A Higgs Discovery via Exotic Higgs Decays

work with Baradhwaj Coleppa, Shufang Su

arXiv: 1404.1992, 1408.4119

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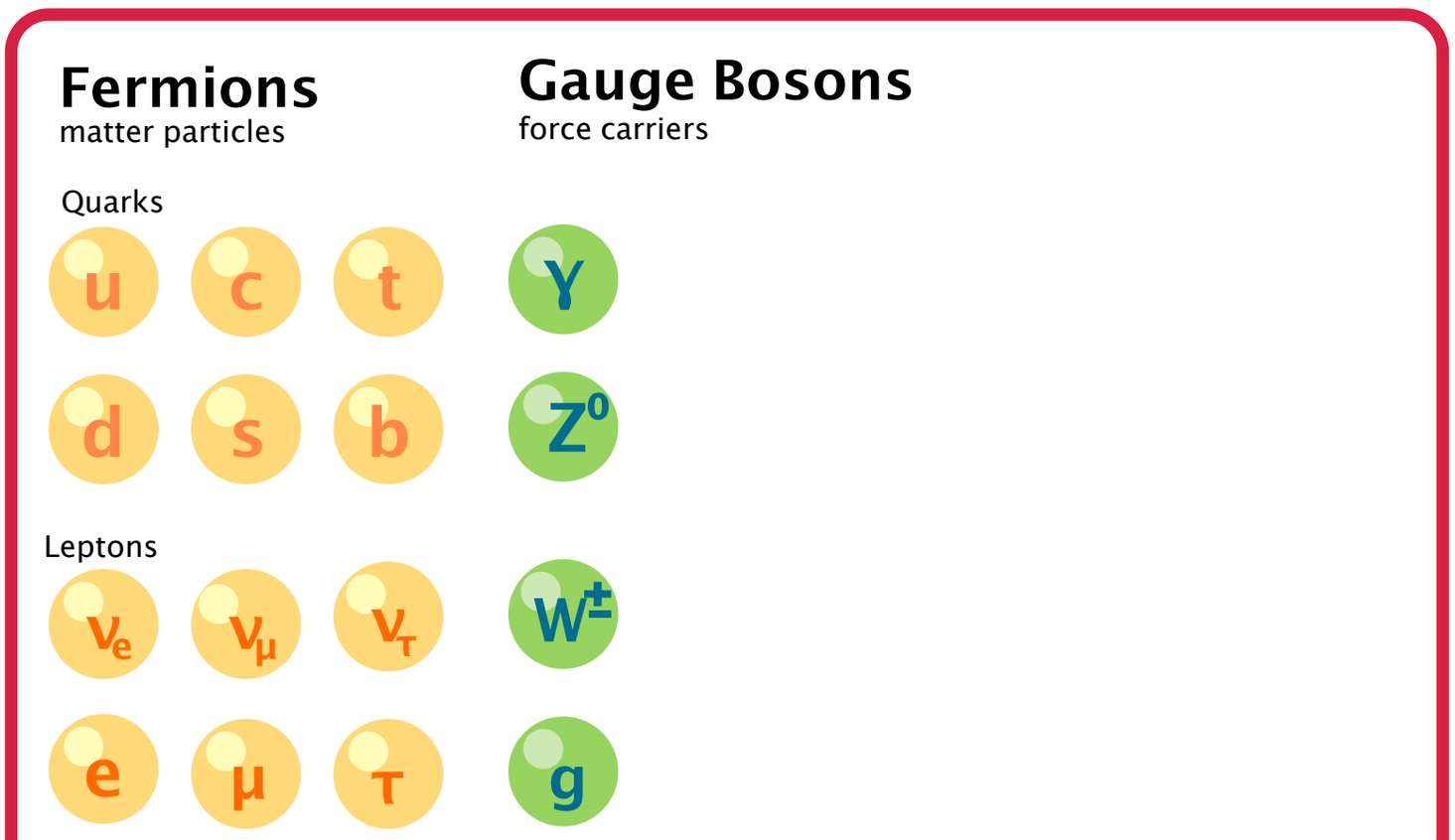
University of Arizona

APS 4CS Meeting, 17th October 2014

Introduction

Standard Model (before July 4th 2012)



Introduction

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

Y

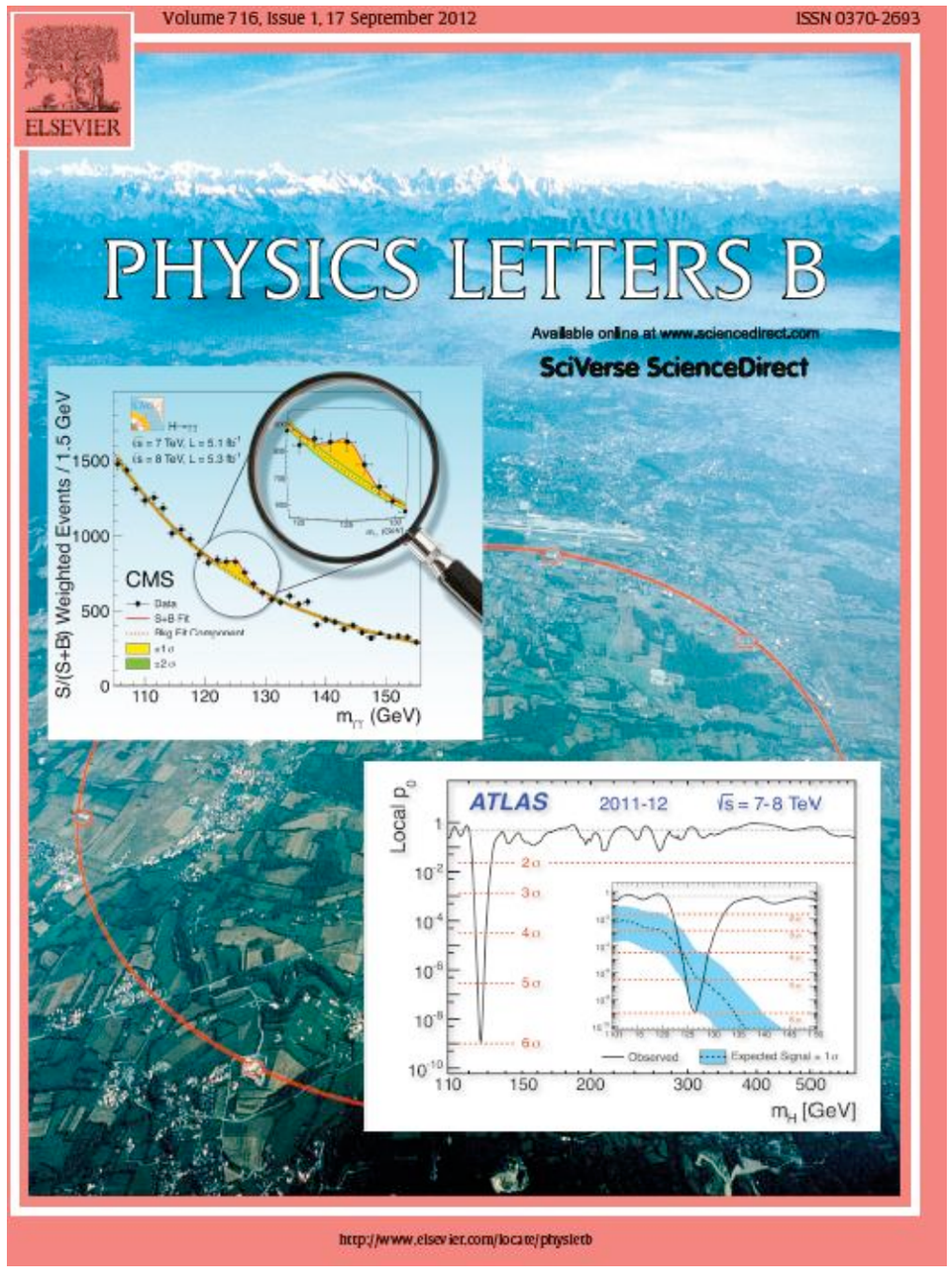
Z^0

$W^\pm$

g

Higgs Bosons

h



July 4th 2012
We find a Higgs Boson!

What comes next?

Did we solve all problems?

Do we have a complete description of nature?

Can we stop doing High Energy Physics?

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Did we solve all problems?

Do we have a complete description of nature?

Can we stop doing High Energy Physics?

NO!

There are still open questions!

Open Questions

Theoretical

Fundamental Spin 0 Particle

Origin of EWSB

Unstable Higgs Mass?

- Quadratically divergent radiative corrections
- additional symmetries?

Naturalness

- Hierarchy Problem
- Fine-tuning ?

Unified Theories

Experimental

Is it SM Higgs?

- Mass, Spin, Width
- Coupling to other particles
- Unexpected Decays?

What is Dark Matter?

- New Particles?
- Can we find them at LHC?

Deviations from SM?

- Precision Measurements
- Flavor Constraints

What comes next?

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Physics beyond the Standard Model

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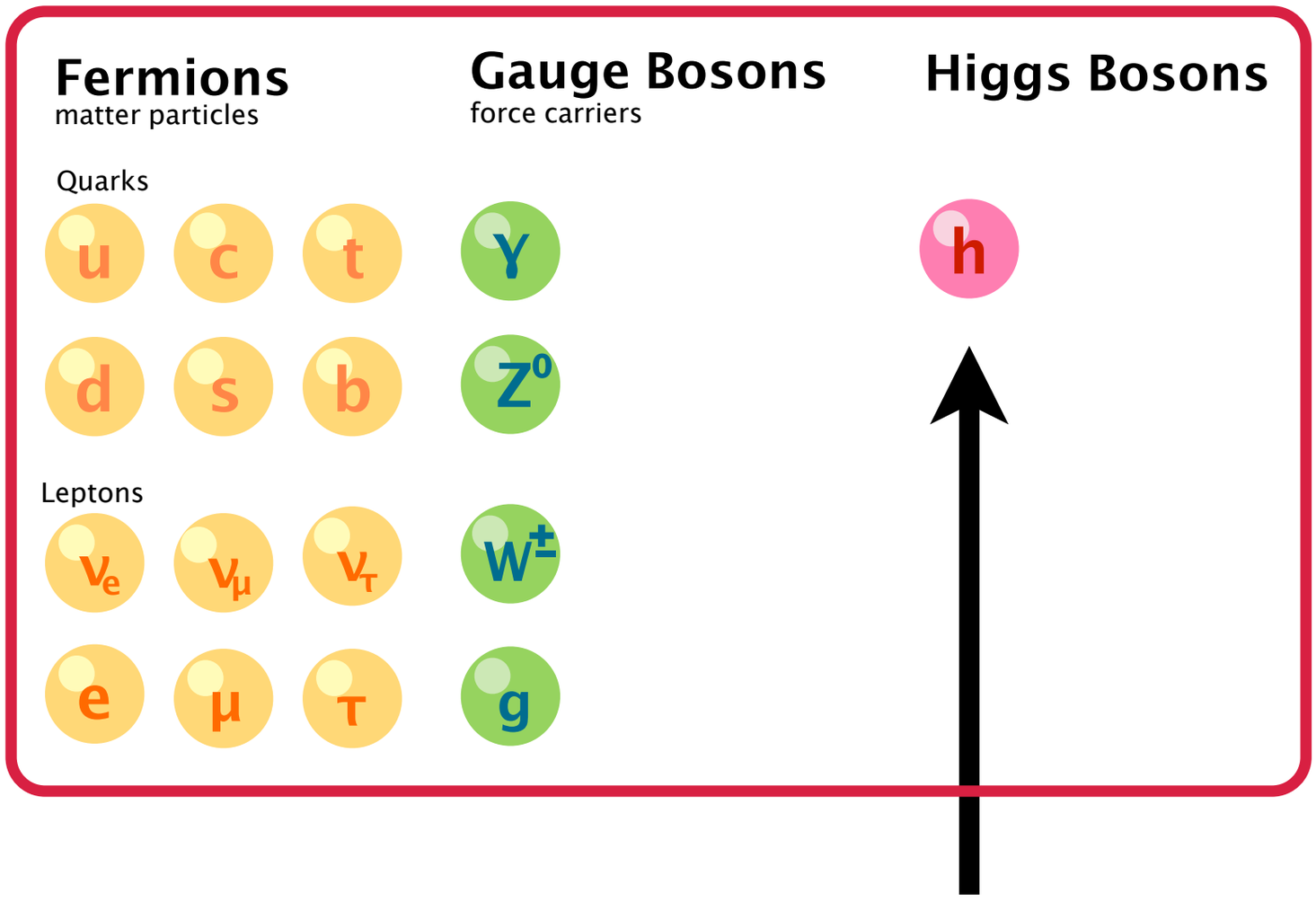
Standard Model



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Supersymmetry

Sfermions
Supersymmetric particle

$\tilde{u}$ $\tilde{c}$ $\tilde{t}$

$\tilde{d}$ $\tilde{s}$ $\tilde{b}$

$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$

$\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$

Gaugino
Supersymmetric particle

$\tilde{\chi}^0$

$\tilde{\chi}^\pm$

$\tilde{g}$

But there might be more!

