A Higgs Discovery via Exotic Higgs Decays

work with Baradhwaj Coleppa, Shufang Su

arXiv: 1404.1992

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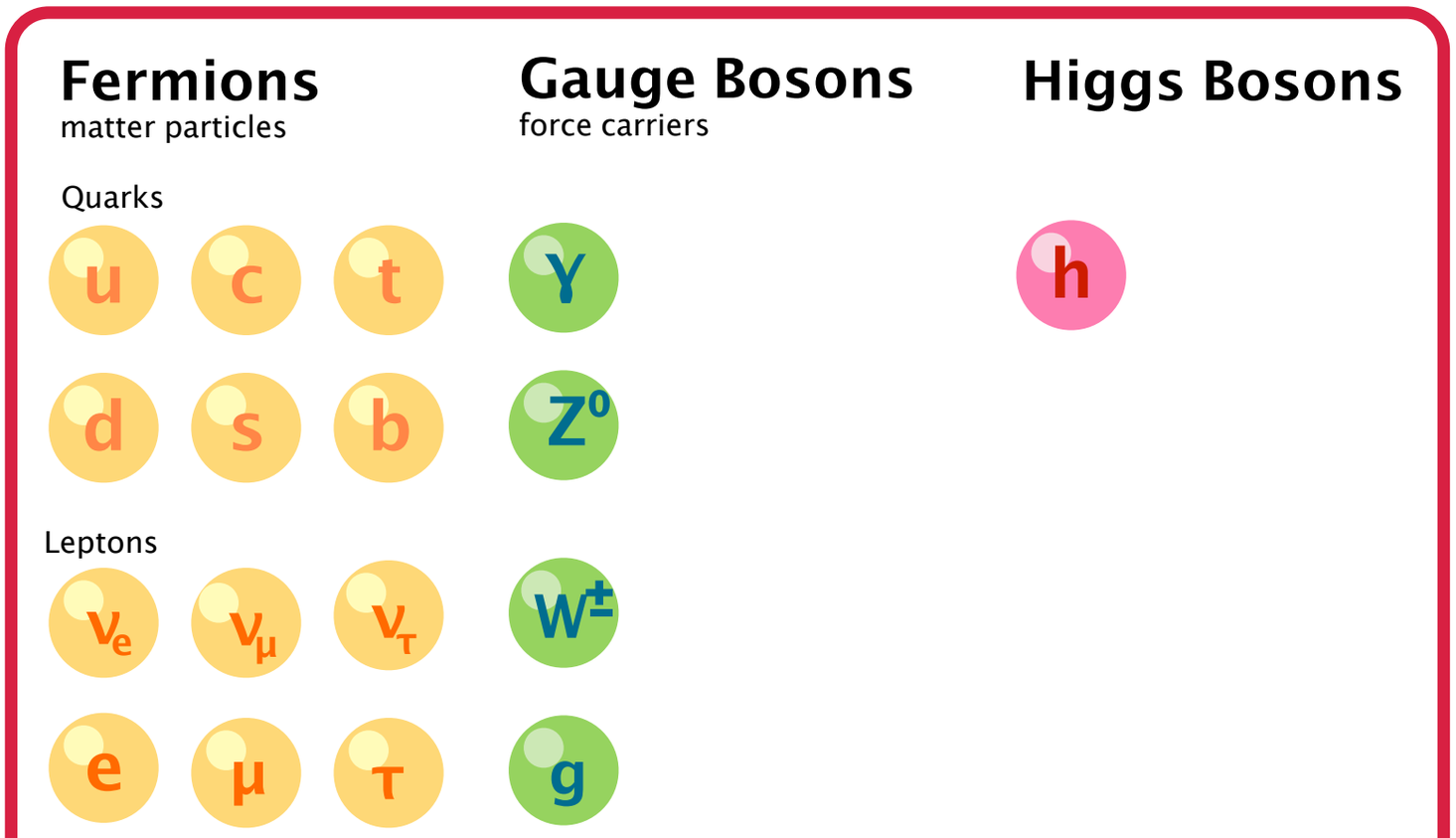
University of Arizona

Phenomenology Symposium, 6th May 2014

Introduction

Standard Model



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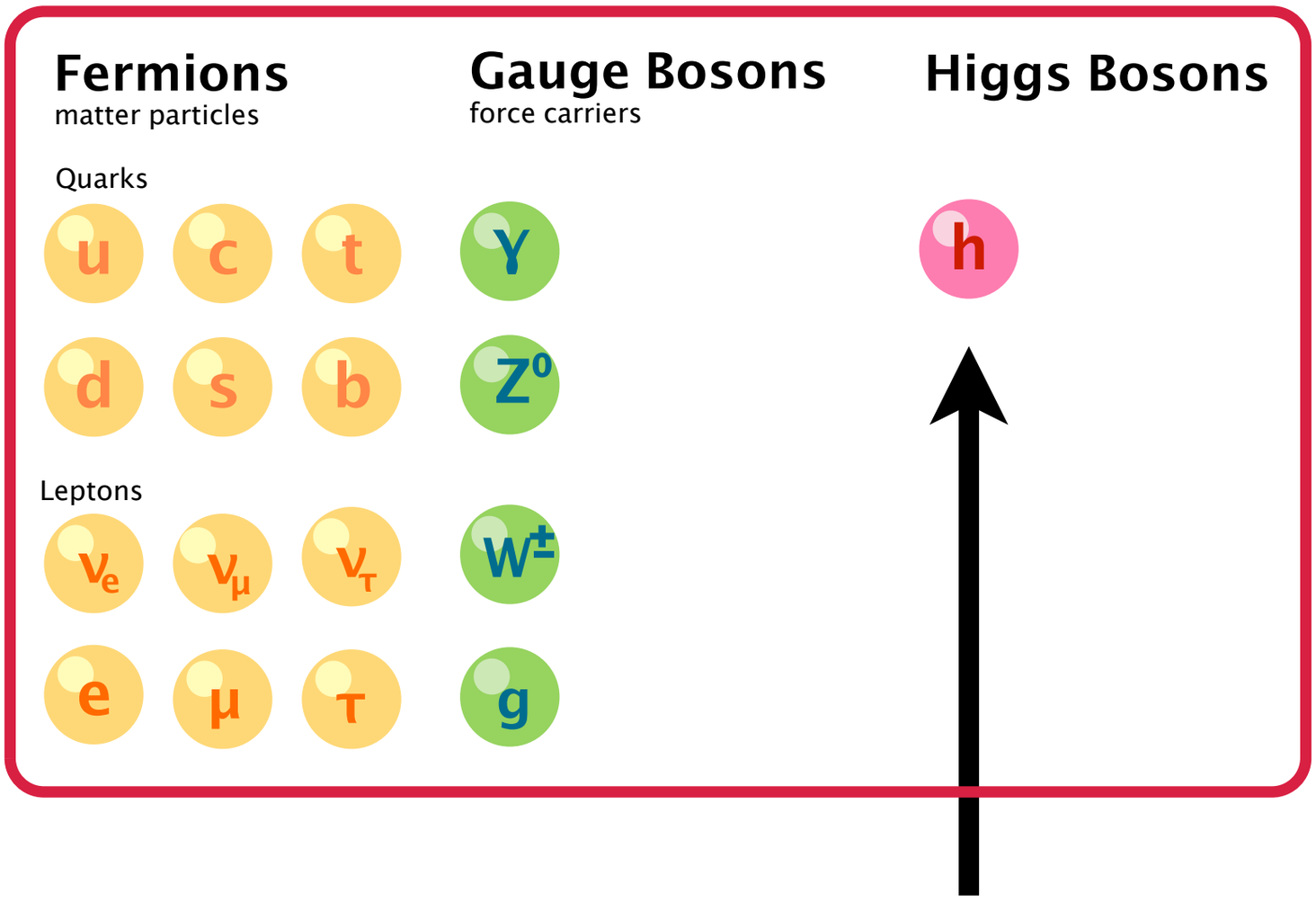

We found a Higgs boson!

Introduction

Beyond the Standard Model

Fermions
matter particles

Quarks

u c t

d s b

Leptons

ν_e ν_μ ν_τ

e μ τ

Gauge Bosons
force carriers

γ

Z^0

$W^\pm$

g

Higgs Bosons

h

H

A

$H^\pm$

Most theoretical models have more Higgs Bosons!

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Higgs Bosons

Most theoretical models have more Higgs Bosons!

How can we find them?

How can we describe them?

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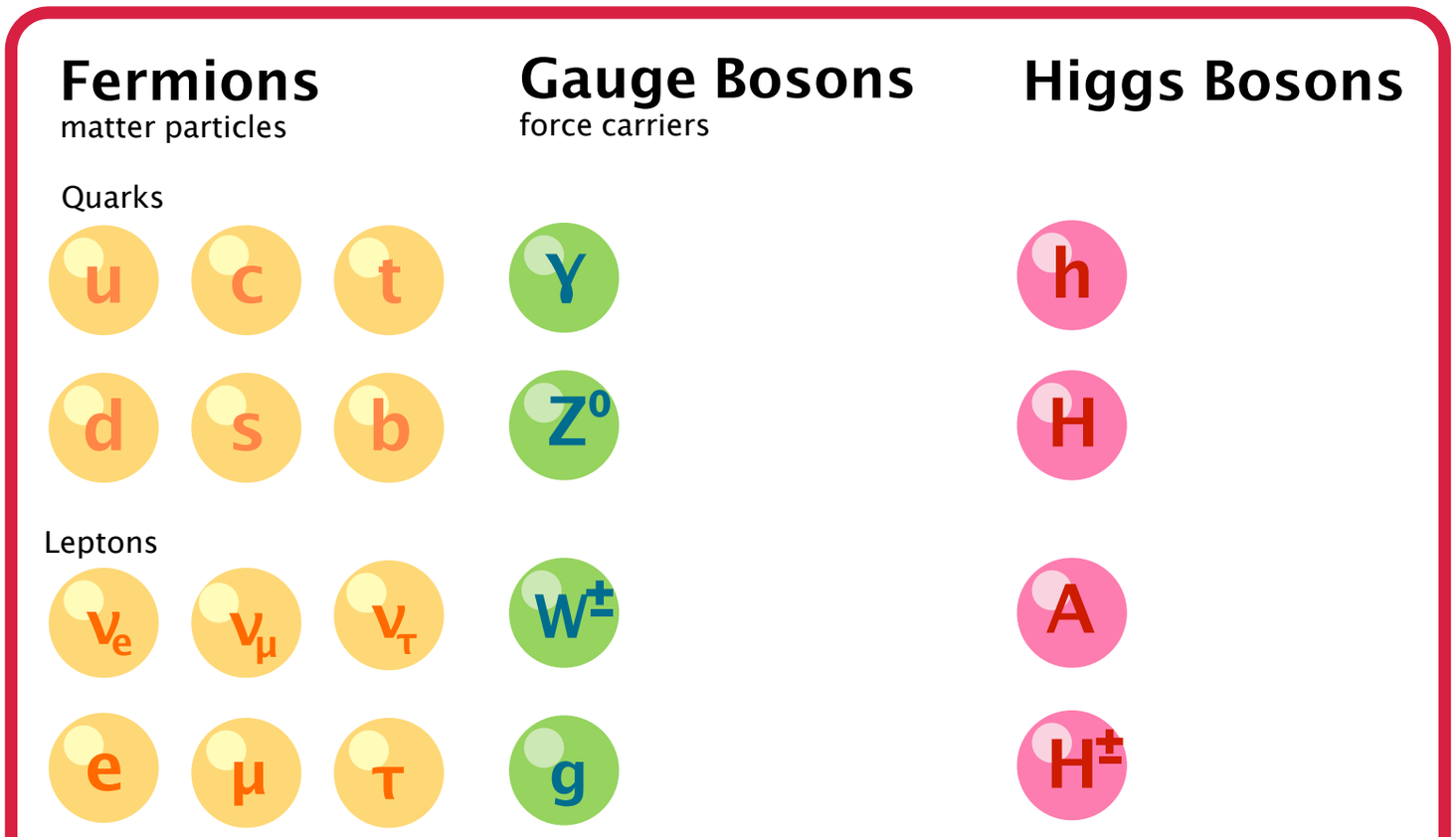

