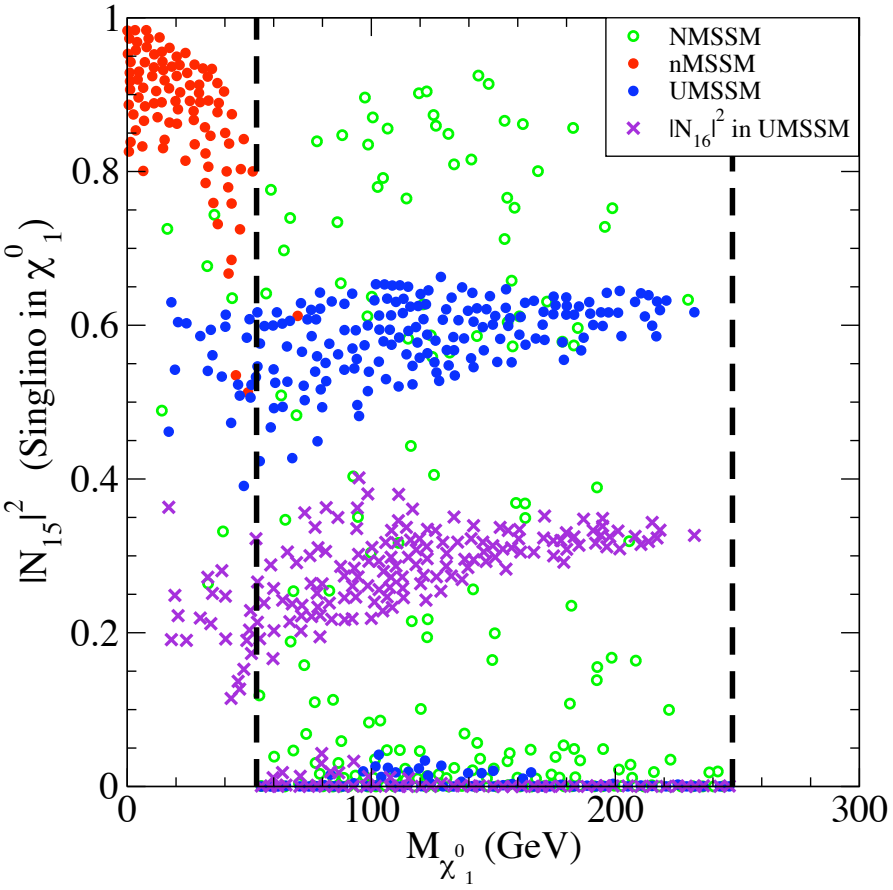
Higgs, neutralinos and exotics beyond the MSSM



- Beyond the MSSM
- Heavy Z'
- Higgs
- Neutralinos
- Exotics

References

- V. Barger, PL and H. S. Lee,
  "Lightest neutralino in extensions of the MSSM,"
  Phys. Lett. B 630, 85 (2005), hep-ph/0508027

- T. Han, PL and B. McElrath,
  "The Higgs sector in a $U(1)'$ extension of the MSSM,"
  Phys. Rev. D 70, 115006 (2004), hep-ph/0405244

- "Higgs Sector in Extensions of the MSSM", V. Barger, PL, H.S. Lee and G. Shaughnessy, to appear

- "Quasi-Chiral Exotics", J. Kang, PL and B. Nelson, to appear

- **Abel, Bagger, Barger, Bastero-Gil, Batra, Birkedal, Carena, Choi, Cvetic, Dedes, Delgado, Demir, Dermisek, Dobrescu, Drees, Ellis, Ellwanger, Erler, Espinosa, Everett, Godbole, Gunion, Haber, Han, Hooper, Hugonie, Kaplan, King, Landsberg, Li, Matchev, McElrath, Menon, Miller, Moretti, Morrissey, Nevzorov, Panagiotakopoulos, Perelstein, Pilaftsis, Poppitz, Randall, Rosner, Roy, Sarkar, Sopczak, Tait, Tamvakis, Vempati, Wagner, White, Zerwas, Zhang**

Beyond the MSSM

Even if supersymmetry holds, MSSM may not be the full story

Most of the problems of standard model remain (hierarchy of electroweak and Planck scales is stabilized but not explained)

μ problem introduced: $W_\mu = \mu \hat{H}_u \cdot \hat{H}_d, \quad \mu = O(\text{electroweak})$

Could be that all new physics is at GUT/Planck scale, but there could be remnants surviving to TeV scale

Specific string constructions often have extended gauge groups, exotics, extended Higgs/neutralino sectors

Important to explore alternatives/extensions to MSSM

Remnants Physics from the Top-Down

- Z' or other gauge
- Extended Higgs/neutralino (doublet, singlet)
- Quasi-Chiral Exotics
- Charge $1/2$ (Confinement?, Stable relic?)
- Quasi-hidden (Strong coupling? SUSY breaking? Composite family?)
- Time varying couplings
- LED (TeV black holes, stringy resonances)
- LIV, VEP (e.g., maximum speeds, decays, (oscillations) of HE γ, e, gravity waves (ν's))

A TeV-Scale Z'

- Strings, GUTs, DSB, little Higgs, LED often involve extra Z'
- Typically $M_{Z'} > 600 - 900$ GeV (Tevatron, LEP 2, WNC); $|\theta_{Z-Z'}| < \text{few} \times 10^{-3}$ (Z-pole)
  (CDF di-electron: 850 (Z_{seq}), 740 (Z_χ), 725 (Z_ψ), 745 (Z_η))
- Discovery to $M_{Z'} \sim 5 - 8$ TeV at LHC, ILC, $(pp \to e^+e^-, \mu^+\mu^-, q\bar{q})$ (depends on couplings, exotics, sparticles)
- Diagnostics to 1-2 TeV (asymmetries, y distributions, associated production, rare decays)
- Implications: μ problem; extended Higgs/neutralino sector (cosmology); exotics; FCNC; decays into sparticles/exotics

Higgs singlets S_i

- Standard model singlets extremely common in string constructions
- Needed to break extra $U(1)'$ gauge symmetries
- Solution to μ problem ($U(1)'$, NMSSM, nMSSM)

$$W \sim h_s \hat{S} \hat{H}_u \hat{H}_d \rightarrow \mu_{eff} = h_s \langle S \rangle$$

- Relaxed upper limits, couplings, parameter ranges (e.g., $\tan\beta = v_u/v_d$ can be close to 1), singlet-doublet mixing
- Large A term and possible tree-level CP violation $\rightarrow$ electroweak baryogenesis

Models with Dynamical μ

Model	Symmetry	Superpotential	CP-even	CP-odd
MSSM	–	$\mu \hat{H}_u \cdot \hat{H}_d$	H_1^0, H_2^0	A_2^0
NMSSM	Z_3	$h_s \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$	H_1^0, H_2^0, H_3^0	A_1^0, A_2^0
nMSSM	Z_5^R, Z_7^R	$h_s \hat{S} \hat{H}_u \cdot \hat{H}_d + \xi_F M_{\rm n}^2 \hat{S}$	H_1^0, H_2^0, H_3^0	A_1^0, A_2^0
UMSSM	$U(1)'$	$h_s \hat{S} \hat{H}_u \cdot \hat{H}_d$	H_1^0, H_2^0, H_3^0	A_2^0
sMSSM	$U(1)'$	$h_s \hat{S} \hat{H}_u \cdot \hat{H}_d + \lambda_s \hat{S}_1 \hat{S}_2 \hat{S}_3$	$H_1^0, H_2^0, H_3^0, H_4^0, H_5^0, H_6^0$	$A_1^0, A_2^0, A_3^0, A_4^0$

- MSSM: gaugino unification but general μ
- NMSSM: may be domain wall problems
- nMSSM: avoids domain walls; tadpoles from high order loops
- UMSSM: additional Z' ($\mu_{eff}, M_{Z'}$ generated by single S)
- sMSSM: stringy NMSSM w. decoupled μ_{eff}, $M_{Z'}$
  ($\hat{H}_u, \hat{H}_d, \hat{S}$ reduces to nMSSM in S_i decoupling limit $\longrightarrow$n/sMSSM)

A Unified Analysis of Higgs and Neutralino Sectors

(B. Barger, PL, H.-S. Lee, G. Shaughnessy, hep-ph/0508027 (BLL) and to appear)

$$
\begin{aligned}
V_F &= |h_s H_u \cdot H_d + \xi_F M_{\rm n}^2 + \kappa S^2|^2 + |h_s S|^2 \left(|H_d|^2 + |H_u|^2\right) \\
V_D &= \frac{G^2}{8}\left(|H_d|^2 - |H_u|^2\right)^2 + \frac{g_2^2}{2}\left(|H_d|^2|H_u|^2 - |H_u \cdot H_d|^2\right) \\
&+ \frac{{g_1'}^2}{2}\left(Q_{H_d}|H_d|^2 + Q_{H_u}|H_u|^2 + Q_S|S|^2\right)^2 \\
V_{\rm soft} &= m_d^2|H_d|^2 + m_u^2|H_u|^2 + m_s^2|S|^2 \\
&+ \left(A_s h_s S H_u \cdot H_d + \frac{\kappa}{3} A_\kappa S^3 + \xi_S M_{\rm n}^3 S + h.c.\right)
\end{aligned}
$$

black = MSSM (with $\mu = h_s\langle S\rangle$); blue= extensions;
cyan = NMSSM; magenta = UMSSM; red= n/sMSSM

Mass matrices in $\{H_d, H_u, S\}$ basis

- **CP-even (tree level)** ($\langle H^0_{u,d}\rangle \equiv v_{u,d}/\sqrt{2}, \langle S\rangle \equiv s/\sqrt{2}$)

$$(\mathcal{M}^0_+)_{dd} = \left[\frac{G^2}{4} + Q^2_{H_d} {g_1'}^2\right] v_d^2 + (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M^2_{\rm n}}{s})\frac{v_u s}{v_d}$$

$$(\mathcal{M}^0_+)_{du} = -\left[\frac{G^2}{4} - h_s^2 - Q_{H_d} Q_{H_u} {g_1'}^2\right] v_d v_u - (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M^2_{\rm n}}{s})$$

$$(\mathcal{M}^0_+)_{ds} = \left[h_s^2 + Q_{H_d} Q_S {g_1'}^2\right] v_d s - (\frac{h_s A_s}{\sqrt{2}} + h_s \kappa s) v_u$$

$$(\mathcal{M}^0_+)_{uu} = \left[\frac{G^2}{4} + Q^2_{H_u} {g_1'}^2\right] v_u^2 + (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M^2_{\rm n}}{s})\frac{v_d s}{v_u}$$

$$(\mathcal{M}^0_+)_{us} = \left[h_s^2 + Q_{H_u} Q_S {g_1'}^2\right] v_u s - (\frac{h_s A_s}{\sqrt{2}} + h_s \kappa s) v_d$$

$$(\mathcal{M}^0_+)_{ss} = \left[Q^2_S {g_1'}^2 + 2\kappa^2\right] s^2 + (\frac{h_s A_s}{\sqrt{2}} - \frac{\sqrt{2}\xi_S M^3_{\rm n}}{v_d v_u})\frac{v_d v_u}{s} + \frac{\kappa A_\kappa}{\sqrt{2}} s$$

- **Also CP-odd and charged Higgs** (CP breaking ignored)
- **Leading loop corrections (top-stop loops) are common**
- **Theoretical upper limits on H_1^0 relaxed** ($\longrightarrow$smaller $\tan\beta$ allowed)
  - MSSM

$$M_{H_1^0}^2 \leq M_Z^2 \cos^2 2\beta + \tilde{\mathcal{M}}^{(1)}$$

$$\tilde{\mathcal{M}}^{(1)} = (\mathcal{M}_+^{(1)})_{dd} \cos^2\beta + (\mathcal{M}_+^{(1)})_{uu} \sin^2\beta + (\mathcal{M}_+^{(1)})_{du} \sin 2\beta$$

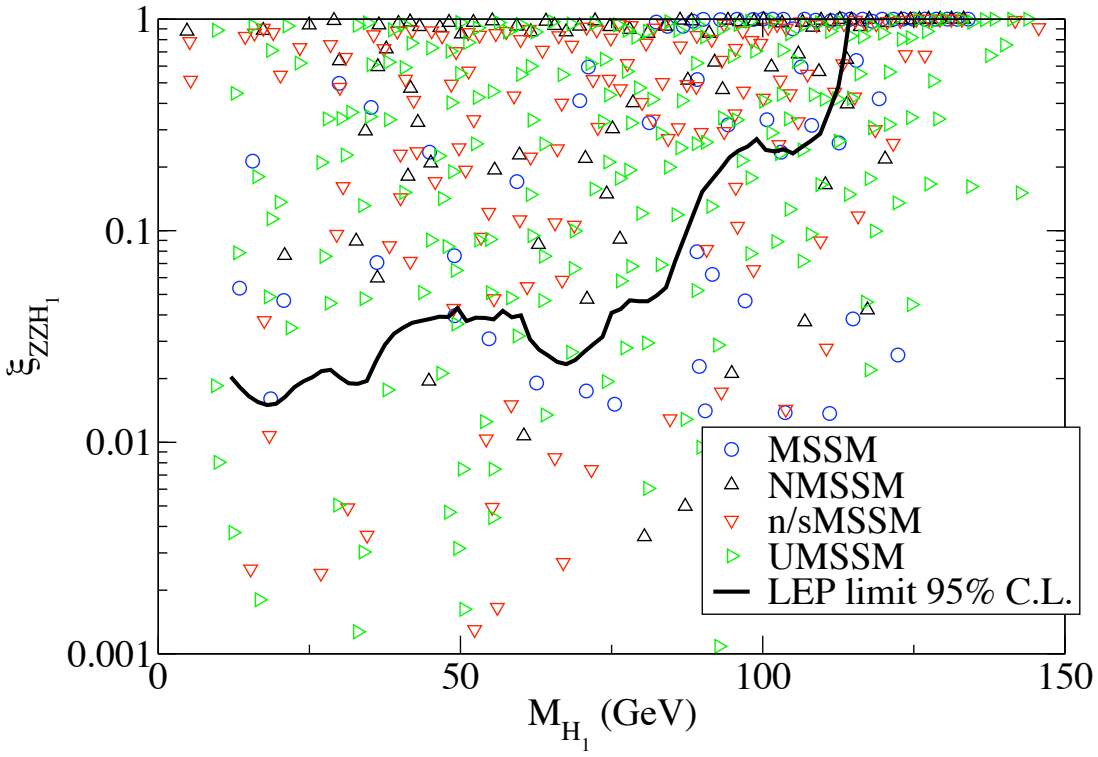
  - NMSSM, n/sMSSM, and Peccei-Quinn limits

$$M_{H_1^0}^2 \leq M_Z^2 \cos^2 2\beta + \frac{1}{2} h_s^2 v^2 \sin^2 2\beta + \tilde{\mathcal{M}}^{(1)}$$

  - UMSSM

$$M_{H_1^0}^2 \leq M_Z^2 \cos^2 2\beta + \frac{1}{2} h_s^2 v^2 \sin^2 2\beta + g_{Z'}^2 v^2 (Q_{H_d} \cos^2\beta + Q_{H_u} \sin^2\beta)^2 + \tilde{\mathcal{M}}^{(1)}$$

- **Experimental LEP SM and MSSM bounds may be relaxed by singlet-doublet mixing**



- **Reduced ZZH_i coupling**

$$\xi_{ZZH_i} = (R_+^{i1}\cos\beta + R_+^{i2}\sin\beta)^2$$

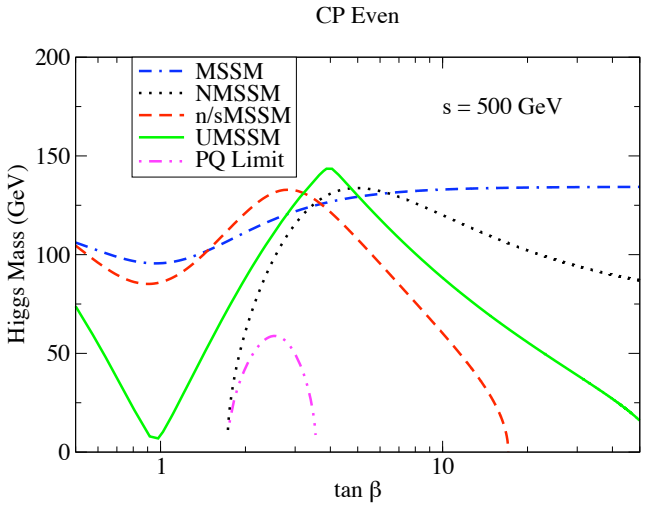
- **Also, $X \to HA$, Z width, $\chi^\pm$ mass, $Z - Z'$ mixing, V minimum, RGE**

Limiting Cases

- **MSSM limit** ($s \to \infty$ with $\mu_{eff} = h_s s/\sqrt{2}$ fixed) $\to$ **two MSSM-like CP-even Higgs and one largely singlet** (heavy in UMSSM, light in n/sMSSM, depends on κ in NMSSM)

- **PQ and R limits (massless pseudoscalar)**

Model	Limits	Symmetry	Effects
MSSM	$B \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
NMSSM	$\kappa, A_\kappa \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
NMSSM	$A_s, A_\kappa \to 0$	$U(1)_R$	$M_{A_1} \to 0$
n/sMSSM	ξ_F, $\xi_S \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
UMSSM	$g_{1'} \to 0$	$U(1)$	$M_{Z'}, M_{A_1} \to 0$



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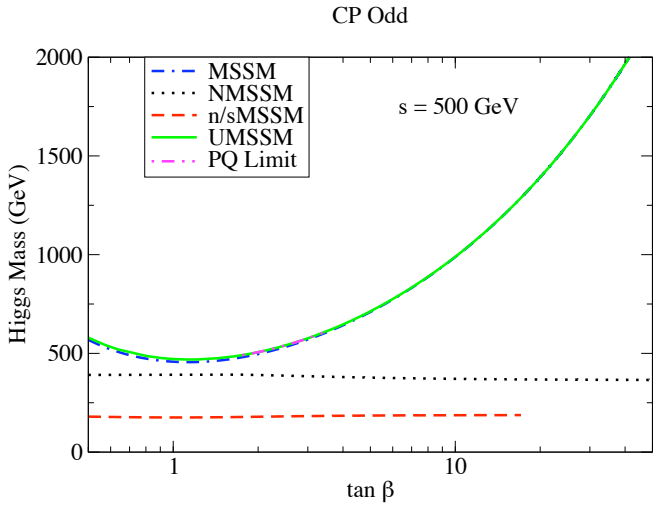

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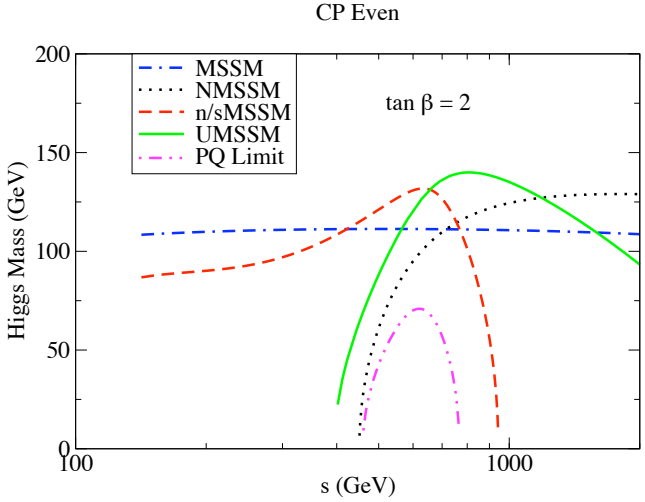

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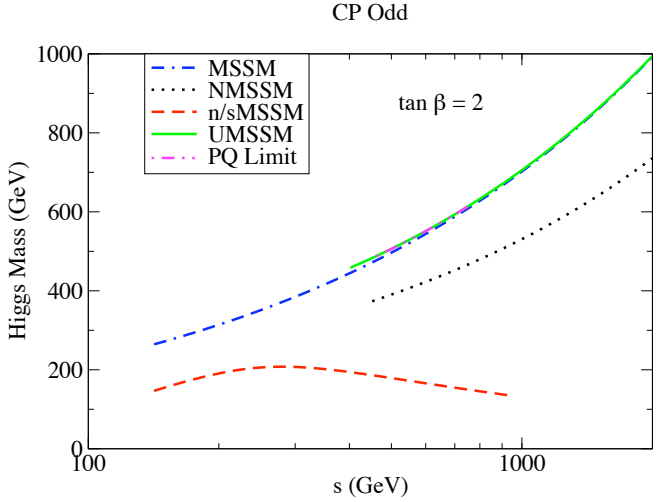
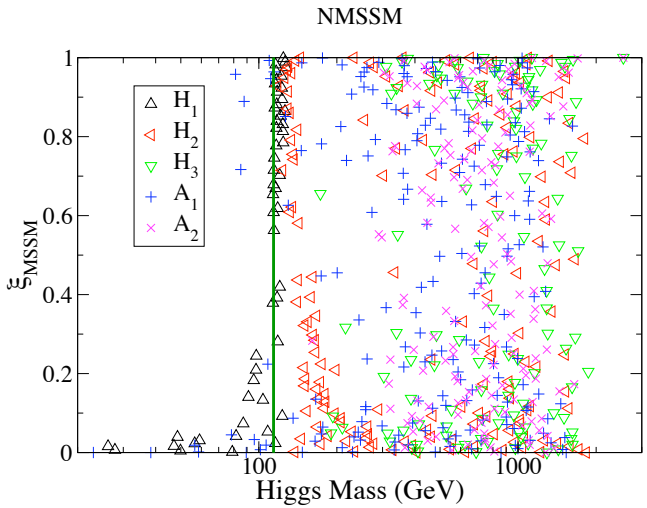


(d)

$$(A_s = M_n = 500 \text{ GeV},\ A_\kappa = -250 \text{ GeV},\ h_s = \kappa = 0.5,\ \xi_{F,S} = -0.1)$$



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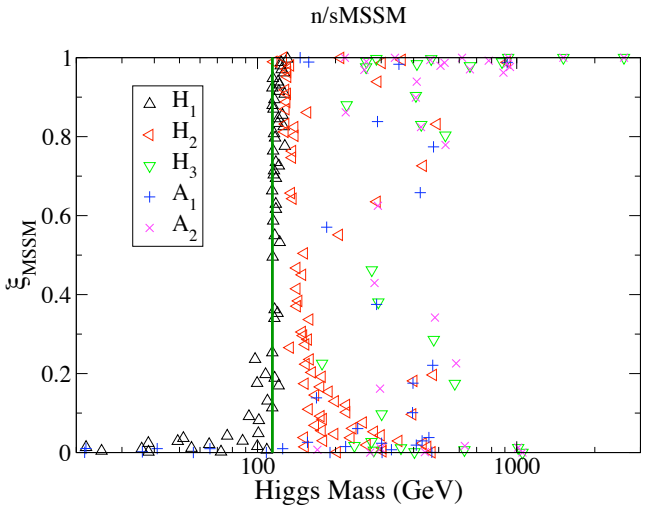

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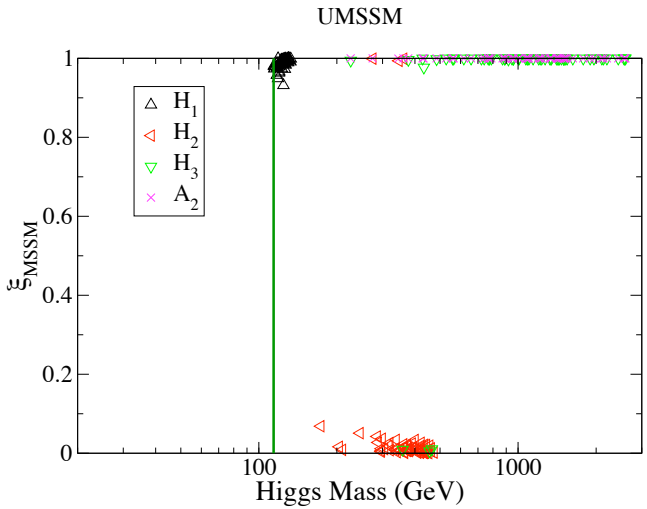

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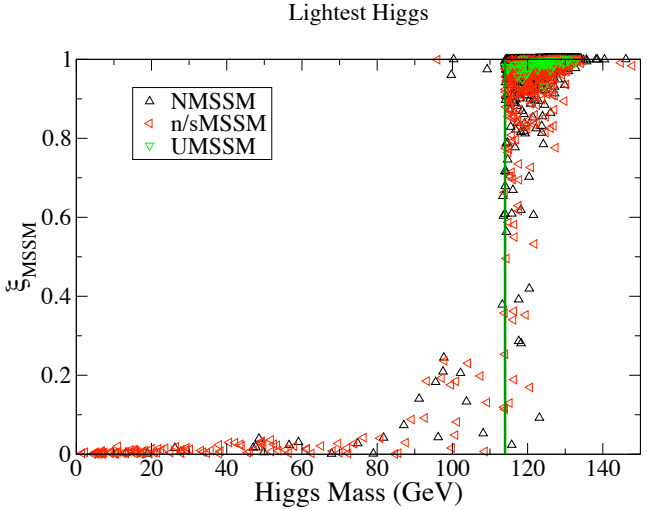
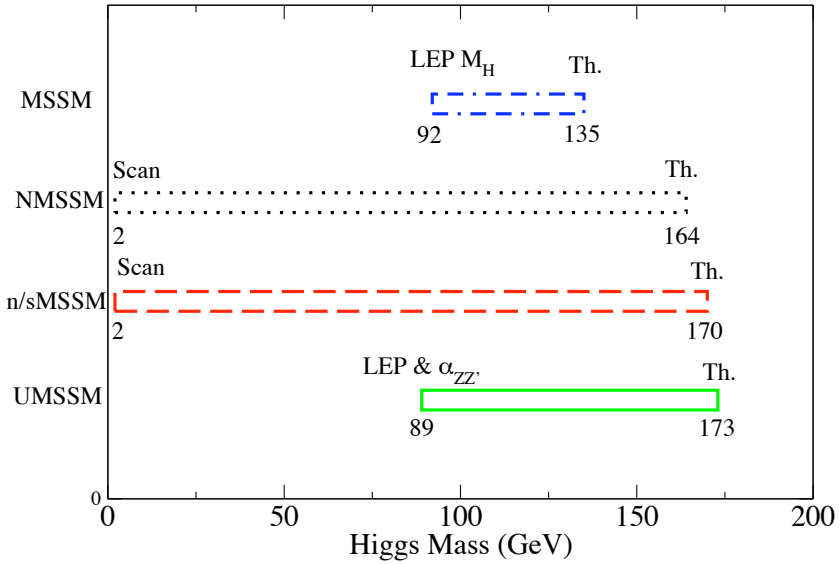


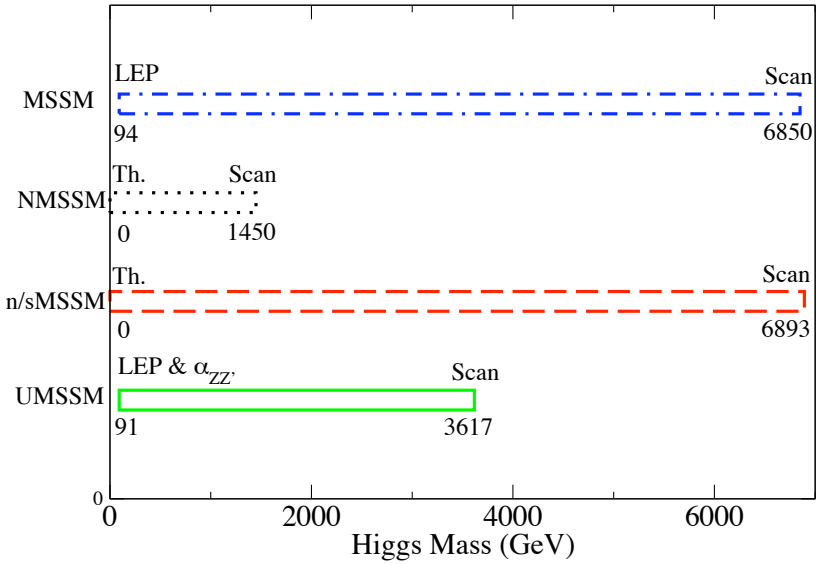
(d)

(MSSM fraction $\xi^{H_i}_{\rm MSSM} = \sum_{j=d}^{u} (R_+^{ij})^2$)

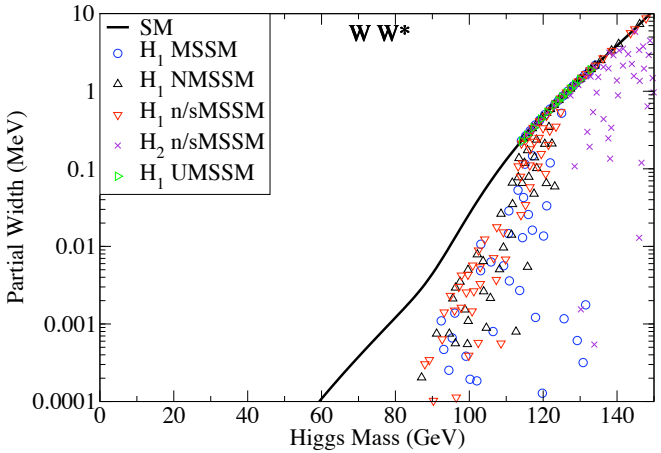
CP-Even Higgs Mass Range

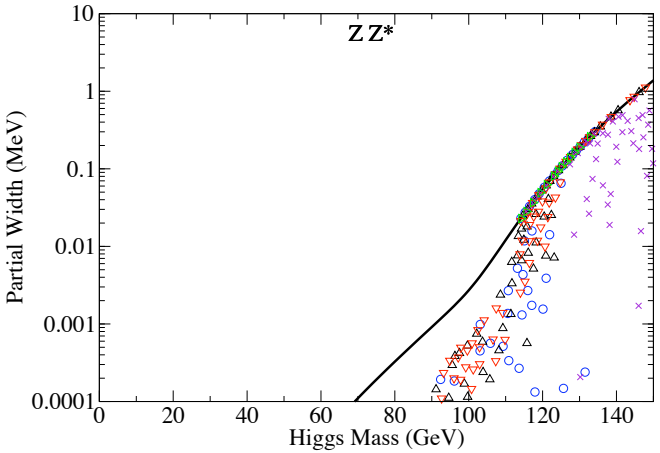


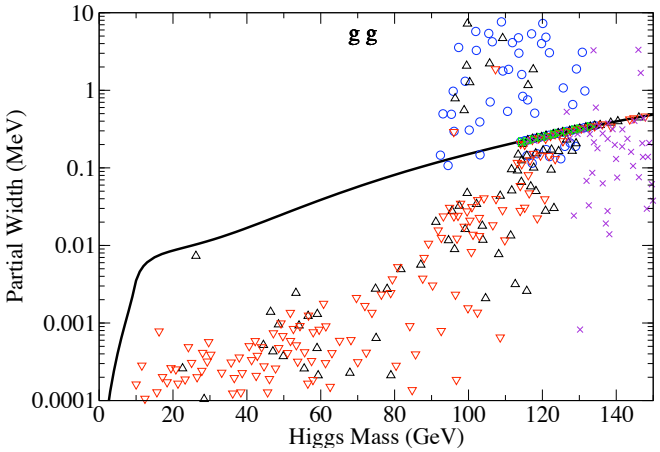
CP-Odd Higgs Mass Range



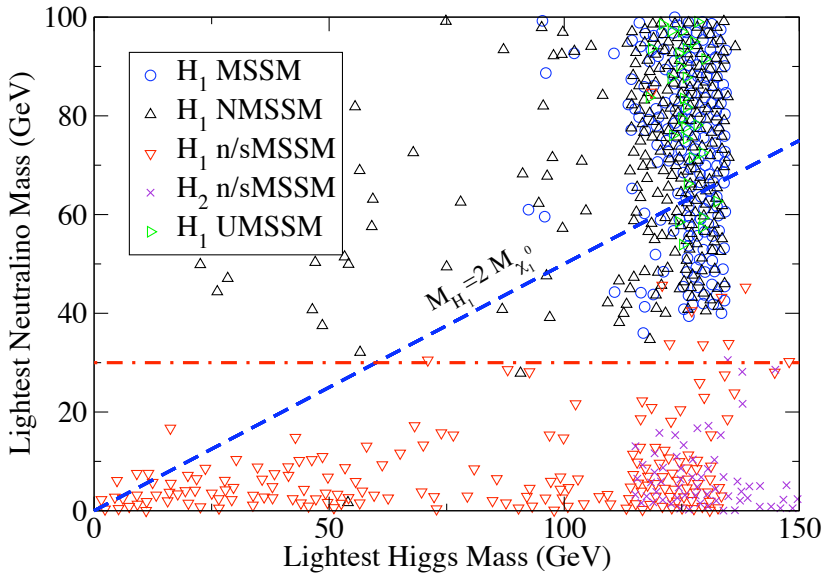
Lightest Higgs Decays







Invisible Decays



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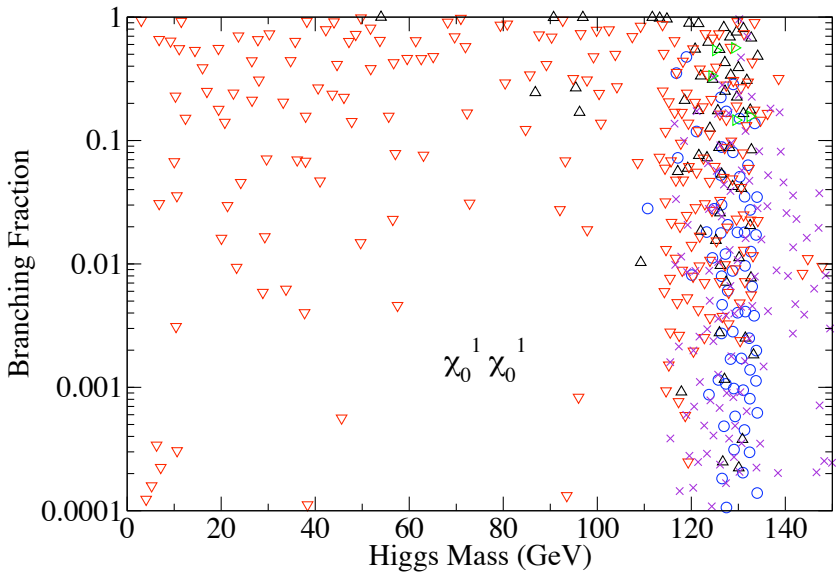
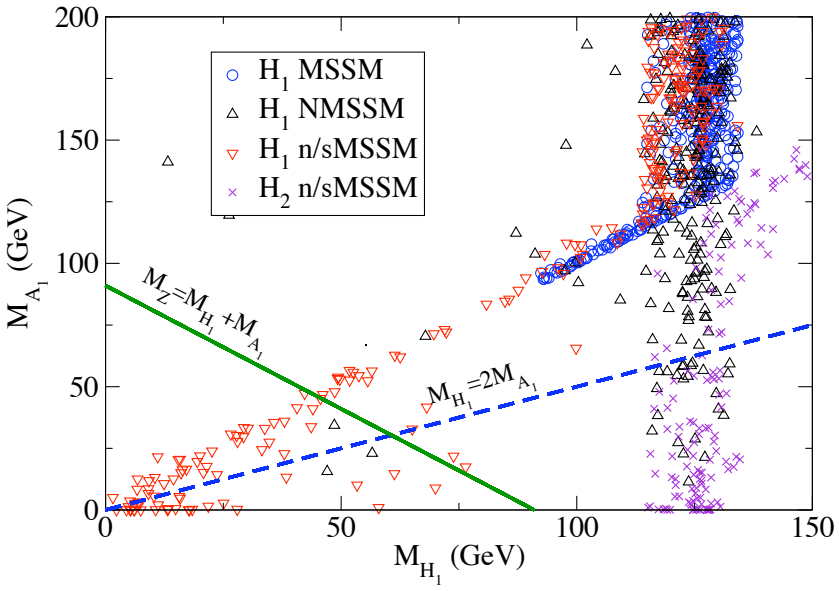


(b)

$H_{1,2} \rightarrow A_1 A_1$



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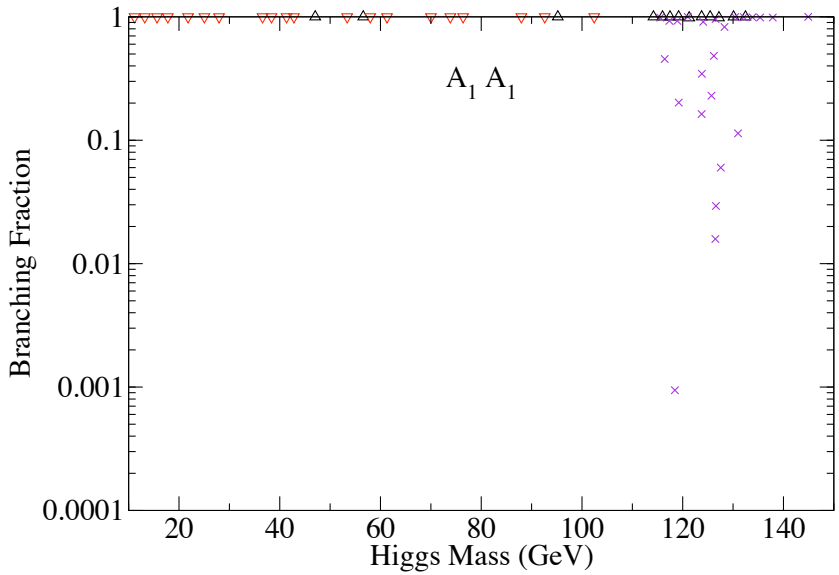
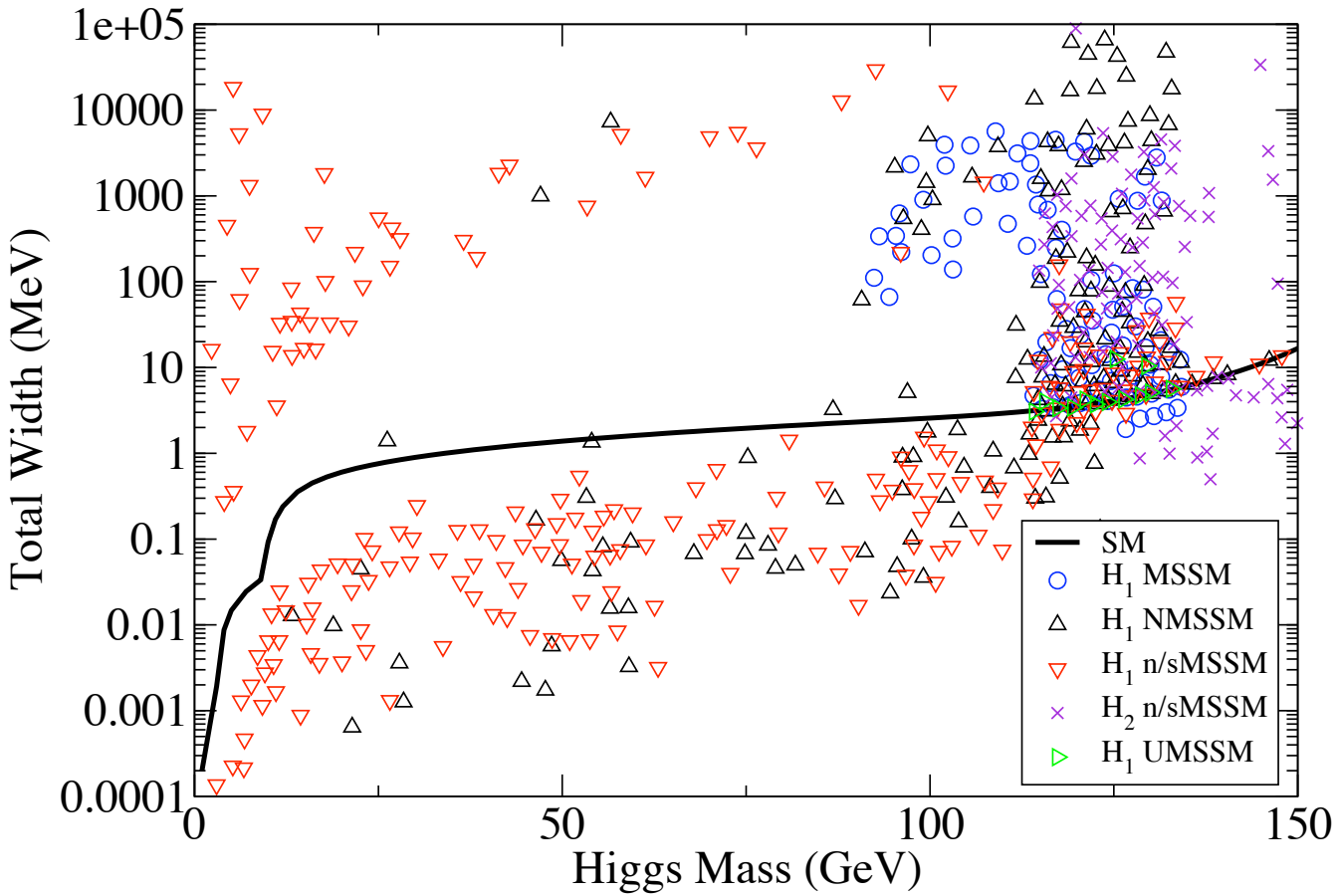


(b)

Total Width


1e+05
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
Total Width (MeV)
0
50
100
150
Higgs Mass (GeV)
SM
H1 MSSM
H1 NMSSM
H1 n/sMSSM
H2 n/sMSSM
H1 UMSSM

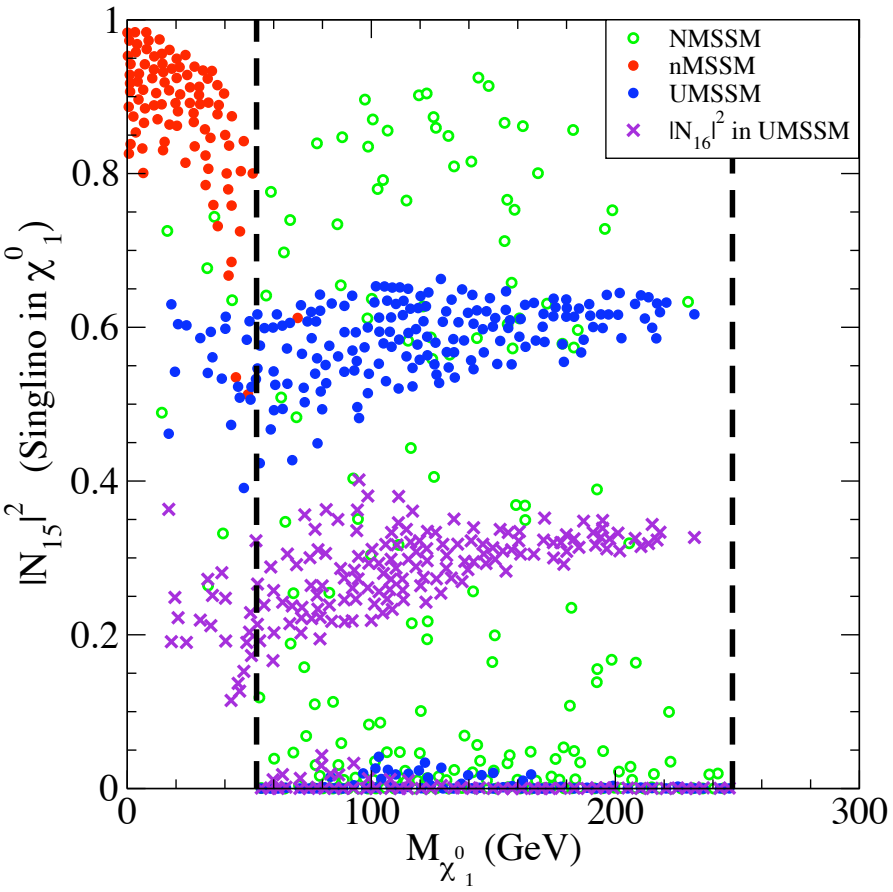
Lightest Neutralino

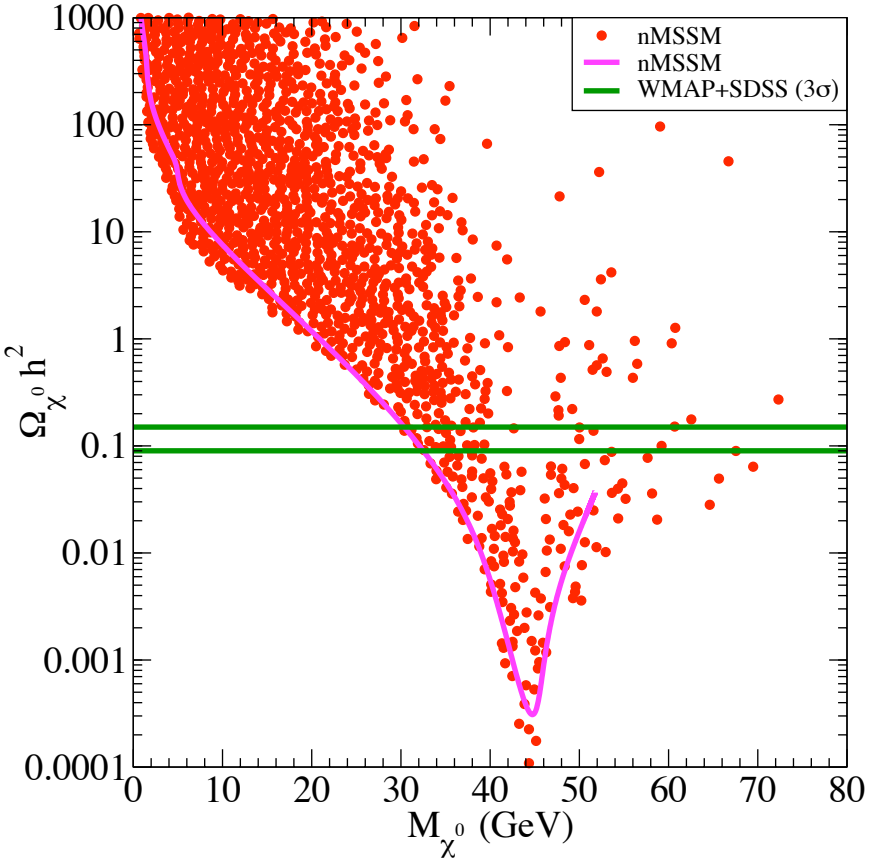
Mass matrix (M_{χ^0}) in basis $\{\tilde{B},\ \tilde{W}_3,\ \tilde{H}_1^0,\ \tilde{H}_2^0,\ \tilde{S},\ \tilde{Z}'\}$:

$$\begin{pmatrix}
M_1 & 0 & -g_1 v_1/2 & g_1 v_2/2 & 0 & 0 \\
0 & M_2 & g_2 v_1/2 & -g_2 v_2/2 & 0 & 0 \\
-g_1 v_1/2 & g_2 v_1/2 & 0 & -\mu_{eff} & -\mu_{eff} v_2/s & g_{Z'} Q'_{H_1} v_1 \\
g_1 v_2/2 & -g_2 v_2/2 & -\mu_{eff} & 0 & -\mu_{eff} v_1/s & g_{Z'} Q'_{H_2} v_2 \\
0 & 0 & -\mu_{eff} v_2/s & -\mu_{eff} v_1/s & \sqrt{2}\kappa s & g_{Z'} Q'_S s \\
0 & 0 & g_{Z'} Q'_{H_1} v_1 & g_{Z'} Q'_{H_2} v_2 & g_{Z'} Q'_S s & M_{1'}
\end{pmatrix}$$

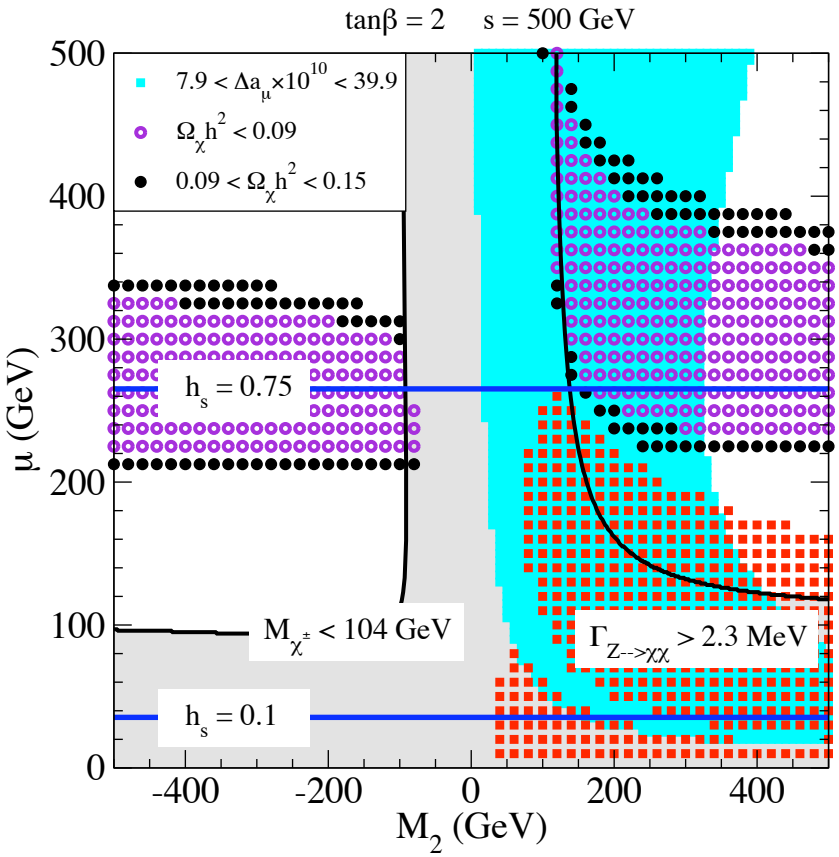
($\langle S \rangle \equiv \frac{s}{\sqrt{2}}$, $\langle H_i^0 \rangle \equiv \frac{v_i}{\sqrt{2}}$, $\sqrt{v_1^2 + v_2^2} \equiv v \simeq 246$ GeV, $Q'_\phi = \phi$ $U(1)'$ charge)

(black = MSSM; blue= extensions; cyan = NMSSM; magenta = UMSSM)

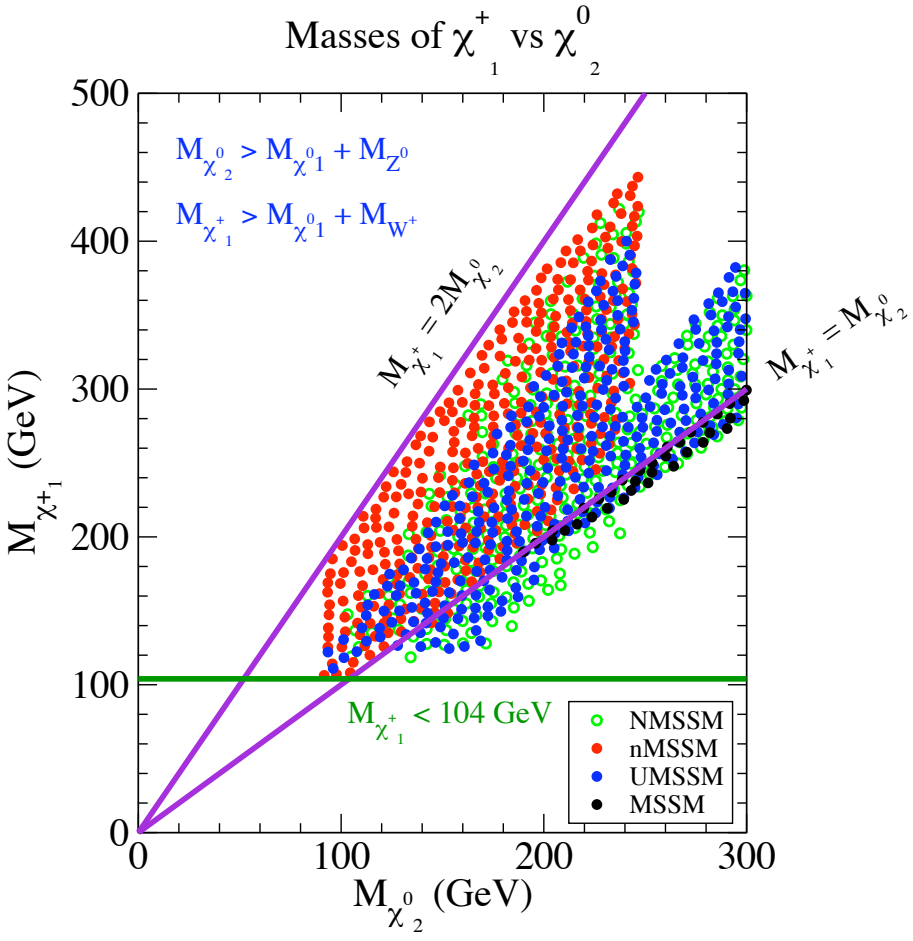


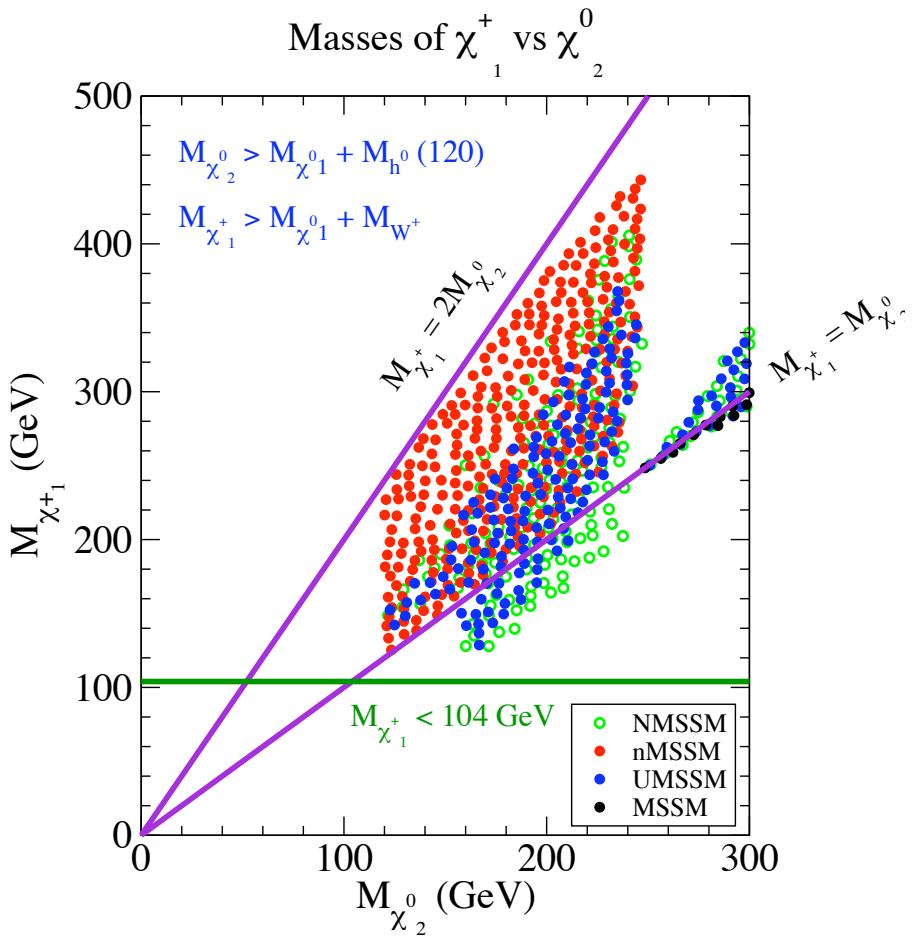


(Relic density in nMSSM from $\chi_1^0\chi_1^0 \rightarrow Z$ only; may be $\chi_1^0 \rightarrow$ secluded in sMSSM)



(Relic density and $g_\mu - 2$ in n/sMSSM)





- Often $\chi_2^0 \cdots \chi_5^0$ are MSSM-like with light singlino-dominated χ_1^0
- MSSM-like cascades with *extra* $\chi_2^0 \to \chi_1^0 + (l\bar{l}, q\bar{q}, Z, h)$
- Often $\chi_2^0 \to \chi_1^0 + (Z, h)$; $\chi_1^+ \to \chi_1^0 + (W^+, H^+)$ are open

(e.g., $\chi_1^+ \chi_2^0 \to W^+ h + \not{E}_T \to l^+ b \bar{b} + \not{E}_T$)

Quasi-Chiral Exotics

(J. Kang, PL, B. Nelson, in progress)

- Often find exotic (wrt $SU(2)\times U(1)$) quarks or leptons at TeV scale
  - Assume non-chiral wrt SM gauge group (strong constraints from precision EW, expecially on extra or mirror families)
  - Can be chiral wrt extra $U(1)$'s or other extended gauge
  - Usually needed for $U(1)'$ anomaly cancellation
  - Modify gauge unification unless in complete GUT multiplets
  - Can also be more extreme exotics (e.g., adjoints, symmetric, fractional charge, mixed quasi-hidden)
  - Experimental limits relatively weak

- **Examples in 27-plet of E_6**
  - $D_L + D_R$ ($SU(2)$ singlets, chiral wrt $U(1)'$)
  - $\begin{pmatrix} E^0 \\ E^- \end{pmatrix}_L + \begin{pmatrix} E^0 \\ E^- \end{pmatrix}_R$ ($SU(2)$ doublets, chiral wrt $U(1)'$)
- **Pair produce $D + \bar{D}$ by QCD processes** (smaller rate for exotic leptons)
- **D or $\tilde{D}$ decay by**
  - $D \to u_i W^-$, $D \to d_i Z$, $D \to d_i H^0$ if driven by $D - \bar{d}$ mixing (not in minimal E_6; FCNC) $\to m_D \gtrsim 200$ GeV (future: ~ 1 TeV)
  - $\tilde{D} \to$ quark jets if driven by diquark operator $\bar{u}\bar{u}\bar{D}$
  - $\tilde{D} \to$ quark jet + lepton if driven by leptoquark operator $lq\bar{D}$
  - May be stable at renormalizable level due to accidental symmetry (e.g., from extended gauge group) $\to$ hadronizes and escapes or stops in detector (Quasi-stable from HDO $\to \tau < 1/10$ yr)

Conclusions

- Combination of theoretical ideas and new experimental facilities may allow testable theory to Planck scale
- From the bottom up: there may be more at TeV scale than (minimal SUGRA) MSSM (e.g., Z', extended Higgs/neutralino, quasi-chiral exotics)
- From the top down: there may be more at TeV scale than (minimal SUGRA) MSSM
- Dynamical μ term leads to very rich Higgs/neutralino physics at colliders and for cosmology

Implications of a TeV-scale $U(1)'$

- **Natural Solution to μ problem $W \sim hSH_uH_d \rightarrow \mu_{eff} = h\langle S\rangle$** ("stringy version" of NMSSM)

- **Extended Higgs sector**
  - Relaxed upper limits, couplings, parameter ranges (e.g., $\tan\beta$ can be close to 1)
  - Higgs singlets needed to break $U(1)'$
  - Doublet-singlet mixing $\rightarrow$highly non-standard collider signatures

- **Large A term and possible tree-level CP violation** (no new EDM constraints) **$\rightarrow$electroweak baryogenesis**

- **Extended neutralino sector**
  - **Additional neutralinos, non-standard couplings, e.g., light singlino-dominated, extended cascades**
  - **Enhanced possibilities for cold dark matter, $g_\mu - 2$ (even small $\tan\beta$)**
- **Exotics (anomaly-cancellation)**
  - **May decay by mixing; by diquark or leptoquark coupling; or be quasi-stable**
- **Constraints on neutrino mass generation**
- **Flavor changing neutral currents (for non-universal $U(1)'$ charges)**
  - **Tree-level effects in B decay competing with SM loops (or with enhanced loops in MSSM with large $\tan\beta$)**

Extended Higgs Sector

- Standard model singlets S_i and additional doublet pairs $H_{u,d}$ very common.

- Additional doublet pairs
  - Richer spectrum, decay possibilities
  - May be needed (or expand possibiities for) quark/lepton masses/mixings (e.g., stringy symmetries may restrict single Higgs couplings to one or two families)
  - Extra neutral Higgs $\longrightarrow$ FCNC (suppressed by Yukawas)
  - Significantly modify gauge unification

The μ problem

Superpotential: $W = \mu \underbrace{\hat{H}_u \hat{H}_d}_{\text{superfields}} + h_t \underbrace{\hat{Q} \hat{H}_u \hat{d}^c}_{\text{superfields}} \Rightarrow$

$$L_{\text{fermion}} = \mu \underbrace{\tilde{H}_u \tilde{H}_d}_{\text{Higgsino mass}} + h_t (\underbrace{Q H_u d^c}_{\text{top Yukawa}} + \underbrace{Q \tilde{H}_u \tilde{d}^c + \tilde{Q} \tilde{H}_u d^c}_{\text{Higgsino-quark-squark}})$$

$$-L^W_{\text{scalar}} = \sum_\phi \left| \frac{\delta W}{\delta \phi} \right|^2 = \mu^2 \underbrace{\left(|H_u|^2 + |H_d|^2 \right)}_{\text{Higgs masses}} + h_t \text{ terms}$$

$$-L^D = \frac{g^2 + g'^2}{8} \left(|H_u|^2 - |H_d|^2 \right)^2 + \text{charged Higgs, squark, slepton}$$

$$-L^{\text{soft}} = m_u^2 \, |H_u|^2 + m_d^2 \, |H_d|^2 + (m_3^2 \, H_u H_d + \text{h.c.})$$

$$+ \text{squark/slepton} + M_3 \underbrace{\tilde{g}\tilde{g}}_{\text{gluino}} + M_2 \underbrace{\tilde{w}\tilde{w}}_{\text{wino}} + M_1 \underbrace{\tilde{b}\tilde{b}}_{\text{bino}}$$

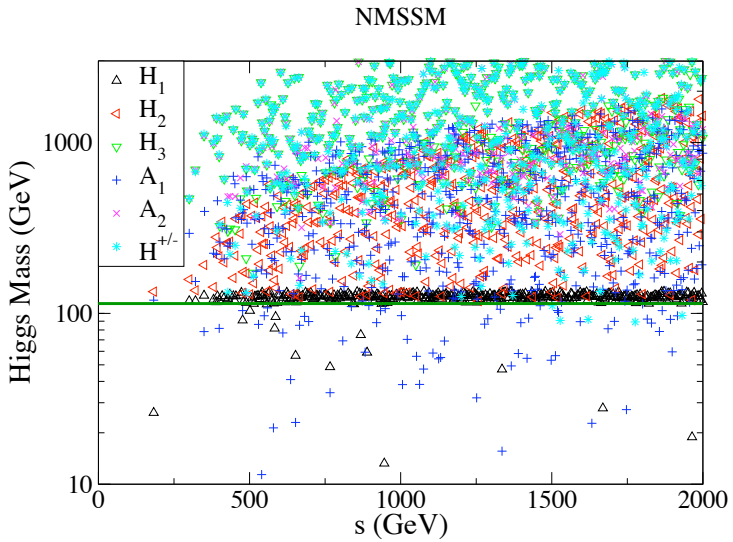
- Soft terms set ew scale, e.g., $m_{\rm soft} \sim F^2/M_{pl}$, $F \sim 10^{11}$ GeV, $M_{pl} \sim 10^{19}$ GeV

- μ problem: μ is supersymmetric $\Rightarrow$ could be very large (or exactly zero in string theory), but *need* $\mu \sim m_{\rm soft} \lesssim 1$ TeV

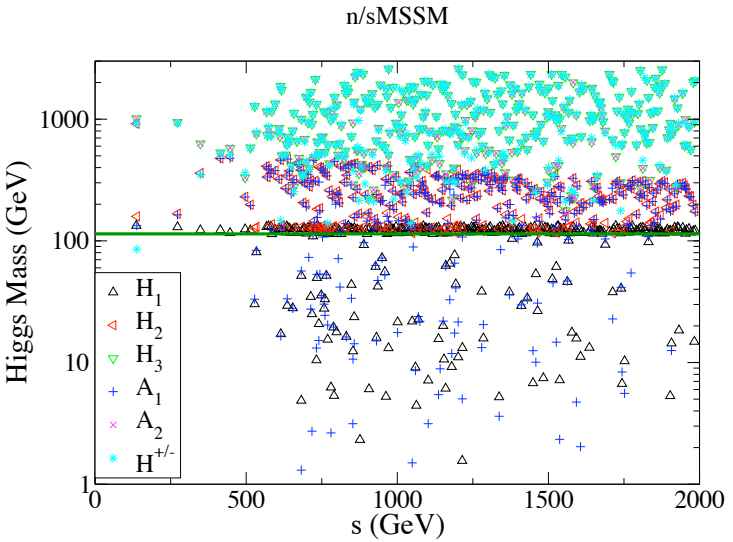
- Two classes of solutions
  - Generate μ in hidden sector along with $m_{\rm soft}$
  - Dynamical: $\mu \equiv 0$ by symmetry or string, but

$$W = h_s \underbrace{\hat{S}}_{\text{SM singlet}} \hat{H}_u \hat{H}_d \Rightarrow \mu_{eff} = h_s \langle S \rangle, \quad \langle S \rangle \sim m_{\rm soft}$$

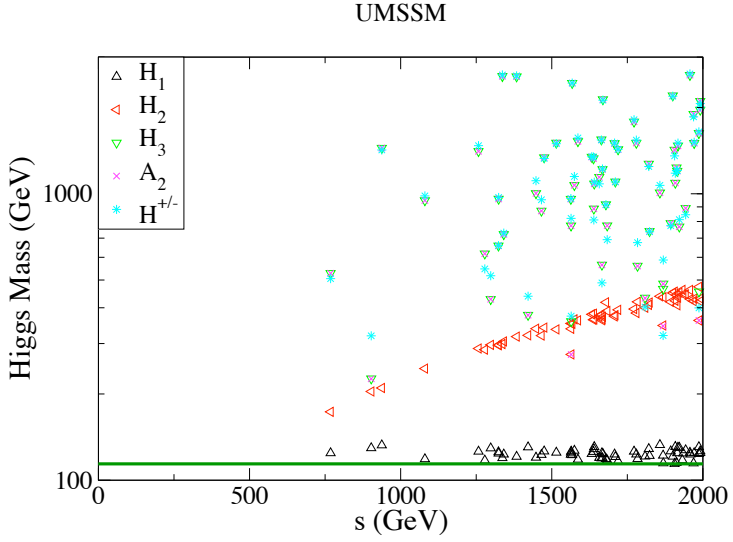
(Examples: Z' models, NMSSM, nMSSM)


NMSSM
Higgs Mass (GeV)
s (GeV)
H1
H2
H3
A1
A2
H+/-
10
100
1000
0
500
1000
1500
2000

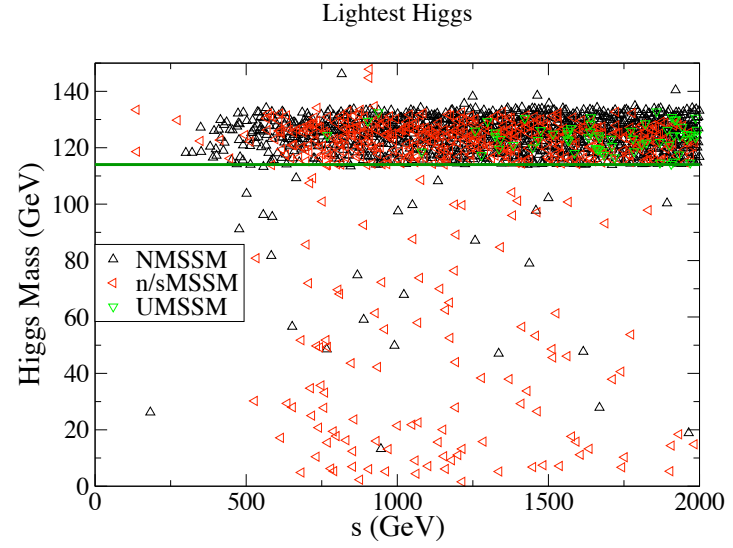
(a)


n/sMSSM
Higgs Mass (GeV)
s (GeV)
H1
H2
H3
A1
A2
H+/-
1
10
100
1000
0
500
1000
1500
2000

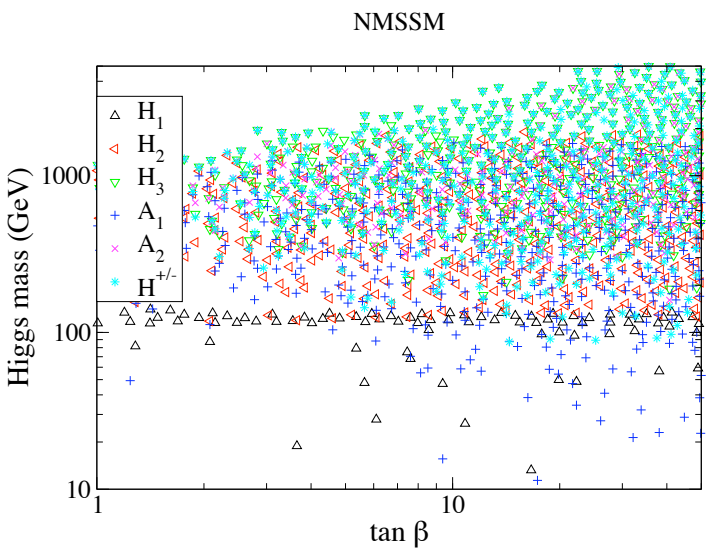
(b)


UMSSM
Higgs Mass (GeV)
s (GeV)
H1
H2
H3
A2
H+/-
100
1000
0
500
1000
1500
2000

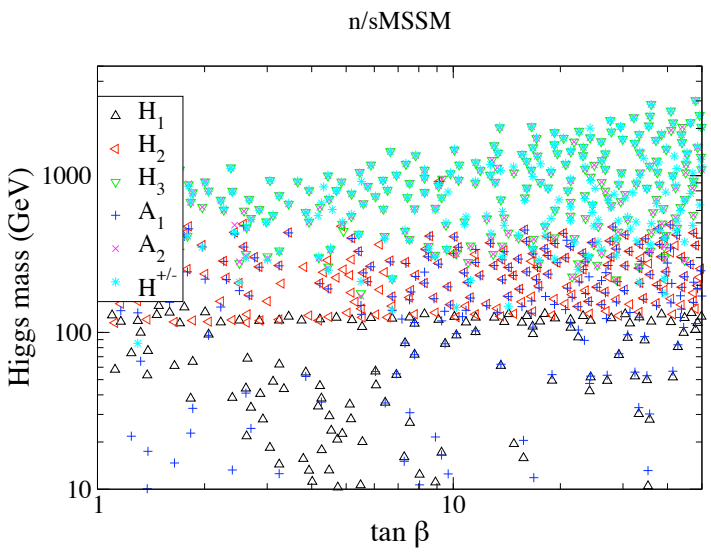
(c)


Lightest Higgs
Higgs Mass (GeV)
s (GeV)
NMSSM
n/sMSSM
UMSSM
0
20
40
60
80
100
120
140
0
500
1000
1500
2000

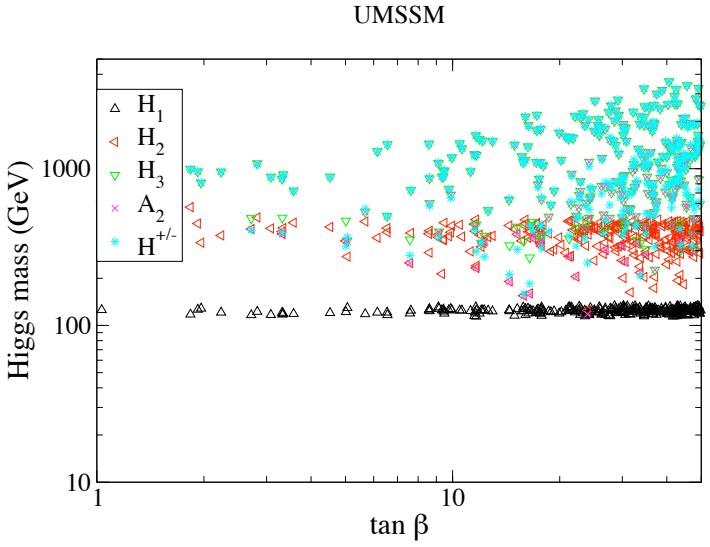
(d)


NMSSM
Higgs mass (GeV)
tan β
H1
H2
H3
A1
A2
H+/-
10
100
1000
1
10

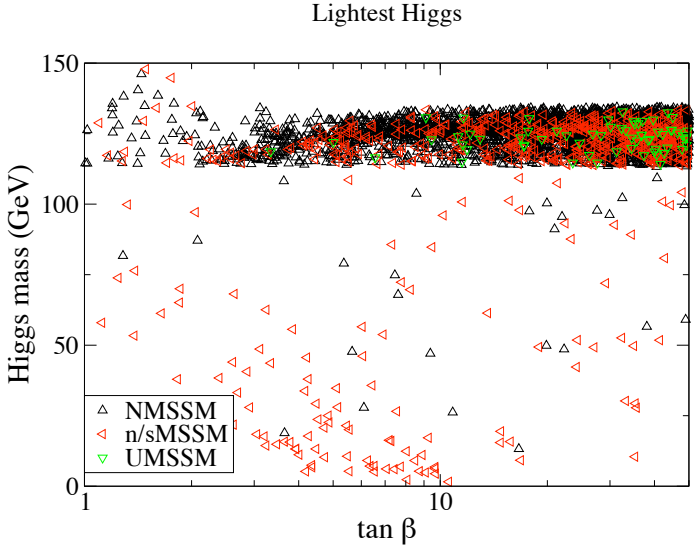
(a)


n/sMSSM
Higgs mass (GeV)
tan β
H1
H2
H3
A1
A2
H+/-
10
100
1000
1
10

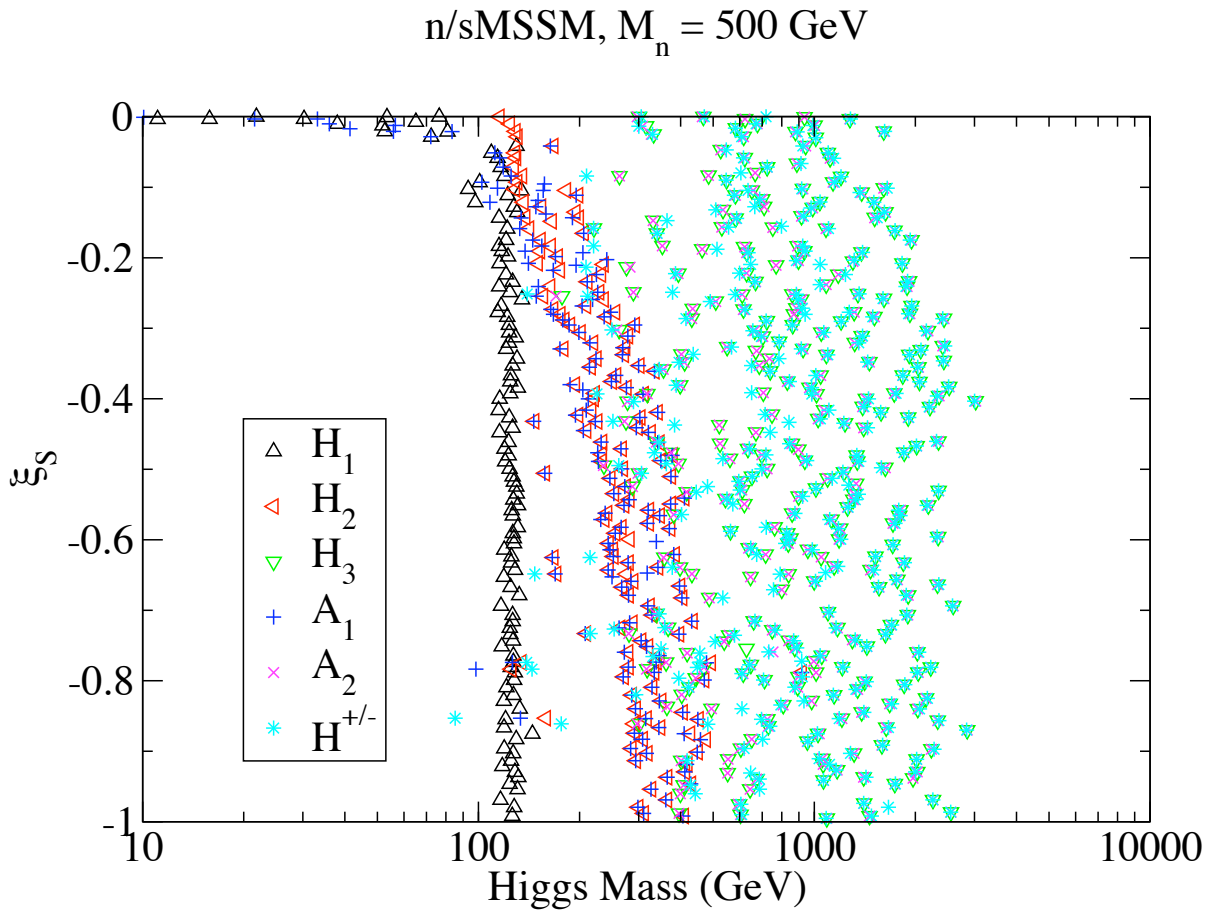
(b)

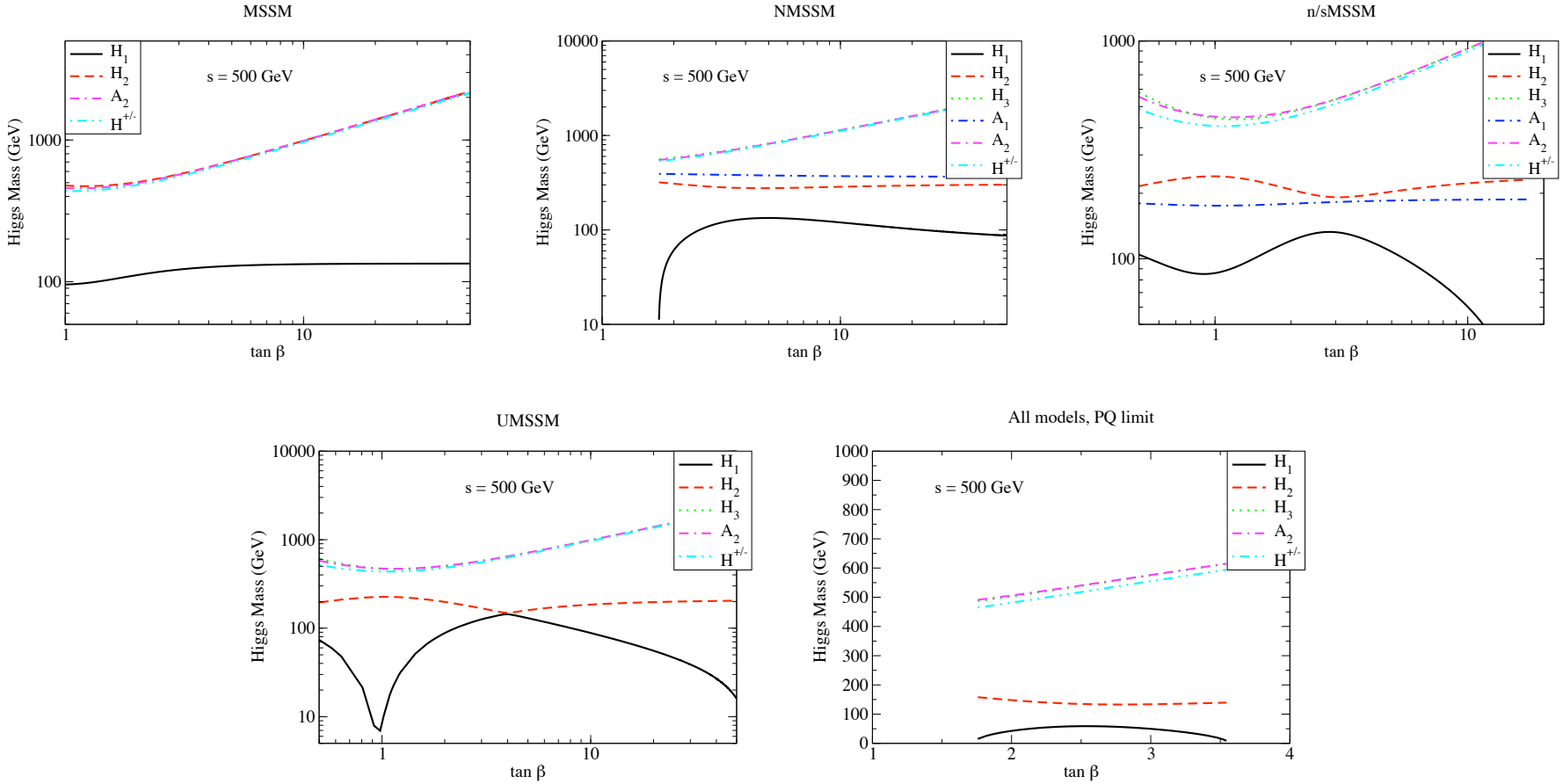

UMSSM
Higgs mass (GeV)
tan β
H1
H2
H3
A2
H+/-
10
100
1000
1
10

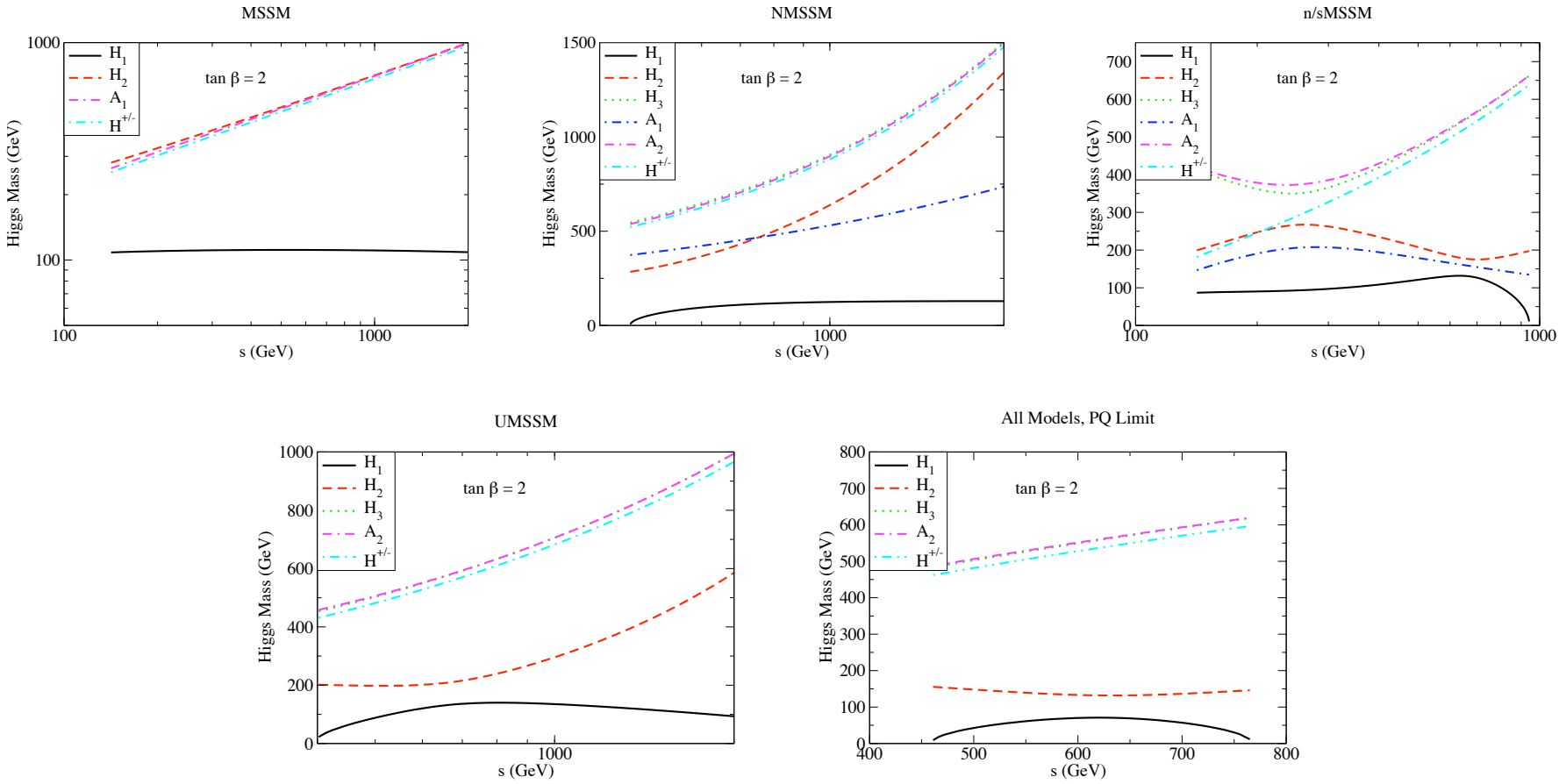
(c)

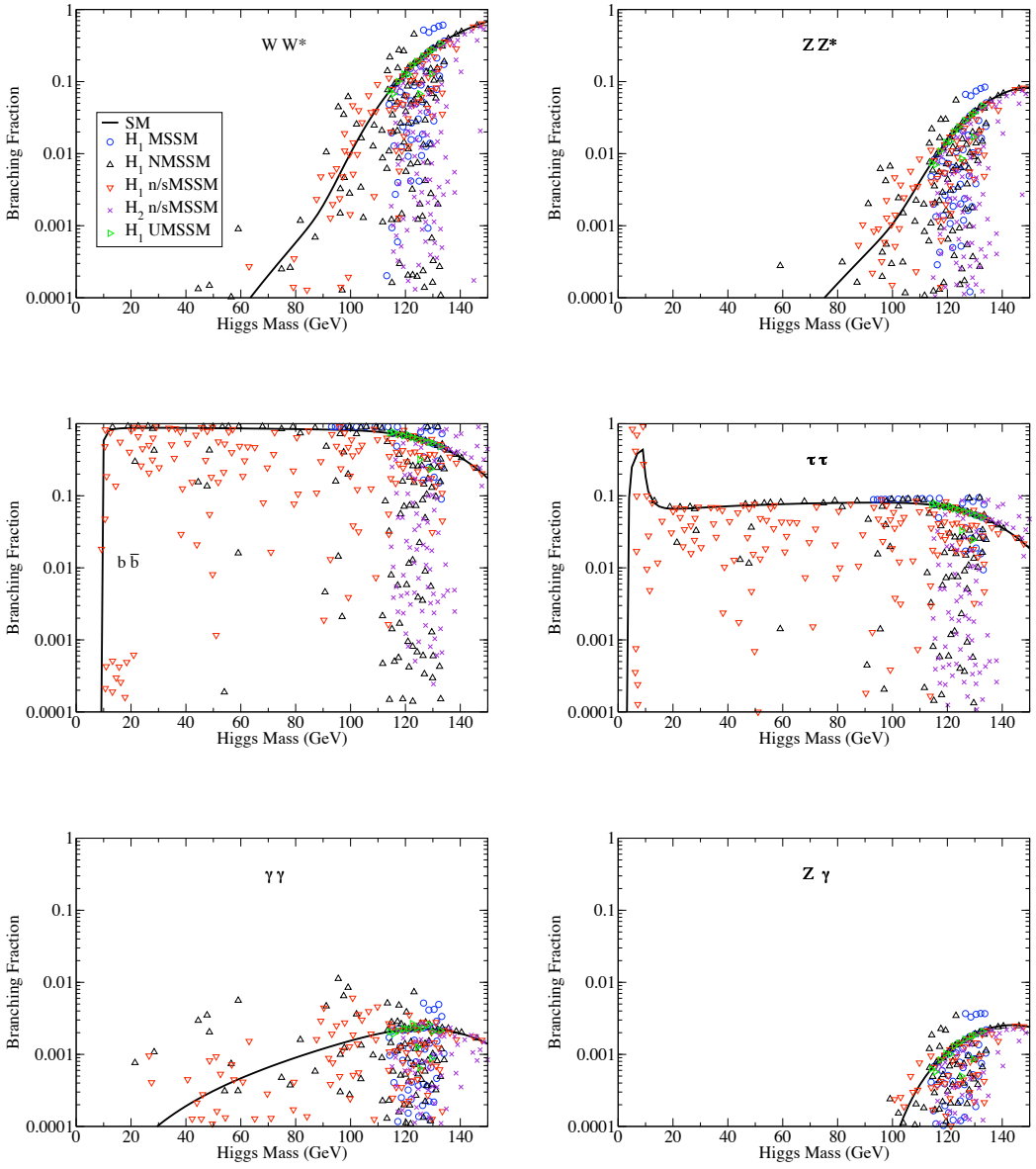

Lightest Higgs
Higgs mass (GeV)
tan β
NMSSM
n/sMSSM
UMSSM
0
50
100
150
1
10

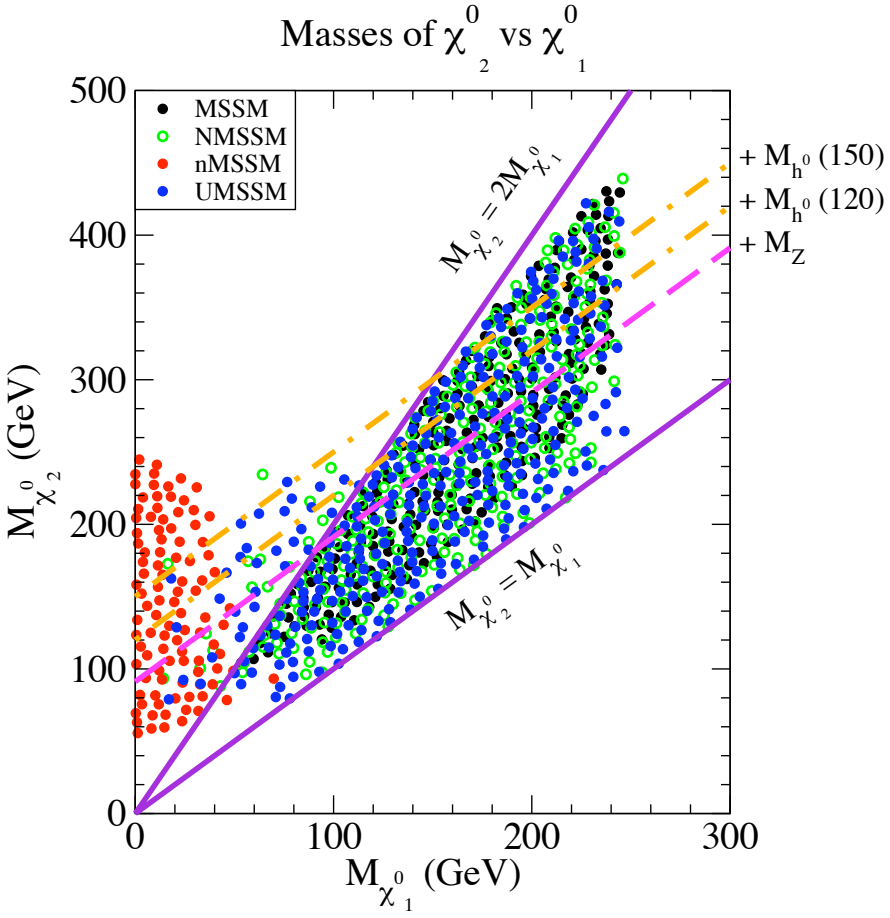
(d)

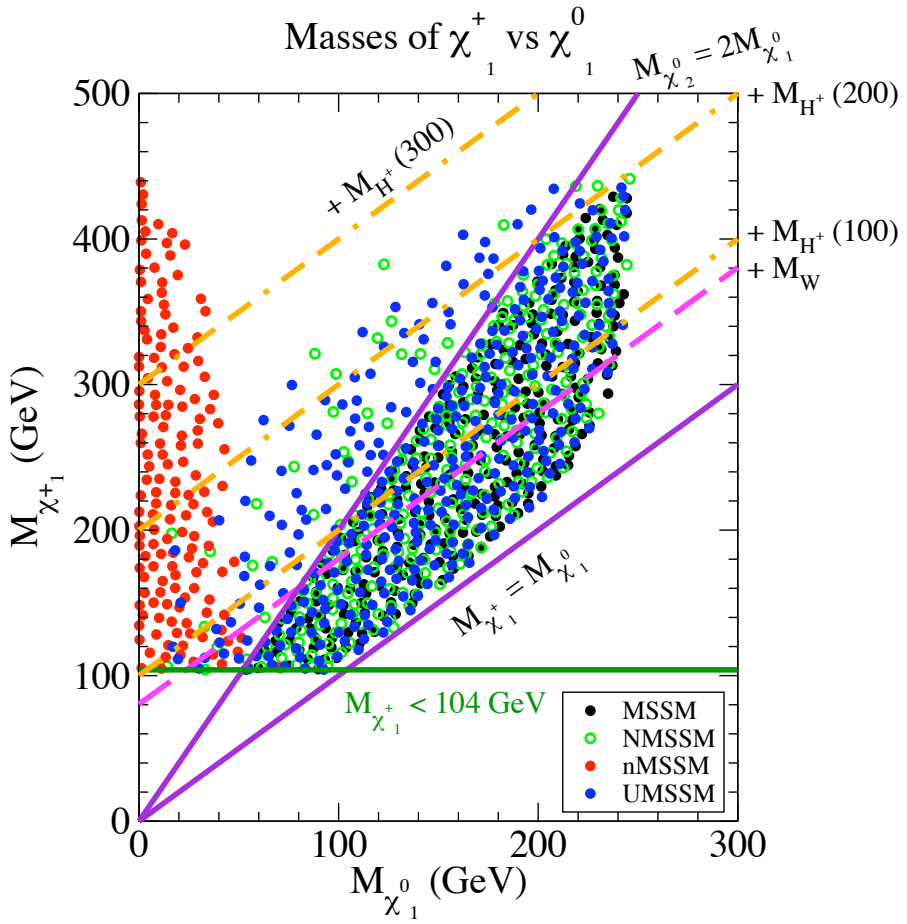

n/sMSSM, M_n = 500 GeV
0
-0.2
-0.4
-0.6
-0.8
-1
ξ_S
H_1
H_2
H_3
A_1
A_2
H^+/-
10
100
1000
10000
Higgs Mass (GeV)


MSSM
s = 500 GeV
H1
H2
A2
H+/-
Higgs Mass (GeV)
tan β
NMSSM
s = 500 GeV
H1
H2
H3
A1
A2
H+/-
Higgs Mass (GeV)
tan β
n/sMSSM
s = 500 GeV
H1
H2
H3
A1
A2
H+/-
Higgs Mass (GeV)
tan β
UMSSM
s = 500 GeV
H1
H2
H3
A2
H+/-
Higgs Mass (GeV)
tan β
All models, PQ limit
s = 500 GeV
H1
H2
H3
A2
H+/-
Higgs Mass (GeV)
tan β


MSSM
NMSSM
n/sMSSM
UMSSM
All Models, PQ Limit
tan β = 2
Higgs Mass (GeV)
s (GeV)
H1
H2
H3
A1
A2
H+/-


W W*
Z Z*
b b̄
τ τ
γ γ
Z γ
SM
H1 MSSM
H1 NMSSM
H1 n/sMSSM
H2 n/sMSSM
H1 UMSSM
Branching Fraction
Higgs Mass (GeV)





- **Often $\chi_2^0 \to \chi_1^0 + (Z, h)$; $\chi_1^+ \to \chi_1^0 + (W^+, H^+)$ open w. fairly light χ_1^+, χ_2^0**
  (e.g., $\chi_1^+ \chi_2^0 \to W^+ h + \not{E}_T \to l^+ b \bar{b} + \not{E}_T$,
  or $\chi_1^+ \chi_2^0 \to W^+ Z + \not{E}_T \to l^+ l' \bar{l}' + \not{E}_T$)