DETERMINATION OF THE B HADRON LIFETIME

USING THE L3 DETECTOR

G. Rahal-Callot

Inst. für Hochenergiephysik
ETH Zürich
Switzerland

ABSTRACT

The average B hadron lifetime has been measured, tagging the b quarks by the semileptonic decay of the Z^0 to $b\bar{b}$. The lifetime is extracted from a fit to the impact parameter distribution of the leptons, either electrons or muons. The result is: $\tau_B = (1.31 \pm 0.06(\text{stat}) \pm 0.08(\text{syst})\ )\text{ps}$

Introduction

The b-quark lifetime provides informations on the transition amplitudes of the b quark to lighter ones i.e. c and u quarks; these parameters of quark flavour mixing are fundamental elements of the Standard Model.

Experimentally, we measure an average lifetime of a mixture of B hadrons created during the fragmentation of the b-quarks. Due to the high mass of this quark, we expect the lifetime of the B-hadron to be similar to the one of the quark [1].

The L3 Detector

A full description of the L3 detector is given in reference [2]. The main components for our purpose are, from inside to outside:

- the central tracking device, a Time Expansion Chamber (TEC) which samples a charged track 62 times in the (R-ϕ) plane transverse to the beam line. The average single point resolution is 58μm, the double track resolution is 640μm. The chamber extends from an inner radius of 109.8mm to an outer radius of 427.2mm;
- the electromagnetic calorimeter composed of BGO crystals;
- the hadronic calorimeter, a sandwich of Uranium and Brass with proportionnal wire chambers for the readout;
- a precise muon chamber made of 3 layers of drift chambers. The track is sampled 56 times in the bending plane and 8 times in the direction parallel to the beam;
- the whole detector is included in a 12m diameter magnet which provides a uniform field of 0.5 T along the beam direction.

This system allows us to measure the direction of the jets with an angular precision of 2.5° and the total energy with a resolution of 10.2%.

Selection of B Events

The goal is to get a clean sample of hadronic events which contain at least one lepton coming from the semi-leptonic decay of the b or $\bar{b}$ quark. After this selection, we insure that we have a good quality muon or electron, using tight cuts on the muon chamber or the calorimeters respectively. Then these charged particles must match properly with a track well defined in the vertex chamber to insure a good extrapolation to the e^+e^- interaction point. We reject the tracks going through lower resolution regions in the TEC, i.e. near the cathode and the grid planes. The selection is described in the reference [3]. The main cuts which give us a very clean sample of prompt b decays are the momentum cuts:

- momentum cut in the BGO calorimeter or the Muon detector: p_{lepton} >4 GeV;
- cut on the transverse momentum in the TEC chamber: $p_{\perp lepton}$ >3.5 GeV;

- cut on the transverse momentum with respect to the jet axis: $p_{\perp_{muon}}$ >1.5 GeV or $p_{\perp_{electron}} > 1.0$ GeV.

The data sample corresponds to 5.5 pb^{-1} collected in 1990 using the L3 detector at LEP. The center-of-mass energies are distributed over the range $88.2 \leq \sqrt{s} \leq 94.2$GeV . From a total of 115000 hadronic events, we select

- 673 inclusive electrons;
- 712 inclusive muons;

The main contribution to this sample comes from $b \rightarrow \ell$ decays; However, there are other sources of high p, high $p_{\perp}$ leptons which contribute to the sample. The different contributions have been estimated by Monte-Carlo using the Lund generator with 5 flavors [4], and are listed in table 1.

category	μ P>4GeV $p_{\perp} > 3.5GeV$	e P>4GeV $p_{\perp} > 3.5GeV$
1: $b \dashrightarrow \ell$	82.1%	84.4%
2: $b \dashrightarrow c \dashrightarrow \ell$	5.3%	4.3%
3: $c \dashrightarrow \ell$	4.5%	1.7%
4:background dec	1.2%	0.2%
5:background mis	6.9%	9.4%

Table 1: Contribution to the sample from the different sources of leptons.

