AN ANALYSIS OF THE LEP DATA*

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ABSTRACT

A global analysis of the LEP data is presented and discussed. The results of a 5(9) parameter fit, as performed by the LEP Collaborations to the lineshape and forward-backward asymmetry data, are used to discuss the range of variation of the unknown parameters of the minimal standard model. At the same time it is illustrated the feasibility of a direct fit to the experimental data, including acceptance corrections and avoiding the so called $t-$channel subtraction procedure.

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The main question to be answered in this talk will be why an extra analysis of the LEP data and of the minimal standard model (MSM)? Basically the answer can be given in two steps

- In a few years from now when LEP is not operating and LEP Collaborations do not exist while new developments in particle theory will require re-doing the comparison of the MSM + X with LEP data using *published* data, then an extra, independent analysis may turn out to be very important.
- Independent checks may be important already now because if published data are not suitable then it is still relatively easy to correct for.

There are several examples of electroweak libraries [1, 2, 3] that have been cross-checked many times but new developments are given almost continuously in the field of radiative corrections and not all of the new effects are always updated in the various libraries. The FORTRAN code TOPAZ0 [4] includes all relevant and presently known effects, i.e.

- The possibility of computing physical observables with a realistic setup, including as much as possible of the experimental cuts after efficiency corrections
- the possibility of computing the Z^0 partial widths and the deconvoluted observables, such as the forward-backward asymmetry $A^0_{FB}(f)$
- full one loop weak corrections [5, 6] including higher order effects, among which
  1. $\mathcal{O}(G^2_F m^4_t)$, a *new* calculation [7]
  2. $\mathcal{O}(\alpha_S G_F m^2_t)$, both for vector boson self energies [8] and (*new*) for the $Z^0\bar{b}b$ vertex [9]
- initial state QED radiation (ISR) with soft multi-photon effects and hard photon corrections [10] [11, 12, 13, 14]
- final state QED radiation (FSR) including hard photon radiation with realistic cuts [14]
- initial state leptonic and hadronic pair production (not included by the experiments in the 1990 analysis) [16]
- QCD final state corrections up to $\mathcal{O}(\alpha^3_S)$ and including $\mathcal{O}(\alpha^2_S)$ m_t dependent corrections and complete $\mathcal{O}(\alpha^2_S m^2_b/M^2_Z)$ corrections to the axial Z^0 coupling [17]
- the possibility of fitting the unknown parameters of the MSM to the experimental data [18], without the procedure of $t-$channel subtraction, and therefore putting the electron data at the same level of any other annihilation process

In writing a code for analyzing LEP data we must satisfy two criteria, namely the code has to be fast and accurate. In order to understand how much one has to push for the accuracy it is better to consider the experimental accuracy, both for the deconvoluted quantities (Table 1a) and for some of the $1991-92$ peak cross sections (Table 1b). From that we understand that very often it is one per mill physics but sometimes it is not. In order to understand the present status of the theoretical accuracy we compare the results produced by TOPAZ0 [4] with those obtained by ALIBABA [1] or ZFITTER [2] for various quantities, deconvoluted as in Table 2, or including ISR as shown in Table 3a-b, and in Figures 1a-b,2a-b. The overall agreement is satisfactory even if, in the light of the aimed experimental accuracy, some improvement will be needed for all codes, expecially concerning the deconvoluted asymmetries. Also when introducing new effects it is interesting to learn something about their impact on the analysis of the data. This is shown in Table 4 where the default results of TOPAZ0 are compared with those obtained without some of the new features. The outcome is always the same, namely unless m_t is relatively high we cannot find any relevant deviation. For the time being we can safely assume that all relevant corrections have been included in TOPAZ0.

