Radiative corrections, New Physics and LHC

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Sources

- LEPTOP – approach to EWRC worked out by V.A.N., L.B. Okun, A.N. Rozanov and M.I. Vysotsky in the 90s.
- Phys. Lett. B **476** (2000) 107-115
- Phys. Lett. B **572** (2002) 111-116
- ....

Using LEPTOP it was found that the precision data do not exclude an existence of additional generation of quarks and leptons.

- V.A.N., A.N. Rozanov, M.I. Vysotsky arXiv:0904.4570 (hep-ph)

Not excluded yet

Contradictions with New Bible – PDG booklet (2008) – claims:

- There is no room for 4th generation of quark and leptons. They are excluded by precision data analysis.
- Precision data prefer a light higgs

$$m_H = 84^{+32}_{-24}\ \mathrm{GeV} \quad .$$

General introduction

Two strategies to search a New Physics beyond the SM

- Direct accelerator searches

  Direct production of New particles
  LEP2 $m_{N_P} \gtrsim 95$ GeV
  Tevatron $m_q \gtrsim 130$ GeV
  No trace of New Physics

- Indirect searches – Precision measurements v.s. Precision calculation.
  Radiative corrections equivalent to virtual production of New particles.

$$\Delta E \gtrsim \frac{\hbar}{\Delta t}$$

New particles do not mix with SM particles
$\Rightarrow$ we have "oblique" corrections to SM observables.

Decoupling of Heavy d.o.f. from Low-Energy Physics
(Appelquist–Carazzone Theorem (1975))

Vector-like theories

$$\left\{ \begin{array}{c} \text{gauge field} \\ \text{propagator} \end{array} \right\} \equiv \frac{g_0^2}{q^2 - \Sigma(q^2)} = \frac{g^2}{q^2(1 - \Pi(q^2))}$$

Let renormalization procedure respects gauge-invariance, i.e.

- massless gauge boson
- one and the same gauge coupling for all particles

Then the contribution of heavy degrees of freedom into low-energy observables is suppressed by some power: Indeed

$$[\Pi] = m^0$$

$$\Pi(q^2) \sim q^2$$

then

$$\Pi(q^2) \sim q^2/m^2_{\mathrm{heavy}}$$

That’s why nobody has bothered about top-quark contribution into $(g-2)$ in 60s.

Not absolutely correct!!

BNL precision experiment E821 on muon anomalous magnetic moment

$$a_\mu = \frac{1}{2}(g_\mu - 2) = \frac{\alpha}{2\pi} + ...$$

Latest data

$$a_\mu = 11659208.0(6.3) \cdot 10^{-10} \quad \text{experiment}$$

Comparison with theory

$$\Delta a_\mu(\exp - \text{SM}) = (22.4 \pm 10 \text{ to } 26.1 \pm 9.4)10^{-10}$$

That is

$$2.2\sigma \text{ to } 2.7\sigma \qquad (2006)$$

New Physics in $(g-2)$!

No decoupling in the SM

- An example – the third generation:

$$\begin{pmatrix} t \\ b \end{pmatrix} \text{ with } m_t \gg m_b$$

Thus for low-energy scattering ($E \ll m_t$) we have direct violation of $SU(2) \times U(1)$ symmetry

$$\Downarrow$$

Effective nonrenormalizable theory

$$\Downarrow$$

Power divergencies $\sim \Lambda^2/m_W^2$

Natural cut-off $\Lambda \sim m_t$

Thus EWRC depend on top quark mass as

$$\alpha \left(m_t^2/m_W^2\right) \ , \ \ \alpha^2 \left(m_t^2/m_W^2\right)^2 \quad \text{etc.}$$

$$\Downarrow$$

In this way top quark was found.

(Partly the same is true for c-quark.)

- Degenerate case

$$\begin{pmatrix} U \\ D \end{pmatrix} \quad \text{with} \;\; m_U \to \infty \; ; \;\; m_D \to \infty \; ; \;\; m_U - m_D = \text{finite}$$

In this case we have finite non-zero contribution into observables.

General theory of a heavy d.o.f.

Peskin and Takeuchi (1990, 1992)
Contributions of New Physics can be hidden into universal three variables S, T and U.

$$S = 16\pi \left[\Sigma'_A(0) - \Sigma'_V(0)\right]$$

$$T = \frac{4\pi}{s^2 m_W^2} \left[\Sigma_{11}(0) - \Sigma_{33}(0)\right]$$

$$U = 16\pi \left[\Sigma'_{11}(0) - \Sigma'_{33}(0)\right]$$

This approach equivalent to Effective Field Theory for low-energy d.o.f.
PDG claims that using S, T U analysis one can't find a room for the fourth generation.

Main body of the talk

SM fit by LEPTOP, summer 2008

Observable	Exper. data	LEPTOP fit	Pull
Γ_Z, GeV	2.4952(23)	2.4963(15)	-0.5
σ_h, nb	41.540(37)	41.476(14)	1.8
R_l	20.771(25)	20.743(18)	1.1
$A^l_{\rm FB}$	0.0171(10)	0.0164(2)	0.8
A_τ	0.1439(43)	0.1480(11)	-0.9
R_b	0.2163(7)	0.2158(1)	0.7
R_c	0.172(3)	0.1722(1)	-0.0
$A^b_{\rm FB}$	0.0992(16)	0.1037(7)	-2.8
$A^c_{\rm FB}$	0.0707(35)	0.0741(6)	-1.0
s^2_l ($Q_{\rm FB}$)	0.2324(12)	0.2314(1)	0.8

