MEASUREMENT OF THE τ POLARIZATION AT LEP AND DETERMINATION OF THE STANDARD MODEL PARAMETERS

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Abstract

The results of the measurement of the τ polarization at LEP are presented. A fit to all available measurements from neutral and charged current processes has been performed and a precise determination of the parameters of the Standard Model is obtained. The fit yields a value of $m_{\mathrm{top}} = 162^{+15+18}_{-16-20}$ GeV, where the second error is for a variation of the mass of the Higgs between 60 and 1000 GeV.

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1 Introduction

The latest results of the measurements of the τ polarization in Z decay, performed at LEP, will be first reviewed. All electro–weak measurements presented at this conference will then be summarized and used to make a global fit of the Standard Model parameters.

2 Measurement of the τ polarization at LEP

At LEP the electro–weak parameters are determined from the precise measurement of the cross–section of the process:

$$\mathrm{e}^+\mathrm{e}^- \to \mathrm{Z} \to f\bar{f},$$

where the incoming electron and positron beams are unpolarized. For each fermion type four observable can be constructed corresponding to the four possible combinations of direction (forward or backward) and helicity (positive or negative) of the final state fermion. For most of the cases the helicity of the final state fermions can not be determined, leaving only two measurable observables: the total cross section and the forward-backward asymmetry. The τ lepton is the notable exception and the measurement of its helicity permits to measure the other two observables: the average polarization $\mathcal{P}_\tau$ and the forward-backward polarization asymmetry A_{FB}^{Pol}.

The angular dependence of the τ polarization can be written as

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

where θ is the angle between the τ^- and the direction of the incoming electron and

$$\mathcal{A}_\ell \equiv \frac{2g_A^\ell g_V^\ell}{(g_A^\ell)^2 + (g_V^\ell)^2}.$$

It's easy to see that

$$\begin{aligned} \mathcal{P}_\tau &= -\mathcal{A}_\tau; \\ A_{FB}^{Pol} &= -\frac{3}{4}\mathcal{A}_\mathrm{e}. \end{aligned}$$

Remembering that $g_V^\ell/g_A^\ell = 1 - 4\sin^2\theta_\mathrm{W}^\mathrm{eff}$, we can see how

$$\begin{aligned} \delta\mathcal{P}_\tau &\propto 8\delta\sin^2\theta_\mathrm{W}^\mathrm{eff}; \\ \delta A_{FB}^{Pol} &\propto 6\delta\sin^2\theta_\mathrm{W}^\mathrm{eff} \end{aligned}$$

which shows the high sensitivity of the polarization measurements to $\sin^2\theta_\mathrm{W}^\mathrm{eff}$.

Channel	J	Branch. Ratio	Anal. Power	Stat. Weight
$e^-\overline{\nu}_e\nu_\tau$	1/2	0.178	0.22	0.07
$\mu^-\overline{\nu}_\mu\nu_\tau$	1/2	0.175	0.22	0.07
$\pi^-(K^-)\nu_\tau$	0	0.125	0.58	0.30
$\rho^-\nu_\tau$	1	0.230	0.50	0.47
$a_1{}^-\nu_\tau$	1	0.070	0.44	0.10

Table 1: *Sensitivity to $\mathcal{P}_\tau$ for the five relevant decay modes.*

2.1 Experimental technique

The polarization of a τ lepton is measured from the analysis of its decay products. In this analysis the τ is supposed to decay through a charge current process with $V - A$ structure. The kinematics of the two body decays $\tau^- \to \pi^-(K^-)\nu_\tau$, $\rho^-\nu_\tau$ and $a_1^-\nu_\tau$ and the three body decays $\tau^- \to e^-\overline{\nu}_e\nu_\tau$ and $\mu^-\overline{\nu}_\mu\nu_\tau$ have been studied, which together comprise 77% of all τ decays.

