SUMMARY ON THE STATUS OF ELECTROWEAK INTERACTIONS *

G. ALTARELLI

Theoretical Physics Division, CERN
CH-1211 Geneva 23, Switzerland
and
Terza Università di Roma, Rome, Italy

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We describe the status of precision tests of the Standard Model and the implications on the search for new physics.

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Content

1. Introduction

The running of LEP1 was terminated in 1995 and close-to-final results of the data analysis are now available and were presented at the Warsaw Conference in July 1996 [1, 2]. LEP and SLC started in 1989 and the first results from the collider run at the Tevatron were also first presented at about

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that time. I went back to my reporter talk at the Stanford Conference in August 1989 [3] and I found the following best values quoted there for some of the key quantities of interest for the Standard Model (SM) phenomenology: $m_Z = 91120(160)$ MeV; $m_t = 130(50)$ GeV; $\sin^2\theta_{\rm eff} = 0.23300(230)$ and $\alpha_s(m_Z) = 0.110(10)$. Now, after seven years of experimental and theoretical work (in particular with 16 million Z events analysed altogether by the four LEP experiments) the corresponding numbers, as quoted at the Warsaw Conference, are: $m_Z = 91186.3(2.0)$ MeV; $m_t = 175(6)$ GeV; $\sin^2\theta_{\rm eff} = 0.23165(24)$ and $\alpha_s(m_Z) = 0.118(3)$. Thus the progress is quite evident. The top quark has been at last found and the errors on m_Z and $\sin^2\theta_{\rm eff}$ went down by two and one orders of magnitude respectively. At the start the goals of LEP, SLC and the Tevatron were: *(i)* perform precision tests of the SM at the level of a few permil accuracy; *(ii)* count neutrinos ($N_\nu = 2.989(12)$); *(iii)* search for the top quark ($m_t = 175(6)$ GeV); *(iv)* search for the Higgs ($m_{\rm H} > 65$ GeV); *(v)* search for new particles (none found). While for most of the issues the results can be summarized in very few bits, as just shown, the first one is by far more complex. The validity of the SM has been confirmed to a level that I can say was unexpected at the beginning. This is even more true after Warsaw. Contrary to the situation presented at the winter '96 Conferences we are now left with no significant evidence for departures from the SM. The discrepancy on R_c has completely disappeared, that on R_b has been much reduced and so on and no convincing hint of new physics is left in the data (also including the first results from LEP2). The impressive success of the SM poses strong limitations on the possible forms of new physics. Favoured are models of the Higgs sector and of new physics that preserve the SM structure and only very delicately improve it, as is the case for fundamental Higgs(es) and Supersymmetry. Disfavoured are models with a nearby strong non perturbative regime that almost inevitably would affect the radiative corrections, as for composite Higgs(es) or technicolor and its variants.

2. Status of the data

The relevant new electro-weak data together with their SM values are presented in Table I. The SM values correspond to a fit in terms of m_t,$m_{\rm H}$ and $\alpha_s(m_Z)$, described later in Sec. 3, Eq. (9), of all the available data including the CDF/D0 value of m_t . A number of comments on the novel aspects of the data are now in order.

What happened to R_c? The tagging method for charm is based on the reconstruction of exclusive final channels. This is rather complicated and depends on the probability that a charm quark fragments into given hadrons and on branching ratios. A shift in the measured value of the branching ratio for $D^0 \to K^-\pi^+$ and the measurement at LEP of $P(c \to D^*)$, acting on R_c in the same direction, have been sufficient to restore a perfect agreement with the SM.

TABLE I

Quantity	Data (Warsaw '96)	Standard Model	Pull
m_Z (GeV)	91.1863(20)	91.1861	0.1
Γ_Z (GeV)	2.4946(27)	2.4960	−0.5
σ_h (nb)	41.508(56)	41.465	0.8
R_h	20.788(29)	20.757	0.7
R_b	0.2178(11)	0.2158	1.8
R_c	0.1715(56)	0.1723	−0.1
$A^l_{\rm FB}$	0.0174(10)	0.0159	1.4
A_τ	0.1401(67)	0.1458	−0.9
A_e	0.1382(76)	0.1458	−1.0
$A^b_{\rm FB}$	0.0979(23)	0.1022	−1.8
$A^c_{\rm FB}$	0.0733(48)	0.0730	0.1
A_b	SLD direct 0.863(49)	0.935	−2.2
	LEP indir. 0.895(23)		
	Average 0.889(21)		
A_c	SLD direct 0.625(84)	0.667	−0.2
	LEP indir. 0.670(44)		
	Average 0.660(39)		
$\sin^2\theta_{\rm eff}$(LEP-combined)	0.23200(27)	0.23167	1.2
$A_{\rm LR} \to \sin^2\theta_{\rm eff}$	0.23061(47)	0.23167	−2.2
m_W (GeV)	80.356(125)	80.353	0.3
m_t (GeV)	175(6)	172	0.5

What happened to R_b? The old result at the winter '96 Conferences was (assuming the SM value for R_c) $R_b = 0.2202(16)$. The present official average, shown in Table I, is much lower and only 1.8σ away from the SM value. The essential difference is the result of a new-from-scratch, much improved analysis from Aleph, which is given by [1, 2]

$$R_b = 0.2161 \pm 0.0014 \qquad \text{(Aleph)}\,. \tag{1}$$

In fact if one combines the average of the "old" measurements, given above, with the "new" Aleph result one practically finds the official average given by the electroweak LEP working group and reported in Table I. This happens to be true in spite of the fact that in the correct procedure one has to take away the Aleph contribution, now superseded, from the "old" average and add to it some newly presented refinements to some of the "old" analyses.

In view of this it is clear that the change is mainly due to the new Aleph result. There are objective improvements in this new analysis. Five mutually exclusive tags are simultaneously used in order to decrease the sensitivity to individual sources of systematic error. Separate vertices are reconstructed in the two hemispheres of each event to minimize correlations between the hemispheres. The implementation of a mass tag on the tracks from each vertex reduces the charm background that dominates the systematics. As a consequence it appears to me that the weight of the new analysis in the combined value should be larger than what is obtained from the stated errors. In view of the Aleph result the necessity of new physics in R_b has disappeared, while the possibility of some small deviation (more realistic than before) of course still is there. In view of the importance of this issue the other collaborations will go back to their data and freshly reconsider their analyses with the new improvements taken into account.

It is often stated that there is a 3σ deviation on the measured value of A_b vs the SM expectation [1, 2]. But in fact that depends on how the data are combined. In my opinion one should rather talk of a 2σ effect. Let us discuss this point in detail. A_b can be measured directly at SLC taking advantage of the beam longitudinal polarization. SLD finds

$$A_b = 0.863 \pm 0.049 \qquad \text{(SLD direct: } - 1.5\sigma) \,, \tag{2}$$

where the discrepancy with respect to the SM value, $A_b^{\rm SM} = 0.935$, has also been indicated. At LEP one measures $A_b^{\rm FB} = 3/4\ A_e A_b$. As seen in Table I, the value found is somewhat below the SM prediction. One can then derive A_b by using the value of A_e obtained, using lepton universality, from the measurements of $A_l^{\rm FB}$, A_τ, A_e: $A_e = 0.1466(33)$:

$$A_b = 0.890 \pm 0.029 \quad (\text{LEP}\,,\ \text{A}_\text{e}\ \text{from LEP} : - 1.6\sigma)\,. \tag{3}$$

By combining the two above values one obtains

$$A_b = 0.883 \pm 0.025 \quad (\text{LEP} + \text{SLD}, \text{A}_\text{e}\ \text{from LEP} : - 2.1\sigma)\,. \tag{4}$$

The LEP electroweak working group combines the SLD result with the LEP value for A_b modified by adopting for A_e the SLD+LEP average value which also includes $A_{\rm LR}$ from SLD: $A_e = 0.1500(25)$:

$$A_b = 0.867 \pm 0.020 \quad (\text{LEP} + \text{SLD},\ \text{A}_\text{e}\ \text{from LEP+SLD:} - 3.1\sigma)\,. \tag{5}$$

There is nothing wrong with that but, in this case, the well known $\sim 2\sigma$ discrepancy of $A_{\rm LR}$ with respect to A_e measured at LEP and also to the SM, which is not related to the b couplings, further contributes to inflate the number of σ's. Since the b couplings are more suspected than the lepton couplings it is perhaps wiser to obtain A_b from LEP by using the SM value for A_e: $A_e^{\rm SM} = 0.1458(16)$, which gives

$$A_b = 0.895 \pm 0.023 \quad (\text{LEP},\ \mathrm{A_e} = \mathrm{A_e^{SM}} : -1.7\sigma)\,. \tag{6}$$

Finally, combining the last value with SLD we have

$$A_b = 0.889 \pm 0.021 \quad (\text{LEP} + \text{SLD},\ \mathrm{A_e} = \mathrm{A_e^{SM}} : -2.2\sigma)\,, \tag{7}$$

Note that these are the values reported in Table I.

