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A preliminary, precise measurement of the average B hadron lifetime

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Abstract

The average B hadron lifetime was measured using data collected with the SLD detector at the SLC in 1993. From a sample of ∼50,000 Z^0 events, a sample enriched in $Z^0 \rightarrow b\bar{b}$ was selected by applying an impact parameter tag. The lifetime was extracted from the decay length distribution of inclusive vertices reconstructed in three dimensions. A binned maximum likelihood method yielded an average B hadron lifetime of $\tau_B = 1.577 \pm 0.032(\text{stat.}) \pm 0.046(\text{syst.})$ ps.

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I Introduction

The precision measurement of the average B hadron lifetime τ_B is important for the study of the b quark and its weak couplings to u and c quarks. It can be used to determine the Cabibbo-Kobayashi-Maskawa matrix element $|V_{cb}|$. Measurements of the average B hadron lifetime have been performed in e^+e^- collisions at PEP[1], PETRA[2], and LEP[3] as well as in $p\overline{p}$ collisions[4].

Results of τ_B measurements presented in 1993[5] differed substantially from the 1992 world average[6]. Reports of additional independent precision measurements of τ_B are interesting and timely.

In this paper, results are presented on a measurement of τ_B using data taken at the Stanford Linear Collider (SLC) with the SLC Large Detector (SLD). The very small spotsize ($0.8\times2.4\ \mu m^2$) for SLC and the superb vertex detector of SLD are well-suited for a precision measurement of τ_B. The analysis for τ_B presented here is novel. It was performed on ∼50,000 Z^0 decays recorded during the 1993 run of SLC. A sample enriched in $Z^0 \to b\overline{b}$ events was selected using an impact parameter technique. In this sample, geometrical reconstruction was performed for all possible secondary vertices that passed selection cuts. The imposing list of resultant vertices was pared down by selecting the global event topology that gave the maximum joint probability for all the vertices in the event such that no two vertices were allowed to share a track. Additional cuts were performed to reduce the number of surviving vertices containing tracks coming from the interaction point (IP) and to limit the number of vertices per event hemisphere to one. A maximum likelihood technique was then used to extract a value for τ_B from the decay length distribution of the surviving vertices.

II The SLD Detector

This analysis utilized a subset of the SLD detector. Charged particle tracking was done using the central drift chamber (CDC) and the vertex detector (VXD)[7]. The CDC is 2 m long and extends radially from 0.2 m to 1.0 m from the beam line. It consists of ten superlayers, providing efficient tracking coverage out to $|\cos(\theta)| = 0.75$. An average spatial resolution of 70 μm was obtained with this device. The VXD consists of 9.2-cm-long ladders of charged coupled devices (CCDs) placed on four concentric cylinders. The inner ladders are located 29 mm from the beam line and the outer ones at 41 mm. On average, 2.3 CCDs are traversed by charged tracks originating from the interaction point. Charged tracks were reconstructed in the CDC and linked with pixel clusters in the VXD. A combined fit using the Billoir method[8] was performed. The angular errors of the CDC combined with local errors $\sigma(r\phi)$ and $\sigma(rz)$ of ~ 6 μm for the VXD clusters, lead to an rϕ (plane perpendicular to the e^+e^-beams) impact parameter resolution of $(\alpha, \beta)_{r\phi}$ = (11μm, 70μm).[1] The rz (plane containing the beam axis) impact parameter resolution is $(\alpha, \beta)_{rz}$ = (38μm, 70μm).

The liquid argon calorimeter (LAC) was used in the event trigger and in the determination of event shape quantities, such as jet and thrust axes. The LAC[9] covers 95% π sr. The radiator is Pb. It consists of a 21-radiation-length-thick electromagnetic (EM) section followed by a 2.8-interaction-length hadronic (HAD) section. Each section is subdivided into two longitudinal layers. The tower segmentation is approximately 33 mrad in the EM section and 66 mrad in the HAD section. The electromagnetic energy resolution of the calorimeter is $\sim$15%/$\sqrt{E}$. The hadronic energy resolution is $\sim$60%/$\sqrt{E}$.

III Interaction Point Determination

The beams of the SLC had an rms transverse profile of 2.4 μm $\times$ 0.8 μm for the 1993 SLD run. The luminous region in z had an rms of $\sim$ 700 μm. Frequent beam-beam scans coupled with feedback utilizing the pulse-to-pulse beamstrahlung monitor information was used to maintain the beams in collision and stabilize the interaction point (IP) position. The IP position was tracked by SLD using hadronic Z^0 events[10]. To find the average IP position and error in the rϕ plane, a fit to a common vertex was performed using tracks with small impact parameter from $\sim$30 consecutive Z^0 events. Studies of the two-dimensional impact parameter of tracks to the IP position in the 1993 data yielded an average σ_{IP} = (7 ± 2) μm in rϕ. The z position of the interaction point was measured event by event. For each track which extrapolated to within three standard deviations of the interaction point in the rϕ plane, the z coordinate at the rϕ point of closest approach was calculated. The median z coordinate of these tracks was defined as the z coordinate of the interaction point. Simulation studies indicate that this procedure has a z resolution of $\sim$35 μm.

