EWRC versus 4^{th} quark-lepton generation

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plan

- LEPTOP
- SM fit
- extra gen fits
- bridge to S, T, U
- $M_N = M_Z/2$ singularity
- how to find quasi stable N
- $N_g = ?$
- conclusions

basics of LEPTOP

The approach to ew rc worked out by V.A.Novikov, L.B.Okun, A.N.Rozanov and M.V. in the -90s.

Using LEPTOP in the paper written together with Michele Maltoni in 2000 it was found that the precision data do not exclude an existence of additional generations of quarks and leptons.

heavy top and higgs

$$\frac{M_W}{M_Z} = c + \frac{3\bar{\alpha}c}{32\pi s^2(c^2 - s^2)} \left[(\frac{m_t}{M_Z})^2 - \frac{11}{9} s^2 \ln(\frac{M_H}{M_Z})^2 \right],$$

$$g_A = -\frac{1}{2} - \frac{3\bar{\alpha}}{64\pi c^2 s^2} \left[(\frac{m_t}{M_Z})^2 - s^2 \ln(\frac{M_H}{M_Z})^2 \right],$$

$$\frac{g_V}{g_A} = 1 - 4s^2 + \frac{3\bar{\alpha}}{4\pi(c^2 - s^2)} \left[(\frac{m_t}{M_Z})^2 - (s^2 + \frac{1}{9}) \times \right.$$

$$\left. \times \ln(\frac{M_H}{M_Z})^2 \right].$$

$$A = \sqrt{\sqrt{2} G_\mu M_Z^2} \bar{l} [g_A \gamma_\alpha \gamma_5 + g_V \gamma_\alpha] l \ Z_\alpha \quad .$$

real case

The expressions in square brackets are substituted by three functions:

$$V_m(t,h)\ ,V_A(t,h)\ ,V_R(t,h)\ ;$$

$$t \equiv (m_t/M_Z)^2, h \equiv (M_H/M_Z)^2,$$

which take into account all the existing loop calculations ($\alpha_W, \alpha_s\alpha_W$,..., for details see Novikov, Okun, Rozanov, Vysotsky,“LEPTOP”, hep-ph/9503308; Rep.Prog.Phys.$\mathbf{6}2$, 1275(1999)).

At the next slides the results of the data fit by the LEPTOP code performed by Alexandre Rozanov in summer 2008 are presented.

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

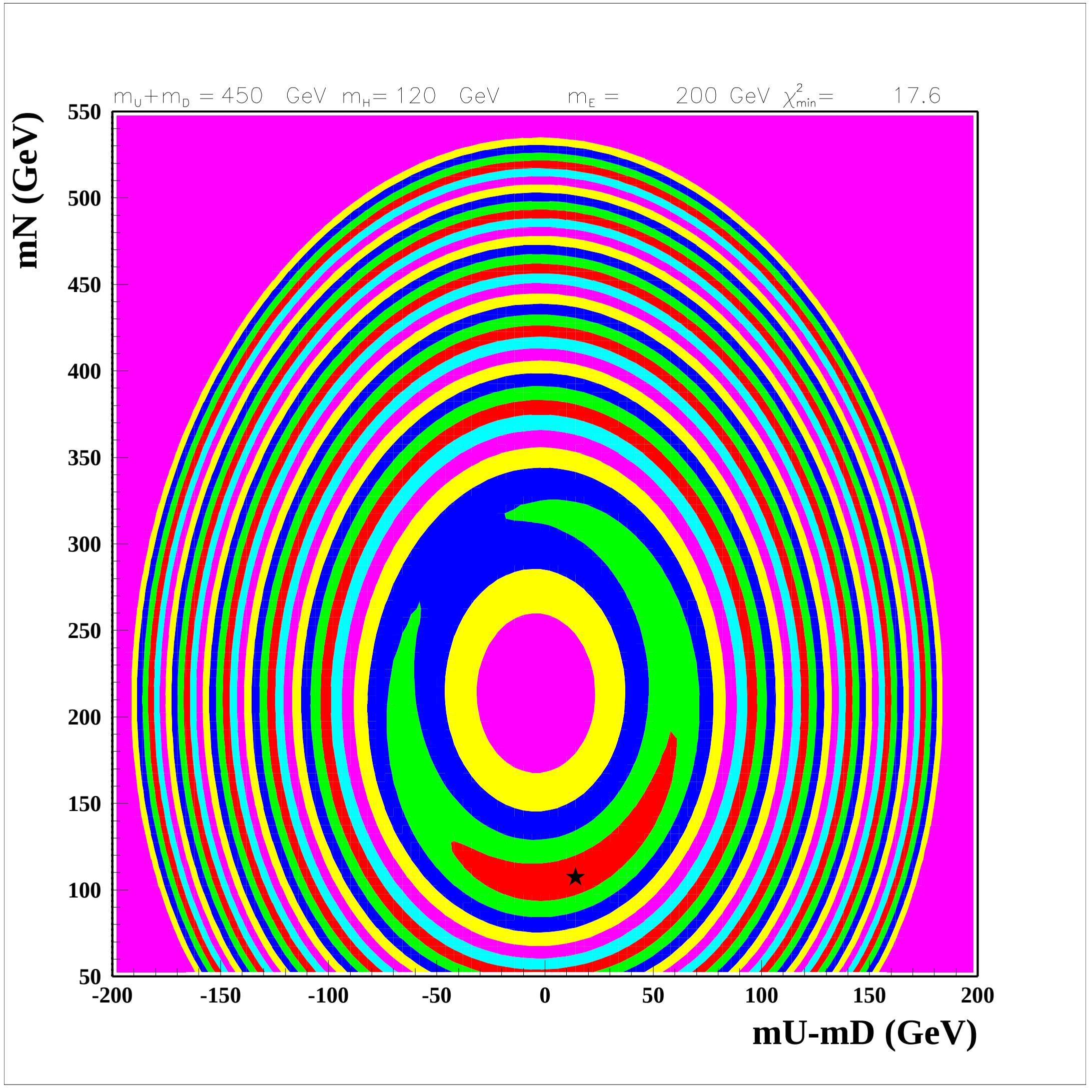
Observable	Exper. data	LEPTOP fit	Pull
A_{LR}	0.1513(21)	0.1479(11)	1.6
A_b	0.923(20)	0.9349(1)	-0.6
A_c	0.670(27)	0.6682(5)	0.1
m_W, GeV	80.398(25)	80.377(17)	0.9
m_t, GeV	172.6(1.4)	172.7(1.4)	-0.1
M_{H}, GeV		84^{+32}_{-24}	
$\hat{\alpha}_s$		0.1184(27)	
$1/\bar{\alpha}$	128.954(48)	128.940(46)	0.3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

