A Heavy Higgs and a Light Sneutrino NLSP In the MSSM with Enhanced SU(2) D-terms

Anibal D. Medina

Department of Physics

UC Davis

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Co-authors: Nausheen Shah and Carlos Wagner.

Motivation

- MSSM solves the hierarchy problem and provides a DM candidate with R-parity.

- Includes a Higgs boson with a mass naturally of order M_z.

- LEP bound $\longrightarrow$ large radiative corrections $\longrightarrow$ large squark masses $\longrightarrow$ tension with solving the hierarchy problem.

- Situation may improve by extending weak gauge group to $SU(2)_1 \times SU(2)_2$ (*Batra et al,JHEP 0406.032,2004*):

1. Higgs sector and 3rd generation fermions charged under $SU(2)_1$.
2. 1st and 2nd generation fermions charged under $SU(2)_2$.

- SUSY breaking mass associated with scalars that break $SU(2)_1 \times SU(2)_2 \longrightarrow SU(2)_W$ larger than their vevs lead to enhanced D-terms raise Higgs mass (m_h <300 GeV).

- Corrections to EWPT:

1. Gauge boson mixing small if gauge symmetry breaking scalars vev's are large.
2. Large Higgs mass $\longrightarrow$ negative contribution to ΔT.

Review of the Model

- Breakdown $SU(2)_1 \times SU(2)_2 \longrightarrow SU(2)_W$ governed by,

$$W = \lambda_1 S \left(\frac{\Sigma\Sigma}{2} - w^2 \right)$$

- Leads to a Σ potential,

$$V = m_\Sigma^2 \Sigma^\dagger \Sigma + \frac{\lambda_1^2}{4} |\Sigma\Sigma|^2 - \frac{B}{2} (\Sigma\Sigma + h.c.) + \ldots$$

where $B=\lambda_1 \omega$ and m^2_Σ is a soft SUSY breaking mass. Also D-terms contribution,

$$\Delta V = \frac{g_1^2}{8} \left(\mathrm{Tr}[\Sigma^\dagger \tau^a \Sigma] + \mathrm{H_u^\dagger} \tau^a \mathrm{H_u} + \mathrm{H_d^\dagger} \tau^a \mathrm{H_d} + \mathrm{L}^\dagger \tau^a \mathrm{L} + \mathrm{Q}^\dagger \tau^a \mathrm{Q} \right)^2 + \frac{g_2^2}{8} \left(\mathrm{Tr}[\Sigma^\dagger \tau^a \Sigma] + \ldots \right)^2$$

- For $B > m^2_\Sigma$, $\langle \Sigma \rangle = uI$, with $u^2 = (B - m^2_\Sigma)/\lambda_1^2$. Assuming $B \gg v^2$, integrate out heavy d.o.f,

$$\Delta V = \frac{g^2}{2} \Delta \sum_a \left(H_u^\dagger \tau^a H_u + H_d^\dagger \tau^a H_d + L_3^\dagger \tau^a L_3 + Q_3^\dagger \tau^a Q_3 \right)^2$$

with

$$\Delta = \frac{1 + \frac{2 m_\Sigma^2}{g_2^2 u^2}}{1 + \frac{2 m_\Sigma^2}{(g_2^2 + g_1^2) u^2}}$$

- Therefore,

$$m_h^2 = \frac{1}{2} \left(g^2 \Delta + g_Y^2 \right) v^2 \cos^2 2\beta + \text{loop corrections}$$

Sparticle mass splitting and contributions to ΔT

- Re-write SU(2) D-term effective potential,

$$V_D = \frac{g^2\Delta}{8}\left(\sum_i \Phi_i^\dagger \Phi_i\right)^2 - \frac{g^2\Delta}{4}\sum_{ij}\left|\Phi_i^T i\sigma_2 \Phi_j\right|^2$$

