

Constraining Type II 2HDM in Light of LHC Higgs Searches

work with Baradhwaj Coleppa, Shufang Su
[\[arXiv:1305.0002\]](#)

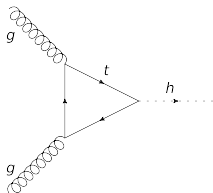
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APS 4 Corners Section Meeting, 18th October 2013

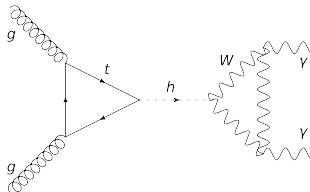
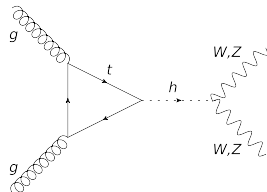
Discovery of the Higgs Boson at LHC

- mainly produced in gluon-gluon Fusion



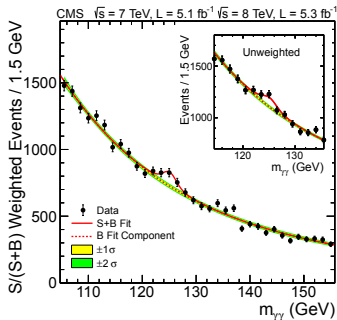
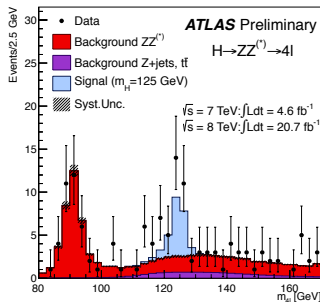
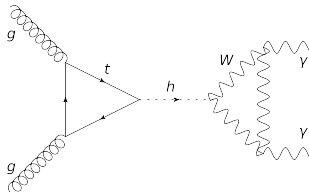
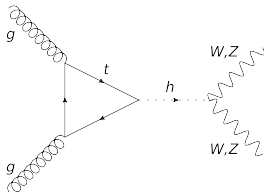
Discovery of the Higgs Boson at LHC

- mainly produced in gluon-gluon Fusion
- observed mainly through WW , ZZ , $\gamma\gamma$ decay



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Standard Model (SM)

- SM Higgs Lagrangian: $\mathcal{L} = D_\mu \Phi^\dagger D^\mu \Phi - V$
with Potential: $V = \mu^2 \Phi^\dagger \Phi - \frac{\lambda}{2} (\Phi^\dagger \Phi)^2$
- There is one scalar Higgs doublet

$$\Phi = \begin{pmatrix} \phi^+ \\ (v + \phi^0 + iA)/\sqrt{2} \end{pmatrix}$$

v : vacuum expectation value

ϕ^0 : physical Higgs field

A, ϕ^+, ϕ^- : Goldstone Bosons (get eaten by gauge bosons)

Two Higgs-Doublet Model

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

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

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- 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 Higgses: A^0

Mixing between CP-even Higgses: $\sin \alpha$

Charged Higgses: H^\pm

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Charged Higgses: H^\pm

Type II 2HDM

– Coupling to fermions

u like quarks couple to Φ_2

d like quarks and leptons couple to Φ_1

Coupling for Type II 2HDM

- 2HDM Higgs Spectrum: h^0 , H^0 , A , H^+ , H^-

	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

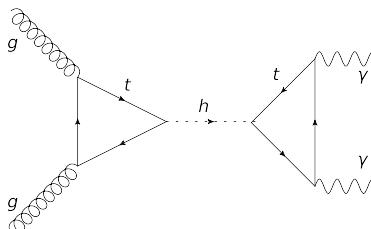
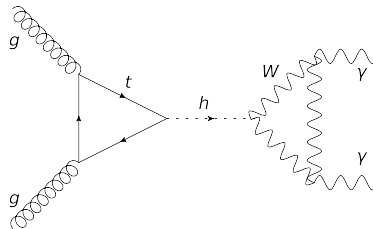
Coupling for Type II 2HDM

