BMSSM Higgs bosons

Based on:

- M. Carena, K. Kong, E.Pontón, J.Z: **Phys.Rev.D81:015001, 2010**
- M. Carena, E.Pontón, J.Z: **arXiv 1005.4887**

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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

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

scalars (h, H) pseudoscalar (A)

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: $X = m_S\, \theta^2$

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

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 + Tevatron data (2009) + EWPO.

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See slides from Karina's talk on Monday (version 2.0.0)

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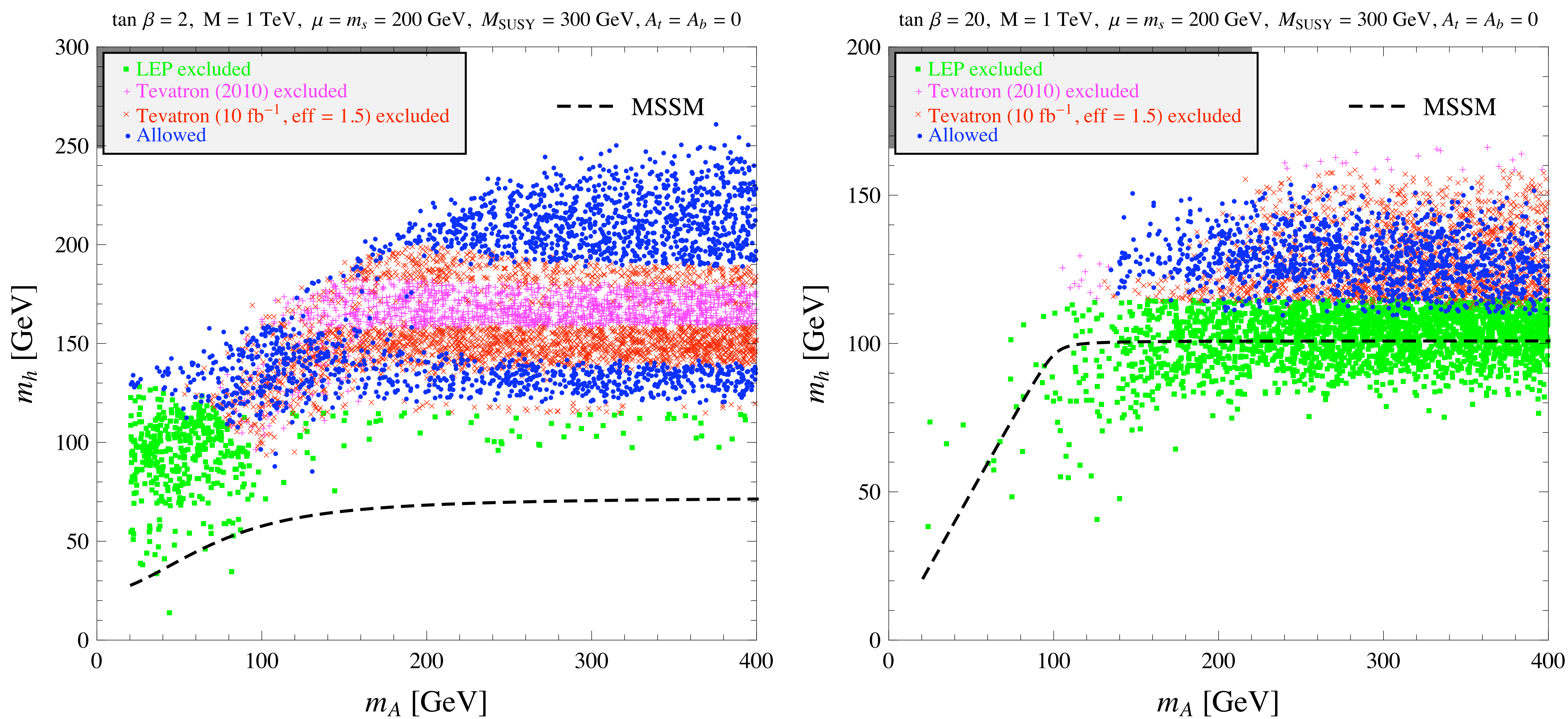
Collider phenomenology

