

# Search for a Heavy Neutral Higgs Boson in BLSSM at the LHC

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## Outline

### 1 *B – L Supersymmetric Extension of the Standard Model (BLSSM)*

- MSSM
- BLSSM
- Mass Spectrum
- Higgs Sector

### 2 *Search for Heavy Higgs Bosons at the LHC*

- $h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$
- $h' \rightarrow ZZ \rightarrow 4\ell$
- $h' \rightarrow WW \rightarrow \ell^+\ell^- + \cancel{E}_T$

### 3 Conclusion

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## ■ The MSSM gauge group

$$SU(3)_C \times SU(2)_L \times U(1)_Y. \quad (1)$$

## ■ MSSM Chiral supermultiplet [3, 4].

Names		spin 0	spin 1/2	SU(3) <sub>c</sub> , SU(2) <sub>L</sub> , U(1) <sub>y</sub>
squarks, quarks (× 3 families)	$Q$	$(\tilde{u}_L, \tilde{d}_L)$	$(u_L, d_L)$ or $(\chi_u, \chi_d)$	<b>3, 2, 1/3</b>
	$\bar{u}$	$\tilde{\bar{u}}_L = \tilde{u}_R^\dagger$	$\bar{u}_L = (u_R)^c$ or $\chi_{\bar{u}} = \psi_u^c$	<b>3̄, 1, -4/3</b>
	$\bar{d}$	$\tilde{\bar{d}}_L = \tilde{d}_R^\dagger$	$\bar{d}_L = (d_R)^c$ or $\chi_{\bar{d}} = \psi_d^c$	<b>3̄, 1, 2/3</b>
sleptons, leptons (× 3 families)	$L$	$(\tilde{\nu}_e L, \tilde{e}_L)$	$(\nu_e L, e_L)$ or $(\chi_{\nu_e}, \chi_e)$	<b>1, 2, -1</b>
	$\bar{e}$	$\tilde{\bar{e}}_L = \tilde{e}_R^\dagger$	$\bar{e}_L = (e_R)^c$ or $\chi_{\bar{e}} = \psi_e^c$	<b>1, 1, 2</b>
	$H_u$	$(H_u^+, H_u^0)$	$(\tilde{H}_u^+, \tilde{H}_u^0)$	<b>1, 2, 1</b>
	$H_d$	$(H_d^0, H_d^-)$	$(\tilde{H}_d^0, \tilde{H}_d^-)$	<b>1, 2, -1</b>

■ MSSM Gauge supermultiplet [3, 4].

Names	spin 1/2	spin 1	SU(3) <sub>c</sub> , SU(2) <sub>L</sub> , U(1) <sub>y</sub>
gluinos, gluons	$\tilde{g}$	$g$	<b>8</b> , <b>1</b> , 0
winos, W bosons	$\tilde{W}^\pm, \tilde{W}^0$	$W^\pm, W^0$	<b>1</b> , <b>3</b> , 0
bino, B boson	$\tilde{B}$	$B$	<b>1</b> , <b>1</b> , 0

■ MSSM gauge invariant Superpotential [3, 4]

$$W_{\text{MSSM}} = y_u^{ij} \bar{u}_i Q_j \cdot H_u - y_d^{ij} \bar{d}_i Q_j \cdot H_d - y_e^{ij} \bar{e}_i L_j \cdot H_d + \mu H_u \cdot H_d \quad (2)$$

- MSSM gauge invariant soft SUSY breaking terms are [3, 4]
  - 1 Gaugino masses for each gauge group (gluino, wino and bino):

$$-\frac{1}{2}(M_3 \tilde{g}^a \tilde{g}^a + M_2 \tilde{W}^a \tilde{W}^a + M_1 \tilde{B} \tilde{B}) \quad (3)$$

- 2 Squark mass terms:

$$-m_{\tilde{Q}_{ij}}^2 \tilde{Q}_i^\dagger \tilde{Q}_j - m_{\tilde{\bar{u}}_{ij}}^2 \tilde{\bar{u}}_{Li}^\dagger \tilde{\bar{u}}_{Lj} - m_{\tilde{\bar{d}}_{ij}}^2 \tilde{\bar{d}}_{Li}^\dagger \tilde{\bar{d}}_{Lj} \quad (4)$$

- 3 Slepton mass terms:

$$-m_{\tilde{L}_{ij}}^2 \tilde{L}_i^\dagger \tilde{L}_j - m_{\tilde{\bar{e}}_{ij}}^2 \tilde{\bar{e}}_{Li}^\dagger \tilde{\bar{e}}_{Lj} \quad (5)$$

- 4 Higgs mass terms:

$$-m_{H_u}^2 H_u^\dagger H_u - m_{H_d}^2 H_d^\dagger H_d - (b H_u H_d + h.c.) \quad (6)$$

