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Measurement of the Λ_b lifetime in the decay channel $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda(p\pi^-)$ at the $D\O$ experiment

The DØ Collaboration
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We present a measurement of the Λ_b lifetime in the exclusive decay channel $\Lambda_b \to J/\psi\Lambda$, with $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi$. In adition, the B^0 lifetime is measured in the decay $B^0 \to J/\psi K^0_S$, with $J/\psi \to \mu^+\mu^-$ and $K^0_S \to \pi^+\pi^-$, and the ratio of these lifetimes is computed. The data used in this analysis correspond to aproximately 1 fb^{-1}. The Λ_b lifetime is found to be $\tau(\Lambda_b) = 1.298 \pm 0.137(\text{stat}) \pm 0.050(\text{syst})$ ps, the B^0 lifetime is $\tau(B^0) = 1.492 \pm 0.075(\text{stat}) \pm 0.047(\text{syst})$ ps, and the ratio of these lifetimes is $\tau(\Lambda_b)/\tau(B^0) = 0.870 \pm 0.102$ (stat) ± 0.041 (syst).

Preliminary Results for Summer 2006 Conferences

I. INTRODUCTION

The lifetime of all B hadrons are expected to be equal in a simple quark-spectator model [1], where the b quark decays independently from other (spectator) quarks. However, non-spectator effects give rise to a hierarchy of $\tau(B^+ \geq \tau(B^0) \approx \tau(B_s) > \tau(\Lambda_b) \gg \tau(B_c)$. The measurements of B-hadron lifetimes therefore provide means to determine the importance of non-spectator contributions in B-hadron decays.

This note reports a measurement of the Λ_b lifetime in the decay channel $\Lambda_b \rightarrow J/\psi + \Lambda$, where the J/ψ is reconstructed in the dimuon decay mode and the Λ decays [5] in the $p\pi^-$ mode. A previous measurement on this subject exists [2], but it was perform with around a quarter of the statistics used in the present analysis. As a complementary measurement and in order to compute the ratio of lifetimes $\tau(\Lambda_b)/\tau(B^0)$, which can be compared directly with predictions, the B^0 lifetime is measured through the decay channel $B^0 \rightarrow J/\psi(\mu^+\mu^-) + K^0_S(\pi^+\pi^-)$. This channel is topologically similar to the $\Lambda_b \rightarrow J/\psi + \Lambda$ decay. The data set used for this study corresponds to an integrated luminosity of about 1 fb^{-1}.

II. DATA SELECTION

Preliminary selection of dimuon events requires the presence of at least two muons of opposite charge reconstructed in the toroid system. The muon candidates must have either a central track matched to hits in the muon system, or calorimeter energies consistent with a muon trajectory along the direction of hits extrapolated from the muon layers. The sample of $J/\psi \rightarrow \mu^+\mu^-$ candidates consists of events with at least two muons, with their trajectories constrained in a fit to a common origin. The fit must have a χ^2 probability of $> 1\%$ and the invariant mass of the dimuons must be in the range 2.8$< M(\mu^+\mu^-) <$3.35 GeV/c^2. To reconstruct possible Λ_b or B^0, the J/ψ sample is examined for Λ and K^0_S candidates. The $\Lambda \rightarrow p\pi$ candidates are also required to have two tracks of opposite charge, and must originate from a common vertex with a χ^2 probability of $> 1\%$. A candidate is selected if the mass of the fitted proton-pion system after the vertex constrained fit falls in the 1.1100$< M(p\pi) <$1.1285 GeV/c^2 window. The proton (or $\bar{p}$) mass is assigned to the track of higher momentum, and the p_T of the Λ (or $\bar{\Lambda}$) is required to be $>$2.4 GeV/c. The $K^0_S \rightarrow \pi^+\pi^-$ selection follows the same criteria, except that the mass window is 0.460$< M(\pi^+\pi^-) <$0.525 GeV/c^2, and the $p_T >$1.8 GeV/c. We reconstruct the Λ_b or B^0 by doing a constrained fit to a common vertex for the Λ or K^0_S and the two muon tracks, with the latter constrained to the J/ψ mass of 3.097 GeV/c^2 [3]. If more than one candidate is found in the events then the candidate with the best χ^2 probability is selected as the choice Λ_b (or B^0).

III. FITTING METHOD

We determine the lifetime of a Λ_b and B^0 by measuring the distance traveled in the transverse plane by each B-hadron candidate before it decays, and apply a correction for the Lorentz boost. This distance is defned by the position of the B-hadron decay vertex relative to the primary interaction vertex in the event. The primary vertex is determined for each event by minimizing a $\chi 2$ function that includes the parameters of all tracks and a constraint to the beam spot. We define the transverse decay length as

$$L_{xy} = \frac{\mathbf{L} \cdot \mathbf{p}_T}{|\mathbf{p}_T|} \tag{1}$$

where $\mathbf{L}$ is the vector that points from the primary to the secondary vertex and $\mathbf{p}_T$ is the transverse momentum vector of the B-hadron. The proper decay length (λ) is then given by:

$$\lambda = \frac{L_{xy}}{(\beta\gamma)^B_T} = L_{xy} \cdot \frac{M_B}{p_T} \tag{2}$$

where $(\beta\gamma)^B_T$ and M_B are the tranverse B hadron boost and the mass of the B hadron, respectively. In our measurement the value of M_B in Eq. 2 is set to the known mass values of Λ_b or B^0 [3].

We used unbinned extended likelihood fit to measure the Λ_b and B^0 lifetime. Information of the mass and the proper decay length distributions are used simultaneously to perform the fit. The probability density function (p.d.f.)

used to model the data defined as:

$$\mathcal{F} = \frac{N_s}{N_s + N_b} S_M(M_j) S_\lambda(\lambda_j, \sigma_j) S_E(\sigma_j)$$
$$+ \frac{N_b}{N_s + N_b} \{ f_0 B_{M[sh]}(M_j) B_{\lambda[sh]}(\lambda_j, \sigma_j)$$
$$+ (1 - f_0) B_{M[lg]}(M_j) B_{\lambda[lg]}(\lambda_j, \sigma_j) \} B_E(\sigma_j) \tag{3}$$

where N_s and N_b are the number of signal and background events in the mass peak; S_M is the p.d.f. used to model the mass distributions for signal; $B_{M[sh(lg)]}$ models the mass distributions for the prompt (non-prompt) background; S_λ models the distribution of proper decay length for the signal; $B_{\lambda[sh(lg)]}$ models the distribution of proper decay length for the prompt (non-prompt) background; S_E and B_E are the p.d.f. used to model the σ (error on λ) distribution for the signal and background and f_0 is the fraction of background events in the prompt component.

The mass distribution for signal is modeled by a single Gaussian. The mass distribution of the background is divided in prompt and non-prompt background. The prompt background is assume to follow a flat distribution and the non-prompt component is a second-order polynomial distribution. All zero lifetime distributions have been modeled by the resolution function, which is assumed to be a single Gaussian:

$$G(\lambda_j, \sigma_j) = \left(\frac{1}{\sqrt{2\pi} s \sigma_j} \right) e^{\frac{-\lambda_j^2}{2(s\sigma)_j^2}} \tag{4}$$

where σ_j represent the uncertainty for a given event j, and s is a free parameter in the fit that is introduced to account for possible misestimation of the error on proper decay length. The proper decay length (λ_j) distribution for signal is described by a convolution of an exponential decay with the resolution function:

$$S_\lambda(\lambda_j, \sigma_j) = \frac{1}{\lambda_B} \int_0^\infty G(x - \lambda_j, \sigma_j) e^{-x/\lambda_B} dx \tag{5}$$

where λ_B is $c\tau$ of the Λ_b we want to measure.

The lifetime distribution of background is divided in prompt and non-prompt background. The prompt component is modeled by the resolution function presented by Eq. 4. To describe the non-prompt component we used negative and positive exponential decays to model the combinatory background. In additional, an extra exponential decay was used to take into account any long-lived component.

The distribution of the error on the proper decay length is modeled by a Gaussian convoluted with two exponential decays for the background component (B_E), and a Gaussian convoluted with a exponential decay for the signal component (S_E).

IV. SYSTEMATIC UNCERTAINTIES

Table I summarizes the systematic uncertainties on our measurements. The contribution from any misaligmment of the detector was estimated in a previous analysis [2] by reconstructing the B^0 candidates assuming a geometry for the SMT that is shifted outwards radially by 10 μm. We estimate the systematic uncertainty due to the resolution on lifetime by using two Gaussians for the resolution model. The contribution to systematic uncertainty from the model describing background lifetimes is studied by varying the parametrizations of the different components: (i) the exponential functions are replaced by exponentials convoluted with the resolution function of Eq. 3, (ii) a uniform background is added to account for outlier events (this has only a negligible effect), (iii) the short-lived, positive, and negative lifetime components are forced to be symmetric, and the exponential decay constants of the positive and negative shortlived components are forced to be equal. To study the systematic uncertainty from the model for the mass distributions, we vary the shapes of the mass distributions for signal and background. For the signal, we use two Gaussians instead of a single Gaussian, and for the background distribution a linear function instead of the nominal quadratic form. In order to take into account correlations between the different models, we performed a fit which combines these models. The difference between the result of this fit and the reported lifetime measurement is quoted as the systematic uncertainty.

The decay constant of the exponential decay modeling the long-lived component of the background, is determined by the fit as the average of the long-lived background events in the low and high mass regions around the signal of the Λ_b or B^0. To estimate the effect of any difference between the events in the low and high mass background regions, the model for the long-lived background was replaced with two exponential decays, setting the decay constants to the values found in the high and low mass regions. The difference between the result of the fit using this model and the reported lifetime is taken as the systematic uncertainty.

We also study contamination of our Λ_b sample from B^0 events that pass the Λ_b selection. It has been estimated [4] using Monte Carlo that 6.5% of events in the B^0 sample pass the Λ_b criteria. The invariant mass of B^0 events which contaminate the Λ_b sample are distributed almost uniformly across the entire Λ_b mass range and their proper decay lengths therefore tend to be incorporated in the long-lived component of the background. To estimate the systematic uncertainty due to this contamination, models of the invariant mass and lifetime distributions found in MC are added to the data fit. The difference of the result of this fit to the reported Λ_b lifetime measurement is quoted as the systematic uncertainty. For the B^0 lifetime, any event that is identified as Λ_b is not used in the fit, avoiding this source of systematic for the B^0 lifetime measurement.

Source	Λ_b (μm)	B^0 (μm)	Ratio
Alignment	5.4	5.4	0.0
Models for lifetime and mass distributions	0.7	13.0	0.026
Long-lived background components	1.0	0.4	0.001
Contamination	13.9	–	0.031
Total(added in quadrature)	15.0	14.1	0.041

TABLE I: Summary of systematic uncertainties in the measurements of the Λ_b and B^0 lifetimes and their ratio.

V. RESULTS AND CONCLUSIONS

Using an integrated luminosity of approximately 1 fb^{-1}, the Λ_b lifetime was measured in the decay channel $J/\psi\Lambda$ to be:

$$c\tau(\Lambda_b) = 389.2 \pm 41.0(\text{stat}) \pm 15.0(\text{syst})\ \mu\text{m} \tag{6}$$

$$\tau(\Lambda_b) = 1.298 \pm 0.137(\text{stat}) \pm 0.050(\text{syst})\ \text{ps} \tag{7}$$

The number of reconstructed Λ_b was found to be 174 ± 21. As a consistency check, the lifetime of the B^0, in the decay channel $J/\psi K^0_S$, was also measured:

$$c\tau(B^0) = 447.2 \pm 22.6(\text{stat}) \pm 14.1(\text{syst})\ \mu\text{m} \tag{8}$$

$$\tau(B^0) = 1.492 \pm 0.075(\text{stat}) \pm 0.047(\text{syst})\ \text{ps} \tag{9}$$

The fit finds 762 ± 40 B^0. Using the results of Eq. 6 and Eq. 8, the ratio of lifetimes is found to be:

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.870 \pm 0.102\ (\text{stat})\ \pm 0.041\ (\text{syst}) \tag{10}$$

Correlations have been taken into account in the computing of the systematic uncertainty of this ratio. Both lifetime measurements, $\tau(\Lambda_b)$ and $\tau(B^0)$, are consistent with the world averages.

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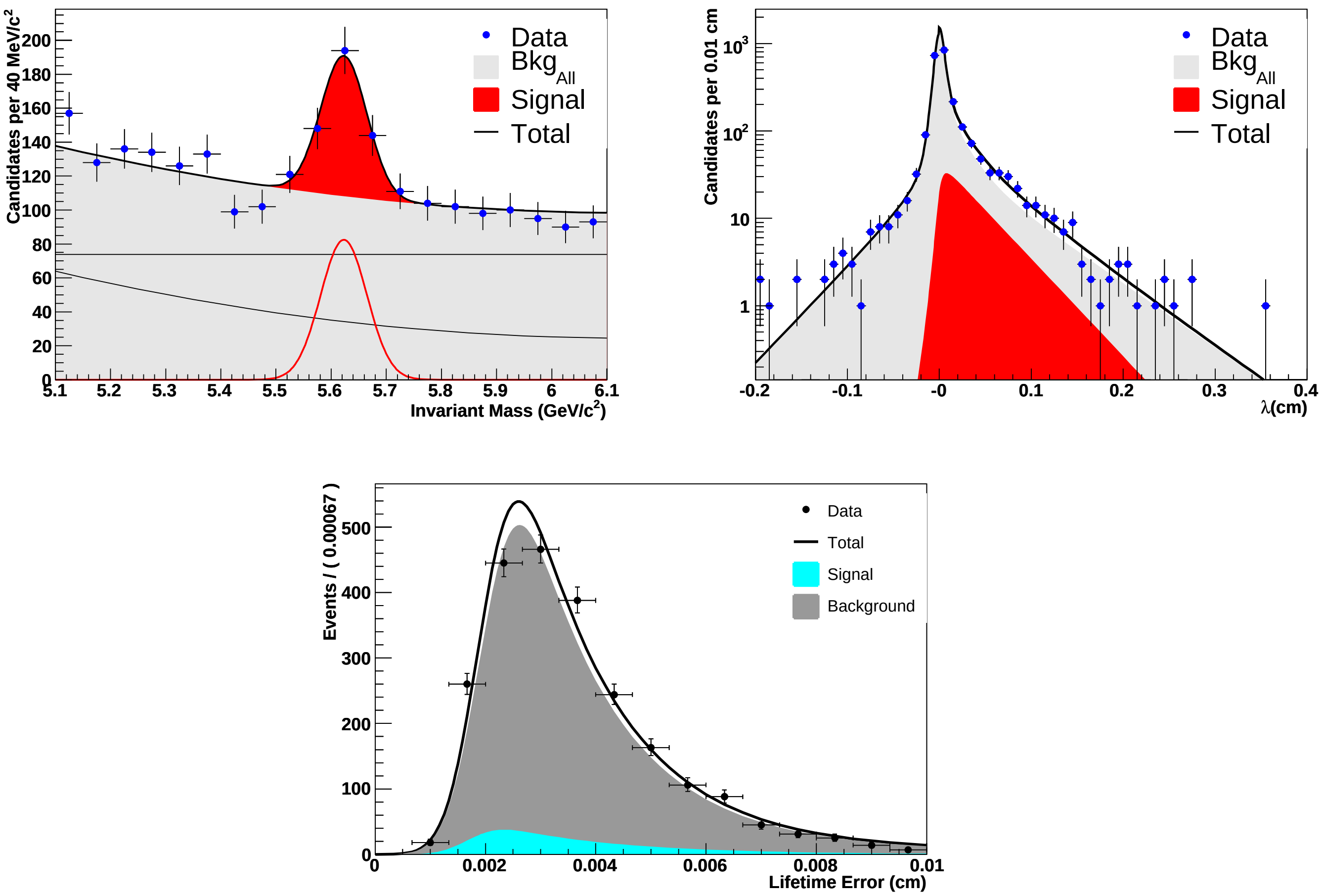

FIG. 1: Projection of the fit result for Λ_b invariant mass (top left) and lifetime (top right) distributions. Distribution of lifetime error (bottom).

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[2] "Measurement of the Λ_b Lifetime in the Decay $\Lambda_b \to J/\psi\Lambda$ with the DØ Detector", V. M. Abazov et al, Phys. Rev. Lett. **94** 102001 (2005); hep-ex/0410054; FERMILAB-Pub-04-286-E.

[3] Particle Data Group, S. Eidelman et. al, Phys. Lett. B **592**, 1 (2004).

[4] E. De La Cruz Burelo, D0 Note 4360.

[5] Unless explicity stated otherwise, the appearance of a specific charge state will also imply its charge conjugate throughout this note