NMSSM in the low m_A region and Type II 2HDM

Shufang Su • U. of Arizona

Davis HEFTI Higgs Workshop, April 23

In collaboration with
N. Christensen, T. Han, Zhen Liu, 1303.2113
B. Coleppa, F. Kling, SS, 1304.xxxx

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Outline

- Introduction: Higgs searches @ LHC (skip)
- A little bit on MSSM...
- NMSSM Higgs sector
  - general discussion
  - H1 126 GeV
  - H2 126 GeV
- LHC phenomenology
- Type II 2HDM Higgs sector
  - general discussion
  - h^0 126 GeV
  - H^0 126 GeV

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ATLAS + CMS Higgs Results

- SM-like Higgs excluded @ 95% CL in m_H: 110.0 - 122.5, 128 - 700 GeV
  surviving mass window: 122.5 - 128 GeV
- Excess of events above SM bg in γγ and ZZ final states
  ~ 126 GeV with ~ 7 σ @ ATLAS and CMS
- excess in WW, ττ, bb

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Study consequence of the above finding on the Higgs sector of NMSSM
(low m_A region)

Strategy

- Focus on the Higgs sector (and stop sector)
- Only consider Higgs search results

  flavor? g-2? DM? ...

Study the consequence of

(I) current Higgs search limit of 95% CL limit on σXBr

(II) H_i in the mass range of 124 - 128 GeV

(III) σXBr $(gg \to H_i \to \gamma\gamma)_{NMSSM} > 80\% \, (\sigma XBr)_{SM}$

σXBr $(gg \to H_i \to WW/ZZ)_{NMSSM} > 40\% \, (\sigma XBr)_{SM}$

MSSM Higgs Sector

- Type II Two Higgs Doublet Model

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \quad H_u^0 \rightarrow v_u/\sqrt{2} \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix} \quad H_d^0 \rightarrow v_d/\sqrt{2}$$

$$v_u^2 + v_d^2 = v^2 = (246\mathrm{GeV})^2 \qquad \tan\beta = v_u/v_d$$

after EWSB
5 physical Higgs
CP-even Higgses: h^0, H^0
CP-odd Higgs: A^0
Charged Higgses: $H^\pm$

- tree level masses determined by m_A, $\tan\beta$

$$m^2_{h^0,H^0} = \frac{1}{2}\left((m_A^2 + m_Z^2) \mp \sqrt{(m_A^2 - m_Z^2)^2 + 4m_A^2 m_Z^2 \sin^2 2\beta}\right)$$

$$m^2_{H^\pm} = m_A^2 + m_W^2, \quad \cos^2(\beta - \alpha) = \frac{m^2_{h^0}(m_Z^2 - m^2_{h^0})}{m_A^2(m^2_{H^0} - m^2_{h^0})}.$$

Higgs Masses

- large radiative corrections from stop sector: large Yukawa coupling

$$\Delta m_{h^0}^2 \approx \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{\tilde{A}_t^2}{M_S^2}\left(1 - \frac{\tilde{A}_t^2}{12M_S^2}\right)\right] + \ldots,$$

$$\tilde{A}_t = A_t - \mu\cot\beta.$$

- (m_h^{min}) scenario: $\tilde{A}_t = 0$
  $m_{h0} < 117$ GeV for Ms < 2 TeV

- (m_h^{max}) scenario: $\tilde{A}_t = \sqrt{6}\, M_s$
  $m_{h0} < 127$ GeV for $M_s < 2$ TeV

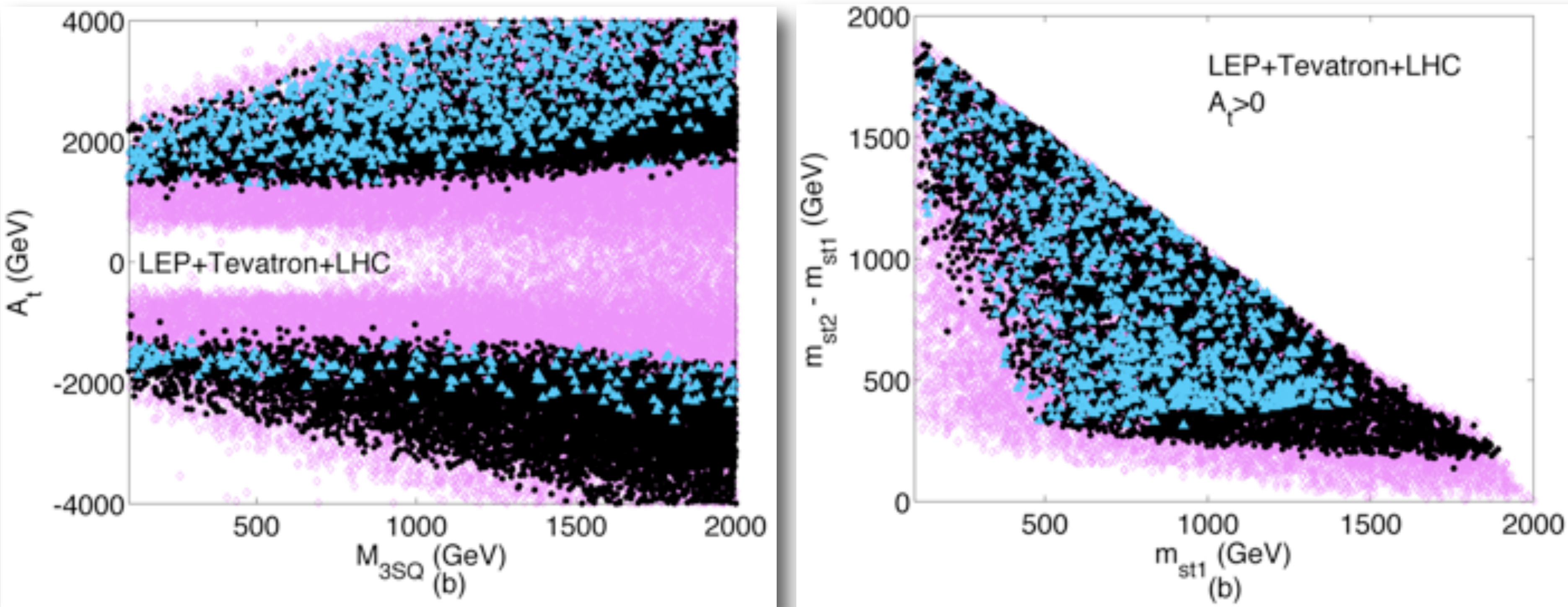
- To obtain relative large correction to m_{h0}
  - relatively large stop masses (at least one)
  - large stop LR mixing

Stop Masses

◉ M_{3SQ} vs A_t

Heavy stops and/or large LR mixing.

◉ m_{st1} vs m_{st2}-m_{st1}



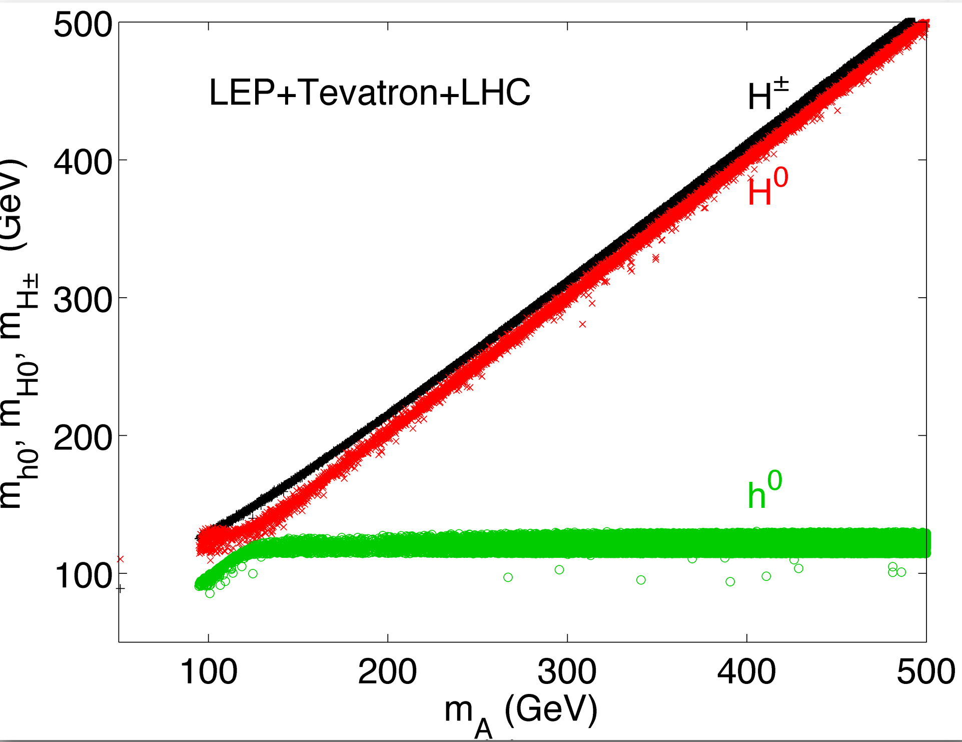
purple: pass exp

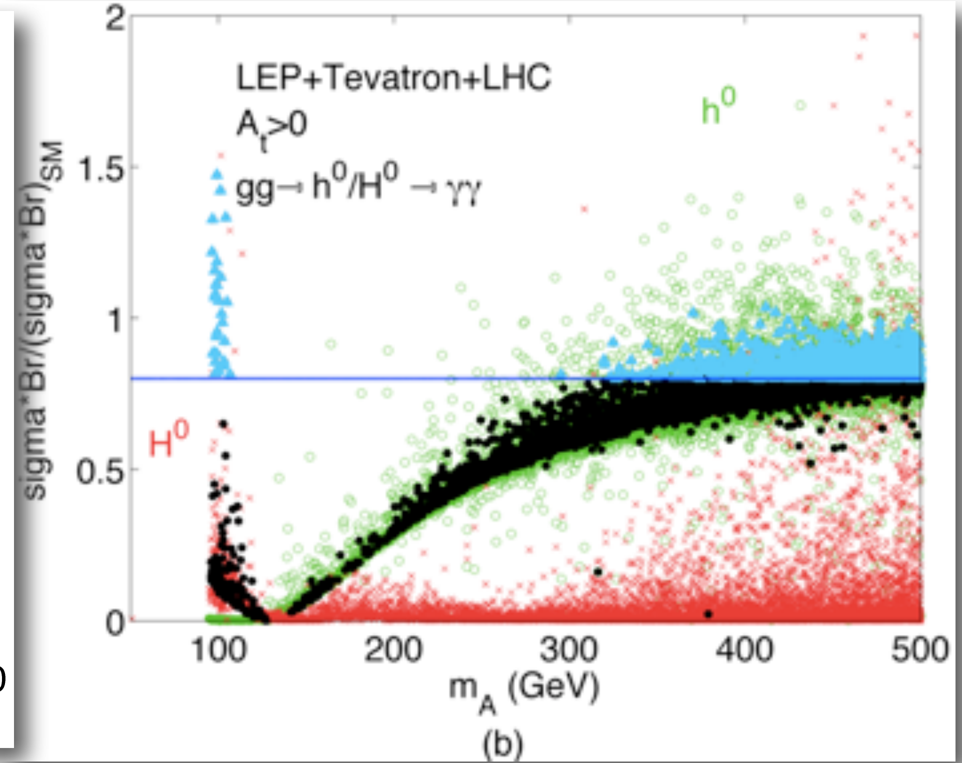
black dots: 123 < m_{h0} or m_{H0} < 127 GeV

blue dots: σXBr (gg→ h^0, H^0 →$\gamma\gamma$)$_{MSSM}$ > 80% (σXBr)$_{SM}$

S. Su

non-decoupling vs. decoupling region





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non-decoupling vs. decoupling region

- decoupling limit

  $m_A \gg m_Z$

  $\sin(\beta-\alpha) \sim 1,\ \cos(\beta-\alpha) \sim 0$

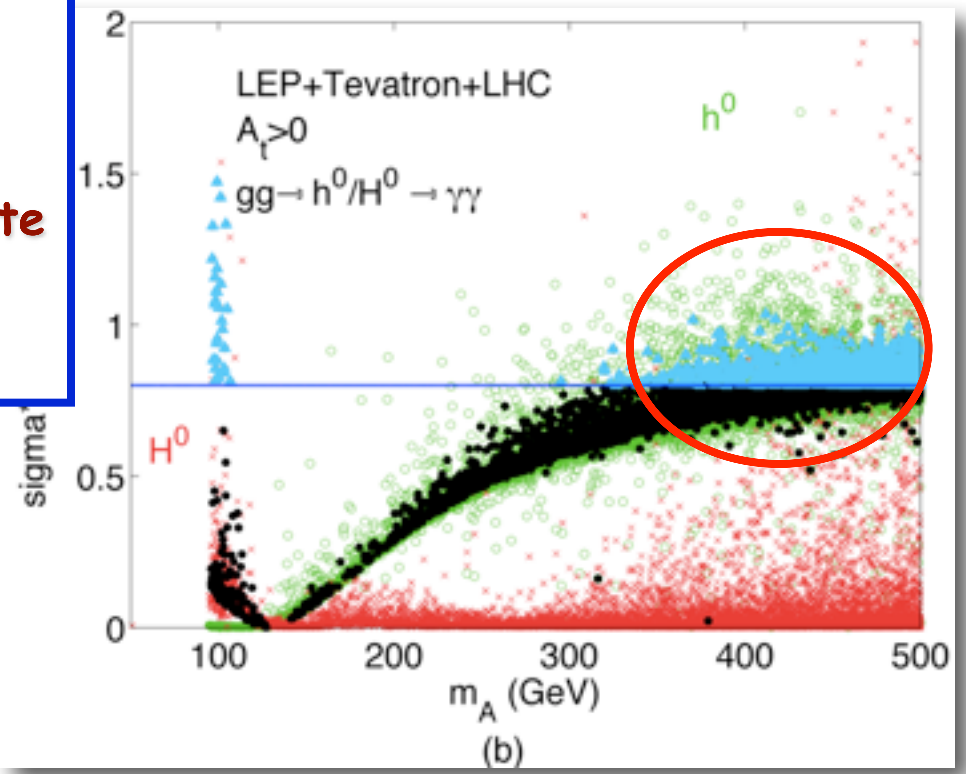
  – h^0 light, SM like,

  – H^0, A^0, $H^\pm$ heavy, nearly degenerate

  – H^0WW, H^0ZZ coupling suppressed

  ~ $\cos(\beta-\alpha)$

decoupling region



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non-decoupling vs. decoupling region

- **decoupling limit**

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  – h^0 light, SM like,

  – H^0, A^0, $H^\pm$ heavy, nearly degenerate

  – H^0WW, H^0ZZ coupling suppressed

  ~ $\cos(\beta-\alpha)$

- **non-decoupling limit**

  $m_A \sim m_Z$

  $\sin(\beta-\alpha) \sim 0,\ \cos(\beta-\alpha) \sim 1$

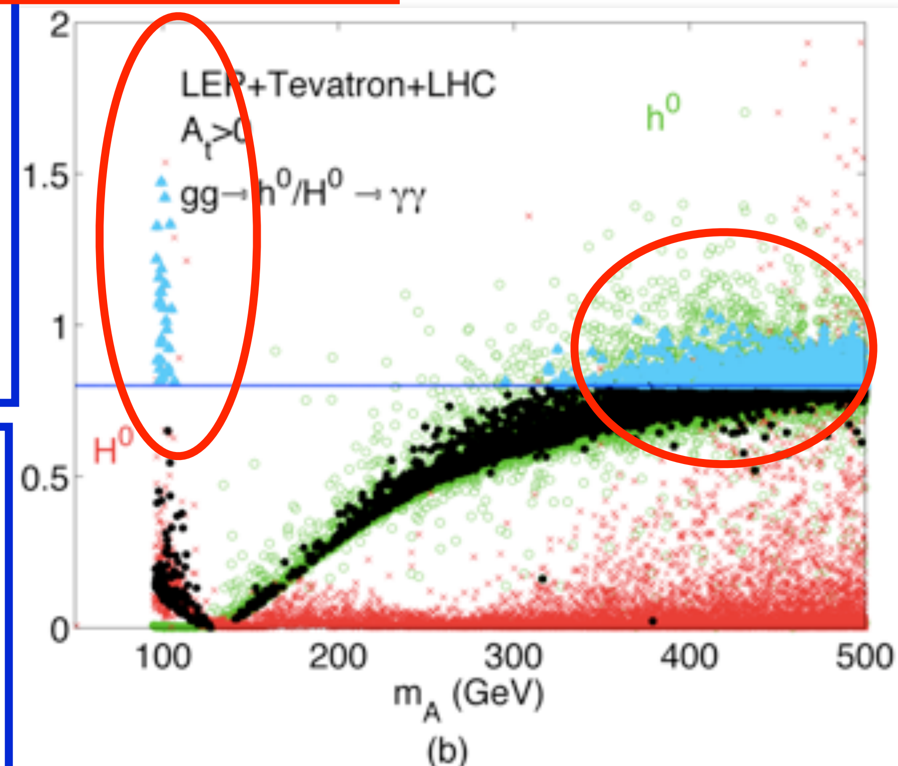
  – all Higgses light

  – H^0 SM like

  – h^0WW, h^0ZZ coupling suppressed

non-decoupling region

decoupling region



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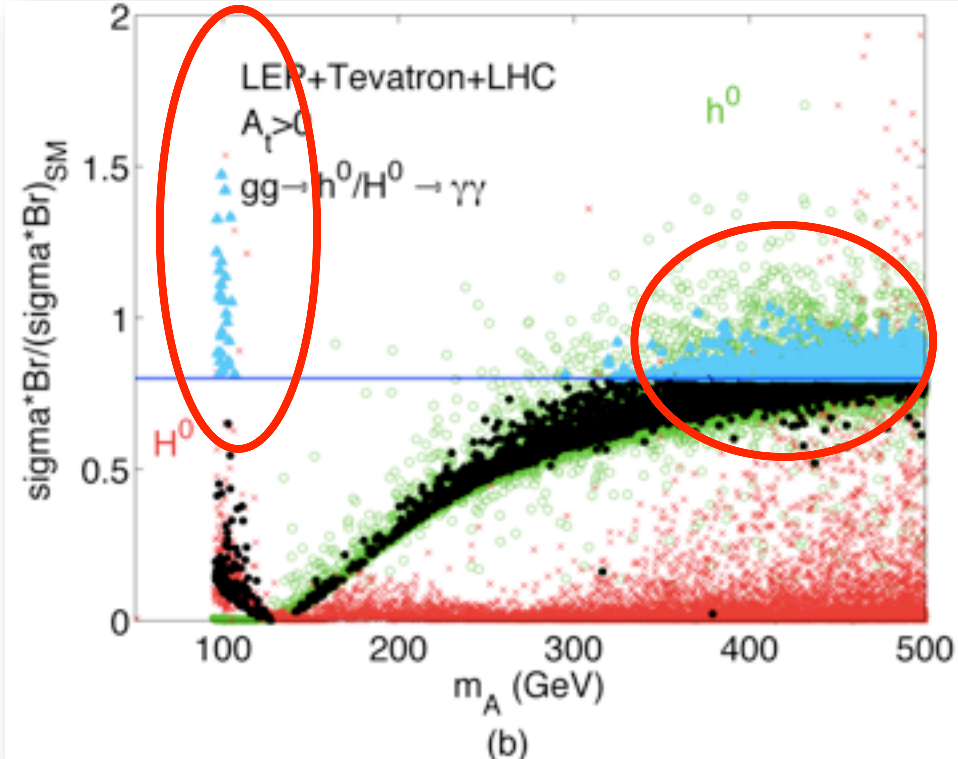
non-decoupling vs. decoupling region

- h⁰ SM-like: large mA ≥ 300 GeV
- small $m_A \sim m_Z$: H^0 SM-like

Not always true in NMSSM!

non-decoupling region

decoupling region



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NMSSM Higgs Sector

- Type II Two Higgs Doublet Model plus singlet S

$$W_{\rm NMSSM} = Y_u \hat{u}^c \hat{H}_u \hat{Q} + Y_d \hat{d}^c \hat{H}_d \hat{Q} + Y_e \hat{e}^c \hat{H}_d \hat{L} + \lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{1}{3}\kappa \hat{S}^3$$

$$V_{H,Soft} = m_{H_u}^2 H_u^\dagger H_u + m_{H_d}^2 H_d^\dagger H_d + M_S^2 |\mathcal{S}|^2 + \left(\lambda A_\lambda (H_t^T \epsilon H_d)\mathcal{S} + \frac{1}{3}\kappa A_\kappa \mathcal{S}^3 + c.c. \right)$$

- SSB

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad H_u^0 \to v_u/\sqrt{2} \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}, \quad H_d^0 \to v_d/\sqrt{2}$$

$$S \to v_s/\sqrt{2} \quad (\mu = \lambda v_s/\sqrt{2})$$

$$v_u^2 + v_d^2 = v^2 = (246\,\mathrm{GeV})^2$$

$$\tan\beta = v_u/v_d$$

after EWSB, 7 physical Higgses

CP-even Higgses: H_1, H_2, H_3

CP-odd Higgs: A_1, A_2

Charged Higgses: $H^\pm$

NMSSM: Masses for Higgses

- **CP-odd Higgses**

$$\begin{pmatrix} A_v \\ G^0 \end{pmatrix} = \begin{pmatrix} \sin\beta & \cos\beta \\ -\cos\beta & \sin\beta \end{pmatrix} \begin{pmatrix} \sqrt{2}\,\mathrm{Im}H_d^0 \\ \sqrt{2}\,\mathrm{Im}H_u^0 \end{pmatrix}, \quad A_S = \sqrt{2}\,\mathrm{Im}S$$

$$\frac{1}{2}(A_v, A_S) \begin{pmatrix} m_A^2 & \\ * & \end{pmatrix} \begin{pmatrix} A_v \\ A_S \end{pmatrix}$$

$$m_A^2 = \frac{\lambda v_s}{\sin 2\beta}\left(\sqrt{2}A_\lambda + \kappa v_s\right) = \frac{2b_{eff}}{\sin 2\beta}$$

mA as in MSSM

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$$\frac{1}{2}(A_v, A_S) \begin{pmatrix} m_A^2 & \frac{1}{2}(m_A^2 \sin 2\beta - 3\lambda\kappa v_s^2)\frac{v}{v_s} \\ * & \frac{1}{4}(m_A^2 \sin 2\beta + 3\lambda\kappa v_s^2)\frac{v^2}{v_s^2}\sin 2\beta - \frac{3}{\sqrt{2}}\kappa v_s A_\kappa \end{pmatrix} \begin{pmatrix} A_v \\ A_S \end{pmatrix}$$

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mA as in MSSM

CP-odd Higgs mass eigenstates: A_1, A_2

NMSSM: Masses for Higgs

- **Charged Higgs**

$$\begin{aligned} H_d^- &= H^- \sin\beta - G^- \cos\beta, \\ H_u^+ &= H^+ \cos\beta + G^+ \sin\beta, \end{aligned}$$

$$m^2_{H^\pm} = m^2_A + m^2_W$$

NMSSM: Masses for Higgses

- **Charged Higgs**

$$H_d^- = H^- \sin\beta - G^- \cos\beta,$$
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$$m^2_{H^\pm} \geq 0 \quad \longrightarrow \quad \lambda \leq \frac{\sqrt{2}}{v}\sqrt{m^2_A + m^2_W}.$$

NMSSM: Masses for Higgses

- **CP-even Higgses**

$$\begin{pmatrix} h_v \\ H_v \end{pmatrix} = \begin{pmatrix} -\sin\beta & \cos\beta \\ \cos\beta & \sin\beta \end{pmatrix} \begin{pmatrix} \sqrt{2}\,(\mathrm{Re}H_d^0 - v_d) \\ \sqrt{2}\,(\mathrm{Re}H_u^0 - v_u) \end{pmatrix}, \quad S = \sqrt{2}\,(\mathrm{Re}S - v_s)$$

$$\frac{1}{2}(H_v, h_v, S) \begin{pmatrix} m_A^2 + m_Z^2 \sin^2 2\beta & * & * \\ * & m_Z^2 \cos^2 2\beta & * \\ * & * & \end{pmatrix} \begin{pmatrix} H_v \\ h_v \\ S \end{pmatrix}$$

NMSSM: Masses for Higgses

- CP-even Higgses

couples exactly the same as the SM Higgs

$$\begin{pmatrix} h_v \\ H_v \end{pmatrix} = \begin{pmatrix} -\sin\beta & \cos\beta \\ \cos\beta & \sin\beta \end{pmatrix} \begin{pmatrix} \sqrt{2}\,(\mathrm{Re}H_d^0 - v_d) \\ \sqrt{2}\,(\mathrm{Re}H_u^0 - v_u) \end{pmatrix}, \quad S = \sqrt{2}\,(\mathrm{Re}S - v_s)$$

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NOT couple to W/Z, couple to up (down) as $\tan\beta^{-1}$ ($\tan\beta$)

$$\frac{1}{2}(H_v, h_v, S) \begin{pmatrix} m_A^2 + m_Z^2 \sin^2 2\beta & * & * \\ * & m_Z^2 \cos^2 2\beta & * \\ * & * & \end{pmatrix} \begin{pmatrix} H_v \\ h_v \\ S \end{pmatrix}$$

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$$\frac{1}{2}(H_v, h_v, S) \begin{pmatrix} m_A^2 + m_Z^2 \sin^2 2\beta & * & * \\ -\frac{1}{2}(\lambda v)^2 \sin^2 2\beta & & \\ * & m_Z^2 \cos^2 2\beta & * \\ * & * & \end{pmatrix} \begin{pmatrix} H_v \\ h_v \\ S \end{pmatrix}$$

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NMSSM: Masses for Higgses

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CP-even Higgs mass eigenstates: H_1, H_2, H_3

NMSSM: Masses for Higgses

- Effects of singlet
  - lift $(m_{hv})_{tree}$, small tanβ, large λ

$$(m_{h_v}^2)_{\rm tree} = m_Z^2 \cos^2 2\beta + \frac{1}{2}(\lambda v)^2 \sin^2 2\beta$$

  - mixing with singlet: change H_iWW/ZZ, H_ibb, H_igg, $H_i\gamma\gamma$

- Lots of work on (125 GeV) Higgs in NMSSM framework ...

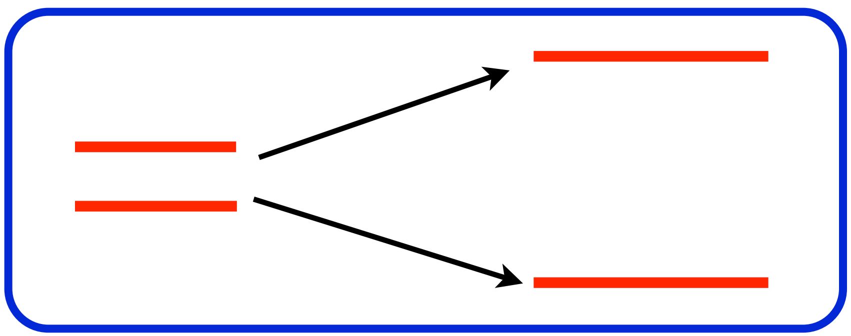
Gunion et. al, 1201.0982
Ellwanger 1112.3548
King et. al., 1201.2671
Cao et. al., 1202.5821
EllWanger et. al., 1203.5048
Benbrik et. al., 1207.1096
Gunion et. al., 1207.1545
Gunion et. al., 1208.1817
Cheng et. al., 1207.6392
Belanger et. al., 1208.4952
Agashe et. al., 1209.2115
Belanger et. al., 1210.1976
Heng, 1210.3751
Choi et. al., 1211.0875
King et. al., 1211.5074
Dreiner et. al., 1211.6987
Das et. al., 1301.7548
... many other Jack's, Ellwanger's paper ...
(incomplete list)

- H3 heavy, m_A large
- H1 126 or H2 126
- h_v/S mixing

NMSSM: Masses for Higgses

- CP-even Higgses

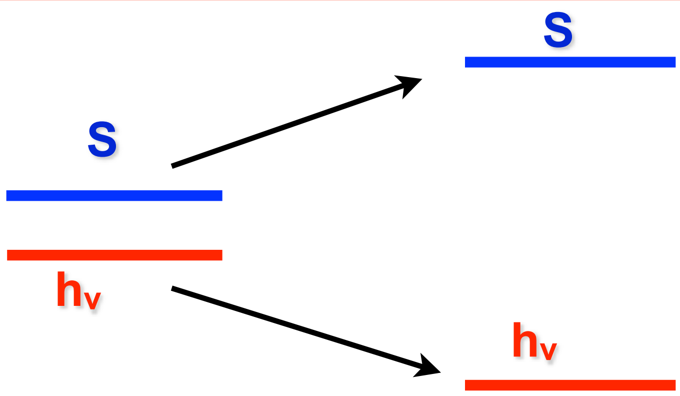
$$\frac{1}{2}(H_v, h_v, S)\begin{pmatrix} m_A^2 + m_Z^2 \sin^2 2\beta - \frac{1}{2}(\lambda v)^2 \sin^2 2\beta & * & * \\ * & m_Z^2 \cos^2 2\beta + \frac{1}{2}(\lambda v)^2 \sin^2 2\beta & * \\ * & * & \frac{1}{4} m_A^2 \sin^2 2\beta \frac{v^2}{v_s^2} + 2\kappa^2 v_s^2 + \frac{1}{\sqrt{2}}\kappa v_s A_\kappa - \frac{1}{4}\lambda\kappa v^2 \sin 2\beta \end{pmatrix}\begin{pmatrix} H_v \\ h_v \\ S \end{pmatrix}$$



- mass splitting: off-diag comparing to average of diag
- state mixing: off-diag comparing to difference of diag

NMSSM: m_A decouple case

◉ push down: $m_{h_v} < m_S$

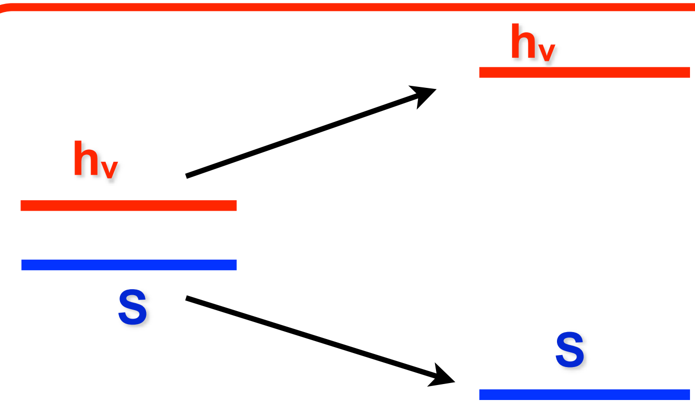


◉ H_1 (SM-like) still heavy enough ≥ 124 GeV

⇒ not too large mass mixing

(to push down m_{H1} too low)

◉ push up: $m_{h_v} > m_S$



◉ H_1 (singlet-like) not ruled out by LEP

⇒ not too large state mixing

(to have too much H_1ZZ coupling)

Agashe et. al., 1209.2115

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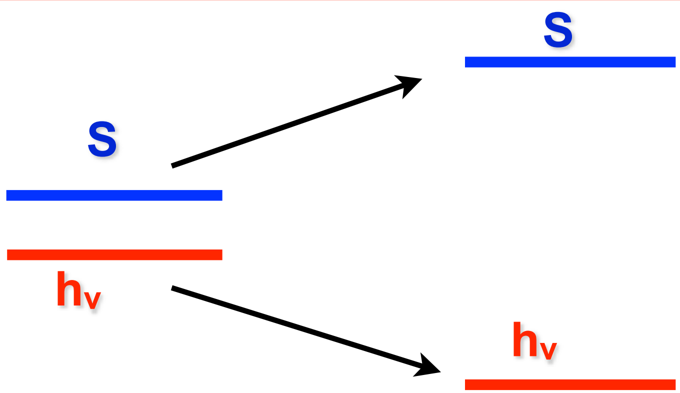

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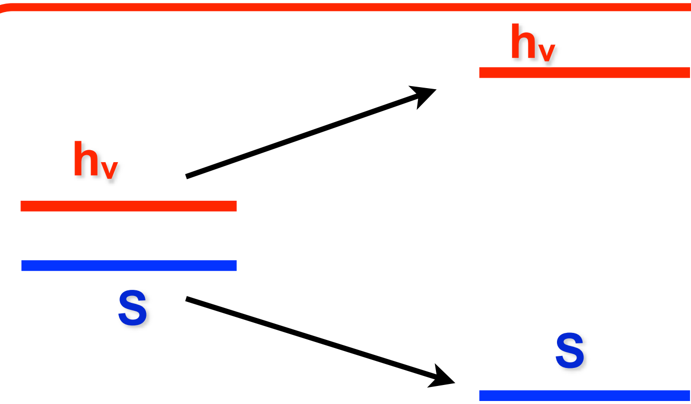

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Need some tuning to make it work (without too much help from stops)

Agashe et. al., 1209.2115

NMSSM: Masses for Higgses

Our work: Focus on the NMSSM low m_A region: $m_A \lesssim 2\, m_Z$

All Higgses light
- could have large mixing effects
- can be probed experimentally

$$(m^2_{h_v})_{\rm tree} = m_Z^2 \cos^2 2\beta + \frac{1}{2}(\lambda v)^2 \sin^2 2\beta$$

$$(m^2_{H_v})_{\rm tree} = m_A^2 + (m_Z^2 - \frac{1}{2}(\lambda v)^2) \sin^2 2\beta$$

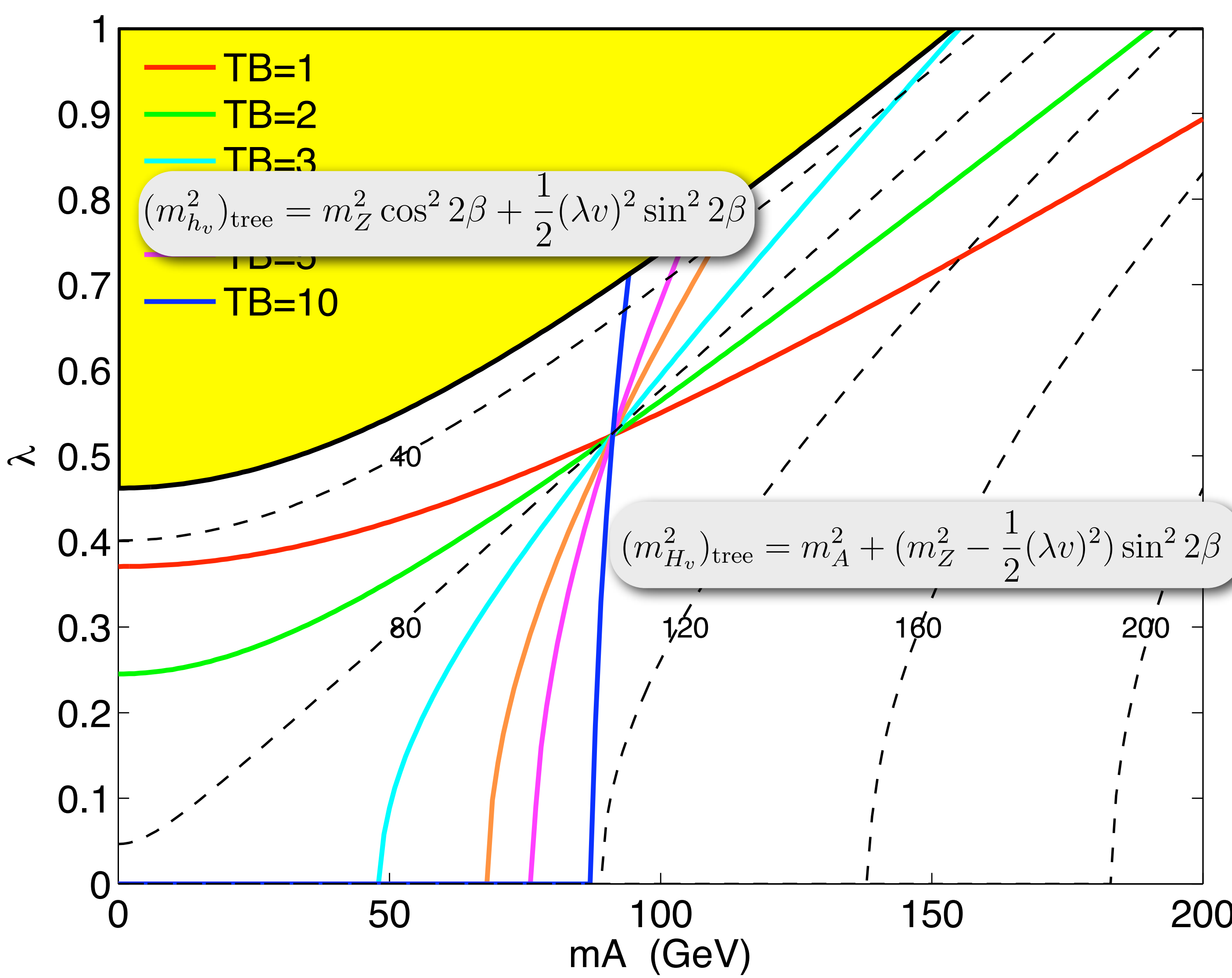
- ignore singlet for now...

MSSM
- $m_A^2 \geq m_Z^2$ (cos 4 β): H_1 SM-like
- $m_A^2 \leq m_Z^2$ (cos 4 β): H_2 SM-like

S. Su

NMSSM (small m_A)
- H_1 or H_2 SM-like, depending on m_A, λ, tanβ
- small m_A, large λ, small tan β, H_2 SM-like

NMSSM: Masses for Higgses

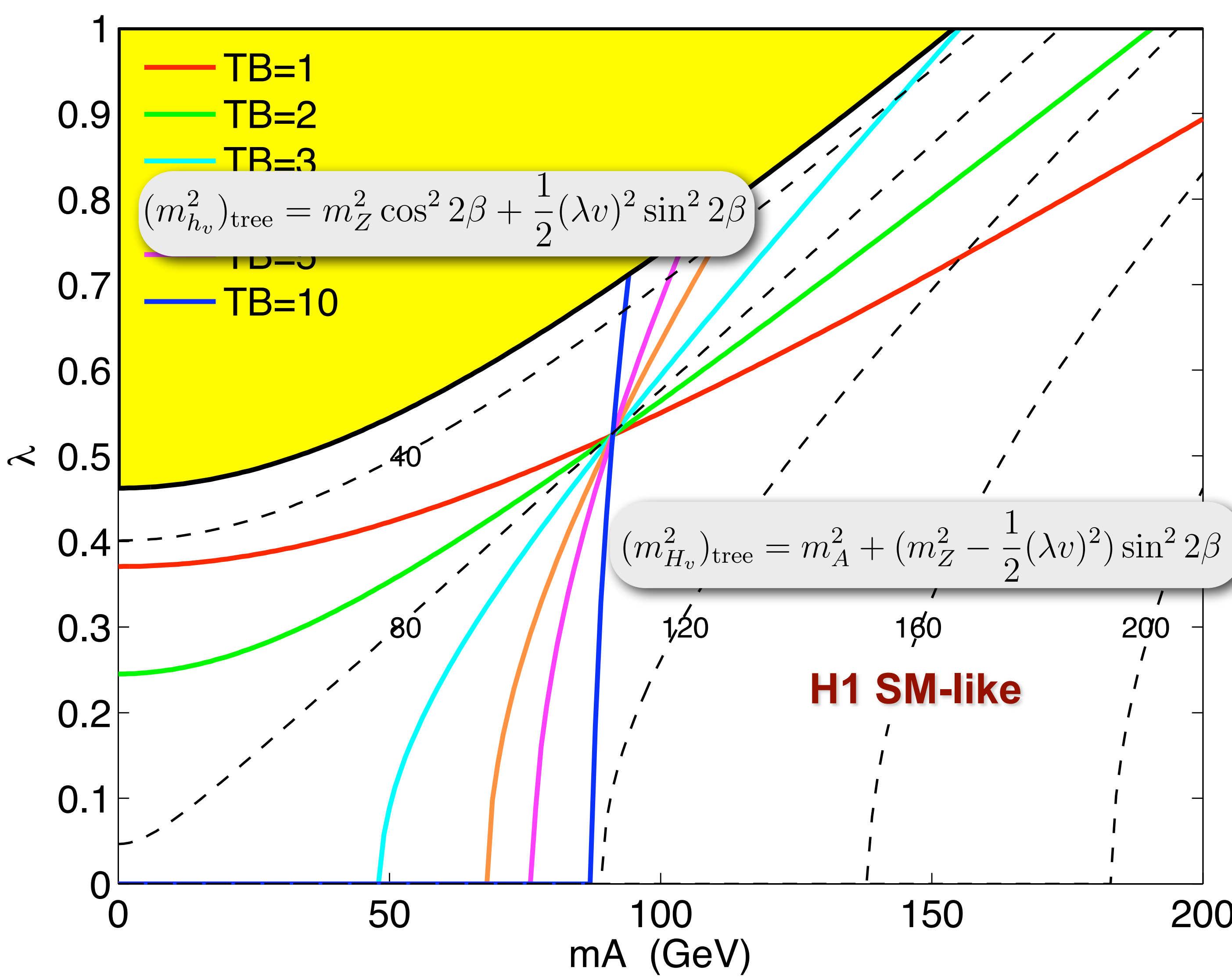


$$(m_{h_v}^2)_{\rm tree} = m_Z^2 \cos^2 2\beta + \frac{1}{2}(\lambda v)^2 \sin^2 2\beta$$

$$(m_{H_v}^2)_{\rm tree} = m_A^2 + (m_Z^2 - \frac{1}{2}(\lambda v)^2) \sin^2 2\beta$$

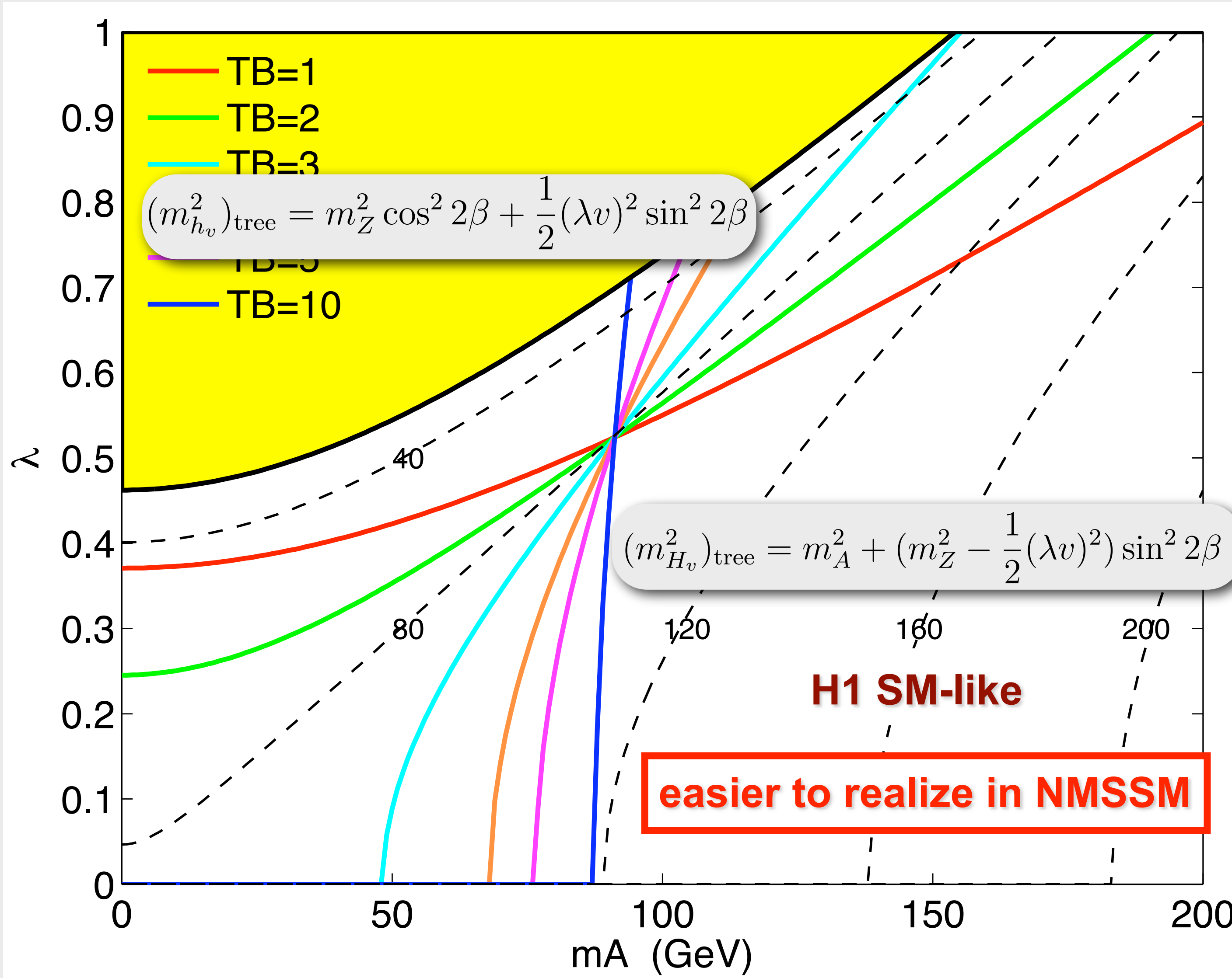
S. S

NMSSM: Masses for Higgses



S. S

NMSSM: Masses for Higgses



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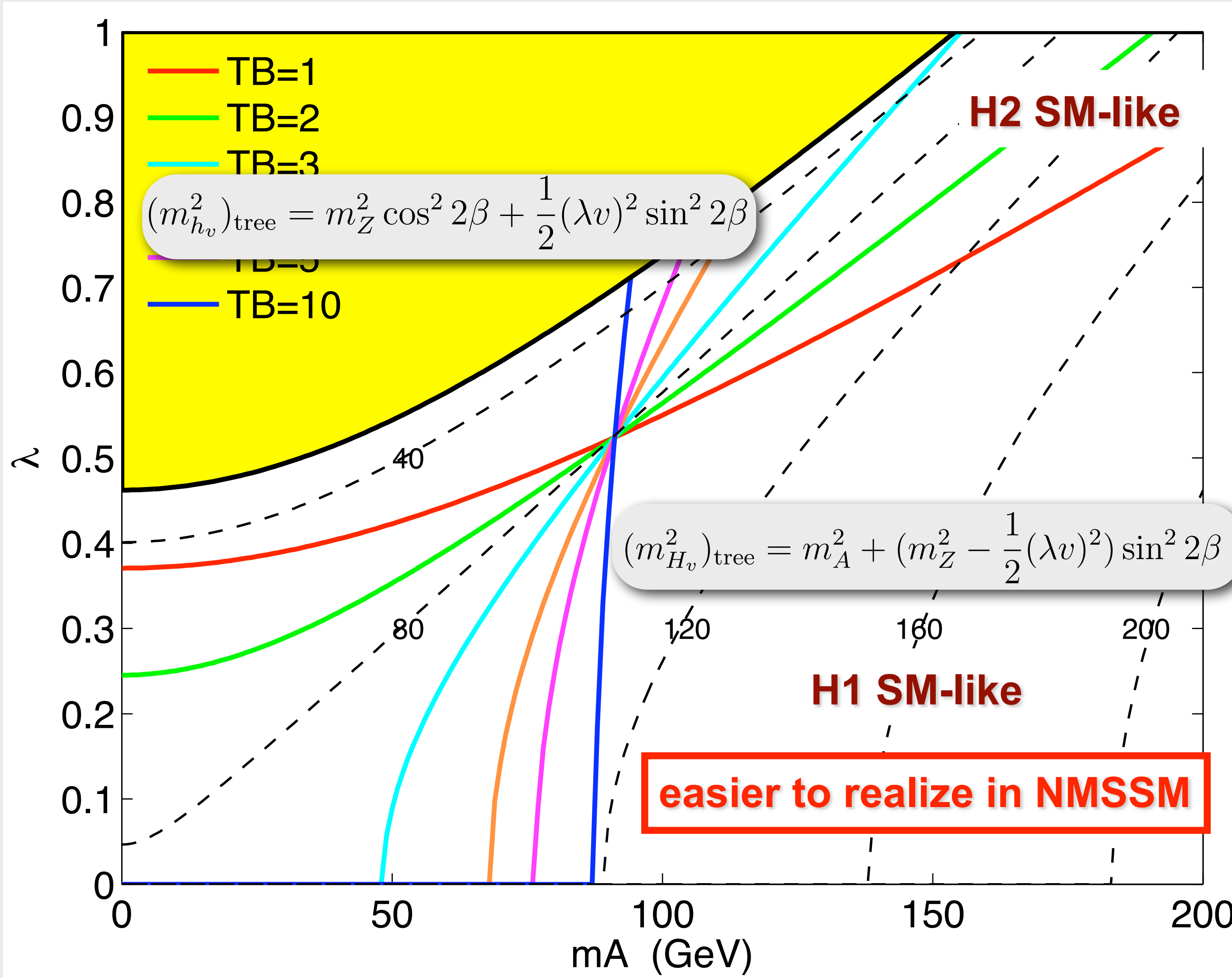
S. S

NMSSM: Masses for Higgses



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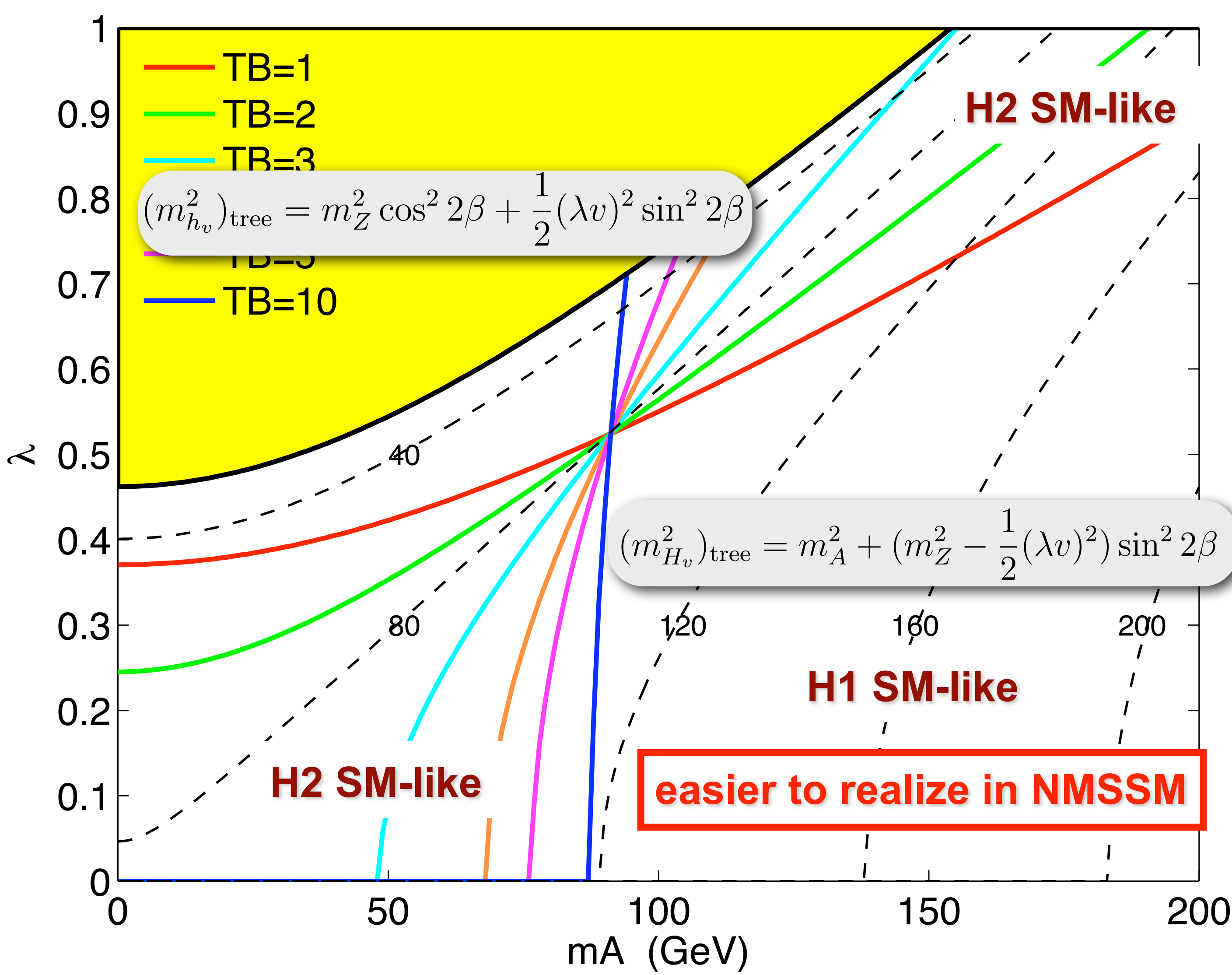
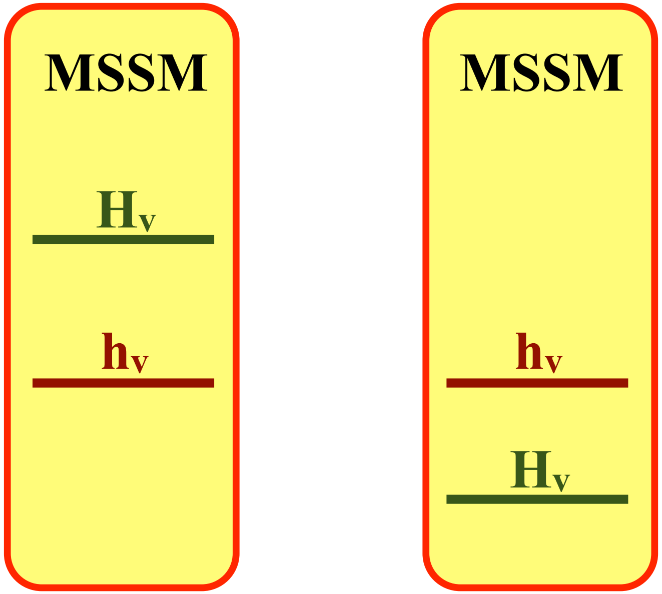
S. S

NMSSM: Masses for Higgses

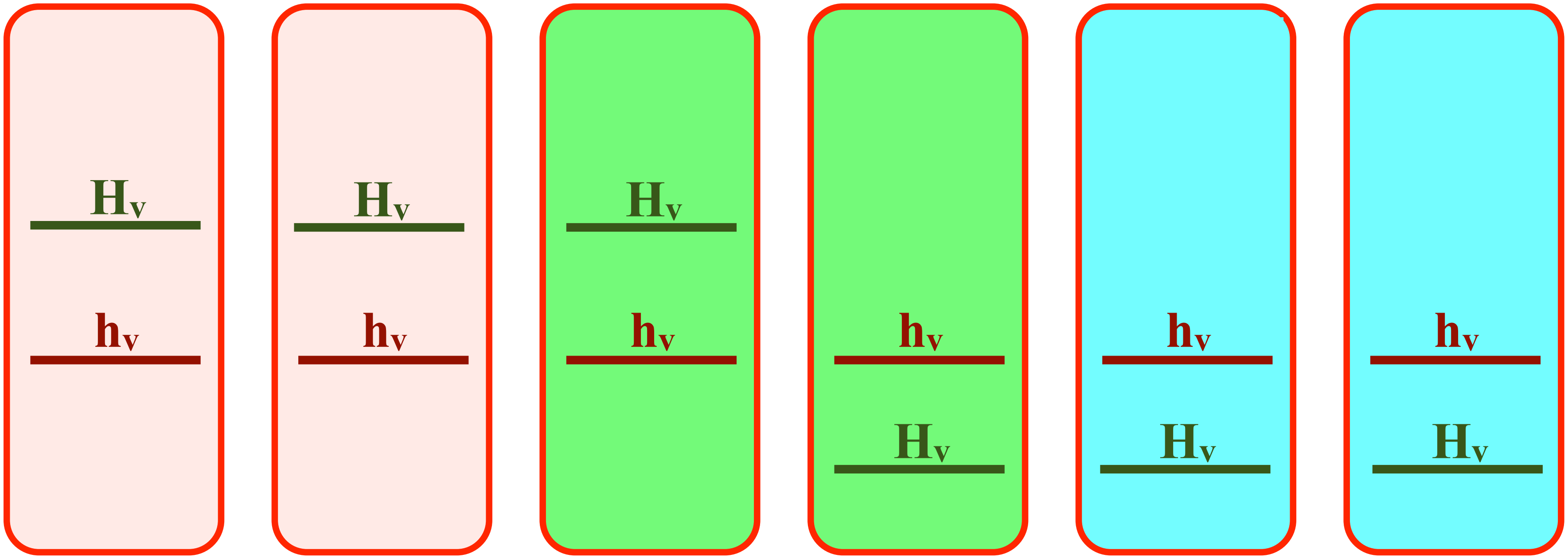


S. S

NMSSM non-decoupling cases



NMSSM non-decoupling cases



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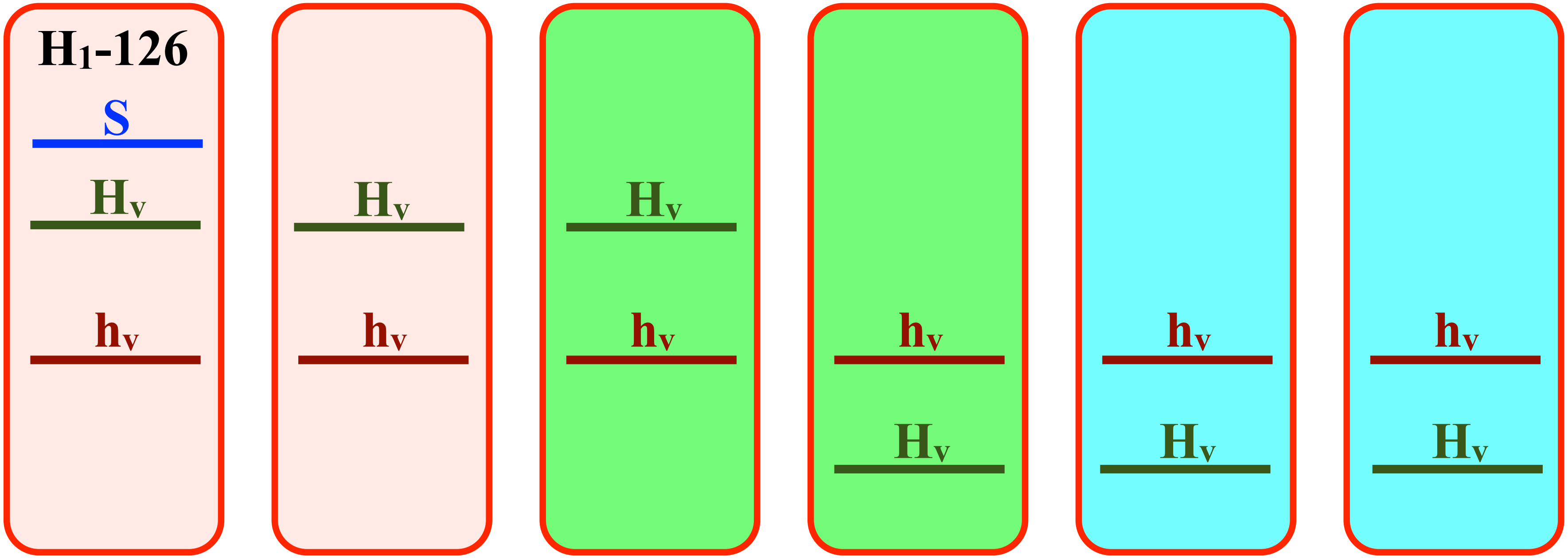
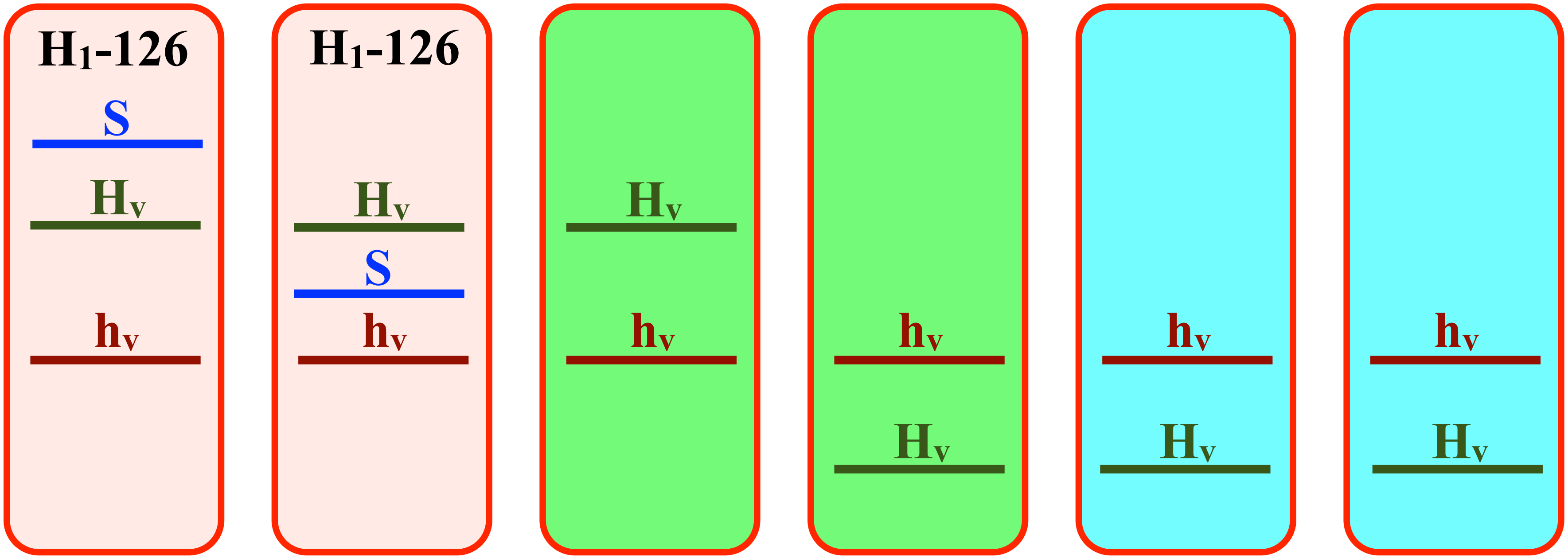
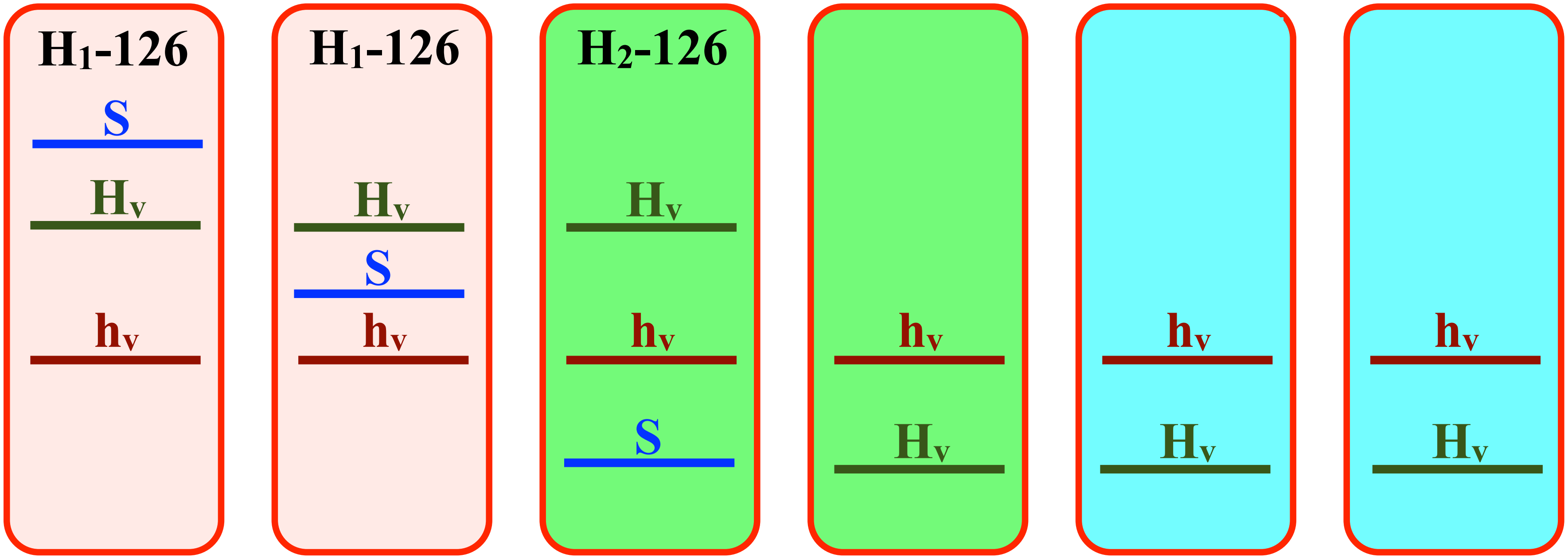
NMSSM non-decoupling cases



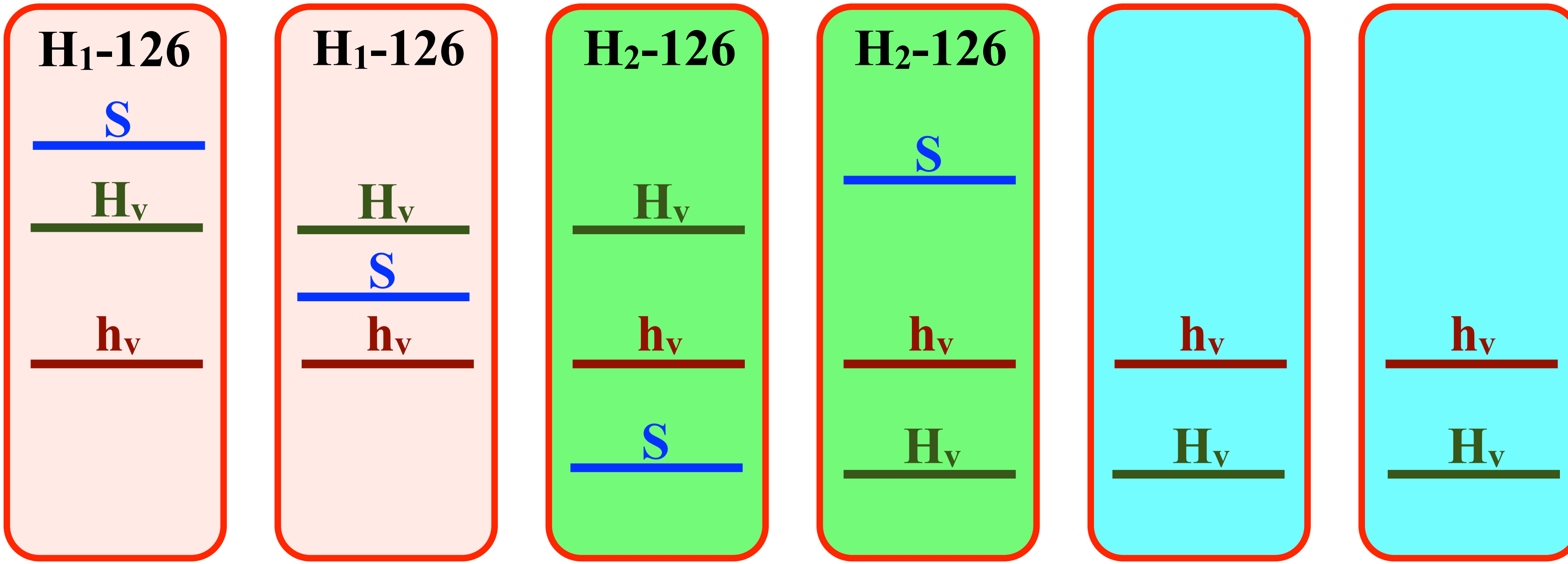
NMSSM non-decoupling cases



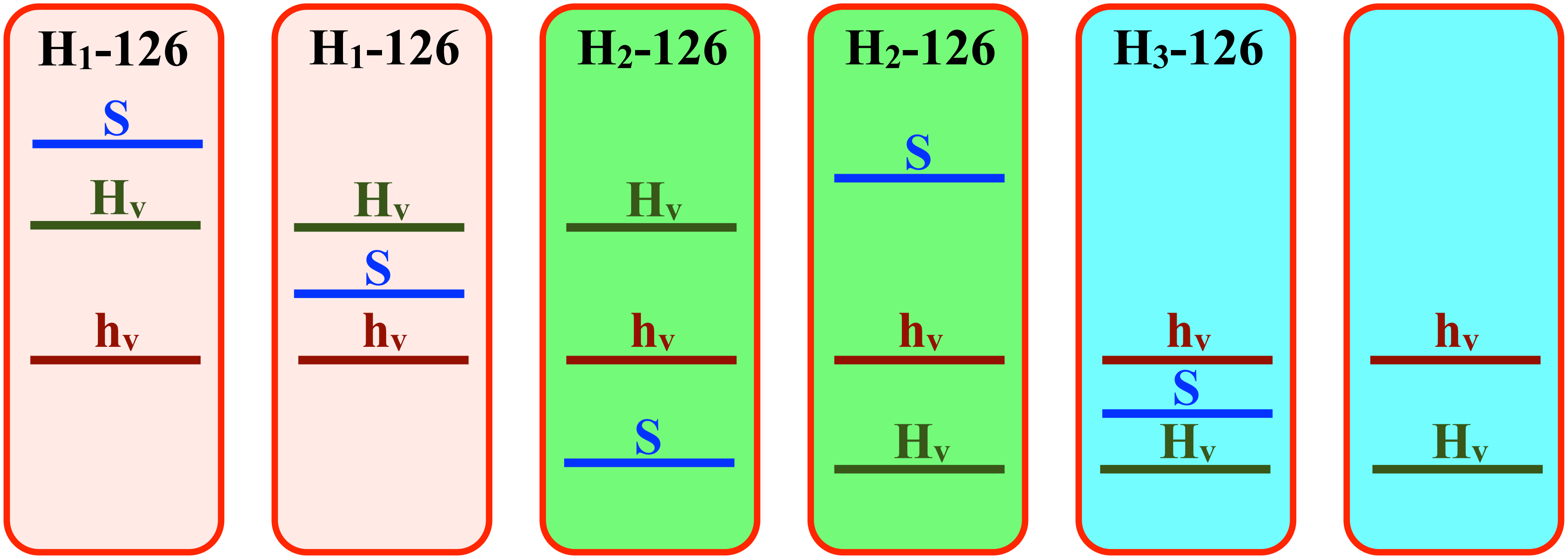
NMSSM non-decoupling cases



NMSSM non-decoupling cases



NMSSM non-decoupling cases



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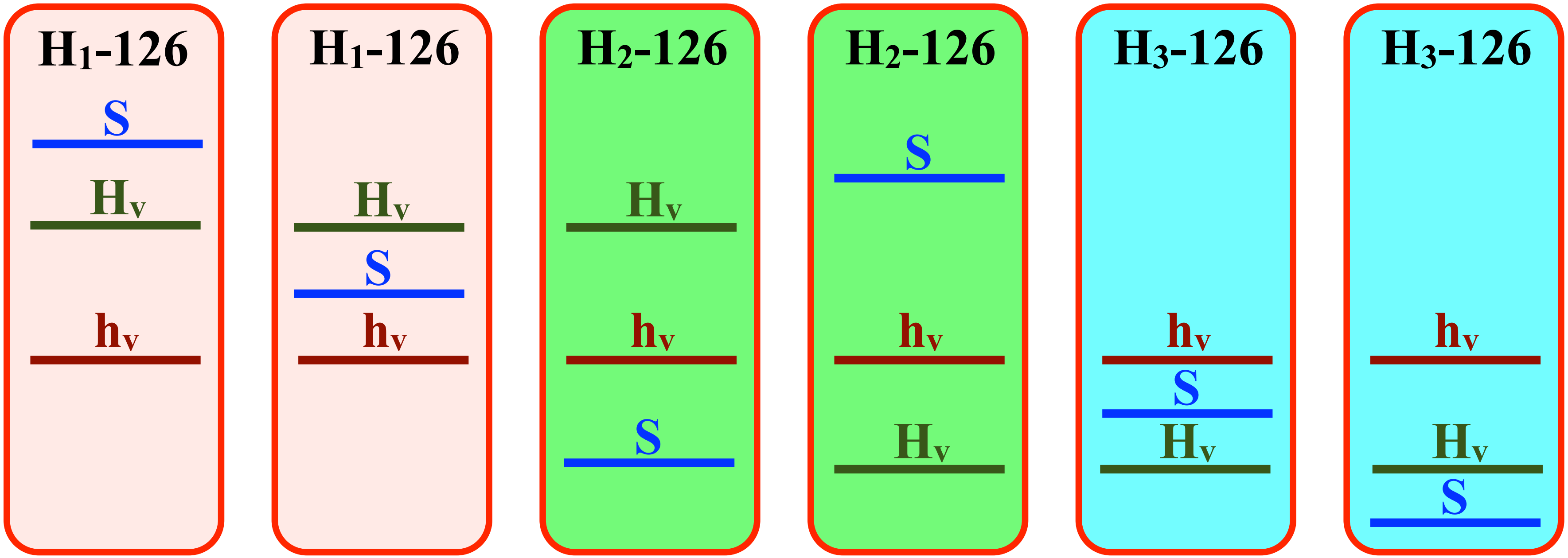
NMSSM non-decoupling cases



NMSSM Higgs Couplings

- **Wave function overlap**

$$H_i = \sum_\alpha \xi_{H_i}^{H_\alpha} H_\alpha, \quad \text{for } i = 1,2,3, \; H_\alpha = (h_v, H_v, S),$$

$$|\xi_{H_1}^{H_\alpha}|^2 + |\xi_{H_2}^{H_\alpha}|^2 + |\xi_{H_3}^{H_\alpha}|^2 = 1, \quad |\xi_{H_i}^{h_v}|^2 + |\xi_{H_i}^{H_v}|^2 + |\xi_{H_i}^{S}|^2 = 1.$$

$$A_i = \sum_\alpha \xi_{A_i}^{A_\alpha} A_\alpha$$

$$|\xi_{A_1}^{A_v}|^2 = |\xi_{A_2}^{A_s}|^2 = 1 - |\xi_{A_1}^{A_s}|^2 = 1 - |\xi_{A_2}^{A_v}|^2.$$

- **Wave function overlap**

	H_i	A_i		$H^\pm$
R_{uu}	$\xi_{H_i}^{h_v} + \xi_{H_i}^{H_v}/\tan\beta$	$\xi_{A_i}^{A_v}/\tan\beta$	$R_{d_L u_R^c}$	$-\sqrt{2}/\tan\beta$
R_{dd}	$\xi_{H_i}^{h_v} - \xi_{H_i}^{H_v}\tan\beta$	$\xi_{A_i}^{A_v}\tan\beta$	$R_{u_L d_R^c}$	$-\sqrt{2}\tan\beta$
R_{VV}	$\xi_{H_i}^{h_v}$			

s.

NMSSM parameters

parameters

MSSM

m_A, $\tan\beta$, μ, (v)

M3SQ, M3SU, A_t

NMSSM

λ, κ, A_λ, A_κ, $\tan\beta$, v_s, (v)

M3SQ, M3SU, At

↓

NMSSM

λ, κ, m_A, A_κ, $\tan\beta$, μ, (v)

M3SQ, M3SU, A_t

Parameter Scan

$1 < \tan\beta < 10$

$0\ \text{GeV} < m_A < 200\ \text{GeV}$

$100\ \text{GeV} < \mu < 1000\ \text{GeV}$

$0.01 < \lambda < 1$

$0.01 < \kappa < 1$

$-1200\ \text{GeV} < A_\kappa < 200\ \text{GeV}$

$100\ \text{GeV} < M_{3SU}, M_{3SQ} < 3000\ \text{GeV}$

$-4000\ \text{GeV} < A_t < 4000\ \text{GeV}$

decoupling other parameters (3 TeV)

NMSSMTools

Signal Regions

Study the consequence of

(I) current Higgs search limit of 95% CL limit on $\sigma X Br$

(II) H_i in the mass range of 124 - 128 GeV

(III) $\sigma X Br\ (gg \to H_i \to \gamma\gamma)_{NMSSM} > 80\%\ (\sigma X Br)_{SM}$

$\sigma X Br\ (gg \to H_i \to WW/ZZ)_{NMSSM} > 40\%\ (\sigma X Br)_{SM}$

- H_1 126 GeV
- H_2 126 GeV
- H_3 126 GeV

Signal Regions

Study the consequence of

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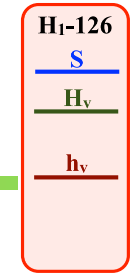
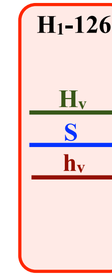
σXBr $(gg \to H_i \to WW/ZZ)_{NMSSM} > 40\% \, (\sigma XBr)_{SM}$

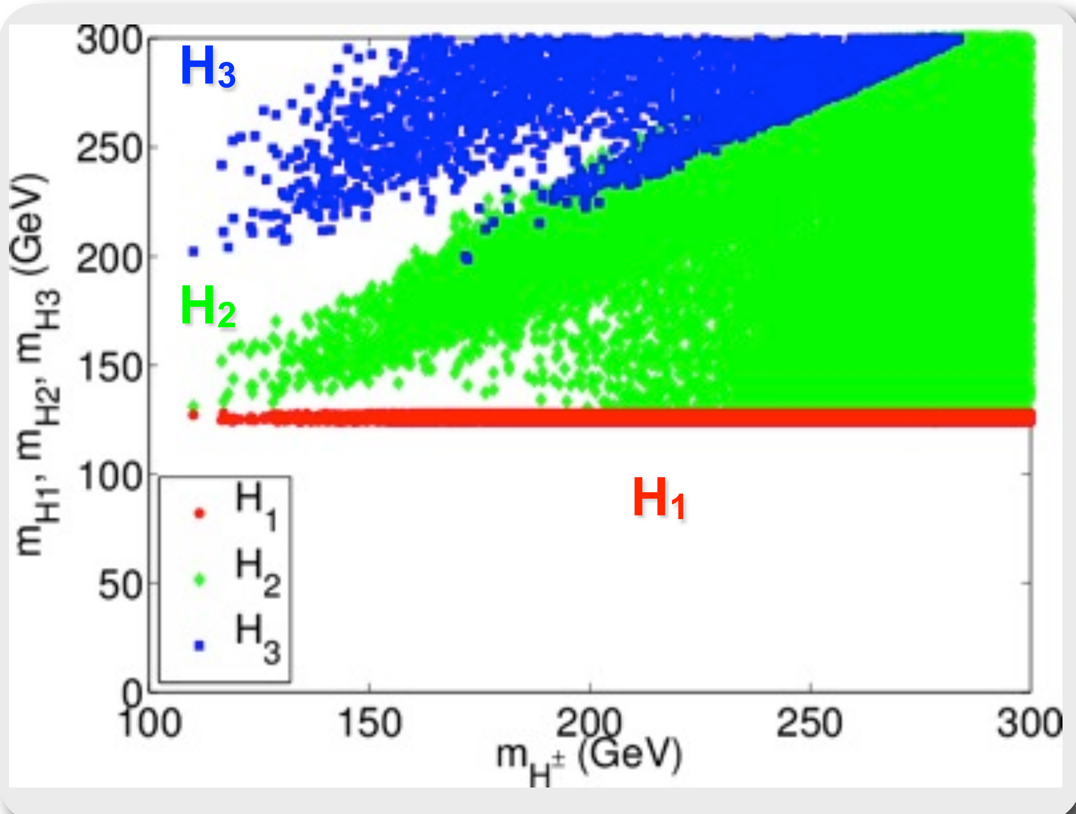
- H_1 126 GeV
- H_2 126 GeV
- ~~H_3 126 GeV~~

H_1 126 GeV: mass region

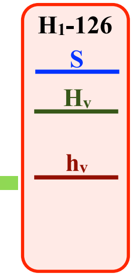


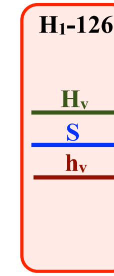


- M_{Hi} vs m_{Hpm}

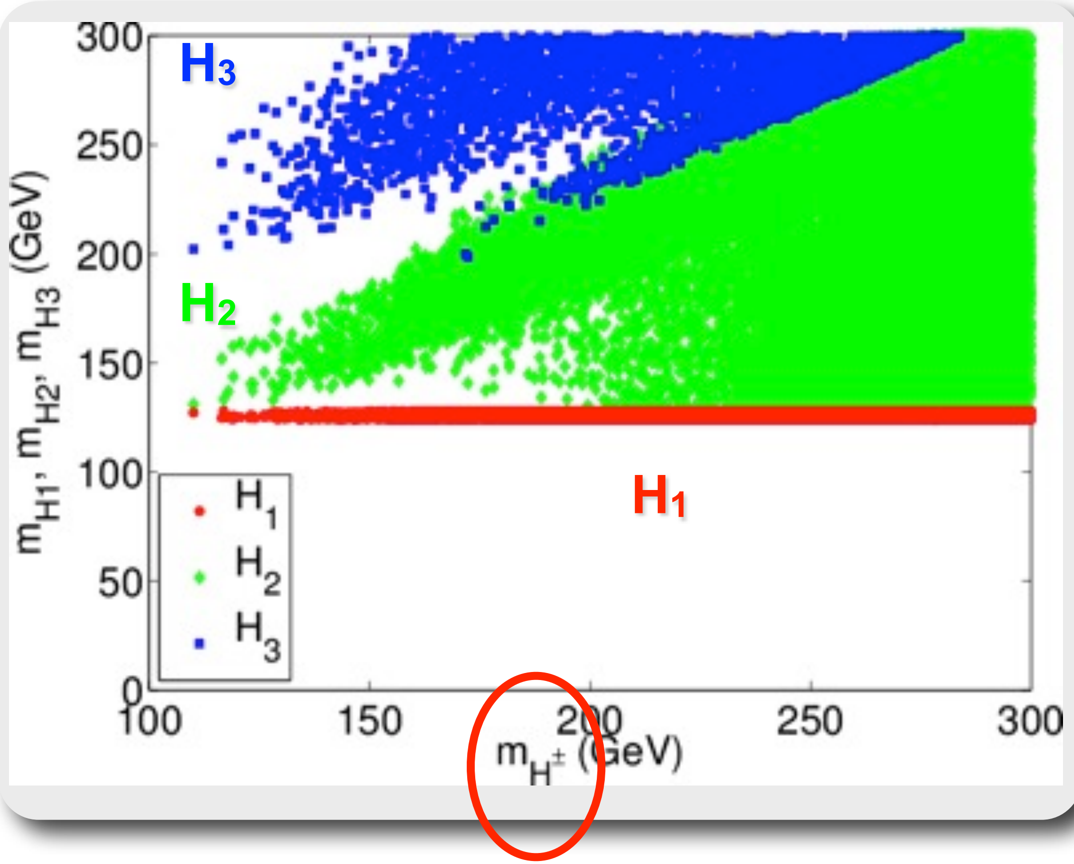


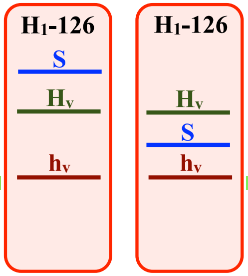
H_1 126 GeV: mass region





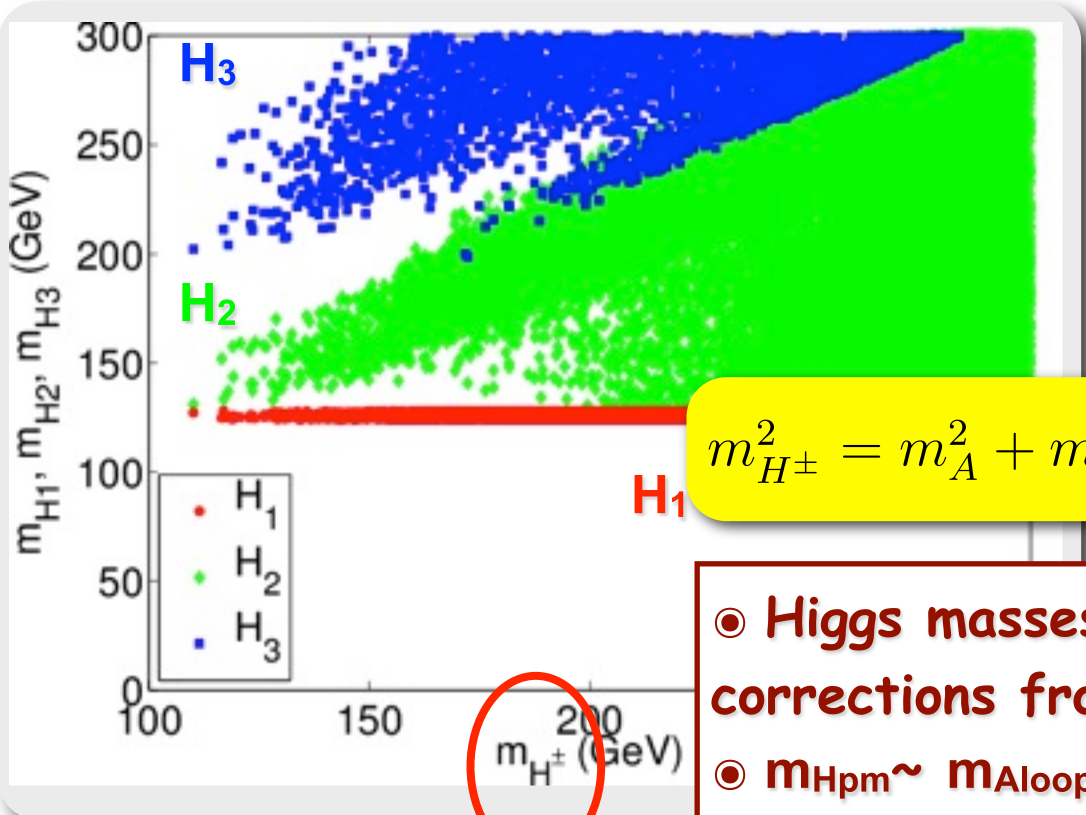
- M_{Hi} vs m_{Hpm}





H_1 126 GeV: mass region

◉ M_{Hi} vs m_{Hpm}

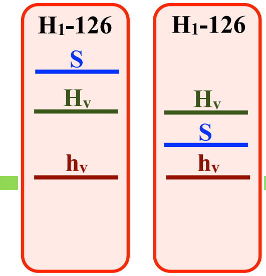


$$m^2_{H^\pm} = m^2_A + m^2_W - \frac{1}{2}(\lambda v)^2$$

◉ Higgs masses receive large radiative corrections from stop loops

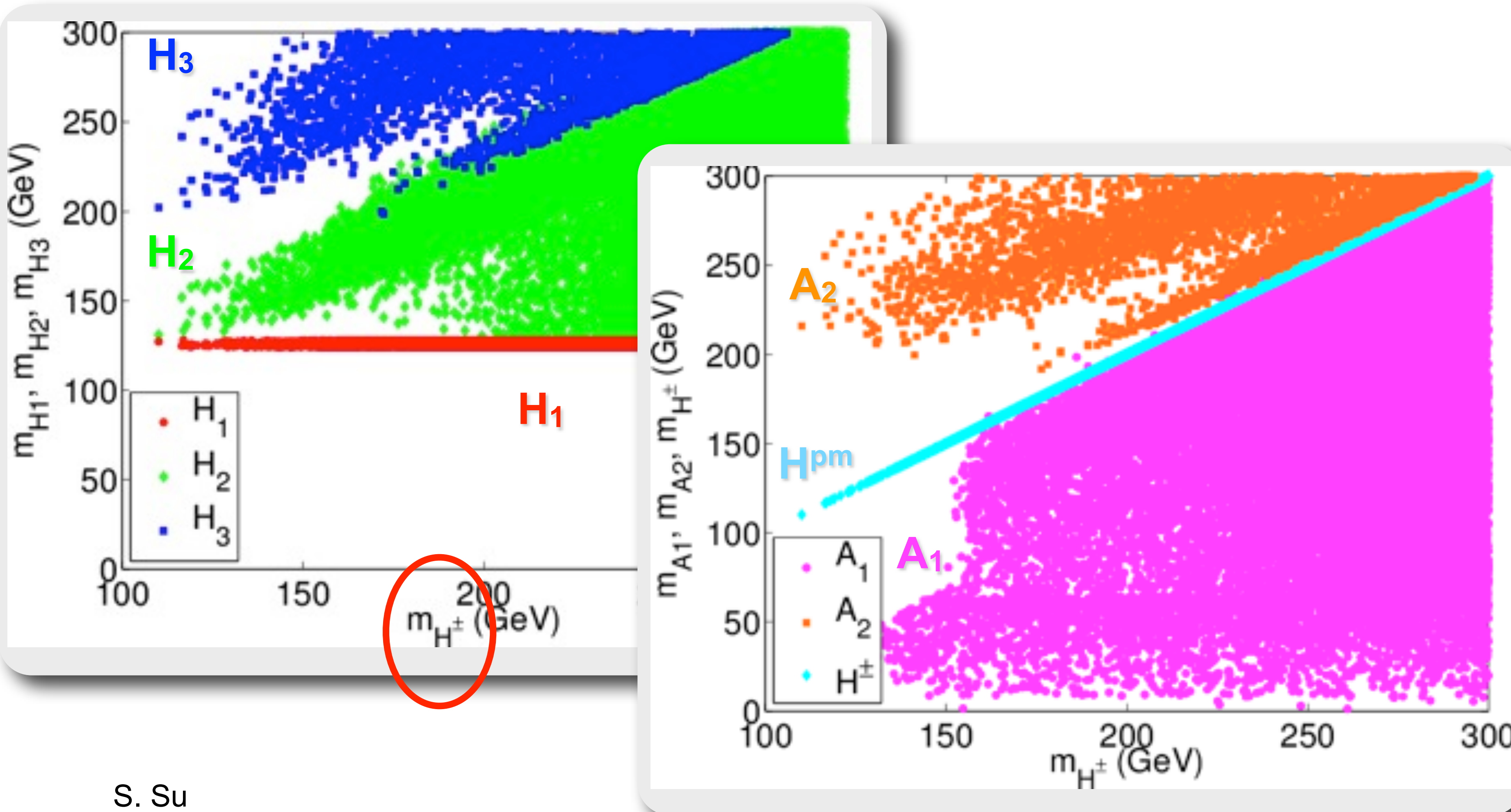
◉ $m_{Hpm} \sim m_{Aloop}$ (so-called m_A in MSSM)

◉ in NMSSM, m_{Aloop} is not physical Higgs mass; m_{A1}, m_{A2} after diagonalization



H_1 126 GeV: mass region

- M_{Hi} vs m_{Hpm}



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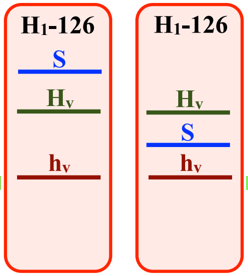
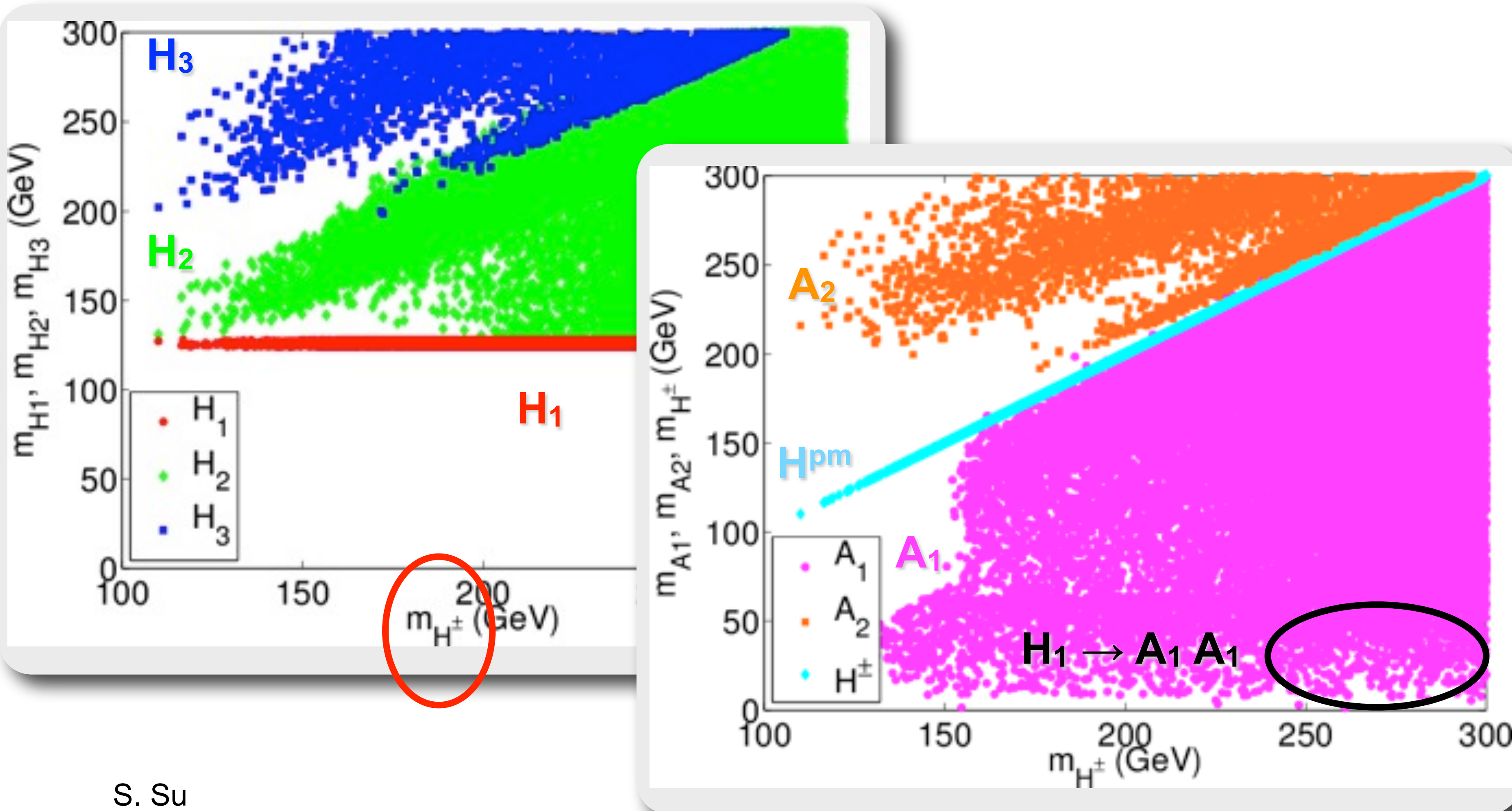
H_1 126 GeV: mass region



- M_{Hi} vs m_{Hpm}



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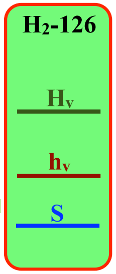
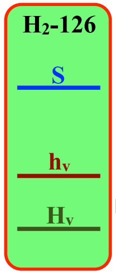
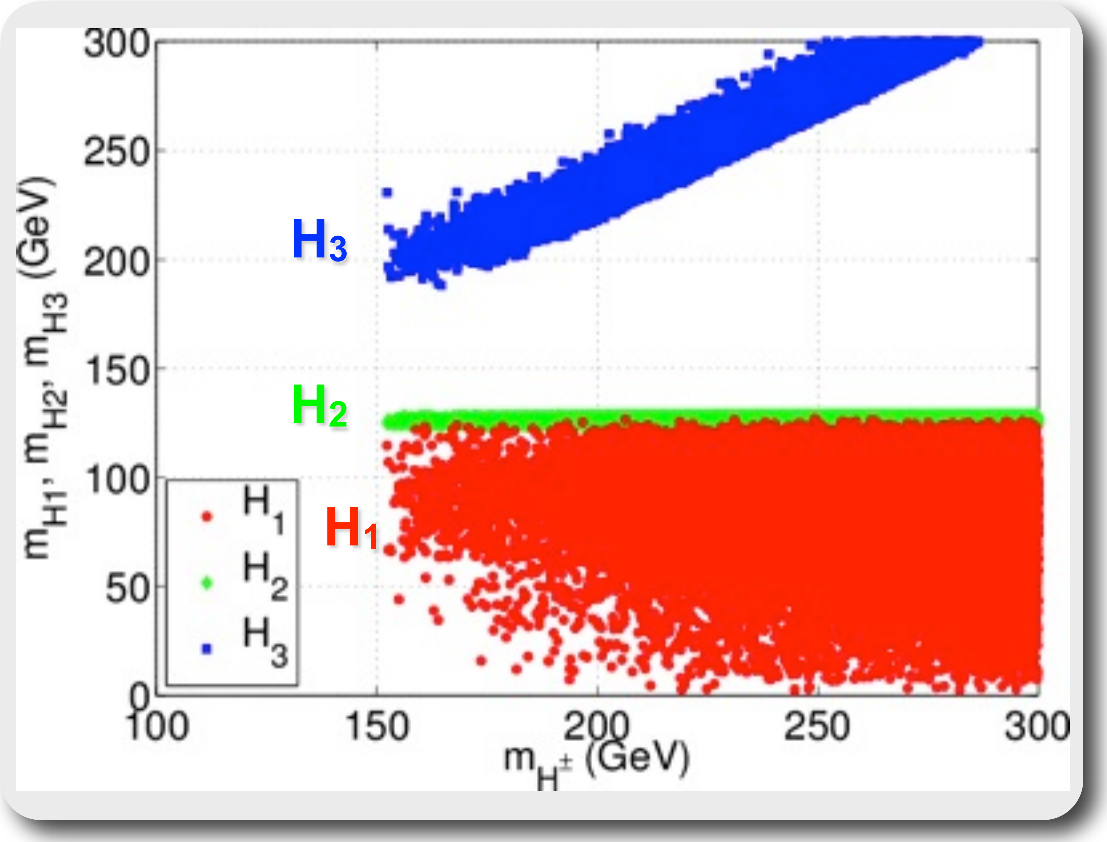
H_2 126 GeV: mass region

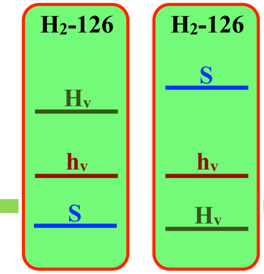




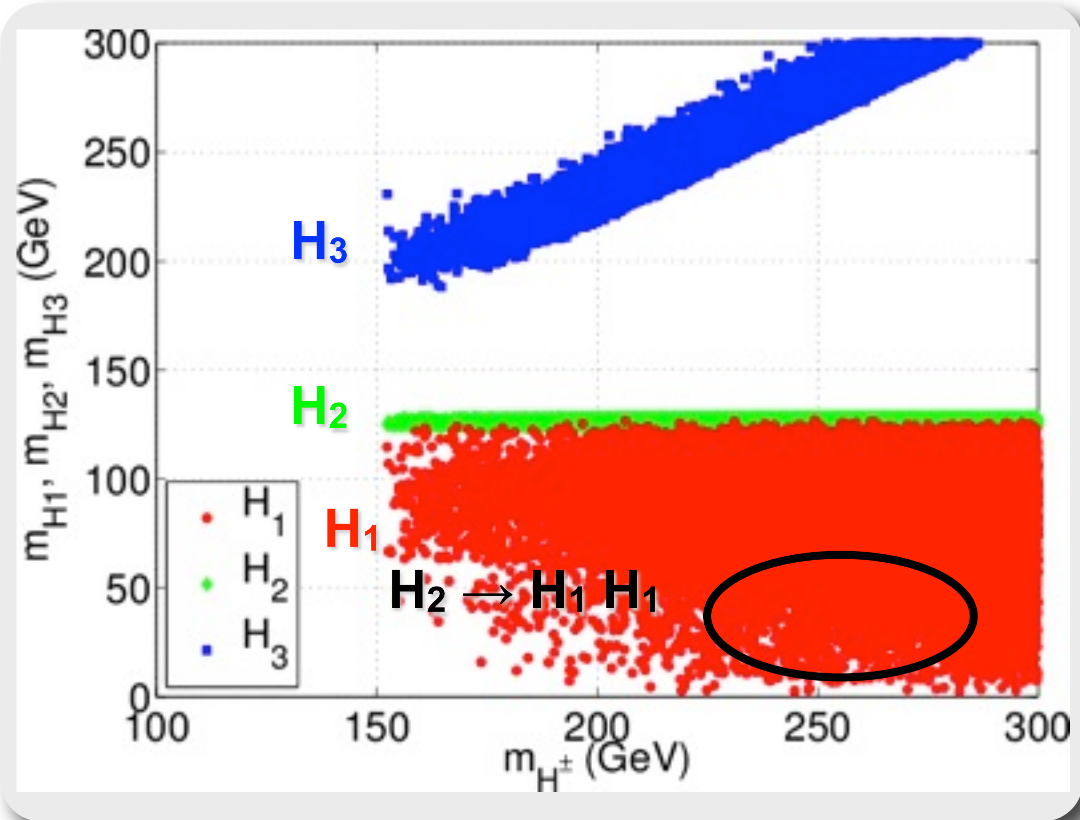
- M_{Hi} vs m_{Hpm}



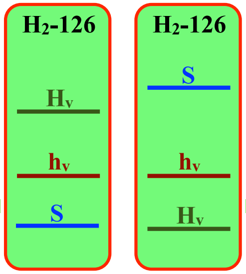
H_2 126 GeV: mass region



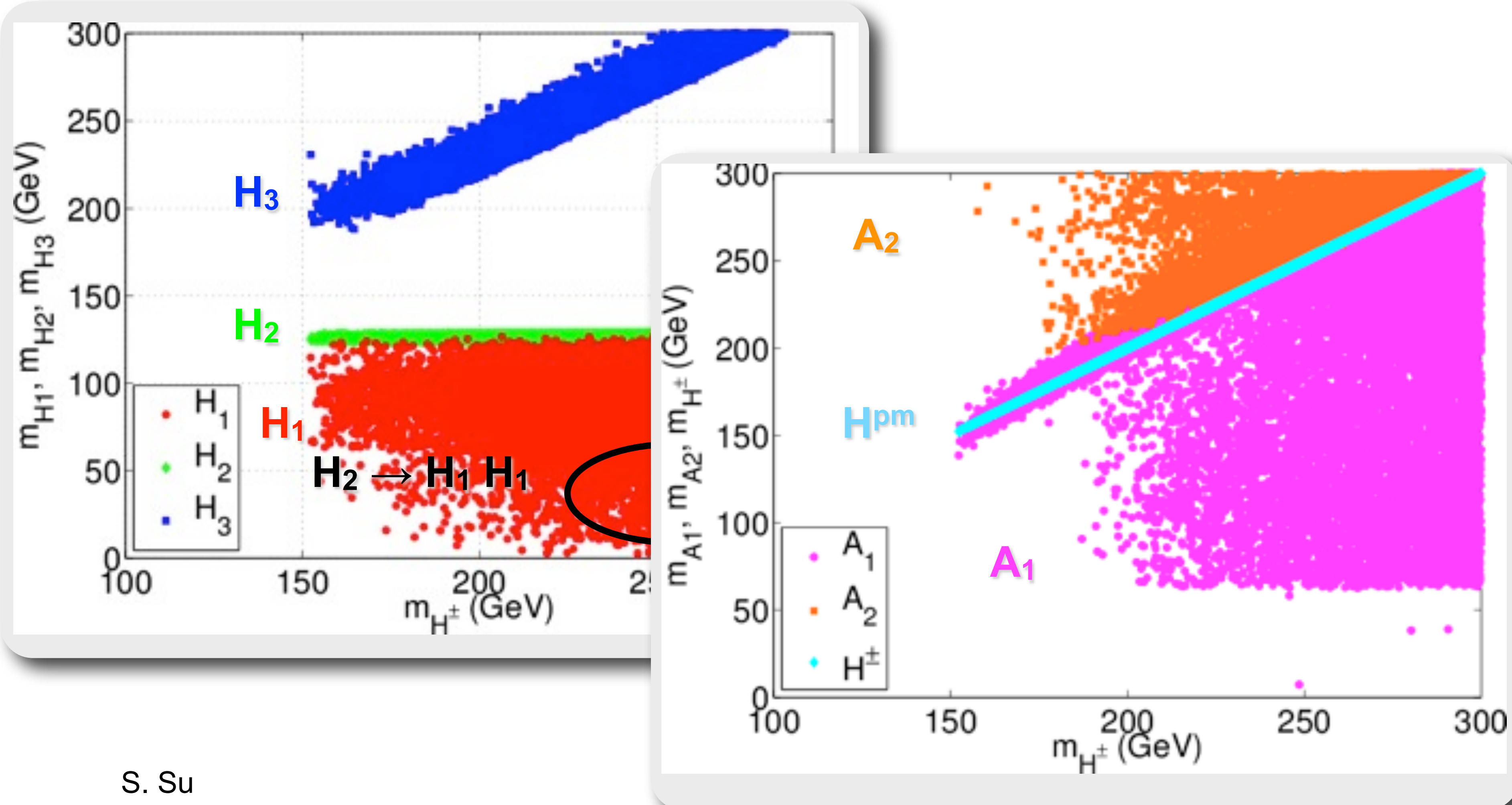
◉ M_{Hi} vs m_{Hpm}



H_2 126 GeV: mass region



- M_{Hi} vs m_{Hpm}



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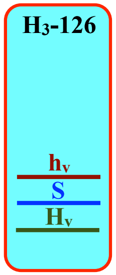
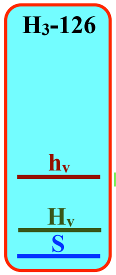
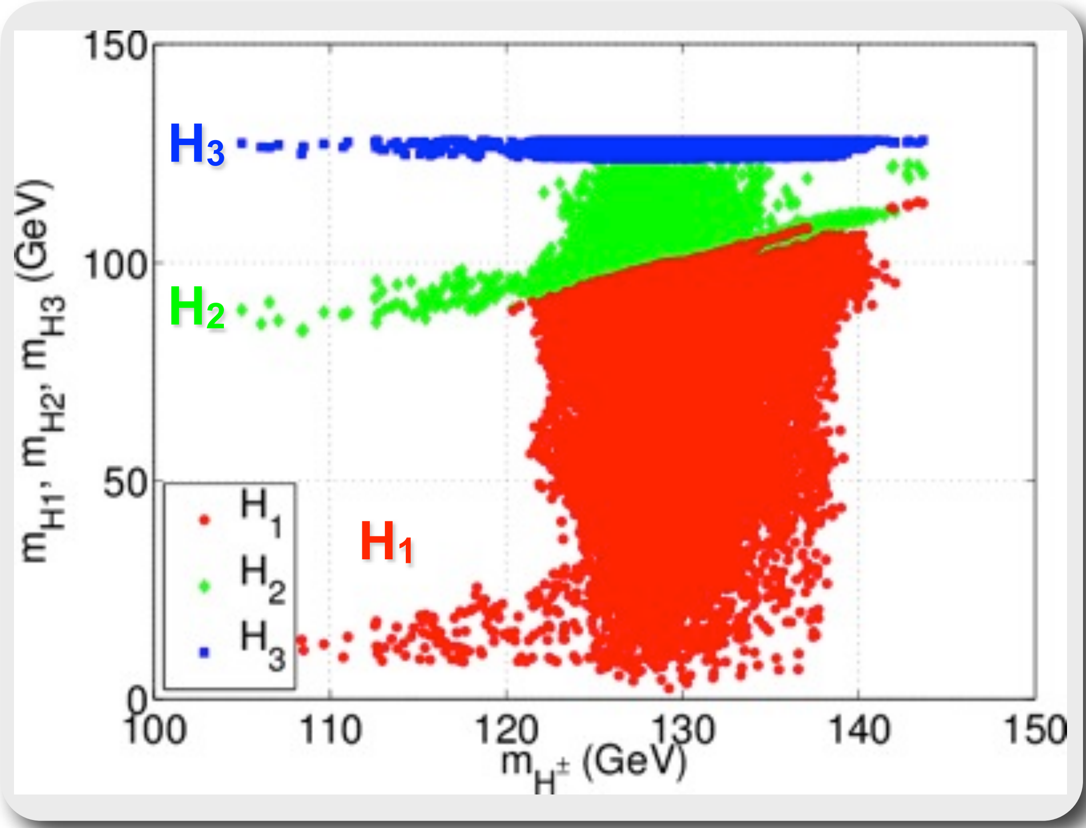
H_3 126 GeV: mass region

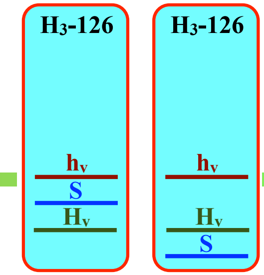




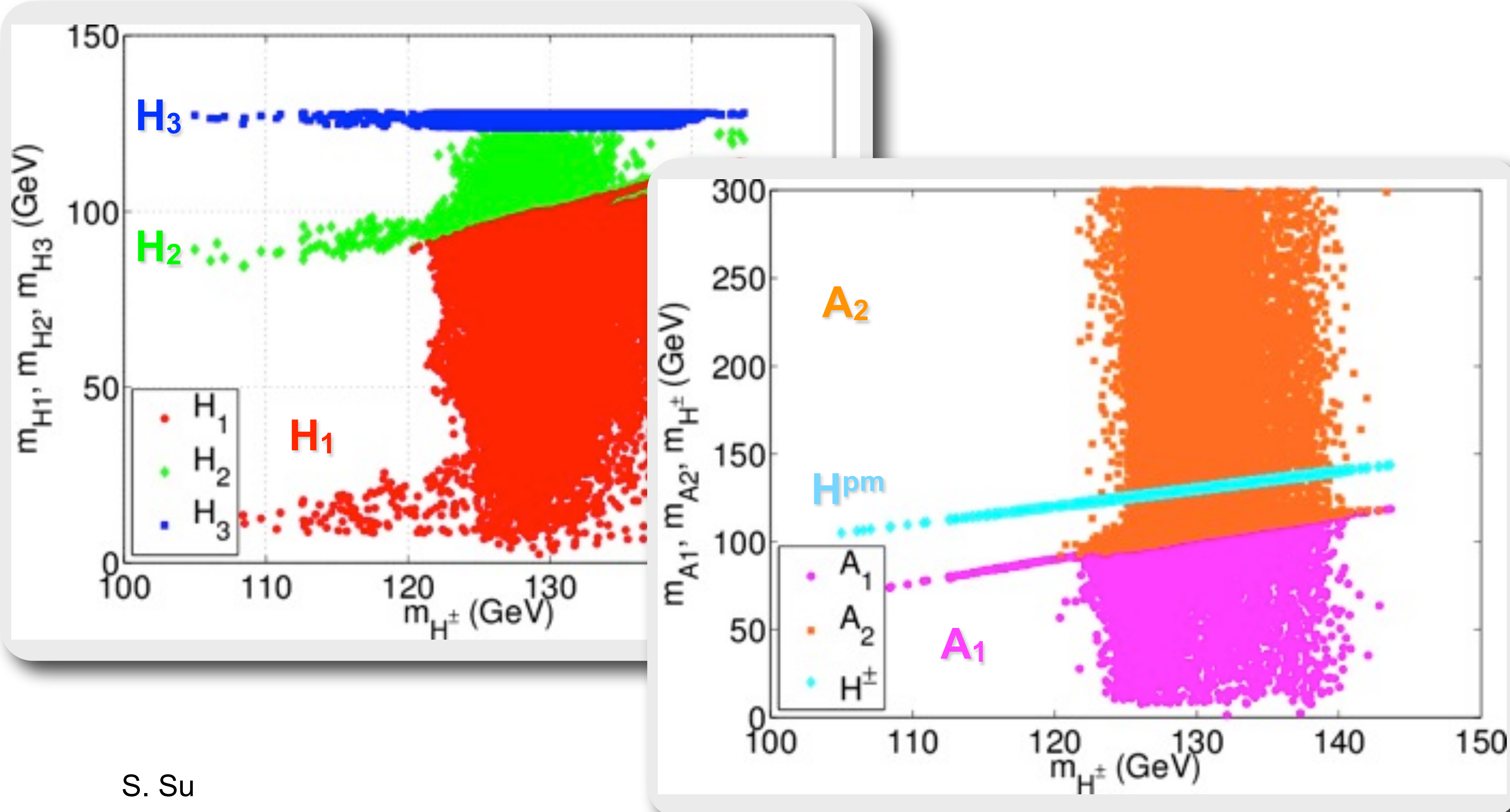
- M_{Hi} vs m_{Hpm}



H_3 126 GeV: mass region



- M_{Hi} vs m_{Hpm}



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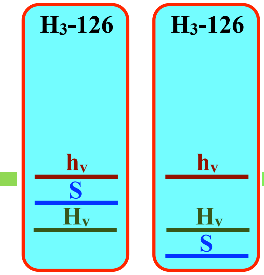
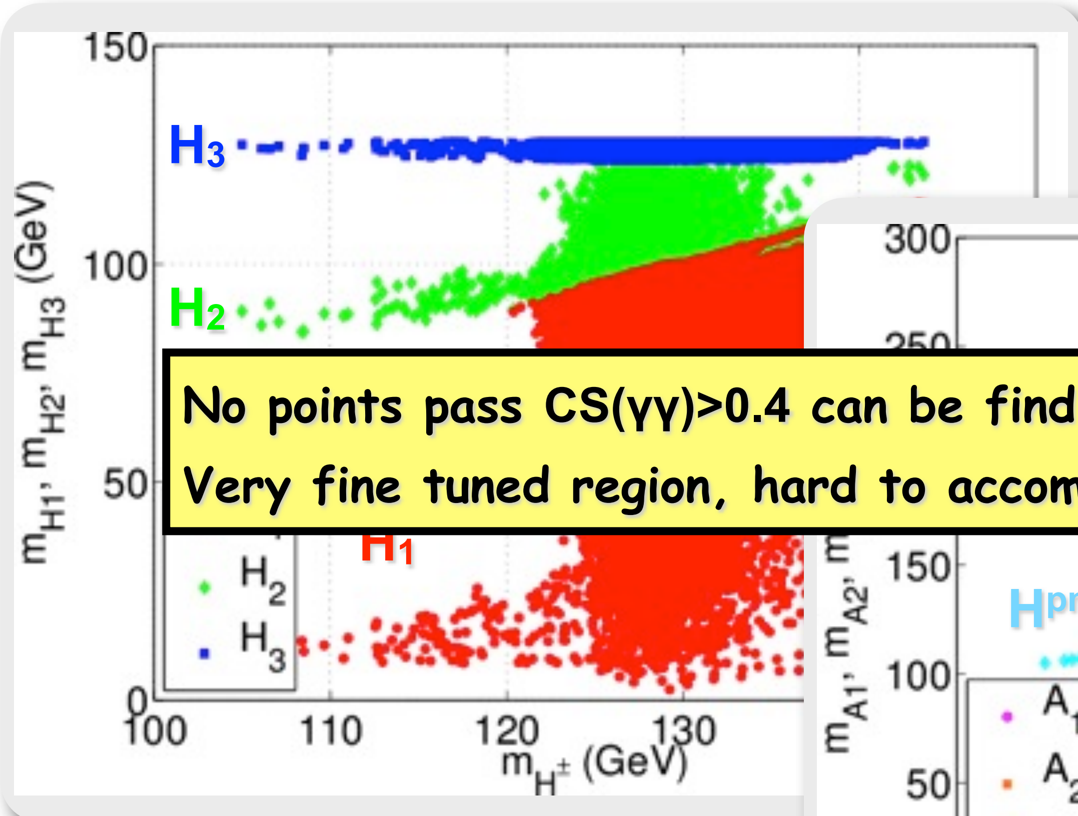
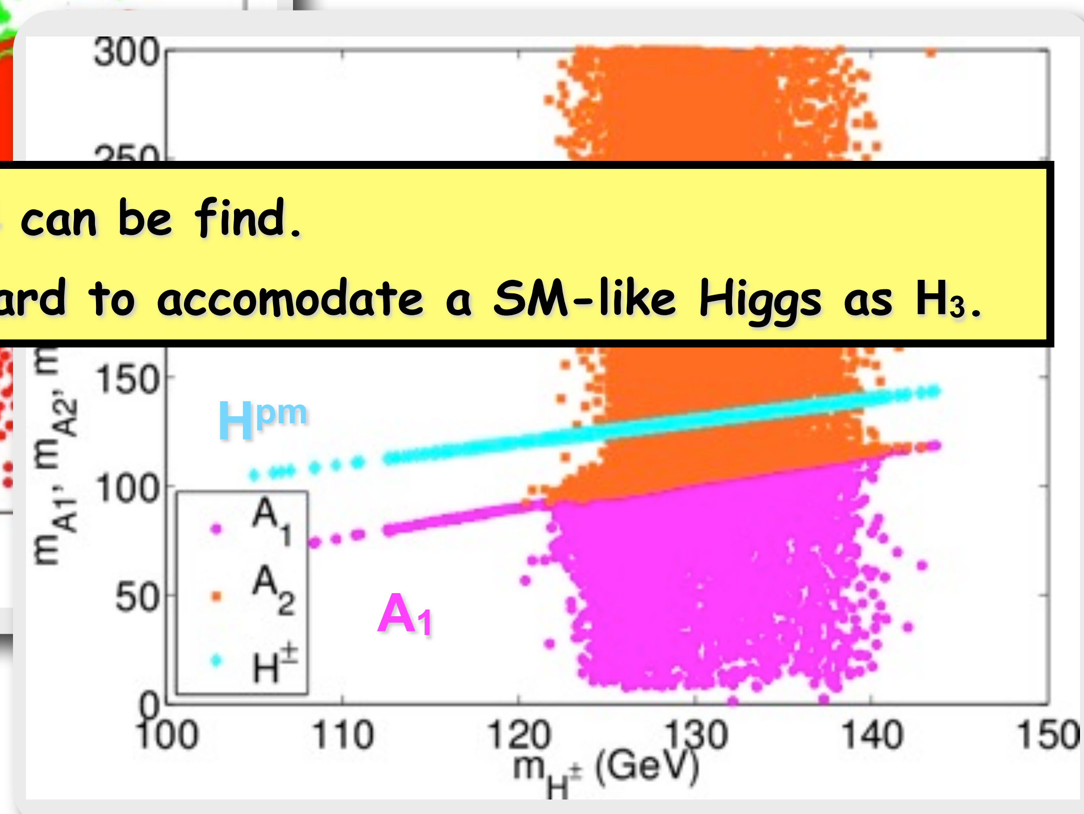
H_3 126 GeV: mass region



- M_{Hi} vs m_{Hpm}





No points pass CS(γγ)>0.4 can be find.

Very fine tuned region, hard to accomodate a SM-like Higgs as H_3.

S. Su

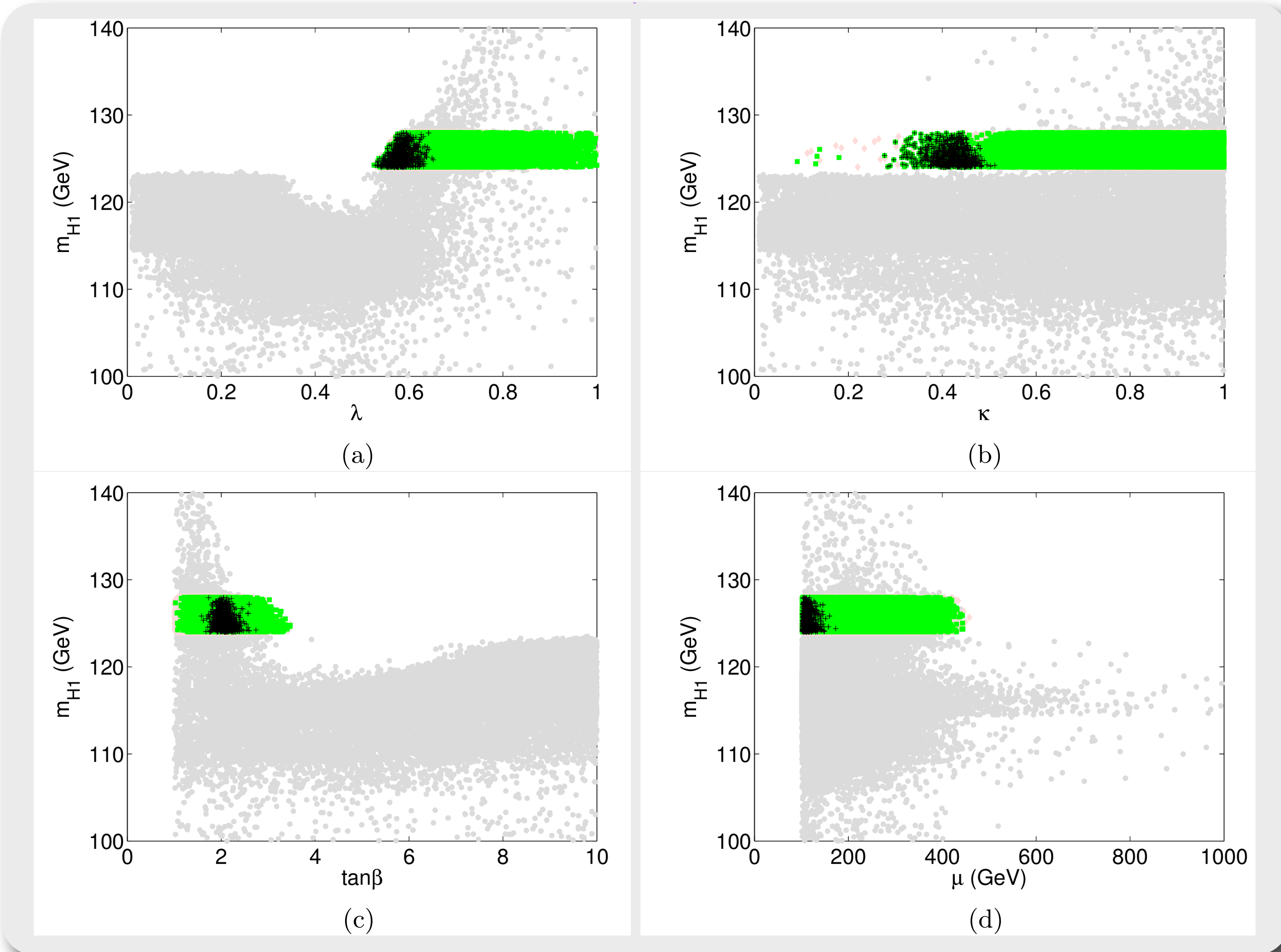
H_1 126 GeV, SM-like

H_1 as 126 GeV SM-like Higgs

- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_1 region IA, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2>0.7$
  - H_1 region IB, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2<0.7$
  - H_1 region II, $m_{A1}<m_{H1}/2$, $H_1 \rightarrow A_1A_1$
- black: perturbativity till m_{GUT}

H_1 126 GeV: m_{H1} vs. para.

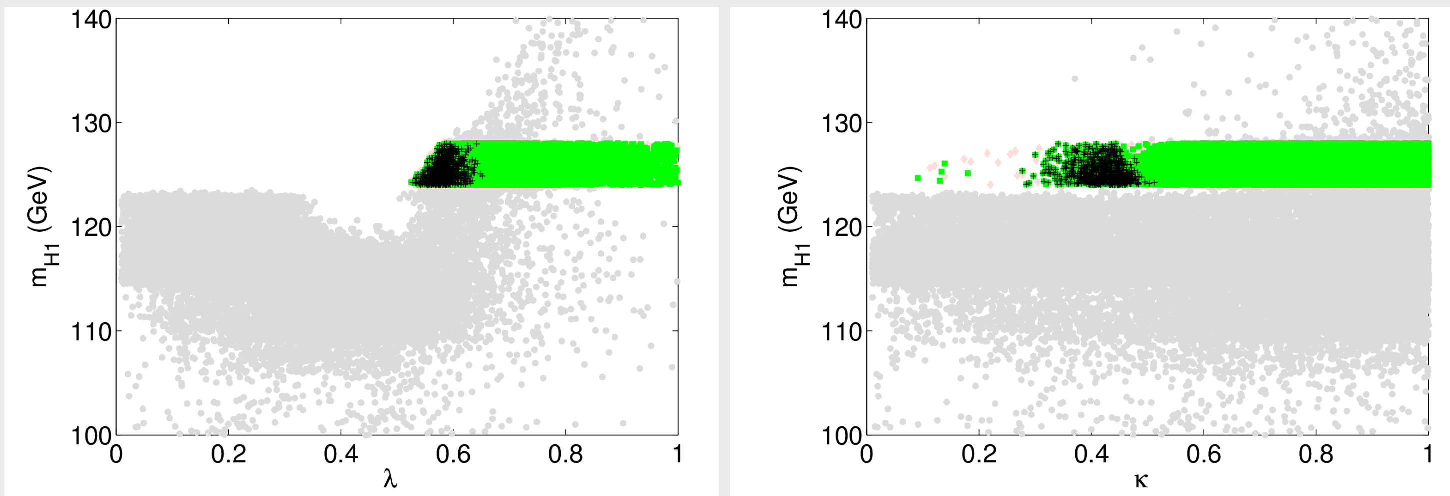
- grey: pass exp
- pink: 124 < m_{H1} < 128 GeV
- green, black: satisfy σXBr(γγ, WW)
- black: perturbativity till m_{GUT}



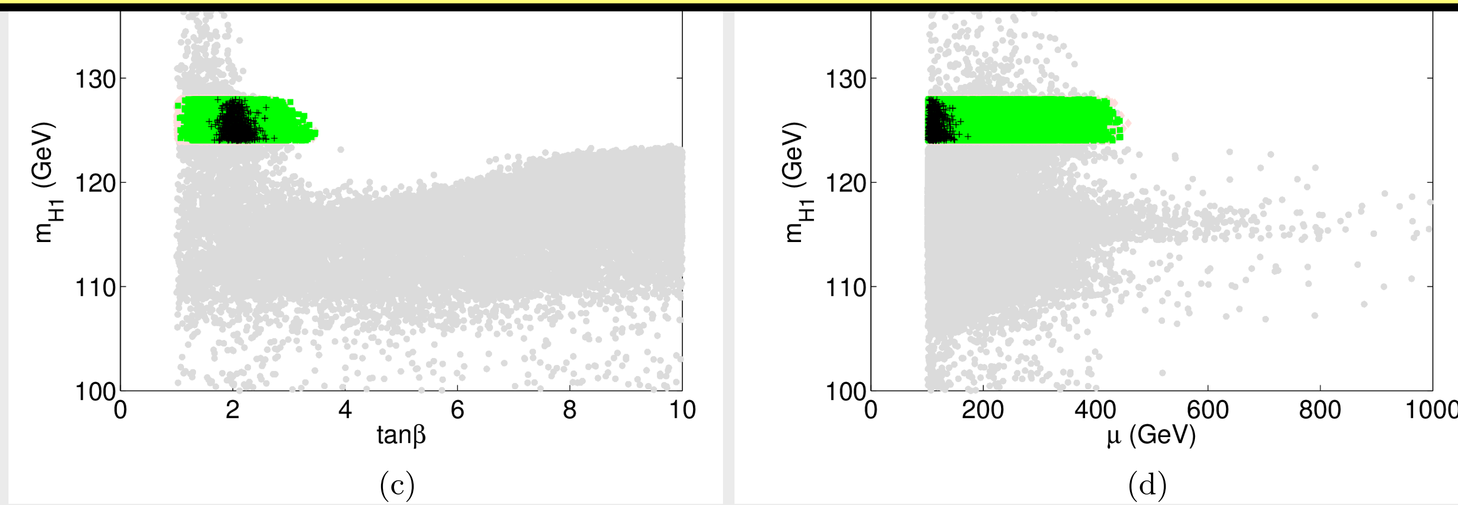
S

H_1 126 GeV: m_{H1} vs. para.

- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, black: satisfy $\sigma X Br(\gamma\gamma, WW)$
- black: perturbativity till m_{GUT}



Impose CS requirement does NOT shrink the parameter regions.



S

H_1 126 GeV: para regions

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- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr($\gamma\gamma$, WW)
  - H_1 region IA, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2>0.7$
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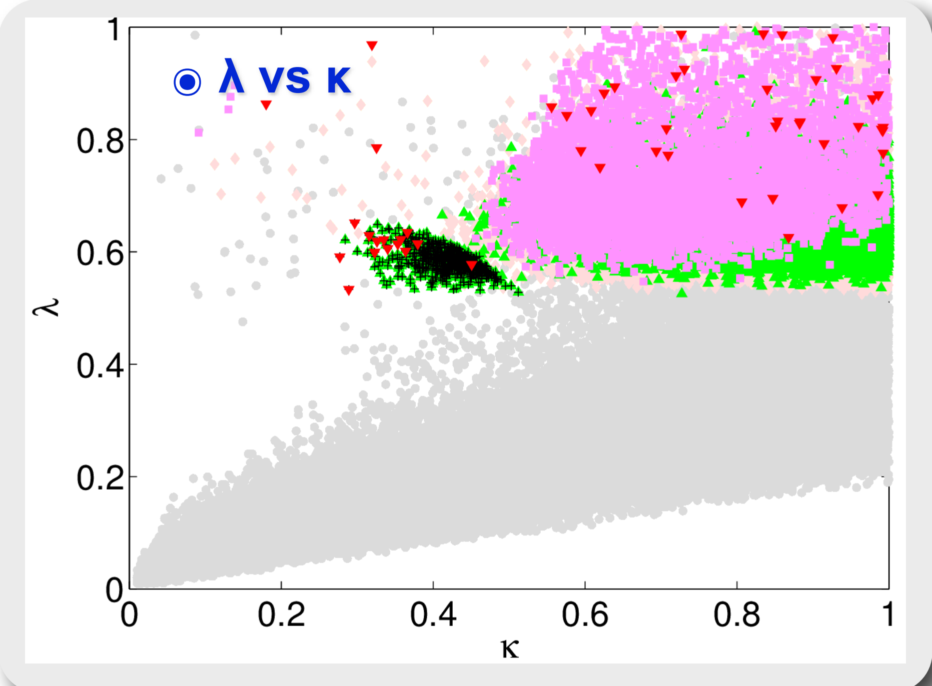
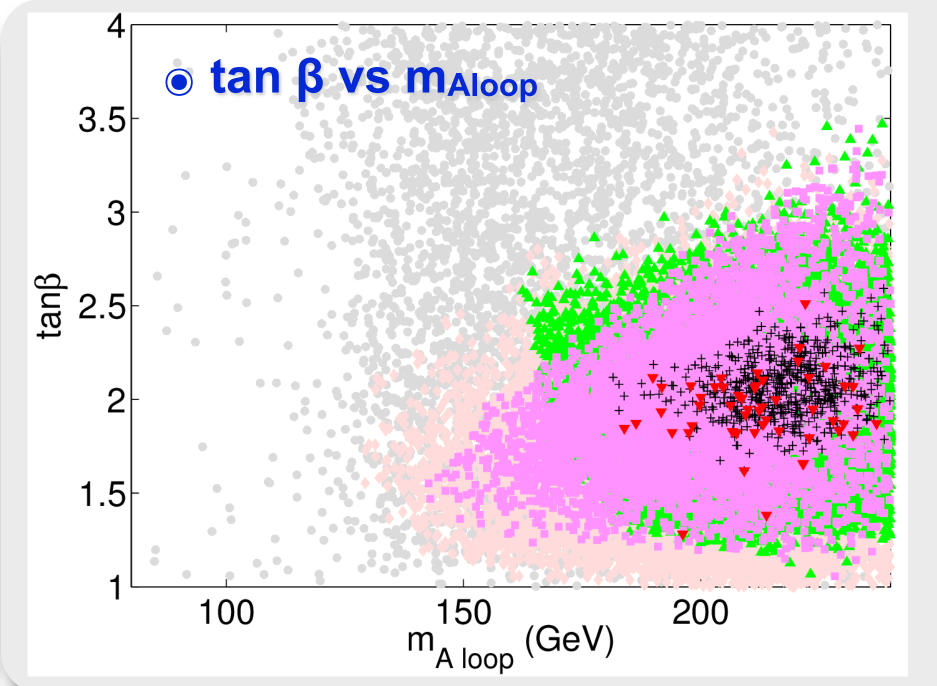
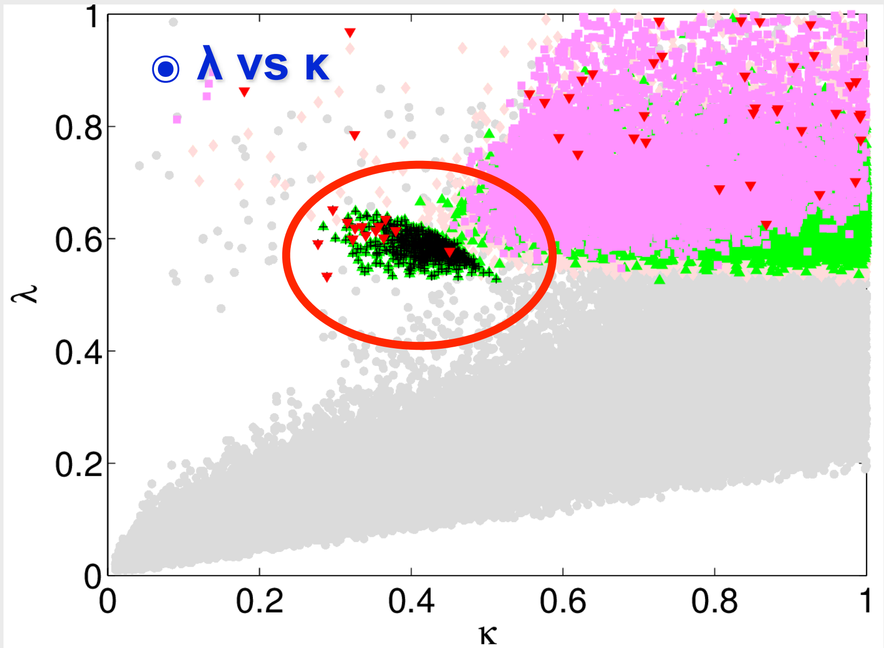


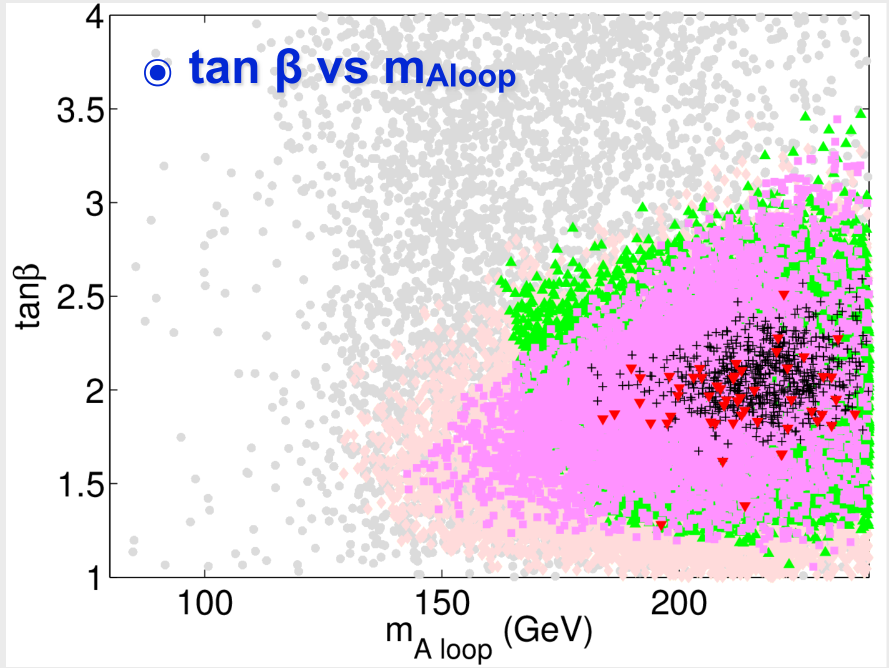


tanβ	1 to 3.5	1.5 to 2.5	1 to 3.5
m_A	0 to 200 GeV	150 to 200 GeV	100 to 200 GeV
λ	≥ 0.55	0.55 to 0.65	≥ 0.55
κ	≥ 0.3	0.3 to 0.5	≥ 0.5

H_1 126 GeV: para regions

- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr($\gamma\gamma$, WW)
  - H_1 region IA, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 > 0.7$
  - H_1 region IB, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 < 0.7$
  - H_1 region II, $m_{A1} < m_{H1}/2$, $H_1 \to A_1 A_1$
- black: perturbativity till m_{GUT}





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κ	≥ 0.3	0.3 to 0.5	≥ 0.5

H_1 126 GeV: stops

- grey: pass exp
- pink: 124 < m_{H1} < 128 GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_1 region IA, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2>0.7$
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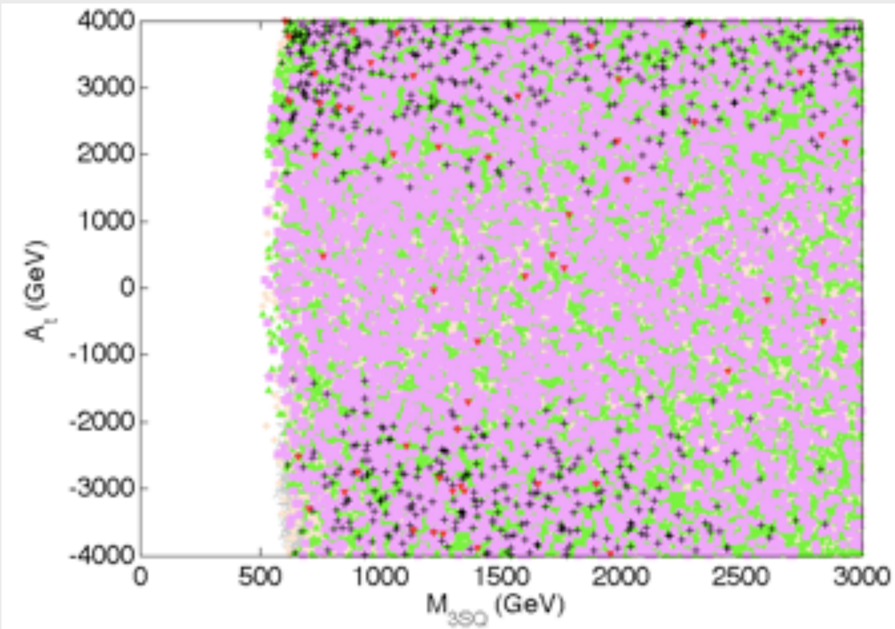
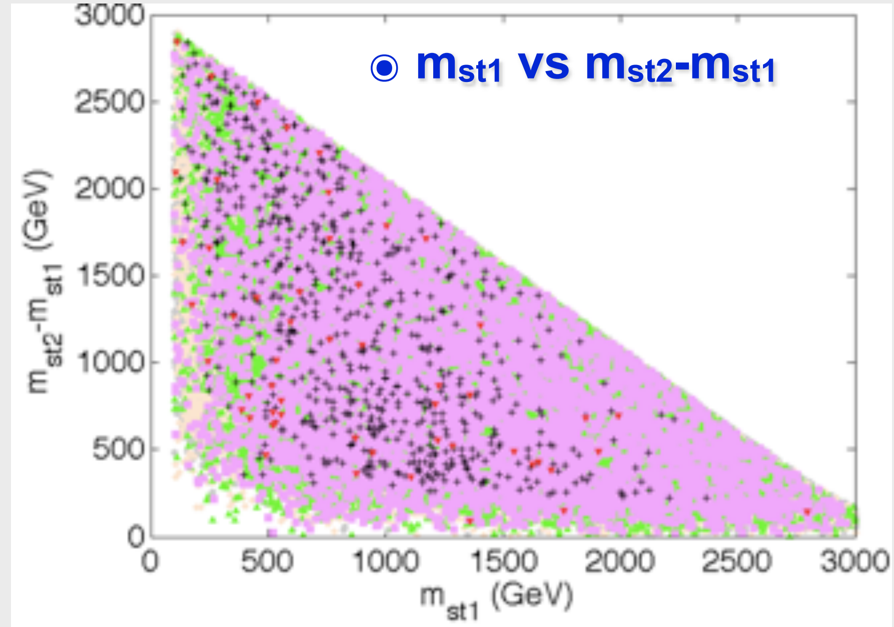
◉ M_{3SQ} vs A_t



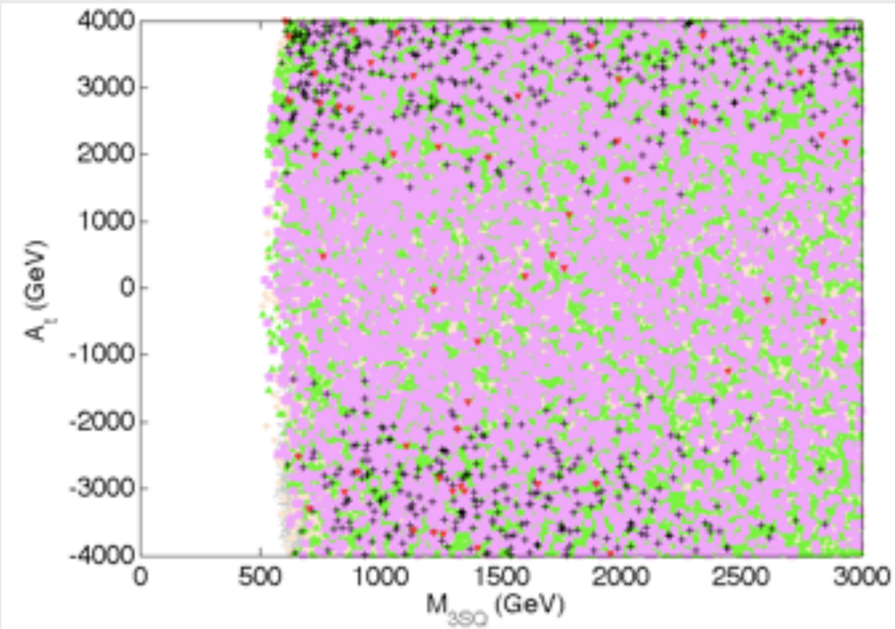
◉ m_{st1} vs m_{st2}-m_{st1}

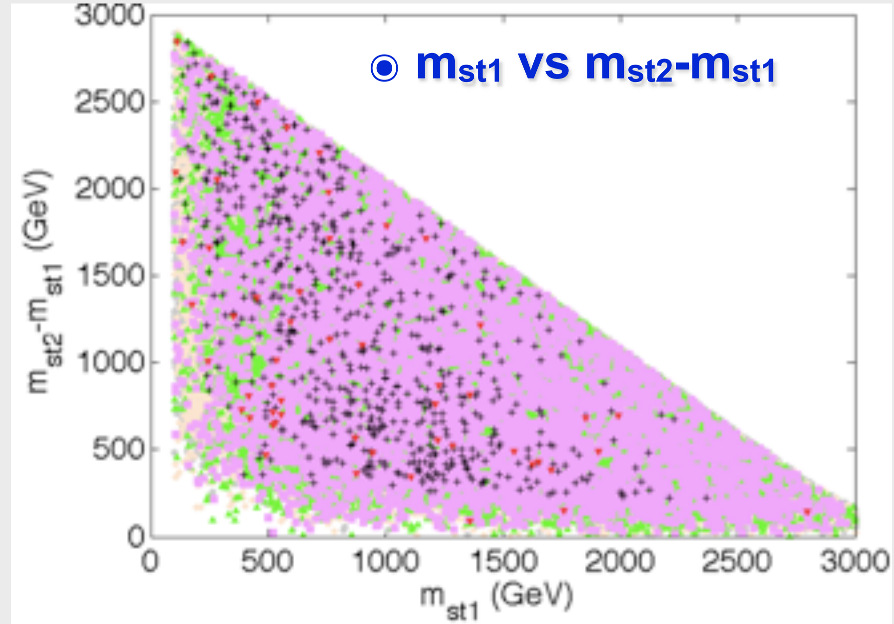


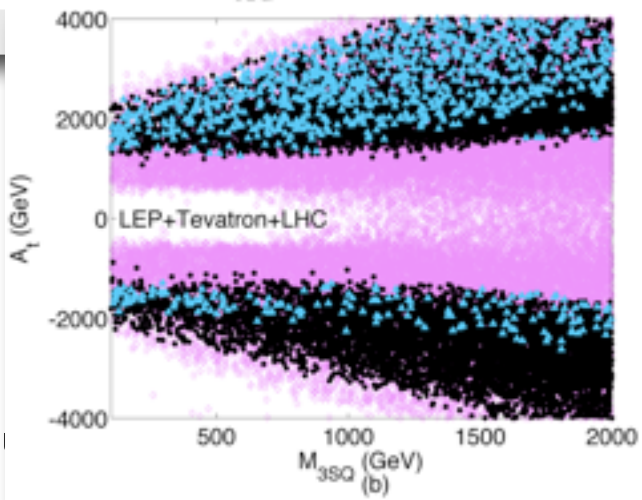
H_1 126 GeV: stops

- grey: pass exp
- pink: 124 < m_{H1} < 128 GeV
- green, red, purple, black: satisfy σXBr($\gamma\gamma$, WW)
  - H_1 region IA, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2>0.7$
  - H_1 region IB, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2<0.7$

◉ M_{3SQ} vs A_t



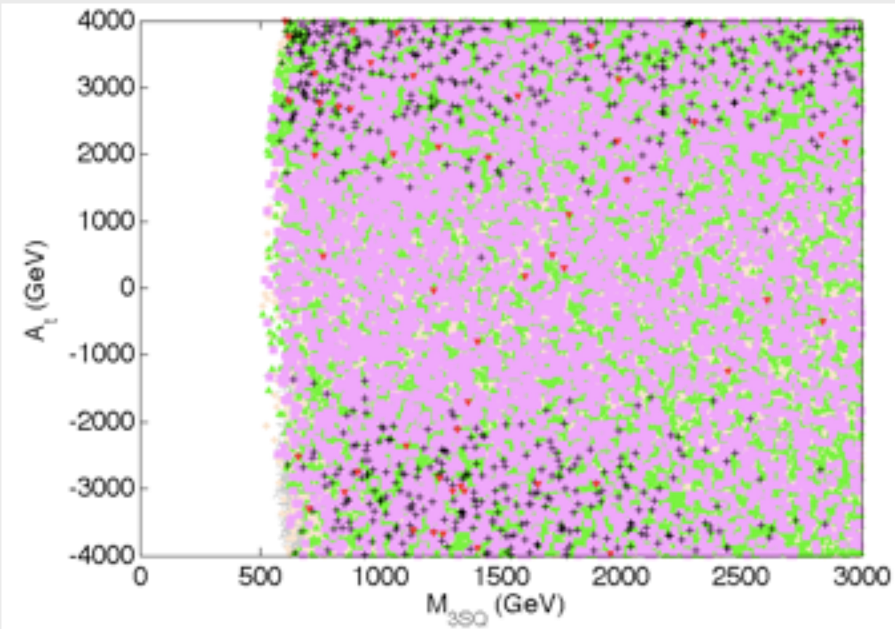




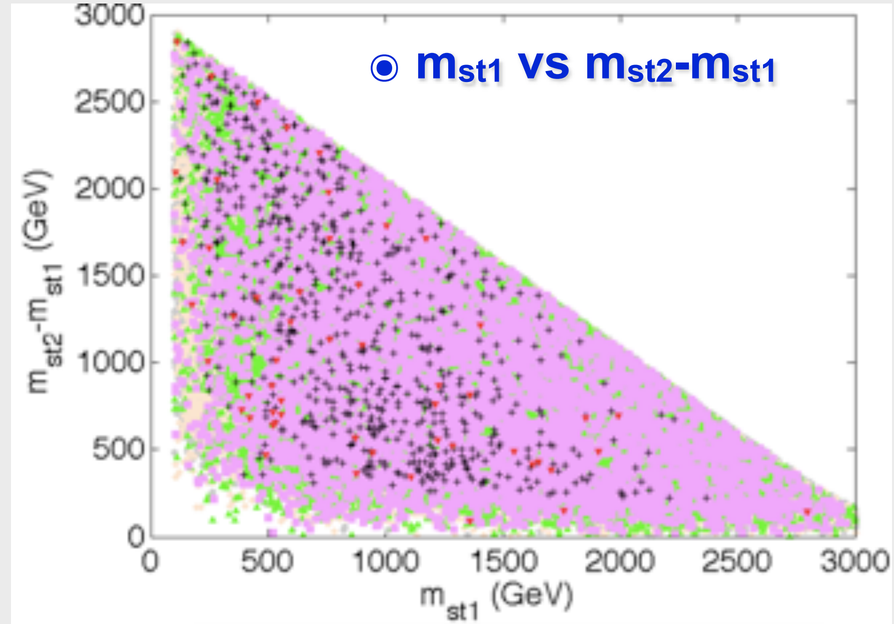
H_1 126 GeV: stops

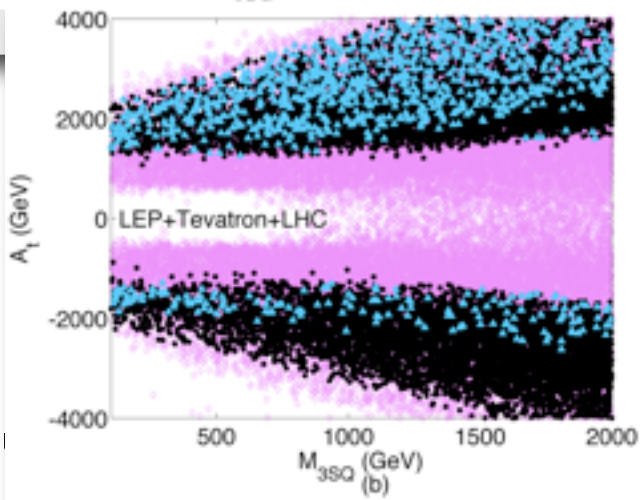
- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_1 region IA, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 > 0.7$
  - H_1 region IB, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 < 0.7$

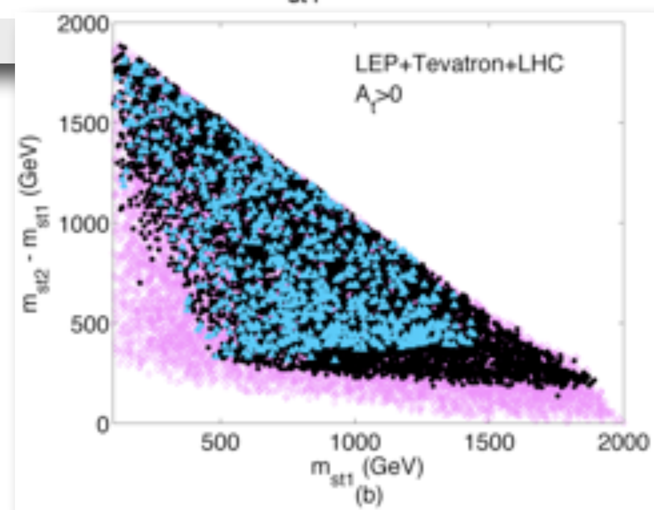
◉ M_{3SQ} vs A_t



◉ m_{st1} vs m_{st2}-m_{st1}







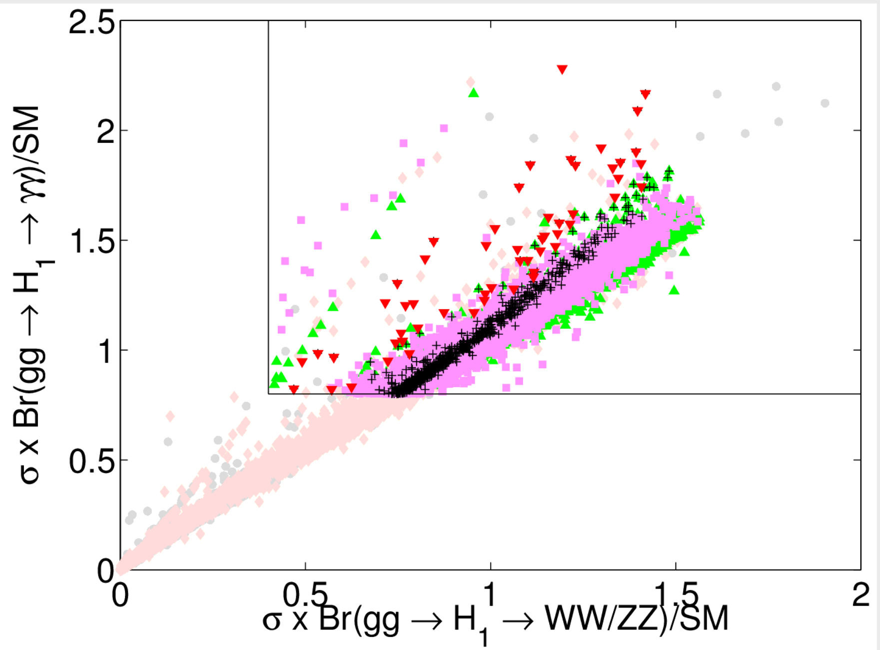
S. S

Parameter regions

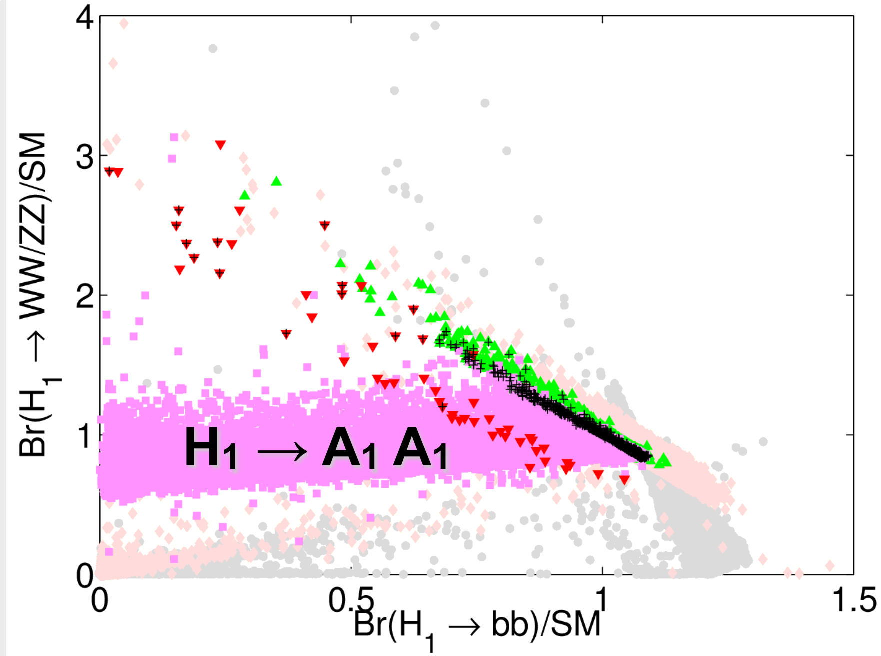
	H_1 126	perturbativity	$m_{A1}<m_{H1}/2$
$\tan\beta$	1 to 3.5	1.5 to 2.5	1 to 3.5
m_A	0 to 200 GeV	150 to 200 GeV	100 to 200 GeV
μ	$\mu \leq$ 500 GeV	100 to 150 GeV	100 to 200 GeV
λ	$\geq$ 0.55	0.55 to 0.6.5	$\geq$ 0.55
κ	$\geq$ 0.3	0.3 to 0.5	$\geq$ 0.5
A_κ	-1200 to 200 GeV	-150 to 100 GeV	-50 to 30 GeV
A_λ	-650 to 300 GeV	-30 to 230 GeV	-150 to 150 GeV
$\|A_t\|$		$\geq$ 1200 GeV	

H_1 126 GeV: cross sections

◉ $\sigma_{\gamma\gamma}$ vs σ_{WW}

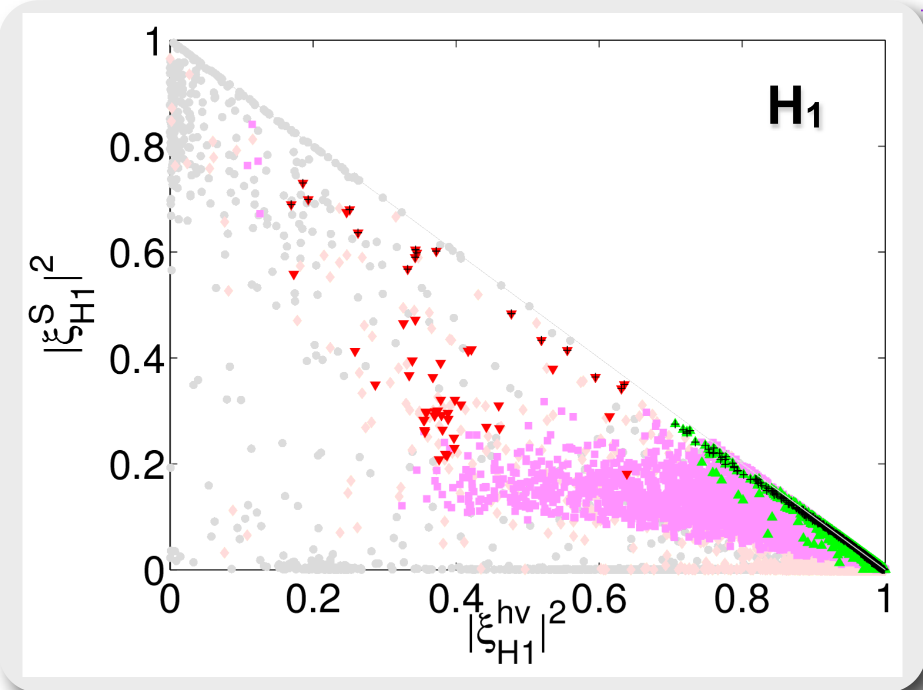


◉ Br_{WW} vs Br_{bb}



- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_1 region IA, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 > 0.7$
  - H_1 region IB, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 < 0.7$
  - H_1 region II, $m_{A1} < m_{H1}/2$, $H_1 \to A_1 A_1$
- black: perturbativity till m_{GUT}

H_1 126 GeV: h_v-, H_v-, S- fraction



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- green, red, purple, black: satisfy $\sigma \times Br(\gamma\gamma, WW)$
  - H_1 region IA, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 > 0.7$
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  - H_1 region II, $m_{A1} < m_{H1}/2$, $H_1 \to A_1 A_1$
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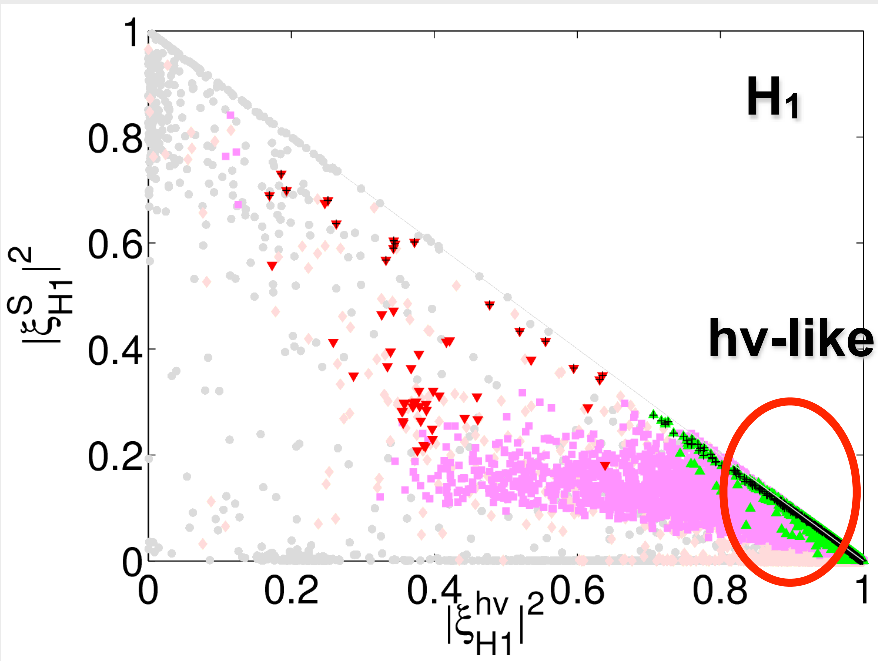
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



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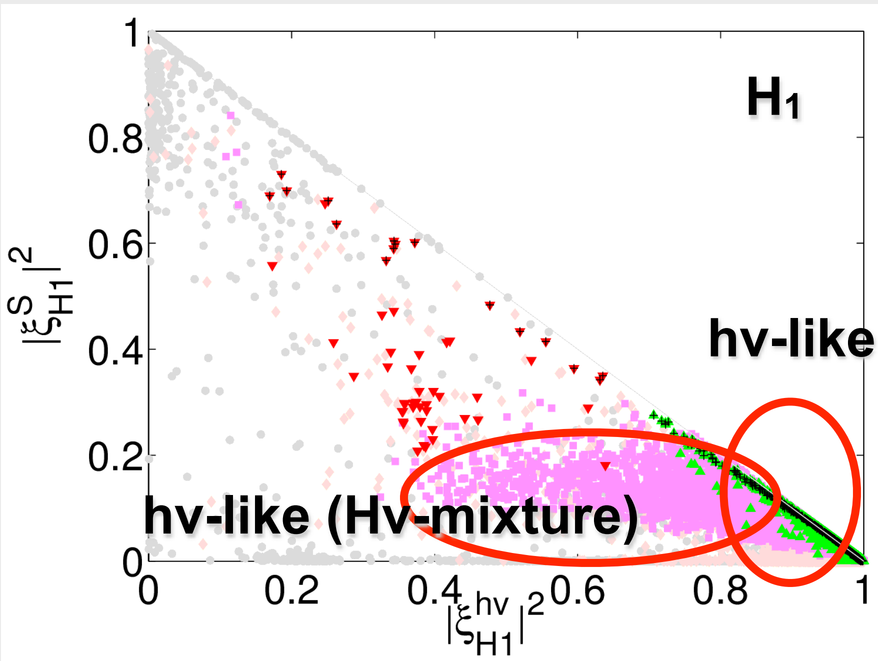
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



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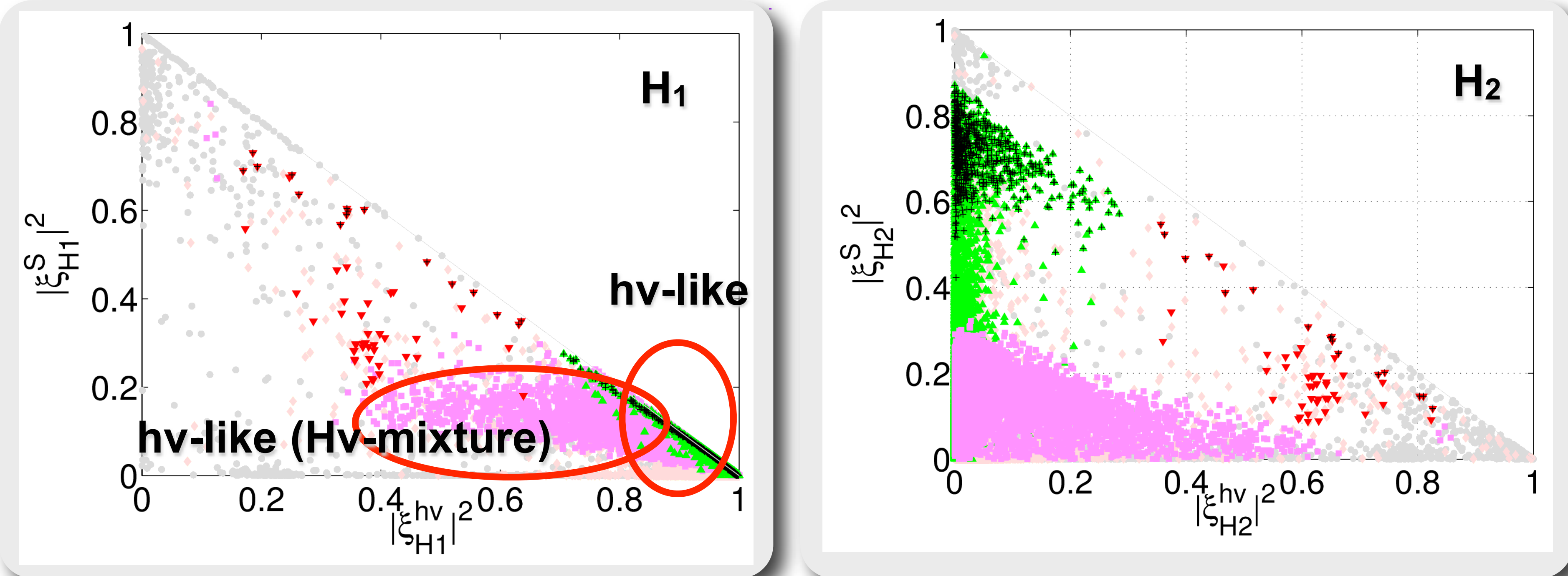
  - H_1 region II, $m_{A1}<m_{H1}/2$, $H_1 \to A_1A_1$
- black: perturbativity till m_{GUT}

S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



- grey: pass exp
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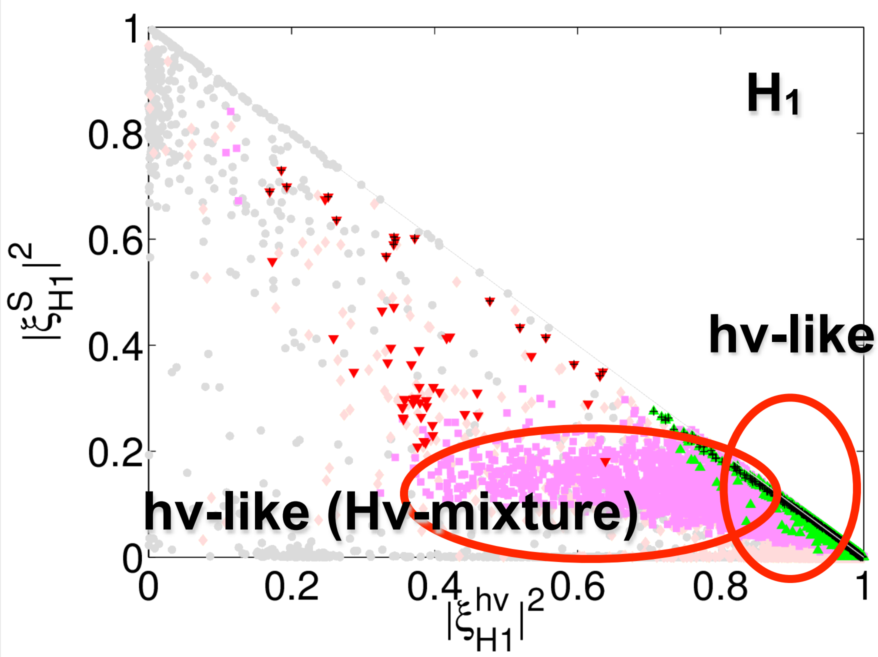
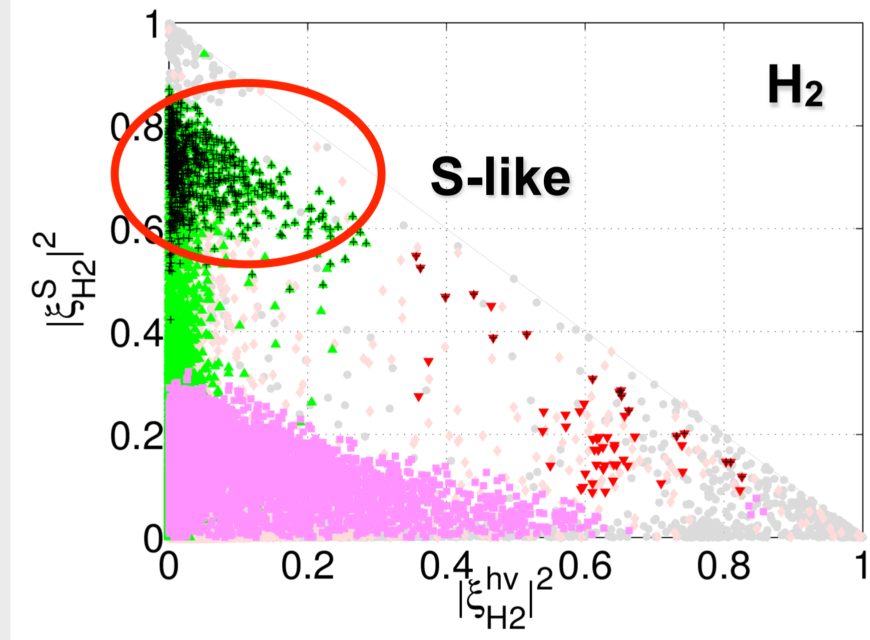
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction





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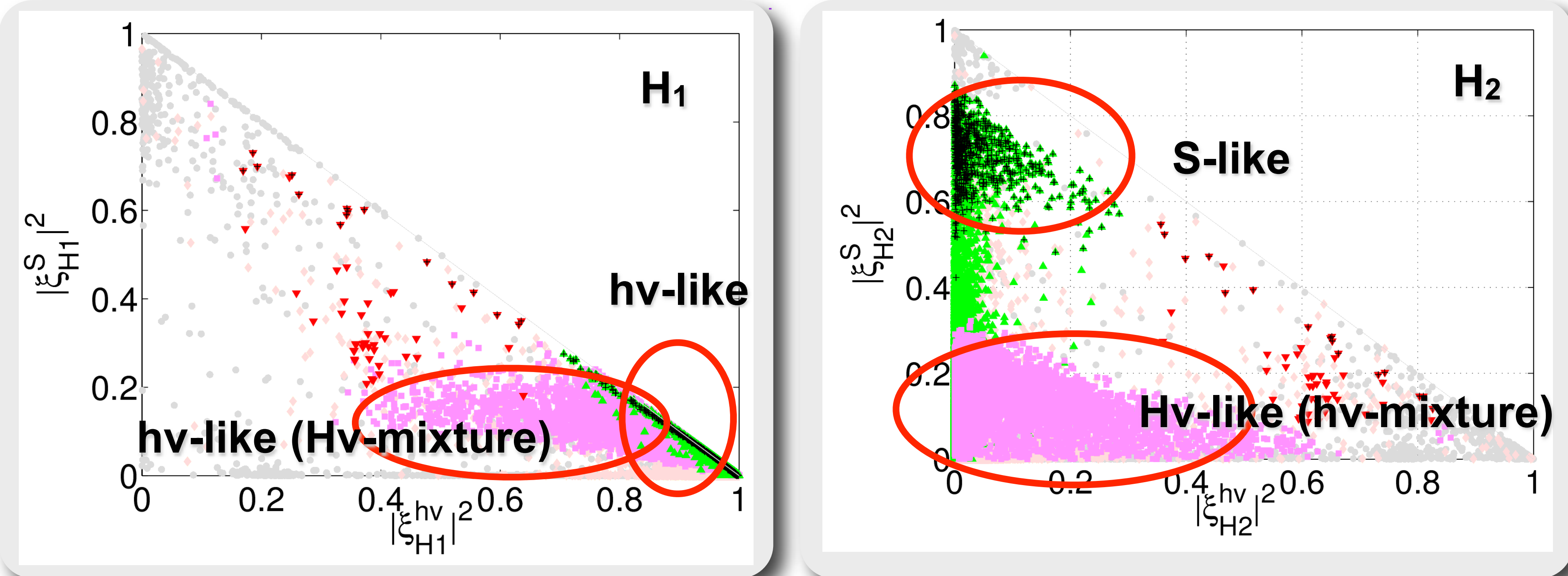
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



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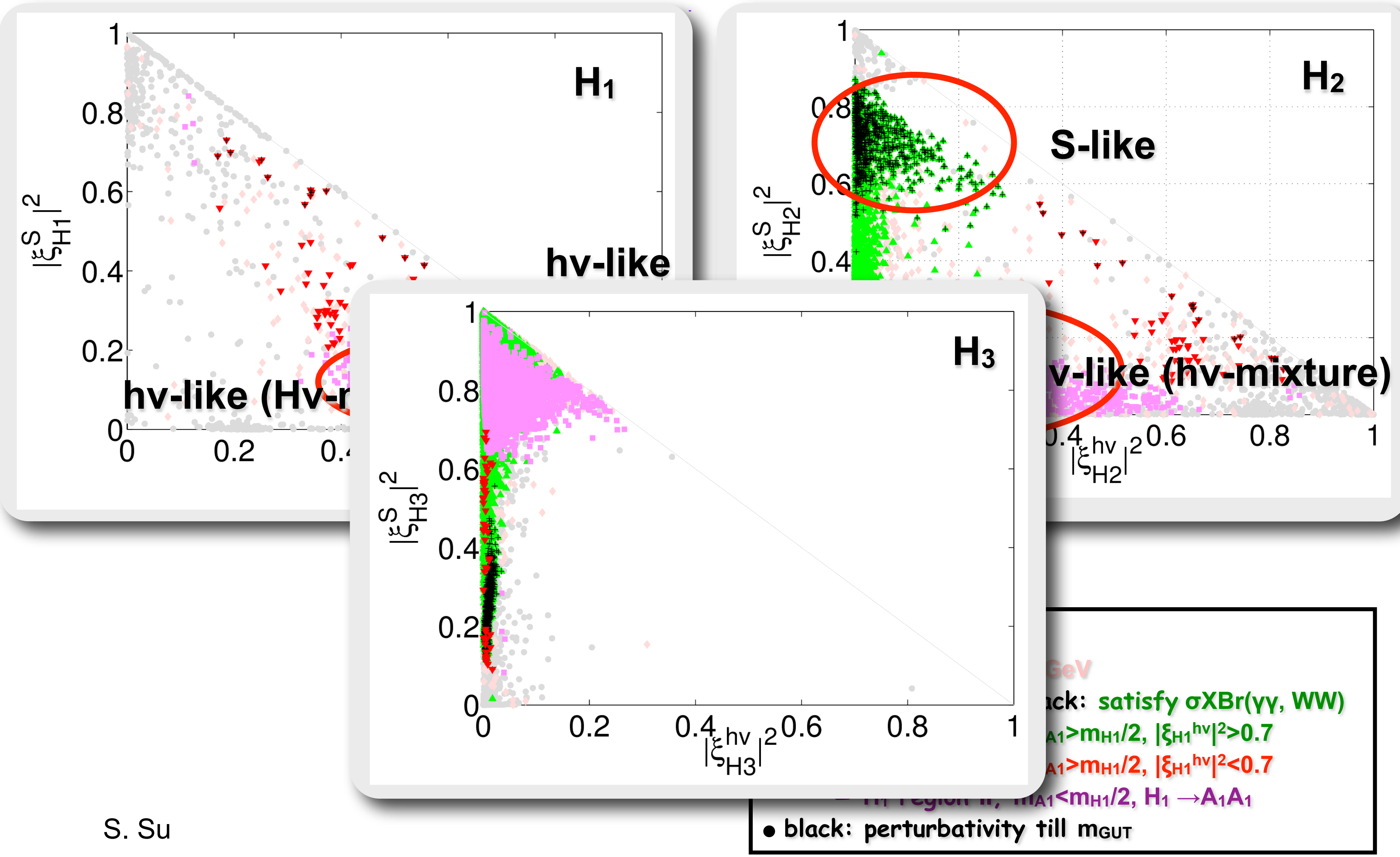
  - – H_1 region IA, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2>0.7$
  - – H_1 region IB, $m_{A1}>m_{H1}/2$, $|\xi_{H1}^{hv}|^2<0.7$
  - – H_1 region II, $m_{A1}<m_{H1}/2$, $H_1 \rightarrow A_1A_1$
- black: perturbativity till m_{GUT}

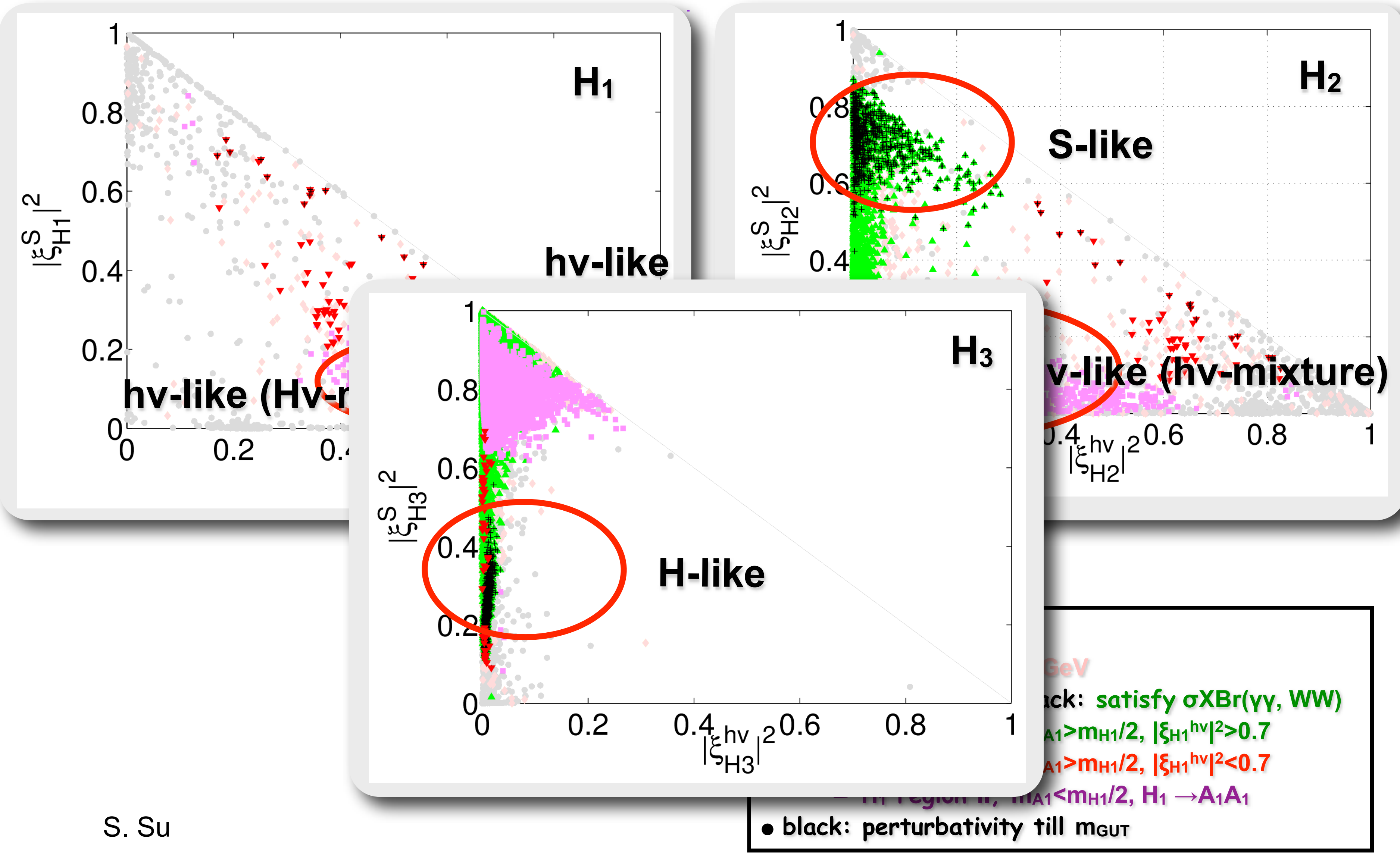
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



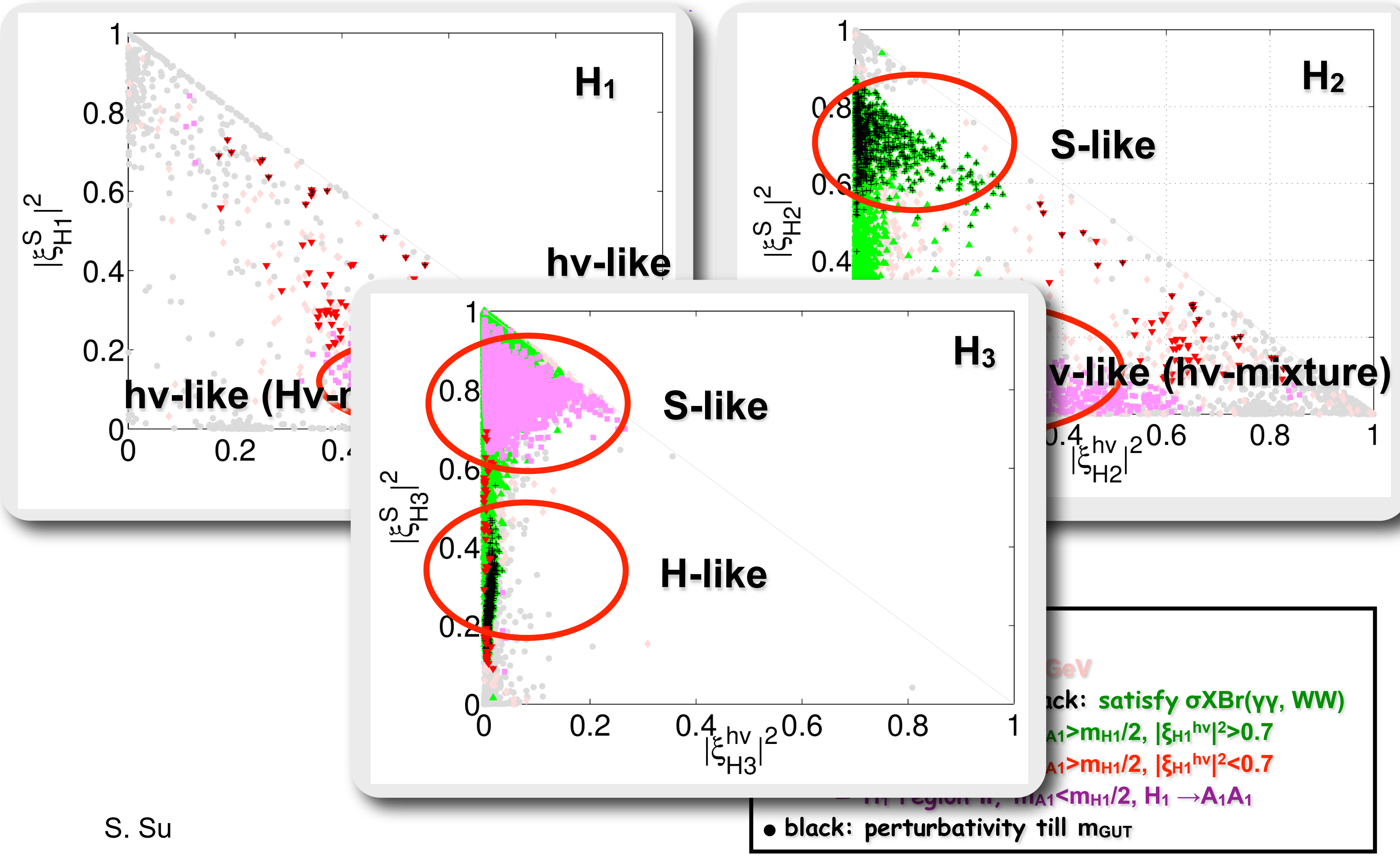
S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



S. Su

H_1 126 GeV: h_v-, H_v-, S- fraction



S. Su

H_2 126 GeV, SM-like

H_2 as 126 GeV SM-like Higgs

- grey: pass exp
- pink: $124 < m_{H2} < 128$ GeV
- green, red, purple, black: satisfy $\sigma \times Br(\gamma\gamma, WW)$
  - H_2 region IA, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 > 0.5$
  - H_2 region IB, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 < 0.5$
  - H_2 region II, $m_{H1} < m_{H2}/2$, $H_2 \rightarrow H_1 H_1$
- black: perturbativity till m_{GUT}

Parameter regions

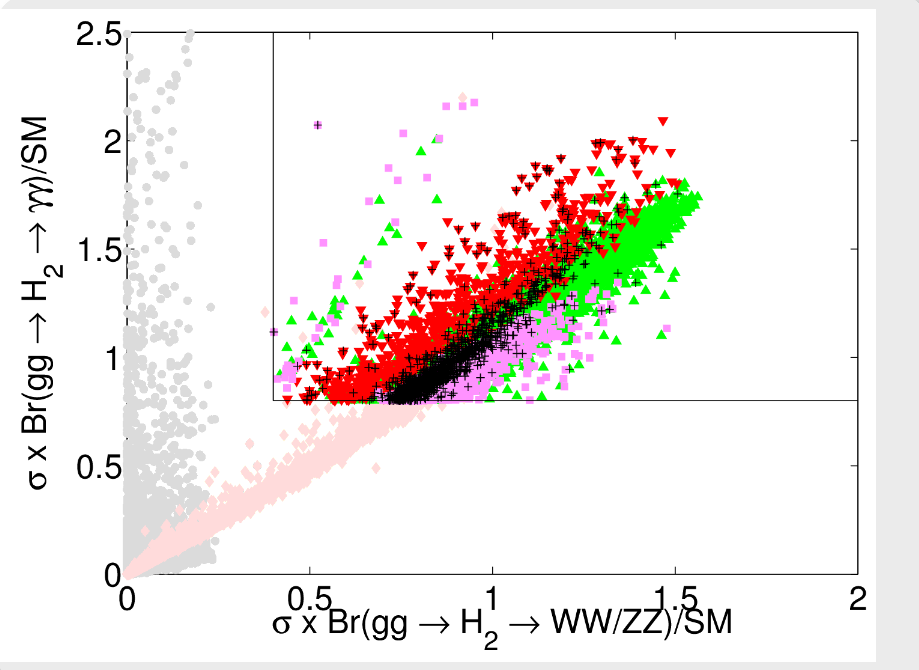
	m_{H2} ~ 126	H_2 126	perturbativity	$m_{H1}<m_{H2}/2$
tanβ	>1	1 to 3.25	1.5 to 2.5	1.25 to 2.5
m_A	0 to 200	100 to 200 GeV	170 to 200 GeV	125 to 200 GeV
μ	100 to 300	100 to 200 GeV	100 to 130 GeV	100 to 150 GeV
λ	0 to 0.75	0.4 to 0.75	0.5 to 0.7	0.5 to 0.75
κ	0 to 1	≥ 0.05	0.05 to 0.6	≥ 0.3
A_κ	-1200 to 50	-1200 to 50 GeV	-300 to 50 GeV	-500 to -250 GeV
A_λ	-600 to 300	-300 to 300 GeV	0 to 300 GeV	0 to 200 GeV

Parameter regions

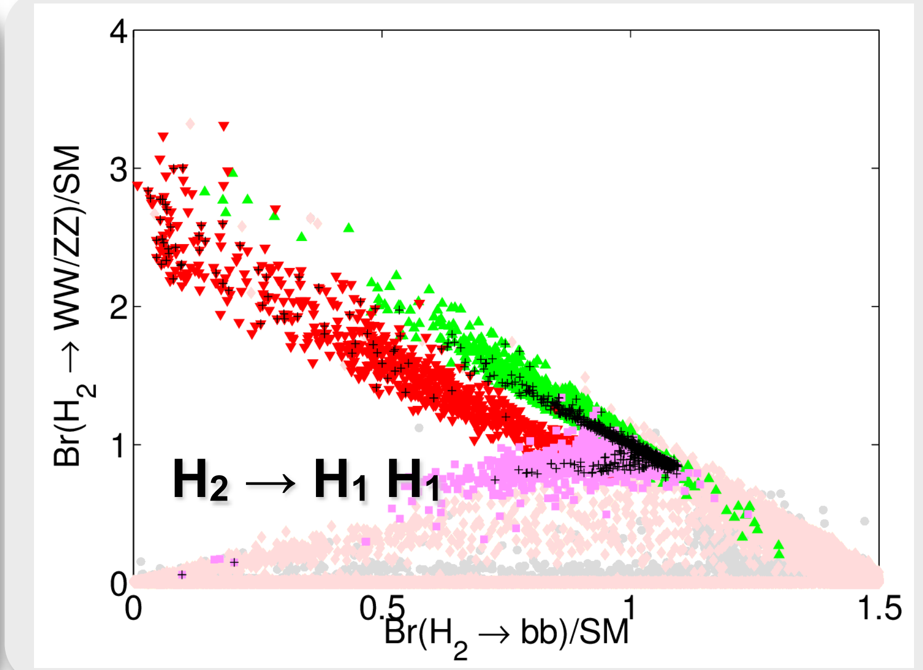
	m_{H2} ~ 126	H_2 126	perturbativity	$m_{H1}<m_{H2}/2$
tanβ	>1	1 to 3.25	1.5 to 2.5	1.25 to 2.5
m_A	0 to 200	100 to 200 GeV	170 to 200 GeV	125 to 200 GeV
μ	100 to 300	100 to 200 GeV	100 to 130 GeV	100 to 150 GeV
λ	0 to 0.75	0.4 to 0.75	0.5 to 0.7	0.5 to 0.75
κ	0 to 1	≥ 0.05	0.05 to 0.6	≥ 0.3
A_κ	-1200 to 50	-1200 to 50 GeV	-300 to 50 GeV	-500 to -250 GeV
A_λ	-600 to 300	-300 to 300 GeV	0 to 300 GeV	0 to 200 GeV

H_2 126 GeV: cross sections

◉ $\sigma_{\gamma\gamma}$ vs σ_{WW}



◉ Br_{WW} vs Br_{bb}



- grey: pass exp
- pink: $124 < m_{H2} < 128$ GeV
- green, red, purple, black: satisfy σXBr($\gamma\gamma$, WW)
  - H_2 region IA, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 > 0.5$
  - H_2 region IB, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 < 0.5$
  - H_2 region II, $m_{H1} < m_{H2}/2$, $H_2 \to H_1 H_1$
- black: perturbativity till m_{GUT}

H_2 126 GeV: h_v-, H_v-, S- fracti

- grey: pass exp
- pink: $124 < m_{H2} < 128$ GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_2 region IA, $m_{H1}>m_{H2}/2$, $|\xi_{H2}^{hv}|^2>0.5$
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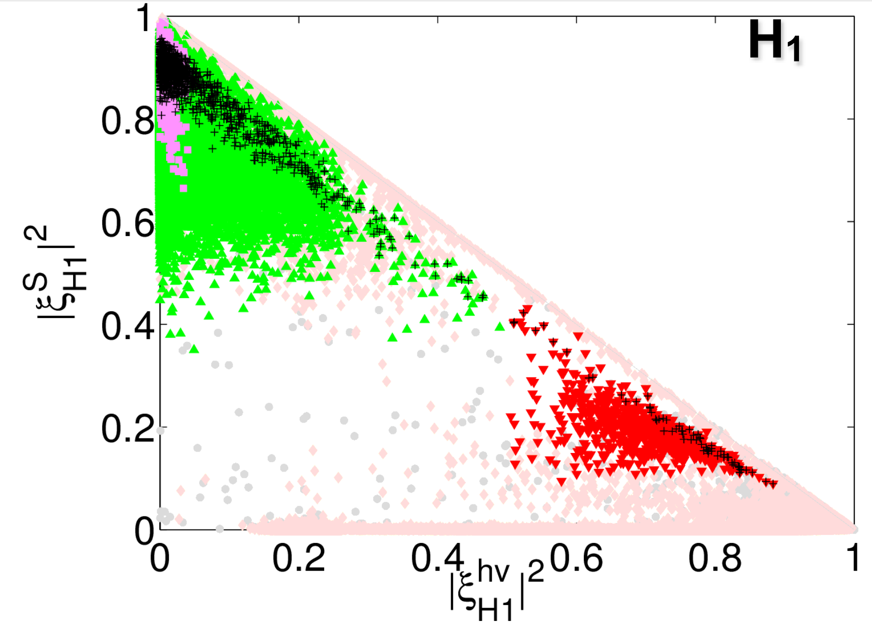
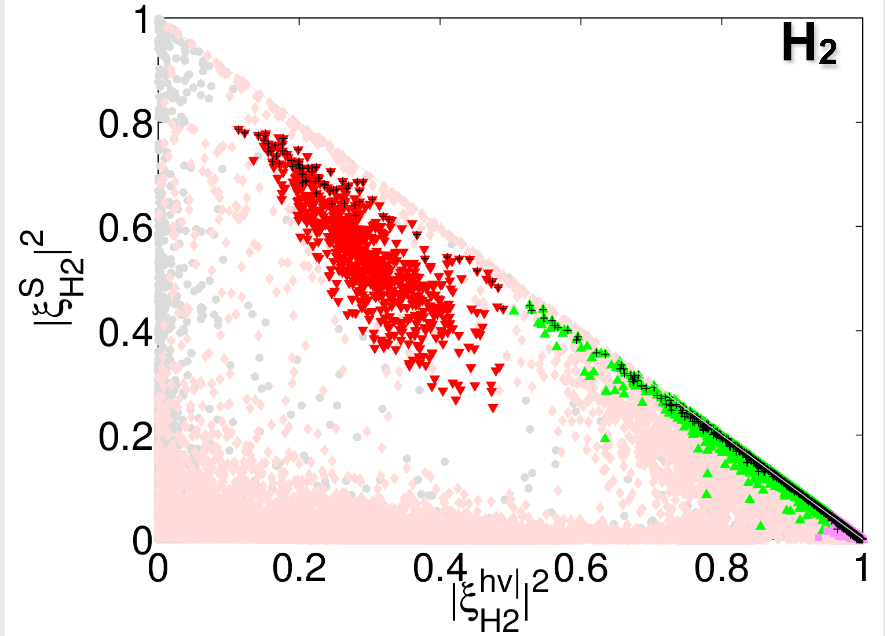
- black: perturbativity till m_{GUT}





H_2 126 GeV: h_v-, H_v-, S- fracti

- grey: pass exp
- pink: $124 < m_{H2} < 128$ GeV
- green, red, purple, black: satisfy σXBr($\gamma\gamma$, WW)
  - H_2 region IA, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 > 0.5$
  - H_2 region IB, $m_{H1} > m_{H2}/2$, $|\xi_{H2}^{hv}|^2 < 0.5$
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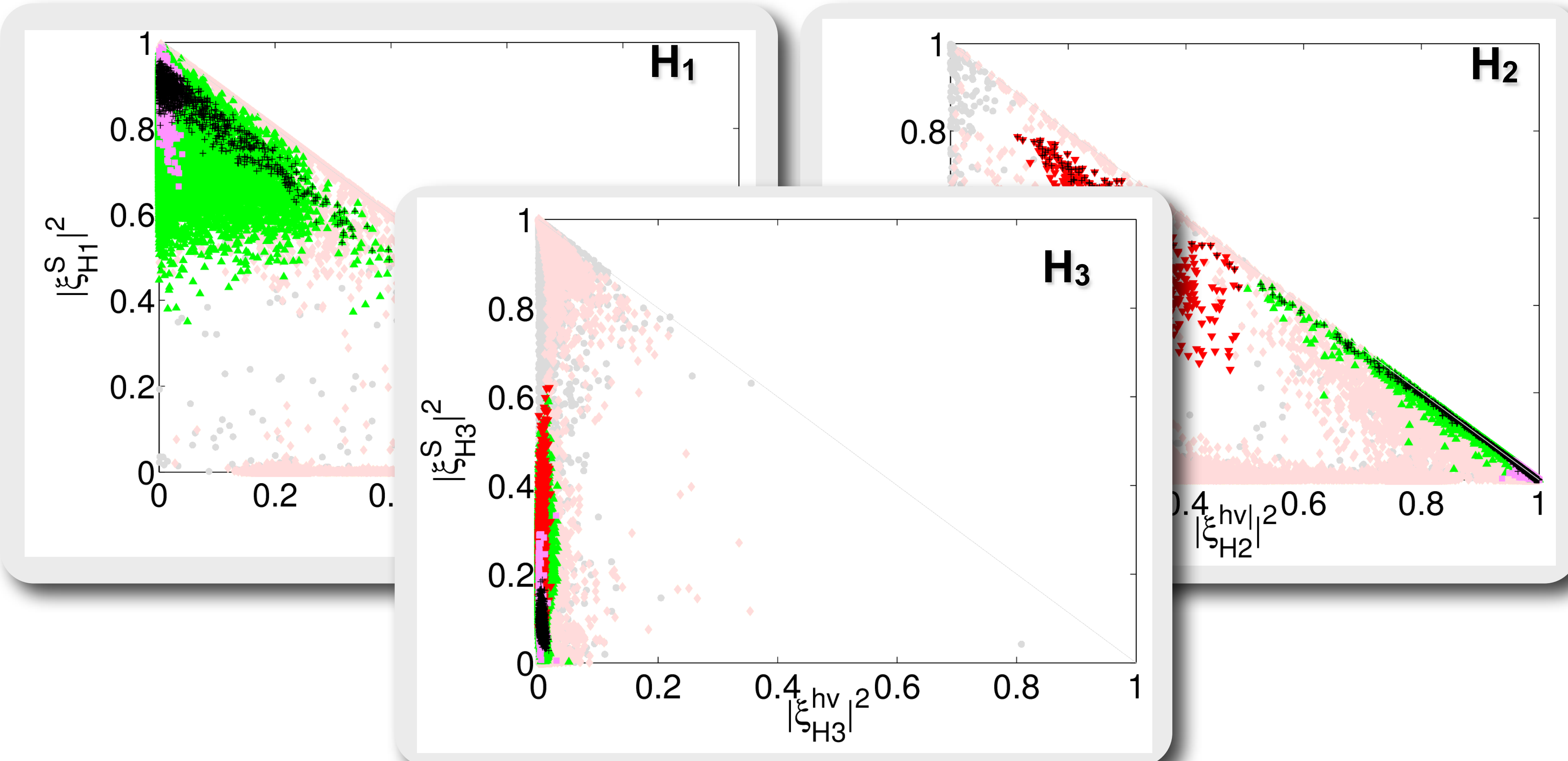
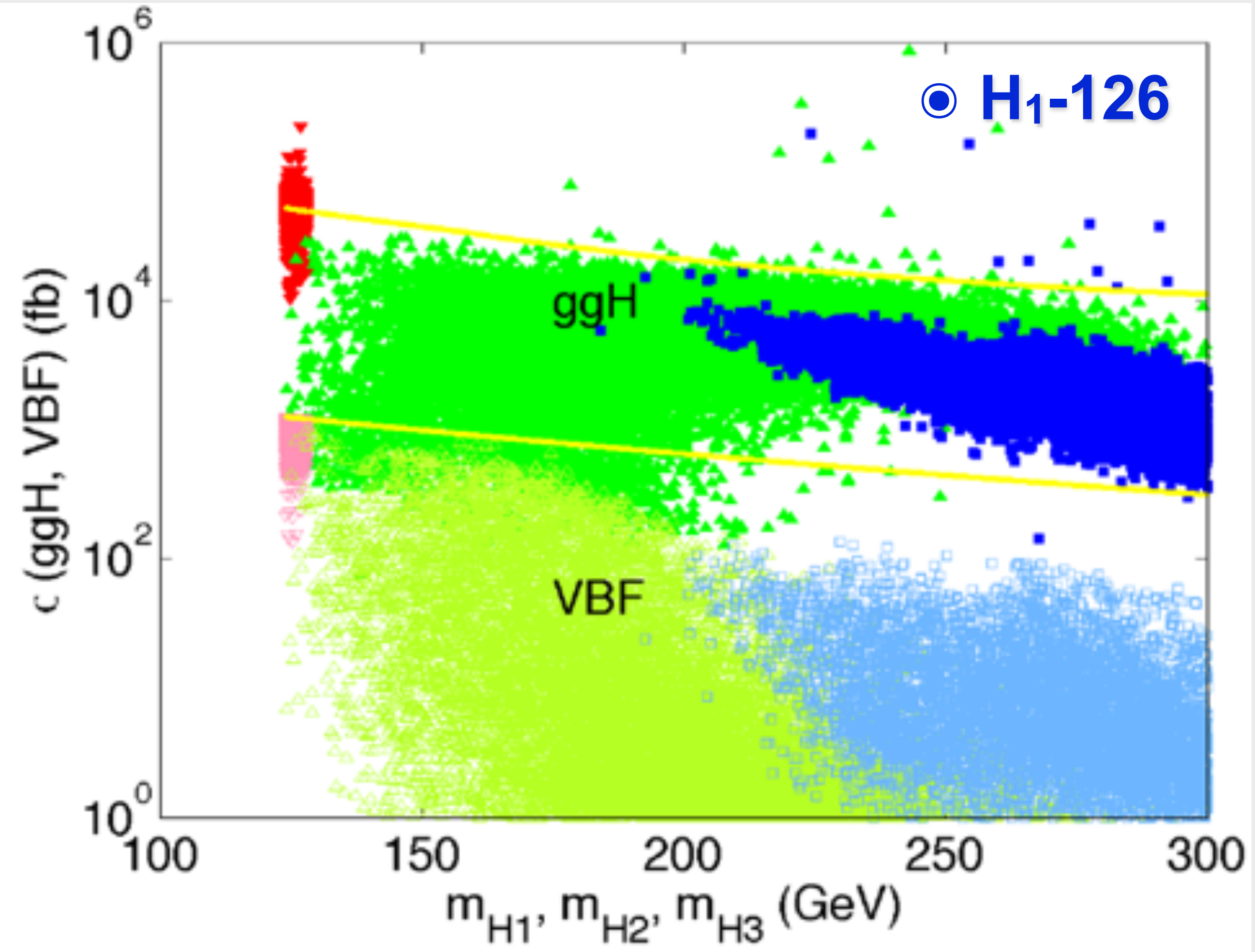
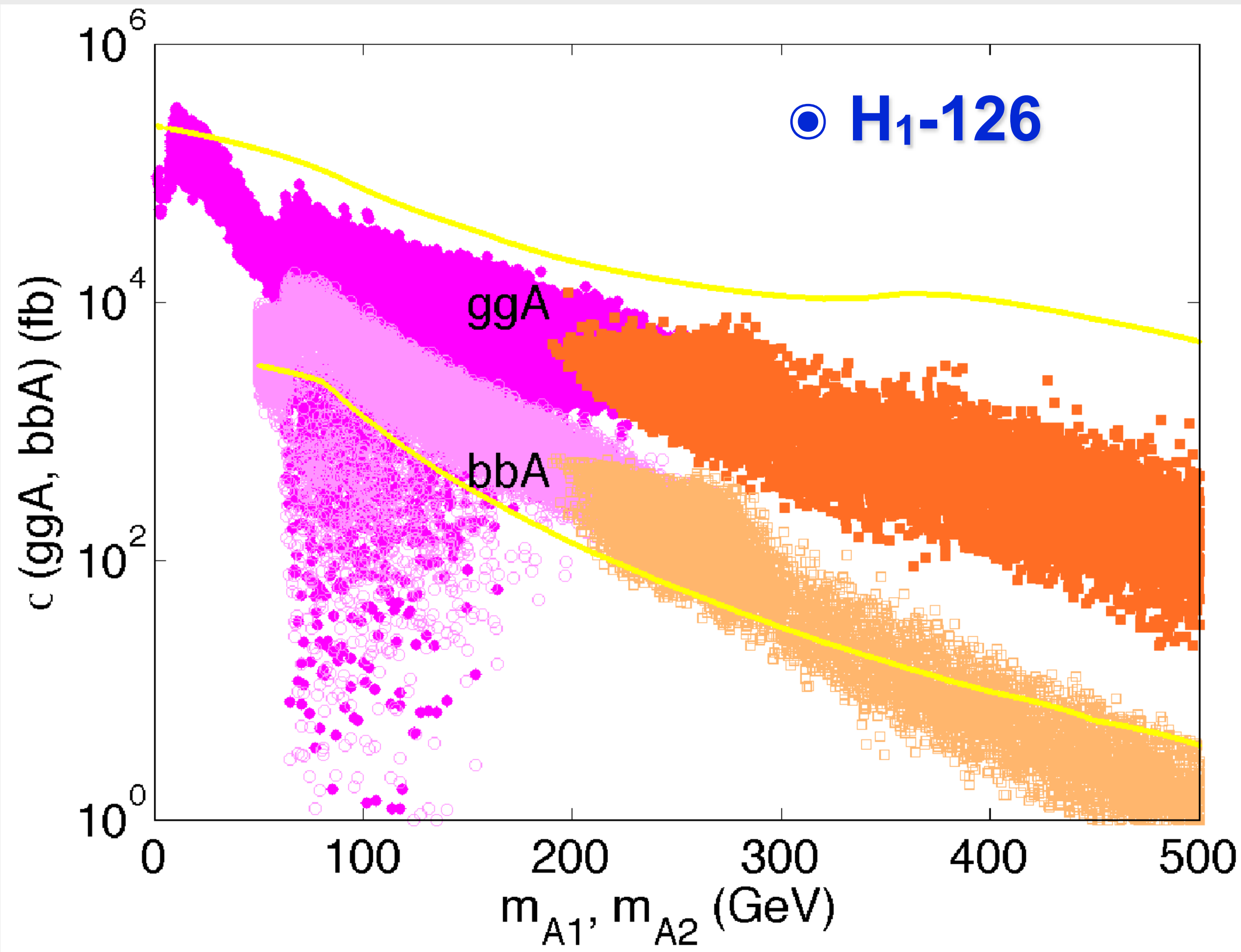


LHC phenomenology

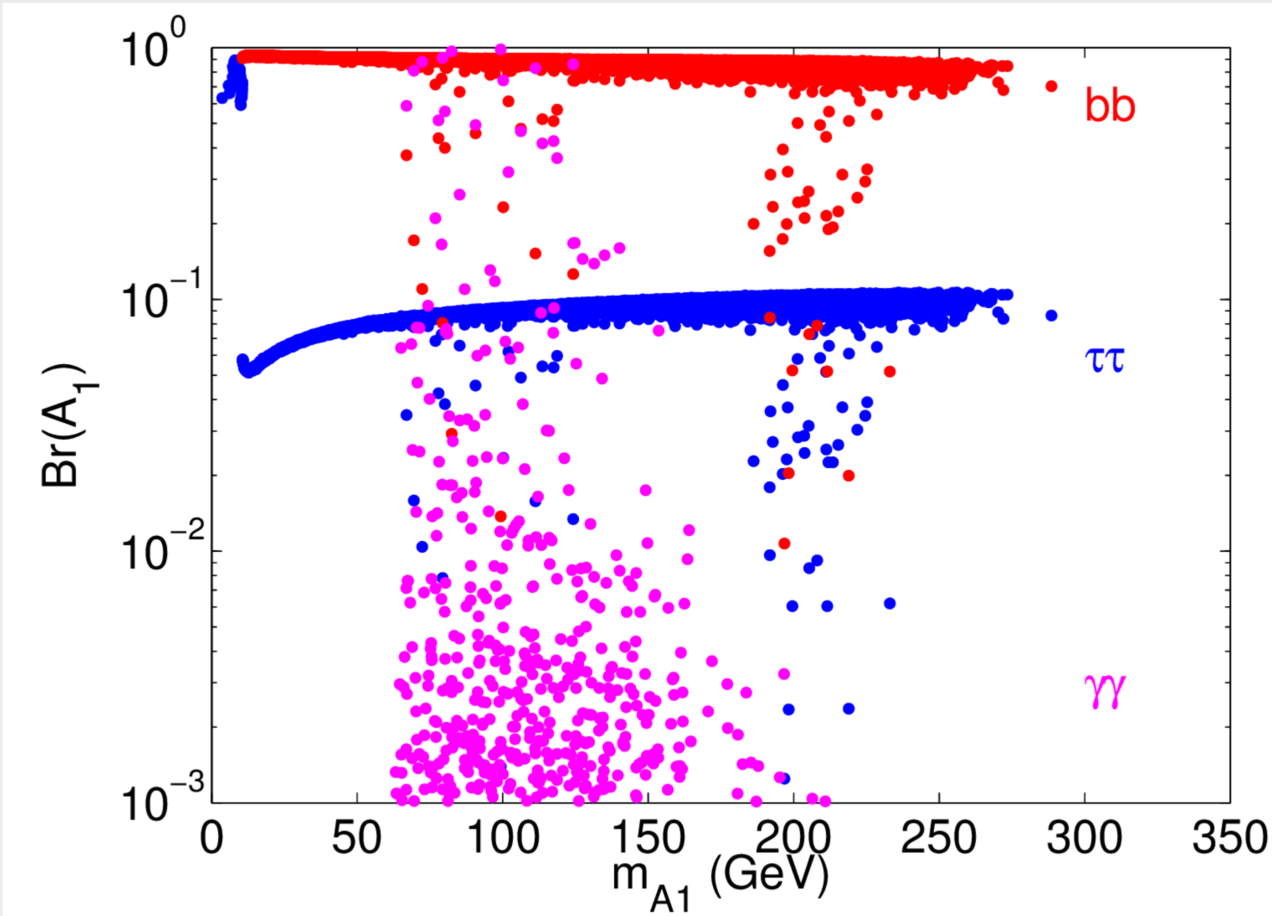


LHC phenomenology



LHC phenomenology

- **H_1-126, A_1 decay**



S. Su

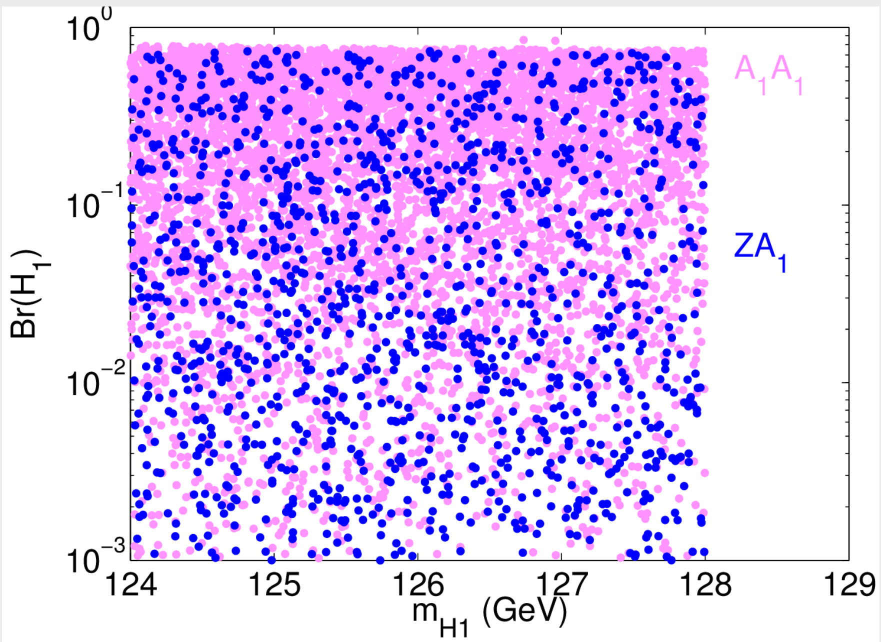
LHC phenomenology

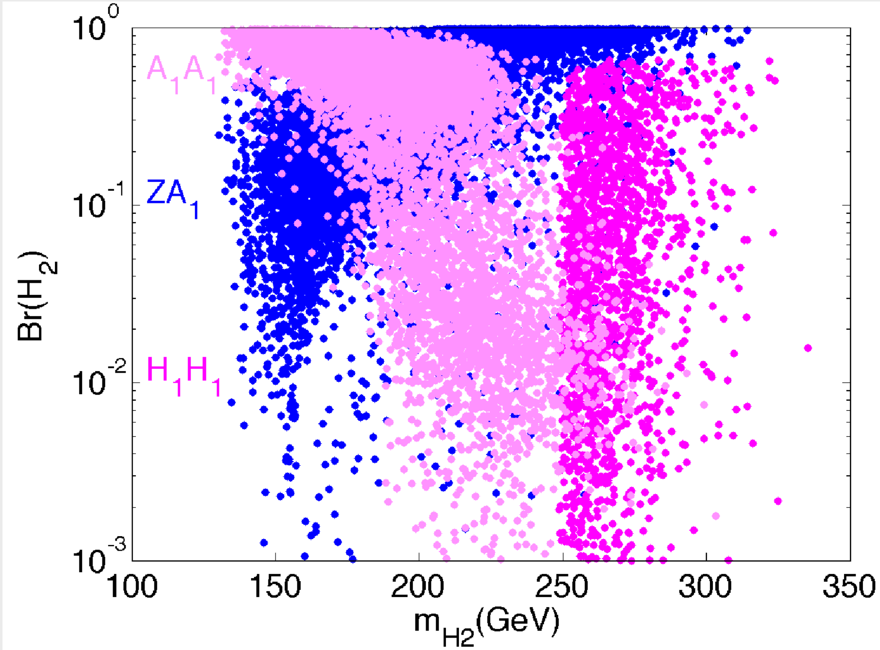
- H_1-126, decay to Higgs boson

$$H_1 \to A_1 A_1, \quad Z A_1,$$
$$H_2 \to A_1 A_1, \quad Z A_1, \quad H_1 H_1,$$
$$H_3 \to A_1 A_1, \quad H_1 H_1, \quad Z A_1, \quad W^{\pm} H^{\mp}, \quad A_1 A_2, \quad H_1 H_2, \quad H_2 H_2, \quad H^{+} H^{-},$$
$$H^{\pm} \to W^{\pm} A_1, \quad W^{\pm} H_2, \quad W^{\pm} H_1,$$
$$A_1 \to Z H_1,$$
$$A_2 \to A_1 H_1, \quad A_1 H_2, \quad W^{\pm} H^{\mp}, \quad Z H_1, \quad Z H_2, \quad Z H_3, \quad A_1 H_3,$$

LHC phenomenology

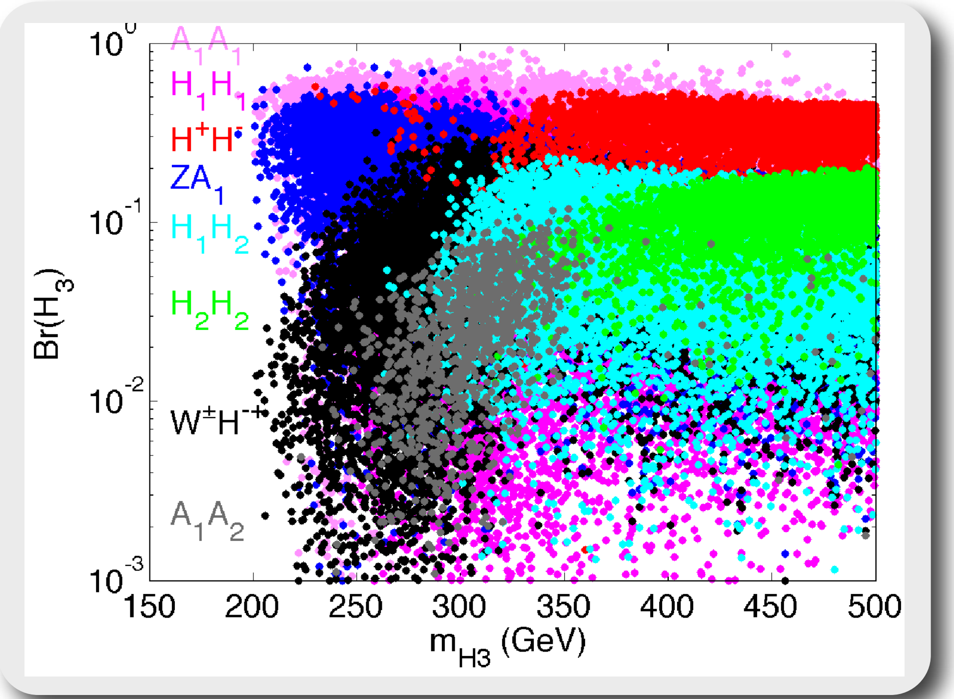
- H_1-126, H_1 , H_2 decay

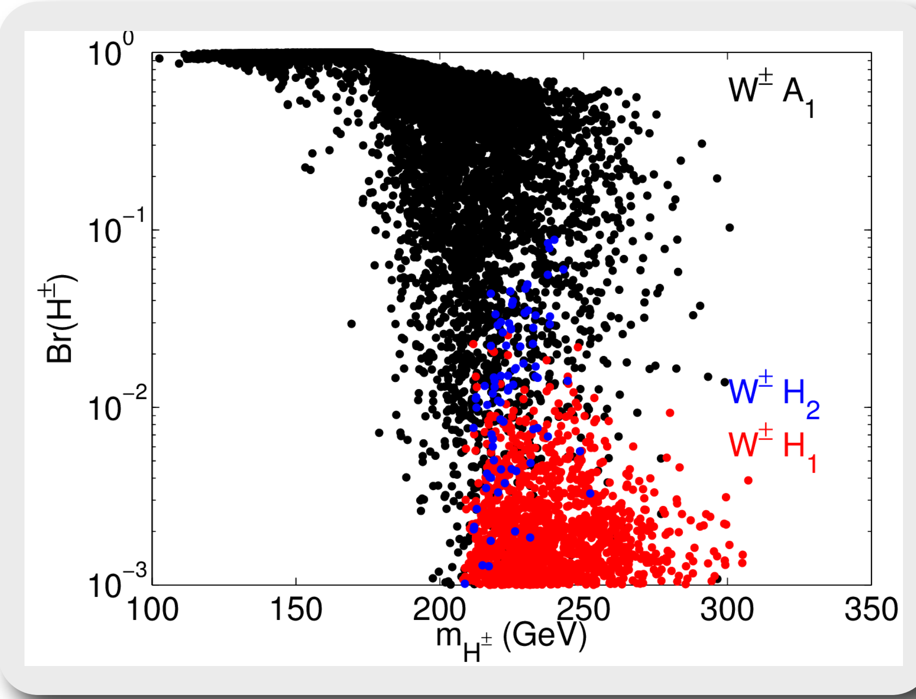




LHC phenomenology

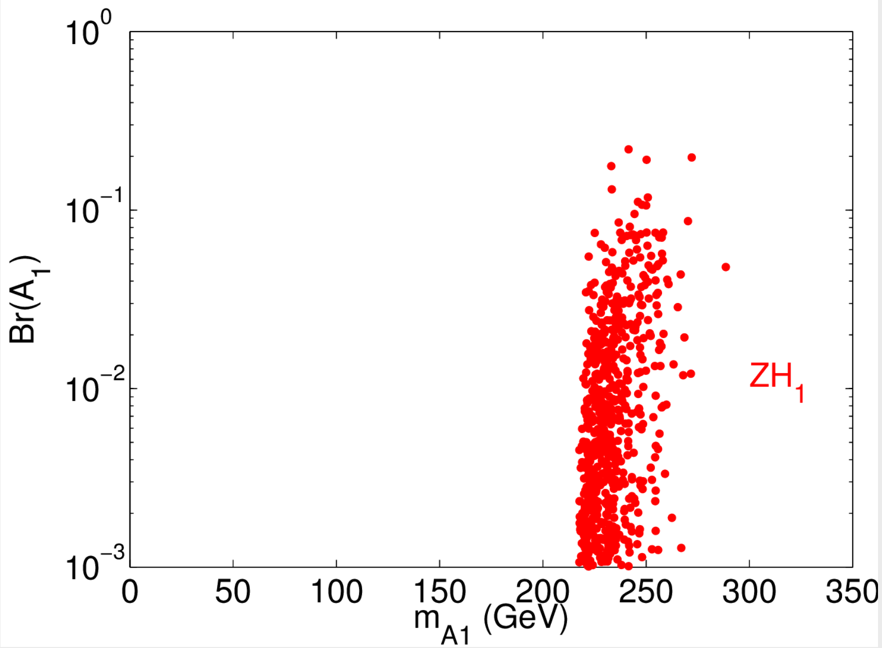
- H_1-126, H_3 , $H^{\pm}$ decay

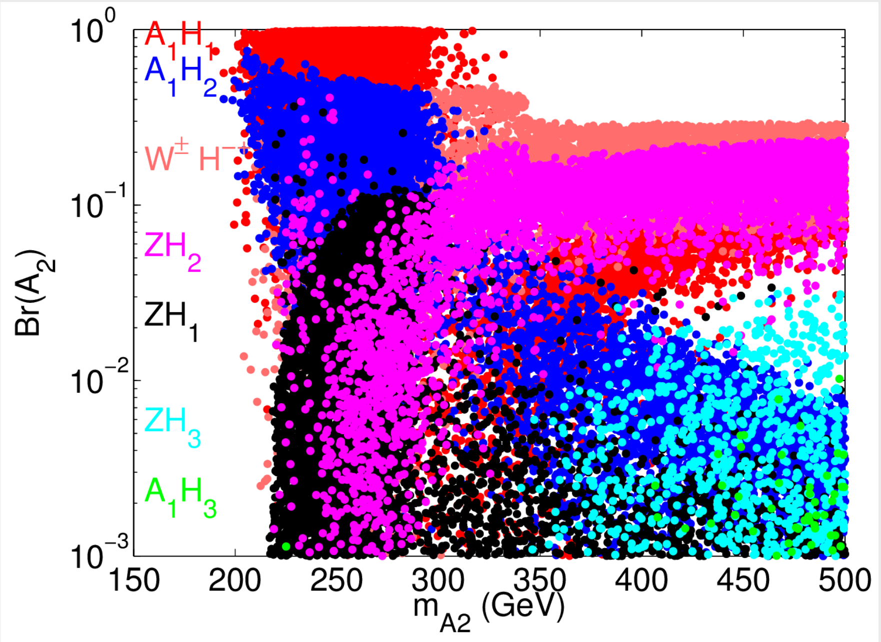




LHC phenomenology

- **H_1-126, A_1 , A_2 decay**





LHC phenomenology

- H_2-126, decay to Higgs bosons

$$
\begin{aligned}
&H_2 \to H_1 H_1, \\
&H_3 \to H_1 H_1, \quad H_1 H_2, \quad Z A_1, \quad A_1 A_1, \quad H_2 H_2, \\
&H^\pm \to W^\pm H_1, \quad W^\pm A_1, \quad W^\pm H_2, \\
&A_1 \to Z H_1, \quad Z H_2, \\
&A_2 \to Z H_1, \quad A_1 H_1, \quad A_1 H_2, \quad Z H_2, \quad W^\pm H^\mp, \quad Z H_3, \quad A_1 H_3,
\end{aligned}
$$

Conclusion (part I)

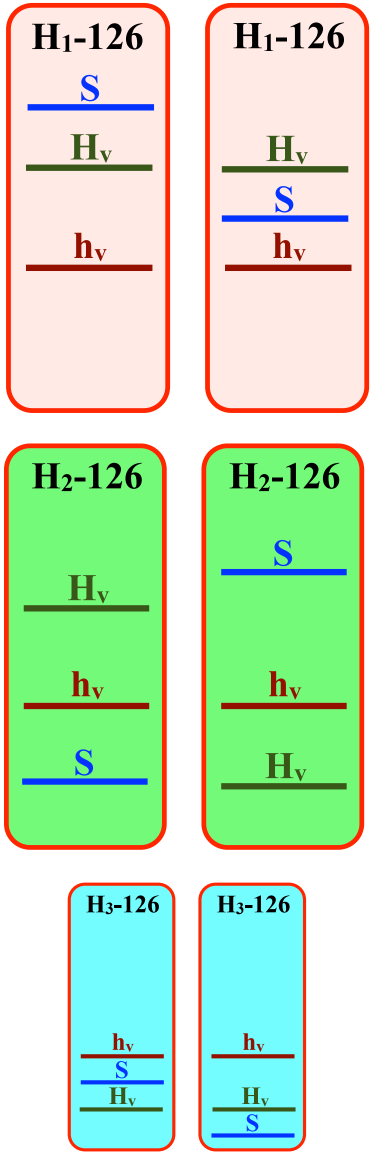
- 126 ± 2 GeV (~SM strength) in NMSSM: low m_A region
  - small m_A ($\lesssim 200$ GeV), all Higgses light, possible large mixing effects
  - singlet helps to lift mass: large λ, small $\tan\beta$
  - mixing with singlet, change Γ_{bb}, $\Gamma_{WW/ZZ}$, ...

- MSSM
  - $m_A \sim m_Z$, non-decoupling, H^0 SM-like
  - $m_A \gtrsim 300$ GeV, decoupling, h^0 SM-like
  - stops either heavy or large LR-mixing

- NMSSM
  - m_A : 0 - 200 GeV
  - either H_1 or H_2 SM-like (hard to realize H_3 SM-like)
  - interesting features in each region
  - stop sector less constrained

Conclusion (part I)

- H_1 126 GeV
  - $\lambda \geq 0.55$, $\kappa \geq 0.3$, $1 \leq \tan\beta \leq 3.5$
  - H_1 SM h-like, H_2, H_3 S-H mixture
  - $H_1 \rightarrow A_1 A_1$: H_1, H_2 h-H mixture, H_3 S-like
- H_2 126 GeV
  - $0.4 \leq \lambda \leq 0.75$, $\kappa \geq 0.05$, $1 \leq \tan\beta \leq 3.25$
  - $100 \leq m_A \leq 200$ GeV, small μ
  - case with $H_2 \rightarrow H_1 H_1$
  - H_2 h-S mixture, H_3 S-H mixture
  - H_1, H_2, h-H-S mixture; H_3: S-H mixture
- H_3 126 GeV: fine tuned region, hard to realize



S. Su

Conclusion (part I)

- relax perturbativity requirement, allowed region enlarge significantly
- SM-like Higgs signal might be modified: prod and decay
- $\gamma\gamma$ rate can be enhanced, $\gamma\gamma$/WW, WW/bb ratios can be violated.
- New Higgs bosons may be readily produced
  - production could be similar to that of the SM production
  - decay could be larger than that of the SM.
- Heavy Higgs $\rightarrow$ light Higgs bosons or light Higgs+W/Z, multiple t,b,tau

2HDM Higgs Sector

- **Type II Two Higgs Doublet Model**

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - (m_{12}^2\Phi_1^\dagger\Phi_2 + \text{h.c.}) + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$
$$+\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \left\{\frac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\right\} + \left\{\lambda_6\left[(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)\right](\Phi_1^\dagger\Phi_2) + \text{h.c.}\right\}$$

- **Z2 symmetry**
- **EWSB**

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \quad H_u^0 \rightarrow v_u/\sqrt{2} \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix} \quad H_d^0 \rightarrow v_d/\sqrt{2}$$

$$v_u^2 + v_d^2 = v^2 = (246\text{GeV})^2$$
$$\tan\beta = v_u/v_d$$

after EWSB, 5 physical Higgses
CP-even Higgses: h^0, H^0
CP-odd Higgs: A^0
Charged Higgses: $H^\pm$

2HDM Higgs Sector

- **Type II Two Higgs Doublet Model**

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - \cancel{(m_{12}^2\Phi_1^\dagger\Phi_2 + \text{h.c.})} + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$
$$+\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \left\{\frac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\right\} + \left\{\lambda_6\left[(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)\right](\Phi_1^\dagger\Phi_2) + \text{h.c.}\right\}$$

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2HDM Higgs Sector

- **Type II Two Higgs Doublet Model**

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 \cancel{-(m_{12}^2\Phi_1^\dagger\Phi_2 + \mathrm{h.c.})} + \frac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \frac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$
$$+\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \left\{\frac{1}{2}\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \mathrm{h.c.}\right\} \cancel{+\left\{\lambda_6\left[(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)\right](\Phi_1^\dagger\Phi_2) + \mathrm{h.c.}\right\}}$$

- **Z2 symmetry**
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after EWSB, 5 physical Higgses

CP-even Higgses: h^0, H^0

CP-odd Higgs: A^0

Charged Higgses: $H^\pm$

2HDM Higgs Sector

- **couplings**

ξ_h^{VV}	$\sin(\beta-\alpha)$	ξ_H^{VV}	$\cos(\beta-\alpha)$	ξ_A^{VV}	0
ξ_h^u	$\cos\alpha/\sin\beta$	ξ_H^u	$\sin\alpha/\sin\beta$	ξ_A^u	$\cot\beta$
ξ_h^d	$-\sin\alpha/\cos\beta$	ξ_H^d	$\cos\alpha/\cos\beta$	ξ_A^d	$\tan\beta$
ξ_h^l	$-\sin\alpha/\cos\beta$	ξ_H^l	$\cos\alpha/\cos\beta$	ξ_A^l	$\tan\beta$

- **parameters**

$$m_{11}^2,\ m_{22}^2,\ \lambda_1,\ \lambda_2,\ \lambda_3,\ \lambda_4,\ \lambda_5 \longrightarrow v, \tan\beta, \alpha, m_h, m_H, m_A, m_{H^\pm}$$

- **Theoretical constrains**
  - vacuum stability
  - perturbativity
  - unitarity
  - Δρ

- **Experimental constraints**
  - LEP Higgs searches (neutral Higgs, charged Higgs)
  - Tevatron Higgs searches
  - LHC Higgs searches (SM-like Higgs searches, MSSM Higgs searches)

S. Su

2HDM Higgs Sector

- previous work in 2HDM ...

Ferreira et. al., 1112.3772, 2HDM, H1 125, tan β vs. sin α
Basso et. al., 1205.6569, CP violating 2HDM, H1 125,
Cheon et. al., 1207.1083, Type II 2HDM, H1 or H2 125
Chang et. al., 1210.3439, 2HDM, H1 or H2 or degenerate H1/A, χ2 fit
Drozd et. al., 1211.3580, Type I and II 2HDM, H1 or H2 125 or degenerate, $m_{12}^2 \neq 0$,
Craig and Thomas, 1207.4835, 2HDM, H1 125, various search channels
Ferreira et. al., 1211.3131, degenerate Higgses
...

Our work:

- Type II 2HDM with $m_{12}^2=0$, 5 parameter scan
- impose theoretical and experimental constraints
- h^0 or H^0 126 GeV
- study parameter space and correlations

S. Su

Analyses Methods

◉ h^0-126

$0.25 \le \tan\beta \le 5$

$-1 \le \sin(\beta-\alpha) \le 1$

$126 \text{ GeV} < m_H \le 1000 \text{ GeV}$

$20 \text{ GeV} \le m_A, m_{Hpm} \le 1000 \text{ GeV}$

◉ H^0-126

$1 \le \tan\beta \le 30$

$-1 \le \sin(\beta-\alpha) \le 1$

$6 \text{ GeV} < m_H < 121 \text{ GeV}$

$20 \text{ GeV} \le m_A, m_{Hpm} \le 1000 \text{ GeV}$

$$0.9 < \frac{\sigma(gg \to h/H \to \gamma\gamma)}{\sigma_{\rm SM}} < 2.2, \quad 0.2 < \frac{\sigma(gg \to h/H \to VV)}{\sigma_{\rm SM}} < 1.4.$$

2HDM Calculator (2HDMC) + HIGGSBOUNDS (+ latest LHC bounds) + SUPERISO for flavor constraints

h^0 126 GeV

Light CP-even Higgs as 126 GeV SM-like Higgs

Type II 2HDM: h^0 126 GeV

$$\frac{\sigma(gg\to h\to\gamma\gamma, WW/ZZ)}{\sigma(gg\to h_{\rm SM}\to\gamma\gamma, WW/ZZ)} = \frac{\sigma(gg\to h)}{\sigma(gg\to h)_{\rm SM}} \times \frac{{\rm BR}(h\to\gamma\gamma, WW/ZZ)}{{\rm BR}(h_{SM}\to\gamma\gamma, WW/ZZ)}$$

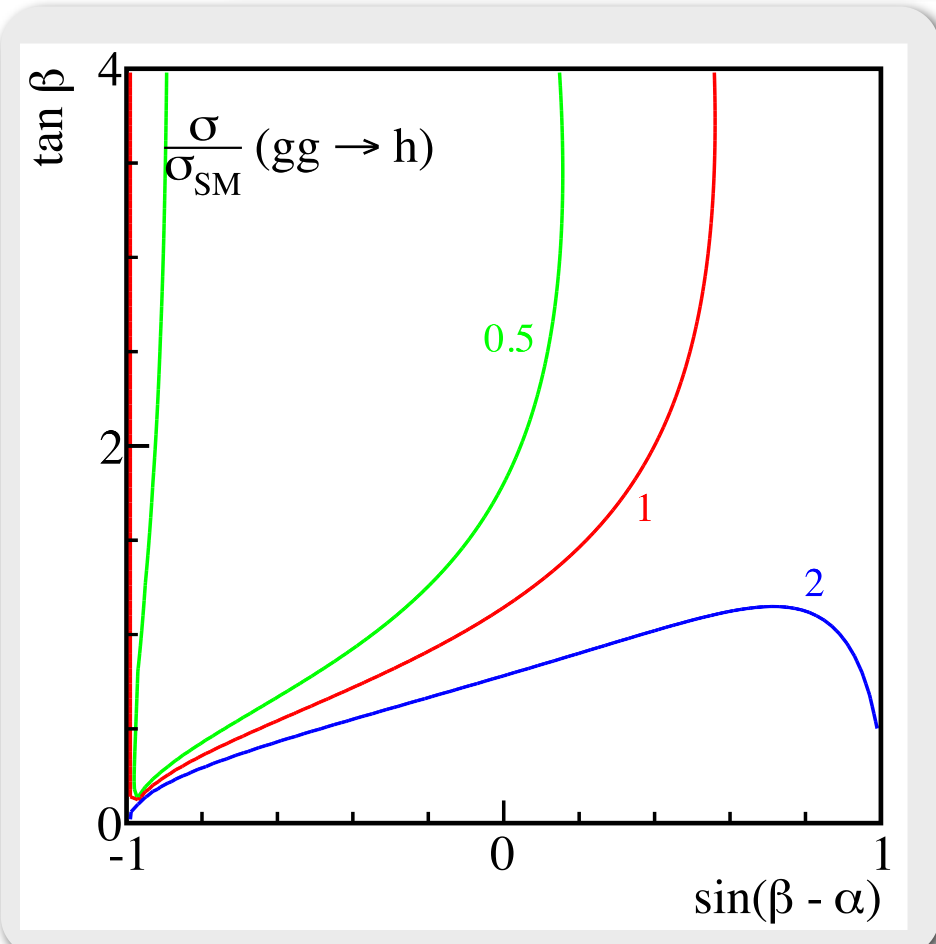
Type II 2HDM: h^0 126 GeV

$$\frac{\sigma(gg \to h \to \gamma\gamma, WW/ZZ)}{\sigma(gg \to h_{\rm SM} \to \gamma\gamma, WW/ZZ)} = \frac{\sigma(gg \to h)}{\sigma(gg \to h)_{\rm SM}} \times \frac{{\rm BR}(h \to \gamma\gamma, WW/ZZ)}{{\rm BR}(h_{SM} \to \gamma\gamma, WW/ZZ)}$$

$$\frac{\cos^2\alpha}{\sin^2\beta} + \frac{\sin^2\alpha}{\cos^2\beta}\frac{|A(\tau_b)|^2}{|A(\tau_t)|^2}$$

Type II 2HDM: h^0 126 GeV

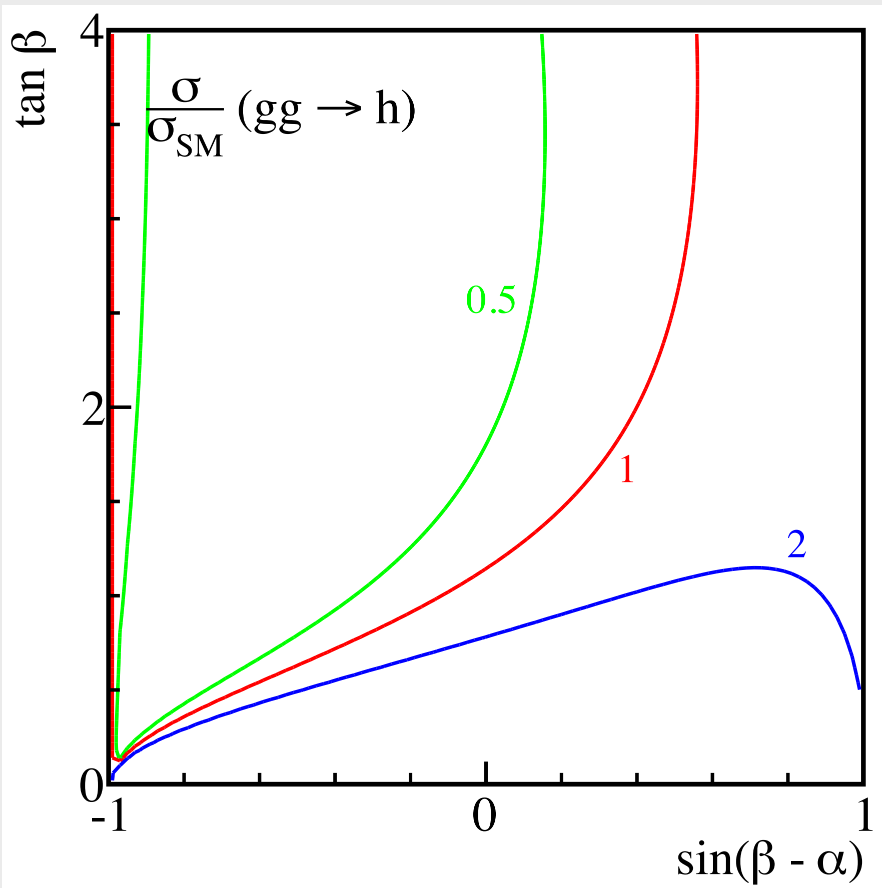
$$\frac{\sigma(gg \to h \to \gamma\gamma, WW/ZZ)}{\sigma(gg \to h_{\rm SM} \to \gamma\gamma, WW/ZZ)} = \frac{\sigma(gg \to h)}{\sigma(gg \to h)_{\rm SM}} \times \frac{\mathrm{BR}(h \to \gamma\gamma, WW/ZZ)}{\mathrm{BR}(h_{SM} \to \gamma\gamma, WW/ZZ)}$$

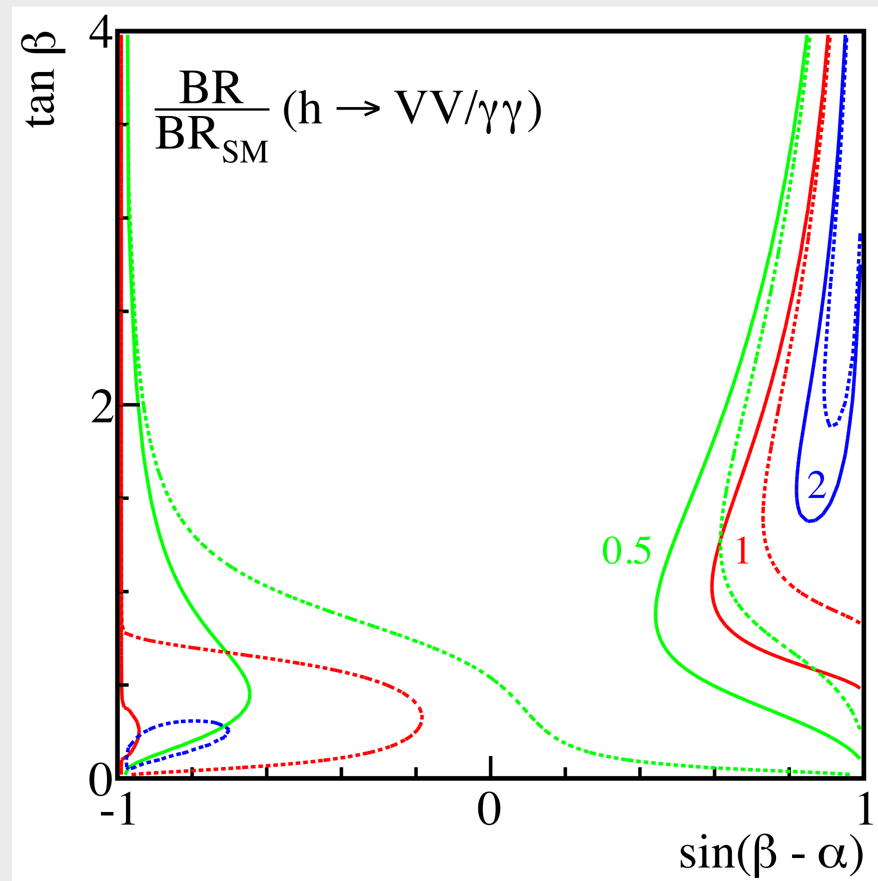


$$\frac{\sin^2\alpha}{\cos^2\beta}\frac{|A(\tau_b)|^2}{|A(\tau_t)|^2}$$

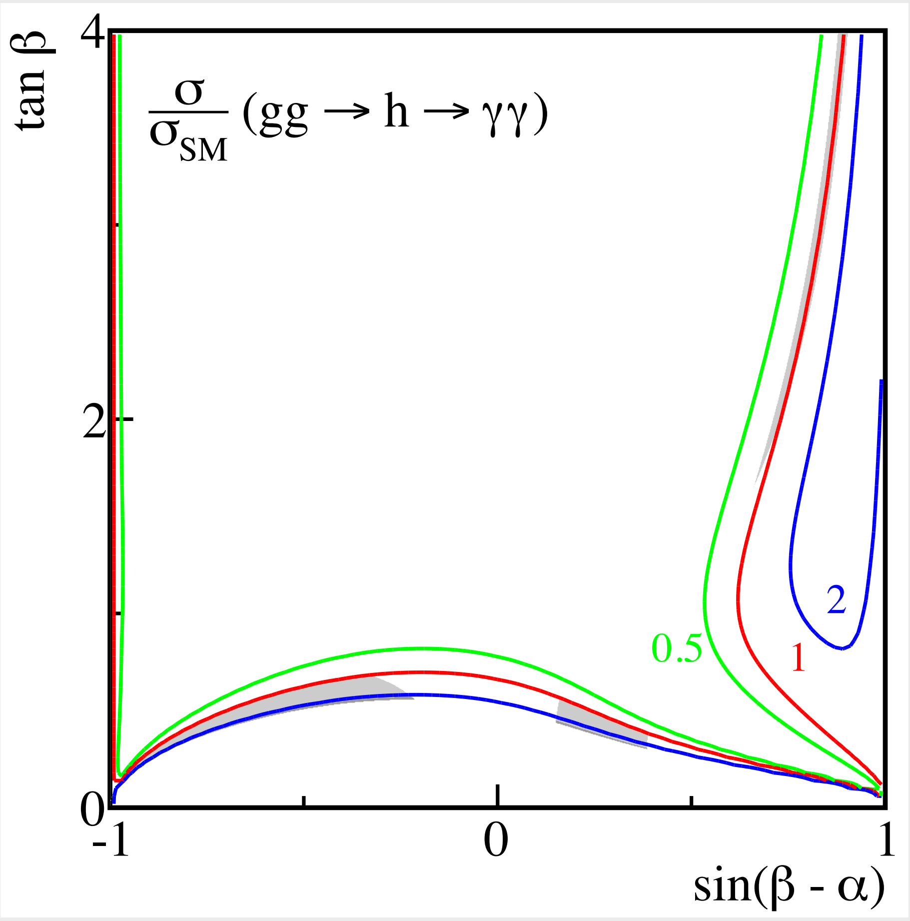
Type II 2HDM: h^0 126 GeV

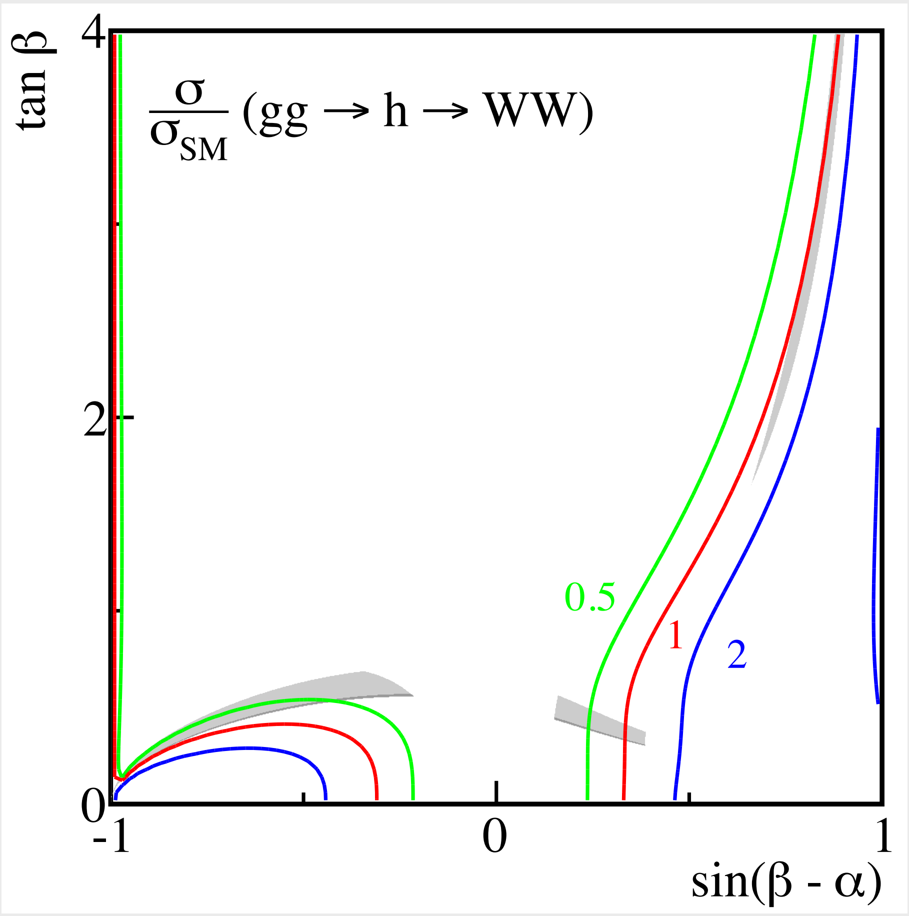
$$\frac{\sigma(gg \to h \to \gamma\gamma, WW/ZZ)}{\sigma(gg \to h_{\rm SM} \to \gamma\gamma, WW/ZZ)} = \frac{\sigma(gg \to h)}{\sigma(gg \to h)_{\rm SM}} \times \frac{{\rm BR}(h \to \gamma\gamma, WW/ZZ)}{{\rm BR}(h_{SM} \to \gamma\gamma, WW/ZZ)}$$



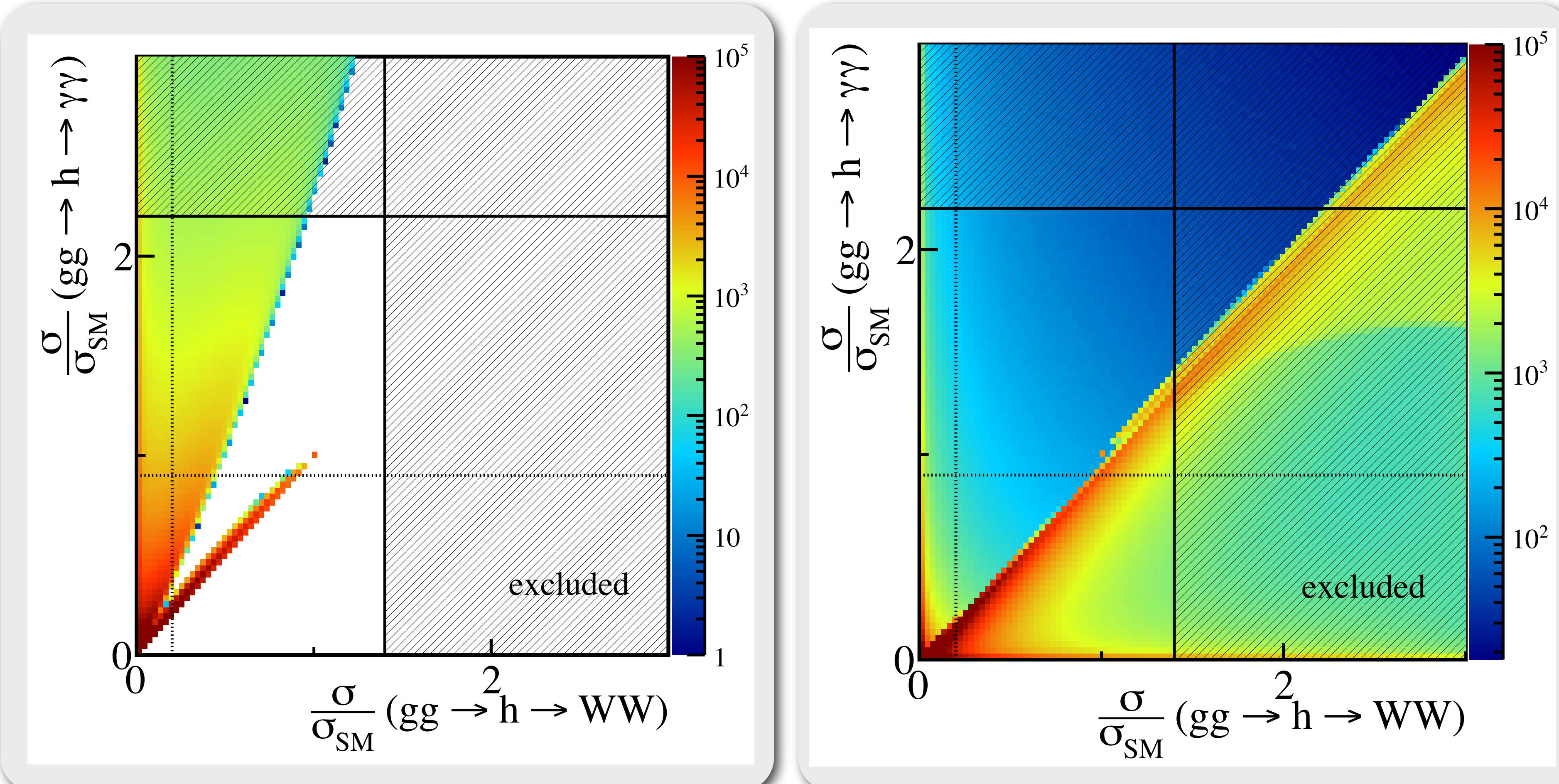


Type II 2HDM: h^0 126 GeV

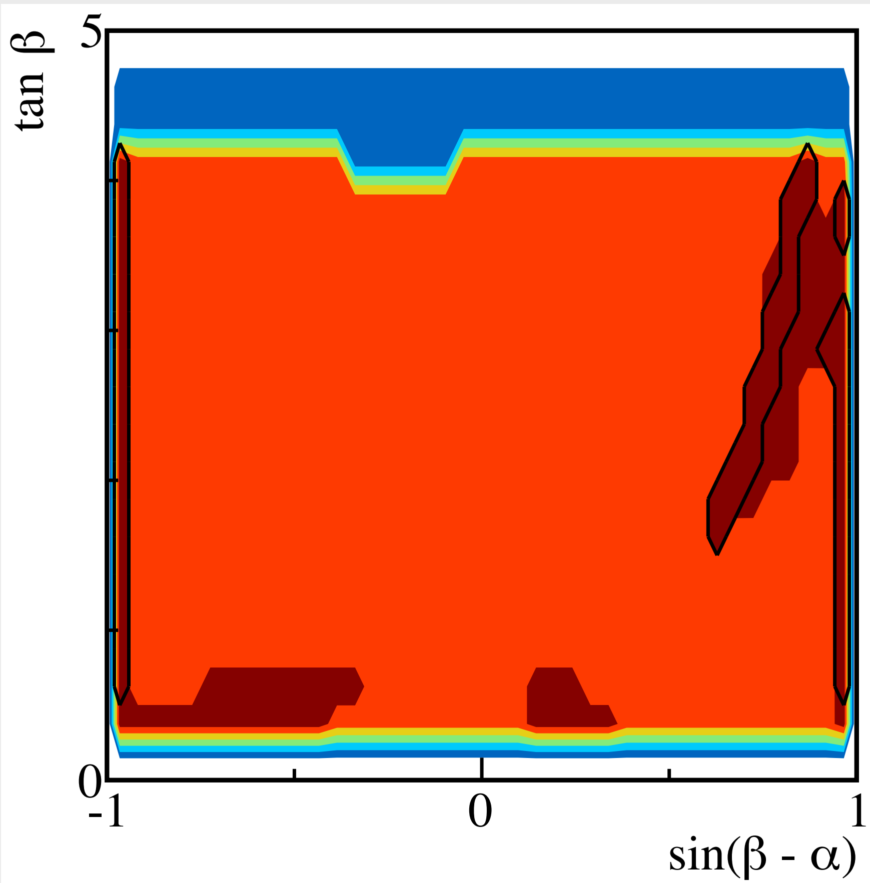




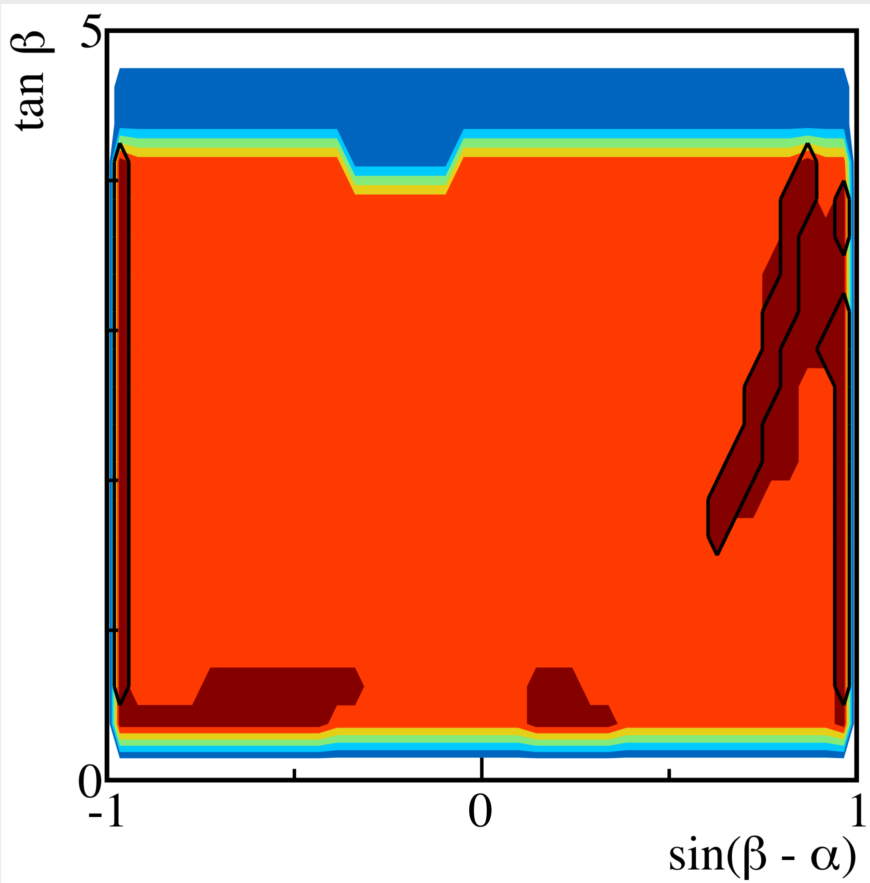
h^0 126 GeV: γγ vs. WW correlation

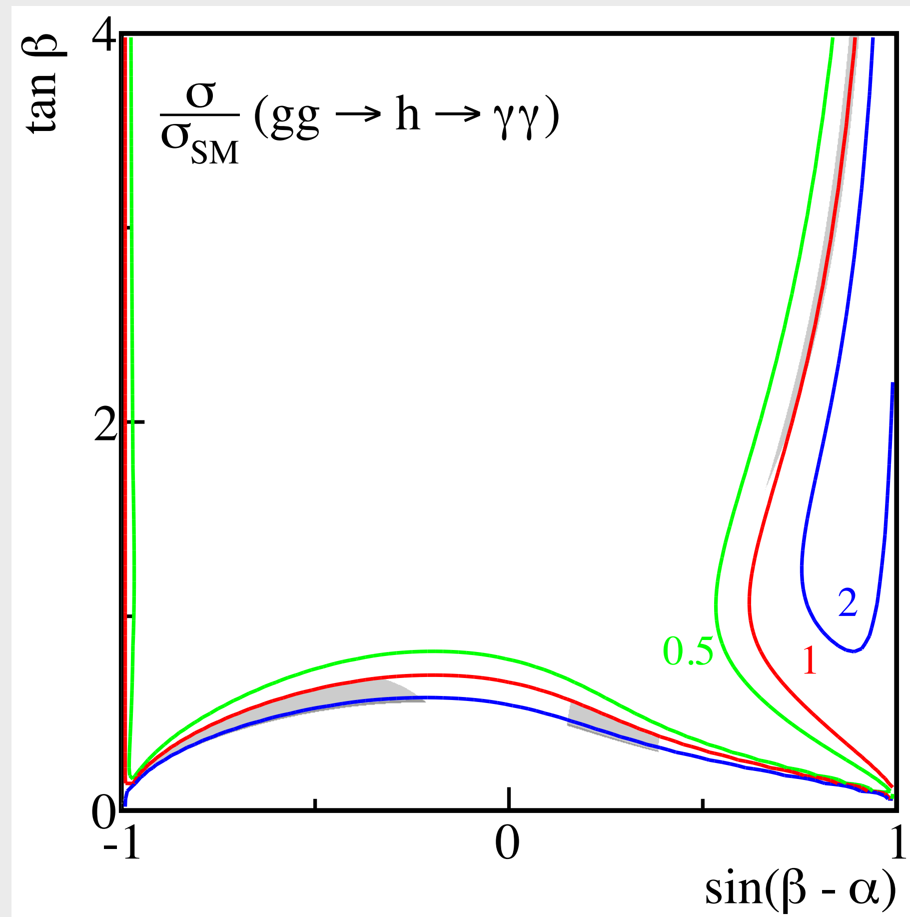


h^0 126 GeV: sin(β-α)

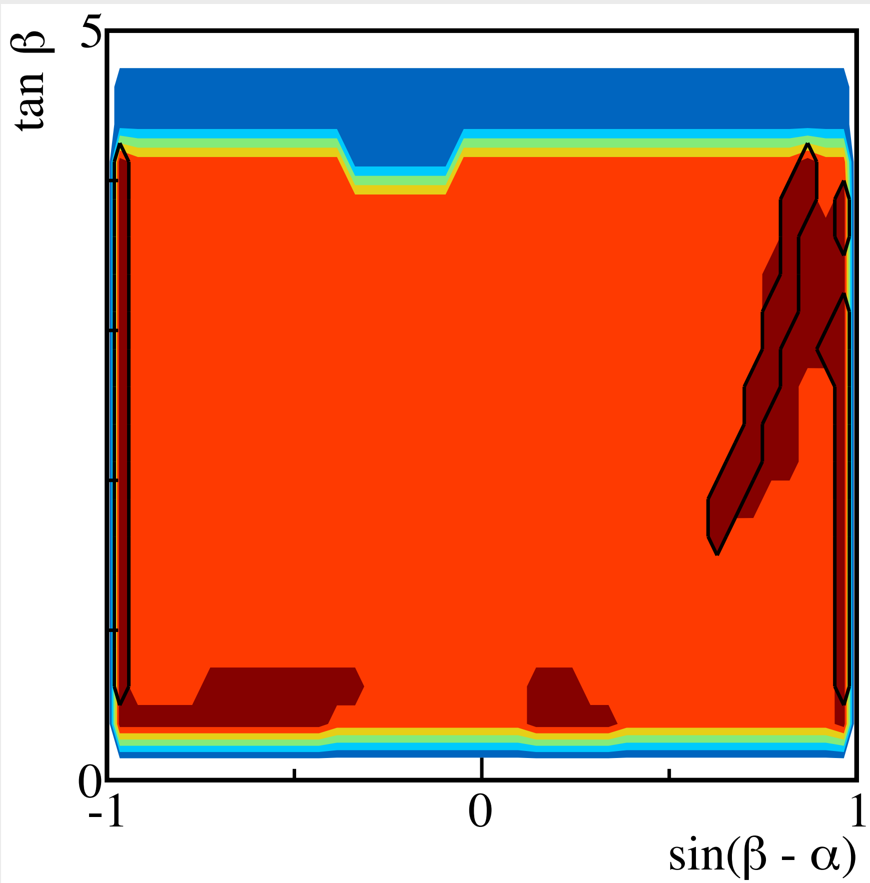


h^0 126 GeV: $\sin(\beta-\alpha)$

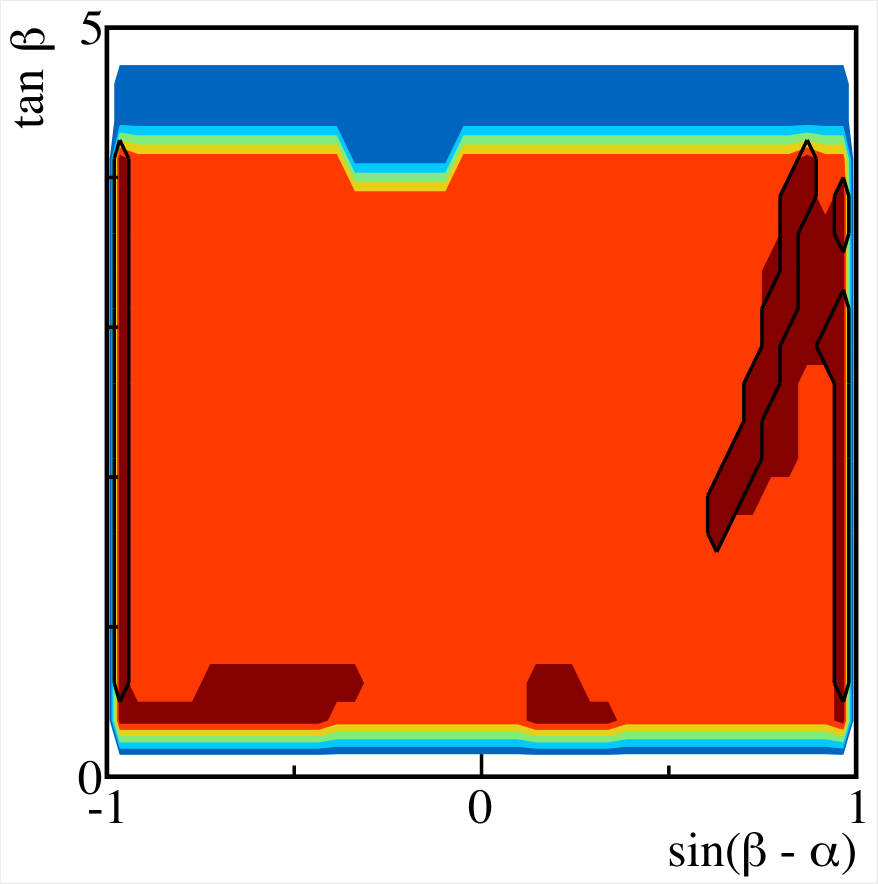


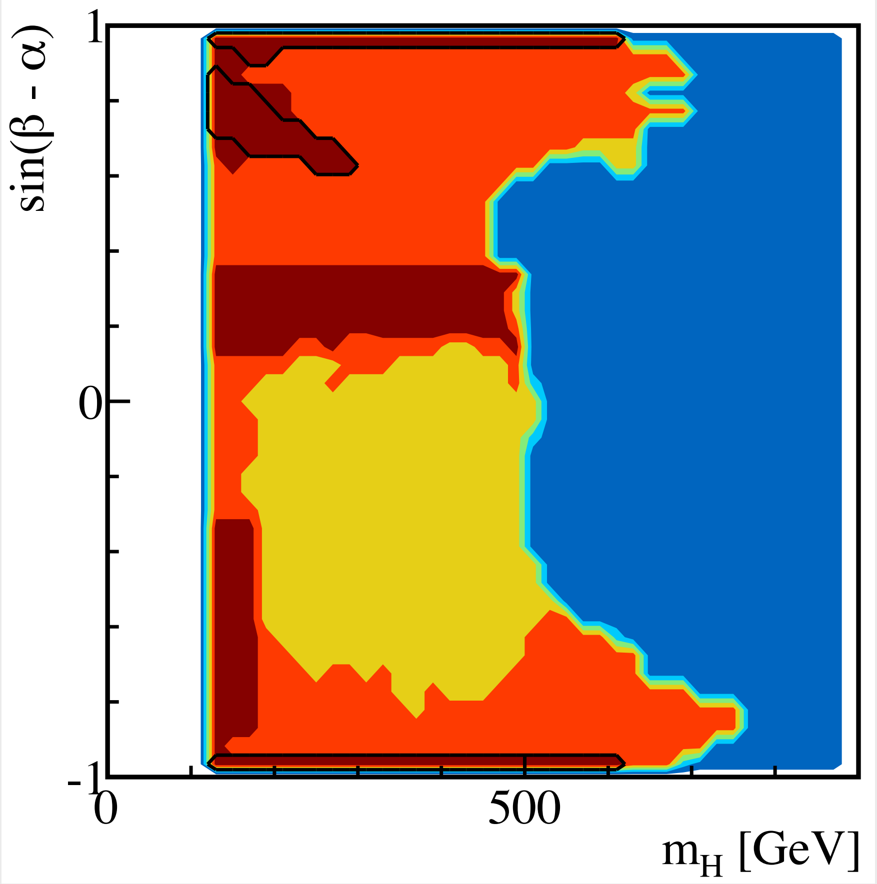


h^0 126 GeV: $\sin(\beta-\alpha)$



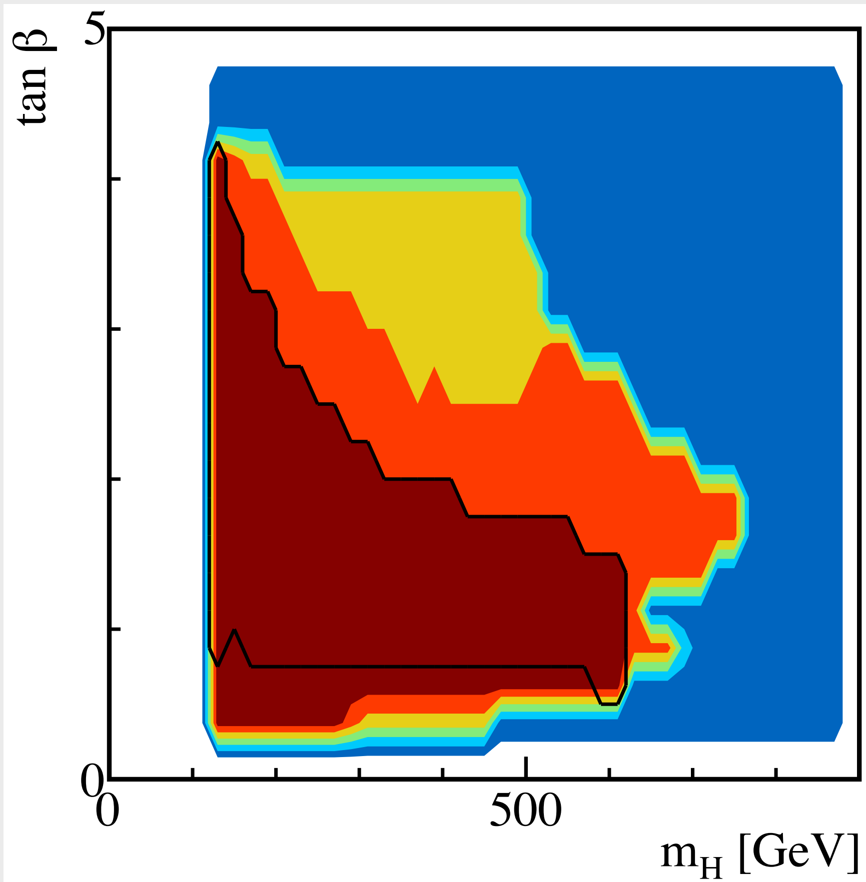
h^0 126 GeV: $\sin(\beta-\alpha)$



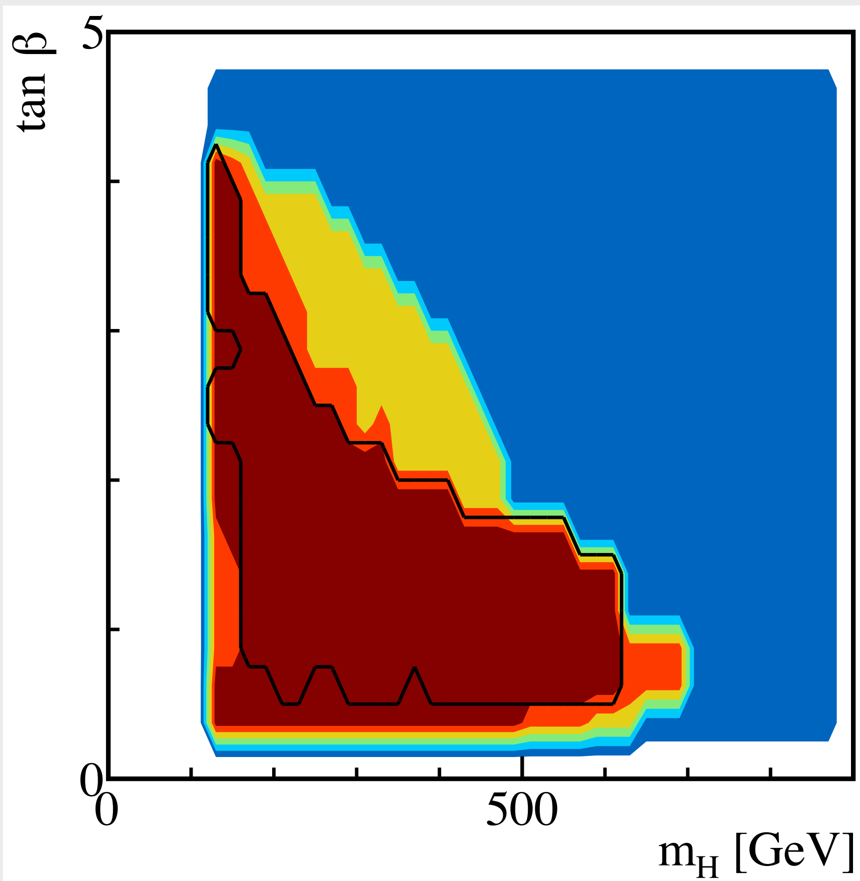


h^0 126 GeV: m_H vs. tanβ

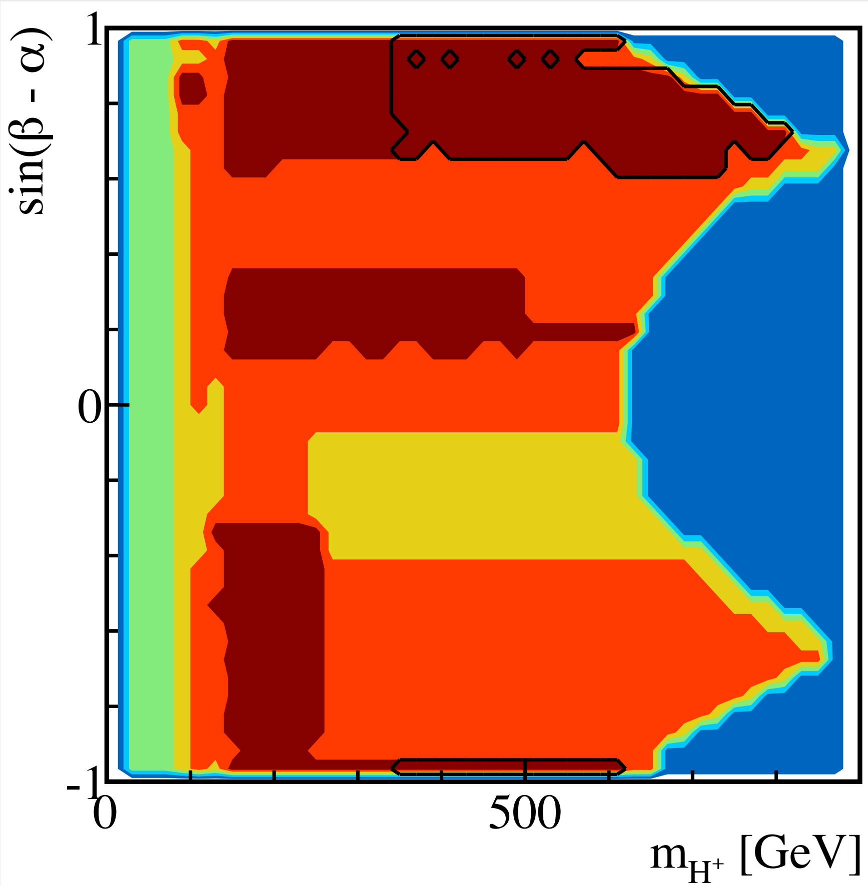
sin(β-α)<0

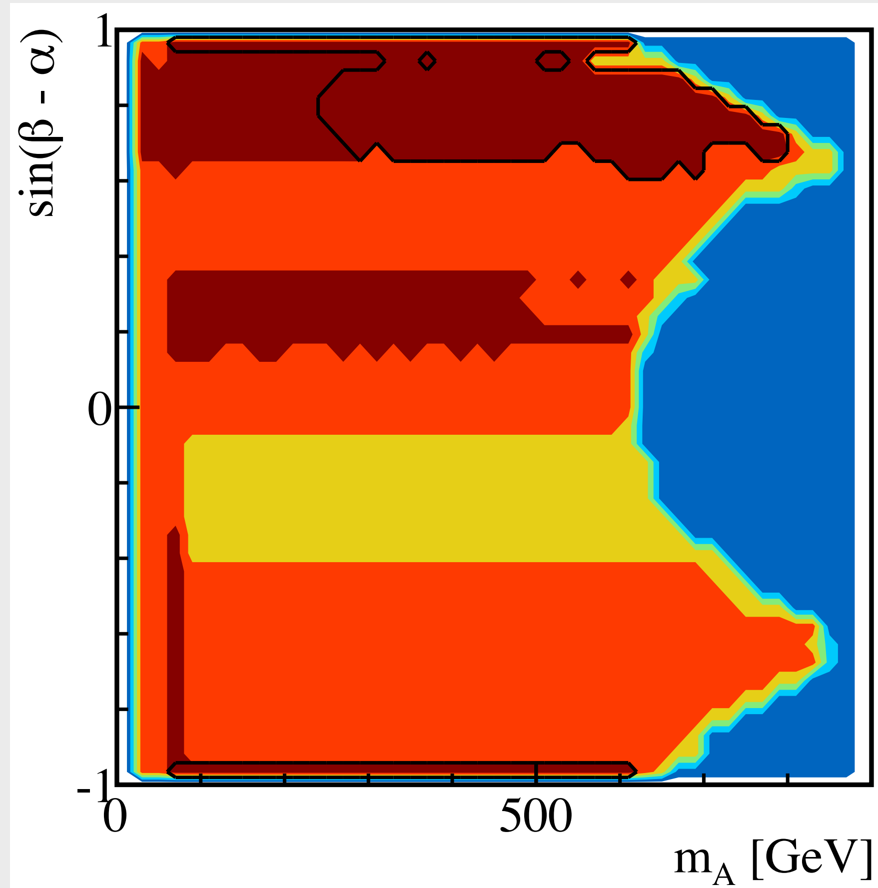


sin(β-α)>0



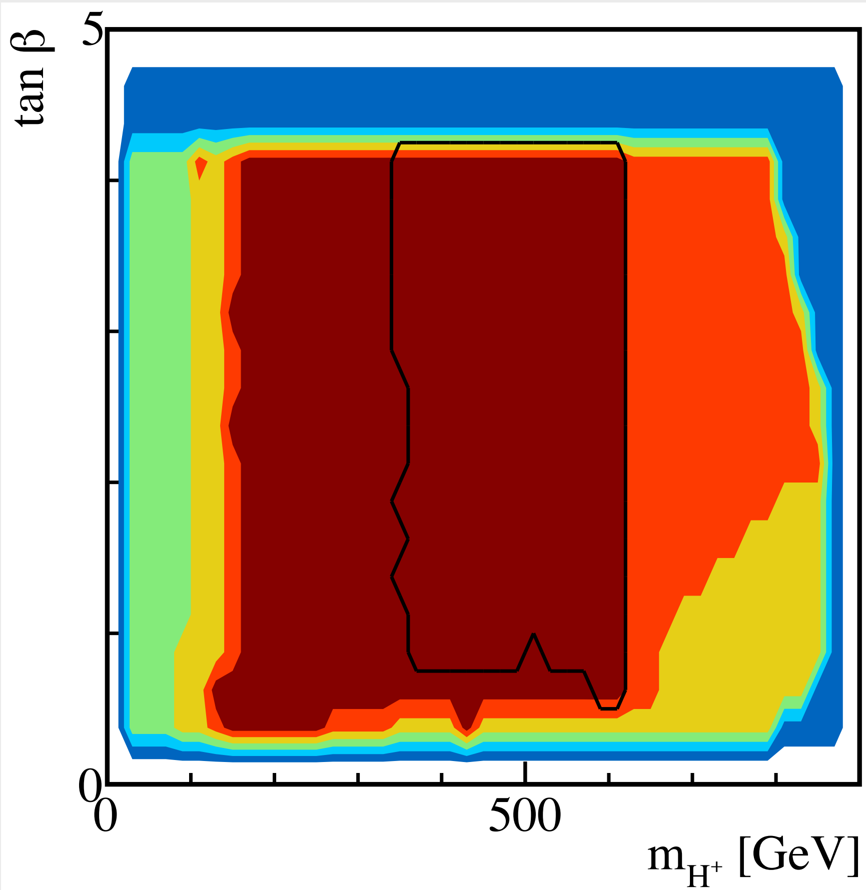
h^0 126 GeV: $\sin(\beta-\alpha)$ vs. m_A (m_{Hpm})



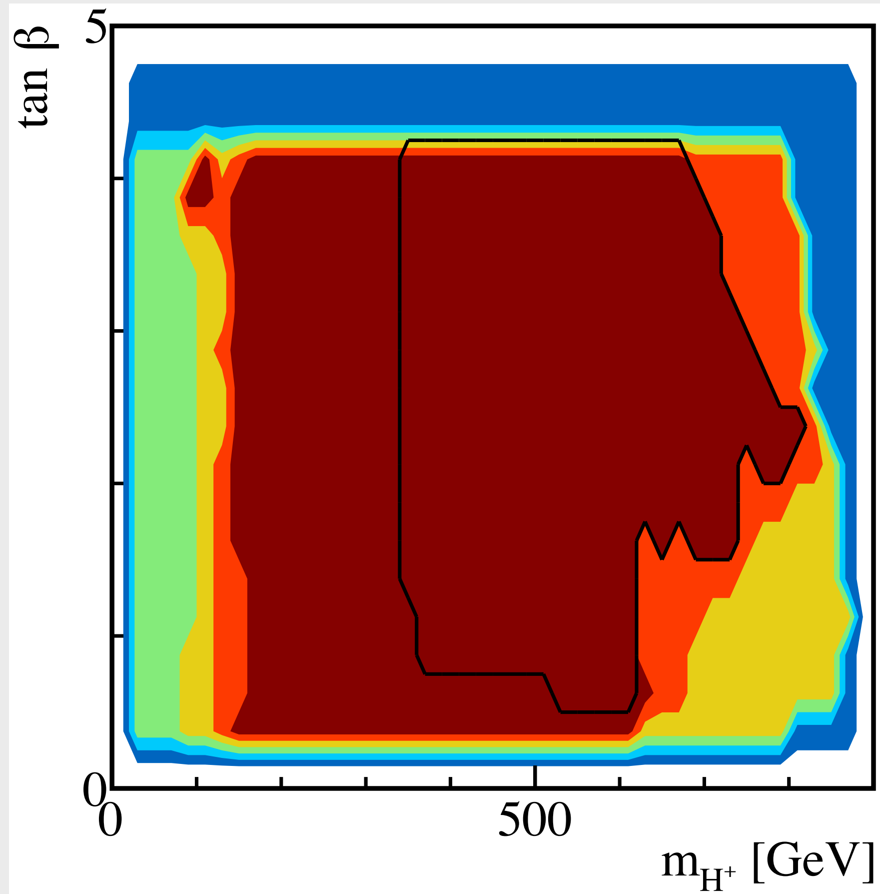


h^0 126 GeV: m_{Hpm} vs. $\tan\beta$

$\sin(\beta-\alpha)<0$

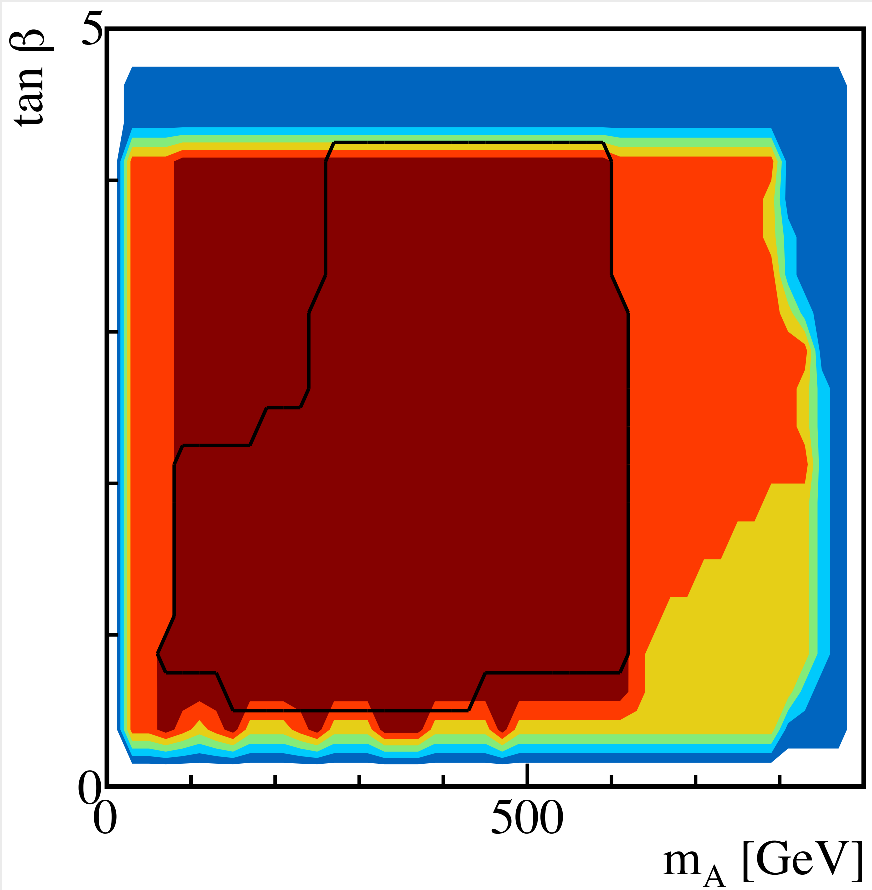


$\sin(\beta-\alpha)>0$

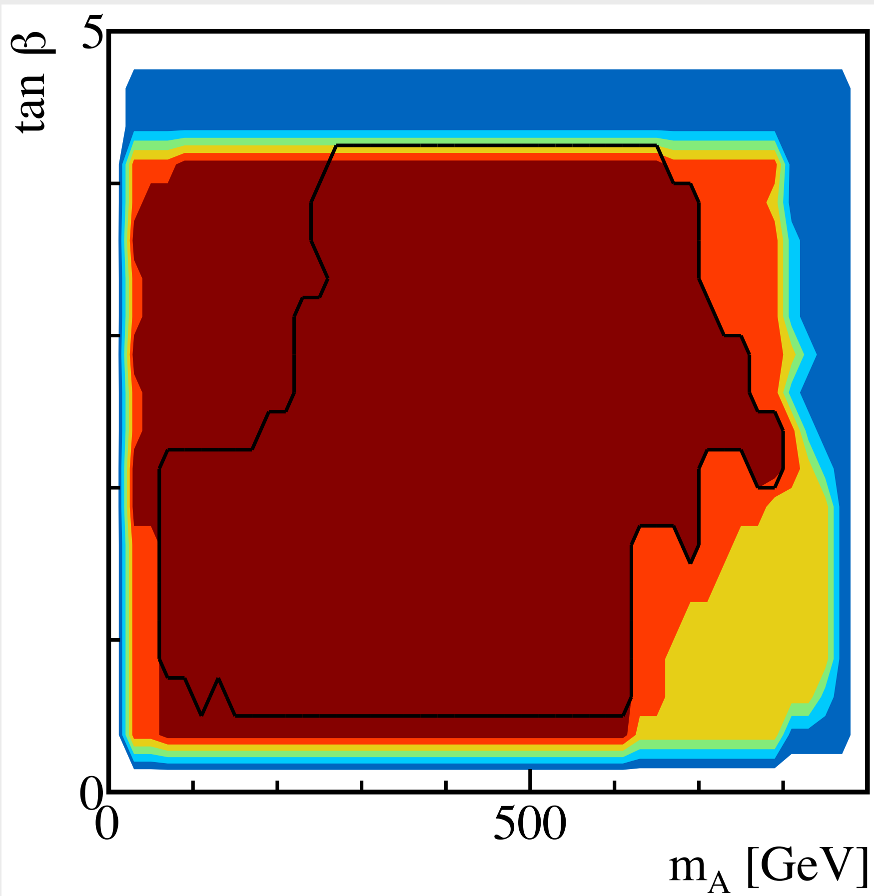


h^0 126 GeV: m_A vs. $\tan\beta$

$\sin(\beta-\alpha)<0$

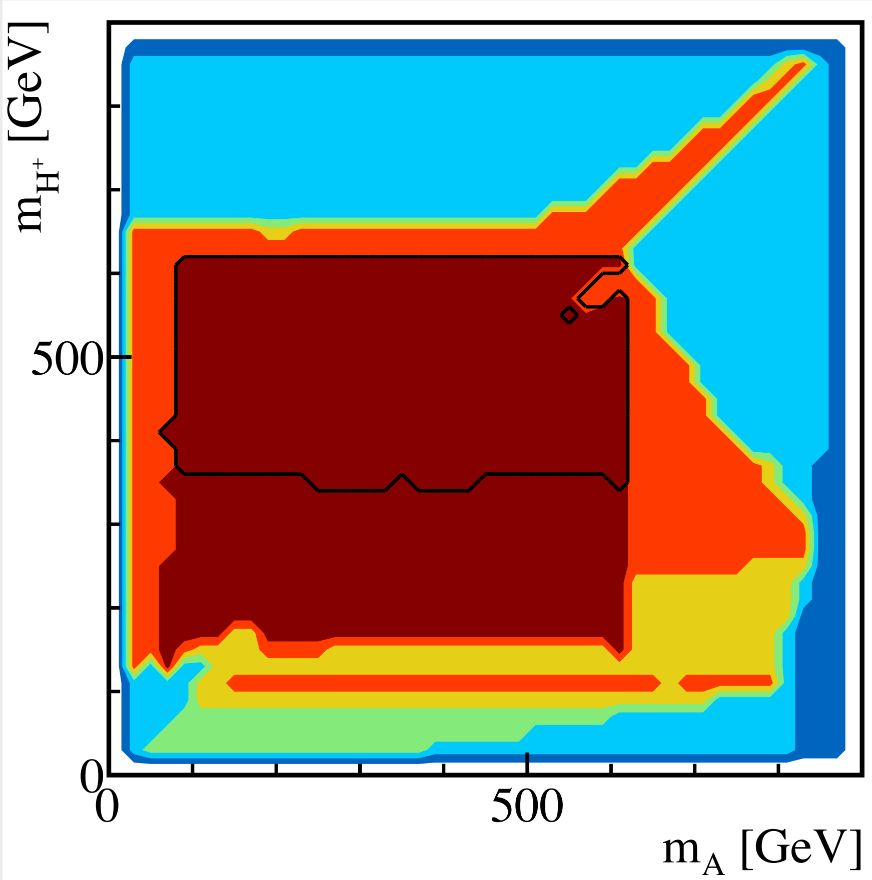


$\sin(\beta-\alpha)>0$

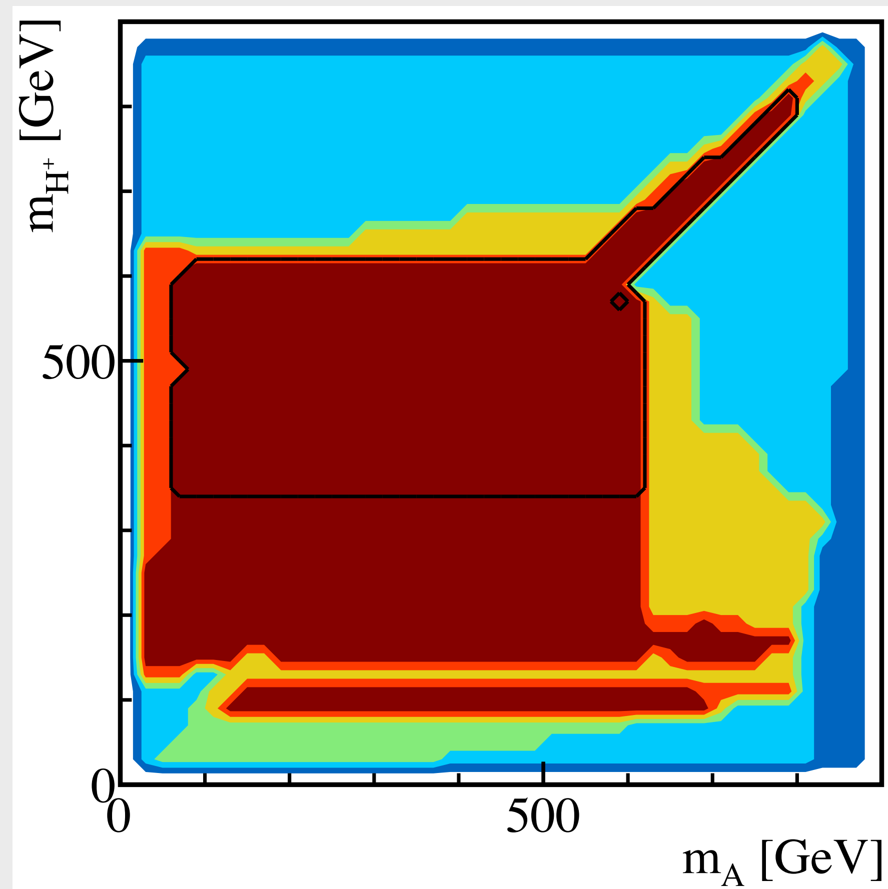


h^0 126 GeV: m_A vs. m_{Hpm}

sin(β-α)<0

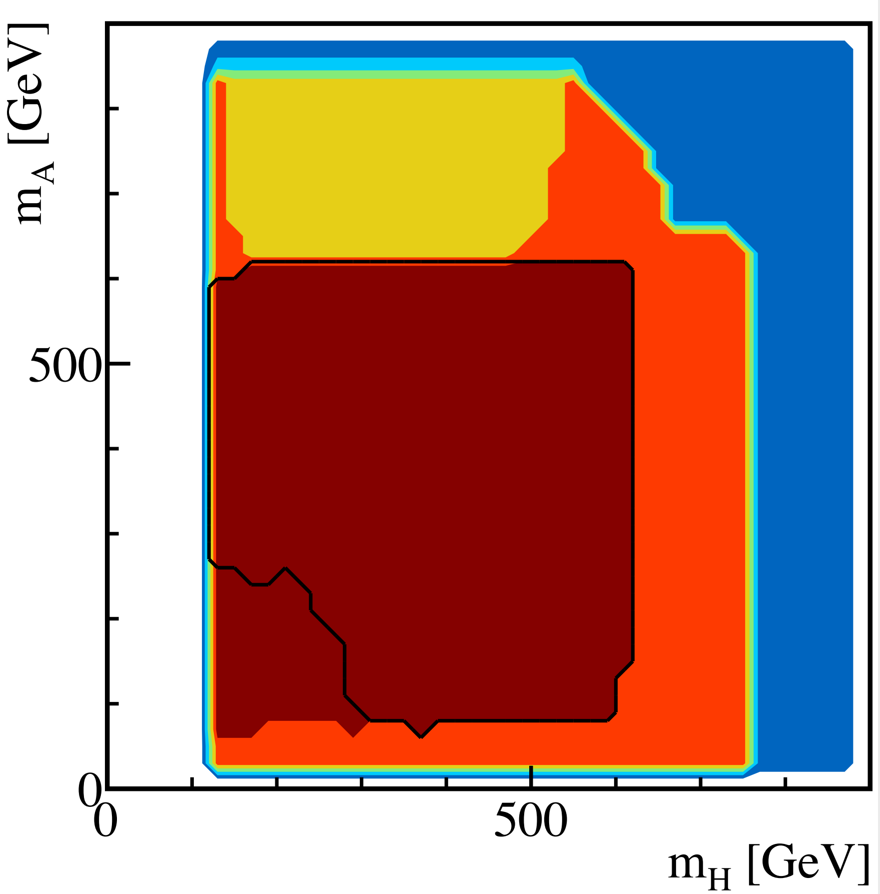


sin(β-α)>0

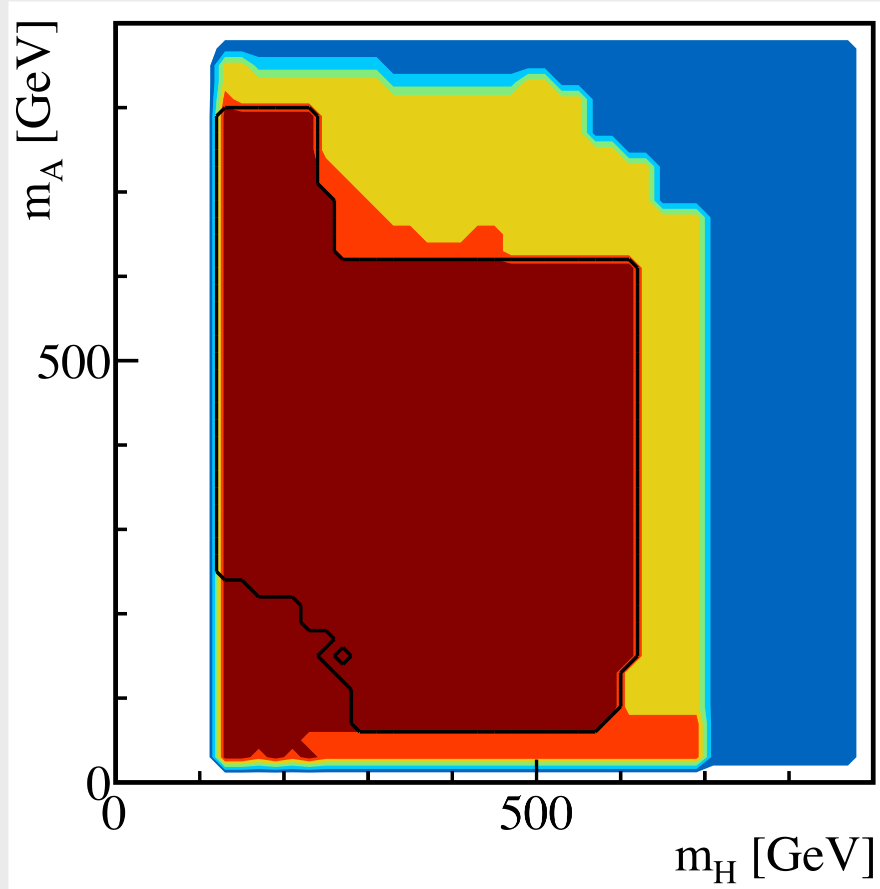


h^0 126 GeV: m_A vs. m_H

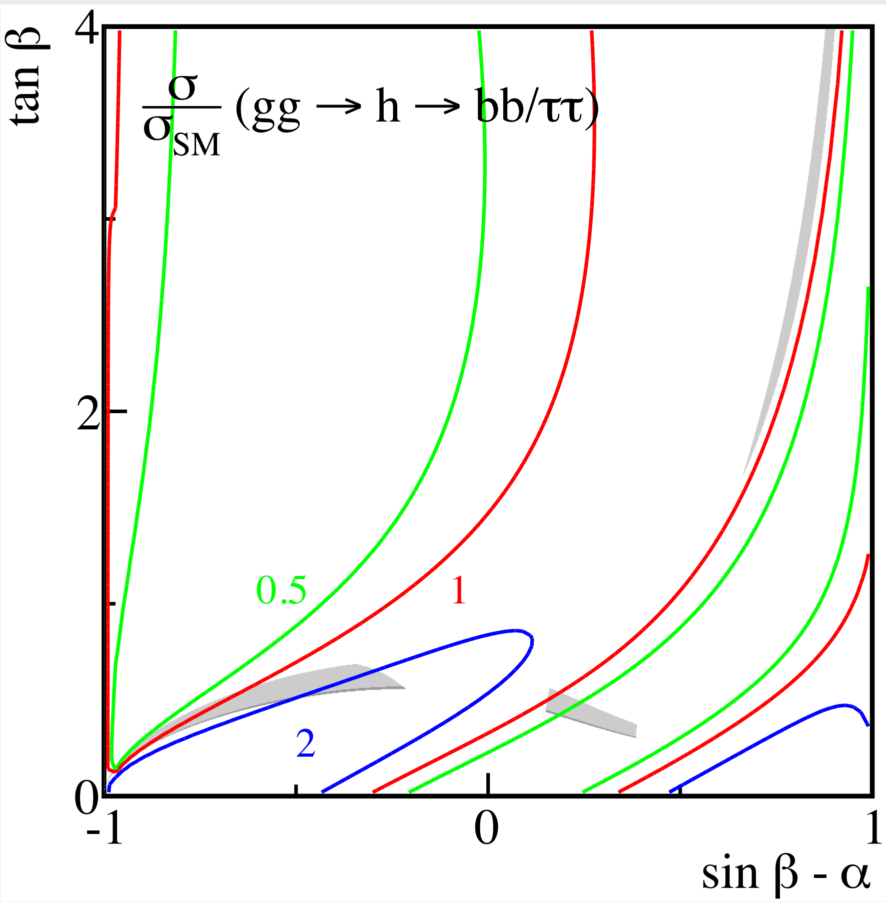
$\sin(\beta-\alpha)<0$

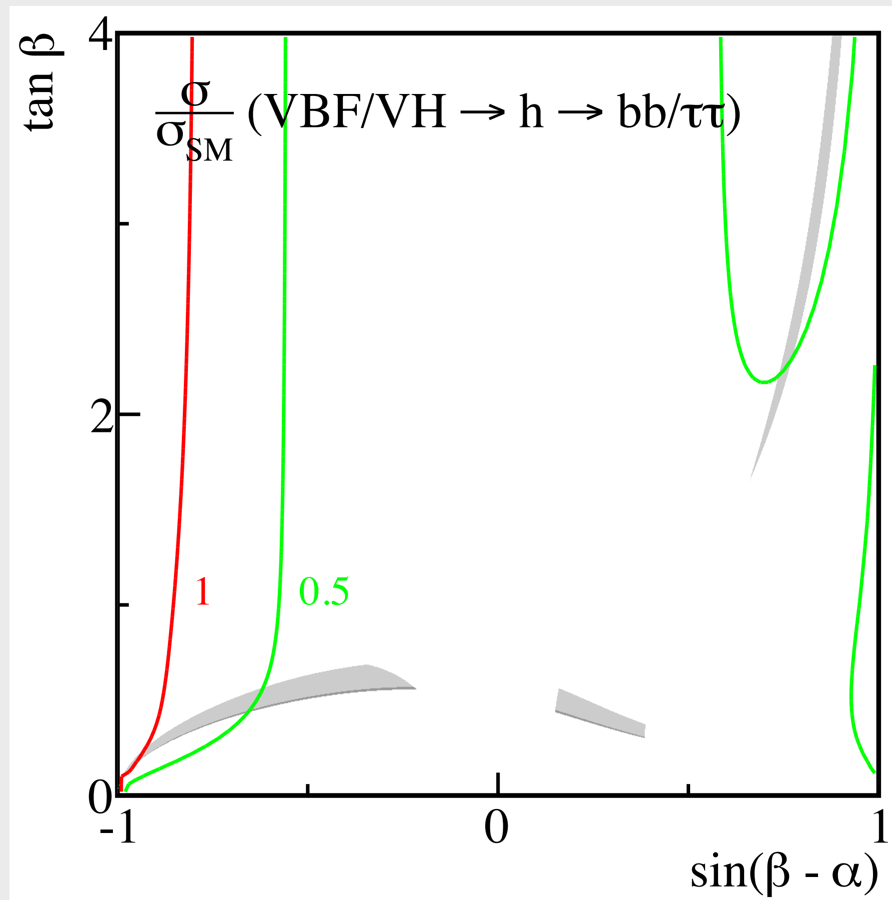


$\sin(\beta-\alpha)>0$

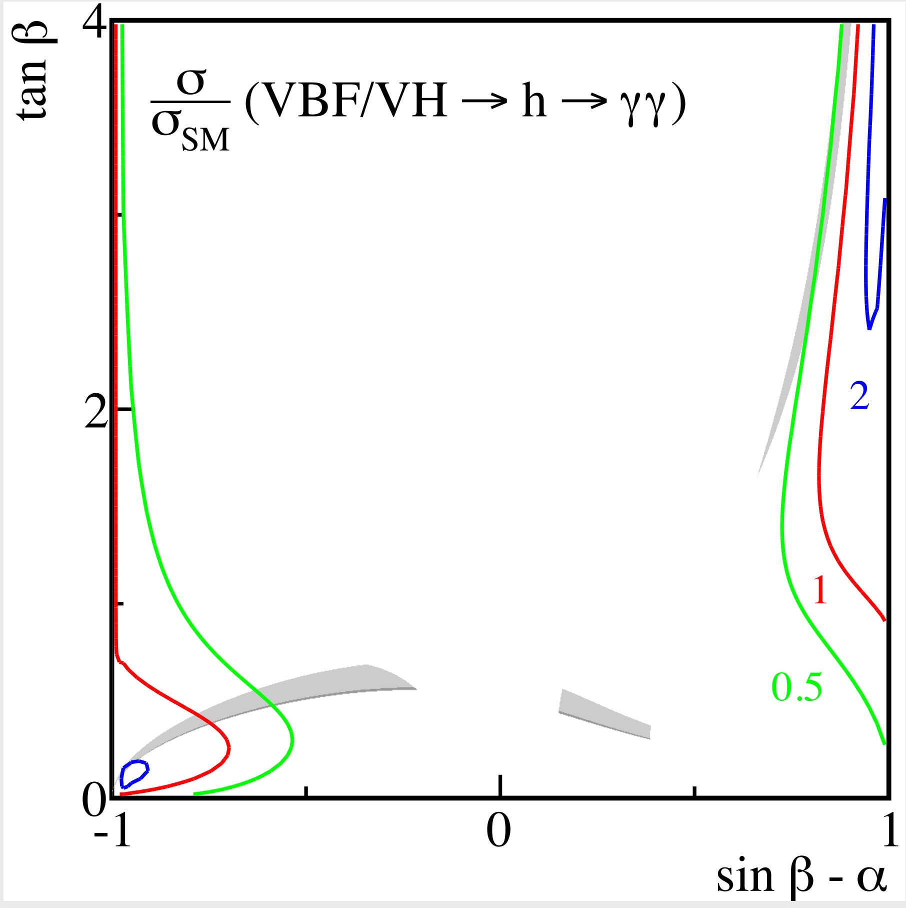


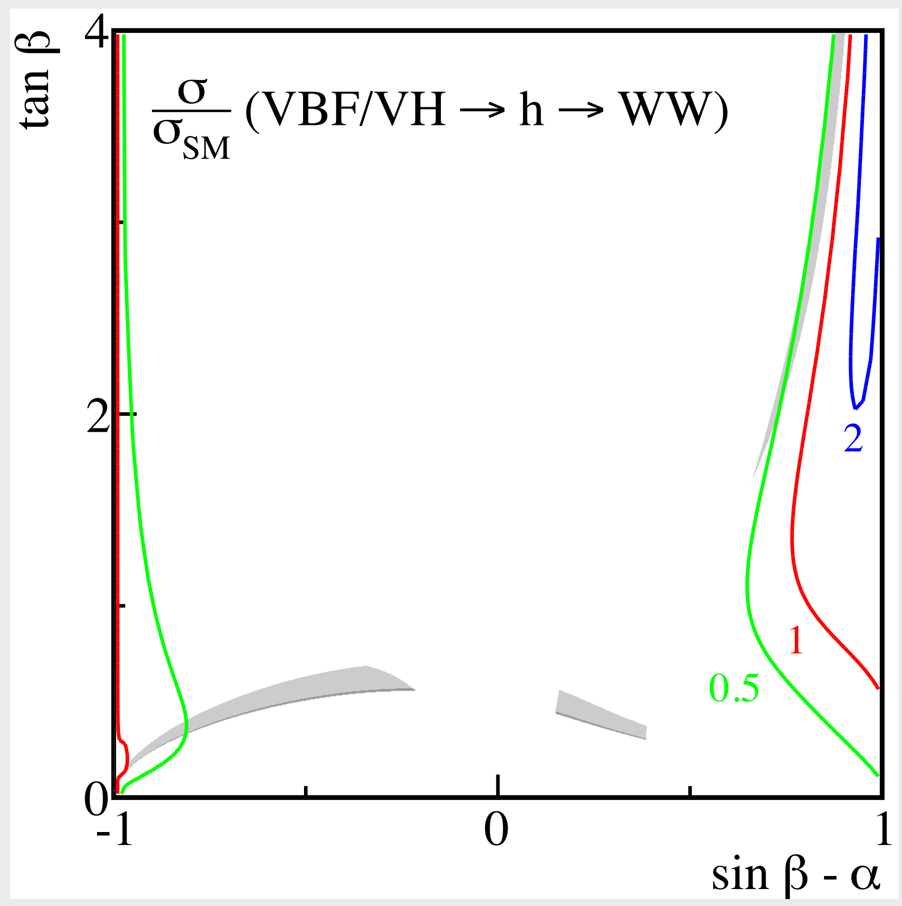
h^0 126 GeV: bb/ττ





h^0 126 GeV: γγ and WW/ZZ

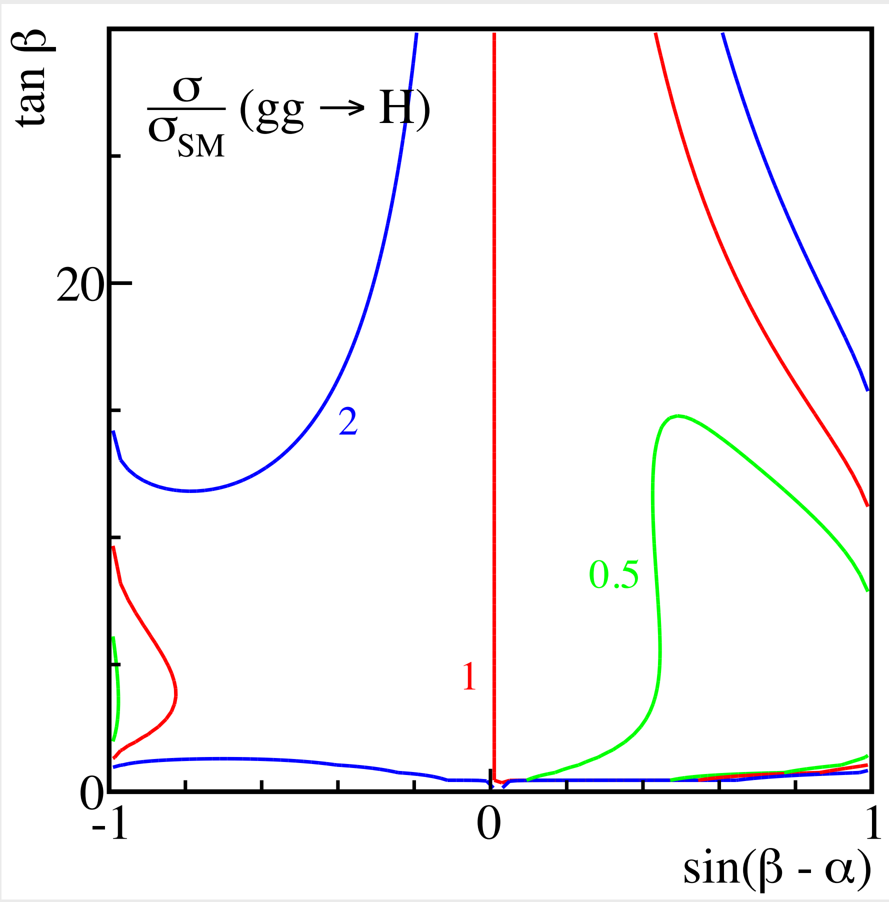


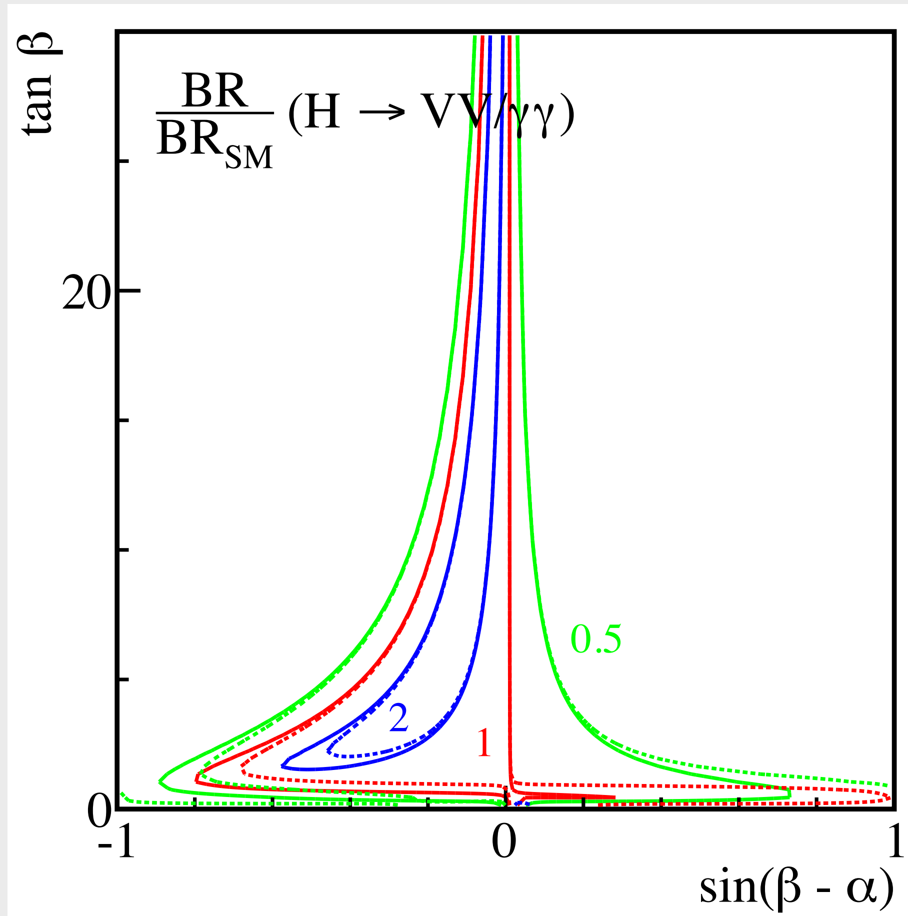


H^0 126 GeV

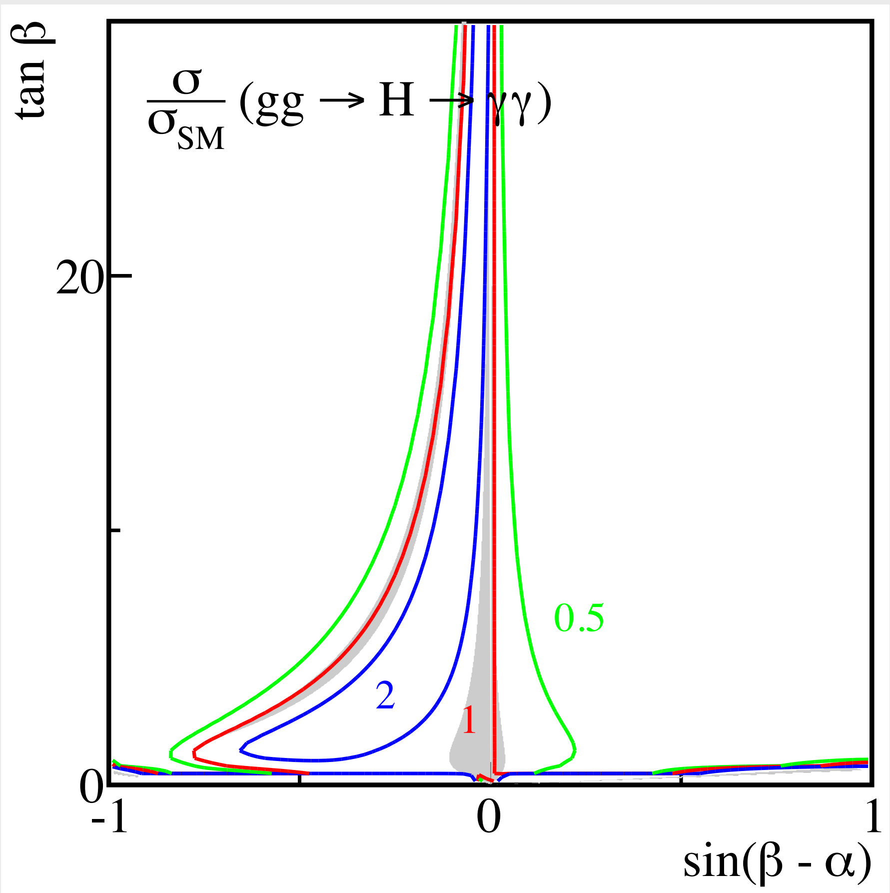
Heavy CP-even Higgs as 126 GeV SM-like Higgs

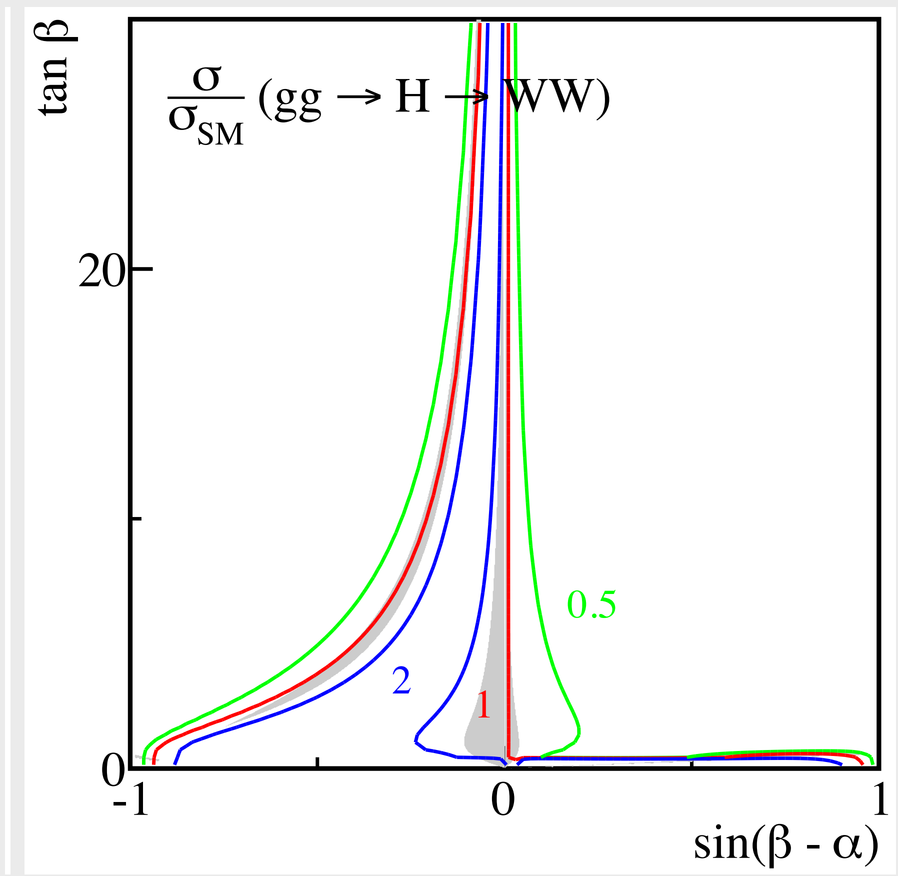
Type II 2HDM: H^0 126 GeV



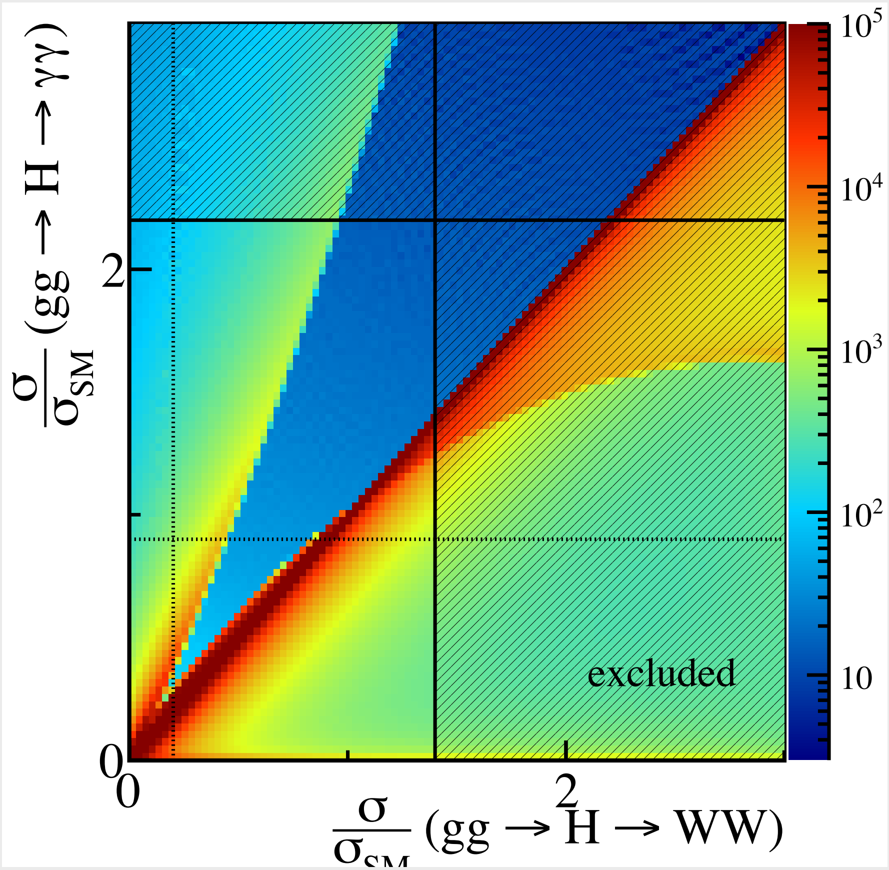


H^0 126 GeV: γγ and WW

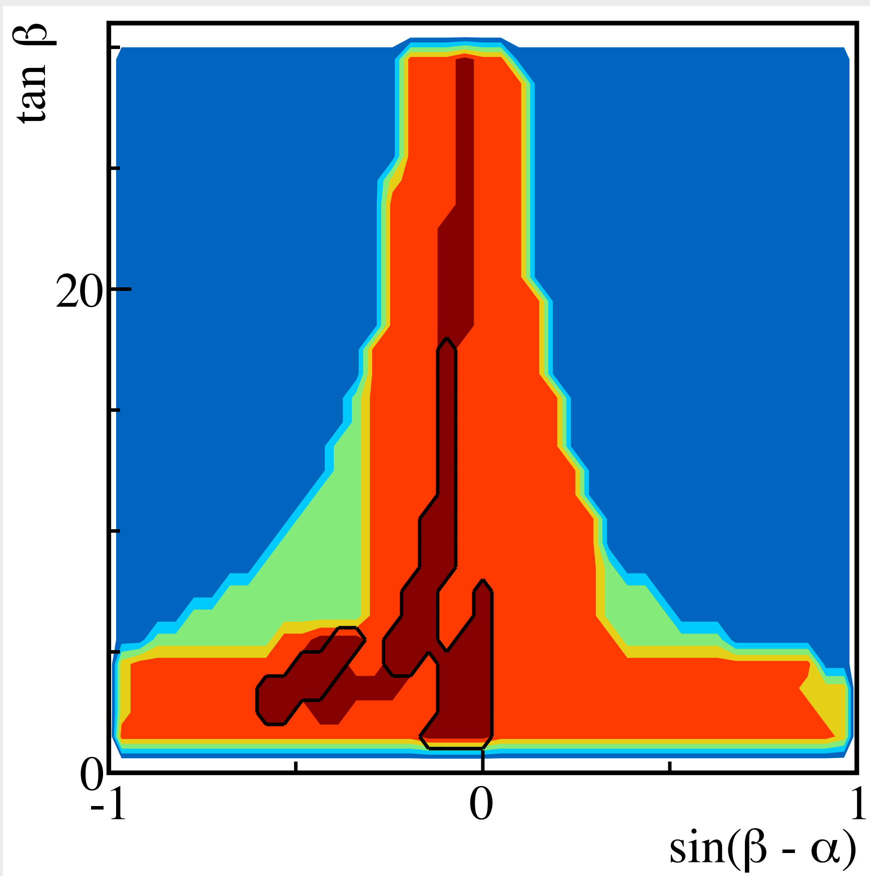




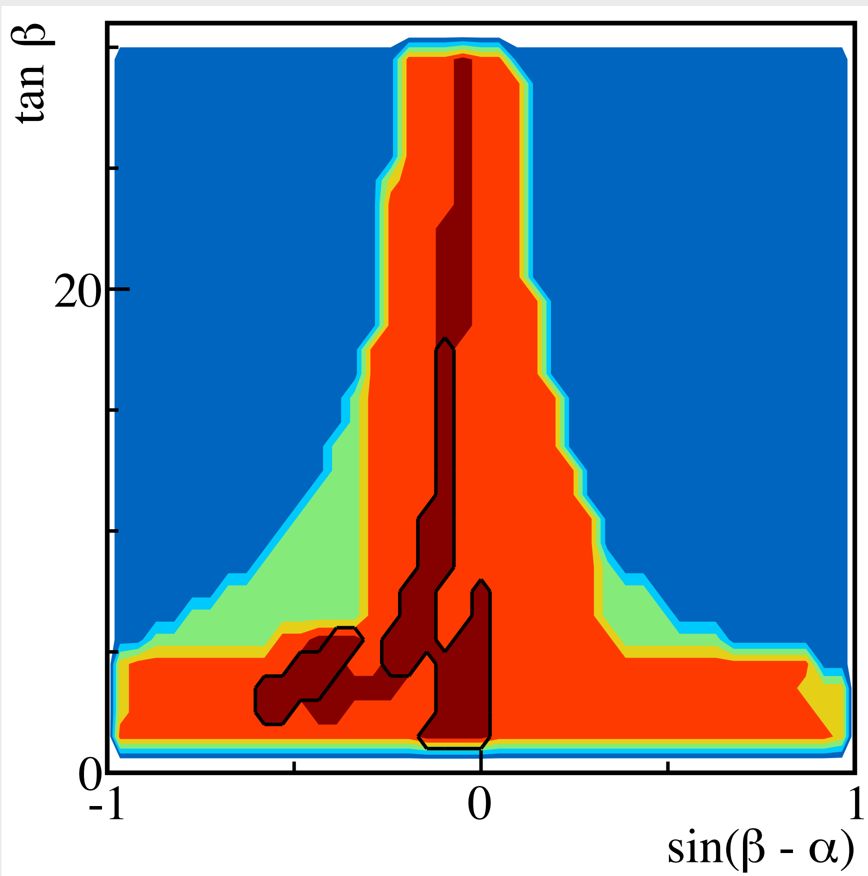
H^0 126 GeV: γγ vs. WW correlation

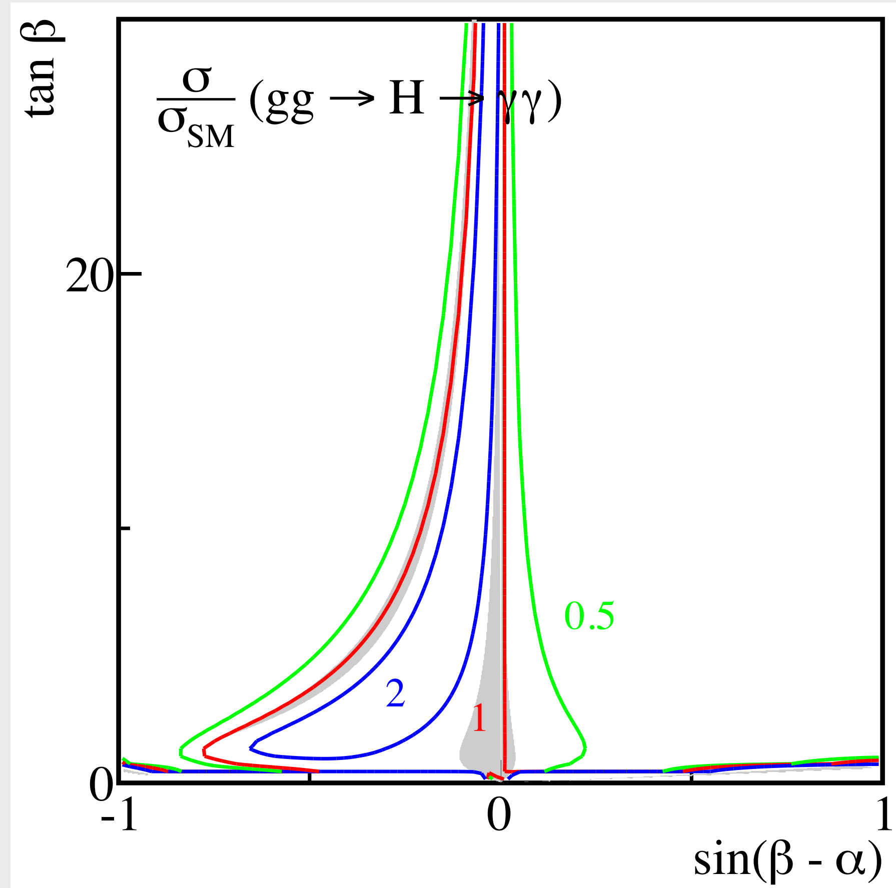


H^0 126 GeV: sin(β-α) vs. tan β

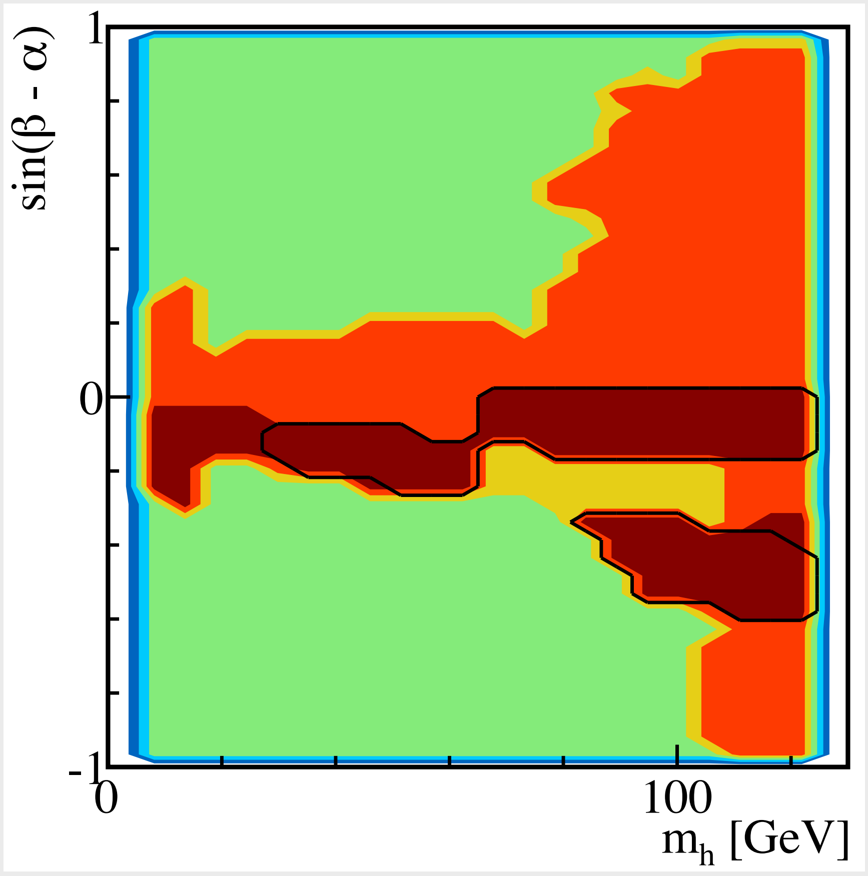


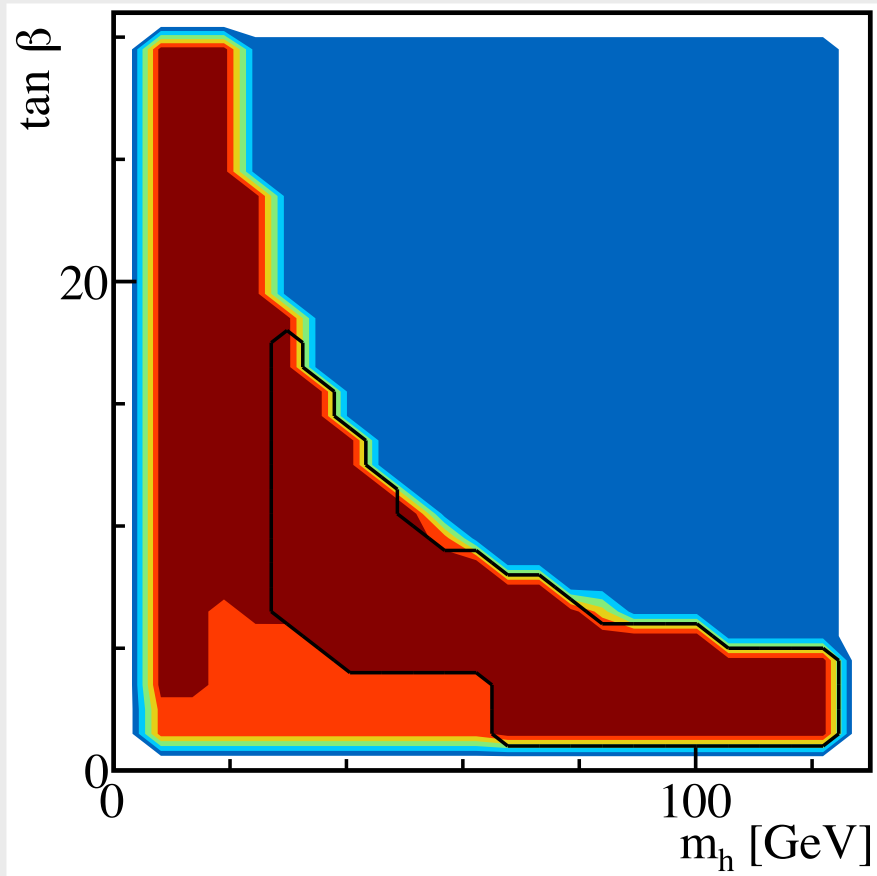
H^0 126 GeV: sin(β-α) vs. tan β



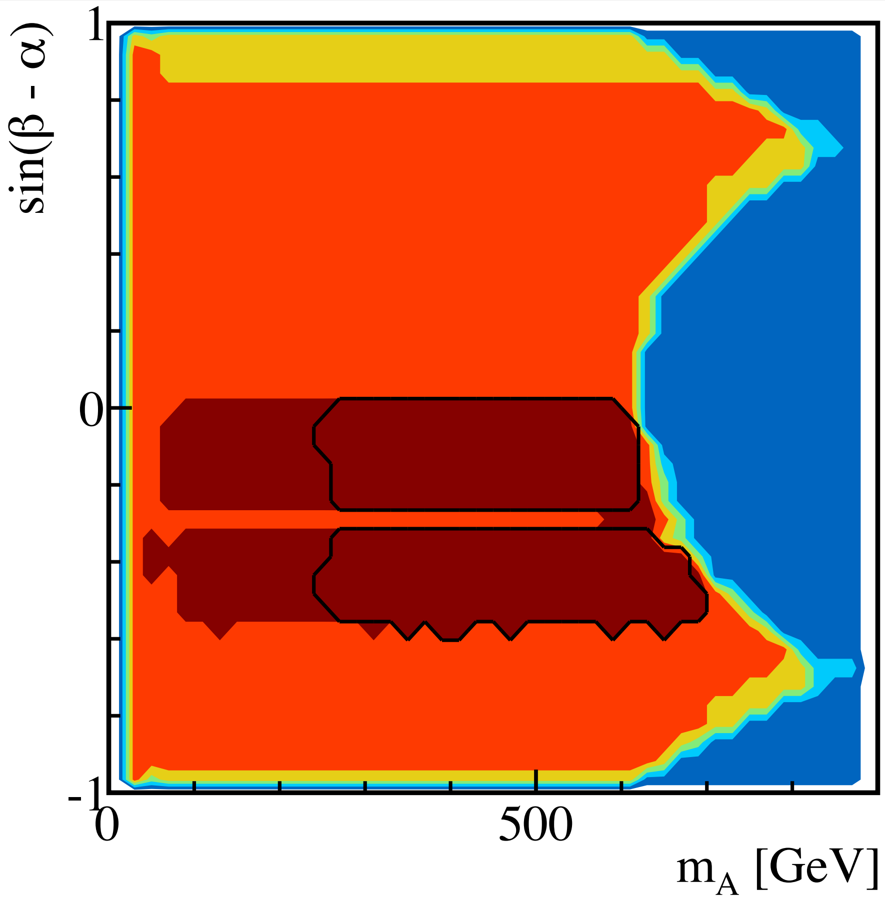


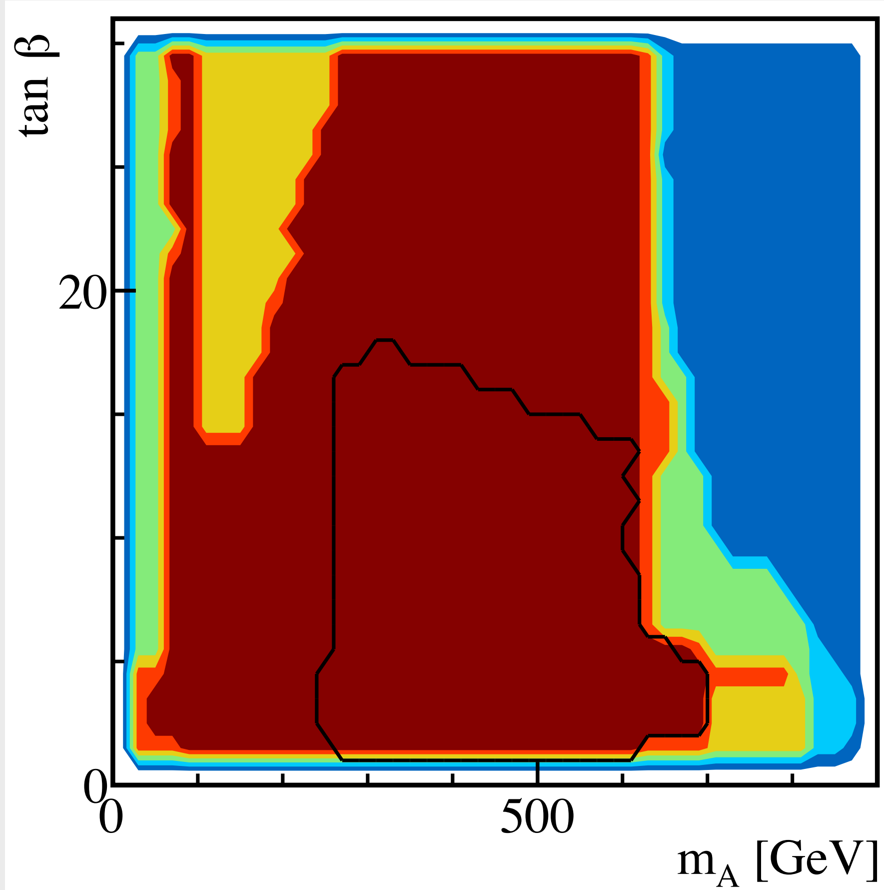
H^0 126 GeV: h^0



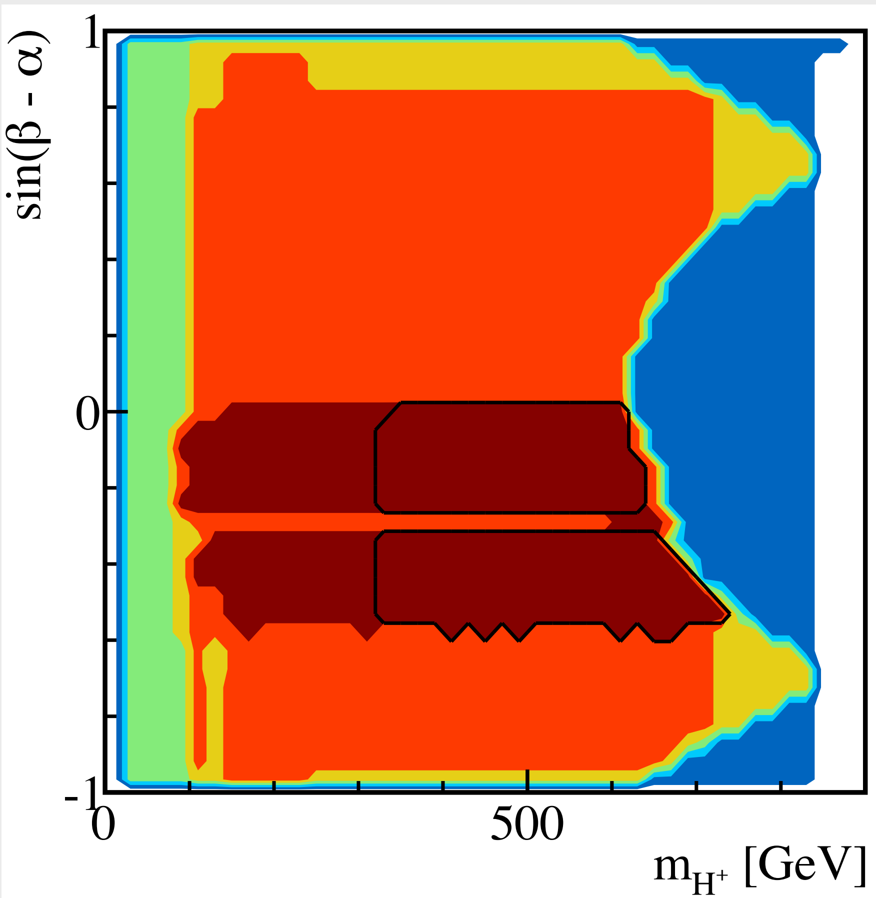


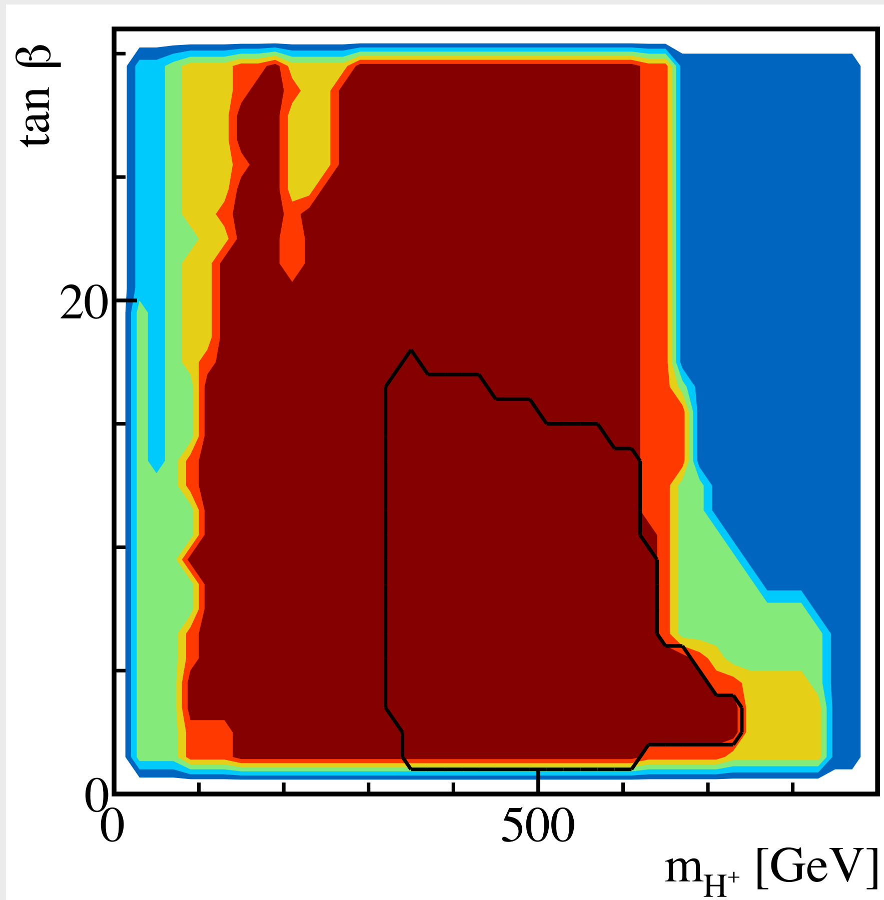
H^0 126 GeV: m_A vs. $\sin(\beta-\alpha)$, $\tan\beta$



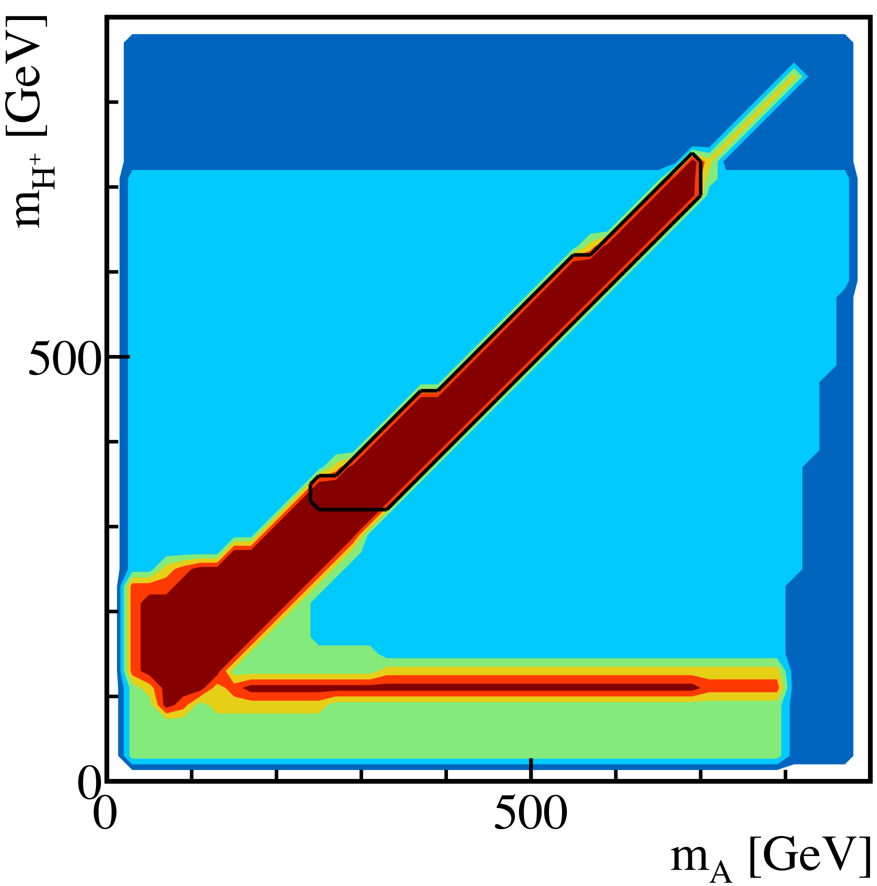


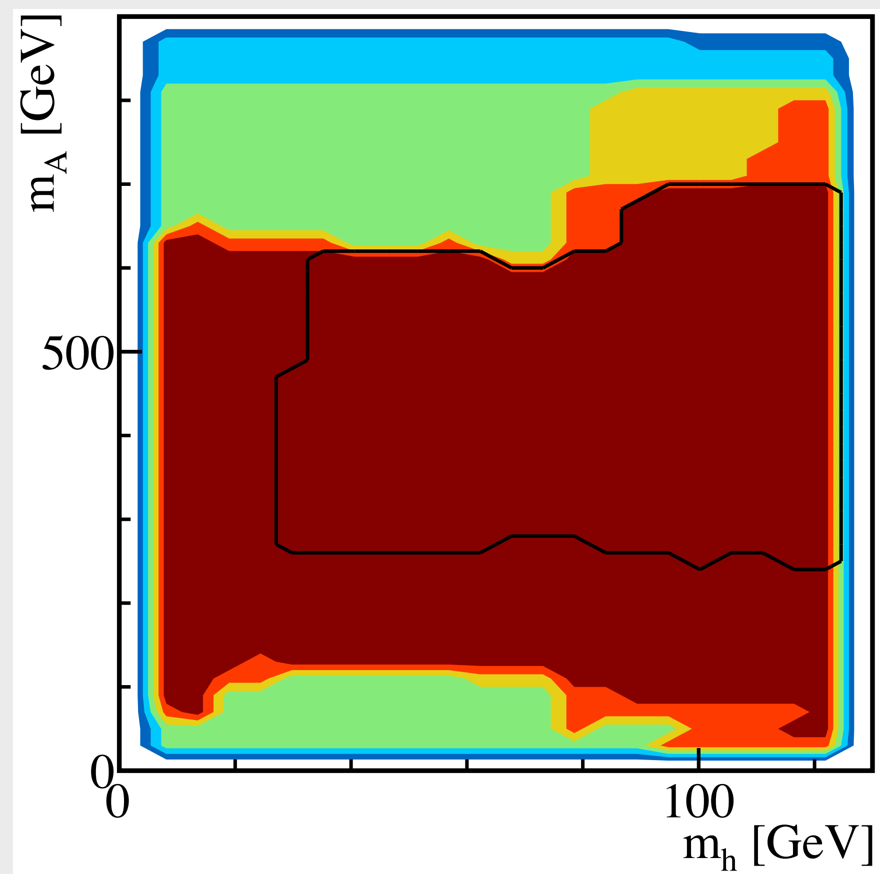
H^0 126 GeV: m_{Hpm} vs. $\sin(\beta-\alpha)$, $\tan\beta$



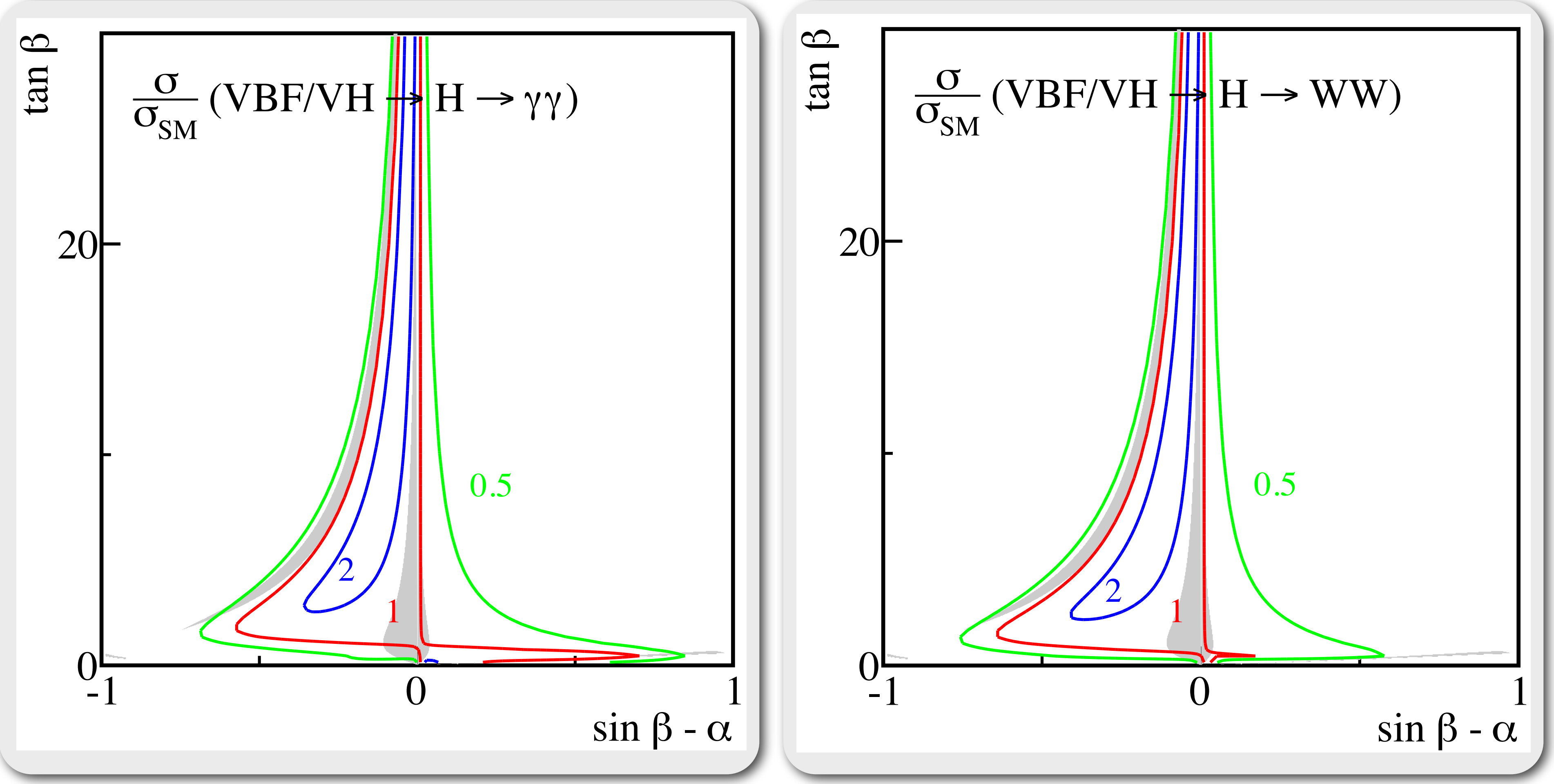


H^0 126 GeV: m_h vs. $m_{A/Hpm}$

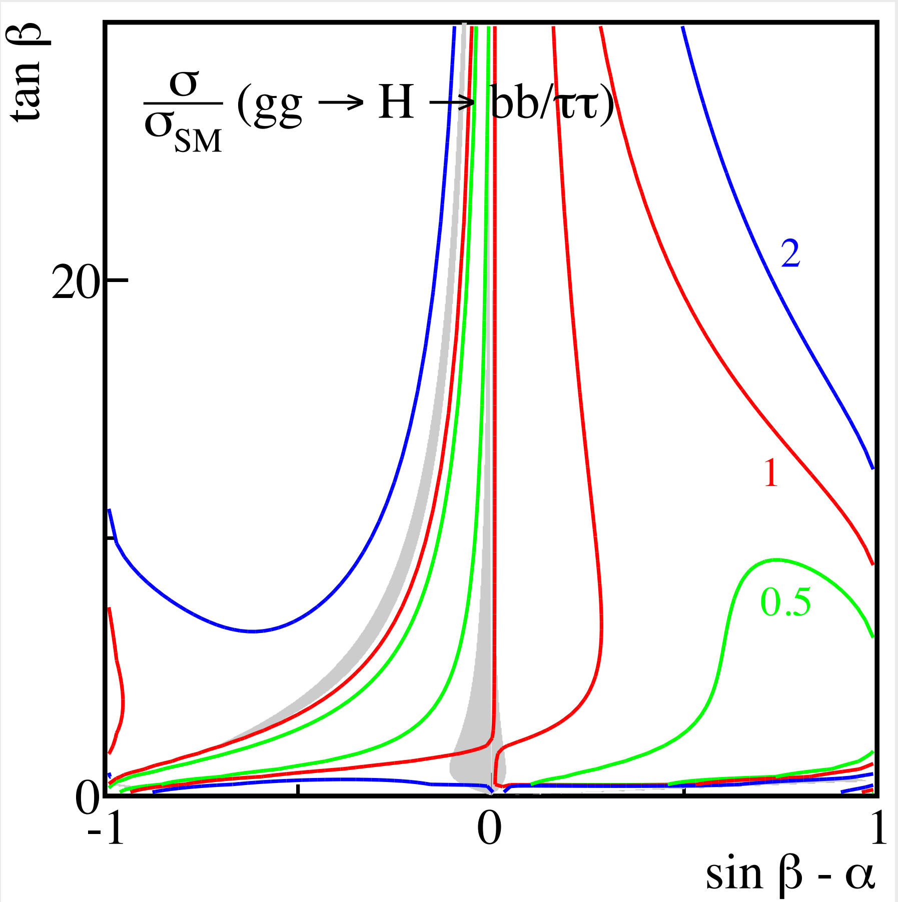


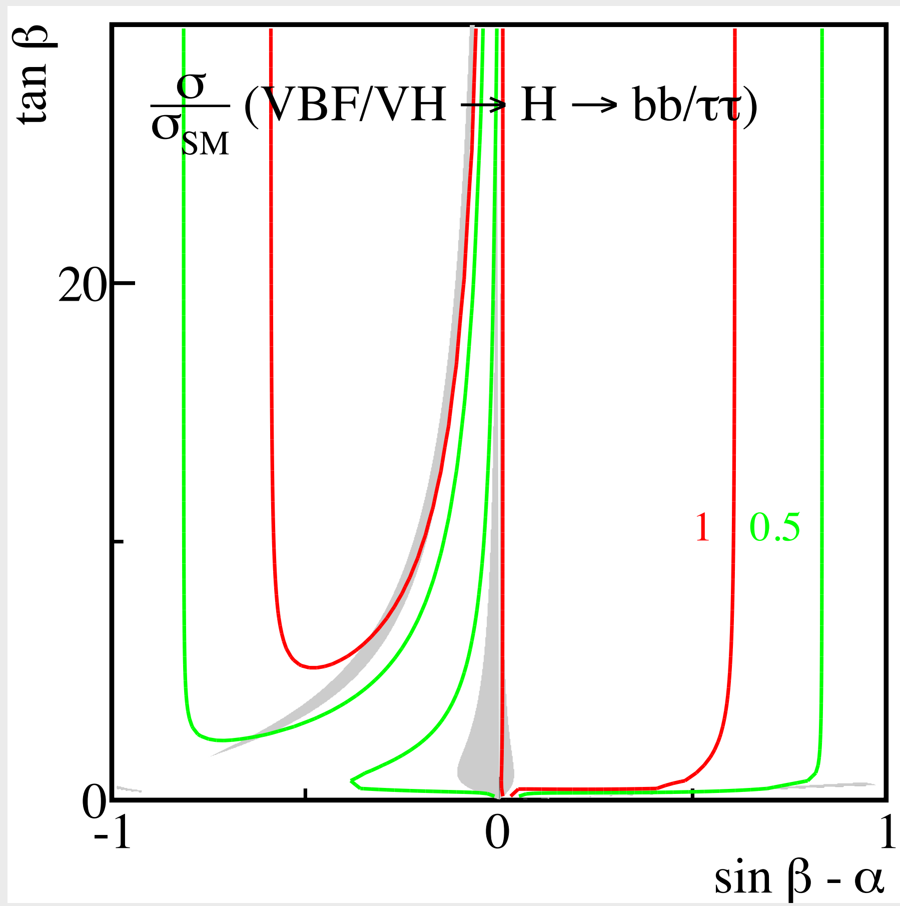


H^0 126 GeV: γγ and WW



H^0 126 GeV: bb and ττ





Conclusion (part II)

- 125 GeV (~SM strength) in Type II 2HDM
  - parameters and σ XBr study
- h^0 125 GeV
  - small tan $\beta \leq 4$
  - $\sin(\beta-\alpha)$ - tan β branches (with flavor)
  - correlations between m_H and tan β
  - correlation between m_A and m_{Hpm} for $\sin(\beta-\alpha)>0$
  - correlation between $\gamma\gamma$ and WW/ZZ
- H^0 125 GeV
  - accommodate large tan β
  - $\sin(\beta-\alpha) \leq 0$ versus tan β branch (with flavor)
  - m_h up to 126 GeV possible, with small m_h for $\sin(\beta-\alpha) \leq 0$
  - correlation between m_A and m_{Hpm}
  - correlation between $\gamma\gamma$, WW/ZZ