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Updated Measurement of the Average b Hadron Lifetime

The ALEPH Collaboration

Abstract

An improved measurement of the average lifetime of b hadrons has been performed with the ALEPH detector. From a sample of 260,000 hadronic Z^0 decays, recorded during the 1991 LEP run with the Silicon Vertex Detector fully operational, a fit to the impact parameter distribution of lepton tracks coming from semileptonic decays yields an average b hadron lifetime of $1.49 \pm 0.03 \pm 0.06$ ps.

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1 Introduction

The b hadron lifetime has been measured in the past few years at PEP[1] and Petra[2] and more recently by the four LEP experiments[3, 4]. Up to now the precision achieved in the measurement has been limited by the resolution of the tracking devices or by the amount of available statistics. In 1991 260,000 hadronic Z^0 decays were recorded by the ALEPH detector upgraded with a silicon vertex detector[5] and with a second two layer stack of muon chambers. At the same time significant improvements were made in the selection of $Z^0 \to b\bar{b}$ events. This has allowed a new, high precision measurement of the b lifetime, which supersedes the 1990 ALEPH measurement[3].

In the present analysis the same technique as the previous ALEPH measurement is used. A high purity sample of semileptonic b decays is selected by means of the characteristically high transverse momentum of the leptons with respect to the jet axis. Then the signed impact parameter distribution of the lepton tracks, relative to the reconstructed primary vertex, is used to measure the b hadron lifetime via a maximum likelihood fit.

2 The detector

A detailed description of the ALEPH detector as was operational in 1989 and 1990 can be found in reference [6]. Only a brief description is given here.

Charged tracks are measured over the range $|\cos\theta| < 0.95$ by means of an Inner Tracking Chamber (ITC) and a Time Projection Chamber (TPC). The ITC is a cylindrical drift chamber with eight axial wire layers at radii from 16 to 26 cm. The TPC provides up to 21 space points per track at radii between 40 and 171 cm. The $r\phi$ position of a coordinate is measured with a resolution of 150μm by the ITC and 170μm by the TPC.

In 1991, tracks in the central polar region are also measured by a Silicon Vertex Detector (VDET)[5] which consists of two concentric barrels of microstrip silicon detectors, with double-sided readout, positioned between the beam pipe and the ITC at radii of 6.4 and 11.5 cm. The detectors are arranged in such a way as to provide full azimuthal coverage as well as a 5% overlap, in order to allow a better internal alignment. The coverage in the polar angle is $|\cos\theta| < 0.85$ for the inner layer only, and $|\cos\theta| < 0.65$ for both. The VDET point resolution, as measured with the data[7], is 12μm at normal incidence for both $r\phi$ and rz projections.

A magnetic field of 1.5 Tesla inside the chambers leads to an overall momentum resolution of $\delta p/p = 0.0006\ p$ (with p in GeV/c) for high momentum particles measured in all three tracking devices.

The TPC provides in addition up to 330 measurements of the specific ionization (dE/dx) of each charged track. For electrons in hadronic events, the dE/dx resolution is 4.6% for 330 ionization samples.

The electromagnetic calorimeter (ECAL), which surrounds the TPC and is completely contained within the superconducting coil of the magnet, is a lead proportional tube calorimeter with cathode pads arranged in projective towers subtending typically a solid angle of 0.8° x 0.8° and is read out in three separate longitudinal stacks. The calorimeter is used to measure the electromagnetic energy and, together with the TPC, to identify electrons and reject those which have radiated energetic photons. The energy resolution is $\delta E/E \sim 18\%/\sqrt{E}$.

Muons are identified with the hadron calorimeter (HCAL), composed of the iron of the magnet return yoke interleaved with 23 layers of streamer tubes, and by the muon chambers which surround the calorimeter. The muon chambers, also made of streamer tubes, are read out by cathode strips both parallel and perpendicular to the tubes and provide three-dimensional coordinates for charged tracks penetrating the 7.5 interaction lengths of iron. During the 1991 LEP run these chambers consisted of four layers of streamer tubes while previously only two layers where installed. This addition has increased by $\sim 10\%$ the muon detection efficiency.

3 The signed impact parameter

The impact parameter δ is defined as the distance of closest approach to the estimated b production point in the $r\phi$ projection. A sign is given to the impact parameter depending upon the crossing point of the lepton track with the b line of flight. If it is in the same (opposite) hemisphere as the track, the sign of δ is positive (negative). The hemisphere is defined by the plane perpendicular to the b direction and containing the primary vertex. The b direction is approximated by the jet axis. Jets are reconstructed with the JADE algorithm[8], using both tracks and the energy deposition of neutral particles in the calorimeters. The error on the measured impact parameter, σ_δ, is obtained by summing in quadrature the tracking error, which also includes the contribution from multiple scattering, and the primary vertex error. These are taken from the covariance matrix of the relative fits.

To reconstruct the primary vertex, a method is used which combines the position of the beam spot, found from averaging every 100 Z^0 decays[3], with the track information from the particular event. The method is designed to be insensitive to the presence of secondary vertices. After grouping the tracks into jets, tracks within each particular jet are projected into the plane perpendicular to the jet direction. This removes any dependence on the lifetime of the particle in the approximation that the jet axis reproduces the direction of the b hadron. The primary vertex is then calculated as the point which is most consistent with the projected tracks and the beam envelope, which is taken as the average beam position with the dimensions of the LEP beam spot. With this algorithm resolutions of the primary vertex position of 50μm and 10μm in the horizontal and vertical directions are obtained on simulated events.

