Mass Spectrum and Higgs Profile in BLSSM

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Higgs Couplings
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Outline

1. Introduction
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   - Minimal Supersymmetric Extension of the SM
2. B-L extension of the Standard Model
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3. Results
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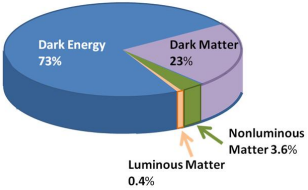
   - Higgs Sector
   - Higgs Boson Production
   - Higgs Decays

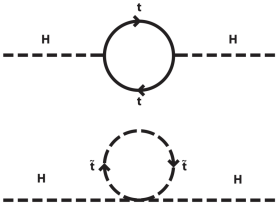
Outline

The SM is not the chosen one!

Dark Matter!

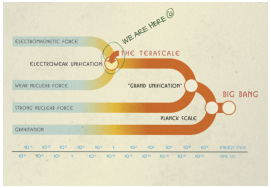


Gauge Hierarchy Problem!



Neutrino Masses & Oscillations!

Grand Unification!

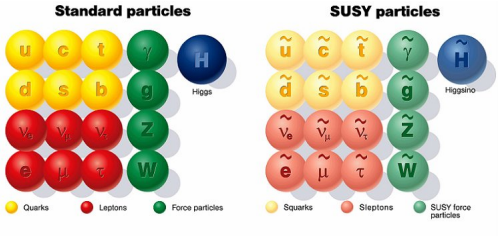


- Supersymmetry has reasonable solution to all of these problems.

Minimal Supersymmetric Extention of the SM

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \;\; \tilde{d}_L)$	$(u_L \;\; d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
($\times$3 families)	$\overline{u}$	$\tilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\overline{d}$	$\tilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \;\; \tilde{e}_L)$	$(\nu \;\; e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
($\times$3 families)	$\overline{e}$	$\tilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H^+_u \;\; H^0_u)$	$(\tilde{H}^+_u \;\; \tilde{H}^0_u)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H^0_d \;\; H^-_d)$	$(\tilde{H}^0_d \;\; \tilde{H}^-_d)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

$$W = Y_u^{ij} \hat{Q}_i \hat{H}_u \hat{u}_j^c - Y_d^{ij} \hat{Q}_i \hat{H}_d \hat{d}_j^c - Y_e^{ij} \hat{L}_i \hat{H}_d \hat{e}_j^c + \mu H_u H_d$$



Solutions to the SM problems

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

But still..

- Neutrino masses ?
- μ problem
- Muon anomalous magnetic moment
- No sparticle has yet to be detected!

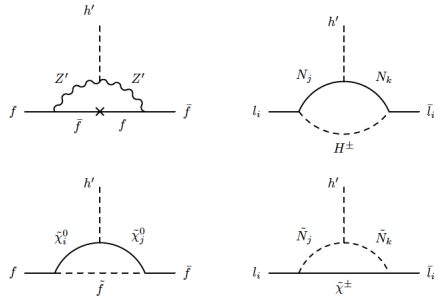
Outline

B-L extension of the Standard Model

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

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

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



SF	$U(1)_Y \otimes SU(2)_L \otimes SU(3)_C \otimes U(1)_{B-L}$
$\hat{Q}$	$(\frac{1}{6}, \mathbf{2}, \mathbf{3}, 1/6)$
$\hat{L}$	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1}, -1/2)$
$\hat{d}$	$(\frac{1}{3}, \mathbf{1}, \overline{\mathbf{3}}, -1/6$
$\hat{u}$	$(-\frac{2}{3}, \mathbf{1}, \overline{\mathbf{3}}, -1/6)$
$\hat{e}$	$(\mathbf{1}, \mathbf{1}, \mathbf{1}, 1/2)$
$\hat{N}$	$(\mathbf{0}, \mathbf{1}, \mathbf{1}, 1/2)$
$\hat{H}_d$	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1}, 0)$
$\hat{H}_u$	$(\frac{1}{2}, \mathbf{2}, \mathbf{1}, 0)$
$\hat{\chi}_1$	$(-\frac{1}{2}, \mathbf{2}, \mathbf{1}, -2)$
$\hat{\chi}_2$	$(\frac{1}{2}, \mathbf{2}, \mathbf{1}, +2)$

- Light h_2 masses $\lesssim 150$ GeV
- Additional Dark Matter Candidate
- Muon anomalous magnetic moment

