Workshop Summary

K. Mönig

DESY-Zeuthen
Platanenallee 6, D-15738 Zeuthen

Abstract

The status of the electroweak precision data as of winter 2003 and the corresponding theoretical calculations are presented. The possible problems within the data and the calculations are discussed in a critical way. If the NuTeV anomaly cannot be explained by unknown effects like higher order parton distribution functions and if it is not just a statistical fluctuation the Standard Model of electroweak interactions is in deep problems. Otherwise the conclusions that the Higgs Boson is relatively light seems quite robust within the Standard Model.

1 Introduction

For a long time the electroweak precision data have been consistent with the Standard Model prediction for a relatively light Higgs with fit probabilities of order 50% [1]. With the more precise data from LEP, SLD and the TEVATRON and especially with the $\sin^2\theta$ measurement from NuTeV in deep inelastic neutrino nucleon scattering the fit probability decreased to 1.3% [2]. This decrease triggered the valid question if the Standard Model is still valid and if we can still believe that the Higgs is light.

The workshop on "Electroweak Precision Data and the Higgs Mass" was organised in order to answer the following questions:

- Can we believe the precision data?
- Can we believe the theoretical calculations?
- Are the data consistent within the model?

Within the workshop the data presented at the winter 2003 conferences have been used [3]. As compared to summer 2002 the W-mass has decreased by 0.7 standard deviations due to a correction of an inadequacy in the ALEPH calorimeter simulation. In addition new theoretical calculations brought the atomic parity violation in Caesium from a 1.5σ deviation exactly to the Standard Model prediction. These changes brought the total χ^2

of the fit to 25.5 for 15 degrees of freedom corresponding to a probability of 4.4%. The left plot in Figure 1 shows the data used in the fit and their agreement with the fit prediction. The largest deviations are still the $\sin^2\theta$ measurement from NuTeV with 2.9σ, the b-quark forward-backward asymmetry from LEP, $A_{\rm FB}^{\rm b}$, with 2.4σ and the left-right asymmetry from SLD, $A_{\rm LR}$, with 1.7σ. $A_{\rm FB}^{\rm b}$ and $A_{\rm LR}$ both measure the effective weak mixing angle $\sin^2\theta_{\mathit{eff}}^{l}$ and deviate by roughly 3σ. How this deviation is distributed between the pulls of the two measurements is determined by the other Higgs mass dependent observables, mainly the W-mass, $m_{\rm W}$. The error breakdown for the worrying observables is shown in Table 1. $m_{\rm W}$ has been included in this table because of its correlation with the $\sin^2\theta_{\mathit{eff}}^{l}$ measurements. Its error breakdown is approximate.

	value	stat	exp. syst	theo. syst	pull
$\sin^2\theta(\nu N)$	0.2277	0.0013	0.0006	0.0006	2.9
$A_{\rm FB}^{\rm b}$	0.0995	0.0015	0.0005	0.0004	2.4
$A_{\rm LR}$	0.1513	0.0018	0.0010	< 0.0001	1.7
$m_{\rm W}$	80.449	0.024	0.019	0.017	1.2

Table 1: Error breakdown of the worrying observables in the electroweak fit. The breakdown for $m_{\rm W}$ is approximate and unofficial.

The global electroweak fit predicts the Higgs mass to be $m_{\rm H} = 91^{+58}_{-37}\,\text{GeV}$. The $\Delta\chi^2$ as a function of the Higgs mass is shown in the right plot of Figure 1. Including theoretical uncertainties, which are shown as the blue band, the 95% c.l. upper limit on $m_{\rm H}$ is 211 GeV.

2 The Consistency of the Data with the direct Higgs Mass Limit

The present situation has been outlined by Michael Chanowitz [4]. If all data are fitted the χ^2 probability is only 1.9%.[1] Even without the NuTeV result the probability increases to only 17%. In addition the central value of the Higgs mass is somewhat lower than the LEP direct search limit decreasing the combined probability, which is defined as the product of the χ^2 probability and the probability that the Higgs is heavier than 114 GeV, to 4.9%. On the contrary, if one assumes that the hadronic measurements of $\sin^2\theta_{\mathit{eff}}^{l}$ are not trustable, the fit probability gets acceptable (71%), however the combined probability falls to about 3.5% which is again worryingly low.

