SLAC-PUB-6016
December 1992
(E)

A Monte Carlo Study of $B^0 - \bar{B}^0$ Mixing in Decays of Z^0s Produced with a Polarized Electron Beam*

THE SLD COLLABORATION+

Represented by

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ABSTRACT

We present a feasibility study of the time development of $B_d^0 - \bar{B}_d^0$ and $B_s^0 - \bar{B}_s^0$ mixing in Z^0 decays produced with a polarized electron beam and measured by the SLD. A high electron beam polarization and good vertex detection capability are essential for this measurement.

1. Introduction

$B^0 - \bar{B}^0$ mixing is one of the most important topics in high energy physics. It gives essential information about Kobayashi-Maskawa matrix elements containing b-quark. Time-integrated measurements of $B_d^0 - \bar{B}_d^0$ mixing were made by ARGUS [1] and CLEO [2] on the $\Upsilon(4\,s)$ state. They determined the time-integrated probability of $B_d^0 - \bar{B}_d^0$ mixing (χ_b) to be $\sim$17%, which translates to a B_d^0 mixing rate, $x_d \equiv (\Delta m/\Gamma)_{B_d^0}$ of 0.7. The Standard Model indicates that a B_s^0 mixing rate, $x_s \equiv (\Delta m/\Gamma)_{B_s^0}$ is greater than $\sim$5. For $x_s \gg 1$, a time-integrated measurement of $B_s^0 - \bar{B}_s^0$ mixing is insensitive to x_s, so a measurement of the time development of $B_s^0 - \bar{B}_s^0$ mixing is necessary. To date there has been no time-development measurement of either $B_s^0 - \bar{B}_s^0$ or $B_d^0 - \bar{B}_d^0$ mixing.

The measurement of the time-development of $B^0 - \bar{B}^0$ mixing by the SLD is based on several key features of the SLD/SLC: 1) a large forward-backward asymmetry (A_{FB}) of $e^+e^- \rightarrow Z^0 \rightarrow b\bar{b}$ with a longitudinally polarized electron beam produced by the SLC; 2) excellent SLD vertex detection capability in conjunction with small SLC beam sizes; and 3) excellent SLD particle identification capability[3].These features place the SLD in a unique position to measure the time-development of $B_s^0 - \bar{B}_s^0$ mixing as well as that of $B_d^0 - \bar{B}_d^0$ mixing.

⋆ Work supported in part by Department of Energy contract DE-AC03-76SF00515 (SLAC).

Presented at the 10th International Symposium on High Energy Spin Physics, Nagoya, Japan, November 9-14, 1992.

2. The SLD

A detailed description of the SLD is given in Reference [4]. Here we briefly describe the SLD vertexing system, a vertex detector (VXD)[5] and a central drift chamber (CDC), which play essential roles in this $B^0 - \bar{B}^0$ mixing study.

The VXD, which is based on CCD technology with 22 μm square pixels, is located just outside the beam pipe and has inner radius of 2.5 cm. It has excellent three-dimensional tracking capability, with a local resolution of 6 μm in (x,y,z). The CDC surrounds the VXD and provides charged particle tracking. A combined fit using both VXD and CDC information is performed for vertex finding and gives impact resolutions of $\sigma_{R\phi}^{imp} = 13 \oplus 70/(p\sqrt{sin^3\theta})$ and $\sigma_{Rz}^{imp} = 52 \oplus 70/(p\sqrt{sin^3\theta})$ (μm), where the sum is taken in quadrature. In addition to these devices, a Cherenkov ring imaging detector (CRID)[6], surrounding the CDC is used for a particle identification.

The SLD took data from February through September of 1992 and collected about 11,000 Z^0 decay events produced with a longitudinally polarized electron beam and an unpolarized positron beam from the SLC. An average electron beam polarization of 22% and beam size of (2,2,650μm) in (x,y,z) at the interaction point were achieved. Preliminary results of the SLD vertexing system are given in Reference [7].

3. Time development measurement of $B^0 - \bar{B}^0$ mixing

A measurement of the time-development of $B^0 - \bar{B}^0$ mixing is possible by making use of the excellent vertex reconstruction capability of the SLD and the large A_{FB} of the b-quark with a highly polarized electron beam ($A_{FB} \sim 70\%$ for $P_{e^-} = 100\%$ compared with $A_{FB} \sim 10\%$ for $P_{e^-} = 0\%$).