For all the decay modes, the differential cross section with respect to the energy of the decay particle can be calculated as a function of the $\mathcal{P}_\tau$ [1], and can be thus used to measure the tau polarization. Table 1 summarizes the sensitivity of each decay mode to $\mathcal{P}_\tau$ [2]. The analyzing power is maximal for $\tau^- \to \pi^-(K^-)\nu_\tau$ since π^- is spinless, the decay is two-body and the neutrino is purely left-handed. For the two-body decays into vector particles, the analyzing power of the energy distribution is smaller since there are two allowed spins states. The sensitivity can be recovered by analyzing their subsequent decays [3–5], gaining information about the spin state from the decay angular distribution. After accounting for the various branching fractions, the largest statistical significance comes from $\tau^- \to \rho^-\nu_\tau$. For the three-body decay modes, the analyzing power is significantly smaller due to the presence of two unmeasured neutrinos.

In each case, $\mathcal{P}_\tau$ is measured by obtaining the linear combination of the positive and negative helicity Monte Carlo distributions (*i.e.* reweighting), of the relevant kinematic variables which best fits the data. The Monte Carlo distributions are obtained after event generation [6] and full detector simulation and after applying the same selection as that for the data. In the fits, $\mathcal{P}_\tau$ and the overall normalization are left as free parameters. The dominant systematic errors arise from distortions of the energy distributions from efficiency corrections, calibration and final state radiation, and from uncertainties in the background subtraction mainly from other τ decays.

In figure 1 the results of the $\mathcal{P}_\tau$ measurement in each channel are summarized for the four experiments[1].

Averaging the τ polarization measurements from all four experiments a value of $\mathcal{A}_\tau =$

[1]ALEPH and L3 results are final, OPAL and DELPHI results are preliminary. ALEPH, L3 and OPAL results include 1990 and 1991 data, DELPHI results include only 1991 data and, for the a_1 channel, part of 1992 data.

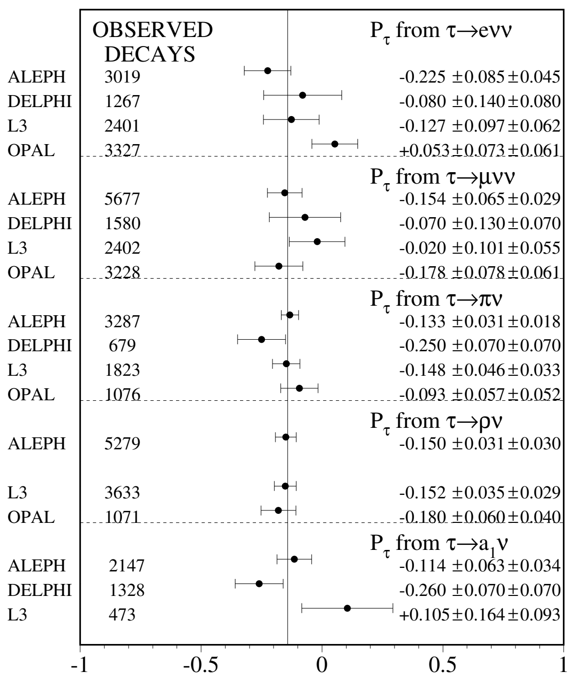

Figure 1: *Compilation of all $\mathcal{P}_\tau$ measurements at LEP.*

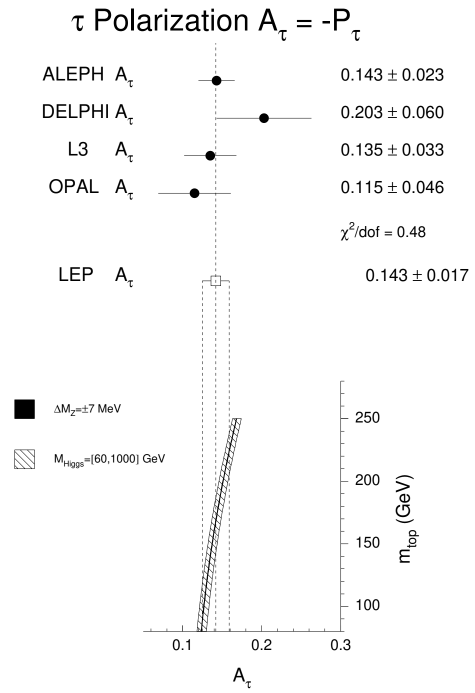

Figure 2: *Comparison of the $\mathcal{P}_\tau$ measurements with the Standard Model expectation.*

0.142 ± 0.017 is obtained. Figure 2 shows the results of the measurements from the four experiments compared with the expectation from the Standard Model as a function of m_{top}.

