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B Hadron Spectroscopy and Lifetimes - results from the Tevatron

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The Tevatron is an ideal place to study the physics of B hadrons. The production cross-section is much higher than at the B factories and higher mass states such as B baryons and the B_s and B_c mesons are produced. The Tevatron has delivered an integrated luminosity of over 7 fb^{-1} and continues to run with improved performance. In this paper I review recent results from CDF and D0 on the spectroscopy of B baryons, excited B mesons, charmonium-like states, and the lifetime of the Λ_b baryon.

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1. Introduction

The Tevatron produces very large numbers of B hadrons, which can provide sensitive tests of perturbative QCD, CKM matrix parameters and the search for physics beyond the Standard model.

The high B hadron cross-section is accompanied by a much larger inelastic cross-section, so an efficient trigger is required to reduce the high event rate and to achieve a reasonable signal to background ratio.

Both CDF and D0 use di-muon triggers, typically for selecting final states which include a J/ψ. D0 also uses single muon triggers where the muon is matched with a track from the central tracking system. CDF can also trigger on final states without leptons with displaced vertex triggers.

2. B Baryons

Until 2006 the only B baryon that had been observed was the Λ_b. The $\Sigma_b^{(*)}$ baryon states (bdd) and (buu) were discovered by CDF in 2007 through their strong decay $\Sigma_b^{(*)\pm} \to \Lambda_b \pi^\pm$ using fully reconstructed $\Lambda_b \to \Lambda_c^+ \pi^-$ candidates [1].

The $\Xi_b^-(bds)$ baryon has been observed by both CDF and D0 in the decay mode $\Xi_b^- \to J/\psi \Xi^-, \Xi^- \to \Lambda\pi^-$ [2],[4].

In August 2008 D0 announced the observation of the doubly strange $\Omega_b^-(bss)$ baryon in the decay mode $\Omega_b^- \to J/\psi\Omega^-, \Omega^- \to \Lambda K^-$. They reported a mass of $6165 \pm 10 \pm 13$ MeV/c^2 based on a signal of $17 \pm 4.9 \pm 0.8$ events with a significance of 5.04σ [3].

In May 2009 CDF published a study of both Ξ_b^- and Ω_b^- decays to J/ψ, using 4.2 fb^{-1} of data [4]. They reconstruct 61 ± 10 Ξ_b^- and 12 ± 4 Ω_b^- candidates with mass measurements of $5790.9 \pm 2.6 \pm 0.8$ MeV/c^2 and $6054.4 \pm 6.8 \pm 0.9$ MeV/c^2 respectively. While the CDF and D0 Ξ_b^- mass measurements are in reasonable agreement, there is a significant difference ($111 \pm 12 \pm 14$ MeV/c^2) in the Ω_b^- mass measurements. The mass plots are shown in Fig.1. The production rate is also not well matched. D0 hopes to soon have an updated mass measurement based on 6 fb^{-1} of data.

CDF has also measured the lifetime of both states, finding $\tau(\Xi_b) = 1.56^{+0.27}_{-0.25}(stat) \pm 0.02(sys)$ ps and $\tau(\Omega_b) = 1.13^{+0.53}_{-0.40}(stat) \pm 0.02(sys)$ ps. D0 compares the proper decay length distribution of their Ω_b candidates with Monte Carlo events generated with a lifetime of 1.54 ps and finds that the lifetime is consistent with a weak decay.

3. Λ_b Lifetime

Weak decays of hadrons with one heavy quark are dominated by the decay of the heavy quark and in the limit of $m_b \to \infty$ all B hadrons have the same lifetime. The theoretical prediction of the ratio of the Λ_b lifetime to the B_d lifetime is 0.88 ± 0.05 [5].

