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TOTAL WIDTH AND LEPTONIC BRANCHING RATIO OF THE Υ(9.46)

LENA Collaboration

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Abstract:

Using the LENA detector at the DORIS e^+e^- storage ring we measured the hadronic cross section and the μ-pair decay of the Υ (9.46) resonance. From these we obtain the electronic width $\Gamma_{ee} = (1.23 \pm 0.10 \pm 0.14)$ keV and the mass $M = (9\,461.6 \pm 0.6 \pm 10.0)$ MeV, the μ-pair branching ratio $B_{\mu\mu} = (3.5 \pm 1.4 \pm 0.4)\%$ and the total width $\Gamma_{tot} = (35 \begin{smallmatrix} +25 \\ -10 \end{smallmatrix} \begin{smallmatrix} +9 \\ -7 \end{smallmatrix})$ keV.

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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 explain 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 two 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 DESY-Heidelberg 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_o) each with 32 elements. The outer hodoscope counters H_o 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 86% of 4π solid angle and the energy detector provides more than 10 radiation lengths of absorber over 70% of 4π. Surrounding the energy detector are additional ToF counters, steel absorber, and muon drift chambers. The ToF counters are labelled "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. Since the hodoscopes are highly segmented and the detector is nonmagnetic, multiple coincidences were defined between elements of H_i and H_o corresponding to tracks leaving the beam pipe radially. Depending on the number of tracks different energy thresholds were applied to the total energy seen in the energy detector. For ≥ 3 tracks the threshold was roughly 250 MeV. For 2 (1) 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_o and the Muon hodoscope and required exactly 2 tracks. For the muon trigger the energy threshold was 200 MeV, corresponding to one minimum ionizing track in the energy detector.

The luminosity was measured in two independent ways. A small angle luminosity (SAB) monitor measured Bhabha 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 two measurements is $L(SAB)/L(LAB) = (1.03 \pm 0.01)$ before radiative corrections (statistical error only).

For the measurement of the hadronic cross section the following conditions were required:

the event was within ± 12 ns of the bunch crossing
≥ 3 tracks were in the inner detector
≥ 1.8 GeV was in the energy detector
not all the energy was deposited in one half of the detector.

These computer selected events were all hand 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 inefficiency by normalizing to $R = \sigma_h / \sigma_{\mu\mu} = (3.7 \pm 0.4)$ measured by the PLUTO collaboration at a center of mass energy of ~ 9.4 GeV [5]. Here σ_h and $\sigma_{\mu\mu}$ are the hadronic and μ-pair cross sections in the continuum. The corrections corresponded to an efficiency of $\varepsilon_h = 65\%$ in the continuum. Since the Υ is expected to decay primarily via 3 gluons, while the annihilation events are primarily 2 quark jets, a different efficiency ε_R was applied to the resonance. The ratio $\varepsilon_R/\varepsilon_h$ was calculated by a Monte Carlo calculation to be 1.17. Therefore, $\varepsilon_R = 1.17 \cdot \varepsilon_h = .76$. The resulting hadronic cross section is shown in Fig.2, where the errors are statistical only. Our systematic error comes from the 10% error in R and would tend to change the normalization.

The production cross section of the Υ resonance by e^+e^- and its subsequent hadronic decay is described by a Breit-Wigner formula. As the total width of the resonance is much smaller than the machine energy resolution the Breit-Wigner cross section is smeared out. The quantity

$$\overline{\Gamma}_{ee} := \frac{\Gamma_{ee}\,\Gamma_h}{\Gamma_{tot}} = \frac{M^2}{6\pi^2} \int \sigma_h(\Upsilon)\, dW$$

is independent of the machine energy resolution. Here M refers to the mass of the Υ and W to the center of mass energy. We fitted the total cross section to a continuum plus a convolution of a radiatively corrected Breit-Wigner cross section and a gaussian machine energy distribution [6]. We obtained[+]

$$\overline{\Gamma}_{ee} = (1.10 \pm .07 \pm .11)\ \text{keV}$$

$$\text{and} \qquad M = (9\,461.6 \pm .6 \pm 10)\ \text{MeV}.$$

To obtain Γ_{ee} from $\overline{\Gamma}_{ee}$, the leptonic widths must be subtracted from Γ_{tot}. Under the assumption of e, μ, τ universality

$$\Gamma_{tot} = \Gamma_h + \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau} = \Gamma_h + 3\Gamma_{ee}$$

$$\text{and} \qquad \Gamma_{ee} = \overline{\Gamma}_{ee} / (1 - 3B_{\mu\mu})$$

$$\text{where} \qquad B_{\mu\mu} = \Gamma_{\mu\mu} / \Gamma_{tot} = \Gamma_{ee} / \Gamma_{tot}.$$

We measured $B_{\mu\mu}$ using the data taken with the muon trigger. To separate muons from hadron events we made the following cuts:

2 collinear tracks in the inner detector,
detected energy $\leq$ 1200 MeV.

The drift chambers measured independently $\cot\theta$ (where θ is the polar angle of the track with respect to the positron beam direction) and the azimuthal angle ϕ. We found from cosmic ray muons that our rms resolutions were

$$\delta\phi = .015$$
$$\delta \cot\theta = .070.$$

We defined for each event a normalized acollinearity

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

$$\delta^2 = (\Delta\phi/0.015)^2 + (\Delta \cot\theta/0.070)^2$$

where $\Delta\phi$ and $\Delta \cot\theta$ were the measured acollinearities of the two tracks. Two tracks were classified as collinear if $\delta^2 \leq 25$.

Most cosmic ray muons were removed by requiring the event to have been in time with the bunch crossing to ± 5 ns and to have crossed the intersection region within 6 mm transverse to the beam axis and 60 mm parallel to the beam axis. The final selection was made using 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. Fig.3 shows the resulting ToF distributions obtained for the Roof and Muon counters. The two peaks 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 of this background has been obtained using four-prong hadron events which have tracks pointing to the muon drift chambers. For these events we measured the average hadron punch through plus accidentals to be (6.8 ± 0.8)% per track. A direct measure of the residual hadron background was made using a subsample of events which had both tracks pointing at the muon drift chambers. Within this sample we found (13.6 ± 2.0)% of the events had at least one track which did not record a hit in the chamber. Since the muon drift chamber efficiency, as determined from cosmic ray muons, is nearly 100%, these must have been hadron background events. Tightening the cut on δ^2 to 12 reduced this to 8%. Therefore to purify the sample, we rejected any event which pointed at the muon chambers and did not record a hit. For those events which did not point at a muon chamber we cut at $\delta^2 = 12$. Our final sample consists of 451 events with 359 (92) hitting (not hitting) the muon chambers. The residual hadron background is (.08) x 92/451 = 1.6% and is not correlated with the resonance.

Outside the resonance region (see Fig.2) the μ-pair cross section is given by QED

$$\sigma_{QED}\ (e^+e^- \rightarrow \mu^+\mu^-) = 86.8 \text{ nb GeV}^2/W^2.$$

In this region we observed 102 μ-pair events and had an integrated luminosity of 330 nb^{-1}. The average visible cross section is therefore (.31 ± .03) nb. Dividing this by σ_{QED} measures our efficiency to be $\varepsilon_\mu = (.32 \pm .03)$. Note that in addition to geometric acceptance this accounts for trigger inefficiencies and systematic errors in luminosity measurements which are not calculable by Monte Carlo methods. We obtained $\bar{B}_{\mu\mu} = \Gamma_{ee}/\Gamma_h$ by fitting the measured μ-pair cross section in the resonance region to the form

$$\sigma\ (e^+e^- \rightarrow \mu^+\mu^-) = \varepsilon_\mu\ [\ \sigma_{QED} + \bar{B}_{\mu\mu}\ \sigma_h(\Upsilon)\ ]$$

where $\sigma_h(\Upsilon)$ was taken from our fit to the hadronic cross section with the continuum subtracted. We find

$$\bar{B}_{\mu\mu} = (3.9 \pm 1.7 \pm 0.5)\%$$

$$\text{and} \qquad B_{\mu\mu} = \bar{B}_{\mu\mu}\ /\ (1 + 3\bar{B}_{\mu\mu}) = (3.5 \pm 1.4 \pm 0.4)\%.$$

Additional data taken in the Υ' energy region will further reduce this error. At this stage we have also not included radiative corrections as these are estimated to be smaller than our present statistical error.

