LEP1 AND LEP200: RESULTS AND PROSPECTS

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In this paper I will give a very short overview of what we have learned from the now completed LEP1 and the ongoing LEP200 programmes; I will also briefly describe the prospects of the latter.

1. Introduction

At LEP much activity has been devoted to a set of accurate tests of the Standard Model (SM), through the measurement of a large variety of observables. This activity is summarized in Section 2. The measurement accuracy was generally such that a meaningful confrontation of the data with the corresponding expectations, at the loop-level, was possible. Besides checking the tree-level relations, this gave access to the contributions of heavy particles through their virtual effects. In the SM frame, it allowed the top mass to be measured indirectly, and a crude indication of the Higgs-boson mass to be obtained. In non-standard models, involving potential new mechanisms and particles, it allowed limits on their existence and masses to be set.

Owing to the abundance of events (4×10^6 $Z^0 \rightarrow$ hadrons, registered by each of the experiments), a large set of heavy-fermion pairs ($\tau\tau^+$, $b\bar{b}$, $c\bar{c}$) was made available and provided detailed specific information on the properties of these fermions. Section 3 will give some highlights.

Besides indirect search strategies, another aspect of LEP activity was the direct exploration of search channels, looking in particular for non-standard topologies. This led to a complementary and generally more stringent ensemble of limits. LEP200, on its way to a c.m. energy which should approach 200 GeV in 1999–2000, allows us to pursue actively this programme of searches, in particular for the lightest SUSY Higgs boson, in an especially exciting mass domain, and also gives access to the new physics of W pairs. Results and prospects will be summarized in Sections 4 and 5.

2. Standard Model tests at LEP1

2.1. The Standard Model basic entries and M_Z measurement

At tree-level all SM observables can be expressed in terms of the three quantities g, g' and v: the SU(2) and U(1) coupling constants and the Higgs vacuum expectation values, respectively. These abstract quantities are actually replaced by three well-measured ones, $\alpha(M_Z), G_\mu$ and M_Z: the fine structure constant, evolved to the Z mass scale, the muon decay constant and the Z^0 mass, respectively. A heroic effort at LEP has allowed M_Z to be obtained with an accuracy of 20 ppm: this is described in Ref. [1] and represents the first major result of LEP1 ($M_Z = 91186.7 \pm 2.0$ MeV). G_μ is also known with a 20 ppm accuracy. Unfortunately, the running of α to the Z scale, in spite of the extremely precise determinations of $\alpha(0)$ in the Thomson limit and owing to an insufficiently accurate knowledge of the $e^+e^- \rightarrow$ hadrons cross-section at low $\sqrt{s}$, induces on $\alpha(M_Z)$ an uncertainty of 700 ppm [2]. Only a concerted experimental programme at various low-energy e^+e^- colliding rings could decrease this uncertainty, which is currently on the verge of being the limiting factor to the accuracy of a number of SM tests and in particular the indirect Higgs mass determination.

2.2. From tree-level to loop-level

The tree-level expression of the electroweak observables or relations between them are modified at the loop-level. An example is the expression of M_W, which at loop-level becomes

$$M_W^2 \left[1 - \left(\frac{M_W^2}{M_Z^2}\right)\right] = \frac{\pi\alpha}{\sqrt{2}G_\mu} \frac{1}{1-\Delta r}.$$

Through the quantity $\Delta r(e, M_W, M_Z, M_H, m_t)$, the Higgs mass, and possible new physics, play a role. For observables involving at tree-level the vector and axial couplings of flavour f, v_f and a_f, a particularly transparent method consists in substituting them at the loop-level by effective couplings g_V^f and g_A^f [3].

The weak mixing angle $\sin^2\theta_W$, correctly defined at loop-level as an effective quantity, will be used to assess the quality of individual measurements and their overall coherence.

Table 1 gives a synoptic view of the observables and their sensitivities.

For a systematic discussion of the Z electroweak observables and of the physical content of the quantities mentioned, see Ref. [4]. We also restate that one can build combinations of these quantities which present a simple and specific physical meaning: these are known in the literature as the S, T, U set [5], the ε_i set [6], etc.

Table 1: Various observables, their experimental error and their sensitivity to basic quantities. (From G. Altarelli [8]).

Parameter	$\Delta^{\rm exp}_{\rm now}$	$\Delta\alpha^{-1}$	$\Delta_{\rm th}$	Δm_t	$\Delta m_{\rm H}$	$\Delta\alpha_{\rm s}$
$\Gamma_{\rm Z}$ (MeV)	± 2.5	± 0.7	± 0.8	± 1.4	± 4.6	± 1.7
σ_h (pb)	53	1	4.3	3.3	4	17
$R_h \times 10^3$	27	4.3	5	2	13.5	20
Γ_l (keV)	100	11	15	55	120	3.5
$A^l_{\rm FB} \times 10^4$	10	4.2	1.3	3.3	13	0.18
$\sin^2\theta \times 10^4$	~ 3.2	2.3	0.8	1.9	7.5	0.1
$m_{\rm W}$ (MeV)	80	12	9	37	100	2.2
$R_{\rm b} \times 10^4$	9	0.1	1	2.1	0.25	0
$\varepsilon_1 \times 10^3$	1.2		~ 0.1			0.2
$\varepsilon_3 \times 10^3$	1.4	0.5	~ 0.1			0.12
$\varepsilon_{\rm b} \times 10^3$	2.1		~ 0.1			1

2.3. Secondary entries to the Standard Model

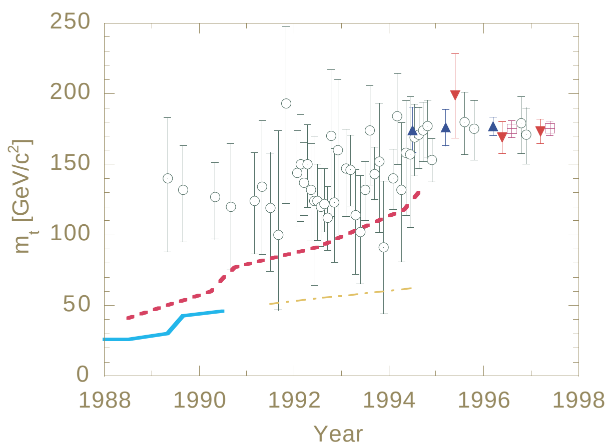

Figure 1: The history of $m_{\rm t}$ determinations, indirect from LEP (open circles), direct from Tevatron. (From C. Quigg [7]).

At loop-level, heavy particles, not necessarily accessible in the final state, intervene as virtual states. The most obvious case is the top, whose contribution to quantities like Δr is $\sim m_{\rm t}^2$. Now that $m_{\rm t}$ is well known from the Fermilab direct observation ($m_{\rm t} = 175 \pm 6$ GeV) one can consider it as an input. But in the past, on the contrary, $m_{\rm t}$ was obtained from LEP observables. Fig. 1 [7] summarizes the full history of these indirect and direct determinations of $m_{\rm t}$.

Using the present knowledge of $m_{\rm t}$, one can then turn, within the SM frame, to the indirect determination of the Higgs mass. Unfortunately the dependence on $M_{\rm H}$ of the relevant quantities is only logarithmic and, as we will see later, the information one obtains is not very precise.

For observables involving hadrons in the final state, the strong coupling $\alpha_{\rm s}(M_{\rm Z})$ intervenes as well. Table 2 [8] summarizes the present knowledge of this quantity, to which LEP itself gave essential contributions.

Table 2: Measurements of $\alpha_s(m_Z)$. In parentheses is indicated whether the dominant source of error is theoretical or experimental. Theoretical ambiguities are discussed in Ref. [8].

Measurements	$\alpha_s(m_Z)$
R_τ	0.122 ± 0.006 (Th)
Deep inelastic scattering	0.116 ± 0.005 (Th)
$Y_{\rm decay}$	0.112 ± 0.010 (Th)
Lattice QCD	0.117 ± 0.007 (Th)
$Re^+e^-(\sqrt{s} < 62$ GeV)	0.124 ± 0.021 (Exp)
Fragmentation functions in e^+e^-	0.124 ± 0.012 (Th)
Jets in e^+e^- at and below the Z	0.121 ± 0.008 (Th)
Z line shape (Assuming SM)	0.120 ± 0.004 (Exp)

Among those which are uncorrelated with the electroweak tests under discussion and can be used as input, one may quote the α_s determinations obtained from $R_\tau \equiv \Gamma^\tau_{\rm hadr}/\Gamma^\tau_l$ [9] and from Z^0 event shapes.

2.4. The line shape and leptonic observables

Besides M_Z, the study of the Z^0 line shape through a scanning procedure has given Γ_Z and $\sigma_{\rm hadr}$. Thanks to the selective identification of leptonic final states, the corresponding partial widths were obtained, compatible with a universal value, Γ_l, as well as the important observable $R_l \equiv \Gamma_{\rm hadr}/\Gamma_{\rm lept}$ (Fig. 2) [10].

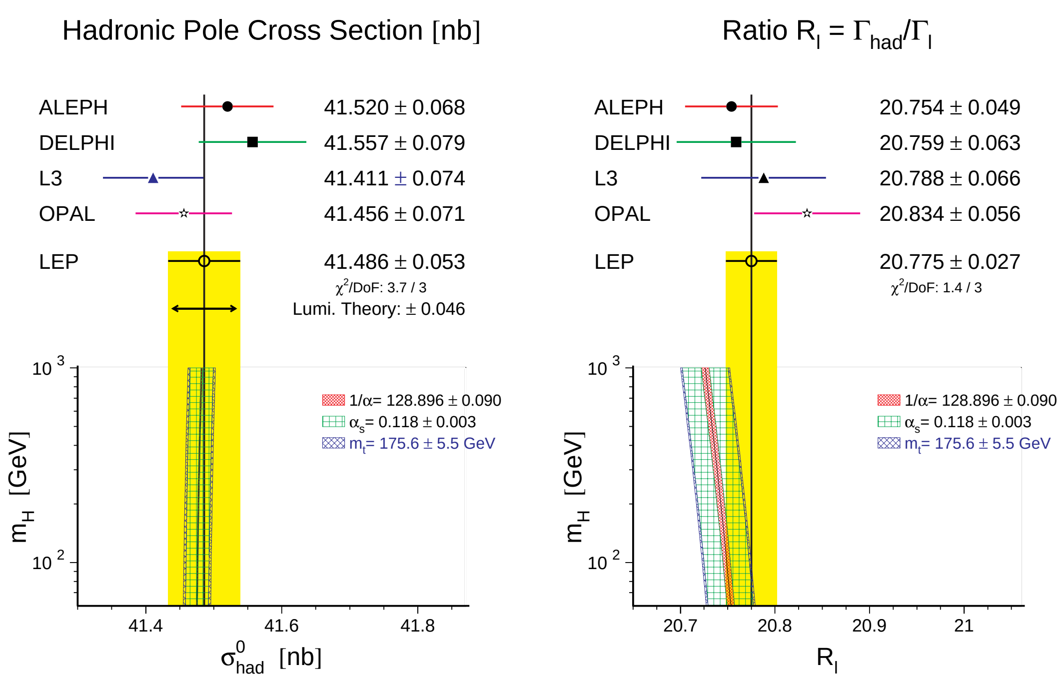

Figure 2: The Z^0 hadronic cross-section and R_l.

