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Time Dependent B^0–$\overline{B^0}$ Mixing at SLD [1]

Julia Thom for the SLD Collaboration

Stanford Linear Accelerator Center Stanford, CA 94309

Abstract

We report several preliminary studies of the time dependence of B_s^0–$\overline{B_s^0}$ and B_d^0–$\overline{B_d^0}$ mixing using a sample of 400,000 hadronic Z decays collected by the SLD experiment at the SLC. The study of B_d^0–$\overline{B_d^0}$ mixing determines a value of $\Delta m_d = 0.503 \pm 0.028(\text{stat}) \pm 0.020(\text{sys})\text{ps}^{-1}$. In the study of B_s^0–$\overline{B_s^0}$ mixing, oscillation frequencies up to $\Delta m_s < 11.1\text{ps}^{-1}$ are excluded at 95% C.L. The combined sensitivity is 13.2 ps^{-1}.

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1 Introduction

In the Standard Model description neutral mesons like K^0, B_d^0 and B_s^0 mesons can mix into their antiparticles via second order weak interactions. These flavor oscillations occur with a frequency Δm given by the mass difference between the two mass eigenstates. Measurements of Δm are interesting because they allow the extraction of poorly constrained Cabibbo-Kobayashi-Maskawa matrix elements, e.g., $\Delta m_d \propto \mid V_{td} \mid^2$, providing important information about the Wolfenstein parameters ρ and η.

The extraction of V_{td} is complicated by large uncertainties in the determination of $f_{B_q}\sqrt{B_{B_q}}$. Currently, lattice QCD calculations [1] give a $20-30\%$ uncertainty. It is advantageous to extract the ratio V_{ts}/V_{td} from the ratio $\frac{\Delta m_s}{\Delta m_d}$, as many theoretical uncertainties cancel. The uncertainty is reduced to $\sim 5-10\%$. Δm_s is expected to be about a factor $\frac{1}{\lambda^2} \sim 20$ larger than Δm_d. Large mixing frequencies are very hard to measure and require the ability to resolve fast oscillations in the detector.

SLD is well suited for such a measurement because of its excellent CCD pixel vertex detector and small beam spots (1.5μm$\times 0.65\mu$m transverse to the beam direction), allowing the precise location of B decay vertices and the interaction point (IP) in three dimensions. Another advantage is the highly polarized electron beam (average $P_e \approx 73\%$ in the 1996-98 data), which is crucial for the initial state flavor tag. For details on the SLD experiment see [2]. The data presented here were collected by the SLD detector at the SLC between 1996 and 1998, and amounts to a total of 400,000 hadronic Z^0 decays.

2 Event Selection and Initial State Tag

Each of the B_d^0–$\overline{B_d^0}$ and B_s^0–$\overline{B_s^0}$ mixing analyses tag the initial state B^0 flavor in the same way, but use different final state tags and different techniques to reconstruct the proper time of the B decay. For all of them, b hadrons are selected by searching for hemispheres with an inclusive topological vertex displaced from the IP (see Ref.[4]). $Z \rightarrow b\bar{b}$ events are selected using a Neural Net based on the vertex mass (assuming that all tracks are pions and correcting for neutral decay products), the total charged track momentum, the flight distance of the vertex and the track multiplicity. The light flavor *udsc* background is effectively reduced to 1%.

The initial state flavor tag relies on the large forward-backward asymmetry for $Z^0 \rightarrow b\bar{b}$ decays, as produced by the polarized electron beam. Left- (right-)polarized electrons tag b ($\bar{b}$) quarks in the forward hemisphere, and $\bar{b}$ (b) quarks in the backward hemisphere. This yields an average mistag probability of 28%. In addition to this tag, information from charged tracks in the hemisphere opposite the tagged B vertex is used. It includes a standard jet charge technique, the total track charge and the charge dipole of reconstructed vertices (see below), the charge of kaons identified with the Cherenkov Ring Imaging Detector and the charge of a lepton attached to the B vertex. When combining all of these tags an overall initial state tag with an average mistag probability of 22-25% is obtained. The initial state tag is 100% efficient. Fig. 1 shows the b-quark probability for data and Monte Carlo in the Charge Dipole analysis (see below), b and $\bar{b}$ quarks are clearly separated.

