Signals of New Gauge Bosons in Gauged Two Higgs Doublet Model

Chih-Ting Lu
(NTHU)
National Tsing Hua University, Hsinchu, Taiwan

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- ***Collaborators :***
- Prof. Tzu-Chiang Yuan
- Dr. Yue-Lin Sming Tsai
- Dr. Wei-Chih Huang
- Dr. Hiroyuki Ishida
- ***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 for various reasons :

  - 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.

  - Type-II 2HDM was embedded in Minimal Supersymmetric Standard Model (MSSM).

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 ⓧ 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'^(p,m) are electrically neutral
- Neutrinos would be Dirac fermions unless additional lepton number violation terms are involved.

Signals of new gauge bosons in various models

- S : single production ; P : pair production

Models		Production	EM charge
LRSM	Z'	S	0
	$W'^{\pm}$	S	± 1
G2HDM	Z'	S	0
	$W'^{(p,m)}$	P	0
?	Z'	P	?
	W'	S	?
LHT	Z_H	P	0
	$W_H^{\pm}$	P	± 1

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

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

- 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

Model configuration – Higgs potential

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

$$\begin{aligned}
V(H) &= \mu_H^2 H^\dagger H+\lambda_H\left(H^\dagger H\right)^2 \ , \\
&= \mu_H^2\left(H_1^\dagger H_1+H_2^\dagger H_2\right)+\lambda_H\left(H_1^\dagger H_1+H_2^\dagger H_2\right)^2 \ , \\
V(\Phi_H) &= \mu_\Phi^2 \Phi_H^\dagger \Phi_H+\lambda_\Phi\left(\Phi_H^\dagger \Phi_H\right)^2 \ , \\
&= \mu_\Phi^2\left(\Phi_1^*\Phi_1+\Phi_2^*\Phi_2\right)+\lambda_\Phi\left(\Phi_1^*\Phi_1+\Phi_2^*\Phi_2\right)^2 \ , \\
V(\Delta_H) &= -\mu_\Delta^2 \operatorname{Tr}\left(\Delta_H^\dagger \Delta_H\right)+\lambda_\Delta\left(\operatorname{Tr}\left(\Delta_H^\dagger \Delta_H\right)\right)^2 \ , \\
&= -\mu_\Delta^2\left(\frac{1}{2}\Delta_3^2+\Delta_p\Delta_m\right)+\lambda_\Delta\left(\frac{1}{2}\Delta_3^2+\Delta_p\Delta_m\right)^2 \ ,
\end{aligned}$$

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

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

Model configuration – Higgs potential

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

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

Model configuration – Symmetry Breaking

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

- If $<\Delta_3>= -v_\Delta \neq 0$, 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 $<\Delta_3>= -v_\Delta \neq 0$, the quadratic terms for $\mathbf{\Phi}_1$ and $\mathbf{\Phi}_2$ 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
- $$\mathcal{L}_{\text{Yuk}} \supset + y_d \bar{Q}_L \left(d_R^H H_2 - d_R H_1 \right) - y_u \bar{Q}_L \left(u_R \tilde{H}_1 + u_R^H \tilde{H}_2 \right)$$
- $$+ \; y_e \bar{L}_L \left(e_R^H H_2 - e_R H_1 \right) - y_\nu \bar{L}_L \left(\nu_R \tilde{H}_1 + \nu_R^H \tilde{H}_2 \right) + \text{H.c.} \, ,$$
-
- with $\tilde{H}_{1,2} = i\tau_2 H_{1,2}^*$.
- The corresponding SU(2)_H invariant Yukawa couplings are
- $$\mathcal{L}_{\text{Yuk}} \supset \, - y'_d \overline{d_L^H} \left(d_R^H \Phi_2 - d_R \Phi_1 \right) - y'_u \overline{u_L^H} \left(u_R \Phi_1^* + u_R^H \Phi_2^* \right)$$
- $$- y'_e \overline{e_L^H} \left(e_R^H \Phi_2 - e_R \Phi_1 \right) - y'_\nu \overline{\nu_L^H} \left(\nu_R \Phi_1^* + \nu_R^H \Phi_2^* \right) + \text{H.c.} \, .$$
-

Model configuration – Gauge boson

- The SU(2)_H gauge boson mass spectrum is
-

$$m^2_{W'^{(p,m)}} = \frac{1}{4} g_H^2 \left(v^2 + v_\Phi^2 + 4 v_\Delta^2 \right) \; ,$$

$$m^2_{Z'} = \frac{1}{4} g_H^2 \left(v^2 + v_\Phi^2 \right) \; ,$$

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

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

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,

$$\begin{aligned} \mathcal{L}(\gamma) &= \sum_f Q_f e \bar{f} \gamma^\mu f A_\mu \,, \\ \mathcal{L}(W) &= \frac{g}{\sqrt{2}} \left(\overline{\nu_L} \gamma^\mu e_L + \overline{u_L} \gamma^\mu d_L \right) W_\mu^+ + \text{H.c.} \,, \end{aligned} \tag{5}$$

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):

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

Model configuration – Gauge boson

where

$$\mathcal{L}(Z) = \frac{g}{\cos\theta_w} J^\mu_Z Z_\mu \ ,$$
$$\mathcal{L}(Z') = g_H J^\mu_{W'^3} Z'_\mu \, ,$$
$$\mathcal{L}(W'^{(p,m)}) = \frac{1}{\sqrt{2}} g_H \left(J^\mu_{W'^m} W'^p_\mu + \text{H.c.} \right) \ ,$$

and

$$J^\mu_Z = \sum_{f=e,\nu} \left(\overline{f_L} \gamma^\mu (I_3 - Q_f \sin^2\theta_w) f_L + \overline{f_R} \gamma^\mu (-Q_f \sin^2\theta_w) f_R \right) + \sum_e \overline{e^H_R} \gamma^\mu (\sin^2\theta_w) e^H_R \, ,$$
$$J^\mu_{W'^3} = \sum_{f=N_R,E_R} \overline{f_R} \gamma^\mu (I^H_3) f_R \, , \tag{8}$$
$$J^\mu_{W'^m} = \sum_e \left(\overline{e^H_R} \gamma^\mu e_R + \overline{\nu_{eR}} \gamma^\mu \nu^H_{eR} \right) \, ,$$

where I_3 (I^H_3) is the third generator of $SU(2)_L$ ($SU(2)_H$), and $\sin\theta_w$ is the Weinberg angle.

Phenomenology – Methodology

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

Methodology – Spectrum-A

Spectrum-A: Heavy and decoupled new quark scenario.

