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B-Lifetime Measurements at CDF

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B-LIFETIME MEASUREMENTS AT CDF

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Abstract

The average b-hadron lifetime has been measured using a high statistics sample of $B \to J/\psi X$ decays recorded with the Collider Detector at Fermilab. The decay vertices of $J/\psi \to \mu^+\mu^-$ 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 $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, weighted by their branching ratios into J/ψ is:

$$\tau_B = 1.46 \pm 0.06(\text{stat.}) \pm 0.06(\text{sys.})\text{ps} \quad \text{(preliminary)}$$

In addition we used the fully reconstructed final states $B^\pm \to J/\psi\, K^\pm$ and $B^0 \to J/\psi\, K^{0*}$ to measure the the exclusive lifetime of charged and neutral B-mesons. We measure:

$$\tau_{B^\pm} = 1.59 \pm 0.27\,(\text{stat.}) \pm 0.17\,(\text{sys.})\text{ ps} \quad \text{(preliminary)}$$
$$\tau_{B^0} = 1.34 \pm 0.31\,(\text{stat.}) \pm 0.17\,(\text{sys.})\text{ ps} \quad \text{(preliminary)}$$

From this we obtain the following result for the lifetime ratio:

$$\tau_{B^\pm}/\tau_{B^0} = 1.19 \pm 0.35\,(\text{stat.}) \pm 0.12\,(\text{sys.}) \quad \text{(preliminary)}$$

This represents the first measurements of the b-lifetime at a hadron collider.

1 Introduction

We report here a high statistics measurement of the B lifetime determined from a sample of $B \rightarrow J/\psi X \rightarrow \mu^+\mu^- X$ decays recorded by the Collider Detector at Fermilab (CDF) using a sample of 10.1 ± 0.7 pb^{-1} of $p\bar{p}$ collider data at $\sqrt{s} = 1.8$ TeV collected during the first half of the 1992-93 Tevatron run. This is the first measurement of the inclusive and exclusive B lifetime from a hadron collider experiment. Because the B production cross section is large in $p\bar{p}$ collisions [1], it is now possible to obtain statistical uncertainties of $\sim 4\%$ for the inclusive mode, which has a product branching ratio $BR(B \rightarrow J/\psi X) \cdot BR(J/\psi \rightarrow \mu^+\mu^-) = 7.7 \times 10^{-4}$.

The CDF detector has been described in detail elsewhere [2]. For the 1992-93 collider run, a silicon vertex detector (SVX) has been installed [3]. The SVX consists of 4 layers of silicon-strip detectors with r-ϕ readout, including 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 ~ 10 μm for high momentum tracks. A new central muon extension (CMX) system, installed 1992, extends the muon coverage to be used in the trigger up to $|\eta| < 1$ compared to $|\eta| < 0.65$ previously.

2 Data selection

Here we describe the data selection criteria which are in common for both analysis.

CDF uses a three-level trigger system. At Level 1 the relevant trigger for this analysis required the presence of 2 charged tracks in the central muon chambers. For the inclusive lifetime we restricted ourselves on muon pairs in the central muon system which covers $|\eta| <$ 0.65. For this system the trigger efficiencies are well measured and could be used in computer simulations which was necessary for the inclusive lifetime measurement to obtain the correction factor (see below). For the exclusive lifetime measurement the kinematics is closed. To obtain higher statistics we used also muons measured in the CMX.

Level 2 required that at least one of the muon tracks match a charged track in the Central Tracking Chamber (CTC) found by the Central Fast Track (CFT) processor [4]. The CFT selected tracks with $P_t > 2.5$ GeV/c. The level 3 software trigger required that the invariant mass of the dimuon system be between 2.8 and 3.4 GeV/c^2.

To reduce the background from "fake" muons, the following muon selection cuts were applied:
1) the distance 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 a standard deviation is calculated as the quadratic sum 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, corresponding to the presence of a minimum ionizing track.
3) the reconstructed P_t of at least one of the muons was required to be > 2.5 GeV/c. In addition we required that both muons were reconstructed in the SVX with at least three out of the four possible hits.