After this preliminary discussion we move on to consider the so called standard analysis of the LEP data and review the whole procedure. Usually the four LEP Collaborations present [19, 20, 21] the result for an $n-$parameter fit ($n = 5, 9$ depending on the assumption of lepton universality) to the lineshape and asymmetry data and

- after *efficiency* corrections each of the experiments uses some code or some other for *acceptance* corrections and the lineshapes may or may not be extrapolated to the full solid angle while removing the kinematical cuts
- the $t-$channel subtraction for electrons is performed (usually with ALIBABA) for a fixed value of m_t or in a grid. At this point the process $e^+e^- \to e^+e^-$ is on the same level as any other annihilation process and ZFITTER can be used for fitting m_t etc ...
- the peak cross sections and the asymmetries are deconvoluted of ISR and of final state QCD radiation if needed, but

$$\begin{aligned} \sigma^0 &= 12\,\pi \frac{\Gamma_e \Gamma_h}{M_Z^2 \Gamma_Z^2} \quad \text{is not} \quad \sigma(e^+e^- \to \text{hadrons}) \\ A^0_{FB}(l) &= 3\,\frac{g_V^2 g_A^2}{(g_V^2 + g_A^2)^2} \quad \text{is not} \quad A_{FB}(e^+e^- \to \text{leptons}) \end{aligned}$$

  at the Z^0 peak deconvoluted of ISR. In particular the Z^0 widths includes by definition the factor $1 + \frac{3}{4}\frac{\alpha}{\pi} Q_f^2$ which should really be extracted from Γ_e

- a correlation matrix for M_Z, Γ_Z, σ^0 etc... is given

No matter how successful this procedure may be we would like to stress the opportunity of confirming or not the MSM directly at the level of the original data, i.e. data corrected only for the efficiency. THis will avoid any interference arising from the use of different codes with their own prejudices and any ad hoc procedure. In any case in the standard treatment of the LEP data one starts, at this point, in fitting m_t or any other unknown parameter of the MSM. The result is always : a successful confirmation of the MSM. However it would be rather significant to be able in reducing the number of free parameters of the MSM on a pure theoretical basis.

In the following we select a particular possibility, namely the MSM augmented by the request of cancellation of the one loop quadratic divergences (CQD), and compare the standard analysis to this alternative scenario [22, 23, 24, 25]. We will discover that in the latter case much more stringent bounds can be obtained for the Higgs boson mass, essentially because of the relation

$$m_H^2 = 4\,m_t^2 - M_Z^2 - 2\,M_W^2 + \mathcal{O}(m_{light}^2) \tag{1}$$

This is certainly not the place where to examine the open problems left with the request of cancellation of the quadratic divergences in the MSM and we maintain a rather pragmatic attitude, namely we use this example as a paradigm for new theoretical developments. If the Dallas data are considered (9−parameter fit including $\Gamma_Z, \sigma^0, R_{e,\mu,\tau}$, and $A_{FB}^0(e,\mu,\tau)$, without assumption of lepton universality) then

$$\begin{array}{rcl} \mathrm{MSM} & \Longleftrightarrow & \mathrm{MSM + CQD} \\ m_t = 135^{+27+18}_{-33-18}\,\mathrm{GeV} & & m_t = 129^{+32}_{\dots}\,\mathrm{GeV} \\ \alpha_S = 0.132 \pm 0.008^{+0.003}_{-0.002} & & \alpha_S = 0.131 \pm 0.008 \end{array}$$

where for the left column the central values refer to $m_H = 300\,\mathrm{GeV}$ and we take into account a variation between 65 GeV and 1 TeV for m_H. From the non-standard analysis we derive $m_H < 320\,\mathrm{GeV}$ at the 68% CL. This bound becomes 335(363) GeV at 68%(90%) of CL if the preliminary 1992 LEP data are considered instead. However new physics could enter into the game already at the one loop level, in general without effecting too much the radiative corrections but altering the cancellation condition. One example is given by the presence of a new family of degenerate fermion with common mass m_f. In this case we get

$$m_H^2 \to m_H^2|_{MSM} + \frac{32}{3}\,m_f^2 \tag{2}$$

and

$$\begin{array}{l} m_t = 191^{+23}_{-24}\,\mathrm{GeV} \\ \\ \alpha_S = 0.139^{+0.007}_{-0.008} \end{array} \quad \Longrightarrow \quad m_f, m_H \quad \text{unbounded}$$

