Constraining Type II 2HDM in Light of LHC Higgs Searches

work with Baradhwaj Coleppa, Shufang Su
[arXiv:1305.0002]

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Type II 2HDM

Two Higgs-Doublet Model

- two scalar doublets Φ_1 and Φ_2 with $\Phi_i = \begin{pmatrix} \phi_i^+ \\ (v_i + \phi_i^0 + iG_i)/\sqrt{2} \end{pmatrix}$
- Higgs potential:

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

Type II 2HDM

Two Higgs-Doublet Model

- two scalar doublets Φ_1 and Φ_2 with $\Phi_i = \begin{pmatrix} \phi_i^+ \\ (v_i + \phi_i^0 + iG_i)/\sqrt{2} \end{pmatrix}$
- impose a discrete Z_2 symmetry: $m_{12}, \lambda_6, \lambda_7 = 0$

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

- model described by masses and mixing angles

  CP-even Higgses: h^0, H^0 — Ratio of vev: $\tan\beta = v_2/v_1$

  CP-odd Higgs: A^0 — Mixing between CP-even Higgses: $\sin\alpha$

  Charged Higgses: $H^\pm$

Coupling for Type II 2HDM

- coupling normalized by SM-value: ξ_{H_i}

	couples to	ξ_h	ξ_H	ξ_A
u	Φ_2	$\cos\alpha/\sin\beta$	$\sin\alpha/\sin\beta$	$\cot\beta$
d, l	Φ_1	$-\sin\alpha/\cos\beta$	$\cos\alpha/\cos\beta$	$\tan\beta$
V		$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0

Type II 2HDM

Previous work in 2HDM

- Ferreira et. al., 2HDM, H1 125, $\tan\beta$ vs. $\sin\alpha$ [arXiv:1112.3772]
- Basso et. al., CP violating 2HDM, H1 125 [arXiv:1205.6569]
- Cheon et. al., Type II 2HDM, H1 or H2 125 [arXiv:1207.1083]
- Chang et. al., 2HDM, H1 or H2 or degenerate H1/A, χ^2 fit [arXiv:1210.3439]
- Drozd et. al., Type I and II 2HDM, H1 or H2 125 or degenerate, $m_{12}^2 \neq 0$, [arXiv:1211.3580]
- Craig and Thomas, 2HDM, H1 125, various search channels [arXiv:1207.4835]
- Ferreira et. al., degenerate Higgses [arXiv:1211.3131]
- Dawson et. al., 2HDM Higgs production [arXiv:1301.0309]
- Grinstein et. al., 2HDM, H1 125 [arXiv:1304.0028]

Our work

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

Constraints

Theoretical Contraints

- implemented by 2HDMC [arXiv:0902.0851]
- **Vaccuum Stability:** potential bounded from below
- **Perturbativity:** quartic Higgs couplings inside the perturbative regime
- **Unitarity:** tree level unitarity for scattering of Higgs and V_L
- $\Delta\rho$: $\rho_0 \equiv \frac{m_W^2}{\rho\ m_Z^2 \cos^2\theta_W} = 1 + \Delta\rho_0^{\text{new}}$ [J. Phys. G **37**, 075021 (2010)]

$$0.0001 \leq \Delta\rho_0^{\text{new}} \leq 0.0025$$

Experimental Contraints

- **Higgs searches:** LEP, Tevatron and LHC Higgs searches implemented by HIGGSBOUNDS 3.8 [arXiv:0811.4169]
- **Signal Region:** $0.9 < \sigma \times \text{Br}/\text{SM}(gg \to h^0/H^0 \to \gamma\gamma) < 2.2$

  $0.2 < \sigma \times \text{Br}/\text{SM}(gg \to h^0/H^0 \to VV) < 1.4$

- **Flavor:** Flavor constraints implemented by SuperIso [arXiv:0808.3144]

$$B \to X_s\gamma,\ \Delta M_{B_d},\ D_s \to \tau\nu_\tau \text{ and } B \to \mu^+\mu^-$$

Analysis Method

Parameter scan

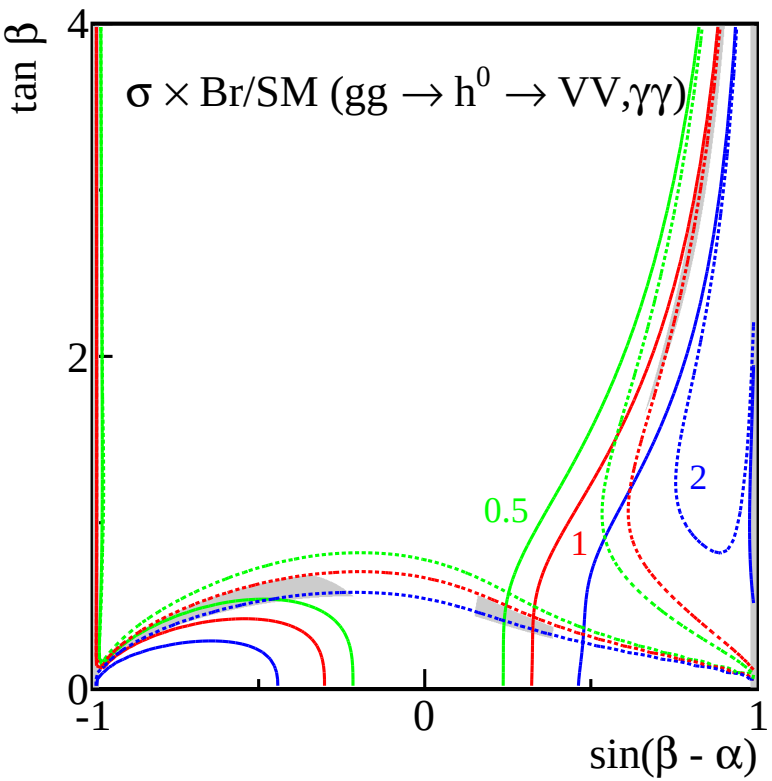
$h^0 - 126$

$$0.25 < \tan\beta < 5$$
$$-1 < \sin(\beta - \alpha) < 1$$
$$126\ \text{GeV} < m_H < 900\ \text{GeV}$$
$$20\ \text{GeV} < m_A, m_{H^+} < 900\ \text{GeV}$$

$H^0 - 126$

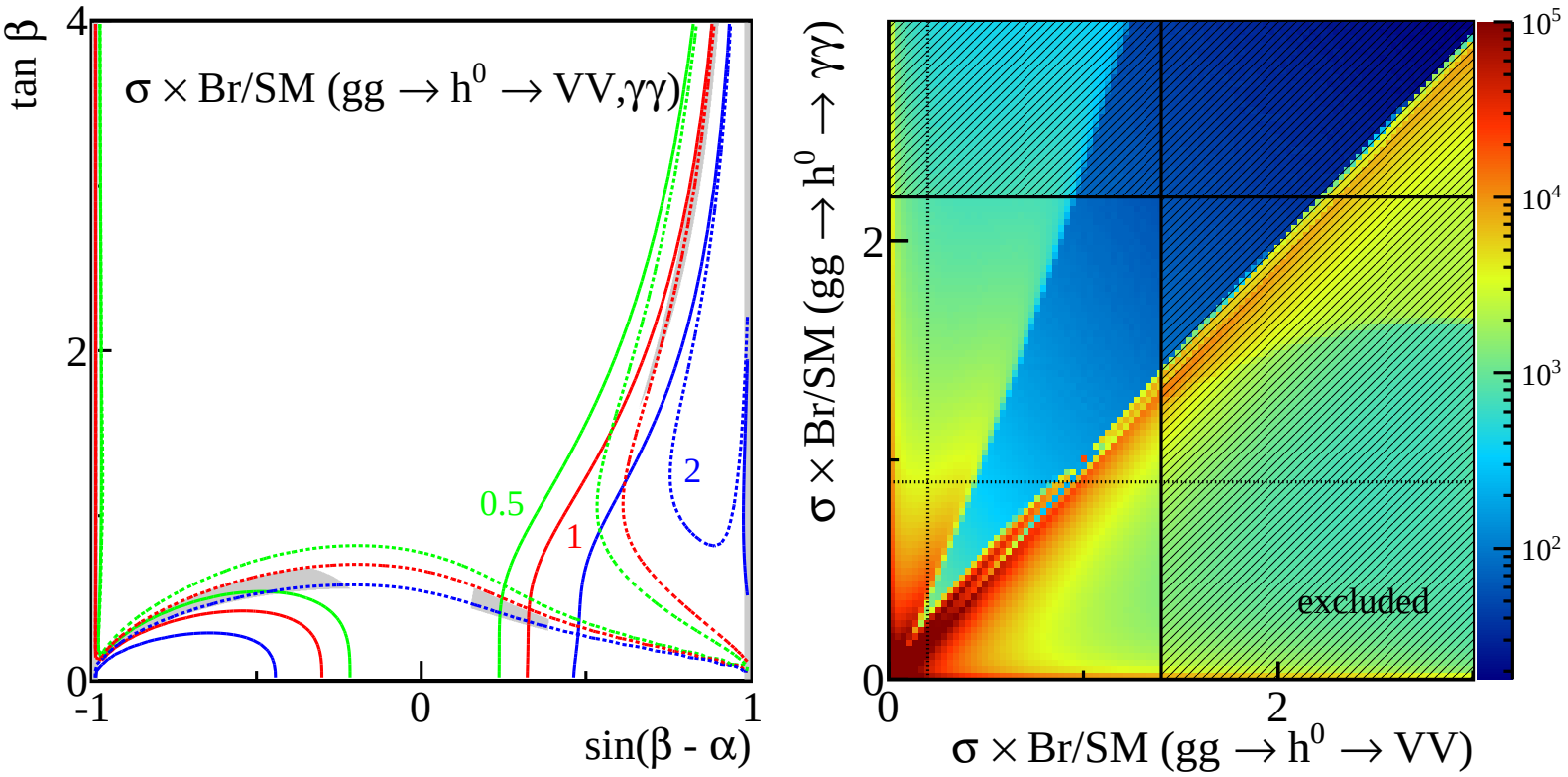
$$1 < \tan\beta < 30$$
$$-1 < \sin(\beta - \alpha) < 1$$
$$5\ \text{GeV} < m_h < 125\ \text{GeV}$$
$$20\ \text{GeV} < m_A, m_{H^+} < 900\ \text{GeV}$$

