ON THE ELECTROWEAK AND GLUONIC CORRECTIONS TO THE HADRONIC WIDTH OF THE Z BOSON

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ABSTRACT

The electroweak corrections to the Z -boson hadronic width are presented in a simple analytical form for the width itself, Γ_h , for its ratio to the leptonic width, $R_l = \Gamma_h/\Gamma_l$, for the Γ_b/Γ_h ratio, and for the total width Γ_Z . The rational parametrization, advocated in our recent papers on leptonic decays, simplifies the analysis of the hadronic decays too. The two main results of this analysis are:

1. All electroweak precision measurements agree within 1σ with the electroweak Born approximation if the gluon coupling constant $\bar{\alpha}_s = 0.12$. Thus the electroweak radiative corrections have not been observed experimentally. The unexpected smallness of electroweak radiative corrections is caused by the mutual cancellation of the large positive contribution of a heavy top quark and the large negative contribution of all other virtual particles.

2. With electroweak radiative corrections being taken into account, the value of $\bar{\alpha}_s$ extracted from the experimental value of Γ_Z differs by $\geq 3\sigma$ from that obtained from R_l , if $m_t \geq 200$ GeV; they agree within 1σ if $m_t \leq 150$ GeV. Thus a low upper limit on m_t can be obtained from hadronic decays of the Z -boson alone, even without data on its leptonic decays.

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In a recent series of papers [1]–[8] we made an attempt to reparametrize and recalculate electroweak radiative corrections. In this paper we apply our parametrization to the hadronic widths of the Z boson, expressing them in terms of three sets of parameters:

1) The most accurately measured electroweak observables:

$$G_\mu = 1.16639(2) \times 10^{-5} \text{ GeV}^{-2}, \quad m_Z = 91.187(7) \text{ GeV}, \quad \bar{\alpha} = 1/128.87(12); \quad (1)$$

2) less accurately known values of the “running” parameters $\bar{\alpha}_s \equiv \alpha_s(m_Z)$ and $\bar{m}_b \equiv m_b(m_Z)$;

3) parameters unknown at present, m_t and m_H .

The partial width of the Z decay into a pair of fermions $f\bar{f}$ is:

$$\Gamma_f = \frac{N_c f^2 m_Z}{48\pi} [g_{Af}^2 G_{Af} + g_{Vf}^2 G_{Vf}] \left(1 + \frac{3\bar{\alpha} Q_f^2}{4\pi} \right), \quad (2)$$

where

$$f^2 = 4\sqrt{2} G_\mu m_Z^2 = 0.54864(8), \quad (3)$$

$N_c = 1(3)$ for leptons (quarks), the axial and vector couplings g_{Af} and g_{Vf} do not take into account the purely photonic and gluonic corrections, which are written out explicitly $(3\bar{\alpha} Q_f^2/4\pi, G_{Af} - 1, G_{Vf} - 1)$, but they include electroweak corrections V_{Af} and V_{Hf} [2]:

$$g_{Af} = T_3^f \left(1 + \frac{3\bar{\alpha} V_{Af}}{32\pi s^2 c^2} \right) \quad (4)$$

$$g_{Vf}/g_{Af} = (1 - 4 |Q_f| s^2) + \frac{3\bar{\alpha} |Q_f| V_{Hf}(t, h)}{4\pi(c^2 - s^2)}, \quad (5)$$

where $t = (m_t/m_Z)^2$, $h = (m_H/m_Z)^2$; $s \equiv \sin \theta$, $c \equiv \cos \theta$ are defined by the equation (see [9], [10], [1], [2], [6]):

$$s^2 c^2 = 4\pi \bar{\alpha} / f^2. \quad (6)$$

The functions $V_{Af}(t, h)$ and $V_{Hf}(t, h)$ for charged leptons have been presented in analytical, graphical and numerical forms in refs. [2] and [4]. Using the equations of paper [2] one can easily derive similar functions for u - and d -quarks:

$$V_{Au} - V_{Al} = \frac{128\pi s^3 c^3}{3\bar{\alpha}} [F_{Au} + F_{Al}] = 0.263 \quad (7)$$

$$V_{Ad} - V_{Al} = -\frac{128\pi s^3 c^3}{3\bar{\alpha}} [-F_{Ad} + F_{Al}] = 0.629 \quad (8)$$

