A MEASUREMENT OF THE MEAN SEMI-MUONIC BRANCHING RATIO OF B HADRONS PRODUCED AT PETRA

JADE Collaboration

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Received 29 July 1985

A measurement has been made of the mean semi-muonic branching ratio for the decay of b-flavoured hadrons produced in e^+e^- annihilation events at PETRA. The result, $(11.4 \pm 1.8 \pm 2.5)\%$, agrees well with other recent measurements and is consistent with the predictions of the spectator model with QCD and non-spectator corrections.

For footnotes see next page.

The weak decay of hadrons containing the b quark proceeds via the charged weak current and the leptonic coupling to the W ensures that a fraction of these decays will produce a "prompt" muon. For the heavy b quark states, the decay process is expected to be described, to a good approximation, by the spectator model where all the dynamics of the decay are determined by the b quark. In this model, the semi-muonic branching ratios of all weakly decaying hadrons containing a b quark (B's) are expected to be similar and, once QCD corrections have been incorporated, of order 12–15% [1,2]. A reduction of up to 20% of this predicted value is expected when non-spectator processes are taken into account. In the experiment reported here the mean semi-muonic branching ratio for the decays $B \to \mu\nu X$ has been measured.

The JADE detector [3] at PETRA has been used to collect a sample of high-energy e^+e^- annihilation events with multihadronic final states containing a muon. Subsequent analysis of the data enabled the number of events with prompt muons (produced in the decay of hadrons containing a b or a c quark) to be enhanced relative to those with non-prompt muons and other background events.

The data were taken at an average centre of mass energy of 34.6 GeV and correspond to an integrated luminosity of about 60 pb^{-1}. A sample of 21 419 annihilation events with multihadronic final states was selected by the method described in a previous publication [3]. Events containing a muon candidate were subsequently selected from this sample.

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. A full description of the muon-detection system and the procedure used for selecting prompt muons can be found in refs. [4,5], respectively. A summary of the main selection criteria is, however, given here for convenience. For each event the muon-selection programs extrapolated every charged particle track found by the jet chamber pattern recognition program [6] 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 1.8 GeV, were treated as candidate muon tracks. It was then necessary to enhance further the proportion of prompt muons relative to other candidate tracks. These other tracks could have been caused either by non-prompt muons (primarily from π and K decay) or by "punch-through" hadrons which either penetrated the layers of absorber without interaction or were produced as secondary particles in hadronic interactions in the absorber. This enhancement was achieved by requiring muon-candidate tracks to traverse a minimum of 5.8 absorption lengths, to cross at least 3 chamber layers and to have an associated chamber hit in every layer crossed. A total of 994 tracks satisfied all these criteria.

The LUND Monte Carlo program [7] was used to generate a sample of 54 000 multihadronic events which could be used both in the assessment of the efficiency of the selection criteria and in the final determination of the branching ratios. The symmetric LUND fragmentation function [8] was used for the u, d and s quarks; the values for the parameters of this function ($a = 1.0$, $b = 0.6$) had previously been chosen to give good agreement with JADE data [9]. The function of Peterson et al. [10] was used for the c and b quarks; the values used for the parameters of this function ($\epsilon_c = 0.05$, $\epsilon_b = 0.018$) were those measured by the DELCO Collaboration [11]. At this stage the semi-muonic branching ratios of the charmed hadrons (C's) given in ref. [12] were used. Taking into account the relative abundances of these hadrons as generated in the Monte Carlo, these ratios give a weighted average branching ratio of 8% for $C \to \mu\nu X$. A mean value of 12% for the semi-muonic branching ratio for B hadrons was assumed. Subsequently, values for these average branching ratios would be determined from a comparison of the present data with the Monte Carlo predictions.

The hadronic events which had been generated by the Monte Carlo program were processed by routines which determined the trajectory of each particle through the JADE detector and which took into account the effects of nuclear interactions, decays, energy loss and the resolution and efficiency of the apparatus. The simulated events were then subjected to the

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same analysis and selection programs as the data.

