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Measurements of Z^0 Electroweak Couplings at SLD[1]

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Abstract

In this paper we report a summary of the results of several electroweak measurements performed by the SLD experiment at the Stanford Linear Collider (SLC). Most of these results are preliminary and are based, unless otherwise indicated, on the full 1993-1998 dataset of 560,000 hadronic Z^0 decays, produced with an average electron beam polarization of 73%.

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1 Theoretical Overview

The $SU(2)_L \times U(1)$ Standard Model (SM) has the following Feynman rule for neutral current (NC) fermion$-Z^0$ boson interaction:

$$\frac{-i}{\sqrt{2}} \left(\frac{G_F M_Z^2}{\sqrt{2}} \right) \bar{f} \gamma^\lambda \left(g_V - g_A \gamma_5 \right) f Z_\lambda, \tag{1}$$

where G_F is the Fermi constant, M_Z the Z^0 mass and g_V and g_A the vector and axial-vector fermion couplings:

$$g_V = (g_L + g_R) = I_L^3 - 2Q \sin^2 \theta_W \qquad g_A = (g_L - g_R) = I_L^3. \tag{2}$$

I_L^3 is the third component of the fermion weak isospin, Q the fermion electric charge and θ_W the Weinberg angle.

The observables at the Z^0 pole are the following combinations of these couplings: A_f, which represents the extent of the parity violation at the $Zf\bar{f}$ vertex:

$$A_f = \frac{2 g_V g_A}{g_V^2 + g_A^2} = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}, \tag{3}$$

and R_f, the fraction of $Z^0 \to f\overline{f}$ events in hadronic Z^0 decays:

$$R_f = \frac{\Gamma(Z^0 \to f\bar{f})}{\Gamma(Z^0 \to \text{hadrons})} \propto g_L^2 + g_R^2. \tag{4}$$

The precise measurements of these quantities should ultimately verify whether or not the couplings for all generations and weak isospin states are given by the theory isospin assignments and a universal value of $sin^2\theta_W$.

The differential cross section for $e^+e^- \to Z^0 \to f\bar{f}$ and longitudinally polarized electrons is given by:

$$\frac{d\sigma}{dz} \propto (1 - P_e A_e) \left(1 + z^2\right) + 2z \left(A_e - P_e\right) A_f, \tag{5}$$

where z is the cosine of the polar angle of the outgoing fermion f with respect to the incident electron, P_e the electron beam longitudinal polarization, and A_e and A_f the asymmetry parameters for the initial and final state fermions, respectively.

The presence of the parity violation parameters introduces a forward-backward asymmetry, which is, for unpolarized beams:

$$A_{FB}^f(z) \equiv \frac{\sigma_f(z) - \sigma_f(-z)}{\sigma_f(z) + \sigma_f(-z)} = A_e A_f \frac{2|z|}{1 - z^2}. \tag{6}$$

In the presence of e^- beam polarization, as at the SLC, it is possible to construct the left-right forward-backward asymmetry

$$\begin{aligned} \tilde{A}_{FB}^f(z) &\equiv \frac{[\sigma_L^f(z) - \sigma_L^f(-z)] - [\sigma_R^f(z) - \sigma_R^f(-z)]}{[\sigma_L^f(z) + \sigma_L^f(-z)] + [\sigma_R^f(z) + \sigma_R^f(-z)]} \\ &= |P_e| A_f \frac{2z}{1 + z^2}, \end{aligned} \tag{7}$$

for which the dependence on the initial state coupling parameter A_e disappears, allowing a *direct* measurement of the final state coupling parameters A_f. Thus electron beam polarization permits a unique measurement of A_f, independent of that inferred from the unpolarized forward-backward asymmetry[1] which measures the combination $A_e A_f$, and gives a statistical advantage of $(P_e/A_e)^2$ which is roughly equivalent to a factor 25 at the SLC.

The left-right cross section asymmetry is defined as:

$$A_{LR}^{meas} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = P_e A_e. \tag{8}$$

It yields a very precise direct measurement of the initial state Zee coupling and gives a very sensitive measurement of the weak mixing angle since $\delta A_e \sim 8\delta(sin^2\theta_W)$. Measuring and comparing the asymmetry parameters A_f for the different lepton types also provides a direct test of lepton universality, which is assumed in the SM.