One should, however, notice, that the product of two flat probability distributions is distributed like $-\ln(x)$ with a mean of 0.25, a median of 0.18 and a most probable value of 0. If instead a combined probability $P_c = P_1P_2(1-\ln(P_1P_2))$ is calculated, which is again flat between 0 and 1 if P_1 and P_2 are flat [5], the combined probability for the fit without NuTeV is 20%. For the fit without NuTeV and the hadronic $\sin^2\theta_{\mathit{eff}}^{l}$ measurements P_c is 15%. Both probabilities don't appear worryingly low. Using the procedure of the LEP Electroweak Working group, the 95% c.l. upper limit for the Higgs mass including

[1] Details of the fit in [4] differ slightly from to the standard LEP Electroweak Working Group fit presented in [3].

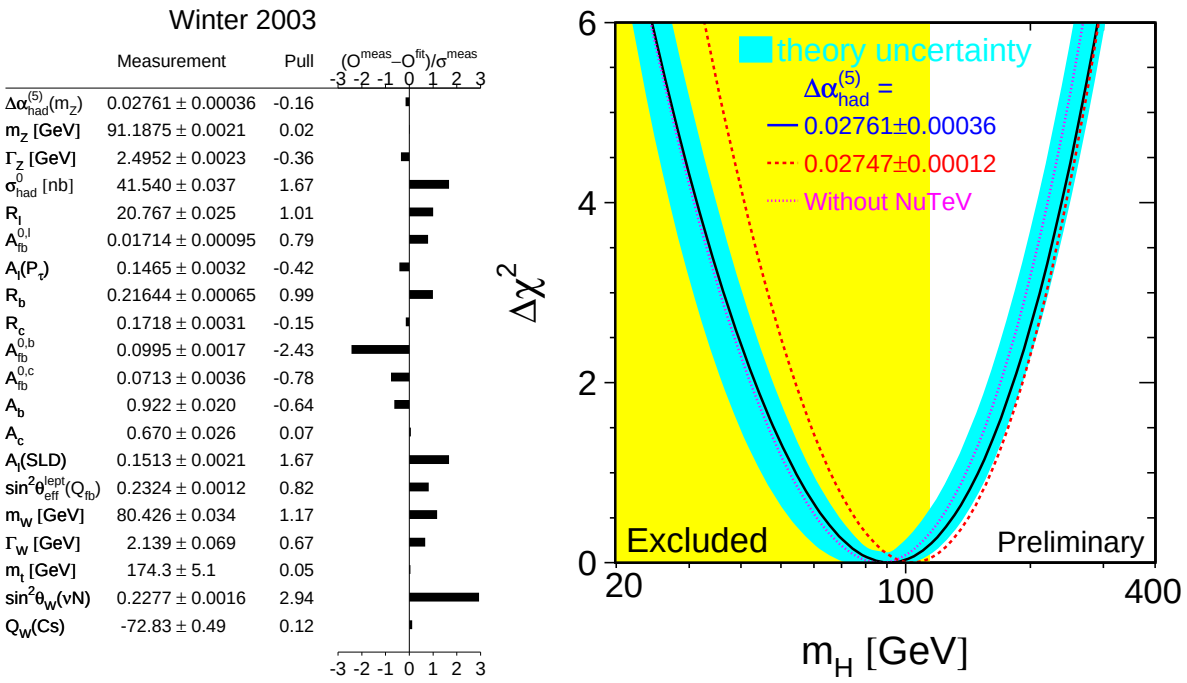

Figure 1: Left: Used data in the electroweak fit and their agreement with the Standard Model; right: $\Delta\chi^2$ as a function of the Higgs mass for the electroweak precision data.

theoretical uncertainties in the last case becomes 149 GeV sufficiently above the search limit.

3 $\sin^2\theta$ from NuTeV

The $\sin^2\theta$ measurement from NuTeV can be discussed in isolation. The measurement contributes roughly nine units to the χ^2, but does not influence any of the fit results significantly. In total there are three possibilities to interpret this measurement. The measurement can be wrong or some theoretical ingredient has been overlooked. In this case it is reasonable to continue without it. The 3σ can be just a statistical fluctuation. In this case also all conclusions don't alter, only all fit probabilities are worsened by this result. As a third possibility the measurement is correct and the deviation from the prediction is real. In this case the Standard Model breaks down in an unknown way and the rest of this writeup becomes meaningless.

