Implications of sgoldstino-Higgs mixing

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Outline

- Introduction: spontaneous SUSY breaking
- Goldstino supermultiplet: minimal model
- Interactions of sgoldstino with SM particles and phenomenology
- Sgoldstino-Higgs mixing: consequences
- Implications for phenomenology
- Conclusions

- SUSY - attractive extension of SM
- Higgs-like resonance: $m_h \approx 125$ GeV
- The lightest Higgs boson in MSSM

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right) + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$

where $X_t = A_t - \frac{\mu}{\tan\beta}$.

- heavy stops $m_{\tilde{t}} \gtrsim 500$ GeV and/or maximal mixing $X_t^{max} = \sqrt{6} m_{\tilde{t}}$
- Spontaneous SUSY breaking $\rightarrow$ hidden sector
- Goldstino and its superpartners

(Chiral) Goldstino supermultiplet

- $\Phi = \phi + \sqrt{2}\theta\psi + F_\phi\theta^2$, F_ϕ – auxiliary field
- SUSY — broken $\to F \equiv \langle F_\phi \rangle \neq 0$
- ψ – Goldstone fermion,
- $\phi = (S + iP)/2$, where $S(P)$ — scalar(pseudoscalar) sgoldstino
- $\sqrt{F}$ — supersymmetry breaking scale
- $\sqrt{F} \gg M_{EW}$ — goldstino supermultiplet decouples – usual MSSM
- $\sqrt{F} \gtrsim M_{EW}$ — we should include S, P and ψ in low energy theory — low scale supersymmetry
- goldstino $\to$ longitudinal gravitino in SUGRA: $m_{3/2} = \sqrt{8\pi/3}F/M_{Pl}$
- sgoldstino mass: $m_S, m_P \sim$ electroweak scale allowed!!!

Interactions of goldstino supermultiplet with SM

- MSSM + sgoldstino couplings $\Phi = \phi + \sqrt{2}\theta\psi + F_\phi\theta^2,\ \langle F_\phi\rangle = F$,

$$\mathscr{L} = \mathscr{L}_{MSSM} + \mathscr{L}_{\Phi-K\ddot{a}hler} + \mathscr{L}_{\Phi-gauge} + \mathscr{L}_{\Phi-superpotential}$$

$$\mathscr{L}_{\Phi-K\ddot{a}hler} = -\int d^2\theta\, d^2\bar{\theta}\ \Phi^\dagger\Phi \cdot \sum_k \frac{m_k^2}{F^2}\,\Phi_k^\dagger\, e^{g_1V_1+g_2V_2+g_3V_3}\,\Phi_k$$

$$\mathscr{L}_{\Phi-gauge} = \frac{1}{2}\int d^2\theta\ \Phi \cdot \sum_\alpha \frac{M_\alpha}{F}\, TrW^\alpha W^\alpha + h.c.\,,$$

$$\mathscr{L}_{\Phi-superpotential} = \int d^2\theta\ \Phi \cdot \varepsilon_{ij}\left(-\frac{B}{F}\,H_D^iH_U^j + \frac{A_{ab}^D}{F}\,Q_a^jD_b^cH_D^i + \ldots\right) + h.c.$$

- Low energy effective theory $E \lesssim \sqrt{F}$
- Higher order interactions are suppressed by higher powers of F
- Weak coupling regime: hierarchy $m_{soft} \lesssim \sqrt{F}$

Sgoldstino phenomenology without mixing

- Goldstino ψ – LSP, $m_{3/2} = \sqrt{8\pi/3}F/M_{Pl}$ – very light
  for $\sqrt{F} \sim 10$ TeV $m_{3/2} \sim 10^{-2} eV$
  interaction lagrangian: $\mathscr{L}_\psi = \frac{1}{F} J^\mu_{SUSY} \partial_\mu \psi$
  missing energy signature!
  $R = -1$: production in pairs, suppressed by $\frac{1}{F^2}$
- Sgoldstino $X = S, P$ $\quad R = 1$, suppressed by $\frac{1}{F}$
- Sgoldstino interaction lagrangian with gauge fields and fermions

$$\mathscr{L}_\phi = -\sum_\alpha \frac{M_\alpha}{4\sqrt{2}F} S F^\alpha_{a\,\mu\nu} F_a^{\alpha\,\mu\nu} - \varepsilon_{ij} \left(\frac{A^D_{ab}}{\sqrt{2}F} q^j_a d^c_b \cdot h^i_D S + \ldots \right)$$