Most theoretical models have more Higgs Bosons!

→ How can we find them?

How can we describe them?

→ Type II 2HDM

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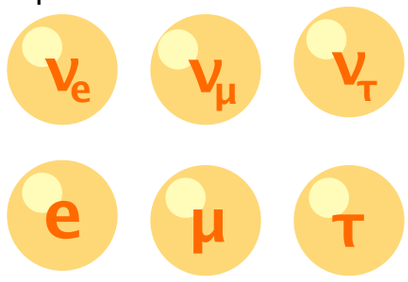
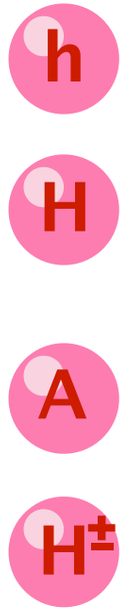


Gauge Bosons
force carriers

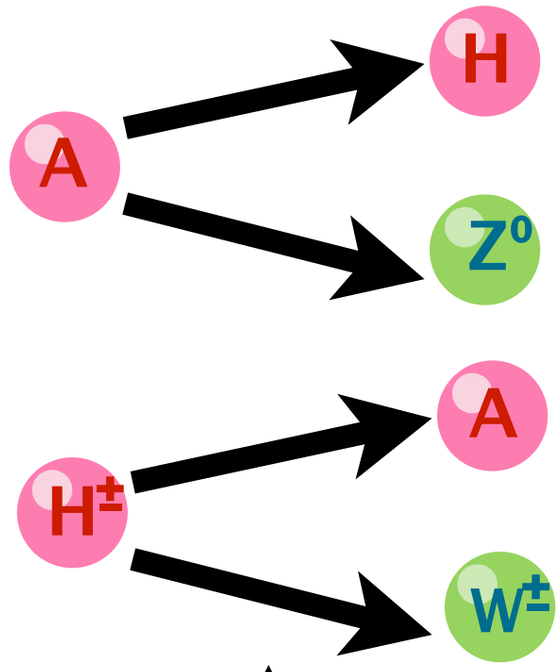
Higgs Bosons



Most theoretical models have more Higgs Bosons!

How can we describe them?

Exotic Higgs Decays



How can we find them?

Type II 2HDM

Type II 2HDM

Two Higgs-Doublet Model:

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

Type II 2HDM

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- model described by masses and mixing angles

CP even Higgses:	h^0, H^0	$H^0 = \phi_1^0 \cos\alpha + \phi_2^0 \sin\alpha$
CP odd Higgs:	A	$h^0 = -\phi_1^0 \sin\alpha + \phi_2^0 \cos\alpha$
Charged Higgses:	$H^\pm$	$A = -G_1 \sin\beta + G_2 \cos\beta$
Ratio of vev:	$\tan\beta$	$H^\pm = -\phi_1^\pm \sin\beta + \phi_2^\pm \cos\beta$

Mixing between CP-even Higgses: α

Type II 2HDM

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$$A = -G_1 \sin\beta + G_2 \cos\beta$$
$$H^\pm = -\phi_1^\pm \sin\beta + \phi_2^\pm \cos\beta$$

Couplings for Type II 2HDM:

- Coupling to fermions

up-like quarks couple to Φ_1

down-like quarks and leptons couple to Φ_2

Constraints on Parameter Space

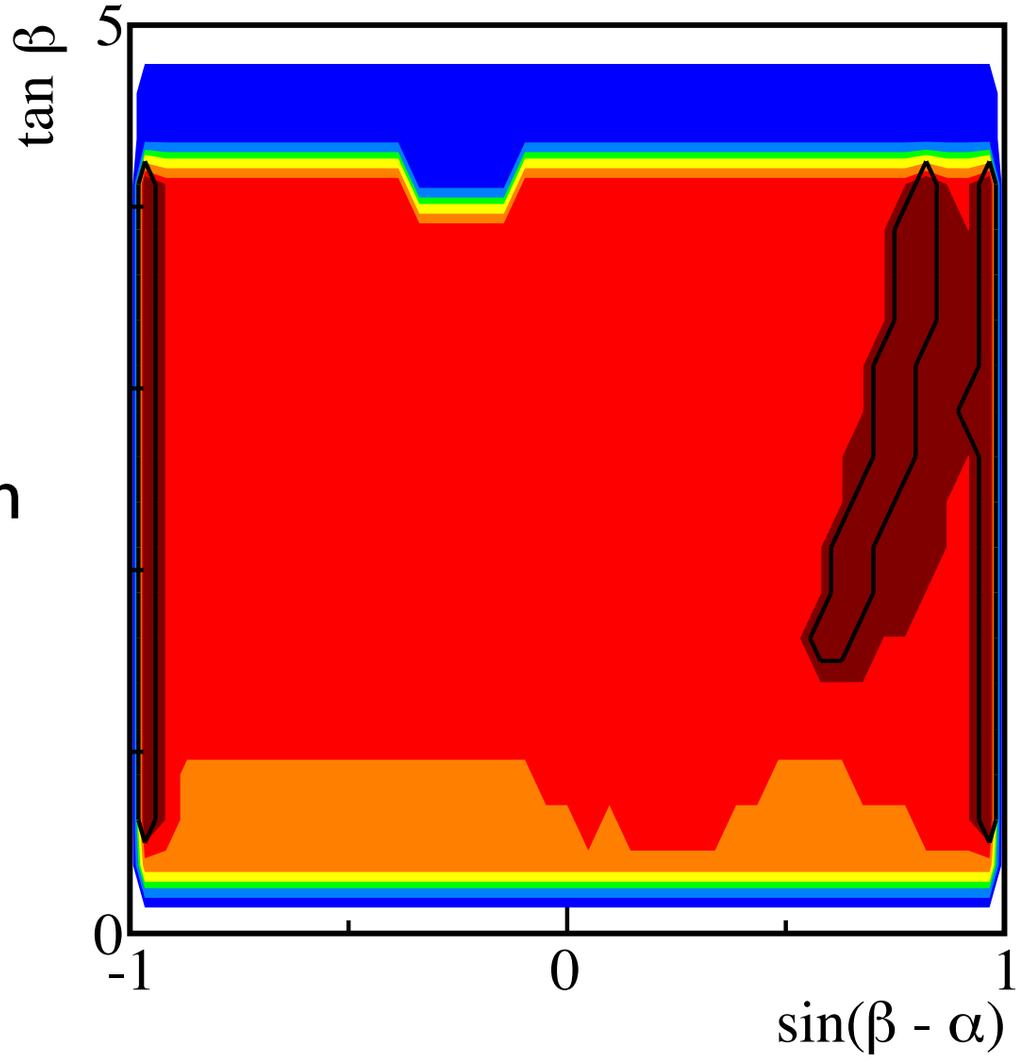
see arXiv 1305.002

non perturbative

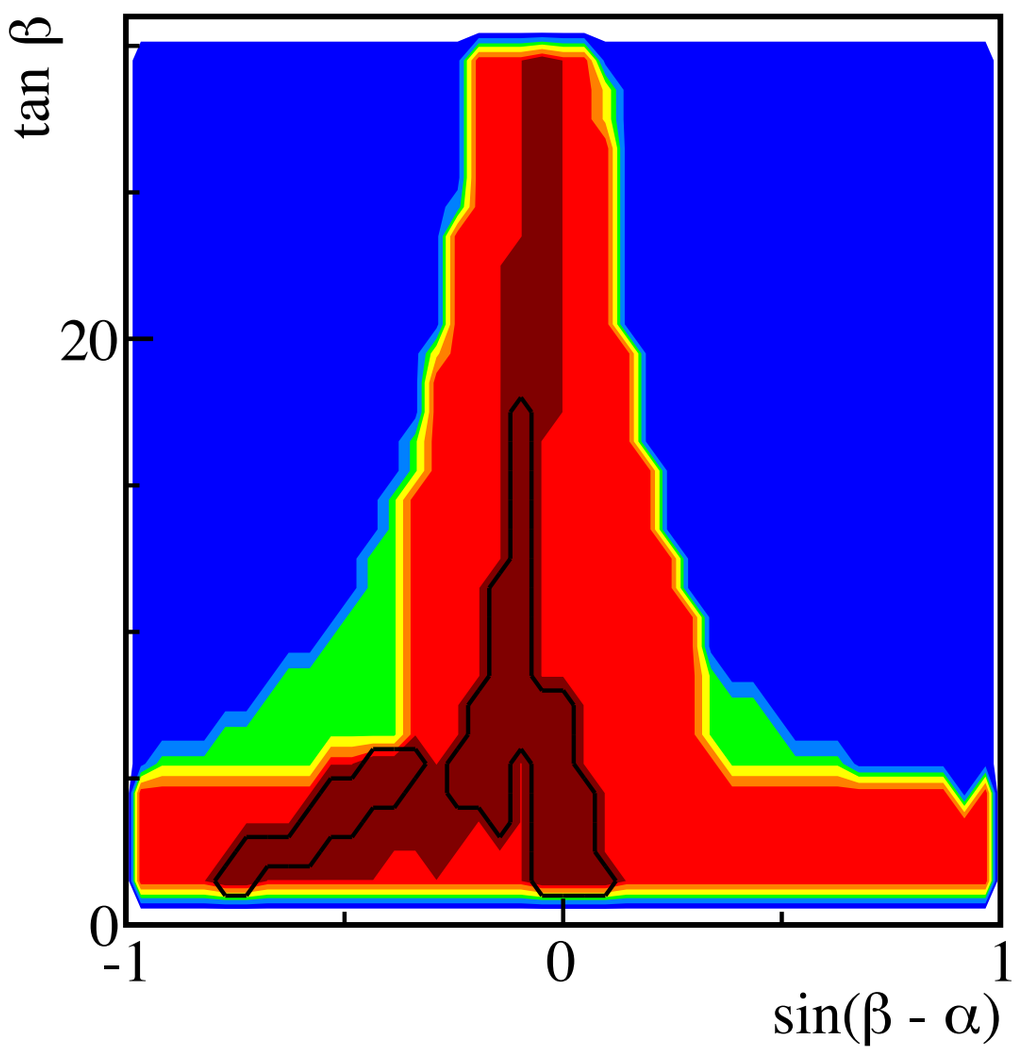
pass exclusion bounds

signal region

$h^0 - 126$

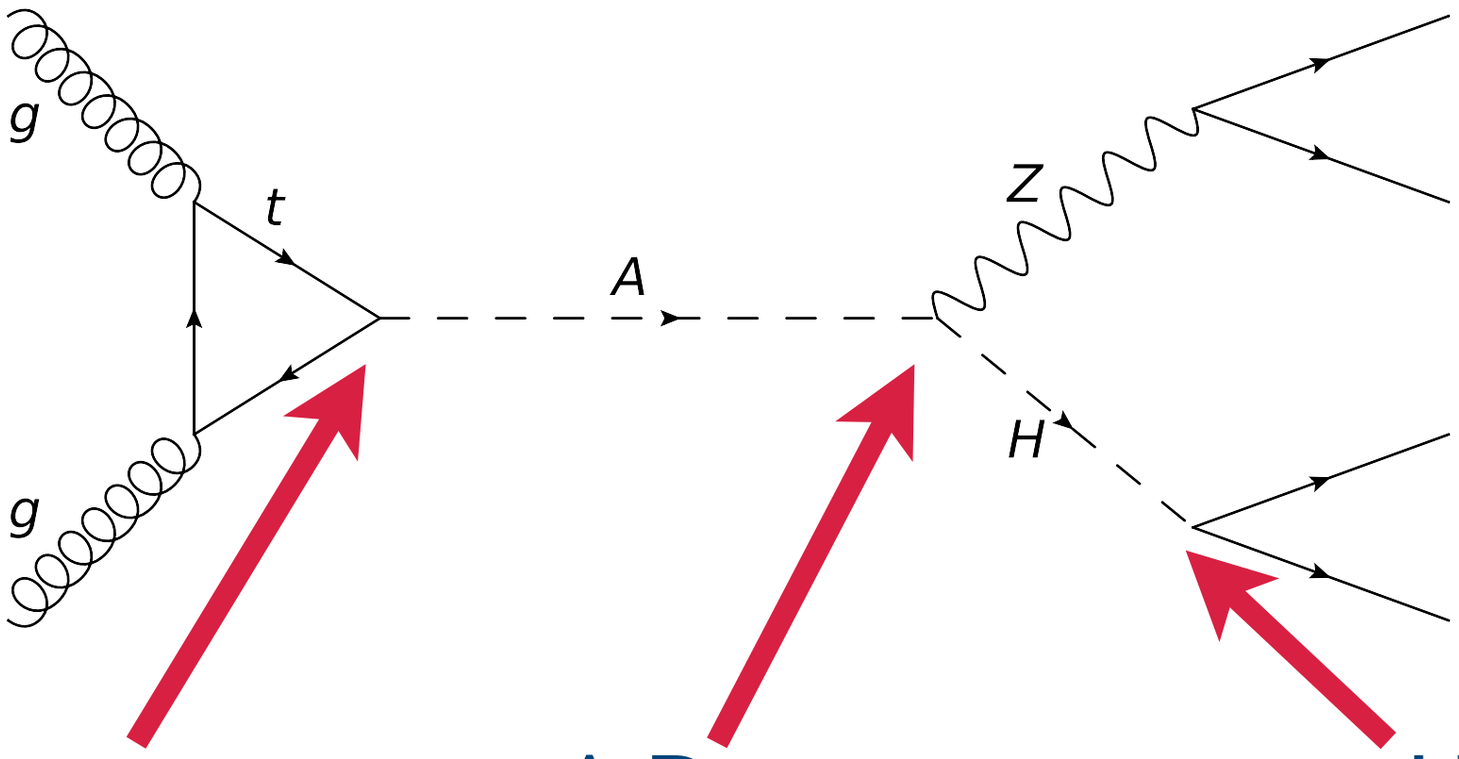


$H^0 - 126$



SM like region:	$\sin(\beta-\alpha)=\pm 1$	$\sin(\beta-\alpha)=0$
extended region:	$0.5<\sin(\beta-\alpha)<1$	$-0.8<\sin(\beta-\alpha)<0$

Exotic Higgs Decays - Neutral Higgs



Production:

gluon-gluon fusion

$$g_{ttA} \sim \cot\beta$$

$$g_{bbA} \sim \tan\beta$$

A Decay:

$$A \to HZ$$

$$g_{H^0AZ} \sim \sin(\beta-\alpha)$$

$$g_{h^0AZ} \sim \cos(\beta-\alpha)$$

H Decay:

$$H \to bb, \tau\tau$$

$$g_{H^0bb,\tau\tau} \sim \cos\alpha/\cos\beta$$

$$g_{h^0bb,\tau\tau} \sim \cos\alpha/\sin\beta$$

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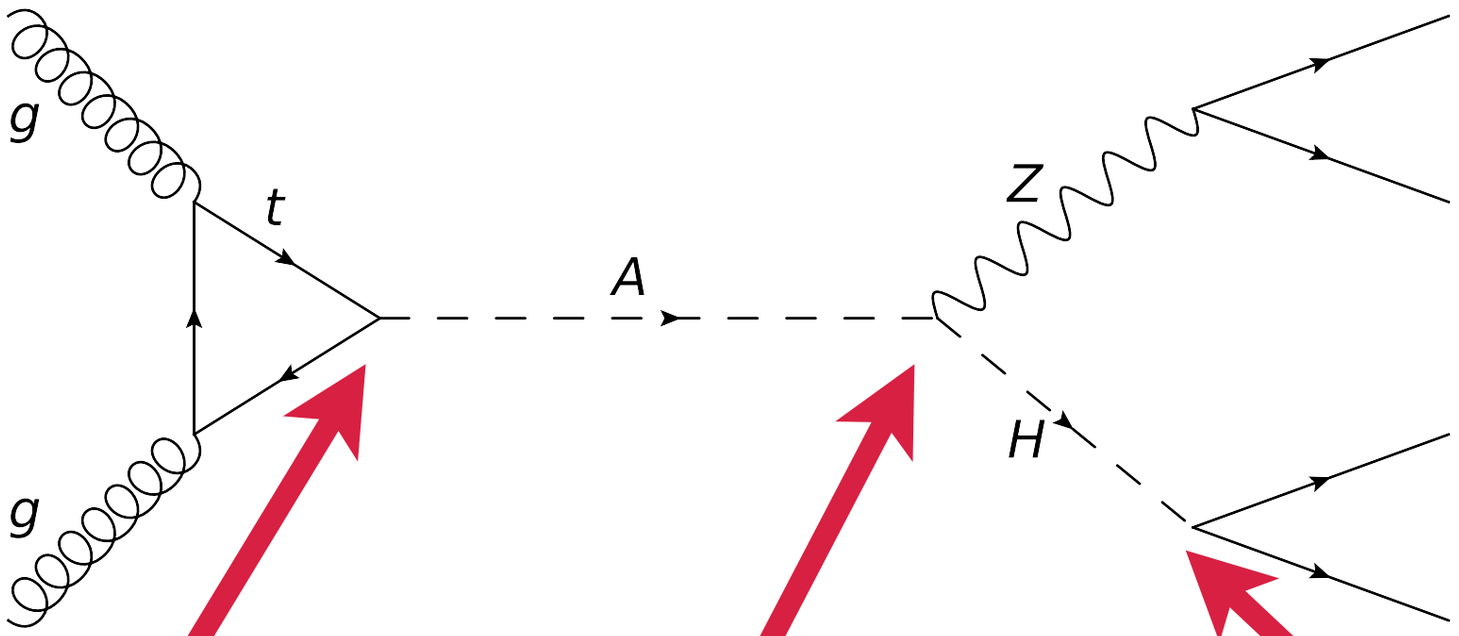