The progress in the NuTeV result comes from the separately available neutrino and antineutrino beams [6]. In this case $\sin^2\theta$ can be measured using the Paschos-Wolfenstein relation

$$R^- = \frac{\sigma^\nu_{NC} - \sigma^{\bar\nu}_{NC}}{\sigma^\nu_{CC} - \sigma^{\bar\nu}_{CC}} = \rho^2\left(\frac{1}{2} - \sin^2\theta\right)$$

where σ_{NC} (σ_{CC}) is the cross section for neutral (charged) current interactions. If the kinematic range of all four cross section measurements is the same a lot of theoretical uncertainties cancel, especially the dependence on the charm quark mass which was limiting

this measurement up to now. In practice the charged to neutral current ratio is measured for neutrino and antineutrino beams separately and $\sin^2\theta$ is fitted together with the charm quark mass using a Monte Carlo simulation. Their final result, expressed as an on-shell mixing angle, is

$$\sin^2\theta(\nu N) = 1 - \frac{m_{\mathrm{W}}^2}{m_{\mathrm{Z}}^2} = 0.2277 \pm 0.0013(\mathrm{stat}) \pm 0.0009(\mathrm{syst}).$$

Experimentally the measurement looks solid and it will be assumed that it is correct. Also most theoretical uncertainties have been checked, however a few worries remain [6].

The analysis has been done with leading order parton distribution functions (PDF). For the exact Paschos-Wolfenstein relation the dependence on the parton distribution functions is almost negligible. However due to the non equal kinematic range of the different measurements some dependence might come in, so that it is worth to test the Next-to-leading-order PDFs with errors. The NuTeV result gets modified directly if the PDFs don't obey the assumed symmetries, mainly the assumptions that the strange sea is symmetric ($s(x) = \bar{s}(x)$) and that there is isospin symmetry between the proton and the neutron. A PDF analysis by Barone et al. [7] suggests that a charge asymmetry in the strange sea exists with the right size to explain the NuTeV deviation. This fit is however excluded now with the NuTeV data on charm production [8]. The perturbative QCD corrections have been checked in NLO including approximate experimental cuts and have been found to be rather small [6].

For isospin symmetry breaking the situation is not completely clear. Typical models predict effects one order of magnitude smaller than the experimental error, however the exact size of the violation is hard to quantify.

As another possible explanation nuclear effects are discussed. The anomaly could be explained if the nuclear effects are different in charged and weak neutral currents. However the nuclear effects agree well in charged and electromagnetic neutral currents, rendering this possibility somewhat artificial.

In summary there is no hadronic effect that is a probable candidate to explain the NuTeV anomaly. Nevertheless it is desirable that the data are reanalysed with next to leading order PDFs using primarily NuTeV data.

Another possible worry are QED corrections. These corrections are large and only one complete calculation exists [9]. In the appropriate limits it agrees with calculations taking only muon bremsstrahlung into account [10], but nevertheless it would be good if the full calculation could be checked by another group.

4 Consistency of the High Energy Data

Since apart from the χ^2 value the electroweak fit is not affected by the NuTeV and the atomic parity violation data, in the following only the high energy data will be discussed. The most prominent inconsistency within the high energy data is the 2.9σ discrepancy between $\sin^2\theta^l_{eff}$ derived from A_{LR} and $A_{\mathrm{FB}}^{\mathrm{b}}$. Figure 2 shows $\sin^2\theta^l_{eff}$ derived from the different measurements at LEP and SLD. The average of all numbers yields $\sin^2\theta^l_{eff} = 0.23206 \pm 0.00017$ with $\chi^2/ndf = 10.2/5$ corresponding to 7% probability.

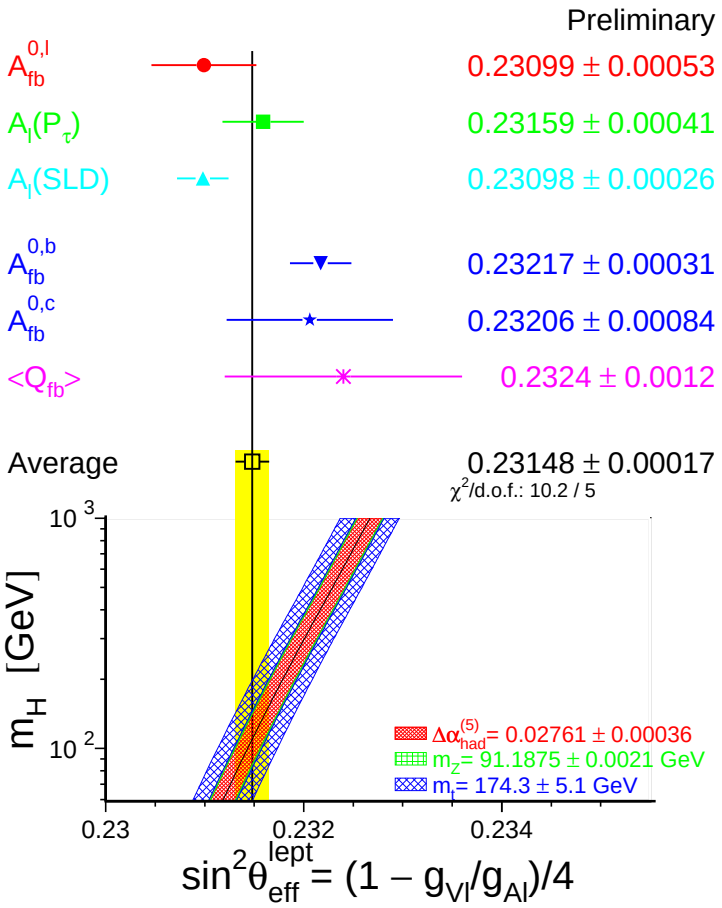

Figure 2: LEP end SLD measurements of the effective weak mixing angle.

It is often argued that the hadronic measurements of $\sin^2\theta^l_{eff}$ cluster around a high value while the leptonic ones are low. Table 2 shows the agreement of the other $\sin^2\theta^l_{eff}$ measurements with $A_{\rm LR}$ and $A^{\rm b}_{\rm FB}$. If $A_{\rm LR}$ is left out of the average the χ^2-probability is 36%, if $A^{\rm b}_{\rm FB}$ is left out, the probability is 43%. From this it can be concluded that apart from the $A_{\rm LR} - A^{\rm b}_{\rm FB}$ discrepancy no further structure can be observed and that the other measurements cannot decide which of the two might have a problem.

The electroweak fit to the high energy data yields $\log(m_{\rm H}) = 1.94 \pm 0.21$ with $\chi^2/{\rm ndf} = 16.6/13$ corresponding to 22% probability which is certainly not unacceptable. The fit results, leaving out the worrying observables one by one are shown in Table 3. Two conclusions can be drawn from these fits. All fits have an acceptable χ^2, however within the Standard Model $m_{\rm W}$ slightly prefers $A_{\rm LR}$ compared to $A^{\rm b}_{\rm FB}$. But even if $A_{\rm LR}$ and $m_{\rm W}$ are excluded from the electroweak fit the data prefer a relatively light Higgs. As a further cross check the high energy data have been fitted replacing all $\sin^2\theta^l_{eff}$ measurements by the LEP/SLD average $\sin^2\theta^l_{eff} = 0.23148 \pm 0.00012$. The fits give identical results to the full one with $\chi^2/{\rm ndf} = 6.5/8$.

Theoretical uncertainties that effect derivations of specific uncertainties, like the luminosity error or the error on QCD corrections to the asymmetries are already included

observable	$\Delta A_{\rm LR}[\sigma]$	$\Delta A_{\rm FB}^{\rm b}[\sigma]$
$A_{\rm FB}^{\ell}$	0	-1.9
$\mathcal{P}_\tau$	$+1.3$	-1.1
$A_{\rm FB}^{\rm c}$	$+1.2$	-0.1
$< Q_{FB} >$	$+1.2$	$+0.2$

Table 2: Deviation of the other $\sin^2\theta_{eff}^{l}$ measurements from $A_{\rm LR}$ and $A_{\rm FB}^{\rm b}$ in units of standard deviations.

