RESONANCE PARAMETERS OF Υ AND Υ' AND INCLUSIVE SPECTRA MEASURED AT DORIS

DESY - Dortmund - Heidelberg - Lund - Moscow - Collaboration

W. Schmidt-Parzefall
Deutsches Elektronen-Synchrotron DESY, Hamburg.

ABSTRACT

Results on measurements of the Υ and Υ' resonances by the DASP2 collaboration obtained at the DORIS storage ring are reported. From the cross sections for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow$ hadrons we obtain a branching ratio for the $\Upsilon(9.46)$ of $B_{\mu\mu} = (2.9 \pm 1.3 \pm 0.5)$ %, a leptonic width $\Gamma_{ee}^{\Upsilon} = (1.35 \pm 0.11 \pm 0.22)$ keV and a total width of $(47 {}^{+37}_{-15})$ keV. We studied inclusive particle production and observed an excess of antiprotons produced on the Υ and Υ' resonances.

RESUME

Les résultats présentés sur les résonances Υ et Υ' ont été obtenus par la collaboration DASP2 auprès de l'anneau de stockage DORIS. A partir des sections efficaces $e^+e^- \rightarrow \mu^+\mu^-$ et $e^+e^- \rightarrow$ hadrons, nous obtenons un rapport de branchement $B_{\mu\mu} = (2.9 \pm 1.3 \pm 0.5)$ % pour la résonance $\Upsilon(9.46)$, une largeur leptonique $\Gamma_{ee}^{\Upsilon} = (1.35 \pm 0.11 \pm 0.22)$ keV et une largeur totale de $(47 {}^{+37}_{-15})$ keV. Nous avons également étudié des productions inclusives et observé un excès d'antiprotons produits sur les résonances Υ et Υ'.

RESONANCE PARAMETERS

The Υ and Υ' were first seen in e^+e^- collisions [1] at DORIS in 1978. Then DORIS had to serve PETRA as injector. After construction of the positron accumulation ring PIA, high energy physics could resume at DORIS. New data were taken during a run from December 1979 until Easter '80. Fig. 1 shows the energy range covered by DORIS so far. Note the small statistical errors on the peaks of the resonances. Recently, detailed acceptance calculations have been performed[2] and the absolutely normalized resonance cross sections have been obtained, as shown in Fig. 2. The observed shape of a resonance is dependent upon the beam energy spread of the storage ring and on radiative effects. However the area under a resonance gives its electronic width, Γ_{ee} ($\Upsilon \to ee$)

$$\Gamma_{ee} = \frac{M^2}{6\pi^2(1-3B_{\mu\mu})} \int \sigma_h \, d\sqrt{s}$$

where M denotes the resonance mass and $B_{\mu\mu}$ ($\Upsilon \to \mu\mu$) its branching ratio into muon pairs. Our preliminary result is $\Gamma_{ee} = (1.35 \pm 0.11 \pm 0.22)$ keV.

The total width of the Υ can be determined indirectly using

$$\Gamma_{tot} = \frac{\Gamma_{ee}}{B_{ee}} = \frac{\Gamma_{ee}}{B_{\mu\mu}}$$

The branching ratio $B_{\mu\mu}$ ($\Upsilon \to \mu\mu$) has recently been measured by DASP2 [3] and LENA [4]. In order to reduce a large background counting rate due to cosmic muons, time-of-flight measuring equipment was added. Thus muon pairs from e^+e^- annihilation could be safely identified over a large solid angle. We obtained $B^{\Upsilon}_{\mu\mu} = (2.9 \pm 1.3 \pm 0.5)\%$, and, finally, for the total width $\Gamma^{\Upsilon}_{tot} = (47 {}^{+37}_{-15})$ keV.

Whereas in 1978 at DORIS just the first evidence for the Υ' resonance was obtained, it has been precisely measured by now. For the mass difference between Υ' and Υ we obtain ΔM ($\Upsilon' - \Upsilon$) = (556 ± 10) MeV and for the ratio of the electronic widths $\Gamma_{ee}(\Upsilon) / \Gamma_{ee}(\Upsilon') = 0.45 \pm 0.1$.