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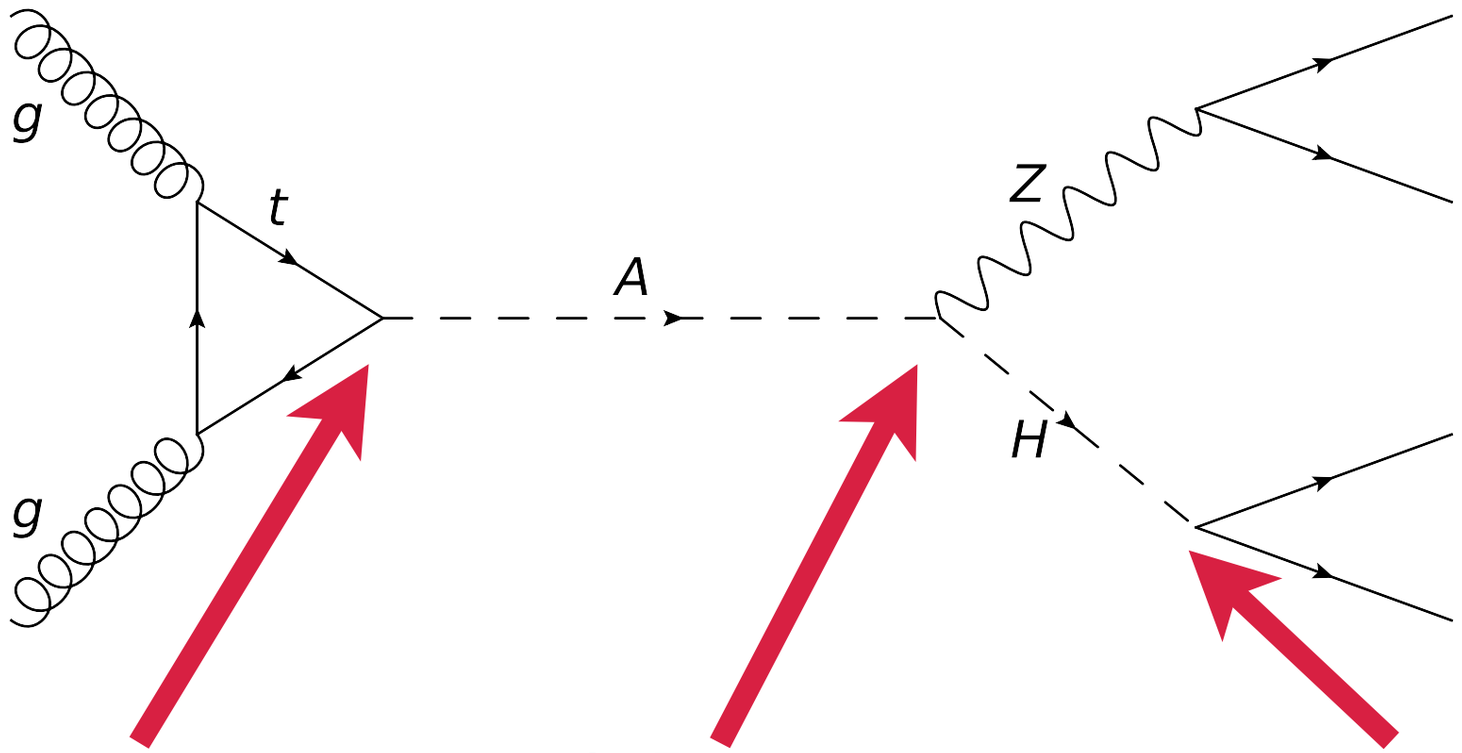
Both $A \to H^0 Z$ and $A \to h^0 Z$ can be dominating decay channel

Exotic Higgs Decays - Neutral Higgs

This also applies to $H \to AZ$



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Exotic Higgs Decays - Neutral Higgs

Analysis:

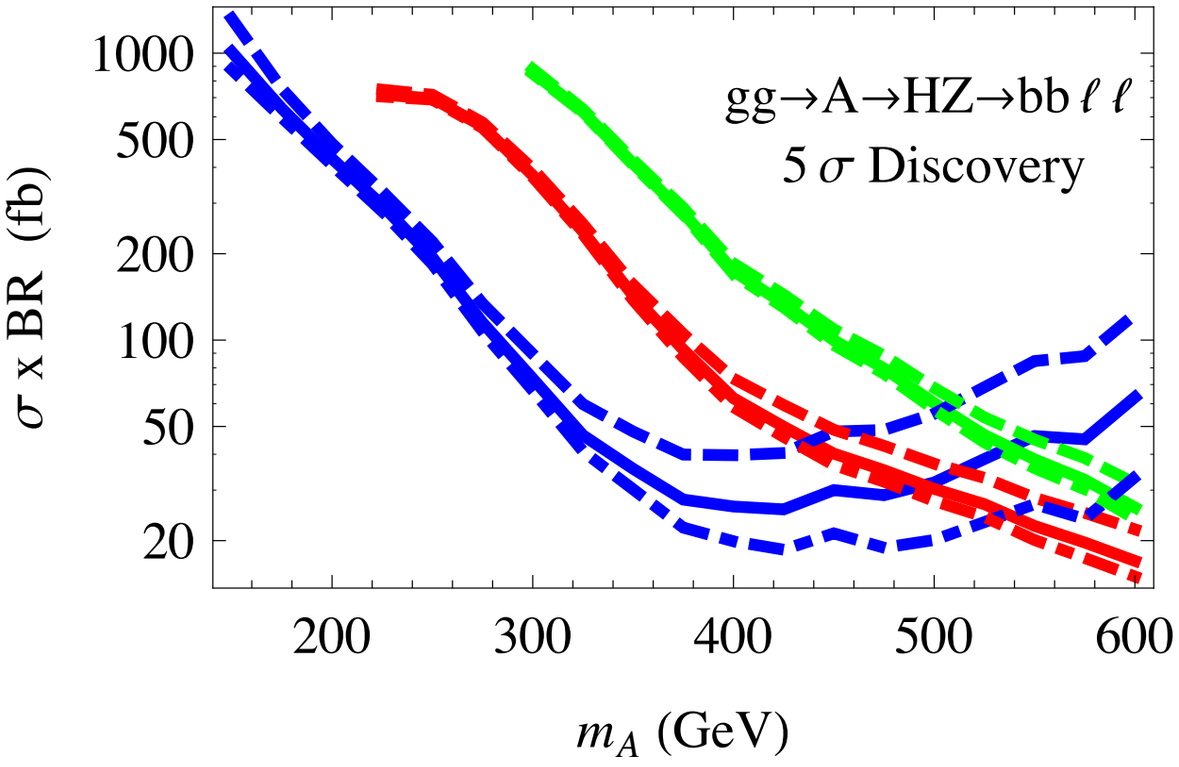
- dominating backgrounds: $t\bar{t},\ Z/\gamma^* bb,\ h_{SM}Z$
- for details see: arXiv 1404.1922