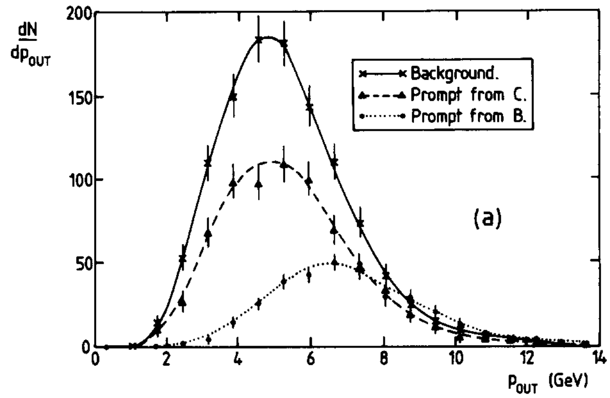
The purpose of the present experiment is to determine the relative proportions of each class of penetrating track needed in the overall Monte Carlo simulation so as to provide the best fit to the data. These proportions can be determined most accurately by comparing the distributions of muon candidates in the data and Monte Carlo simulation as a function of flavour-dependent quantities [13]. The independent weak decays of a heavy quark and anti-quark bias the event topology and this property is used to select two such quantities: p_{out}, the sum of the magnitudes of the momentum components normal to the apparent event plane of all detected particles, and p_T, the component of the muon momentum transverse to the reconstructed thrust axis.

p_{out} is flavour dependent since it has a contribution from the momentum component transverse to the primary quark direction given to particles produced in decays [14]. This contribution will be largest for the decay of heavy particles. There is also a contribution to p_{out} from the hadronisation process. The following definition of p_{out} is chosen as it is relatively insensitive to both small inefficiencies in particle detection in a given event and the choice of the longitudinal fragmentation function, and also because the distribution of p_{out} for each flavour is almost independent of the beam energy.

$$p_{out} = E_{CM} \sum_i |\hat{\boldsymbol{n}}_1 \cdot \boldsymbol{p}_i| \Big/ \sum_i |\boldsymbol{p}_i| ,$$

where $\boldsymbol{p}_i$ are the measured particle momenta, $\hat{\boldsymbol{n}}_1$ is the unit vector perpendicular to the event plane and the summation is over all charged and neutral particles detected in the event.

Fig. 1a shows separately the Monte Carlo distributions of p_{out} for three classes of events with muon candidates derived from background (non-prompt decay and punch-through), from prompt C decay (including $B \to C \to \mu$) and from prompt B decay. These classes have been chosen to facilitate the determination of the branching ratio and differ from those chosen in an earlier publication [15] to illustrate the flavour dependence of the variables. The total Monte Carlo distribution is compared with the data in fig. 1b. Here the Monte Carlo results have been normalised such that the total number of accepted multihadronic events prior to muon selection is the same for both the



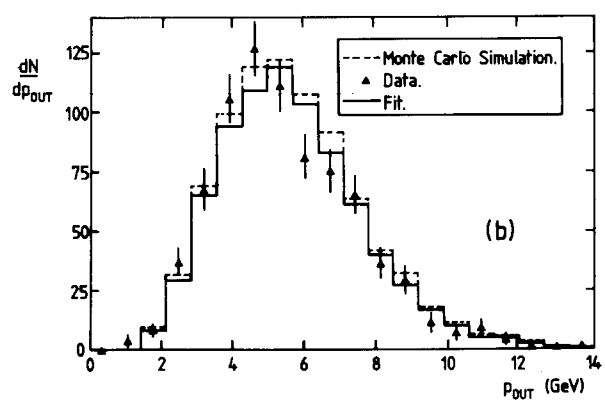


Fig. 1. (a) The distributions of p_{out} for the different sources of muon-candidate tracks generated by the Monte Carlo. The curves are shown to guide the eye. (b) Comparison of the distributions of p_{out} for the data, Monte Carlo simulation and maximum-likelihood fit.

Monte Carlo simulation and the data.

When a muon is produced in a decay the component of its momentum perpendicular to the direction of its parent will depend on the mass difference between the parent and daughter particles and will, therefore, be a flavour-dependent quantity. Here again, the distribution in this transverse quantity will not depend directly on the longitudinal fragmentation function. Fig. 2a shows the Monte Carlo distribution in p_T for each class of event and fig. 2b shows the comparison with the data.

In order to estimate the number of events in each category, a maximum-likelihood fit was performed in

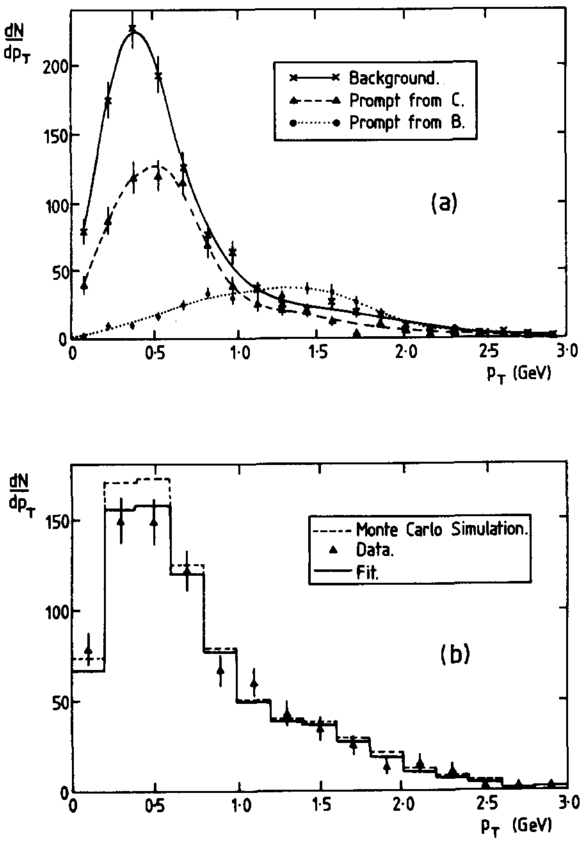


Fig. 2. (a). The distributions of p_T for the different sources of muon-candidate tracks generated by the Monte Carlo. The curves are shown to guide the eye. (b) Comparison of the distributions of p_T for the data, Monte Carlo simulation and maximum-likelihood fit.

bins of p_T and p_{out}. In this fit the fractions of all three sources of penetrating tracks were allowed to vary. The two-dimensional fit to the distributions reduces the correlations between the relative contributions and reduces the sensitivity of the semi-muonic branching ratio of the B hadrons to both the semi-muonic branching ratio for C hadrons and the number of background tracks. The fit, which is shown in figs. 1b and 2b, gives the following results:

fraction of background events = (45 ± 4)% ,

branching ratio ($C \to \mu\nu X$) = (8.9 ± 1.8)% ,

branching ratio ($B \to \mu\nu X$) = (11.4 ± 1.8)% .

The correlation coefficients between background and $C \to \mu$, background and $B \to \mu$, and $C \to \mu$ and $B \to \mu$ are −0.88, −0.13 and −0.10, respectively. The errors quoted are purely statistical but do take these correlations into account. The significant correlation between the background and the $C \to \mu$ sample tends to counteract the effect of the larger number of $C \to \mu$ events relative to the number of $B \to \mu$ events and leads to similar statistical errors being obtained for both branching ratios.

A background fraction of (52 ± 2)% had been predicted by the Monte Carlo [5] compared with the (45 ± 4)% given by the fit. The value of the $B \to \mu\nu X$ branching ratio is, however, relatively insensitive to this fraction; a fit which constrained the background to the Monte Carlo predictions gave a value of (11.0 ± 1.8)% for this branching ratio.

