NMSSM parameters compatible with LEP constraints on the Higgs mass

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Motivation

We focused on the phenomenology of the NMSSM and the learning and usage of the NMSSMTools package.

The questions are:

- what is the role of the phenomenological constraints in the allowed parameter space of the NMSSM?
- could the "mapping" of the allowed parameter space give us information about how to solve the so-called "little fine-tuning" problem?

But firstly we need to introduce...

Standard Model: open issues and the “cure”

The Standard Model augmented by neutrino masses provides a beautiful description of known phenomena, nevertheless:

- it does not explain the dark matter relic density
- it is affected by the “hierarchy problem”
- it does not provide a satisfying unification picture

For this, an elegant solution has been proposed:

Supersymmetry!

$$Q|F\rangle = B, \qquad Q|B\rangle = F.$$

MSSM: open issues and a possible solution

The supersymmetric extension of the Standard Model with a minimal field content in the Higgs sector is denoted as Minimal Supersymmetric Standard Model (MSSM).

Unfortunately the MSSM itself contains two problems:

- the "μ-problem"
- the "little hierarchy problem"

A (next to) elegant solution has been proposed:

Next to MSSM

$$\Downarrow$$

$$\mu_{eff} = \lambda\langle\hat{S}\rangle$$

Next to MSSM: the Higgs sector

The scalar superpotential is:

$$W = \lambda \hat{S}\hat{H}_u \cdot \hat{H}_d + \frac{k}{3}\hat{S}^3,$$

from which one could obtain the Higgs potential (in combination with the soft SUSY breaking terms).

H-potential is specified by 6 parameters:

- $\tan\beta = v_u/v_d$, λ, κ
- μ_{eff}, A_λ, A_κ ($\mathcal{L}_{soft} = [\ldots] - \lambda A_\lambda H_u \cdot H_d S - \frac{1}{3}\kappa A_\kappa S^3$)

Three CP-even Higgs: S (singlet), h (SM-like), H (decoupled).

SHEP Southampton High Energy Physics

Little fine-tuning in the MSSM

The "Stop/top" induced quantum corrections to the SM-like Higgs mass are necessary in order to lift the m_h above the LEP bound, and this calls for a large $tan\beta$ and large soft SUSY breaking "stop" mass (and/or a large "stop" trilinear coupling).

Such "stop" masses induce negative soft Higgs mass terms of the order of 1 TeV via the Renormalisation Group Equations.

A Higgs vev of 1 TeV would be natural! In order to scale it down to ~ 170 GeV a tuning between the soft Higgs mass terms and the μ-parameter (both squared) of the order of $\sim 1\%$ is required.

The NMSSM offers another theoretical scenario that mitigates the problem...

Little fine-tuning in the NMSSM

At the tree level, the MSSM choice implies:

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \qquad + \\ + \frac{3m_t^4}{4\pi^2 v^2}\left(\ln\left(\frac{m_T^2}{m_t^2}\right) + \frac{A_t^2}{m_T^2}\left(1 - \frac{A_t^2}{12 m_T^2}\right)\right).$$

This leads to:

- a positive contribution (for low $\tan\beta$)
- "negative" consequences from the S-h mixing

Negative consequences are possible both for $m_S > m_h$ and $m_S < m_h$.

Little fine-tuning in the NMSSM

At the tree level, the NMSSM choice implies:

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta - \frac{\lambda^2}{\kappa^2} v^2 \left(\lambda - \kappa \sin 2\beta\right)^2 + + \frac{3m_t^4}{4\pi^2 v^2}\left(\ln\left(\frac{m_T^2}{m_t^2}\right) + \frac{A_t^2}{m_T^2}\left(1 - \frac{A_t^2}{12 m_T^2}\right)\right).$$

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S heavier than h

The hierarchy between two eigenvalues of a 2×2 matrix is increased by a symmetrical off-diagonal perturbative contribution:

$$\begin{pmatrix} a & \\ & b \end{pmatrix} \Rightarrow \lambda_1 = \mathrm{Min}(a, b)$$

λ_1 decreases with increasing c^2.

If S is heavier than h then the m_h^2 is decreased by the mixing effect (through a term that is proportional to λ^2).

Not good for the little fine-tuning solution!

S heavier than h

The hierarchy between two eigenvalues of a 2×2 matrix is increased by a symmetrical off-diagonal perturbative contribution:

$$\begin{pmatrix} a & c \\ c & b \end{pmatrix} \Rightarrow \lambda_1 = \mathrm{Min}(a,b) - c^2|f(a,b,c)|$$

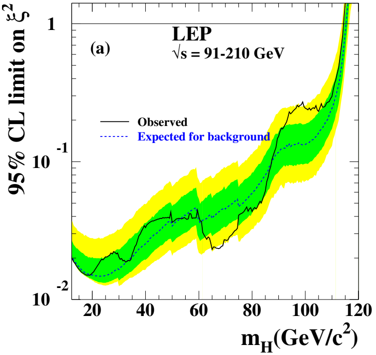
λ_1 decreases with increasing c^2.

If S is heavier than h then the m_h^2 is decreased by the mixing effect (through a term that is proportional to λ^2).

Not good for the little fine-tuning solution!

S lighter than h

S is always lighter than 120 GeV, and typically below 114 GeV!



S-h mixing induces a doublet component for SM-Higgs like state, not compatible with the "singlet"-ness required by LEP.

Not good for the little fine-tuning solution!

NMSSMTools

NMSSMtools: set of tools for the calculation of the Higgs and sparticle spectrum in the NMSSM (U. Ellwanger, J. F. Gunion and C. Hugonie, JHEP **0502** (2005) 066).

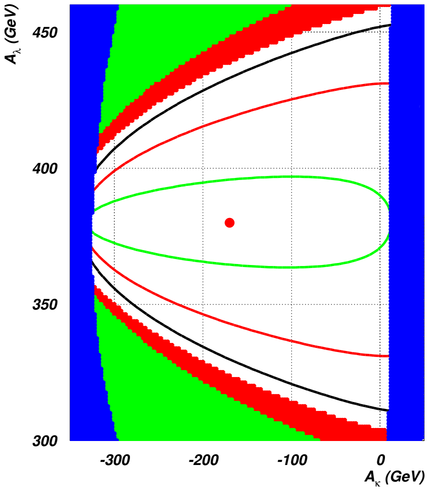
We made a grid-scan over some interesting portion of the NMSSM parameter space in order to understand how the fine-tuning enters in the "game" in the comparison between the LEP excluded regions and the LEP allowed regions.

Starting from a "safe" choice of the parameters:

- λ, κ within an IR quasi-fixed point region
- low $stop$ and μ_{eff} masses

we tried to answer the question: what is the range of the NMSSM parameters in which the positive effects of λ are more important than the negative effects of the S-h mixing?

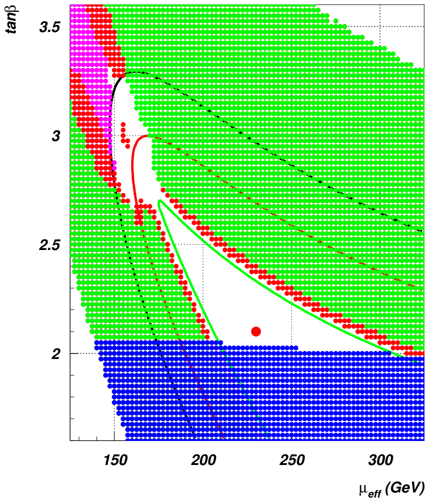
Allowed parameter space: A_λ-A_κ (1)



$\tan\beta = 2.1$
$\mu_{eff} = 230$ GeV
$\kappa = 0.3$
$\lambda = 0.64$

Contour for m_h:
115 GeV, black line
117 GeV, red line
119 GeV, green line.

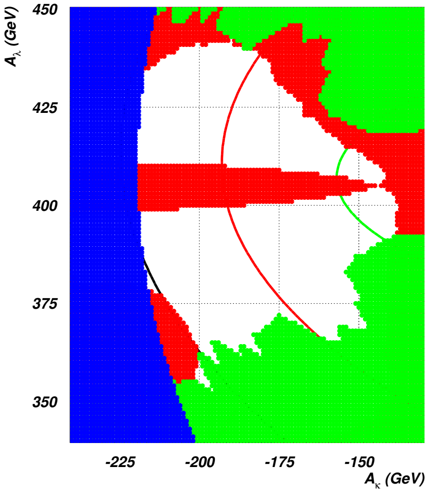
Allowed parameter space: $\tan\beta$-μ_{eff}



$A_\lambda = 380$ GeV
$A_\kappa = -170$ GeV
$\kappa = 0.3$
$\lambda = 0.64$

Contour for m_h:
85 GeV, black line
100 GeV, red line
115 GeV, green line.

Allowed parameter space: A_λ-A_κ (2)



$\tan\beta = 3$
$\mu_{eff} = 165$ GeV
$\kappa = 0.3$
$\lambda = 0.64$

Contour for m_h:
85 GeV, black line
97.5 GeV, red line
110 GeV, green line.

Conclusions

- √ Two separated allowed regions in the $tan\beta$-μ_{eff} plane related to two "different" light CP-even Higgs: a singlet-like (low μ_{eff}, high $tan\beta$) with 85 GeV$< m_h < 114$ GeV and a doublet-like (high μ_{eff}, low $tan\beta$) with 114 GeV$< m_h < 120$ GeV.
- √ A light singlet-like Higgs is part of the "natural" allowed parameter space; it would also explain the $2.3\ \sigma$ bump at LEP.
- √ If p denotes any of the parameters that we varied in the allowed region then $\Delta p/p \sim 10\%$, hence the little fine-tuning problem is less severe.

Work in progress

- More investigation is needed: we did not go any further than the preliminary level of analysis (short time)! The final goal is to “map” the whole parameter space.

- The implementation of the fine-tuning evaluation has not (yet) be done in NMSSMTools (Work in progress).

- The study of the possible impact on the phenomenology and the implications both in particle and cosmology experiments is in progress.

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