SLAC-PUB-9514
October 2002

SLD Results on B Physics

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Abstract. Results on B-lifetimes, B_d^o and B_s^o mixing, and B decay charm counting studies from the SLD experiment at the Stanford Linear Accelerator Center are presented. These results which exploit the small stable beam spots and high precision detector and the polarized electron beam are among the most precise measurements to date.

INTRODUCTION

The SLD experiment collected a sample of about 550K hadronic Z^0 decays from data taken between 1993 and 1998. These events were the results of e^+e^- collisions at the Stanford Linear Collider(SLC) using an average electron beam polarization of 73%. The small and stable beam spot at the interaction point allowed the SLD detector to make full use of its high precision CCD vertex detector to reconstruct secondary and tertiary vertices in heavy flavor decays. The polarization is used as a powerful tool in discriminating between initial state B's and $\bar{B}$'s. The combination of the assets of the accelerator and detector resulted in some of the most precise heavy flavor measurements. Several of the important contributions of the SLD experiment to heavy flavor physics are discussed here. These include B lifetimes, B_d^o and B_s^o mixing, and B decay charm counting studies.

DETECTOR

For the final 400K Z^o decays (from the 1996→1998 runs), the tracking systems, consisting of a 3 layer 300 million pixel CCD Detector (VXD3)[1], and a 80 layer 5120 wire Central Drift Chamber (CDC)[2] yield impact parameter resolutions of 8 μm ($r\phi$ projection) and 10 μm (rz projection) for high momentum particles and multiple scattering contributions of 33 $\mu\mathrm{m}/(p sin^{3/2}\theta)$ in both projections where p is in GeV/c. The earlier 150K Z^o sample used a 120 million pixel CCD detector (VXD2) which when combined with the same CDC yielded impact parameter resolutions of 11 μm ($r\phi$ projection) and 38 μm (rz projection) for high momentum particles and multiple scattering contributions of 70 $\mu\mathrm{m}/(p sin^{3/2}\theta)$ in both projections. The excellent resolutions in both projections allow efficient 3-D vertexing. The micron-sized SLC Interaction Point (IP) contributes only $4 \pm 2\,\mu$m to the overall uncertainty in the $r\phi$ plane. A Cherenkov Ring Imaging Detector (CRID) is used for K/π separation. Electron identification and event shape measurements use a Liquid Argon Calorimeter (LAC) with an energy resolution

Presented at 9th International Symposium on Heavy Flavor Physics, 9/10/2001-9/13/2001, Pasadena, CA, USA

*Work supported in part by Department of Energy Contract DE-AC03-76SF00515.

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for electromagnetic showers of $\sigma/E = 15\%/\sqrt{E(GeV)}$. Muon identification is provided by a Warm Iron Calorimeter (WIC).

B-LIFETIME MEASUREMENTS

The comparison of lifetimes of charged and neutral B-mesons is important to verify predictions of Heavy Quark Expansion, which predicts that the lifetime of different *b* hadrons differ by no more than 10%. The analysis uses an inclusive topological vertexing technique to exploit the 3-D vertexing capabilities of the SLD. Secondary vertices are found in 65% of *b* hemispheres but in only 20% of *c* hemispheres and in less than 1% of *uds* hemispheres. After the vertices have been identified, a cut on the mass of the vertex corrected for the transverse component of the total momentum of tracks relative to the vertex axis is used to eliminate charm and light flavor contamination. Requiring $M > 2$ GeV/c^2 yields a *b*-hadron sample with 98% *b* purity and 50% efficiency (for normalized decay length $> 5\sigma$). The lifetime is determined from the decay length of the reconstructed vertex and the charge is determined from the total charge of tracks associated with the vertex. The *B*-lifetimes are obtained from the decay length distributions using a binned χ^2 fit to reweighted Monte Carlo distributions. The SLD results for the B^0 and the B^+ lifetimes and their ratio are:

$$\tau_{B^0} = 1.585 \pm 0.048 \text{ ps}, \ \tau_{B^+} = 1.623 \pm 0.039 \text{ ps}$$
$$\tau_{B^+}/\tau_{B^0} = 1.037 \pm 0.035.$$

Only the new result from BaBar [3] surpasses the precision of the SLD result.