IV Monte Carlo Simulation

Approximately 200,000 Monte Carlo Z^0 decays were used in this analysis. The Z^0 and heavy flavor decays were modeled by the LUND JETSET 6.3 Monte Carlo generator[11]. It was adjusted to reflect current knowledge of the B and D decay spectra. Spectra of $B \to D^0 + X$, $B \to D^+ + X$, $B \to D^{*+} + X$ and $B \to D^{*0} + X$ were tuned using CLEO data[12, 13]; $\pi^\pm$, $K^\pm$, and $p(\overline{p})$ particle spectra from B decays were tuned to spectra from

[1]The impact parameter resolution function is parametrized as $\alpha \oplus \beta/P\sqrt{sin^3\theta}$.

ARGUS data[14]. The total charge multiplicity for B_u and B_d decays ($\langle \mathrm{N_{ch}} \rangle$=10.88) was tuned to match the average of CLEO and ARGUS. Average lifetimes of 1.55 ps for B mesons and 1.10 ps for B baryons were used.[5] QCD parameters were used which were determined by the TASSO Collaboration at $\sqrt{s}$ = 35 GeV[15], and have been found to be in good agreement with Z^0 data[16]. For b and c fragmentation we used the Peterson function[17] with $\langle \mathrm{X}_E \rangle = 0.700$ and $\langle \mathrm{X}_E \rangle = 0.494$, respectively. These values are reasonable given recent measurements[18, 19].

The Monte Carlo detector simulation was based on GEANT version 3.15[20]. It produced raw data that modeled the average response of the detector to charged and neutral particles. Simulated Z^0 events were overlaid with random background events taken in close time-proximity to each recorded Z^0. They were then reconstructed with the standard SLD pattern recognition and tracking code.

A difference in track finding efficiency between data and Monte Carlo was observed, and the Monte Carlo program was adjusted accordingly. The correction was performed as a function of momentum, $\cos(\theta)$, ϕ, and ξ (angle with respect to jet direction), by randomly removing Monte Carlo tracks. Approximately 7% of the Monte Carlo tracks passing CDC and VXD cuts (see below) were removed. After this correction, good agreement between Monte Carlo and data in both shape and normalization was obtained[10].

V Event Selection

The SLD trigger was based on loose calorimetric criteria to eliminate primary beam-related backgrounds such as conventional $e^{\pm}$ and γ scattered from the beam pipe and masks and upstream beam-induced muons (unique to SLC). The former were reduced by total energy and asymmetry cuts, while the latter were reduced by utilizing the fine-grained tower structure of the LAC and the pattern of energy deposition of the muons. Approximately 50,000 Z^0 decays were recorded by SLD during the 1993 run.

Hadronic Z^0 events were selected off-line for analysis. For this analysis, the total energy from charged tracks was required to be >18 GeV. The thrust axis was required to lie well within the acceptance of the VXD ($| cos(\theta) | < 0.71$). A minimum of seven reconstructed charged tracks was required in the drift chamber (to reduce $\gamma\gamma$ and $\tau\overline{\tau}$ backgrounds). Finally, to insure optimal CDC and VXD operation, known bad running periods were rejected, and at least three tracks were required to have VXD links. After these cuts, the number of selected hadronic Z^0 events was 29,400.

VI Track Selection

CDC tracks were required to start at a radius r $<$ 39 cm, have $>$ 40 hits, extrapolate to the IP within 1 cm in x-y and 1.5 cm in z, and have good fit quality (χ^2/d.o.f. < 5). At least one good VXD link was required, and the combined CDC/VXD fit satisfied χ^2/d.o.f. < 5. In addition, tracks having a two-dimensional impact parameter error greater than 250 μm and tracks with a two-dimensional impact parameter greater than 3 mm were removed. The former removed poorly measured tracks, and the latter helped remove tracks from long-lived decays, i.e., strange particle decays and gamma conversions. Tracks that passed these cuts were considered to be of high quality and were used in the analysis.

VII Heavy Quark Tag

The large mass and long lifetime of B hadrons lead to the production of relatively more large impact parameter tracks in $Z^0 \to b\bar{b}$ events than in any other type of Z^0 decay. This has been used in the past by many experiments to enrich for $Z^0 \to b\bar{b}$ decays. Such a method of tagging heavy quark events is ideal for the SLD experiment due to the small and stable beam position provided by SLC and the superb impact parameter resolution of the SLD tracking system.

For this analysis, events were tagged as potentially containing a B hadron by using the signed two-dimensional impact parameter. The track impact parameters were signed using the following technique. The JADE jet finding algorithm[21] with $y_{cut} = 0.02$ was used to determine the jet axes in the event from calorimetry clusters. For each track, the impact parameter was signed $+(-)$ if the track crossed its jet axis (i.e., projection onto the jet axis of distance of closest approach to the jet axis) in the same(opposite) hemisphere as the direction of jet axis momentum. A signed, normalized impact parameter was formed by dividing the signed impact parameter by the error on the extrapolated track added in quadrature with the beam position error. Events were tagged by requiring at least three quality tracks in the event with positive normalized two-dimensional impact parameter > 3. With this tag a $Z^0 \to b\bar{b}$ efficiency of 69% and purity of 82% was obtained according to Monte Carlo studies. From the data sample passing the hadronic event selection described above, 4,294 events were tagged.

