Sgoldstino physics and flavor-violating Higgs boson decays

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Motivation. LFV processes.

- Extremely suppressed in SM. In SM with non-zero neutrino masses LFV can happen but its rate is tiny

$$Br(\tau \to \mu\,\gamma) = \frac{3\alpha}{32\pi}\left|\sum_i U^*_{\tau\,i}\,U_{\mu\,i}\frac{m_i^2}{M^2}\right|^2 \leq 10^{-53} \sim 10^{-49}$$

- Due to their small probability this processes are ideal tests for physics beyond SM
- Recently a slight excess of signal events of decay $H \to \mu\tau$ was observed by CMS group (2.4σ) (hep-ex/1502.07400).

Motivation. Why MSSM?

MSSM is attractive extension of SM:

- MSSM helps to solve hierarchy problem, e.g. instability of small Higgs mass to large corrections in a theory with a large mass scale in addition to the weak scale (for example in Grand Unified Theory (GUT)).
- Unification of gauge couplings in MSSM.
- MSSM provides CDM candidate.
- Local supersymmetry $\Longrightarrow$ supergravity.

SUSY breaking and its scale.

- For phenomenological viability SUSY should be broken.
- We need hidden sector, where breaking of SUSY takes place and then transmitted to visible sector (via gauge mediation, gravity mediation,...). Chiral superfield in hidden sector $\Phi = \phi + \sqrt{2}\psi\theta + F\theta^2$. $\langle\sqrt{F}\rangle$ – SUSY breaking scale and $\phi = (s + \imath p)/\sqrt{2}$
- $\sqrt{F} \gg M_{EW}$ – hidden sector decouples. Conventional MSSM with soft terms.
- $\sqrt{F} \sim O(TeV)$ hidden sector is not so hidden. We should include ϕ and ψ particles to our effective theory.

Model description. MSSM and sgoldstino interaction.

$$\mathcal{L}_{\Phi-MSSM} = \mathcal{L}_{Kahler} + \mathcal{L}_{superpotential} + \mathcal{L}_{\Phi}$$

$$\mathcal{L}_{Kahler} = \int d^2\theta d^2\bar{\theta} \sum_k \left(1 - \frac{m_k^2}{F^2}\Phi^\dagger\Phi\right)\Phi_k^\dagger e^{g_1 V_1 + g_2 V_2 + g_3 V_3}\Phi_k$$

$$\mathcal{L}_{superpotential} = \int d^2\theta \Big\{ \epsilon_{ij}\Big((\mu - \frac{B}{F}\Phi) H_d^i H_u^j) + (Y_{ab}^L + \frac{A_{ab}^L}{F}\Phi) L_a^j E_b^c H_d^i) \Big) +$$

$$+ (Y_{ab}^D + \frac{A_{ab}^D}{F}\Phi) Q_a^j D_b^c H_d^i) \Big) + (Y_{ab}^U + \frac{A_{ab}^U}{F}\Phi) Q_a^j U_b^c H_u^i) \Big) +$$

$$+ \frac{1}{4}\sum_a (1 + \frac{2M_a}{F}\Phi) Tr W^a W^a + h.c. \Big\}$$

$$\mathcal{L}_{\Phi} = \int d^2\theta \, d^2\bar{\theta} (\Phi^\dagger\Phi + \tilde{K}(\Phi^\dagger, \Phi)) - \left(\int d^2\theta F\Phi + h.c. \right)$$

- Our theory is an effective one. It is valid at energies $E \leq \sqrt{F}$.
- We assume that $\langle\phi\rangle = 0$ and there is no CP-violation.

Higgs-sgoldstino mixing.

CP-even higgs-sgoldstino mass matrix (in h, H and s basis)

$$\mathcal{M}_s^2 = \begin{pmatrix} m_H^2 & 0 & \frac{Y}{F} \\ 0 & m_h^2 & \frac{X}{F} \\ \frac{Y}{F} & \frac{X}{F} & m_s^2 \end{pmatrix}$$

where the relevant off-diagonal terms are

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

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

and we work in decoupling limit of MSSM

$$m_A \gg m_h$$

Higgs-sgoldstino mixing.

Higgs-sgoldstino mixing angle

$$\tan 2\theta = \frac{2X}{F(m_s^2 - m_h^2)}$$

Mass states

$$\begin{pmatrix} \tilde{h} \\ \tilde{s} \end{pmatrix} = \begin{pmatrix} \cos\,\theta & -\sin\,\theta \\ \sin\,\theta & \cos\,\theta \end{pmatrix} \begin{pmatrix} h \\ s \end{pmatrix}$$

Modified Higgs interaction with leptons.

After the EWSB the interaction between Higgs and leptons

$$\mathcal{L} \supset (v_d \, \bar{l}'_R \, Y^L \, l'_L + h.c.) + \left(v_d \, \bar{l}'_R \left(\frac{Y^L}{\sqrt{2}v} \cos\theta + \frac{A^L}{\sqrt{2}F} \sin\theta \right) l'_L \tilde{h} + h.c. \right)$$

Using double unitary transformation we diagonalize Y^L matrix and in fermion mass basis

$$\mathcal{L} \supset -m_a \, \bar{l}^a \, l^a - (\bar{l}^a_L \, l^b_R \, Y_{ab} \tilde{h} + h.c),$$

where

$$Y_{ab} = \frac{m_a \, \delta_{ab} \, \cos\theta}{\sqrt{2}v} - \frac{v_d (V_L (A^L)^\dagger V_R^\dagger)_{ab} \, \sin\theta}{\sqrt{2}F}$$

Decay width of LFV process

$$\Gamma(\tilde{h} \to l_a l_b) = \frac{\tilde{m}_h v_d^2 \sin^2\theta}{16\pi F^2} (|\tilde{A}_{ab}|^2 + |\tilde{A}_{ba}|^2),$$

where

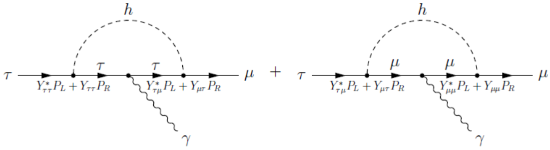
$$\tilde{A}_{ab} = (V_L (A^L)^\dagger V_R^\dagger)_{ab}$$

τ flavour-violating decay mediated by Higgs.

hep-ph/1304.2783:

$$\mathcal{L}_{eff} = c_L \frac{e}{8\pi^2} m_\tau (\bar{\mu}\, \sigma^{\alpha\beta} P_L \tau) F_{\alpha\beta} + c_R \frac{e}{8\pi^2} m_\tau (\bar{\mu}\, \sigma^{\alpha\beta} P_R \tau) F_{\alpha\beta} + h.c.$$

$$\Gamma(\tau \to \mu\,\gamma) = \frac{\alpha m_\tau^5}{64\pi^4}(|c_L|^2 + |c_R|^2)$$

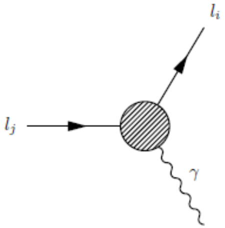


Constraint is weak!

$$\sqrt{|Y_{\tau\mu}|^2 + |Y_{\mu\tau}|^2} < 1.6 \cdot 10^{-2}$$

Flavour violating occurs in slepton sector and then is transmitted to lepton sector via loop diagrams. The branching ratio (hep-ph/1304.2783)

$$BR(\tau \to \mu\gamma) = \frac{\alpha\alpha_2^2}{4}\left(\frac{v}{48\pi}\right)^2 \frac{m_\tau^3}{\Gamma_\tau}\left(\frac{M_1 \cos\beta}{m_{\tilde{L}} m_{L_2} m_{L_3}}\right)^2 (|\tilde{A}_{\mu\tau}|^2 + |\tilde{A}_{\tau\mu}|^2)$$



For simplicity we assume that only $\tilde{A}_{\mu\tau}$ constants are non-zero.

Constraints on off-diagonal Yukawa couplings. Modified couplings.

Effective lagrangian for Higgs boson in SM

$$\mathcal{L}_h^{eff} = \frac{2m_w^2}{\sqrt{2}v}\, h\, W_{mu}^{+} W^{\mu -} + \frac{2m_Z^2}{\sqrt{2}v}\, h\, Z_{mu}^{+} Z^{\mu -} -$$

$$- \frac{m_b}{\sqrt{2}v} h\bar{b}b + g_{h\gamma\gamma} h\, F_{\mu\nu} F^{\mu\nu} + g_{hgg} h\, trG_{\mu\nu} G^{\mu\nu}$$

Effective lagrangian for sgoldstino

$$\mathcal{L}_s^{eff} = -\frac{M_2}{\sqrt{2}F}\, s\, W_{\mu\nu} W^{\mu\nu *} - \frac{M_{ZZ}}{2\sqrt{2}} s Z^{\mu\nu}\, Z_{\mu\nu} -$$

$$- \frac{M_{\gamma\gamma}}{2\sqrt{2}} s F_{\mu\nu} F^{\mu\nu} - \frac{M_3}{2\sqrt{2}F} s\, trG_{\mu\nu} G^{\mu\nu}$$

$$M_{ZZ} = M_1 \sin^2\theta_W + M_2 \cos^2\theta_W$$

$$M_{\gamma\gamma} = M_1 \cos^2\theta_W + M_2 \sin^2\theta_W$$

Constraints on off-diagonal Yukawa couplings. Modified couplings.

$$g_{\tilde{h}\gamma\gamma} = g_{h\gamma\gamma}\ \cos\theta + \frac{M_{\gamma\gamma}}{2\sqrt{2}F}\ \sin\theta$$

$$g_{\tilde{h}gg} = g_{hgg}\ \cos\theta + \frac{M_3}{2\sqrt{2}F}\ \sin\theta$$

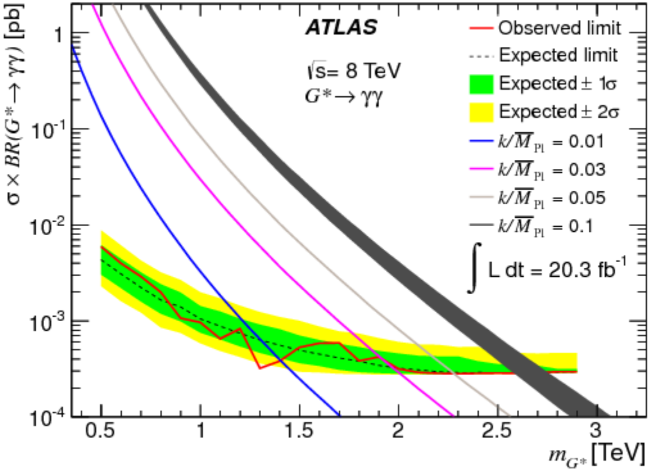
$$g_{\tilde{h}ZZ} = g_{hZZ}\ \cos\theta + \frac{M_{ZZ}}{\sqrt{2}F}((k_{Z_1}, k_{Z_2})\eta^{\mu\nu} - k^{Z_2\mu}k^{Z_1\nu})\sin\theta$$

$$g_{\tilde{h}ZZ} = g_{hW^+W^-}\ \cos\theta + \frac{M_2}{\sqrt{2}F}((k_{W^+}, k_{W^-})\eta^{\mu\nu} - k^{W^+\mu}k^{W^-\nu})\sin\theta$$

$$g_{\tilde{h}bb} = g_{hbb}\ \cos\theta$$

Effective coupling constants for sgoldstino-like state $\tilde{s}$ can be obtained from those above by the replacement $\cos\theta \to \sin\theta$ and $\sin\theta \to -\cos\theta$.

Constraints on off-diagonal Yukawa couplings. Diphoton resonances. hep-ex/1504.05511



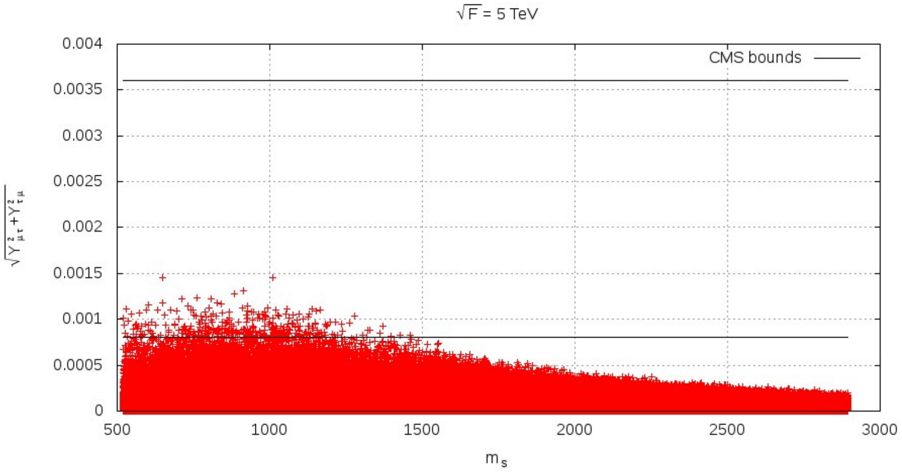
Analysis strategy.

$\tan\beta$	$1.5\ldots 50.5$
μ	$100\ldots 2000.0$ GeV
$A_{\mu\tau}$	$0.1\sqrt{F}\ldots\sqrt{F}$
M_1	$100.0\ldots\sqrt{F}$ GeV
M_2	$200.0\ldots\sqrt{F}$ GeV
M_3	$1.5\ldots 4.0$ TeV
$\tilde{m}_{sl}$	300.0 GeV $\ldots\sqrt{F}$

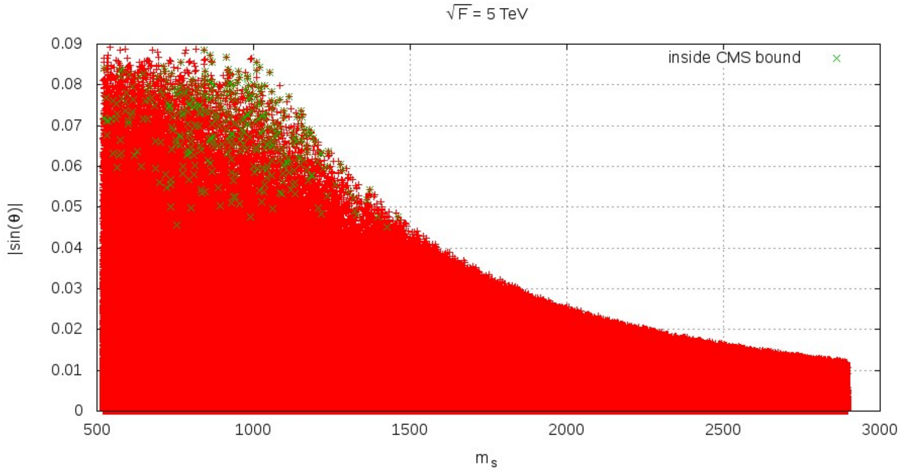
Table : Parameter space

1. We have assumed that $m_{\tilde{L}_i} = m_{\tilde{E}_i} \equiv \tilde{m}_{sl}$.
2. Sgoldstino mass parameter $500\,GeV < m_s < 3000\,GeV$
3. Calculate signal strength $\frac{\sigma(pp\to\tilde{h})\cdot Br(\tilde{h})}{\sigma(pp\to h)\cdot Br(h)_{SM}}$ for every final state ($\gamma\gamma$, bb, $\tau\tau$,WW,ZZ)
4. $\sigma(pp\to s)\cdot Br(s\to\gamma\gamma)$
5. Slepton mass matrix must be positive definite.
6. $BR(\tau\to\mu\gamma) < 4.4\cdot 10^{-8}$

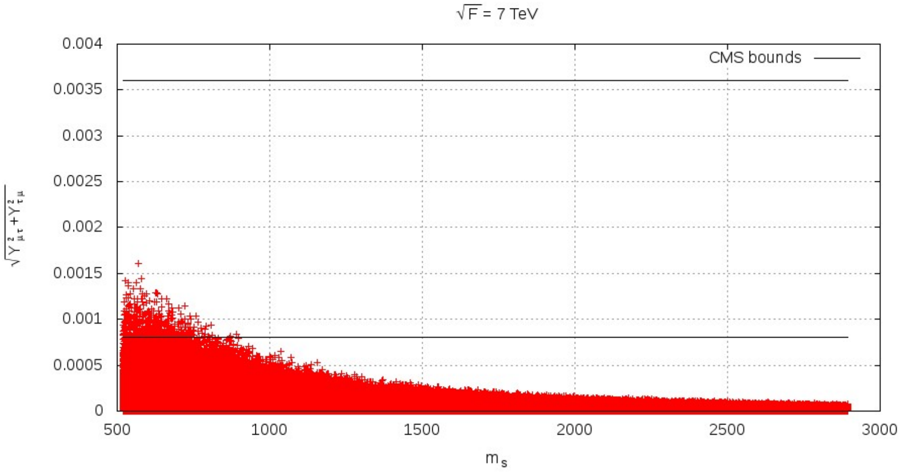
Results. $\sqrt{F} = 5\,\text{TeV}$. Yukawa couplings



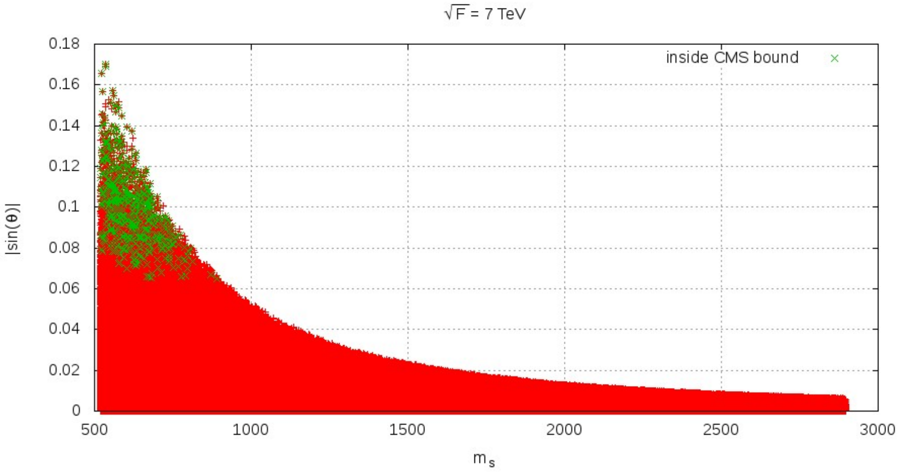
Results. $\sqrt{F} = 5$ TeV. Mixing angle.



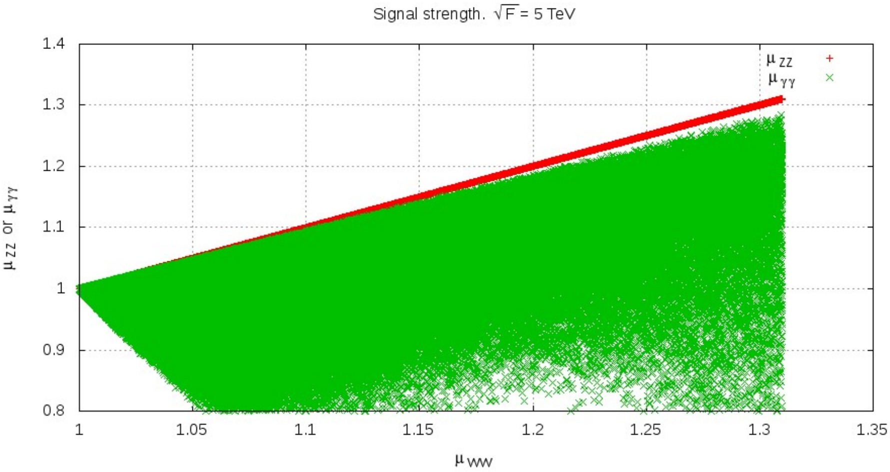
Results. $\sqrt{F} = 7\,\text{TeV}$. Yukawa couplings.



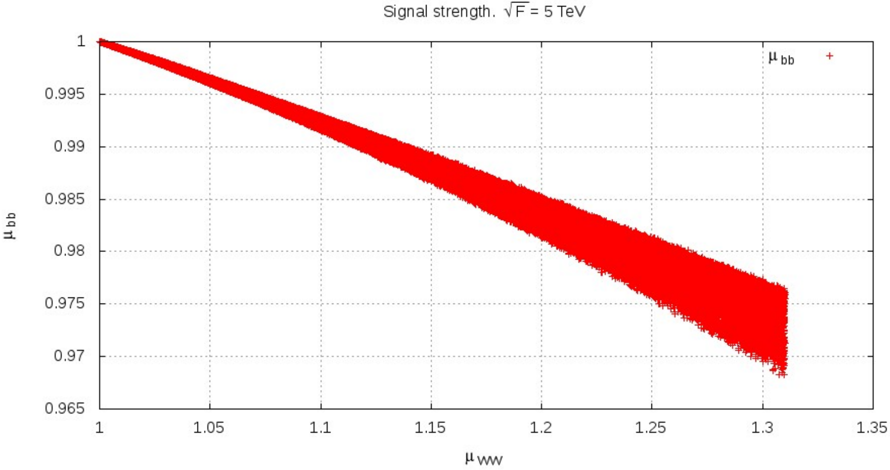
Results. $\sqrt{F} = 7$ TeV. Mixing angle.



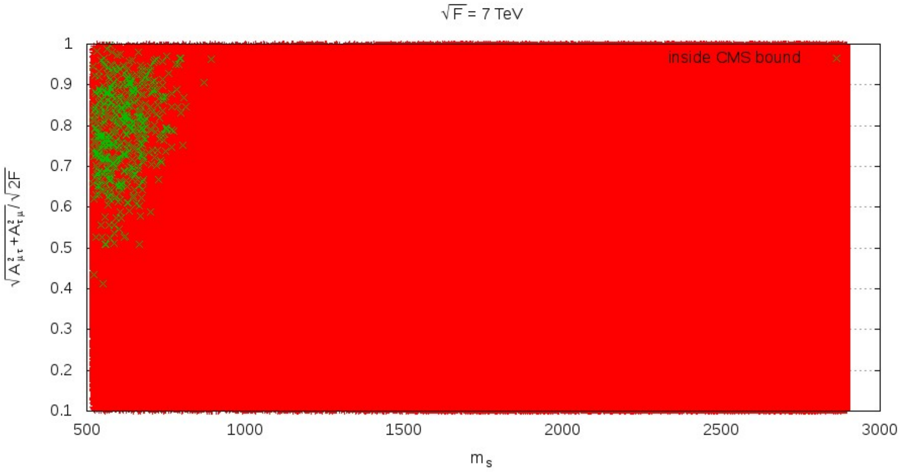
Results. $\sqrt{F} = 5\,\text{TeV}$. Signal strength.



Results. $\sqrt{F} = 5$ TeV. Signal strength.



Results. $\sqrt{F} = 7\,\text{TeV}$. Naturalness.



Conclusions.

- Low scale supersymmetry – sgoldstinos can mix with Higgs bosons.
- Flavour violating processes can be possible.
- This scenario can be probed at the LHC.

Thank you for your attention!