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Most theoretical models have more Higgs Bosons!

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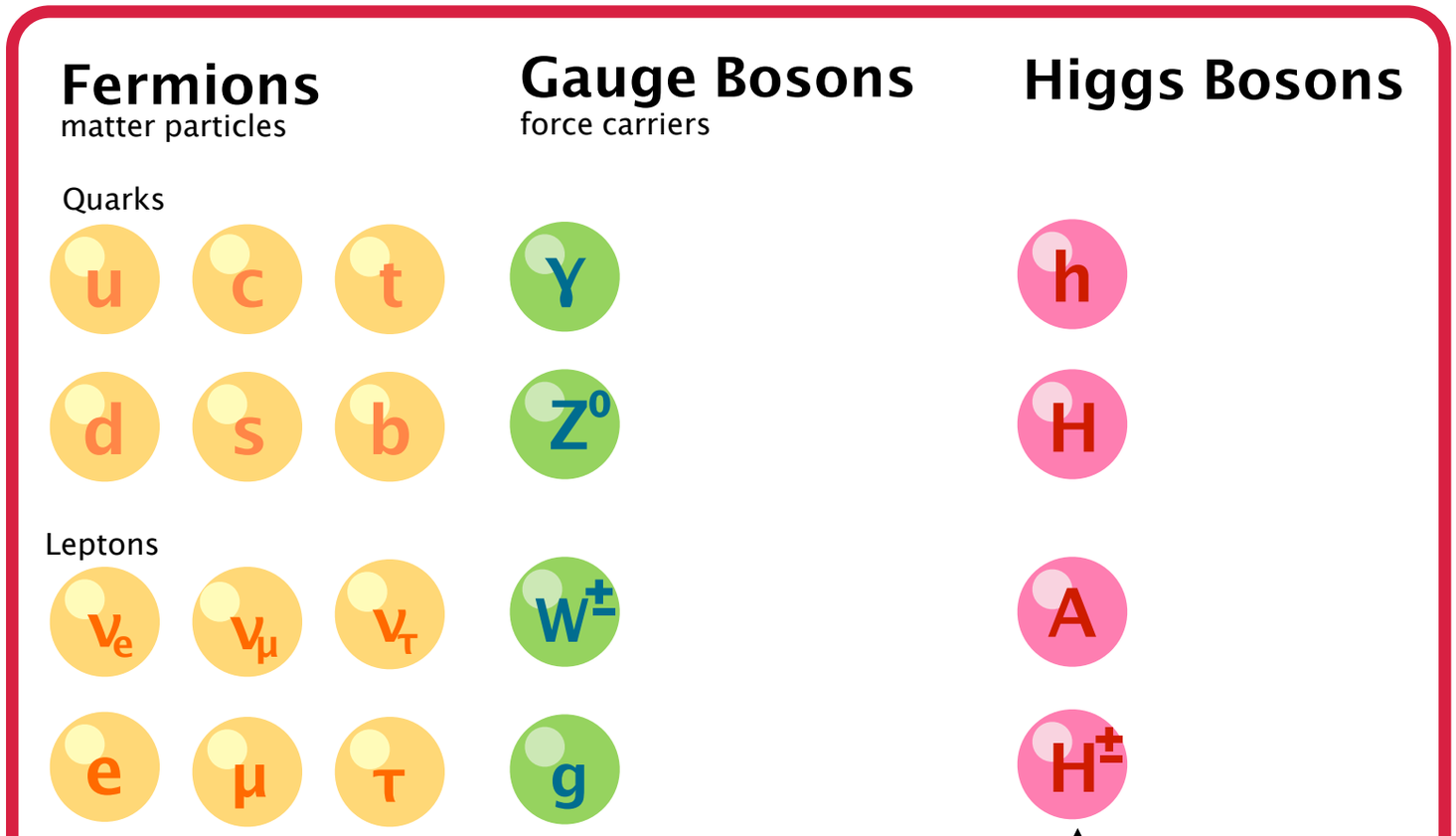

Most theoretical models have more Higgs Bosons!

How can we find them?

How can we describe them?

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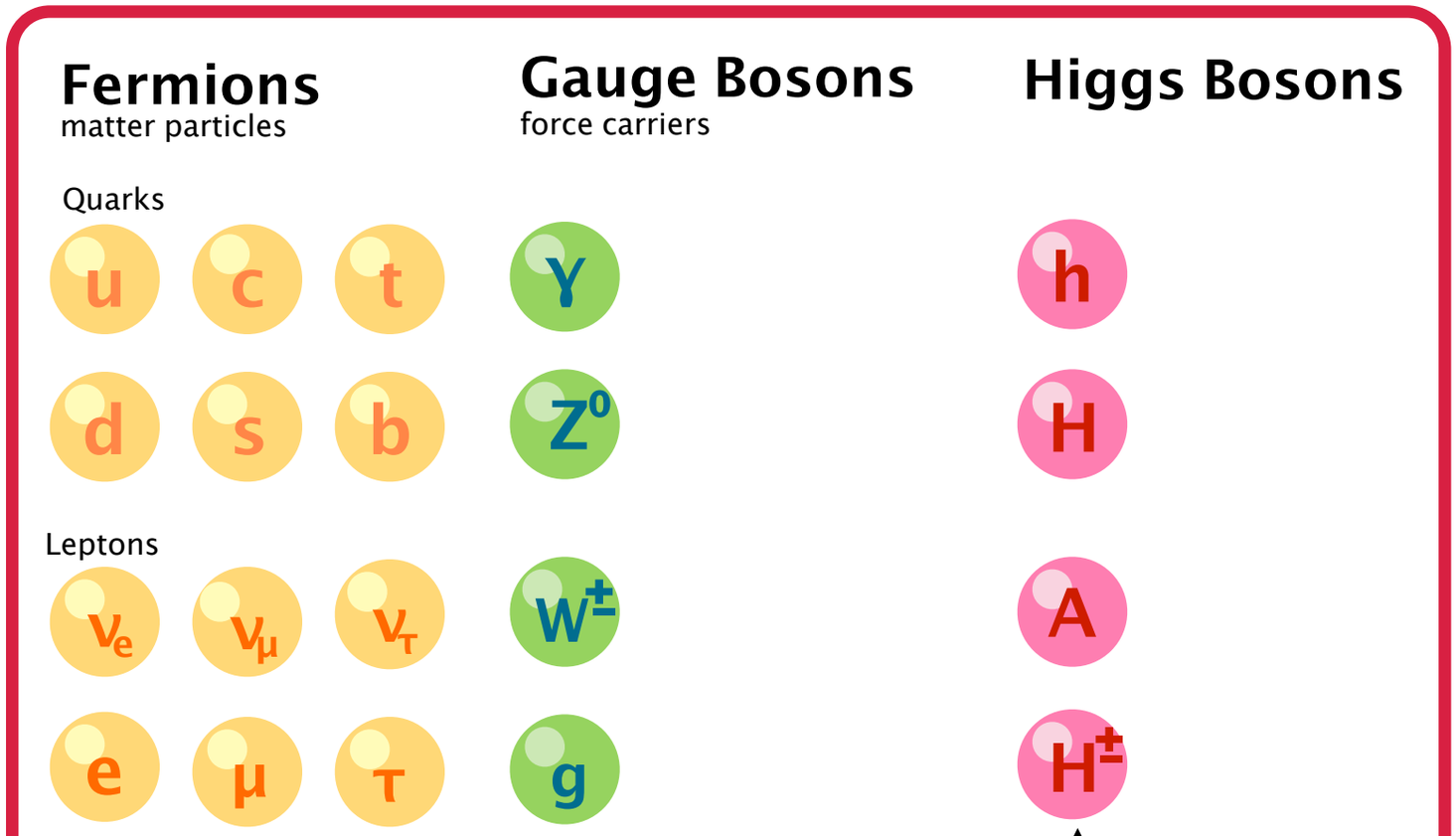

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Type II 2HDM

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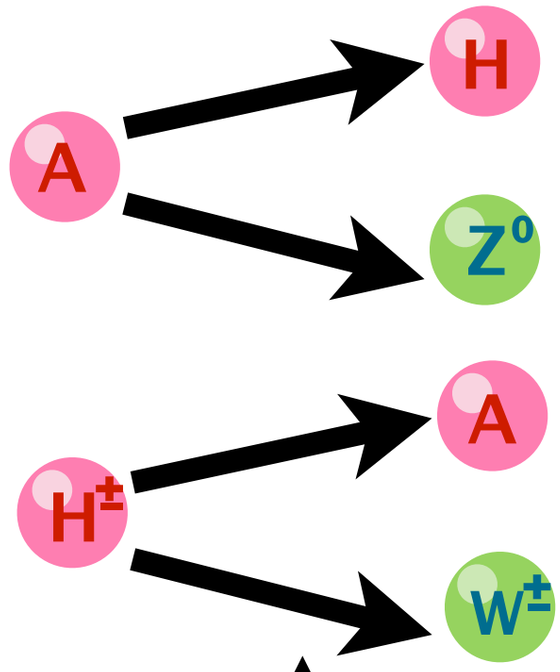
Exotic Higgs Decays



How can we find them?

Type II 2HDM

Theory: SM

Standard Model:

- one scalar doublet Φ with $\Phi = \begin{pmatrix} \phi^+ \\ (v + \phi^0 + iG)/\sqrt{2} \end{pmatrix}$

where we use:

v	vacuum expectation value
ϕ^0	physical Higgs boson
G, ϕ^+, ϕ^-	Goldstone Bosons

Theory: 2HDM

Two Higgs-Doublet Model:

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

Theory: 2HDM

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- model described by masses and mixing angles

CP even Higgses: h^0, H^0

CP odd Higgs: A

Charged Higgses: $H^\pm$

Ratio of vev: $\tan\beta$

$$H^0 = \phi_1^0 \cos\alpha + \phi_2^0 \sin\alpha$$
$$h^0 = -\phi_1^0 \sin\alpha + \phi_2^0 \cos\alpha$$
$$A = -G_1 \sin\beta + G_2 \cos\beta$$
$$H^\pm = -\phi_1^\pm \sin\beta + \phi_2^\pm \cos\beta$$

Mixing between CP-even Higgses: α

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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

