PROMPT MUONS IN MULTIPARTICLE EVENTS FROM e^+e^- ANNIHILATION AT PETRA

JADE Collaboration

W. BARTEL, D. CORDS, P. DITTMANN, R. EICHLER, R. FELST, D. HAIDT, S. KAWABATA, H. KREHBIEL, B. NAROSKA, L.H. O'NEILL, J. OLSSON, P. STEFFEN and W.L. YEN [1]
Deutsches Elektronen-Synchrotron, Hamburg, Germany

E. ELSEN, M. HELM [2], A. PETERSEN, P. WARMING and G. WEBER
II. Institut für Experimentalphysik der Universität Hamburg, Germany

H. DRUMM, J. HEINTZE, G. HEINZELMANN, R.D. HEUER, J. von KROGH, P. LENNERT, H. MATSUMURA, T. NOZAKI, H. RIESEBERG and A. WAGNER
Physikalisches Institut der Universität Heidelberg, Germany

D.C. DARVILL, F. FOSTER, G. HUGHES and H. WRIEDT
University of Lancaster, England

J. ALLISON, J.C.M. ARMITAGE [3], A.H. BALL, 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 and K. STEPHENS
University of Manchester, England

D. CLARKE, M.C. GODDARD, R. MARSHALL and G.F. PEARCE
Rutherford Laboratory, Chilton, England

M. IMORI, T. KOBAYASHI, S. KOMAMIYA, M. KOSHIBA, M. MINOWA, S. ORITO, A. SATO, T. SUDA [4], H. TAKEDA, Y. TOTSUKA, Y. WATANABE, S. YAMADA and C. YANAGISAWA [5]
Lab. of Int. Coll. on Elementary Particle Physics and Department of Physics, University of Tokyo, Japan

Received 12 September 1980

We have observed the production of prompt muons in e^+e^- annihilation in the centre of mass energy range 33.0 GeV to 35.8 GeV. The rate of such muons with momentum greater than 1.4 GeV was measured to be 0.069 ± 0.024 per multiparticle event. When compared with currently accepted models, this rate is consistent with that expected from charm and bottom decays, but does not support the production also of a top quark of mass less than about 15 GeV.

[1] Present address: Purdue University, Indianapolis, IN, USA.
[2] Present address: Texaco AG, Hamburg, Germany.
[3] Present address: NIKHEF, The Netherlands.
[4] Present address: Cosmic Ray Laboratory, University of Tokyo, Japan.
[5] Partly supported by the Yamada Science Foundation.

0 031–9163/81/0000–0000/\$ 02.50

e^+e^- annihilation at high energies is known to produce hadrons containing u, d, s, c and b quarks. If the heavier t quark exists, hadrons containing it (T's) should also be produced at sufficiently high energy. It is likely [1] that a T-hadron would have a branching ratio of about 10% for decay into $\mu + \nu$ + hadrons, where one of the hadrons is a B (i.e. it contains a b quark). A B, produced directly in the e^+e^- annihilation or from the decay of a T, should have a similar branching ratio for decay into $\mu + \nu$ + hadrons, with a charmed particle (C) amongst the hadrons. The C hadrons have an average branching ratio of about 10% [2] [‡1] for decays yielding a muon. If the lifetimes of these hadrons with new quantum numbers are sufficiently short ($\lesssim 10^{-10}$ s), their production should lead to apparently direct muons in detectable numbers. In this paper we report a test for the production of T's by this method. The data were taken by the JADE experiment from January to May 1980. During this period, PETRA ran mainly in the centre of mass energy range 33.0 GeV to 35.8 GeV with an average of 35.1 GeV. The integrated luminosity in this energy range was $\sim$1620 nb^{-1}.

Muons are identified as penetrating tracks in the JADE muon filter, which is a segmented system with five layers of absorber and drift chambers covering a solid angle of 92% of 4π [3]. The main hadron-absorbing components are lead-glass shower counters, an iron return yoke and three layers of iron-loaded concrete which, in total, present a minimum of 6 absorption lenghts of material to particles originating from the interaction region. The segmented nature of the filter allows the detection of muons with momenta as low as 1 GeV with good efficiency, although in the results presented here, because of uncertainties in the background rate, the low momentum cut-off was set to 1.4 GeV. The 618 single wire drift chambers (each 30 cm wide, maximum drift distance 15 cm, and 3.3 to 4.7 m long) have a total area of approximately 800 m^2. Using cosmic muons, the average efficiency of the chambers was measured to be greater than 96% per chamber.