- Combination of F-term and D-term contributions for 3rd generation sleptons and squarks imply,

$$\begin{aligned} m_{\tilde{\tau}_L}^2 - m_{\tilde{\nu}_\tau}^2 &= \Delta_D \\ m_{\tilde{b}_L}^2 - m_{\tilde{t}_L}^2 &= \Delta_D - m_t^2 \end{aligned}$$

with

$$\begin{aligned} \Delta_D &= \frac{g^2 v^2}{2}\Delta |\cos 2\beta| \\ &= \left(\Delta m_h^2\right)_D / |\cos 2\beta| \end{aligned}$$

- For the charged Higgs H^+ and CP-odd Higgs A,

$$m_{H^\pm}^2 - m_A^2 = \frac{g^2\Delta}{2} v^2$$

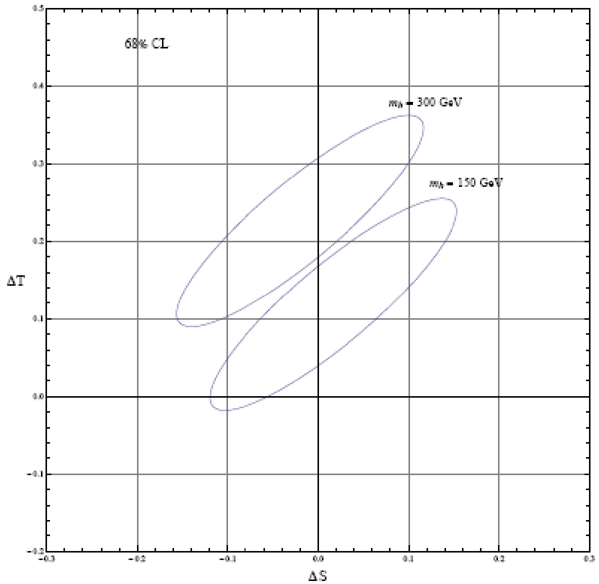
- Upper and lower component mass splitting of SU(2) doublet lead to,

$$\begin{aligned} \Delta T &= \frac{N_c}{12\pi s_W^2 m_W^2}(\Delta m_{ud})^2 \\ &= \frac{N_c}{12\pi s_W^2 m_W^2}\frac{(\Delta m_{ud}^2)^2}{(m_u + m_d)^2} \end{aligned}$$

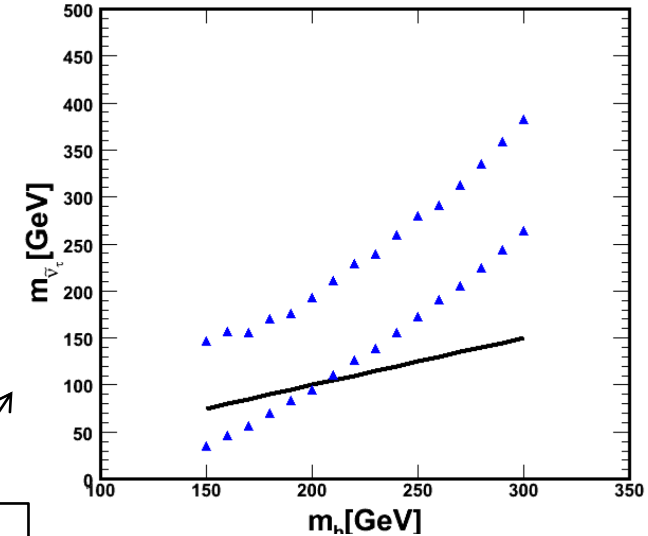
- Which must be added to

$$\begin{aligned} \Delta T &= -\frac{3}{8\pi c_W^2}\ln\frac{m_h}{m_{h_{\rm ref}}} \\ \Delta S &= \frac{1}{6\pi}\ln\frac{m_h}{m_{h_{\rm ref}}}, \end{aligned}$$

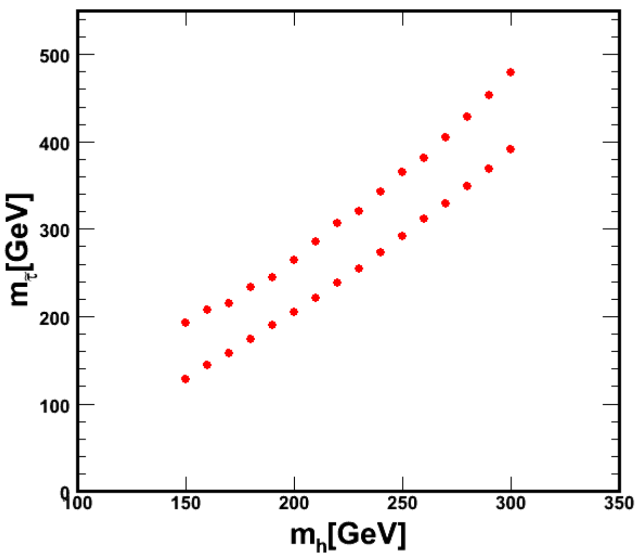
Slepton spectrum with no mixing

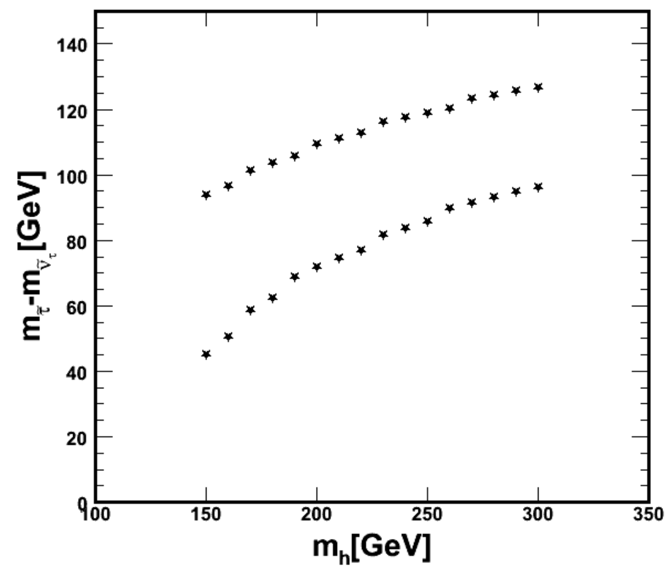


$$\Delta T_{150} \simeq 0.10 \pm 0.06$$
$$\Delta T_{300} \simeq 0.24 \pm 0.07$$



Black line represents $m_h/2$





Supersymmetric Model

• Input: Moderate tan β, universal gaugino mass $M_{1/2}$, universal soft scalar mass M_0 for squarks and sleptons, soft SUSY breaking Higgs masses $m^2_{Hu}=m^2_{Hd}$, positive sign(μ) and $A_t=A_b=A_\tau=0$, at the messenger scale $M \sim M_{GUT}$.

• SUSY breaking transmitted to the visible sector only via $SU(3)_c \times SU(2)_2 \times U(1)_Y$ gauginos for 3rd generation sleptons to remain light.

• One loop RGE for 3rd generation sleptons and gauginos

$$16\pi^2 \frac{d}{dt} m^2_{L_3} = -\frac{6}{5} g_Y^2 |M_Y|^2 - \frac{3}{5} g_Y^2 S$$
$$16\pi^2 \frac{d}{dt} m^2_{\tilde{\tau}_R} = -\frac{24}{5} g_Y^2 |M_Y|^2 + \frac{6}{5} g_Y^2 S$$

$$16\pi^2 \frac{d}{dt} M_i^2 = 4 b_i\, g_i^2\, M_i^2$$

where $b_i = (36/5,-1,1,-3)$ at high energy and after gauge breakdown $b_i = (33/5,1,-3)$.

