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MEASUREMENT OF THE b LIFETIME WITH MAC

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MEASUREMENT OF THE b LIFETIME WITH MAC

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ABSTRACT

In this talk, a recent measurement of the lifetime of particles containing the b quark is presented; the experiment was performed at PEP with the MAC* detector using $b\bar{b}$ events produced in e^+e^- annihilation at $E_{cm} = 29$ GeV. The distribution of the impact parameter of high p_{\perp} leptons was studied to determine $\tau_b = (1.8^{+0.6}_{-0.4}) 10^{-12}$ sec.

* MAC is a collaboration of: COLORADO, FRASCATI, HOUSTON, NORTHEASTERN, SLAC, STANFORD, UTAH, WISCONSIN.

MAC is one of the five experiments that are currently taking data at PEP, the SLAC e^+e^- 29 GeV storage ring. It is a detector whose strength lies mostly in the good lepton identification capability and in the large solid angle coverage, with total energy measurement. We have used these features to study a wide range of e^+e^- physics; in this talk I will only discuss the recent measurement of the lifetime of particles containing the b quark¹⁾.

Since at PEP energy no exclusive b state has been identified yet, it is not possible to measure directly the lifetime of a given B meson from its momentum and the secondary vertex distance. We have instead used the method of the "impact parameter": we select a sample of hadronic events which have one track that is likely to come from a B decay and study the distribution of the distance of minimum approach of this track respect to the center of the interaction region.

It is well known that $c\bar{c}$ and $b\bar{b}$ events can be "tagged" through the semileptonic decays of D's and B's, by selecting multihadronic events containing a lepton. Since the b quark is about 3 times heavier than the c quark, leptons from B decay tend to be emitted wider angle and can be identified for having high p_{\perp} respect to the thrust axis, which is in turn close to the B direction. A cut in p_{\perp} will then provide a way to select a "b enriched" sample of events; from the distribution of the impact parameter of the lepton track, the average lifetime of the mixture of B particles produced at 29 GeV can be inferred. I cannot enter in further analysis details without giving first a brief description of the apparatus and of the criteria used to select the event sample²⁾.

A sketch of the detector is shown in Fig. 1: the Central Drift Chamber, (CD in the following), provides tracking and momentum measurement ($\sigma(p_{\perp})/p_{\perp}=0.065p_{\perp}$) of the

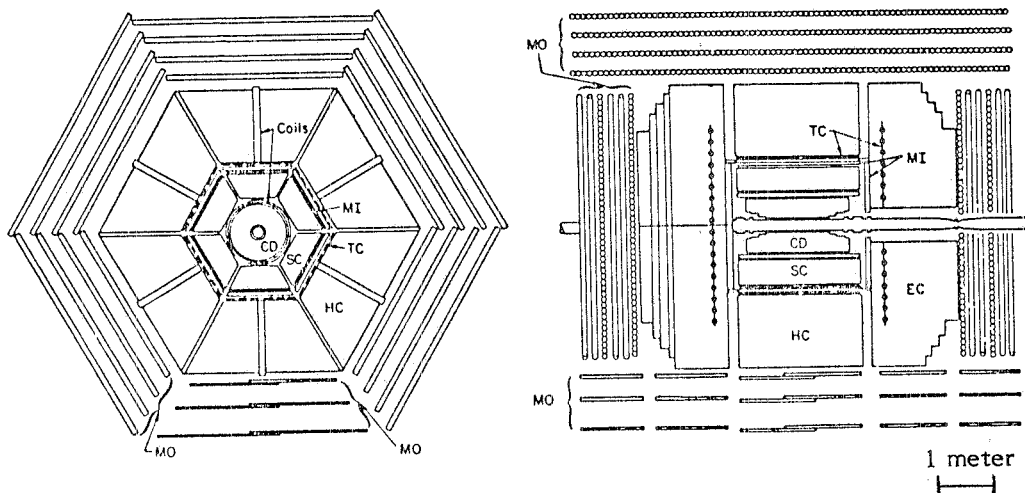
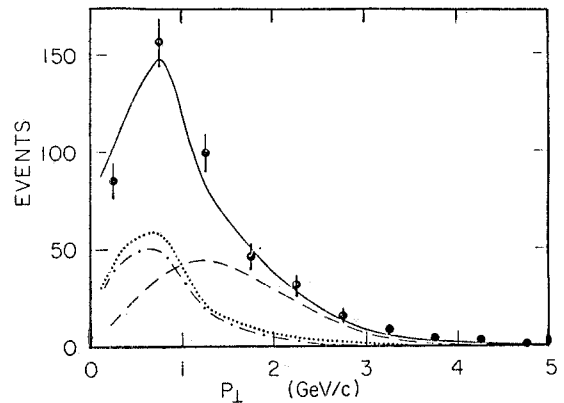


