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LEP ELECTROWEAK PHYSICS RESULTS*

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The precise electroweak measurements obtained from LEP and SLD Z data are presented. Since 1996 LEP has been running above the W pair threshold, and results on the mass and couplings of the W boson are also given. The LEP results are combined with the SLD, Tevatron and ν-nucleon results to infer the mass of the Higgs boson. This is especially interesting in light of recent improvements in the calculation of the radiative corrections.

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1. Introduction

In this review, physics results on three fundamental bosons: the Z boson, the W boson, and the as-yet-undiscovered Higgs boson, are presented. The results on the Z are derived from measurements of the cross-section as a function of center-of-mass energy (the "Z-lineshape"), the forward-backward asymmetries, tau polarization, and heavy flavor properties. An important measurement of the left-right asymmetry is provided by SLD.

The properties of W bosons are now also measured by LEP experiments, as LEP has been running above the W pair production threshold since 1996. The direct measurement of the W mass at LEP is now as precise as that from the $p\overline{p}$ collider experiments. LEP also provides several measurements of the W coupling constants.

Through the effects of radiative corrections, these measurements can be used to infer the mass of the Higgs boson in the framework of the Standard Model. In this context, results on the top quark mass from the Tevatron experiments and on the weak mixing angle, $\sin^2\theta_{\mathrm{W}}$, from neutrino-nucleon experiments are used as additional constraints.

The results presented here are those presented at the Moriond 1998 conferences. Most are still preliminary.

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2. The Z boson

The measurements performed using Z decays can be roughly divided into two classes: cross-sections and asymmetries.

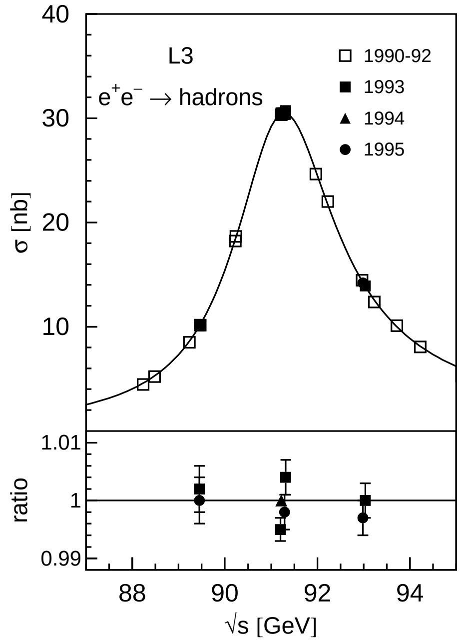

Fig. 1. The hadronic cross-section as a function of center-of-mass energy as measured by L3. The curve is the Standard Model fit to the data points. As the errors are very small, the ratio of the data to the fit is shown below on an expanded scale.

As an example of a cross-section measurement, Fig. 1 shows the hadronic cross-section as a function of the center-of-mass energy. The cross-section is essentially the Breit–Wigner of the Z pole convoluted with initial-state radiation (as well as interference between Z and photon exchange). From the full set of LEP data [1–4] (14.8 million hadronic and 1.6 million leptonic Z decays), the following have been determined:

$$m_{\mathrm{Z}} = 91.1867 \pm 0.0020 \text{ GeV}, \tag{1a}$$
$$\mathit{\Gamma}_{\mathrm{Z}} = 2.4948 \pm 0.0025 \text{ GeV}, \tag{1b}$$
$$\sigma_{\mathrm{h}}^0 = 41.486 \pm 0.053 \text{ nb}, \tag{1c}$$
$$R_\ell = 20.775 \pm 0.027. \tag{1d}$$

The mass and the width are those based on a running-width Breit-Wigner denominator $(s - m_{\mathrm{Z}}^2 + is\mathit{\Gamma}_{\mathrm{Z}}/m_{\mathrm{Z}})$ [5]. The hadronic pole cross-section is defined as $\sigma_{\rm h}^0 \equiv \frac{12\pi}{m_{\rm Z}^2}\frac{\Gamma_{\rm ee}\Gamma_{\rm had}}{\Gamma_{\rm Z}^2}$, where $\Gamma_{\rm ee}$ and $\Gamma_{\rm had}$ are the partial widths of the Z into electrons and hadrons. The ratio $R_\ell \equiv \Gamma_{\rm had}/\Gamma_{\ell\ell}$ is the ratio of the partial widths into hadrons and a pair of massless leptons, and is derived assuming lepton universality. This set of parameters was chosen to minimize the experimental correlations.