The impact parameter resolution has undergone a substantial improvement after the installation of the VDET. This can be seen for instance from the apparent separation at the origin of the two tracks in dimuon events. With the VDET the miss distance, without constraint on the muon curvature, in the $r\phi$ projection has a dispersion of 35μm, which implies an impact parameter resolution of 25μm. The corresponding resolution before the addition of VDET was 140μm. The average resolution on the impact parameter of lepton tracks, as measured on Monte Carlo data, has improved from the previous value of 200μm to 120μm when measured with respect to the beam spot position and down to 60μm when measured relative to the reconstructed vertex.

4 Event selection

In order to maximise the purity of the sample of semileptonic b decays the following selection criteria are applied to the data. First, hadronic events are selected by requiring the total charged energy of the event to be greater than 10% of the centre-of-mass energy and that at least five tracks from the interaction region are reconstructed in the TPC. This cut has an efficiency for rejecting non-hadronic events of 97.4% and the background from $\tau^+\tau^-$ and two-photon events is estimated to be less than 0.65%[9]. The presence of a primary vertex reconstructed with at least three tracks, excluding the lepton candidates, is further required.

From this sample, high p_t lepton candidates are selected. Tracks having at least 10 hits in the TPC, 4 in the ITC and 1 $r\phi$ hit in the VDET, a χ^2/DOF less than 3 and an impact parameter relative to the average beam crossing point less than 2 cm in $r\phi$ and 10 cm in rz are selected. Tracks compatible with coming from the decay of K^0 and Λ are rejected by discarding those which form an invariant mass within 30 MeV/c^2 of these particles, when paired with any oppositely charged track that is consistent with coming from a common vertex. Then the lepton identification procedure is applied to the tracks satisfying these criteria. Finally leptons are required to have a momentum above 3 GeV/c and a transverse momentum greater than 1 GeV/c relative to the associated jet axis.

Electrons are identified by the transverse and longitudinal profile of the shower in the ECAL and by the requirement that the dE/dx measured by the TPC be within 2.5 standard deviations from the expected value for an electron. The same method used in reference [10] is used to remove photon conversions and π^0 decays from the prompt electron signal. Tracks identified as electrons are required not to have radiated a bremsstrahlung photon producing a variation of the impact parameter greater than 10μm. Evidence for photon radiation by the electron is detectable by the high granularity of the ECAL, searching for additional energy deposition in the vicinity of the electron cluster. With this definition of bremsstrahlung the Monte Carlo predicts less than 1% residual contamination in the electron sample selected by this analysis.

Muon identification relies on the matching of a charged track with a pattern of hits in the HCAL consistent with coming from a muon, plus at least one space point reconstructed by the muon chambers. Further details on lepton identification and jet clustering with the ALEPH detector can be found in reference [10, 11].

The final data sample contains 4909 lepton candidates of which 3103 are identified as muons and 1806 as electrons. The lower efficiency of the electron channel is mainly due to the hard requirements in the identification procedure and to the rejection to minimize the bremsstrahlung contamination. The same procedure, when applied to a Monte Carlo sample of about 500,000 $q\bar{q}$ events, yields a b purity of

Muons	%	Electrons	%
$b \to \mu$	79.5%	$b \to e$	87.7%
$b \to (c/\tau) \to \mu$	8.0%	$b \to (c/\tau) \to e$	7.5%
$c \to \mu$	3.5%	$c \to e$	3.5%
Misidentified hadrons	4.5%	Misidentified hadrons	0.7%
π and K decays	4.5%	γ conversions	0.6%

Table 1: Monte Carlo lepton sample composition.

87.5% in the muon channel and of 95.2% in the electron channel, with a background composition as shown in Table 1.

Comparing with the previous ALEPH measurement of the b lifetime, there is a significant improvement in the purity of the sample (from 73% to 90%). This comes mainly from the use of the neutral particles in the jet definition. A reanalysis of the 1990 data with the new algorithms gives a value consistent with the one presented in this paper within statistical errors.

5 Resolution function

In order to simulate the detector resolution and compensate for small deviations from the expected behavior, a resolution function is extracted from the data using the following procedure. From real $q\bar{q}$ events, tracks are selected that satisfy all the previous kinematic and quality criteria but fail the lepton identification. The impact parameter of such tracks receives two contributions, one from the detector resolution and one from possible true impact parameters from long lived parents. As it is the projection of the impact parameter on the $r\phi$ plane which is relevant, the second contribution can be reduced selecting those events for which the track, the jet axis and the z direction are coplanar. This is achieved by requiring that the angle θ_t between the p_t of the track and the z axis be small; a cut of $|sin\theta_t| < 0.5$ has been used. In the remaining sample the resolution effects dominate the impact parameter distribution.

