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ABSTRACT

A study of the reaction $e^+e^- \rightarrow \mu^+\mu^-$ + anything at a mean centre of mass energy of ≈ 35 GeV has been carried out to investigate the possible flavour-changing neutral current decay of the b quark. An upper limit of 0.7% at 95% C.L. has been placed on the branching ratio for this process. This limit conflicts with the predictions of a 5-quark model (without top) which assigns the b quark to left- and right-handed singlets.

In the standard model of electroweak interactions [1], the left-handed b-quark is assigned to a doublet with the t quark. Flavour-changing neutral currents (FCNC) are then not allowed so that the b quark only decays via the charged currents. However, all attempts to detect either the bound toponium states or open top production have so far yielded negative results, so although the t quark may be found at higher energies, several theories have been suggested [2-4] which accommodate the possibility that it does not exist. One consequence of many of these theories is that the b quark would be expected to have a small - but non-zero - probability of decaying by an FCNC process to another charge $-\frac{1}{3}$ quark together with a fermion - antifermion pair. A specific prediction [2], based on the assumption that the b quark exists as left- and right-handed singlets, is that the inclusive dimuonic branching ratio for the decay of B hadrons should be about 2.5%.

In the experiment reported here the JADE detector at PETRA was used to investigate those high energy e^+e^- interactions which produced pairs of oppositely charged prompt muons in multihadronic events. (In the present context, a prompt muon is one which has been produced in the decay of a hadron containing a b or a c quark). The quark decay under investigation was

$$b \to \mu^+\mu^- + s \text{ (or d)}$$

and the overall process involved was

$$e^+e^- \to \mu^+\mu^- + \text{anything.}$$

The data were taken during 1980 and 1981 at centre of mass energies in the range from 33.0 GeV to 36.7 GeV and correspond to an integrated luminosity of about 30 pb^{-1}. 10005 annihilation events with multihadronic final states were selected by the method described in a previous publication [5].

Muons were 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 [5]. For each event the muon selection program [6] extrapolated every charged particle track found by the jet chamber pattern recognition program [7] outwards into the muon filter as if it were a muon. All projected tracks which could be associated with a series of hits in the muon drift chambers and which had a momentum greater than 1.4 GeV/c were accepted as candidate muon tracks. The criteria adopted in this search were designed to achieve high efficiency which was gained at the cost of relatively poor background rejection. Computer reconstructions of all events which had at least two candidate muon tracks were visually examined and 90 events each of which had two such tracks and one event which had three were finally accepted. A typical candidate dimuon event is shown in Fig. 1.

The Lund Monte Carlo program [8] was used to assess the efficiency of the selection criteria, the amount of background in the muon candidate sample and the significance of the observed dimuon signal. The branching ratio for the process $B \to \mu\nu X$ was assumed to be 12% [9] and the $B \to \psi X$ decay mode was not simulated [10]. In addition, the fragmentation functions given in ref. [11] were used.

Hadronic events were generated by the Monte Carlo program and processed by routines which determined the trajectory of each particle through the JADE detector and which took into account the effects of nuclear interactions [12], decays, energy loss and the resolution of the apparatus. The simulated events were then subjected to the same analysis and selection programs as the real data so that the efficiency of these routines could be determined.

The final estimate of the background in the muon sample was carried out by the following procedure. The passage through the detector of single particles of known type ($\mu^\pm$, $\pi^\pm$, $K^\pm$, p and $\bar{p}$) and known momentum was simulated and analysed with the selection criteria described above and the probability of a given hadron faking a muon by punch-through or decay was parametrised as a function of momentum. The parametrisation was then applied to the tracks of a statistically large sample of Monte Carlo events. By considering all possible pairs of particles, a combined probability that an event contained two (or more) muon candidates was calculated. Each track combination was classified according to the jet assignments (whether the tracks projected into the same or opposite hemispheres around the thrust axis of the event) and the charge combination (+ +, − −, + −). Thus the Monte Carlo events were grouped into four categories; the resulting "quadrant plot" is shown in Table 1. Separate totals, normalised to the number of multihadronic events in the data sample, were kept for prompt dimuon events and for background events where at least one of the penetrating tracks was not caused by a prompt muon. Both the total quadrant plot and its prompt dimuon component are shown in the table; the errors are purely statistical and do not represent any other uncertainties in the Monte Carlo model.

