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LIFETIME MEASUREMENTS FOR BOTTOM HADRONS*

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The determination of the lifetimes of bottom (b) hadrons is still in its infancy. A first measurement had been performed by JADE.[1] Analysing the distribution of the impact parameter δ for muons from semileptonic b-decay they had obtained an upper limit of 1.4 psec. Last year, the MAC[2] and MKII[3] groups following the same method reported the first positive lifetime values, ($1.8\pm0.6\pm0.4$) psec (MAC) and ($1.2+0.45-0.36\pm0.30$) psec (MKII). These values indicated a much larger lifetime and hence a much smaller (bc) mixing angle than previously anticipated.

At this conference four groups reported new results: MAC,[4] DELCO,[5] and JADE[6] using leptons and TASSO[7] studying the distribution of all charged particles from b-decay.

The impact parameter δ is defined as the distance of closest approach between a track and the production vertex, projected into the plane perpendicular to the beams where the precision is best. For relativistic decay particles the lifetime τ is related to the average δ by $\tau = f \cdot \langle\delta\rangle/c$, where $c = 3.10^{10}$ cm sec^{-1}, and f is a geometrical factor of the order of 2.

The MAC data were based on a total of 75,000 multihadron events taken at a c.m. energy $W = 29$ GeV. In order to enrich the contribution from $b\bar{b}$ events the leptons were required to have momentum $P_\ell > 2$ GeV/c and transverse momentum w.r.t. to the jet axis $P_{\ell T} > 1.5$ GeV/c. The accuracy with which δ could be measured was on average $\sigma_\delta = 550$ μm. A significant portion of σ_δ in this and all other experiments results from the broad beam spread in the horizontal direction; e.g. in the case of MAC σ_δ(beam) = 350 μm.

According to Monte Carlo calculations, 18% of the lepton candidates stem from charm decay and roughly 30% are misidentified hadrons. Figure 1 shows the b distribution for muon (238 events) (a) and electron candidates (160 events) (b) and for both (c). A significant shift to positive values is observed, the median to the combined sample being $\langle\delta\rangle = 120 \pm 28$ μm.

The value of τ_b was deduced from $\langle\delta\rangle$ by comparison with Monte Carlo generated events. The result is sensitive to a series of input parameters describing b and c hadrons and the contribution from background, in particular to the $b(c)$ semileptonic branching ratio, the momentum spectra of leptons in the $b(c)$ rest system and of $b(c)$ hadrons in the overall c.m., and the lifetimes of c hadrons. Charm decays and background were found to contribute only $5-10$ μm to $\langle\delta\rangle$. A possible bias to the measurement of δ was determined from a control sample to be < 10 μm. The observed value of $\langle\delta\rangle$ was therefore attributed mainly to the b lifetime yielding

$$\tau_b = (1.6 \pm 0.4 \pm 0.3) \text{ psec} \ .$$

DELCO studied electrons obtained from $\sim 42{,}000$ multihadron events at $W = 29$ GeV. The electrons were identified

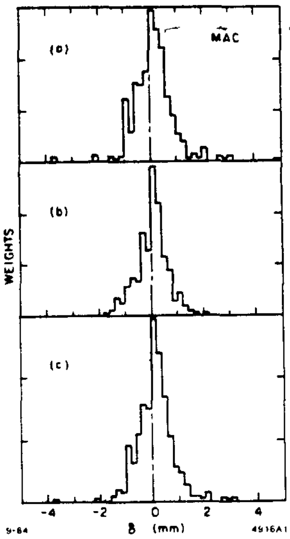

Figure 1

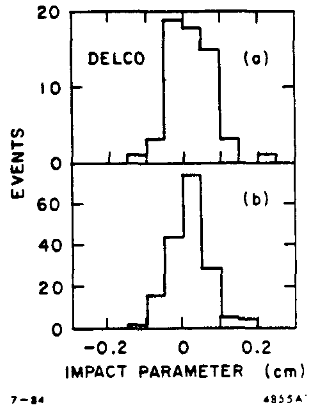

Figure 2

by means of Cerenkov counters. The superior electron identification permitted DELCO to accept rather small electron momenta. b and c enriched electron samples were defined by requiring $P_{eT} > 1$ GeV/c (60 candidates) and $P_e > 1$ GeV/c, $P_{eT} < 1$ GeV/c (128 candidates), respectively. The background from misidentified hadrons was small (see Table 1). The fraction of electrons from direct $b(c)$ decays was estimated to be 77% (49%) for the $b(c)$ region. Figure 2 shows the δ distributions for the two data samples with means of $\langle\delta\rangle = 215 \pm 81$ μm for the b region and 137 ± 54 μm for the c region. Fixing the lifetimes of charmed particles to their measured values, the b lifetime was found to be

