Some Phenomenological Aspects of U(1) Extended Minimal Supersymmetric Model

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University of Sussex
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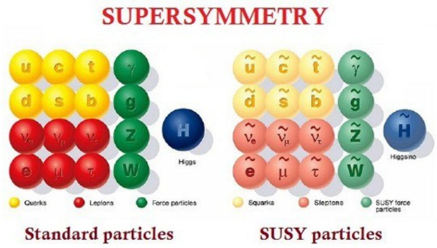
Outline


SUPERSYMMETRY
Higgs
Quarks
Leptons
Force particles
Higgsino
Squarks
Sleptons
SUSY force particles
Standard particles
SUSY particles

	$SU(3)_C \times SU(2)_L \times U(1)_Y$	I_3	$Q_{\rm EM}$
$Q = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$(\mathbf{3},\, \mathbf{2},\, \frac{1}{3})$	$1/2$ $-1/2$	$2/3$ $-1/3$
u_R	$(\overline{\mathbf{3}},\, \mathbf{1},\, \frac{4}{3})$	0	$2/3$
d_R	$(\overline{\mathbf{3}},\, \mathbf{1},\, -\frac{2}{3})$	0	$-1/3$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$(\mathbf{1},\, \mathbf{2},\, -1)$	$1/2$ $-1/2$	0 -1
e_R	$(\overline{\mathbf{1}},\, \mathbf{1},\, -2)$	0	-1
$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$	$(\mathbf{1},\, \mathbf{2},\, 1)$	$1/2$ $-1/2$	1 0
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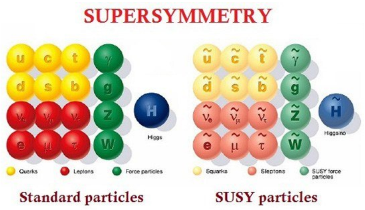

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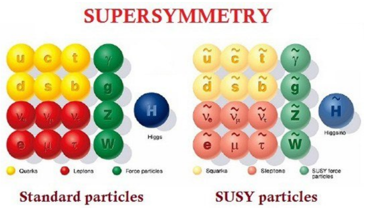

$$W_{MSSM} = \mu H_u H_d + Y_u \hat{Q} H_u \hat{U} + Y_d \hat{Q} H_d \hat{D} + Y_e \hat{L} H_d \hat{E}$$

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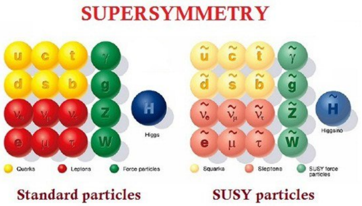

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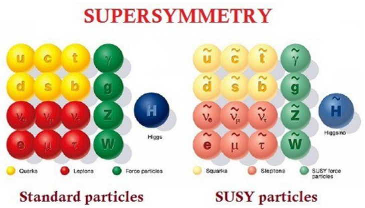

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$$m_h^{tree} \leq M_Z |cos2\beta|$$

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

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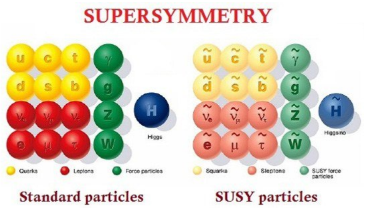

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$$Neutralinos(\tilde{\chi}_i^0) : MixingOf(\tilde{B}, \tilde{W}, \tilde{H}_d, \tilde{H}_u)$$

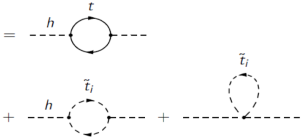
$$Charginos(\tilde{\chi}_i^{\pm}) : MixingOf(\tilde{W}^{\pm}, \tilde{H}^{\pm})$$

Pros

Hierarchy Problem!!!

$$(m_h^{\text{pole}})^2 = (m_h^{\text{tree}})^2 + \Delta m_h^2$$

$\Delta m_h^2 =$



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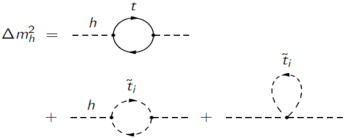

Dark Matter!!!

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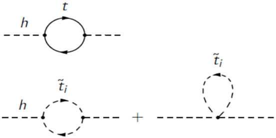
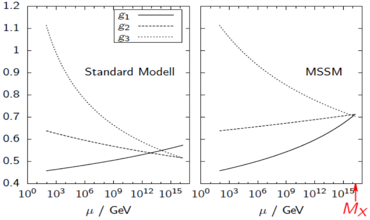


Dark Matter!!!

Gauge coupling unification!!!



Cons

Little Hierarchy Problem!!!

$$(m_h^{pole})^2 \approx m_Z^2 cos^2 2\beta + \Delta m_h^2$$

$$m_h^{pole} \approx 125\, GeV$$

$$m_Z \approx 91\, GeV$$

$$\Delta m_h \gtrsim 87\, GeV$$

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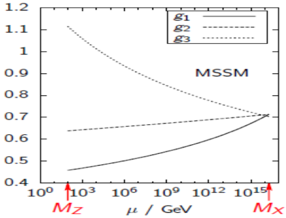

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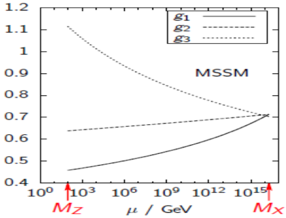
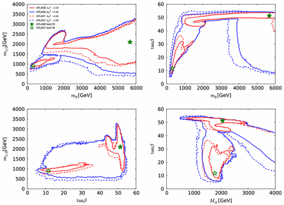


Excluded Parameter Space!!!



$E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi$

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

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$2\sqrt{6}\ U(1)_\psi$	1	1	1	1	1	-2	-2	4
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$$m_h^{tree\,2} = M_Z^2 \cos^2 2\beta + \boxed{\left(v_u^2 + v_d^2\right)\left[\frac{h_S^2 \sin^2 2\beta}{2} + g^2_{Y'}\left(Q_{H_u}\cos^2\beta + Q_{H_d}\sin^2\beta\right)\right]}$$

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

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$2\sqrt{10}\ U(1)_\chi$	-1	-1	3	3	-1	-2	2	0

$$V_{Higgs}^{UMSSM} = V_{Higgs}^{MSSM}|_{\mu=h_S S} + m_S^2|S|^2 + \frac{g'^2}{2}\left(Q_{H_u}|H_u|^2 + Q_{H_d}|H_d|^2 + Q_S|S|^2\right)$$

$$Q^i = Q^i_\chi \cos\theta_{E_6} + Q^i_\psi \sin\theta_{E_6}$$

$$M_{Z'}^2 = g'^2(Q_{H_u}^2 v_u^2 + Q_{H_d}^2 v_d^2 + Q_S^2 v_S^2)$$

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

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

$$\tilde{\chi}_i^0 : Mixingof(\tilde{B}', \tilde{B}, \tilde{W}, \tilde{H}_d, \tilde{H}_u, \tilde{S})$$

Parameter Space with Universal Boundary Conditions

	UMSSM	
$0 \leq$	m_0	$\leq 3\ (\mathrm{TeV})$
$0 \leq$	$M_{1/2}$	$\leq 3\ (\mathrm{TeV})$
$1.2 \leq$	$\tan\beta$	≤ 50
$-3 \leq$	A_0/m_0	≤ 3
$0 \leq$	h_s	≤ 0.7
$1 \leq$	v_s	$\leq 25\ (\mathrm{TeV})$
$-10 \leq$	A_s	$\leq 10\ (\mathrm{TeV})$
$-\frac{\pi}{2} \leq$	θ_{E_6}	$\leq \frac{\pi}{2}$

$$
\begin{aligned}
m_0 &= m_{\tilde{Q}} = m_{\tilde{U}} = m_{\tilde{D}} = m_{\tilde{E}} = m_{\tilde{L}} = m_{\tilde{Q}} = m_{H_u} = m_{H_d} = m_{\tilde{S}} \\
M_{1/2} &= M_1 = M_2 = M_3 = M_4 \\
A_0 &= A_t = A_b = A_\tau = A_S .
\end{aligned}
$$

