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Extra Generations and Discrepancies of EW Data.

(ITEP, Moscow)

Extra generations and discrepancies of electroweak precision data

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Abstract

It is shown that additional chiral generations are not excluded by the latest electroweak precision data if one assumes that there is no mixing with the known three generations. In the case of "heavy extra generations", when all four new particles are heavier than Z boson, quality of the fit for the one new generation is as good as for zero new generations (Standard Model). In the case of neutral leptons with masses around 50 GeV ("partially heavy extra generations") the minimum of χ^2 is between one and two extra generations.

Two years ago in paper [1] we analyzed bounds from the electroweak precision data on the non-decoupled New Physics in a form of additional heavy quark-lepton generations. It was shown that while the case of all four new fermions (U and D quarks, neutral lepton N and charged lepton E) heavier than Z boson was excluded at 2.5 σ level, existence of new generations with relatively light neutral lepton N ($m_N \approx 50$ GeV) was allowed. At that time quality of Standard Model (SM) fit of the data was very good, $\chi^2/n_{\rm d.o.f.} = 15/14$. At the time of Osaka Conference, summer 2000, nothing radical happened but χ^2 became 21/13 and the level at which one extra heavy generation was excluded went down to 2σ [2]. However the latest precision data announced summer 2001 [3] has changed the situation: the fit is still bad, 24/13, but now the presence of one heavy generation does not make the fit worse as compared with SM.

In Table 1 the LEPTOP fit of summer 2001 data is presented. There are two significant changes in comparison with previous data presented in Table 2:

1. Due to precision measurement of the cross-section of e^+e^- annihilation into hadrons in the interval 2-5 GeV at BES the error in $\bar{\alpha} \equiv \alpha(M_Z)$ is now two times smaller. (Following Electroweak Working Group (EWWG) we use result [4] though other estimates can be found in the literature as well);

2. Central value of M_W is now bigger by a half of σ.

Mass of the higgs versus fourth generation masses

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Abstract

The predicted value of the higgs mass m_H is analyzed assuming the existence of the fourth generation of leptons (N, E) and quarks (U, D), which are not mixed with the known three generations. The steep and flat directions are found in the five-dimensional parameter space: m_H, m_U, m_D, m_N, m_E. The LEPTOP fit of the precision electroweak data is compatible (in particular) with $m_H \sim 300$ GeV, $m_N \sim 50$ GeV, $m_E \sim 100$ GeV, $m_U + m_D \sim 500$ GeV, and $|m_U - m_D| \sim 75$ GeV. The quality of fits drastically improves when the data on b- and c-quark asymetries and new NuTeV data on deep inelastic scattering are ignored.

It is well known that in the framework of Standard Model the fit of electroweak precision data results in prediction of light higgs, the central value of its mass being lower than the direct lower limit set by LEP II [1].

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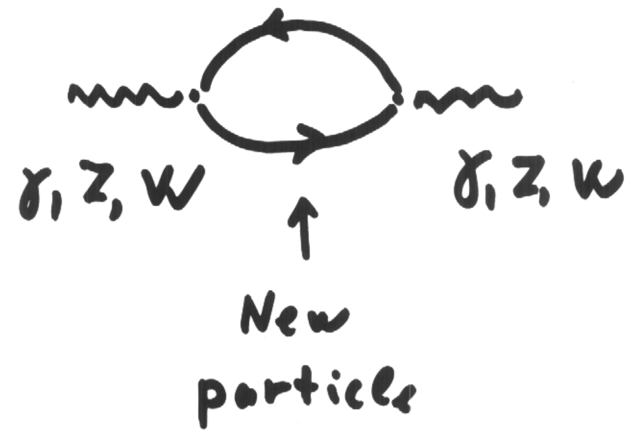
Indirect bounds on New Physics



"Oblique" corrections

~20 observables at LEP 1 } ~ 10^{-3}

New generation: $\begin{pmatrix} N \\ E \end{pmatrix}_L$ $\begin{pmatrix} U \\ D \end{pmatrix}_L$ $\left(\begin{matrix} N_R, E_R \\ U_R, D_R \end{matrix} \right)$

- No decoupling from low-energy (from LEP 1)

($SU(2)_V$, ~~$SU(2)$~~$_A$)

- $m_U, m_D \to \infty$; $m_U - m_D$ – finite

$$\left.\begin{aligned} \delta V_m &= -\frac{16}{9} s^2 \\ \delta V_A &= 0 \\ \delta V_R &= -\frac{8}{9} \end{aligned}\right\} + \frac{16}{9} \left(\frac{m_U - m_D}{m_Z} \right)^2 + \ldots$$

- $|m_U - m_D| \gg m_Z$; SU(2) breaking

$$\delta V_i = \frac{|m_U^2 - m_D^2|}{m_Z^2} + \frac{1}{3}\frac{|m_N^2 - m_E^2|}{m_Z^2}$$

Low-energy observables

- $$m_W/m_Z = c\left\{1 + \frac{3\bar{\alpha}}{32\pi s^2(c^2-s^2)} V_m\right\}$$

$$g_A^\ell = -\frac{1}{2}\left\{1 + \frac{3\bar{\alpha}}{64\pi s^2 c^2} V_A\right\}$$

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

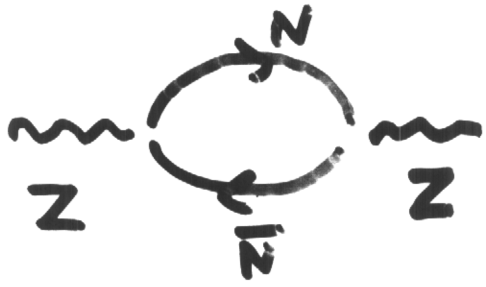
Γ_Z, σ_h, R_e .... (18 observables)

where $c = \cos\theta$; $s = \sin\theta$

$$\sin^2 2\theta = \frac{4\pi}{\sqrt{2}}\frac{\bar{\alpha}}{G_\mu m_Z^2}$$

"Partially Heavy" Generation

$m_N \simeq m_Z/2$



Degenerate Perturbation Theory ⇒

⇒ Large mixing ⇒ Large corrections to w.f. renormalization.

