Implication of Higgs at 125 GeV within Stochastic Superspace Framework

Manimala Chakraborti

Department of Theoretical Physics

Indian Association for the Cultivation of Science

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arxiv:1305.4020[hep-ph]]

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SUSY must be broken

- Non observation of SUSY particles $\Rightarrow$ SUSY must be broken.
- Minimal Supersymmetric Standard Model has a large no of soft SUSY breaking terms.
- Choosing a particular model like mSUGRA, GMSB, AMSB etc can be useful to reduce the no of parameters.

In this work we study a SUSY breaking scenario by considering a superspace where some unknown but fundamental mechanism of SUSY breaking can be manifested as the stochasticity of Grassmann variables.

ref:Kobakhidze,Pesor,Volkas
arXiv:0809.2426 [hep-ph]
arXiv:1003.4782 [hep-ph]
arXiv:1201.1624 [hep-ph]

Stochastic superspace formulation

θ and $\bar{\theta}$ are stochastic and a probability distribution function $P(\theta, \bar{\theta})$ describes this stochasticity.

$$\mathcal{P}(\theta,\bar{\theta}) = A + \theta^\alpha \Psi_\alpha + \bar{\theta}_{\dot{\alpha}} \bar{\Xi}^{\dot{\alpha}} + \theta^\alpha \theta_\alpha B + \bar{\theta}_{\dot{\alpha}} \bar{\theta}^{\dot{\alpha}} C + \theta^\alpha {\sigma^\mu}_{\alpha\dot{\beta}} \bar{\theta}^{\dot{\beta}} V_\mu$$
$$+ \theta^\alpha \theta_\alpha \bar{\theta}_{\dot{\alpha}} \bar{\Lambda}^{\dot{\alpha}} + \bar{\theta}_{\dot{\alpha}} \bar{\theta}^{\dot{\alpha}} \theta^\alpha \Sigma_\alpha + \theta^\alpha \theta_\alpha \bar{\theta}_{\dot{\alpha}} \bar{\theta}^{\dot{\alpha}} D$$

Here A, B, C, D and V_μ are complex numbers. Ψ, $\bar{\Xi}$, $\bar{\Lambda}$, and Σ are Grassmann numbers.

Now,

- **Normalisation:**
  $\int d^2\theta d^2\bar{\theta}\ \mathcal{P}(\theta,\bar{\theta}) = 1. \Rightarrow\ D = 1$

- **Vanishing of fermionic moments due to Lorentz invariance:**
  $< \theta > = < \bar{\theta} > = < \theta\bar{\theta} > = < \theta^2\bar{\theta} > = < \theta\bar{\theta}^2 > = 0$

  $\Rightarrow\ \Sigma = \bar{\Lambda} = V_\mu = \bar{\Xi} = \Psi = 0$

- **Bosonic moments:**
  $< \theta\theta > = C$, $< \bar{\theta}\bar{\theta} > = B$
  Calling $B = 1/\xi$ one has $B = C^* = 1/\xi$

  $< \theta\theta\bar{\theta}\bar{\theta} > = A \Rightarrow\ A = 1/|\xi|^2$

  ξ is a quantity of mass dimension.
  Thus :

$$\mathcal{P}(\theta,\bar{\theta})|\xi|^2 = \widetilde{\mathcal{P}}(\theta,\bar{\theta}) = 1 + \xi^*(\theta\theta) + \xi(\bar{\theta}\bar{\theta}) + |\xi|^2(\theta\theta)(\bar{\theta}\bar{\theta})$$

Let's consider a single chiral superfield Φ in the Wess-Zumino model :

$$\Phi = \phi(x) - i\theta\sigma^{\mu}\bar{\theta}\partial_{\mu}\phi(x) - \frac{1}{4}\theta^2\bar{\theta}^2\partial_{\mu}\partial^{\mu}\phi(x) + \sqrt{2}\theta\psi(x) + \frac{i}{\sqrt{2}}\theta^2\partial_{\mu}\psi(x)\sigma^{\mu}\bar{\theta} + \theta^2 F(x)$$

