A PRECISION MEASUREMENT OF THE Υ′ MESON MASS

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The e^+e^--storage ring DORIS II provides polarized beams with polarizations up to 80% in the energy range of the Υ' meson. The method of resonance depolarization allows the average beam energy to be determined to a precision of ±0.1 MeV. An energy scan of the hadronic cross section over the resonance range with the detectors ARGUS and Crystal Ball determines the Υ' mass to be (10023.1 ± 0.4) MeV.

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We report here the results of a mass measurement of the Υ' meson using the method of resonance depolarization. This method has already been used to determine the mass of the Υ meson [1] at Novosibirsk. The Υ' experiment was performed from July 20 to July 24, 1983 at the electron–positron storage ring DORIS II. The result is of obvious spectroscopic interest. In addition, it will allow a better control of the beam energy for resonance data taking in the future.

Details of DORIS II are described elsewhere [2]. The main operating characteristics for this experiment were as follows: electron and positron currents between 18 and 30 mA, peak luminosity at $1.5 \times 10^{31}/\mathrm{cm}^2/\mathrm{s}$, beam life times of around 3.5 hours, and beam polarizations of up to 80%.

Electrons and positrons in storage rings become polarized as a result of emission of synchrotron radiation according to the Sokolov–Ternov effect [3]. However, the polarization of the beams can be destroyed by applying a weak time-dependent magnetic field to the beam [4,5] and the frequency of this depolarizing field gives precise information on the mean energy of the beams as will be explained in greater detail below.

The spins of the polarized electrons precess around the vertical guide field of the storage ring dipole magnets. The number of spin precessions per orbit revolution is $\gamma(g-2)/2$, where γ is the Lorentz factor and g is the magnetic moment of the electron. If a particle is kicked vertically by a radial magnetic field at a certain position in the ring, its spin is tilted forward or backward. If the radial field is time-dependent and in phase with the spin precession at the fixed ring position, the spin is rotated over many revolutions from the vertical into the horizontal direction, and the polarization is destroyed. The resonance condition for the frequency f_D of the applied depolarizing field is

$$|\tfrac{1}{2}(g-2)\gamma - n|\, f_0 = f_D\,, \qquad (1)$$

where n is any integer, which in our case is II, and f_0 is the orbit revolution frequency.

The block diagram of the DORIS depolarizer is shown in fig. 1a. The sine-wave generated by a very precise frequency synthesizer (± 1 Hz) is added to the input of a power amplifier which drives the vertical feedback coil in DORIS.

The peak field integral of the coil is of the order of 0.1 Gauss meter. The synthesizer is swept over a frequency range, and the resulting beam polarization is measured for each sweep range by the DORIS polarimeter [6].

The layout of the polarimeter is shown in fig. 1b. A circularly polarized laser beam is directed head-on against the electron beam. The vertical distribution of the back-scattered photons shows an asymmetry which is proportional to the electron beam polarization. This asymmetry is measured by a lead-scintillator-sandwhich shower counter with a movable slit in front.

Fig. 2. shows the result of a typical depolarization measurement. The curve gives the degree of polarization (arbitrary scale) as a function of the central depolarizer frequency. The sweep range at each point is indicated by the horizontal error bars. The average beam energy is then calculated from the resonance frequency by the formula given above. In the region of the dip in fig. 2 the sweep was ±0.125 kHz corresponding to ±0.055 MeV per beam, i.e. ±0.11 MeV in the CMS energy of e^+e^- collisions. During the energy scan described below, the various energies were determined using different sweep interval widths and thus with different precisions.

The energy of each particle in the beam fluctuates around the average energy owing to quantum emission. However, the time of these fluctuations is small compared to the depolarization time, and the depolarizer therefore averages over the energy fluctuations. The width of the depolarizing resonance is then much smaller than the natural energy spread of the beam.

The cross section for the reaction

$$e^+e^- \to \text{hadrons}\,, \qquad (2)$$

was measured by the ARGUS and Crystal Ball detectors at 13 different CMS energies in the range from 9.96 to 10.04 GeV. A total integrated luminosity of about 2.0 pb^{-1} was collected by each of the two detectors.

