Latest results on b–hadron spectroscopy from CDF

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Abstract. B–hadron spectroscopy presents an interesting window for the study of QCD. CDF has performed a number of studies involving the production and spectroscopy of B mesons. Among these studies are the first direct observation of the $B_{c}^{-}$, and the first observation of both narrow states of the $B_{s}^{*+}$. In addition, measurements are made of the $B_{s}^{*+}$ masses and widths and the best limit on the production of $\eta_{b}$ is set.

1. Observation of the $B_{c}^{-}$
A first evidence of the $B_{c}^{-} \rightarrow J/\psi \pi^{-}$ was obtained in [1], and after confirmed in higher statistics samples\(^1\) [2], [3]. The candidate selection is optimized using the reference decay $B^{-} \rightarrow J/\psi K^{-}$ which has similar kinematics but with much higher statistics. The $B^{-}$ selection is applied to ($J/\psi \pi^{-}$) combinations to search for $B_{c}^{-}$ candidates. Figure 1(a) shows the invariant mass distribution of the selected candidates on the reference decay and Figure 1(b) shows the invariant mass of the $B_{c}^{-}$ candidates. To measure the mass an unbinned maximum likelihood fit is used with a linear and a Gaussian function for describing the background and the signal, respectively. In total, there are 87.1 ± 12.8 signal events and the measured mass is $m(B_{c}^{-}) = 6274.1 ± 3.2 ± 2.6$ MeV/c\(^2\). The determined signal significance is greater than 8$\sigma$.

2. Search for the $\eta_{b}$
The $\eta_{b}$ is the last undiscovered ground state meson. The search for the $\eta_{b}$ at CDF [4] is performed through the exclusive decay into two $J/\psi$’s. The theoretically predicted branching ratio for this decay is rather low: $\text{BR}(\eta_{b} \rightarrow J/\psi J/\psi) = 7 \cdot 10^{-4}$\(^{+1}\). Together with the calculated differential cross section this corresponds to a rough estimate of 0.2 – 20 expected events within 1.1 fb\(^{-1}\) of data.
Since no significant resonance peak is seen in the mass spectrum, the selection cuts are tightened to avoid regions where the efficiencies are not well understood. Thereafter, three events are remaining in the search window which can be seen in Figure 2(a). Because only three events are observed, a 95% C.L. upper limit on the number of $\eta_{b}$ produced is calculated using a Bayesian method. A maximum of 7.2 events is seen at 9.32 GeV/c\(^2\) in the $\eta_{b}$ yield upper limit as a function of $J/\psi$–$J/\psi$ invariant mass (Figure 2(b)). This limit is translated to an upper limit relative to an inclusive $J/\psi$ production from b–hadron decays of $\sigma(p\overline{p} \rightarrow \eta_{b} X) \cdot \text{BR}(\eta_{b} \rightarrow J/\psi J/\psi) / \sigma(p\overline{p} \rightarrow H_{b} \rightarrow J/\psi X) < 5 \cdot 10^{-3}$.

\(^1\) Charge conjugated decays are also implied in all analyses reported in this article.
3. Orbitally excited $b$–mesons

The mass spectra of orbitally excited $b$–mesons can be described using the Heavy Quark Effective Theory (HQET). HQET describes mesons consisting of a heavy and a light quark in the limit where the mass of the heavy quark is considered to be infinity.

In the above limit, the spins of the heavy and light quark are decoupled. Thus, for the angular momentum $L = 1$, the total spin, $\vec{J}_q = \vec{s}_q + \vec{L}$, of the light quark can either be $j_q = \frac{1}{2}$ or $j_q = \frac{3}{2}$. Adding the angular momentum of the light system, $j_q$, with the spin of the heavy quark, $S_Q$, one obtains four spin states with $J^P = 0^+, 1^+, 1^+, 2^+$ which are collectively called $B^{(*)}$ states.

Orbitally excited states are searched for $B_s$ and $B_d$ mesons [5]. The excited $B_s$ states $B_{s1}$ and $B_{s2}$ are considered [5].

![Figure 1](image1.png)

(a) Mass distribution of the $B^-$ candidates (reference decay).

(b) Mass distribution of the $B_c^-$ candidates.

Figure 1. Observation of the $B_c^-$.

![Figure 2](image2.png)

(a) Mass distribution of the $\eta_b$ candidates.

(b) Yield upper limit for $\eta_b$ search at 95% C.L.

Figure 2. Search for the $\eta_b$. 
$B_{s2}^*$ (summarized as $B_{s2}^{**}$ states) were observed through their decay to $B^+ K^-$, with the $B^+$ decaying into $J/\psi K^+$ or $D^0 \pi^+$. The $B^+$ candidates are preselected by using distinct neural networks for each $B^+$ decay. The selection of the $B_{s2}^{**}$ candidates is done by using again different neural networks in each $B^+$ decay mode. For the final selection cuts on the network output and the number of candidates per event are applied. Figure 3(a) shows the $Q$ value distribution of the $B_{s2}^{**}$ candidates. The $Q$ value is the defined as $Q = m(B^+ K^-) - m(B^+) - m(K^-)$.

To measured the $B_{s2}^{**}$ masses an unbinned maximum likelihood fit is used with a Gaussian and an exponential function to describe the signal and the background respectively. The determined signal significance is larger than 5$\sigma$.

The analysis of the $B^{**}$ mesons is analog to the $B_{s2}^{**}$ analysis. It is performed on the decay $B^{**} \rightarrow B^+ \pi^-$ with the same $B^+$ decay modes using the same neural networks for preselecting the $B^+$ candidates as for the $B_{s2}^{**}$ analysis. Additionally the decay mode $B^+ \rightarrow D^0 \pi^+ \pi^- \pi^-$ is also used. The final candidate selection is based again on distinct neural networks and cuts on the same quantities as in the $B_{s2}^{**}$ analysis. Figure 3(b) shows the $Q$ distribution of the $B^{**}$ candidates. The masses are measured with a non–relativistic Breit–Wigner distribution modelling the signal. The masses are $m(B_{s2}^{**}) = 5739.6 \pm 0.3 \pm 0.4$ MeV/c$^2$ and $m(B_{s1}) = 5829.4 \pm 0.21 \pm 0.2$ MeV/c$^2$.

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![Figure 3. Orbitally excited b–mesons.](image-url)