

BMSSM Higgses at 125 GeV

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Implications of LHC results for TeV-scale physics

Based on F. Boudjema, G. DLR arXiv:1203.3141

see also F. Boudjema, G. DLR PhysRevD.85.035011 (arXiv:1112.1434)



1 Model Description

- Motivations
- New operators

2 Analysis

- Parameter space
- Input from experiments

3 Results

- Signal features
- Expectations for other signals

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- MSSM limitations
 - fine-tuning problem
 - light Higgs constrained $m_h < 135$ GeV
- Natural extensions : NMSSM, U(1)'MSSM ...
- Effective Field Theory approach

$$M = 1.5 \text{ TeV}$$

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

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

F. Boudjema, GDLR arXiv:1203.3141

Brignole et al . arXiv:0301121

Antoniadis et al. arXiv:0910.1100

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$h/H, A_0, H^+$

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Higher dimensionnal operators in the Higgs sector

- Include only operators involving Higgs superfields H_1, H_2
- Effective Field Theory expansion on K and W :

$$\begin{aligned} K \rightarrow & K + \frac{a_1}{M^2} \left(H_1^\dagger e^{V_1} H_1 \right)^2 + \frac{a_2}{M^2} \left(H_2^\dagger e^{V_2} H_1 \right)^2 \\ & + \frac{a_3}{M^2} \left(H_1^\dagger e^{V_1} H_1 \right) \left(H_2^\dagger e^{V_2} H_2 \right) + \frac{a_4}{M^2} (H_1 \cdot H_2)^\dagger (H_1 \cdot H_2) \\ & + \frac{a_5}{M^2} \left(H_1^\dagger e^{V_1} H_1 \right) (H_1 \cdot H_2 + h.c.) + \frac{a_6}{M^2} \left(H_2^\dagger e^{V_2} H_2 \right) (H_1 \cdot H_2 + h.c.) \\ W \rightarrow & W + \frac{\zeta_1}{M} (H_1 \cdot H_2)^2 \end{aligned}$$

- The effective coefficients can also have susy-breaking parts

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

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

with $m_s = 300$ GeV.

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- Scalar Higgs potential

- $$V_{\text{MSSM}} = \tilde{m}_1^2 |H_1|^2 + \tilde{m}_2^2 |H_2|^2 + \tilde{m}_{12}^2 (H_1 \cdot H_2 + h.c.) + \frac{1}{8} (g_1^2 + g_2^2) H^4$$

- Only one non-trivial minimum possible

- Minimisation :

- **First** v_1, v_2 determined from M_Z, t_β
- **Then** $\tilde{m}_1, \tilde{m}_2, \tilde{m}_{12}$ can be fully determined from v_1, v_2, M_{A_0} using the tadpole condition.
- **Finally** V_{BMSSM} is evaluated numerically to check that the point v_1, v_2 is a global minimum.

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- Main effect : m_h goes up to 250 GeV.
- Couplings also affected

$$\sigma_{gg \rightarrow h} / \sigma_{gg \rightarrow h}^{SM}$$

$$\sigma_{VBF} / \sigma_{VBF}^{SM}$$

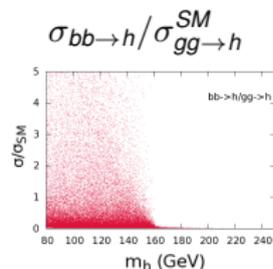
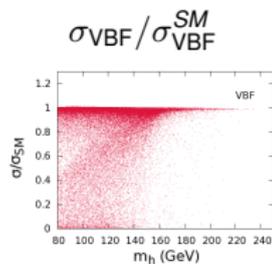
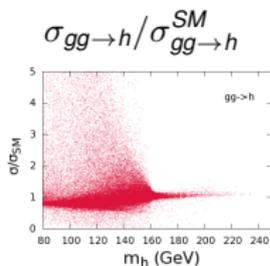
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- But this was soon constrained by LHC searches ($\mathcal{L} = 2.3\text{fb}^{-1}$)

F. Boudjema, G. DLR
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Higgs Phenomenology

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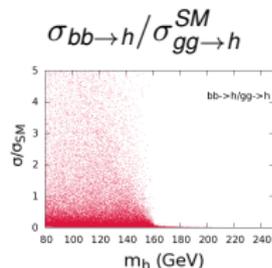
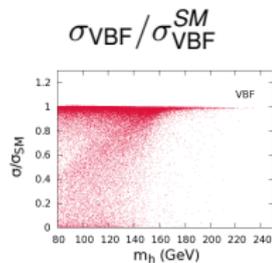
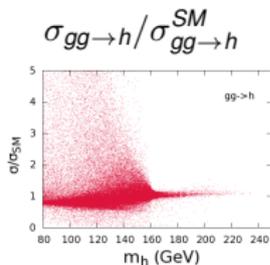


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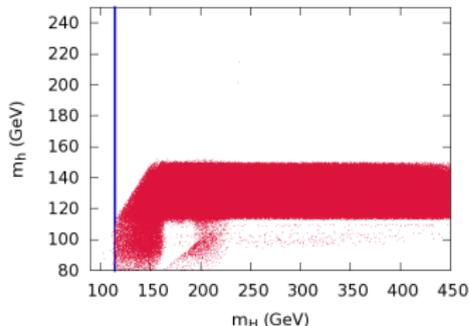
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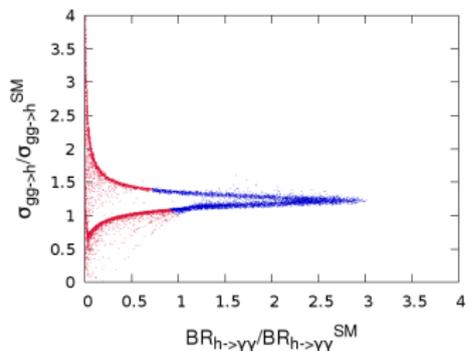


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- Effective operators change $g_{h\bar{b}b}$ (\Rightarrow Extreme case $g_{h\bar{b}b} = 0$)
- Enhance branching ratios in all over channels



- Correlation with the gluon fusion

$$\frac{\sigma_{gg \rightarrow h}}{\sigma_{gg \rightarrow h}^{\text{SM}}} = \frac{|\mathcal{A}_t + x\mathcal{A}_b|^2}{|\mathcal{A}_t + \mathcal{A}_b|^2}$$

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Parameter Space

- MSSM free parameters $t_\beta \in [2, 40]$ and $M_{A_0} \in [50, 450]$
- Stop sector
- A) $M_{U3} = M_{d3} = M_{q3} = 400$ GeV, $A_t = 0$. \Rightarrow No mixing scenario
- B) $m_{\tilde{t}_1} = 200$ GeV, $m_{\tilde{t}_2} \in [300, 1000]$ GeV, $|\sin 2\theta_{\tilde{t}}| = 1$. \Rightarrow Maximal mixing
- All other superpartners are at $M_{\text{soft}} = 1$ TeV, $\mu = M_2 = 300$ GeV.
- Effective coefficients ζ, a taken in $[-1, 1]$.

• Suppression factors will arise as

$$\frac{\mu}{M} = \frac{m_a}{M} = 0.2 \sim \frac{v}{M}$$

Constraints

- Perturbativity check for $\frac{1}{M}$ expansion.
- Electroweak precision test ($\Delta_\rho = \Delta_\rho^{\text{MSSM}} + \frac{1}{M^2} \Delta_\rho^{\text{eff}}$)
- Colliders Higgs searches applied to h, H, A_0 and H^\pm (LEP/Tevatron/LHC)

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- Neutral channels are

$VH \rightarrow V\bar{b}b$	$H \rightarrow \bar{\tau}\tau$	$H \rightarrow WW$
$H \rightarrow ZZ$	$H \rightarrow \gamma\gamma$	$(H \rightarrow \gamma\gamma + 2 \text{ jets})$

- For neutral bosons Φ and each final state XX we define

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- Look for a signal (with $R_{XX \Phi}$) in [122, 128] GeV.
- Apply exclusion ($R_{XX \Phi}^{\text{Exclusion}} < 1$) on all other Higgses
- $R^{\text{Exclusion}}$ are added in quadrature among all channels to determine whether the point is excluded.
 - $R^{\text{Exclusion}}$ shows the sensitivity : e.g.
 - $R^{\text{Exclusion}} = 0.5 \Rightarrow$ we need $\mathcal{L} \sim 4 \times 5 = 20\text{fb}^{-1}$.

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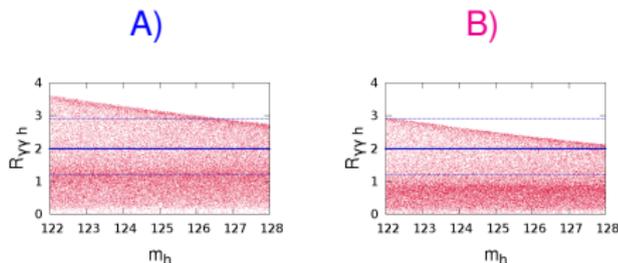
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Signal features : case of the light h

- Enhancement in the $h \rightarrow \gamma\gamma$ channel



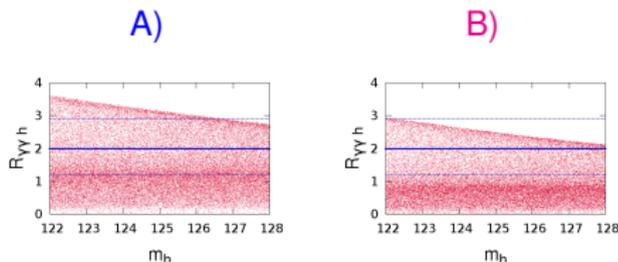
- Blue lines : 1σ error band on ATLAS best fit.
- Correlations between $ZZ, \gamma\gamma$ (inclusive) and $\gamma\gamma+2$ jets

A) B)

- Blue : R_{ZZ} , Red : $R_{\gamma\gamma+2 \text{ jets}}$

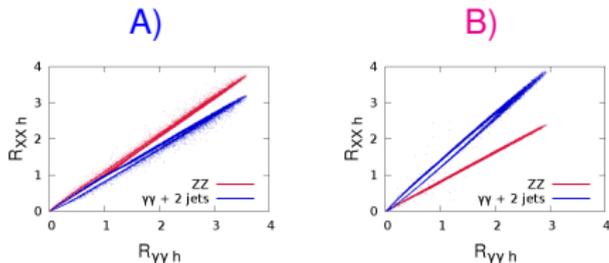
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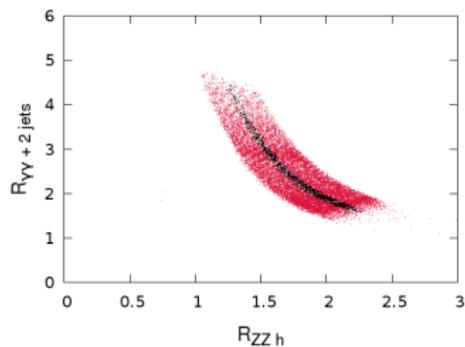


A) $m_{\tilde{t}_1} \sim m_{\tilde{t}_2} \sim 400$ GeV

B) $m_{\tilde{t}_1} = 200$ GeV, $m_{\tilde{t}_2} = 600$ GeV

- **Blue** : R_{ZZ} , **Red** : $R_{\gamma\gamma+2 \text{ jets}}$.

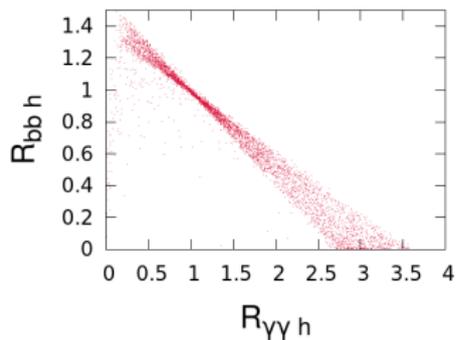
- Effect of the light stop loop



- **Black** : $R_{\gamma\gamma} = 2.0 \pm 1\%$
- **Red** : $R_{\gamma\gamma} = 2.0 \pm 10\%$

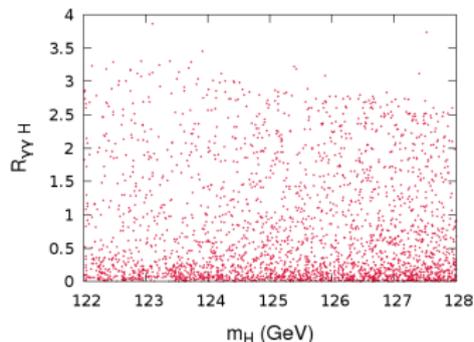
$$m_{\tilde{t}_2} \in [300 - 1000] \text{ GeV}$$

- How does the $VH \rightarrow V\bar{b}b$ behave?

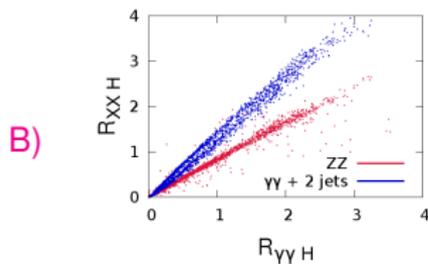


- Predictions not too suppressed, but strong correlation!

Signal features : case of the heavy H

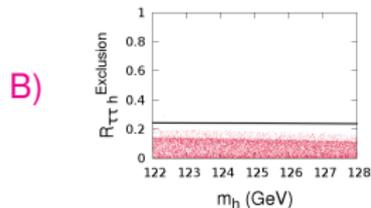
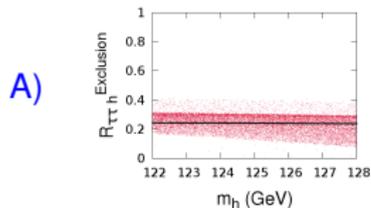


- A parameter space more contrived : less points.
- Similar features of the h case
- The spread in the correlations has increased



Prospect for other signals : case of the light h

- Signal from h : the $\bar{\tau}\tau$ channel.



- The other Higgses have very low expectations in $\gamma\gamma$, ZZ and WW channels

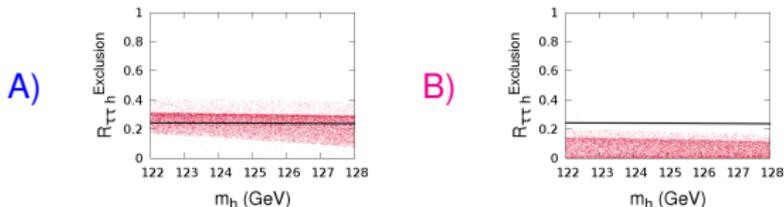
A)

- There is more to see in the $\bar{\tau}\tau$ channel

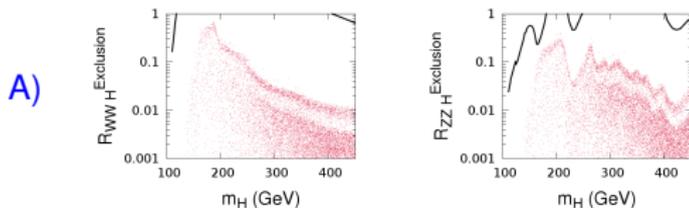
It does depend on t_β

Prospect for other signals : case of the light h

- Signal from h : the $\bar{\tau}\tau$ channel.



- The other Higgses have very low expectations in $\gamma\gamma$, ZZ and WW channels

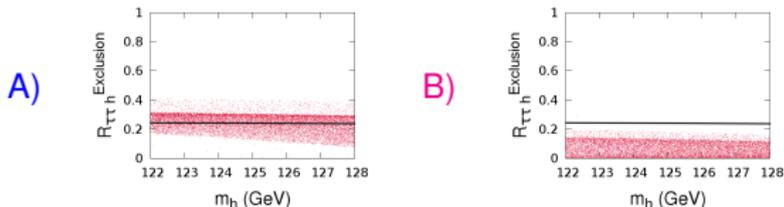


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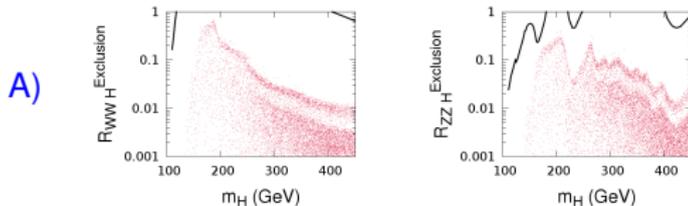
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Prospect for other signals : case of the light h

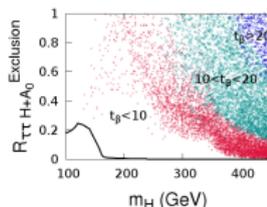
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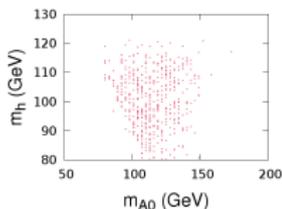
- There is more to see in the $\bar{\tau}\tau$ channel



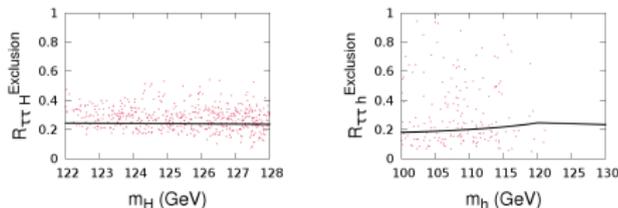
It does depend on t_β

Prospect for other signals : case of the heavy H

- All Higgses in a light mass range



- The best prospects are in the $\bar{\tau}\tau$ channel, again



- The chances in $h \rightarrow \bar{\tau}\tau$ are unaffected by the choice of scenario.

Summary

- The BMSSM framework can accommodate $R_{\gamma\gamma + 2 \text{ jets}} > R_{\gamma\gamma} > R_{ZZ}$.
- It could be either h or H .
- Correlations among channels will be the most constraining information, since it cannot be too flexible.
- Signal of other Higgses are possible within the next run.

Outlook

- Achieve a more precise use of LHC analyses on the SM Higgs.
- See to what extent this can be related to the direct searches for the stop particle.

