mH = 125 GeV and a light stop in the NMSSM

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The NMSSM

In terms of the superpotential:

$$W_{MSSM} = \mu H_u H_d + \ldots \rightarrow W_{NMSSM} = \lambda S H_u H_d + \frac{\kappa}{3} S^3 + \ldots$$

The simplest supersymmetric extension of the Standard Model with scale invariant supersymmetric interactions (no "μ"-problem)

All nice features of the MSSM are preserved: Solution of the hierarchy problem, unification of gauge couplings, LSP as possible dark matter

Now:
3 neutral CP-even Higgs bosons, mixtures of H_u, H_d and S
2 neutral CP-odd Higgs bosons
5 neutralinos, mixtures of the bino, wino, and the fermionic components of H_u, H_d (higgsinos) and S (singlino)

Recall: MSSM:

Typically: one light SM-like state $h \sim H_{SM}$ with $M_h \lesssim 130$ GeV
(BUT: $M_h \sim 125$ GeV only if $M_{susy} \gtrsim$ TeV, large A_{top}, large finetuning...)
One heavy state H

NMSSM: Typically: one heavy state H, but
possibly strong mixings among $h \sim H_{SM}$ and S

A state near 125 GeV can be the lighter or the heavier eigenstate in the $(H_{SM} - S)$ sector

$\longrightarrow$ If the state near 125 GeV is the second lightest state H_2, H_1 must and can easily comply with LEP constraints:
$M_{H_1} < 114$ GeV: reduced couplings to Z, or $114 < M_{H_1} < 125$ GeV

(J. F. Gunion, Y. Jiang and S. Kraml: H_1 and H_2 can be nearly degenerate)

It is known since 2011 that the pNMSSM (with parameters defined at the weak scale) can easily accomodate a 125 GeV Higgs boson and a $\gamma\gamma$ signal rate above the one of a SM Higgs boson

And if universal soft Susy breaking terms at the GUT scale are imposed? J. F. Gunion, Y. Jiang and S. Kraml (small λ, near the MSSM-limit, small $h-S$ mixing): a 125 GeV Higgs boson is possible if universality is relaxed in the Higgs sector (like NUHM in the MSSM, here: "sNMSSM"), but not an enhanced $\gamma\gamma$ signal rate

U. E., C. Hugonie (1203.5048): In the sNMSSM for large λ, large $h-S$ mixing can easily lead to a 125 GeV Higgs boson, a $\gamma\gamma$ signal rate above the one of a SM Higgs boson, for parameters complying with a good dark matter relic density

As before: the 125 GeV Higgs boson is H_2!

Results of a scan over the parameter space of the sNMSSM:

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

Imposing 124 GeV $< M_{H_2} <$ 127 GeV and $\sigma_{obs}^{\gamma\gamma}(H_2)/\sigma_{SM}^{\gamma\gamma} > 1$:

$0.41 < \lambda < 0.69$, $\quad 0.21 < \kappa < 0.46$, $\quad 1.7 < \tan\beta < 6$

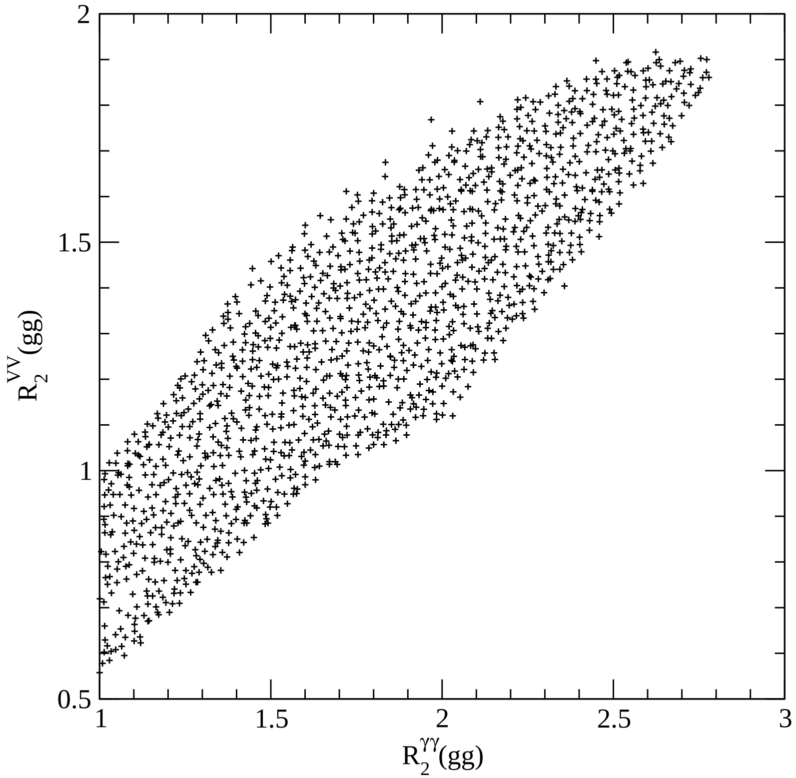
Constraints on H_1 and H_3 from LEP + LHC, constraints from B-physics, constraints from WMAP on the dark matter relic density, from XENON100 on the dark matter direct detection cross section are satisfied
(But: the Susy contribution to $(g-2)_\mu$ is small since $\tan\beta$ is small)
Using MicrOmegas inside NMSSMTools