FIG. 1 - MAC (Magnetic Calorimeter): CD = central drift chamber, SC = electromagnetic shower chamber, HC = hadron calorimeter, EC = endcap calorimeter, TC = trigger scintillators and MI, MO = muon tracking chambers.

charged particles; it has 10 layers of sense wires, a spatial resolution per point of 200 μm ; since the inner radius is of 12 cm, it can practically be considered a vertex detector. The CD is immersed in a magnetic field of 5.7 KGauss, produced by a solenoidal coil, 1 m in diameter. Outside the coil there is the system of calorimeters: a lead-proportional tubes sandwich for the Shower Chamber (SC) and iron-proportional tubes for the Hadron Calorimeter and the End Caps (ED); the thickness of the SC is 15 r.l., while the hadron absorber is $6 \lambda_s$. The iron is magnetized by toroidal coils which produce a field of ~ 18 KGauss; on the outside 4 layers of drift tubes provide muon tracking over 97% of the total solid angle.

This analysis was performed on a data sample corresponding to an integrated luminosity of 108 pb^{-1} ; we started by selecting events having 5 or more charged prongs and energy flow consistent with a single photon annihilation process³⁾; we obtained a sample of $\sim 50,000$ multihadrons. The direction of the thrust axis was determined from the energy hits in all the calorimeters; muon or electrons candidates were searched for, requiring a minimum momentum of 2 GeV/c, and a transverse momentum respect to the thrust axis of at least 1.5 GeV/c. In a previous study of the b fragmentation function, based on muons, we have shown that these cuts ensure a $b\bar{b}$ enriched sample, with low level of background (Fig. 2).

FIG. 2 - p_{\perp} spectrum of muons with $b\bar{b}$ (dashed-curve) $c\bar{c}$ (dot dashed curve) background (dotted curve) and total (solid curve) predictions.



Muons are identified as tracks in the external chambers which point toward the interaction region and match to a segment reconstructed from the energy deposited in the calorimeters (the pulse heights must be compatible with that of a minimum ionizing particle) and to a CD track. The actual cut was applied to the appropriate χ^2 , taking into account all the experimental resolutions and the effect of multiple scattering; typically, it corresponds to $\sim 1^\circ$ in polar angle, and is slightly momentum dependent.

Electron candidates were obtained requiring a track in the CD followed by energy deposition in the SC compatible with an electromagnetic shower. The set of cuts applied was obtained from the study of isolated electrons in the apparatus (radiative and non radiative bhabhas). Hadron misidentification probability was calculated by Montecarlo and also checked from the analysis of 3 charged prongs τ decays, where no leptons are present.

The final sample obtained consists of about 300 tracks, candidates for muons or electrons. To estimate the background, to study the c and b quarks decay products and their interactions in the detector, we have used a Montecarlo simulation in which all the known effects of the apparatus were reproduced⁵⁾.

The background was calculated to be (14+7)% in the muon sample, roughly divided in 6% from pion and kaon decays, and 8% from hadronic punch-throughs.

The background is higher for the electron sample, (25+8)% and is mainly due to misidentification of hadrons due to interaction in the SC, which fakes an electromagnetic shower; the contribution of accidental overlapping of a charged track and a photon, and that of electrons from other sources (γ conversions; π^0 , τ , ψ decays, etc.) is negligible, due the cuts in p and p_{\perp} .

For all these lepton tracks, the impact parameter δ respect to the center of the interaction region was measured, in the plane perpendicular to the beam axis. Fig. 3

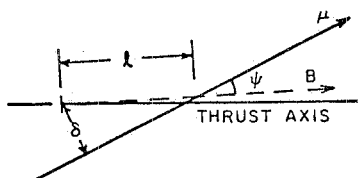


FIG. 3 - Direction vector and production and decay points relevant in B semileptonic decay.

shows the definition of δ , together with the decay angle ψ and the path length ℓ . It is important to point out that δ can be of either sign: it is defined positive if a particle leaving the origin in the direction of the thrust axis, toward the intersection with the lepton track, would decay in the lepton with a forward angle. In the case of the background, the experimental resolution will produce δ of both signs; for a true decay δ can be negative, even with perfect resolution, in two cases: if the decay is backward and if the lepton is emitted in between the parent direction and the thrust axis. This effect, which decreases the sensitivity of the method, has been studied in detail with a Montecarlo and has been found to be very small for B mesons, and larger for D's: for π or K decays, or for γ conversions, the cancellation is nearly complete.