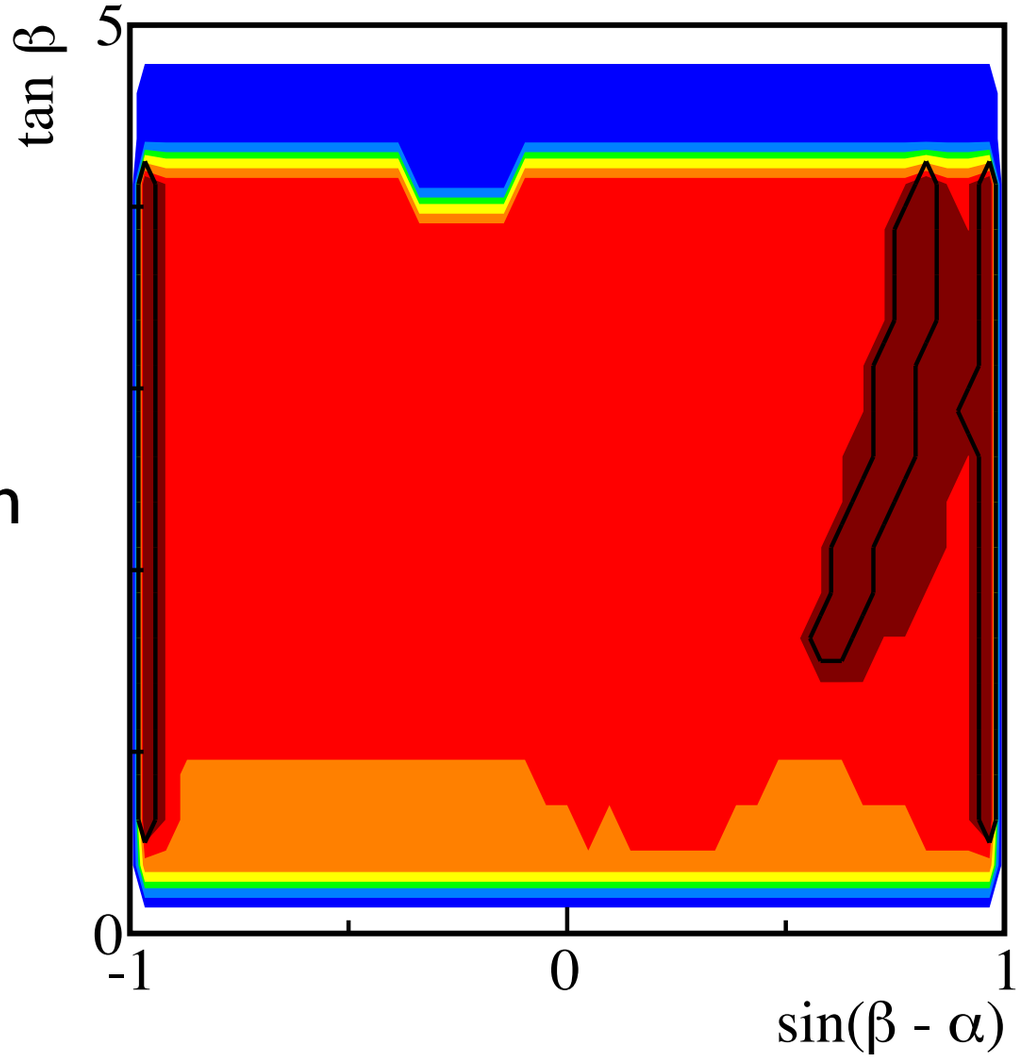
see arXiv 1305.002

non perturbative

pass exclusion bounds

signal region

$h^0 - 126$



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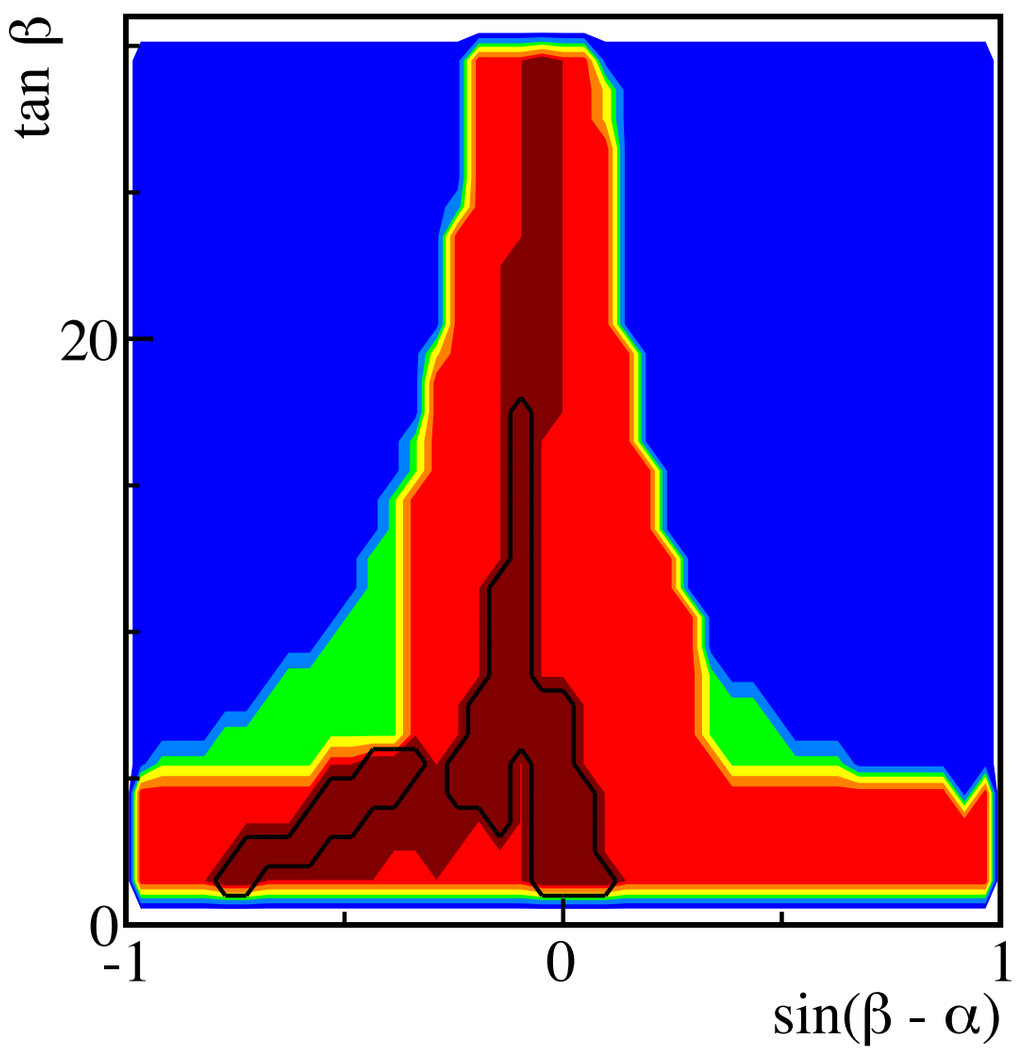

SM like region:	$\sin(\beta-\alpha)=\pm 1$	$\sin(\beta-\alpha)=0$
extended region:	$0.5<\sin(\beta-\alpha)<1$	$-0.8<\sin(\beta-\alpha)<0$

Possible Higgs Decays

How to test 2HDM?

- discovery of extra Higgs: direct evidence for BSM new physics

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Conventional Channels

Exotic decay Channels

Results already available

New!

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- discovery of extra Higgs: direct evidence for BSM new physics

Conventional Channels

Neutral Higgs:

$$A/H \to WW, ZZ, bb, \tau\tau, \gamma\gamma$$

Exotic decay Channels

Neutral Higgs:

$$A/H \to HH, hh, AH/AA, hh$$
$$A/H \to HZ/AZ$$
$$A/H \to WH^{\pm}$$
$$A/H \to H^{+}H^{-}$$

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$A/H \to HZ/AZ$ This talk

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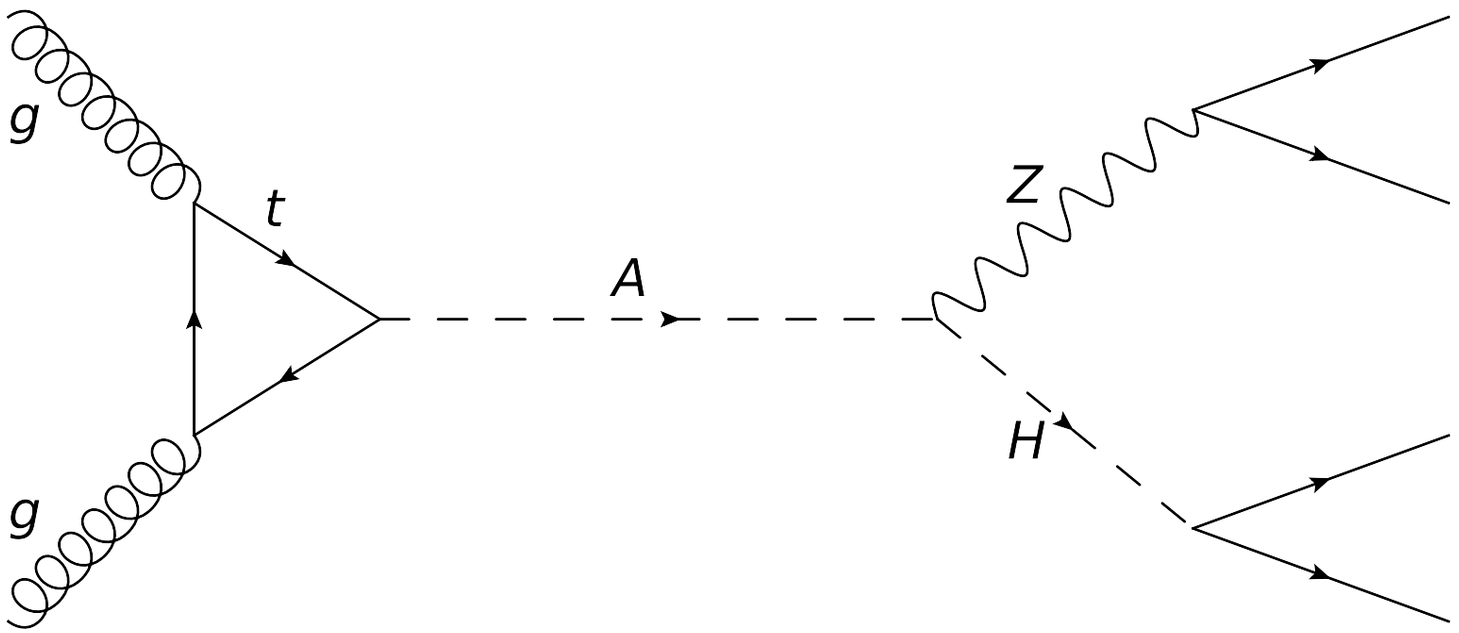
Exotic Higgs Decays - Neutral Higgs



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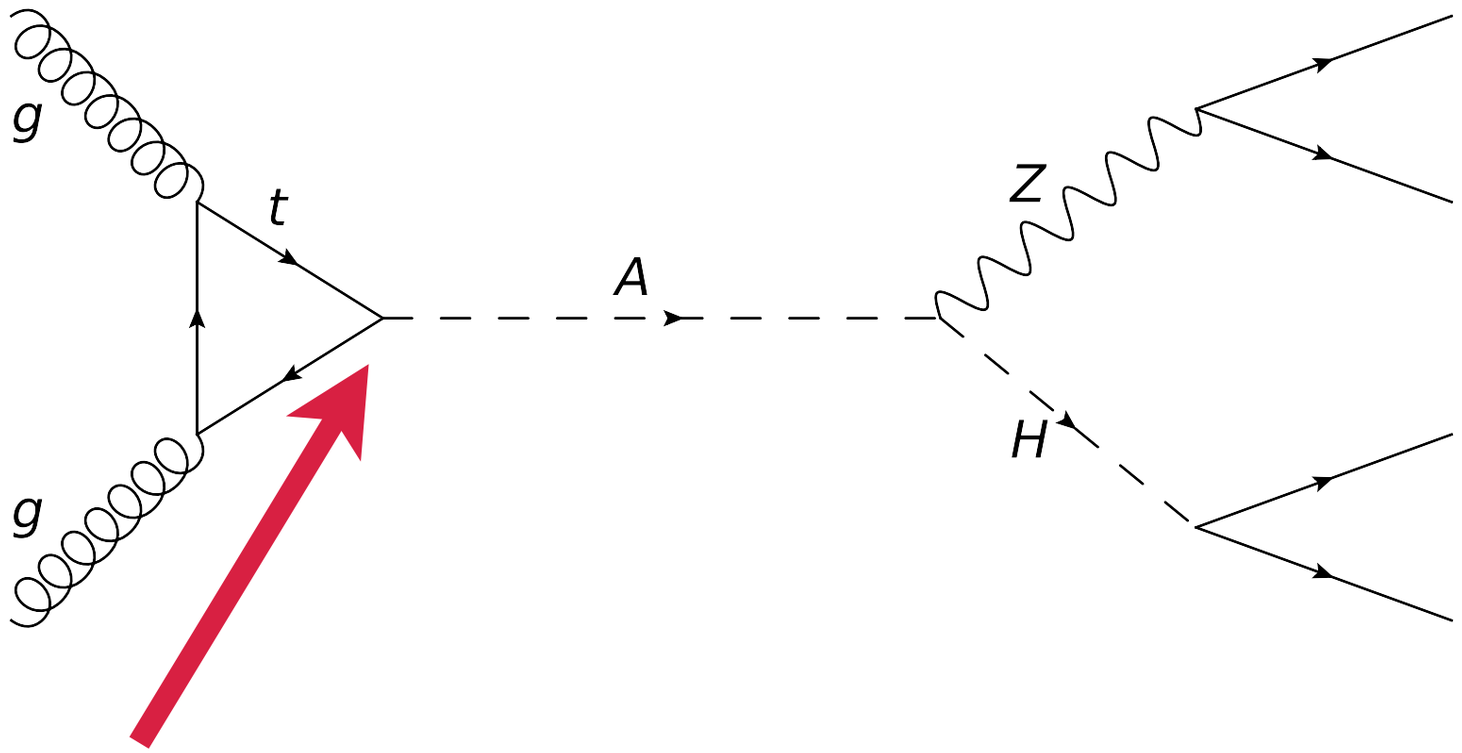


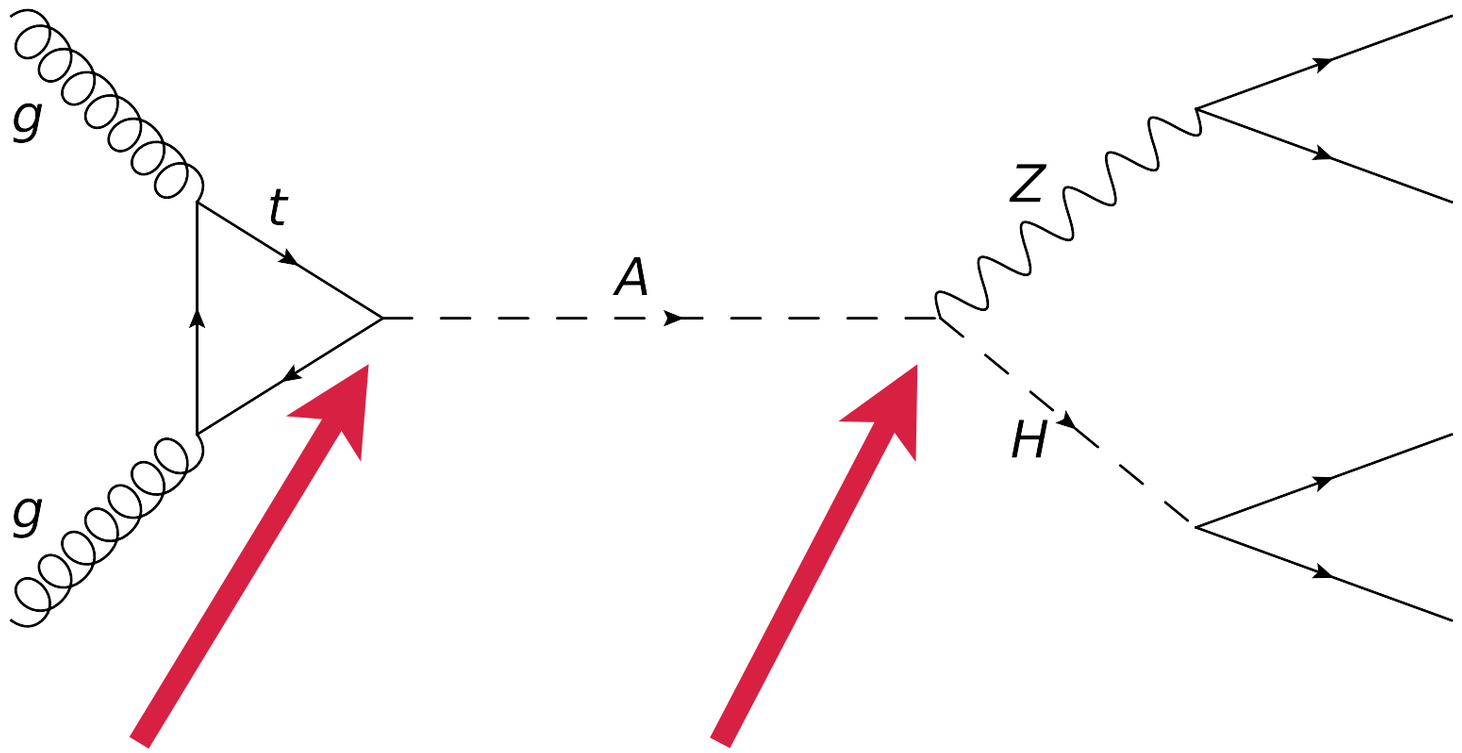
Production:

gluon-gluon fusion

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

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

Exotic Higgs Decays - Neutral Higgs



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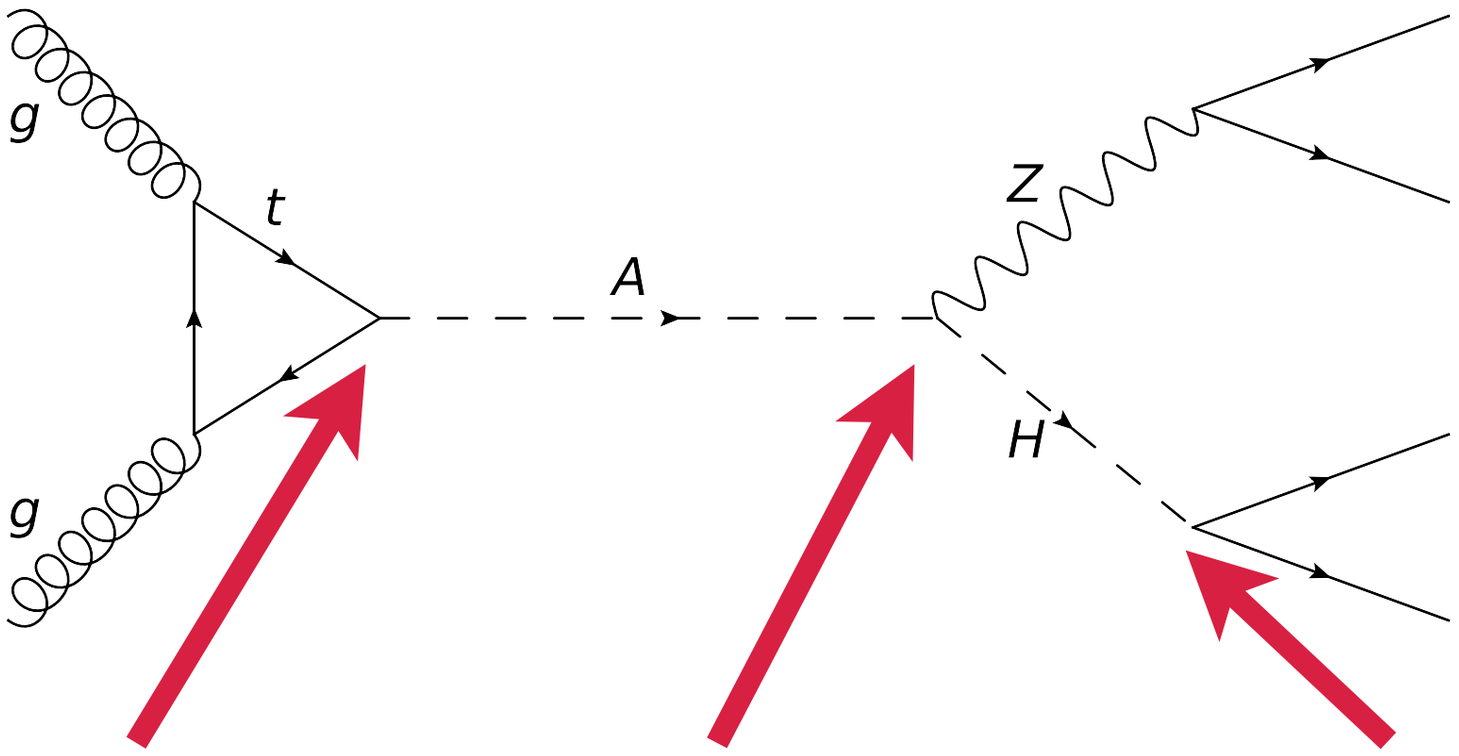
A Decay:

$$A \to HZ$$

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

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

Exotic Higgs Decays - Neutral Higgs



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H Decay:

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

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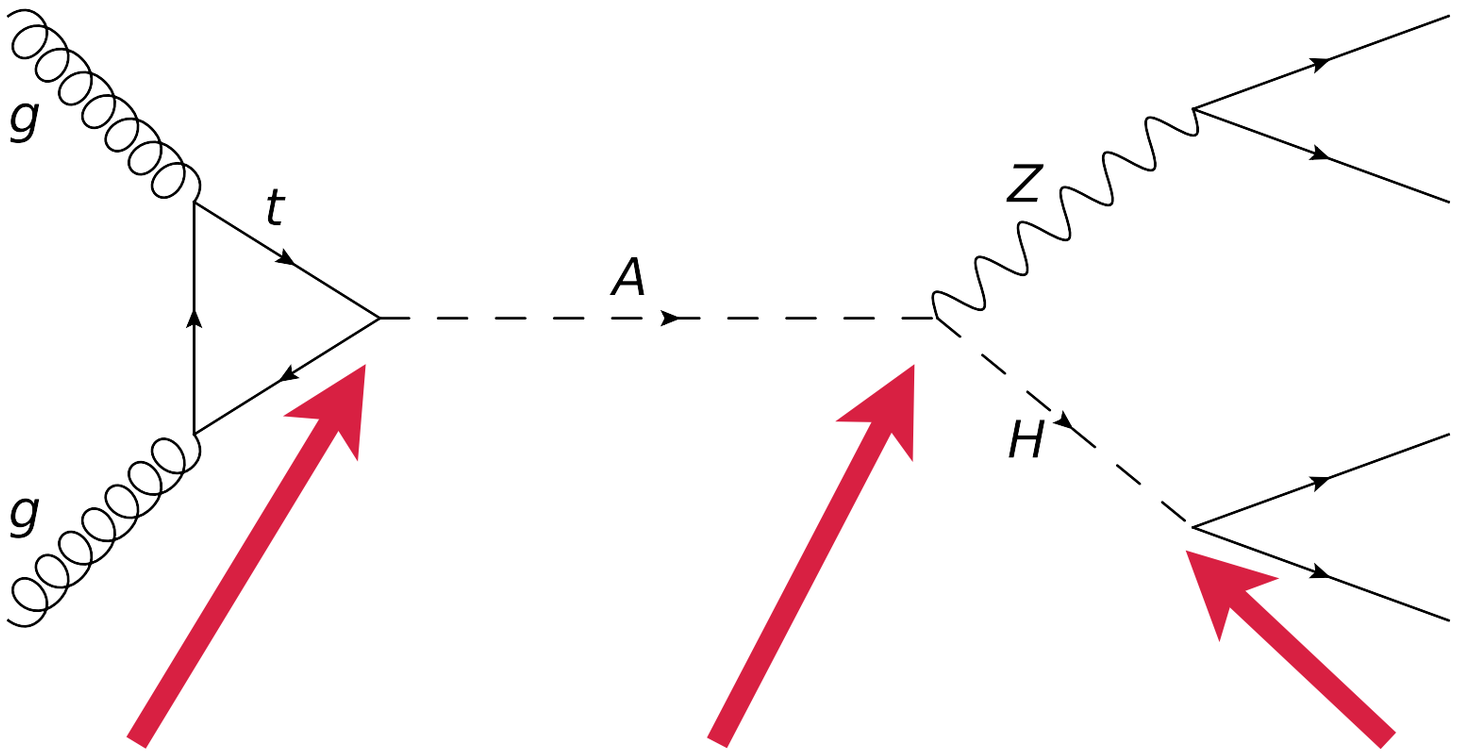

