

Implications of naturalness for the heavy Higgs bosons of supersymmetry

Michael R. Savoy

Based on work of Bae, Baer, Barger, Mickelson, and Savoy
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Outline

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- 2 Naturalness
 - Fine-tuning measure
 - Fine-tuning limit
- 3 Heavy Higgs
 - Mass bounds
 - $m_A - \Delta_{EW}$ plane
 - $m_A - \tan\beta$ plane
- 4 A, H, H^\pm decays
 - Branching Fractions
 - Decay modes
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Supersymmetry

Supersymmetry: fermions \longleftrightarrow bosons
symmetry



SUSY crisis?

Where are sparticles?



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$m_h \approx 125 \text{ GeV} \implies m_{\tilde{t}_{1,2}} \mathcal{O}(\text{multi-TeV})$



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Is SUSY in a crisis?



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$$\frac{m_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2$$



$$\Delta_{EW}$$

Δ_{EW} requires no large unnatural cancellations in m_Z

$$\begin{aligned} \frac{m_Z^2}{2} &= \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2 \\ &\approx -m_{H_u}^2 - \Sigma_u^u - \mu^2 \end{aligned}$$



$$\Delta_{EW}$$

Generate SUSY spectra using Isajet

NUHM2 $\{ m_0, m_{1/2}, \mu, m_A, A_0, \tan\beta \}$



Generate SUSY spectra using Isajet

NUHM2 $\{ m_0, m_{1/2}, \mu, m_A, A_0, \tan\beta \}$

$$m_0 = 5 \text{ TeV},$$

$$m_{1/2} = 0.7 \text{ TeV},$$

$$110 \text{ GeV} \leq \mu \leq 600 \text{ GeV},$$

$$m_A = 1 \text{ TeV},$$

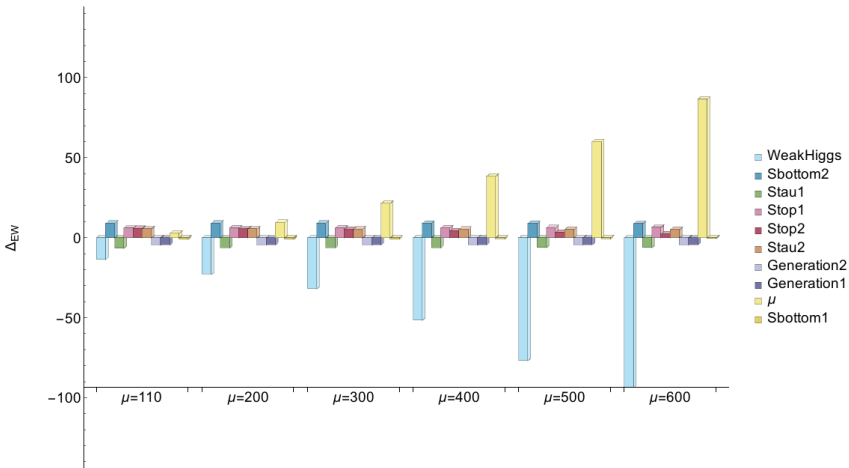
$$A_0 = -8.3 \text{ TeV},$$

$$\tan\beta = 10$$



Fine-tuning limit

$$\Delta_{EW} \lesssim 30$$



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Implications

$$\mu \approx 100 - 200 \text{ GeV}$$



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$m_{\tilde{t}_1, \tilde{t}_2}$ multi-TeV, but highly mixed

$m_{\tilde{g}} \lesssim 3 - 5 \text{ TeV}$ (outside LHC reach?)

Mass bounds

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For $\Delta_{EW, \max}=10$, $\tan\beta=10 \implies m_A \lesssim 2 \text{ TeV}$

For $\Delta_{EW, \max}=30$, $\tan\beta=25 \implies m_A \lesssim 9 \text{ TeV}$



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m_{A,H,H^\pm} can be multi-TeV with little cost to naturalness

NUHM model

Generate SUSY spectra using Isajet

NUHM2 $\{ m_0, m_{1/2}, \mu, m_A, A_0, \tan\beta \}$



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Generate SUSY spectra using Isajet

NUHM2 $\{ m_0, m_{1/2}, \mu, m_A, A_0, \tan\beta \}$

$$0 \text{ TeV} \leq m_0 \leq 20 \text{ TeV}$$

$$0.3 \text{ TeV} \leq m_{1/2} \leq 2 \text{ TeV}$$

$$-3 \leq A_0/m_0 \leq 3$$

$$0.1 \text{ TeV} \leq \mu \leq 1.5 \text{ TeV}$$

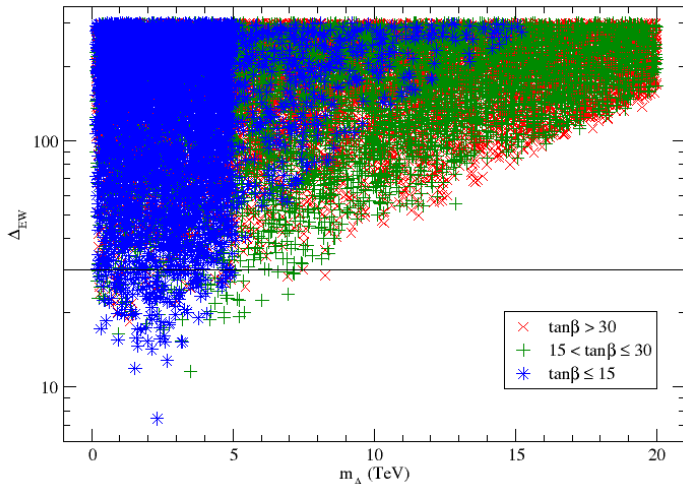
$$0.15 \text{ TeV} \leq m_A \leq 20 \text{ TeV}$$

$$3 \leq \tan\beta \leq 60$$

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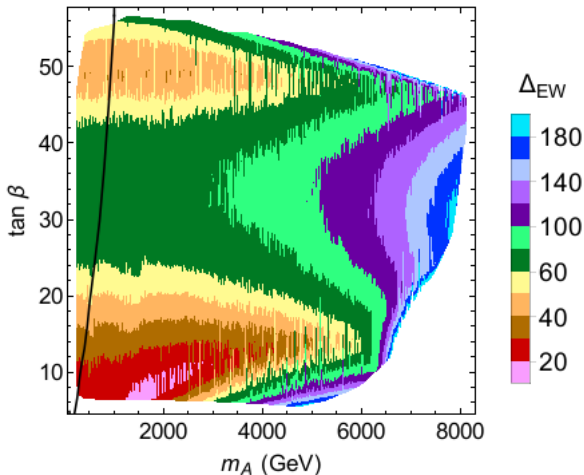
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 $m_A - \Delta_{EW}$ plane $m_A - \Delta_{EW}$ plane

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 $m_A - \tan\beta$ plane $m_A - \tan\beta$ plane



Branching Fractions

LHC reach assumes SM decays only

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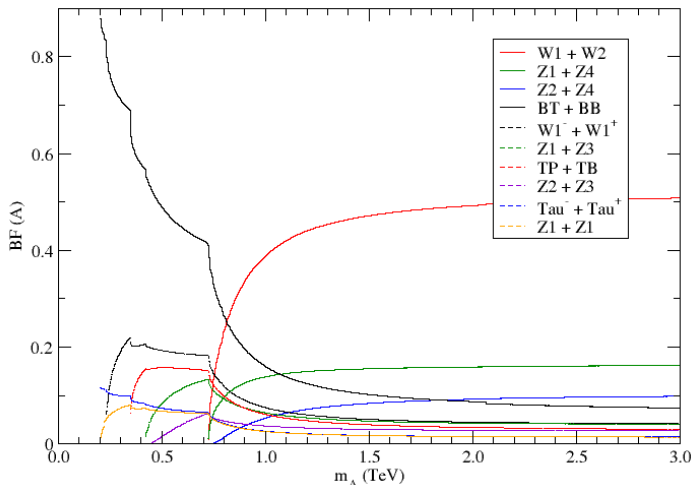
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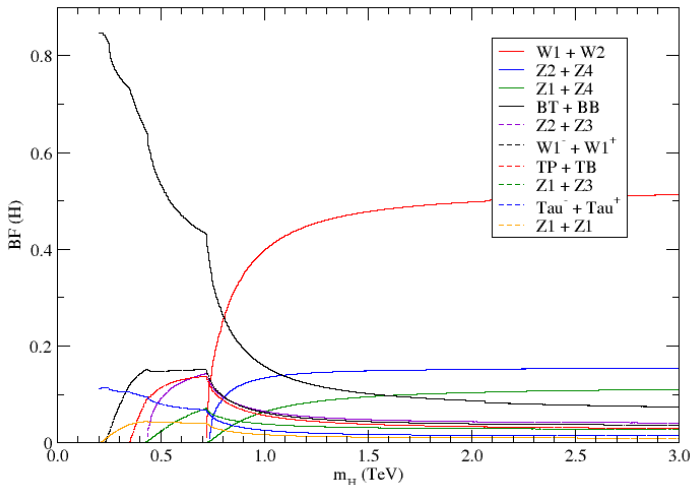
$$m_{A,H,H^\pm} \gg 2\mu$$

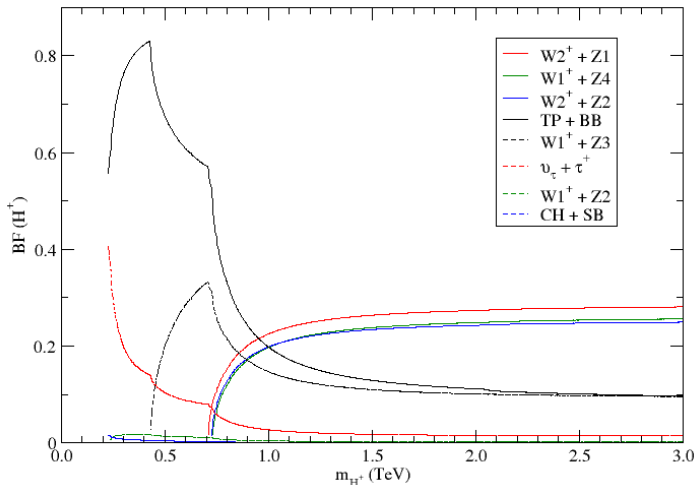
Must include SUSY decay modes



BF A

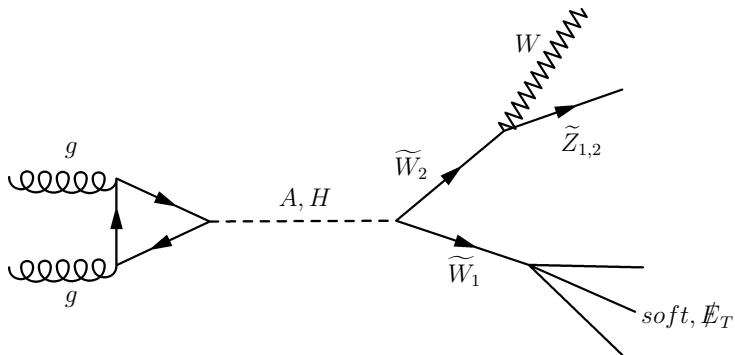


BF H 

BF H^+ 



New signatures for Heavy Higgs



$$gg \rightarrow H, A \rightarrow \widetilde{W}_2 + \widetilde{W}_1$$

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$$\widetilde{W}_2 \rightarrow W + \widetilde{Z}_{1,2}$$

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$$\widetilde{W}_1 \rightarrow \text{soft tracks} + \cancel{E}_T$$



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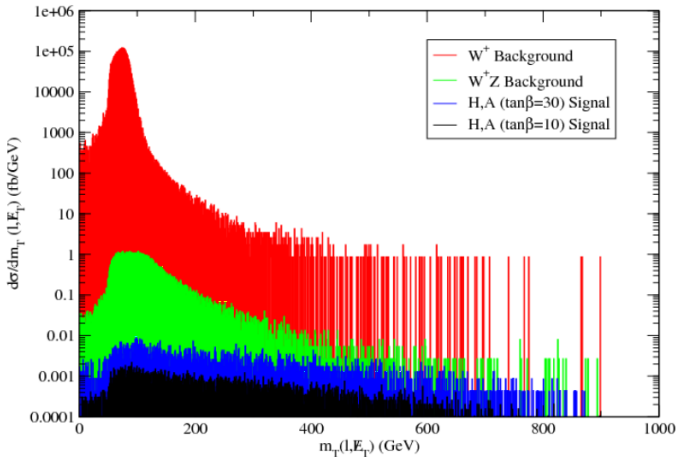
$$\widetilde{W}_2 \rightarrow h + \widetilde{W}_1$$

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$$H, A \rightarrow \begin{array}{l} W + \cancel{E}_T \\ Z + \cancel{E}_T \\ h + \cancel{E}_T \end{array}$$



Decay modes





Big picture points

- $|\mu^2| \approx m_Z^2$
- $m_{\tilde{t}_1, \tilde{t}_2}$ multi-TeV, highly mixed
- $m_{A, H, H^\pm} \lesssim 4 - 8 \text{ TeV}$



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Work in progress : possibility of low m_A