Precise measurements of the asymmetry parameters A_f and the partial widths R_f can probe the effect of radiative corrections to the Z^0 propagator or to the the $Zf\bar{f}$ vertex. Since the radiative corrections depend on the top and Higgs masses, precise electroweak measurements can also measure or constrain these quantities.

In particular, especially interesting is the measurement of the Z^0 to b quark couplings for several reasons. First, the quantity A_b is largely independent of propagator effects that modify the effective weak mixing angle, hence it is complementary to other electroweak measurements performed at the Z^0 pole. Second, physics beyond the SM may couple more strongly to third generation fermions, producing larger deviations in b couplings than in other quark couplings. Finally, since for b quarks $g_L^2 \simeq 30 g_R^2$, the observable R_b has large sensitivity to possible deviations from the predicted left-handed coupling between the Z^0 and b-quarks and is complementary to the measurement of A_b, which, instead, has greater sensitivity to right-handed components.

2 SLD/SLC Unique Features

The recent (1997-98) performance of the SLC has been excellent, with peak luminosities of $3 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$ (20,000 Z^0 decays/week), nearly a factor of three improvement compared to the best previous results. The total number of Z^0 hadronic decays collected during the running period 1993-98 has raised to about 560,000.

A detailed description of the SLD detector can be found elsewhere[2]. Here are listed some of the unique features which allow the SLD experiment to perform many competitive electroweak and heavy flavor physics measurements:

- Highly longitudinally polarized (average $\sim$73%) electron beams.
- A small and stable beam spot ($1.5 \times 0.8 \times 700\mu m$) and a high precision 3D CCD-based pixel vertex detector (Interaction point (IP) determined to $6 \times 6 \times 25\mu m$ with an impact parameter resolution of $11 \times 23\mu m$ ($r\phi \times rz$) for high momentum tracks).
- Good particle identification, using a Čerenkov Ring Imaging Detector (CRID).

3 Lepton Coupling Asymmetry Meaurements

3.1 Left-Right Cross Section Asymmetry (A_{LR})

A_{LR} is an inclusive measurement that depends only on the initial state electron couplings and the magnitude of the electron beam polarization. No efficiency or acceptance effects enter and no significant final state identification is required, consequently practically all of the data can be used and this contributes to the high statistical precision of this measurement. Nevertheless, due to the high precision of the polarization measurement, the results is still statistically limited (systematic error $\sim$ .75%, statistical error $\sim$ 1.3%). Most recently, a dedicated experiment using the End Station A fixed target polarimeter confirmed that accidental e^+ polarization is consistent with zero ($-0.02 \pm 0.07\%$).

The A_{LR} measurement uses all hadronic events and is effectively a counting experiment. In fact, with equal luminosity for right- and left-handed events, we can replace the cross sections in equation 8 with the number of events N_L and N_R, so that $A_e = \frac{1}{P_e} \frac{N_L - N_R}{N_L + N_R}$. Additional corrections must be applied due to direct channel $\gamma-$exchange and from γZ^0 interference. After applying these corrections, which are well known and of the order of $\sim$2.5%, we measure $sin^2\theta_W = 0.23101 \pm 0.00031$.

The quantity A_{LR} can be measured only in the presence of polarized beams and provides by far the most precise determination of $sin^2\theta_W$ presently available, without need to assume lepton universality.

3.2 A_{lepton} Measurements from $\tilde{A}_{FB}$

A_e, A_μ and A_τ are measured at SLD from leptonic decays of the Z^0 boson via the corresponding left-right forward-backward asymmetries for each lepton type. A likelihood fit is used to simultaneously measure A_e and A_l (where $l = e, \mu, \tau$). SLD's A_μ constitutes the world's best measurement, while A_τ is best measured at LEP I, by combining the results for all four experiments. The SLD A_τ result is statistically comparable to one LEP I experiment. The SLD results are consistent with lepton universality (see Table 1). Assuming lepton universality, we can combine these results with that from A_{LR} for a measurement of $sin^2\theta_W$ of 0.23109 ± 0.00029[3, 4].

4 R_b and R_c Measurements

The measurements of R_b[5] and R_c[6] heavily exploit the capabilities of the SLD vertexing via a topological vertex algorithm[7], which has proven to be efficient and robust. After a standard hadronic decay selection, each event is divided into two hemispheres where secondary (and tertiary) vertices are found. Secondary vertices are found in 65% of the b hemispheres and in 20% of the c hemispheres. The vertex invariant mass is calculated and corrected for missing transverse momentum. Hemispheres are tagged as containing a b quark if their corrected vertex mass is greater than 2 GeV and the secondary vertex is at least 5 standard deviations away from the primary vertex. The hemisphere purity for b events is $\sim$98% with an efficiency of $\sim$50%. Events are selected and tagged as $b\bar{b}$ if at least one of their hemispheres satisfies the previous conditions.

Similarly, an hemisphere is tagged as $c\bar{c}$ if the following conditions are satisfied:

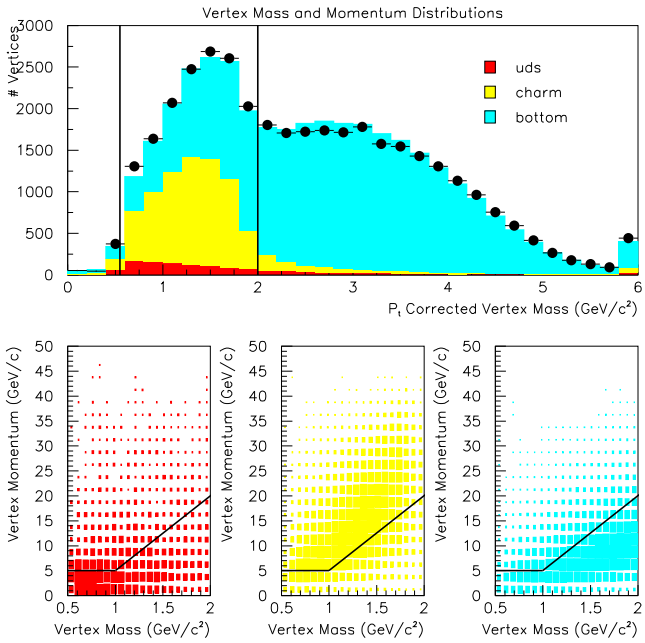

Figure 1: Top: distribution of the vertex mass hemisphere for data and Monte Carlo. Bottom: vertex mass vs vertex momentum for *uds* (left), charm (middle) and *b* (right) events.

- At least one track present with 3D impact parameter more than 3 standard deviations from the primary vertex.
- $0.55 < M_{vtx} < 2$ GeV.
- $P_{vtx} > 5$ GeV.
- $P_{vtx} > 15 M_{vtx} - 10$ GeV.

The last cut uses the fact that *b* events that populates the low mass region, do so because they are missing some tracks and, consequently, have a lower momentum for the same vertex mass (see fig 1). The resultant hemiphere purity is ∼70% with ∼16% efficiency.

The charm and bottom tagging efficiencies are self-calibrated, using the single, double and mixed tag rates, directly from the experimental data. The Monte Carlo (MC) is used as input for the *c* and *uds* efficiencies in the *b* tag region. For this reason it is very important to have high purity in the sample of events tagged as *b*, in order to reduce the systematic uncertainties due to modelling of the charm production and decay in the MC. Hemisphere correlations are also derived from the MC.

We measure: $R_b = 0.2159 \pm 0.0014(\text{stat}) \pm 0.0014(\text{syst})$ and $R_c = 0.1685 \pm 0.0047(\text{stat}) \pm 0.0043(\text{syst})$. 150,000 Z^0 hadronic decays from the last part of the 1998 run have not yet been included in the R_b result.

5 Quark Coupling Asymmetry Measurements (A_q)

SLD provides several methods to measure the quantites A_q, which are largely independent. Their statistical and systematic correlations are taken into account in the combinations of their results. All these measurements construct the left-right forward-backward asymmetries

defined previously and use, in different ways, the secondary vertex information. Three different techniques are employed to measure the parity violating parameter A_b. They use respectively the jet charge, the kaon charge and the lepton charge to tag the b and the $\bar{b}$ hemispheres. Four methods are instead used to determine A_c. To determine the c hemisphere they use the kaon or vertex charge, the lepton charge, the soft pion charge or $D^{(*)}$ meson decays reconstructed exclusively. Finally, SLD is able to produce a very good measurement of A_s, using identified kaons and Λ particles.