The resonance parameters are summarized in Table I. The average for DORIS is computed by taking into account also the results of the LENA [4] and PLUTO [5] collaborations. From these figures some important results can be deduced. Each of them is connected with interesting physics.

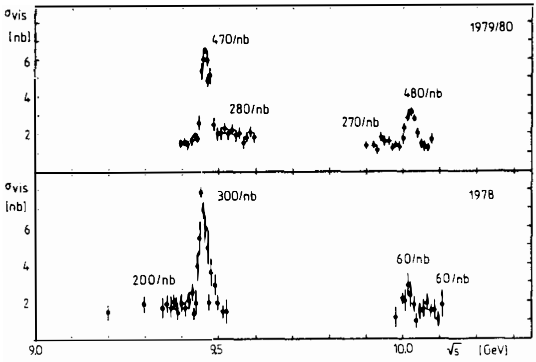

Fig. 1 DASP2 visible cross section and luminosity for all energies in the Υ and Υ' region scanned at DORIS.

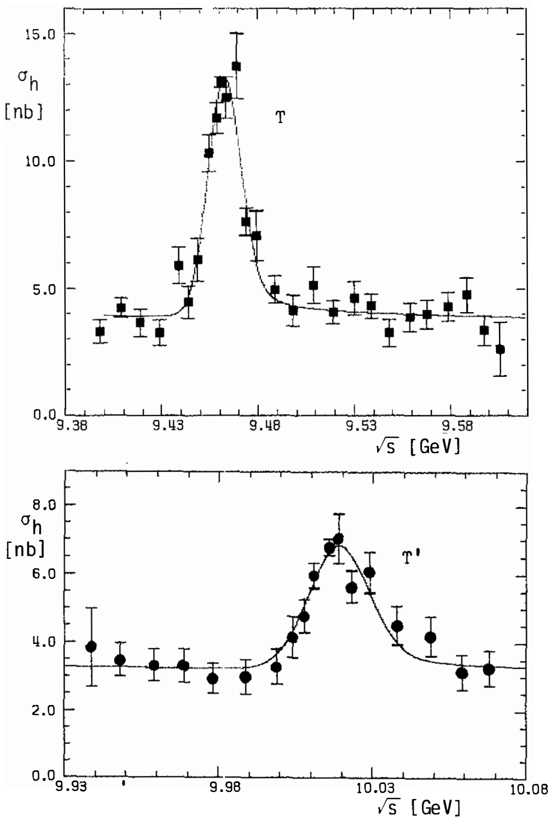

Fig. 2 Cross section for $e^+e^- \rightarrow$ hadrons showing the Υ and Υ' resonance.

TABLE I

Resonance parameters of the Υ and Υ' (preliminary)

		DASP2	DORIS average
$\Gamma_{ee}(\Upsilon)$	[keV]	1.35 ± 0.22	1.29 ± 0.13
$B_{\mu\mu}(\Upsilon)$	[%]	2.9 ± 1.3	3.0 ± 0.8
$\Gamma_{tot}(\Upsilon)$	[keV]	$47 {+37 \atop -15}$	$43 {+20 \atop -11}$
$\Delta M(\Upsilon',\Upsilon)$	[MeV]	556 ± 10	556 ± 10
$\Gamma_{ee}(\Upsilon')$ / $\Gamma_{ee}(\Upsilon)$		0.45 ± 0.1	0.45 ± 0.04

Γ_{ee} gives the charge e_b of the b-quark. To lowest order

$$\Gamma_{ee}(\Upsilon \rightarrow e^+e^-) = 16\pi\alpha^2 \, e_b^2 \, \frac{|\psi(o)|^2}{M^2}$$

holds, where $\psi(o)$ denotes the quark wave-function at the origin and α the electromagnetic coupling constant. Though the wave function is unknown, it can be shown experimentally, Fig. 3, and also argued theoretically using quark potentials, that $|\psi(o)|^2/M^2$ does not vary strongly as a function of quark mass. Assuming then that Γ_{ee}/e_Q^2 is roughly constant, one obtains the result that the b-quark charge is $|e_b| = 1/3$.

$B_{\mu\mu}$ is connected to the strong coupling constant α_s. According to QCD a Υ state decays into 3 gluons just as orthopositronium decays into 3 photons. The first order expression for the width is [6)]

$$\Gamma_{3g}(\Upsilon \rightarrow 3g) = \frac{160}{81} (\pi^2 - 9)\alpha_s^3 \frac{|\psi(o)|^2}{M^2} \quad .$$

Using the above expression for Γ_{ee}, the unknown wave function cancels

$$\Gamma_{3g} = \frac{10(\pi^2 - 9)\alpha_s^3}{9\pi\alpha^2} \Gamma_{ee} \quad .$$

The unknown width Γ_{3g} can be approximated noting that the dominant decays of the Υ go into 3 gluons and into lepton- or quark-pairs, and neglecting other decay modes,

$$\Gamma_{tot} = \Gamma_{3g} + (R + 3)\,\Gamma_{ee} + \ldots .$$

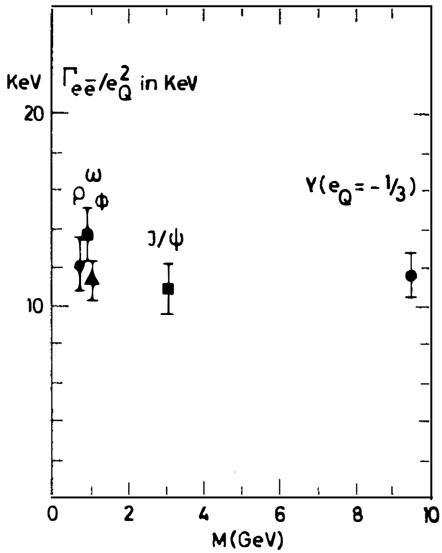

Fig. 3 The ratio of the electronic width Γ_{ee} over the square of the e_Q^2 for radial ground state vector mesons as a function of mass.

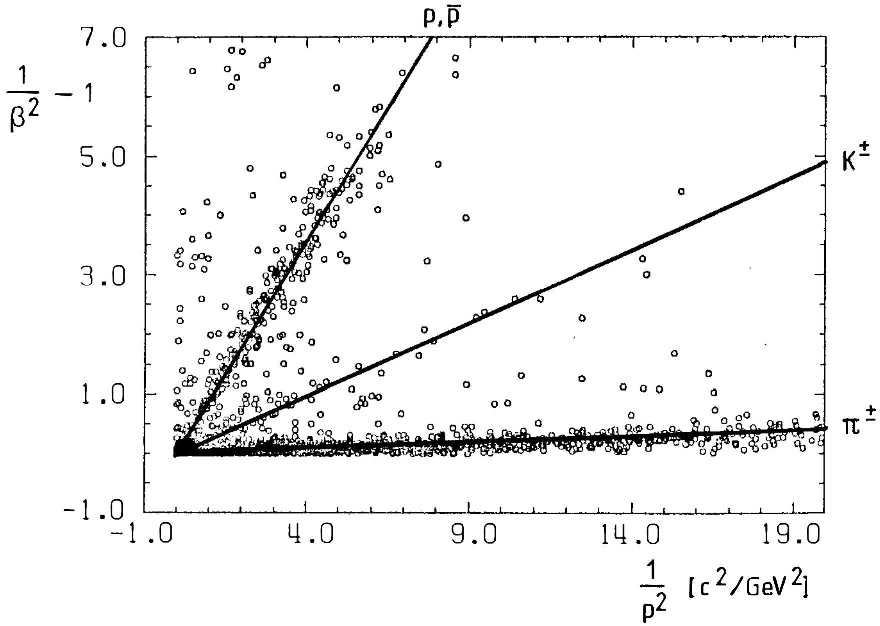

Fig. 4 The particle separation properties of the DASP detector.

