B-Mixing and Lifetime Difference at CDF and DØ

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Abstract. After years of searching we are narrowing in on a measurement of the oscillation frequency in the B_s meson system. Exciting results have recently emerged in this area from the Tevatron. These results are discussed as well as related measurements of the B_s lifetime difference. Taken together, these measurements comprise a sensitive probe of the electro-weak symmetry breaking mechanism.

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INTRODUCTION

Within the Standard Model (SM), flavor structure, as parameterized by the CKM matrix, arises via the electro-weak symmetry breaking mechanism. (See [1] for a recent review). Because the SM breaks electro-weak symmetry in a very simple way, using a single Higgs doublet, the flavor sector is highly constrained with most observables being strongly correlated. Models of New Physics, however, tend to have different relationships between flavor observables. Comparisons of these relationships as measured in experiment with the predictions made by various models, then, provide a sensitive means of determining the structure of physics beyond the SM that is complementary to direct searches for new phenomena, as reviewed recently in [2].

In the last few months, new measurements using B_s mesons have significantly increased the precision of these tests. The neutral B_s meson is a particularly important window onto possible new physics effects because of the fact that it experiences oscillations between particle (B_s) and anti-particle ($\bar{B}_s$) states as it evolves in time. The frequency of this oscillation is given by Δm_s, the mass difference between the two mass eigenstates that mix to form the flavor states, B_s and $\bar{B}_s$. Two other variables are needed to fully describe the time evolution of the meson: $\Delta\Gamma_s$, the difference in the decay widths of the two mass states; and ϕ_s, a CP violating phase in the B_s system.

Starting in 2001, upgraded CDF and DØ detectors have been collecting data during Run 2 of the Fermilab Tevatron accelerator. Both detectors, described in more detail in [3] and [4], are well suited to making precise B-Physics measurements. As of the end of 2005, both collaborations have collected more than 1 fb^{-1} of high quality data. Nearly all of this data is used in most of the analyses outlined in the following.

MIXING

The challenge of measuring the B_s oscillation frequency, Δm_s, lies in the fact that it is much larger than the well-known equivalent in B_d-mesons, Δm_d. In fact, at the end of 2005, Δm_d was known to an accuracy of better than 1% (0.507$\pm$0.004 ps^{-1}) while Δm_s was only constrained to be larger than 16.6 ps^{-1} at the 95 % C.L. [5]. Measurements of both parameters are necessary to get at the important element of the CKM matrix, V_{td}, because theoretical uncertainties in relating the ratio $\Delta m_d/\Delta m_s$ to V_{td}, from lattice calculations of decay constants and bag parameters, are significantly smaller than those in the Δm_d-to-V_{td} transformation [6].

Both DØ and CDF have produced exciting new results in this area. Details are available in [7] and [8]. DØ started the process in March of 2006 when they announced the first two-sided bound on Δm_s from a single experiment using approximately 21,000 $B_s \to D_s^{\mp}\mu^{\pm}\nu X$ decays. The results are presented in Fig. 1 (left plot) using the Amplitude Method [9] where a Fourier-like analysis is performed on the data yielding *amplitudes* at various *probe* values of Δm_s. These amplitudes are related to the probability of the probe value of Δm_s being consistent with the true value found in nature. A peak in the data is visible around 19 ps^{-1} which deviates from 0(1) by 2.5 (1.6) σ. This peak can be translated into a two-sided bound of $17 < \Delta m_s < 21$ ps^{-1} at the 90% C.L.

Shortly after DØ's result was announced, CDF released a first measurement of Δm_s using approximately 53,000 semileptonic and 3,700 fully hadronic B_s decays. Because of the better proper time resolution in hadronic decay modes, where no particles are missed in the reconstruction, CDF's analysis has higher sensitivity to oscillations than DØ's as is apparent in Fig. 1 (center plot), which shows a peak in the amplitude spectrum around 17 ps^{-1} with a significance of 3.5 σ. Translating this into a measurement of the oscillation frequency gives, $\Delta m_s = 17.33\ ^{+0.42}_{-0.21} \pm 0.07$ ps^{-1}.

Both the DØ and CDF results are to be interpreted under the assumption that the observed structure in the amplitude scan is a true signature for B_s oscillations. Extensive studies have been done to evaluate the likelihood that this hypothesis is true. They indicate that the probability for background fluctuations to produce the observed signals are at the 5% (DØ) and 0.5% (CDF) levels. Combining the new analyses with previous results [5], increases the significance of the peak in the amplitude spectrum around 17 ps^{-1} to 4.0 σ. Finally, CDF has used their new measurement, along with the world average value for Δm_d [5] and the latest lattice result on the ratio of decay constants and bag parameters [6] to derive $|V_{td}/V_{ts}| = 0.208\ ^{+0.008}_{-0.007}$, where the error is now dominated by the uncertainty on the lattice calculation.

B_s LIFETIME DIFFERENCE

Two general strategies are used to search for $\Delta\Gamma_s$: fits to angular distributions in B_s decays involving both CP-even and -odd components, such as $B_s \to J/\psi\phi$, that allow the separate decay widths to be disentangled; and measurements of branching ratios and lifetimes of B_s decays to pure CP eigenstates.

DØ has performed a preliminary analysis of the angular distributions in 978 $\pm$ 45 $B_s \to J/\psi\phi$ candidates. Larger statistics compared to the previously published analyses

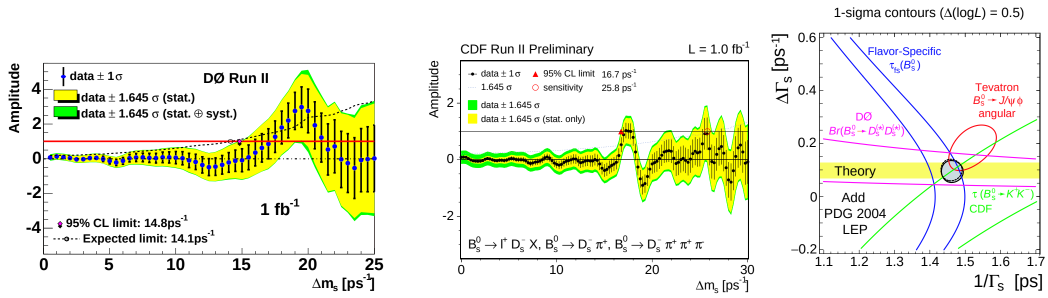

FIGURE 1. Amplitude scans as a function of probe Δm_s for the DØ semileptonic analysis (left plot) and the combined CDF hadronic and semileptonic analysis (center plot). A preliminary average of all experimental inputs to $\Delta\Gamma_s$ and the average B_s lifetime (right plot).

[10, 11] allow the extraction of the CP violating phase, $\phi_s = -0.9\pm0.7$, in addition to $\Delta\Gamma_s = 0.15\pm0.10^{+0.03}_{-0.04}$ ps^{-1}, the average B_s lifetime, $\overline{\tau_s} = 1.53\pm0.08^{+0.01}_{-0.04}$ ps and the CP-odd fraction in these decays, $R_\perp = 0.19\pm0.05\pm0.01$.

Both CDF and DØ have produced new, preliminary results in the area of CP-specific decays of the B_s meson. CDF has measured the lifetime in 718±55 $B_s \to K^+K^-$ candidates to be $\tau_s^{CP-even} = 1.53\pm0.18\pm0.02$ ps. Comparing this to the world average flavor-specific lifetime [5] yields a value of $\Delta\Gamma_s/\Gamma_s = -0.08\pm0.23\pm0.03$. DØ derives $\Delta\Gamma_s$ using a measurement of the branching ratio of the predominantly CP-even decays, $B_s \to D_s^{(*)} D_s^{(*)}$. The branching ratio found, $0.071\pm0.035^{+0.029}_{-0.025}$ implies $\Delta\Gamma_s/\Gamma_s = 0.142\pm0.064^{+0.058}_{-0.050}$.

Putting all these new measurements together, as displayed in Fig. 1, gives a new world average value of $\Delta\Gamma_s = 0.097^{+0.041}_{-0.042}$, which is consistent with SM predictions [12] and differs from zero by 2.4 σ.

SUMMARY AND PROSPECTS

The last few months have seen a lot of excitement in the B_s sector. After more than 10 years of searching, a measurement of Δm_s has now been made, the world average value of $\Delta\Gamma_s$ is significantly (2.4σ) away from zero and we are beginning to be sensitive to the CP violating phase, ϕ_s. All of these measurements are overwhelmingly statistics limited, although the precision on V_{td}, extracted using Δm_s and Δm_d, is now set by lattice calculations.

Prospects for improvements are therefore bright, with the Tevatron expected to deliver a factor of 3 – 6 more data by 2009. Additionally, experimental improvements such as DØ's new Layer-0 silicon detector and trigger upgrades by both experiments will further extend the collaborations' reach into the realm of the B_s meson and the new physics that may be found there.

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