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Electroweak Measurements with Heavy Quarks at SLD *

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Abstract

The SLD detector collected a sample of 550K hadronic events at the Z^0 peak from e^+e^- collisions at the SLC during the 1993 to 1998 period. Polarized electron beams, a small and stable interaction point and the excellent performance of the 3-D CCD vertex detector provide a unique environment for precision electroweak tests of the Standard Model. Improved measurements of heavy quark electroweak parameters are presented here.

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1 Introduction

The strength of the fermion couplings to the Z^0 can be measured via two clean experimental observables: the partial width

$$R_f = \frac{\Gamma(Z^0 \to f\bar{f})}{\Gamma(Z^0 \to hadrons)} = \frac{g_L^{f^2} + g_R^{f^2}}{\sum_i^{udscb}(g_L^{i^2} + g_R^{i^2})}, \quad (1)$$

and the coupling asymmetry

$$A_f = \frac{g_L^{f^2} - g_R^{f^2}}{g_L^{f^2} + g_R^{f^2}}, \quad (2)$$

where g_L^f and g_R^f are the left-handed and right-handed couplings of the fermion f respectively. The Standard Model (SM) predictions for the magnitude of these parameters for all the quark and lepton families are listed in Table 1. The differ-

	g_L^f	g_R^f	R_f	A_f	$\frac{\delta A_f}{\delta \sin^2\theta_W}$
e, μ, τ	-0.27	0.23	0.05	0.15	-7.9
u, c	0.35	0.15	0.17	0.67	-3.5
d, s, b	-0.42	0.08	0.22	0.94	-0.6

Table 1: Magnitude of the fermion coupling parameters to the Z^0 for $\sin^2\theta_W = 0.23$.

ent sensitivities of R_f and A_f to these couplings makes them two complementary observables in the complete determination of the $Z^0 \to f\bar{f}$ vertex. Taking as an example the case of the b quark:

$$\begin{aligned} \delta R_b/R_b &\sim -1.78\delta g_L^b + 0.33\delta g_R^b, \\ \delta A_b/A_b &\sim -0.15\delta g_L^b + 0.86\delta g_R^b, \end{aligned} \quad (3)$$

which indicate that R_b is more sensitive to possible deviations in the left-handed coupling, while A_b is more sensitive to deviations to the right-handed coupling. $Z^0 \to b\bar{b}$ vertex corrections in the SM depend only on the left-handed coupling, and are particularly large due to the large top quark mass and the fact that $|V_{tb}| \sim 1$. Anomalous right-handed currents are predicted in proposed extensions of the SM [1]. The SLAC Linear Collider and its operation with a polarized electron beam have been described in detail elsewhere [2]. Polarization, along with the small dimensions of the interaction point and the excellent vertexing capabilities [3] provide a unique environment to do precision studies of the electroweak theory of the SM, especially in the heavy quarks sector.

2 Flavour Tagging

Flavour tagging at SLD is performed through the topological reconstruction of the secondary vertex mass [4]. The efficiency of the tag is improved by adding a mini-

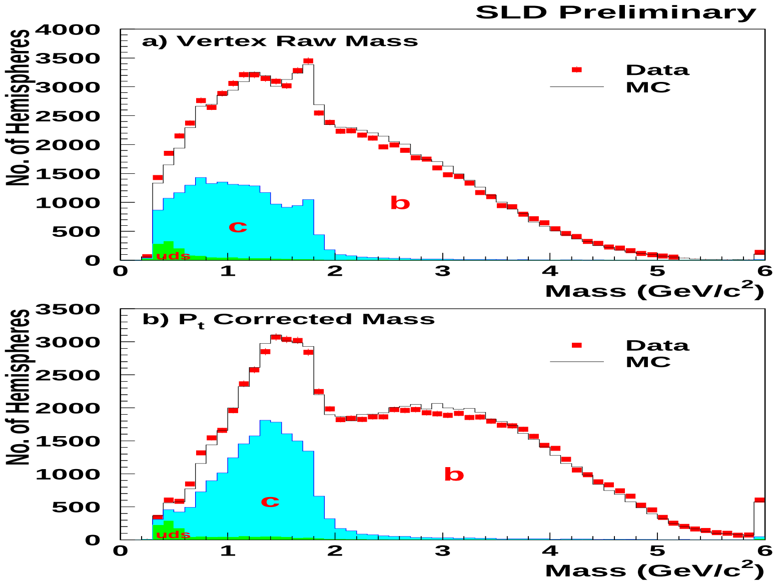

Figure 1: Distributions of the reconstructed raw and P_t corrected vertex masses for data (points) and Monte Carlo (histogram).

mum missing P_t correction to account for the contribution of neutral particles (see fig. 1). A standard cut used for b tagging, $M_{vtx} > 2$ GeV/c^2, gives a 98% pure selected sample, with a hemisphere efficiency of about 50%. Charm tagging is performed in the region $0.55 < M_{vtx} < 2$ GeV/c^2, using a 2-dimensional cut in the (P_{vtx}, M_{vtx}) plane, as shown in fig. 2. The cuts applied require P_{vtx} >5 GeV/c and 15M_{vtx}-P_{vtx} <10, for an overall hemisphere efficiency of 15% and a purity of 70%.

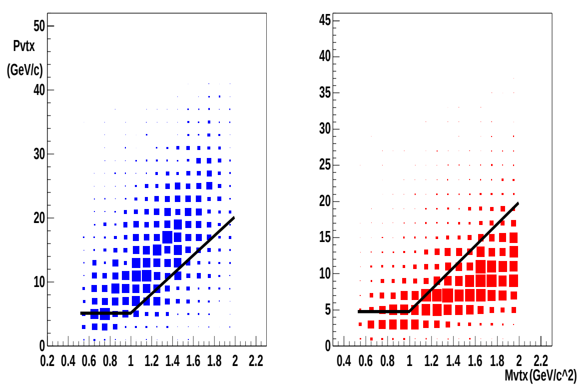

Figure 2: Dependence of the secondary vertex momentum on the secondary vertex mass for charm (left) and bottom (right) events.

3 B physics at SLD

3.1 R_b measurement

The SLD R_b measurement is based on the double-tag technique [5]. Events are divided into two hemispheres and a b-tag is applied in each of them. Both R_b and the tag efficiency ϵ_b are extracted from the data by simultaneously resolving equations for the single and double tag rates. The only dependence on Monte Carlo is limited to the background efficiencies for uds and charm that enter these equations, and to the hemisphere correlation parameter λ_b $(= \frac{\epsilon_b^d - \epsilon_b^2}{\epsilon_b - \epsilon_b^2})$. This analysis is thus not affected by uncertainties related to B production and decay modelling. A SM value for R_c is also assumed. The new SLD preliminary measurement from the 1993-1998 dataset is $R_b = 0.2159 \pm 0.0014(\mathrm{stat}) \pm 0.0014(\mathrm{syst})$, in good agreement with the SM expectation of 0.2158.

3.2 b Asymmetry

Four different techniques are used at SLD to measure A_b. One technique, performed only at SLD, uses $K^\pm$ tracks identified by the Čerenkov Ring Imaging Detector (CRID) from the $b \to c \to s$ decay chain [6]. $b\bar{b}$ events are tagged by requiring at least one heavy-tagged hemisphere while the b quark sign is deduced from the total charge of the kaon tracks in the vertex. The correct sign probability is calibrated from the data by using events with both hemispheres b-tagged and nonzero charge in each hemisphere: we find $p_b^{corr} = 70.7 \pm 1.4\%$ to be compared with a MC prediction of 72.4%. The sensitivity to the charm background fraction is reduced by the fact that, for the cascade nature of the tag, the signals for $b \to c \to s$ and $c \to s$ decays have the same sign. The largest systematic error comes from calibration statistics. A maximum likelihood fit yields a preliminary measurement of $A_b = 0.960 \pm 0.040(\mathrm{stat}) \pm 0.069(\mathrm{syst})$ for the 1993-98 data sample.

A second technique uses semileptonic decays into muons and electrons to perform a simultaneous maximum likelihood fit to the b and c asymmetries [7]. The b-quark sign is determined from the charge of the lepton and the direction from the jet axis nearest to it. Leptons are weighted according to their decay source probabilities (b direct, b cascade, c or background) as a function of the total momentum, transverse momentum w.r.t. the jet axis, vertex mass and track decay length information. In the muon analysis weights are calculated with a nearest neighbours technique in a MC phase space parametrized in terms of these variables; the electron analysis combines this and other vertexing information into a neural net algorithm, after applying a vertex requirement. The agreement between data and MC has been checked in thorough systematic studies. The preliminary result for the 1993-98 data sample is $A_b = 0.922 \pm 0.029 \pm 0.024$.

Another analysis uses the momentum-weighted track charge to sign the b quark, using the correlation between the charge of the quark and the high momentum tracks [8]. This is defined as:

$$Q = -\sum_{tracks} q_i \cdot sgn(\vec{p}_i \cdot \hat{T})|(\vec{p}_i \cdot \hat{T})|^{\kappa}, \quad (4)$$

where q_i, $\vec{p}_i$ are the charge and momentum vector of track i. $\hat{T}$ is the thrust axis and κ is chosen at $\sim$0.5 to optimize the charge separation. The correct sign probability is calibrated from data by reconstructing the unsigned momentum-weighted track charge in both hemispheres: the shape of these distributions allows for a simple parametrization of the analyzing power as a function of the jet charge. Both the small *udsc* background subtraction and the hemisphere charge correlation are estimated from MC. The preliminary result for the 1993-98 data sample is $A_b = 0.882 \pm 0.020(\text{stat}) \pm 0.029(\text{syst})$.
The most recent analysis developed at SLD uses the charge of the reconstructed vertex to identify the sign of the quark [9]. An upgraded b-tagging which uses neural nets for background rejection and track association is applied and only heavy-tagged hemispheres with non-zero vertex charge are selected. The reconstruction of the vertex charge benefits from the vertex detector (VXD3) self-tracking capabilities, by using $\geq$3 hit vectors in VXD3 (not linked to the drift chamber) along with fully linked tracks. The correct sign probability is calibrated from double-tag events, and is in good agreement with the MC prediction of $p_b^{corr} \sim 85\%$. The preliminary result with 1997-98 data is $A_b = 0.926 \pm 0.019(\text{stat}) \pm 0.027(\text{syst})$.
The SLD combined average of the A_b measurements (taking into account correlations) gives a result of $A_b = 0.914 \pm 0.024$.

4 Charm physics at SLD

4.1 R_c measurement

The SLD R_c measurement is based on a double-tag technique [10]. A b-tag and c-tag are applied to every hemisphere. R_b and the efficiency for tagging a B hadron are derived from data by comparing single and double tag rates:

$$\begin{aligned} F_s &= R_b\epsilon_b + R_c\epsilon_c + (1 - R_c - R_b)\epsilon_{uds}, \\ F_d &= R_b(\epsilon_b^2 + \lambda_b^h(\epsilon_b - \epsilon_b^2)) + R_c(\epsilon_c^2 + \lambda_c^h(\epsilon_c - \epsilon_c^2)) \\ &\quad +(1 - R_c - R_b)\epsilon_{uds}^2 \end{aligned} \quad (5)$$

where ϵ_c, ϵ_{uds} and the hemisphere correlations λ_f^h are taken from Monte Carlo. Two similar equations hold for the c-tagged hemispheres:

$$\begin{aligned} G_s &= R_b\eta_b + R_c\eta_c + (1 - R_b - R_c)\eta_{uds} \\ G_d &= R_b(\eta_b^2 + \lambda_b^l(\eta_b - \eta_b^2)) + R_c(\eta_c^2 + \lambda_c^l(\eta_c - \eta_c^2)) \\ &\quad +(1 - R_b - R_c)\eta_{uds}^2 \end{aligned} \quad (6)$$

and an additional one gives the mixed rate fraction:

$$M = 2[R_b \epsilon_b \eta_b + R_c \epsilon_c \eta_c + (1 - R_b - R_c)\epsilon_{uds}\eta_{uds}]. \qquad (7)$$

The *uds* efficiency and the correlations are again taken from MC, so that with the knowledge of R_b and ϵ_b, there are 3 equations left with 3 unknowns. A high purity tag is generally needed for a double-tag measurement; in this case however, the background in the charm sample is mainly from b's and the mixed equation allows to solve η_b from data using the high purity tag in the opposite hemisphere. The preliminary measurement for 1993-98 data is: $R_c = 0.169 \pm 0.005(\text{stat}) \pm 0.004(\text{syst})$.

4.2 Charm Asymmetry

Three techniques are used at SLD to determine A_c, all featuring the use of a b-veto to reject events with high vertex mass in either hemisphere.
The cleanest method is based on the exclusive reconstruction of D^* and D mesons in six different channels [11]. Kinematics and event topology information are used to reject b and uds background. The charge of the quark is given by the sign of the D^*(or K) and its direction by the D meson direction. The asymmetry of the background is estimated in the mass sidebands. The low reconstruction efficiency for this method is compensated by the high correct sign probability and the good determination of the quark direction. Preliminary result with the 1993-98 data sample is: $A_c = 0.689 \pm 0.042(\text{stat}) \pm 0.019(\text{syst})$.
In the inclusive soft-pion analysis [11] c-quarks are identified by the presence of soft pions from the decay $D^{*+} \rightarrow D^0\pi_s^+$. Given the small Q value for this decay, the pion is produced along the D^* flight direction with a transverse momentum $p_T^2 \sim 0$. By cutting at $p_T^2 < 0.01$ (GeV/c)^2, a S/N ratio of 1:2 is achieved. The direction of the quark is estimated from the jet axis and its sign by the charge of the π_s. Preliminary result for the 1993-98 data is: $A_c = 0.683 \pm 0.052(\text{stat}) \pm 0.036(\text{syst})$.
Another technique uses an inclusive charm tagging [12] based on the reconstructed vertex mass in a similar way as the R_c analysis. The charm quark sign is obtained from either a non-zero vertex charge in the hemisphere ($\epsilon \sim 50\%$) or from the charge of the attached kaon tracks ($\epsilon \sim 25\%$), for a total correct sign fraction of 94%, calibrated from the data. Backgrounds from b events are constrained by the double-tag calibration. The preliminary measurement from the 1993-98 data sample is: $A_c = 0.603 \pm 0.028(\text{stat}) \pm 0.023(\text{syst})$. This analysis benefits from a significantly higher statistical power than all the other methods.
The SLD combined average of the A_c measurements gives $A_c = 0.634 \pm 0.027$.

5 Conclusions

Thanks to its vertexing capabilities and the presence of polarized beams, SLD has performed measurements of world-class precision. The direct measurement of A_b to better than 3% precision is the best of any single collaboration, A_c is at a 4% precision (best average) and R_c is the best double-tag measurement. Results are consistent with the Standard Model and analyses are still being improved.

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