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$$g_{H^0bb,\tau\tau} \sim \cos\alpha/\cos\beta$$

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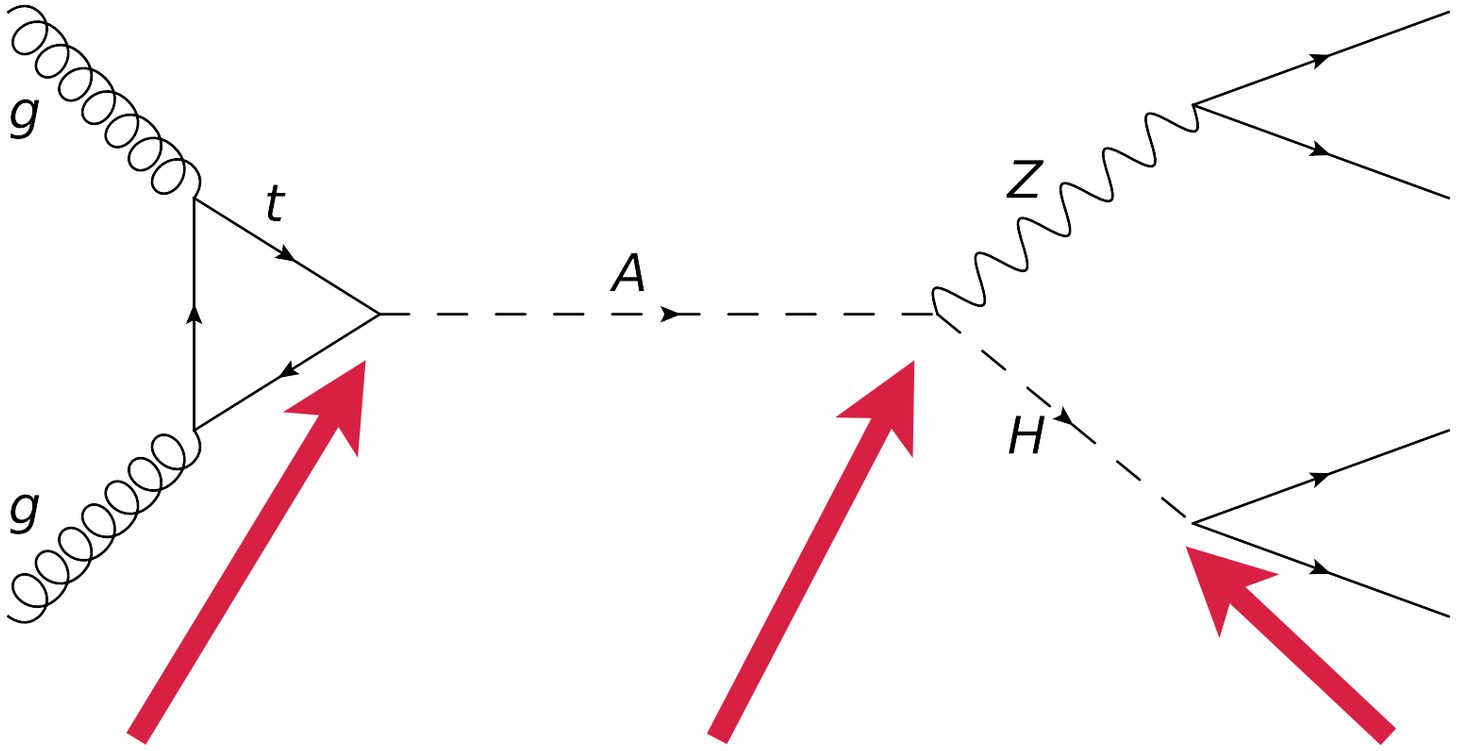
Both $A \to H^0 Z$ and $A \to h^0 Z$ can be dominating decay channel

Exotic Higgs Decays - Neutral Higgs

This also applies to $H \to AZ$



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gluon-gluon fusion	$A \to HZ$	$H \to bb, \tau\tau$
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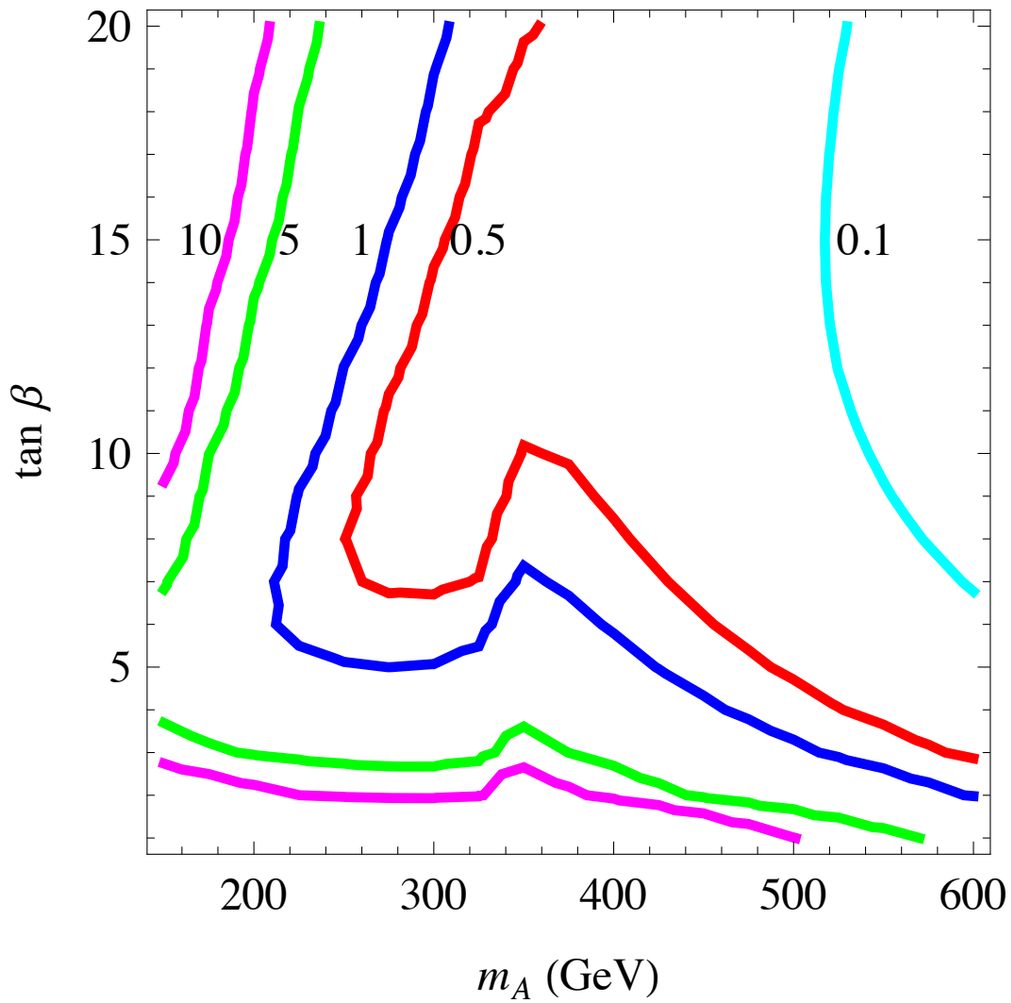
Obtain Theoretical Production Rate



Exotic Higgs Decays - Neutral Higgs

Perform Collider Study for HZ final state:

Signal

$A \to HZ \to bbll$

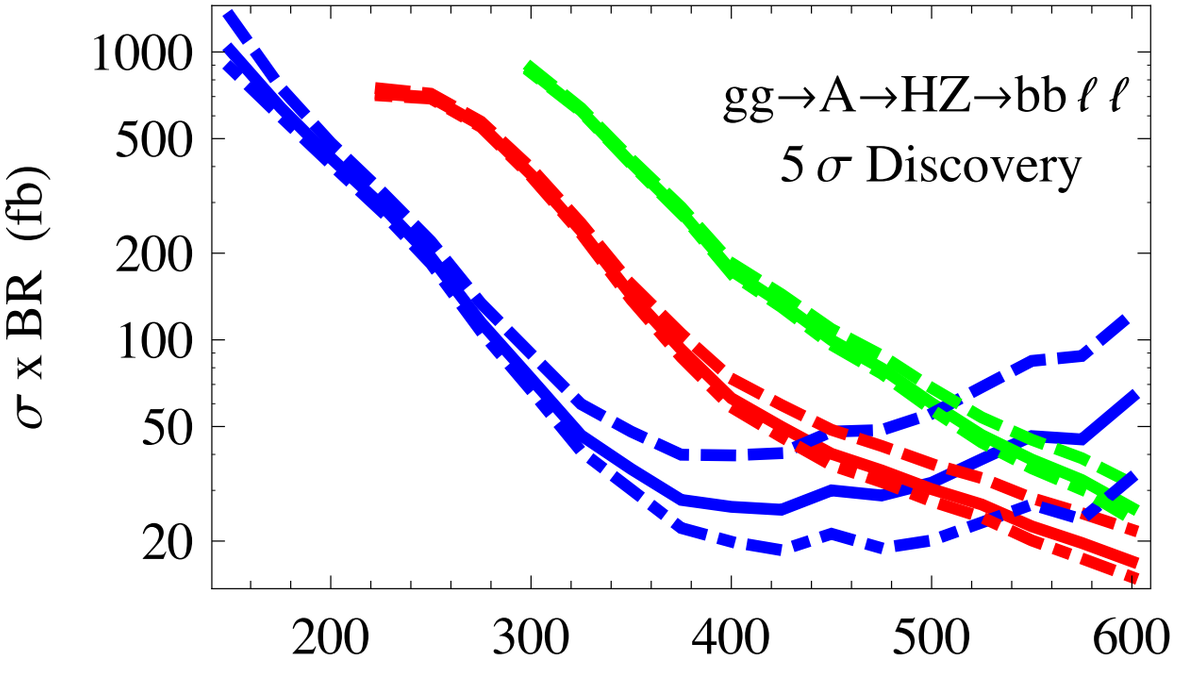
Background

$tt \to bbll\nu\nu, Zbb \to bbll$

perform analysis to extract signal

[arXiv:1404.1922]

Exotic Higgs Decays - Neutral Higgs



Obtain Limits for Exclusion/Discovery

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Exotic Higgs Decays - Neutral Higgs

Production:	A Decay:	H Decay:
gluon-gluon fusion	$A \to HZ$	$H \to bb, \tau\tau$
$g_{ttA} \sim \cot\beta$	$g_{H^0AZ} \sim \sin(\beta-\alpha)$	$g_{H^0bb,\tau\tau} \sim \cos\alpha/\cos\beta$
$g_{bbA} \sim \tan\beta$	$g_{h^0AZ} \sim \cos(\beta-\alpha)$	$g_{h^0bb,\tau\tau} \sim \cos\alpha/\sin\beta$

Obtain Theoretical Production Rate

Compare!