B-MIXING

B mixing proceeds via second order weak interactions of the type shown in Figure 1. The oscillation rate between the B^0 and $\bar{B}^0$ depends on the mass difference Δm_d in the B^0_d system or Δm_s in the B^0_s system. Measurements of the $B^0 - \bar{B}^0$ mixing rate allow one to constrain the location of the apex of the unitarity triangle (a.k.a. "Bjorken triangle" - shown in Figure 1), given by (ρ,η), which determines CP violation in the Standard Model. A measurement of Δm_d constrains $|V_{td}|^2 \propto (1-\rho)^2 + \eta^2$ and Δm_s constrains $|V_{ts}|^2$ but the ratio $\Delta m_s/\Delta m_d$ is more powerful because the sources of uncertainty from hadronic matrix elements cancel out. The ratio yields $\Delta m_s/\Delta m_d = (1.15 \pm .05)^2 \, |V_{ts}/V_{td}|^2$ which if one uses the near equality $|V_{ts}| = |V_{cb}|$ allows a measurement of the ratio $|V_{td}|/|V_{cb}|$, which is the least known side of the triangle.

To extract *B*-mixing from the data, the production and decay flavor (*B* or $\bar{B}$) are tagged and the proper decay time is determined from the decay length and boost.

The initial state tag uses all of the strengths of the detector and accelerator. It combines a tag exploiting the large forward-backward asymmetry of polarized $Z^0 \to b\bar{b}$ decays with a neural net applied to the hemisphere opposite that being analyzed. The neural net uses jet charge, vertex charge, the lepton charge from ($b \to \ell^-$) decays, the kaon charge in ($b \to c \to s$) decay and the dipole charge between the *D* and *B* vertices. An initial state tag is possible on every event thanks to the polarization. The initial state b-quark probability is shown in Figure 2. The average mistag rate is 22-25%, for the different analyses.

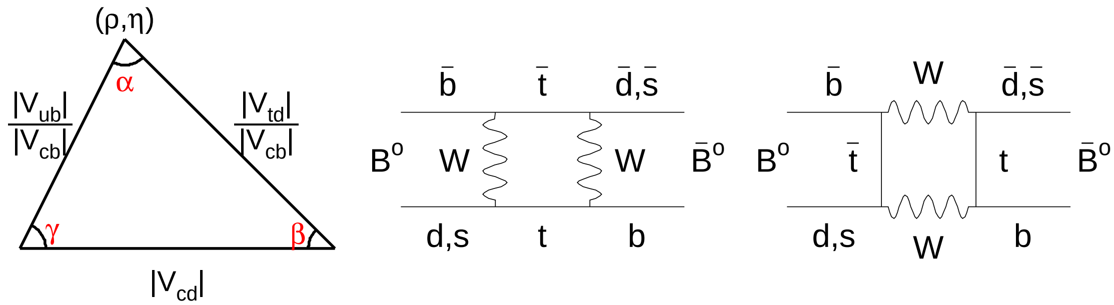

FIGURE 1. (left) The Bjorken triangle. (middle and right) Diagrams of $B^0 - \bar{B}^0$ mixing.

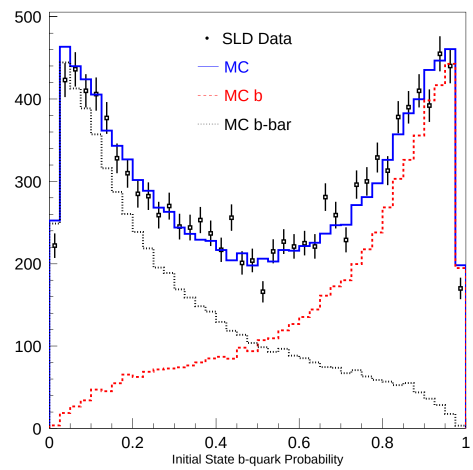

FIGURE 2. Distribution of the computed initial state b-quark probability for data (points) and Monte Carlo (histograms) showing the b and $\bar{b}$ components for the events selected in the Charge Dipole analysis.

The significance (signal to noise) of the mixing signal is expressed by the equation: $S = \sqrt{\frac{N}{2}} f_{B_s}(1-2w)e^{-\frac{1}{2}(\Delta m_s \sigma_t)^2}$ where N is the number of events, w is the mistag rate, f_{B_s} is the purity and $\sigma_t{}^2 = (\frac{\sigma_L}{\gamma\beta c})^2 + (\frac{\sigma_p}{p}t)^2$. This shows the importance of having excellent decay length resolution (σ_L). The decay length resolution is very important for measurements of Δm_s where the oscillation rate is expected to be about a factor of 20 ($\approx \Delta m_s/\Delta m_d$) higher than in the B_d^o system. Figure 3 shows a comparison of the fraction of decays observed to have mixed versus time is shown for $\Delta m_s = 20\text{ps}^{-1}$ for the typical decay length resolution obtained from LEP analyses (200 μm) and SLD analyses (60 μm).

