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B PHYSICS AT LEP AND SLD

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Recent B physics results from LEP and SLD are reviewed. In particular, results of B lifetimes, semileptonic B decays, charm counting, CKM matrix elements and mixing are presented.

1 Introduction

LEP and SLD offer favorable environments to study the detailed properties of the B hadrons. The clean $e^+e^- \to Z^0$ environment along with precision vertexing tools, allow one to easily identify B hadrons, which have a typical decay length of about 3mm at the Z^0. The four LEP experiments have each accumulated 0.9 million $Z^0 \to b\bar{b}$ events and the SLD experiment has roughly 120K $b\bar{b}$ events on tape. Even with a small data size, SLD remains highly competitive in B physics due to the polarized e^- beam, small beam spot and a unique pixel based CCD vertex detector. These data sets have been used in a broad B physics program and some recent results (lifetimes, semileptonic decays, charm counting, V_{ub}, V_{cb}, and mixing) are presented in this paper.

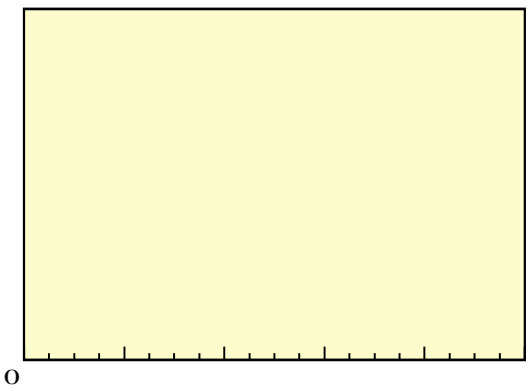
2 B Hadron Lifetimes

The spectator model predicts that the lifetime of a heavy hadron depends only on the properties of the decaying heavy quark Q. This model fails in the charm hadron sector for which the lifetime hierarchy of $\tau_{D^+} > \tau_{D_s^+} > \tau_{D^0} > \tau_{\Lambda_c^+}$ is observed. Corrections to the spectator model can be calculated in the context of the heavy quark expansion and are predicted to scale with $1/m_Q^2$. For the B hadrons, the lifetime differences are expected to be less than 10%. Hence, precise measurements of B lifetimes provide a test of our understanding of QCD in the heavy quark limit. In addition, B hadron lifetimes are important inputs to many heavy flavor analyses.

The most precise B^+ lifetime measurements are based on inclusive topological techniques where charged secondary vertices are selected to obtain a pure B^+ sample.[1] The B_d^0 lifetime has also been measured using the inclusive method by selecting neutral vertices, although for the inclusive B_d^0 measurements, the background tends to be higher due to contamination from the other neutral B hadrons (B_s and B baryons). Recently, OPAL has made a measurement of B_d^0 lifetime using $B_d^0 \to D^{*-} l^+ \nu$ decays. The $D^{*-} \to D^0 \pi^+$ decays are reconstructed inclusively by identifying the soft pions from the D^{*-} decays. This approach yields the most precise B_d^0 lifetime measurement to date ($\tau_{Bd} = 1.541 \pm 0.028 \pm 0.023$ ps).[2]

The lifetime measurements are most easily compared with theory through the lifetime ratios. The measurements along with theoretical predictions [3] are shown in Figure 1. The agreement

is excellent in the meson sector. However, the B baryon lifetime measurements are consistently lower than predictions. It remains to be seen whether better theoretical predictions based on lattice calculations can resolve the discrepancy.



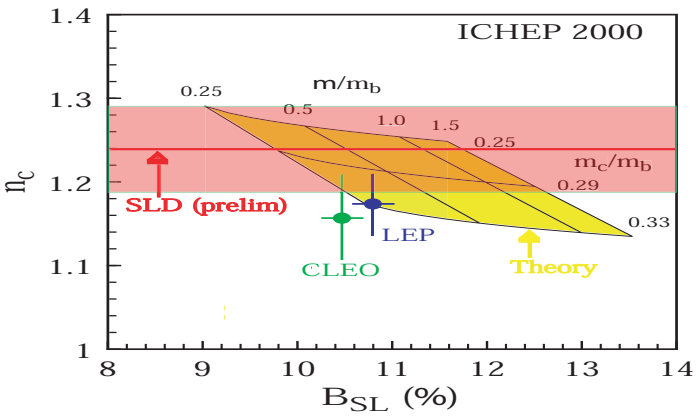


Figure 2: Semileptonic B.R. vs. n_c. Yellow box is the theoretical predictions.

4 The Unitarity Triangle

The major challenge in B physics for the coming decade is to perform precision measurements of the CKM matrix elements and to test the Standard Model description of CP violation. The CKM matrix elements are required to satisfy the unitarity conditions such as $V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$. This relation is commonly presented as a triangle in a complex plane with the apex of the triangle denoted by the Wolfenstein parameters ρ and η. The experimental goal is to over-constrain the triangle by measuring all three sides and three internal angles. Any detected inconsistency in the triangle relation may be a hint of new physics.

4.1 $|V_{cb}|$ and $|V_{ub}|$

LEP uses both inclusive and exclusive approaches to measure the magnitude of V_{cb}.[1] For the inclusive method, the partial width for semileptonic B decay to charm mesons is related to $|V_{cb}|$ using the expression: $|V_{cb}| = 0.044 \times \sqrt{(Br(b \to c l\nu) \times 1.55ps)/(0.105 \times \tau_b)}$. In the exclusive method, the value of $|V_{cb}|$ is extracted by measuring the differential decay rate for $B_d^0 \to D^{*-} l^{+} \nu$ as a function of ω, where ω is the four-momentum product of D^{*-} and B_d^0. The differential decay rate for the decay is given by: $\frac{d\Gamma}{d\omega} = K(\omega)F^2(\omega)|V_{cb}|^2$, where K is the kinematic phase space term and F is the hadronic form factor of the decay. The unknown term in the expression is the form factor, however, it can be calculated in the heavy quark limit at ω=1 which corresponds to the scenario where the D^{*-} is at rest in the B_d^0 rest frame. Experimentally, one measures the differential decay rate near the kinematic endpoint and extrapolates to ω=1 to obtain the value of $|V_{cb}|$. Results from the inclusive and exclusive measurements are in good agreement. The combined results of the four LEP experiments gives $|V_{cb}| = 0.0404 \pm 0.0018$.

ALEPH, DELPHI, and L3 collaborations have recently extracted the value of $|V_{ub}|$ from the measurements of $Br(b \to u l\nu)$.[1] The expression relating V_{ub} to the semileptonic $b \to u$ transition has been derived in the context of the heavy quark expansion and is given as follows: $|V_{ub}| = 0.00445 \times \sqrt{(Br(b \to u l\nu) \times 1.55ps)/(0.002 \times \tau_b)}$. The inclusive method has the advantage of larger statistics and less model dependence compared to the exclusive and lepton endpoint analyses. The combined average of the three analyses gives $|V_{ub}| = 0.0041 \pm 0.0007$.

4.2 B Mixing

Measuring the B_d^0 oscillation frequency is the most direct way to extract the CKM matrix element $|V_{td}|$. The oscillation frequency, Δm_d, has been measured to within a few percent. However, the extraction of $|V_{td}|$ from Δm_d is severely limited by theoretical uncertainties of about 20%. The problem can be circumvented if one measures the ratio of Δm_d and Δm_s, where Δm_s is the oscillation frequency in the B_s^0 system. As shown in equation 1, in the ratio, many theoretical

uncertainties cancel and that allows one to extract $|V_{td}|$ to about 5%.

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s} f_{B_s}^2 B_{B_s}}{m_{B_d} f_{B_d}^2 B_{B_d}} |\frac{V_{ts}}{V_{td}}|^2 = (1.15 \pm 0.05)|\frac{V_{ts}}{V_{td}}|^2 \quad (1)$$

Experimentally, three basic ingredients are needed to study the time dependent B_s^0 oscillations: 1.) select a sample enriched in B_s^0 decays, 2.) determine the flavor of the B meson at production and decay and 3.) recontruct the proper decay time. The B_s^0 oscillation frequency is expected to be large in the Standard Model and no direct observation (maybe a hint) has been established yet. Nevertheless, a limit on Δm_s is a strong constraint on the apex of the Unitarity triangle (a lower limit on Δm_s translates to an upper limit on $|V_{td}|$).

LEP and SLD have carried out complementary programs to search for B_s^0 oscillations. A wide variety of techniques from the fully inclusive SLD charge dipole to the fully exclusive B_s^0 reconstruction at ALEPH and DELPHI have been studied. The results have been combined based on the amplitude fit method.[7] The world amplitude plot combining LEP, SLD and CDF results is shown in Figure 3. The result excludes Δm_s <15 ps^{-1} at the 95% confidence level.[8] The most significant deviation from the amplitude of zero occurs at about 17 ps^{-1}. The significance of the structure has been evaluated using toy Monte Carlo and is estimated to be consistent with a fluctuation at the 3% level.

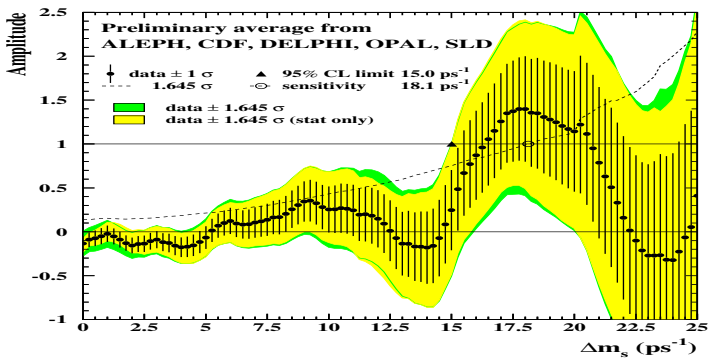


Figure 3: World amplitude plot showing the combined B_s^0 oscillation amplitudes as a function of Δm_s.

5 Conclusion

LEP and SLD have made significant contributions in B physics over the past few years. The topics discussed in this paper represent only a small fraction of heavy flavor physics that have been studied at the Z^0 pole. As this paper is being written, many results are still being finalized. The B physics era at LEP and SLD is not over yet. Stay tuned.

References

1. ALEPH, DELPHI, L3, OPAL, CDF, and SLD Collaborations, CERN-EP-2000, SLAC-PUB-8492, hep-ex/0009052.
2. G. Abbiendi *et al.* [OPAL collaboration], *Phys. Lett.* B **493**, 266 (2000), hep-ex/0010013.
3. G. Bellini, I.I. Bigi and P.J. Dornan, Phys. Rep. **289** (1997).
4. N. Marinelli *et al.* [ALEPH collaboration], ALEPH 2000-069 (2000).
5. K. Abe *et al.* [SLD collaboration], SLAC-PUB-8686 (2001).
6. E. Bagan, P. Ball, B. Fiol and P. Gosdzinsky, Nucl. Phys. Lett B **351** 546 (1995); M. Neubert, C.T. Sachrajda, Nucl. Phys. B **483** 339 (1997).
7. H.G. Moser and A. Roussarie, *Nucl. Instrum. Methods* A **384**, 491 (1997).
8. B Oscillations Working Group 2000, http://www.cern.ch/LEPBOSC/