Kinetic term $\Rightarrow$ $\Phi^{\dagger}\Phi$

Superpotential term $\Rightarrow$ $W = \frac{1}{2}m\Phi^2 + \frac{1}{3}h\Phi^3$

averaging over Grassmannian coordinates

$$L = < \mathcal{L} > = \int d^2\theta d^2\bar{\theta}\widetilde{\mathcal{P}}(\theta,\bar{\theta})\mathcal{L}$$

Where, $\mathcal{L} = \Phi^\dagger\Phi + W\delta^{(2)}(\bar{\theta}) + W^\dagger\delta^{(2)}(\theta)$

$$< \mathcal{L}_{\text{kinetic}} > = \left[\Phi^\dagger\Phi\right]_D + \overbrace{|\xi|^2|\phi|^2 + \xi^*\phi F^* + \xi\phi^* F}^{\not{SUSY}}$$

$$< W + h.c. > = [W + h.c.]_F + \left[\overbrace{\xi^*\left(\frac{1}{2}m\phi^2 + \frac{1}{3}h\phi^3\right) + h.c.}^{\not{SUSY}}\right]$$

$$L = <\mathcal{L}>_{\rm SUSY} + <\mathcal{L}>_{\not{SUSY}}$$

where,

$$<\mathcal{L}>_{\rm SUSY} = \left[\Phi^\dagger\Phi\right]_D + [W + h.c.]_F$$

and

$$<\mathcal{L}>_{\not{SUSY}} = |\xi|^2|\phi|^2 + \xi^*\phi F^* + \xi\phi^* F + \left[\xi^*\left(\frac{1}{2}m\phi^2 + \frac{1}{3}h\phi^3\right) + h.c.\right]$$

The eqns of motion of auxiliary field :

$$F = -(\xi^* \phi + m\phi^* + h{\phi^*}^2)$$

Substituting for F and F^* in L :

$$L = L_{\mathrm{On-shell-SUSY}} + L_{\mathrm{soft}},$$

where,

$$\begin{aligned} L_{\mathrm{On-shell-SUSY}} &= \partial_\mu \phi^* \partial^\mu \phi + \frac{i}{2}\left(\psi\sigma^\mu\partial_\mu\bar{\psi} - \partial_\mu\psi\sigma^\mu\bar{\psi}\right) \\ &\quad - m^2|\phi|^2 - h^2(|\phi|^2)^2 \\ &\quad - \left[\left(mh|\phi|^2\phi + \frac{1}{2}m\psi\psi + h\psi\psi\phi\right) + h.c.\right] \end{aligned}$$

and L_{soft} is given by,

$$-L_{\mathrm{soft}} = \left[\left(\frac{1}{2}\xi^* m\phi^2 + \frac{2}{3}h\xi^*\phi^3\right) + h.c.\right]$$

- **MSSM Superpotential :**
  $W_{MSSM} = \bar{u}Y_uQH_u - \bar{d}Y_dQH_d - \bar{e}Y_eLH_d + \mu H_uH_d$
- $\mu H_uH_d \Rightarrow \ \xi^*\mu\tilde{H}_u\tilde{H}_d$
- $\bar{u}Y_uQH_u \Rightarrow \ 2\xi^*\hat{y}^{up}\tilde{Q}\tilde{U}_c\tilde{H}_u$
- gaugino mass term $\Rightarrow \ \frac{\xi^*}{2}\Sigma_i\lambda^{(i)}\lambda^{(i)}$
- **Fundamental parameters :** $m_{1/2} = \frac{1}{2}|\xi|$, $B_\mu = \xi^*$,$A_0 = 2\xi^*$
  All depend on a single parameter $\xi \Rightarrow$ the scale of SUSY breaking
  No SUSY breaking scalar soft mass term.
- ξ considered to be real for simplicity.
- scale of input taken to be : $M_{GUT} < \Lambda < M_{pl}$

SSM : advantages and drawbacks

- Non zero A parameter $\Rightarrow$ can enhance the loop correction to m_h :

$$\Delta m_h^2 = \frac{3\bar{m}_t{}^4}{2\pi^2 v^2 \sin^2\beta}\left[\log\frac{M_S^2}{\bar{m}_t{}^2} + \frac{X_t^2}{2M_S^2}\left(1 - \frac{X_t^2}{6M_S^2}\right)\right]$$