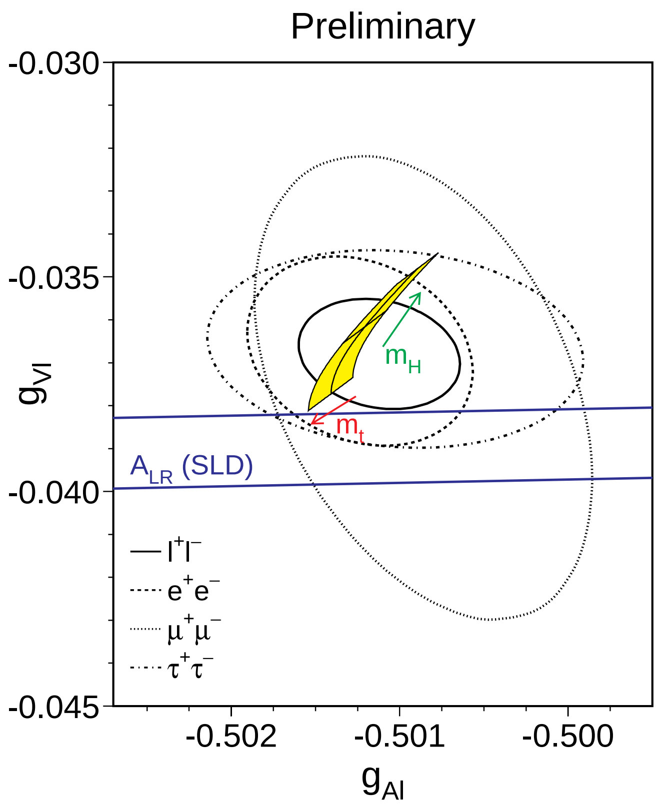

Figure 3: The effective vector and axial couplings from line shape, leptonic asymmetries and tau polarization.

From these one can derive the invisible width of the Z and the corresponding number of light neutrinos:

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

Conversely, setting $N_\nu = 3$, one can give the upper limit of the invisible width that one can still attribute to new physics: $\Gamma_{\rm inv}^{\rm new} < 2.9$ MeV at 95% CL. We can also restate that $N_\nu = 3$ leads to the prediction of 25% He from the primordial nucleosynthesis, quite close to the observed 24 $\pm$ 1%. Leptonic width measurements, giving $g_{\rm V}^{l2} + g_{\rm A}^{l2}$, complemented by leptonic front–back (FB) asymmetries, giving $g_{\rm V}^l g_{\rm A}^l$, and P_τ, allow the extraction of the effective couplings for each lepton species. The result is shown in Fig. 3 and again supports universality.

An asymmetry measurement which is potentially much more powerful than leptonic ones, the left-right $A_{\rm LR}$ asymmetry [11], was performed at SLC, thanks to the high level of longitudinal polarization of its e$^-$. The modest integrated luminosity ($\sim 1.5 \times\ 10^5$ Z^0) of SLC sets a limit on the achieved accuracy, which is nevertheless impressive (Fig. 4).

2.5. Heavy-quark observables

Although all quark flavours treated together can provide interesting electroweak results [12], for instance through their global front–back asymmetry measurement, most activity was devoted to the identification and separation of flavours, to obtain individual partial widths ($R_{\rm b}, R_{\rm c}, \ldots$) and FB asymmetries ($A_{\rm FB}^{\rm b}, A_{\rm FB}^{\rm c}, A_{\rm FB}^{\rm s}$).

The $\sin^2\theta_{\rm W}$ value extracted from the b FB asymmetry (Fig. 5) corresponds, with the one from $A_{\rm LR}$, to the most accurate single measurement [12].

Unfortunately, as seen in Fig. 4, the disagreement between them is embarrassing and unexplained. We can note that the accuracy on $A_{\rm FB}^{\rm b}$ is still, at the end of LEP1, dominated by statistics: one would then need a very gross underestimate of its systematic error to explain the discrepancy.

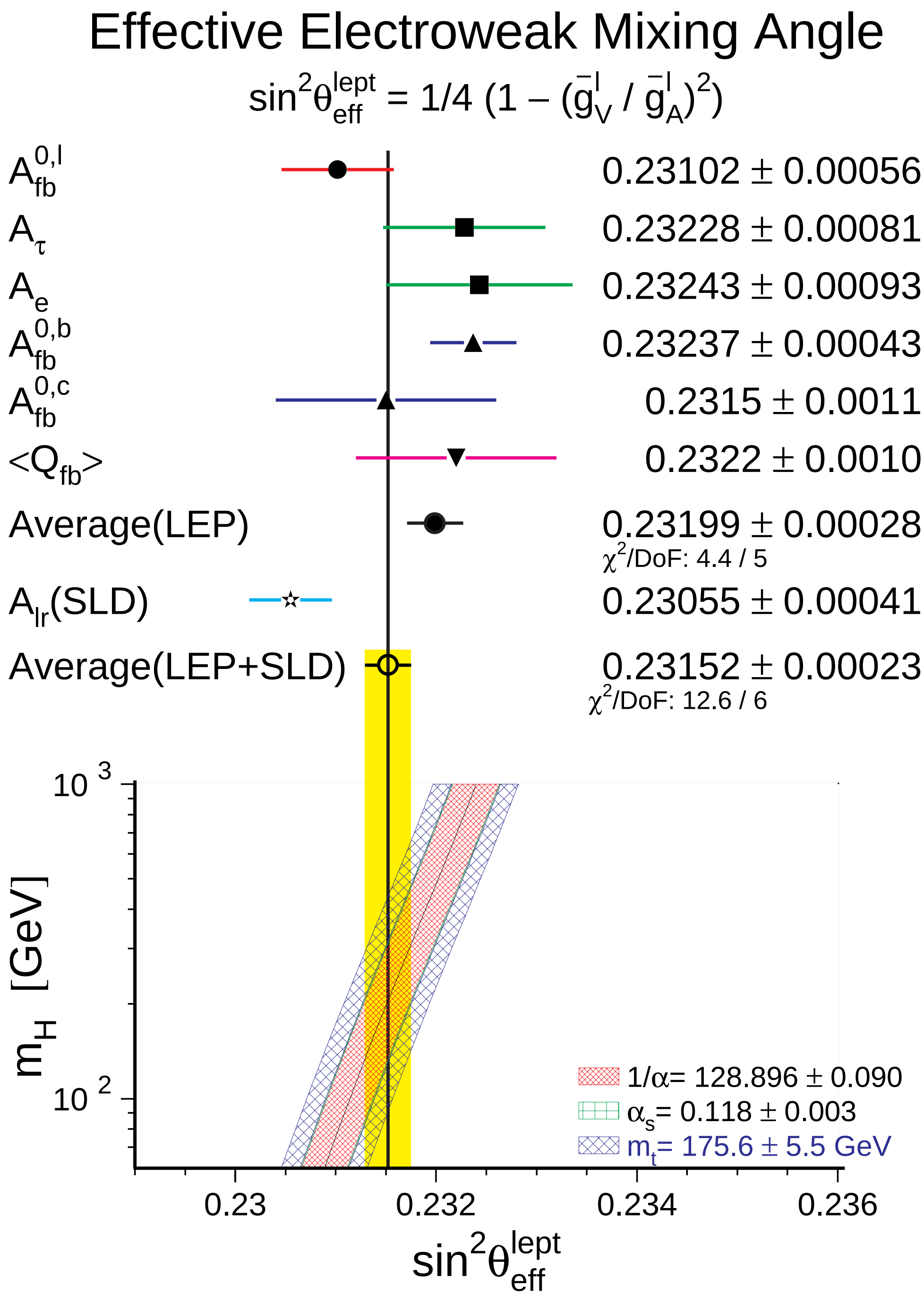

Figure 4: The various determinations of the effective $\sin^2\theta_{\mathrm{W}}$.

