DØnote 4519-CONF

Measurement of the B_s^0 lifetime in the exclusive decay channel $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ at DØ

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URL http://www-d0.fnal.gov

(Dated: August 5, 2004)

We report a measurement of the B_s^0 lifetime in the exclusive decay channel $B_s^0 \to J/\psi(\mu^+\mu^-)$ $\phi(K^+K^-)$. The data sample consists of approximately 220 pb^{-1} collected with the Run II DØ detector. We reconstruct 337 signal candidates, from which we extract the B_s^0 lifetime of $\tau_s = 1.444^{+0.098}_{-0.090}\,(\mathrm{stat}) \pm 0.020\,(\mathrm{syst})$ ps. We also report a measurement for the exclusive decay $B^0 \to J/\psi(\mu^+\mu^-)K^{*0}(K^+\pi^-)$ of $\tau_d = 1.473^{+0.052}_{-0.050}\,(\mathrm{stat}) \pm 0.023\,(\mathrm{syst})$ ps, and the ratio of lifetimes as $\tau_s/\tau_d = 0.980^{+0.075}_{-0.070}\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst})$.

Preliminary Results for Summer 2004 Conferences

I. INTRODUCTION

Lifetime differences among hadrons containing b quarks can be used to probe decay mechanisms that go beyond the quark-spectator model [1]. It has been observed in the charm sector that such differences are quite large [2]. However, for the bottom sector, due to the larger b-quark mass, these differences should be smaller. Phenomenological models predict differences of about 5% between the lifetimes of B^+ and B^0, but no more than 1% for B^0 and B_s^0 lifetimes [1]. These predictions are consistent with previous measurements of B-meson lifetimes [2]. It has also been postulated [3] that the lifetimes of the two CP eigenstate mixtures of the B_s^0 and $\bar{B}_s^0$ may differ. This could be observed in a difference in lifetime between B_s^0 semileptonic decays, which should have an equal mixture of the two CP eigenstates, and the lifetime for $B_s^0 \rightarrow J/\psi\phi$, which is expected to be dominated by CP even eigenstates [3].

In this note, we report a measurement of the lifetime of the B_s^0 meson using the exclusive decay channel $B_s^0 \rightarrow J/\psi$ ϕ, followed by $J/\psi \rightarrow \mu^+\mu^-$, and $\phi \rightarrow K^+K^-$. The lifetime is extracted using a simultaneous unbinned maximum likelihood fit to distributions in the mass and the proper decay length. We also measure the lifetime of the B^0 meson in the exclusive decay $B^0 \rightarrow J/\psi\ K^{*0}$, followed by $J/\psi \rightarrow \mu^+\mu^-$, and $K^{*0} \rightarrow \pi^-K^+$, and extract the ratio of lifetimes of the B_s^0 and B^0 mesons. The analysis is based on data collected with the Run II DØ detector during the period September 2002– February 2004, which corresponds to approximately 220 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

II. ANALYSIS

A. Detector

The DØ detector has been described in detail elsewhere [4]. We describe here only the detector componentes most relevants to this analysis. The magnetic central-tracking system of the detector, consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located inside a 2 T superconducting solenoidal magnet [5]. The SMT has $\approx 800,000$ individual strips, with typical pitch of $50 - 80$ μm, and a design optimized for tracking and vertexing capability at $|\eta| < 3$, where $\eta = -ln[tan(\theta/2)]$. 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 radial 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. The MUON system resides beyond the calorimetry [4], and consists of a layer of tracking detectors and scintillation trigger counters before 1.8 T toroids, followed by two more similar layers after the toroids. Tracking at $|\eta| < 1$ relies on 10 cm wide drift tubes [4], 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. Luminosity is measured using plastic scintillator arrays located in front of the end cap calorimeter cryostats, covering $2.7 < |\eta| < 4.4$.

The data collection for this analysis was based on a three-level trigger system, which was designed to accommodate the large luminosity of Run II. The first level uses preliminary information from tracking, calorimetry, and muon systems to reduce the rate for accepted events to ≈ 1.5 kHz. At the next trigger stage, with more refined information, the rate is reduced further to ≈ 800 Hz. These first two levels of triggering rely purely on hardware and firmware. The third and final level of the trigger, with access to all the event information, uses software algorithms and a computing farm, and reduces the output rate to ≈ 50 Hz, which is written to tape for further analysis.

