Probing the light sterile neutrino decayed from heavy charged Higgs boson on the LHC

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- $m_N \sim$ GeV-TeV, $\frac{m_D}{v} \ll 1 \rightarrow$ small mixings, too small l-N-h, l-N-W/Z couplings.
- Current collider is only sensitive to the mixing parameter $\left(\frac{m_D}{v}\right)^2 > 10^{-5}$.

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- All the SM particles couple with Φ_2, while the neutrino sector couple with Φ_1.
- Φ_1-l-N Yukawa couplings can be large, however $h_{\rm SM}$-l-N can be significantly suppressed by $\frac{1}{\tan\beta}$.

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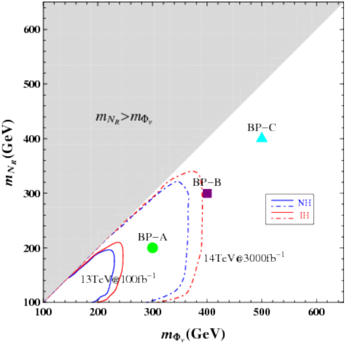

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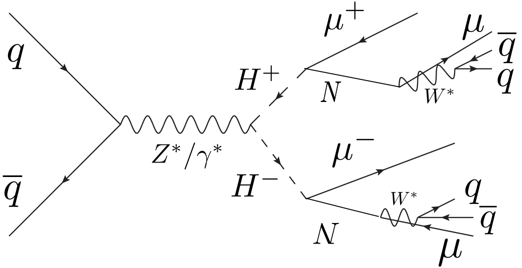

Figure: *N* decays into a bunch of collimated objects, and looks like a jet

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- The distribution of the transverse missing energy depends strongly on the performance of the collider and detector. The performance of the future colliders are unknown currently. Therefore, we show the two results: $t\bar{t}$ background included result, and $t\bar{t}$ background excluded result, indicating two extreme cases that the MET background can/cannot be fully cut out.

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  - two isolated muons with at least two $p_T \geq 50$ GeV and $|\eta| <= 5.0$ jets appear. The isolated muons are selected according to the CMS card settings in the Delphes, and the jets are clustered by the anti-k_T method with the parameter $R = 0.9$ by all the $|\eta| <= 5.0$ particles. The two isolated muons do not participate the jet clustering processes.

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  - The invariant mass between the two muons should be outside the Z-boson mass window $[75, 105]$ GeV. The invariant mass between the two p_T leading jets should be outside the mass window $[60, 130]$ GeV.
  - Group the two muons and two jets into two pairs. Each pair contains one muon and one jet. The absolute value of the invariant mass difference should be the smallest among all grouping possibilities (2 possibilities for each event). The invariant mass of each pair should be within the $[m_{H^\pm} - 50\mathrm{GeV}, \mathrm{m_{H^\pm}} + 50\mathrm{GeV}]$ range.

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  - examining each constituent within the jet. If there is a muon carrying more than 30% of the total jet energy, then this jet is tagged as a "N-jet". The events containing at least one tagged N-jet is suffixed by "-1N-jet", and the ones with two tagged N-jet is suffixed by "-2N-jet".

Result

Only some examples:

$m_{H^\pm}$/GeV	100	150	200	250
$\sigma_{\mathrm{BKG-KIN}}$/fb	1.43e+03	730	301	129
$\sigma_{\mathrm{BKG-1N-jet}}$/fb	5.31	2.58	0.686	0.407
$\sigma_{\mathrm{BKG-2N-jet}}$/fb	0.0106	0.00562	0.00239	0.00103
$m_{H^\pm}$/GeV	300	350	400	
$\sigma_{\mathrm{BKG-KIN}}$/fb	58.2	27.9	13.3	
$\sigma_{\mathrm{BKG-1N-jet}}$/fb	0.169	0.0845	0.0467	
$\sigma_{\mathrm{BKG-2N-jet}}$/fb	0.000413	0.000213	0.00011	

Table: Background cross sections corresponding to each mass window around $m_{H^\pm}$ and different sterile-neutrino-jet number criteria.
$pp \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu\bar{\nu}$ contributions are not included.

$m_{H^\pm}$/GeV	100	150	200	250
$\sigma_{\mathrm{BKG-KIN}}$/fb	2.06e+03	1.2e+03	427	181
$\sigma_{\mathrm{BKG-1N-jet}}$/fb	31.4	17.3	3.56	1.57
$\sigma_{\mathrm{BKG-2N-jet}}$/fb	0.183	0.134	0.0371	0.0152
$m_{H^\pm}$/GeV	300	350	400	
$\sigma_{\mathrm{BKG-KIN}}$/fb	81.2	37.5	17.9	
$\sigma_{\mathrm{BKG-1N-jet}}$/fb	0.612	0.306	0.132	
$\sigma_{\mathrm{BKG-2N-jet}}$/fb	0.00673	0.00283	0.00138	

Table: The same with the Tab. 1. However, $pp \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu\bar{\nu}$ contributions are included.

$m_{H^\pm}$/GeV	100	150	200	250
$\sigma_{pp\to H^+H^-}$/fb	204	47	15.9	6.65
$R_{\mathrm{SIG-KIN}}$	0.154	0.16	0.214	0.206
$R_{\mathrm{SIG-1N-jet}}$	0.102	0.106	0.144	0.136
$R_{\mathrm{SIG-2N-jet}}$	0.0275	0.0284	0.0379	0.0364
$m_{H^\pm}$/GeV	300	350	400	
$\sigma_{pp\to H^+H^-}$/fb	3.17	1.65	0.916	
$R_{\mathrm{SIG-KIN}}$	0.254	0.252	0.296	
$R_{\mathrm{SIG-1N-jet}}$	0.174	0.166	0.204	
$R_{\mathrm{SIG-2N-jet}}$	0.0477	0.0461	0.0576	

Table: The total cross section of $pp \to H^+H^-$ on a 13 TeV proton-proton collider and the cut efficiencies of the signal corresponding to each mass window on $m_{H^\pm}$ and different sterile-neutrino-jet number criteria. The sterile neutrino mass m_N is fixed at 10 GeV.

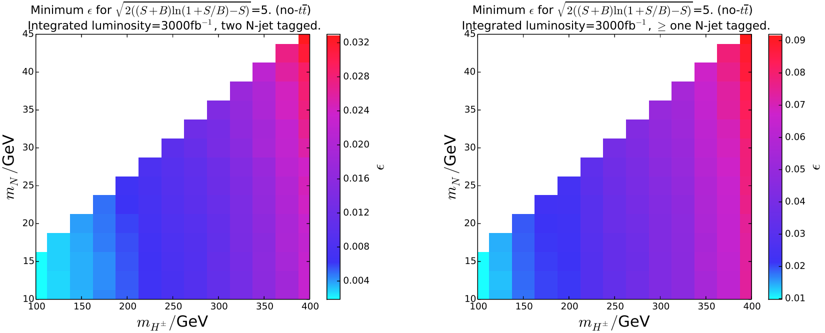
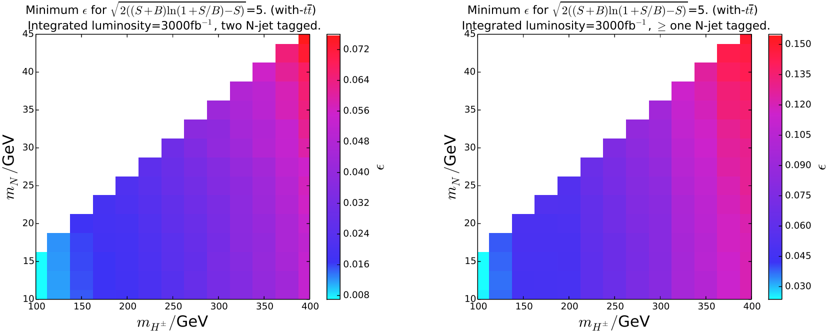


Figure: Minimum ϵ for $\sqrt{2((S+B)\ln(1+S/B)-S)} = 5$. The integrated luminosity is set 3 ab^{-1} on a 13 TeV proton-proton collider. $pp \to t\bar{t} \to \mu^+\mu^- b\bar{b}\nu\bar{\nu}$ contributions are not included.



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- By detecting the μ appeared in the jet, it can help us efficiently discriminate a N-jet from the SM jets.
- Future (HL-)LHC experiment can have a sensitivity of $\epsilon \sim 0.01 - 0.05$ in the ν-THDM within the parameter space $m_N \ll m_H^{\pm}$ and 100 GeV$< m_H^{\pm} < 400$ GeV.