Finally if one looks at the values of $\sin^2\theta_{\rm eff}$ obtained from different observables, shown in Fig. 1, one notices that the value obtained from $A_l^{\rm FB}$ is somewhat low (indeed quite in agreement with the determination by SLD from $A_{\rm LR}$). Looking closer, this is due to the FB asymmetry of the τ lepton that, systematically in all four LEP experiments, has a central value above that of e and μ [1, 2]. The combined value for the τ channel is $A_\tau^{\rm FB}$ =0.0201(18) while the combined average of e and μ is $A_{e/\mu}^{\rm FB} = 0.0162(11)$. On the other hand A_τ and Γ_τ appear normal. In principle these two facts are not incompatible because the FB lepton asymmetries are very small. The extraction of $A_\tau^{\rm FB}$ from the data on the angular distribution of τ's could be biased if the imaginary part of the continuum was altered by some non universal new physics effect. But a more trivial experimental problem is at the moment more plausible. The distribution of measured values of $\sin^2\theta_{\rm eff}$ as it is summarized in Fig. 1 is somewhat wide (χ^2/d.o.f. =2.13) with $A_l^{\rm FB}$ and $A_{\rm LR}$ far on one side and $A_b^{\rm FB}$ on the other side. In view of this it would perhaps be appropriate to enlarge the error on the average from $\pm$ 0.00024 up to $\pm\sqrt{2.13}\ 0.00024 = \pm 0.00034$, according to the recipe adopted by the Particle Data Group. Thus from time to time in the following we will use the average

$$\sin^2\theta_{\rm eff} = 0.23165 \pm 0.00034\,. \tag{8}$$

3. Precision electroweak data and the standard model

For the analysis of electroweak data in the SM one starts from the input parameters: some of them, α, G_F and m_Z, are very well measured, some other ones, $m_{f_{\rm light}}$, m_t and $\alpha_s(m_Z)$ are only approximately determined while $m_{\rm H}$ is largely unknown. With respect to m_t the situation has much improved since the CDF/D0 direct measurement of the top quark mass [4]. From the input parameters one computes the radiative corrections [5, 6] to a sufficient precision to match the experimental capabilities. Then one compares the theoretical predictions and the data for the numerous observables which have been measured, checks the consistency of the theory and derives constraints on m_t, $\alpha_s(m_Z)$ and hopefully also on $m_{\rm H}$.

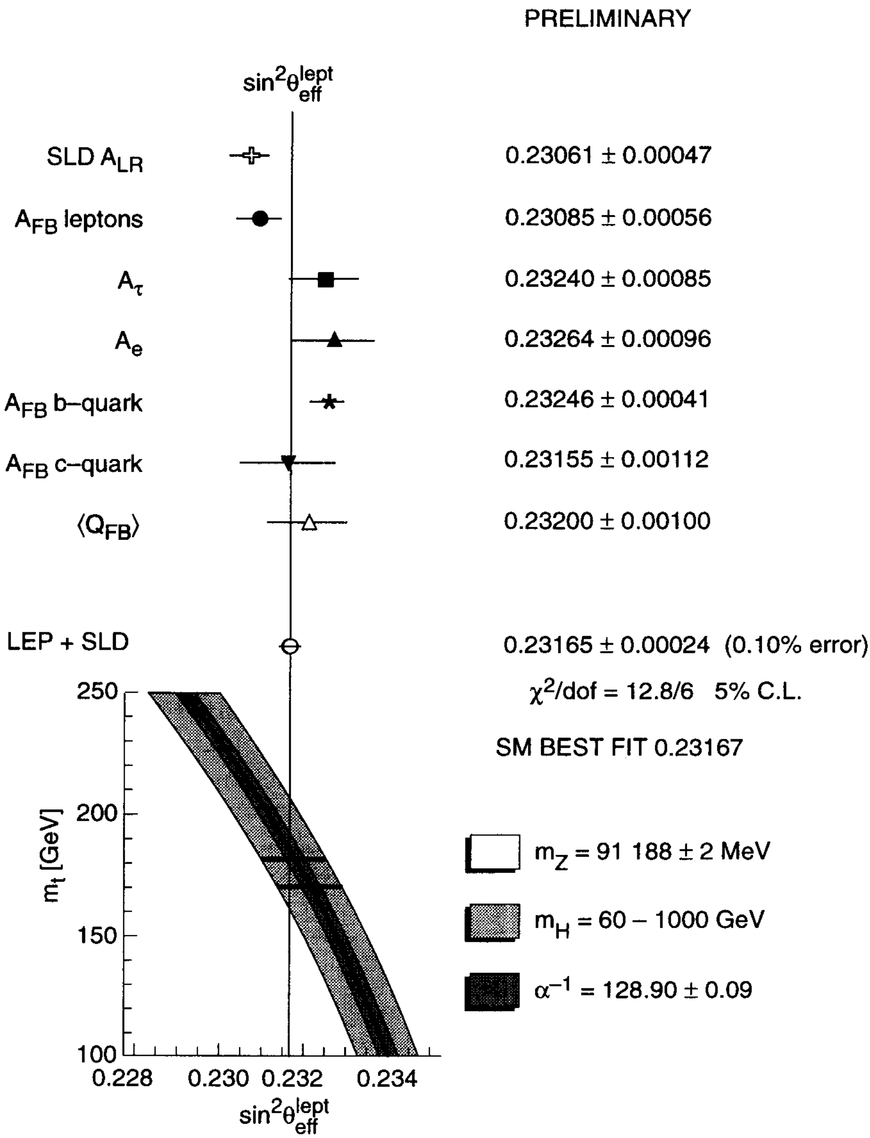

Fig. 1.

Some comments on the least known of the input parameters are now in order. The only practically relevant terms where precise values of the light quark masses, $m_{f_{\text{light}}}$, are needed are those related to the hadronic contribution to the photon vacuum polarization diagrams, that determine

$\alpha(m_Z)$. This correction is of order 6%, much larger than the accuracy of a few per mill of the precision tests. Fortunately, one can use the actual data to, in principle, solve the related ambiguity. But we shall see that the left over uncertainty is still one of the main sources of theoretical error.

Recently there has been a lot of activity on this subject and a number of independent new estimates of $\alpha(m_Z)$ have appeared in the literature [7]. In Table II we report the results of these new computations together with the most significant earlier determinations (previously the generally accepted value was that of Jegerlehner in 1991 [11]).

