PROCEEDINGS OF SCIENCE

Probing the Light Sterile Neutrino Through the Heavy Charged Higgs Decay at the LHC

Yi-Lei Tang*
School of Physics, Korea Institute for Advanced Study
E-mail: tangyilei@kias.re.kr

I will show in this paper that a sterile neutrino emerged from the decay of a heavy charged Higgs boson can be probed by utilizing the muon-jet tagging technique at the LHC.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

*Speaker.

PoS(ICHEP2018)576

1. Introduction

Probing the TeV-scale sterile neutrino through the W or Z bosons [1, 2, 3] suffers from the extremely smalll see-saw Yukawa coupling constants. In some models, other new physics sector might help enhance the signal. For example, in the ν-Two-Higgs-Doublet-Model (ν-THDM) [4, 5, 6, 7, 8, 9], Ref. [9] had discussed the $(m_N) \gtrsim 100$ GeV situation when separated objects can be detected. Secondary vertices are also discussed in Ref. [8].

In this work, we only concern the $m_N < 100$ GeV. When $m_{H^\pm} \gg m_N$, the highly boosted sterile neutrino decays via the $\mu^\pm$+jet+jet channel. Fig. 1 shows the complete diagram

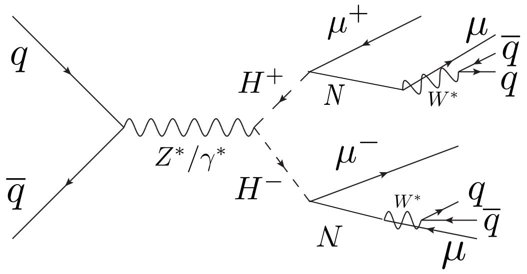

Figure 1: Production and subsequent decay channel of the N at the LHC.

2. Model Setup

We briefly show the Lagrangian of the ν-THDM, which is a variant of the type-I Two-Higgs doublet model [10]. There are two Higgs doublet fields, $\Phi_{1,2}$, with the hypercharge $Y = \frac{1}{2}$. Φ_2 couples with the Standard Model (SM) particles Q_L, u_R, d_R, L_L, e_R through

$$\mathscr{L}^{\rm SM}_{\rm Yukawa} = -Y_{uij}\overline{Q}_{Li}\tilde{\Phi}_2 u_{Rj} - Y_{dij}\overline{Q}_{Li}\Phi_2 d_{Rj} - Y_{lij}\overline{L}_{Li}\Phi_2 l_{Rj} + \text{h.c.}. \tag{2.1}$$

The Φ_1 is in charge of the neutrino,

$$\mathscr{L}^{\nu}_{\rm Yukawa} = -m_N\overline{N}N - (Y_i\overline{L}_{Li}\tilde{\Phi}_1 N + \text{h.c.}), \tag{2.2}$$

where the subscript $i = 1,2,3$ corresponds to the e, μ, τ lepton doublets, respectively. In this model, Y_i can be significantly amplified by a sizeable $\tan\beta \equiv \frac{v_2}{v_1}$, keeping the effective coupling with the standard-model Higgs boson $h_{\rm SM}$ small.

3. Background Analysis and the Cut Flow

We identify the sterile neutrino jet finding out the high-energy-fraction muons in a jet. For the SM backgrounds, b-jet might fake the signal through the semi-leptonic decay of a B-meson. The main irreducible background is therefore $pp \to b\bar{b}l^+l^-$, $b \to B + X \to \mu + \nu + X$. We also considered the $pp \to jb + l^+l^-$ and $pp \to jj + l^+l^-$ processes, in which a non-b-jet can also produce a muon inside.

We also calculated the important reducible $pp \to t\bar{t} \to b\bar{b}l^+l^- +$ background. Considering the MET reconstruction efficiency and the large pile-up effect in the future, we will show both the results with and without this background, which two extreme cases are covered.

We select the signal events by some anti-mass window around the Z-boson mass, and the mass window around the $H^\pm$ mass. Then a μ-jet will be identified if it carries more than 30% of the total jet energy. The events containing at least one tagged N-jet are suffixed by "-1N-jet" and the ones with two tagged N-jet by "-2N-jet".

4. Numerical Results

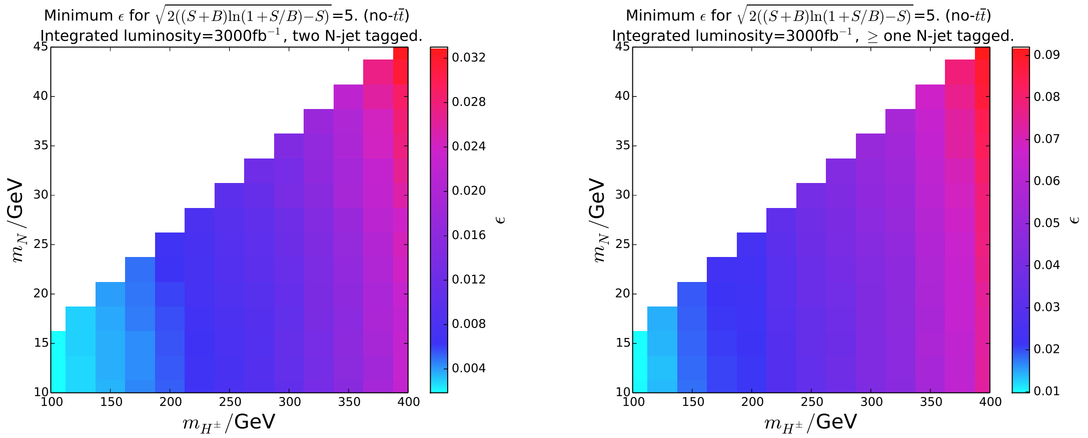

Figure 2: Minimum ε for $\sqrt{2((S+B)\ln(1+S/B)-S)} = 5$. The integrated luminosity is set to 3 ab^{-1} for a 13 TeV LHC. $pp \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu\bar{\nu}$ contributions to the background are not taken into account.

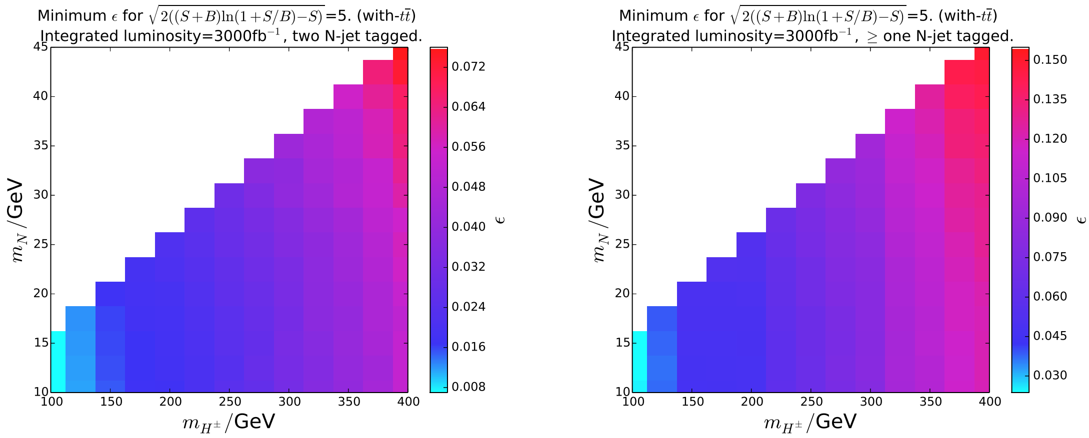

Figure 3: Minimum ε for $\sqrt{2((S+B)\ln(1+S/B)-S)} = 5$. The integrated luminosity is set to 3 ab^{-1} for a 13 TeV LHC. $pp \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu\bar{\nu}$ contributions are included.

In Fig. 2 and Fig. 3, we show the minimum efficiency, ε in the 3 ab^{-1} integrated luminosity at the LHC for the "no-$t\bar{t}$" and $t\bar{t}$ cases respectively, required to obtain a 5σ significance. The ε is defined by multiplying all the branching ratios corresponding to each decay vertex in the process shown in Fig. 1. The left panels in the figures shows the "-2N-jet" and the right panels shows the "-1N-jet" results.

5. Summary

We have simulated the signal and backgrounds at a 13 TeV LHC for the production of a sterile neutrino with the mass $m_N < 100$ GeV within the framework of a ν-THDM. With the muon-jet tagging technique, the QCD jet backgrounds have been eliminated and in some regions of the parameter space, the proposed 3000 ab^{-1} expected at the HL-LHC can be sensitive to the $\varepsilon \lesssim 0.01$ cases. The reducible $pp \to t\bar{t}$ may be crucial if the pile-up effects will not be improved.[11].

References

[1] Georges Aad et al. Search for heavy Majorana neutrinos with the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV. *JHEP*, 07:162, 2015.

[2] P. Abreu et al. Search for neutral heavy leptons produced in Z decays. *Z. Phys.*, C74:57–71, 1997. [Erratum: *Z. Phys.C75,580(1997)]*.

[3] Vardan Khachatryan et al. Search for heavy Majorana neutrinos in $\mu^\pm\mu^\pm+$ jets events in proton-proton collisions at $\sqrt{s} = 8$ TeV. *Phys. Lett.*, B748:144–166, 2015.

[4] Ernest Ma. Naturally small seesaw neutrino mass with no new physics beyond the TeV scale. *Phys. Rev. Lett.*, 86:2502–2504, 2001.

[5] S. Gabriel and S. Nandi. A New two Higgs doublet model. *Phys. Lett.*, B655:141–147, 2007.

[6] Shainen M. Davidson and Heather E. Logan. Dirac neutrinos from a second Higgs doublet. *Phys. Rev.*, D80:095008, 2009.

[7] Enrico Bertuzzo, Yuber F. Perez G., Olcyr Sumensari, and Renata Zukanovich Funchal. Limits on Neutrinophilic Two-Higgs-Doublet Models from Flavor Physics. *JHEP*, 01:018, 2016.

[8] Naoyuki Haba and Koji Tsumura. ν-Two Higgs Doublet Model and its Collider Phenomenology. *JHEP*, 06:068, 2011.

[9] Chao Guo, Shu-Yuan Guo, Zhi-Long Han, Bin Li, and Yi Liao. Hunting for Heavy Majorana Neutrinos with Lepton Number Violating Signatures at LHC. *JHEP*, 04:065, 2017.

[10] G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, Marc Sher, and Joao P. Silva. Theory and phenomenology of two-Higgs-doublet models. *Phys. Rept.*, 516:1–102, 2012.

[11] Yi-Lei Tang. Probing a light sterile neutrino through heavy charged Higgs boson decays at the LHC. *Phys. Rev.*, D98(3):035043, 2018.