B_d Mixing

The analysis of $B_d{}^0 - \bar{B_d}{}^0$ mixing uses kaons to identify the final state in the decays $B_d \to D^-/\bar{D}^0 \to K^+$ and $\bar{B}_d \to D^+/D^0 \to K^-$. Here, the sign of the kaon differentiates

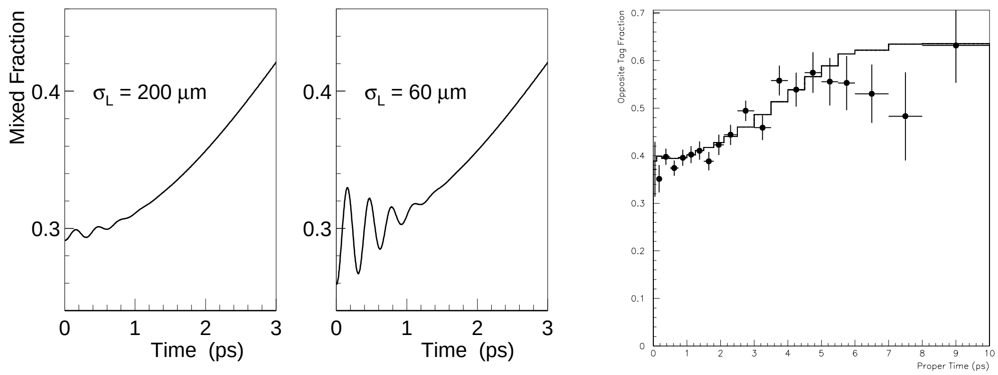

FIGURE 3. (left) The fraction of b-hadron decays tagged as mixed versus proper time for decay lengths resolutions of 200 μm and 60 μm for Δm_s=20 ps^{-1}, f_{B_s}=18%, w=0.25 and σ_p/p=10%. (right) The B_d mixed fraction plot versus proper time showing the data as points and the curve of the likelihood fit overlayed.

between the B_d and $\overline{B}_d$ final states. The value of Δm_d is extracted by performing a likelihood fit to the mixed fraction distribution shown in Figure 3. The preliminary result for the ${B_d}^0 - \overline{B_d}^0$ mass difference is

$$\Delta m_d = 0.503 \pm 0.028 \text{ (stat.)} \pm 0.020 \text{ (syst.)}\ ps^{-1}.$$

The largest contribution to the systematic uncertainty is the B_u right sign fraction which contributes 0.012 to the uncertainty on Δm_d. Each of the other sources contribute less than 0.007.

B_s *Mixing*

The B_s mixing study combines three analyses exploiting different decay topologies and final states. The three analyses ("D_s+tracks", "lepton+D" and "Charge Dipole") make use of the inclusive topological vertexing technique [4] developed for B lifetime [5] and R_b [6] analyses to tag and reconstruct b-hadron decays. This inclusive vertexing technique has been adapted for semileptonic decays to reconstruct the D decay topology.

The "D_s+tracks" analysis [7] does a full reconstruction of the D_s in the decays $D_s \to \phi\pi^-, K^{*o}K^-$ using the CRID to discriminate between π's and K's. A total of 280 $D_s \to \phi\pi^-$ candidates and 81 $D_s \to K^{*o}K^-$ candidates pass the selection. As shown in Table 1, this analysis has excellent decay length resolution, a high B_s fraction (compared to the B_s^0 production fraction in the $Z^0 \to b\overline{b}$ which is 10.0%), and a clean final state tag.

In the lepton+"D" analysis, semileptonic decays are selected and the B decay point is reconstructed by intersecting a lepton track with the trajectory of a topologically reconstructed D meson. A neural-network is used to clean up the D vertex candidates and reduce the contamination from cascade ($b \to c \to l$) charm semileptonic decays. Only multiprong D decays were used at this time. The final state B^0 or $\overline{B^0}$ flavor is tagged by

TABLE 1. Decay length resolution, momentum resolution, and purities of the three B_s analyses.

Method	D_s+tracks	lepton+D	Vertex Charge Dipole
σ_L core (60%)	48 μm	54 μm	81 μm
σ_L tail (40%)	152 μm	213 μm	297 μm
σ_p/p core (60%)	0.08	0.07	0.07
σ_p/p tail (40%)	0.19	0.17	0.21
B_s fraction	38%	16%	16%
final state mistag	10%	4%	22%

the sign of the lepton charge. To enhance the fraction of B_s^0 decays, the sum of lepton + D vertex track charges is required to be $Q = 0$. A sample of 2087 decays is obtained in the 1997-98 data. An opposite sign lepton-kaon tag is used to enhance the B_s^0 fraction. The overall performance is shown in Table 1. The analysis also has good decay length resolution and exceptionally good final state tagging.

