# OBSERVATION OF A NARROW RESONANCE FORMED IN e+e− ANNIHILATION AT 9.46 GeV

PLUTO Collaboration

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An experiment using the PLUTO detector has observed the formation of a narrow, high mass, resonance in e+e− annihilations at the DORIS storage ring. The mass is determined to be 9.46 ± 0.01 GeV which is consistent with that of the Upsilon. The gaussian width σ is observed as 8 ± 1 MeV and is equal to the DORIS energy resolution. This suggests that the resonance is a bound state of a new heavy quark-antiquark pair. An electronic width $\Gamma_{ee}$ = 1.3 ± 0.4 keV was obtained. In standard theoretical models, this favors a quark charge assignment of −1/3.

The existence of the Upsilon particle recently discovered in proton interactions by Herb et al. [1] is of considerable interest. Not only is it exceptionally massive (9.4 GeV), but its observed decay to muon pairs implies that it is probably quite narrow. The observed width of about 500 MeV is consistent with their experimental resolution. The situation is analogous to that of the $J/\psi$ and suggests that the Upsilon is a bound state of a new heavy quark-antiquark pair [2]. We report on an experiment, which has observed the formation of the Upsilon, using the PLUTO detector at the electron positron storage ring DORIS. It sets a substantially lower upper limit on the total width. From our measurement of the Upsilon production cross section we obtain $\Gamma_{ee}$ − its electronic partial width. $\Gamma_{ee}$ in turn may be used to determine the charge of the constituent quark-antiquark pair.

The energy of the storage ring DORIS has recently
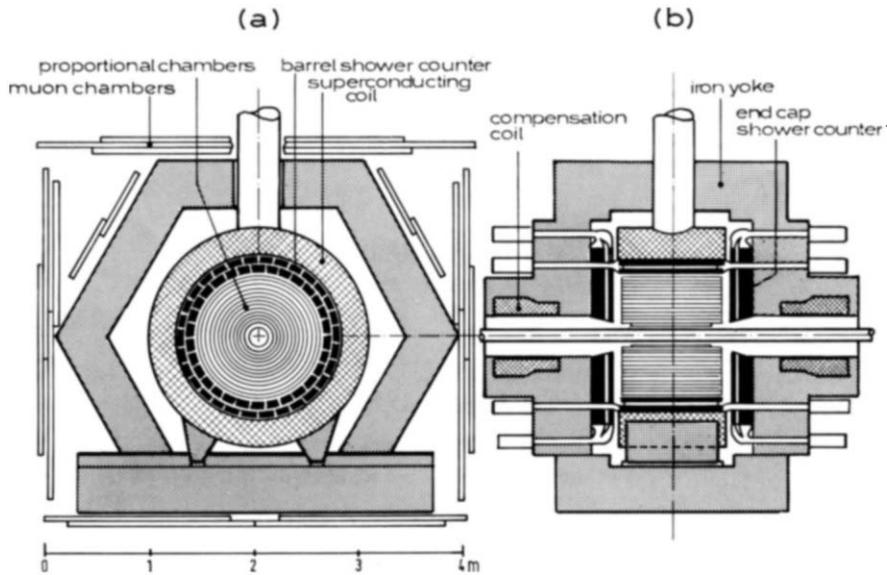
Fig. 1. Schematic views of the PLUTO detector. Sections (a) perpendicular to and (b) containing the beam axis.

been upgraded to make possible measurements for center of mass energies up to 10 GeV. In order to achieve this goal the machine was modified to operate in a single ring, single bunch mode. The detector PLUTO [3], see fig. 1, has also been improved by installing a cylindrical array (barrel) of shower counters (8.6 radiation lengths) and proportional tubes and by covering the ends of the cylindrical detector by a second set of shower counters (10.5 radiation lengths) and proportional wire chambers. These improvements bring the total gamma and electron coverage to approximately 94% of $4\pi$. Cylindrical proportional wire chambers covering 92% of $4\pi$ and operating in a field of 1.69 T are used for track recognition and momentum measurement. The detector was triggered either by the presence of tracks in the wire chambers, by sufficient detected energy in the shower counters, or by a combination of the two. The luminosity was monitored by a set of shower counter telescopes which record Bhabha scatters at an angle to the beam of about 7°. We find good agreement between this monitor and the rate of large angle Bhabhas observed in the barrel shower counters. Reference points were taken at center of mass energies of 9.20 GeV and 9.30 GeV. The resonance search was made from 9.35 GeV upwards in steps of either 5 or 10 MeV. The average integrated luminosity per 10 MeV was ~20 nb$^{-1}$.