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

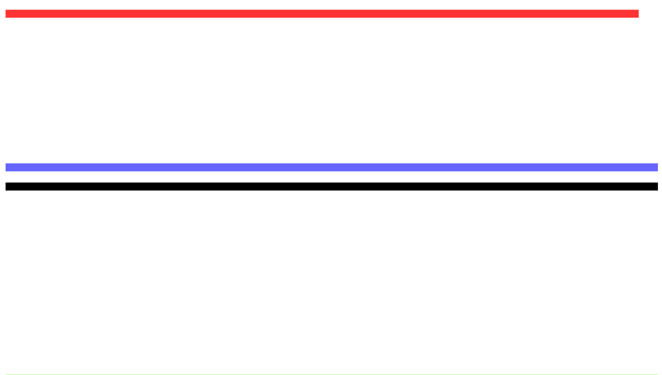
$$m_{Z'} \simeq m_{W'(p,m)} = 5\, m_D.$$

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

$$m_D$$

Methodology – Spectrum-B

Spectrum-B: Light new quark scenario.



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

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

$$m_D$$

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 $(e\ (\nu_e), \mu\ (\nu_\mu), \tau\ (\nu_\tau))$.

Z'	$BR(Q\overline{Q})$	$BR(L^+L^-)$	$BR(\nu\overline{\nu})$	$BR(Q^H\overline{Q^H})$	$BR(L^H\overline{L^H})$	$BR(\nu^H\overline{\nu^H})$
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.

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

Methodology – Search Strategy

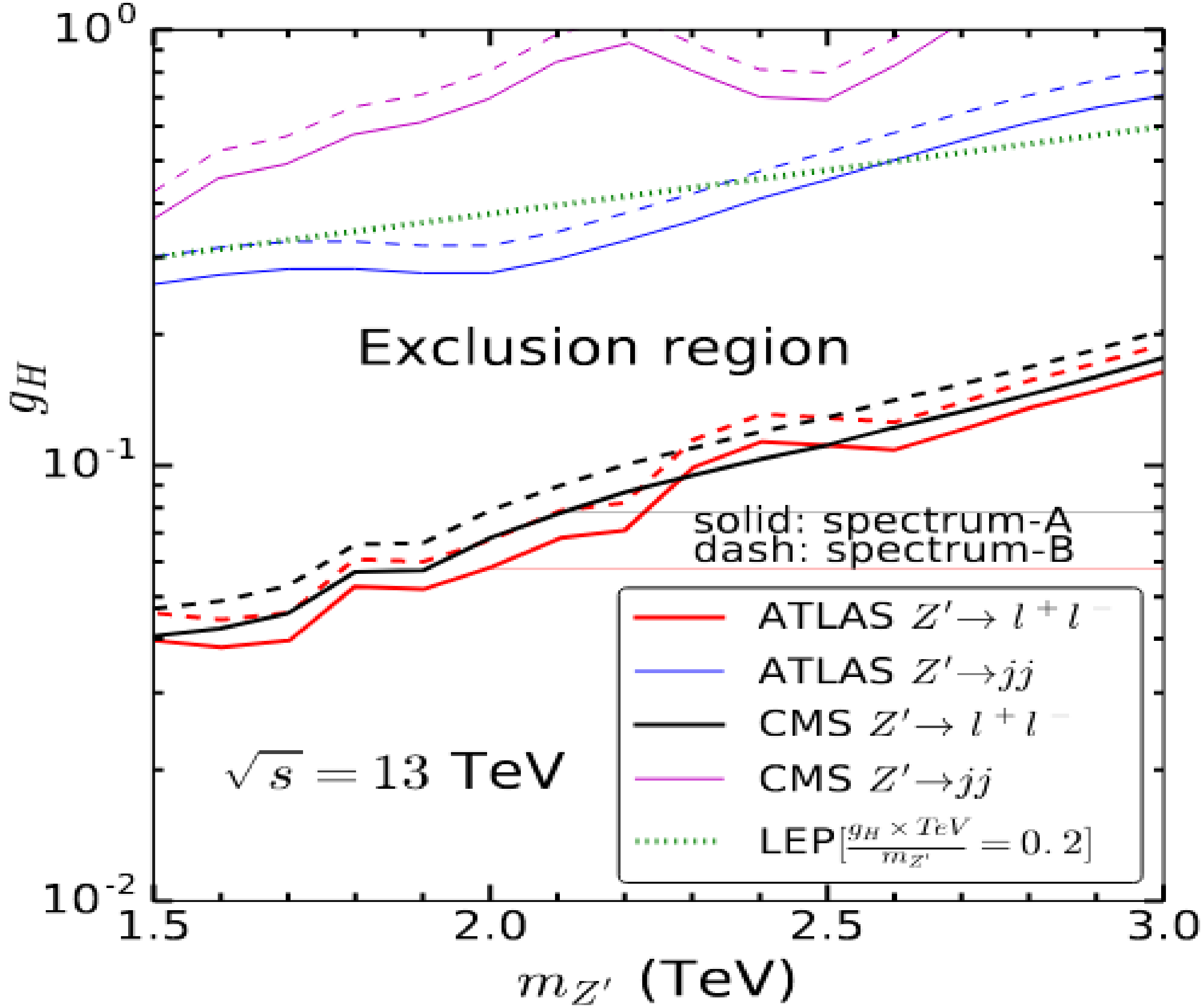
In both scenarios, the new heavy fermions are kinematically allowed to be produced by either Z' or $W'^{(p,m)}$ decays. As a result, we propose searches for the new fermions as follows. †

- For Spectrum-A, the heavy charged leptons can be produced via $pp \to Z' \to L^H \overline{L^H}$ and $pp \to W'^p W'^m \to \overline{L^H} L \overline{L} L^H$, and the corresponding final states will be (1) $2l + \not{E}_T$, (2) $2\tau + \not{E}_T$, (3) $4l + \not{E}_T$, (4) $2l+2\tau + \not{E}_T$, and (5) $4\tau + \not{E}_T$.

- For Spectrum-B, the new quark pairs can also be on-shell produced through $pp \to Z' \to Q^H \overline{Q^H}$, and thus the following final states (1) $2j + \not{E}_T$, (2) $2b + \not{E}_T$, and (3) $2t + \not{E}_T$ 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

- **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+mET :
- $$pp \to \gamma/Z \to \tilde{l}^{+}\tilde{l}^{-} \to 2l + \not{E}_T$$
- Similarly, in G2HDM decays of Z′ into a pair of exotic fermions can also lead to the same final states: $$pp \to Z' \to l^{H}\overline{l^{H}} \to 2l + \not{E}_T$$
-

Phenomenology – Z' searches at the LHC

Spectrum-A$'$: $2\,m_{L^H} < m_{Z'} < 2\,m_{Q^H}$ and $m_{\rm DM} = 50$ GeV.

