MEASUREMENTS OF THE B^+ AND B^0 LIFETIMES AT SLD

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The lifetimes of B^+ and B^0 mesons have been measured using a sample of 150,000 hadronic Z^0's collected by the SLD experiment at the SLC between 1993 and 1995. Two analyses are presented. The first identifies semileptonic decays of B mesons and reconstructs the B decay by vertexing the lepton with a partially reconstructed D meson. The second analysis reconstructs the B meson decay length and charge using a novel topological vertex reconstruction method.

1 Introduction

Since the startup of data taking in 1992, the SLC Large Detector (SLD) operating at the SLAC Linear Collider (SLC) has collected in excess of 200,000 hadronic Z^0 decays with a polarized electron beam. Along with the unique polarized electron beam, SLD has been able to utilize its high precision 3-D CCD vertex detector in combination with the micron-sized SLC beam to perform several measurements competitive to experiments with much larger hadronic Z^0 decay samples. Two analysis techniques for measuring the B^+ and B^0 lifetimes are presented here, utilizing data sets collected from 1993 to 1995 for a total of 150,000 hadronic Z^0 decays.

In the first technique, the semileptonic analysis, the goal is to reconstruct the total charge of tracks produced in B meson semileptonic decays. The algorithm reconstructs both B and D vertices, and takes into consideration the existence of decays of the type $B^0 \to D^{*-}l^+\nu$ or $B^0 \to D^{**-}l^+\nu$, in which a slow transition pion, with charge opposite that of the lepton, is produced at the B decay vertex. This technique does not rely on the charge correlation between the lepton and the D vertex to determine the total charge of the B meson. It should be noted that a fraction of decays of the type $B^+ \to \bar{D}^{**0}l^+\nu$ yield two slow transition pions which tends to dilute the charge assignment purity. The method has the advantage of a high charge reconstruction purity.

The goal of the second technique, the topological analysis, is to use the high resolution 3-D vertexing to reconstruct the total charge of tracks produced in hadronic, as well as semileptonic, B meson decays. An original technique is employed which uses the parameters of high quality tracks in each hemisphere to define a vertex probability function in 3-D space. This function is used to try to identify a seed vertex to which further tracks may be associated in order to reconstruct a single secondary vertex. This vertex consists mainly of tracks of B and D decay origin. The decay length is taken from the reconstructed secondary. The charge is taken from the secondary plus the charges of tracks passing looser cuts consistent with the secondary. This analysis has the advantage of a larger reconstruction efficiency than the semileptonic analysis, but with a somewhat reduced charge reconstruction purity.

Observations of the hadronic Z^0 decay products made using the SLD,[1] and used in the analyses presented here, employ the Warm Iron Calorimeter (WIC) for muon identification; the Liquid Argon Calorimeter(LAC) for electron identification; and the Central Drift Chamber (CDC) for charged track identification and momentum measurements. A CCD pixel Vertex Detector (VXD) provides precise position measurements near the interaction point. The VXD, together with the micron-sized SLC Interaction Point (IP), allows accurate 3-D vertex reconstruction.

2 Semileptonic Analysis

The goal of the semileptonic analysis is to correctly identify all charged tracks resulting from a semileptonic decay of a B meson. The initial step in this analysis is to identify a track as an electron or muon from the decay of a B meson in a given event hemisphere. To enhance the fraction of $Z^0 \to b\bar{b}$ events with small loss in efficiency, lepton candidates are required to pass relatively loose cuts: total momentum $p > 2$ GeV/c and momentum transverse to the nearest jet > 0.4 GeV/c (where jets are found from calorimeter clusters using the JADE algorithm [2] with $y_{cut} = 0.005$). Application of these cuts yields a sample of 34K events, including approximately 75% of the electrons and muons from semileptonic B decays within $|\cos\theta| < 0.6$.

The B and D decay vertex reconstruction proceeds separately for each event hemisphere containing a lepton using a multi-pass algorithm which operates on those tracks which have at least one VXD hit and are classified as either "primary" (consistent with coming from the IP) or "secondary" (consistent with coming from a secondary decay). First, a D decay vertex is reconstructed in 3-D from a set of tracks classified as secondary. Then, the B decay vertex is defined by the intersection between the D vertex total momentum vector and the lepton direction. An attempt is then made to form a two-prong B vertex by attaching one primary track to the lepton near the point of intersection. This is followed by an attempt to attach up to two primary tracks to the D vertex.

The analysis described above isolates 1367 semileptonic B decay candidates (for a reconstruction efficiency for B semileptonic decays of $\sim 24\%$ within $|\cos\theta| < 0.6$). Of these, 783 are reconstructed as charged decays and 584 as

	B Vertex	D Vertex		Data	MC
	1 prong	2 prong	519	$(38.0 \pm 1.3)\%$	38.2%
B^+	1 prong	4 prong	115	$(8.4 \pm 0.8)\%$	8.4%
	2 prong	3 prong	149	$(10.9 \pm 0.8)\%$	9.3%
	1 prong	3 prong	341	$(24.9 \pm 1.2)\%$	27.1%
B^0	2 prong	2 prong	175	$(12.8 \pm 0.9)\%$	13.3%
	2 prong	4 prong	68	$(5.0 \pm 0.6)\%$	3.7%

Table 1: Summary of reconstructed topologies, including the fraction of each topology in the combined charged and neutral semileptonic B decay sample for data and Monte Carlo simulation.

neutral decays, with the topological breakdown given in Table 1 along with predictions from the simulation. Monte Carlo studies indicate that the B^+ topology consisting of two-prong B and three-prong D vertices has very poor B^+ purity due to the relatively small branching ratio for $B^+ \to D^- \pi^+ l^+ \nu$. This topology is rejected for the remainder of the analysis, reducing the number of decays reconstructed as charged from 783 to 634. Monte Carlo studies show that the remaining charged (neutral) sample is 97.5% (99.1%) pure in B hadrons. The simulated flavor contents are 66.9% B_u^+, 22.5% B_d^0, 5.7% B_s^0, and 2.4% B baryons for the charged sample, and 19.6% B_u^+, 60.8% B_d^0, 14.0% B_s^0, and 4.7% B baryons for the neutral sample.

The B^+ and B^0 lifetimes are extracted from the decay length distribution of the reconstructed B vertices using a binned maximum likelihood technique. The distributions for the charged and neutral samples, shown in Fig. 1, are fitted simultaneously to determine two parameters: the lifetime ratio τ_{B^+}/τ_{B^0} and either the B^+ or the B^0 lifetime (the results do not depend on which set of two parameters are used in the fit). For each set of parameters, Monte Carlo decay length distributions are obtained by reweighting the original Monte Carlo decay length distributions for B^+ and B^0.

The best fit Monte Carlo distributions (the overlays in Fig. 1) give a $\chi^2 = 80$ for 76 degrees of freedom for the combined fit to both charged and neutral distributions.

Systematic uncertainties due to detector and physics modeling, as well as those related to the fitting procedure, have been investigated.[3] The individual contributions to the total systematic uncertainty in the B^+ and B^0 lifetimes and their ratio are summarized in Table 2. The resulting lifetimes are:

$$\tau_{B^+} = 1.60^{+0.12}_{-0.11}(\text{stat}) \pm 0.06(\text{syst}) \text{ ps},$$
$$\tau_{B^0} = 1.55^{+0.13}_{-0.12}(\text{stat}) \pm 0.09(\text{syst}) \text{ ps}.$$

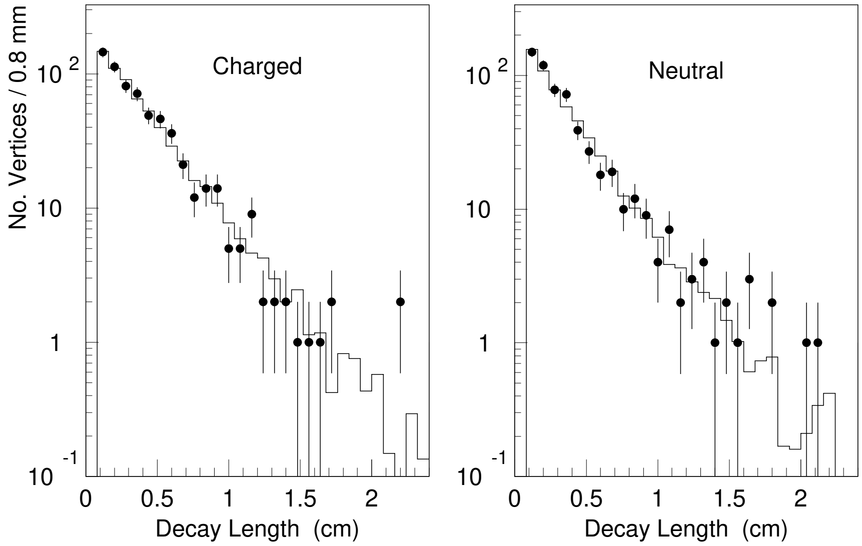

Figure 1: Decay length distributions for charged and neutral decays in the semileptonic analysis for data (points) and Monte Carlo corresponding to the best fit (histograms).

The resulting lifetime ratio is:

$$\frac{\tau^{B^+}}{\tau^{B^0}} = 1.03^{+0.15}_{-0.13}(\text{stat}) \pm 0.08(\text{syst}).$$

3 Topological Analysis

The goal of the topological analysis is to associate tracks with a single reconstructed secondary vertex in an event hemisphere in order to reconstruct the charge of the B meson decay. This is achieved by employing a novel topological vertexing technique for reconstructing the secondary vertices.[4] The technique starts with a set of tracks in a given event hemisphere which have passed strict quality cuts.[5] Secondary vertices are identified as regions of high track overlap probability, where tracks are represented as gaussian 3-D probability functions, their transverse size reflecting impact parameter errors. The inclusive efficiency for reconstructing at least one secondary vertex in a B hemisphere is $\sim 50\%$. The secondary vertex farthest from the IP is selected in hemispheres containing more than one vertex. Additional tracks are associated with this "seed" vertex if they pass within 1 mm of the vertex axis (the line joining the

Systematic Error	$\Delta\tau_{B^+}$ (ps)	$\Delta\tau_{B^0}$ (ps)	$\Delta\left(\frac{\tau_{B^+}}{\tau_{B^0}}\right)$
	Detector Modeling		
Tracking efficiency	0.006	0.029	0.023
Tracking resolution	0.004	0.027	0.020
Lepton ID	0.006	0.006	0.001
	Physics Modeling		
b fragmentation	0.034	0.036	0.004
BR($B \to D^{**}l\nu X$)	0.010	0.008	0.011
BR($B \to DDX$)	0.009	0.008	0.011
BR($B \to X \to l$)	0.001	0.001	0.001
B_s fraction	0.009	0.005	0.009
B baryon fraction	0.009	0.015	0.004
B_s lifetime	0.002	0.035	0.024
B baryon lifetime	0.001	0.011	0.008
D multiplicity	0.013	0.011	0.001
Charm hadron lifetime	0.004	0.003	0.003
	Monte Carlo and Fitting		
Fit systematics	0.038	0.042	0.056
MC statistics	0.030	0.033	0.038
TOTAL	0.064	0.087	0.081

Table 2: Summary of contributions to the systematic uncertainty in the B^+ and B^0 lifetimes and their ratio.

IP to the seed) and if the distance between the IP and their point of closest approach to the vertex axis is at least 30% of the distance to the seed. Since the purity of the B charge reconstruction is lower for decays close to the IP where tracks are more likely to be wrongly assigned, vertices with decay length $<$ 1mm are discarded. The invariant mass of all the tracks associated with the secondary must exceed 2 GeV/c^2 in order to remove most of the light-quark and charm contamination. [6]

The secondary vertex charge reconstruction is improved by considering tracks which fail the initial selection but have $P_T >$200 MeV/c and $\sqrt{\sigma_{r\phi}^2 + \sigma_z^2} <$ 700μm, where $\sigma_{r\phi}$ (σ_z) is the uncertainty in the track position transverse (longitudinal) to the beam direction close to the IP. These tracks which also pass within 1 mm of the vertex axis, and whose distance between the IP and their point of closest approach to the vertex axis is at least 30% of the distance to the secondary vertex, have their charge added to the secondary vertex charge.

The charged sample consists of hemispheres with secondary vertex charge,

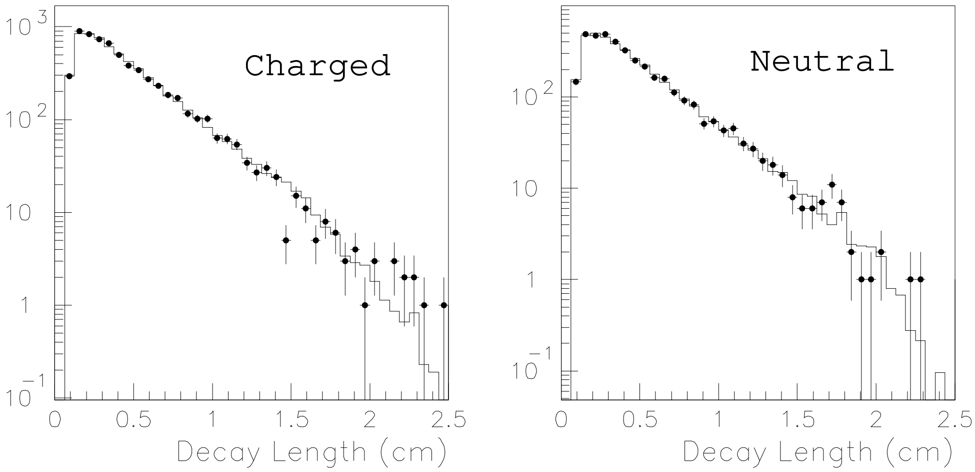

Figure 2: Decay length distributions for charged and neutral decays in the topological analysis for data (points) and Monte Carlo corresponding to the best fit (histograms).

