A Higgs Boson near 125 GeV in the NMSSM

U. Ellwanger, LPT Orsay

Motivation

Recall: MSSM: SM particles + sparticles + soft Susy breaking terms (Masses for scalars + gauginos) of $\mathcal{O}(M_{susy})$
$\to$ Higgs vevs of $\mathcal{O}(M_{susy}) \sim M_{weak}$

BUT: Need a Higgsino mass term $\mu\, \psi_{H_u}\psi_{H_d}$, with $|\mu| \gtrsim 100$ GeV which is a priori NOT of $\mathcal{O}(M_{susy})$ (NOT a soft Susy breaking term)

Simplest origin of μ: Introduce a gauge singlet superfield S, and a Yukawa coupling $\lambda\, S\, \psi_{H_u}\psi_{H_d}$ with $\langle S\rangle \sim \mathcal{O}(M_{susy})$ from soft Susy breaking terms
$\to \mu_{eff} = \lambda\, \langle S\rangle$;

NMSSM: $W_{MSSM} = \mu H_u H_d + \ldots \to W_{NMSSM} = \lambda S H_u H_d + \frac{\kappa}{3} S^3 + \ldots,$
the simplest Susy extension of the SM with scale invariant supersymmetric interactions

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

Recall: MSSM: 2 neutral CP-even Higgs bosons, mixtures of H_u and H_d
Typically: one light SM-like state $h \sim H_{SM}$ with $M_h \lesssim 130$ GeV
($M_h \gtrsim 125$ GeV only if $M_{susy} \approx$ TeV), 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 eigenstate in the ($H_{SM} - S$) sector (which requires a suppression of the mixing), or the heavier eigenstate (which is very natural in the parameter space)

$\longrightarrow$ The state near 125 GeV would be the second lightest state H_2,
the lightest state H_1 has to satisfy constraints from LEP:
if $M_{H_1} \lesssim 114$ GeV, H_1 must have reduced couplings to Z

Possible impact on the branching ratios of H_2:

Recall:

$$BR(H_2 \to \gamma\gamma) = \frac{\Gamma(H_2 \to \gamma\gamma)}{\Gamma(H_2 \to bb) + \ldots}$$

where the dots denote $\Gamma(H_2 \to gg)$, $\Gamma(H_2 \to WW^*)$, ...
($< \Gamma(H_2 \to bb)$ for $H_2 \sim H_{SM}$)

$\longrightarrow$ If $\Gamma(H_2 \to bb)$ is (strongly) reduced due to the mixing, the $BR(H_2 \to \gamma\gamma)$ is (strongly) enhanced!

This effect can compensate a somewhat smaller H_2 production cross section due to the $h - S$ mixing, and lead to an enhanced signal rate in the $\gamma\gamma$ channel for H_2 production both via gg fusion and VBF

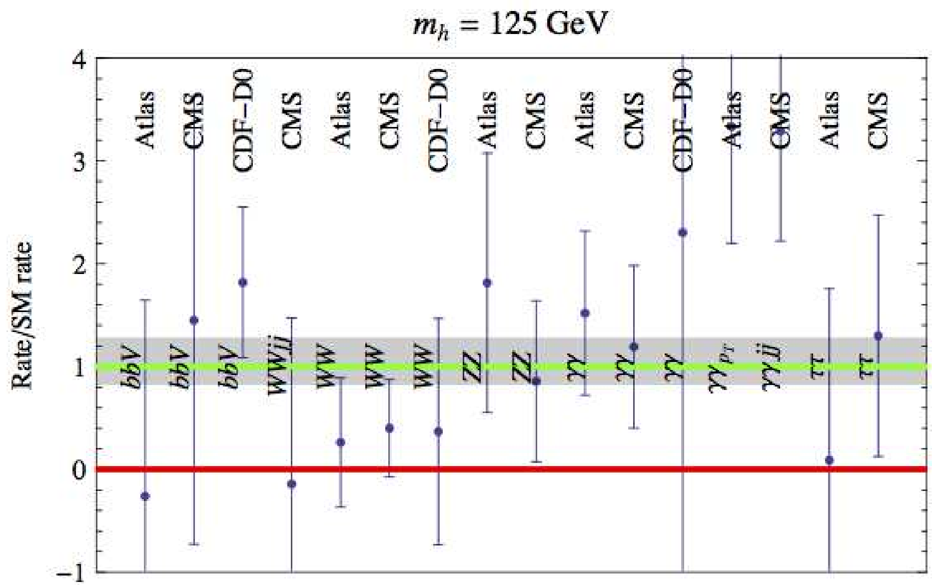
Note:

$$BR(H_2 \to bb) = \frac{\Gamma(H_2 \to bb)}{\Gamma(H_2 \to bb) + \ldots}$$

remains large as long as $\Gamma(H_2 \to bb)$ remains dominant

$\longrightarrow$ Consistent with a Higgs signal in the bb channel at the Tevatron

Higgs boson properties from the LHC and Tevatron data, from Giardino, Kannike, Raidal, Strumia, arXiv:1203.4254 (relative to a SM Higgs boson)



Cannot discuss all details here, but:

– the bb signal rate (production cross section $\times$ BR, $\equiv \tau\tau$ signal rate here) seems compatible with the SM expectation

– the WW signal rate ($\equiv ZZ$ signal rate here) may be somewhat below the SM expectation,

– the $\gamma\gamma$ signal rate is systematically above the SM expectation

It has been noticed by L. J. Hall, D. Pinner and J. T. Ruderman; U. E.; S. F. King, M. Muhlleitner and R. Nevzorov; J. Cao, Z. Heng, J. M. Yang, Y. Zhang and J. Zhu, 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: 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 $\sigma^{\gamma\gamma}_{obs}(H_2)/\sigma^{\gamma\gamma}_{SM} > 1$:

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

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, and from stop searches at the Tevatron and the LHC (see below) 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, as function of the lighter M_{H_1}:

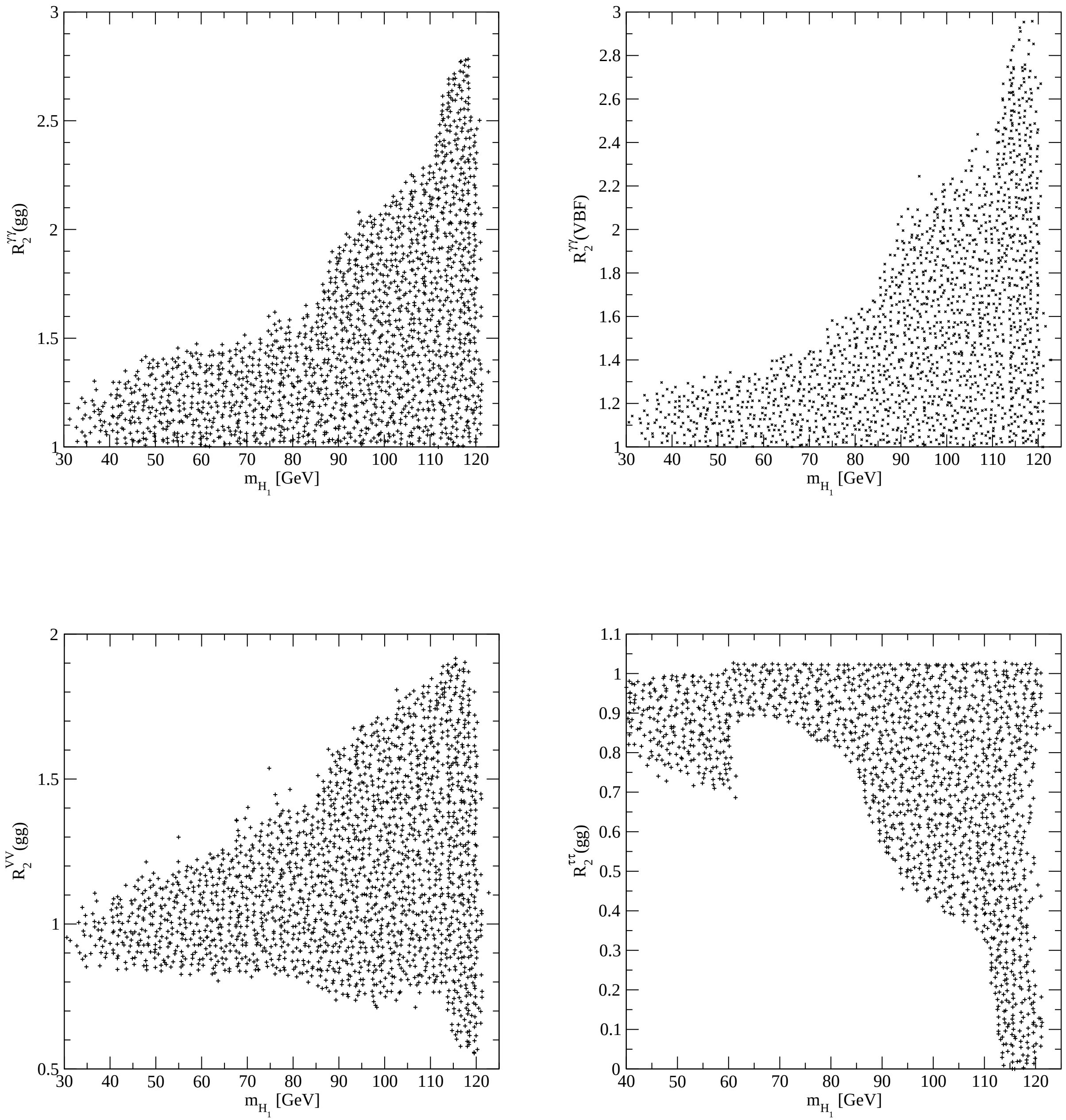
upper left: $R_2^{\gamma\gamma}(gg)$
(H_2 via gluon fusion)