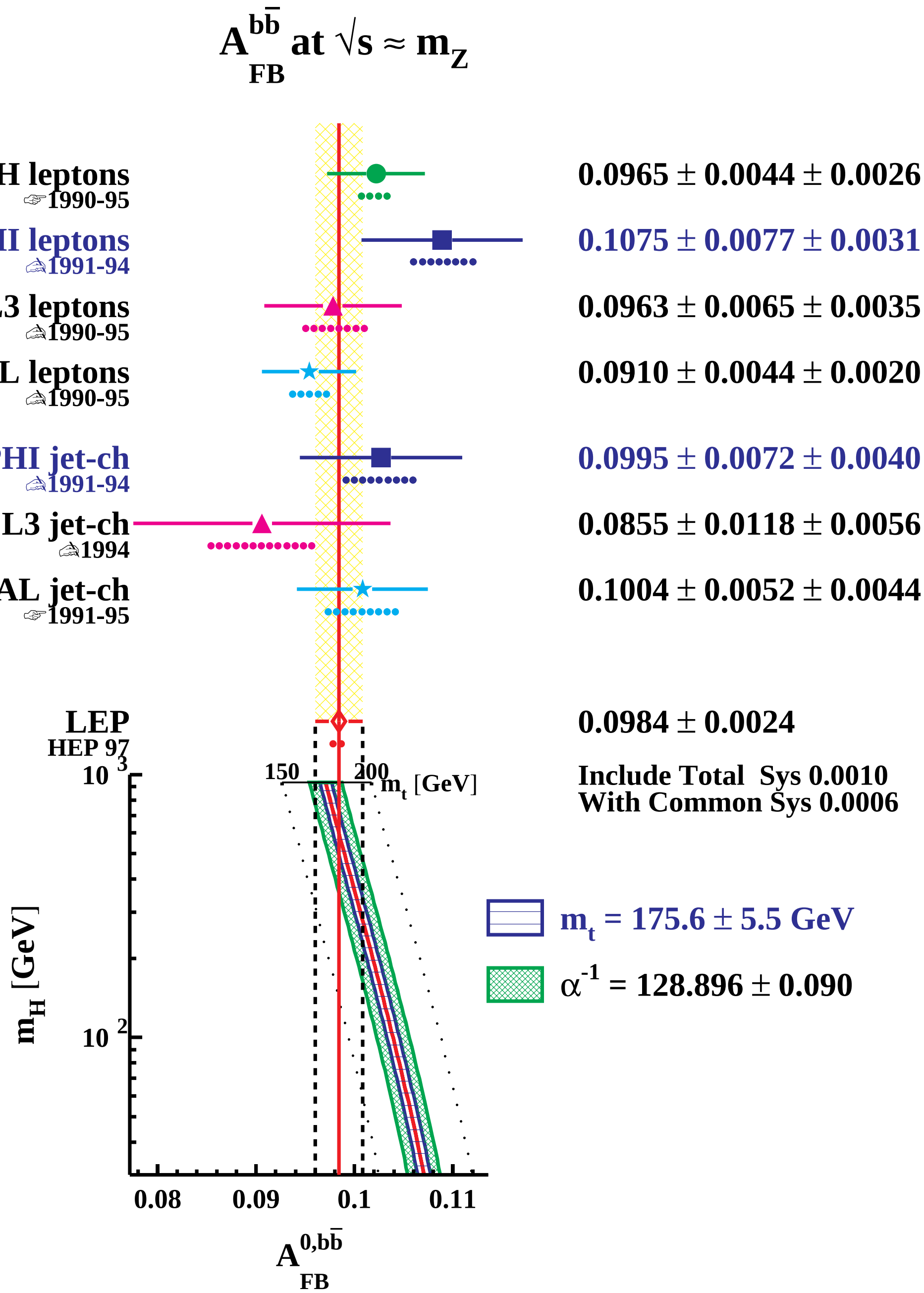

Figure 5: The b front–back asymmetry determinations.

After a long saga, which created a premature and now deceived faith in the existence of low-lying new physics, the value of R_b (and R_c) is in the end quite compatible with the SM expectation. Details on these very difficult measurements can be found in Ref. [13]. Figures 6 and 7 summarize the final situation.

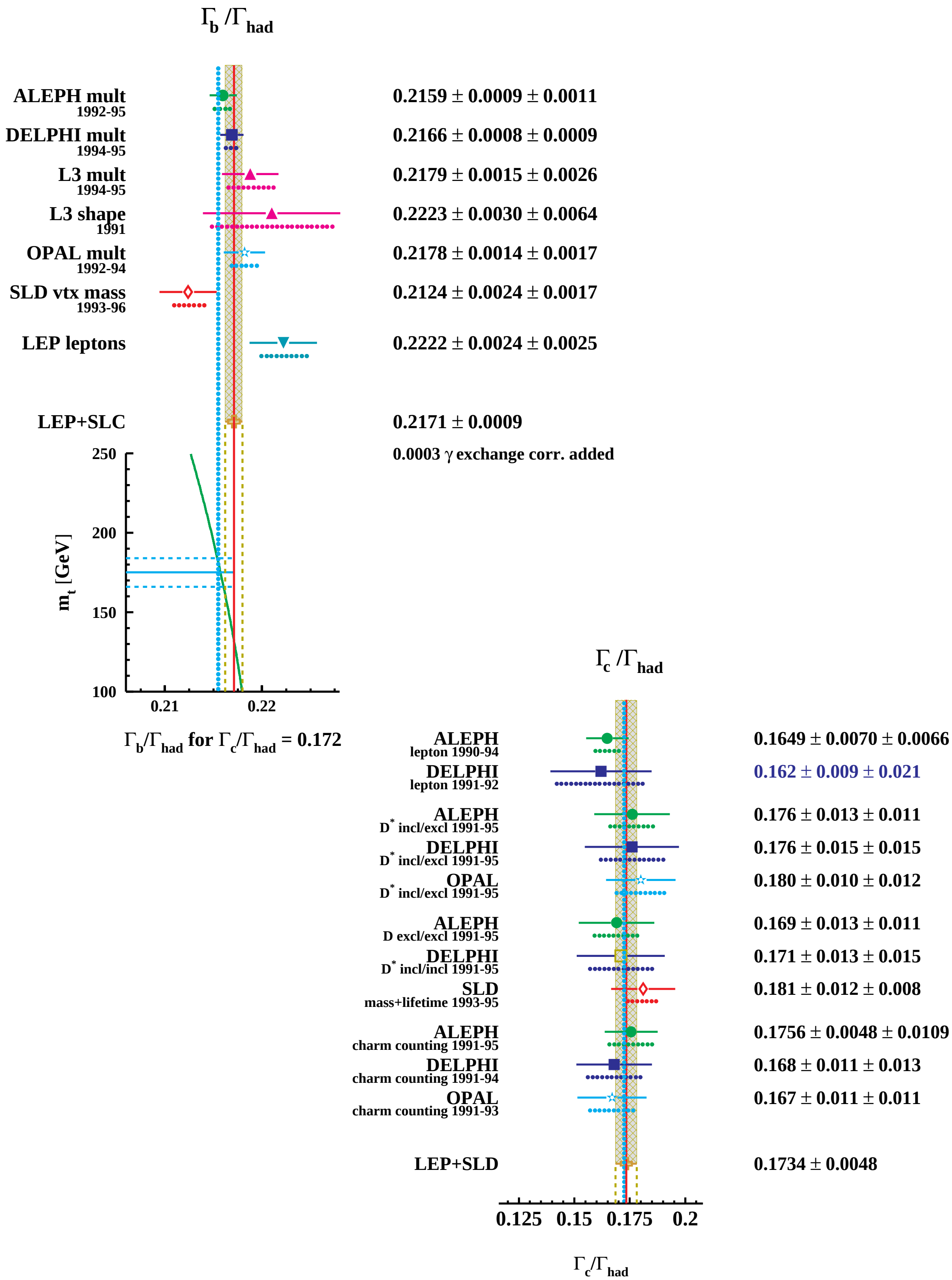

Figure 6: The R_b and R_c determinations.

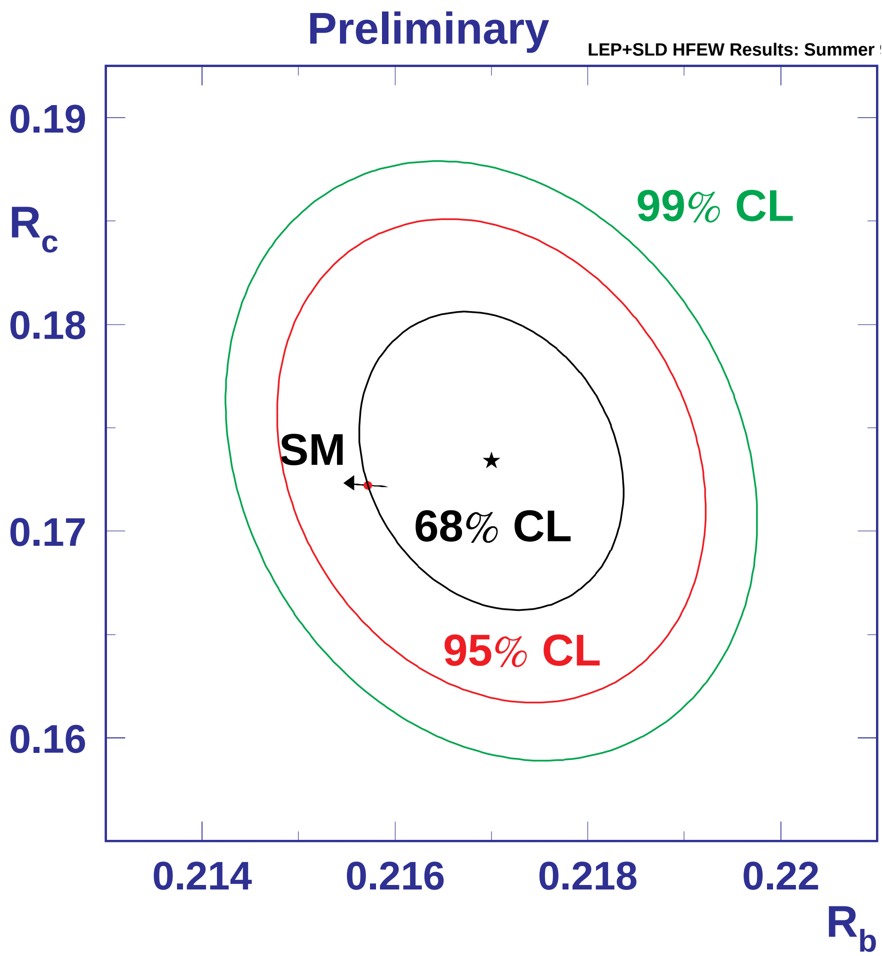

Figure 7: Comparison of R_b and R_c determinations to the SM expectation.

No clear explanation has been given for the previous results on R_b which gave higher values: it is likely that the culprit was charm contamination, now eliminated by very powerful lifetime (using 3-D information from microvertices) and mass b-tagging methods.

2.6. "Bilan"

It had already been shown last year in this meeting [14] that LEP data require imperatively the presence of loop contributions and more precisely of boson-loop contributions.

Both S, T, U and ε_i analyses, which are basically equivalent, have been performed with quasi-final LEP data. Fig. 8 [15] shows an example of the former, giving both the present and the foreseeable situations, and Fig. 9 [16] summarizes the latter.

