

**THE LEFT-RIGHT FORWARD-BACKWARD ASYMMETRY
OF HEAVY QUARKS MEASURED WITH
JET CHARGE AND WITH LEPTONS AT THE SLD***

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ABSTRACT

We present direct measurements of the left-right asymmetry of b - and c -quarks from the decay of Z^0 bosons produced in the annihilation of longitudinally polarized electrons and unpolarized positrons. Two complementary techniques are presented: 1) $Z^0 \rightarrow b\bar{b}$ decays are tagged using track impact parameters with $b\bar{b}$ discrimination provided by momentum-weighted track charge; 2) Semileptonic b -decays are tagged using high p and p_T muons and electrons. The preliminary results from our 1993 data sample are: $A_b = 0.93 \pm 0.13 \pm 0.13$ for the jet charge and $A_b = 0.93 \pm 0.14 \pm 0.09$, and $A_c = 0.40 \pm 0.23 \pm 0.20$ for the leptons, where the first error is statistical and the second systematic.

1. Introduction

Measurements of the fermion asymmetries at the Z^0 provide direct probes of the parity violating left-right asymmetry $A_f = 2v_f a_f / (v_f^2 + a_f^2)$ and hence provide a sensitive test of Standard Model predictions. The left-right forward-backward asymmetry \tilde{A}_{FB}^b isolates the A_f term by taking advantage of the electron beam polarization:¹

$$\tilde{A}_{FB}^f(y = \cos \theta) = \frac{(\sigma_L(y) - \sigma_L(-y)) - (\sigma_R(y) - \sigma_R(-y))}{(\sigma_L(y) + \sigma_L(-y)) + (\sigma_R(y) + \sigma_R(-y))} = P_e A_f \frac{2y}{1+y^2} \quad (1)$$

where σ is the differential cross section for $e^+e^- \rightarrow Z \rightarrow f\bar{f}$ and L (R) refers to left (right) incident electron helicity, with $P_e < 0$ ($P_e > 0$).

We present preliminary measurements² of A_b and A_c from a sample of 50,000 Z^0 decays observed at $\sqrt{s} = 91.26$ GeV, with an average longitudinal electron polarization of $63.0 \pm 1.1\%$.³ The SLD detector is described elsewhere.^{4,6}

2. Track-Charge Analysis

Hadronic Z^0 decays are selected by requiring that at least 7 well reconstructed tracks within $|\cos \theta| < 0.80$ carry a large visible energy $E_{vis} > 18$ GeV. The dominant contribution to the residual background, $Z^0 \rightarrow \tau\bar{\tau}$ events, is estimated to be less than 0.2% of the sample. Details of the impact parameter b -tag are given in Ref. 5.

The jet charge Q_p can be written:

$$Q_p = \sum_{\text{tracks}} Q_i \vec{p}_i \cdot \hat{t} |\vec{p}_i \cdot \hat{t}|^{k-1} \quad (2)$$

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where \hat{t} is a unit vector in the direction of the thrust axis. To determine A_b , the sign of \hat{t} measured by calorimetry in tagged events is chosen such the Q_p is negative. \hat{t} is then used as the estimate of the b -quark direction where a κ of 0.5 is chosen to maximize the correct-sign probability. The result is shown in Fig. 1.

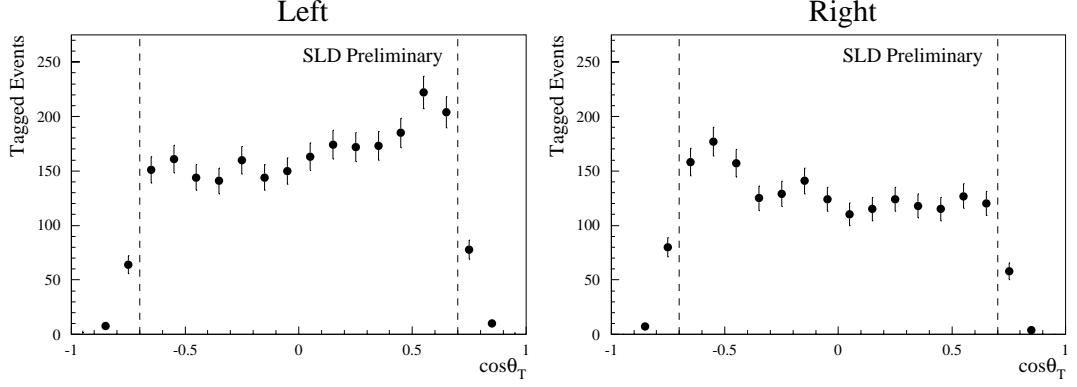


Fig. 1. Signed $\cos\theta_T$ distribution for tagged events produced with left- and right-handed beams, illustrating the significant effect of polarization on the forward-backward asymmetry.

