

Signals of New Gauge Bosons in Gauged Two Higgs Doublet Model

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- ***Reference :***

- G2HDM: Gauged Two Higgs Doublet Model (JHEP 1604 (2016) 019)
- Signals of New Gauge Bosons in Gauged Two Higgs Doublet Model (arXiv:1708.02355)

Outline

- Motivation
- Model configuration
- Phenomenology
 - Methodology
 - Z' searches at the LHC
 - Future W' searches
- Summary and Outlook

Motivation from experimental evidents

- After the discovery of Standard Model (SM) Higgs at the LHC, one could ask if there exist other scalar particles.
- What is dark matter (DM) ?
- Where does the tiny neutrino mass come from ?

Motivation from model building

- Two Higgs doublet model (2HDM) is very popular!
 - It is just a simple extension of SM scalar sector.
 - It can provide an additional CP phase, so the general 2HDM is a prototype model to discuss [matter-antimatter asymmetry](#) in the universe.
 - The general 2HDM can also be a prototype model for some [Axion models](#).

Motivation from model building

- Out of many 2HDMs, the inert two Higgs doublet model (IHDM) (Despande and Ma '78) can provide dark matter candidate, with a discrete Z_2 symmetry imposed.
- There is also no FCNC at tree level for IHDM, thanks to this Z_2 symmetry.
- However, the Z_2 symmetry is just imposed by hand without justification !

Motivation from aesthetics

- We embed the two Higgs doublets into a fundamental representation of a new gauge group $SU(2)_H$.
- This new gauge group $SU(2)_H$ to align 2HDM as new doublet is used to replace the artificial discrete Z_2 symmetry.

Some Highlights of G2HDM

- New gauge group $SU(2)_H \otimes U(1)_X$
- Symmetry breaking of $SU(2)_L$ is triggered or induced by $SU(2)_H$ breaking
- One of the Higgs doublet (H_2) can be *inert* and may play the role of dark matter, whose stability is protected by gauge invariance
- Unlike Left-Right symmetric models, the complex vector fields $W'^{\mu}(p,m)$ are *electrically neutral*
- Neutrinos would be *Dirac fermions* unless additional lepton number violation terms are involved.

Model configuration – Particle Content

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Matter Fields	$SU(3)_C$	$SU(2)_L$	$SU(2)_H$	$U(1)_Y$	$U(1)_X$
$H = (H_1, H_2)^T$	1	2	2	1/2	1
$\Phi_H = (\Phi_1, \Phi_2)^T$	1	1	2	0	1
$\Delta_H = \begin{pmatrix} \Delta_{3/2} & \Delta_p/\sqrt{2} \\ \Delta_m/\sqrt{2} & -\Delta_{3/2} \end{pmatrix}$	1	1	3	0	0
$Q_L = (u_L, d_L)^T$	3	2	1	1/6	0
$U_R = (u_R, u_R^H)^T$	3	1	2	2/3	1
$D_R = (d_R^H, d_R)^T$	3	1	2	-1/3	-1
u_L^H	3	1	1	2/3	0
d_L^H	3	1	1	-1/3	0
$L_L = (\nu_L, e_L)^T$	1	2	1	-1/2	0
$N_R = (\nu_R, \nu_R^H)^T$	1	1	2	0	1
$E_R = (e_R^H, e_R)^T$	1	1	2	-1	-1
ν_L^H	1	1	1	0	0
e_L^H	1	1	1	-1	0

❖ H_1 and H_2 are embedded into a $SU(2)_H$ doublet

❖ $SU(2)_L$ doublet fermions are singlets under $SU(2)_H$ while $SU(2)_L$ singlet fermions pair up with heavy fermions as $SU(2)_H$ doublets

❖ VEVs of Φ_H and Δ_H give a mass to $SU(2)_H$ gauge bosons

❖ VEV of Φ_H gives a Dirac mass to heavy fermions

VEV of Δ_H give mass to charged Higgs

TABLE I. Matter field contents and their quantum number assignments in G2HDM.

Model configuration – Higgs potential

$$V(H, \Delta_H, \Phi_H) = V(H) + V(\Phi_H) + V(\Delta_H) + V_{\text{mix}}(H, \Delta_H, \Phi_H)$$

$$V(H) = \mu_H^2 H^\dagger H + \lambda_H (H^\dagger H)^2 ,$$

$$= \mu_H^2 (H_1^\dagger H_1 + H_2^\dagger H_2) + \lambda_H (H_1^\dagger H_1 + H_2^\dagger H_2)^2 ,$$

$$V(\Phi_H) = \mu_\Phi^2 \Phi_H^\dagger \Phi_H + \lambda_\Phi (\Phi_H^\dagger \Phi_H)^2 ,$$

$$= \mu_\Phi^2 (\Phi_1^* \Phi_1 + \Phi_2^* \Phi_2) + \lambda_\Phi (\Phi_1^* \Phi_1 + \Phi_2^* \Phi_2)^2 ,$$

$$V(\Delta_H) = -\mu_\Delta^2 \text{Tr}(\Delta_H^\dagger \Delta_H) + \lambda_\Delta (\text{Tr}(\Delta_H^\dagger \Delta_H))^2 ,$$

$$= -\mu_\Delta^2 \left(\frac{1}{2} \Delta_3^2 + \Delta_p \Delta_m \right) + \lambda_\Delta \left(\frac{1}{2} \Delta_3^2 + \Delta_p \Delta_m \right)^2 ,$$

$$\Delta_H = \begin{pmatrix} \Delta_3/2 & \Delta_p/\sqrt{2} \\ \Delta_m/\sqrt{2} & -\Delta_3/2 \end{pmatrix}$$

$$\Delta_m = (\Delta_p)^* \text{ and } (\Delta_3)^* = \Delta_3$$

Model configuration – Higgs potential

$$\begin{aligned}
 V_{\text{mix}}(H, \Delta_H, \Phi_H) = & + M_{H\Delta} \left(H^\dagger \Delta_H H \right) - M_{\Phi\Delta} \left(\Phi_H^\dagger \Delta_H \Phi_H \right) \\
 & + \lambda_{H\Delta} \left(H^\dagger H \right) \text{Tr} \left(\Delta_H^\dagger \Delta_H \right) + \lambda_{H\Phi} \left(H^\dagger H \right) \left(\Phi_H^\dagger \Phi_H \right) \\
 & + \lambda_{\Phi\Delta} \left(\Phi_H^\dagger \Phi_H \right) \text{Tr} \left(\Delta_H^\dagger \Delta_H \right) , \\
 = & \boxed{+ M_{H\Delta} \left(\frac{1}{\sqrt{2}} H_1^\dagger H_2 \Delta_p + \frac{1}{2} H_1^\dagger H_1 \Delta_3 + \frac{1}{\sqrt{2}} H_2^\dagger H_1 \Delta_m - \frac{1}{2} H_2^\dagger H_2 \Delta_3 \right)} \\
 & \boxed{- M_{\Phi\Delta} \left(\frac{1}{\sqrt{2}} \Phi_1^* \Phi_2 \Delta_p + \frac{1}{2} \Phi_1^* \Phi_1 \Delta_3 + \frac{1}{\sqrt{2}} \Phi_2^* \Phi_1 \Delta_m - \frac{1}{2} \Phi_2^* \Phi_2 \Delta_3 \right)} \\
 & \boxed{+ \lambda_{H\Delta} \left(H_1^\dagger H_1 + H_2^\dagger H_2 \right) \left(\frac{1}{2} \Delta_3^2 + \Delta_p \Delta_m \right)} \\
 & \boxed{+ \lambda_{H\Phi} \left(H_1^\dagger H_1 + H_2^\dagger H_2 \right) \left(\Phi_1^* \Phi_1 + \Phi_2^* \Phi_2 \right)} \\
 & \boxed{+ \lambda_{\Phi\Delta} \left(\Phi_1^* \Phi_1 + \Phi_2^* \Phi_2 \right) \left(\frac{1}{2} \Delta_3^2 + \Delta_p \Delta_m \right) ,}
 \end{aligned}$$

Note that term like $\Phi_H^T \Delta_H \Phi_H$ is $SU(2)_H$ invariant but forbidden by $U(1)_X$!

Model configuration – Symmetry Breaking

$$H_1 = \begin{pmatrix} G^+ \\ \frac{v+h}{\sqrt{2}} + i\frac{G^0}{\sqrt{2}} \end{pmatrix} \quad \Phi_H = \begin{pmatrix} G_H^p \\ \frac{v_\Phi + \phi_2}{\sqrt{2}} + i\frac{G_H^0}{\sqrt{2}} \end{pmatrix} \quad \Delta_H = \begin{pmatrix} \frac{-v_\Delta + \delta_3}{2} & \frac{1}{\sqrt{2}}\Delta_p \\ \frac{1}{\sqrt{2}}\Delta_m & \frac{v_\Delta - \delta_3}{2} \end{pmatrix}$$

- If $\langle \Delta_3 \rangle = -v_\Delta \neq 0$, the quadratic terms for H_1 and H_2 read:

$$\mu_H^2 \mp \frac{1}{2}M_{H\Delta} \cdot v_\Delta + \frac{1}{2}\lambda_{H\Delta} \cdot v_\Delta^2 + \frac{1}{2}\lambda_{H\Phi} \cdot v_\Phi^2$$

- If $\langle \Delta_3 \rangle = -v_\Delta \neq 0$, the quadratic terms for Φ_1 and Φ_2 read:

$$\mu_\Phi^2 \pm \frac{1}{2}M_{\Phi\Delta} \cdot v_\Delta + \frac{1}{2}\lambda_{\Phi\Delta} \cdot v_\Delta^2 + \frac{1}{2}\lambda_{H\Phi} \cdot v^2$$

- Therefore, $SU(2)_H$ spontaneous symmetry breaking can trigger $SU(2)_L$ symmetry breaking even if μ_H^2 is positive

