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Extra quark-lepton generations and precision measurements

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Abstract

The existence of extra chiral generations with all fermions heavier than M_Z is strongly disfavoured by the precision electroweak data. However the data are fitted nicely even by a few extra generations, if one allows neutral leptons to have masses close to 50 GeV. The data allow inclusion of one additional generation of heavy fermions in SUSY extension of Standard Model if chargino and neutralino have masses close to 60 GeV with $\Delta m \simeq 1$ GeV.

1 Introduction

The aim of this article is to analyze to what extent the existing data on the Z-boson parameters, the W-boson and the top quark masses allow to bound effectively New Physics at high energies which does not decouple at "low" ($\sim m_Z$) energies. The most straightforward generalization of the Standard Model (SM) through inclusion of extra chiral generation(s) of heavy fermions, quarks ($q = U, D$) and leptons ($l = N, E$), is an example of such non decoupled New Physics. We show that it is excluded by the electroweak precision data, if all extra fermions are heavy: $m \gtrsim m_Z$. We find however that if masses of new neutrinos are close to 50 GeV, additional generations become allowed: even three extra generations with ≈ 50 GeV neutrinos can exist.

Finally inclusion of new generations in SUSY extension of Standard Model is discussed.

When speaking on extra generations the first thing to bother about is the extra neutrinos, N. Being coupled to Z-boson they would increase the invisible Z-width. To avoid contradiction with experimental data their masses should be larger than 45 GeV [1]. In order to meet this condition one has to introduce not only left-handed neutrinos N_L, but also right-handed neutrinos N_R and supply new "neutrinos" with Dirac masses analogously to the case of charged leptons and quarks. Unfortunately gauge symmetries do not forbid Majorana mass for N_R, and if it is large one would get light N_L through the see-saw mechanism. To avoid such a failure we will suppose that the Majorana mass of N_R is negligible, closing eyes on the emerging (un)naturalness problem. Thus, our neutral lepton N is a heavy Dirac particle.

Contribution of new generations to electroweak radiative corrections was considered in papers [2] - [7]. In what follows we will assume that the mixing among new generations and the three existing ones is small, hence new fermions contribute only to oblique corrections (vector boson self energies). This case is discussed in [7] and the authors come to the conclusion that one extra generation of heavy fermions is excluded at 99.2% CL. The authors of [7] follow a two step procedure: first they find that experimental bounds on parameter ρ exclude existence of nondegenerate extra generation (degenerate generation is decoupled from ρ). Then they consider parameter S [8] from which degenerate generation is not decoupled and find that experimental value of S excludes the existence of extra degenerate generation as well. Such procedure is not general enough: it does not use all precision data. In the present paper we perform global fit of all precision data.

We study both degenerate and nondegenerate extra generations on the equal footing. By considering the contributions of new generations into all precision electroweak observables simultaneously we see that the fit of the data is worsened by them if all new particles are heavy. Taking the number of new generations N_g as a continuous parameter (just as it was done with the determination of the number of neutrinos from invisible Z width) we get a bound on it. The χ^2 minimum corresponds to $N_g \simeq -0.5$, while $N_g = 1$ is excluded by more than 2 standard deviations.

Section 2 contains general formulas for oblique radiative corrections caused by an extra doublet of quarks or leptons. In section 3 we consider the case when all extra fermions are heavy ($m \gtrsim m_Z$). In section 4 we consider the case when U, D, E are heavy, while N is "light", $m_N \simeq 50GeV$. In this case the contribution of N compensates that of U, D, E. Section 5 analyzes the SUSY version of four generations.

2 Formulas

New particles contribute to physical observables through self-energies of vector and axial currents. This gives corrections δV_i to the functions $V_i (i = A, R, m)$ which determine the values of physical observables (axial coupling g_A, the ratio $R = g_V/g_A$, and the ratio m_W/m_Z) [9]:

$$\frac{3\bar{\alpha}}{16\pi s^2 c^2}\delta V_A = \Pi_Z(m_Z^2) - \Pi_W(0) - \Sigma'_Z(m_Z^2) \ , \tag{1}$$

$$\frac{3\bar{\alpha}}{4\pi}\delta V_R = 4c^2 s^2[\Pi_Z(m_Z^2) - \Pi_W(0) - \Sigma'_\gamma(0)] - 4cs(c^2 - s^2)\Pi_{\gamma Z}(m_Z^2) \ , \tag{2}$$

$$\frac{3\bar{\alpha}}{16\pi s^4}\delta V_m = \frac{c^2}{s^2}\Pi_Z(m_Z^2) + \frac{s^2 - c^2}{s^2}\Pi_W(m_W^2) - \Pi_W(0) - \Sigma'_\gamma(0) \ , \tag{3}$$

where $\bar{\alpha} \equiv \alpha(m_Z^2)$ – the value of electromagnetic coupling at $q^2 = m_Z^2$; $s \equiv \sin\theta$, $c \equiv \cos\theta$, θ being the electroweak mixing angle, $s^2 = 0.23116(23)$; $\Pi_i(q^2) = \Sigma_i(q^2)/m_i^2, i = W, Z$; $\Pi_{\gamma Z} = \Sigma_{\gamma Z}/m_Z^2$; $\Sigma'(0) = \lim_{q^2 \to 0}\Sigma(q^2)/q^2$, where Σ is a vector boson self-energy (see [9]).