$$\tau_b = (1.16 + 0.37 - 0.34 \pm 0.23) \text{ psec} \ .$$

Several cross checks were made to test the reliability of the method. Analysis of τ pair production leading to $1+3$ charged particle events yielded a τ lifetime of (0.29 ± 0.08) psec in good agreement with measured data.[8]

JADE analysed 22,000 multihadron events at $W = 35$ GeV. Two methods were applied to extract τ_b. In the first method a set of cuts provided a sample of b-enriched events yielding a total of 74 muon (25 electron) candidates with $P_{\mu T} > 0.9$ GeV/c ($P_e > 1.5$ GeV/c). $71 \pm 4\%$ (88%) of the $\mu(e)$ stem from b decay. The mean error of δ for these lepton tracks was $\sigma_\delta = 480$ μm. The average δ values were 282 ± 66 μm for muons and 457 ± 107 μm for electrons, leading to $\tau_b =$ ($1.76+0.59-0.35$) psec and ($1.82+1.00-0.6$) psec, respectively. Cross checks showed that the average δ of hadronic tracks was small (42 ± 21 μm) and that for τ leptons the correct lifetime value was obtained (0.35 ± 0.11) psec. The second method used weighted distributions. $b\bar{b}$ events with semimuonic decay

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are characterized by a large $P_{\mu T}$ and broad jets producing a sizeable aplanarity A. For each event with given $P_{\mu T}$ and A the probabilities were calculated that it is or is not a genuine $b\bar{b}$ event. Figure 3 shows the δ distribution for the signal (a) and the noise (b) with average values $\langle\delta\rangle = 195 \pm 62\ \mu m$ and $74 \pm 39\ \mu m$. The first yielded $\tau_b = (1.7 \pm 0.5)$ psec. Combining all results yielded the final value,

$$\tau_b = (1.8 + 0.5 - 0.3 \pm 0.4) \text{ psec} \quad .$$

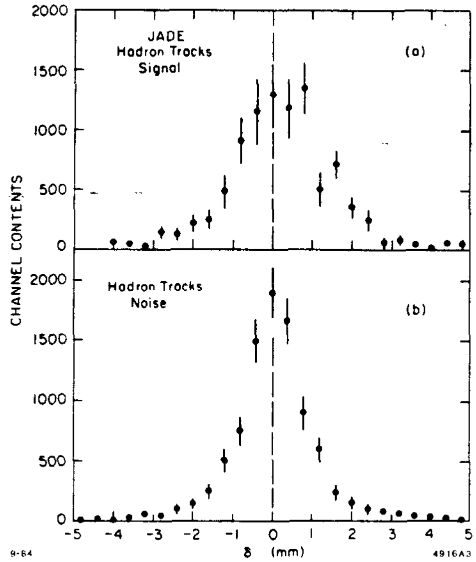

Figure 3

The TASSO reusults were obtained with two different configurations of the detector. In the first analysis based on 22473 events at $W = 34.6$ GeV δ was measured by the drift chamber with a precision of $\sigma_\delta = 1100\ \mu m$. The second data set of 2001 events at 43.3 GeV was taken after installing a vertex detector which in combination with the drift chamber yielded $\sigma_\delta = 380\ \mu m$ ($\sigma_\delta \simeq 100\ \mu m$ if the beam sizes were zero).

The b-lifetime was measured using all charged particles rather than considering only leptons from b decay. An essential ingredient to this method is the fact that since the mean charged multiplicity in the decay of B mesons is ~ 5.8 the B impact parameter enters $\simeq 11.6$ times for an average $b\bar{b}$ event while charmed meson decays yield only 4.6 entries per $c\bar{c}$ event. Furthermore, since a given event contributes several tracks to the δ distribution uncertainties in the beam position tend to cancel.

