SEARCH FOR NARROW RESONANCES IN e^+e^- ANNIHILATION AT PETRA

PLUTO Collaboration

Ch.BERGER, H. GENZEL, R. GRIGULL, W. LACKAS and F. RAUPACH
I. Physikalisches Institut der RWTH Aachen [1], *Germany*

A. KLOVNING, E. LILLESTÖL, E. LILLETHUN and J.A. SKARD
University of Bergen [2], *Norway*

H. ACKERMANN, F. BARREIRO, J. BÜRGER, L. CRIEGEE, H.C. DEHNE, R. DEVENISH [4], A. ESKREYS [5], G. FLÜGGE [10], G. FRANKE, W. GABRIEL, Ch. GERKE, G. KNIES, E. LEHMANN, H.D. MERTIENS, U. MICHELSEN, K.H. PAPE, H.D. REICH, B. STELLA [6], T.N. RANGA SWAMY [7], U. TIMM, W. WAGNER, P. WALOSCHEK, G.G. WINTER and W. ZIMMERMANN
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

O. ACHTERBERG, V. BLOBEL [8], L. BOESTEN, V. HEPP [9], H. KAPITZA, B. KOPPITZ, B. LEWENDEL, W. LÜHRSEN, R. van STAA and H. SPITZER
II. Institut für Experimentalphysik der Universität Hamburg [1], *Germany*

C.Y. CHANG, R.G. GLASSER, R.G. KELLOGG, K.H. LAU, R.O. POLVADO, B. SECHI-ZORN, A. SKUJA, G. WELCH and G.T. ZORN
University of Maryland [3], *College Park, MD, USA*

A. BÄCKER, S. BRANDT, K. DERIKUM, A. DIEKMANN, C. GRUPEN, H.J. MEYER, B. NEUMANN, M. ROST and G. ZECH
Gesamthochschule Siegen [1], *Germany*

T. AZEMOON [11], H.J. DAUM, H. MEYER, O. MEYER, M. RÖSSLER, D. SCHMIDT and K. WACKER [12]
Gesamthochschule Wuppertal [1], *Germany*

Received 22 January 1980

We have performed a search for narrow resonances in the center of mass energy range from 29.90 to 31.46 GeV using the e^+e^- storage ring PETRA at DESY. We present the total cross section for hadron production and an upper limit for resonance production, indicating that no bound state of charge-2/3 quarks exists in this energy range.

[1] Supported by the BMFT, Germany.
[2] Partially supported by the Norwegian Research Council for Science and Humanities.
[3] Partially supported by Department of Energy, USA.
[4] Now at Oxford University, England.
[5] On leave from Institute of Nuclear Physics, Krakow, Poland.
[6] On leave from University of Rome, Italy; partially supported by INFN.
[7] On leave from Tata Institute, Bombay, India.
[8] Now at CERN, Geneva, Switzerland.
[9] On leave from Heidelberg University, Germany.
[10] Now at Insitut für Instrumentelle Kernphysik, Karlsruhe, Germany.
[11] Now at University College, London, England.
[12] Now at Harvard University, Cambridge, MA, USA.

Unified weak and electromagnetic interaction models require that the charge sum of all leptons and quarks be zero. The existing experimental evidence for charm and bottom quarks as well as for three lepton pairs then predicts a doublet partner for the b quark. It is called t (top or truth) and has charge 2/3. PETRA results have shown that the threshold for producing mesons which contain one t quark is above 31.6 GeV. c.m. energy [1–3]. This, however, does not exclude the existence of bound $t\bar{t}$ states below 31.6 GeV, which would form narrow resonances. The gap between the threshold for t mesons and the lowest lying vector resonance is expected to be of the order of 2 GeV [4]. Therefore we have perfomred and energy scan for a possible $t\bar{t}$ bound state in the region below 31.6 GeV, the highest energy available at present.

The step width and the luminosity per step were optimized to find a possible $t\bar{t}$ resonance with a significance of at least 2 standard deviations. For a 2/3 charged quark and for an energy spread of σ_W = 20 MeV [5] a step width of 20 MeV in the c.m. energy W and a luminosity of 20 nb^{-1} per energy point is required. The electronic width of the bound state was assumed to be Γ_{ee} = 5 keV, which is the experimental value for the J/ψ resonance.

The data were taken with the PLUTO detector. A detailed description of the detector has been given in ref. [1]. The detector is sensitive to charged particles and photons. Charged particles are detected in 13 cylindrical proportional chambers operating in an axial magnetic field of 1.65 T. They cover 87% of 4π sr. Photons are detected in lead scintillator shower counters covering 94% of the full solid angle. The luminosity is determined using Bhabha scatters observed in a small angle tagging system covering a region of $1.3° < \theta < 4°$ [6]. The small angle rate was found to be in agreement with the wide angle Bhabha rate measured in the central detector. The total integrated luminosity for the complete scan was 1745 nb^{-1}, the averaged luminosity per point was 23 nb^{-1}.

The trigger conditions for hadronic events were:

(i) at least 2 tracks from charged particles with an azimuthal-angle separation of greater than 94°, or

(ii) more than 6 GeV of energy deposited in the shower counters.

The selection criteria for hadronic events were:

(i) more than 2 tracks have a common vertex at the interaction point;

(ii) the total observed energy is more than 1/3 of the c.m. energy;

(iii) after dividing each event into two hemispheres by a plane perpendicular to the sphericity axis the invariant mass of all particles in at least one hemisphere has to be larger than 2 GeV;

(iv) the energy deposited in the small-angle tagging system is less than 2 GeV.

To be accepted an event had to fulfill conditions (i) to (iv). Cut (iii) was introduced to remove QED events including $\tau^+\tau^-$.

Applying these cuts we obtained 639 events with an estimated background of 24 events from beam–gas interactions and cosmic rays. The detection efficiency for hadronic events was calculated using a Monte Carlo program. The events were generated following the algorithm given by Field and Feynman [7], which had been modified to allow also for heavy quarks, hard gluon emission [8] and photon radiation in the initial state [9]. Monte Carlo events were processed by a vectector simulation program and finally analysed with the standard data processing routines. The detection efficiency after all cuts was 78%. The background contribution from the process $e^+e^- \to (e^+e^- + \text{hadrons})$ was estimated using a Monte Carlo program [6] and found to be 10%. Acceptance-weighted radiative effects were −12%.

The corrected total hadronic cross section normalized to the QED μ-pair cross section, R, is shown in fig. 1. The errors shown are statistical only, the systematic error, which reflects the uncertainties in the efficiency, the background and the luminosity, is 15%. The value of R averaged over the scan region is R = 3.8 ± 0.2. Combined with our previous values at 30.0

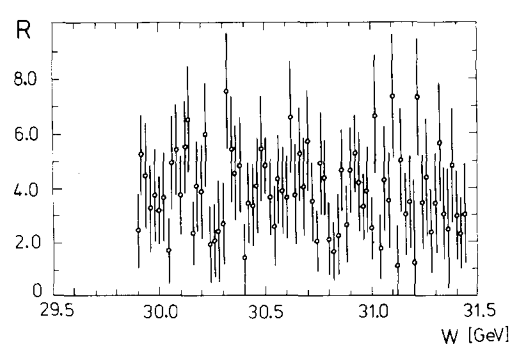

Fig. 1. Ratio R of the total hadronic cross section σ_{tot} to $\sigma_{\mu\mu}$ as a function of c.m. energy.

and 31.6 GeV [1] this yields a final average of

$$R = 3.9 \pm 0.2\ \text{(statist.)} \pm 0.5\ \text{(system.)}\ ,$$

for $30.0 < W < 31.6$ GeV, W = c.m. energy. This result is in agreement with the expected value of $R = \Sigma Q_q^2(1 + \alpha_s/\pi) = 3.9$, where the summation runs over the charges Q^2 of the quarks u, d, s, c and b and α_s is QCD coupling constant. The cutoff parameter for the coupling constant was taken to be 500 MeV.

A possible resonance in this region would give a contribution to the total cross section of

$$\sigma_H = (3\pi/W^2)\Gamma_{ee}\Gamma_H/[(W - M_R)^2 + \Gamma^2/4]\ ,$$

with Γ, Γ_{ee} and Γ_H being the total, the electronic and the hadronic decay widths, M_R the resonance mass and W the center of mass energy. The total decay width is assumed to be small compared to the spread of the e^+e^- c.m. energy. Therefore the expected resonance curve is represented by the gaussian energy distribution of the incoming particles (σ_W = 20 MeV at W = 30 GeV) folded with the energy spectrum of the radiated photons, which is of the form $1/k$, where k is the photon energy. This spectrum is no longer of gaussian form, but can be approximated by a gaussian distribution with a maximum value of $\epsilon_r = 0.6$ times the maximum value for the unfolded distribution [9]. The integral over the resonance curve including this correction is given by

$$A = \int \sigma_H\, dW = (6\pi^2/M_R^2)B_H\Gamma_{ee}\epsilon_r\ ,$$

where B_H is the branching ratio into hadrons Γ_H/Γ.

With these assumptions the observed cross section was fitted to the sum of the measured non-resonant cross section plus a gaussian of variance σ_W^2 and area A. The largest value for A was found at a mass of M_R = 30.337 GeV/c^2 with $A = 9.2 \pm 6.6$ nb MeV, corresponding to an upper limit of $B_H\Gamma_{ee} < 1.4$ keV at a 95% confidence level.

The signal to continuum ratio can be improved by exploiting the expected differences in event topology. Continuum events of the class $e^+e^- \to q\bar{q} \to$ hadrons have a two-jet structure with low sphericity, while events of the class $e^+e^- \to V \to$ hadrons, where V is a $q\bar{q}$ bound state, are expected to have a more isotropic decay structure with higher sphericities, especially if they decay via three vector gluons [10]. Twenty percent of the non-resonant events have a sphericity greater than 0.25, while Monte Carlo studies showed that this number would be 75% for direct quarkonium decays into three gluons. The normalized cross section for events with an observed sphericity greater than 0.25, R_{sph}, is shown in fig. 2. There is no significant indication for an excess of events especially not at the energy of 30.337 GeV, where the highest value for $B_H\Gamma_{ee}$ was found.

For the lowest lying $^3S_1$ $t\bar{t}$ state with a quark charge of 2/3 one expects an electronic decay width of $\Gamma_{ee} \approx 5$ keV. This value is obtained from the empirical rule Γ_{ee}/Q^2 = constant, where Q is the charge of the underlying quark. If we assume a value for B_H of 0.75 [‡1], we obtain an upper limit $\Gamma_{ee} < 2.0$ keV at a 95% confidence level. This limit clearly excludes the existence of a $^3S_1$ $t\bar{t}$ state in the scanned energy region. If we in addition combine our results with those of the TASSO collaboration [2], the limits are reduced to $B_H\Gamma_{ee} < 1.1$ keV or $\Gamma_{ee} < 1.4$ keV at a 95% confidence level.

No strong conclusions can be drawn on the existence of bound states formed by 1/3 charged quarks, where we expect $\Gamma_{ee}(Q = 1/3) = \frac{1}{4}\Gamma_{ee}(Q = 2/3) \approx 1.3$ keV.

We conclude that the result for the hadronic cross section is in agreement with the expected value for five excited quark flavours. The existence of a narrow

[‡1] If the three-gluon decay width is half the total decay width and if for the vacuum polarisation contribution the leptonic decay width divided by the hadronic decay width is $\Sigma Q_\ell^2/3\ \Sigma Q_q^2$, where Q_ℓ are the charges of the leptons e, μ and τ and Q_q are the charges of the quarks u, d, s, c and b, the total hadronic decay width is 73%.

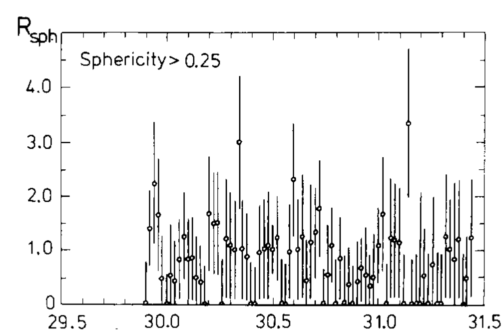

Fig. 2. Ratio R_{sph} of the hadronic cross section for events with a sphericity greater than 0.25 as a function of c.m. energy.

$q\bar{q}$ 1^{--} resonance with a 2/3-charged quark in the region from 29.9 GeV to 31.6 GeV center of mass energy can be excluded.

We gratefully acknowledge the outstanding efforts of the PETRA machine group. We are also indebted to the technicians of the service groups who have supported the experiment during data taking, namely our cryogenic group, the computer center, the gas supply group, the vacuum group and the Hallendienst. We like to thank our technicans for the construction and maintenance of the PLUTO detector. The non-DESY members of the collaboration want to thank the DESY directorate for support and hospitality extended to them.

References

[1] PLUTO Collab., C. Berger et al., Phys. Lett. 86B (1979) 413.
[2] TASSO Collab., R. Brandelik et al., DESY report 79/75 (1979).
[3] MARK J. Collab., D.P. Barber et al., MIT report 107 (1979); JADE Collab., W. Bartel et al., Phys. Lett. 89B (1979) 136.
[4] C. Quigg and J.C. Rosner, Phys. Lett. 72B (1978) 462; G. Bhanot and S. Rudaz, Phys. Lett. 78B (1978) 119; H. Krasemann and S. Ono, DESY report 79/9 (1979).
[5] PETRA, updated version of the PETRA proposal, DESY, Hamburg (1976).
[6] PLUTO Collab., C. Berger et al., DESY report 79/65 (1979).
[7] R. Field and R.P. Feynman, Nucl.Phys. B136 (1978) 1.
[8] P. Hoyer, P. Olsland, H.G. Sander, T.T. Walsh and P.M. Zerwas, DESY report 79/21 (1979).
[9] G. Bonneau and F. Martin, Nucl. Phys. B27 (1971) 381; D.R. Yennie, Phys. Rev. Lett. 34 (1975) 239; J.D. Jackson and D.D. Scharre, Nucl. Instrum. Methods 128 (1975) 13.
[10] PLUTO Collab., C. Berger et al., Phys. Lett. 82B (1979) 449.