Obtain Limits for Exclusion/Discovery

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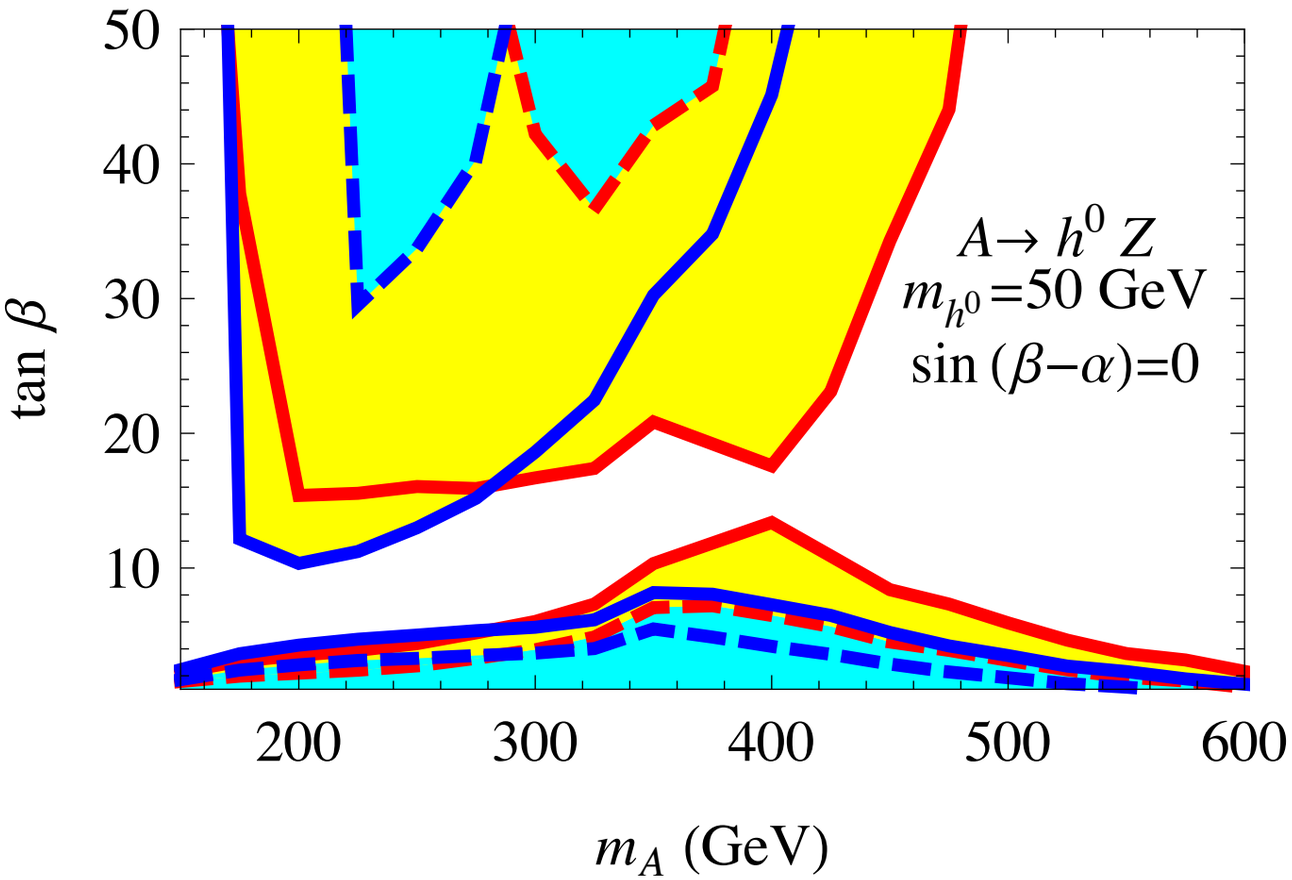
Exotic Higgs Decays - Neutral Higgs

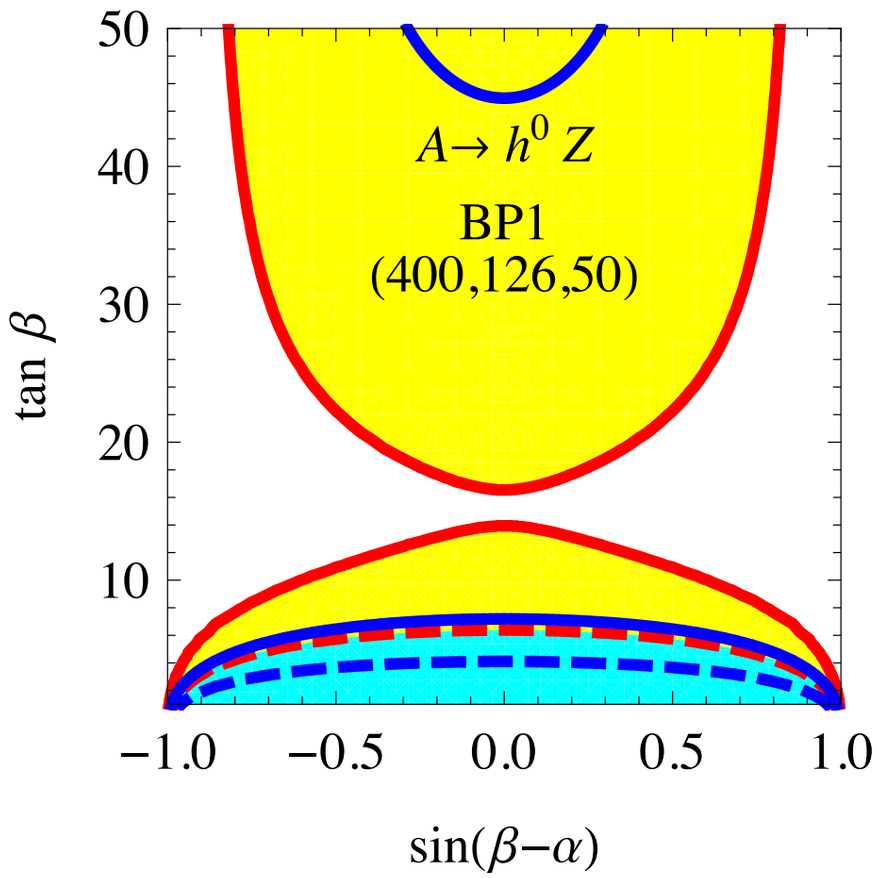
Implication for Type II 2HDM:

$H^0 - 126$ 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

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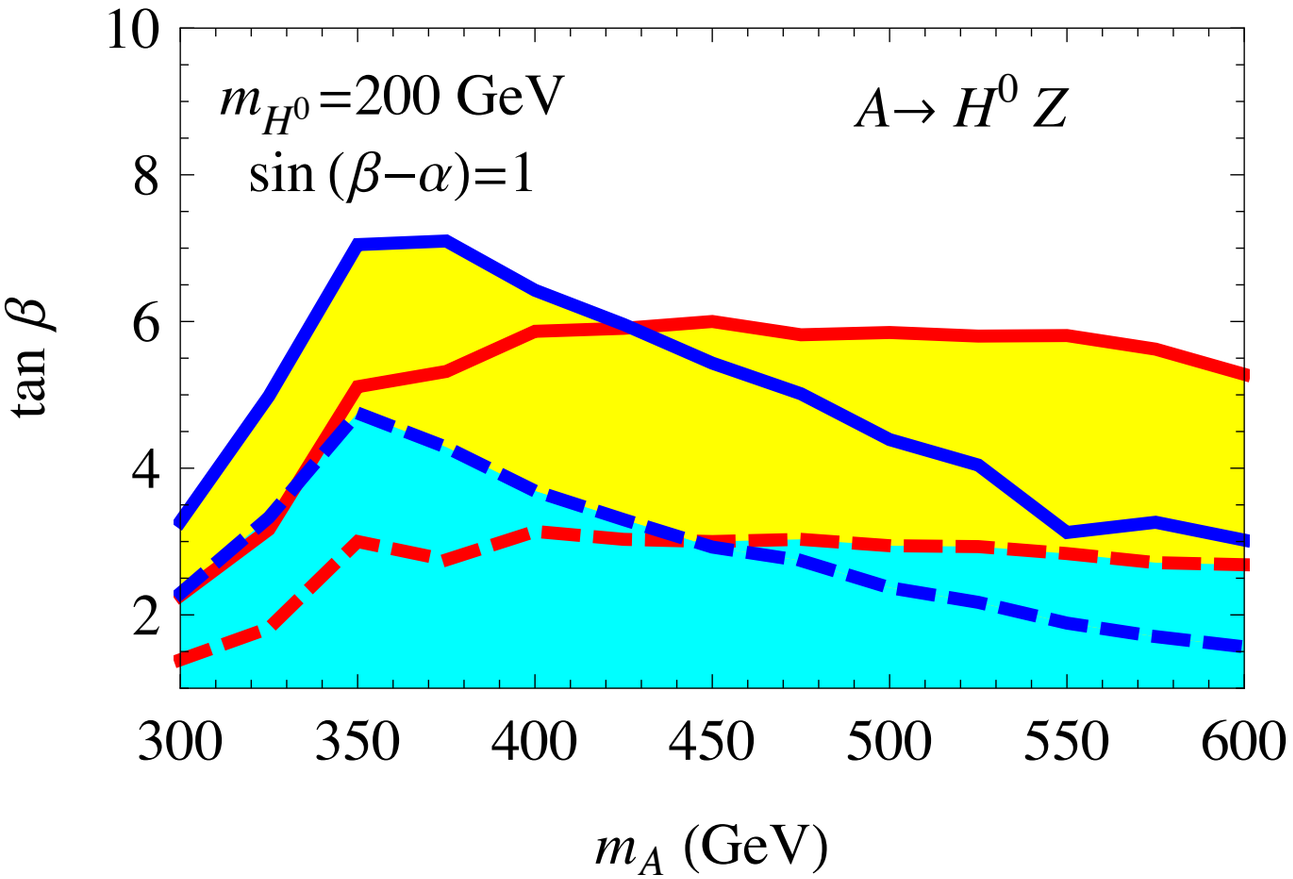
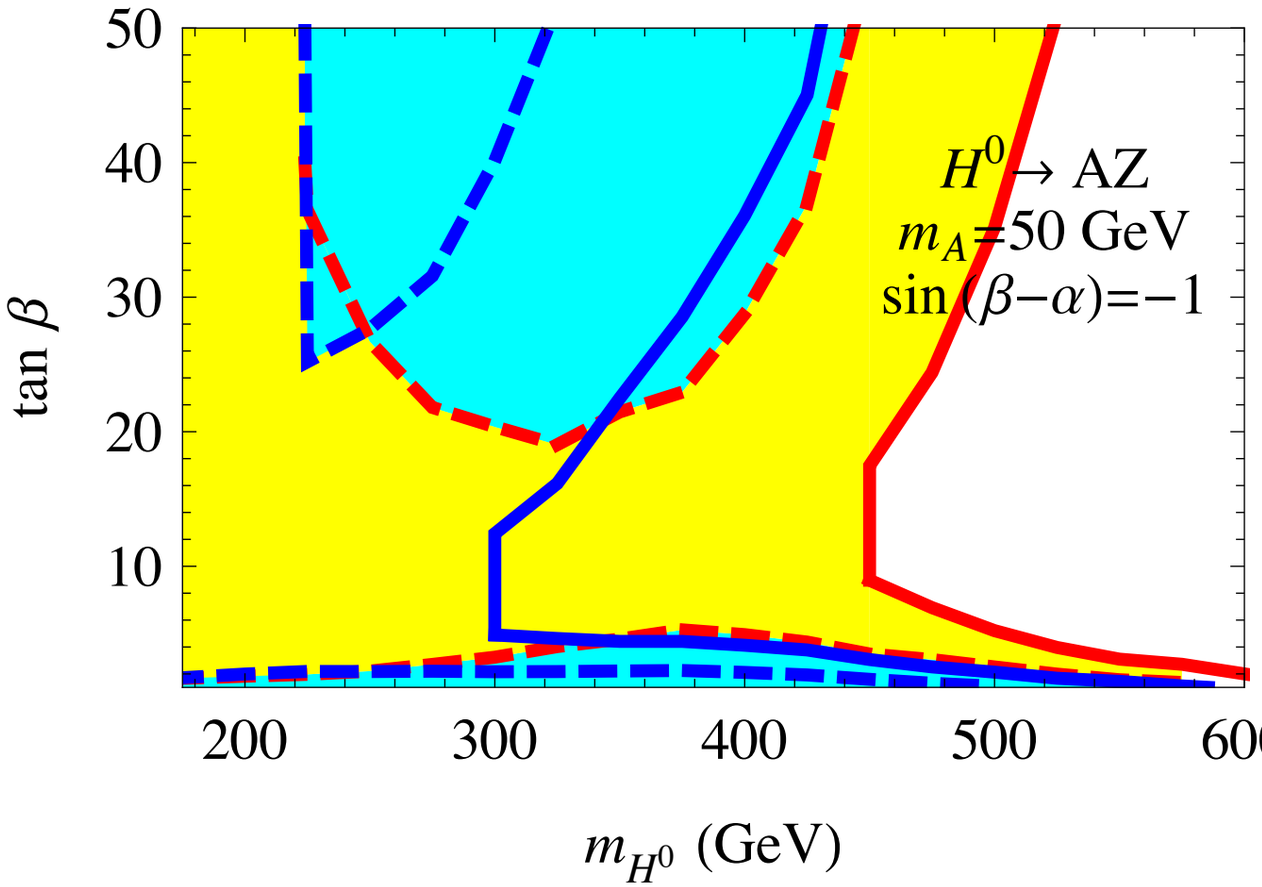