The systematic uncertainty in the branching ratios is dominated by a contribution of 2% arising from errors in the shapes of the p_T and p_{out} distributions. These errors arise primarily from uncertainties in the reconstruction of the thrust axes and event planes. Smaller contributions to the systematic error come from uncertainties in (a) the detection efficiency for muons generated by the Monte Carlo (1%), (b) the fragmentation parameters (varying ϵ_c and ϵ_b over the ranges 0.026–0.072 and 0.009–0.030, respectively, leads to changes in the branching ratios of less than 0.6%) and (c) the background of $\tau^+\tau^-$ and two-photon events in the data (0.2%). The resulting overall systematic error in the semi-muonic branching ratios is estimated to be ±2.5%.

In conclusion, a mean value for the semi-muonic branching ratio of B hadrons has been determined to be (11.4 ± 1.8 ± 2.5)%. This result is in excellent agreement with other recent measurements which have, after adding the statistical and systematic errors in quadrature, an average value of (11.4 ± 1.3)% [1,16]. The result is also consistent with the predictions of the spectator model with QCD and non-spectator corrections. A mean value for the semi-muonic branching ratio of c-flavoured hadrons has also been determined. The result, (8.9 ± 1.8 ± 2.5)%, is also consistent with the average value of (9.5 ± 1.1)% obtained by other recent experiments [16].

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. The experiment was supported by the Bundesministerium für Forschung und Technologie, by the Ministry of Education, Science and Culture of Japan, by the UK Science and Engineering Research Council through the Rutherford Appleton Laboratory and by the US Department of Energy. The visiting groups at DESY wish to thank the DESY directorate for the hospitality extended to them.

References

[1] S. Stone, Proc. 1983 Intern. Symp. on Lepton and photon interactions at high energies, eds. D.G. Cassel and D.L. Kreinick (Newman Lab., Cornell University, Ithaca, 1983) p. 203.
[2] R. Rückl, CERN preprint, CERN-TH 4013/84.
A. Soni, Phys. Rev. Lett. 53 (1984) 1407.
[3] JADE Collab., W. Bartel et al., Phys. Lett. 88B (1979) 171.
[4] J. Allison et al., Nucl. Instrum. Methods A238 (1985) 220.
[5] J. Allison et al., Nucl. Instrum. Methods A238 (1985) 230.
[6] J. Olsson et al., Nucl. Instrum. Methods 176 (1980) 403.
[7] T. Sjöstrand, Comput. Phys. Commun. 27 (1982) 243; 28 (1983) 229.
[8] B. Anderson et al., Phys. Rep. 97 (1983) 33.
[9] JADE Collab., W. Bartel et al., Z. Phys. C25 (1984) 231.
[10] C. Peterson et al., Phys. Rev. D27 (1983) 105.
[11] DELCO Collab., D.E. Koop et al., Phys. Rev. Lett. 52 (1984) 970;
S. Bethke, in: Proc. XXth Rencontre de Moriond (Les Arcs, 1985), to be published.
[12] Particle Data Group, M. Aguilar-Benitez et al., Phys. Lett. 111B (1982) 1.
[13] R. Marshall, Z. Phys. C26 (1984) 291.
[14] JADE Collab., W. Bartel et al., Phys. Lett. 114B (1982) 71.
[15] JADE Collab., W. Bartel et al., Phys. Lett. 146B (1984) 437.
[16] CELLO Collab., H.J. Behrend et al., Z. Phys. C19 (1983) 291;
CLEO Collab., K. Chadwick et al., Phys. Rev. D27 (1983) 475;
CUSB Collab., G. Levman et al., Phys. Lett. 141B (1984) 271;
MAC Collab., E. Fernandez et al., Phys. Rev. Lett. 50 (1983) 2054;
MARK J Collab., B. Adeva et al., Phys. Rev. Lett. 51 (1983) 443;
MARK II Collab., G.G. Hanson, Proc. Intern. Europhysics Conf. on High energy physics, eds. J. Guy and C. Costain (Rutherford Appleton Laboratory, 1983) p. 147;
TASSO Collab., M. Althoff et al., Z. Phys. C22 (1984) 219.