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Combined SLD Measurement of A_b at the Z^0 Resonance using Various Techniques.*

The SLD Collaboration**

Abstract

We present a new preliminary combination of measurements of the parity-violation parameter A_b made by the SLD collaboration using various experimental techniques. The techniques differ in detail, but in general a sample of $b\bar{b}$ events is selected or enhanced by using the topologically reconstructed mass of the separated vertices formed by decaying B hadrons. The direction of the $b(\bar{b})$ quark is signed by one of four final state tags: jet charge, vertex charge, leptons, or identified $K^{\pm}$ from the b vertex. We account for statistical and systematic correlations between the four analyses to arrive at our combined result: $A_b = 0.905 \pm 0.017(\mathrm{stat}) \pm 0.020(\mathrm{syst})$.

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This note provides a brief overview of four separate analyses performed by the SLD Collaboration to measure the parity-violation parameter A_b in polarized Z^0 decays, and a description of how the analyses are combined to form a overall SLD result. The reader is referred to the detailed notes available for each analysis for specific information on how each analysis is performed.

The most statistically powerful analysis selects $b\bar{b}$ events using an inclusive topological vertexing technique[1] and forms the momentum-weighted jet charge of all selected events to identify the quark direction[2]. This analysis was most recently updated at Moriond '99 to include the full 1993-8 SLD dataset[3]. The updated systematic errors are reproduced in Table 1. The combined jet-charge result is:

$$A_b = 0.882 \pm 0.020(\mathrm{stat}) \pm 0.029(\mathrm{syst}) \quad (\textbf{jet-charge}). \tag{1}$$

The next analysis uses identified high-momentum muons and electrons to tag heavy flavor (b, c) events and then employs a number of kinematic and vertexing variables to try to distinguish leptons arising from b-hadron decays from those arising from c-hadron decays. The lepton sign is used to sign the quark direction and A_b and A_c are measured simulataneously[4]. This analysis was most recently updated at Moriond '99 to include the full 1993-8 SLD dataset[3]. The updated systematic errors are reproduced in Tables 2 ($\mu^\pm$ tag) and 3 ($e^\pm$ tag). The combined lepton-tag result is:

$$A_b = 0.924 \pm 0.032(\mathrm{stat}) \pm 0.026(\mathrm{syst}) \quad (\textbf{leptons}). \tag{2}$$

Another analysis uses identified $K^\pm$ associated with separated topological vertices to sign the quark direction, exploiting the dominant $b \to c \to s$ decay chain. In the original version of this analysis[5], the error in the result was dominated by the experimental uncertainty in the relative rates of $B \to K^+X$ vs. $B \to K^-X$ decay. This analysis has been updated at this conference[6] to include data from the 1997-8 data run and now employs a self-calibration technique which removes the reliance on relative production rates of $K^\pm$ in B decays. The combined $K^\pm$-tag result is:

$$A_b = 0.960 \pm 0.040(\mathrm{stat}) \pm 0.056(\mathrm{syst}) \quad (\textbf{kaons}). \tag{3}$$

The last analysis uses the charge of the separated topological vertices themselves to assign the quark direction. The vertex charge is weighted in the analysis based on the mass of the reconstructed vertex, which gives an indication of the fraction of the B decay tracks which have been correctly assigned to the vertex. This analysis, which has been first presented at this conference[7], includes data from the 1996-8 data run and also employs a self-calibration technique to determine the correct-sign probability directly from the data. The vertex-charge result is:

$$A_b = 0.897 \pm 0.027(\mathrm{stat})^{+0.036}_{-0.034}(\mathrm{syst}) \quad (\textbf{vertex-charge}). \tag{4}$$

We have combined these four results as follows. The statistical overlap between the analyses was determined by explicitly tabulating events used by the four analyses for a subset of the total data which is common to all four and was marked by stable detector performance. Each event in this dataset used by a given analysis was assigned a weight by that analysis based on its estimated b-hadron purity, correct-signing probability, and reconstructed polar angle. The statistical correlations between analyses for this dataset was then determined from the overlapping event fractions, the fractions of events where different tags assigned the same (opposite) quark directions, and the individual event weights. This statistical correlation was then diluted to account for the fact that not all analyses use the same dataset.