Impact Parameter Distribution

To extract the lifetime, we use the impact parameter distribution of the lepton track, i.e. the distance of closest approach of the lepton to the e^+e^- interaction point. Because the B-hadron direction is not known, it is approximated by the event thrust axis. The impact parameter is signed positive if the lepton intersects with the thrust axis in the direction of flight, negative otherwise. The distribution obtained is shown in figure 1 where one can see a clear shift of the mean towards positive values. Uncertainties in the measurement of the impact parameter come from the following sources:

- the experimental resolution σ_{trk} on the track parameters: this error is taken from the covariance matrix obtained after the fit of the track. It is adjusted to reflect the mean value of 144μm obtained while looking at the shortest distance between the two electrons in bhabha events;
- the error on the e^+e^- interaction point: Since the e^+e^- interaction point cannot be determined event by event, an average primary vertex is measured fill by fill using the whole sample of e^+e^- events. As one can expect from the LEP optics, this beam spot is elliptical. Its width has been determined using a clean dimuon and bhabha sample, and looking at the rms of the distance of closest approach

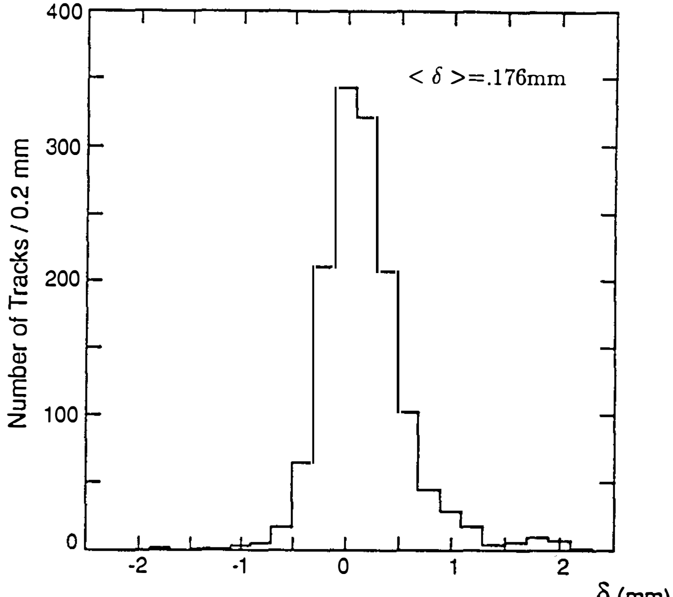

Figure 1: Impact parameter distribution

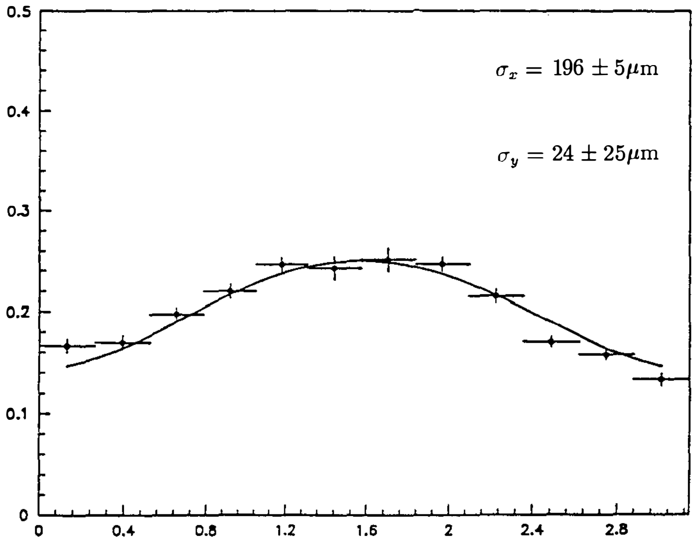

Figure 2: Width of the impact parameter distribution as a function of ϕ

in different bins of the ϕ angle. the variation of this variables reflects the biggest spread in the horizontal plane of the primary vertex. The values found for σ_x and σ_y are shown in the figure 2

- The mutiple scattering inside the Beryllium pipe: The multiple scattering contribution is small, typically 4μm for a track of 20GeV momentum.

All these error contribute to the resolution, added in quadrature:

$$\sigma^2 = \sigma_{trk}^2 + \sigma_{MS}^2 + \sigma_x^2 sin^2(\phi) + \sigma_y^2 cos^2(\phi)$$

The resolution function has been parametrized using a sample of tracks from either bhabha or $q\bar{q}$ events with no lifetime contribution. The figure 3 shows the distribution of the impact parameter divided by the error defined above. The distribution is centered at zero with an r.m.s. of 1 which shows that the error is well understood.

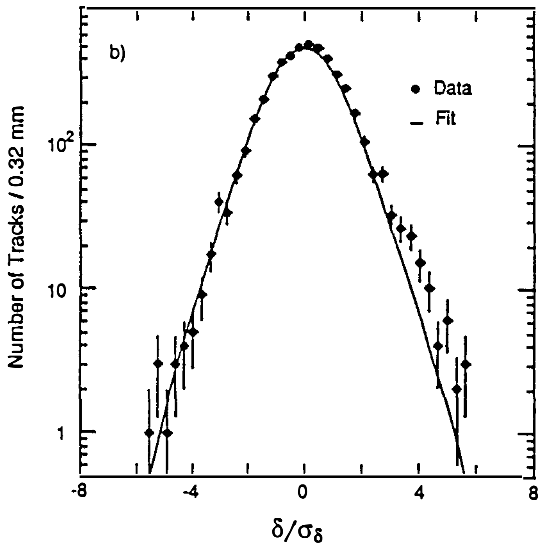

Figure 3: Fit of the resolution function

Extraction of the lifetime

An unbinned maximum likelihood fit is then performed, with contributions to the fit coming from all possibles sources of high p, high $p_\perp$ leptons, namely:

1: $b \to \ell$
2: $b \to c \to \ell$
3: $c \to \ell$
4: background decay

5: background from misidentified hadrons

The probability function is of the form:

$$P = \sum_i f_i P_i$$

where

- i is one of the contributions listed above.
- f is the fraction of the leptons coming from each contribution as determined from the simulation (Table 1).

The first three contributions are prompt lepton contributions and are parametrized with the same formula:

$$P_i = E(\delta, \tau_i) \otimes R(\delta, \sigma_\delta)$$

- R is the resolution function which contains the error on the impact parameter;
- E represents the impact parameter distribution of the decay of a particle with lifetime τ_i before it has been smeared by the Vertex Chamber resolution. It contains the uncertainty due to the fact that the B-hadron direction is approximated by the thrust axis. Figure 4-a shows for Lund Monte-Carlo events the impact parameter at the generator level after it has been signed by the thrust axis. A fit is done to this distribution, scaled by the lifetime (figure 4-b) , to parametrize E(δ, τ_i).

The contribution from background decay is very small and is parametrized by using Monte-Carlo events with a sample of tracks coming from π and K decays. The background from misidentified hadrons has been parametrized using our own data: we select tracks in $q\bar{q}$ events which meet the same selection criteria as our lepton sample but fail the lepton identification.

The result of the maximum likelihood fit is shown in the figure 5, together with the different contributions are drawn.

Consistency checks and systematics

sample	lifetime (ps)
muon sample	1.34±0.08
electron sample	1.28±0.08
$\|\sin\phi\| < .5$	1.26±0.10
negative leptons	1.38±0.09
positive leptons	1.24±0.08

Table 2: Consistency checks on the data

Consistency checks have been performed with sub-samples of the data to insure that the result obtained is stable (table 2). The systematic error has been estimated varying

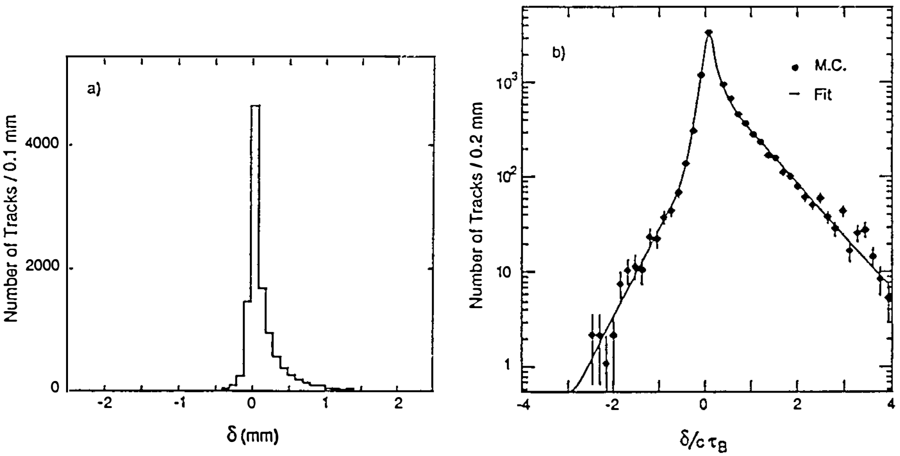

Figure 4: a:Impact parameter distribution for simulated events, b:scaled impact parameter distribution for simulated events

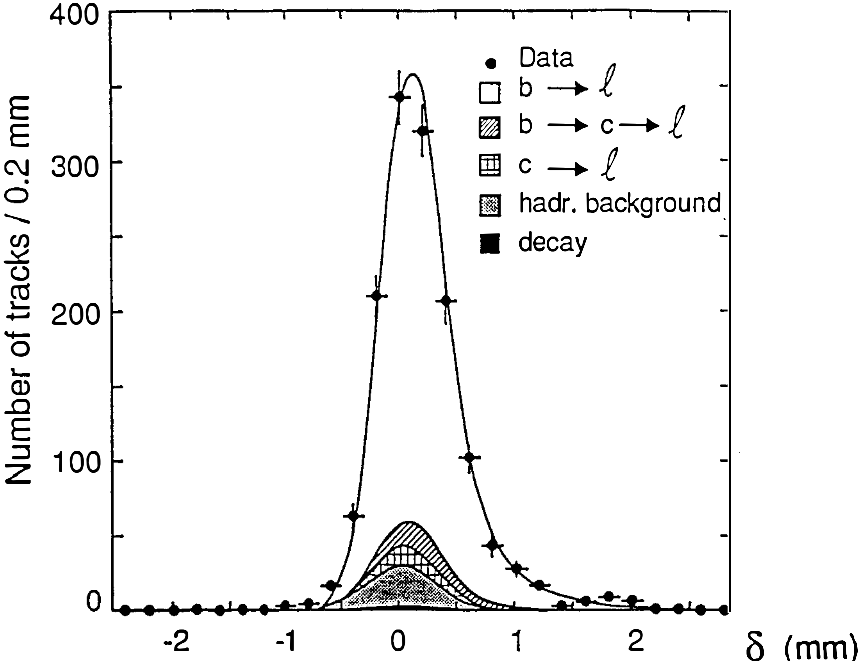

Figure 5: Result of the fit on the Impact parameter distribution

the differents elements which contribute to the extraction of the lifetime: The results are summarized in Table 3. The overall systematic error is 0.08ps.

Contribution	Error (ps)
changing the $b \to \ell$ branching ratio by the associated error	0.001
varying $\Gamma_{b\bar{b}}$ by 1σ	0.001
varying the b fragmentation parameter ϵ_b by $\pm 20\%$	0.001
varying τ_C by 20%	<0.001
varying $b \to \ell$ fraction by 30%	0.01
varying the shape of the background	0.03
varying $b \to \ell$ probability density function	0.05
varying $b \to c \to \ell$ probability density function	0.001
varying $c \to \ell$ probability density function	0.001
varying σ_δ in the resolution function by 10%	0.04
varying TEC drift velocity by 1σ	0.02
varying TEC time 0 by 1σ	0.02

Table 3: Details on the systematic error.

Conclusion

We have measured the lifetime of the B hadrons to be:

$$\tau_B = (1.31 \pm 0.06(\text{stat}) \pm 0.08(\text{syst}))\text{ps}$$

The accuracy of the measurement is already better than the previous world average (LEP excluded) which was : (1.18 ± 0.11)ps, and is in a good agreement with the previous LEP measurement from Aleph [5] $(1.29 \pm 0.06 \pm 0.11)$ps

References

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