MEASUREMENTS OF THE MASSES, MIXING, AND LIFETIMES OF B HADRONS AT THE TEVATRON

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The B production cross section at the Tevatron is about 150 μb, producing many B hadrons, including B_s mesons and B baryons. Measurements of various properties of these B hadrons have been made at CDF and DØ with almost 400 pb^{-1} of data. This paper is a review of the recent measurements of the masses, mixing and lifetimes of the B hadrons produced at the Tevatron.

1 Introduction

The Fermilab Tevatron is truly a B factory with a production cross section for $\sigma(p\overline{p} \rightarrow b\overline{b}) \approx$ 150 μb, including the production of B_s mesons and B baryons. Measurements of the properties of B hadrons are important for they give insight in the structure of flavor dynamics, they probe QCD at large distances, and give insight into physics not predicted by the standard model. The DØ and CDF detectors at the Fermilab Tevatron have recorded about 400 pb^{-1} of data this year, while the analyses presented in this paper use between 150 and 350 pb^{-1}.

2 Detectors

CDF and DØ have both undergone major detector upgrades. Each detector now has a silicon vertex tracker, an axial solenoid, and a central tracking system. Some strengths of the CDF detector include particle identification for low momentum tracks, excellent mass resolution, and a trigger on displaced vertices. The DØ detector has track reconstruction and muon acceptance for pseudorapidity $|\eta| < 2$.

3 Mass Measurements

Both the CDF and DØ collaborations have confirmed Belle's discovery of the $X(3872)$.[1] It has been proposed that the X may not be a simple $c\overline{c}$ state because it has not been observed to decay by radiative decay, its mass does not easily fit into any calculated $c\overline{c}$ state, and its mass is just above the D^0 D^{*0} threshold. CDF has measured the mass to be (3871.3±0.7 (stat) ±0.4 (sys)) MeV/c^2. DØ has measured the mass difference between the X and the J/ψ and finds the mass of the X is (3871.8±3.1 (stat) ±3.0 (sys)) MeV/c^2. Both CDF and DØ have measured various properties of the X and compared them with the ψ(2S) state to help determine the makeup of the X. CDF has compared the fraction of decays that have a long lifetime, most likely from

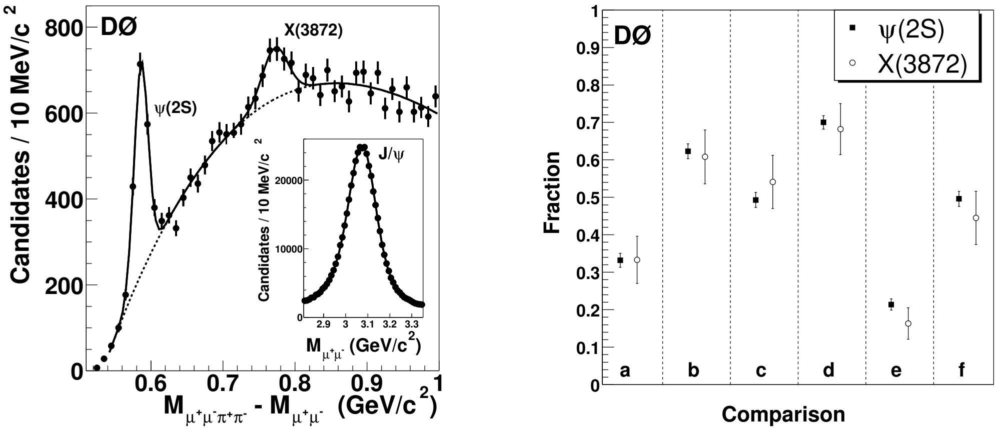

Figure 1: Left: $X(3872)$ mass from DØ. Right: Comparison of event-yield fractions for $X(3872)$ and $\psi(2S)$ in the regions: (a) $p_T(J/\psi\pi^+\pi^-) > 15$ GeV/c; (b) $|y|$ of $J/\psi\pi^+\pi^- < 1$; (c) $\cos(\theta_\pi) < 0.4$; (d) effective proper decay length, $dl < 0.01$ cm; (e) isolation=1; (f) $\cos(\theta_\mu) < 0.4$;

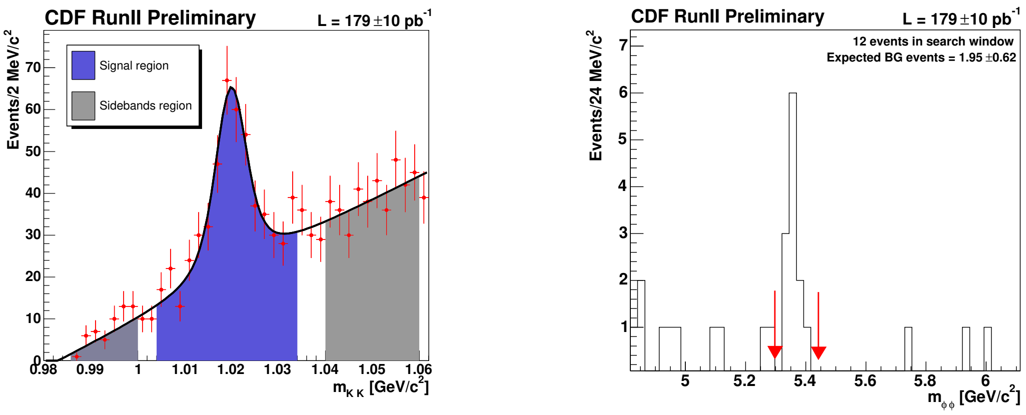

Figure 2: Left: $\phi \to K + K^-$ invariant mass. Right: $B_s \to J/\psi\phi$ invariant mass.

decays of B hadrons and measured that (28.3±1.0 (stat) ±0.7 (sys))% of $\psi(2S)$ mesons have long lifetimes, while the fraction of X particles with long lifetimes is (16.1±4.9 (stat) ±2.0 (sys))%. The DØ collaboration has compared the fraction of X particles that pass one of six kinematic cuts with the fraction of $\psi(2S)$ mesons that pass those same cuts, as shown in Fig. 1.

The CDF collaboration has made the first observation of the decay $B_s \to \phi\phi$, and measured the branching ratio as BR$(B_s \to \phi\phi) = (1.4 \pm 0.6$ (stat) ± 0.2 (syst) ± 0.5 (BR)) $\times 10^{-5}$ where the largest systematic uncertainty, labeled (BR), is from the uncertainty in the branching ratio of the decay $B_s \to J/\psi\phi$. Fig. 2 shows the invariant mass of the K mesons from ϕ decay, and the invariant mass of the B_s decay.

The decay $B_s \to \mu^+\mu^-$ is a rare decay in the standard model with a branching ratio of about $(3.4\pm0.5)\times10^9$. However, in certain extensions to the standard model, like R-parity violating SUSY or minimal supergravity, this branching ratio can be greatly enhanced. Both the CDF and DØ collaborations have looked for this rare decay and set an upper limit on the branching ratio. After selection criteria, CDF expects to see 1.05±0.30 events in the signal region, and DØ expects to see 3.7±1.1 events. The CDF and DØ experiments observe 1 and 4 events, respectively, and set 95% confidence limits on this branching of BR$(B_s \to \mu^+\mu^-) < 7.5 \times 10^{-7}$ and BR$(B_s \to \mu^+\mu^-) < 4.6 \times 10^{-7}$, respectively. Plots of the signal and side band regions for the experiments are shown in Fig. 3.

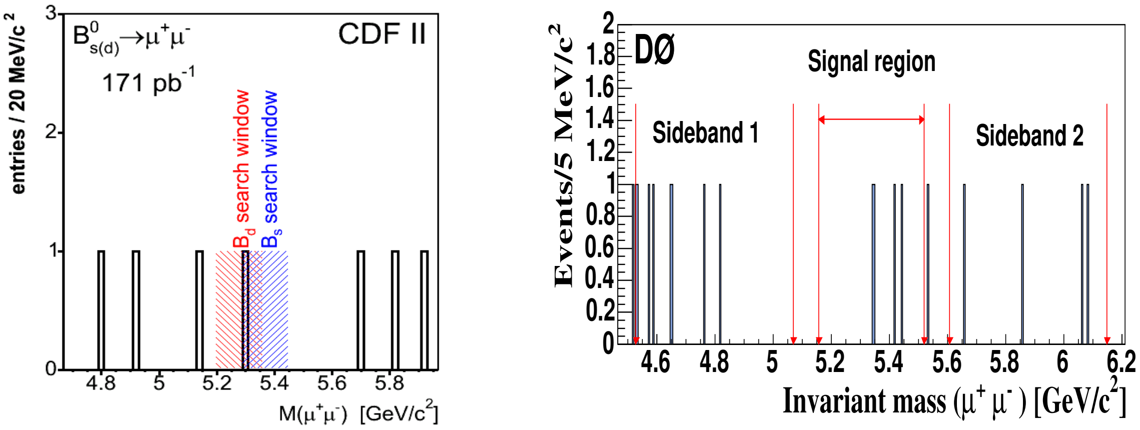

Figure 3: Search region for the rare decay $B_s \to \mu^+\mu^-$ for the CDF (left) and DØ (right) experiments.

4 Mixing Measurements

In the standard model, neutral B mesons can change from particles to antiparticles, or mix, via box diagrams involving virtual quarks and vector bosons. To measure mixing, the original flavor of the B meson must be tagged, (whether it was a particle or antiparticle), as well as the flavor of the B meson when it decays. The original flavor of the B can be tagged using a variety of methods. The opposite side jet charge tag sums the momentum weighted charge of the jet. Since b quarks have a charge of $-1/3$, the jet will, on average, have a negative charge if it originated from a b quark and a positive charge if it originated from a b antiquark. The flavor can also be determined by measuring the sign of the lepton from a b decay in the jet opposite of the B meson, because b quarks decay to negative leptons while b antiquarks decay to positive leptons. Finally, a soft pion on the same side as the B meson can tag the original flavor of the quark since b quarks will usually produce π^- mesons, while b antiquarks produce π^+ mesons.

The long term goal of the CDF and DØ collaborations will be to measure oscillations of the B_s meson. Because the datasets are not yet large enough to observe these oscillations, the two collaborations are currently measuring B_d oscillations, which have previously been measured quite accurately at Belle and BaBar. An oscillation parameter often quoted is Δm_d, the difference in mass between the heavier and the lighter B_d mass eigenstate. The current world average for this value is $\Delta m_d = (0.502 \pm 0.007)$ ps^{-1}. [2]

CDF and DØ have used same side tagging and measured $\Delta m_d = (0.443 \pm 0.052$ (stat) ± 0.030 (sc) ± 0.012 (sys)) ps^{-1} (where "sc" means sample composition) and $\Delta m_d = (0.448 \pm 0.064$ (stat) ± 0.044 (sys)) ps^{-1}, respectively. DØ has used an opposite side μ tag to measure $\Delta m_d = (0.506 \pm 0.055$ (stat) ± 0.049 (sys)) ps^{-1}.

5 Lifetime Measurements

Lifetime measurements of B hadrons give insight into Heavy Quark Expansion (HQE) theory and probes QCD at large distances. In particular, measuring the ratio of the lifetimes of different B hadrons can accurately probe HQE to 3rd order in Λ_{QCD}/m_b. Current measurements indicate that the ratio of $\tau(\Lambda_b)/\tau(B^0)$ is about two standard deviations below the expected range of 0.9 to 1.0.

DØ has measured the Λ_b lifetime as $\tau(\Lambda_b) = (1.221^{+0.217}_{-0.179} \pm 0.043)$ ps, giving a ratio of $\tau(\Lambda_b)/\tau(B^0) = (0.874^{+0.169}_{-0.142} \pm 0.028)$ ps, which has a large uncertainty, but does agree with theoretical calculations.

CDF and DØ have both measured $\tau(B_s)$ using $B_s \to J/\psi\phi$ decays, and determined that

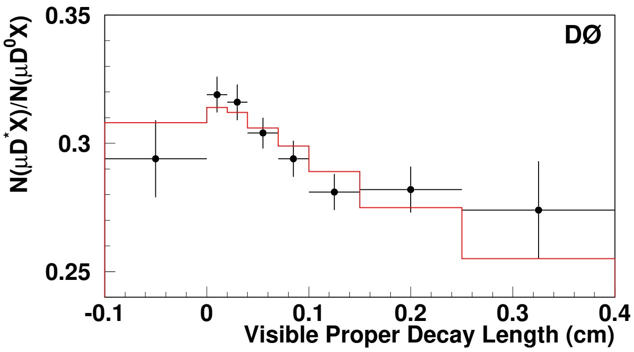

Figure 4: Ratio of the number of D^* to D^0 decays as a function of visible proper decay length showing the difference in lifetime between B^0 and B^+ hadrons.

$\tau(B_s) = (1.369 \pm 0.100^{+0.008}_{-0.010})$ ps, and $\tau(B_s) = (1.444^{+0.098}_{-0.090} \pm 0.030)$ ps, respectively, which can be combined with lifetime measurements of $B0$ mesons to give $\tau(B_s)/\tau(B^0) = 0.890 \pm 0.072$ and $\tau(B_s)/\tau(B^0) = 0.980^{+0.075}_{-0.070} \pm 0.003$.

The DØ collaboration has made a novel direct measurement of $\tau(B^+)/\tau(B^0)$ using the decay $B^+ \to \mu D^0 X$ and $B^0 \to \mu D^{*+} X$. The only difference between these two decays is that in the former the D meson decays via $D^0 \to K\pi$ while the latter has a second (slow) pion, decaying via $D^{*+} \to K\pi\pi$. By using the slow pion only to tag the B^0, but not to determine the lifetime of the B mesons, the systematic uncertainties almost completely cancel in the ratio. The DØ collaboration, then measures $\tau(B^+)/\tau(B^0) = 1.093 \pm 0.021$ (stat) ± 0.022 (sys). Fig. 4 shows the number of D^* to D^0 decays as a function of visible proper decay length. If the lifetime of the B^0 and B^+ are identical, this ratio would be flat.

6 Conclusions

The CDF and DØ collaborations are measuring many properties of B hadrons that nicely complement those measured at B factories. More exciting results are expected in the future.

Acknowledgments

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References

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