TABLE II

Author	Year and Ref.	$\Delta\alpha(m_Z^2)_h$	$\alpha(m_Z^2)^{-1}$
Jegerlehner	1986 [8]	0.0285 ± 0.0007	128.83 ± 0.09
Lynn *et al.*	1987 [9]	0.0283 ± 0.0012	128.86 ± 0.16
Burkhardt *et al.*	1989 [10]	0.0287 ± 0.0009	128.80 ± 0.12
Jegerlehner	1991 [11]	0.0282 ± 0.0009	128.87 ± 0.12
Swartz	1994 [12]	0.02666 ± 0.00075	129.08 ± 0.10
Swartz (rev.)	1995 [13]	0.0276 ± 0.0004	128.96 ± 0.06
Martin *et al.*	1994 [14]	0.02732 ± 0.00042	128.99 ± 0.06
Nevzorov *et al.*	1994 [15]	0.0280 ± 0.0004	128.90 ± 0.06
Burkhardt *et al.*	1995 [16]	0.0280 ± 0.0007	128.89 ± 0.09
Eidelman *et al.*	1995 [17]	0.0280 ± 0.0007	128.90 ± 0.09

The differences among the recent determinations are due to the procedures adopted for fitting the data and treating the errors, for performing the numerical integration *etc.* The differences are also due to the threshold chosen to start the application of perturbative QCD at large s and to the value adopted for $\alpha_s(m_Z)$. For example, in its first version Swartz [12] used parametric forms to fit the data, while most of the other determinations use a trapezoidal rule to integrate across the data points. It was observed that the parametric fitting introduces a definite bias [13]. In fact Swartz gets systematically lower results for all ranges of s. In its revised version [13] Swartz improves his numerical procedure. Martin et al [14] use perturbative QCD down to $\sqrt{s} = 3$ GeV (except in the upsilon region) with $\alpha_s(m_Z) = 0.118 \pm 0.007$. Eidelman *et al.* [17] only use perturbative QCD for $\sqrt{s} > 40$ GeV and with $\alpha_s(m_Z) = 0.126 \pm 0.005$, *i.e.* the value found at LEP. They use the trapezoidal rule. Nevzorov *et al.* [15] make a rather crude model with one resonance per channel plus perturbative QCD with $\alpha_s(m_Z) = 0.125 \pm 0.005$. Burkhardt *et al.* [16] use perturbative QCD for $\sqrt{s} > 12$ GeV but with a very conservative error on $\alpha_s(m_Z) = 0.124 \pm 0.021$. This value was determined in Ref. [18] from e^+e^- data below LEP energies. The excitement produced by the original claim by Swartz [12] of a relatively large discrepancy with respect to the value obtained by Jegerlehner [11] resulted in a useful debate. As a conclusion of this reevaluation of the problem the method of Jegerlehner has proven its solidity. As a consequence I think that the recent update by Eidelman and Jegerlehner [17] gives a quite reliable result (which is the one used by the LEP groups and in the following). Also I do not think that a smaller error than quoted by these authors can be justified.

As for the strong coupling $\alpha_s(m_Z)$ we will discuss in detail the interesting recent developments in Sec. 4. The world average central value is quite stable around 0.118, before and after the most recent results. The error is going down because the dispersion among the different measurements is much smaller in the most recent set of data. The error is taken between ± 0.003 and ± 0.005 depending on how conservative one wants to be. Thus in the following our reference value will be $\alpha_s(m_Z) = 0.118 \pm 0.005$.

Finally a few words on the current status of the direct measurement of m_t. The error is rapidly going down. It was ± 9 GeV before the Warsaw Conference, it is now ± 6 GeV [4]. I think one is soon approaching a level where a more careful investigation of the effects of colour rearrangement on the determination of m_t is needed. One wants to determine the top quark mass, defined as the invariant mass of its decay products (*i.e.* $b + W$ + gluons + γ's). However, due to the need of colour rearrangement, the top quark and its decay products cannot be really isolated from the rest of the event. Some smearing of the mass distribution is induced by this colour cross talk which involves the decay products of the top, those of the antitop and also the fragments of the incoming (anti)protons. A reliable quantitative computation of the smearing effect on the m_t determination is difficult because of the importance of non perturbative effects. An induced error of the order of a few GeV on m_t is reasonably expected. Thus further progress on the m_t determination demands tackling this problem in more depth.

The measured top production cross section is in fair agreement with the QCD prediction but the central value is a bit large (see Fig. 2) [19]. The world average for the cross section times branching ratio is $\sigma B = 6.4 \pm 1.3$ pb and the QCD prediction for σ is $\sigma_{\text{QCD}} = 4.75 \pm 0.65$ pb. Thus the branching ratio $B = B(t \to bW)$ cannot be far from 100% unless there is also some additional production mechanism from new physics.

In order to appreciate the relative importance of the different sources of theoretical errors for precision tests of the SM, I report in Table III a comparison for the most relevant observables, evaluated using Ref. [20].

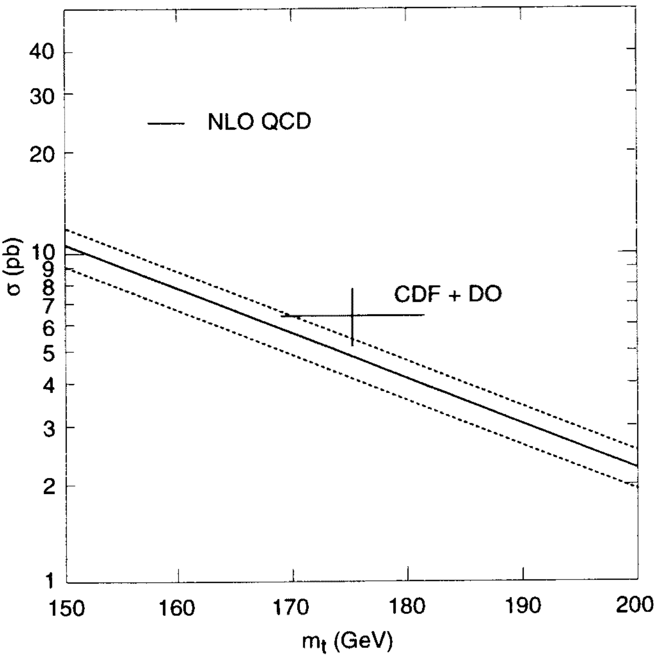

Fig. 2.

TABLE III

Errors from different sources: $\Delta_{\rm expnow}$ is the present experimental error; $\Delta\alpha^{-1}$ is the impact of $\Delta\alpha^{-1} = \pm 0.09$; $\Delta_{\rm th}$ is the estimated theoretical error from higher orders; Δ_{m_t} is from $\Delta_{m_t} = \pm 6$GeV; $\Delta_{m_{\rm H}}$ is from $\Delta_{m_{\rm H}} = 60$–1000 GeV; $\Delta\alpha_s$ corresponds to $\Delta\alpha_s = \pm 0.005$. The epsilon parameters are defined in Ref. [21].

	$\Delta^{\rm exp}_{\rm now}$	$\Delta\alpha^{-1}$	$\Delta_{\rm th}$	Δm_t	$\Delta m_{\rm H}$	$\Delta\alpha_s$
Γ_Z (MeV)	± 2.7	± 0.7	± 0.8	± 1.4	± 4.6	± 2.7
σ_h (pb)	56	1	4.3	3.3	4	2.7
$R_h \cdot 10^3$	29	4.3	5	2	13.5	34
Γ_l (keV)	110	11	15	55	120	6
$A^l_{\rm FB} \cdot 10^4$	10	4.2	1.3	3.3	13	0.3
$\sin^2\theta \cdot 10^4$	~3	2.3	0.8	1.9	7.5	0.15
m_W (MeV)	125	12	9	37	100	4
$R_b \cdot 10^4$	11	0.1	1	2.1	0.25	0
$\varepsilon_1 \cdot 10^3$	1.3		~0.1			0.4
$\varepsilon_3 \cdot 10^3$	1.4	0.6	~0.1			0.25
$\varepsilon_b \cdot 10^3$	3.2		~0.1			2

What is important to stress is that the ambiguity from m_t, once by far the largest one, is by now smaller than the error from $m_{\rm H}$. We also see from Table III that the error from $\Delta\alpha(m_Z)$ is especially important for $\sin^2\theta_{\rm eff}$ and, to a lesser extent, is also sizeable for Γ_Z and ε_3.

We now discuss fitting the data in the SM. As the mass of the top quark is now rather precisely known from CDF and D0 one must distinguish two different types of fits. In one type one wants to answer the question: is m_t from radiative corrections in agreement with the direct measurement at the Tevatron? For answering this interesting but somewhat limited question, one must clearly exclude the CDF/D0 measurement of m_t from the input set of data. Fitting the data in terms of m_t, $m_{\rm H}$ and $\alpha_s(m_Z)$ one finds the results shown in Table IV [2].

TABLE IV

	LEP	LEP + SLD	All $\neq m_t$
$\alpha_s(m_Z)$	0.1211(32)	0.1200(32)	0.1202(33)
m_t (GeV)	155(14)	156(11)	157(10)
$m_{\rm H}$ (GeV)	86(+202 − 14)	48(+83 − 26)	149(+148 − 82)
$(m_{\rm H})_{\rm MAX}$ at 1.64σ	417	184	392
χ^2/dof	5/8	18/11	18/13

The extracted value of m_t is typically a bit too low. For example, from LEP data alone one finds $m_t = 155(14)$ GeV. But this is simply due to R_b being taken from the official average: $R_b = 0.2178(11)$. If $m_{\rm H}$ is not fixed the fit prefers lower values of m_t to adjust R_b. In fact, removing R_b from the input data increases the central value of m_t from 155 to 171 GeV. In this context it is important to remark that fixing $m_{\rm H}$ at 300 GeV, as is often done, is by now completely obsolete, because it introduces a strong bias on the fitted value of m_t. The change induced on the fitted value of m_t when moving $m_{\rm H}$ from 300 to 65 or 1000 GeV is in fact larger than the error on the direct measurement of m_t.

In a more general type of fit, *e.g.* for determining the overall consistency of the SM or the best present estimate for some quantity, say m_W, one should of course not ignore the existing direct determination of m_t. Then, from all the available data, including $m_t = 175(6)$ GeV, by fitting m_t, $m_{\rm H}$ and $\alpha_s(m_Z)$ one finds (with $\chi^2/{\rm d.o.f.} = 19/14$) [2] (see also [22]):

$$\begin{aligned} m_t &= 172 \pm 6 \text{ GeV}\,, \\ m_{\rm H} &= 149 + 148 - 82 \text{ (or } m_{\rm H} < 392 \text{ GeV at } 1.64\sigma)\,, \\ \alpha_s(m_Z) &= 0.1202 \pm 0.0033\,. \end{aligned} \tag{9}$$

This is the fit reported in Table I. The corresponding fitted values of $\sin^2\theta_{\text{eff}}$ and m_W are:

$$\begin{aligned} \sin^2\theta_{\text{eff}} &= 0.23167 \pm 0.0002\,, \\ m_W &= 80.352 \pm 0.034 \text{ GeV}\,. \end{aligned} \tag{10}$$

The error of 34 MeV on m_W clearly sets up a goal for the direct measurement of m_W at LEP2 and the Tevatron.

4. Status of $\alpha_s(m_Z)$

There are important developments in the experimental determination of $\alpha_s(m_Z)$ [23]. There is now a much better agreement among different methods of measuring $\alpha_s(m_Z)$. In fact the value of $\alpha_s(m_Z)$ from the Z line shape went down and the values from scaling violations in deep inelastic scattering and from lattice QCD went up. We will discuss these developments in detail in the following.

The value of $\alpha_s(m_Z)$ from the Z line shape (assuming that the SM is valid for Γ_h, which is not completely evident in view of R_b) went down for two reasons [1, 2]. First the value extracted from R_h only, which was $\alpha_s(m_Z) = 0.126(5)$ is now down to $\alpha_s(m_Z) = 0.124(5)$. Second the value from all the Z data changed from $\alpha_s(m_Z) = 0.124(5)$ down to $\alpha_s(m_Z) = 0.120(4)$ which corresponds to the fit in Eq. (9) . The main reason for this decrease is the new value of σ_h (with a sizably smaller error than in the past) that prefers a smaller $\alpha_s(m_Z)$. However this determination depends on the assumption that Γ_b is given by the SM. We recall that R_b itself with good approximation is independent of α_s, but its deviation from the SM would indicate an anomaly in Γ_b hence in Γ_h. Taking a possible anomaly in R_b into account the Z line shape determination of $\alpha_s(m_Z)$ becomes approximately:

$$\alpha_s(m_Z) = (0.120 \pm 0.004) - 4\delta R_b\,. \tag{11}$$

If the Aleph value for R_b (see Eq. (1) is adopted the central value of $\alpha_s(m_Z)$ is not much changed but of course the error on δR_b is transferred on $\alpha_s(m_Z)$ which becomes

$$\alpha_s(m_Z) = (0.119 \pm 0.007)\,. \tag{12}$$

If, instead, one takes R_b from Table I one obtains a much smaller central value:

$$\alpha_s(m_Z) = (0.112 \pm 0.006)\,. \tag{13}$$

Summarizing: the Z line shape result for $\alpha_s(m_Z)$, obtained with the assumption that Γ_h is given by the SM, went down a bit. The central value could be shifted further down if R_b is in excess with respect to the SM.

While $\alpha_s(m_Z)$ from LEP goes down $\alpha_s(m_Z)$ from the scaling violations in deep inelastic scattering goes up. To me the most surprising result from Warsaw was the announcement by the CCFR collaboration that their well known published analysis of $\alpha_s(m_Z)$ from xF_3 and F_2 in neutrino scattering off Fe target is now superseded by a reanalyzes of the data based on better energy calibration [24]. We recall that their previous result, $\alpha_s(m_Z) = 0.111(3\ \mathrm{exp})$, being in perfect agreement with the value obtained from e/μ beam data by BCDMS and SLAC combined [25], $\alpha_s(m_Z) = 0.113(3\ \mathrm{exp})$, convinced most of us that the average value of $\alpha_s(m_Z)$ from deep inelastic scattering was close to 0.112. Now the new result presented in Warsaw is [24, 23]

$$\alpha_s(m_Z) = 0.119 \pm 0.0015(\mathrm{stat}) \pm 0.0035(\mathrm{syst}) \pm 0.004(\mathrm{th})\ \ (\mathrm{CCFR\ revised}), \tag{14}$$

where the error also includes the collaboration estimate of the theoretical error from scale and renormalization scheme ambiguities. As a consequence the new combined value of $\alpha_s(m_Z)$ from scaling violations in deep inelastic scattering is given by

$$\alpha_s(m_Z) = 0.115 \pm 0.006 \tag{15}$$

with my more conservative estimate, of the common theoretical error (Schmelling, the reporter in Warsaw quotes ± 0.005 [23]). If we compare with LEP we see that, whatever your choice of theoretical errors is, there is no need for any new physics in R_b to fill the gap between the two determinations of $\alpha_s(m_Z)$.

Finally $\alpha_s(m_Z)$ from lattice QCD is also going up [26]. The main new development is a theoretical study of the error associated with the extrapolation from unphysical values of the light quark masses which is used in the lattice extraction of $\alpha_s(m_Z)$ from quarkonium splittings. According to Ref. [27] this effect amounts to a shift upward of $+0.003$ in the value of $\alpha_s(m_Z)$. From the latest unquenched determinations of $\alpha_s(m_Z)$, Flynn, the reporter in Warsaw [26], gives an average = 0.117(3). But the lattice measurements of $\alpha_s(m_Z)$ moved very fast over the last few years. At the Dallas conference in 1992 the quoted value (from quenched computations) was $\alpha_s(m_Z) = 0.105(4)$ [28], while at Beijing in 1995 the claimed value was $\alpha_s(m_Z)$=0.113(2) but the error was estimated to be ± 0.007 by the reporter Michael [29]. So, with the present central value, I will keep this more conservative error in the following:

$$\alpha_s(m_Z) = 0.117 \pm 0.007\,. \tag{16}$$

To my knowledge, there are no other important new results on the determination of $\alpha_s(m_Z)$. Adding a few more well established measurements of

$\alpha_s(m_Z)$ we have the following Table V, where the errors denote my personal view of the weights the different methods should have in the average (in brackets Th and Exp are labels that indicate whether the dominant error is theoretical or experimental):

TABLE V

Measurements	$\alpha_s(m_Z)$	
R_τ	0.122 ± 0.007	(Th)
Deep Inelastic Scattering	0.115 ± 0.006	(Th)
Y_{decay}	0.112 ± 0.010	(Th)
Lattice QCD	0.117 ± 0.007	(Th)
$Re^+e^-(\sqrt{s} < 62$ GeV$)$	0.124 ± 0.021	(Exp)
Frag.functs in e^+e^-	0.124 ± 0.010	(Th)
Jets in e^+e^- at and below the Z	0.121 ± 0.008	(Th)
Z line shape (taking R_b from Aleph)	0.119 ± 0.007	(Exp)

The average value given by

$$\alpha_s(m_Z) = 0.118 \pm 0.003 \tag{17}$$

is very stable. The same value was quoted by the reporter Schmelling at the Warsaw Conference [23], with a different treatment of errors. Had we used $\alpha_s(m_Z)$ from the Z line shape assuming the SM value for R_b , *i.e.* $\alpha_s(m_Z) = 0.120 \pm 0.004$, the average value would have been 0.119. To be safe one could increase the error to ± 0.005.

5. Electroweak data and new physics

We now discuss an update of the epsilon analysis [21]. The epsilon method is more complete and less model dependent than the similar approach based on the variables S, T and U [30–33] which, from the start, necessarily assumes dominance of vacuum polarization diagrams from new physics and truncation of the q^2 expansion of the corresponding amplitudes. In a completely model independent way we define [21] four variables, called ε_1, ε_2, ε_3 and ε_b, that are precisely measured and can be compared with the predictions of different theories. The quantities ε_1, ε_2, ε_3 and ε_b are defined in Ref. [21] in one to one correspondence with the set of observables m_W/m_Z, Γ_l, A_l^{FB} and R_b. The four epsilons are defined without need of specifying m_t and m_{H}. In the SM, for all observables at the Z pole, the whole dependence on m_t and m_{H} arising from one-loop diagrams only enters through the epsilons. The same is true for any extension of the SM such that all possible deviations only occur through vacuum polarization diagrams and/or the $Z \to b\bar{b}$ vertex.

The epsilons represent an efficient parameterization of the small deviations from what is solidly established in a way that is unaffected by our relative ignorance of m_t and m_H. The variables S, T, U depend on m_t and m_H because they are defined as deviations from the complete SM prediction for specified m_t and m_H. Instead the epsilons are defined with respect to a reference approximation which does not depend on m_t and m_H. In fact the epsilons are defined in such a way that they are exactly zero in the SM in the limit of neglecting all pure weak loop-corrections (*i.e.* when only the predictions from the tree level SM plus pure QED and pure QCD corrections are taken into account). This very simple version of improved Born approximation is a good first approximation according to the data. Values of the epsilons in the SM are given in Table VI [20, 21].

TABLE VI

Values of the epsilons in the SM as functions of m_t and m_H as obtained from recent versions [20] of ZFITTER and TOPAZ0. These values (in 10^{-3} units) are obtained for $\alpha_s(m_Z) = 0.118$, $\alpha(m_Z) = 1/128.87$ but the theoretical predictions are essentially independent of $\alpha_s(m_Z)$ and $\alpha(m_Z)$ [21].

m_t (GeV)	ε_1 m_H (GeV) =			ε_2 m_H (GeV) =			ε_3 m_H (GeV) =			ε_b All m_H
	65	300	1000	65	300	1000	65	300	1000	
150	3.47	2.76	1.61	−6.99	−6.61	−6.4	4.67	5.99	6.66	−4.45
160	4.34	3.59	2.38	−7.29	−6.9	−6.69	4.6	5.91	6.55	−5.28
170	5.25	4.46	3.21	−7.6	−7.2	−6.97	4.52	5.82	6.43	−6.13
180	6.2	5.37	4.1	−7.93	−7.51	−7.24	4.42	5.72	6.34	−7.02
190	7.2	6.33	5.07	−8.29	−7.81	−7.49	4.31	5.6	6.26	−7.95
200	8.26	7.34	6.1	−8.65	−8.12	−7.75	4.19	5.49	6.19	−8.92

By combining the value of m_W/m_Z with the LEP results on the charged lepton partial width and the forward-backward asymmetry, all given in Table I, and following the definitions of Ref. [21], one obtains:

$$\begin{aligned} \varepsilon_1 &= \Delta\rho = (4.3 \pm 1.4)10^{-3}, \\ \varepsilon_2 &= (-6.9 \pm 3.4)10^{-3}, \\ \varepsilon_3 &= (3.0 \pm 1.8)10^{-3}. \end{aligned} \tag{18}$$

Finally, by adding the value of R_b listed in Table I and using the definition of ε_b given in Ref. [21] one finds (note that ε_b is defined through R_b and the expression of R_b as function of ε_b is practically independent on α_s):

$$\varepsilon_b = (-1.1 \pm 2.8)10^{-3} \qquad (R_b \text{ from Table I}) \tag{19}$$

This is the value that corresponds to the official average reported in Table I which I have criticised. Here in this epsilon analysis we prefer to use the Aleph value for R_b, ($R_b = 0.2161(14)$), which leads to

$$\varepsilon_b = (-5.7 \pm 3.4)10^{-3} \qquad (R_b \text{ from Aleph})\,. \tag{20}$$

To proceed further and include other measured observables in the analysis we need to make some dynamical assumptions. The minimum amount of model dependence is introduced by including other purely leptonic quantities at the Z pole such as $A_{\tau_{\rm pol}}$, A_e (measured from the angular dependence of the τ polarisation) and $A_{\rm LR}$ (measured by SLD). For this step, one is simply relying on lepton universality. Note that the choice of $A_l^{\rm FB}$ as one of the defining variables appears at present not particularly lucky because the corresponding determination of $\sin^2\theta_{\rm eff}$ markedly underfluctuates with respect to the average value (see Fig. 1). We then use the combined value of $\sin^2\theta_{\rm eff}$ obtained from the whole set of asymmetries measured at LEP and SLC with the error increased according to Eq. (8) and the related discussion. At this stage the best values of ε_1, ε_2, ε_3 and ε_b are modified according to

$$\begin{aligned}
\varepsilon_1 &= \Delta\rho = (4.7 \pm 1.3)10^{-3}\,,\\
\varepsilon_2 &= (-7.8 \pm 3.3)10^{-3}\,,\\
\varepsilon_3 &= (4.8 \pm 1.4)10^{-3}\,,\\
\varepsilon_b &= (-5.7 \pm 3.4)10^{-3}\,.
\end{aligned} \tag{21}$$

In Fig. 3 we report the 1σ ellipse in the ε_1-ε_3 plane that correspond to this set of input data.

All observables measured on the Z peak at LEP can be included in the analysis provided that we assume that all deviations from the SM are only contained in vacuum polarisation diagrams (without demanding a truncation of the q^2 dependence of the corresponding functions) and/or the $Z \to b\bar{b}$ vertex. From a global fit of the data on m_W/m_Z, Γ_T, R_h, σ_h, R_b and $\sin^2\theta_{\rm eff}$ (for LEP data, we have taken the correlation matrix for Γ_T, R_h and σ_h given by the LEP experiments [2], while we have considered the additional information on R_b and $\sin^2\theta_{\rm eff}$ as independent) we obtain:

$$\begin{aligned}
\varepsilon_1 &= \Delta\rho = (4.7 \pm 1.3)10^{-3}\,,\\
\varepsilon_2 &= (-7.8 \pm 3.3)10^{-3}\,,\\
\varepsilon_3 &= (4.7 \pm 1.4)10^{-3}\,,\\
\varepsilon_b &= (-4.8 \pm 3.2)10^{-3}\,.
\end{aligned} \tag{22}$$

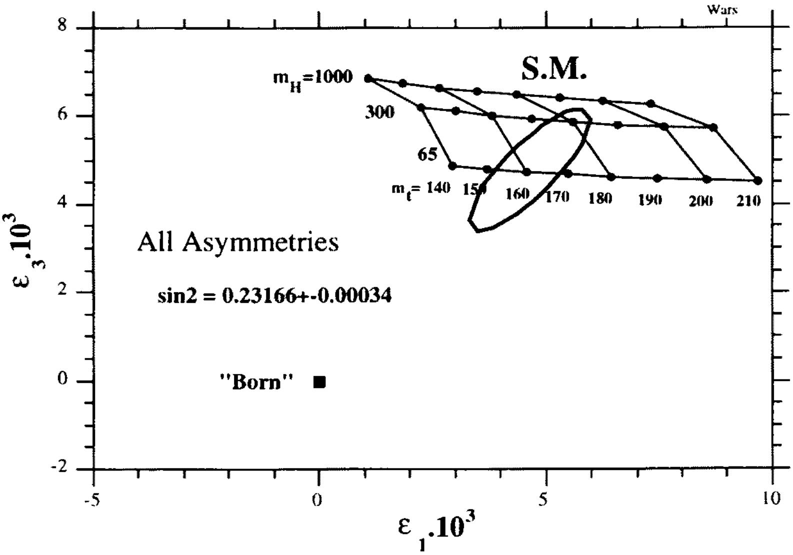

Fig. 3.

The comparison of theory and experiment in the planes ε_1-ε_3 and ε_b-ε_3 is shown in Figs 4 and 5, respectively. Note that adding the hadronic quantities hardly makes a difference in the ε_1-ε_3 plot in comparison with Fig. 3 which only included the leptonic variables. In other words the inclusive hadronic quantities do not show any peculiarity. A number of interesting features are clearly visible from this plot. First, the good agreement with the SM and the evidence for weak corrections, measured by the distance of the data from the improved Born approximation point (based on tree level SM plus pure QED or QCD corrections). Second, we see the preference for light Higgs or, equivalently, the tendency for ε_3 to be rather on the low side (both features are now somewhat less pronounced than they used to be). Finally, that if the Higgs is light the preferred value of m_t is somewhat lower than the Tevatron result (which in this analysis is not included among the input data). The data ellipse in the ε_b-ε_3 plane is consistent with the SM and the CDF/D0 value of m_t. This is because we have taken for R_b the Aleph value. For comparison, we also show in Figs 6 and 7 the same plots as in Figs 4 and 5 but for the official average values of R_b and $\sin^2\theta_{\rm eff}$ as reported in Table I. The main difference is the obvious displacement of ε_b and the smaller errors in the ε_1-ε_3 plot. Finally, the status of ε_2 is presented in Fig. 8. The agreement is very good. ε_2 is sensitive to m_W and a more precise test will only be possible when the measurement of m_W will be much improved at LEP2 and the Tevatron.

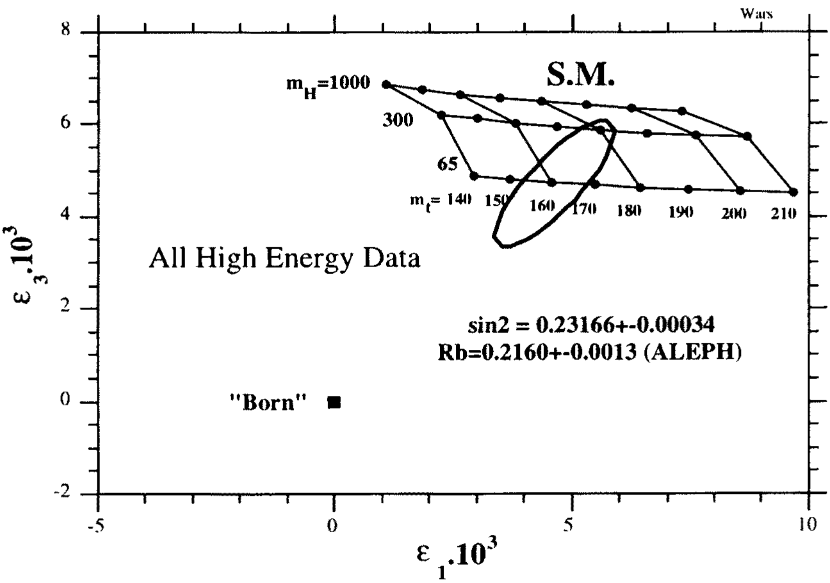
Wars
S.M.
m_H=1000
300
65
m_t= 140 150 160 170 180 190 200 210
All High Energy Data
sin2 = 0.23166+-0.00034
Rb=0.2160+-0.0013 (ALEPH)
"Born"
$\varepsilon_3 . 10^3$
$\varepsilon_1 . 10^3$

Fig. 4.

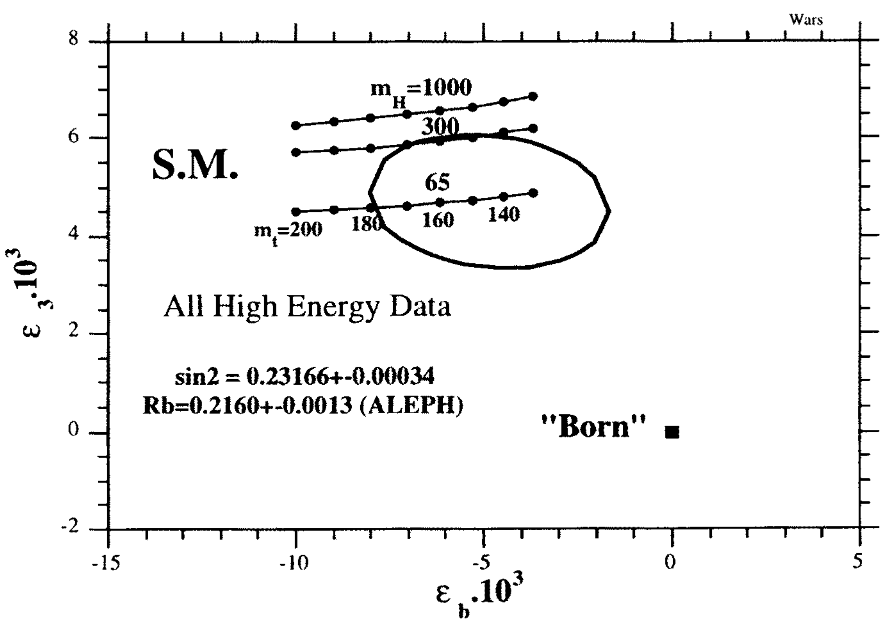
Wars
m_H=1000
300
S.M.
65
m_t=200 180 160 140
All High Energy Data
sin2 = 0.23166+-0.00034
Rb=0.2160+-0.0013 (ALEPH)
"Born"
$\varepsilon_3 . 10^3$
$\varepsilon_b . 10^3$

Fig. 5.

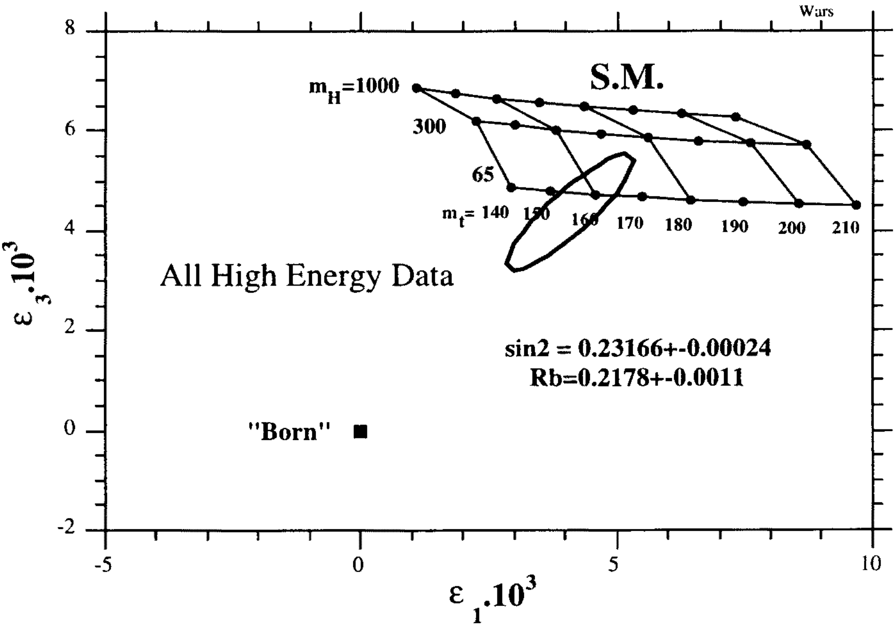
Wars
S.M.
m_H=1000
300
65
m_t= 140 150 160 170 180 190 200 210
All High Energy Data
sin2 = 0.23166+-0.00024
Rb=0.2178+-0.0011
"Born"
$\varepsilon_3 .10^3$
$\varepsilon_1 .10^3$

Fig. 6.