Figure 1 shows the invariant mass distribution of dimuons as selected for the exclusive lifetime measurement. A gaussian fit over a linear background gives 3.0957 ± 0.0002 GeV/c^2 and a mass resolution of 18.5 MeV. The luminosity of this sample is approximately $9pb^{-1}$.

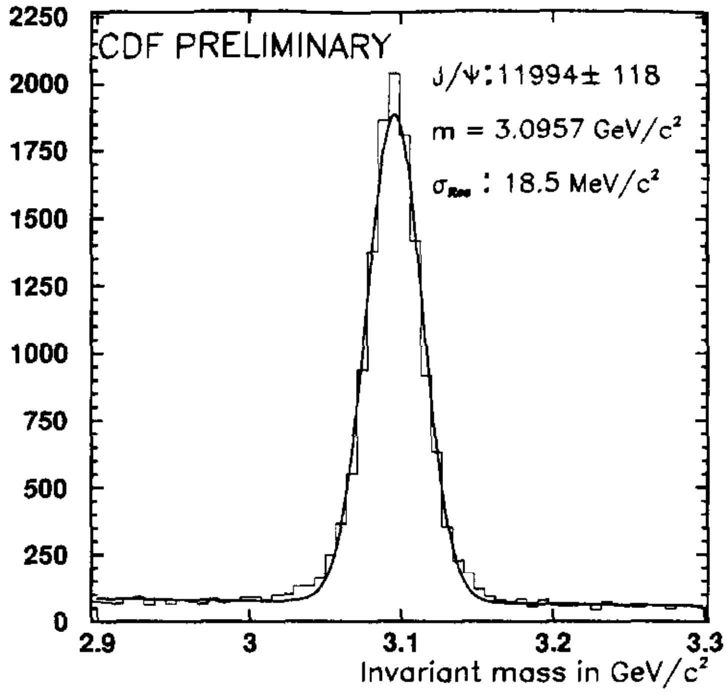

Figure 1: Invariant mass distribution of oppositely charged dimuons as selected for the exclusive lifetime measurement.

3 Measurement of the inclusive b-lifetime.

To ensure that the J/ψ decay vertex was well measured, strict track quality cuts were imposed on the sample:
1) all SVX track residuals were required to be less then 4 σ;
2) SVX tracks where one or more hits were assigned to more than one track were removed;
3) SVX hits with total charge more than 4 times the charge deposited by a minium ionizing particle were removed;
4) the two muons were required to come from a well-measured vertex;
5) the χ^2 for SVX hits for each muon was required to be less than 20 for 4 d.o.f.

After applying the above cuts, a sample of 5667 events in the J/ψ mass range, defined to be ± 50 MeV/c^2 around the J/ψ-mass, remained. The luminosity of this sample was measured to be 10.1 pb^{-1}. After background subtraction there are 5344 $J/\psi \to \mu^+\mu^-$ candidates. Sideband regions are defined to have invariant mass from 2.9 to 3 GeV/c^2 and 3.2 to 3.3 GeV/c^2. These sidebands were used to determine the shape of the lifetime distribution for "fake" J/ψ's.

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:

$$L_{xy} = \frac{\vec{X} \cdot \vec{P}_t^{\psi}}{|P_t{}^{\psi}|}$$

Here the decay vertex position is obtained from the vertex-constrained fit to the two muon tracks. The primary vertex is approximated by the average beam position, determined run-by-run by averaging over many events. The transverse profile of the beam is circular and has a rms of approximately 40 μm.

To convert the transverse decay length into a proper lifetime the $(\beta\gamma)_B$ of the b-hadron must be determined. Since the J/ψ's selected by the dimuon trigger carry most of the B momentum, the $(\beta\gamma)_\psi$ of the J/ψ is a good first approximation to $(\beta\gamma)_B$. A correction factor F was determined from Monte Carlo as a function of the transverse momentum of the J/ψ. F varies only weakly over the P_t range of the J/ψ sample and is approximately 0.86. Thus the best estimate of the proper time of the B decay (the "pseudo-$c\tau$") is:

