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CDF RESULTS ON B LIFETIMES AND MIXING

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The CDF experiment has produced many B physics results. We discuss, in particular, B^+,B^- and B_s^0 lifetime measurements using exclusive and semi-inclusive decays and $B^0\bar{B}^0$ mixing results obtained with both time-integrated and time-dependent analysis.

1 Introduction

B physics, during these years, is become feasible also at hadron colliders. Many results are coming from CDF experiment which runs at the Tevatron collider where protons and antiprotons collide at center-of-mass energy of 1.8 TeV. The CDF detector is described in detail elsewhere [1]. The b production cross section, $\sigma_b \sim 30\mu$m ($|\eta| < 1$ [a] < 1.1;), is quite large at the Tevatron, but the total inelastic cross section is about three order of magnitude larger. For this reason the trigger quality is of great importance in order to find B decay products. All B triggers at CDF are based on leptons.

2 B Meson Lifetimes

In the B system decay models predict a lifetime difference between the $B^\pm$ and B^0 of $\sim 5-10\%$. For B_s^0 the lifetime between the two CP eigenstates may differ by as much as 15%. Such an effect may manifest itself as a difference in lifetimes between the B_s^0 semileptonic decay which is almost an equal mixture of the two CP eigenstates and the decay $B_s^0 \to J/\Psi\varphi$ dominated by the CP even state. Sensitivities of this order or smaller are, therefore, necessary in order to constrain the theory.

[a] $\eta = -\ln[\tan\theta/2]$

2.1 *Exclusive B^0 and B^+ Lifetimes*

The measurement of the charged and neutral B meson lifetimes has been performed using fully reconstructed B decays $B \to \Psi K$ [b], where K can be any of the following: K^+, $K^*(892)^0$, K^0_S, or $K^*(892)^+$ and Ψ is J/Ψ or $\Psi(2S)$. The analysis starts with the selection of $J/\Psi \to \mu^+\mu^-$. The vertex and mass constrained J/Ψ candidates are vertexed with the K candidates yielding the transverse decay length L_{xy}. We extract the proper lifepath, $c\tau$, by correcting for the appropriate $\beta_t\gamma$ factor:

$$c\tau = L_{xy}\frac{M_B}{p_t^B} \tag{1}$$

The signal region is defined to be within ± 30 MeV/c^2 of the world average B mass [2]. The shape of the background is determined by fitting the sidebands regions, defined to be between 60 and 120 MeV/c^2 away from the world average. The B^+ and B^0 proper decay length distributions, for both the signal and sidebands regions, are shown in figure 1. In the combined Run 1a + 1b data

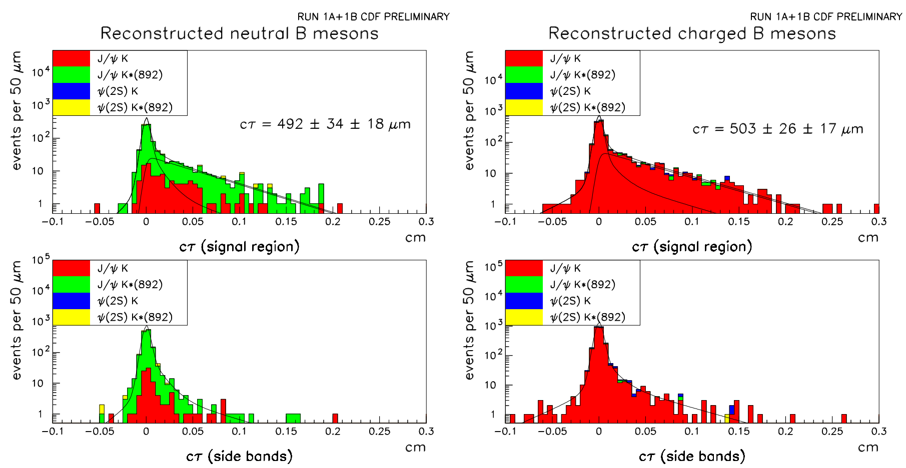

Figure 1: Proper decay length distributions of neutral (left) and charged (right) B candidates (top) and background (bottom) as obtained from sidebands.

sample (67.7 pb^{-1}), the preliminary measurements of τ^+, τ^0 and τ^+/τ^0 are :

$$\tau^+ \quad = \quad 1.68 \pm 0.09(stat.) \pm 0.06(syst.)\ ps$$

[b] Throughout this paper, references to a specific charge state imply the charge-conjugate state as well

$$\tau^0 = 1.64 \pm 0.11(stat.) \pm 0.06(syst.)\ ps$$
$$\tau^+/\tau^0 = 1.02 \pm 0.09(stat.) \pm 0.01(syst.)$$

Residual misalignment, trigger bias and beam stability give the dominant contributions to the systematic uncertainty. However, these are common to the B^+ and B^0 lifetime measurements and cancel in the lifetime ratio.

2.2 Semi-inclusive B^0 and B^+ Lifetimes

Another approach to measure the charge and neutral B lifetime is to use the B semileptonic decays. The principle of the this analysis, which uses about 20 pb^{-1} of Run 1a single lepton trigger events is the following: in a cone around the electron or muon, D^* meson candidates are reconstructed through their decay modes:

1. $D^0 \to K^-\pi^+$, where the D^0 is not from a D^{*+},
2. $D^{*+} \to D^0\pi_s^+$, $D^0 \to K^-\pi^+$
3. $D^{*+} \to D^0\pi_s^+$, $D^0 \to K^-\pi^+X$
4. $D^{*+} \to D^0\pi_s^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$

where X represents a π^0 which is not reconstructed. A well defined correlation between the lepton charge sign and that of the kaon is present if the lepton and the D originate from the B decay (see figure 2). The transverse decay length, L_{xy}, is defined as the displacement in the transverse plane of the secondary vertex from the primary vertex, projected onto the direction of the p_t of the lepton-D^* system. The proper decay length is defined as in 1, but since in this case we miss the neutrino the $\beta_t\gamma$ can not be calculated exactly, $\beta_t\gamma = p_t^{(l+D)}/(M_B \cdot K)$ where K is an average correction calculated by Monte Carlo.

The obtained lifetime distributions from lepton-D^* are used to determine the individual B^+ and B^0 lifetimes. A $l^+\bar{D}^0$ usually originates from a charged B meson while l^+D^{*-} comes from a B^0. In practice there is some cross talk between the two samples due to B decays to $D^{**}l\nu$ and some inefficiency in the association of the π to the D^0. The relative amount of charge and neutral B present in all samples is modeled with a Monte Carlo. A combined lifetime fit yield the following results:

$$\tau^- = 1.51 \pm 0.12(stat.) \pm 0.08\ ps$$
$$\tau^0 = 1.57 \pm 0.08(stat.) \pm 0.07(syst.)\ ps$$
$$\tau^-/\tau^0 = 0.96 \pm 0.10(stat.) \pm 0.05(syst.)$$

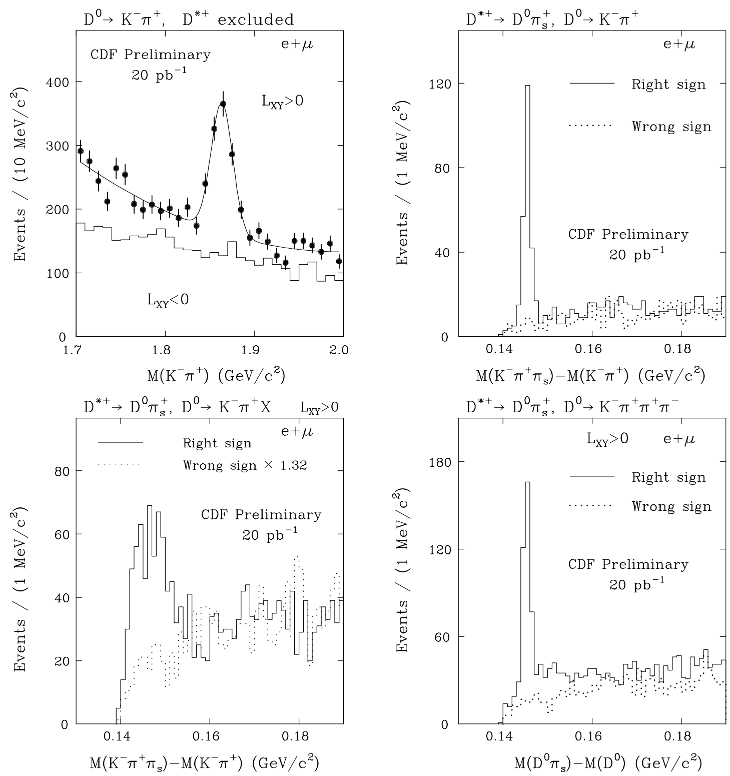

Figure 2: Charm signal mass peak for combined electron and muon sample.

The main systematic errors arise from the background shape, residual misalignment, $\beta_t\gamma$ correction and D^{**} modeling.

We can combine these results with exclusive lifetime measurements described in section 2.1 obtaining CDF average values:

$$\begin{aligned} \tau^+_{CDF} &= 1.62 \pm 0.09\ ps \\ \tau^0_{CDF} &= 1.60 \pm 0.09\ ps \\ (\tau^+/\tau^0)_{CDF} &= 1.00 \pm 0.07 \end{aligned}$$

The precision on the CDF lifetime averages is now nearly identical to the latest LEP values [4].

2.3 B_s^0 Lifetime

The B_s^0 meson lifetime has been measured [3] using both the exclusive and the semi-inclusive decay. The analysis techniques are similar to those described in section 2.1 and 2.2. In the first case the B_s^0 is reconstructed through the decay to $J/\Psi\varphi$. Since the statistics is very low, just 8 events after background subtraction, the result has a very large error: $\tau_{B_s^0} = 1.74^{+1.08}_{-0.69}(\textit{stat.}) \pm 0.07(\textit{syst.})\ ps$.

In the second case we exploit the decay to $D_S l\nu$. The statistics is larger, 76 events "right sign", and the result is more precise $\tau_{B_s^0} = 1.42^{+0.27}_{-0.23}(\textit{stat.}) \pm 0.11(\textit{syst.})\ ps$, but still statistics limited.

3 $B^0\bar{B}^0$ Mixing

The $B^0_{d(s)}\ \bar{B}^0_{d(s)}$ mixing parameters are important to estimate the magnitude of CP violating effects and to measure the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements V_{td}, V_{ts}.

Given an initially pure B^0 state the probability density of observing a $\bar{B}^0$ at time t is:

$$P(B^0 \to \bar{B}^0(t)) = \frac{1}{2\tau} e^{-t/\tau} \left(1 - \cos \Delta m t\right) \tag{2}$$

where Δm is the mass difference and τ the average lifetime of the eigenstates of the mass matrix. Δm is tightly related to the CKM matrix elements.

Integrating the formula 2 over the time we obtain the probability that a B^0 mixes to a $\bar{B}^0$:

$$P(B^0 \to \bar{B}^0) = \chi = \frac{x^2}{2\,(1 + x^2)} \qquad x = \Delta m \cdot \tau \tag{3}$$

If both B_d^0 and B_s^0 mesons are produced, χ has to be replaced by $\bar{\chi} = F_d\chi_d + F_s\chi_s$ where F_d and F_s are the fractions of b hadrons that are produced as B_d^0 and B_s^0 mesons respectively.

3.1 Time-integrated Measurements

CDF has updated its old time-integrated measurement [5] of $\bar{\chi}$ with 2 new results based on data from $e\mu$ and $\mu\mu$ triggers. Both analysis exploit the charge correlation between the b-quark type and the charge sign of the lepton: $b \to l^- + c$, $\bar{b} \to l^+ + \bar{c}$. If we neglect sequential decays ($b \to c \to l$) and background, events with like-sign leptons can come only from B^0 mixing. In practice we have to take in account also these contributions, reduced, in the $e\mu$ analysis, by applying strict lepton identification cuts and a cut on the p_t of the lepton relative to the average direction of the nearby tracks (p_t^{rel}). Their remain contributions are however taken into account when relating R, the ratio between like-sign (LS) and opposite-sign (OS) leptons, to $\bar{\chi}$:

$$R = \left(\frac{LS}{OS}\right)_{exp} \frac{(1 - F_{e\mu}(LS))}{(1 - F_{e\mu}(OS))} = \left(\frac{2\bar{\chi}(1-\bar{\chi}) + [\bar{\chi}^2 + (1-\bar{\chi})^2]f_s}{\bar{\chi}^2 + (1-\bar{\chi})^2 + 2\bar{\chi}(1-\bar{\chi})f_s + f_c}\right) \quad (4)$$

The ratio of sequential to direct b decays, f_s, estimated with a Monte Carlo, is 0.186$\pm$0.034. By fitting the experimental p_t^{rel} distribution has been determined f_c the ratio of charm to beauty production passing the analysis cuts. $F_{e\mu}(LS)$ and $F_{e\mu}(OS)$ are the fractions of fake leptons in the like-sign and opposite-sign samples. These quantities are estimated by data with the help of Monte Carlo for the efficiency determinations. The results are: $F_{e\mu}(LS) = 0.365 \pm 0.039$ and $F_{e\mu}(OS) = 0.217 \pm 0.022$. From the observed 1710 OS and 861 LS we obtain :

$$\bar{\chi} = 0.118 \pm 0.008(stat.) \pm 0.020(syst.)$$

where the main systematic come from the f_s and $F_{e\mu}$ determinations.

In the $\mu\mu$ analysis the number of $b\bar{b}$ in the like-sign and opposite-sign events $((1 - F_{\mu\mu}(LS) = 882.4 \pm 55.5)$ and $(1 - F_{\mu\mu}(OS) = 1804.4 \pm 102.9))$ is determined by fitting the impact parameter distribution of the muons. The sequential decay fraction f_s is taken from Monte Carlo and is 0.132 ± 0.026 while f_c turn out to be negligible. The result for the average mixing parameter is

$$\bar{\chi} = 0.118 \pm 0.021(stat.) \pm 0.026(syst.)$$

where the systematic error is dominated by the uncertainty on f_s.

3.2 Time-dependent Measurement

In the time-dependent mixing analysis we still use the muon charge sign in order to determine the B flavour either at production and decay time. Moreover we need to know the proper decay time t of at least one B. This is achieved applying a secondary vertex $b-$tagging algorithm and then assigning all tracks in the tag, excluding the muon, to an inclusive "D" decay and fit all these tracks to a common vertex. We then define a transverse decay length, L_{xy} as intersection of the "D" trajectory with that of the associated μ projected onto the transverse direction of the μ"D" system. The proper decay length cannot be calculated exactly and is defined as in the semi-inclusive analysis. One of the major cuts is $p_t^{rel} > 1.3$ Gev/c, where p_t^{rel} is the p_t of the muon relative to the "D" direction. With this cut we reduce significantly the contribution of the sequential decays and the direct charm background which would otherwise dilute the effect of the mixing. In figure 3 we show the dependence on $c\tau$ of the like-sign fraction, defined as: $N_{LS}(c\tau)/(N_{LS}(c\tau) + N_{OS}(c\tau))$. A clear oscillation signal is observed.

From data we extract the background fraction, while the sequential decay fraction and the $c\tau$ resolution is determined using the Monte Carlo. Additional inputs to the fit are χ_s which is assumed to saturate at 0.5 and F_d and F_s the B_d^0 and B_s^0 fraction in our sample. We take the values 0.37 ± 0.03 and 0.15 ± 0.04 respectively. The fit result of the like-sign fraction is :

$$\Delta m_d = 0.44 \pm 0.12 \pm 0.14 \; ps^{-1}$$

We notice that the systematic error is largely dominated by the uncertainty on the sequential decay fraction and can be reduced easily in the future using the LEP measurements.

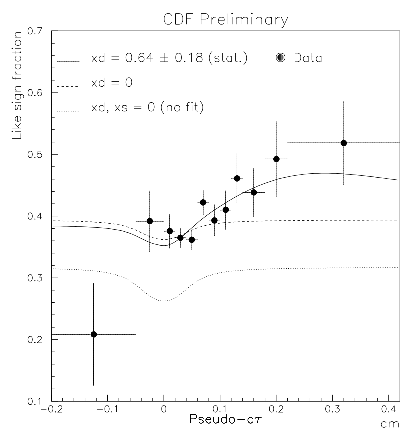

Figure 3: Like-sign fraction versus $c\tau$. The solid line is our fit to the data; the dashed line is our fit after forcing $\Delta M_d = 0$ and the dotted line is a prediction assuming just the sequential decay contribution and both $\Delta M_d = 0$ and $\Delta M_s = 0$.

4 Conclusions

CDF has shown competitive results on the B lifetime measurements. Mixing results are still dominated by systematics, but the situation is rapidly changing thanks to the new LEP results and the new data collected.

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