VIII Vertex Selection

The algorithms for vertex finding and selection used in this analysis were designed to preserve statistics and use the power of the precision three-dimensional vertexing capability of SLD. The general method was to find all possible geometric vertices and then choose the best set of vertices for an event by looking at the global event topology, i.e., choosing the set of independent vertices that maximized the product of the vertex fit probabilities. Additional cuts were used to reduce the number of vertices in the sample not associated with a b quark decay.

Candidate secondary vertices were formed from all pairs of charged tracks in the same hemisphere with at least one hit in the VXD. A vertex constrained fit was performed on all such pairs that extrapolated to within three standard deviations of a common point having their common point in the same hemisphere as the two tracks. To reduce background from tracks originating from the interaction point, the distance from the interaction point to the secondary vertex was required to be at least 1 mm. Furthermore, two-prong vertices consistent with arising from γ conversions, K^0, or Λ^0 decays were removed from the sample.

Next, the two-prong vertices that shared common tracks were combined to form multi-prong vertices using a similar procedure. Tracks from multi-prong candidates were required to extrapolate to within 10 standard deviations of a common point. A total vertex fit χ^2 $< 27(35)$ was required for three(four)-prong candidates. No candidates with more than four prongs were kept.

Events with more than 100 vertices remaining were removed. This was done to reduce the computer time consumed in the succeeding stages of the analysis. This cut removed 122 events. There were 22 events which had no secondary vertices. At this point, some vertex quality cuts were imposed on the sample. Vertices were removed if the vertex fit probability was $< 5\%$ or if all tracks in the vertex had a normalized two-dimensional impact parameter to the IP < 2.5. These cuts removed poor vertex fits and vertices with a high probability of containing a track originating from the IP, i.e., not from a secondary vertex. There were approximately 84,000 vertices in 4,172 events remaining at this stage of the analysis. The distribution of the number of vertices per event is shown in Fig. 1(a). Note that the vertices in each event were not independent in this sample.

The first column of Table 1 shows the percentage of remaining vertices broken down by vertex type according to a Monte Carlo study. A vertex is in the 'b' category if all its tracks originate from the weak decay of a b quark. A vertex is in the 'primary c' category if all its tracks originate from the weak decay of a primary c quark. Vertices arising from cascade c quark decays are in the 'cascade c' category. Vertices made up of tracks arising from the weak decay of a b quark and from cascade decay of a c quark are in the '(cascade c)+b' category. Vertices composed of tracks emanating from the interaction point are indicated by the name 'ip'. The other categories are similarly defined.

In most events, the remaining vertices were not independent. Some tracks were shared by more than one vertex. In addition, finding a multi-pronged vertex satisfying the geometric vertex finding criteria meant that many smaller vertices, subsets of the larger vertex, were found as well. An algorithm was developed to reduce these remaining vertices to a set of independent vertices. First, all possible unique sets of independent vertices were found. Each of these unique sets of independent vertices was called a partition of the event. The choice of the best partition for a given event is analysis dependent. In this analysis, the partition chosen maximized the joint fit probability of the event (product of the fit probabilities for each of the vertices in the partition, $P(\chi^2, d.o.f.)$). Table 1, column 2 shows the constitution of the remaining vertex sample according to a Monte Carlo study. The distribution of the number of vertices per event is shown in Fig. 1(b).

The primary background to real secondary vertices in the remaining sample were vertices made up entirely, or in part, of tracks originating from the IP. This background was substantially reduced by the decay length cut implemented earlier in the analysis. An additional cut was made to further reduce this background. Vertices were removed if the angle between the vertex line of flight and the nearest jet axis was >150 mrad. Two other cuts were made to enhance the track quality, and thus the vertex quality, as well as to reduce the number of vertices arising from IP tracks. Vertices were removed if any track in the vertex had momentum <0.7 GeV/c or if any track had a transverse momentum with respect to the vertex line-of-flight <0.07 GeV/c. The distribution of the number of vertices per event is shown in Fig. 1(c).

The final cut in the vertex selection was to demand no more than one vertex per event hemisphere by selecting the vertex closest to the IP. This simplified the statistical and systematic error calculations. Table 1, column 3 shows the constitution of the final vertex sample used in the analysis according to a Monte Carlo study. The final sample consisted of 5,427 vertices, made up of 4,104 two-prong vertices, 1,068 three-prong vertices and 255 four-prong vertices. Note that 63% of the event hemispheres in selected, heavy quark tagged events have at least one vertex at the end of vertex selection. Of these, 88% contain B hadron lifetime information according to a Monte Carlo study, i.e., they contain tracks associated with a weak b quark decay or the decay of the cascade c quark from the b quark.

