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Λ_b^0 Lifetime measurement

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Abstract

From a data sample of 889,000 hadronic Z^0 decays collected with the ALEPH detector in 1991 and 1992, a total of 22 $\Lambda_c^+ l^-$ combinations candidates in which 16.5 ± 4.7 are attributed to the Λ_b^0 semileptonic decay $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu_l}$ followed by $\Lambda_c^+ \to pK^-\pi^+$ have been selected and are used to measure the Λ_b^0 lifetime. An extended maximum likelihood fit to the proper time distribution of these events, obtained from their three dimensional decay length and relativistic boost, yields a Λ_b^0 lifetime of :

$$\tau_{\Lambda_b} = 1.20^{+0.43}_{-0.31} \pm 0.06 \ ps.$$

1 Introduction

The Λ_b^0 lifetime has previously been measured by ALEPH [1] from a fit to the impact parameter distribution of the lepton in the Λl^- sample originating from $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu_l}$ followed by $\Lambda_c^+ \to \Lambda X$ decay. From 450,000 hadronic Z^0 events collected in 1990 and 1991, 178 lepton candidates from Λl^- sample with $\Lambda_b^0 \to l$ purity of 57% were selected and used in the fit. The fit yields a Λ_b^0 lifetime of $\tau_{\Lambda_b} = 1.12^{+0.32}_{-0.24} \pm 0.16$ ps. Here we report on a new Λ_b^0 lifetime measurement based on $\Lambda_c^+ l^-$ correlation events from $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu_l}$ followed by $\Lambda_c^+ \to pK^-\pi^+$ decay. This technique sensitive to Λ_b^0 semileptonic decay in hadronic Z decays [2], enables the measurement of the Λ_b^0 decay vertex and hence its decay length event by event. It leads to a complementary and independant way of measuring the Λ_b^0 lifetime.

This note is organized as follows : In section 2 we describe the $\Lambda_c^+ l^-$ selection from hadronic Z^0 decays and review the various $\Lambda_c^+ l^-$ background sources. In sections 3 and 4 the measurement of the Λ_b^0 decay length and its relativistic boost are presented. The fitting procedure to extract the Λ_b^0 lifetime is described in detail in section 5, finally the result and the systematic errors are presented in sections 6 and 7.

2 Λ_b^0 selection and Backgrounds

The data sample used in this analysis is based on 889,000 hadronic class 16 events from 1991 and 1992 (PERF and MAYBE) data, with VDET fully operational.

The $\Lambda_c^+ l^-$ selection from Λ_b^0 semileptonic decay has already been reported and discussed in a previous ALEPH paper [2]. Here we present on a similar selection procedure with additional cuts specific to the Λ_b^0 lifetime measurement. For the lepton identification we use the standard heavy flavour lepton selection [3] which is for electrons :

- good charged track[1]
- $P_l > 3.\ GeV/c$
- $-1.8 < R_2 < 3.0$, $-2.1 < R_3 < 3.0$
- $(dE/dx)_e < -2.5$ and $N_{wires} > 50$ when the dE/dx is available
- Pair conversion rejection (PAIRFD)

[1] We use the following definition of a good charged track : $|cos\theta| < 0.95$, $|D0| < 0.5cm$, $|Z0| < 10.cm$ and at least 4 TPC hits.

and for muons :

- good charged track
- $P_l > 3.\ GeV/c$
- QMUIDO flag IDF > 12

For the $\Lambda_c^+ \to pK^-\pi^+$ the selection cuts are :

- $P_p > 4.\ GeV/c$, $P_K > 2.\ GeV/c$, $P_\pi > 1.\ GeV/c$
- $(dE/dx)_p < 0.$ and $N_{wires} > 50$
- For the kaons and the pions the dE/dx cut is applied only when it is available. For the kaons we use $|(dE/dx)_K| < 2.5$ and $N_{wires} > 50$ and for the pions $|(dE/dx)| < 3$.
- The $pK^-\pi^+$ vertex fit is required to have Prob(χ^2) $> 1.\%$
- $P_{pK^-\pi^+} > 8.\ GeV/c$ after vertexing

$\Lambda_c^+ \to pK^-\pi^+$ candidates surviving these cuts are combined with an identified lepton from the same hemisphere[2] and the $\Lambda_c^+ l^-$ system is then required to satisfy the following criteria :

- $\theta_{\Lambda_c^+, l^-} < 45°$
- $M_{\Lambda_c^+ l^-} > 3.5\ GeV/c^2$
- $P_{\Lambda_c^+ l^-} > 20.\ GeV/c$
- $\Lambda_c^+ l^-$ vertex fit with Prob(χ^2) $> 1\%$.

In order to insure a good $\Lambda_c^+ l^-$ vertex reconstruction, the lepton and two out of the three Λ_c^+ tracks are required to have one or more vertex detector hits and at least two ITC hits.

Figure (1-a) shows the $pK^-\pi^+$ invariant mass distribution for the opposite sign $\Lambda_c^+ l^-$ events with a clear Λ_c^+ peak. For like sign $\Lambda_c^+ l^+$ events (1-b) no such peak is observed. A fit to the $pK^-\pi^+$ distribution (1-a) with a Gaussian representing the Λ_c^+ signal and a second order polynomial for the background yields a Λ_c^+ mass of $2.283 \pm 0.003\ GeV/c^2$ and a width of $8.5 \pm 3.3\ MeV/c^2$, consistent with expectations from Monte Carlo simulation. A total of 22 $\Lambda_c^+ l^-$ events are found within $\pm 2\sigma_{MC}$ ($\pm 15\ MeV/c^2$) of the Λ_c^+ mass and are used for the Λ_b^0 lifetime measurement. From the fit the contribution of the combinatorial background is estimated to be 5.5 ± 0.7 events.

[2] In this analysis each event is divided into two hemispheres separated by the plane perpendicular to the thrust axis.

Besides $\Lambda_c^+ l^-$ pairs from Λ_b^0 semileptonic decay, four possible sources of background can contribute to $\Lambda_c^+ l^-$ combinations in hadronic Z decays :

1. $\overline{B} \to \Lambda_c^+ \overline{(p/n)} l^- \overline{\nu_l}$
2. $\overline{B} \to \Lambda_c^+ D_s^- \overline{(p/n)}$, $D_s^- \to X l^- \overline{\nu_l}$
3. $\Lambda_b^0 \to \Lambda_c^+ D_s^- X$, $D_s^- \to X l^- \overline{\nu_l}$
4. Accidental correlations

To date none of three first background processes have any experimental evidence. Their rates are expected to be less than 0.32%, 0.1% and 1.2% respectively [2]. Besides their very low rates these three processes are, due to phase space supression, characterized by relatively low $\Lambda_c^+ l^-$ invariant mass compared to the Λ_b^0 semileptonic decay events. In processes (1) this is a consequence of baryon number conservation while in process (3) this is due to a non reconstructed energy in the cascade decay of the D_s^-. Process (2) suffers from both. The lepton from these processes is soft either due to phase space suppression (1 and 2) or due to its origin in the cascade decay $b \to c \to l$ (2 and 3).