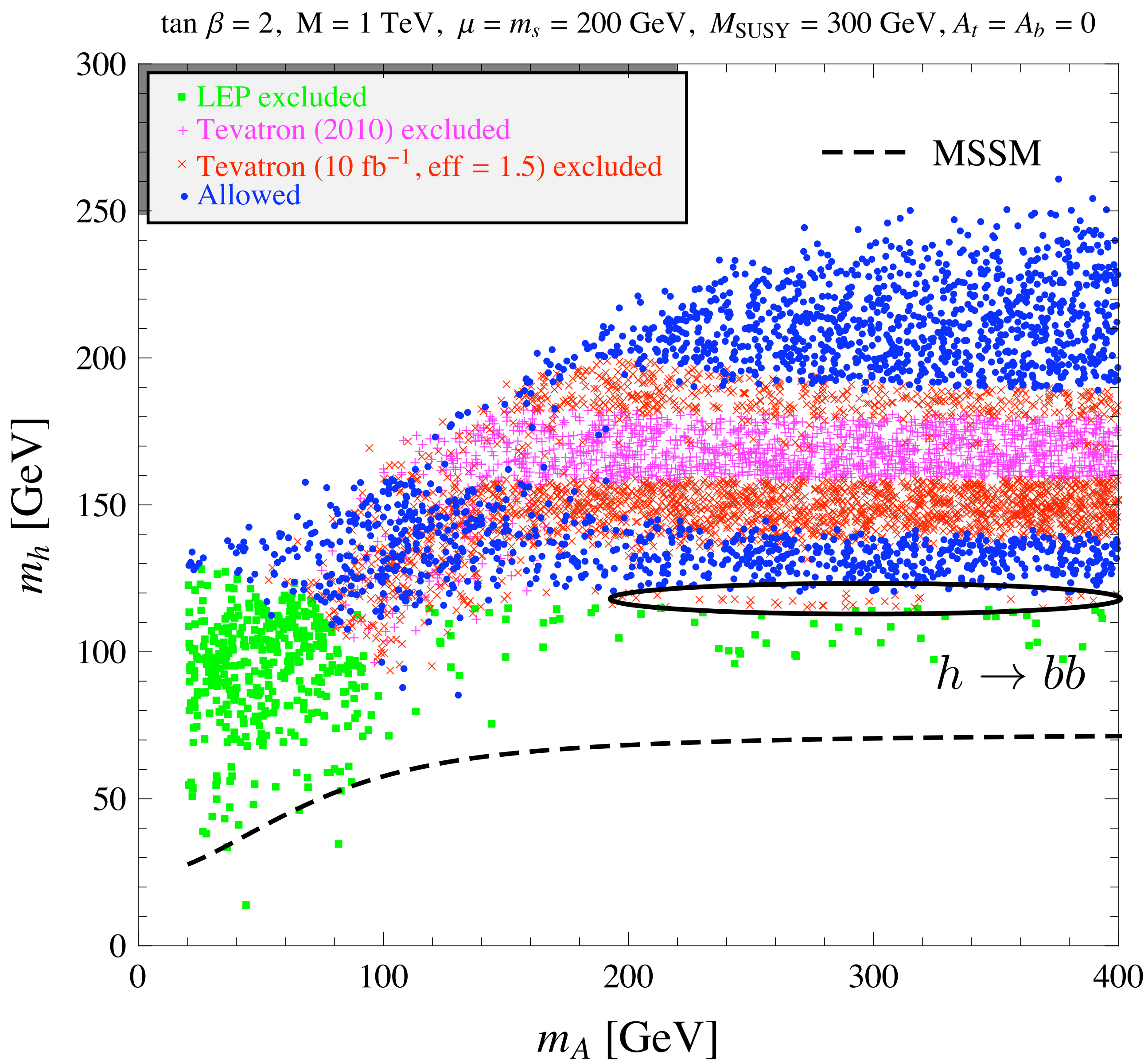
Lightest Higgs mass

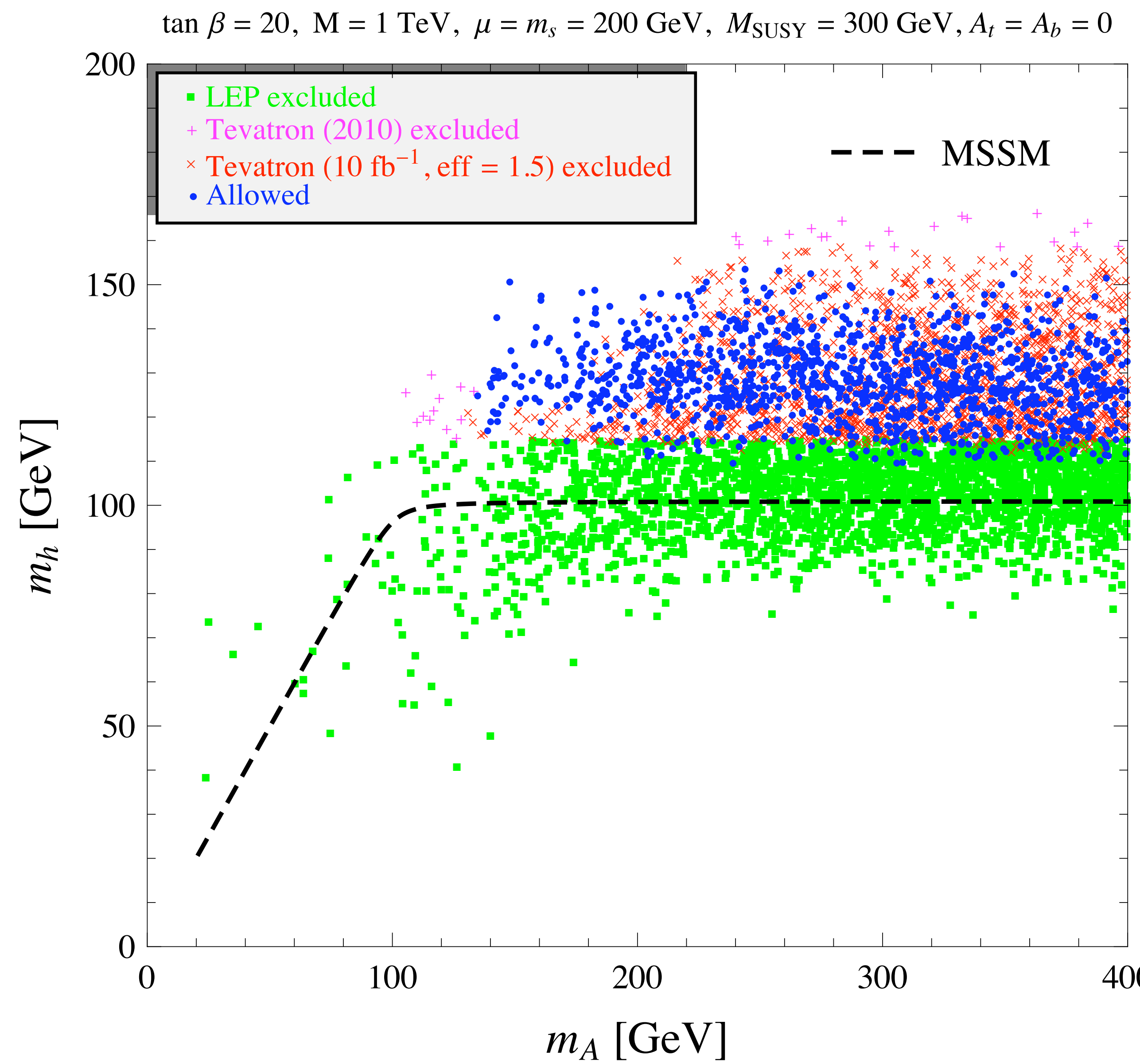


- Sizable region of parameter space at Tevatron reach.

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

Lightest Higgs mass





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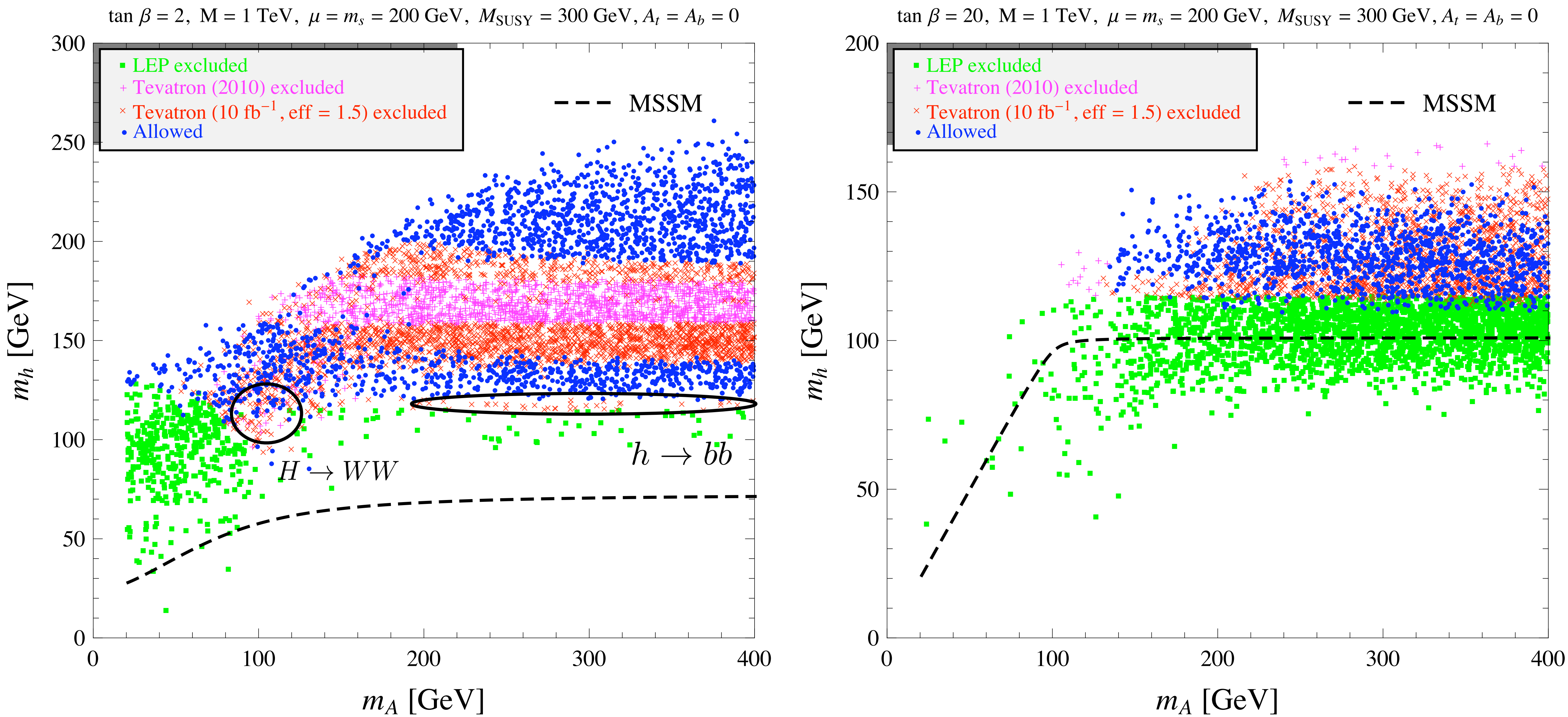

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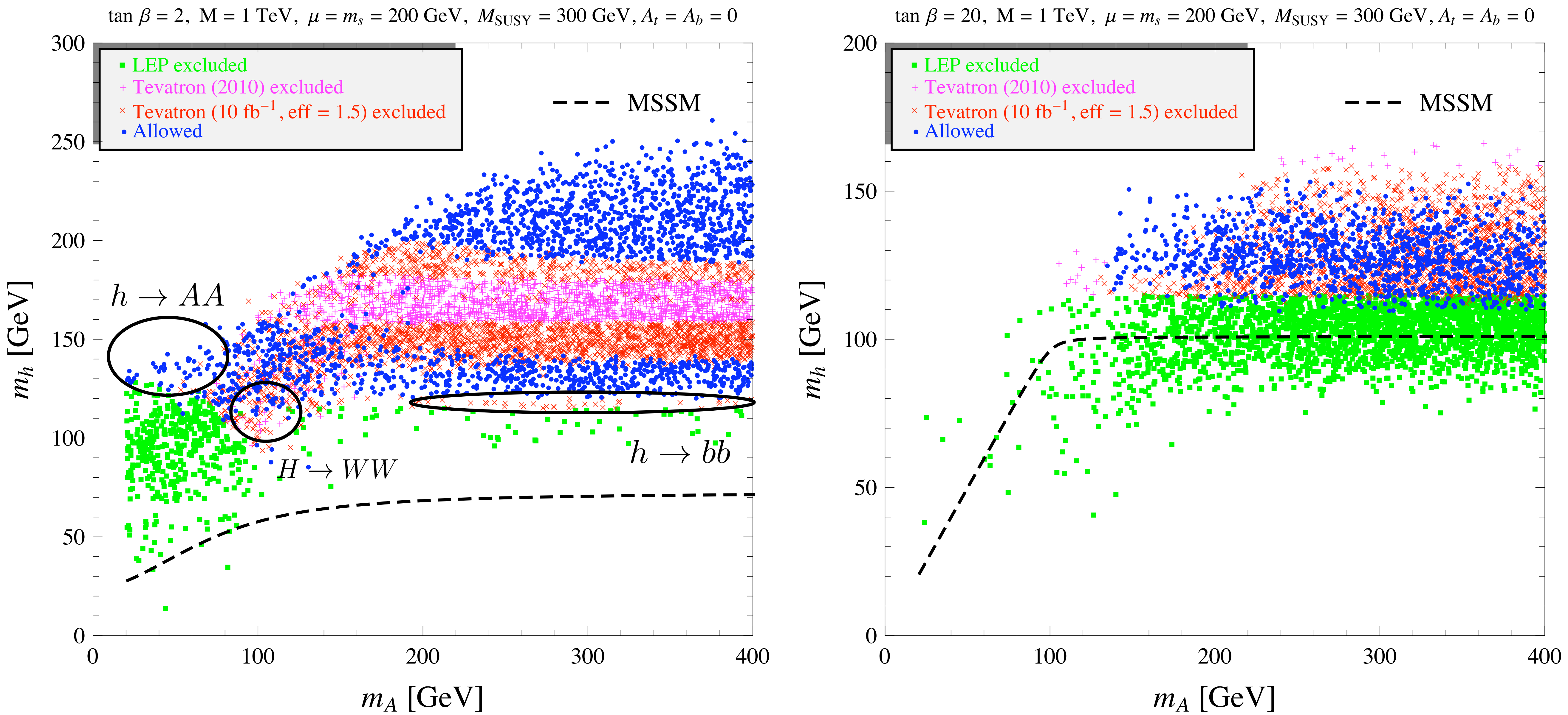

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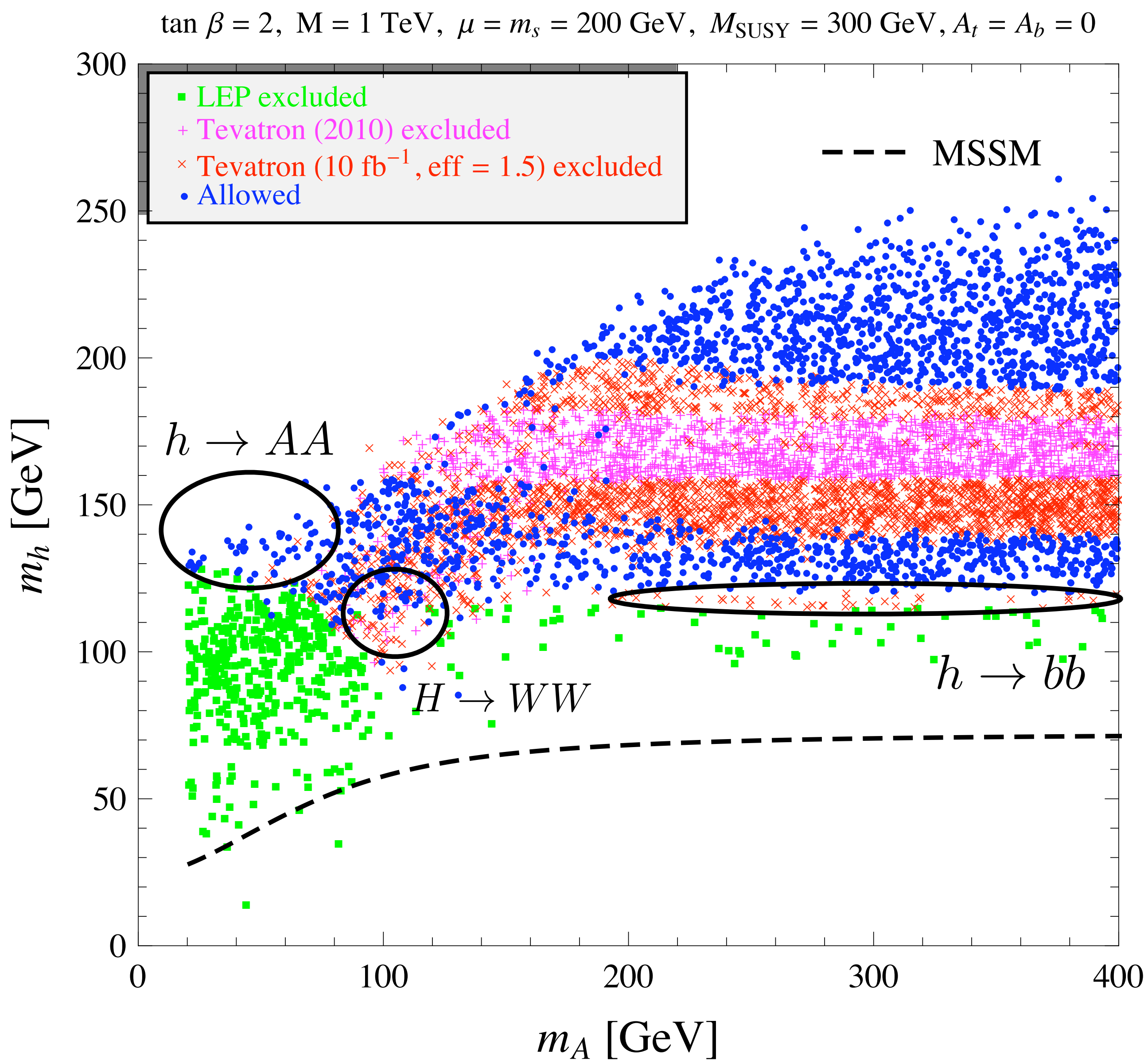

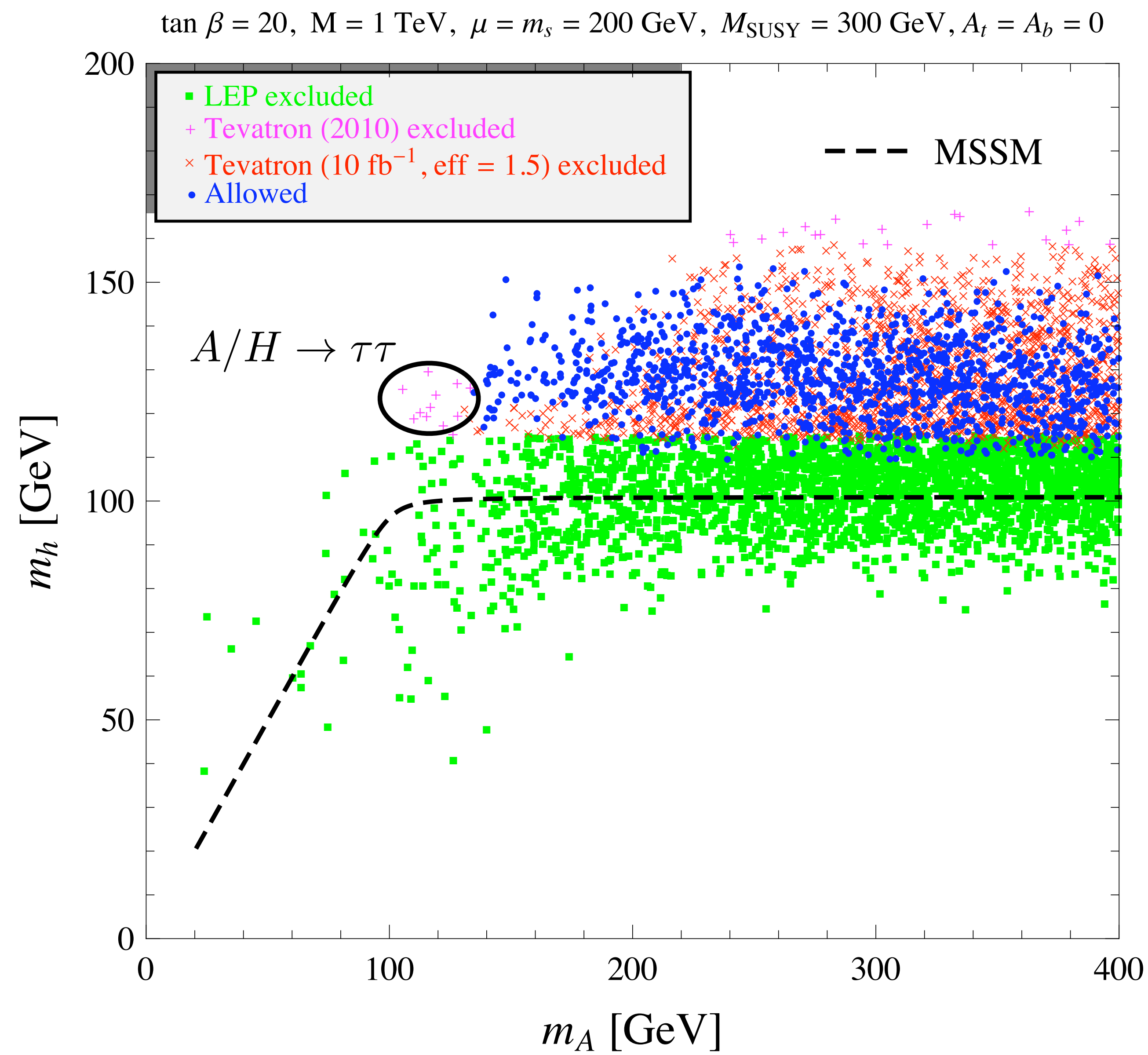

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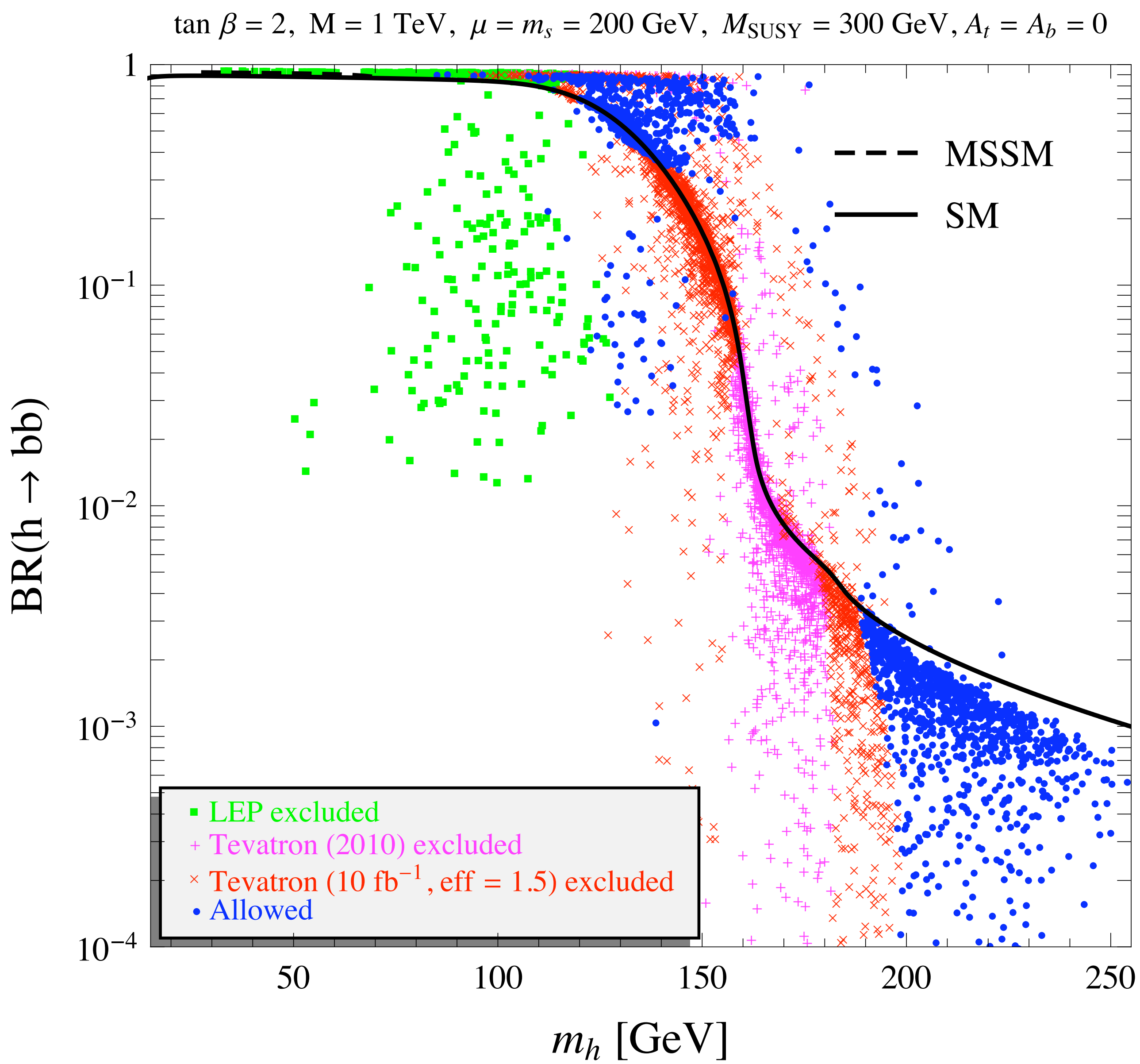
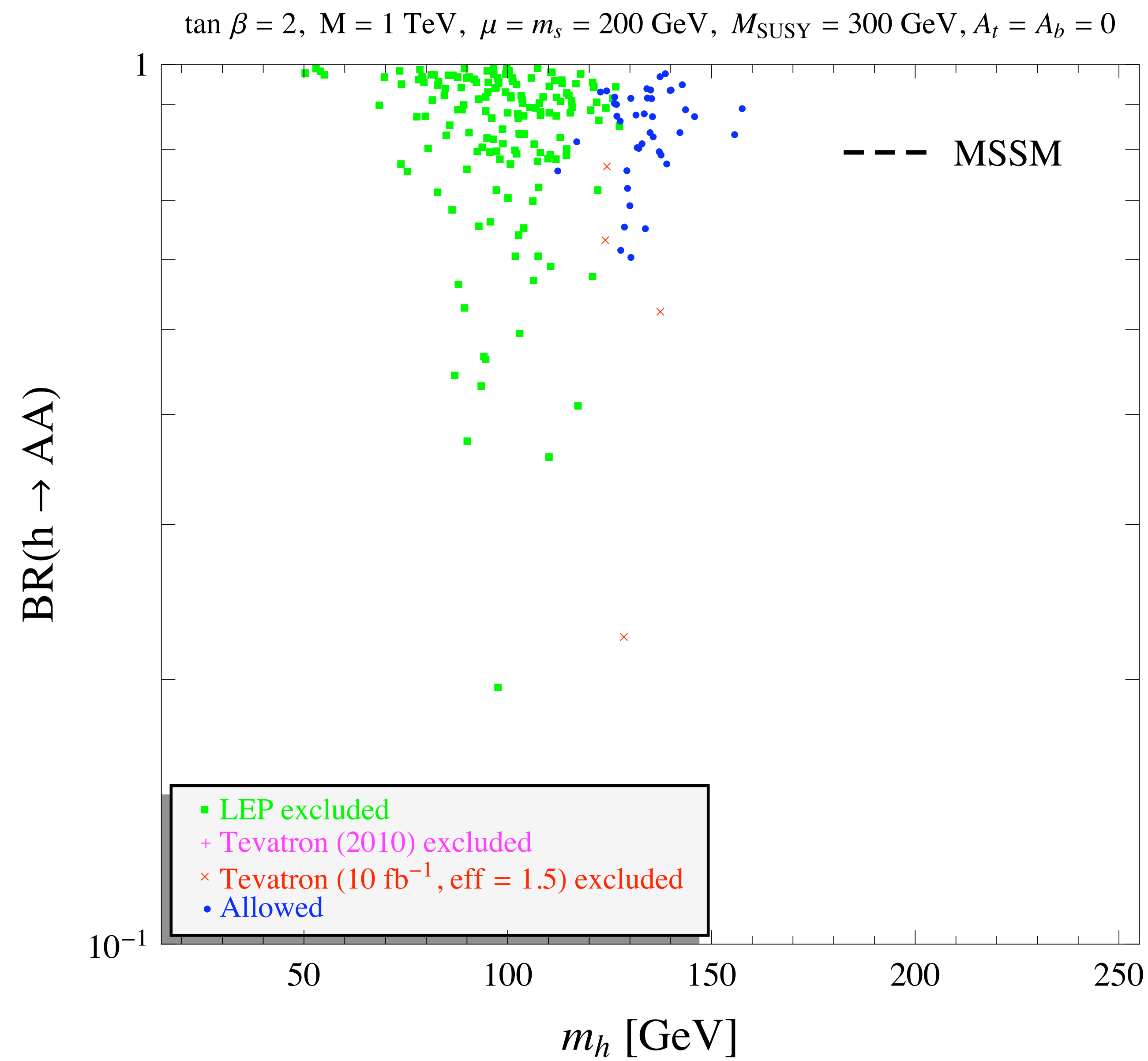
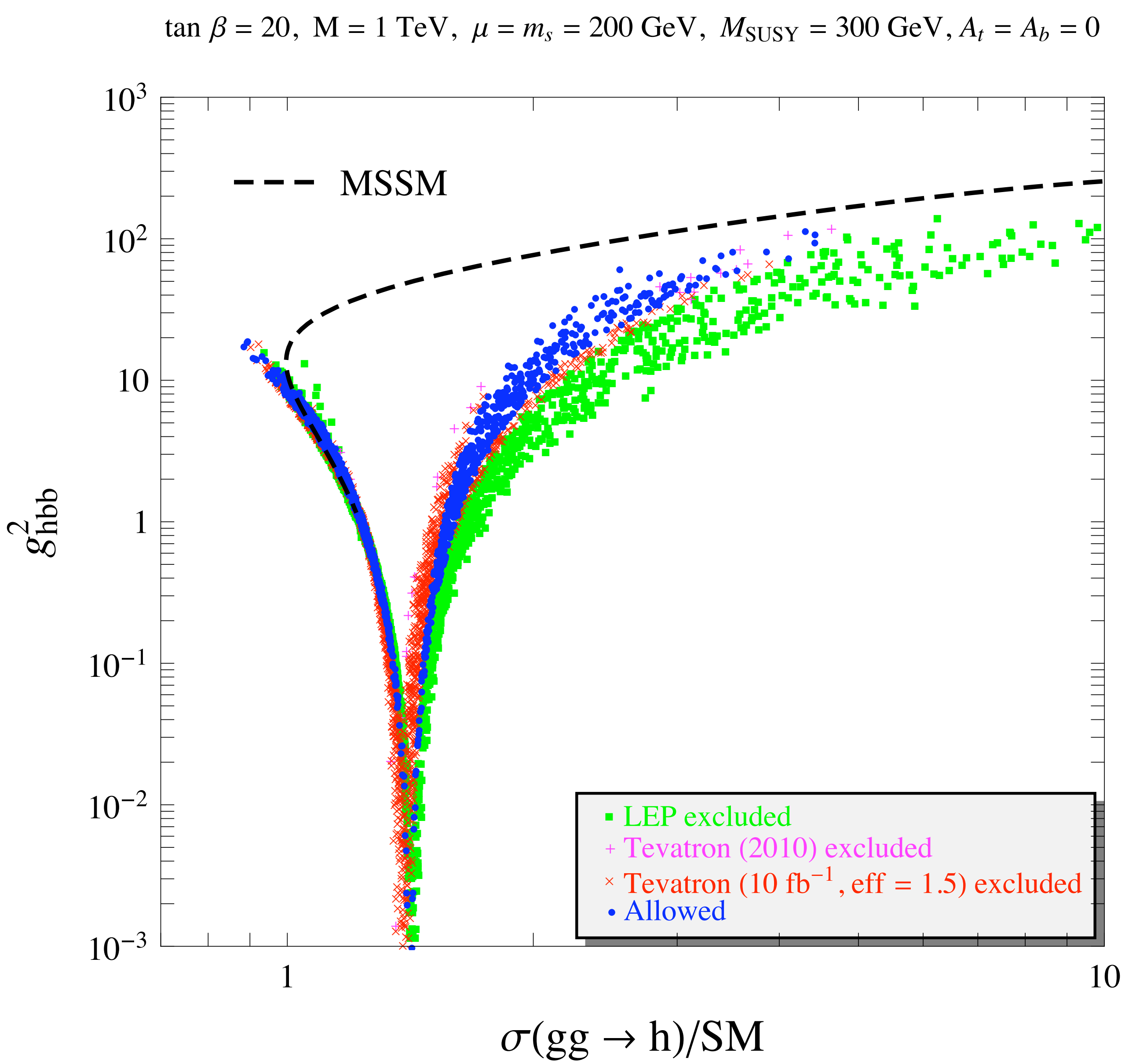
Low tan beta: *h* BRs

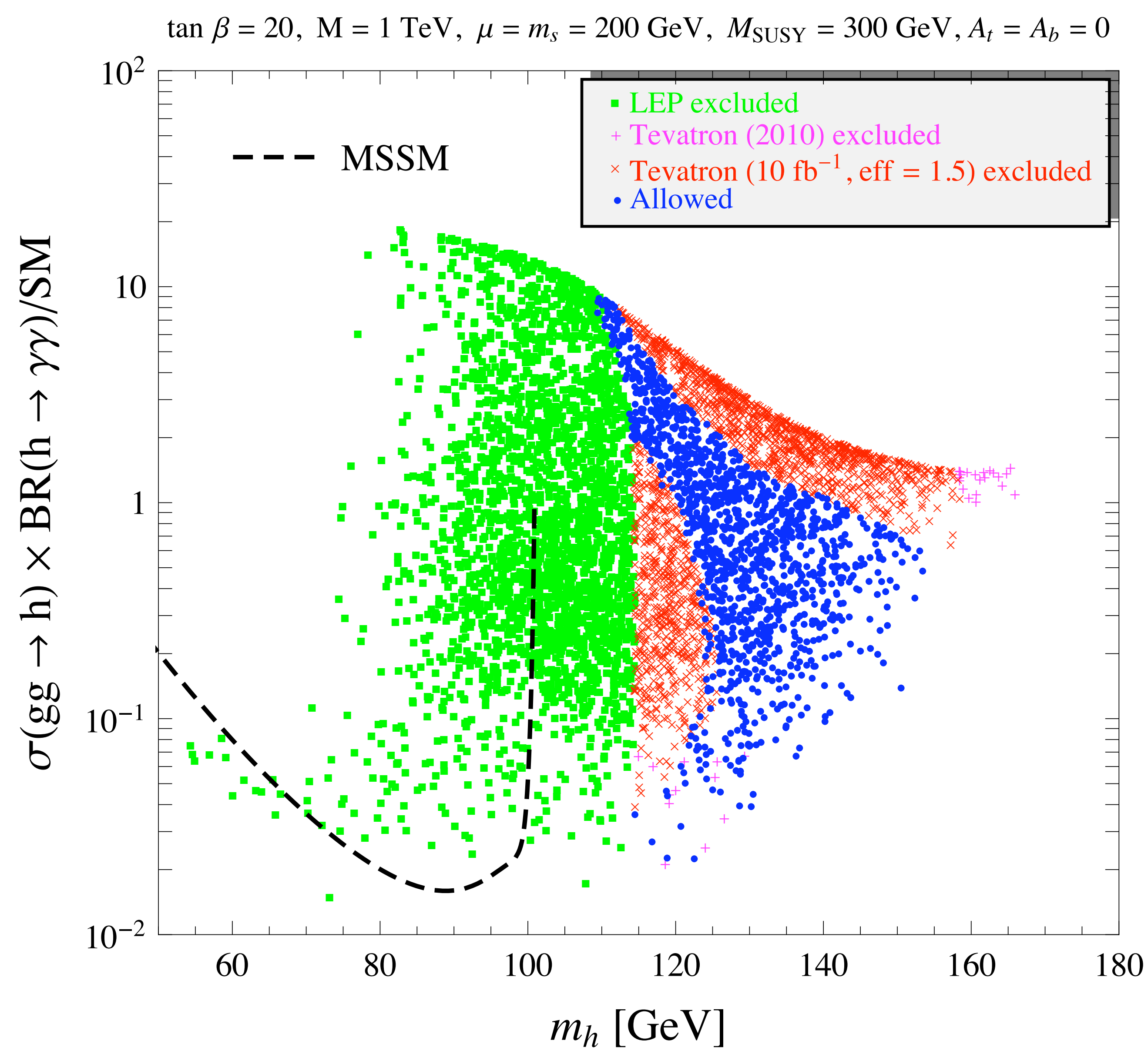




- Supression of $h \to bb$ since $h \to AA$ is kinematically allowed.
- *A*/*h* "inversion" in MSSM channels (i.e: $A/H \to hh$ ➡ $h/H \to AA$)

Large tanb: hbb supression





- *hbb*: cancellation between tree level and higher dim operators.
- Enhancements in diphoton and diboson channel of $\mathcal{O}(10)$.

Tevatron signal (C) (tb=2)

m_A (GeV)	m_h (GeV)	m_H (GeV)	$m_{H^\pm}$ (GeV)
135	174	186	164
g^2_{hWW}	g^2_{HWW}	g^2_{hgg}	g^2_{Hgg}
0.11	0.89	1.05	0.65
channel	BMSSM (SM)	channel	BMSSM (SM)
$h \to b\bar{b}$	0.12 (0.01)	$h \to WW$	0.84 (0.96)
$H \to WW$	0.81 (0.82)	$H \to ZZ$	0.17 (0.17)
$A \to b\bar{b}$	0.90	$A \to \tau\bar{\tau}$	0.10
$H^+ \to \tau\nu_\tau$	0.59	$H^+ \to t\bar{b}$	0.38

- *H, h* heavier than the MSSM max. value and *A* lighter than *h*.
- *h*: small coupling to *WW*, but sizable BR.
- *H* in reach of the LHC in the $H \to ZZ \to 4l$ channel.

Multi-Higgs decay chains (F) (tb=2)

m_A (GeV)	m_h (GeV)	m_H (GeV)	$m_{H^\pm}$ (GeV)
64	135	155	125
g^2_{hWW}	g^2_{HWW}	g^2_{hgg}	g^2_{Hgg}
0.002	0.991	0.65	1.17
channel	BMSSM	channel	BMSSM
$h \to b\bar{b}$ $H \to WW$ $H \to b\bar{b}$ $H^+ \to \tau\nu_\tau$	0.15 0.12 0.02 0.56	$h \to AA$ $H \to AA$ $A \to b\bar{b}$ $H^\pm \to W^\pm + A$	0.84 0.84 0.92 0.40

- Dominant decay mode: $h/H \to AA\,,\ A \to bb/\tau\tau\,.$
- $gg \to H \to WW$ requires high luminosity $(\sim 100\ \mathrm{fb}^{-1})\,.$
- Promising channel: $H^\pm \to W^\pm A\,.$

LHC signal (D) (tb=2)

m_A (GeV)	m_h (GeV)	m_H (GeV)	$m_{H^\pm}$ (GeV)
184	204	234	203
g^2_{hWW}	g^2_{HWW}	g^2_{hgg}	g^2_{Hgg}
0.3	0.7	1.39	0.36
channel	BMSSM (SM)	channel	BMSSM (SM)
$h \to WW$ $H \to WW$ $A \to b\bar{b}$	0.73 (0.72) 0.70 (0.71) 0.87	$h \to ZZ$ $H \to ZZ$ $H^+ \to t\bar{b}$	0.25 (0.27) 0.29 (0.29) 0.99

- All Higgs bosons outside Tevatron range.
- No Higgs chain decays allowed.
- Both *h* and *H* have similar BRs into *WW*/*ZZ*.
- Signature: two distinguishable peaks in $ZZ \to 4l$.

Enhanced diphoton (H) (tb=20)

m_A (GeV)	m_h (GeV)	m_H (GeV)	$m_{H^\pm}$ (GeV)
210	111.3	215	225
g^2_{hWW}	g^2_{HWW}	g^2_{hgg}	g^2_{Hgg}
0.98	0.02	1.39	0.84
channel	BMSSM (SM)	channel	BMSSM (SM)
$h \to b\bar{b}$	0.03 (0.79)	$h \to \gamma\gamma/10^{-3}$	12.1 (2.1)
$h \to$ jets	0.56 (0.07)	$h \to WW$	0.36 (0.05)
$H \to b\bar{b}$	0.86	$H \to \tau\bar{\tau}$	0.14
$A \to b\bar{b}$	0.86	$A \to \tau\bar{\tau}$	0.14
$H^\pm \to \tau\nu_\tau$	0.35	$H^\pm \to t\bar{b}$	0.64

- *h* escaped detection at LEP due to small hbb coupling.
- LHC: enhanced di-photon channel (~8).

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).
- Light *A* bosons are possible.
- "Non-MSSM" benchmark points were shown.
- Other phenomenological consequences: DM

M. Carena, R. Hernández Pinto, A. Menon (in preparation)

Backup slides

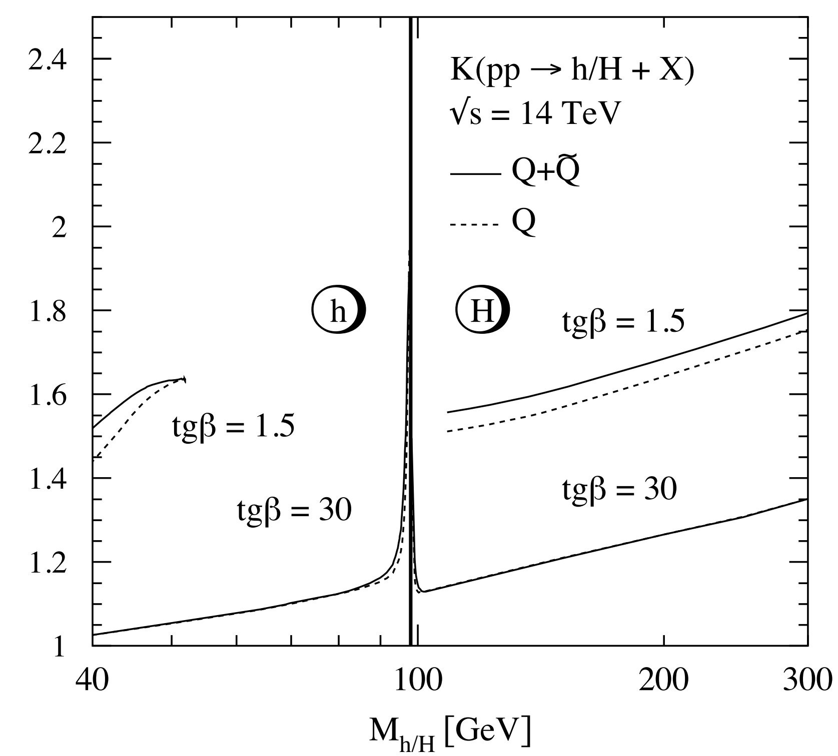
Production cross sections

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

Reach @ colliders

- Tevatron:

SM-like searches: $H \to WW$, $h \to bb$, $h \to WW$ ⇨ disjoint subsets

Non-SM-like searches: $A/H/h \to \tau\tau$ → large $\tan\beta$

- LHC reach

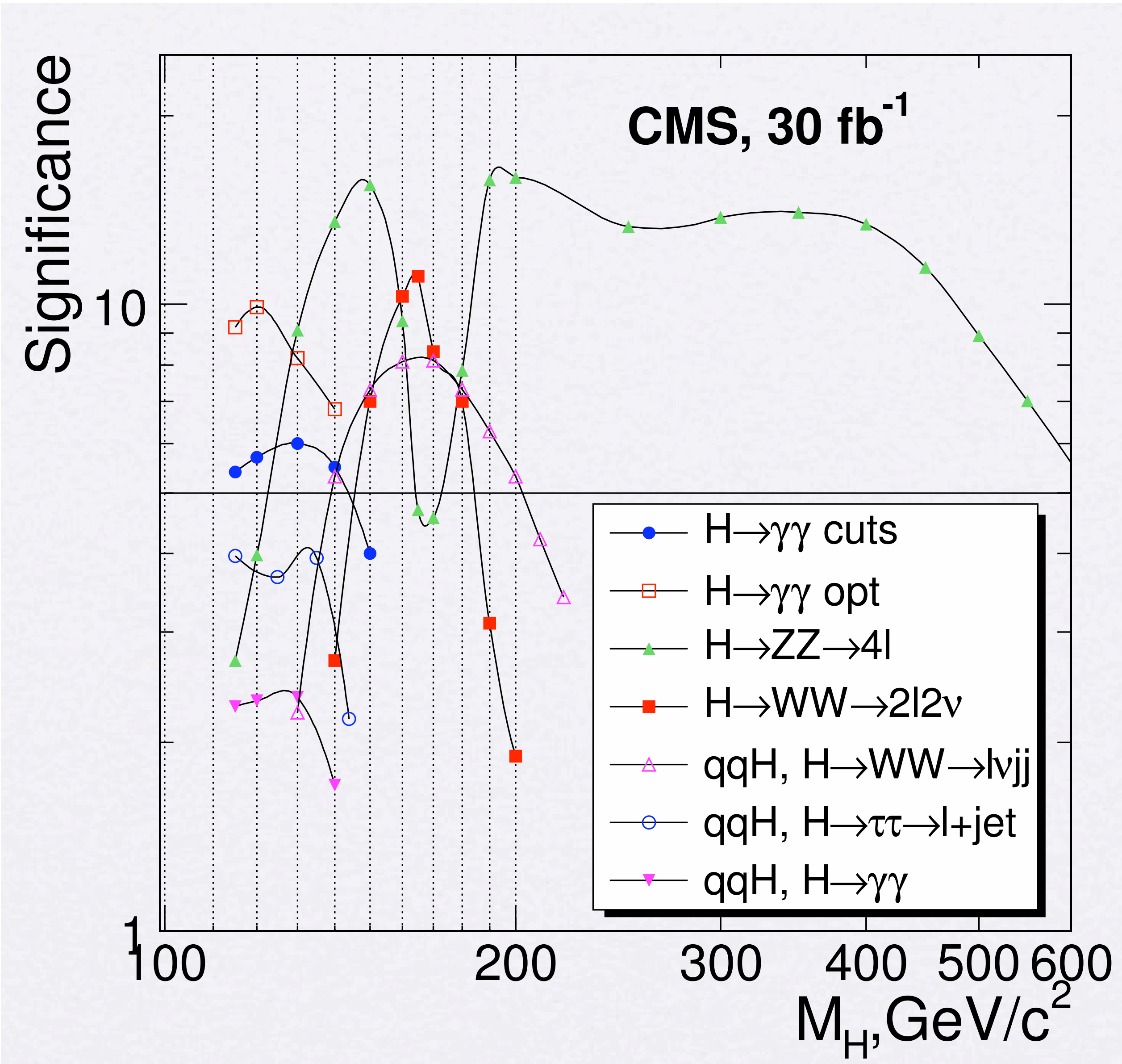
SM-like searches: $\gamma\gamma, WW/ZZ, \tau\tau$

Non-SM-like searches: $A/H/h \to \tau\tau$

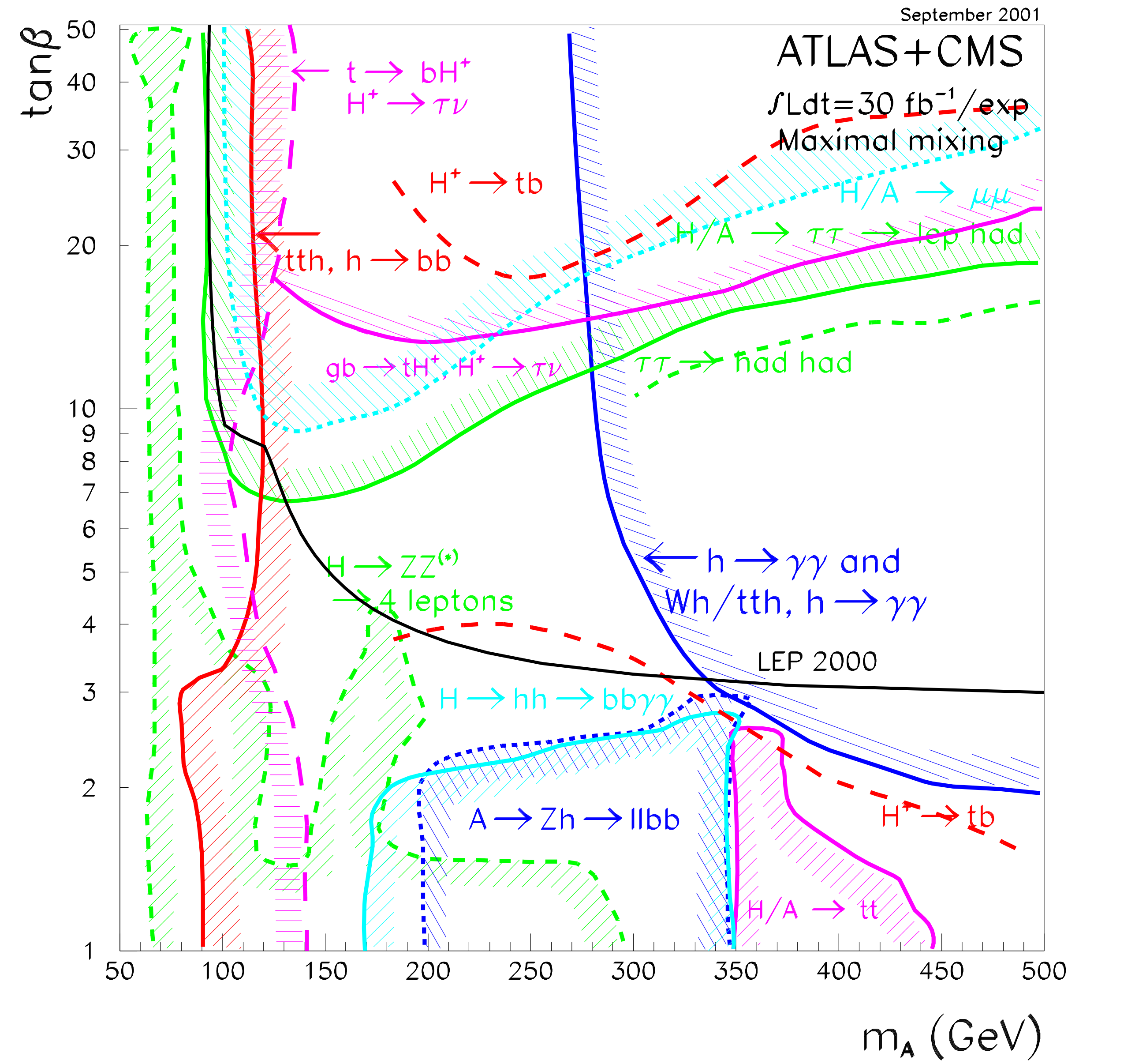
$H^+ \to t\bar{b}, \tau\nu_\tau$

multi-chain decays (light A)

LHC reach



CMS TDR

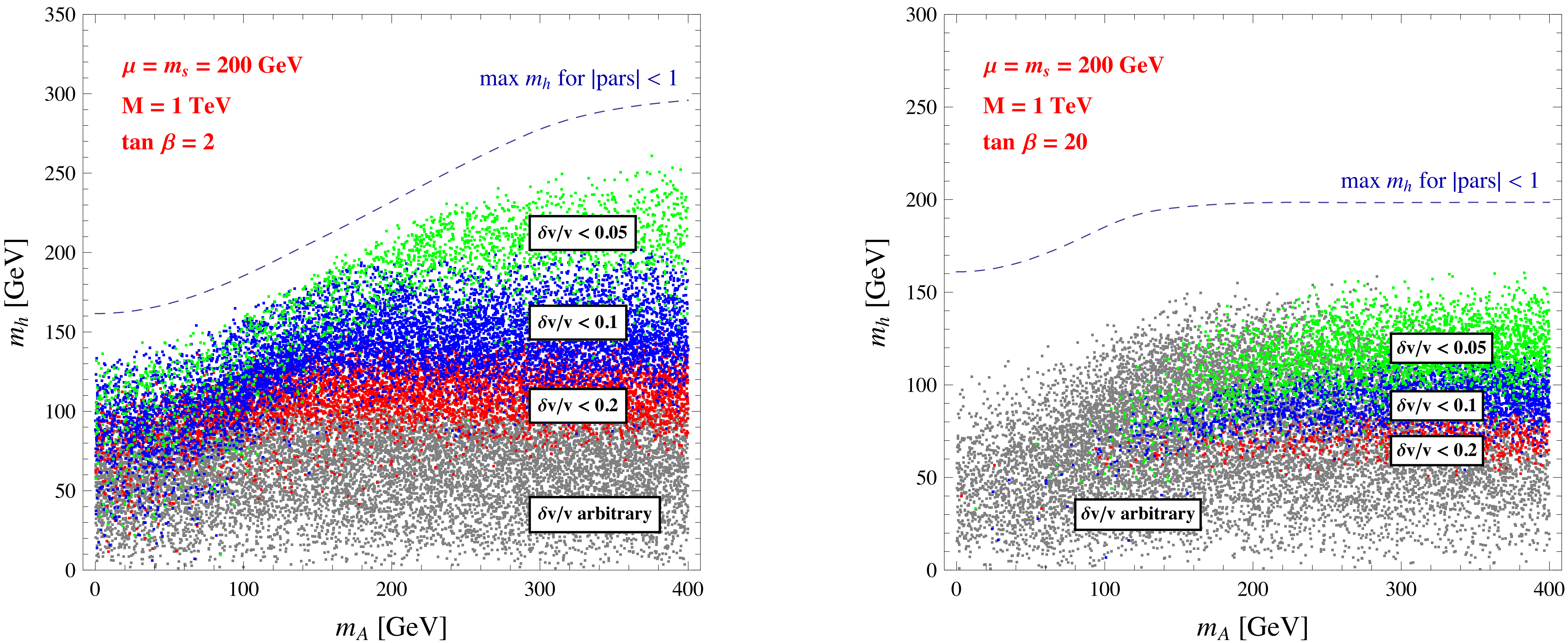


Taken from Büscher and Jakobs, hep-ph/0504099

SM-like searches

MSSM Non SM-like searches

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

  $T^{SUSY} \sim 0.2$

Medina, Shah, Wagner ('09)