Higgs physics after the discovery of a new state at 126 GeV

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DESY

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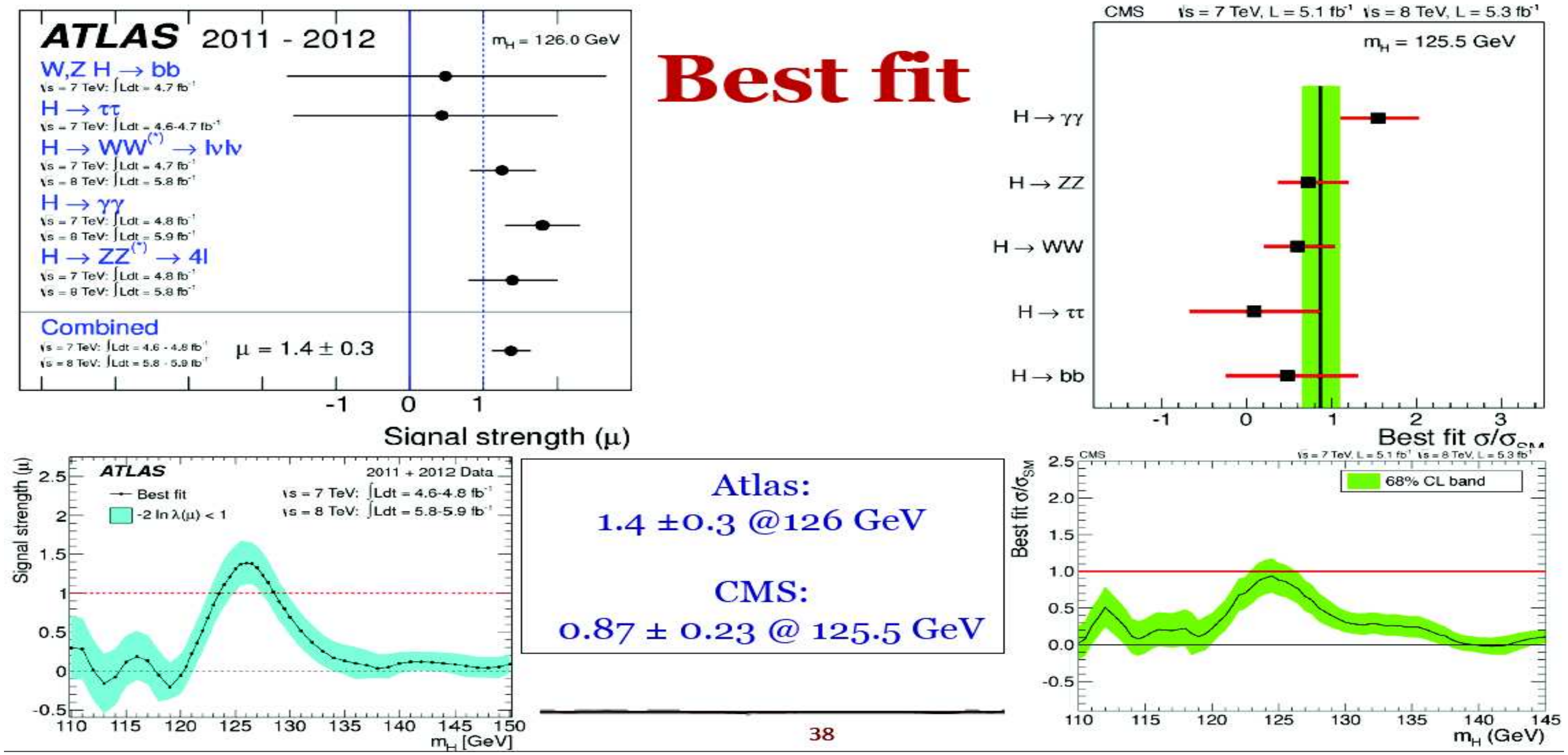
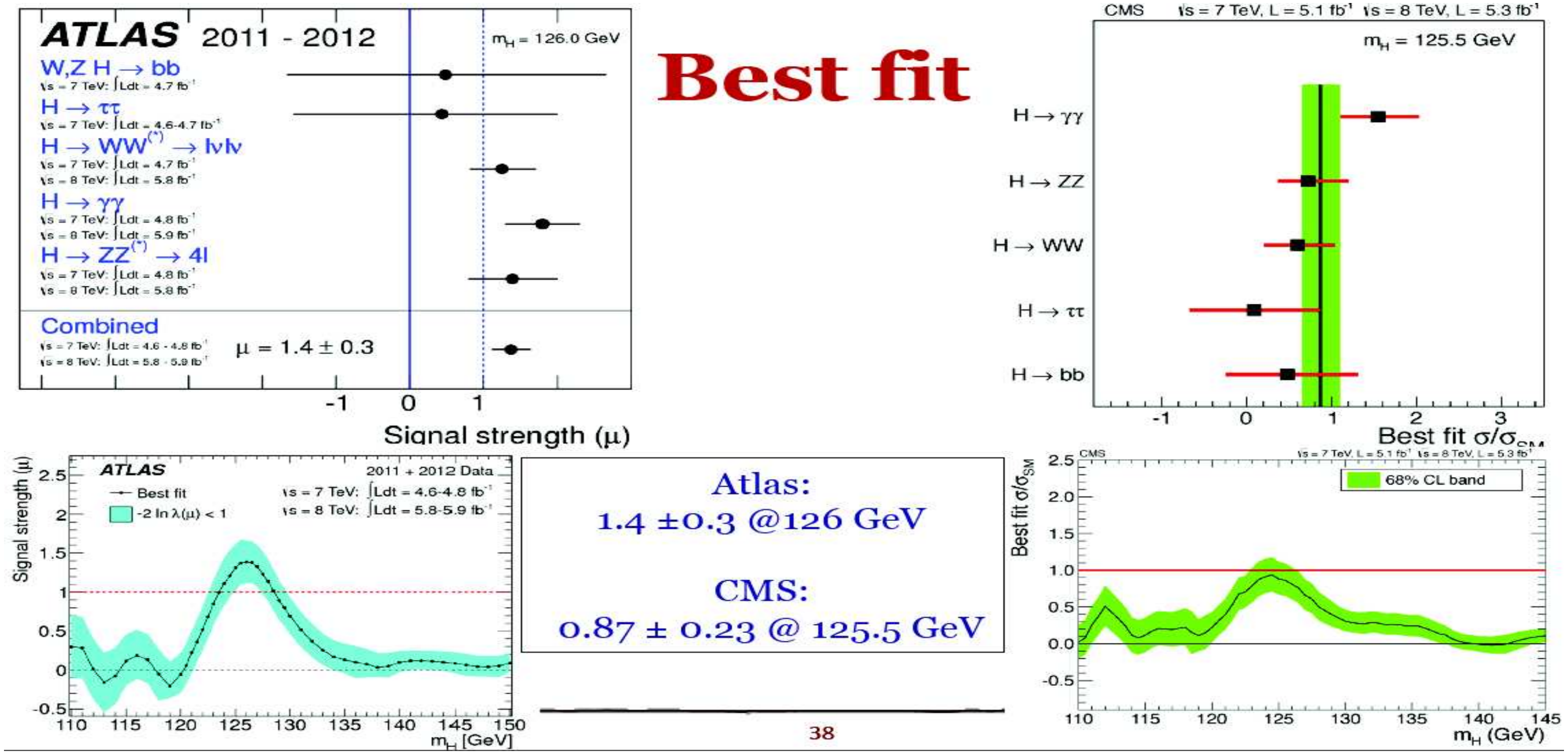
- Introduction
- Determination of the properties of the state at 126 GeV
- SUSY interpretation of the observed signal?
- Conclusions

Introduction



Observation compatible with Standard Model (SM) Higgs

Introduction



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Observed (slight) deviations: fluctuations or . . . ?

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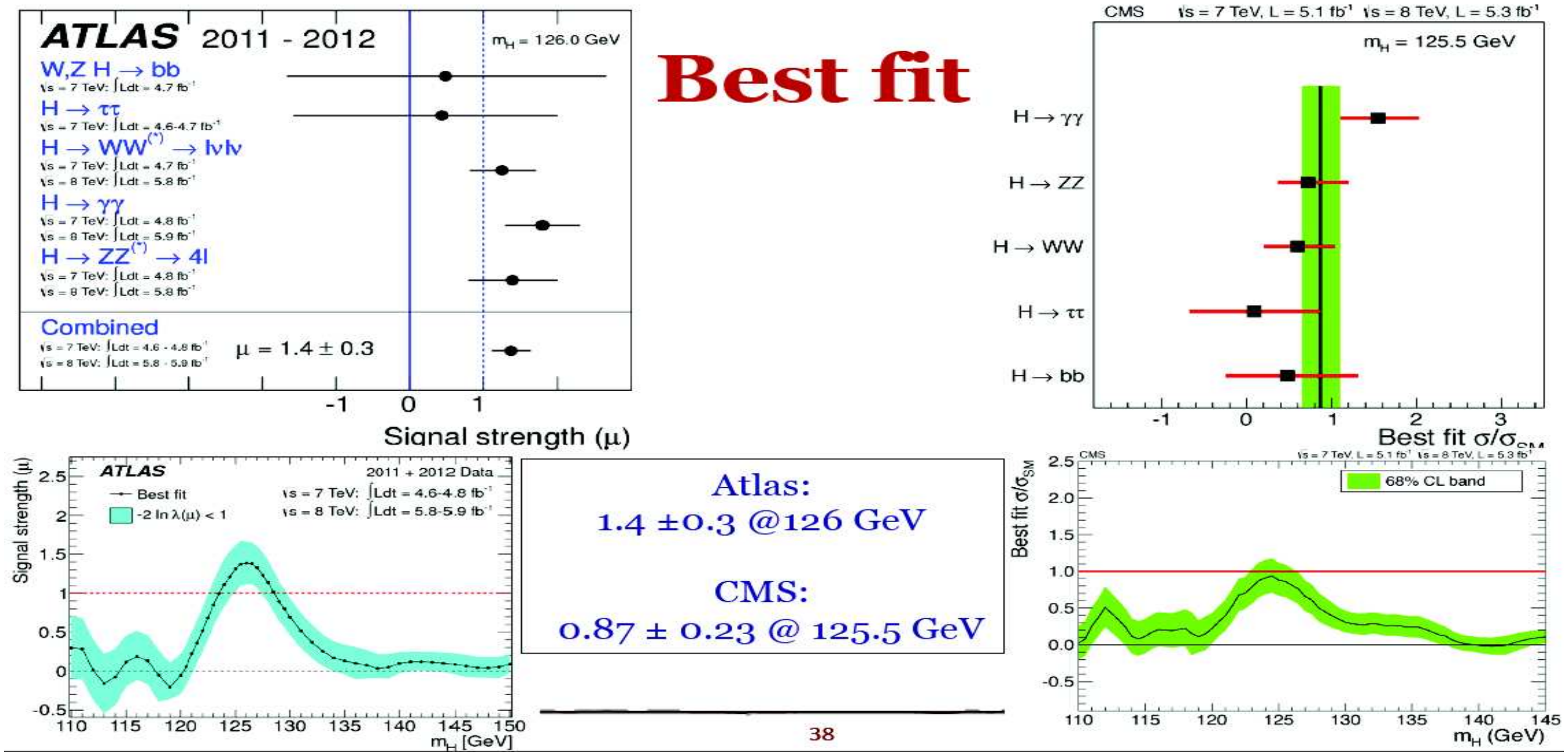

Observation compatible with Standard Model (SM) Higgs

Observed (slight) deviations: fluctuations or . . . ?

The best way of experimentally proving that the observed state is not the SM Higgs is to find in addition (at least one) non-SM like Higgs!

Higgs phenomenology beyond the SM

Standard Model: a single parameter determines the whole Higgs phenomenology: M_{H}

In the SM the same Higgs doublet is used “twice” to give masses both to up-type and down-type fermions

$\Rightarrow$ extensions of the Higgs sector having (at least) two doublets are quite “natural”

$\Rightarrow$ Would result in several Higgs states

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Many extended Higgs theories have over large part of their parameter space a lightest Higgs scalar with properties very similar to those of the SM Higgs boson

Example: SUSY in the “decoupling limit”

Higgs physics in Supersymmetry

"Simplest" extension of the minimal Higgs sector:

Minimal Supersymmetric Standard Model (MSSM)

- Two doublets to give masses to up-type and down-type fermions (extra symmetry forbids to use same doublet)
- SUSY imposes relations between the parameters

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$\Rightarrow$ Upper bound on lightest Higgs mass, M_h (*FeynHiggs*):

[*S. Heinemeyer, W. Hollik, G. W. '99*], [*G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich, G. W. '02*]

$$M_\mathrm{h} \lesssim 135\,\mathrm{GeV}$$

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$$M_\mathrm{h} \lesssim 135\,\mathrm{GeV}$$

Detection of a SM-like Higgs with $M_\mathrm{H} \gtrsim 135$ GeV would have unambiguously ruled out the MSSM, signal at ~ 126 GeV is well compatible with MSSM prediction

NMSSM Higgs sector: additional singlet

Motivated by "μ problem":

MSSM contains term $\mu H_d H_u$ in superpotential

μ: dimensionful parameter

For EW symmetry breaking required: $\mu \sim$ electroweak scale

But: no a priori reason for $\mu \neq 0$, $\mu \ll M_{\rm Pl}$

NMSSM: μ related to v.e.v. of additional field

$\Rightarrow$ Introduction of extra singlet field S, v.e.v. s

Superpotential: $\mathcal{V} = \lambda H_d H_u S + \frac{1}{3}\kappa S^3 + \ldots$

Physical states in NMSSM Higgs-sector:

S_1, S_2, S_3 (CP-even), P_1, P_2 (CP-odd), $H^\pm$

Determination of the properties of the state at 126 GeV

Mass: statistical precision with 2012 data will be remarkable

$\Rightarrow$ Need careful assessment of systematic effects, e.g. interference of signal and background, . . .

Spin: need to discriminate between hypotheses for spin 0, (1), 2

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Spin: need to discriminate between hypotheses for spin 0, (1), 2

At which level of significance can the hypothesis spin $= 1$ be excluded (2 γ's vs. 4 γ's)?

$\mathcal{CP}$ properties

$\mathcal{CP}$-properties: Observed state can be any admixture of $\mathcal{CP}$-even and $\mathcal{CP}$-odd components

Observables investigated up to now ($H \to ZZ^*, WW^*$ and H production in weak boson fusion) involve HVV coupling

General structure of HVV coupling (from Lorentz invariance):

$$a_1(q_1, q_2) g^{\mu\nu} + a_2(q_1, q_2) \left[(q_1 q_2)\, g^{\mu\nu} - q_1^\mu q_2^\nu \right] + a_3(q_1, q_2) \epsilon^{\mu\nu\rho\sigma} q_{1\rho} q_{2\sigma}$$

Pure $\mathcal{CP}$-even state: $a_1 = 1, a_2 = 0, a_3 = 0$,

Pure $\mathcal{CP}$-odd state: $a_1 = 0, a_2 = 0, a_3 = 1$

However, in most BSM models a_3 would be loop-induced and heavily suppressed $\Rightarrow$ Realistic models usually predict $a_3 \ll a_1$

$\Rightarrow$ Observables involving HVV coupling provide little sensitivity to effects of a $\mathcal{CP}$-odd component

$\mathcal{CP}$ ***properties***

Observables involving the HVV coupling “project” to the $\mathcal{CP}$-even component of the observed state

$\mathcal{CP}$ *properties*

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The fact that we have observed the new state in the ZZ^* and WW^* channels (at a certain level of significance) already tells us that it is most likely not a pure $\mathcal{CP}$-odd state

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Which upper limit on a $\mathcal{CP}$-odd admixture can be set?

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Which upper limit on a $\mathcal{CP}$-odd admixture can be set?

$\Rightarrow$ Channels involving only Higgs couplings to fermions provide much higher sensitivity

Couplings

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data:

Assumptions:

- Signal corresponds to only one state, no overlapping resonances, etc.
- Zero-width approximation
- Only modifications of coupling strenghts (absolute values of the couplings) are considered, no modification of the tensor structure as compared to the SM case

  $\Rightarrow$ Assume that the observed state is a $\mathcal{CP}$-even scalar

Single channel results vs. simultaneous information from several channels

Single channel results: signal strength parameters μ_i for separate search channels

$\Rightarrow$ Most robust information for testing different models

Very useful for confronting theory predictions with experimental results

Adding information from different channels increases sensitivity

But: interpretation of the results is in general more difficult

Analysis in the long run

As long as the SM continues to be (roughly) compatible with the data:

$\Rightarrow$ Use full SM predictions including all available higher-order corrections $+$ anomalous couplings

$\Rightarrow$ Appropriate tools needed

Anomalous couplings would in general change kinematic distributions

$\Rightarrow$ No simple rescaling of MC predictions possible

$\Rightarrow$ Not feasible for analysis of 2012 data set

$\Rightarrow$ Proposal of “interim framework”

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$\Rightarrow$ Proposal of "interim framework"

If SM is ruled out $\Rightarrow$ Move to other reference model

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Use state-of-the-art predictions in the SM and rescale the predictions with “leading order inspired” scale factors κ_i ($\kappa_i = 1$ corresponds to the SM case)

Note: scaling of couplings is in general not possible if higher-order electroweak corrections are included

In the SM: Higgs sector is determined by single parameter $M_{\rm H}$ ($+$ higher-order contributions)

$\Rightarrow$ Once $M_{\rm H}$ is fixed the Higgs couplings are determined and cannot be varied within the SM

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Scaling of couplings $\Leftrightarrow$ test of deviations from the SM

Note: acceptances and efficiencies are assumed to be as in the SM

$\Rightarrow$ This will have an impact on the interpretation in case a sizable deviation from the SM prediction gets established

$\Rightarrow$ Results obtained from the analysis with scaled couplings cannot be interpreted as “coupling measurements”

Recommendations of the LM subgroup of the LHC Higgs XS WG for analyses of 2012 data

Which kind of scaling factors should be considered?

In general, scale factors are needed for couplings of the new state to
t, b, τ, W, Z, $\ldots$

$+$ extra loop contribution to $\sigma(gg \to H)$, $\Gamma(H \to gg)$

$+$ extra loop contribution to $\Gamma(H \to \gamma\gamma)$

$+$ additional contributions to total width, Γ_H, from undetectable final states

Total width Γ_H cannot be measured without further assumptions (otherwise only coupling ratios can be determined, not absolute values of couplings)

Proposed "benchmarks" for scale factors κ_i

Different "benchmark" proposals, based on simplifying assumptions to reduce the number of free parameters

1 parameter: overall coupling strength μ

2 parameters: e.g. common scale factor κ_V for W, Z, and common scale factor for all fermions, κ_F

$\ldots$

For each benchmark (except overall coupling strength) two versions are proposed:

with and without taking into account the possibility of additional contributions to the total width

Proposed "benchmarks" for scale factors κ_i

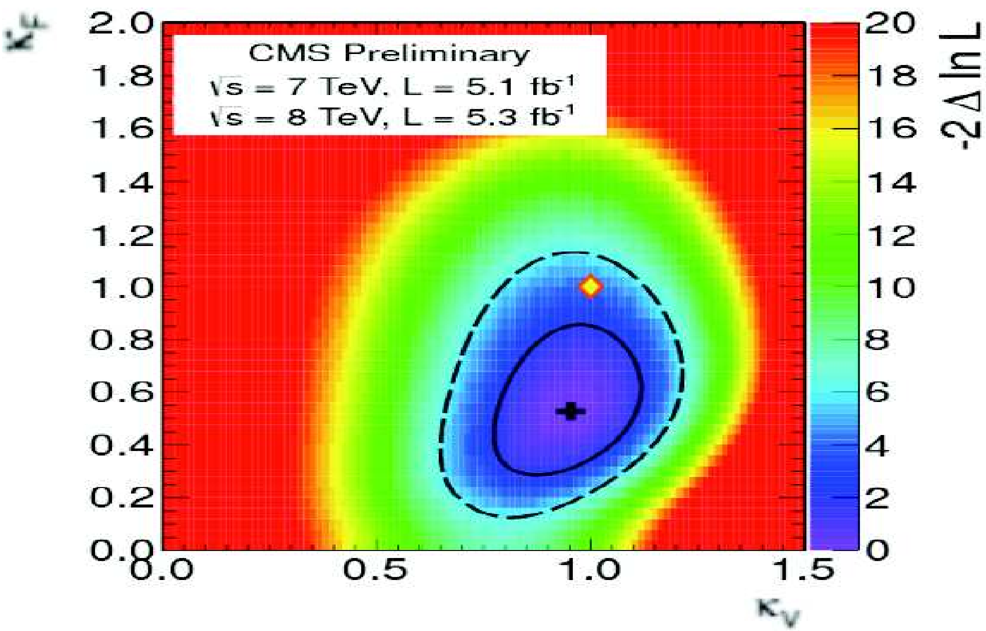
If additional contributions to Γ_H are allowed

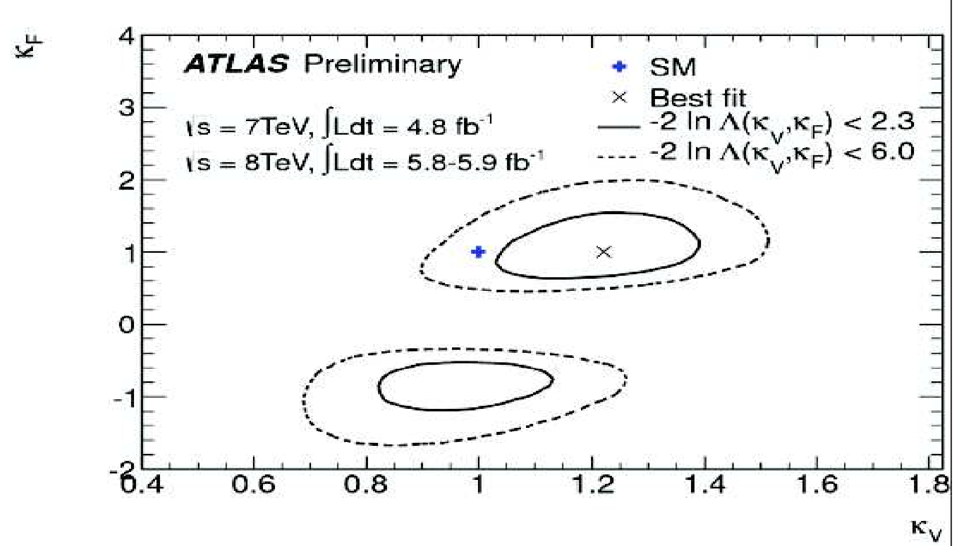
$\Rightarrow$ Determination of ratios of scaling factors, e.g. $\kappa_i \kappa_j / \kappa_H$

If no additional contributions to $\Gamma(H \to \gamma\gamma)$, Γ_H, $\ldots$ are allowed

$\Rightarrow$ κ_γ can be determined in terms of κ_b, κ_t, κ_τ, κ_W
evaluated to NLO QCD accuracy

Example: κ_V, κ_F analyses from CMS and ATLAS





MSSM interpretation of scale factors κ_i?

- Higgs couplings to up-type and down-type fremions are different $\Rightarrow$ cannot be described in terms of common κ_F
- Large SUSY contributions can affect relation between coupling to $b\bar{b}$ and $\tau^+\tau^-$
- Extra contributions to $\sigma(gg \to H)$, $\Gamma(H \to gg)$, $\Gamma(H \to \gamma\gamma)$: $\tilde{t}$, $\tilde{\tau}$, $\tilde{\chi}^\pm$, ...
- Extra contribution to total width: $H \to$ invisible, ...

It seems difficult to go beyond three free parameters in the near future

$\Rightarrow$ Benchmark scenarios of this kind are in general too restrictive to allow an interpretation within a “realistic” model like the MSSM

SUSY interpretation of the observed signal?

Interpretation of the observed signal at $\sim 126\ \mathrm{GeV}$ in terms of the light MSSM CP-even Higgs h

Observed signal at $\sim 126\ \mathrm{GeV}$ implies lower bound on M_h

$\Rightarrow$ Set parameters entering via higher-order corrections such that M_h is maximised ($m_\mathrm{h}^\mathrm{max}$ benchmark scenario)

$\Rightarrow$ Lower bounds on M_A, $\tan\beta$

Search limits from LEP and from LHC ($H, A \to \tau^+\tau^-$ search) taken into account:

HiggsBounds

[*P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. W., K. Williams '08, '12*]

HiggsBounds: *determination of 95% C.L. exclusion region from given cross section limits*

[*P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. W., K. Williams '08, '12*]

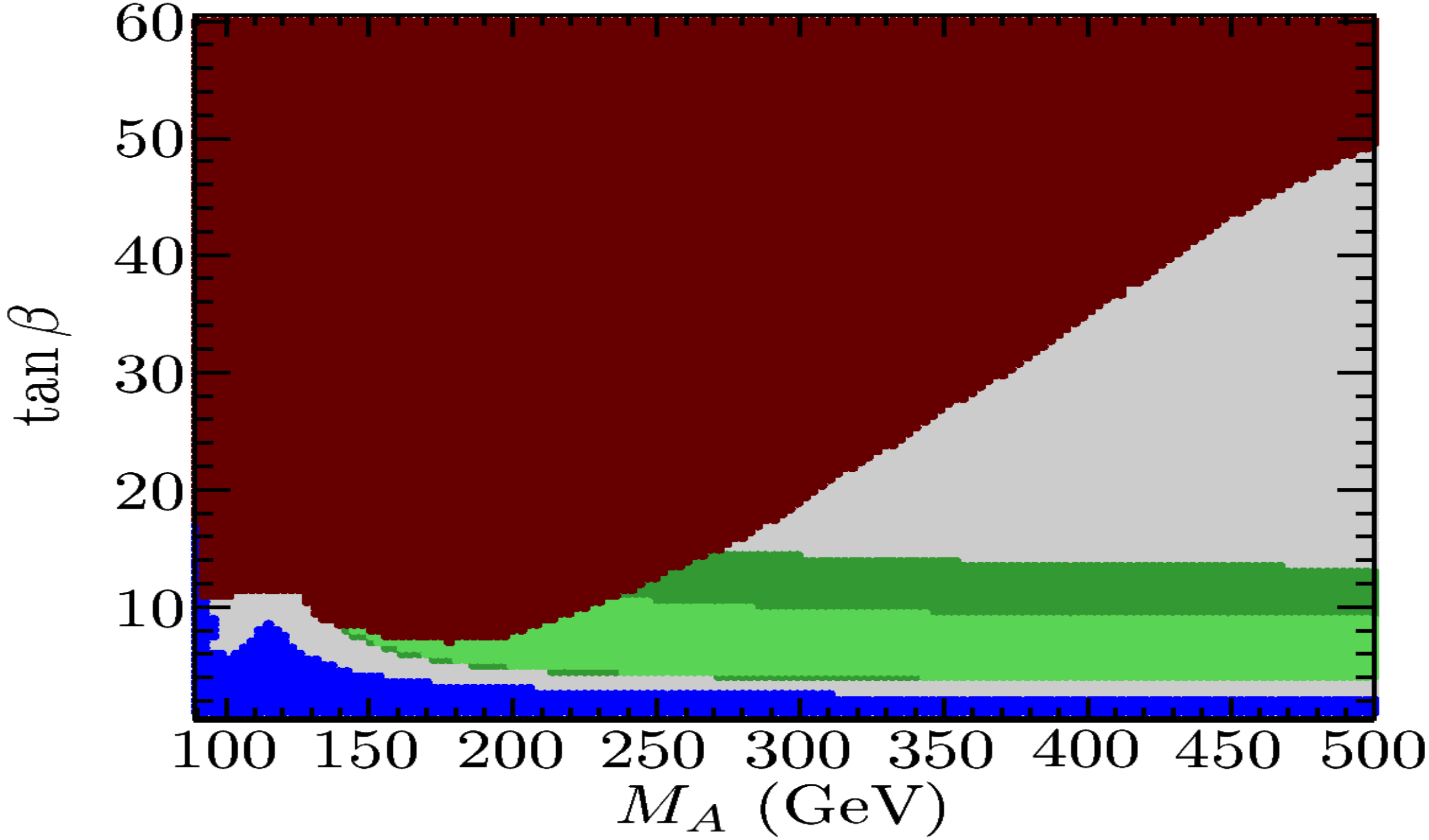
In order to obtain an exclusion limit having the correct statistical interpretation as a 95% C.L.:

- On the basis of the expected search limits for different channels in a given model one needs to determine for every parameter point the search channel having the highest statistical sensitivity for setting an exclusion limit

- For this single channel only one needs to compare the observed limit with the theory prediction for the Higgs production cross section times decay branching ratio to determine whether or not the considered parameter point of the model is excluded at 95% C.L.

Lower bounds on M_A ***and*** $\tan\beta$ ***from interpreting signal at*** ~ 126 GeV ***as light MSSM Higgs boson*** h

Red: LHC limits from $H, A \to \tau^+\tau^-$ search; Blue: LEP limits
Green: compatible with interpreting signal at 126 GeV as light MSSM Higgs h (+ m_t variation) [*S. Heinemeyer, O. Stål, G. W. '11, '12*]

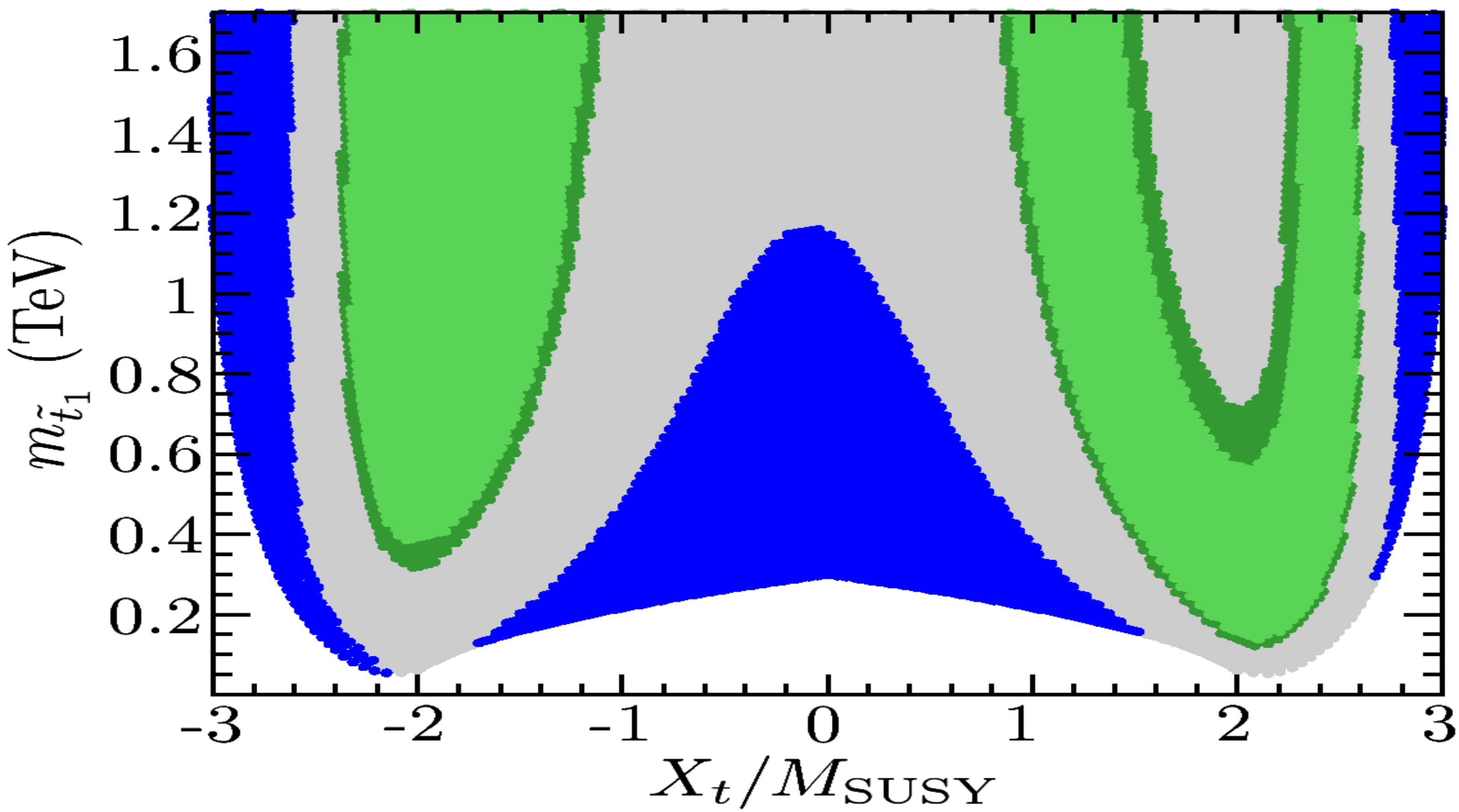


$\Rightarrow \tan\beta \gtrsim 4$, $M_\mathrm{A} \gtrsim 140$ GeV, $M_{\mathrm{H}^\pm} \gtrsim 160$ GeV

Lower bound on the lightest stop mass from assumed Higgs signal at ~ 126 GeV

M_A, $\tan\beta$ chosen in decoupling region: $M_A = 1$ TeV, $\tan\beta = 20$

[*S. Heinemeyer, O. Stål, G. W. '11, '12*]



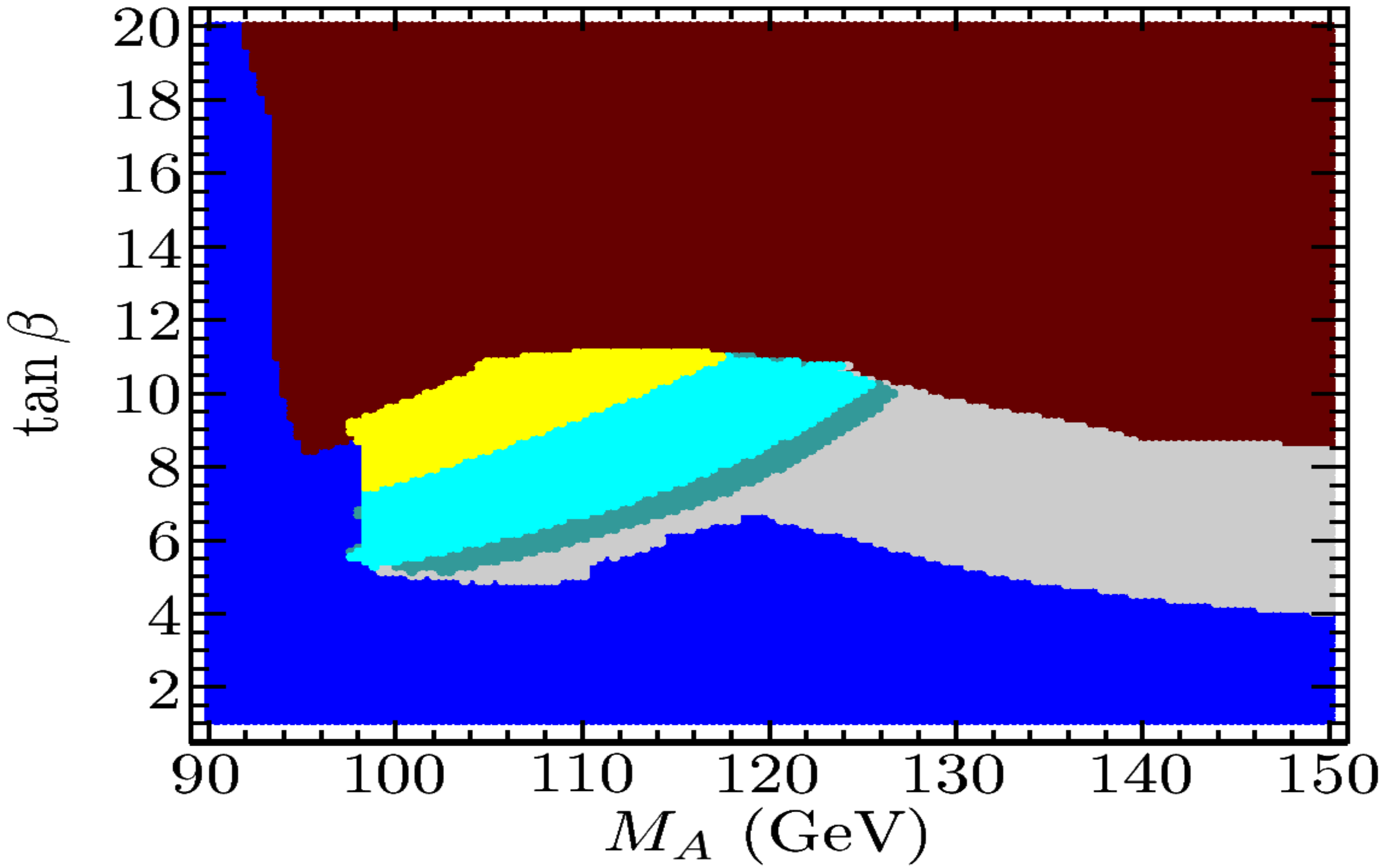
$\Rightarrow m_{\tilde{t}_1} > 150\ (300)$ GeV for positive (negative) X_t

$\Rightarrow M_h \sim 126$ GeV is compatible with a light Stop!

Interpretation of the observed signal at ~ 126 GeV *in terms of the heavy MSSM CP-even Higgs* H

Scan over M_A, $\tan\beta$, M_SUSY, X_t

[*S. Heinemeyer, O. Stål, G. W. '11*]



$\Rightarrow$ possible for low M_A, moderate $\tan\beta$
(in yellow region: $\gamma\gamma$ rate compatible with LHC results)

Can an enhanced rate in the $\gamma\gamma$ channel be accomodated for a ~ 126 GeV Higgs in SUSY: MSSM and NMSSM?

[*R. Benbrik, M. Gomez Bock, S. Heinemeyer,O. Stål, G. W., L. Zeune '12*]

Investigate MSSM and NMSSM predictions for the $\gamma\gamma$ rate, normalised to the SM prediction

$$R^{h_i}_{\gamma\gamma} = \frac{\sigma(pp \to h_i) \times \mathrm{BR}(h_i \to \gamma\gamma)}{\sigma(pp \to H_{\mathrm{SM}}) \times \mathrm{BR}(H_{\mathrm{SM}} \to \gamma\gamma)}$$

$$\approx \frac{\Gamma(h_i \to gg) \times \mathrm{BR}(h_i \to \gamma\gamma)}{\Gamma(H_{\mathrm{SM}} \to gg) \times \mathrm{BR}(H_{\mathrm{SM}} \to \gamma\gamma)}$$

$\Rightarrow$ Parameter scans in both models

MSSM results from *FeynHiggs*

NMSSM results obtained using *FeynArts* (new NMSSM model file generated), *FormCalc* and *LoopTools*

Applied constraints

- Direct search limits for SUSY particles $+$ theo. constraints (perturbativity up to M_{GUT}, no charge / colour breaking minima, . . .)

  $\longrightarrow$ grey points

- Higgs searches at LEP, Tevatron and the LHC (2011): HiggsBounds

  $\longrightarrow$ blue points

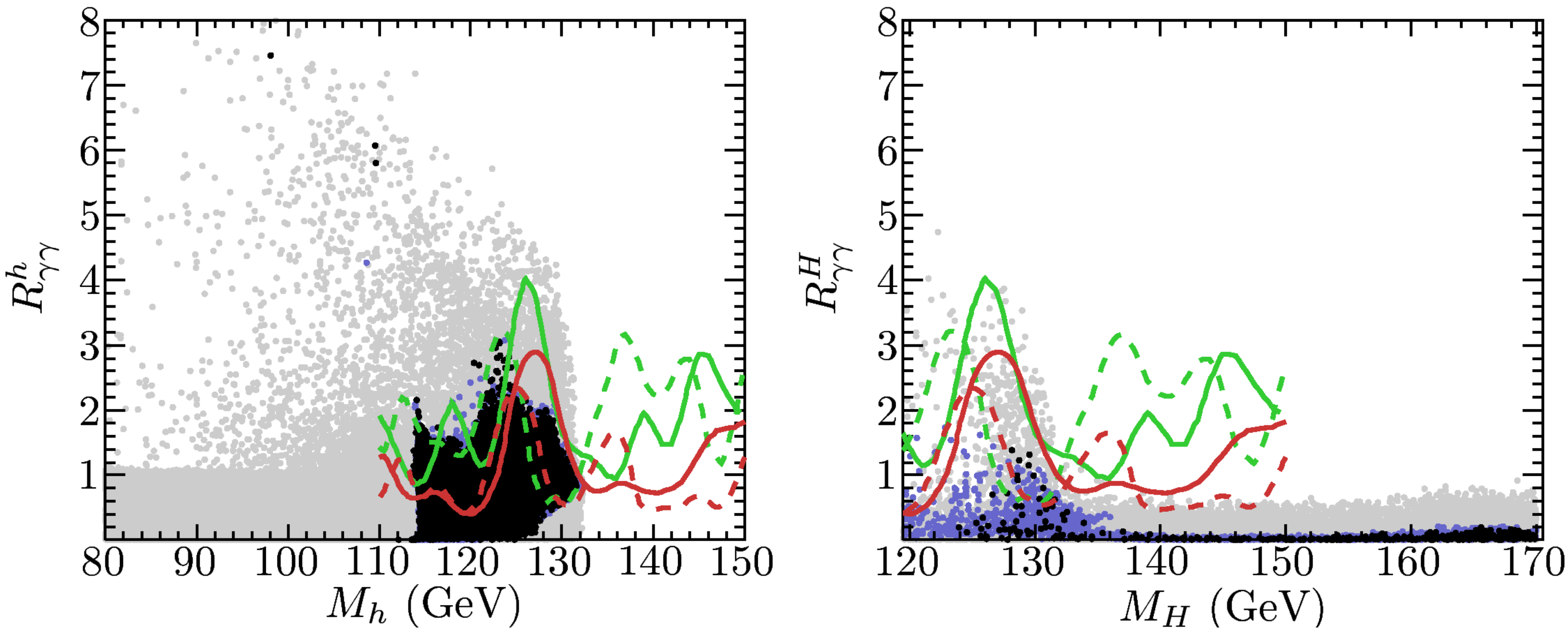
- $(g-2)_\mu$, flavour physics observables ($\mathrm{BR}(b \to s\gamma)$, . . .)

  $\longrightarrow$ black points

MSSM predictions for the $\gamma\gamma$ rate of h and H normalised to the SM prediction

Comparison with search limits from ATLAS (solid) and CMS (dashed) from 2011 data (green) and from 2012 data (July 4)

[*R. Benbrik, M. Gomez Bock, S. Heinemeyer,O. Stål, G. W., L. Zeune '12*]



$\Rightarrow$ Sizable enhancement possible around 126 GeV for h and H

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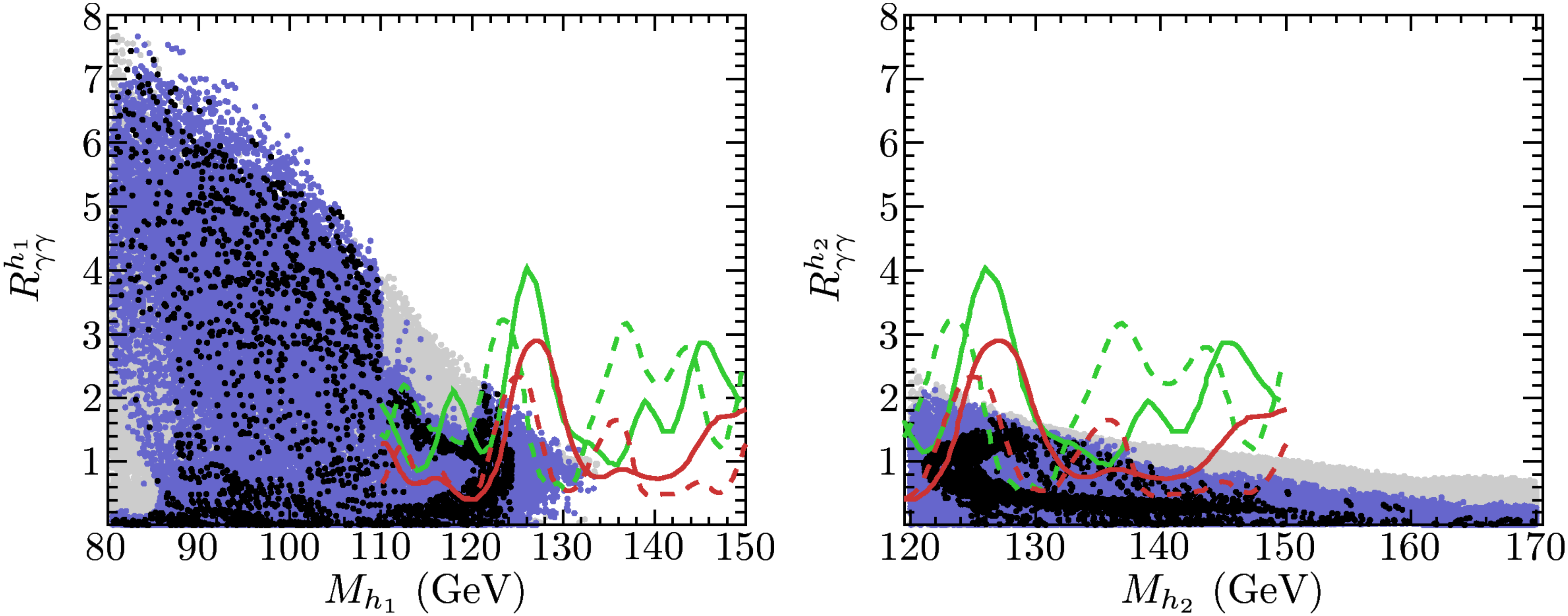


$\Rightarrow$ Sizable enhancement possible for ~ 126 GeV for h_1 and h_2

Possible mechanisms for enhancing the $\gamma\gamma$ rate in the MSSM

- Enhancement of $\Gamma(h, H \to \gamma\gamma)$:
  loop contributions from light staus, ...

- Suppression of Higgs (h, H) coupling to $b\bar{b}$:
  $\Rightarrow$ Enhancement of $\mathrm{BR}(h, H \to \gamma\gamma)$

$$\frac{g_{hb\bar{b}}}{g_{H_{\mathrm{SM}}b\bar{b}}} = \frac{1}{1+\Delta_b}\left(-\frac{\sin\alpha_{\mathrm{eff}}}{\cos\beta} + \Delta_b\frac{\cos\alpha_{\mathrm{eff}}}{\sin\beta}\right)$$

Suppression of $g_{hb\bar{b}}$ because of large Higgs propagator-type corrections ($\to$ small α_{eff}) or large correction to the relation between m_b and the bottom Yukawa coupling (Δ_b) [similar for H]

Experimental situation for $\tau^+\tau^-$ and $b\bar{b}$ channels still inconclusive

Additional mechanism in the NMSSM

Additional mechanism for suppression of Higgs coupling to $b\bar{b}$ in the NMSSM:

Mixing of Higgs singlet to doublet fields can result in small H_d component

$\Rightarrow$ coupling to down-type fermions suppressed

MSSM fit

[P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, G. W., L. Zeune '12]

- Scanning over 7 MSSM parameters (~10 million points)
- Standard χ^2 method:

$$\chi^2 = \sum_{i=1}^{N_{\rm obs}} \frac{(R_i - \hat{R}_i)^2}{\sigma_i^2} + \frac{(M_h - M_h^{\rm ref})^2}{\Delta M_h^2}$$

$$M_h^{\rm ref} = 125.7 \text{ GeV}$$
$$\Delta M_h = 1 \text{ GeV}$$
$$\text{SM: } R_i = 1$$

$$N_{\rm obs} = N_{\rm ATLAS} + N_{\rm CMS} (+N_{\rm others})$$

Tevatron data not included yet!

- χ^2 calculated with/without B-physics observables and $(g-2)_\mu$
- MSSM Higgs decay rates calculated with channel efficiencies as weights

Weights available only for $\gamma\gamma$
Naive prediction for other channels

$$R_{xx} = \frac{\sum_k w_k \sigma_k \times BR(h \to xx)}{\sum_k w_k \, \sigma_k^{SM} \times BR(h \to xx)^{SM}}$$

Additional constraints applied and further observables used in the fit

- “Hard” limits (not included in χ^2):

  - Higgs constraints at 95% CL (up to LHC-7) : HiggsBounds [3.8.0]

  - Sparticle masses from the PDG

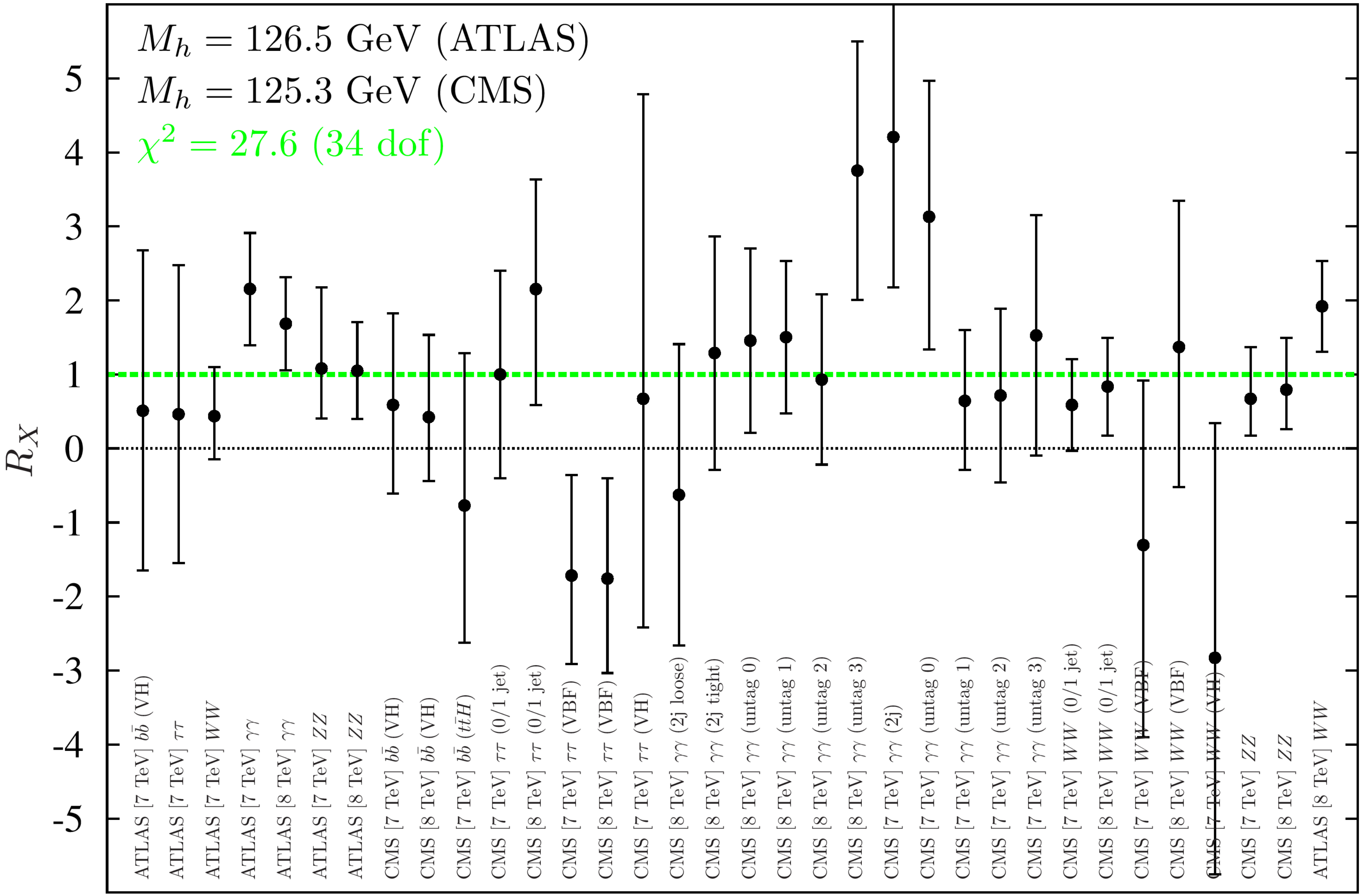
  - Neutral LSP (but no CDM constraint applied)

- χ^2 evaluated with / without B-physics observables and $(g\text{-}2)_\mu$:

Observable	Experiment	SM prediction	Total unc. used
$\mathrm{BR}(B \to X_s\gamma)_{E_0>1.6\,\mathrm{GeV}}$	$(3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$	$(3.08 \pm 0.24) \times 10^{-4}$	0.7×10^{-4}
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$< 4.5 \times 10^{-9}$ (95% CL)	$3.5 \pm 0.4 \times 10^{-9}$	0.5×10^{-9}
$\mathrm{BR}(B \to \tau^+\nu_\tau)$	$(1.64 \pm 0.34) \times 10^{-4}$	$(1.01 \pm 0.29) \times 10^{-4}$	0.45×10^{-4}
δa_μ	$(30.2 \pm 8.8) \times 10^{-10}$	0	9×10^{-10}

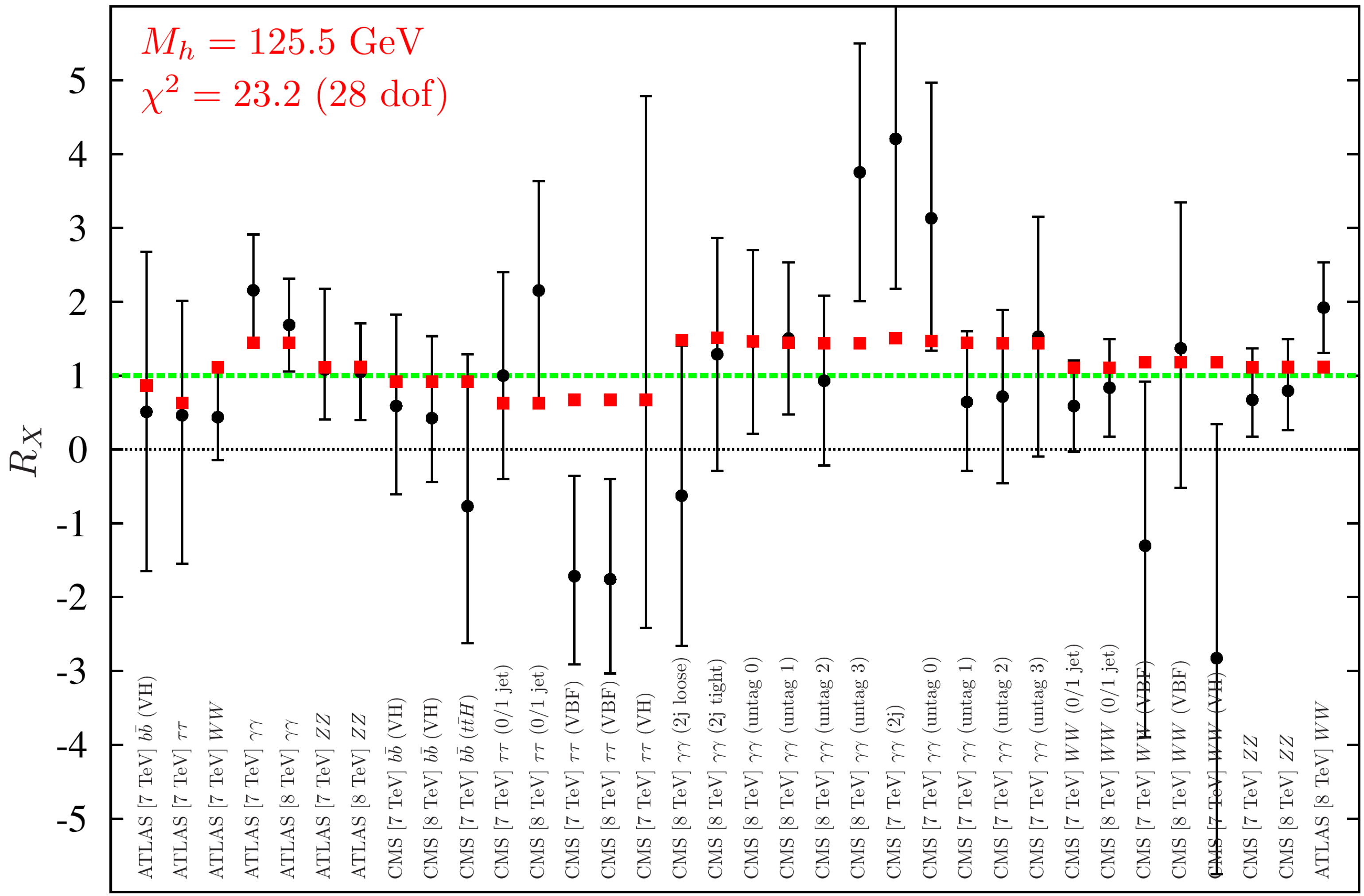
F. Mahmoudi [SuperIso v. 3.2]
http://superiso.in2p3.fr

SM fit to the LHC data set



MSSM fit to the LHC data set, interpretation of observed signal in terms of light Higgs h

• LHC data, ■ MSSM best fit



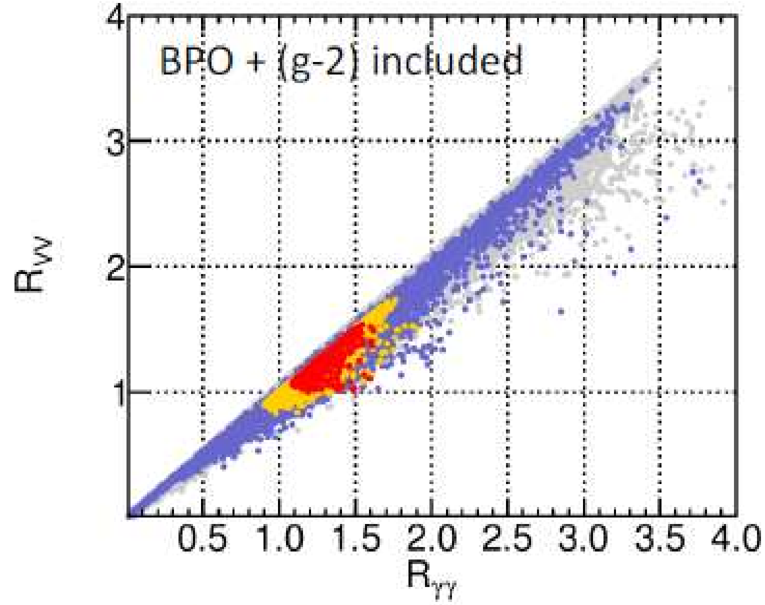
$\Rightarrow \chi^2$ reduced compared to SM case

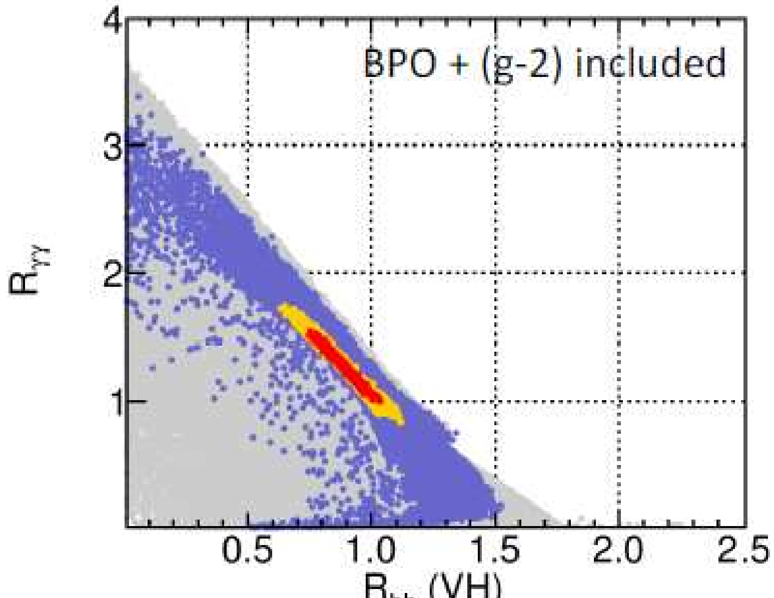
Rates in different channels normalised to the SM

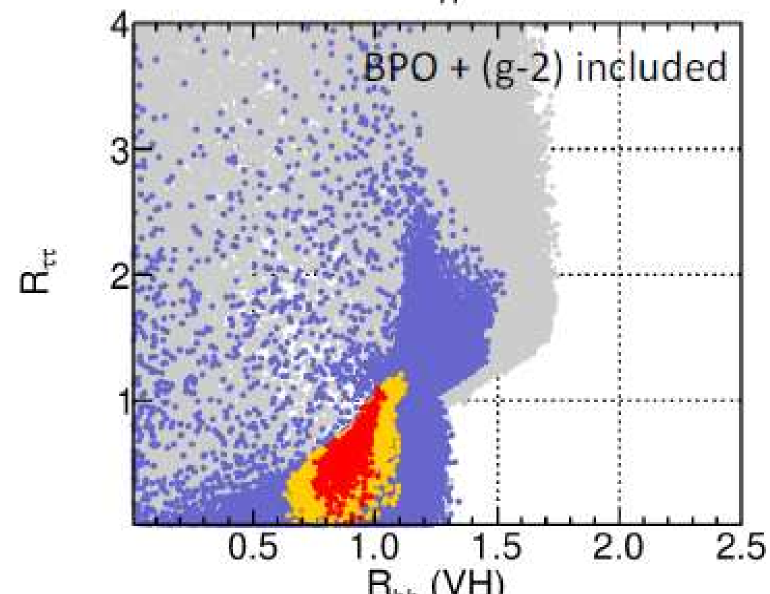
Rate modifiers

- All points: $121 < M_h < 129$ GeV
- Allowed by HiggsBounds
- $\Delta\chi^2 < 2.30$
- $\Delta\chi^2 < 5.99$

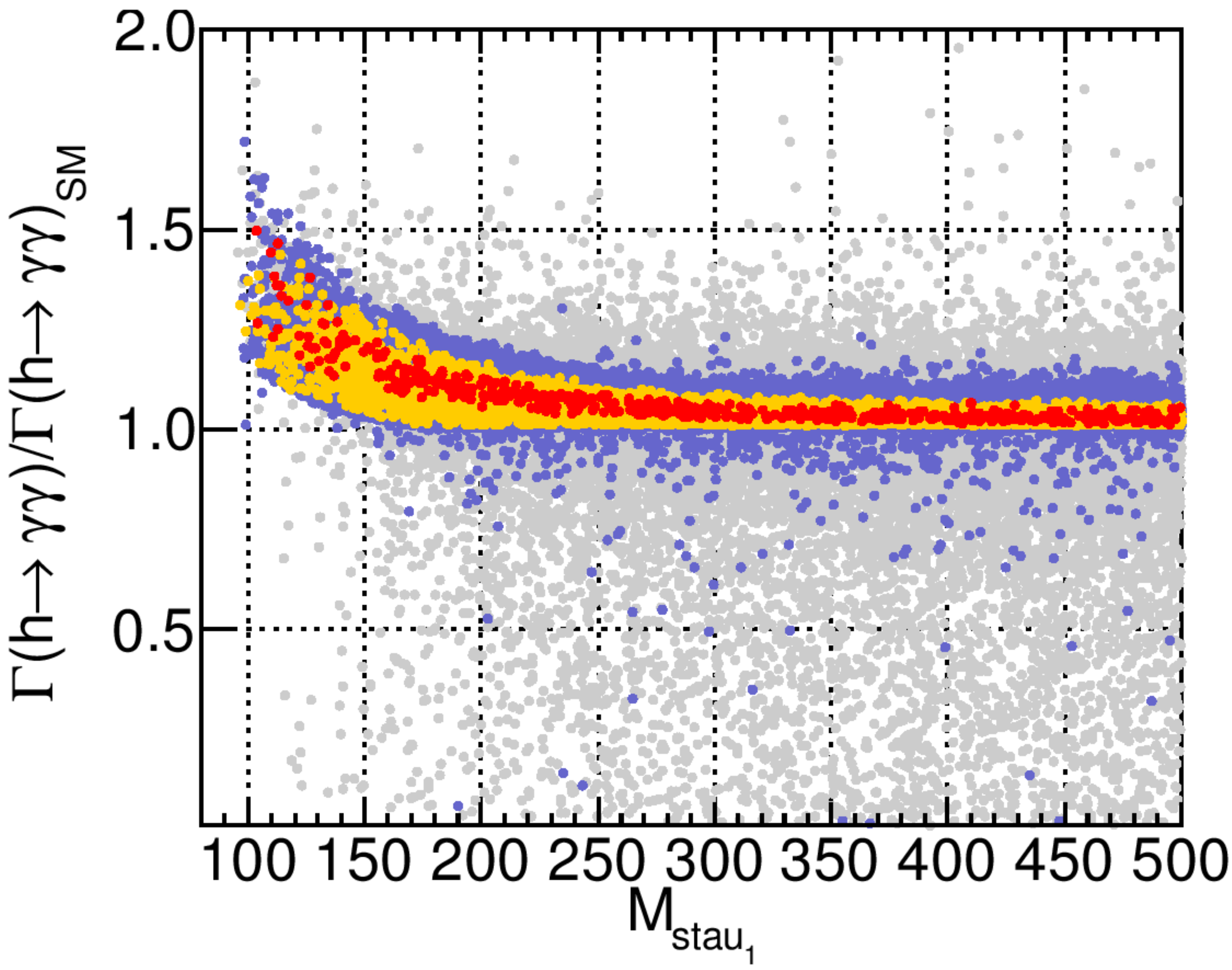
$$\Delta\chi^2 = \chi^2 - \chi^2_{\rm min}$$





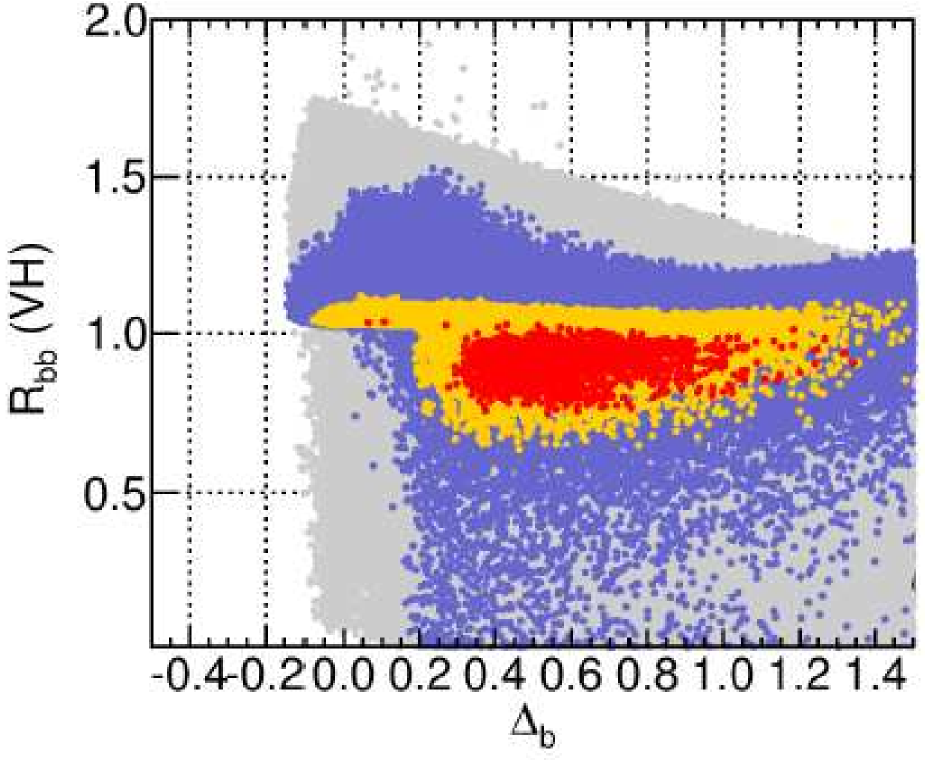


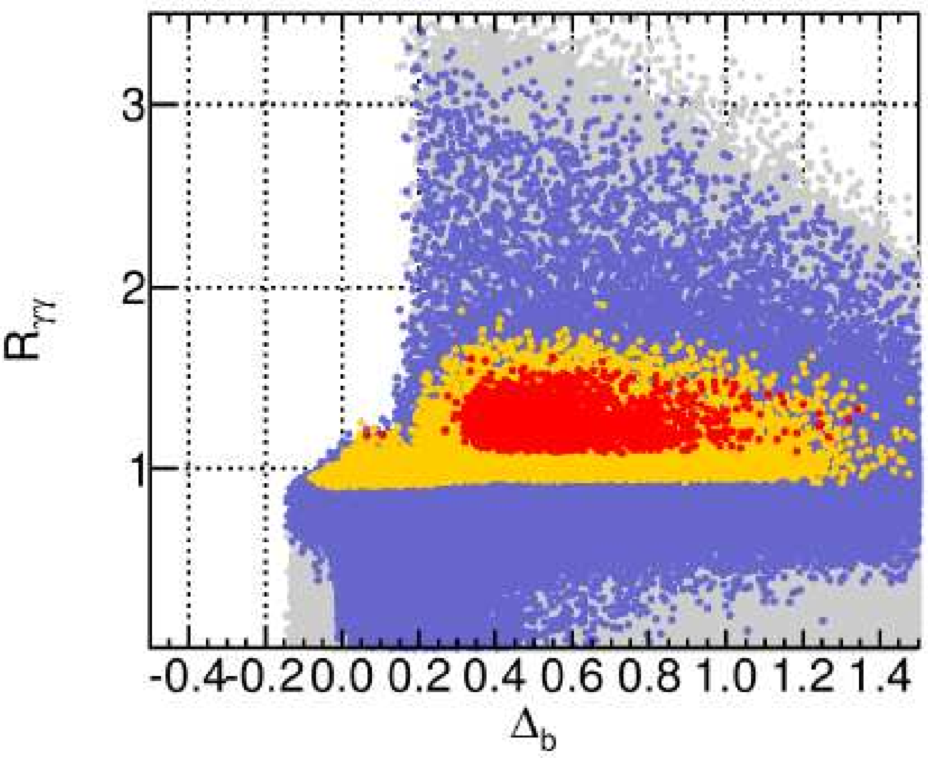
Enhancement of $\gamma\gamma$ partial width from light staus



$\Rightarrow$ Light staus can lead to significant enhancement

Impact of Δ_b corrections

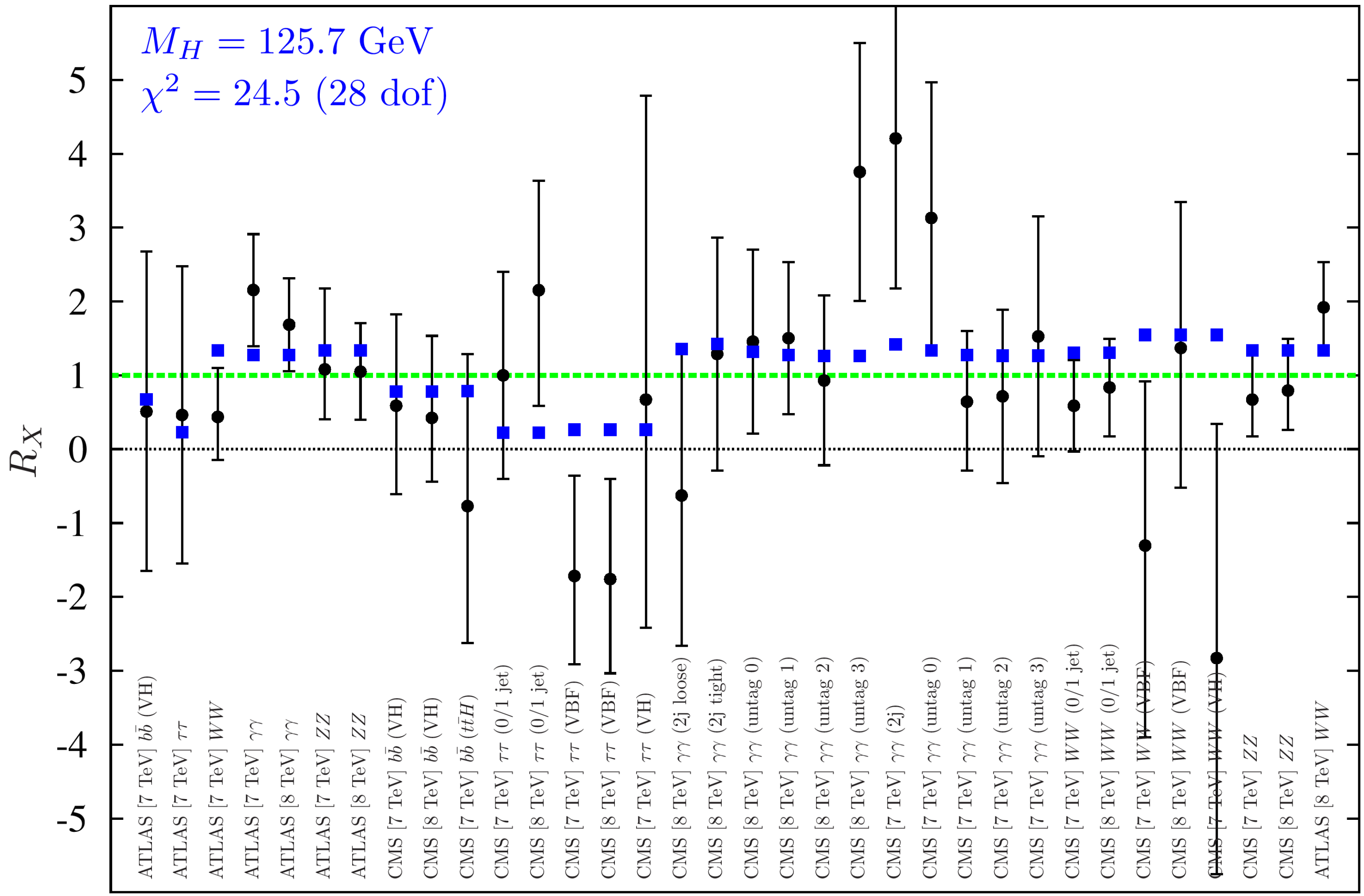




$\Rightarrow$ Intermediate and large values of Δ_b are favoured

MSSM fit to the LHC data set, interpretation of observed signal in terms of heavy Higgs H

- LHC data, ■ MSSM best fit



$\Rightarrow \chi^2$ is only slightly worse that for interpretation in terms of h

Fit results: comparison of SM with MSSM–h and MSSM–H

	Only LHC data				LHC + BPO + $(g\text{-}2)_\mu$			
Case	min χ^2	dof	χ^2/dof	p	min χ^2_{tot}	dof	χ^2_{tot}/dof	p
SM	27.6	34	0.811	0.77	42.3	38	1.11	0.29
MSSM-h	23.2	28	0.828	0.72	28.3	32	0.886	0.65
MSSM-H	24.5	28	0.874	0.65	31.0	32	0.969	0.52

$$\text{dof} = N_{\text{obs}} - N_{\text{para}}$$

$\Rightarrow$ Good fit probabilities

No clear preference between SM and MSSM, both for interpretation in terms of h and H

SUSY interpretation

Interpretation of the observed signal at $\sim 126\ \mathrm{GeV}$:
SM, SUSY, . . .

Interpretation in SUSY possible in terms of the lightest (MSSM: h, NMSSM: h_1, . . . ; has SM-like behaviour in the decoupling limit, $M_\mathrm{A} \gg M_\mathrm{Z}$) and the next-to-lightest (MSSM: H, NMSSM: h_2, . . .) neutral Higgs

Latter possibility would imply an additional non-SM like light Higgs, often has mass below the LEP limit of $M_{\mathrm{H}_\mathrm{SM}} > 114.4\ \mathrm{GeV}$ (with reduced couplings to gauge bosons, in agreement with LEP bounds)

$\Rightarrow$ It is important to extend the LHC Higgs searches to the region below $114\ \mathrm{GeV}$!

Not only the observed signal at $\sim 126\ \mathrm{GeV}$ but also the latest limits have important impact on MSSM Higgs searches

Limits in M_A–$\tan\beta$ plane of the MSSM:

- LEP limits: highest sensitivity for small M_A and / or small $\tan\beta$
- LHC limits from $H, A \to \tau^+\tau^-$ search: highest sensitivity for small M_A and / or large $\tan\beta$

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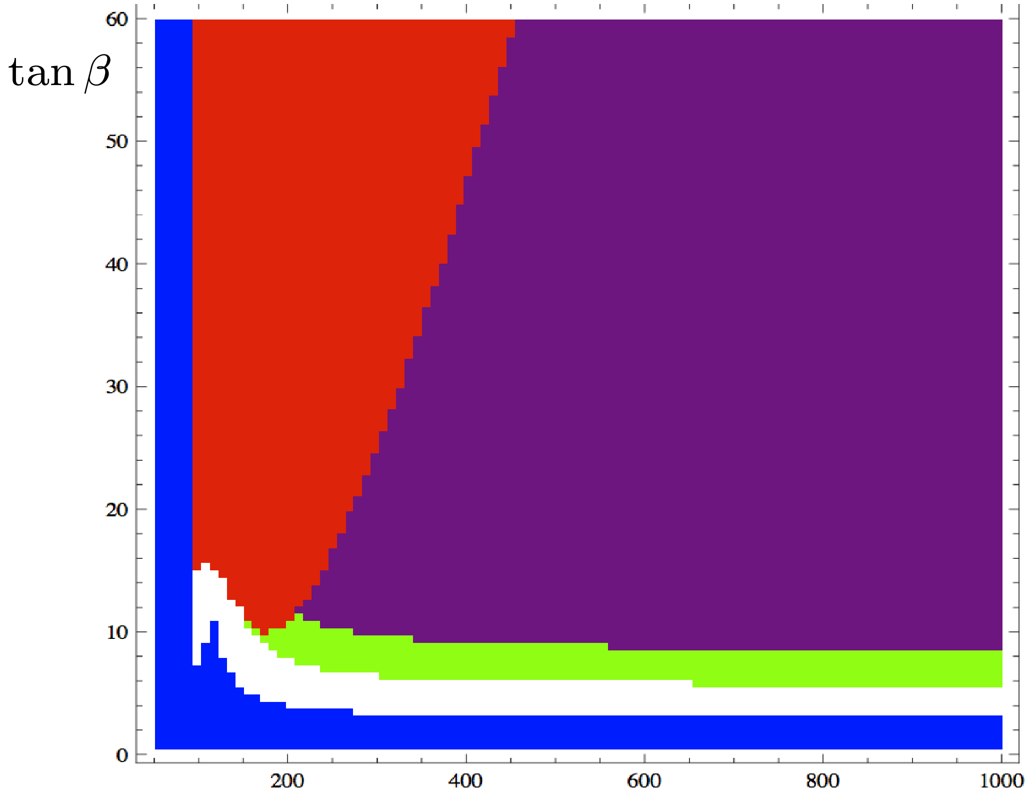
- LHC limits from SM Higgs search: rules out region outside of $123\ \mathrm{GeV} \lesssim M_{\mathrm{H}_\mathrm{SM}} \lesssim 127\ \mathrm{GeV}$

  $\Rightarrow$ Depending on the mixing in the $\tilde{\mathrm{t}}$ sector, limits can lead to exclusion in decoupling region, $M_\mathrm{A} \gg M_\mathrm{Z}$

Modified m_h^{max} ***scenario:*** $X_t = 1300$ GeV

[Y. Linke, G. W. '12]



M_A [GeV]

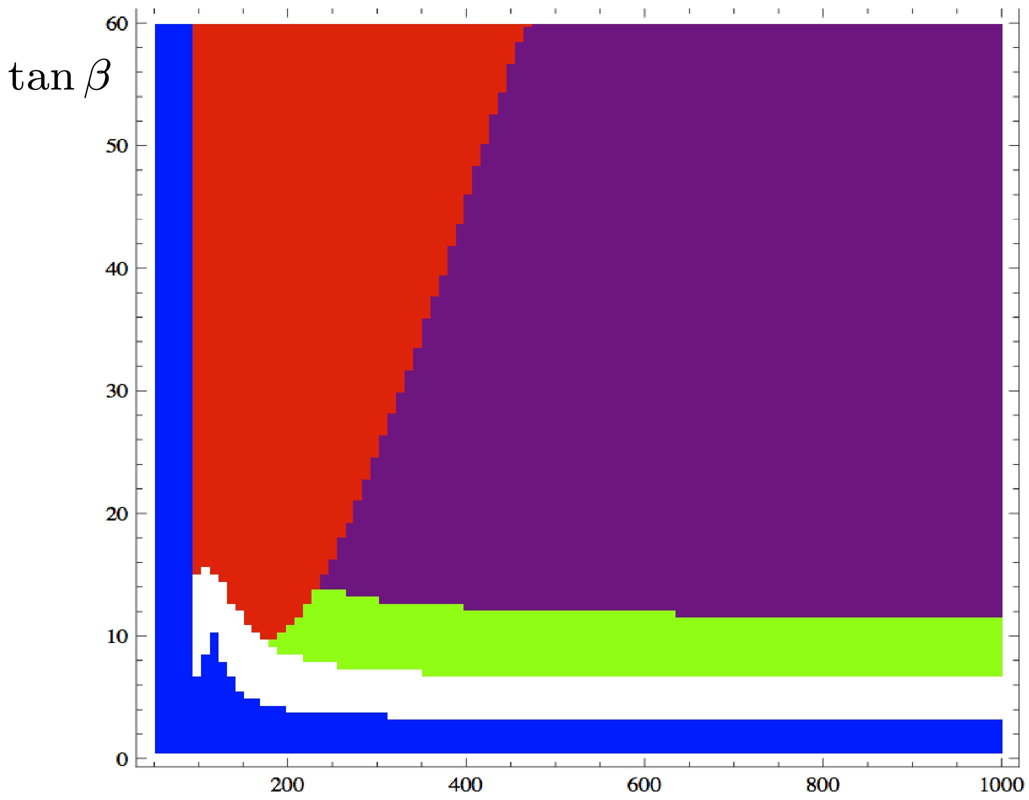
(■) : Excluded by LHC, (■) : Excluded by LEP

(■) : $M_h = 125.5 \pm 1$ GeV, (■) : $M_h = 125.5 \pm 3$ GeV

$\Rightarrow$ Large region compatible with signal at $M_h \approx 126$ GeV

Modified m_h^{max} ***scenario:*** $X_t = -1500$ GeV

[Y. Linke, G. W. '12]



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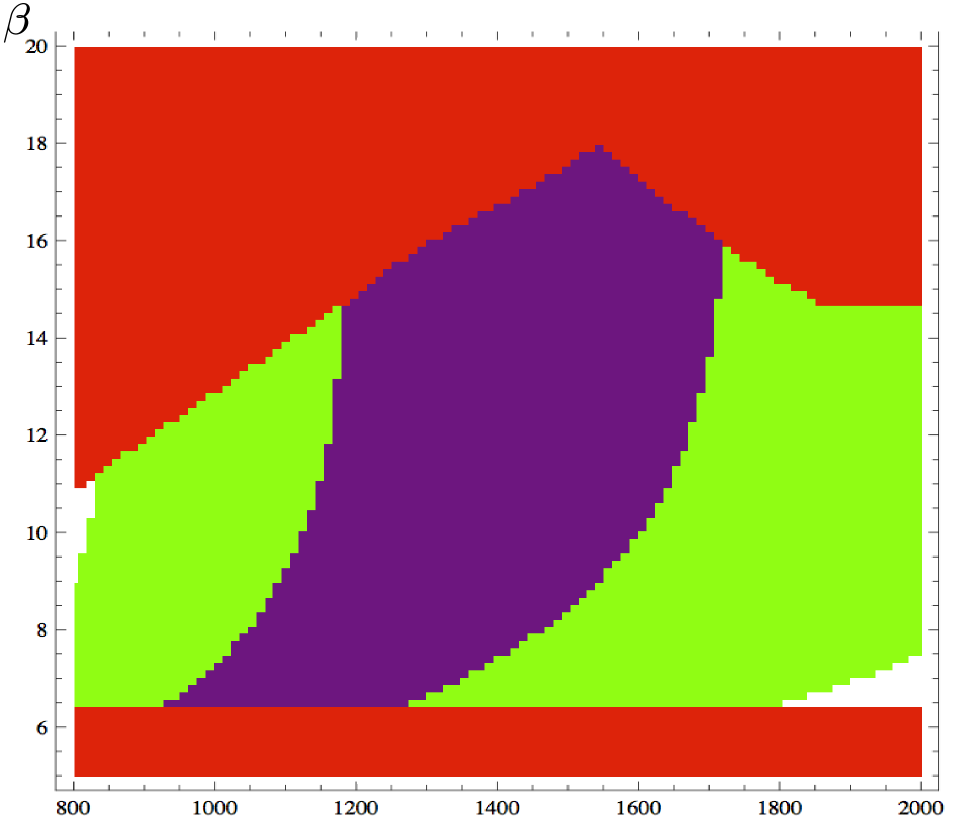
Benchmark scenario where signal at 126 GeV *is interpreted as the heavy* $\mathcal{CP}$*-even MSSM Higgs*

$M_{\rm SUSY}$ varied, $X_{\rm t} = -1.5 M_{\rm SUSY}$, $\mu = 2 M_{\rm SUSY}$ [*Y. Linke, G. W. '12*]



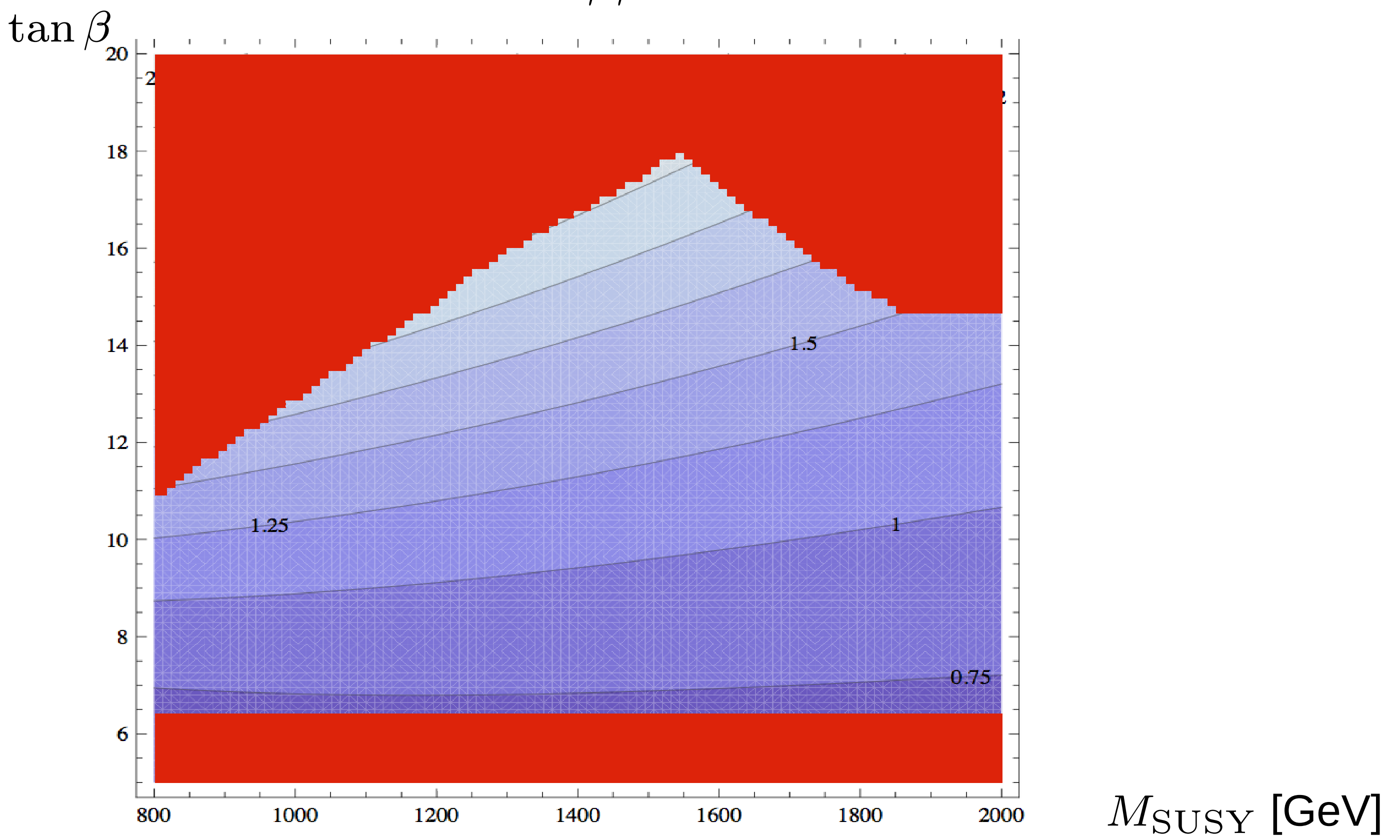
(■) : Excluded by LHC, (■) : Excluded by LEP

(■) : $M_{\rm H} = 125.5 \pm 1$ GeV, (■) : $M_{\rm H} = 125.5 \pm 3$ GeV

$\Rightarrow$ Large region compatible with signal at $M_{\rm H} \approx 126$ GeV

Benchmark scenario where signal at $126\ \mathrm{GeV}$ *is interpreted as the heavy* $\mathcal{CP}$*-even MSSM Higgs*

$\gamma\gamma$ rate relative to SM: $R_{\gamma\gamma}$ [*Y. Linke, G. W. '12*]



(■) : Excluded by LHC, (■) : Excluded by LEP

(■) : $M_\mathrm{h} = 125.5 \pm 1\ \mathrm{GeV}$, (■) : $M_\mathrm{h} = 125.5 \pm 3\ \mathrm{GeV}$

$\Rightarrow R_{\gamma\gamma} \gtrsim 1$ possible

Conclusions

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- Similar fit probabilities for SM, MSSM–h and MSSM–H
- $m_{\rm h}^{\rm max}$ benchmark scenario can easily be modified to be compatible with observed signal at $\sim 126\ \mathrm{GeV}$

Backup

Comparison of ATLAS analysis with HiggsSignals

[P. Bechtle, O. Brein, S. Heinemeyer, O. Stål, T. Stefaniak, G. W., K. Williams ’12]

- scale cross sections by factors $\mu_{ggF+ttH}$ and μ_{VBF+VH}.
- fix all partial widths to SM value.
- ATLAS: Combination of all 10 categories of $H \to \gamma\gamma$ search.
- HiggsSignals: Combination of *untagged* and *VBF-tagged* categories.

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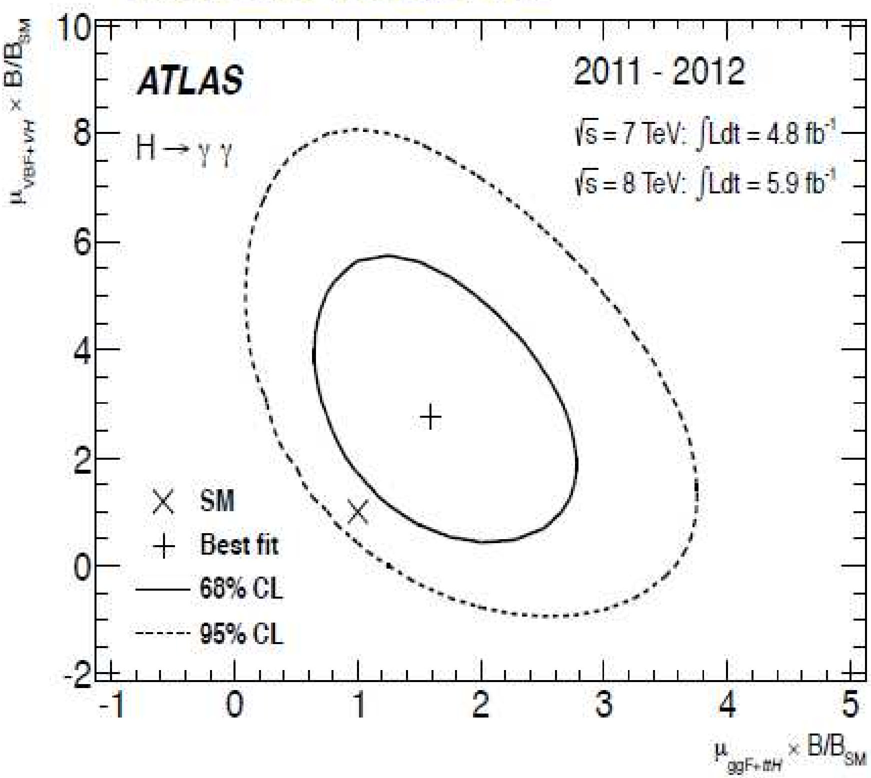
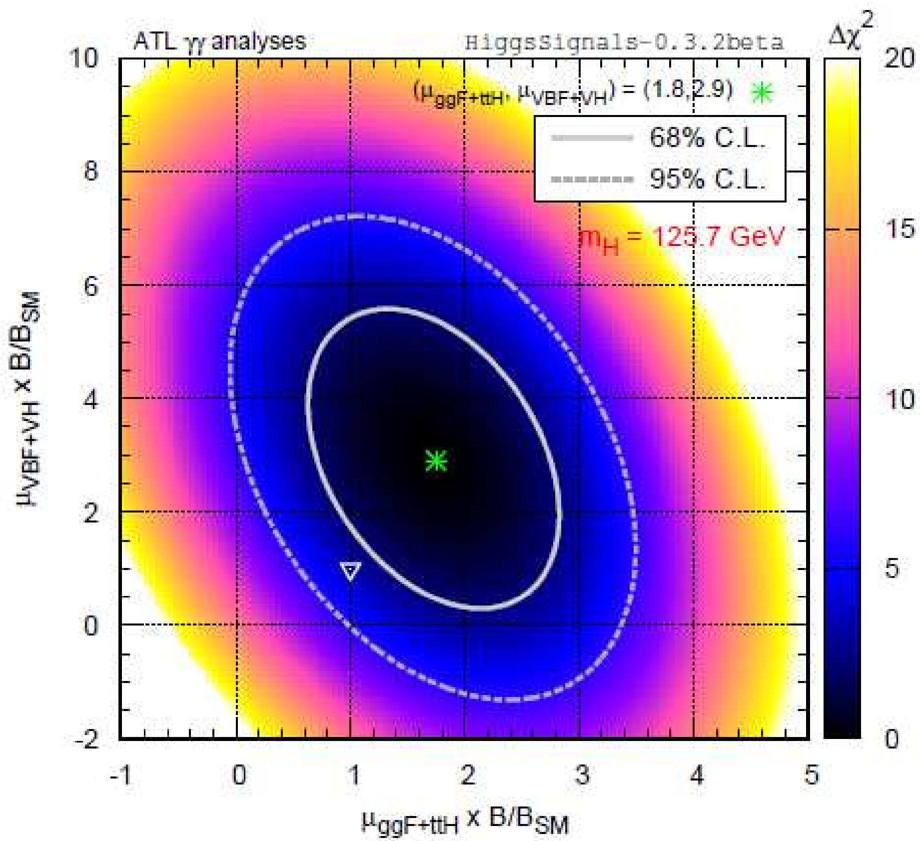
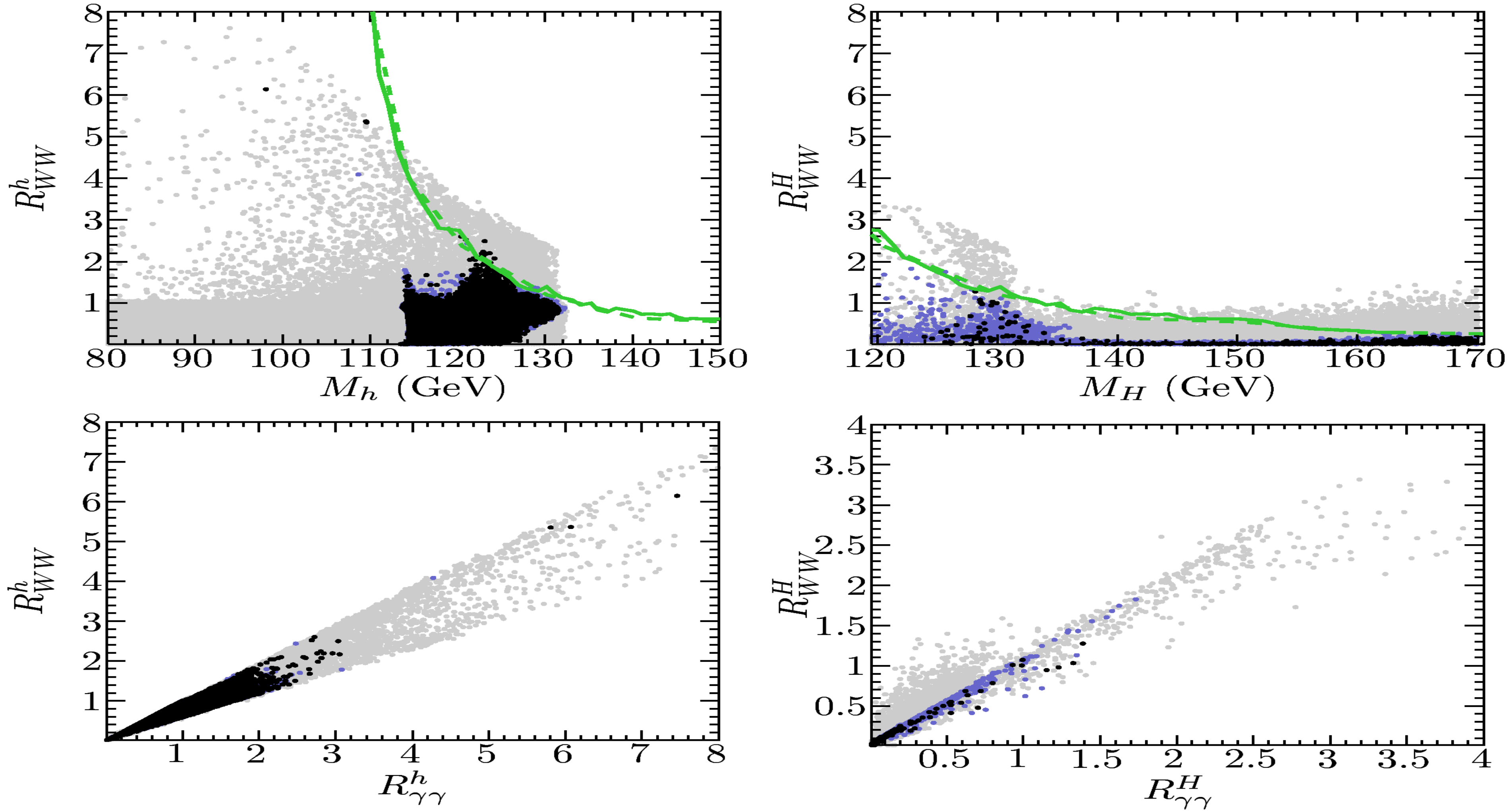




Comparison with WW^* channel



$\Rightarrow$ Strong correlation, but enhanced $\gamma\gamma$ rate possible for SM-like (or even slightly suppressed) WW^* rate

Some details of the fit

- Random scan of 7 "pMSSM" parameters (~10 M points) (+m_t varied in 2σ interval)

	Min	Max
M_A	90	1000
$\tan\beta$	1	60
M_{Q_3}	200	1500
A_t	$-3\,M_{Q_3}$	$3\,M_{Q_3}$
μ	200	3000
M_{L_3}	200	1500
M_2	200	500

$$M_{Q_{1,2}} = M_{U_{1,2}} = M_{D_{1,2}} = 1\,\text{TeV}$$
$$M_{D_3} = M_{U_3} = M_{Q_3}$$
$$M_{L_{1,2}} = M_{E_{1,2}} = 300\,\text{GeV}$$
$$M_{E_3} = M_{L_3}$$
$$A_b = A_\tau = A_t$$
$$M_3 = 1\,\text{TeV}$$

M_1 fixed by GUT relation

- MSSM predictions calculated using FeynHiggs [2.9.2]
  No additional MSSM uncertainties assumed on rates/xsections

- Two cases: either light or heavy CP-even Higgs @ 126 GeV

Details of the fit: input data

- Signal strength data R_X taken for *different* Higgs masses from ATLAS and CMS, corresponding to two best-fit values

- Normalized rate predictions compared at mass for experimental observation, regardless of calculated MSSM Higgs mass.
  -> incorporates MSSM uncertainty on the M_h prediction.

- Data treated separately for 7 and 8 TeV for consistent predictions.
  For ATLAS WW, ZZ only results for 7 TeV, 7+8 TeV is public

Espinosa, Grojean, Mühlleitner, Trott, [1207.1717]

8 TeV results "reconstructed" assuming uncorrelated Gaussians

$$\frac{(R_X)_{7+8}}{\sigma^2_{7+8}} = \frac{(R_X)_7}{\sigma^2_7} + \frac{(R_X)_8}{\sigma^2_8} \qquad \frac{1}{\sigma^2_{7+8}} = \frac{1}{\sigma^2_7} + \frac{1}{\sigma^2_8}$$

Example points from the fit

Parameter	$M_h \sim 126$ GeV	$M_H \sim 126$ GeV
M_A (GeV)	277.0	107.3
$\tan\beta$	17.49	15.88
M_{Q_3} (GeV)	567.46	738.79
A_t (GeV)	1344.	1733.
μ (GeV)	2400.	1411.
M_{L_3} (GeV)	1239.	953.6
M_2 (GeV)	459.5	245.9
Calculated		
M_h (GeV)	125.8	86.4
M_H (GeV)	235.7	125.4
M_A (GeV)	277.0	107.3
$M_{H^\pm}$ (GeV)	280.0	130.5

Higgs hunting: cross section limits vs. benchmark scenarios

Higgs searches at LEP, the Tevatron and the LHC:

Searches in different production and decay channels

Limits have been presented in two ways:

- For a specific model: SM, MSSM benchmark scen., ...
  $\Rightarrow$ combination of different channels possible

  difficult to interpret for other models or w.r.t. changes in the input parameters or the theoretical predictions

- As cross section limits for a certain search topology
  $\Rightarrow$ exclusion bounds have to be tested channel by channel

  fairly model-independent and generally applicable

Search for heavy neutral SUSY Higgs bosons

- Experimental results in the MSSM are usually interpreted in the plane of the parameters M_A, $\tan\beta$, which govern the Higgs sector at tree level

  Search for heavy SUSY Higgs bosons via $H, A \to \tau^+\tau^-$ has highest sensitivity for small M_A and large $\tan\beta$

- Higher-order corrections, Higgs decays into SUSY particles

  $\Rightarrow$ full structure of the SUSY model enters

  $\Rightarrow$ other parameters are fixed in certain "benchmark scenarios"

How are the benchmark scenarios affected by the latest results from the LHC and how robust are the limits in the M_A–$\tan\beta$ plane w.r.t. other SUSY effects?

Benchmarks used so far for Higgs searches at the Tevatron and the LHC ($\mathcal{CP}$-conserving case)

[*M. Carena, S. Heinemeyer, C. Wagner, G. W. '02*]

Scenarios for general MSSM, no specific SUSY-breaking scenario assumed, no external constraints, $M_{\rm A}$, $\tan\beta$ varied

- $m_{\rm h}^{\rm max}$-scenario: $X_{\rm t} = 2\,M_{\rm SUSY}$, $M_{\rm SUSY} = 1$ TeV, $\mu = +200\ {\rm GeV}$

  $\Rightarrow$ maximal $m_{\rm h}(\tan\beta)$ for fixed $m_{\rm t}$, $M_{\rm SUSY}$

- no-mixing scenario: $X_{\rm t} = 0$, $M_{\rm SUSY} = 2$ TeV

- small $\alpha_{\rm eff}$ scenario:

  $M_{\rm SUSY} = 800\,{\rm GeV}$, $\mu = 2.5\,M_{\rm SUSY}$, $X_{\rm t} = -1100$ GeV

  $\Rightarrow$ suppression of $h \to b\bar{b}$, $h \to \tau\tau$

- gluophobic Higgs scenario: $M_{\rm SUSY} = 350$ GeV, $X_{\rm t} = -750$ GeV

  $\Rightarrow$ suppression of $gg \to h$

Most widely used: $m_{\mathrm{h}}^{\mathrm{max}}$*-scenario*

Maximal $m_{\mathrm{h}}(\tan\beta)$ for fixed m_{t}, M_{SUSY}

$\Rightarrow$ Most conservative limits from LEP

Limits from $H, A \to \tau^+\tau^-$ searches at the LHC and the Tevatron are rather robust w.r.t. variations of the SUSY parameters

$\Rightarrow$ $m_{\mathrm{h}}^{\mathrm{max}}$-scenario has been the standard for presenting LHC results up to now

Note: limits from $H, A \to b\bar{b}$ searches have a much higher sensitivity to variations of the SUSY parameters