left out	$\log(m_{\rm H})$	χ^2/ndf	Prob
$A_{\rm FB}^{\rm b}$	1.72	9.2/12	69%
$A_{\rm LR}$	2.09	13.1/12	36%
$m_{\rm W}$	2.00	15.2/12	24%
$A_{\rm LR}$ & $m_{\rm W}$	2.24	9.6/11	58%

Table 3: Electroweak fits to the high energy data omitting some observables.

in the uncertainties of the observables and thus in the χ^2 definition. On the contrary the uncertainties in the Standard Model predictions of the pseudo observables are not accounted for in the χ^2 definition and might therefore potentially affect the consistency of the data. However, if as a representative test the recent corrections to $m_{\rm W}$ by Freitas et al [11] that are implemented in ZFITTER [12] are activated χ^2 changes by only 0.3 and if, as the authors of [11] suggest, $\sin^2\theta_{eff}^{l}$ is increased simultaneously by $8 \cdot 10^{-5}$, χ^2 changes by additional 0.5 so that the theoretical uncertainties on the prediction of the pseudo-observables do not affect the consistency of the data.

5 The Forward-Backward Asymmetry for b-Quarks

To measure the forward-backward asymmetry for b-quarks at LEP ($A_{\rm FB}^{\rm b}$) [13] three ingredients are needed. b-quark events need to be identified, the quark direction needs to be measured and the quark charge has to be tagged. For the quark direction the thrust axis is always used. Thrust is infrared and collinear safe, so that QCD corrections can be calculated and it is stable against hadronisation effects. For the quark charge determination mainly two methods are in use, leptons and jet-charge/vertex-charge techniques. In the case of leptons one has to separate direct b-decays, $\rm b \to \ell$, from cascade decays, $\rm b \to c \to \ell$, which lead to opposite sign leptons. The separation is mainly done using the lepton momentum, p, and transverse momentum with respect to the jet axis, p_t. These two variables can also be used to identify $\rm b\bar{b}$ events, so that in principle no other flavour tagging algorithms are needed. However, some analyses use lifetime tagging algorithms in addition to cleanup their samples. For the jet-charge analyses the flavour tag always has to be done with lifetime tagging. Because of the high efficiencies and purities of these tags they can be calibrated mostly from data and only some small tagging efficiencies for the background and hemisphere correlations have to be taken from the simulation. The charge tag is a combination of jet-charge, vertex-charge and possibly some additional

information where either a weighting method or a cut method is used. Details vary from experiment to experiment but in all cases the charge tagging efficiencies are calibrated from data comparing the charge assignment in the two hemispheres.

Because of these self calibration procedures $A_{\rm FB}^{\rm b}$ is largely statistics dominated with a LEP-combined result of

$$A_{\rm FB}^{\rm b} = 0.0995 \pm 0.0015(\text{stat}) \pm 0.0005(\text{exp syst}) \pm 0.0004(\text{cor syst}).$$

The largest correlated error in $A_{\rm FB}^{\rm b}$ is due to QCD corrections [14, 15]. For full acceptance using the thrust axis as event direction the total correction is $A_{\rm FB}^{\rm b} = A_{\rm FB}^{\rm b}(\text{no QCD}) \cdot (1 - 0.0354 \pm 0.0063)$. This calculation contains all mass effects in first order and second order for massless quarks. Two calculations exist using the quark direction instead of the thrust direction [16, 17] which agree numerically very well although some conceptual differences exist. One of them [17] exist also for the thrust axis and is thus used by the LEP experiments. The error estimate contains uncertainties from the knowledge of α_s, higher order effects, quark mass effects and fragmentation and is considered to be conservative.

In the analyses b-quarks with high momentum are tagged preferentially, so that the seen QCD corrections are typically a factor two smaller. The bias factor is calculated with the simulation and the applied correction and its error is scaled by this factor. The uncertainty on the LEP-combined $A_{\rm FB}^{\rm b}$ due to QCD corrections is $\Delta A_{\rm FB}^{\rm b}(\text{QCD}) = 0.00035$.