The expected number of $\Lambda_c^+ l^-$ combinations from the three physics background processes after all cuts is estimated from Monte Carlo simulation to be less than 0.1 event and their contribution to the lifetime are therefore neglected.

3 Proper time measurement

To measure the Λ_b^0 lifetime we need to know the proper time distribution of the event sample (here the selected $\Lambda_c^+ l^-$ sample) representing the Λ_b^0 signal. For each Λ_b^0 candidate the proper time is obtained from the Λ_b^0 decay length (l_{Λ_b}), its boost $(\gamma\beta)_{\Lambda_b}$ and the speed of light c using :

$$t_{\Lambda_b} = \frac{l_{\Lambda_b}}{(\gamma\beta)_{\Lambda_b} c} = \frac{l_{\Lambda_b}}{(p/m)_{\Lambda_b} c} \qquad (1)$$

3.1 Λ_b^0 decay length measurement

From the $\Lambda_c^+ l^-$ selected sample, the Λ_b^0 decay length (figure 2) is measured in three dimensions event by event by projecting the vector joining the interaction point (primary vertex) (V_p) and the Λ_b^0 decay vertex (V_{Λ_b}) onto the Λ_b^0 flight direction (U_{Λ_b})[3] :

[3] One of the advantages of the projected decay length method compared to the most probable decay length method used in other analysis, is its small sensitivity to the Λ_b^0 flight direction [6].

$$l_{\Lambda_b} = U^T_{\Lambda_b}(V_{\Lambda_b} - V_p) \quad (2)$$

Due to the lack of neutrino information we use the $\Lambda_c^+ l^-$ vector sum as an estimate of the Λ_b^0 direction. From Monte Carlo simulation, the resolution on the Λ_b^0 direction (figure 3) with this approximation is equal to 26.0 ± 1.3 mrads after all $\Lambda_c^+ l^-$ selection cuts.

3.2 Primary and Λ_b^0 vertices reconstruction

The primary vertex is reconstructed event by event using the QFNDIP algorithm [4]. This algorithm uses the information from all charged tracks projected into a plane perpendicular to the jet to which they belong, combined with the average beam position determined every 75 Z^0 decays. The primary vertex is taken as the most consistent intersection point between the projected tracks points (one point for each jet) and the beam envelope. With this algorithm the reconstructed primary vertex resolution, estimated from Monte Carlo simulation, is 65 μm along the Λ_b^0 flight direction.

The Λ_b^0 decay vertex is determined from a fit of the reconstructed Λ_c^+ track and the lepton to a common vertex in three dimensions with the aid of the vertex detector. For both Λ_c^+ and Λ_b^0 vertex reconstruction we use the YTOP package [5] and require for each vertex, as mentioned in section 2, the probability of the χ^2 fit to be greater than 1%. From Monte Carlo simulation the resolution on the Λ_c^+ and the Λ_b^0 decay vertices along their directions of flight are 300 μm and 185 μm respectively.

The Λ_b^0 decay length resolution (figure 4) which depends on the Λ_b^0 and primary vertices resolutions is about 250 μm dominated mainly by the Λ_b^0 decay vertex resolution.

3.3 Λ_b^0 decay length reconstruction error

The error on the Λ_b^0 decay length reconstruction ($\sigma_{l_{\Lambda_b}}$) is given event by event by :

$$\sigma^2_{l_{\Lambda_b}} = U^T_{\Lambda_b} M U_{\Lambda_b} \quad (3)$$

where the matrix M is the sum of the Λ_b^0 decay vertex and the primary vertex covariant matrices. From equation 1 the relation between the error on the decay length and the error on the proper time for a given boost is :

$$\sigma_{t_{\Lambda_b}} = \frac{\sigma_{l_{\Lambda_b}}}{(p/m)_{\Lambda_b} c} \quad (4)$$

	1991	1992
$\sigma^{(1)}_{pull}$	1.11 ± 0.09	1.04 ± 0.11
$\sigma^{(2)}_{pull}$	4.49 ± 3.67	2.11 ± 0.71
$f^{(2)}_{pull}$	0.05 ± 0.04	0.13 ± 0.15

Table 1: The pull parameters values

To estimate how well the Λ_b^0 decay length error ($\sigma_{l_{\Lambda_b}}$) and hence the Λ_b^0 proper time error ($\sigma_{t_{\Lambda_b}}$) is measured we use the pull distribution given by :

$$(l_{\Lambda_b}^{measured} - l_{\Lambda_b}^{true})/\sigma_{l_{\Lambda_b}}^{measured} \tag{5}$$

The pull distribution (figure 5), determined from Monte Carlo simulation, is fitted with two gaussians of widths $\sigma^{(1)}_{pull}$, $\sigma^{(2)}_{pull}$. The second gaussian is introduced to account for the tails. For the years 1991 and 1992 the values of these two pull widths and the relative fraction $f^{(2)}_{pull}$ of the second gaussian area with respect to the total are given in table 1.

The values of the gaussian widths show that the measured decay length errors and hence the proper time errors are underestimated and have to be rescaled by the appropriate factors event by event. To this end the proper time resolution function is parametrised by two gaussians of widths equal to $\sigma_t^{(1)} = \sigma^{(1)}_{pull} \times \sigma_{t_{\Lambda_b}}$ and $\sigma_t^{(2)} = \sigma^{(2)}_{pull} \times \sigma_{t_{\Lambda_b}}$:

$$G(t, \sigma_t^{(1)}, \sigma_t^{(2)}, f^{(2)}) = (1 - f^{(2)}_{pull})\ G(t, \sigma_t^{(1)}) + f^{(2)}_{pull}\ G(t, \sigma_t^{(2)}) \tag{6}$$

4 Λ_b^0 boost estimation

To measure the Λ_b^0 boost $(p/m)_{\Lambda_b}$ we need to know the Λ_b^0 mass and momentum. As there is no direct information on the neutrino involved in the Λ_b^0 semileptonic decay under study a momentum correction factor, determined from Monte Carlo simulation, is introduced. This correction factor is defined as the ratio of the reconstructed over the true Λ_b^0 momentum :

$$\kappa = \frac{(P)^{reco}}{(P)^{true}_{\Lambda_b}} \tag{7}$$

For the Λ_b^0 mass we use the quark model prediction value $M_{\Lambda_b} = 5.6\ GeV/c^2$ [7].

