# B HADRON PROPERTIES WITH D0 DETECTOR

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Several analyses of B hadron properties are described which use the 1 $fb^{-1}$ dataset collected with the D0 detector at the Tevatron proton-antiproton collider with the centre of mass energy of 1.96 TeV. The production of $B^{**}$ and $B_s^{**}$ states has been observed and their masses and the branching fractions measured. The semileptonic decay $B_s \rightarrow D_s(2536)\mu\nu X$ has been observed for the first time and its branching fraction measured. The lifetime of the $\Lambda_B$ baryon has been measured reconstructing the baryon in the $J/\psi\Lambda$ decay mode.

*Keywords*: B meson, $\Lambda_B$ baryon, lifetime

## 1. Tevatron Collider and D0 Detector

By the time of this conference the D0 detector [1] operating at the Tevatron collider (Fermilab, Illinois USA) has recorded to tape about 1.2 $fb^{-1}$. During five years of operation the integrated luminosity has been increasing approximately by factor of two every year and by the summer 2006 has reached the peak values of about 30 $pb^{-1}$/week. The record instantaneous luminosity of $2x10^{32}$ $1/cm^2/sec$ has been achieved with the detector logging the data with average efficiency of 85%.

B hadrons of all kinds are produced strongly at the Tevatron with a total cross section which is a factor of $10^4$ larger than at the B-factories. However the registration of the hadrons suffers from the large background and requires elaborated triggering techniques. The multipurpose D0 detector comprises a spectrometer based on the fiber and silicon trackers in the 2 T solenoid field. The energy flow is measured with a liquid Ar sampling calorimeter The three layer muon system is combined with absorber in a toroidal field. It features excellent pseudorapidity coverage ($|\eta|<2$) where it provides robust and quiet single- and di-muons triggers.

All the below results are based on 1 $fb^{-1}$ of integrated luminosity accumulated between April 2002 and January 2006 and are considered preliminary at this stage.

## 2. Orbitally Excited Heavy Mesons

Mesons composed of a pair of light and heavy quarks can be regarded as hydrogenic atoms of QCD when in the heavy quark limit the color field is static and the light degrees of freedom decouple [2]. The light quarks are characterized by their total angular momentum $j_q = s_q + L$ composed of the light quark spin and its orbital angular momentum. The angular momentum, $j_q$, is combined with the spin of the heavy quark, $s_Q$ , to give the total angular momentum of the heavy-light system. The $s_Q$ and $j_q$ values are separately conserved so, in the heavy quark limit, each energy level has a pair of degenerate states corresponding to a different direction of $s_Q$. The states corresponding to $j_q$=1/2 and L = 0 are called B and $B^*$ while the states corresponding to $j_q$ = 1/2 or 3/2 and L = 1 are called collectively $B^{**}$ mesons. The $j_q$ = 3/2 states (also known as $B_1$ and $B^*_2$) are narrow resonances as they decay through the D-wave. Oppositely the $j_q$ = 1/2 states ($B^*_0$ and $B^*_1$) are wide resonances which are difficult to distinguish from the background.

### 2.1. *Observation of $B^{**}$ mesons*

Orbitally excited $B^{**}$ mesons have been searched as narrow states decaying to $B^{+(*)}\pi$ with possible decay modes:

- $B_1 \rightarrow B^{*+}\pi^-$; $B^{*+} \rightarrow B^+\gamma$

- $B_2^* \to B^{*+}\pi^-$; $B^{*+} \to B^+\gamma$
- $B_2^+ \to B^+\pi^-$

Charged B mesons have been reconstructed as $B^+ \to J/\psi\ K^+$ with $J/\psi \to \mu\mu$. For each $B^+$ an additional track with $P_T > 0.75$ GeV and correct charge correlation ($B^+\pi^-$ or $B^-\pi^+$) has been looked for. Since the $B^{**}$ meson decays immediately after production, the track was required to originate from the primary vertex. The invariant mass difference $\Delta M = M(B\pi) - M(B)$ with a clearly visible three peak structure is shown in Fig.1.

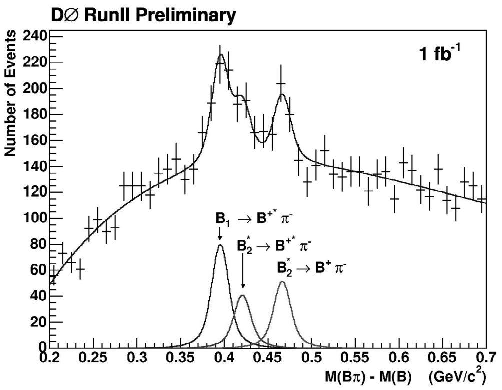


Fig. 1. Mass difference between Bπ and B states.