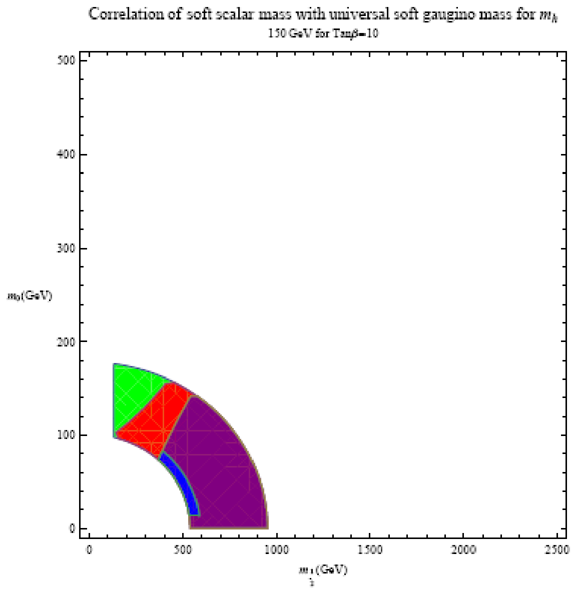
• Approximate solutions,

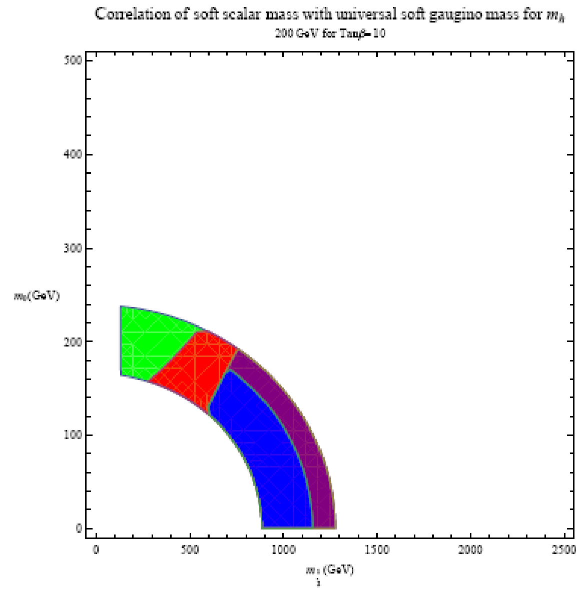
$$m^2_{L_3} \simeq m_0^2 + 0.04\, M^2_{1/2}, \qquad m^2_{\tilde{\tau}_R} \simeq m_0^2 + 0.15\, M^2_{1/2} \qquad M_Y \simeq 0.35\, M_{1/2}, \qquad M_2 \simeq 0.8\, M^2_{1/2}$$

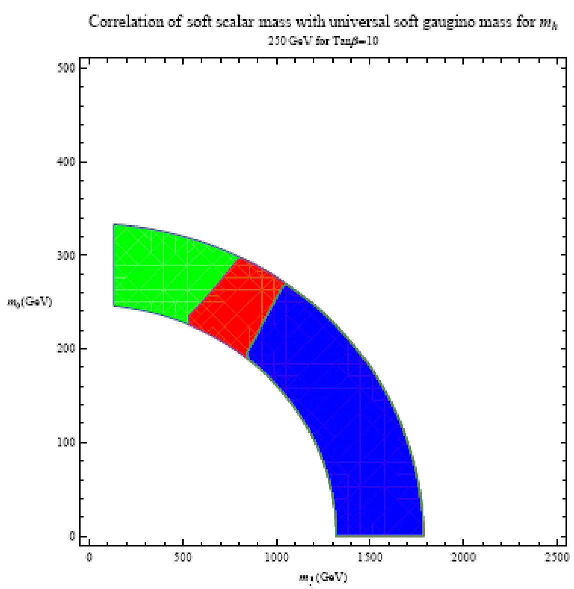
imply that tau sneutrino is the lightest SM partner.