Finally we obtain

$$\Gamma_{ee} = (1.23 \pm 0.10 \pm 0.14) \text{ keV}$$

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

The total width can be divided into a sum of five partial widths,

$$\Gamma_{tot} = \Gamma_{3g}\ (\ \Upsilon \rightarrow 3 \text{ gluons} \rightarrow h\ ) + \Gamma_\gamma\ (\ \Upsilon \rightarrow \gamma \rightarrow h\ ) + \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau}.$$

Because of $\Gamma_\gamma = R \cdot \Gamma_{ee} = 3.7 \cdot \Gamma_{ee}$ and lepton universality, the last four terms sum up to $6.7 \cdot \Gamma_{ee}$. From the Γ_{tot} equation it follows that

$$\Gamma_{3g}/\Gamma_{ee} = (\Gamma_{tot}/\Gamma_{ee}) - 6.7 = B_{\mu\mu}^{\ -1} - 6.7 = (22\ {}^{+\,19}_{-\,8}\ {}^{+\,4}_{-\,3})$$

The ratio Γ_{3g}/Γ_{ee} has been calculated in lowest order QCD and QED perturbation theory. For non-relativistic quark models the result turns out to be model independent [7]. The result is

$$\Gamma_{3g}/\Gamma_{ee} = \frac{10}{9}\ \frac{\pi^2 - 9}{\pi}\ \frac{\alpha_s^{\ 3}}{\alpha^2}$$

where α_s is the strong coupling constant and $\alpha = 1/137$. Solving for α_s we obtain $\alpha_s = (0.16\ {}^{+\,0.04}_{-\,0.02} \pm 0.01)$ from our Γ_{3g}/Γ_{ee} value. Relativistic corrections and higher order contributions $\propto \alpha_s^{\ 4}$ may be considerable [8]. This is to be compared with $\alpha_s = .19$ obtained from the 3-gluon decay of J/ψ [9].

Our results agree with earlier measurements of Γ_{ee} as well as $B_{\mu\mu}$. A compilation of all the known measurements is given in Table 1. As one can see only the measurements done in fall 1979 give a μ-pair branching ratio $B_{\mu\mu}$ which is significantly different from zero. This is due to much higher statistics and partly to better muon identification. Now one can derive meaningful values for the total width Γ_{tot} of the Υ (9.46) resonance.

Acknowledgements

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Table 1: Compilation of known results on the Υ (9.46) resonance parameters

	year	result	group	reference
Γ_{ee} in keV	1978	1.33 ± 0.14	PLUTO	Z. Phys. C1 (1979) 343
		1.5 ± 0.4	DASP-II	Phys. Lett. 80B (1979) 419
		$1.04\pm0.28^{+}$	NaI-Pb-glass	Phys. Lett. 78B (1978) 360
	1979	$1.35\pm0.11\pm0.22$	DASP-II	DESY 80/30
		$1.23\pm0.10\pm0.14$	LENA	this publication
$B_{\mu\mu}$ in %	1978	2.2 ± 2.0	PLUTO	Z. Phys. C1 (1979) 343
		5.1 ± 3.0	"	DESY 80/15
		2.5 ± 2.1	DASP-II	Phys. Lett. 80B (1979) 419
		$1.0^{+3.4}_{-1.0}$	NaI-Pb-glass	quoted by Flügge, Tokyo conference 1978 and to be published
	1979	3.1 ± 1.6	DASP-II	DESY 80/30
		$3.5\pm1.4\pm0.4$	LENA	this publication

$^{+}$value given is $\Gamma_{ee}\cdot\Gamma_h/\Gamma_{tot}$

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Figure Captions

Fig.1 The LENA detector seen along the beam direction. For details of the detector components see text.

Fig.2 The hadronic cross section σ_h ($e^+e^- \to h$) in the Υ energy region. The data have been corrected for efficiency and the τ-contribution has been subtracted. The errors shown are only statistical. A systematic error of 10% would tend to change the normalization. The full line shown is the fit described in the text.

Fig.3 Time-of-flight distributions for the Roof and Muon sidewall counters. The annihilation μ-pairs are cleanly separated from the cosmic ray muons. The cuts are indicated. The separation of the signals is larger for the Roof counters due to their greater distance.

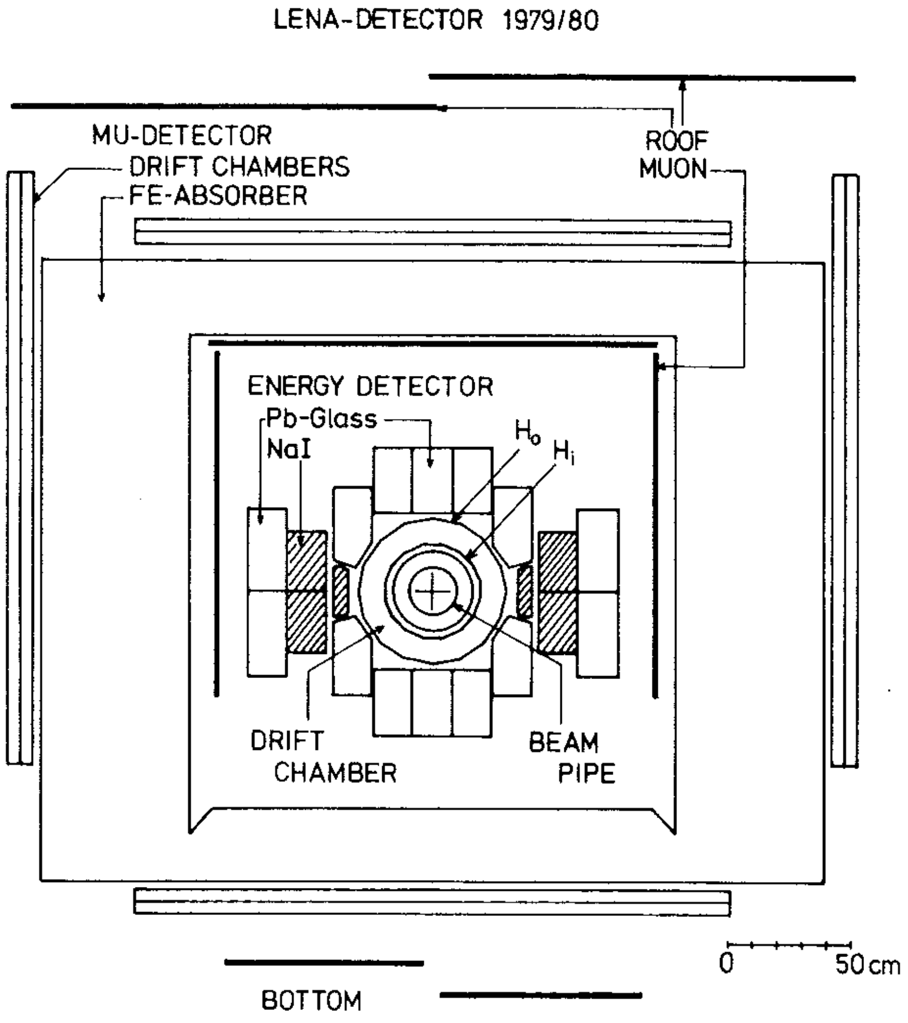

Fig.1

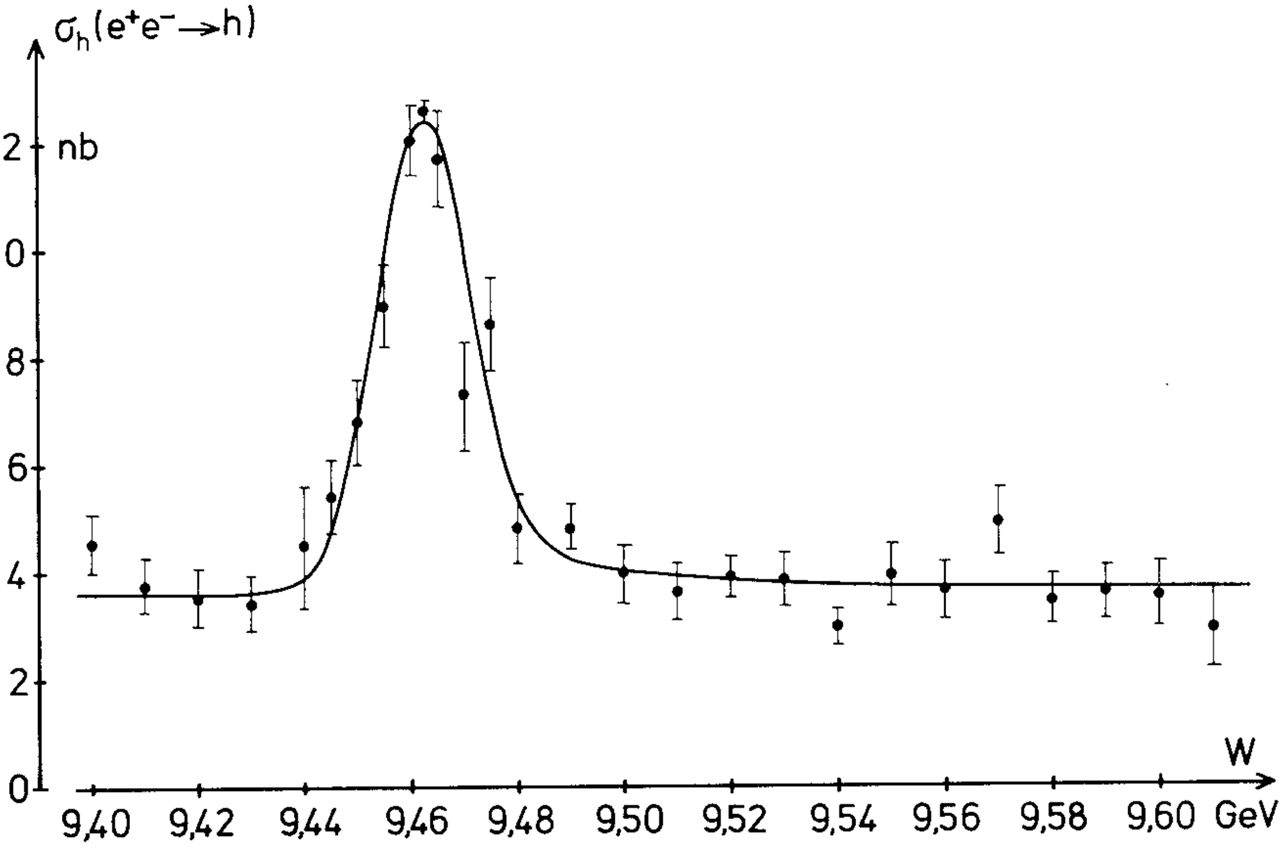
σ_h(e⁺e⁻→h)
nb
0
2
4
6
8
10
12
W
9,40
9,42
9,44
9,46
9,48
9,50
9,52
9,54
9,56
9,58
9,60
GeV