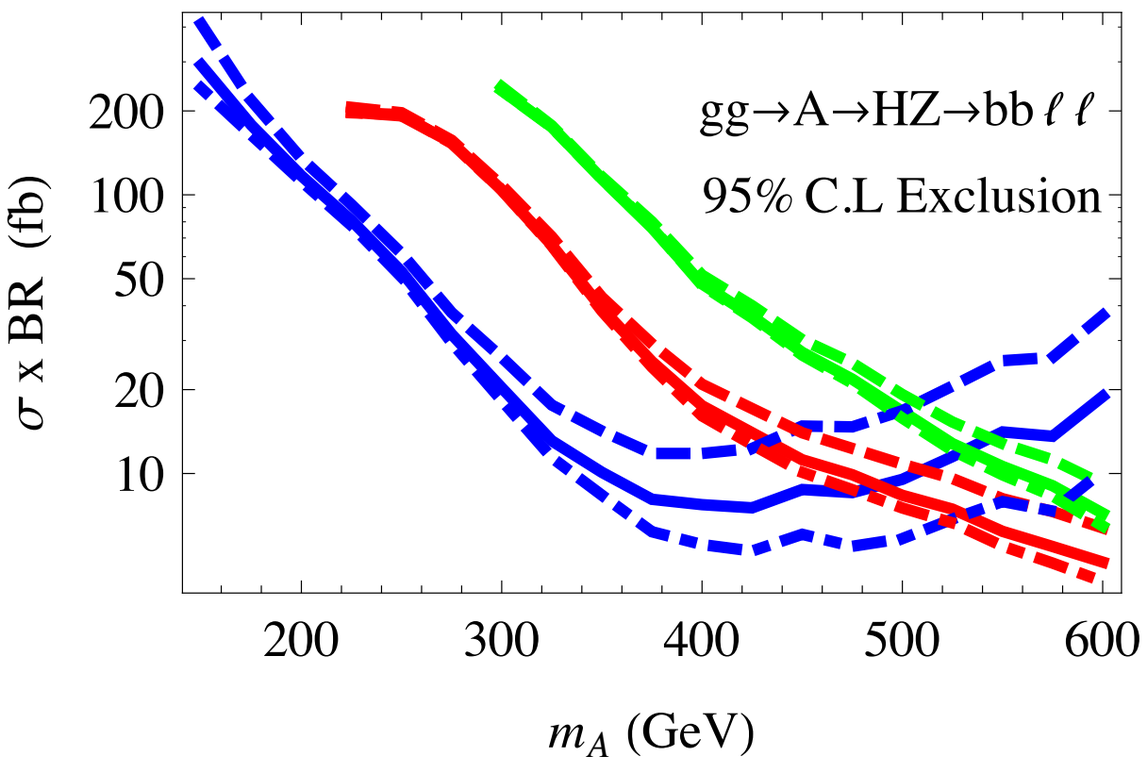
$m_H = 50$ GeV

$m_H = 126$ GeV

$m_H = 200$ GeV

Discovery/Exclusion limits





these limits are model independent

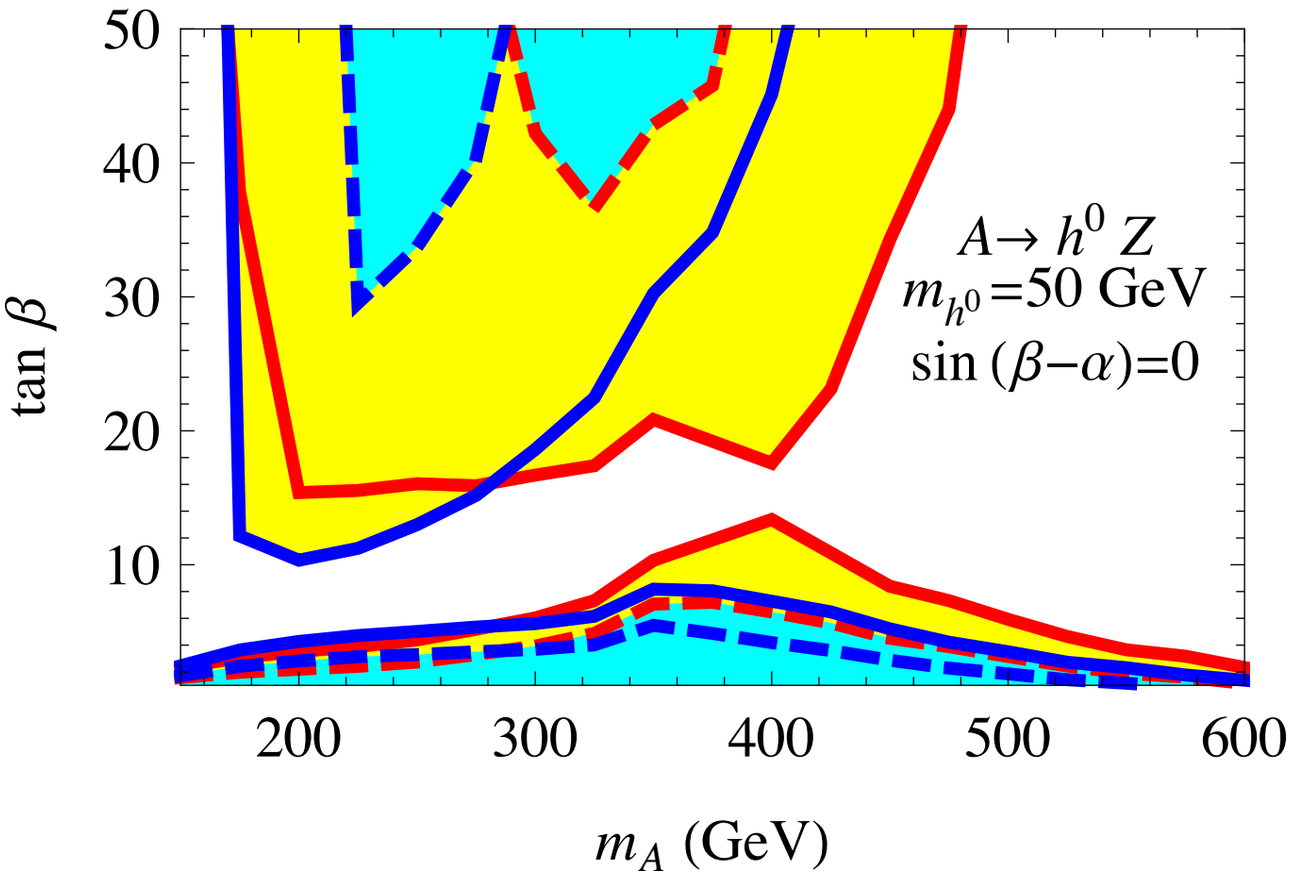
Exotic Higgs Decays - Neutral Higgs

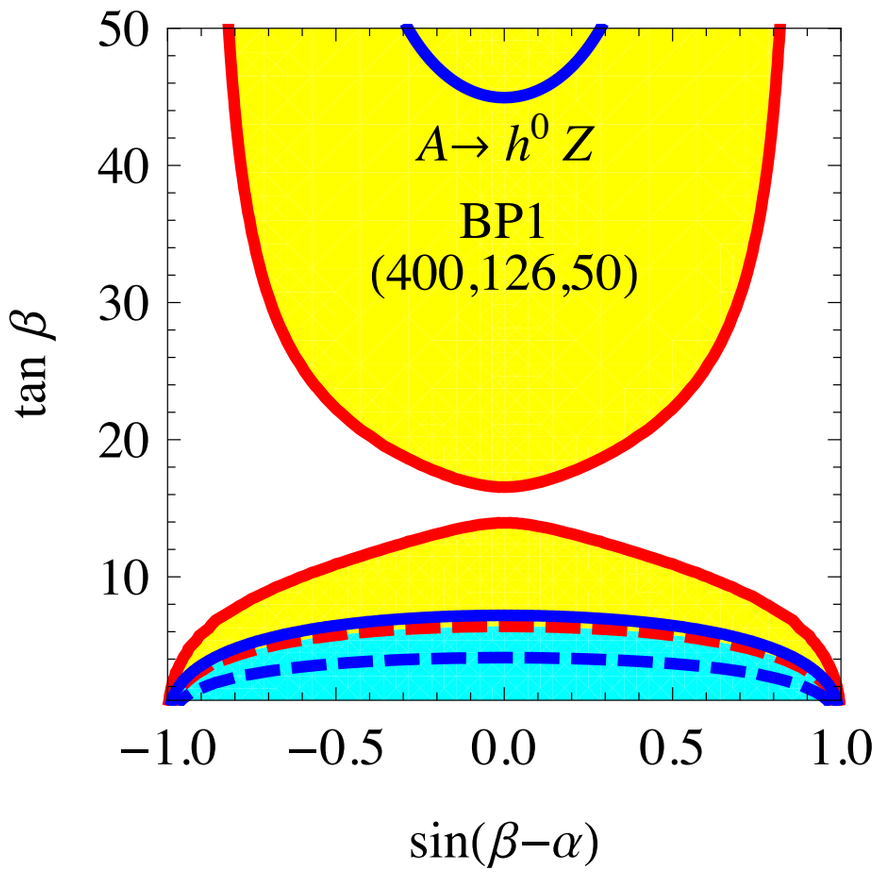
Implication for Type II 2HDM:

$H^0 - 126$ Scernario

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

$$m_A = 400 \text{ GeV}$$
$$m_{H^0} = 126 \text{ GeV}$$
$$m_{h^0} = 50 \text{ GeV}$$





95% C.L. Excl. / 5 σ Discovery for $h^0 \to bb$

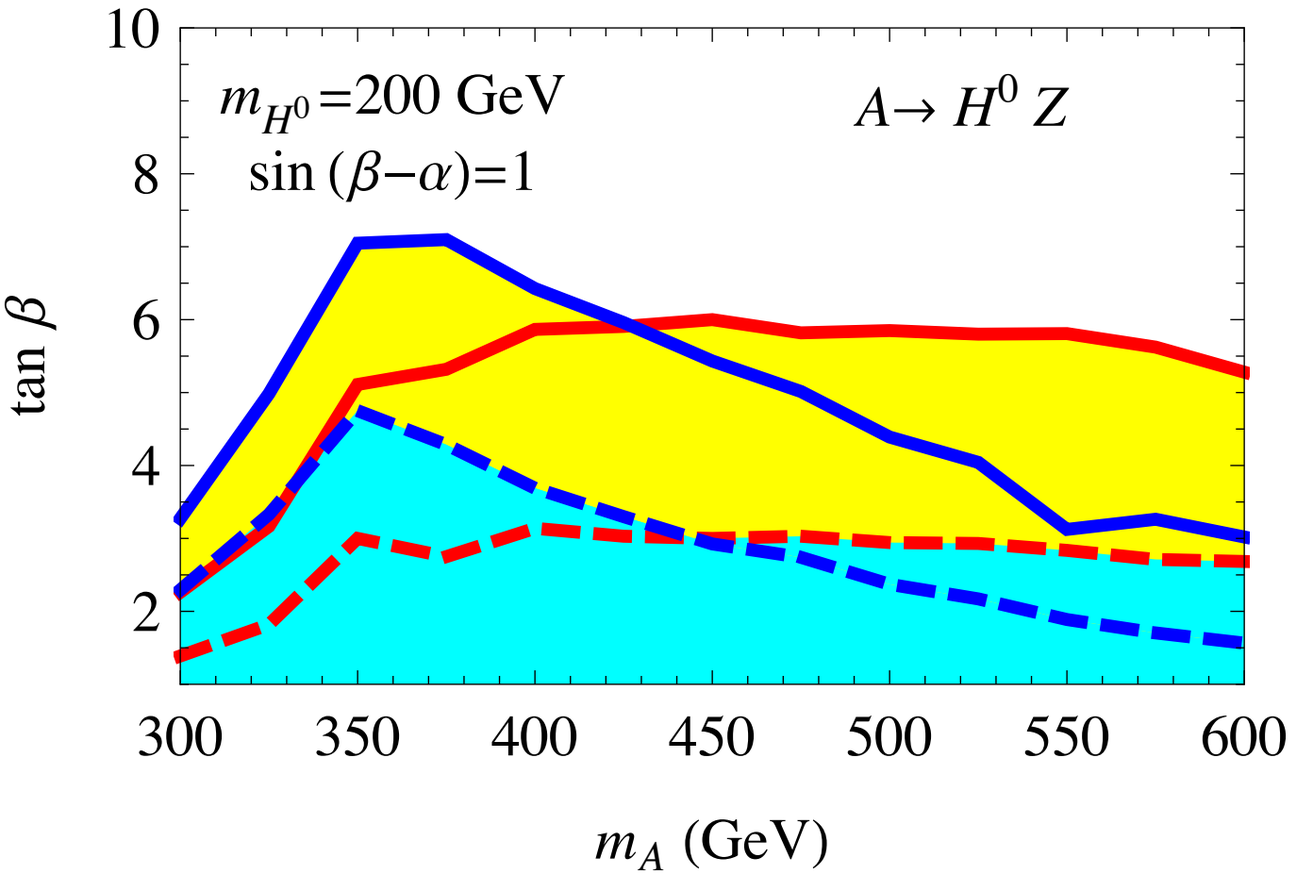
95% C.L. Excl. / 5 σ Discovery for $h^0 \to \tau\tau$

Exotic Higgs Decays - Neutral Higgs

Implication for Type II 2HDM:

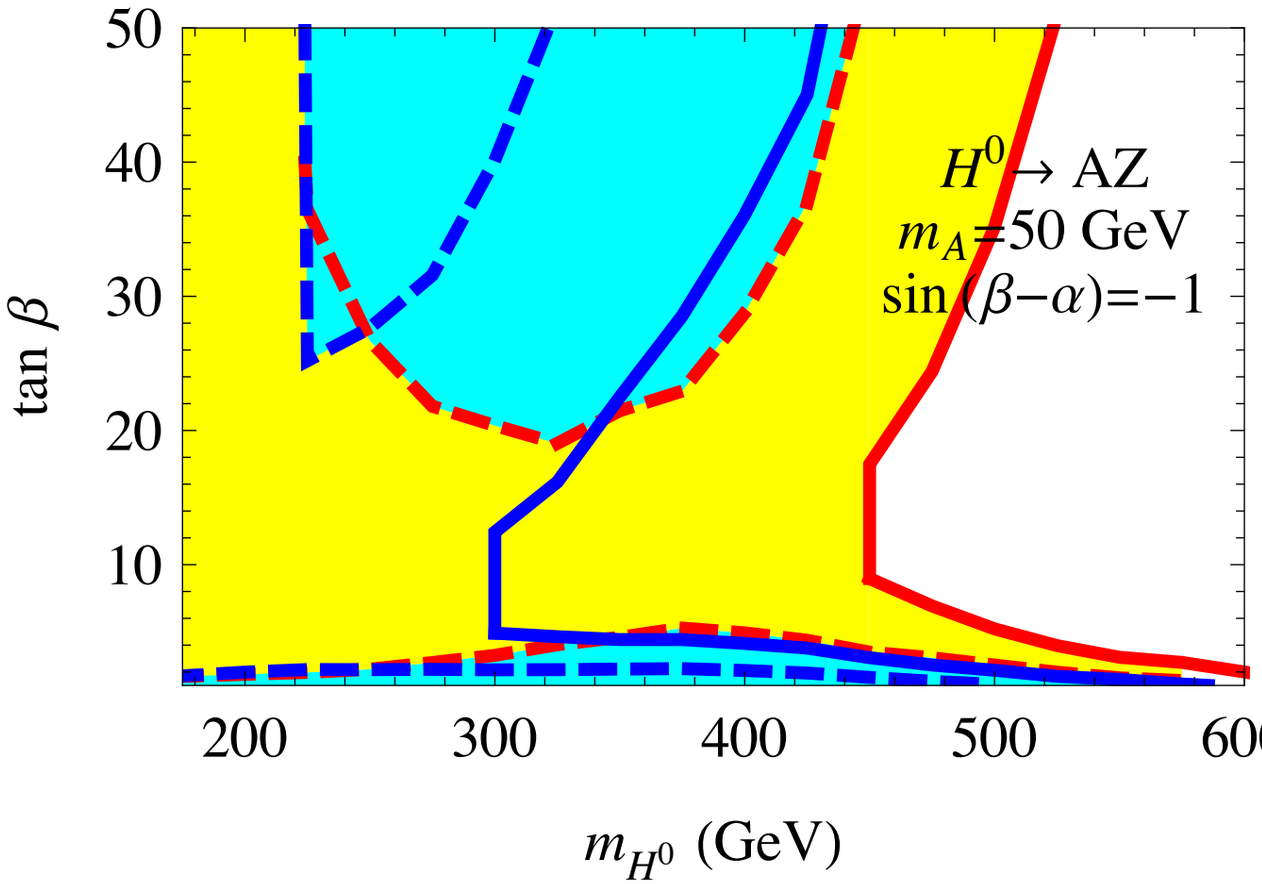
$h^0 - 126$ Scernario

$\sin(\beta - \alpha) = 1$ (SM like region)



$h^0 - 126$ Scernario

$\sin(\beta - \alpha) = -1$ (SM like region)



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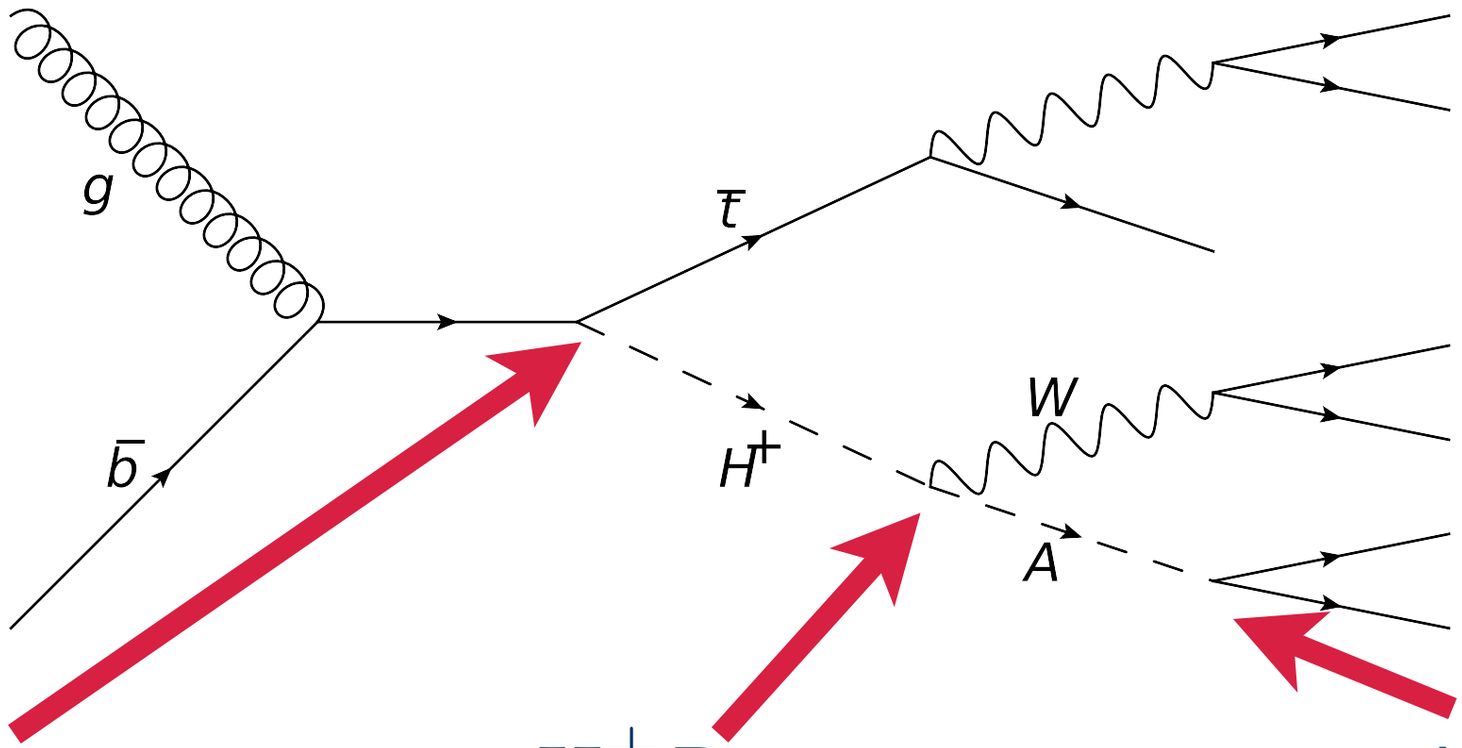
Exotic Higgs Decays - Charged Higgs



Production:

$tH^{\pm}$ associate production

$$\sigma \sim m_t^2 \cot^2\beta + m_b^2 \tan^2\beta$$

$H^{\pm}$ Decay:

$$H^{\pm} \to AW$$

$$g_{H^{\pm}WA} \sim g$$

A Decay:

$$A \to bb, \tau\tau$$

$$g_{Abb,\tau\tau} = \tan\beta$$

- to be pusblished soon

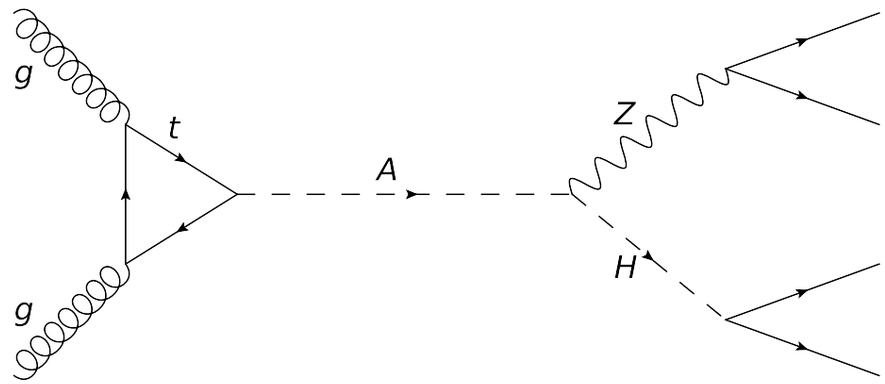
Conclusion

Exotic Higgs Decays:

- possible decay channels:

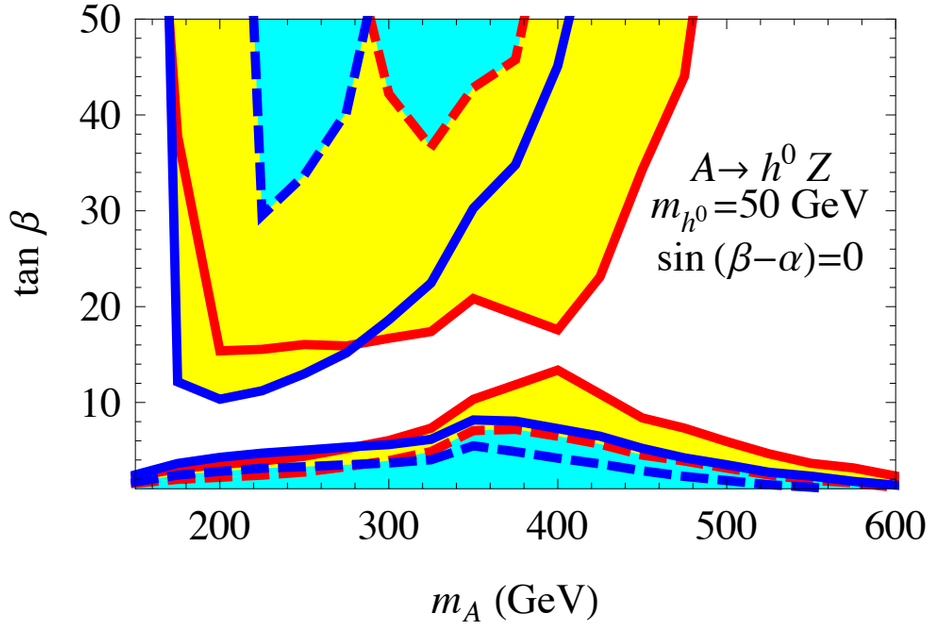
$$A/H \to H/AZ, \;\; H^{\pm} \to A/HW$$

- develop search strategy
- obtain model independent exclusion/discovery limits



Implication for Type II 2HDM:

- large part of parameter space can be discovered/ excluded

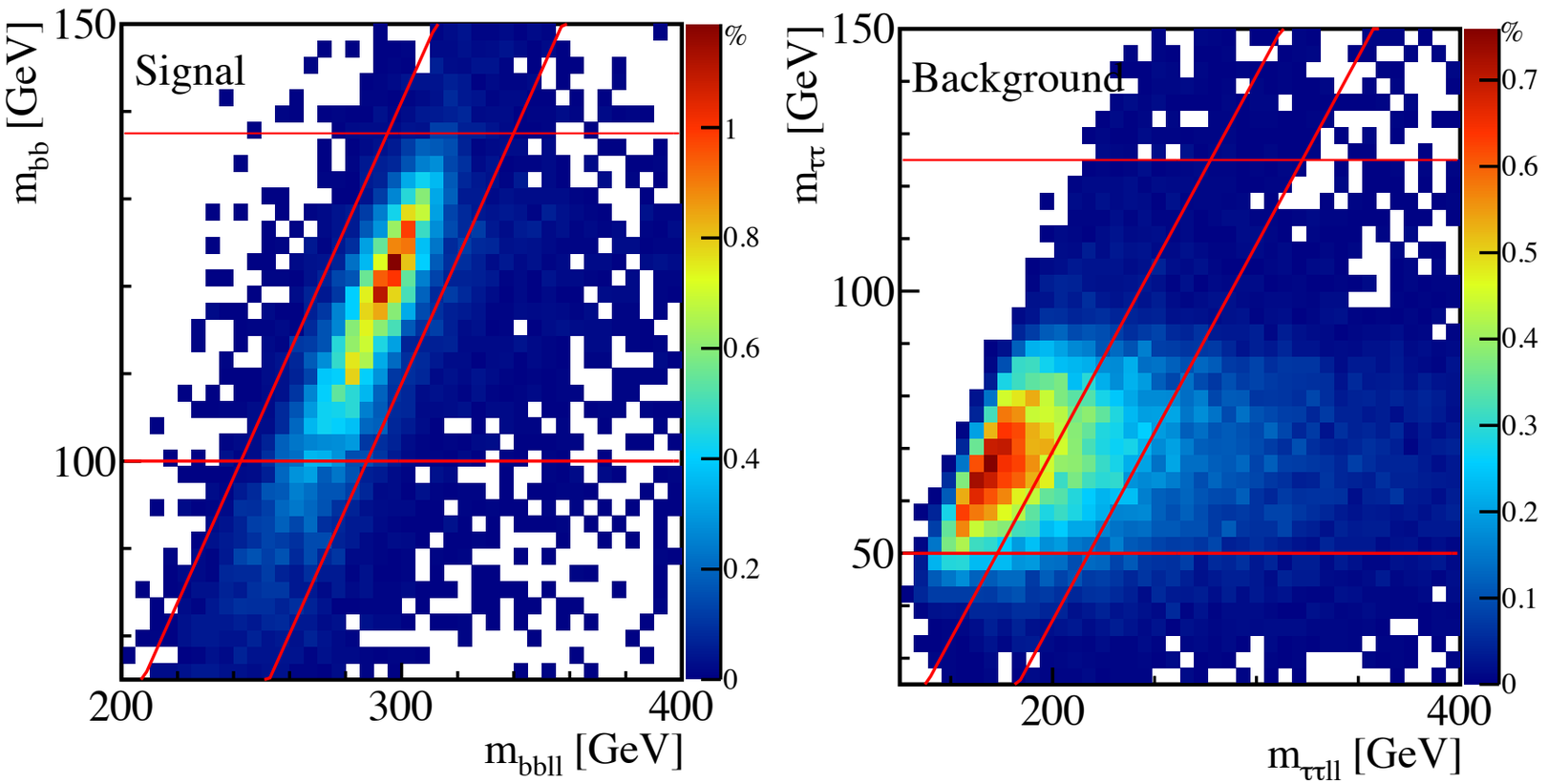


Search Strategy

Identification cuts: $n_b = 2,\ n_\ell = 2$

Dilepton mass: $80\ \mathrm{GeV} < m_{\ell\ell} < 100\ \mathrm{GeV}.$

m_{bb} versus m_{bbll} :

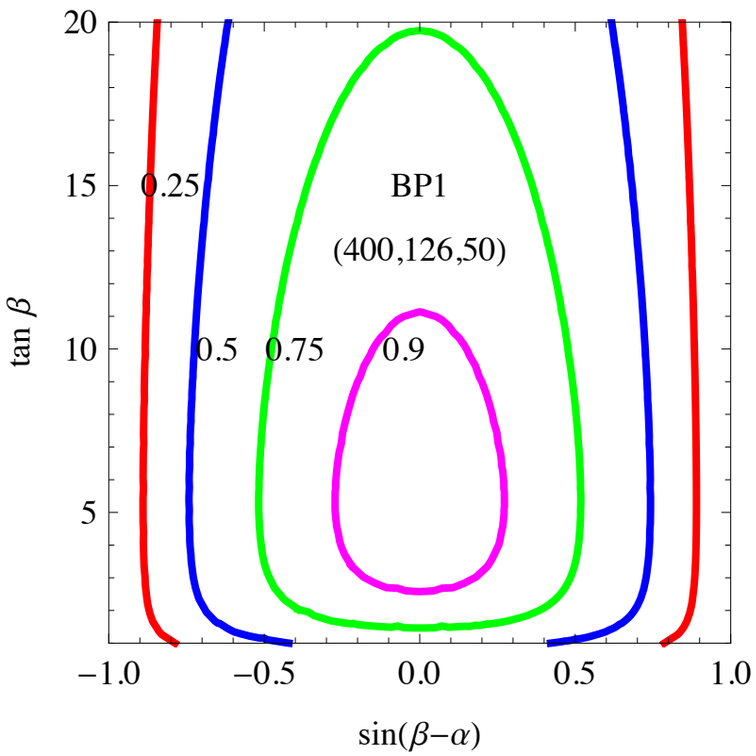


Transverse momentum cut:

$$\sum_{b\,\mathrm{jets}} p_T > 0.6 \times \frac{m_A^2 + m_H^2 - m_Z^2}{2m_A}, \qquad \sum_{\ell,\, b\,\mathrm{jets}} p_T > 0.66 \times m_A$$