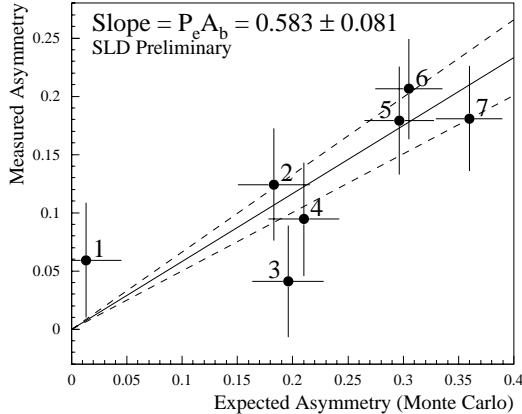


Fig. 2. The observed asymmetry $\tilde{A}_{FB}^b(\cos\theta_T)$, corrected for light-quark contamination, plotted against the Monte Carlo prediction for 100% asymmetry for each bin (numbered points) of $|\cos\theta_T|$. The slope of the fit yields $P_e A_b$.

To determine A_b , the double asymmetry $\tilde{A}_{FB}^b(\cos\theta)$ is formed for each bin in $|\cos\theta|$ and corrected for bin-dependent tag contamination. The result is compared against Monte Carlo predictions at 100% asymmetry to account for bin-dependent Q_p resolution and thrust axis smearing. In addition a first-order QCD correction^{7,8} (2–5%) is applied. A linear fit through points representing each bin plotted as data versus Monte Carlo produces a slope equal to a measurement of $P_e A_b$ (see Fig. 2).

The dominant systematic error arises from a lack of a satisfactory explanation for variation in the measured value of A_b when the tag requirement is varied from 2 tracks at

Table 1. Relative systematic errors on A_b for the track-charge analysis.

Contribution	% Error
<i>Physics</i>	
B -Decay Model	7
b Fragmentation	2
B – \bar{B} mixing	1
Polarization	2
<i>Detector and Tag</i>	
Tracking Efficiency	4
Thrust Axis Resolution	2
Tag Modeling	10
Monte Carlo Statistics	5
Total (Quadrature Sum)	14

$+2\sigma$ impact parameter to 4 tracks at $+4\sigma$. Table 1 summarizes our estimates of these and other errors, which are combined in quadrature for our preliminary result:

$$A_b = 0.93 \pm 0.13 \text{ (stat)} \pm 0.13 \text{ (sys)} \quad (3)$$

3. Lepton Analysis

Electrons are identified by extrapolating charged tracks to the barrel liquid argon calorimeter (LAC) and analyzing the energy deposited in nearby towers. The energy is required to match the momentum of the track and follow the longitudinal profile of an immediate electromagnetic shower. The efficiency for identifying electrons in hadronic Z^0 events is 55% within acceptance. Above 2 GeV, pion misidentification is less than 0.8%. Ninety percent of electron candidates from gamma conversions are identified and removed by searching for a match with a second track consistent with the decay of a massless particle outside a radius of 2 cm.

Muons are identified by matching charged tracks to hits in the 18 active layers of the warm iron calorimeter. Muons candidates are also required to have at least two hits in the last four active layers, forcing the track to penetrate at least 7.3 interaction lengths. Above 3 GeV efficiency is 85% and pion misidentification is below 0.3%.⁶

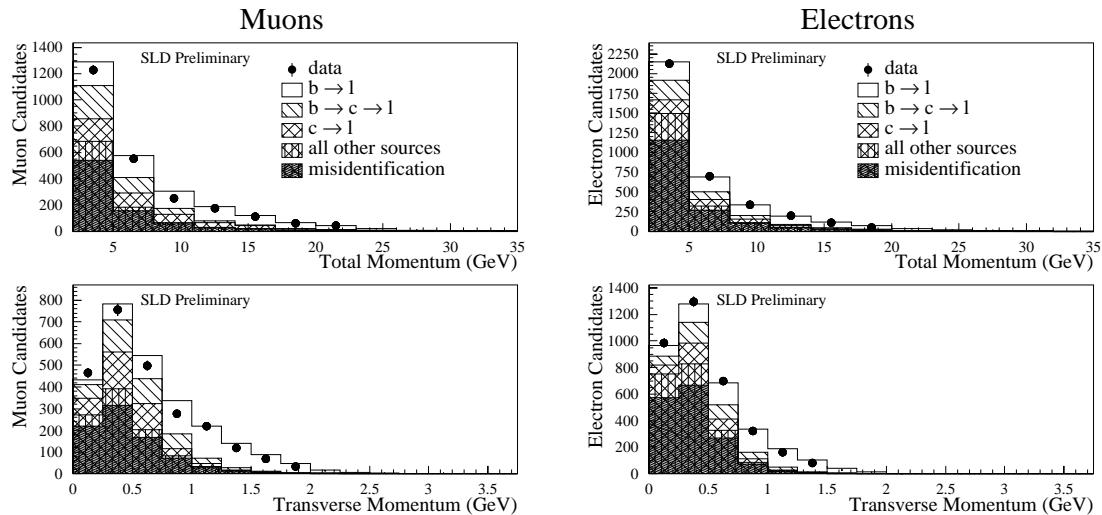


Fig. 3. Spectra of tagged lepton candidates projected onto p and p_T with Monte Carlo estimations of contributions from signal and background sources.

Jets are identified using LAC energy clusters and the JADE⁹ algorithm with $y_{cut} = 0.005$. The jet angular resolution is approximately 20 millirad. Event selection is a slightly looser version of the one used for the jet charge.

To determine the best estimates of A_b and A_c , we use the following probability function:

$$\begin{aligned} p_i(A_b, A_c) &= 1 + \cos^2 \theta + 2PA \cos \theta \\ A &= w_b A_b (1 - 2\chi)(1 + \Delta_{QCD}^b(\theta)) - w_c A_c (1 + \Delta_{QCD}^c(\theta)) + w_h A_h \end{aligned} \quad (4)$$

where Δ_{QCD} are the θ -dependent first-order QCD corrections^{7,8} and A_h is the p and p_T

dependent asymmetry of all non-lepton charged tracks. The weights w_b , w_c , and w_h are the p and p_T dependent amount each lepton is affected by b -quark, c -quark, or hadron asymmetries. Each weight is derived from the Monte Carlo by tabulating the fraction of the leptons at a particular p and p_T that come from one of six relevant sources:

$$w_b(p, p_T) = f_{b \rightarrow l} - f_{b \rightarrow c \rightarrow \bar{l}} + f_{b \rightarrow \bar{c} \rightarrow l} \quad w_c(p, p_T) = f_{c \rightarrow \bar{l}} \quad w_h(p, p_T) = f_{hadron} + f_{mis-id} \quad (5)$$

To determine f , the subset of 50 leptons in the Monte Carlo closest in $\ln|p|/2$ and p_T to each lepton in the data is identified and the various sources tallied.

The results of the maximum likelihood fit are:

Muons:	$A_b = 0.94 \pm 0.20 \pm 0.10$	$A_c = 0.42 \pm 0.29 \pm 0.18$
Electrons:	$A_b = 0.92 \pm 0.19 \pm 0.12$	$A_c = 0.37 \pm 0.37 \pm 0.31$
Combined:	$A_b = 0.93 \pm 0.14 \pm 0.09$	$A_c = 0.40 \pm 0.23 \pm 0.20$

(6)

where the first error is statistical and the second systematic (see Table 2). The statistical correlation between A_b and A_c is 0.03 for muons and 0.29 for electrons.

Table 2. The absolute systematic errors for A_b and A_c measured using maximum likelihood.

Source	A_b		A_c	
	Muons	Electrons	Muons	Electrons
Tracking Efficiency	0.013	0.016	0.013	0.004
Jet Axis Simulation	0.060	0.045	0.061	0.130
Background Level	0.019	0.008	0.028	0.014
B mixing	0.027	0.025	—	—
Method of determining w	0.040	0.083	0.082	0.185
$\Gamma(Z^0 \rightarrow bb)$	0.005	0.002	0.001	0.003
$\Gamma(Z^0 \rightarrow cc)$	0.007	0.002	0.027	0.033
B^0, B^\pm Lepton Spectrum	0.022	0.046	0.116	0.140
B_s Lepton Spectrum	0.032	0.018	0.046	0.054
Λ_b Lepton Spectrum	0.008	0.012	0.023	0.026
D Lepton Spectrum	0.022	0.020	0.037	0.098
b Fragmentation	0.011	0.015	0.012	0.011
c Fragmentation	0.001	0.002	0.001	0.001
Background Asymmetry	0.006	0.011	0.027	0.087
Polarization	0.018	0.018	0.008	0.007
Second Order QCD	0.008	0.008	0.040	0.040
Total (Quadrature Sum)	0.096	0.117	0.179	0.308

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