We could also consider an $SU(2)$ quark singlet (β) mixed with the bottom quark in which case the ρ−parameter is also effected

$$\rho^{-1} \approx 1 - \frac{G_F M_Z^2}{2\pi^2}\,x, \qquad x = \tfrac{3}{4}\frac{m_t^2 - m_\beta^2 \sin^2\theta_L}{M_Z^2} \tag{3}$$

$$m_H^2 \rightarrow m_H^2|_{MSM} + 4\,\sin\theta_L^2 m_\beta^2 \tag{4}$$

where θ_L is some mixing angle relevant to the case $m_\beta \gg m_b$. In this case we get

$$\begin{array}{rl} m_t = 134^{+28}_{\cdots}\,\mathrm{GeV} & \\ \alpha_s = 0.129^{+0.008}_{-0.007} & m_H < 323\,\mathrm{GeV} \\ \sin\theta_l = 0.0002^{+0.0612}_{-0.0629} & m_\beta \quad \text{independent} \end{array}$$

Next we reconsider a three parameter fit (M_Z, m_t, α_s) to the various data including the full 5×5 correlation matrix, as given by OPAL [26]. Experimental quantities will be now $M_Z, \Gamma_Z, \sigma^0, R_l$ and $A^0_{FB}(l)$. By comparing Dallas [21] data with La Thuile [27] data we obtain

$$\begin{array}{rcl} \text{Dallas} & \Longleftrightarrow & \text{La Thuile} \\ M_Z = 91.187 & \pm & 0.007\,\mathrm{GeV} \\ m_t = 131^{+27+19}_{-33-18}\,\mathrm{GeV} & & m_t = 149^{+22+17}_{-25-17}\,\mathrm{GeV} \\ \alpha_s = 0.133 \pm 0.008 \pm 0.002 & & \alpha_s = 0.125 \pm 0.007^{+0.003}_{-0.002} \end{array}$$

There are other quantities which are measured with increasing precision, like

$$\begin{array}{rcl} M_W & = & 79.91 \pm 0.39\,\mathrm{GeV} \\ M_W/M_Z & = & 0.8807 \pm 0.0031 \\ \text{Dallas} & \Longleftrightarrow & \text{La Thuile} \\ \Gamma_b/\Gamma_h = 0.2147 \pm 0.0052 & & 0.223 \pm 0.005 \\ A^0_{FB}(b) = 0.098 \pm 0.012 & & 0.097 \pm 0.008 \\ A^\tau_{pol} = 0.140 \pm 0.018 & & 0.143 \pm 0.017 \end{array}$$

A global fit, including these quantities gives

$$\begin{array}{rcl} \text{Dallas} \quad 10 - \text{parameters} & \Longleftrightarrow & \text{Dallas} \quad 14 - \text{paramameters} \\ m_t = 142^{+20+18}_{-22-19}\,\mathrm{GeV} & & m_t = 140^{+19+18}_{-22-19}\,\mathrm{GeV} \\ \alpha_s = 0.130 \pm 0.008 \pm 0.002 & & \alpha_s = 0.131 \pm 0.008 \pm 0.002 \end{array}$$

showing good consistency of the data and of the lepton universality. If we consider the La Thuile data then

$$\begin{aligned} m_t &= 147^{+17+18}_{-19-19}\,\text{GeV} \\ \alpha_s &= 0.124 \pm 0.007 \pm 0.002 \end{aligned}$$