The three peak structure is explained by the following three contributions:

1. Direct decay $B_2^* \to B^+\pi$
2. $B_2^* \to B^{+*}\pi$ with $B^{+*} \to B^+\gamma$. Energy of $\gamma$ is equal to 46 MeV and, since $\gamma$ is not reconstructed; a peak separated from direct peak by the $\gamma$ energy is expected.
3. $B_1 \to B^{+*}\pi$ with $B^{+*} \to B^+\gamma$. Note that $B_1 \to B\pi$ is forbidden by the angular momentum and parity conservation.

The mass, mass difference and the width of the narrow mesons have been measured to be equal to (all values in MeV):

- $M(B_1)=5720.8\pm2.5(stat)\pm5.3(sys)$
- $M(B_2^*)-M(B_1)=25.2\pm3.0(stat)\pm1.1(sys)$
- $\Gamma_1=\Gamma_2=6.6\pm5.3(stat)\pm4.2\ (sys)$.

The probability of b-quark to decay to the Bπ final state through the orbitally exited B mesons normalized to the probability of the b-quark to fragment to the $B^+$ meson has been determined to be equal to $0.165\pm0.024(stat)\pm0.028(sys)$. These are the first measurements of the production rates and also the world's best mass measurement for the $B^{**}$ mesons.

### 2.2. *Observation of Bs** mesons*

States similar to $B_1$ and $B_2^*$should exist in the system of b- and s-quarks but almost no information exists on these objects apart from claims of indirect observation at LEP by OPAL and DELPHI [3]. Similarly to the $B^{**}$ states considered in the previous section there should be narrow $B_{s1}$ and $B_{s2}^*$ states. Due to the isospin conservation, the possible decay modes are:

- $B_{s1} \to B^*\ K$
- $B_{s2}^* \to B\ K$; $B_{s2} \to B^*\ K$

The same sample of $B^+$ meson as in the $B^{**}$ search described above has been used for this analysis. For each $B^+$ meson candidate an additional track with $P_T>0.6$GeV and the charge opposite to the charge of the $B^+$ meson has been searched for. The track with assigned kaon mass was required to originate from the primary vertex. The invariant mass difference $\Delta M = M(BK) - M(B) - M(K)$ is shown in Fig.2. The peak corresponding to the $B_{s2}^*$ meson is clearly visible with the signal significance exceeding five standard deviations.

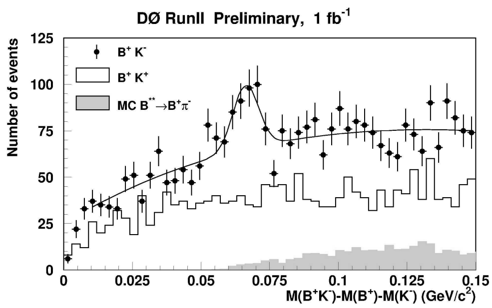


Fig. 2. Mass difference between the invariant mass of BK and masses of B and K mesons.

The wrong sign combinations (i.e. $B^+K^+$ or $B^-K^-$) show no evidence of the peak. The same statement is true for the MC sample of $B^{**}$

mesons decaying to $B^{(*)}\pi$ but reconstructed as $B^+K^-$. The mass of the resonance has been determined to be equal to $M(B_{s2}^*) = 5839.1 \pm 1.3$ MeV. Presented for the first time at the spring 2006 conferences this result is the first observation of the $B_{s2}^*$ state, also confirmed by the CDF detector at this conference [4].

### 2.3. *Observation of Semileptonic Decay $B_s \rightarrow D_s(2536)\mu\nu X$*

Considerations for the orbitally excited B mesons are directly applicable to the system consisting of charm and strange quarks. At D0 these states can be observed in semileptonic decays of B mesons. The narrow $D_{s1}(2536)$ meson with quantum numbers L=1; $j_Q$=3/2; $J^P=1^+$ has been reconstructed using the following decay chain:
$B_s^0 \rightarrow D_{s1}^-(2536)\mu^+\nu X \rightarrow D^{*-}K_s\,\mu^+\nu X$.
The invariant mass of the $D^*K_s$ system shown in Fig.3 corresponds to 82130 $D^*$ candidates reconstructed in the decay mode $D^* \rightarrow \pi D^0 \rightarrow \pi K\pi$.

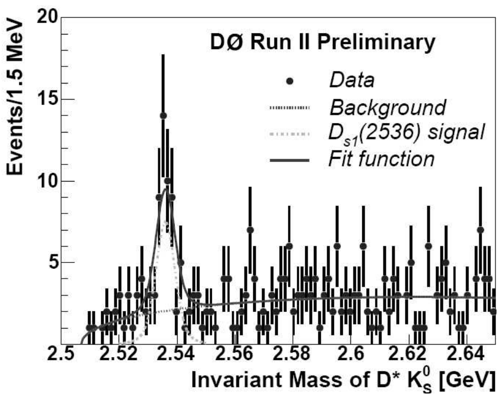


Fig. 3. Invariant mass of the $D^*K_s$ system.

The $D_{s1}^-(2536)$ signal has been fit by a Gaussian function and the background has been described by an exponential with a cut-off at the sum of the $D^*$ and $K_s$ masses. In total 43.8±8.3 $D_{s1}(2536)$ candidates have been reconstructed corresponding to a 5.3σ significance of the observation. The mass of the resonance extracted from the fit was 2535.7±0.5(stat)±0.6(sys) MeV in agreement with the corresponding PDG value. Assuming the $B_s$ meson production fraction $f(b\rightarrow B_s)$=0.107 and $Br(D_{s1}\rightarrow D^*K_s)$=0.25 the branching fraction of $B_s^0 \rightarrow D_{s1}^-(2536)\mu^+\nu X$ has been measured: (0.86±0.16(stat)±0.13(sys) ±0.09(prod.frac))%.

## 3. $\Lambda_B$ baryons

$\Lambda_B$ baryon is the lightest b-baryon consisting of u-, d- and b-quarks. Precise measurement of the lifetime of this baryon is a stringent test of the Heavy Quark Effective Theory (HQET) in b-baryons and is necessary to clarify disagreement between theory and experiment and also between various experimental measurements of this value [5].

### 3.1. *Measurement of $\Lambda_B$ Lifetime*

The result presented at this conference is an update of the previously published result of the D0 collaboration [6]. It is based on the four-fold increase of statistics and corresponds to the integrated luminosity of 1 $fb^{-1}$. Total 174±21 $\Lambda_B$ candidates have been reconstructed as $\Lambda_B \rightarrow J/\psi\,\Lambda$; $J/\psi \rightarrow \mu\mu$ . The lifetime has been measured using unbinned likelihood fit simultaneously for the proper decay length and invariant mass distributions. The invariant mass of the $J/\psi\,\Lambda$ system and the fit results are shown in Fig.4.

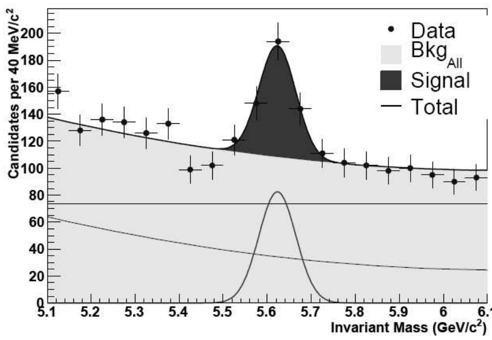


Fig. 4. Invariant mass of $J/\psi\,\Lambda$ and results of the fit.

Fig.5 shows the distribution of the proper decay length together with the results of the lifetime fit. A topologically similar decay mode of the $B^0$ meson, $B^0 \rightarrow J/\psi\ K_s$, has been used to measure the ratio of lifetimes of the baryon and the meson. The main results of the analysis are as follows:

$\tau(\Lambda_B) = 1.298 \pm 0.137(\text{stat}) \pm 0.050(\text{syst})$ ps
$\tau(\Lambda_B)/\tau(B^0) = 0.870 \pm 0.102(\text{stat}) \pm 0.041(\text{syst})$

These results agree well with the world average but is in a slight disagreement with a recent measurement of CDF in the same decay mode [7]. The main systematic uncertainty is caused by the background modeling and by the contamination of the $\Lambda_B$ sample with mis-reconstructed $B^0 \rightarrow J/\psi\ K_s$ events.

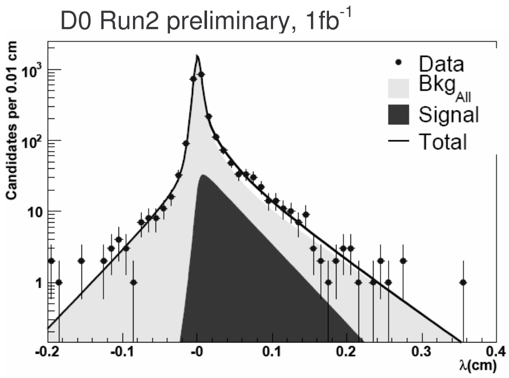


Fig. 5. Proper decay length distribution and results of the fit.

## 4. Summary

Using $1\text{fb}^{-1}$ of integrated luminosity the D0 detector at the Tevatron performed several interesting measurements of excited heavy flavor mesons. The $B_1$ and $B_2^*$ have been observed as two separate peaks and their masses measured. The first direct observation of $B_{s2}^*$ with higher than $5\sigma$ significance, the precise mass measurement of $B_{s2}^*$ and, at last, the first observation of the $B_S \rightarrow D_S(2536)\mu\nu X$ decay and measurement of its branching fraction have been all reported. The updated result on the $\Lambda_B$ lifetime agrees well with the world average.

The increase of statistics by the factor between four and eight before year 2009 with detectors upgraded in 2006 will allow providing further important information on properties of B hadrons.

## Acknowledgments

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