Enhanced Diphoton Signal in the NMSSM

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Recall: In the MSSM, considerable effort (large radiative corrections $\leftrightarrow$ fine-tuning) is required in order to obtain a Higgs mass of ~ 125 GeV

NMSSM:

$$W_{MSSM} = \mu H_u H_d + \ldots \longrightarrow W_{NMSSM} = \lambda S H_u H_d + \tfrac{1}{3}\kappa S^3 + \ldots$$

(scale invariant!)

$\longrightarrow$ $\mu_{\text{eff}} = \lambda \langle S \rangle \sim M_{Susy}$ automatically ✓

$\longrightarrow$ 3 CP-even neutral scalars H_1, H_2, H_3,
mixtures of the real neutral components of H_u, H_d and S
Recall, in the MSSM: $(H_u,\ H_d) \to (h_{SM},\ H)$, H typically heavy

NMSSM Mass matrix in the h_{SM}, S sector:

$$\begin{array}{cc} & \begin{array}{cc} h_{SM} & S \end{array} \\ \begin{pmatrix} h_{SM} \\ S \end{pmatrix} & \begin{pmatrix} M_{11}^2 & M_{12}^2 \\ M_{21}^2 & M_{22}^2 \end{pmatrix} \end{array}$$

where (with $s = \langle S \rangle$)

$$\begin{aligned} M_{11}^2 &= M_Z^2 \left(\cos^2 2\beta + \frac{2\lambda^2}{g_1^2 + g_2^2} \sin^2 2\beta \right) + \text{rad. corrs.} \\ M_{12}^2 &= \lambda v \left(2\mu_{\text{eff}} - \sin 2\beta \left(A_\lambda + 2\kappa s \right) \right) + \text{rad. corrs.} \\ M_{22}^2 &\simeq \kappa s \left(A_\kappa + 4\kappa s \right) + \text{rad. corrs.} \end{aligned}$$

$\longrightarrow$ The NMSSM-specific contribution $\sim \lambda^2$ helps to increase the SM-like Higgs mass M_{11}^2 ✓ (if $\tan\beta$ is small), BUT

$\longrightarrow$ the mixing with S induced by M_{12}^2 reduces the SM-like Higgs mass if $M_{22}^2 > M_{11}^2$ (unless M_{12}^2 is tuned to 0)

$\longrightarrow$ Preferably: $M_{22}^2 < M_{11}^2$, mixing increases the SM-like Higgs mass further ✓

$\longrightarrow$ the dominantly singlet-like CP-even Higgs boson is lighter than h_{SM}!

Of course, for $M^2_{22} \lesssim 114$ GeV the mixing must not be too large such that the dominantly singlet-like Higgs boson H_1 complies with LEP constraints.

$\longrightarrow$ It is easy to find regions in the parameter space of the general NMSSM where all these conditions are met!
(e.g. $0.5 \lesssim \lambda \lesssim 0.6$, $0.3 \lesssim \kappa \lesssim 0.4$, $1.7 \lesssim \tan\beta \lesssim 2$,
and μ_{eff}, A_λ, $|A_\kappa|$, $M_A \approx 100 - 300$ GeV, not fine-tuned!)

Now: The lightest eigenstate H_1 is dominantly singlet-like, the next-to-lightest eigenstate H_2 with $M_{H_2} \sim 125$ GeV is mostly SM-like; in general:

$$\begin{aligned} H_1 &= S_{1,d}\, H_d + S_{1,u}\, H_u + S_{1,s}\, S\ , \\ H_2 &= S_{2,d}\, H_d + S_{2,u}\, H_u + S_{2,s}\, S\ . \end{aligned}$$

Note: The mixing reduces the couplings of H_2 to quarks and electroweak gauge bosons; in the above region one finds
(i) a reduction of the coupling to b-quarks (and τ-leptons),
(ii) a mild reduction of the coupling to t-quarks and electroweak gauge bosons, relevant for the loop-induced gluon-gluon fusion production cross section and the partial width into $\gamma\gamma$, respectively

Effect of the reduction of the coupling to b-quarks:

$\longrightarrow$ The total width $\Gamma(H_2)_{Tot}$ is reduced by a factor $\lesssim 0.5$, since it is dominated by the width into $b\bar{b}$;

