Charged Higgs in MSSM and Beyond

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"Charged Higgs boson in MSSM and beyond" Phys. Rev. D 97, 115041 (2018)

Outline

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  - In the SUSY theories, the stability problem of the hierarchy between the Electroweak (EW) and Planck scales is solved by introducing new particles, called superpartners, for each particle of the SM.
  - One of the main motivations of the SUSY is its natural Weakly Interacting Massive Particle (WIMP) candidate for DM puzzle, called Lightest Supersymmetric Particle (LSP).

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- Charged Higgs boson plays a crucial role among these extra Higgs bosons.
  - SM does not have any charged scalar.
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- **Its decays channels can be directly related to new physics.**
- **Different SUSY models may give different predictions for this distinguishing particle.**

Models

MSSM

Gauge Structure:

$SU(3) \times SU(2) \times U(1)_Y$

Superpotential:

$W_{MSSM} = \mu \hat{H}_u \hat{H}_d + Y_u \hat{Q} \hat{H}_u \hat{U} + Y_d \hat{Q} \hat{H}_d \hat{D} + Y_e \hat{L} \hat{H}_d \hat{E}$

Mass of Lightest Higgs:

$m_{h,H} = \frac{1}{2}(m_A^2 + M_Z^2 \mp \sqrt{(m_A^2 - M_Z^2)^2 + 4M_Z^2 m_A^2 \sin^2(2\beta)})$

Mass of Charged Higgs:

$m_{H\pm}^2 = m_A^2 + M_W^2$

NMSSM

Gauge Structure:

$G_{\mathrm{MSSM}} \times U(1)_{PQ}$

Superpotential:

$W_{\mathrm{NMSSM}} = W_{\mathrm{MSSM}}(\mu = 0) + h_s \hat{S} \hat{H}_u \hat{H}_d + \frac{1}{3}\kappa \hat{S}^3$

Mass of Lightest Higgs:

$m_h^2 = M_Z \left(\cos^2(2\beta) + \frac{h_s}{g}\right)$

Mass of Charged Higgs:

$m_{H\pm}^2 = M_W^2 + \frac{2h_s v_s}{\sin(2\beta)}(A_s + \kappa v_s) - h_s(v_u^2 + v_d^2)$

UMSSM

Gauge Structure:

$G_{\mathrm{MSSM}} \times U(1)'$

Superpotential:

$W_{\mathrm{UMSSM}} = W_{\mathrm{MSSM}}(\mu = 0) + h_s \hat{S} \hat{H}_u \hat{H}_d$

Mass of Lightest Higgs:

$m_h^2 = M_Z^2 \cos^2 2\beta + (v_u^2 + v_d^2)\,[\frac{h_S^2 \sin^2 2\beta}{2} + g_{Y'}^2\,(Q_{H_u} \cos^2\beta + Q_{H_d} \sin^2\beta)]$

Mass of Charged Higgs:

$m_{H\pm}^2 = M_W^2 + \frac{\sqrt{2} h_s A_s v_s}{\sin(2\beta)} - \frac{1}{2} h_s^2 (v_d^2 + v_u^2)$

Scaning Procedure

We have employed SPheno 3.3.3 package obtained with SARAH 4.5.8. Production cross sections of the charged Higgs calculated by CalcHEP.Then, the DM observables in our scan are calculated by micrOMEGAs obtained by SARAH.

MSSM			NMSSM			UMSSM		
$0 \leq$	m_0	≤ 5 (TeV)	$0 \leq$	m_0	≤ 3 (TeV)	$0 \leq$	m_0	≤ 3 (TeV)
$0 \leq$	$M_{1/2}$	≤ 5 (TeV)	$0 \leq$	$M_{1/2}$	≤ 3 (TeV)	$0 \leq$	$M_{1/2}$	≤ 3 (TeV)
$1.2 \leq$	$\tan\beta$	≤ 50	$1.2 \leq$	$\tan\beta$	≤ 50	$1.2 \leq$	$\tan\beta$	≤ 50
$-3 \leq$	A_0/m_0	≤ 3	$-3 \leq$	A_0/m_0	≤ 3	$-3 \leq$	A_0/m_0	≤ 3
	$\mu > 0$		$0 \leq$	h_s	≤ 0.7	$0 \leq$	h_s	≤ 0.7
			$1 \leq$	v_s	≤ 25 (TeV)	$1 \leq$	v_s	≤ 25 (TeV)
			$-10 \leq$	A_s, A_κ	≤ 10 (TeV)	$-10 \leq$	A_s	≤ 10 (TeV)
			$0 \leq$	κ	≤ 0.7	$-\frac{\pi}{2} \leq$	θ_{E_6}	$\leq \frac{\pi}{2}$