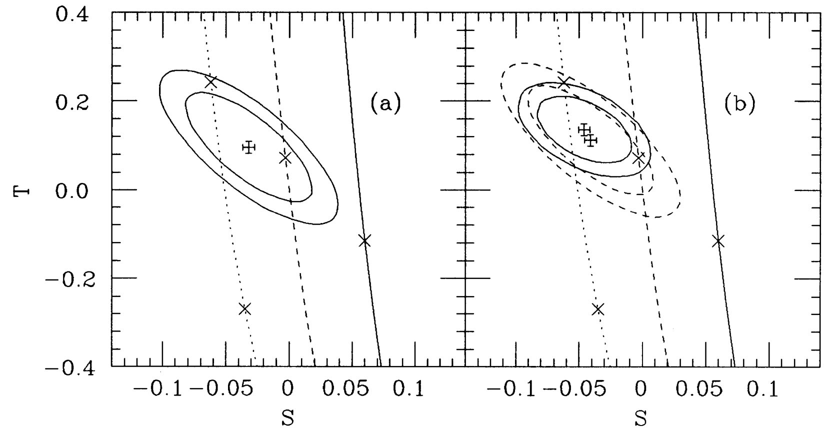

Figure 8: A recent S, T analysis: dotted, dashed and solid lines correspond to SM predictions for $M_{\rm H} = 100, 300, 1000$ GeV/c^2. Symbols denote predictions for $m_{\rm t} = 140$ (bottom) and 180 (top) GeV/c^2 on the $M_{\rm H} = 100$ GeV/c^2 curve, and for $m_{\rm t} = 180$ GeV/c^2 on $M_{\rm H} = 300, 1000$ GeV/c^2 curves. (a) The constraint $m_{\rm t} = 175.5 \pm 5.5$ GeV/c^2 has been imposed. (b) Dashed ellipses: same as (a) but with $\Delta Q_{\rm W}({\rm Cs}) = 0.3$. Solid ellipses: same as (a) but with $\Delta M_{\rm W} = 30$ MeV/c^2.

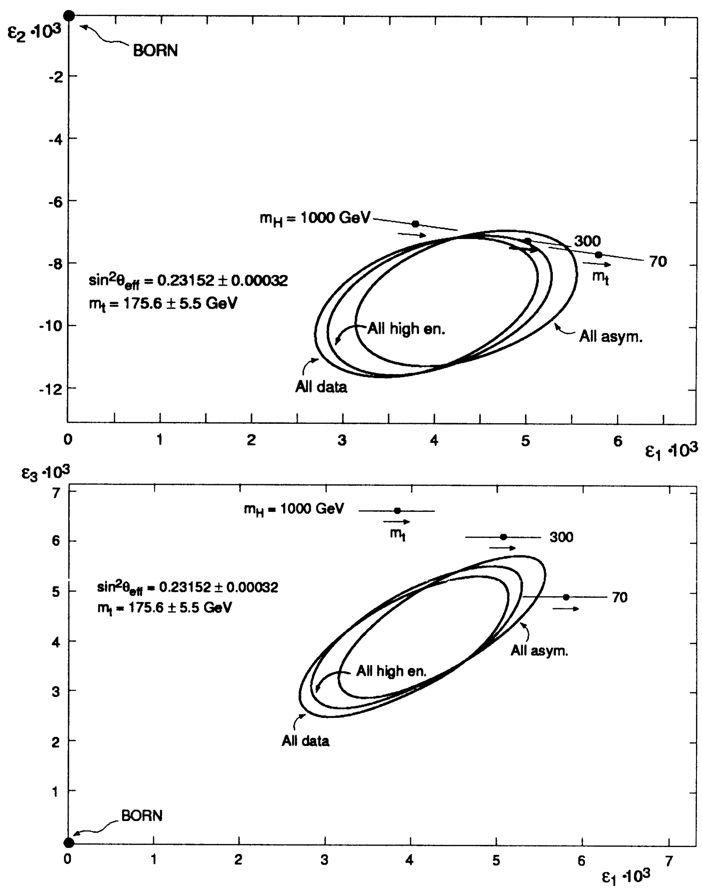

Figure 9: A recent ε_i analysis, from Ref. [16].

Data agree well with the SM, but not with models like technicolour where new fermions would give a strong positive contribution to S or to ε_3 and ε_b. They also confirm the point made above about the need for the loop contributions, as one can see in the figures.

A global fit to various sets of data gives the results shown in Table 3 [17].

Table 3: Results from a global fit to various sets of data, from LEP and elsewhere.

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

The indirectly found top mass agrees with the direct value. One finds in the frame of the SM that $m_H < 420$ GeV at the 95% CL, as can be read from Fig. 10. It can also be seen that the MSSM, for instance, can reproduce data as well as the SM does [18].

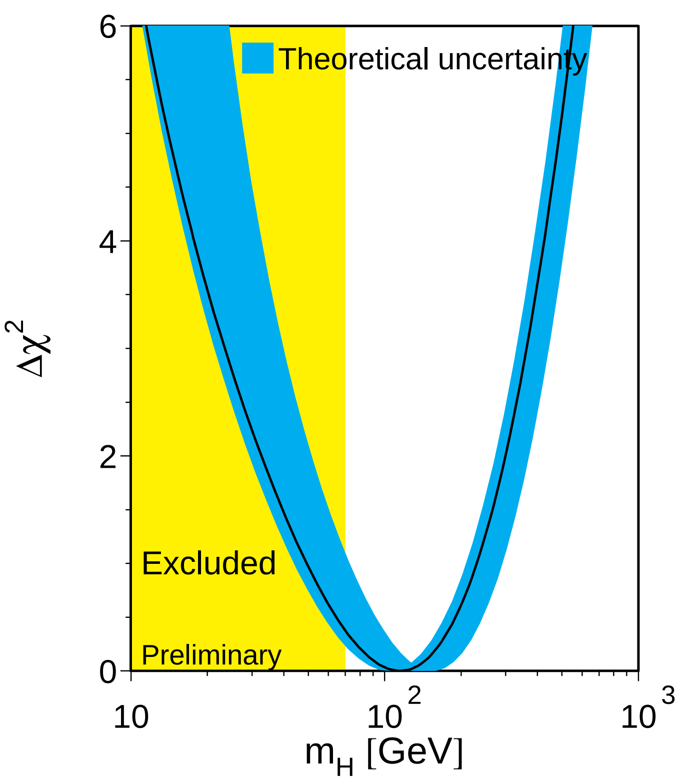

Figure 10: The indirect determination of m_H, from accurate measurements of electroweak observables.

3. Heavy-flavour physics at LEP1

3.0.1. Some aspects of tau physics at LEP

The main themes of tau physics at LEP1 [19] are the following:

- LEP, through the measurement of the tau leptonic branching ratio and especially of its lifetime, has helped to show that the tau is 'normal', i.e. looks like a mere recurrence of e and μ (Fig. 11) [20]. All discrepancies in the past, concerning the validity of universality, the individual decay branching ratios not adding up to one, etc., have now disappeared. The Lorentz structure of the charged current is also as expected in the SM.

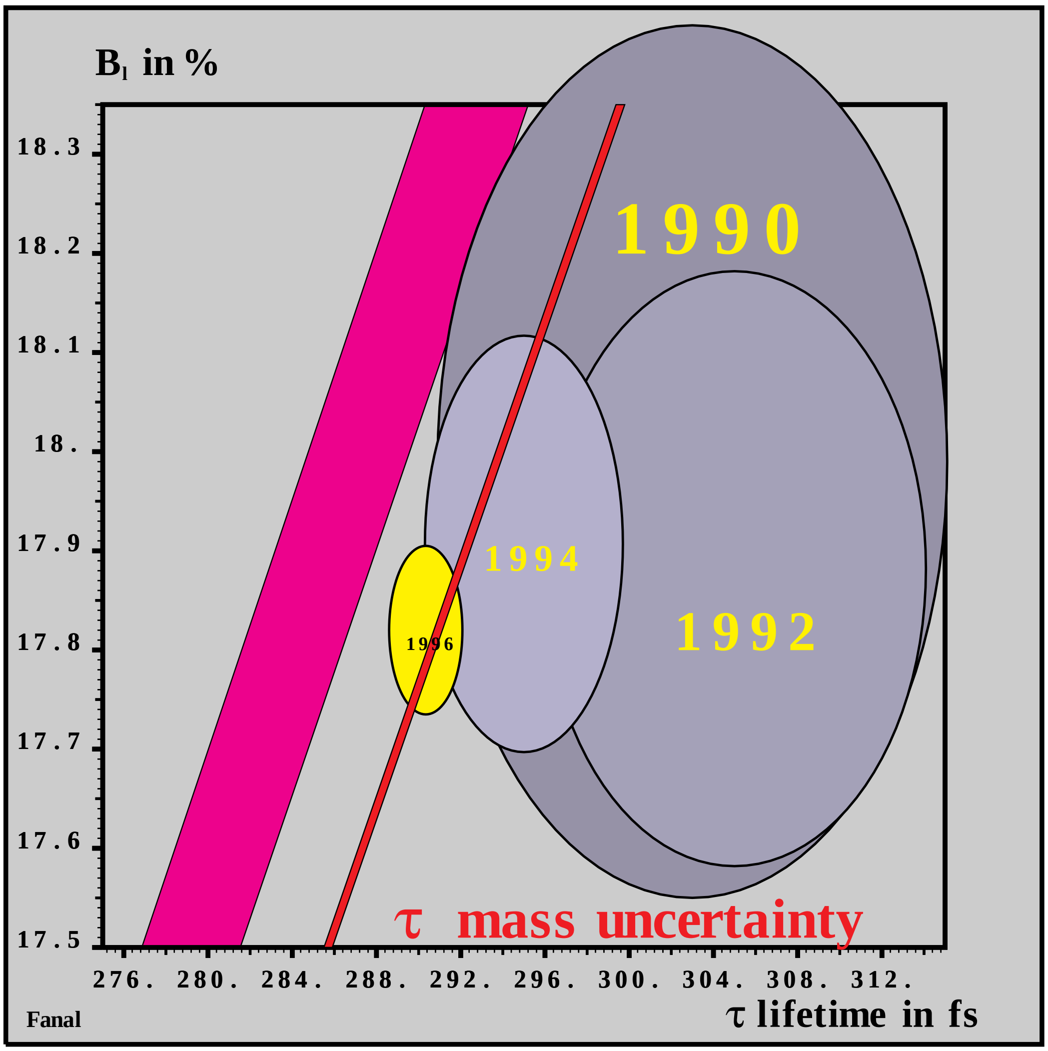

Figure 11: Test of tau universality. The thin oblique band is the SM prediction corresponding to the present determination of m_τ.

- The tau has contributed to the electroweak tests through the measurements of its polarization and the angular dependence of this polarization. The former gives directly A_τ while the latter gives A_e: this represents, assuming universality, the same information as from A_{LR}. The statistical power of the tau-polarization measurement is much weaker in principle, since the useful final state represents only O(1%) of the Z^0 decays; but the number of tau pairs registered at LEP, close to 0.5×10^6, is nevertheless larger than the total number of Z^0 at SLC. Tau pairs also allowed the transverse spin correlation, a new SM observable [21], to be measured.