The success of this lifetime analysis depends on accurate modeling of the Z^0 and secondary particle decays as well as the tracking and vertex-finding capability of the detector. Figure 2 compares data and Monte Carlo distributions. Figure 2(a) shows the joint probability distribution just after the partition selection cut. Figure 2(b) shows the prong multiplicity of the final sample. Figure 2(c) gives the track momentum distribution for tracks in the selected vertices. Finally, Fig. 2(d) shows the transverse momentum to the vertex line-of-flight for these same tracks. Figures 2(a) and (b) are normalized to the number of tagged events. Figures 2(c) and (d) have arbitrary normalization. These comparisons show that the data is well reproduced by the Monte Carlo. The slight discrepancy between the data and the Monte Carlo in the prong multiplicity is associated with the tracking efficiency correction and contributes to the systematic error.

Vertex type	Before Partition selection (%)	After Partition selection (%)	Final Sample (%)
b	16	19	22
cascade c	12	21	23
b+(cascade c)	44	33	35
b+other	12	7	4
(cascade c)+other	7	7	4
primary c	2	5	9
ip	1	3	1
Other	6	5	2

Table 1: Vertex type in sample according to Monte Carlo study.

It is interesting to examine the b decay length residual for the different categories of vertices containing at least one track from a weak b decay (according to a Monte Carlo study). These are shown in Fig. 3(a–d). Figure 3(a) contains vertices composed of tracks from the b decay, (b) gives the same for the cascade c decay, (c) shows vertices composed of tracks from the b decay and the cascade c decay and (d) contains all vertices containing at least one track from the b decay or cascade c decay. The positive tail in the 'cascade c' and 'b+(cascade c)' plots is expected. It should not affect the lifetime analysis adversely so long as the data is modeled well by the Monte Carlo.

IX Lifetime Analysis

The lifetime was extracted from the decay length distribution by using the following binned likelihood function:

$$\mathcal{L}(\tau_B) = \prod_{i=1}^{nbins} e^{-f_i^{MC}(\tau_B)} \left[f_i^{MC}(\tau_B) \right]^{n_i^{DAT}} / \left(n_i^{DAT}! \right) \quad , \tag{1}$$

where n_i^{DAT} and $f_i^{MC}(\tau_B)$ represent the number of data and Monte Carlo vertices in the i^{th} bin, respectively. The procedure is then to vary the value of τ_B and to find the value corresponding to the maximum likelihood.

However, as indicated in Sec. IV, the Monte Carlo was generated with fixed values of τ_B corresponding to an average B hadron lifetime of $\tau_B = 1.515$ ps. To simulate samples with different values of τ_B we apply the following weight to each vertex:

$$W(\tau_B) = W_1(t_1, \tau_B) \; W_2(t_2, \tau_B)$$
$$W_k(t_k, \tau_B) = \frac{\frac{1}{\tau_B} \, e^{-t_k/\tau_B}}{\frac{1}{\tau_{gen}} \, e^{-t_k/\tau_{gen}}}, \quad (2)$$

where τ_{gen} is the average lifetime value used in the Monte Carlo generation, and t_k is the proper time of each decay. Weight W_1 applies to the B hadron decay the current vertex is associated with, whereas weight W_2 applies to the B hadron decay in the opposite hemisphere. Using the above weights, decay length distributions were produced for τ_B values ranging from 0.7 to 2.3 ps, in steps of 0.02 ps. The likelihood was then computed for each value of τ_B.

The maximum likelihood fits to the decay length distribution yielded an average B hadron lifetime of $\tau_B = 1.577 \pm 0.032$ ps where the error is statistical only. Figure 4 shows the vertex decay length distribution compared to the Monte Carlo distribution giving the best lifetime fit. The $\chi^2/d.o.f.$ for this fit was $\sim$2.

A number of checks were made to increase confidence in this analysis. In one check, the Monte Carlo events were divided into five independent samples, each containing events scattered throughout the entire sample. Each of the five sets was successively analyzed as if it were the data and the other four subsets were Monte Carlo events. The five lifetime measurements yielded 1.528 ± 0.036 ps, 1.539 ± 0.037 ps, 1.449 ± 0.036 ps, 1.563 ± 0.039 ps, and 1.524 ± 0.037 ps, respectively, all in good agreement with the generated value.

In another check of the analysis method and weighting scheme, Monte Carlo events were generated with an average B hadron lifetime of 1.954 ps. If these events were used (instead of the 1.515 ps sample) in the lifetime analysis, a measurement of 1.573 ± 0.030 ps resulted.

A final check was performed to verify that no significant bias resulted from using events which passed the heavy quark tag. An impact parameter based heavy quark jet tag was used on the data. Jets were tagged as containing a heavy quark if $\geq$2 tracks with a normalized impact parameter $\geq$3 were present in the jet. The lifetime analysis was done using only hemispheres opposite a tagged jet. The lifetime resulting from this study was 1.596 ± 0.039 ps, consistent with the result found above.

