B hadron lifetime measurements at the Tevatron experiments

E. De La Cruz Burelo * [a]
(On behalf of the CDF and D0 collaborations)

[a]Department of Physics, The University of Michigan, Ann Arbor, Michigan 48109, USA.

We present the recent B hadron lifetime measurements in the CDF and D0 collaborations at the Tevatron collider. D0 reports a new world-best measurement of the B_s lifetime in semileptonic decays, and CDF presents the most precise Λ_b lifetime measurement for a single experiment, and which precision is at the level of the uncertainty in the world average of the Λ_b lifetime.

1. INTRODUCTION

The measurement of B hadron lifetimes is a important part of the rich B physics program at the Tevatron experiments, CDF[1] and D0[2]. The lifetime of B hadrons provide information on the b quark decay, and what is the role that play the lighter quarks which along with the b-quark form the B hadron. Also, b-quark decays are related to the V_{ub} and V_{cb} elements of the CKM matrix.

In this note we present the lifetime measurement of the B_s in the semileptonic decays $B_s \to D_s l \nu X$. These decays are 50% CP-even and 50% CP-odd at time t=0, and impose an extra constraint to the $\Delta\Gamma_s/\Gamma_s$ measurement [3], and then to new physics in the B_s-$\overline{B}_s$ mixing sector. We also present the recent Λ_b lifetime measurement from CDF. The reported earlier difference in the measured Λ_b lifetime and the prediction created a great deal of interest and it was named as the Λ_b *lifetime puzzle*[4]. This new measurement from CDF is at the precision level of the current world average, however it is higher than previous measurements, situating the Λ_b-baryon decay at the same level of the B-meson decays.

2. LIFETIME MEASUREMENT TECHNIQUES

The lifetime measurements presented here are based on the determination of the distance L from the decay vertex of the B hadron to the primary interaction vertex. The proper decay length $\lambda = \vec{L} \cdot \vec{P}_T(B) M_B / P_T(B) = L_{xy}/(\beta\gamma)_T$ is determined on an event-per-event basis, and its distribution $F(\lambda)$ is related to the lifetime of the B hadron by:

$$F(\lambda) = \int_0^\infty R(\lambda - \lambda') \frac{1}{c\tau_B} \exp\left(\frac{-\lambda'}{c\tau_B}\right) d\lambda' \qquad (1)$$

where $R(\lambda - \lambda')$ is the detector resolution. In semileptonic decays, where the momentum $\vec{P}(B)$ of the B hadron is not fully determined, the momentum $\vec{P}(semi)$ of the semi-reconstructed B hadron decay is used instead, and a correction factor $K = P_T(semi)/P_T(B)$ is introduced to account for the missing part of the momentum. The K factor is extracted from Monte Carlo(MC) simulation. Then, Eq. 1 is rewritten using the pseudo-proper decay length (PPDL) $\lambda = \vec{L} \cdot \vec{P}_T(semi) M_B / P_T(semi)$, in the form:

$$G(\lambda) = \int dK H(K) \left[\int_0^\infty R(\lambda - \lambda') \frac{K}{c\tau_B} \exp\left(\frac{-K\lambda'}{c\tau_B}\right) d\lambda' \right] \qquad (2)$$

where $H(K)$ is the distribution of the K factor.

A background contribution is added to the probability density function in Eq. 1 or 2, and then fitted to the λ distribution extracted from data. The background contribution can be modeled from data by using the sidebands to the B hadron signal, or from MC simulation.

*Mailbox E26610, CERN CH-1211 Genéve 23, Switzerland. Email: *Eduard.Burelo@cern.ch* .

3. B_s LIFETIME IN SEMILEPTONIC DECAYS

The D0 collaboration measured the B_s lifetime in the semileptonic decays $B_s \to D_s^- \mu^+ \nu X$, where the D_s^- decays to $\phi\pi^-$, and $\phi \to K^+K^-$. From a sample of integrated luminosity of 400 pb^{-1}, D0 reconstructed 5176 ± 242 (stat.) ± 314 (syst.) B_s candidates.

The lifetime was measured using an unbinned maximum likelihood fit to the pseudo-proper decay length distribution. The B_s signal was modeled by Eq. 2, with the K factor extracted from MC. The background contributions from B hadron decays, such as $\bar{B}^0 \to D_s^{(*)-} D^{(*)+} X$, $B^- \to D_s^{(*)-} \bar{D}^{(*)0} X$, and $\bar{B}_s \to D_s^{(*)-} D^{(*)} X$, were taking into account by including similar components to those in the signal, but using fixed lifetimes according to the world average values. The weight and K factor of each component were determined from MC. A $c\bar{c}$ background was included in the fit as a Gaussian with fixed parameters as found in MC. Finally, the combinatorial background was parametrized using a Gaussian for zero-lived events, plus several exponential decays as found in the sideband events to the B_s signal. Figure 1 shows the invariant mass distribution of the $\phi\pi^+$ candidates, and Fig. 2 shows the PPDL distribution of the $D_s^- \mu^+$ candidates. The B_s lifetime was measured[5] to be:

$$\tau(B_s) = 1.398 \pm 0.044(\text{stat.})^{+0.028}_{-0.025}(\text{syst.})\ \text{ps} \quad (3)$$

This measurement is in good agreement with previous experiments, as well with the current world average lifetime for all flavor-specific B_s decays, and its precision is better than the current world average of the B_s lifetime, when measurements from semileptonic and hadronic decays are combined[6]. The major contribution to the systematic uncertainties comes from the modeling of the combinatoric background.

Similarly, the CDF collaboration measured the B_s lifetime in the decays $B_s \to D_s l \nu X$, where l is a lepton (e or μ) . This measurement was performed in a data sample of integrated luminosity of 360 pb^{-1}. The extracted B_s lifetime was[7]:

$$\tau(B_s) = 1.381 \pm 0.055(\text{stat.})^{+0.052}_{-0.046}(\text{syst.})\ \text{ps} \quad (4)$$

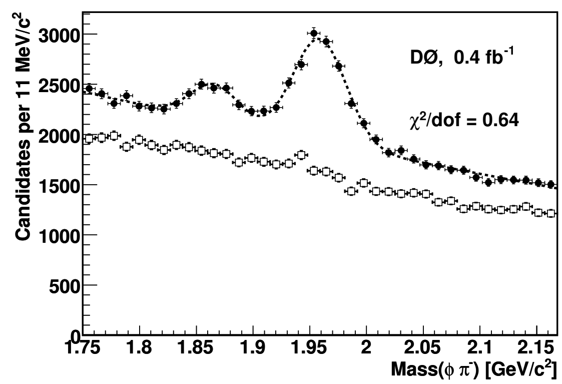

Figure 1. Invariant mass distribution of $\phi\pi^-$ candidates. The open squares show the distribution from same sign combination of μ and D_s candidates. The peak around 1.96 GeV/c^2 is due to B_s semileptonic decays, and the second peak is from the Cabibbo-suppressed decay $D^- \to \phi\pi^-$ which main contribution was found to come from $B^0 \to D^- \mu^+ \nu X$ decays.

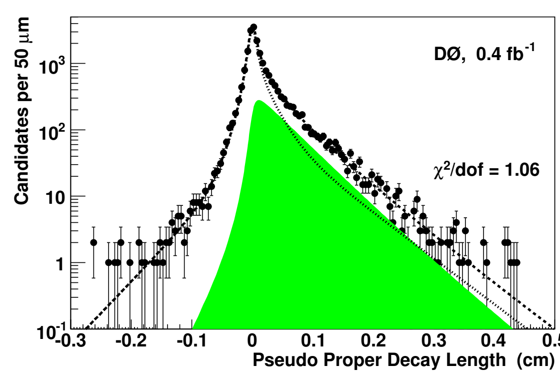

Figure 2. Pseudo-proper decay length distribution of $D_s^- \mu^+$ candidates from the D0 experiment. The dotted curve represents the combinatorial background and the filled area represents the B_s signal.

This measurement in very consistent with the D0 measurement reported in Eq. 3.

