Beyond MSSM Higgs sectors

José Francisco Zurita (ITP, Univ. Zürich)

Based on:

- M. Carena, K. Kong, E.Pontón, J.Z: **Phys.Rev.D81:015001, 2010**
- M. Carena, E.Pontón, J.Z: in preparation (**arXiv 0805.XXXX?**)

Phenomenology Symposium 2010

10th May, Madison, USA

Outline

- Motivation
- BMSSM Higgs sectors
- Collider phenomenology
- Conclusions

Motivation

- MSSM Higgs sector is strongly constrained
  - LEP search: $m_h > 90 \ \mathrm{GeV}$
  - MSSM 2 loops: $m_h < 130 \ \mathrm{GeV}$
- Tension can be relaxed with new d.o.f (i.e: NMSSM)
- Effective Field Theory (EFT) analysis by:
  - Brignole, Casas, Espinosa, Navarro (2003).
  - Dine, Seiberg, Thomas (2007).

Higgs in the MSSM

$$H_u,\, H_d \to h,\, H,\, A,\, H^{\pm} \qquad v^2 = v_u^2 + v_d^2$$

h, H → scalars A → pseudoscalar

Tree level: $\tan\beta = v_u/v_d$, m_A

$$\begin{aligned} V &= m_{11}^2 H_u^\dagger H_u + m_{22}^2 H_d^\dagger H_d - [bH_u H_d + \text{c.c}] \\ &+ \frac{1}{2}\lambda_1 (H_d^\dagger H_d)^2 + \frac{1}{2}\lambda_2 (H_u^\dagger H_u)^2 + \lambda_3 (H_u^\dagger H_u)(H_d^\dagger H_d) + \lambda_4 (H_u H_d)(H_u^\dagger H_d^\dagger) \\ &+ \left\{ \frac{1}{2}\lambda_5 (H_u H_d)^2 + \left[\lambda_6 (H_d^\dagger H_d) + \lambda_7 (H_u^\dagger H_u)\right] (H_u H_d) + \text{c.c} \right\}. \end{aligned}$$

MSSM: $\lambda_1 = \lambda_2 = (g_1^2 + g_2^2)/4, \quad \lambda_3 = (g_2^2 - g_1^2)/4, \quad \lambda_4 = -g_2^2/4, \quad \lambda_5 = \lambda_6 = \lambda_7 = 0$

Tree level: $m_h^{(0)} \leq m_Z |\cos(2\beta)|$ **2-loops:** $m_h < 130 \text{ GeV}$

m_S, A_t, A_b

BMSSM Higgs sectors

BMSSM

Starting point: Effective theory (valid below scale M)

$$W = \mu H_u H_d + \frac{\omega_1}{2M}(1 + \alpha_1 X)(H_u H_d)^2$$

M. Dine, N. Seiberg, S. Thomas (2007)

Only 2 parameters: $\omega_1, \alpha_1 \sim \mathcal{O}(1)$ Spurion: $X = m_S\, \theta^2$

$$\Delta\lambda_5 = \alpha_1 \omega_1 \frac{m_S}{M} \qquad \Delta\lambda_6 = \Delta\lambda_7 = \omega_1 \frac{\mu}{M} \qquad \mathcal{O}(1/M) \equiv \mathrm{Dim5}$$

Our choices:

- $\mu = m_S = 200\ \mathrm{GeV}$ and $M = 1\ \mathrm{TeV}$
- $\tan\beta = 2\ (20)$: Low (large) $\tan\beta$ regime.

Related work in HDO

- MSSM: Antoniadis, Dudas, Ghilencea, Tziveloglou ('08, '09), Strumia ('99)
- Stability: Blum, Delaunay, Hochberg ('09)
- Fine tuning: Casas, Espinosa, Hidalgo ('04), Cassel, Ghilencea, Ross ('10)
- DM: Cheung, Choi, Song ('09), Berg, Edsjo, Gondolo, Lundstrom, Sjors ('09), Bernal, Goudelis ('10)
- Cosmology: Bernal, Blum, Losada, Nir ('09)
- EW baryogenesis: Grojean, Servant, Wells ('05), Bodeker, Fromme, Huber, Seniuch ('05), Delaunay, Grojean, Wells ('08), Noble, Perelstein ('08), Grinstein, Trott ('08), Blum, Delaunay, Nir, Losada, Tulin ('10)
- S(upersymmetric)EWSB vacua: Batra, Pontón ('09)

Dimension 6 Lagrangian

$$
\begin{aligned}
K &= H_d^\dagger e^V H_d + H_u^\dagger e^V H_u \\
&+ \frac{c_1}{M^2}(1+\gamma_1(X+X^\dagger)+\beta_1 XX^\dagger)(H_d^\dagger e^V H_d)^2 \\
&+ \frac{c_2}{M^2}(1+\gamma_2(X+X^\dagger)+\beta_2 XX^\dagger)(H_u^\dagger e^V H_u)^2 \\
&+ \frac{c_3}{M^2}(1+\gamma_3(X+X^\dagger)+\beta_3 XX^\dagger)(H_u^\dagger e^V H_u)(H_d^\dagger e^V H_d) \\
&+ \frac{c_4}{M^2}(1+\gamma_4(X+X^\dagger)+\beta_4 XX^\dagger)(H_u H_d)(H_u H_d)^\dagger \\
&+ \{[\frac{c_6}{M^2}(1+\beta_6 XX^\dagger+\gamma_6 X+\delta_6 X^\dagger)H_d^\dagger e^V H_d \\
&+ \frac{c_7}{M^2}(1+\beta_7 XX^\dagger+\gamma_7 X+\delta_7 X^\dagger)H_u^\dagger e^V H_u](H_u H_d) + h.c\}\,,
\end{aligned}
$$

$\mathcal{O}(1/M^2)$: 20 extra free parameters.

Combining with loops

$$\lambda_i = \lambda_i^{(0)} + \Delta\lambda_i^{(5)} + \Delta\lambda_i^{(6)} + \Delta\lambda_i^{(1-loop)}$$

- Obtain masses and couplings of the Higgs sector

↓

- BRs: Modifying HDECAY v 3.4   A. Djouadi, J. Kalinowski, M. Spira (1996)

↓

- Experimental Bounds: HiggsBounds v1.2.0 *

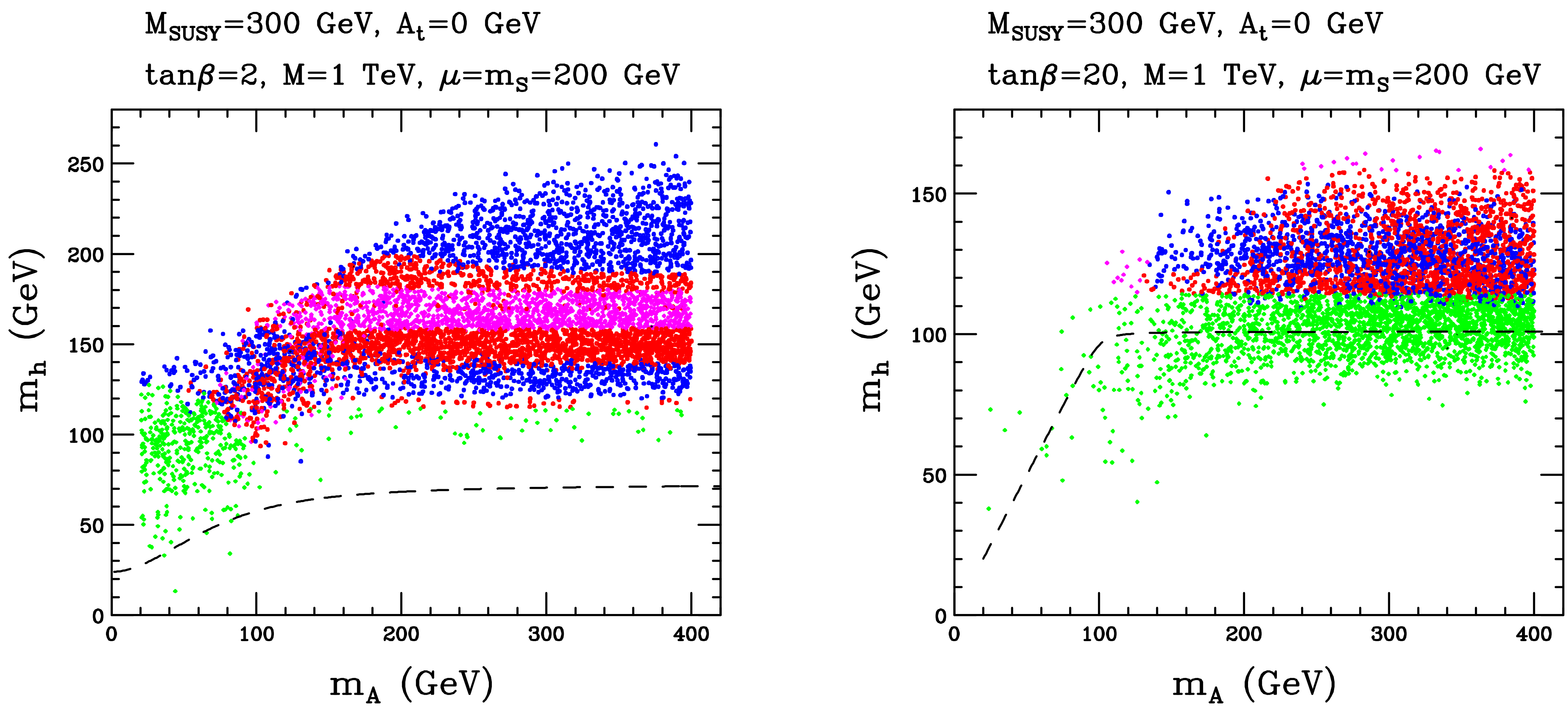
P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein, K. E. Williams (2008-2009)