Model configuration – Yukawa Couplings

- The SM quarks and leptons obtain their masses from the vev of H_1 via the Yukawa couplings

$$\mathcal{L}_{\text{Yuk}} \supset + y_d \bar{Q}_L (d_R^H H_2 - d_R H_1) - y_u \bar{Q}_L (u_R \tilde{H}_1 + u_R^H \tilde{H}_2) \\ + y_e \bar{L}_L (e_R^H H_2 - e_R H_1) - y_\nu \bar{L}_L (\nu_R \tilde{H}_1 + \nu_R^H \tilde{H}_2) + \text{H.c.},$$

$$\text{with } \tilde{H}_{1,2} = i\tau_2 H_{1,2}^*.$$

- The corresponding $SU(2)_H$ invariant Yukawa couplings are

$$\mathcal{L}_{\text{Yuk}} \supset - y'_d \bar{d}_L^H (d_R^H \Phi_2 - d_R \Phi_1) - y'_u \bar{u}_L^H (u_R \Phi_1^* + u_R^H \Phi_2^*) \\ - y'_e \bar{e}_L^H (e_R^H \Phi_2 - e_R \Phi_1) - y'_\nu \bar{\nu}_L^H (\nu_R \Phi_1^* + \nu_R^H \Phi_2^*) + \text{H.c.}.$$

Model configuration – Gauge boson

- The SU(2)_H gauge boson mass spectrum is
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$$m_{W'^{(p,m)}}^2 = \frac{1}{4} g_H^2 (v^2 + v_\Phi^2 + 4v_\Delta^2) ,$$
$$m_{Z'}^2 = \frac{1}{4} g_H^2 (v^2 + v_\Phi^2) ,$$

where $(v/\sqrt{2}, v_\Phi/\sqrt{2}, -v_\Delta) = (\langle H_1^0 \rangle, \langle \Phi_2 \rangle, \langle \Delta_3 \rangle)$. Note that $W'^{(p,m)}$ is always heavier than Z' in G2HDM.

Model configuration – Gauge boson

As the SM right-handed fermions as well as the new fermions are charged under $SU(2)_H$, they couple to the $W'^{(p,m)}$ and Z' bosons. The relevant gauge interactions without the $Z - Z'$ mixing read

$$\mathcal{L} \supset \mathcal{L}(W) + \mathcal{L}(\gamma) + \Delta\mathcal{L}. \quad (4)$$

Here $\mathcal{L}(W)$ and $\mathcal{L}(\gamma)$ refer to the charged current mediated by the W boson and the electric current by the photon γ respectively,

$$\begin{aligned} \mathcal{L}(\gamma) &= \sum_f Q_f e \bar{f} \gamma^\mu f A_\mu, \\ \mathcal{L}(W) &= \frac{g}{\sqrt{2}} (\bar{\nu}_L \gamma^\mu e_L + \bar{u}_L \gamma^\mu d_L) W_\mu^+ + \text{H.c.}, \end{aligned} \quad (5)$$

where Q_f is the corresponding fermion electric charge in units of e . $\Delta\mathcal{L}$ represents (electrically) neutral current interactions of the massive bosons, Z , Z' and $W'^{(p,m)}$ (for demonstration, only the lepton sector is shown but it is straightforward to include the quark sector):

$$\Delta\mathcal{L} = \mathcal{L}(Z) + \mathcal{L}(Z') + \mathcal{L}(W'^{(p,m)}), \quad (6)$$

Model configuration – Gauge boson

where

$$\begin{aligned}\mathcal{L}(Z) &= \frac{g}{\cos \theta_w} J_Z^\mu Z_\mu , \\ \mathcal{L}(Z') &= g_H J_{W'3}^\mu Z'_\mu , \\ \mathcal{L}(W'^{(p,m)}) &= \frac{1}{\sqrt{2}} g_H (J_{W'm}^\mu W'^p_\mu + \text{H.c.}) ,\end{aligned}$$

and

$$\begin{aligned}J_Z^\mu &= \sum_{f=e,\nu} (\bar{f}_L \gamma^\mu (I_3 - Q_f \sin^2 \theta_w) f_L + \bar{f}_R \gamma^\mu (-Q_f \sin^2 \theta_w) f_R) + \sum_e \bar{e}_R^H \gamma^\mu (\sin^2 \theta_w) e_R^H , \\ J_{W'3}^\mu &= \sum_{f=N_R, E_R} \bar{f}_R \gamma^\mu (I_3^H) f_R , \\ J_{W'm}^\mu &= \sum_e \left(\bar{e}_R^H \gamma^\mu e_R + \bar{\nu}_{eR} \gamma^\mu \nu_{eR}^H \right) ,\end{aligned}\tag{8}$$

where I_3 (I_3^H) is the third generator of $SU(2)_L$ ($SU(2)_H$), and $\sin \theta_w$ is the Weinberg angle.

Phenomenology – Methodology

- There are **five** relevant mass scales in our analysis
- The mass of dark matter particle H_2^{0*} : m_D
- The mass of heavy leptons
- $L^H = (e^H, \mu^H, \tau^H)$ $\nu^H = (\nu_e^H, \nu_\mu^H, \nu_\tau^H)$.
- The mass of heavy quarks
- $Q^H = (u^H, d^H, c^H, s^H, t^H, b^H)$,
- Two heavy gauge bosons $W'^{(p,m)}$ and Z' .

Methodology – Spectrum-A

Spectrum-A: Heavy and decoupled new quark scenario.


$$m_{Q^H} = m_{Z'} + 1 \text{ TeV}$$

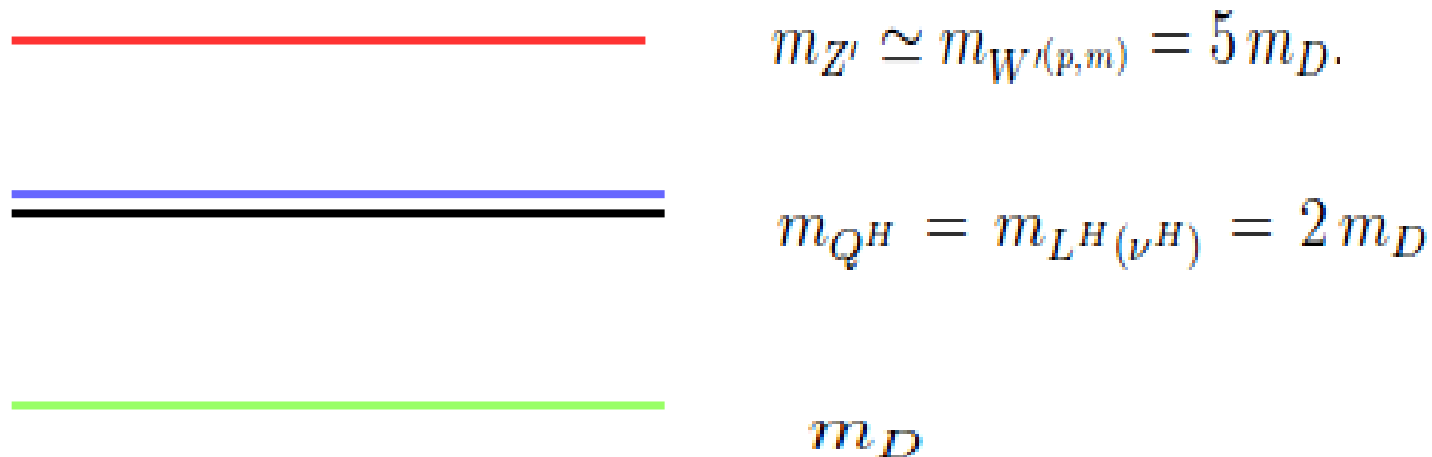

$$m_{Z'} \simeq m_{W'_{(p,m)}} = 5 m_D.$$


$$m_{L^H(\nu^H)} = 2 m_D$$


$$m_D$$

Methodology – Spectrum-B

Spectrum-B: Light new quark scenario.



Methodology – Branching ratios

TABLE II. Branching ratios for different decay modes of Z' with $1.5 \leq m_{Z'} \leq 3$ TeV. Here Q denotes 6 quark flavors (u, d, c, s, t, b) and L (ν) represents 3 lepton flavors (e (ν_e), μ (ν_μ), τ (ν_τ)).

Z'	$BR(Q\bar{Q})$	$BR(L^+L^-)$	$BR(\nu\bar{\nu})$	$BR(Q^H\bar{Q}^H)$	$BR(L^H\bar{L}^H)$	$BR(\nu^H\bar{\nu}^H)$
Spectrum-A	66.52%	11.13%	11.13%	–	5.61%	5.61%
Spectrum-B	49.84%	8.31%	8.31%	25.14%	4.20%	4.20%

TABLE III. Branching ratios for different decay modes of $W'^{(p,m)}$ with $1.5 \leq m_{W'^{(p,m)}} \leq 3$ TeV.