Study $R = \frac{\text{production cross section} \times BR}{\text{production cross section} \times BR_{SM}}$ in various channels

Reduced signal cross sections R_2 for H_2 with $M_{H_2} \sim 125$ GeV:

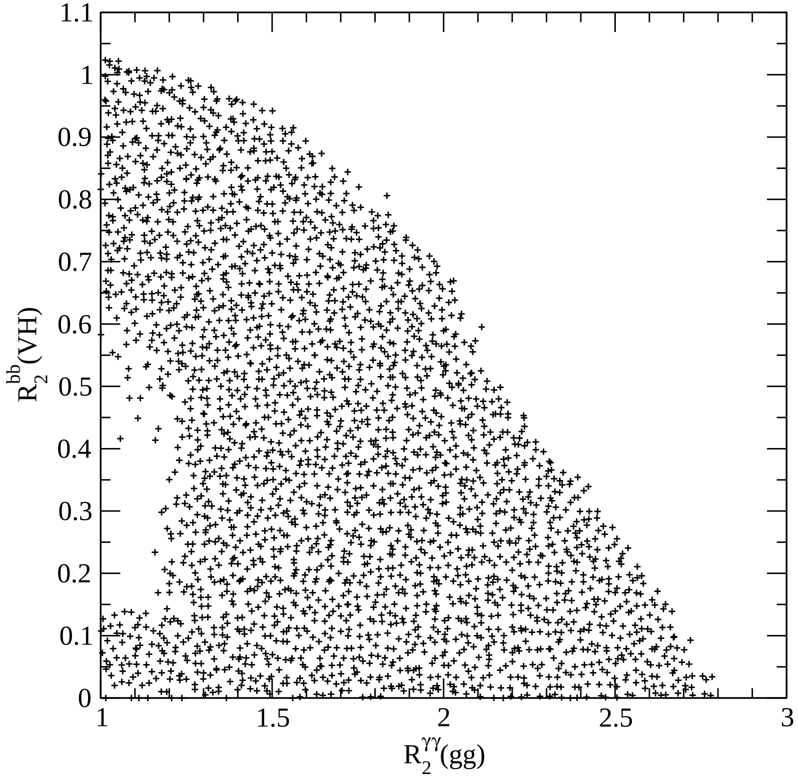
Would an enhanced $R_2^{\gamma\gamma}$ be compatible with a reduced $R_2^{VV}(gg)$?