hoverer if we consider the region

$$R = \{100\,\text{GeV} < m_t < 300\,\text{GeV}, 0.10 < \alpha_s < 0.16\}$$

then

$$\max_{m_t,\alpha_s \in R} \frac{\Gamma_b}{\Gamma_h} = 0.2179$$

This is clearly only a $1-\sigma$ effect, however in search for an anomaly in the $Z^0\bar{b}b$ vertex, we follow a strategy somehow similar to the one of ref. [28], namely we write

$$\gamma^\mu \left[g^b_v + \epsilon + \left(g^b_a + \epsilon\right)\gamma^5\right] \tag{5}$$

where $\epsilon = G_{_F} M^2_{_Z}/(2\pi^2)\,\lambda$. Notice that the standard couplings contain weak corrections, including $\mathcal{O}(\alpha_s G_{_F} m_t^2)$. A 4 parameter fit to the data gives now

$$\begin{array}{rcl} \text{Dallas} & \Longleftrightarrow & \text{La Thuile} \\ m_t = 140^{+20+18}_{-23-19}\,\text{GeV} & & m_t = 147^{+17+18}_{-19-19}\,\text{GeV} \\ \alpha_s = 0.139 \pm 0.008 & & \alpha_s = 0.099 \pm 0.007 \\ \lambda = 0.848 \pm 0.694^{+0.222}_{-0.259} & & \lambda = -2.330 \pm 0.643^{+0.214}_{-0.249} \\ \chi^2/\text{dof} = 2.8/(10-4) & & \chi^2/\text{dof} = 2.0/(10-4) \end{array}$$

From this point of view there was almost no potentiality for new physics in the $Z^0\bar{b}b$ vertex from Dallas data while there is some from La Thuile data. At the same time the value for α_s is decreasing, which is more than welcome, since the average for it is $\alpha_s = 0.118 \pm 0.007$, even if the decrease is really too strong. If moreover we include the possibility of an anomalous coupling such that $\lambda_V \neq \lambda_A$ then

$$\begin{array}{ll} m_t = 148^{+17+17}_{-19-18}\,\text{GeV} & \alpha_s = 0.099 \pm 0.007 \\ \lambda_V = 0.403^{+1.563+2.333}_{-1.565-1.212} & \lambda_A = -4.305^{+1.088+0.441}_{-1.089-1.300} \end{array}$$

and the b data can be reproduced with very high accuracy. Therefore an anomalous behavior prefers the axial coupling. However from Dallas to La Thuile σ^0 went back into order, so we may ask what about R_b? Indeed few weeks later, from La Thuile to Moriond, the following happened

	Γ_b/Γ_h	$A^0_{FB}(b)$
La Thuile	0.223 ± 0.005	0.097 ± 0.008
Moriond	0.220 ± 0.003	0.098 ± 0.009

as a consequence of the ALEPH result. If we repeat the fit then

$$m_t = 148^{+17+18}_{-19-19}\,\text{GeV} \qquad \alpha_s = 0.110 \pm 0.007$$
$$\lambda = -1.245 \pm 0.585^{+0.209}_{-0.250} \qquad \chi^2/\text{dof} = 1.9/(10-4)$$

and the only possible conclusion is that we have to wait for improved results of the other experiments. After this brief review of the standard analysis of the LEP data we would like to advocate once more the opportunity of a global fit directly to the lineshape and asymmetry data [18] by showing its feasibility. For this we start by considering the experimental strategy as far as the kinematical cuts are concerned, channel by channel.

