

Spectroscopy of Hadrons with b Quarks

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Recent experimental results on the spectroscopy of B hadrons are presented. The focus is primarily on the heavier states currently accessible only at the Tevatron and the B factories running at the $\Upsilon(5S)$ resonance, i.e., B_s^* , the orbitally excited states B^{**} and B_s^{**} , and the new b -baryon states $\Sigma_b^{(*)}$, Ξ_b , and Ω_b .

1. Introduction

Heavy quark hadrons are the hydrogen atom of QCD, and b hadrons offer the heaviest quarks that form bound systems. The study of their spectroscopy provides sensitive tests of potential models, Heavy Quark Effective Theory (HQET [1]), and all regimes of QCD in general, including the non-perturbative regime described by lattice gauge calculations [2].

There has been somewhat of a “renaissance” of new heavy flavor spectroscopy results these past few years with new data coming from the B factories and the Tevatron. This contribution focuses on new experimental results from the Tevatron and the B factories running on the $\Upsilon(5S)$ resonance, although a very recent result on the B^0 - B^+ mass difference from the BaBar Collaboration is included for completeness.

The Tevatron has the capability of producing heavier states not accessible at the B factories running at the $\Upsilon(4S)$, i.e., the heavy B mesons: B_s^0 ($\bar{b}s$, the ground state with the spins of the quarks anti-aligned), B_s^* ($\bar{b}s$, with the spins of the quarks aligned), B_c ($\bar{b}c$, the ground state), B^{**} ($\bar{b}d$, with the quarks having relative orbital angular momentum), and B_s^{**} ($\bar{b}s$, with the quarks having relative orbital angular momentum); and the heavy b baryons: Λ_b^0 (bud), $\Sigma_b^{(*)\pm}$ (buu and bdd), and Ξ_b (bsd), with many more baryonic states possible from the remaining combinations of quarks. Properties of the B_s^0 are covered by other contributions to this conference [3]. These results are complementary to those from the $\Upsilon(4S)$ B factories, but there are exciting new results on B_s^* from some luminosity collected on the $\Upsilon(5S)$ resonance by the CLEO and Belle Collaborations.

Charge conjugate modes and reactions are always implied in this contribution.

2. B^0 - B^+ Mass Difference

The B^0 - B^+ mass difference probes the size of Coulomb contributions to the quark structure of mesons. Precise predictions of this mass split are fairly uncertain since contributions from the quark-mass difference $m(d) - m(u)$ and from Coulomb effects have similar magnitudes and opposite signs.

The BaBar Collaboration has made a precision measurement of this mass splitting [4] by making full reconstructions of the two B mesons with similar final states: $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow J/\psi K^+ \pi^- \rightarrow \mu^+ \mu^- K^+ \pi^-$. By carefully comparing the two reconstructed momenta distributions as shown in Fig. 1, they have measured

$$\Delta M_B = M(B^0) - M(B^+) = +0.33 \pm 0.05 \pm 0.03 \text{ MeV}, \quad (1)$$

which is consistent with, but much more precise than the PDG 2008 world average of $+0.37 \pm 0.24 \text{ MeV}$ [5].

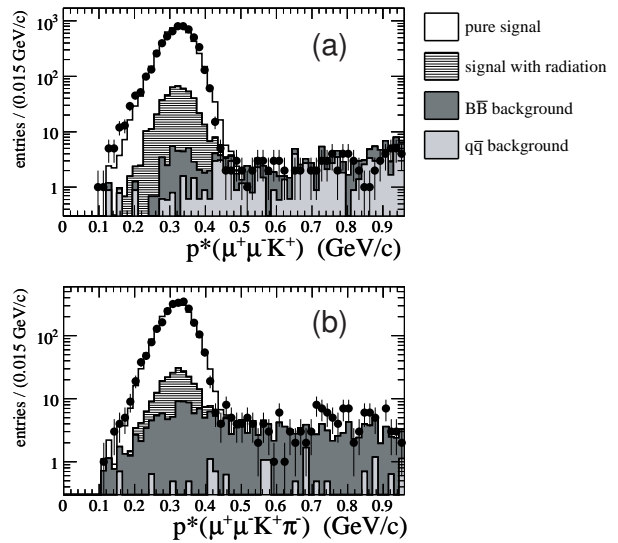


Figure 1: (a) Reconstructed momenta of $B^+ \rightarrow J/\psi K^+$ candidates and (b) reconstructed momenta of the similar topology $B^0 \rightarrow J/\psi K^+ \pi^-$ by the BaBar Collaboration.

3. Mass of B_c Meson

One of the more interesting mesons that can be studied at the Tevatron is the B_c ($\bar{b}c$) meson. It is unique in that it contains two *different* heavy quarks, both with relatively large widths to decay. While charmonium ($c\bar{c}$) or bottomonium ($b\bar{b}$) mesons are also interesting with two heavy quarks, these both decay strongly, whereas the B_c meson decays weakly. The B_c meson is expected to have the shortest lifetime of

all weakly decaying b hadrons, with a predicted lifetime of about one-third of the other B mesons. It can decay via the b quark: $B_c \rightarrow B_s^0 \pi^+, B_s^0 \ell^+ \nu$; via the c quark: $B_c \rightarrow J/\psi \pi^+, J/\psi D_s^+, J/\psi \ell^+ \nu$; or by annihilation: $B_c \ell^+ \nu$.

First evidence for the B_c meson was via its decay into $J/\psi \ell^+ \nu$ [6], but with the missing neutrino, this did not provide a very precise mass measurement. With the greater statistics collected by the Tevatron, the reconstruction of the exclusive decay $B_c \rightarrow J/\psi \pi^+$ provides for a much more precise mass measurement and in both cases, the $J/\psi \rightarrow \mu^+ \mu^-$ allows for very efficient dimuon triggering. In similar analyses, CDF [7] and DØ [8] optimized their selection criteria on large control samples of $B^+ \rightarrow J/\psi K^+, J/\psi \rightarrow \mu^+ \mu^-$ with a topology similar to that of the signal channel.

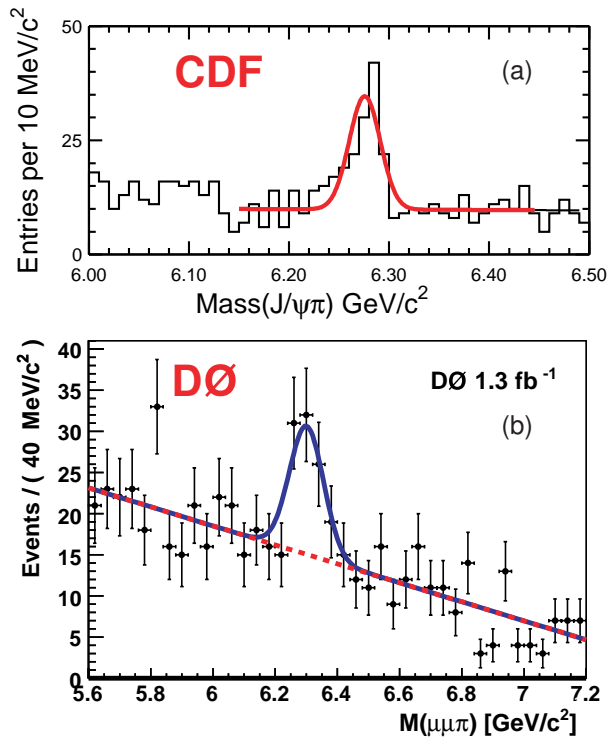


Figure 2: B_c candidate signals in reconstructed $J/\psi \pi$ invariant mass distributions after all cuts from the described (a) CDF and (b) DØ analyses.

Making unbinned likelihood fits to the $J/\psi \pi$ invariant mass distributions as shown in Fig. 2, CDF, using 2.4 fb^{-1} of data finds 108 ± 15 signal candidates with a significance above background of greater than 8σ , and DØ, using 1.3 fb^{-1} of data finds 54 ± 12 signal candidates with a significance above background of greater than 5σ . Mass measurements are made with results of:

$$\begin{aligned} M(B_c^+) &= 6275.6 \pm 2.9 \pm 2.5 \text{ MeV CDF,} \\ M(B_c^+) &= 6300 \pm 14 \pm 5 \text{ MeV DØ.} \end{aligned} \quad (2)$$

These measurements can be compared to a number of

theoretical predictions [9] as shown in Fig. 3. These experimental measurements now have smaller uncertainty than the corresponding uncertainties on the theoretical predictions, indicating a need for more theoretical work in this area.

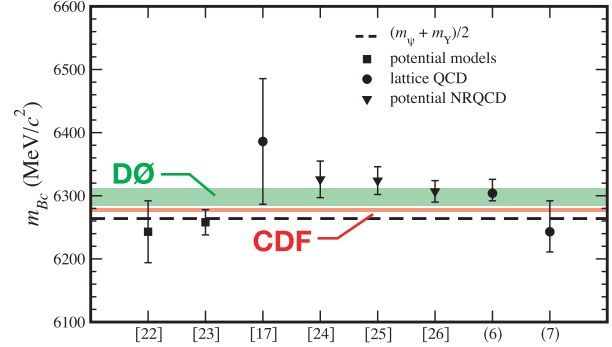


Figure 3: CDF and DØ B_c mass measurements (horizontal bands with width equal to $\pm 1\sigma$) compared to various theoretical predictions as collated in Ref. [9] (figure adapted from same reference).

4. Spectroscopy of Excited B Mesons

In the heavy-quark limit, the spin of the heavy quark decouples from the light degrees of freedom and the heavy and light systems can be considered separately. Furthermore, as the system has been shown to not depend, to first order, on the flavor of the heavy quark, the system can be defined by the quantum numbers of the “brown muck” of the light degrees of freedom describing the gluons and light quarks.

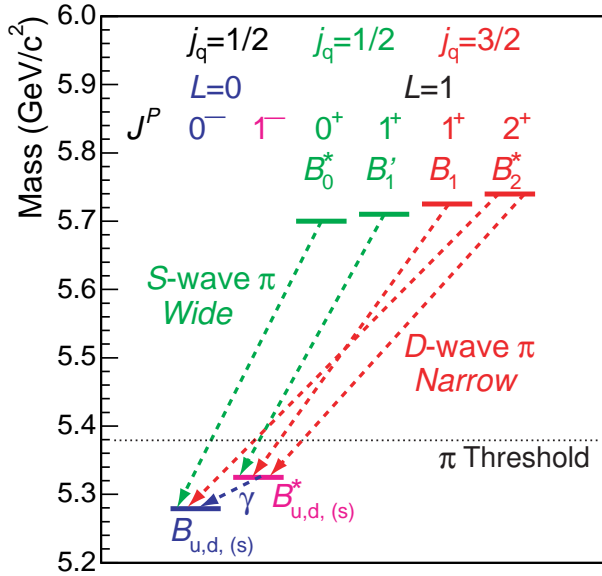
Given the approximation within HQET that the heavy quark is at rest in the frame of the hadron, we can describe the heavy quark through the assignment of a spin quantum number, \vec{s}_Q . The light degrees of freedom which, following the simple hydrogen atom model of HQET, can be thought of as orbiting the heavy quark are assigned a total angular momentum $\vec{j}_q = \vec{s}_q + \vec{L}$, where s_q and L are the spin and orbital angular momentum of the light degrees of freedom. Finally the total angular momentum is given by $\vec{J} = \vec{s}_Q + \vec{j}_q$. B^{**} and B_s^{**} mesons (also denoted B_J and B_{sJ} , respectively) are composed of a heavy b quark and a lighter down or strange quark in a $L = 1$ state of orbital momentum, with four possible states in each case as shown in Table I.

All the orbitally excited states are expected to have masses more than a pion mass above the ground or first excited state and therefore decay strongly as shown in Fig. 4. By conservation of parity and angular momentum, the decay $B_{(s)1}^0 \rightarrow B_{(s)}^+ \pi^-$ is not allowed. The decay of the two $j_q = \frac{1}{2}$ states in each case proceeds via an S -wave and hence have widths

Table I Quantum numbers of orbitally excited B and B_s states.

	$L = 0$	
$j_q = \frac{1}{2}$	$J = 0$	$J = 1$
wide	B_{0}^*, B_{s0}^*	B_1', B_{s1}'
$j_q = \frac{3}{2}$	$J = 1$	$J = 2$
narrow	B_1, B_{s1}	B_2^*, B_{s2}^*

of a few hundred MeV, difficult to distinguish from combinatorial background in effective mass spectra, while the $j_q = \frac{3}{2}$ states, $B_{(s)1}$ and $B_{(s)2}^*$, undergo D -wave decays, and due to the angular momentum barrier have narrow widths making them experimentally accessible.


 Figure 4: Expected spectroscopy of the excited B meson states.

4.1. Mass of B_s^* Meson

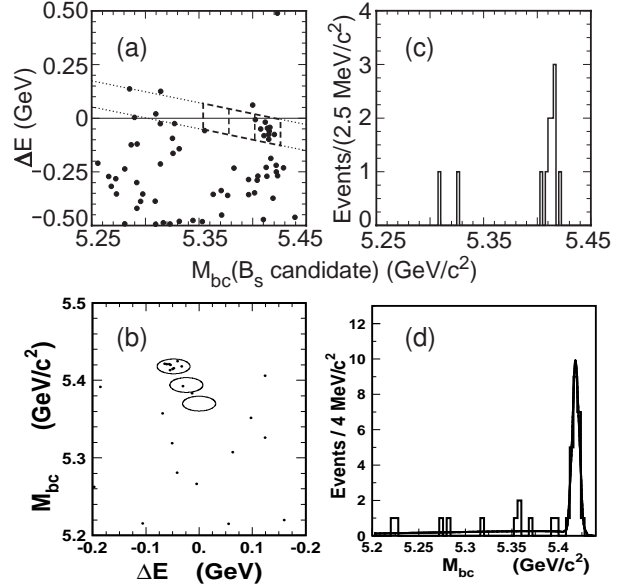
Focusing in particular on the B_s^0 system, for completeness, measurements are described of the mass splitting between the B_s^* where the spins of the \bar{b} and s quarks are aligned and the ground state B_s^0 with anti-aligned quark spins.

The B factories can produce the B_s^* by running on the $\Upsilon(5S)$ resonance, i.e., $\Upsilon(5S) \rightarrow B_s^* \bar{B}_s^*$.

Using the kinematic variables of the energy difference $\Delta E \equiv E_{\text{beam}} - E_B$ and the beam-constrained mass $M_{bc} \equiv \sqrt{E_{\text{beam}}^2 - \vec{p}_B^2}$, where E_B (\vec{p}_B) is the energy (momentum) of the reconstructed B (or B_s) and E_{beam} is the beam energy, both the CLEO and Belle Collaborations have isolated B_s^* states.

The CLEO Collaboration finds 14 candidates consistent with B_s decays into final states with a J/ψ or a $D_s^{(*)-}$ [10] as shown in Fig. 5(a). From an update [11] of $M(B^*)$, they find the beam-constrained mass difference $M_{bc}(B_s^* \bar{B}_s^*) - M_{bc}(B^* \bar{B}^*)$ to translate into the mass difference $M(B_s^*) - M(B^*)$ and the most precise measurement of the B_s^* mass and mass splitting:

$$\begin{aligned} M(B_s^*) &= 5411.7 \pm 1.6 \pm 0.6 \text{ MeV}, \\ \Delta M(B_s^* - B_s) &= 45.7 \pm 1.7 \pm 0.7 \text{ MeV}. \end{aligned} \quad (3)$$


 Figure 5: B_s^* : M_{bc} versus ΔE scatter plots for the $B_s^0 \rightarrow D_s^- \pi^+$ decay mode for the (a) CLEO Collaboration and (b) Belle Collaboration. Beam-constrained mass in the ΔE region where the B_s^0 signal from the $B_s^* \bar{B}_s^*$ channel is expected for (c) CLEO and (d) Belle.

The Belle Collaboration using similar techniques [12], as shown in Fig. 5(b), find a mass of:

$$M(B_s^*) = 5418 \pm 1 \pm 3 \text{ MeV}, \quad (4)$$

with a 1.8σ difference between the CLEO and Belle measurements, as well as the mass splitting, including an older CUSB2 measurement [13], is:

$$\begin{aligned} M(B_s^*) &= 5412.8 \pm 0.9 \text{ MeV}, \\ \Delta M(B_s^* - B_s) &= 46.7 \pm 1.0 \text{ MeV}. \end{aligned} \quad (5)$$

4.2. Masses of B^{**} Narrow States

As described earlier, of the four possible B^{**} states, the B_1 and B_2^* are narrow enough to appear as distinct invariant mass peaks. Up to recently, almost all observations of the narrow states have been made only indirectly (at LEP [5]) in inclusive or semi-inclusive

decays that prevents their model-independent separation and precise measurement of properties. Both the DØ and CDF Collaborations have reconstructed these states by first reconstructing a $B^+ \rightarrow J/\psi K^+$ where the J/ψ decays to $\mu^+\mu^-$ providing a solid dimuon trigger. In the DØ analysis [14], 23k such decays in 1.3 fb^{-1} of data are reconstructed and then a pion is added to this combination to search for the decay chains $B_1 \rightarrow B^{*+}\pi^-$ and $B_2^* \rightarrow B^{*+}\pi^-$. In addition, there is also the direct decay into the ground state: $B_2^* \rightarrow B^+\pi^-$; the direct decay $B_1 \rightarrow B^+\pi^-$ is forbidden by conservation of parity and angular momentum. The photon from the subsequent decay $B^{*+} \rightarrow B^+\gamma$ is not reconstructed, and as a result, invariant mass peaks in the $M(B^+\pi^-) - M(B^+)$ mass difference spectrum are shifted down by 46 MeV, and three peaks are expected as shown in Fig. 6(a), with two arising from the B_2^* state. For DØ, the experimental resolution is larger than the expected line widths of the states, and they are set to 10 MeV, but varied over large ranges in the systematic error determination. This is the first time that these two states have been cleanly separated in a model-independent way, and the statistical significance of the three peaks is greater than 7σ . The masses are measured to be:

$$\begin{aligned} M(B_1^0) &= 5720.6 \pm 2.4 \pm 1.4 \text{ MeV}, \\ M(B_2^{*0}) &= 5746.6 \pm 2.4 \pm 1.4 \text{ MeV}. \end{aligned} \quad (6)$$

The CDF Collaboration has a preliminary result [15] from a similar analysis. In 1.7 fb^{-1} of data, they also first reconstruct 52k $B^+ \rightarrow J/\psi K^+$, but add 40k $B^+ \rightarrow D\pi^+$ and 11k $B^+ \rightarrow D\pi^+\pi^-\pi^+$ candidates. They add a pion to the reconstructed B^+ candidates and observe clear peaking structure in each of the above three channels. The distribution of the Q value as shown in Fig. 6(b) is fit to a similar three-peak structure as above, but also includes peaking reflection backgrounds from $B^{(*)}K$ candidates. Measured masses of:

$$\begin{aligned} M(B_1^0) &= 5725.3^{+1.6+1.4}_{-2.2-1.5} \text{ MeV}, \\ M(B_2^{*0}) &= 5740.2^{+1.7+0.9}_{-1.8-0.8} \text{ MeV}, \end{aligned} \quad (7)$$

are the most precise to date. The good mass resolution of the CDF detector allows for the first preliminary measurement of the B_2^{*0} width:

$$\Gamma(B_2^{*0}) = 22.7^{+3.8+3.2}_{-3.2-10.2} \text{ MeV}. \quad (8)$$

4.3. Masses of B_s^{**} Narrow States

CDF and DØ have also recently measured the masses of the narrow B_s^{**} states. Again, beginning with $B^+ \rightarrow J/\psi K^+$ (and CDF adds $B^+ \rightarrow D\pi^+$), instead of adding a pion, a kaon is added. The decay chains of interest are therefore $B_{s1} \rightarrow B^{*+}K^-$, $B_{s2}^* \rightarrow B^{*+}K^-$, and the direct decay $B_{s2}^* \rightarrow B^+K^-$.

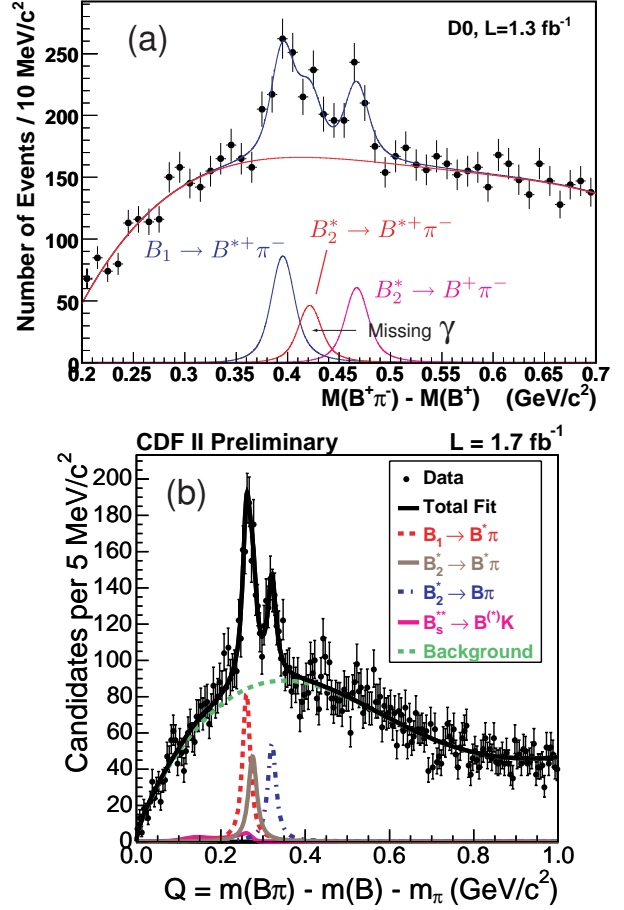


Figure 6: B^{**} : (a) Invariant mass difference for exclusive B decays for the DØ analysis with the contribution of background and the three signal peaks shown separately; (b) Q value for the CDF analysis along with fit contributions.

In the analysis from the DØ Collaboration [16], Fig. 7(a) shows the fit for the total number of B_{s2}^* in the direct decay $B_{s2}^* \rightarrow B^+K^-$ with a statistical significance greater than 5σ in 1.3 fb^{-1} with a mass measurement of

$$M(B_{s2}^{*0}) = 5839.6 \pm 1.1 \pm 0.7 \text{ MeV}. \quad (9)$$

There should be a second peak due to decay $B_{s2}^* \rightarrow B^{*+}K^-$, shifted down by 46 MeV in mass since the photon from the B^{*+} decay is not reconstructed. Since the mass difference in the decay $B_{s2}^* \rightarrow B^{*+}K^-$ is very small, there is a heavy phase-space suppression factor estimated to be 0.074; therefore, no detectable signal is expected in the ΔM distribution with the current statistics. To test for the existence of a B_{s1} signal in the data, a two-peak hypothesis is used to fit the data as shown in Fig. 7(a). The statistical significance of the B_{s1} peak is less than 3σ so that the presence of a B_{s1} state in the data can be neither confirmed nor excluded.

In CDF's analysis [17] in 1 fb^{-1} of data, they com-

bine B^+ channels from $B^+ \rightarrow J/\psi K^+$ and $B^+ \rightarrow D\pi^+$. A two-peak structure is observed in both, and the combined fit with excellent mass resolution is shown in Fig. 7(b). This is the first observation of the narrow B_{s1} state with yields of $N(B_{s1}) = 36 \pm 9$ events and $N(B_{s2}^*) = 95 \pm 23$. The resulting mass measurements are:

$$\begin{aligned} M(B_{s1}^0) &= 5829.4 \pm 0.7 \text{ MeV}, \\ M(B_{s2}^{*0}) &= 5839.6 \pm 0.7 \text{ MeV}, \\ \Delta M(B_{s2}^{*0} - B_{s1}^0) &= 10.5 \pm 0.6 \text{ MeV}. \end{aligned} \quad (10)$$

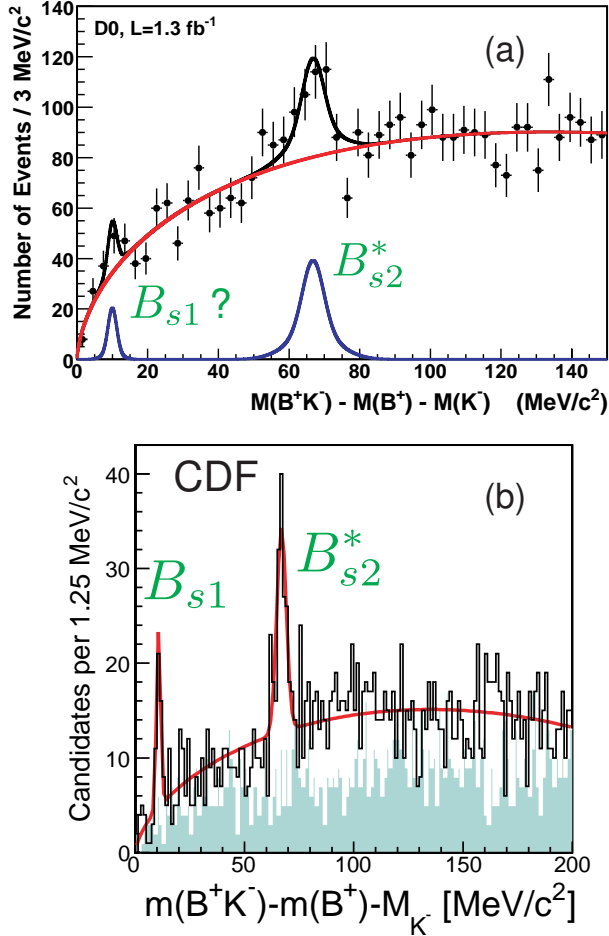


Figure 7: B_s^{**} : (a) Invariant mass difference for exclusive B decays for the $D\emptyset$ analysis and the fit for the two-peak hypothesis (existence of B_{s1} peak inconclusive); and (b) Q value for the CDF analysis with fit. The filled area is for the wrong-sign combination B^+K^+ .

4.4. $B_{(s)}^{**}$ Summary

The experimental results of the masses of the narrow $B_{(s)J}$ states of the previous two subsections are summarized in Fig. 8 and compared to some representative theoretical predictions [18–20].

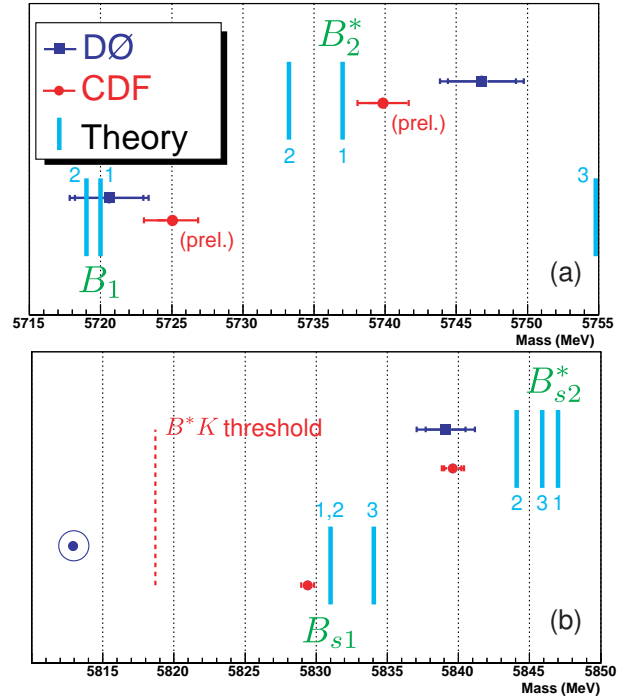


Figure 8: Summary of mass measurements from previous subsections for the narrow states (a) B_{s1}^0 and B_{s2}^{*0} and (b) B_{s1}^0 and B_{s2}^{*0} and some representative theoretical predictions (1: Ref. [18], 2: Ref. [19], 3: Ref. [20]).

As can be seen, there are varying degrees of agreement between experimental measurements and predictions. In the case of the B_{s1} state, not conclusively observed by $D\emptyset$, if the same mass split observed in the $B_2^*-B_1$ system is applied to the B_s^{**} system, the B_{s1} would in fact be expected to be below the B^*K threshold as shown by the circled point in Fig. 7(b). More experimental data is needed to clarify the spectra of both the orbitally excited states of B and B_s .

5. New b -Flavored Baryons

Until recently, the only directly observed b baryon was the Λ_b [5] (there is indirect evidence for Ξ_b through Ξ -lepton correlations at LEP [21]). As the Tevatron collects larger and larger data-sets, the prospects improve for observing the rarer b baryons in decay channels providing good triggers. If we consider combinations of only the heavier b quark and the three light quarks s , d , and u quarks, multiplets of possible states are shown in Fig. 9, very similar to the multiplets for charm baryons. Double-heavy baryons containing both a charm and b quark are not shown here.

We can also consider a heavy b baryon as a $L = 0$ “atomic” system if we take the heavy b quark approximately at rest in the rest frame of the b baryon, and orbited by the *diquark* of the two light quarks. The

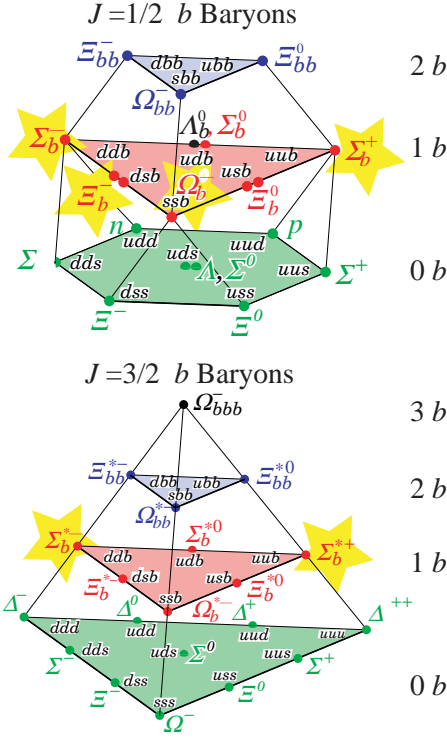


Figure 9: Multiplets of possible combinations of the heavy b quark with the s , d , and u light quarks (figure adapted from Ref. [5]).

two light quarks in the diquark can be anti-aligned, giving diquark spin $s_{qq} = 0$ as for the ground state Λ_b^0 (bud). If the spins of the u and d quarks are instead aligned so that $s_{qq} = 1$, it results in the more massive Σ_b^0 baryon. For the $L = 0$ baryons, the total angular momentum is $J = s_Q + s_{qq}$, where s_Q is the spin of the heavy b quark. The two possibilities are therefore the $J^P = \frac{1}{2}^+$ Σ_b^0 or the $J^P = \frac{3}{2}^+$ Σ_b^{*0} as shown in Fig. 9.

Such baryonic systems are valuable for testing predictions from HQET, lattice gauge QCD, potential models, and sum rules. The mass difference $M(\Sigma_b) - M(\Lambda_b)$ probes the energy from the diquark spin alignment, $M(\Sigma_b^*) - M(\Sigma_b)$ the equivalent of hyperfine splitting, and $M(\Sigma_b^-)[bdd] - M(\Sigma_b^+)[buu]$ the difference due to isospin or effective mass of the u and d quarks. Equivalent measures are also now accessible now that we have evidence for and measurements of the properties of b baryons containing strange quarks such as the Ξ_b (bsd) and the Ω_b (bss).

5.1. Masses of $\Sigma_b^{(*)}$ Baryons

In 1.1 fb^{-1} of data, the CDF Collaboration has observed and measured the properties of all four $\Sigma_b^{(*)\pm}$ charged baryons [22]. The neutral states $\Sigma_b^{(*)0}$ would

decay into $\Lambda_b^0 \pi^0$ which is difficult to reconstruct at the Tevatron. Starting with an optimized selection, they form a large, clean sample of $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ decays where $\Lambda_c \rightarrow pK\pi$. Since the Λ_b^0 decays weakly, decay length cuts can be used to further reduce combinatorial background. Since the decay of interest is a strong decay, each of the fitted $N(\Lambda_b) = 3180 \pm 60$ candidates is combined with a pion that is constrained to originate from the primary vertex. The largest background is combinatorial with random hadronization tracks being combined with Λ_b^0 baryons.

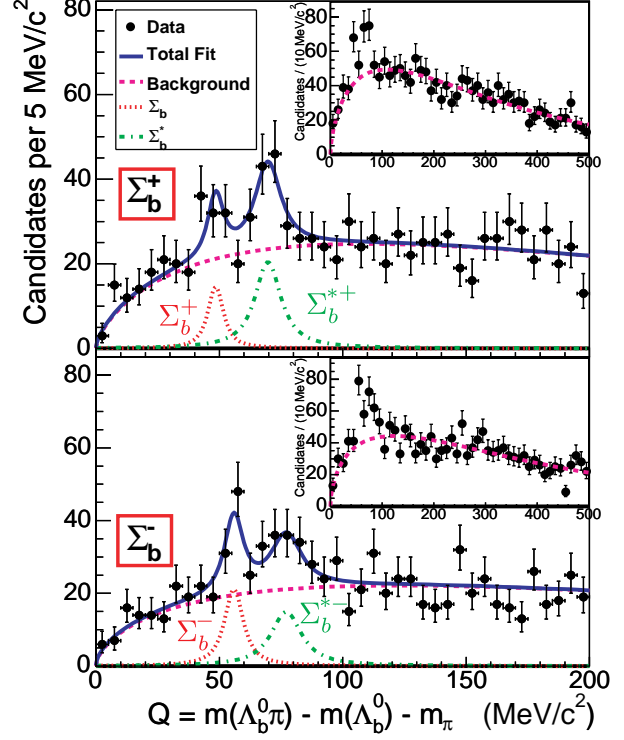


Figure 10: $\Sigma_b^{(*)\pm}$: Q value distributions and fits for CDF analysis: top plot for the $\Lambda_b^0 \pi^+$ subsample that contains Σ_b^+ and Σ_b^{*+} and bottom plot for the $\Lambda_b^0 \pi^-$ subsample that contains Σ_b^- and Σ_b^{*-} .

Figure 10 shows the resulting Q value mass difference distributions for the subsequent samples. The different charge sign samples are kept separate and a simultaneous fit performed applying the constraint that the mass splitting between the $J^P = \frac{1}{2}^+$ and $\frac{3}{2}^+$ states is the same: $M(\Sigma_b^{*+}) - M(\Sigma_b^+) = M(\Sigma_b^{*-}) - M(\Sigma_b^-)$. Both charge signs Σ_b^- (bdd) and Σ_b^+ (buu) show clear double peak structures, with a 5.2σ significance above background for signal. Using the precision measurement of the Λ_b^0 mass [23], the absolute masses are measured to be:

$$\begin{aligned} M(\Sigma_b^+) &= 5807.8_{-2.2}^{+2.0} \pm 1.7 \text{ MeV}, \\ M(\Sigma_b^-) &= 5815.2 \pm 1.0 \pm 1.7 \text{ MeV}, \\ M(\Sigma_b^{*+}) &= 5829.0_{-1.8}^{+1.6} \pm 1.7 \text{ MeV}, \end{aligned}$$

$$M(\Sigma_b^{*-}) = 5836.4 \pm 2.0_{-1.7}^{+1.8} \text{ MeV}. \quad (11)$$

These values can be used to calculate various mass splittings of interest as shown in Table II and compared to expectations [22]. Theoretical predictions are discussed thoroughly elsewhere in these proceedings [25] and show good agreement with measurements.

Table II Comparison of measured CDF mass differences to expected values [22].

Property	Values (MeV/c ²)	
	Expected	Measured (CDF)
Diquark spin alignment		
$M(\Sigma_b^+) - M(\Lambda_b^0)$	180 – 210	$188.1_{-2.2-0.3}^{+2.0+0.2\dagger}$
$M(\Sigma_b^-) - M(\Lambda_b^0)$ (isospin averaged)	180 – 210	$195.5 \pm 1.0 \pm 0.2^\dagger$
$M(\Sigma_b) - M(\Lambda_b^0)$	194 [24]	192
Hyperfine splitting	10 – 40	$21.1_{-1.9-0.3}^{+2.0+0.4}$
$M(\Sigma_b^*) - M(\Sigma_b)$	20.0 ± 0.3 [25]	
Isospin (<i>u, d</i>) diff.		
$M(\Sigma_b^-) - M(\Sigma_b^+)$	5 – 7	$7.4_{-2.4}^{+2.2\dagger}$
Widths		
$\Gamma(\Sigma_b), \Gamma(\Sigma_b^*)$	$\sim 8, \sim 15$	–

[†] Calculated by author.

5.2. Mass of Ξ_b Baryon

The Tevatron has also recently discovered the first *b* baryons containing strange quarks. A possible candidate Ξ_b^0 (*bsu*) should have dominant decays $\Xi_b^0 \rightarrow \Xi_c^0 \pi^0$ and $D^0 \Lambda$ with neutral states difficult to reconstruct cleanly at the Tevatron. A better candidate is the charged *b* baryon Ξ_b^\pm , first observed [26] by the DØ Collaboration in the decay $\Xi_b^\pm \rightarrow J/\psi \Xi^\pm$ and also observed [27] CDF Collaboration soon after in the same decay mode plus the additional decay mode $\Xi_b^\pm \rightarrow \Xi_c^0 \pi^\pm$. The Ξ_b^\pm is expected to decay weakly with a lifetime roughly comparable to other *b* hadrons.

Both collaborations reconstruct the new state in the decay chain $\Xi_b^\pm \rightarrow J/\psi \Xi^\pm$, $J/\psi \rightarrow \mu^+ \mu^-$, $\Xi \rightarrow \Lambda \pi$, $\Lambda \rightarrow p \pi$. The reconstruction of the charged Ξ^\pm with an average decay length of approximately 5 cm is challenging in the tracking systems. CDF uses silicon-only tracking, a first for an experiment at a hadron collider, and also modified their vertexing software to include this supplement. DØ reprocesses tracks using special parameter settings to improve the efficiency to reconstruct tracks with high impact parameters.

In 1.1 fb^{-1} of data, DØ reconstructs 1151 ± 46 Ξ^\pm baryons, and in 1.9 fb^{-1} of data, CDF reconstructs 23500 ± 340 Ξ^\pm baryons. Further selection cuts

based on momenta, decay lengths, and vertex quality with the J/ψ are made, with selections optimized on wrong-sign data and signal Monte Carlo samples by DØ, and on a $B^+ \rightarrow J/\psi K^+$ control sample by CDF. The resulting invariant mass distributions, including mass constraints to the J/ψ mass, are shown in Fig. 11 with signal yields of 15.2 ± 4.4 events (significance of 5.5σ above background) and 17.5 ± 4.3 events (significance of 7.7σ above background) for DØ and CDF, respectively. Fits to these distributions yield:

$$M(\Xi_b) = 5774 \pm 11 \pm 15 \text{ MeV DØ}, \quad (12)$$

$$M(\Xi_b) = 5792.9 \pm 2.4 \pm 1.7 \text{ MeV CDF}.$$

DØ also observes a lifetime consistent with expectations.

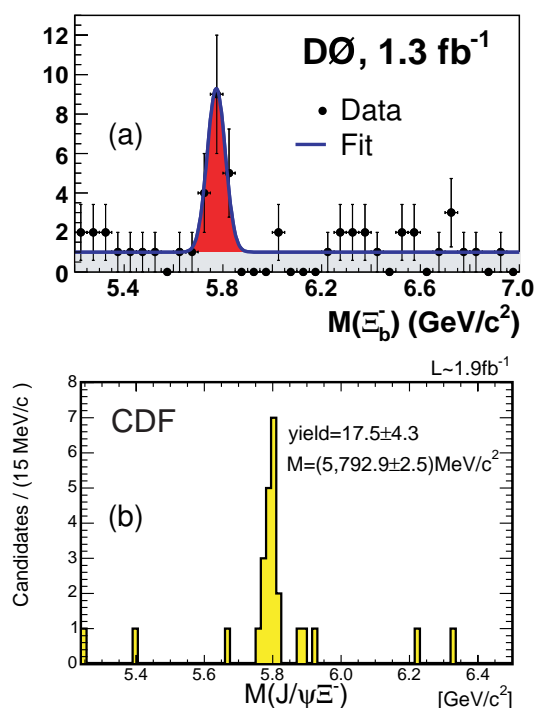


Figure 11: Ξ_b^\pm signal mass peaks in $J/\psi \Xi^\pm$ invariant mass distributions following selection cuts for (a) the DØ Collaboration and (b) the CDF Collaboration.

These measurements show good agreement compared to theoretical predictions [28] as shown in Fig. 12.

5.3. Mass of Ω_b Baryon

(Added in press.) Although not reported at the conference, the DØ Collaboration has subsequently observed a signal of 17.8 ± 5.0 events (statistical significance of 5.4σ above background) and measured the mass of the doubly strange Ω_b^- (*bss*) baryon [29] in

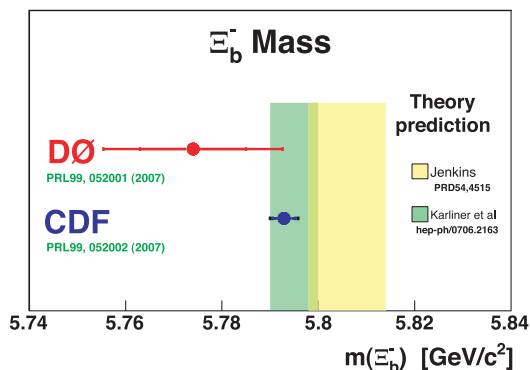


Figure 12: Measurements of the Ξ_b^\pm mass compared to theoretical predictions.

1.3 fb^{-1} of data. Without details, the measured mass is:

$$M(\Omega_b^\pm) = 6165 \pm 10 \pm 13 \text{ MeV}. \quad (13)$$

6. Conclusions and Prospects

The renaissance of b hadron spectroscopy (and measurement of properties) continues as new b baryon states continue to be discovered and a number of excited B meson states separated in a model-independent way for the first time. The agreement of data to theory predictions is good for most B mesons, but less so for the orbitally excited B^{**} and B_s^{**} states. There is excellent data-theory agreement for the new heavy b baryons. These measurements are providing useful input and comparisons to potential models, HQET, lattice gauge calculations, and other QCD models. There are outstanding prospects for continued *precision* predictions (e.g., $\Sigma_b^{(*)}$ inputs for Ξ_b predictions).

The performance of the Tevatron collider has been excellent, with expectations to at least double the data-set to approximately $6\text{--}8 \text{ fb}^{-1}$ by the end of running in 2009–2010. There are very good prospects for increasing the sample sizes of heavier b hadron states and for the discovery of even more states such as the double-heavy baryons.

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