# A BMSSM Higgs at 125 GeV

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Based on F. Boudjema, GDLR arXiv:1203.3141

# Outline

# Beyond a Standard Model Higgs

- Naturalness issue of the SM Higgs
- Assuming complete Standard Model except for new particles appearing at Planck scale $\Lambda_{\text{Planck}}$

  $m_h(\Lambda_{\text{Planck}}) \gg m_h$

  ➞ A fine-tuning issue
- Supersymmetry protects the running Higgs mass
  - The fine-tuning is $M_Z \leftrightarrow M_{SUSY}$
  - Tension to raise $m_h \sim 125$ GeV
  - $h$ has very SM-like couplings

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# Signal features from ATLAS/CMS

- $m_h = 125 - 127$ GeV
- We take $\hat{\mu}$ from the most indicative channels
  - The uncertainties quoted are for $1\sigma$ bands.

$$R_{XX} = \frac{\sigma_{pp\to h\to XX}}{\sigma^{\rm SM}_{pp\to h\to XX}}$$

| | ATLAS | CMS |
|---|---|---|
| $\gamma\gamma$ | $1.9 \pm 0.5$ | $1.4 \pm 0.5$ |
| $\gamma\gamma + 2j$ | $2.8 \pm 1.2$ | $1.6 \pm 1.1$ |
| $ZZ \to 4\ell$ | $1.35 \pm 0.9$ | $0.8 \pm 0.6$ |

- Other channels are dominated by uncertainties

| | ATLAS | CMS |
|---|---|---|
| $WW \to l\nu l\nu$ | $1.4 \pm 0.5$ | $0.8 \pm 0.5$ |
| $\bar{\tau}\tau$ | $0.4 \pm 2$ | $0 \pm 1$ |
| $VH \to V\bar{b}b$ | $0.5 \pm 2.5$ | $0.4 \pm 0.8$ |

# Towards non-minimal Supersymmetry

- A natural MSSM (i.e. with light stops)
  → $h$ either too small or SM-like

- These issues can be relaxed by not restricting to minimal Supersymmetry.
  - Non-minimal extensions : NMSSM, U(1)'MSSM
  - Effective approach :

$$K = K_{\text{MSSM}} + \frac{1}{M} K^{(1)} + \frac{1}{M^2} K^{(2)} + \cdots$$

$$W = W_{\text{MSSM}} + \frac{1}{M} W^{(1)} + \frac{1}{M^2} W^{(2)} + \cdots$$

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# Reducing the number of operators

- Restrictions : truncate at order 2 ($1/M^2$), and include only Higgs superfields

$$O_i = \frac{1}{M^k} O_i(H_1, H_2), \quad k = 1 \text{ or } 2$$

- Fields redefinition and equations of motion

$$\begin{aligned}
W_{\text{eff}} &= \zeta_1 \frac{1}{M} (H_1.H_2)^2 \\
K_{\text{eff}} &= a_1 \frac{1}{M^2} \left(H_1^\dagger e^{V_1} H_1\right)^2 + a_2 \frac{1}{M^2} \left(H_2^\dagger e^{V_2} H_2\right)^2 \\
&\quad + a_3 \frac{1}{M^2} \left(H_1^\dagger e^{V_1} H_1\right)\left(H_2^\dagger e^{V_2} H_2\right) + a_4 \frac{1}{M^2} (H_1.H_2)\left(H_1^\dagger.H_2^\dagger\right) \\
&\quad + \frac{1}{M^2} \left(H_1.H_2 + H_1^\dagger.H_2^\dagger\right)\left(a_5 H_1^\dagger e^{V_1} H_1 + a_6 H_2^\dagger e^{V_2} H_2\right)
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**Supersymmetry Breaking**

$$\zeta_1 \longrightarrow \zeta_{10} + \zeta_{11} m_s \theta^2$$

$$a_i \longrightarrow a_{i0} + a_{i1} m_s \theta^2 + a_{i1}^* m_s \bar{\theta}^2 + a_{i2} m_s^2 \bar{\theta}^2 \theta^2$$

$$+ \frac{1}{M^2} \left( H_1.H_2 + H_1^\dagger.H_2^\dagger \right) \left( a_5 H_1^\dagger e^{V_1} H_1 + a_6 H_2^\dagger e^{V_2} H_2 \right)$$

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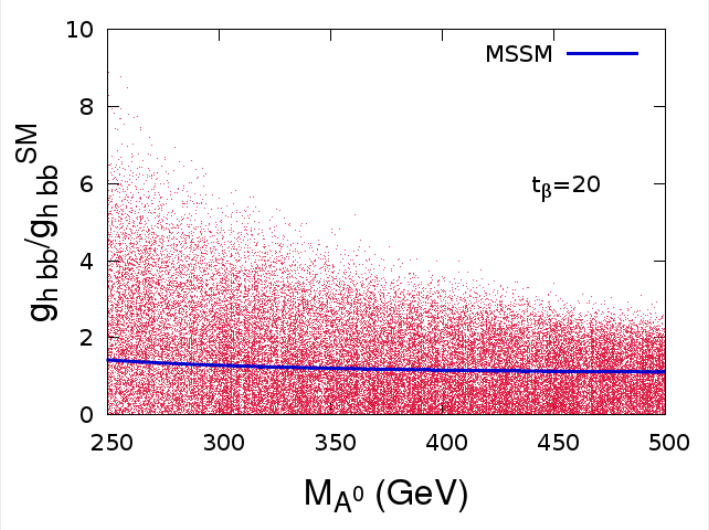


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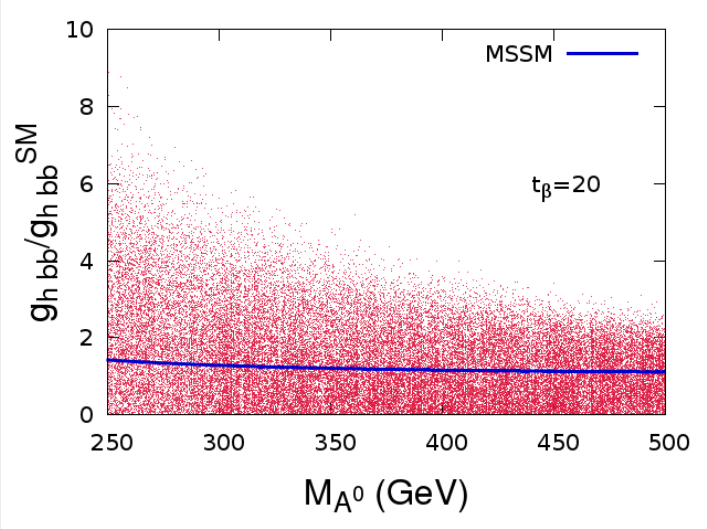


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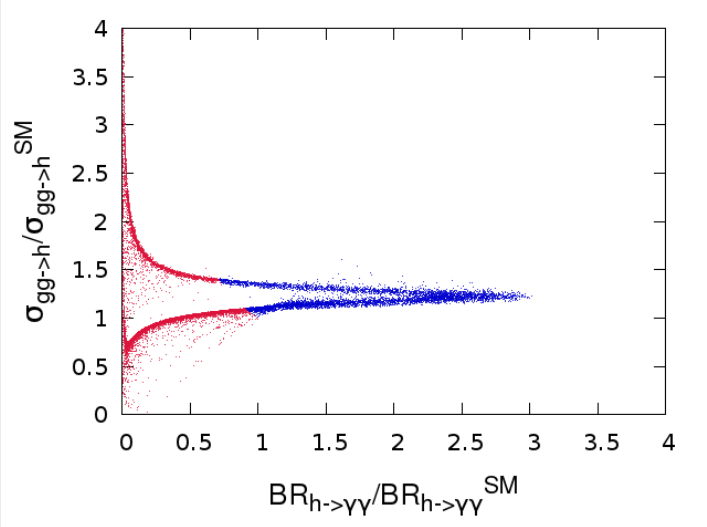

# MSSM Parameter Space

- $M_2 = 300$ GeV, $M_1 = \frac{5}{3}\tan^2\theta_W M_2 \simeq M_2/2$, $M_3 = 800$ GeV.
- $M_{\tilde{f}} = 1$ Tev, $A_f = 0$, except for third generation
  - A): Light degenerate stops $M_{u3} = M_{q3} = M_{d3} = 400$ GeV, $A_t = A_b = 0$
  - B): Light stops mass separated and maximal mixing $m_{\tilde{t}_1} = 200$ GeV, $m_{\tilde{t}_2} \in [300, 800]$ (GeV) and $|\sin 2\theta_{\tilde{t}}| = 1$
- Higgs sector

$$t_\beta \in [2, 40], \quad M_{A^0} \in [50, 450] \text{ GeV}$$

- Effective parameter space

$$\zeta_{1j}, a_{ij} \in [-1, 1]$$

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# Experimental constraints

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- Electroweak Precision Test (EWPT)
- Flavour Physics : $B_s \to \mu^+\mu^-$ and $B \to X_s\gamma^*$
- Muon anomalous magnetic moment $g_\mu - 2$
- Dark Matter constraints (Relic density and direct detection)
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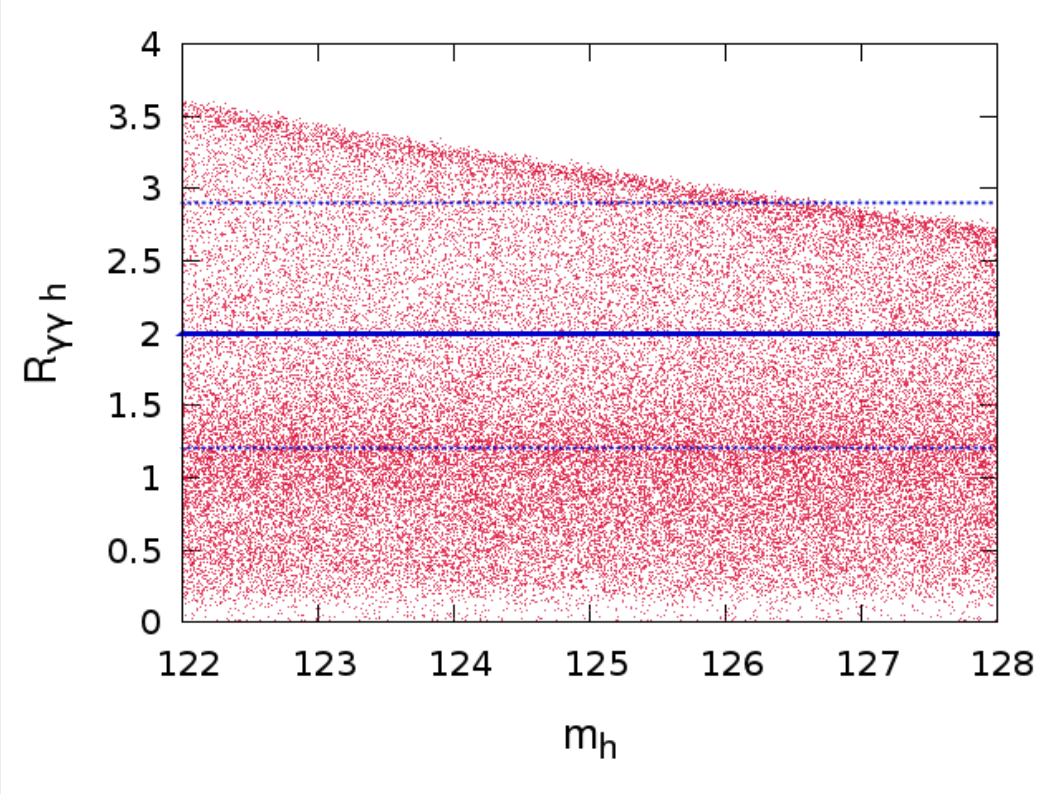


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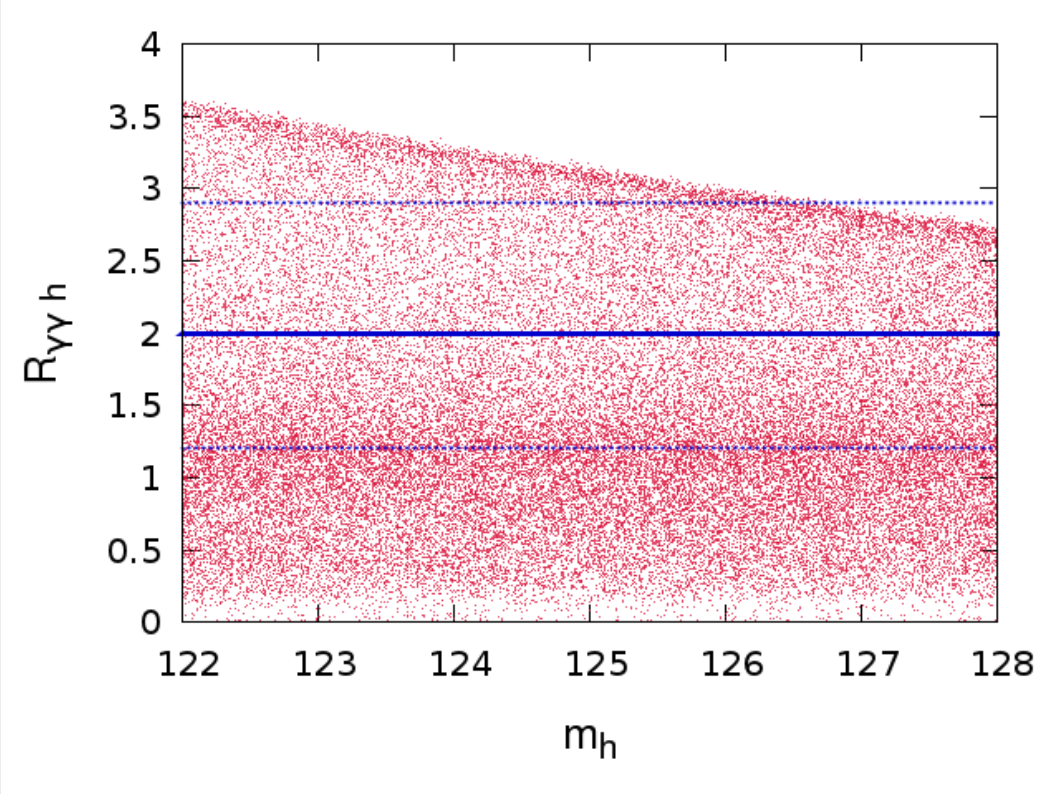


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- Effect of the stops loops
  - Opposite contributions to $gg \to h$ and $h \to \gamma\gamma$.
  - Model B) : $\Delta m_{\tilde{t}} = 400$ GeV, $s_{2\theta_t} = 1$
  - $R_{\gamma\gamma}$ is reduced as compared as scenario A) but now there is a hierarchy

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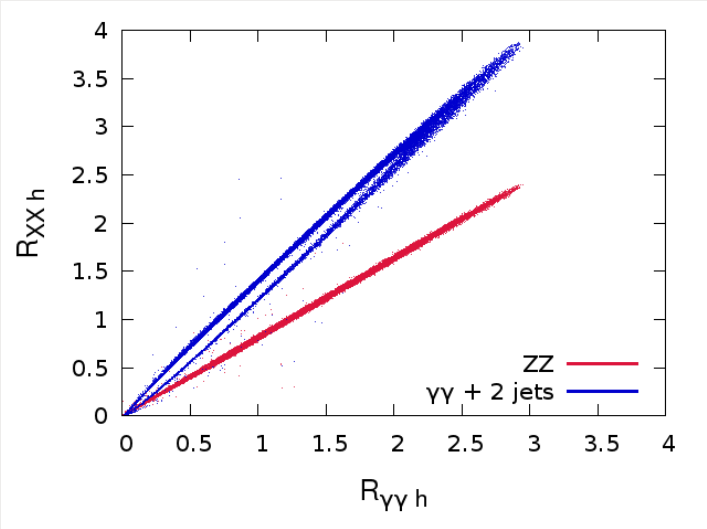


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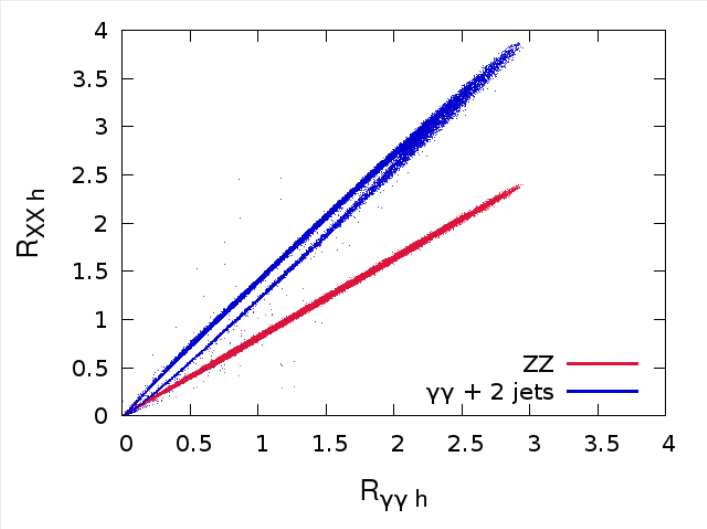


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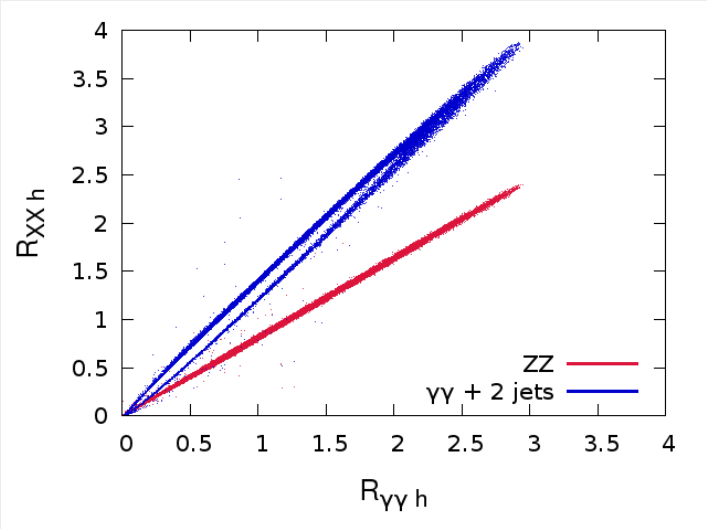


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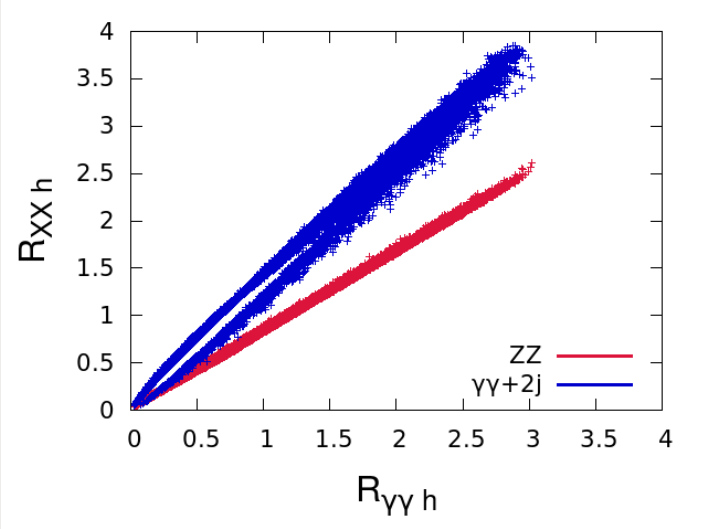
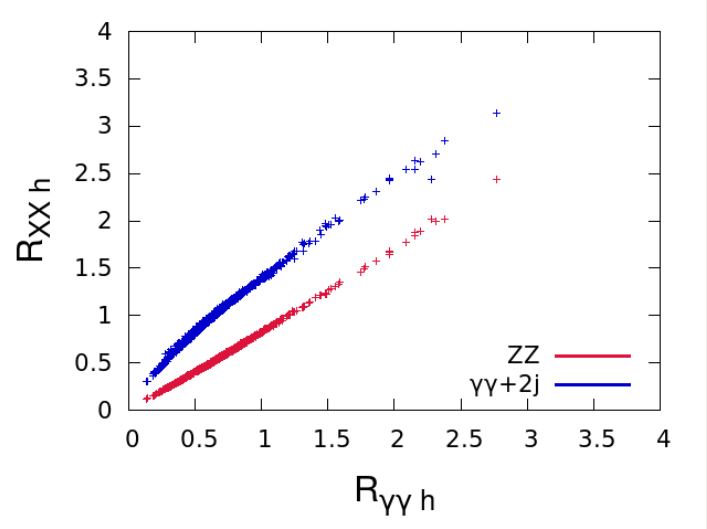
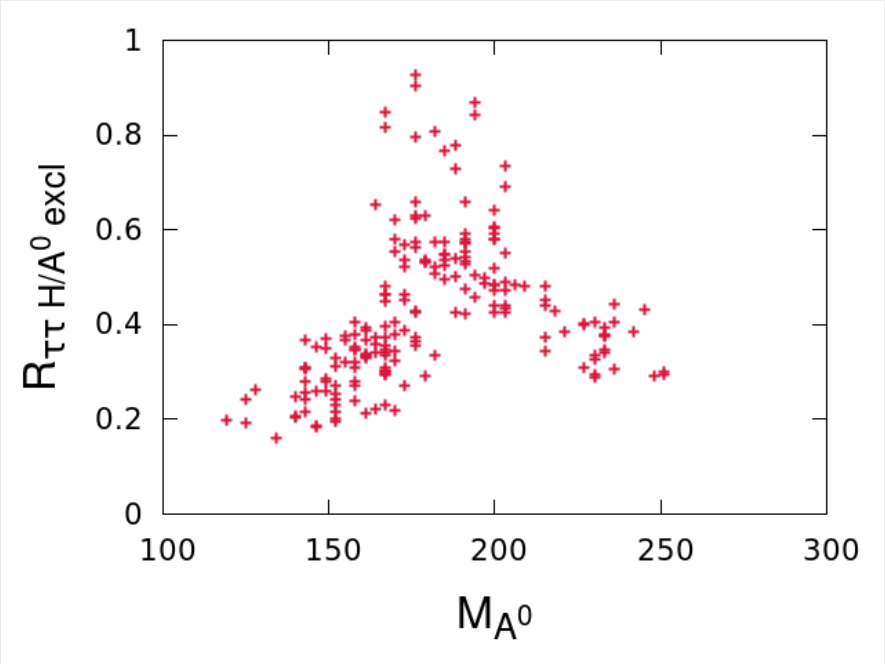


# Heavier Higgses

- Model A): Flavour restricts $M_{A^0} > 200$ GeV
- Model B): Flavour + Higgs signal
  → $A^0/H$ not too elusive

$$R^{\text{excl}} = \frac{\sigma}{\sigma^{\text{excl 95\%}}_{5\ \text{fb}^{-1}}}$$



# Conclusion

- Supersymmetry consistent with significant deviations
  - Generic non-minimal framework → BMSSM
  - Consistent with an enhancement of $R_{\gamma\gamma}$
  - Can produce hierarchies between channels
- Will it stay so?
  - A model quite constrained (Flavour, other Higgses)
  - More data → Beyond the speculative level