Two methods will be presented to estimate the Λ_b^0 momentum. In the first method we use $\Lambda_c^+ l^-$ momentum, in the second method we use in addition the neutrino energy estimated from the missing energy in the event using the energy flow package ENFLW.

4.1 Method 1

The Λ_b^0 momentum is estimated from the recontructed $\Lambda_c^+ l^-$ momentum. With this approach the correction κ distribution (figure 7-a) estimated from Monte Carlo simulation is, due to the missing neutrino energy, not centered at one and has a non gaussian shape with a r.m.s. of 0.11.

4.2 Method 2

Taking advantage of the energy flow package, the Λ_b^0 momentum resolution can be improved using the missing energy in the event to estimate the neutrino energy. The technique used to reconstruct the missing neutrino energy is similar to that used in the B_s lifetime measurement [8]. The event is divided in two hemispheres. In the $\Lambda_c^+ l^-$ hemisphere[4] the neutrino energy is estimated as :

$$E_\nu \;=\; P_\nu \;=\; E_{same} - E_{vis} \tag{8}$$

where E_{same} is the total energy in the hemisphere calculated from the energy-momentum conservation and defined as follow :

$$E_{same} = \frac{\sqrt{s}}{2} + \frac{M_{same}^2 - M_{oppo}^2}{2\sqrt{s}} \tag{9}$$

where M_{same} and M_{oppo} are the hemisphere masses calculated from charged tracks and photons energies.
and E_{vis} is the visible energy defined as the sum of the charged tracks and the gammas energies in the hemisphere :

$$E_{vis} = E_{charged} + E_\gamma \tag{10}$$

The neutrino energy measured by this method is over estimated on average by 2.4 GeV due to the none counted hadron energy and has a resolution of 2.8 GeV (figure 6). The reconstructed Λ_b^0 momentum defined now as $P_{\Lambda_b} = P_{\Lambda_c l} + P_\nu$ leads to a new κ distribution (figure 7-b) better centered at 1 with a r.m.s. of 0.10.

5 The fitting technique

The event sample used to extract the Λ_b^0 lifetime is selected, as mentioned in section 2, from the $\Lambda_c^+ l^-$ events within $\pm 2\sigma_{MC}$ ($\pm 15\ MeV/c^2$) of the Λ_c^+ peak. It consists of $N_{peak}^{obs} = 22$ events in which 16.5±4.7 are attributed to $\Lambda_b^0 \to \Lambda_c^+ l^- \overline{\nu_l}$ decay and the remaining 5.5 ± 0.7 events are purely combinatorial background.

[4]In what follow the $\Lambda_c^+ l^-$ hemisphere will be called "same" and the opposite hemisphere "oppo"

The Λ_b^0 lifetime is extracted from an unbinned extended maximum likelihood fit [9] to the proper time distribution of these events. To improve the statistical error on the fitted background component a total of $N_{back}^{obs} = 136$ events from side band $\Lambda_c^+ l^-$ events at $\pm 4\sigma$ outside the Λ_c^+ peak and wrong sign $\Lambda_c^+ l^+$ events are included in the fit. The likelihood function used to fit simultaneously the 22 events in the peak and the 136 combinatorial background events is :

$$\mathcal{L} = \prod_i^{N_{peak}^{obs}} \mathcal{P}_{peak} \times f(N_{peak}^{obs}, N_{peak}^{exp}) \times \prod_i^{N_{back}^{obs}} \mathcal{P}_{back} \times f(N_{back}^{obs}, N_{back}^{exp}) \quad (11)$$

- $\mathcal{P}_{peak}$ is the proper time probability density function for events in the peak. It consists of two components :

$$\mathcal{P}_{peak} = (1 - f_{back})\, \mathcal{P}_{sig} + f_{back}\, \mathcal{P}_{back} \quad (12)$$

  f_{back} is the fraction of background events in the peak given by :

$$f_{back} = \frac{N_{peak}^{back}}{N_{peak}^{exp}}$$

  where $N_{peak}^{exp} = N_{peak}^{sig} + N_{peak}^{back}$, is the expected number of events in the peak[5]. N_{peak}^{exp} is constrained in the fit by the Poisson term $f(N_{peak}^{obs}, N_{peak}^{exp})$:

$$f(N_{peak}^{obs}, N_{peak}^{exp}) = \frac{N_{peak}^{exp\; N_{peak}^{obs}} e^{-N_{peak}^{exp}}}{N_{peak}^{obs}!} \quad (13)$$

  The two probability density function terms in $\mathcal{P}_{peak}$ are :

  1. The signal probability density function $\mathcal{P}_{sig}$ which consists of an exponential function having lifetime τ_{Λ_b} convoluted with the Gaussian resolution function given in equation (6) and with the κ distribution representing the error on the boost :

$$\mathcal{P}_{sig} = exp(t, \tau_{\Lambda_b}) \otimes G(t, \sigma_t^{(1)}, \sigma_t^{(2)}, f^{(2)}) \otimes \kappa \quad (14)$$

  2. The background probability density function $\mathcal{P}_{back}$, described below, is parametrised from N_{back}^{obs} combinatorial background events.

- The background probability density function $\mathcal{P}_{back}$ is given by :

$$\begin{aligned}\mathcal{P}_{back} &= f_0\, G(t, \sigma_t^{(1)}, \sigma_t^{(2)}, f^{(2)}) + \\ &\quad (f_1 exp(t, \tau_{back,1}) + f_2 exp(t, \tau_{back,2})) \otimes G(t, \sigma_t^{(1)}, \sigma_t^{(2)}, f^{(2)}) \quad (15)\end{aligned}$$

[5] In the fit N_{peak}^{back} is fixed and N_{peak}^{sig} is allowed to vary.

It consists of three components : a fraction f_0 of events with zero lifetime which is just the Gaussian resolution function and fractions f_1 and $f_2 = 1 - f_0 - f_1$ of events having lifetimes $\tau_{back,1}$ and $\tau_{back,2}$ convoluted with the same resolution function. In the fit f_0, f_1 and f_2 are taken as :

$$f_0 = \frac{N^{(0)}_{back}}{N^{exp}_{back}} \ , \ f_1 = \frac{N^{(1)}_{back}}{N^{exp}_{back}} \text{ and } f_2 = \frac{N^{(2)}_{back}}{N^{exp}_{back}} \tag{16}$$

where $N^{exp}_{back} = N^{(0)}_{back} + N^{(1)}_{back} + N^{(2)}_{back}$ is the expected number of backgound events in which the number of events with zero lifetime ($N^{(0)}_{back}$) and the number of events with lifetimes $\tau_{back,1}$ ($N^{(1)}_{back}$) and $\tau_{back,2}$ ($N^{(2)}_{back}$) are allowed to vary. N^{exp}_{back} is constrained in the fit by the Poisson term $f(N^{obs}_{back}, N^{exp}_{back})$:

$$f(N^{obs}_{back}, N^{exp}_{back}) \ = \ \frac{N^{exp \ N^{obs}_{back}}_{back} e^{-N^{exp}_{back}}}{N^{obs}_{back}!} \tag{17}$$

In $\mathcal{P}_{sig}$ and $\mathcal{P}_{back}$ probability density functions the convolution of the exponential with the gaussian is performed analytically using :

$$H(t, \sigma_t, \tau) \ = \ G(t, \sigma_t) \otimes exp(t, \tau) \ = \ \frac{1}{2\tau} \, e^{\frac{\sigma_t^2}{2\tau}} \, e^{-\frac{t}{\tau}} \ erfc\Big(\frac{1}{\sqrt{2}}(\frac{\sigma_t}{\tau} \ - \ \frac{t}{\sigma_t})\Big) \tag{18}$$

where the function $erfc(z)$ is defined as :

$$erfc(z) \ = \ \frac{1}{\sqrt{2\pi}} \int_z^{\infty} \ e^{-t^2} \ dt \tag{19}$$

As the κ distribution is not known analytically, the convolution of $H(t, \sigma_t, \tau)$ with the κ distribution in $\mathcal{P}_{sig}$ is performed by a numerical integration :

$$\mathcal{P}(t \ , \tau \ , \sigma_t) \ = \ \sum_{j=1}^{m} \kappa_j K(\kappa_j) \ H(\kappa_j t \ , \tau \ , \kappa_j \sigma_t) \tag{20}$$

Where κ_j is the kappa value for the κ histogram entry j.

In summary, there are seven parameters in the fit :

- τ_{Λ_b} : the Λ_b^0 lifetime,
- N^{sig}_{peak} : the number of expected signal events (in the Λ_c^+ mass peak),
- $N^{(0)}_{back}$: the number of background events with zero lifetime,
- $N^{(1)}_{back}$: the number of background events with $\tau_{back,1}$ lifetime,
- $\tau_{back,1}$: the background lifetime for the $N^{(1)}_{back}$ background events,

- $N_{back}^{(2)}$: the number of background events with $\tau_{back,2}$ lifetime,
- $\tau_{back,2}$: the background lifetime for the $N_{back}^{(2)}$ background events.

6 Results of the lifetime fits

Figure (8-a) shows, in the case where neutrino energy is used, the result of the simultaneous fit of signal and background events. For the combinatorial background figure (8-b) shows the result of the fit. In table 2 we give a summary of the seven fitted parameters values for κ distribution with and without neutrino energy. The fitted Λ_b^0 lifetime value is $\tau_{\Lambda_b} = 1.19^{+0.43}_{-0.31}$ ps with neutrino and $\tau_{\Lambda_b} = 1.15^{+0.42}_{-0.31}$ ps without neutrino.

7 Systematic errors

Various sources of systematic errors have been considered. Their contributions are summarised in table 3 for Λ_b^0 lifetime measurement with and without neutrino. They are now discussed in more detail.

7.1 Resolution function

The resolution function is parametrized from Monte Carlo simulation with two gaussians of parameters $\sigma^{(1)}, \sigma^{(2)}$ and $f^{(2)}$ (equation 6). To account for possible differences between data and Monte Carlo, the two sigmas are varied by $\pm 20\%$ and the fraction $f^{(2)}$ from 0. to 0.2. These variations lead to Λ_b^0 lifetime change of ± 0.013 either with or without neutrino.

7.2 Background

The background is purely combinatorial. Its contribution to the $\Lambda_c^+ l^-$ events in the peak is estimated from a second order polynomial fit and the shape of its proper time distribution from a fit to side band $\Lambda_c^+ l^-$ events and wrong sign $\Lambda_c^+ l^+$ events with the probability density function $\mathcal{P}_{back}$ (equation 15). To estimate the systematic errors coming from these two sources we vary the number of background events in the peak within its statistical error and use an alternative parametrization of its proper time distribution shape which in addition to the zero lifetime component consists of just one exponential. These changes yield Λ_b^0 lifetime variation of ± 0.017 and ± 0.04 with neutrino for background events number and background shape respectively and comparable values ± 0.016 and ± 0.03 without neutrino.

7.3 κ distribution

The κ distribution which accounts for the Λ_b^0 momentum mis-measurement is obtained from a fully reconstructed Monte Carlo simulation and is subject to variation with Monte Carlo inputs such as decay models, fragmentation scheme and Λ_b^0 polarisation.

7.3.1 Decay models

To estimate the systematic errors from the κ shape variation due to different decay models we used for the κ distribution the following semileptonic decay schemes : J.G. Korner and G.A. Schuler [10], M. Bauer, B. Stech and M.B. Wirbel [11] and B. Grinstein, N. Isgur and M. Wise [12]. The Λ_b^0 lifetime changes due to these different decay schemes are ± 0.021 with neutrino and a comparable value ± 0.018 without neutrino.

7.3.2 b fragmentation

The Λ_b^0 momentum spectrum from Monte Carlo simulation vary with the input value of the Peterson fragmentation function ϵ_b. This variation reflects on the κ distribution. To take into account this effect the ϵ_b input value is varied from 0.003 to 0.01 [13]. This variation leads to a systematic of ± 0.01 either with or without neutrino.

7.3.3 Λ_b four body decays

The Λ_b^0 semileptonic decay final state multiplicity can consist of four or more particles, though by analogy with B mesons decays, the three body decays are expected to be dominant. If we suppose that the Λ_b^0 decay $\Lambda_b^0 \rightarrow \Lambda_c^+ l^- \overline{\nu_l}$ is at the level of 80% and that the remaining 20% are shared equally by the following four body decays : $\Lambda_b^0 \rightarrow \Lambda_c^+ l^- \overline{\nu_l} \pi^0$ and $\Lambda_b^0 \rightarrow \Lambda_c^+ l^- \overline{\nu_l} \rho^0$. The effect on the κ distribution leads to a Λ_b^0 lifetime variation of ± 0.03 with neutrino and a comparable value ± 0.02 without neutrino.

In the case of the κ distribution with neutrino, to estimate the effect due to the bad detector simulation of the tails, the κ distribution is fitted with two gaussians (figure 7) one for the central core and the other for the tail. If we vary the relative proportion of the two gaussian by 20%, the Λ_b^0 lifetime change by ± 0.007

7.3.4 Λ_b^0 polarization

The b polarization in $Z^0 \rightarrow b\bar{b}$ decays is expected to survive (at least partially) the hadronization phase in the case of Λ_b^0. If this is the case the polarization will have an effect on the Λ_b^0 lepton spectrum [14] which reflects on the κ distribution. To account for this possible effect, the Λ_b^0 lifetime is measured with a κ distribution determined from Monte Carlo simulation with a maximum Λ_b^0 polarization (94%). The effect on the Λ_b^0 lifetime leads to a systematic error of $+0.05$ without neutrino and a negligible systematic of $+0.008$ with neutrino. Since the Λ_b^0 polarization is not know, the Λ_b^0 lifetime final value will be quoted with 47% polarization and a systematic error due to polarization of ± 0.025 and ± 0.004 without and with neutrino respectively.

7.4 Λ_b^0 mass

To account for Λ_b^0 mass effect on the Λ_b^0 lifetime, the uncertainty on the Λ_b^0 mass value is taken from theoritical predictions [7] : $M_{\Lambda_b} = (5.6 \pm 0.1)\ GeV/c^2$. This leads to Λ_b^0 lifetime change of ± 0.02 either with or without neutrino.

7.5 Likelihood fit bias

The use of the maximum likelihood fit method on a statisticaly limited sample may introduce a bias on the Λ_b^0 lifetime measurement. To investigate this possible source of systematic error 20,000 Monte Carlo experiments were produced with signal and background events generated according to their respective measured proper time distributions and event numbers. In these Monte Carlo experiments the number of events in the peak N_{peak}^{obs} was fixed to 22 and the number of background events N_{peak}^{back} was allowed to vary within its statistical error following the Poisson law. The lifetime bias is found to be negligible : 0.2 ± 0.2 %. Actually 68.6 ± 0.3 % of the Λ_b^0 lifetime values obtained from these Monte Carlo experiments fall within one sigma of the measured value.

As a final check, we used the standard maximum likelihood fit instead of the extended maximum likelihood fit method. The Λ_b^0 lifetime change is found to be less than 0.005 *ps* either with or without neutrino.

Combining the systematic errors from the different sources in quadrature, the total systematic error with neutrino is ± 0.063 *ps* and without neutrino is ± 0.056 *ps*. These two numbers are similar and as a final systematic value we use ± 0.06 *ps* in both cases.

Including the systematic error, the Λ_b^0 lifetime for 47% Λ_b^0 polarization is :

$$\tau_{\Lambda_b} = 1.20^{+0.43}_{-0.31} \pm 0.06\ ps.$$

with neutrino, and :

$$\tau_{\Lambda_b} = 1.18^{+0.42}_{-0.31} \pm 0.06\ ps.$$

without neutrino.

8 Conclusions

From a data sample of 889,000 hadronic Z^0 decays collected with the ALEPH detector in 1991 and 1992, a total of 22 $\Lambda_c^+ l^-$ combinations candidates in which 16.5 ± 4.7 are attributed to the Λ_b^0 semileptonic decay $\Lambda_b^0 \rightarrow \Lambda_c^+ l^- \overline{\nu_l}$ followed by $\Lambda_c^+ \rightarrow pK^-\pi^+$ have been selected and are used to measure the Λ_b^0 lifetime. The proper time distribution of these events is obtained from their three dimensional decay length reconstructed with the aid of the vertex detector and their relativistic boost. Two methods are used to compute the proper time distribution of these events : one without neutrino information and the second including neutrino from the missing energy in the event. An extended maximum likelihood fit to the proper time distribution in both cases yields a Λ_b^0 lifetime of :

$$\tau_{\Lambda_b} = 1.20^{+0.43}_{-0.31} \pm 0.06\ ps.$$

with neutrino, and :

$$\tau_{\Lambda_b} = 1.18^{+0.42}_{-0.31} \pm 0.06\ ps.$$

without neutrino.

The two results are consistent and are in good agreement with the previous ALEPH Λ_b^0 lifetime result $\tau_{\Lambda_b} = 1.12^{+0.32}_{-0.24} \pm 0.16\ ps$ measured from the impact parameter of the lepton in the Λl^- sample.

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κ without neutrino (method 1)	κ with neutrino (method 2)
$\tau_{\Lambda_b} = 1.15^{+0.42}_{-0.31}\ ps$	$\tau_{\Lambda_b} = 1.19^{+0.43}_{-0.31}\ ps$
$N^{peak}_{sig} = (16.0^{+5.0}_{-4.3})$ events	$N^{peak}_{sig} = (16.1^{+5.0}_{-4.3})$ events
$N^{(0)}_{back} = (34.1 \pm 9.5)$ events	$N^{(0)}_{back} = (26.5 \pm 10.0)$ events
$N^{(1)}_{back} = (89.1 \pm 13.1)$ events	$N^{(1)}_{back} = (86.3 \pm 13.7)$ events
$\tau_{back,1} = 0.82^{+0.18}_{-0.16}\ ps$	$\tau_{back,1} = 0.56^{+0.17}_{-0.13}\ ps$
$N^{(2)}_{back} = (12.9 \pm 3.6)$ events	$N^{(2)}_{back} = (17.2 \pm 4.1)$ events
$\tau_{back,2} = 5.34^{+3.55}_{-1.75}\ ps$	$\tau_{back,2} = 3.65^{+2.36}_{-1.08}\ ps$

Table 2: Λ_b^0 lifetime results.