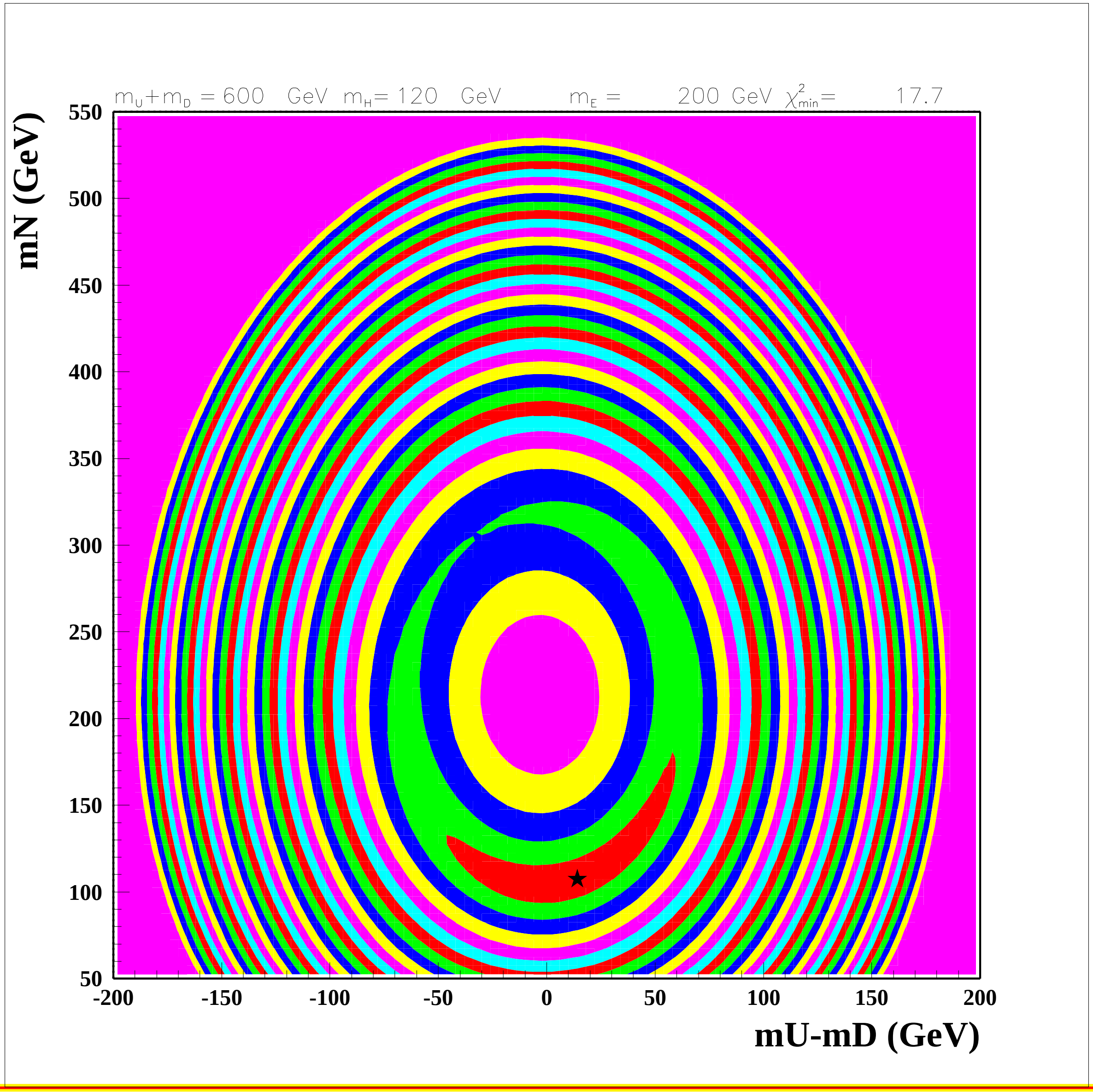
Observable	Exper. data	LEPTOP fit	Pull
A_{LR}	0.1513(21)	0.1479(11)	1.6
A_b	0.923(20)	0.9349(1)	-0.6
A_c	0.670(27)	0.6682(5)	0.1
m_W, GeV	80.398(25)	80.377(17)	0.9
m_t, GeV	172.6(1.4)	172.7(1.4)	-0.1
M_{H}, GeV		84^{+32}_{-24}	
$\hat{\alpha}_s$		0.1184(27)	
$1/\bar{\alpha}$	128.954(48)	128.940(46)	0.3
$\chi^2/n_{\mathrm{d.o.f.}}$		18.1/12	

