Fermi National Accelerator Laboratory

FERMILAB-Conf-96/204-E
CDF

Measurement of the Average Lifetime of B-Hadrons Produced in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV

Hans Wenzel
For the CDF Collaboration

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

August 1996

Contributed Paper at the *28th International Conference on High Energy Physics (ICHEP96)*, Warsaw, Poland, July 25-31, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

CDF/PHYS/BOTTOM/CDFR/3734

Measurement of the Average Lifetime of B-hadrons produced in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV

(CDF Collaboration)

Abstract

The average b-hadron lifetime has been measured using a high statistics sample of $B \rightarrow J/\psi X$ decays recorded with the Collider Detector at Fermilab. We use a sample with an integrated luminosity of $\approx 90\ pb^{-1}$ recorded during the 1994-95 running period. The decay vertices of ≈ 62656 inclusive $J/\psi \rightarrow \mu^+\mu^-$ candidates have been reconstructed using information from a silicon vertex-detector. The measured B lifetime, which is the average over all b-hadrons produced in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV weighted by their branching ratios into J/ψ, is $1.524 \pm 0.015\ (stat)\ ^{+0.035}_{-0.026}\ (sys)\ ps$ The precision of this measurement is significantly improved compared to the inclusive lifetime measurement published previously using $\approx 10\ pb^{-1}$

In 1993 the CDF collaboration published the first average B-lifetime result obtained at a hadron collider [1]. The measurement of the decay vertices of $B \rightarrow J/\psi X$ candidates provided an alternative method of determining the B lifetime compared to impact parameter methods with quite different systematic uncertainties. Because the B production cross section is large in $p\overline{p}$ collisions [2], it is possible to obtain small statistical uncertainties of for this mode, which has an effective branching ratio $BR(B \rightarrow J/\psi X) \cdot BR(J/\psi \rightarrow \mu^+\mu^-) = 7.7 \pm 1.3 \times 10^{-4}$ [3]. The result obtained was competitive to the LEP results which dominated the world average.

We report here an update of this measurement using a sample of $B \rightarrow J/\psi X \rightarrow \mu^+\mu^- X$ decays recorded by the CDF during the 1994-95 Tevatron run with ≈ 12 times the statistic used in the previous measurement. The sample corresponds to an integrated luminosity of $\approx 90\ pb^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV.

The CDF detector has been described in detail elsewhere [4]. For the 1992-93 collider run, a silicon vertex detector (SVX) has been installed [5] which has been replaced with a radiation hard version for the 94-95 running period. The SVX consists of 4 layers of silicon-strip detectors with r-ϕ readout, that includes pulse height information. The pitch between readout strips is 60 μm, resulting in a spatial resolution of 13 μm. The first measurement plane is located 2.9 cm from the interaction point, leading to an impact parameter resolution of $\sim$ 15 μm for high momentum tracks.

CDF uses a three-level trigger system. At Level 1 the relevant trigger for this analysis requires the presence of 2 charged tracks in the central muon chambers, which cover the pseudorapidity range $|\eta| < 0.6$, where the pseudorapidity $\eta \equiv -\ln(\tan(\theta/2))$. The efficiency of finding a muon at Level 1 rises from 30% at transverse momentum $p_T = 1.5$ GeV/c to 93% for $p_T > 3$ GeV/c. Level 2 requires that both muon tracks match a charged track in the Central Tracking Chamber (CTC) found with the Central Fast Track (CFT) processor [6]. The efficiency of finding a track in the CFT rises from 50% at 1.95 GeV/c to 97% for $p_T > 2.4$ GeV/c. The Level 3 software trigger requires the presence of two oppositely charged muon candidates with invariant mass between 2.8 and 3.4 GeV/c^2 [7].

To reduce the background in the dimuon sample, the following muon selection cuts were applied [8]:

1. The separation between the track in the muon chamber and the extrapolated CTC track was calculated in both the transverse and longitudinal planes. In each view, the difference was required to be less than 3.0 standard deviations (σ) from zero, where σ is the sum in quadrature of the multiple scattering and measurement errors.

2. The energy deposited in the hadronic calorimeter by each muon was required to be greater than 0.5 GeV, the smallest energy expected from a minimum ionizing particle.

To ensure that the J/ψ decay vertex was well measured, strict track quality cuts were imposed on the sample:

1. both muon tracks were required to be reconstructed in the SVX with hits in all four layers.

2. For the SVX track fit we required χ^2/DoF< 5.

3. The two muons were required to have track parameters consistent with a single decay vertex.

4. The transverse momentum of the J/ψ was required to be larger than 4 GeV/c.

The invariant mass distribution of the final dimuon sample is shown in Figure 1. The grey-hatched area indicates the J/ψ signal region, defined to be ± 50 MeV/c^2 around the J/ψ-mass. This region contains 66541 events. The cross-hatched area shows the two sideband regions, one with mass from 2.9 to 3.0 GeV/c^2, and the other from 3.2 to 3.3 GeV/c^2. The sidebands contain 7769 events. These sidebands were used to determine the shape of the lifetime distribution for background events in the J/ψ signal region. After background subtraction the number of J/ψ's in the signal region is found to be 62656 ± 250. The fitted J/ψ mass is (3095) MeV/c^2 with a mass resolution of 16 MeV/c^2.

For each J/ψ in the sample, a two dimensional decay distance L_{xy} was calculated. L_{xy} is the projection of the vector $\vec{X}$, pointing from the primary to the secondary vertex, onto the transverse momentum of the J/ψ:

$$L_{xy} \equiv \frac{\vec{X} \cdot \vec{p_T}^{\psi}}{|\vec{p_T}^{\psi}|}$$

The position of the secondary vertex is obtained by constraining the two muon tracks to come from a common decay vertex. The primary vertex position is approximated by the mean beam position, determined run-by-run by averaging over many events. We favored the beam position over a primary vertex determined event by event because it is always available and unbiased. The transverse profile of the beam is circular and has a rms of ~ 26 μm. Studies have shown that with the low multiplicity of $b\bar{b}$-events it is not always possible to reconstruct the primary vertex and the resolution is not more precise. In addition there are always two b-hadrons in the event. If tracks from b-decay are used in the determination of the primary vertex a systematic bias to the b-lifetime measurement is introduced. The mean uncertainty of L_{xy} is ~ 57 μm, where the dominant contributions are the uncertainty in determining the primary and secondary vertex positions.

To convert the transverse decay length into a proper lifetime, the relativistic quantity $(\beta\gamma)_B$ of the b-hadron must be determined. Since the J/ψ's selected by the dimuon trigger typically carry most of the momentum of the B, the $(\beta\gamma)_\psi$ of the J/ψ is a good first approximation to $(\beta\gamma)_B$. Using a Monte Carlo procedure, a $(\beta\gamma)$ correction factor F was calculated as a function of p_T^ψ. Figure 2 shows the parameterization of F(p_T^ψ) used to calculate the B lifetime. F varies only weakly over the p_T range of the J/ψ in our sample and is ~ 0.84. The calculation of $F(p_T^\psi)$ used a b-quark p_T spectrum generated from the next-to-leading order QCD calculation [9]. To estimate the systematic uncertainties in the shape of this cross section, it was compared to simple power law spectra which reproduced softer p_T spectra than that of our data $F(p_T^\psi)$ is also shown in Figure 2.

The b-quarks were then fragmented using the Peterson fragmentation function [10] where the fragmentation parameter and its uncertainty ($\epsilon = 0.006 \pm 0.002$) have been taken from reference [11]. The b-hadrons were forced to decay into $J/\psi + X$. The resulting muons were passed through a computer simulation of the detector and trigger. The systematic uncertainty associated with modeling the decay of b-baryons and higher mass b-mesons has been studied using Monte Carlo calculations assuming the probability for a b-quark to fragment into the various possible b-flavored mesons and baryons to be: $B_u : B_d : B_s : B_{baryon} = 0.375 : 0.375 : 0.125 : 0.125$. The best estimate of the proper b-hadron decay length is:

$$\lambda = L_{xy} \frac{M_\psi}{p_T^\psi F(p_T^\psi)}$$

In order to obtain the B lifetime from the λ distribution, we fit to 3 sources of dimuon events in the J/ψ invariant mass region:

(i) J/ψ's from B decays: this part is parameterized by a Gaussian function convoluted with an exponential. The fit parameter f_b gives the fraction of J/ψ coming from b-decay.

(ii) J/ψ's directly produced in $p\bar{p}$ collisions, or resulting from the decay of intermediate states which are sufficiently short-lived so that their vertex is indistinguishable from the primary vertex (*e.g.* from χ_c's): this part is parameterized by a Gaussian function.

(iii) Background coming from processes whose invariant mass falls accidentally in the J/ψ mass window: these events include dimuons from Drell-Yan production, double semileptonic b-decays, meson decays-in-flight and residual hadron punch-through. The shape of this contribution is obtained by fitting the corresponding J/ψ sideband distributions. The fit is parameterized as the sum of a Gaussian function and two exponentials, one above the Gaussian and one below, each with a different slope. Since the dimuon sample contains events from sequential b-decays ($b \to c\mu\nu \to s\mu\nu\mu\nu$), the λ distribution is expected to be asymmetric.

Figure 3 shows the result of an unbinned likelihood fit to the data. The dark-shaded area is the contribution obtained from a fit to the λ distribution of the J/ψ sidebands. The light-shaded area shows the sum of the background distribution and the Gaussian function convoluted with the exponential from b-decay. The remaining Gaussian centered at 0 (unshaded area) is due to prompt decays. The fit results in:

$$\tau_{\rm B} = 1.524 \pm 0.015 \text{ (stat.) ps and } {\rm f_b} = 17.8 \pm 0.2\%\text{(stat.)}$$

The fit parameter $\rm f_b$ obtained in the above procedure does not provide an unbiased measurement of the fraction of J/ψ's coming from b decay. The applied track quality cuts favor isolated muons and systematically decrease this fraction.

Our estimates of the systematic uncertainties on the above measurement are listed in Table 1. The systematic uncertainty in the production and decay kinematics is estimated to be $^{+2.2}_{-1.5}\%$ and comes from studying the parameters of our model, including the b quark production spectrum, J/ψ momentum spectrum in the B rest frame, J/ψ polarization and fragmentation.

The result of the maximum likelihood fit depends on the error on the decay-length calculated for each event. The uncertainty in the decay vertex resolution has been studied using several independent datasets. Studies of a sample of prompt $\Upsilon(1S) \to \mu^+\mu^-$ events and of a high statistics sample of tracks selected from jet events indicate that the resolution function for tracks from the primary vertex is symmetric. A fit to the jet sample results in a mean decay length consistent with zero. The resolution obtained from this fit agrees to within 5% with the mean of the resolution obtained event-by-event from our vertex-constrained fit. Therefore we have varied these errors by an overall scale factor ($\pm 5\%$) and studied the result of this variation on the fit. This gives an additional 0.5% uncertainty in the lifetime. Note that this error includes effects like the beam instability (actually the beam position was found to be very stable during a run) and some of the residual misalignment but excludes the error on the total length scale. This was studied by varying the radial scale of the SVX resulting in an estimate of 0.3%. The effect of impact parameter bias in the CFT and Level 3 trigger was found to be negligible. The systematic error due to the background parameterization was estimated to be 0.4% by varying the slope of the two exponentials by varying the shape and by varying the normalization.

