PRECISION MEASUREMENTS, EXTRA GENERATIONS AND HEAVY NEUTRINO

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The existence of extra chiral generations with all fermions heavier than M_Z is strongly disfavored by the precision electroweak data. The exclusion of one additional generation of heavy fermions in SUSY extension of Standard Model is less forbidden if chargino and neutralino have low degenerate masses with $\Delta m \simeq 1$ GeV. However the data are fitted nicely even by a few extra generations, if one allows neutral leptons to have masses close to 50 GeV. Such heavy neutrino can be searched in the reaction $e^+e^- \to N\bar{N}\gamma$ at LEP-200 with total final luminosity of $2600 pb^{-1}$.

1 Introduction

The 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 New Physics at high energies which does not decouple at "low" ($\sim m_Z$) energies. New particles contribute to physical observables through self-energies of vector and axial currents. This gives corrections [1] δV_i to the functions $V_i (i = A, R, m)$ which determine [2] the values of physical observables (axial coupling g_A, the ratio $R = g_V/g_A$, and the ratio m_W/m_Z).

We consider the case of several lepton and quarks $SU(2)_L$ doublets and their right-handed singlet companions: $(UD)_L$, U_R, D_R, $(NE)_L$, N_R, E_R. 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).

2 LEPTOP fit to experimental data

We compare theoretical predictions for the case of the presence of extra generations with experimental data [3] with the help of the code LEPTOP [4]. These experimental data are the latest updates presented at this conference and they are well fitted by Standard Model. We perform the four parameter ($m_t, m_H, \alpha_s, \bar{\alpha}$) fit [a] to 18 experimental observables.

The fitted parameters [b] together with the values of the predicted observables and their pulls from the experimental data are given in the Table 1. Only the experimental value of the forward-backward assymetry in the Z decay into the pair of b-quarks A^b_{FB} shows a hint for disagreement with Standard Model. We take $m_D = 130$ GeV – the lowest value allowed for the new quark mass from Tevatron search [7] 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 $m_N = m_U$,

[a] The mass of Z-boson in the fit was fixed to the latest experimental value $M_Z = 91.1875(21)$ GeV

[b] During this conference the new results on the electron-positron annihilation into hadrons in the range $\sqrt{s} = 2 - 5$ GeV from BES [5] were released. With $\bar{\alpha}^{-1} = 128.945(60)$ [6] recalculated using these new BES results, we get from LEPTOP fit slighly higher prediction for the higgs mass $m_H = 78^{+53}_{-32}$ GeV, $m_t = 174.1(4.5)$ GeV, $\alpha_s = 0.1182(27)$, $\bar{\alpha}^{-1} = 128.927(58)$ and $\chi^2/ndf = 21.1/14$.

Table 1. LEPTOP fit of the precision observables.

Observ.	Exper. data	LEPTOP fit	Pull
Γ_Z [GeV]	2.4952(23)	2.4964(16)	-0.5
σ_h [nb]	41.541(37)	41.479(15)	1.7
R_l	20.767(25)	20.739(18)	1.1
A^l_{FB}	0.0171(10)	0.0164(3)	0.7
A_τ	0.1439(42)	0.1480(13)	-1.0
A_e	0.1498(48)	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
s^2_l (A_{LR})	*0.2310(3)*	*0.2314(2)*	-1.5
A_b	0.911(25)	0.9349(1)	-1.0
A_c	0.630(26)	0.6683(6)	-1.5
m_W [GeV]	80.434(37)	80.397(23)	1.0
s^2_W (νN)	0.2255(21)	0.2231(2)	1.1
m_t [GeV]	174.3(5.1)	174.0(4.2)	0.1
m_H [GeV]		55^{+45}_{-26}	
$\hat{\alpha}_s$		0.1183(27)	
$\bar{\alpha}^{-1}$	128.88(9)	128.85(9)	0.3
χ^2/n_{dof}		21.4/14	

$m_E = m_D$. Any value of higgs mass above 113.3 GeV is allowed [8] in our fits, however χ^2 appears to be minimal for $m_H = 113$ GeV.