$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$, $X_t = A_t - \mu \cot\beta$, $v = 246$ GeV

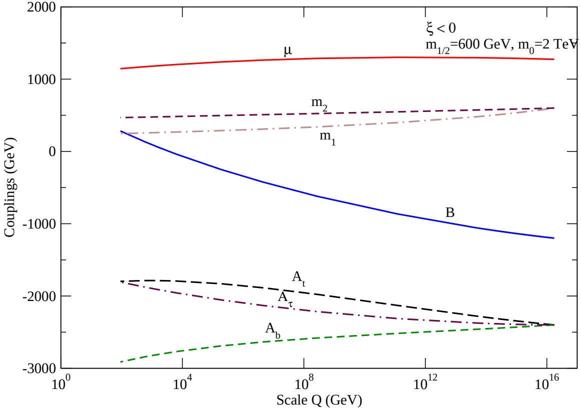
- in ref [hep-ph 0809.2426] the authors used $m_0 = 0$ at $\Lambda = M_{GUT}$ $\Rightarrow$ tachyonic sleptons.
- With $\Lambda > M_{GUT}$ they could reach only upto $m_h \sim 116\ geV$. ref [hep-ph 1201.1624]

- SSM is naturally favourable for large higgs loop correction.
- can we reach $m_h \sim 125\ GeV$?
- We consider $m_0 \neq 0 \Rightarrow$ helps to meet phenomenological demands like FCNC constraints.
- input scale $\Lambda = M_{GUT} \Rightarrow$ to avoid the issues related to post-GUT Physics.

mod-SSM contd

- $\xi \Rightarrow$ real,positive number with an additional input $sign(\xi)$. We discuss only the case $\xi < 0$ because the other sign does not produce a spectra satisfing DM relic density constraint.
- $m_{1/2}$ taken to be independent parameter with $A_0 = sign(\xi)4m_{1/2}$ and $B_0 = sign(\xi)2m_{1/2}$
- **Model parameters :** $m_0, m_{1/2}, sign(\xi), sign(\mu)$

  tanβ is a derived quantity here . Since we are using the code SUSPECT [version 2.41], which takes tanβ as an input, Newton Raphson root finding scheme is used to find out the value of tanβ for a given $B(M_{GUT})$.



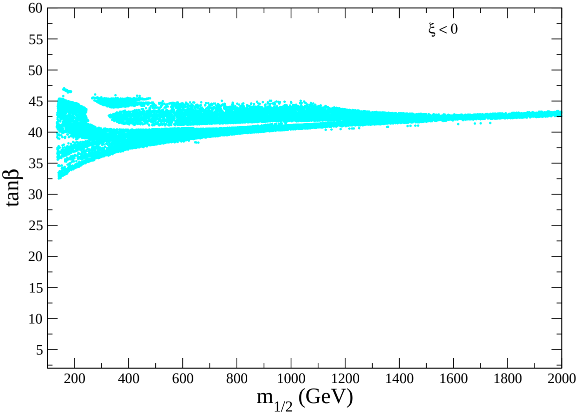
- $m_{1/2} = 600$ GeV, $m_0 = 2$ TeV and $\mu > 0$
- B must evolve to a positive value at EW scale.

- REWSB conditions:

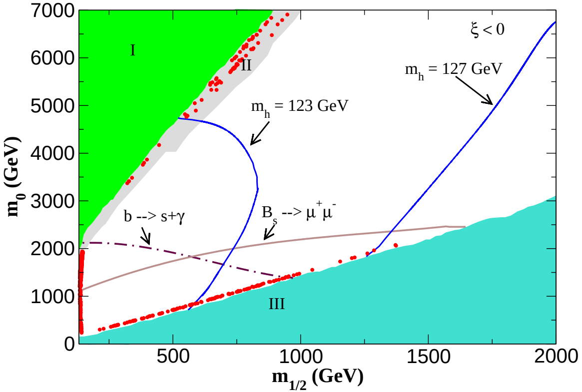
$$\mu^2 = -\frac{1}{2}M_Z^2 + \frac{m_{H_D}^2 - m_{H_U}^2 \tan^2\beta}{\tan^2\beta - 1} + \frac{\Sigma_1 - \Sigma_2 \tan^2\beta}{\tan^2\beta - 1}$$