Experiment: LEP II $e^- e^+ \to N\bar{N}\gamma$

$m_N > 50\,\text{GeV}$ at 95% c.l.

Brief History of the SM

March 2000

- SM fit: $\chi^2/n_{d.o.f.} = 15/14$
- Heavy Generation $\binom{U}{D}, \binom{N}{E}$ with $m_4 > m_Z$ was excluded at 2.5σ

March 2001

- SM fit $\Rightarrow$ $\chi^2/n = 21/13$
- Heavy Generation: $\Rightarrow 2\sigma$

$\Downarrow$

March 2002 ≡ (summer 2001)

- SM : $\chi^2/n = 24/13$!!! In ruins
- Heavy Generation: the same χ^2!

Heavy Generation.

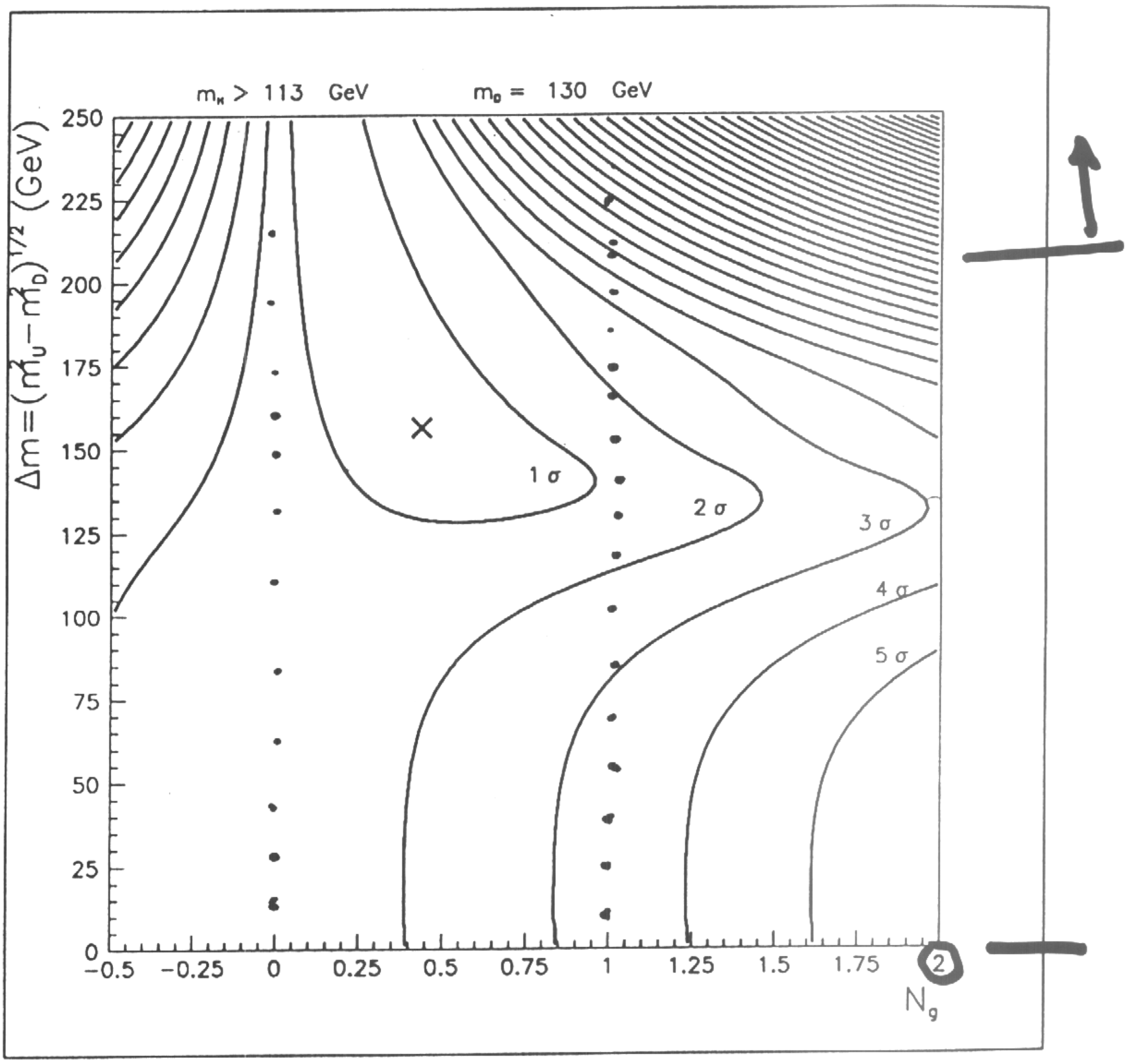


Figure 1: Exclusion plot for heavy extra generations with the input: $m_D = m_E = 130$ GeV, $m_U = m_N$. χ^2 minimum shown by cross corresponds to $\chi^2/n_{d.o.f.} = 22.2/12$, $N_g = 0.4$, $\Delta m = 160$ GeV, $m_H = 116$ GeV. N_g is the number of extra generations. Borders of regions show domains allowed at the level $1\sigma, 2\sigma$, etc.