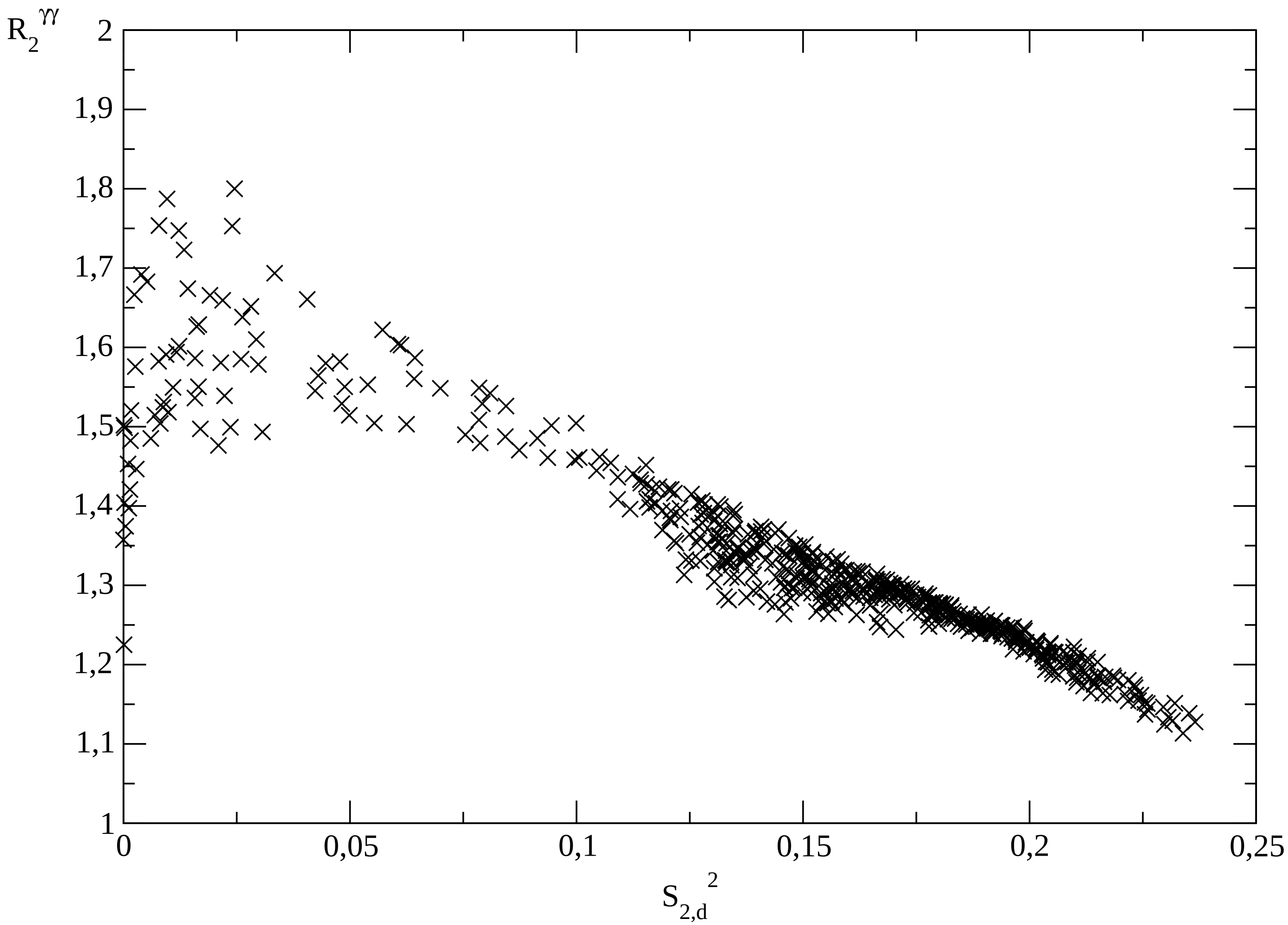
$\longrightarrow$ The branching ratio into $\gamma\gamma$,

$$BR(H_2 \to \gamma\gamma) = \frac{\Gamma(H_2 \to \gamma\gamma)}{\Gamma(H_2)_{Tot}} \,,$$

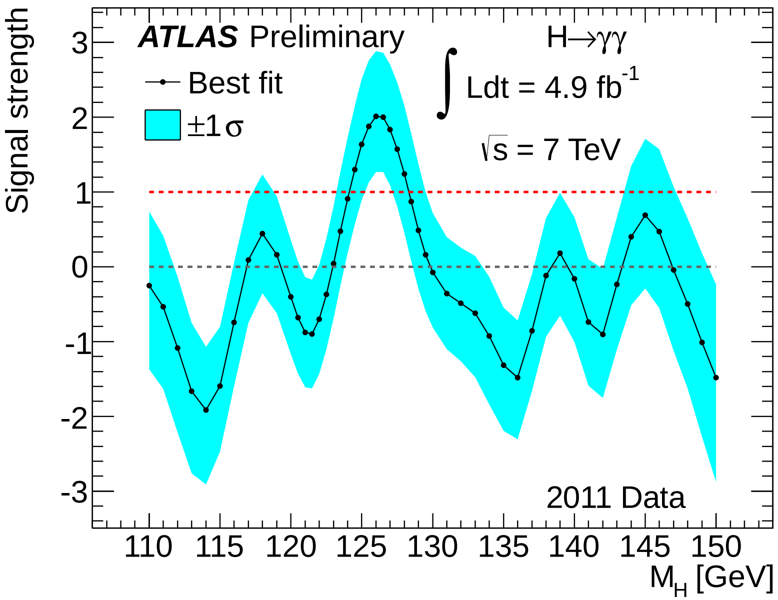
is enhanced!

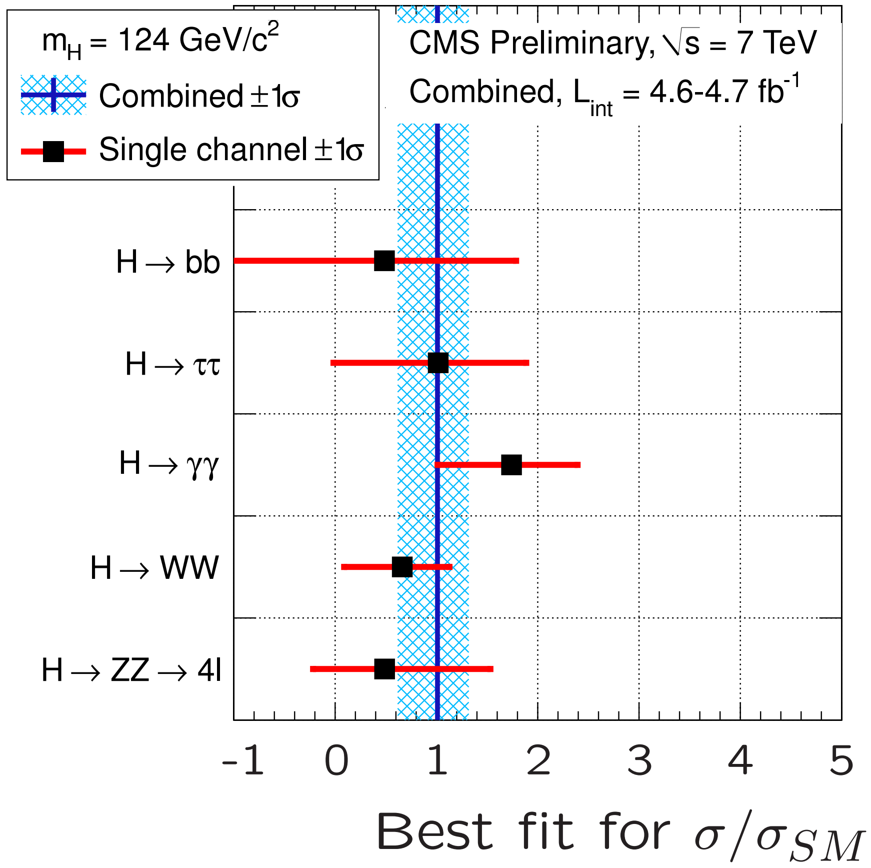
(But $BR(H_2 \to b\bar{b})$ remains dominant)

Signal strength $\sigma_2^{\gamma\gamma} = \sigma_{prod} \times BR(H_2 \to \gamma\,\gamma)$ relative to the SM, $R_2^{\gamma\gamma} = \sigma_2^{\gamma\gamma}/\sigma_{SM}^{\gamma\gamma}$, as function of the H_d-component $S_{2,d}$ of H_2:



What has been observed by ATLAS and CMS in the $\gamma\gamma$ channel?

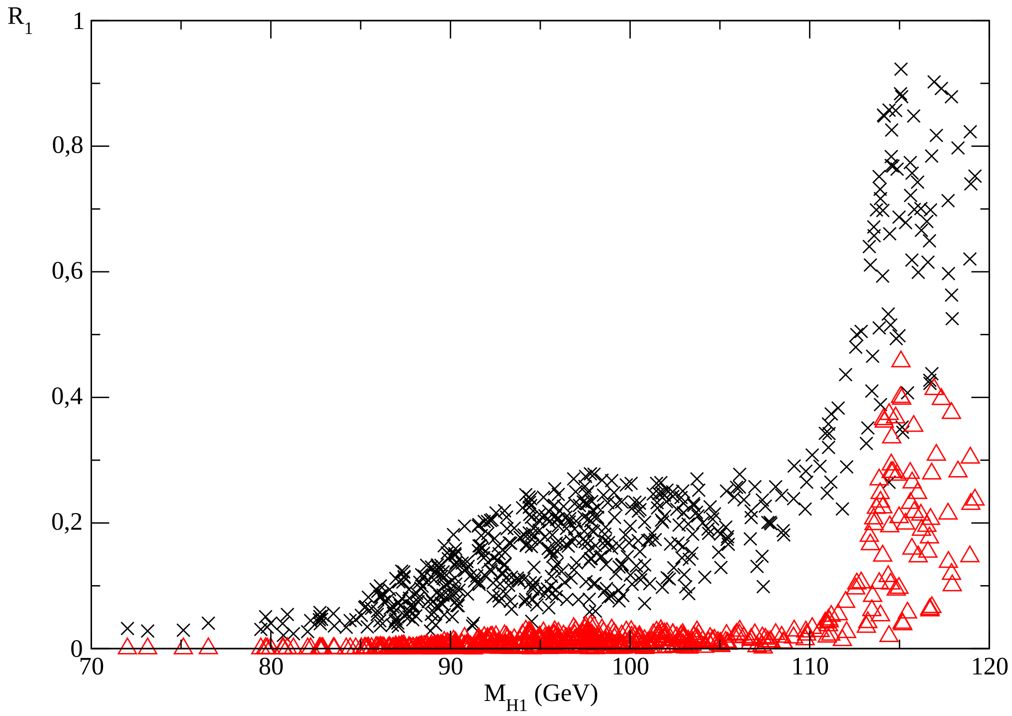




$\longrightarrow$ $\sim 1.3\sigma$ excess w.r.t. the SM at ATLAS, $\sim 1\sigma$ excess at CMS

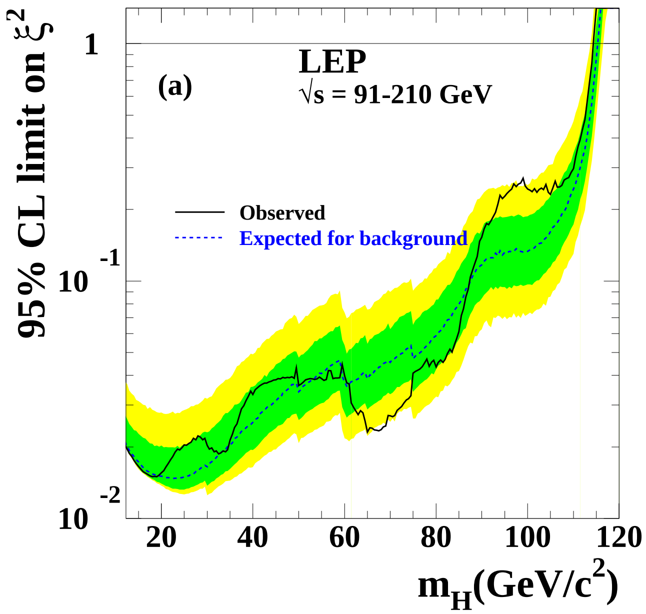
Would the lighter eigenstate H_1 be detectable?
70 GeV $\lesssim M_{H_1} \lesssim$ 120 GeV $\longrightarrow$ $\gamma\gamma$ and $\tau\tau$ channels, the latter via VBF

The relative signal rate $R_1 = R_1^{\gamma\gamma} = \sigma_1^{\gamma\gamma}/\sigma_{SM}^{\gamma\gamma}$ (red triangles) and $R_1 = R_1^{\tau\tau} = \sigma_1^{\tau\tau}/\sigma_{SM}^{\tau\tau}$ (black crosses) as function of M_{H_1}:



$\longrightarrow$ No enhancement, $R_1^{\tau\tau} \gtrsim 0.6$ only for $M_{H_1} \gtrsim 113$ GeV

Side note: For M_{H_1} in the $97 - 108$ GeV range, LEP constraints (upper bounds) on ξ^2 =(Higgs-Z-coupling)^2 $\times$ $BR(Higgs \to b\bar{b})$ relative to the SM are particularly weak:



In the present scenario ξ^2 coincides with $R_1^{\tau\tau}$, since the scalings w.r.t. the SM of $BR(H_1 \to b\bar{b})$ and $BR(H_1 \to \tau\tau)$ are identical, and the VBF production cross section scales like the (H_1-Z-coupling)^2

$\longrightarrow$ LEP-bump can be explained (but not be checked at the LHC...), see earlier papers by Dermisek/Gunion

Conclusions

$\longrightarrow$ In a natural region in the parameter space of the NMSSM, the NMSSM-specific coupling λ and mixing effects push up the mass of a SM-like CP-even Higgs boson into the $124 - 127$ GeV range, without requiring excessive radiative corrections from heavy sparticles

$\longrightarrow$ The relative signal rate in the $\gamma\gamma$ channel is always enhanced by a factor $1.1 - 1.8$ with respect to a SM-like Higgs boson of the same mass

Under the following circumstances it might be possible to distinguish this scenario from the SM and/or the MSSM:

a) the enhanced signal rate in the $\gamma\gamma$ channel is confirmed, and incompatible with a SM-like Higgs boson;
b) sparticles are detected, and their masses turn out to be incompatible with the necessarily large radiative corrections to the Higgs mass in the MSSM;
c) an additional lighter Higgs H_1 is discovered (if heavier than ~ 113 GeV)