In this section we present expressions for these corrections. We start with the case of one $SU(2)_L$ doublet and its two right-handed singlet companions: $(UD)_L$, U_R, D_R. Let $N_c^{q,l}$ be the number of colors ($N_c^q = 3, N_c^l = 1$) and $u \equiv m_U^2/m_Z^2$, $d \equiv m_D^2/m_Z^2$. $Y^{q,l}$ is the doublet hypercharge, $Y^{q,l} = Q_U + Q_D$, where Q_U and Q_D are U and D electric charges (the hypercharge of isosinglets being equal to its doubled electric charge). Corrections produced by the one generation fermions are equal to the sum of lepton and quark contributions:

$$\Delta V_i = \delta V_i^q + \delta V_i^l \tag{4}$$

Contributions of quark or lepton doublets are given by:

$$\begin{aligned}
\delta V_A^{q,l} &= \frac{N_c^{q,l}}{3}\left[u + d + \frac{2ud}{d-u}\ln(\frac{u}{d}) - F'(u) - F'(d)\right] + \\
&+ N_c^{q,l}(-\frac{4}{9}s^2 - \frac{1}{9})\left[2uF(u) - (1+2u)F'(u) + 2dF(d) - (1+2d)F'(d)\right] + \\
&+ \frac{16}{9}N_c^{q,l}s^4\left\{Q_U^2\left[2uF(u) - (1+2u)F'(u)\right] + Q_D^2[2dF(d) - (1+2d)F'(d)]\right]\right\} + \\
&+ \frac{4}{9}N_c^{q,l}s^2 Y^{q,l}\left[2dF(d) - (1+2d)F'(d) - 2uF(u) + (1+2u)F'(u)\right] \ ,
\end{aligned} \tag{5}$$

$$\begin{aligned}
\delta V_R^{q,l} &= -\frac{2N_c^{q,l}}{3}\left\{uF(u) + dF(d) + \frac{ud}{u-d}\ln(\frac{u}{d}) - \frac{1}{2}(u+d)\right\} + \\
&+ \frac{16}{9}N_c^{q,l}s^2c^2\left\{Q_U^2[(1+2u)F(u) - \frac{1}{3}] + Q_D^2[(1+2d)F(d) - \frac{1}{3}]\right\} + \\
&+ \frac{2N_c^{q,l}Y^{q,l}}{9}\left\{(1+2d)F(d) - (1+2u)F(u) + \ln(\frac{u}{d})\right\} \ ,
\end{aligned} \tag{6}$$

$$\delta V_m^{q,l} = \frac{2}{9}N_c^{q,l}(1 - \frac{s^2}{c^2})\left\{-F(m_W^2, m_U^2, m_D^2)[2c^2 - u - d - \frac{(u-d)^2}{c^2}] + u + d - \frac{4}{3}c^2\right\} -$$

$$
\begin{aligned}
&- \frac{4s^2}{9} N_c^{q,l} Y^{q,l} \left[(1+2u)F(u) - (1+2d)F(d) - \ln(\frac{u}{d}) \right] + \\
&+ \frac{16}{9} N_c^{q,l} s^4 \left[Q_U^2 \left((1+2u)F(u) - \frac{1}{3} \right) + Q_D^2 \left((1+2d)F(d) - \frac{1}{3} \right) \right] + \frac{s^2}{3c^2} N_c^{q,l}(u+d) + \\
&+ \frac{2}{9} N_c^{q,l} \left[(1-u)F(u) + (1-d)F(d) - \frac{2}{3} \right] - \\
&- \frac{4}{9} N_c^{q,l} s^2 \left[(1+2u)F(u) + (1+2d)F(d) - \frac{2}{3} \right] + \\
&+ \frac{2}{9} N_c^{q,l} \ln(\frac{u}{d}) \left[(1+\frac{1}{c^2}) \frac{ud}{d-u} + (s^2 - c^2) \frac{d+u}{d-u} \right] \quad , \qquad (7)
\end{aligned}
$$

where

$$
\begin{aligned}
F(m_W^2, m_U^2, m_D^2) \;&=\; -1 + \frac{m_U^2 + m_D^2}{m_U^2 - m_D^2} \ln(\frac{m_U}{m_D}) - \\
&- \int\limits_0^1 dx \ln \frac{x^2 m_W^2 - x(m_W^2 + m_U^2 - m_D^2) + m_U^2}{m_U m_D} \quad , \qquad (8)
\end{aligned}
$$

$$
F(u) = F(m_Z^2, m_U^2, m_U^2) = \begin{cases} 2\left[1 - \sqrt{4u-1} \arcsin(\frac{1}{\sqrt{4u}}) \right] , & u > \frac{1}{4} \\ 2\left[1 - \sqrt{1-4u} \ln\left(\frac{1+\sqrt{1-4u}}{\sqrt{4u}} \right) \right] , & u < \frac{1}{4} \end{cases} \qquad (9)
$$

$$
F'(u) \equiv -u \frac{d}{du} F(u) = \frac{1 - 2uF(u)}{4u-1} \quad . \qquad (10)
$$

The following relation is useful in deriving eqs (5) - (7):

$$
\int\limits_0^1 dx (x^2 - x) \ln(x^2 - x + u) = \frac{1+2u}{6} F(u) - \frac{1}{18} - \frac{1}{6} \ln u \quad . \qquad (11)
$$

In the asymptotic limit (denoted by prime) where the fourth generation particles are much heavier than Z-boson ($u, d \gg 1$) neglecting power suppressed terms we obtain from eqs (5) - (7):

$$
\delta' V_A^{q,l} = \frac{N_c^{q,l}}{3} [u + d + \frac{2ud}{d-u} \ln(\frac{u}{d})] \;, \qquad (12)
$$

$$
\delta' V_R^{q,l} = \delta' V_A^{q,l} - \frac{2}{9} N_c^{q,l} + \frac{2}{9} N_c^{q,l} Y^{q,l} \ln(\frac{u}{d}) \;, \qquad (13)
$$

$$
\begin{aligned}
\delta' V_m^{q,l} \;&=\; \delta' V_A^{q,l} - \frac{2}{9} N_c^{q,l} + \frac{4}{9} N_c^{q,l} s^2 Y^{q,l} \ln(\frac{u}{d}) + \frac{4}{9} N_c^{q,l} (s^2 - c^2) \times \\
&\times \left[\frac{1}{3} - \frac{2}{(\frac{u}{d} - 1)^2} \frac{u}{d} + \frac{3}{(\frac{u}{d} - 1)^3} (\frac{u}{d} - \frac{1}{3} - \frac{1}{6} (\frac{u}{d} - 1)^3) \ln(\frac{u}{d}) \right] \quad . \qquad (14)
\end{aligned}
$$