- The tau is the only lepton which decays into hadrons. It provides a clean environment to study weak hadronic currents and certain aspects of QCD [22]. In particular, hadronic and leptonic decays, through their ratio R_τ, provide a unique way to measure α_{s} at $Q^2 \approx m_\tau^2$ [9].

3.1. Some aspects of beauty physics at LEP

With 15% of the Z^0 final states being $\mathrm{b\bar{b}}$, i.e. $\sim 3.5 \times 10^6$ $\mathrm{b\bar{b}}$ pairs produced, and quasi-ideal topological and experimental conditions, it is not surprising that LEP has obtained a vast harvest of results on B physics, besides the measurements of the electroweak observables previously described. Actually the Z^0 source of beauty is the largest cross-section for $\mathrm{b\bar{b}}$ production in $\mathrm{e^+e^-}$ physics: 6 nb, instead of 1.1 nb at the $\Upsilon(4s)$, with comparable S/B = 0.23. Furthermore, all B species are produced in a single exposure: B, B_{s}, baryons, and their excited states, allowing for a rich set of original spectroscopic studies. Finally, the clear back-to-back topology, making it possible, when necessary, to tag a hemisphere on one side without biasing the opposite side, and the strong boost imparted to the B, key to lifetime measurement and purity of selection, allow specific results, not accessible at a threshold machine, to be obtained. A couple of them are presented.

The b quark is heavy, compared to the QCD Λ scale, and is an ideal laboratory to check the ideas and predictions of the heavy-quark effective theory (HQET). In particular the spectroscopic rules have original features: I will however leave aside these spectroscopic studies, which are discussed elsewhere [23].

Fig. 12 gives a summary of all lifetime measurements of individual species It can be seen that the baryon lifetime is found to be short compared with the prediction of HQET. Although this does not harm the general idea, it probably requires more refined calculations.

A very active field was that of B^0 oscillations [25]: both B_d^0 and B_{s}^0. For the former, Fig. 13 gives the set of measurements of Δm_d.

For the latter, only a limit on Δm_{s} could be obtained, given by Fig. 14, where the amplitude method is used.

Here, one is entering the region of Δm_{s} for which B_{s}^0 oscillation should occur (Fig. 15 [26]).

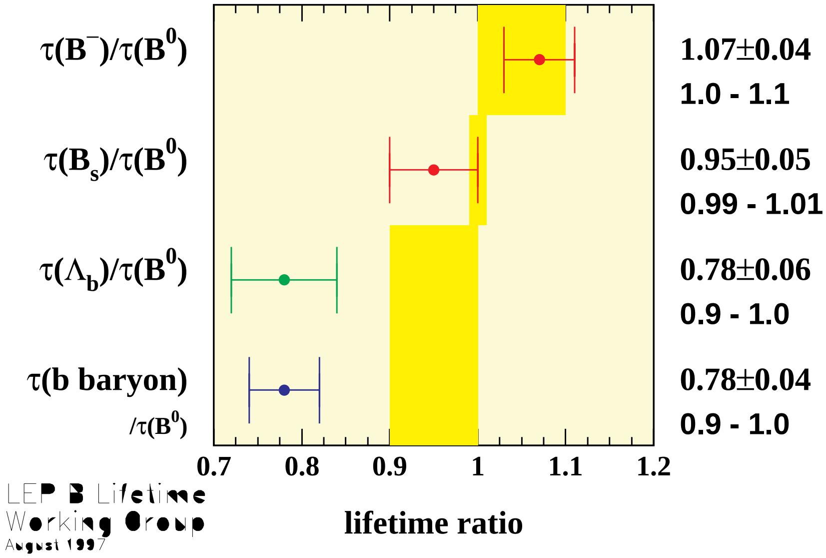

Figure 12: The lifetime of individual B species, compared to expectations.

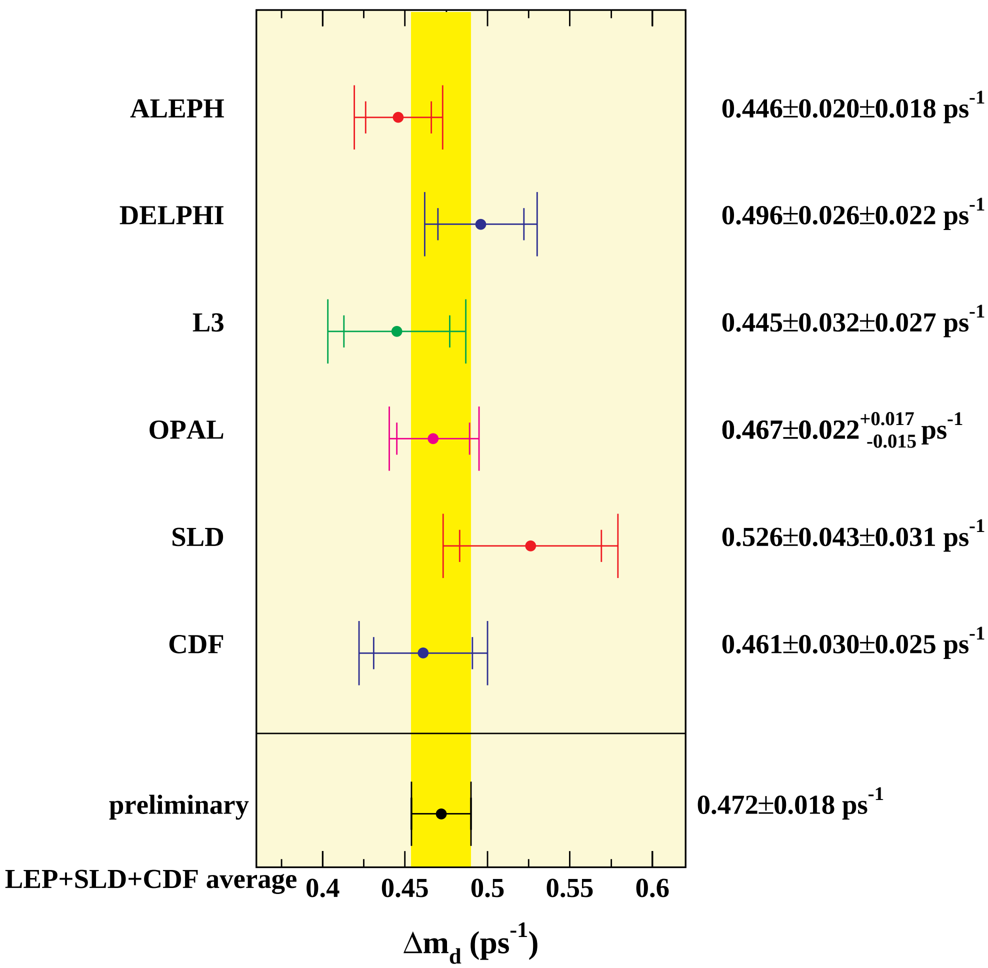

Figure 13: The Δm_d determinations at LEP and elsewhere.

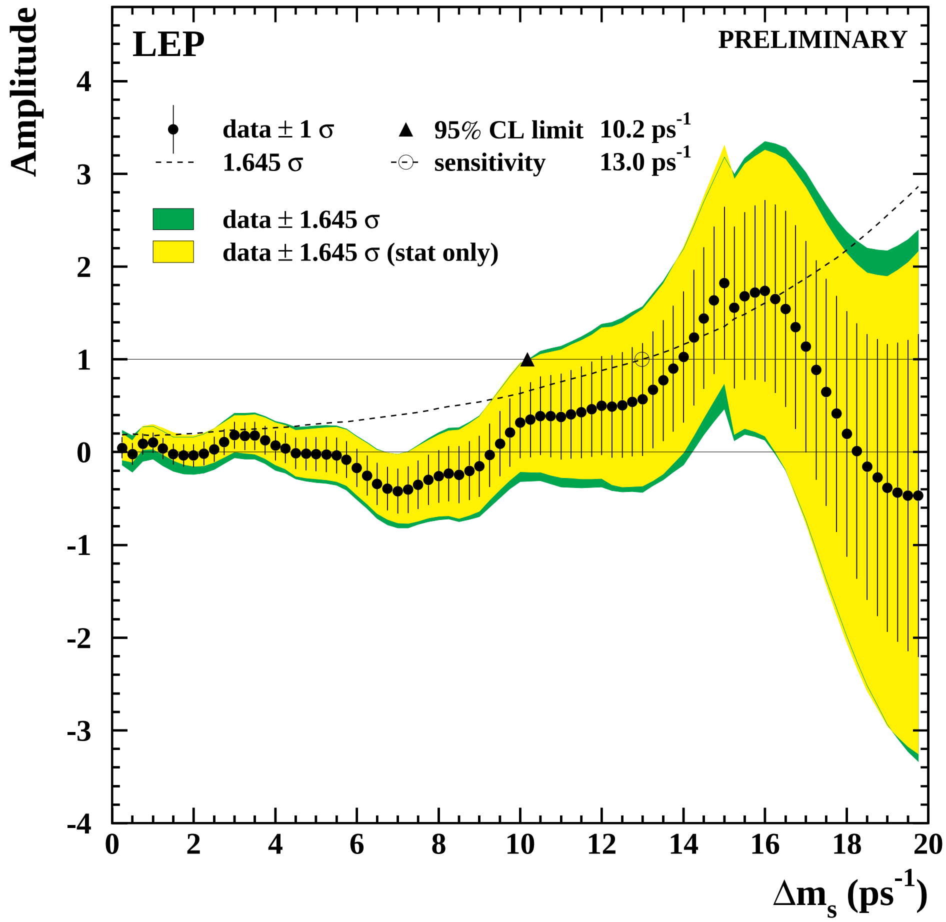

Figure 14: Lower limit on Δm_s as determined by the amplitude method.