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Modified cross section

Example: $gg \rightarrow h^0 \rightarrow \gamma\gamma$



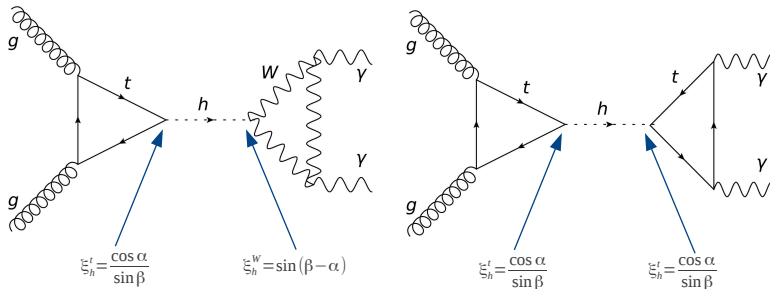
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Our work

- Type II 2HDM: Scanning over 5 parameters
- Impose theoretical and experimental constraints
- h^0 or H^0 is 126 GeV Higgs
- Study surviving parameter space and correlations

Theoretical Constraints

- implemented by 2HDMC [arXiv:0902.0851]
- **Vacuum Stability:** potential bounded from below
- **Perturbativity:** couplings inside the perturbative regime
- **Unitarity:** tree level unitarity for scattering of Higgs and V_L

Experimental Constraints

- **Higgs searches:** LEP, Tevatron and LHC Higgs searches implemented by HIGGSBOUNDS 3.8 [arXiv:0811.4169]
- **Precision observables:** Oblique parameters S , T and R_b parameter.
[J. Phys. G 37, 075021 (2010), arXiv:1012.2367]
- **Signal Region:** $0.7 < \sigma \times \text{Br}/\text{SM}(gg \rightarrow h^0/H^0 \rightarrow \gamma\gamma) < 1.5$
 $0.6 < \sigma \times \text{Br}/\text{SM}(gg \rightarrow h^0/H^0 \rightarrow VV) < 1.3$
- **Flavor:** Flavor constraints implemented by SuperIso [arXiv:0808.3144]

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

SM Higgs Boson

Type II 2HDM

Constraints

Results

Summary

Results

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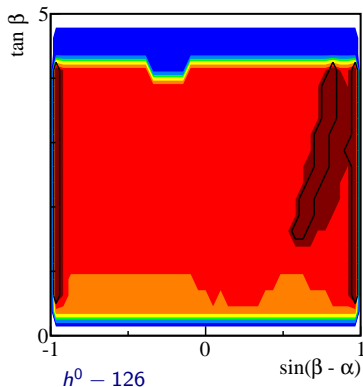
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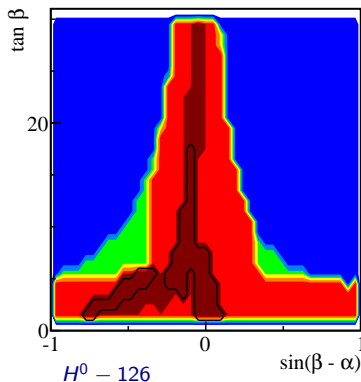
- $\tan \beta > 4$ excluded by perturbativity
- signal region splits into three distinct regions:

SM-like regions:

$$\sin(\beta - \alpha) = \pm 1$$

extended region:

$$0.55 < \sin(\beta - \alpha) < 0.9$$



- large $\tan \beta$ allowed by perturbativity
- signal region splits into two distinct regions:

SM-like region: $\sin(\beta - \alpha) \sim 0$

with $\tan \beta < 8$

extended region:

$$-0.8 < \sin(\beta - \alpha) < 0.05$$

Results

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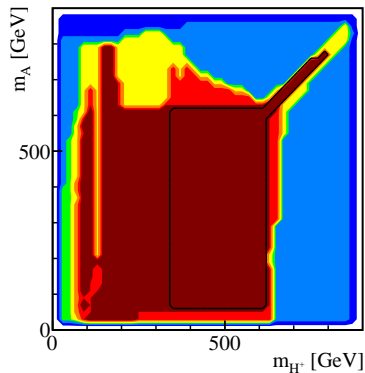
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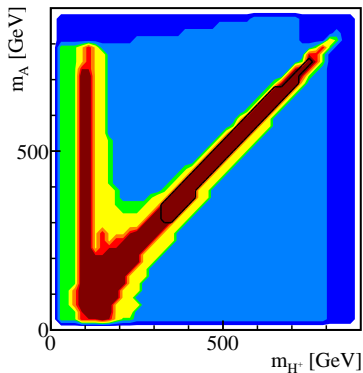
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Summary



$h^0 - 126$

- masses mostly uncorrelated



$H^0 - 126$

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

Type II 2HDM

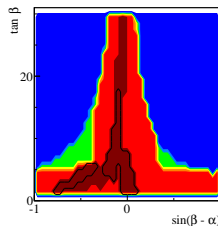
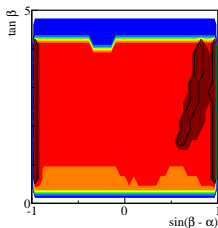
- 2HDM Higgs Spectrum: h^0 , H^0 , A , H^+ , H^-
- Modified couplings

Analysis

- Impose theoretical and experimental constraints
- Study parameter space and 2HDM signal region

Signal regions

- Both SM-like and non-SM-like signal regions survive



Additional Plots - h^0 -126

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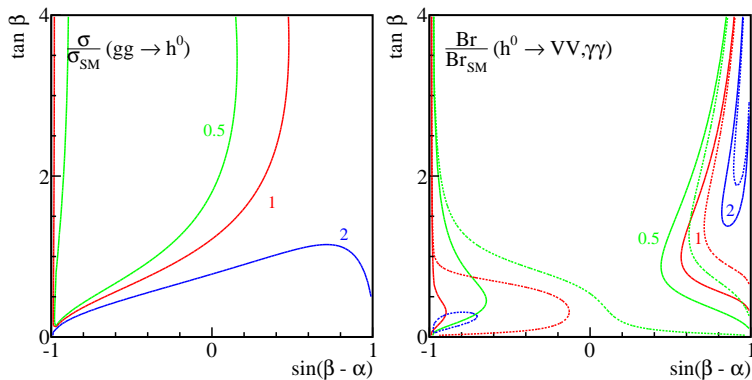
SM Higgs Boson

Type II 2HDM

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- h^0 interpreted as observed 126 GeV Higgs

Additional Plots - h^0 -126

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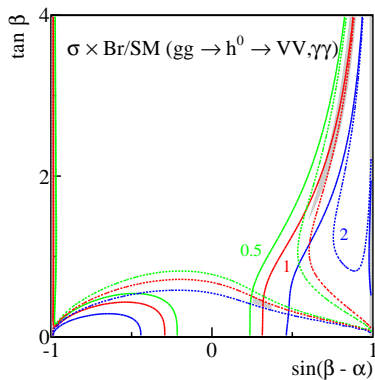
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- signal region (grey area) splits into four distinct regions

Additional Plots - h^0 -126

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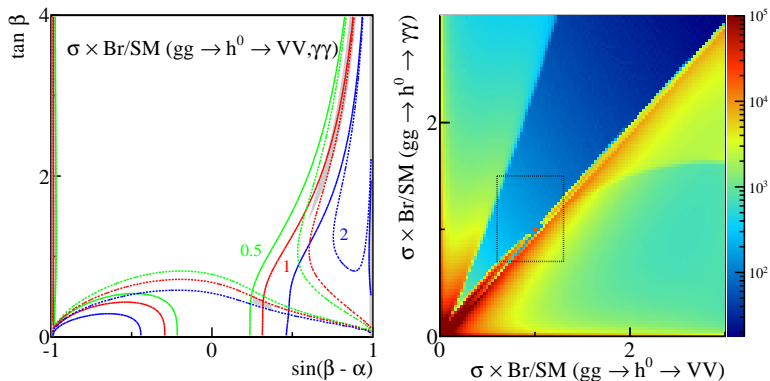
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- most likely: $\gamma\gamma : VV \approx 1$