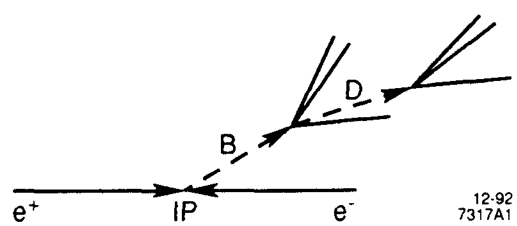

Figure 1. A chain of two decay vertices in the reaction $e^+e^- \to Z^0 \to B^0\bar{B}^0$. The B meson decays into a D meson.

In this study, we use an improved A_{FB}, $\tilde{A}_{FB}(b)$, for b-quark production to tag the B^0 or the $\bar{B}^0$ at $t = 0$ in the forward direction. $\tilde{A}_{FB}(b)$ is defined:

$$\tilde{A}_{FB}(b) = \frac{(N_F(b) - N_B(b))_L - (N_F(b) - N_B(b))_R}{(N_F(b) + N_B(b))_L + (N_F(b) + N_B(b))_R}$$

where $N_F(b)$ and $N_B(b)$ represent the number of events with forward-going and backward-going b-quarks, respectively, and $L(R)$ represents the events produced with left(right)-handed electron beams, respectively. This asymmetry maximizes the effects of polarization and the number of available events. In order to measure the time-development of the $B^0 - \bar{B}^0$ mixing, we actually measure $\tilde{A}_{FB}(B^0)$ instead of $\tilde{A}_{FB}(b)$ as a function of the proper decay time of B^0. One has $\tilde{A}_{FB}(B^0) = \tilde{A}_{FB}(b)(1-2\chi)$ where χ is the mixing probability of $B^0 \to \bar{B}^0$. Thus, instead of tagging both B^0s, we can do a single B^0 tag experiment to see if a B^0 decays as B^0 or $\bar{B}^0$ in the e^+ beam direction.

For a Monte Carlo study of $B^0 - \bar{B}^0$ mixing, we generated $b\bar{b}$ events using the JETSET 6.3 Monte Carlo program[8] with added information on non-zero B^0 lifetimes and mixing rates, and finite detector resolution. We chose $x_d = 0.68$, $x_s = 10$ and $(c\tau_0)_{B^0} = 405\mu$m as input parameters, and assumed measurement errors of $(\Delta L)_{B^0} = 200\mu$m in the B^0 decay length measurement and $(\Delta E/E)_{B^0} = 10\%$ in the B^0 energy measurement[9].

Table 1. Assumption of efficiencies of the B^0 tagging process.

Tagging process	Efficiency (%)
Find a chain of two decay vertices	30
Separate $B^{\pm}$ from B^0	80
Identify B^0 or $\bar{B}^0$	40
Separate B_d^0 and B_s^0	$80(B_d^0)$, $20(B_s^0)$
Total efficiency	$8(B_d^0)$, $2(B_s^0)$

For inclusive B^0 or $\bar{B}^0$ decay identification, we make use of the SLD vertexing system. It consists of several steps[10]:

1. Looking at events with two consecutive decays, such as B meson decay followed by D meson decay (Fig. 1) for tagging a $b\bar{b}$ event.
2. Counting the total charge at the B vertex to separate $B^{\pm}$ from B^0. The average charged multiplicity at the B vertex is expected to be 3.5, so charge counting is fairly reliable.
3. Identifying the lepton charge out of either the B or D vertex to identify B^0 or $\bar{B}^0$. B^0 produces l^+ at the B vertex and l^- at the D vertex. Thus a single lepton tag is enough to identify B^0 or $\bar{B}^0$.
4. Counting the number of kaons in the decay chain to separate B_s^0 from B_d^0 decay. B_s^0 tends to produce two kaons, one from the $\bar{b} \to \bar{c} \to \bar{s}$ decay chain, the other from the spectator s in the B_s^0. On the other hand, B_d^0 usually produces only one kaon in its decay chain. In this step, the CRID must be used to identify kaons.

Our assumptions for the efficiency of each step are listed in Table 1.

Figure 2(a) shows the distribution of $\hat{A}_{FB}(B_d^0)$ as a function of the proper decay time of the B^0 with an event sample of about 1,600 tagged B_d^0