Event shape cuts were used to select samples of b enriched (32% $b\bar{b}$, 35% $c\bar{c}$) and b depleted (6% $b\bar{b}$, 37% $c\bar{c}$) events. To suppress contributions from K^0, Λ decays and from multiple scattering only particles with $p > 1$ GeV/c were accepted. Figure 4(a) shows the δ distribution obtained with the vertex detector for the b enriched (716 tracks) and b depleted events (2821 tracks). The b enriched sample shows an excess of positive values while the b depleted data are almost symmetric around $\delta = 0$. This is seen also from Figs. 4(b,c), where the asymmetries ($F(\delta) = (N(\delta) - N(-\delta))/(N)_{tot}\Delta$) are shown ($N(\delta)$ is the number of tracks in $\delta \pm 1/2\Delta$). The lifetime τ_b was determined by comparing the average δ with the Monte Carlo predictions for different τ_b values (see Table I). The b enriched events yielded $\tau_b = (1.85 \pm 0.48)$ psec (DC) and (1.80 ± 0.57) psec (VDC). Various checks were performed to test the method, e.g., the lifetime τ_c was determined from the b depleted events for which $< \delta >$ is dominated by τ_c. A value of $\tau_c = (1.3 \pm 0.3) \cdot \tau_c$ (nominal) was obtained. Combining the two measurements yielded the final result,

$$\tau_b = \left(1.83 {}^{+0.38\,+0.37}_{-0.37\,-0.34}\right) \text{ psec} \,.$$

TABLE I

	No. tracks	$\langle\delta\rangle$ (μm)	MC prediction for $\langle\delta\rangle$ $\tau_b = 0$	$\tau_b = 1.8$ psec
a) Drift Chamber (DC)			(μm)	(μm)
All events	48,800	63 ± 6	41 ± 2	68 ± 1
b enriched	7,526	105 ± 13	40 ± 5	107 ± 5
b depleted	28,682	58 ± 8	40 ± 2	48 ± 2
b) Vertex + Drift Chamber (VDC)				
All events	4,835	63 ± 9	33 ± 2	56 ± 2
b enriched	716	109 ± 23	32 ± 6	115 ± 2
b depleted	2,821	39 ± 12	33 ± 2	47 ± 2

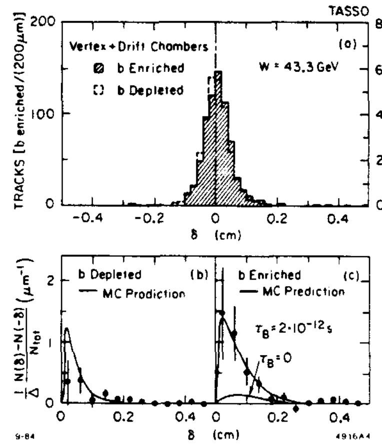

Figure 4

The average of the semileptonic measurements from MKII, MAC, DELCO and JADE is

$$\tau_b^\ell = (1.44 \pm 0.2 \pm 0.3) \text{ psec} \quad .$$

This values represents an average of τ_b weighted by the semileptonic branching ratios of B hadrons. The value from TASSO,

$$\tau_b^{tot} = \left(1.83 {}^{+0.38\,+0.37}_{-0.35\,-0.34}\right) \text{ psec}$$

represents an average over all B decays and can, in principle, differ from τ_b^ℓ (c.f. D^0 and D^+). Within errors the measured values of τ_b^ℓ and τ_b^{tot} agree with each other. The b lifetime can be related to the matrix element U_{bc} of the KM mixing matrix,[9] $\tau_b \approx 2.77 \cdot 10^{-3}$ psec $|U_{bc}|^{-2}$. Combining all τ_b measurements yields

$$|U_{bc}| = 0.0423 {}^{+0.0027\,+0.0051}_{-0.0023\,-0.0036}$$

and the same value for the Maiani mixing angle, $|\sin\gamma| \simeq |U_{bc}|$.

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