$(V = W, Z)$



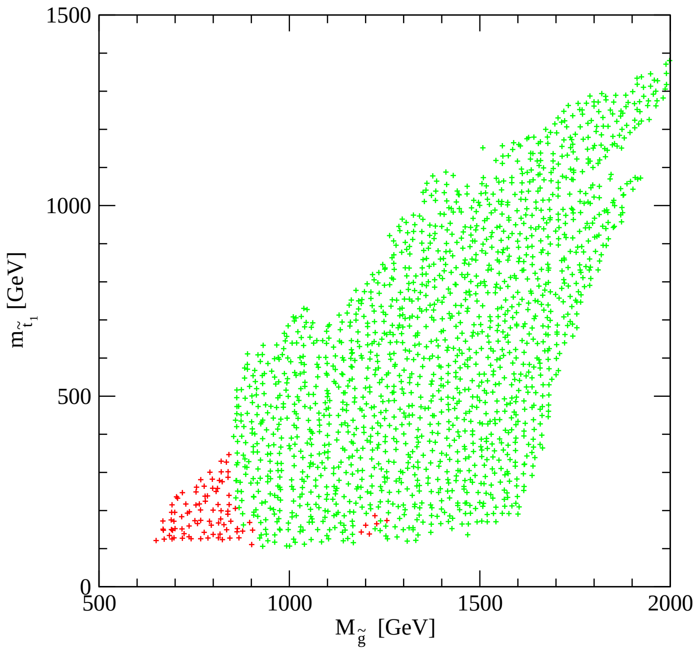
Yes, if $R_2^{\gamma\gamma} \lesssim 1.5$

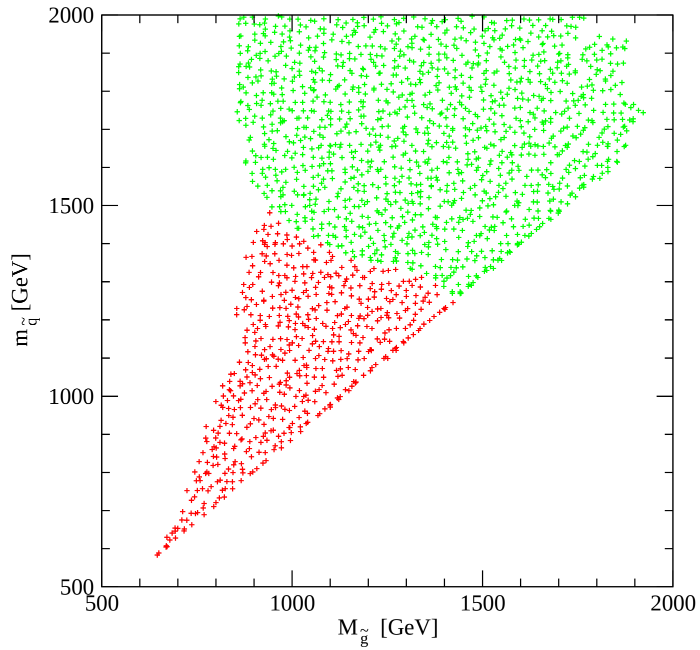
Would an enhanced $R_2^{\gamma\gamma}$ imply a reduced $R_2^{b\bar{b}}$(VH)
(associate production $W/Z + H_2$ with $H_2 \to b\bar{b}$, as at the Tevatron)?



Not necessarily! $R_2^{\gamma\gamma} \sim 1.5$ implies just $R_2^{b\bar{b}}(\mathrm{VH}) \lesssim 0.95$

Stop$_1$, squark and gluino masses:





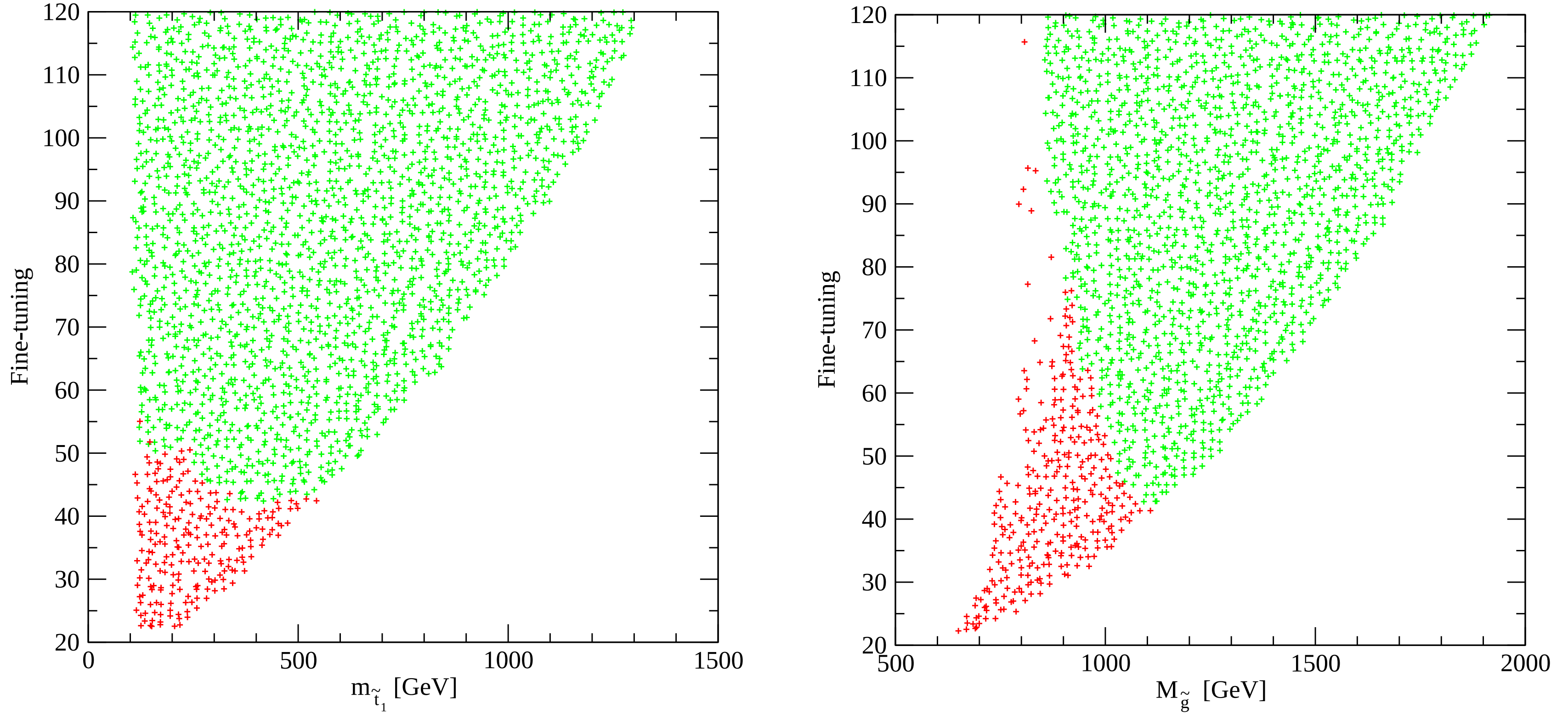
The green points satisfy CMSSM-like constraints in the $m_0, M_{1/2}$ plane from CMS which, however, do not have to hold in the NMSSM

The red points would be forbidden in the CMSSM

The Stop$_1$ can be very light due to the low values of $\tan\beta$ ($\rightarrow$ large h_t, which affects the RGEs for the soft susy breaking stop masses)

In the cMSSM/NUHM with $M_h \sim 125$ GeV, the finetuning is of $\mathcal{O}(10^3)$ (D. M. Ghilencea, H. M. Lee and M. Park, arXiv:1203.0569)

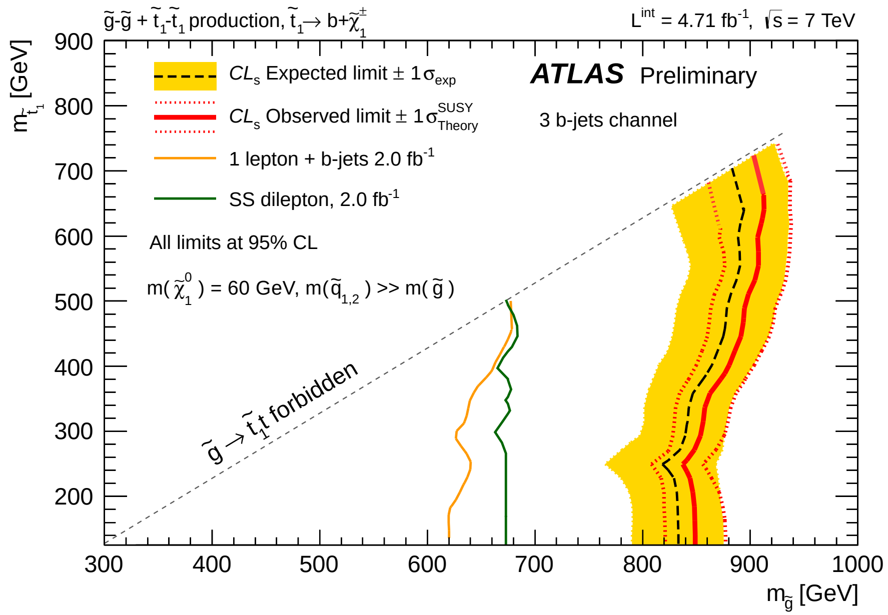
Fine-tuning as a function of $m_{\tilde{t}_1}$ (left panel) and $M_{\tilde{g}}$ (right panel) in the sNMSSM:



$\longrightarrow$ At least an order of magnitude better than in the cMSSM, below 50 if $M_{gluino} \lesssim 1.3$ TeV, $M_{stop_1} \lesssim 700$ GeV

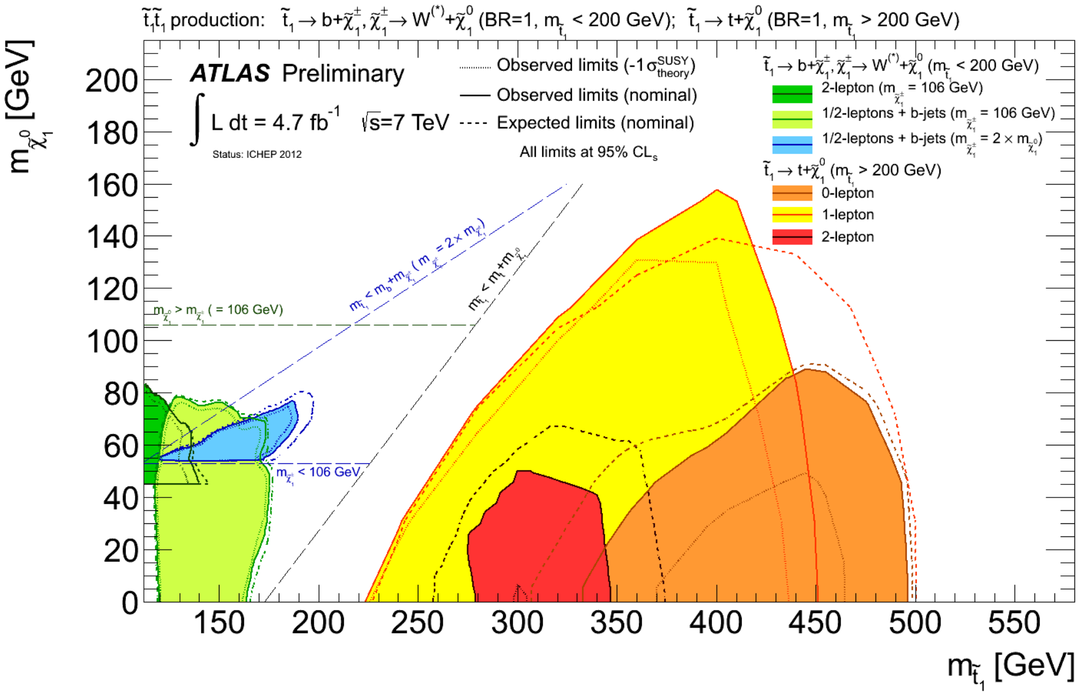
Present constraints on light stops:

From $\tilde{g} \to t + \tilde{t}_1 \to t + b + \chi_1^+ \to t + b + W + \chi_1^0 \to 2b + 2W + \chi_1^0$:



$\longrightarrow M_{gluino} \gtrsim 850$ GeV

From stop pair production:



Here: $M_{\chi_1^0} \sim 60 - 80$ GeV $\longrightarrow$ $170 \lesssim M_{stop1} \lesssim 230$ GeV or $500 \lesssim M_{stop1}$

Conclusions

— The sNMSSM can naturally accomodate a Higgs boson in the $124-127$ GeV mass range, explain excesses in the $\gamma\gamma$ channel and, due to the extended Higgs sector, potential excesses at other values of the Higgs mass.

— Requiring a visible signal rate in the $b\bar{b}$ channel of 0.95 times the SM value still allows for a signal rate in the $\gamma\gamma$ channel about 1.5 as large as the one of a SM-like Higgs boson

— The fine-tuning with respect to parameters at the GUT scale remains modest, an order of magnitude below the one required in the MSSM, provided $170 \gtrsim M_{stop1} \gtrsim 230$ GeV and $M_{gluino} \gtrsim 850$ GeV which is consistent with present constraints!