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SEARCH FOR NARROW RESONANCES IN e^+e^- ANNIHILATION AT C.M. ENERGIES BETWEEN 33.0 AND 36.72 GeV

by

JADE Collaboration

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JADE - COLLABORATION

W. Bartel, D. Cords, P. Dittmann, R. Eichler, R. Felst, D. Haidt, H. Krehbiel, B. Naroska, L.H. O'Neill, P. Steffen, H. Wenninger[1], Y. Zhang[2]

Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

E. Elsen, M. Helm[3], A. Petersen, P. Warming, G. Weber

II. Institut für Experimentalphysik der Universität Hamburg, Germany

S. Bethke, H. Drumm, J. Heintze, G. Heinzelmann, K.H. Hellenbrand, R.D. Heuer, J. von Krogh, P. Lennert, S. Kawabata, H. Matsumura, T. Nozaki, J. Olsson, H. Rieseberg, A. Wagner

Physikalisches Institut der Universität Heidelberg, Germany

A. Bell, F. Foster, G. Hughes, W. Wriedt

University of Lancaster, England

J. Allison, A.H. Ball, G. Bamford, R. Barlow, C. Bowdery, I.P. Duerdoth, J.F. Hassard, B.T. King, F.K. Loebinger, A.A. Macbeth, H. McCann, H.E. Mills, P.G. Murphy, H.B. Prosper, K. Stephens

University of Manchester, England

D. Clarke, M.C. Goddard, R. Marshall, G.F. Pearce

Rutherford Laboratory, Chilton, England

M. Imori, T. Kobayashi, S. Komamiya, M. Koshiba, M. Minowa, M. Nozaki, S. Orito, A. Sato, T. Suda[4], H. Takeda, Y. Totsuka, Y. Watanabe, S. Yamada, C. Yanagisawa

Lab. of Int. Coll. on Elementary Particle Physics and Department of Physics, University of Tokyo, Japan

1) On leave from CERN, Geneva, Switzerland
2) Visitor from Institute of High Energy Physics, Chinese Academy of Science, Peking, People's Republic of China
3) Present address: Texaco AG, Hamburg, Germany
4) Present address: Cosmic Ray Lab., University of Tokyo, Japan

Abstract:

A search for narrow resonances in e^+e^- annihilation between 33.00 and 36.72 GeV is reported. No evidence is found for the existence of such states. The 90% confidence upper limit on the integrated resonance cross section is determined to be 28 nb · MeV, a value significantly below that expected for the lowest $t\bar{t}$ bound state.

In previous papers we have presented the results of experimental searches for the production of a new heavy quark in e^+e^- annihilation at PETRA for C.M. energies W up to 35 GeV. These have concentrated on three possible manifestations of this production by a) looking for an increase in the ratio $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ (1) or an excess of non-collinear, non-planar events (2) expected from the production of a new heavy quark above threshold; b) searching ($29.90 \leq W \leq 31.46$ GeV) for the formation of narrow bound states of heavy quarks $(Q\bar{Q})$ (3) which are predicted to lie below the threshold for the corresponding flavour production; c) looking for a yield of prompt muons (4) greater than that expected from hadrons containing only the five known quarks u, d, s, c and b.

In this letter we extend our search for narrow resonances to higher energies. We have measured the total cross section, $\sigma_{tot}(e^+e^- \rightarrow \text{hadrons})$, using the JADE detector over the C.M. energy range 33.00 to 36.72 GeV in steps of 20 MeV. This increment was chosen to match the energy resolution of PETRA which, at these energies, is about 27 MeV. The luminosity accumulated per point was determined by measuring small angle Bhabha scattering and averaged at 43 nb^{-1}.

The JADE detector is sensitive to charged particles and photons over 97% and 90%* of the full solid angle, respectively, and has been described previously in ref. (1). The trigger conditions and event selection criteria applied to select and identify e^+e^- annihilation into hadrons were the same as those used in our earlier measurements of σ_{tot} (1). The detection efficiency was calculated to be 80% by a Monte Carlo simulation of the experiment based on a jet model including u, d, s, c and b quark production. Radiative corrections, including the vacuum polarization effect of e, μ, τ and hadrons, were applied to the production process according to ref. (5).

Fig. 1(a) shows the result of this analysis, where the ratio $R = \sigma(e^+e^- \rightarrow \text{hadrons})/ \sigma(e^+e^- \rightarrow \mu^+\mu^-)$ is plotted as a function of the C.M. energy. No significant structure is evident.

In order to obtain an upper limit on the production cross section of a hypothetical narrow resonance in these data, we have assumed that the resonance width,

* These numbers are printed, wrongly, in the reverse order in our previous paper (ref. (3)).

Γ, is much smaller than the C.M. energy resolution $\sigma_W = 2.2 \times 10^{-5} W^2$(GeV) (W in GeV) and performed a series of maximum likelihood fits to the sum of a constant and a Gaussian of fixed width σ_W (for more detail see ref. (3)). The fit to this hypothesis which yielded the largest Gaussian amplitude was obtained with the Gaussian centred at a mass of M_R = 33.34 GeV and is entirely consistent with expected statistical fluctuations. The curve shown in Fig. 1(a) corresponds to the 90% upper limit from this fit.

The integrated cross section of a narrow $J^P = 1^-$ Breit-Wigner resonance is

$$\Sigma = \int \sigma_R(W)dW = \left(\frac{6\pi^2}{M_R^2}\right) \frac{\Gamma_{ee}\,\Gamma_h}{\Gamma}$$

where Γ_{ee} and Γ_h are the leptonic and hadronic decay widths respectively. From the fit at M_R = 33.34 GeV, taking radiative corrections into account[6], we have used this relation to obtain an upper limit on the production of a narrow (Γ << 20 MeV) resonance of Σ < 28 nb · MeV or $\Gamma_{ee} \cdot \Gamma_h / \Gamma$ < 1.3 keV (90% confidence).

The sensitivity of this method to the production of a heavy ($Q\overline{Q}$) bound state can be enhanced by further selecting events on the basis of their reconstructed sphericity, S, where

$$S = \frac{3}{2} \frac{\sum_i P_{Ti}^2}{\sum_i P_i^2}$$

for P_i = momentum of particle i and P_{Ti} = transverse momentum of particle i relative to the axis which minimises $\sum_i P_{Ti}^2$. At these energies the dominant continuum process of two jet production is known to produce final states of small sphericity whereas the direct hadronic decays of heavy ($Q\overline{Q}$) bound states are expected to yield states of relatively large sphericity. Any signal from the latter will therefore be enhanced relative to the background continuum process by selecting only those events with large S. Fig. 1(b) shows R for events with S > 0.25. Once more no significant structure is seen.

The leptonic width, Γ_{ee}, of the lowest lying bound state of a new charge 2/3 quark ($t\overline{t}$) is expected to be about 5 keV[7]. Even if we pessimistically assume a hadronic branching ratio (Γ_h/Γ) of 0.5, our upper limit on $\Gamma_{ee} \cdot \Gamma_h/\Gamma$ clearly excludes the existence of such a state within the energy region covered. A bound state of charge 1/3 quarks however, with a leptonic width four times smaller than this, cannot be excluded.

We also see no evidence for any broader structure in the data. Averaging the data in Fig. 1(a) within different energy intervals yields the same values of <R> within the statistical uncertainties. The overall average is $\langle R \rangle = 3.95 \pm 0.08 \pm 0.4$, a value in good agreement with our previous measurements at lower energies (1,3). The systematic error of $\pm$ 0.4 is a conservative estimate of our present systematic uncertainties and will be improved in a forthcoming paper.

We acknowledge the efforts of the PETRA machine group, who provided us with the opportunity of doing this experiment, and also the efforts of the technical support groups of the participating institutes in the construction and maintenance of our apparatus. This experiment was supported by the Bundesministerium für Forschung und Technologie, by the Education Ministry of Japan and by the U.K. Science Research Council through the Rutherford Laboratory. The visiting groups at DESY wish to thank the DESY directorate for their hospitality.

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Figure Captions

Figure 1: The ratio $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ as a function of C.M. energy W for all events (a) and for events with sphericity > 0.25(b). The curve shown represents the 90% confidence upper limit quoted in the text.