The other class of Z measurements are the asymmetries. The forward-backward asymmetry is defined as $A_{\rm FB} = \frac{\sigma_F - \sigma_B}{\sigma_{\rm tot}}$ where σ_F and σ_B are the cross-sections for events with the out-going fermion going in the direction of the incoming electron or positron, respectively. The asymmetries are corrected for effects of initial-state radiation, and, in the case of electron final states, for t-channel exchange and s-t interference. The resulting pole asymmetries, $A_{\rm FB}^{0,\,{\rm f}}$ can be expressed in terms of the vector and axial-vector coupling constants:

$$A_{\rm FB}^{0,\,{\rm f}} = \frac{3}{4}\mathcal{A}_{\rm e}\mathcal{A}_{\rm f}; \tag{2a}$$

$$\mathcal{A}_{\rm f} = \frac{2g_{V{\rm f}}g_{A{\rm f}}}{g_{V{\rm f}}^2 + g_{A{\rm f}}^2}. \tag{2b}$$

From these coupling constants, the effective weak mixing angle is defined:

$$\sin^2\theta_{\rm eff}^{\rm lept} = \frac{1}{4}(1 - g_{V\ell}/g_{A\ell}). \tag{3}$$

Parity violation both in the production of Z bosons as well as in their decay produces polarized final states even if the incoming electron and positrons are unpolarized. At LEP, only the $\tau^+\tau^-$ final states can be analyzed, using the tau decay products as a polarimeter. The angular dependence of the polarization is given by

$$\mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_{\rm e}\cos\theta}{1+\cos^2\theta + 2\mathcal{A}_\tau\mathcal{A}_{\rm e}\cos\theta}, \tag{4}$$

where θ is the tau production angle. From a measurement of the tau polarization, $\mathcal{A}_\tau$ and $\mathcal{A}_{\rm e}$ can be independently determined. In addition, as the measurement is linear in $\mathcal{A}_\tau$ and $\mathcal{A}_{\rm e}$, the relative sign of $g_{A\ell}$ and $g_{V\ell}$ can also be determined. An example of a measurement is shown in Fig. 2.

A very similar physics result has been obtained by the SLD collaboration at the SLC [6]. In their case, the incoming electron beam is given either right- or left-handed polarization. A straight-forward measurement of the hadronic cross-section for right and left polarized electrons is then used to determine $\mathcal{A}_{\rm e}$:

$$A_{\rm LR} = \frac{1}{\mathcal{P}_{\rm e}}\frac{\sigma_L - \sigma_R}{\sigma_{\rm tot}} = \mathcal{A}_{\rm e}. \tag{5}$$

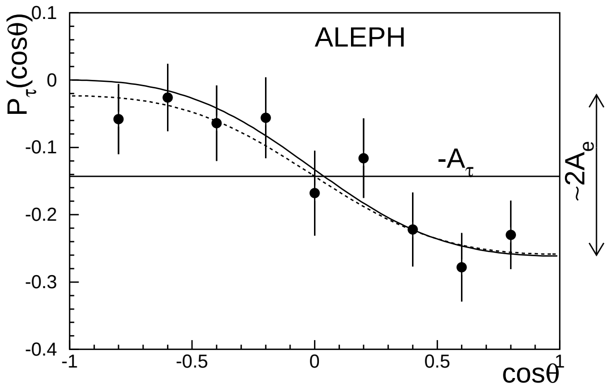

Fig. 2. The measurement of the tau polarization as a function of the tau production angle by the ALEPH collaboration. As can be seen, the average yields information on $\mathcal{A}_\tau$, whereas the forward-backward asymmetry depends on $\mathcal{A}_{\rm e}$.

The physics is the same as in tau polarization. However, at SLC the electron beam is polarized to 77%, whereas the natural polarization of Z decays is only 14%.