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

The momentum spectrum of the b-quarks was generated using the next-to-leading order QCD calculation of [5] using the parametrization that gives the best agreement with the CDF b cross-section measurement [1], [6]. To estimate the systematic uncertainties in modeling this cross section this model was compared with a simple power law which produced a softer J/ψ P_t-spectrum than the data or the QCD prediction. The b-quarks were then fragmented using the Peterson fragmentation function [7] where the fragmentation parameter and its uncertainty ($\epsilon = 0.006 \pm 0.002$) have been taken from [8]. The b-hadrons were then decayed into $J/\psi + X$. The J/ψ spectrum in the B rest frame was obtained from the experimental results of Argus and CLEO [9]. We also used their results [10] , to set the bounds for the polarization when modeling the decay $J/\psi \rightarrow \mu^+\mu^-$. The resulting muon decays were passed through a computer simulation of the detector and trigger.

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 parametrized as a Gaussian 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 that their vertex is indistinguishable from the primary vertex (eg. χ_c's). This part is parametrized as a Gaussian resolution function.

(iii) 'fake' J/ψ's 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 hadron punch-through. The shape of this contribution is obtained by fitting the sidebands. The fit is parametrized as the sum of a central Gaussian and left-side and right-side exponentials with different slopes. Since the dimuon sample contains events from sequential b-decays ($b \rightarrow c\mu\nu \rightarrow s\mu\nu\mu\nu$), the λ distribution is expected to be asymmetric. The background fraction, f_{BGR}, is also determined from the sidebands and is not a fit variable.

Figure 2 shows the result of an unbinned likelihood fit to the data. The dark-shaded area shows the contribution from the background as obtained by the fit to the sidebands. The light-shaded area shows the sum of the background distribution and the Gaussian convoluted with the exponential from b-decay. The remaining Gaussian centered at 0 (unshaded area) is due to prompt decays. The fit results in:

$$\tau_B = 1.46 \pm 0.06 \text{ (stat.) and } f_B = 15.1 \pm 0.6\% \text{(stat.)}$$

The fit parameter 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 events. These cuts systematically decrease this fraction.

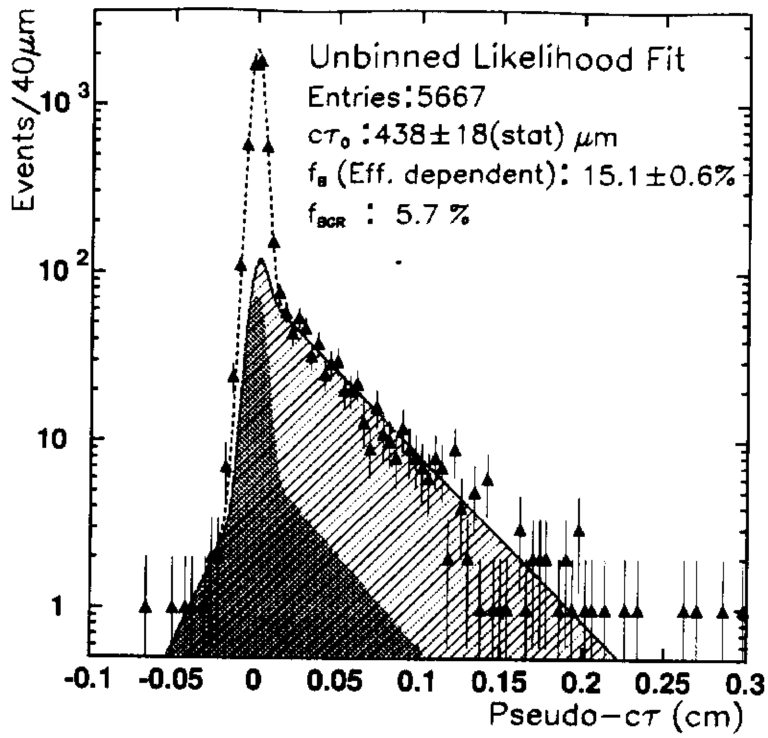

Figure 2: Pseudo-$c\tau(\lambda)$-distribution signal region with unbinned likelihood fit superimposed

Description	Contribution in %
Production and decay kinematics	3
Residual misalignment	2
Beam stability	1
Trigger bias	1.4
Background parameterization	0.5
Uncertainty in $c\tau$ resolution	1.6
Total(preliminary)	4.3 %

Table 1: *Systematic uncertainties*

The systematic uncertainties on this measurement are listed in Table 1. The systematic uncertainty due to model dependence, including the b quark production spectrum, J/ψ momentum spectrum in the B rest frame, J/ψ polarization and fragmentation, is 3%. The uncertainty in the decay vertex resolution has been studied using several independent datasets. Studies of a sample of prompt $\Upsilon(1S) \rightarrow \mu^+\mu^-$ events and of a sample of tracks selected from jet events indicate that the resolution function for tracks from the primary vertex is symmetric and centered at zero decay length. A fit resulted in a mean of $0.2 \pm 0.9\mu$m, consistent with zero. The uncertainty due to residual misalignment of the SVX has been studied by varying the alignment correction constants. The systematic error due to misalignment was estimated to be 2%. The beam position variations within a run have been measured to be less than 4 μm, which leads to a 1% systematic error on the $c\tau$ measurement. The uncertainty due to possible impact parameter bias in the CFT trigger is estimated to be 1.4%.

To get the systematics due to the background parameterization we varied the slope of the left and right side exponential by one sigma and studied the effect on the lifetime. From this we obtain a systematic error of 0.5% due to the background parametrization. The effect of varying the $c\tau$ error scale in the maximum likelihood fit gives an additional 1.6% uncertainty.

In conclusion, we have measured the average B lifetime from the CDF inclusive J/ψ data sample. We find the following value:

$$\tau_{\rm B} = 1.46 \pm 0.06 \text{ (stat.) } \pm 0.06 \text{ (syst.)ps (preliminary)}$$

This measurement is the average over all b-hadrons produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV, weighted by their branching ratios into J/ψ and their production cross sections.

4 Measurement of $B^{\pm}$ and B^{0} lifetimes

The errors on this measurement are statistics limited and so strict track quality cuts to reduce the systematics due to tails in the resolution function don't pay off. The exclusive lifetime analysis starts with a sample of approximately 12000 J/ψ events over a background of 1700 (see Figure 1), the mass resolution returned by the fit is 18.5 MeV.

Candidates for $\mathrm{B}^{\pm} \rightarrow \mathrm{J}/\psi\, \mathrm{K}^{\pm}$ are selected by forming the invariant mass combination of a J/ψ and a charged track with P_t above 2 GeV/c. Since CDF has no Particle identification the particle is assumed to be a kaon. Fitting a Gaussian plus a flat background to the invariant mass distribution results in a central value of 5.278 ± 0.003 GeV/c^2 and a width of 11 MeV. The signal region is defined as 30 Mev around the B-mass. We observe 37 events in the signal over a background of 35.

For the decay $\mathrm{B}^{0} \rightarrow \mathrm{J}/\psi\, \mathrm{K}^{0*}$ we first search for two charged tracks to form K^{0*}-candidates and compute the invariant mass for the $\mathrm{K}\pi$ and $\pi\mathrm{K}$ mass assignment. We choose the combination which is closest to the K^{0*}-mass. A K^{0*}-candidate was then selected to be within 80 Mev of the K^{0*}-mass and was required to have a P_t of at least 2 GeV/c. In addition, we require the P_t of the B^0 to be above 6 GeV/c and that the vertex is well measured. Fitting a Gaussian plus a flat background to the invariant mass distribution results in a central value of 5.278 ± 0.004 GeV and a width of 12 MeV. The signal region is defined as 30 Mev around the B-mass. In this region we observe 18 events in the signal over a background of 46.

In both cases the $c\tau$ distribution of the background is obtained from the sidebands which are defined to be the mass regions 5.185-5.215 GeV and 5.345-5.375 GeV. The proper $c\tau$-distribution of the sidebands is in first order a Gaussian centered at 0, so we choose the sum of a Gaussian and a Gaussian convoluted with an exponential as the parametrization for the fit to the proper $c\tau$-distribution.