6 $\sin^2\theta_{eff}^{l}$ from Polarised Asymmetries

SLD measures $\sin^2\theta_{eff}^{l}$ mainly with the left-right cross section asymmetry [18]

$$A_{\rm LR}(\sqrt{s}) = \frac{1}{\mathcal{P}} \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}.$$

Apart from Bhabha scattering, where also the t-channel contributes, $A_{\rm LR}$ is independent on the final state and, as long as the detector acceptance is symmetric in the polar angle, independent from experimental cuts. The cross section asymmetry at the SLC running energy can thus be measured basically without systematic uncertainties using a relatively tight hadronic event selection. The largest challenge in the analyses is an accurate measurement of the beam polarisation. With a Compton polarimeter behind the interaction point and some other polarimeters for cross check, SLD was able to measure the beam polarisation with a relative precision of 0.5%. The second largest systematic error source (0.4%) is due to the correction for γZ-interference which depends strongly on the beam energy. The error is mainly given from the statistics of a miniscan to calibrate the energy spectrometer with the Z-mass. The final result from the left-right asymmetry is

$$A_{\rm LR}^0 = 0.1514 \pm 0.0019(\text{stat}) \pm 0.0010(\text{syst}) = 0.1514 \pm 0.0022$$

which, after adding the polarised lepton asymmetries, results in $\mathcal{A}_{\rm e} = 0.1513 \pm 0.0021$. The measurement looks rather robust and there are basically no theoretical uncertainties involved.

7 The W-Boson Mass

The W-boson mass, m_{W}, is measured at present with similar precision in $\mathrm{e^+e^-}$ collisions at LEP and in $\mathrm{p\bar{p}}$ at the TEVATRON.

At LEP W-bosons are produced in pairs and practically all the precision comes from reconstruction of the invariant mass of the decaying Ws [19]. In roughly 45% of the cases both Ws decay hadronically and with the same probability one W decays hadronically and one leptonically. The remaining events, where both Ws decay leptonically, are not usable for the mass determination because of the missing neutrinos. The resolution can be greatly improved by constrained fits, forcing energy-momentum conservation. These fits also reduce some systematic uncertainties, however they make the W-mass dependent on the knowledge of the beam energy and initial state radiation. The experimental precision of the fully hadronic and the mixed decays is roughly equal. However the fully hadronic events have a large uncertainty from colour reconnection and Bose-Einstein correlations between hadrons from the two Ws which is hard to quantify. This uncertainty reduces the weight of the fully hadronic events to about 10% in the combination, so that it plays no significant role in the final result. The LEP-combined W-mass is $m_{\mathrm{W}} = 80.412 \pm 0.0029(\mathrm{stat}) \pm 0.0031(\mathrm{syst})\,\mathrm{GeV}$. The largest systematic uncertainties are hadronisation (18 MeV) and the knowledge of the beam energy (17 MeV).

In $\mathrm{p\bar{p}}$ collisions Ws are produced singly in quark-antiquark annihilation [20]. Only leptonic W-decays can be used, since the hadronic ones are completely hidden in the QCD background. Traditionally the W-mass has been measured from the transverse momentum spectrum of the decay lepton. This leads however to a large uncertainty from the transverse momentum of the produced W. In the current analyses the so called transverse mass $M_t = \sqrt{2p_t^{\ell}p_t^{\nu}(1-\cos\varphi_{\ell\nu})}$ is used where the transverse momentum of the neutrino is reconstructed from the lepton and the hadronic recoil. The main uncertainties are now the leptonic energy scale and the hadronic recoil model. Both can be fixed with leptonic Z decays assuming the Z-mass from LEP, so that the corresponding uncertainties are mainly of statistical nature.

The largest theoretical uncertainties are from the parton distribution functions and from QED effects. The PDF error (15 MeV) is mainly coming from events at the edge of the experimental acceptance. It might increase slightly in future because the input errors in the PDF fits could until recently not be properly propagated to the results. On the other hand they should decrease in future because of the better acceptance of the Run-II detectors and because they can be constrained by TEVATRON data. The QED errors are $10-12$ MeV at present, but improved calculations are under way. The combined W-mass from the TEVATRON is $m_{\mathrm{W}} = 80.454 \pm 0.059\,\mathrm{GeV}$. The error is systematics dominated, but the largest part of the systematic error is of purely statistical nature.

8 The Fine Structure Constant at the Z-scale

For the prediction of the precision observables the fine structure constant at the Z-scale, $\alpha(m_{\mathrm{Z}}^2)$, is needed. Its uncertainty is mainly given by the contribution from the hadronic vacuum polarisation, $\Delta\alpha^{(5)}_{\mathrm{had}}$ [21].

Several calculations of $\Delta\alpha^{(5)}_{\rm had}$ exist that use in different ways the cross section $\sigma(e^+e^- \to$ hadrons) and perturbative QCD. Conservatively the calculations which use data up to $\sqrt{s} = 12\,\mathrm{GeV}$ are taken and the value used by the LEP electroweak working group is the analysis from Burkhardt and Pietrzyk [22] ($\Delta\alpha^{(5)}_{\rm had} = 0.02761 \pm 0.00036$) which leads to uncertainties of $\Delta \sin^2\theta^l_{eff} = 0.00013$ and $\Delta m_{\rm W} = 6.6\,\mathrm{MeV}$ [3]. This analysis uses the final results from BES in the J/Ψ region and preliminary data from CMD2 in the ρ region. CMD2 corrected recently a bug in their normalisation [23]. Using the final CMD2 data with the normalisation correction, the Burkhardt and Pietrzyk analysis gives $\Delta\alpha^{(5)}_{\rm had} = 0.02768 \pm 0.00036$ [24]. An analysis from Jegerlehner, using the same data yields $\Delta\alpha^{(5)}_{\rm had} = 0.027773 \pm 0.000354$ in good agreement with Burkhardt and Pietrzyk [21].

A problem at the moment is the disagreement between the τ spectral functions and the CMD2 data which has been found in the analysis of the hadronic contribution to $g-2$ [25]. The difference in $\Delta\alpha^{(5)}_{\rm had}$ using either the τ or the e^+e^- data without the normalisation correction corresponds to 0.8σ of the used value. Adding the correction it diminishes to about 0.6σ. This discrepancy has to be resolved, especially for the understanding of $g-2$. Some additional information might be obtained from radiative return measurements at DAΦNE. Adding the $e^+e^- - \tau$ discrepancy as an additional error to $\Delta\alpha^{(5)}_{\rm had}$ increases the error on $\log m_{\rm H}$ in the global fit by less than 10%.

The so called "theory driven" analyses, which use perturbative QCD at lower energies decrease the error on $\Delta\alpha^{(5)}_{\rm had}$ by up to a factor of three. They all agree individually with the data driven ones, however if they agree amongst each other is not completely clear. Because of the smaller error it would, however, be desirable that the differences could be understood.

9 The Theoretical Error on the Luminosity

The luminosity at e^+e^- machines is always measured using Bhabha scattering at low angles and the precision critically depends on the theoretical prediction of this process. Within the LEP/SLD pseudo-observables [3] the luminosity error only affects the hadronic pole cross section, $\sigma_0^{\rm had}$. In the electroweak fit a change in $\sigma_0^{\rm had}$ has a modest effect on the strong coupling constant, α_s. In interpretations beyond the Standard Model it affects strongly the number of light neutrino species, which is currently about 2σ below three.

Bhabha scattering at low angles has been modelled accurately and a careful error estimate exists [26]. The theoretical uncertainty for the analyses of the LEP experiments varies between 0.061% and 0.052% roughly matching the experimental precision. The largest single error source (0.04%) is from hadronic vacuum polarisation. This contribution can be reduced substantially with the new data from CMD2, however, this suffers also from the $e^+e^- - \tau$ discrepancy and the error reductions requires that the central values of experimental luminosities will change which makes a new combination of the results necessary.

10 Pseudo Observables

The experiments provide as results so called pseudo observables which are "particle properties" of the W and the Z, like their masses or the ratio of the vector and axial vector

coupling [27]. To arrive at these observables a three step procedure is needed. First the experiments obtain their experimental signals which are per definition not dependent on theoretical input. Out of these signals realistic observables, i.e. cross sections and asymmetries within simple cuts are constructed. This step introduces necessarily already some dependence on QED and QCD. In the last step the pseudo observables are obtained from these realistic observables which introduces further dependence on QED and QCD but also requires corrections due to γ-exchange, γZ interference and imaginary parts of couplings.