Using the results of the lepton asymmetries, the tau polarization, the $A_{\rm LR}$ measurement, and the determinations of $\Gamma_{\ell\ell}$, the values of the vector and axial-vector coupling constants for leptons can be extracted ($\Gamma_{\ell\ell} \propto g_{V\ell}^2 + g_{A\ell}^2$). The result, assuming lepton universality, is:

$$g_{V\ell} = -0.03770 \pm 0.00053, \tag{6a}$$
$$g_{A\ell} = -0.50104 \pm 0.00031. \tag{6b}$$

This is shown graphically in Fig. 3. As can be seen from the Figure, the latest SLD results are in much better agreement with the LEP results than they were last summer [7].

The analysis of hadronic final states containing heavy quarks, especially b quarks, also yields important information. Because of the large t-b mass splitting, the decay $\rm Z \to b\overline{b}$ has large vertex corrections involving loops with t quarks. The ratio $R_{\rm b} \equiv \Gamma_{\rm b\bar{b}}/\Gamma_{\rm had}$ therefore has a unique sensitivity to $m_{\rm t}$. In addition, because the b quark has charge 1/3, the forward-backward $\rm b\overline{b}$ asymmetry is very sensitive to $\mathcal{A}_{\rm e}$, and thus $\sin^2\theta_{\rm eff}^{\rm lept}$.

A couple of years ago, the measurement of $R_{\rm b}$ was the cause of some concern, as it was several standard deviations away from its Standard Model prediction. However, with the addition of significantly more data, greatly improved analysis techniques, and some new measurements of auxiliary branching ratios, the situation has changed considerably. This is shown in Fig. 4, which shows the evolution of the measurements over the past 3 years.

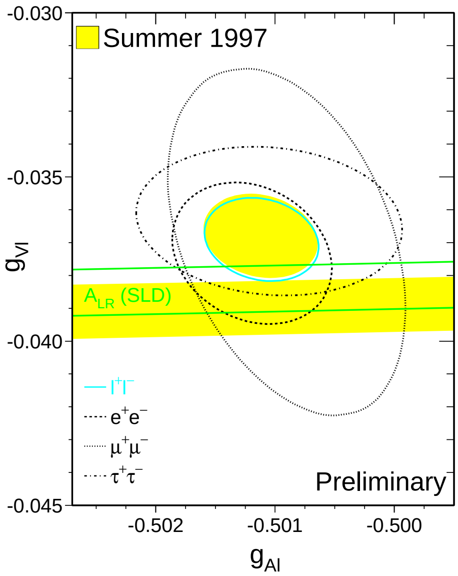

Fig. 3. The 68% contours in the $g_{V\ell}$, $g_{A\ell}$ plane. The shaded areas represent the results from the Summer 1997 conferences, and the open areas the latest results. The solid ellipses are for the assumption of lepton universality.

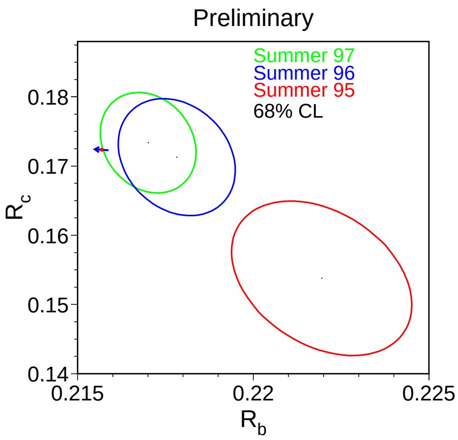

Fig. 4. The 68% contours for the measurements of $R_{\rm b}$ and $R_{\rm c}$. The arrow represents the Standard Model prediction for a top quark mass of 175 ± 5 GeV.

The summary of all the asymmetry results from the Z data, interpreted in terms of $\sin^2\theta_{\rm eff}^{\rm lept}$ is shown in Fig. 5. Also here there has been a significant change since last year. The χ^2 per degree of freedom for the average is 8.6/6. Last summer it was 12.5/6. The major differences are from $A_{\rm FB}^{0,\,\rm b}$ which moved down by about 0.6 standard deviations due to a new result by

ALEPH, and A_{LR}, which has moved up by about 0.7 standard deviations due to the new 1997 SLD data. Although the LEP and SLD results still disagree by 2.3 standard deviations, the situation is considerably improved compared to previous years.

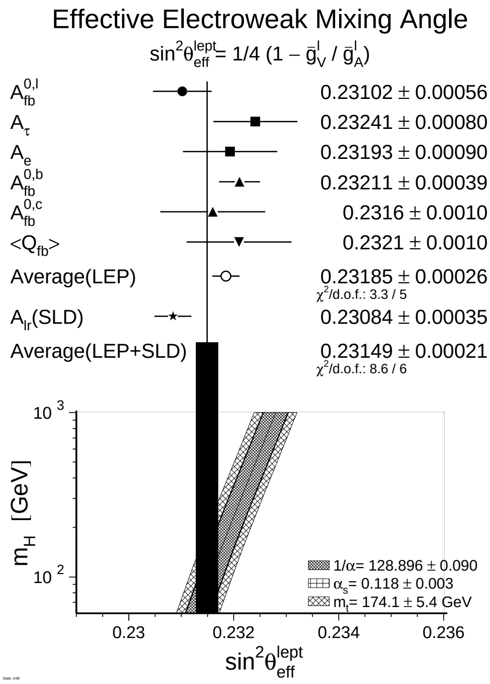

Fig. 5. The measurement of $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ from asymmetry measurements at LEP and SLD.

3. The W Boson

Since 1996, LEP has been running at energies in excess of 160 GeV, *i.e.*, above the threshold for the production of a pair of W bosons. We have thus moved from the Z physics era to the W physics era.

The W properties which have been measured to date include the decay branching ratios, the mass, and the W couplings to the Z and photon (triple gauge boson couplings, or TGC for short).

The W-pair production cross-section has been measured now at three different energies: 161.3 GeV and 172.1 GeV in 1996 and at 182.7 GeV in 1997. The cross-sections from the combination of the four LEP experiments is shown in Fig. 6. The measurement of the cross-section serves two different purposes. Near threshold (161 GeV) the cross-section depends strongly on the W mass, and the first measurement of the mass at LEP resulted from the cross-section measurement. Above the threshold, the cross-section depends on the values of the TGC's. This is shown in Fig. 6, where the dashed and dotted lines are for "extreme" values of the couplings, *i.e.*, for the case of no ZWW coupling, and for the case where only the *t*-channel neutrino exchange takes place. As can be seen from this figure, the Standard Model describes the data very well (as usual!).

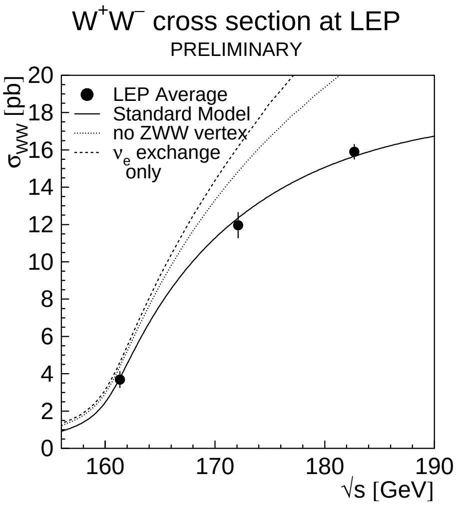

Fig. 6. The W^+W^- production cross-section as a function of center-of-mass energy.

TABLE I

The measurements of the W decay branching ratios in percent (results are preliminary) [8–11]. The hadronic branching ratio is determined assuming lepton universality. There are large correlations between the individual leptonic branching ratios, which have been taken into account in determining the hadronic branching ratio.

Experiment	Br(W→eν)	Br(W→ $\mu\nu$)	Br(W→ $\tau\nu$)	Br(W→hadrons)
ALEPH	$11.2 \pm 0.8 \pm 0.3$	$9.9 \pm 0.8 \pm 0.2$	$9.7 \pm 1.0 \pm 0.3$	$69.0 \pm 1.2 \pm 0.6$
DELPHI	$9.9 \pm 1.1 \pm 0.5$	$11.4 \pm 1.1 \pm 0.5$	$11.2 \pm 1.7 \pm 0.7$	$67.5 \pm 1.5 \pm 0.9$
L3	$10.7 \pm 0.9 \pm 0.2$	$10.3 \pm 0.9 \pm 0.2$	$9.2 \pm 1.2 \pm 0.3$	$69.5 \pm 1.3 \pm 0.4$
OPAL	$11.7 \pm 0.9 \pm 0.3$	$10.1 \pm 0.8 \pm 0.3$	$10.3 \pm 1.0 \pm 0.3$	$67.9 \pm 1.2 \pm 0.6$
LEP Average	11.0 ± 0.5	10.3 ± 0.5	10.0 ± 0.6	68.6 ± 0.8