$h^0 - 126$ Scernario

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



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Conclusion

Physics beyond Standard Model:

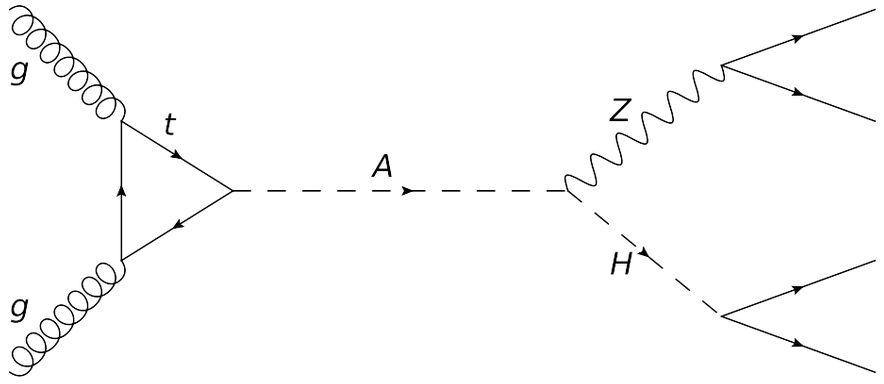
- theoretically well motivated
- most models contain enlarged Higgs sector

Exotic Higgs Decays:

- possible decay channel:

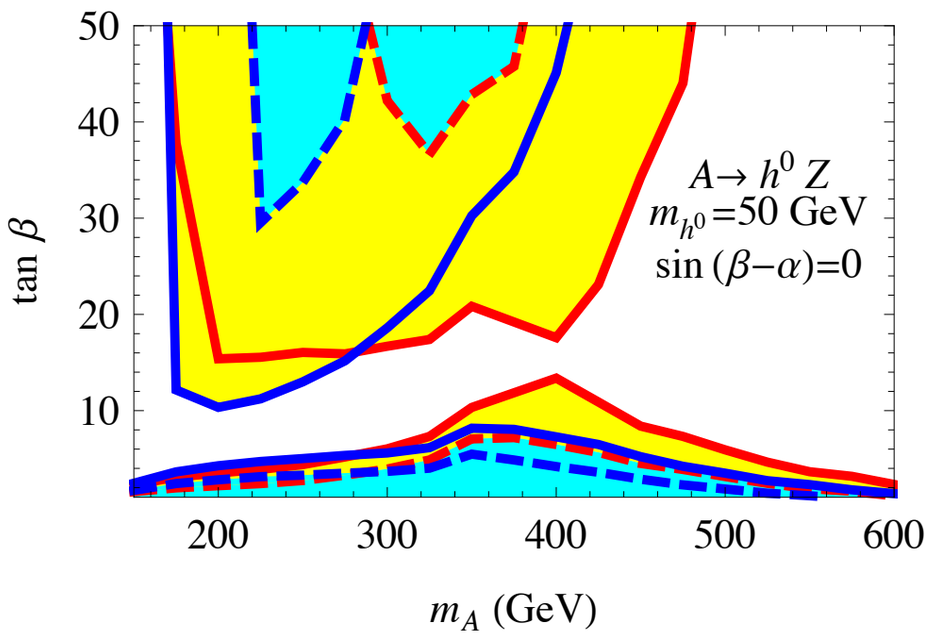
$$A/H \rightarrow H/AZ$$

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



Implication for Type II 2HDM:

- large part of parameter space can be discovered/ excluded

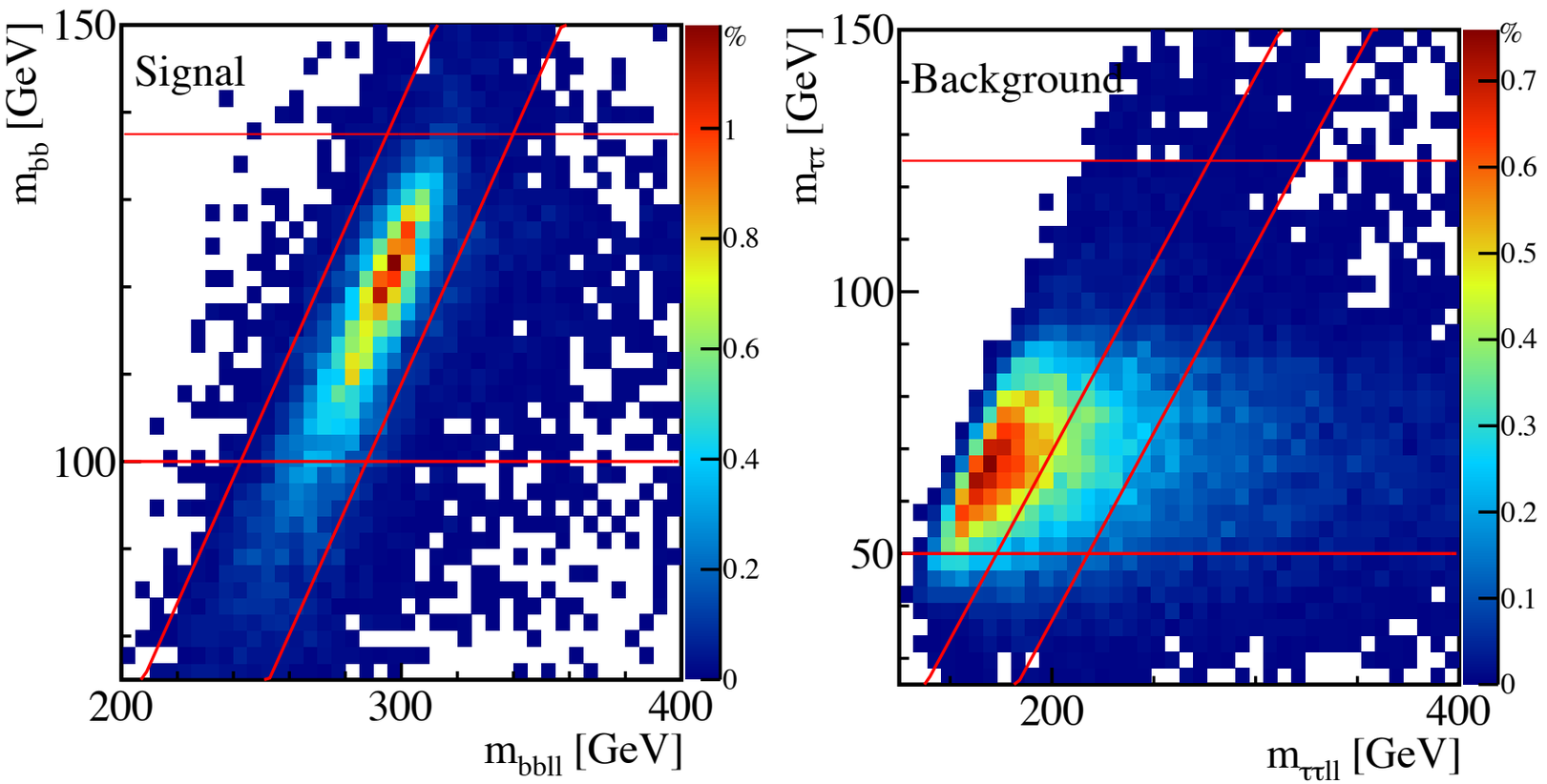


Search Strategy

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

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

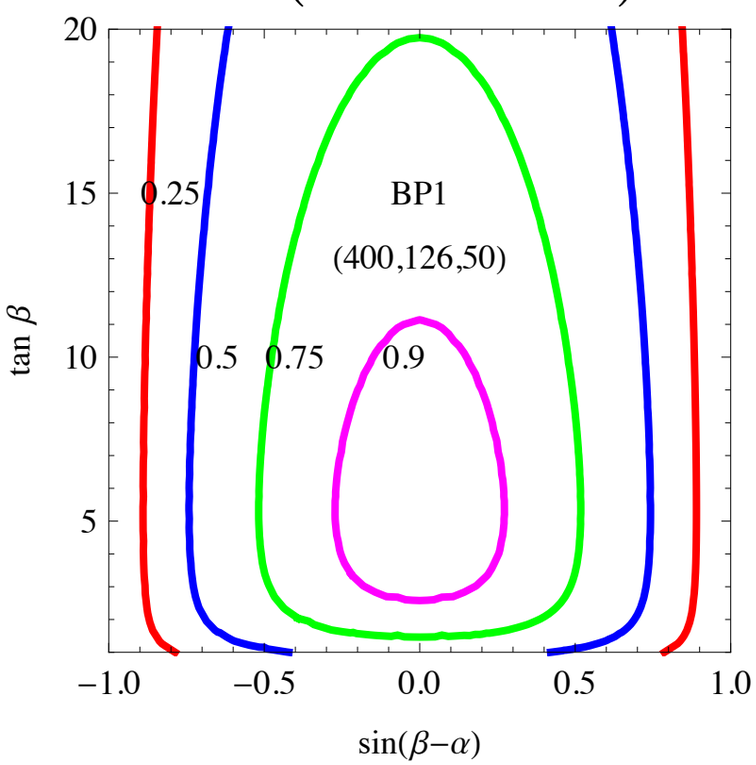
m_{bb} versus m_{bbll} :



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



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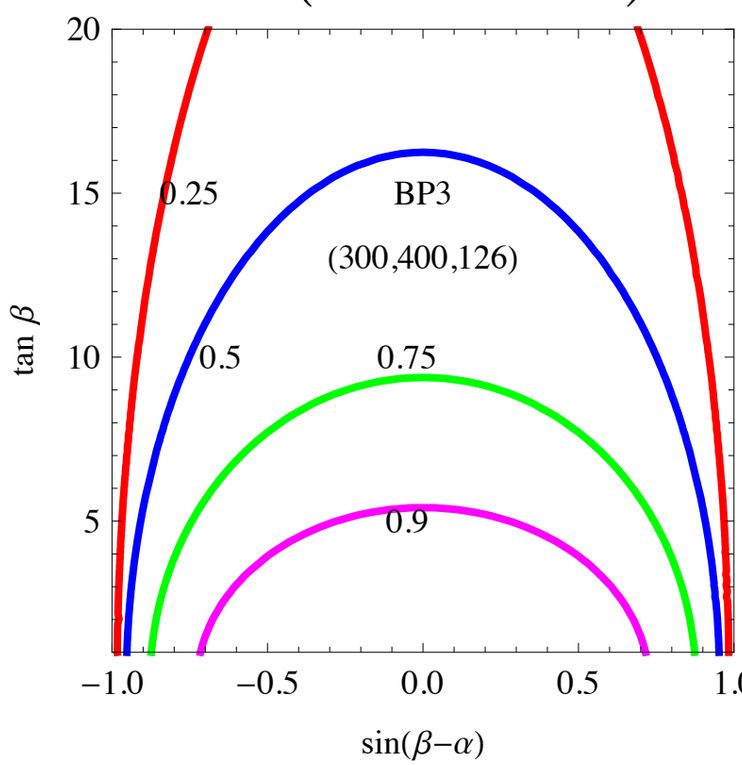

