Higgs Bosons and Z' Phenomenology of $U(1)$-MSSM

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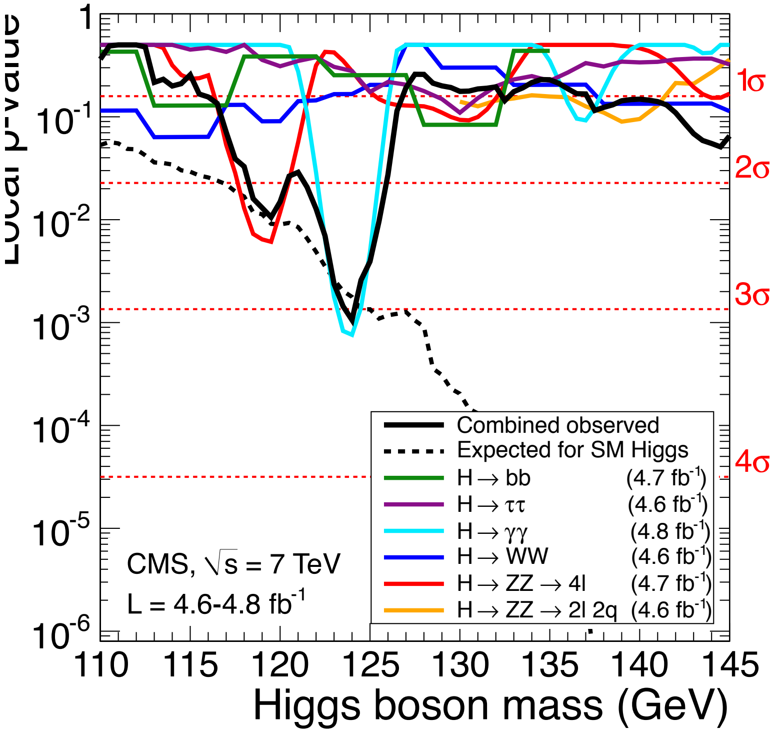
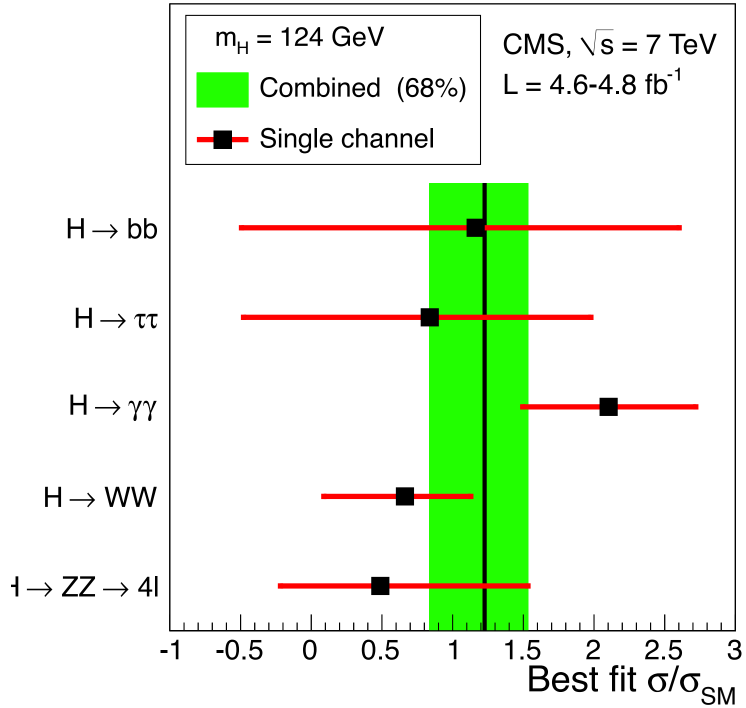
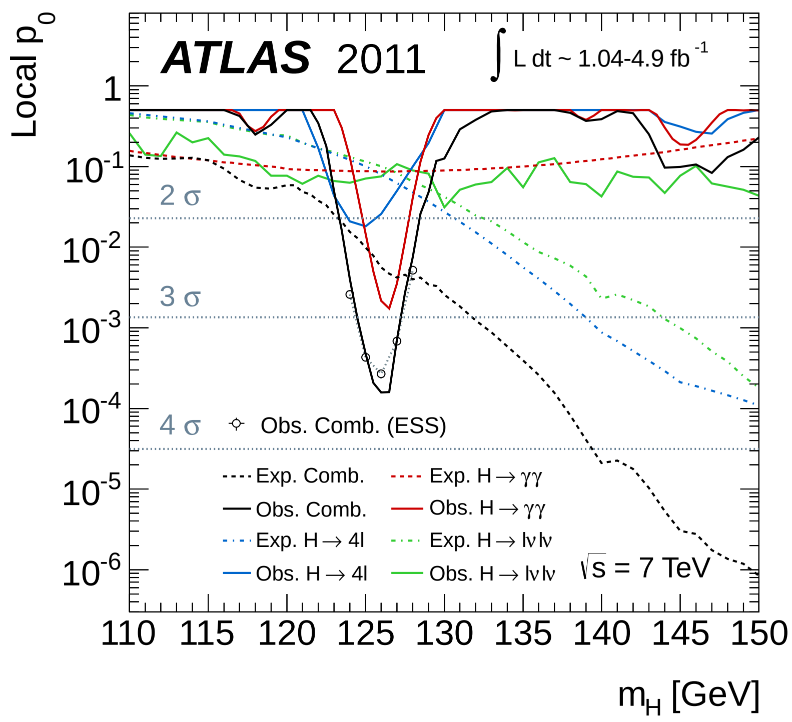
Konkuk WCU/NTHU Cross Strait Meeting 2012

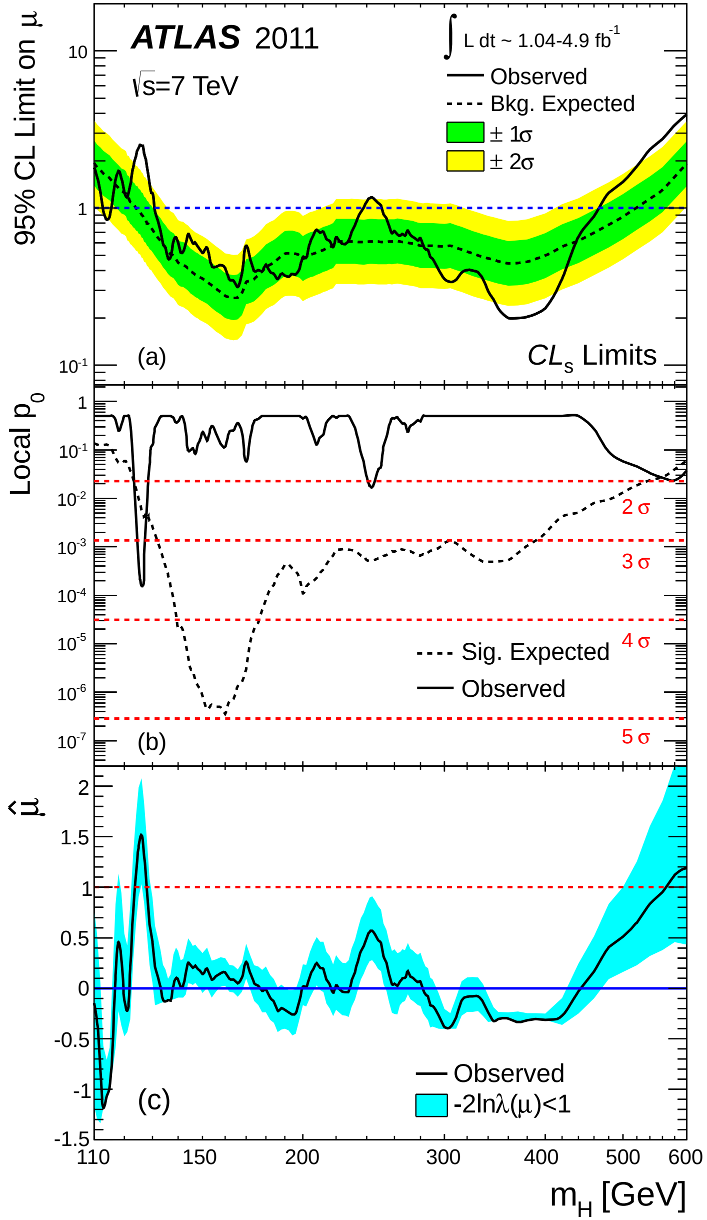


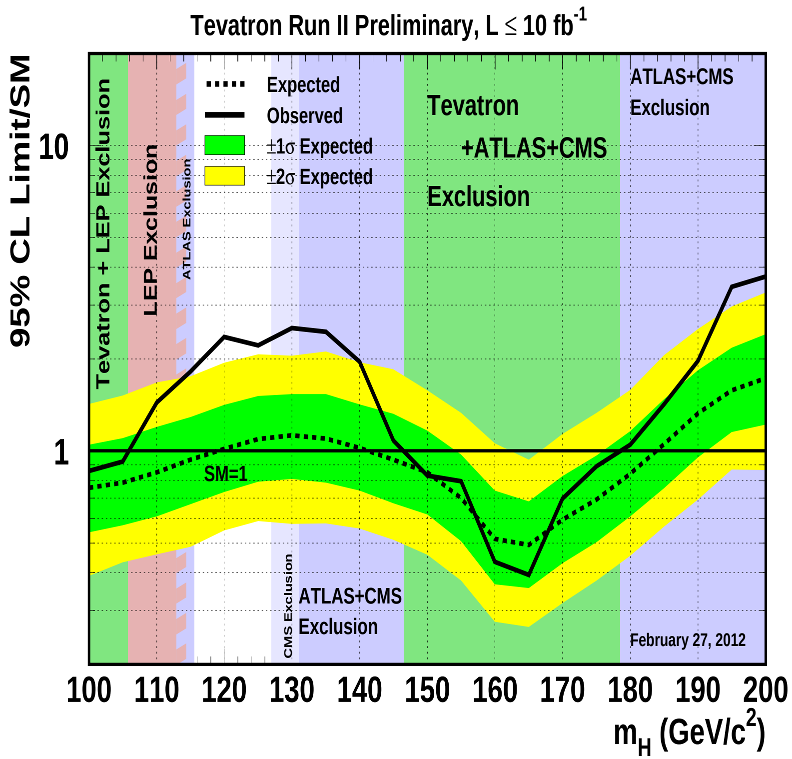
Combined observed
Expected for SM Higgs
H → bb (4.7 fb^{-1})
H → ττ (4.6 fb^{-1})
H → γγ (4.8 fb^{-1})
H → WW (4.6 fb^{-1})
H → ZZ → 4l (4.7 fb^{-1})
H → ZZ → 2l 2q (4.6 fb^{-1})
CMS, √s = 7 TeV
L = 4.6-4.8 fb^{-1}
1σ
2σ
3σ
4σ
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
110 115 120 125 130 135 140 145
Higgs boson mass (GeV)

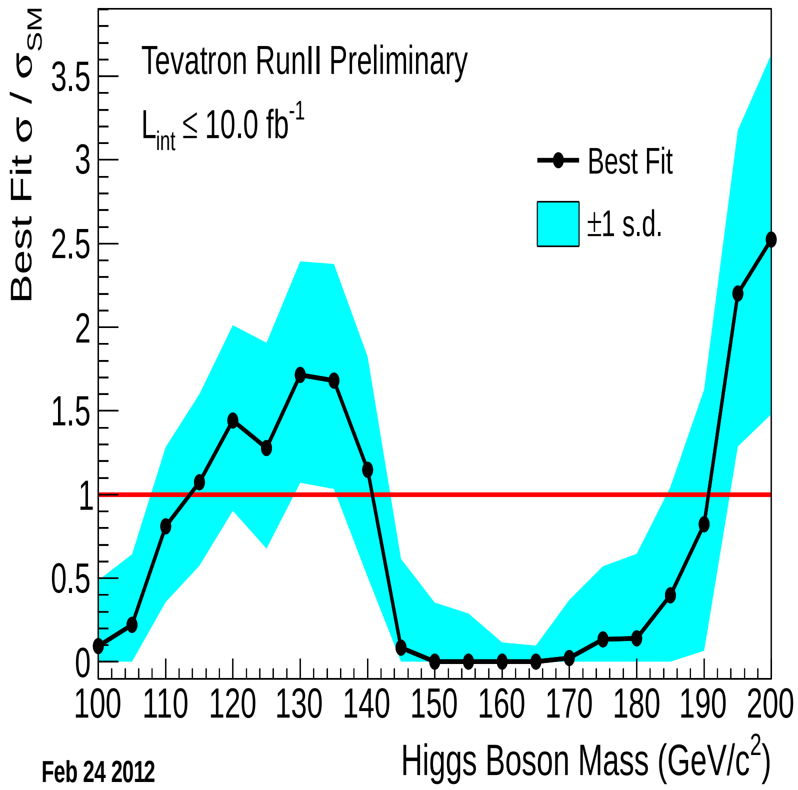


m$_H$ = 124 GeV
Combined (68%)
Single channel
CMS, √s = 7 TeV
L = 4.6-4.8 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ → 4l
-1 -0.5 0 0.5 1 1.5 2 2.5 3
Best fit σ/σ$_{SM}$


ATLAS 2011
∫ L dt ~ 1.04-4.9 fb-1
Local p0
2 σ
3 σ
4 σ
Obs. Comb. (ESS)
Exp. Comb.
Obs. Comb.
Exp. H→4l
Obs. H→4l
Exp. H→γγ
Obs. H→γγ
Exp. H→lνlν
Obs. H→lνlν
√s = 7 TeV
mH [GeV]


ATLAS 2011
√s=7 TeV
∫ L dt ~ 1.04-4.9 fb-1
Observed
Bkg. Expected
± 1σ
± 2σ
95% CL Limit on μ
(a)
CLs Limits
Local p0
Sig. Expected
Observed
2 σ
3 σ
4 σ
5 σ
(b)
μ̂
Observed
-2lnλ(μ)<1
(c)
mH [GeV]


Tevatron Run II Preliminary, L ≤ 10 fb-1
95% CL Limit/SM
Expected
Observed
±1σ Expected
±2σ Expected
Tevatron + LEP Exclusion
LEP Exclusion
ATLAS Exclusion
Tevatron
+ATLAS+CMS
Exclusion
ATLAS+CMS
Exclusion
SM=1
CMS Exclusion
ATLAS+CMS
Exclusion
February 27, 2012
mH (GeV/c2)


Best Fit σ / σSM
Tevatron RunII Preliminary
Lint ≤ 10.0 fb-1
Best Fit
±1 s.d.
Feb 24 2012
Higgs Boson Mass (GeV/c2)

Various Interpretations

- MSSM: the most straight forward, SUSY predicts a light Higgs boson. But to give a 125 GeV Higgs puts a tight constraint on the stop mass sector, and difficult to enhance the $\gamma\gamma$ rate. (Baer et al; Heinemeyer et al; Arbey et al; Draper et al; Carena et al; Cao et al, ...)
- NMSSM: easier to obtain a 125 GeV Higgs boson, but still controversial to obtain enhanced $\gamma\gamma$ rate. (Gunion et al; Ellwanger; King et al.,)
- RS Radion/dilaton: the anomaly couplings to gg and $\gamma\gamma$ easily enhance the diphoton rate. (KC and TC, PRL)
- 2HDM: Ferreira et al.
- 4th generation: Guo, Ren, and He
- Inert Higgs doublet model: Arhrib et al.
- $U(1)$-extended MSSM: C.F. Chang, KC, Y.C. Lin, TC

U(1)-MSSM

- Extra $U(1)$s exist in the breaking of E_6:

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

and each family of left-handed fermions is promoted to a fundamental **27**. The two $U(1)$s can mix to form various Z' models.

- We require one of the $U(1)$ remains unbroken until TeV and then broken to give mass to Z' and Z'-ino.

$SO(16)$	$SU(5)$	$2\sqrt{10}Q'_\chi$	$2\sqrt{6}Q'_\psi$	$2\sqrt{15}Q'_\eta$
16	$\mathbf{10}(u, d, u^c, e^c)$	-1	1	-2
	$\mathbf{5}^*(d^c, \nu, e^-)$	3	1	1
	ν^c	-5	1	-5
10	$\mathbf{5}(D, H_u)$	2	-2	4
	$\mathbf{5}^*(D^c, H_d)$	-2	-2	1
1	$\mathbf{1}S$	0	4	-5

- Based on the $U(1)$ quantum number the allowed terms in superpotential

$$W_{\rm eff} = \epsilon_{ab}\left[y^u_{ij}Q^a_j H^b_u U^c_i - y^d_{ij}Q^a_j H^b_d D^c_i - y^l_{ij}L^a_j H^b_d E^c_i + h_s S H^a_u H^b_d\right]$$

The $U(1)$ charges of S, H_u, H_d are related by $Q'_{H_u} + Q'_{H_d} + Q'_S = 0$.

- The gauge interactions involving Z' and the supermultiplet (ϕ, ψ) is

$$\mathcal{L} = \frac{1}{2}\bar{\psi}_i\, i\gamma^\mu D_\mu\, \psi_i + (D^\mu \phi_i)^\dagger\,(D_\mu \phi_i)\ ,$$

where

$$D_\mu \phi_i = \left[\partial_\mu + ieQA_\mu + i\frac{g}{\sqrt{2}}(\tau^+ W^+_\mu + \tau^- W^-_\mu) + ig_1(T_{3L} - Qx_{\rm w})Z_\mu + ig_2 Z'_\mu Q'\right]\,\phi_i\ .$$

- The Z' mass arises from VEVs of H_u, H_d, S:

$$m_{Z'} \approx g_2(Q'^2_{H_u}v_u^2 + Q'^2_{H_d}v_d^2 + Q'^2_s v_s^2)^{1/2}$$

The Z'-ino mass comes from the soft SUSY breaking gaugino mass term.

Physical States

- Higgs bosons:

$$H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix} , \qquad H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \qquad \text{and} \qquad S \ .$$

Similar to NMSSM, UMSSM has 3 CP-even Higgs bosons, 1 charged Higgs, but only one pseudoscalar boson, because one is eaten by the Z' boson.

$$\begin{aligned} H_d^0 &= \frac{1}{\sqrt{2}} (v_d + \phi_d + i\chi_d) \ , \\ H_u^0 &= \frac{1}{\sqrt{2}} (v_u + \phi_u + i\chi_u) \ , \\ H_d^0 &= \frac{1}{\sqrt{2}} (v_s + \phi_s + i\chi_s) \ , \end{aligned}$$

So h_1, h_2, h_3, A, $H^\pm$.

- Neutralinos, total 6: in the basis of $(\tilde{B},\, \tilde{W}^3,\, \tilde{h}_d^0,\, \tilde{h}_u^0,\, \tilde{S},\, \tilde{Z}')^T$

$$\mathcal{M}_N = \left(\begin{array}{cccc|cc} M_1 & 0 & -\frac{e}{2c_W}v_d & \frac{e}{2c_W}v_u & 0 & 0 \\ 0 & M_2 & \frac{g}{2}v_d & -\frac{g}{2}v_u & 0 & 0 \\ -\frac{e}{2c_W}v_d & \frac{g}{2}v_d & 0 & -\mu_{\rm eff} & -\frac{h_s}{\sqrt{2}}v_u & g_2 Q'_{H_d} v_d \\ \frac{e}{2c_W}v_u & -\frac{g}{2}v_u & -\mu_{\rm eff} & 0 & -\frac{h_s}{\sqrt{2}}v_d & g_2 Q'_{H_u} v_u \\ \hline 0 & 0 & -\frac{h_s}{\sqrt{2}}v_u & -\frac{h_s}{\sqrt{2}}v_d & 0 & g_2 Q'_S v_s \\ 0 & 0 & g_2 Q'_{H_d} v_d & g_2 Q'_{H_u} v_u & g_2 Q'_S v_s & M_{\tilde{Z}'} \end{array}\right) .$$

Two Higgs Scenarios

- The SM-like Higgs boson: $130 < M_{h_{\rm SM-like}} < 141$ GeV. We have to hide it from showing up in the WW, ZZ, $\gamma\gamma$, $b\bar{b}$, and $\tau^+\tau^-$ channels. A possible way is to allow decay into neutralinos.
- The SM-like Higgs boson: $120 < M_{h_{\rm SM-like}} < 130$ GeV. This is what LHC and Tevatron are seeing. So have to make sure that the WW, ZZ, $\gamma\gamma$, $b\bar{b}$, and $\tau^+\tau^-$ channels are there. We have to suppress decay into neutralinos.

Scanning of Parameter Space

- Fix some parameters:

$$M_1 = 0.5 M_2 = 0.2 \text{ TeV}, \quad M_3 = 2 \text{ TeV} \; ;$$

$$M_{\tilde{Q}} = M_{\tilde{U}} = A_t = 1 \text{ TeV}, \quad M_{\tilde{L}} = M_{\tilde{E}} = 0.2 \text{ TeV} \; . M_S = 0.5\,\text{TeV}, \quad A_s = 0.5\,\text{TeV}$$

- Vary

$$0.2\,\text{TeV} < v_s < 2 \text{ TeV}, \quad 0.2 < h_s < 0.7, \quad 1.1 < \tan\beta < 40 \;, \; 0.2\,\text{TeV} < M_{\tilde{Z}'} < 2\,\text{TeV}$$

- Constraints:
  1. Chargino mass > 94 GeV
  2. Invisible width of Z

$$\Gamma(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) = \frac{g_1^2}{96\pi} \left(|N_{13}|^2 - |N_{14}|^2 \right)^2 m_Z \left(1 - \frac{4 m_{\tilde{\chi}_1^0}^2}{m_Z^2} \right)^{3/2} < 3 \text{ MeV}$$

Higgs Decays

- Higgs decays into gauge bosons
- Higgs decays into fermions
- Higgs decays into neutralinos
- Higgs decays into lighter Higgs

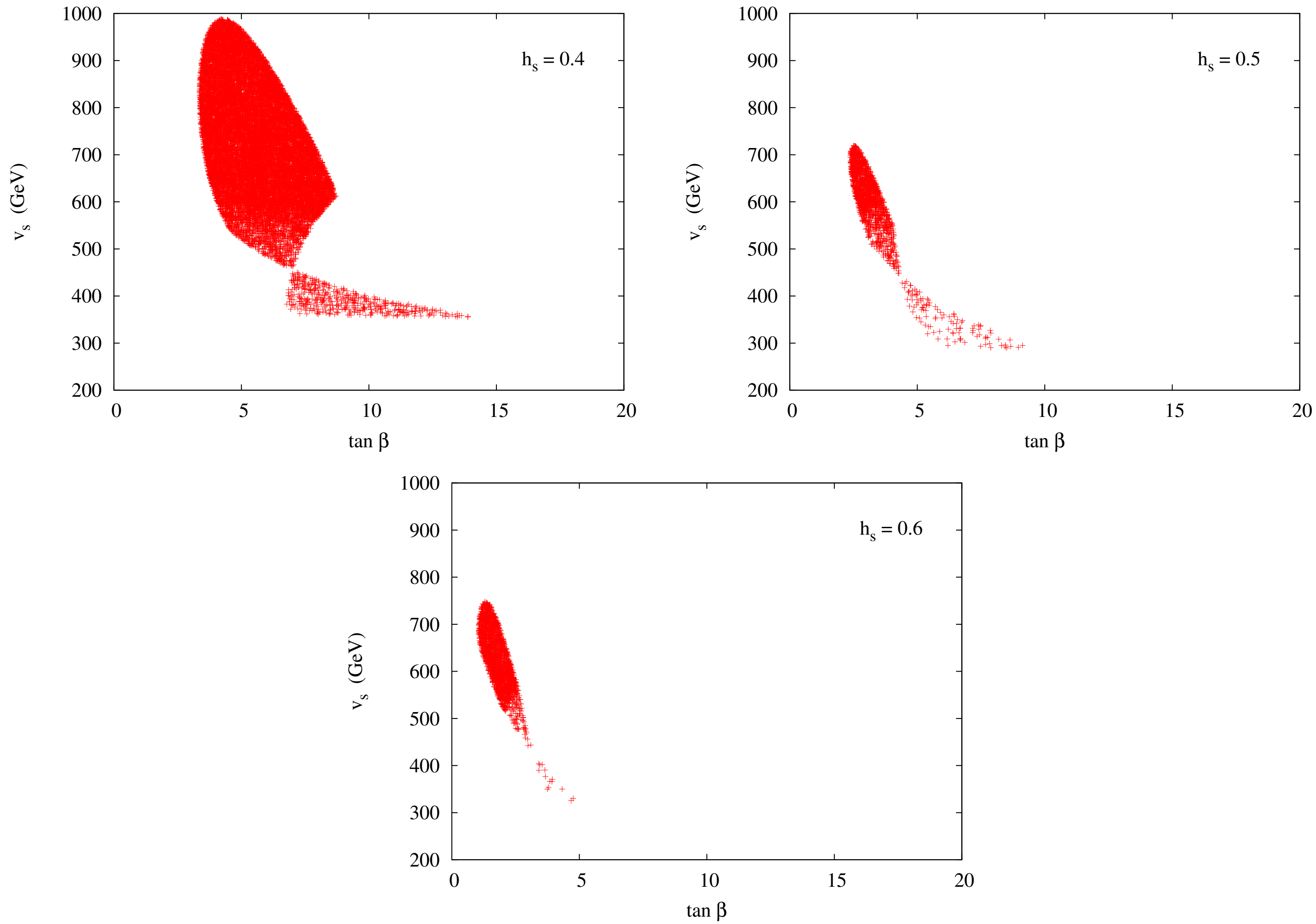
Scenario 1: $130 < M_{h_{\rm SM-like}} < 141$ GeV.

- The physical Higgs states are

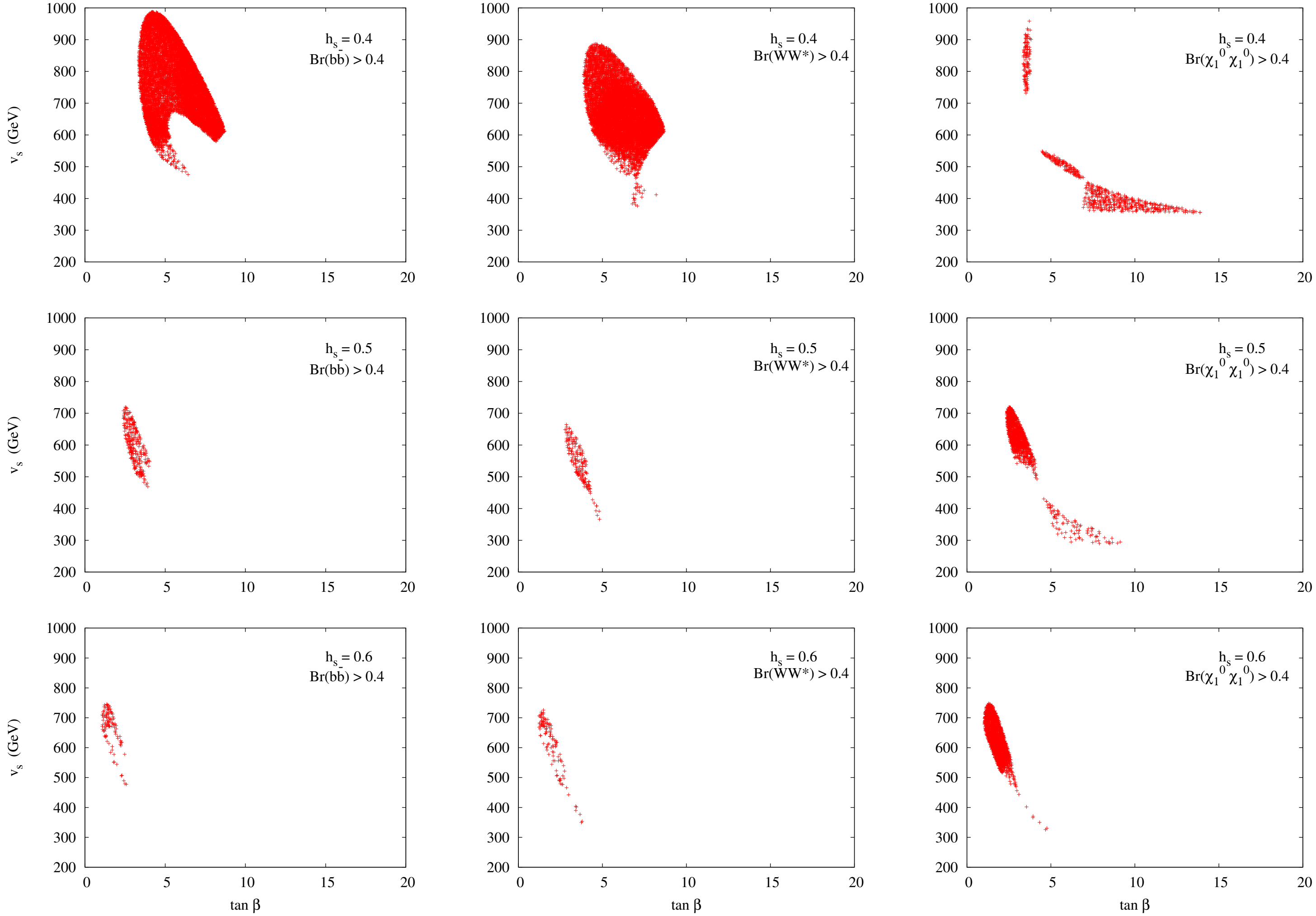
$$h_k = O_{k1}\phi_d + O_{k2}\phi_u + O_{k3}\phi_s$$

  Require the singlet component to be small: $O_{k3}^2 < 0.1$ to be the SM-like.

- In our scan we do not find more than one SM-like Higgs boson.
- A smaller h_s is more likely to give a Higgs boson in mass range $130 - 140$ GeV.
- If $B(h_{\rm SM-like} \to \tilde{\chi}_1^0 \tilde{\chi}_1^0) > 0.4$, we are able to hide the Higgs boson under the current data. Larger h_s will make invisible mode dominant.

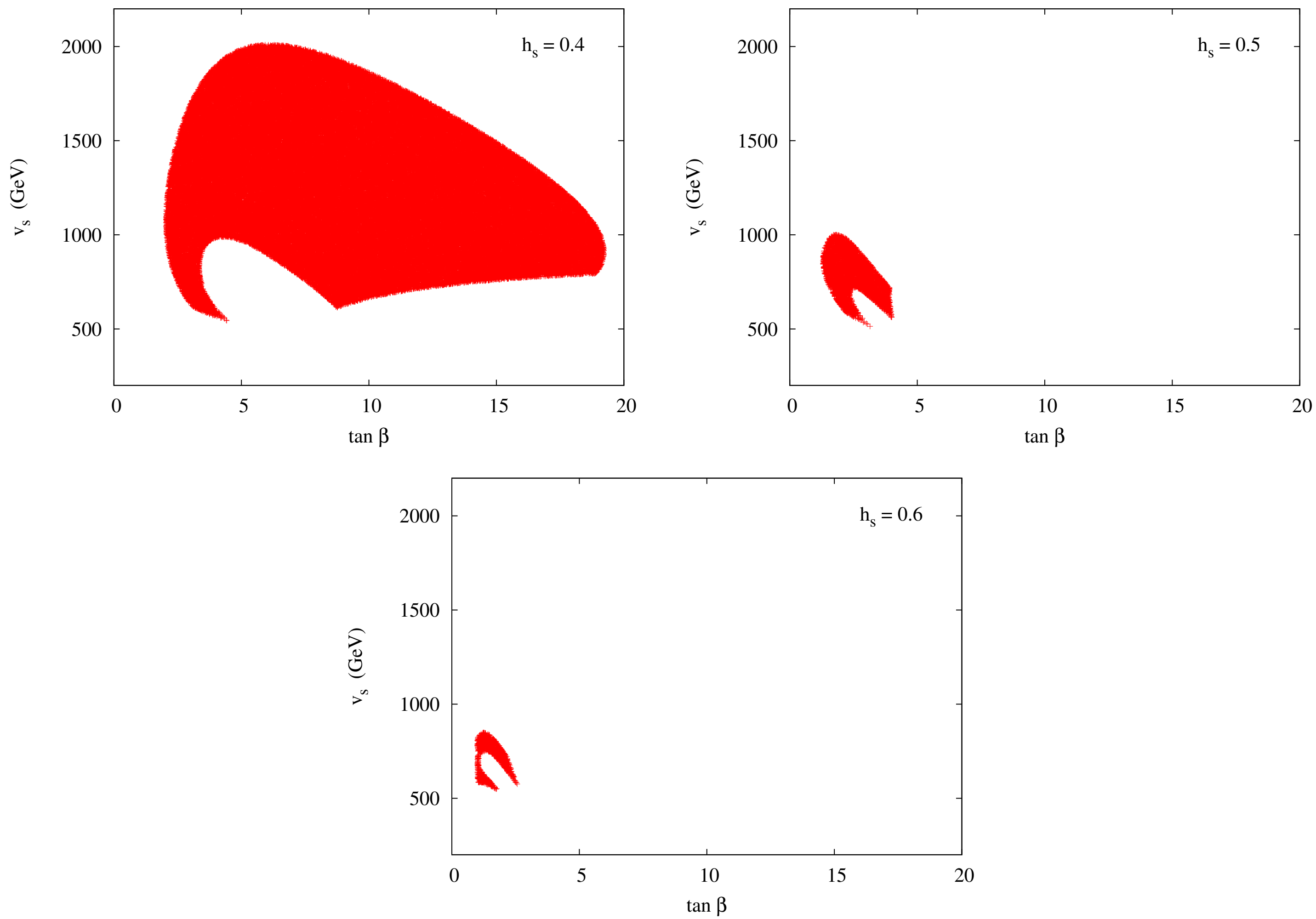


1000
900
800
700
600
500
400
300
200
0
5
10
15
20
tan β
v_s (GeV)
h_s = 0.4
h_s = 0.5
h_s = 0.6

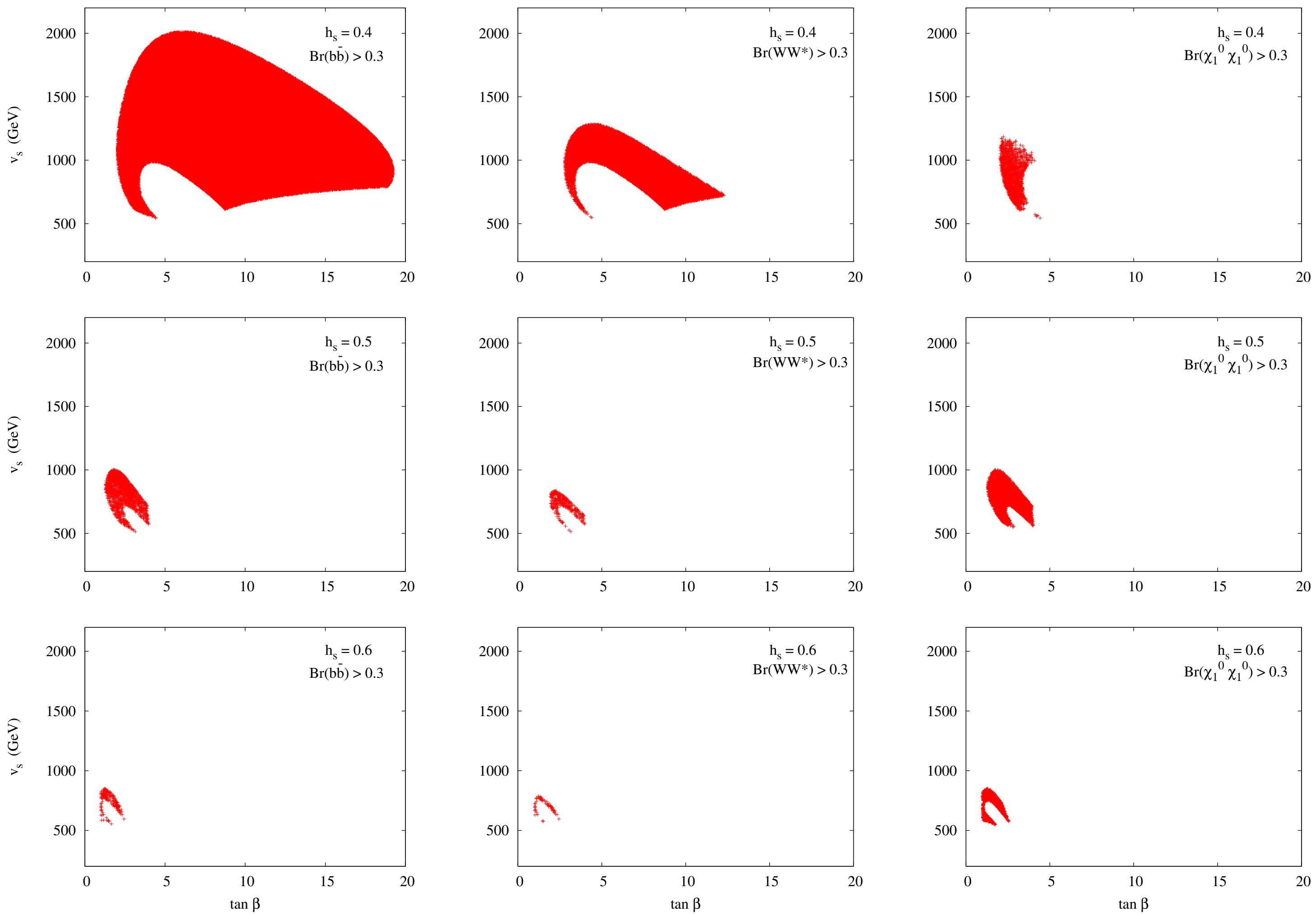

h_s = 0.4
Br(bb̄) > 0.4
h_s = 0.4
Br(WW*) > 0.4
h_s = 0.4
Br(χ_1^0 χ_1^0) > 0.4
h_s = 0.5
Br(bb̄) > 0.4
h_s = 0.5
Br(WW*) > 0.4
h_s = 0.5
Br(χ_1^0 χ_1^0) > 0.4
h_s = 0.6
Br(bb̄) > 0.4
h_s = 0.6
Br(WW*) > 0.4
h_s = 0.6
Br(χ_1^0 χ_1^0) > 0.4
v_s (GeV)
tan β

Scenario 2: $120 < M_{h_{\rm SM-like}} < 130$ GeV.

- A smaller h_s is more likely to give 120 GeV $< M_{\rm SM-like} <$ 130 GeV.
- Again larger h_s will make invisible mode dominant.



$h_s = 0.4$
$h_s = 0.5$
$h_s = 0.6$
v_s (GeV)
tan β
2000
1500
1000
500
0
5
10
15
20



$h_s = 0.4$
$Br(b\bar{b}) > 0.3$
$h_s = 0.4$
$Br(WW^*) > 0.3$
$h_s = 0.4$
$Br(\chi_1^0 \chi_1^0) > 0.3$
$h_s = 0.5$
$Br(b\bar{b}) > 0.3$
$h_s = 0.5$
$Br(WW^*) > 0.3$
$h_s = 0.5$
$Br(\chi_1^0 \chi_1^0) > 0.3$
$h_s = 0.6$
$Br(b\bar{b}) > 0.3$
$h_s = 0.6$
$Br(WW^*) > 0.3$
$h_s = 0.6$
$Br(\chi_1^0 \chi_1^0) > 0.3$
v_s (GeV)
tan β

Conclusions

- Extensions to the MSSM easily raises the Higgs boson mass, e.g., NMSSM, UMSSM.
- The UMSSM only has one pseudoscalar such that $h_{\mathrm{SM-like}}$ cannot decay into two a_1, in contrast to NMSSM.
- If the $h_{\mathrm{SM-like}}$ falls in the range $130 - 141$ GeV, it can be hidden from current data by decaying into neutralinos. Still allowed.
- If the $h_{\mathrm{SM-like}}$ falls in the range $120 - 130$ GeV, it can decay similar to the SM Higgs boson. Thus, allowed by current data.