Prospects of Higgs boson scenarios beyond the SM

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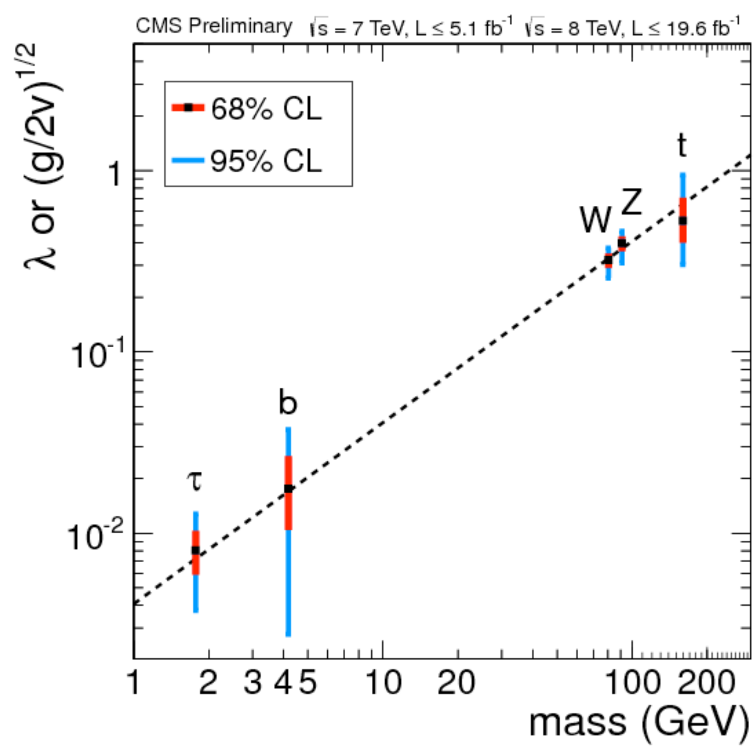
The LHC boson looks like the SM Higgs

ATLAS and CMS

- The new particle is seen in multiple production modes and decay channels, including those with vector bosons
  → Very likely related to electroweak symmetry breaking

- Its couplings are consistent with a SM Higgs boson (within current uncertainties)

- Impressive progress in the last year to determine properties in detail



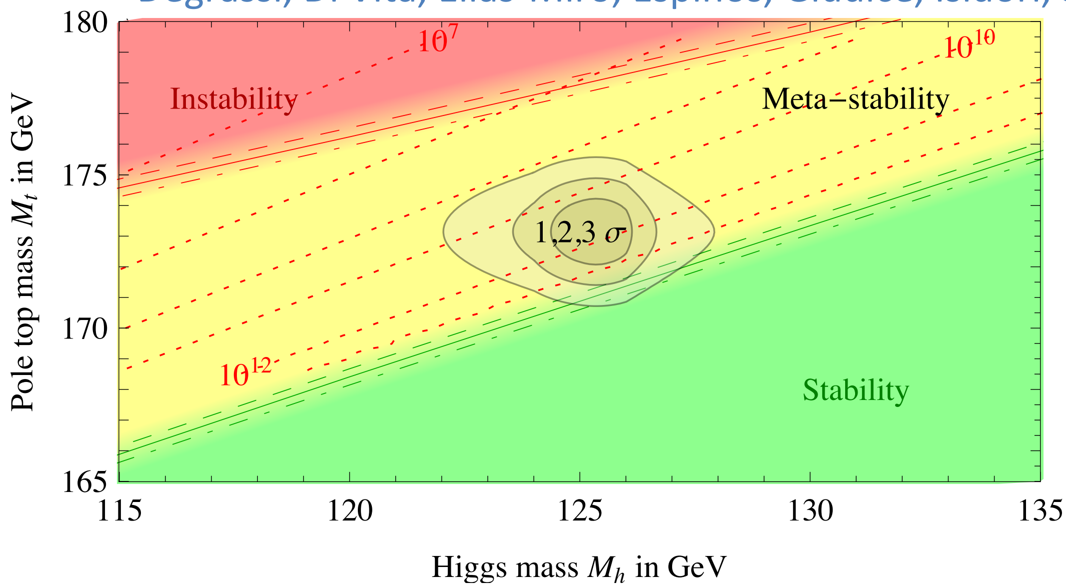
The LHC boson looks like the SM Higgs

- The measured resonance mass is about 125 GeV
(not predicted in SM, but in agreement with EW precision tests)

- Spin/CP-properties consistent with CP-even scalar
(not discussed in more detail here)

- 125 GeV implies that the EW vacuum can be stable up to high scale, with metastability (long lifetime) possible up to 10^{16} GeV

Degrassi, Di Vita, Elias-Miro, Espinos, Giudice, Isidori, Strumia, [1205.6497]



But BSM arguments have not changed (much)

- Quadratic instability of scalar mass under quantum corrections (hierarchy/naturalness/fine-tuning problem)
- No SM candidate for dark matter of the universe
- Amount of CP-violation not consistent with baryogenesis
- No unification of the fundamental forces
- No way to incorporate gravity in a consistent theory

-> Several of these points can be addressed by introducing new physics at the TeV scale, and often involves modification of the SM Higgs sector → BSM Higgs scenarios.

At the LHC we have not seen

- Signs of this new physics, as predicted by BSM theories:
- Jet resonances (strongly interacting particles, "black holes", …)
- New dilepton resonances (Z', W')
- Supersymmetric particles / dark matter candidates
- Evidence for BSM physics in rare flavour (e.g. $B_s \to \mu^+\mu^-$)

→ Constraints on BSM Higgs scenarios

NB: LHC non-observations are necessarily *not incompatible* with a SM-like Higgs in BSM scenarios, but challenges *naturalness arguments*

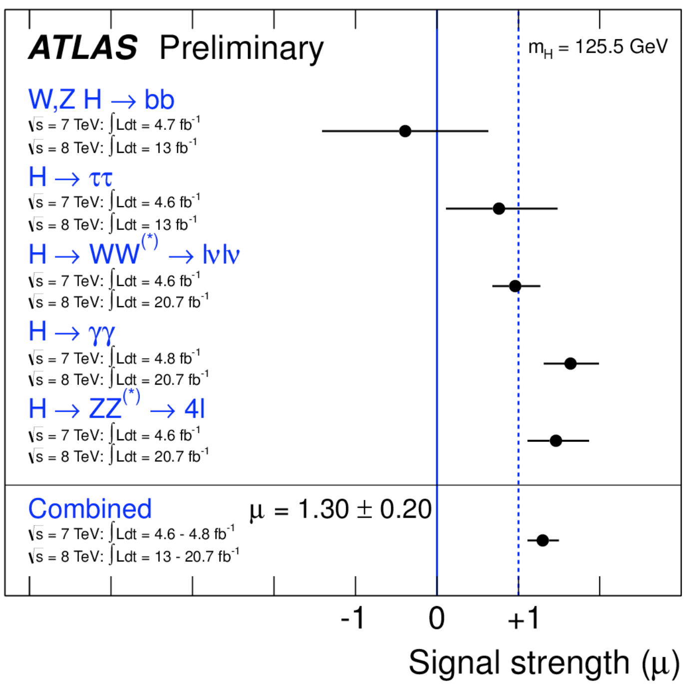
Direct constraints on BSM Higgs scenarios

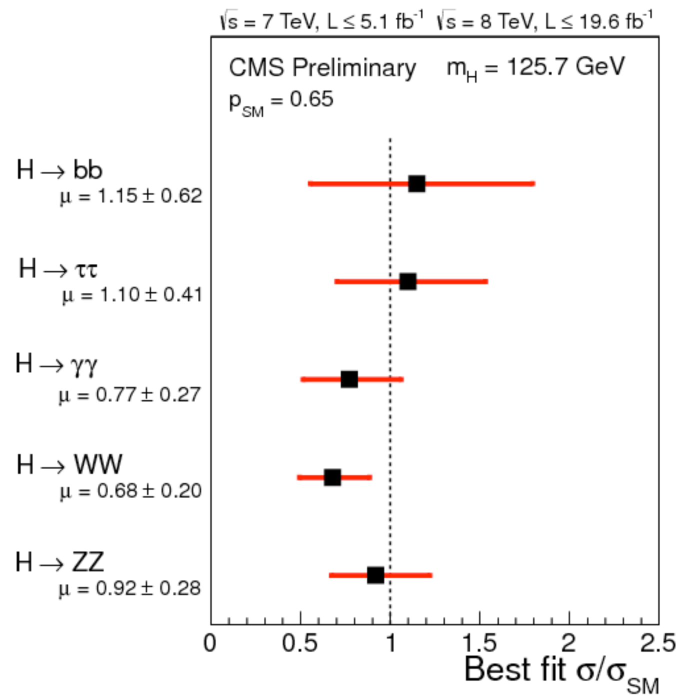
- The Higgs mass constrains only theories with mass prediction

ATLAS: $M_h = (125.5 \pm 0.2 \pm 0.6)\,\mathrm{GeV}$

CMS: $M_h = (125.3 \pm 0.4 \pm 0.5)\,\mathrm{GeV}$

- Signal strengths constrains *all* BSM Higgs scenarios





Some BSM Higgs scenarios

1. Higgsless scenarios
   → Strong WW scattering, …
   Disfavored by Higgs discovery

2. Weakly interacting scenarios (fundamental scalar)
   → Minimial supersymmetry (MSSM)
   → Non-minimal supersymmetry
   → Simple extensions of the SM Higgs sector (2HDM, …)
   → …

3. Scenarios with strong interactions
   → Technicolor
   → Composite Higgs
   → …

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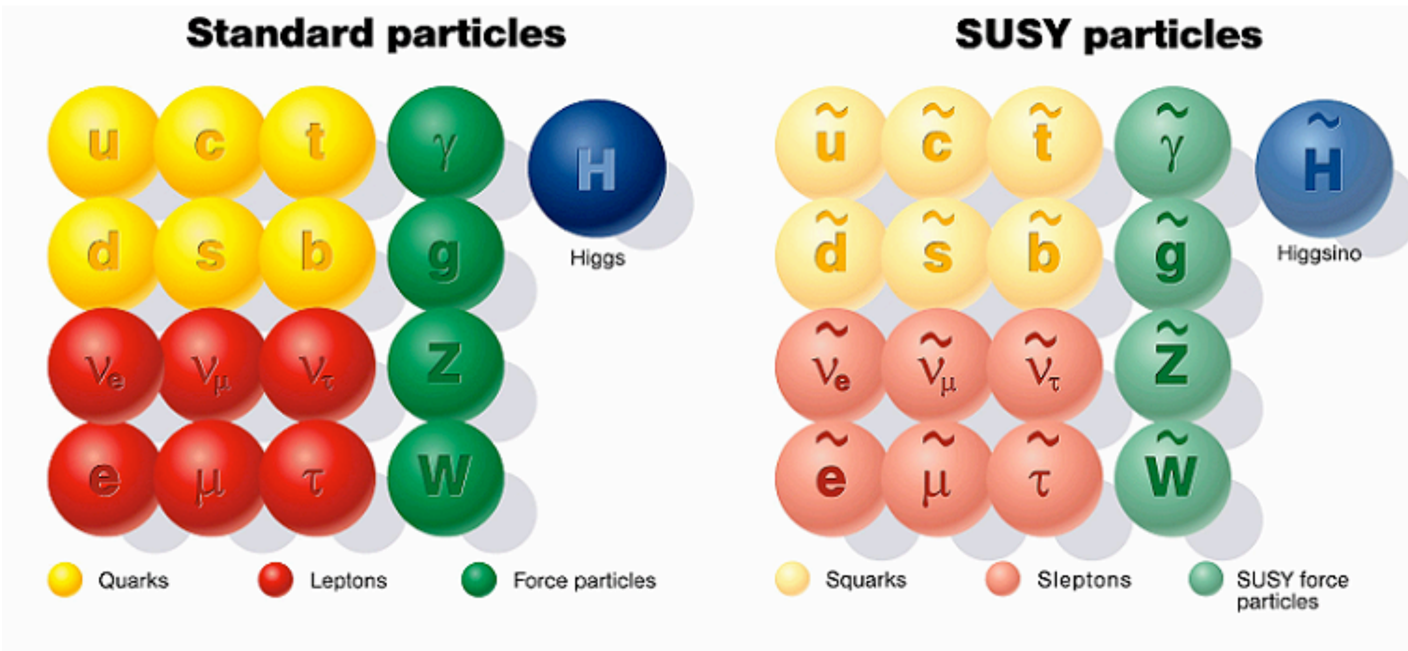
Supersymmetry