Additional Plots - h^0 -126

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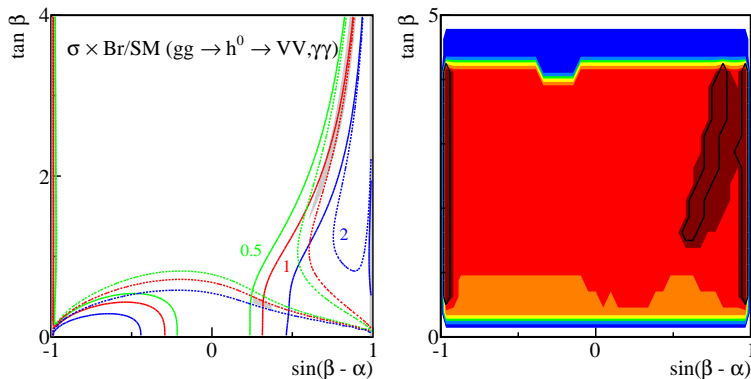
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- signal region (grey area) splits into four distinct regions
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- flavor constraints do not reduce signal region much

Additional Plots - h^0 -126

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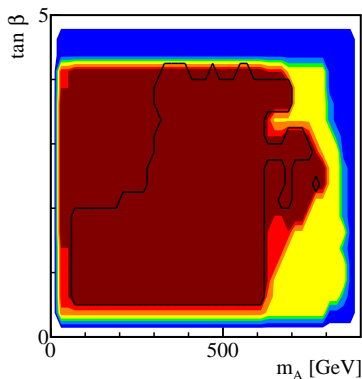
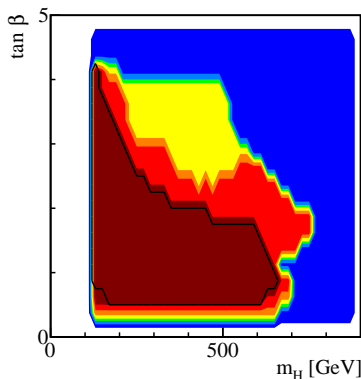
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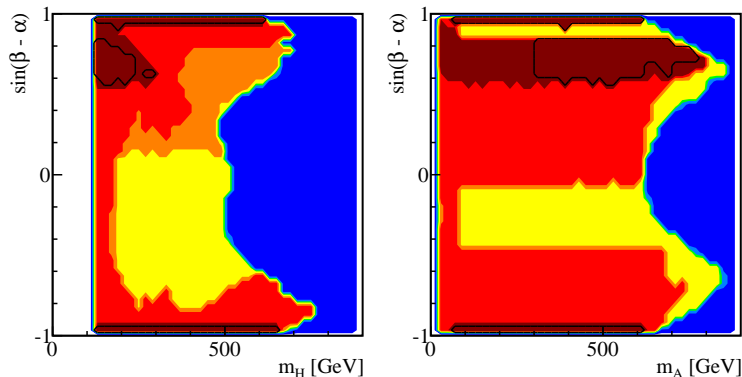
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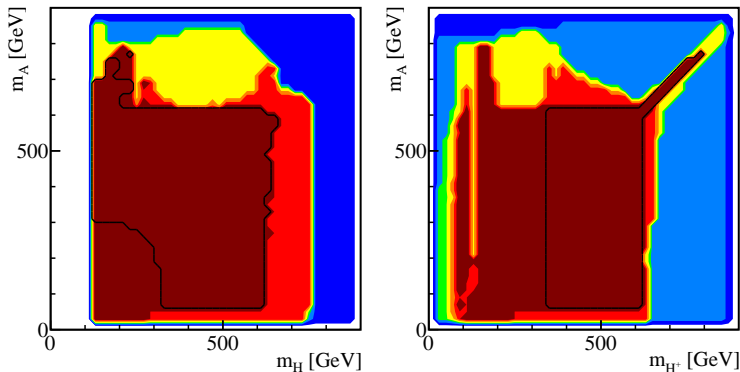
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- $m_H > 750$ GeV and $m_A, m_{H^\pm} > 800$ GeV excluded by perturbativity



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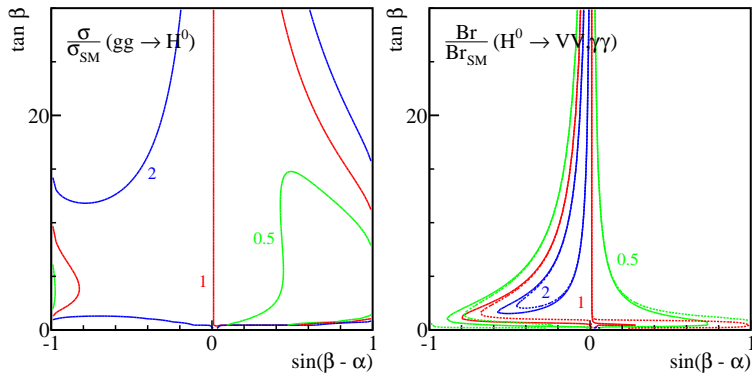
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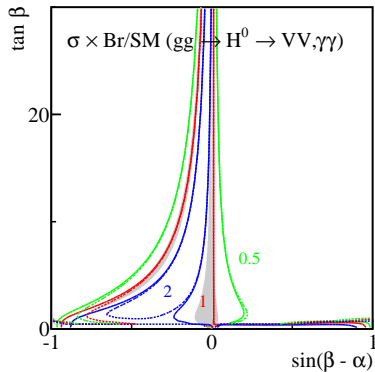
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Additional Plots - H^0 -126

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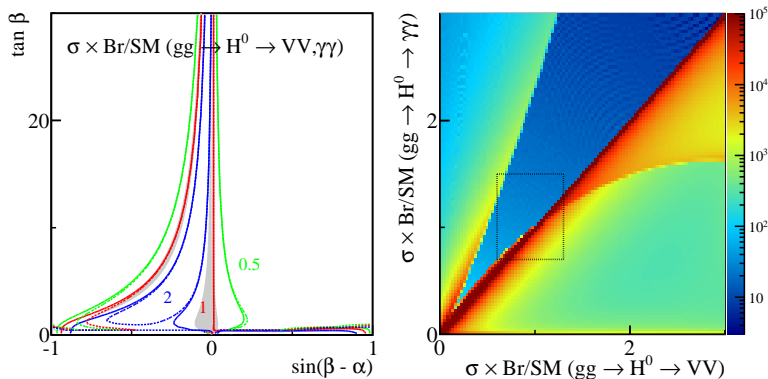
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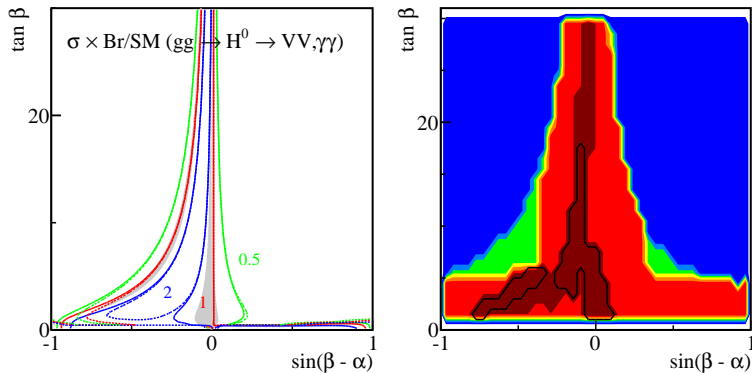
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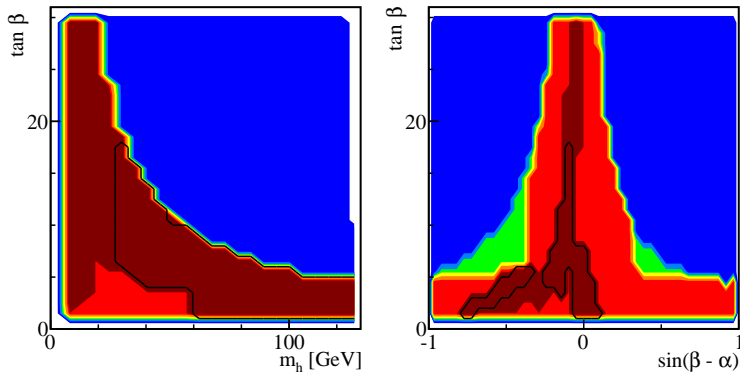
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- signal region splits into two distinct regions
- for $m_h < 63$ / $\tan \beta > 8$: $H^0 \rightarrow h^0 h^0$ channel is open
- $m_h < 25$ GeV and $\tan \beta > 18$ excluded by flavor constraints

Additional Plots - H^0 -126

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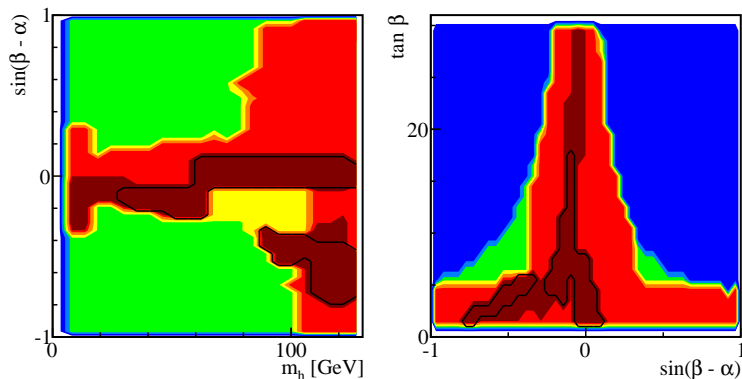
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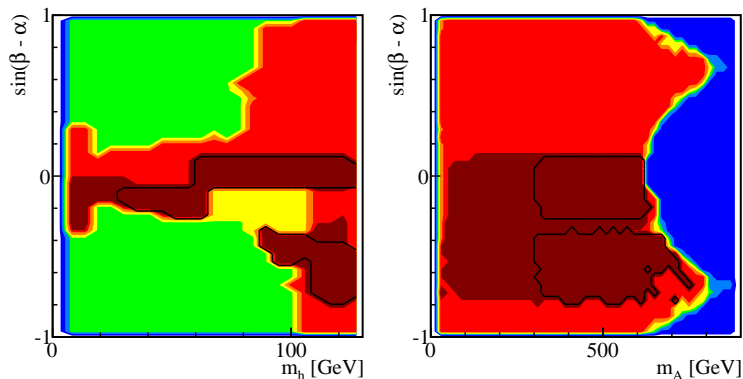
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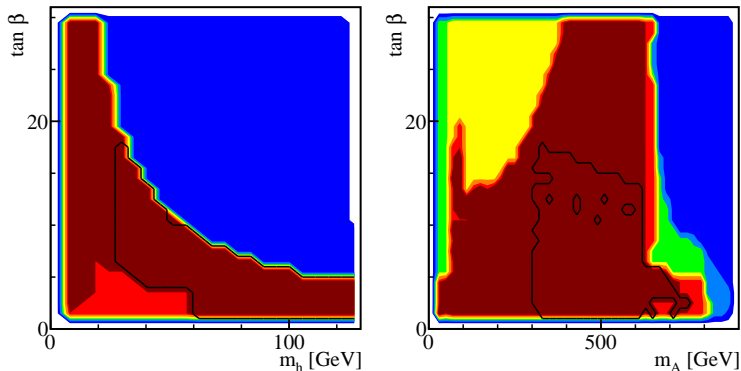
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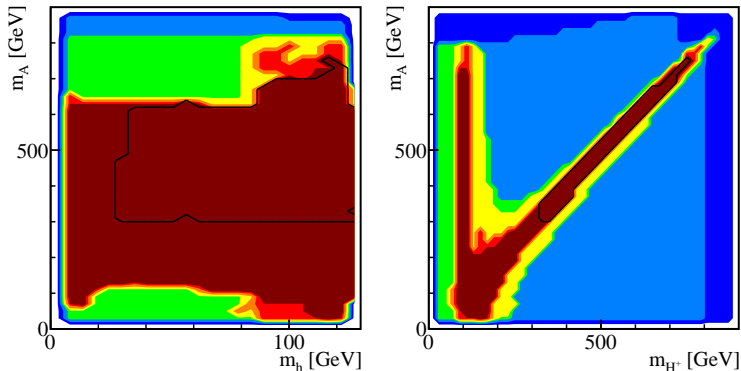
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Additional Plots - Other Higgs Channels

