PROCEEDINGS OF SCIENCE

See-saw signals at the LHC

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In this talk I will review the recently proposed nonsupersymmetric SU(5) grand unified model with an extra fermionic adjoint representation. It predicts a light fermionic weak triplet that contributes via the type III seesaw mechanism to the neutrino masses. One of these masses turn out to be zero, and the others are functions of the same parameters that describe the triplet decays. The search at the LHC for such triplets and their decays could thus lead to a direct determination of the seesaw parameters.

Physics at LHC 2008
29 September - October 4, 2008
Split, Croatia

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[†]This is a short summary of various works done with Abdesslam Arhrib, Dilip K. Ghosh, Tao Han, Gui-Yu Huang, Miha Nemevšek, Ivica Puljak and Goran Senjanović. The author thanks the conference organizers and especially Ivica Puljak. This work has been supported by the Slovenian Research Agency. Due to lack of space the list of references is incomplete. We refer the reader to the original papers.

PoS(2008LHC)009

1. Introduction

With the degrees of the standard model (SM) the neutrino mass matrix m_ν can be parametrized by the $d = 5$ Weinberg's effective operator

$$\mathscr{L} = Y_{ij} \frac{L_i H H L_j}{M} \ , \tag{1.1}$$

where the symmetric matrix Y can be diagonalized by the unitary PMNS matrix U ($v = \langle H \rangle$)

$$\frac{v^2}{M} Y = m_\nu \equiv U m_\nu^{diag} U^T \ . \tag{1.2}$$

M signals the appearance of new physics.

There are only 3 ways of producing the Weinberg operator: by the exchange of a heavy fermion singlet $(1,1,0)$ (type I seesaw [1]), boson weak triplet $(1,3,1)$ (type II seesaw [2]) or fermion weak triplet $(1,3,0)$ (type III seesaw [3]). The first two cases are very well studied, while the type III has been almost ignored in the past. The whole subject can be interesting for LHC only if

- the mediators have a small enough mass M,
- they are coupled with our world (SM particles) strongly enough to be produced.

I will present in the following the only known (to my knowledge) model which predicts both: the minimal non-supersymmetric SU(5) with extra adjoint fermionic 24_F [4].

2. Weinberg operator from grand unification

Let us motivate the origin of the Weinberg operator and thus of neutrino masses from a grand unified theory. The minimal proposal for a grand unified model is the nonsupersymmetric Georgi-Glashow SU(5), which is defined by three copies of fermionic 10_F, $\overline{5}_F$ and the Higgses 24_H and 5_H. The model is ruled out because

1. gauge couplings do not unify,
2. neutrinos are massless, as in the SM.

In [4] we proposed to add to it an additional fermionic 24_F, which solves both problems:

1. under the SM decomposition the new fermionic adjoint has extra states, the weak triplet $(1,3)_0$, the colour octet $(8,1)_0$ and the leptoquarks $(3,2)_{5/6} + h.c.$., whose in principle arbitrary masses m_3, m_8 and $m_{(3,2)}$ modify the RGE. The requirement for unification of gauge couplings at two loops determine this masses to be [4, 5]

   $$m_3 \approx 10^{2-3}\text{GeV} \ , \ m_8 \approx 10^{6-9}\text{GeV} \ , \ m_{(3,2)} \approx 10^{13-14}\text{GeV} \ , \ M_{GUT} \approx 10^{15-16}\text{GeV} \ . \tag{2.1}$$

   So the first prediction is a light (order TeV) weak fermionic triplet. What is also important is that the GUT scale decreases with increasing triplet mass. This means that for short proton lifetime the triplet mass must be in the 100 GeV range, which is very promising for LHC. On the contrary, a triplet can be heavier (in the TeV region) only when proton decay is relatively fast: this situation is disappointing for LHC, but very appealing for the next generation of proton decay searches.

2. In the fermionic adjoint there are two candidates for seesaw mediators. These are the SM singlet $S = (1,1)_0$ and the weak triplet $T = (1,3)_0$ that have in general Yukawa couplings with the SM leptons L_i and Higgs H

$$\mathscr{L}_Y = L_i \left(y_T^i T + y_S^i S\right) H + h.c. \tag{2.2}$$

which brings us to the mixed type I and II seesaw:

$$m_\nu^{ij} = v^2 \left(\frac{y_T^i y_T^j}{m_T} + \frac{y_S^i y_S^j}{m_S} \right) . \tag{2.3}$$

The matrix is rank 2, so the second prediction is one massless neutrino.