The dimuon events from the real data were also classified according to the charges of the muons and their assignment to jets and the resulting quadrant plot is also shown in Table 1. (For the one trimuon event, entries were made for each of the three possible muon pairs.) The agreement between the real data and the Monte Carlo data is quite good in all quadrants. FCNC decays of b quarks would produce muon pairs of opposite sign in the same jet and there is no indication of the data showing any excess over the Monte Carlo in that sector of the quadrant plot.

Further Monte Carlo studies using the same single-particle parametrisations showed that, whereas the number of background and normal (i.e. non-FCNC) dimuon events falls sharply as the opening angle between the two muons is increased, the number of FCNC dimuon events (approximated using the V-A matrix element) increases to a maximum at an opening angle around 40°. The Monte Carlo and real data distributions are shown as a function of the muon opening angle in Fig. 2. The relative sensitivity to FCNC events was therefore enhanced by imposing a minimum opening angle cut of 12° which left 12 real data and 15.5 normal Monte Carlo events. The overall acceptance of the system to the two muons from the FCNC decay was determined to be 32%. This figure includes the geometrical acceptance of the muon filter, the efficiencies of the analysis and selection routines and the probability of both prompt muons having a momentum greater than 1.4 GeV/c and an opening angle greater than 12°. At the 95% confidence level (C.L.) the difference between the data and the Monte Carlo prediction

implies that the branching ratio for the FCNC process $B \to \mu^+\mu^-X$ is less than 0.7% [13]. If this branching ratio were 2.5%, as in ref. [2], a total of 29.7 events would be predicted compared with the 12 events observed.

A similar experiment has been performed by the Mark J collaboration who also quote an upper limit for the same FCNC process of 0.7% at 95% C.L. [14]. The CLEO collaboration at CESR has combined its results from the investigation of dimuon and dielectron events at the Υ(4S) to give an upper limit on the FCNC process $B \to \ell^+\ell^-X$ of 0.35% at 95% C.L. [15].

All of these limits are significantly below the 2.5% branching ratio predicted by the 5-quark model which treats the b quark as left- and right-handed singlets. Another prediction [4] which is less sensitive to the theoretical uncertainties of the 5-quark model is that the ratio of the branching fractions

$$\frac{B \to \mu^+\mu^-\ X}{B \to \mu\nu\ X}$$

should be >0.12. The upper limit on this ratio obtained from the present data assuming a branching ratio of 12% for the process $B \to \mu\nu X$ [9] is 0.06 at 95% C.L., again in conflict with the predictions.

In conclusion, this experiment has placed an upper limit of 0.7% at 95% C.L. on the FCNC decay of B hadrons to $\mu^+\mu^-X$. This limit rules out a 5-quark model where the b quark is treated as a weak singlet. The result, however, agrees with the predictions of the standard 6-quark model in which the top quark is assumed to exist.

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 also like to thank Dr. T. Sjöstrand for his helpful comments. This experiment was supported by the Bundesministerium für Forschung und Technologie, by the Education Ministry of Japan and by the UK Science and Engineering Research Council through the Rutherford Appleton Laboratory. One of us (C.K.B.) would like to thank the Royal Society, London for financial support. The visiting groups at DESY wish to thank the DESY directorate for their hospitality.

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9. The following values of the branching ratio for the decay $B \rightarrow \mu\nu X$ have recently been reported.

   CLEO Collab., K. Chadwick et al., Phys. Rev. D27 (1983) 475: (12.4 ± 1.7 (stat) ± 3.1 (syst))%.

   Mark J Collab., B. Adeva et al., DESY 83-029: (10.5 ± 1.5 (stat) ± 1.3 (syst))%.

   TASSO Collab., D. Lüke, Proc. 21st Int. Conf. on High Energy Physics (Paris, 1982) p C3-67: (15.0 ± 3.5 (stat) ± 3.5 (syst))%.

   The present analysis used an average of 12% for this branching ratio. The final result for the FCNC limit rises to 0.8% if a 10% branching ratio is used.

10. A preliminary upper limit of 1.4% for the branching ratio for $B \rightarrow \psi X$ has been reported by the CLEO Collab., B. Gittelman, Proc. 21st Int. Conf. on High Energy physics (Paris, 1982) p C3-110.