$$\sin 2\beta = 2B\mu/(m_{H_D}^2 + m_{H_U}^2 + 2\mu^2 + \Sigma_1 + \Sigma_2)$$

Allowed range of tanβ

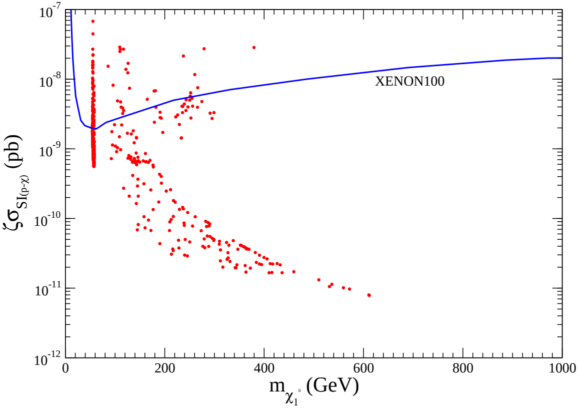


tanβ is constrained to have large values.



- reigion I ⇒ can not satisfy REWSB. Region III ⇒ stau becomes LSP.
- region II ⇒ chargino coannihilation region: gives underabundant DM.
- m_h is considered to have a theoretical uncertainity of 3 GeV.

Direct detection



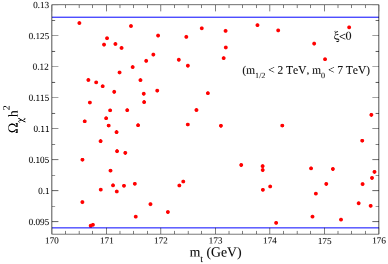
The scaling factor $\Rightarrow$ $\zeta = \Omega_{\widetilde{\chi}} h^2 / (\Omega_{CDM} h^2)_{\rm min} = \rho_\chi / \rho_0$
ref :Fornengo,Scopel,Bottino [arXiv:1011.4743 [hep-ph]]

let's vary m_t !

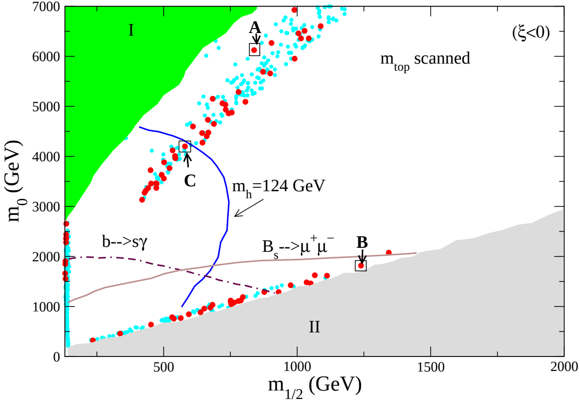
- The small μ region is very sentitive to REWSB.
- Sentitivity can be reduced by varying a non-SUSY parameter like m_t.
- experimental data : $m_t \Rightarrow$ 173.3 $\pm$0.9 GeV from $pp \rightarrow t\bar{t} + X$ crosssection.
- NNLO QCD prediction of the inclusive $pp \rightarrow t\bar{t} + X$ cross section and the exp data of the same used to extract m_t in the modified $(\overline{\mathrm{MS}})$ scheme. This was then used to compute the pole mass $\Rightarrow$ m_t $\Rightarrow$ 173.3 $\pm$2.8 GeV.

ref:Alekhin,Djouadi,Moch arXiv:1207.0980 [hep-ph]

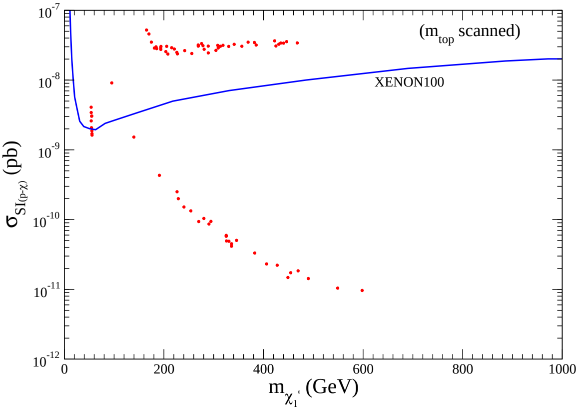
Relic density satisfied points shown in red for $m_t = 173.3 \pm 2.8$ GeV. The central value of 173.3GeV is clearly disfavoured.



m_0-mhalf plane with m_t scanned



- DM satisfied points of right abundance obtained.



- effect of varying m_t on $\sigma^{SI}_{p\widetilde{\chi}^0_1}$
- Significant amount of hadronic uncertainity in $\sigma^{SI}_{p\widetilde{\chi}^0_1}$. ref:Perelstein and Shakya[arXiv:1208.0833 [hep-ph]]

  $\Rightarrow$ may cause a reduction in $\sigma^{SI}_{p\widetilde{\chi}^0_1}$ by almost an order of magnitude.

Parameter	A	B	C
m_t	173.10	173.87	171.58
$m_{1/2}$	838.78	1239.16	579.69
m_0	6123.75	1817.69	4200.55
$(A_0 = -4m_{1/2})$	-3355.13	-4956.64	-2318.75
$(B_0 = -2m_{1/2})$	-1677.56	-2478.32	-1159.37
B_0 (*as output*)	-1683.56	-2478.32	-1160.27
$\tan\beta$ (*as output*)	45.86	40.92	45.11
$sgn(\mu)$	1	1	1
μ	403.86	2508.85	310.43
$m_{\tilde{g}}$	2145.53	2727.64	1525.80
$m_{\tilde{u}_L}$	6247.84	2994.87	4292.70
$m_{\tilde{t}_1}, m_{\tilde{t}_2}$	3758.76, 4376.60	1333.10, 2078.60	2587.56, 3026.20
$m_{\tilde{b}_1}, m_{\tilde{b}_2}$	4397.10, 4886.58	2054.58, 2339.25	3037.22, 3381.67
$m_{\tilde{e}_L}, m_{\tilde{\nu}_e}$	6119.53, 6119.05	1983.72, 1982.21	4197.61, 4196.89
$m_{\tilde{\tau}_1}, m_{\tilde{\nu}_\tau}$	4750.43, 5482.91	549.62, 1536.41	3281.31, 3770.25
$m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}$	406.25, 741.03	1038.00, 2491.42	304.84, 518.70
$m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}$	356.62, 417.02	548.95, 1038.00	241.80, 316.70
$m_{\tilde{\chi}_3^0}, m_{\tilde{\chi}_4^0}$	424.40, 741.06	2489.56, 2491.14	322.35, 518.80
$m_A, m_{H^\pm}$	2573.69, 2573.69	1967.83, 1967.50	1846.04, 1846.04
m_h	124.42	126.55	*121.57*
$\Omega_{\tilde{\chi}_1} h^2$	0.1105	0.1002	0.1106
$BF(b \to s\gamma)$	3.23×10^{-4}	2.96×10^{-4}	3.15×10^{-4}
$BF(B_s \to \mu^+\mu^-)$	2.98×10^{-9}	5.23×10^{-9}	2.89×10^{-9}
$R_{(b\to\tau\nu^\pm)}$	0.98	0.98	0.97
Δa_μ	5.78×10^{-11}	1.65×10^{-10}	1.22×10^{-10}
$\sigma_{p\chi}^{SI}$	3.05×10^{-8}	1.04×10^{-11}	2.64×10^{-8}

Table 1: Spectra of three specimen parameter points A, B and C as shown in Fig.6. Results

conclusion

- The model has a natural advantage of having a non zero A parameter $\Rightarrow$ helps to raise m_h in the region $m_h \sim 125\ GeV$.
- This framework can be extended to non minimal models like NMSSM ,RPV models etc.


THANK
YOU

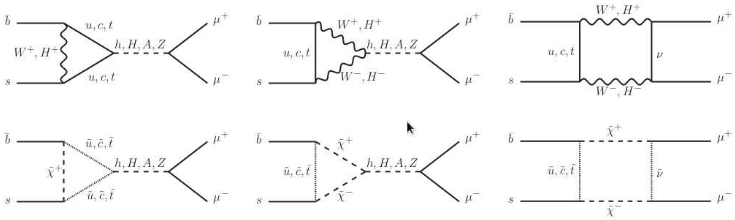
b $\longrightarrow$ s γ

- SM contribution (almost saturates the experimental value) $\longrightarrow$ $t - W^{\pm}$ loop.
- MSSM contribution:
  1. $\widetilde{\chi}^{\pm} - \tilde{t}$ loop:
  $BR(b \rightarrow s\gamma)|_{\widetilde{\chi}^{\pm}} = \mu A_t tan\beta f(m_{\tilde{t}_1}, m_{\tilde{t}_2}, m_{\widetilde{\chi}^{\pm}})\frac{m_b}{v(1+\Delta m_b)}$
  2. $H^{\pm} - t$ loop:
  $BR(b \rightarrow s\gamma)|_{H^{\pm}} = \frac{m_b(y_t cos\beta - \delta y_t sin\beta)}{vcos\beta(1+\Delta m_b)} g(m_{H^{\pm}}, m_t)$ where,

  $$\delta y_t = y_t \frac{2\alpha_s}{3\pi} \mu M_{\tilde{g}} tan\beta(cos^2\theta_t I(m_{\tilde{s}_L}, m_{\tilde{t}_2}, M_{\tilde{g}}) + sin^2\theta_t I(m_{\tilde{s}_L}, m_{\tilde{t}_1}, M_{\tilde{g}}))$$

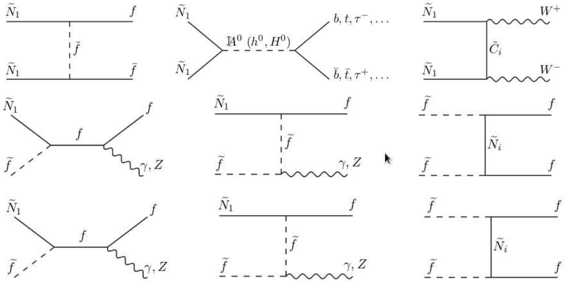
- destructive interference for $A_t\mu < 0 \longrightarrow$ prefered.
- NLO contributions (from squark-gluino loops: due to the corrections of top and bottom yukawa couplings) become important at large μ or large tanβ.

$B_s \longrightarrow \mu^+\mu^-$



- dominant SM contribution from : Z penguin top loop & W box diagram.
- SM value : $BR(B_s \to \mu^+\mu^-)$=3.23 $\pm$ 0.27$\times 10^{-9}$.
- LHCb result : $3.2^{+1.4}_{-1.2}(stat.)^{+0.5}_{-0.3}(syst.) \to$ no room for large deviation.
- $BR(B_s \to \mu^+\mu^-)_{SUSY} \propto \frac{tan^6\beta}{{m_a}^4}$

Some diagrams contributing to relic density:



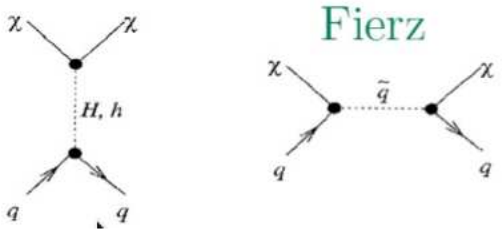
Direct Detection

- The elastic scattering of LSP depends on their scattering off heavy neucli in a detector.
- effective Lagrangian for SI/SD interaction between a WIMP and a neucleon:
  $\mathcal{L}|_{SI} = \lambda_N \bar{\psi}_\chi \psi_\chi \bar{\psi}_N \psi_N$

  $\mathcal{L}|_{SD} = \xi_N \bar{\psi}_\chi \gamma_5 \gamma_\mu \psi_\chi \bar{\psi}_N \gamma_5 \gamma^\mu \psi_N$
- $\sigma_0^{SI} = \frac{4\mu_\chi^2}{\pi} \left(\lambda_p Z + \lambda_n (A - Z)\right)^2$

  Where μ_χ is the WIMP-nucleous reduced mass. There is strong enhancement for large nuclei $\rightarrow \sigma_0^{SI} \propto A^2$ for $\lambda_p \simeq \lambda_n$.

Diagrams corresponding to SI scattering:



Diagrams corresponding to SD scattering: