Experimental Results on Lifetimes, Width and Mass Differences from the Tevatron

Daniela Bauer, Imperial College London, United Kingdom*

October 16, 2008

1 Introduction

The upgraded Tevatron $p\bar{p}$ collider at Fermilab has been running at $\sqrt{s} = 1.96$ TeV since 2001 and has now produced approximately 4 fb^{-1} of integrated luminosity. Located at the Tevatron storage ring are two multi-purpose detectors, CDF and DØ, which have been upgraded [1], [2], [3] in parallel with the accelerator. Further upgrades were made in 2006, with the addition of a layer of Silicon tracker close to the beam pipe at DØ and the upgrade of the first level track trigger at CDF most relevant for b-physics.
All results presented in this article are preliminary, unless a journal reference is given.

2 The B_s System

In the B_s system the two flavour eigenstates mix according to

$$i\frac{\partial}{\partial t}\begin{pmatrix}|B_q^0(t)\rangle \\ |\overline{B}_q^0(t)\rangle\end{pmatrix} = \left[\begin{pmatrix}M_0 & M_{12} \\ M_{12}^* & M_0\end{pmatrix} - \frac{i}{2}\begin{pmatrix}\Gamma_0 & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_0\end{pmatrix}\right]\begin{pmatrix}|B_q^0(t)\rangle \\ |\overline{B}_q^0(t)\rangle\end{pmatrix} \tag{1}$$

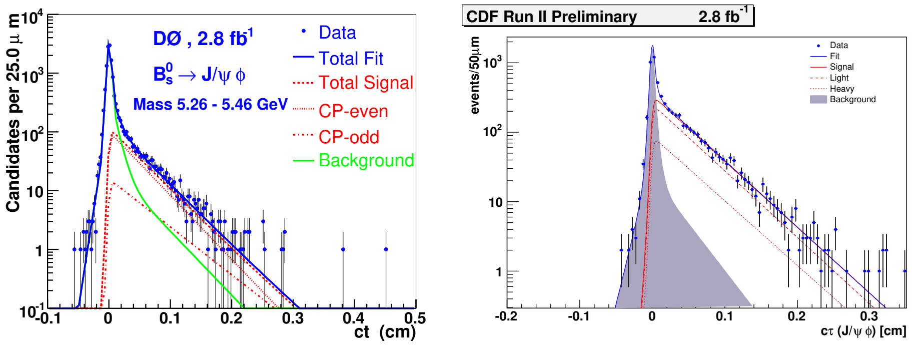
where M is the mass and Γ the decay matrix. The mass eigenstates are an admixture of the B_s flavour eigenstates according to $|B_s^H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$ and $|B_s^L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$ with $\frac{q}{p} = \frac{V_{tb}^*V_{ts}}{V_{tb}V_{ts}^*}$. Assuming CP violation is negligible [4] (Standard Model) the mass and CP eigenstates are identical with the light eigenstate being CP even and short lived, and the CP odd eigenstate heavy and long lived.
The experimental observables describing the system are:

$\Delta m_s = m_H - m_L \sim 2\|m_{12}\|$	Oscillations between B_s^0 and $\bar{B}_s^0$
$\Delta\Gamma = \Gamma_L - \Gamma_H \sim 2\|\Gamma_{12}\|cos(\phi_s)$	Lifetime/width difference
$\phi_s = arg(-M_{12}/\Gamma_{12})$	CP phase (discussed in section [articles by L. Sonnenschein and D. Tonelli])

2.1 Measuring Δm_s

To determine Δm_s it is necessary to determine whether a particle oscillated before it decayed. As b-quarks are produced in pairs, this is achieved by flavour tagging either the signal or the 'opposite side' b-quark. The methods vary slightly between the experiments, but are generally

*for the CDF and DØ collaborations



(a) DØ

(b) CDF

Figure 1: Lifetime projection for B_s^0 candiates in the signal region.

based either on jet charge tagging where the flavour of the b-quark is related to the weighted sum of the particle charges the jet, lepton tagging in semileptonic decays and same side tagging where the charge of a 'nearby' track is correlated with the b-quark flavour. Both experiments also use combination of taggers to enhance their tagging capabilities. The purity of this flavour tag feeds directly into the amplitude scan used to determine Δm_s. After DØ initially set a two-sided limit [5] on Δm_s of $17 < \Delta m_s < 21$ ps^{-1} at 90% CL, CDF [6] has measured Δm_s to be 17.77 ± 0.10 (stat) $\pm$ 0.07 (syst) ps^{-1}. This corresponds to 5.4 σ significance. A recent update [7] by DØ ($\Delta m_s = 18.53 \pm 0.93$ (stat) $\pm$ 0.30 (sys) ps^{-1}) is in good agreement with the CDF measurement.

2.2 Lifetime differences

At the Tevatron the lifetime difference in the B_s system is accessible in the decay $B_s \to J/\psi\phi$ which gives rise to both CP-even and CP-odd final states. It is possible to separate the two CP components of the decay and therefore to measure the lifetime difference, through a simultaneous fit to the time evolution and angular distributions of the decay products of the J/ψ and ϕ mesons. Figure 1 shows the lifetime projections for the $\Delta\Gamma$ measurements at CDF and DØ with the CP even and CP odd components fitted separatly. Both experiments have so far analysed 2.8 fb^{-1} of data. The results [8, 9] are still compatible with a $\Delta\Gamma$ of zero. It should be noted that if $\Delta\Gamma$ is not zero, the flavour specific (equal mix of B_s^H and B_s^L at t=0) and CP specific B_s lifetimes will be distinct.

2.3 B Hadron Lifetimes

As discussed in the preceding article [Theory: B lifetimes, width differences and Δm in the Standard Model] while in the spectator model the lifetimes of all B hadrons are equal, effects such as Pauli interference and weak annihilation and exchange can introduce considerable differences between the lifetimes of different B hadrons.
The Tevatron experiments have published lifetime measurements for all types of B-hadrons. A small selection of these are discussed below.
The B_c meson occupies a special place amongst the B-hadrons as it can decay weakly via the b or c quark, hence its lifetime is considerably shorter than those of light B mesons. Due to its

relatively large branching fraction the Tevatron experiments measure the B_c lifetime in semileptonic decays ($B_c \to J/\Psi l\nu$), while the B_c mass is measured in hadronic decays where lifetime cuts are used to reject background. As the B_c momentum in semileptonic decays cannot be fully reconstructed it is necessary to derive a correction factor from Monte Carlo. The current measurements of $\tau(B_c) = 0.475^{+0.053}_{-0.049}$(stat)$\pm$0.018 (sys) ps by CDF [10] and $\tau(B_c) = 0.448^{+0.038}_{-0.036}$ (stat) $\pm$0.032(sys) ps by DØ [12] are in agreement with theoretical predictions (see e.g. [11]). The lifetime ratio of $\tau(\Lambda_b)/\tau(B^0)$ has been of considerable interest as there has been a long stating disagreement between theoretical predictions and experimental results. Most of the recent Tevatron measurements [13, 14, 15, 16] now agree within errors with updated theoretical predictions (see e.g. [17]).

2.4 Conclusions

The Tevatron experiments continue to produce precision heavy flavour measurements that are complementary to and competitive with the b-factories. With ongoing data taking and a doubling of the data set further improvements are to be expected within the near future.

References

[1] CDF II Collaboration, *The CDF II Detector: Technical Design Report*, FERMILAB-PUB-96/390-E.

[2] D. Acosta et al. (CDF Collaboration), Phys. Rev. D 71, 032001 (2005).

[3] V. Abazov *et al.* (DØ Collaboration), Nucl. Instr. and Methods A 565, 463 (2006)

[4] A. Lenz, and U. Nierste, J. High Energy Physics 0706,072 (2007)

[5] V. Abazov *et al.* (DØ Collaboration), PRL 97, 021802 (2006)

[6] A. Abulencia *et al.* (CDF Collaboration),

[7] DØ Collaboration, D0 Note 5618-CONF (2008) Phys.Rev.Lett. 97 (2006) 242003

[8] CDF Collaboration, CDF Note 9458 (2008)

[9] DØ Collaboration, arXiv:0802.2255v1 [hep-ex]

[10] CDF Collaboration, CDF Note 9294 (2008)

[11] V.V. Kiselev, arXiv:0308214 [hep-ph]

[12] DØ Collaboration, arXiv:0805.2614 [hep-ex]

[13] CDF Collaboration, arXiv:0609021v1 [hep-ex]

[14] CDF Collaboration, CDF Note 9408 (2008)

[15] DØ Collaboration, PRL 99, 182001 (2007)

[16] DØ Collaboration, PRL 99, 142001 (2007)

[17] C. Tarantino, Nucl. Phys. B 156 (Proc. Suppl.) 33 (2006)