In order to obtain the contribution of a generation one should sum those of quarks and leptons:

$$
\Delta' V_i = \delta' V_i^q + \delta' V_i^l \qquad (15)
$$

In the case of fully degenerate doublets ($m_U = m_D = m_N = m_E$) one obtains from (12) - (14):

$$\Delta' V_A = 0 \ , \quad \Delta' V_R = -\frac{8}{9} \ , \quad \Delta' V_m = -\frac{16}{9} s^2 \quad . \tag{16}$$

In the opposite case when $SU(2)_V$ is strongly violated ($m_U \gg m_D$ or $m_U \ll m_D$) all corrections $\Delta' V_i$ become equal:

$$\Delta' V_i = \frac{|m_U^2 - m_D^2|}{m_Z^2} + \frac{1}{3}\frac{|m_N^2 - m_E^2|}{m_Z^2} \quad . \tag{17}$$

In the present paper we consider the general case described not by asymptotic formulas (12) - (14) but by general formulas (5) - (7) which will allow us to study the case of "light" new neutrinos ($m_N \approx m_Z/2$). Using formulas (12) - (14) we already analyzed the effect of new generations with all fermions heavy, $m \gtrsim m_Z$, in paper [6] (see also [4],[5]). However with new experimental data we get much more restrictive bounds than those obtained in [6] (see the next section).

Let us present at the end of this section formulas for the "horizontally degenerate" case ($m_U = m_N$, $m_D = m_E$):

$$\begin{aligned} \Delta V_A &= \frac{4}{9}\Big\{(\frac{16}{3}s^4 - 4s^2 - 1)[2uF(u) - (1+2u)F'(u) + 2dF(d) - (1+2d)F'(d)] + \\ &+ 3[u + d - \frac{2ud}{u-d}\log\frac{u}{d} - F'(u) - F'(d)]\Big\} \quad , \end{aligned} \tag{18}$$

$$\Delta V_R = -\frac{8}{3}[uF(u) + dF(d) + \frac{ud}{u-d}\log\frac{u}{d} - \frac{u+d}{2}] + \frac{64}{27}s^2c^2[(1+2u)F(u) + (1+2d)F(d) - \frac{2}{3}] \ , \tag{19}$$

$$\begin{aligned} \Delta V_m &= (\frac{64}{27}s^4 - \frac{16}{9}s^2)[(1+2u)F(u) + (1+2d)F(d) - \frac{2}{3}] + \\ &+ \frac{8}{9}[(1-u)F(u) + (1-d)F(d) - \frac{2}{3}] + \frac{4}{3}\frac{s^2}{c^2}[u + d - \frac{2ud}{u-d}\log\frac{u}{d}] + \\ &+ \frac{8}{9}(1 - \frac{s^2}{c^2})[\frac{u-d}{2}\log\frac{u}{d} + (u+d) + (c^2 - \frac{u+d}{2})\frac{u+d}{u-d}\log\frac{u}{d} - \frac{4}{3}c^2 - \\ &- (2c^2 - u - d - \frac{(u-d)^2}{c^2})F(m_W^2, m_U^2, m_D^2)] \quad . \end{aligned} \tag{20}$$

In Fig. 1 the u dependence of the functions ΔV_i and $\Delta' V_i$ for $d = 1$ is shown. It is clear that accuracy of equations (12) - (14) is very good as soon as new fermions are heavier than Z-boson.

3 Comparison with experimental data: heavy fermions

We compare theoretical predictions for the case of the presence of extra generations with experimental data [10] with the help of the code LEPTOP [11] (see also [9]). These experimental data are exactly the same as used in the review [9] and they are very well fitted by Standard Model with $m_H = 71^{+82}_{-43}$ GeV $m_t = 171(5)$ GeV $\alpha_s = 0.119(3)$ $\bar{\alpha}^{-1} = 128.88(9)$ and

$\chi^2/ndf = 15.0/14$. We take $m_D = 130$ GeV – the lowest value allowed for the new quark mass from Tevatron search [12] and take $m_U \gtrsim m_D$. As for the leptons from the extra generations, their masses are independent parameters. To simplify the analyses we start with $m_N = m_U$, $m_E = m_D$. Any value of higgs mass above 90 GeV is allowed in our fits, however χ^2 appears to be minimal for $m_H = 90$ GeV. In Figure 2 the excluded domains in coordinates (N_g, Δm) are shown (here $\Delta m = (m_U^2 - m_D^2)^{1/2}$). Minimum of χ^2 corresponds to $N_g = -0.5$ and the case $N_g = 0$ is in the one standard deviation domain (1σ). We see that one extra generation corresponds to 2.5σ approximately. The behaviour of division lines in Fig. 2 can be understood qualitatively. For degenerate extra generations the corrections ΔV_i are negative. They become positive and large when Δm increases. That is why at large Δm division lines approach $N_g = 0$ value. In the intermediate region ($\Delta m \approx 125$ GeV) ΔV_i cross zero and this explains the turn to the right of the division lines. However, for different i zero is reached for different Δm values, that is why extra generations are excluded even for $\Delta m \approx 125$ GeV (see [6]).

We checked that similar bounds are valid for the general choice of heavy masses of leptons and quarks. In particular we found that for $m_N = m_D = 130$ GeV and $m_E = m_U$ one extra generation is excluded at 2 σ level, while for $m_E = m_U = 130$ GeV and $m_N = m_D$ the limits are even stronger than in Fig.2.

