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Combined Analysis of Precision Electroweak Results

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Abstract

Preliminary and published results on measurements of parameters of the electroweak Standard Model are presented. Averages are derived from measurements of cross sections and asymmetries measured by SLD and the four LEP experiments, of the electroweak mixing angle measured in neutrino-nucleon reactions, of the W mass measured at LEP-2 and at the TEVATRON, and of the mass of the top quark measured by the TEVATRON experiments. These data are used to test the Standard Model and to constrain its parameters.

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COMBINED ANALYSIS OF PRECISION ELECTROWEAK RESULTS

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Preliminary and published results on measurements of parameters of the electroweak Standard Model are presented. Averages are derived from measurements of cross sections and asymmetries measured by SLD and the four LEP experiments, of the electroweak mixing angle measured in neutrino-nucleon reactions, of the W mass measured at LEP-2 and at the TEVATRON, and of the mass of the top quark measured by the TEVATRON experiments. These data are used to test the Standard Model and to constrain its parameters.

1 Introduction

The four LEP experiments, ALEPH, DELPHI, L3 and OPAL, and the SLD collaboration at SLC study e^+e^- interactions at centre-of-mass energies, $\sqrt{s}$, around 91 GeV. This energy corresponds to the mass of the Z boson which is resonantly produced and decays into fermion-antifermion pairs. The precision measurements analysed here consist of total cross sections for the inclusive hadronic and the three charged-lepton final states, the leptonic forward-backward asymmetries, the tau polarisation asymmetries, and the Z to $b\bar{b}$ and $c\bar{c}$ decay widths and forward-backward asymmetries. Because of beam polarisation at SLC, SLD is also able to measure the left-right polarisation asymmetry and the left-right forward-backward polarisation asymmetries. In the following, the combination procedure to perform the averages and the results are discussed. Comparisons with the Standard Model (SM) are made, and SM parameters are determined. For this analysis, the results on the electroweak mixing angle measured in neutrino-nucleon scattering, the W mass measured at LEP-2 and at the TEVATRON, and the mass of the top quark measured at the TEVATRON are also included.

Many results are still preliminary. Note that numerical results presented here have been updated with respect to the results shown during the conference in order to take into account recent SLD results in Sections 3 and 4, and a corrected value of $\alpha(M_Z^2)$ in the SM analyses presented in Section 7.

2 Z Lineshape and Forward-Backward Asymmetries

Each LEP experiment analyses the interactions $e^+e^- \to \mathrm{hadrons}(\gamma)$, $\ell^+\ell^-(\gamma)$, where $\ell = e,\ \mu,\ \tau$, and (γ) denotes the possible presence of radiative photons. In a χ^2 fit to the hadronic and leptonic cross sections and leptonic forward-backward asymmetries in the vicinity of the Z pole, $|\sqrt{s} - M_Z| < 4$ GeV (LEP-1), each experiment determines a set of 9 electroweak parameters describing the Z resonance.[1] These analyses take into account QED radiative corrections as well as correlations between the measurements arising from the LEP centre-of-mass energy calibration, experimental systematic errors and theoretical errors (luminosity, QED convolution, calculation of large-angle Bhabha scattering).

The $\sqrt{s}$ dependence is parametrised based on a Breit-Wigner resonance χ describing the Z boson with mass M_Z and total decay width Γ_Z, $\chi \propto 1/(s - M_Z^2 + is\Gamma_Z/M_Z)$. The other seven parameters are: the hadronic pole cross section, $\sigma^\circ_{\mathrm{had}} \equiv \frac{12\pi}{M_Z^2}\frac{\Gamma_e\Gamma_{\mathrm{had}}}{\Gamma_Z\Gamma_Z}$; the ratios of the pole cross sections for hadrons and the three lepton flavours, or equivalently the ratio of the Z partial widths, $R_\ell \equiv \sigma^\circ_{\mathrm{had}}/\sigma^\circ_\ell \equiv \Gamma_{\mathrm{had}}/\Gamma_\ell$; and the pole forward-backward asymmetries, $A_{FB}^{\circ,\ell} \equiv \frac{3}{4}A_e A_\ell$ ($\ell = e, \mu, \tau$).

The average of the LEP measurements is calculated on the basis of the four sets of nine parameters. Correspondingly, the correlated errors on these parameters arising from common error sources listed above must be determined. The following inter-experimental correlated errors are considered:

1.) The uncertainty in the LEP $\sqrt{s}$ energy calibration,[2] resulting in errors of 1.7 MeV on M_Z, 1.3 MeV on Γ_Z, and 0.03% on $\sigma^\circ_{\mathrm{had}}$.

2.) The luminosity theory error of currently 0.11%[3] on cross sections. This error will decrease to 0.06%.[4]

3.) The QED convolution to $O(\alpha^3)$.[5] The third-order effect is currently treated as an uncertainty, leading to errors of 0.5 MeV on M_Z, 0.6 MeV on Γ_Z, and 0.05% on $\sigma^\circ_{\mathrm{had}}$. Once the effect is understood it will be treated as a correction with a negligible error.