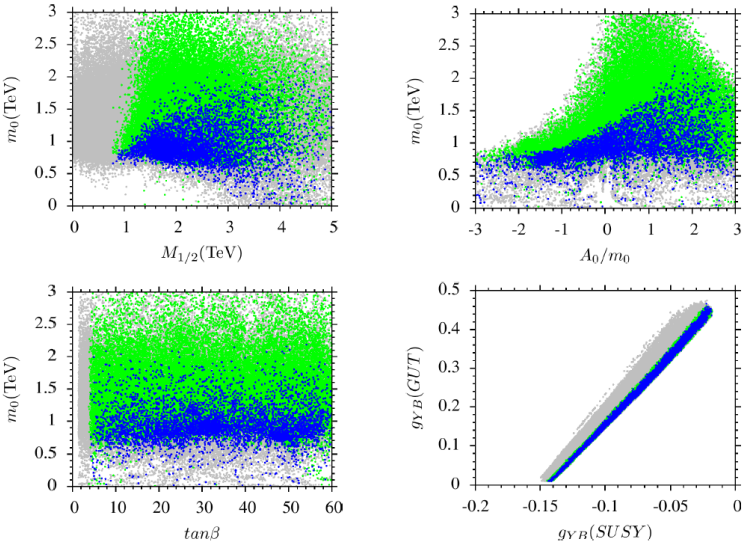
Parameter Space & Constraints

Universality Boundary Conditions

Parameter	Scanned range	Parameter	Scanned range
m_0	$[0., 3.]$ TeV	$diag(Y_\nu^{ij})$	$[0.001, 0.99]$
$M_{1/2}$	$[0., 5.]$ TeV	$diag(Y_N^{ij})$	~ 0.4
A_0/m_0	$[-3., 3.]$	sign of μ	positive
$\tan\beta$	$[1.2, 60.]$	sign of μ'	positive
$\tan\beta'$	$[1., 1.2]$		

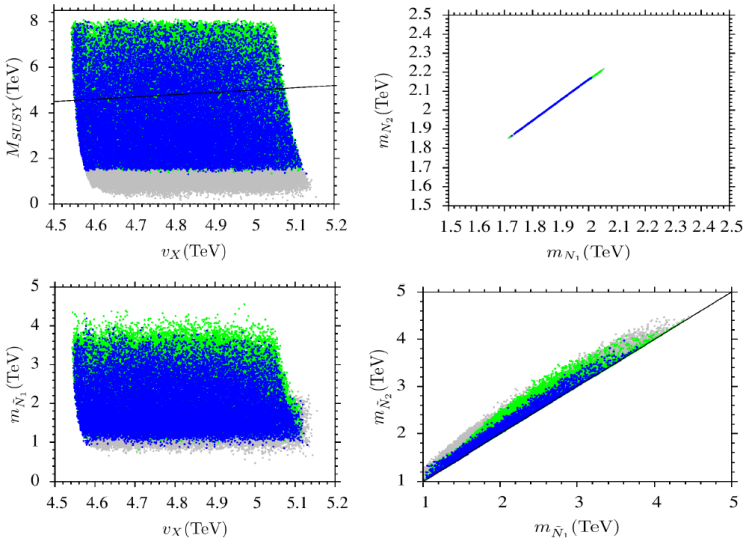
Observable	Constraints	Observable	Constraints
m_{h_1}	$[123, 127]$ GeV	$m_{\tilde{t}_1}$	$\geqslant 730$ GeV
$m_{\tilde{g}}$	> 1.8 TeV	$m_{\chi_1^\pm}$	$\geqslant 103.5$ GeV
$m_{\tilde{\tau}_1}$	$\geqslant 105$ GeV	$m_{\tilde{b}_1}$	$\geqslant 222$ GeV
$m_{\tilde{q}}$	$\geqslant 1400$ GeV	$m_{\tilde{\tau}_1}$	> 81 GeV
$m_{\tilde{e}_1}$	> 107 GeV	$m_{\tilde{\mu}_1}$	> 94 GeV
$\chi^2(\hat{\mu})$	≤ 2.3	$\mathrm{BR}(B_s^0 \to \mu^+\mu^-)$	$[1.1, 6.4] \times 10^{-9}$
$\frac{\mathrm{BR}(B \to \tau\nu_\tau)}{\mathrm{BR}_{SM}(B \to \tau\nu_\tau)}$	$[0.15, 2.41]$	$\mathrm{BR}(B^0 \to X_s\gamma)$	$[2.99, 3.87] \times 10^{-4}$
$m_{Z'}$	$\gtrsim 2.5$ TeV	$\Omega_{DM}h^2$	-

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.