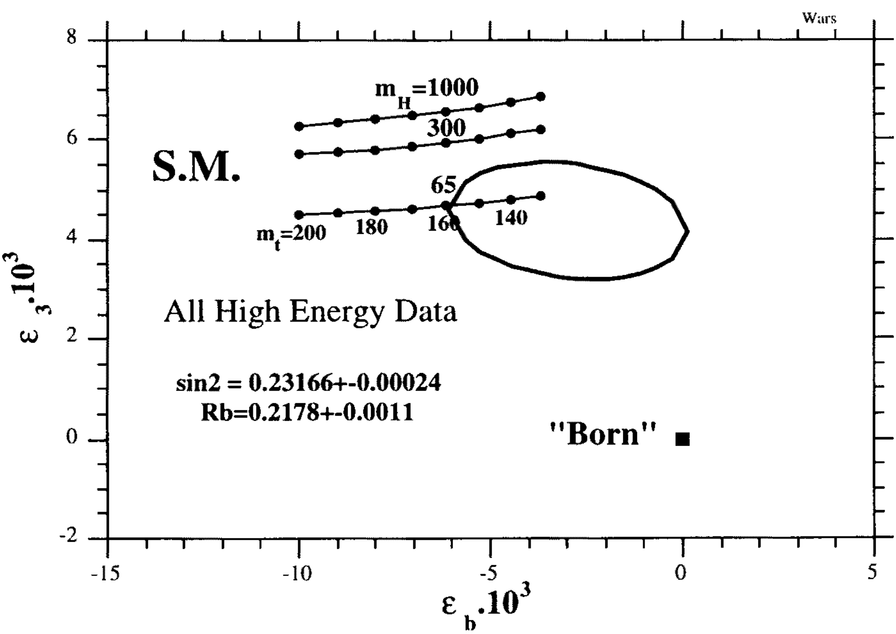
Wars
m_H=1000
300
S.M.
65
m_t=200 180 160 140
All High Energy Data
sin2 = 0.23166+-0.00024
Rb=0.2178+-0.0011
"Born"
$\varepsilon_3 .10^3$
$\varepsilon_b .10^3$

Fig. 7.

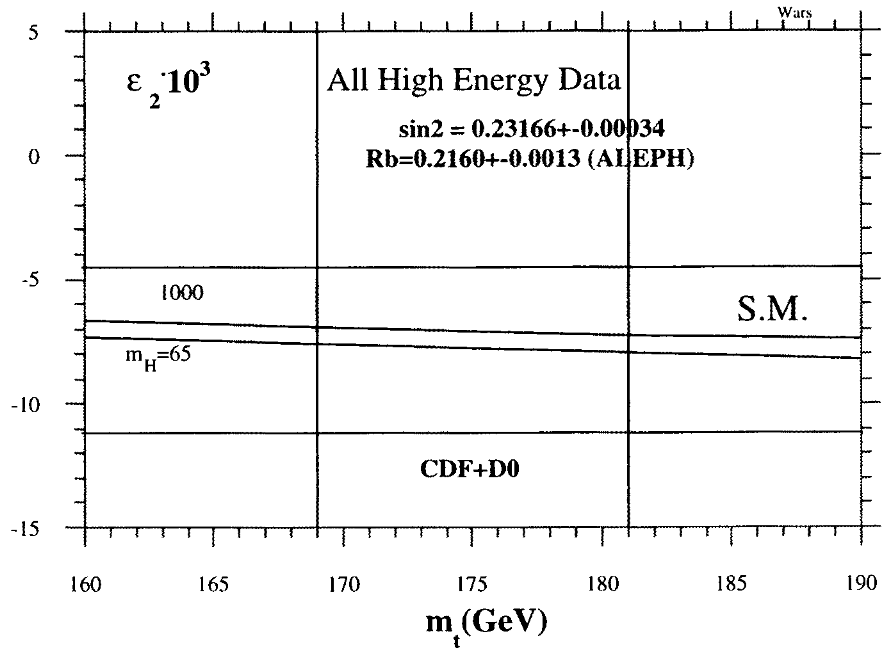

Fig. 8.

To include in our analysis lower energy observables as well, a stronger hypothesis needs to be made: vacuum polarization diagrams are allowed to vary from the SM only in their constant and first derivative terms in a q^2 expansion [31–33], a likely picture, *e.g.*, in technicolor theories [34–36]. In such a case, one can, for example, add to the analysis the ratio R_ν of neutral to charged current processes in deep inelastic neutrino scattering on nuclei [37],the "weak charge" Q_W measured in atomic parity violation experiments on Cs [38] and the measurement of g_V/g_A from $\nu_\mu e$ scattering [39]. In this way one obtains the global fit (R_b from Aleph, $\sin^2\theta_{\rm eff}$ with enlarged error as in Eq. (8)):

$$\begin{aligned}
\varepsilon_1 &= \Delta\rho = (4.3 \pm 1.2)10^{-3}\,,\\
\varepsilon_2 &= (-8.0 \pm 3.3)10^{-3}\,,\\
\varepsilon_3 &= (4.4 \pm 1.3)10^{-3}\,,\\
\varepsilon_b &= (-4.6 \pm 3.2)10^{-3}\,.
\end{aligned} \tag{23}$$

With the progress of LEP the low energy data, while important as a check that no deviations from the expected q^2 dependence arise, play a lesser role in the global fit. Note that the present ambiguity on the value of $\delta\alpha^{-1}(m_Z) = \pm 0.09$ [17] corresponds to an uncertainty on ε_3 (the other epsilons are not much affected) given by $\Delta\varepsilon_3\ 10^3 = \pm 0.6$ [21]. Thus the theoretical error is still comfortably less than the experimental error.

To conclude this section I would like to add some comments. As is clearly indicated in Figs 3–8 there is by now a solid evidence for departures from the "improved Born approximation" where all the epsilons vanish. In other words a strong evidence for the pure weak radiative corrections has been obtained and LEP/SLC are now measuring the various components of these radiative corrections. For example, some authors [40] have studied the sensitivity of the data to a particularly interesting subset of the weak radiative corrections, *i.e.* the purely bosonic part. These terms arise from virtual exchange of gauge bosons and Higgses. The result is that indeed the measurements are sufficiently precise to require the presence of these contributions in order to fit the data.

We now concentrate on some well known extensions of the SM which not only are particularly important per se but also are interesting in that they clearly demonstrate the constraining power of the present level of precision tests.

5.1. Minimal Supersymmetric Standard Model (MSSM)

The MSSM [41] is a completely specified, consistent and computable theory. There are too many parameters to attempt a direct fit of the data to the most general framework. So one can consider two significant limiting cases: the "heavy" and the "light" MSSM.

The "heavy" limit correspond to all s-particles being sufficiently massive, still within the limits of a natural explanation of the weak scale of mass. In this limit a very important result holds [42]: for what concerns the precision electroweak tests, the MSSM predictions tend to reproduce the results of the SM with a light Higgs, say $m_{\rm H} \lesssim 100$ GeV.

In the "light" MSSM option some of the superpartners have a relatively small mass, close to their experimental lower bounds. In this case the pattern of radiative corrections may sizably deviate from that of the SM. The most interesting effects occur in vacuum polarisation amplitudes and/or the $Z \to b\bar{b}$ vertex and therefore are particularly suitable for a description in terms of the epsilons (because in such a case, as explained in Ref. [21], the predictions can be compared to the experimental determination of the epsilons from the whole set of LEP data). They are:

i) a threshold effect in the Z wave function renormalization [42] mostly due to the vector coupling of charginos and (off-diagonal) neutralinos to the Z itself. Defining the vacuum polarisation functions by $\Pi_{\mu\nu}(q^2) = -ig_{\mu\nu}[A(0) + q^2 F(q^2)] + q_\mu q_\nu$ terms, this is a positive contribution to

$\varepsilon_5 = m_Z^2 F'_{ZZ}(m_Z^2)$ the prime denoting a derivative with respect to q^2 (*i.e.* a contribution to a higher derivative term not included in the usual S,T,U formalism). The ε_5 correction shifts ε_1, ε_2 and ε_3 by $-\varepsilon_5$, $-c^2\varepsilon_5$ and $-c^2\varepsilon_5$ respectively, where $c^2 = \cos^2\theta_W$, so that all of them are reduced by a comparable amount. Correspondingly all the Z widths are reduced without affecting the asymmetries. This effect falls down particularly fast when the lightest chargino mass increases from a value close to $m_Z/2$. Now that we know, from the LEP1.5 and LEP2 runs, that the chargino mass is not so light its possible impact is drastically reduced.

ii) a positive contribution to ε_1 from the virtual exchange of the scalar top and bottom superpartners [43], analogous to the contribution of the top-bottom left-handed quark doublet. The needed isospin splitting requires one of the two scalars (in the MSSM the s-top) to be light. From the value of m_t not much space is left for this possibility. If the stop is light then it must be mainly a right-handed stop

iii) a negative contribution to ε_b due to the virtual exchange of a charged Higgs [44]. If one defines, as customary, $\tan\beta = v_2/v_1$ (v_1 and v_2 being the vacuum expectation values of the Higgs doublets giving masses to the down and up quarks, respectively), then, for negligible bottom Yukawa coupling or $\tan\beta \ll m_t/m_b$, this contribution is proportional to $m_t^2/\tan^2\beta$.

iv) a positive contribution to ε_b due to virtual chargino–s-top exchange [45] which in this case is proportional to $m_t^2/\sin^2\beta$ and prefers small $\tan\beta$. This effect again requires the chargino and the s-top to be light in order to be sizeable.

v) a positive contribution to ε_b due to virtual h and A exchange [46], provided that $\tan\beta$ is so large that the higgs couplings to the b quarks are as large or more than to the t quark.

If really there is an excess in R_b it could be explained by either of the two last mechanisms [47]. For small $\tan\beta$ one has a positive contribution to R_b [44–58] if charginos and stops are light and the charged Higgs is heavy. Not to spoil the agreement for $\varepsilon_1 = \Delta\rho$, we need the right stop to be light, while the left stop and the s-bottom are kept heavy and nearby among them, which is quite possible. Alternatively, for large $\tan\beta$, of the order 30 to 60, if h and A, the two neutral Higgses that can be lighter than the Z, are particularly light, then one also obtains [46] a substantial positive contribution to R_b. The large $\tan\beta$ value is needed in order to have a large coupling to $b\bar{b}$. However, such large values of $\tan\beta$ are somewhat unnatural. Also in this case having light charginos and stop helps.

5.2. Technicolour

It is well known that technicolour models [34–36] tend to produce large and positive corrections to ε_3. From Ref. [36] where the data on ε_3 and ε_1 are compared with the predictions of a class of simple versions of technicolour models, one realizes, that the experimental errors on ε_3 are by now small enough that these models are hopelessly disfavoured with respect to the SM.

More recently it has been shown [59] that the data on ε_b also produce evidence against technicolour models. The same mechanism that in extended technicolour generates the top quark mass also leads to large corrections to the $Z \to b\bar{b}$ vertex that have the wrong sign. For example, in a simple model with two technidoublets, ($N_{\rm TC}$=2), the SM prediction is decreased by the amount [59, 60]:

$$\Delta\varepsilon_b = -28.10^{-3}\left|\frac{\xi}{\xi'}\left(\frac{m_t}{174\text{GeV}}\right)\right|, \qquad (24)$$

where ξ and ξ' are Clebsch-like coefficients, expected to be of order 1. The effect is even larger for larger $N_{\rm TC}$. In a more sophisticated version of the theory, the so called "walking" technicolour [60], where the relevant coupling constants walk (*i.e.* they evolve slowly) instead of running, the result is somewhat smaller [61] but still gigantic. Later it was shown [62] that in order to avoid this bad prediction one could endow the extended technicolour currents with a non trivial behaviour under the electroweak group.

In conclusion, it is difficult to really exclude technicolour because it is not a completely defined theory and no realistic model could be built sofar out of this idea. Yet, it is interesting that the most direct realizations tend to produce $\Delta\varepsilon_3 \gg 0$ and $\Delta\varepsilon_b \ll 0$ which are both disfavoured by experiment.

6. Outlook on the search for new physics

As we have seen in the previous sections, at present the whole set of electroweak tests is quite consistent with the SM. The pattern of observed pulls shown in Table I accurately matches what we expect from a normal distribution of measurement errors. Even the few hints of new physics that sofar existed have now vanished: R_c is back to normal and R_b is much closer to the SM prediction. We do not any more need new physics to explain R_b. Even the faint indication that $\alpha_s(m_Z)$ would prefer an excess in R_b has disappeared. Of course it is not excluded that a small excess of R_b is indeed real. For example the chances of nearby SUSY have not really been hit. Actually, with the absence of chargino signals at LEP1.5 and LEP2, which implies an increase of the lower bound on the chargino mass, the most plausible range for a possible effect on R_b in the MSSM is bounded within $\sim 1\sigma$ or $\sim 1.5\sigma$ of the Aleph result (or $R_b \leq 0.2175 - 0.2180$) [47].

What is the status of other possible signals of new physics? The Aleph multijet signal at LEP1.5 [63] awaits confirmation from LEP2 before one can really get excited. Sofar no such convincing confirmation has been reported from the first $\sim 10\text{pb}^{-1}$ of integrated luminosity collected at LEP2 at $\sqrt{s} =$ 161 GeV. The ALEPH multijet signal [63], if real, cannot be interpreted in the MSSM. But it could be a signal of some more unconventional realization of supersymmetry (*e.g.* with very light gluinos [64] or, more likely, with R-parity breaking [65]). It is perhaps premature to speculate on these events: in a few months we will know for sure if they are real or not, as soon as LEP2 will collect enough luminosity.

The CDF excess of jets at large transverse energy is also not very convincing [66]. It is presented as an excess with respect to the QCD prediction. But the QCD prediction can be to some extent forced in the direction of the data by modifying the parton densities, in particular the gluon density. At the price of a somewhat unnatural shape of the gluon density one can sizably reduce the discrepancy without clashing with other data [67]. On the contrary this is not the case for the quark densities which are tightly constrained by deep inelastic scattering data in the same x range [68]. Also the newly released D0 data do not show any additional evidence for the effect [69]. However the D0 precision is less accurate. Thus on the one hand one can say that D0 is compatible with either QCD or CDF. On the other hand their data are flat so that, to explain the missing of the signal, one should imagine a cancellation between the effect and the variation of systematics with E_T. It was pointed out in Ref. [70, 71] that if the effect was real it could be explained in terms of a new vector boson Z' of mass around 1 TeV coupled mainly to quarks rather than leptons. In presence of simultaneous anomalies in R_b. R_c and the jet yield at large E_T it was attractive to present a unique explanation for all three effects. Now if only the jet excess is what remains this solution has lost most of its appeal. But in principle it is still possible to reduce the mixing of the Z' to the ordinary Z in such a way that its effect is only pronounced for jets while it remains invisible at LEP.

It is representative of the present situation that perhaps the best hint for new physics in the data is given by the single CDF event with $e^+e^-\gamma\gamma \not{E}_T$ in the final state [72]. Indeed this event is remarkable and it is difficult to imagine a SM origin for it. It is true that it is easier to imagine an experimental misinterpretation of the event (*e.g.* a fake electron, two events in one or the like) than a SM process that generates it. But it is a single event and even an extremely unlikely possibility can occur once. Several papers have already been devoted to this event [73]. In SUSY models two main possibilities have been investigated. Both interpret the event as a selectron pair production followed by decays $\tilde{e} \rightarrow eN', N' \rightarrow N\gamma$. The observed production rate and the kinematics demand a selectron with mass around 100 GeV and large branching ratios. In the first interpretation, within the MSSM, N' and N are neutralinos. In order to make the indicated modes dominant one has to restrict to a very special domain of the parameter space of the model. Neutralinos and charginos in the LEP2 range are then favoured. The second interpretation is based on the newly revived alternative approach in which SUSY breaking is mediated by ordinary gauge rather than gravitational interactions [41, 74]. In the most familiar approach SUSY is broken in a hidden sector and the scale of SUSY breaking is very large of order $\Lambda \sim \sqrt{G_F^{-1/2} M_P}$ where M_P is the Planck mass. But since the hidden sector only communicates with the visible sector through gravitational interactions the splitting of the SUSY multiplets is much smaller, in the TeV energy domain, and the Goldstino is practically decoupled. In the alternative scenario the (not so much) hidden sector is connected to the visible one by ordinary gauge interactions. As these are much stronger than the gravitational interactions, Λ can be much smaller, as low as 10–100 TeV. It follows that the Goldstino is very light in these models (with mass of order or below 1 eV typically) and is the lightest, stable SUSY particle, but its couplings are observably large. Then, in the CDF event, N' is a neutralino and N is the Goldstino. The signature of photons comes out more naturally in this SUSY breaking pattern than in the MSSM. If the event is really due to selectron production it would be a manifestation of nearby SUSY that could be confirmed at LEP2. This what we all wish. We shall see!

It is a pleasure for me to thank Stanisław Jadach, Zbigniew Wąs and all the members of the Local Organizing Committee for their kind invitation and warm hospitality in Cracow.

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