3. Triplets at the LHC

Is it possible to produce these light triplets at the LHC? Different to the case of right-handed neutrinos, these triplets feel the weak interactions. So they can be produced in a Drell-Yan process

$$pp \to W^\pm \to T^\pm T^0 \, , \tag{3.1}$$

$$pp \to Z(\text{or})\gamma \to T^+ T^- \, . \tag{3.2}$$

Once they are produced, they will also decay, and the possible modes are

$$T^\pm \to Z l_k^\pm, h l_k^\pm, W^\pm \nu_k \, , \; T^0 \to Z\nu_k, h\nu_k, W^\pm l_k^\mp \, . \tag{3.3}$$

To avoid events with missing energy we could use two channels:

1. only charged leptons

$$T^\pm \to Z l^\pm \to l'^+ l'^- l^\pm \, , \tag{3.4}$$

2. charged leptons plus jets

$$T^\pm \to (Z \text{ or } h) l^\pm \to l^\pm + 2\text{jets} \, , \tag{3.5}$$

$$T^0 \to W^\mp l^\pm \to l^\pm + 2\text{jets} \, . \tag{3.6}$$

The most promising channel is like-sign dileptons plus four jets, similar as in left-right models with low W_R and $m_{\nu_R} \le m_{W_R}$ [6]. This gives a suppression

$$BR(T^\pm T^0 \to l_i^\pm l_j^\pm + 4\text{jets}) \approx \frac{1}{20} \times \frac{|y_T^i|^2 |y_T^j|^2}{\left(\sum_k |y_T^k|^2\right)^2} \, . \tag{3.7}$$

The crucial point is that the same couplings y_T^i contribute to the ν mass matrix and to T decays. To analyze it better, we use the standard parametrization for the normal (NH) and inverse hierarchy (IH) cases:

$$\frac{v y_T^{i*}}{\sqrt{2}} = i\sqrt{M_T} \left(U_{i2} \sqrt{m_2^\nu} \cos z \pm U_{i3} \sqrt{m_3^\nu} \sin z \right) \quad (\text{NH}) \, , \tag{3.8}$$

$$\frac{v y_T^{i*}}{\sqrt{2}} = i\sqrt{M_T} \left(U_{i1} \sqrt{m_1^\nu} \cos z \pm U_{i2} \sqrt{m_2^\nu} \sin z \right) \quad (\text{IH}) \tag{3.9}$$

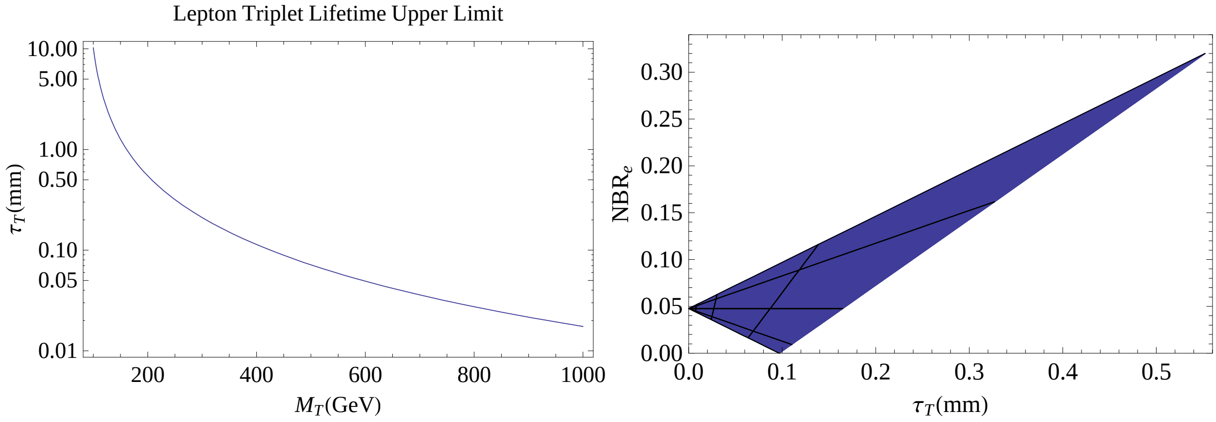

Figure 1: Left: the upper limit on the triplet lifetime as a function of its mass for Higgs mass of 120 GeV. Right: The allowed values of the triplet lifetime and the electron normalized branching ratio in the NH case with $\theta_{13} = 0$, $M_T = 200$ GeV.

in terms of the PMNS matrix U and the complex number z. Measuring triplet decays thus give constraints on z and the unknown parameters θ_{13} and phases of U.

Using (3.8) one can obtain [7] the maximal lifetime as function of the triplet mass T, which is shown in Fig. 1 (left) (the limits are $\sqrt{\Delta m_A^2/\Delta m_S^2} \approx 5$ smaller in the IH case). Scanning over the available parameter space it is possible to see the preferred regions for the triplet Yukawas. In fact they turn out to be partially correlated, i.e. connected by the unknown complex number z and the not yet measured angle θ_{13} and two CP violating phases in U [7]:

$$y_T^1 < y_T^2 \approx y_T^3 \;\; (\mathrm{NH}) \quad , \quad y_T^1 > y_T^2 \approx y_T^3 \;\; (\mathrm{IH}) \; . \tag{3.10}$$

These are good news: the (hard to measure) $\tau\tau$ final states never dominates!

One can also reverse the analysis. Imagine that the triplets will be found at the LHC, and their branching ratios and lifetime measured. Then one can first test the consistency of the model. An example of this kind is shown on Fig. 1 (right), where the electron normalized branching ratio is

$$\mathrm{NBR}_e = \frac{|y_T^1|^2}{\sum_k |y_T^k|^2} \; . \tag{3.11}$$

On Fig. 2 (from [7]) we show the triplet pair $(T^+T^0 + T^-T^0)$ production cross section σ_{prod}, the cross section $\sigma_{prod} \times BR$ for final states $l^+l^+4j + l^-l^-4j$ and the signal cross section $\sigma_{signal} = \sigma_{prod} \times BR$ after the cuts

$$\begin{aligned} &p_T(\ell) > 15 \text{ Gev}, \; |\eta_\ell| < 2.5; \quad p_T(j) > 20 \text{ Gev}, \; |\eta_j| < 3; \\ &\Delta R(jj) > 0.5, \; \Delta R(j\ell) > 0.5, \; \Delta R(\ell\ell) > 0.3, \; E_T^{miss} < 25 \text{ GeV}. \end{aligned} \tag{3.12}$$

This signal should be compared with the SM background. Since it is lepton flavour violating, the fake SM signals are expected to be small. The main channels are $t\bar{t}W$, $WW4j$, $WWV2j$ and $WWVV$ with $V = W, Z$. Already after the basic cuts (3.12) they turn out to be at the level of 1 fb, which can be further reduced by the requirements [7] that two pairs of jets must have a W, Z or Higgs invariant mass, or that two three body invariant masses m_{ljj} must equal M_T. An independent study of similar backgrounds has been done in [8].

PoS(2008LHC)009

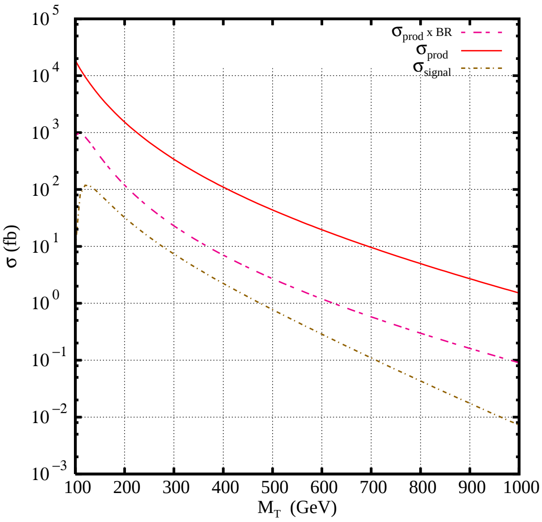

Figure 2: The cross sections connected with the triplet productions and decays as explained in the text.

4. Conclusions

We showed an explicit example of a predictive grand unified theory: this is simply the minimal nonsupersymmetric SU(5) with an extra fermionic adjoint representation. It predicts a weak fermionic triplet in the TeV range, with decays connected to neutrino mass, and one massless neutrino. A careful analysis shows good chances to find the presence of this triplet at the LHC. This is a rare example of measurable seesaw parameters directly from colliders. It provides a possibility for getting information on the yet unmeasured neutrino parameters.

References

[1] P. Minkowski, Phys. Lett. B **67** (1977) 421; T. Yanagida, proceedings of the *Workshop on Unified Theories and Baryon Number in the Universe*, Tsukuba, 1979, eds. A. Sawada, A. Sugamoto; S. Glashow, in *Cargese 1979, Proceedings, Quarks and Leptons* (1979) ; M. Gell-Mann, P. Ramond, R. Slansky, proceedings of the *Supergravity Stony Brook Workshop*, New York, 1979, eds. P. Van Niewenhuizen, D. Freeman R. Mohapatra, G. Senjanović, Phys.Rev.Lett. **44** (1980) 912.

[2] M. Magg and C. Wetterich, Phys. Lett. B **94** (1980) 61; G. Lazarides, Q. Shafi and C. Wetterich, Nucl. Phys. B **181** (1981) 287; R. N. Mohapatra and G. Senjanović, Phys. Rev. D **23** (1981) 165.

[3] R. Foot, H. Lew, X. G. He and G. C. Joshi, Z. Phys. C **44** (1989) 441;

[4] B. Bajc and G. Senjanović, JHEP **0708** (2007) 014 [arXiv:hep-ph/0612029].

[5] B. Bajc, M. Nemevšek and G. Senjanović, Phys. Rev. D **76** (2007) 055011 [arXiv:hep-ph/0703080].

[6] W. Y. Keung and G. Senjanović, Phys. Rev. Lett. **50** (1983) 1427.

[7] A. Arhrib, B. Bajc, D.K. Ghosh, T. Han, G.-Y. Huang, I. Puljak and G. Senjanović, to appear.

[8] R. Franceschini, T. Hambye and A. Strumia, Phys. Rev. D **78** (2008) 033002 [arXiv:0805.1613 [hep-ph]]; F. del Aguila and J. A. Aguilar-Saavedra, arXiv:0808.2468 [hep-ph].