We concentrate on the following two channels,

$$pp \to Z' \to l^H \overline{l^H} \to 2l + \not{E}_T\,,$$

$$pp \to Z' \to \tau^H \overline{\tau^H} \to 2\tau + \not{E}_T\,,$$

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

Phenomenology – Z' searches at the LHC

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

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

$$pp \to j^H\overline{j^H} \to 2j + \not{E}_T\,, \quad (13)$$

$$pp \to b^H\overline{b^H} \to 2b + \not{E}_T\,, \quad (14)$$

$$pp \to t^H\overline{t^H} \to 2t + \not{E}_T\,, \quad (15)$$

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 $m_{Z'} > 2\,m_{Q^H}$, three subdominant but nevertheless important processes have to be included:

$$pp \to Z' \to j^H\overline{j^H} \to 2j + \not{E}_T\,, \tag{16}$$

$$pp \to Z' \to b^H\overline{b^H} \to 2b + \not{E}_T\,, \tag{17}$$

$$pp \to Z' \to t^H\overline{t^H} \to 2t + \not{E}_T\,. \tag{18}$$

Phenomenology – Future W' searches

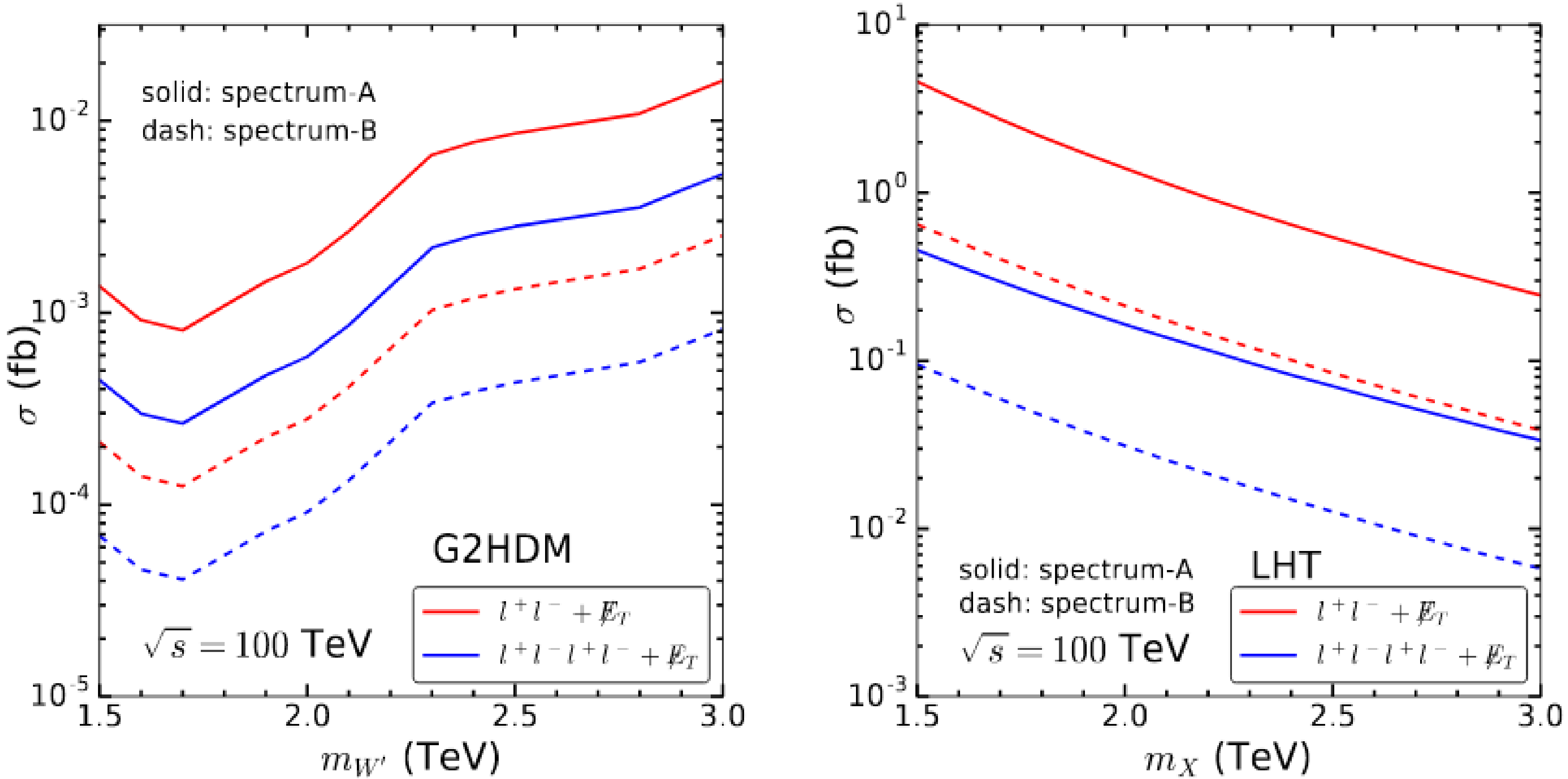
Two search channels: $2l + \not{E}_T$ **and** $4l + \not{E}_T$

Model	Production	Prompt Decay	Final State	Signal
$l^+l^- + \not{E}_T$				
G2HDM	$pp \to W'^p W'^m$	$(\bar{l}l^H)(\overline{\nu^H}\nu)$ + c.c.	$(\bar{l}lH_2^0)(\bar{\nu}H_2^{0*}\nu)$	$l^+l^- + \{\nu\bar{\nu}H_2^0H_2^{0*}\}$
LHT	$pp \to W_H^+W_H^-$	$(l_H^+\nu)(\overline{\nu_H}l^-)$ + c.c.	$(l^+A_H\nu)(\bar{\nu}A_Hl^-)$	$l^+l^- + \{\nu\bar{\nu}A_HA_H\}$
LHT	$pp \to Z_HZ_H$	$(l_H^\pm l^\mp)(\overline{\nu_H}\nu)$	$(l^\pm A_Hl^\mp)(\bar{\nu}A_H\nu)$	$l^+l^- + \{\nu\bar{\nu}A_HA_H\}$
$l^+l^-l^+l^- + \not{E}_T$				
G2HDM	$pp \to W'^p W'^m$	$(\bar{l}l^H)(l\overline{l^H})$	$(\bar{l}lH_2^0)(l\bar{l}H_2^{0*})$	$l^+l^-l^+l^- + \{H_2^0H_2^{0*}\}$
LHT	$pp \to Z_HZ_H$	$(l_H^\pm l^\mp)(l_H^\pm l^\mp)$	$(l^\pm A_Hl^\mp)(l^\pm A_Hl^\mp)$	$l^+l^-l^+l^- + \{A_HA_H\}$