Fits with the fourth generation

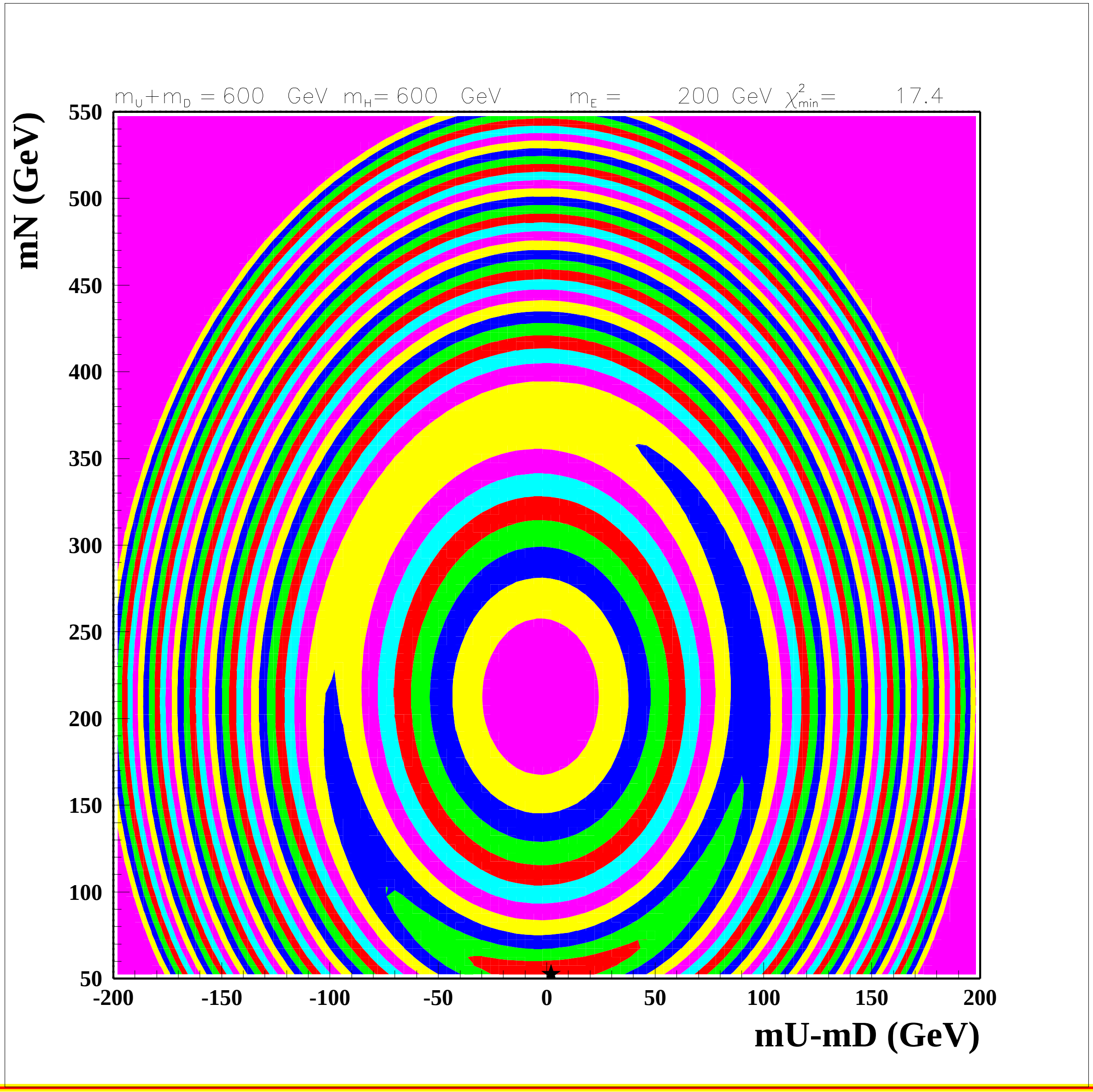
- Let us suppose that mixing is small.
- Separate steep and flat directions in the dependence of χ^2 over new particle masses.
(V.A. Novikov et al. (2002))

Fix $m_U + m_D = 600$ GeV to avoid Tevatron direct search bounds; fix $m_E = 200$ GeV; vary the difference of neutral lepton mass and the difference of Up- and Down-quark masses.

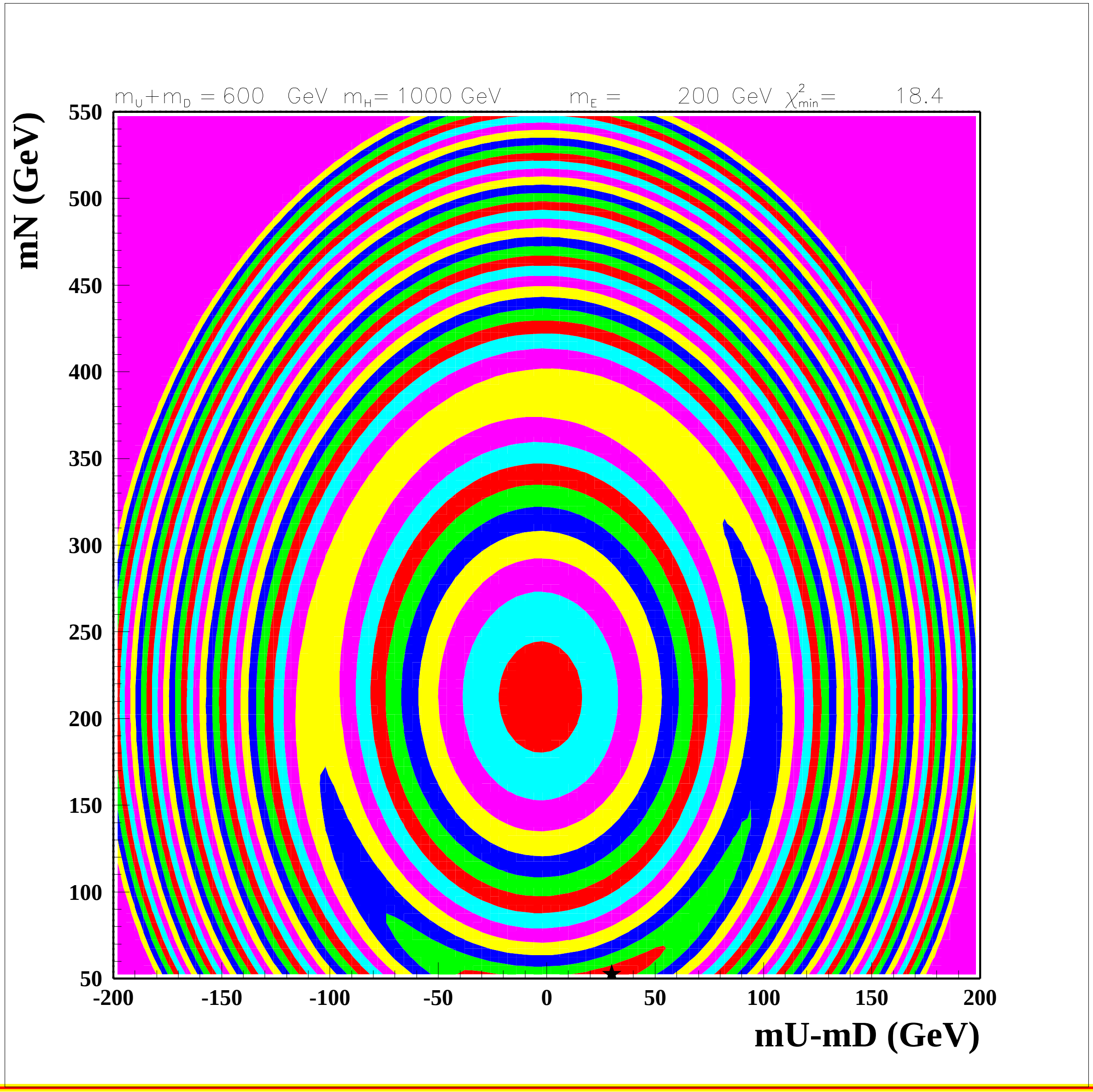
The results of the fit are presented in Fig. 1 for $m_H = 120$ GeV and in Fig. 2 for $m_H = 600$ GeV and in Fig. 3 for $m_H = 1000$ GeV.



m_U+m_D = 600 GeV m_H= 120 GeV m_E = 200 GeV χ^2_{min}= 17.7
mN (GeV)
550
500
450
400
350
300
250
200
150
100
50
-200
-150
-100
-50
0
50
100
150
200
mU-mD (GeV)



$m_U+m_D = 600$ GeV $m_H= 600$ GeV $m_E =$ 200 GeV $\chi^2_{min}=$ 17.4
mN (GeV)
550
500
450
400
350
300
250
200
150
100
50
-200
-150
-100
-50
0
50
100
150
200
mU-mD (GeV)

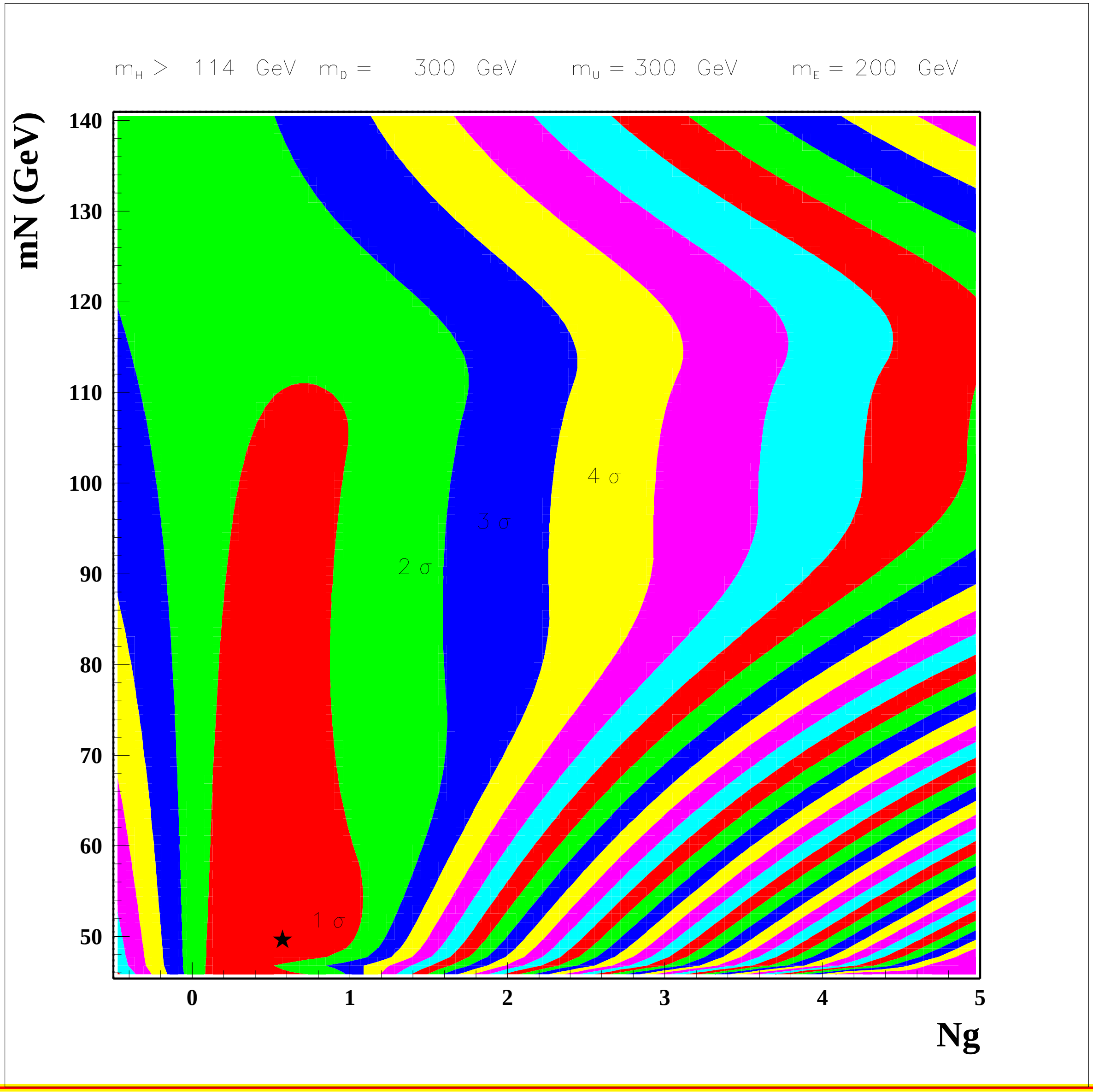

$m_U+m_D = 600$ GeV $m_H= 1000$ GeV $m_E =$ 200 GeV $\chi^2_{min}=$ 18.4
mN (GeV)
550
500
450
400
350
300
250
200
150
100
50
-200
-150
-100
-50
0
50
100
150
200
mU-mD (GeV)

We see that in all cases the quality of the fits is good and not worse than for Standard Model without additional generation.