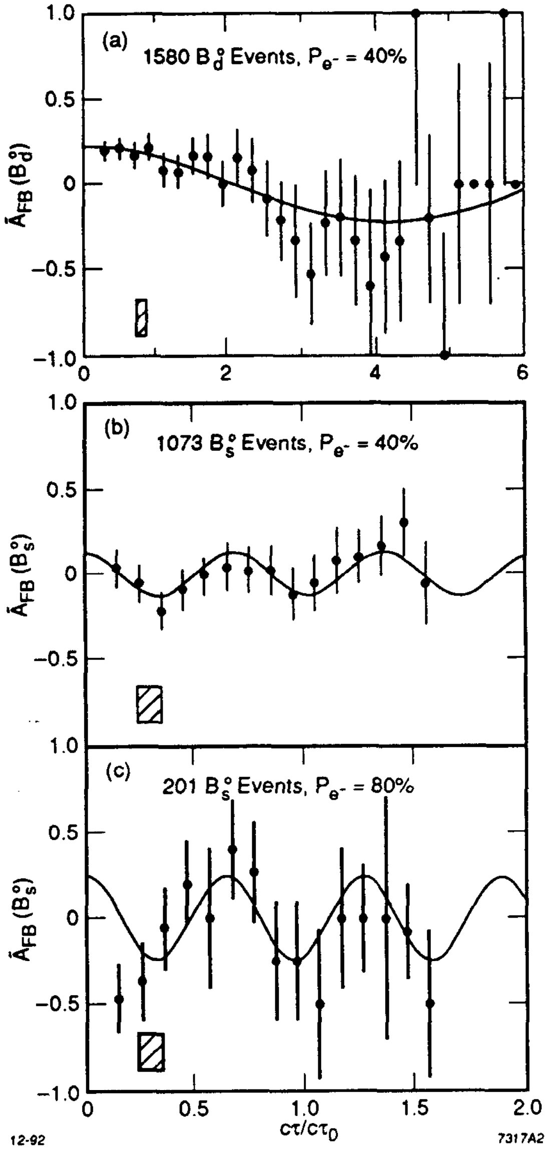

Figure 2. Distributions of $\tilde{A}_{FB}(B^0)$ as a function of the proper decay time of the B^0 with a) about 1,600 tagged B_d^0 events for $P_{e^-} = 40\%$ and x_d=0.68. The solid line indicates the result of a fit: $x_d^{fit} = 0.76 \pm 0.10$ with χ^2/dof=10.7/25. b) about 1,000 tagged B_s^0 events for $P_{e^-} = 40\%$ and x_d=10. $x_s^{fit} = 9.2 \pm 0.5$ with χ^2/dof=3.5/13. c) about 200 tagged B_s^0 events for $P_{e^-} = 80\%$ and x_d=10. $x_s^{fit} = 10.0 \pm 0.7$ with χ^2/dof=10.9/13. In these figures, the width of the shaded area shows the assumed detector resolution.

events with $P_{e^-} = 40\%$ and x_d=0.68, corresponding to 10^5 hadronic Z^0 decays. The time development of $B_d^0 - \bar{B}_d^0$ mixing can be clearly seen with this event size and polarization. This oscillation measurement is our goal in the 1993 SLC/SLD run, in which we expect at least 5×10^4 hadronic Z^0 decays with 40% electron beam polarization.

Figure 2 b) shows the same distribution of $\tilde{A}_{FB}(B_s^0)$ for about 1,000 tagged B_s^0 events with $P_{e^-} = 40\%$ and x_s=10. This event sample corresponds to 10^6 hadronic Z^0 decays. A measurement of the time development of $B_s^0 - \bar{B}_s^0$ mixing can be seen with this number of events with $P_{e^-} = 40\%$ if x_s is not much greater than 10. We note that detector resolution is critical for $x_s > 10$. Collecting 10^6 hadronic Z^0 events is, however, optimistic considering the current luminosity of the SLC.

Figure 2 c) shows the same distribution of $\tilde{A}_{FB}(B_s^0)$ for about 200 tagged B_s^0 events with $P_{e^-} = 80\%$ and x_s=10. This number of tagged B_s^0 events corresponds to 2×10^5 hadronic Z^0 decays. Oscillation of B_s^0 can be seen with the limited event size for $P_{e^-} = 80\%$. A measurement of the time development of $B_s^0 - \bar{B}_s^0$ mixing will be feasible with a higher polarized electron beam in the SLC.

4. Summary

We performed a Monte Carlo study of the time development of $B^0 - \bar{B}^0$ mixing in decays of Z^0's produced with a polarized electron beam. A measurement of the time development of $B_d^0 - \bar{B}_d^0$ mixing will be possible with less than 10^5 Z^0's with $P_{e^-} = 40\%$ in the 1993 SLC/SLD run. A measurement of the time development of $B_s^0 - \bar{B}_s^0$ mixing will be possible with $2 \times 10^5 Z^0$'s with $P_{e^-} = 80\%$ if $x_s < 15$. This could be achieved in future high polarization SLC/SLD runs.

Acknowledgements

I wish to thank Yoshihito Iwasaki for his contributions to this study.

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