- Unique extension of space-time symmetry to include spin

$$Q|\text{Fermion}\rangle = |\text{Boson}\rangle \qquad Q|\text{Boson}\rangle = |\text{Fermion}\rangle$$

- Doubling the particle content of the SM



- Complete framework to address many shortcomings of the SM

MSSM Higgs sector

- Minimal Supersymmetric Standard Model (MSSM)
  Minimal particle content (double SM) + Minimal interactions

- Two complex Higgs Doublets: $H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \quad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$

$$V = (m_{H_u}^2 + |\mu|^2)|H_u|^2 + (m_{H_d}^2 + |\mu|^2)|H_d|^2 + B\mu(H_u \cdot H_d + \text{h.c.})$$
$$+ \frac{g^2 + g'^2}{8}(|H_u|^2 - |H_d|^2) + \frac{g^2}{2}|H_d^\dagger H_u|^2$$

- SUSY: Quartic couplings in potential fixed by gauge couplings

- 8 scalar degrees of freedom, 5 physical Higgs bosons (SM: 4, 1)

With CP conservation: h, H (CP-even), $m_H > m_h$, mixing α
A (CP-odd), and
$H^\pm$ charged Higgs

MSSM Higgs masses

- At tree-level, the MSSM Higgs sector is determined by two parameters:

$$M_A, \tan\beta \quad \underline{\text{or}} \quad M_{H^\pm}, \tan\beta$$

$$\tan\beta = \frac{v_u}{v_d}$$

$$v_u^2 + v_d^2 = v^2 \simeq (174\,\mathrm{GeV})^2$$

- Other Higgs masses are *predictions*:

$$M_{h,H}^2 = \frac{1}{2}\left[M_A^2 + M_Z^2 \mp \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}\right]$$

$$\tan 2\alpha = \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2}\tan 2\beta$$

$$M_{h,\mathrm{tree}}^2 \leq M_Z^2 \cos^2 2\beta \leq M_Z^2$$

$$M_{H^\pm}^2 = M_A^2 + M_W^2$$

Tree-level mass of M_h too low compared to experiment!

Higgs masses beyond leading order

- Radiative corrections to MSSM Higgs masses sizeable

$$M_h^2 = M_{h,\text{tree}}^2(M_A, \tan\beta) + \Delta M_h^2\,(M_{\text{SUSY}}, A_i, M_i, \ldots)$$

- Beyond leading order, the full SUSY spectrum enters determination of Higgs masses.

- Soft SUSY-breaking parameters

Scalar masses	M_{SUSY} or M_{Q_3}, M_{L_3}, etc.
Gaugino masses	$M_i \quad (i = 1 \ldots 3)$
Trilinear scalar couplings	A_t, A_b, A_τ

- To make predictions for Higgs phenomenology, we need either
  i) a theory which predicts these parameters at the weak scale
  ii) some strategy to choose them directly

Fixing the soft-breaking parameters

Top-down

GUT-constrained models motivated by high-scale assumptions about how SUSY breaking is mediated

Ex: constrained MSSM (cMSSM, mSUGRA), GMSB, AMSB

Few input parameters, evolved from high- to low scale

$$m_0, m_{1/2}, A_0, \tan\beta, \mathrm{sgn}\,\mu$$

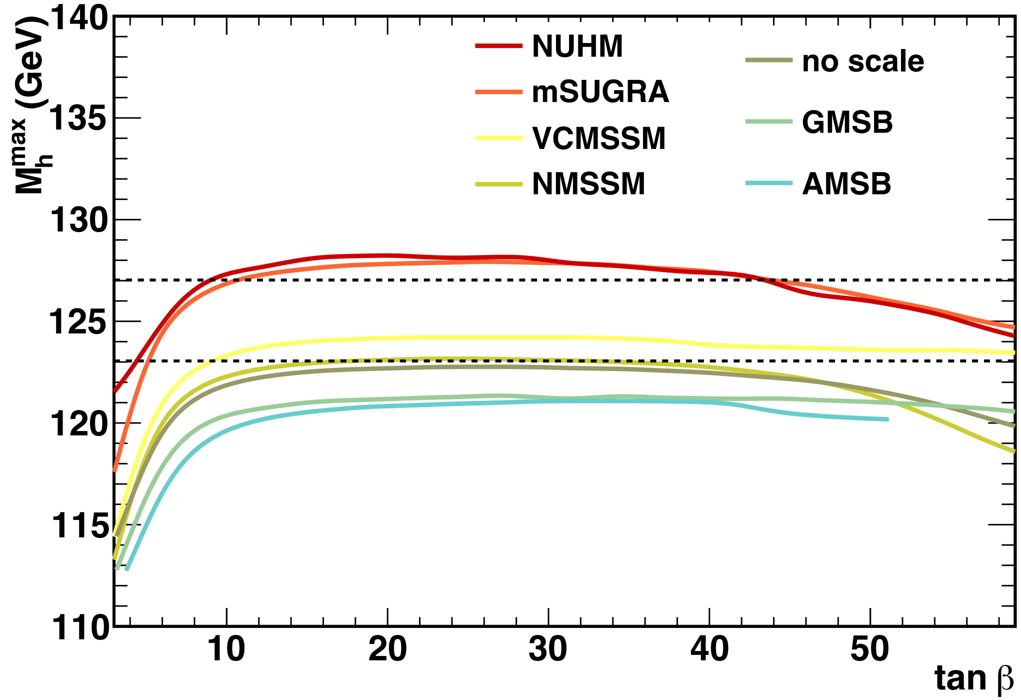
Bottom-up

Low-energy benchmark scenarios to study phenomenologically interesting aspects of the MSSM Higgs sector without reference to ‘higher’ model, “Phenomenological MSSM (pMSSM)”.

$$M_{\tilde{q}_i}, M_1, M_2, M_3, A_t, (A_b, A_\tau, \ldots), \mu, M_A, \tan\beta$$

Higgs mass in constrained SUSY models

- Minimal constrained (top-down) scenarios in general have difficulty to produce the required large Higgs mass



Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon, [1112.3028]

- Additional model-building possible to remedy the situation, but minimal scenarios for GMSB and AMSB challenged

Corrections to the lightest Higgs mass

- Public codes with known two-loop corrections implemented: FeynHiggs, SoftSusy, Suspect, Spheno, …
  Typical difference in calculated M_h (theory unc.) of a few GeV

- Leading corrections depend strongly on top/stop sector:

$$M_h^2 \sim M_Z^2 + \frac{3m_t^4}{2\pi^2 v_u^2}\left[\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

$$X_t = A_t - \mu\cot\beta \qquad\qquad M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

- Basis for 'no mixing' and 'M_h-max' benchmark scenarios

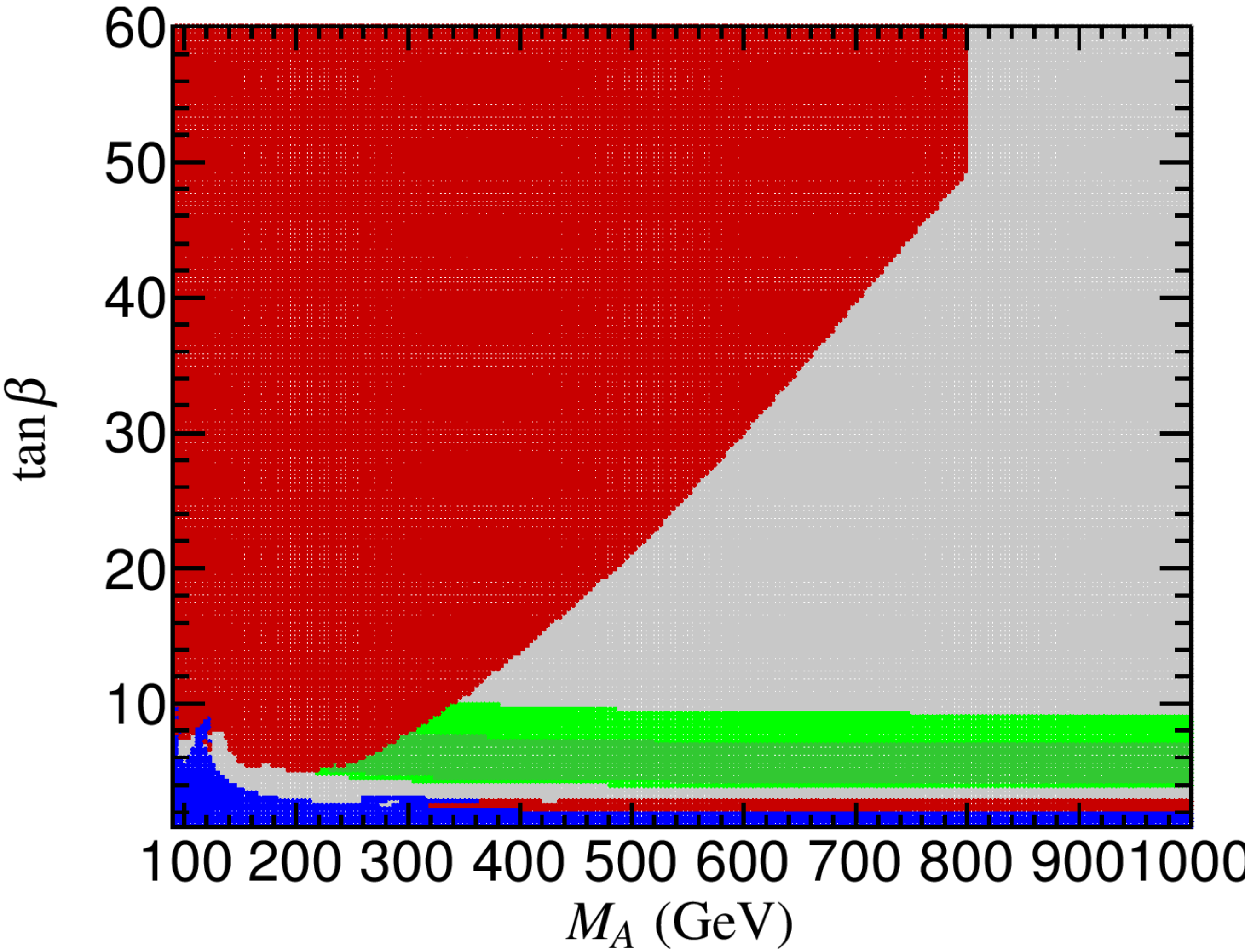
$$X_t = 0 \qquad\qquad M_h \lesssim 120\,\mathrm{GeV}$$

$$X_t^{\overline{\mathrm{DR}}} = \sqrt{6}M_S \qquad\qquad M_h \lesssim 135\,\mathrm{GeV}$$ Maximal value

Weak scale supersymmetry predicted a light Higgs boson!

