The 125 GeV Higgs in the NMSSM in light of LHC results and astrophysics constraints

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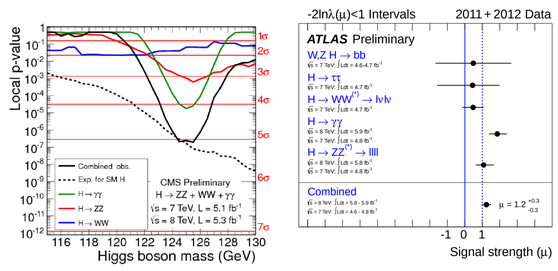
Motivations

- Recently, observation at 5σ significance of a new boson with a mass around 125 GeV was presented by ATLAS and CMS collaborations:
  ⇒ compatible with the Standard Model (SM) Higgs boson,
  ⇒ **but** also suggesting a possible excess in the Higgs boson decay channel into two photons whose signal strength is approximately twice as large as expected in the SM.



Local p-value (CMS, [1]) and signal strength (ATLAS, [2]) for individual and combined channels.

- Consequences in Supersymmetry, and especially in the Minimal Supersymmetric Standard Model (MSSM):
  – Some fine-tuning required to get SM-like Higgs mass $m_H \sim 125$ GeV [3];
  – Enhancement of the di-photon production rate in little corners of the parameter space (e.g. large mixing in stau sector, [4]).
- In the Next-to-MSSM (NMSSM):
  – New gauge singlet superfield $\hat{S}$ (v_S being the vev of its real scalar part) and couplings:
  ⇒ MSSM Higgses + 2 (1 CP-even, 1 CP-odd) $= H_{1,2,3}, H^{\pm}, A_{1,2}$;
  – New superpotential/μ terms:

$$W_{\rm NMSSM} = W_{\rm MSSM}(\mu = 0) + \lambda \hat{S}\hat{H}_u\hat{H}_d + \frac{1}{3}\kappa\hat{S}^3 + ..., \; \mu_{\rm eff} = \lambda v_S;$$

  – New soft breaking terms in the supersymmetric Lagrangian, thus new terms in the Higgs potential such as $\lambda A_\lambda H_u H_d S$:
  ⇒ **easy to get $\mathbf{m_{H_1} \sim 125}$ GeV**;
  – Doublet-singlet mixing (low $\tan\beta$, large λ):
  ⇒ **reduced $\mathbf{H_1 \to b\bar{b}}$**,
  ⇒ **$\mathcal{B}(\mathbf{H_1} \to \gamma\gamma)$ and then NMSSM signal strength $\mathbf{R_{gg\gamma\gamma}}$ increased [5]**:

$$R_{ggXX} = \frac{\sigma(gg \to H_1)_{\rm NMSSM}\mathcal{B}(H_1 \to XX)_{\rm NMSSM}}{\sigma(gg \to H)_{\rm SM}\mathcal{B}(H \to XX)_{\rm SM}}.$$

  – MSSM neutralinos + 1 (singlino $\tilde{S}$): ⇒ easier to get very light Dark Matter (< 15 GeV, [6])
- **Could we explain a possible $\gamma\gamma$ excess if we add constraints on the neutralino Dark Matter (DM) candidate, namely:**
  – **No overproduction of gamma rays coming from dwarf spheroidal galaxies and radio emission in the Milky Way and in galaxy clusters,**
  – **No anomalous excess in the dark matter direct detection experiments,**
  – **No dark matter overabundance?**

Probing the NMSSM parameter space

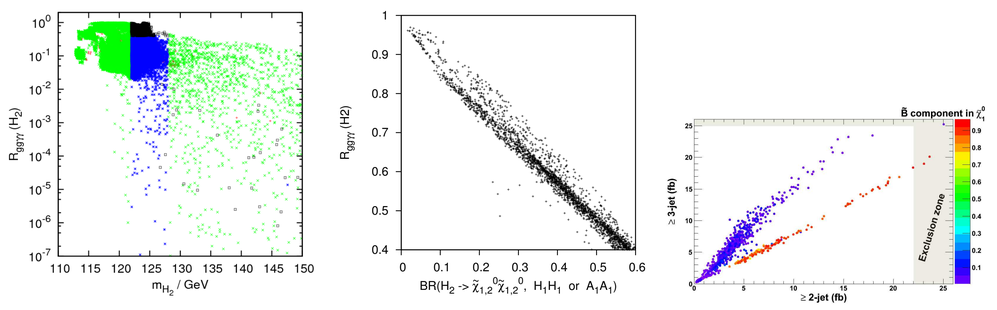
- Scanning method: Markov Chain Monte Carlo (MCMC) with Electroweak scale input parameters: gaugino masses, $\mu_{\rm eff}$, $\tan\beta$, A_t, soft terms in sfermion sector, new NMSSM terms (computation of the NMSSM spectrum with `NMSSMTools`).
- Two scans: the one with light neutralino condition ($m_{\tilde{\chi}_1^0} < 15$ GeV) motivated by hints of a signal in direct detection expriments ([7] for instance), the other with this condition relaxed.
- Constraints imposed on the scan:
  – LSP relic density, computed using `micrOMEGAs`, required to not exceed WMAP observed value:

$$\Omega_{\rm WMAP}\,h^2 > \Omega_{\tilde{\chi}_1^0}\,h^2 > 10\%\Omega_{\rm WMAP}\,h^2 \quad \text{with} \quad \Omega_{\rm WMAP}\,h^2 = 0.1131 \pm 0.0034;$$

  – Limits from B-physics ($b \to s\gamma$, $B_s \to \mu^+\mu^-$, $B^+ \to \tau\nu_\tau$, $\Delta M_{d,s}$) ;
  – Electroweak observables ($(g-2)_\mu$, $Z \to \tilde{\chi}_1^0\tilde{\chi}_1^0$, $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_{2,3}^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 Z$);
  – LEP and Tevatron limits on Higgs bosons and supersymmetric particles.
- Additional constraints superimposed on the points selected by the scan:
  – DM direct detection limits (XENON100);
  – DM indirect detection limits (Fermi-LAT);
  – Higgs search results from ATLAS and CMS seminar at CERN on 13th December 2011, with `HiggsBounds-3.6.1beta`;
  – $\mathcal{B}(B_s \to \mu^+\mu^-) < 4.5 \times 10^{-9}$ from LHCb;
  – SUSY searches@LHC with ATLAS's 1.04 fb^{-1} 0-lepton jets + $\not{E_T}$ search using Herwig++ 2.5.1 and RIVET 1.5.2 [8];

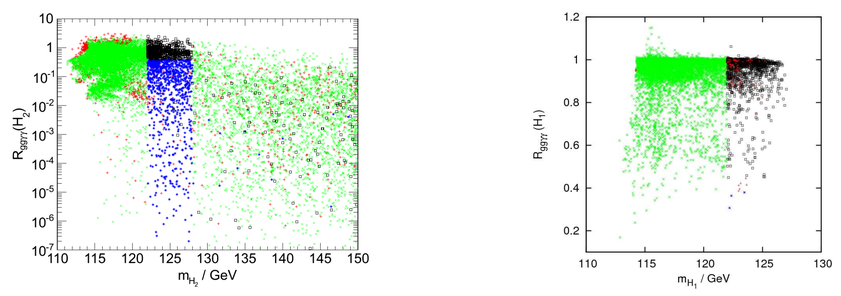
Results

- In the case of light LSP scan:
  – WMAP satisfied for $\tilde{\chi}_1^0$ near $m_{H_1,A_1}/2$, singlet-like Higgses, H_2 around 125 GeV;
  – Large non standard decays widths + low doublet-singlet mixing:
  ⇒ **difficult to reach $\mathbf{R_{gg\gamma\gamma} > 1}$**:
  Ruled out by `HiggsBounds` or SUSY searches@LHC, no Higgs boson with a mass in the [122, 128] GeV range, H_1 and/or H_2 within this mass range, such a Higgs with $R_{gg\gamma\gamma} > 0.4$.



$R_{gg\gamma\gamma}(H_2)$ vs. m_{H_2} and H_2 invisible branching ratio. *Signal cross sections in the 2- and 3- jets channels (red $\tilde{B}$, blue $\tilde{S}$).*

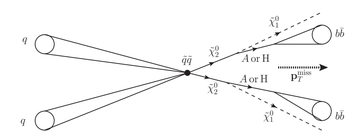
  – Jets + $\not{E_T}$ constraint exclude squarks lighter than 0.6 - 1 TeV and gluinos below 0.5 TeV in the MSSM.
  – In the NMSSM:
    * Reduced acceptance into jets + $\not{E_T}$ search channels ⇒ squarks lighter than 300 GeV still allowed: $\tilde{q} \to q + \tilde{\chi}_2^0 \to q + \tilde{\chi}_1^0 + (f\bar{f}$ or A_1 or $H_1)$;
    * More jets for singlino LSP.
- Relaxing LSP mass:
  – Singlet-like H_1 not needed:
  ⇒ easier to get important doublet-singlet mixing for large λ and low μ_{eff}, thus with large $\tilde{H}$ component in $\tilde{\chi}_1^0$ and low relic density values;
  ⇒ then possible to obtain $\mathbf{R_{gg\gamma\gamma} \sim 2}$, except if a strict lower bound on $\Omega_{\tilde{\chi}_1^0}h^2$ is imposed.



$R_{gg\gamma\gamma}(H_2)$ vs. m_{H_2} w/o strict $\Omega^{min}_{\tilde{\chi}_1^0}h^2$. *$R_{gg\gamma\gamma}(H_1)$ vs. m_{H_1} w/ strict $\Omega^{min}_{\tilde{\chi}_1^0}h^2$.*

Conclusions

- **The NMSSM can explain both Higgs boson mass and excess in the $\gamma\gamma$ channel;**
- DM constraints powerful on the exclusion of some good candidates in the parameter space;
- Interesting NMSSM signatures (very light Higgs allowed, two Higgses in the preferred mass range, ...);
- Modified jets + $\not{E_T}$ signal with $\tilde{S}$-like LSP and the decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 +$ Higgs is kinematically accessible:



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