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ELECTROWEAK B PHYSICS AT LEP

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The decay width of the Z into $\mathrm{b\bar{b}}$ quark pairs and the forward-backward asymmetry of b quarks coming out of such decays are powerful tests of electroweak interactions. The measurements performed at LEP are reviewed and compared to the results obtained at SLC and the Standard Model expectations.

1 Introduction

A total of 17 millions Z decays into hadrons and leptons have been collected altogether by the four experiments at LEP collider between 1990 and 1995. The Z vector and axial-vector couplings to fermions, g_{Vf} and g_{Af}, have been measured with high precision using this sample and in particular the $Z \to \mathrm{b\bar{b}}$ decays.

The ratio R_{b} of the decay width into $\mathrm{b\bar{b}}$ to that into any $\mathrm{q\bar{q}}$ pair is especially sensitive to the top-quark mass, while it is almost independent from the Higgs boson mass. Therefore it has been very important until the top mass has been firmly established by direct measurement at Tevatron. As the measured value of R_{b} has not changed recently, however, this review will concentrate on the b forward-backward asymmetry, $A_{\mathrm{FB}}^{\mathrm{b}}$, which depends on the effective electroweak mixing angle $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$.

2 Forward-backward asymmetry measurements

The b forward-backward asymmetry, $A_{\mathrm{FB}}^{\mathrm{b}}$, is measured from the distribution of the angle between the direction of the outgoing b quark and the incoming electron,

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{3}{8}(1+\cos^2\theta) + A_{\mathrm{FB}}^{\mathrm{b}}\cos\theta \ ,$$

at each centre-of-mass energy point. Results are then extrapolated to $s = \mathrm{M_Z}$ and corrected for the effects of higher order QED and QCD diagrams and for $\mathrm{Z}-\gamma$ interference [1] to obtain the pole asymmetry $A_{\mathrm{FB}}^{0,\mathrm{f}} = \frac{3}{4}A_e A_{\mathrm{b}}$, where

$$A_{\mathrm{f}} = \frac{2 g_{\mathrm{Vf}} g_{\mathrm{Af}}}{g_{\mathrm{Vf}}^2 + g_{\mathrm{Af}}^2} \ .$$

To measure the forward-backward asymmetry the quark flavour needs to be tagged and the quark has to be separated from the antiquark. Several methods have being exploited. In particular, leptons issued by direct $\mathrm{b} \to \ell$ decays provide both flavour and charge tag. A lifetime based tagging allows the selection of a high purity sample of b-quarks. In this case the quark charge is estimated from jet or secondary vertex charge.

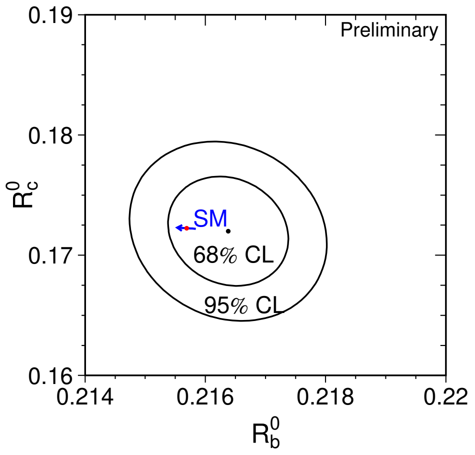

Figure 1. Results for the partial decay widths $R_{\rm b}$ and $R_{\rm c}$. The arrow represents the the Standard Model expectations for $m_{\rm t} = 178.0 \pm 4.3$ GeV/c^2.

3 LEP and SLD combination

The four LEP collaborations and SLD have agreed on a common list of input parameters needed to extract the most important electroweak observables from data and on an averaging procedure to take into account correlations between them [2]. The χ^2/d.o.f. of this 14-parameter fit [3] is 51/91. Results for $R_{\rm b}$ and $R_{\rm c}$ are within one sigma of the Standard Model expectations, as shown in Fig. 1. The spread of $A_{\rm FB}^{0,\rm b}$ results around the average value $< A_{\rm FB}^{0,\rm b} >= 0.0997 \pm 0.0015(\rm stat) \pm 0.007(\rm syst)$ is shown in Fig. 2. The uncertainty is dominated by the statistical error, while systematics are mostly uncorrelated since the error common to the four experiments is only ± 0.0004.

The parameters $A_{\rm b}$ and $A_{\rm c}$ are also measured directly by SLD from the corresponding $A_{\rm FB}$'s with left and right polarised electron beam. It is therefore possible to compare these results with the ones obtained from $A_{\rm FB}^{\rm b}$ and $A_{\rm FB}^{\rm c}$ and direct measurements of A_ℓ. In Fig. 3 the results are shown in the (A_ℓ,$A_{\rm b}$) plane. The measured $A_{\rm FB}^{\rm b}$ is compatible with $A_{\rm b}$ measured by SLD and the Standard Model, but the resulting prediction for A_ℓ is significantly lower than the measured value.