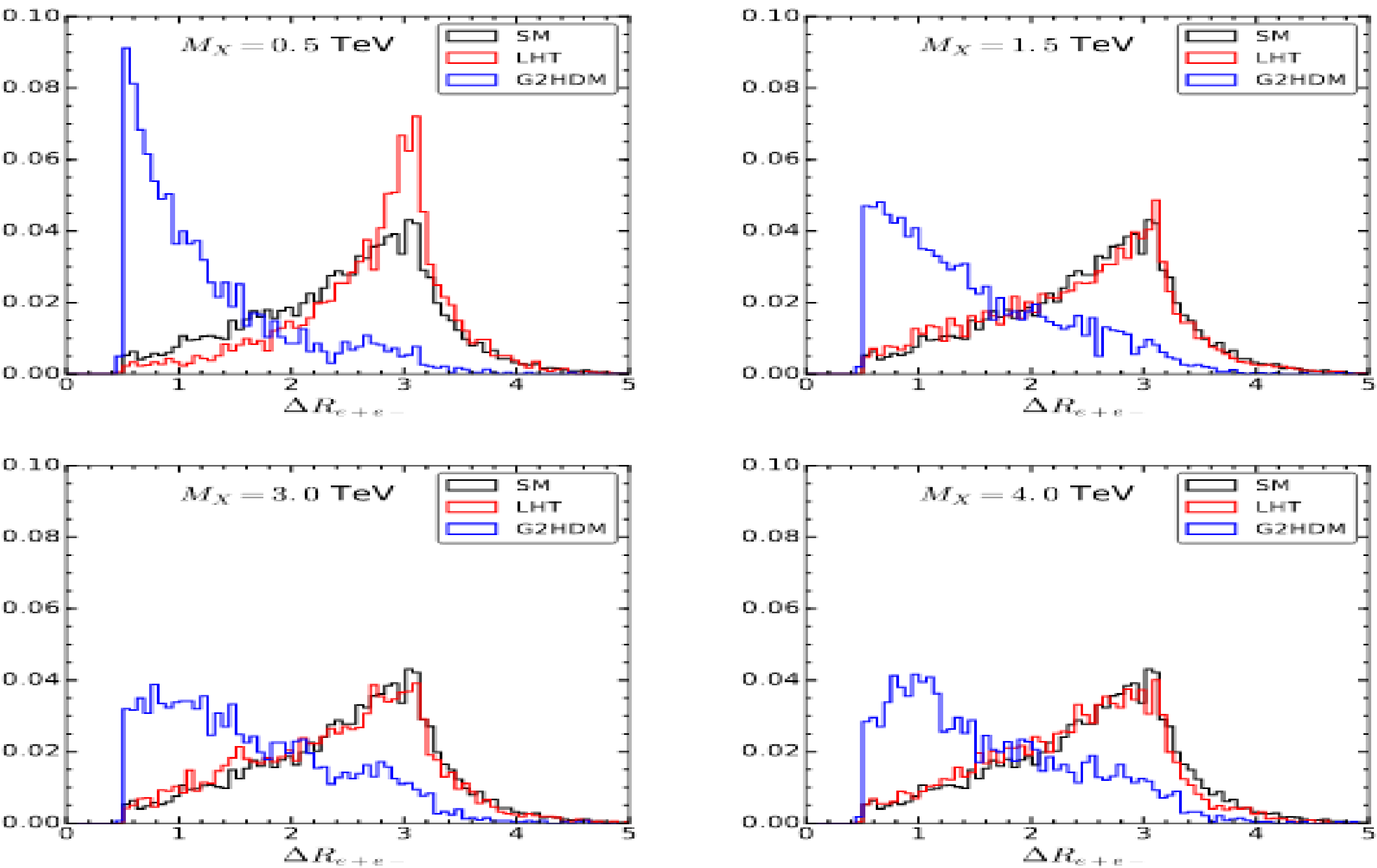
TABLE V. List of the production and leptonic decay channels for the exotic gauge bosons in G2HDM and LHT.