In order to obtain substantial background reduction and fast feedback during the energy scan we analysed in the first off-line pass only those events with energy equivalent in the shower counters greater than 2 GeV. The bulk of the data reported here are subject to this restriction. Cosmic ray background was further reduced by making use of the bunch crossing time.

To obtain the total cross section for hadron production, we selected events with at least two charged tracks having a vertex within the prescribed interaction region. QED events were removed by the combined usage of a coplanarity cut and a shower recognition algorithm. To remove beam gas interactions cuts were imposed on the total visible energy and the missing mass in the final state. Remaining beam gas events were removed if they showed a substantial excess of positive charge. The effect of the energy cut was studied by analysing a subsample completely. We estimate that 51% of the hadronic events are being detected and analysed in the first off-line step.

Fig. 2 shows the total cross section for hadron production as a function of the center of mass energy. In addition to the statistical errors, shown in the figure, there is an overall estimated systematic uncertainty of 20%. Radiative corrections have not been applied. A resonance is seen in the region of 9.5 GeV. Fitting a gaussian to the peak on a 1/s background we obtain a
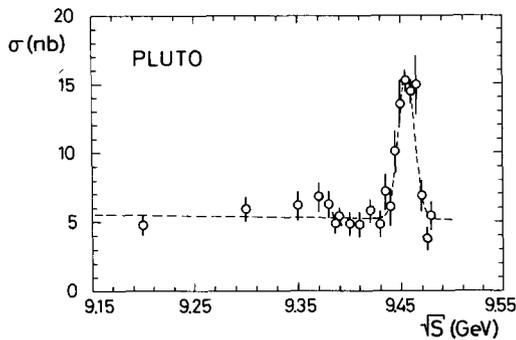
Fig. 2. Total cross section for hadron production in $e^+e^-$-annihilation as a function of center of mass energy. There is an additional systematic error (not shown) of 20%. Contributions from the heavy lepton are included.

mass of 9.46 ± 0.01 GeV. The error in mass comes from the 0.1% uncertainty in the absolute calibration of DORIS energy. Our mass value is in agreement with the value of 9.40 GeV measured by Innes et al. [1], when their quoted systematic uncertainty of less than 1% is considered [4]. The gaussian width $\sigma$ is 7.8 ± 0.9 MeV which is consistent with the theoretically estimated energy spread [5] of 8 MeV in the storage ring. The actual resonance width is therefore less than 18 MeV (FWHM). This adds weight to the supposition that the Upsilon is a bound state of a new quark-antiquark pair.

The relation between the integral over the cross section for resonant hadronic production $\sigma_h$, the resonance mass $M_R$, the electronic width $\Gamma_{ee}$, the hadronic width $\Gamma_h$, and the total width $\Gamma_{tot}$ is given by

$$\int \sigma_h \, dM = \frac{6\pi^2}{M_R^2} \frac{\Gamma_{ee}\Gamma_h}{\Gamma_{tot}}.$$

On the standard assumption that the hadronic width dominates the total width, $(\Gamma_h \approx \Gamma_{tot})$ one obtains $\Gamma_{ee}$ directly from the measured integral and the mass. Our result is $\Gamma_{ee} = 0.8 \pm 0.2$ keV. An estimate of the radiative corrections raises this to $1.3 \pm 0.4$ keV. Models for quark binding in nonrelativistic potentials relate $\Gamma_{ee}$ to the charge of the constituent quarks. In the standard model [6] our measurement implies a charge of $-1/3$ for the new heavy quark.

In summary we have observed the formation of a high mass, narrow resonance in $e^+e^-$ annihilation at DORIS. We determine the mass to be (9.46 ± 0.01) GeV and therefore associate it with the Upsilon resonance seen by Herb et al. [1]. We observe a gaussian width of 7.8 MeV which is consistent with the energy resolution of the storage ring and supports the interpretation that the Upsilon is a bound state of a new heavy quark-antiquark pair. Our determination of $\Gamma_{ee}$ as 1.3 ± 0.4 keV favors an assignment of $-1/3$ for the charge of the new quark.

## References

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