ELECTROWEAK DATA AND STANDARD MODEL FIT RESULTS

T. KAWAMOTO
ICEPP, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan

Most recent tests of the Standard Model of the electroweak interaction are reported using data from the four LEP experiments ALEPH, DELPHI, L3 and OPAL, the SLD experiment at SLC, the Tevatron $p\bar{p}$ experiments CDF and D0, and the NuTeV neutrino experiment. Consistency of the Standard Model is studied. The value of the Higgs mass is inferred from a global fit.

1 A Global fit and Higgs mass

Latest precision electroweak data (some of them are preliminary) are used for a global fit in the framework of the Standard Model (SM). The data used for the present analysis consist of:

- The Z parameters
  - lineshape and lepton asymmetry at LEP: m_{Z}, Γ_{Z}, σ_{h}^{0}, R_{ℓ} and $A_{\mathrm{FB}}^{0,\ell}$.
  - $\mathcal{A}_{\mathrm{e}}$ and $\mathcal{A}_{\tau}$ from τ polarisation at LEP.
  - $\mathcal{A}_{\ell}$ from polarised left-right asymmetry by SLD.
  - Heavy quark (b and c) measurements at LEP and SLD: R_{b}, R_{c}, $A_{\mathrm{FB}}^{0,\mathrm{b}}$, $A_{\mathrm{FB}}^{0,\mathrm{c}}$, $\mathcal{A}_{\mathrm{b}}$, $\mathcal{A}_{\mathrm{c}}$.
  - $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ from quark forward-backward asymmetry at LEP.
- W mass m_{W} at LEP and $p\bar{p}$ colliders.
- Top mass m_{t} at $p\bar{p}$ collider Tevatron.
- $\sin^2\theta_{\mathrm{W}} = 1 - m_{\mathrm{W}}^2/m_{\mathrm{Z}}^2$ from νN scattering data by the NuTeV experiment.

These parameters follow the usual definition [1]. Observables are calculated in the SM with a few input parameters. $\alpha(m_Z)$, m_Z and G_μ (the μ decay constant) are chosen as the three basic parameters of the electroweak interaction, and $\alpha_s(m_Z)$ for QCD. In addition the top quark mass, m_t, and Higgs mass, m_H are needed to calculate higher order corrections. The latest version of ZFITTER and TOPAZ0 programs are used [a]. The parameters in the fits are m_Z, m_t, m_H, $\Delta\alpha_h^{(5)}(m_Z)$ and $\alpha_s(m_Z)$, where $\Delta\alpha_h^{(5)}(m_Z)$ is the light quark contribution to the running of α. Figure 1 shows the dependence of χ^2 of the fit using all data as a function of the Higgs mass m_H. The pulls of data are also shown. The minimum χ^2 is 25.5/15 d.o.f corresponding to a fit probability of 4.3%. Data are in general consistent with the SM fit. An exception is the b forward-backward asymmetry $A_{FB}^{0,b}$ which is 3.2σ away from the fit.

The result of m_H from the global fit using all data is

$$m_H = 98^{+58}_{-38} \ \text{GeV} , \tag{1}$$

and the upper limit on m_H is 212 GeV at the 95% CL. The central value of m_H has increased compared to the 2000 summer result [1]. The main reason is due to the update of $\Delta\alpha_h^{(5)}(m_Z)$ (see below). When the old value of $\Delta\alpha_h^{(5)}(m_Z) = 0.02804 \pm 0.0065$ is used, $m_H = 65$ GeV is obtained.

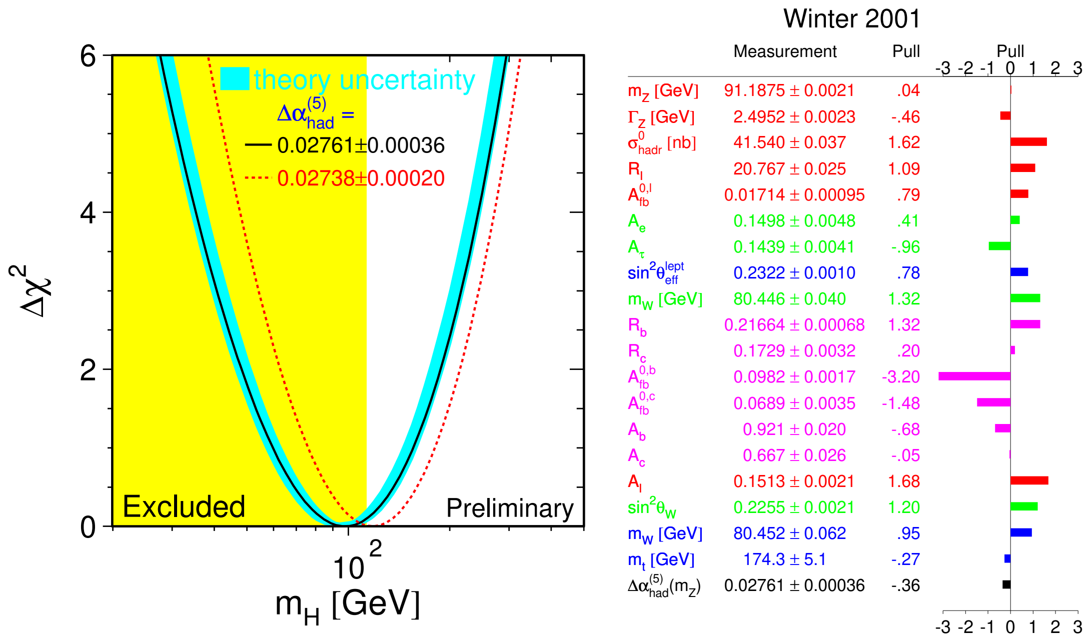

Figure 1: Left: $\Delta\chi^2$ of the fit as a function of m_H. The main result is shown by the solid curve. The associated band represents the estimate of theoretical uncertainty. The dashed curve is the result using a theory-driven determination [4] of $\Delta\alpha_h^{(5)}(m_Z)$. Right: Summary of measurements and the pulls.

2 Discussion on the Updates of Electroweak data

2.1 Measurements at the Z

All LEP collaborations have finalised the Z lineshape and lepton A_{FB} measurements, and the final combination has been made [2]. Final results of $\mathcal{A}_e$ and $\mathcal{A}_\tau$ from τ polarisation measurements are also available from the LEP collaborations. A preliminary combination is made. The SLD collaboration finalised the measurement of $\mathcal{A}_\ell$ using polarised left-right cross-section asymmetry, and polarised left-right-forward-backward asymmetry $\mathcal{A}_{FB,LR}$ for leptonic final states.

[a] Recent two loop calculation [3] of Δr is not used here.

Production rate, $A_{\rm FB}$ and $\mathcal{A}_{\rm FB,LR}$ are measured for b and c quarks from Z decays by the LEP experiments and the SLD experiment. Combined results of $R_{\rm b}^0$, $R_{\rm c}^0$, $A_{\rm FB}^{0,\rm b}$, $A_{\rm FB}^{0,\rm c}$, $\mathcal{A}_{\rm b}$ and $\mathcal{A}_{\rm c}$ are obtained. New preliminary results of $A_{\rm FB}^{\rm b}$ by ALEPH and DELPHI, and $\mathcal{A}_{\rm b}$ and $\mathcal{A}_{\rm c}$ from $\mathcal{A}_{\rm FB,LR}$ and $R_{\rm c}$ by SLD are included.

The $\mathcal{A}_\ell$ from the asymmetries can be represented by the effective electroweak mixing angle $\sin^2\theta_{\rm eff}^{\rm lept}$. Figure 2 shows comparison of results from several asymmetry measurements. The two most precise ones, from the SLD $\mathcal{A}_{\rm LR}$ and the $A_{\rm FB}^{0,\rm b}$ at LEP, show a large difference between them of 3.5 σ. This tendency is not new, but due to the reduced error on $A_{\rm FB}^{0,\rm b}$ the effect becomes sharper. While the SLD $\mathcal{A}_\ell$ prefers low $m_{\rm H}$, $A_{\rm FB}^{0,\rm b}$ corresponds to large $m_{\rm H}$.

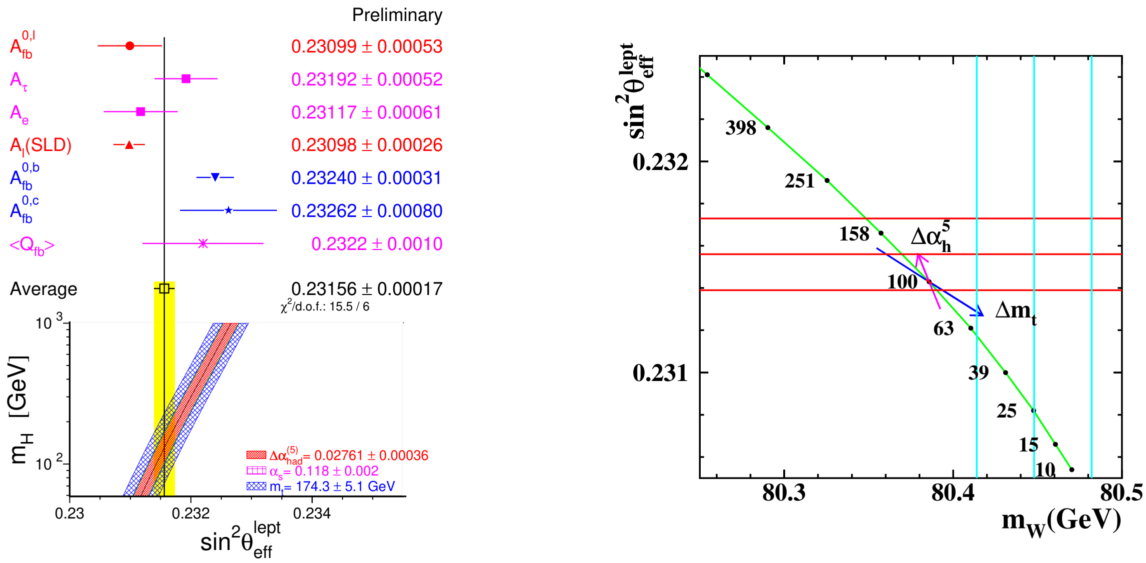

Figure 2: Left: Comparison of determinations of $\sin^2\theta_{\rm eff}^{\rm lept}$ from asymmetry measurements. Also shown is the prediction of the SM as a function of $m_{\rm H}$. Right: Dependence of $\sin^2\theta_{\rm eff}^{\rm lept}$ and $m_{\rm W}$ on $m_{\rm H}$. The arrows indicate the shift of the SM prediction due to uncertainty on $\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z})$ and $m_{\rm t}$ for $m_{\rm H}$ around 100 GeV.

The parameters $\sin^2\theta_{\rm eff}^{\rm lept}$ and $m_{\rm W}$ are sensitive to $m_{\rm H}$. Their dependence on $m_{\rm H}$ is shown in figure 2. The experimental precision of $\sin^2\theta_{\rm eff}^{\rm lept}$ is similar to the uncertainty on the SM prediction arising from $\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z})$. The uncertainty on $m_{\rm t}$ corresponds to the precision of both $\sin^2\theta_{\rm eff}^{\rm lept}$ and $m_{\rm W}$. Further improvement of $m_{\rm t}$ and $\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z})$ would yield significant improvements.

2.2 W mass

During the period of LEP 2, the four LEP collaborations have collected about 40,000 $\rm W^+W^-$ events. Since the 2000 summer conferences, ALEPH and L3 have updated the preliminary $m_{\rm W}$ results including the data from year 2000. The combined preliminary $m_{\rm W}$ result from LEP is:

$$m_{\rm W} = 80.446 \pm 0.026({\rm stat}) \pm 0.030({\rm sys}) \quad ({\rm LEP\ prelim.}). \tag{2}$$

This and the result from $\rm p\bar{p}$ colliders, $m_{\rm W} = 80.452 \pm 0.062 \quad ({\rm p\bar{p}})$, are in good agreement. A current average is : $m_{\rm W} = 80.448 \pm 0.034 \quad ({\rm p\bar{p}} + {\rm LEP})$.

The direct measurement of $m_{\rm W}$ can be compared to indirect determination from the SM fit using the Z and νN data. Figure 3 makes this comparison in the $m_{\rm W}$ - $m_{\rm t}$ plane. Also shown in figure 3 is a comparison of direct $m_{\rm t}$ measurement and the result of the SM fit without using $m_{\rm t}$. These are in agreement each other.

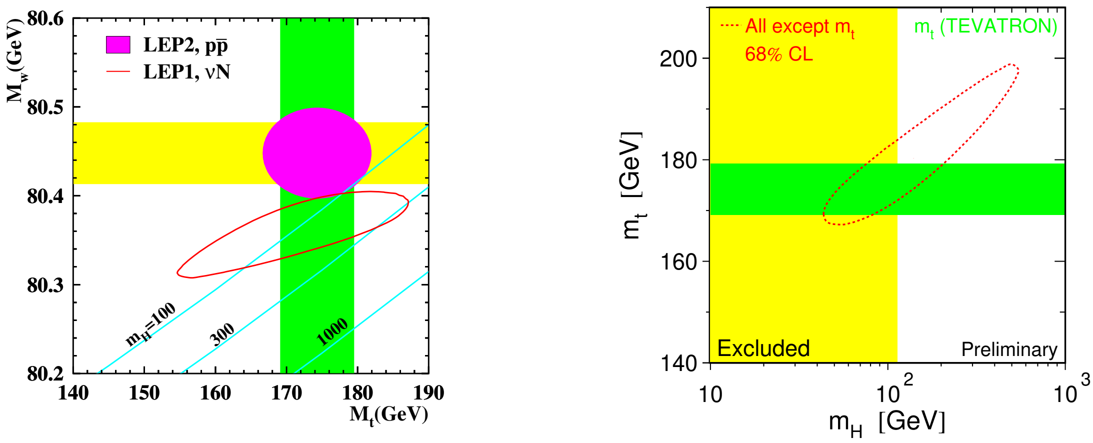

Figure 3: Left: The 68% CL contours in the $m_{\rm W}$-$m_{\rm t}$ plane for the direct and indirect determinations. Right: The 68% CL contour in the $m_{\rm t}$-$m_{\rm H}$ plane and comparison with the direct $m_{\rm t}$ determination.

2.3 $\alpha(m_{\rm Z})$

Though the QED coupling constant $\alpha(0)$ is precisely known, evaluation of $\alpha(m_{\rm Z})$ at the energy scale $m_{\rm Z}$ requires elaboration. While contributions from leptonic loops have been accurately calculated, the largest uncertainty is on the contribution from light quarks. The hadronic contribution $\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z})$ is calculated by a dispersion integral of the total $\rm e^+e^-$ hadronic cross-section, $R = \sigma_{\rm had}/\sigma_{\mu\mu}$. The precision is limited by the error on the R data, in particular at low energies. Attempts have been made to improve the accuracy by adopting QCD at low energy [4]. The BES experiment recently reported a new measurement of R in the energy range 2 - 5 GeV [5]. This allows improved determination of $\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z})$ not relying on QCD. A new evaluation [6] using the BES result is used in the analyses presented here.

$$\Delta\alpha_{\rm h}^{(5)}(m_{\rm Z}) = 0.02761 \pm 0.0036. \tag{3}$$

3 Summary

The combined results of many precision electroweak measurements allows tests of the Standard Model. The results are sensitive to $m_{\rm H}$ and an estimate is obtained from a global fit. Most of the data are consistent with each other and agree with the SM predictions. A large difference in the results interpreted in terms of $\sin^2\theta_{\rm eff}^{\rm lept}$ is observed. In the global SM fit, this manifests itself as a large deviation of $A_{\rm FB}^{0,{\rm b}}$. The indirect $m_{\rm W}$ from the SM fit also shows a slight deviation from the direct measurement. There are many electroweak data still to be finalised. Thanks are due to the LEP electroweak working group and all those who helped me.

References

1. The LEP collaborations, the LEP electroweak working group and SLD heavy flavour and electroweak group, CERN-EP-2000-021; `http://lepewwg.web.cern.ch/LEPEWWG/`.
2. The LEP collaborations and the LEP EWWG, CERN-EP-2000-153.
3. A. Freitas *et al.*, *Phys. Lett.* B **495**, 338 (2000).
4. An example of recent one is: A. D. Martin *et al.*, *Phys. Lett.* B **492**, 69 (2000).
5. The BES collaboration, J. Z. Bai *et al.*, hep-ex/0102003; N. Wu, Moriond QCD 2001.
6. H. Brukhardt and B. Pietrzyk, LAPP-EXP 2001-03, accepted by *Phys. Lett.* B.