Phenomenology – Future W’ searches

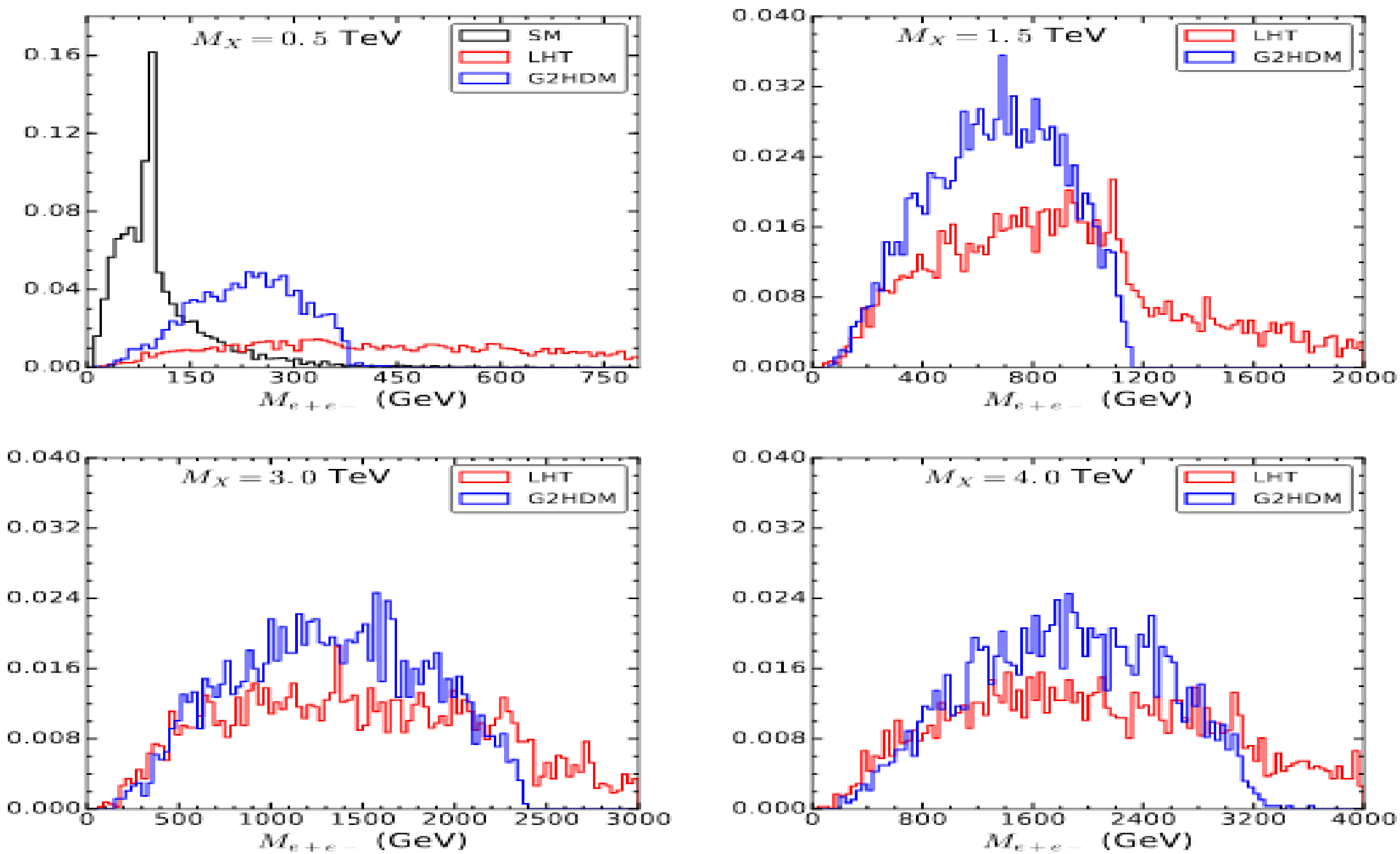
The quantitative study: cross sections



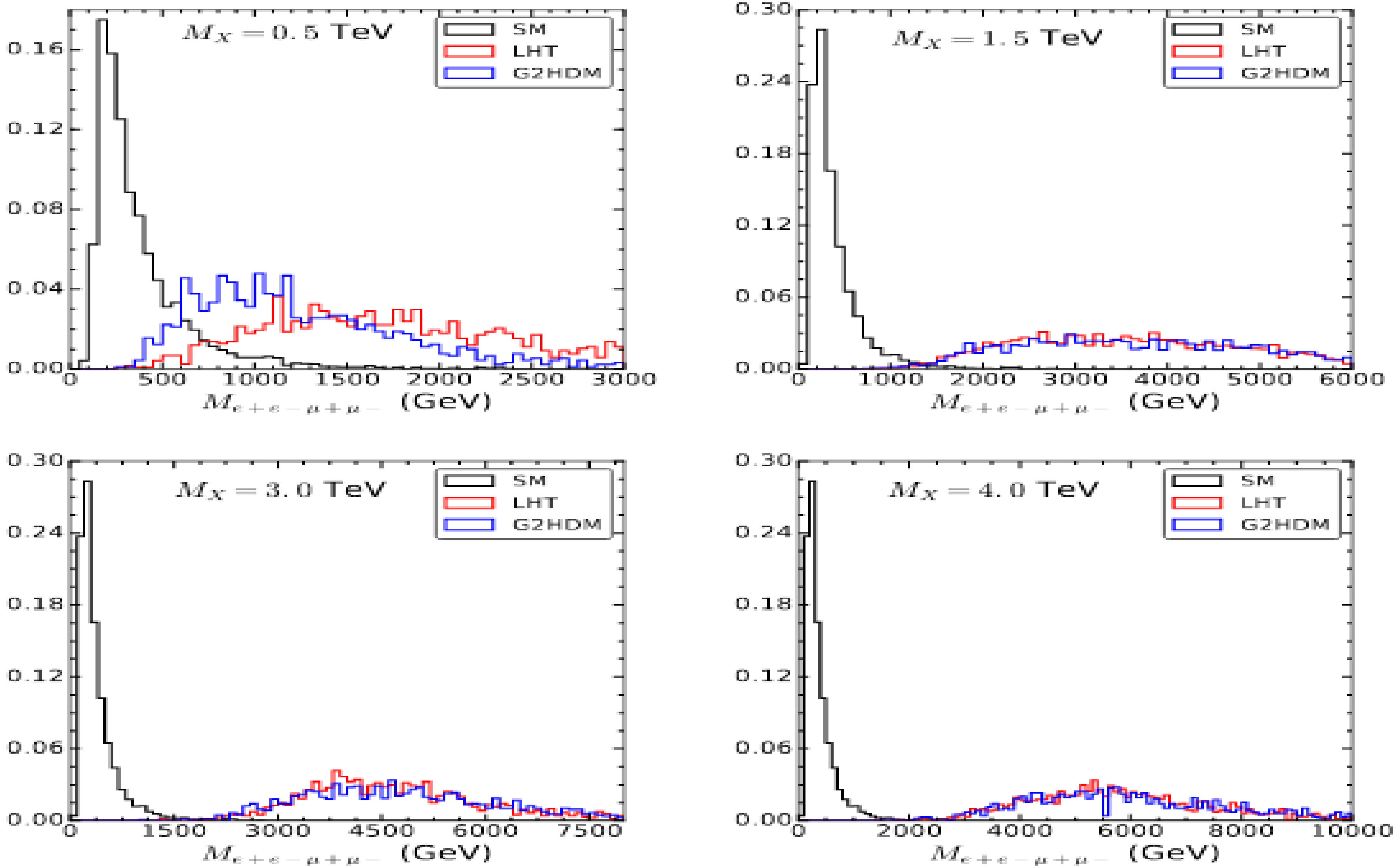
The qualitative study: the kinematical distributions $\triangle R_{e^+e^-}$



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



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



Summary and Outlook

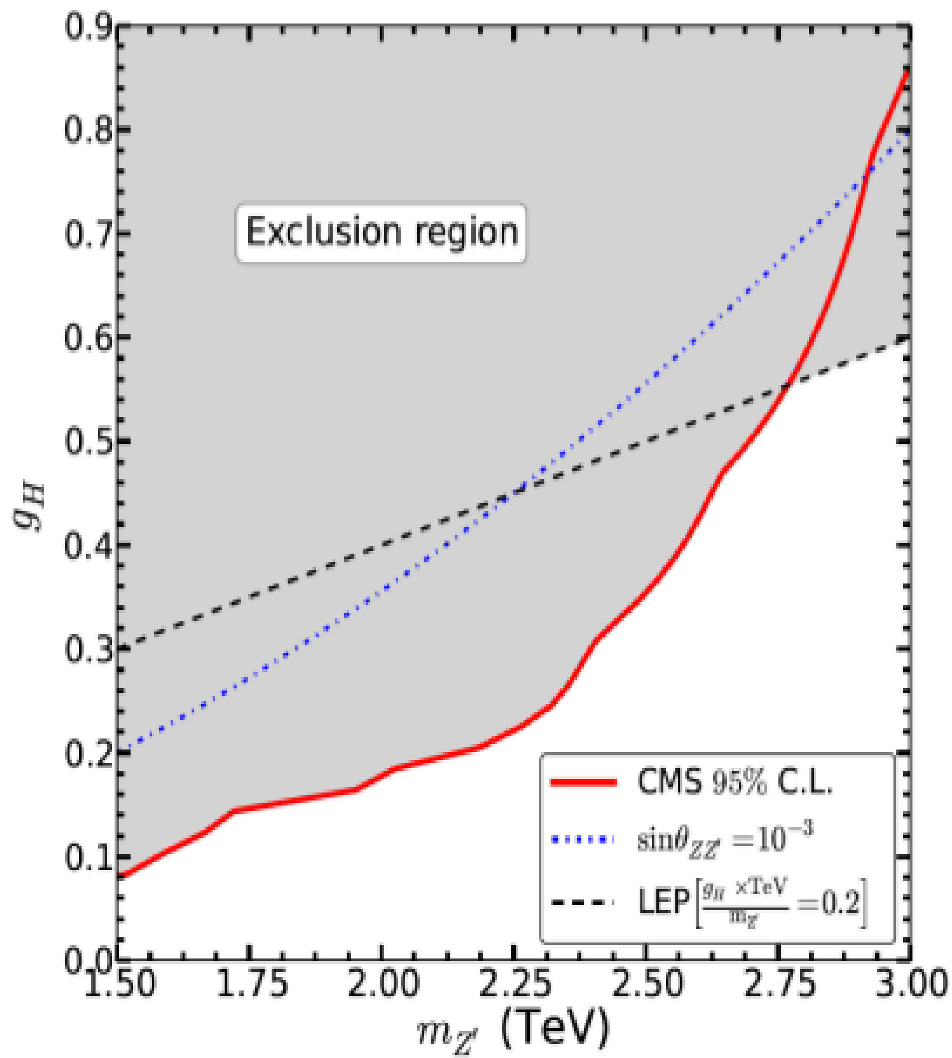
- We have constructed a model with the 2 Higgs doublets embedded into a 2 dim spinor representation of a new gauge group $SU(2)_H$.
- Spontaneous symmetry breaking of $SU(2)_H$ by a triplet triggers the breaking of the SM $SU(2)_L$.
- An inert doublet can be emerged as DM candidate due to local gauge 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.

Thank you for your attention ! !

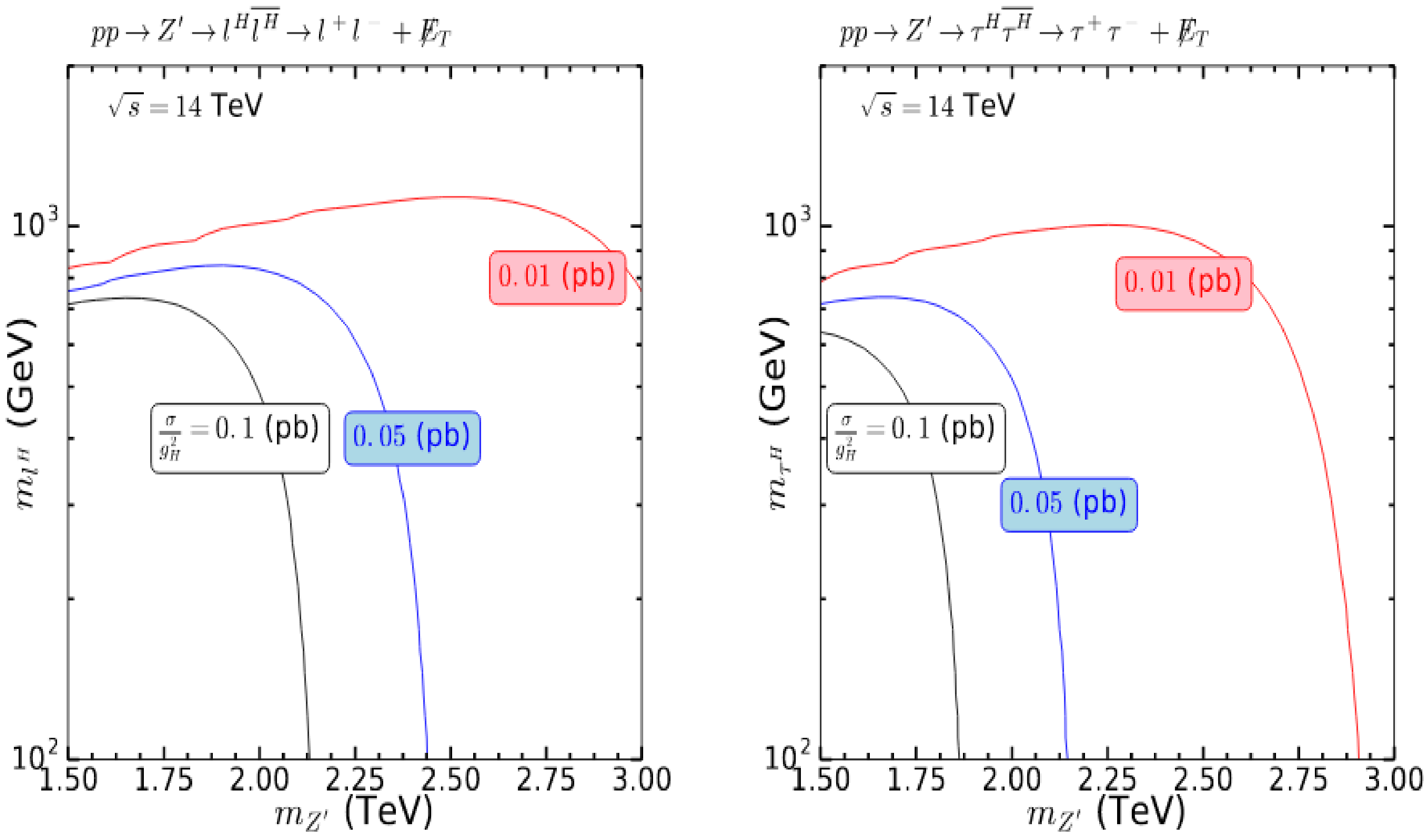
Phenomenology – Z' searches at the LHC



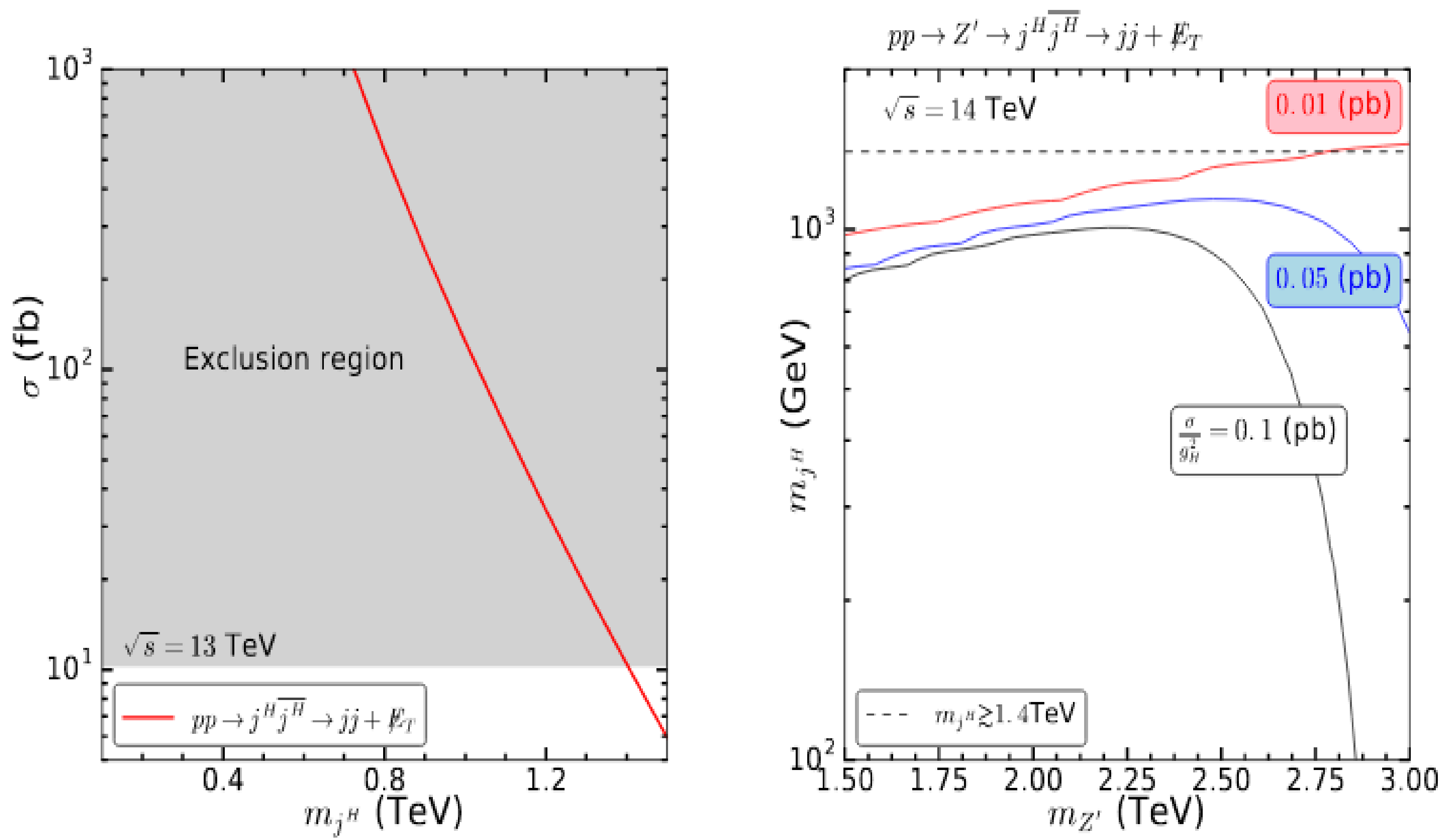
- The red line comes from direct Z' resonance searches (1412.6302)
- The black dashed line comes from LEP constraints on the cross-section of $e^+e^- \to e^+e^-$ (hep-ex/0312023) $\Rightarrow v_\Phi > 10$ TeV
- The blue dotted line comes from EWPT data and collider constraints on the Z-Z' mixing(0906.2435,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

