Studies of Orbitally Excited $D^{**}_{(s)}$ and $B^{**}$ Mesons at CDF and DØ

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Abstract. Using a large data sample of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV recorded by the CDF and DØ detectors operating at the Fermilab Tevatron, the orbitally excited $B$ mesons $B_1$ and $B_2^*$ are observed directly as two separate states in fully reconstructed decays to $B^{(*)}\pi$. The masses and the mass differences between the states are presented. In the charm system, the orbitally excited $D$ mesons $D_1$ and $D_2^*$ are observed in fully reconstructed decays to $D^{(*)}\pi$. Measurements of the product branching rates of semileptonic decays $B\bar{D}\mu\nu\bar{\nu}$ and their ratio are presented. We also present the observation of the semileptonic decays $B_s\mu\nu D_s$ where the excited $D_s^{**}$ states are reconstructed in the mode $D_s^{**} \to D^* K^{0}_S$.

Keywords: Orbitally excited mesons, $D^{**}$, $D^{**}_{(s)}$, $B^{**}$, Heavy Quark Effective Theory


THEORETICAL MOTIVATION

The $D$ and $B$ mesons are examples of a heavy-light quark bound state. The spectroscopy of these mesons may be predicted through application of Heavy Quark Effective Theory and the ideas behind it, particularly in the limit $m_{(c,b)} \to \infty$. In this limit, the excited states are described by the light degrees of freedom with spin-parity $J^P$. This leaves a degenerate doublet for each meson state, with the degeneracy broken by effects of the order $\Lambda_{QCD}/m_{(c,b)}$. These first excited states are known as the $B^{**}$ and $D^{**}_{(s)}$ in the $B$ and charm systems respectively. Measuring the properties of these mesons tests HQET.

The CDF and DØ detectors are described in detail in Ref [1] and Ref [2] respectively.

$D^{**}$ mass measurement

CDF measures the masses and widths of the $D_1^0$ and $D_2^0$ states using two fully hadronic decay channels in $210 \text{ pb}^{-1}$ of data [3]:

- $D^{**} \to D^{*+}\pi^-, D^{*+} \to D^0\pi^+$
- $D^{**} \to D^{+}\pi^-$, with feed-down from $D^{*+} \to D^+\pi^0$ channel

The $D^{**}$ invariant mass difference for both channels is shown in Figure 1. The wide $D^{**}$ states are taken from the PDG [4]. The results are

1 Charge conjugated states are always implied.

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DØ measures the branching fractions of the decays $B \to \bar{D}^0(2420)\mu^+\nu\mu X$ and $B \to \bar{D}^0(2460)\mu^+\nu\mu X$, and makes the first direct measurement of their ratio in 460 pb$^{-1}$ of data [5]. The $D^{**}$ invariant mass shown in Figure 2a is fit with the sum of two relativistic Breit-Wigners for the narrow states.

The branching fraction for the decays $B \to \bar{D}^{**}\mu^+\nu\mu X$ are determined by normalization to the known value of the branching fraction for $B(B \to D^{*-}\ell^+\nu\mu X) = (2.75 \pm 0.19)\%$ [4]. To compare with theory, the fragmentation $B(\bar{t} \to B)$ is included where $B$ is either $B^0$ or $B^\pm$. The results for the $D^{**}$ narrow branching fractions are

$$B(\bar{t} \to B) \cdot B(B \to \bar{D}_1^0, \bar{D}_2^0) \mu^+\nu\mu X \cdot B((\bar{D}_1^0, \bar{D}_2^0) \to D^{*-}\pi^+) = (0.122 \pm 0.007 (stat) \pm 0.015 (syst))\%$$

$$B(\bar{t} \to B) \cdot B(B \to \bar{D}_1^0) \mu^+\nu\mu X \cdot B(\bar{D}_1^0 \to D^{*-}\pi^+) = (0.087 \pm 0.007 (stat) \pm 0.014 (syst))\%$$

$$B(\bar{t} \to B) \cdot B(B \to \bar{D}_2^0) \mu^+\nu\mu X \cdot B(\bar{D}_2^0 \to D^{*-}\pi^+) = (0.035 \pm 0.007 (stat) \pm 0.008 (syst))\%$$

$$\frac{B(\bar{t} \to B) \cdot B(B \to \bar{D}_1^0) \mu^+\nu\mu X \cdot B(\bar{D}_1^0 \to D^{*-}\pi^+)}{B(\bar{t} \to B) \cdot B(B \to \bar{D}_2^0) \mu^+\nu\mu X \cdot B(\bar{D}_2^0 \to D^{*-}\pi^+)} = 0.39 \pm 0.09 (stat) \pm 0.12 (syst)$$

### Observation of $D_{s}^{**}$

DØ observes $B_s \to \mu\nu D_{s}^{**}$ through the decay channel $D_{s}^{**} \to D^{**}K_{s}^0$ with $D^{**} \to D^0\pi^+, D^0 \to K^+\pi^-$ and $K_{s}^0 \to \pi^+\pi^-$ in 485 pb$^{-1}$ of data. The significance of the signal...
FIGURE 2. Right: The invariant mass $M(D\pi)$ of $D\pi^*$ combinations with opposite charges and the hatched histogram corresponds to same charge combinations. Left: The invariant mass of $D\pi K$, which shows evidence of the $D$ state.

Both CDF and DØ measured the narrow $B$ states. DØ uses the fully reconstructed decays of $B\psi K$, $B_0\psi K$, and $B_0\psi K_S$ to reconstruct a mixture of $B_0$ and $B_0$ states in 350 pb$^{-1}$ of data [7]. The two narrow $B$ states are fit by a relativistic Breit-Wigner convoluted with a Gaussian detector resolution function. With the widths of the two narrow states set equal, the results shown in Figure 3 are

- $M = 5724^{+4}_{-7}$ stat # $7^{+5}_{-6}$ syst MeV/c$^2$
- $M = 23^{+12}_{-7}$ stat # $9^{+9}_{-7}$ syst MeV/c$^2$
- $\Gamma_1 = 9^{+9}_{-7}$ stat # $9^{+9}_{-7}$ syst MeV/c$^2$
- $\Gamma_2 = 12^{+12}_{-7}$ stat # $12^{+12}_{-7}$ syst MeV/c$^2$
CDF uses the fully reconstructed decays of $B^+ \to J/\psi K^+$ and $B^+ \to \bar{D}^0 \pi^+$ to reconstruct the $B^{*+0}$ states in 370 $pb^{-1}$ of data [8]. Due to very different signal to background structure, $B^{*0}$ events could not be added together and were fit simultaneously in both channels. Narrow $B^{*+0}$ states are fit with a non-relativistic Breit-Wigner convoluted with a double Gaussian detector resolution. The results shown in Figure 4 are

- $M(B^0) = 5734 \pm 3(stat) \pm 2(syst)$ MeV/c$^2$
- $M(B^{*0}) = 5738 \pm 5(stat) \pm 1(syst)$ MeV/c$^2$

### CONCLUSIONS

All measurements agree well with HQET models. Many measurements are statistically limited, and will improve as more data is analyzed. The results are all interesting and competitive; the semileptonic branching fractions, for example, are an order of magnitude better than previous measurements.

### REFERENCES

6. DØ Collaboration, “Evidence of $B_s \to D_{s1}^{*+} \mu \nu X$ at DØ,” DØ Note 4727 (Mar. 4, 2005). http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B19/B19.pdf