisken [5], Ch. Fukunaga [5], D.J. Gilkinson [6], D.M. Gingrich [6], M. Goddard [5], P.C.H. Kim [6], R. Kutschke [6], D.B. MacFarlane [6], J.A. McKenna [6], K.W. McLean [3], A.W. Nilsson [3], R.S. Orr [6], P. Padley [6], P.M. Patel [3], J.D. Prentice [6], H.C.J. Seywerd [6], B.J. Stacey [6], T.-S. Yoon [6], J.C. Yun [4]

Institute of Particle Physics [7], Canada

R. Ammar, D. Coppage, R. Davis, S. Kanekal, N. Kwak

University of Kansas [8], Lawrence, KS 66044, USA

P. Böckmann [9], L. Jönsson, Y. Oku

Institute of Physica, University, S-22362 Lund [10], Sweden

M. Danilov, V. Lubimov, V. Matveev, V. Nagovitsin, V. Ryltsov, A. Semenov, Yu. Semenov, V. Shevchenko, V. Soloshenko, V. Sopov, I. Tichomirov, Yu. Zaitsev

Institute of Theoretical and Experimental Physics, SU-117259 Moscow, USSR

R. Childers, C.W. Darden, H. Gennow [11]

University of South Carolina [12], Columbia, SC 29208, USA

Received 1 March 1985

1 Supported by the Bundesministerium für Forschung und Technologie, FRG
2 Now at DESY
3 McGill University, Montreal
4 Carleton University, Ottawa
5 York University, Downsview
6 University of Toronto, Toronto
7 Supported by the Natural Sciences and Engineering Research Council, Canada
8 Supported by the U.S. National Science Foundation and a University of Kansas Faculty Improvement award
9 Now at CERN
10 Supported by the Swedish Research Council
11 On leave of absence from the University of Stockholm, Sweden
12 Supported by the U.S. Department of Energy, under contract DE-AS09-80ER10690

Abstract. Using the ARGUS detector at the e^+e^- storage ring DORIS-II, we have observed the decays of $\Upsilon(9{,}460)$ and $\Upsilon'(10{,}023)$ into muon pairs. The ratio of the two observed rates determines $B_{\mu\mu}(\Upsilon')$ largely independent of acceptance uncertainties and absolute luminosity calibration, if $B_{\mu\mu}(\Upsilon)$ is known. From data with an integrated luminosity of 6.11/pb on the Υ and 9.93/pb on the Υ', using the present world average $B_{\mu\mu}(\Upsilon)=(2.9\pm0.2)\%$, we obtain $B_{\mu\mu}(\Upsilon')=(1.57\pm0.59\pm0.68)\%$.

In this paper we present a determination of the muon pair branching ratio $B_{\mu\mu}(\Upsilon')$ of the $\Upsilon'(10{,}023)$ meson using the ARGUS detector at the e^+e^- storage ring DORIS-II. A schematic view of the detector is shown in Fig. 1.

ARGUS is a solenoidal magnetic spectrometer with a drift chamber 2 m long and 0.9 m in radius located in a magnetic field of 0.8 Tesla. The drift chamber is surrounded by time-of-flight and shower counters located within the magnet coil. Outside the coil are muon chambers [1] consisting of 1,744 proportional tube counters arranged in three layers. One layer is inside the magnet yoke with 3.3 absorption lengths of material between it and the interaction point. The other two layers are outside the yoke which contributes additional 1.8 absorption lengths. Further details of the detector, including trigger conditions, are described in [2].

The number of muon pairs N' of the Υ' is given by

$$N'=L'\eta'(\sigma'_c+\tilde{B}'\sigma') \quad (1)$$

where L' is the integrated luminosity, η' is the acceptance, σ'_c is the continuum muon pair production cross section at the Υ' energy, $\tilde{B}'=B_{\mu\mu}(\Upsilon')/(1-3B_{\mu\mu}(\Upsilon'))$, and σ' is the cross section for formation and subsequent hadronic decay of the Υ'.

The direct evaluation of $\tilde{B}'$ from (1) is not reliable since $\tilde{B}'\sigma'\ll\sigma'_c$ and since it is not possible to determine η' with sufficient precision. The usual method is to relate N' to the muon pair rate in the continuum near the resonance and to assume that

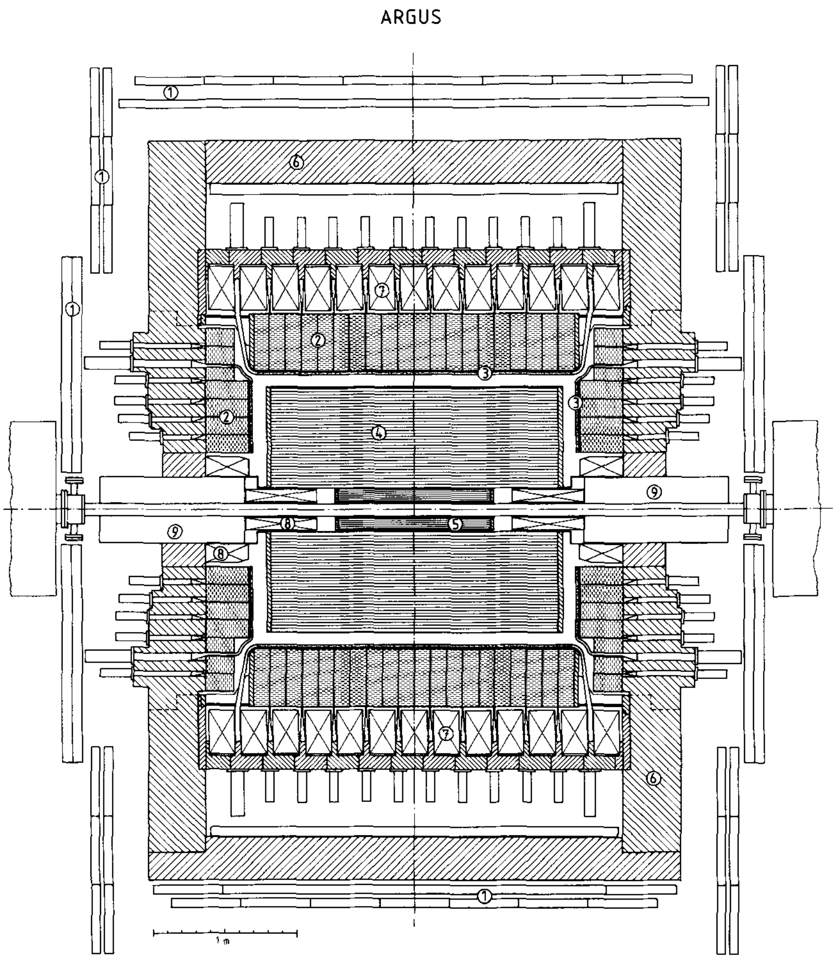

Fig. 1. Schematic view of the ARGUS detector. 1–muon chambers, 2–shower counters, 3–time-of-flight counters, 4–drift chamber, 5–vertex chamber, 6–iron yoke, 7–solenoid coils, 8–compensation coils, 9–mini-beta quadrupole

the acceptance in the continuum is the same as on the resonance. This method was used for example in obtaining the DASP-II result [3] for $B_{\mu\mu}(\Upsilon)$. At present, ARGUS has not accumulated enough continuum data to use this approach. However there are sufficient data on the Υ resonance for which we have the analogous relation to (1), namely

$$N=L\eta(\sigma_c+\tilde{B}\sigma). \tag{2}$$

A measurement of the ratio N'/N allows a reliable determination of $\tilde{B}'$ if $\tilde{B}$ is known, namely

$$\tilde{B}'=\frac{1}{\sigma'}\left[\frac{N'L\eta}{NL'\eta'}(\sigma_c+\tilde{B}\sigma)-\sigma'_c\right]. \tag{3}$$

Muon pair events are selected by requiring two charged particles of opposite charge originating in the interaction region. Additional tracks in the event are only allowed if they do not come from the interaction region. The total energy deposited in the shower counters must be less than 3.5 GeV. One track must fulfil the muon requirement that there are at least one hit in the outer layer of muon chambers and hits in all traversed chambers. If the second track traverses two layers without associated hits, the event is rejected. Each track momentum p must be between 3.5 and 6.5 GeV/c. Time-of-flight information for both tracks must be good and the time difference $|\delta t|$ must be less than 3.5 ns for a clean separation between muon pairs and cosmic rays. Both tracks must be in the barrel region with $|\cos\theta|\leq 0.75$ and, in addition, their acollinearity angle must be less than 11°. At least one track must have a shower counter energy deposit $E_{sh}<0.6$ GeV. The geometrical acceptance for detecting muon pairs using the above cuts is 97% of the $|\cos\theta|\leq 0.75$ range. The efficiency for muon identification, estimated by comparing numbers of events with one and two reconstructed muons, is found to be (98 ±1)% for the entire data sample.

Figure 2a shows the momentum spectra for all two prong Υ' events and for those events satisfying the cuts described above. Figure 2b shows the time-of-flight distribution for events satisfying all cuts except that on δt.

The integrated luminosity has been determined with the help of reconstructed barrel Bhabha events following the procedure described in [4]. The cross section for this Bhabha selection is 11.8 nb±3% at 10 GeV, and the reconstruction efficiency is 0.96 ±0.01. Runs with exceptionally low or high multihadron cross sections are rejected. The total number of selected muon pair events for retained Υ' runs is $N'=4{,}248$, and the corresponding luminosity is $L'=9.93$/pb. On the Υ we obtain $N=3{,}534$ and $L=6.11$/pb. The ratio L'/L is independent of the 3% systematic error mentioned above; the systematic error in the ratio is estimated to be 1.5%.

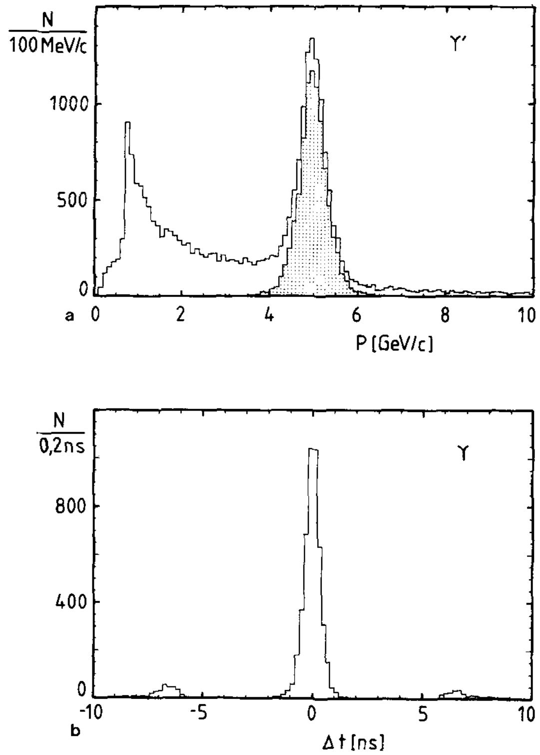

Fig. 2. a Momentum spectrum of decay particles for all Υ' events with two tracks from the interaction region. The shadowed histogram gives the spectrum after all cuts mentioned in the text. **b** δt distribution from the time-of-flight counters for Υ' events fulfilling all cuts except $|\delta t|<3.5$ ns

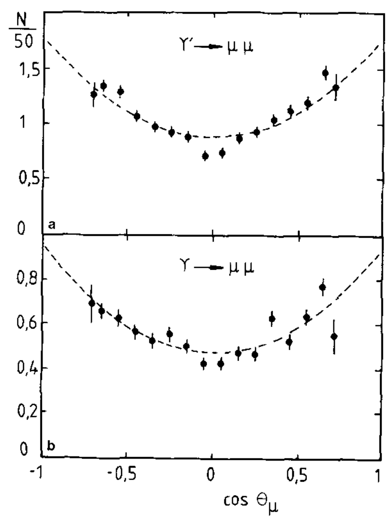

Fig. 3. a Uncorrected $\cos\theta$ distribution of all selected muon pair events on the Υ'. **b** The corresponding distribution for the Υ energy as in **a**

Figure 3 shows the $\cos\theta$ distribution for selected muon pair events from both resonances. The ob-

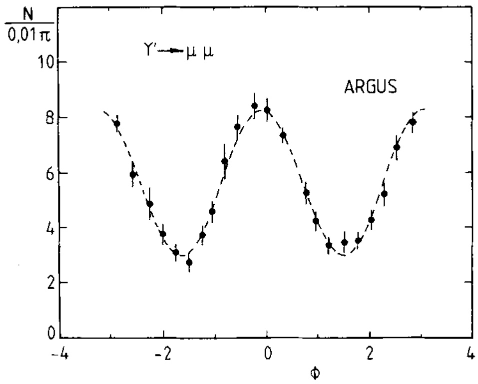

Fig. 4. Azimuthal angular distribution of all selected muon pair events on the Υ'. The corresponding distribution for the Υ is flat