The polarization-dependent forward-backward asymmetry is shown in Fig. 4. A clear asymmetry is observed, in reasonable agreement with the Monte Carlo, indicating that the final state tag purity is adequately modeled in the simulation.

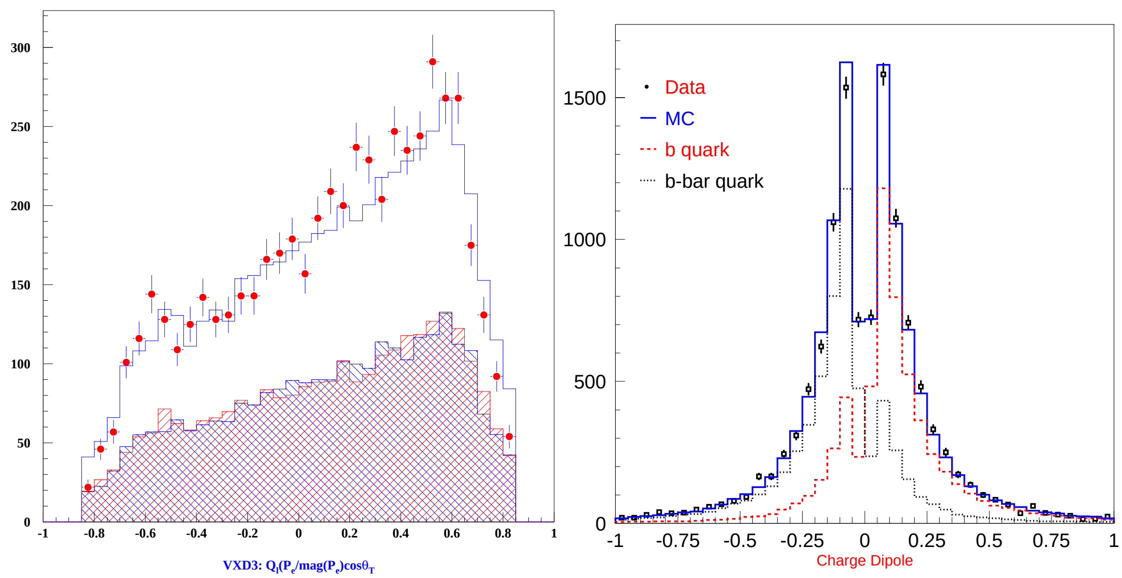

FIGURE 4. (left) Distribution of $\cos\theta$ for the thrust axis direction signed by the product $(Q_{lept} \times P_e)$ for data (points) and Monte Carlo (histograms) from the lepton+D analysis. (right) Distribution of the charge dipole for data (points) and Monte Carlo (solid histogram). Also shown are the contributions from b hadrons containing a b quark (dotted histogram) or a $\bar{b}$ quark (dashed histogram).

The Charge Dipole analysis reconstructs the B and D vertex topologies in inclusive decays and tags the B^0 or $\overline{B^0}$ decay flavor based on the charge difference between the B and D vertices. This analysis technique is unique to SLD and relies extensively on the excellent resolution of the vertex detector. A "Charge Dipole" is defined as $\delta Q \equiv D_{BD} \times SIGN(Q_D - Q_B)$, where D_{BD} is the distance between the two vertices and Q_B (Q_D) is the charge of the B (D) vertex. Positive (negative) values of δQ tag $\overline{B^0}$ (B^0)

decays. The total track charge Q (from both secondary and tertiary vertices) is required to be 0 to enhance the fraction of B_s^0 decays in the sample and to increase the quality of the charge difference reconstruction for neutral B decays. The distribution of δQ for the data and Monte Carlo is shown in Figure 4. The performance of the method is shown in Table 1. While the resolutions and purities are comparable to the other two analyses, this method greatly benefits from a an event sample that is more than three times that of the lepton+D analysis and twenty times that of the D_s+tracks analysis.

The D_s+tracks, lepton+D, and Charge Dipole analyses are combined taking into account correlated systematic errors. Events shared by two or more analyses are assigned to the analysis with the best sensitivity such as to produce statistically independent analyses. Figure 5 shows the measured amplitude as a function of Δm_s for the combination. As noted earlier, the measured values are consistent with $A = 0$ for the whole range of Δm_s up to 25 ps^{-1} and no evidence is found for a preferred value of the mixing frequency. Using the condition $A + 1.645\,\sigma_A < 1$, the range $\Delta m_s < 13.2\ \text{ps}^{-1}$ is exclude at 95% C.L.. 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}. These results are preliminary. The overall sensitivity is expected to continue improving as further analysis refinements are implemented.

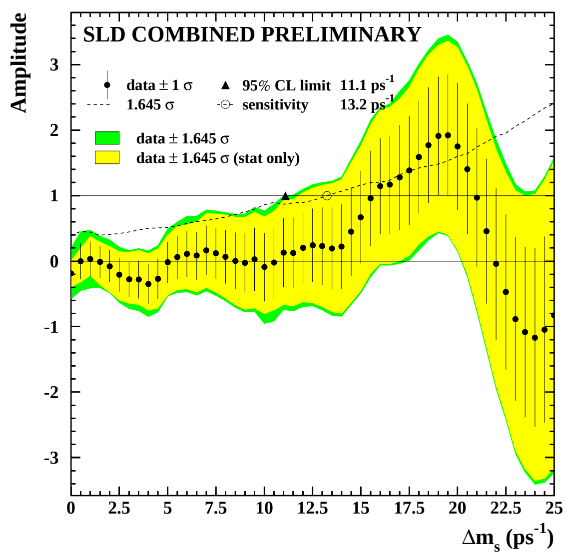

FIGURE 5. Measured amplitude as a function of Δm_s for the D_s+tracks, lepton+D, and Charge Dipole analyses combined.

Charm counting in B-decays

The ability of the SLD detector to identify tertiary decays from charm in B-decays has been exploited [8] to help answer why the world averaged b-semileptonic branching ratio is lower than the prediction and why the current value of the average number of charm in B-decays (N_c) is low. An increased width from non-semileptonic decay modes could resolve the problem. The analysis measures the rates for having zero, one or two open charm mesons by fitting the nearest neighbor vertex seperations for the number of secondary vertices (N_{vtx}) being $N_{vtx} = 0, 1, 2$ and ≥ 3. In the case of two charm vertices the average distances with respect to the B vertex are 0.5 mm and 1.0 mm.

Event hemispheres opposite B-tagged hemispheres are used. The same topological vertexing algroithm as for the B-lifetime and B-mixing analyses is used to reconstruct vertices in the sample hemispheres. Samples containing zero, one or two tertiary reconstructed vertices are simultaneously fitted to linear combinations of Monte Carlo shapes for zero, one and two open charm mesons to determine the rates. The number of found secondary vertices, the vertex seperations for two and three vertices are shown in Figure 6 for the data and Monte Carlo. The prelimnary results of the fit are:

$$BR(b \to 0D) = (5.6 \pm 1.1 \text{ (stat.) } \pm 2.0)\% \text{ (syst.)}$$
$$BR(b \to 2D) = (24.6 \pm 1.4 \text{ (stat.) } \pm 4.0)\% \text{ (syst.)}$$
$$N_c = 1.238 \pm 0.027 \text{ (stat.) } \pm 0.048 \text{ (syst.) } \pm 0.006 \text{ (charmonia)}$$

The value of N_c pulls the world average towards the region preferred by the Standard Model.

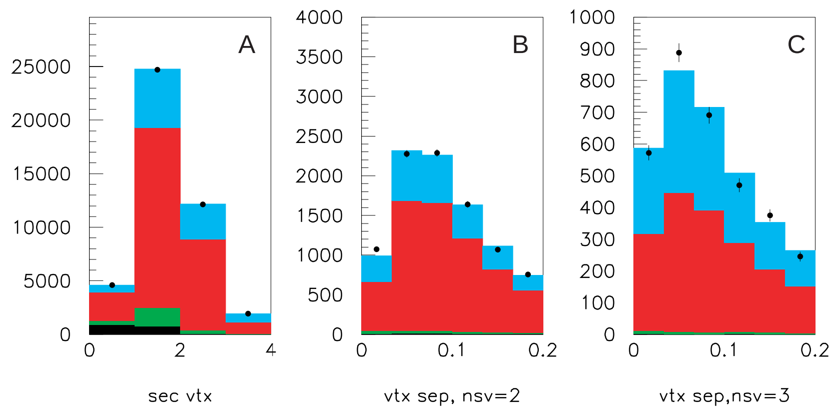

FIGURE 6. The number of found secondary vertices is shown in plot A. The measured $b-D$ vertex seperation for two and three vertices is shown in plots B and C. The contributions to each histogram from bottom to top are *udsc*, zero, one and two open charm decays.

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