4.) The calculation of large-angle Bhabha scattering receiving t-channel and s/t-interference contributions, resulting in errors of typically 0.1% on cross sections and 0.001 on forward-backward asymmetries.[6]

Not assuming lepton universality, the LEP average has a χ^2/dof of 28/27, corresponding to a probability of 42%. The results for R_ℓ and $A_{FB}^{\circ,\ell}$ agree well for the different species of charged leptons as shown in Figure 1.

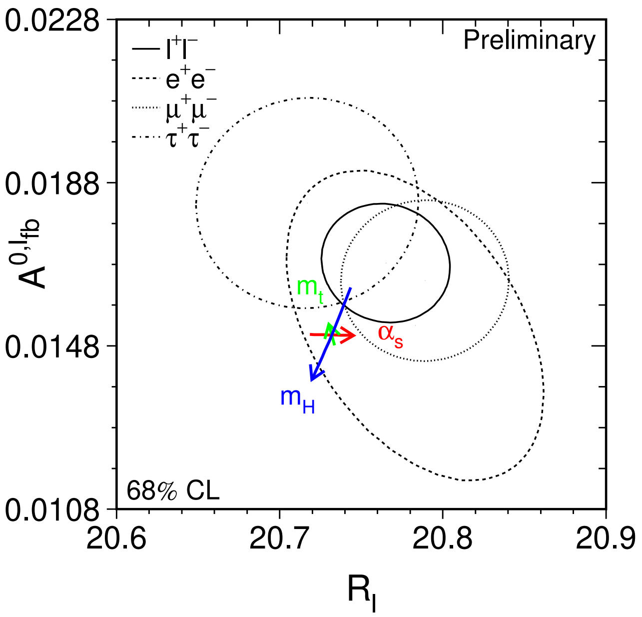

Figure 1: Contours of 68% probability in the $(R_\ell, A^{\circ,\ell}_{FB})$ plane with and without the assumption of lepton universality. For better comparison the results for the τ lepton are corrected to correspond to the massless case. The SM prediction is shown for $M_t = 173.8 \pm 5.0$ GeV, $M_H = 300^{+700}_{-210}$ GeV and $\alpha_S(M_Z^2) = 0.119 \pm 0.002$. The arrows point in the direction of increasing values of M_t, M_H and $\alpha_S(M_Z^2)$.

Assuming lepton universality, the average has a χ^2/dof of 31/31 (47%), and yields:

$$M_Z = 91186.7 \pm 2.1 \text{ MeV} \quad (1)$$

$$\Gamma_Z = 2493.9 \pm 2.4 \text{ MeV} \quad (2)$$

$$\sigma^\circ_{had} = 41.491 \pm 0.058 \text{ nb} \quad (3)$$

$$R_\ell = 20.765 \pm 0.026 \quad (4)$$

$$A^{\circ,\ell}_{FB} = 0.01683 \pm 0.00096 . \quad (5)$$

The off-diagonal elements in the correlation matrix are below 19%. The parameter $R_\ell = \Gamma_{had}/\Gamma_\ell$ is especially sensitive to the strong coupling constant $\alpha_S(M_Z^2)$ through QCD corrections to Γ_{had} and rather insensitive to top and Higgs effects, as they cancel in the ratio of partial widths. The result is: $\alpha_S(M_Z^2) = 0.124 \pm 0.004 \pm 0.002(M_H)$, where the second error arises due to the variation of M_H from 90 GeV to 1 TeV. Theoretical errors due to QCD are not included.

The partial decay widths of the Z are: $\Gamma_{had} = 1742.3 \pm 2.3$ MeV and $\Gamma_\ell = 83.90 \pm 0.10$ MeV, where Γ_ℓ is defined as the decay width into a pair of massless charged leptons. The partial width of the Z decay into invisible final states is: $\Gamma_{inv} = 500.1 \pm 1.9$ MeV. Within the SM, the invisible width arises from the Z decay into $\nu\bar{\nu}$ pairs. Hence it is possible to determine the number of light neutrino species:

$$N_\nu = (\Gamma_{inv}/\Gamma_\ell) \cdot (\Gamma_\ell/\Gamma_\nu)_{SM} = 2.994 \pm 0.011 . \quad (6)$$

The error on N_ν is dominated by the 0.11% theory error on the luminosity measurement (δN_ν(luminosity) = ± 0.008). Alternatively, the contribution of additional invisible decay modes of the Z boson are restricted to $\Delta\Gamma_{inv} < 2.8$ MeV at 95% CL.