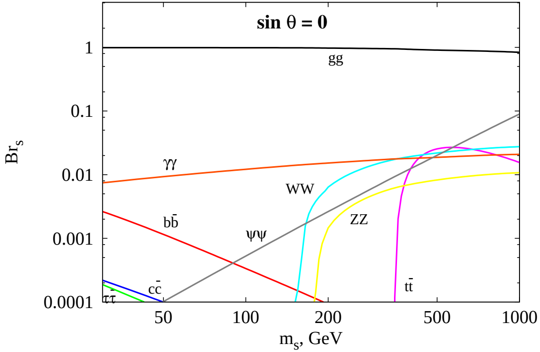
$$-\sum_\alpha \frac{M_\alpha}{8\sqrt{2}F} P F^\alpha_{a\,\mu\nu} \varepsilon^{\mu\nu\lambda\rho} F^\alpha_{a\lambda\rho} - \varepsilon_{ij} \left(i \frac{A^D_{ab}}{\sqrt{2}F} q^j_a d^c_b \cdot h^i_D P + \ldots \right)$$

Sgoldstino phenomenology (continued)

- Main decay channels for sgoldstinos $X = S, P$:
  - $X \to \psi\psi$: $\frac{E}{F}$ $\Gamma(X \to \psi\psi) \sim \frac{m_X^5}{F^2}$
  - $X \to l^+l^-, \bar{q}q$: $\frac{m_f A_f}{F}$ $\Gamma(X \to \bar{f}f) \sim A_f^2 m_f^2 m_X$
  - $X \to \gamma\gamma, gg, ZZ, WW, Z\gamma$: $\frac{M_\lambda}{F}$ $\Gamma(X \to \lambda\lambda) \sim M_\lambda^2 m_X^3$
  - similar to the SM Higgs boson, but different hierarchy!
- Sgoldstino production in *pp* collisions
  - strongly dominant channel: $pp \to gg \to X$: governed by $\frac{M_3}{F}$, i.e. mass of gluino!
  - $pp \to qqX$, $pp \to XZ$, $pp \to XW^\pm$, $pp \to Xt\bar{t}$, $pp \to X\gamma$ – typically suppressed by several orders of magnitude

Sgoldstino decays, no mixing

Branching ratios for sgoldstino S (similar for P):
$\sqrt{F} = 10$ TeV, $M_1 = 400$ GeV, $M_2 = 800$ GeV, $M_3 = -1200$ GeV, $A_{ab}^{U,D,E} = 700$ GeV



Branchings depend on hierarchy of soft parameters, but not on $\sqrt{F}$

- In superfields

$$\mathscr{L}_{\Phi-Higgs} = \left[\int d^2\theta \left(-\frac{B}{F}\Phi\varepsilon_{ij}H_d^i H_u^j + \sum_\alpha \frac{M_\alpha}{2F}\Phi \mathrm{Tr} W^\alpha W^\alpha\right) + h.c.\right]$$

$$-\int d^2\theta d^2\bar{\theta}\Phi^\dagger\Phi\left(\frac{m_{H_u}^2}{F^2}H_u^\dagger \mathrm{e}^{g_\alpha V_\alpha}H_u + \frac{m_{H_u}^2}{F^2}H_u^\dagger \mathrm{e}^{g_\alpha V_\alpha}H_u\right)$$

- relevant lagrangian up to $\frac{1}{F}$ terms $\phi = \frac{1}{2}(S+iP)$

$$\mathscr{L}_{\phi-Higgs} = -\left(\frac{B\mu}{F}\phi(|h_u|^2+|h_d|^2) + \frac{g_1^2 M_1 + g_2^2 M_2}{8F}\phi(|h_d|^2 - |h_u|^2)^2\right.$$

$$\left. - \frac{\mu(m_{H_u}^2 + m_{H_d}^2)}{F}\phi^* \varepsilon_{ij} h_d^i h_u^j + h.c.\right)$$

Sgoldstino-Higgs mixing

- Assumptions:
  - $\langle \phi \rangle = 0$, no v.e.v. for sgoldstino
  - no CP-violation
  - decoupling limit, $m_H, m_A \gg m_h$
- Mixing lagrangian: $\mathscr{L}_{mix} = \frac{X}{F} h \cdot S + \frac{Y}{F} H \cdot S + \frac{Z}{F} A \cdot P$

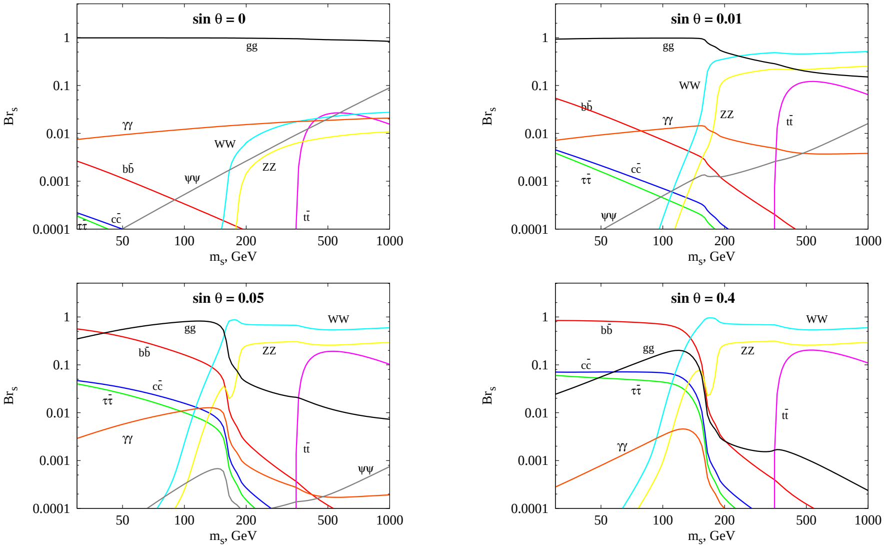
$$X = 2\mu^3 v \sin 2\beta + \frac{1}{2} v^3 (g_1^2 M_1 + g_2^2 M_2) \cos^2 2\beta$$

$$Y = \mu v (m_A^2 - 2\mu^2) + \frac{1}{4} (g_1^2 M_1 + g_2^2 M_2) \sin 4\beta, \quad Z = -\mu v (m_A^2 - 2\mu^2)$$

- Massive states $\tilde{S}$ and $\tilde{h}$: $\tan 2\theta = \frac{2X}{F(m_S^2 - m_h^2)}$
- case $m_S \gg m_h$ (Dudas, Petersson, Tziveloglou, 2013)
  $m_{\tilde{h}}^2 = m_h^2 + \mathscr{O}\left(\frac{1}{F^2 m_S^2}\right)$ – suppression in the shift of the mass
- $m_S \lesssim m_h$ – possible large positive contribution to the mass $m_{\tilde{h}}$

Modifications of sgoldstino branchings

$\sqrt{F} = 10 TeV$



Similar to the SM Higgs boson!

MSSM parameter space 1

Scan over MSSM parameter space

Naturalness-inspired region:

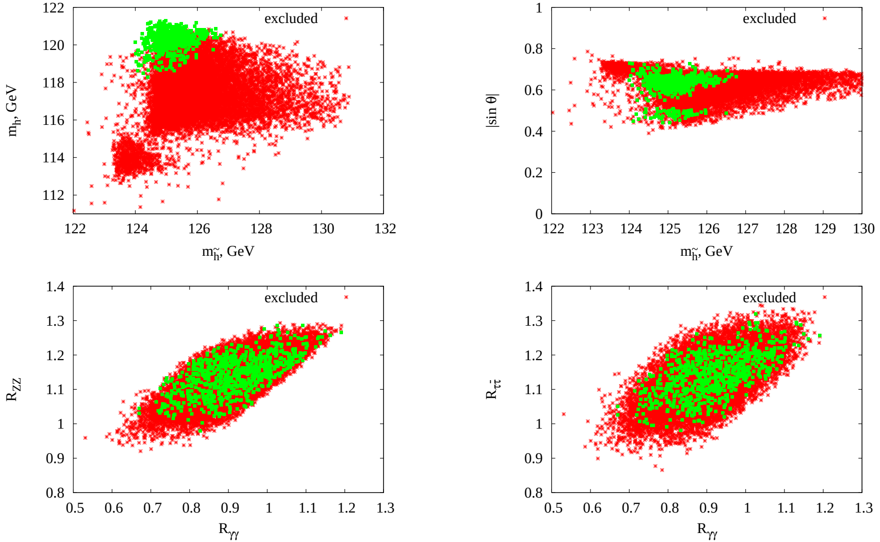
$\tan\beta$	$1.5 - 50$
M_1	$100 - 500$ GeV
M_2	$200 - 500$ GeV
M_3	$1500 - 2000$ GeV
$\vert\mu\vert$	$100 - 1500$ GeV
m_A	$1500 - 2500$ GeV
$\vert A_{33}^{U,D,E}\vert$	$0 - 1000$ GeV
$m_{33}^{U,D,E}$	$700 - 1300$ GeV

Calculate quantities for final state f:

$$R_f = \frac{\sigma(pp\to\tilde{h})\cdot\mathrm{Br}(\tilde{h}\to f)}{\sigma(pp\to h)_{SM}\cdot\mathrm{Br}(h\to f)_{SM}}$$

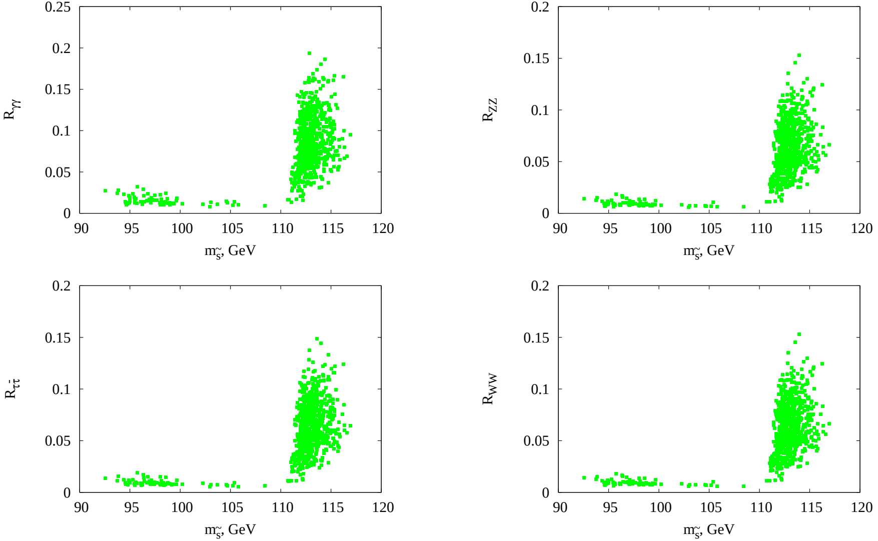
- NMSSMTools in MSSM regime
- $\sqrt{F} = 10$ TeV
- sgoldstino mass parameter $80 < m_S < 120$ GeV
- select phenomenologically allowed models with mass of the Higgs-like resonance $124 < m_{\tilde{h}} < 128$ GeV
- Experimental constraints (LEP, TeVatron, ...)

Higgs-like resonance



Sgoldstino-like resonance

$$R_f^{\tilde{S}} = \frac{\sigma(pp\to\tilde{S})\cdot\mathrm{Br}(\tilde{S}\to f)}{\sigma(pp\to h)_{SM}\cdot\mathrm{Br}(h\to f)_{SM}}$$



MSSM parameter space 2

Broad region:

$\tan\beta$	$1.5 - 50$
M_1	$100 - 2000$ GeV
M_2	$200 - 2000$ GeV
M_3	$1000 - 4000$ GeV
$\lvert\mu\rvert$	$10 - 2000$ GeV
m_A	$1500 - 4000$ GeV
$\lvert A_{33}^{U,D,E}\rvert$	$0 - 4000$ GeV
$m_{33}^{U,D,E}$	$0 - 5000$ GeV

Calculate quantities for final state f:

$$R_f = \frac{\sigma(pp\to\tilde{h})\cdot\mathrm{Br}(\tilde{h}\to f)}{\sigma(pp\to h)_{SM}\cdot\mathrm{Br}(h\to f)_{SM}}$$

- NMSSMTools in MSSM regime
- $\sqrt{F} = 10$ TeV
- sgoldstino mass parameter $80 < m_S < 120$ GeV
- select phenomenologically allowed models with mass of the Higgs-like resonance $124 < m_{\tilde{h}} < 128$ GeV
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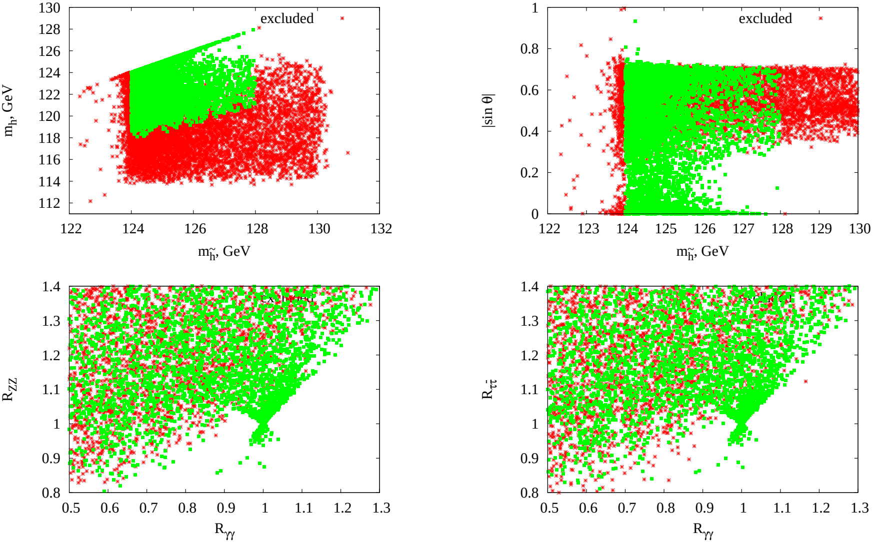
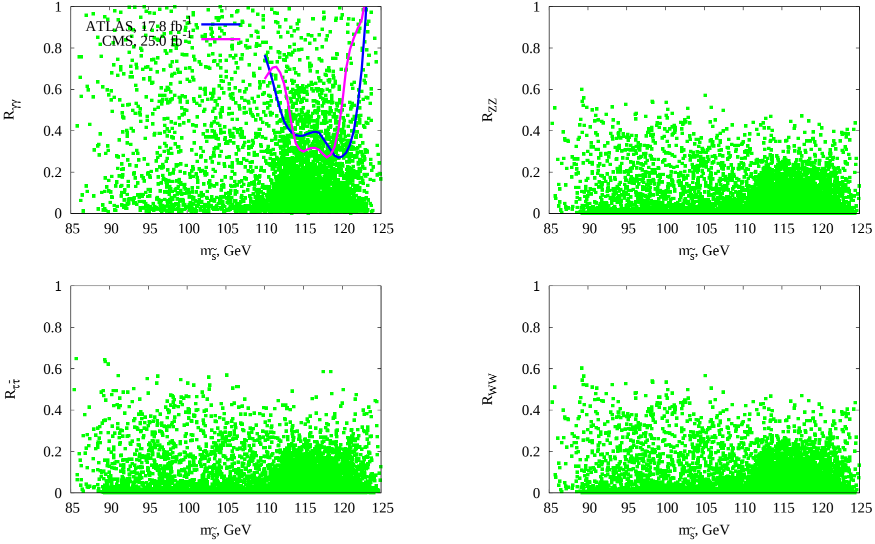
Higgs-like resonance



Sgoldstino-like resonance

$$R_f^{\tilde{S}} = \frac{\sigma(pp\to\tilde{S})\cdot\mathrm{Br}(\tilde{S}\to f)}{\sigma(pp\to h)_{SM}\cdot\mathrm{Br}(h\to f)_{SM}}$$



Conclusions

- Low scale supersymmetry - sgoldstinos - mixing with the Higgs bosons
- Sgoldstino-Higgs mixing can increase mass of the lightest Higgs boson in the MSSM
- The scenario can be probed at the LHC