CDF and D0 have measured the Λ_b lifetime in various decay modes. Both experiments have used the $\Lambda_b \to J/\psi\Lambda$ decay mode that is easily triggered with a di-muon trigger [6] This decay can be compared to the topologically similar $B^0 \to J/\psi K_s$. There is approximately a 2σ difference between the two experiments in the ratio $\tau(\Lambda_b)/\tau(B^0)$. D0 has also measured the lifetime using the semileptonic decay $\Lambda_b \to \mu\nu\Lambda_c, \Lambda_c \to K_s p$ with 1.3 fb^{-1} of data[7]. They use a single muon

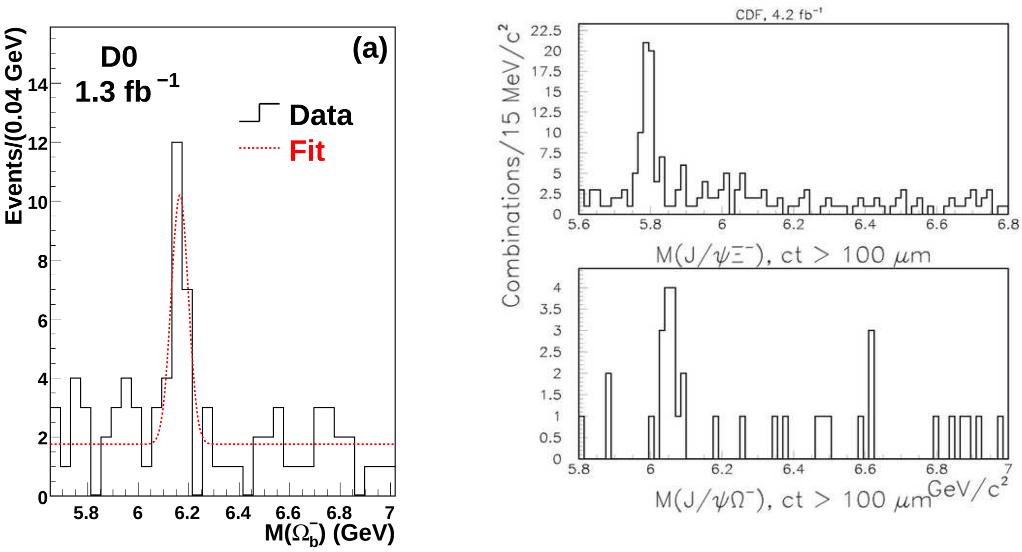

Figure 1: Ω_b mass (a) D0, (b) CDF

trigger, and correct for the missing neutrino using Monte Carlo data. The measured lifetime is $\tau(\Lambda_b) = 1.29 \pm 0.11 \pm 0.09$ ps. CDF makes another measurement using the decay mode $\Lambda_b \to \Lambda_c \pi, \Lambda_c \to pK\pi$ 1.1 fb^{-1} of data[8]. They obtain a very clean, high statistics sample using a displaced two-track trigger. This trigger has a lifetime bias, which is corrected for using the Monte Carlo. The measured lifetime is $\tau(\Lambda_b) = 1.401 \pm 0.046 \pm 0.035$ ps.

Using the PDG(2009) value for $\tau(B_d)$ the ratio $\tau(\Lambda_b)/\tau(B_d)$ is 0.846 ± 0.093 for the D0 semileptonic mode and 0.919 ± 0.038 for the CDF $\Lambda_c\pi$ mode. Both of these are in agreement with the theoretical prediction. A comparison of the Λ_b lifetime measurements from different experiments is shown in Fig.2.

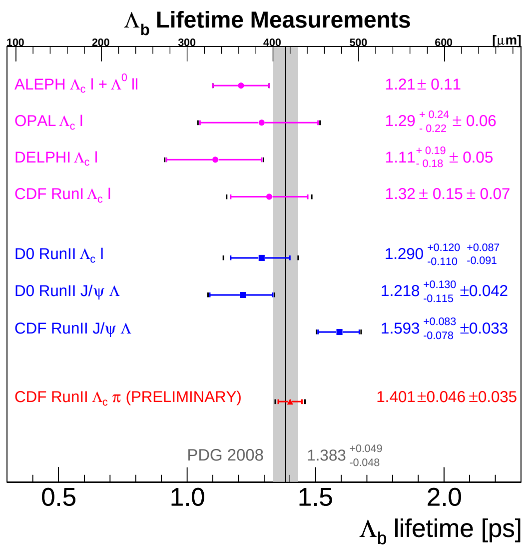

Figure 2: Comparison of Λ_b lifetime measurements

4. Charmonium-Like States

A large number of charmonium and charmonium-like states have been observed at the B-factories and the Tevatron. Many of these states are not easily accommodated by the theoretical expectations for $c\bar{c}$ mesons. Several models have been proposed for these states, including meson-antimeson molecules, diquark-antidiquark bound states, $c\bar{c}$-gluon hybrids and threshold effects.

The state X(3872) was first observed by Belle[10] and has since been seen by Babar, CDF and D0. The quantum numbers have been determined to be $J^{PC} = 1^{++}$ or 2^{-+}. The available charmonium states are not expected to have large branching fractions to the observed decay mode $J/\psi\rho$. As the mass is very close to the D^0D^* threshold, it has been proposed that the X(3872) is a D^0D^* molecule. Maiani et al.[9]. have suggested that it is a tetraquark state. A prediction of the tetraquark interpretation is that there would be a second neutral state produced in B^0 decays, with a mass that differs by 8 ± 3 MeV/c^2 from the mass of the X(3872) produced in B^+ decays. CDF has published the most precise measurement to date of the X(3872) mass using 2.4 fb^{-1} of data[11]. The measured mass is $3871.61\pm0.16\pm0.19$ MeV/c^2. They find no evidence for 2 states and set a limit of $\Delta m < 3.2(3.6)$ MeV/c^2 at 90% (95%) CL under the assumption that the two states have equal production.

CDF have also published evidence for a narrow state near the $J/\psi\phi$ threshold in exclusive $B^+ \to J/\psi\phi K^+$ decays[12] using 2.7 fb^{-1} of data. The observation of Y(3930) near the $J/\psi\omega$ threshold motivates a search for similar states near the $J/\psi\phi$ threshold. The search in B^+ decays is used because the additional mass constraint reduces background. To further suppress background dE/dx and Time-Of-Flight information is used to identify all 3 kaons in the final state. The Dalitz plot and mass difference plot are shown in Fig.3. They report a yield of 14 ± 5 signal events with significance of 3.8σ. The mass is measured to be $4143\pm2.9\pm1.2$ MeV/c^2 and the width $11.7^{+8.3}_{-5.0}\pm3.7$ MeV/c^2.

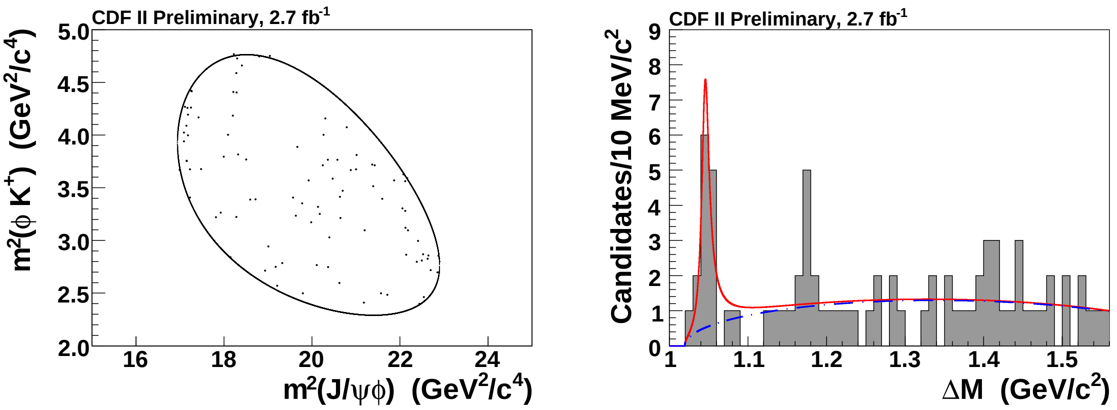

Figure 3: Evidence for a state near 4140 MeV/c^2 left: Dalitz plot of $m^2(\phi K^+)$ vs. $m^2(J/\psi\phi)$ in the B^+ mass window. right: Mass difference between $\mu^+\mu^-K^+K^-$ and $\mu^+\mu^-$ in the B^+ mass window.

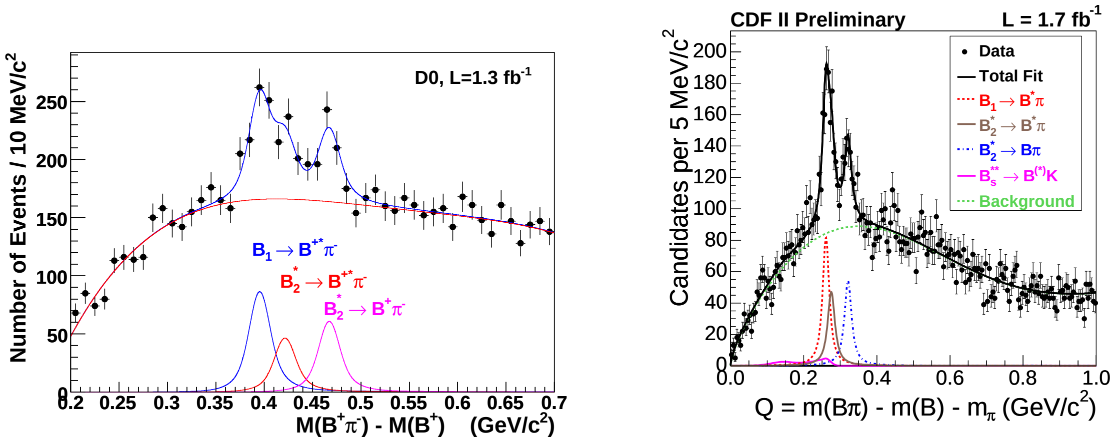

Figure 4: Mass difference plots for L=1 B^0 candidates; left: D0, right: CDF

5. Orbitally Excited B mesons

Mesons with one heavy quark are analogous to the hydrogen atom, the heavy quark acting as a static source of charge and color and the meson's properties being governed by the dynamics of the light quark.

For orbitally excited mesons with L=1, we expect four states for each heavy-light quark pair. Two states have j=1/2, where j is the total momentum of the light quark. These states are expected to be broad and difficult to identify. The other 2 states have j=3/2 and are expected to be narrow.

Both CDF and D0 have observed the decays $B_1^0 \to B^{*+}\pi^-$; and $B_2^* \to B^+\pi^-$ and $B_2^* \to B^{*+}\pi^-$ [13]. CDF has made the most precise mass measurements of these states to date, and also measured the width of the B_2^*. The measured masses are $m(B_1^0) = 5725.3^{+1.6}_{-2.2}(stat)^{+1.4}_{-1.5}(sys)$ MeV/c^2, and $B_2^* = 5740.2^{+1.7}_{-1.8}(stat)^{+0.9}_{-0.8}(sys)$ MeV/c^2. The width is $\Gamma(B_2^*) = 22.7^{+3.8}_{-3.2}(stat)^{+3.2}_{-10.2}(sys)$ MeV/c^2. The mass plots are shown in Fig.4. Both experiments have also observed the B_s excited states [14].

6. Conclusions

Both Tevatron experiments have produced exciting results in the field of B-physics. At this time both experiments have recorded over 6 fb^{-1} of data, however many results presented here are based on a much smaller sample. The Tevatron continues to run well, with increasing luminosity and reliability, and if we continue running until October 2011, we expect both experiments to have about 10 fb^{-1} of data for analysis. We look forward to producing higher precision measurements of current results, especially in those cases where there is some disagreement between the two experiments; and to probing more rare modes where we may challenge the Standard Model.

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