Solving μ and little hierachy problems of the MSSM with electroweak triplets

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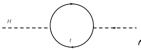
SUSY

- SUSY is one of the most motivated scenarios of the Beyond Standard Model Physics.
- SUSY protects Higgs mass from quadratic divergences



$$\sim \frac{\Lambda^2 y^2}{16\pi^2}$$

In the SM, $\Lambda \sim M_{Pl} \sim 10^{18}$GeV, so naturall scale of the Higgs mass $M_H \sim M_{Pl}$ but in MSSM $\Lambda \sim m_{soft} \sim 100$GeV

- Other attractive features: dark matter candidate, coupling unification...

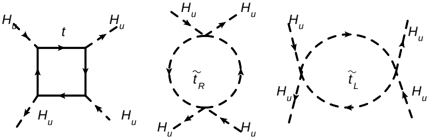
MSSM and little hierarchy problem

- Higgs quartic coupling H^4 is fixed by the gauge interactions, this leads to the

$$m_h < |\cos 2\beta|\, M_Z \lesssim 91\text{GeV}$$

LEP constraint : $m_h > 115\text{GeV}$

- tree level bound will be modified by the radiative corrections to the quartic interactions:



$\Rightarrow$

$$\delta\left(m_h^2\right) \sim \frac{3}{4\pi^2} y_t^2 m_t^2 \ln\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$$

$$m_{h^0} \lesssim 135\text{GeV}$$

for all stop masses below 1 TeV

Higgs mass bound in the extensions of the MSSM

- NMSSM $\sim \lambda S H_u H_d \Rightarrow \Delta V \sim \lambda^2 \left|(H_u H_d)\right|^2$

$$m_h^2 > M_z^2 \left(\cos^2 2\beta + \frac{2\lambda^2}{g^2 + g_1^2} \sin^2 2\beta \right)$$

  effect of the coupling $\lambda S H_u H_d$ is important only for the small values of $\tan\beta$

- problematic large values of the coupling with perturbativity up to the GUT scale.

Generic Superpotential with trilinear terms

- Let us consider generic lagrangian where N are neutral scalars *(Espinosa,Quiros)*

$$W \sim \lambda^{(i)}_{ud} N_{ud} H^0_u H^0_d + \lambda_{uu} N_{uu} \left(H^0_u\right)^2 + \lambda_{dd} N_{dd} \left(H^0_d\right)^2$$

$$m_h^2 \leq M_z^2 \left[\cos^2 2\beta + \frac{2}{g^2+g^2}\left(\lambda^2_{ud}\sin^2 2\beta + \lambda^2_{uu}\sin^4\beta + \lambda^2_{dd}\cos^4\beta\right)\right]$$

- fields that can couple to the H_u^2 in the superpotential will give the correction which will not have $\frac{1}{\tan\beta}$, $\Rightarrow$
- we need EW triplets

The Model with electroweak triplets *(Espinosa,Quiros)*

- $$W = \mu H_u H_d + \mu_T H_u H_d + \chi_u H_u \bar{T} H_u + \chi_d H_d T H_d$$
- to be consistent with bounds on ρ parameter we need $\langle T \rangle \to$ small, but F term of the triplets leads to the
$$|F_T|^2 \sim \chi_u \mu_T H_u^2 \bar{T}^*$$
- the tadpole of the triplet, we will have nonzero $\langle T \rangle$ even in the case when $m_T^2 > 0$
- need to suppress vev of the triplet

Supersymmetric vs nonsupersymmetric integration of the triplets

- Supersymmetric integration of the triplets
  (Dine,Seiberg,Thomas;Carena,Kong,Ponton,Zurita)
  $\mu_T \gg m_{T,soft}$

$$\Delta V \sim \frac{m^2_{T,soft}}{\mu^2_T + m^2_{T,soft}} \chi^2_u \left|H^2_u\right|^2$$

- $m_{soft} \gg \mu_T$ limit large correction to the quartic!

$$\Delta V \sim \chi^2_u \left|H^2_u\right|^2$$

EW precision

- bosonic contirbution seems under control

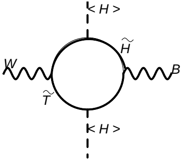
$$\langle T \rangle \sim \frac{\chi_u \mu_T v^2}{m_T^2 + \mu_T^2} \sim 6 \text{ GeV}$$

for $\mu_T = 150, m_T = 600, \chi_u = 0.5$

- fermionic contribution?

$$\begin{pmatrix} \mu & \sqrt{2}\chi_d v_d \\ -\sqrt{2}\chi_u v_u & \mu_T \end{pmatrix} \begin{pmatrix} H_u^+ \\ T^+ \end{pmatrix},$$