Appendix

Table of cross sections shown in Fig. 1a

W (GeV)	Lumi. (nb^{-1})	No. of events	R
33.00	135.0	42	3.72 ± 0.57
33.02	35.1	9	3.07 ± 1.02
33.04	42.9	16	4.48 ± 1.12
33.06	42.1	15	4.28 ± 1.11
33.08	42.3	14	3.98 ± 1.06
33.10	33.9	11	3.91 ± 1.18
33.12	30.1	9	3.61 ± 1.20
33.14	40.0	15	4.53 ± 1.17
33.16	38.4	14	4.41 ± 1.18
33.18	38.7	8	2.50 ± 0.88
33.20	35.0	10	3.46 ± 1.09
33.22	47.0	15	3.87 ± 1.00
33.24	34.8	15	5.24 ± 1.35
33.26	49.8	7	1.71 ± 0.65
33.28	38.3	16	5.09 ± 1.27
33.30	32.6	13	4.86 ± 1.35
33.32	37.4	13	4.24 ± 1.18
33.34	26.5	16	7.38 ± 1.84
33.36	33.7	17	6.17 ± 1.50
33.38	26.2	6	2.81 ± 1.15
33.40	34.9	10	3.51 ± 1.11
33.42	30.7	4	1.69 ± 0.80
33.44	34.4	5	1.79 ± 0.80
33.46	37.0	16	5.99 ± 1.41
33.48	31.4	13	5.10 ± 1.42
33.50	34.1	8	2.89 ± 1.02
33.52	33.4	7	2.59 ± 0.98
33.54	35.7	11	3.81 ± 1.15
33.56	35.7	11	3.82 ± 1.15
33.58	32.0	15	5.81 ± 1.50
33.60	31.2	10	3.98 ± 1.26
33.62	37.8	16	5.26 ± 1.32
33.64	37.2	5	1.67 ± 0.75
33.66	27.1	7	3.22 ± 1.22
33.68	33.7	9	3.33 ± 1.11
33.70	32.0	13	5.07 ± 1.41
33.72	31.5	12	4.76 ± 1.37
33.74	35.9	11	3.83 ± 1.16
33.76	33.0	13	4.94 ± 1.37
33.78	31.2	7	2.81 ± 1.06
33.80	30.1	9	3.76 ± 1.25
33.82	37.3	20	6.74 ± 1.51
33.84	18.1	3	2.09 ± 1.20
34.00	43.8	16	4.64 ± 1.16
34.02	56.5	18	4.05 ± 0.96
34.04	42.4	15	4.51 ± 1.16
34.06	39.3	11	3.57 ± 1.08
34.08	40.9	13	4.06 ± 1.13
34.10	43.2	18	5.33 ± 1.26
34.12	42.5	7	2.11 ± 0.80
34.14	37.5	9	3.08 ± 1.03
34.16	36.5	15	5.27 ± 1.36
34.18	22.3	5	2.88 ± 1.29
34.20	24.3	9	4.76 ± 1.59
34.22	35.0	12	4.41 ± 1.27
34.24	44.3	9	2.62 ± 0.87
34.26	40.6	16	5.09 ± 1.27
34.28	34.9	15	5.55 ± 1.43
34.30	42.1	12	3.69 ± 1.06
34.32	32.6	13	5.16 ± 1.43

W (GeV)	Lumi. (nb^{-1})	No. of events	R	W (GeV)	Lumi. (nb^{-1})	No. of events	R
34.34	34.3	11	4.16 ± 1.25	34.94	43.6	9	2.77 ± 0.92
34.36	33.9	11	4.21 ± 1.27	34.96	47.8	20	5.62 ± 1.26
34.38	39.1	11	3.66 ± 1.10	34.98	34.6	14	5.44 ± 1.45
34.40	42.2	15	4.62 ± 1.19	35.00	363.4	100	3.93 ± 0.38
34.42	43.3	15	4.51 ± 1.17	35.02	70.1	24	4.62 ± 0.94
34.44	42.1	16	4.96 ± 1.24	35.04	66.7	16	3.24 ± 0.81
34.46	37.7	12	4.16 ± 1.20	35.06	30.0	9	4.05 ± 1.35
34.48	39.6	17	5.61 ± 1.36	35.08	32.2	12	5.04 ± 1.46
34.50	44.5	17	5.00 ± 1.21	35.10	27.4	7	3.46 ± 1.31
34.52	39.4	8	2.66 ± 0.94	35.12	29.3	8	3.70 ± 1.31
34.54	43.0	9	2.75 ± 0.92	35.14	31.6	11	4.73 ± 1.42
34.56	43.2	12	3.65 ± 1.05	35.16	32.7	7	2.91 ± 1.10
34.58	37.8	10	3.48 ± 1.10	35.18	32.1	15	6.36 ± 1.64
34.60	46.1	6	1.71 ± 0.70	35.20	34.2	7	2.79 ± 1.05
34.62	49.3	10	4.28 ± 1.07	35.22	33.3	11	4.50 ± 1.36
34.64	[illegible].9	16	4.70 ± 1.18	35.24	60.4	20	3.99 ± 0.89
34.66	42.2	8	2.50 ± 0.89	35.26	52.9	24	6.20 ± 1.27
34.68	19.2	10	6.89 ± 2.18	35.28	37.3	8	2.93 ± 1.04
34.70	39.6	8	2.67 ± 0.95	35.30	37.2	14	5.16 ± 1.38
34.72	40.4	15	4.92 ± 1.27	35.32	38.8	13	4.60 ± 1.27
34.74	29.5	7	3.15 ± 1.19	35.34	37.0	9	3.34 ± 1.11
34.76	39.0	15	5.11 ± 1.32	35.36	39.0	9	3.17 ± 1.06
34.78	46.4	10	2.87 ± 0.91	35.38	30.7	13	5.83 ± 1.62
34.80	45.1	13	3.84 ± 1.06	35.40	41.1	7	2.35 ± 0.89
34.82	44.9	11	3.27 ± 0.98	35.42	32.0	7	3.02 ± 1.14
34.84	48.6	12	3.30 ± 0.95	35.44	35.6	15	5.82 ± 1.50
34.86	45.2	10	4.73 ± 1.18	35.46	34.4	13	5.22 ± 1.45
34.88	33.7	10	3.97 ± 1.26	35.51	38.2	9	3.27 ± 1.09
34.90	34.6	6	2.32 ± 0.95	35.53	41.1	6	2.03 ± 0.83
34.92	41.1	10	3.26 ± 1.03	35.55	40.2	13	4.49 ± 1.25