where $R = \sigma_h/\sigma_{\mu\mu}$ denotes the ratio of the cross sections for hadron to muon production in the continuum below the Υ. Finally the strong coupling constant α_s is given by

$$\alpha_s = 0.0557 \sqrt[3]{1/B_{\mu\mu} - (R+3)} ,$$

which leads to

$$\alpha_s(\Upsilon) = 0.17 \pm 0.02 , \quad \text{to be compared with}$$

$$\alpha_s(J/\psi) = 0.19 \pm 0.02 , \quad \text{obtained the same way.}$$

Experimentally the reaction $\Upsilon \to \mu\mu$ determines α_s with a maximum of precision. This should be a challenge to theory, to compute the higher order corrections to the now available first order expressions.

$\Gamma_{tot}(\Upsilon)$ has almost the same size as $\Gamma_{tot}(J/\psi) = (67 \pm 12)$ keV. This suggests that the nature of the two mesons is indeed very similar, and is in fact the strongest proof that the Υ is a bound state of b-quarks, carrying the fifth flavour.

$\Delta M(\Upsilon',\Upsilon)$, the mass difference between the Υ' and the Υ resonance, gives evidence for the flavour independence of the quark force. Over the range, where the quark potential is probed by the J/ψ and Υ states, it is well described by a logarithmic shape. For a logarithmic potential the level spacing is independent from the quark mass. Thus, the observation of about equal level spacing for the Υ- and the J/ψ-states is evidence for the flavour independence of the quark force.

INCLUSIVE SPECTRA

It is believed that e^+e^- annihilation proceeds via an initial quark-antiquark pair fragmenting into hadrons in the continuum. In contrast, intermediate quarkonium states such as J/ψ or Υ decay predominantly into three gluons, which again fragment into hadrons. Hence one might expect to find differences in the particle spectra from quarkonium decay and from non-resonant production.

The inclusive spectra of $\pi^\pm$, $K^\pm$ and $\bar{p}$ produced at the Υ, the Υ' and the nearby continuum have been measured [7]. The DASP detector is ideally suited for these measurements due to its excellent particle identification properties, as can be seen in Fig. 4.

Fig. 5 shows the invariant cross section $E\, d^3\sigma/dp^3$ as a function of the hadron energy E in the three regions of interest. The on-resonance cross sections refer

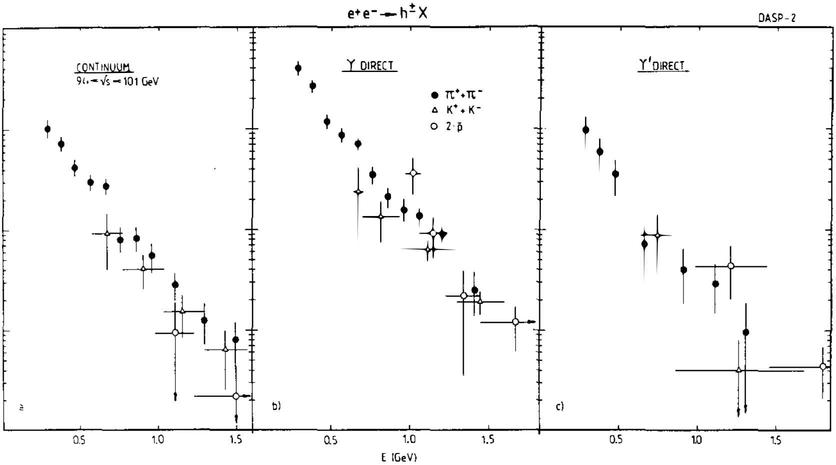

Fig. 5 Invariant cross sections E $d\sigma^3/dp^3$ as a function of particle energy E for the sum of π^+ and π^-, K^+ and K^- and twice the $\bar{p}$ production in the continuum (a), and for direct decays of Υ(b) and Υ' (c).

