We present recent results on b-hadron lifetimes and mixing obtained from the analysis of the data collected at the Tevatron Collider by the CDF and D0 Collaborations in the period 2002 - 2004. Many lifetime measurements have been updated since the Summer 2004 conferences, sometimes improving significantly the accuracy. Likewise the measurement of the $B_d$ oscillation frequency has been updated. New limits on the $B_s$ oscillation frequency have been determined using for the first time Run II data.

1 Data samples

The results described in this paper refer to the analysis of data collected at the Fermilab Tevatron Collider from February 2002 till August 2004. During this period the accelerator has been continually improving its luminosity delivering over 600 pb$^{-1}$ to each experiment. Initial store luminosities exceeding $1 \times 10^{32} cm^{-2} sec^{-1}$ have now become quite common.

The CDF and D0 detectors have been reliably taking data over this period. The data set sizes used for B physics analyses are in the range of 220 to 450 pb$^{-1}$. These data sets are collected with three major trigger categories:

- di-lepton triggers: these provide a sample of millions of $J/\psi$’s many of which originate from the decay of a b-hadron. From this sample several thousands fully reconstructed b-hadrons are obtained;

- single lepton triggers: these provide a large sample of b-hadrons decaying semi-leptonically. The background is significantly reduced by requiring a fully reconstructed D meson with the right charge correlation with the lepton. Samples sizes of up to $\sim 100$ thousand lepton plus D events are achieved;

- triggers on displaced vertices: these provide large samples of b-hadrons decaying hadronically. From these samples several thousand fully reconstructed hadronic B decays are obtained. At present only CDF implements this kind of trigger.
### Table 1: HFAG summer 2004 averages compared to theory calculations

| b-hadron type | Lifetime \( \tau(B_d) \) | \( \tau(B_d)/\tau(B_s) \) experiments | \( \tau(B_d)/\tau(B_s) \) theory |
|---------------|--------------------------|---------------------------------|-------------------------------|
| \( B_d \)     | 1.534 ± 0.013 ps         | 1.081 ± 0.015                  | 1.06 ± 0.02                  |
| \( B_s \)     | 1.653 ± 0.014 ps         | 0.958 ± 0.039                  | 1.00 ± 0.01                  |
| \( A_B \)     | 1.232 ± 0.072 ps         | 0.803 ± 0.047                  | 0.86 ± 0.05                  |

### 2 b-hadron lifetimes

The lifetime of b-hadrons is governed primarily by the decay of the b-quark, however contributions from the spectator quarks can be up to \( \sim 15\% \). Presently these spectator effects are mostly calculated in the framework of the Heavy Quark Expansion. Theory errors on the ratio with the \( B_d \) lifetime are in the few \% range as shown in table 1. The experimental situation updated to the summer 2004 has been summarized in a recent report of the Heavy Flavor Averaging Group (HFAG) and is also shown in table 1.

Several new results which update the table above have been obtained by the CDF and D0 Collaborations. A summary of these new results is shown in table 2. Both experiments have improved their measurements with fully reconstructed modes involving a \( J/\psi \). CDF has measured for the first time the lifetimes of \( B \) mesons using completely reconstructed fully hadronic decays like \( B \rightarrow D\pi \) or \( B \rightarrow D^0\bar{\pi} \), the small systematic error indicates a good control of the secondary vertex trigger efficiency turn on. CDF has also measured the \( B_u \) and \( B_d \) lifetimes using a subsample of its semileptonic data. D0 has measured the ratio of \( B_u \) and \( B_d \) lifetimes in their semileptonic samples with new technique that involves fitting the bin by bin ratio of the lifetime distributions. Of particular interest is the D0 measurement of the \( B_s \) lifetime in a very high statistics semileptonic sample, as shown in fig. 2. This is currently the best available measurement of this quantity.

### Table 2: Summary of new lifetime results

| Luminosity pb\(^{-1} \) | CDF \( J/\psi \) modes | D0 \( J/\psi \) modes | CDF hadronic modes | CDF semileptonic modes | D0 semileptonic modes | HFAG 2004 |
|--------------------------|------------------------|------------------------|---------------------|------------------------|-----------------------|------------|
| 240                      | 1.59±0.005±0.008       | 1.60±0.005±0.008       | 1.41±0.002±0.013    | 1.45±0.002±0.014       | 1.53±0.008±0.013      | 1.53±0.014 |
| 400                      | 1.66±0.007±0.008       | 1.64±0.007±0.008       | 1.61±0.002±0.013    | 1.55±0.002±0.014       | 1.65±0.009±0.014      | 1.65±0.014 |
| 0.30±0.01±0.02           | 0.69±0.01±0.02         | 0.73±0.01±0.02         | 0.73±0.01±0.02      | 0.73±0.01±0.02         | 0.73±0.01±0.02        |
| 0.30±0.01±0.02           | 0.69±0.01±0.02         | 0.73±0.01±0.02         | 0.73±0.01±0.02      | 0.73±0.01±0.02         | 0.73±0.01±0.02        |
| 0.30±0.01±0.02           | 0.69±0.01±0.02         | 0.73±0.01±0.02         | 0.73±0.01±0.02      | 0.73±0.01±0.02         | 0.73±0.01±0.02        |

### 3 \( B_d \) and \( B_s \) mixing

\( B_d \) and \( B_s \) mesons can turn into their anti-particle with a frequency which is related to the CKM matrix elements \( V_{td} \) and \( V_{ts} \) respectively. A measurement of both mixing frequencies, \( \Delta m_d \) and \( \Delta m_s \), would yield a measurement of the ratio of these two elements with about 5\% theory uncertainty, thus providing a strong constraint in global fits of the Unitary Triangle. Very precise measurements of \( \Delta m_d \) have been available for some time, and are currently dominated by the results of the B-factories. Recent CDF and D0 measurements are consistent with those results. \( \Delta m_s \) is constrained to be larger than 14.5 \( \text{ps}^{-1} \) at 95\% C. L. from previous work by the LEP experiments, SLD and CDF. Both CDF and D0 have recently obtained new limits on \( \Delta m_s \). In the following we’ll report on the CDF result, while the D0 result is described in a separate paper.

CDF makes two parallel measurements using both fully reconstructed hadronic decays and semileptonic decays with a fully reconstructed \( D_s \) meson. In the former case about 900
Figure 1: D0 Collaboration: Pseudo-proper decay length distribution for $B^0_s$ semileptonic data with the result of the fit superimposed. The dotted curve represents the combinatorial background and the filled histogram represents the $B^0_s$ signal.

$B_s \to D_s \pi$ events are found after summing over three possible $D$ decay modes: $\varphi \pi$, $K^*K$ and $\pi \pi \pi$; the latter yields a significantly larger statistics of about 7,500 $B_s \to l\nu D_s$ events, however the proper time resolution is worse because of the incomplete knowledge of the decay kinematics due to the missing neutrino. Signals using the decay $D \to \varphi \pi$ are shown in fig. 3.

Flavor tagging is performed using only opposite side taggers. The tag sign is provided either by the sign of an electron or muon, or by the average weighed charge of the tracks in a jet. A combined tagging power in the order of 1.4% is obtained.

CDF performs an amplitude scan on both samples and then combines them to obtain a 95% C.L. limit of 7.9 ps$^{-1}$ for an expected limit of 8.4 ps$^{-1}$. The scan result is shown in fig. 3 and is clearly dominated by the statistical error. This result can be improved significantly in the near future by implementing more powerful taggers, improving the vertex resolution and including more final states in this analysis. A positive observation will require more statistics, but appears to be within reach.

Figure 2: CDF Collaboration: $B_s^0$ signals in the hadronic (left) and semileptonic (right) data samples.
Figure 3: CDF Collaboration: Amplitude scan combining hadronic and semileptonic $B^0_s$ signals.

References

1. C. Tarantino, Eur. Phys. J. C 33, S895 (2004) [arXiv:hep-ph/0310241];
   F. Gabbiani et al., Phys. Rev. D 70, 094031 (2004) [arXiv:hep-ph/0407004].
2. J. Alexander et al. [Heavy Flavor Averaging Group (HFAG) Collaboration], “Averages of
   b-hadron properties as of summer 2004,” arXiv:hep-ex/0412073.
3. The CDF Collaboration, May 2004, http://www-cdf.fnal.gov/cdfnotes/cdf7409_excLft_public.ps;
   The D0 Collaboration: V. M. Abazov et al., Phys. Rev. Lett. 94, 042001 (2005).
4. The CDF Collaboration, March 2005, http://www-cdf.fnal.gov/physics/new/bottom/050303.blessed-bhadlife/blessed-bhadlife.ps.
5. The CDF Collaboration, March 2005, http://www-cdf.fnal.gov/physics/new/bottom/050224.blessed-bsemi-life/blessed-bsemi-life.ps.
6. The D0 Collaboration: V. M. Abazov et al., arXiv:hep-ex/0410052.
7. The D0 Collaboration, March 2005, http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B16/B16.pdf.
8. M. Bona et al. [UTfit Collaboration], arXiv:hep-ph/0501199;
   J. Charles et al. [CKMfitter Group Collaboration], arXiv:hep-ph/0406184 and http://www.slac.stanford.edu/xorg/ckmfitter/ckm_results_winter2005.html.
9. K. Abe et al. [BELLE Collaboration], arXiv:hep-ex/0408111;
   B. Aubert et al. [BABAR Collaboration], arXiv:hep-ex/0408039.
10. The CDF Collaboration, February 2005, http://www-cdf.fnal.gov/physics/new/bottom/050224.blessed-mix-bld/bmix-ld-pub.ps;
    http://www-cdf.fnal.gov/physics/new/bottom/050224.blessed-hadr-ost/mix-excl-pub.ps;
    The D0 Collaboration, August 2004, http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B15/B15.pdf.
11. S. Burdin, These proceedings.
12. The CDF Collaboration, March 2005, http://www-cdf.fnal.gov/physics/new/bottom/050310.bsmix-combined/combined-pub.ps.
13. H. G. Moser and A. Roussarie, Nucl. Instrum. Meth. A 384, 491 (1997).