From the measurements of the total WW production cross-section, along with the measurements of specific channels, *e.g.*, $e^+e^- \to W^+W^- \to q\bar{q}\mu\nu$, the W branching ratios can be determined. The ratios for the individual lepton species are shown in Table I, as well as the hadronic branching ratio assuming lepton universality. It should be noted that the branching ratios are not independent: there is about 25% anti-correlation between the tau branching ratio and those of the other two leptons, and the hadronic branching ratio is 100% anti-correlated with the leptonic average. The measurements are in very good agreement with the Standard Model expectations of 10.8% per lepton species and 67.6% for the hadronic channel.

The measurements of the total and differential cross-sections have also been used to determine the TGC's, typically in terms of anomalous couplings which are zero in the Standard Model. The most general Lorentz invariant Lagrangian which describes the triple boson interaction vertex has fourteen independent terms, seven describing the WWγ vertex and seven describing the WWZ vertex [12–17]. As this set is rather large to be measured simultaneously, models which reduce the number of free parameters by making additional assumptions have been considered. A common assumption is to consider only CP-conserving operators which neither affect the gauge-boson propagators at tree-level, nor generate anomalous Higgs couplings. In this case, there are operators that give rise to C- and P-conserving couplings, with deviations from the Standard Model denoted by $\alpha_{W\phi}$, α_W and $\alpha_{B\phi}$ [17]. These can also be expressed in a somewhat more familiar form:

$$\alpha_{W\phi} \equiv \delta_{\mathrm{Z}} \cos\theta_{\mathrm{W}} \sin\theta_{\mathrm{W}}, \tag{7a}$$

$$\alpha_W \equiv \lambda_\gamma, \tag{7b}$$

$$\alpha_{B\phi} \equiv \Delta\kappa_\gamma - \delta_{\mathrm{Z}} \cos\theta_{\mathrm{W}} \sin\theta_{\mathrm{W}}, \tag{7c}$$

where δ_{Z} is the deviation of the ZWW coupling from its Standard Model value of $\cot\theta_{\mathrm{W}}$, and $\Delta\kappa_\gamma$ and λ_γ parameterize the deviations of the W magnetic dipole and electric quadrupole moments: $\mu_{\mathrm{W}} = \frac{e}{2m_{\mathrm{W}}}(2+\Delta\kappa_\gamma+\lambda_\gamma)$ and $Q_{\mathrm{W}} = -\frac{e}{m_{\mathrm{W}}^2}(1+\Delta\kappa_\gamma-\lambda_\gamma)$. The results are shown in Fig. 7 for the α set, where not only the LEP results, but also results from the D0 Collaboration, have been combined. In no case is the Standard Model value of 0 excluded.

The W mass has been measured at LEP using two different methods. The first, mentioned earlier, was performed by measuring the production cross-section at 161.33 GeV. From the LEP average of the cross-section, 3.69 ± 0.45 pb, the mass was determined to be 80.40 ± 0.22 GeV.

The more interesting, and more model-independent, method is from the direct reconstruction of the W decay products [8–11]. Here, the masses of the two W bosons are reconstructed from their decay products. There are two general classes of events that are used: those where both W's decay hadronically ($\mathrm{q\bar{q}q\bar{q}}$) and those where one W decays hadronically and one

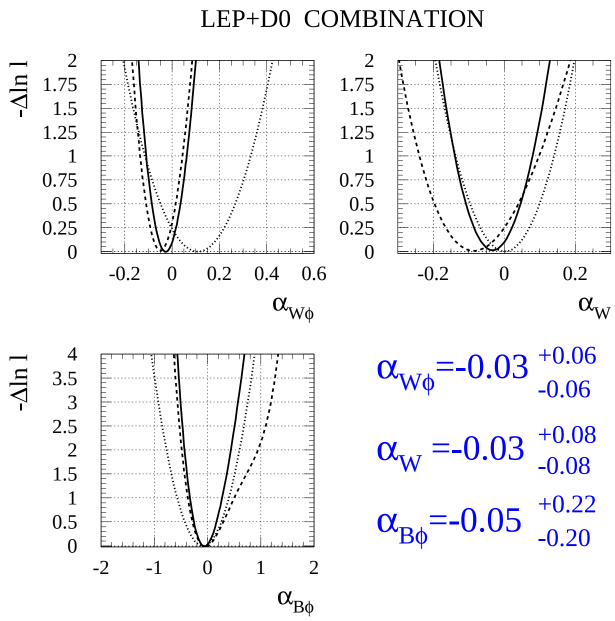

Fig. 7. The log-likelihood curves for the combination (solid lines) of the LEP (dashed lines) and D0 (dotted lines) results on $\alpha_{W\phi}$, α_W and $\alpha_{B\phi}$ [18–22].

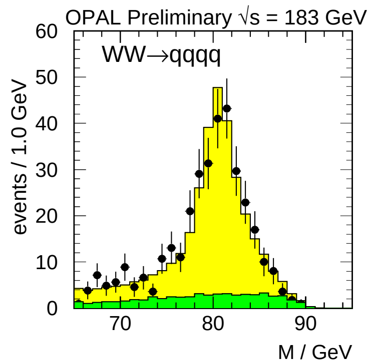

Fig. 8. The reconstructed mass distribution for $q\overline{q}q\overline{q}$ events from the OPAL Collaboration.

leptonically ($q\overline{q}\ell\nu$). The third category, fully leptonic events are not used because the two neutrinos carry away too much information. For both event classes, a kinematic fit is used to improve the resolution on the mass. Also, typically an equal mass constraint is used, so that there is only one mass reconstructed per event. An example of a mass distribution is shown in Fig. 8.

TABLE II

Summary of the W mass measurements by direct reconstruction in the semi-leptonic and hadronic channels. The χ^2/d.o.f. for the combinations is 1.7/3 and 5.9/3, respectively.

Experiment	m_{W} (GeV) $\mathrm{q\overline{q}}\ell\nu$	m_{W} (GeV) $\mathrm{q\overline{q}q\overline{q}}$
ALEPH (prel.)	80.20 ± 0.20	80.57 ± 0.21
DELPHI (prel.)	80.50 ± 0.24	80.01 ± 0.22
L3 (prel.)	80.09 ± 0.24	80.59 ± 0.23
OPAL (prel.)	80.29 ± 0.19	80.40 ± 0.24
LEP Average	80.27 ± 0.11	80.40 ± 0.15

The results from the 172 and 183 GeV data is shown in Table II. The four LEP experiments are in excellent agreement with each other. In addition, the masses measured in the $\mathrm{q\overline{q}q\overline{q}}$ channel and the $\mathrm{q\overline{q}}\ell\nu$ channel agree very well. Of course, in principle, they should agree; however final state interaction in the fully hadronic final state (Bose-Einstein correlations and "color-reconnection") could cause a flow of energy between the two W bosons, and could thus affect the reconstructed mass. Although no indication of a mass shift has been observed, 100 MeV has been assigned as systematic error on the $\mathrm{q\overline{q}q\overline{q}}$ channel. Including this error, the combined W mass result from the LEP results (including also the cross-section measurements) is

$$m_{\mathrm{W}} = 80.35 \pm 0.09 \mathrm{GeV}. \tag{8}$$

4. The Higgs Boson

Via radiative corrections, particles that are not produced at LEP energies can nevertheless make their presence be felt. Within the framework of the Standard Model, the two most important are the top quark and the Higgs Boson. For most processes, the leading dependence of the radiative corrections is quadratic in the top quark mass and logarithmic in the Higgs mass. One exception is the quantity R_{b}, which due to cancellations has almost no dependence on the Higgs mass. A careful comparison of the theory with the measurements can thus yield interesting information about the structure of the radiative corrections as well as the mass of the Higgs boson. This is especially true since the discovery of the top quark at the Tevatron.

The measurements used in the following Standard Model fits are shown in Table III. In addition to the measurements at LEP and SLD, measurements

TABLE III

The experimental input values to the Standard Model fits. Note that many of the results are correlated. Although not shown in the table, the correlation matrices, where appropriate, have been used in the fits. The numbers in brackets give the error in the last digits.

$G_{\rm F}$	$1.16639(2) \times 10^{-5}$	$\sin^2\theta_{\rm eff}^{\rm lept}$ $A_{\rm LR}$	0.23084(35)
$\alpha(m_{\rm Z}^2)^{-1}$	1.2896(90)	$R_{\rm b}^0$	0.2173(9)
$m_{\rm Z}$ (GeV)	91.1687(20)	$R_{\rm c}^0$	0.1731(44)
$\Gamma_{\rm Z}$ (GeV)	2.4948(25)	$A_{\rm FB}^{0,\,\rm b}$	0.0998(22)
$\sigma_{\rm h}^0$ (pb)	41.486(53)	$A_{\rm FB}^{0,\,\rm c}$	0.0735(45)
R_ℓ	20.775(27)	$\mathcal{A}_{\rm b}$	0.899(49)
$A_{\rm FB}^{0,\,\ell}$	0.0171(10)	$\mathcal{A}_{\rm c}$	0.660(45)
$\mathcal{A}_\tau$	0.1400(63)	$\sin^2\theta_{\rm W}$ νN	0.2198(21)
$\mathcal{A}_{\rm e}$	0.1438(71)	$m_{\rm W}$ (GeV) $\rm p\overline{p}$	80.40(9)
$\sin^2\theta_{\rm eff}^{\rm lept}$ $Q_{\rm FB}$	0.2321(10)	$m_{\rm t}$ (GeV) $\rm p\overline{p}$	174.1(5.4)
$m_{\rm W}$ (GeV) LEP	80.35(9)		

of $G_{\rm F}$ from muon decay, $m_{\rm t}$ [23] and $m_{\rm W}$ [24] from $\rm p\overline{p}$ colliders, $\sin^2\theta_{\rm W}$ from neutrino-nucleon experiments [25], and the determination of $\alpha(m_{\rm Z}^2)$ [26] from low energy $\rm e^+e^-$ interactions are also used. The main differences between now and the Summer 1997 Conferences on the experimental side are:

- As mentioned earlier, both the value of $\sin^2\theta_{\rm eff}^{\rm lept}$ from the SLD $A_{\rm LR}$ measurement and the value of the $\rm b\overline{b}$ asymmetry have increased. The net effect is that the value of $\sin^2\theta_{\rm eff}^{\rm lept}$ is essentially unchanged; however, the χ^2 of the fit improves significantly.
- The error on the LEP value for $m_{\rm W}$ is significantly smaller due to the 183 GeV data. It is now the same size as the Tevatron result.
- Both the error and the central value of the $\sin^2\theta_{\rm W}$ result from the νN experiments (dominated by NuTeV) are smaller[1].

On the theoretical side, there have also been significant improvements. Although many of the new calculations have been available for a while, they have only recently been incorporated into the analytical programs that the experimentalists use to perform the fits, *e.g.*, the ZFITTER and TOPAZ0 packages. The most important of the corrections are the $\mathcal{O}(g^4 m_{\rm t}^2/MW^2)$ corrections [27], which reduce the theoretical uncertainty on the prediction

[1] Since the time of the conference, a mistake was discovered in the result. The central value changed from 0.2198 to 0.2255. However, this has only a small effect on the final results.

of the Higgs mass (and at the same time reduce the predicted mass!). The other important contribution is the nonfactorizable QCD-EW corrections [28] which have the effect of increasing $\alpha_s(m_Z^2)$ by about 0.001.

In addition, there have been several recent evaluations of $\alpha(m_Z^2)$ [29–31], which are somewhat more theoretically motivated than the evaluation currently used. Because of this, the error is significantly reduced. As the error on $\alpha(m_Z^2)$ is one of the dominant sources of uncertainty on the Higgs mass, the use of the newer evaluations significantly improves any limit on the Higgs mass. The fits shown here use the more model-independent result given in Table III; however, the effects of using the value of $\alpha(m_Z^2)^{-1} = 128.923 \pm 0.036$ [30] are also shown.

In the Standard Model, relations exist between all masses. Thus, in addition to extracting limits on the Higgs mass, one can test the consistency of the Standard Model. As an example, indirect measurements of m_t and m_W using all the data except the direct LEP and $p\bar{p}$ measurements can made. The results are

$$m_t = 161^{+9}_{-8} \text{ GeV} \tag{9a}$$
$$m_W = 80.351 \pm 0.040 \text{ GeV}, \tag{9b}$$

which can be compared with the direct measurements of $m_t = 174.1 \pm 5.4$ GeV and $m_W = 80.375 \pm 0.064$ GeV. This is also shown in Fig. 9 where the 68% confidence level contours are given.

