Tevatron results on b-hadron lifetimes and rare decays

A. Sánchez-Hernández for the CDF and DØ Collaborations
Physics Department, CINVESTAV,
Mexico City, 07360, Mexico

We present the most recent measurements on b-hadron lifetimes and rare decays performed by the CDF and DØ Collaborations at the Tevatron Collider, FERMILAB. We report the first Tevatron measurement based on 2 fb^{-1} of data collected during Run II.

Keywords: Tevatron, lifetimes, rare decays

1 Introduction

Since the start of RunII at the Tevatron $p\bar{p}$ Collider at the Fermi National Accelerator Laboratory (Fermilab), CDF and DØ experiments have produced a substantial amount of b–physics results. The Tevatron b–physics program is complementary to the program of the B factories, where a clear understanding of B^0 and B^+ mesons has been achieved. Currently, heavier b–hadron production is only possible at the Tevatron. Although the environment at $p\bar{p}$ is not as clean as in the e^+e^- case, it has the advantage of the high $b\bar{b}$ production cross section and the high integrated luminosity.

In this document, we present the most recent results obtained by the Tevatron experiments: CDF and DØ. In Sect. 2, we discuss the new and most precise lifetime measurements for b–hadrons; B_s, and Λ_b; using data samples of integrated luminosity ranging from 0.4 to 1.3 fb^{-1}. In Sect. 3, we show the most precise limits on $B_{s,d} \to \mu^+\mu^-$ rare decays. We will also present the first ever measurement made at the Tevatron from an integrated luminosity dataset of 2 fb^{-1}.

2 Lifetimes

Over the last years, the understanding of b–hadron lifetimes has improved considerably. Models, like the Heavy Quark Expansion (HQE) [1], allow for a systematic expansion in orders of α_s and $1/m_Q$ of the total decay widths of heavy-quark hadrons. HQE gives very precise predictions on the ratios of the different b–hadron lifetimes. All these predictions have been in good agreement with the experimental data, except for the Λ_b baryon. Here the measured lifetime ratio $\tau(\Lambda_b)/\tau(B_d)$ is significantly below the theoretical prediction. This has caused a review of all theoretical predictions. Recently improved lattice gauge theory computations for b–hadron lifetimes [2] have decreased this theoretical expectation substantially to 0.88 ± 0.05, which now is in better agreement with the experimental data.

Both experiments at the Tevatron, CDF and DØ, have measured the lifetime of Λ_b using the exclusive decay channel $\Lambda_b \to J/\psi(\to \mu^+\mu^-)\Lambda(\to p\pi)$. For purposes of calibration and normalization they used the B_d decay channel $B_d \to J/\psi K_S(\to \pi^+\pi^-)$, which has a very similar final state topology to the Λ_b decay. Apart from that, the lifetime of the B_d is very well known from the B factories. When reconstructing these two final states the J/ψ decay vertex is combined with the reconstructed Λ (or K_S) track to form the Λ_b (B_d) vertex in the plane perpendicular to the beam direction; correcting for the boost gives the proper decay length (PDL) estimate. Then, a simultaneous unbinned maximum likelihood fit of the invariant mass and PDL distributions (taking into account the event-by-event PDL resolution) is performed to extract the lifetime.

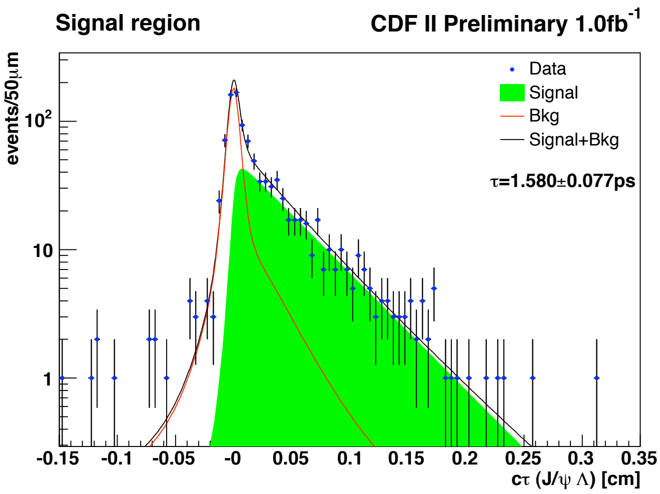

Figure 1: CDF. Likelihood fit projection in the proper decay length distribution for $\Lambda_b \to J/\psi\Lambda^0$ decay channel in the signal region. Dashed line represents the Λ_b signal.

CDF and DØ have measured the B_d lifetime compatible with the world average. While, for the Λ_b, DØ has measured a lifetime ratio $\tau(\Lambda_b)/\tau(B_d) = 0.811^{+0.096}_{-0.087}(\text{stat.}) \pm 0.034(\text{syst.})$ [4] and CDF $\tau(\Lambda_b)/\tau(B_d) = 1.018 \pm 0.062(\text{stat.}) \pm 0.007(\text{syst.})$ [3] they are different but still compatible with previous measurements and the theoretical predictions. Fig. 1 shows the likelihood fit projection in the proper decay length distribution for CDF Λ_b lifetime measurement, while the proper decay length distribution and the result of the fit for DØ measurement is shown in the left plot of figure 2. CDF result is higher than previous measurements, which are dominated by semileptonic decays.

DØ has recently reported a measurement of the Λ_b lifetime using the inclusive semileptonic decay channel $\Lambda_b \to \Lambda_c^+\mu^-\bar{\nu}_\mu X$. The measurement benefits from large statistics of semileptonic decay channels, but suffers from not being able to observe the actual Λ_b "peak". DØ reconstructs the Λ_c^+ baryon using its decay channel $\Lambda_c^+ \to K_S p$. This particle is observed on top of a large

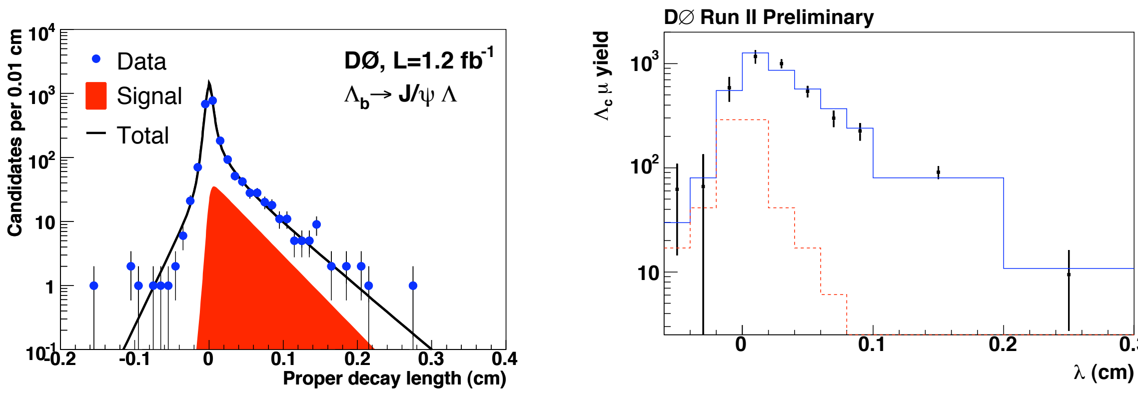

Figure 2: DØ. Left plot shows the Proper Decay Length distribution for $\Lambda_b \to J/\psi\Lambda^0$ decay channel and the result of the fit superimposed. The dashed region represents the signal. Right plot shows measured yields in the Virtual Proper Decay Length bins and the result of the lifetime fit for semileptonic $\Lambda_b \to \Lambda_c^+\mu^-\nu X$ decay channel. The dashed line shows the $c\bar{c}$ contribution.

background, which is subtracted statistically, in bins of the visible proper decay length. All sources of remaining background to the Λ_b decay as well as corrections for the boost are properly taken into account by means of Monte Carlo simulations. The measured lifetime, $\tau(\Lambda_b) = 1.28^{+0.12}_{-0.11}(\text{stat.}) \pm 0.09(\text{syst.})$ ps [4], is in a good agreement with the measurement performed by DØ in the $J/\psi\Lambda$ decay channel. The measured yields in the virtual proper decay length bins and the result of the lifetime fit are shown in the right plot of figure 2. As we can see, even when the apparent differences between theory and experiment have been resolved we still have an experimental issue to address to fully understand the Λ_b lifetime.

Tevatron experiments have also measured the lifetimes of the other b–hadrons. Using a large J/ψ sample, CDF has measured the lifetimes of B^+ and B_s mesons trough theirs fully reconstructed decay channels. For B^+, by reconstructing the decay channel $B^+ \to J/\psi K^+$ they have measured $\tau(B^+) = 1.630 \pm 0.016(\text{stat.}) \pm 0.011(\text{syst.})$. For B_s they reconstructed $B_s \to J/\psi\phi$, follow by $\phi \to K^+K^-$, and have measured a lifetime of $\tau(B_s) = 1.494 \pm 0.054(\text{stat.}) \pm 0.009(\text{syst.})$ ps[3]. Both measurements are in good agreement with earlier measurements, as well as with HQE predictions. DØ has measured the B_s lifetime using the flavor specific decay channel $B_s \to D_s^-\mu^+\nu_\mu X$, with the D_s^- reconstructed through $D_s^- \to \phi\pi^-$, and $\phi \to K^+K^-$. They find $\tau(B_s^0) = 1.398 \pm 0.044\text{stat.})^{+0.028}_{-0.025}(\text{syst.})$ ps [5]. Fig. 3 shows the pseudo proper decay length distribution for $D_s^-\mu^+$ candidates with the result of the fit superimposed. This measurement is the current best world measurement, even more precise than the current world average. The measurement is also in fair agreement with previous measurements. It is important to notice that current lifetime measurements are reaching precision of the order 1-3% in the systematic uncertainty determination and with further data accumulation more incisive tests of HQE can be achieved.

3 Rare decays

Searches for the decays $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ can be a powerful tool to probe for physics beyond the Standard Model (SM). The purely leptonic decay $B_{d,s} \to \mu^+\mu^-$ is a Flavor-Changing Neutral Current (FCNC) process. In the SM, this decay is forbidden at the tree level and even when higher order contributions are taken into account the predicted rate is very low. The SM branching ratio for this channel was first calculated [6] and later refined to include QCD corrections [7]. The latest SM prediction [8] is, $\text{Br}(B_s \to \mu^+\mu^-) = (3.42 \pm 0.54) \times 10^{-9}$, where the error is dominated by non-perturbative hadronic uncertainties. The corresponding leptonic

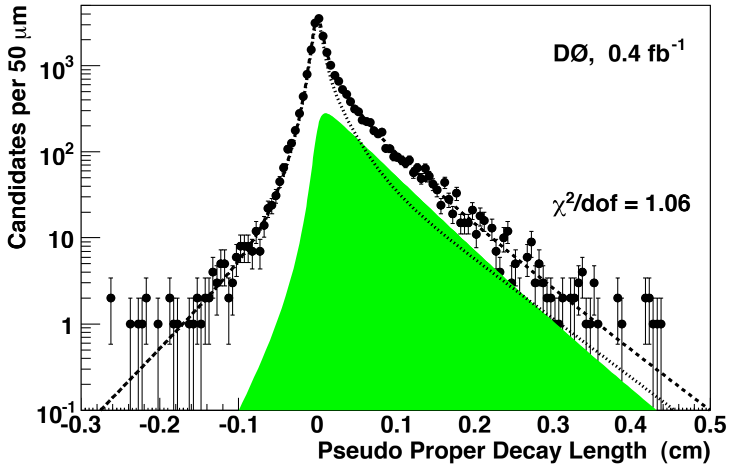

Figure 3: DØ. Pseudo Proper Decay Length distribution for $D_s^- \mu^+$ candidates with the result of the fit superimposed as the dashed curve. The dotted curve represents the combinatorial background and the filled area represents the B_s signal.

branching fraction for the B_d meson is suppressed by an additional factor of $|V_{td}/V_{ts}|^2$ leading to an expected SM branching ratio of $(1.00\pm0.14)\times 10^{-10}$. There are various extensions to the SM that predict an enhancement of this branching ratio by 1 to 3 orders of magnitude [9].

CDF and DØ have performed very sophisticated likelihood ratio studies of $B_{s,d} \rightarrow \mu^+\mu^-$ starting with dimuon trigger data samples. Using kinematic and topological information based on Monte Carlo predictions they have been able to isolate a tiny set of candidate events. Then using the $B^+ \rightarrow J/\psi(\rightarrow \mu^+\mu^-)K^+$ decays as normalization (where the efficiency of the reconstructed two muons almost cancel in the ratio) they are able to extract the branching ratio limit for $B_{s,d} \rightarrow \mu^+\mu^-$. CDF searches using 0.78 fb^{-1} of data have found 1 candidate event for B_s and 2 candidates for B_d yielding 90% C.L. limits on the branching ratio of 8.0×10^{-8} and 2.3×10^{-8}, respectively. Fig. 4 shows the invariant mass distribution of surviving events versus the likelihood ratio distribution [10]. Meanwhile DØ using 2 fb^{-1} of accumulated data has found 3 candidate events for B_s which translate to a limit on the branching ratio at the 90% C.L. of 7.5×10^{-8}. Fig. 5 shows the invariant mass distribution of surviving events for RunIIa and RunIIb (before and after the last summer shutdown) [11]. These measurements are the best existing experimental bounds and are just 20 times larger than the SM prediction for the case of B_s and 300 times for the case of B_d. Improving analysis techniques and accessing data as they become available will allow us to reach limits close to the SM expectations.

4 Summary

We have presented the most recent new measurements of b–hadron lifetimes and rare decays from the Tevatron, in all cases an improve understanding of the the experimental uncertainty is evident. CDF has reached experimental uncertainties on the lifetime determination of an order of 1% in fully reconstructed decay channel. DØ has reached 2% level for the case of semileptonic decay channels. Small discrepancies between the DØ and CDF measurements are observed, further studies should shed light on them. The limits on $B_s \rightarrow \mu^+\mu^-$ are getting closer to the SM prediction, further data accumulation will soon rule out or confirm the known extensions of the SM.

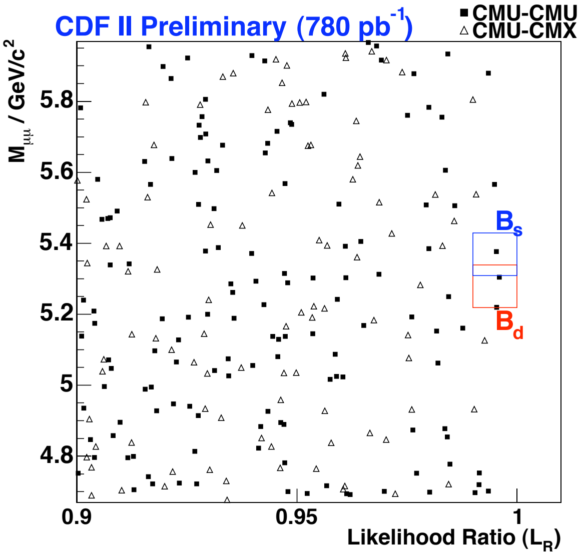

Figure 4: CDF. Dimuon candidates invariant mass versus likelihood ratio distribution with final selection.

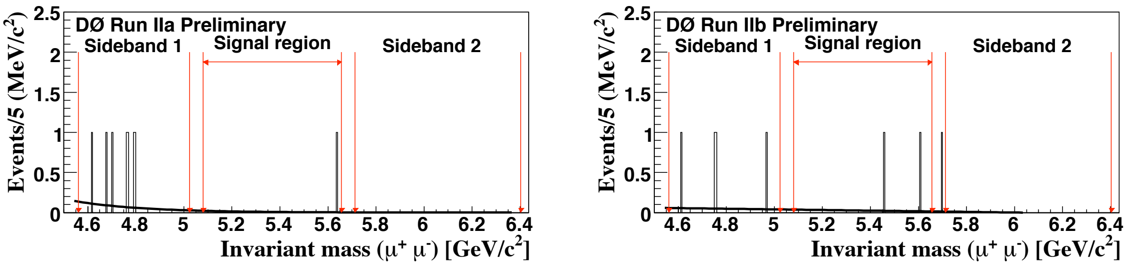

Figure 5: DØ. Dimuon invariant mass distribution of survival candidate events.

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