Fig. 2

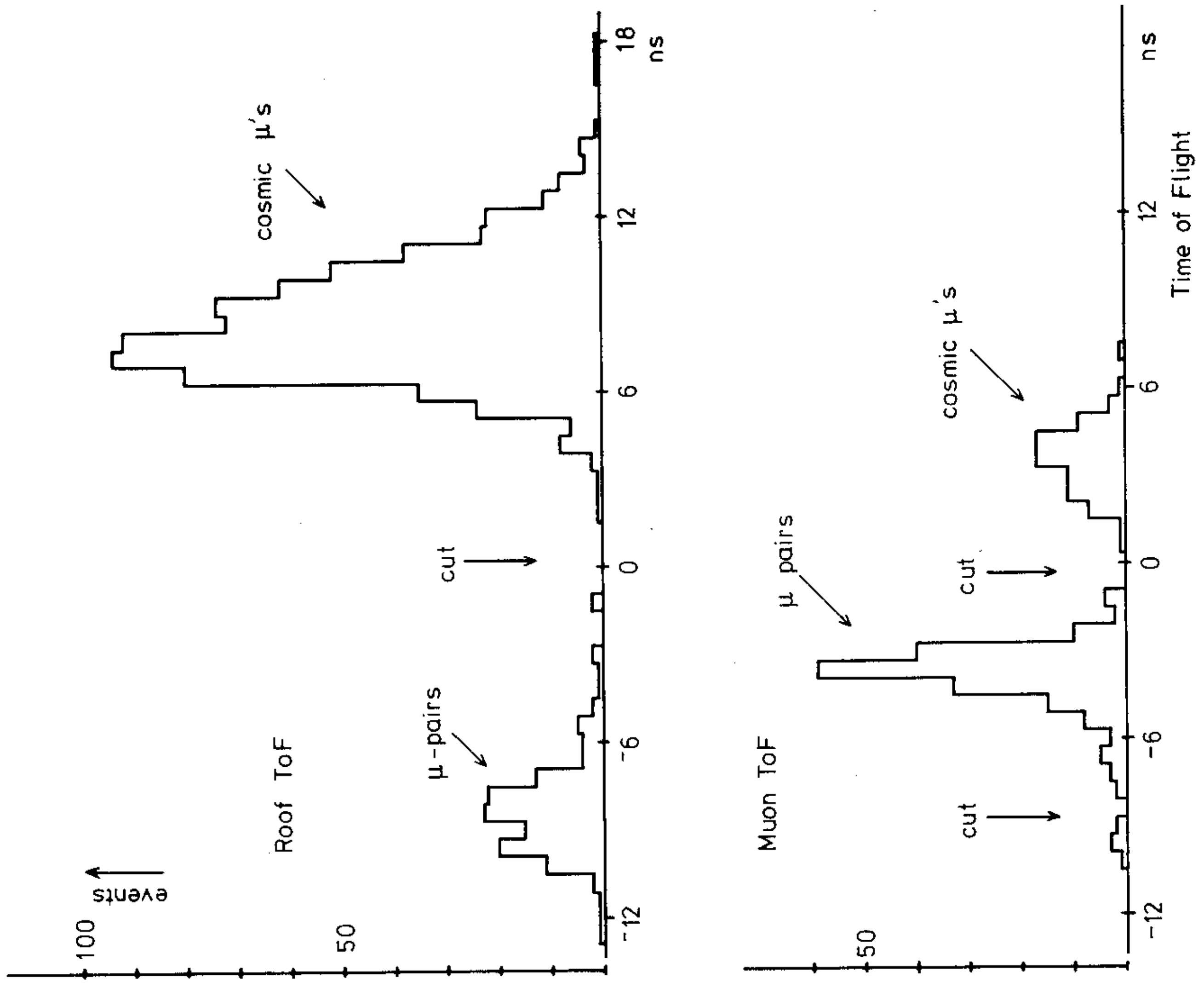
events
100
50
Roof ToF
μ-pairs
cut
cosmic μ's
-12
-6
0
6
12
18
ns
Muon ToF
50
cut
μ pairs
cut
cosmic μ's
-12
-6
0
6
12
ns
Time of Flight

Fig. 3