B. Reconstruction of $B_s^0 \rightarrow J/\psi\phi$

Reconstruction of $B_s^0 \rightarrow J/\psi\phi$ candidates is based on having a pair of oppositely charged tracks that extrapolated from the muon system to match trajectories in the central tracker. All charged tracks used in this analysis are required to have at least one hit in the SMT and one in the CFT. We require that the two muon tracks have a minimum p_T of 1.5 GeV/c and that them form a common vertex, according to the algorithm described in Ref. [6] which is based on a χ^2 fit that requires a χ^2 probability of $> 1\%$. The invariant mass of the dimuon system must be consistent with the J/ψ mass, i.e., reconstructed between 2.90 and 3.25 GeV/c^2, and have a $p_T > 4.5$ GeV/c. This is subsequently combined with another pair of oppositely charged tracks, each with $p_T > 0.8$ GeV/c, consistent with the decay $\phi \rightarrow K^+K^-$. The p_T of the ϕ candidate has to be > 2 GeV/c, and must have an invariant mass between 1.008 and 1.032 GeV/c^2. A four-track vertex is fitted to the products of the J/ψ and ϕ decays, and required to have a χ^2 probability $> 1\%$. The mass of the J/ψ candidate is constrained in the fit to the known J/ψ mass of 3.097 GeV/c^2 [2]. The resulting B_s^0 candidate is required to have $p_T > 6.5$ GeV/c. We allow only one B_s^0 candidate per event, and when multiple candidates exist, we chose the one with the best vertex probability. The resulting invariant mass distribution of the J/ψ-ϕ system is shown in Fig. 1(a).

We take the four-track vertex as the position of the secondary vertex, to measure the lifetime of the B_s^0, we use the transverse distance traveled by each B_s^0 candidate from the primary vertex. Each primary vertex is reconstructed using selected tracks and the mean beam-spot position. The latter is calculated for every run, where a typical run lasts several hours. The initial primary vertex is defined by all available tracks, tracks are removed when a track causes a change of more than 9 units in the χ^2 for a fit to a common vertex. The process is repeated until no more tracks can be removed [6].

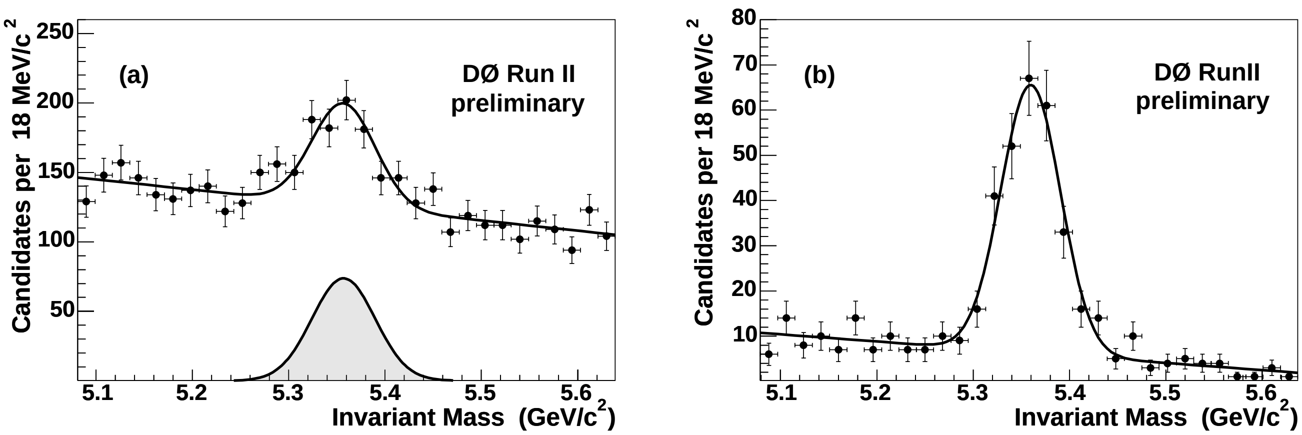

FIG. 1: (a) Invariant mass distribution for reconstructed B_s^0 candidates; (b) same distribution after applying a cutoff on the significance $c\tau/\sigma(c\tau) > 5$.

C. Lifetime-Fitting Technique

To determine the distance traveled by each B_s^0 candidate, we calculate the signed transverse decay length, defined as $L_{xy} = \vec{x} \cdot (\vec{p_T}/|\vec{p_T}|)$, where $\vec{x}$ is the length vector pointing from the primary to the secondary vertex and $\vec{p_T}$ is the reconstructed transverse momentum vector of the B_s^0. The proper decay length of the B_s^0 candidate is then defined as $c\tau = L_{xy}(M_{B_s^0}/p_T)$, where $M_{B_s^0}$ is taken as the known mass of the B_s^0 meson [2].

Figure 1(b) shows the reconstructed invariant mass distribution of the B_s^0 candidates after a lifetime significance requirement of $c\tau/\sigma(c\tau) > 5$ is imposed, where $\sigma(c\tau)$ is the uncertainty on $c\tau$. The signal region clearly contains lifetime information, and the background mass region is expected to be dominated by prompt components.

The proper decay length (without cutoffs on significance) and the invariant mass distributions for candidates passing the above criteria are fitted simultaneously using an unbinned maximum likelihood method. The likelihood function $\mathcal{L}$ is given by:

$$\mathcal{L} = \prod_i^N [f_s \mathcal{F}_s^i + (1 - f_s)\mathcal{F}_b^i],$$

where $\mathcal{F}_s$ is the product of probability density functions for mass and proper decay length for B_s^0, $\mathcal{F}_b$ is the equivalent for background, f_s is the fraction of signal, and N is the total number of candidate events in the sample.

The proper decay length for signal is modeled by a normalized exponential-decay function convolved with a Gaussian of width equal to the uncertainty on the proper decay length, which is typically $\approx 25\ \mu$m. This uncertainty is obtained from the full covariance matrix for tracks at the secondary vertex and the uncertainty in position of the primary vertex. The uncertainty is multiplied by a scale factor, that is parameter in the fit, to allow for a possible misestimation of the resolution in decay length. The signal mass is modeled by a Gaussian function.

The proper decay length for background is parametrized as a sum of a Gaussian function centered at zero, and exponential decay functions, with a short-lived and a long-lived term. The long-lived component used accounts for heavy-flavor backgrounds, while the other terms account for resolution and prompt contributions to background. The mass distribution for background is modeled by a first-order polynomial.

To determine the background we use a wide mass range of 5.0780–5.6360 GeV/c^2 in the fit. The number of background candidates in this range is sufficiently large to measure the parameters of the background with a good accuracy and thereby extract a good measure of the signal fraction and lifetime. The fit provides the lifetime and mass of the B_s^0, the shape of proper decay length and mass distributions for background, and the fraction of signal. Table I lists the fitted values of the parameters and their uncertainties. The distribution in proper decay length and fits to the B_s^0 candidates are shown in Fig. 2(a).

TABLE I: Values of extracted mass (M_B), resolution on the reconstructed mass (σ_M), the measured lifetimes (λ^B), and the signal fraction.

Parameter	$B_s^0 \to J/\psi\phi$ fitted values	$B^0 \to J/\psi K^{*0}$ fitted values
M_B	5357.0 ± 2.5 MeV/c^2	5271.2 ± 1.5 MeV/c^2
σ_M	$32.9^{+2.5}_{-2.3}$ MeV/c^2	$37.9^{+1.4}_{-1.3}$ MeV/c^2
λ^B	$432.9^{+29.5}_{-27.0}$ μm	$441.7^{+15.7}_{-15.1}$ μm
f_s	0.080 ± 0.006	0.045 ± 0.002

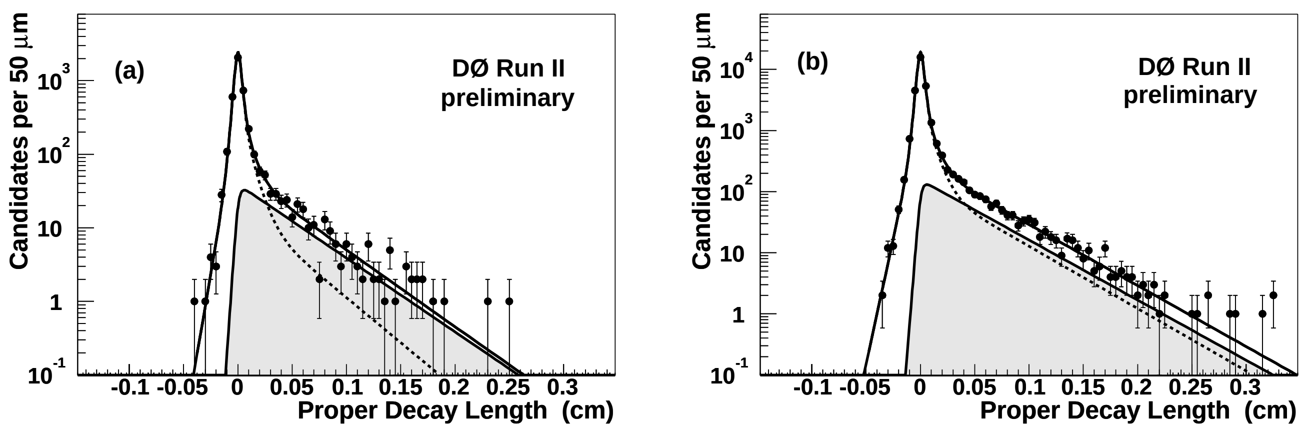

FIG. 2: Proper decay length distributions for (a) B_s^0 and (b) B^0 candidates. The solid line shows the total fit, the dashed line the background component, and the shaded region the signal.