The selection of multiparticle annihilation events from the data has been described in a previous publication [3]. Cuts were applied to remove $\tau^+\tau^-$ events, and events of the type $e^+e^- \to e^+e^-$ + anything. The resulting sample of 473 multiparticle events was studied for the presence of penetrating tracks, both by a purely software analysis and by a visual scan. In the software analysis, tracks identified by the inner detector pattern recognition program [4] were extrapolated outwards through the muon filter as if they were muons. The conditions imposed on the quality of the pattern recognition fits resulted in (11 ± 2)% of real tracks not being extrapolated. Muon chamber hits within three standard deviations of an extrapolated track were associated with the track. The deviations of hits from an extrapolated track were mainly due to multiple Coulomb scattering. The calculated range of the track was required to be consistent with the observed range. The χ^2 for the association of the hits with the track was calculated using a full correlation error matrix, and left-right ambiguities were resolved by selecting the solution with the lowest χ^2.

Fig. 1 shows the χ^2 probability distribution for the

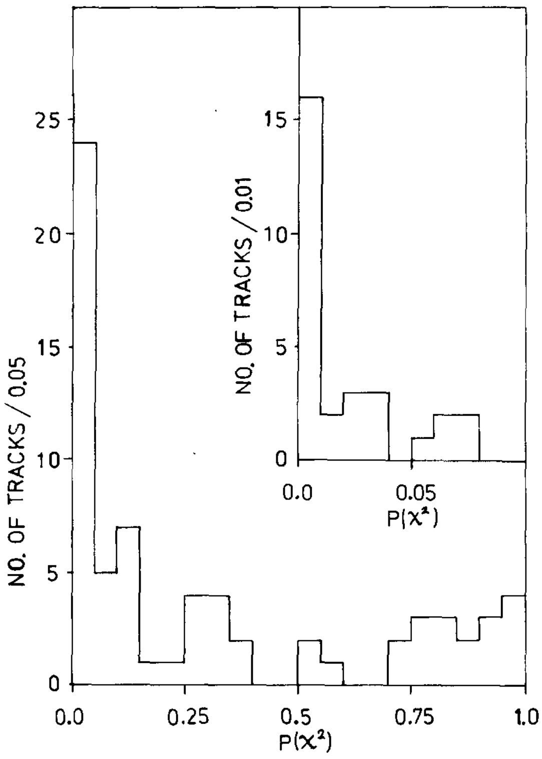

Fig. 1. The χ^2 probability distribution of the penetrating tracks with momentum greater than 1.4 GeV in the 473 multiparticle events. The inset shows the region $0.00 < P(\chi^2) < 0.10$ in more detail. Events with $P(\chi^2) < 0.01$ have been rejected (see text).

‡1 Bacino et al. [2] have measured the semi-leptonic branching ratio for the D^+ to be 22% and have given an upper limit of 4% for the D^0.

Table 1
Number of muons with momenta greater than 1.4 GeV in 473 multiparticle events for $\sqrt{s}$ = 33.0 → 35.8 GeV.

observed penetrating tracks	52 ± 7.2
estimated background	28.3 ± 4.0
prompt muon signal	23.7 ± 8.2
expected, $c\bar{c}$	20.5 ± 1.2
expected, $c\bar{c} + b\bar{b}$	28.7 ± 1.7
expected, $c\bar{c} + b\bar{b} + t\bar{t}$	55.2 ± 3.3

penetrating tracks with momentum greater than 1.4 GeV in the sample of 473 multiparticle events. This distribution is flat, except for an accumulation below $P(\chi^2)$ = 1%. The tracks with probability less than 1% were rejected (such tracks are to be expected from K-mesons which decay to give muons at large angles with respect to the direction of the K), giving a final sample of 52 tracks (see table 1). The visual scan corroborated the software analysis. Of these 52 tracks, 25 were negatively charged and 27 were positively charged. In this sample of 473 multiparticle events, there were 5 events with two muons (which are included in the above results). Four events have opposite sign muons, the other has two negative muons.

The probability that an extrapolated muon track of momentum greater than 1.4 GeV was correctly identified by the above procedure was calculated to be (92 ± 2)% for tracks within the muon filter solid angle. Taking account of this selection efficiency, the muon filter solid angle (92%), the efficiency of the inner detector pattern recognition program (97%) [4] and the selection of tracks found by this program [(89 ± 2)%], the overall efficiency for the detection of a muon with momentum greater than 1.4 GeV is (73 ± 3)%.

In addition to the muonic decays of short-lived particles, penetrating tracks may result from three processes:

(1) The decays $\pi \to \mu$ and $K \to \mu$ can occur before the hadron is absorbed. These are important because of the large flight path from the interaction point to the first substantial absorber (≈1.5 m) and are the dominant sources of background below 5 GeV.

(2) There is a non-zero probability that a hadron "sneaks through" by not interacting absorptively with nuclei.

(3) Secondary particles, produced when a hadron undergoes a nuclear interaction, may penetrate the absorber, giving muon chamber hits which appear to be associated with the track of the original hadron. The probability that a hadron will contaminate the final sample in this way is estimated to be 1% for a hadron with momentum greater than 5 GeV and negligible below 5 GeV [5].

Background from cosmic ray muons is negligible in multiparticle events because of the short sensitive time for track detection and because each track is required to originate from the interaction point.

The background from these processes was estimated using the extrapolation procedure employed in the search for penetrating tracks. Every track, whether associated with hits in the muon chambers or not, was assigned a probability of simulating a penetrating track due to the processes 1–3 above. It was assumed that 70% of the tracks were pions, 20% were kaons and 10% were protons [6]; the result is not sensitive to these proportions. The momentum spread and angular distribution of muons resulting from π and K decay was taken into account. This method of estimating the background is independent of the efficiency of the inner detector and of the solid angle of the muon filter, and takes account of the jet configurations of multiparticle events. The background processes 1, 2 and 3 above account for 79.3%, 10.3% and 10.4%, respectively, of the total estimated background given in table 1.

Table 1 shows that, after background subtraction, there remains a prompt muon signal with a statistical significance of 3 standard deviations. After accounting for the overall detection efficiency, the fraction of prompt muons above 1.4 GeV is 0.069 ± 0.024 muons per multiparticle annihilation event (the number of prompt muons actually observed in the JADE detector, uncorrected for efficiencies, was 0.050 ± 0.017 per event).

In order to assess the significance of the observed muon signal, the results have been compared with the prediction of a theoretical model. Hadronic events were generated using a Monte Carlo program [7] and the expected muon spectrum was determined from the decays of C, B and T particles. The top quark was assumed to have a charge of $\frac{2}{3}e$ and a mass of 15 GeV, giving a threshold for naked top production of ≈30.4 GeV. No threshold factor was included. For each of the heavy quarks, a fragmentation function $f(z)$ = constant was assumed [8]. It was also assumed that the top quark decays predominantly to bottom, and bottom predominantly to charm. T and B mesons were given an average branching ratio of 10% for muonic decay, while for charmed particle muonic decays, the branching ratios [2] [‡1] were taken to be 4% for neutral mesons and 22% for charged mesons. The process $\Upsilon \to \tau + \nu +$ hadrons was included, with a branching ratio of 9% [7]; the branching ratio for $\tau \to \mu\nu\nu$ was taken to be 18%. The decay $B \to \tau + \nu +$ hadrons was neglected, since the branching ratio is estimated to be only 3% [7].

The predictions in table 1 were obtained by normalising to the observed number of multiparticle events, thus making them independent of the overall JADE detector trigger efficiency. Also, they were scaled down by the overall muon detection efficiency. Within the framework of the theoretical model, our measurements are consistent with the muon production expected from charm and bottom decays but are more than 3 standard deviations below that expected with production of a top quark. Other PETRA experiments [9,10] have reached similar conclusions at energies up to $\sqrt{s} = 31.6$ GeV. The presently observed number of dimuon events is insufficient to test for the production of heavy quark flavours.

We are indebted to the PETRA machine group for their excellent support during the experiment and to all the engineers and technicians of the collaborating institutions who have participated in the construction and maintenance of the apparatus. We would like to thank Dr. A. Ali for useful discussions about lepton production in multiparticle events, and are grateful to Dr. D. Pandoulas for his investigation of hadron shower development in the muon filter. This experiment was supported by the Bundesministerium für Forschung und Technologie, by the Education Ministry of Japan and by the UK Science Research Council through the Rutherford Laboratory. The visiting groups at DESY wish to thank the DESY directorate for their hospitality.

References

[1] A. Ali, Z. Phys. C1 (1979) 25.
[2] W. Bacino et al., Phys. Rev. Lett. 45 (1980) 329; Mark II results presented at 1980 Intern. Conf. on High energy physics (Madison, USA).
[3] JADE Collab., W. Bartel et al., Phys. Lett. 88B (1979) 171.
[4] H. Drumm et al., DESY Report 80/38 (1980).
[5] D. Pandoulas, Internal JADE Note (1977).
[6] TASSO Collab., R. Brandelik et al., Phys. Lett. 94B (1980) 444; JADE Collab., submission to 1980 Intern. Conf. on High energy physics (Madison, USA).
[7] A. Ali, E. Pietarinen and J. Willrodt, DESY Internal Report T-80/01 (March 1980).
[8] A. Ali, J.G. Körner, G. Kramer and J. Willrodt, Nucl. Phys. B168 (1980) 409; A. Ali, E. Pietarinen, G. Kramer and J. Willrodt, Phys. Lett. 93B (1980) 155.
[9] PLUTO Collab., Ch. Berger et al., Phys. Rev. Lett. 45 (1980) 1533.
[10] MARK J Collab., D.P. Barber et al., Phys. Rev. Lett. 44 (1980) 1722.