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Left-Right Forward-Backward Asymmetry for c and b Quarks

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1 Introduction

Measurements of fermion production asymmetries at the Z^0 pole provide probes of the combination of vector (v) and axial vector (a) couplings $A_f = 2v_f a_f/(v_f^2 + a_f^2)$, which express the extent of parity violation in the $Zf\overline{f}$ coupling. For $Z^0 \to f\overline{f}$ events with final-state fermion f at polar angle $z = \cos\theta$ with respect to the electron-beam direction, the Born level expression for conventional forward-backward asymmetry is $A^f_{\mathrm{FB}}(z) = \frac{\sigma^f(z)-\sigma^f(-z)}{\sigma^f(z)+\sigma^f(-z)} = A_e A_f \frac{2z}{1+z^2}$. The ability to manipulate the electron-beam helicity allows the formation of the left-right forward-backward asymmetry $\tilde{A}^f_{\mathrm{FB}}(z) = \frac{[\sigma^f_L(z)-\sigma^f_L(-z)]-[\sigma^f_R(z)-\sigma^f_R(-z)]}{[\sigma^f_L(z)+\sigma^f_L(-z)]+[\sigma^f_R(z)+\sigma^f_R(-z)]} = |P_e| A_f \frac{2z}{1+z^2}$, where P_e is the electron-beam longitudinal polarization. The use of $\tilde{A}^f_{\mathrm{FB}}$ eliminates the dependence on the initial state A_e, so the final state A_f can be measured directly. The achieved high $|P_e|$ of $\sim 77\%$ at SLC/SLD also brings a large gain of $(P_e/A_e)^2 \sim 25$ in statistics compared to conventional A^f_{FB} on the sensitivity to A_f. The effects of detector acceptance and efficiency non-uniformity also cancel to first order for this double asymmetry. Measurements of A_b are particularly important in light of the apparent anomaly in the current R_b measurements.

This report reviews preliminary direct measurements of A_b and A_c from a sample of 100,000 hadronic Z^0 decays accumulated during the 1994–1995 run with a luminosity-weighted average e^- polarization $|P_e| \simeq 77.3 \pm 0.6\%$ combined with another 50,000 events from the 1993 run with $|P_e| = 63.0 \pm 1.1\%$. The description of SLD detector components can be found in references of the individual analysis papers. All asymmetry measurement results described in this paper apply $\cos\theta$-dependent QCD corrections.

2 A_c using Reconstructed D^{*+}, D^+

This measurement of A_c using reconstructed D^{*+} and D^+ decays updates the analysis of the 1993 data[1] to include all 1993–1995 data. The $D^{*+} \to \pi_s^+ D^0$ decays are reconstructed by a combination of kinematic and decay-length analyses for the decay modes $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+(\pi^0)$ without explicit π^0 reconstruction. The $D^+ \to K^-\pi^+\pi^-$ decays are reconstructed using the decay topology. Since D^0's and D^+'s in $Z^0 \to c\overline{c}$ events are produced at the Z^0 primary vertex (PV), the excellent 3-D vertexing and the precise knowledge of the PV at SLD[2] allow suppression of D mesons from cascade decays and random combinatorial background (RCBG) for the D^{*+} decay-length and the D^+ analyses. For instance, the 2-D impact parameter of the D^0 momentum vector to the PV is required to be less than 20 μm in the decay-length technique. The distributions of $D^{*+} - D^0$ mass

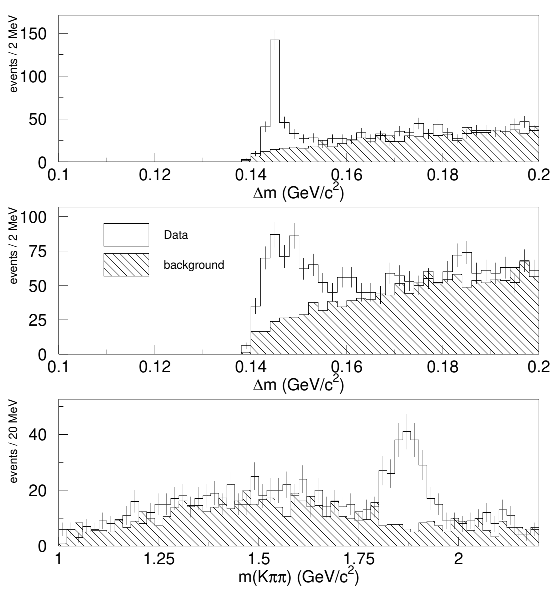

Figure 1: Distributions of $D^{*+} - D^0$ mass difference for $D^0 \to K^-\pi^+$ (top), $D^0 \to K^-\pi^+(\pi^0)$ (middle) modes, and $D^+ \to K^-\pi^+\pi^-$ mass (bottom).

differences and the distribution of $D^+ \to K^-\pi^+\pi^-$ mass are shown in Figure 1. The signal and sidebands are used to estimate the background fraction and asymmetry. An unbinned maximum-likelihood fit to the data gives

$$A_c = 0.64 \pm 0.11\ (\text{stat}) \pm 0.06\ (\text{syst}).$$

The dominant systematic errors result from our uncertainty in the RCBG estimation due to limited statistics; they will decrease with a larger data sample.

3 A_b, A_c using Leptons

This analysis of A_b and A_c using leptons updates the measurement based on the 1993 data by including all 1993–1995 data.[3] Electrons and muons are identified in hadronic decays of the Z^0. At high momentum and transverse momentum, these leptons come predominantly from semileptonic b and c decays. The lepton charge provides quark-antiquark discrimination, while the jet nearest the lepton approximates the quark direction. Lepton-source probabilities are derived from Monte Carlo (MC) using tracks with similiar momentum and transverse momentum to each lepton in the data. The MC semileptonic decays of B mesons are generated according to the ISGW formalism[4] with a 23% D^{**} fraction. A_b and A_c are extracted from a maximum-likelihood analysis of the event beam polarization, lepton charge, and quark direction. The preliminary combined muon and electron results for all 1993–1995 data are

$$A_b = 0.87 \pm 0.07\ (\text{stat}) \pm 0.08\ (\text{syst})$$

$$A_c = 0.44 \pm 0.11\ (\text{stat}) \pm 0.13\ (\text{syst}).$$

The statistical correlation between the A_b and A_c measurements is +18%. Two of the largest systematic errors are due to MC weights and jet-axis smearing; these are expected to decrease in the future.

4 A_b using Momentum-Weighted Track Charge

This new measurement[5] of A_b using momentum-weighted track charge improves the analysis on the 1993 data[6]. A sample enriched in $Z^0 \to b\bar{b}$ events is identified by selecting hadronic events with ≥ 3 quality tracks with an $r\phi$ impact parameter $> 3\sigma$ from the PV. Monte Carlo studies indicate that the tag is 61% efficient for identifying $Z^0 \to b\bar{b}$ events with a purity of 89%. The hemisphere momentum-weighted track charge sum and difference are given by $Q_{\text{sum}} = \sum_i q_i |\vec{p}_i \cdot \hat{T}|^\kappa$ and $Q_{\text{diff}} = -\sum_i q_i \cdot \text{sgn}(\vec{p}_i \cdot \hat{T})|\vec{p}_i \cdot \hat{T}|^\kappa$; q_i and $\vec{p}_i$ are the i^{th} track's charge and momentum, and $\hat{T}$ is the unit vector in the direction of the reconstructed thrust axis (signed so that $Q_{\text{diff}} > 0$) that estimates the b-quark direction. We choose $\kappa = 0.5$ to maximize the measurement's sensitivity. The distribution of the signed thrust axis in the tagged sample is shown separately for left- and right-handed electron beams in Figure 2.

The A_b asymmetry is measured with a self-calibrated maximum-likelihood analysis, which determines the probability that the b direction is correctly signed in an event from the data; this greatly reduces model dependence. The calibration procedure for the correct-sign probability for an event uses the parameterization $P(|Q_{\text{diff}}|) = 1/(1 + e^{-\alpha_b |Q_{\text{diff}}|})$, where α_b is determined from the measured widths of the Q_{sum} and $|Q_{\text{diff}}|$ distributions in the data. In addition, α_b includes a correction for a 3% hemisphere-charge correlation mainly due to overall charge conservation in the hadronization process. This correction is currently estimated from MC. The preliminary result for the 1993–1995 data sample is

$$A_b = 0.843 \pm 0.046\ (\text{stat}) \pm 0.051\ (\text{syst}).$$

The dominant systematic error is due to the uncertainty in the hemisphere-charge correlation. The significant calibration statistical error and b-tag composition systematic error will decrease with more data and with improvements in the b tag.

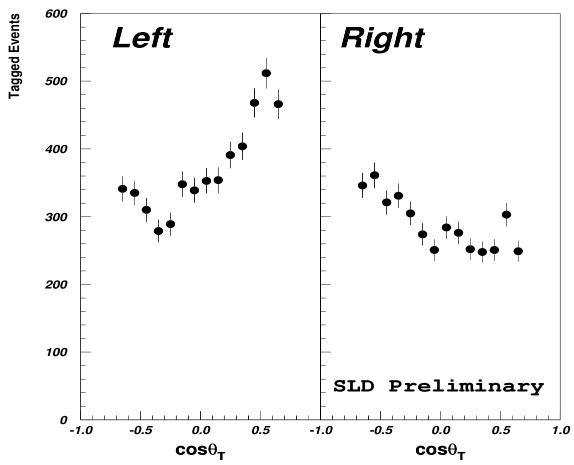

Figure 2: Distributions of raw signed thrust axis cosθ for 1994–1995 data using momentum-weighted track charge.

5 A_b using Identified Charged Kaons

In this new preliminary asymmetry measurement[7] of A_b using the 1994–1995 data, $b\bar{b}$ events are selected with a 2-D impact parameter tag similiar to that described in the previous section. Charged kaons with high-impact parameter tracks ($r\phi$ impact parameter $> +1.5\sigma$) and a momentum of 3–20 GeV are identified using the gas-radiator data of the Cherenkov Ring Imaging Detector, resulting in a K:π efficiency ratio of ~12:1. The MC $\pi \to K$ mis-identification rate is calibrated from $Z \to \tau\bar{\tau}$ events. The kaon candidate charges are summed in each hemisphere, and the difference between the two hemisphere charges is used to determine the polarity of the thrust axis for the b-quark direction. The kaon-charge signing is successful for 30% of the tagged events, and 71% of the $b\bar{b}$ events have their b direction signed correctly. The fractions of double-tagged events with opposite hemisphere charges are 62.4±2.9% and 61.9±1.5% in the data and MC, respectively, which provides a consistency check of the MC analyzing power. The *udsc* background subtracted left-right forward-backward b asymmetry ($\tilde{A}^{\rm corr}_{\rm data}$) is then formed as a function of cosθ. The $\tilde{A}^b_{\rm MC}$ is formed from MC $b\bar{b}$ events through the same analysis and scaled to fit the data, as shown in Figure 3. The

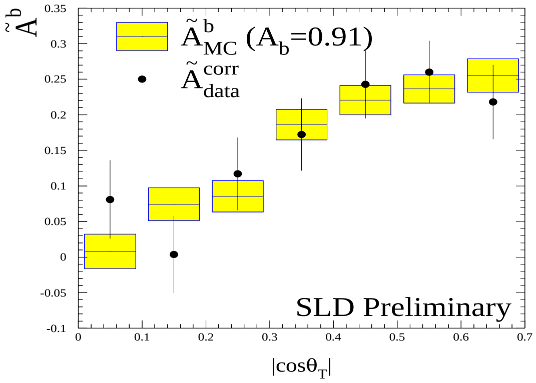

Figure 3: Distribution of kaon signed left-right forward-backward asymmetry for 1994–1995 data.

preliminary result from the 1994–1995 data is

$$A_b = 0.91 \pm 0.09 \text{ (stat)} \pm 0.09 \text{ (syst)}.$$

Most of the detector and physics systematics associated with the b-event analyzing power should decrease with a self-calibrating technique when more data is available.

6 Combined A_b, A_c Results

The preliminary SLD measurements presented in this report are combined with a simultaneous fit to A_b and A_c, taking into account the systematic correlations between measurements. The combined SLD results are

$$A_b = 0.858 \pm 0.054 \text{ and } A_c = 0.577 \pm 0.097,$$

with a 12.3% A_b, A_c correlation. These results can be compared with the average LEP measurements: $A_b = 0.884 \pm 0.032$ and $A_c = 0.642 \pm 0.053$, which are derived from the $A^{0,b}_{\rm FB}$ and $A^{0,c}_{\rm FB}$ results[8] using $A_e = 0.1506 \pm 0.0028$ from a combination of the SLD $A_{\rm LR}$ and LEP A_ℓ. Following the scheme of a full $Zb\bar{b}$ coupling analysis proposed by Takeuchi et al.[9], the deviations from the SM can be represented as a cross section-like variable ξ_b and a parity violation-like variable ζ_b, in addition to $\delta \sin^2\theta^{\rm eff}_W$. The ζ_b versus $\delta \sin^2\theta^{\rm eff}_W$ plot for various current experimental results is shown in Figure 4. The Standard Model point at (0,0) is defined by $m_t = 180$ *GeV*, $m_H = 300$ *GeV*, $\alpha_s = 0.117$ and $\alpha_{\rm em} = 1/128.96$. The thin horizontal band around (0,0) corresponds to the SM m_t, m_H variations indicated on the plot. The 68% and 90% C.L. contours for the best fit to all measurements are also

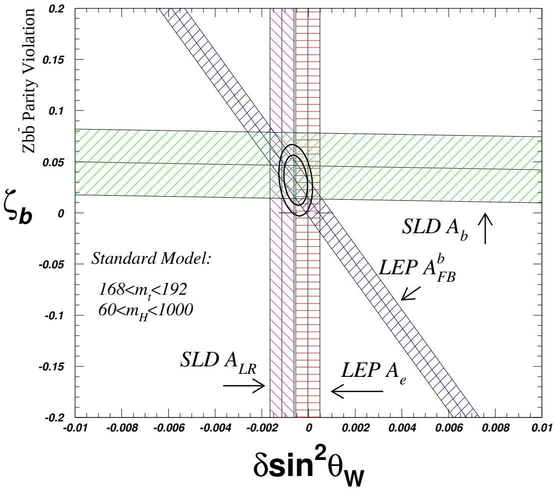

Figure 4: Zbb coupling parity violation versus $\delta \sin^2\theta^{\rm eff}_W$.

shown. This plot graphically demonstrates that a direct measurement of A_b is complementary to the electroweak measurements of $\sin^2\theta^{\rm eff}_W$.

References

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