D. Reconstruction of $B^0 \to J/\psi K^{*0}$

With a very similar four-track topology in the final state, the exclusive decay $B^0 \to J/\psi K^{*0}$ followed by $J/\psi \to \mu^+\mu^-$ and $K^{*0} \to K^+\pi^-$ is reconstructed using the same selection criteria and algorithms as for the B_s^0 channel described above. The only differences are the requirement that the p_T of the pion be > 0.5 GeV/c, and the selection of the K^{*0} candidates. The combination of two oppositely charged tracks, assuming a pion for one and a kaon mass for the other, that gives an invariant mass closest to the known mass of K^{*0} [2] is selected for candidacy. This invariant mass is required to be between 0.850 and 0.930 GeV/c^2. The resulting invariant mass distribution is shown in Fig. 3(a). Figure 3(b) shows the same invariant mass distribution after imposing a requirement on significance of proper decay length. Using the sample of B^0 candidates in the mass range 4.9355–5.6105 GeV/c^2, we determine the lifetime and mass of the B^0 using exactly the same procedure as used for B_s^0 mesons. Results are also given in Table I, and the distribution in proper decay length is shown in Fig. 2(b).

E. Consistency Checks and Systematics

Detailed Monte Carlo studies were performed on emsembles of events comparable to data samples, regarding resolutions, pulls, and fitting and selection criteria and no significant biases were observed resulting from our analysis procedures. To test the stability of the lifetime of the B_s^0 and B^0 mesons, we split each data sample roughly in

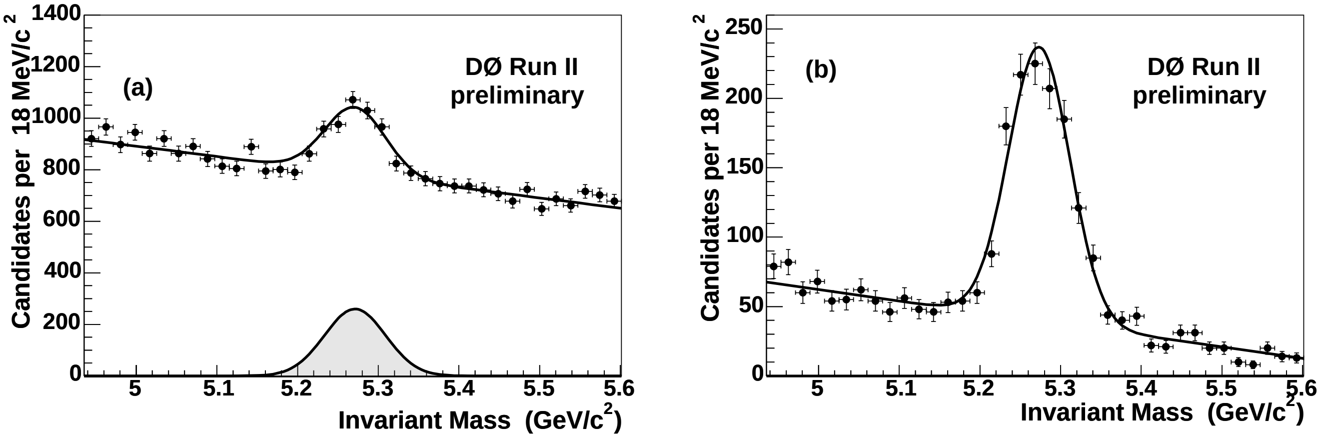

FIG. 3: (a) Invariant mass distribution for reconstructed B^0 candidates; and (b) after the requirement on $c\tau/\sigma(c\tau) > 5$ is applied to the data.

two parts according to different kinematic and geometric parameters, and compared the fitted results, and found the lifetimes consistent within their uncertainties. We varied the selection criteria and mass fit ranges, and did not observe any significant shifts. To study possible baises from our fitting procedure, we used Monte Carlo emsembles with statistics of our data and with distributions as those in data, these samples were fitted, and the mean and width of the distributions of extracted parameters was found to be consistent with the fits to data. Monte Carlo samples with different input lifetime were used to check the response of our fits to lifetime, and found to be linear in the range of lifetimes corresponding to 340 to 560 μm. We studied the contamination of our sample from cross-feed between B_s^0 and B^0 using Monte Carlo. The estimated contamination was 4.4% for B_s^0 and 1.1% for B^0 but with invariant mass spread almost uniformly across the entire mass range, and their lifetimes therefore incorporated into the long-lived heavy-flavor component of the background.