The hadrons are always extrapolated, usually with a cut $\hat{s} \geq s_0$, where $\sqrt{\hat{s}}$ is the invariant mass of the event after ISR.

$$\sigma_c(s) = \int_0^{1-\epsilon} dx H(x,s)\,\sigma^0(\hat{s}), \quad \hat{s} = (1-x)s \tag{6}$$

and $\epsilon = s_0/s$. For μ and τ the lineshapes are usually fully extrapolated, i.e $\epsilon = 4m_f^2/s$, sometimes also with a cut on $\hat{s}$. The asymmetries are always with cuts, i.e. $|\cos\theta| < c_{max}$ and with acollinearity less then some xi. When cuts are present it is usually not specified if in addition the experiment also requires a cut $m^2(\bar{f}f) \geq M^2$ or $E_{\bar{f}f} \geq E_{th}$. All of this may have some relevance because in going from a fully extrapolated cross section to a cut $\hat{s} \geq 0.01\,s$ we find a 0.05% variation in the μ cross section at the peak (and few % away from it), while moving m_t from 150 GeV to 200 GeV gives a variation of 0.03% on the same quantity. Clearly if these effects are not under control then we loose information on m_t.

For electrons some of the experiments report the $s-$channel data only, in which case the lineshape is usually extrapolated while the asymmetry is not, and others report instead the full $s+t$ result with cuts. Even in this case there are differences since sometimes a cut is introduced for both the fermion and anti-fermion scattering angles, while sometimes only the fermion angular acceptance is constrained. Moreover E_{th} is usually not reported and not all experiments publish $\sigma^s(e)$ and $\sigma^{s+t}(e)$. We conclude that a global fit to the lineshape and asymmetry data, without $t-$channel subtraction, is an *independent* check of the analysis for the LEP data.

Before presenting the results of our analysis we consider few additional problems connected with radiative corrections. Higher order final state QED corrections may be implemented in different ways, all equally plausible [18, 10]. The leading term is given by [15]

$$-2\frac{\alpha}{\pi}Q_f^2\ln\left(1-\frac{s_0}{s}\right)\left(\ln\frac{m_f^2}{s}+1\right) \tag{7}$$

where $s \geq s_0$ is an invariant mass cut and it should be exponentiated, giving sizeable effects for high thresholds. However in the presence of an acollinearity cut the infrared logarithm is replaced by

$$\ln(1-x), \qquad x = \max\left\{\frac{s_0}{s}, \frac{1-\sin\frac{\xi}{2}}{1+\sin\frac{\xi}{2}}\right\} \tag{8}$$

where ξ is the maximum allowed acollinearity and this term could be exponentiated instead or we could just decide to exponentiate the full $\mathcal{O}(\alpha)$ term. At the Z^0 peak all these choices are compatible within 0.1% but this is not true anymore away from it and in the presence of severe experimental cuts. Moreover, as shown in ref. [10], there is a problem connected with the calorimetric measurement in Bhabha scattering. For final state QED corrections we must include both an exclusive algorithm for hard non-collinear photons (such as $m^2(e^+e^-) \geq M^2$ or $E_\pm \geq E_{th}$) and a jet-like algorithm for photons such that the $e^+e^-\gamma$ system is degenerate with the e^+e^- system. Finally few words for the strategy adopted in dealing with QED IS radiation. The full description can be found elsewhere [18, 10] and here we only stress that the basic idea, which allows in the end for fitting the Bhabha data at the same level of any other annihilation channel, relays on the observation that kinematical effects and acollinearity cuts, although important, are always small when compared with those arising from an invariant mass cut alone [18, 10]. Therefore we define a regulating cross section $\sigma^\pm_{reg}$

$$\sigma^\pm_{reg} = \int_0^{1-s_0/s} dx\, H(x,s)\left[\int_{R^\pm}\frac{d\sigma^0}{d\Omega}(x_1=x_2=1)\right]F^\pm_{cut} \tag{9}$$

where H is the radiator function, F_{cut} takes into account the final state radiation and $\pm$ refers to the forward(backward) region. The corrected cross section is computed as

$$\sigma^\pm_c = \sigma^\pm_{reg} + \Delta\sigma^\pm \tag{10}$$

and the difference $\Delta\sigma^\pm$, which is given by two and three dimensional integrals, accounts for all kinematical effects and it has a much simpler structure of (integrable) singularities. Even more important it is always numerically small when compared with $\sigma^\pm_{reg}$ [10]. By standard techniques [18] the regulating cross sections can always be reduced to a large analytical term, we only need to compute the primitive of the radiator, and to small numerical contributions.