5.1 A_b with a Kaon Tag

This measurement[8] exploits the decay chain $b \to c \to s$ to tag the initial b quark sign. It heavily relies on the good kaon identification from the CRID detector and the excellent separation between kaons coming from the IP and those from the secondary vertex. The error is at this moment dominated by the uncertainty in the K^+/K^- production ratio in B meson decays, but it will likely improve soon employing a self-calibrated method. The A_b value from this measurement (derived only from the 1994-95 data sample) is $0.855 \pm 0.088(\text{stat}) \pm 0.102(\text{syst})$.

5.2 A_b with a Momentum Weighted Track Charge

The momentum-weighted track charge, commonly referred to as "jet charge", is defined as:

$$Q_{\text{diff}} = Q_b - Q_{\bar{b}} = - \sum_{tracks} q_i \cdot \text{sgn}(\vec{p_i} \cdot \hat{T}) |(\vec{p_i} \cdot \hat{T})|^{\kappa}, \tag{9}$$

where $\vec{p_i}$ is the ith track momentum, q_i its charge and $\hat{T}$ the direction of the event thrust axis. The coefficient κ was chosen to be 0.5 in order to maximize the analyzing power of the tag. The quantity Q_{diff} represents the difference between the momentum-weighted charges in the two hemispheres.

This methods[9, 10] uses all the available events, hence it is possible for this analysis to estimate the analyzing power directly from the data (self-calibration). The main input from the MC is the hemisphere correlation.

The forward-backward asymmetries obtained for left- and right-handed incident electrons are shown in fig 2. A maximum likelihood analysis on the entire data sample yields: $A_b = 0.882 \pm 0.020(\text{stat}) \pm 0.029(\text{syst})$.

5.3 A_b and A_c with a Lepton Tag

A_b and A_c can also be measured by tagging bottom and charmed hadrons using their semileptonic decays[11]. The lepton total and transverse momenta (with respect to the nearest jet) are used to calculate the probabilities that a lepton comes from each of the possible physics processes: $Z^0 \to b\bar{b}, b \to l$; $Z^0 \to b\bar{b}, \bar{b} \to \bar{c} \to l$; $Z^0 \to b\bar{b}, b \to \bar{c} \to l$; $Z^0 \to c\bar{c}, \bar{c} \to l$; and background (leptons from light hadron decays, photon conversions, and misidentified hadrons). The lepton charge provides quark-antiquark discrimination, while the direction of the jet nearest to the lepton approximates the direction of underlying quark.

Electrons are identified[12] with both calorimeter and CRID information for tracks with $p > 2$ GeV/c in the angular range $|\cos\theta| < 0.72$. This information is incorporated into

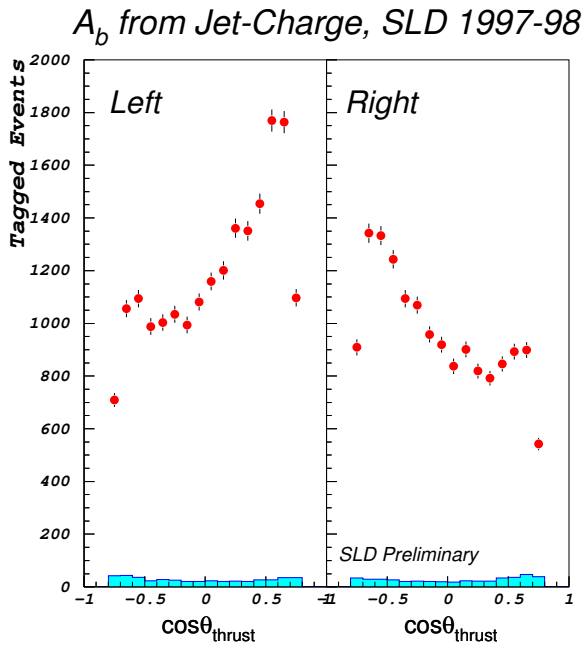

Figure 2: Distributions of the cosine of the thrust axis $|\cos\theta_{thrust}|$ for left- and right-handed electron beams for the jet-charge analysis (1997-98 data).