ARGUS is a new magnetic spectrometer [7] equipped with a central drift chamber, time-of-flight scintillators, shower counters and muon chambers. The trigger conditions and the selection criteria for hadronic events are described in ref. [7]. In addition to three well reconstructed charged particles pointing to the interaction point, a minimum total energy deposition of 1.7 GeV in the shower counters is required. This additional requirement speeds up the reconstruction procedure and considerably reduces the contamination from τ pairs and from two-photon interactions.

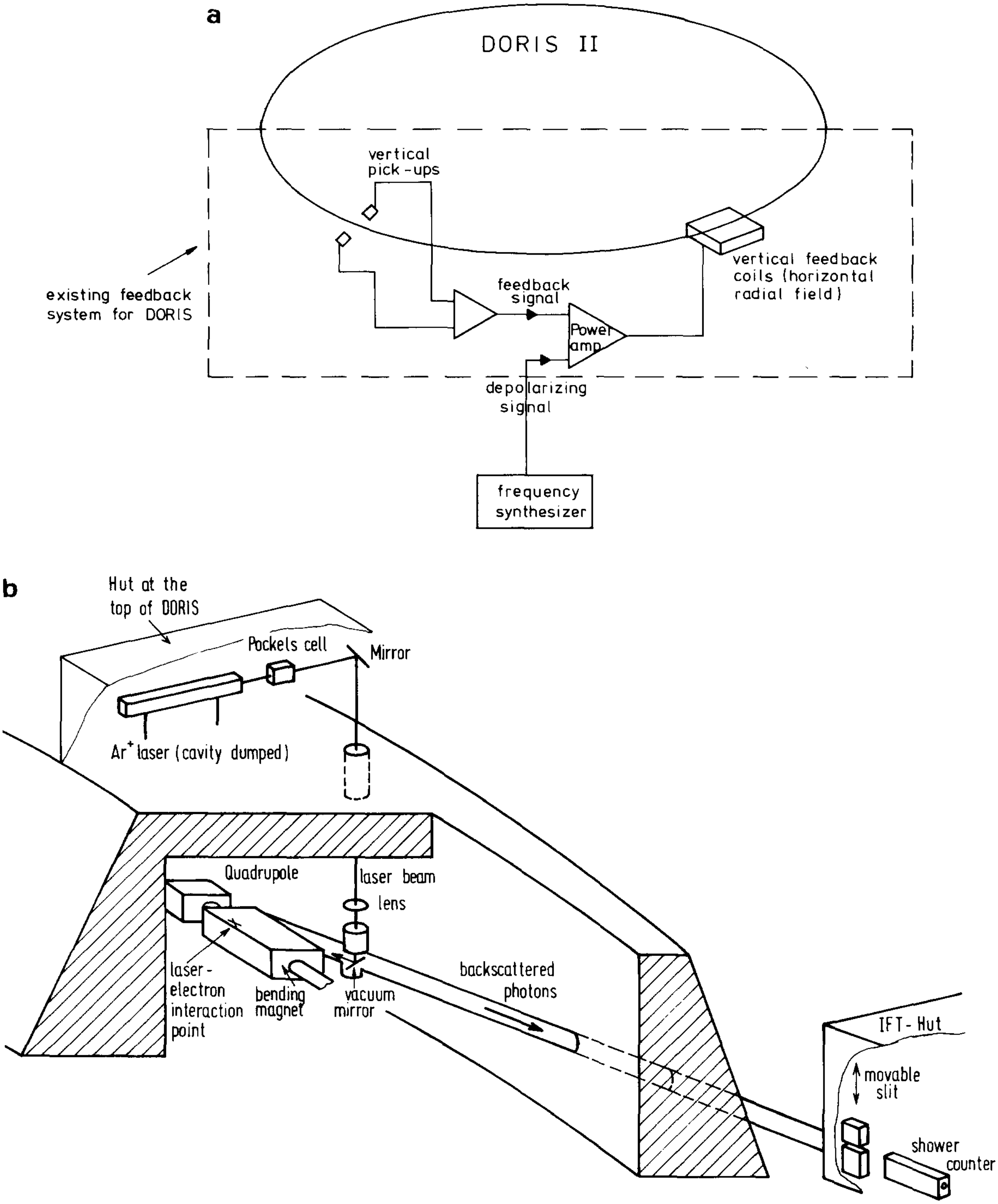

Fig. 1 (a) Block diagram of the DORIS depolarizer. (b) Schematic view of the DORIS polarimeter.