2.2 The measurement of the angular dependence of $\mathcal{P}_\tau$

Measuring the angular dependence of $\mathcal{P}_\tau$ permits to have an independent determination of the Z coupling to electrons. Figure 3 shows the measurement performed by the ALEPH collaboration of $\mathcal{P}_\tau$ as a function of the polar angle θ. The result of a fit to the data, with and without lepton flavor universality assumption, is also shown. A similar analysis has been also performed by the OPAL collaboration. The results of these measurements are presented in figure 4. Their average gives a value of $\mathcal{A}_e = 0.130 \pm 0.025$. Assuming lepton flavor universality, the final result from τ polarization measurements at LEP is $\mathcal{A}_\ell = 0.138 \pm 0.014$, corresponding to a value of $\sin^2\theta_W^{\mathrm{eff}} = 0.2328 \pm 0.0017$.

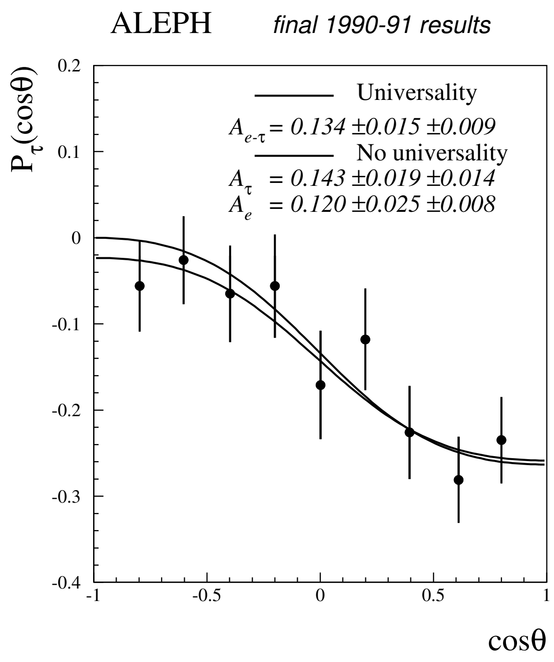

Figure 3: *The angular dependence of $\mathcal{P}_\tau$ as measured in the ALEPH experiment.*

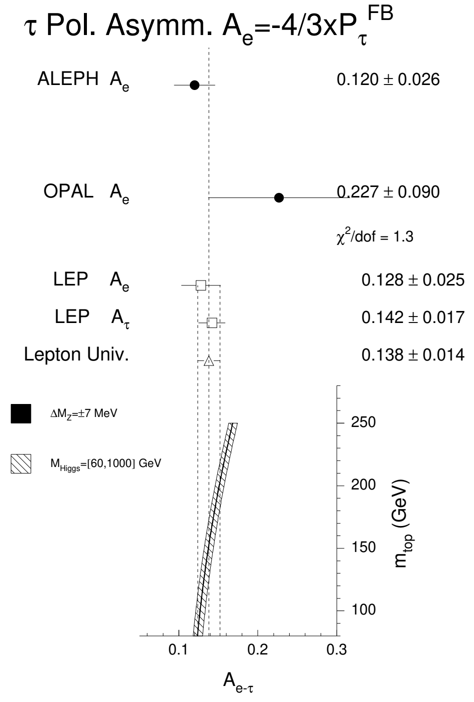

Figure 4: *Comparison of the A_{FB}^{Pol} measurements with the Standard Model expectation.*

3 Determination of $\sin^2\theta_{\mathrm{W}}^{\mathrm{eff}}$ from all asymmetry measurements at LEP

The precise determination of the effective weak mixing angle is one of the primary goal of LEP. The possibility of performing such a measurement from a variety of different processes permits to check the universality of the neutral currents in both the lepton and the quark sectors and provides a unique test of the Standard Model.

The measurements of the forward–backward asymmetries for leptons [8] and heavy quarks [9] are reported in other contributions to these proceedings. The ALEPH collaboration has submitted to this conference a new measurement of the charge asymmetry in hadronic Z decays based on the analysis of all data collected so far. This result, combined with the previous published results [10], leads to a value of $\sin^2\theta_{\mathrm{W}}^{\mathrm{eff}} = 0.2320 \pm 0.0016$.

Figure 5 shows the values of $\sin^2\theta_{\mathrm{W}}^{\mathrm{eff}}$ determined from all asymmetry measurements at LEP. They all agree with each other and with the expectation of the Standard Model. Assuming lepton and quark universality it is possible to average these measurements and

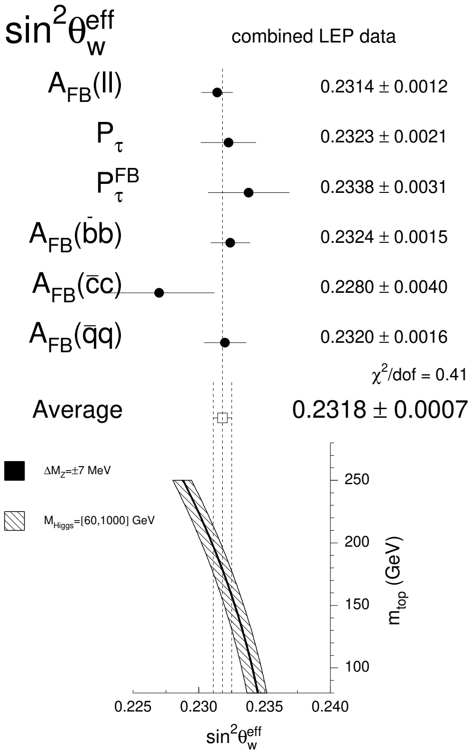

Figure 5: *Compilation of all measurements of $\sin^2\theta_{\rm W}^{\rm eff}$ from asymmetry measurements at LEP compared with the Standard Model expectation.*

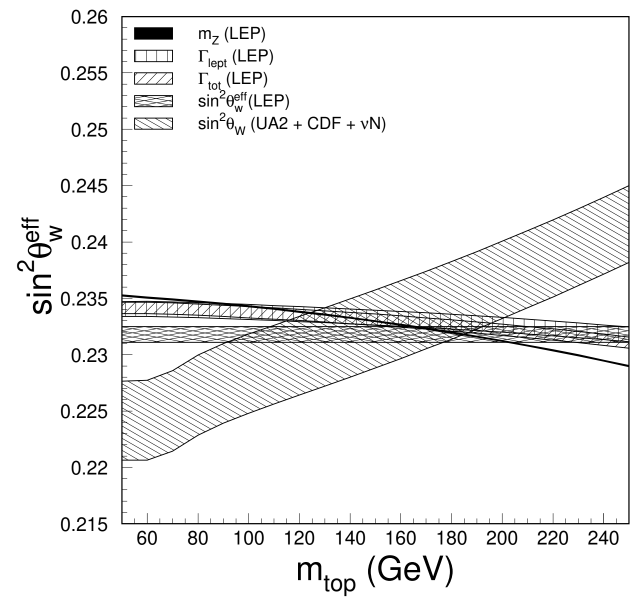

Figure 6: *The dependence of various measurements of $\sin^2\theta_{\rm W}^{\rm eff}$ from the mass of the top quark. The mass of the Higgs Boson has been fixed to 300 GeV and $\alpha_s = 0.123$.*

obtain a precise determination (at the 0.3% level) of the effective weak mixing angle:

$$\sin^2\theta_{\rm W}^{\rm eff} = 0.2318 \pm 0.0007.$$

This measurement is compared, in the framework of the Standard Model, with other determination of $\sin^2\theta_{\rm W}^{\rm eff}$ as a function of $m_{\rm top}$ in figure 6. The measurements are all in agreement with each other for a mass of the top in the range 100-200 GeV.

4 Determination of the Standard Model parameters

Standard Model predictions depend essentially on 6 parameters:

$$\alpha \quad {\rm G_F} \quad m_{\rm Z} \quad m_{\rm H} \quad m_{\rm top} \quad \alpha_s.$$

The first two are known with high precision, the others are measured at LEP and in many other experiments. These measurements are used to constrain the still unknown parameters of the Standard Model, mainly $m_{\rm top}$.