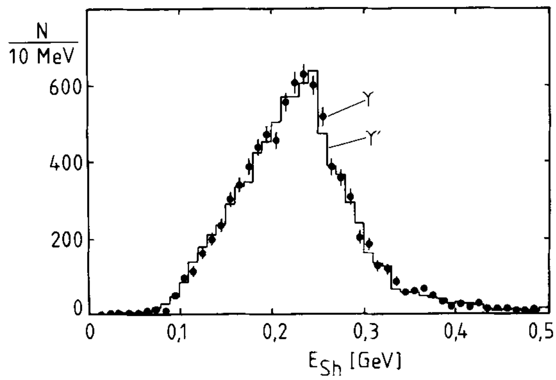

Fig. 5. Distribution of deposited shower counter energy for all selected muon pair events on the Υ' (histogram) compared with that on the Υ (points) normalized between 0.2 and 0.35 GeV

served deviation from a $1+\cos^2\theta$ distribution near $\cos\theta=0$ is due to the detector structure. On the Υ, using published values for $B_{\mu\mu}$, we can estimate the overall acceptance η within the selected $\cos\theta$ range by using (2). It is found to be about 70%, however only the acceptance ratio η'/η is critical for this analysis. η and η' include 1) geometry, 2) muon angular distributions, 3) logical trigger efficiency and 4) analogue trigger efficiency. Point 2 is nontrivial since the DORIS-II beams on the Υ are unpolarized whereas on the Υ' they are strongly polarized. This can be seen in the azimuthal angular distribution shown in Fig. 4. The separation into points 3 and 4 is necessary since the muon pair trigger contains logical elements derived from the time-of-flight scintillator signals and analogue elements derived from the shower counter pulse heights. The trigger performance was studied for Υ and Υ' run periods separately. The logical efficiencies η_3 and η'_3 were determined absolutely by comparing selected collinear Bhabha events with $|\cos\theta|<0.75$ under two trigger conditions: a) requiring only a large energy deposit in both detector hemispheres and b) requiring in addition two track candidates exactly as in the muon pair trigger. From the quotients N_b/N_a in each run period we obtain average efficiencies of $\eta_3=0.884$ and $\eta'_3=0.879$.

Absolute values for the analogue efficiencies η_4 and η'_4 cannot be obtained in this way. The method used here is to look for a difference between the Υ and Υ' run periods. Figure 5 shows the distributions of the shower counter energy deposit dN/dE_{sh} for the Υ' (histogram) compared with the corresponding distribution of the Υ (circles). The Υ distribution is normalized to the Υ' distribution between 0.2 and 0.35 GeV. There are no visible differences in the energy deposit region less than 0.15 GeV, where the analogue thresholds for the muon pair trigger are located. We therefore estimate $\eta'_4/\eta_4=1.00\pm0.01$.

The resonance formation cross sections are determined experimentally. Combining ARGUS and DASP-II [3] measurements, world averages on $\Gamma_{ee}(\Upsilon')/\Gamma_{ee}(\Upsilon)$ and the known variation of the storage ring energy resolution with energy, we estimate $\sigma=(9.1\pm0.5)$ nb and $\sigma'=(3.4\pm0.3)$ nb. Fixing $B_{\mu\mu}(\Upsilon)$ to 2.9% (5), we obtain

$$B_{\mu\mu}(\Upsilon', \text{uncorrected})=(1.98\pm0.59\pm0.53)\%, \qquad (4)$$

where the first error is statistical from N'/N and the second error is systematic from η'_4/η_4, L'/L, σ' and σ.

The value in (4) must be corrected for contributions from the cascade decays $\Upsilon'\to\Upsilon+X$, $\Upsilon\to\mu\mu$ where the cascade particles escape detection. These decay modes are $\Upsilon'\to\Upsilon\pi^+\pi^-$ with $(17.9\pm2.3)\%$ branching ratio [2], $\Upsilon'\to\Upsilon\pi^0\pi^0$ with $(9.4\pm1.7)\%$ combining results from [6] and [7], $\Upsilon'\to\Upsilon\eta$ with less than 0.2% [6] and $\Upsilon'\to\gamma^3P$, $^3P\to\gamma\Upsilon$ with $(3.6\pm0.9)\%$ [8]. The second and fourth modes are completely accepted by our cuts. For the first mode we estimate an accepted fraction of 0.07 ± 0.02. In total, $(14.3\pm2.0)\%$ of all Υ' decays are undetected cascades to the Υ. This value is multiplied by $B_{\mu\mu}(\Upsilon)$ to obtain the correction $\delta B_{\mu\mu}(\Upsilon')=-(0.41\pm0.06)\%$. Our final result is

