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15: Tests of the Standard Model: W mass and WWZ Couplings

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Abstract. Recent tests of the electroweak Standard Model are reviewed, covering the precise measurements of Z decays at LEP I and SLC and measurements of fermion pair production at higher energies at LEP II. Special emphasis is given to new results on W physics from LEP and FNAL.

1 Precision measurements of the Z boson

1.1 Lineshape and leptonic forward-backward asymmetries

The accurate measurement of the Z mass is essential for precise tests of the Standard Model. This measurement is dominated by the energy scans performed at LEP in 1993 and 1995, in which approximately 40 pb^{-1} of data were recorded at energies $\pm 1.8 \text{ GeV}$ away from the Z peak. Important progress has been made in the last year in understanding the LEP beam energy for these scans, and final results became available shortly before the conference. The estimated errors on the centre-of-mass energy (in MeV) are:

	peak-2	peak	peak+2
1993	3.5	6.7	3.0
1994		3.7	
1995	1.8	5.4	1.7

The path is now clear for the LEP experiments to complete their analyses of the data. The principal changes to the results compared to those presented in 1996 [1, 2] are (see [3] for more details):

- The new beam energy values have already been incorporated by ALEPH and DELPHI; OPAL and L3 have chosen not to update their results at this stage, but an appropriate correction to the Z mass and width values has been applied.
- Some data from the 1995 run have been added by OPAL and L3, and there have been significant changes to the $\tau^+\tau^-$ measurements from ALEPH.
- L3 have included the 1995 data in their τ polarization measurements [4].
- A preliminary measurement of A_{LR} from the SLD 1996 data is available.

Overall the changes in the combined results since last year are quite small. The basic combined LEP measurements are [3]:

Without lepton universality		Assuming lepton universality	
M_Z /GeV	91.1867 ± 0.0020	M_Z /GeV	91.1867 ± 0.0020
Γ_Z /GeV	2.4948 ± 0.0025	Γ_Z /GeV	2.4948 ± 0.0025
σ_h^0 /nb	41.486 ± 0.053	σ_h^0 /nb	41.486 ± 0.053
R_e	20.757 ± 0.056	R_ℓ	20.775 ± 0.027
R_μ	20.783 ± 0.037		
R_τ	20.823 ± 0.050		
$A_{\text{FB}}^{0,e}$	0.0160 ± 0.0024	$A_{\text{FB}}^{0,\ell}$	0.0171 ± 0.0010
$A_{\text{FB}}^{0,\mu}$	0.0163 ± 0.0014		
$A_{\text{FB}}^{0,\tau}$	0.0192 ± 0.0018		
$\chi^2/\text{dof}=21/27$		$\chi^2/\text{dof}=23/31$	

The data from the four experiments are in excellent agreement, as shown by the values of χ^2/dof .

From these measurements, it is possible to infer a value for the invisible width of the Z:

$$\Gamma_{\text{inv}} = 500.1 \pm 1.8 \text{ MeV}$$

which can be converted into a measurement of the number of light neutrino species assuming they have Standard Model couplings:

$$N_\nu = 2.993 \pm 0.011$$

A limit on the possible additional invisible width arising from new physics can also be inferred: $\Delta\Gamma_{\text{inv}} < 2.8 \text{ MeV}$ at 95% c.l.

The results from the Z leptonic lineshape and asymmetries can be combined with measurements of the τ polarization and its asymmetry (which are sensitive to the electron and τ couplings separately) to perform the best tests of lepton universality. In fig. 1 we show the vector and axial couplings for each lepton species, as inferred from the LEP data. The measurements are clearly consistent with universality of the Z leptonic couplings, with a precision of $\sim 0.2\%$ for g_A and 5-10% for g_V , and also with the Standard Model expectation, indicated by the shaded area with uncertainties arising from varying the Higgs mass between 60 and 1000 GeV and the t-quark mass in the range $175.6 \pm 5.5 \text{ GeV}$. The measurement of A_{LR} from SLD is also shown. Under the assumption of lepton universality, the following values for the couplings are obtained:

	LEP	LEP+SLD
$g_{V\ell}$	-0.03681 ± 0.00085	-0.03793 ± 0.00058
$g_{A\ell}$	-0.50112 ± 0.00032	-0.50103 ± 0.00031

1.2 Heavy flavour electroweak measurements

The main changes in the past year, reviewed in [5, 6], are:

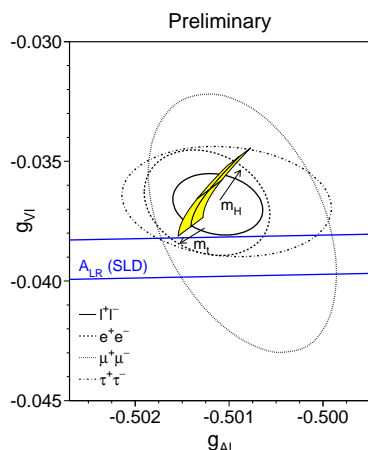


Fig. 1. 68% probability contours of vector and axial vector couplings of the Z to leptons.

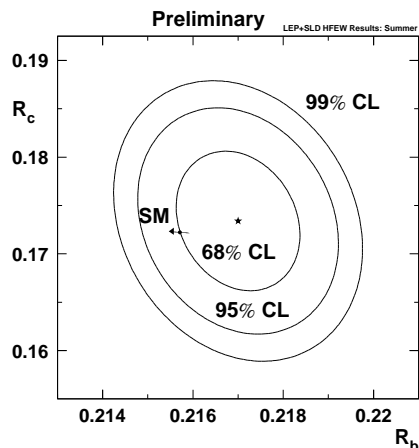


Fig. 2. Measurements of R_b and R_c , compared with the Standard Model.

- Measurements of $R_b = \Gamma_{b\bar{b}}/\Gamma_{\text{had}}$ from ALEPH [7], OPAL [8] and SLD have been finalised for publication in the last year, and new preliminary measurements from DELPHI [9], L3 [10] and SLD [11] have led to significantly improved precision.
- New determinations of R_c from OPAL [12], ALEPH [13] and SLD [14] (the latter exploiting a double vertex tag), have led to continued improvement in the precision of this measurement.
- There are new measurements of the forward backward asymmetry A_{FB}^b from L3 [15] and OPAL [16], but an ALEPH result has been withdrawn, so the overall precision of the measurement is unchanged.
- The SLD measurements of the polarized asymmetries [17] have led to a much improved determination of \mathcal{A}_c .

The combined LEP/SLD heavy flavour measurements may be summarized as follows:

R_b	0.2170 ± 0.0009
R_c	0.1734 ± 0.0048
$A_{\text{FB}}^{0,b}$	0.0984 ± 0.0024
$A_{\text{FB}}^{0,c}$	0.0741 ± 0.0048
\mathcal{A}_b	0.900 ± 0.050
\mathcal{A}_c	0.650 ± 0.058

In fig. 2 we compare the measured values of R_b and R_c with the Standard Model expectations. The apparent disagreement which excited much interest in previous years has evaporated.

The various measurements of polarizations and asymmetries at LEP and SLD can be interpreted, in the context of the Standard Model, as measurements of the effective electroweak mixing parameter $\sin^2 \theta_{\text{eff}}^{\text{lept}}$. In fig. 3 we show a comparison of the various determinations of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$. The values are not incompatible with a common value ($\chi^2/\text{dof}=12.6/6$), though it should be noted that the two most precise determinations (from A_{LR} and the forward-backward b-quark asymmetry) show the largest discrepancies from the mean. In fig. 4 we show the measured values of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ and the leptonic width Γ_ℓ , which are in good agreement with the Standard Model expectation. The star indicates the prediction if only photonic radiative corrections are applied, with the arrow showing the non-negligible uncertainty induced by the running of the electromagnetic coupling. The data clearly demonstrate the need for electroweak radiative corrections, and their sensitivity to the Higgs mass m_H is also evident.

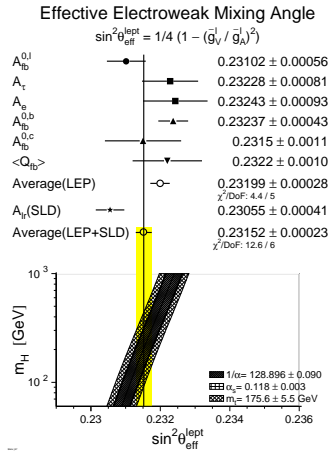


Fig. 3. Determinations of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ from asymmetry and τ polarization measurements. The Standard Model expectation as a function of m_H is shown.

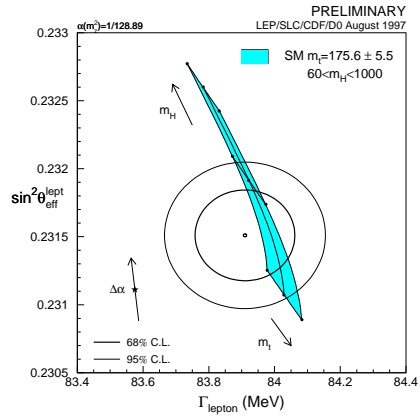


Fig. 4. Combined measurements of $\sin^2 \theta_{\text{eff}}^{\text{lept}}$ and Γ_ℓ , compared with the Standard Model expectation with and without electroweak radiative corrections.

2 Fermion pair production at LEP II

Fermion-pair production at energies well above the Z resonance is characterized by a tendency for *radiative return* to the Z through the emission of one or more photons from the initial state. The main physics interest, and the

greatest sensitivity to new physics, lies in the events with only a small amount of initial state radiation. *Non-radiative* events are selected by imposing a cut on the effective c.m. energy of the fermion-pair, $\sqrt{s'}$, which can be reconstructed from the event kinematics. Measurements now exist of fermion pair cross-sections and forward-backward asymmetries up to 183 GeV (see [18] for a compilation and detailed references).

The measurements are all in excellent agreement with the Standard Model. They may be interpreted in various ways – either to constrain parameters of the Standard Model, or to place limits on new physics (for more details, see [18]). For example, the hadronic cross-section at LEP II can be used to constrain $Z-\gamma$ interference. The data taken on the Z peak constrain this interference only weakly, so it is normally fixed to its Standard Model expectation. A more model independent interpretation of the data can be performed using the S-matrix formalism [19], allowing the parameter $j_{\text{had}}^{\text{tot}}$ which parametrizes γ -W interference in the hadronic cross-section to be free. By including data above and below the Z, where interference is sizeable, the precision of the determination of $j_{\text{had}}^{\text{tot}}$, and hence of M_Z in this framework, are greatly improved. The values obtained are $M_Z = 91.1882 \pm 0.0029$ and $j_{\text{had}}^{\text{tot}} = 0.14 \pm 0.12$ (c.f. $j_{\text{had}}^{\text{tot}} = 0.22$ in the Standard Model).

3 Mass of the W boson

As we shall see below, the precise measurements of the Z boson allow the mass of the W boson to be predicted with a precision of of around ± 40 MeV. A major goal of the LEP II and Tevatron programs is to match this precision by direct measurement, so as to provide a new test of the Standard Model.

At LEP II, W^+W^- pairs are produced either via s -channel W/γ or t -channel neutrino exchange. The first runs at LEP II were at 161 GeV, just above W^+W^- threshold. At this energy, the W^+W^- cross-section is very sensitive to the W mass. The W^+W^- cross-section, averaged over all four LEP experiments [20], is shown in fig. 5. From the cross-section at 161 GeV, the W mass is obtained as $M_W = 80.40 \pm 0.22$ GeV, where the error is predominantly statistical.

At higher energies, the cross-section is much less sensitive to the W mass, and the better technique is to reconstruct the W mass directly from the invariant mass of its decay products. The final states $W^+W^- \rightarrow q\bar{q}q\bar{q}$ and $W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$ can both be used for this purpose. Kinematic fit techniques, imposing energy and momentum conservation and equality of the two W masses in each event, are used to improve the mass resolution. The results obtained after averaging the measurements from each LEP experiment [21, 22], are:

Channel	M_W /GeV
$W^+W^- \rightarrow q\bar{q}q\bar{q}$	80.62 ± 0.26
$W^+W^- \rightarrow q\bar{q}\ell\nu_\ell$	80.46 ± 0.24
Combined (172 GeV)	80.53 ± 0.18
LEP 161 and 172 GeV	80.48 ± 0.14

In this direct reconstruction approach, the $q\bar{q}q\bar{q}$ final state is potentially more problematical than $q\bar{q}\ell\nu_\ell$ because it can be affected by hadronic final state interaction effects. These can arise because the two Ws typically decay so close together that they are within the range of the strong interaction. It has been suggested that *colour reconnection* effects [23] could bias the reconstructed W mass in the $q\bar{q}q\bar{q}$ channel by several hundred MeV. However, the models which predict the largest effect [24] also predict other observable effects, such as a $\sim 10\%$ reduction in the hadron multiplicity in the $q\bar{q}q\bar{q}$ case. Data already exist [25] comparing the hadronic W decay multiplicity in the $q\bar{q}q\bar{q}$ and $q\bar{q}\ell\nu$ final states, yielding a ratio of 1.04 ± 0.03 . At first sight this appears inconsistent with the most extreme colour reconnection model, though caution is needed because the models used to correct the data do not include the colour reconnection effect. Another possible problem could result from Bose-Einstein correlations between pions from different Ws. Data from LEP so far [26], with large errors, show no evidence for such correlations, consistent with the most recent theoretical investigations [27].

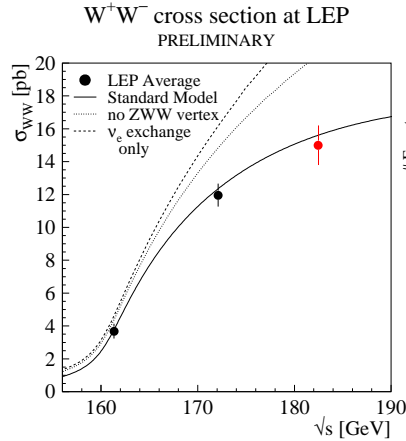


Fig. 5. Measurements of the $e^+e^- \rightarrow W^+W^-$ cross-section at LEP II.

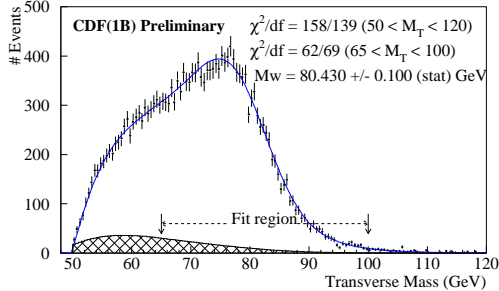


Fig. 6. Transverse mass distribution in CDF, from which the W mass can be extracted.

At the Tevatron, W bosons are produced singly from $q\bar{q}'$ fusion. The leptonic W decays $W \rightarrow \ell\nu$ ($\ell = e/\mu$) are used to defeat QCD background, with the neutrino inferred from missing momentum. The value of M_W may be extracted from the distribution of transverse mass of $\ell\nu$, as shown in fig. 6. The current results from CDF and D0 are 80.375 ± 0.120 GeV and 80.44 ± 0.11 GeV respectively [28, 29, 30]. The combined W mass measurement from hadron collider experiments (including UA2) is 80.41 ± 0.09 GeV.

The measurements of M_W from hadron colliders and from LEP II are therefore in excellent agreement. The combined “World Average” is:

$$M_W = 80.43 \pm 0.08 \text{ GeV}$$

At present this average is dominated by the Tevatron measurements. However, if LEP delivers say 50 pb^{-1} of data per experiment in 1997, the LEP error can be expected to reduce to around 0.08 GeV. By the end of LEP II and after the Tevatron upgrade, both LEP and Fermilab expect to be able to reach a precision on M_W around 0.03–0.04 GeV.

4 Global Standard Model Fits

Combined fits of the Standard Model have been performed to the measurements of Z decays and the W mass outlined above. Additional measurements can also be included: the top quark mass $m_t = 175.6 \pm 5.5$ GeV [31], the value of $1 - M_W^2/M_Z^2 = 0.2254 \pm 0.0037$ from νN scattering (which includes a new result from CCFR [32]) and the value of the electromagnetic coupling, $1/\alpha(M_Z) = 128.894 \pm 0.090$ [33], which carries an error because of the need to run it to scale M_Z . In the fits, m_H , $\alpha_s(M_Z)$ and optionally m_t and M_W are treated as free parameters.

Three fits have been performed, with the results shown below:

- i)* A fit to LEP I and LEP II data only.
- ii)* A fit to all data except the direct measurements of M_W and m_t . This permits a direct comparison between the direct and indirect determinations of these masses, as shown in fig. 7. The two sets of measurements are seen to be consistent.
- iii)* A fit to all data. As in the previous two fits, the χ^2/dof value is excellent, showing that the data are globally compatible with the Standard Model. In fig. 8 we show the input measurements and the *pulls* for this fit, i.e. the difference between fitted and measured values divided by the error. The distribution of pulls is satisfactory, with only one measurement ($\sin^2 \theta_{\text{eff}}^{\text{lept}}$ from A_{LR}) more than two standard deviations from the Standard Model.

	<i>i)</i> LEP (inc. M_W)	<i>ii)</i> All but M_W, m_t	<i>iii)</i> All data
m_t / GeV	158^{+14}_{-11}	157^{+10}_{-9}	173.1 ± 5.4
m_H / GeV	83^{+168}_{-49}	41^{+64}_{-21}	115^{+116}_{-66}
$\log m_H$	$1.92^{+0.48}_{-0.39}$	$1.62^{+0.41}_{-0.31}$	$2.06^{+0.30}_{-0.37}$
$\alpha_s(M_Z)$	0.121 ± 0.003	0.120 ± 0.003	0.120 ± 0.003
χ^2/dof	8/9	14/12	17/15
M_W / GeV	80.298 ± 0.043	80.329 ± 0.041	80.375 ± 0.030

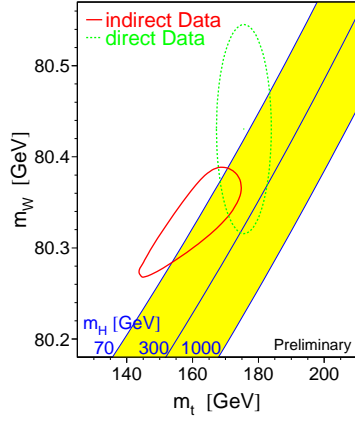


Fig. 7. Direct and indirect measurements of M_W and m_t , compared with the Standard Model for various values of m_H (68% probability contours).

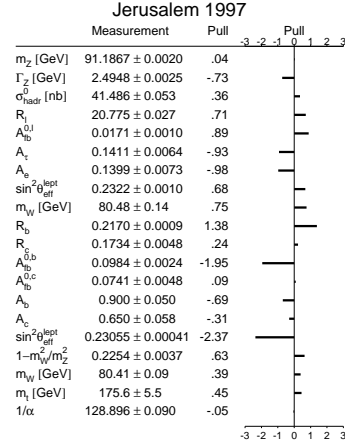


Fig. 8. Measured quantities and their pulls in the global Standard Model fit.