The measurements considered are:

- the measurement of the strong coupling constant from the study of the hadronic event shape at LEP [11]:
$$\alpha_s = 0.123 \pm 0.006;$$
- the Higgs mass limit obtained by direct search at LEP [12]:
$$m_{\mathrm{H}} > 62.5 \text{ at the 95\% C.L.};$$
- the Z lineshape parameters and lepton forward–backward asymmetry measured at LEP [8]:
$$m_{\mathrm{Z}} = 91187 \pm 7 \text{ MeV}, \qquad \Gamma_{\mathrm{Z}} = 2488 \pm 7 \text{ MeV},$$
$$\sigma_0 = 41.45 \pm 0.17 \text{ nb},$$
$$R_\ell = \frac{\Gamma_{\mathrm{had}}}{\Gamma_\ell} = 20.830 \pm 0.056, \qquad A^0_{FB} = 0.0165 \pm 0.0021;$$
- the left-right polarization asymmetry measured by SLD at SLC [13]:
$$A_{LR} = 0.100 \pm 0.044;$$
- the measurement of $\mathcal{A}_\ell$ from the observation of the τ polarization at LEP:
$$\mathcal{A}_\tau = 0.142 \pm 0.017, \qquad \mathcal{A}_e = 0.130 \pm 0.025;$$
- the heavy quark forward–backward asymmetries measured at LEP [9]:
$$A^0_{b\bar{b}} = 0.0984 \pm 0.0086, \qquad A^0_{c\bar{c}} = 0.090 \pm 0.019;$$
- the charge asymmetry in hadronic Z decay measured at LEP:
$$\sin^2\theta_{\mathrm{w}}^{eff} = 0.2320 \pm 0.0016;$$
- the Z partial decay width in b quarks measured at LEP [9]:
$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{\mathrm{had}}} = 0.2201 \pm 0.0032;$$
- the measurement of the W mass at the Tevatron and Sp$\bar{\mathrm{p}}$S Colliders [14]:
$$m_{\mathrm{W}} = 79.91 \pm 0.39 \text{ GeV}, \qquad \frac{m_{\mathrm{W}}}{m_{\mathrm{Z}}} = 0.8813 \pm 0.0041;$$
- the measurement of charged and neutral currents in the νN interactions [15]:
$$\sin^2\theta_{\mathrm{W}} = 0.2256 \pm 0.0047;$$
- The measurement of neutral current in νe scattering [16]:
$$g^e_A = -0.503 \pm 0.018 \quad g^e_V = -0.025 \pm 0.019;$$
- the measurement of parity violation in atomic transitions of $^{133}_{53}$Cs [17]:
$$Q_{\mathrm{W}} = -71.0 \pm 1.8.$$

Two sets of fits have been performed: one to the LEP data only and one to the whole set. In both cases the fit has been performed two times: once with no constraint on α_s and once using the α_s measurement as a constraint. The fit has been performed using a

