Mass Spectrum and Higgs Profile in BLSSM
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Higgs Couplings
Oxford, UK
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Outline

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   Problems of the Standard Model
   Minimal Supersymmetric Extension of the SM

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   Parameter Space & Constraints

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   Higgs Decays
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The SM is not the chosen one!

- Supersymmetry has reasonable solution to all of these problems.
Minimal Supersymmetric Extention of the SM

Solutions to the SM problems

- Dark Matter candidate!
- Cancellation terms to the Higgs mass loop corrections.
- Force unification.

But still..

- Neutrino masses ?
- \( \mu \) problem
- Muon anomalous magnetic moment
- No sparticle has yet to be detected!
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**B-L extension of the Standard Model**

GUT-inspired $U(1)_{B-L}$ extended MSSM symmetry breaking scheme

$$SO(10) \rightarrow SU(5) \otimes U(1)_X$$
$$\rightarrow SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_{B-L}$$

$$W = Y_{ij}^u \hat{Q}_i \hat{H}_u \hat{d}_j^c - Y_{ij}^d \hat{Q}_i \hat{H}_d \hat{e}_j^c - Y_{ij}^e \hat{L}_i \hat{H}_d \hat{e}_j^c + \mu H_u H_d$$
$$+ Y_{ij}^\nu \hat{L}_i \hat{H}_u N_j^c + Y_{ij}^N \hat{N}_j^c N_j^c \chi_1 + \mu' \chi_1 \chi_2$$

<table>
<thead>
<tr>
<th>SF</th>
<th>$U(1) \otimes SU(2)_L \otimes SU(3)<em>C \otimes U(1)</em>{B-L}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{Q}$</td>
<td>$(\frac{1}{6}, 2, 3, 1/6)$</td>
</tr>
<tr>
<td>$\hat{L}$</td>
<td>$(-\frac{1}{2}, 2, 1, -1/2)$</td>
</tr>
<tr>
<td>$\hat{d}$</td>
<td>$(\frac{1}{3}, 1, 3, -1/6)$</td>
</tr>
<tr>
<td>$\hat{u}$</td>
<td>$(-\frac{2}{3}, 1, 3, -1/6)$</td>
</tr>
<tr>
<td>$\hat{e}$</td>
<td>$(1, 1, 1, 1/2)$</td>
</tr>
<tr>
<td>$\hat{N}$</td>
<td>$(0, 1, 1, 1/2)$</td>
</tr>
<tr>
<td>$\hat{H}_d$</td>
<td>$(-\frac{1}{2}, 2, 1, 0)$</td>
</tr>
<tr>
<td>$\hat{H}_u$</td>
<td>$(\frac{1}{2}, 2, 1, 0)$</td>
</tr>
<tr>
<td>$\hat{\chi}_1$</td>
<td>$(-\frac{1}{2}, 2, 1, -2)$</td>
</tr>
<tr>
<td>$\hat{\chi}_2$</td>
<td>$(\frac{1}{2}, 2, 1, +2)$</td>
</tr>
</tbody>
</table>

- Light $h_2$ masses $\lesssim 150$ GeV
- Additional Dark Matter Candidate
- Muon anomalous magnetic moment
### Parameter Space & Constraints

#### Universality Boundary Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scanned range</th>
<th>Parameter</th>
<th>Scanned range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_0$</td>
<td>[0.0, 3.0] TeV</td>
<td>$\text{diag}(Y_{ij}^U)$</td>
<td>[0.001, 0.99]</td>
</tr>
<tr>
<td>$M_{1/2}$</td>
<td>[0.0, 5.0] TeV</td>
<td>$\text{diag}(Y_{ij}^N)$</td>
<td>~ 0.4</td>
</tr>
<tr>
<td>$A_0/m_0$</td>
<td>[−3.0, 3.0]</td>
<td>$\text{sign of } \mu$</td>
<td>positive</td>
</tr>
<tr>
<td>$\tan \beta$</td>
<td>[1.2, 60.0]</td>
<td>$\text{sign of } \mu'$</td>
<td>positive</td>
</tr>
<tr>
<td>$\tan \beta'$</td>
<td>[1.0, 1.2]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Observable Constraints

<table>
<thead>
<tr>
<th>Observable</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{h_1}$</td>
<td>[123, 127] GeV</td>
</tr>
<tr>
<td>$m_{\tilde{g}}$</td>
<td>&gt; 1.8 TeV</td>
</tr>
<tr>
<td>$m_{\tilde{\tau}_1}$</td>
<td>&gt; 105 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{q}}$</td>
<td>&gt; 1400 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{\ell}_1}$</td>
<td>&gt; 107 GeV</td>
</tr>
<tr>
<td>$\chi^2(\hat{\mu})$</td>
<td>≤ 2.3</td>
</tr>
<tr>
<td>$\frac{\text{BR}(B \rightarrow \tau \nu_\tau)}{\text{BR}<em>{SM}(B \rightarrow \tau \nu</em>\tau)}$</td>
<td>[0.15, 2.41]</td>
</tr>
<tr>
<td>$m_{Z'}$</td>
<td>≥ 2.5 TeV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\tilde{\tau}_1}$</td>
<td>≥ 730 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{\ell}_1}$</td>
<td>≥ 103.5 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{\mu}_1}$</td>
<td>≥ 222 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{\mu}_1}$</td>
<td>&gt; 81 GeV</td>
</tr>
<tr>
<td>$m_{\tilde{\mu}_1}$</td>
<td>&gt; 94 GeV</td>
</tr>
<tr>
<td>$\Omega_{\text{DM}} h^2$</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observable</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-)}{\text{BR}(B_s^0 \rightarrow X_s \gamma)}$</td>
<td>[1.1, 6.4] × 10$^{-9}$</td>
</tr>
<tr>
<td>$\frac{\text{BR}(B_s^0 \rightarrow X_s \gamma)}{\text{BR}(B_s^0 \rightarrow \tau \nu_\tau)}$</td>
<td>[2.99, 3.87] × 10$^{-4}$</td>
</tr>
</tbody>
</table>
Free Parameters

- Green points satisfy the mass bounds and the constraints from the rare B decays.
- Blue points form a subset of green and they represent solutions with $m_{h^2} \lesssim 150$ GeV.
$U(1)_{B-L}$ Symmetry Breaking

- The breaking of $U(1)_{B-L}$ happens at about $v_X \approx 5$ TeV.
- $U(1)_{B-L}$ breaking can happen when both ($v_X > M_{SUSY}$) and ($v_X < M_{SUSY}$).
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BLSSM Sparticle Masses

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BLSSM Sparticle Masses

- \( m_{\chi_1^0} \) vs. \( m_{\chi_1^0} \)
- \( m_{\chi_2^0} \) vs. \( m_{\chi_1^0} \)
- \( m_{\chi_1^+} \) vs. \( m_{\chi_1^0} \)
- \( m_{\chi_1^0} \) vs. \( m_{\chi_1^0} \)
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BLSSM Sparticle Masses and Higgs Sector
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**ATLAS**

Run 1: $\sqrt{s} = 7-8$ TeV, 25 fb$^{-1}$, Run 2: $\sqrt{s} = 13$ TeV, 36.1 fb$^{-1}$

- **Run 1** $H \rightarrow 4\ell$: $124.51 \pm 0.52 (\pm 0.52)$ GeV
- **Run 1** $H \rightarrow \gamma\gamma$: $126.02 \pm 0.51 (\pm 0.43)$ GeV
- **Run 2** $H \rightarrow 4\ell$: $124.79 \pm 0.37 (\pm 0.36)$ GeV
- **Run 2** $H \rightarrow \gamma\gamma$: $124.93 \pm 0.40 (\pm 0.21)$ GeV
- **Run 1+2** $H \rightarrow 4\ell$: $124.71 \pm 0.30 (\pm 0.30)$ GeV
- **Run 1+2** $H \rightarrow \gamma\gamma$: $125.32 \pm 0.35 (\pm 0.19)$ GeV
- **Run 1 Combined** $H \rightarrow \gamma\gamma$: $125.38 \pm 0.41 (\pm 0.37)$ GeV
- **Run 2 Combined** $H \rightarrow \gamma\gamma$: $124.86 \pm 0.27 (\pm 0.18)$ GeV
- **Run 1+2 Combined** $H \rightarrow \gamma\gamma$: $124.97 \pm 0.24 (\pm 0.16)$ GeV

**Total**

<table>
<thead>
<tr>
<th><strong>Stat. only</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$125.09 \pm 0.24 (\pm 0.21)$ GeV</td>
</tr>
</tbody>
</table>

$m_H$ [GeV]

arXiv 1806.00242
Higgs Decays \((h \rightarrow \gamma \gamma)\)

\[
R^{\text{eff}}_{\gamma\gamma} = R^{1}_{\gamma\gamma} + R^{2}_{\gamma\gamma}
\]

\[
R^{i}_{\gamma\gamma} = \frac{\sigma(pp \rightarrow h_{i}) \times BR(h_{i} \rightarrow \gamma \gamma)}{\sigma(pp \rightarrow h)_{SM} \times BR(h \rightarrow \gamma \gamma)_{SM}}
\]

\[
m^{\text{eff}}_{h} = \frac{m_{h_{1}} R^{1}_{\gamma\gamma} + m_{h_{2}} R^{2}_{\gamma\gamma}}{R^{1}_{\gamma\gamma} + R^{2}_{\gamma\gamma}}
\]
BLSSM predictions for $h \rightarrow ZZ^* \rightarrow 4\ell$ at about 125 GeV are only as good as the SM!

The excess for $h \rightarrow ZZ^* \rightarrow 4\ell$ at about 145 GeV can be realized.
Conclusion

- $U(1)_{B-L}$ symmetry breaks at about 5 TeV.

- Right-handed neutrinos can trigger baryon and lepton number violating process till they decouple from the SM sector at 1.7 - 2.2 TeV.

- Radiative breaking of B - L symmetry can happen in both supersymmetric ($\nu_X > M_{\text{SUSY}}$) and non-supersymmetric ($\nu_X < M_{\text{SUSY}}$).

- The sneutrino-antisneutrino mixing can be counted as another source for baryon and lepton asymmetry in the Universe.

- $m_{\tilde{b}} \gtrsim 1.5$ TeV

- $m_{\tilde{t}} \gtrsim 1$ TeV

- $m_{\tilde{g}} \gtrsim 2$ TeV

- $m_{h_2} < 150$ GeV

- $h \rightarrow \gamma\gamma$ at about 125 GeV mass scale can be realized.

- The excess $h \rightarrow \gamma\gamma$ at about 137 GeV mass scale are rather excluded by the 125 GeV Higgs boson constraint.

- $h \rightarrow ZZ^* \rightarrow 4\ell$ are only as good as the SM but such solutions can be cured by considering non-universal boundary conditions in BLSSM.
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thank you!