a neural network trained on Monte Carlo electrons. The efficiency (purity) for electron identification is on average 62% (70%) and over 78% (80%) for electrons with momenta greater than 15 GeV/c. Muon identification[13] is performed for tracks with $p > 2$ GeV/c in the angular range $|\cos\theta| < 0.70$ and uses information from the tracking and the Warm Iron Calorimeter. As for the electron identification, CRID information is added to reject π, K, and p background. The simulated prompt muon identification efficiency is 81%, with a purity of 68%. Both muon and electron identification algorithms have been tested on control samples from data.

This analysis presents the following new features:

- In case of an identified electron in the event, a secondary vertex is required in either hemisphere to achieve *uds* rejection.
- When an identified muon is present, the vertex mass and the L/D variable of the muon tracks (see fig 3) are included in the probability function together with the total and transverse lepton momenta.

As shown in fig 4, L/D discriminates between muons from direct and cascade b decays. This is due to the fact that the topological vertexing algorithm often finds only one vertex for both the B and the D decay, thus $L/D <$ (>)1 indicates a muon from direct (cascade) b decay.

A maximum likelihood analysis, applied to all hadronic Z^0 events containing leptons, is used to determine A_b and A_c simultaneously. We measure: $A_b = 0.924 \pm 0.032(\text{stat}) \pm 0.026(\text{syst})$ and $A_c = 0.567 \pm 0.051(\text{stat}) \pm 0.064(\text{syst})$.

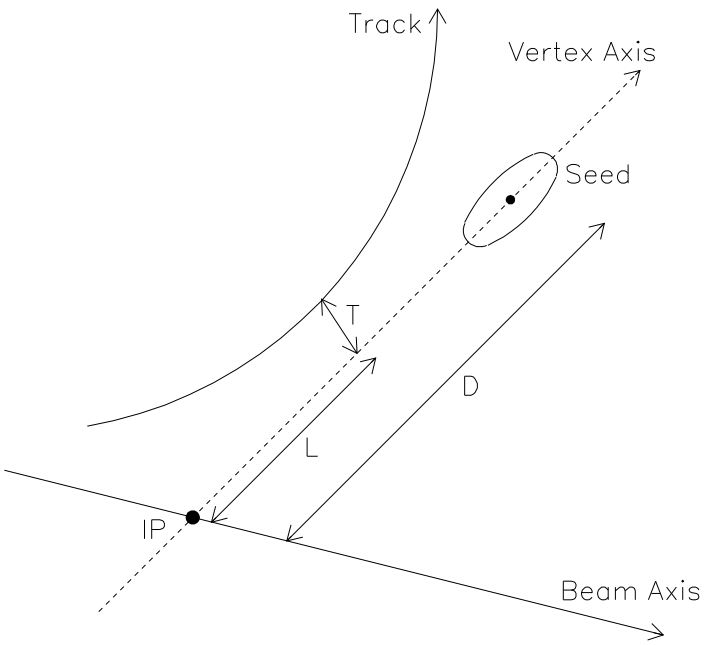

Figure 3: Topological parameters of a track: D is the distance of the secondary vertex (seed) from the interaction point along the line connecting them and L the distance from the IP of the projection of the point of closest approach on the vertex axis.

5.4 A_c with Exclusive D Mesons

In this analysis six modes are exclusively reconstructed to tag the charm quark: $D^* \to D^0\pi_{soft}$ with D^0 decaying into $K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$ and $Kl\nu$, $D^+ \to K^+\pi^+\pi^-$ and $D^0 \to K^-\pi^+$. The vertex information is used to reject both b and uds background. The reconstruction efficiency is low ($\sim$4%), but the high correct sign probability and the good determination of the underlying charm quark direction assures very low systematic errors.

The charm signal is obtained by selecting a signal region in the invariant mass distribution of the D meson (see fig 5). For the D^* the selection is improved with a cut on the $D^* - D^0$ mass difference. The background under the signal is estimated from the sidebands.

An unbinned likelihood analysis to the full differential cross section is used to extract: $A_c = 0.690 \pm 0.042(\text{stat}) \pm 0.022(\text{syst})$.

5.5 A_c with Inclusive Soft Pion

In this analysis the charm quark is tagged by the presence of a slow pion from the decay $D^* \to D^0\pi_{soft}$. In this decay the pion is produced along the D^* jet direction ($P_T^2 \sim 0$). Fig 6 shows the distribution of the P_T^2 signal. A signal to background ratio of 1:2 can be achieved with similar vertexing cut as for the previous analysis The result of this method is: $A_c = 0.683 \pm 0.052(\text{stat}) \pm 0.050(\text{syst})$.

5.6 A_c with Vertex Charge and Identified Kaons

The same charm tag used in the R_c measurement is used in this analysis[14]. Furthermore we required at least one hemisphere passing the charm selection, while neither hemisphere

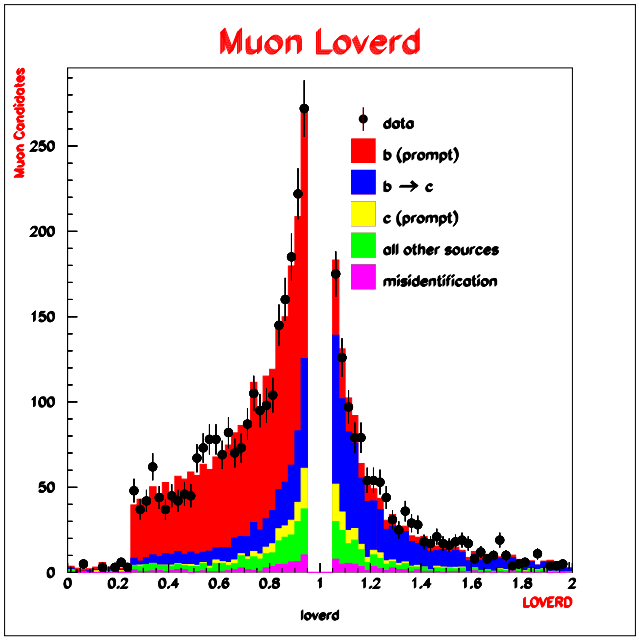

Figure 4: Tails of the L/D distribution for muons in 1996-8 data (dots) and Monte Carlo (histogram).

passing the bottom selection. The final charm efficiency is 28% with a purity of 82%. The quark charge is given by the charge of an identified kaon in the event (which is present in ∼25% of the selected events and gives 90% correct sign fraction) or by the vertex charge (present in ∼25% of the events with 91% correct sign fraction). This gives high statistics, hence the possibility to self-calibrate also this analysis. The results for the 1993-97 data sample is: $A_c = 0.650 \pm 0.041(\text{stat}) \pm 0.033(\text{syst})$.

6 A_s Measurement

$s\bar{s}$ events at SLD can be effectively identified thanks mainly to the good separation of tracks from secondary vertices and the contribution of the CRID to particle identification. $c\bar{c}$ and $b\bar{b}$ events are suppressed by requiring no tracks inconsistent with the IP. Each thrust hemisphere of a light-flavor tagged event is then required to contain at least one identified strange particle with large momentum ($K^{\pm}$ with $p > 9$ GeV and K^0_s or $\Lambda^0/\bar{\Lambda}^0$ with $p > 5$ GeV). Strange hemispheres are tagged using the highest momentum strange particle present in the hemisphere. A tag is required in both hemispheres and at least one of the tags must be signed. If both are signed, signs must be opposite.

Using these criteria we obtain an overall $s\bar{s}$ purity of 69%. The initial s quark direction is approximated by the thrust axis of the event, signed to point in the direction of negative strangeness, whose distributions for negative and positive polarization events are shown in fig 7.

The result, the most precise in the world, is: $A_s = 0.82 \pm 0.10(\text{stat}) \pm 0.08(\text{syst})$[15].

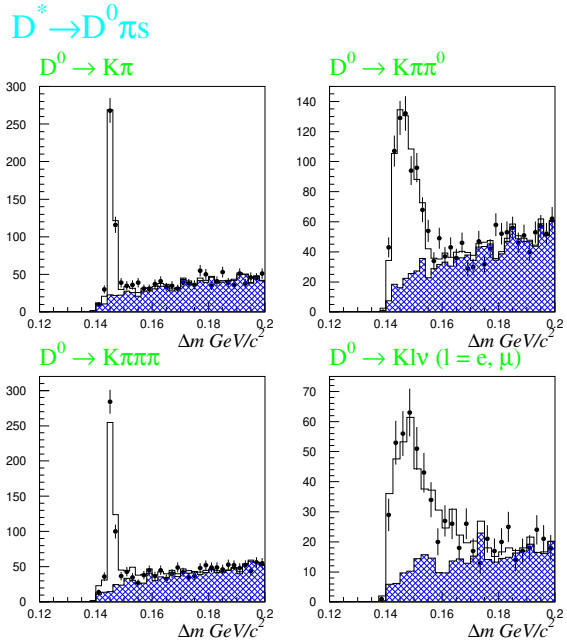

Figure 5: Invariant mass for $D \to K\pi\pi$ and $D^0 \to K\pi$ reconstructed decays.

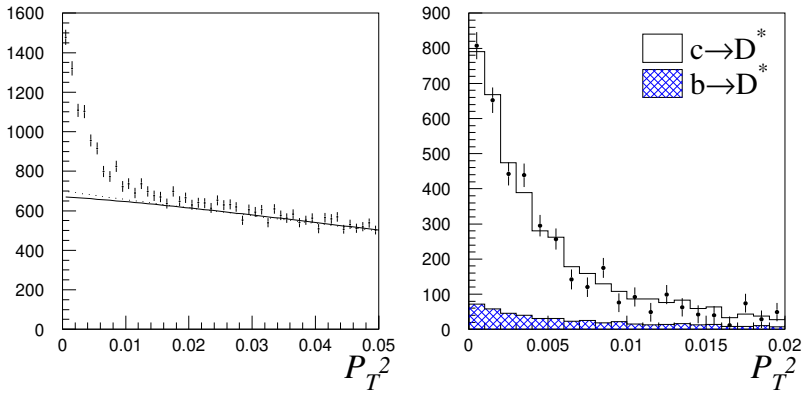

Figure 6: Distribution of the transverse momentum (with respect to the jet axis) of the soft pion candidates. Left: full sample. Right: after background subtraction.

7 Conclusions

We have presented the results of several important electroweak measurements performed by the SLD Collaboration. The A_{LR} and A_{lepton} measurements yield: $\sin^2\theta_W = 0.23109 \pm 0.00029$. It is interesting to note that this result is in agreement with the LEP leptonic asymmetry combined result ($\sin^2\theta_W = 0.23153 \pm 0.00034$), but differs by over 2 standard deviations from the LEP results obtained from "hadron-only" measurements (A^b_{FB}, A^c_{FB}, and Q_{FB}).

Both the R_c and the R_b results are in good agreement with the Standard Model predictions as well as with the LEP results. The SLD R_c measurement constitutes the most precise single measurement of this observable in the world.

The three A_b results described previously have been combined taking into account the small statistical and systematic correlations. The resulting SLD average is $A_b(\mathrm{SLD}) =$

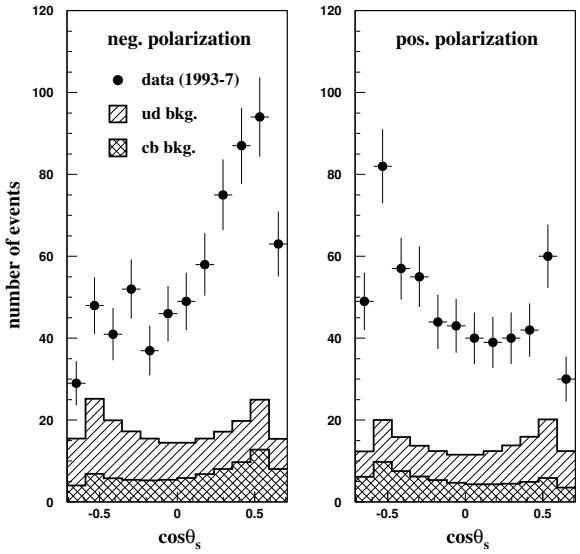

Figure 7: Distributions of the thrust axis for left- and right-handed events tagged as $s\bar{s}$.