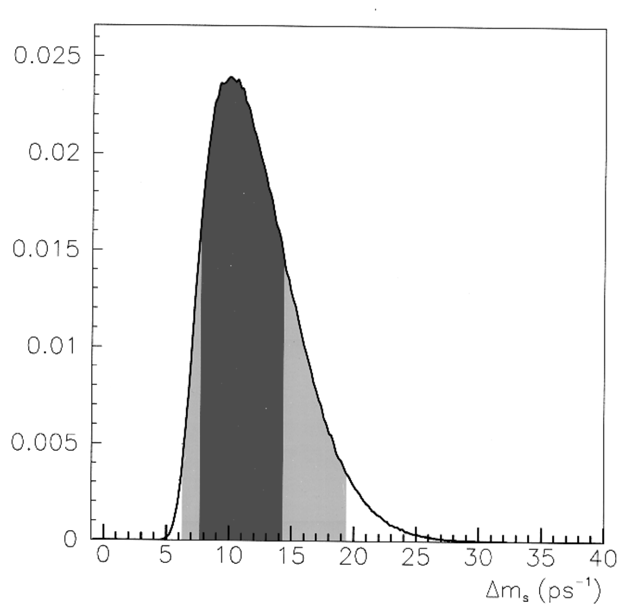

Figure 15: Region expected for Δm_s, according to [26].

It is somewhat frustrating to stop at this level, but spanning the whole domain would require ~ 4 times more statistics, which is clearly incompatible with LEP priorities and LHC planning. Note that by putting together all information about B physics one already has a fair knowledge of the unitary triangle [26].

4. W-pairs at LEP200: M_{W} and triple-gauge couplings

A precise determination of the W mass (which however will remain an order of magnitude less precise than the Z-mass determination at LEP1) and direct evidence for triple-gauge boson couplings are the main objectives of W-pair physics at LEP200. The scenery of LEP200 physics is shown in Fig. 16: the cross-sections of interest are three to four orders of magnitude below the Z peak cross-section.

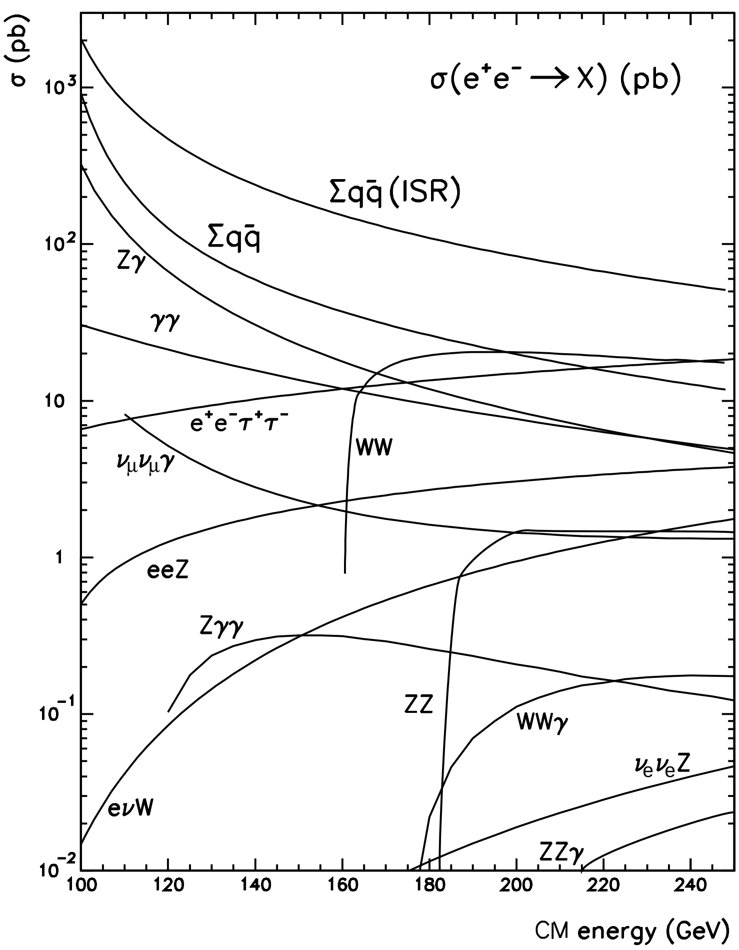

Figure 16: The scenery of LEP200.

Even with the quantum of 500 pb^{-1}, generally considered but looking now very optimistic if it refers to the luminosity per experiment, only $\sim 10^4$ W pairs will be registered. We are thus definitively leaving the domain of very high statistics measurements: a luminosity determination at $\sim 1\%$ would be sufficient and the requirements on systematic errors are substantially reduced. We will see that nevertheless some of these requirements are still quite demanding, for instance with regard to radiative phenomena. It is indeed quite unusual to perform physics measurements just above a huge resonance, to which an abundant return occurs through initial-state radiation effects: these should therefore be well under control. The W-mass determination comes from two methods:

- A specific threshold method [27], exploiting the dependence of the WW cross-section on the W mass not far from threshold. 161 GeV is the optimal energy and LEP accumulated there ~ 10 pb^{-1} per experiment. The results are given in Fig. 17.

- The reconstruction method [28] which was already applied on a modest exposure of ~ 10 pb^{-1} per experiment at 172 GeV c.m. energy. Results are given in Figs. 18 and 19. The potential of this method is high: provided colour recombination and Bose–Einstein phenomena do not confuse the picture in the four-jet final states, the accuracy should be governed by statistics. For 500 pb^{-1} one can expect $\Delta M_{\mathrm{W}} \sim 55$ MeV.

For triple-gauge couplings, being far above threshold is vital for sensitivity [29]. These measurements are therefore still in their infancy (Fig. 20).

The prospects are to reach, at LEP200, measurements of the couplings, or limits on them, at the 10% level. It is doubtful however that this will be sufficient to uncover new phenomena [30].

5. Higgs physics at LEP and other searches

The Higgs idea is at present no more than an assumption: one may conceive other ways to break dynamically the electroweak symmetry provided they do not conflict with the information of electroweak accurate measurements. It may also be just a mechanism, not accompanied by the existence of a Higgs boson, but leading instead to an excess of $V_L V_L$ scattering at higher energies. On the other hand nothing contradicts the simplest SM picture, nor its supersymmetric version, and it is perfectly legitimate that experimentation gives priority to the search for the Higgs sector and shapes its future accordingly. LEP, except through its accurate measurements at LEP1 and LEP200, has probably nothing to say about technicolour or strong coupling scenarios, and I will stick to the description of the search for the 'classical' Higgs boson(s) in the SM and in SUSY models, especially the Minimal Supersymmetric Standard Model (MSSM).

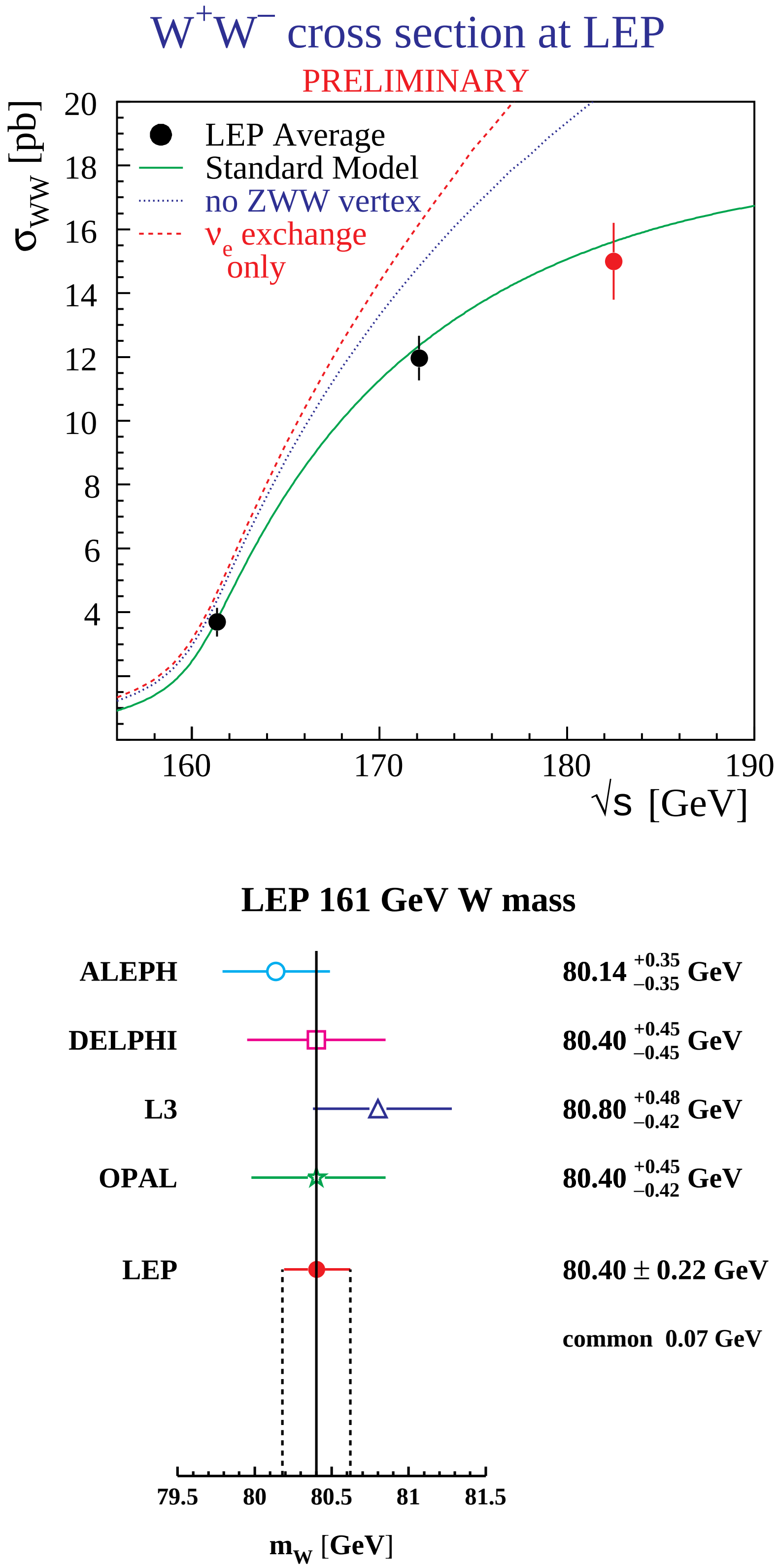

Figure 17: The W pair cross-section and the m_{W} determination from threshold measurements.