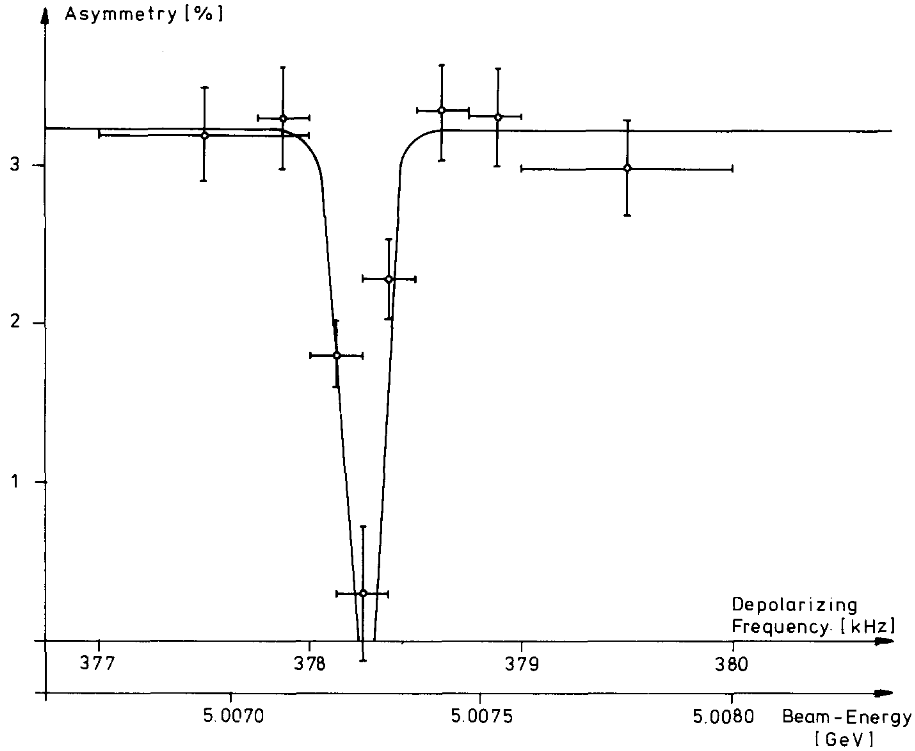

Fig. 2. Example of a depolarization curve. Horizontal error bars indicate the sweep range of the frequency generator.

For each scan point, the number of selected hadronic events is divided by the number of Bhabha events in an angular range of 20 to 160 degrees. This ratio determines the visible cross section shown in fig. 3a. In addition to the displayed vertical error bars, which are of a statistical origin only, there is an overall vertical scale error of about 10%, which has no influence on the mass determination. The ratio of subsamples of Bhabha events has been controlled to be constant within statistics for all scan points. Beam–gas or beam–wall background contributes less than 0.5% as has been checked with several separated beam runs during the scan. The horizontal error bars indicate the different precision with which the energy is determined by depolarization for each point.

The curve in fig. 3a is the result of a four-parameter fit to the ARGUS data using the expression of Jackson and Scharre [8] for radiative corrections. The four parameters are the Υ' mass, the energy spread in DORIS, the continuum level and the peak cross section. The fit takes into account cross section errors as well as energy errors, since these are slightly different for each point as mentioned above. The fit results in $m(\Upsilon') = (10023.43 \pm 0.45)$ MeV and a RMS width of the CMS energy of (8.2 ± 0.5) MeV. The quoted errors include the energy uncertainties on each scan point.

The Crystal Ball detector consists mainly of a spherical segmented shell of NaI (Tl) shower counters which cover 93% of 4π solid angle. The coverage is increased to 98% of 4π by NaI (Tl) endcaps. The direction of charged particles is measured in 3 double layers of proportional tube chambers. The Crystal Ball in its configuration at SPEAR has been described in detail elsewhere [9]; at DORIS the main detector is unchanged. For the detection of hadronic events it is used as a calorimeter. The thickness of the NaI (Tl) shell corresponds to 16 radiation lengths and to one absorption length for high energy pions. Therefore the distribution of energy deposited by charged hadrons peaks at around 200 MeV due to non-interacting minimum-ionizing charged particles and has a