The statistical correlations extracted range from $\sim 10-30\%$ depending on the pair of analyses considered. The largest correlation (28%) was observed between the jet-charge and vertex-charge analyses, as expected; due to its statistical power the jet-charge analysis has significant overlap with all three other analyses. The smallest correlation (8%) was between the lepton tag and vertex charge analyses.

Correlations between analyses due to common systematic error sources have been treated in the standardized fashion developed by the LEP Electroweak Working Group [8]. Since three of the four analyses (all but the lepton tag) use self-calibration techniques based on the data, most of the quoted systematic errors are in fact dominated by data statistics and thus (mostly) uncorrelated. For the purposes of this combination, we assume A_c is fixed at its Standard Model value.

The analyses are then combined in a weighted average using the individual analysis errors and the statistical correlation matrix. Each analysis receives a weight in the overall combination based on its statistical and uncorrelated systematic error. Statistical and uncorrelated systematic errors are combined in quadrature and correlated systematic errors are combined linearly. The final analysis weights are 38% (jet-charge), 30% (leptons), 22% (vertex-charge), and 10% (kaons). The combined SLD preliminary result obtained with this procedure is:

$$A_b = 0.905 \pm 0.017(\mathrm{stat}) \pm 0.020(\mathrm{syst}) \quad (\textbf{combined}). \tag{5}$$

This result differs slightly from the LEP Electroweak Working Group fit [9, 10] of the same data due to correlations between the A_b and A_c results which enter here primarily through the lepton-tag analysis. We explicitly ignore such correlations in our average whereas the LEP global fits include them.

Our average result for A_b agrees well with the Standard Model expectation of 0.935, and also with that derived from the current combination of LEP results (0.892 ± 0.024) used in the global electroweak fit[9]. The combined LEP and SLD results, however, imply that A_b deviates from the Standard Model at the $\sim 2.5\sigma$ level; this intriguing situation has persisted since 1996 despite significant improvements in statistical and systematic errors. One recent analysis [11] of the world's A_b data shows no evidence of systematic bias or underestimated errors. Thus the experimental question of possible anomalies in the $Zb\bar{b}$ coupling remains unresolved.

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Table 1: Relative systematic errors on the 1997-98 measurement of A_b (**jet-charge**).

Error Source	**Variation**	$\delta A_b/A_b$
Self-Calibration		
α_b statistics	$\pm 1\sigma$	1.8%
λ_b Correlation	JETSET, HERWIG	1.4%
$P(Q_b)$ shape	Different shapes	0.8%
$\cos\theta$ shape of α_b	MC Shape *vs* Flat	0.4%
Light Flavor	50% of correction	0.3%
Analysis		
Tag Composition	Mostly ϵ_c	0.3%
Detector Modeling	Tracking eff. and resolution corrections on/off	2.4%
Beam Polarization	$\pm 0.8\%$	0.8%
QCD	x_{QCD}, $\alpha_s \pm 0.007$, 2^{nd} order terms	0.6%
Gluon Splitting	$\pm 100\%$ of JETSET	0.2%
A_c	0.67 ± 0.08	$<$0.1%
A_{bckg}	0 ± 0.50	0.2%
Total		**3.6%**

Source	$\Delta A_b(1993-8)$	$\Delta A_c(1993-8)$
Monte Carlo statistics	$\pm.0022$	$\pm.0104$
Tracking efficiency	$\pm.0055$	$\pm.0035$
Jet axis simulation	$\pm.0013$	$\pm.0016$
Background level	$\pm.0082$	$\pm.0306$
Background asymmetry	$\mp.0027$	$\pm.0142$
BR($Z^0 \to b\bar{b}$)	$\mp.0004$	$\pm.0006$
BR($Z^0 \to c\bar{c}$)	$\pm.0008$	$\mp.0094$
BR($b \to \mu^-$)	$\mp.0035$	$\pm.0034$
BR($b \to c \to \mu^+$)	$\pm.0039$	$\mp.0038$
BR($b \to \bar{c} \to \mu^-$)	$\pm.0037$	$\pm.0113$
BR($b \to \tau \to \mu^-$)	$\pm.0002$	$\pm.0023$
BR($b \to J/\psi \to \mu^\pm$)	$\pm.0028$	$\pm.0004$
BR($c \to \mu^+$)	$\pm.0018$	$\mp.0197$
$B^{\pm,0}$ leptonic spectrum- D^{**} fraction	$\pm.0028$	$\pm.0028$
B_s leptonic spectrum- D^{**} fraction	$\pm.0007$	$\pm.0003$
D leptonic spectrum	$\pm.0037$	$\pm.0006$
BR($B \to D\bar{D}$)	$\pm.0027$	$\pm.0003$
L/D syst	$\pm.0037$	$\pm.0032$
B tag calibration	$\pm.0137$	$\pm.0487$
B_s fraction in $b\bar{b}$ events	$\pm.0009$	$\mp.0012$
Λ_b fraction in $b\bar{b}$ events	$\pm.0018$	$\mp.0007$
b fragmentation	$\pm.0013$	$\pm.0014$
c fragmentation	$\pm.0025$	$\pm.0118$
Aleph/Peterson B fragmentation	$\pm.0034$	$\pm$ .0022
Polarization	$\mp.0087$	$\mp.0051$
Gluon splitting	$\pm.0022$	$\pm.0022$
Other QCD	$\pm.0040$	$\pm.0030$
B mixing	$\pm.0105$	$<.0001$
B mixing (cascade)	$\pm$ .0003	$\pm.0041$
Total systematic error	0.0250	0.0670

Table 2: Systematic errors on A_b and A_c measurements from 1993-8 data (μ **tag**).

Source	Variations adopted	$\Delta A_b(1997)$	$\Delta A_b(1998)$
Monte Carlo statistics	weights w_i variation	$\pm.011$	$\pm.007$
Tracking efficiency	MC/data track multiplicity	$<.001$	$<.001$
Jet axis simulation	smearing 10 mrad	$\pm.017$	$\pm.049$
Background level	$\pm$ 15%	$\pm.005$	$\pm.007$
Background asymmetry	$\pm$ 40%	$\mp.003$	$\pm.004$
BR($Z^0 \to b\bar{b}$)	$(21.73 \pm\ .09)\%$	$<.001$	$<.001$
BR($Z^0 \to c\bar{c}$)	$(17.30 \pm\ .44)\%$	$\pm.002$	$\mp.002$
BR($b \to e^-$)	$(11.06 \pm\ .19)\%$	$\mp.003$	$\pm.005$
BR($b \to c \to e^+$)	$(8.02 \pm\ .32)\%$	$\pm.003$	$\mp.008$
BR($b \to \bar{c} \to e^-$)	$(1.3 \pm\ 0.5)\%$	$\pm.001$	$\pm.003$
BR($b \to \tau \to e^-$)	$(0.472 \pm\ .075)\%$	$<.001$	$\pm.001$
BR($b \to J/\psi \to e^{\pm}$)	$(0.07 \pm\ .02)\%$	$\pm.002$	$\pm.002$
BR($c \to e^+$)	$(9.8 \pm\ 0.5)\%$	$\pm.004$	$\mp.005$
$B^{\pm,0}$- D^{**} fraction	$(23 \pm\ 10)\%$	$\pm.003$	$\pm.001$
B_s -D^{**} fraction	$(32 \pm\ 10)\%$	$\pm.003$	$\pm$ .002
D lepton spectrum	$ACCMM1^{+2}_{-3}$	$\pm.003$	$\pm.006$
B_s fraction in $b\bar{b}$ events	$.115 \pm\ .050$	$\pm.004$	$\mp.010$
Λ_b fraction in $b\bar{b}$ events	$.072 \pm\ .030$	$\pm.002$	$\mp.005$
b fragmentation	$\epsilon_b = .0045 - .0075$	$<.001$	$\pm.002$
c fragmentation	$\epsilon_c = .045 - .070$	$<.001$	$\pm.001$
Aleph	reweighting	$\pm.004$	$\pm.004$
Polarization	$P = 0.733 \pm\ 0.0080$	$\mp.008$	$\mp.009$
Second order QCD	$\Delta_{QCD} uncertainties$	$\pm.004$	$\pm.004$
B mixing	$\bar{\chi} = .1217 \pm\ .0046$	$\pm.010$	$\pm.011$
B mixing cascade	$\bar{\chi} = .1285 \pm\ .0071$	$\pm.001$	$\pm.004$
Total systematic error		0.027	0.055

Table 3: Systematic errors on A_b from 1997 and 1998 data ($e^{\pm}$ **tag**).