Lower limits on MSSM parameters from Higgs mass

- Maximizing radiative corrections (for fixed $M_{\rm SUSY} = 1\,{\rm TeV}$) we can determine lower limits on tree-level parameters



LEP Excluded

LHC Excluded

M_h = 125.5+-2(3) GeV

$M_A \gtrsim 200\,{\rm GeV}$

$\tan\beta \gtrsim 4$

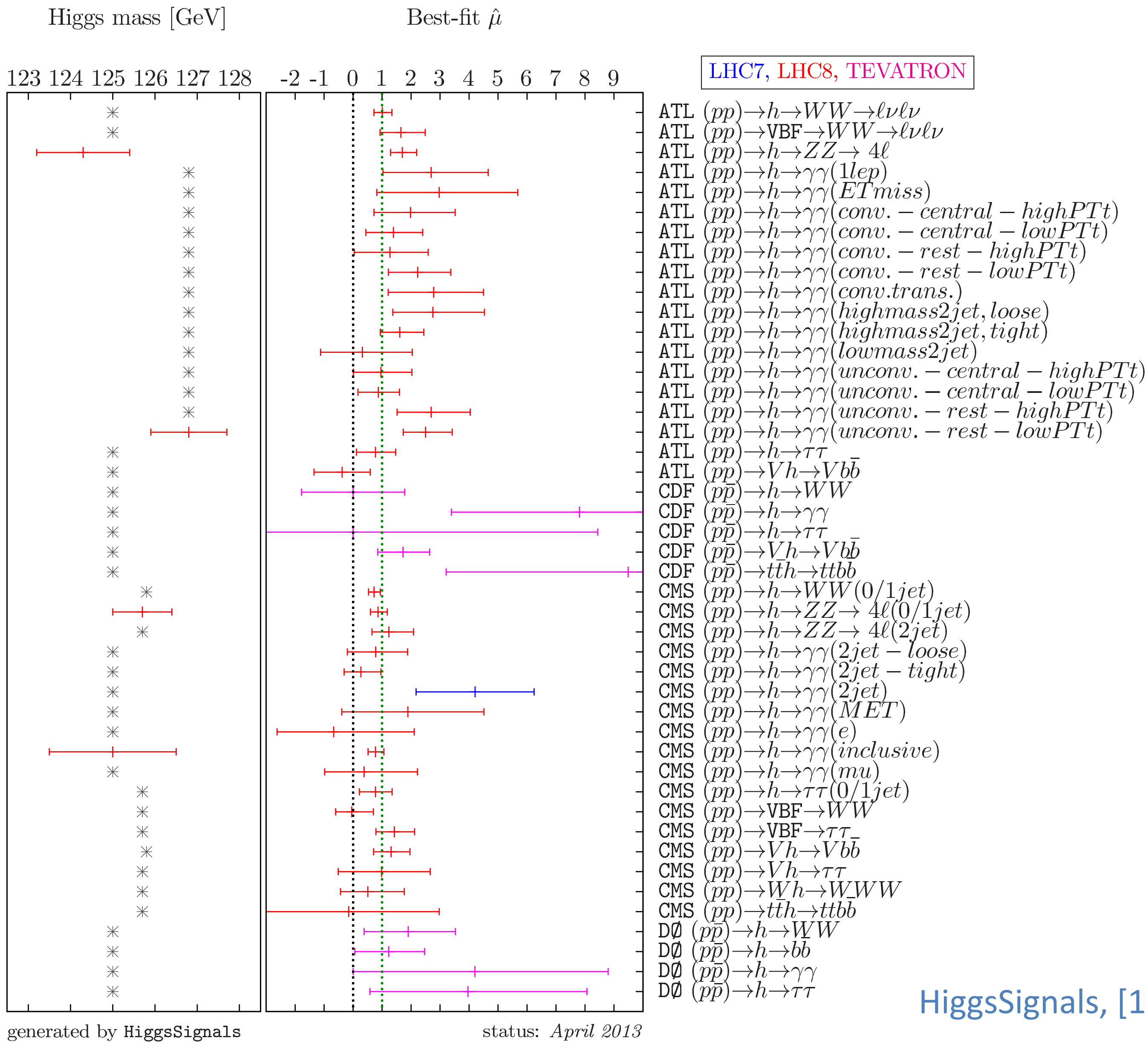
Global analysis of low-energy MSSM

- Scan over pMSSM parameters, evaluate χ^2 including direct constraints, measured Higgs mass and rates, data from flavour physics and precision measurements

Parameter	Minimum	Maximum
M_A [GeV]	90	1000
$\tan\beta$	1	60
μ [GeV]	200	4000
$M_{\tilde{Q}_3}$ [GeV]	200	1500
$M_{\tilde{U}_3}$ [GeV]	200	1500
$M_{\tilde{l}_3}$ [GeV]	200	1500
A_f [GeV]	-3 $M_{\tilde{Q}_3}$	3 $M_{\tilde{Q}_3}$
M_2 [GeV]	200	500

Bechtle, Heinemeyer, Stal, Stefaniak, Weiglein, Zeune, [1211.1955];
Arbey, Battaglia, Mahmoudi; Cao, Heng, Yang, Zhang, Zhu; and many others…

LHC/Tevatron Higgs measurements



HiggsSignals, [1305.1933]

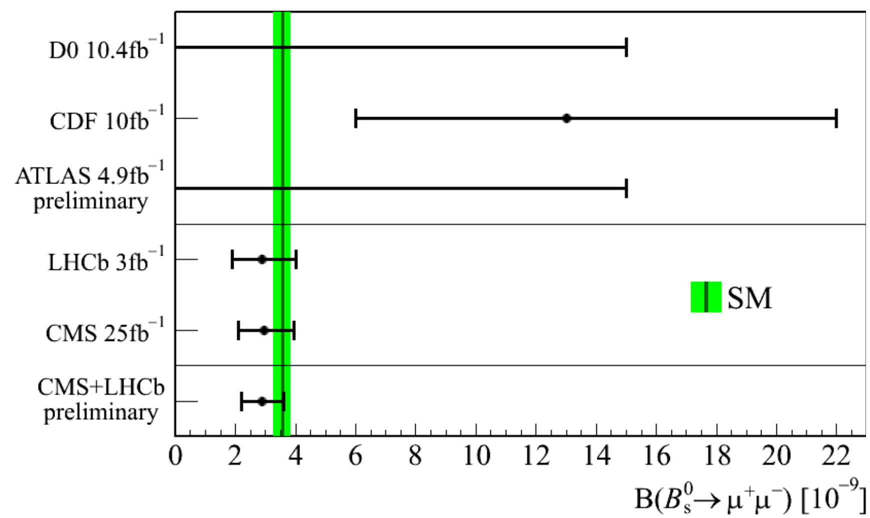
Low-Energy Observables

- Values used in 2012 fit under revision for update

Observable	Experimental value	SM value
$\mathrm{BR}(B \to X_s \gamma)$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$	$(3.08 \pm 0.22) \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu^+ \mu^-)$	$(3.2^{+1.5}_{-1.2}) \times 10^{-9}$	$(3.55 \pm 0.38) \times 10^{-9}$
$\mathrm{BR}(B_u \to \tau \nu_\tau)$	$(1.66 \pm 0.33) \times 10^{-4}$	$(1.01 \pm 0.29) \times 10^{-4}$
δa_μ	$(30.2 \pm 9.0) \times 10^{-10}$	–
M_W	(80.385 ± 0.015) GeV	(80.363 ± 0.004) GeV

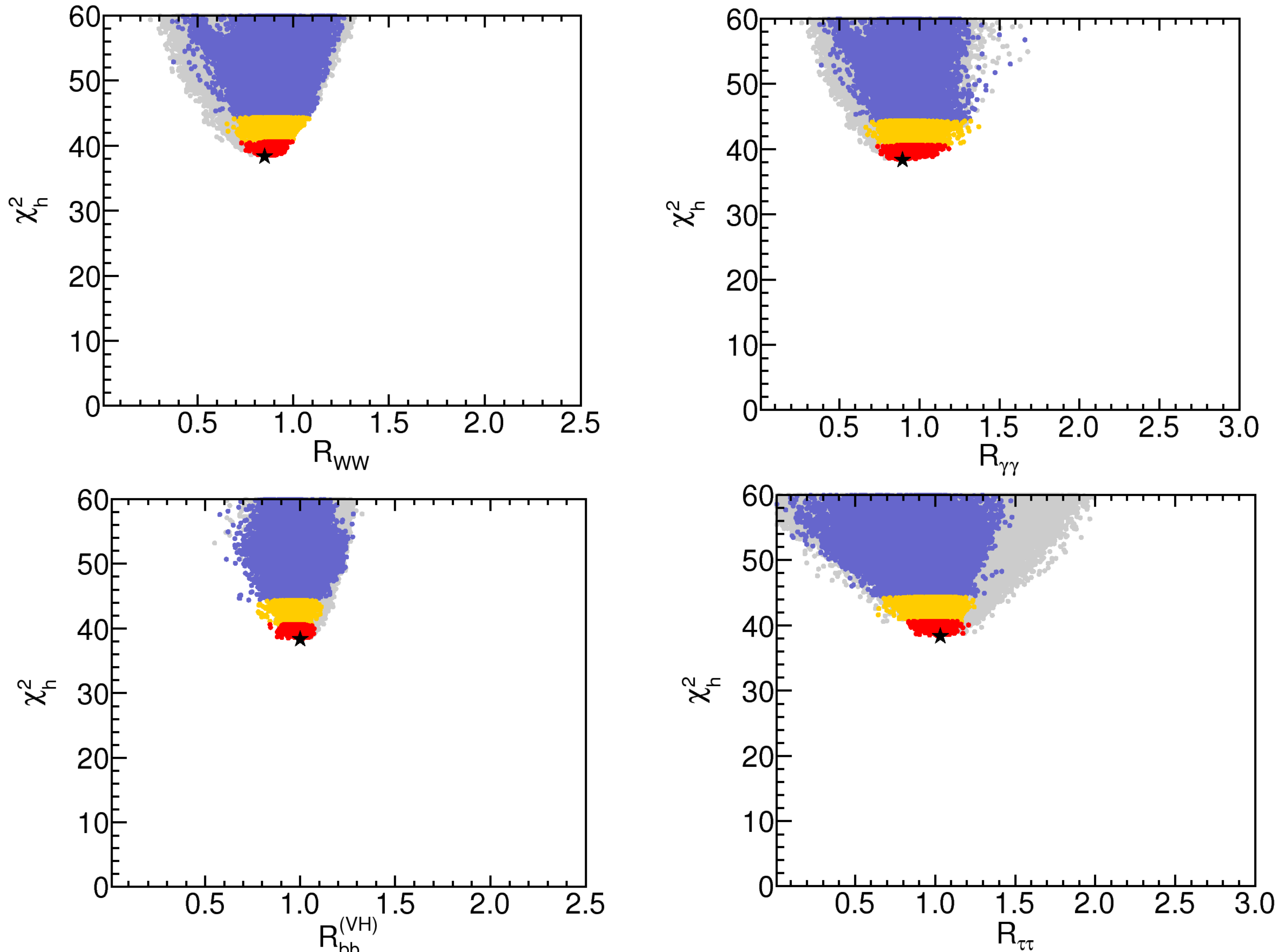
- This summer:
  New combined LHCb/CMS value

$$\mathrm{BR}(B_s \to \mu^+ \mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

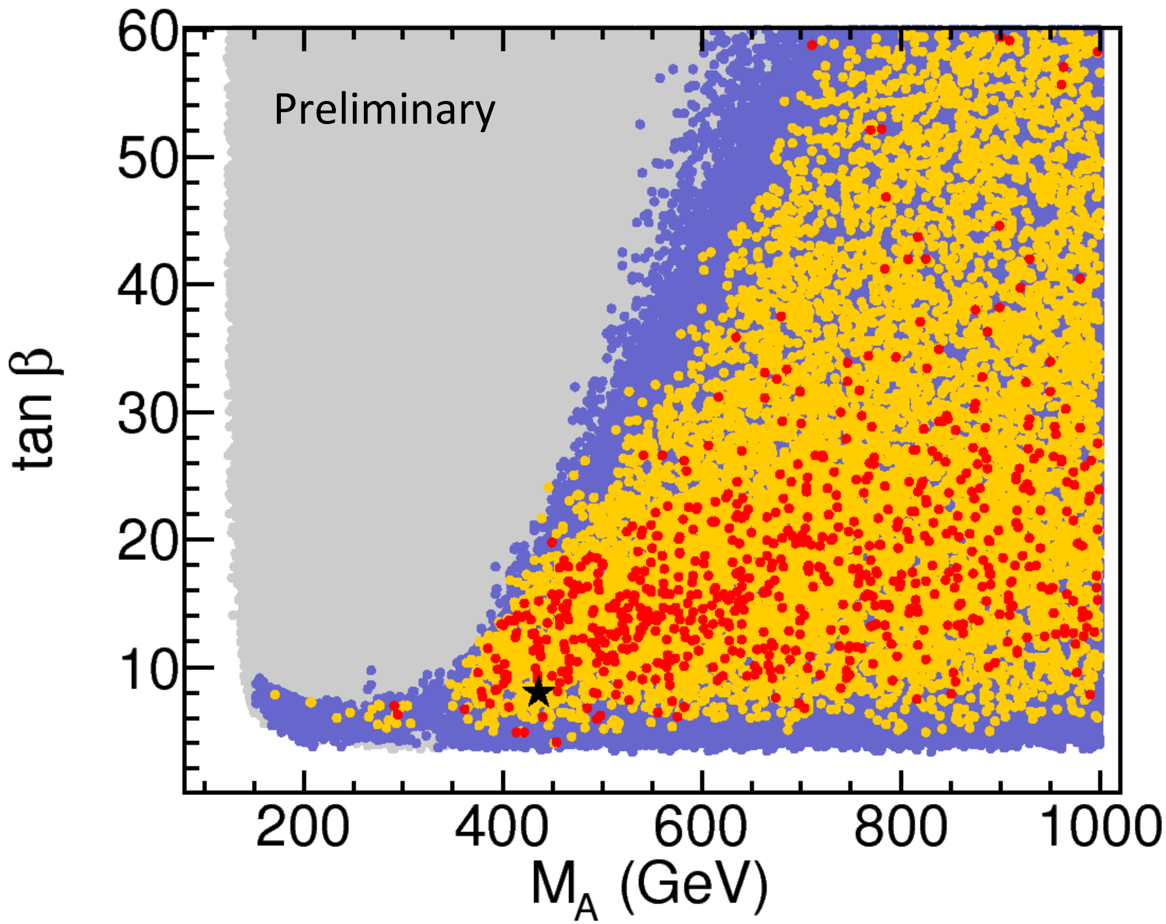


Higgs rates from Global MSSM analysis

$$R_{xx} = \frac{\sigma \times \mathrm{BR}(h \to xx)}{(\sigma \times \mathrm{BR}(h \to xx))_{\mathrm{SM}}}$$



Global MSSM analysis



Excluded by direct searches
Allowed by direct searches

Black star: best fit point
1 sigma allowed points
2 sigma allowed region

- Exclusion by direct constraints and flavour physics probe the same parameter region at low M_A, high tan β.
- The low-M_A region is also disfavored by rates for lightest Higgs

Decoupling limit

- Best MSSM fit to the combined data is in the decoupling limit

$$M_A \gg M_Z \qquad \tan\beta \gg 1$$

$$M_H \sim M_{H^\pm} \sim M_A \gg M_Z$$

$$M_h \sim 125\,\mathrm{GeV}$$

- Couplings of the lightest MSSM Higgs boson approaches SM values

- "Typical" MSSM scenario is SM-like, but a good fit with deviations of O(20%-30%) on individual rates for the light Higgs are possible

- Phenomenology of heavy Higgs bosons ($H/A/H^+$) can also be substantially different within the allowed region

Benchmark scenarios for MSSM Higgs searches

- Benchmark scenarios for MSSM Higgs searches was defined and used extensively at LEP/Tevatron

Carena, Heinemeyer, Wagner, Weiglein [hep-ph/991223], [hep-ph/0202167]

- Soft parameters given at the low scale, fixes radiative corrections to Higgs masses and mixing

- Higher-order SQCD corrections to productions cross sections and decay rates can be calculated

- Provides full SUSY spectrum, which is important in order to consider non-BSM processes, like cascade production and SUSY decays:

$$\tilde{\chi}_i \to H\tilde{\chi}_j \qquad H \to \tilde{\chi}_i\tilde{\chi}_j \qquad H \to hh$$

Benchmark scenarios for MSSM Higgs searches

- With the discovery of a "heavy" neutral Higgs boson, many of these original scenarios have become obsolete

  -> Updated benchmark scenarios for MSSM Higgs searches

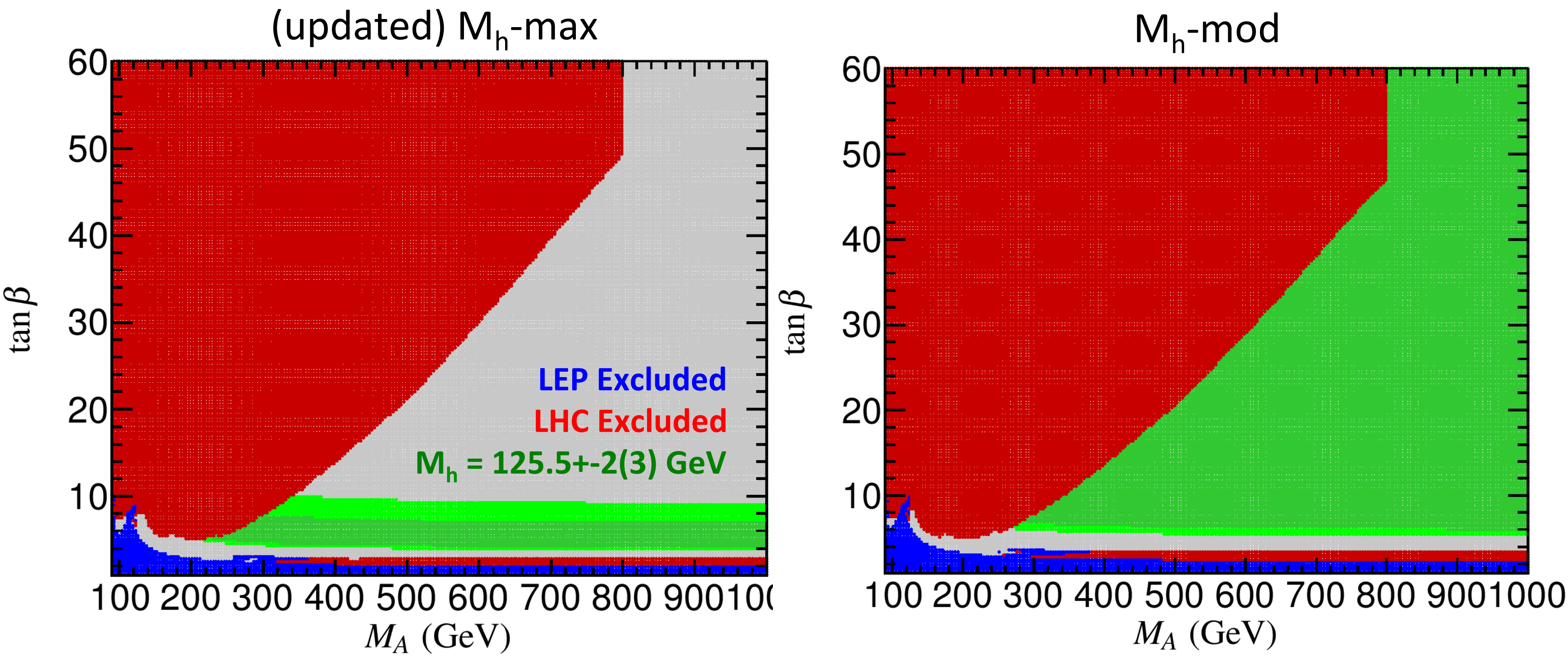
  Carena, Heinemeyer, OS, Wagner, Weiglein [1302.7033]

- Strategy:
  - New scenarios should be compatible with Higgs discovery
  - SUSY at the "TeV"-scale, while respecting current experimental bounds: $m_{\tilde{q}_{1,2}} = 1500\,\mathrm{GeV}$ $m_{\tilde{g}} = 1500\,\mathrm{GeV}$
  - Capture different phenomenological aspects
  - Possible modification of properties of "SM" Higgs
  - Include opportunity for heavy CP-even Higgs as LHC signal
  - Indirect constraints ignored (benchmarks)

Overview of updated benchmark scenarios

- M_h-max – *Maximizes lightest Higgs mass for given tan* β
- M_h-mod(+/-) – *Maximize allowed region in* M_A, *tan* β
- Light stop – *Minimze stop mass (to modify light h cross section)*
- Light stau – *Minimize stau mass (to enhance h ->* $\gamma\ \gamma$*)*
- Tauphobic Higgs – *Suppress light Higgs couplings to taus*/bb
- Low-M_H – *Interpret LHC signal as heavy CP-even Higgs H*

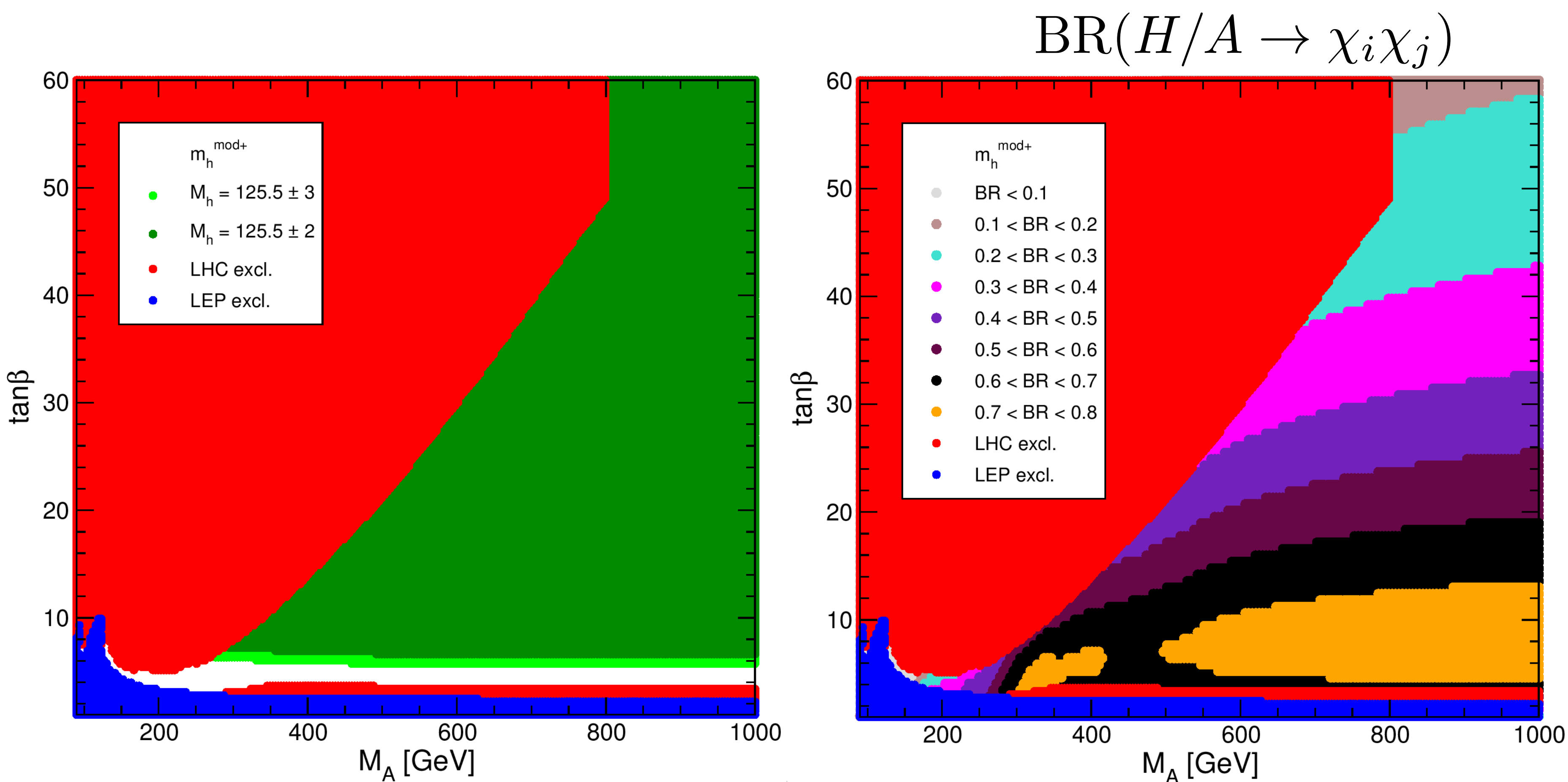
M_h-max and M_h-mod scenarios



- In the M_h-max scenario, only a narrow strip in tan β is compatible with the discovered Higgs mass
- In the M_h-mod scenario, the full range of tan β is available

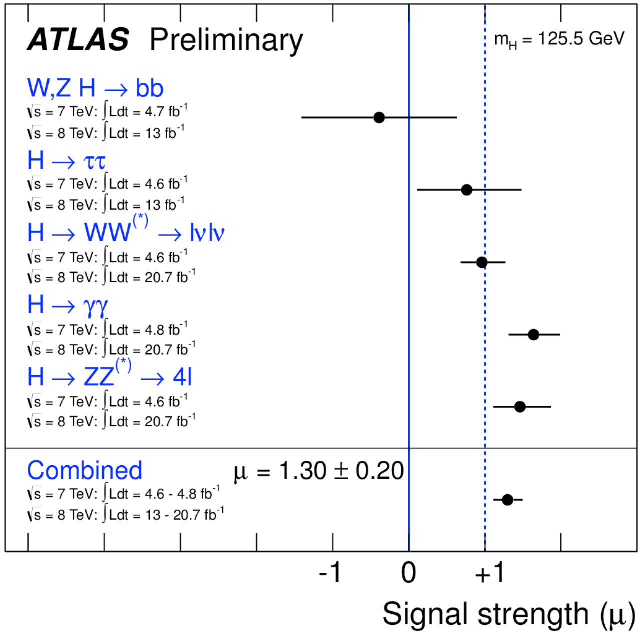
Heavy Higgs Decays to SUSY particles

- In the M_h-mod scenario, the gauginos are rather light – O(200 GeV)
- Heavy Higgs boson decays to gaugino pairs can be dominant



MSSM Enhancement of h -> γγ

- If the h -> γγ rate is enhanced, this can be accommodated in the MSSM in two ways:
  - Suppression of main decay modes to bb and ττ
  - Additional contributions to $\Gamma(h \to \gamma\gamma)$



- Light stau scenario:

$$\delta\mathcal{A}_{h\gamma\gamma}/\mathcal{A}_{h\gamma\gamma}^{\rm SM} \simeq -\frac{2\, m_\tau^2}{39\, m_{\tilde\tau_1}^2 m_{\tilde\tau_2}^2}\left(m_{\tilde\tau_1}^2 + m_{\tilde\tau_2}^2 - X_\tau^2\right),$$

$$X_\tau \propto \mu \tan\beta \gg m_{\tilde\tau}$$

Enhancing h --> γγ by light staus

$$R_{\gamma\gamma} = \frac{\sigma(gg \to h) \times \mathrm{BR}(h \to \gamma\gamma)}{(\sigma(gg \to h) \times \mathrm{BR}(h \to \gamma\gamma))_{\mathrm{SM}}}$$

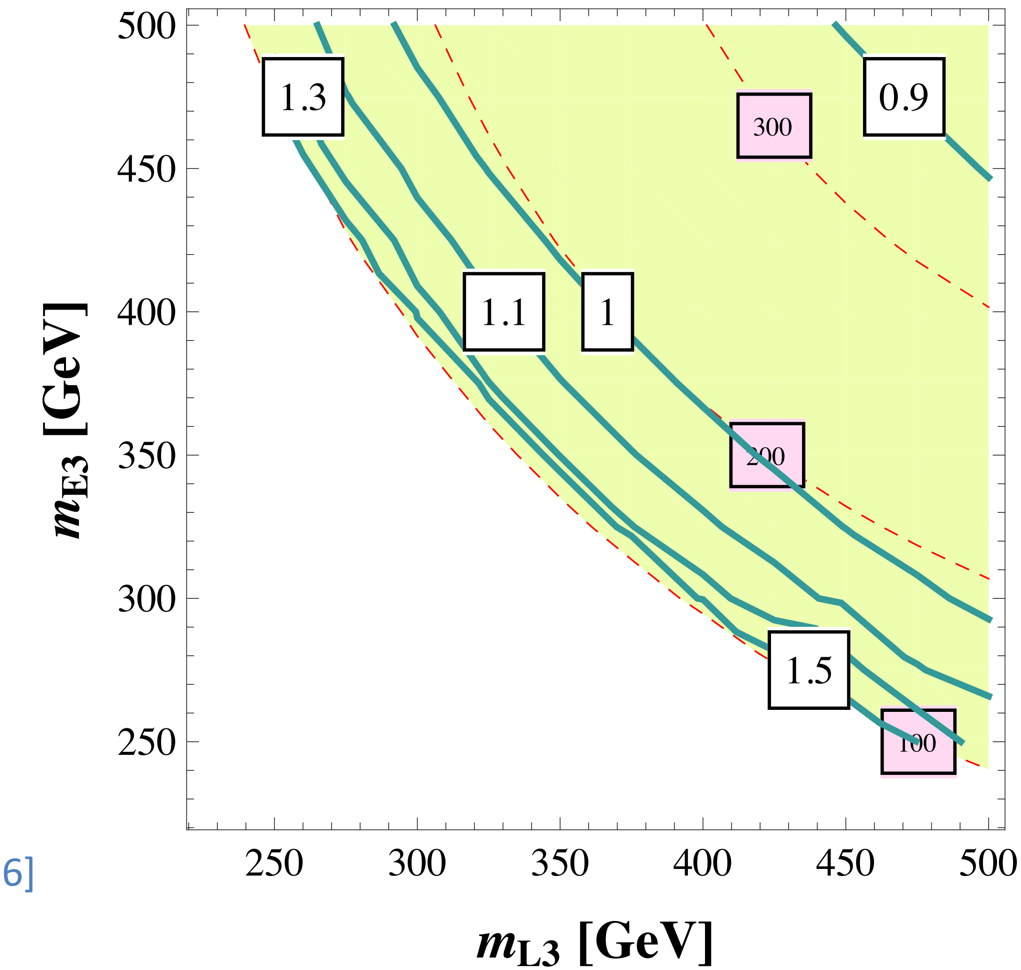
- Enhancement of

  $R_{\gamma\gamma} \lesssim 1.5$

  possible for

  $m_{\tilde{\tau}_1} \simeq 100\,\mathrm{GeV}$

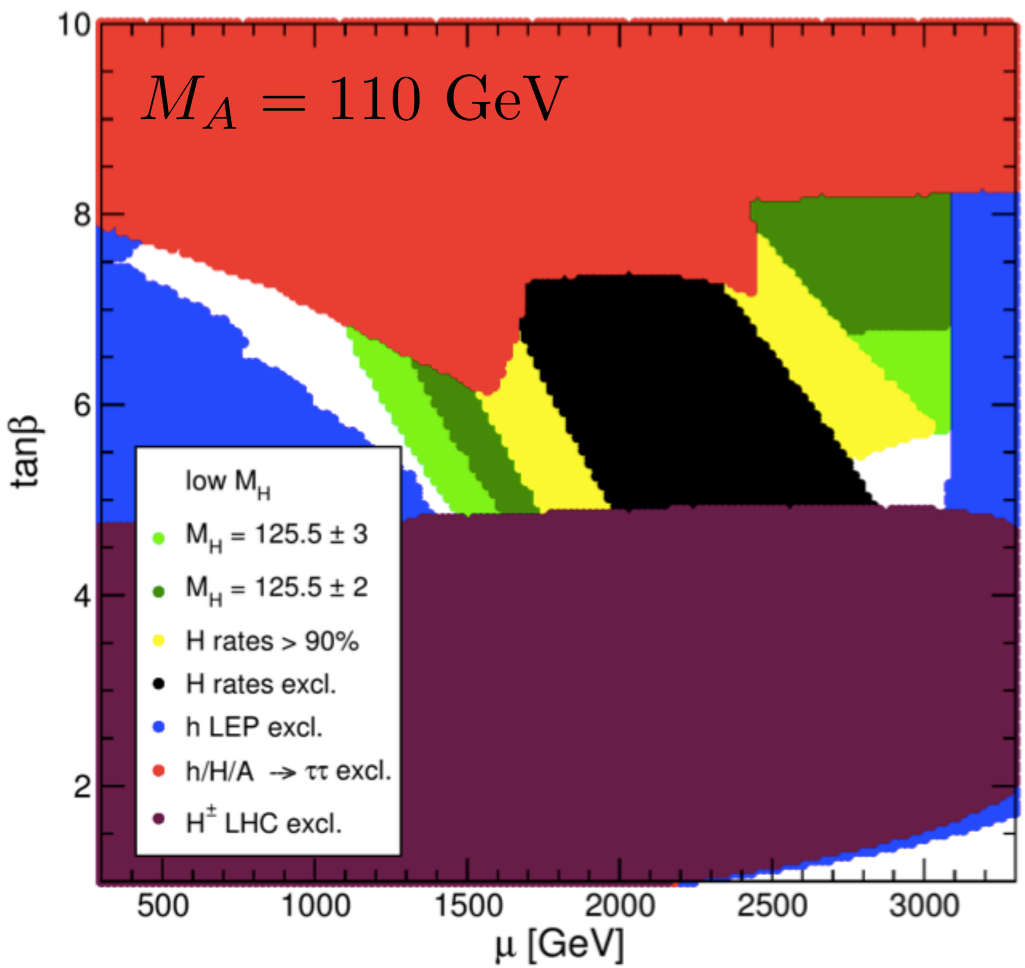
  (close to current limit)



Carena, Gori, Shah, Wagner, [1112.3336]

Low-M_H scenario

- Alternative scenario: *Heavy* CP-even Higgs boson H around 125 GeV. Lightest Higgs below LEP limit (reduced couplings to vector bosons)



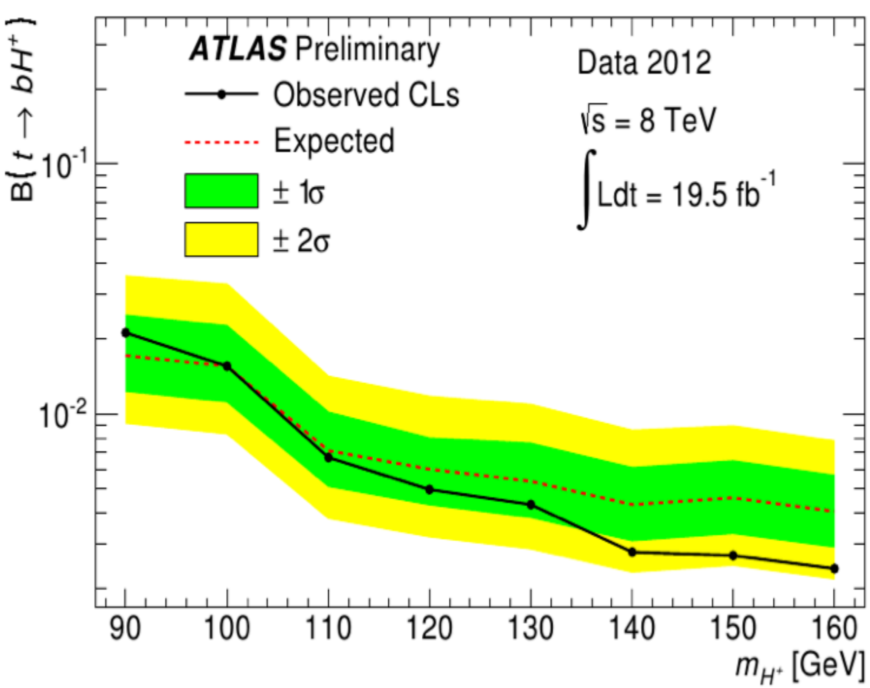
Charged Higgs limits challenge Low-M_H scenario

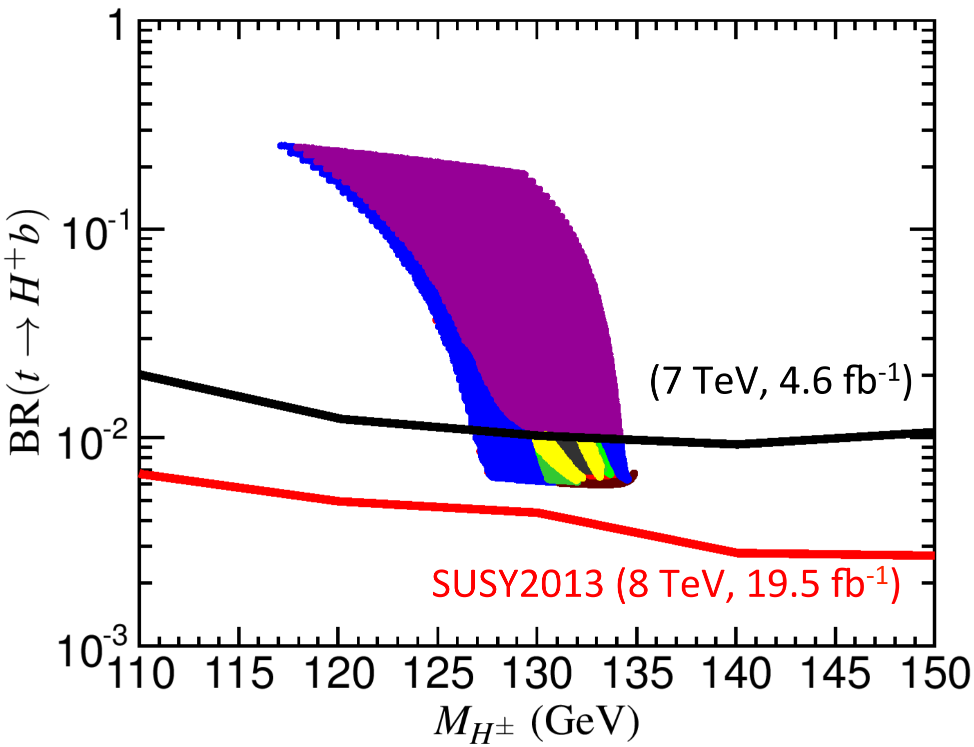
- In the low-M_H scenario, the MSSM is far from the decoupling limit

$$M_h < M_H \sim M_A \sim 125\,\text{GeV} \qquad M_{H^\pm}^2 = M_A^2 + M_W^2$$

$$M_{H^\pm} < m_t \qquad t \to bH^+ \qquad \text{BR}(H^+ \to \tau^+\nu_\tau) \simeq 1$$

ATLAS-CONF-2013-90





Beyond minimal supersymmetry

- Beyond minimal SUSY, there are other scenarios where M_h can be increased already at tree-level.
  Less need for large radiative corrections → improved fine-tuning.

