MEASUREMENT OF THE LIFETIME OF BOTTOM HADRONS

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Abstract

The average lifetime of bottom hadrons from \(Z^0\) decays was measured with the Aleph detector at the new LEP storage ring. The lifetime was determined by measuring the impact parameter distribution of leptons produced in bottom decays. The result of the analysis is

\[
\tau_B = (1.28 \pm 0.08 \pm 0.12) \times 10^{-12} \text{ sec.}
\]

The measurement of the bottom hadron lifetime is an important factor in the determination of the matrix elements and of the Kobayashi - Maskawa mixing matrix. It is therefore of great interest to determine this number as precisely as possible. Current measurements of the B-lifetime still suffer from large experimental errors (> 10%) [1,2,3]. In the decay of \(Z^0\) particles B - B hadrons are produced with a branching fraction of about 15%. These B's can be efficiently tagged by searching for high (p,pr) leptons originating from the semileptonic decays of these hadrons. Therefore the data collected by the ALEPH detector [5] at the LEP storage ring at CERN offer a sample of events well suited to measuring the B - lifetime. The analysis presented in this article is based on total sample of 120000 \(Z^0\) decays recorded in the running periods from October 1989 to June 1990.

The average lifetime of the B - hadrons is determined from the projected signed impact parameter distribution of leptons produced in the decays of the hadrons [4]. The impact parameter \(S\) is defined as the distance of closest approach between the lepton trajectory, projected in the plane perpendicular to the beams, and the production vertex of the hadrons. The impact parameter is signed positive if the intersection of the lepton trajectory with the trajectory of the parent hadron Mes in the direction of flight of the hadron as seen from the production point. It is signed negative otherwise.

Since the production point is difficult to determine on an event by event basis it is estimated by the centroid of the beamspot averaged over a fill. By plotting the distance of closest approach to the origin as a function of the azimuthal angle of a track, for all tracks in a fill we are able to determine the position of the beam centroid with an accuracy of \(\Delta \phi \sim 30/\mu\text{m}.

The direction of flight of the B - hadron is estimated by the axis of the jet to which the decay lepton is associated. The jets are formed with the scaled invariant mass clustering algorithm using all charged tracks in the event with a momentum > 0.2GeV and setting \(y_c = 0.02\).

Candidates for semileptonic B - decays are selected from the hadronic events by the following selection criteria. All candidates are required to have a total charged energy of > 0.2E_c and > 5 good charged tracks, where a good track is considered to have > 5 coordinates in the Time Projection Chamber (TPC) and a polar angle in the range of \(I \cos \theta | < 0.95\). The distance of the trajectory to the beam spot must be \(|d| < 2 cm\) in the \(r\phi\) plane perpendicular to the beams and the distance along the beam must be \(|z| < 10 cm\). These cuts select hadronic decays from the \(Z^0\) with an efficiency of 97.5 ± 0.6%. The background from \(TT\) and \(e^+e^-\) hadrons events is < 0.3% with this selection.

The methods for muon and electron identification are described in detail in [6]. The main features of the methods will be described briefly in the following paragraphs.

Candidates of muon tracks are identified by the penetration of the track in the hadronic calorimeter. The calorimeter consists of 23 layers of 5cm thick iron slabs interspaced with streamer tubes. A muon candidate is required to have >10 planes hit, > 5 planes hit out of the last 10 and >1 out of the last
3 planes. The efficiency of the muon identification is 83 ± 3%. The background in the muon sample due to decays in flight, hadron punch-through and sail-trough is in the order of a few percent.

The electrons are identified by using the information on the energy - momentum balance of their shower in the electromagnetic calorimeter, the longitudinal and transverse profile of the shower and the $dE/dx$ measurement of the track in the TPC. The efficiency of the electron identification is 70 ± 3%. The background from 7 conversions and $\nu^+ \nu^-$ is reduced to 3 - 10%, depending on the momentum range, by a pair finding algorithm and a cut on $d\theta$.

The hadron misidentification background amounts to 0.05 - 0.3% as measured from the data.

From this sample of events with lepton candidates an enriched subsample of bottom decay candidates is selected by cutting on the lepton momentum $p$ and the momentum component $p_T$ transverse to the jet containing the lepton. The signed impact parameter distribution obtained from these leptons with $p > 2 GeV$ and $p_T > 2 GeV$ is shown in figure 1. The distribution shows a clear skew to positive values with $<$ 8 >= 140μm. To extract the average lifetime of the B - hadrons contained in the event sample a fit with a maximum likelihood technique is used.

The events contain lepton candidates from five possible sources: direct b - hadron decays (B); B - hadron cascade decays (BC); direct c - hadron decays (C); misidentification background from hadrons which are identified as leptons (MIS); decay background, these are real leptons coming from decays in flight or from 7 - conversions (DEC). The contribution to the measured impact parameter distribution from an event i can be described by the following fitting function:

$$\kappa = f_{B,BC,C,\ldots} \times P_{K}(\delta)$$

The function $f_{B,BC,C,\ldots}$ determines for each lepton the probability to be from source $K$ as a function of $(p, p_T)$\textsuperscript{a}. The probability density function $P_{K}$ determines for each lepton source the probability of having a measured impact parameter $\delta$.

The values of $f_{K}$ are obtained from the analysis of the semileptonic branching fractions of the decays $Z^0 \to b\bar{b}$ [6] The functions $P_{K}$ are obtained from data and Monte Carlo calculations. For the misidentification background the impact parameter distribution for tracks that satisfy all selection cuts except the lepton identification is obtained from data. This distribution is then weighted by the fraction of misidentified hadrons (MIS and parametrized using gaussian and exponential functions. Monte Carlo studies of the decay background showed that one can use the $PMIS$ distribution broadened by a factor 2 to describe the contribution from this lepton source. The impact parameter distribution for the direct lepton sources are obtained in a two-step process. Monte Carlo techniques are used to generate semileptonic decays of the three different types (B, BC, C) without taking resolution effects into account. The resulting distribution is parameterized with exponential functions which scale with the quantity $y = 8/cr$. The lifetime of the charm quark was fixed to be $r_c = (0.68 \pm 0.10)ps$, so the lifetime of the bottom quarks remains the only free parameter in the fit. In the second step the true impact parameter distributions from the Monte Carlo are convoluted with the experimental resolution function. This resolution function is obtained from data by selecting tracks with a $p^2$ vector pointing out of the $p\theta$ plane. Any nonzero impact parameter of these tracks must be due to resolution effects.

The result of the fit for leptons with $p > 5 GeV$ and $p_T > 2 GeV$ is shown as solid line in figure 1, the lifetime derived is $T_B = (1.28 \pm 0.08)10^{-12}$ sec. Several checks on the consistency of the analysis have been made. The lifetime was evaluated for electrons and muons seperately, the lifetime obtained from positive and negative tracks was compared and also the results from the 89 and 90 data were compared to

![Figure 1: Impact parameter distribution for lepton candidate tracks with momentum $p > 2 GeV$. The solid line shows the result of the fit.](image)

\textsuperscript{a} The probability density function $P_{K}(\delta)$ determines for each lepton source the probability of having a measured impact parameter $\delta$. Any nonzero impact parameter of these tracks must be due to resolution effects.
each other. All values of the lifetime are consistent within the experimental error. A careful evaluation of the systematic errors was done. Uncertainties in the lepton source fractions $f$, the resolution function, the lepton bremsstrahlung, the charm lifetime and the fragmentation effects amount to a 10% systematic error in the measured $B^-$ lifetime.

To conclude, we have measured the average lifetime of $B^-$ hadrons produced in the decay of $Z^0$ particles and found $\tau = (1.28\pm0.08\pm0.12)\times10^{-12}$ sec. This result is still preliminary, there are further studies in progress to reduce the systematic error and to make full use of the data sample available from the 1990 run period. Nevertheless our measurement of $TB$ has already a greater precision than previous measurements [1,2,3].

References