An objection which often is raised to our, or similar, procedure is the following. Since the 1990 data are available but only the OPAL Collaboration has published the 1991 (and partially the 1992) data, while the ALEPH Collaboration has presented the preliminary 1991 data and the other data are still unofficial, the usual criticism is that such an analysis is doomed to be obsolete. Nevertheless, in view of the importance of an independent analysis, we present some of the results which can be obtained with our code TOPAZ0. Sometimes they should be considered for their face value, namely as consistency checks and as a prove of the feasibility of the whole approach and not really for what you learn about the latest value for m_t.

Starting from ALEPH we compare the 1990 data with/without $s-$channel electrons with the 1990 + 1991(preliminary) data. In the first case we include the 7 points with the highest luminosity and introduce $\hat{s} \geq 0.01\, s$ for hadrons only

$$
\begin{aligned}
\text{ALEPH data} \quad & \quad 1990, 7 \quad \text{energies} \\
\text{without} \quad e \quad & \quad \text{with} \quad e \\
M_z = 91.177 \pm 0.011\,\text{GeV} \quad & \quad = 91.180 \pm 0.011\,\text{GeV} \\
m_t = 115^{+55}_{\dots}\,\text{GeV} \quad & \quad = 112^{+54}_{\dots}\,\text{GeV} \\
\alpha_s = 0.144 \pm 0.024 \quad & \quad = 0.139 \pm 0.021 \\
\chi^2/\text{dof} = 1.47 \quad & \quad = 1.41
\end{aligned}
$$

The points become 14 and require a cut also for the leptonic channels when 1991(preliminary) data are included. As a result

$$
\begin{aligned}
\text{ALEPH data} \quad & \quad 1990 + 1991, 14 \quad \text{energies} \\
\text{without} \quad e \quad & \quad \text{with} \quad e \\
M_z = 91.184 \pm 0.007\,\text{GeV} \quad & \quad = 91.184 \pm 0.007\,\text{GeV} \\
m_t = 187^{+26}_{-30}\,\text{GeV} \quad & \quad = 186^{+25}_{-26}\,\text{GeV} \\
\alpha_s = 0.124 \pm 0.015 \quad & \quad = 0.121 \pm 0.013 \\
\chi^2/\text{dof} = 1.17 \quad & \quad = 1.14
\end{aligned}
$$

Therefore there is good agreement between the results with or without $s-$ channel electrons. In Figure 3a-b we give the electron lineshape and asymmetry at the best value of the MSM parameters. From the DELPHI Collaboration we take the 1990 data where both the $s-$channel and the $s+t$ electrons are reported. In the analysis muons and taus are always extrapolated while the $s+t$ electrons correspond to $44^o < \theta_\pm < 136^o$ and $\theta_{ac} < 10^o$. The $s-$channel electrons are given for an extrapolated lineshape and a forward-backward asymmetry with cuts. We find

$$
\begin{array}{rl}
\text{DELPHI data} & 1990, 7 \quad \text{energies} \\
s+t \quad \text{electrons} & s \quad \text{electrons} \\
M_z = 91.175 \pm 0.012\,\text{GeV} & = 91.177 \pm 0.013\,\text{GeV} \\
m_t = 192^{+41}_{-62}\,\text{GeV} & = 181^{+46}_{-61}\,\text{GeV} \\
\alpha_s = 0.119 \pm 0.010 & = 0.120 \pm 0.010 \\
\chi^2/\text{dof} = 0.89 & = 0.90
\end{array}
$$

where we have constrained $\alpha_s = 0.125 \pm 0.011$. This represents a consistency check on the $t-$channel subtraction since we can start from the full set of data and fit the parameters of the MSM, after which we compute the $s-$channel quantities and compare with the data as reported after the subtraction. This procedure is illustrated in Figure 4a-b for the lineshape and the asymmetry.

From the 1990 data published by the L3 Collaboration we have μ, τ fully extrapolated and

1. $s+t$ electrons with $44^o < \theta_\pm < 136^o$ and $\theta_{ac} < 25^o$ or
2. $s-$channel electrons with $44^o < \theta_\pm < 136^o$ and $\theta_{ac} < 25^o$ or
3. $s-$ channel electrons with a fully extrapolated lineshape and cuts for the asymmetry

Correspondingly we obtain

$$
\begin{array}{rl}
\text{L3 data} & 1990, 7 \quad \text{energies} \\
s+t \quad \text{data} & s \quad \text{data with cuts} \\
M_z = 91.178 \pm 0.012\,\text{GeV} & = 91.180 \pm 0.013\,\text{GeV} \\
m_t = 88^{+68}_{\dots}\,\text{GeV} & = 97^{+61}_{\dots}\,\text{GeV} \\
\alpha_s = 0.139^{+0.027}_{-0.026} & = 0.132^{+0.036}_{-0.020} \\
\chi^2/\text{dof} = 0.93 & = 0.94 \\
s \quad \text{data extrapolated} & \\
M_z = 91.179 \pm 0.012\,\text{GeV} & \\
m_t = 84^{+70}_{\dots}\,\text{GeV} & \\
\alpha_s = 0.139 \pm 0.027 & \\
\chi^2/\text{dof} = 0.95 &
\end{array}
$$

From a fit to the $s+t$ data we can derive p_{s+t} parameters in the MSM while from a fit to the s data we obtain p_s parameters and construct the quantity

$$R_{sub} = 1 - \frac{\sigma_e^s(p_{s+t})}{\sigma_e^s(p_s)} \tag{11}$$

As shown explicitly in Figure 5 this ratio is such that $|R_{sub}| < 0.4\%$. The lineshape and the forward-backward asymmetry for electrons are shown in Figure 6a-b.

As far as the $OPAL$ Collaboration is concerned we have considered the 1991(92) data for a total of 8 points in energy. Here we have that

1. Hadrons are always extrapolated
2. μ and τ lineshapes are extrapolated with a cut $\hat{s} < 0.01\,s$
3. for the asymmetries we have $|\cos\theta(\mu^-)| < 0.95$, $\theta_{ac}(\mu) < 15^o$, $|\cos\theta(\tau^-)| < 0.90$ and $\theta_{ac}(\tau) < 15^o$
4. $s+t$ electrons with $|\cos\theta(e^-)| < 0.7$ and $\theta_{ac}(e) < 10^o$

Also the spread of the CM energy ($51 \pm 5\,\mathrm{MeV}$) is taken into account by OPAL by correcting the measured cross sections in the fitting procedure. By including initial state pair production we obtain

OPAL data	1991 + 1992, 8 energies
with correction	without correction
$M_z = 91.184 \pm 0.008\,\mathrm{GeV}$	$= 91.184 \pm 0.008\,\mathrm{GeV}$
$m_t = 101^{+47}_{\dots}\,\mathrm{GeV}$	$= 97^{+48}_{\dots}\,\mathrm{GeV}$
$\alpha_s = 0.129 \pm 0.014$	$= 0.133 \pm 0.014$
$\chi^2/\mathrm{dof} = 0.76$	$= 0.75$

If instead the IS pair production is not included (with energy spread corrections) we get $m_t = 93^{+49}_{\dots}\,\mathrm{GeV}$ and $\alpha_s = 0.136 \pm 0.014$ with a $\chi^2/\mathrm{dof} = 0.75$. The various lineshapes and asymmetries for leptonic channels are given in Figure 7-9.

Our final conclusion is that a global analysis of the LEP data, including acceptance cuts and avoiding the $t-$channel subtraction is possible, and indeed in the worst case our code TOPAZ0 can perform a fit to the data in about 1 h of CPU time (on a VAX·4000 · 90). We want to stress that *original* data should also be published and would like to argue that in ten years from now there will be little use of a quantity such as $A^0_{FB}(b)$ if something goes wrong in the theory. Indeed in this quantity there are no QED corrections, no $\gamma-$interference, no imaginary part of the photon vacuum polarization and expecially no final state QCD corrections. As a final comment we point out that there could be an anomalous $Z^0\bar{b}b$ coupling, but as usual beware of anomalies!

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Figure and Table Captions

Table 1a-b

The experimental accuracy for some of the deconvoluted quantities and their projection for the end of the 1993 run (1a) and the statistical error on the peak cross sections for the 1991 − 92 ALEPH and OPAL data (1b).

Table 2a-b

Comparison between TOPAZ0 (first entry) and ZFITTER (second entry) for some of the deconvoluted quantities, including the new $\mathcal{O}(G_F^2 m_t^4)$ corrections [7].

Table 3a

Comparison with ZFITTER for $m_t = 100\,\mathrm{GeV}$. Here $\delta = 2\,(\mathrm{TOPAZ0}{-}\mathrm{ZFITTER})/(\mathrm{TOPAZ0}{+}\mathrm{ZFITTER})$ while $\Delta = |\mathrm{TOPAZ0} - \mathrm{ZFITTER}|$. Pair production is not included and no cuts are applied.

Table 3b

The same as in Table 3a with $m_t = 200\,\mathrm{GeV}$.

Table 4a-b

The effect of the $\mathcal{O}(g_f^2 m_t^4)$ and $\mathcal{O}(\alpha_S G_F m_t^2)$ for some of the deconvoluted quantities.

Figure 1a-b

The ratio σ(TOPAZ0)/σ(ZFITTER) (a) and the difference A_{FB}(TOPAZ0)-A_{FB}(ZFITTER) (b) for muon decay channel. Weak and strong parameters are $M_Z = 91.175$ GeV, $m_t =$ 100 GeV, $m_H = 300$ GeV and $\alpha_s = 0.125$. The set-up is defined as $40° \leq \vartheta_- \leq 140°$, $0° \leq \vartheta_+ \leq 180°$, $E_{th} = 1$ GeV and maximum acollinearity 25° (dashed line) and 10° (solid line).

Figure 2a-b

The same as in Fig. 1 for the full Bhabha cross section. The comparison with ALIBABA is shown for a maximum acollinearity of 25° (dashed line) and 10° (solid line). The comparison with the Bhabha package of ZFITTER (BHANG) is shown only for a maximum acollinearity of 25° (dash-dotted line).

Figure 3a-b

The electron lineshape (a) and forward-backward asymmetry for ALEPH data at our best value for the parameter of the MSM. Dotted line refers to 1990 data only, while the solid line includes the 1991 data.

Figure 4a-b

The electron lineshape (a) and the forward backward asymmetry (b) for the 1990 DELPHI $s+t$ data at our best value for the parameters of the MSM (solid line). The dashed line refers to the $s-$channel quantities computed with the derived parameters.

Figure 5

The ratio $1 - \sigma^s_e(p_{s+t})/\sigma^s_e(p_s)$ for the L3 1990 data. Here p_{s+t} refers to the set of MSM parameters obtained from a fit to the $s+t$ data, while p_s to those obtained from a fit to the s data.

Figure 6a-b

The electron lineshape (a) and forward-backward asymmetry for L3 1990 data at our best value for the parameter of the MSM.

Figure 7a-b

The μ lineshape (a) and forward-backward asymmetry (b) for the $1991-92$ OPAL data at our best value for the parameters of the MSM.

Figure 8a-b

The same as in Figure 7 for τ's.

Figure 8a-b

The same as in Figure 7 for electrons.