Experimental Constraints

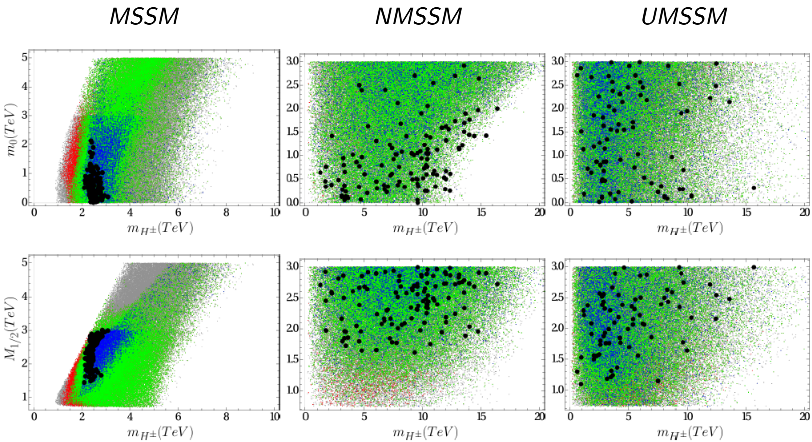
In scanning the parameter space, we use our interface, which employs Metropolis-Hasting algorithm. After collecting the data, we impose the mass bounds on all the sparticles, and the constraint from the rare B-decays such as $B_s \to \mu^+\mu^-$, $B_s \to X_s\gamma$, and $B_u \to \tau\nu_\tau$. In addition, the WMAP bound on the relic abundance of neutralino LSP within 5σ uncertainty. These experimental constraints can be summarized as follows:

$$
\begin{aligned}
& m_h = 123 - 127 \text{ GeV} \\
& m_{\tilde{g}} \geq 1.8 \text{ TeV} \\
& M_{Z'} \geq 2.5 \text{ TeV} \\
& 0.8 \times 10^{-9} \leq \mathrm{BR}(B_s \to \mu^+\mu^-) \leq 6.2 \times 10^{-9} \; (2\sigma) \\
& m_{\tilde{\chi}_1^\pm} \geq 103.5 \text{ GeV} \\
& m_{\tilde{\tau}} \geq 105 \text{ GeV} \\
& 2.99 \times 10^{-4} \leq \mathrm{BR}(B \to X_s\gamma) \leq 3.87 \times 10^{-4} \; (2\sigma) \\
& 0.15 \leq \frac{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{MSSM}}}{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{SM}}} \leq 2.41 \; (3\sigma) \\
& 0.0913 \leq \Omega_{\mathrm{CDM}} h^2 \leq 0.1363 \; (5\sigma)
\end{aligned}
$$

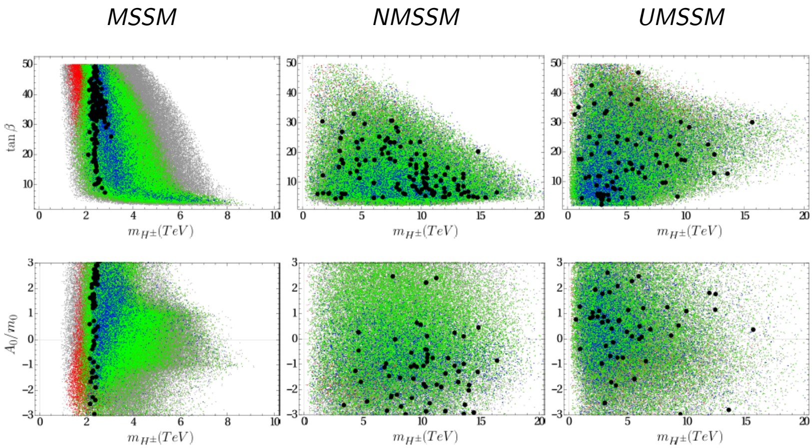
Results:Parameter Space - GUT Scale Masses

Grey: REWSB and Neutralino LSP conditions.
Red: Grey + Higgs boson mass constraint.
Green: Red + SUSY particle mass bounds, and B-physics constraints.
Blue: Green + LHC constraints on the Higgs boson couplings.

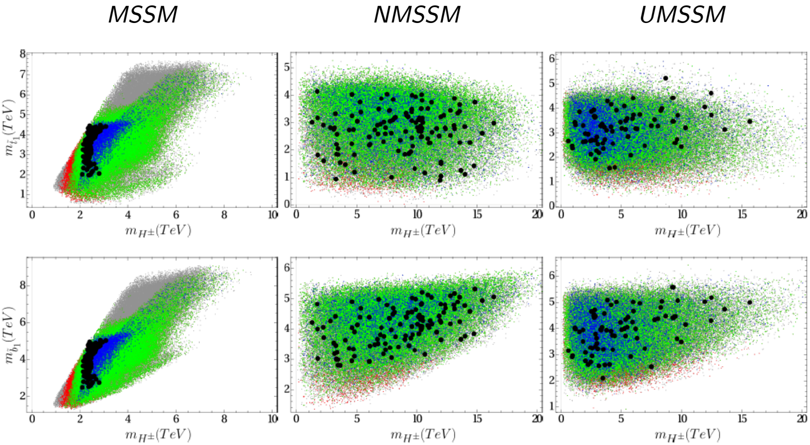
Black: Blue + Dark Matter constraints on the relic abundance of neutralino LSP within 5σ.



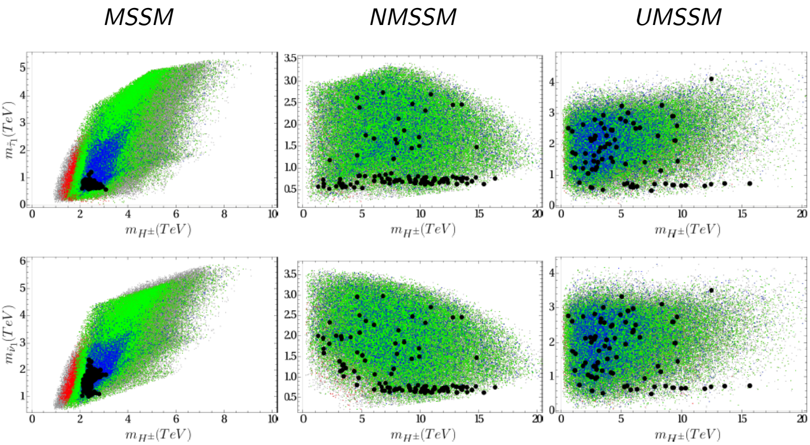
Results:Parameter Space - *tanβ* and Trilinear Coupling