The resolution function is measured using the variable δ/σ_δ because it is insensitive to most of the dependence of the resolution on quantities such as the momentum or the polar angle of the particles. The ratio δ/σ_δ from the selected tracks is shown in Figure 1a. There is a clear positive tail, from the remaining b and c lifetime contributions. To minimize this effect, only the entries with a negative impact parameter are used in extracting the resolution function, obtained by a fit to the sum of two Gaussians. Correlations between the tracking errors on ϕ and the impact parameter will in general produce a positive bias on $\langle\delta\rangle$. In this experiment the tracking errors on ϕ are much smaller than the typical azimuthal angle between the lepton and the

Parameter	Raw	Corrected
σ_1	1.04	1.09
σ_2	3.22	2.10
A_2/A_1	0.125	0.110

Table 2: Resolution function parameters.

jet axis, so the bias is negligible.

Since tracks coming from long-lived hadrons can still be assigned a negative impact parameter, the independence of the fit on the negative side from any remaining lifetime contribution is verified by varying the $|sin\theta_t|$ cut. No significant variation is found by a further reduction of the cut value.

Correction factors, evaluated from Monte Carlo, are then applied to the fit parameters in order to better approximate the true resolution function of the lepton tracks. These corrections account for the slightly worse vertex resolution (by $\sim 20\mu$m) in $b\bar{b}$ events with respect to $q\bar{q}$ events and for the difference in the momentum spectra of the high p_t hadrons with respect to the lepton sample, as the resolution changes with the particle momentum. The correction factors are given by the ratio of the parameters of two distributions: the impact parameter distribution of MC hadronic tracks, selected using the same criteria as applied to the data, and the *true* resolution function i.e. the impact parameter distribution of lepton tracks after subtracting the contribution to the impact parameter due to the lifetime of the parent hadron. This is obtained by subtracting the true impact parameter relative to the b production point, obtained using only the generator level information, from the reconstructed impact parameter relative to the primary vertex after the detector simulation. Figure 1b shows the true resolution function of MC lepton tracks. The raw and corrected parameters used for the resolution function in the lifetime fit are given in Table 2, where the σ_i are the widths and A_i the areas of the two Gaussians.

6 The lifetime fit

The average b lifetime is extracted via an unbinned maximum likelihood fit to the impact parameter distribution. The method used here is based on the procedure described in reference [12].

The observed impact parameter distribution, determined by the particle lifetime, the decay kinematics and the detector resolution, is described as the sum of five different components which are supposed to contribute to the lepton candidates sample:

1. Leptons coming from the decay of b-flavoured hadrons

2. Leptons coming from the decay of either c-flavoured hadrons or τ leptons produced by b hadron decays (cascade)

3. Leptons coming from prompt c-flavoured hadrons produced in $Z^0 \to c\bar{c}$ events

4. Hadrons that are misidentified as leptons

5. Decay background: muons coming from π and K decay or electrons from photon conversion.

A lepton candidate has a probability f_x to come from each of these five sources. These probabilities, estimated from the Monte Carlo, have already been shown in Table 1. For each component a probability density function, P_x, which describes the expected distribution of the impact parameter for that particular source is considered. These probability density functions P_x will depend on the impact parameter and its error, and in the case of the first two components also on the average lifetime τ_b.

The likelihood function to be maximised is built up as the product of the total probability density functions for all the N lepton candidates:

$$\mathcal{L} = \prod_{j=1}^{N}(f_b P_b(\tau_b, \delta_j, \sigma_j) + f_{bc} P_{bc}(\tau_b, \delta_j, \sigma_j) + f_c P_c(\delta_j, \sigma_j) + f_{mis} P_{mis}(\delta_j) + f_{dec} P_{dec}(\delta_j))$$

where δ_j is the impact parameter of the j-th lepton candidate and σ_j is the related error. The average b hadron lifetime τ_b is the only free parameter of the fit.

The probability density functions for the prompt lepton sources (components 1, 2 and 3) are determined from the convolution of the physics functions (PF_x), that are the true impact parameter distributions which depend on the lifetime of the b or c hadron, and the resolution function described previously. The physics functions are derived from Monte Carlo in the following way. Leptons are selected using the same cuts as in the real data and classified in the various samples using the generator level information. The *true* impact parameter is then determined, for each of the three components, using the generated tracks with respect to the true Z^0 production point, but its sign is defined according to the reconstructed jet axis.

This procedure is used in order to separate errors in the tracking and in the estimate of the production point from the sign error due to imprecise knowledge of the b hadron direction. The physics functions scale with the lifetime τ_b and are therefore expressed as a function of $\delta/c\tau$. The three distributions are parametrized using the sum of four exponentials: two exponential functions for the negative part of the distribution and the other two for the positive part.

The probability density function for the fourth component, the misidentified hadrons, is determined using the data from the impact parameter distribution of the tracks which pass the selection cuts for the lepton candidates, but fail the lepton identification.

The decay background function is found using a large sample of π and K decays simulated in the Monte Carlo. The procedure used is almost the same as the one used in the previous ALEPH measurement. The mesons are generated with different momenta and forced to decay inside the tracking volume. Then, taking real hadronic events, the tracks which pass the selection cuts ($p > 3$ GeV/c and $p_t > 1$ GeV/c) are replaced by simulated π and K tracks with similar momentum. The resulting decay background distribution is therefore determined by adding the impact parameter of the decay muons (taken from the simulated events) to the impact parameter of the tracks with high p and p_t, selected in the real hadronic events. A Gaussian fit with exponential tails is performed to parametrize the distributions of the decay background, misidentified hadrons and photon conversions.

Using all the above-determined probability density functions, a common fit is made to the electron and muon candidates. The result is: $\tau_b = 1.49 \pm 0.03$ ps. Figure 2 shows the data together with the corresponding fit and the predicted background.

7 Consistency checks

Several checks have been performed to look for possible systematic effects. As a consistency check of the procedure, the full b lifetime analysis has been applied to a MC sample of 500,000 $q\bar{q}$ events generated with an input b lifetime of 1.3 ps. The values of $\tau_b = 1.29 \pm 0.02$ ps for the full sample, $\tau_b^{\mu} = 1.28 \pm 0.03$ ps and $\tau_b^{e} = 1.30 \pm 0.04$ ps for the muon and electron samples respectively have been obtained.

The analysis has also been repeated on various subsets of the data selected according to different criteria. The results obtained are listed in Table 3 where the errors are statistical only. The lifetime has been measured separately for negatively and positively charged leptons, for events in which the lepton falls in the region $|sin\phi_\ell| < 0.5$, where the vertex resolution is improved by the small vertical size of the beam spot, and for events with the lepton in the complementary angular region. Furthermore a subdivision of the events selecting those in which the lepton is measured by the central calorimetry, corresponding to $|cos\theta_\ell| < 0.6$, or the forward complementary calorimetry, has also been performed. Harder requirements on the track quality have also been investigated, like the presence, in the VDET, of both the $r\phi$ and the z coordinate or of two points per track. The results obtained always agree within their statistical uncertainties.

To evaluate possible biases coming from the cuts on the kinematic variables, the fit has been repeated on subsamples obtained with more stringent requirements on the p and p_t of the lepton track: p cuts of 5 and 8 GeV/c and p_t cuts of 1.3 and 1.6 GeV/c have been investigated. For these selections the Monte Carlo predicts an increase in the purity from 87.5% to 91.2% for the muon sample, and from 95.2% to 97.3% for the electron sample. The values of the lifetime obtained changing the p and p_t cuts do not show any systematic trend and are consistent within their statistical accuracy.

The lifetime fit has also been performed for the muon and electron samples separately (Figure 3), giving, with the standard cuts, the values $\tau_b^{\mu} = 1.55 \pm 0.06$ ps and $\tau_b^{e} = 1.40 \pm 0.06$ ps. Here the errors include also the systematic effects specific

Selection	Lifetime (ps)	
Lepton charge	τ_{+}=1.48 ± 0.04	τ_{-}=1.50 ± 0.04
$\|sin\phi_\ell\|$	$\tau_{<0.5}$=1.54 ± 0.05	$\tau_{>0.5}$=1.46 ± 0.04
$\|cos\theta_\ell\|$	$\tau_{<0.6}$=1.46 ± 0.04	$\tau_{>0.6}$=1.56 ± 0.06
Lepton flavour	τ_μ=1.55 ± 0.04	τ_e=1.40 ± 0.05
Trimmed Mean	τ_μ=1.54 ± 0.06	τ_e=1.48 ± 0.07
p cut	$\tau_{p>5}$=1.53 ± 0.04	$\tau_{p>8}$=1.52 ± 0.04
p_t cut	$\tau_{p_t>1.3}$=1.53 ± 0.04	$\tau_{p_t>1.6}$=1.47 ± 0.06

Table 3: Consistency checks. Errors are statistical only.

to the electron or muon sample, while in Table 3 only the statistical error is reported. No appreciable modification of this difference has been obtained by changing the p, p_t cuts, which clearly alter the relevance of the different background sources.

8 Trimmed mean

In order to investigate a possible systematic origin for the difference between the electron and muon samples, the average b hadron lifetime has also been extracted from the information of the mean value of the impact parameter distribution. In order to be less sensitive to the tails of the distribution the trimmed mean technique is used. This consists in evaluating the mean of the impact parameter from the distribution obtained by removing from the original set a fraction $t/2$ of events from both sides, thus discarding the same number of the highest and of the lowest measured values. The dependence of the trimmed mean on the lifetime is found using Monte Carlo events. In this case, a single Monte Carlo sample, generated with an average lifetime of 1.3 ps, has been used and the impact parameter distributions at different lifetimes have been determined by assigning decay time dependent weights to each event. This procedure yields a linear parametrization of the trimmed mean values as a function of the input lifetime. From the value of the trimmed mean obtained in the data the b lifetime is easily derived.

Choosing as trim cut $t = 0.1$ (5% of the tracks are removed from each tail), the separate μ and e lifetimes are $\tau_b^\mu = 1.54 \pm 0.06$ ps and $\tau_b^e = 1.48 \pm 0.07$ ps, while the lifetime of the total sample is $\tau_b = 1.51 \pm 0.05$ ps; the errors are only due to the statistics of the data and Monte Carlo samples. The trimmed mean result is consistent within statistical and systematic errors with the likelihood lifetime value. One can observe that the difference between the lifetime of the two samples is reduced with respect to what is obtained with the maximum likelihood method.

To check that this measurement is not sensitive to the particular value chosen for the trim factor t the lifetime has been determined by varying t in the range 0-0.9.

The result is shown in Figure 4. The values are self consistent within the expected statistical fluctuations. A similar test has been done by performing the likelihood fit on the trimmed samples. No statistically significant variation of the result has been observed changing the trim factor in the range 0-0.4.

9 Systematic errors

A first source of systematic errors on the lifetime is due to the statistical uncertainty on the underlying parameters used in the fit. The dependence of the lifetime on each parameter has been calculated numerically. When necessary the correlation between different parameters has been taken into account. The following groups of potentially correlated parameters can be identified: the three physics functions PF_x, the probability density functions of the background P_{mis} and P_{dec}, the resolution function and the fractions of the lepton sources f_x.

Due to the high statistics of the generated Monte Carlo sample, the statistical uncertainties in the parametrization of the physics functions contribute only a small amount to the lifetime systematic error: $\sigma_\tau^{P_b} = 0.012$ ps, $\sigma_\tau^{P_{bc}} = 0.005$ ps, $\sigma_\tau^{P_c} = 0.005$ ps. To allow for any possible inaccuracy from the choice of fitting the physics functions to the sum of four exponentials, an overall systematic error of 0.015 ps from the PF_x parametrization has been assumed.

One has also to consider that a number of ingredients in the Monte Carlo influence directly the shape of the physics functions. For instance to study the uncertainties arising from the b hadrons decay scheme the following models have been investigated as alternatives to the Korner-Shuler[13] usually employed: Bauer-Stech-Wirbel[14], Grinstein-Wise-Isgur[15] and standard Lund[16]. The maximum variation of the fitted value of τ_b has been found with the GWI model and resulted in a change of 0.02 ps. The fragmentation parameter ϵ_b of the Peterson function has also been changed between 0.003 and 0.010, corresponding to a variation of one standard deviation from the value quoted in reference [10], leading to a variation of 0.02 ps in the lifetime. The branching fraction of the $B \rightarrow D^{**} l \nu$ channel has been varied from 15% to 30% of the total semileptonic b decay with no significant variation in the b lifetime. Taking into account all the previous sources of systematic errors, an overall uncertainty of 0.035 ps has been estimated, due to the decay and fragmentation models used in the Monte Carlo.

Regarding the parametrization of the misidentification and decay backgrounds, the samples are sufficiently large to make the statistical contributions negligible, $\sigma_\tau^{P_{mis}} = 0.001$ ps, $\sigma_\tau^{P_{dec}} = 0.001$ ps. An additional systematic uncertainty from the decay distribution shape must be accounted for because the decay background is partially simulated and not directly measured. The maximum variation in the fitted value of τ_b for various parametrizations is 0.015 ps, which is taken as the corresponding systematic uncertainty.

The statistical uncertainties on the parametrization of the resolution function have been found to give a negligible contribution to the overall systematic error. The sensitivity of the fit to the resolution function can be seen by increasing by 10% each of the three parameters of Table 2. A maximum decrease of 0.007 ps is observed varying σ_2, while the other parameters produce a decrease of 0.004 ps. To estimate the effect of the correction factors applied to the hadronic track resolution, the lifetime has been calculated with the uncorrected resolution function, yielding a variation of 0.015 ps. A total systematic error of 0.015 ps arising from the resolution function parametrization has been therefore estimated.

The systematic error deriving from the MC lepton source fractions, f_x, has been investigated with more than one procedure. Applying the standard error propagation, the predicted systematic error for the lifetime is $\sigma_\tau = 0.005$ ps. Varying the branching ratios by 10% or the background components by 50% yields a value of $\sigma_\tau = 0.02$ ps. Furthermore, as a check of the values of the f_x and of their assumed uncertainties, the fractions have been allowed to vary in a maximum likelihood fit to the $p - p_t$ distribution of the leptons from the data. The fit yields values of the fractions that do not differ from the MC values by more than the previously quoted variations. A systematic error due to the uncertainties on the fractions of 0.02 ps is therefore assumed.

The average c lifetime, assumed equal to 0.68 ps, has been varied by $\pm 10\%$ to account for the uncertainties in the relative production rates and semileptonic branching ratios of the various charmed hadrons. The corresponding variation of 0.005 ps in the b lifetime has been taken as systematic error.

To evaluate the effect of bremsstrahlung, the events discarded by this cut have been reintroduced and a variation of 0.01 ps in the fitted value of the lifetime of the single electron sample has been observed. This value has been taken as an upper limit to the systematic error for the complete sample.

Finally the two sigma discrepancy between the two lepton channels, which might be coming from a systematic error in one of the channels or from a statistical fluctuation, has been considered. Several tests were performed to trace systematic errors due to different tracking and backgrounds. Varying the track quality cuts, the kinematical cuts or requiring an additional b tag in the hemisphere opposite to the lepton did not produce a reduction in the lifetime difference, leading to the conclusion that the effect is most likely statistical. However, a systematic effect can not be ruled out. Therefore a systematic uncertainty of 0.03 ps has been added, corresponding to the effect on the mean of changing either of the channels by the amount necessary to make them agree within one standard deviation.

The single components of the systematic error are shown in Table 4. A total value of 0.06 ps is obtained by summing in quadrature.

10 Conclusions

From a total of 260,000 hadronic Z^0 decays collected with the ALEPH detector during the 1991 run, a sample of 4909 b candidates has been isolated and the average lifetime of b hadrons extracted from a maximum likelihood fit to the impact parameter distribution of the lepton tracks. The result is:

$$\tau_b = 1.49 \pm 0.03 \pm 0.06 \; ps.$$

Source of systematic error	σ_τ^{sys} (ps)
Physics Functions Parametrization	0.015
Monte Carlo decay and fragm. models	0.035
Decay background	0.015
Resolution Function	0.015
Lepton Source Fractions f_i	0.020
Average Charm Lifetime	0.005
Bremsstrahlung	0.010
Muon-Electron Discrepancy	0.030
Total	0.058

Table 4: Systematic Error.

This value is a weighted average over the production fractions and semileptonic branching ratios of the various b hadrons produced in multihadronic Z^0 decays. As a consequence of the improvements both in the detector and in the purity of the b sample, this result supersedes the previous ALEPH measurement based on the 1990 data[3].

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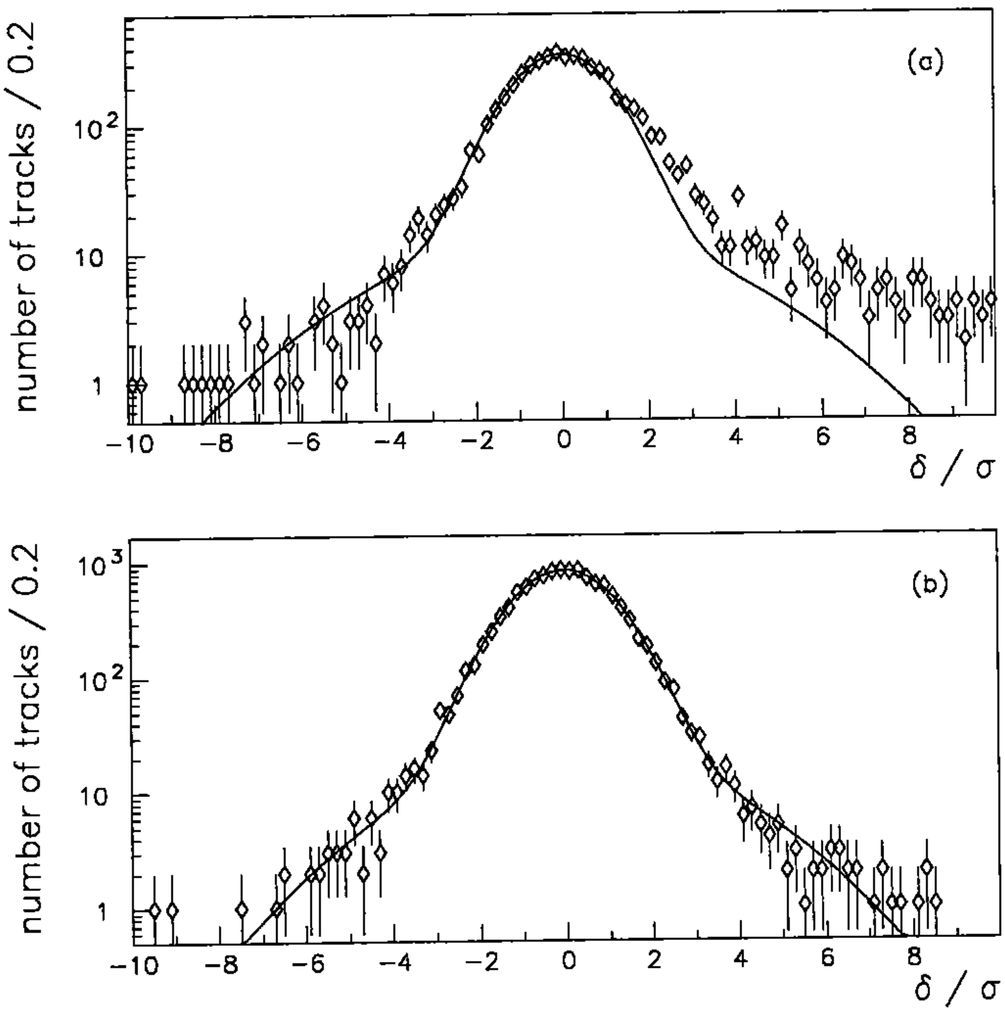

Figure 1: (a) Resolution function of hadrons from data. (b) Resolution function of Monte Carlo leptons. The curves are the results of double Gaussian fits.

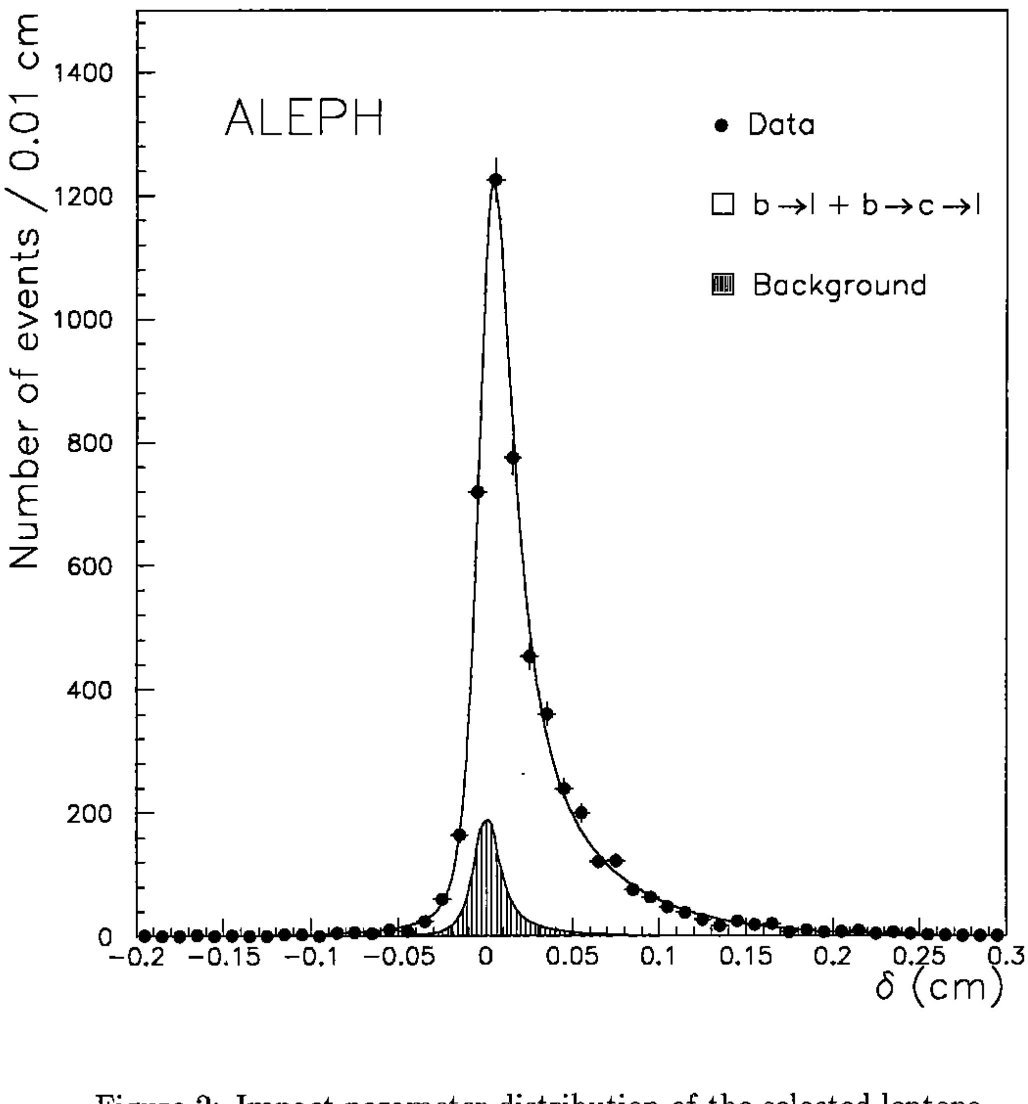

Figure 2: Impact parameter distribution of the selected leptons.

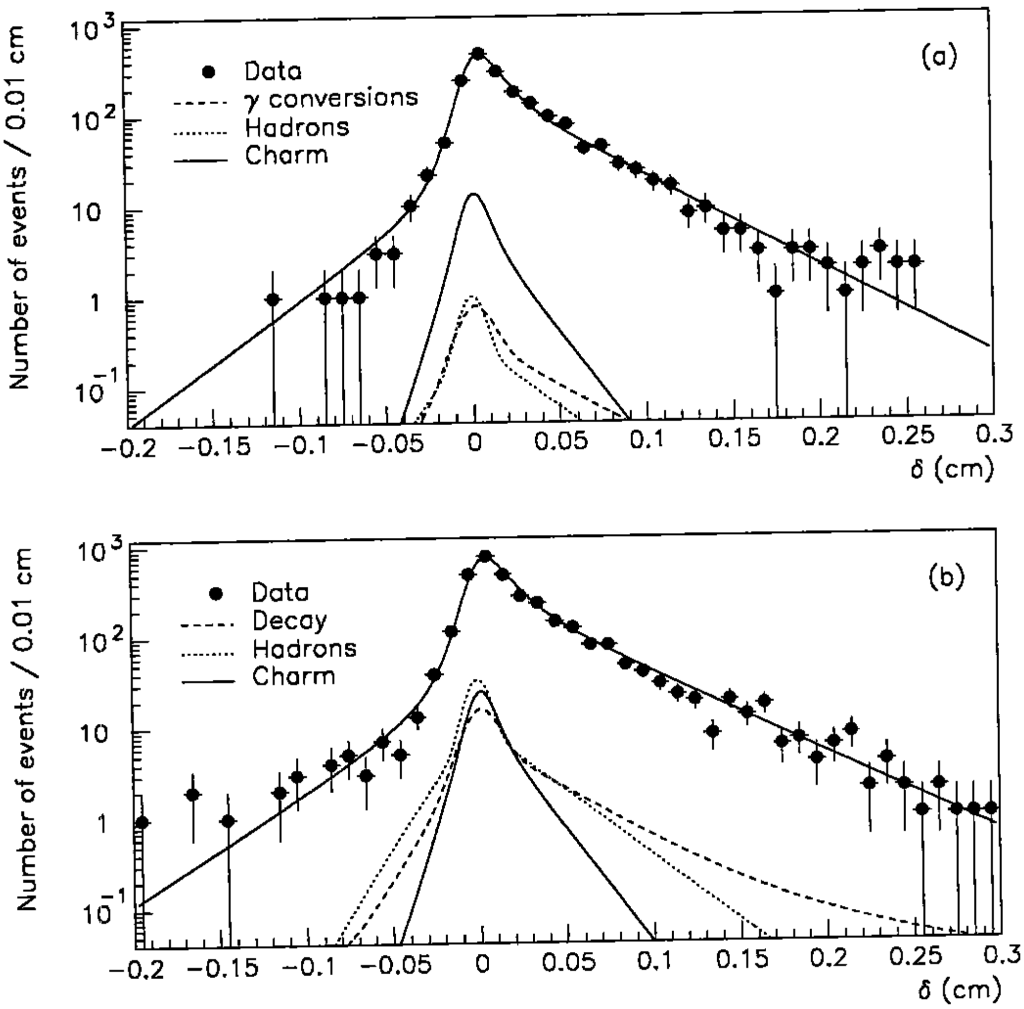

Figure 3: (a) Impact parameter distribution of electrons. (b) Impact parameter distribution of muons. The upper curve is the result of the likelihood fit. The other curves give the contribution from the background sources.

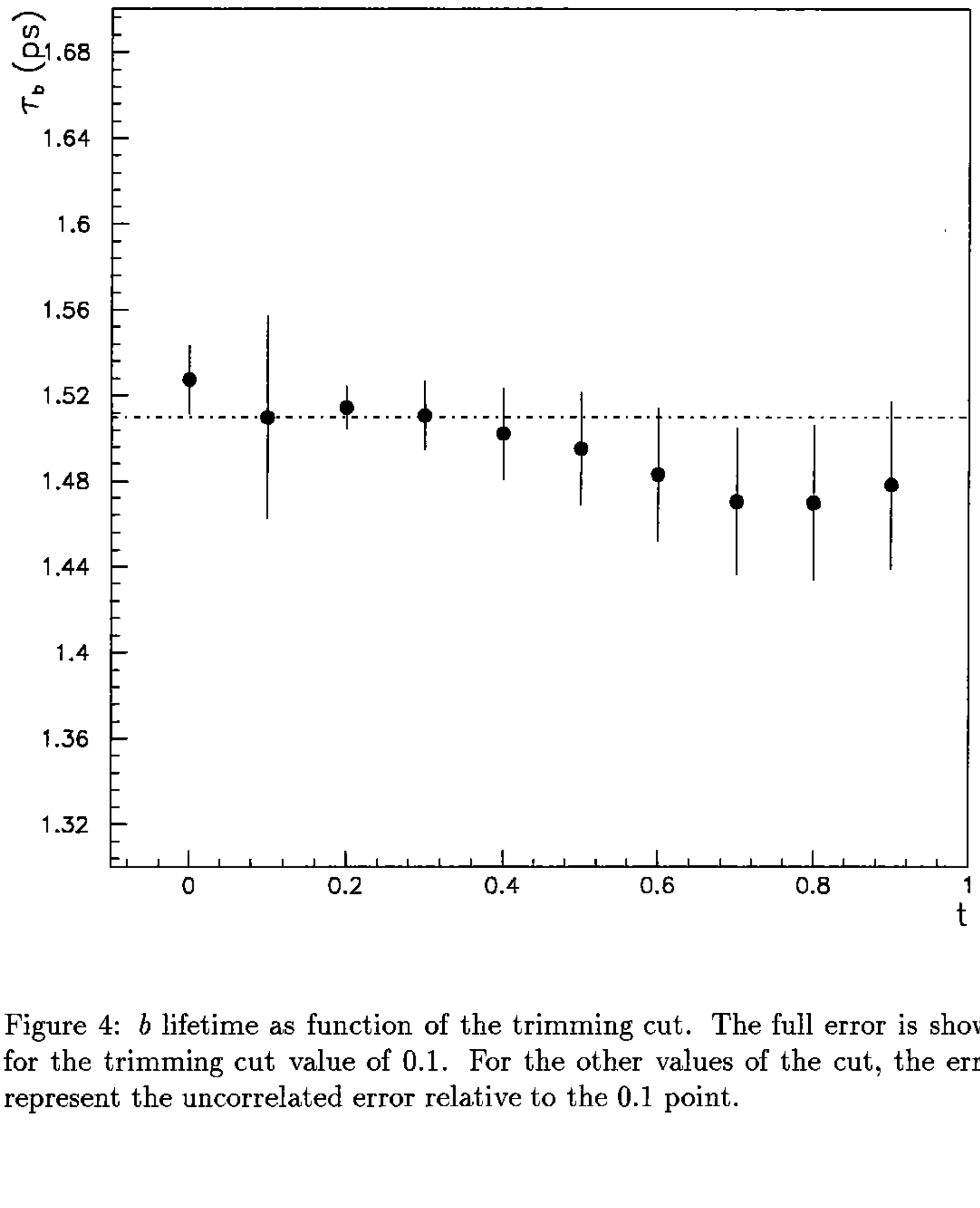

Figure 4: b lifetime as function of the trimming cut. The full error is shown only for the trimming cut value of 0.1. For the other values of the cut, the error bars represent the uncorrelated error relative to the 0.1 point.