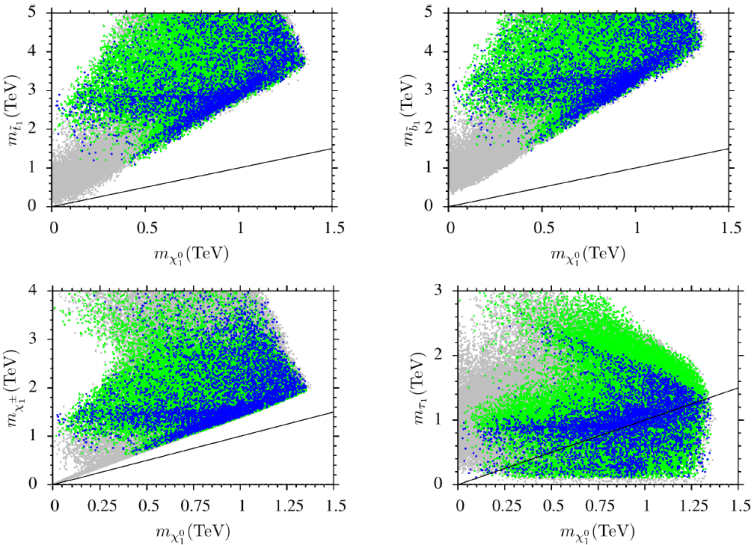
$U(1)_{B-L}$ Symmetry Breaking



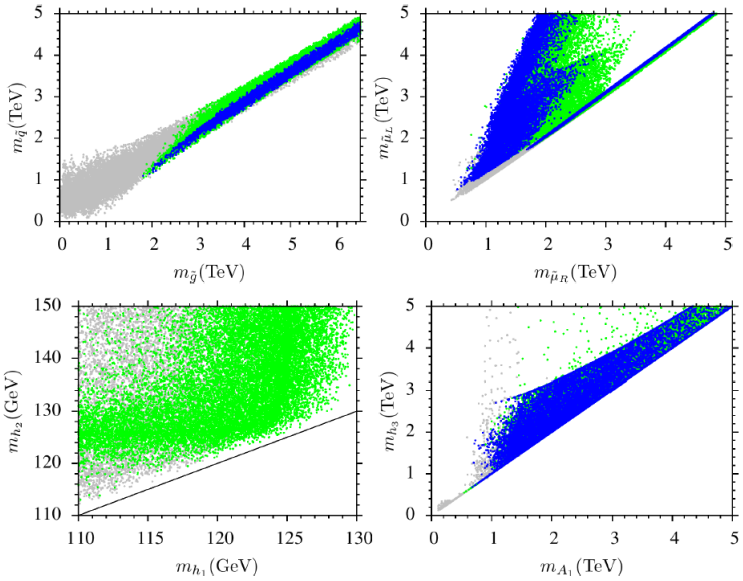
- The breaking of $U(1)_{B-L}$ happens at about v_X 5 TeV.
- $U(1)_{B-L}$ breaking can happen when both ($v_X > M_{\mathrm{SUSY}}$) and ($v_X < M_{\mathrm{SUSY}}$)