Results:Sparticle Spectrum - stop&sbottom

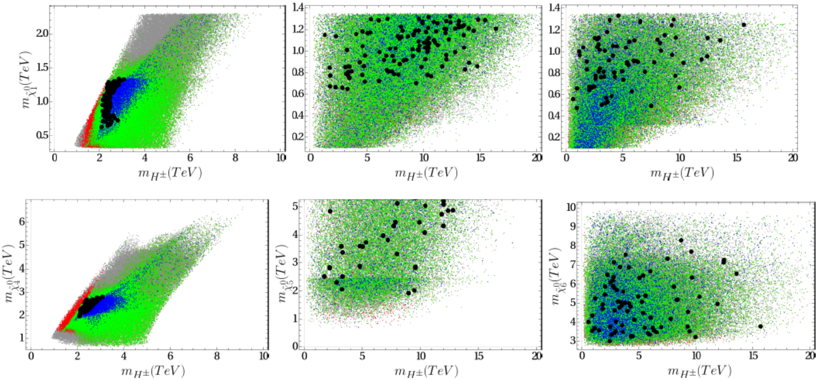


Results:Sparticle Spectrum - stau&sneutrino

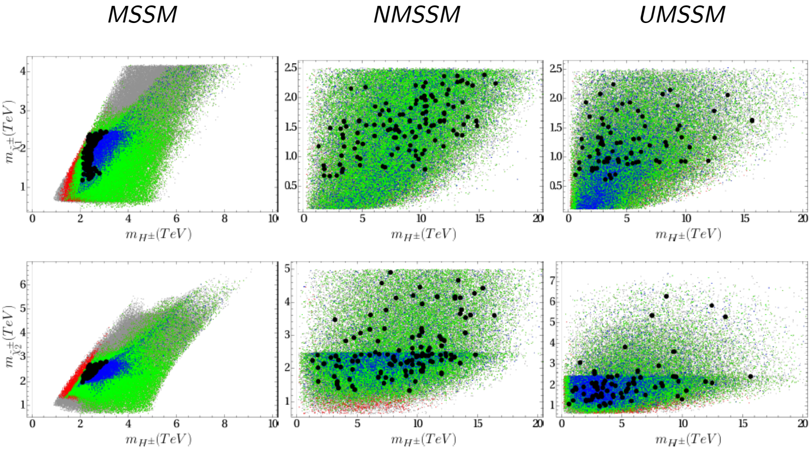


Results:Sparticle Spectrum - Neutralino Masses

MSSM *NMSSM* *UMSSM*



Results:Sparticle Spectrum - Chargino Masses



Results:Production Modes of Charged Higgs

Observables	MSSM		NMSSM		UMSSM	
	$m_{H^\pm}$(GeV)	σ(pb)	$m_{H^\pm}$(GeV)	σ(pb)	$m_{H^\pm}$(GeV)	σ(pb)
$pp \to tH^\pm$	2019	4.5×10^{-5}	1011	1.0×10^{-3}	**551**	$\mathbf{1.6 \times 10^{-2}}$
	3001	3.1×10^{-6}	2055	1.2×10^{-4}	1015	8.3×10^{-4}
	4002	1.0×10^{-7}	5849	5.8×10^{-9}	2061	1.7×10^{-5}
$pp \to W^\mp H^\pm$	2019	5.2×10^{-6}	1011	1.3×10^{-4}	**551**	$\mathbf{1.0 \times 10^{-3}}$
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	3001	3.7×10^{-10}	2055	5.9×10^{-6}	1015	1.0×10^{-5}
	4002	1.5×10^{-12}	5849	3.0×10^{-18}	2061	4.0×10^{-8}
$pp \to H^0_{1,2,3} H^\pm$	2019	1.6×10^{-8}	1011	5.2×10^{-6}	**551**	$\mathbf{1.3 \times 10^{-4}}$
	3001	9.3×10^{-11}	2055	1.5×10^{-8}	1015	4.4×10^{-6}
	4002	2.4×10^{-13}	5849	1.8×10^{-15}	2061	1.3×10^{-8}
$pp \to t\bar{b}H^\pm$	2019	1.7×10^{-5}	1011	4.1×10^{-2}	**551**	$\mathbf{7.2 \times 10^{-3}}$
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Results:Decay Modes of Charged Higgs

Parameters	MSSM		NMSSM		UMSSM	
	Min(%)	Max(%)	Min(%)	Max(%)	Min(%)	Max(%)
$BR(H^\pm \to \tilde{\chi}^0_1 \tilde{\chi}^\pm_1)$	–	0.5	–	20	–	23
$BR(H^\pm \to \tilde{\chi}^0_2 \tilde{\chi}^\pm_1)$	–	–	–	3	–	1
$BR(H^\pm \to \tilde{\chi}^0_3 \tilde{\chi}^\pm_1)$	–	-	–	24	–	21
$BR(H^\pm \to \tilde{\chi}^0_4 \tilde{\chi}^\pm_1)$	–	-	–	26	–	25
$BR(H^\pm \to \tilde{\chi}^0_5 \tilde{\chi}^\pm_1)$	–	–	–	25	–	19
$BR(H^\pm \to \tilde{\chi}^0_6 \tilde{\chi}^\pm_1)$	–	–	–	–	–	8
$BR(H^\pm \to \tilde{\tau}\tilde{\nu})$	–	13	–	33	–	5
$BR(H^\pm \to \tilde{t}\tilde{b})$	–	–	–	35	–	8
$BR(H^\pm \to A^0_1 W^\pm)$	–	–	–	43	–	–
$BR(H^\pm \to H^0_2 W^\pm)$	–	–	–	16	–	2
$BR(H^\pm \to Z W^\pm)$	–	–	–	3	–	2
$BR(H^\pm \to tb)$	73	83	7	95	8	98
$BR(H^\pm \to \tau\nu)$	-	16	–	17	–	18

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- The sbottom mass cannot be lighter than about 2 TeV in MSSM and 1 TeV in NMSSM and UMSSM. Such masses for the stop and sbottom exclude $H^\pm \to \tilde{t}\tilde{b}$ in MSSM, while it can still be open in NMSSM and UMSSM but this channel has large top quark background, it is not clear.

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- Another pair of supersymmetric particles relevant to the charged Higgs boson decay modes is $\tilde{\tau}$ and $\tilde{\nu}$, whose masses are bounded as $m_{\tilde{\tau}} \gtrsim 500$ GeV and $m_{\tilde{\nu}} \gtrsim 1$ TeV. Even though their total mass is close by the charged Higgs boson mass, there might be a small window which allows $H^\pm \to \tilde{\tau}\tilde{\nu}$.

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- Additionally, the lightest chargino mass in NMSSM and UMSSM is bounded from below as $m_{\tilde{\chi}_1^\pm} \gtrsim 1$ TeV, which seems testable in near future LHC experiments through the analyses for the chargino-neutralino production processes.

Thank You for Your Attention!!!