X Systematic Errors

The systematic errors associated with this measurement are listed in Table 2. The dominant systematic error is that due to b quark fragmentation. This error was estimated by varying the Peterson fragmentation function ϵ_b parameter in the Monte Carlo. This parameter was taken to be $0.0060^{+0.0025}_{-0.0020}$ (corresponding to $\langle X_E \rangle = 0.700 \pm 0.011$). The fragmentation function was generated for the central value and the $\pm 1\sigma$ values. The effect on the lifetime was calculated by reweighting the Monte Carlo histograms associated with a given B hadron by the ratio of the fragmentation function for $\pm 1\sigma$ in ϵ_b to that with $\epsilon_b = 0.0060$ at the energy of the given B hadron. The reweighted histograms were then used in the lifetime analysis. The change in the lifetime for $\pm 1\sigma$ in ϵ_b was ± 0.036 ps.

In an attempt to measure the sensitivity of lifetime measurement to the shape of the fragmentation function, as opposed to the mean value as was done above, the lifetime was determined using a different fragmentation function (Bowler-Lund[22]). This made a change in the measured lifetime of 0.013 ps. This value was added in quadrature to 0.036 ps to give a total systematic error of 0.038 ps in the lifetime from lack of knowledge of the b fragmentation function.

The error in the c quark fragmentation was calculated in a similar fashion to that for the b quark fragmentation. The value of ϵ_c was taken to be 0.06 ± 0.03. This was a $\pm 2\sigma$ variation in ϵ_c, giving a variation in the lifetime of ± 0.007 ps. The $\pm 1\sigma$ error in the lifetime was taken to be 0.004 ps.

Another systematic error in the lifetime determination arises from the lack of knowledge of the exact charm content of b quark decays. The error comes about because different charm species have different lifetimes. Changes in the Monte Carlo charm fractions for b decays have a direct effect on the decay length distribution. The systematic error from this effect was estimated by varying the charm content in the Monte Carlo events while keeping the overall normalization of charm constant. The lifetime was determined using Monte Carlo events where the relevant fractions of $B \to D^+X$, D^0X, and D_sX were varied by $\pm 2\sigma$ about their Particle Data Group values[6]. The charmed baryon content was varied in a similar fashion, using the $B \to$ baryons + X measurement (all baryons assumed to be charm). These quantities were varied by $\pm 2\sigma$ to fully encompass the tuned values used in the B model in the Monte Carlo package and to account for any possible differences between the b decay charm content in Z^0 decays as compared to decays at the Υ_{4s}. The variations in the lifetime due to changes in the four different modes were added in quadrature to arrive at a systematic error in the lifetime from this source of 0.018 ps.

The sensitivity of the lifetime measurement to variation in the B baryon fraction of Z^0 decays was investigated. A systematic error of 0.002 ps was assigned after observing the variation in the measured lifetime as the baryon fraction was varied by $\pm 1\sigma$, using a value of $(8 \pm 4)\%$.

The error in the lifetime calculation due to an uncertainty in the average multiplicity of B hadron decays was determined to be 0.006 ps. This was estimated by shifting the mean of the multiplicity distribution in the Monte Carlo by ± 0.3 tracks, reweighting each event

Systematic error	$\sigma\tau_B$ in ps
b fragmentation	0.038
c fragmentation	0.004
charm content	0.018
B baryon fraction	0.002
R_b	0.001
R_c	0.003
b multiplicity	0.006
detector effects	0.013
fit and binsize	0.010
TOTAL	0.046 ps

Table 2: Summary of systematic errors in this lifetime analysis

containing a b quark by the ratio of the shifted distribution to the unshifted distribution at the particular value of the multiplicity generated for that event and calculating the lifetime with the reweighted histograms.

The parameters $R_b = \Gamma(Z^0 \to b\bar{b})/\Gamma(Z^0 \to q\bar{q})$ and $R_c = \Gamma(Z^0 \to c\bar{c})/\Gamma(Z^0 \to q\bar{q})$ were varied by ± 0.015 and ± 0.03, respectively, corresponding to the Particle Data Group error in each of these numbers[6]. In each case the other quark fractions were adjusted by a constant factor so the sum of all hadronic fractions was 1.0. Histograms were weighted accordingly. The resulting change in the lifetime was measured to be 0.001 ps for variation in R_b and 0.003 ps for R_c variation.

Two types of detector effects were investigated. In the first, the lifetime was measured in four separate ϕ quadrants of the detector. Each result was consistent with the result using the full ϕ coverage. No systematic error was assigned for this effect. In the second, the tracking efficiency correction to the Monte Carlo events was removed (see Sec. IV). This resulted in a change in the measured lifetime of 0.025 ps. This is a very conservative upper bound to the possible effect from this source on the lifetime. The $\pm 1\sigma$ error in the lifetime due to lack of knowledge of the tracking efficiency was taken to be 0.013 ps.

The sensitivity of the lifetime measurement to the heavy quark tag was investigated by performing the analysis using different tagging criteria. The tags were varied to give significantly lower and higher $Z^0 \to b\bar{b}$ event purity. The resultant lifetimes were all consistent with the one reported here.

XI Summary

From a sample of 50,000 Z^0 decays recorded by the SLD detector at the SLC in 1993, 4,294 events were tagged as a sample enriched in the fraction of heavy quarks using an impact parameter technique. In the tagged events, all of the geometrically possible secondary vertices passing selection cuts were reconstructed in three dimensions. Vertices were selected by choosing the global event topology giving the maximum joint fit probability for the independent vertices in the event. This method was very efficient for selecting vertices with lifetime information. The B hadron lifetime was extracted from the decay length distribution of these vertices. A binned maximum likelihood method yielded an average lifetime for B hadrons of $\tau_B = 1.577 \pm 0.032(\text{stat.}) \pm 0.046(\text{syst.})$ ps. The dominant systematic errors in this measurement are due to uncertainties in the b quark fragmentation function, the charm content of b decays and the tracking efficiency.

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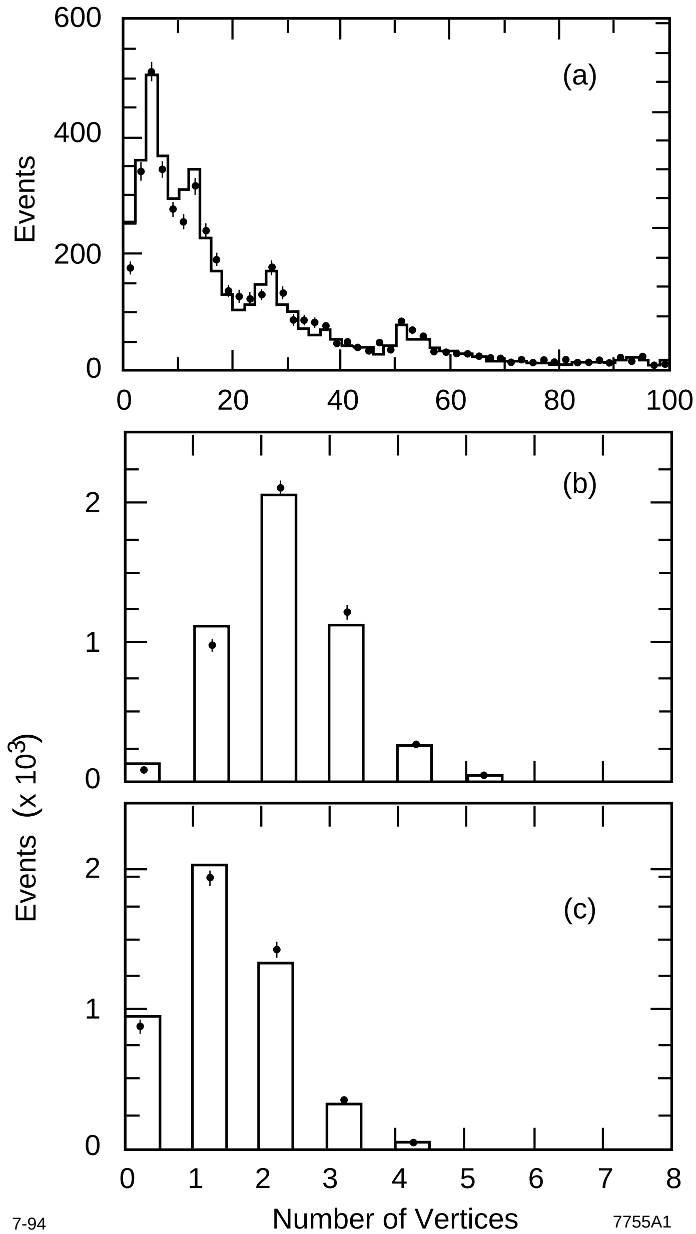
Figure Captions

Figure 1: Distributions of the number of vertices/event for data (points) and Monte Carlo (histogram) events, (a) before the joint probability cut selecting unique sets of vertices, (b) after the cut, and (c) the final sample just before the cut demanding only one vertex per event hemisphere.

Figure 2: Various distributions comparing data (points) and Monte Carlo (histogram) events.