- 5 Triple scalar couplings:

$$-a_u^{ij} \tilde{\bar{u}}_{Li}^\dagger \tilde{Q}_j H_u - a_d^{ij} \tilde{\bar{d}}_{Li}^\dagger \tilde{Q}_j H_d - a_e^{ij} \tilde{\bar{e}}_{Li}^\dagger \tilde{L}_j H_d + h.c. \quad (7)$$

- The ‘minimal supergravity (mSUGRA)’ unification theory lead naturally to the suppression of dangerous terms that in a framework in which the soft parameters take a particularly simple form at the GUT scale:

$$M_3 = M_2 = M_1 = m_{1/2}, \quad (8)$$

$$m_{\tilde{Q}}^2 = m_{\tilde{u}}^2 = m_{\tilde{\bar{d}}}^2 = m_{\tilde{L}}^2 = m_{\tilde{\bar{e}}}^2 = m_0^2, \quad (9)$$

$$m_{H_u}^2 = m_{H_d}^2 = m_0^2, \quad (10)$$

$$a_u = A_0 y_u, \quad a_d = A_0 y_d, \quad a_e = A_0 y_e. \quad (11)$$

## ■ The Higgs potential for the neutral fields

$$\begin{aligned} V_{\text{neutral}} = & (|\mu|^2 + m_{H_u}^2) |H_u^0|^2 + (|\mu|^2 + m_{H_d}^2) |H_d^0|^2 - (b H_u^0 H_d^0 + h.c.) \\ & + \frac{g^2 + g'^2}{8} (|H_u^0|^2 - |H_d^0|^2)^2. \end{aligned} \quad (12)$$

## ■ Tree level neutral $CP$ -even Higgs (symmetric) $2 \times 2$ mass matrix

$$\begin{pmatrix} b \cot \beta + m_Z^2 \sin^2 \beta & -b - \frac{1}{2} m_Z^2 \sin 2\beta \\ . & b \tan \beta + m_Z^2 \cos^2 \beta \end{pmatrix} \quad (13)$$

with tree-level highly non-degenerate masses

$$m_{h,H}^2 = \frac{1}{2} \left( m_A^2 + m_Z^2 \mp \sqrt{(m_A^2 + m_Z^2)^2 - 4m_A^2 m_Z^2 \cos 2\beta} \right) \quad (14)$$

and mixing

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} H_u^0 \\ H_d^0 \end{pmatrix}, \quad \tan 2\alpha = \tan 2\beta \frac{m_A^2 + m_Z^2}{m_A^2 - m_Z^2} \quad (15)$$

- **MSSM Spectrum** Many more particles arise in MSSM than in the SM

- 1 **Higgs:** One extra neutral scalar  $H$ , one neutral pseudoscalar  $A$ , and two conjugate charged Higgs  $H^\pm$ .
- 2 **Sfermions:** Squarks and Sleptons
- 3 **Charginos:** of the charged gauginos and Higgsinos
- 4 **Neutralinos:** of the neutral gauginos and Higgsinos
- The lightest supersymmetric particle (LSP) (Sneutrino Neutralinos) is a candidate for the nonbaryonic cold Dark Matter (DM).
- **MSSM Problems:** Massless neutrinos and the  $\mu$ -problem of naturalness.

## ■ The BLSSM gauge group

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L} \quad (16)$$

- The BLSSM model is a natural extension of the MSSM [6] with
  - 1 (at least) three RH neutrino chiral superfields ( $N_i$ ) for neutrino masses [5, 2, 1],
  - 2 two SM-singlet Higgs chiral superfields ( $\chi_1, \chi_2$  with  $B - L$  charges  $Y_{BL} = -2, +2$ , respectively, for their Higgsonos  $U(1)_{B-L}$  anomaly freedom). Their scalar components' vevs  $v'_{1,2} = \langle \chi_{1,2} \rangle$  spontaneously break the  $U(1)_{B-L}$ ,
  - 3 a vector superfield for the  $U(1)_{B-L}$  gauge.
- The general expression for the covariant derivative  $D_\mu$  is defined as

$$D_\mu = \partial_\mu - ig_s T^a G_\mu^a - ig\tau^i W_\mu^i - ig' Y B_\mu - ig'' Y_{B-L} B'_\mu, \quad (17)$$

- The BLSSM superpotential is [6]

$$W_{\text{BLSSM}} = W_{\text{MSSM}} + W_{\text{BL}}, \quad (18)$$

where  $W_{\text{MSSM}}$  is the MSSM superpotential and the extra  $B - L$  part is

$$W_{\text{BL}} = (Y_\nu)_{ij} L_i H_2 N_j^c + (Y_N)_{ij} N_i^c \chi_1 N_j^c + \mu' \chi_1 \chi_2. \quad (19)$$

- BLSSM Spectrum:** Extra particles arise in BLSSM rather than in the MSSM

- 1 **Higgs:** Extra two scalars  $h'$ ,  $H'$ , and one pseudoscalar  $A'$
- 2 **Gauge:** Extra neutral gauge boson  $Z'$
- 3 **Neutrinos:** Extra three RH neutrinos.
- 4 **Sfermions:** Extra RH Sneutrinos
- 5 **Neutralinos:** Extra three neutralinos of  $Z'$ ,  $h'$ ,  $H'$

- BLSSM Problems:** Succeeded to introduce massive neutrinos but suffers  $\mu$ -problems of naturalness.

- The gauge kinetic mixing  $-\frac{k}{4}F_{\mu\nu}F'^{\mu\nu}$  [7, 8] induces the MSSM and  $B-L$  gauge sectors and Higgs sectors

$$G = \begin{pmatrix} g_Y & \tilde{g} \\ 0 & g_{BL} \end{pmatrix}, \quad Q_i = \begin{pmatrix} Q_Y \\ Q_{BL} \end{pmatrix}_i, \quad B_{U(1)} = \begin{pmatrix} B_\mu \\ B'_\mu \end{pmatrix}_i, \quad (20)$$

via the  $U(1)$   $D$ -term

$$\mathcal{L}_{U(1)-D-term} = \frac{1}{2} \sum (\phi_i^\dagger \phi_i) (Q_i^T G) (G^T Q_j) (\phi_j^\dagger \phi_j) \quad (21)$$

and the covariant derivative

$$D_\mu \supset -iQ_\phi^T G B_{U(1)} = -ig_Y Q_Y B_\mu - i(\tilde{g} Q_Y B_\mu + g_{BL} Q_{BL}) B'_\mu \quad (22)$$

- The complete electroweak symmetry breaking pattern of the LRIS is accomplished in the following two stages

$$SU(2)_L \times U(1)_Y \times U(1)_{B-L} \xrightarrow{\langle \chi_{1,2} \rangle} SU(2)_L \times U(1)_Y \xrightarrow{\langle H_{u,d} \rangle} U(1)_{\text{em}} \quad (23)$$

- The BLSSM neutral Higgs potential is

$$\begin{aligned} V = & |\mu|^2(|H_u^0|^2 + |H_d^0|^2) + |\mu'|^2(|\chi_1|^2 + |\chi_2|^2) + \frac{g^2}{8}(|H_u^0|^2 - |H_d^0|^2)^2 \\ & - \frac{\tilde{g}g_{BL}}{4}(|H_u^0|^2 - |H_d^0|^2)(|\chi_1|^2 - |\chi_2|^2) + \frac{g_{BL}^2}{2}(|\chi_1|^2 - |\chi_2|^2)^2 \\ & - m_u^2|H_u^0|^2 - m_d^2|H_d^0|^2 + \{B_\mu H_u^0 H_d^0 + h.c.\} \\ & - m_1^2|\chi_1|^2 - m_2^2|\chi_2|^2 - (B_{\mu'} \chi_1 \chi_2 + h.c.) \end{aligned} \quad (24)$$

- The  $4 \times 4$  scalar higgs mass matrix is the block matrix in the basis

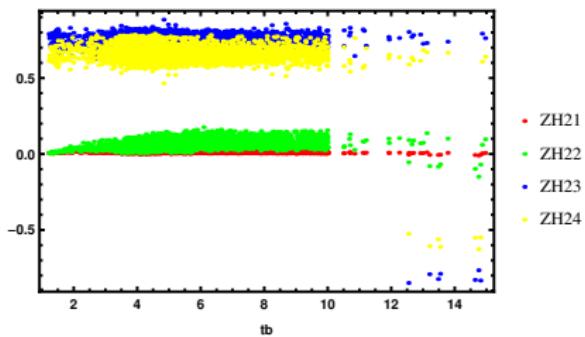
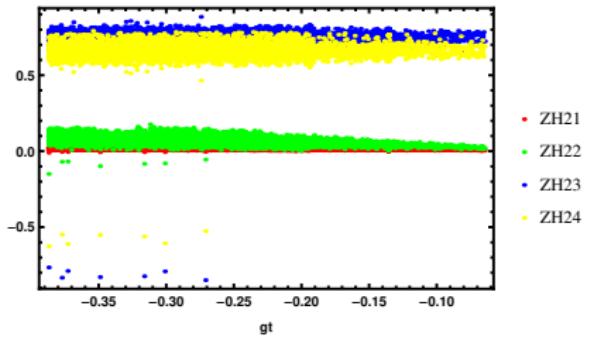
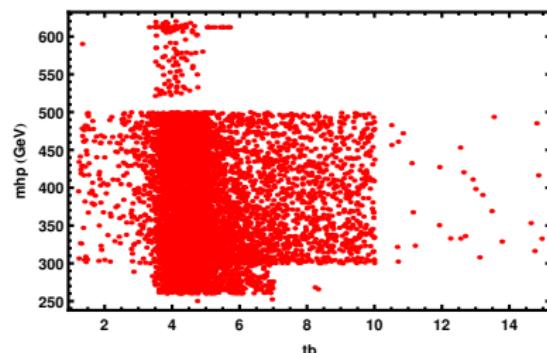
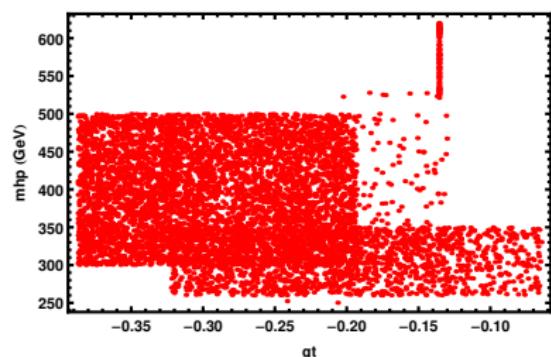
$$M_H^2 = \begin{pmatrix} M_{hH} & M_{hh'} \\ M_{hh'}^T & M_{h'H'} \end{pmatrix} \quad (25)$$

where the  $2 \times 2$  off-diagonal mixing block is

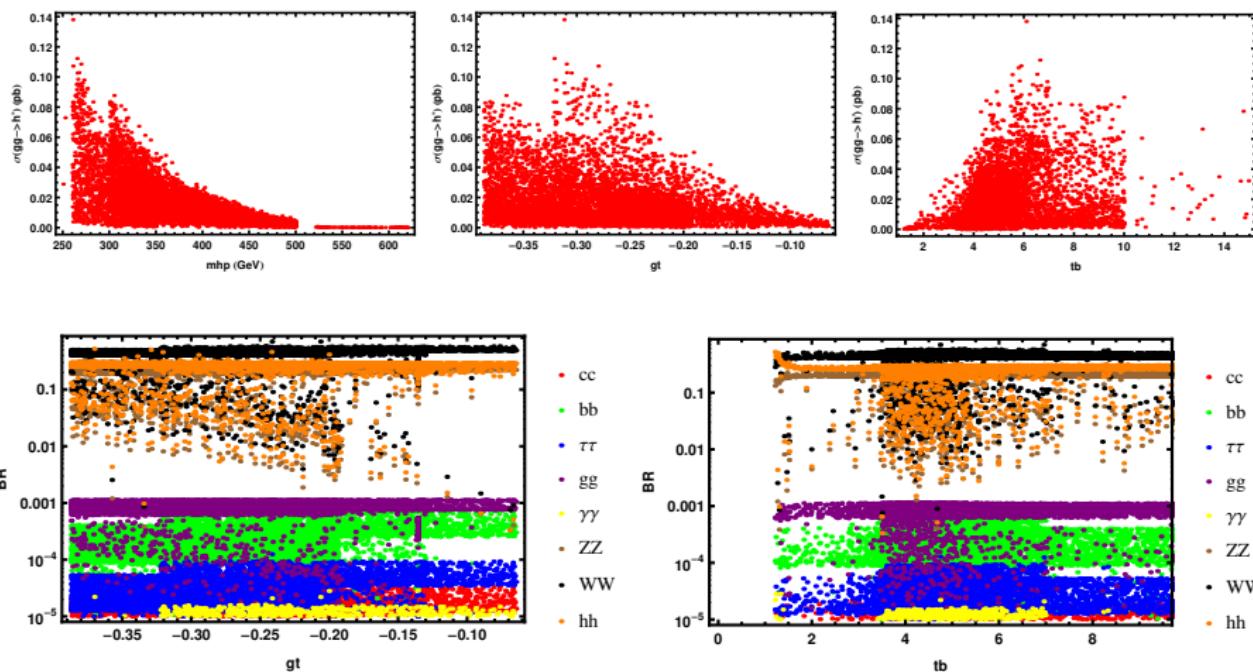
$$M_{hh'} = \frac{vx}{2} \tilde{g} g_{BL} \begin{pmatrix} -s_\beta s_{\beta'} & s_\beta c_{\beta'} \\ c_\beta s_{\beta'} & -c_\beta c_{\beta'} \end{pmatrix} \quad (26)$$

- Parameters are scanned over for

$$\begin{aligned} g_{BL} &\in [0.20, 0.80], \quad \tilde{g} \in [-0.50, 0.50], \quad t_\beta \in (1.00, 20.00], \\ t_{\beta'} &\in (1.00, 20.00], \quad x \sim \mathcal{O}(1 - 3) \text{ TeV}, \\ m_u^2 &\sim \mathcal{O}(-10^{7-6}) \text{ GeV}^2, \quad m_d^2 \sim \mathcal{O}(10^{6-7}) \text{ GeV}^2, \\ m_1^2 &\sim \mathcal{O}(-10^{6-7}) \text{ GeV}^2, \quad m_2^2 \sim \mathcal{O}(10^{6-7}) \text{ GeV}^2. \end{aligned} \quad (27)$$

The next lightest  $CP$ -even neutral Higgs boson mass  $\mathcal{O}(\text{GeV})$ 

# The next lightest $CP$ -even neutral Higgs boson production and decay branching ratios



- The interaction couplings of  $h'$  with  $Z_\mu$  gauge boson, and with the SM-like Higgs are

$$\begin{aligned}
 g_{h_i h_j h_k} = & \frac{i}{4} \left( Z_{i1}^H \left( g^2 Z_{j2}^H (v_d Z_{k2}^H + v_u Z_{k1}^H) - 2\bar{g} g_{BL} (Z_{j3}^H (v_d Z_{k3}^H + x_1 Z_{k1}^H) - Z_{j4}^H (x_2 Z_{k1}^H + v_d Z_{k4}^H)) \right. \right. \\
 & + Z_{j1}^H \left( -2\bar{g} g_{BL} (-x_2 Z_{k4}^H + x_1 Z_{k3}^H) + g^2 (-3v_d Z_{k1}^H + v_u Z_{k2}^H) \right) \\
 & + Z_{i2}^H \left( g^2 Z_{j1}^H (v_d Z_{k2}^H + v_u Z_{k1}^H) + 2\bar{g} g_{BL} (Z_{j3}^H (x_1 Z_{k2}^H + v_u Z_{k3}^H) - Z_{j4}^H (x_2 Z_{k2}^H + v_u Z_{k4}^H)) \right. \\
 & + Z_{j2}^H \left( 2\bar{g} g_{BL} (-x_2 Z_{k4}^H + x_1 Z_{k3}^H) + g^2 (-3v_u Z_{k2}^H + v_d Z_{k1}^H) \right) \\
 & + 2Z_{i3}^H \left( \bar{g} g_{BL} (Z_{j1}^H (v_d Z_{k3}^H + x_1 Z_{k1}^H) - Z_{j2}^H (x_1 Z_{k2}^H + v_u Z_{k3}^H)) - 2g_{BL}^2 Z_{j4}^H (x_2 Z_{k3}^H + x_1 Z_{k4}^H) \right. \\
 & + Z_{j3}^H \left( 2g_{BL}^2 (3x_1 Z_{k3}^H - x_2 Z_{k4}^H) + \bar{g} g_{BL} (v_d Z_{k1}^H - v_u Z_{k2}^H) \right) \\
 & \left. \left. + 2Z_{i4}^H (\bar{g} g_{BL} (Z_{j1}^H (x_2 Z_{k1}^H + v_d Z_{k4}^H) - Z_{j2}^H (x_2 Z_{k2}^H + v_u Z_{k4}^H)) + 2g_{BL}^2 Z_{j3}^H (x_2 Z_{k3}^H + x_1 Z_{k4}^H) \right. \right. \\
 & + Z_{j4}^H \left( 2g_{BL}^2 (-3x_2 Z_{k4}^H + x_1 Z_{k3}^H) + \bar{g} g_{BL} (v_d Z_{k1}^H + v_u Z_{k2}^H) \right) \quad (28)
 \end{aligned}$$

$$g_{h_i ZZ} = \frac{i}{2} \left[ v(g_1 c_{w'} s_w + g_2 c_w c_{w'})^2 (Z_{i1}^H c_\beta + Z_{i2}^H s_\beta) + 4x(-g_{BL} s_{w'})^2 (Z_{i3}^H s_{\beta'} + Z_{i4}^H c_{\beta'}) \right] \quad (29)$$

Par	$g_Y$	$g_{BL}$	$\tilde{g}$	$g_L$	$t_\beta$	$t_{\beta'}$
<b>BP1</b>	0.356	0.616	<b>-0.403</b>	0.662	6.083	0.134
<b>BP2</b>	0.356	0.675	<b>-0.441</b>	0.662	12.568	1.333

Par	$x$ (GeV)	$m_u^2$ (GeV $^2$ )	$m_d^2$ (GeV $^2$ )	$m_1^2$ (GeV $^2$ )	$m_2^2$ (GeV $^2$ )
<b>BP1</b>	6400	$-1.796 \times 10^7$	$1.087 \times 10^6$	$-5.550 \times 10^4$	$3.788 \times 10^6$
<b>BP2</b>	2500	$-1.796 \times 10^7$	$1.087 \times 10^6$	$-7.000 \times 10^5$	$3.000 \times 10^6$

**Table 1:** Benchmark points (BP) for analysis.

Mass (GeV)	$m_{h^\pm}$	$m_A$	$m_{A'}$	$m_{h_1}(h)$	$m_{h_2}(h')$	$m_{h_3}(H')$	$m_{h_4}(H)$
<b>BP1</b>	4255	3515	4255	125	320	3796	4275
<b>BP2</b>	4255	3160	4166	126	326	3573	4180

**Table 2:** Higgs spectrum corresponding to BPs of Table 1.

Mix	$Z_{11}^H$	$Z_{12}^H$	$Z_{13}^H$	$Z_{14}^H$	$Z_{21}^H$	$Z_{22}^H$	$Z_{23}^H$	$Z_{24}^H$
<b>BP1</b>	0.160	0.971	-0.138	-0.110	0.029	0.174	0.757	0.629
<b>BP2</b>	0.078	0.985	-0.120	-0.096	0.012	0.153	0.751	0.642
Mix	$Z_{31}^H$	$Z_{32}^H$	$Z_{33}^H$	$Z_{34}^H$	$Z_{41}^H$	$Z_{42}^H$	$Z_{43}^H$	$Z_{44}^H$
<b>BP1</b>	0.005	0.003	0.638	-0.770	-0.987	0.162	0.003	-0.003
<b>BP2</b>	0.002	0.005	0.649	-0.761	-0.997	0.079	0.002	-0.002

**Table 3:** Neutral  $CP$ -even Higgs mixing corresponding to the BPs of Table 1.

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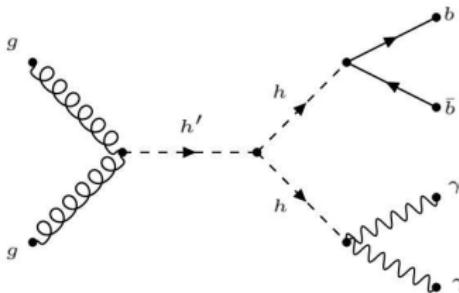
- $h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$
- $h' \rightarrow ZZ \rightarrow 4\ell$
- $h' \rightarrow WW \rightarrow \ell^+\ell^- + \not{E}_T$

### 3 Conclusion

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$$h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$$

## ■ Feynman diagram



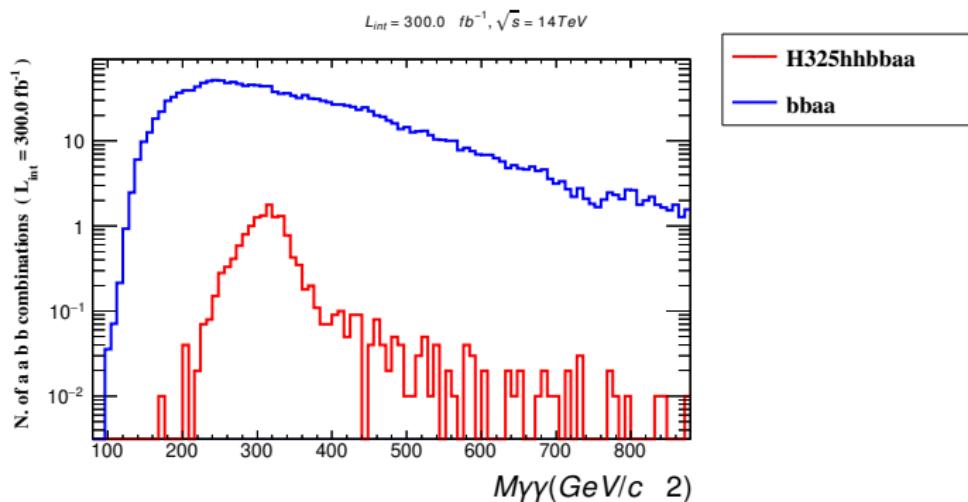
- We have  $\Gamma_{h'}/m_{h'} \ll 1$  and in the narrow width approximation the total cross section  $\sigma(pp \rightarrow h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma)$  is decomposed into

$$\sigma(pp \rightarrow h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma) \approx \sigma(pp \rightarrow h') \times \text{BR}(h' \rightarrow hh) \times \text{BR}(h \rightarrow b\bar{b}) \times \text{BR}(h \rightarrow \gamma\gamma), \quad (30)$$

- The relevant background from the SM processes are

$$pp \rightarrow bbh\gamma\gamma/bbj\alpha/bbjj/cc\gamma\gamma/ccj\gamma/jj\gamma\gamma/ggh\gamma\gamma/tt/tt\gamma/tth\gamma\gamma/bbz\gamma\gamma/zh\gamma\gamma.$$

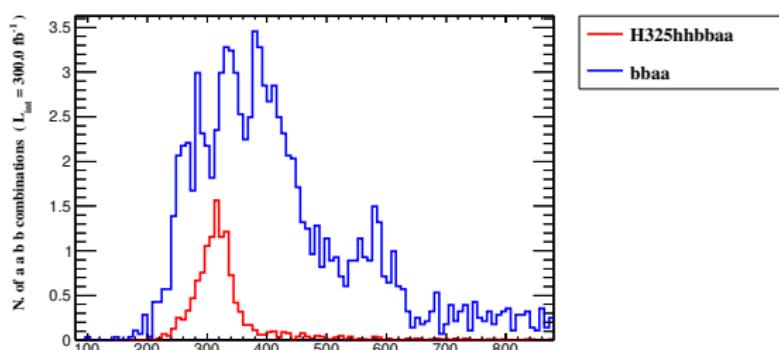
- All these backgrounds can be reduced by appropriate kinematics cuts as Tab. 6.



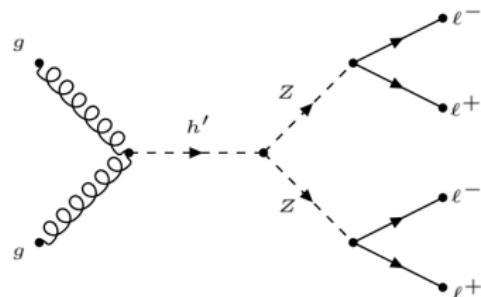
**Figure 1:** Number of signal events for  $h' \rightarrow b\bar{b}\gamma\gamma$  decays at mass  $m_{h'} = 250 \text{ GeV}$  (blue) and  $400 \text{ GeV}$  (red) induced by ggF versus the invariant mass of the final states  $b\bar{b}\gamma\gamma$ , at  $\sqrt{s} = 14 \text{ TeV}$  and  $L_{int} = 300 \text{ fb}^{-1}$  alongside with the relevant background events (black) before (left) and after (right) applying the cut flow of Tab. 6.

Cuts (select)	Signal (S): $m_{h'} = 325$ GeV)	Background (B)	$S/\sqrt{B}$
Initial (no cut)	99.70	24948.0	0.63100
$E_T > 240.0$	$84.40 \pm 3.60$	$10909.3 \pm 78.4$	$0.80771 \pm 0.00033$
$M_{\gamma\gamma} < 130.0$	$37.55 \pm 4.84$	$1834.4 \pm 41.2$	$0.87683 \pm 0.00257$
$M_{\gamma\gamma} > 120.0$	$36.00 \pm 4.80$	$275.0 \pm 16.5$	$2.16900 \pm 0.01500$

**Table 4:**  $pp \rightarrow h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$  cut flow  $m_{h'} = 325$  GeV.

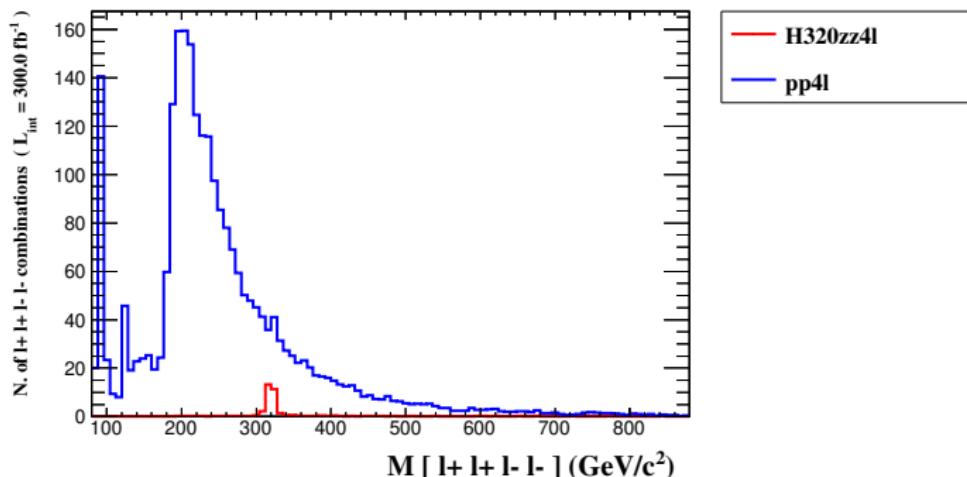


- The process  $pp \rightarrow h' \rightarrow ZZ \rightarrow 4\ell$  ( $\ell = e, \mu$ ) Feynman diagram



- In the narrow width approximation, the total cross section can be written as

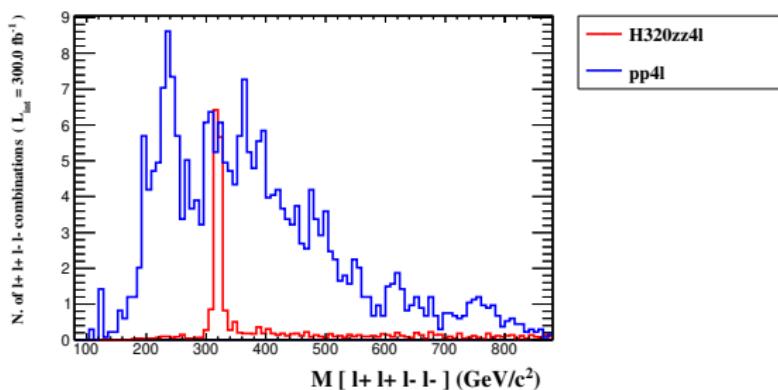
$$\sigma(pp \rightarrow h' \rightarrow ZZ \rightarrow 4\ell) \approx \sigma(pp \rightarrow h') \times \text{BR}(h' \rightarrow ZZ) \times (\text{BR}(Z \rightarrow 2\ell))^2, \quad (31)$$



**Figure 3:** Number of signal events for  $pp \rightarrow h' \rightarrow ZZ \rightarrow 4\ell$  decays at mass  $m_{h'} = 320 \text{ GeV}$  (red) induced by ggF and VBF versus the invariant mass of the final state  $4\ell$ , at a center-of-mass energy  $\sqrt{s} = 14 \text{ TeV}$  and integrated luminosity  $300 \text{ fb}^{-1}$  of luminosity alongside the relevant background events background (blue) before (left) and after (right) applying the cut flow set of Table 5. Corresponding cross sections and branching ratios are given in Table 5.

Cuts (select)	Signal (S): $m_{h'} = 320$ GeV	Background (B)	$S/\sqrt{B}$
Initial (no cut)	163.00	7491.0	1.88000
$E_T > 340.0$	$90.44 \pm 6.35$	$874.9 \pm 27.8$	$3.05764 \pm 0.00654$

**Table 5:**  $pp \rightarrow h' \rightarrow ZZ \rightarrow 4\ell$  Sg vs Bkg number of events for  $m_{h'} = 320$  GeV before and after cut on the scalar sum of the transverse energy of all final state objects  $E_T$ .

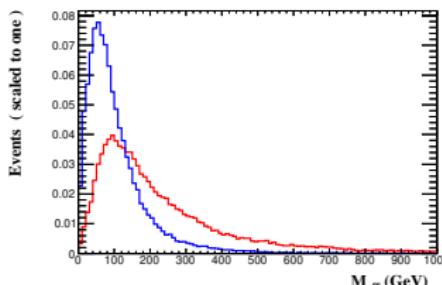
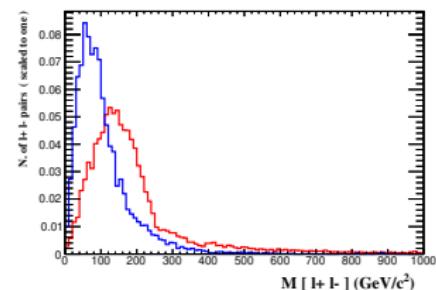
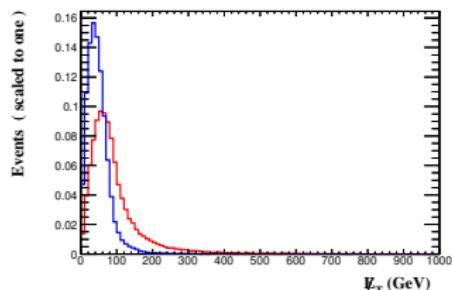


$$h' \rightarrow WW \rightarrow \ell^+\ell^- + \cancel{E}_T$$

- The process  $pp \rightarrow h' \rightarrow ZZ \rightarrow 4\ell$  ( $\ell = e, \mu$ ) Feynman diagram

$$\sigma(h' \rightarrow WW \rightarrow \ell^+\ell^- + \cancel{E}_T) \sim 0.015 \text{ (pb)}, \quad (32)$$

$$\sigma(pp \rightarrow WW \rightarrow \ell^+\ell^- + \cancel{E}_T) \sim 3.400 \text{ (pb)}, \quad \ell = e, \mu. \quad (33)$$



Cuts (select)	Signal (S): $m_{h'} = 320$ GeV	Background (B)	$S/\sqrt{B}$
Initial (no cut)	4611.0	1020000	4.57
$\cancel{E}_T > 120$	$973.1 \pm 27.7$	$31395.0 \pm 174.0$	$5.49 \pm 0.00085$
$M_{\ell^+ \ell^-} > 120$	$362.0 \pm 18.3$	$3672.0 \pm 60.5$	$5.97 \pm 0.00434$
$M_{\text{eff}} > 220$	$321.4 \pm 17.3$	$2346.0 \pm 48.4$	$6.64 \pm 0.00611$

**Table 6:**  $pp \rightarrow h' \rightarrow WW \rightarrow \ell^+ \ell^- + \cancel{E}_T$  Signal versus Background number of events for  $m_{h'} = 320$  GeV.

## Outline

### 1 *B – L Supersymmetric Extension of the Standard Model (BLSSM)*

- MSSM
- BLSSM
- Mass Spectrum
- Higgs Sector

### 2 *Search for Heavy Higgs Bosons at the LHC*

- $h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$
- $h' \rightarrow ZZ \rightarrow 4\ell$
- $h' \rightarrow WW \rightarrow \ell^+\ell^- + \cancel{E}_T$

### 3 **Conclusion**

### 4 **References**

- BLSSM is a minimal extension to MSSM which accounts for neutrino masses.
- Phenomenology of BSM Higgs is viable in BLSSM than in MSSM.
- Proof of a heavy  $CP$ -even neutral Higgs boson is possible in BLSSM than in MSSM through  $h' \rightarrow hh, ZZ, WW$  for  $m_{h'} \sim \mathcal{O}$  (few GeVs).

## Outline

### 1 *B – L Supersymmetric Extension of the Standard Model (BLSSM)*

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- $h' \rightarrow hh \rightarrow b\bar{b}\gamma\gamma$
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### 3 Conclusion

### 4 References

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*Thank you!  
Questions?*