4. Λ_b LIFETIME

The Λ_b lifetime has been measured by the CDF collaboration in the exclusive decay channel $\Lambda_b \to J/\psi\Lambda$, where the J/ψ decays to $\mu^+\mu^-$ and the Λ to $p\pi$. From a data sample of integrated luminosity of 1 fb^{-1}, CDF reconstructed 538 $\pm$ 38 Λ_b candidates. This is the largest collected sample of fully reconstructed Λ_b baryons.

The lifetime was extracted using an unbinned maximum likelihood fit to mass, proper decay length, and their errors distributions. The λ distribution for signal was modeled by $F(\lambda)$ in Eq. 1, and the background was described with a negative and two positive exponential decays accounting for mis-measured decay vertices and background from other heavy-flavor decays. The mass distribution was modeled as the sum of a Gaussian signal and linear background. Figure 3 shows the proper decay length distribution with the projection of the fit result superimposed. The Λ_b lifetime was found to be[8]:

$$\tau(\Lambda_b) = 1.593^{+0.083}_{-0.078}(\text{stat.}) \pm 0.033(\text{syst.})\ \text{ps} \quad (5)$$

This measurement is comparable in precision to the world average, however, it is 3.1 standard deviations higher. Figure 4 shows this new measurement compared to the previous measurements and to the world average. The main contribution to the systematics uncertainties comes from the resolution model in Eq. 1.

5. OTHER B HADRON LIFETIME MEASUREMENTS

The CDF and D0 collaborations have measured the lifetime of B hadrons in different decay modes. Many of these measurements are very competitives at the world level. However due to the lack of space, it is not possible to cover all of them here. Those important measurements which have not been reported in other contributions to these proceedings are presented in Table 1, and the reference are given in [12]. Some important B hadron lifetime measurements pre-

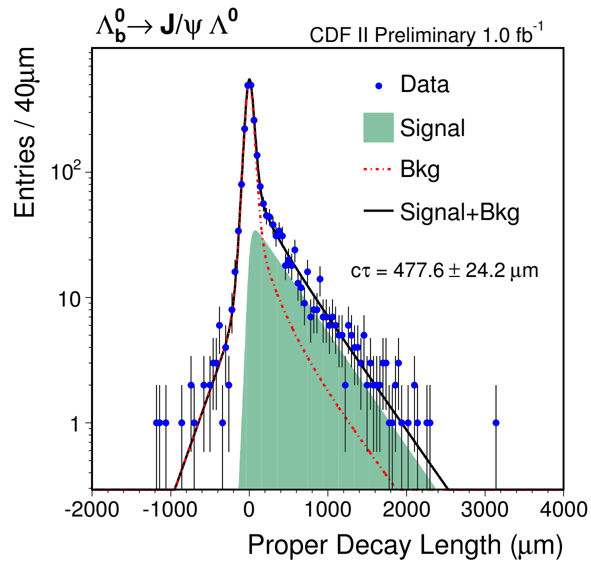

Figure 3. Proper decyay length distribution of the Λ_b candidates from CDF experiment.

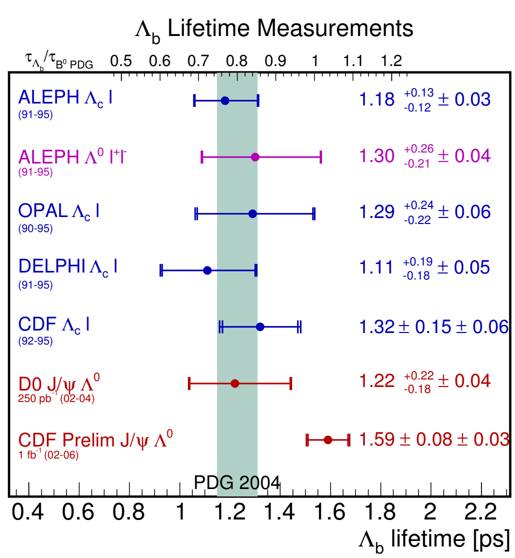

Figure 4. Comparison between the new Λ_b lifetime measurement from CDF and those reported in the PDG.

sented in other contributions are: the first report on the B_c meson lifetime, which was part of the special contribution on the B_c properties [13]; and the $\Delta\Gamma_s/\Gamma_s$ measurement in the $B_s \to J/\psi\phi$ decay and in the CP-even (to within 5%) decay mode $B_s \to K^+K^-$ presented by K. Yip[3].

Table 1
B hadron lifetime measurements which are not presented in this note.

B lifetimes in hadronic decays (CDF)
$\tau(B^+) = 1.66\pm0.03(\text{stat})\pm0.01(\text{syst.})$ ps.
$\tau(B^0) = 1.51\pm0.02(\text{stat})\pm0.01(\text{syst.})$ ps.
$\tau(B_s) = 1.60\pm0.10(\text{stat})\pm0.02(\text{syst.})$ ps.
B lifetimes in semileptonic decays (CDF)
$\tau(B^+) = 1.653\pm0.029(\text{stat})^{+0.033}_{-0.031}(\text{syst.})$ ps.
$\tau(B^0) = 1.473\pm0.036(\text{stat})\pm 0.054(\text{syst.})$ ps.
Direct lifetime ratio (D0)
$\frac{\tau(B^+)}{\tau(B^0)} = 1.080\pm0.016(\text{stat})\pm0.014(\text{syst.})$

6. SUMMARY

The CDF and D0 collaborations at the Tevatron collider have measured the B_s lifetime in semileptonic decays. Both measurements are very consistent between them, and the new measurement from D0 have a better precision than the current world average. This new measurement impossed indirectly an extra constraint to the search for new physics in the B_s-$\overline{B}_s$ mixing sector.

The CDF experiment reported a new measurement of the Λ_b lifetime, which precision is comparable to the world average, however, it is 3.1 standard deviations highter than the world average value. Recently, in the time of the preparation of this summary, a preliminary measurement was released by the D0 experiment[9] in the same decay channel $\Lambda_b \to J/\psi\Lambda$. This new measurement is consistent with the world average and with the previous D0 measurement[10] in the same decay channel, suggesting a shorter lifetime nature of the Λ_b lifetime than what was found by CDF. However, both measurements are consistent within two standard deviations, and the theoretical prediction [11] is consistent with both of them. More statistics is needed to settle the issue of the Λ_b lifetime.

Many other measurements of B hadron lifetimes in different decay modes have been performed by the CDF and D0 experiments. The first lifetime measurements of the B_c meson have confirmed its expected short-lived nature. Also, the $\Delta\Gamma_s/\Gamma_s$ measurement in the $B_s \to J/\psi\phi$ and $B_s \to K^+K^-$ has been found to be consistent with the Standard Model predictions. With the increase of the collected data, more precise measurements will come, and the B-baryon lifetime sector will be an unexplored area accessible to the Tevatron experiments.

REFERENCES

1. CDF Collaboration, F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res. A **271**, 388 (1998); S. Donati, these proceedings.
2. D0 Collaboration, V. Abazov *et al.*, "The Upgraded D0 Detector", submitted to Nucl. Instrum. Methods Phys. Res. A; Fermilab-Pub-05/341-E; physics/0507191; L. Welty, these proceedings.
3. R. Van Kooten, talk at the Flavour Physics and CP Violation Conference, Vancouver 2006, hep-exp/0606005; K. Yip, these proceedings.
4. F. Gabbiani *et al.* Phys. Rev. Lett. **D** 68, (2003) 114006-1-4.
5. To appear in Phys. Rev. Lett.; Fermilab-Pub-06/085-E; hep-ex/0604046.
6. S. Eidelman *et al.*, Phys. Lett. **B** 592, 1 (2004).
7. CDF note 7757.
8. CDF note 8268.
9. D0 note 5179-Conf.
10. V.M. Abazov *et al.*, Phys. Rev. Lett. **94**, 102001 (2005).
11. C. Tarantino, Nucl. Phys. B (Proc. Suppl.) 156 (2006), 33-37.
12. CDF note 7514; CDF note 7386; Phys. Rev. Lett. **94**, 182001 (2005).
13. M.A. Rahaman, these proceedings.