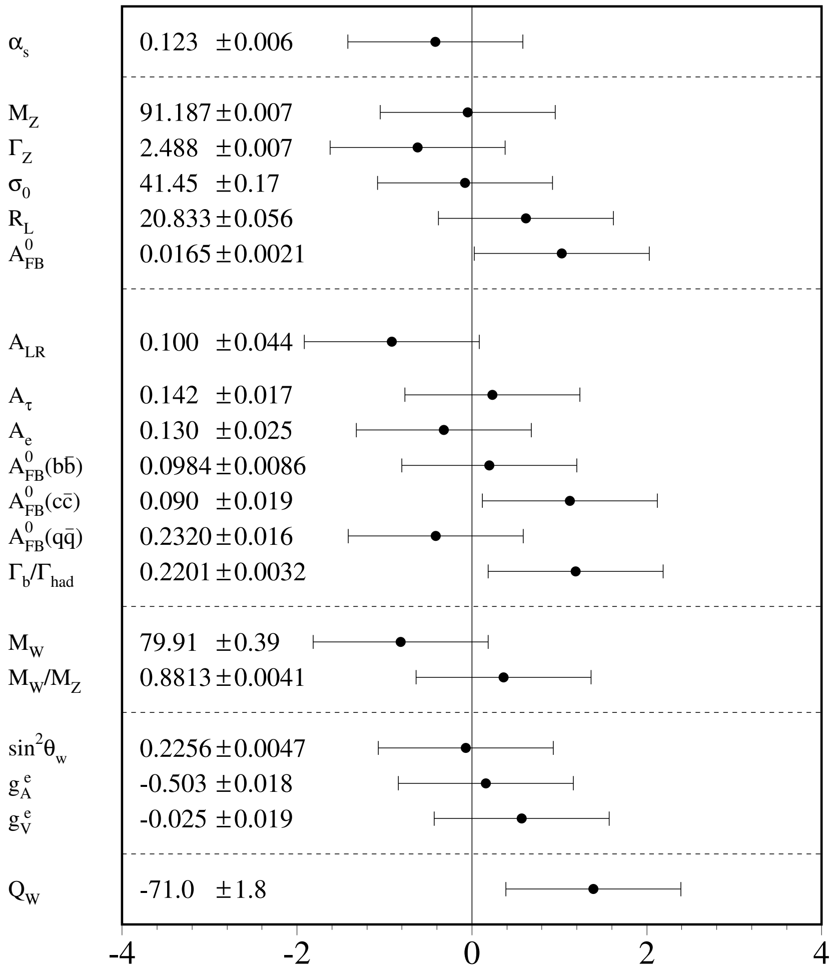

Figure 7: *Summary of all measurement considered. The error bars represent their residuals from the fitted values, in units of their error, for the α_s constrained fit to the whole set.*

program [18] which computes one-loop corrections to electro-weak processes and includes additional recent computations of higher order terms [19,20]. Its output has been compared and found in agreement with other independent calculations [19,21]. Free parameters in the fit are:

$$m_{\mathrm{Z}}, \quad m_{\mathrm{top}}, \quad \alpha_s.$$

The mass of the Higgs Boson has been set to 300 GeV. The effect of m_{H} has been estimated repeating the fit for $m_{\mathrm{H}} = 60$ and 1000 GeV. The results are summarized in table 2. They are all consistent with each other and the low value of the χ^2 confirms the validity of the Standard Model. The residuals from the fitted values for all measurements, in units of their error, are plotted in figure 7 for the α_s constrained fit to the whole set.

	LEP only	
	α_s unconstr.	α_s constr.
m_Z (GeV)	91.186 ± 0.007	91.186 ± 0.007
m_{top} (GeV)	165^{+18+18}_{-19-21}	166^{+17+19}_{-19-21}
α_s	$0.127 \pm 0.007 \pm 0.002$	$0.124 \pm 0.005 \pm 0.001$
m_W (GeV)	$80.24 \pm 0.11 \pm 0.02$	$80.25 \pm 0.11 \pm 0.02$
$\sin^2\theta_W^{eff}$	$0.2326 \pm 0.0006^{+0.0001}_{-0.0002}$	$0.2326 \pm 0.0006^{+0.0001}_{-0.0002}$
χ^2/d.o.f.	4.8/8	4.9/9
	ALL measurements	
	α_s unconstr.	α_s constr.
m_Z (GeV)	91.186 ± 0.007	91.186 ± 0.007
m_{top} (GeV)	162^{+15+18}_{-16-20}	162^{+15+18}_{-16-20}
α_s	$0.127 \pm 0.007 \pm 0.002$	$0.125 \pm 0.005 \pm 0.001$
m_W (GeV)	$80.22 \pm 0.09 \pm 0.01$	$80.23 \pm 0.09 \pm 0.01$
$\sin^2\theta_W^{eff}$	$0.2327 \pm 0.0005^{+0.0001}_{-0.0002}$	$0.2327 \pm 0.0005^{+0.0001}_{-0.0002}$
χ^2/d.o.f.	8.7/15	8.9/16

Table 2: *Results of the Standard Model fits. The second error corresponds to a variation of the mass of the Higgs between 60 and 1000 GeV.*

5 Conclusion

LEP has proven to be the laboratory for precise measurements of electro-weak physics. From the measurements of lepton and quark forward–backward asymmetries and of the τ polarization a precise determination of the weak mixing angle

$$\sin^2\theta_W^{eff} = 0.2318 \pm 0.0007$$

has been obtained, independent of Standard Model assumptions.

The comparison and the combination of a great variety of measurements of neutral and charged current processes, performed at LEP and in other laboratories, make possible to precisely test the validity of the Standard Model. A fit to all these measurements yields a value of

$$m_{top} = 162^{+15+18}_{-16-20}\ \mathrm{GeV},$$

where the second uncertainty corresponds to a variation of the mass of the Higgs between 60 and 1000 GeV.

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