* includes LEP bound h to jets

+ LEP charged Higgs + latest Tevatron data + EWPO

Collider phenomenology

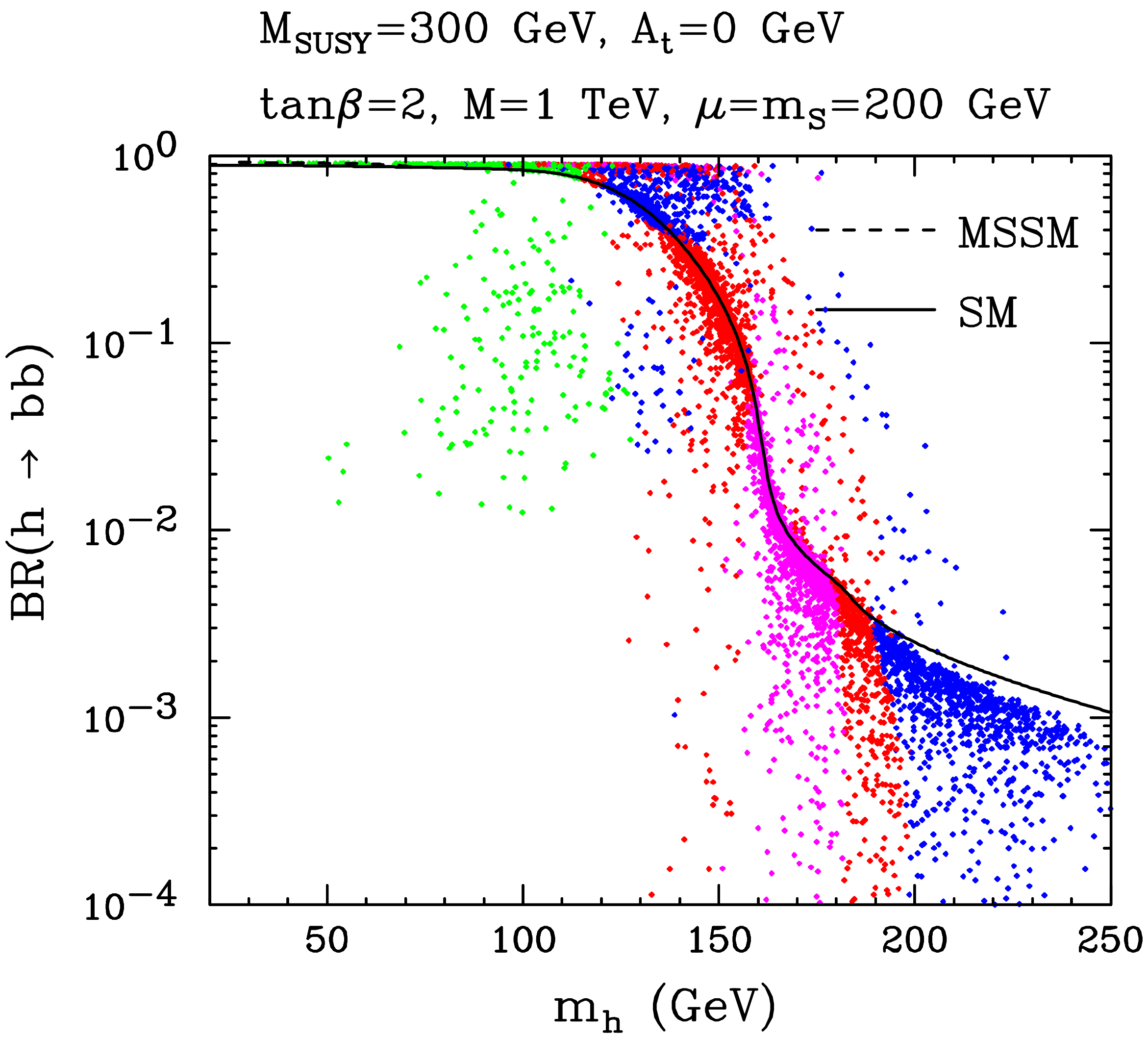
Lightest Higgs mass

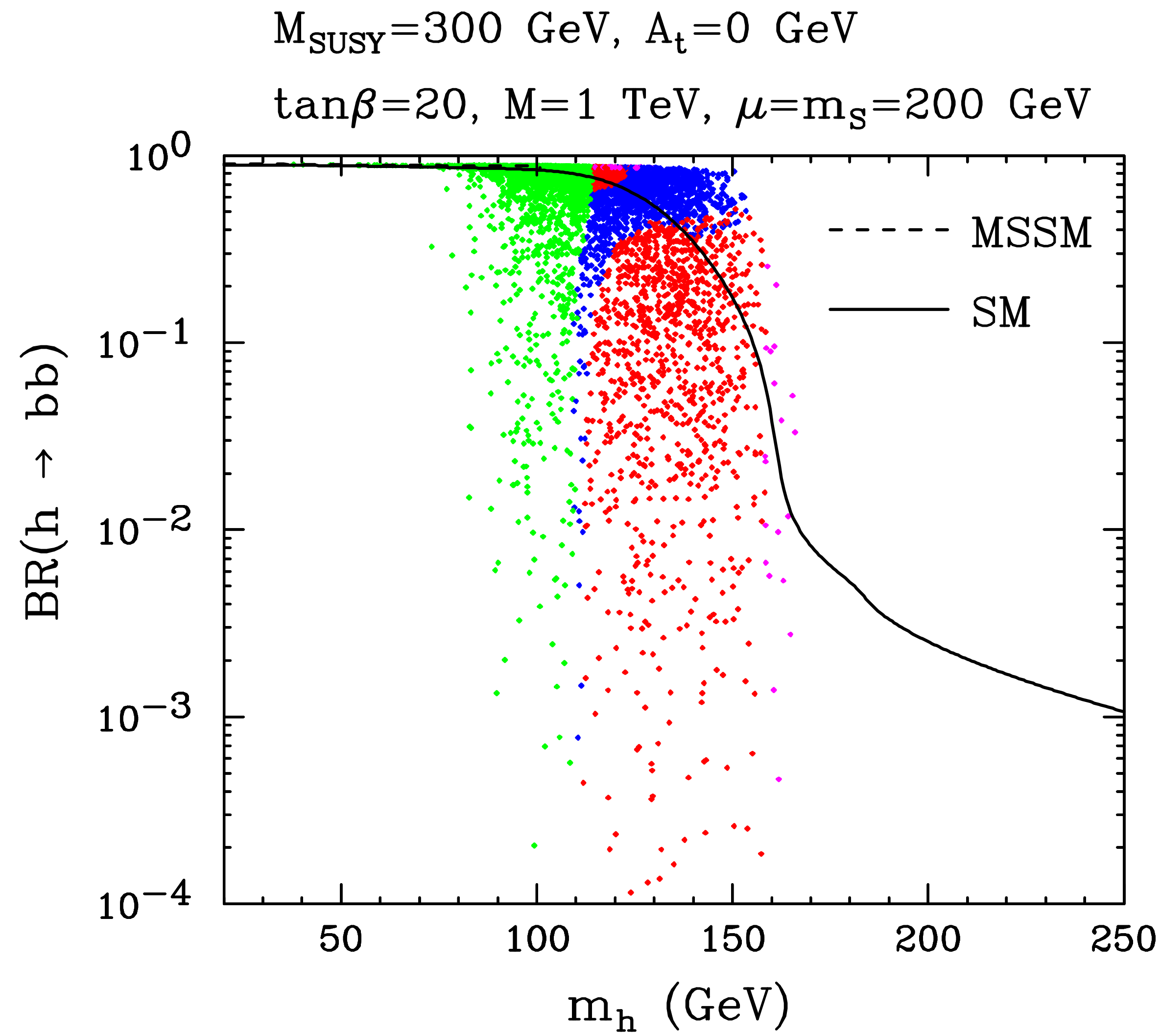


- Excluded by LEP
- Excluded by Tevatron
- Tevatron upgrade → $10\ \text{fb}^{-1} + 50\%$ efficiency in $b\bar{b}$, WW
- Allowed

MSSM: P. Draper, T. Liu, C. Wagner (2009)

BR into b pairs





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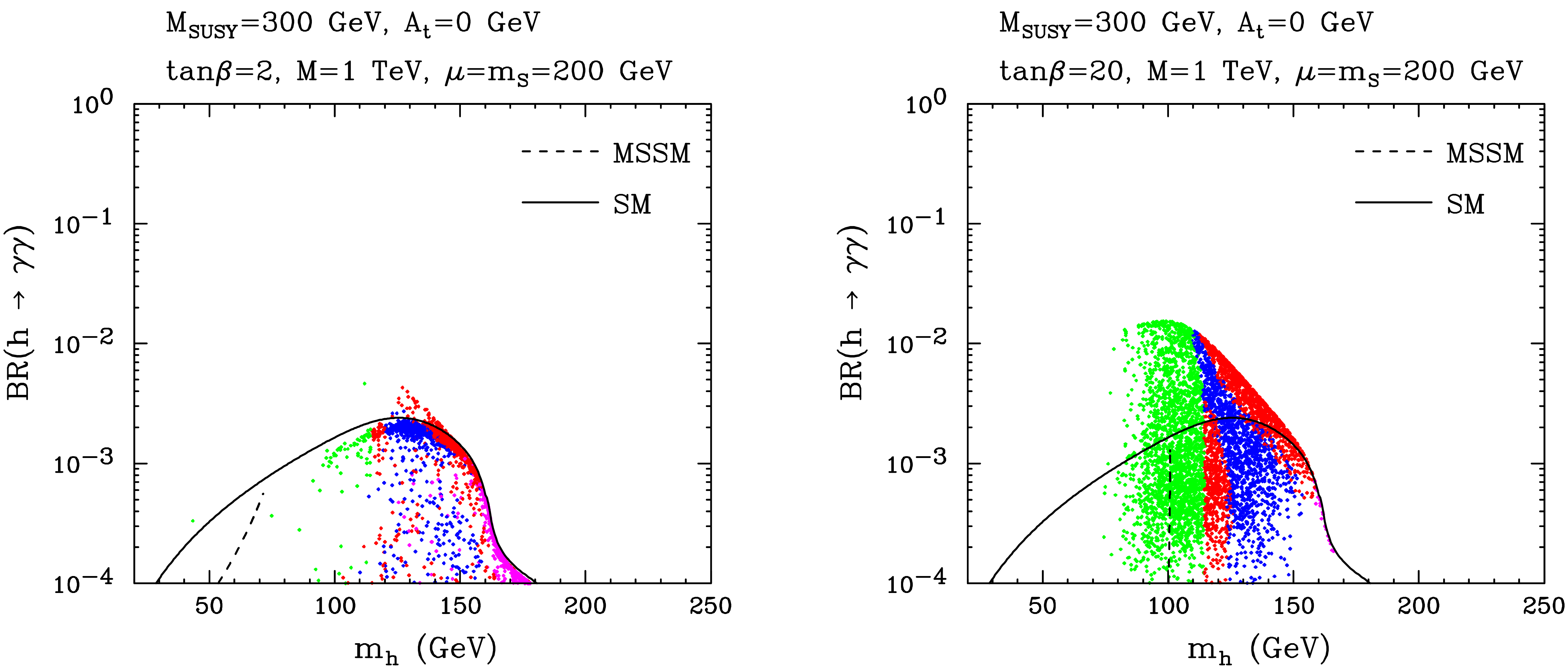
- Suppression of $h \to b\bar{b}$ enhances other channels

Diphoton channel



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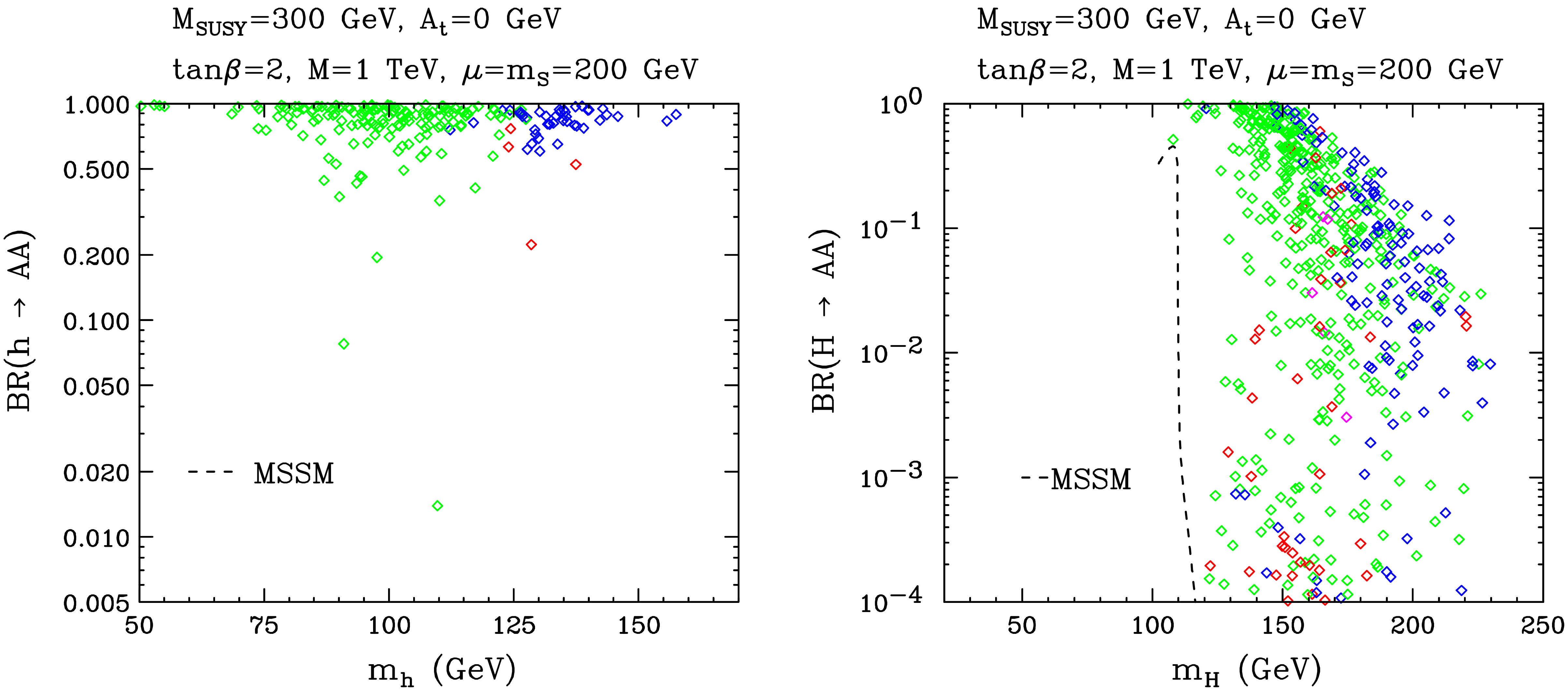
- Enhancements for large $\tan\beta$.

"Exotic" channels



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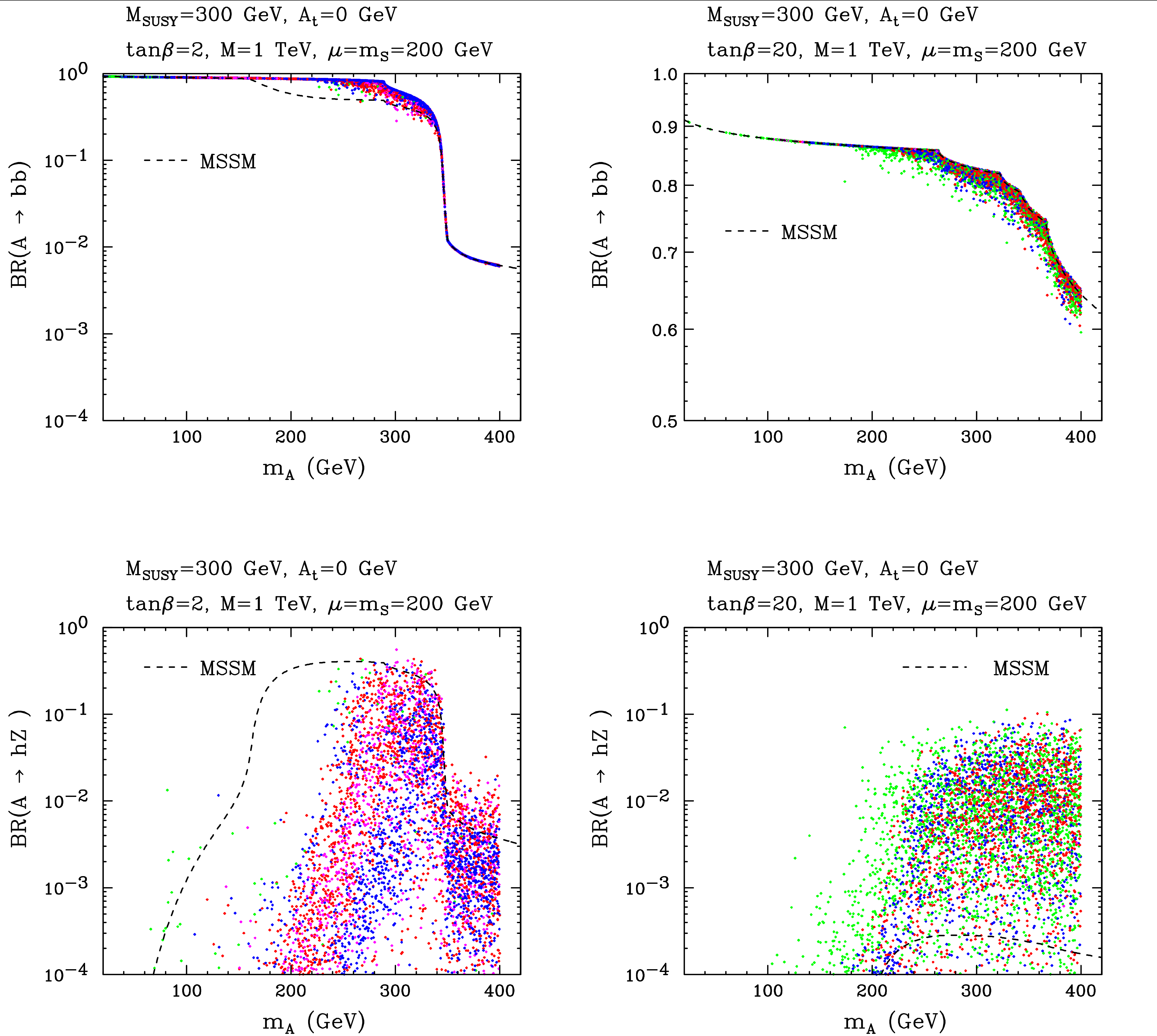
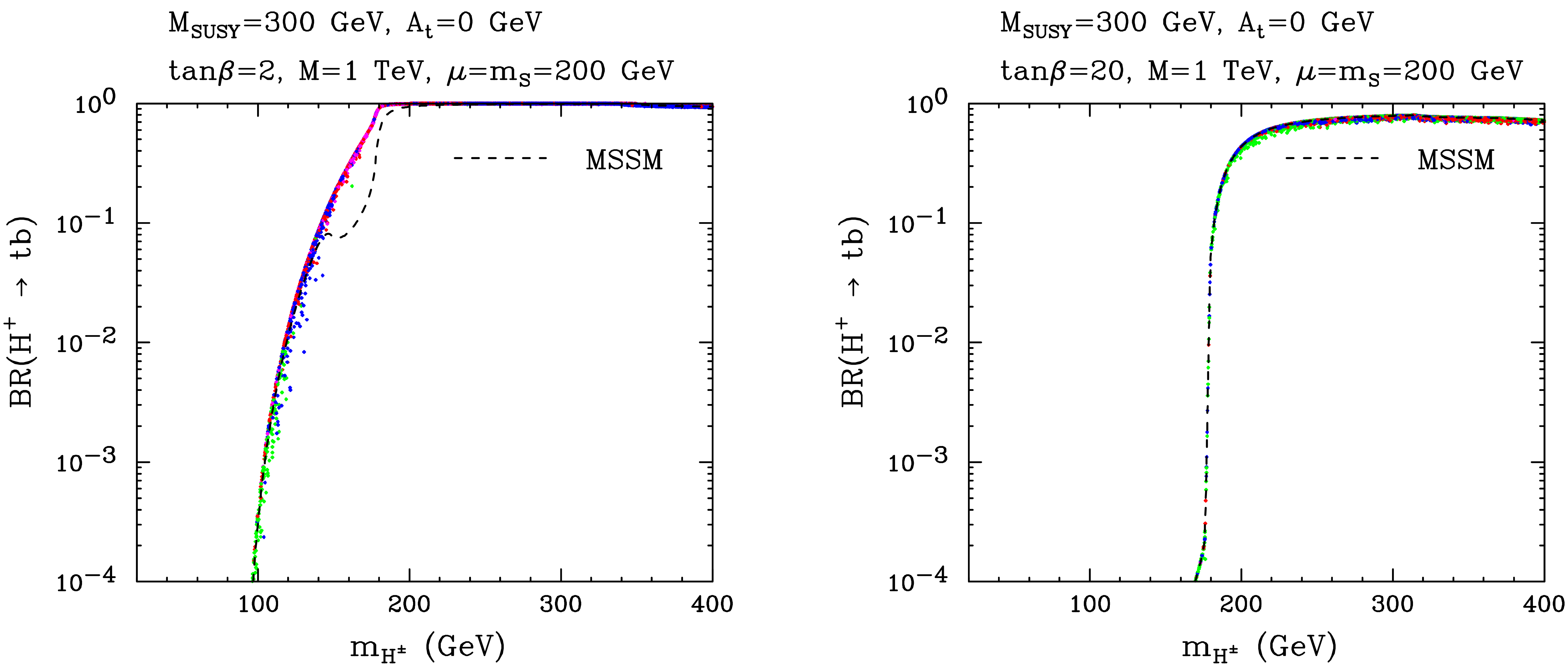
$h, H \to AA$
can become the dominant channel

A decays


M_SUSY=300 GeV, A_t=0 GeV
tanβ=2, M=1 TeV, μ=m_S=200 GeV
BR(A → bb)
MSSM
m_A (GeV)
M_SUSY=300 GeV, A_t=0 GeV
tanβ=20, M=1 TeV, μ=m_S=200 GeV
BR(A → bb)
MSSM
m_A (GeV)
M_SUSY=300 GeV, A_t=0 GeV
tanβ=2, M=1 TeV, μ=m_S=200 GeV
BR(A → hZ)
MSSM
m_A (GeV)
M_SUSY=300 GeV, A_t=0 GeV
tanβ=20, M=1 TeV, μ=m_S=200 GeV
BR(A → hZ)
MSSM
m_A (GeV)

Charged Higgs decays



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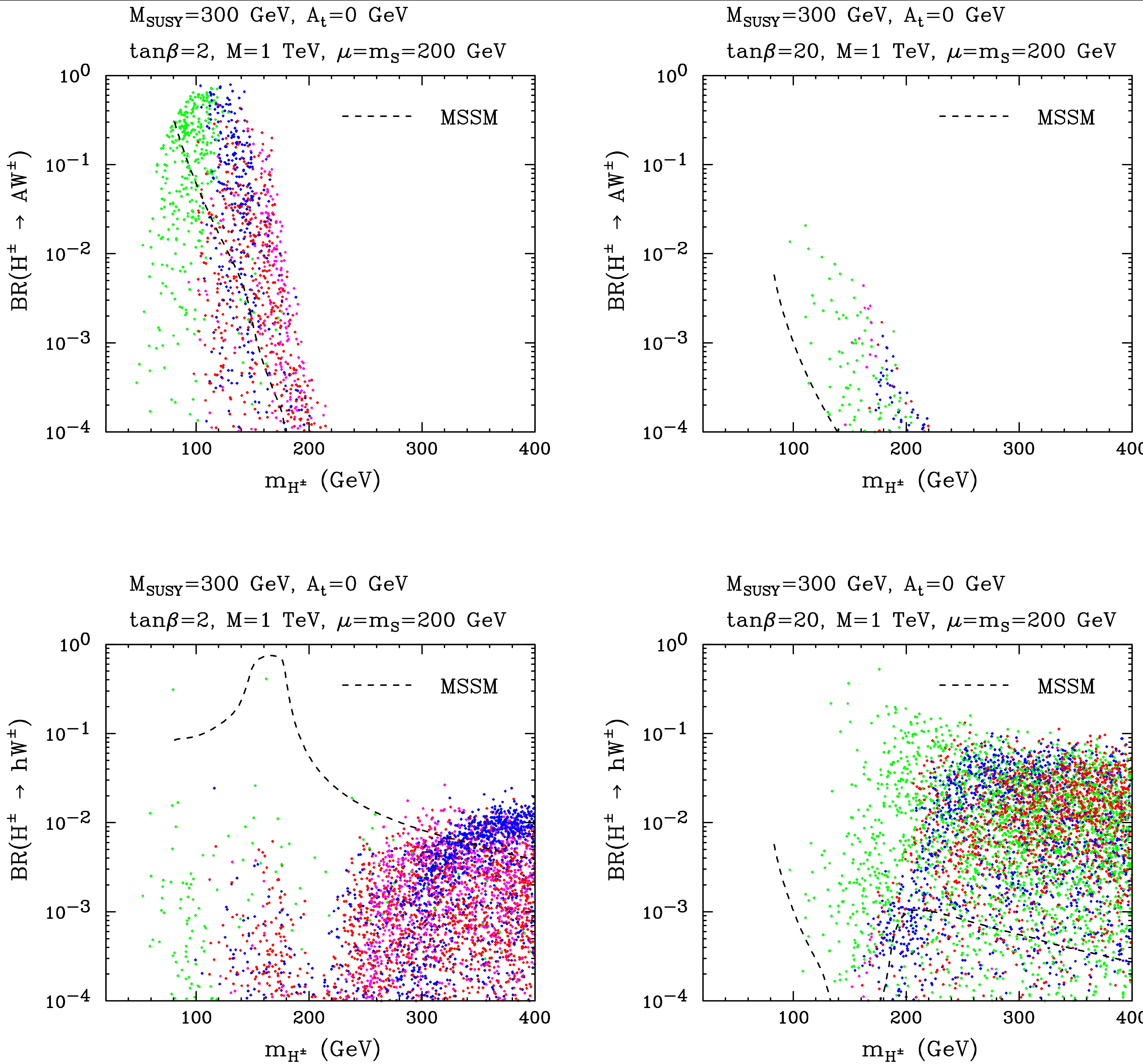
- *Standard* MSSM channels changes due to changes in the spectrum (rise of m_h).

$H^{\pm}$

Exotic decays



Conclusions

- We have studied BMSSM extensions with an EFT approach up to the second order in the 1/M expansion.
- Modified phenomenology with respect to MSSM.
- Great rise of the lightest Higgs mass, specially for low tangent beta (relax the MSSM tension).
- Current work: establish benchmarks.
- Other phenomenological consequences: DM

M. Carena, R. Hernández Pinto, A. Menon

Backup slides

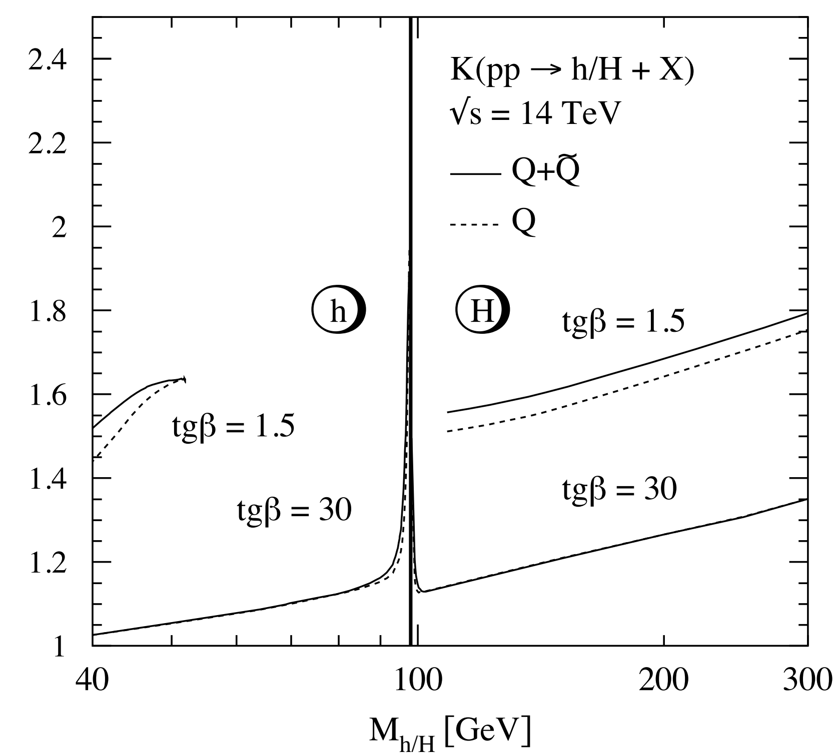
Production cross sections

- VBF, HS: scale by $(g_{hVV})^2$
- Gluon fusion: $\frac{\sigma^{model}(gg \to h)}{\sigma^{SM}(gg \to h)} \simeq \left(\frac{g_{ggh}^{model}}{g_{ggh}^{SM}}\right)^2 \equiv \frac{\Gamma_{h \to gg}^{model}}{\Gamma_{h \to gg}^{SM}}$ holds at LO

bottom loop (NLO):
K factors from
HIGLU (SM vs MSSM)

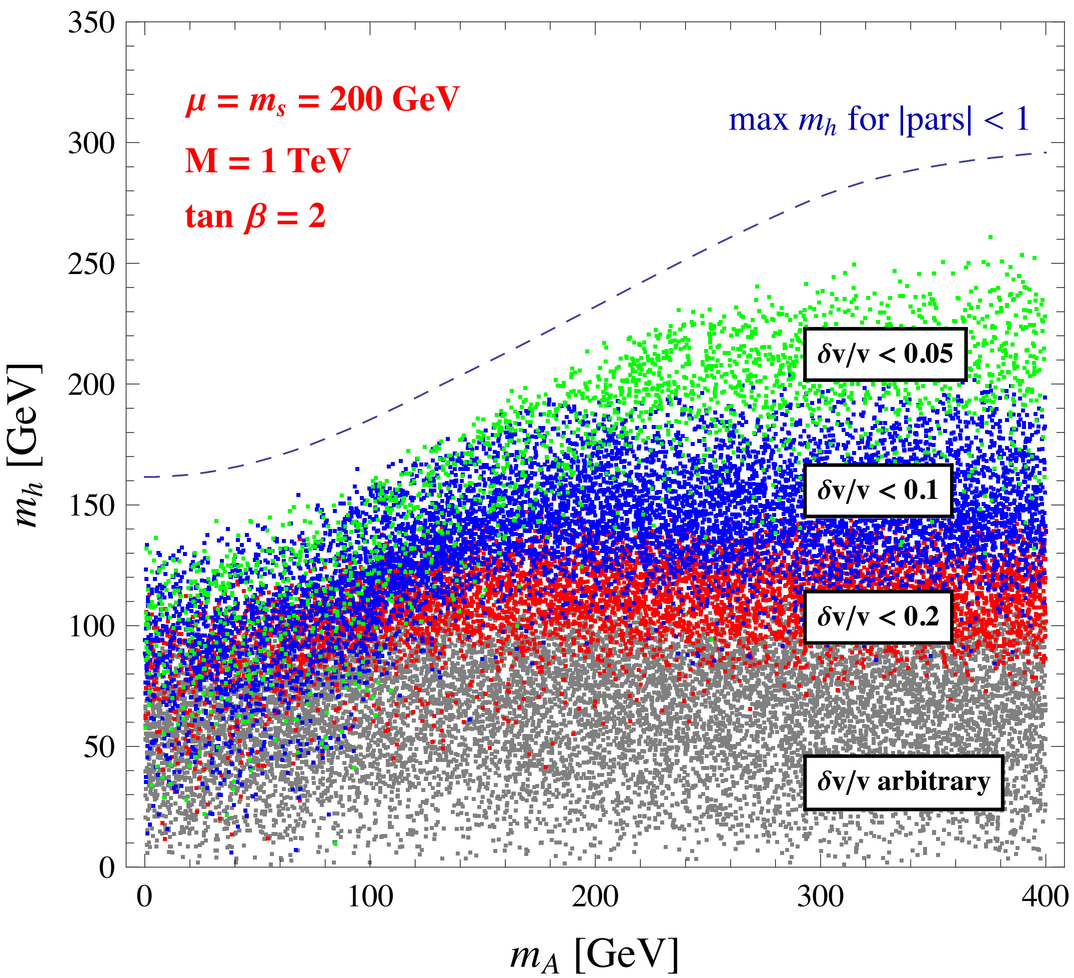
Sparticles:

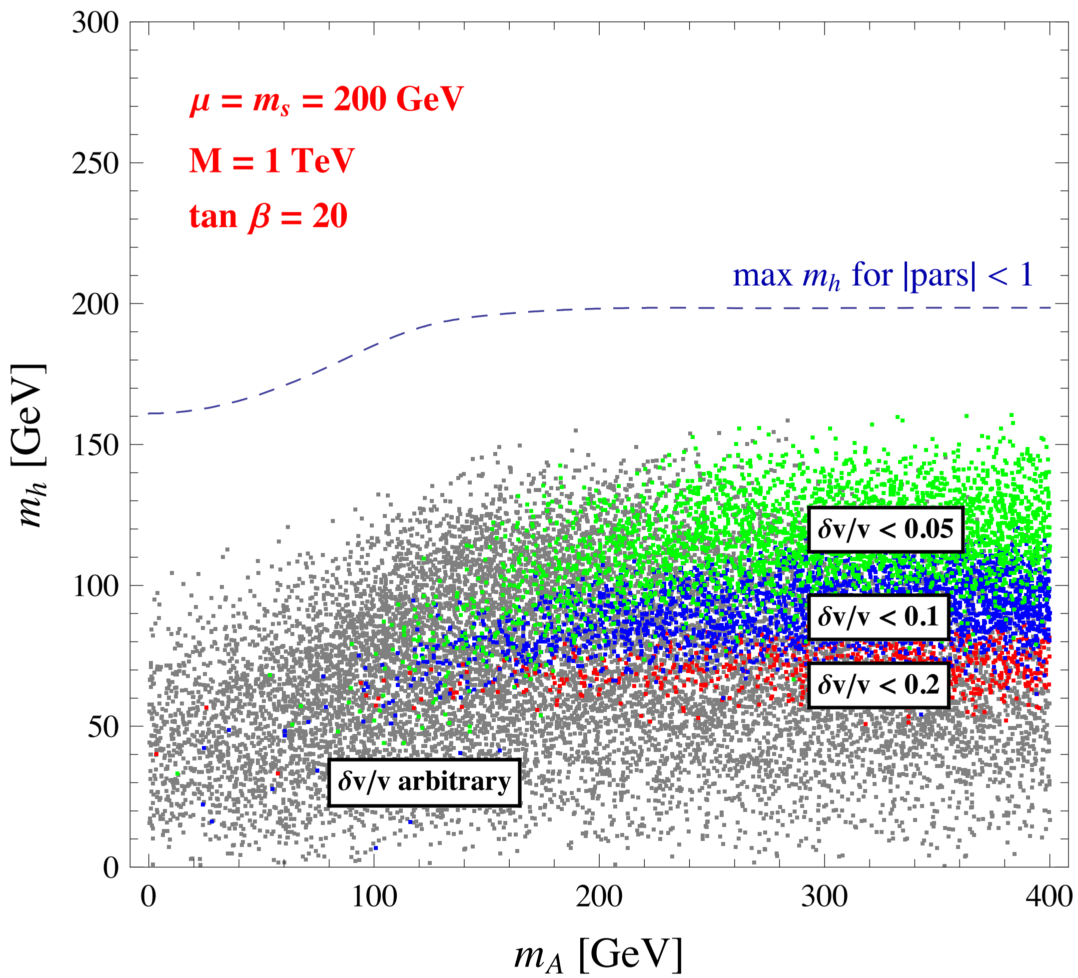
Effect	$\tan\beta = 2$	$\tan\beta = 20$
sparticles	3 %	negl.
bottom loop	< 5 %	20 %



M. Spira, Fortsch.Phys. 46 (1998)

Numerical Scan





- Keep if $\delta v/v < 10\%$ and $1.5(15) < \tan\beta < 2.5(25)$.
- Retain only global CP conserving minima.

Numerical scan

- Parameter region: $|\omega_1|,\ |c_1|,\ |c_2|,\ |c_3|,\ |c_4|,\ |c_6|,\ |c_7| \in [0,1].$

  $|\alpha_1|,\ |\beta_i|,\ |\gamma_i|,\ |\delta_6|,\ |\delta_7| \in [1/3, 1]$ for $i = 1,2,3,4,6,7.$

- Convergence criteria:

$$\lambda_i \to \lambda_i \pm 2\,\mathrm{Max}\,\{|\omega_1|, |c_1|, |c_2|, |c_3|, |c_4|, |c_6|, |c_7|\} \left(\frac{\mu}{M}\right)^3 \ ,\ i = 1, \ldots 7\ ,$$

  Solve (with fixed params) for $v, \tan\beta$.

  Keep if $\delta v/v < 10\%$ and $1.5(15) < \tan\beta < 2.5(25)$.

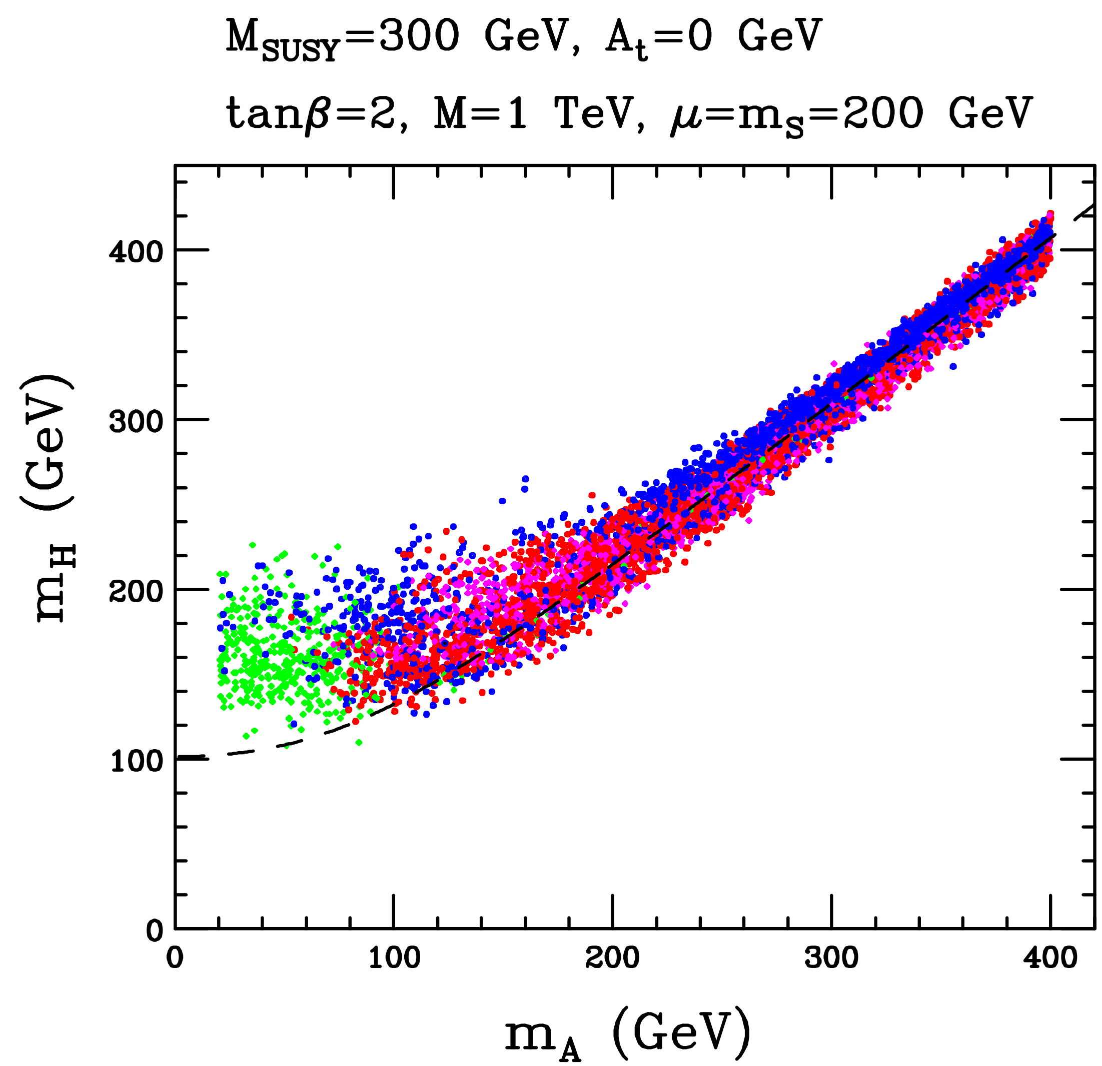
- Only retain CP and charge conserving global minima.

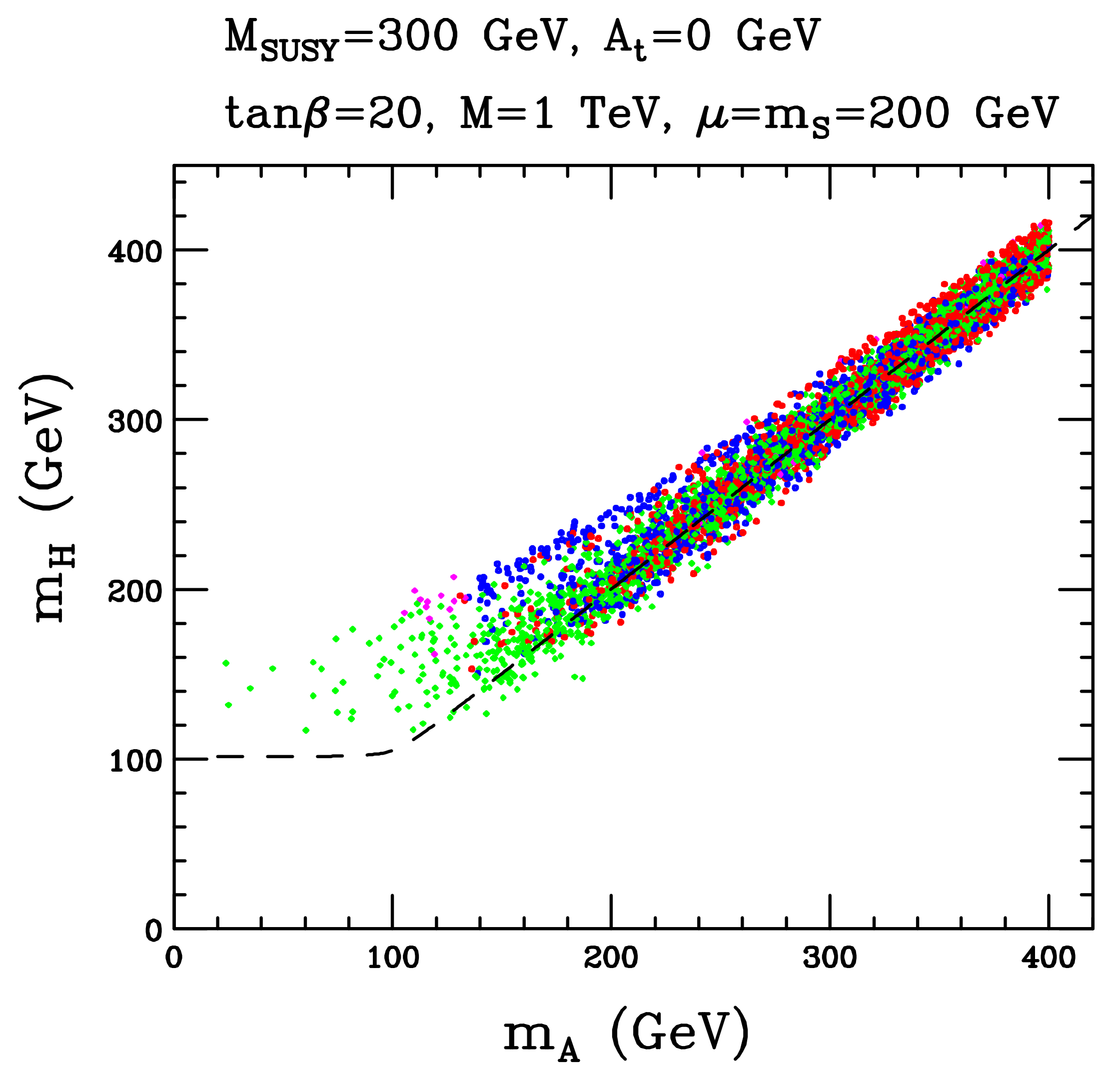
- EW constraints: $-0.2 < T^{tree} + T^{Higgs} + T^{SUSY} < 0.3$

  $T^{SUSY} \to \sim 0.2$

Medina, Shah, Wagner ('09)

Heavy CP-even Mass





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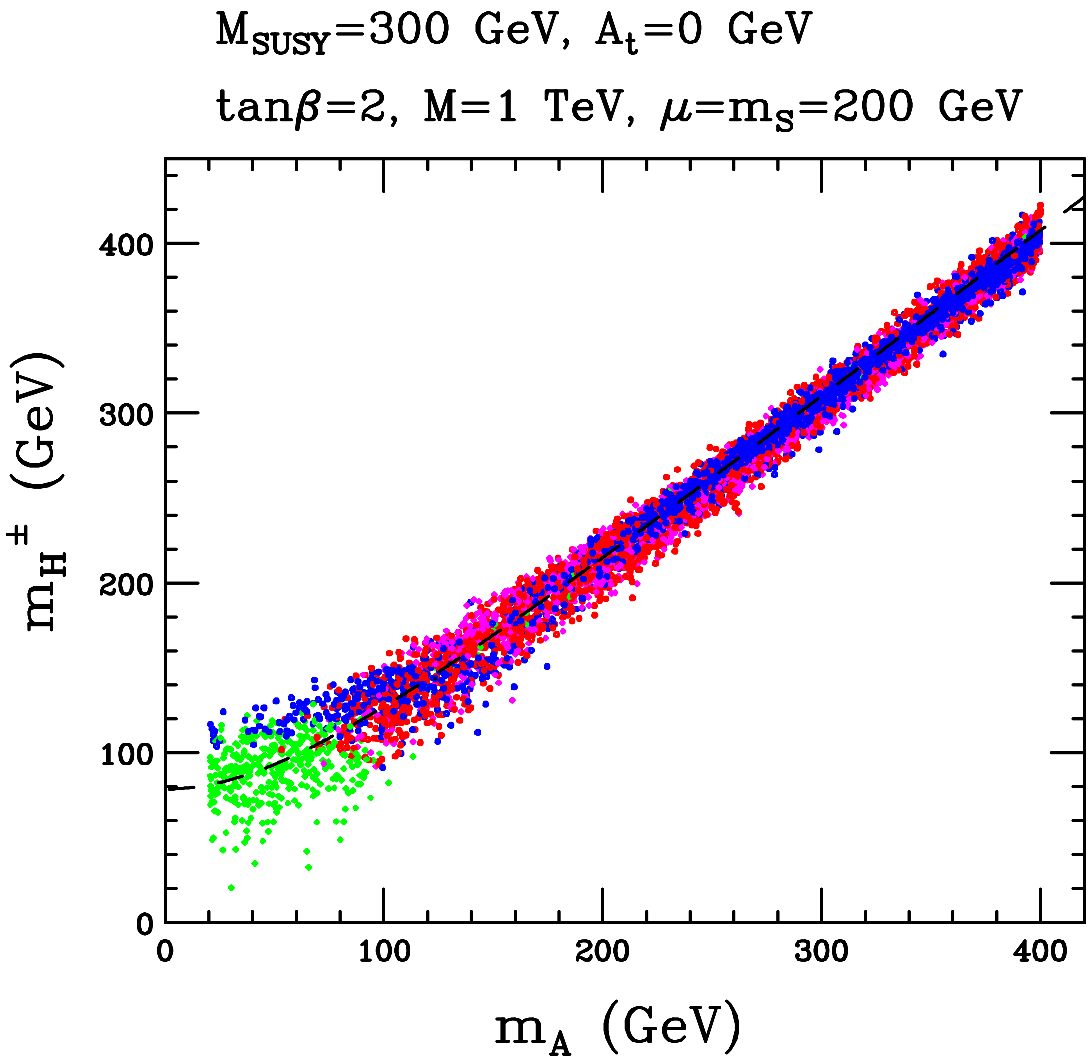
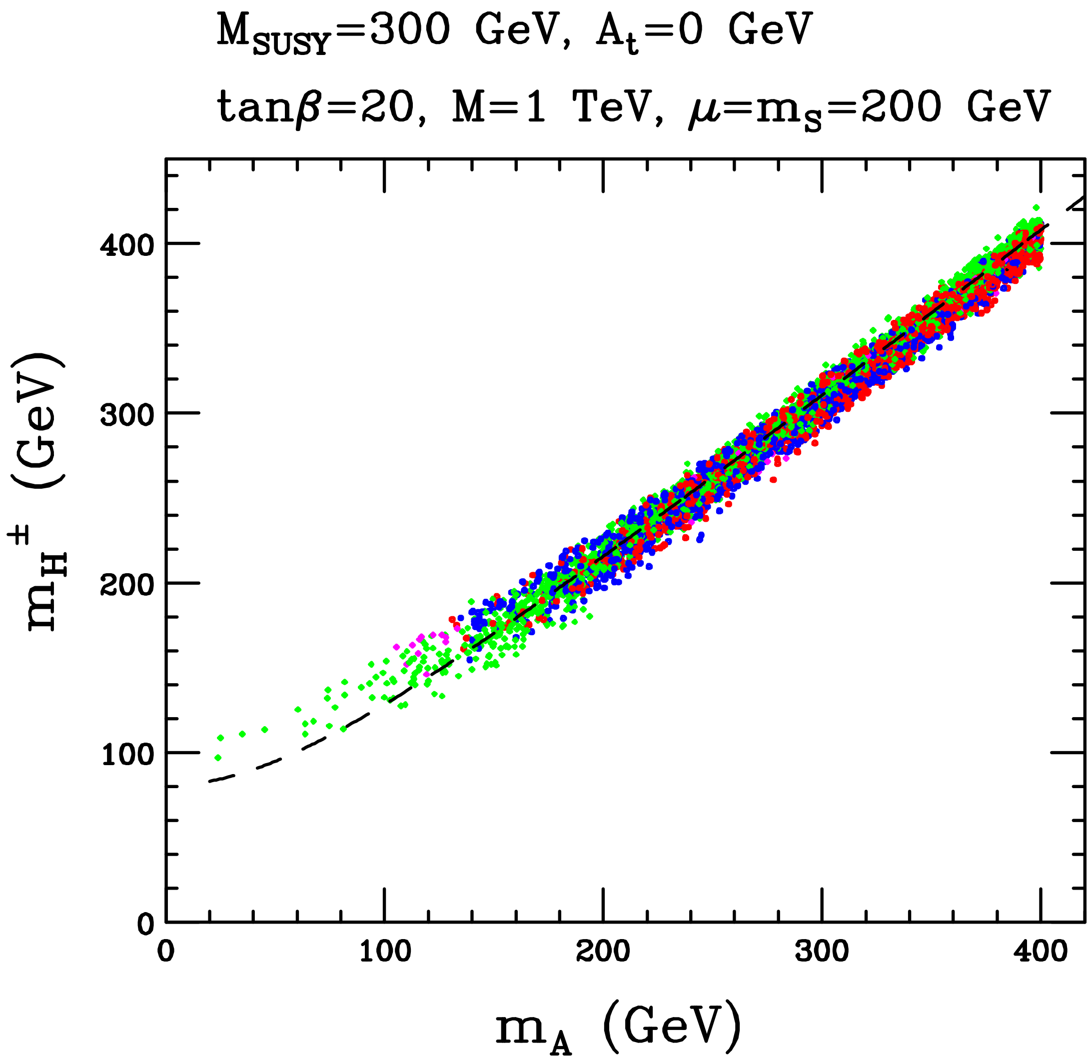
Charged Higgs mass





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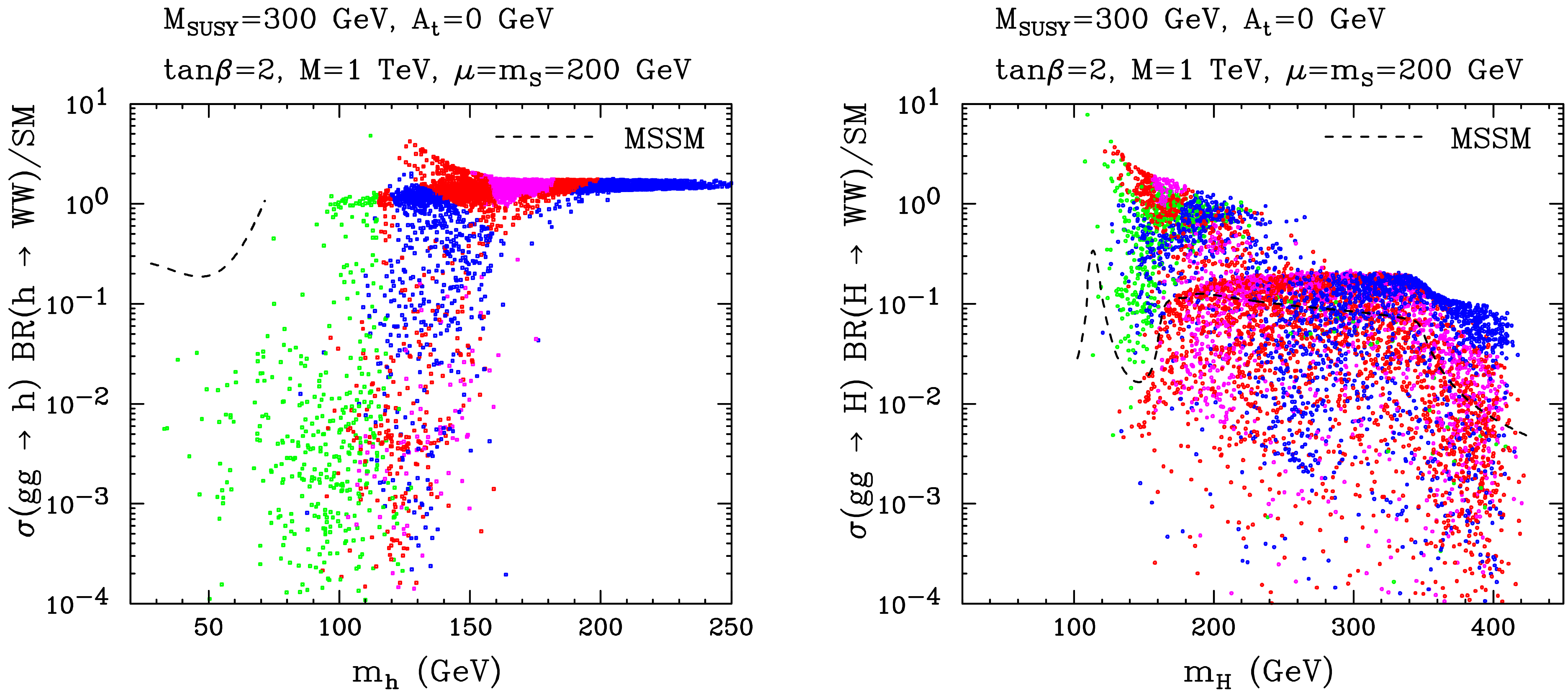
$gg \to h/H \to W^+W^-$



$$\frac{\sigma^{model}(gg \to h)}{\sigma^{SM}(gg \to h)} \simeq \left(\frac{g^{model}_{ggh}}{g^{SM}_{ggh}} \right)^2 \equiv \frac{\Gamma^{model}_{h \to gg}}{\Gamma^{SM}_{h \to gg}}$$

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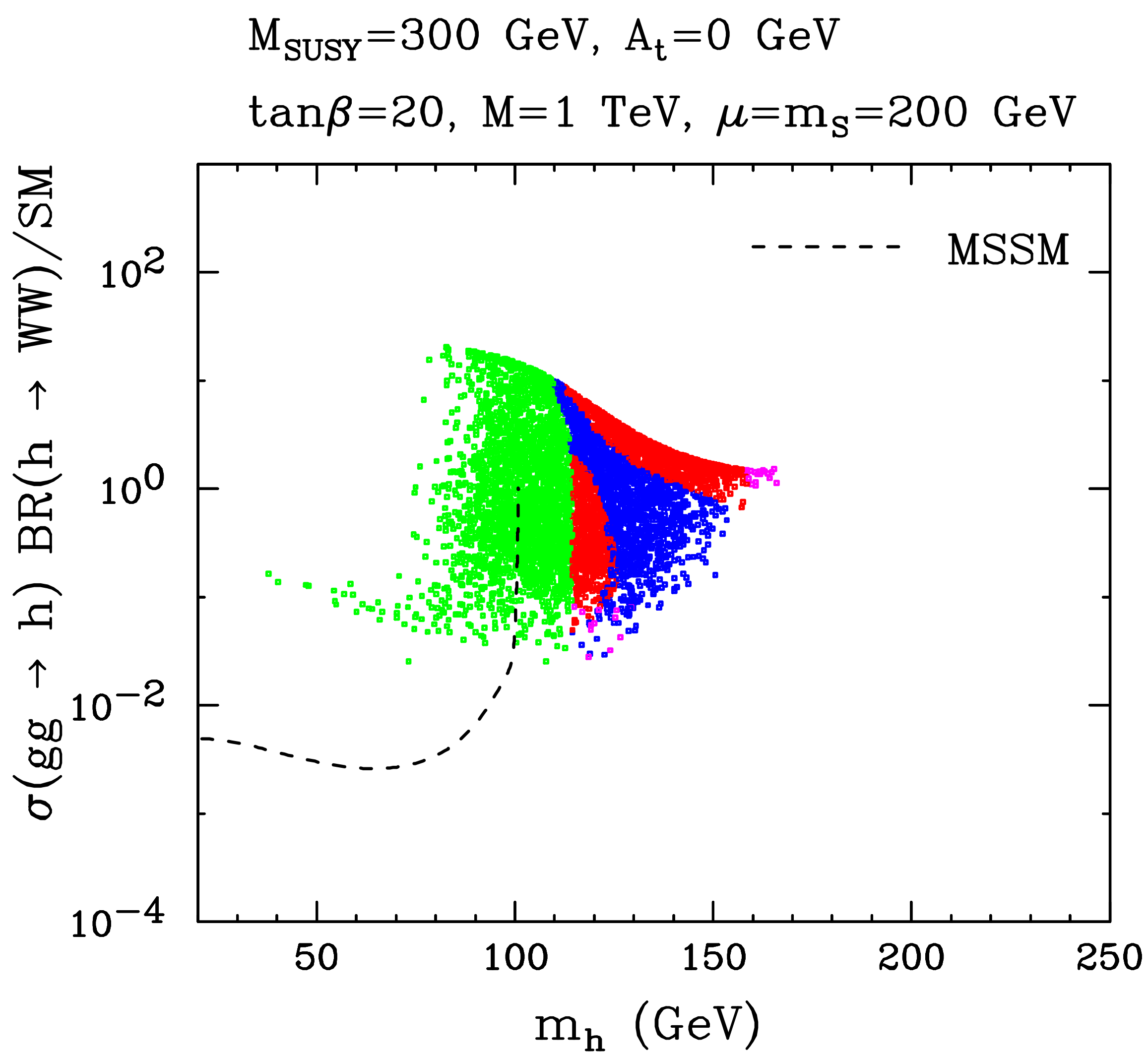

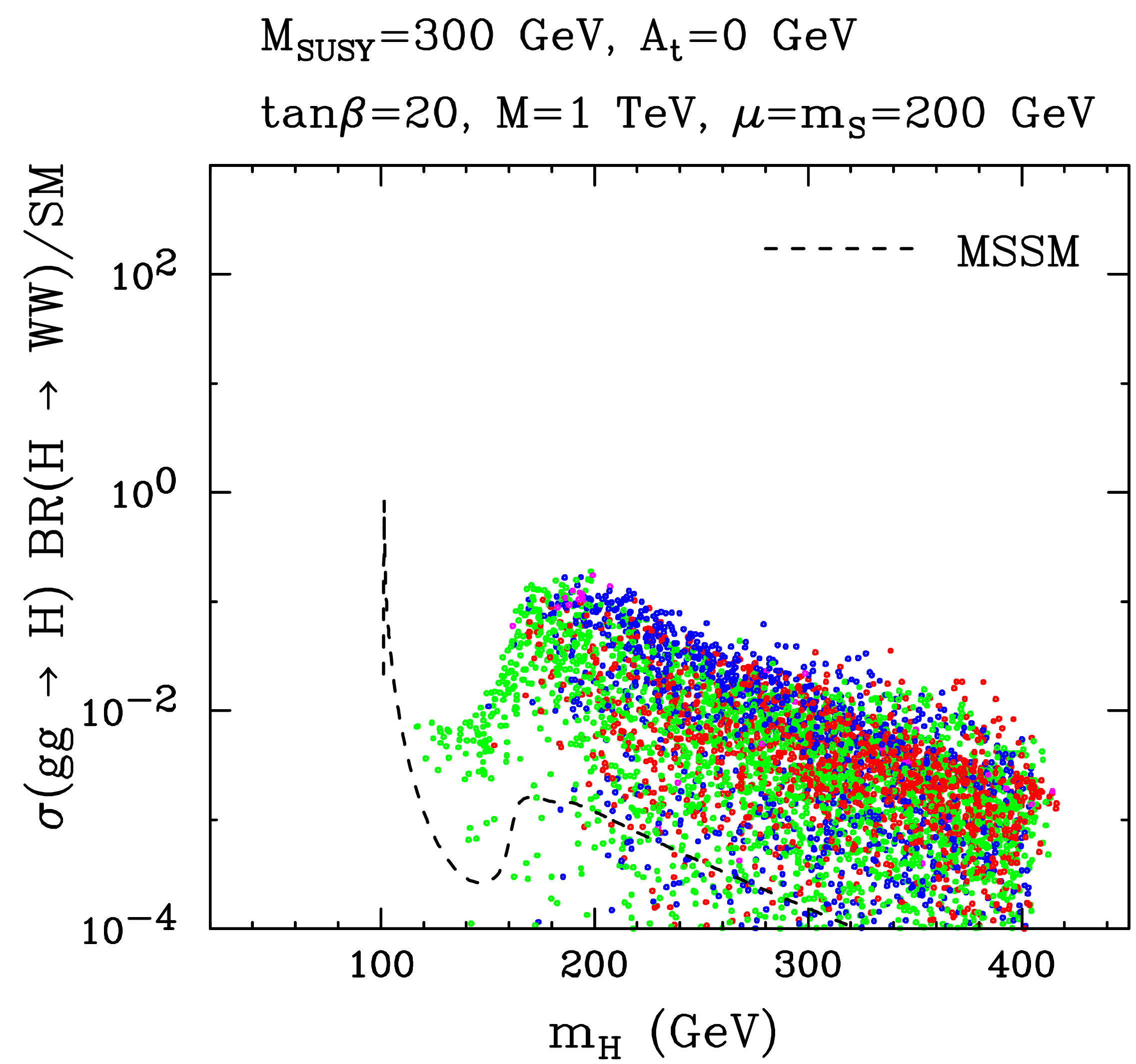

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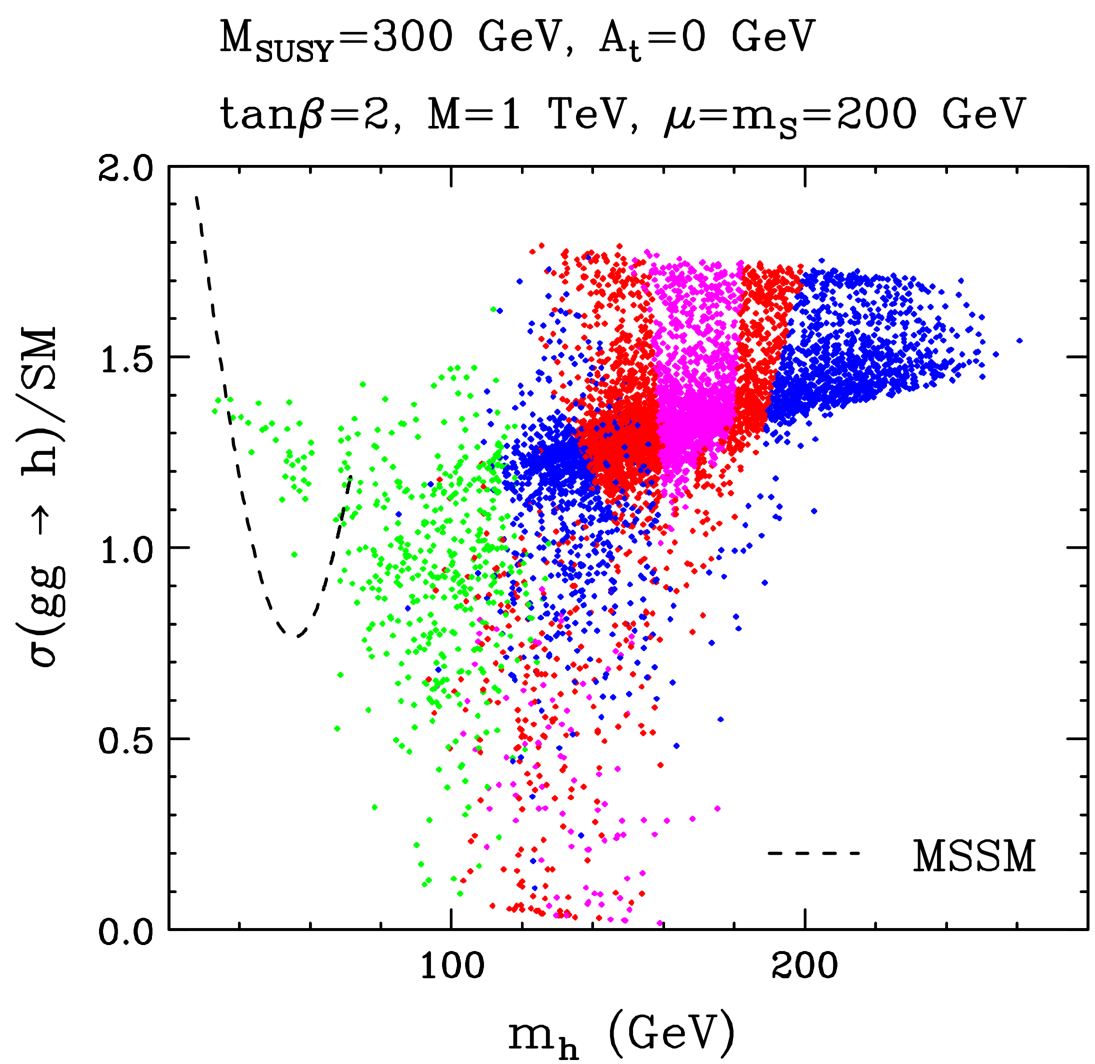
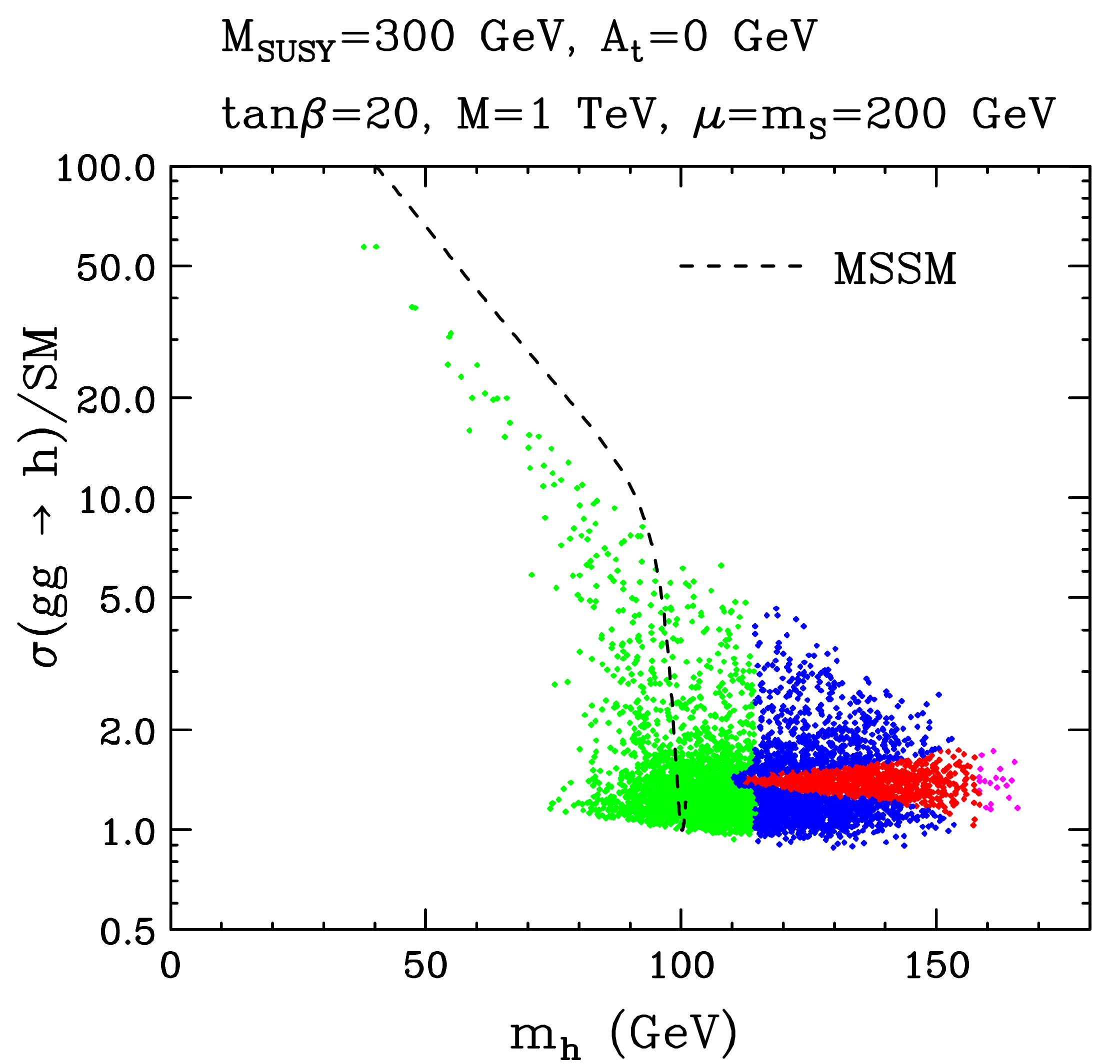
Gluon fusion production