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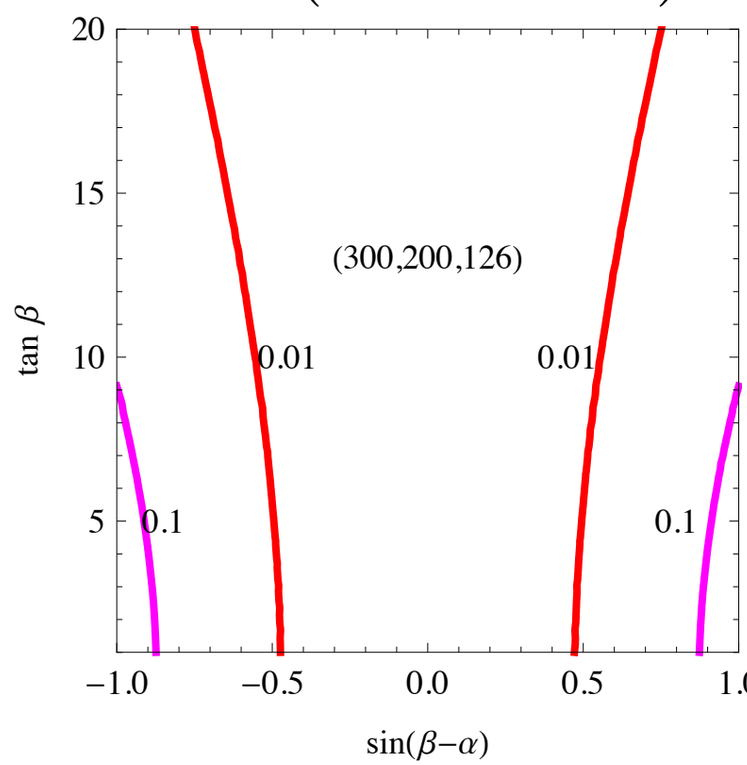


$h^0 - 126$

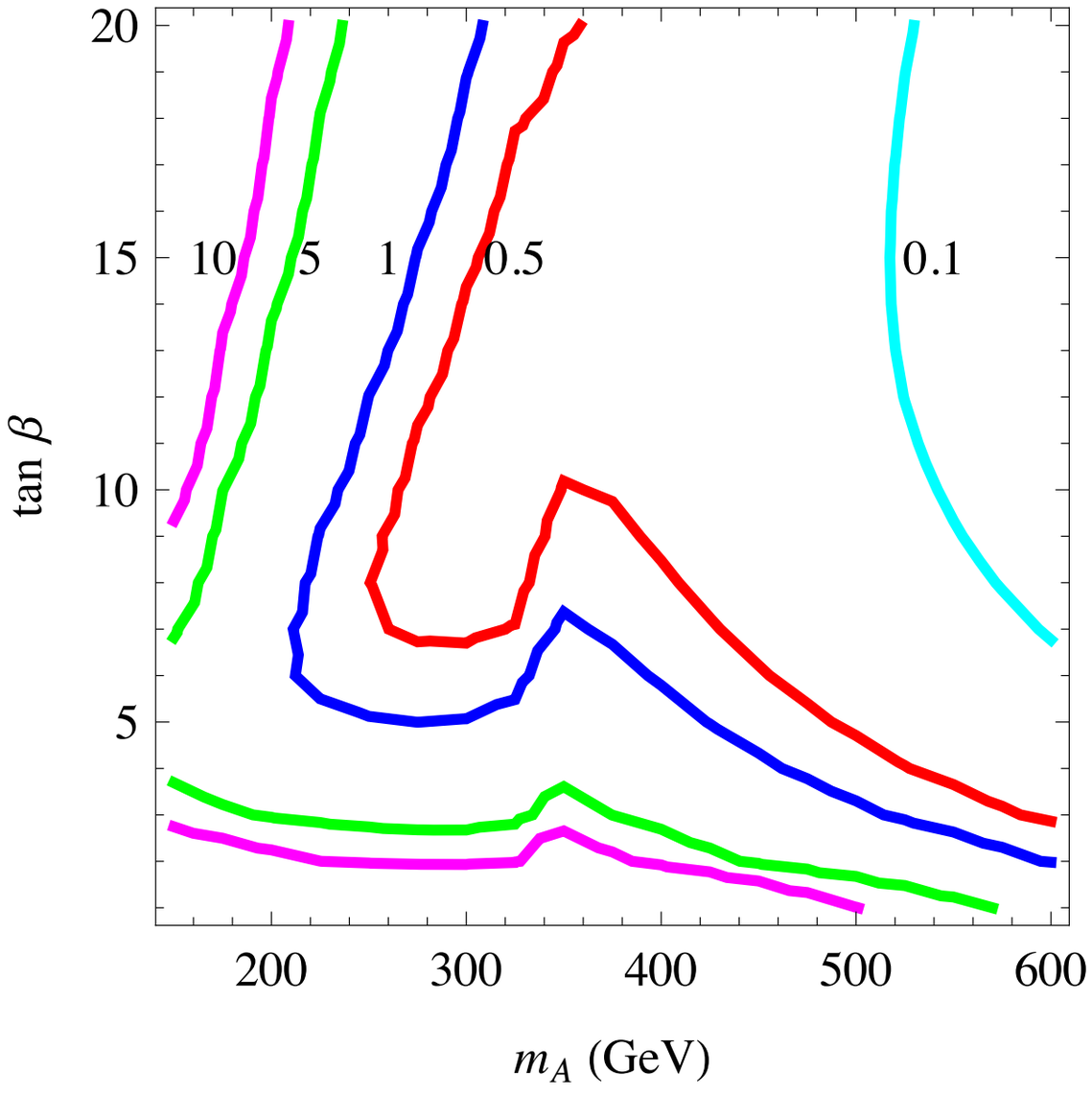
$m_A = 300$ GeV

$m_{H^0} = 200$ GeV

$m_{h^0} = 126$ GeV

Production Cross Section

$$\sigma(gg \to A)[\mathrm{pb}]$$

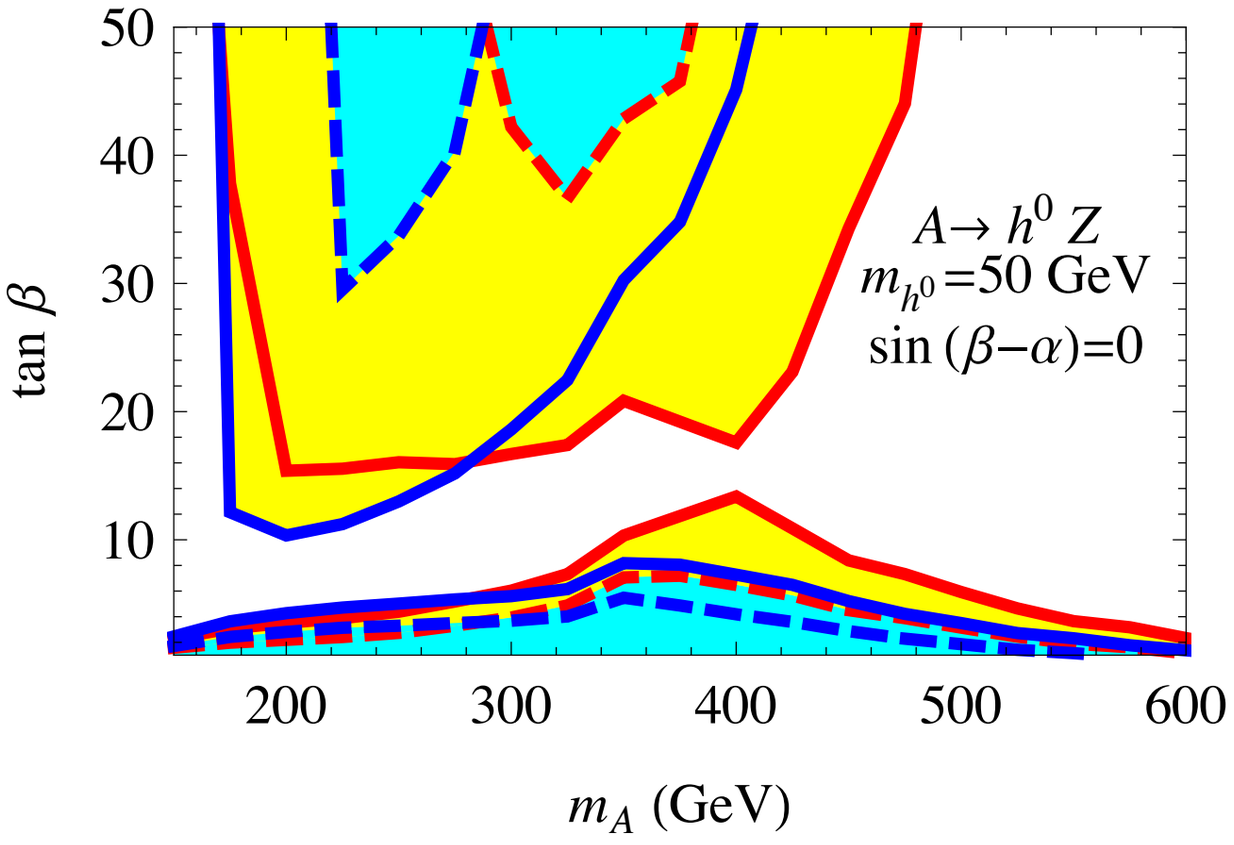


Exotic Higgs Decays - Neutral Higgs

Implication for Type II 2HDM:

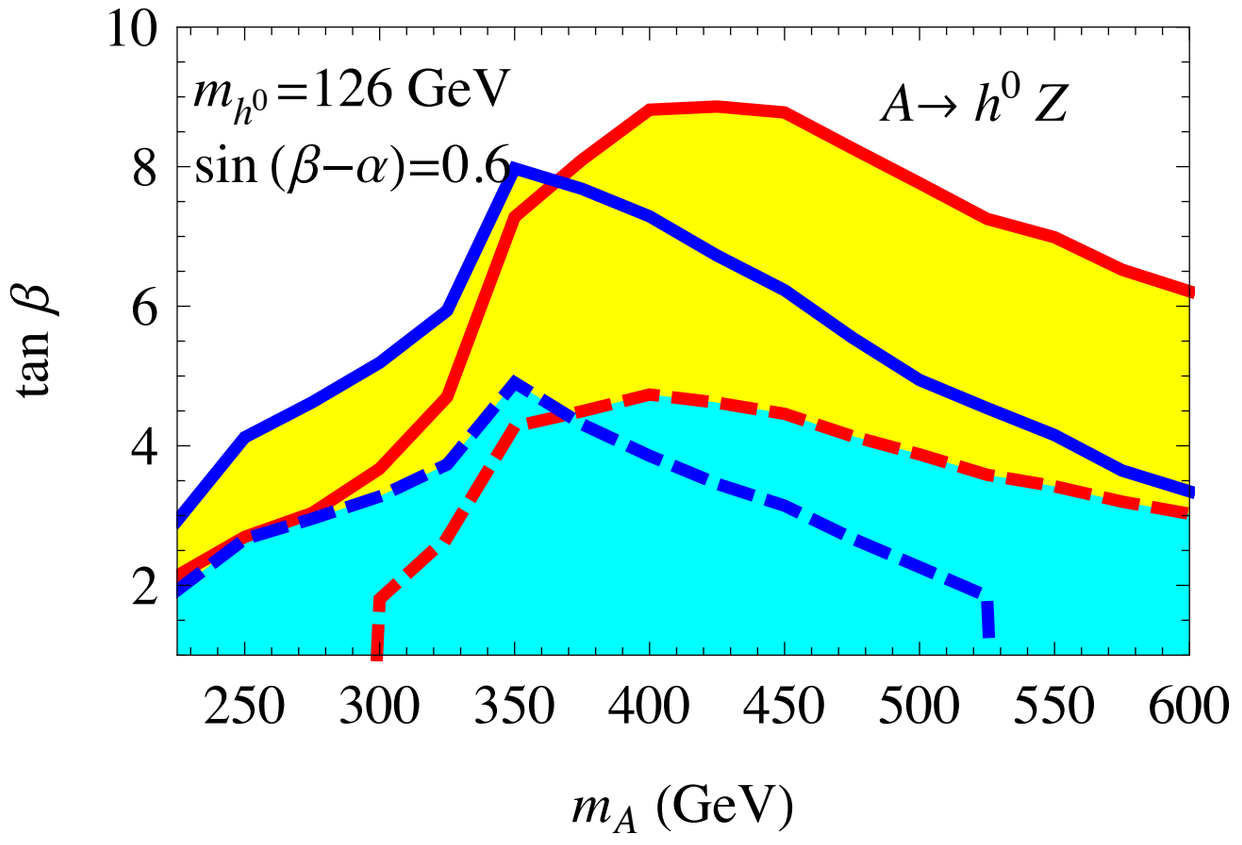
$H^0 - 126$ Scernario

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



$h^0 - 126$ Scernario

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



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

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