Source	σ_τ^{syst} (ps)	
	κ without neutrino	κ with neutrino
Resolution function	±0.013	±0.013
Background fraction	±0.016	±0.017
Background shape	±0.030	±0.040
Decay models	±0.018	±0.021
b fragmentation	≤ 0.010	±0.010
Λ_b^0 4 body decays	±0.020	±0.030
E_ν calibration	-	±0.007
Λ_b^0 polarisation	±0.025	±0.004
Λ_b^0 mass	±0.020	±0.020
total	0.056	0.063

Table 3: Systematic errors on the Λ_b^0 lifetime

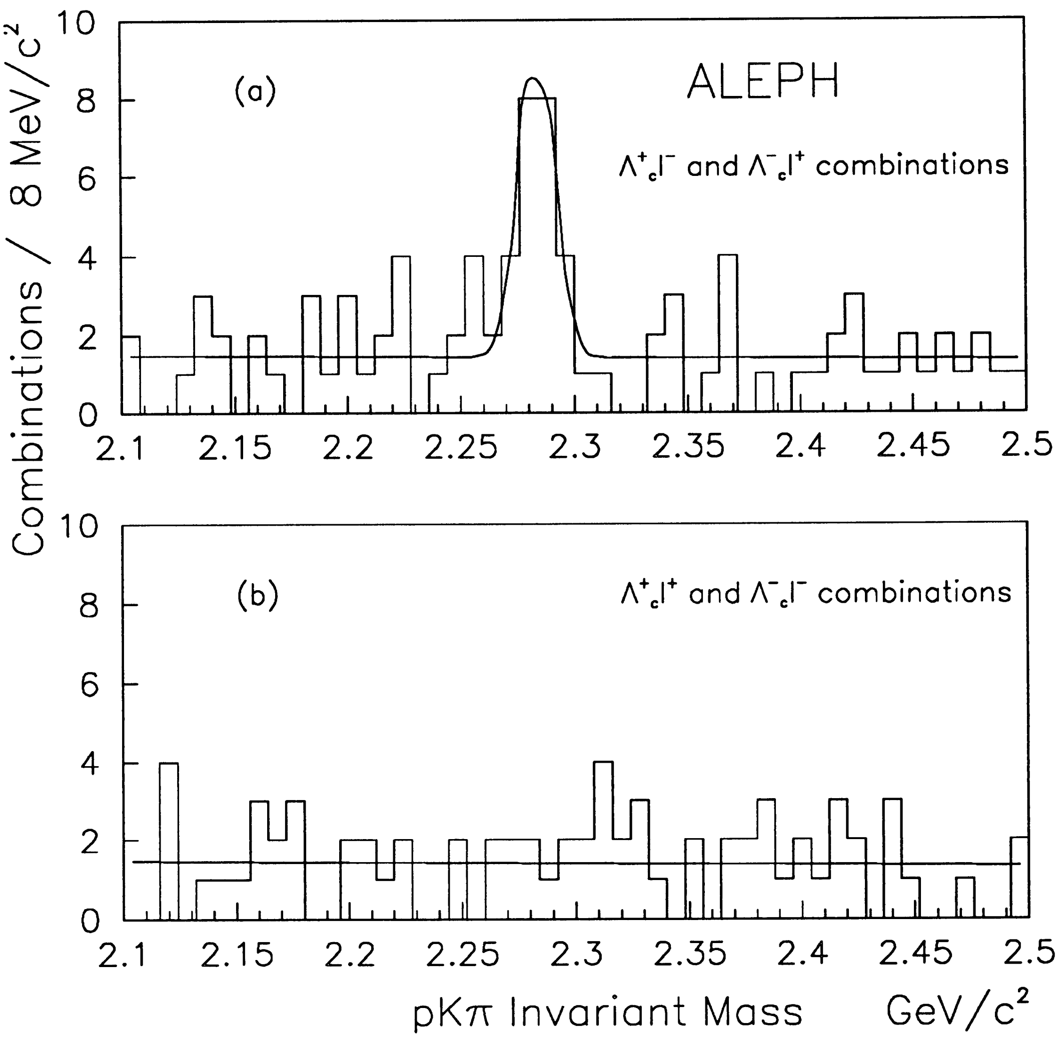

Figure 1: The $pK^-\pi^+$ effective mass for (a) same sign and (b) opposite sign Λ_c^+ lepton correlation.

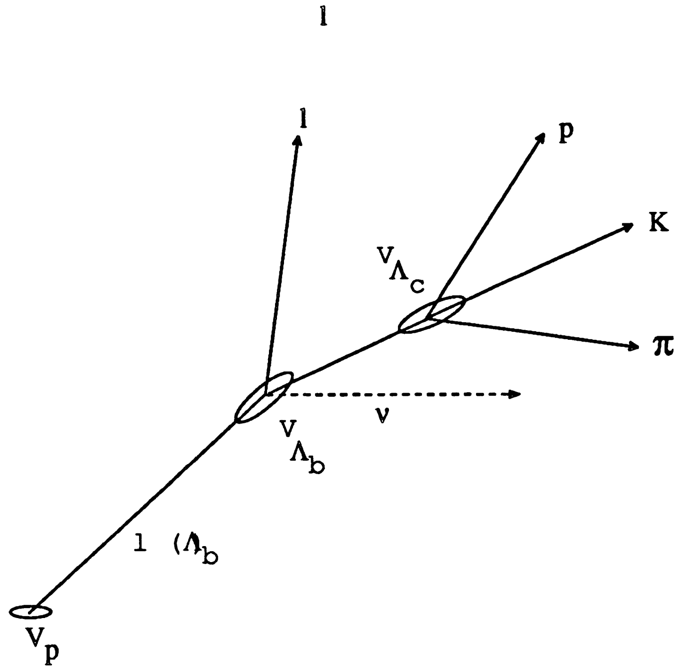

Figure 2: Λ_b^0 semileptonic decay topology.

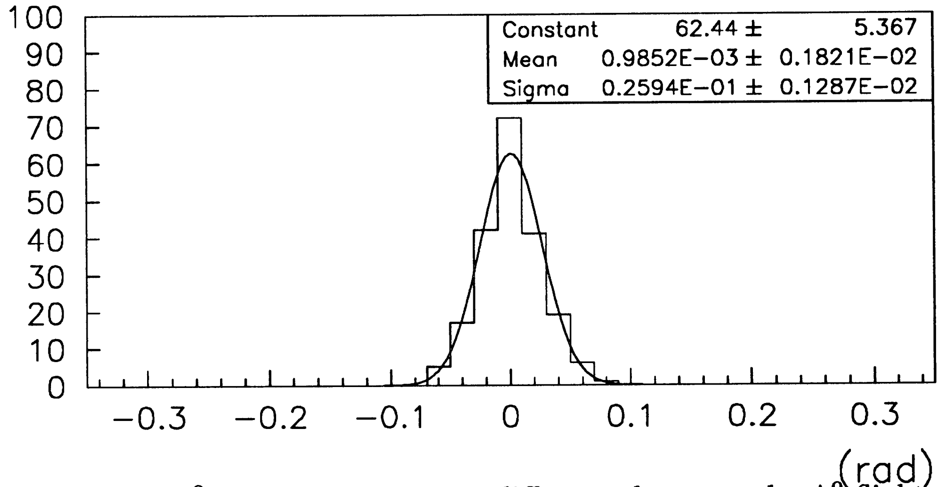

Figure 3: The Λ_b^0 angular resolution : difference between the Λ_b^0 flight direction and the $\Lambda_c^+ l^-$ flight direction obtained from Monte Carlo simulation.

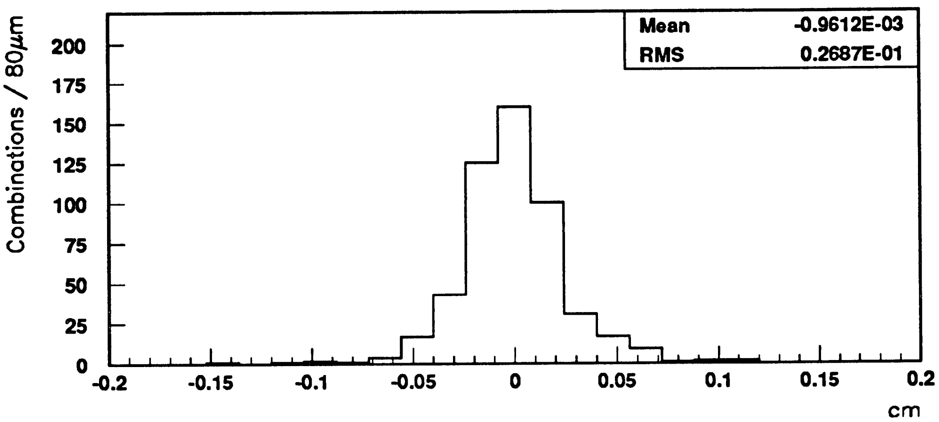

Figure 4: The Λ_b^0 decay length resolution.

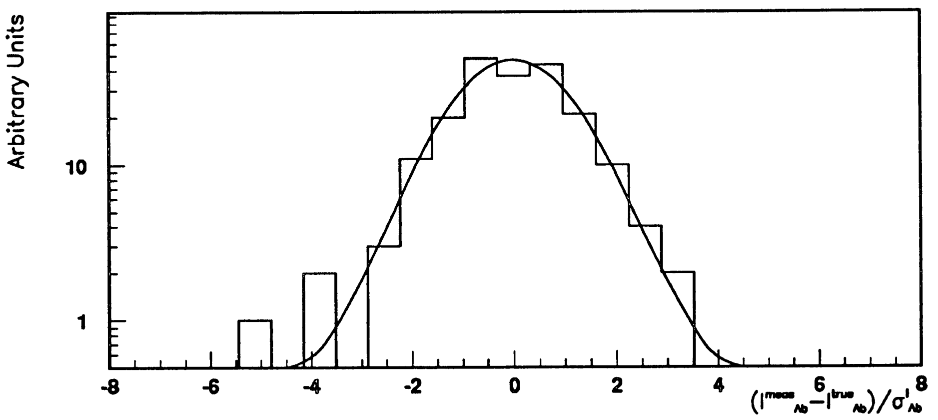

Figure 5: The pull distribution : difference between the reconstructed and the true decay lengths obtained from Monte Carlo simulation.

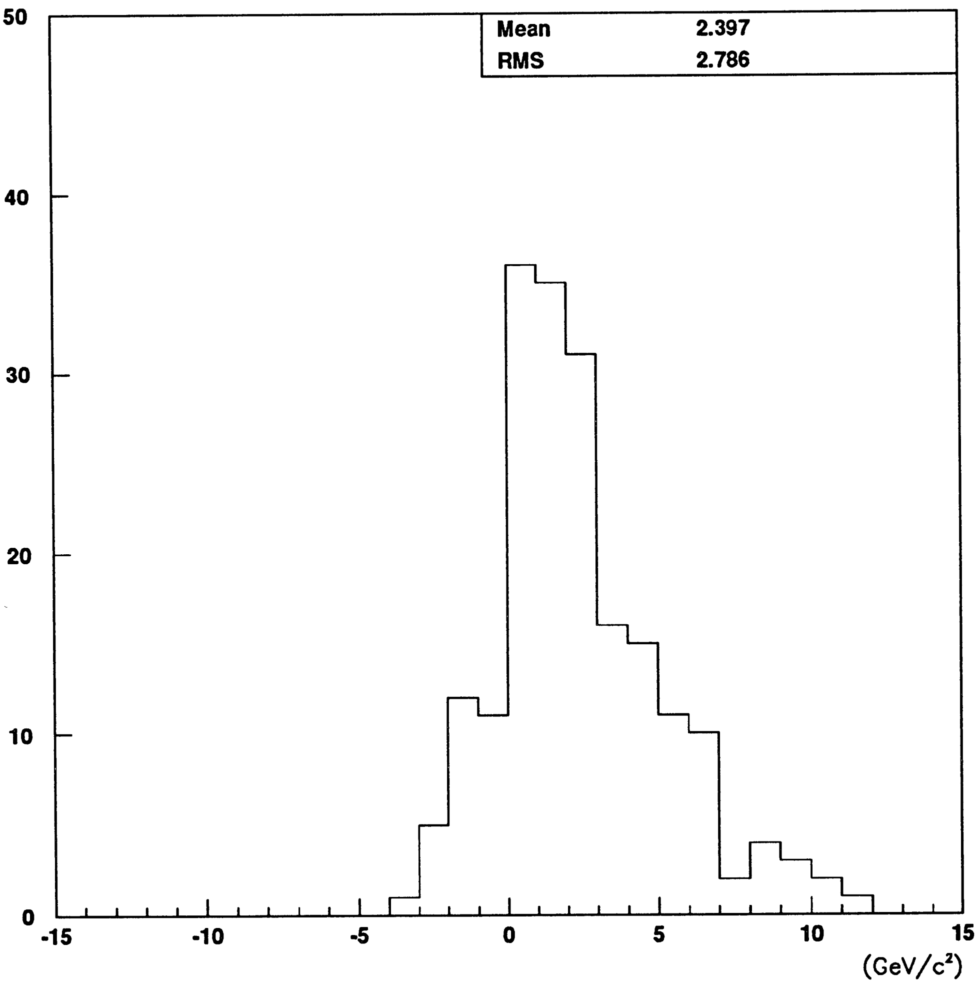

Figure 6: The neutrino energy resolution : difference between reconstructed missing energy and the true neutrino energy obtained from Monte Carlo simulation.

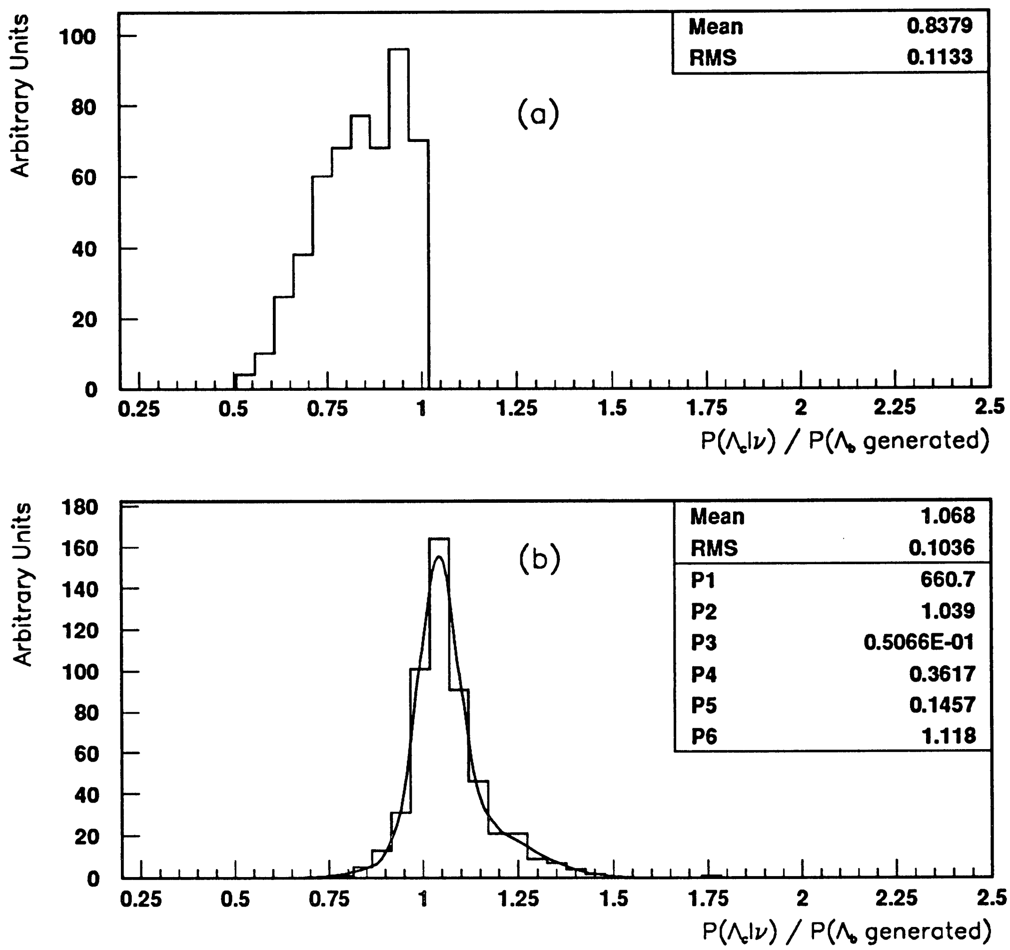

Figure 7: The kappa distribution from the fully reconstructed Monte Carlo simulation, (a) without neutrino, (b) with neutrino.

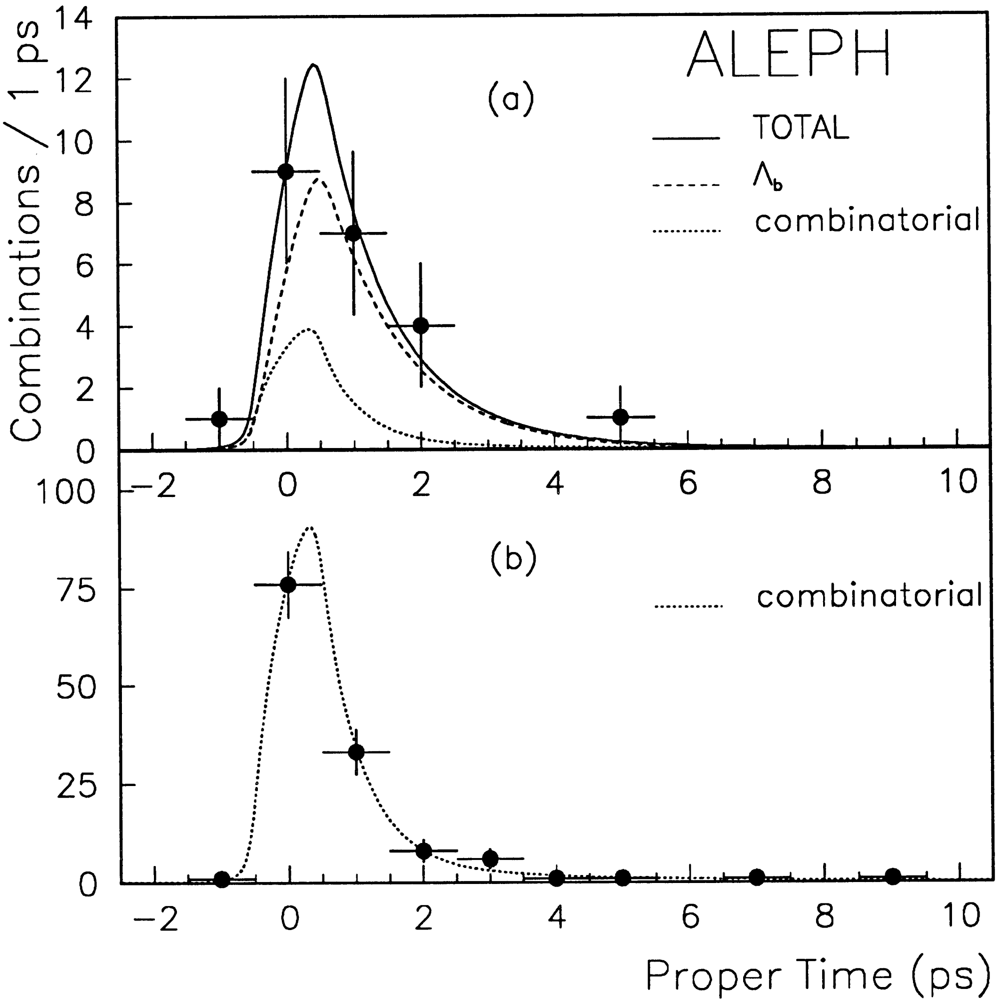

Figure 8: Result of the extended maximum likelihood fit to the proper-time distribution of opposite sign $\Lambda_c^+ l^-$ events in the Λ_c^+ peak region (a) and the combinatorial background events (b) from side band $\Lambda_c^+ l^-$ events and all wrong sign $\Lambda_c^+ l^+$ events.