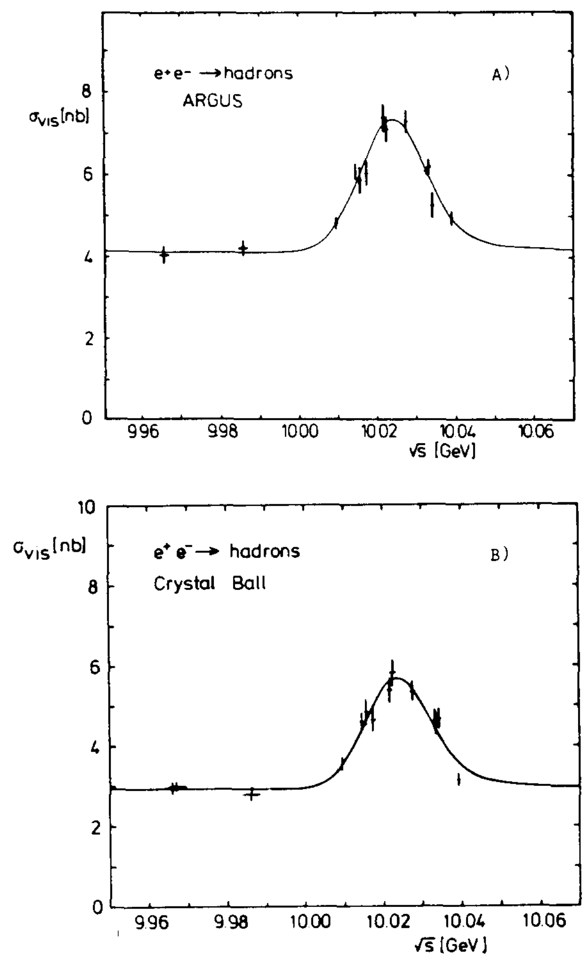

Fig. 3. The visible hadronic cross section of the Υ′ resonance.

long tail caused by nuclear interactions. Neutral, electromagnetically decaying hadrons deposit all their energy in the detector.

In the selection of hadronic events and the determination of the visible cross section three different methods which gave compatible results were used. Two of the methods yielded results so rapidly that they were used to optimize the scan strategy during the run. In the following, one particular method is presented.

The events used in this analysis triggered the apparatus by passing a total-energy threshold at about 1800 MeV. The pattern of energy deposition was required to be symmetric with respect to the interaction point in order to remove cosmic ray and beam–gas events. A minimum of 5 detected particles (charged or neutral) was required. The latter cut also removed events due to the QED processes $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$.

The contamination of the hadron sample due to cosmic ray and beam–gas events was measured with separated-beam runs which were distributed over the period of data taking and was found to be less than 2%.

The luminosity was measured in two ways. In the first method, a small angle luminosity monitor was used to detect Bhabha scattering events in the range of 6–10 degrees of the scattering angle. In the second method, the main detector was used to identify Bhabha and $e^+e^- \to \gamma\gamma$ events in the angular range given by $|\cos\theta| < 0.85$. The two luminosities agreed well, to better than 10%, and their ratio was constant within statistical errors over the run period.

The resulting visible cross section is shown in fig. 3b. Runs without depolarization energy measurement were not used. The data points were fitted with the same function as in fig. 3a (solid line). The resulting mass value is (10022.8 ± 0.5) MeV, where the error is statistical only. The gaussian width due to the beam energy spread was found to be 8.1 ± 0.5 MeV.

The two beam width results agree with the expected DORIS resolution [2]. The two mass results are averaged to give

$$m(\Upsilon') = (10023.1 \pm 0.4)\ \mathrm{MeV}\ . \qquad (3)$$

In combining the errors of the two experiments, correlations due to common errors in the beam energy were taken into account. The difference between the sum of the average electron and positron energies determined by depolarization and the sum of the actual mean electron energy and mean positron energy in each of the two interaction areas is estimated to be small. A detailed estimate of the difference results in a systematic error of less than 0.1 MeV on the Υ′ mass which is included in the overall systematic error estimate.

After finishing the experiment, we learnt that the Novosibirsk group [10] had also measured the Υ′ mass using the depolarization method at their storage ring VEPP-4. Their result is

$$m(\Upsilon') = (10023.8 \pm 0.5)\ \mathrm{MeV}\ , \qquad (4)$$

The two values, (3) and (4), are in good agreement.

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