Properties and decays of *b* hadrons at DØ

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The Tevatron, with $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, can produce all flavours of b hadrons and allows several studies in the B physics sector. This paper presents a selection of recent results on heavy hadron physics using data up to 10.4 fb^{-1} of integrated luminosity collected with the DØ detector.

1 Results for Λ_b baryon

1.1 $\Lambda_b \to J/\psi\Lambda$ Branching Ratio

b-hadrons such as the Λ_b are currently the subject of much research in both the theoretical and experimental particle physics communities. Measurements of the production and decays of b-hadrons could improve understanding of the electroweak and strong interactions described by the Standard Model of particle physics, in addition to providing opportunities to search for physics beyond the Standard Model. The DØ Collaboration, using 6.1 fb^{-1} of $p\bar{p}$ collisions, reports an improved measurement on the relative production fraction [1], specifically

$$\sigma_{\rm rel} \equiv \frac{f(b\to\Lambda_b)\cdot\mathcal{B}(\Lambda_b\to J/\psi\Lambda)}{f(b\to B^0)\cdot\mathcal{B}(B^0\to J/\psi K^0_s)} = \frac{N_{\Lambda_b\to J/\psi\Lambda}}{N_{B^0\to J/\psi K^0_S}}\cdot\frac{\mathcal{B}(K^0_s\to\pi^+\pi^-)}{\mathcal{B}(\Lambda\to p\pi^-)}\cdot\epsilon.$$

For this analysis it is first necessary to find events with two oppositely charged reconstructed muons, forming a common vertex and invariant mass consistent with a J/ψ meson. The next step is to search in the dimuon selection for pairs of oppositely charged tracks with a common vertex, such as $p\pi^-$ or $\pi^+\pi^-$. Possible Λ_b and B^0 ($B^0 \to J/\psi\ K^0_s$ is the normalization channel) candidates are reconstructed by performing a constrained fit to a common vertex. Moreover, several conditions are imposed on the quality of the reconstructed objects (tracks, vertices and parent particles). To extract the yields of the observed Λ_b and B^0 hadrons, an unbinned likelihood fit is performed to each mass distribution assuming a double Gaussian function for signal and a second order polynomial distribution for background, as shown in Fig. 1.

Monte Carlo (MC) simulated data was analyzed in order to obtain the reconstruction efficiencies and several cross checks to ensure that the MC was correctly modeling the signal data. Studies of different sources of systematic uncertainty were performed: the determination of the Λ_b and B^0 yields, the determination of the relative efficiency, the contamination from Λ_b in B^0 and vice versa, and Λ_b polarization effects, with the final source being the most significant. As a final cross-check, lifetime measurements were performed for the Λ and K^0_S with results in agreement with the world average values.

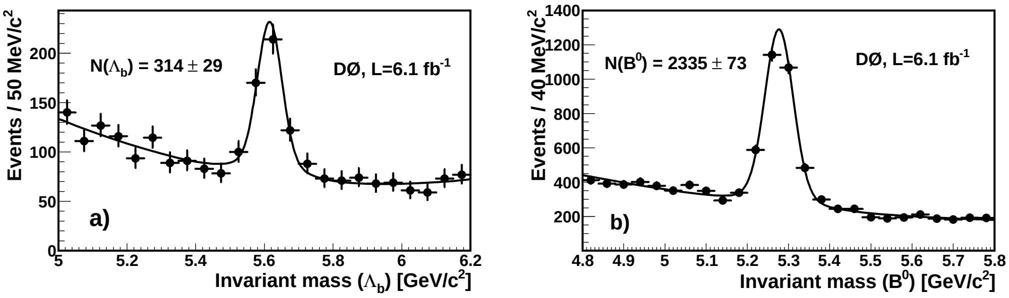

Figure 1: Invariant mass distribution in data for (a) $\Lambda_b \to J/\psi\Lambda$ and (b) $B^0 \to J/\psi K_s^0$ decays. Fit results are superimposed

The DØ Collaboration has obtained the production fraction multiplied by the branching fraction for the decay $\Lambda_b \to J/\psi\Lambda$ relative to that for the decay $B^0 \to J/\psi K_s^0$ to be

$$\sigma_{\text{rel}} = 0.345 \pm 0.034 \text{ (stat.)} \pm \ 0.033 \text{ (syst.)} \pm 0.003 \text{ (PDG)}.$$

The measurement is the most precise to date and exceeds the precision of the current value reported as the world average, 0.27 $\pm$0.13 [2] . Using the PDG value $f(b \to B^0) \cdot \mathcal{B}(B^0 \to J/\psi K_s^0) = (1.74 \pm 0.08) \times 10^{-4}$ (from [2]),

$$f(b \to \Lambda_b) \cdot \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = [6.01 \pm 0.60 \text{ (stat.)} \pm 0.58 \text{ (syst.)} \pm 0.28 \text{ (PDG)}] \times 10^{-5}$$

which can be compared directly to the world average value of $(4.7 \pm 2.3) \times 10^{-5}$ [2]. This result represents a reduction by a factor of $\sim$3 of the uncertainty with respect to the previous measurement [3]. With this result the CDF experiment was able to report the branching ratio $\mathcal{B}(\Lambda_b \to \mu\mu\Lambda^0)$, and they found no significant deviation from the Standard Model [4].

1.2 Λ_b lifetime in the exclusive decay $\Lambda_b \to J/\psi\Lambda$

Lifetime measurements of particles containing b quarks provide important tests of the significance of strong interactions between the constituent partons in the weak decay of b hadrons. These interactions produce measurable differences between b hadron lifetimes that heavy quark expansion (HQE) [5] predicts with good accuracy through the calculation of lifetime ratios, but currently there are remaining discrepancies between experimental results and theoretical predictions for b baryons.

The data used in this analysis were collected with the DØ detector during the complete Run II of the Tevatron Collider, from 2002 to 2011, and correspond to an integrated luminosity of 10.4 fb^{-1}. The main difference with the previous analysis is that events with J/ψ candidates are reprocessed with a version of the track reconstruction algorithm that increases the efficiency for tracks with low p_T and high impact parameter [6].

The samples of Λ_b and B^0 candidates have two primary background contributions: combinatorial background and partially reconstructed b hadron decays. In order to extract the lifetimes,

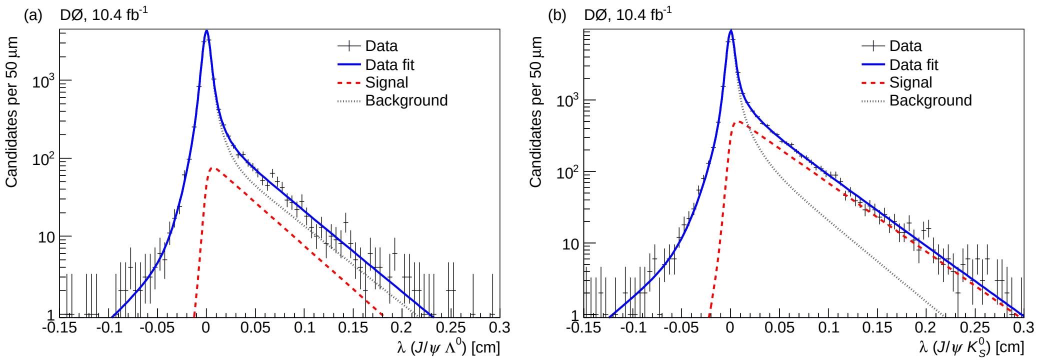

Figure 2: Proper decay length distributions for (a) $\Lambda_b \to J/\psi\Lambda$ and (b) $B^0 \to J/\psi K^0_s$ candidates, with fit results superimposed.

we perform separate unbinned maximum likelihood fits for Λ_b and B^0 candidates. The likelihood function ($\mathcal{L}$) depends on the probability of reconstructing each candidate event j in the sample with the mass m_j , the proper decay length λ_j and proper decay length uncertainty σ^λ_j:

$$\mathcal{L} = \prod_{j=1}^{N} [f_s \mathcal{F}_s(m_j, \lambda_j, \sigma^\lambda_j) + (1 - f_s)\mathcal{F}_b(m_j, \lambda_j, \sigma^\lambda_j)]$$

where f_s is the fraction of signal events, and $\mathcal{F}_s$ ($\mathcal{F}_b$) is the product of the probability distribution functions that model each of the three observables being considered for signal (background) events.

The maximum likelihood fits to the data yield $c\tau(\Lambda_b) = 390.7 \pm 22.4$ μm and $c\tau(B^0) = 452.2 \pm 7.6$ μm. The numbers of signal events, derived from f_s, are 755 ± 49 (Λ_b) and 5671 ± 126 (B^0). Figure 2 shows the λ distributions for the Λ_b and the B^0 candidates. Fit results are superimposed. Using the full data sample collected by the DØ experiment, we measure the lifetime of the Λ_b baryon in the $J/\psi\Lambda$ final state to be [7]

$$c\tau(\Lambda_b) = 1.303 \pm 0.075 \text{ (stat.)} \pm 0.035 \text{ (syst.) ps},$$

consistent with the world average, 1.425 ± 0.032 ps [2].

The method to measure the Λ_b lifetime is also used for $B^0 \to J/\psi K^0_s$ decays, for which we obtain

$$c\tau(B^0) = 1.508 \pm 0.025 \text{ (stat.)} \pm 0.043 \text{ (syst.) ps},$$

in good agreement with the world average, 1.519 ± 0.007 ps [2].

Using these measurements we calculate the ratio of lifetimes, $\tau_{\Lambda_b}/\tau_{B^0} = 0.864 \pm 0.052(\text{stat.}) \pm 0.033(\text{syst.})$ The result, is in good agreement with the HQE prediction of 0.88 ± 0.05 [9] and compatible with the current world-average, 1.00±0.06 [2], but differs with the latest measurement of the CDF Collaboration, 1.02 ± 0.03 [8] , at the 2.2 standard deviations level. These measurements supersede the previous DØ results of τ_{Λ_b}, τ_{B^0} and $\tau_{\Lambda_b}/\tau_{B^0}$ [10].

2 Measurement of the relative branching ratio of $B_s^0 \to J/\psi f_0(980)$ to $B_s^0 \to J/\psi\phi$

The decay $B_s^0 \to J/\psi f_0(980)$, offers an interesting probe of CP violation [14]. In particular, this channel allows us to search for CP-violating New-Physics contributions to $B_s^0\bar{B}_s^0$ mixing, which is conventionally studied via the $B_s^0 \to J/\psi\phi$. The drawback of the $B_s^0 \to J/\psi\phi$ mode is that its final state contains two vector mesons and is thereby a mixture of CP-even and CP-odd eigenstates. Consequently, in order to disentangle the CP eigenstates, a time-dependent angular analysis of the decay products $J/\psi \to \mu^+\mu^-$ and and $\phi \to K^+K^-$ is necessary [15, 16]. In contrast, because the $f_0(980)$ is a scalar state with quantum numbers $J^{PC} = 0^{++}$ [17] , the final state of $B_s^0 \to J/\psi f_0(980)$ is a p-wave state with the CP eigenvalue -1 and thus an angular analysis is not needed [14].

Early in 2011, the LHCb Collaboration released an observation of the $B_s^0 \to J/\psi f_0(980)$ decay mode [11]. This was quickly followed by results from Belle [12] and CDF [13]. The results of these measurements are all in general agreement and point to a ratio of the fraction of $J/\psi f_0(980)$ decays to $J/\psi\phi$ decays.

Based on 8 fb^{-1} of data, DØ has extracted a measurement of the relative branching fraction [18]

$$\frac{\mathcal{B}(B_s \to J/\psi f_0(980); f_0(980) \to \pi^+\pi^-)}{\mathcal{B}(B_s \to J/\psi\phi; \phi \to K^+K^-\ )} = 0.275 \pm 0.041\ (\text{stat.}) \pm 0.061\ (\text{syst.})$$

This agrees with theoretical expectations and with previous measurements of the ratio of widths.

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