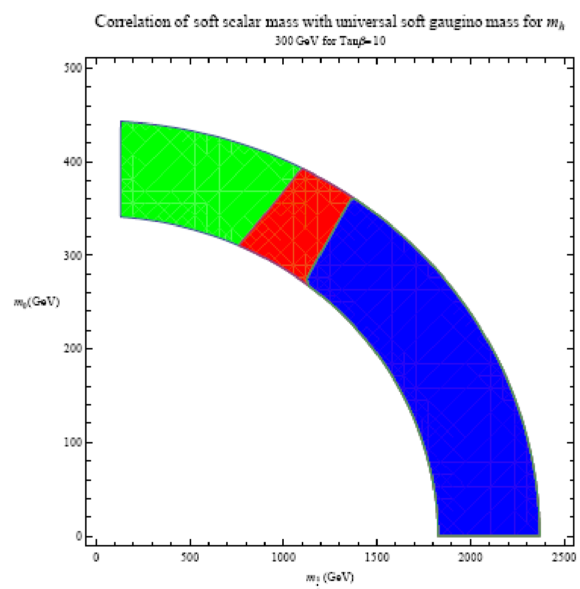
• For a fixed Higgs mass and no mixing $\longrightarrow$ ellipsoidal area in M_0 vs $M_{1/2}$ plane from demanding consistency with EWPT.

M_0 vs $M_{1/2}$


Correlation of soft scalar mass with universal soft gaugino mass for m_h
150 GeV for Tanβ=10
m_0(GeV)
$m_{\frac{1}{2}}$(GeV)


Correlation of soft scalar mass with universal soft gaugino mass for m_h
200 GeV for Tanβ=10
m_0(GeV)
$m_{\frac{1}{2}}$(GeV)


Correlation of soft scalar mass with universal soft gaugino mass for m_h
250 GeV for Tanβ=10
m_0(GeV)
$m_{\frac{1}{2}}$(GeV)


Correlation of soft scalar mass with universal soft gaugino mass for m_h
300 GeV for Tanβ=10
m_0(GeV)
$m_{\frac{1}{2}}$(GeV)

Low energy spectrum

• Calculate low energy particle spectrum using SDECAY. Hard leptons from W decay in $\tilde{\tau}_1^\pm \to W^\pm \tilde{\nu}_\tau$. Presence of many tau's and copious missing energy in the final states. Example for m_h =210 GeV, $M_{1/2}$=700 GeV, tan β=10, M_0=150 GeV, m_{Hu} =m_{hd} =(100 GeV)^2 and Δ=6.13.

Sparticle	Mass[GeV]	Dominant decay modes
$\tilde{g}$	1564	$\tilde{q}_L q$ (16.2)%, $\tilde{q}_R q$ (31.4)%, $\tilde{b}_{1,2} b$ (20) %, $\tilde{t}_1 t$ (24) %
$\tilde{u}_L, \tilde{d}_L$	1428, 1429	$\tilde{\chi}_2^0 q$ (32) %, $\tilde{\chi}_1^\pm q'$ (64) %
$\tilde{u}_R, \tilde{d}_R$	1374,1368	$\tilde{\chi}_1^0 q$ (99) %
$\tilde{t}_1$	1112	$\tilde{\chi}_1^+ b$ (19) %, $\tilde{\chi}_1^0 t$ (25) %, $\tilde{\chi}_3^0 t$ (17) %, $\tilde{\chi}_2^+ b$ (23) %
H^+	967	
A	946	
$\tilde{\chi}_4^0$	864	$\tilde{\chi}_1^\pm W^\mp$ (56) %, $\tilde{\chi}_2^0 h$ (19) %
$\tilde{\chi}_2^\pm$	864	$\tilde{\chi}_2^0 W^\pm$ (28) %, $\tilde{\chi}_1^\pm Z$ (28) %, $\tilde{\chi}_1^\pm h$ (20) %
$\tilde{\chi}_3^0$	852	$\tilde{\chi}_1^\pm W^\mp$ (56) %, $\tilde{\chi}_2^0 Z$ (26) %
$\tilde{\chi}_2^0$	551	$\tilde{\nu}_\tau \nu_\tau$ (47) %, $\tilde{\tau}_1^\pm \tau^\mp$ (39) %
$\tilde{\chi}_1^\pm$	551	$\tilde{\nu}_\tau \tau^\pm$ (49) %, $\tilde{\tau}_1^\pm \nu_\tau$ (37) %
$\tilde{e}_L$	486	$\tilde{\chi}_1^0 e$ (100) %
$\tilde{\nu}_e$	480	$\tilde{\chi}_1^0 \nu_e$ (100) %
$\tilde{e}_R$	300	$\tilde{\chi}_1^0 e$ (100) %
$\tilde{\tau}_2$	303	$\tilde{\chi}_1^0 \tau$ (72) %, $\tilde{\nu}_\tau W$ (28) %
$\tilde{\chi}_1^0$	249	$\tilde{\nu}_\tau \nu_\tau$ (90) %, $\tilde{\tau}_1^\pm \tau^\mp$(10) %
$\tilde{\tau}_1$	217	$\tilde{\nu}_\tau W$ (100) %
$\tilde{\nu}_\tau$	132	$\tilde{G} \nu_\tau$

Cosmological Constraints

- Gravitino LSP produced by scattering processes at reheating epoch ($\Omega_{\tilde{\nu}_\tau} h^2 \approx \mathcal{O}(10^{-3})$)

- Sneutrino NLSP $\tilde{\nu}_\tau \rightarrow \tilde{G} + \nu_\tau$. Bino NLSP excluded by late decay into photon and gravitino .

- For the range of masses considered (40 GeV< m_{snu} <400 GeV, 1 GeV< m_{grav} <100 GeV) the lifetime Γ_{snu} > 10^7 seconds.

- Possible constraints from high energy neutrinos scattering off of BG neutrinos and multibody sneutrino decays lead to almost no constraint ($m_{snu} - m_{grav}$ <300 GeV for m_{grav} <10 GeV) except for the larger Higgs masses.

Non-vanishing $SU(2)_1$ gaugino masses

• Assume non-vanishing $M_2 \longrightarrow$ slepton and squark masses increase at low energy.

• At one loop, M_2 effect is small for m_A and m_{H+} in the large tan β limit, since m_{Hu} and m_{Hd} are both affected in analogous way. It is up to the non-standard Higgs bosons to compensate for ΔT.

• Phenomenology similar to light stau NLSP in gaugino mediation models. Model constraint by searches at Tevatron (m_A >170 GeV).

• If the messenger scale M is very close to M_{GUT} we can have neutralino NLSP which co-annihilates with stau giving proper DM relic density.

• Point example, for $M_Y=M_2=M_3$ 700 GeV, M_1=400 GeV, tan β=48, M_0=360 GeV, m_{Hu} $=m_{hd}$ =(200 GeV)^2 and Δ=5.9.

m_h [GeV]	m_A [GeV]	m_{H+} [GeV]	$m_{\tilde{\tau}_R}$ [GeV]	$m_{\tilde{\tau}_L}$ [GeV]	$m_{\tilde{\chi}_1^0}$ [GeV]	μ [GeV]	ΔT_{tot}
200	176	255	293	1020	275	321	0.12

Conclusions

- By D-term induced mass splitting in 3rd generation fermions and non-standard Higgs bosons, we are able to consistently raise the SM like Higgs mass up to 300 GeV.

- Phenomenological viable scenario of SUSY breaking that provides light sleptons determined by re-establishing agreement with EWP data.

- Collider signatures characterized by the presence of many tau's and copious missing energy in the final states. Presence of hard leptons for large values of Higgs mass.

- Small region of parameter space where Higgs can decay into sneutrinos (avoid Tevatron bounds).

- Alternative scenario with non-vanishing $M_2 \longrightarrow$ large $\tan\beta$ for light non-standard Higgs A and H^+ to remain light.