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13. The FCNC limit obtained from this analysis increases to a maximum of about 1% on varying the opening angle cut by ±10° from the chosen value of 12°.

14. Mark J Collab., B. Adeva et al., Phys. Rev. Lett. 50 (1983) 799.

15. CLEO Collab., preliminary result presented by E.H. Thorndike at the XVIII Rencontre de Moriond (La Plagne, France, March 1983).

Figure Captions

Fig. 1 Reconstruction of a typical candidate dimuon event.

The two penetrating tracks are in opposite jets and have opposite charges.

Fig. 2 Distributions of the opening angle between the opposite sign, same jet penetrating tracks in the candidate dimuon events.

(a) Monte Carlo simulation for normal (non-FCNC) and background dimuon events.

(b) Monte Carlo simulation for the FCNC dimuon events only (assuming a V-A matrix element and with arbitrary normalisation).

(c) Real data.

		Charges of the Tracks	
		(++)or(--)	+-
Assignment of the Penetrating Tracks	Same Jet	8	20
	Opposite Jet	30	35

(a) Data

12.1±0.9	22.4±1.5
22.3±1.6	30.0±1.8

(b) Monte Carlo : Prompt dimuons + background

0.19±0.04	3.18±0.20
2.16±0.16	8.56±0.53

(c) Monte Carlo : Prompt dimuons only

Table 1. The quadrant plots showing the charge combinations and jet assignments of the 2 penetrating tracks in the dimuon candidate events of both the data and the Monte Carlo simulation (assuming no flavour-changing neutral currents).