- $S \sim$



Small μ_T term no strong suppression of the S, T parameters

S,T from the tripletino -higgsino mixing

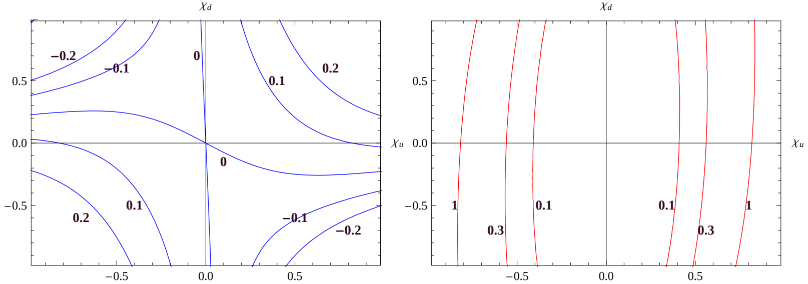


Figure: Contour plots of the regions with different values of the S (blue) and T(red) parameters in the, $\mu = \mu_T = 150\text{GeV}$

minisummary

- The models with triplets can help to solve little hierarchy problem
- Need large soft masses of the triplets and small μ_T term to get viable spectra with suppressed triplet vev.
  - Although vev of the triplet is small it still not enough to get neutrino masses.
- Generically gauge mediation leads to the spectrum where the soft masses of the triplets are larger than the doublets due to the larger Casimir invariant, can be a good candidate for the UV theory
- Need small μ_T for triplets, new μ problem ?

Combining NMSSM with triplets

- one of the easiest solution to the μ problem comes from NMSSM where the μ is vev of the scalar singlet $\langle S \rangle$.
- NMSSM + gauge mediation is problematic, needs some generation of negative m_S^2, solutions:
  - extra matter that couples to singlets *(Dine,Nelson,Shirman; Agashe,Graesser;de Gouvea,Friedland,Murayama)*
- MSSM+EW triplets we need generation of the μ terms for both doublets and triplets
- can these models solve each others problem?

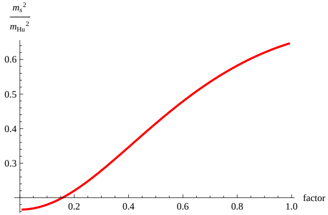
RGE analysis

- Using triplets to generate tachyonic m_S^2
  - NMSSM

$$\frac{dm_S^2}{dt} \sim 2[\lambda^2(m_{H_u}^2 + m_{H_d}^2 + m_S^2)] + 2[3\kappa^2 m_S^2]$$

  - NMSSM+triplets

$$\frac{dm_S^2}{dt} \sim 2[\lambda^2(m_{H_u}^2 + m_{H_d}^2 + m_S^2)] + 2[3\kappa^2 m_S^2] + 3[\lambda_T^2(m_T^2 + m_{\bar{T}}^2 + m_S^2)] \Rightarrow$$



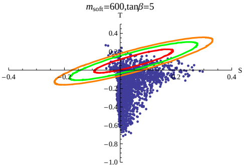
Tension in the parameter space

- EW fit prefers smaller values of the triplet coupling λ_T

$$\langle T \rangle \sim \frac{\chi_u \mu_T v^2}{m_T^2 + \mu_T^2}, \quad \mu_T \sim \lambda_T \langle S \rangle$$

- To get large contribution to the singlet mass squared we need large values of λ_T

$$\frac{dm_S^2}{dt} \sim 3[\lambda_T^2 (m_T^2 + m_{\bar{T}}^2 + m_S^2)]$$

- 

To verify whether we can satisfy both requirments we checked whether points passing EW constraints can have zero soft mass for the singlet in the UV, keeping all the couplings perturbative.

R axion

- In the limit when all the A terms vanish the model like usual MSSM is invariant under

$$H_u, H_d, T, \bar{T}, S \to e^{i\phi_R} H_u, H_d, T, \bar{T}, S.$$

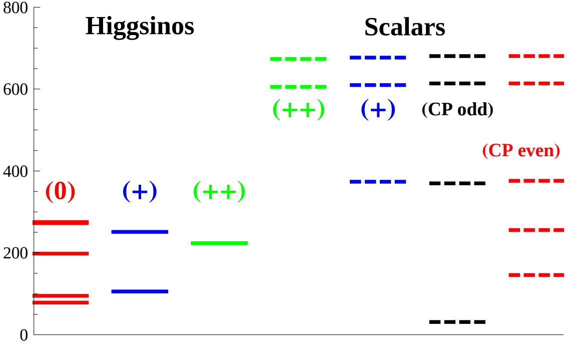
- n the limit when $\langle T(\bar{T})\rangle \to 0$ we recover the usual NMSSM expression for the R axion in the terms of the field components

$$R_{axion} \approx \frac{v_s S_I + 2v c_\beta s_\beta (c_\beta H_{uI} + s_\beta H_{dI})}{\sqrt{v_s^2 + v^2 \sin^2 2\beta}}$$

- mass of the axion will be proportional to the A terms

$$m_{ax}^2 \sim -3A_S v_s - \frac{14 A v_u v_d}{v_s} + \ldots$$

- Typical spectrum of the Higgs-Higgsino sector



Summary

- NMSSM + triplets is a viable model
  - electroweak triplets help to solve little hierarchy problem and also help to drive the mass of the singlet to be negative
  - vev of the singlet field is used to explain both μ terms of the doublet and triplet Higgs fields
- Model has an interesting spectrum of the new physics excitations, with higgsinos and tripletinos being the lightest states and the scalar triplets including doubly charged particles in the $O(600)$ GeV range.
- Questions:
  - phenomenology of light higgsino-tripletinos?
  - realistic UV completion?