The combination of all the asymmetry measurements yields $\sin^2\theta_{\rm eff}^{\rm lept} = 0.23150 \pm 0.00016$, but as shown in Fig. 4 the most precise results, those from $A_{\rm LR}$ and $A_{\rm FB}^{\rm b}$, differ by 2.9 standard deviations. Altogether, the χ^2/d.o.f. of $\sin^2\theta_{\rm eff}^{\rm lept}$ fit is 10.5/5, which has a probability to occur of 6%.

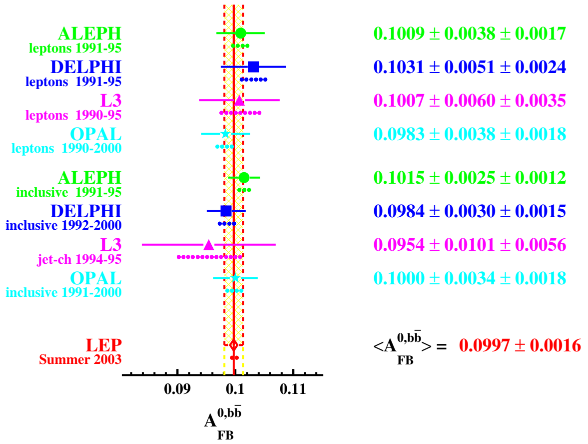

Figure 2. $A_{\rm FB}^{\rm b}$ measurements used in the heavy flavour combination. The $A_{\rm FB}^{\rm b}$ measurements with D-mesons contribute only very little weight and are not shown in the plot. The values shown are corrected to the same input parameters (including the other fitted observables which are fixed to the results of the full fit).

4 Conclusions

An impressive precision has been reached on $R_{\rm b}$ and on $A_{\rm FB}^{\rm b}$ by the four LEP collaborations. A three sigma discrepancy, however, is found between the values of $\sin^2\theta_{\rm eff}^{\rm lept}$ extracted from $A_{\rm LR}$ and $A_{\rm FB}^{\rm b}$. A deviation of the Z couplings to the quarks which shows up only in these measurements is unlikely. Only a large systematic effect, either common to all LEP experiments or much larger than the estimated systematic uncertainty on $A_{\rm LR}$, could explain such a difference, if it is not a statistical fluctuation.

References

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2. LEP and SLD Collaborations, NIM A **378** (1996) 101.
3. The LEP Electroweak Working Group and the SLD Heavy Flavour Group, “A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model”, hep-ex/0312023; http://lepewwg.web.cern.ch/LEPEWWG/Welcome.html for winter 2004 updates.

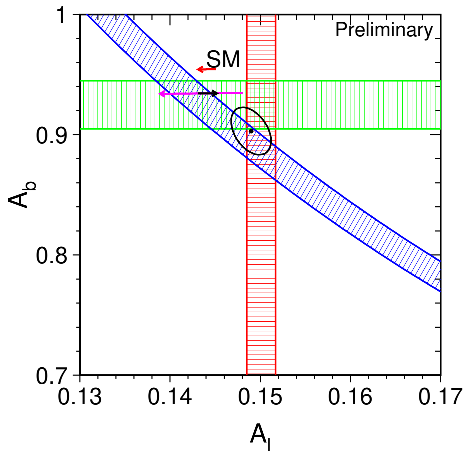

Figure 3. Comparison of the measurements of A_{b}, $A_{\mathrm{FB}}^{\mathrm{b}}$ and A_ℓ. Bands of ± 1 standard deviation are shown, together with the 68% confidence level contour for the joint analysis. The arrows pointing to the right and to the left show the variation in the Standard Model prediction for varying m_{t} in the range 178.0 ± 4.3 GeV/c^2 and m_{H} in the range 300^{+700}_{-186} GeV/c^2, respectively.

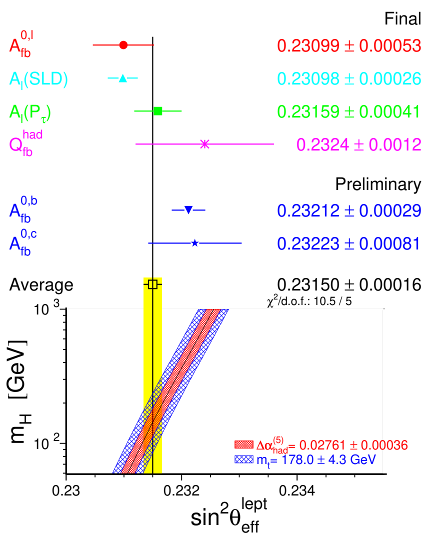

Figure 4. Results for $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$. The Standard Model prediction is also shown.