The average value of the δ distribution is proportional to the lifetime:

$$\langle \delta \rangle = \langle \beta \gamma \sin \theta \sin \psi \rangle \quad c \tau \cong \alpha c \tau$$

where θ is the polar angle of the track. In first approximation α is Lorentz invariant: the decay angle ψ shrinks when the parent momentum increases at about the same rate at which the path length grows. The value of α , that is obtained by Montecarlo, is not sensitive to the parameters introduced to simulate the B and D mesons production and decay⁶⁾: fragmentation function, rates, etc.; we find α to be about 0.45 for bottom and 0.15 for charm.

We use our previously measured values for the b ⁴⁾, and the values reported in the literature for the c ⁷⁾; for the charmed particles lifetimes⁸⁾ we use, in units of 10^{-13} sec,

4.0 for D^0 , 9.3 for D^\pm , 2.9 for F^\pm , with a population-weighted average of 5.5; the expected $\langle \delta \rangle$ for charm and background is 20-30 μm , while for a b lifetime of 10^{-12} sec we would have

$$\langle \delta \rangle = (129 \pm 5) \mu\text{m}.$$

The error with which we measure δ is considerably larger than that: it is due to the effective size of the beam interaction area and depends on the precision of the extrapolation of the lepton track. We monitor the beam position on a run by run basis; from the fit to bhabha events we find that the effective rms beam size is about 0.4 mm (horizontal) by 0.1 mm (vertical).

The distribution of the global error in δ is shown in Fig. 4, all tracks having an

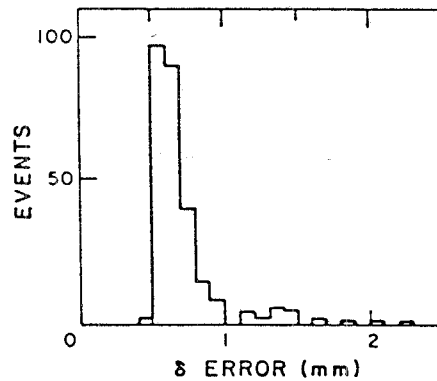


FIG. 4 - Distribution of measurement uncertainties of the impact parameter δ .

uncertainty bigger than 1 mm were removed from our sample; for the remaining leptons we plot the distribution of δ , weighted by the inverse squared of the error; the result is shown separately for muons and electrons in Fig. 5a) and 5b): in both cases the average value is sensibly bigger than zero:

$$\langle \delta_\mu \rangle = (158 + 81) \mu\text{m} \quad \langle \delta_e \rangle = (174 + 75) \mu\text{m}$$

To check the possibility of biases in our measurement, we have studied a control sample consisting of all tracks in our hadronic events satisfying the same cuts in p and p_\perp applied to the leptons; the δ distribution obtained with more than 18,000 tracks is shown in Fig. 5c), the average value is

$$\langle \delta \rangle = (34 + 8) \mu\text{m}$$

to be compared with a Montecarlo prediction from 20 μm (zero b lifetime) to 30 μm ($2 \cdot 10^{-12}$ sec b lifetime).

From the measured $\langle \delta \rangle$, the b lifetime can be inferred by unfolding the contribution of the components of the data sample:

$$\langle \delta \rangle = f_b a c \tau_b + f_c \delta_c + f_{bg} \delta_{bg}$$

where f_c includes the contribution of the cascade $b \rightarrow c \rightarrow$ lepton.

The values used are summarized in Table I: the b lifetime computed from the two

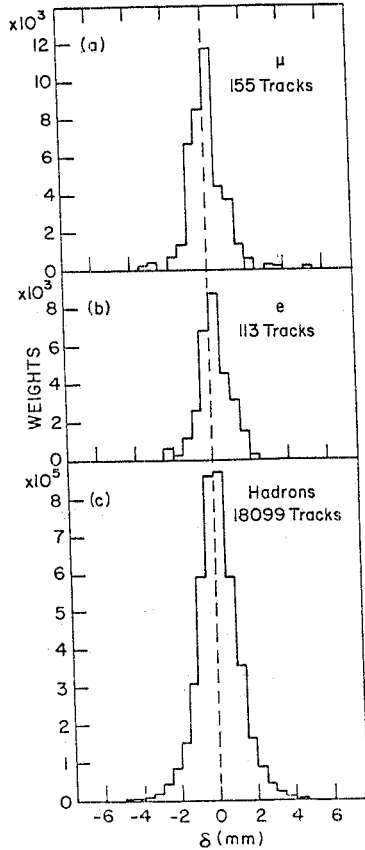


TABLE I

Summary of parameters used to compute τ_b .