defined above, equal to $\pm$ 1,2 or 3, while the neutral sample consists of the secondary vertices with charge equal to 0. This separates the reconstructed decays into a charged sample of 6033 vertices and a neutral sample of 3665 vertices. Monte Carlo studies indicate that the resulting charged sample is 97.3% pure in B hadrons consisting of 54.6% B^+, 30.5% B^0, 8.6% B_s^0, and 3.6% B baryons. Similarly, the neutral sample is 98.0% pure in B hadrons consisting of 23.3% B^+, 54.5% B^0, 14.6% B_s^0 and 5.6% B baryons.

The resulting decay lengths for the charged and neutral samples are shown in figure 2. A fitting procedure identical to that employed for the semileptonic analysis is used to obtain the lifetimes and their ratio. Contributions to the systematic error on these values are listed in Table 3. The best fit Monte Carlo distributions (the overlays in figure 2) give a $\chi^2 = 48.1(37.8)$ for 38 degrees of freedom for the charged(neutral) sample. The resulting lifetimes are:

$$\begin{aligned} \tau_{B^+} &= 1.69 \pm 0.06(\mathrm{stat}) \pm 0.06(\mathrm{syst})\ \mathrm{ps}, \\ \tau_{B^0} &= 1.63 \pm 0.07(\mathrm{stat}) \pm 0.08(\mathrm{syst})\ \mathrm{ps}. \end{aligned}$$

The resulting lifetime ratio is:

$$\frac{\tau^{B^+}}{\tau^{B^0}} = 1.04^{+0.08}_{-0.07}(\mathrm{stat}) \pm 0.06(\mathrm{syst}).$$

Systematic Error	$\Delta\tau_{B^+}$ (ps)	$\Delta\tau_{B^0}$ (ps)	$\Delta\left(\frac{\tau_{B^+}}{\tau_{B^0}}\right)$
	Detector Modeling		
Tracking efficiency	0.005	0.032	0.022
Tracking resolution	0.030	0.003	0.021
	Physics Modeling		
b fragmentation	0.036	0.038	0.011
B decay charm	0.012	0.008	0.009
B decay multipl.	0.016	0.008	0.006
B_s^0 fraction	0.012	0.004	0.005
B baryon fraction	0.013	0.041	0.017
B_s^0 lifetime	0.001	0.036	0.022
B baryon lifetime	$<.001$	0.008	0.005
$B \to D$ spectrum	0.006	0.025	0.019
D decay multiplicity	0.011	0.010	0.013
D decay K^0 yield	0.001	0.019	0.012
Charm hadron lifetime	0.002	0.004	0.002
	Monte Carlo and Fitting		
Fit systematics	0.024	0.013	0.022
MC statistics	0.017	0.018	0.021
TOTAL	0.063	0.085	0.060

Table 3: Summary of contributions to the systematic error for the B^+ and B^0 lifetimes and the lifetime ratio.

4 Analyses Overlap

The overlap of reconstructed B meson decays between the two analysis techniques has been investigated. Of the 1218 decays in the semileptonic analysis and the 9698 decays in the topological analysis, there are 657 decays in common. 80% of the overlap events agree in their charge assignment (284 reconstructed as charged, 240 reconstructed as neutral). Good agreement between the topological and semileptonic analyses is observed for reconstructed secondary vertex decay lengths and momenta.

5 summary

The B^+ and B^0 lifetimes have been measured from a sample of 150K hadronic Z^0 decays collected by SLD between 1993 and 1995. This has been done using two techniques, one partially reconstructing B and D vertices in semileptonic events, the other applying a novel topological vertexing method to all hadronic Z^0 decays. The results are summarized in the table below:

	Semileptonic analysis	Topological analysis
τ_{B^+}	$1.51 \pm 0.10(\text{stat}) \pm 0.05(\text{syst})$ ps	$1.67 \pm 0.06(\text{stat}) \pm 0.06(\text{syst})$ ps
τ_{B^0}	$1.56^{+0.14}_{-0.13}(\text{stat}) \pm 0.10(\text{syst})$ ps	$1.55 \pm 0.07(\text{stat}) \pm 0.08(\text{syst})$ ps
$\frac{\tau_{B^+}}{\tau_{B^0}}$	$0.97^{+0.13}_{-0.12}(\text{stat}) \pm 0.06(\text{syst})$	$1.08^{+0.09}_{-0.08}(\text{stat}) \pm 0.07(\text{syst})$

The results of the lifetime fits and the systematic errors are consistent with the expectation of a small difference between the B^+ and B^0 lifetimes. They are also consistent with current world averages.

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