4 Comparison with experimental data: $m_N < m_Z$

According to [12] lower bound on m_E from LEP II is approximately 80 GeV. However, quasi-stable neutral lepton N can be considerably lighter. From LEP II searches of the decays $N \to lW^*$, where W^* is virtual while l is e, μ or τ, it follows that $m_N > 70 - 80$ GeV for the mixing angle with three known generations larger than 10^{-6} [13]. Thus let us take in this section this mixing to be less than 10^{-6}. In this case only DELPHI bound from the measurement of the Z-boson width is applicable, $m_N > 45$ GeV [1]. If m_N is larger than $m_Z/2$ searches at LEP II of the reaction $e^+e^- \to N\bar{N}\gamma$ should bound m_N. The observation of a "lonely photon" was suggested long time ago as a method to study cross section of the e^+e^- annihilation into neutrinos [14]. DELPHI collaboration performed such a search at $E \leq 183$ GeV and found that total number of neutrinos $N_\nu = 2.92 \pm 0.25(\text{stat}) \pm 0.14(\text{syst})$ [15, a].

ALEPH collaboration also reported [15, b] the measurement of the cross-section of the reaction $e^+e^- \to \gamma\nu\bar{\nu}$, which is compatible with SM prediction. However no special search was reported for the reaction $e^+e^- \to \gamma N\bar{N}(m_N > m_Z/2)$ so far. The data of [15] show the missing mass peak of Z decaying into three types of neutrinos and a contribution from W-exchange in the t-channel ($e^+e^- \to \nu_e\bar{\nu}_e\gamma$). Estimates show that for N masses around 47 GeV the most sensitive region is on the shoulder of the Z-peak (missing mass 95-105 GeV), where extra contribution to the differential cross-section is about 10 %. For heavier N one is forced to go to larger values of missing mass, where the effect of N is smaller. Taking into account that the expected cross-section for this reaction is rather low, we conclude that until now there is no bounds on the stable heavy neutrino with $m_N > m_Z/2$

For particles with masses of the order of $m_Z/2$ oblique corrections drastically differ from what we have for masses $\gtrsim m_Z$. In particular, renormalization of Z-boson wave function produces large negative contribution to V_A. From the analysis of the initial set of precision data in papers [2, 3] (published in years 1994 - 1995) it was found that the existence of additional light fermions with masses ≈ 50 GeV is allowed. Now analyzing all precision data and using bounds from direct searches we conclude, that the only presently allowed light fermion is neutral lepton N. As an example we take $m_U = 220$ GeV, $m_D = 200$ GeV, $m_E = 100$ GeV and draw exclusion plot in coordinates (m_N, N_g), see Fig.3 (we use small $m_U - m_D$ for fitting purposes). From this plot it is clear that for the case of fourth generation with $m_N \approx 50$ GeV description of the data is not worse than for the Standard Model and that even two new generations with $m_{N_1} \approx m_{N_2} \approx 50$ GeV are allowed within 1.5σ.

5 The case of SUSY

In this section we investigate bounds on extra generations which occur in SUSY extensions. When SUSY particles are heavy they decouple (i.e. their contributions to electroweak observables become power suppressed) and the same standard model exclusion plots shown in Fig.2 and Fig.3 are valid. The present lower bounds on the sparticle masses from direct searches leave mainly this decoupled domain. One possible exception is a contribution of the third generation squark doublet, enhanced by large stop-sbottom splitting. In this way we get noticeable positive contributions to functions V_i [16, 17]. They may help to compensate negative contributions of degenerate extra generations. We analyze the simplest case of the absence of $\tilde{t}_L - \tilde{t}_R$ mixing in Fig.4. In this figure the case of degenerate extra generations with common mass 130 GeV is considered (contributions of superpartners of new generations to V_i are negligible since new up- and down- particles are degenerate). Exclusion plot is presented in coordinates $(N_g, m_{sbottom})$. We see that with inclusion of SUSY new heavy generations are also disfavoured.

One can notice that in the differences $\delta V_m^{q,l} - \delta V_R^{q,l}$ and $\delta V_A^{q,l} - \delta V_R^{q,l}$ the dependence on the up-down mass splitting cancels to a large extent for fermions and for sfermions as well, that is why *if* degenerate doublets are not allowed by experimental data *then* splitting does not help. In case of fermions contribution of degenerate family is given by eq.(16) and it is not allowed because of large negative value of $\Delta' V_R$. In case of sfermions the degenerate family decouples and one can not compensate contribution of fermions.

Situation qualitatively changes in case of light chargino and neutralino. The latter are still not excluded - dedicated search at LEP II by DELPHI still allows the existence of such particles with masses as low as 45 GeV if their mass difference is ≈ 1 GeV (for larger Δm values charged decay products of chargino would be observable; for smaller Δm chargino would be seen by its ionization) [18]. Analytical formulas for corrections to the functions V_i from quasi degenerate chargino and neutralino were derived and analyzed in [19]. Corrections are big and this allows one to get lower bounds on masses of chargino and neutralino: $m_\chi > 51$ GeV for the case of higgsino domination and $m_\chi > 56$ GeV for the case of wino domination at 95% CL. [1] Fig.5 demonstrates how presence of chargino-neutralino pair (dominated by higgsino) with mass 57 GeV relaxes the bounds shown on Fig.2. We see that one extra generation of heavy fermions is allowed within 1.5σ domain in case of the light chargino.

6 Conclusions

Inclusion of new generations in Standard Model is not excluded by precision data if new neutral leptons are rather light having mass of the order of 50 GeV (see Fig.3). Mixing of new leptons with leptons from three known generations should be small, $\theta \leq 10^{-6}$, to avoid bounds from

[1] These bounds on m_χ follow from the global fit to all electroweak precision data, while those given in [19] are slightly different since only gluon-free observables were used.

direct search at LEP II. We can not exclude stability of one of these new neutrinos; in this case it becomes interesting for cosmology. If the early universe was charge symmetric annihilation of $N\bar{N}$ in primordial plasma leads to the abundance of these particles at present time $\Omega < 10^{-3}$ (formula for heavy neutrino abundance in case $m_N << m_Z$ was obtained in [20]). If the early universe was charge asymmetric abundance of relic N's is larger. However their contribution to mass density of the halo of our galaxy can not be larger than 0.1 - 0.01 - otherwise they would be already detected in laboratory searches for dark matter [21]. Even this small admixture of 50 GeV neutrino in the halo of our galaxy can help to explain gamma background through $N\bar{N}$ annihilation into e^+e^- with subsequent scattering of electrons and positrons on optical photons [22].

Concerning SUSY extensions: if masses of sparticles are of the order of several hundred GeV or larger their contribution to electroweak radiative corrections is negligible, hence the above statements remain valid. However in the case of quasi degenerate chargino and neutralino with masses about 60 GeV extra generations of heavy fermions appear to be less forbidden than without SUSY.

In order to experimentally investigate the case of $m_N < 50GeV$ a special post-LEP II run of LEP I $'$ measuring the Z-line shape slightly above the Z-peak is needed. In this way the bound [1] will be improved. For $m_N > 50GeV$ search for the reaction $e^+e^- \to \gamma Z^* \to \gamma N\bar{N}$ with larger statistics than that of [15] and improved systematics is needed. Finally, further experimental search for light chargino and neutralino [18] is of interest. These searches could close the existing windows of "light" extra particles, or open a door into a realm of New Physics.

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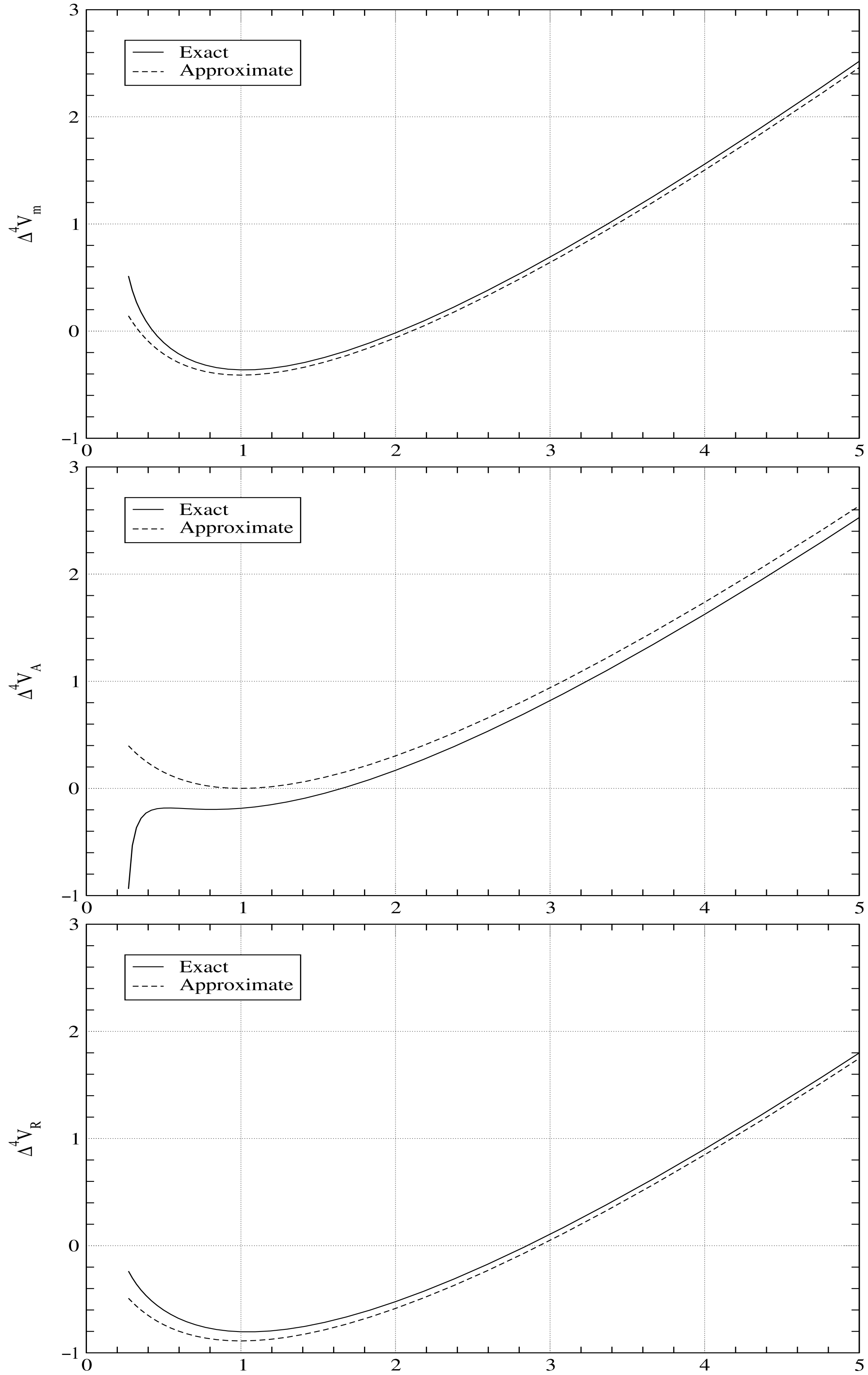

Figure 1: Contributions of a fourth generation of fermions to ΔV_i as a function of $u \equiv (m_U/m_Z)^2$. We assume $m_N = m_U$ and $m_E = m_D = m_Z$. Solid lines correspond to exact eq (4); dashed lines correspond to approximation given in eq(15). These plots help to study accuracy of approximation (12 - 14) outside its formal domain of validity, that is why we neglect experimental bounds on m_D and m_U.

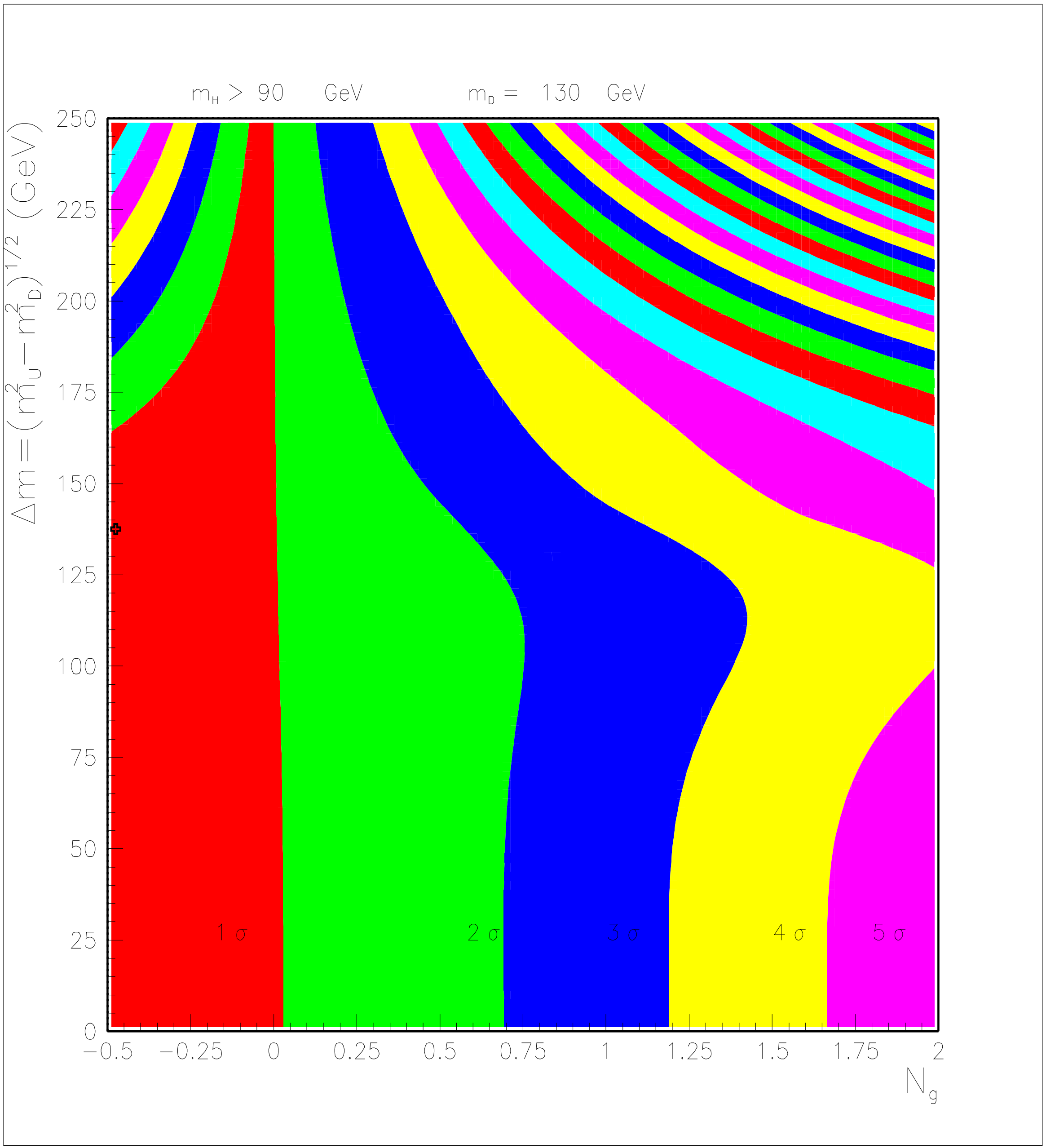

Figure 2: Constraints on the number of extra generations N_g and the mass difference in the extra generations Δm. The lowest allowed value $m_D = 130$ GeV from Tevatron search [12] was used and $m_E = m_D$, $m_N = m_U$ was assumed. All electroweak precision data and $m_H > 90$ GeV at 95 % C.L. [23] were used in the fit. The cross corresponds to χ^2 minimum; regions show $< 1\sigma$, $< 2\sigma$, etc. allowed domains.

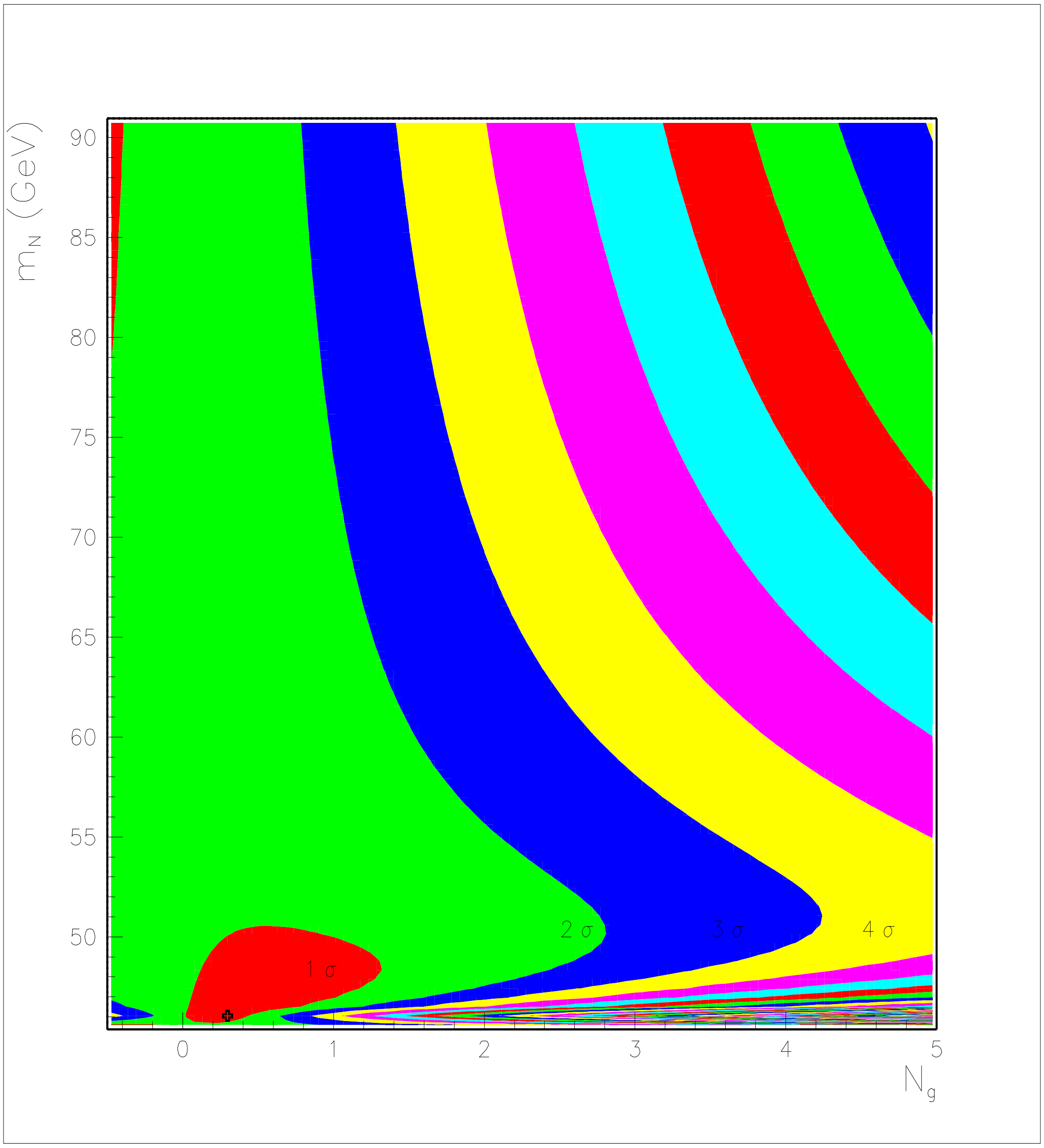

Figure 3: Constraints on the number of extra generations N_g and the mass of the neutral heavy lepton m_N. The values $m_U = 220$ GeV, $m_D = 200$ GeV, $M_E = 100$ GeV were used. All electroweak precision data and $m_H > 90$ GeV at 95 % C.L. from LEP II [23] were used in the fit. The cross corresponds to χ^2 minimum; regions show $< 1\sigma$, $< 2\sigma$, etc. allowed domains. The lower bound on m_N from LEP I data ($m_N = 45 GeV$) [1] corresponds to the lowest point on the y axis $m_Z/2$.