Constraints

$$m_h = 123 - 127 \text{ GeV}$$
$$m_{\tilde{g}} \geq 1.8 \text{ TeV}$$
$$M_{Z'} \geq 2.5 \text{ TeV}$$
$$0.8 \times 10^{-9} \leq \text{BR}(B_s \rightarrow \mu^+\mu^-) \leq 6.2 \times 10^{-9} \; (2\sigma)$$
$$m_{\tilde{\chi}_1^0} \geq 103.5 \text{ GeV}$$
$$m_{\tilde{\tau}} \geq 105 \text{ GeV}$$
$$2.99 \times 10^{-4} \leq \text{BR}(B \rightarrow X_s\gamma) \leq 3.87 \times 10^{-4} \; (2\sigma)$$
$$0.15 \leq \frac{\text{BR}(B_u \rightarrow \tau\nu_\tau)_{\text{MSSM}}}{\text{BR}(B_u \rightarrow \tau\nu_\tau)_{\text{SM}}} \leq 2.41 \; (3\sigma)$$
$$0.0913 \leq \Omega_{\text{CDM}} h^2 \leq 0.1363 \; (5\sigma)$$

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Least fine-tuned $U(1)$ extended SSM

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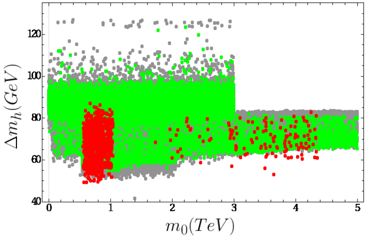
Parameter Space

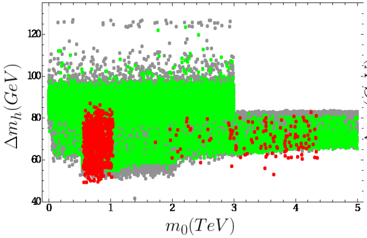
$$\Delta m_h \equiv \sqrt{m^2_{h_{\rm loop}} - m^2_{h_{\rm tree}}}$$

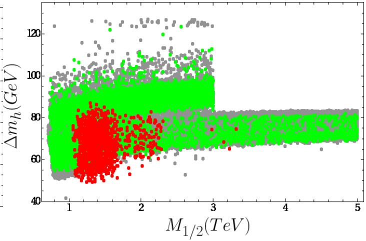


Excluded Solutions.
Experimental constraints.
Green + the relic abundance.

Parameter Space

$$\Delta m_h \equiv \sqrt{m^2_{h_{\rm loop}} - m^2_{h_{\rm tree}}}$$





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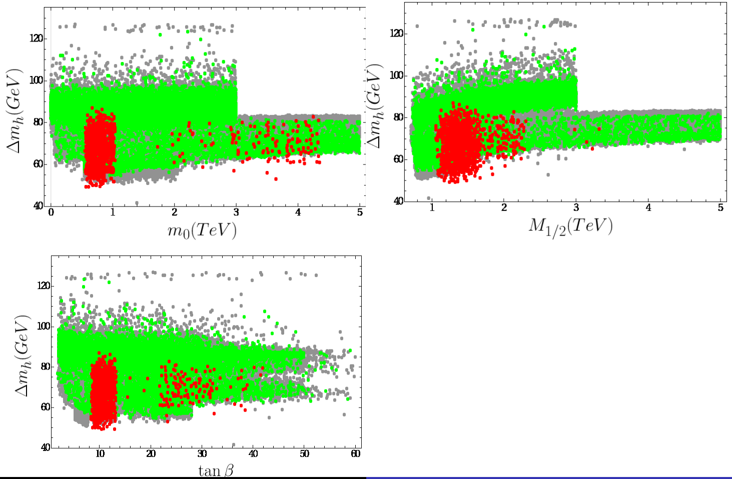

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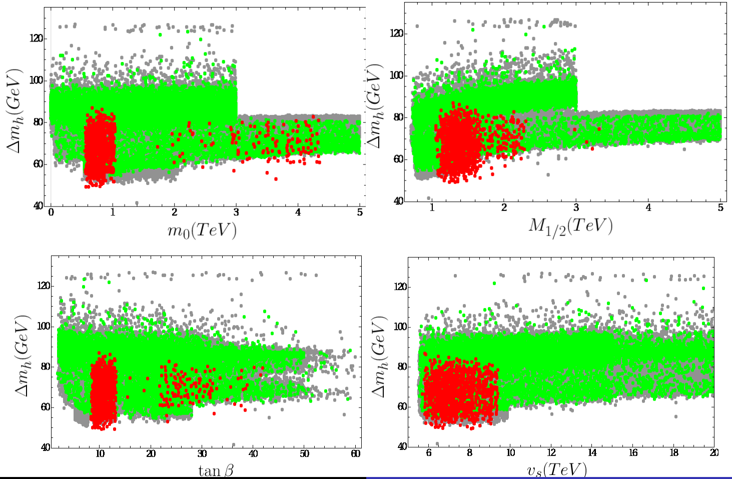

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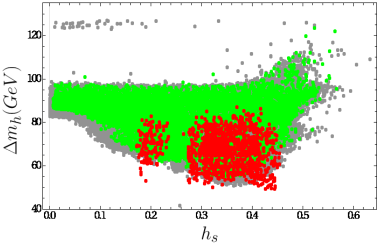

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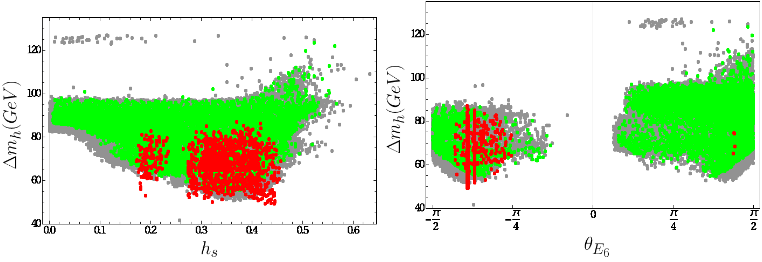

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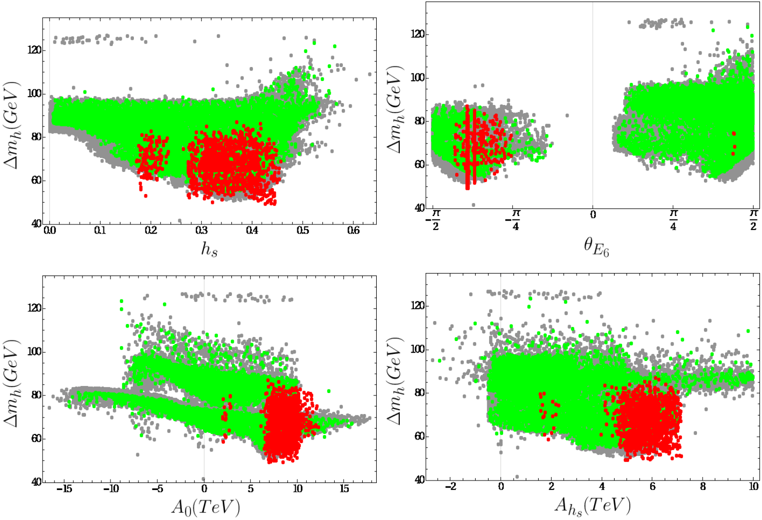
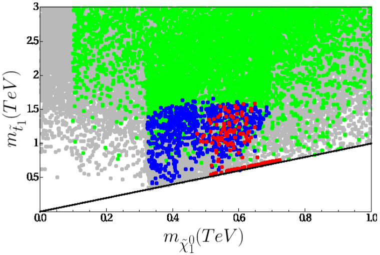
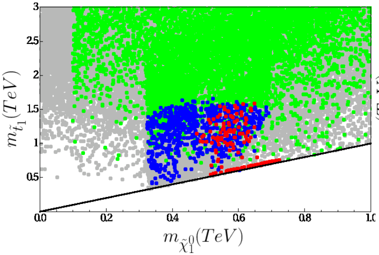


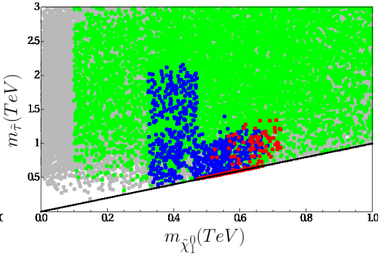
Sparticle Spectrum



Excluded Solutions.
Experimental constraints.
Green+$\Delta m_h \leq 60 GeV$.
Blue + the relic abundance.

Sparticle Spectrum





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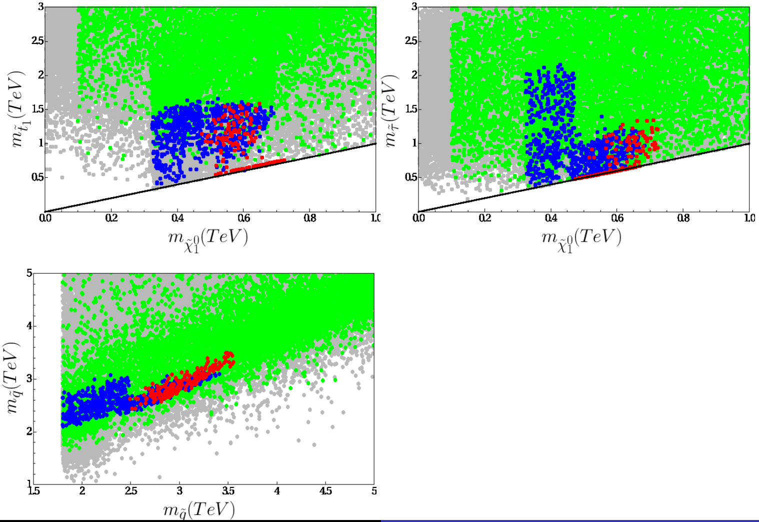

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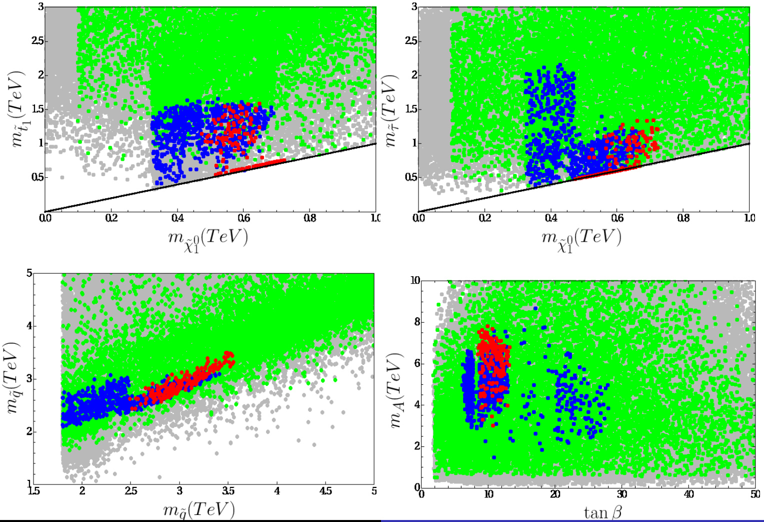
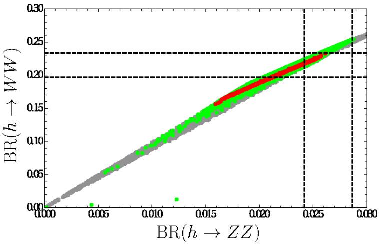
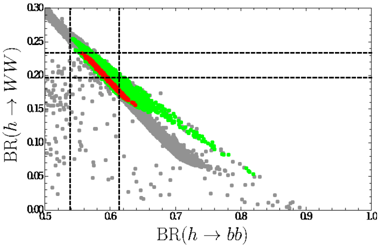


Higgs Profile





Charged Higgs

PHYSICAL REVIEW D **97,** 115041 (2018)

Charged Higgs boson in MSSM and beyond

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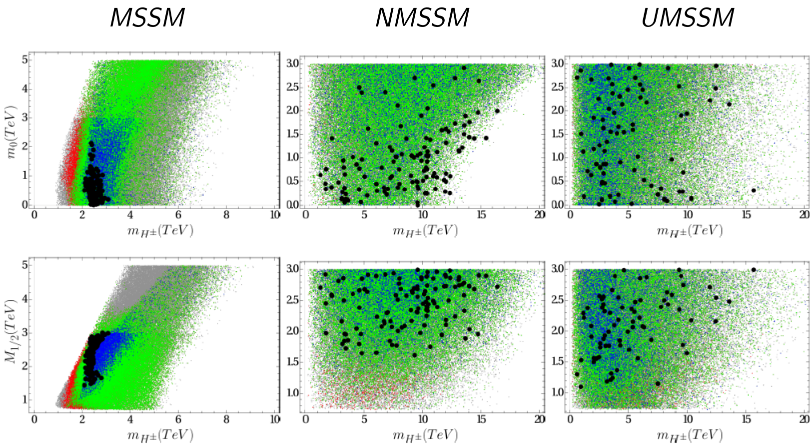
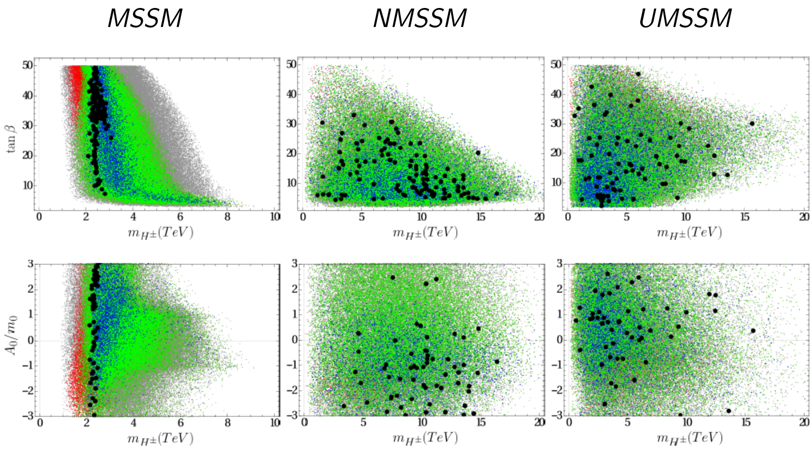
We conduct a numerical study over the constrained MSSM (CMSSM), next-to-MSSM (NMSSM) and $U(1)$ extended MSSM (UMSSM) to probe the allowed mass ranges of the charged Higgs boson and its dominant decay patterns, which might come into prominence in the near future collider experiments. We present results obtained from a limited scan for CMSSM as a basis and compare its predictions with the extended models. We observe within our data that a wide mass range is allowed as $0.5(1) \lesssim m_{H^\pm} \lesssim 17$ TeV in UMSSM (NMSSM). We find that the dominant decay channel is mostly $H^\pm \to tb$ such that $\mathrm{BR}(H^\pm \to tb) \sim 80\%$. While this mode remains dominant over the whole allowed parameter space of CMSSM, we realize some special domains in the NMSSM and UMSSM, in which $\mathrm{BR}(H^\pm \to tb) \lesssim 10\%$.

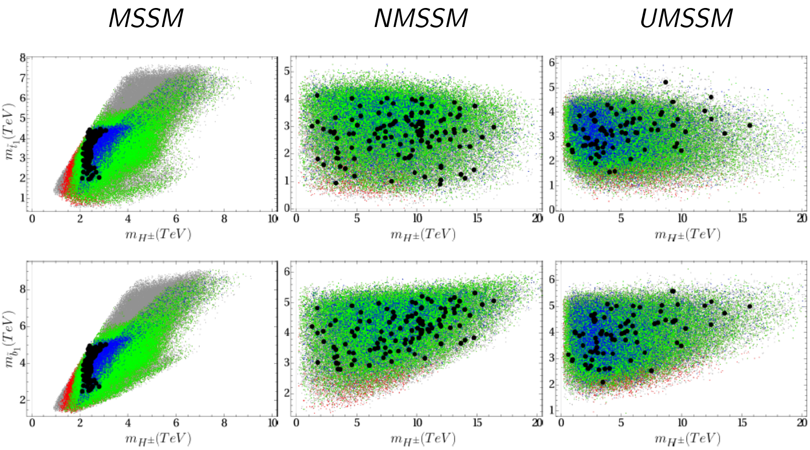
Charged Higgs-Parameter Space



Charged Higgs-Parameter Space



Charged Higgs-Sparticle Spectrum



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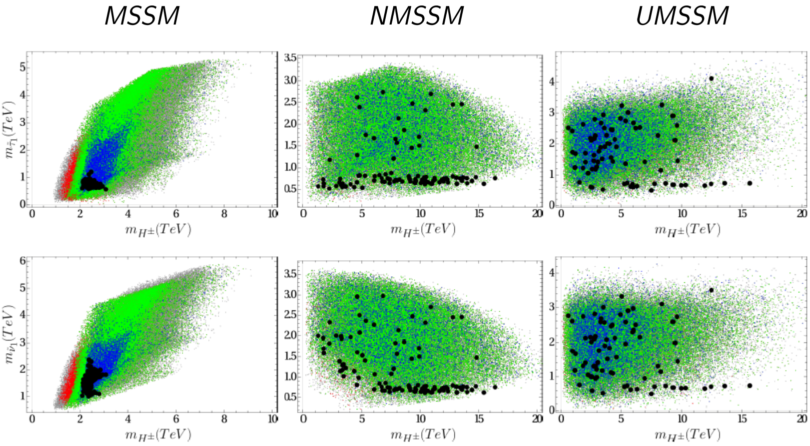
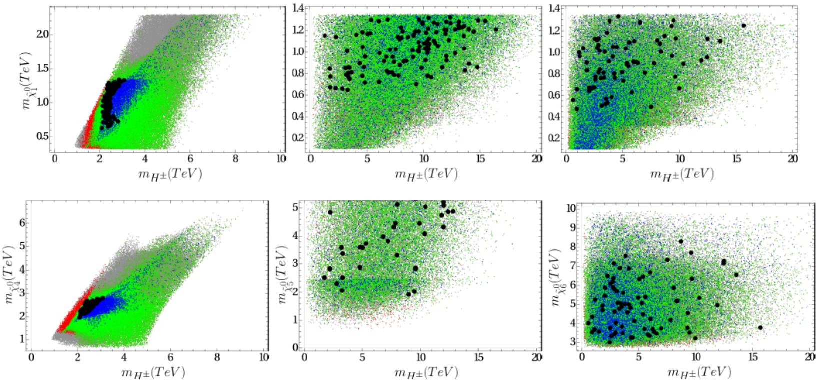


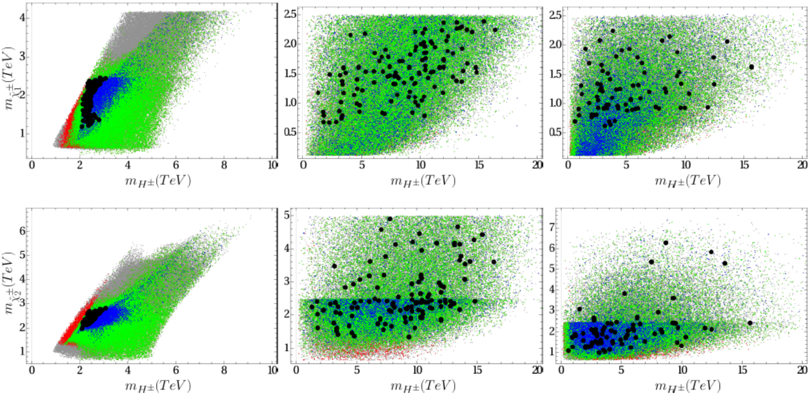
Charged Higgs-Sparticle Spectrum

MSSM *NMSSM* *UMSSM*



Charged Higgs-Sparticle Spectrum

MSSM *NMSSM* *UMSSM*



Parameters	CMSSM		NMSSM		UMSSM	
	Min(%)	Max(%)	Min(%)	Max(%)	Min(%)	Max(%)
BR($H^\pm \to \tilde{\chi}_1^0 \tilde{\chi}_1^\pm$)	–	0.5	–	20	–	23
BR($H^\pm \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm$)	–	–	–	3	–	1
BR($H^\pm \to \tilde{\chi}_3^0 \tilde{\chi}_1^\pm$)	–	-	–	24	–	21
BR($H^\pm \to \tilde{\chi}_4^0 \tilde{\chi}_1^\pm$)	–	-	–	26	–	25
BR($H^\pm \to \tilde{\chi}_5^0 \tilde{\chi}_1^\pm$)	–	–	–	25	–	19
BR($H^\pm \to \tilde{\chi}_6^0 \tilde{\chi}_1^\pm$)	–	–	–	–	–	8
BR($H^\pm \to \tilde{\tau}\tilde{\nu}$)	–	13	–	33	–	5
BR($H^\pm \to \tilde{t}\tilde{b}$)	–	–	–	35	–	8
BR($H^\pm \to A_1^0 W^\pm$)	–	–	–	43	–	–
BR($H^\pm \to H_2^0 W^\pm$)	–	–	–	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

- The smallest amount of radiative contributions to the Higgs boson mass is about 50 GeV in UMSSM, this result is much lower than that obtained in the MSSM framework, which is around 90 GeV.

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- In UMSSM, lightest Higgs boson can behave similar to the SM Higgs boson under the current experimental constraints.
- Unlike constrained MSSM, it is possible to realize the mode in NMSSM and UMSSM in which the charged Higgs boson decays into a chargino-neutralino, stop-sbottom pairs.
- UMSSM is one of the most powerful beyond MSSM models.

Thank You for Your Attention!!!