NP in LEPTOP

The additional contributions to V_i which depend on NP parameters.

A simple case: extra generations almost not mixed with 3 already known to exist: contribute to V_i through IVB polarization operators.

4 generation with 120 GeV higgs



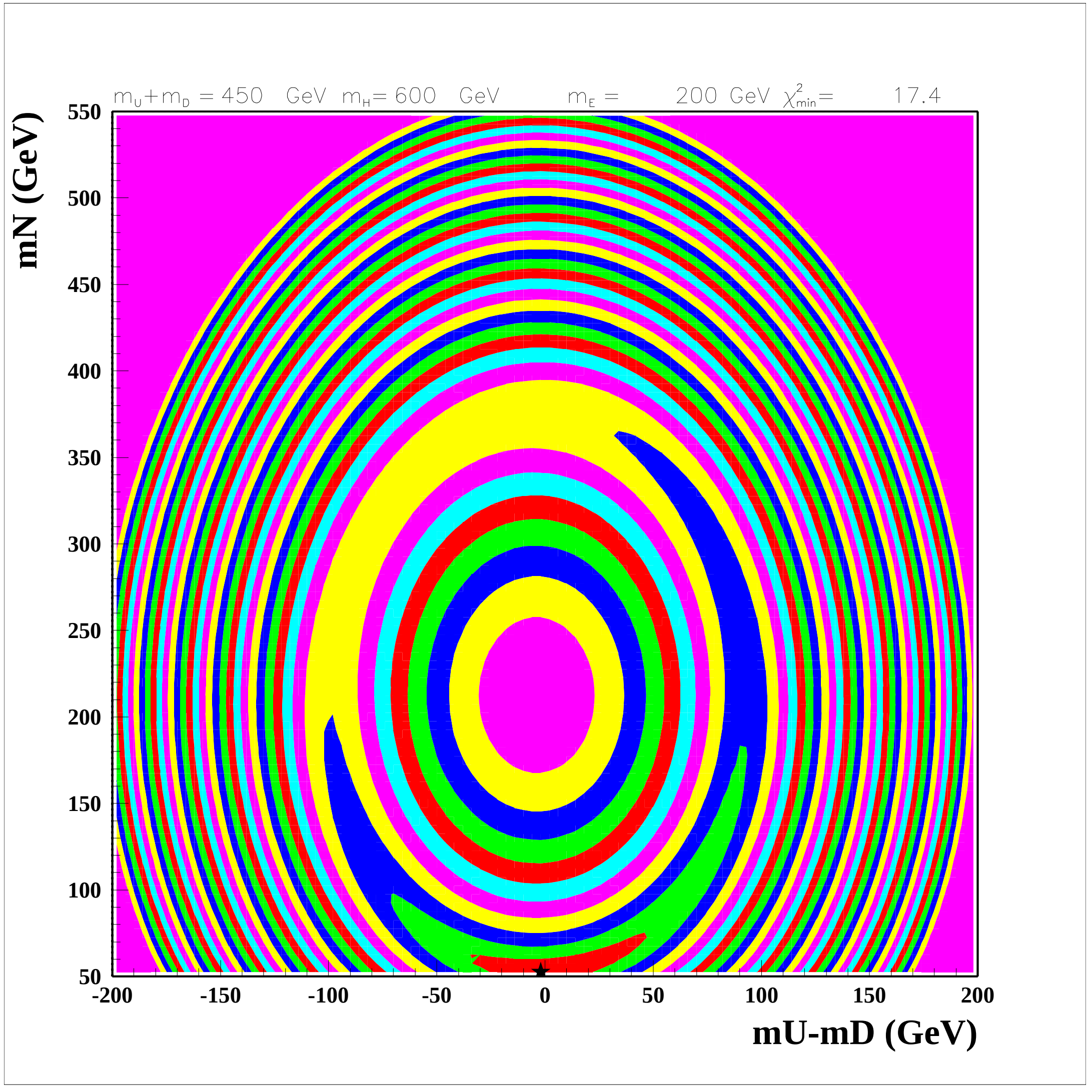
$m_E = 200$GeV, $m_U + m_D = 450$ GeV, $\chi^2/d.o.f. = 17.6/11$, the quality of fit is the same as in SM.