How many new generations?

- To simplify analysis we assume degeneracy of new particles with identical quantum numbers: $m_{E_1} = m_{E_2} = ...,\ m_{N_1} = m_{N_2} = ...,\ m_{U_1} = m_{U_2} = ...,$ $m_{D_1} = m_{D_2} = ...$
- To study this problem we fix $m_E = 200$ GeV, $m_U = m_D = 300$ GeV.
- Take $m_H > 114$ GeV.

The levels of χ^2 are shown in Fig. 4.



m_H > 114 GeV m_D = 300 GeV m_U = 300 GeV m_E = 200 GeV
mN (GeV)
140
130
120
110
100
90
80
70
60
50
0
1
2
3
4
5
Ng
1 σ
2 σ
3 σ
4 σ

The value of χ^2 for Standard Model and for $N_g = 1$ are almost the same, while three and more additional generations are strongly excluded.

$\mathbf{S}, \mathbf{T}, \mathbf{U}$ versus $\mathbf{V_m}, \mathbf{V_A}, \mathbf{V_R}$

Radiative corrections to electroweak observables were expressed in LEPTOP through three functions V_i:

$$\frac{m_W}{m_Z} = c + \frac{3\bar{\alpha}c}{32\pi s^2(c^2 - s^2)} V_m \quad ,$$

$$g_A = -\frac{1}{2} - \frac{3\bar{\alpha}}{64\pi c^2 s^2} V_A \quad ,$$

$$\frac{g_V}{g_A} = 1 - 4s^2 + \frac{3\bar{\alpha}}{4\pi(c^2 - s^2)} V_R \quad ,$$

$$s^2c^2 \equiv \sin^2\theta_W \cos^2\theta_W = \frac{\pi\bar{\alpha}}{\sqrt{2}G_\mu m_Z^2} \, , \quad \bar{\alpha} \equiv \alpha(m_Z) = (128.87)^{-1} \quad ,$$

$$V_i \equiv V_i^{\mathrm{SM}} + \delta_{NP} V_i \quad .$$

Compare with S, T and U variables.

$$T = \frac{3}{16\pi s^2 c^2}\delta_{NP}V_A + \Delta \equiv T' + \Delta \quad ,$$

$$S = \frac{3}{4\pi}[\delta_{NP}V_A - \delta_{NP}V_R] + 4s^2c^2\Delta \equiv S' + 4s^2c^2\Delta \quad ,$$

$$S + U = \frac{3}{4\pi(c^2 - s^2)}(\delta_{NP}V_m - \delta_{NP}V_R) \equiv S' + U' \quad ,$$

$$\Delta \equiv \frac{1}{\bar{\alpha}}\left[\Pi'_Z(m_Z^2) - \frac{\Pi_Z(m_Z^2)}{m_Z^2} + \frac{\Pi_Z(0)}{m_Z^2}\right] \quad ,$$

$\mathbf{S, T, U}$ **versus** $\mathbf{V_m, V_A, V_R}$

Numbers

Table 2

	$m_H = 120$		$m_H = 600$	
	$m_U = 230$ $m_D = 220$	$m_N = 120$ $m_E = 200$	$m_U = m_D = 225$	$m_N = 50$ $m_E = 200$
T'	-0.001	0.11	-0.006	0.25
T	0.005	0.12	0	0.38
S'	0.15	-0.01	0.15	-0.23
S	0.15	-0.01	0.16	-0.14

Conclusions

- Electroweak data do not contradict the existence of one extra family with specially adjusted masses.
- Three examples corresponding to light and heavy higgs bosons are presented. The properly made analysis based on S, T, U (for $m_H = 120$ GeV) and S', T', U' (for $m_H = 1000$ GeV) confirms the results of the analysis based on V_i.