upper right: $R_2^{\gamma\gamma}$(VBF)
(H_2 via VBF)

Enhancement up to
a factor 3,
if M_{H_1} close to 120 GeV!

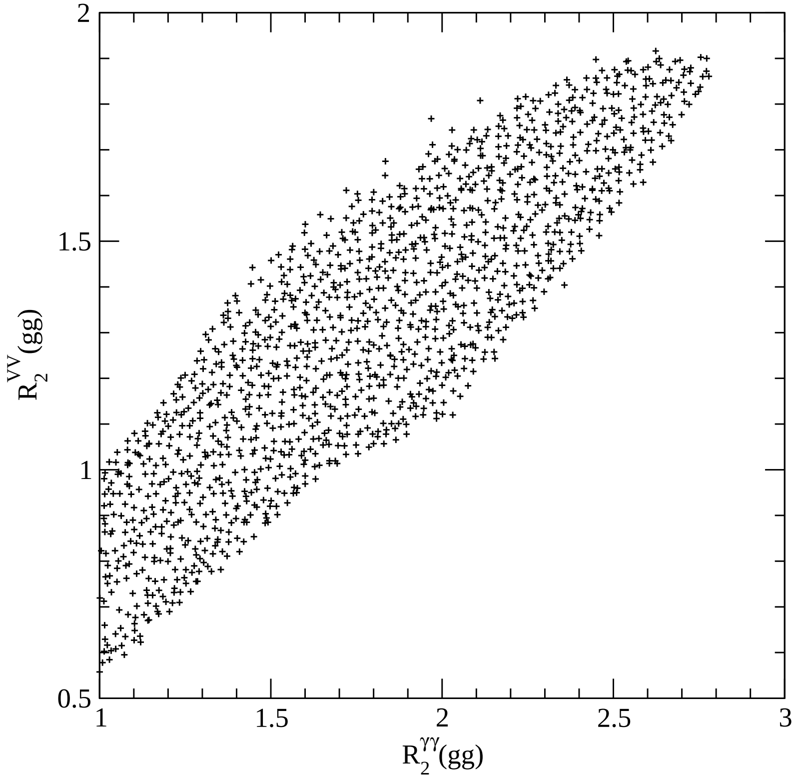
lower left: $R_2^{VV}(gg)$
(ZZ, WW, H_2 via gg fusion)
Varies from 0.5 to 1.8,
if M_{H_1} close to 120 GeV

lower right: $R_2^{\tau\tau}$(VBF)
($\tau\tau$ channel,
H_2 production via VBF)
Never enhanced



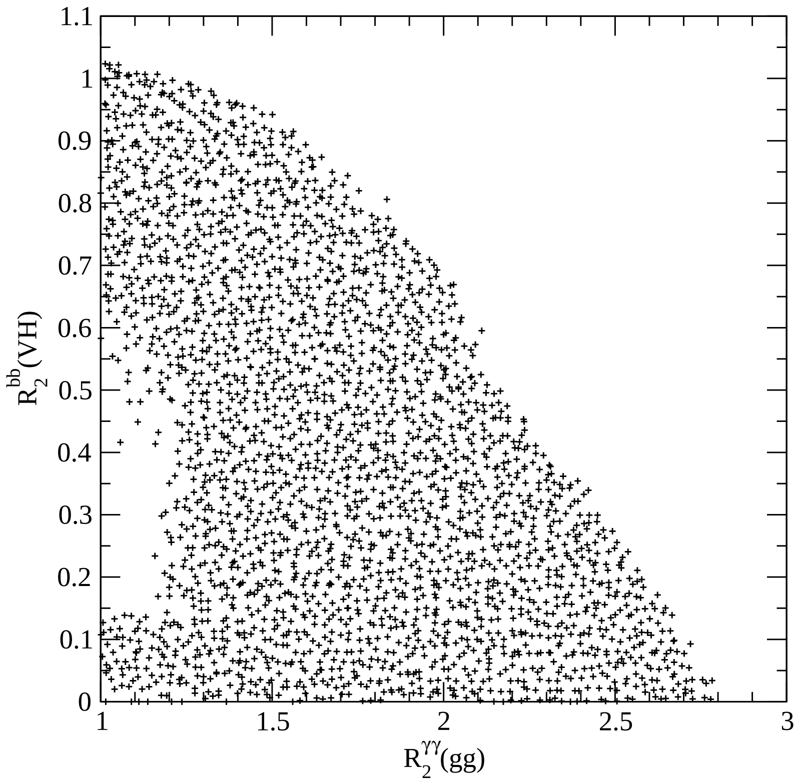
Would an enhanced $R_2^{\gamma\gamma}$ be compatible with a reduced $R_2^{VV}(gg)$?

$(V = W, Z)$



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 $R_2^{b\bar{b}}(\text{VH}) \lesssim 0.95$

Would H_1 be visible?
Reduced signal cross sections R_1 for H_1 as function of M_{H_1}:

upper left: $R_1^{\gamma\gamma}(gg)$
(H_1 via gluon fusion)

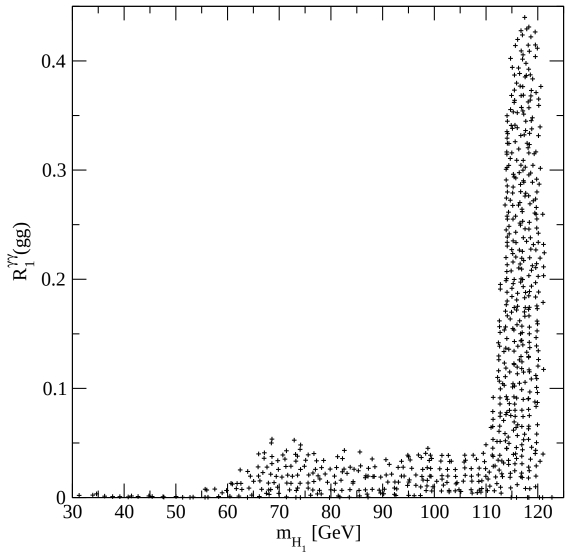
upper right: $R_1^{\gamma\gamma}$(VBF)
(H_1 via VBF)

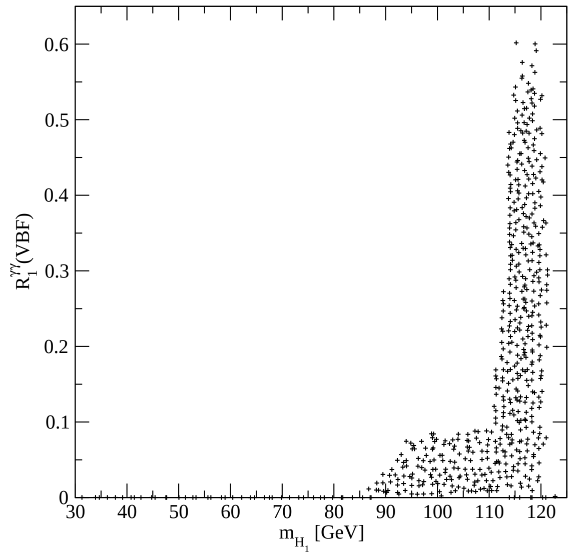
$R_1^{\gamma\gamma}$ up to ~ 0.5,
but only if $M_{H_1} \gtrsim 114$ GeV!

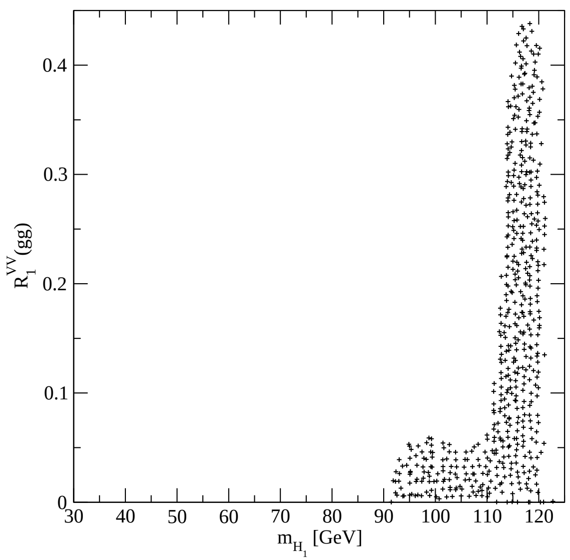
lower left: $R_1^{VV}(gg)$
(ZZ, WW, H_1 via gg fusion)

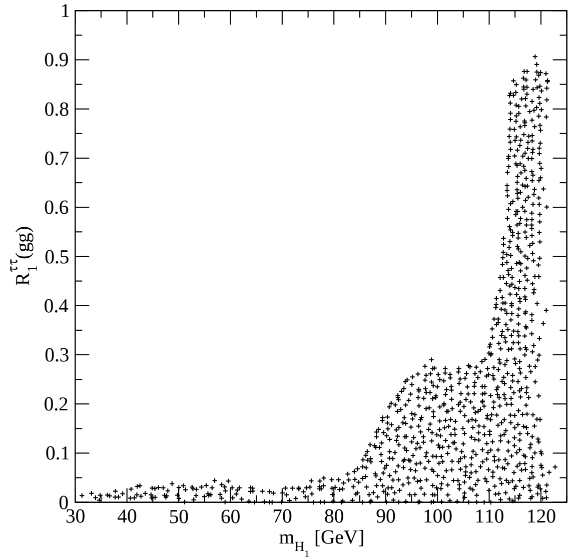
lower right: $R_1^{\tau\tau}$(VBF)
($\tau\tau$ channel,
H_1 production via VBF).

$R_1^{\tau\tau}$(VBF) up to ~ 0.9,
but only if $M_{H_1} \gtrsim 114$ GeV!

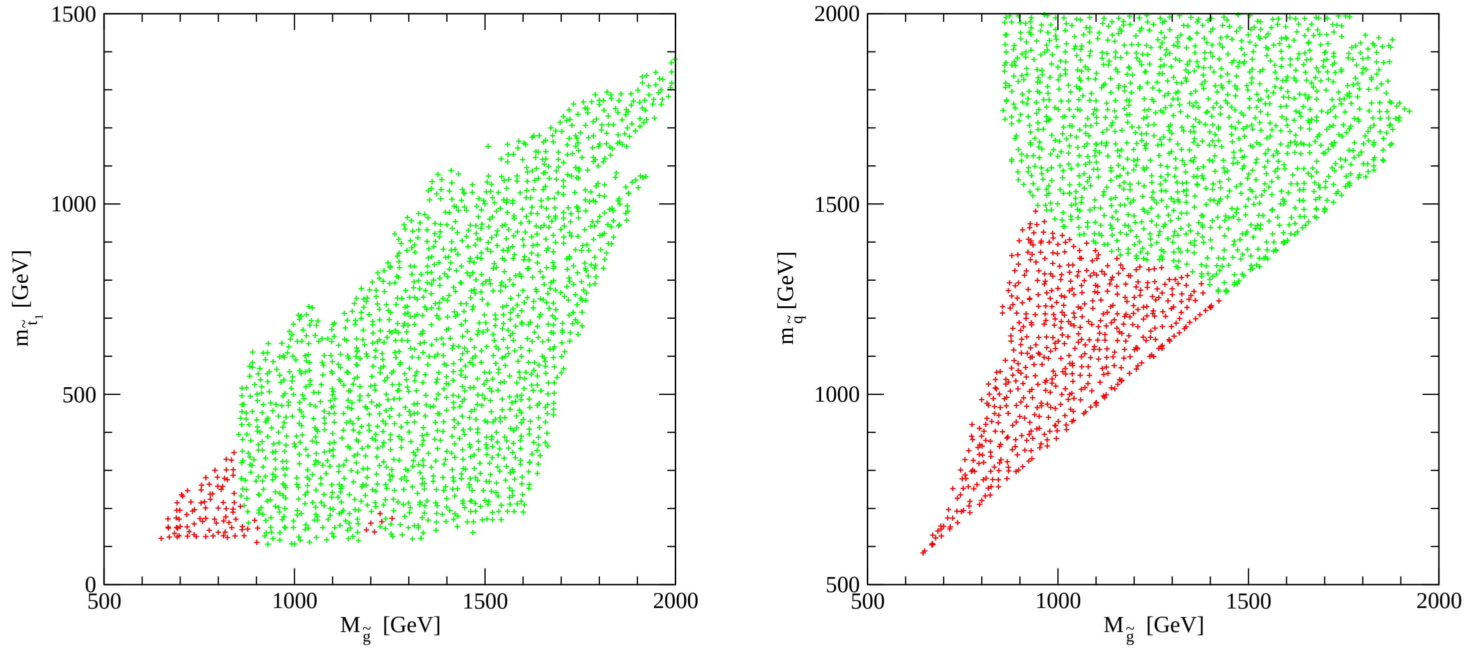








Stop$_1$, squark and gluino masses:

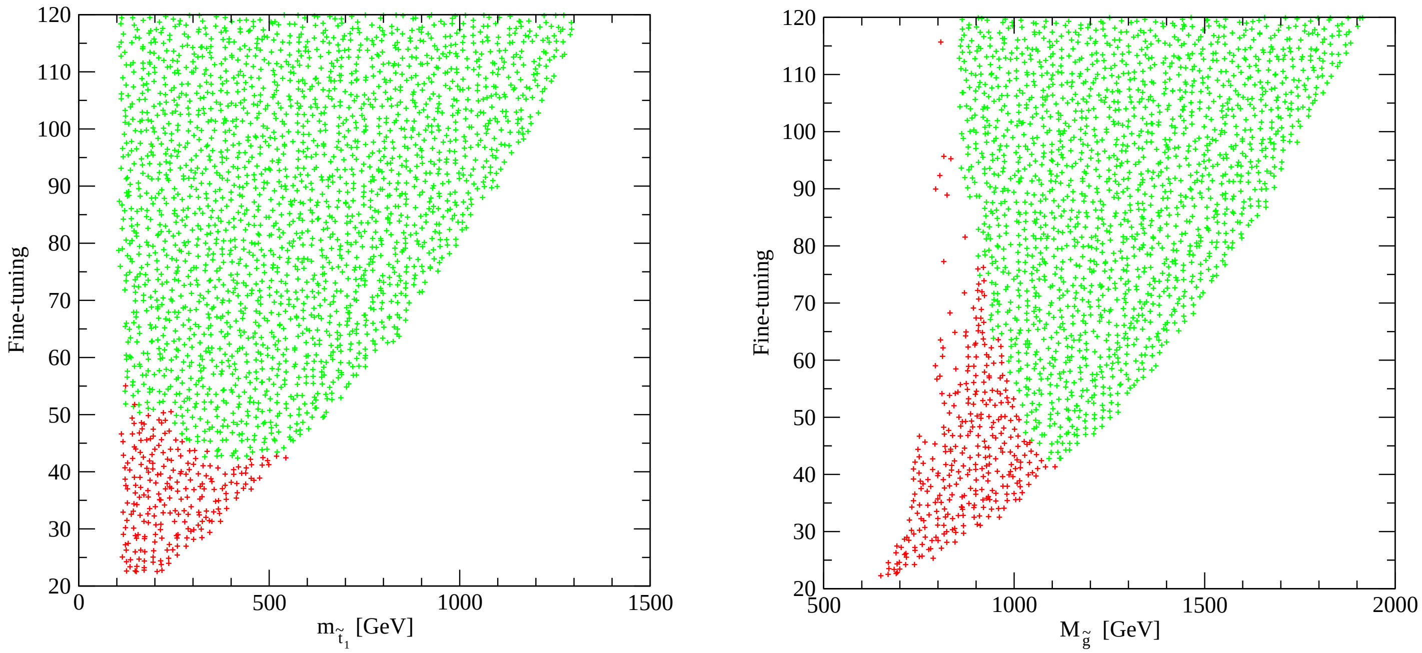


The Stop$_1$ can be very light due to the low values of $\tan\beta$ ($\rightarrow$ large h_t, which affects the RGEs for the soft susy breaking stop masses)

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 (see the talk by Debottam Das).

The red points satisfy only constraints from stop/chargino searches.

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)

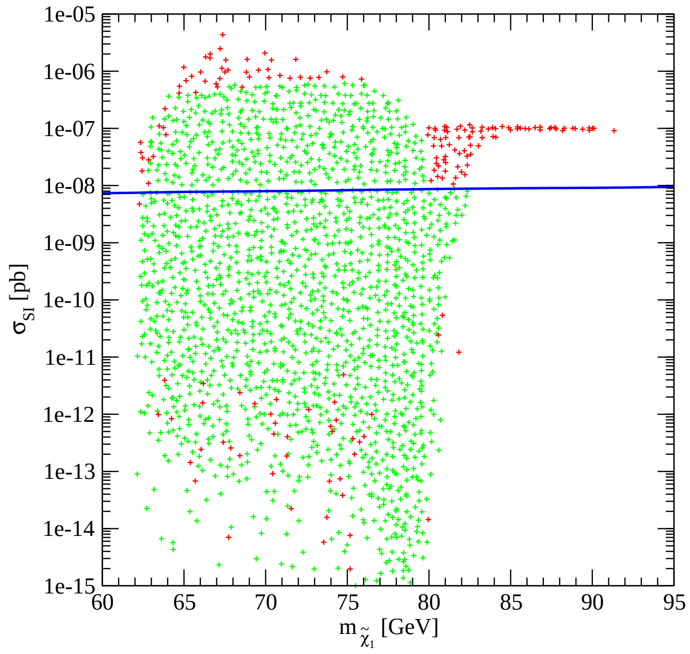


Fine-tuning as a function of $m_{\tilde{t}_1}$ (left panel) and $M_{\tilde{g}}$ (right panel) in the sNMSSM

$\longrightarrow$ At least an order of magnitude better than in the cMSSM!

Note: All points have a dark matter relic density complying with WMAP constraints. In general, the LSP χ_1^0 is a strong mixture of singlino, higgsino, bino and wino with a mass of $60 - 80$ GeV

What about its direct detection?



The spin-independent χ_1^0-proton scattering cross section $\sigma^{si}(p)$ as function of $M_{\chi_1^0}$. The blue line indicates the upper bound from XENON100. (Points above this line had not been included in the previous plots.)

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. In particular:

— The signal rate in the $\gamma\gamma$ channel can be 2.8 as large as the one of a SM-like Higgs boson, provided the mass of the lighter CP-even state H_1 is in the $115-123$ GeV range

— Requiring a visible signal rate in the $b\bar{b}$ channel of 0.9 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 lighter CP-even state H_1 could explain a mild excess of events around $95-100$ GeV observed at LEP, or a second Higgs boson above ~ 114 GeV visible at the LHC

— The mass of the lightest stop can be as small as 105 GeV, complying with present constraints for $M_{\tilde{g}} \gtrsim 640$ GeV;

— The fine-tuning with respect to parameters at the GUT scale remains modest, an order of magnitude below the one required in the MSSM;

— The eigenstates in the neutralino sector are strongly mixed, and the lightest neutralino can have a relic density in agreement with WMAP constraints. Its direct detection cross section can be above or below present XENON100 bounds; most of the points below these bounds should be observable in the near future.

Of course, first of all the present evidence for a Higgs boson in the $124 - 127$ GeV mass range should be confirmed by more data;
then possible evidence for non-SM properties of the Higgs sector like an enhanced cross section in the diphoton channel will show whether the scenarios presented here are more likely than the SM