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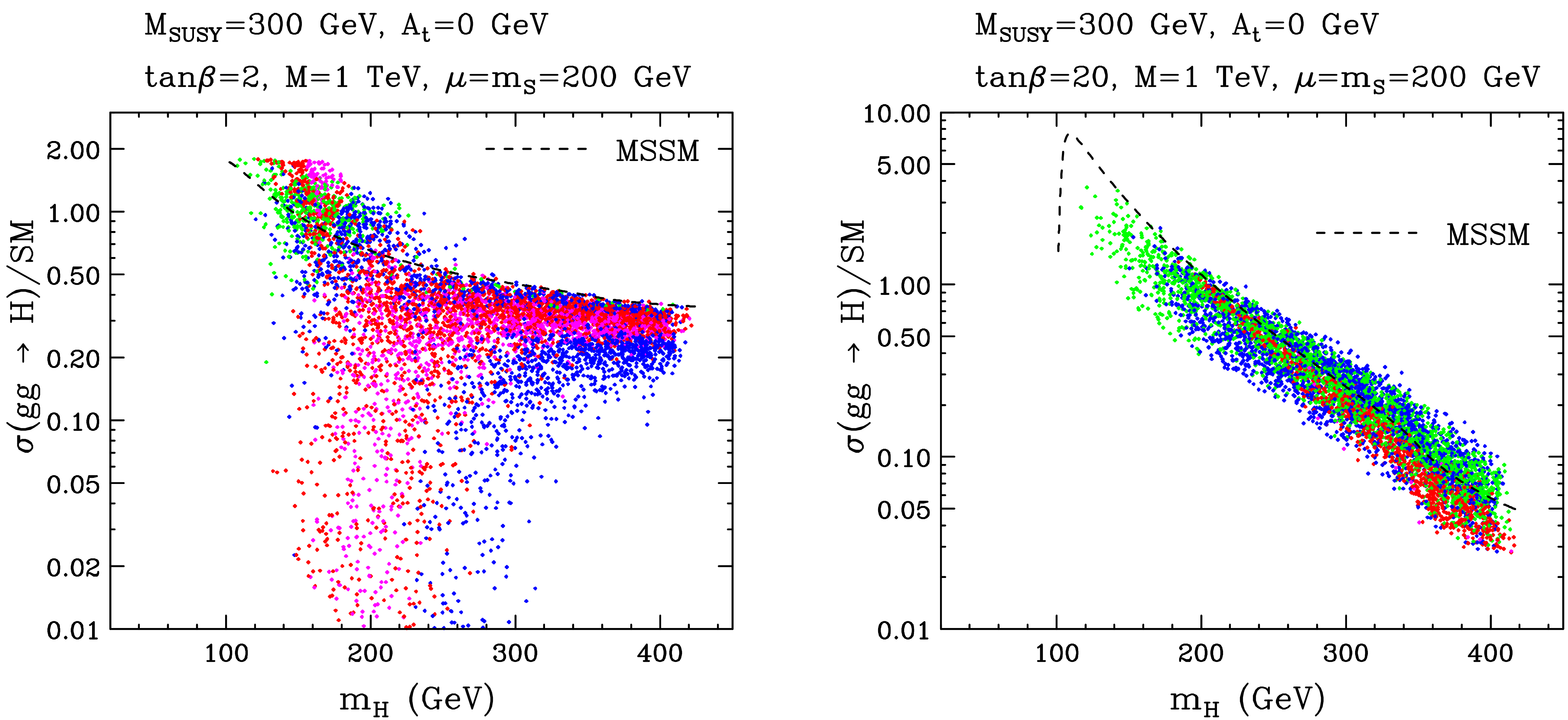

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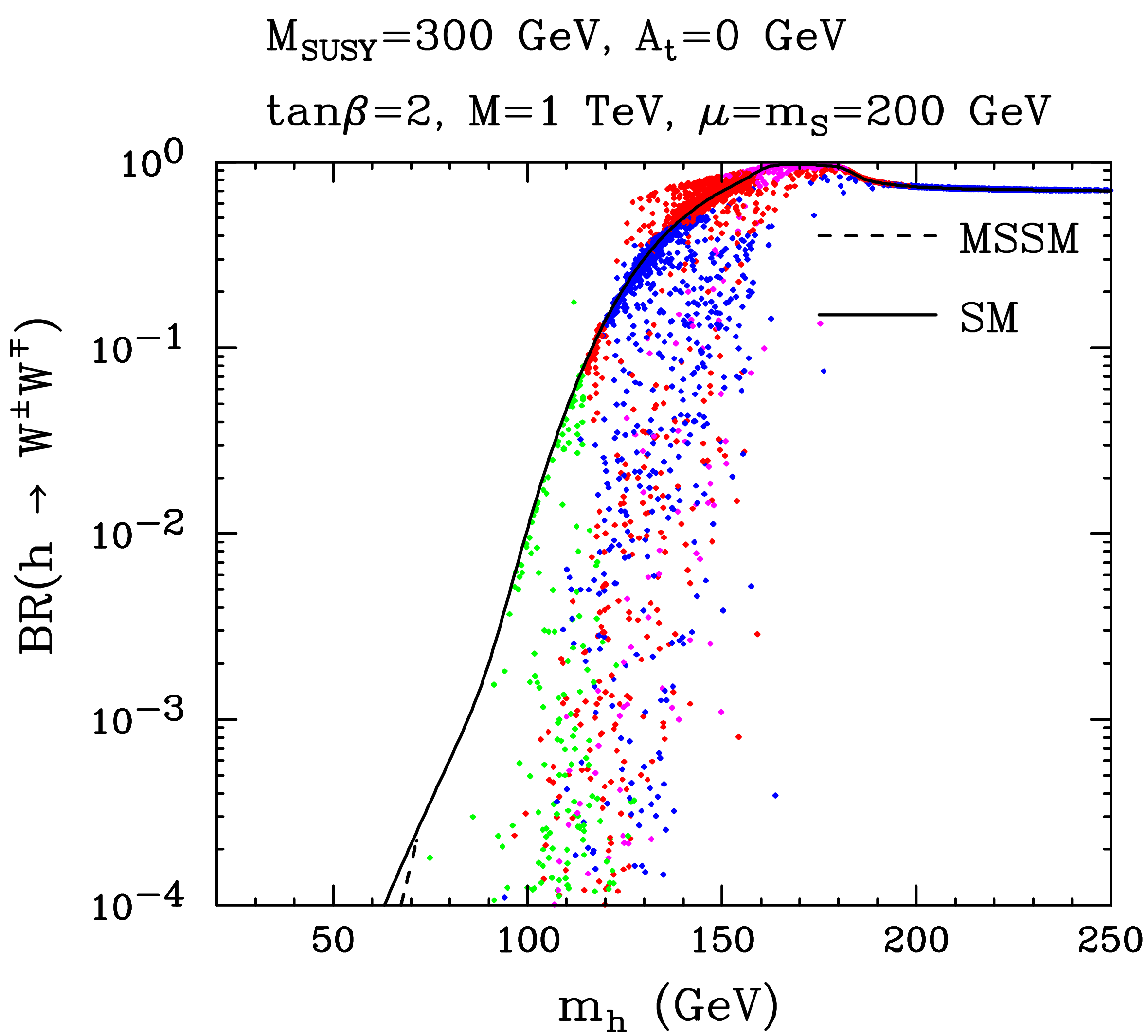
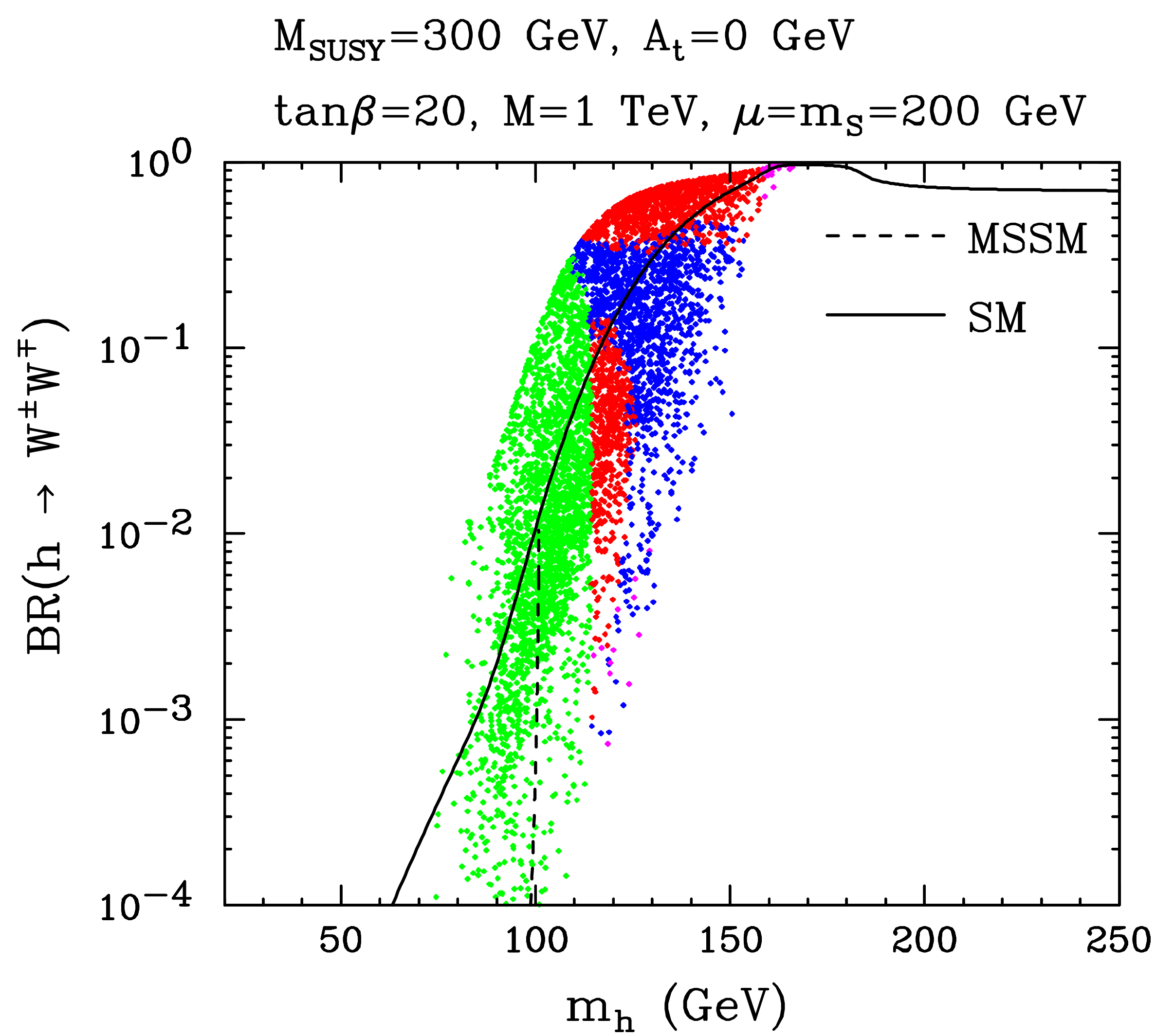
BR into WW





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