$W'^{(p,m)}$	$BR(Q^H\bar{Q}, Q\bar{Q}^H)$	$BR(L^H\bar{L}, L\bar{L}^H)$	$BR(\nu^H\bar{\nu}, \nu\bar{\nu}^H)$
Spectrum-A	–	50%	50%
Spectrum-B	74.96%	12.52%	12.52%

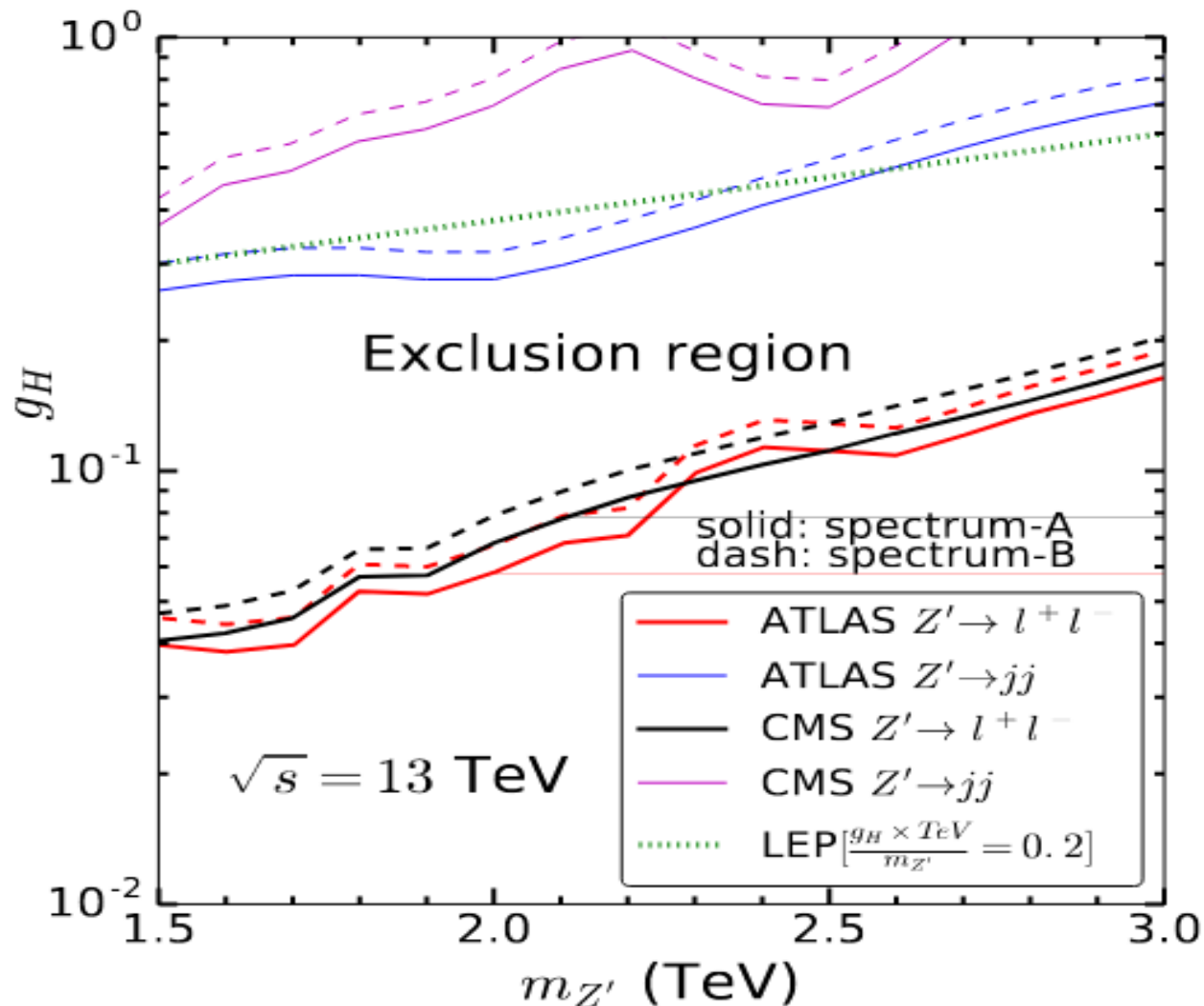
Methodology – Search Strategy

In both scenarios, the new heavy fermions are kinematically allowed to be produced by either Z' or $W'^{(p,m)}$ decays. As a result, we propose searches for the new fermions as follows.†

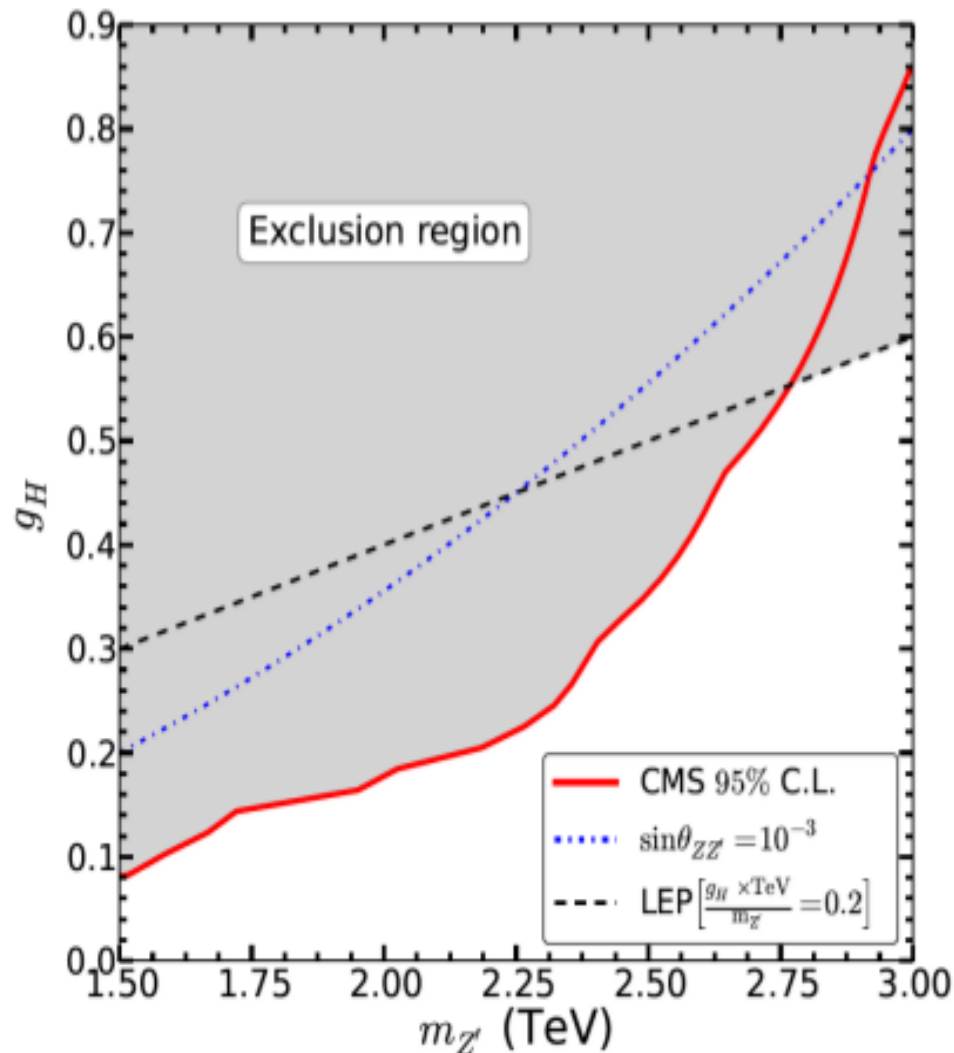
- For Spectrum-A, the heavy charged leptons can be produced via $pp \rightarrow Z' \rightarrow L^H \bar{L}^H$ and $pp \rightarrow W'^p W'^m \rightarrow \bar{L}^H L \bar{L} L^H$, and the corresponding final states will be (1) $2l + \cancel{E}_T$, (2) $2\tau + \cancel{E}_T$, (3) $4l + \cancel{E}_T$, (4) $2l + 2\tau + \cancel{E}_T$, and (5) $4\tau + \cancel{E}_T$.
- For Spectrum-B, the new quark pairs can also be on-shell produced through $pp \rightarrow Z' \rightarrow Q^H \bar{Q}^H$, and thus the following final states (1) $2j + \cancel{E}_T$, (2) $2b + \cancel{E}_T$, and (3) $2t + \cancel{E}_T$ will be considered. These processes are relevant to the dijet plus missing transverse energy searches for Z' . Needless to say, the continuum contributions from QCD to the new quark pair production should be taken into account.

Phenomenology – Z' searches at the LHC

A. Constraints on Z' from current dilepton and dijet searches



Phenomenology – Z' searches at the LHC



- The red line comes from direct Z' resonance searches (1412.6302)
- The black dashed line comes from LEP constraints on the cross-section of $e^+e^- \rightarrow e^+e^-$ (hep-ex/0312023)
 $\Rightarrow \underline{v_\Phi > 10 \text{ TeV}}$
- The blue dotted line comes from EWPT data and collider constraints on the Z-Z' mixing (0906.2435, 1406.6776)

$$m_{Z'} \simeq g_H \frac{v_\Phi}{2}$$

Phenomenology – Z' searches at the LHC

- **B. Z' exotic decays into heavy fermions**
- Compare the exotic decay modes of G2HDM with MSSM :
- For the MSSM slepton searches at the LHC, the major process is $2l + \cancel{E}_T$:
- $$pp \rightarrow \gamma/Z \rightarrow \tilde{l}^+ \tilde{l}^- \rightarrow 2l + \cancel{E}_T$$
- Similarly, in G2HDM decays of Z' into a pair of exotic fermions can also lead to the same final states:
$$pp \rightarrow Z' \rightarrow l^H \bar{l}^H \rightarrow 2l + \cancel{E}_T$$
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Phenomenology – Z' searches at the LHC

Spectrum-A': $2 m_{LH} < m_{Z'} < 2 m_{QH}$ and $m_{\text{DM}} = 50$ GeV.

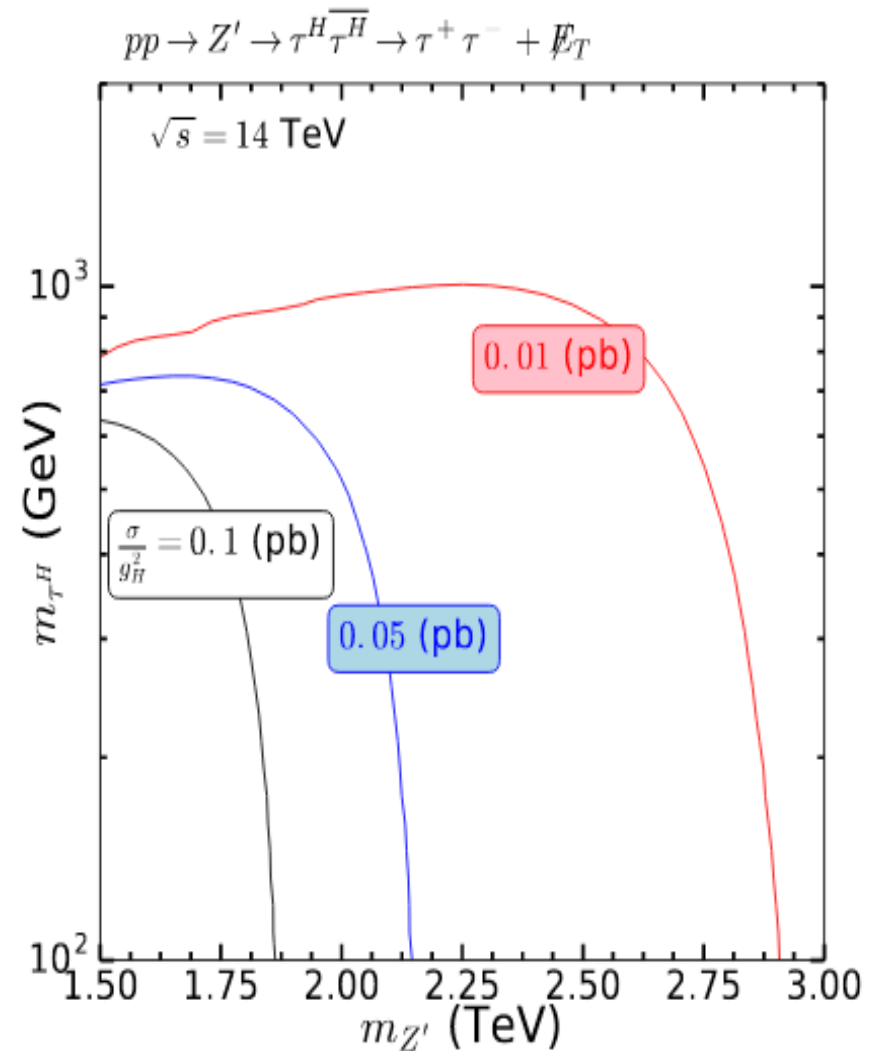
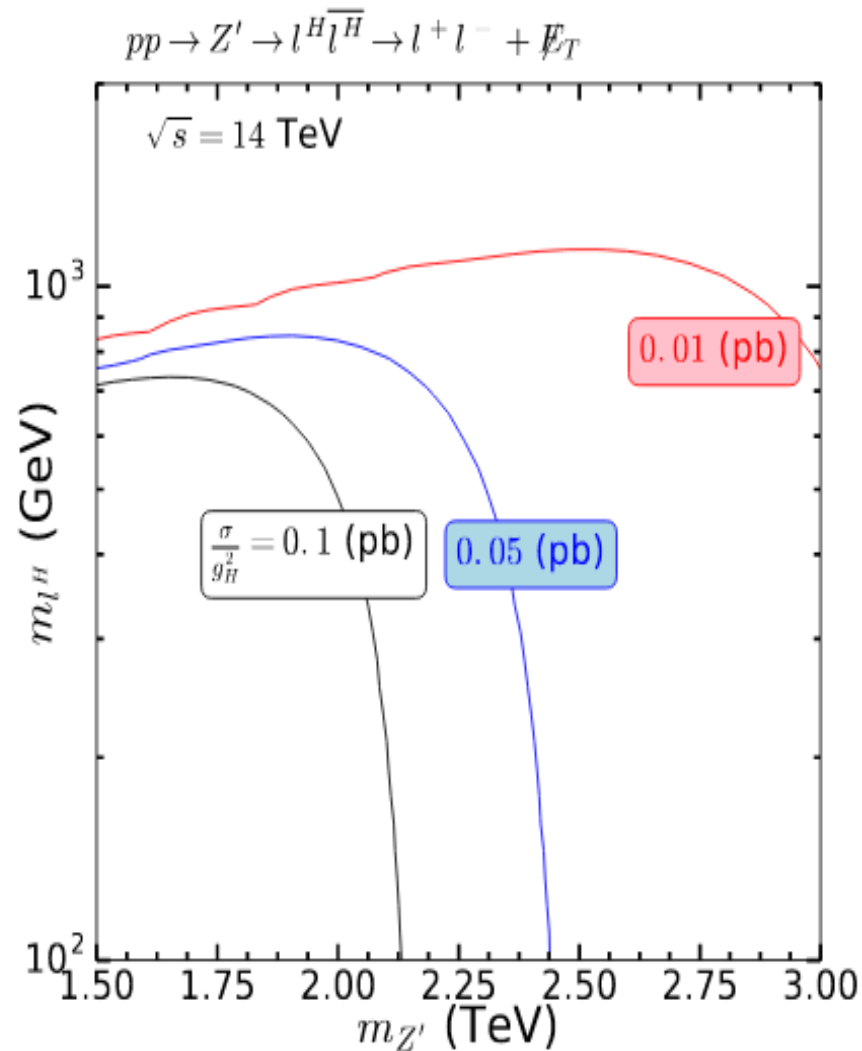
We concentrate on the following two channels,

$$pp \rightarrow Z' \rightarrow l^H \bar{l}^H \rightarrow 2l + \cancel{E}_T,$$

$$pp \rightarrow Z' \rightarrow \tau^H \bar{\tau}^H \rightarrow 2\tau + \cancel{E}_T,$$

where $l^H = (e^H, \mu^H)$, and $l = (e, \mu)$.

Phenomenology – Z' searches at the LHC



Phenomenology – Z' searches at the LHC

- Spectrum-B': $2 m_{(L^H, Q^H)} < m_{Z'}$ and $m_{\text{DM}} = 50$ GeV.

For the new quarks, they can always be pair produced dominantly by strong processes, like $q\bar{q}, gg \rightarrow Q^H \overline{Q^H}$ via s -channel gluon exchange or t -channel heavy exotic quark exchange. The cross sections for the strong processes

$$pp \rightarrow j^H \overline{j^H} \rightarrow 2j + \cancel{E}_T, \quad (13)$$

$$pp \rightarrow b^H \overline{b^H} \rightarrow 2b + \cancel{E}_T, \quad (14)$$

$$pp \rightarrow t^H \overline{t^H} \rightarrow 2t + \cancel{E}_T, \quad (15)$$

where $j^H = (u^H, d^H, c^H, s^H)$ and $j = (u, d, c, s)$ are computed.

Phenomenology – Z' searches at the LHC

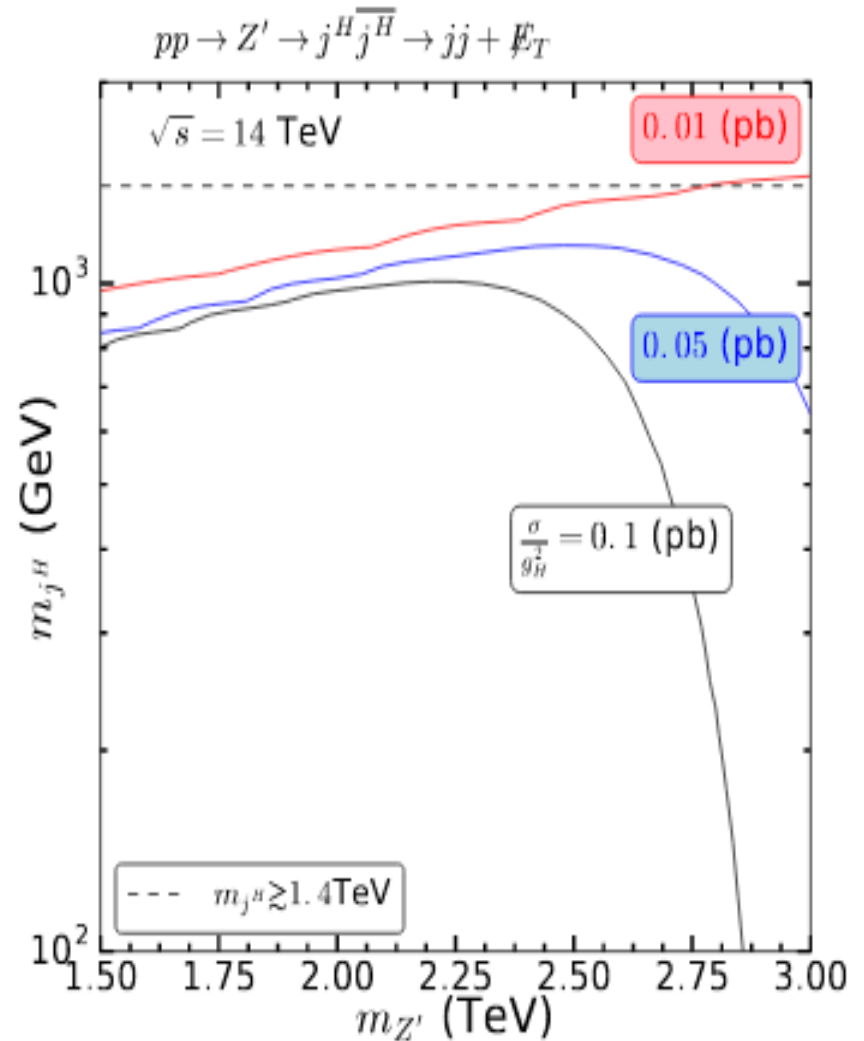
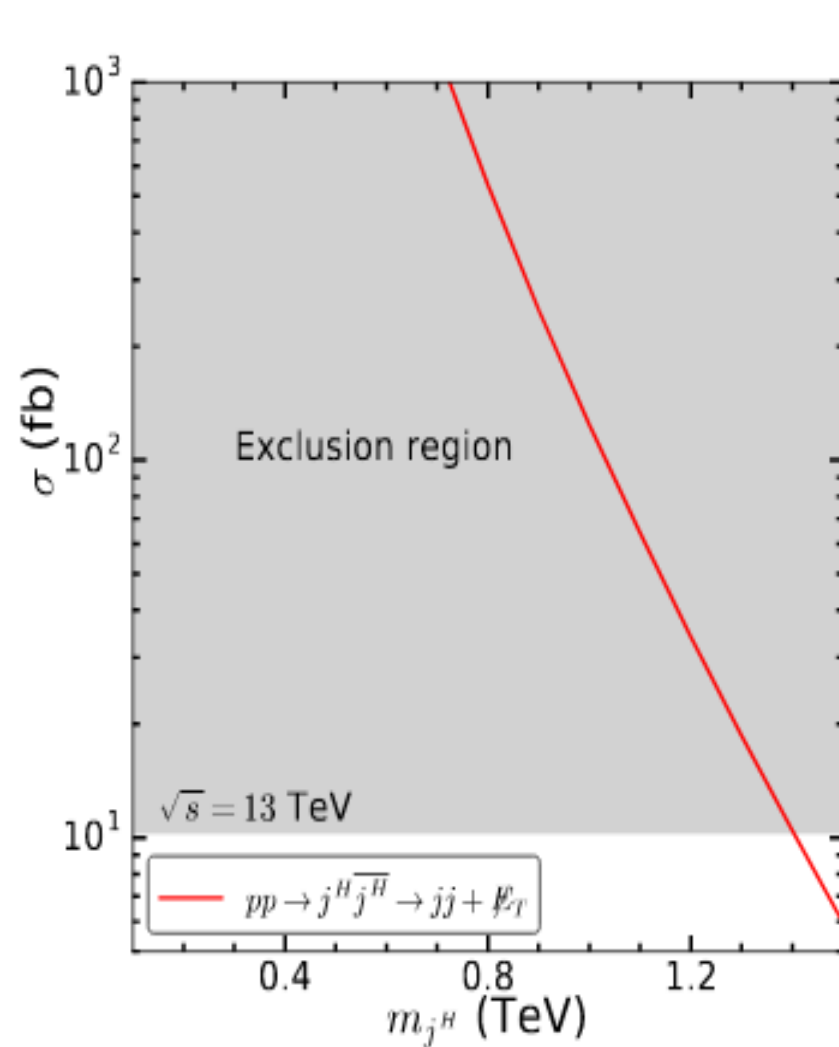
On the other hand, if $m_{Z'} > 2m_{Q_H}$, three subdominant but nevertheless important processes have to be included:

$$pp \rightarrow Z' \rightarrow j^H \overline{j^H} \rightarrow 2j + \cancel{E}_T, \quad (16)$$

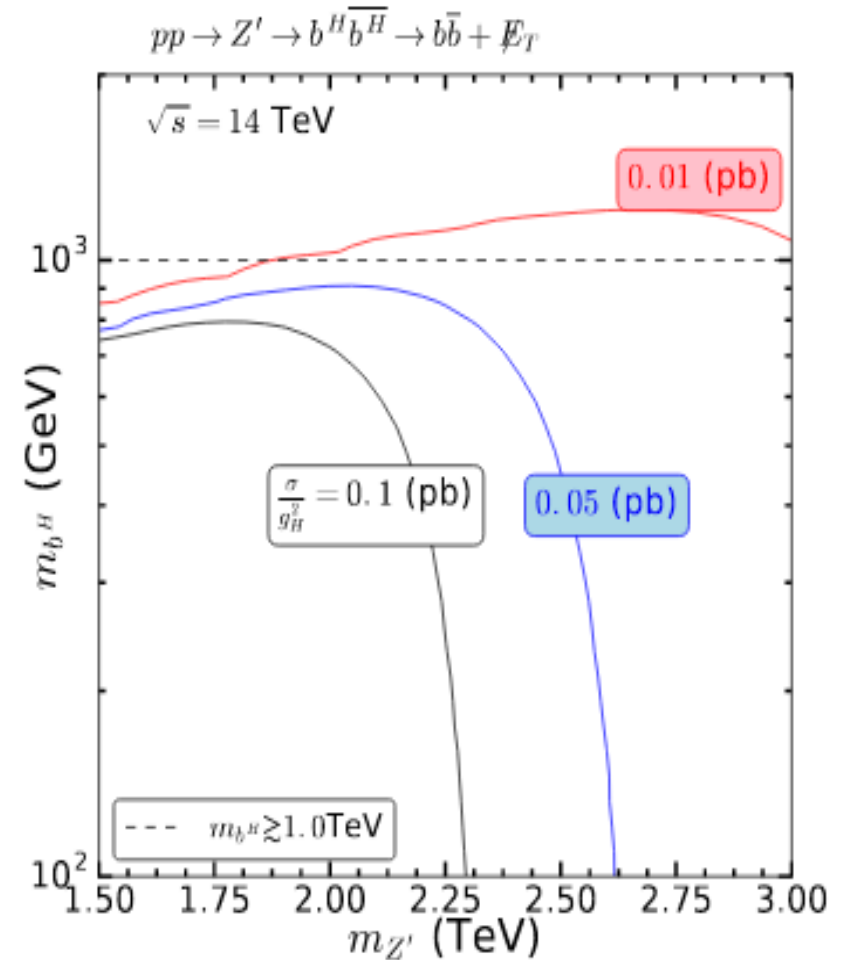
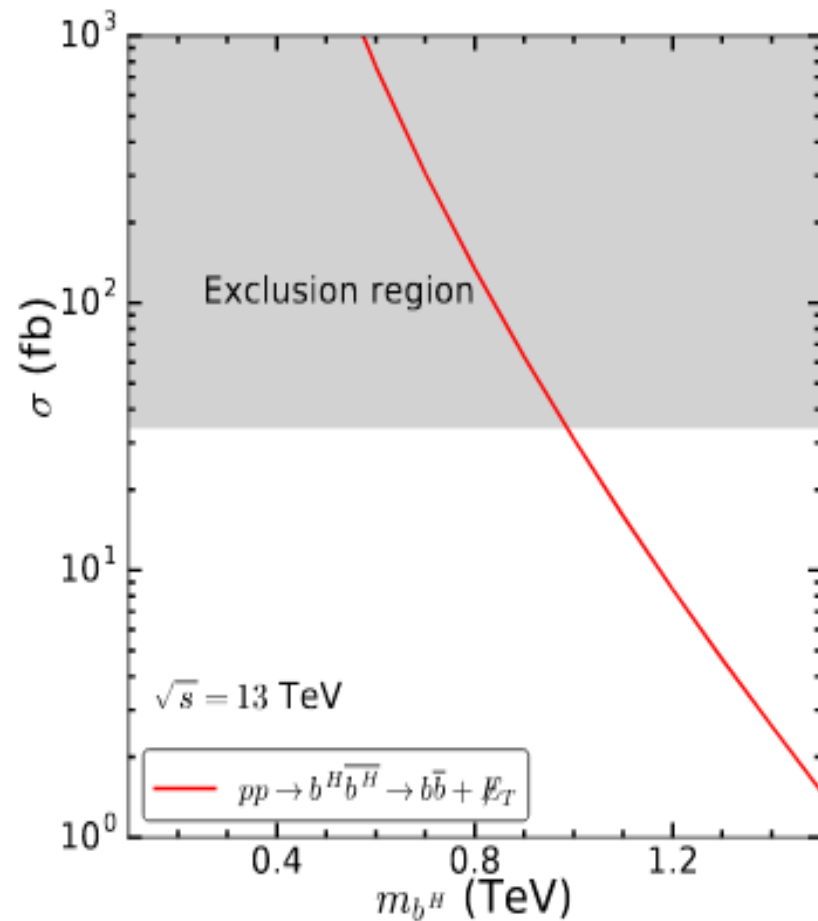
$$pp \rightarrow Z' \rightarrow b^H \overline{b^H} \rightarrow 2b + \cancel{E}_T, \quad (17)$$

$$pp \rightarrow Z' \rightarrow t^H \overline{t^H} \rightarrow 2t + \cancel{E}_T. \quad (18)$$

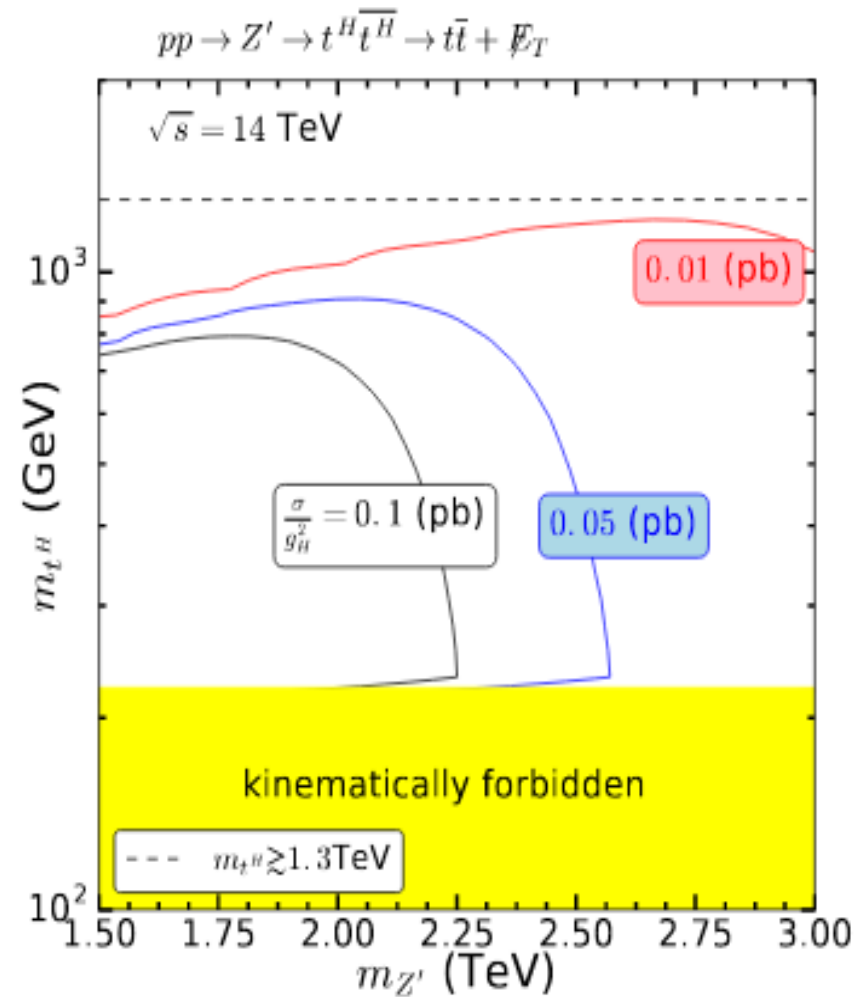
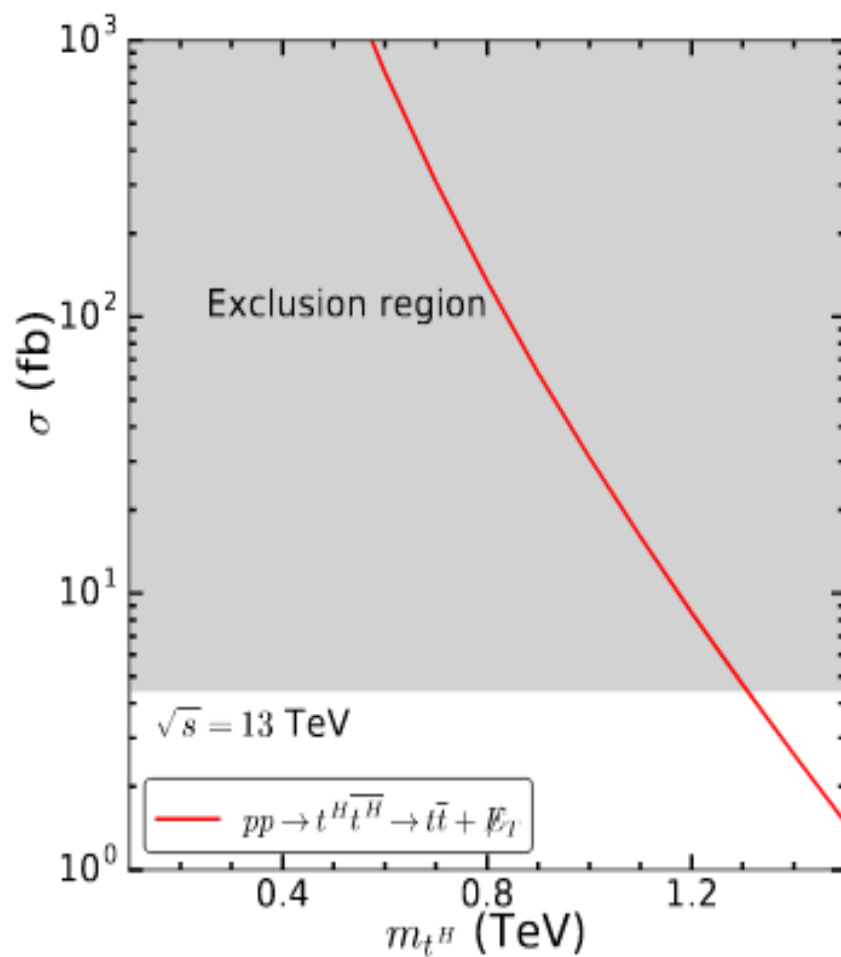
Phenomenology – Z' searches at the LHC



Phenomenology – Z' searches at the LHC



Phenomenology – Z' searches at the LHC



Phenomenology – Future W' searches

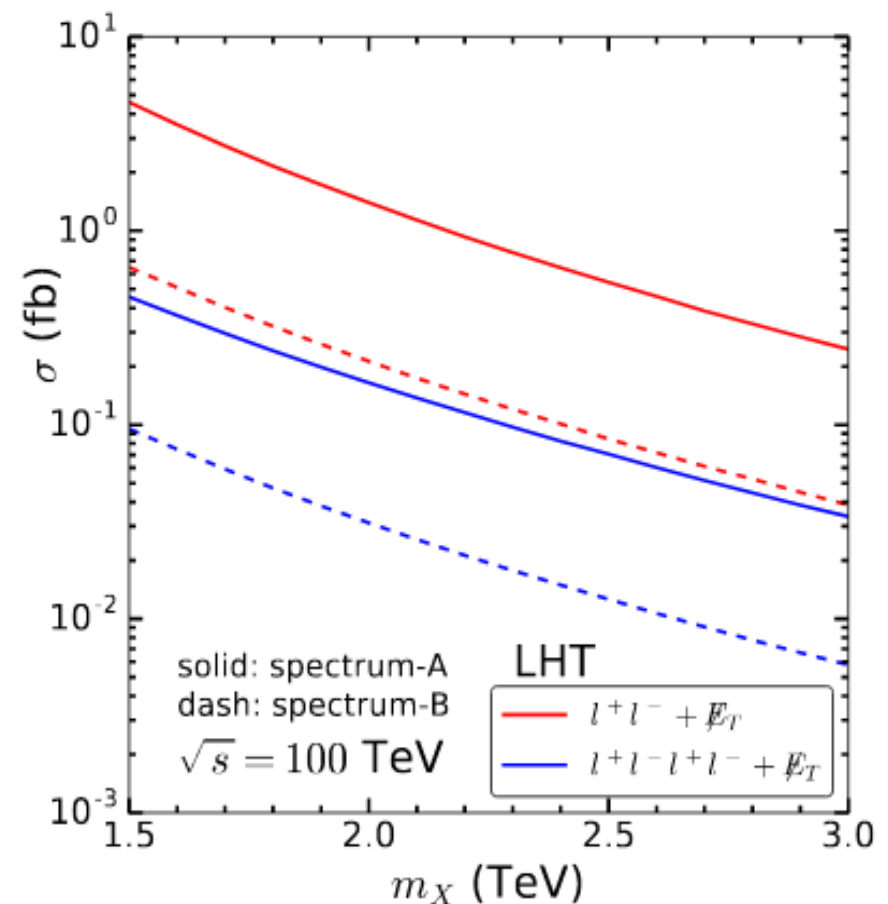
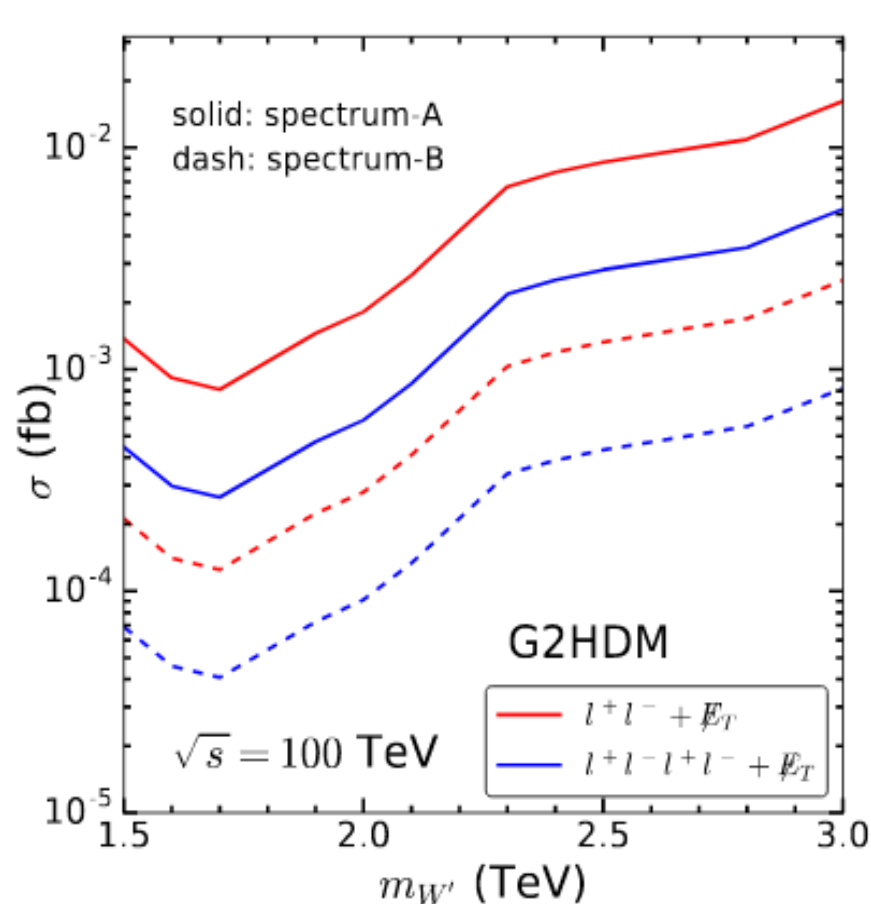
Two search channels: $2l + \cancel{E}_T$ and $4l + \cancel{E}_T$

Model	Production	Prompt Decay	Final State	Signal
$l^+l^- + \cancel{E}_T$				
G2HDM	$pp \rightarrow W'^p W'^m$	$(\bar{l}l^H)(\bar{\nu}^H \nu) + \text{c.c.}$	$(\bar{l}l H_2^0)(\bar{\nu} H_2^{0*} \nu)$	$l^+l^- + \{\nu \bar{\nu} H_2^0 H_2^{0*}\}$
LHT	$pp \rightarrow W_H^+ W_H^-$	$(l_H^+ \nu)(\bar{\nu}_H l^-) + \text{c.c.}$	$(l^+ A_H \nu)(\bar{\nu} A_H l^-)$	$l^+l^- + \{\nu \bar{\nu} A_H A_H\}$
LHT	$pp \rightarrow Z_H Z_H$	$(l_H^\pm l^\mp)(\bar{\nu}_H \nu)$	$(l^\pm A_H l^\mp)(\bar{\nu} A_H \nu)$	$l^+l^- + \{\nu \bar{\nu} A_H A_H\}$
$l^+l^-l^+l^- + \cancel{E}_T$				
G2HDM	$pp \rightarrow W'^p W'^m$	$(\bar{l}l^H)(\bar{l}l^H)$	$(\bar{l}l H_2^0)(\bar{l}l H_2^{0*})$	$l^+l^-l^+l^- + \{H_2^0 H_2^{0*}\}$
LHT	$pp \rightarrow Z_H Z_H$	$(l_H^\pm l^\mp)(l_H^\pm l^\mp)$	$(l^\pm A_H l^\mp)(l^\pm A_H l^\mp)$	$l^+l^-l^+l^- + \{A_H A_H\}$

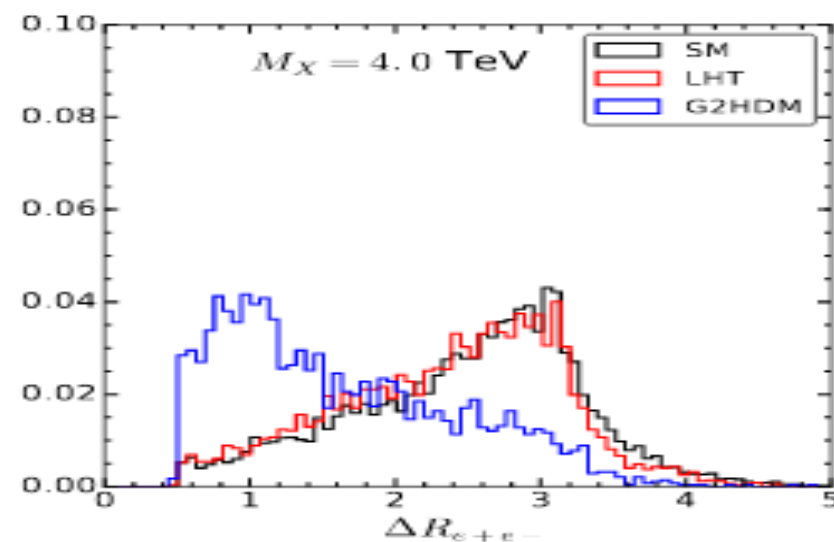
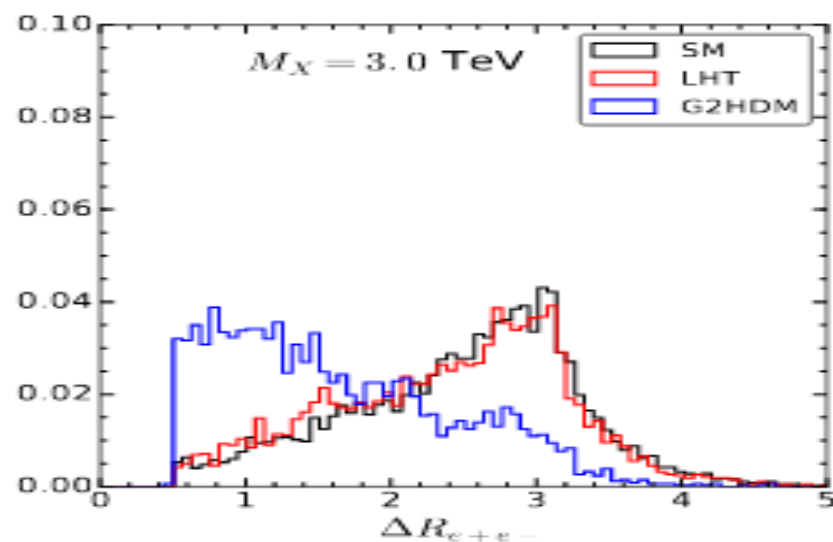
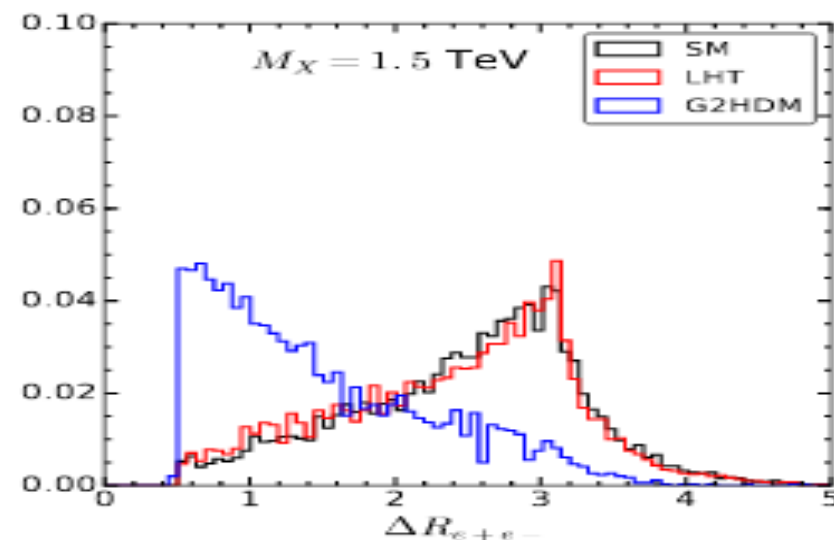
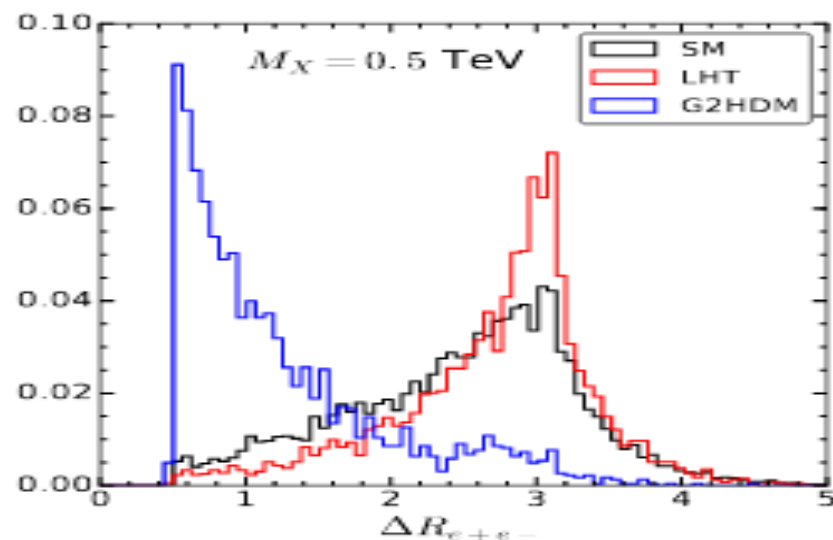
TABLE V. List of the production and leptonic decay channels for the exotic gauge bosons in G2HDM and LHT.

Phenomenology – Future W' searches

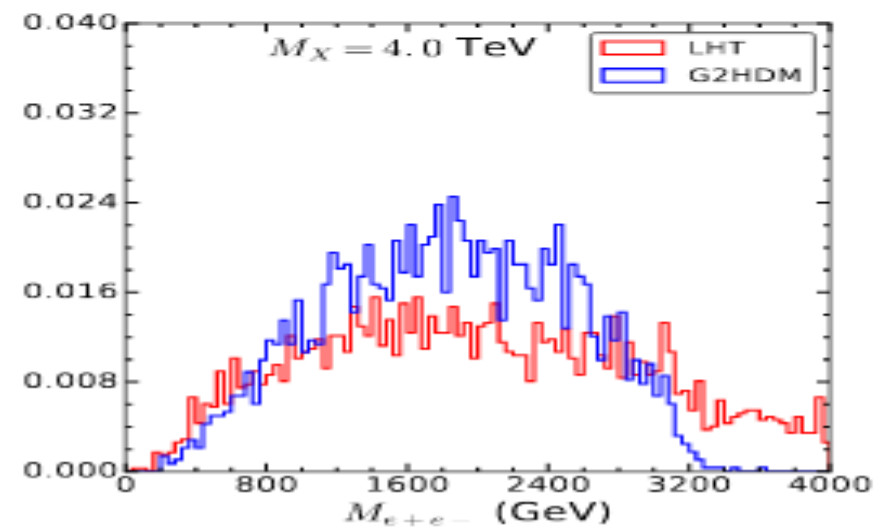
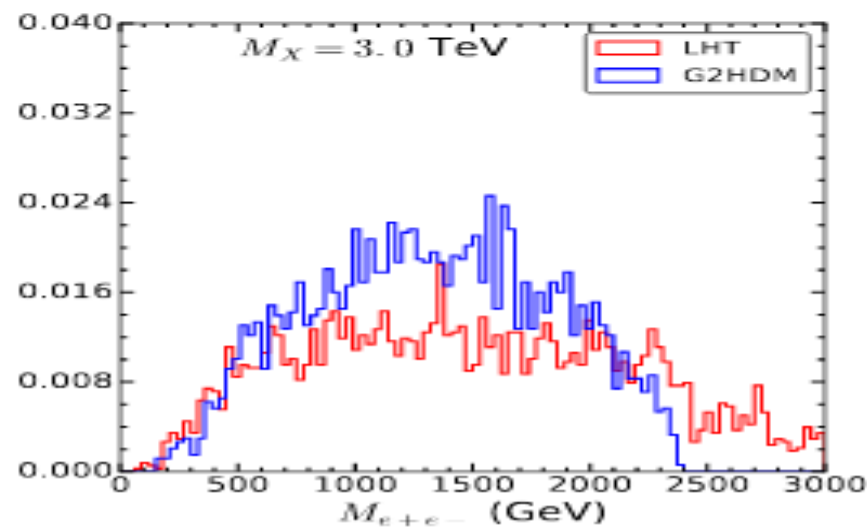
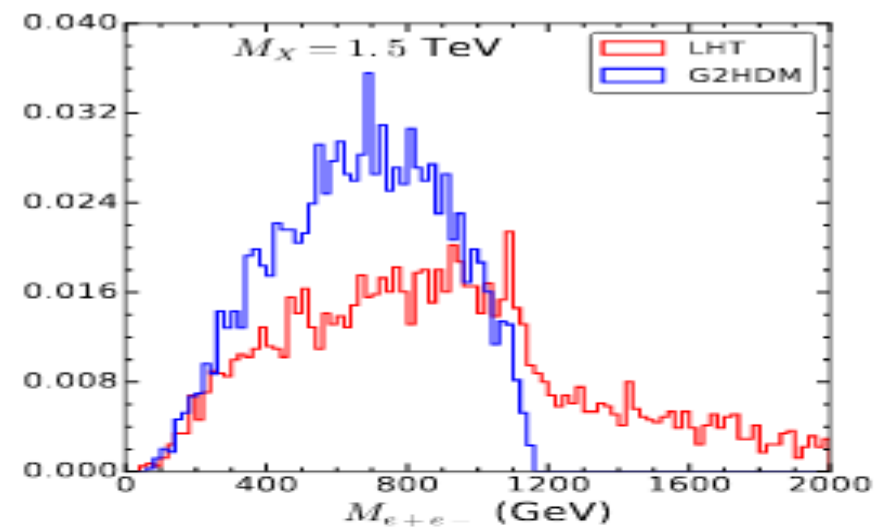
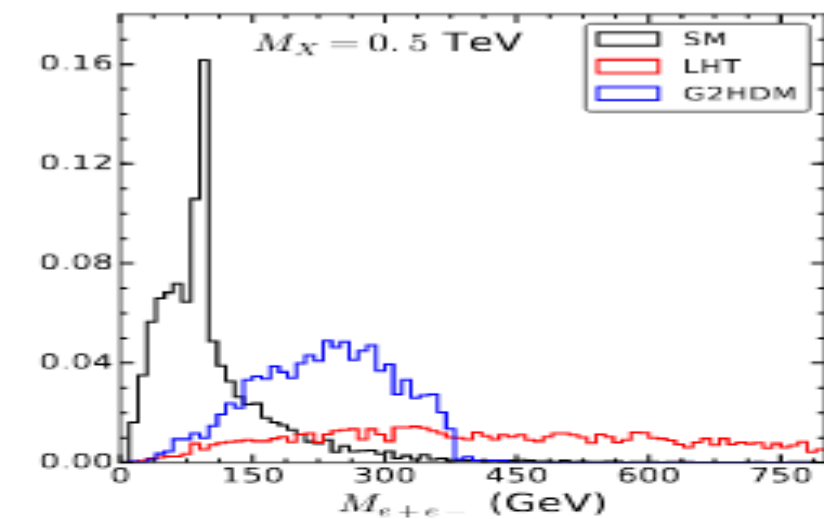
The quantitative study: cross sections



