FERMILAB Conf-96/407-E
CDF

Time Dependent $B^0 \bar{B}^0$ Mixing at CDF

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

George Michail
Harvard University
44 Oxford Street, Cambridge, Massachusettes 02138

For the CDF Collaboration

November 1996

Submitted to the *Proceedings of the 1996 Meeting of the Division of Particles and Fields, American Physical Society, Minneapolis, Minnesota, August 10-15, 1996.*

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

Time Dependent $B^0\bar{B}^0$ Mixing at CDF [a]

Fritz DeJongh
Fermilab, PO Box 500 ms 318, Batavia IL 60510

George Michail
Harvard University, 44 Oxford St., Cambridge MA 02138

We describe two measurements of Δm_d. The first uses $B \to \nu\ell D^{(*)}$ events and a same-side flavor tagging algorithm. The second uses dilepton events. From the average of these two measurements we find $\Delta m_d = 0.466 \pm 0.037 \pm 0.031$ ps^{-1}.

1 Introduction

Measurements of the frequencies for B_d and B_s mesons to oscillate into $\bar{B}_d$ and $\bar{B}_s$, respectively, can potentially constrain the magnitudes of the CKM matrix elements V_{ts} and V_{td}. These frequencies are proportional to Δm_d and Δm_s, the mass differences between the CP eigenstates of the B_d and B_s mesons. Recent measurements have provided precise determinations of Δm_d and lower limits on Δm_s [1]. The large $b\bar{b}$ cross-section in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ GeV has enabled the reconstruction of large B signals using the CDF detector [2]. The measurement of a time-dependent mixing probability is made possible by a precise decay length measurement from the Silicon Vertex Detector (SVX) [3]. The charges of the decay products tag the flavor of the B at the time of decay. To tag the flavor of the B at production, several tagging algorithms have been developed. The measurement of the mistag probabilities of these algorithms is also useful for future measurements of CP violation [4].

We present herein two measurements of the B_d mixing frequency. The first uses semileptonic B decays in which the charm has been fully reconstructed, and a same-side flavor tagging algorithm using correlations between B mesons and charged tracks. Such correlations have been observed at LEP [5] and in $B^\pm \to J/\psi K^\pm$ events at CDF [6]. The second uses semileptonic B decays in which the charm has been inclusively reconstructed, and a flavor tagging algorithm using the semileptonic decay of the other B in the event.

[a] Submitted to the Proceedings of the 1996 Meeting of the Division of Particles and Fields, American Physical Society, Minneapolis MN, August 10-15, 1996.

2 B^0 mixing in $B \to \nu \ell D^{(*)}$ events

For this analysis, we use B mesons reconstructed in the following channels:

$$
\begin{array}{llll}
B^0 \to \nu\ell^+ D^{*-}, & D^{*-} \to \bar{D}^0 \pi_s^-, & \bar{D}^0 \to & K^+\pi^- \\
 & & \to & K^+\pi^-(\pi^0 \text{ not reconstructed}) \\
 & & \to & K^+\pi^-\pi^-\pi^+ \\
B^0 \to \nu\ell^+ D^-, & D^- \to K^+\pi^-\pi^- & & \\
B^+ \to \nu\ell^+ \bar{D}^0, & \bar{D}^0 \to K^+\pi^- & & (\text{Veto D}^* \text{ candidates})
\end{array}
$$

An electron or muon with transverse momentum with respect to the beam axis (p_t) greater than 9 GeV/c triggers the event. We then reconstruct the charmed mesons from the tracks in a cone of radius 1.0 in $\eta - \phi$ space around the lepton. To decrease combinatorial background from prompt tracks, we select tracks with impact parameters significantly displaced from the primary interaction vertex. The signals are identified as peaks in the mass spectra of the charm decay products, as shown in Fig. 1 and Fig. 2.

Using the SVX information, we reconstruct the decay length of the B in the plane transverse to the beam axis (L_{xy}^B). To obtain the proper decay time we estimate the boost of the B from the observed decay products and apply a correction factor for the missing neutrino:

$$c\tau = L_{xy}^B \frac{m_B}{p_t(B)} = L_{xy}^B \frac{m_B}{p_t(\ell D)} K \tag{1}$$

On average, we reconstruct 86% of the momentum of the B, with an r.m.s. of 11%.

We use a "Same-side tagging" (SST) algorithm to tag the flavor of the B at $t = 0$. This algorithm exploits the correlation between the B flavor and the charge of tracks from either the fragmentation process or B^{**} decay [7]. We expect a B^- to be correlated with a π^+ and a $\bar{B}^0$ to be correlated with a π^-. Due to the production of s quarks in the fragmentation process, and since we do not apply K/π separation, we expect the observed correlation to be stronger for the B^- than for the $\bar{B}^0$ [8].

For our algorithm, we approximate the B momentum as the momentum of the reconstructed portion of the B. We define a cone whose axis is the momentum vector of the B, and with radius 0.7 in $\eta - \phi$ space. We consider all tracks in this cone with $p_t > 0.4$ GeV and which pass within 3 s.d. of the primary vertex. We define p_t^{rel} for a track as the transverse momentum of the track relative to the sum of the momenta of the B and that track. Of the candidate tracks, we select the track with lowest p_t^{rel}, and compare the charge of that track to the charge of the lepton from the semileptonic decay. Our efficiency (ϵ) for finding such a tag is $\approx 72\%$.

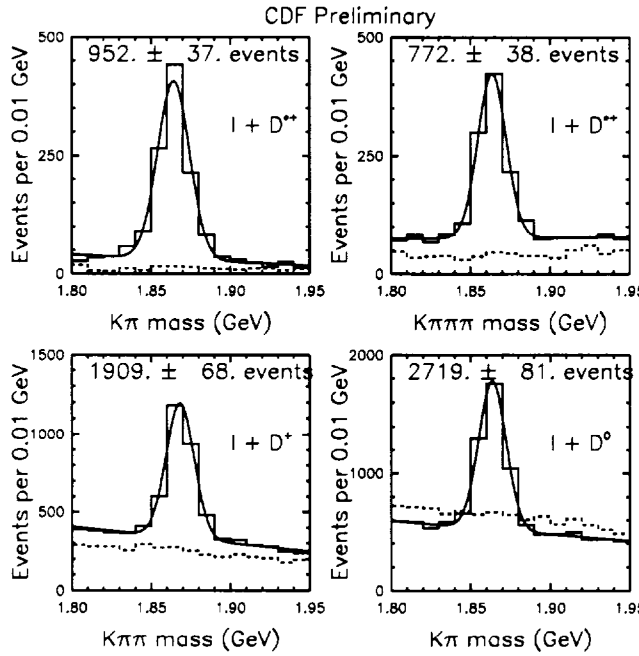

Figure 1: **Charm signals in semileptonic B decays**

We compare the number of right-sign (RS) correlations (*i.e.* $\bar{B}^0\pi^-$, $B^-\pi^+$) to the number of wrong-sign (WS) correlations (*i.e.* $\bar{B}^0\pi^+$, $B^-\pi^-$) as a function of $c\tau$. For the $\bar{B}^0$ we expect the asymmetry $A(t)$:

$$A(t) = \frac{N_{RS}(t) - N_{WS}(t)}{N_{RS}(t) + N_{WS}(t)} = D\cos(\Delta m t) \tag{2}$$

where Δm is the frequency of the oscillation, and D is the dilution of the flavor tagging algorithm. D is often expressed in terms of the mistag fraction w as $D = 1 - 2w$. We fit for both Δm and D.

To obtain the asymmetry for B^0 or B^+, we correct for the fact that each signal has contributions from both B^0 and B^+ decays. For example, the following decay chains contribute to the same data sample:

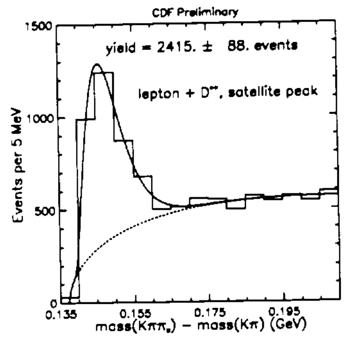

Figure 2: D^* signal for $\bar{D}^0 \to K^+\pi^-$(π^0 not reconstructed)

$B^+ \to \nu\ell^+\bar{D}^0$ (Veto D^*)
$B^0 \to \nu\ell^+D^{**-}$ $D^{**-} \to \bar{D}^0(\pi^-_{**}$ unobserved)
We correct for this cross-talk by performing a fit bin by bin in $c\tau$. The inputs to the fit are the raw aymmetries as measured in each sample for a given $c\tau$ bin, and parameters describing the D^{**} composition in semileptonic decays. The outputs are the true B^0 and B^+ asymmetries. We fit the true B^0 asymmetry as a function of $c\tau$ to a cosine convoluted with the $c\tau$ resolution function, and extract the mixing frequency and dilution of the algorithm. The results are shown in Fig. 3. We also observe an asymmetry for the B^+ which is flat with $c\tau$ as expected.

In summary, we find $\Delta m_d = 0.446 \pm 0.057^{+0.034}_{-0.031}$ ps^{-1}, and an effective tagging efficiency for the $\bar{B}^0$, $\varepsilon D_0^2 = 3.4 \pm 1.0^{+1.2}_{-0.9}$%. The dominant systematic uncertainty is from the fraction of D^{**} in semileptonic B decay.

3 B^0 Mixing in $e\mu$ Events

For this analysis, we trigger on leptons from the semileptonic decay of both b hadrons in an event: $b_1 \to eX$ and $b_2 \to \mu X$. We estimate that 70% of our signal events come from an $e\mu$ trigger which requires $p_t(e) > 5$ GeV/c and $p_t(\mu) > 3$ GeV/c, and 30% come from single lepton triggers with $p_t(\ell) > 9$ GeV/c and the other lepton found offline. Offline, we require $M_{e\mu} > 5$ GeV/c^2 in order to reject sequential decays.

The principle of this analysis is to search for an inclusive secondary vertex associated with one of the leptons. The decay length of this vertex and the momenta of tracks associated with the lepton provide an estimate of $c\tau$. The

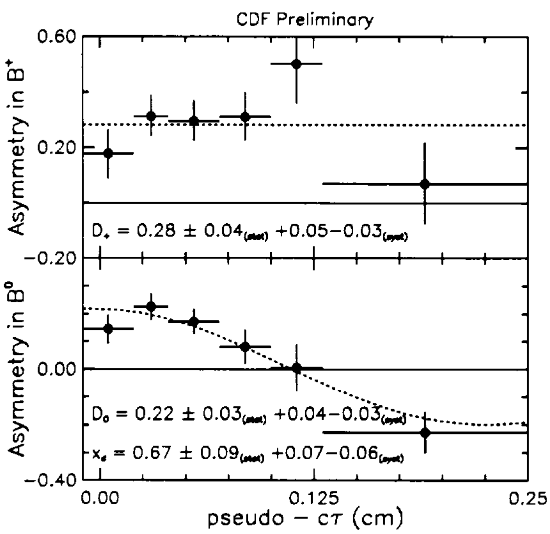

Figure 3: Time dependent asymmetry

boost resolution for this technique is $\approx 21\%$ for the electrons and $\approx 24\%$ for the muons. The charge of the other lepton provides the flavor tag.

To search for an inclusive secondary vertex, we consider tracks in a cone around each lepton that are significantly displaced from the primary vertex. For each lepton we first search for a secondary vertex with at least two tracks in addition to the lepton with $p_t > 0.5$ GeV/c. If no such vertex is found, we allow a secondary vertex with only one additional track with $p_t > 1.0$ GeV/c. This algorithm is tuned for high efficiency near $c\tau = 0$, with the efficiency reaching a plateau of $\approx 40\%$ for $c\tau > 0.05$ cm according to a Monte Carlo simulation.

Since the signal cannot be observed as a narrow peak in a mass distribution, accounting for backgrounds is a challenge. We define a fake event as an event with at least one fake lepton. We have found that to a very good approximation, the fake electron events are a subset of the fake muon events, due to the higher electron p_t cut. This greatly simplifies the accounting of fake backgrounds. To obtain magnitudes and distributions for fake events, we use the following samples: 1) Prescaled 5 GeV single electron triggers with another track passing all cuts except for the presence of a muon stub. 2) $e\mu$ events for which the μ candidate fails quality cuts. We then assume that fake events for which the muon passes our selection criteria have the same properties as these samples.

Other backgrounds arise from sequential decays: $b \to c \to \ell$. These backgrounds can be estimated from p_t^{rel} distributions, and the invariant mass distribution of the secondary vertex tags. Here, p_t^{rel} is defined as the transverse momentum of the muon with respect to the highest p_t track in a cone of radius 0.7 in $\eta - \phi$ space around the muon. We require $p_t^{rel} > 1.25$ GeV/c for the muon in order to reduce sequential backgrounds. The final sample composition is shown in table 1.

Table 1: Final sample composition of vertex-tagged $e\mu$ events. "e tag" and "μ tag" indicate that the vertex is associated with the electron or muon. The sequential fractions are fractions of the $b\bar{b}$ component.

Component	e Tags	μ Tags
Fake e with Real μ	$\leq 1\%$	$\leq 1\%$
Fake μ Fraction	$15 \pm 4\%$	$7 \pm 3\%$
$c\bar{c}$ events	$2 \pm 2\%$	$4 \pm 3\%$
$b\bar{b}$ events	$83 \pm 5\%$	$89 \pm 4\%$
Sequential e	$8.8 \pm 1.3\%$	$7.9 \pm 1.2\%$
Sequential μ	$13.6 \pm 2.0\%$	$16.5 \pm 2.5\%$

We extract Δm_d from a fit to the like-sign fraction as a function of $c\tau$, with the results shown in Fig. 4. This fit includes components for direct $b\bar{b}$, sequential b decays, $c\bar{c}$, and fake events. In $\approx 16\%$ of the events with a secondary vertex found around one lepton, we also find a secondary vertex around the other lepton. These events enter the like-sign fraction plot twice, and we allow for a statistical correlation between the two entries. We find $\Delta m_d = 0.50 \pm 0.05 \pm 0.06$ ps^{-1}, where the dominant systematic uncertainties arise from uncertainties in the sample composition.

4 Summary

We have reported two measurements of Δm_d. In $B \to \nu\ell D^{(*)}$ events tagged with a same-side algorithm we find $\Delta m_d = 0.446 \pm 0.057^{+0.034}_{-0.031}$ ps^{-1} and $\epsilon D_0^2 = 3.4 \pm 1.0^{+1.2}_{-0.9}$ %. In $e\mu$ events we find $\Delta m_d = 0.50 \pm 0.05 \pm 0.06$ ps^{-1}. The average of these results is $\Delta m_d = 0.466 \pm 0.037 \pm 0.031$ ps^{-1}.

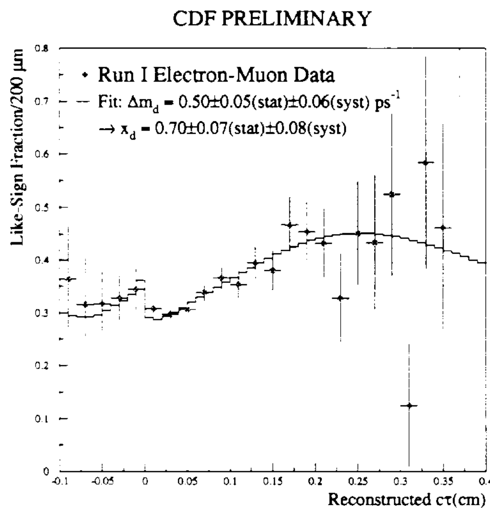

Figure 4: Like-sign fraction vs. $c\tau$

References

1. For a review, see P. Sphicas, these proceedings.
2. F. Abe et al., ***Nucl. Instrum. Methods*** **A271**, 387 (1988).
3. D. Amidei et al., ***Nucl. Instrum. Methods*** **A350**, 74 (1994).
4. See M. Paulini, these proceedings.
5. R. Akers et al., ***Z. Phys.*** C **66**, 19 (1995), D. Buskulic et al., ***Z. Phys.*** C **69**, 393 (1996).
6. F. Abe et al., FERMILAB-CONF-96/175-E.
7. M. Gronau, A. Nippe, and J. Rosner, ***Phys. Rev.*** D **47**, 1988 (1993).
8. I. Dunietz and J. Rosner, ***Phys. Rev.*** D **51**, 2471 (1995).