In Figure 1 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 $N_g = 0.1$. We see that one extra generation corresponds to 2σ approximately.

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 1.5 σ level, while for $m_E = m_U = 130$ GeV and $m_N = m_D$ the limits are even stronger than in Fig. 1. So the extra generations are excluded by the electroweak precision data, if all extra fermions are heavy: $m \gtrsim m_Z$.

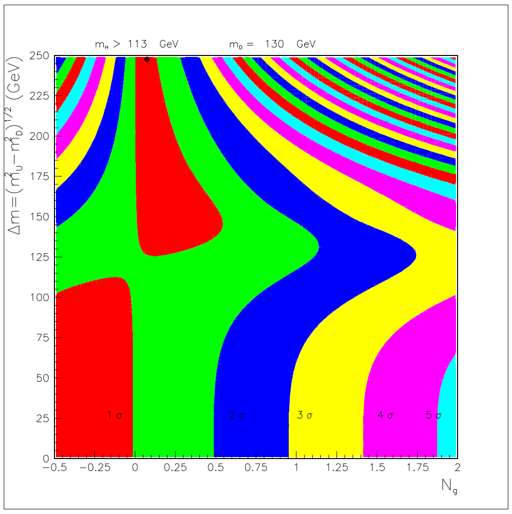

Figure 1. Constraints on the number of extra generations N_g and the mass difference in the extra generations Δm. The lowest allowed value $m_D = 130$ GeV from Tevatron search was used and $m_E = m_D$, $m_N = m_U$ was assumed.

3 Extra generations in SUSY

When SUSY particles are heavy they decouple [9,10] and the same standard model exclusion plots shown in Fig. 1 are valid.

One possible exception is the case of light chargino and neutralino. The latter are still not excluded - dedicated search at LEP II still allows the existence of such particles with masses as low as 68 GeV (gaugino region with light sneutrino) [11] or 77 GeV (higgsino case) [12] if their mass difference is ≈ 1 GeV. Analytical formulas for corrections to the functions V_i from quasi degenerate chargino and neutralino were derived and analyzed in [13]. Corrections are big and this allows one to get lower bounds on masses of chargino and neutralino: $m_\chi > 54$ GeV for the case of higgsino domination and $m_\chi > 61$ GeV for the case of wino domination at 95% CL.

The presence of chargino-neutralino pair (dominated by higgsino) with mass 80 GeV slightly relaxes the bounds on extra generations. We see that one extra generation of heavy fermions is allowed within 1.5σ domain

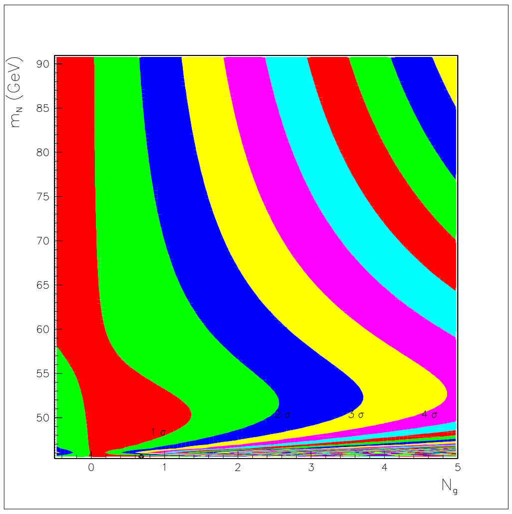

Figure 2. Constraints on the number of extra generations N_g and the mass of the neutral heavy lepton m_N. The values $m_U = 220$ GeV, $m_D = 200$ GeV, $M_E = 100$ GeV were used.

in case of the light chargino.

4 Heavy neutrino with $m_N < m_Z$

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. Quasi-stable neutral lepton N should have the mass slightly above $m_Z/2$ to avoid increasing the invisible Z-width and it should have the mixing angle with three known generations smaller than 10^{-6} to avoid desintegration in the detector. We consider new heavy neutrino with Dirac mass and we suppose that the Majorana mass of N_R is negligible. From the analysis of the initial set of precision data in papers [14,15] 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. 2. 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 Possibility for the direct search of the 50 GeV heavy neutrino

The direct search of the heavy neutrino is possible in e^+e^--annihilation into a pair of heavy neutrinos with the emission of initial state bremsstrahlung photon

$$e^+e^- \to \gamma + \mathrm{N\bar{N}} \qquad (1)$$

The main background is the production of the pairs of conventional neutrinos with initial state bremsstrahlung photon

$$e^+e^- \to \gamma + \nu_i\bar{\nu}_i \qquad (2)$$

where $i = e, \mu, \tau$. These background neutrinos are produced in decays of real and virtual Z. In case of $\nu_e\bar{\nu}_e$, two mechanisms contribute, through s-channel Z boson and from t-channel exchange of W boson. We calculated the signal and background distributions and rates [16] using CompHEP [17] computer code.

In Fig. 3 the distribution on "invisible" mass M_{inv} (invariant mass of the neutrino pair) is represented for SM background and the $N\bar{N}$ signal for $\sqrt{s} = 200$ GeV and different values of N masses, $M_N = 46 - 100$ GeV. Here we applied kinematical cuts on the photon polar angle and transverse momentum, $|\cos\vartheta_\gamma| < 0.95$ and $p_T^\gamma > 0.0375\sqrt{s}$, being the ALEPH selection criteria [18]. The photon detection efficiency 74% is assumed. For highest significance of the $N\bar{N}$ signal, evaluated as $N_S/\sqrt{N_B}$, one should include whole interval on M_{inv} allowed kinematically, so we applied $M_{inv} > 2m_N$ cut.

From the calculated signal significance [16] one can derive that only the analysis based

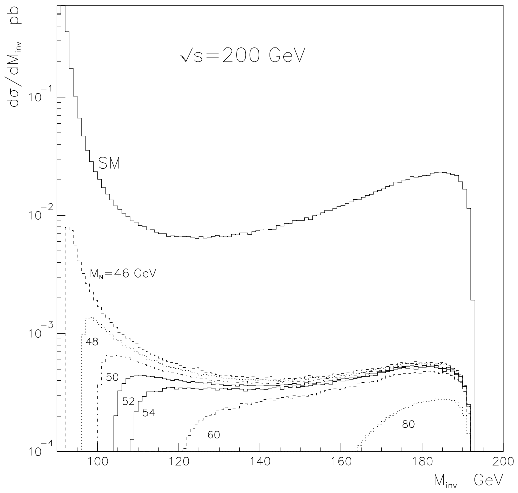

Figure 3. $d\sigma/dM_{inv}$ (in pb) for Standard Model and for the different values of m_N.

on combined data from all four experiments both from 1997-1999 runs ($\sqrt{s} = 182 - 202$ GeV) and from the current run, in total $\sim$ 2600 pb^{-1}, can exclude at 95% CL the interval of N mass up to $\sim$ 50 GeV.

Another possibility is to search for 50 GeV neutrino at the future TESLA $e^+ - e^-$ electron-positron linear collider. The increase in energy leads to the decrease both of the signal and the background, but it is compensated by the proposed increase of luminosity of 300 fb^{-1}/year [19]. Further advantage of the linear collider is the possibility to use polarized beams. This is important in suppressing the cross section of $e^+e^- \to \nu_e\bar{\nu}_e\gamma$ as this reaction goes mainly through the t-channel exchange of the W boson. However, even without exploiting the beam polarization the advantage of TESLA in the total number of events is extremely important. Thus, Standard Model is expected to give approximately 0.3 million single photon events for $M_{inv} > 100$ GeV while the number of 50 GeV neutrino pairs would be about 4000. Although the signal over background ratio is still small (2.3-0.5% for $m_N = 45 - 100$ GeV correspondingly) the significance of the signal is excellent, higher than 5 standard deviations for $m_N < 60$ GeV.

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