Review of Particle Physics (2000)

$\Delta m = 0$ or $\Delta m > 200$ GeV

" Partially Heavy " Generation

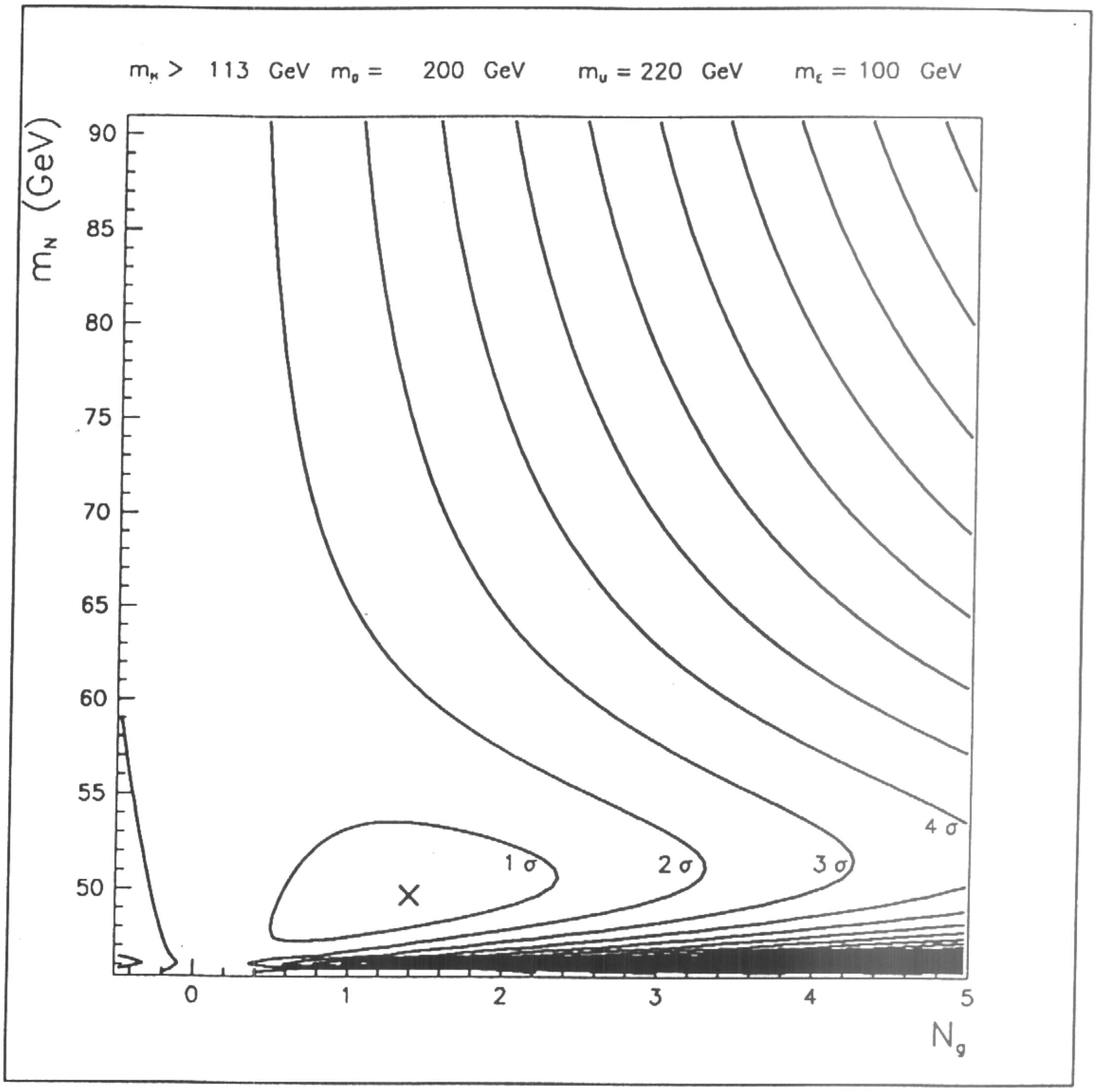


Figure 2: Exclusion plot for the number of partially heavy extra generations with light neutral lepton N. On horizontal axis the number of extra generations N_g, on vertical axis – the mass of the neutral lepton m_N. The input: $m_U = 220$ GeV, $m_D = 200$ GeV, $m_E = 100$ GeV. At the minimum $\chi^2/n_{d.o.f.} = 21.6/12$, $N_g = 1.4$, $m_N = 50$ GeV, $m_H = 116$ GeV. The spectacular behaviour of lines at the bottom of this figure as well as Fig.4 is caused by the threshold singularity. This singularity must manifest itself also in the Z lineshape. We have not studied it because according to experimental data by LEP collaborations on the emission of initial state bremsstrahlung photon $m_N > 50$ GeV at 95% c.l. [6, 7] and the effect at such distance above threshold is not prominent.

Table 1: LEPTOP fit to electroweak observables. Year 2001. By italics we designate calculated (not measured) quantities.

Source	Observable	Exp. data	LEPTOP fit	Pull
LEP I	Γ_Z [GeV]	2.4952(23)	2.4966(16)	-0.6
	σ_h [nb]	41.540(37)	41.480(14)	1.6
	A^l_{FB}	0.0171(10)	0.0165(3)	0.7
	R_l	20.767(25)	20.738(18)	1.1
	A_τ, A_e	0.1465(33)	0.1483(11)	-0.5
	R_b	0.2165(7)	0.2157(1)	1.2
	R_c	0.1719(31)	0.1723(1)	-0.1
	A^b_{FB}	0.0990(17)	0.1040(8)	-2.9
	A^c_{FB}	0.0685(34)	0.0743(6)	-1.7
	$s^2_l(Q_{FB})$	0.2324(12)	0.2314(1)	0.9
SLC	A_{LR}	0.1513(21)	0.1483(11)	1.4
	s^2_l (A_{LR})	*0.2310(3)*	*0.2314(1)*	-1.4
	A_b	0.9220(200)	0.9349(1)	-0.6
	A_c	0.6700(260)	0.6684(5)	0.1
LEP II, Tevatron	m_W [GeV]	80.451(33)	80.392(20)	1.8
	$s^2_W(m_W)$	*0.2216(6)*		
Tevatron	s^2_W (νN)	0.2255(21)	0.2230(3)	1.2
	$m_W(\nu N)$ [GeV]	*80.250(109)*		
	m_t [GeV]	174.3(5.1)	175.0(4.4)	-0.1
Fit	m_H [GeV]		79^{+47}_{-29}	
	$\hat{\alpha}_s$		0.1182(27)	
$e^+e^- \to$ hadrons	$\bar{\alpha}^{-1}$	128.936(49)	128.918(45)	0.4
	$\chi^2/n_{d.o.f.}$		23.8/13	

① The errors in $\hat{\alpha}_s = \alpha_s(m_Z)$ are 2 times smaller. } BES

② m_W is bigger by $1/2\,\sigma$.

Table 2: LEPTOP fit to electroweak observables. Year 2000.

Source	Observable	Exp. data	LEPTOP fit	Pull
LEP I	Γ_Z [GeV]	2.4952(23)	2.4964(16)	-0.5
	σ_h [nb]	41.541(37)	41.479(15)	1.7
	A^l_{FB}	0.0171(10)	0.0164(3)	0.7
	R_l	20.767(25)	20.739(18)	1.1
	A_τ, A_e	0.1467(32)	0.1480(13)	-0.4
	R_b	0.2165(7)	0.2157(1)	1.2
	R_c	0.1709(34)	0.1723(1)	-0.4
	A^b_{FB}	0.0990(20)	0.1038(9)	-2.4
	A^c_{FB}	0.0689(35)	0.0742(7)	-1.5
	$s^2_l(Q_{FB})$	0.2321(10)	0.2314(2)	0.7
SLC	A_{LR}	0.1514(22)	0.1480(16)	1.5
	s^2_l (A_{LR})	*0.2310(3)*	*0.2314(2)*	-1.5
	A_b	0.9110(250)	0.9349(1)	-1.0
	A_c	0.6300(260)	0.6683(6)	-1.5
LEP II, Tevatron	m_W [GeV]	80.434(37)	80.397(23)	1.0
	$s^2_W(m_W)$	*0.2219(7)*		
Tevatron	s^2_W (νN)	0.2255(21)	0.2231(2)	1.1
	$m_W(\nu N)$ [GeV]	*80.250(109)*		
	m_t [GeV]	174.3(5.1)	174.0(4.2)	0.1
Fit	m_H [GeV]		55^{+45}_{-26}	
	$\hat{\alpha}_s$		0.1183(27)	
$e^+e^- \to$ hadrons	$\bar{\alpha}^{-1}$	128.878(90)	128.850(90)	0.3
	$\chi^2/n_{d.o.f.}$		21.4/13	

Discrepancy # 1.

$(m_W)_{\text{LEP II, Tevatron, NuTev}}$ $\Downarrow$

$$m_H = 50^{+50}_{-35}\ \text{GeV}$$

$(s_e^2)_{\text{LEP, SLAC}}$ $\Downarrow$

$$m_H = 150^{+75}_{-50}\ \text{GeV}$$

$N_g \simeq 0.4$ sligtly improves SM fit.

Discrepancy # 2

$$s_e^2$$

Leptons	0.23113(21)	$\updownarrow$	$3.3\,\sigma$!!
Hadrons	0.23230(29)		

$\Updownarrow$

The root of poor quality of the SM fit !!

Discrepancy #3

LEP I vs SLAC

s_e^2 from hadrons.

LEP $\quad (A^b_{FB})_{LEP} = 0.0990\ (17)$

SLAC $\quad$ LR asymmetries $\quad A_b, A_e$

$$(A^b_{FB})_{SLAC} \equiv \frac{3}{4} A_b A_e$$

$$\Rightarrow \; = 0.1038\ (25)$$

>20

SM fit $\quad 0.1040\ (8)$

Lev Landau: "Take exp. data and multiply errors by a factor 3"

M. Chanowitz: hep-ph/0104024 (2001)

$\Downarrow$

We introduced factor (10) for $(A^{b,c}_{FB})_{LED}$!!

$\Rightarrow$

$$\chi^2/n = 23.8/13 \Longrightarrow 10.9/13 \text{ !!}$$

SM

New problem!

$\Downarrow$

$$m_H = 42^{+30}_{-18} \text{ GeV}$$

One "Heavy Generation" is excluded ~ 2.5 σ

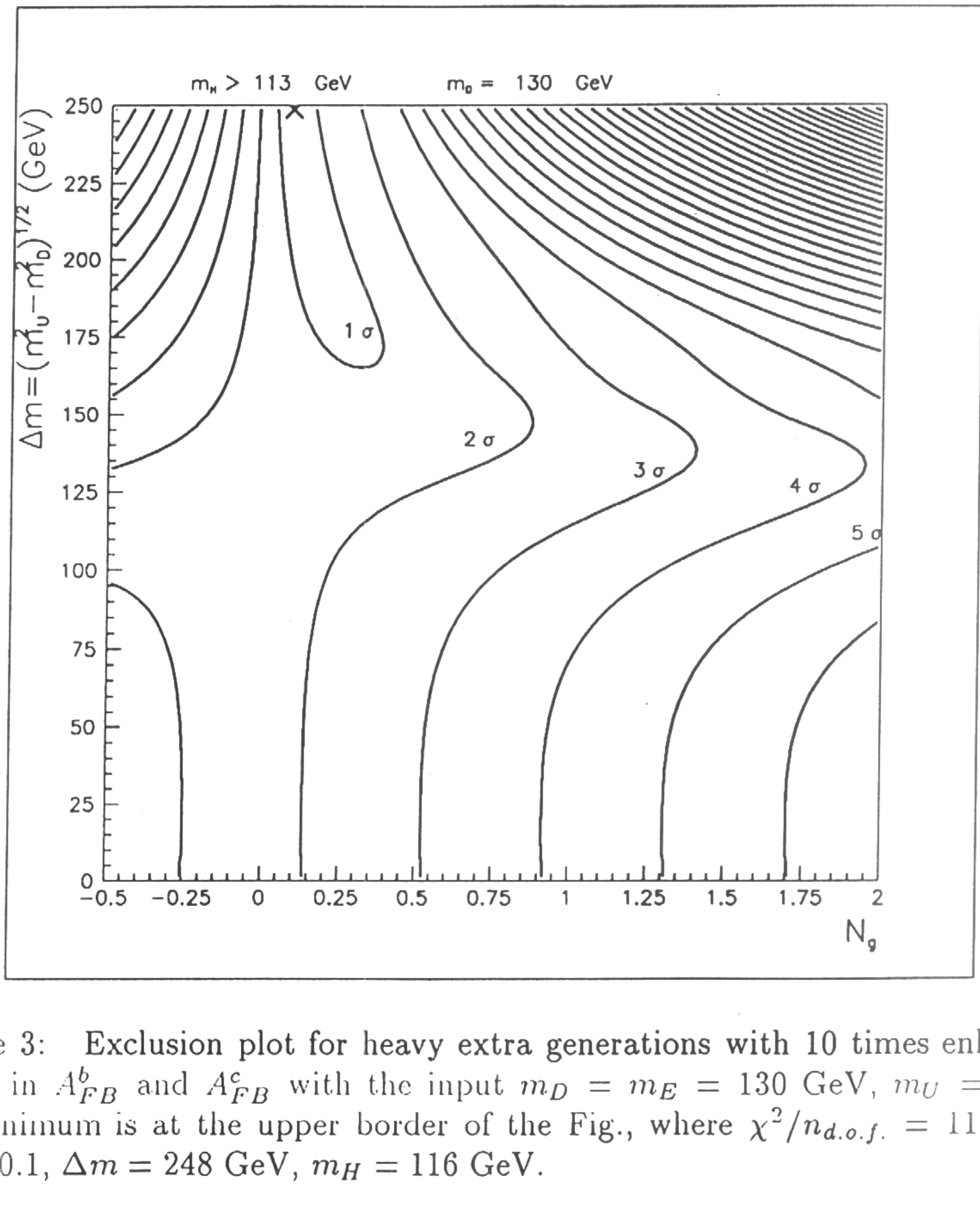


Figure 3: Exclusion plot for heavy extra generations with 10 times enlarged errors in A^b_{FB} and A^c_{FB} with the input $m_D = m_E = 130$ GeV, $m_U = m_N$. χ^2 minimum is at the upper border of the Fig., where $\chi^2/n_{d.o.f.} = 11.8/12$, $N_g = 0.1$, $\Delta m = 248$ GeV, $m_H = 116$ GeV.

"Partially Heavy Generation" fits the data

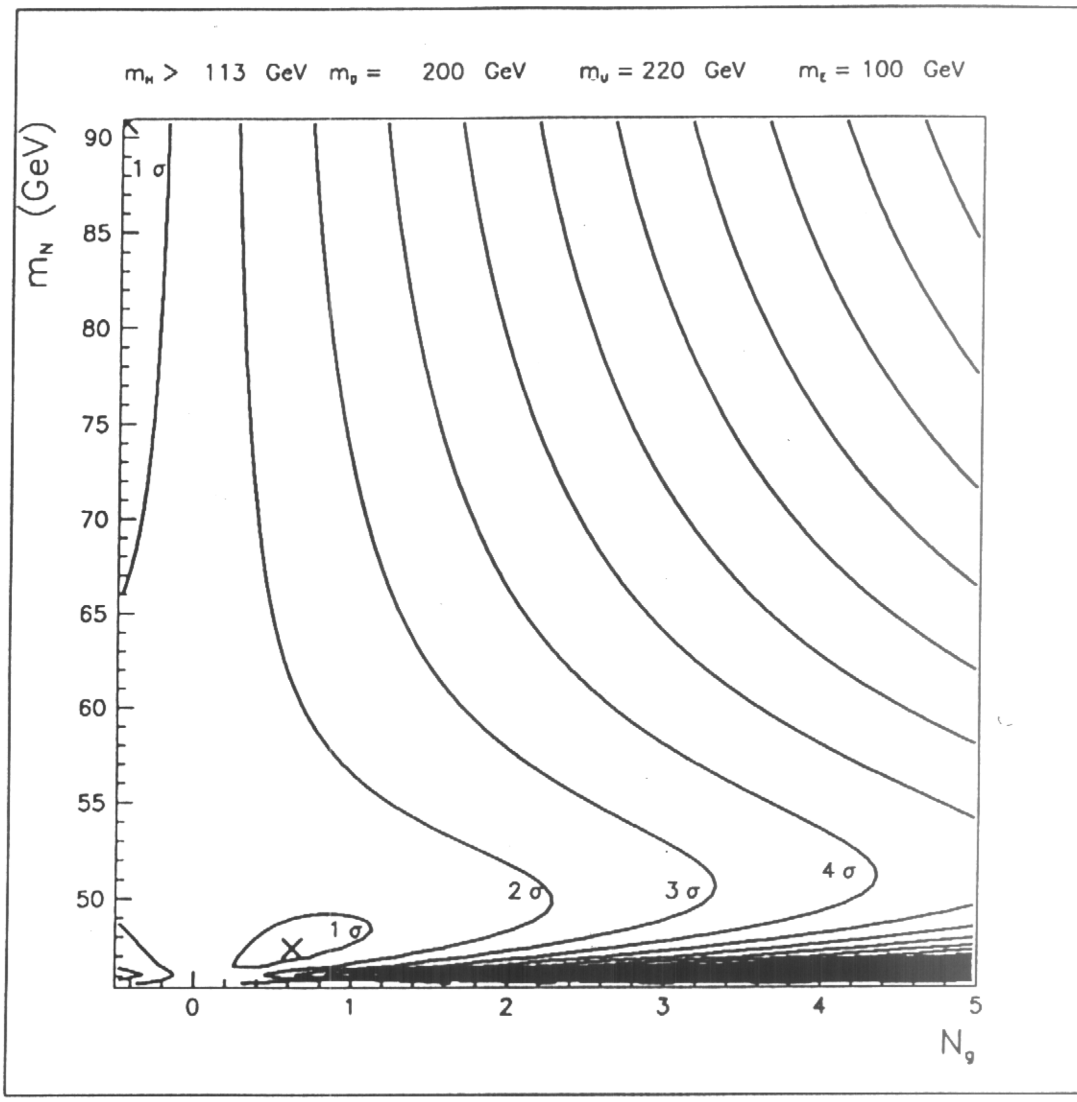


Figure 4: Exclusion plot for partially heavy extra generations with 10 times enlarged errors in A^b_{FB} and A^c_{FB} with the input m_D = 200 GeV, m_U = 220 GeV, m_E = 100 GeV. Two local χ^2 minima are shown. At the first minimum $\chi^2/n_{d.o.f.}$ = 12.4/12, $N_g = -0.5$, m_N = 90 GeV, m_H = 116 GeV (see upper left corner of the plot). At the second minimum $\chi^2/n_{d.o.f.}$ = 13.1/12, $N_g = 0.6$, m_N = 48 GeV, m_H = 116 GeV.

M_H versus 4th generation mass

SM $\qquad m_H = 79^{+47}_{-29}$ GeV

SM (A^b_{FB}) $\qquad m_H = 42^{+30}_{-18}$ GeV

Below LEP II bounds!

$m_H > 113$ GeV

⇓

To raise predicted value m_H

we need 4th generations

NORV hep-ph/0111028

H.J He et al hep-ph/0102144

$D=5$ parameter space

$(m_H, m_U, m_D, m_E, m_N)$

Weak dependence of χ^2_{min} on

$m_U + m_D$; m_H

Strong dependence on

$m_U - m_D$ and m_N, m_E

$\Downarrow$

Solution of m_H problem!

$m_N \approx 50$ GeV

$m_H = 120$. $\chi^2 = 20.6/1$[illegible]

$m_H = 500$ $\chi^2 = 21.4/1$[illegible]

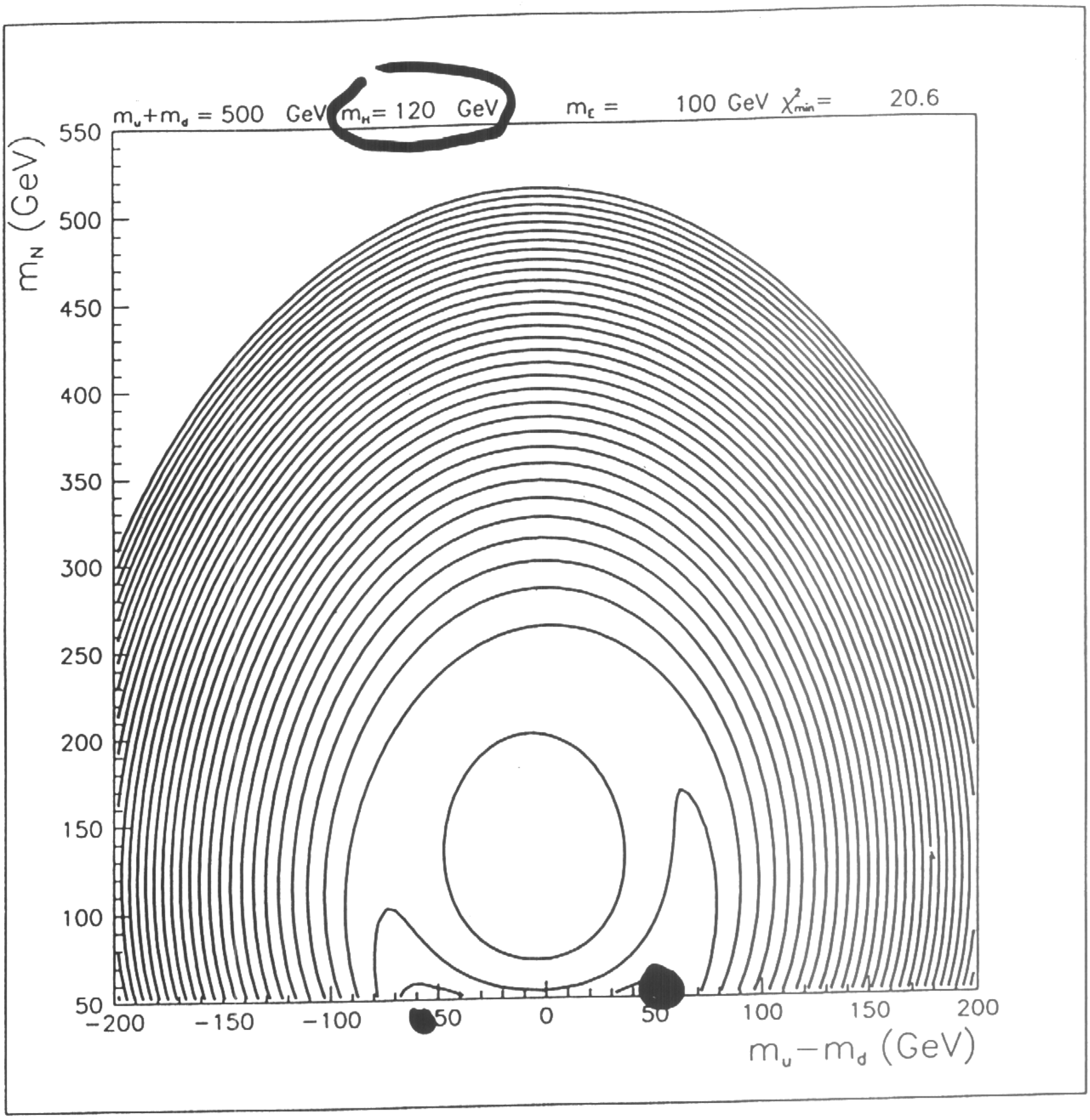


Figure 1: Exclusion plot on the plane $m_N, m_U - m_D$ for fixed values of $m_H = 120$ GeV, $m_U + m_D = 500$ GeV and $m_E = 100$ GeV. $\chi^2_{\rm min}$ shown by two crosses corresponds to $\chi^2/n_{d.o.f.} = 20.6/12$. (The left-hand cross is slightly below $m_N = 50$ GeV.) Borders of regions show domains allowed at the level $1\sigma, 2\sigma$, etc. The plot was based on the old NuTeV data. The new NuTeV data preserve the pattern of the plot, but lead to $\chi^2_{\rm min}/n_{d.o.f.} = 27.7/12$. If A^b_{FB} and A^c_{FB} uncertainties are multiplied by factor 10 we get $\chi^2_{\rm min}/n_{d.o.f.} = 19.1/12$ for new NuTeV, and $\chi^2_{\rm min}/n_{d.o.f.} = 11.3/12$ for old NuTeV.

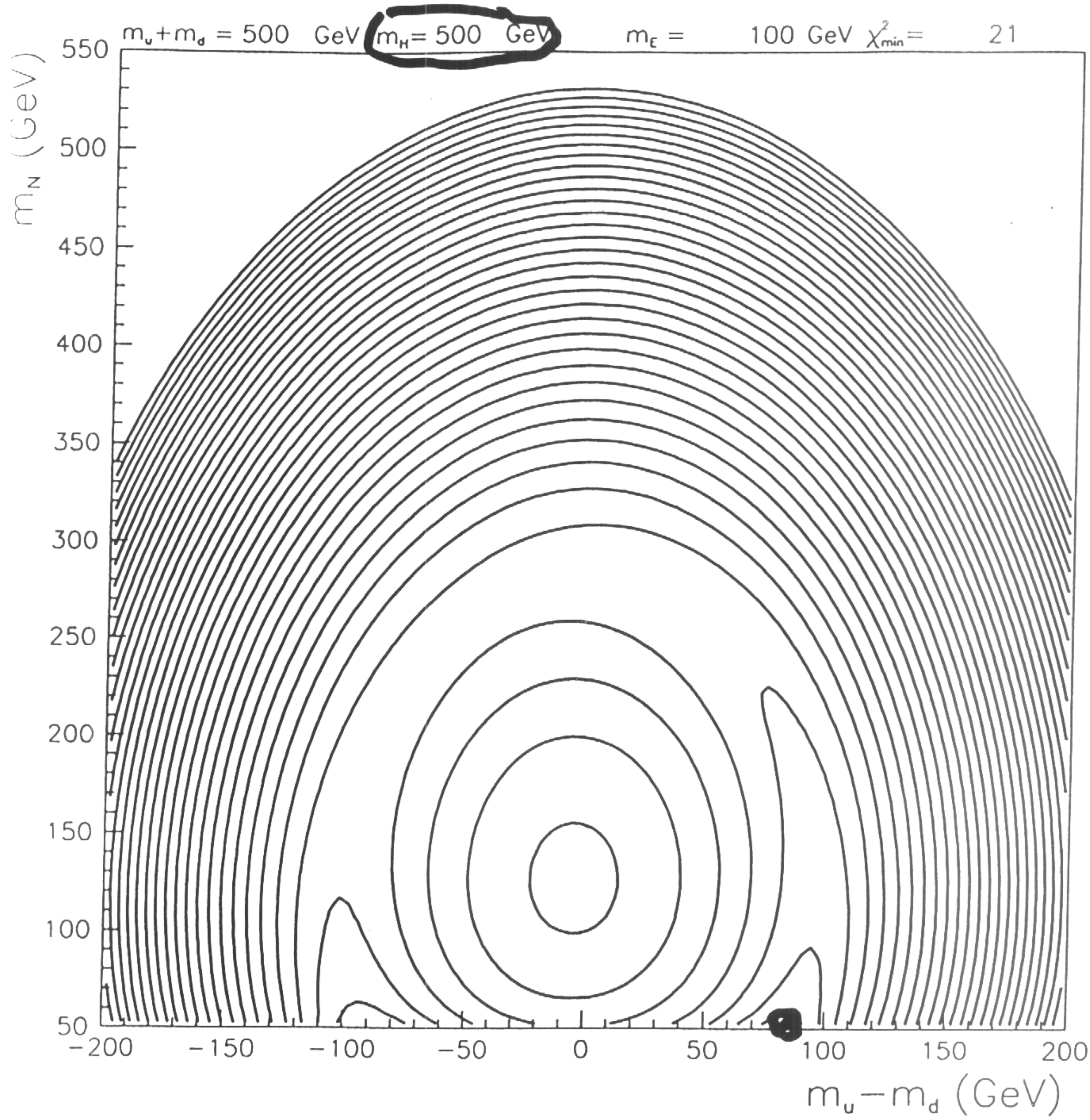


Figure 2: Exclusion plot on the plane $m_N, m_U - m_D$ for fixed values of $m_H = 500$ GeV, $m_U + m_D = 500$ GeV and $m_E = 100$ GeV. $\chi^2_{\rm min}$ shown by two crosses corresponds to $\chi^2/n_{d.o.f.} = 21.4/12.$ (The left-hand cross is slightly below $m_N = 50$ GeV.) Borders of regions show domains allowed at the level $1\sigma, 2\sigma$, etc. The plot was based on the old NuTeV data. The new NuTeV data preserve the pattern of the plot, but lead to $\chi^2_{\rm min}/n_{d.o.f.} = 28.3/12.$ If A^b_{FB} and A^c_{FB} uncertainties are multiplied by a factor 10, we get $\chi^2_{\rm min}/n_{d.o.f.} = 21.2/12$ for new NuTeV, and $\chi^2_{\rm min}/n_{d.o.f.} = 13/12$ for old NuTeV.

Theoretical "explanation".

$$\delta v^i \simeq \left\{ - \begin{pmatrix} \frac{11}{9} s^2 \\ s^2 \\ s^2 + \frac{1}{9} \end{pmatrix} \ln \frac{m_H^2}{m_Z^2} + \right.$$

$$\left. + \frac{4}{3} \frac{(m_U - m_D)^2}{m_Z^2} \right\}$$

Since $\frac{11}{9} s^2 \approx s^2 \simeq s^2 + \frac{1}{9}$

increase in m_H is compensated

by increase in $|m_U - m_D|$.

$\Downarrow$

Valley in parameter space

NuTev data

$m_W = 80.26 \pm 0.11$ GeV; "Old"

hep/exp /9904028

$\Downarrow$

$m_W = 80.14 \pm 0.08$ GeV; "New"

80.136 ± 0.084 GeV hep/ex /0110059

$\Downarrow$

3.7σ from $(m_W)_{\text{LEP, Tevatron}}$

$\Downarrow$

$$\chi^2/n = 30.3/13$$

Drastical worsening of the SM fit.

Conclusion

- SM is in trouble
- The quality of SM fit **can be improved** if ignore
  1) A_{FB}^{b}
  2) new NuTev data
- 4^{th} generation **solves** the problem of **light** Higgs
- E.-W. data are compatible with 4^{th} generations

$m_N \sim 50$ GeV

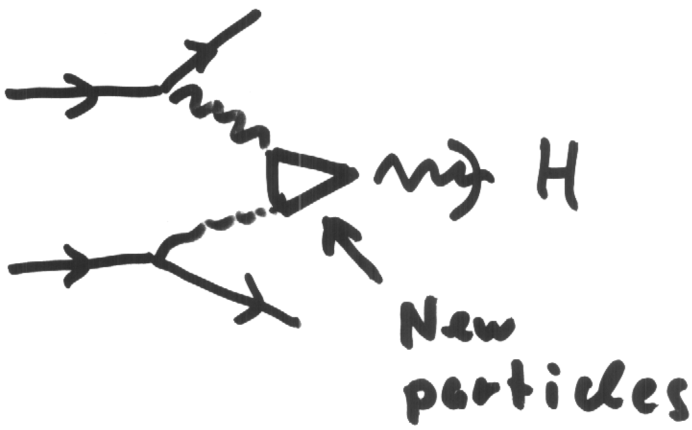
$m_H \sim 300$ GeV

$m_E \sim 100$ GeV

$|m_U - m_D| \sim 75$ GeV

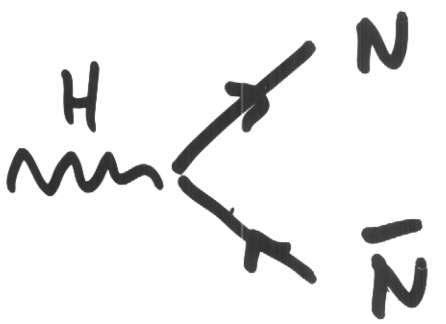
New generation and Higgs

- Higgs production at LHC



Rate ↑

- Higgs decay



Invisible Higgs.

$(m_N \sim 50\ \text{GeV})$