$$B_{\mu\mu}(\Upsilon')=(1.57\pm0.59\pm0.53)\%,$$

where $B_{\mu\mu}(\Upsilon)$ is fixed to 2.9%. Allowing for a variation of $B_{\mu\mu}(\Upsilon)$, we derive from (3):

$$B_{\mu\mu}(\Upsilon)=(1.57\pm0.59\pm0.53)\% + 2.1[B_{\mu\mu}(\Upsilon)-2.9\%]. \qquad (5)$$

The present world average for $B_{\mu\mu}(\Upsilon)$, assuming $e-\mu-\tau$ universality, is $(2.9\pm0.2)\%$ [5]. Adding the $B_{\mu\mu}(\Upsilon)$ error quadratically to the systematic error of our final result in (5), we obtain

$$B_{\mu\mu}(\Upsilon')=(1.57\pm0.59\pm0.68)\%. \qquad (6)$$

Table 1. Experimental results on $B_{\mu\mu}(\Upsilon')$

Experiment	$B_{\mu\mu}(\Upsilon')$ in %	Ref.
CUSB	$1.9 \pm 0.3 \pm 0.5$	[9]
CLEO	$1.8 \pm 0.8 \pm 0.5$	[10]
ARGUS	$1.57 \pm 0.59 \pm 0.68$	this paper
Average	1.80 ± 0.44	

In Table 1, we compare this result to the values obtained by CUSB [9] and CLEO [10]. The three experiments are in good agreement. We may therefore combine the results and obtain an average of

$$B_{\mu\mu}(\Upsilon') = (1.80 \pm 0.44)\%, \tag{7}$$

where the combined statistical and the combined systematic error are added quadratically.

Together with the world average [5] on the Υ' leptonic width

$$\Gamma_{ee}(\Upsilon') = (0.54 \pm 0.03)\ \text{keV}$$

we derive the following Υ' total width from the average in (7):

$$\Gamma_{\text{tot}}(\Upsilon') = (30.0 \pm 7.5)\ \text{keV}. \tag{8}$$

We would like to note that this value for $\Gamma_{\text{tot}}(\Upsilon')$ is derived from experimental observations only and is not based on theoretical assumptions for Υ' decays. The assumption

$$\Gamma_{ee}(\Upsilon')/\Gamma_{ggg}(\Upsilon') = \Gamma_{ee}(\Upsilon)/\Gamma_{ggg}(\Upsilon) \tag{9}$$

has been used [11, 12] earlier to estimate $\Gamma_{\text{tot}}(\Upsilon')$. Here, Γ_{ggg} are the partial widths of Υ and Υ' for their decays into three gluons. The ratios in (9) could differ due to different contributions of nonperturbative processes in these decays [13].

With the new result for $B_{\mu\mu}(\Upsilon')$ we are able to check how well assumption (9) is fulfilled. For the Υ ground state we have:

$$\Gamma_{\text{tot}} = \Gamma_{ggg} + \Gamma_{\gamma gg} + (3+R)\Gamma_{ee}$$

where $R = \sigma_{\text{had}}(\text{off-resonance})/\sigma_{\mu\mu}$ takes into account hadronic decays through one virtual photon. With $\Gamma_{ee} = B_{\mu\mu}\Gamma_{\text{tot}}$ we obtain:

$$\frac{\Gamma_{ee}}{\Gamma_{ggg}}(\Upsilon) = \frac{1 + \Gamma_{\gamma gg}/\Gamma_{ggg}}{1/B_{\mu\mu} - (3+R)} = (3.7 \pm 0.3)\% \tag{10}$$

where the numerical result follows from the world average of $B_{\mu\mu}(\Upsilon)$ [5], the average of the two experimental results on $\Gamma_{\gamma gg}/\Gamma_{ggg}$ [14, 15], and $R = 3.6 \pm 0.1$.