Several other sources of systematic uncertainty have been considered, and the contributions listed in Table II. For the B_s^0 lifetime, there are major contributions from determination of the background, the model for resolution, and the reconstruction of the secondary vertex. To determine the systematic error due to the uncertainty on background, we consider different models for the mass and decay-length distributions. In particular, to account for any dependence of the model on the invariant mass of misreconstructed heavy-flavor hadrons, we fitted separately the probability distributions in the lower-mass and higher-mass side-band regions. Combining the two lifetime values for the long-lived components, we then modified the functional form of the long-lived components for the global background in our fit. The two long-lived components were combined using a parameter to weight the two contributions. Then, this weighting parameter was changed by $\pm$ one standard deviation (s.d.) of its original value. The largest difference in lifetime observed in these variations of background modeling was found to be 4 μm, and is taken to be the systematic error due to this source. The effect of uncertainty in the resolution of the decay length wass studied by using an alternative resolution function consisting of two Gaussian functions (with the same mean but different s.d.), resulting in a difference in fitted lifetime of 3 μm. Uncertainty or biases in the determination of the secondary vertex were estimated using only the J/ψ tracks as the secondary vertex, resulting in a lifetime shift of 3 μm. The effect of a possible misalignment of the SMT system was tested by reprocessing the B_s^0 candidate events through the SMT sensors shifted by their positional uncertainty. The resulting difference in fitted lifetime of 2 μm is taken as a systematic error due to possible misalignment. The total systematic uncertainty from all these sources added in quadrature is 6 μm. The evaluation of systematic uncertainties in the measurement of the B^0 lifetime is determined in the same way as for the B_s^0 lifetime, and each constribution is listed in Table II.

III. RESULTS AND CONCLUSIONS

We have determined the lifetimes of the B_s^0 and B^0 mesons to be

$$\tau(B_s^0) = 1.444^{+0.098}_{-0.090}\ \text{(stat)} \pm 0.020\ \text{(syst) ps},$$

and

$$\tau(B^0) = 1.473^{+0.052}_{-0.050}\ \text{(stat)} \pm 0.023\ \text{(syst) ps}.$$

Both results are consistent with the current world averages of $\tau(B_s^0) = 1.461 \pm 0.057$ and $\tau(B^0) = 1.536 \pm 0.014$ [2]. Using our results we determine the ratio of B_s^0/B^0 lifetimes:

$$\frac{\tau_s}{\tau_d} = 0.980 \ {}^{+0.075}_{-0.070} \ (\text{stat}) \ \pm 0.003 \ (\text{syst}),$$

where the statistical errors were propagated in quadrature, while the systematic uncertainty was evaluated by adding each contribution to the corresponding central value, and evaluating a new ratio, with the difference from nominal value taken as the systematic uncertainty of that source, as shown in Table II. The sum in quadrature of all contributions is reported as the global systematic uncertainty for the ratio of lifetimes.

In conclusion, we have measured the B_s^0 and B^0 lifetimes in exclusive decay modes in $p\bar{p}$ collisions. The measurements are consistent with previous results [2]. The B_s^0 lifetime is the currently best measurement in any single experiment. The ratio is also in good agreement with QCD models based on a heavy quark expansion, which predict a difference between B_s^0 and B^0 lifetimes of the order of 1% [1].

TABLE II: Summary of systematic uncertainties.

	$B_s^0 \to J/\psi\phi$ (μm)	$B^0 \to J/\psi K^{*0}$ (μm)	τ_s/τ_d
Alignment	2	2	0.000
J/ψ vertex	3	4	0.002
Model for resolution	3	3	0.000
Background	4	5	0.002
Total	**6**	**7**	**0.003**

Acknowledgments

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the Department of Energy and National Science Foundation (USA), Commissariat à L'Energie Atomique and CNRS/Institut National de Physique Nucléaire et de Physique des Particules (France), Ministry for Science and Technology and Ministry for Atomic Energy (Russia), CAPES, CNPq and FAPERJ (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), The Foundation for Fundamental Research on Matter (The Netherlands), PPARC (United Kingdom), Ministry of Education (Czech Republic), Natural Sciences and Engineering Research Council and WestGrid Project (Canada), BMBF (Germany), A.P. Sloan Foundation, Civilian Research and Development Foundation, Research Corporation, Texas Advanced Research Program, and the Alexander von Humboldt Foundation.

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