Z - lineshape versus 4th Generation.

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Z-lineshape versus 4th generation masses.

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Abstract

The dependence of the Z-resonance shape on the location of the threshold of the $N\bar{N}$ production (N is the 4th generation neutrino) is analyzed. The bounds on the existence of 4th generation are derived from the comparison of the theoretical expression for the Z-lineshape with the experimental data. The 4th generation is excluded at 95% C. L. for $m_N < 46.7 \pm 0.2$ GeV.

1 Introduction

The straightforward generalization of the Standard Model through the inclusion of extra chiral generations of heavy leptons (N, E) and quarks (U, D) was studied in a number of papers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. In [1, 2, 3] the analysis of deviations from the Standard Model due to 4th generation contribution was carried out in terms of S, T and U parameters for 4th generation particles being much heavier than m_Z. The case of new light physics

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4^{th} Generation

$$\begin{pmatrix} U \\ D \end{pmatrix}_L ; \quad U_R ; D_R \quad \updownarrow SU(2)$$

$$\begin{pmatrix} N \\ E \end{pmatrix}_L ; \quad N_R ; \; E_R \quad \updownarrow SU(2)$$

Hunting for 4^{th} Generation

Radiative correction

$$A = A^{SM}(1 + \Delta(m_4))$$

$$\Delta(m_4) \xrightarrow[m_4 \gg m_Z]{} C\alpha$$

C - is finite number !!

} Non-decoupled New Physics!

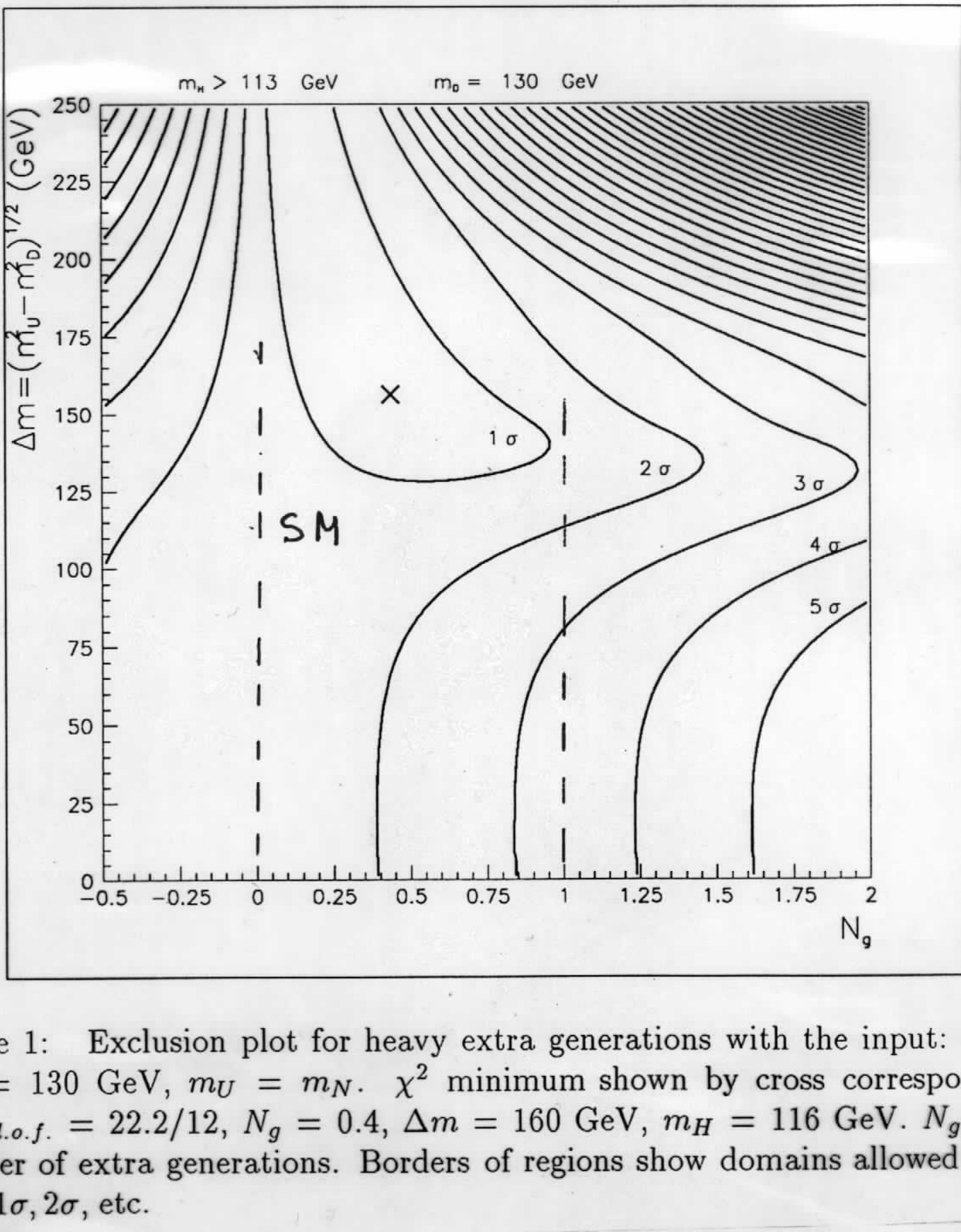


Figure 1: Exclusion plot for heavy extra generations with the input: $m_D = m_E = 130$ GeV, $m_U = m_N$. χ^2 minimum shown by cross corresponds to $\chi^2/n_{d.o.f.} = 22.2/12$, $N_g = 0.4$, $\Delta m = 160$ GeV, $m_H = 116$ GeV. N_g is the number of extra generations. Borders of regions show domains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

Brief History of Hunting for Heavy Generation: $m_4 \gg m_Z$

2000 — strongly forbidden

1 — forbidden

2 — as good as the SM

3 — ?

Partially heavy generation

$$m_N \simeq 50\ \text{GeV}$$

$$m_Z \simeq 2 m_N \Rightarrow Z \overset{\text{mixing}}{\longleftrightarrow} N\bar{N}$$

W.f. renormalization $\sim \dfrac{1}{\sqrt{m_Z^2 - 4m_N^2}}$

Conspiracy of New Physics

Large corrections due to "light" N compensates corrections due to heavy U, D, E!

2 and more partially heavy generations are still allowed!

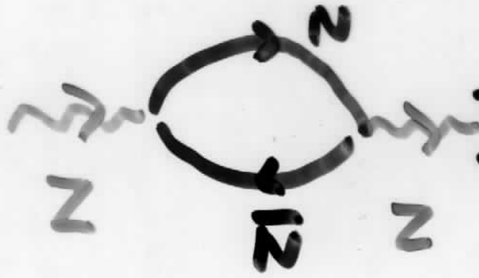
⇓

Direct search for N

1. $e^+e^- \to \gamma N\bar{N}$

2. Z-peak shape

Z-peak shape



$\mathrm{Im}\,\Sigma(p) \sim \sigma \sim \sqrt{s-4m_N^2}$

↑ phase space

⇓

$\Sigma(p) \sim \sqrt{s-4m_N^2} \Rightarrow$ W. f. renormalizatio $\sim \dfrac{1}{\sqrt{m_Z^2-4m_N^2}}$

Limit $m_N \to m_Z/2 \Rightarrow$ w. f. $\to \infty$

Theoretical problem ? Yes and No

⇓

Breakdown of Breit-Wigner approximation

Threshold $N\bar{N}$ near m_Z can't be immitated by B.-W. pole

Casps

$$T = T_0 + i T_1 \sqrt{s - 4m_N^2} \qquad s > 4m_N^2$$

$$\sigma \sim \begin{cases} |T_0|^2 + 2\,\mathrm{Im}\, T_0 T_1^* \sqrt{s - 4m_N^2} \\ |T_0|^2 - 2\,\mathrm{Re}\, T_0 T_1^* \sqrt{4m_N^2 - s} \end{cases}$$

$$s < 4m_N^2$$

Z-boson

Propagator G

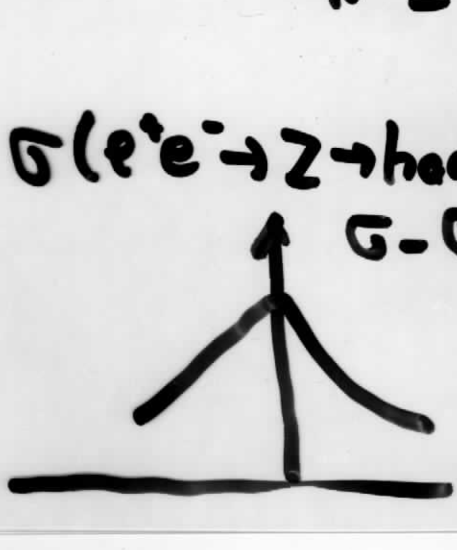
$$G^{-1} = s - m_Z^2 + i \frac{s}{m} \Gamma_Z + [\Sigma(s) - \Sigma(m_Z^2)]$$

$$\Sigma(s) \sim \alpha_W\, C \sqrt{4m_N^2 - s}$$

For $4m_N^2 \equiv m_Z^2$

$$\sigma(e^+e^- \to Z \to \text{hadrons}) \sim \begin{cases} \sigma^{SM}\left(1 + \alpha_W \frac{\sqrt{s - m_Z^2}}{\Gamma_Z}\right) \\ \sigma^{SM}\left(1 - \alpha_W \frac{m_Z^2 - s}{\Gamma_Z}\right) \end{cases}$$

$\sigma - \sigma_{SM}/\sigma$



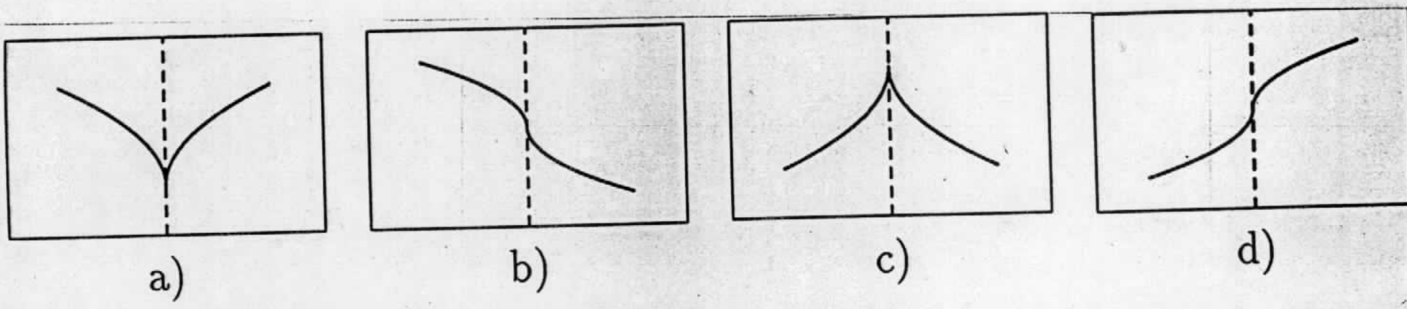


Figure 2: Different cases of cross section behavior near threshold. Vertical axis is σ, while horizontal one is s; dashed line crosses horizontal axis at $4m_N^2$

Variations within $\Gamma_Z \sim \alpha_W m_Z$

$$\sqrt{s} = m_Z + x\Gamma_Z \sim m_Z(1+\alpha_W x)$$

$$s - m_Z^2 \simeq 2x m_Z \Gamma \sim 2x m_Z^2 \alpha_W$$

$$\sigma \sim \sigma^{SM} \begin{cases} 1 - \frac{\alpha_{weak}}{\alpha_{em}}\sqrt{\alpha_W x} \\ 1 + C\alpha_W x \end{cases}$$

↓ Large!

Deviations from B.-W.
are large!

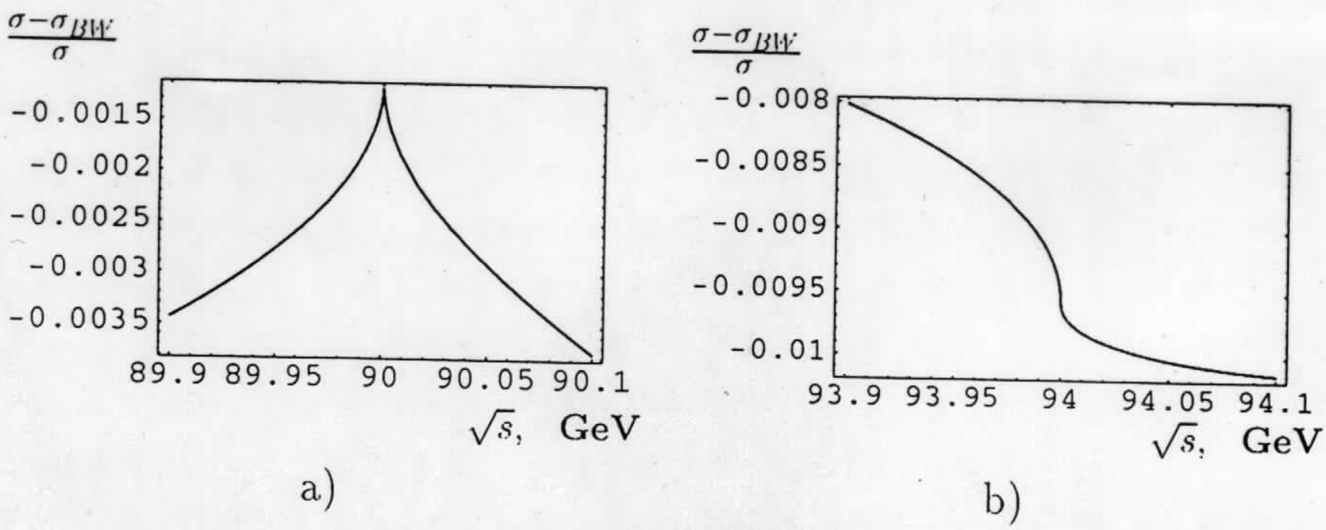


Figure 3: The dependence of relative departure of the $e^+e^- \to hadrons$ cross section in the presence of 4th generation from the SM prediction on the c.m. energy of e^+e^- for $m_N = 45$ GeV (a) and $m_N = 47$ GeV (b).

Comparison with LEP 1.

① 1993-1995

35 points $\sqrt{s} \sim 89.4 - 93.04$ GeV

② E.-m. corrections to

$$\sigma_h = \frac{12\pi \Gamma_e \Gamma_h}{\left[s - m_Z^2 + i\Gamma \frac{s}{m_Z} + \Sigma^{\gamma}(p) - \mathrm{Re}\,\Sigma^{\gamma}(m_Z)\right]} \frac{s^2}{m_Z^2}$$

ZFITTER

③ $$\chi^2 = \sum_1^{35} \left(\frac{\sigma^{th} - \sigma^{exp}}{\delta\sigma^{exp}} \right)^2$$

Valleys in m_H, $m_U - m_D$!

$m_N - m_E$

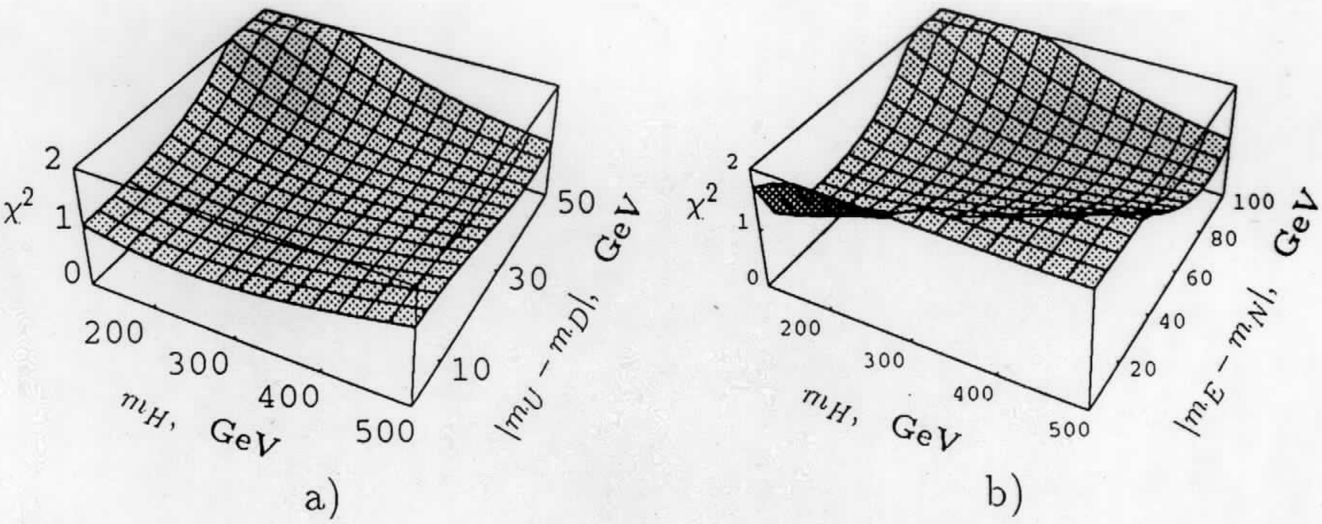


Figure 4: The dependence of χ^2 on m_H, $|m_U - m_D|$ (a) and on m_H, $|m_E - m_N|$.

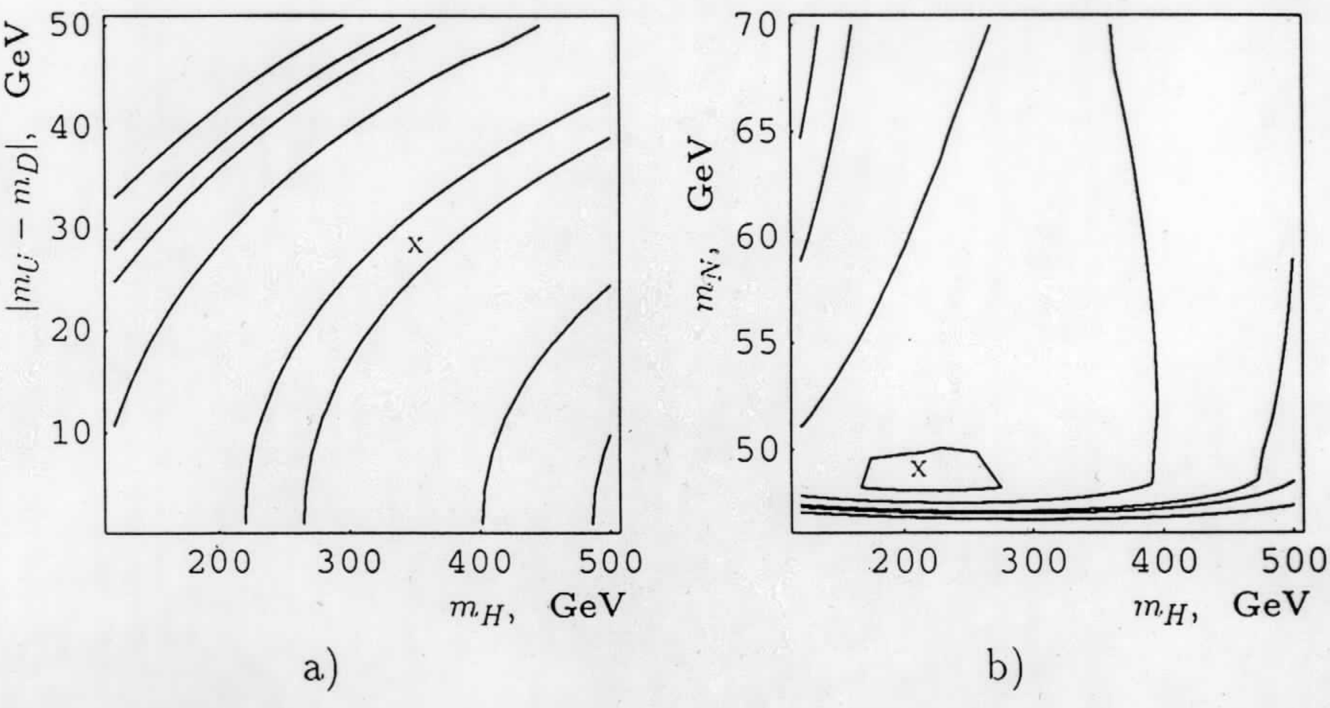


Figure 5: a) Exclusion plot on the plane m_H, $|m_U - m_D|$ for $m_N = 49$ GeV; $\chi^2_{min} = 0.85$ denoted by cross b) Exclusion plot on the plane m_H, m_N for $|m_U - m_D| = 10$ GeV; $\chi^2_{min} = 0.85$ denoted by cross. Solid lines represents the borders of 1σ, 2σ, 3σ, 4σ and 5σ regions.

Results

For $m_E = 100$ GeV

$|m_U - m_D| \sim 0 - 50$ GeV

$m_N < 46.7$ GeV ± 0.2

Excluded 95% C.L.

Summary

1. B.-W. $m_N > 46.7$ GeV
2. $e^+e^- \to \gamma +$ Nothing

   $m_N > 50$ GeV.