It has been checked that this procedure is adequate at the present level of accuracy. The theoretical uncertainties in the extraction of the pseudo observables are typically less than one tenth of the experimental errors. The experiments have performed fits of the Higgs and top-mass and the strong coupling constant either directly to the realistic observables or to the pseudo observables derived from them. Both fits give identical results.

11 Uncertainties in the Electroweak Predictions

For the Higgs mass fit to the electroweak precision data the by far most important observables are the effective weak mixing angle, $\sin^2\theta^l_{eff}$, and the W-mass, $m_{\rm W}$. The status of their predictions and their theoretical uncertainties is discussed in detail in [28]. The derivation of $m_{\rm W}$ from $m_{\rm Z}$ and the Fermi constant $G_{\rm F}$ if now calculated completely in second order [11, 29] and the top quark contributions in third order are known [30]. This leads to an uncertainty in $m_{\rm W}$ of about 3 MeV if the input parameters are known. For $\sin^2\theta^l_{eff}$ important two loop contributions are still missing. If one takes the corresponding contributions to the W mass and varies the on-shell mixing angle $\sin^2\theta = 1 - \frac{m^2_{\rm W}}{m^2_{\rm Z}}$ by this amount one gets an error estimate of $\Delta\sin^2\theta^l_{eff} = 6\cdot 10^{-5}$ which is almost half the experimental error. These uncertainties are included in the width of the blue band in Figure 1.

12 Fits within Supersymmetric Models

Fits to the precision data have also been performed within supersymmetric models [31]. Since Supersymmetry with heavy superpartners looks identical to the Standard Model with a light Higgs, Supersymmetry is clearly consistent with the data. SUSY with light superpartners can fit the W-mass and the anomalous magnetic moment of the muon, $g-2$, somewhat better than the Standard Model, however the $g-2$ interpretation depends strongly on the $\rm e^+e^- - \tau$ problem discussed in section 8. For $\sin^2\theta$ from NuTeV and the $A^{\rm b}_{\rm FB} - A_{\rm LR}$ discrepancy no improvement can be achieved. In general the χ^2 probabilities are similar for the MSSM and the SM fits so that the electroweak precision data cannot distinguish between the two models.

13 Summary and Conclusions

The electroweak precision data are consistent with the Standard Model of electroweak interactions only on the 4% level. The largest deviation is the measurement of $\sin^2\theta$ in

neutrino nucleon scattering with 2.9 standard deviations. This measurement is relatively new and a large effort is still needed to understand it theoretically in all details. However the deviation is still small enough that it can well be a statistical fluctuation.

Apart from this measurement the agreement of the data with the Standard Model fit is satisfactory and the prediction of a light Higgs within this model seems rather robust. The second 3σ effect, the disagreement between $\sin^2\theta^l_{eff}$ from $A_{\rm LR}$ and from $A^{\rm b}_{\rm FB}$ does not spoil the fit quality and in the probability for such a discrepancy to happen one has to take into account that it is the largest difference selected out of many possible combinations. If any single measurement is excluded from the fit the preferred Higgs mass stays rather low. As the first precision observable the W-mass is calculated fully to second order with the top mass dependent corrections known in three loops leading to an error much smaller than the experimental accuracy. For $\sin^2\theta^l_{eff}$ the theoretical uncertainty is about half the experimental error making improvement in the prediction of this quantity very desirable, but there seems no way how the $\sin^2\theta^l_{eff}$ prediction can alter the Higgs mass conclusion. The same is true for $\alpha(m^2_{\rm Z})$ although also here it would be important to understand the problems with this number.

In the near future two improvements on the experimental side can be forseen. The error on the W-mass might shrink somewhat in the final LEP analyses and will shrink substantially with the Run II data from the Tevatron. More importantly, also the error of the top-quark-mass from the Tevatron will shrink by about a factor of two. At present the error on $\sin^2\theta^l_{eff}$ and $m_{\rm W}$ from the $m_{\rm t}$ uncertainty is of the same size as the experimental errors and fully correlated between the two observables. This improvement also makes a better understanding of the theoretical $\sin^2\theta^l_{eff}$ prediction and and $\alpha(m^2_{\rm Z})$ more important.

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