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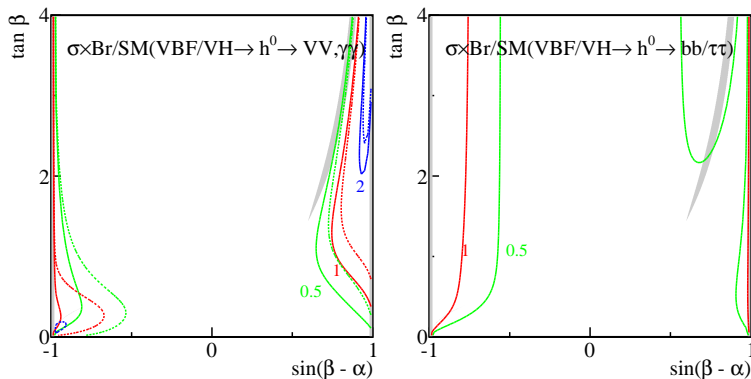
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- h^0 interpreted as observed 126 GeV Higgs
- near $\sin(\beta - \alpha) = \pm 1$: suppression of 0.5 - 1 of SM value
- $\text{VBF/VH} \rightarrow h^0 \rightarrow b\bar{b}/\tau\tau$ channel mostly suppressed
- large suppression for $\tan \beta < 1$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

Additional Plots - Other Higgs Channels

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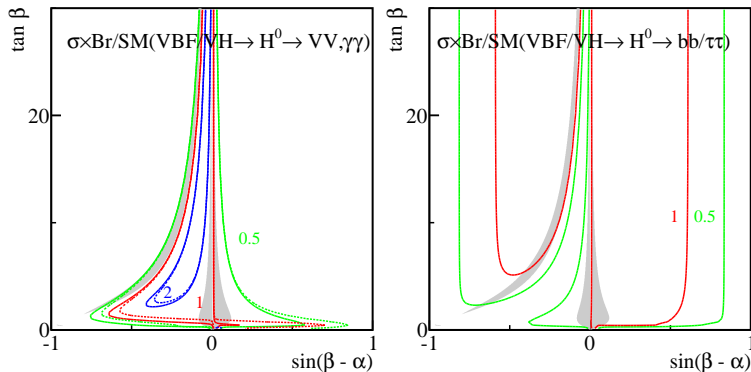
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- H^0 interpreted as observed 126 GeV Higgs
- for $\sin(\beta - \alpha) \approx 0$: $VV/\gamma\gamma$ channel enhanced, $b\bar{b}/\tau\tau$ channel suppressed
- for $-0.7 < \sin(\beta - \alpha) < -0.1$: $VV/\gamma\gamma$ channel suppressed, $b\bar{b}/\tau\tau$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