The results of the fits provide an indirect estimate of the mass of the Higgs boson, m_H . The most precise estimate comes from the fit to all data, yielding $m_H = 115^{+116}_{-66}$ GeV. The two most discrepant measurements in the Standard Model fit tend to pull m_H in opposite directions, A_{LR} favouring a low m_H , and A_{FB}^b preferring a high value. The dependence on m_H of the difference between χ^2 and its minimum value is shown in fig. 9. The band indicates an estimate of the theoretical uncertainties resulting from uncomputed higher order terms. Taking this into account, an upper limit on m_H may be placed:

$$m_H < 420 \text{ GeV (95\% c.l.)}$$

In deriving this limit, the lower mass limit derived from direct searches, $m_H > 77$ GeV [34, 35], has not been taken into account.

The value obtained for $\alpha_s(M_Z) = 0.120 \pm 0.003$ is one of the most accurate measurements, even after including a theoretical systematic error of about

± 0.002 . This measurement is compared with other recent determinations [36] in fig. 10. The measurements display a good level of consistency, which is a pleasing improvement on the situation a couple of years ago. A reasonable World Average value is

$$\alpha_s(M_Z) = 0.119 \pm 0.004$$

where the error has been estimated very simply as the r.m.s. deviation of the measurements from the mean.

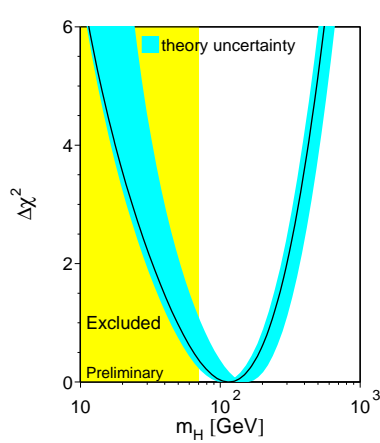


Fig. 9. Dependence of χ^2 of the global electroweak fit on m_H .

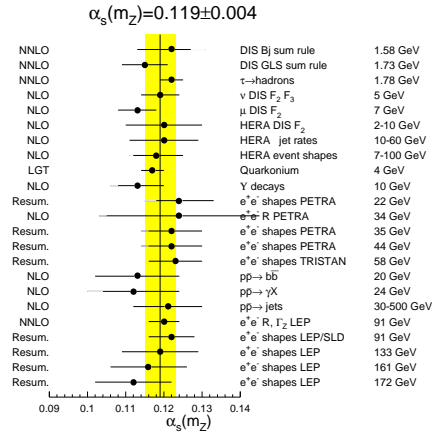


Fig. 10. A compilation of recent measurements of α_s .

5 Width and branching ratios of the W boson

5.1 W Width

The most precise (but indirect) estimate of the W width is based on the observed W and Z cross-sections at the Tevatron, using the relation

$$\frac{\sigma_W \cdot \text{BR}(W \rightarrow \ell\nu)}{\sigma_Z \cdot \text{BR}(Z \rightarrow \ell\ell)} = \frac{\sigma_W \cdot \Gamma(W \rightarrow \ell\nu) \cdot \Gamma_Z}{\sigma_Z \cdot \Gamma(Z \rightarrow \ell\ell) \cdot \Gamma_W}$$

Taking the cross-sections from QCD, the Z data from LEP, and $\text{BR}(W \rightarrow \ell\nu)$ from the Standard Model, the combined CDF/D0 data yield $\Gamma_W = 2.06 \pm 0.06$ GeV, to be compared with the Standard Model expectation of 2.077 ± 0.014 GeV. A more direct measurement can be made from a detailed study

of the tail of the transverse mass distribution (fig. 6). The latest result from CDF [29] is $\Gamma_W = 2.11 \pm 0.17 \pm 0.09$ GeV. First results from LEP [21], based on direct observation of the W lineshape, have started to appear:

$$\begin{aligned}\Gamma_W &= 1.74_{-0.78}^{+0.88}(\text{stat.}) \pm 0.25(\text{syst.}) \text{ (L3)} \\ \Gamma_W &= 1.30_{-0.55}^{+0.62}(\text{stat.}) \pm 0.18(\text{syst.}) \text{ (OPAL)}\end{aligned}$$

At present the errors are not competitive, but an interesting measurement should be possible by the end of the 1997 run.