As can be seen, the agreement is very good.

Now that the consistency of the data has been checked we can go the next step to investigate the limits on the Higgs mass. In the final fit, all of the data are fit to the Standard Model expectations. This results in

$$m_t = 171.1 \pm 5.1 \text{ GeV} \tag{10a}$$
$$m_H = 66^{+74}_{-39} \text{ GeV}, \tag{10b}$$
$$\alpha_s(m_Z^2) = 0.120 \pm 0.003. \tag{10c}$$

The χ^2/d.o.f. is a very good 16/15. As pointed out earlier, the dominant Higgs mass dependency is logarithmic, so some care must be taken in interpreting the Higgs mass result.

In order to extract the mass limit, we plot the $\Delta\chi^2$ of the fit as a function of the Higgs mass. This is shown in Fig. 10. In this rather busy figure, there are several things that can be noticed:

- the fits using ZFITTER (solid curve) and TOPAZ0 (dashed curve) agree very well with each other, especially at high Higgs masses. However, this should be considered a test of the technical precision of the two programs, rather than an estimation of the theoretical uncertainty.

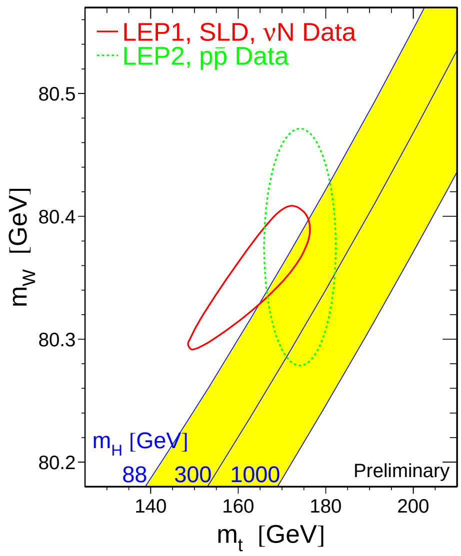

Fig. 9. The 68% C.L. contours for the indirect measurements of $m_{\rm W}$ and $m_{\rm t}$ (solid curve) and the direct measurements (dashed curve). The shaded band shows the Standard Model prediction as a function of the Higgs mass.

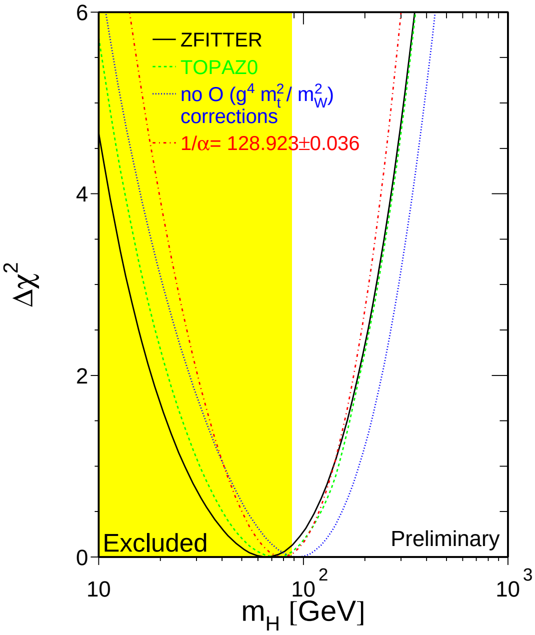

Fig. 10. The $\Delta\chi^2$ curve of the Standard Model fit to the data. See the text for a discussion of the four different curves.

- The prediction using the new radiative corrections gives a much smaller Higgs mass than the previous prediction (dotted curve).
- The error on $\alpha(m_{\rm Z}^2)$ gives an important contribution to the mass limit, as can be seen if a value with a smaller error is used (dashed-dotted curve).
- The central value for the Higgs mass is excluded by the latest LEP search limits ($m_{\rm H} > 88$GeV) [32].

The 95% C.L. lower limit on the Higgs mass is 215 GeV. This does not take into consideration the direct search limit.

I would like to thank the organizers for a very well run conference. This talk would not have been possible without the support and contributions from my colleagues and friends in the LEP experiments and in the LEP Electroweak Working Group.

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