Fine Tuning in the semi-constrained NMSSM

(soon in JHEP [arXiv:1107.2472])

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Content

Hierarchy Problem and Fine Tuning (Δ)

Measuring Fine Tuning (Δ) in SUSY models

(Barbieri & Guidice [Nucl. Phys. B 306 (1988) 63])

$$\Delta = Max\{\Delta_i^{GUT}\}$$

$$\Delta_i^{GUT} = \left| \frac{\partial \ln(M_Z)}{\partial \ln(p_i^{GUT})} \right| = \left| \sum_j \frac{\partial \ln(M_Z)}{\partial \ln(p_j^{SUSY})} \frac{\partial \ln(p_j^{SUSY})}{\partial \ln(p_i^{GUT})} \right|$$

with :

- p_i^{GUT} = GUT scale independent parameters
- p_i^{SUSY} = SUSY scale parameters obtained through RGEs

Little hierarchy problem / LEP II paradox

$$M_Z^2 \simeq -2\mu^2 + \frac{2(m_{H_d}^2 - \tan^2\beta m_{H_u}^2)}{\tan^2\beta - 1}$$ with $$m_{H_u}^2 \sim -\tilde{m}_{stop}^2$$

for $\tan^2\beta >> 1$ and $|m_{H_u}^2| \sim \mu^2$ large :

$$\Delta_{m_{H_u}}^{SUSY} \sim 2\frac{|m_{H_u}^2|}{M_Z^2} \sim \Delta_{\mu}^{SUSY} \sim 2\frac{\mu^2}{M_Z^2}$$

LEP II limit $M_{H_1} > 114.4$ GeV $\Rightarrow (\delta M_h^2)_{1\ loop} \propto \log(\frac{\tilde{m}_{stop}^2}{m_{top}^2})$ is large

Implies large Δ

CMSSM

FT computation

- Computation of Δ at two loop order with the code NMSPEC inside NMSSMTOOLs *(Ellwanger, Hugonie, Gunion [Comput. Phys. Commun. 177 (2007) 399 ; Comput. Phys. Commun. 175 (2006) 290 ; JHEP 02 (2005) 066])*

  using MCMC method and simulated annealing to minimize Δ.

- Experimental constraints considered :
  - LEP
  - B-physics
  - $(g-2)_\mu$

  We do not consider any constraints on the Dark Matter Relic Density.

CMSSM : input and FT parameters

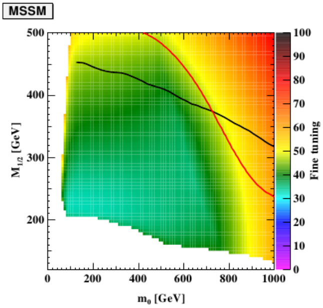
- CMSSM input parameters :
  - $M_{1/2},\ m_0,\ A_0,\ \tan\beta,\ sign(\mu)$

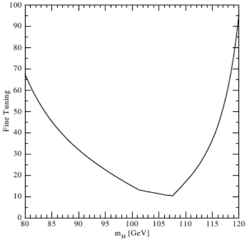
  The MSSM is obtained in the singlet sector decoupling limit of the NMSSM

- Parameters for the FT computation :
  - $p_i^{GUT} = M_{1/2}, m_0, A_0, \mu_0, B_0, h_t$
  - $p_i^{SUSY} = m_{H_u}, m_{H_d}, \mu, B, h_t$

CMSSM : results

Black Line = ATLAS $\sim 1\ fb^{-1}$ *[Atlas Note ATL-COM-PHYS-2011-981]*
Red Line = CMS $\sim 1\ fb^{-1}$ *[CMS Note CMS-PAS-SUS-11-003]*





- Considering LEP limits only : $\Delta_{min} \sim 33$
  $\frac{\partial \ln \mu^2}{\partial \ln \mu_0^2} \simeq 1 \quad \Rightarrow \quad \Delta_\mu^{SUSY} \simeq \Delta_\mu^{GUT}$ large
- Similar results in the litterature : *Cassel, Ghilencea, Ross 2010 Fig. 7d,e [Nucl. Phys. B835 (2010) 110-134]* (but Δ_{h_t} not considered)
- Considering LHC limits on m_{sq} and M_{gl} : $\Delta_{min} \sim 47$
  for $M_{1/2}$ and m_0 large $\Rightarrow$ $\Delta_{h_t}^{GUT}$ large
- $M_{H_1}(\Delta_{min}) \sim 107$ GeV without EWPT :

If the Higgs mass limit is lower then Δ is lower $\Rightarrow$ NMSSM

sNMSSM : defining the model

Gravity Mediated SUSY Breaking Z_3 invariant NMSSM with **non-universal singlet sector** :

$$W_{NMSSM\ (Z_3\ \text{invariant})} = \lambda S H_u.H_d + \frac{\kappa}{3} S^3 + h_t H_u.Q T_R^c + h_b H_d.Q B_R^c + h_\tau H_d.L \tau_R^c$$

$$-\mathcal{L}_{Soft} = \frac{1}{2}\left(M_1 \tilde{B}\tilde{B} + M_2 \sum_{i=1}^3 \tilde{W}^i \tilde{W}_i + M_3 \sum_{a=1}^8 \tilde{G}^a \tilde{G}_a \right) + h.c.$$
$$m_{H_u}^2 \|H_u\|^2 + m_{H_d}^2 \|H_d\|^2 + m_S^2 \|S\|^2 + m_Q^2 \|Q^2\| + m_T^2 \|T_R^2\| + m_B^2 \|B_R^2\| + m_L^2 \|L^2\| + m_\tau^2 \|\tau_R^2\|$$
$$\left(h_t A_t Q.H_u T_R^c + h_b A_b H_d.Q B_R^c + h_\tau A_\tau H_d.L \tau_R^c + \lambda A_\lambda H_u.H_d S + \frac{1}{3}\kappa A_\kappa S^3 \right) + h.c.$$

with :

$$\mu_{eff} = \lambda v_s \text{ (solving the MSSM } \mu \text{ problem)} \qquad B_{eff} = A_\lambda + \kappa v_s$$

sNMSSM input parameters :

- $M_{1/2},\ m_0,\ A_0,\ \tan\beta,\ \lambda,\ A_\kappa$

Parameters for the FT computation :

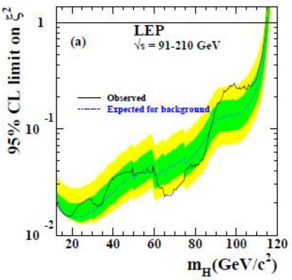
- $p_i^{GUT} = M_{1/2}, m_0, A_0, \lambda, \kappa, m_S, A_\kappa, h_t$
- $p_i^{SUSY} = m_{H_u}, m_{H_d}, m_S^2, A_\lambda, A_\kappa, \lambda, \kappa, h_t$

sNMSSM : scenarios

7 Higgs : $H_1, H_2, H_3, A_1, A_2, H^{\pm}$
$\Rightarrow H_1$ and χ_1^0 can have singlet and singlino components respectively
$\Rightarrow$ new phenomenology

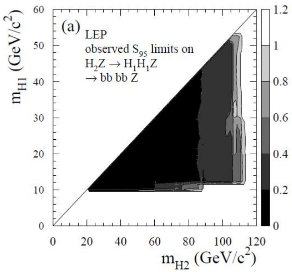
Scenarios :

1. **h/S mixing $\Rightarrow$ reduced coupling $g_{H_1 ZZ}$** $(BR(H_1 \to bb) > 0.7)$
2. **New Higgs to Higgs decays $\Rightarrow$ $H_1 \to A_1 A_1$** $(BR(H_1 \to A_1 A_1) > 0.2)$



[Phys. Lett. B565 (2003) 61]

$$\xi^2 = \left(g_{H_1 ZZ}/g^{SM}_{H_1 ZZ}\right)^2$$

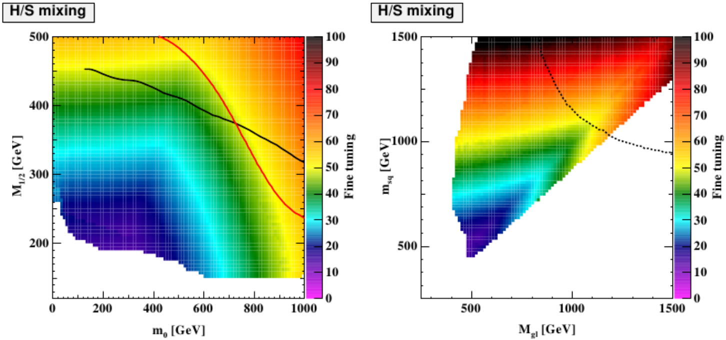


[Eur. Phys. J. C47 : 547-587 (2006)]

sNMSSM : Higgs mixing

Exclusion curves only indicative

⇒ **NMSSM's signals different = weaker bounds ! ! !**



- Considering LEP limits only : M_{H_1} constraints Δ ($\sim \Delta_\mu$)

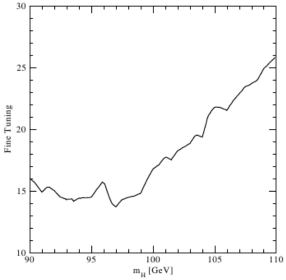
$$\Rightarrow \quad \Delta_{sNMSSM} \sim 10 < \Delta_{CMSSM}$$

- Considering LHC limits : $\tilde{m}^2_{stop}$ constraints Δ ($\sim \Delta_{h_t}$)

$$\Rightarrow \quad \Delta_{sNMSSM} \sim 44 \sim \Delta_{CMSSM}$$

Effect of LHC exclusions $\Rightarrow \Delta \propto M_{SUSY} - M_{EWSB}$

sNMSSM : Higgs mixing



(LHC constraints not applied for this curve)

- Shape of the curve given by the LEP constraint "ξ^2 versus M_{H_1}"
- Δ_{min} for $M_{H_1} \sim 97$ GeV $\Rightarrow$ correspond to the region of the LEP II 2.3σ excess
- **But now : $M_{H_1},_{min} \sim 110$ GeV with LHC constraints on m_{sq} and M_{gl}**

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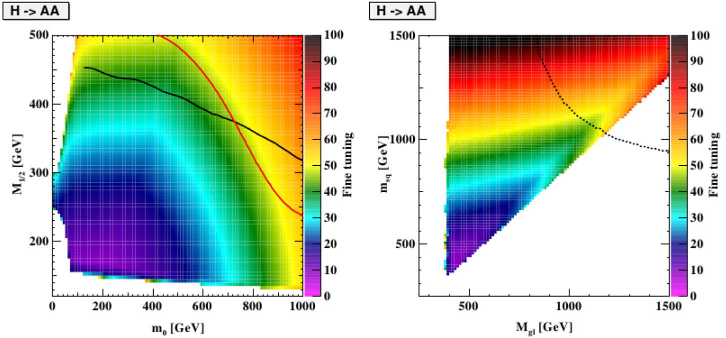
sNMSSM : $H_1 \to A_1 A_1$ sceanario



- Considering LEP limits only : M_{H_1} constraints Δ ($\sim \Delta_\mu$)

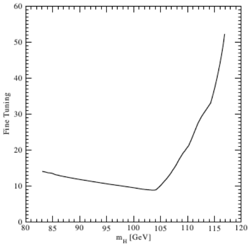
$$\Rightarrow \quad \Delta_{sNMSSM} \sim 9 < \Delta_{CMSSM}$$

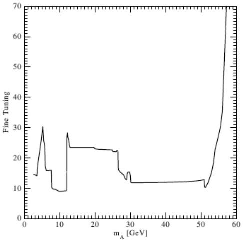
- Considering LHC limits : $\tilde{m}^2_{stop}$ constraints Δ ($\sim \Delta_{h_t}$)

$$\Rightarrow \quad \Delta_{sNMSSM} \sim 39 < \Delta_{CMSSM}$$

Effect of LHC exclusions $\Rightarrow \Delta \propto M_{SUSY} - M_{EWSB}$

sNMSSM : $H_1 \longrightarrow A_1 A_1$ sceanario





- $M_{H_1}(\Delta_{min}) \sim 105$ GeV
- Δ is constrained by $BR(H_1 \longrightarrow A_1 A_1)$ and thus by M_{A_1}
- **But now : $M_{H_1,\ min} \sim 114$ GeV with LHC constraints on m_{sq} and M_{gl}**

Different region in Δ vs M_{A_1} plane :

- $M_{A_1} \gtrsim 12$ GeV $\Rightarrow$ constraints $= H_1 \longrightarrow A_1 A_1 \longrightarrow 4b$
  - $12 \lesssim M_{A_1} \lesssim 30$ GeV $\Rightarrow$ constraints $= H_1 \longrightarrow A_1 A_1 \longrightarrow 4b$ strong
  - $30 \lesssim M_{A_1} \lesssim 57$ GeV $\Rightarrow \Delta$ minimum
  - $M_{A_1} \gtrsim 57$ GeV $\equiv M_{H_1} > 2M_{A_1} > 114$ GeV $\Rightarrow$ increase of Δ
- $M_{A_1} \lesssim 11$ GeV $\Rightarrow$ constraints $= H_1 \longrightarrow A_1 A_1 \longrightarrow 4\tau$
  - $9 \lesssim M_{A_1} \lesssim 11$ GeV $\Rightarrow$ not constrained because of $A_1 - \eta_b$ mixing
  - $M_{A_1} \lesssim 9$ GeV $\Rightarrow H_1 \longrightarrow A_1 A_1 \longrightarrow 4\tau$ and $B_S \longrightarrow \mu^+\mu^-$

Conclusions and Outlook

Conclusions

- LHC results excludes large part of the minimal FT regions of the CMSSM and sNMSSM
- Δ is no more constrained by LEP limits on M_{H_1} but by LHC limits on m_{sq} and M_{gl}
- Little differences CMSSM and sNMSSM, althought LHC M_{gl} and m_{sq} exclusion curves only indicative for sNMSSM $\Rightarrow \Delta_{sNMSSM} \lesssim \Delta_{CMSSM}$

Outlook

Other ways to reduce Δ (escape the LHC constraints on m_{sq} and M_{gl})

- Lowering Λ_{SUSY} and/or Λ_{GUT} (ex. : GMSB models)
- Giving up on universality conditions at $\Lambda_{messenger}$
- Introduce relations between some p_i^{GUT} (and a model to justify this)

More experimental studies on the sNMSSM phenomenology ?