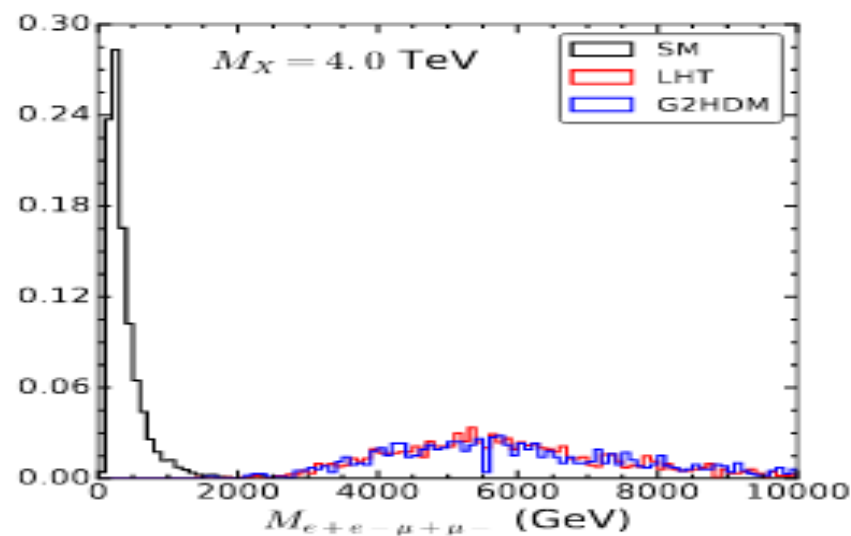
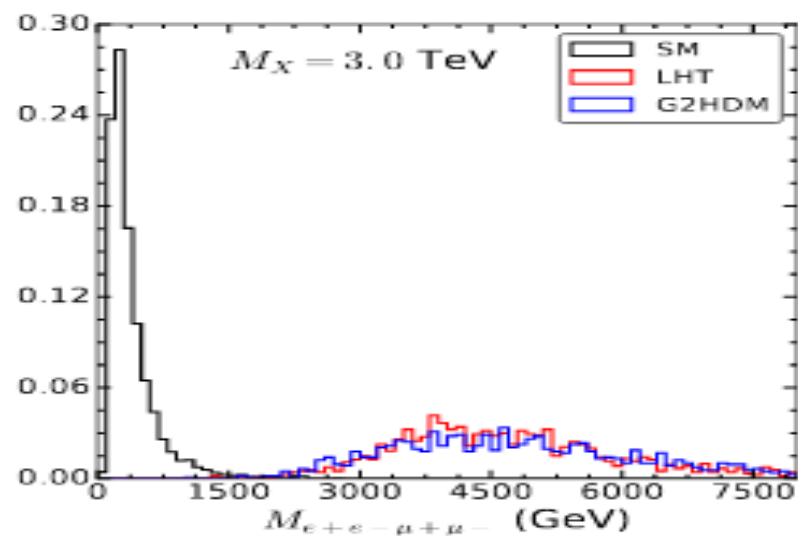
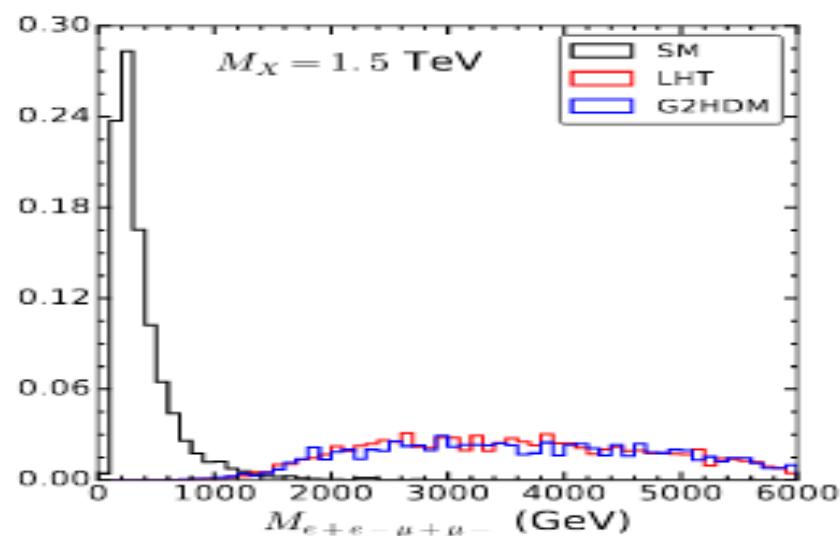
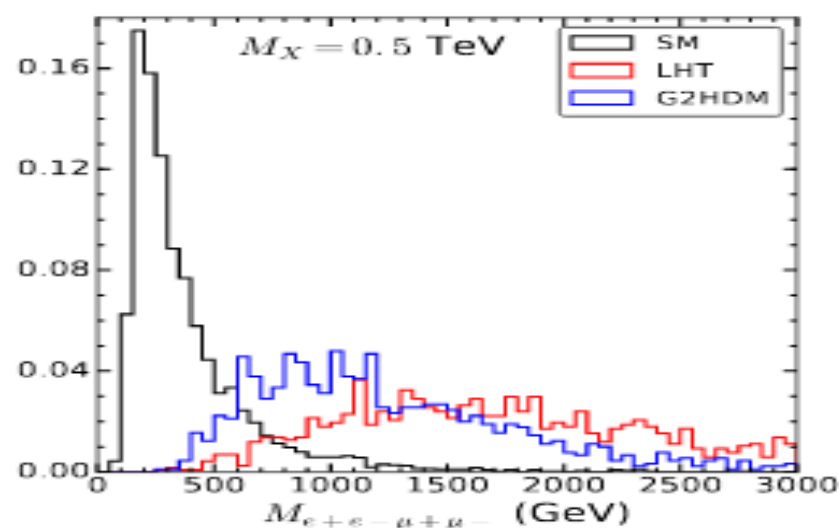
The qualitative study: the kinematical distributions $\Delta R_{e^+e^-}$



The qualitative study: the kinematical distributions $M_{e^+e^-}$



The qualitative study: the kinematical distributions $M_{e^+e^-\mu^+\mu^-}$



Summary and Outlook

- We have constructed a model with the 2 Higgs doublets embedded into a 2 dim spinor representation of a new gauge group $SU(2)_H$.
- Spontaneous symmetry breaking of $SU(2)_H$ by a triplet triggers the breaking of the SM $SU(2)_L$.
- An inert doublet can be emerged as DM candidate due to local gauge invariance rather than the ad hoc Z_2 discrete symmetry.
- Additional gauge bosons are all **electrically neutral** unlike Left-Right symmetric models.

Summary and Outlook

- Both the new gauge boson Z' and $W'^{(p,m)}$ are **electrically neutral**. While Z' can be **singly produced** at colliders, $W'^{(p,m)}$, which is heavier, must be **pair produced**.
- If Z' can be discovered at high luminosity upgrade of the collider, we explore the detectability of extra heavy fermions in the model via the two **$2l+mET$** & **$2j+mET$** signals from the exotic decay modes of Z' .
- For the $W'^{(p,m)}$ pair production in a future 100 TeV pp collider, we demonstrate certain kinematical distributions for the **$2l+mET$** & **$4l+mET$** signals.

Summary and Outlook

Models		Production	$2l + \cancel{E}_T$	$4l + \cancel{E}_T$
G2HDM	Z'	S	Yes	No
	$W'^{(p,m)}$	P	Yes	Yes
LHT	Z_H	P	Yes	Yes
	$W_H^\pm$	P	Yes	No

TABLE VI. Classification and search strategies of the gauge bosons in G2HDM and LHT by single (S) / pair (P) productions and two decay channels.

Thank you for your attention ! !

