

HEAVY FLAVORS AT THE TEVATRON

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The CDF and D0 experiments, running at Fermilab's Tevatron accelerator, are studying a wide range of unique heavy flavor physics. Tragically, space constraints prevent me from discussing the full program here. But I will present highlights of some of the most recent and important results, including new measurements of the Λ_b lifetime; newly discovered B -baryons and charmonium-like states; and measurements of CP -violation in B_s meson systems.

1 Introduction

The study of heavy flavors, particularly of B -hadrons, has been a particularly copious source of results at the Tevatron experiments CDF and D0. In total, the two collaborations have produced 85 publications (50 for CDF and 35 for D0) in this field and show no sign of slackening this furious pace. Thanks to the increasing datasets accumulated by the experiments – at the time of this conference, nearly 7 fb^{-1} delivered to, and around 6 fb^{-1} recorded by the experiments – sensitive searches and precision studies of a wide range of topics in this diverse field are possible. Full lists of heavy flavor results from the experiments are available online^{1,2}.

Obviously, space limitations preclude the possibility of discussing all the Tevatron heavy flavor results in these proceedings. I have chose instead to concentrate on only a few important measurements that have appeared very recently in the areas of B -hadron properties and CP -violation. These results are made possible, not only by the large datasets available to CDF and D0, but also by the excellent capabilities of their detectors for heavy flavor studies. The main drivers are high rate trigger capabilities, wide angle muon coverage, and precision tracking. More details are available in the following references^{3,4}.

2 B -Hadron Properties

2.1 Λ_b Lifetime

CDF takes advantage of its ability to trigger efficiently on events with two displaced tracks to measure the lifetime of the Λ_b baryon in its fully hadronic decay mode: $\Lambda_b^0 \rightarrow \Lambda_c^+(p^+ K^- \pi^+) \pi^-$ (and charge conjugate). The ratio of the Λ_b lifetime to that of the B^0 meson is well predicted by Heavy Quark Effective Theory⁵. The new CDF measurement of $\tau(\Lambda_b)/\tau(B^0) = 0.919 \pm 0.030 \pm 0.023$, derived from a sample of 2905 ± 58 Λ_b signal events, is the most accurate determination yet of this ratio. It agrees well with the HQET prediction (0.88 ± 0.05) ⁵ and also with the current world average $(0.907^{+0.032}_{-0.031})$ ⁶ giving us increased confidence in our ability to predict dynamics in B -hadron systems.

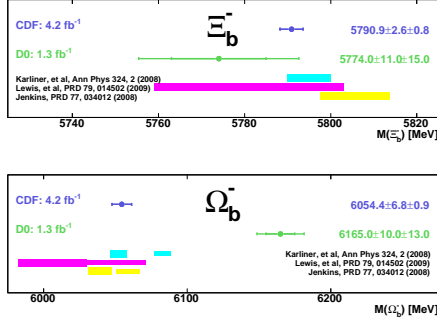


Figure 1: Comparison of Ξ_b and Ω_b mass measurements.

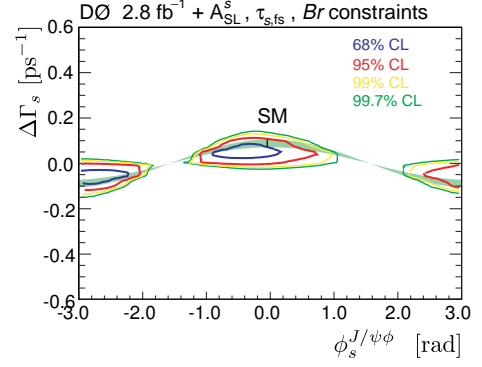


Figure 2: Combination of all D0 measurements of $\Delta\Gamma_s$ and ϕ_s as well as constraints from flavor-specific lifetime measurements.

2.2 Ξ_b and the Ω_b Puzzle

The last few years have been a particularly exciting time for those interested in B -baryons. Between June, 2007 and August, 2008, CDF and D0 discovered four new b -flavored baryons: Σ_b^\pm and $\Sigma_b^{\pm*}$ (uub/ddb)⁷; Ξ_b^- (dsb)^{8,9}; and Ω_b^- (ssb)¹⁰. CDF has recently released their observation of the Ω_b in the $\Omega_b^- \rightarrow J/\psi(\mu^+\mu^-)\Omega^-(\Lambda^0 K^-)$ decay mode as well as an updated measurement of the properties of the Ξ_b ¹¹. Using 4.2 fb^{-1} of data, CDF sees an Ω_b signal with 5.5σ significance. They make first measurements of the lifetimes of the Ω_b and Ξ_b of $1.13_{-0.40}^{+0.53} \pm 0.02 \text{ ps}$ and $1.56_{-0.25}^{+0.27} \pm 0.02 \text{ ps}$, respectively; and measure $M(\Omega_b) = 6054.4 \pm 6.8 \pm 0.9 \text{ MeV}$ and $M(\Xi_b) = 5790.0 \pm 2.6 \pm 0.8 \text{ MeV}$. For the Ξ_b system, agreement is good between the D0⁸ and CDF¹¹ mass measurements and between experimental values and theoretical predictions¹². However, the situation is much less clear for the Ω_b (see Fig. 1) where CDF's mass measurement¹¹ corresponds closely to theoretical expectations¹² but is more than 6σ away from the D0 value of $6165 \pm 10 \pm 13 \text{ MeV}$ ¹⁰. This is particularly puzzling for a number of reasons. First, there is good agreement between the experiments in the topologically similar $\Xi_b^- \rightarrow J/\psi(\mu^+\mu^-)\Xi^-(\Lambda^0 \pi^-)$ decay chain. Second, the difference between the CDF and D0 masses is nearly ten times the magnitude of the largest D0 systematic. And finally, there is reasonable agreement ($\sim 1.3\sigma$) between the relative yields of Ω_b and Ξ_b measured by the two experiment. Only more data will allow us to resolve this dilemma.

2.3 Exotica: $X(3872)$ and $Y(4140)$

Starting with the first observation of a $J/\psi\pi^+\pi^-$ resonance at around 3872 MeV by the Belle collaboration in 2003¹³, experimenters have uncovered a nest of exotic charmonium-like particles with a variety of quantum numbers. While some of these new states sit on rather shaky ground experimentally, many, particularly the original $X(3872)$, are firmly established and cannot be explained by simple $c\bar{c}$ bound states. More exotic explanations are necessary, but none proposed so far have been entirely satisfactory¹⁴.

Both Tevatron experiments have made measurements of the $X(3872)$ state, and CDF has recently added to this area with a preliminary $X(3872)$ mass measurement of $3871.61 \pm 0.16 \pm 0.19 \text{ MeV}$ made using 2.4 fb^{-1} of data. This represents the most accurate measurement to date of the $X(3872)$ mass and is consistent with previous results.

CDF has also observed structure (at the 3.8σ level) in a sample of $75 \pm 10 B^+ \rightarrow J/\psi\phi K^+$ candidates observed in 2.7 fb^{-1} of data. They interpret this preliminary result as evidence of a new resonance, $Y(4140) \rightarrow J/\psi\phi$, with a mass of $4143 \pm 2.9 \pm 1.2 \text{ MeV}$ and a width of $11.7_{-5.0}^{+8.3} \pm 3.7 \text{ MeV}$. This resonance, which occurs above the open-charm threshold, is similar to the previously-observed $Y(3930) \rightarrow J/\psi\omega$, providing yet another piece to be fit into the XYZ puzzle.

3 CP -Violation

The asymmetry of particle interactions under combined charge-parity (CP) operations is intimately entwined with electro-weak symmetry breaking in the Standard Model. In the SM, both the CKM matrix and CP -violation arise through the Higgs mechanism. Because of the minimal implementation of the Higgs mechanism that defines the SM, all CP -violation is governed by a single parameter in that model, meaning that all predictions of CP -violating effects are tightly coupled in the SM. However, most SM extensions, such as supersymmetry, have a more complicated flavor structure, yielding different correlations between observable CP -asymmetries than expected in the SM. This fact makes studies of CP -violating effects a particularly promising method of looking for physics beyond the SM.

CDF and D0 have played an important role in this process by measuring CP -violation in the B_s system. The effect appears in the mixing of B_s^0 and \bar{B}_s^0 mesons – a process that is governed by three observables: Δm_s , the mass difference between B_s mass eigenstates; $\Delta\Gamma_s$, the width difference between B_s weak eigenstates; and ϕ_s or β_s , different measures of the CP -violating phase in this system. The mass difference, Δm_s , has now been firmly established by both experiments¹⁵ as has the width difference⁶. Emphasis is now shifting to measurements of the CP -violating phase, for which recent results are summarized below.

3.1 $B_s \rightarrow J/\psi\phi$, $B_s \rightarrow \mu D_s X$, and $B_s \rightarrow D_s^{(*)} D_s^{(*)}$

The “classical” way to get at CP -violation in the B_s system is by disentangling CP -eigenstates using angular distributions in the decay $B_s \rightarrow J/\psi\phi$. Both CDF (preliminary) and D0¹⁶ have performed analyses of large samples (3166 ± 56 and 1967 ± 65 , respectively) of flavor-tagged $B_s \rightarrow J/\psi\phi$ candidates in 2.8 fb^{-1} of data. Interestingly, both experiments see consistent deviations of the measured CP -violating phase from its SM expectation, with SM p -values of 7–8% for each of their fits.

Asymmetries in the decay rates of semi-leptonic B decays also provide a handle on CP -violation. D0 has recently published an analysis of $B_s \rightarrow \mu D_s X$ decays¹⁷ using flavor-tagged $D_s^- \rightarrow \phi\pi^-$ and $D_s^- \rightarrow K^{*0}K^-$ decays in 5 fb^{-1} of data. The measured asymmetry between rates for decays involving negative and positive muons, which can be related to ϕ_s , is found to be small, $(-1.7 \pm 9.1_{-2.3}^{+1.2}) \times 10^{-3}$, and consistent with SM expectations¹⁸.

Under a variety of theoretical assumptions¹⁹, the width difference between CP -eigenstates in the B_s system, $\Delta\Gamma_s^{CP}$ (which is related to $\Delta\Gamma_s$ and ϕ_s) is saturated by $\Gamma(B_s \rightarrow D_s^{(*)} D_s^{(*)})$. D0 has recently seen evidence for this decay²⁰ in events with two $D_s^{(*)}$ candidates, one of which decays to $\phi\pi^-$, while the other is observed in the $\phi\mu^+\nu$ mode. Using a signal sample of 26.6 ± 8.4 events (3.2σ significance) in 2.8 fb^{-1} of data, the collaboration is able to extract $\Delta\Gamma_s^{CP}/\Delta\Gamma_s = 0.072 \pm 0.021 \pm 0.022$.

3.2 Combination

All of the above measurements contain information¹⁹ on both $\Delta\Gamma_s$ and the CP -violating phase, so combining them will increase the significance of the result. These combinations are complicated, however, by different methods used by CDF and D0 to extract parameters from the data and by the presence of theoretical assumptions. A joint program between CDF and D0 has started to deal with these difficulties, but at the time of this conference had not yet arrived at final results. An example of the type of gain achievable by such a combination is illustrated in Fig. 2, where D0 results on $\Delta\Gamma_s$ and ϕ_s are combined with the world-average value for the B_s lifetime, measured using flavor-specific modes (such as semi-leptonic decays) where CP -even and -odd components contribute with equal weights. This combination results in an approximately

5% gain in sensitivity in the result for ϕ_s over the most sensitive single measurement – from $B_s \rightarrow J/\psi\phi$.

4 Conclusion

The results discussed above represent only a small fraction of the entire Tevatron heavy flavor physics program. Other interesting topics include studies of heavy flavor production; measurements of heavy B meson properties; searches for rare decays of B and D hadrons; and many others. Current estimates indicate that the Tevatron could deliver up to 12 fb^{-1} of data to CDF and D0 by the end of its operation. As a majority of our results are still statistics limited, we can look forward to significant advances in our understanding of heavy flavors from the Tevatron in the coming years.

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