4 generation, 120 GeV higgs

Observable	Exper. data	LEPTOP fit	Pull
Γ_Z, GeV	2.4952(23)	2.4978(15)	-1.1
σ_h, nb	41.540(37)	41.481(14)	1.6
R_l	20.771(25)	20.734(18)	1.5
$A^l_{\rm FB}$	0.0171(10)	0.0161(2)	1.1
A_τ	0.1439(43)	0.1464(8)	-0.6
R_b	0.2163(7)	0.2159(1)	0.7
R_c	0.172(3)	0.1721(1)	-0.0
$A^b_{\rm FB}$	0.0992(16)	0.1027(6)	-2.2
$A^c_{\rm FB}$	0.0707(35)	0.0733(4)	-0.7
s^2_l ($Q_{\rm FB}$)	0.2324(12)	0.2316(1)	0.7

Observable	Exper. data	LEPTOP fit	Pull
A_{LR}	0.1513(21)	0.1464(8)	2.3
A_b	0.923(20)	0.9347(1)	-0.6
A_c	0.670(27)	0.6676(3)	0.1
m_W, GeV	80.398(25)	80.398(9)	0.0
m_t, GeV	172.6(1.4)	172.5(1.3)	0.1
M_{H}, GeV		120	
$\hat{\alpha}_s$		0.1175(27)	
$1/\bar{\alpha}$	128.954(48)	128.963(39)	-0.2
$\chi^2/n_{\mathrm{d.o.f.}}$		17.6/11	

4 generation with 600 GeV higgs



$m_E = 200$GeV, $m_U + m_D = 450$ GeV, $\chi^2/d.o.f. = 17.4/11$, the quality of the fit is the same as in SM.

4 generation, 600 GeV higgs

Observable	Exper. data	LEPTOP fit	Pull
Γ_Z, GeV	2.4952(23)	2.4970(14)	-0.8
σ_h, nb	41.540(37)	41.476(14)	1.8
R_l	20.771(25)	20.740(18)	1.2
$A_{\rm FB}^l$	0.0171(10)	0.0161(2)	1.1
A_τ	0.1439(43)	0.1463(8)	-0.6
R_b	0.2163(7)	0.2159(1)	0.7
R_c	0.172(3)	0.1721(1)	-0.0
$A_{\rm FB}^b$	0.0992(16)	0.1026(6)	-2.1
$A_{\rm FB}^c$	0.0707(35)	0.0733(4)	-0.7
s_l^2 ($Q_{\rm FB}$)	0.2324(12)	0.2316(1)	0.7

Observable	Exper. data	LEPTOP fit	Pull
A_{LR}	0.1513(21)	0.1463(8)	2.4
A_b	0.923(20)	0.9347(1)	-0.6
A_c	0.670(27)	0.6676(3)	0.1
m_W, GeV	80.398(25)	80.414(8)	-0.6
m_t, GeV	172.6(1.4)	172.3(1.3)	0.2
M_{H}, GeV		600	
$\hat{\alpha}_s$		0.1185(27)	
$1/\bar{\alpha}$	128.954(48)	128.959(39)	-0.1
$\chi^2/n_{\mathrm{d.o.f.}}$		17.4/11	

why not S, T, U?