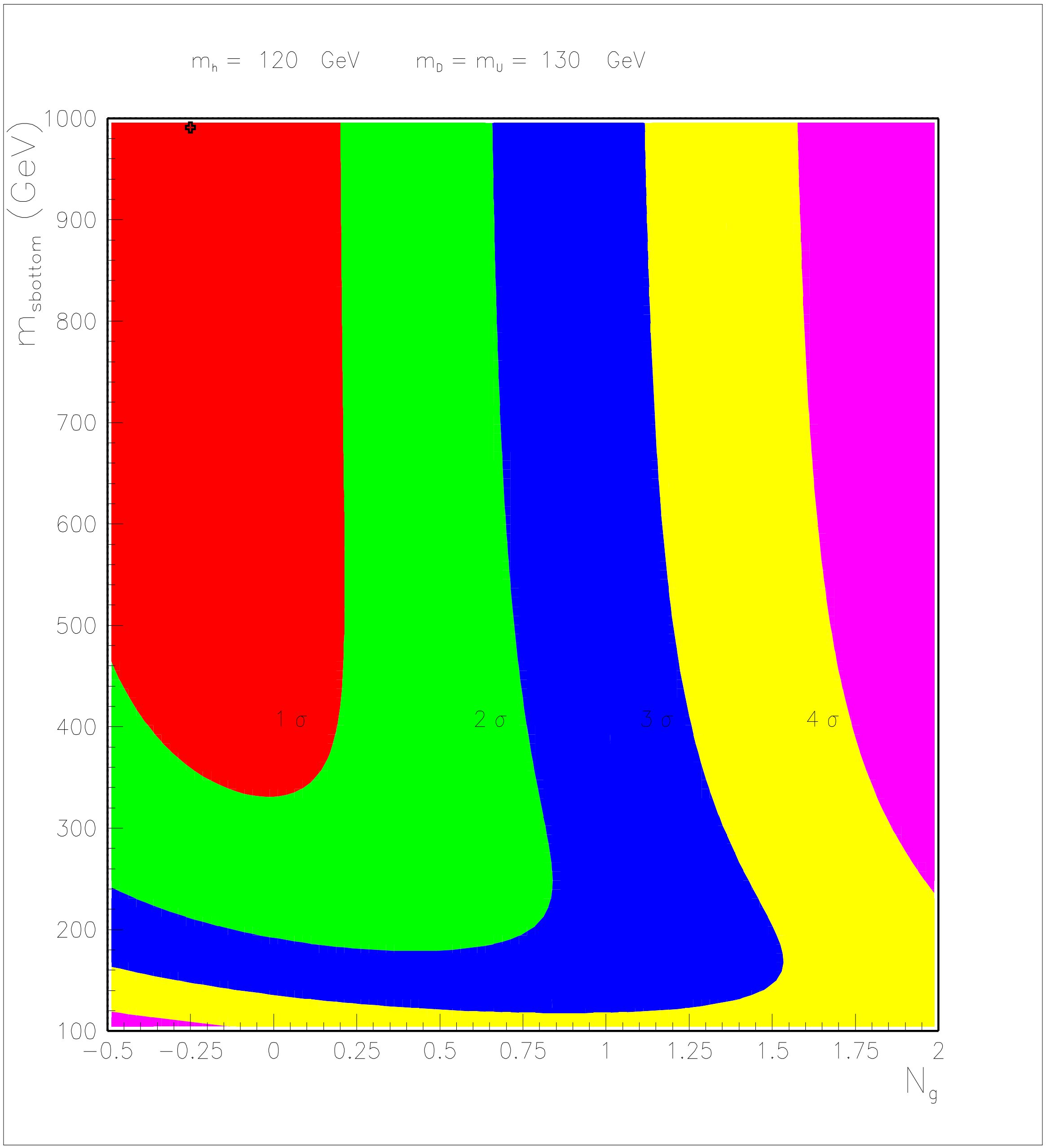

Figure 4: The 2-dimensional exclusion plot for the N_g degenerate extra generations and the mass of sbottom $m_{\tilde{b}}$ in SUSY models and for the choice $m_D = m_U = m_E = m_N = 130$ GeV, using $m_h = 120$ GeV, $m_{\tilde{g}} = 200$ GeV and assuming the absence of $\tilde{t}_L - \tilde{t}_R$ mixing. Little cross corresponds to χ^2 minimum; regions show $< 1\sigma$, $< 2\sigma$, etc. allowed domains.

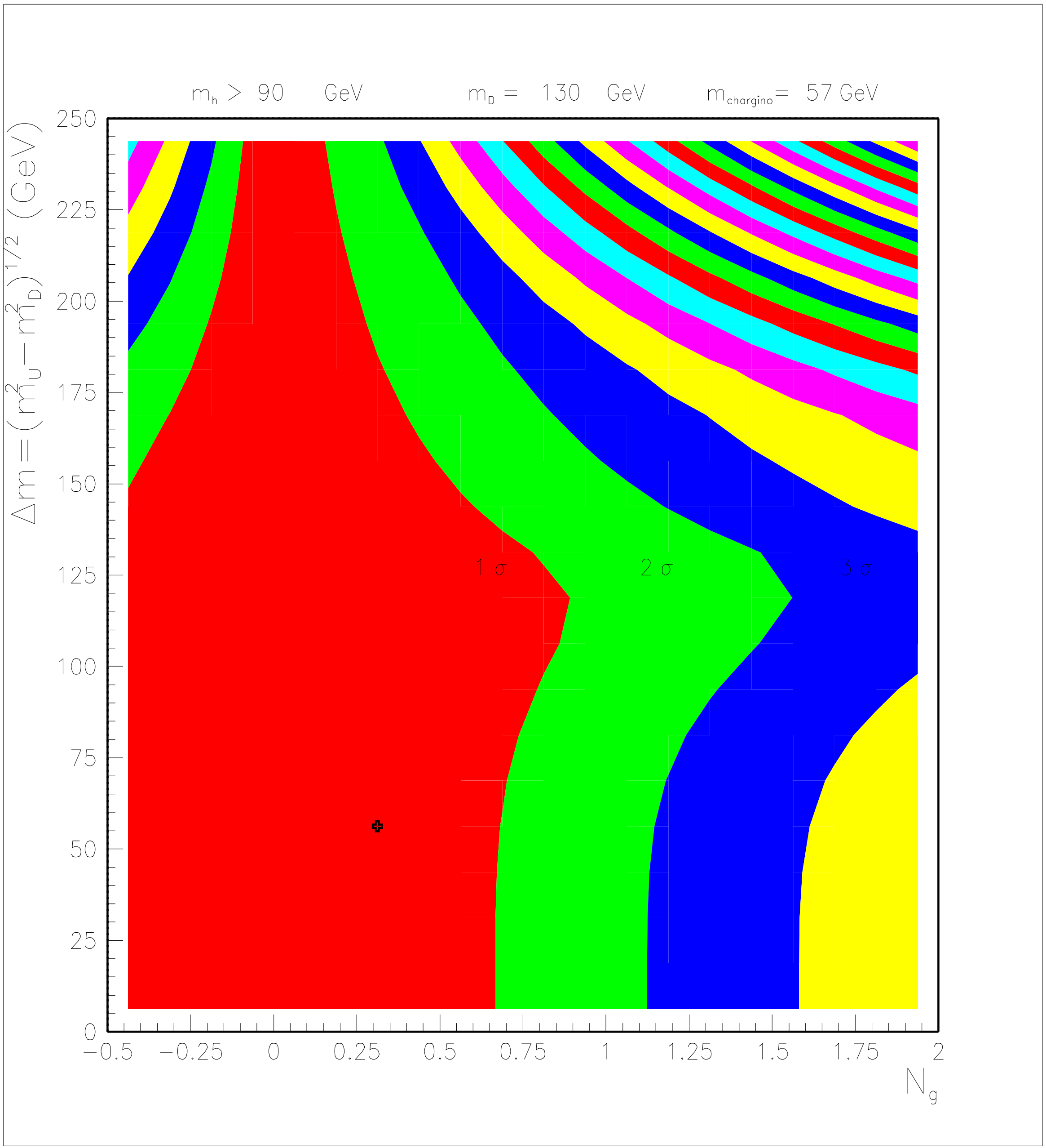

Figure 5: Constraints on the number of extra generations N_g and the mass difference in the extra generations Δm in case of 57 GeV higgsino-dominated quasi degenerate chargino and neutralino. The lowest allowed value $m_D = 130$ GeV from Tevatron search [12] was used and $m_E = m_D$, $m_N = m_U$ was assumed. All electroweak precision data and $m_h > 90$ GeV at 95 % C.L. [23] were used in the fit. The cross corresponds to χ^2 minimum; regions show $< 1\sigma$, $< 2\sigma$, etc. allowed domains.