0.898 ± 0.029. This value can be compared with the LEP results, which use the unpolarized forward-backward asymmetry for b quarks ($A_{FB}^b(\mathrm{LEP}) = 0.0991 \pm 0.0020$). Since the simple forward-backward asymmetry does not measure directly A_b, we need to use the world average value for $A_e = 0.1489 \pm 0.0017$, derived combining the SLD A_{LR} and the LEP A_l measurements. The derived LEP average is then: $A_b(\mathrm{LEP}) = \frac{4}{3}\frac{A_{FB}^b}{A_e} = 0.887 \pm 0.021$ for a combined SLD and LEP average of $A_b = 0.891 \pm 0.017$, which is about 2.6 standard deviations below the Standard Model prediction of 0.935.

Similar considerations are valid for the A_c measurements. The SLD average result is: $A_c(\mathrm{SLD}) = 0.663 \pm 0.032$, which is in agreeement with both the derived LEP average $A_c(\mathrm{LEP}) = 0.635 \pm 0.040$ and the Standard Model Prediction of 0.667.

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References

[1] The LEP collaborations and the LEP electroweak working group, CERN-EP/99-15 and CERN-PPE/97-154 and references therein.

[2] K. Abe *et al*, Phys. Rev. D **53**, 1023 (1996).

Table 1: *Summary of the results of SLD electroweak measurements*

Observable	Prelim. Result
A_{LR}	0.1510 ± 0.0025
$sin^2\theta_W$ (from A_{LR})	0.23101 ± 0.00031
A_e (from $\tilde{A}_{FB}$)	0.1504 ± 0.0072
A_μ	0.120 ± 0.019
A_τ	0.142 ± 0.019
$sin^2\theta_W$ (from A_{LR} and A_l)	0.23109 ± 0.00029
A_c - vertex charge+kaons	$0.650 \pm 0.041 \pm 0.033$
A_c - inclusive soft pion	$0.683 \pm 0.052 \pm 0.050$
A_c - exclusive D	$0.690 \pm 0.042 \pm 0.022$
A_c - lepton tag	$0.567 \pm 0.051 \pm 0.064$
A_c - SLD average	0.663 ± 0.032
A_b - jet charge	$0.882 \pm 0.020 \pm 0.029$
A_b - kaon tag	$0.855 \pm 0.088 \pm 0.102$
A_b - lepton tag	$0.924 \pm 0.032 \pm 0.026$
A_b - SLD average	0.898 ± 0.029
A_s	$0.82 \pm 0.10 \pm 0.08$
R_c	$0.1685 \pm 0.0047 \pm 0.0043$
R_b	$0.2159 \pm 0.0014 \pm 0.0014$

[3] K. Abe *et al*, SLAC-PUB-7878, Contributed to ICHEP 1998.

[4] K. Abe *et al*, Phys. Rev. Lett. **79**, 804 (1997).

[5] K. Abe *et al*, Phys. Rev. Lett. **80**, 660 (1998).

[6] K. Abe *et al*, SLAC-PUB-7880, Contributed to ICHEP 1998.

[7] D. Jackson, Nucl. Instrum. Methods **A338**, 247 (1997).

[8] K. Abe *et al.*, SLAC-PUB-7959, to be published in Phys. Rev. Lett.

[9] K. Abe *et al*, SLAC-PUB-7886, Contributed to ICHEP 1998.

[10] K. Abe *et al*, Phys. Rev. Lett. **81**, 942 (1998).

[11] K. Abe *et al*, SLAC-PUB-7798, submitted to Phys. Rev. Lett.

[12] D. Falciai, Ph.D. Thesis, Universitá di Perugia (1996).

[13] G. Mancinelli, Ph.D. Thesis, Universitá di Perugia (1997).

[14] K. Abe *et al*, SLAC-PUB-7879, Contributed to ICHEP 1998.

[15] K. Abe *et al*, SLAC-PUB-7825, Contributed to ICHEP 1998.

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