For the Υ' decays we have

$$\Gamma_{\text{tot}} = \Gamma_{ggg} + \Gamma_{\gamma gg} + (3+\text{R})\Gamma_{ee} + \Gamma_{\text{tot}}(B_{gg\Upsilon} + B_{\gamma P})$$

where the decays into Υ plus two gluons and into P – states plus one photon contribute in addition to ggg and γgg decays. Their branching ratios

$$B_{gg\Upsilon} = BR(\Upsilon' \to \Upsilon\pi^+\pi^-) + BR(\Upsilon' \to \Upsilon\pi^0\pi^0) + BR(\Upsilon' \to \Upsilon\eta)$$

$$B_{\gamma P} = \sum_{j=0}^{2} BR(\Upsilon' \to 1^3P_j)$$

are known experimentally. We obtain

$$\frac{\Gamma_{ee}}{\Gamma_{ggg}}(\Upsilon') = \frac{1 + \Gamma_{\gamma gg}/\Gamma_{ggg}}{(1 - B_{gg\Upsilon} - B_{\gamma P})/B_{\mu\mu} - (3+R)} = (4.3 \pm 1.4)\%. \tag{11}$$

The numerical value is obtained by using all available experimental results on Υ' decays – the error is dominated by the error on $B_{\mu\mu}(\Upsilon')$. We observe that the results 10 and 11 are in good agreement, but relation 9 is only tested at the 30% level. If we use $\Gamma_{ee}/\Gamma_{ggg}(\Upsilon)$ from (10) in order to derive $\Gamma_{\text{tot}}(\Upsilon')$, we obtain

$$\Gamma_{\text{tot}}(\Upsilon') = (34.0 \pm 3.7)\ \text{keV}. \tag{12}$$

The error on the directly determined value for $\Gamma_{\text{tot}}(\Upsilon)$ in (8) is a factor two larger than the error on this indirect value.

To conclude, we have determined $B_{\mu\mu}(\Upsilon')$ by an acceptance-independent method comparing $\mu\mu$-events from the Υ and from the Υ'. The result is $B_{\mu\mu}(\Upsilon') = (1.57 \pm 0.59 \pm 0.68)\%$, where the systematic error includes the present error on $B_{\mu\mu}(\Upsilon)$. This result leads to world averages $B_{\mu\mu}(\Upsilon') = (1.80 \pm 0.44)\%$ *and* $\Gamma_{\text{tot}}(\Upsilon') = (30.0 \pm 7.5)$ keV. The quotient $\Gamma_{ee}(\Upsilon')/\Gamma_{ggg}(\Upsilon') = (4.3 \pm 1.4)\%$ is in good agreement with the corresponding ratio of the Υ meson, $\Gamma_{ee}(\Upsilon)/\Gamma_{ggg}(\Upsilon) = (3.7 \pm 0.3)\%$.

Acknowledgements. It is a pleasure to thank E. Michel, W. Reinsch, H. Heller, Mrs. E. Konrad and Mrs. U. Djuanda for their competent technical help in running the experiment and processing the data. We thank Drs. H. Nesemann, K. Wille and the DORIS group for the good operation of the storage ring. The visiting groups wish to thank the DESY directorate for the support and kind hospitality extended to them.

References

1. A. Arefiev et al.: DESY preprint 83-025 (1983)
2. H. Albrecht et al. (ARGUS): Phys. Lett. **134B**, 137 (1984)
3. H. Albrecht et al. (DASP-II): Phys. Lett. **116B**, 383 (1982)
4. G. Braunshausen: Diplomarbeit, 1984, Universität Heidelberg (unpublished)

5. P. Tuts: Proceedings of the 1983 International Symposium on Lepton and Photon Interactions at High Energies, Cornell University, 1983, p. 284
6. V. Fonseca et al. (CUSB): Nucl. Phys. **B242**, 31 (1984)
7. R. Heller: Dissertation Universität Heidelberg, 1984 (unpublished)
8. F. Pauss et al. (CUSB): Phys. Lett. **130B**, 439 (1983)
9. J.E. Horstkotte et al.: CUSB-83-09 preprint
10. P. Haas et al. (CLEO): Phys. Rev. **D30**, 1996 (1984)
11. B. Niczyporuk et al. (LENA): Phys. Lett. **100B**, 95 (1981)
12. G. Mageras et al. (CUSB): Phys. Rev. Lett. **46**, 1115 (1981)
13. M.B. Voloshin: Yad. Fiz., **40**, 1039 (1984)
14. R.D. Schamberger et al. (CUSB): Phys. Lett. **138B**, 225 (1984)
15. P. Avery et al. (CLEO): paper C-277 submitted to the Cornell Conf., 1983