In conclusion, we have measured the average lifetime for b-hadrons produced in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. For a sample of b-hadrons decaying into $J/\psi X$, the lifetime is determined to be:

$$1.524 \ \pm\ 0.015\ (\mathrm{stat})\ ^{+0.035}_{-0.026}\ (\mathrm{sys})\ \mathrm{ps}$$

Production and decay kinematic	−1.5 %	+2.2 %
Error scale	−0.5 %	+0.5 %
Background Parameterization	−0.4 %	+0.4 %
Length Scale	−0.3 %	+0.3 %
Total	−1.7%	+2.3%

Table 1: Systematic uncertainties on the average b-hadron lifetime

References

[1] F. Abe et al., The CDF Collaboration
Measurement of the Average Lifetime of B-hadrons Produced in $p\bar{p}$ Collisions at '1.8 TeV
Phys. Rev. Lett. 71, 3421 (1993).

[2] F. Abe et al., Phys. Rev. Lett. 75 (1995) 1451 and references therein.

[3] H. Albrecht et al., Phys. Lett. B 199 (1987) 451; M. S. Alam et al., Phys. Rev. D 34 (1986) 3279.

[4] F. Abe et al., Nucl. Inst. and Meth. A 271 (1988) 387 and references therein.

[5] D. Amidei et. al.
The Silicon Vertex Detector of the Collider Detector at Fermilab
NIM A350 (1994) 73-130.

[6] G.W. Foster et. al., Nucl. Inst. and Meth. A 269 (1988) 93.

[7] J. T. Carroll et al., Nucl. Inst. and Meth. A 300 (1991) 552.

[8] H. Wenzel, "Measurement of the Inclusive B-Lifetime Using J/ψ's at the CDF-Experiment", Doktorarbeit, RWTH Aachen, Oct. 1993.

[9] P. Nason, S. Dawson and R.K. Ellis, Nucl. Phys. B 303 (1988) 607; B 327 (1989) 49; B 335 (1990) 260.

[10] C. Peterson et al., Phys. Rev. D 27 (1983) 105.

[11] J. Chrin, Z. Phys. C 36 (1987) 163.

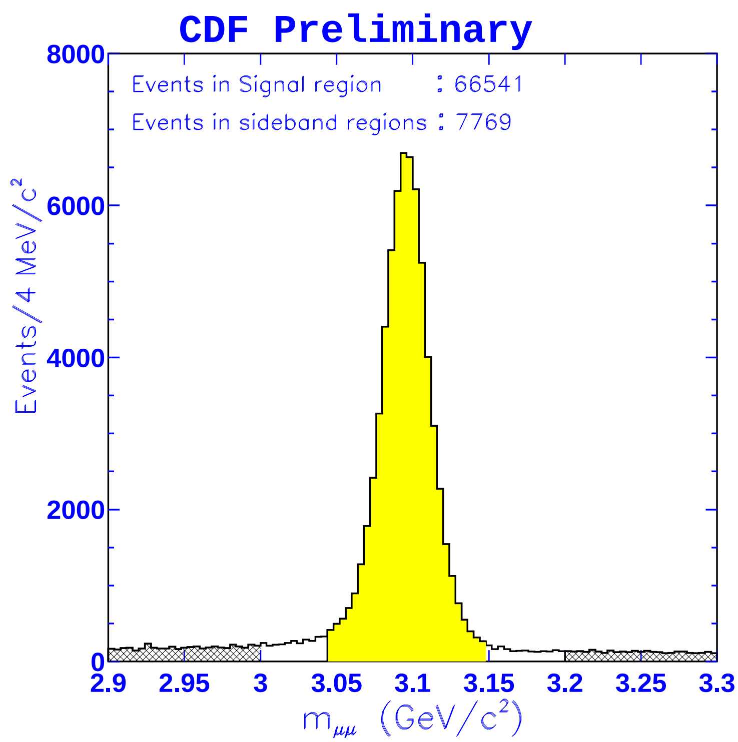

Figure 1: Invariant mass distribution of two oppositely charged muons. The grey-hatched area indicates the J/ψ signal region and the cross-hatched areas show the sideband regions.

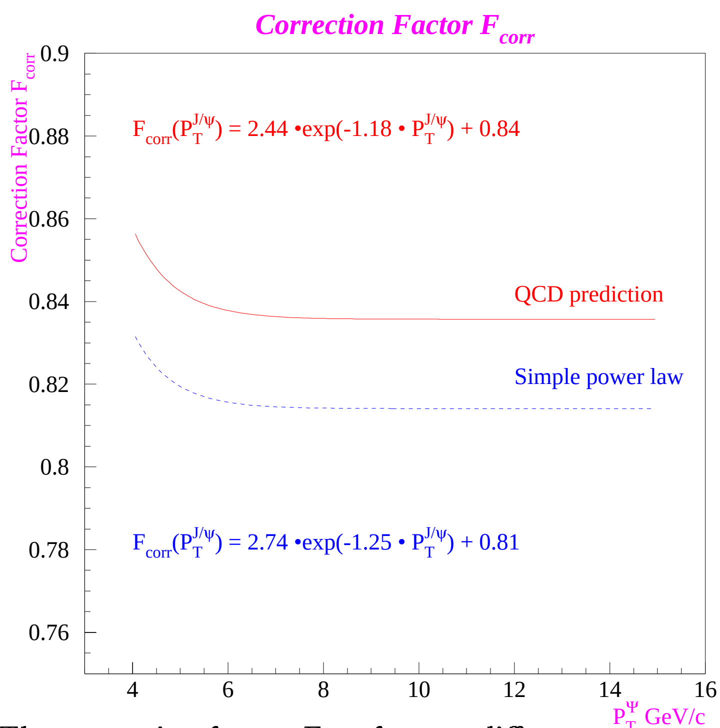

Figure 2: The correction factor F_{corr} for two different parameterizations.

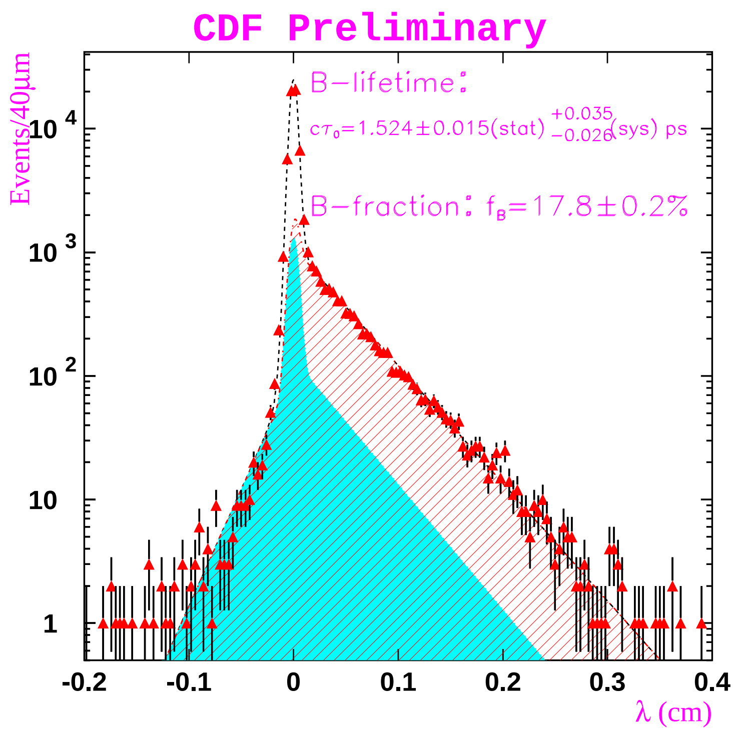

Figure 3: The distribution in λ of data in the signal region. The curves are the result of the unbinned likelihood fit described in the text.