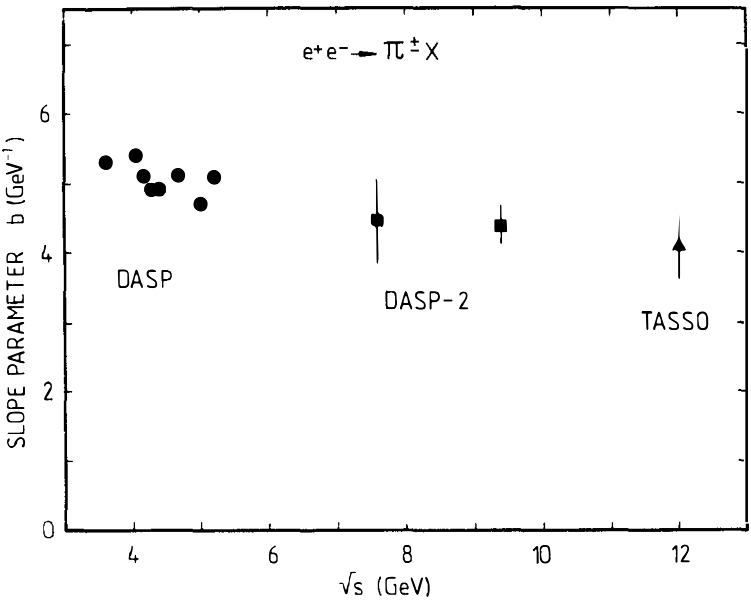

Fig. 6 Slope parameter b versus $\sqrt{s}$ for non-resonant $\pi^{\pm}$ production obtained from exponential fits to the invariant cross sections, $Ed\sigma^3/dp^3 \propto \exp(-bE)$. Data points are from DASP, Ref. 8, TASSO, Ref. 9 and this experiment, where the point of 7.6 GeV was obtained from unpublished data.

to the direct decays only. Contributions from non-resonant background and vacuum polarization have been subtracted.

The invariant cross sections can be approximated by an exponential, $Ed^3\sigma/dp^3 \propto \exp(-bE)$. From the least-squares fit we get $b = (4.4 \pm 0.3)\ \mathrm{GeV}^{-1}$ for non-resonant pion production. This value agrees with the slope parameters for pion production in the continuum measured at other energies [8,9], as shown in Fig. 6. The slope appears to fall slightly, weaker than $1/\sqrt{s}$, with the centre of mass energy.

The pion spectrum from direct Υ decay has a slope which is practically equal to the continuum value, if fitted over the entire measured energy range. However, its lower part ($E < 1$ GeV) falls off faster, with $b = (4.9 \pm 0.2)\ \mathrm{GeV}^{-1}$

The average number of charged pions, kaons and antiprotons can be calculated by a numerical integration of the measured spectra. Using $R = \sigma_h/\sigma_{\mu\mu} = 3.6 \pm 0.2$ and the exponential fits described above in order to extrapolate to zero energy, we find a total charged hadron multiplicity of 6.9 ± 0.6 in the continuum and 7.9 ± 0.6 for direct Υ decay, in agreement with other experiments [10,11]. This observation is in contrast to early speculations, which predicted a much higher multiplicity from gluon fragmentation. The average fraction of the centre of mass energy carried by the charged hadrons was calculated in the same way as the multiplicity. We obtain $\langle E_{ch}\rangle_{off}/\sqrt{s} = (51.8 \pm 8.0)\%$ in the continuum and $\langle E_{ch}\rangle_{on}/\sqrt{s} = (48.0 \pm 3.6)\%$ for direct Υ decays. Again this result is in contrast to speculations, which expected an excess of neutral particles produced by gluon fragmentation.

The invariant cross sections of the three types of hadrons in the continuum and on the Υ resonances are close together (cf. Fig. 5). However, antiproton production appears to be more abundant on resonance than off resonance. The ratio between the yields of $2\bar{p}$ and all charged hadrons is indeed as high as $(8.1 \pm 2.1)\%$ for direct Υ decay compared to $(1.5 \pm 1.1)\%$ in the continuum. This increase of $(6.6 \pm 2.4)\%$ has a statistical significance of 2.8 standard deviations. A similar effect of 2.5 standard deviations is found for direct Υ' decays.

The fractions of the various charged particles are summarized in Table II Using the mean charged multiplicity as determined above, the average number o antiprotons per event comes out to be $\langle\bar{p}\rangle = 0.32 \pm 0.08$ on the Υ, and $\langle\bar{p}\rangle = 0.05 \pm 0.03$ in the continuum.

TABLE II

Particle ratios in the momentum range $0.3 < p < 1.5$ GeV/c

	$2\bar{p}$	$K^{\pm}$	$\pi^{\pm}$
continuum	0.015 ± 0.011	0.183 ± 0.039	0.802 ± 0.059
Υ	0.081 ± 0.021	0.154 ± 0.027	0.765 ± 0.048
Υ'	0.189 ± 0.069	0.119 ± 0.072	0.692 ± 0.129

It is interesting to note that a similar rise in the antiproton yield has been seen on the J/ψ [8)]. In the continuum, a large production of (anti)baryons has recently been reported by PETRA groups around 30 GeV [12)]. Since it is believed that gluon emission processes become appreciable at this energy and that, on the other hand, the J/ψ and Υ states decay primarily via three gluons, one may wonder whether more copious baryon production is connected with gluon fragmentation. This effect of about three standard deviations deserves a more thorough investigation both theoretically and experimentally.

OUTLOOK

A workshop on DORIS experiments was held at DESY in February 1981. Potential improvements of the storage ring and experiments with an upgraded DORIS were discussed. Dr. K. Wille proposed an improvement programme for DORIS, which foresees the following achievements :

An increase of the luminosity at Υ energies from 10^{30} to 10^{31} $cm^{-2}s^{-1}$.
An increase of the maximum centre of mass energy from 10.2 to 11.2 GeV.
A reduction of the power consumption to one half of the present value.

This upgraded machine would be an excellent tool with which to study the Υ-region, including B-mesons. Preparations have been started to have this improvement programme completed in the summer of 1982.

Two detectors will be available at this time. A magnetic universal detector called ARGUS is under construction. In addition a complementary, Crystal Ball type detector will be installed. It could be an upgraded LENA detector or even the famous Crystal Ball itself, which is now running at SPEAR.

The discussion of possible experiments at the Workshop showed that a large number of important but difficult experiments are possible at DORIS.

REFERENCES

1) C.W. Darden et al., Phys.Lett. 76B (1978) 246
   Ch. Berger et al., Phys.Lett. 76B (1978) 243.

2) H. Hasemann, thesis, University of Hamburg, (1981)
3) H. Albrecht et al., Phys.Lett. 93B (1980) 500
4) J. Bienlein et al., Phys.Rev.Lett. 46 (1981) 92
5) Ch.Berger et al., Phys.Lett. 93B (1980) 497
6) T. Appelquist and A.D. Politzer, Phys.Rev.Lett 34 (1975) 43
   V.A. Novikov et al., Physics Reports 41 (1978) 1
7) H. Albrecht et al., DESY 81-011, submitted to Physics Letters;
   E. Steinmann, thesis, University of Hamburg, (1981)
8) R. Brandelik et al., Nucl. Phys. B148 (1979) 181
9) The slope parameter b at 12 GeV was calculated from data in Ref. 12
10) Ch. Berger et al., (PLUTO collaboration), DESY 80/117 (Dec. 1980), Zeitschrift für Physik C 8 (1981) 101
11) B. Niczyporuk et al. (LENA collaboration), DESY 81/8 (Jan. 1981) submitted to Zeitschrift für Physik C.
12) D. Pandoulas, rapporteur talk at the 20th International Conference on High Energy Physics, Madison, Wisconsin, 1980, and Imperial College Preprint IC/HENP/80/5 (1980).