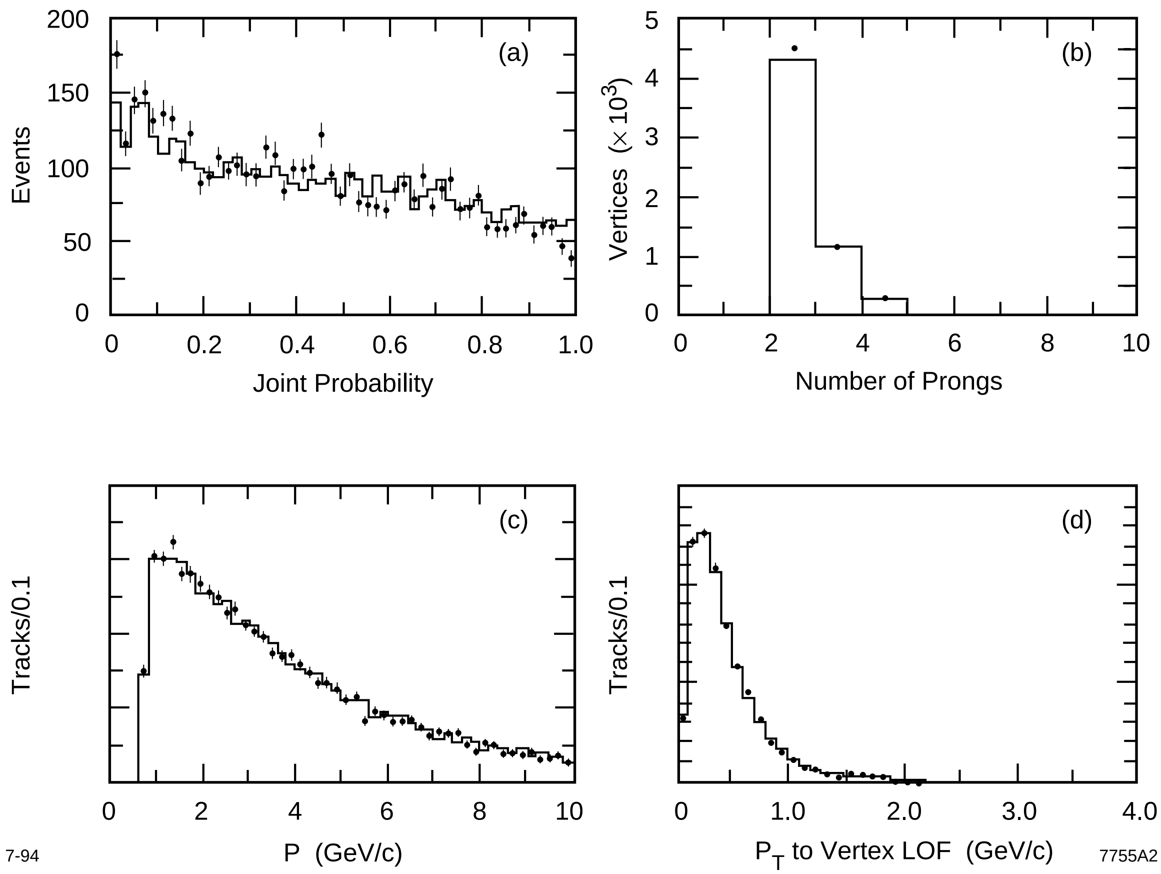
Figure 3: Distributions showing the difference between the reconstructed vertex postion and the generated b decay position along the b quark line of flight for Monte Carlo events. Distributions are given for vertices with different track composition.

Figure 4: Decay length distribution for the final data sample of vertices (points) and the Monte Carlo events weighted with the best-fit lifetime (histogram).



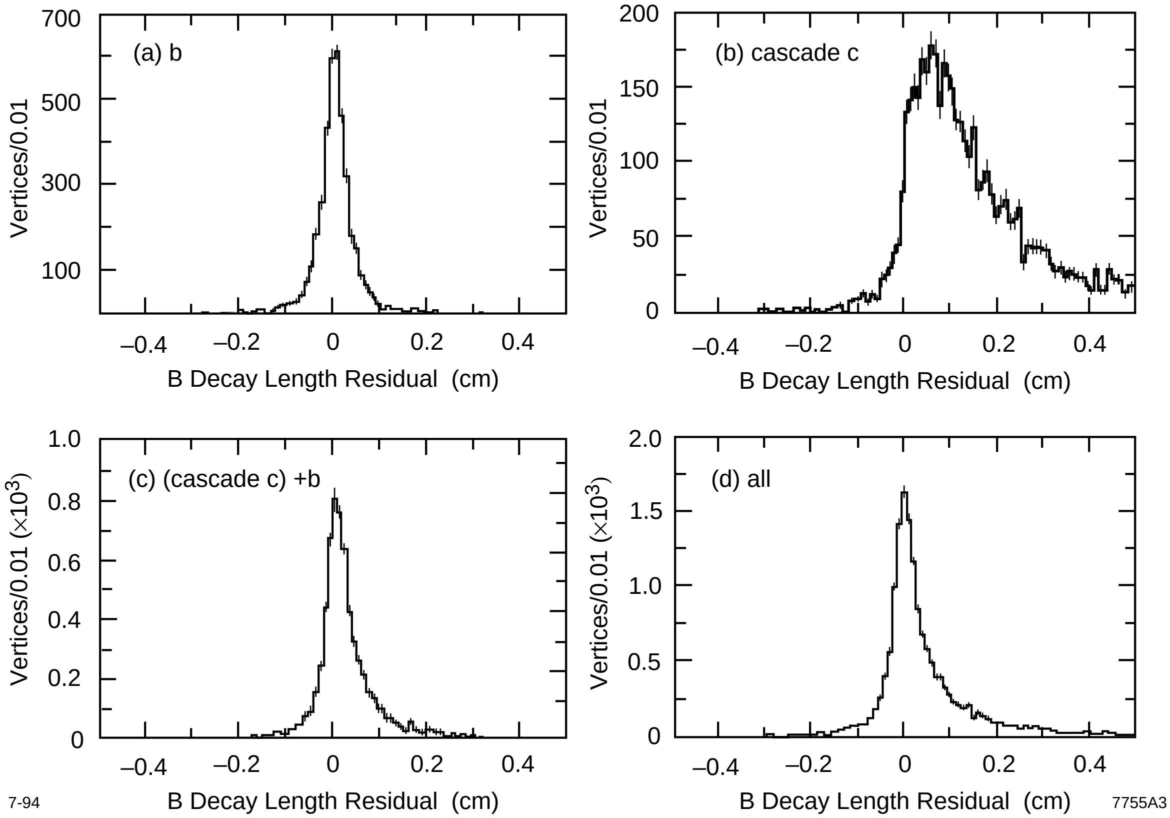
600
400
200
0
Events
(a)
0
20
40
60
80
100
(b)
2
1
0
(c)
2
1
0
Events (x 10^3)
0
1
2
3
4
5
6
7
8
Number of Vertices
7-94
7755A1