The most popular approach to the analysis of NP (not mixed with SM particles) contributions to electroweak observables was suggested by Peskin and Takeuchi in 1990 and is based on these variables.
It is convenient to make connection with our variables V_i in two steps:

1. The identities:

$$T' \sim \delta_{NP} V_A \; , S' \sim \delta_{NP} V_A - \delta_{NP} V_R \; , S' + U' \sim \delta_{NP} V_m - \delta_{NP} V_R \; ,$$

where δ_{NP} means that only NP contribution is taken into account.
Both sets of variables are the functions of NP contributions to IVB polarization operators Π_i.

2. Heavy NP expansion:
The following substitution made in all formulas for S', T', U' converts them into S, T, U:

$$\Pi'_Z(M_Z^2) \Longrightarrow (\Pi_Z(M_Z^2) - \Pi_Z(0))/M_Z^2 \ .$$

The second and higher derivatives are omitted as they are suppressed as $(M_Z^2/M_{NP}^2)^{(n-1)}$.

Conclusion: the analysis based on S, T, U is valid when new particles are heavy in comparison with Z - boson.

from STU to formulas for “light” NP

The example of successful application of S, T, U analysis :
He, Polonsky and Su in 2001 discovered that heavy higgs is allowed by data in case of 4 generations.

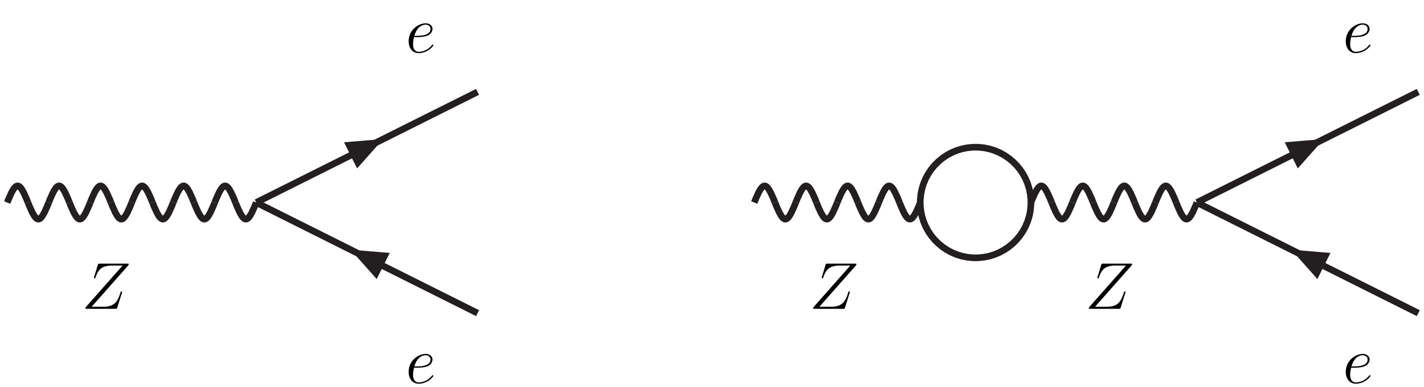
The example of unsuccessful application of S, T, U to 4^{th} generation :
Erler and Langacker PDG articles, 2000 - 2008.

If one wants to apply S, T, U variables to the case of $M_N \sim M_Z/2$ then I would recommend to switch to S', T', U' by the following substitution:

$$\Pi_Z(0) \Longrightarrow \Pi_Z(M_Z^2) - \Pi'_Z(M_Z^2) * M_Z^2 \ .$$

the origin of $\Pi'_Z(M_Z^2)$

The insertion in the Z-boson external leg:



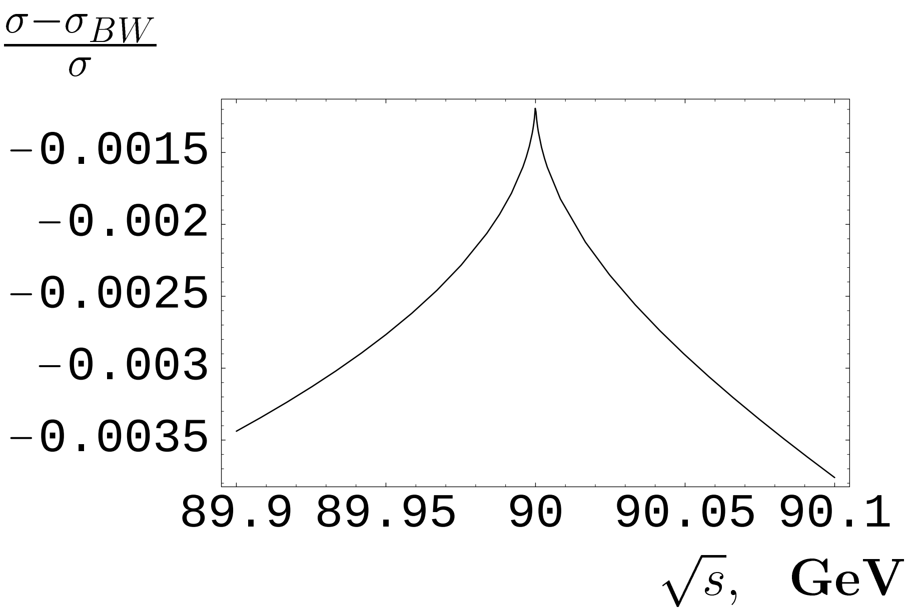
Thus it enters only V_A.
(This is the reason why $S' + U' = S + U$)

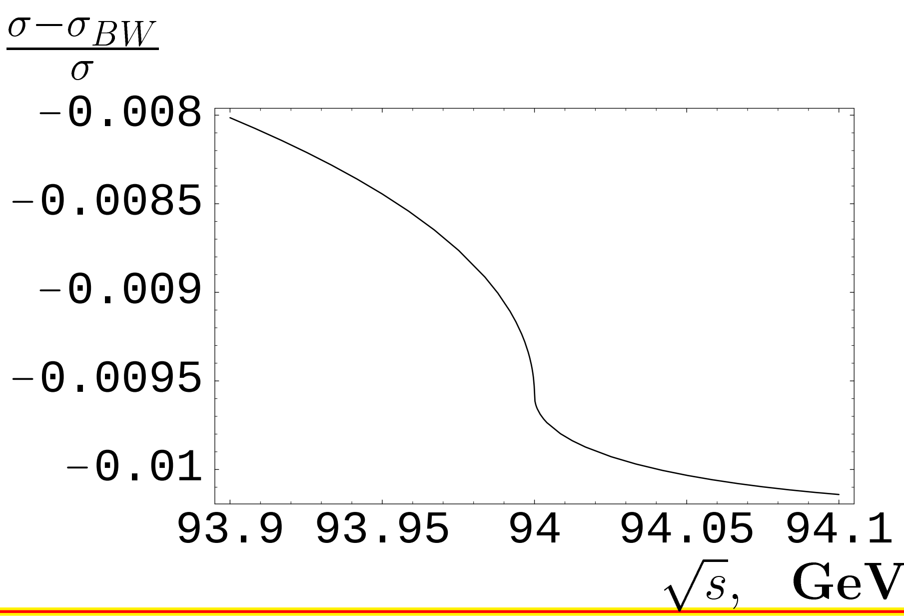
light N

When $2M_N$ is close to M_Z the expression for Z boson polarization operator contains $\sqrt{4M_N^2 - M_Z^2}$ singularity, and its derivatives are enhanced as $1/(4M_N^2 - M_Z^2)^{(n-1/2)}$ making transition to S, T, U wrong.

What should we do with the infinity in $\Pi'_Z(M_Z^2)$ which occurs for $M_N = M_Z/2$?
See paper by Bulanov + 4 of us, 2003, where the change of the shape of Breit - Wigner resonance curve due to the opening of a new channel ($N\bar{N}$) is taking into account.
Very precise measurement of Z-boson production crossection around peak at LEPI allows us to get the lower bound: $M_N > 46.7$ GeV.

cusps





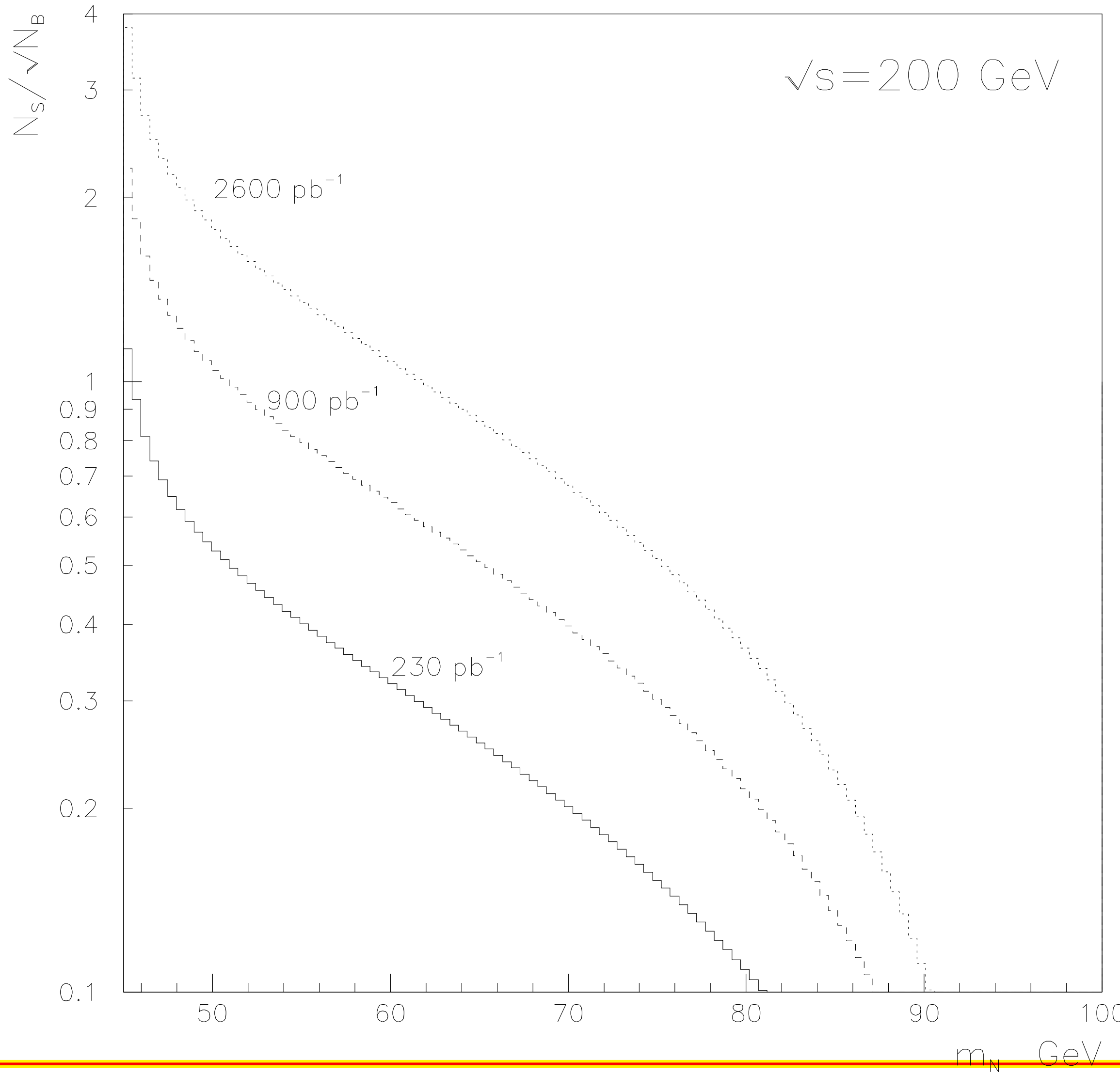
Landau, Lifshitz “Quantum Mechanics”

in search for N

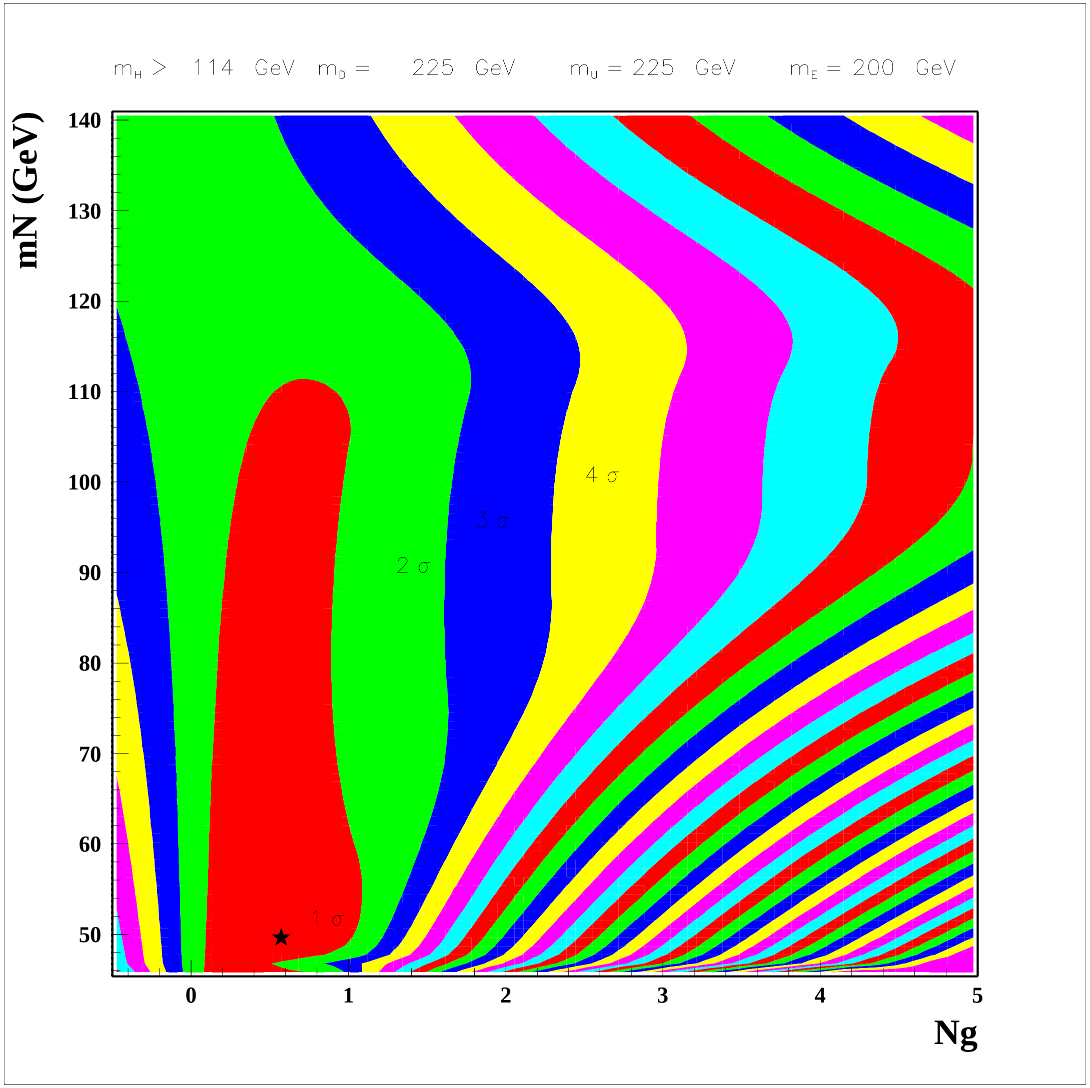
If the mass is below 100 GeV it was produced at LEPII by reaction $e^+e^- \to Z^* \to N\bar{N}$ and it would be detected by the decays to charged light leptons $+W^{(*)}$ if a mixing angle is greater than $3 * 10^{-6}$ (L3 paper hep-ex/0107015).
That is why in our consideration we suppose that if N is lighter than $100 GeV$ then mixing angles of it with three light neutrinos are less than $3 * 10^{-6}$.

Even when N does not decay inside the detector it can be detected indirectly registering the photon produced in the process: $e^+e^- \to Z^*\gamma \to N\bar{N}\gamma$.
In the paper by V.A.Ilyin, M.Maltoni + 4 of us (2000) LEPII and ILC prospects for detection of N was discussed and it was demonstrated that ILC would bound N mass from below at 100 GeV with 99.5% C.L. (or discover it).

$NN\gamma$ at LEPII



N_g



$m_E = 200$GeV, $m_U = m_D = 225$ GeV, fitted $M_h > 114$ GeV, χ^2 levels.

Conclusions

- One extra quark-lepton generation is not excluded by ew precision data while 3 extra generations are excluded with high probability;
- The quality of fit for one extra generation is the same as that for SM for certain values of new particle masses;
- In case of 4^{th} generation the upper bound on higgs mass from SM fit is removed;
- The transition to variables $S'T'U'$ applicable independently of the masses of new particles is suggested.

C versus DCPV puzzle

$$A_{CP}(K^+\pi^-) = A_{CP}(K^+\pi^0) + A_{CP}(K^0\pi^0) \quad ,$$

$$A_{CP}(K^0\pi^0) = \frac{\Gamma(B_d \to \pi^0\pi^0) + \Gamma(\bar{B}_d \to \pi^0\pi^0)}{\Gamma(B_d \to K^0\pi^0) + \Gamma(\bar{B}_d \to \bar{K}^0\pi^0)} *$$

$$* \left| \frac{V_{us}V_{ts}}{V_{td}} \right| \frac{\sin\gamma}{\sin\alpha} C_{00} \quad ,$$

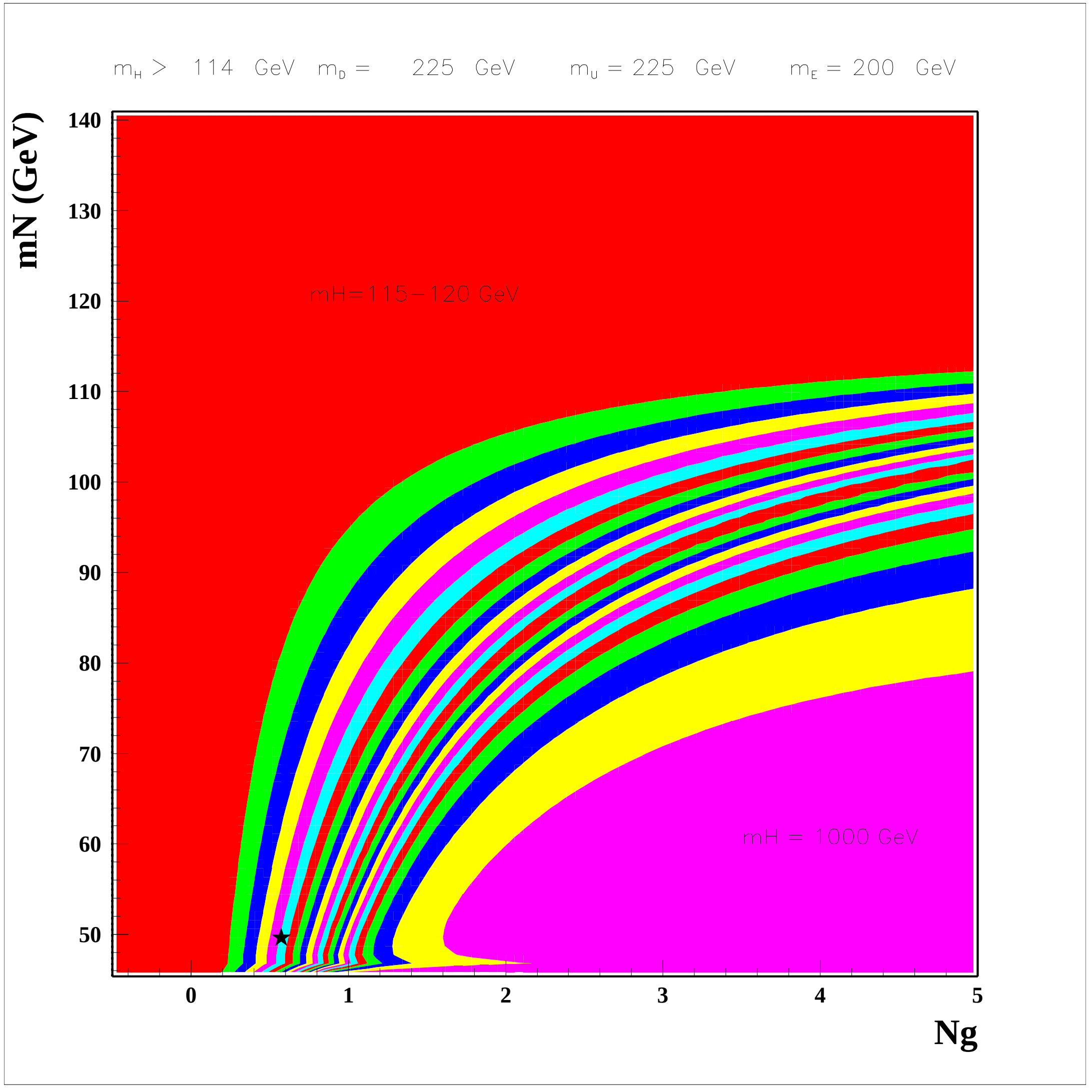
where C_{00} is direct CP asymmetry in $B_d(\bar{B}_d) \to \pi_0\pi_0$ decay.

$$C_{00} \approx -0.6 \;\; (Kaidalov, M.V., 2007),$$

$$-0.094 \pm 0.02 = (0.07 \pm 0.03) + (-0.07 \pm 0.02) \;\; -$$

2 sigma instead of 4.5 sigma discrepancy (which can be a statistical fluctuation).

$N_g M_h$



$m_E = 200$ GeV, $m_U = m_D = 225$ GeV, fitted M_h levels.