3 Polarisation Asymmetries and Effective Coupling Constants

In case of τ-pair production, the τ decay serves as a polarisation analyser allowing a measurement of the longitudinal τ polarisation, $\mathcal{P}_\tau$. As a function of the polar scattering angle $\cos\theta$, $\mathcal{P}_\tau$ is given by:

$$\mathcal{P}_\tau(\cos\theta) = -\frac{A_\tau(1+\cos^2\theta) + 2A_e\cos\theta}{1+\cos^2\theta + 2A_\tau A_e \cos\theta} . \quad (7)$$

Each LEP experiment provides results for A_τ and A_e averaged over all τ-decay modes analysed.[7] Uncertainties correlated between the LEP experiments arise through radiative corrections in $\tau \to \nu\pi$ and $\tau \to \nu\rho$ decays, the modelling of $\tau \to \nu a_1$ decays, and, in case of inclusive analyses, the branching fractions of τ decays. Typically, these uncertainties amount to 0.0001 on A_e and 0.0010 on A_τ[8] and for the moment are treated as uncorrelated. The weighted averages are:

$$A_e = 0.1479 \pm 0.0051 \qquad A_\tau = 0.1431 \pm 0.0045 , \quad (8)$$

which are in good agreement with each other as expected from lepton universality. These results are directly comparable to the left-right polarisation asymmetry measured at SLD:[9]

$$A_{LR} = A_e = 0.1504 \pm 0.0023 , \quad (9)$$

where this result includes also leptonic left-right forward-backward asymmetries but is dominated by the left-right asymmetry. Using $A^{\circ,\ell}_{FB} = \frac{3}{4}A_e A_\ell$ and assuming lepton universality, a fourth measurement of A_ℓ is derived:

$$|A_\ell| = 0.1498 \pm 0.0043 . \quad (10)$$

The average of the above four values of A_ℓ has a χ^2/dof of 2.2/3 (53%) with the result:

$$A_\ell = 0.1489 \pm 0.0017 . \quad (11)$$

The leptonic partial width Γ_ℓ and the leptonic couplings parameter A_ℓ determine the effective coupling constants of the weak neutral current, $g_{V\ell}$ and $g_{A\ell}$, since: $A_\ell = 2\frac{g_{V\ell}/g_{A\ell}}{1+(g_{V\ell}/g_{A\ell})^2}$ and $\Gamma_\ell = \frac{G_F M_Z^3}{6\pi\sqrt{2}}[g_{V\ell}^2 + g_{A\ell}^2](1+\Delta_\ell^{QED})$.

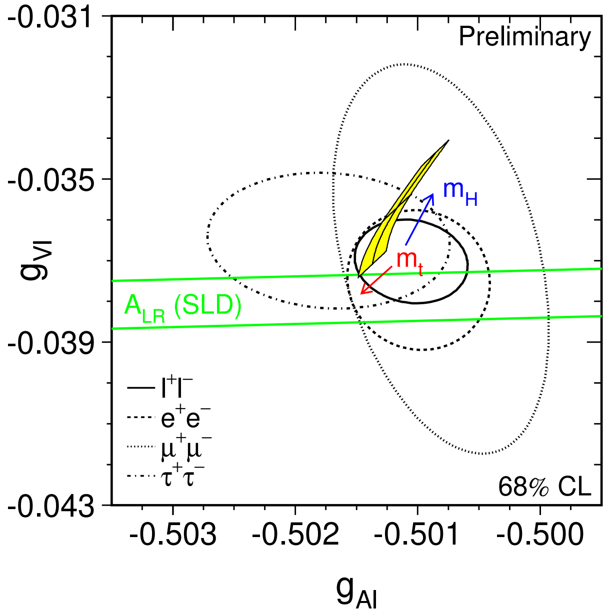

Figure 2: Contours of 68% probability in the $(g_{A\ell}, g_{V\ell})$ plane with and without the assumption of lepton universality derived from LEP data. Also shown is the one standard deviation band resulting from the A_{LR} measurement of SLD. The SM prediction is shown for $M_t = 173.8 \pm 5.0$ GeV and $M_H = 300^{+700}_{-210}$ GeV.

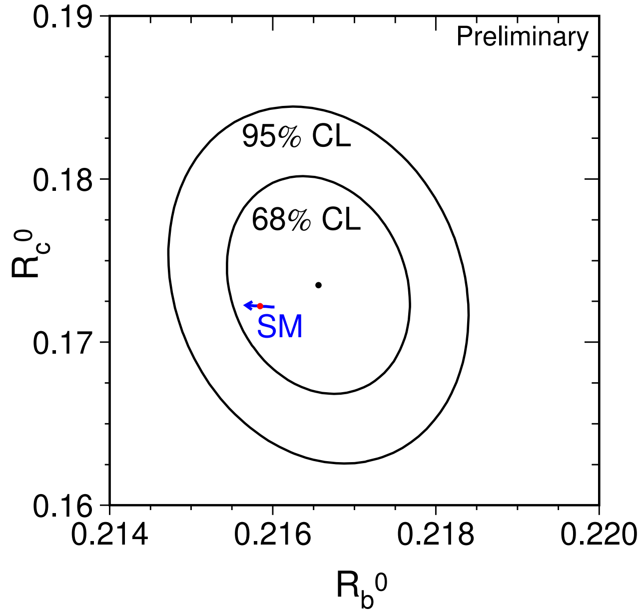

Figure 3: Contours of 68% and 95% probability in the (R_b, R_c) plane. The SM prediction is shown for $M_t = 173.8 \pm 5.0$ GeV.