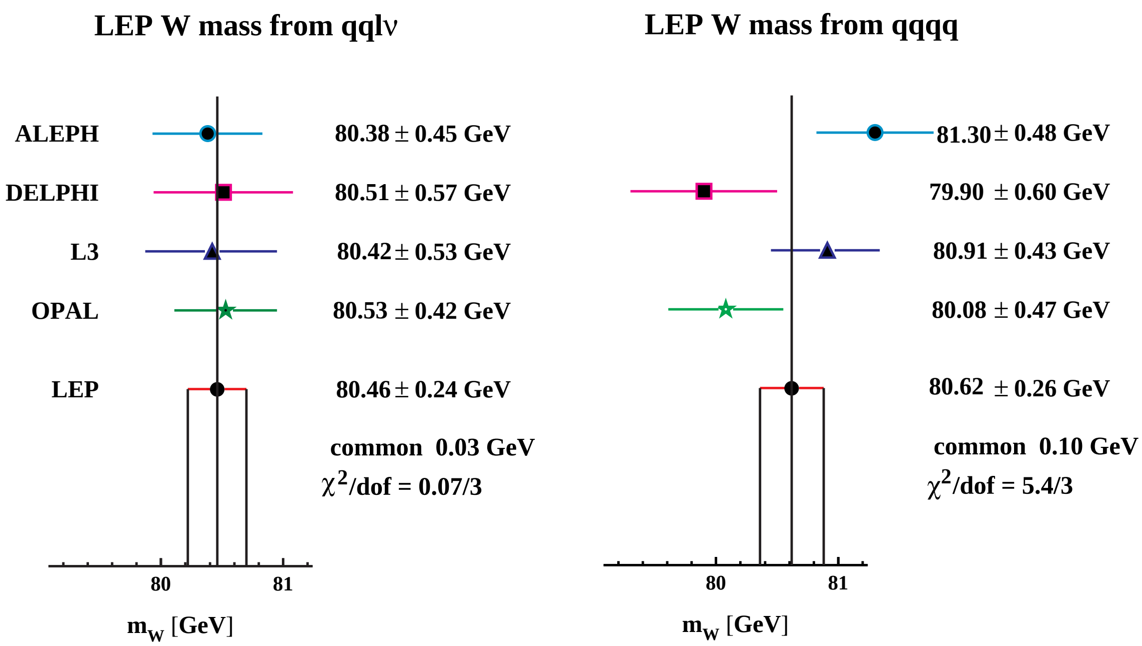

Figure 18: M_{W} determination from the reconstruction method.

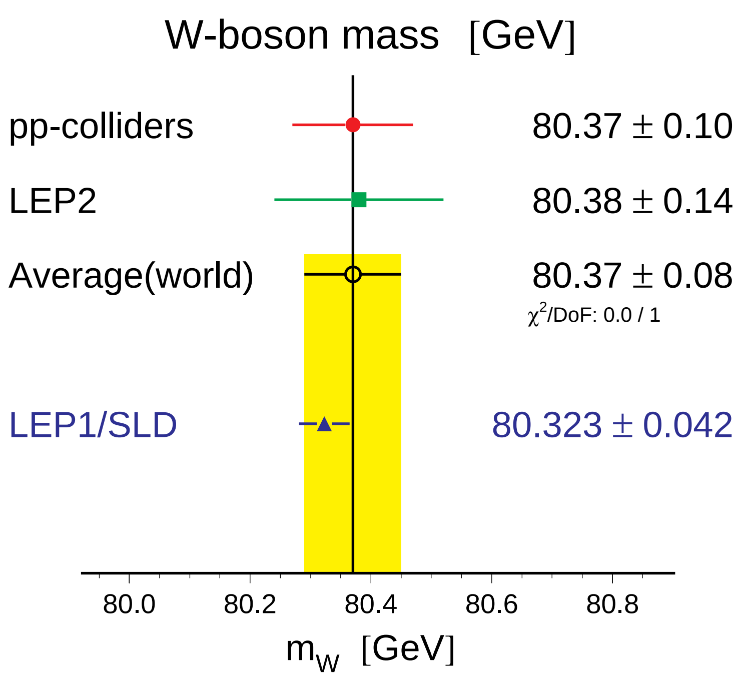

Figure 19: Summary of all M_{W} determinations.

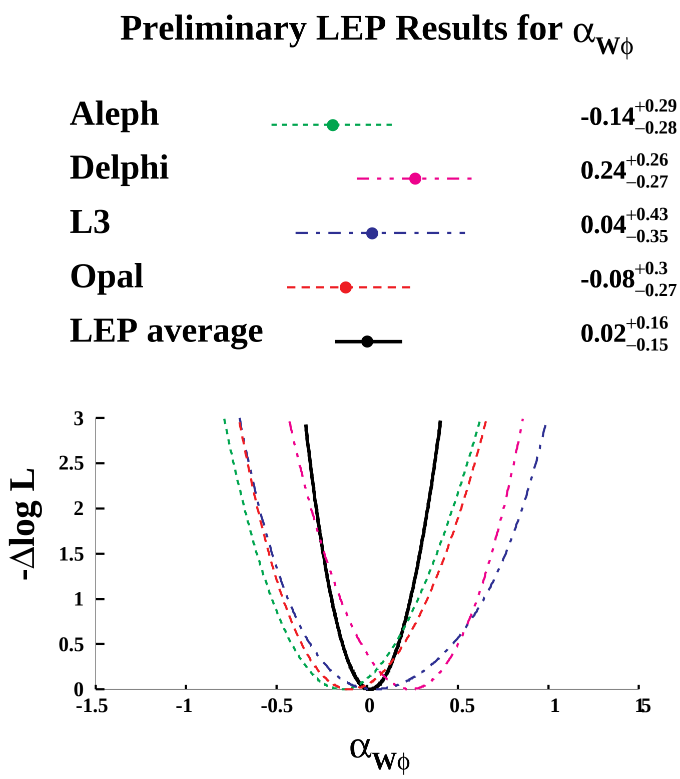

Figure 20: Preliminary measurement of one of the W anomalous couplings at LEP (95% CL limits).

5.1. Some phenomenology

It may be worth recalling a few phenomenological facts to know more precisely what we are actually talking about. In the SM defined, as usual, in terms of the three interactions and the three known families, and characterized by a 'desert' above the top-quark mass, the Higgs mass is unknown. The potential

$$V(\phi) = m^2\phi^2 + \frac{\lambda(\phi)}{2}\phi^4$$

leads indeed to $M_{\mathrm{H}} = \sqrt{2}v\sqrt{\lambda}$ and we do not know the quartic coupling λ. However, some basic requirements set bounds to the possible mass range [31]. If no new physics appears below the GU or Planck scale, these considerations lead to a Higgs mass in the 150–180 GeV range. In particular the boson searched for at LEP cannot be the SM one *stricto sensu.*

The situation is dramatically different in SUSY. Here the scalar self-coupling is given in terms of the gauge couplings g and $g^{'}$, the Higgs sector is always weakly interacting and there must exist a boson at least, h^0, very light: $m_h \sim \mathrm{O}(100\ \mathrm{GeV})$. SUSY is thus a relatively easily falsifiable theory.

Fig. 21 shows the most up-to-date version of the upper limit obtained for m_h, once radiative corrections are included [32].

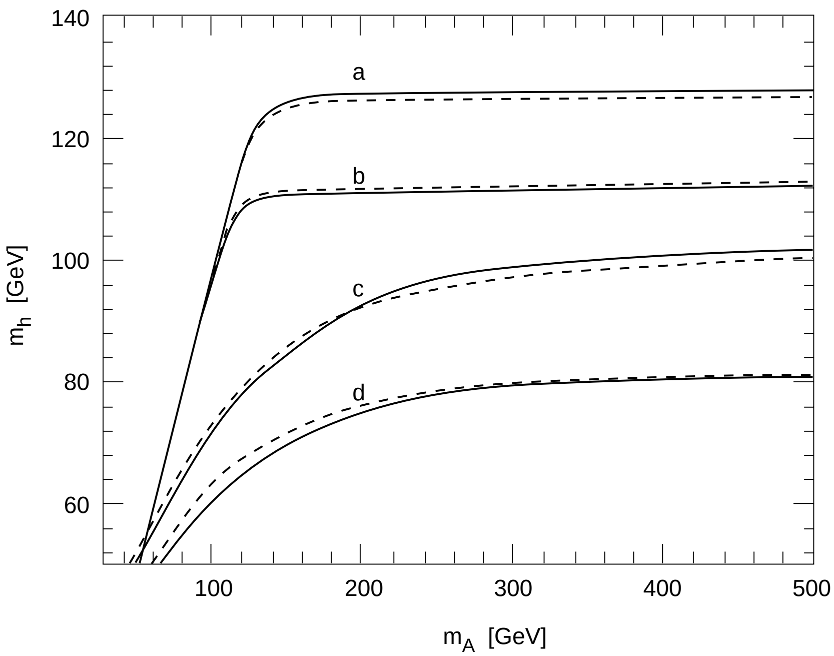

Figure 21: The upper limit for m_h, where h^0 is the lightest MSSM Higgs boson, for various tgβ and stop mixing conditions. The two lower curves are for small tgβ, the two higher for large tgβ. a and c correspond to maximal mixing, b and d to no mixing.

The reach for LEP200 being $m_h \sim \sqrt{s} - 100$ GeV, one understands why even a modest increase in energy is worthwhile: in brief, with $\sqrt{s} \sim 200$ GeV, one will cover the small tgβ scenarios, whatever the mixing in the stop sector. On the other hand LEP200 cannot give the last word for the whole parameter space. The problem is then to ensure a safe overlap of LEP and LHC domains of exploration.

At LEP the h^0 boson can be produced either in $e^+e^- \to h^0Z^0$ (with a real Z^0 at LEP200) or in $e^+e^- \to h^0A^0$ associated production. Couplings can be read from Table 4.

Table 4: The couplings of Higgs bosons to fermion and boson pairs. tgβ is the usual ratio of vacuum expectation values of the two doublets; α is the mixing angle in the $h^0 - H^0$ sector.

ϕ	$g\phi_{\bar{u}u}$	$g\phi_{\bar{d}d}$	$g\phi_{\bar{V}V}$
H_{SM}	1	1	1
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$
A	$1/tan\beta$	$tan\beta$	0

If A^0 is heavy, the h^0 is SM-like. The dominant decay mode is $b\bar{b}$, hence the interest of a highly performat b-tagging. Decay to a tau pair is considered as well, but is much less promising. Since Higgs search at LEP 1 has been extensively described and since, towards high mass, LEP200 has rapidly superseded LEP 1 results, I will restrict myself to LEP200.

5.2. Discovery potential at LEP200

This stems from the production cross-section shape and magnitude (Fig. 22), and from the possibility to exploit all final states.

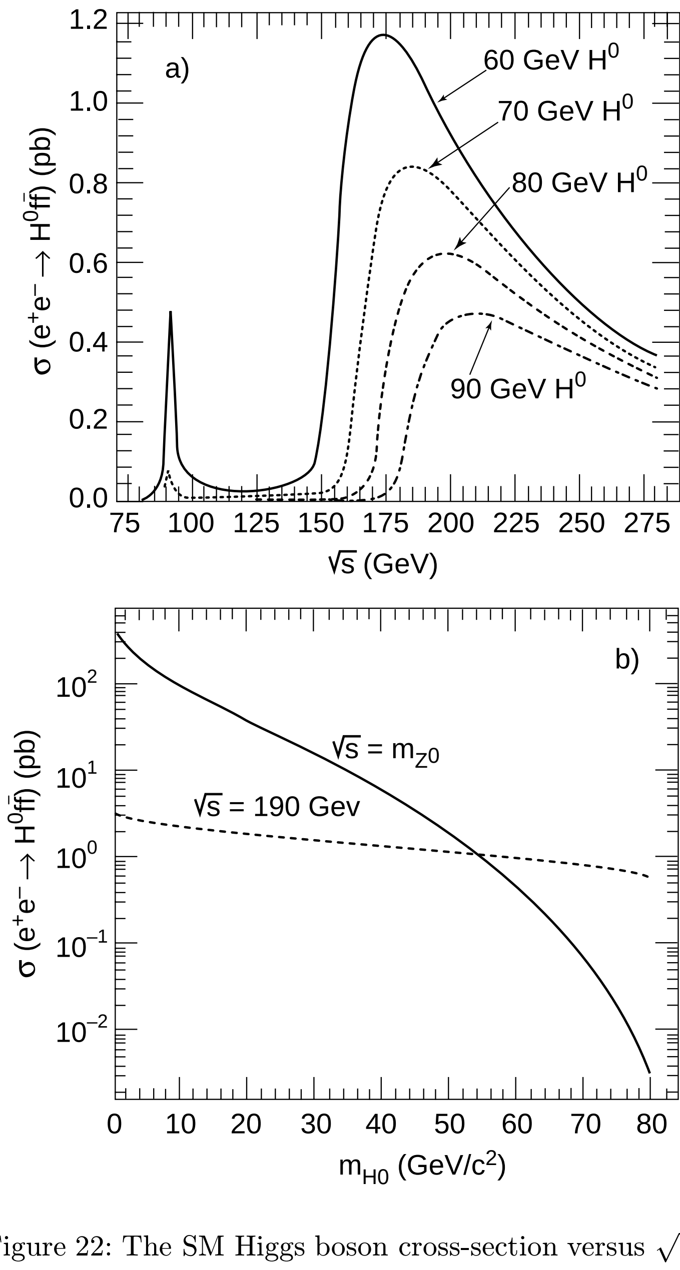

Figure 22: The SM Higgs boson cross-section versus $\sqrt{s}$.

The expected reach can be estimated to be $m_h \simeq \sqrt{s} - 100$, and this has been demonstrated and precised by many MC studies [33]. For $m_h \sim m_Z$ the irreducible ZZ background appears. Its cross-section increases with $\sqrt{s}$ and then saturates, so that more luminosity is needed when energy increases to have access to a boson of mass around m_Z; however, a higher energy also gives access to higher boson masses. A realistic expectation for LEP200, given the time left for its exploitation and the situation of the machine, is to reach the possibility to discover a boson of 100 GeV with $\sqrt{s} \sim 200$ GeV and 150 pb^{-1} per experiment (Fig. 23). The exclusion limit will then be ~ 107 GeV. At present, after 161 and 172 GeV c.m. energy exposures, the limit is ~ 77 GeV, combining all four experiments [34].

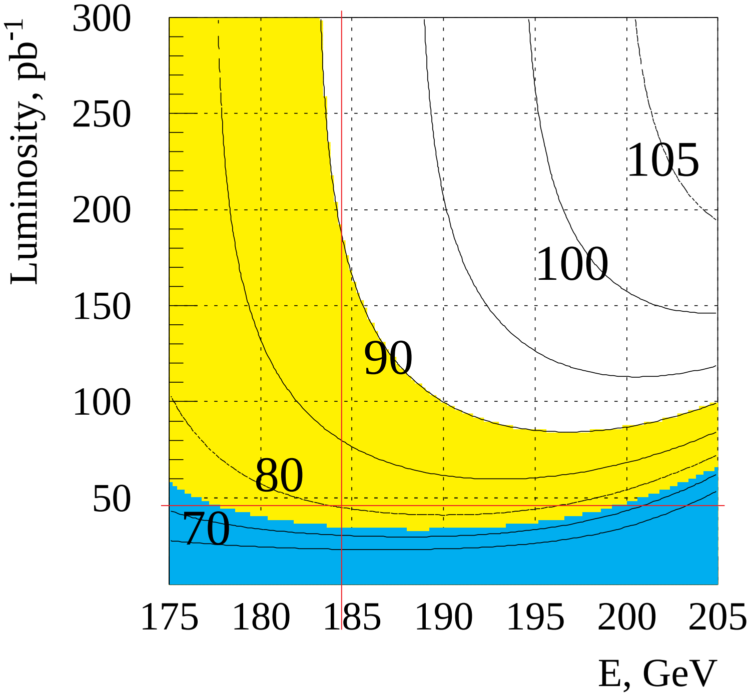

Figure 23: The luminosity per LEP experiment needed to discover a SM like Higgs boson, for various $\sqrt{s}$ values.

5.3. SUSY Higgses

The MSSM interpretation of the searches exploits both the hZ and hA channels: the former determines the exclusion bound for low tgβ, the latter for large tgβ . One way to proceed is to choose a set of the relevant SUSY parameters and show the excluded region, for instance in the tg$\beta - m_h$ plane. Fig. 24 gives DELPHI's result.

The main uncertainty concerns the amount of mixing in the stop sector, which governs the magnitude of the radiative corrections to m_h. Another approach consists in performing an independent variation of the parameters allowing for cancellation effects of the production cross-section. Some parameter regions are not excluded in this general framework, but these regions are much reduced when the four experiments are combined. A lower limit of 60 GeV on m_h is currently achieved [35].

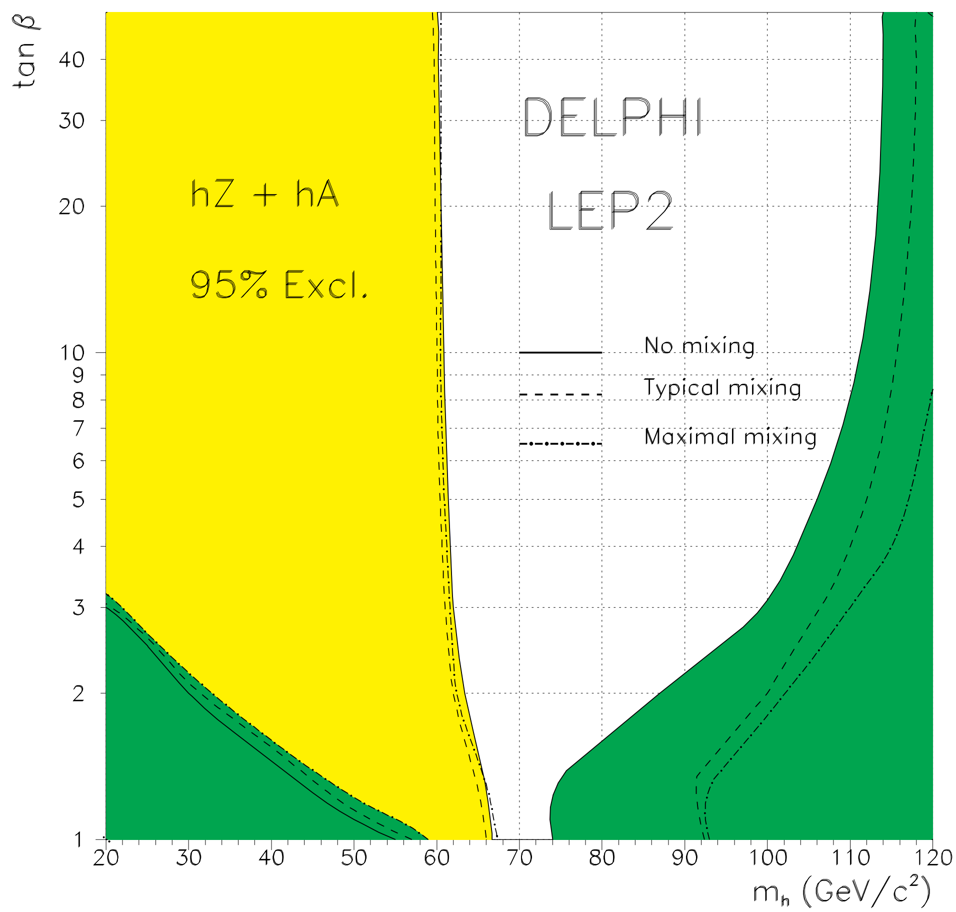

Figure 24: The limit of DELPHI for MSSM bosons in the tg$\beta - m_h$ plane.

5.4. Other searches

A large set of possible scenarios has been explored at LEP, in particular with SUSY in mind. Recently, special versions of SUSY were considered, involving for instance gauge-mediated SUSY breaking, which would lead to the presence of hard photons in the final state [36], or R-parity breaking, which predicts a variety of novel types of channel. No positive signal was found beyond the background that the SM predicts [37].

Charginos are excluded up to 84.3 GeV by the 172 GeV run. Neutralinos lighter than 17 to 40 GeV, depending on the assumptions made, are excluded as well: a good candidate for dark matter is thus, for the time being, excluded [38].

6. Conclusions

The LEP1/SLC era has dramatically improved the quality of the tests of the SM, which seems to accommodate well all present data, although a variant like the MSSM is equally satisfactory.

However the limitations of this programme of measurements and indirect search are now felt, and for the foreseeable future of SM metrology much progress compared to the present situation is not guaranteed.

It is therefore necessary to see directly new particles and new phenomena, if any. For a light Higgs, if the SUSY idea is correct, the remaining years of LEP200 still offer an excellent opportunity of discovery.

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