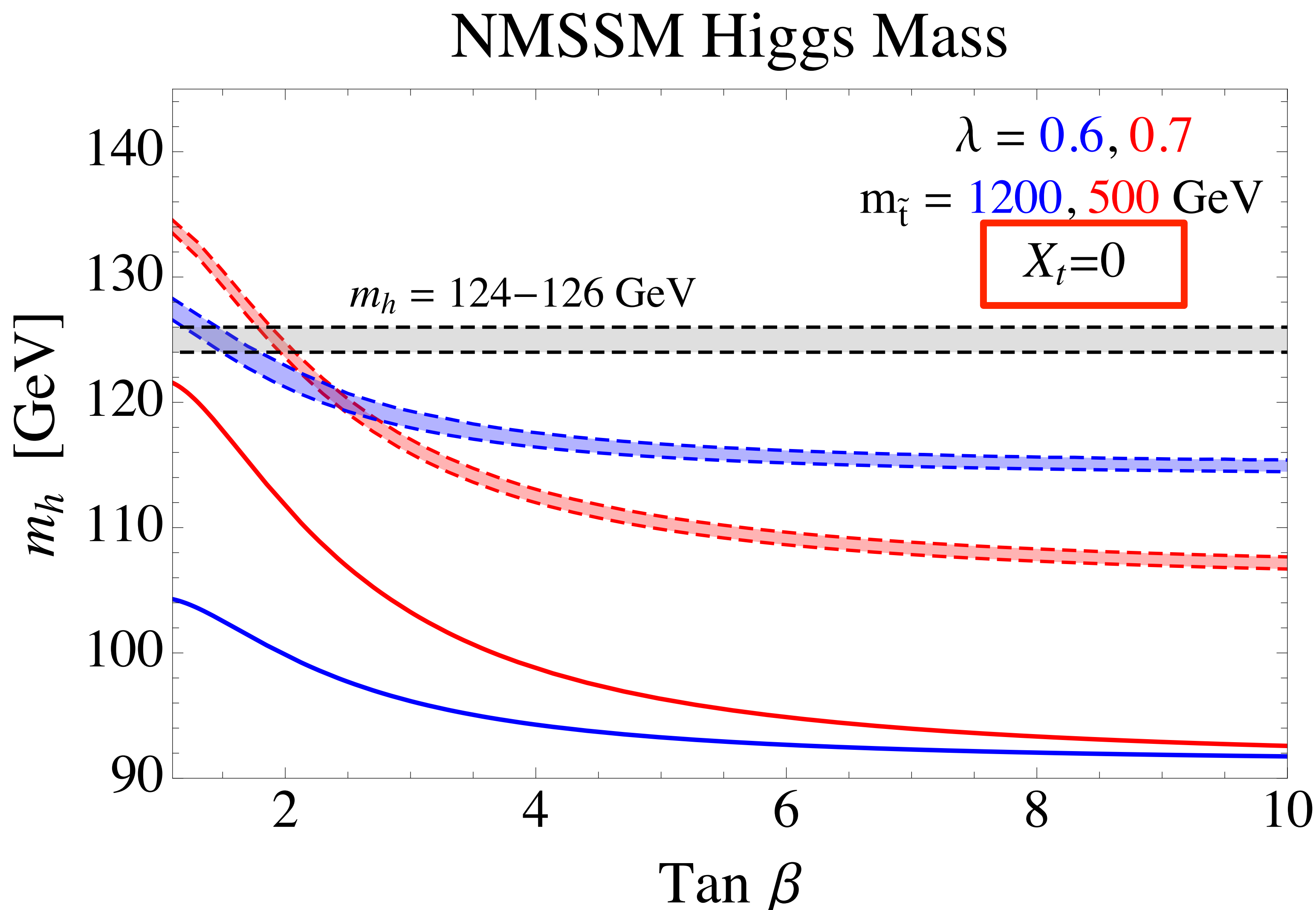
  Singlet extension (NMSSM):

$$
\begin{aligned}
W_{\rm NMSSM} &= W_F + \lambda \hat{H}_u \cdot \hat{H}_d \hat{S} + \frac{1}{3}\kappa \hat{S}^3, \\
V_{\rm soft}^{\rm NMSSM} &= \tilde{m}_u^2 |H_u|^2 + \tilde{m}_d^2 |H_d|^2 + \tilde{m}_S^2 |S|^2 + (A_\lambda \lambda S H_u \cdot H_d + \frac{A_\kappa}{3}\kappa S^3 + h.c.)
\end{aligned}
$$

- Seven physical Higgs states h_1, h_2, h_3 a_1, a_2 $h^\pm$

$$M_{h_1}^2 \leq M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \Delta M_{h_1}^2$$

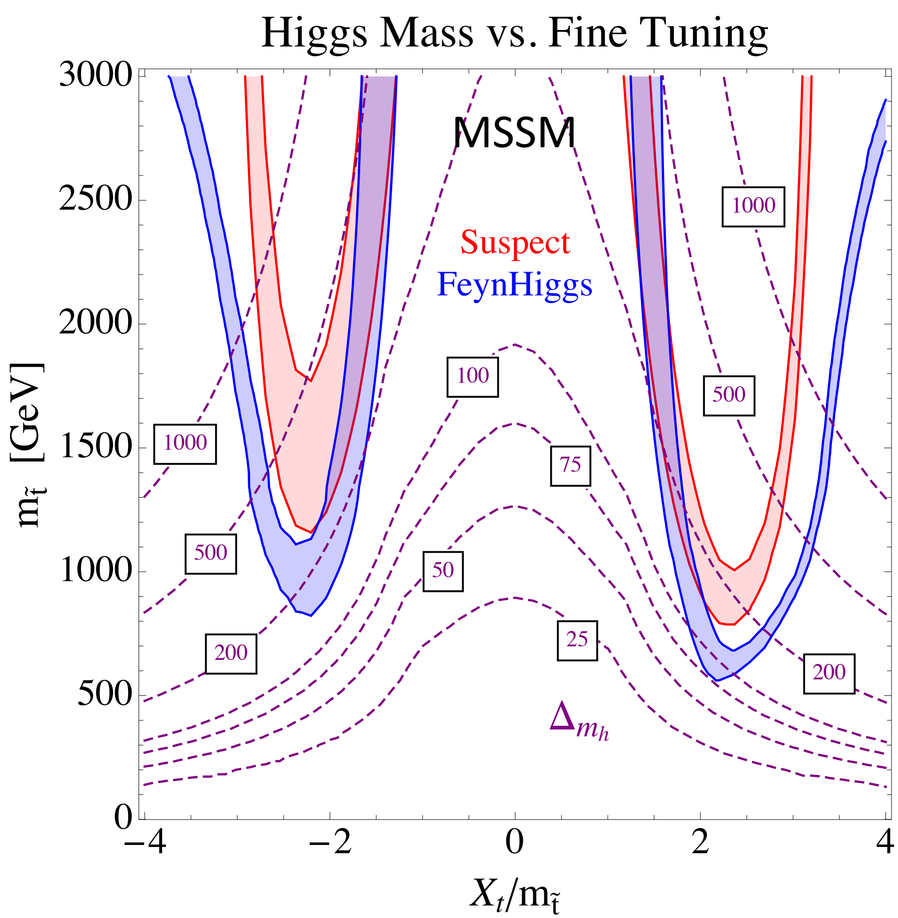
Right Higgs mass without stop mixing

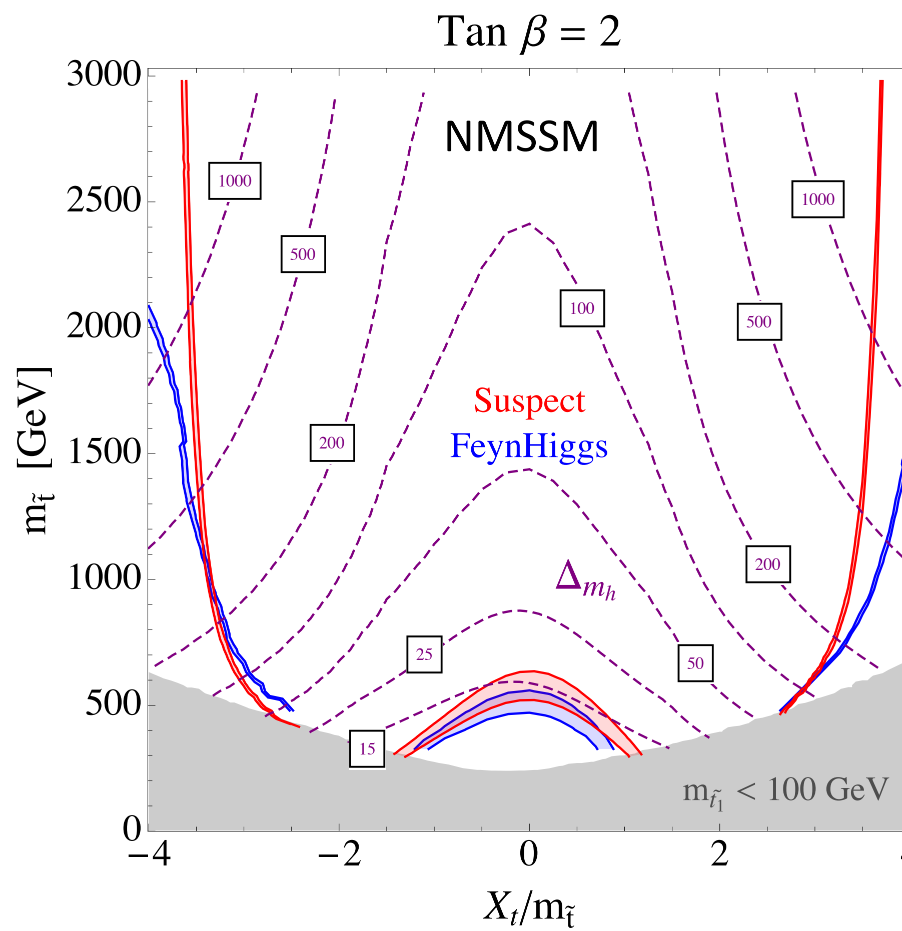


Hall, Pinner, Ruderman, [1112.2703]

Improved NMSSM naturalness

- Quantitative measure of (technical) fine-tuning $\Delta_{m_h} = \max_i \left| \frac{\partial \ln m_h^2}{\partial \ln p_i} \right|$





Hall, Pinner, Ruderman, [1112.2703]

NMSSM modifications to Higgs phenomenology

- Singlet-doublet mixing can modify Higgs rates substantially
  Prediction (before LHC discovery) that two-photon rate could be substantially higher than for SM
  Ellwanger, [1012.1201]
  Cao, Heng, Yang, Zhu, [1103.0631]

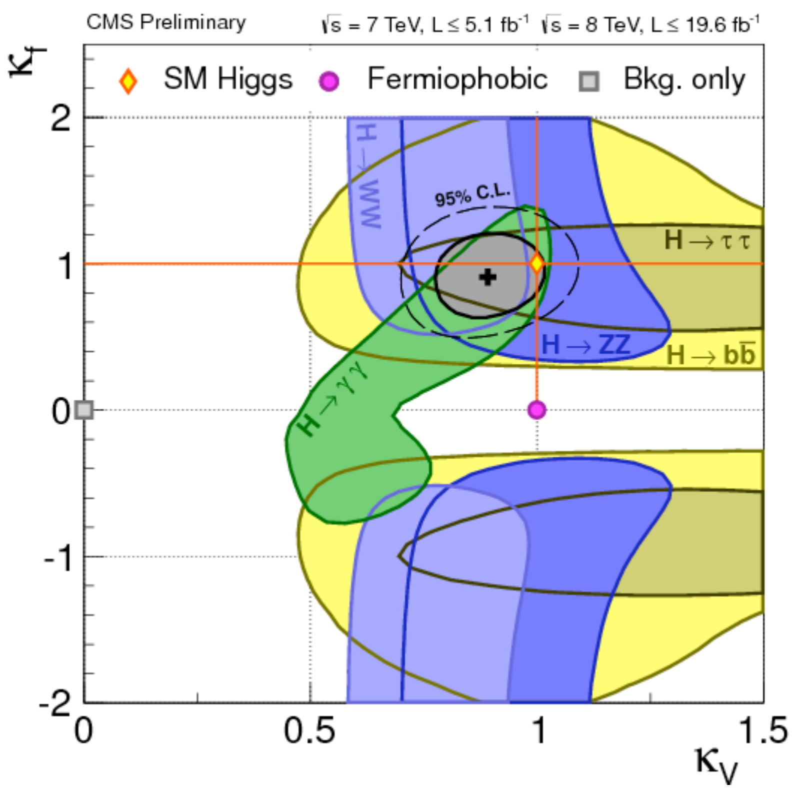
- Two light Higgs bosons is still a viable possibility
  Lightest Higgs below LEP limit, with suppressed couplings to vector bosons, second lightest Higgs@125 GeV
  Belanger, Ellwanger, Gunion, Jiang, Kraml, Schwarz, [1210.1976]

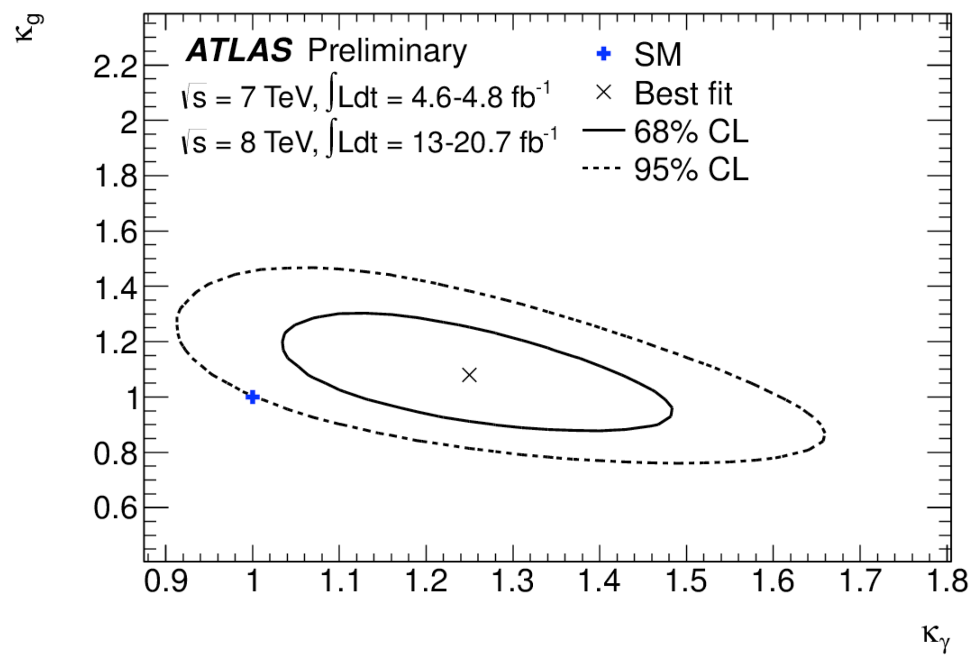
- Light singlet and invisible Higgs decays
  Current limit from ATLAS/CMS is $\mathrm{BR}(h \to \mathrm{inv}) \lesssim 60\%$
  ATLAS-CONF-2013-011, CMS-HIG-13-018

- Relaxed bounds on heavy Higgses from direct searches / flavour
  Heavy Higgs bosons more 'decorrelated' from each other

Model-independent coupling fits

- Deviations of SM couplings fitted in different parametrizations proposed by LHCXSWG → Consistency test of SM





ATLAS-CONF-2013-034, CMS-HIG-13-005

- If a significant deviation is established, need to perform new model-dependent analysis for correct interpretation

Example: Composite Higgs

- An alternative to SUSY, which removes the SM hierarchy problem, is if there is no fundamental scalar

Georgi, Kaplan
Giudice, Grojean, Pomarol, Rattazzi

- A composite Higgs could result as a pseudo-Goldstone Boson from a global symmetry in a strong sector, broken at a scale $f_H > v$ Higgs mass generated at 1-loop → Low mass Higgs natural

ex) SO(5) -> SO(4) 1 Higgs doublet
Minimal Composite Higgs Model (MCHM)

Agashe, Contino, Pomarol, [hep-ph/0412089]

SO(6) -> SO(5) 1 Higgs doublet + 1 singlet
SO(6) -> SO(4) x SO(2) 2 Higgs doublets

Signatures of Higgs compositeness

- The composite Higgs is treated in an effective theory below the compositeness scale. Role of f_H similar to pion decay constant

- Modification of tree-level couplings in MCHM

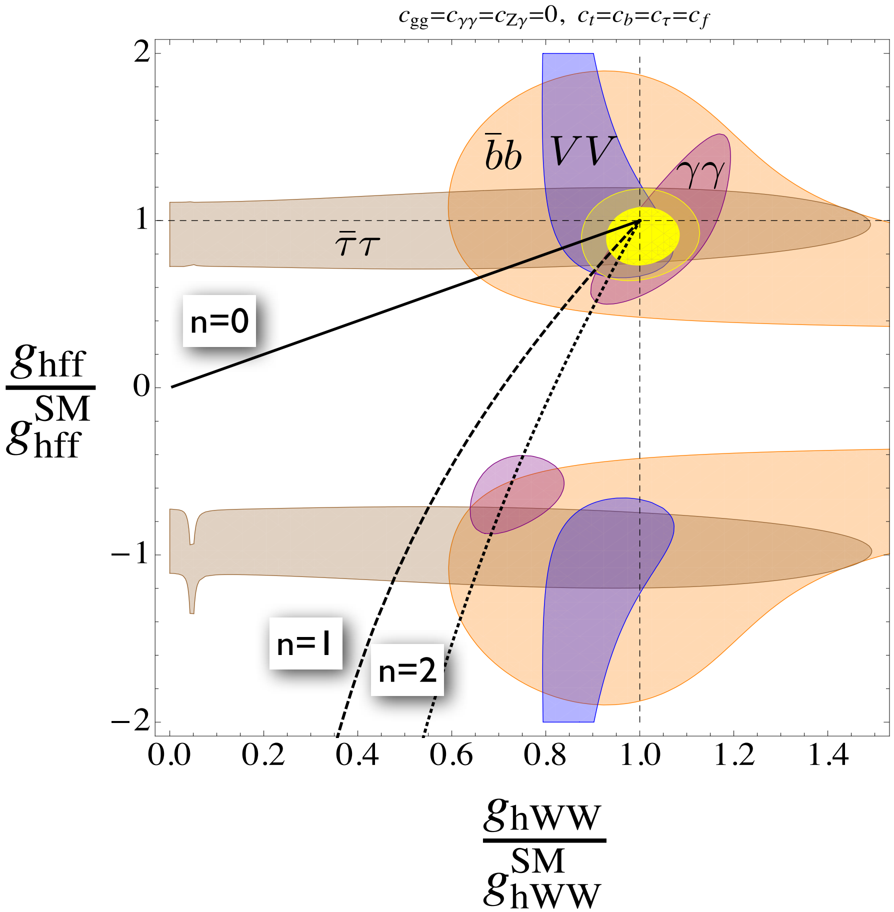
$$\xi = \frac{v^2}{f_H^2}$$

$$\frac{g_{hWW}}{g_{hWW}^{\mathrm{SM}}} = \sqrt{1-\xi} \qquad \frac{g_{hff}}{g_{hff}^{\mathrm{SM}}} = \frac{1-(1+n)\xi}{\sqrt{1-\xi}} \qquad n = 0, 1, 2, \ldots$$

Depending on realization

- Loop-induced couplings to gluons and photons indirectly affected by modifications to top and W couplings

Model-independent coupling measurements



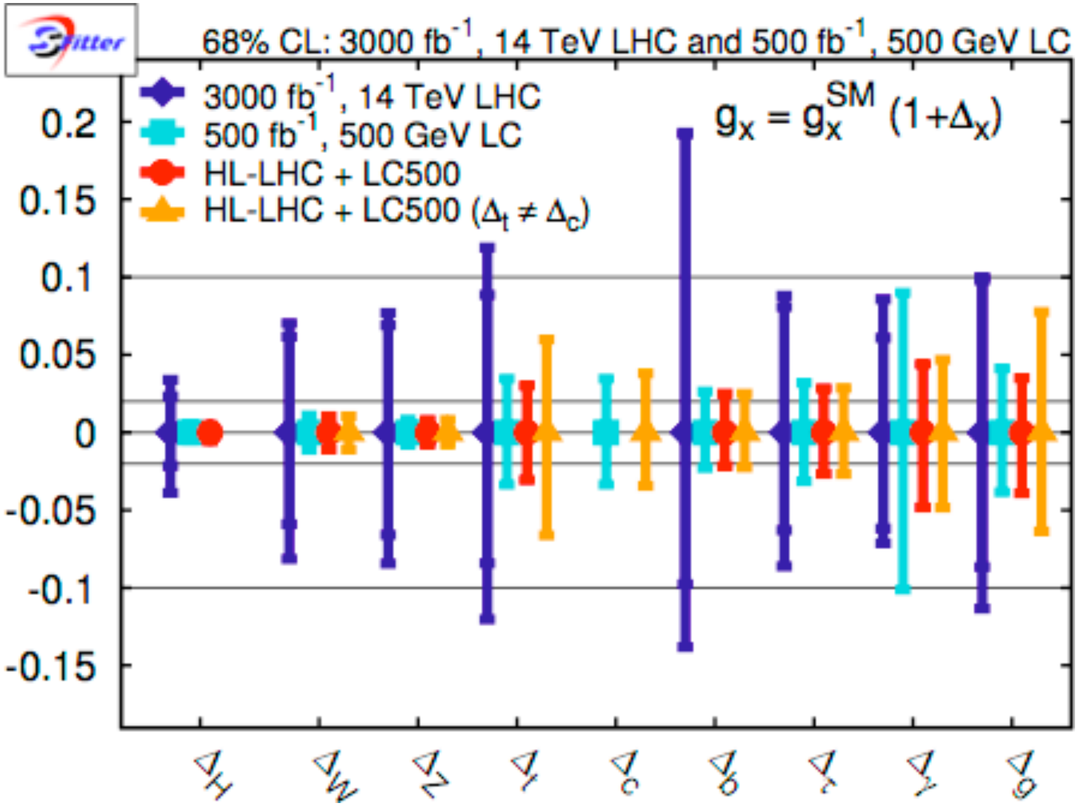
- MCHM limit

$$\rightarrow f_H \gtrsim 700\,\mathrm{GeV}$$

Falkowski, Riva, Urbano, [1303.1812]

- Other models that can be tested in this framework: General two-Higgs-Doublet models (in decoupling limit), EW singlets, portal dark matter, Higgs-radion mixing…

Prospects without new physics



- 5-10% precision on Higgs couplings at **high-lumi LHC** (3000 fb^{-1}), but worse for important top and bottom couplings
- Combining with 500 GeV LC (500 fb^{-1}), precision is O(1%)

Conclusions

- The new particle discovered by ATLAS/CMS is similar to a SM Higgs boson (within uncertainties)

- Scenarios beyond the SM are constrained both by direct Higgs measurements, and from the non-observation of new physics

- Constrained (minimal) SUSY under pressure, more general MSSM analyses show best fit in the decoupling region
  -> Challenge for direct Higgs searches …
  … but large experimental effects and new phenomena are not excluded: $\gamma\gamma$ modification, SUSY decays, H → hh, …

- Benchmark scenarios for MSSM Higgs searches have been updated after discovery to cover features of viable Higgs sector

Conclusions

- Non-minimal SUSY can increase the tree-level Higgs mass, which improves naturalness.
  → Higgs phenomenology can differ substantially from MSSM.
- More precise measurements of the Higgs couplings, perhaps also at a linear collider, provide a generic, indirect, probe of BSM Higgs scenarios (can be used to reject the SM)
- The best way to to prove that the Higgs sector is non-minimal is always to find additional Higgs states ☺

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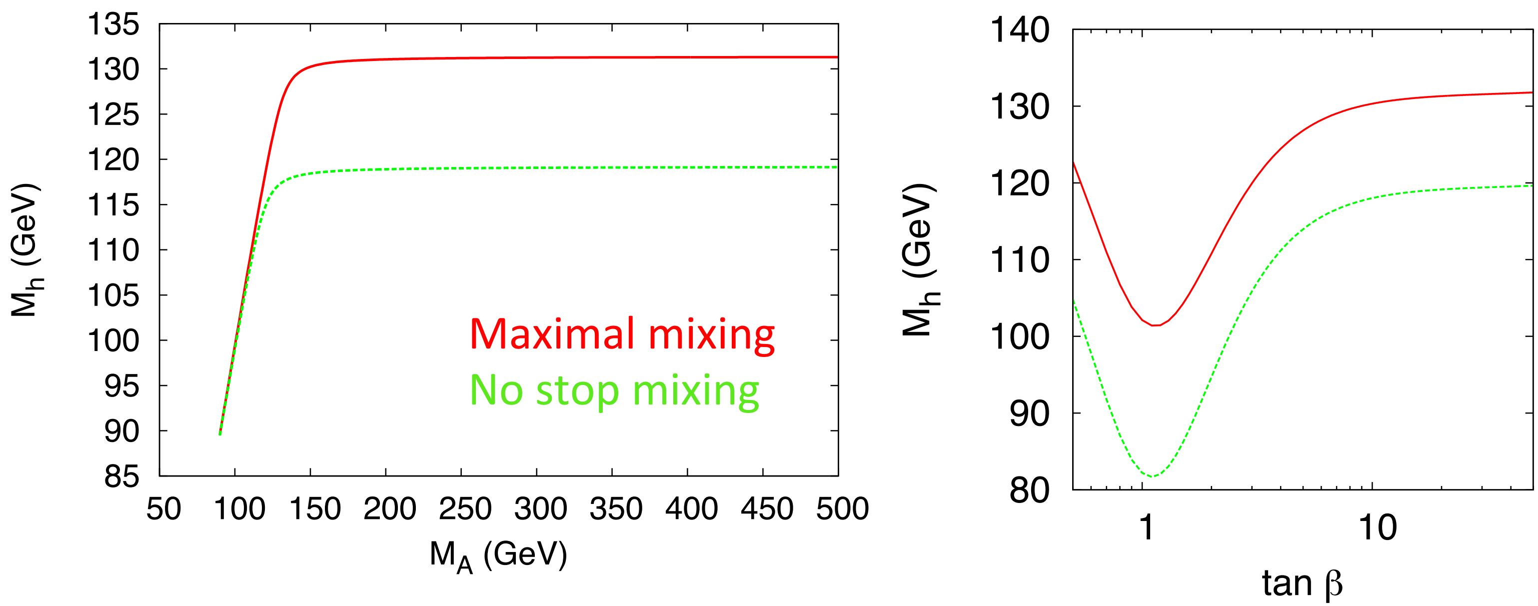
<u>We know that the SM *cannot* be complete</u>


Truth
NEXT EXIT

Backup

Higgs mass dependence on At

- M_h is increasing function of tree-level parameters $M_A, \tan\beta$



- For a given SUSY mass scale M_{SUSY}, maximize the contributions to M_h from radiative corrections -> M_h-max scenario

$$X_t^{\mathrm{OS}} = 2M_{\mathrm{SUSY}}$$

- Conservative (scenario-independent) *lower* bounds on M_A, tan β

Lightest Higgs mass

- Higher-order corrections are particularly important for M_h

$$M_h^2 = M_{h,\text{tree}}^2(M_A, \tan\beta) + \Delta M_h^2\,(M_{\text{SUSY}}, A_i, M_i, \ldots)$$

- Long development to know these corrections very precisely

Dominant 1-loop corrections		1991	Okada, Yamaguchi, Yanagida Ellis, Ridolfi, Zwirner Haber, Hempfling
Complete 1-loop		1992-96	Brignole Chankowski, Rosiek, Pokorski Dabelstein Pierce, Bagger, Matchev, Chang
RGE-improved 1-loop		1995-96	Carena, Espinosa, Quiros, Wagner Haber, Hempfling, Hoang
Dominant 2-loop	$\mathcal{O}(y_t^2\alpha_s + y_b^2\alpha_s + y_t^4 + y_b^4)$	1998-2002	Heinemeyer, Hollik, Weiglein Brignole, Degrassi, Slavich, Zwirner
Leading 3-loop	$\mathcal{O}(y_t^2\alpha_s^2)$	2010	Harlander, Kant, Mihaila, Steinhauser

MSSM Higgs couplings

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$	$g_{\Phi AZ}/g_{\Phi H^+W^-}$
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$	$\propto\cos(\beta-\alpha)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$	$\propto\sin(\beta-\alpha)$
A	$\cot\beta$	$\tan\beta$	0	$\propto 0/1$

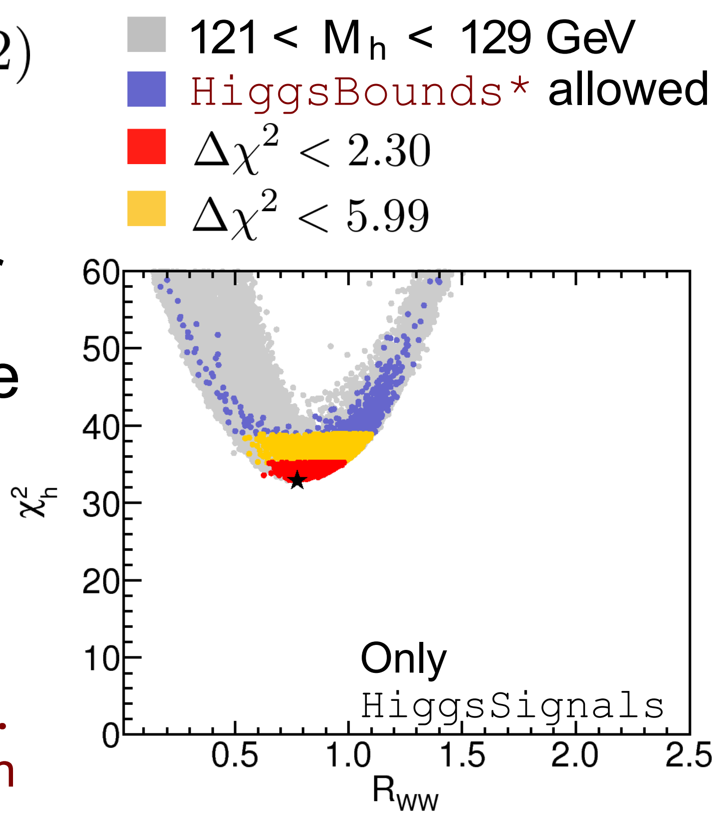
Parameter values of updated MSSM scenarios

Parameter	$m_h^{\max}$	$m_h^{\mathrm{mod}+}$	$m_h^{\mathrm{mod}-}$	*light stop*	*light stau*	τ*-phobic*	*low-*M_H
m_t	173.2	173.2	173.2	173.2	173.2	173.2	173.2
M_A	varied	varied	varied	varied	varied	varied	110
$\tan\beta$	varied	varied	varied	varied	varied	varied	varied
M_{SUSY}	1000	1000	1000	500	1000	1500	1500
$M_{\tilde{l}_3}$	1000	1000	1000	1000	245 (250)	500	1000
$X_t^{\mathrm{OS}}/M_{\mathrm{SUSY}}$	2.0	1.5	-1.9	2.0	1.6	2.45	2.45
$X_t^{\overline{\mathrm{MS}}}/M_{\mathrm{SUSY}}$	$\sqrt{6}$	1.6	-2.2	2.2	1.7	2.9	2.9
A_t	Given by $A_t = X_t + \mu \cot\beta$						
A_b	$= A_t$	$= A_t$	$= A_t$	$= A_t$	$= A_t$	$= A_t$	$= A_t$
A_τ	$= A_t$	$= A_t$	$= A_t$	$= A_t$	0	$= A_t$	$= A_t$
μ	200	200	200	350	500 (450)	2000	varied
M_1	Fixed by GUT relation to M_2						
M_2	200	200	200	350	200 (400)	200	200
$m_{\tilde{g}}$	1500	1500	1500	1500	1500	1500	1500
$M_{\tilde{q}_{1,2}}$	1500	1500	1500	1500	1500	1500	1500
$M_{\tilde{l}_{1,2}}$	500	500	500	500	500	500	500
$A_{f\neq t,b,\tau}$	0	0	0	0	0	0	0

Results of the fit

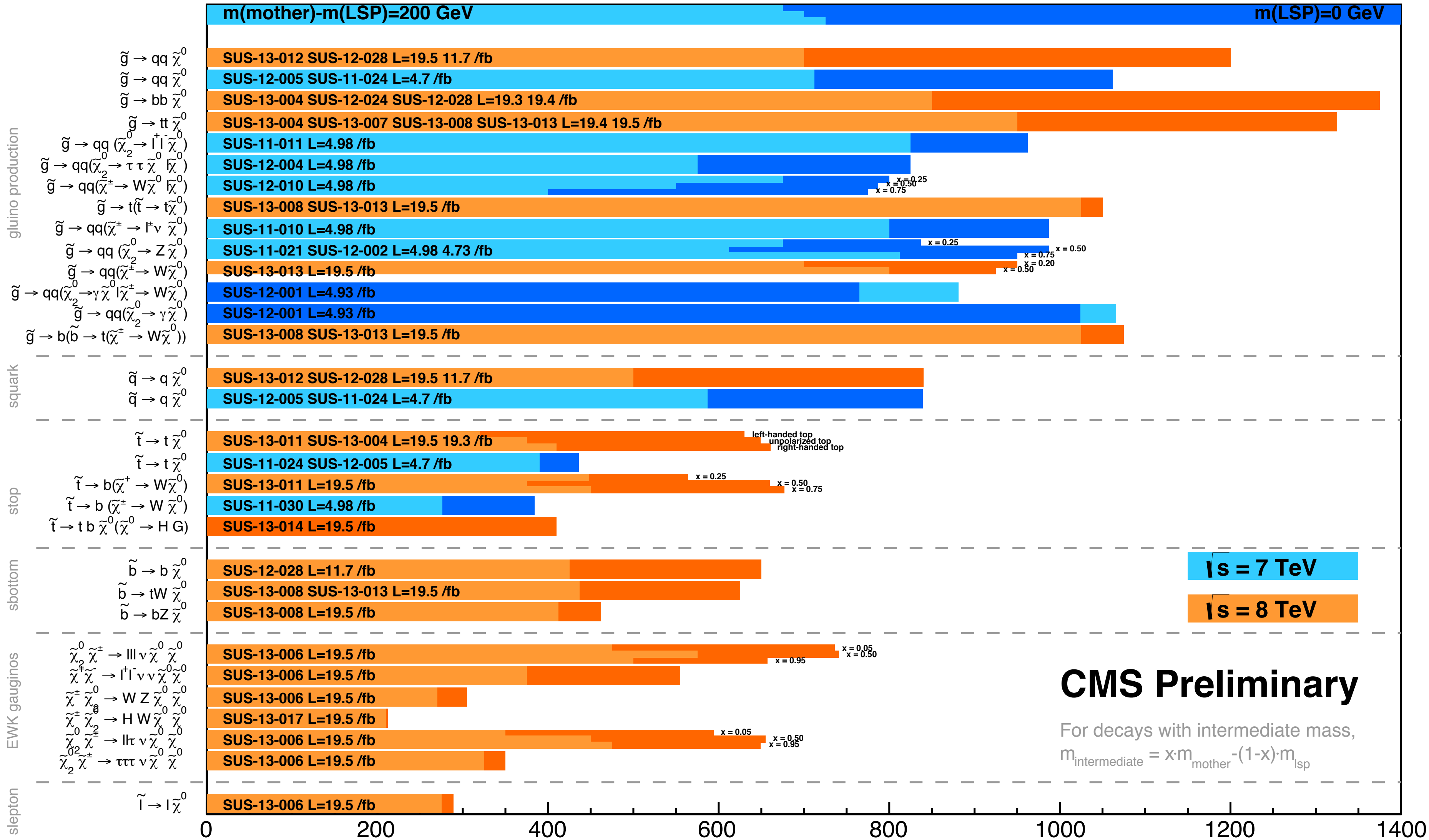
Naive calculation of degrees of freedom: $\nu = n_{\text{obs}} - n_{\text{para}}$

- Minimal χ^2 result:
  - Higgs signal strength and Higgs mass:
    $\chi^2/\nu = 33.9/40$ (SM: $\chi^2/\nu = 38.94/47$)
  - including LEO:
    $\chi^2/\nu = 38.6/45$ (SM: $\chi^2/\nu = 53.27/52$)
- SM and MSSM interpretations similar
- Including LEO, SM gets slightly worse
  - $(g_\mu - 2)$ differs by more than 3 σ
- Overall good MSSM fit



* HiggsBounds 4.0.0.
Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein

Summary of CMS SUSY Results* in SMS framework SUSY 2013



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit