Measurement of the B^- and $\bar{B}^0$ Meson Lifetimes Using Semileptonic Decays with Single Lepton Datasets in CDF Run II

Text for the blessed web page – CDF note 7514

The CDF Collaboration

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Abstract

The lifetimes of the B^- and $\bar{B}^0$ mesons are measured in CDF Run II using $\bar{B} \to \ell^- \bar{\nu} D X$ decay, where ℓ^- is a lepton (e^- or μ^-) and D denotes a D^0 or D^{*+} meson. The data come from the 8 GeV single lepton datasets, corresponding to an integrated luminosity of about 260 pb^{-1}. We find the lifetimes to be

$$\tau(B^-) = 1.653 \pm 0.029 \; ^{+0.033}_{-0.031} \text{ ps}$$

$$\tau(\bar{B}^0) = 1.473 \pm 0.036 \pm 0.054 \text{ ps}$$

$$\tau(B^-)/\tau(\bar{B}^0) = 1.123 \pm 0.040 \; ^{+0.041}_{-0.039},$$

where the first uncertainty is statistical and the second is systematic.

1 Description

The B^- and $\bar{B}^0$ meson lifetimes are measured using $\bar{B} \to \ell^- \bar{\nu} D^0 X$ decays, where the D^0 meson is reconstructed in the $K^-\pi^+$ decay mode. The data are collected with 8 GeV single lepton triggers (both muon and electron) in CDF Run II. The corresponding integrated luminosity used for this analysis is about 260 pb^{-1}, collected through January 2004. After the lepton+D^0 reconstruction, we separate the lepton+D^{*+} candidates according to $D^{*+} \to D^0\pi_s^+$ decay signal. After the separation, the lepton+D^0 (D^{*+} excluded) and lepton+D^{*+} samples are dominated by the B^- and $\bar{B}^0$ mesons respectively. There is a small cross talk, it is estimated using monte carlo simulation. Thus we extract the B^- and $\bar{B}^0$ meson lifetimes by fitting the lepton+D^0 (D^{*+} excluded) and lepton+D^{*+} samples simultaneously. The mass plots for lepton+D^0 (D^{*+} excluded) and lepton+D^{*+} signals are shown in Figure 1. The event yield and signal fractions are summarized in Section 2.1.

From the lepton+D^0 pairs, we reconstruct the B decay vertices and measure B decay length L_B. A schematic view of the reconstruction is shown in Figure 2. The decay length L_B is calculated as the projection of $\vec{V}_B$ on the direction of $\ell^- D^0$ transverse momentum,

$$L_B = \vec{V}_B \cdot \frac{\vec{P}_T(\ell^- D^0)}{|\vec{P}_T(\ell^- D^0)|},$$

where the $\vec{V}_B$ is the vector from the primary vertex to the B decay vertex. From L_B and transverse momentum of the B meson, proper decay length ct is defined as follows.

$$ct(B) = L_B \frac{M_B}{p_T(B)},$$

where the M_B is the B meson mass (5.279 GeV/c^2). However, since the B meson is partially reconstructed, we can only measure the the transverse momentum of the lepton+D^0 system, not the B meson. So the pseudo-proper decay length ct^* is also defined as,

$$ct^*(B) = L_B \frac{M_B}{p_T(\ell^- D^0)} = ct\frac{1}{K}$$

where the K is a correction factor for the missing momentum of the B meson, defined as

$$K \equiv \frac{p_T(\ell^- D^0)}{p_T(B)}$$

The K factor distributions are calculated from the monte carlo simulation, and involved into probability density function for the lifetime fit.

Then we extract the B^- and $\bar{B}^0$ meson lifetimes by fitting the lepton+D^0 (D^{*+} excluded) and the lepton+D^{*+} samples simultaneously. The likelihood function for the semileptonic B decay signal is given by,

$$\mathcal{F}_B(ct^*, \sigma_{ct^*}) = \frac{K}{c\tau} \int D(K)\ dK \exp\left(-\frac{ct^*}{c\tau}K\right) \otimes Gaus(ct^*; s\sigma_{ct^*})$$

ct^*, σ_{ct^*}	...	Pseudo-proper decay length of the B meson, and its resolution.
$c\tau$	...	B meson lifetime.
$D(K)$	...	K factor distribution, which correct the missing momentum of the B meson. It is obtained from monte carlo simulation.
s	...	Resolution scale factor.

Secondly we define the probability density function as follows.

$$\begin{aligned} P(ct^*, \sigma_{ct^*}) &= f_{\text{sig}} \left\{(1 - f_c - f_b)\mathcal{F}_{\text{sl}} + f_c\mathcal{F}_c + f_b\mathcal{F}_b\right\} \\ &\quad + (1 - f_{\text{sig}})\mathcal{F}_{\text{BG}} \\ \mathcal{F}_{\text{sl}} &= g_-\mathcal{F}_{B^-} + (1 - g_-)\mathcal{F}_{\bar{B}^0} \end{aligned}$$

f_{sig}	...	Fraction of D^0 (D^{*+}) events
$\mathcal{F}_{\text{BG}}(ct^*)$	...	Combinatorial background function
f_c, $\mathcal{F}_c(ct^*)$	...	Prompt charm background function
f_b, $\mathcal{F}_b(ct^*)$	...	Bottom background function
g_-	...	fraction of B^- component

Then the following combined likelihood is formed.

$$L = \prod_i P_i,$$

where the product is taken over all the events in signal region of the each sample. We extract the B^- and $\bar{B}^0$ lifetimes by minimizing negative log likelihood $-l = -\log L$. The obtained B^- and $\bar{B}^0$ meson lifetimes and their ratio are listed in Section 2.3.

The systematic uncertainties are mainly from the estimation of sample composition, and treatment of prompt charm background component. Missing momentum correction gives some systematics to the B^- and $\bar{B}^0$ meson lifetimes.

2 Blessed Numbers

This section summarizes the numbers which have been blessed for this analysis.

2.1 Signal yields

Sample	$M(K^-\pi^+)$ range (GeV/c^2)	ΔM range (GeV/c^2)	Events	Signal fraction
$\mu^- D^0$	1.845 - 1.885	0.142 - 0.148 (veto)	21971	0.425 ± 0.004
$\mu^- D^{*+}$	1.835 - 1.895	0.144 - 0.147	2947	0.907 ± 0.007
$e^- D^0$	1.845 - 1.885	0.142 - 0.148 (veto)	8539	0.471 ± 0.007
$e^- D^{*+}$	1.835 - 1.895	0.144 - 0.147	1219	0.908 ± 0.010

2.2 Systematic uncertainties

Source	Contribution to		
	$c\tau(B^-)$ (μm)	$c\tau(\bar{B}^0)$ (μm)	$\tau(B^-)/\tau(\bar{B}^0)$
Prompt charm background			
prompt charm fraction (f_c)	$^{+3.7}_{-1.9}$	$^{+5.7}_{-3.7}$	$^{+0.006}_{-0.007}$
prompt charm shape ($\mathcal{F}_c$)	± 2.6	± 5.2	± 0.007
Bottom background			
Bottom background fraction (f_b)	$^{+0.3}_{-0.9}$	$^{+0.7}_{-1.5}$	$^{+0.001}_{-0.002}$
Bottom background shape ($\mathcal{F}_b$)	± 2.6	± 1.4	± 0.002
Sample composition			
D^{**} fraction (f^{**})	$^{+2.5}_{-0.6}$	$^{+6.5}_{-10.1}$	$^{+0.032}_{-0.018}$
D^{**} composition (P_V)	$^{+0.7}_{-1.4}$	$^{+11.0}_{-8.6}$	$^{+0.023}_{-0.031}$
π_s^+ reconstruction	$^{+0.1}_{-0.6}$	$^{+0.8}_{-0.0}$	$^{+0.000}_{-0.004}$
Missing momentum correction			
$p_T(B)$ spectrum	± 6.1	± 5.3	-
B decay model	± 1.0	± 1.3	-
Electron cuts	± 2.0	± 1.4	-
Signal fraction (f_{sig})	± 2.4	± 0.9	± 0.003
Resolution scale factor	± 3.6	± 1.9	± 0.003
Decay length cut	$^{+0.0}_{-1.8}$	$^{+0.0}_{-2.2}$	$^{+0.001}_{-0.000}$
Combinatorial background shape	± 0.7	± 0.1	± 0.002
Detector alignment	± 2.0	± 2.0	-
Total	$^{+10.0}_{-9.4}$	$^{+16.3}_{-16.3}$	$^{+0.041}_{-0.039}$

2.3 Final lifetime fit results

$$
\begin{aligned}
c\tau(B^-) &= 495.6 \pm 8.6\ ^{+10.0}_{-9.4}\ \mu\text{m} \\
c\tau(\bar{B}^0) &= 441.5 \pm 10.9 \pm 16.3\ \mu\text{m},
\end{aligned}
$$

or

$$
\begin{aligned}
\tau(B^-) &= 1.653 \pm 0.029\ ^{+0.033}_{-0.031}\ \text{ps} \\
\tau(\bar{B}^0) &= 1.473 \pm 0.036 \pm 0.054\ \text{ps}.
\end{aligned}
$$

The ratio of the lifetimes:

$$
\tau(B^-)/\tau(\bar{B}^0) = 1.123 \pm 0.040\ ^{+0.041}_{-0.039},
$$

where the first and second uncertainties are statistical and systematic, respectively.

For comparison, the world averages from 2004 Particle Data Group are:

$$
\begin{aligned}
\tau(B^-) &= 1.671 \pm 0.018\ \text{ps} \\
\tau(\bar{B}^0) &= 1.536 \pm 0.014\ \text{ps} \\
\tau(B^-)/\tau(\bar{B}^0) &= 1.086 \pm 0.017
\end{aligned}
$$

3 Blessed Figures

The following figures have been blessed for the measurement of the B^- and $\bar{B}^0$ meson lifetimes using semileptonic decays. More text can be found in CDF note 7458.

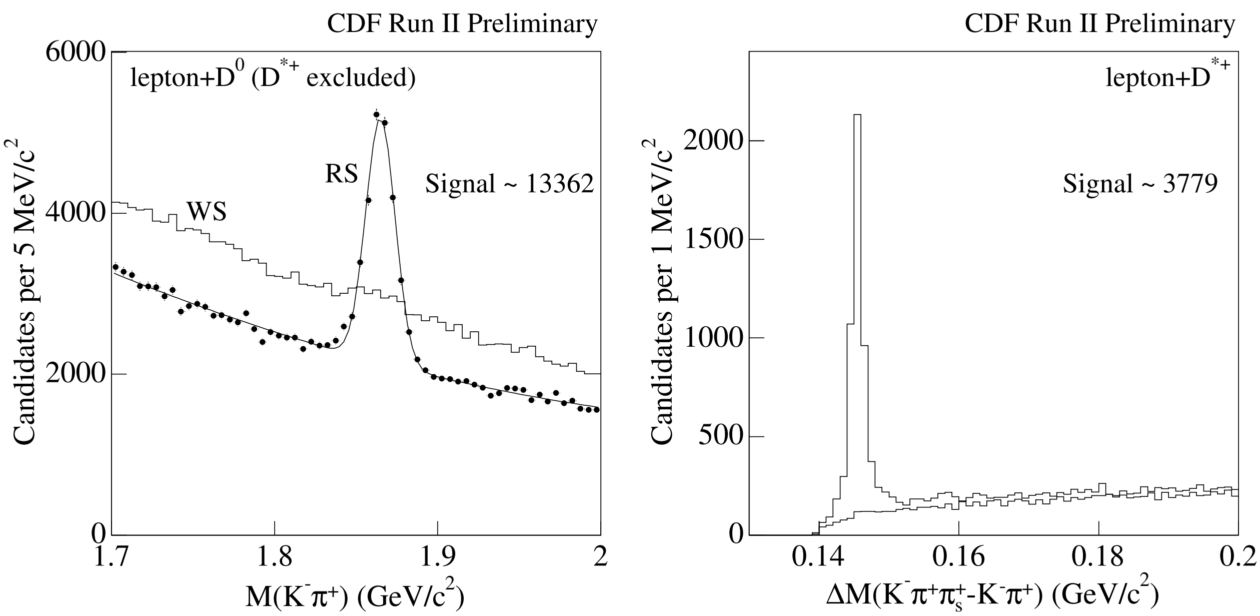

Figure 1: D^0 mass plot for the lepton+D^0 (D^{*+}excluded) sample (left) and plot of mass difference $M(D^0\pi_s^+) - M(D^0)$ for the lepton+D^{*+} sample (right). In the D^0 mass plot, the histogram show events which have wrong charge correlation between lepton and kaon. In the ΔM plot, histogram for events whose π_s track have wrong charge (π_s^- with D^0) is also shown.

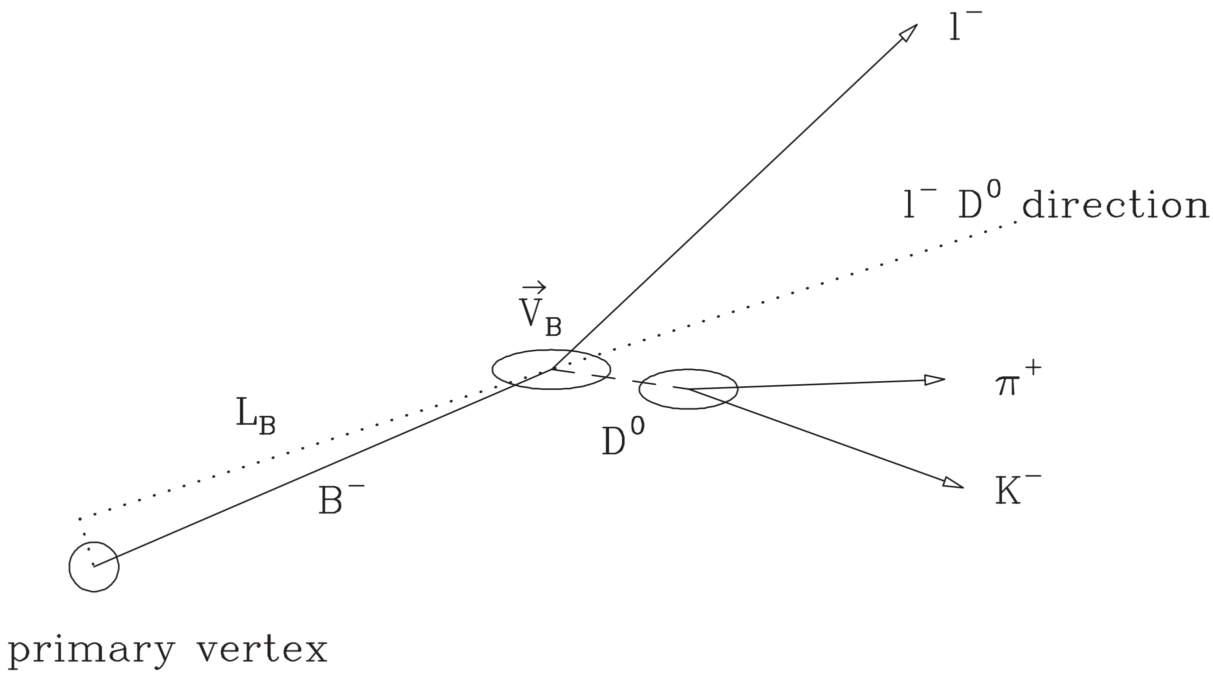

Figure 2: A schematic view of the typical semileptonic decay $B^- \to \ell^- \bar{\nu} D^0$, $D^0 \to K^- \pi^+$ in xy plane.

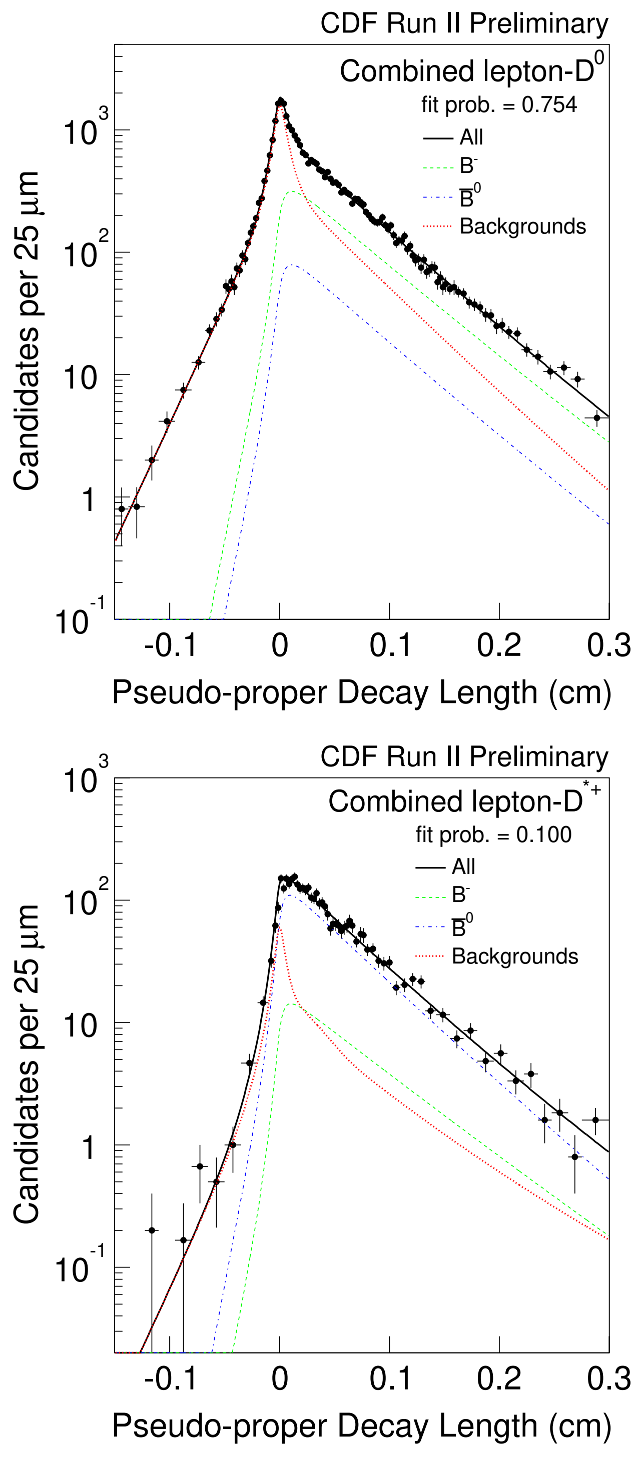

Figure 3: The pseudo-proper decay length distributions for the lepton+D^0 (D^{*+} excluded) and the lepton+D^{*+} samples. Lifetime fit results are overlaid.