Fermi National Accelerator Laboratory

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CDF

Average and Individual B Hadron Lifetimes at CDF

Olivier Schneider
Representing the CDF Collaboration

Lawrence Berkeley Laboratory
Berkeley, California 94720

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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Olivier Schneider

Lawrence Berkeley Laboratory
Berkeley, CA 94720, USA

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Abstract

Bottom hadron lifetime measurements have been performed using $B \rightarrow J/\psi\ X \rightarrow \mu^+\mu^- X$ decays recorded with the Collider Detector at Fermilab (CDF) during the first half of the 1992-1993 Tevatron collider run. These decays have been reconstructed in a silicon vertex detector. Using 5344 ± 73 inclusive J/ψ events, the average lifetime of all bottom hadrons produced in 1.8 TeV $p\bar{p}$ collisions and decaying into a J/ψ is found to be $1.46 \pm 0.06(\text{stat}) \pm 0.06(\text{sys})\,ps$. The charged and neutral B meson lifetimes have been measured separately using 75 ± 10 (charged) and 61 ± 9 (neutral) fully reconstructed decays; preliminary results are $\tau^{\pm} = 1.63 \pm 0.21(\text{stat}) \pm 0.16(\text{sys})\,ps$ and $\tau^0 = 1.54 \pm 0.22(\text{stat}) \pm 0.10(\text{sys})\,ps$, yielding a lifetime ratio of $\tau^{\pm}/\tau^0 = 1.06 \pm 0.20(\text{stat}) \pm 0.12(\text{sys})$.

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1 Introduction

The Collider Detector at Fermilab (CDF) [1] has been upgraded for the 1992-1993 Tevatron Collider run with a silicon microstrip vertex detector, the SVX [2]. Designed as 4 concentric layers of silicon strips (60 μm pitch) parallel to the Tevatron beams at radii ranging from 3 to 8 cm, the SVX provides a very good spatial resolution in the transverse plane [3] and enables CDF to perform the first B lifetime measurements at a hadron collider.

The results summarized here are obtained using the first half of $\sim$ 22 pb^{-1} of data collected by CDF during its first run with the SVX. Because they are limited by the available statistics, the measurements presented in Section 2 on the B^+ and B^0 lifetimes (and described in more detail in Ref. [4]) will remain preliminary until the full data sample is analyzed. The average b-hadron lifetime measurement reported in Section 3 does not suffer from low statistics and has been submitted for publication [5].

2 B^+ and B^0 lifetime analysis *

Estimates for the B^+ and B^0 lifetime are obtained by fitting the proper decay length distributions of charged and neutral B mesons candidates that are fully reconstructed in the SVX in one of the following decay modes (or their charge conjugates),

$$\begin{array}{lcl} B^+ & \rightarrow & J/\psi\ K^+,\ \ J/\psi\ K^*(892)^+,\ \ \psi(2S)\ K^+,\ \text{ or }\ \psi(2S)\ K^*(892)^+, \\ B^0 & \rightarrow & J/\psi\ K^0_S,\ \ J/\psi\ K^*(892)^0,\ \ \psi(2S)\ K^0_S,\ \text{ or }\ \psi(2S)\ K^*(892)^0, \end{array}$$

where $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$, $J/\psi \rightarrow \mu^+\mu^-$, $K^*(892)^0 \rightarrow K^+\pi^-$, $K^*(892)^+ \rightarrow K^0_S\pi^+$, and $K^0_S \rightarrow \pi^+\pi^-$. The hardware part of the J/ψ trigger used for this analysis required two charged tracks in the muon chambers (covering the range $|\eta| < 1$, where $\eta = -\ln[\tan(\theta/2)]$), one of them being matched with a track reconstructed in the central tracking chamber (CTC), whereas the software part required the two muons to have opposite charges and a mass close to the J/ψ mass. Offline requirements applied to clean-up the J/ψ sample include good matching between the CTC tracks and the associated muon chamber hits, a minimum hadronic energy deposition in the calorimeter, and a transverse momentum $p_t > 2.5\ GeV/c$ for one of the muons to ensure a reasonable trigger efficiency. The two muons are required to have at least 2 hits each in the SVX detector, to come from a common vertex (vertex constrained fit), and to have a mass within $\pm 80\ MeV/c^2$ of the world average J/ψ mass (see Figure 1). $\psi(2S)$ candidates are reconstructed by combining a J/ψ candidate with two additional tracks having opposite charges and at least 2 SVX hits each; the 4 tracks are vertex constrained while the two muons are constrained to have the J/ψ mass. K^0_S candidates are reconstructed by vertex constraining pairs of oppositely charged tracks that have a large impact parameter with respect to the beam position; the K^0_S candidates are required to have a positive decay length and an impact parameter of less than 2 mm with

*This analysis has been updated since it was presented at the symposium; the new improved results are reported here.

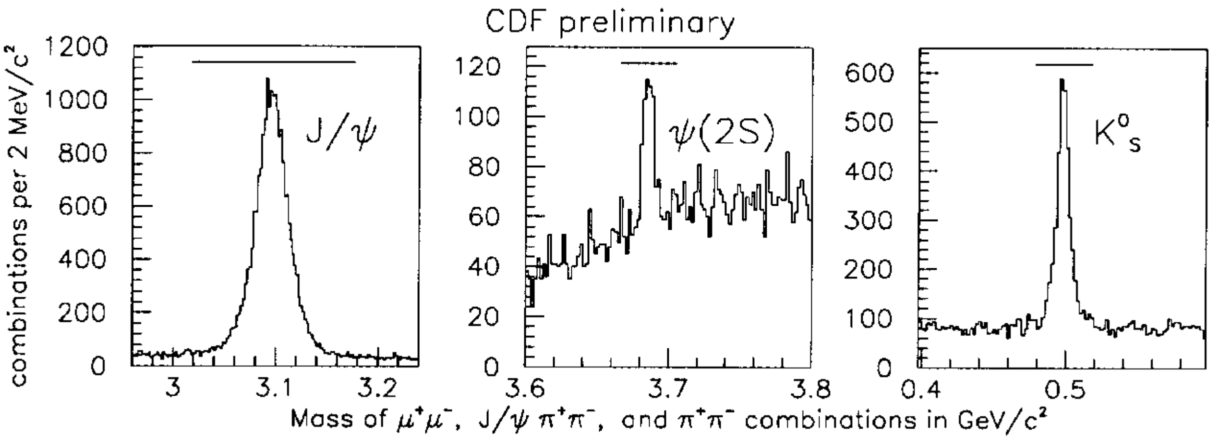

Figure 1: *Mass distributions of the J/ψ, $\psi(2S)$, and K_S^0 candidates. The mass cuts are indicated by the horizontal lines above the histograms.*

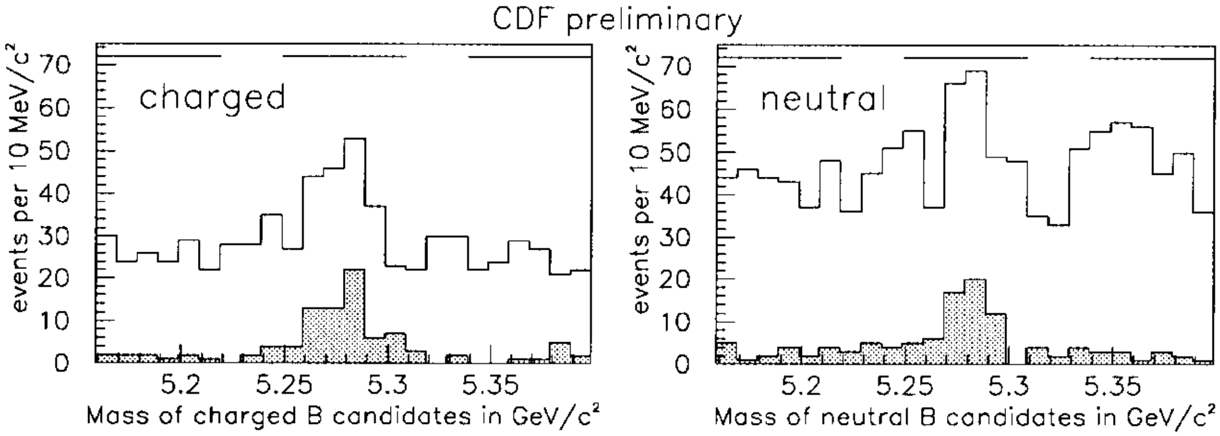

Figure 2: *Mass distributions of the fully reconstructed B samples. The shaded histograms are obtained by requiring $c\tau > 100$ μm. The signal and sideband regions are indicated by the horizontal lines above the histograms.*

respect to the J/ψ vertex. A cut at ± 20 MeV/c^2 around the world average is applied on the mass of the $\psi(2S)$ and K_S^0 candidates (see Figure 1).

The B mesons are reconstructed by combining a J/ψ or a $\psi(2S)$ candidate with a single track (assumed to be a kaon), with a K_S^0 candidate, with two oppositely charged tracks (assumed to be a pion and a kaon) forming a $K^*(892)^0$ candidate, or with a K_S^0 candidate plus a track (assumed to be a pion) forming a $K^*(892)^\pm$ candidate. The J/ψ and $\psi(2S)$ candidates are mass constrained and all the tracks, except the K_S^0 legs, are vertex constrained and requested to have at least 2 SVX hits each (the K_S^0 legs are constrained to come from their own vertex and to have a total momentum that points back to the B vertex). Combinations where the $K^*(892)$ mass is more than 80 MeV/c^2 from the world average mass are rejected. The total p_t of the particles combined with the J/ψ or the $\psi(2S)$ is required to be above 1.25 GeV/c and the p_t of the B candidate is required to be above

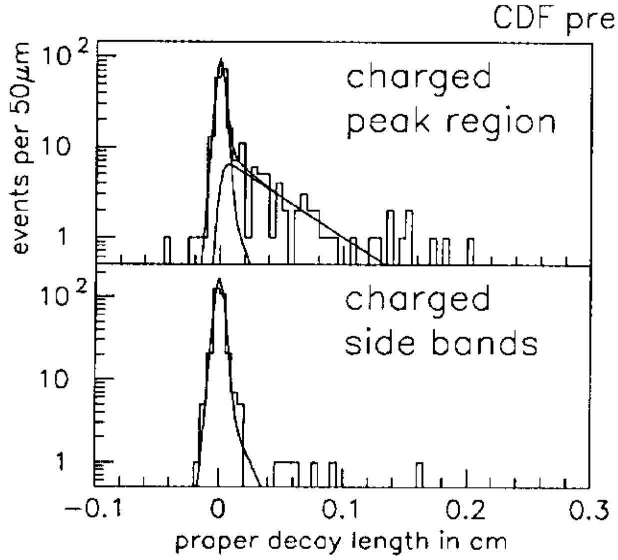

Figure 3: *The proper decay length ($c\tau$) distributions of the fully reconstructed B samples. The fits (curves) are described in the text.*

6 GeV/c. Only one B candidate per event is kept based on the quality of the kinematic and geometrical fit. The mass distributions of the charged and neutral B candidates are shown in Figure 2 (non shaded histograms).

The proper decay length of each B candidate is computed as $c\tau = L_t m^B/p_t^B$, where $L_t = (\vec{x}_{decay} - \vec{x}_{beam}) \cdot \vec{p}_t^B/p_t^B$ is the transverse decay length, $m^B = 5.2786\ GeV/c^2$ is the mass, $\vec{p}_t^B$ is the transverse momentum of the candidate, and $\vec{x}_{decay}$ and $\vec{x}_{beam}$ are the positions in the transverse plane of the B decay vertex and the center of the beam spot. The beam spot, the position of which is determined very accurately from a large sample of tracks for each Tevatron store, is circular with an RMS radius of $\sim 40\ \mu m$. Its size is taken into account in the calculation of the error on $c\tau$ for each candidate. As shown by the mass distributions of the candidates with $c\tau > 100\ \mu m$ (shaded histograms of Figure 2), the samples of selected candidates contain clear B signals.

The proper decay length distributions of the "signal regions" (defined as the mass range $5.2486 - 5.3086\ GeV/c^2$) and of the "sideband regions" (defined as the two mass ranges $5.1586 - 5.2186\ GeV/c^2$ and $5.3386 - 5.3986\ GeV/c^2$) are shown in Figure 3. The curves are the result of unbinned maximum likelihood fits performed simultaneously on the the signal and sideband regions, but separately for the charged and neutral candidates. The background function used for the sideband events is a Gaussian function plus asymmetric exponential tails. The function for the signal region is a linear combination of the background function and the convolution of an exponential with a Gaussian resolution function. For each candidate, the signal resolution and the sigma of the Gaussian part of the background function are taken as the calculated error on $c\tau$ (typically $20 - 60\ \mu m$). The amount of background in the signal region is constrained to be equal to $\frac{1}{2}$ of the population of the sideband regions, within Poisson fluctuations. The results of these fits indicate that there are 75 ± 10 charged and 61 ± 9 neutral B mesons in the signal regions, with lifetimes given by $c\tau^{\pm} = 488 \pm 63\ \mu m$ and $c\tau^0 = 462 \pm 67\ \mu m$. At the present time, the total systematic uncertainties (48 μm on $c\tau^{\pm}$ and 30 μm on $c\tau^0$) are dominated by the presence of events in the sideband regions which are not well described by the background parametrization. Under the assumption that these uncertainties are independent, the lifetime ratio $\tau^{\pm}/\tau^0$ is $1.06 \pm 0.20(\text{stat}) \pm 0.12(\text{sys})$.

3 Average lifetime analysis

Since the average lifetime measurement using the inclusive $J/\psi \rightarrow \mu\mu$ sample is not limited by statistics (there are 19849 ± 162 J/ψ in the signal shown in Figure 1), tighter quality cuts can be applied in order to reduce the background and possible tails in the resolution function. Each muon is required to be detected by the central muon chambers ($|\eta| < 0.6$), and to have at least 3 unambiguously associated hits in the SVX, a good track χ^2, and deposited charge in the silicon layers consistent with a minimum ionizing particle. The two muons are required to come from a well-measured vertex. With these tight quality cuts, 5667 J/ψ candidates remain in a $\pm 50\ MeV/c^2$ window around the world average mass (signal region). The sideband regions (mass ranges $2.9 - 3.0$ and $3.2 - 3.3\ GeV/c^2$) contain 646 events and are used to estimate that the background in the signal region is 5.7%.

The proper decay length of a b-hadron decaying to a J/ψ is approximated by the quantity $\lambda = [L_t\, m/p_t]/F(p_t)$, where L_t is the transverse decay length calculated from the J/ψ vertex and the center of the beam spot, and where $m = 3.0969\ GeV/c^2$ and p_t are the mass and transverse momentum of the J/ψ. The correction factor $F(p_t)$, defined as the average value of $(m/p_t)/(m^B/p_t^B)$, is computed by a Monte Carlo program from assumptions on the b-quark momentum spectrum and fragmentation, and on the J/ψ polarization and momentum spectrum in the B rest frame; it varies only weakly over the p_t range of the J/ψ and is close to 0.86. According to this Monte Carlo program, the unsmeared distribution of λ is well described by an exponential function with a slope consistent (within the $\sim 4\ \mu m$ Monte Carlo statistical uncertainty) with the average $c\tau$ used as input.

The distribution in λ of data from the sideband regions is shown in Figure 4a; the curve is the result of an unbinned maximum likelihood fit using the same parametrization as for the exclusive B lifetime analysis. The asymmetry of this distribution is expected, because this sample contains double (sequential) semileptonic b-decays which produce positive values of λ. The signal region distribution of λ, shown in Figure 4b, is fitted as the sum of 3 contributions: (i) some non J/ψ background (shaded area), assumed to comprise 5.7% of the selected events and to have a shape identical to the result of the fit to the sideband regions, (ii) a prompt J/ψ signal (difference between the dotted and the solid curves) resulting from direct production or decays of short lived particles, e.g. $\chi_c \rightarrow J/\psi\gamma$), and (iii) the $b \rightarrow J/\psi$ signal (difference between the hatched and shaded areas), assumed to have an exponential distribution smeared by the resolution. The resolution function used for contributions (ii) and (iii) is a Gaussian function with a sigma equal to the measured error on λ, determined for each event. The fit returns a fraction of J/ψ from bottom decay of $(15.1 \pm 0.6)\%$, and an exponential slope of

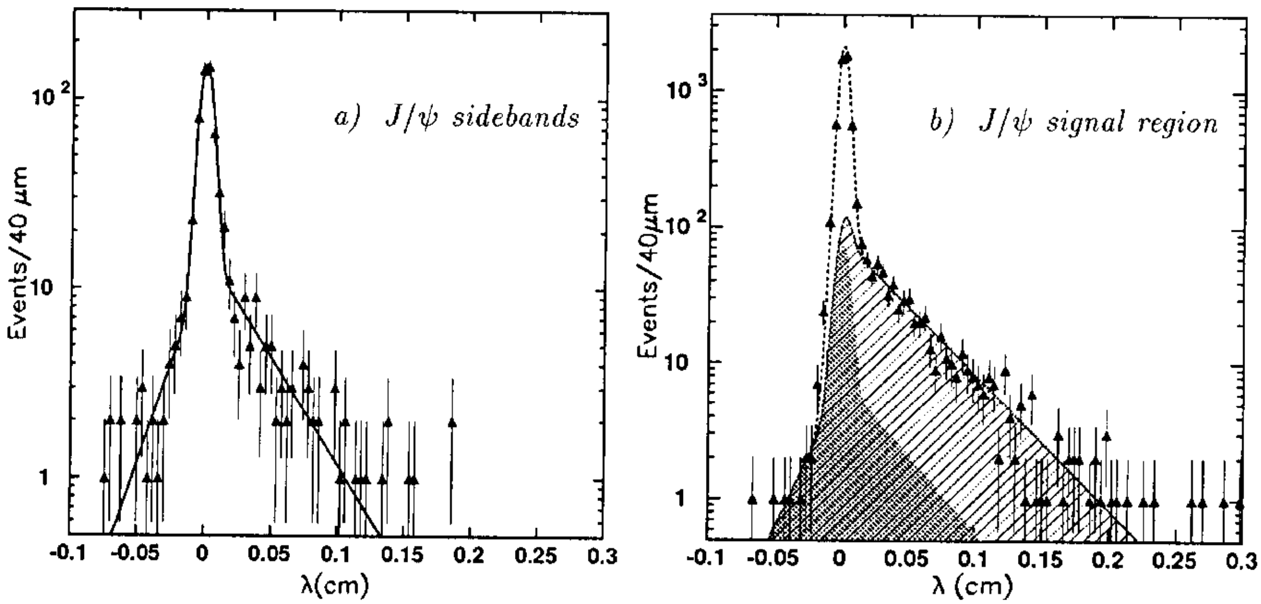

Figure 4: *The λ distributions from a) the J/ψ sideband regions and b) the J/ψ signal region. The fits (curves) are described in the text.*

$438 \pm 18\ \mu m$, interpreted as the average proper decay length of the $b \to J/\psi$ signal.

The dominant source of systematic uncertainty is due to the determination of the correction factor $F(p_t)$; the result changes by 3.0% when the parameters used in the Monte Carlo modeling are varied within the limits of the current theoretical and experimental knowledge on the bottom hadron production and decay. Other systematic uncertainties are due to possible residual misalignment of the SVX (2.0%), discrepancy between the calculated error on λ and the true resolution (1.6%), trigger bias (1.4%), beam instability in the course of a Tevatron store (1.0%), and statistical uncertainty in the determination of the tails of the background distribution (0.5%). Adding all these contributions in quadrature yields a total systematic uncertainty (4.3%) comparable to the statistical uncertainty. The final result is $438 \pm 18(\text{stat}) \pm 19(\text{sys})\ \mu m$.

References

[1] F. Abe et al., Nucl. Inst. and Meth. A271 (1988) 387

[2] D. Amidei et al., Nucl. Inst. and Meth. A289 (1990) 388

[3] O. Schneider et al., Proceedings of the 7th Meeting of the American Physical Society, Division of Particles and Fields, Fermilab, Nov. 1992, World Scientific Press, 1743.

[4] F. Abe et al., FERMILAB-CONF-93/198-E, submitted to the International Symposium on Lepton and Photon Interactions, Cornell University, Ithaca NY, Aug. 1993

[5] F. Abe et al., FERMILAB-PUB-93/158-E, submitted to Phys. Rev. Lett.