Fig. 1



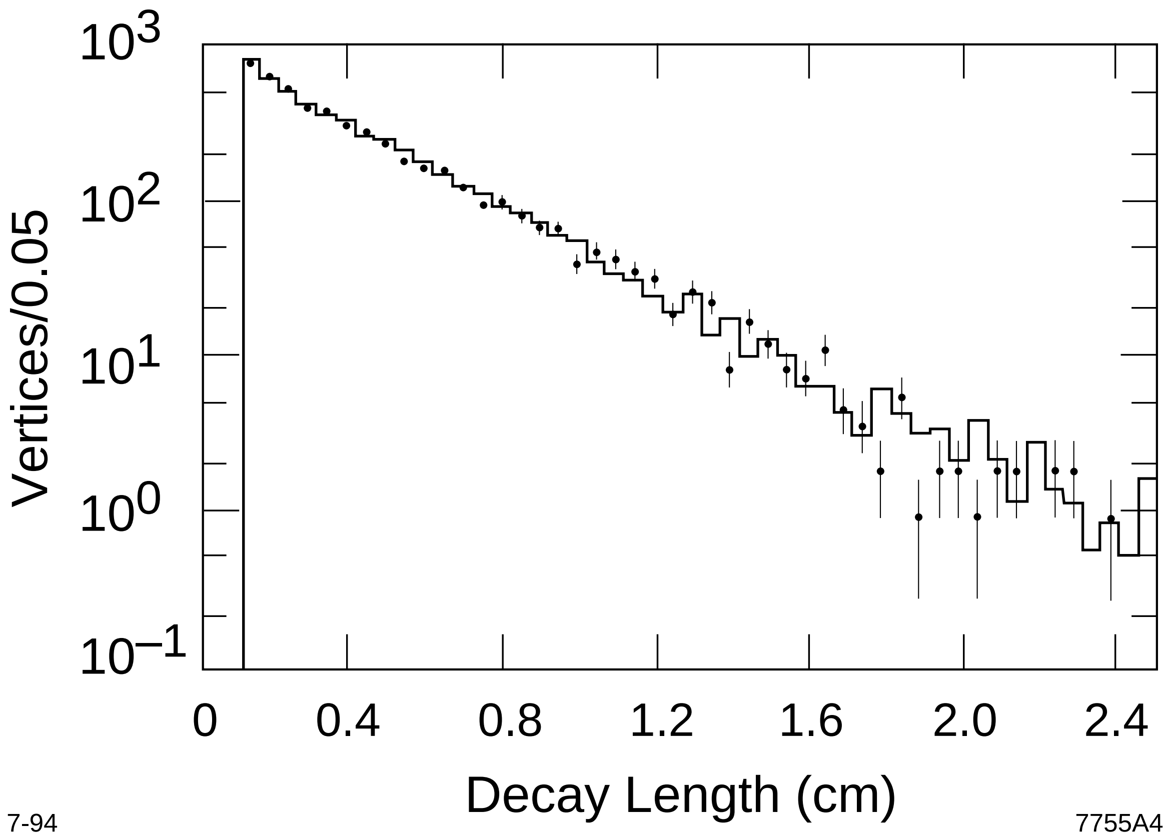
(a)
Events
Joint Probability
(b)
Vertices (×10³)
Number of Prongs
(c)
Tracks/0.1
P (GeV/c)
(d)
Tracks/0.1
P_T to Vertex LOF (GeV/c)
7-94
7755A2

Fig. 2



(a) b
(b) cascade c
(c) (cascade c) +b
(d) all
Vertices/0.01
Vertices/0.01 (×10³)
B Decay Length Residual (cm)
700
500
300
100
200
150
100
50
0
1.0
0.8
0.6
0.4
0.2
2.0
1.5
1.0
0.5
–0.4
–0.2
0.2
0.4
7-94
7755A3

Fig. 3



10^3
10^2
10^1
10^0
10^–1
Vertices/0.05
0
0.4
0.8
1.2
1.6
2.0
2.4
Decay Length (cm)
7-94
7755A4

Fig. 4