The sign of A_ℓ fixes the relative sign between $g_{V\ell}$ and $g_{A\ell}$. The absolute sign is fixed by the convention $g_{Ae} < 0$. There is good agreement between the three lepton species, as shown in Figure 2. Assuming lepton universality, the results derived from the LEP and SLD measurements are:

$$g_{V\ell} = -0.03753 \pm 0.00044 \tag{12}$$
$$g_{A\ell} = -0.50102 \pm 0.00030\,. \tag{13}$$

4 Heavy Flavour Results

Tagging of $b\bar{b}$ and $c\bar{c}$ heavy quark production in e^+e^- annihilation allows a determination of the same electroweak parameters as for leptons, in particular: $R_q \equiv \Gamma_q/\Gamma_{had}$,[10] $A_{FB}^{o,q} \equiv \frac{3}{4} A_e A_q$,[11] and for SLD in addition the left-right forward-backward asymmetry $A_{LR/FB}^{o,q} \equiv A_q$,[12] where q stands for the heavy quark flavours b, c. Especially $b\bar{b}$ production is interesting due to special corrections at the γ/Z-$b\bar{b}$ vertex involving the top quark and the W boson.

The averaging of heavy flavour results involves the most complicated procedure.[13] The reasons are that many results have common systematic errors, are dependent on each other and on additional model assumptions, such as decay models for heavy-quark mesons. The experiments agree on a common set of models and range of variation of their parameters. The shifts in the results due to these variations are determined and treated as correlated systematic errors. The dependencies on other electroweak parameters are parametrised explicitly, for example: $R_b^{updated} = R_b^{measured} + a_{R_c} \frac{R_c^{fit} - R_c^{used}}{R_c^{fit}}$. A χ^2 fit is performed, taking into account the explicit dependencies by comparing $R_b^{fit} \leftrightarrow R_b^{updated}$, and the correlated errors due to model parameters in the error matrix.

The results of the combination of the LEP and SLD measurements has a χ^2/dof of 44/75 (99.8%), with:

$$R_b = 0.21656 \pm 0.00074 \tag{14}$$
$$R_c = 0.1735 \pm 0.0044 \tag{15}$$
$$A_{FB}^{o,b} = 0.0990 \pm 0.0021 \tag{16}$$
$$A_{FB}^{o,c} = 0.0709 \pm 0.0044 \tag{17}$$
$$A_b = 0.867 \pm 0.035 \tag{18}$$
$$A_c = 0.647 \pm 0.040\,. \tag{19}$$

The largest correlations appear between R_b and R_c, with -17%, as shown in Figure 3, and between $A_{FB}^{o,b}$ and $A_{FB}^{o,c}$, with $+13\%$. The main reason is $c\bar{c}$ background in the $b\bar{b}$ analyses. Other correlations are smaller than 7%.

5 The Effective Electroweak Mixing Angle

All asymmetries measured at LEP and SLD determine the ratio of $g_{V\ell}$ and $g_{A\ell}$, and thus a single parameter, the effective electroweak mixing angle, $\sin^2\bar{\theta}_W \equiv (1 - g_{V\ell}/g_{A\ell})/4$. The average of all $\sin^2\bar{\theta}_W$ measurements, Figure 4, has a χ^2/dof of 7.8/6 (25%); reduced by 5.0/6

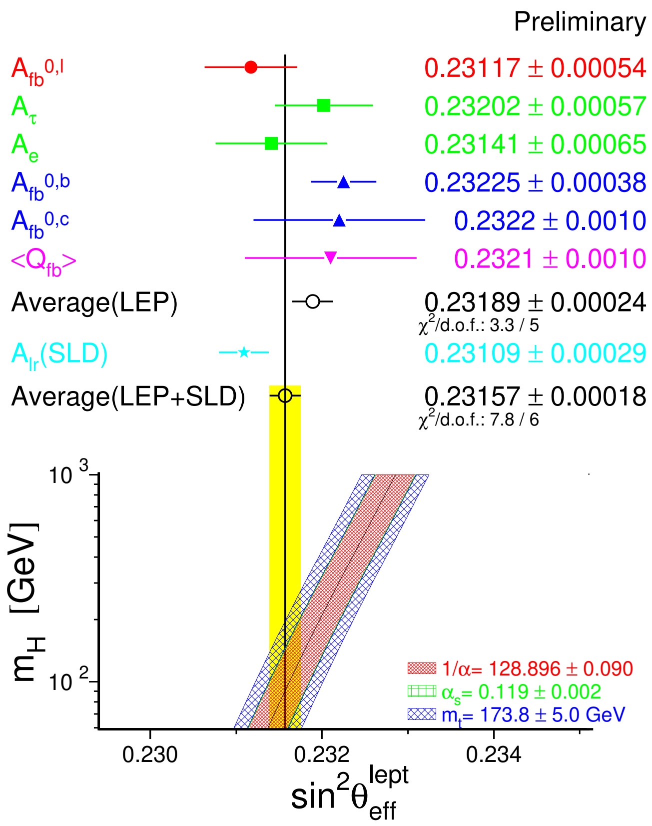

Figure 4: Comparison of several determinations of $\sin^2\bar{\theta}_W$ from asymmetries. Also shown is the prediction of the SM as a function of M_H.

over the last two years.[14] Qualitatively, the situation is as before: the two most precise single determinations of $\sin^2\bar{\theta}_W$, $A_{FB}^{0,b}$ and A_{LR}, are located on opposite sides of the average, which has a value of:

$$\sin^2\bar{\theta}_W = 0.23157 \pm 0.00018\,. \tag{20}$$

6 NUTEV's $\sin^2\theta_W$ Measurement

The CCFR successor experiment NUTEV measures neutrino-nucleon scattering with both a neutrino and an anti-neutrino beam. Thus the Paschos-Wolfenstein relation[15] is applicable, which expresses the neutral and charged current neutrino and anti-neutrino cross sections as a simple function of the electroweak mixing angle $\sin^2\theta_W$. To lowest order:

$$R^- = \frac{\sigma_{NC}^{\nu} - \sigma_{NC}^{\bar{\nu}}}{\sigma_{CC}^{\nu} + \sigma_{CC}^{\bar{\nu}}} = \frac{1}{2} - \sin^2\theta_W \tag{21}$$

Because of accidental cancellations electroweak radiative corrections to R^- are rather small, so that R^- is a measure of the on-shell electroweak mixing angle, $\sin^2\theta_W = 1 - M_W^2/M_Z^2$. The NUTEV result[16] combined with CCFR yields:

$$\sin^2\theta_W = 0.2255 \pm 0.0021 - 0.00142\frac{M_t^2 - (175\text{ GeV})^2}{(100\text{ GeV})^2} + 0.00048\log\frac{M_H}{150\text{ GeV}} \tag{22}$$

Using M_Z from LEP this corresponds to a mass of the W boson of $M_W = 80.25 \pm 0.11$ GeV.

7 Constraints on the Standard Model

The precise electroweak measurements presented above are used to test the SM and constrain its parameters. For this analysis, the relevant SM parameters are the masses M_t, M_Z, M_W, and M_H, and the coupling constants $\alpha_S(M_Z^2)$ and $\alpha(M_Z^2)$. The Fermi constant G_F replaces M_W:

$$\frac{G_F}{\sqrt{2}} = \frac{\pi\alpha(0)}{2}\frac{1}{M_W^2\sin^2\theta_W^2}\frac{1}{1-\Delta r} \tag{23}$$

$$\Delta r = \Delta\alpha - \cot^2\theta_W\Delta\rho + \ldots \tag{24}$$

The Fermi constant G_F is measured precisely in muon decay, $G_F = 1.16639(2)\cdot 10^{-5}\text{ GeV}^{-2}$. Its error is negligible for the SM analysis.

Fermion loops in the photon propagator lead to a running of the electromagnetic fine-structure constant, $1/\alpha(0) = 137.036 \to (1-\Delta\alpha)/\alpha(0) = \alpha(M_Z^2) = 128.896 \pm 0.090$.[17] As there are no precise matrix-element calculations for the hadronic contribution of quark loops, a dispersion integral over the measured hadronic cross section at low $\sqrt{s}$ is performed. The large experimental uncertainties on the hadronic cross section lead to the sizeable error on $\alpha(M_Z^2)$ despite the fact that $\alpha(0)$ is known to much better precision.

The effective coupling constants of the neutral weak current are expressed in terms of the ρ parameter and the effective electroweak mixing angle, $\sin^2\bar{\theta}_W$, as follows:

$$g_{Vf} = T_f^3 - 2q_f\sin^2\bar{\theta}_W \to \sqrt{\rho}(T_f^3 - 2q_f\sin^2\bar{\theta}_W) \tag{25}$$

$$g_{Af} = T_f^3 \to \sqrt{\rho}T_f^3\,, \tag{26}$$

where the electroweak radiative corrections, $\rho = 1/(1-\Delta\rho)$ and $\sin^2\bar{\theta}_W/\sin^2\theta_W = 1 + \cot^2\theta_W\Delta\rho + \ldots$, depend quadratically on M_t and logarithmically on M_H. Thus the measurements have a high sensitivity to M_t and a lower sensitivity to M_H.

The running of α alone is not sufficient to describe the measurements. This is shown in Figure 5 in the plane of the effective electroweak mixing angle and the leptonic partial width of the Z boson, where these quantities are chosen as they are free of QCD effects. A Born type

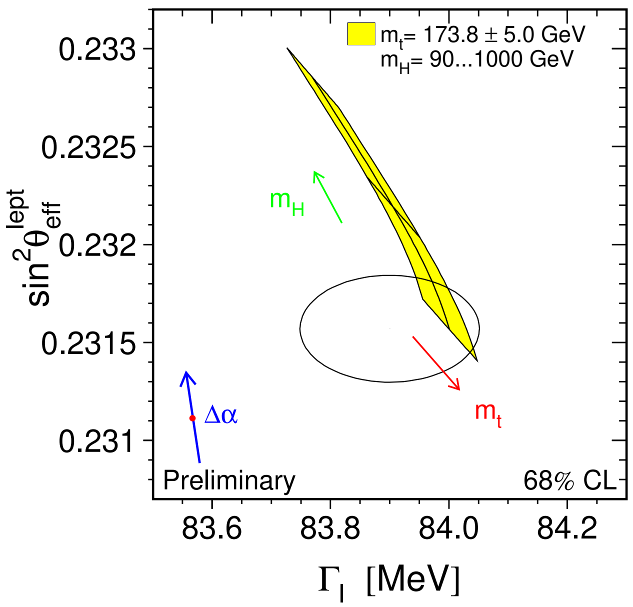

Figure 5: Contour of 68% probability in the $(\Gamma_\ell, \sin^2\bar{\theta}_W)$ plane. The point shows the prediction if among the electroweak radiative corrections only the photonic vacuum polarisation is included. The corresponding arrow shows the variation of this prediction if $1/\alpha(M_Z^2)$ is changed by ± 0.090. This variation gives an additional uncertainty on the SM prediction shown as the dark area.

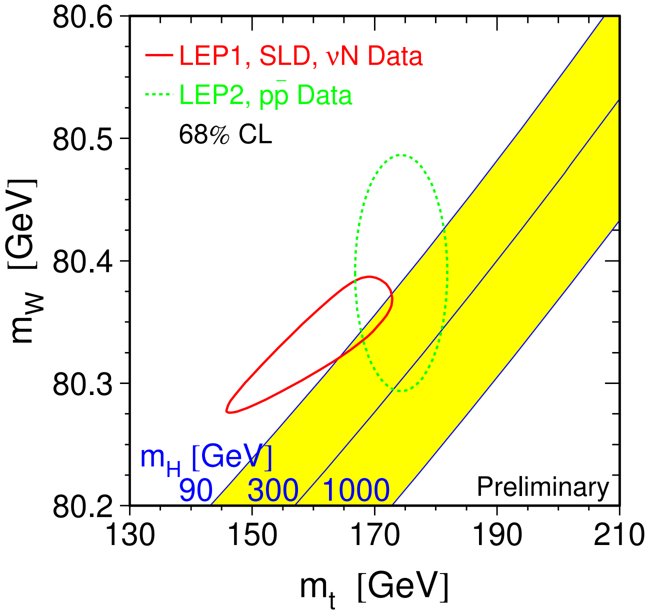

Figure 6: Contours of 68% probability in the (M_t, M_W) plane, derived from the indirect measurements of M_W and M_t (LEP-1, SLD, NUTEV) and the direct measurements (LEP-2 and TEVATRON). Also shown is the SM relationship for the masses as a function of the Higgs mass.

model allowing only for the running of the fine structure constant predicts values for the two parameters which are far away from the actual measurements. Thus also weak corrections, e.g., those depending on M_t and M_H as expected in the SM, are necessary.

The precise electroweak measurements are sensitive to electroweak radiative corrections and are used to predict values for M_W, M_t and M_H, testing the SM and constraining its parameters. Fits to the measurements are performed using the programs[a] TOPAZ0[18] and ZFITTER.[19] They incorporate recent theoretical calculations, *e.g.*, the QED radiator to $\mathcal{O}(\alpha^3)$,[5] four-loop QCD effects,[22] non-factorisable QCD-electroweak corrections,[23] and two-loop subleading $\mathcal{O}(\alpha^2 M_t^2/M_Z^2)$ corrections,[24] resulting in reduced theoretical uncertainties.[25] Good agreement between the implementations of these corrections in the programs is found.[26]

The fit of the SM parameters to the measurements excluding the direct determinations of M_W and M_t has a χ^2/dof of 13/12 (40%), and the results are:

$$M_t = 158.2^{+8.7}_{-8.1}\ \text{GeV} \tag{27}$$

$$\log_{10} M_H = 1.51^{+0.36}_{-0.28} \qquad (M_H = 32^{+41}_{-15}\ \text{GeV}) \tag{28}$$

$$\alpha_S(M_Z^2) = 0.1202 \pm 0.0030\,, \tag{29}$$

where theoretical errors are not included. The result on M_t agrees with the direct determination of M_t at the TEVATRON, $M_t = 173.8 \pm 5.0$ GeV.[27] The predictions of M_W and M_t based on the SM analysis and the results of the direct measurements are compared in Figure 6. Both agree and indicate a slight preference for low Higgs masses. The best M_W prediction is obtained if the direct determination of M_t is included in the SM analysis: $M_W = 80.367 \pm 0.029$ GeV. Also this result compares well with the direct determinations of M_W at the TEVATRON[28] and at LEP-2,[29] $M_W = 80.39 \pm 0.09$ GeV, as shown in Figure 7. Clearly the aim for LEP-2 is to obtain a precision on the direct measurement of M_W matching the accuracy on the SM prediction.

Including the direct determinations of both M_t and M_W, the fit has a χ^2/dof of 15/15 (46%). The results are:

$$M_t = 171.1^{+4.9}_{-4.8}\ \text{GeV} \tag{30}$$

$$\log_{10} M_H = 1.88^{+0.33}_{-0.41} \qquad (M_H = 76^{+85}_{-47}\ \text{GeV}) \tag{31}$$

$$\alpha_S(M_Z^2) = 0.1194 \pm 0.0029\,, \tag{32}$$

where theoretical errors are not included. The following quantities are derived: $\sin^2\bar{\theta}_W = 0.23157 \pm 0.00019$, $\sin^2\theta_W = 0.22315 \pm 0.00051$, $M_W = 80.371 \pm 0.026$ GeV.

A large correlation of 77% between $1/\alpha(M_Z^2)$ and M_H appears. Recently there have been several new

[a] TOPAZ0 and ZFITTER expect as input $\alpha^{(5)}(M_Z)$, *i.e.*, without the top-quark contribution to $\Delta\alpha$. The value of $\alpha^{(5)}(M_Z)$ is calculated based on the 5-flavour hadronic contribution[17,20] and the newly calculated leptonic contribution[21] to $\Delta\alpha$.

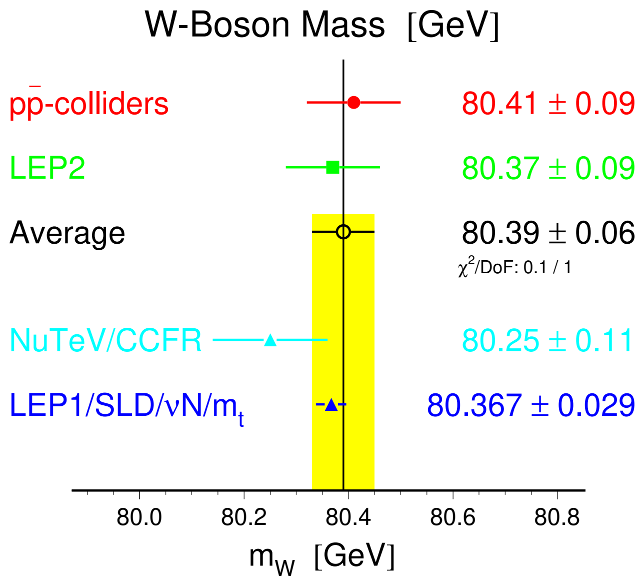

Figure 7: Summary of M_W determinations.

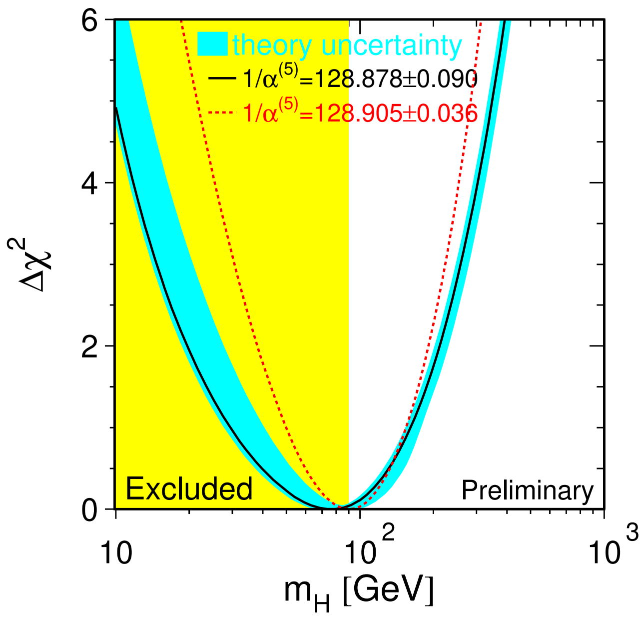

Figure 8: $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ as a function of the Higgs mass, M_H. The width of the band represents an estimate of the theoretical error due to missing higher order corrections. The vertical band shows the 95% CL exclusion limit on M_H from the direct search.[33]

evaluations[20,30,31] of $\alpha(M_Z^2)$, leading to a theory driven error reduction. As an experimental cross check, more precise measurements of the hadronic cross section in the energy range of $\sqrt{s} = 1 - 7$ GeV are needed.[32] With $1/\alpha(M_Z^2) = 128.923 \pm 0.036$[20] instead, $\log_{10} M_H = 1.96^{+0.23}_{-0.26}$ or $M_H = 91^{+64}_{-41}$ GeV, and the correlation between M_H and $1/\alpha(M_Z^2)$ is reduced to 39%.

The $\Delta\chi^2$ curve as a function of the Higgs mass is shown in Figure 8. The impact of a more precise determination of $\alpha(M_Z^2)$ with an error reduced by a factor of three is clearly visible. The width of the band shows the theoretical uncertainty in the SM analysis due to missing higher-order radiative corrections, amounting to about ± 0.05 on the central value of $\log_{10} M_H$. Because of the new theoretical calculations, this uncertainty is reduced as compared to the situation of two years ago.[14] Including the uncertainty, the 95% confidence level upper limit on the Higgs boson mass is 262 GeV.

The measurements all are in good agreement with the SM, as indicated by the pulls shown in Figure 9. Currently no measurement deviates from the SM fit by more than two standard deviations. The largest deviation is seen for the b quark asymmetries $A_{FB}^{o,b}$ and A_b. The mutual consistency of these measurements and A_ℓ is shown in Figure 10. The experimental errors on A_b (and A_c) based on measurements of the forward-backward left-right asymmetry are large compared to the variations due to electroweak radiative corrections of the SM.

In the future, one hopes to reduce the errors on $1/\alpha(M_Z^2)$ to 0.01, and on the direct measurements of M_W and M_t to 30 MeV and 2 GeV. This will decrease the error on the prediction of $\log_{10} M_H$ by a factor of 2.5.

8 Conclusion

The experiments at LEP and at the TEVATRON as well as SLD and NUTEV provide many precision results on the electroweak interaction. The Standard Model describes successfully all these measurements. Analyses of radiative corrections lead to predictions of M_t and M_W which agree well with the direct measurements. The prediction of the Higgs boson mass is selfconsistent within the Standard Model, and $M_H < 262$ GeV at 95% CL.

Many results entering the averages are still preliminary. Final results from LEP-1, SLD and NUTEV will soon become available. Further improvements are expected in the measurements of M_W and M_t at LEP-2 and from the TEVATRON Run II. The discovery of the Higgs boson will allow another test of the predictive power of the Standard Model.

Acknowledgements

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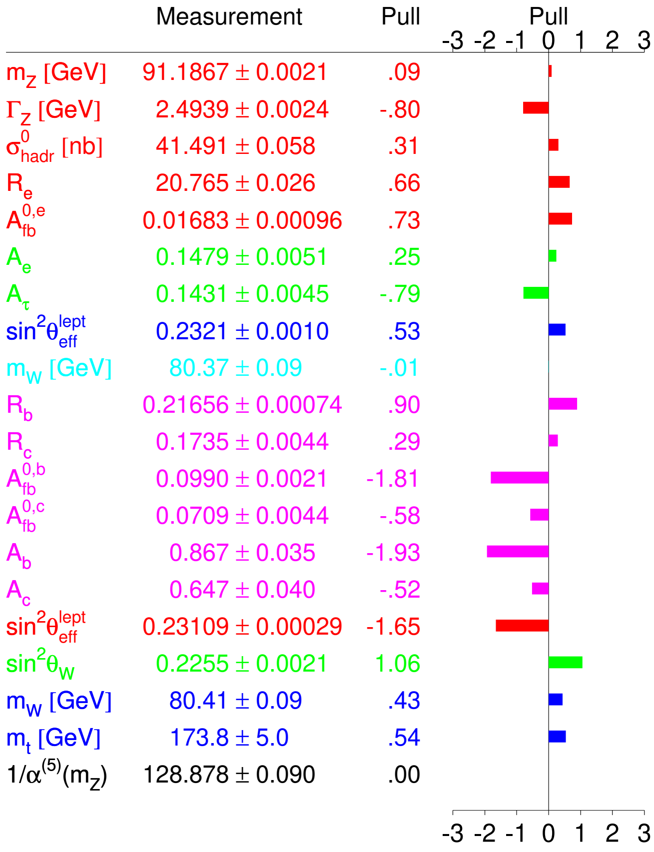

Figure 9: Pulls of the measurements of the electroweak parameters with respect to the fit including the direct determinations of M_W and M_t. The pull is defined as the difference of the measurement to the SM prediction divided by the measurement error.

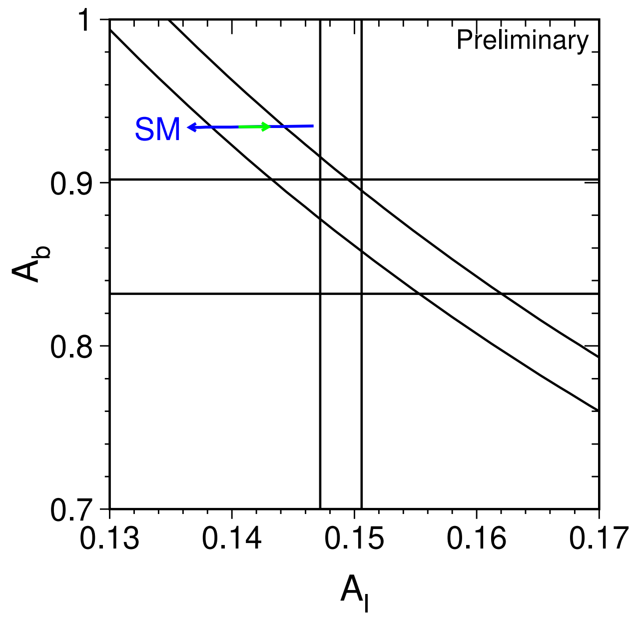

Figure 10: Bands of ± 1-sigma width in the (A_ℓ, A_b) plane, showing the results on A_ℓ (Eq. 11, vertical band), A_b (Eq. 18, horizontal band) and $A^{o,b}_{FB} = \frac{3}{4} A_e A_b$ (Eq. 16, diagonal band). The SM prediction is shown for $M_t = 173.8 \pm 5.0$ GeV and $M_H = 300^{+700}_{-210}$ GeV.

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