h^0-126



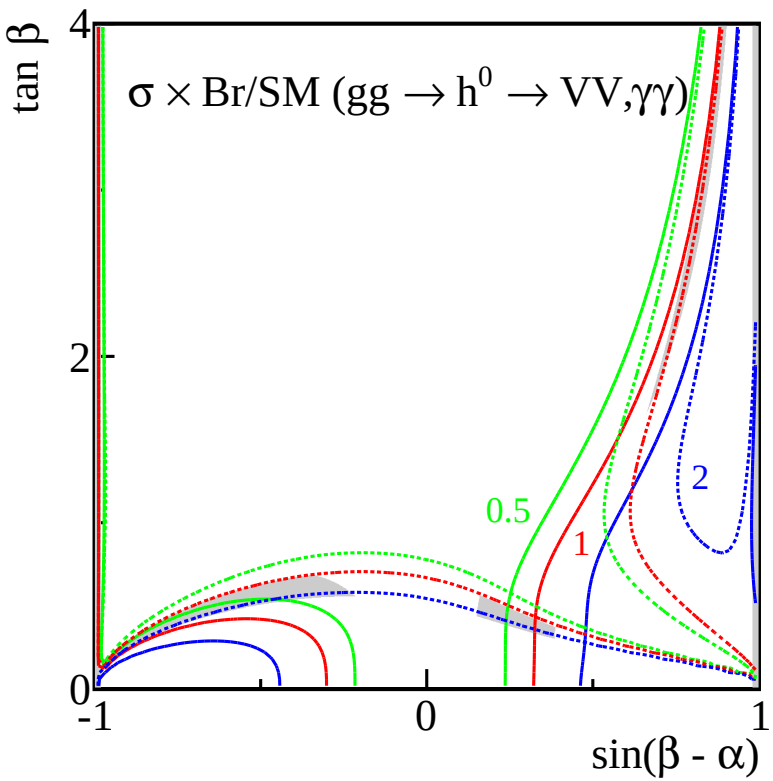
- signal region (gray area) splits into five distinct regions

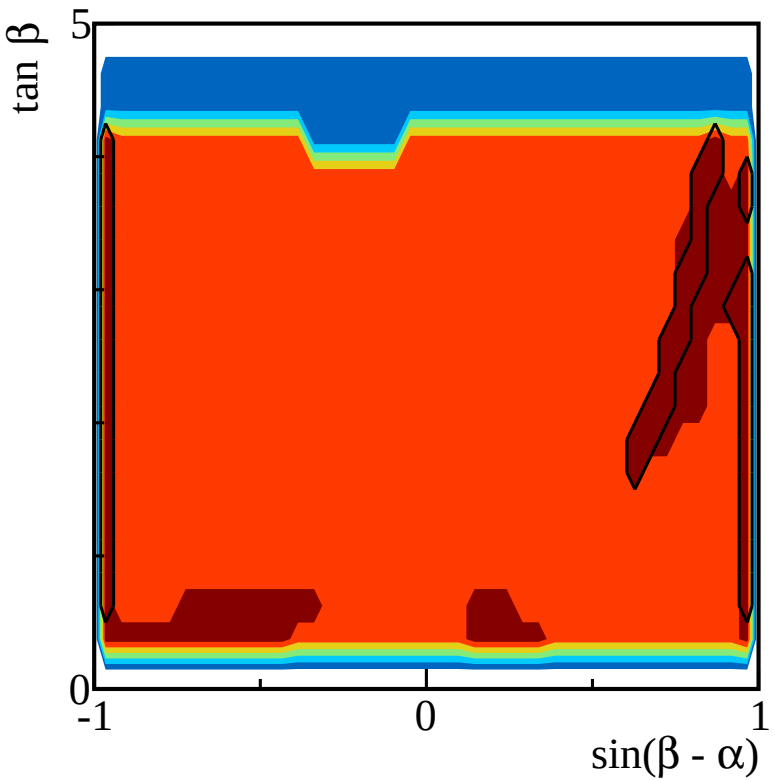
h^0-126



- signal region (gray area) splits into five distinct regions
- most likely: $\gamma\gamma : VV \approx 1$

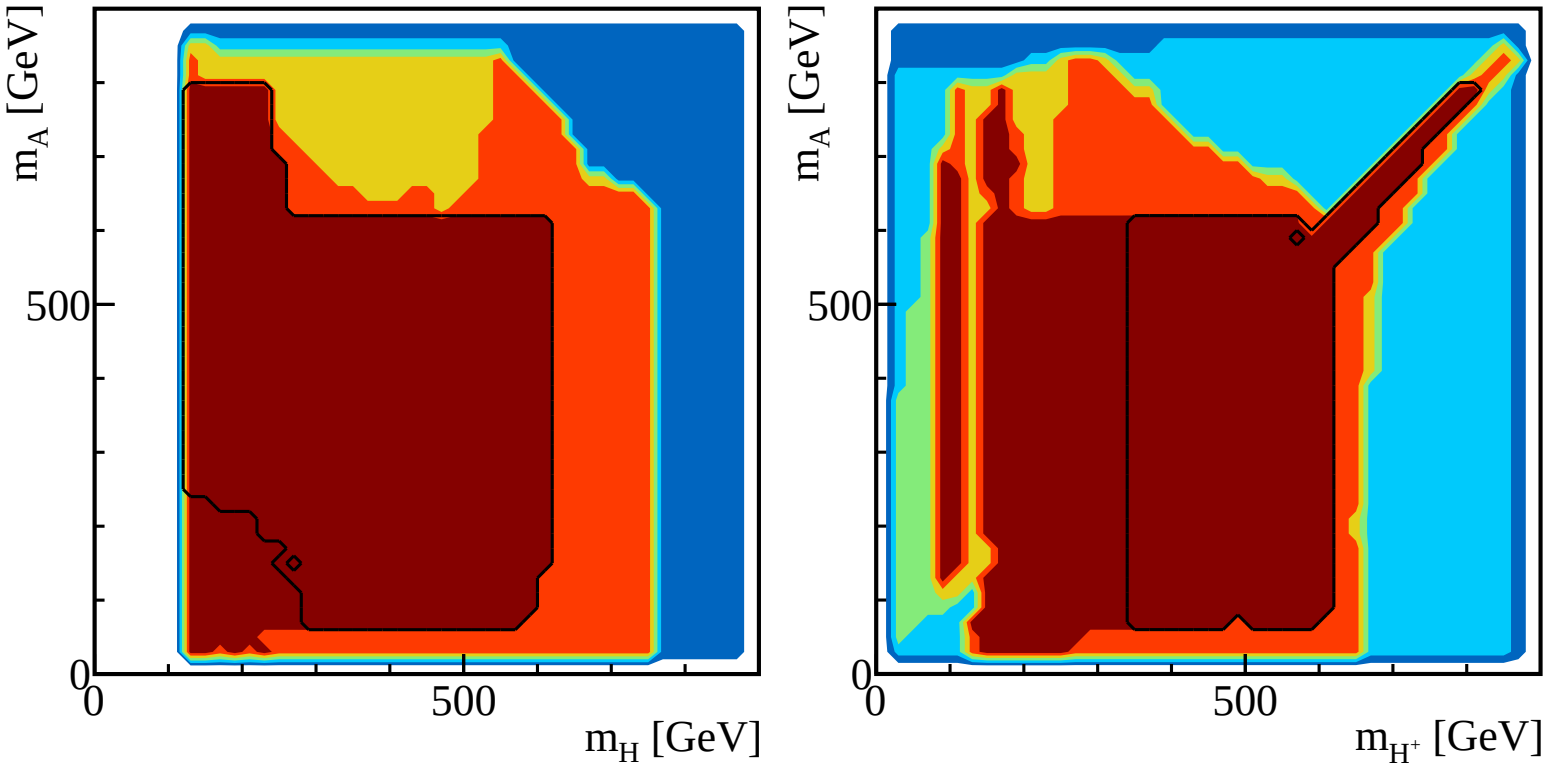
h^0-126





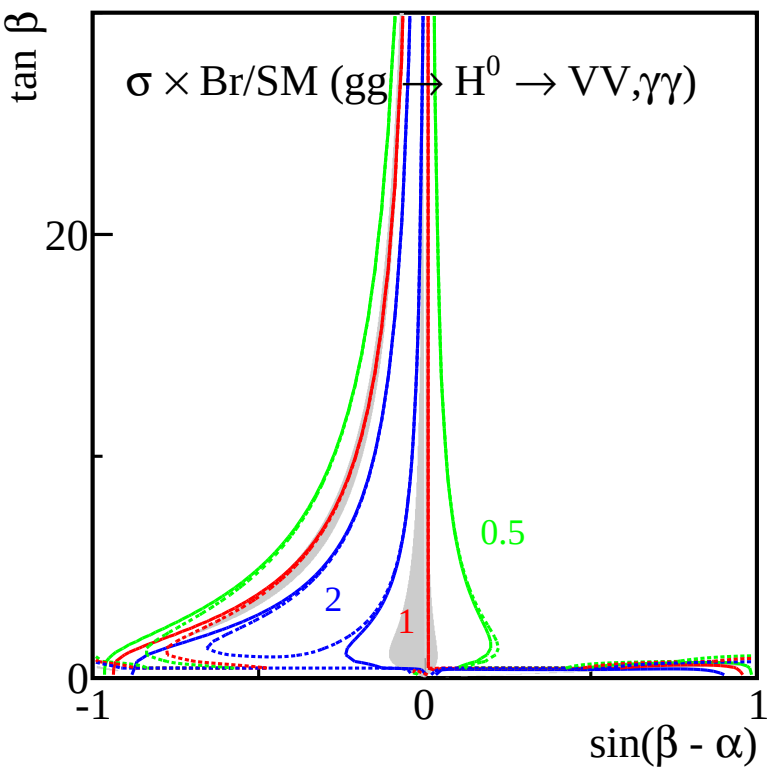
- signal region (gray area) splits into five distinct regions
- most likely: $\gamma\gamma$: $VV \approx 1$
- simulation agrees with theoretical prediction
- $\tan\beta > 4$ excluded by perturbativity
- flavor constraints reduce signal region to $\sin(\beta - \alpha) \approx \pm 1$

h^0-126



- flavor constraints reduce signal region to $\sin(\beta - \alpha) \approx \pm 1$
- $m_H > 750$ GeV and $m_A, m_{H^+} > 800$ GeV excluded by perturbativity
- masses mostly uncorrelated

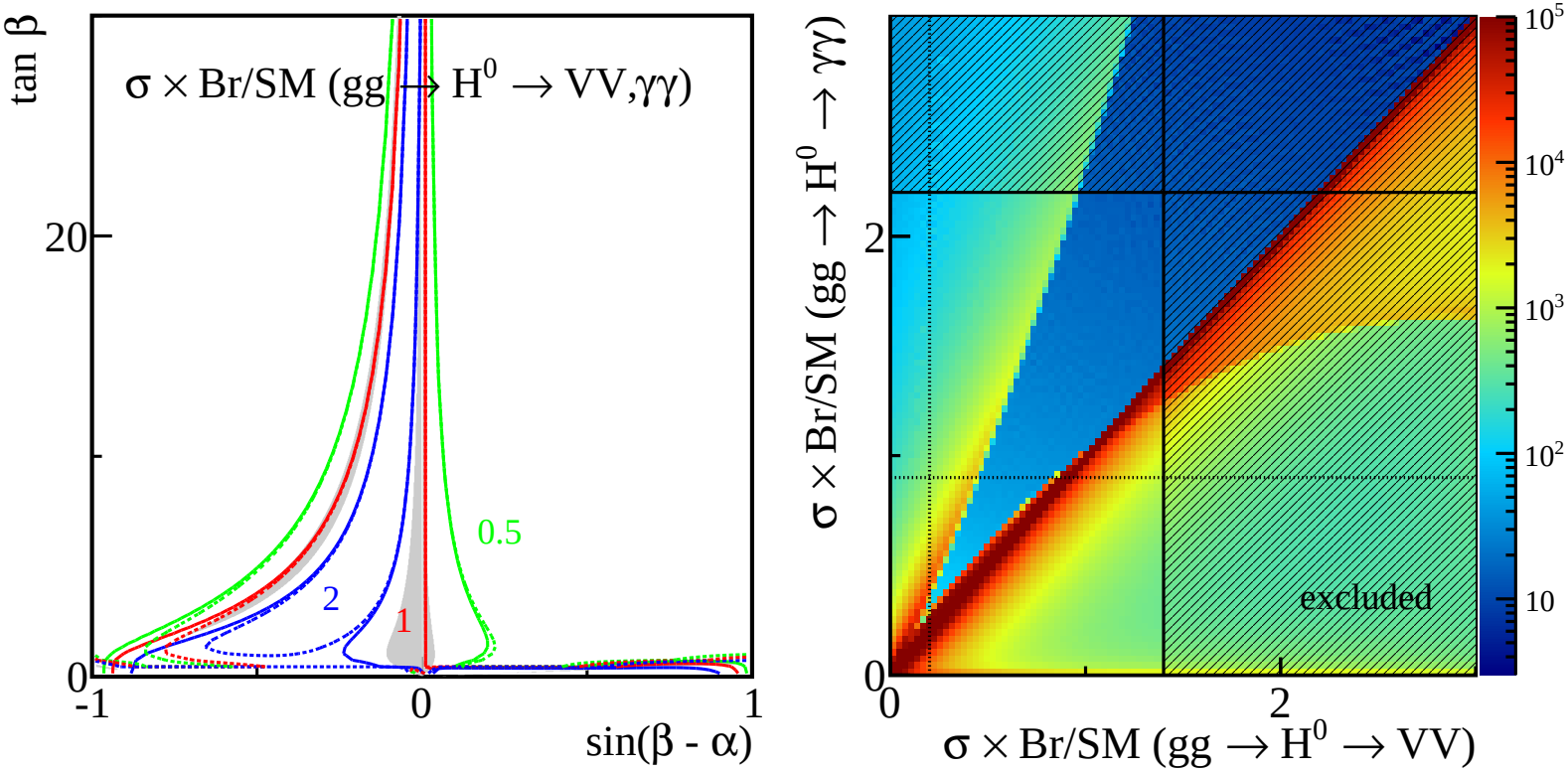
H^0-126



- signal region (gray area) splits into two distinct regions

H^0-126

Felix Kling



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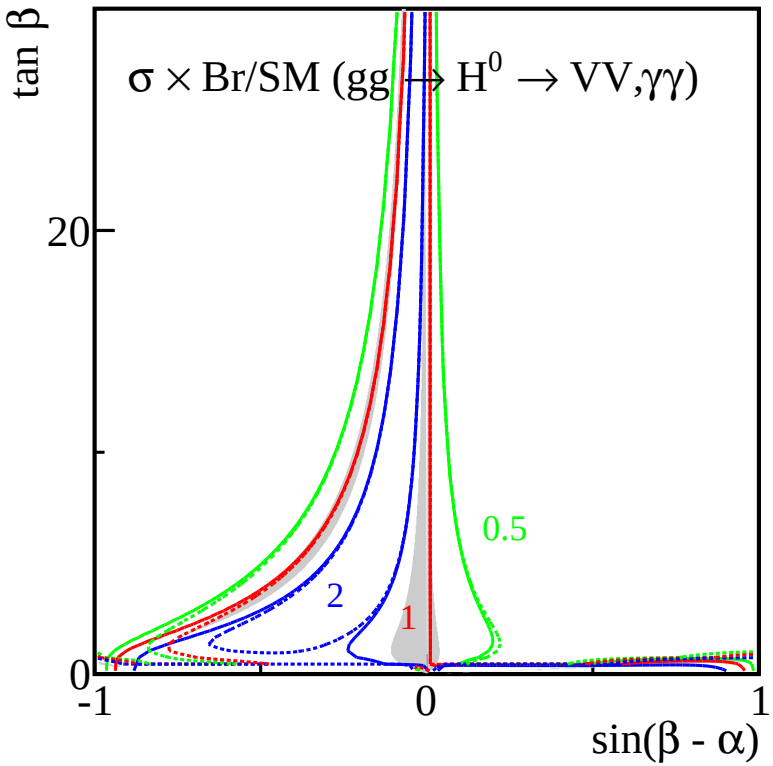

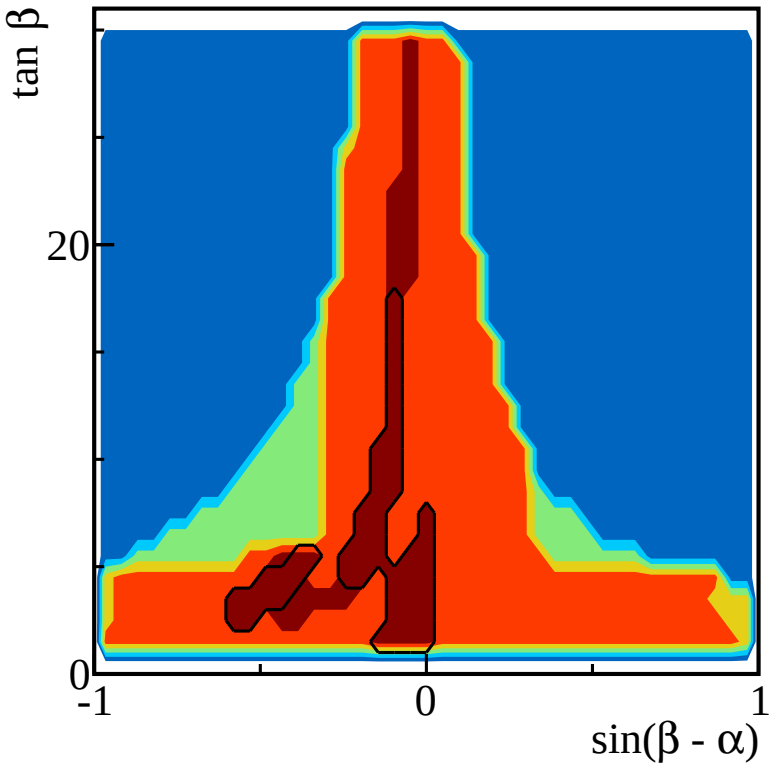

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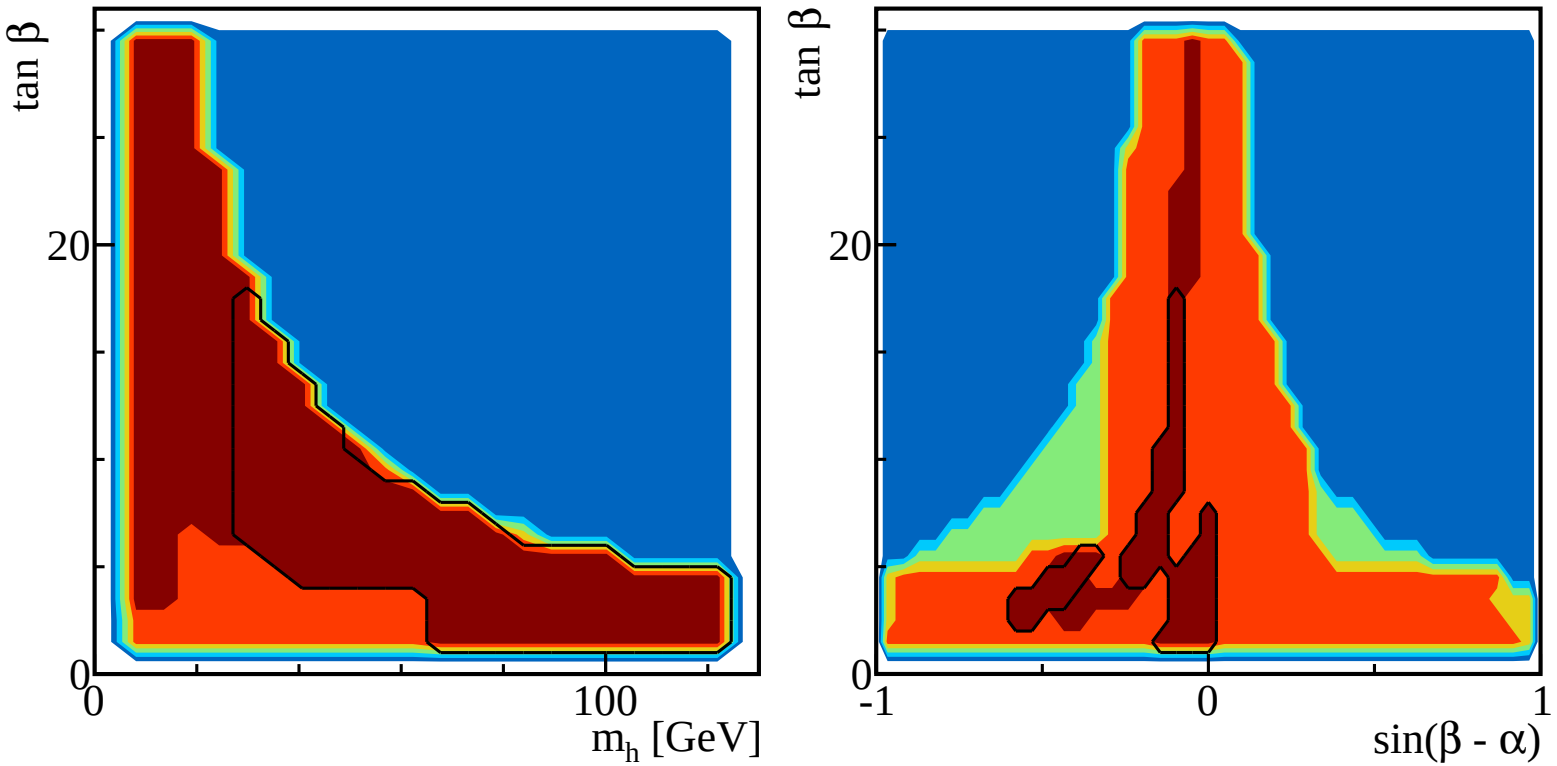
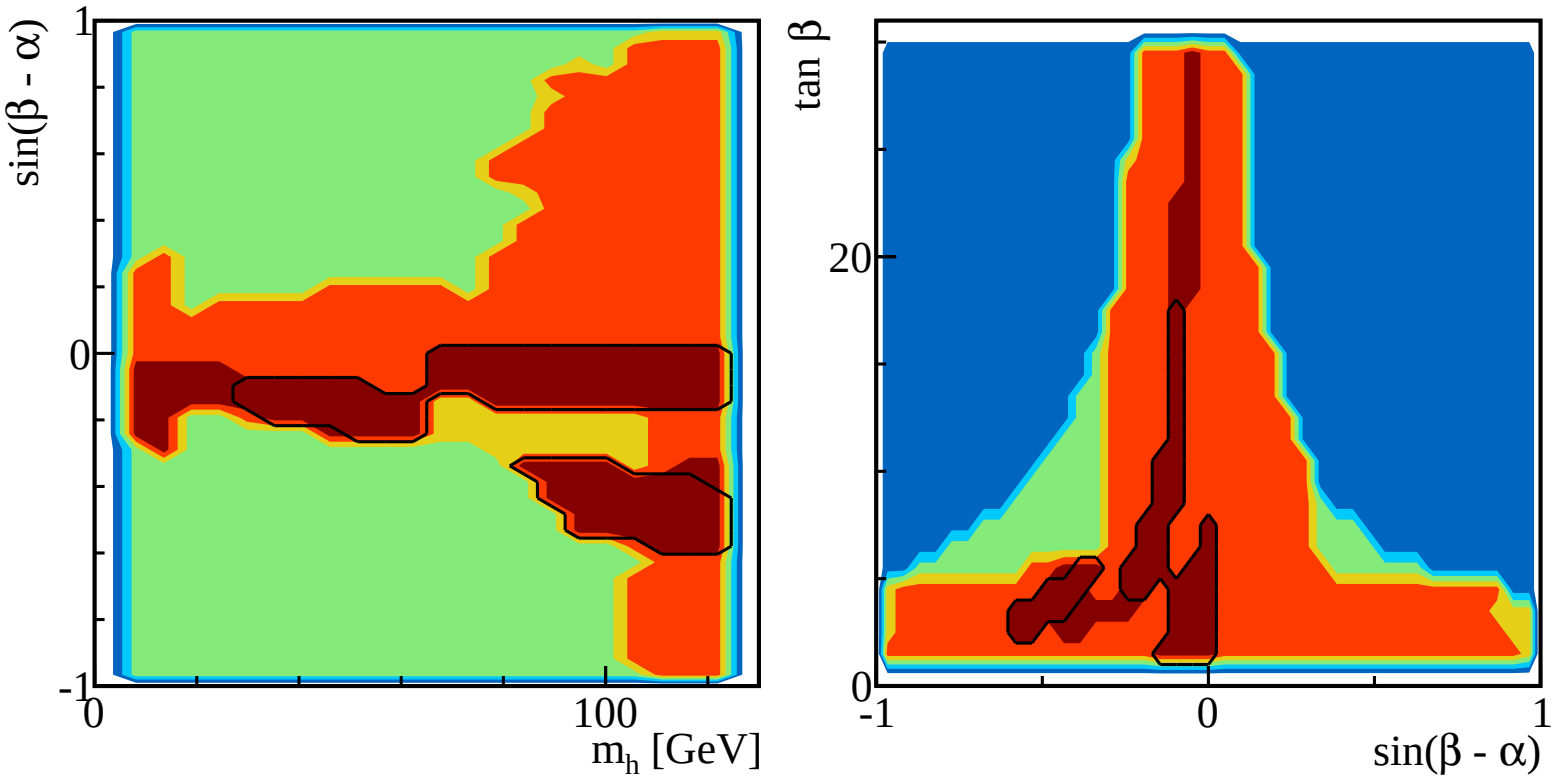


- signal region splits into two distinct regions
- for $m_h < 63$ GeV / $\tan\beta > 8$: $H^0 \to h^0 h^0$ channel is open
- $m_h < 25$ GeV and $\tan\beta > 18$ exluded by flavor constraints

H^0-126



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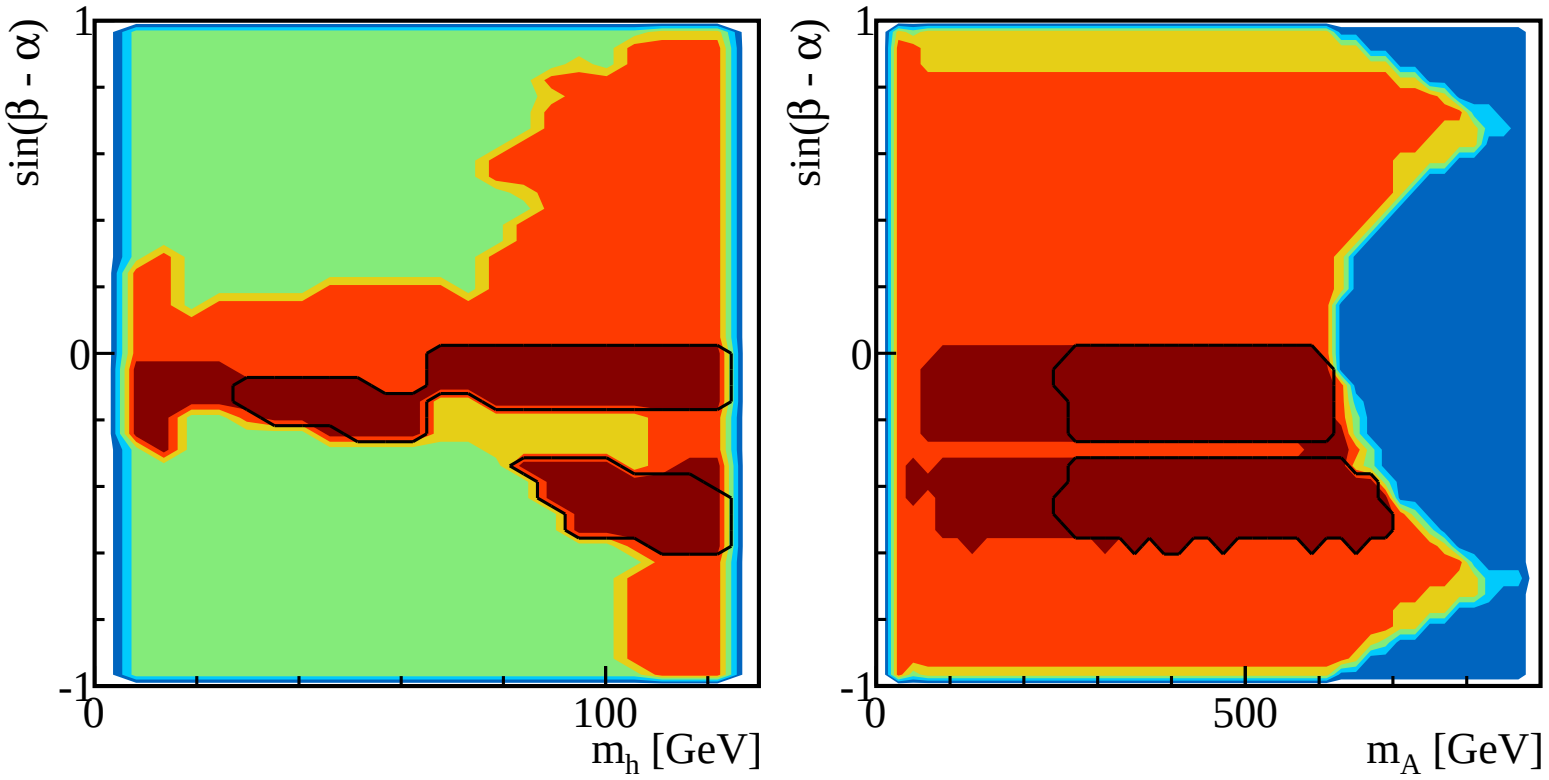
- for $m_h < 80$ GeV: $|\sin(\beta - \alpha)| > 0.3$ region exluded by LEP

H^0-126



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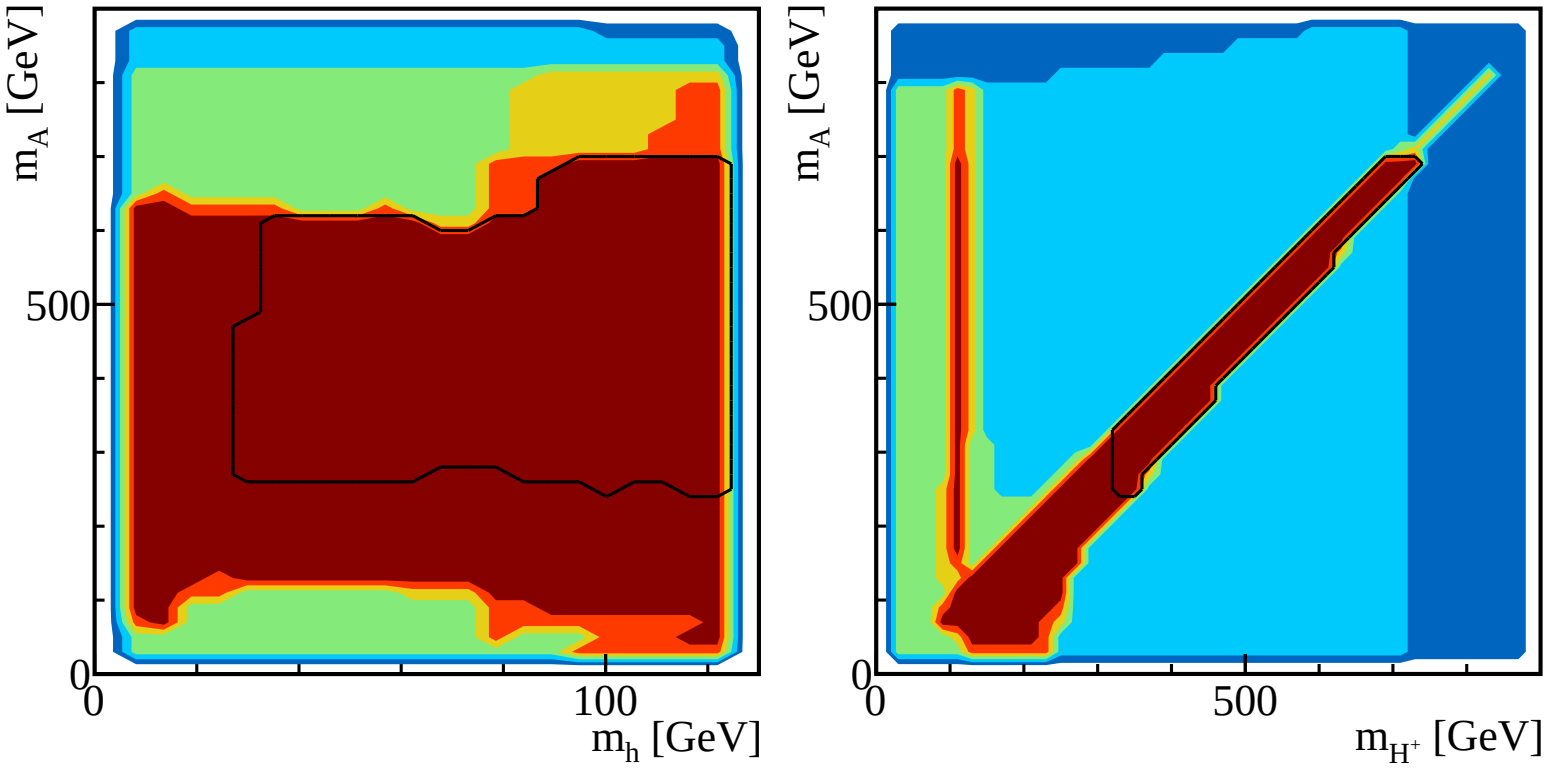

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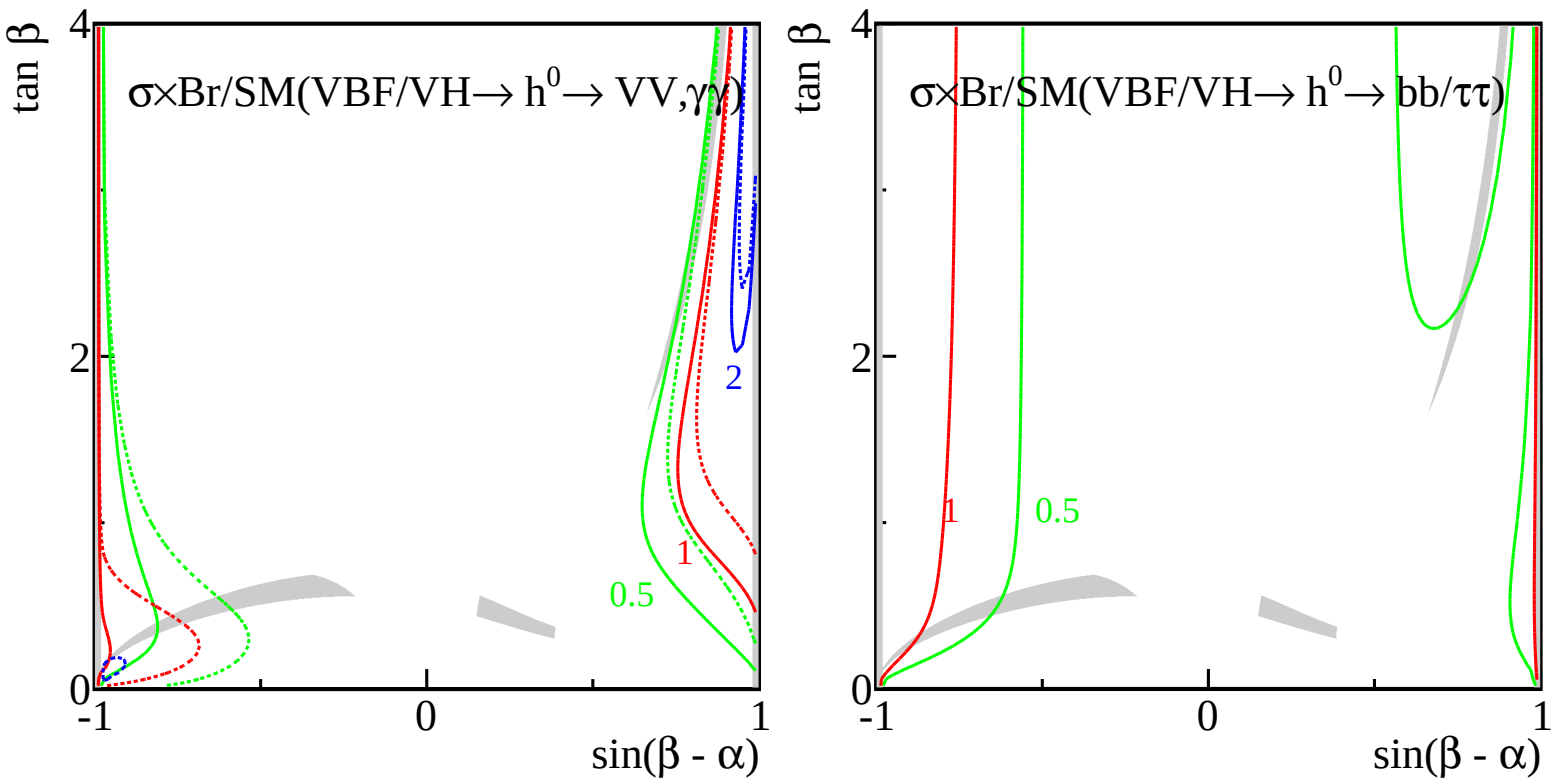
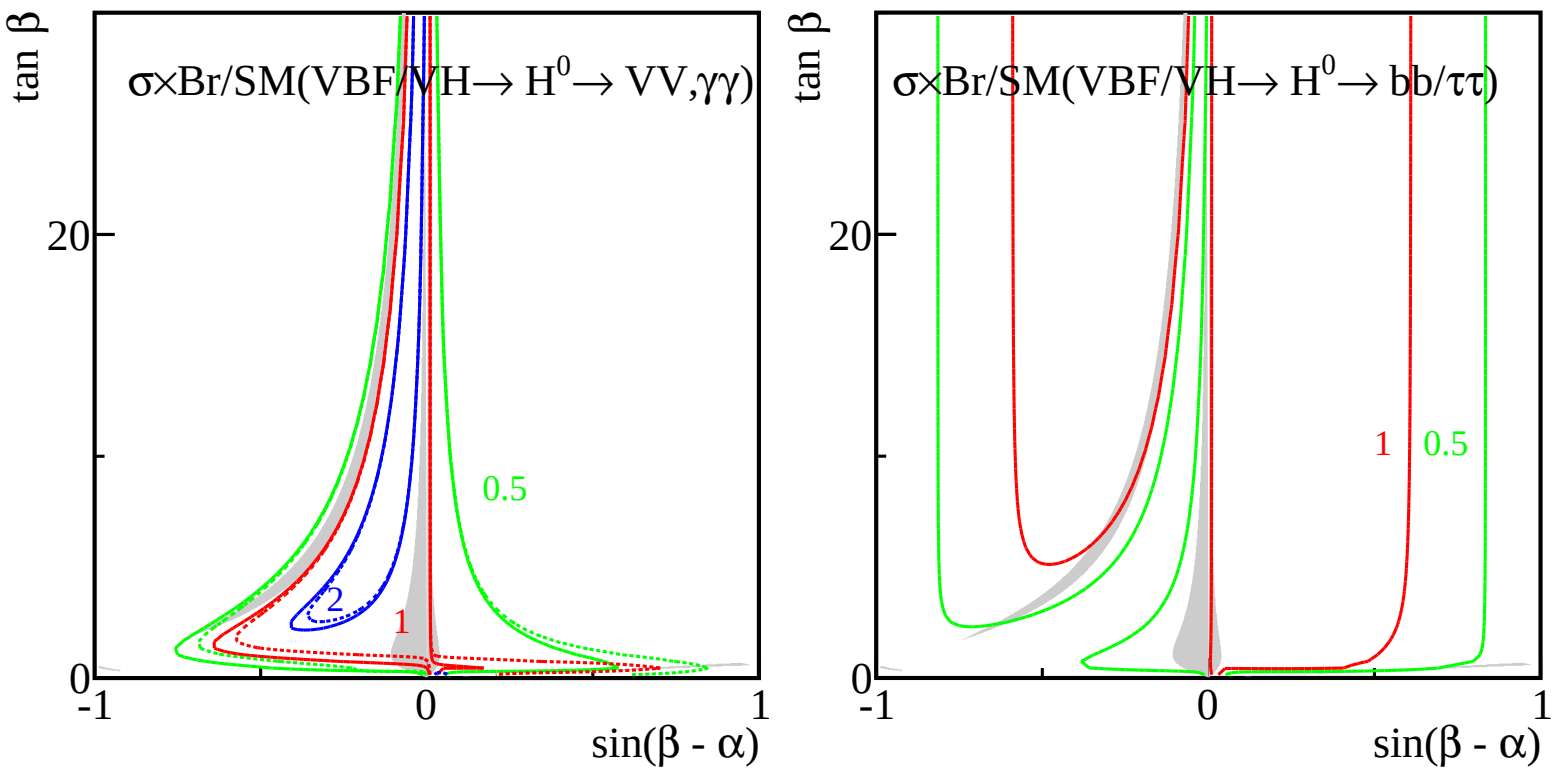
- m_A and m_{H^+} are highly correlated

Other Higgs Channels



- h^0 interpreted as observed 126 GeV Higgs
- near $\sin(\beta - \alpha) = \pm 1$: suppression of 0.5 - 1 of SM value
- $VBF/VH \to h^0 \to bb/\tau\tau$ channel mostly suppressed
- large suppression for $\tan\beta < 1$ region

Other Higgs Channels



- H^0 interpreted as observed 126 GeV Higgs
- for $\sin(\beta-\alpha) \approx 0$: $VV/\gamma\gamma$ channel enhanced, $bb/\tau\tau$ channel suppressed
- for $-0.7 < \sin(\beta-\alpha) < -0.1$: $VV/\gamma\gamma$ channel suppressed, $bb/\tau\tau$ channel mostly enhanced

Summary

Type II 2HDM

- study parameter space and correlations
- impose theoretical and experimental constraints

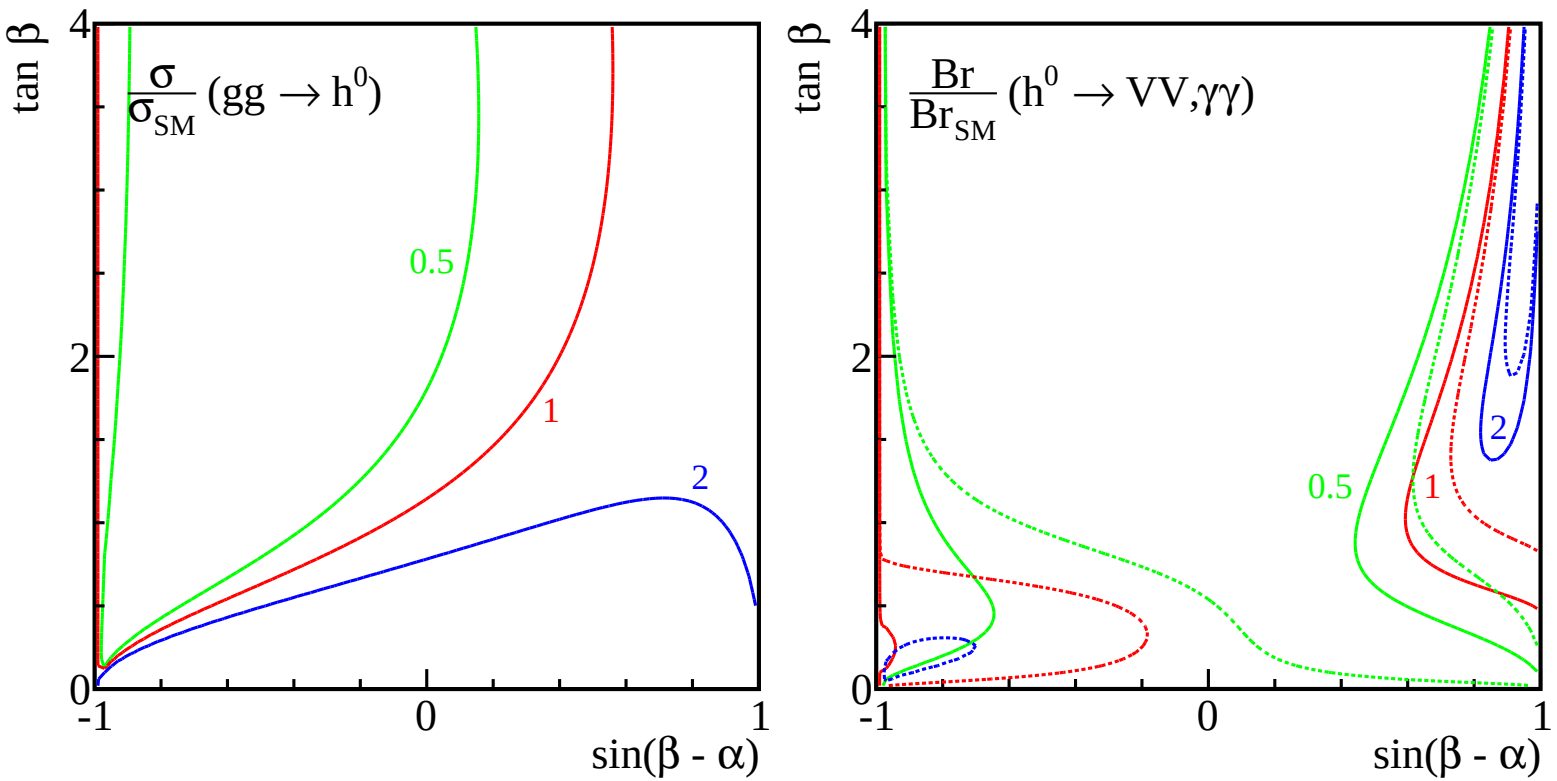
h^0-126 GeV

- $\gamma\gamma$ channel closely correleated with WW/ZZ channel
- $\tan\beta < 4$ bottom-loop contribution negligible
- signal region splits into five distinct regions: $\sin(\beta-\alpha) \approx \pm 1$ or $\tan\beta < 1$
- masses largely uncorrelated

H^0-126 GeV

- $\gamma\gamma$ channel closely correleated with WW/ZZ channel
- signal region splits into two distinct regions: $\sin(\beta-\alpha) \approx 0$ or $-0.7 < \sin(\beta-\alpha) < -0.1$
- m_A and m_{H^+} strongly correlated

Additional Plots



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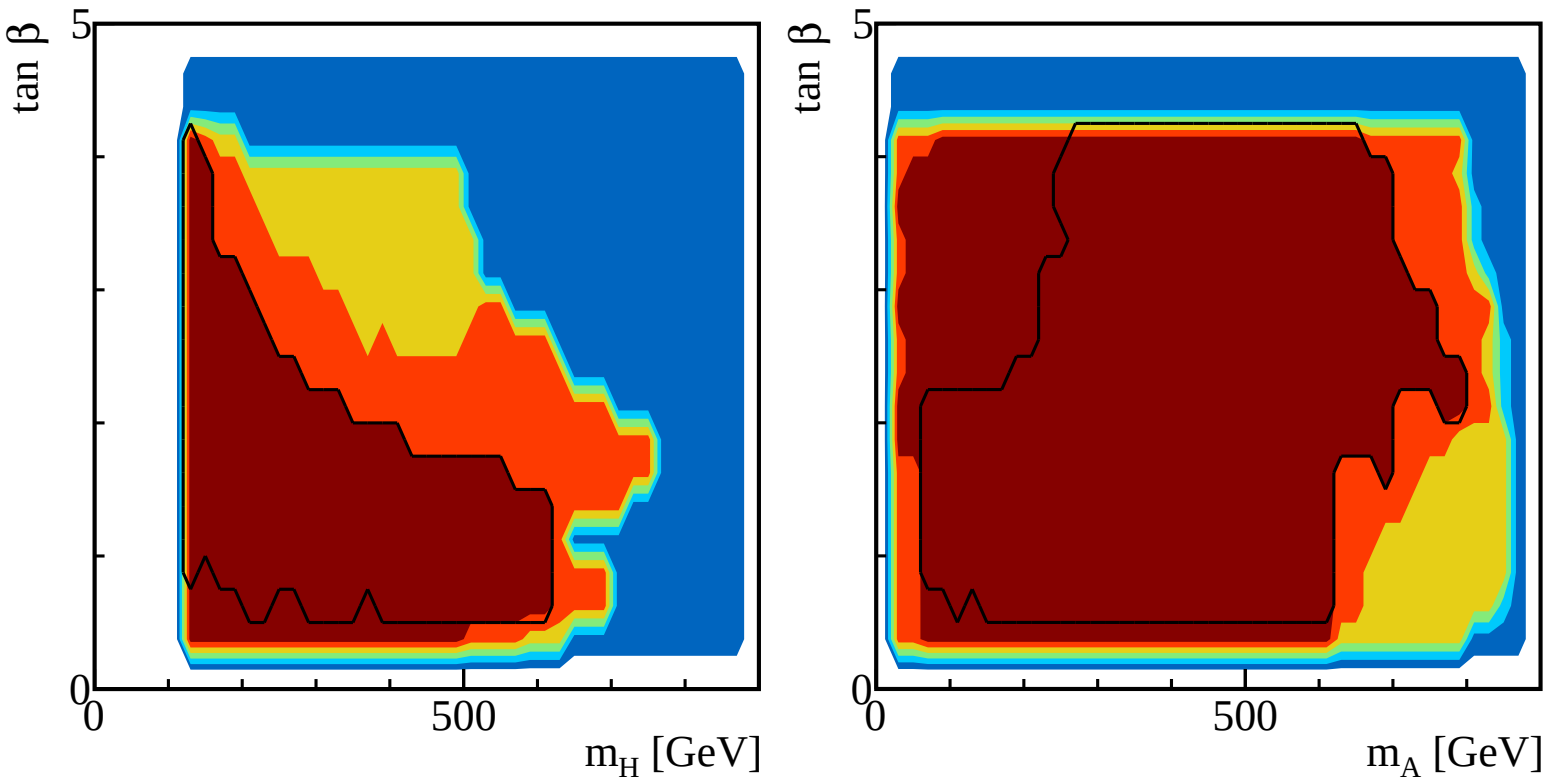

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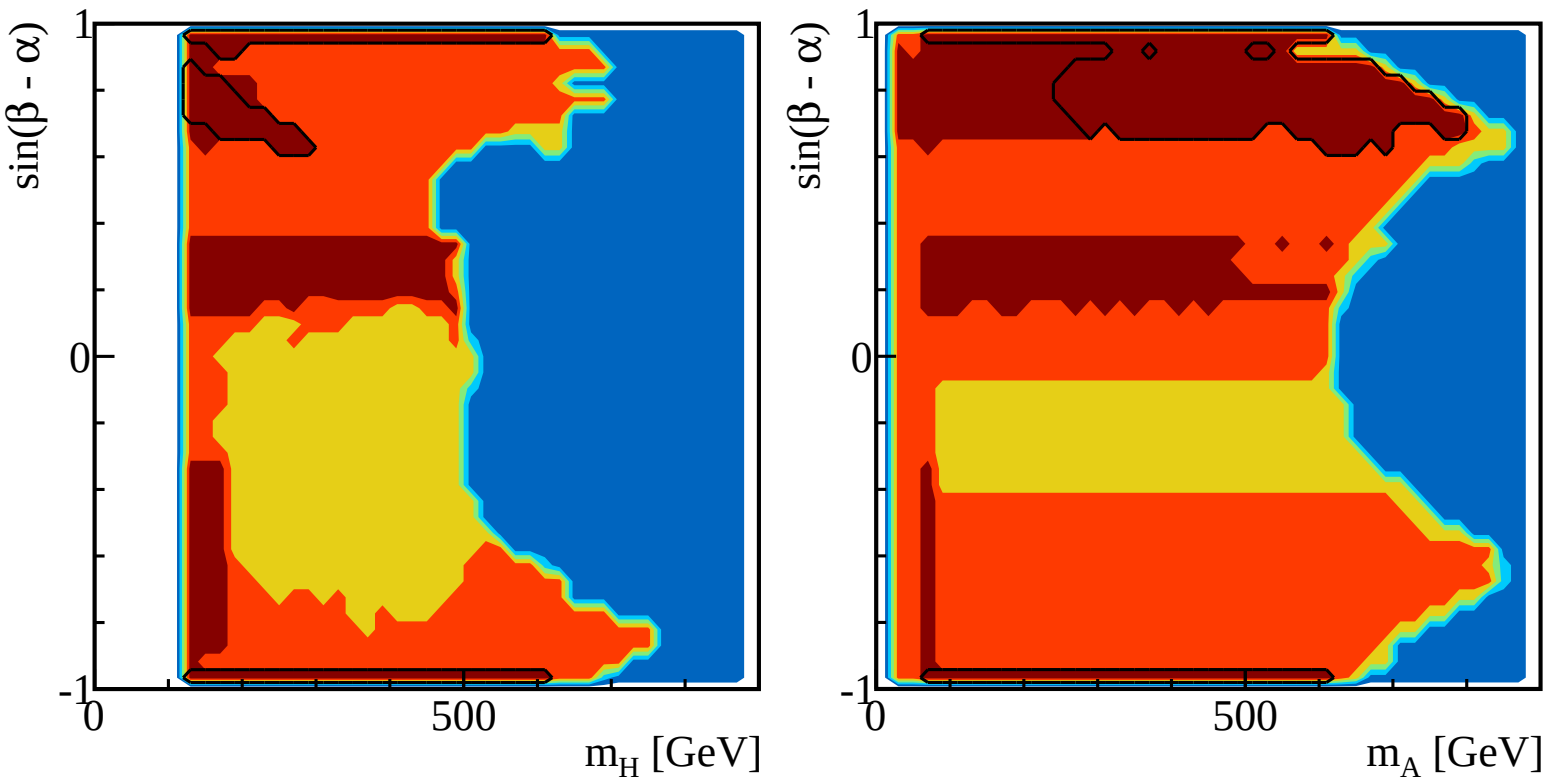

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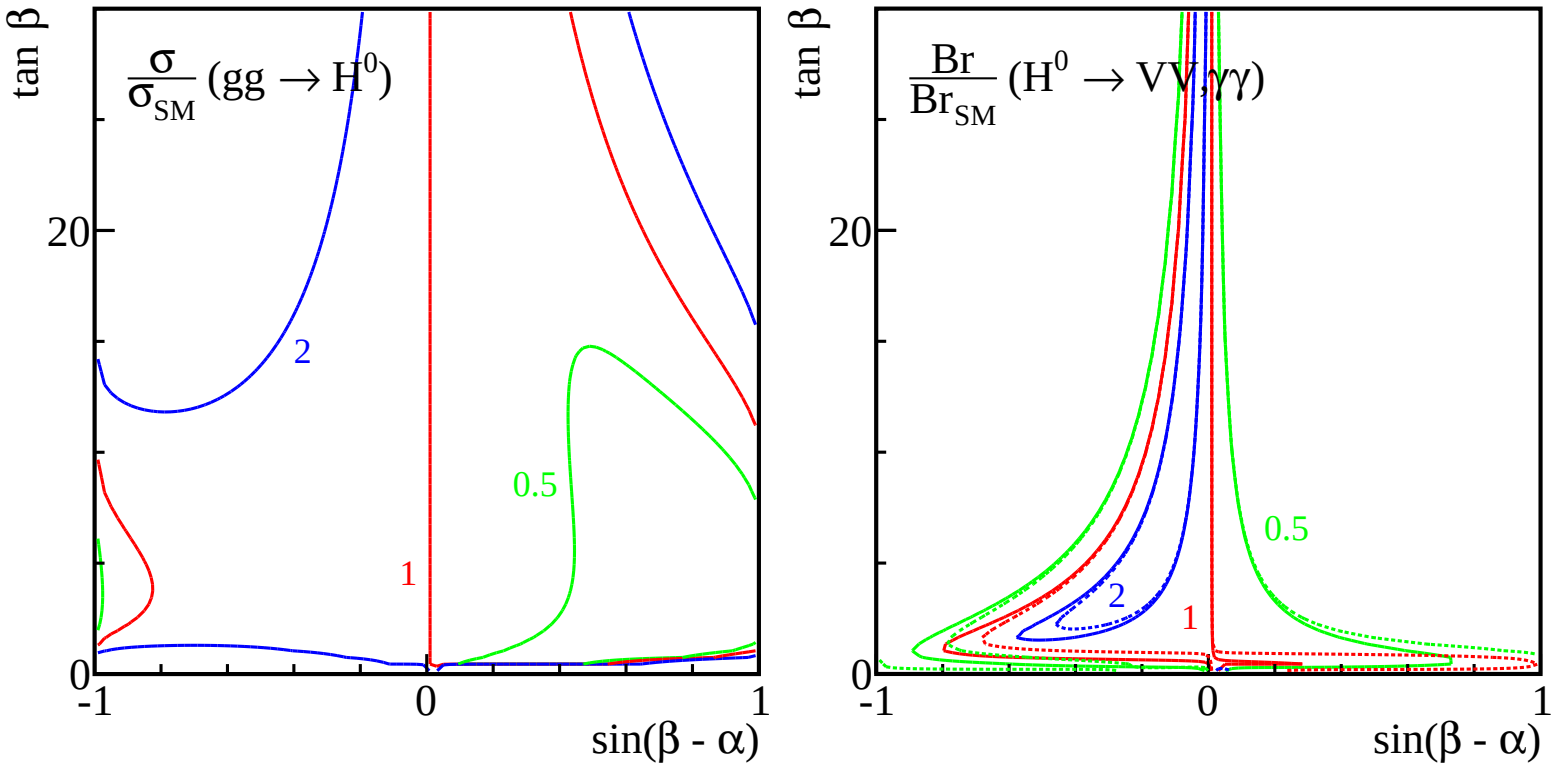

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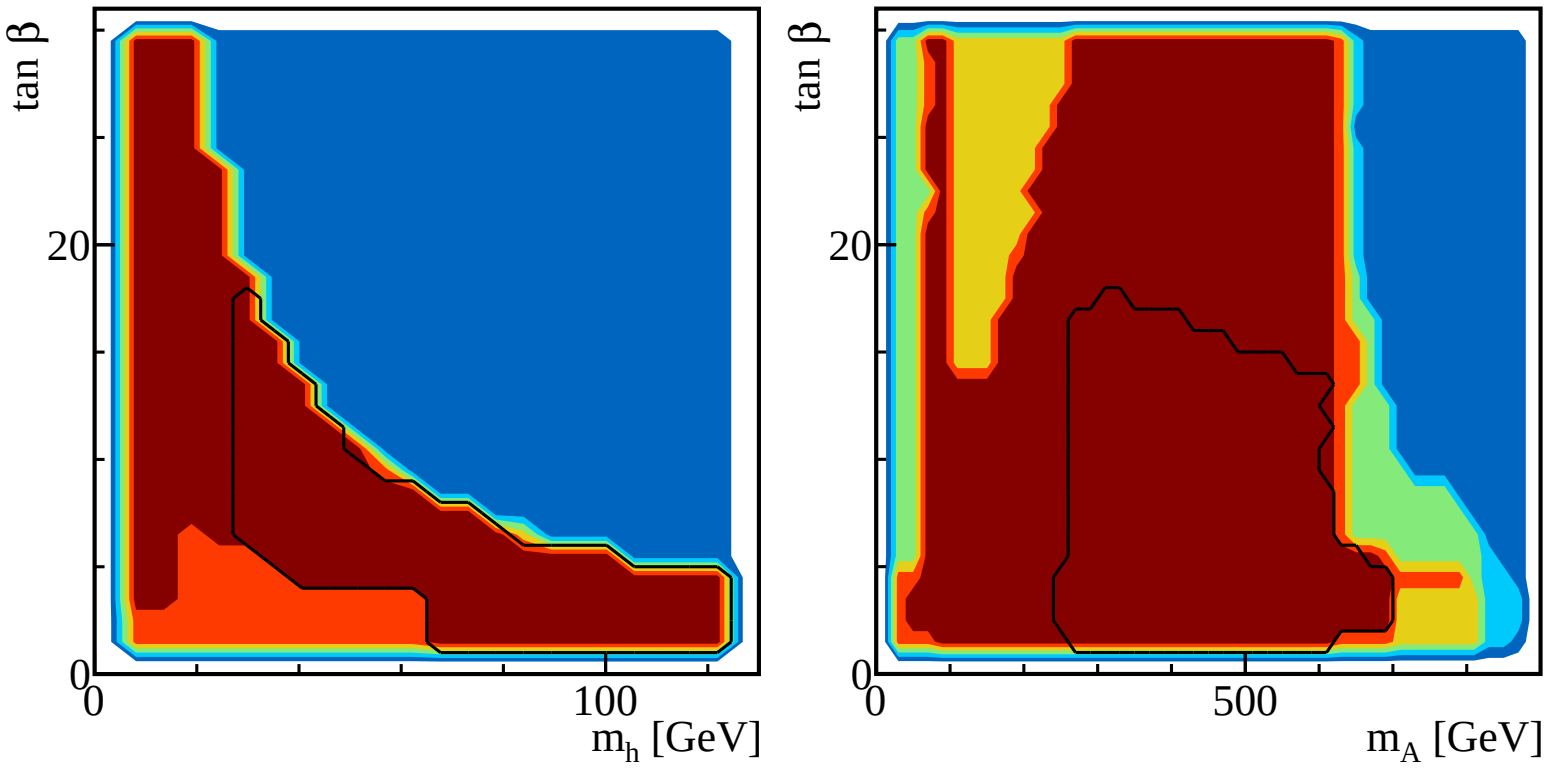

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