Branching Ratio

$\mathrm{BR}(A \to h^0 Z)$



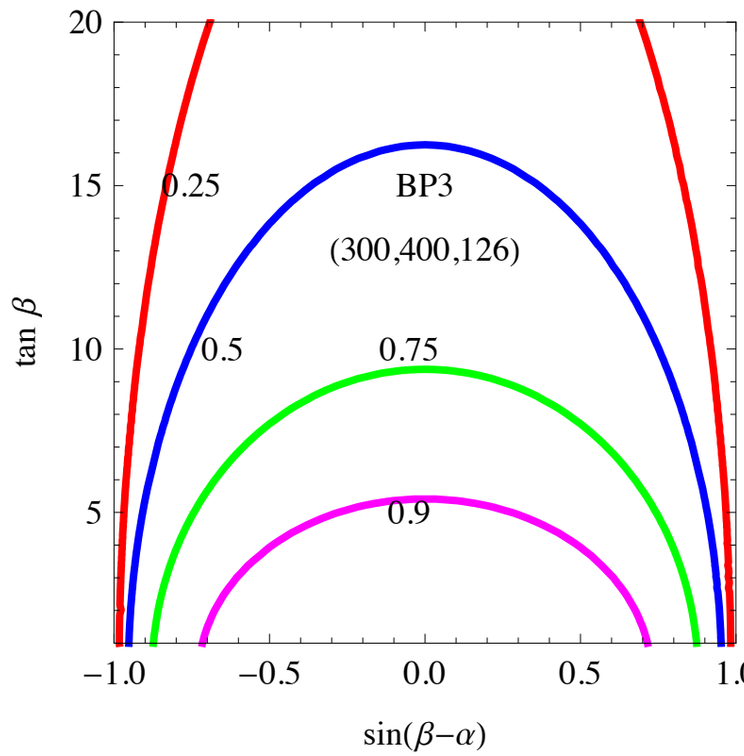
$H^0 - 126$

$m_A = 400$ GeV

$m_{H^0} = 126$ GeV

$m_{h^0} = 50$ GeV

$\mathrm{BR}(A \to h^0 Z)$



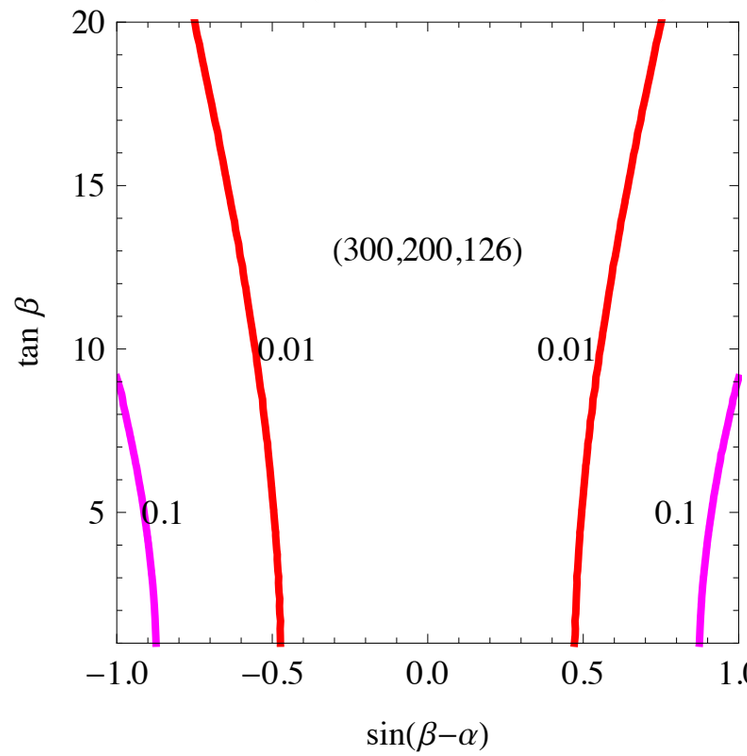
$h^0 - 126$

$m_A = 300$ GeV

$m_{H^0} = 400$ GeV

$m_{h^0} = 126$ GeV

$\mathrm{BR}(A \to H^0 Z)$



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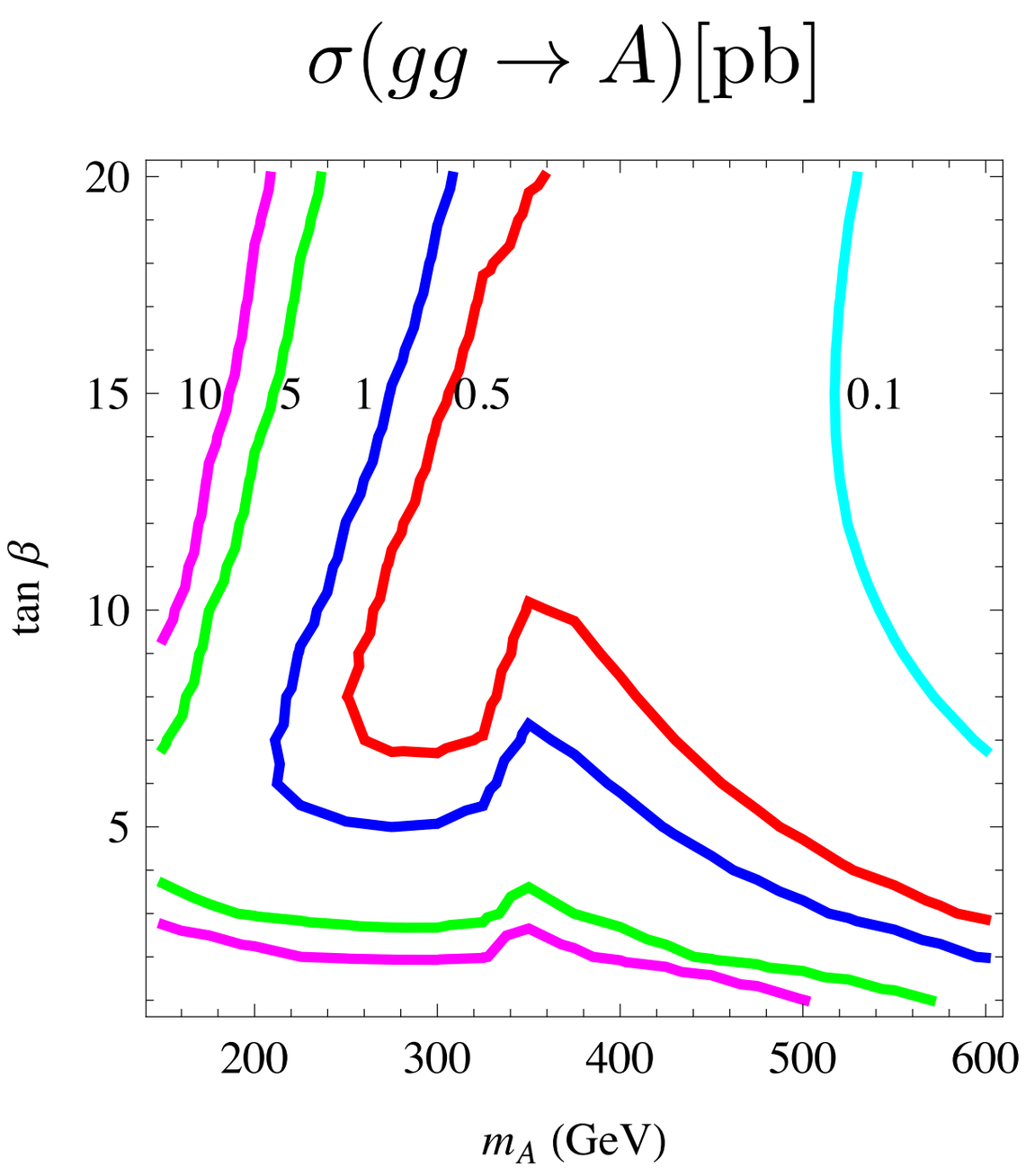
$m_{H^0} = 200$ GeV

$m_{h^0} = 126$ GeV

Production Cross Section



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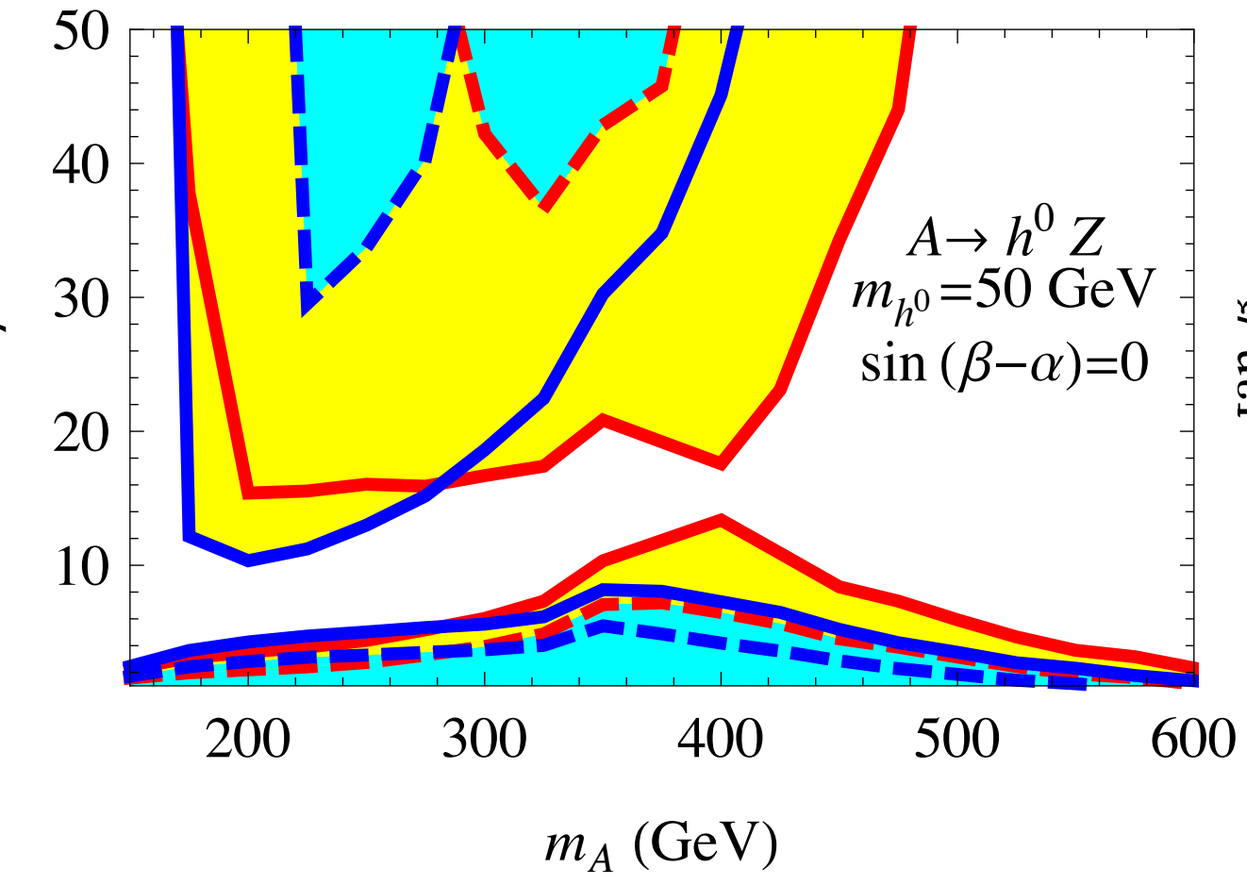
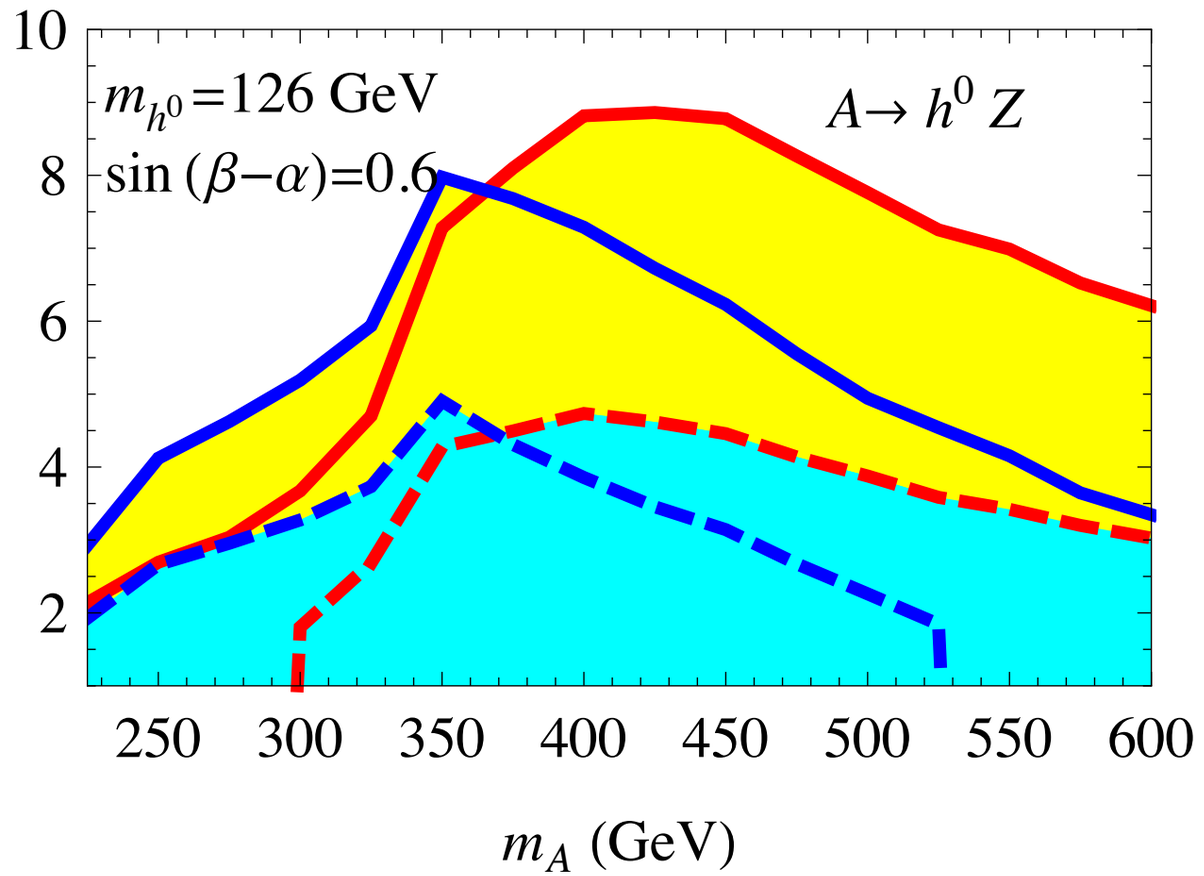
$\sin(\beta - \alpha) = 0$ (SM like region)



$h^0 - 126$ Scernario

$\sin(\beta - \alpha) = 0.6$ (extended region)



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