$$\begin{aligned} V_{Ru} - V_{Rl} &= \frac{16\pi s c(c^2 - s^2)}{3\bar{\alpha}} \left[F_{Vl} - (1 - 4s^2) F_{Al} + \right. \\ &\quad \left. + \frac{3}{2} \left(-\left(1 - \frac{8}{3}s^2\right) F_{Au} + F_{Vu} \right) \right] = 0.122 \end{aligned} \quad (9)$$

$$\begin{aligned} V_{Rd} - V_{Rl} &= \frac{16\pi s c(c^2 - s^2)}{3\bar{\alpha}} \left[F_{Vl} - (1 - 4s^2) F_{Al} + \right. \\ &\quad \left. + 3 \left(\left(1 - \frac{4}{3}s^2\right) F_{Ad} - F_{Vd} \right) \right] = 0.268. \end{aligned} \quad (10)$$

Here the vertex corrections F_{Vf} and F_{Af} are taken from ref. [11] (with the substitutions $\alpha \rightarrow \bar{\alpha}, s_W \rightarrow s, c_W \rightarrow c$):

$$\begin{aligned} F_{Vl} &= 0.00186 & F_{Vc} &= 0.00197 \\ F_{Vu} &= -0.00165 & F_{Vu} &= -0.00169 \\ F_{Ad} &= 0.00137 & F_{Vd} &= 0.00138. \end{aligned} \quad (11)$$

Let us recall [2] that for a leptonic decay $Z \rightarrow l^+l^-$, where $l = e, \mu$, or τ ,

$$\begin{aligned} \Gamma_l &= \Gamma_0 \left[1 + \frac{3\bar{\alpha}V_{Al}}{16\pi s^2 c^2} \right] \left[1 + (1 - 4s^2)^2 + \frac{3\bar{\alpha}(1 - 4s^2)}{2\pi(c^2 - s^2)} V_{Rl} \right] \left(1 + \frac{3\bar{\alpha}}{4\pi} \right) = \\ &= \Gamma_0 [1 + 0.00185 + 0.0026V_{Al}] [1 + 0.0057 + 0.00052V_{Rl}] = \\ &= \Gamma_0 [1.00752 + 0.0026V_{Al} + 0.00052V_{Rl}], \end{aligned} \quad (12)$$

$$\Gamma_0 = \frac{\sqrt{2}G_F m_Z^3}{48\pi} = 82.94 \text{ MeV}. \quad (13)$$

[Neglecting proper electroweak corrections proportional to V_{Al} and V_{Rl} we get: $\tilde{\Gamma}_l = 1.00752\Gamma_0 = 83.56 \text{ MeV}$ in good agreement with experimental data [12, 13]: $\Gamma_l^{\text{exp}} = 83.51 \pm 0.28 \text{ MeV}$. Here and below, the tilde indicates the electroweak Born approximation, the excellent agreement of which with experimental data on leptonic decays was already stressed in Ref. [2]. One of the aims of this paper is to demonstrate that at the present level of experimental accuracy, the electroweak Born approximation (with the gluons duly taken into account) perfectly describes hadronic decays as well.]

Similarly for light quark decays we have:

$$\begin{aligned} \Gamma_u(\Gamma_c) &= 3\Gamma_0 G \left[1 + \frac{3\bar{\alpha}V_{Au}}{16\pi s^2 c^2} \right] \left[1 + (1 - 8s^2/3)^2 + \right. \\ &\quad \left. + \frac{\bar{\alpha}(1 - 8s^2/3)}{\pi c^2 - s^2} V_{Ru} \right] \left(1 + \frac{\bar{\alpha}}{3\pi} \right) = \\ &= 3\Gamma_0 G [1 + 0.00069 + 0.00082 + 0.00261V_{Au}] \times \\ &\quad \times [1.1470 + 0.0018V_{Ru}] = \\ &= 3\Gamma_0 G [1.1490 + 0.00299V_{Au} + 0.00176V_{Ru}]. \end{aligned} \quad (14)$$

(Discarding electroweak corrections proportional to V_{Au} and V_{Ru} , we obtain: $\tilde{\Gamma}_{u(c)} = 1.148 \cdot 3\Gamma_0 G$.) We then have

$$\begin{aligned} \Gamma_d(\Gamma_s) &= 3\Gamma_0 G \left[1 + \frac{3\bar{\alpha}V_{Ad}}{16\pi s^2 c^2} \right] \left[1 + (1 - 4s^2/3)^2 + \frac{\bar{\alpha}(1 - 4s^2/3)}{\pi 2(c^2 - s^2)} V_{Rd} \right] \left(1 + \frac{\bar{\alpha}}{12\pi} \right) = \\ &= 3\Gamma_0 G [1 + 0.00164 + 0.00021 + 0.00261V_{Ad}] [1.4785 + 0.00159V_{Rd}] = \\ &= 3\Gamma_0 G [1.4817 + 0.00386V_{Ad} + 0.00159V_{Rd}]. \end{aligned} \quad (15)$$

(Discarding terms proportional to V_{Ad} and V_{Rd} , we obtain $\tilde{\Gamma}_{d(s)} = 1.479 \cdot 3\Gamma_0 G$.)

The gluonic corrections are taken into account in eqs. (14), (15) by a single factor G , which is flavour- and parity-blind (see, however, a remark at the end of this paper).

According to refs. [14]–[16]

$$G_{Au} = G_{Vu} = G_{Ad} = G_{Vd} = G = \left[1 + \frac{\bar{\alpha}_s}{\pi} + 1.4 \left(\frac{\bar{\alpha}_s}{\pi} \right)^2 - 13 \left(\frac{\bar{\alpha}_s}{\pi} \right)^3 \right], \quad (16)$$

where $\bar{\alpha}_s$ is defined in the framework of the $\overline{MS}$ scheme.

As for the decay $Z \rightarrow b\bar{b}$, it has several specific features [17]–[29], which are reflected by the presence of additional terms in the expression for Γ_b :

$$\Gamma_b = \Gamma_d + \Gamma_0 \left\{ -\frac{\bar{\alpha}}{\pi} \phi(t) + (\bar{\alpha}_s/\pi)^2 I(t) - 0.05\mu^2 \right\}. \quad (17)$$

Here the term proportional to $\phi(t)$ comes from the top contribution to the electroweak vertex [18]–[20].

According to [20], the interpolating formula for $\phi(t)$ has the form:

$$\begin{aligned} \phi(t) &\equiv 4(3 - 2s^2)F(t) = \frac{(3 - 2s^2)}{2s^2 \cdot c^2} \left\{ t + c^2 \left[2.88 \ln \left(\frac{t}{c^2} \right) - \right. \right. \\ &\quad \left. \left. - 6.716 + \frac{8.368c^2 \ln(\frac{t}{c^2}) - 3.408c^2}{t} + \frac{9.126c^4 \ln(\frac{t}{c^2}) + 2.26c^4}{t^2} \right] \right. \\ &\quad \left. + \frac{4.043c^6 \ln(\frac{t}{c^2}) + 7.41c^6}{t^3} \right\} \end{aligned} \quad (18)$$

The accuracy of eq. (18) for $m_t > 115 \text{ GeV}$ is better than 1% according to [20]. (If in eq. (18) only terms proportional to t and $\ln t$ are kept, as was done in [21], [22], then the resulting accuracy is of the order of unity). In the vicinity of $m_t = 150 \text{ GeV}$ eq. (18) may be approximated by:

$$\phi(t) \approx 21.1 \left[1 + 1.4 \frac{m_t - 150}{m_Z} + 0.4 \left(\frac{m_t - 150}{m_Z} \right)^2 \right] \quad (19)$$

The term $(\bar{\alpha}_s/\pi)^2 I(t)$ in eq. (17) originates from two graphs describing the absorptive part of the Z -boson polarization function. One of them contains t - and b -quark triangles connected by two gluons, while in the other both triangles are of the b -type. According to [24]–[26]:

$$I(t) = -9.25 - 3 \ln t + \frac{0.26}{t} + \frac{0.04}{t^2}. \quad (20)$$

In the vicinity of $m_t = 150 \text{ GeV}$ we get:

$$I(t) \approx -12.1 \left[1 + 0.31 \frac{m_t - 150}{m_Z} - 0.10 \left(\frac{m_t - 150}{m_Z} \right)^2 \right] \quad (21)$$

The last term in eq. (17) is due to the non-negligible mass of the b -quark. It includes three effects: 1) the appearance of m_b in the square of the amplitude, 2) its appearance in the phase space, 3) its “running” because of interactions with gluons. The first two effects give the term $-6(m_b/m_Z)^2 = -0.048$ for the “on-the-shell mass” $m_b = 4.8 \text{ GeV}$. The third effect introduces $\bar{m}_b \equiv m_b(m_Z) \equiv \mu \cdot m_b$, with $\bar{m}_b \simeq 2.3 \text{ GeV}$ [16] and [27]–[29], $\mu^2 \simeq 1/4$.

As can be seen from (17), (18), (20), the most important correction comes from eq. (18).

Now we can write down the total hadronic width

$$\Gamma_h = 2\Gamma_u + 2\Gamma_d + \Gamma_b + \Gamma_g, \quad (22)$$

where Γ_g refers to the decay into pure gluons. This effect is expected to be small, because it starts with a decay into three gluons. However the quark loops leading to the decay $Z \rightarrow 3g$ give unequal contributions to vector and axial couplings, thus destroying the $V - A$ universality of the correction G . (See the last term in eq. (16), which should be taken with a large pinch of salt. We just borrow this term from traditional writings, which usually neglect the effect under discussion. In particular, we do not know about any existing calculation with a top-quark loop.) Anyway we will forget about three-gluon decay in what follows and obtain:

$$\begin{aligned} \Gamma_h &= 2\Gamma_u + 3\Gamma_d + \Gamma_0 \left\{ -\frac{\bar{\alpha}}{\pi} \phi(t) + (\bar{\alpha}_s/\pi)^2 I(t) - 0.05\mu^2 \right\} = \\ &= \Gamma_0 G [20.2288 + 0.05268V_{Al} + 0.02487V_{Rl}] + \\ &+ \Gamma_0 \left\{ -\frac{\bar{\alpha}}{\pi} \phi(t) + (\bar{\alpha}_s/\pi)^2 I(t) - 0.05\mu^2 \right\}. \end{aligned} \quad (23)$$

According to [2], where V_{Al} and V_{Rl} were written without subscript l ,

$$V_{Al}(t, h) = t + T_A(t) + H_A(h) - 2.26, \quad (24)$$

$$V_{Rl}(t, h) = t + T_R(t) + H_R(h) - 3.50; \quad (25)$$

the functions $T_{A,R}(t)$ and $H_{A,R}(h)$ were tabulated in [2]. By comparing eq. (23) with the experimental value of the hadronic width [12], [13]:

$$\Gamma_h = 1740 \pm 6 \text{ MeV}, \quad (26)$$

one can derive the values of $\bar{\alpha}_s$ for a set of m_t and m_H inputs (Table I). If we calculate G by inserting in (16) $\bar{\alpha}_s = 0.12$, and use the simplified formula $\bar{\Gamma}_h = 3\bar{\Gamma}_d + 2\bar{\Gamma}_u$, we will obtain $\bar{\Gamma}_h = 1742 \text{ MeV}$, in perfect agreement with experimental data.

In eq. (23), we may use eq. (27) for Γ_b , instead of eq. (17):

$$\begin{aligned} \Gamma_b &= 3\Gamma_0 \left(1 + \frac{\bar{\alpha}}{12\pi} \right) \left\{ (G + \delta G_{Ab}) \left[1 + (1 + (1 - \frac{4s^2}{3}))^2 \right] \right. \\ &\cdot \frac{3\bar{\alpha}V_{Ad}}{16\pi s^2 c^2} - \frac{\bar{\alpha}}{2\pi(3 - 2s^2)} \phi(t) \left. \right\} + (G + \delta G_{Vb}) \cdot \\ &\cdot \left[(1 - 4s^2/3)^2 + \frac{\bar{\alpha}(1 - 4s^2/3)}{2\pi(c^2 - s^2)} V_{Rd} + \frac{\bar{\alpha}}{\pi} \frac{3 - 4s^2}{6(3 - 2s^2)} \phi(t) \right] \Big\} \\ \delta G_{Ab} &= \left(\frac{\bar{\alpha}_s}{\pi} \right)^2 \frac{1}{3} I(t) - 0.016\mu^2 \left[1 + 3.67 \frac{\bar{\alpha}_s}{\pi} + 14.3 \left(\frac{\bar{\alpha}_s}{\pi} \right)^2 \right], \\ \delta G_{Vb} &= 0.032\mu^2 \frac{\bar{\alpha}_s}{\pi} \left[1 + 8.7 \frac{\bar{\alpha}_s}{\pi} + 45.3 \left(\frac{\bar{\alpha}_s}{\pi} \right)^2 \right]. \end{aligned} \quad (27)$$

In this equation gluonic corrections are separately factorized, in the spirit of ref. [16], for vector and axial-vector couplings (with the inclusion of higher-order $\bar{\alpha}\bar{\alpha}_s$ terms).

In this case the last digits in the figures of Table I would increase by no more than unity (the experimental accuracy of the figures is ± 0.012).

However, eq. (27) is theoretically not more accurate than eq. (23) because it does not include the non-factorizable terms arising from gluons connecting quarks in the electroweak loop with external quark "legs".

Table I
Central values of $\bar{\alpha}_s$ derived from Γ_h

m_H	m_t					
	100	120	140	160	180	200
50	0.126	0.121	0.116	0.109	0.102	0.093
100	0.128	0.123	0.117	0.111	0.103	0.095
150	0.129	0.124	0.119	0.112	0.105	0.096
200	0.131	0.126	0.120	0.113	0.106	0.098
250	0.132	0.127	0.121	0.114	0.107	0.099
450	0.135	0.130	0.124	0.118	0.109	0.102
750	0.138	0.133	0.127	0.121	0.113	0.105

A glance at Table I reveals that the value of $\bar{\alpha}_s = 0.118 \pm 0.007$ obtained from event shape measurements, τ -decay, etc. [30]–[32], would be absolutely compatible with the observed Γ_h for

$$m_t \sim 140\text{--}160 \text{ GeV}, \quad 50 \text{ GeV} \leq m_H \leq 450 \text{ GeV}.$$

It should be stressed that a different result, albeit still compatible within 1σ with the left-hand part of Table I, is obtained from consideration of the ratio

$$R_l = \Gamma_h/\Gamma_l. \quad (28)$$

Dividing eq. (23) by eq. (12) we get:

$$\begin{aligned} R_l &= 20.08G + 0.014V_{Rl} - \frac{\bar{\alpha}}{\pi} \phi(t) + \\ &+ (\bar{\alpha}_s/\pi)^2 I(t) - 0.05\mu^2. \end{aligned} \quad (29)$$

which should be compared with [12]

$$R_l^{exp} = 20.83 \pm 0.06. \quad (30)$$

(Let us mention that without proper electroweak corrections we get: $\bar{R}_l = \bar{\Gamma}_h/\bar{\Gamma}_l = 20.84$ for $\bar{\alpha}_s = 0.12$.) The resulting values of $\bar{\alpha}_s$ are presented in Table II.

Table II
Central values of $\bar{\alpha}_s$ derived from R_l

	m_t						
m_H	100	120	140	160	180	200	
50	0.124	0.125	0.126	0.127	0.128	0.129	
100	0.125	0.126	0.127	0.128	0.129	0.130	
150	0.126	0.127	0.127	0.128	0.130	0.131	
200	0.126	0.127	0.128	0.129	0.130	0.131	
250	0.127	0.127	0.128	0.129	0.130	0.131	
450	0.127	0.128	0.129	0.130	0.131	0.132	
750	0.128	0.129	0.130	0.131	0.132	0.133	

The values of $\bar{\alpha}_s$ in Tables I and II were rounded up. This produced some non-monotonicity, which is anyway much smaller than the experimental uncertainties (± 0.012 in Table I; ± 0.010 in Table II).

As was pointed out to us by K.A. Ter-Martirosyan, the systematic difference between Tables I and II may be connected with the fact that the data on electroweak corrections to g_{AI} (i.e. essentially to Γ_l) imply a lighter top mass than the data on corrections to g_V/g_A and m_W/m_Z (see isolines in ref. [8]).

It is worth mentioning that virtual gluons in the “oblique” and vertex t -loop corrections reduce them, because m_t at short distances is smaller than at large ones [4]. As a result $V_{R,A}(t)$ for large t is reduced by a factor $(1 - \frac{2x^2 + 6\bar{\alpha}_s}{\pi}) = 1 - 2.86\frac{\bar{\alpha}_s}{\pi}$ (see ref. [33], [34]), while for $\phi(t)$ the reduction factor is $(1 - \frac{1}{3}(\pi^2 - 3)\frac{\bar{\alpha}_s}{\pi}) = 1 - 2.29\frac{\bar{\alpha}_s}{\pi}$ for the leading t -term [35].

Usually the QCD corrections to Γ_h are presented [36, 37, 38] in the form

$$\Gamma_h = \Gamma_h^0 \left(1 + 1.05 \frac{\bar{\alpha}_s}{\pi} + (0.9 \pm 0.1) \left(\frac{\bar{\alpha}_s}{\pi} \right)^2 - 13 \left(\frac{\bar{\alpha}_s}{\pi} \right)^3 \right), \quad (31)$$

where Γ_h^0 is the hadronic width without QCD corrections ($\bar{\alpha}_s = 0$). This implies in particular that Γ_h^0 is calculated with “on mass shell m_b ” (in fact, in [36] $m_b = 4.8$ GeV is used). The running of m_b is absorbed, somewhat arbitrarily, in the factors 1.05 and (0.9 ± 0.1) . The advantage of our expressions (17) and (23) is that they represent every physical effect separately and show explicit dependence on m_t and m_H .

Let us now discuss two other observables, measured at LEP: the ratio of Γ_b to Γ_h and the total width Γ_Z . As was stressed in [22] (see also [23]), Γ_b/Γ_h does not depend on m_H and a comparison with its experimental value gives a bound on m_t independent of m_H . From (17), (15), and (23), we readily see that the V_{AI} contribution completely cancels in the ratio, while V_{RI} comes with such a small coefficient that it can be omitted. Finally what we obtain is essentially the tree-level result, corrected by b -quark peculiarities:

$$\frac{\Gamma_b}{\Gamma_h} = 0.2197 \left\{ 1 + 0.176 \left[-\frac{\bar{\alpha}_s}{\pi} \phi(t) + (\bar{\alpha}_s/\pi)^2 I(t) - 0.05\mu^2 \right] \right\}. \quad (32)$$

Using (19) and (21), substituting $\mu^2 = 1/4$ and expanding eq.(32) near $\bar{\alpha}_s = 0.12$, we get:

$$\Gamma_b/\Gamma_h = 0.2165 - 0.003 \frac{(m_t - 150)}{m_Z} - 0.011(\bar{\alpha}_s - 0.12), \quad (33)$$

to be compared with the latest experimental number [39]:

$$\frac{\Gamma_b}{\Gamma_h} = 0.2201 \pm 0.0032. \quad (34)$$

From eq. (32) we get the following upper bounds on m_t :

$$m_t < 140 \text{ GeV at } 1\sigma, \quad m_t < 220 \text{ GeV at } 2\sigma.$$

Consider now Γ_Z , the Z -boson total width. Using charge lepton and neutrino universalities we obtain:

$$\Gamma_Z = \Gamma_h + 3\Gamma_l + 3\Gamma_\nu. \quad (35)$$

The expression for Γ_h is contained in (23), that for Γ_l in (12), while for Γ_ν we have [2]:

$$\Gamma_\nu = 8g_\nu^2 \cdot \Gamma_0 \quad (36)$$

$$g_\nu = \frac{1}{2} + \frac{3\bar{\alpha}}{64\pi s^2 c^2} V_\nu, \quad V_\nu = V_A + 1.11. \quad (37)$$

A recent experimental result is [12, 13]:

$$\Gamma_Z = 2488 \pm 7 \text{ MeV}. \quad (38)$$

Comparing this number with the theoretical expression for Γ_Z , we obtain values of $\bar{\alpha}_s$ presented in Table III. The accuracy of these particular values of $\bar{\alpha}_s$ is 0.013.

Table III
Central values of $\bar{\alpha}_s$ derived from Γ_Z

m_H	m_t						
	100	120	140	160	180	200	
50	0.123	0.116	0.108	0.099	0.088	0.077	
100	0.125	0.118	0.110	0.100	0.090	0.078	
150	0.127	0.120	0.111	0.102	0.092	0.080	
200	0.128	0.121	0.113	0.104	0.093	0.081	
250	0.130	0.123	0.114	0.105	0.094	0.083	
450	0.134	0.127	0.118	0.109	0.098	0.087	
750	0.138	0.131	0.122	0.113	0.102	0.091	

The right-hand side of Table III differs from that of Table II even more drastically than did that of Table I. This may indicate that the top is of the order of or lighter than 150 GeV.

Discarding the proper electroweak corrections (for $\bar{\alpha}_s = 0.12$) we obtain:

$$\tilde{\Gamma}_Z = 1742 + 250.7 + 497.6 = 2490 \text{ MeV}. \quad (39)$$

Thus the Born approximation, based on $\bar{\alpha} = \alpha(m_Z^2)$ (see ref. [3]), reproduces the whole set of LEP data, and the genuine electroweak corrections have not yet been seen up

to now. This is the result of a “conspiracy” of 100–200 GeV top quark [8]. The existing upper limits on all electroweak radiative corrections have recently been reanalysed in order to find possible manifestations of non-standard physics [40].

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