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

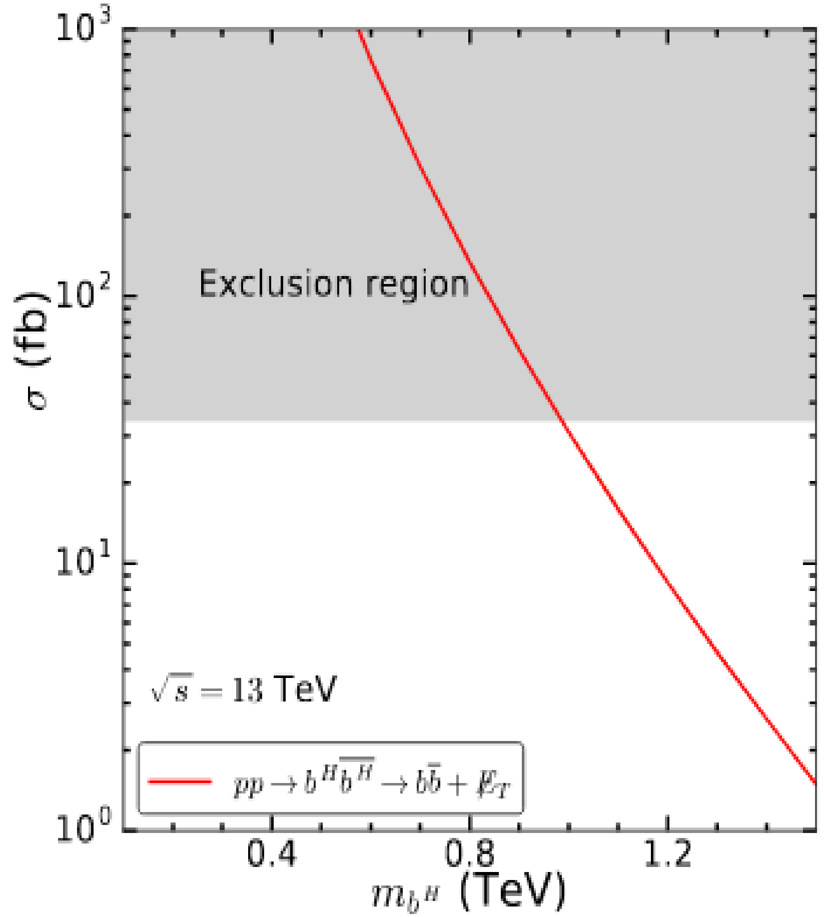
Phenomenology – Z' searches at the LHC

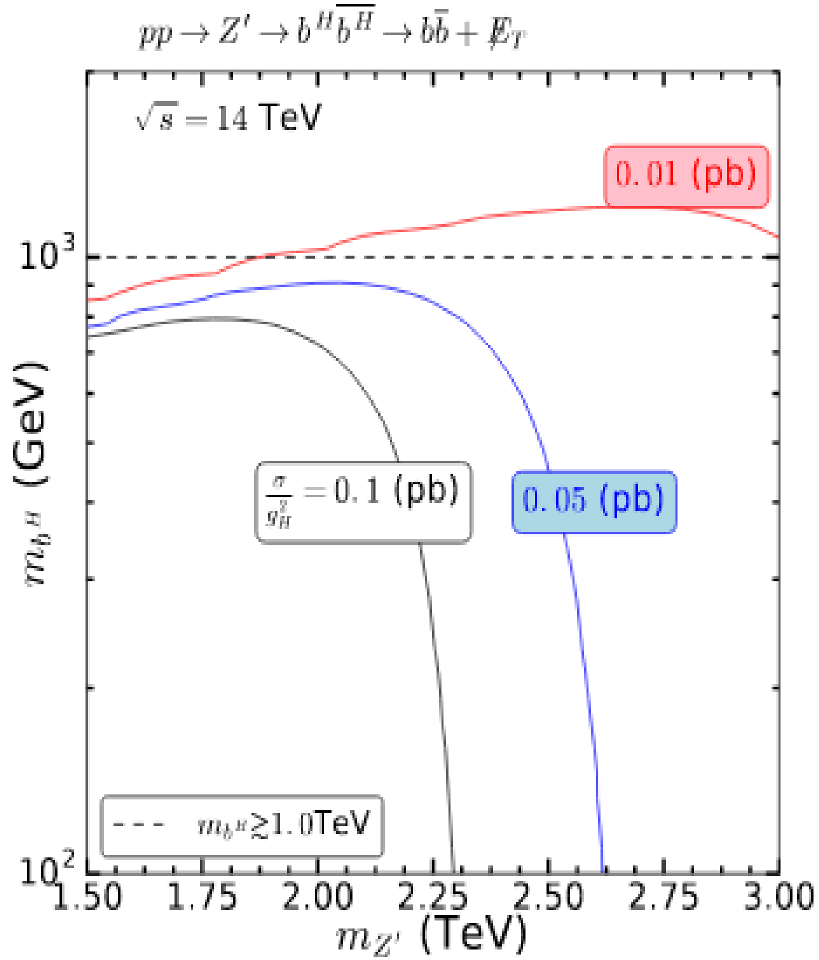


Phenomenology – Z’ searches at the LHC



Phenomenology – Z' searches at the LHC





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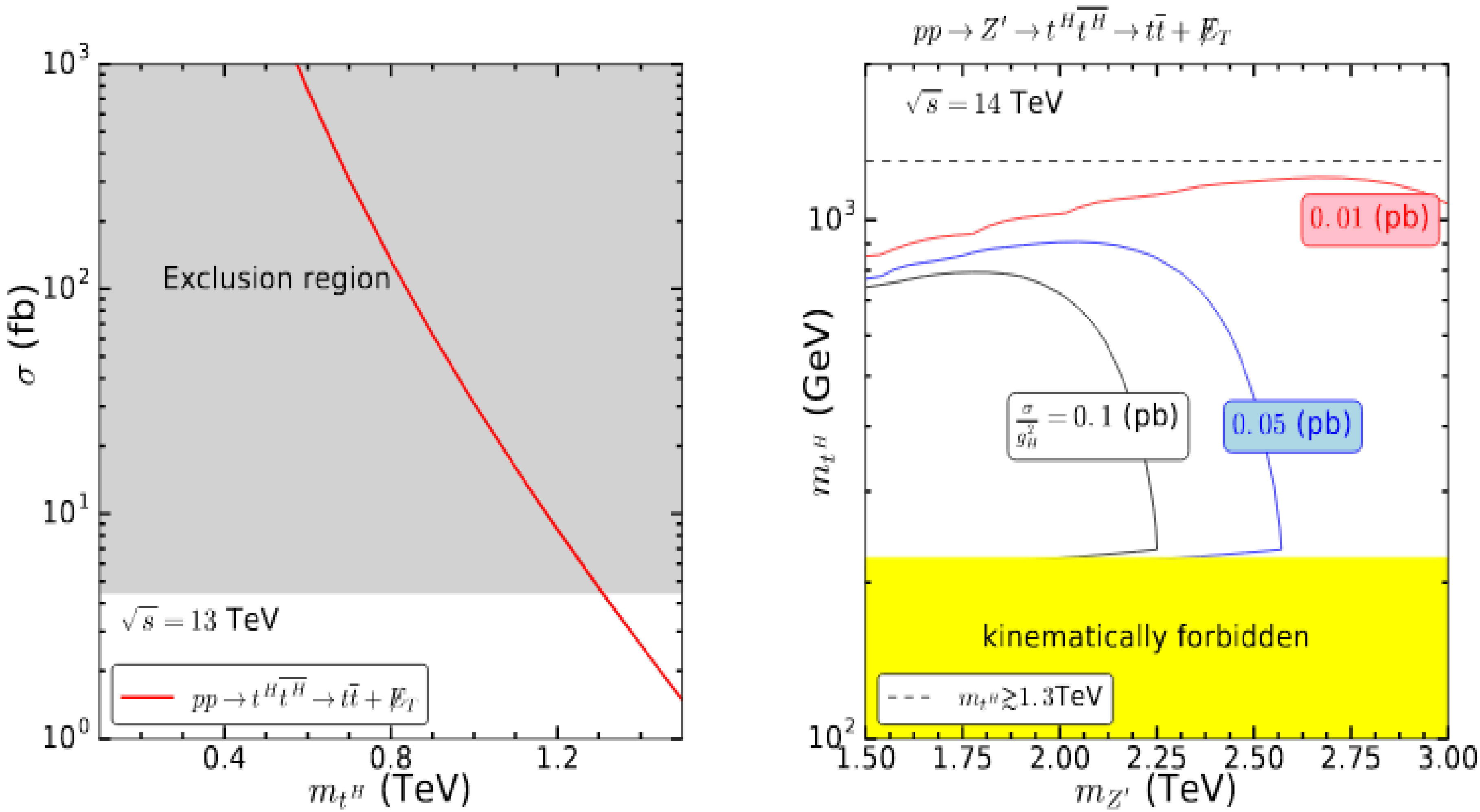

Phenomenology – G2HDM vs. LHT

	G2HDM								LHT				
	U_R	D_R	u_L^H	d_L^H	N_R	E_R	ν_L^H	e_L^H	q_H	t_H	d_H	l_H	e_H
$SU(3)_C$	3	3	3	3	1	1	1	1	3	3	3	1	1
$SU(2)_H$	2	2	1	1	2	2	1	1	/	/	/	/	/
$SU(2)_T$	/	/	/	/	/	/	/	/	2	1	1	2	1
$\mathcal{P}_T$	/	/	/	/	/	/	/	/	-1	-1	-1	-1	-1

TABLE IV. Comparison of quantum numbers of the heavy $SU(2)_L$ singlet fermion fields in G2HDM and LHT. In case of the absence of the symmetries in the models, we put a slash in the cells. $\mathcal{P}_T$ is the T-parity in LHT.

Summary and Outlook

Models		Production	$2l + \not{E}_T$	$4l + \not{E}_T$
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.

Outlook

- S : single production ; P : pair production

Models		Production	EM charge
LRSM	Z'	S	0
	$W'^{\pm}$	S	± 1
G2HDM	Z'	S	0
	$W'^{(p,m)}$	P	0
?	Z'	P	?
	W'	S	?
LHT	Z_H	P	0
	$W_H^{\pm}$	P	± 1