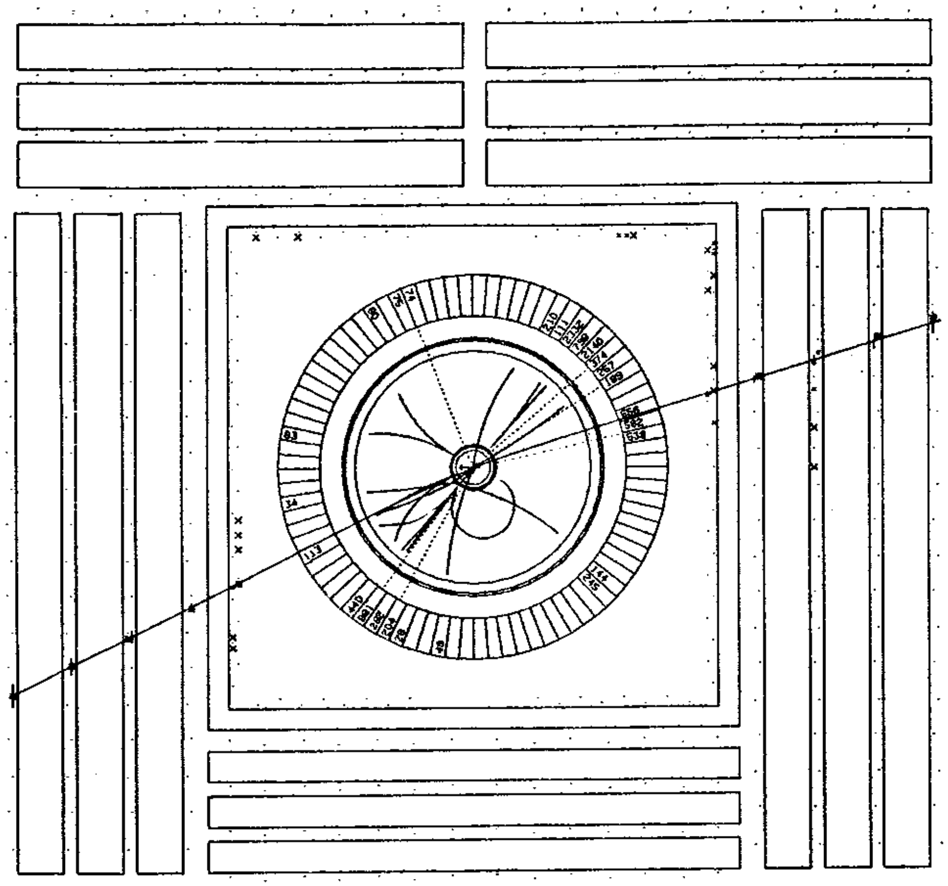

FIG. 1

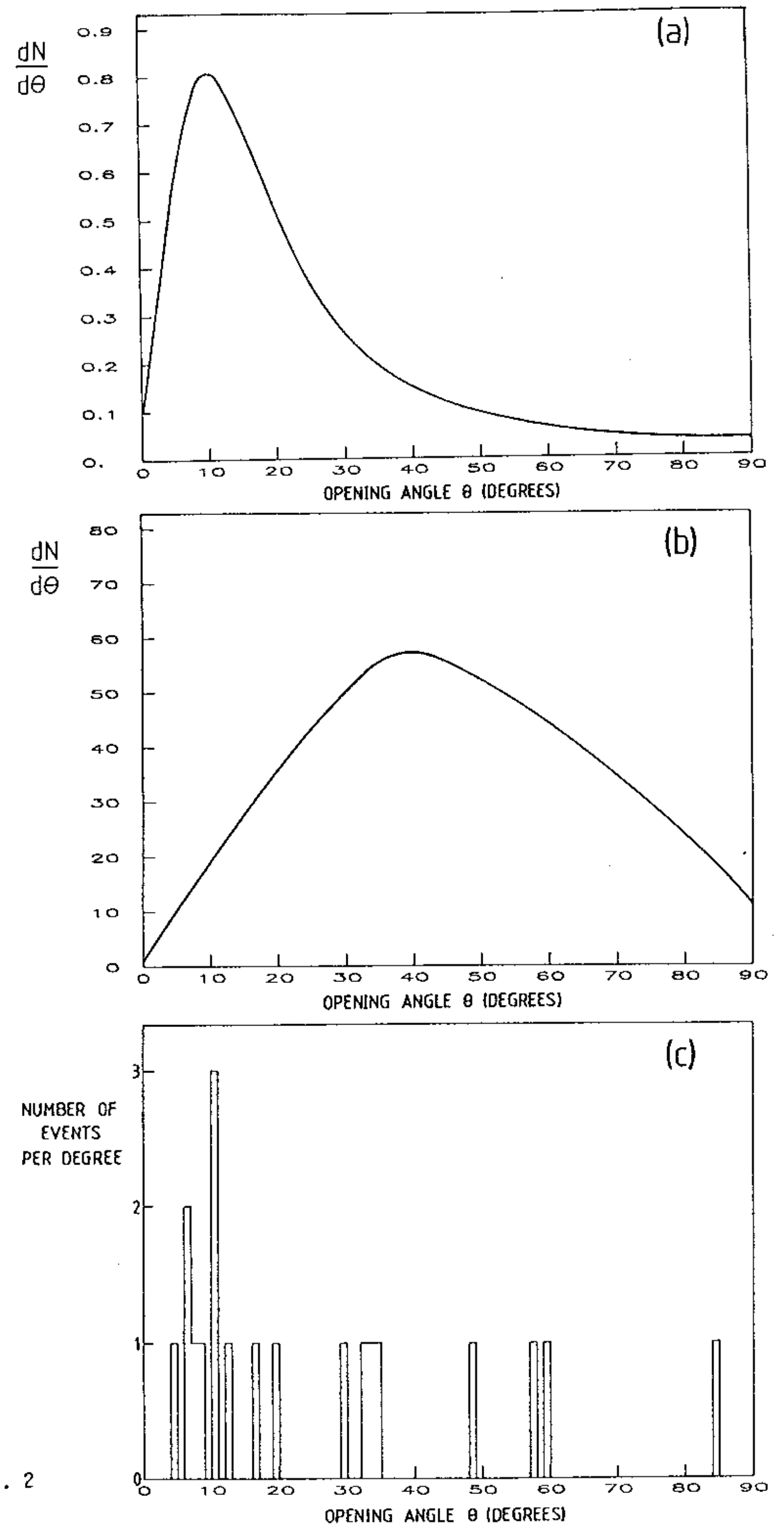
(a)
dN/dθ
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
0
10
20
30
40
50
60
70
80
90
OPENING ANGLE θ (DEGREES)
(b)
dN/dθ
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
OPENING ANGLE θ (DEGREES)
(c)
NUMBER OF EVENTS PER DEGREE
3
2
1
0
0
10
20
30
40
50
60
70
80
90
OPENING ANGLE θ (DEGREES)

Fig. 2