Measurement of the branching fractions of B to narrow D^{**} states and other semi-leptonic b decays at the DØ experiment

Freya Blekman for the DØ Collaboration
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Imperial College, UK
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Using 460 pb^{-1} of integrated luminosity accumulated with the DØ detector, the product branching rates of the semileptonic decays $\bar{B} \to D_1^0(2420)\mu^-\bar{\nu}X$ and $\bar{B} \to D_2^{*0}(2460)\mu^-\bar{\nu}X$ and their ratio have been measured. This result represents a significant improvement in the knowledge of B branching rates to orbitally excited D mesons, and the first direct measurement of their ratio. Furthermore, we also present preliminary results on the observation of $B \to \mu\nu D_s^{**}$ state, where $D_s^{**} \to D^* K_S^0$ and the semi-leptonic decays of beautified baryons $\Lambda_b \to \Lambda_c\mu\nu$.

I. INTRODUCTION

In this paper we study exited states of c quarks, which are formed in the decay of the b quark in a baryonic or mesonic system with a light quark. Because $m_c \gg \Lambda_{QCD}$ in these type of systems, the spin of the c quark decouples from the light quark spin and angular momentum of the system.

When the b quark in a B meson (or baryon) decays to a c quark, heavy quark effective theory (HQET) predicts that the light quark is not influenced by the change in colour field. In the studies presented in this paper, only semi-leptonic b decays where a muon is produced are considered:

$$b + X \to W + c + X \to \ell\nu + c + X \tag{1}$$

A. The DØ Experiment

The DØ detector is a general-purpose particle physics detector that is situated on the Tevatron $p\bar{p}$ collider, which has an interaction energy of $\sqrt{s} = 1.96$ TeV. The detector consists of a Silicon Micro-strip Tracker and central Fibre Tracker in a magnetic field of 2T, a Liquid Argon calorimeter that contains both an electro-magnetic and hadronic section, and a muon system.

II. FIRST MEASUREMENT OF SEMI-LEPTONIC $B \to D^{**}$ BRANCHING FRACTIONS FOR SEPARATE STATES

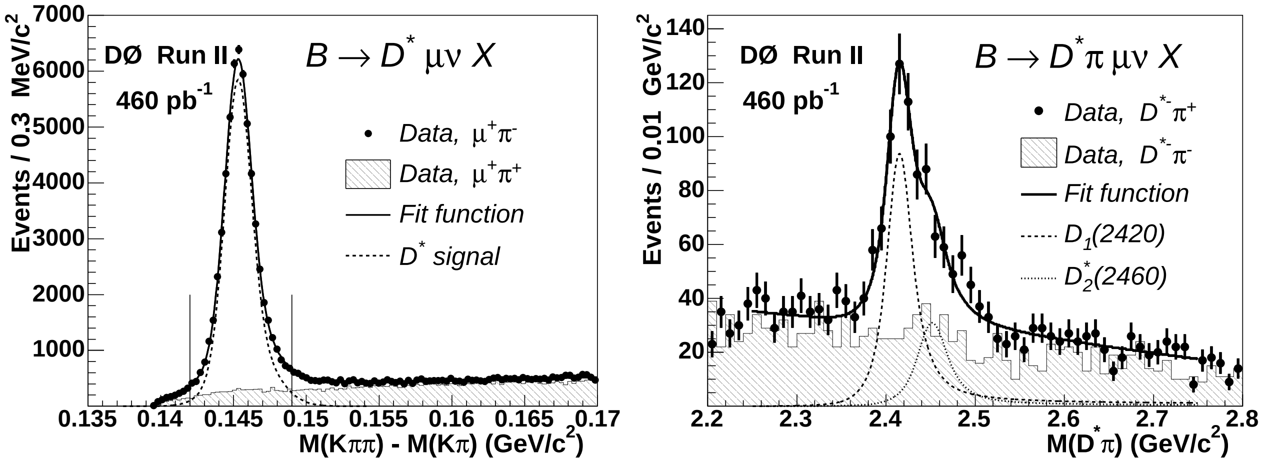

FIG. 1: Left: Selection of D^* candidates as a function of the mass difference between the $K\pi\pi$ and $K\pi$ systems. Right: Reconstruction of the two narrow D^{**} states. The fit to the two resonances is used to determine the relative branching fractions.

The D^{**} is an excited, bound state of a c and light quark. Conservation of parity and angular momentum thus leads to two classes of D^{**} bound states: Narrow states , where the light quark spin and angular momentum are in the same direction; and broader resonances , where the spin and angular momentum of the light quark point in opposite direction. In this paper we will only consider D^{**} states of the first category; two states labelled D_1 and D_2^*.

In quantitative HQET predictions, the free $b \to c$ decay has to be corrected to the order $1/m_c$. One of the properties that is sensitive to these mass corrections is the ratio between the branching fractions of the B to the two narrow D^{**} states:

$$R = \frac{Br(B \to D_2^* \ell \bar{\nu}_\ell)}{Br(B \to D_1 \ell \bar{\nu}_\ell)}. \tag{2}$$

$R = 1.6$ in the mass limit of $m_c \to \infty$. Different HQET models in predict R as low as 0.4, but in general the quantity is considered to be relatively model-independent.

A. Selection of the D^{**} candidates

To measure R, we use the DØ dataset up to 2004, which is equivalent to approximately 460 pb^{-1}. B jet reconstruction and other selection methods are described in detail here[3]. We use the decay chain $D^{**} \to D^*\pi \to D^0\pi\pi \to K\pi\pi\pi$. The D^* candidates are shown in Figure 1 (left). After rejection of $B \to DD$ and $g \to c\bar{c}$ backgrounds, we are left with 31k D * candidates. Adding a $\pi^\pm$ to the D^* leads to the mass spectrum shown in Figure 1 (right). The fit includes two Breit-Wigner functions for the two resonances and a second order polynomial function for the background. The background is examined for a possible wide resonance by comparing to the wrong sign background. Unlike other experiments [2], DØ does not observe a wide resonance.

When the known branching fraction of $B \to D^{*-}\mu^+\bar{\nu}_\mu X$ is used for normalisation, the following branching fractions are observed:

$$Br(\bar{b} \to B) \cdot Br(B \to \bar{D}_2^{*0}\mu^+\bar{\nu}_\mu X) \cdot Br(\bar{D}_2^{*0}\pi) = (0.035 \pm 0.007(\mathrm{stat}) \pm 0.008(\mathrm{syst}))\% \tag{3}$$

and

$$Br(\bar{b} \to B) \cdot Br(B \to \bar{D}_1^0\mu^+\bar{\nu}_\mu X) \cdot Br(\bar{D}_1^0\pi) = (0.087 \pm 0.007(\mathrm{stat}) \pm 0.014(\mathrm{syst}))\%, \tag{4}$$

This leads to a branching fraction ratio of

$$\frac{Br(B \to \bar{D}_1^0\mu^+\bar{\nu}_\mu X) \cdot Br(\bar{D}_1^0\pi)}{Br(B \to \bar{D}_2^{*0}\mu^+\bar{\nu}_\mu X) \cdot Br(\bar{D}_2^{*0}\pi)} = 0.39 \pm 0.09(\mathrm{stat}) \pm 0.12(\mathrm{syst}). \tag{5}$$

This information can be used to extract R [3]:

$$R = 1.31 \pm 0.29(\mathrm{stat}) \pm 0.47(\mathrm{syst}), \tag{6}$$

where the dominant systematic uncertainties include the uncertainty on $Br(B \to D^{*-})$, the mass resolution, the width of the two D^{**} states, fit errors, D^0 selection, possible wide resonances and the difference between Monte Carlo simulation and data.

III. EVIDENCE OF SEMI-LEPTONIC $B_s \to D_s^{**}$

In an analysis very similar to the aforementioned D^{**} measurement, the DØ Collaboration has examined the $B_s \to D_S^{**}\mu\nu$ spectrum. In this case, D_{S1} candidates are extracted from the D^*K_S spectrum. The addition of a charged π to the D^*K_S candidates yields the D_S^{**}. Figure 2 (left) shows the invariant mass spectrum. A resonance peak containing 18 ± 5.5 candidates is attributed to the presence of D_S^{**} in the sample. The significance of this result was examined using two different methods, where in both cases the resonance was more than 3σ confidence level above background. For this analysis, the systematic uncertainties are currently under study, and the D_S^{**} sample will be used to measure its production and properties [4].

IV. OBSERVATION OF SEMI-LEPTONIC $\Lambda_b \to \Lambda_c$ DECAYS

It is also possible to reconstruct the Λ_b, a udb baryon, in semi-leptonic events. The method is to look for $\Lambda_b \to \Lambda_c\mu\nu$ events where Λ_c decays to either K_Sp or $\Lambda\pi$. Figure 2 shows that in both decay channels there is evidence of the Λ_c resonance. In the $\Lambda\pi$ spectrum (Figure 2 right) an additional resonance, attributed to Σ baryons, can be observed. The isolated samples will be used for a Λ_b lifetime measurement [4]

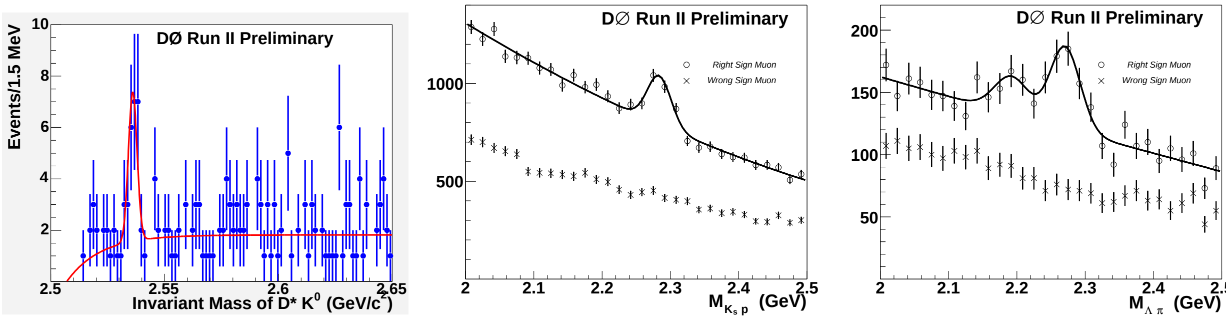

FIG. 2: Left: The invariant mass spectrum of $D^* K^0_S$ in semi-leptonic B decays. The peak is attributed to the D^{**}_S. Center: The plot shows the Λ_c resonance as observed in $\Lambda_c \to K^0_S p$ decays in semi-leptonic B events. Right: A similar invariant mass plot for the $\Lambda_c \to \lambda\pi$ mode, where a possible Σ resonance can be seen around $M_{\Lambda\pi} = 2.2$ GeV/c^2

V. CONCLUSION

For the first time, the narrow D^{**} meson branching fractions have been separately measured in semi-leptonic events. The ratio between the semi-leptonic branching fractions of the two modes is

$$R = 1.31 \pm 0.29(\text{stat}) \pm 0.47(\text{syst}) \tag{7}$$

The DØ Collaboration also observes the D^{**}_S resonance and the measurement of its properties is in progress. It is also possible to reconstruct the Λ^0_b in semi-leptonic decays, and the reconstructed candidates will be used in a Λ_b lifetime measurement.

[1] V.M. Abazov *et al.,* DØ Collaboration, Submitted to Nucl. Instr. and Methods, hep-physics/0507191
[2] K. Abe *et al.,*, Belle Collaboration, Phys.Rev.D 69, 112002 (2004)
[3] V.M. Abazov *et al.,* DØ Collaboration, Submitted to Phys.Rev.Lett,hep-ex/0507046
[4] The DØ Collaboration's Results page (for b-physics), http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm