Beyond the MSSM

- Beyond the MSSM
- Heavy Z'
- Higgs
- Neutralinos
- Exotics
- Neutrino Mass in Strings

References

- J. Kang, P. Langacker, T. j. Li and T. Liu,
  "Electroweak baryogenesis in a supersymmetric $U(1)'$ model,"
  Phys. Rev. Lett. 94, 061801 (2005), hep-ph/0402086.
- J. Kang and P. Langacker,
  "Z' discovery limits for supersymmetric $E(6)$ models",
  Phys. Rev. D 71, 035014 (2005), hep-ph/0412190.
- J. Erler, P. Langacker and T. j. Li,
  "The $Z - Z'$ mass hierarchy in a supersymmetric model with a secluded $U(1)'$-breaking sector,"
  Phys. Rev. D 66, 015002 (2002), hep-ph/0205001.
- V. Barger, C. W. Chiang, J. Jiang and P. Langacker,
  "$B_s - \bar{B}_s$ mixing in Z' models with flavor-changing neutral currents,"
  Phys. Lett. B 596, 229 (2004), hep-ph/0405108.
- T. Han, P. Langacker and B. McElrath,
  "The Higgs sector in a $U(1)'$ extension of the MSSM,"
  Phys. Rev. D 70, 115006 (2004), hep-ph/0405244.

- V. Barger, PL and H. S. Lee,
  "Lightest neutralino in extensions of the MSSM,"
  Phys. Lett. B 630, 85 (2005), hep-ph/0508027
- J. Giedt, G. L. Kane, P. Langacker and B. D. Nelson,
  "Massive neutrinos and (heterotic) string theory,"
  Phys. Rev. D 71, 115013 (2005) hep-th/0502032.
- P. Langacker and B. D. Nelson,
  "String-inspired triplet see-saw from diagonal embedding of $SU(2)_L$ in $SU(2)_A \times SU(2)_B$,"
  Phys. Rev. D 72, 053013 (2005), hep-ph/0507063.
- "Higgs Sector in Extensions of the MSSM", V. Barger, PL, H.S. Lee and G. Shaughnessy, hep-ph/0603247.
- "Quasi-Chiral Exotics", J. Kang, PL and B. Nelson, to appear

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 with 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)

- **String models**
  - Extra $U(1)'$ and SM singlets extremely common
  - Radiative breaking of electroweak (SUGRA or gauge mediated) often yield EW/TeV scale Z' (unless breaking along flat direction $\longrightarrow$ intermediate scale)
  - Breaking due to negative mass^2 for scalar S (driven by large Yukawa) or by A term

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 $\longrightarrow$ highly non-standard collider signatures

- **Large A term and possible tree-level CP violation** (no new EDM constraints) $\longrightarrow$ **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
- **Z' decays into sparticles/exotics**
- **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

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 $\longrightarrow$ electroweak baryogenesis

Dynamical μ

- "Higgs Sector in Extensions of the MSSM", V. Barger, PL, H.S. Lee and G. Shaughnessy, hep-ph/0603247
- V. Barger, PL and H. S. Lee, "Lightest neutralino in extensions of the MSSM," Phys. Lett. B 630, 85 (2005), hep-ph/0508027
- Abel, Bagger, Barger, Bastero-Gil, Batra, Birkedal, Carena, Chang, Choi, Cvetic, Dedes, Delgado, Demir, Dermisek, Dobrescu, Drees, Ellis, Ellwanger, Erler, Espinosa, Everett, Fox, 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, Weiner, White, Zerwas, Zhang

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	$h_s \hat{S} \hat{H}_u \cdot \hat{H}_d + \xi_F M_n^2 \hat{S}$	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 (Z_2^R?)
- 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

$$V_F = |h_s H_u \cdot H_d + \xi_F M_n^2 + \kappa S^2|^2 + |h_s S|^2 \left(|H_d|^2 + |H_u|^2\right)$$

$$V_D = \frac{G^2}{8}\left(|H_d|^2 - |H_u|^2\right)^2 + \frac{g_2^2}{2}\left(|H_d|^2|H_u|^2 - |H_u \cdot H_d|^2\right)$$

$$+ \frac{{g_{1'}}^2}{2}\left(Q_{H_d}|H_d|^2 + Q_{H_u}|H_u|^2 + Q_S|S|^2\right)^2$$

$$V_{\rm soft} = m_d^2|H_d|^2 + m_u^2|H_u|^2 + m_s^2|S|^2$$

$$+ \left(A_s h_s S H_u \cdot H_d + \frac{\kappa}{3} A_\kappa S^3 + \xi_S M_n^3 S + h.c.\right)$$

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

$$(\mathcal{M}^0_+)_{dd} = \left[\frac{G^2}{4} + Q^2_{H_d} g^2_{1'}\right] v_d^2 + (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M_{\rm n}^2}{s})\frac{v_u s}{v_d}$$

$$(\mathcal{M}^0_+)_{du} = \left[-\frac{G^2}{4} + h_s^2 + Q_{H_d} Q_{H_u} g^2_{1'}\right] v_d v_u - (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M_{\rm n}^2}{s})s$$

$$(\mathcal{M}^0_+)_{ds} = \left[h_s^2 + Q_{H_d} Q_S g^2_{1'}\right] v_d s - (\frac{h_s A_s}{\sqrt{2}} + h_s \kappa s) v_u$$

$$(\mathcal{M}^0_+)_{uu} = \left[\frac{G^2}{4} + Q^2_{H_u} g^2_{1'}\right] v_u^2 + (\frac{h_s A_s}{\sqrt{2}} + \frac{h_s \kappa s}{2} + \frac{h_s \xi_F M_{\rm n}^2}{s})\frac{v_d s}{v_u}$$

$$(\mathcal{M}^0_+)_{us} = \left[h_s^2 + Q_{H_u} Q_S g^2_{1'}\right] v_u s - (\frac{h_s A_s}{\sqrt{2}} + h_s \kappa s) v_d$$

$$(\mathcal{M}^0_+)_{ss} = \left[Q_S^2 g^2_{1'} + 2\kappa^2\right] s^2 + (\frac{h_s A_s}{\sqrt{2}} - \frac{\sqrt{2}\xi_S M_{\rm n}^3}{v_d v_u})\frac{v_d v_u}{s} + \frac{\kappa A_\kappa}{\sqrt{2}} s$$

- 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

$$M^2_{H_1^0} \leq M_Z^2 \cos^2 2\beta + \tilde{\mathcal{M}}^{(1)}$$
$$\tilde{\mathcal{M}}^{(1)} = (\mathcal{M}_+^{(1)})_{dd} \cos^2\beta + (\mathcal{M}_+^{(1)})_{uu} \sin^2\beta + (\mathcal{M}_+^{(1)})_{du} \sin 2\beta$$

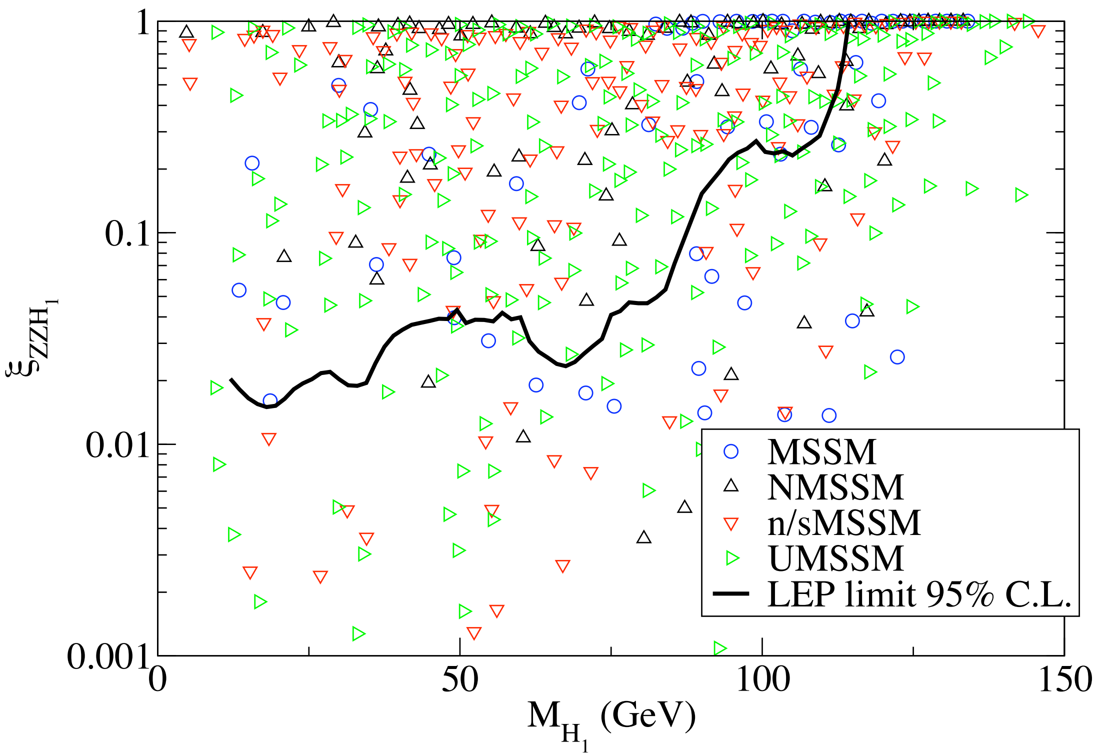
  - NMSSM, n/sMSSM, and Peccei-Quinn limits

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

  - UMSSM

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

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



- **Reduced ZZH_i coupling**

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

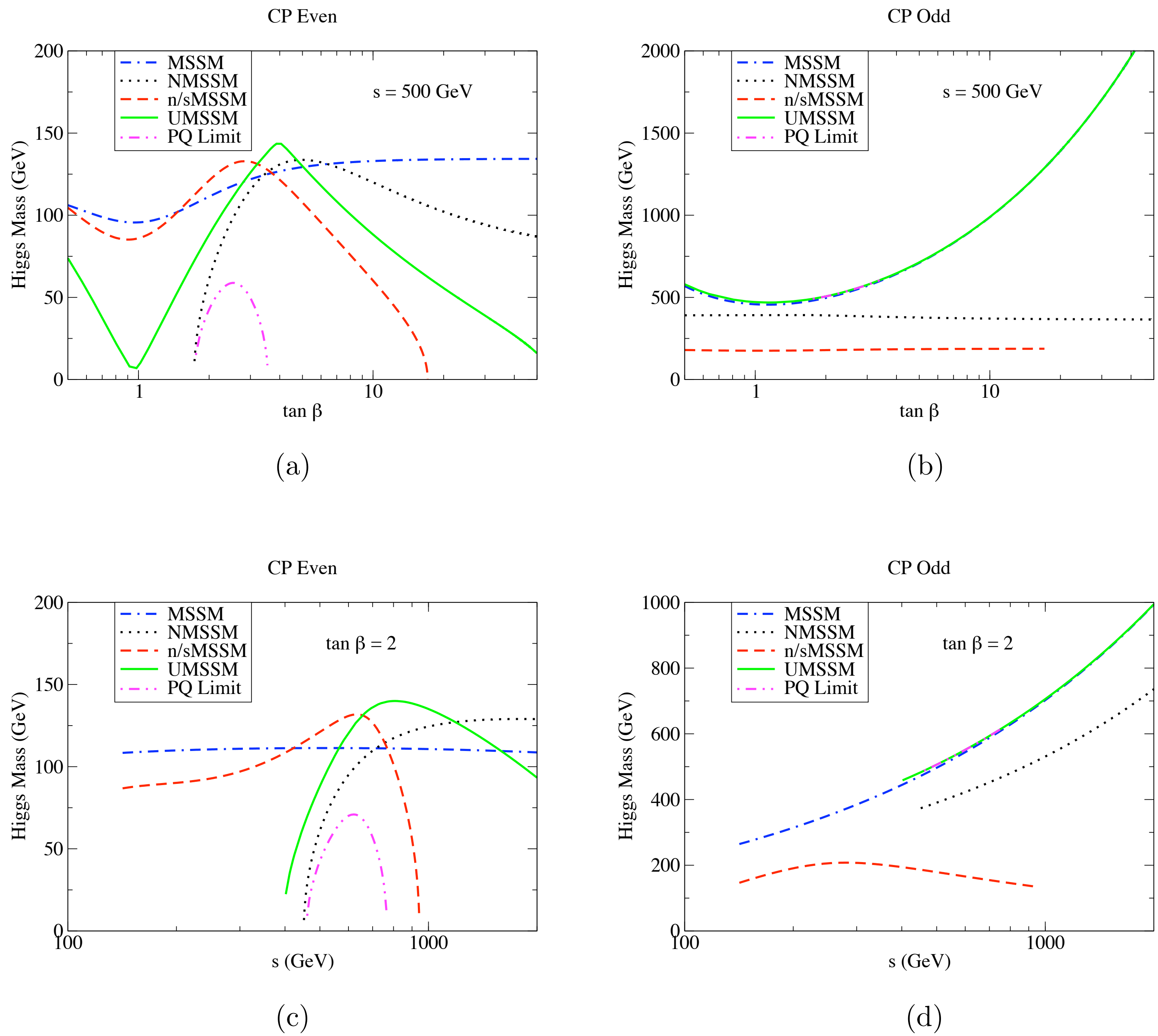
- **Also, $Z \to HA$, Z width, $\chi^\pm$ mass, $Z - Z'$ mixing, V minimum, RGE**