W (GeV)	Lumi. (nb^{-1})	No. of events	R
35.57	36.7	8	3.03 ± 1.07
35.59	68.0	21	4.39 ± 0.94
35.61	44.3	13	4.09 ± 1.13
35.63	54.0	14	3.62 ± 0.97
35.64	35.7	11	4.30 ± 1.30
35.66	28.3	7	3.46 ± 1.31
35.68	31.3	10	4.47 ± 1.41
35.70	30.4	11	5.07 ± 1.53
35.72	77.4	22	3.99 ± 0.85
35.74	68.4	15	3.38 ± 0.80
35.76	73.5	20	3.83 ± 0.86
35.78	42.6	14	4.63 ± 1.24
35.80	132.8	34	3.61 ± 0.62
35.82	40.4	12	4.19 ± 1.21
35.84	39.9	12	4.25 ± 1.23
35.86	41.0	10	3.45 ± 1.09
35.88	36.4	7	2.72 ± 1.03
35.90	39.4	15	5.39 ± 1.39
35.92	67.7	14	2.93 ± 0.78
35.94	50.6	17	4.77 ± 1.16
35.96	46.5	10	3.06 ± 0.97
35.98	43.5	12	3.93 ± 1.13
36.00	61.3	19	4.42 ± 1.01
36.02	54.0	10	3.43 ± 0.95
36.04	32.6	6	2.63 ± 1.07
36.06	46.1	13	4.03 ± 1.12
36.08	36.6	10	3.91 ± 1.24
36.10	30.2	6	2.85 ± 1.16
36.12	33.6	5	2.13 ± 0.95
36.14	32.4	10	4.43 ± 1.40
36.16	33.8	8	3.40 ± 1.20
36.18	32.9	12	5.25 ± 1.52
36.20	37.6	13	4.98 ± 1.38
36.22	46.0	12	3.76 ± 1.09
36.24	34.3	5	2.10 ± 0.94
36.26	34.2	13	5.49 ± 1.52
36.28	33.8	3	1.28 ± 0.74
36.30	31.8	10	4.56 ± 1.44
36.32	37.8	11	4.22 ± 1.27
36.34	36.1	12	4.83 ± 1.39
36.36	37.5	15	5.81 ± 1.50
36.38	32.3	10	4.50 ± 1.42
36.40	36.6	10	3.98 ± 1.26
36.42	32.6	6	2.68 ± 1.10
36.44	23.3	6	3.76 ± 1.53
36.46	26.3	6	3.33 ± 1.36
36.47	177.1	51	4.21 ± 0.59
36.48	27.2	7	3.77 ± 1.42
36.50	37.3	7	2.75 ± 1.04
36.52	32.1	8	3.65 ± 1.29
36.54	32.6	11	4.95 ± 1.49
36.56	28.9	6	3.05 ± 1.25
36.58	30.6	11	5.29 ± 1.59
36.60	35.6	5	2.07 ± 0.93
36.62	35.4	11	4.58 ± 1.38
36.64	31.2	8	3.78 ± 1.34
36.66	57.0	10	2.59 ± 0.82
36.67	194.5	47	3.57 ± 0.52
36.68	34.9	12	5.09 ± 1.47
36.70	33.5	8	3.54 ± 1.25
36.72	15.1	4	3.93 ± 1.96

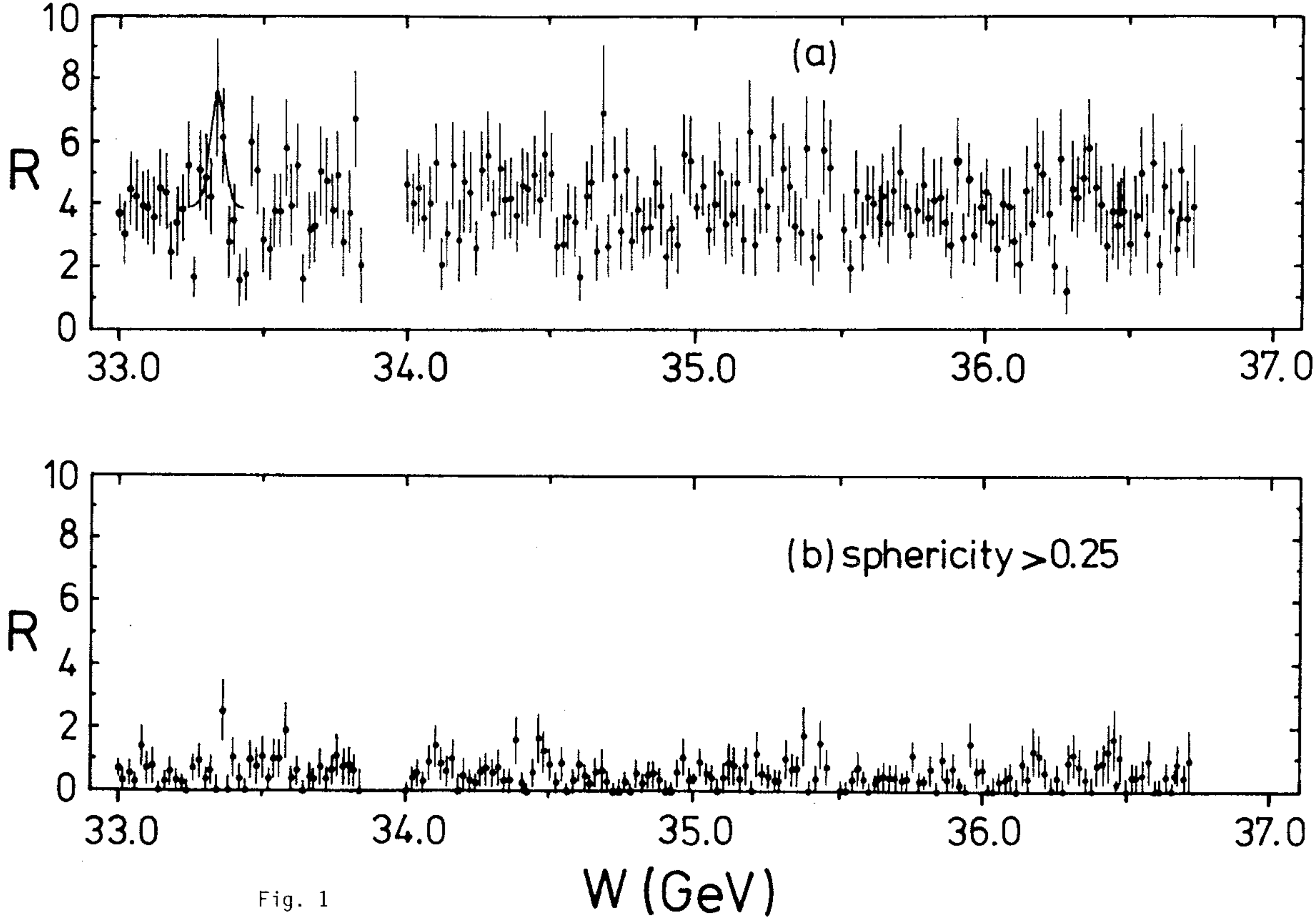

Fig. 1