DØnote 4558-CONF

Measurement of the Λ_b lifetime in the decay $\Lambda_b \to J/\psi\Lambda^0$ with the DØ Detector

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We present a measurement of the Λ_b lifetime in the exclusive decay channel $\Lambda_b \to J/\psi\Lambda^0$, with $J/\psi \to \mu^+\mu^-$ and $\Lambda^0 \to p\pi^-$, and of the B^0 lifetime in the decay $B^0 \to J/\psi K_S^0$ with $J/\psi \to \mu^+\mu^-$ and $K_S^0 \to \pi^+\pi^-$, and we also extract the ratio of those lifetimes. The data used in this analysis correspond to an integrated luminosity of approximately 250 pb^{-1}. The Λ_b lifetime is found to be $1.221^{+0.217}_{-0.179}(\text{stat}) \pm 0.043(\text{syst})$ ps, the B^0 lifetime is $1.397^{+0.107}_{-0.098}(\text{stat}) \pm 0.031(\text{syst})$ ps, and the ratio $\tau(\Lambda_b)/\tau(B^0) = 0.874^{+0.169}_{-0.142}(\text{stat}) \pm 0.028(\text{syst})$.

Preliminary Results for Summer 2004 Conferences

I. MOTIVATION

Calculations based in a simple quark spectator model [1] predict that the lifetimes of all B hadrons are equal. Non-spectator effects predict a hierarchy for lifetimes of $\tau(B^+) \geq \tau(B^0) \sim \tau(B_s^0) > \tau(\Lambda_b) \gg \tau(B_c^+)$ [2] . Measurements of B-hadron lifetimes can therefore provide means for determining the importance of non-spectator effects in B decays. Both from theoretical and experimental perspectives, ratios of individual lifetimes provide cleaner tests of these ideas. The most recent compilation of ratios of lifetimes [3] indicate consistency with predictions [4], except for the ratio of τ_{Λ_b} to τ_{B^0}[5], previous measurements of τ_{Λ_b} use semileptonic decay channels, which suffer from uncertainties arising from undetected neutrinos. A measurement of the lifetime using fully reconstructed Λ_b decays can therefore contribute to a reconciliation of the discrepancy between the predictions and previous measurements. The Tevatron Collider at Fermilab is currently the only operating accelelator that is capable of producing Λ_b baryons, and in this note we report a measurement of the Λ_b lifetime in the decay channel $\Lambda_b \to J/\psi\Lambda^0$, and its ratio to the B^0 lifetime from the $B^0 \to J/\psi\ K_S^0$ channel. The J/ψ is reconstructed in the $\mu^+\mu^-$ decay mode, the Λ^0 in $p\pi^-$ (or $\overline{\Lambda^0}$ in $\bar{p}\pi^+$), and the K_S^0 in $\pi^+\pi^-$. The data used in this analysis were collected with the DØ detector at a center-of-mass energy of 1.96 TeV during the 2002-2004 collider run, and correspond to an integrated luminosity of approximately 250 pb^{-1}.

II. DETECTOR

The DØ detector is comprised of the following main elements [6]. A magnetic central-tracking system, which consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located within a 2 T superconducting solenoidal magnet. The SMT has $\approx 800,000$ individual strips, with typical pitch of $50-80\ \mu$m, and a design optimized for tracking and vertexing capability at pseudorapidities $|\eta| < 3$. The system has a six-barrel longitudinal structure, each with a set of four layers arranged axially around the beam pipe, and interspersed with 16 disks. The CFT has eight thin coaxial barrels, each supporting two doublets of overlapping scintillating fibers of 0.835 mm diameter, one doublet being parallel to the collision axis, and the other alternating by $\pm 3°$ relative to the axis. Light signals are transferred via clear light fibers to solid-state photon counters (VLPC) that have $\approx 80\%$ quantum efficiency.

A muon system resides beyond the calorimetry, and consists of a layer of tracking detectors and scintillation trigger counters preceding 1.8 T toroids, followed by two similar layers downstream of the toroids. Tracking at $|\eta| < 1$ relies on 10 cm wide drift tubes [7], while 1 cm mini-drift tubes are used at $1 < |\eta| < 2$. Coverage for muons is partially compromised in the region of $|\eta| < 1$ and $|\phi| < 0.2$ rad, where the calorimeter is supported mechanically from the ground.

III. 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 $J/\psi \to \mu^+\mu^-$ 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^0 and K_S^0 candidates. The $\Lambda^0 \to p\pi^-$ 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^0 (or $\overline{\Lambda^0}$) is required to be >2.4 GeV/c. The $K_S^0 \to \pi^+\pi^-$ 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 one "Vee" (the Λ^0 or K_S^0) and the two muon tracks, with the latter constrained to the J/ψ mass of 3.097 GeV/c^2 [8]. 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).

IV. MODELING AND FITTING

We determine the lifetime of a Λ_b or 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 defined by the position of the

primary interaction vertex in the event relative to seconday B-decay vertex. The primary vertex (PV) is determined [9] for each event by minimizing a χ^2 function that includes the parameters of all tracks and a term that represents a constraint on the beam spot. The beam spot is stable during a store, and can therefore be used to constrain the primary vertex in the fit. It is calculated for each run, where a run typically lasts several hours. The position of a primary vertex for each event is reconstructed using all tracks. However, if including any track in a fit to the PV increases the χ^2 by >9, then this track is discarded. We define the transverse decay length as $L_{xy} = \boldsymbol{L}_{xy} \cdot \boldsymbol{p}_T/|\boldsymbol{p}_T|$ where $\boldsymbol{L}_{xy}$ is the vector that points from the primary to the secondary vertex and $\boldsymbol{p}_T$ is the transverse momentum vector of the B-hadron. The proper decay length (PDL) is then given by:

$$\lambda_B = \frac{L_{xy}}{(\beta\gamma)_T^B} = L_{xy}\,\frac{M_B}{p_T} \tag{1}$$

where $(\beta\gamma)_T^B$, 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. 1 is set to the known mass values of Λ_b or B^0 [8]. In our final selection of Λ_b and B^0 candidates, we also require that the uncertainty on the proper decay length be less than 100 microns.

We use an unbinned likelihood function ($\mathcal{L}$) to measure the Λ_b and B^0 lifetimes; with $\mathcal{L}$ defined as:

$$\mathcal{L} = \prod_{j=1}^{N} \left[f_s S_M(M_j) S_L(\lambda_j, \sigma_j) + (1 - f_s) B_M(M_j) B_L(\lambda_j, \sigma_j) \right] \tag{2}$$

where N is the total number of selected events, f_s is the fraction of signal in the sample, S_M and B_M are the probability distribution functions used to model the mass distributions for signal and background, respectively; S_L and B_L model the distributions of proper decay lengths for signal and background. The mass (M_j) distribution for signal is modeled by a single Gaussian and the background by a second-order polynomial. The proper decay length (λ_j) distribution for signal is described by a convolution of an exponential decay with a resolution function, with the latter represented by a single Gaussian:

$$G(\lambda_j, \sigma_j) = \left(\frac{1}{\sqrt{2\pi} s \sigma_j} \right) e^{\frac{-\lambda_j^2}{2(s\sigma_j)^2}}. \tag{3}$$

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 lifetime distribution for background is described by a sum of a resolution function, representing the zero-lifetime component and negative and positive exponential decay functions modeling combinatorial background and an exponential decay that accounts for long-lived heavy flavor decays. Minimizing $-\ln \mathcal{L}$ yields $c\tau(\Lambda_b) = 366.0^{+65.2}_{-53.6}\ \mu m$ and $c\tau(B^0) = 418.7^{+32.0}_{-29.3}\ \mu m$. The extracted number of events is, $61 \pm 12\ \Lambda_b$ and $291 \pm 23\ B^0$. Figures 1 and 2; and Figures 3 and 4 show the mass and proper decay-length distributions for the Λ_b and B^0 candidates, respectively, with the result of the fit superimposed on the data points.

V. SYSTEMATIC UNCERTAINTIES

Table I summarizes the systematic uncertainties on our measurements. One of the dominant contributions is from any misalignment of the detector. This effect on our measurement is estimated by reconstructing the higher statistics 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. For the fit to data, the long-lived component is modeled by an exponential decay. The value of the decay constant for that function in the signal region is taken as the average of the decay constants for the low and high-mass regions. A systematic uncertainty is obtained by using two

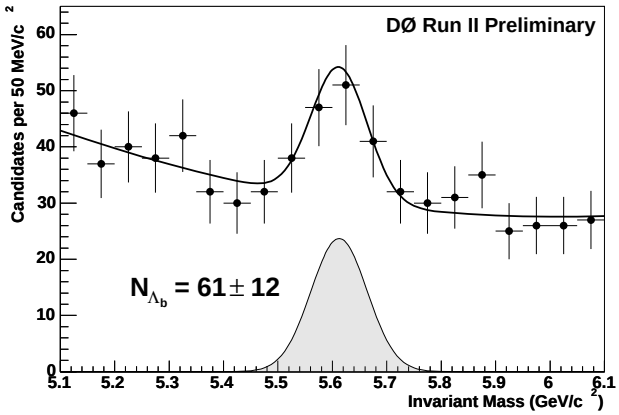

FIG. 1: Mass distribution for Λ_b candidate events. Points are the data, and the solid line represents the result of the fit.

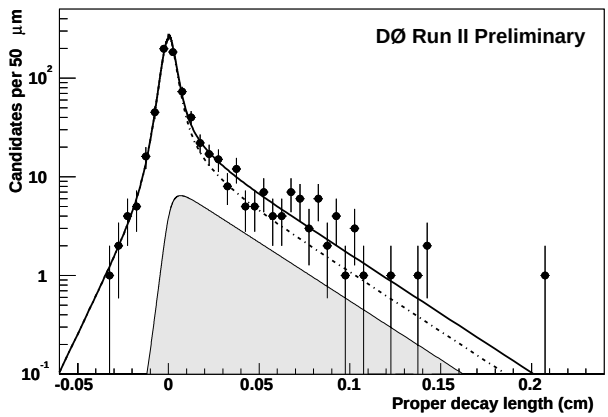

FIG. 2: Distributions in proper decay lengths for Λ_b candidates. The points are the data, and the solid line is the sum of the contributions from signal (gray) and the background (dashed-dotted line).

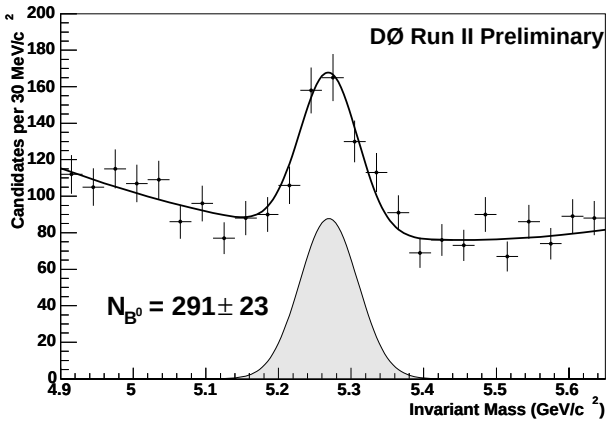

FIG. 3: Mass distribution for B^0 candidate events. Points are the data, and the solid line represents the result of the fit.

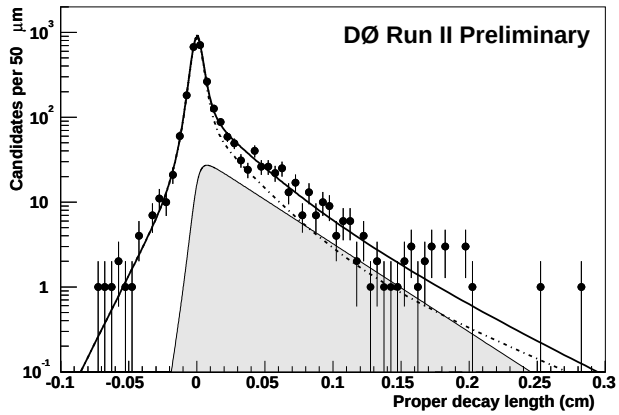

FIG. 4: Distributions in proper decay lengths for B^0 candidates. The points are the data, and the solid line is the sum of the contributions from signal (gray) and the background (dashed-dotted line).

TABLE I: Summary of systematic uncertainties in the measurement of the Λ_b and B^0 lifetimes and their ratio. The individual errors are also shown combined in quadrature.

Source	Λ_b (μm)	B^0 (μm)	Ratio
Alignment	5.4	5.4	0.002
Model for resolution	6.7	2.7	0.010
Decays convoluted	2.7	0.5	0.005
Short-lived decays	0.5	3.1	0.008
Long-lived components	1.5	0.1	0.003
Model for signal mass	0.2	0.0	0.000
Model for background mass	2.5	6.2	0.007
Contamination	8.8	0.8	0.023
Total	12.9	9.2	0.028

exponential decays instead of one, and setting the values of the decay constants to the values in the high and low-mass regions, allowing the fraction of the two factors to float. The difference between this result and the one using a single central value for the lifetime is taken as the contribution to the systematic error. We also explore any possible biases resulting from our fitting procedure. This is based on 1000 MC experiments, each of which is generated with statistics of the data. Similarly, the distribution in uncertainty of lifetimes is generated assuming lifetime uncertainties in data, and the mass and lifetime distributions also generated according to the parameters obtained from the fit to data. The fits performed to those distributions of ensembles indicate that there is no bias inherent in the procedure. We also study contamination of our Λ_b sample from B^0 events that pass the Λ_b selection. From Monte Carlo we find that 6.5% of events in B^0 samples pass the Λ_b criteria and we use those fractions to estimate that of the 291 B^0 events, 19 events are reconstructed as Λ_b. We find that the invariant masses of the B^0 events entering the Λ_b sample are distributed almost uniformly across the entire mass range, and do not peak at the Λ_b mass. Their proper decay lengths therefore tend to be incorporated in our model of the long-lived heavy-flavor component of the background. To estimate the systematic uncertainty, from cross-feed contamination, we first fit the mass and proper decay length MC distributions, and we add this contribution to the likelihood with their parameters fixed, and perform the fit again. The difference between the two results is quoted as the systematic uncertainty from cross-feed.

We also perform several crosschecks. In particular, a fit is done where the background is modeled using sideband regions, the J/ψ vertex is used instead of the B-hadron vertex , the mass windows are varied, the reconstructed B-hadron mass is used instead of the PDG value, the sample is split into different pseudorapidity regions or different regions of azimuth. All results obtained in such variations are consistent with our central values.

VI. RESULTS AND CONCLUSIONS

The results of our measurement of the Λ_b and B^0 lifetimes can be summarized as:

$$\tau(\Lambda_b) = 1.221^{+0.217}_{-0.179}\ (\text{stat}) \pm 0.043\ (\text{syst})\ \text{ps}$$
$$\tau(B^0) = 1.397^{+0.107}_{-0.098}\ (\text{stat}) \pm 0.031\ (\text{syst})\ \text{ps} \tag{4}$$

These can be combined to determine the ratio of lifetimes:

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.874^{+0.169}_{-0.142}\ (\text{stat}) \pm 0.028\ (\text{syst}). \tag{5}$$

where we take into account the correlations among systematic uncertainties in both measurements.

In conclusion, we have measured the Λ_b lifetime in the fully reconstructed exclusive decay channel $J/\psi\Lambda^0$. The measurement is consistent with the world average, 1.229 ± 0.080 ps, and the Λ_b to B^0 ratio of lifetimes is also consistent with current prediction of 0.9 [4] .

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