Limiting Cases

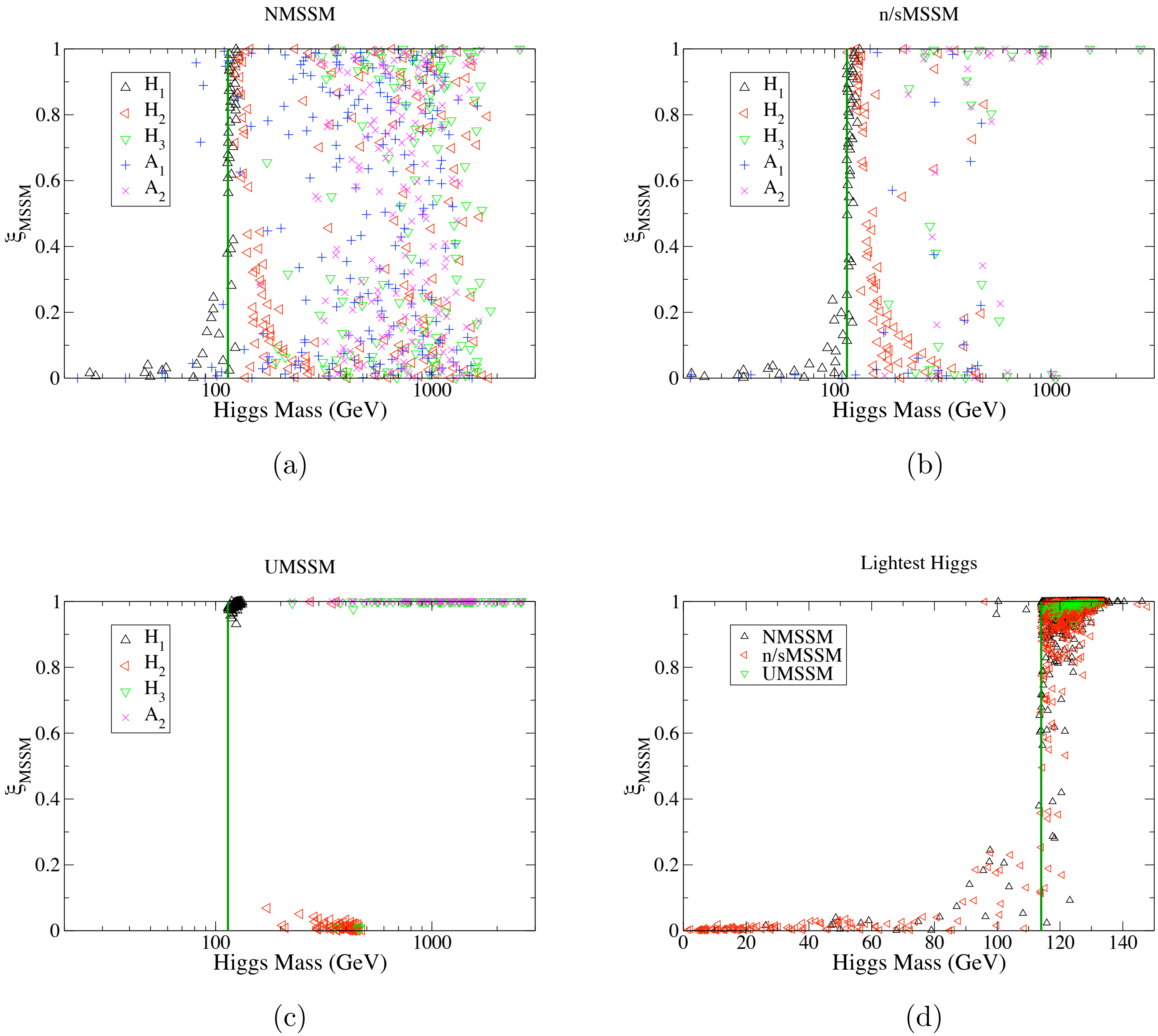
- **MSSM limit** ($s \to \infty$ with $\mu_{eff} = h_s s/\sqrt{2}$ fixed) $\longrightarrow$ **two MSSM-like CP-even Higgs and one largely singlet** (heavy in UMSSM, light in n/sMSSM, depends on κ in NMSSM)

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

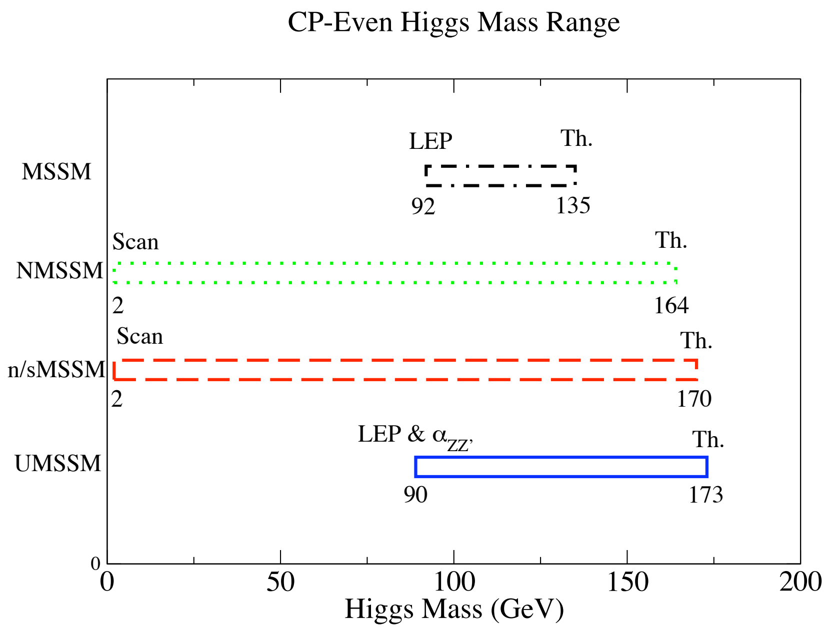
Model	Limits	Symmetry	Effects
MSSM	$B \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
NMSSM	$\kappa, A_\kappa \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
NMSSM	$A_s, A_\kappa \to 0$	$U(1)_R$	$M_{A_1} \to 0$
n/sMSSM	$\xi_F, \xi_S \to 0$	$U(1)_{PQ}$	$M_{A_1} \to 0$
UMSSM	$g_{1'} \to 0$	$U(1)$	$M_{Z'}, M_{A_1} \to 0$

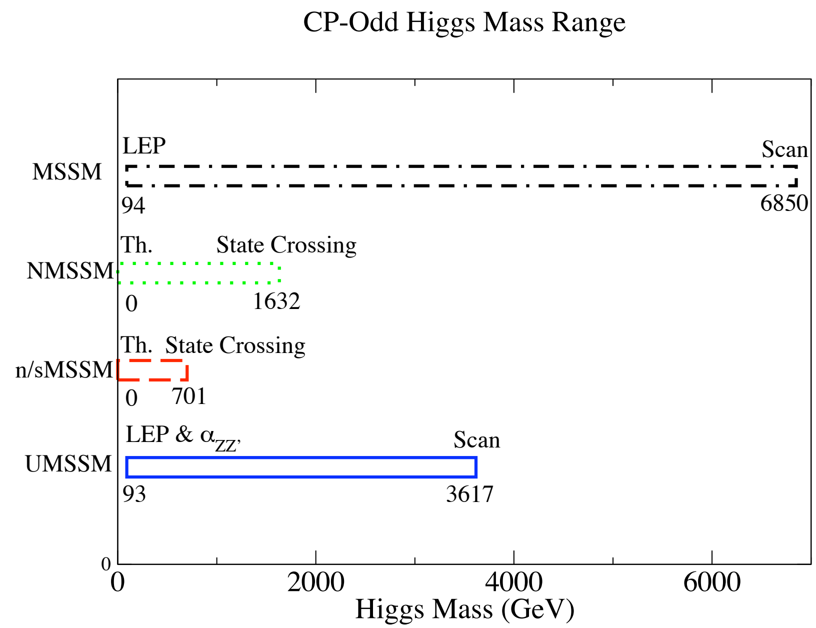


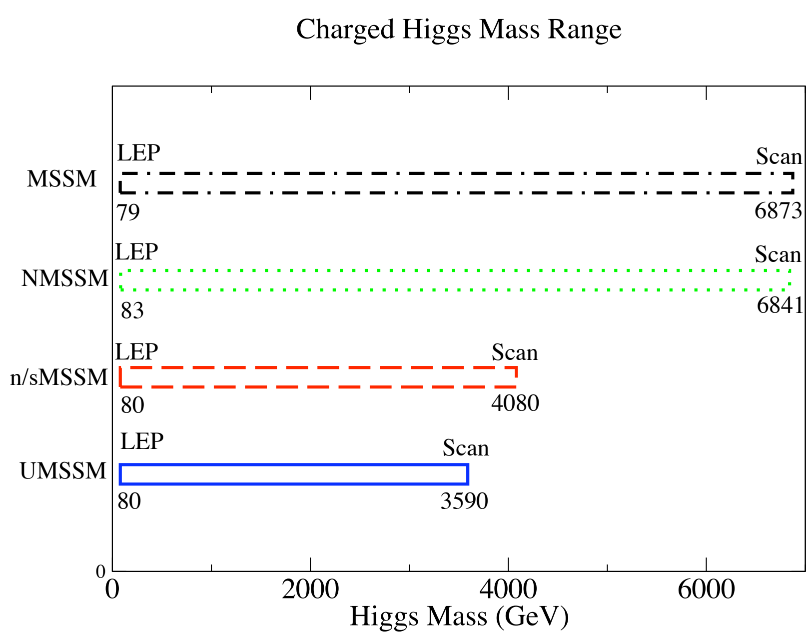
$$(A_s = M_n = 500 \text{ GeV}, \ A_\kappa = -250 \text{ GeV}, \ h_s = \kappa = 0.5, \ \xi_{F,S} = -0.1)$$



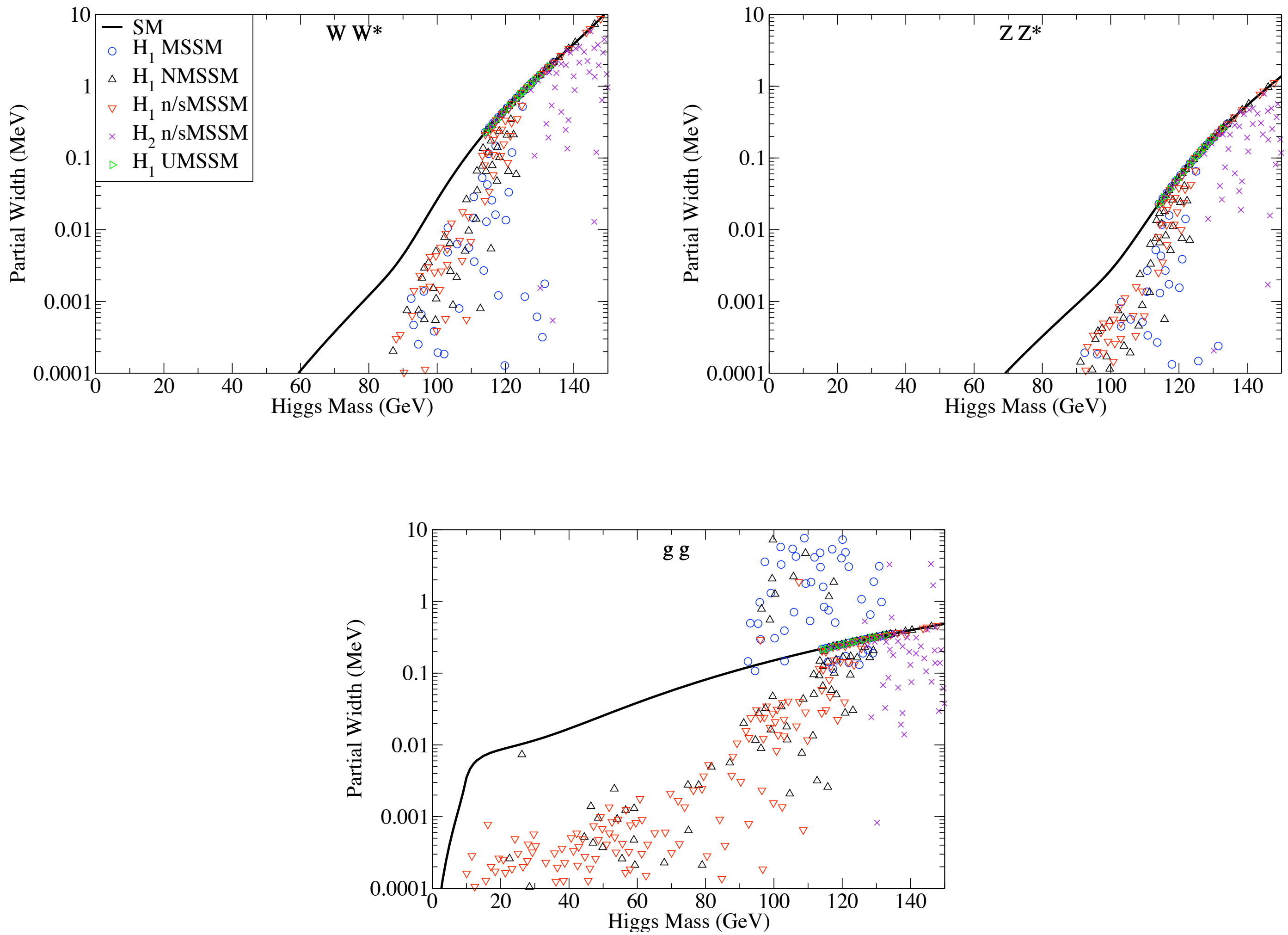
(MSSM fraction $\xi^{H_i}_{\text{MSSM}} = \sum_{j=d}^{u} (R_+^{ij})^2$)


CP-Even Higgs Mass Range
MSSM
NMSSM
n/sMSSM
UMSSM
LEP
Th.
92
135
Scan
Th.
2
164
Scan
Th.
2
170
LEP & α_ZZ'
Th.
90
173
0
0
50
100
150
200
Higgs Mass (GeV)

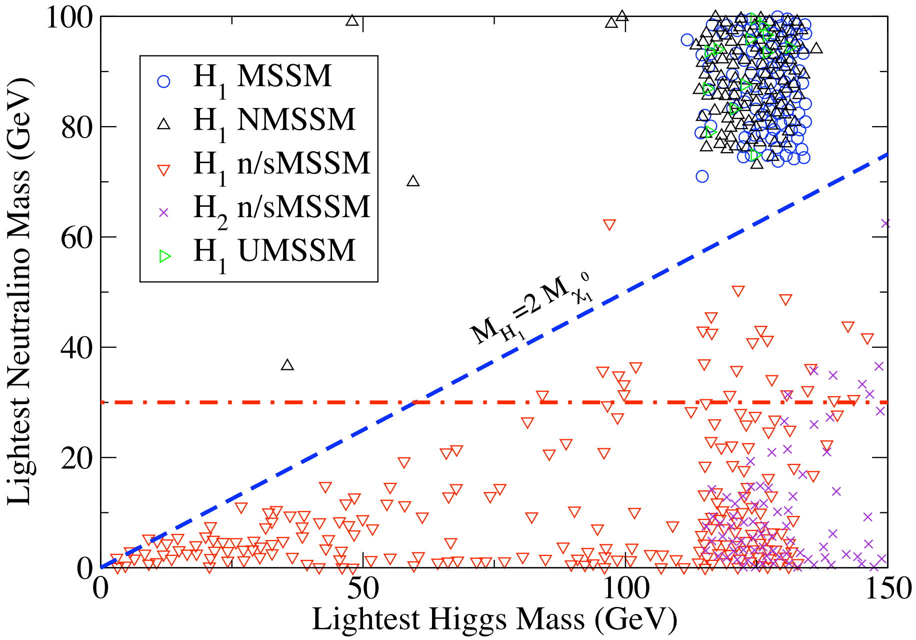

CP-Odd Higgs Mass Range
MSSM
NMSSM
n/sMSSM
UMSSM
LEP
Scan
94
6850
Th.
State Crossing
0
1632
Th.
State Crossing
0
701
LEP & α_ZZ'
Scan
93
3617
0
0
2000
4000
6000
Higgs Mass (GeV)


Charged Higgs Mass Range
MSSM
NMSSM
n/sMSSM
UMSSM
LEP
Scan
79
6873
LEP
Scan
83
6841
LEP
Scan
80
4080
LEP
Scan
80
3590
0
0
2000
4000
6000
Higgs Mass (GeV)

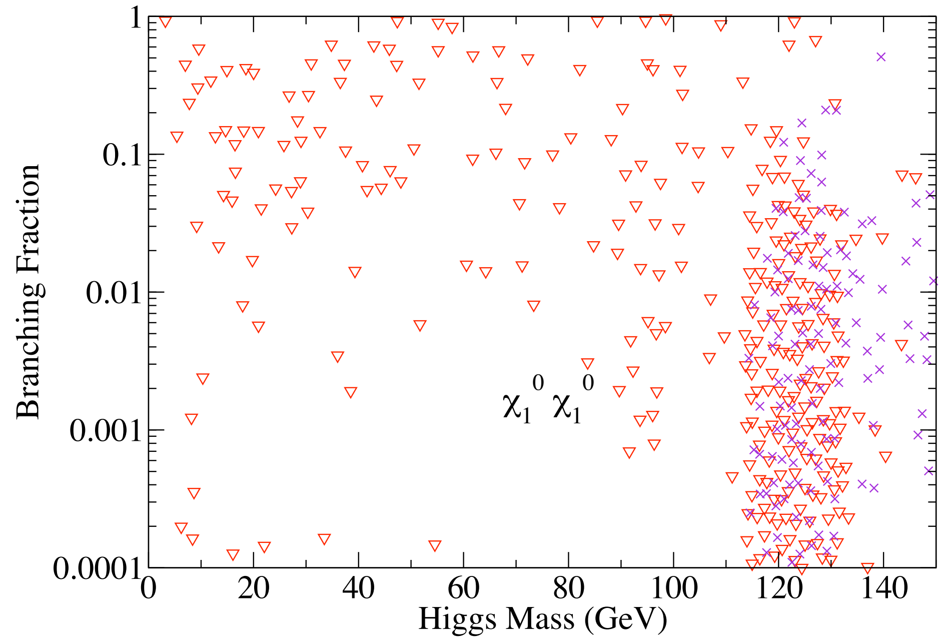
Lightest Higgs Decays



Invisible Decays

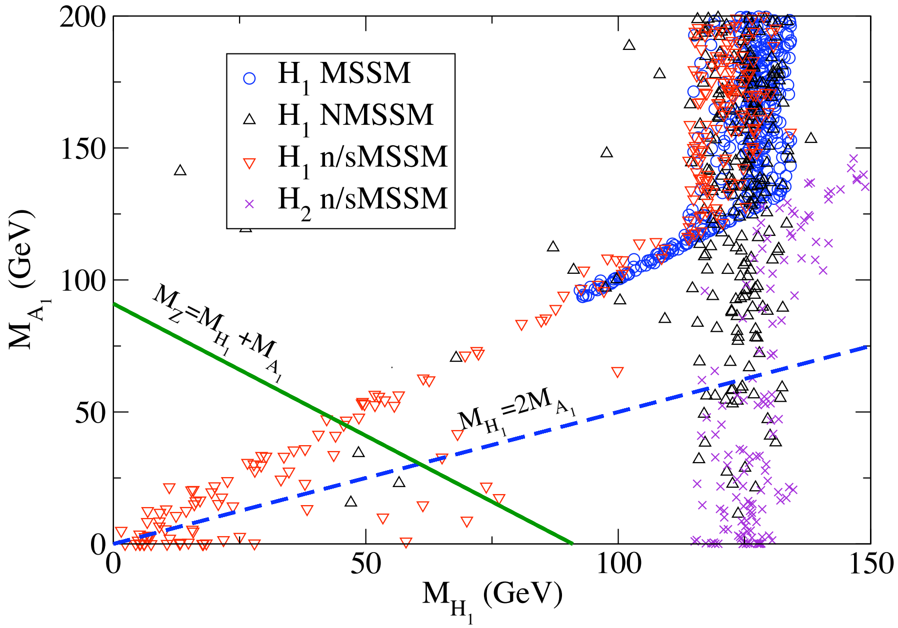


(a)

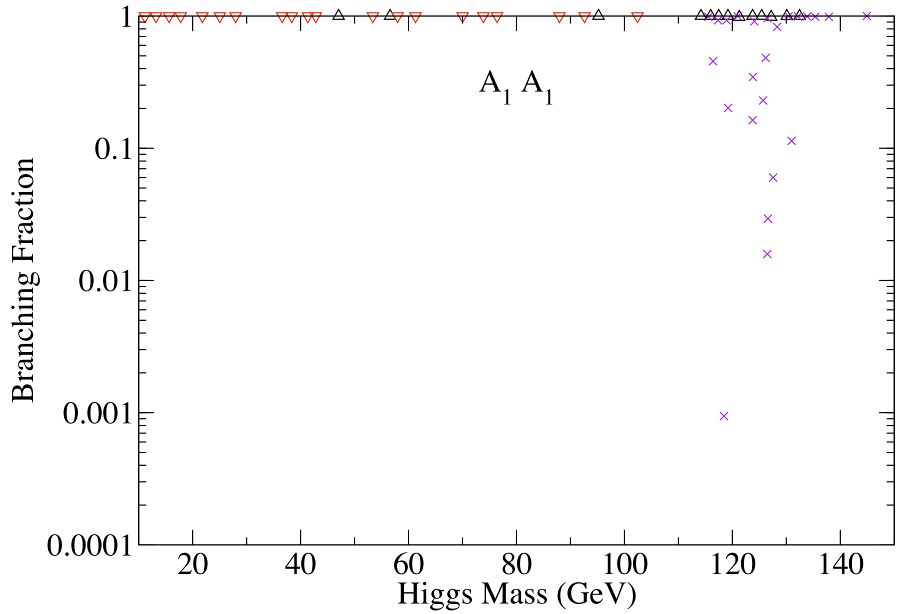


(b)

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

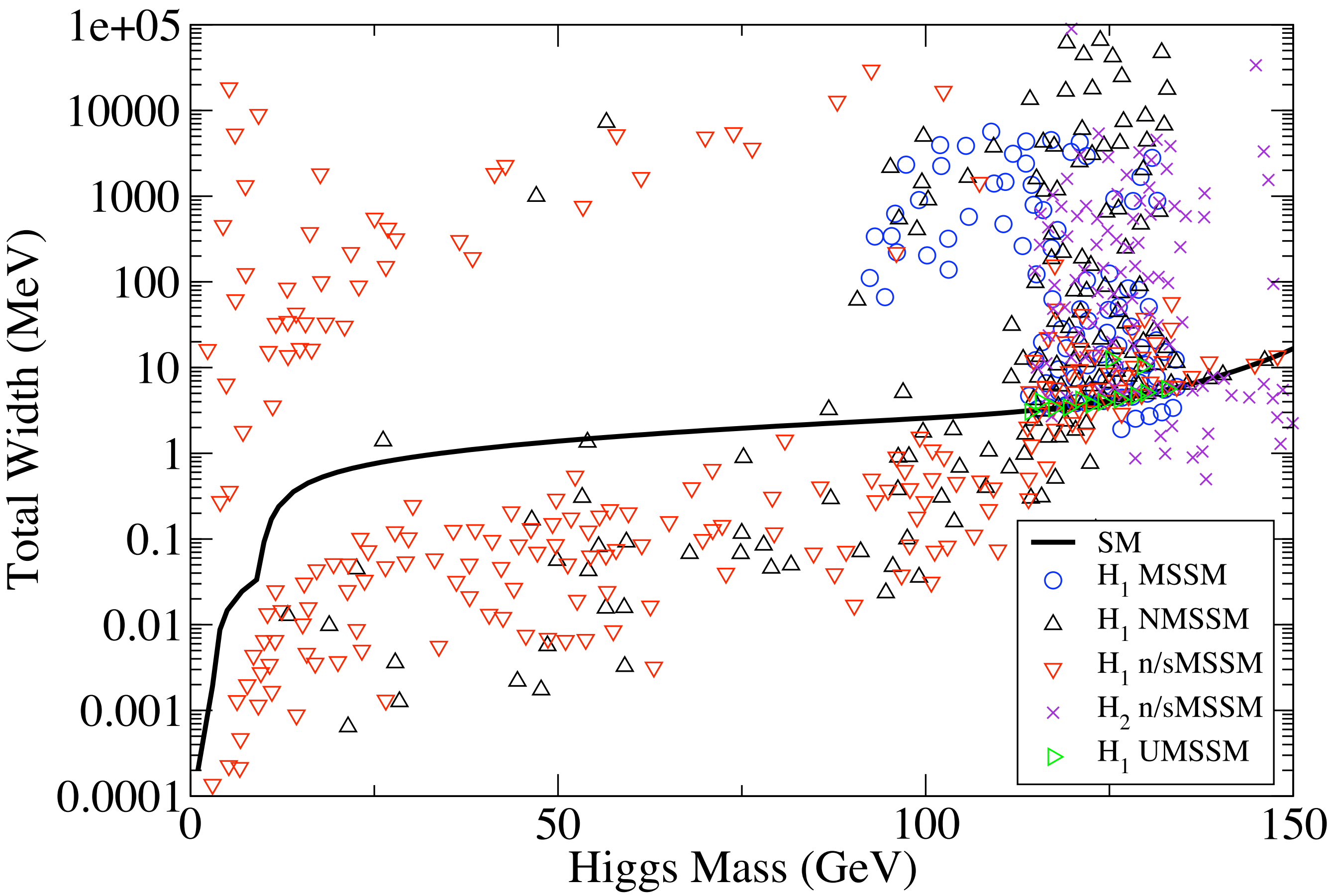


(a)



(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
H_1 MSSM
H_1 NMSSM
H_1 n/sMSSM
H_2 n/sMSSM
H_1 UMSSM

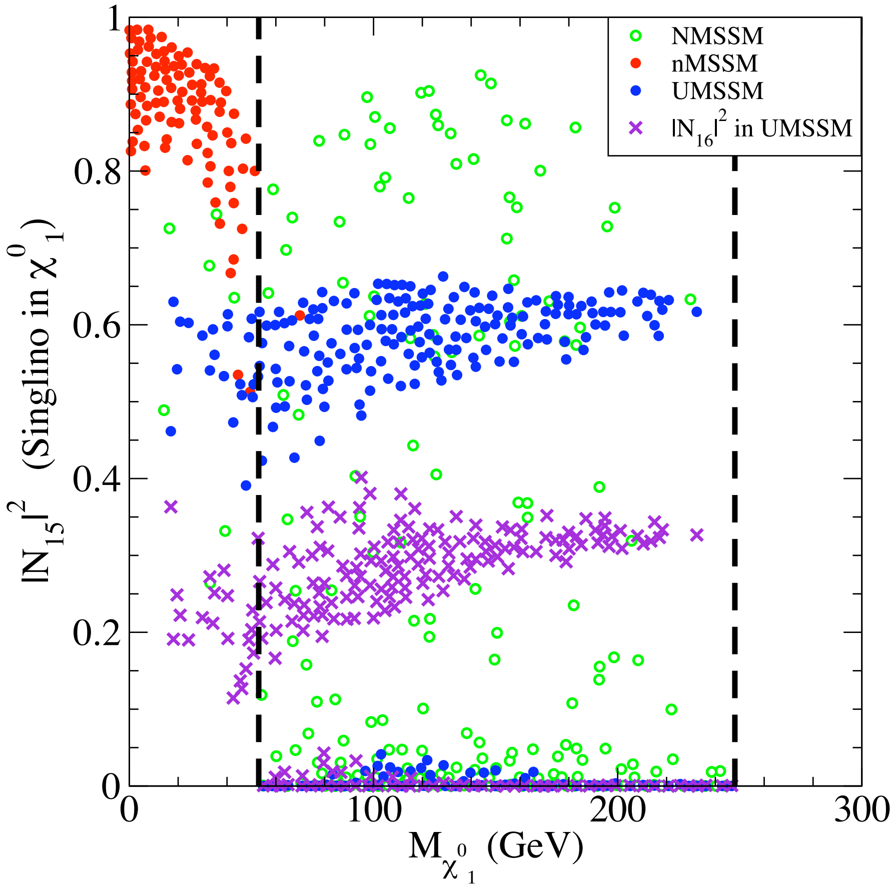
Lightest Neutralino

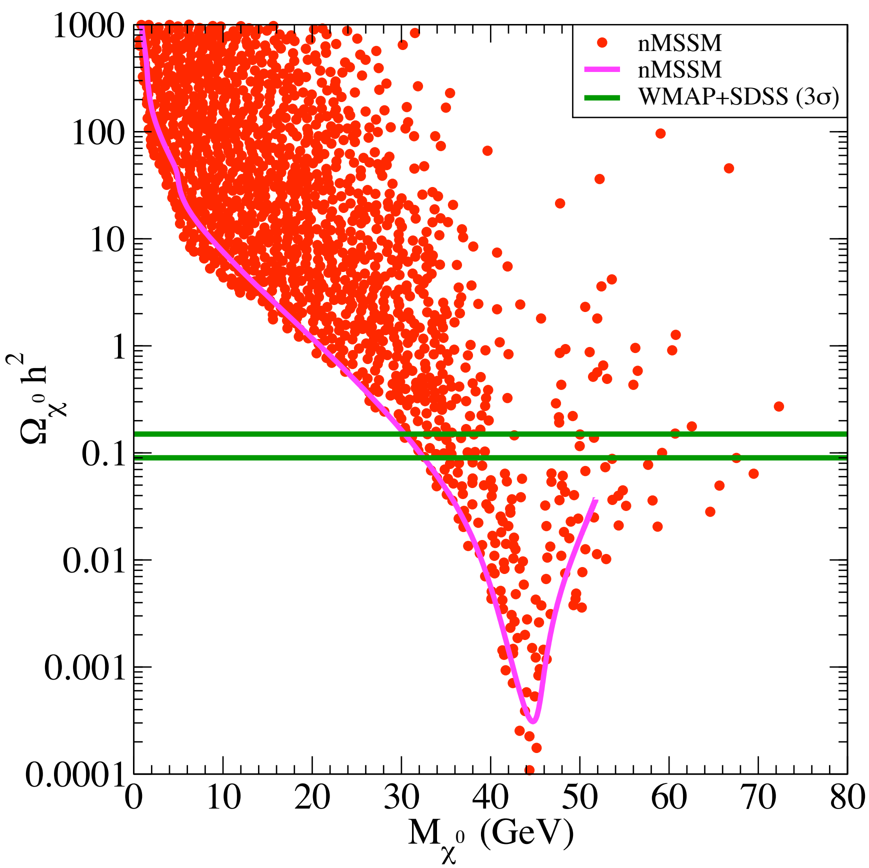
Mass matrix (M_{χ^0}) in basis $\{\tilde{B}, \tilde{W}_3, \tilde{H}_1^0, \tilde{H}_2^0, \tilde{S}, \tilde{Z}'\}$:

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

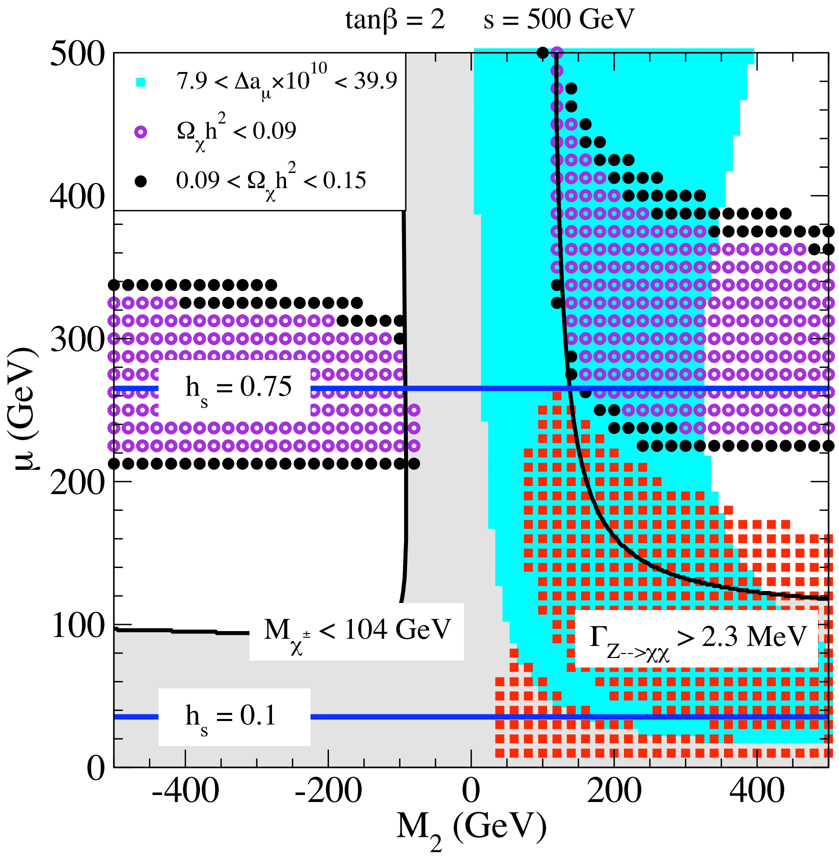
($\langle S \rangle \equiv \frac{s}{\sqrt{2}}$, $\langle H_i^0 \rangle \equiv \frac{v_i}{\sqrt{2}}$, $\sqrt{v_1^2 + v_2^2} \equiv v \simeq 246$ GeV, $Q'_\phi = \phi$ $U(1)'$ charge)

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

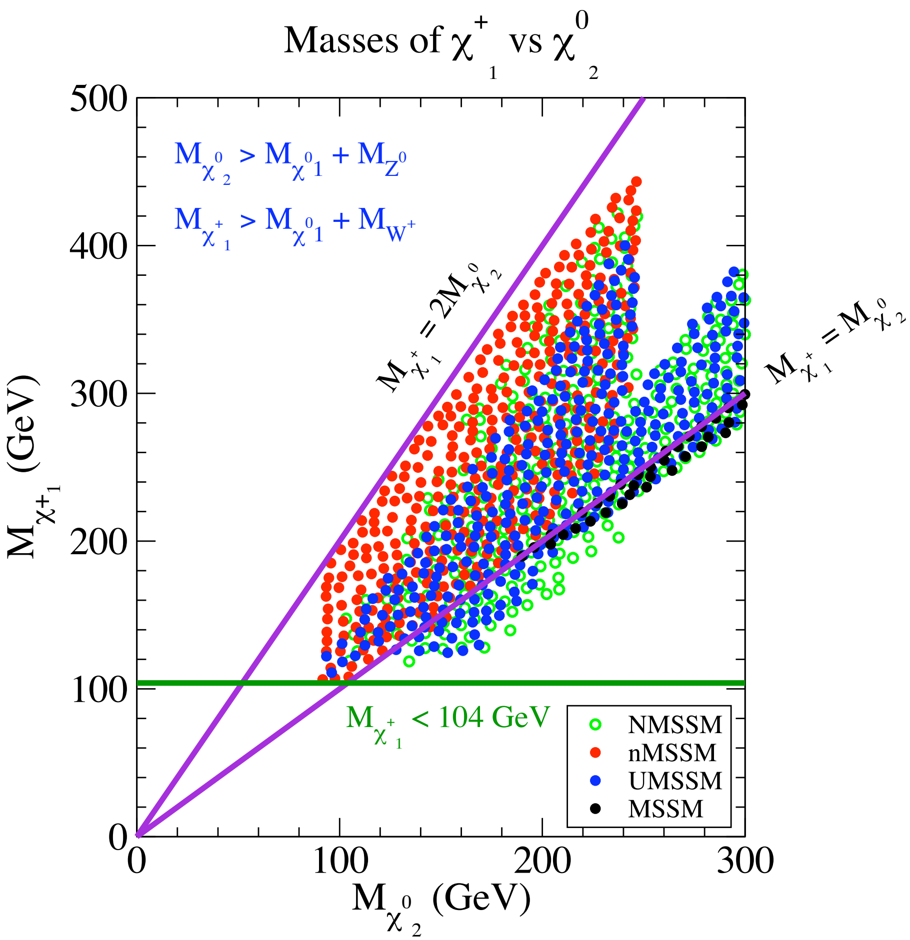


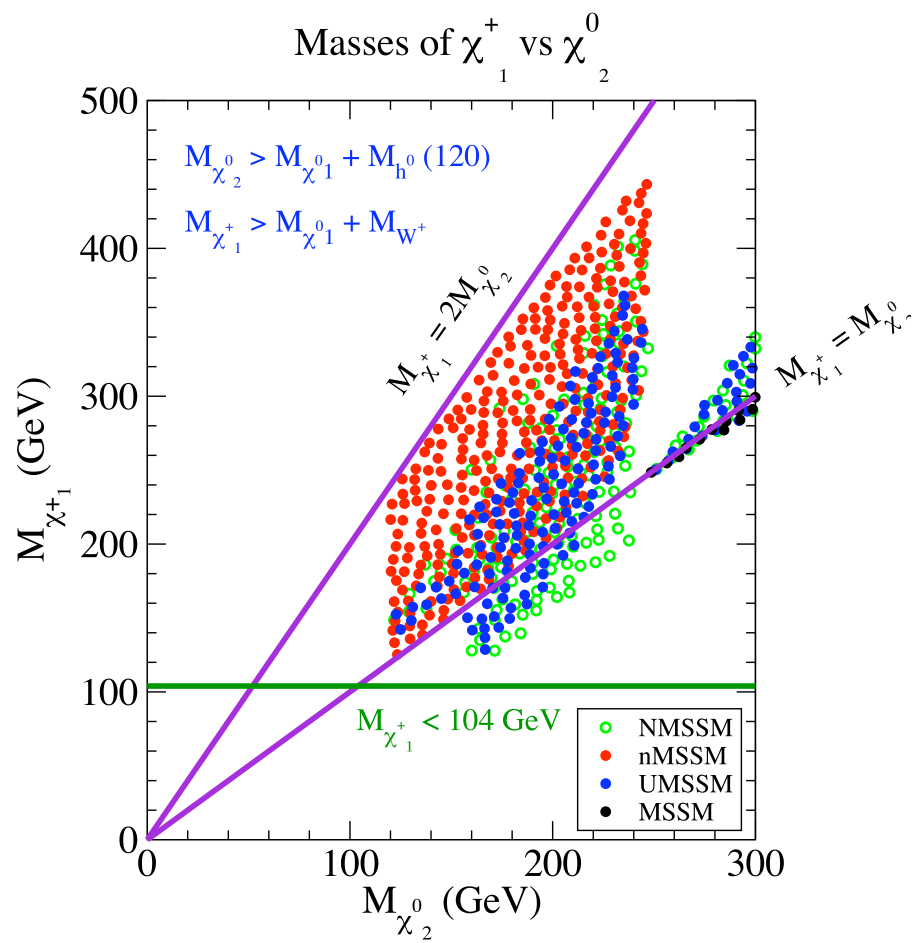


(Relic density in nMSSM from $\chi_1^0\chi_1^0 \to \; Z$ only; may be $\chi_1^0 \to$ secluded in sMSSM)



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





- **Often $\chi^0_2 \cdots \chi^0_5$ are MSSM-like with light singlino-dominated χ^0_1**
- **MSSM-like cascades with** *extra* $\chi^0_2 \to \chi^0_1 + (l\bar{l}, q\bar{q}, Z, h)$
- **Often** $\chi^0_2 \to \chi^0_1 + (Z, h)$; $\chi^+_1 \to \chi^0_1 + (W^+, H^+)$ **are open**
  (e.g., $\chi^+_1 \, \chi^0_2 \to W^+ \, h + \not{E}_T \to l^+ \, b \, \bar{b} + \not{E}_T$**)**

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
  - $D \rightarrow u_i W^-$, $D \rightarrow d_i Z$, $D \rightarrow d_i H^0$ if driven by $D - d$ mixing (not in minimal E_6; FCNC)$\rightarrow$ $m_D \gtrsim$ 200 GeV (future: $\sim$ 1 TeV)
  - $\tilde{D} \rightarrow$ quark jets if driven by diquark operator $\bar{u}\bar{u}\bar{D}$, or quark jet + lepton for leptoquark operator $lq\bar{D}$ (still have stable LSP)
  - May be stable at renormalizable level due to accidental symmetry (e.g., from extended gauge group) $\rightarrow$ hadronizes and escapes or stops in detector (Quasi-stable from HDO $\rightarrow$ $\tau < 1/10$ yr)

Neutrino Mass

- Nonzero mass may be first break with standard model
- Enormous theoretical effort: GUT, family symmetries, bottom up
  - Majorana masses may be favored because not forbidden by SM gauge symmetries
  - GUT (+ family symmetry) seesaw (heavy Majorana singlet). Usually ordinary hierarchy.

- Relatively little work from string constructions, even though may be Planck scale effect

- Key ingredients of most bottom up models forbidden in known constructions (heterotic or intersecting brane)
(Due to string symmetries or constraints, not simplicity or elegance)

  - "Right-handed" neutrinos may not be gauge singlets
  - Large representations difficult to achieve (bifundamentals, singlets, or adjoints)
  - GUT Yukawa relations broken
  - String symmetries/constraints severely restrict couplings, e.g., Majorana masses, or simultaneous Dirac and Majorana masses

Neutrino Mass in Strings

- Dirac masses
  - Can achieve small Dirac masses (neutrino or other) by higher dimensional operators or by large intersection areas

$$L_\nu \sim \left(\frac{S}{M_{Pl}}\right)^p L N_L^c H_2, \quad \langle S \rangle \ll M_{Pl}$$

$$\Rightarrow m_D \sim \left(\frac{\langle S \rangle}{M_{Pl}}\right)^p \langle H_2 \rangle$$

  - Large $p \Rightarrow \langle S \rangle$ close to M_{Pl} (e.g., anomalous $U(1)_A$)
  - Small $p \Rightarrow$ intermediate scale $\ll M_{Pl}$
  - Similar HDO may give light steriles and ordinary/sterile mixing

- **Majorana masses**
  - Existing intersecting brane models: conserved L; no diagonal (Majorana) triangles
  - Heterotic: can one generate large effective m_S from

$$W_\nu \sim c_{ij} \frac{S^{q+1}}{M_{Pl}^q} N_i N_j \quad \Rightarrow (m_S)_{ij} \sim c_{ij} \frac{\langle S \rangle^{q+1}}{M_{Pl}^q},$$

    consistent with D and F flatness?
  - Can one have such terms simultaneously with Dirac couplings, consistent with flatness and other constraints?
  - Are bottom-up model assumptions for relations to quark, charged lepton masses maintained?

- The Z_3 Heterotic Orbifold (Giedt, Kane, PL, Nelson, hep-th/0502032)
  - Systematically studied large class of vacua
    - Is minimal seesaw common?
    - If rare, possibly guidance to model building
    - Clues to textures, etc.
  - Several models from each of 20 patterns; superpotential through degree 9; huge number of D flat directions reduced greatly by F-flatness
  - Only two patterns had Majorana mass operators $\langle S_1 \cdots S_{n-2} \rangle NN/M_{\rm PL}^{n-3}$
  - *None* had simultaneous Dirac operators $\langle S'_1 \cdots S'_{d-3} \rangle NLH_u/M_{\rm PL}^{d-3}$ leading to $\Delta m^2 > 10^{-10}$ eV^2 (one apparent model ruined by off-diagonal Majorana)

- Feature of Z_3 orbifold? Or more general?
- *Systematic* searches in other constructions important (Is seesaw generic? Rare? Alternatives?)
- Alternatives:
  - Small Dirac? (by HDO (common in constructions) or LED)
  - Extended seesaw? $m_\nu \sim m_D^{2+k}/M^{1+k}$, with $k \geq 1$ (TeV scale physics?)
  - Loops, R_P breaking? (TeV physics)
  - Higgs triplet? (higher Kač-Moody or intersecting brane)
    - Higher Kač-Moody embedding in heterotic string (PL, B. Nelson, hep-ph/0507063)
    - *Inverted* hierarchy with bimaximal mixing
    - Solar mixing non-maximal $\rightarrow$ small (Cabibbo-like) charged lepton mixing
    - U_{e3} close to Chooz limit

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**

- **Consider alternatives to the minimal seesaw**