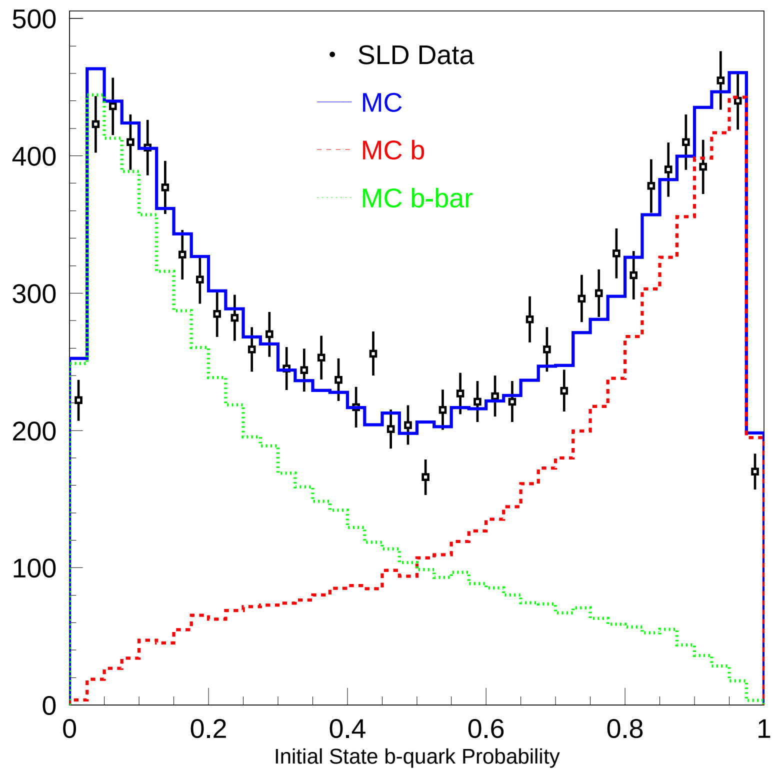

Figure 1: The distribution of the computed initial state tag b quark probability, showing the separation between b and $\overline{b}$ for the Charge Dipole analysis.

3 B_d^0–$\overline{B_d^0}$ mixing

The final state tag of the B_d^0–$\overline{B_d^0}$ mixing analysis presented here relies on the charge of kaons in inclusively reconstructed neutral B events. Positively(negatively) charged kaons from the B decay tag a $\overline{b}(b)$ quark. 7844 events were selected with a B_d^0 purity of $\sim$60%. The value of Δm_d has been extracted using a 2 dimensional maximum likelihood fit, see Fig. 2, simultaneously fitting the B_d^0 right sign kaon fraction and Δm_d. The right sign fraction has been measured to be 0.797 ± 0.022, and $\Delta m_d = 0.503 \pm 0.028(\text{stat}) \pm 0.020(\text{sys})\text{ps}^{-1}$.

4 B_s^0–$\overline{B_s^0}$ mixing

Three analysis techniques are used: "Charge Dipole", "Lepton+D" and "D_s+Tracks"[3]. The three analyses are statistically uncorrelated, i.e. each event can only be used by one of the three analyses. The Charge Dipole technique is a novel method introduced by SLD. It exploits the charge structure of the dominant $b \to c$ decay sequence. An attempt is made to reconstruct both B and D decay vertices inclusively, and the B flavor is tagged according to their charge difference. If two well-separated vertices are found, the vertex

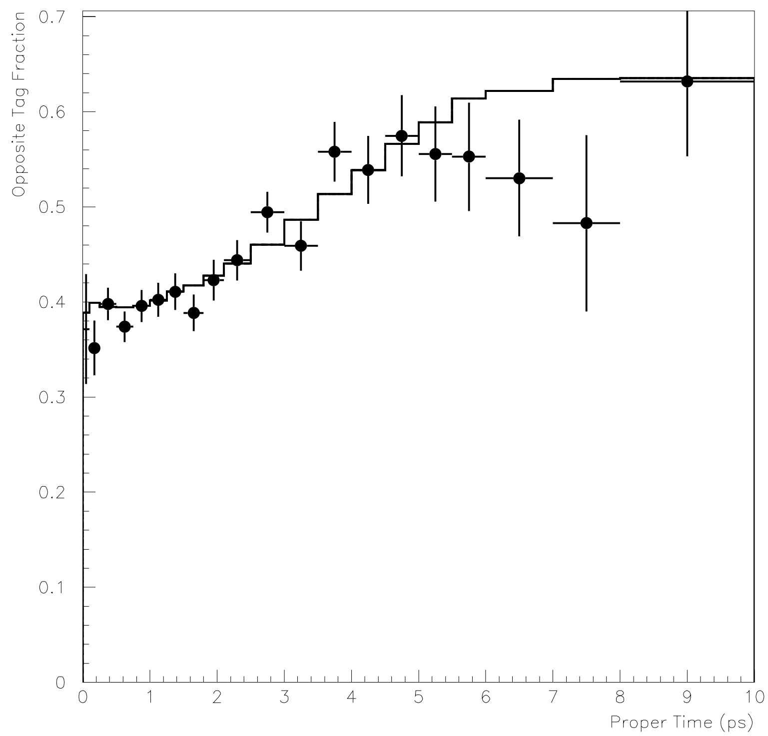

Figure 2: The fraction of events tagged as mixed as a function of reconstructed proper time. Shown are the data (data-points) and the likelihood function (histogram).

closest to the interaction point is assumed to be the B vertex, and the other one the D vertex. Requirements on the two vertices are: 250 μm $< L_{BD} <$ 1 cm, where L_{BD} is the distance between B and D vertices, total mass of tracks from the D vertex $<$ 2.0 GeV/c^2, B vertex decay length $L_B > 0$ and $Q_B \neq Q_D$, where $Q_B(Q_D)$ is the charge of the $B(D)$ vertex. The total charge is required to be zero in order to enhance the fraction of B_s^0 decays in the sample to 16%. The B boost $\gamma\beta = p_B/m_B$ is reconstructed from the momenta of charged tracks associated with the B decay chain combined with information from the electromagnetic calorimeter. The decay proper time is then calculated as $t = L/\gamma\beta c$. A value for the charge dipole is calculated as $\delta q = L_{BD} \times sign(Q_D - Q_B)$. Positive (negative) values of δq tag $\overline{B^0}$ (B^0) decays and the mistag probability decreases with increasing $|\delta q|$. For B_s^0 mesons, it is 22% on average. Fig. 4 shows the charge dipole distribution.

The Lepton+D analysis uses the charge of leptons produced in semileptonic B decays to tag the final state b flavor. Topological vertexing is used to partially reconstruct a D vertex downstream of the selected lepton. This vertex is required to have a reconstructed mass $<$ 1.95 GeV/c^2. The lepton is selected using a Neural Network. The input parameters include the lepton P_t with respect to the D vertex line of flight. The B decay position is located by intersecting the D vertex momentum with the lepton. A double Gaussian fit to the decay residual yields a core width of 54μm and tail width of 213μm with a 60% core

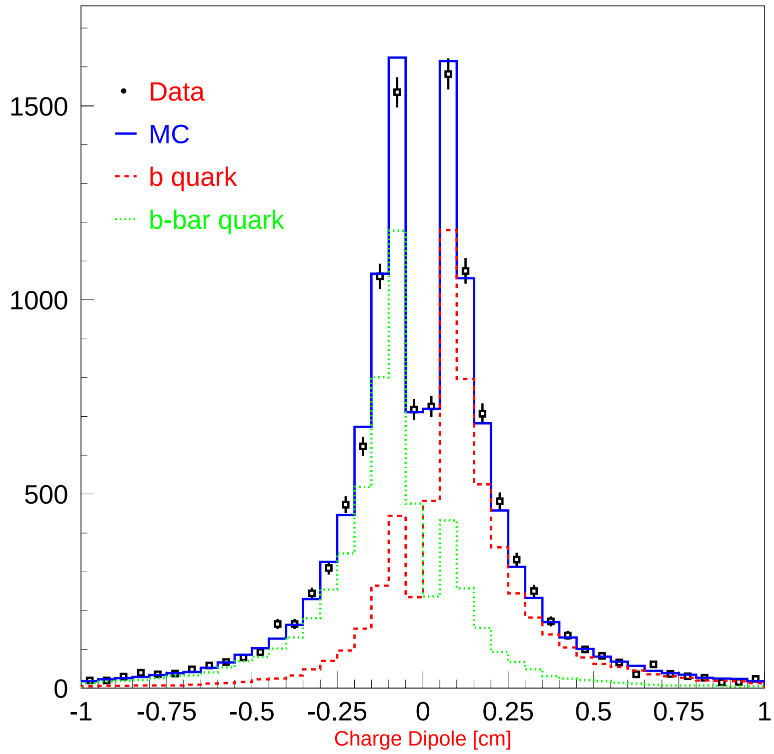

Figure 3: Distribution of the charge dipole for data (points) and Monte Carlo (solid histogram). Also shown are the contributions from b hadrons containing a b-quark (dotted histogram) or a $\overline{b}$-quark (dashed histogram).

fraction. As in the Charge Dipole analysis, the total charge is required to be zero to boost the fraction of B_s^0 decays to 16%. The decay flavor mistag probability for B_s^0 decays is 4%.

The third SLD B_s^0 mixing analysis is the D_s + Tracks analysis. It exclusively reconstructs $D_s^- \to K^{\star 0}K^-$ and $D_s^- \to \phi\pi^-$ decays, thereby boosting the B_s^0 fraction to 38% overall. The D_s candidates are then intersected with secondary tracks, to reconstruct a B vertex. The mistag probabilities are 13% for D_s+ hadrons and 5% for D_s+ lepton. This analysis has the lowest efficiency, however the high B_s^0 purity and the very high decay length resolution of $50\mu m$ (core) and $151\mu m$ (tail) makes this analysis competitive at high Δm_s.

A comparison between the different SLD B_s^0–$\overline{B_s^0}$ mixing analyses is presented in Table 1.

For the extraction of limits on Δm_s, the amplitude method [5] was used, where a factor A is placed in the probability function for mixed and unmixed decays

$$\frac{1}{2}(1 \pm cos\Delta m_s t) \to \frac{1}{2}(1 \pm Acos\Delta m_s t). \quad (1)$$

A is simply a normalized fourier amplitude so that by measuring A for various values of Δm_s one produces a frequency spectrum of the mixing signal and expects $A \approx 1$ near the true value of Δm_s and $A \approx 0$ far from the true value. If a measurement of Δm_s cannot be made,

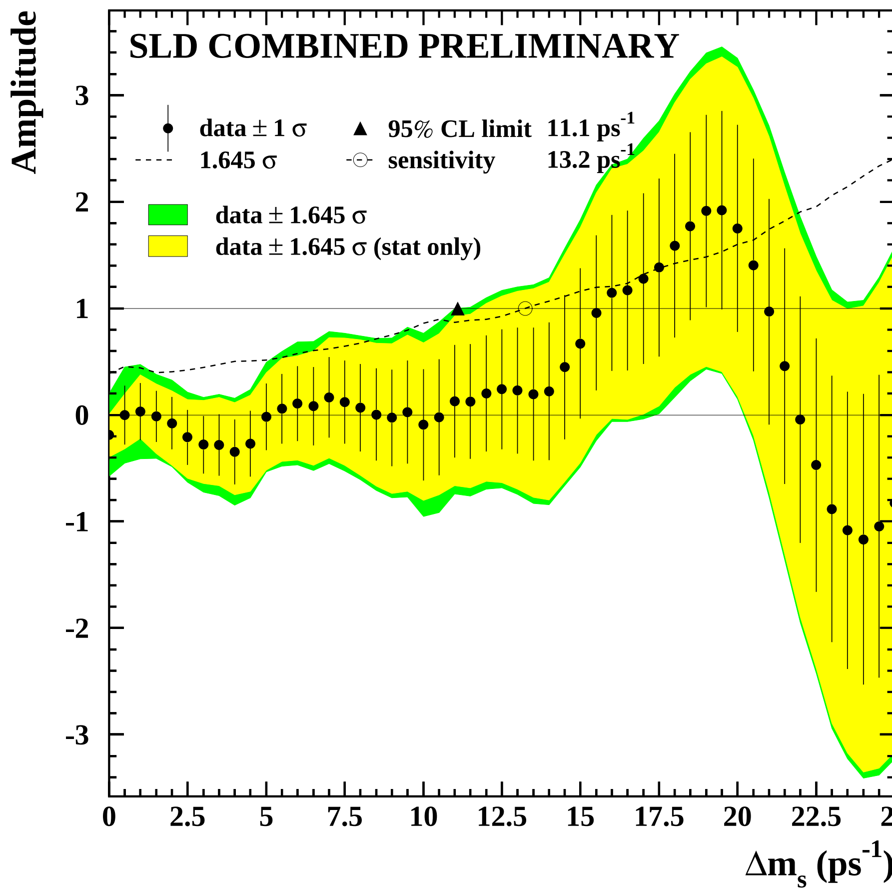

Figure 4: Measured amplitude as a function of Δm_s for the Lepton+D, D_s+Tracks, and Charge Dipole analyses combined.

one may set limits by excluding at 95%C.L. any value of Δm_s for which $A + 1.645\sigma_A < 1$ where σ_A is the combined statistical and systematic error on A. The amplitude fit for all analyses combined is shown in Figure 4. The following range of B_s^0–$\overline{B_s^0}$ oscillation frequencies are excluded at 95% C.L.

$$\Delta m_s < 11.1\mathrm{ps}^{-1}. \tag{2}$$

The combined sensitivity to set a 95% C.L. lower limit is found to be at a Δm_s value of 13.2 ps^{-1}. The dominant systematic uncertainty is the B_s^0-fraction of the data sample, where the production fraction has been varied according to $(9.8 \pm 1.2)\%$. Other systematics include the decay length and boost resolutions, mistag probability and *udsc* fraction.

Table 1: Summary and comparison of the SLD mixing analyses.

	Charge Dipole	Lepton+D	D_s+Tracks
B_s^0 Fraction	0.16	0.16	0.38
$udsc$ fraction	0.01	0.01	0.01
decay flavor mistag probability	0.22	0.04	0.10
$\sigma_L^{core}(\mu\text{m})$	81	54	50
$\sigma_L^{tail}(\mu\text{m})$	297	213	151
σ_p^{core}/p	0.07	0.07	0.08
σ_p^{tail}/p	0.21	0.17	0.19
number of selected events	11462	2087	361
95% C.L. sensitivity (ps^{-1})	8.6	6.5	1.7

5 Summary

The combined SLD B_s^0–$\overline{B_s^0}$ mixing analyses exclude oscillation frequencies up to $\Delta m_s < 11.1\text{ps}^{-1}$ at 95% C.L. The combined sensitivity is 13.2 ps^{-1}. A study of B_d^0–$\overline{B_d^0}$ mixing with a kaon tag yields $\Delta m_d = 0.503 \pm 0.028(\text{stat}) \pm 0.020(\text{sys})\text{ps}^{-1}$. These results are preliminary.

References

[1] T. Draper, *Nucl. Phys. Proc. Suppl. 73* 43 (1999).

[2] P. C. Rowson, D. Su, S. Willocq, *SLAC-PUB-8985* (2001).

[3] K. Abe et al., *SLAC-PUB-8568* (2000).

[4] D. Jackson, *Nucl. Instrum. Meth. A388* 247 (1997).

[5] H. Moser and A. Roussarie, *Nucl. Instrum. Meth. A384* 491 (1997).