Outline

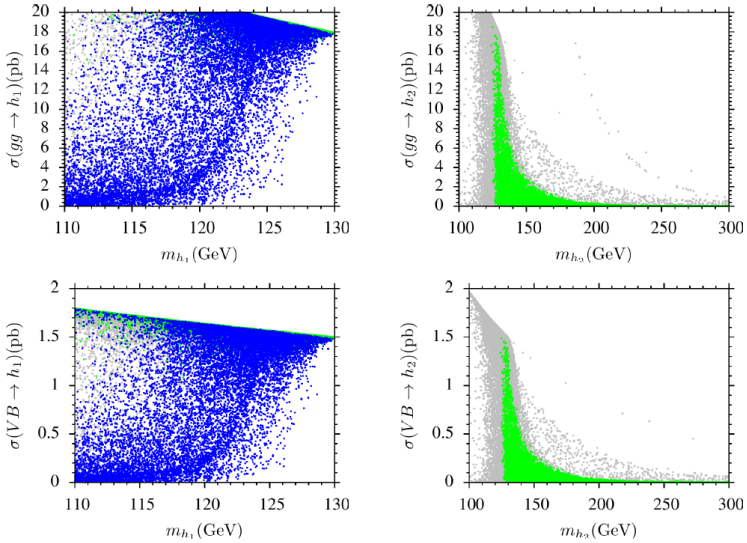
BLSSM Sparticle Masses



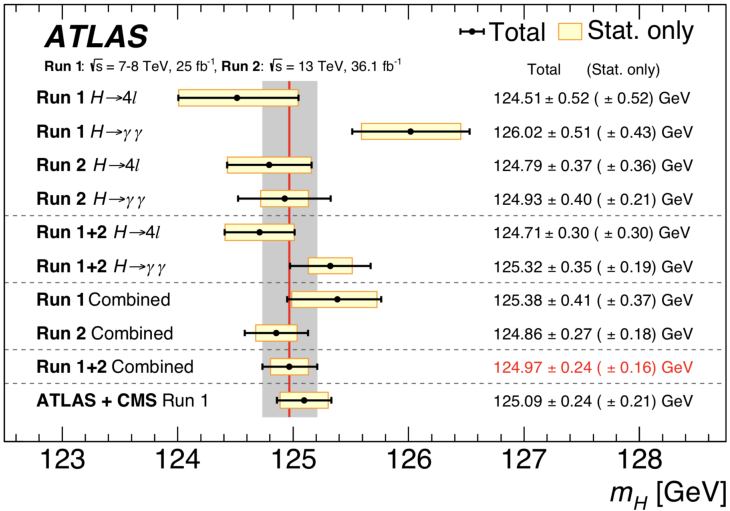
BLSSM Sparticle Masses and Higgs Sector



Higgs Boson Production



Higgs Decays



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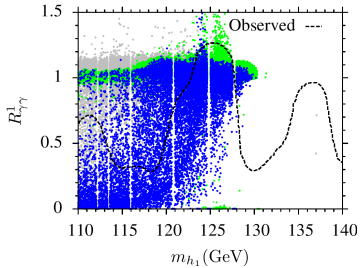
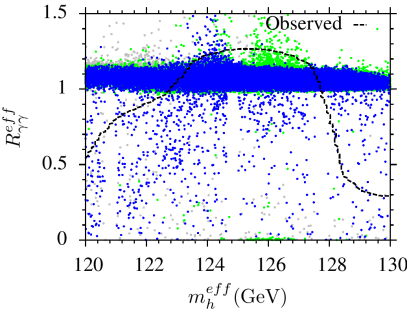
Higgs Decays ($h \to \gamma\gamma$)



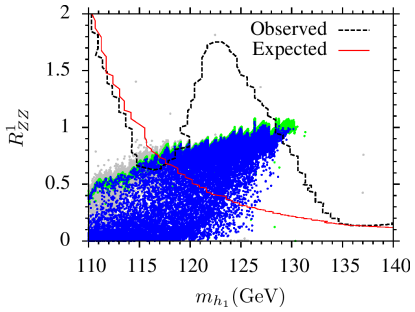


$$R^{eff}_{\gamma\gamma} = R^1_{\gamma\gamma} + R^2_{\gamma\gamma}$$

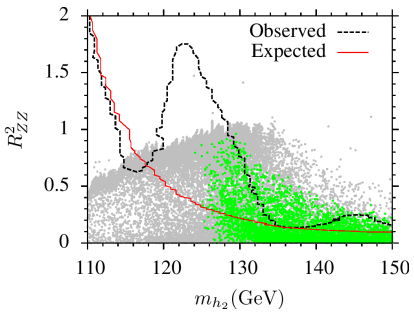
$$R^i_{\gamma\gamma} = \frac{\sigma(pp \to h_i) \times BR(h_i \to \gamma\gamma)}{\sigma(pp \to h)_{SM} \times BR(h \to \gamma\gamma)_{SM}}$$

$$m^{eff}_h = \frac{m_{h_1} R^1_{\gamma\gamma} + m_{h_2} R^2_{\gamma\gamma}}{R^1_{\gamma\gamma} + R^2_{\gamma\gamma}}$$

Higgs Decays ($h \to ZZ^* \to 4\ell$)



BLSSM predictions for $h \to ZZ^* \to 4\ell$ at about 125 GeV are only as good as the SM!



The excess for $h \to ZZ^* \to 4\ell$ 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 supersymemtric ($v_X > M_{\rm SUSY}$) and non-supersymmetric ($v_X < M_{\rm SUSY}$).
- 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

- $h \to \gamma\gamma$ at about 125 GeV mass scale can be realized.
- The excess $h \to \gamma\gamma$ at about 137 GeV mass scale are rather excluded by the 125 GeV Higgs boson constraint.
- $h \to ZZ^* \to 4\ell$ are only as good as the SM but such solutions can be cured by considering non-universal boundary conditions in BLSSM.