	μ sample	e sample
No. of events	155	113
f_b	0.72 ± 0.08	0.63 ± 0.07
f_c	0.14 ± 0.04	0.12 ± 0.05
f_{bg}	0.14 ± 0.07	0.25 ± 0.08
$\delta_c (\mu m)$	24 ± 11	19 ± 11
$\delta_{bg} (\mu m)$	26 ± 8	24 ± 6
a	0.43 ± 0.03	0.46 ± 0.03
$\langle \delta \rangle (\mu m)$	158 ± 81	174 ± 75
$\tau_b (10^{-12} \text{ sec})$	1.62 ± 0.87	2.00 ± 0.84

FIG. 5 - Distribution of δ for (a) muons; (b) electrons; (c) hadrons.

samples are in good agreement, so we take the average as our best estimate:

$$\tau_b = (1.8 \pm 0.6 \pm 0.4) 10^{-12} \text{ sec}$$

where 0.6 is the statistical error and 0.4 is the systematic error, which takes into account the effect of the uncertainties in the Montecarlo inputs as reflected in the errors reported in Table I, plus an additional $30 \mu m$ error introduced in δ to account for other biases in the method of which we are not aware.

As a further test, we have applied the same method to measure a lifetime which is already known, i.e. the τ 's. We have used 1-3 charged prongs configurations of $\tau^+ \tau^-$ events and studied the impact parameter distribution of the single track. The effect expected is considerably smaller than the one we have measured for the b particles, but the event sample is statistically much richer, 2099 tracks.

We find

$$\langle \delta_{\tau} \rangle = (53 \pm 19) \mu\text{m}$$

with a value of α calculated to be 0.48 ± 0.04 and background fraction estimated to be 7%, we find

$$\tau_{\tau} = (3.9 \pm 1.4) 10^{-13} \text{ sec}$$

in very good agreement with previously reported values⁹⁾.

In conclusion, our measurement together with that of the MARK II group¹⁰⁾, gives the first glimpse on the b lifetime, which appears to be considerably longer than expected; in terms of the mixing angles it means that the mixing between second and third quark generation is much smaller than the mixing of first and second, i.e. $|V_{bc}| \leq |V_{su}|$. Using the limit reported by CUSB¹¹⁾:

$$\Gamma(b \rightarrow \ell \nu u) / \Gamma(b \rightarrow \ell \nu c) < 0.055$$

And assuming $m_b = 5 \text{ GeV}/c$, our result implies:

$$\begin{aligned} |\sin \gamma| &= 0.043 \pm 0.01 \\ \sin \beta &< 0.009 \quad (95\% \text{ c.l.}) \end{aligned}$$

REFERENCES

- 1) E. Fernandez et al., Phys. Rev. Letters 51, 1022 (1983)
- 2) For a more detailed description of the apparatus, see for example, W.T. Ford et al., in Proc. of the Inter. Conf. on Instrumentation for Colliding Beams, Ed. by W.W. Ash, SLAC Report No. SLAC-250 (SLAC, Stanford 1982).
- 3) The selection of multihadronic events is discussed in B.K. Heltsey, P.H.D. thesis, University of Wisconsin Report No. WISC-EX-83/233 (1983) unpublished.
- 4) E. Fernandez et al., Phys. Rev. Letters 50, 2054 (1983).
- 5) Electromagnetic showers are simulated by EGS, described in R.L. Ford and W.R. Nelson, SLAC Report No. SLAC-210, (1978) unpublished. Hadronic cascades are simulated by HETC, described in T.W. Armstrong in Computer Techniques in Radiation Transport And Dosimetry, Ed. by W.R. Nelson and T.M. Jenkins (Plenum, New York 1980).
- 6) Models used, are from Ali et al., DESY Report No. T80/d, (1980), and LUND University Report LU-TP-82-7 (1982).
- 7) For the c quark branching ratios, see: R. Brandelik et al., Phys. Letters 70B, 387 (1977), J.M. Feller et al., Phys. Rev. Letters 40, 1677 (1978), W. Bacino et al., Phys. Rev. Letters 43, 1073 (1979), R. Schindler et al., Phys. Rev. D24, 78 (1981).
- 8) For a revue, see for example, G. Kalmis in Proc. of the 21st Inter. Conf. on High Energy Physics, Paris, France (1982).
- 9) For high precision measurement, see J. Jaros et al., SLAC Pub. 3164 (1983), submitted to Physics Rev. Letters.
- 10) J. Jaros, these Proceedings.
- 11) Juliet L. Franzini, these Proceedings.