5.2 W branching ratios and V_{cs}

The observation of W^+W^- production at LEP permits a direct determination of the W branching ratios. The combined results from LEP are [37]:

W decay channel	Branching Ratio (%)
$e\nu$	10.8 ± 1.3
$\mu\nu$	9.2 ± 1.1
$\tau\nu$	12.7 ± 1.7
$\ell\nu$	10.9 ± 0.6
Hadrons	67.2 ± 1.7

The leptonic results are consistent with lepton universality, though not yet competitive with results from other processes, such as τ decays. The hadronic branching ratio can be related to elements of the CKM matrix:

$$\frac{B_h}{1 - B_h} = \sum_{i=u,c; j=d,s,b} |V_{ij}|^2 \left(1 + \frac{\alpha_s}{\pi}\right)$$

Amongst these CKM elements, V_{cs} is by far the least well measured ($V_{cs}=1.01\pm 0.18$ from D meson decays). One can therefore take the other elements from the PDG world averages, and infer a value $|V_{cs}| = 0.96 \pm 0.08$.

Direct measurements of $W \rightarrow c$ using charm tagging are also appearing [38], which yield a more direct determination of V_{cs} . The values to date are:

$$\begin{aligned}V_{cs} &= 1.13 \pm 0.43(\text{stat.}) \pm 0.03(\text{syst.}) \text{ (ALEPH)} \\ V_{cs} &= 0.87_{-0.22}^{+0.26}(\text{stat.}) \pm 0.11(\text{syst.}) \text{ (DELPHI)}\end{aligned}$$

Although V_{cs} can be constrained much more strongly by the unitarity of the CKM matrix, these direct measurements will ultimately provide an interesting check.

6 Triple Gauge Couplings

The WWZ and WW γ couplings are predicted by the Standard Model, and can be tested by the LEP and Tevatron experiments. The effective Lagrangian used to parametrize any anomalous couplings involves 2×7 parameters to describe most general Lorentz invariant WWV ($V=Z,\gamma$) vertices. By assuming C, P, and electromagnetic gauge invariance, this can be reduced to a more practicable set of five parameters: λ_γ , λ_Z ($=0$ in Standard Model) and κ_γ , κ_Z , g_1^Z ($=1$ in Standard Model); $g_1^\gamma = 1$ results from electromagnetic gauge invariance. These parameters may be related to the static moments of the W:

Charge	$Q_W = eg_1^\gamma$
Magnetic dipole moment	$\mu_W = (e/2m_W)(g_1^\gamma + \kappa_\gamma + \lambda_\gamma)$
Electric Quadrupole moment	$q_W = -(e/m_W^2)(\kappa_\gamma - \lambda_\gamma)$

At LEP II, anomalous values for these couplings generally increase the W^+W^- cross-section. We see from fig. 5 that the measured cross-sections clearly require the existence of both WWZ and WW γ couplings. Anomalous couplings also influence the production angle of the W^- and affect the helicity states, and hence the decay angles, of the W^\pm . The $W^+W^- \rightarrow q\bar{q}\ell\nu$ final states are particularly sensitive, because the lepton charge allows an unambiguous assignment of the W charges. Further information can be obtained from “single W production” (i.e. $q\bar{q}e\nu$ final states with only a single on-shell W) and $\nu\bar{\nu}\gamma$ final states, which are particularly sensitive to the WW γ vertex.

The precise measurements of the Z already constrain possible anomalous couplings. For this reason, the LEP experiments have focussed on the following combinations of anomalous couplings, which do not affect gauge boson propagators at tree level, and are therefore not already indirectly constrained:

$$\begin{aligned}\Delta\kappa_\gamma - \Delta g_1^Z \cos^2 \theta_W &= \alpha_{B\phi} \\ \Delta g_1^Z \cos^2 \theta_W &= \alpha_{W\phi} \\ \lambda_Z = \lambda_\gamma &= \alpha_W\end{aligned}$$

with the constraint $\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2 \theta_W$. All these couplings should be zero according to the Standard Model. Combined results from the four experiments have been obtained by adding likelihood curves from each experiment, taking both cross-section and angular information into account, as illustrated in fig. 11. The results are [39, 40]:

	95% c.l. limits
$\alpha_{W\phi} = 0.02 \pm_{0.15}^{0.16}$	$-0.28 < \alpha < 0.33$
$\alpha_W = 0.15 \pm_{0.27}^{0.27}$	$-0.37 < \alpha < 0.68$
$\alpha_{B\phi} = 0.45 \pm_{0.67}^{0.56}$	$-0.81 < \alpha < 1.50$

Thus no discrepancy from the Standard Model is observed.

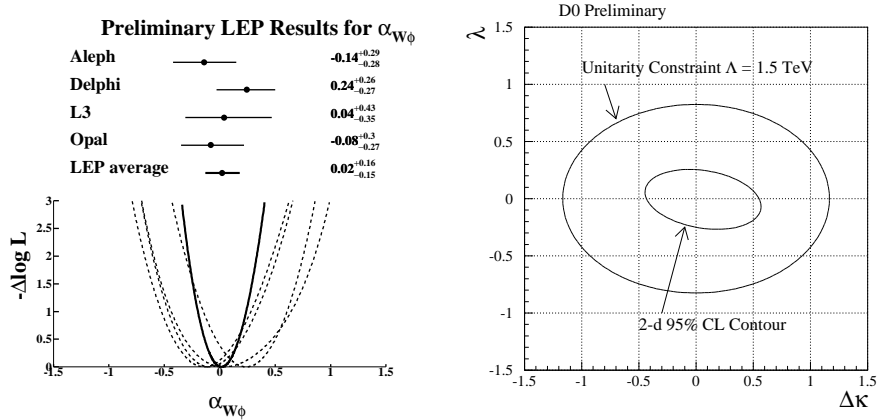


Fig. 11. Likelihood curves for the combined LEP measurement of $\alpha_{W\phi}$.

Fig. 12. Limits on the couplings λ and $\Delta\kappa$ from the combined analysis of D0.

In $\bar{p}p$ experiments, information may be gleaned in two ways. Observation of the rate of $W\gamma$ production, especially for high p_T photons, is sensitive to the $WW\gamma$ coupling (and thus complementary to LEP II, which is sensitive to WWZ as well). The results are:

	$\lambda_\gamma = 0$	$\Delta\kappa_\gamma = 0$
D0 [30, 41]	$-0.93 < \Delta\kappa_\gamma < 0.94$	$-0.31 < \lambda_\gamma < 0.29$
CDF [29]	$-1.8 < \Delta\kappa_\gamma < 2.0$	$-0.7 < \lambda_\gamma < 0.6$

In addition a few instances of WW or WZ pair production are observed in $\ell\nu\ell\nu$ and $\ell\nu jj$ final states. The most stringent limits are obtained by D0 [30, 41] in a combined fit to all channels, assuming equal WWZ and $WW\gamma$ couplings: $-0.33 < \Delta\kappa < 0.45$ and $-0.20 < \lambda < 0.20$, as shown in fig. 12. Where comparison is possible, at present the Tevatron limits are typically better than the LEP II limits by a factor 2. This situation should start to change by the end of the 1997 LEP run.

7 Summary

In summary, the electroweak sector of the Standard Model continues to stand up to all tests. The precise electroweak measurements in Z decays at LEP I are coming to an end, and only modest improvements can be expected. The distinctive contribution from polarized beam measurements at SLC is set to continue. The results on W physics from LEP II and the Tevatron are starting to appear, and over the next few years a factor ~ 20 more data is anticipated at both machines, to pursue tests of the Standard Model.

8 Acknowledgements

Thanks are due to the members of the LEP/SLD Electroweak Working Group, who have done much of the work of professionally combining the data. I should also like to thank the many members of ALEPH, DELPHI, L3, OPAL, SLD, D0 and CDF who have given me help and information, and the organisers of this meeting in Jerusalem for inviting me to speak at such an interesting and well run conference.

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