Figure 3 shows the proper $c\tau$-distribution for both modes with the fit superimposed. To evaluate the systematics the errors for misalignment and trigger bias have been taken from the inclusive lifetime measurement. Since the kinematics is closed there is no error due to model dependence, instead the dominant errors come from the uncertainty in the shape of background (10%) and resolution function (5%). We measure:

$$\tau_{\rm B^{\pm}} = 1.59 \pm 0.27 \text{ (stat.) } \pm 0.17 \text{ (sys.) ps (preliminary)}$$

$$\tau_{\rm B^{0}} = 1.34 \pm 0.31 \text{ (stat.) } \pm 0.17 \text{ (sys.) ps (preliminary)}$$

This gives for the lifetime ratio:

$$\tau_{\rm B^{\pm}}/\tau_{\rm B^{0}} = 1.19 \pm 0.35 \text{ (stat.) } \pm 0.12 \text{ (sys.) (preliminary)}$$

This results are statistic limited. At the end of the collider run 1A we expect to have the statistic at least doubled. In addition work to add other final exclusive channels and to optimize the selection cuts is in progress.

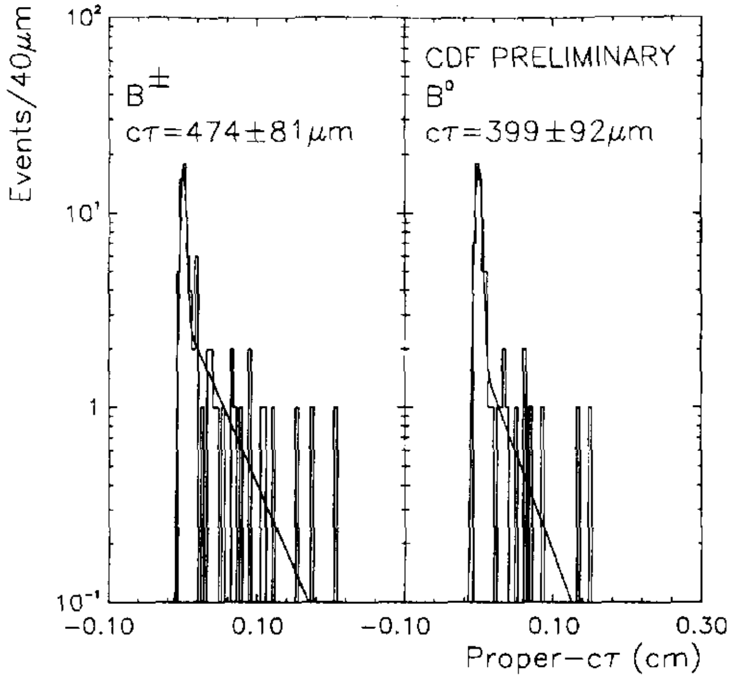

Figure 3: Proper-$c\tau$-distribution for $B^{\pm} \to J/\psi\, K^{\pm}$ (left) and $B^0 \to J/\psi\, K^{0*}$ (right) candidates with likelihood fit superimposed

References

[1] CDF Collab., F. Abe et al., Phys. Rev. Lett. 68 (1992) 3403.
CDF Collab., F. Abe et al., Phys. Rev. Lett. 69 (1992) 3704.
F. Abe et al.(CDF), ; Fermilab-Pub-93/091-E (1993) submitted to Phys. Rev. Let.
M. L. Mangano ; IFUP-TH 2/93 (1993).

[2] see F. Abe et al., Nucl. Inst. and Meth. A271 (1988) 487 and references therein.

[3] D. Amidei et. al., Nucl. Inst. and Meth. A 289 (1990) 388.

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

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

[6] V. Papamitriou, *B - production at CDF* ; this proceedings

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

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

[9] Andreas Hölscher, DESY F15-90-06 October 1990; D.Bortoletto et al. (CLEO), PRL 56 (1986) 800; W. Chen, PhD thesis Purdue University.

[10] Henning Schröder, *New Results on Beauty Physics from ARGUS*, Les rencontres de Physique de la Vallee d'Aoste March 3-9, 1991; R. Mundt (ARGUS) private communication.
WEAK DECAYS, RARE DECAYS, MIXING AND CP VIOLATION. By Persis S. Drell, J.Ritchie Patterson (Cornell U., LNS), CLNS-92-1177, Aug 1992. 30pp. Presented at 26th International Conference on High Energy Physics (ICHEP 92), Dallas, TX, 6-12 Aug 1992.