Benchmark Points for Exotic Higgs Decays

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Higgs Cross Section Working Group
WG3: BSM - Extended Scalars
June 23, 2015

Outline

- Exotic decays of non-SM Higgses
- Benchmark points

Type II 2HDM

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

Searching for Other Higgses

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	(bb/ττ/WW/ZZ/γγ)(bb/ττ/WW/ZZ/γγ)	$h_{SM} \rightarrow AA$, $H \rightarrow h_{SM}\, h_{SM}$, $H \rightarrow AA$, $A_i \rightarrow H_j A_k$,...
	H^+H^- type	(τν/tb)(τν/tb)	$H \rightarrow H^+H^-$
	$WH^\pm$ type	(lν/qq') (τν/tb)	$H/A \rightarrow WH^\pm$
	ZH type	(ll/qq/νν)(bb/ττ/WW/ZZ/γγ)	$H \rightarrow ZA$, $A \rightarrow ZH$, ...
charge Higgs	WH type	(lν/qq')(bb/ττ)	$tH^\pm$ production, $H^\pm \rightarrow WH$ $H^\pm \rightarrow WA$

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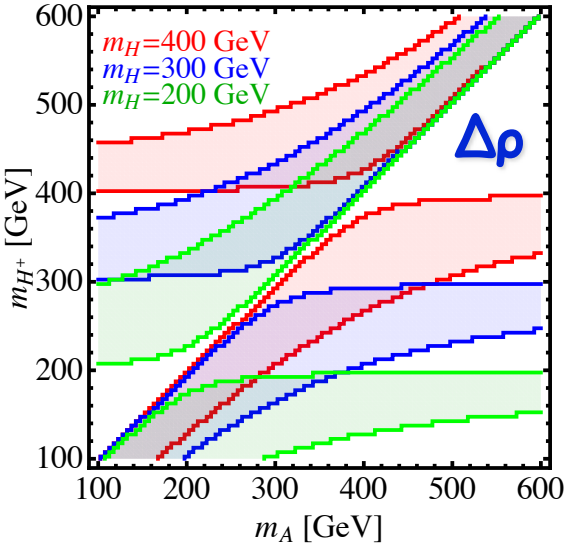
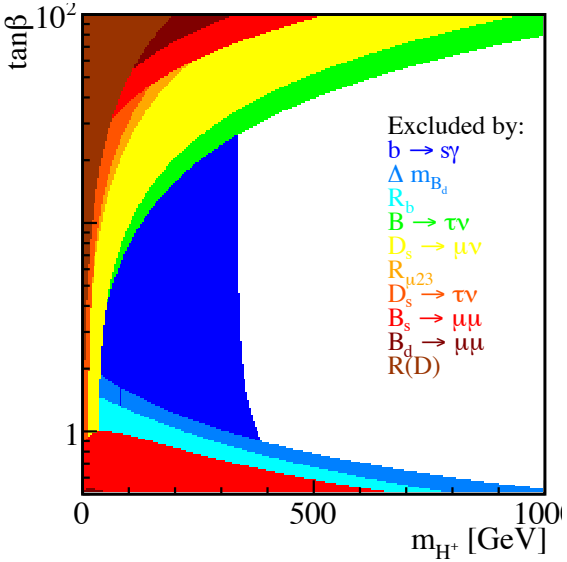
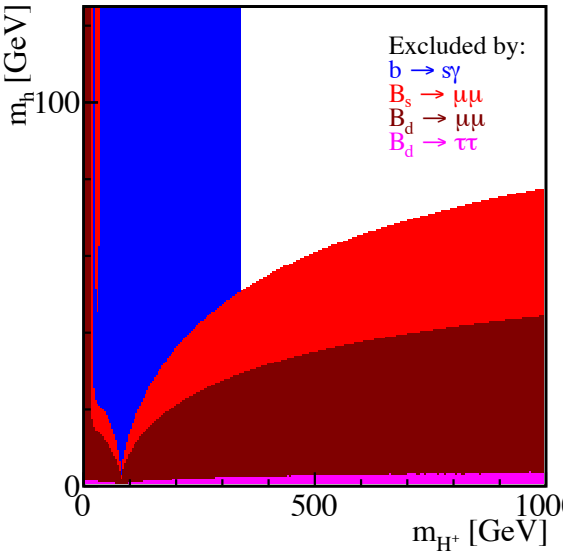
Constraints

- Perturbativity and vacuum stability
- Δ ρ constraint
- Direct Higgs search results
- Flavor constraints (light charged Higgs)







Benchmarks

H in the final states

- **BP1**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	200 GeV	350 GeV	400 GeV	1	2	0 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$A \to HZ$	77.6	ggF	$bbll$, $\tau\tau ll$
$H^\pm \to HW^\pm$	61.7	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$

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- **similar to EWCosmo2HDM BP1**

	m_{H_0}	m_{A_0}	$m_{H^\pm}$	$s_{\beta-\alpha}$	t_β	μ	2HDM Type	Distinctive signature
A1	180	400	400	1	2	100	I, II	$A_0 \to H_0 Z\,(H_0 \to \bar{b}b)$

Benchmarks

A in the final states

- **BP2** similar to Haber/Stal D2.1 (short cascade)

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	300 GeV	200 GeV	375 GeV	1	2	0 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$H \to AZ$	79.5	ggF	$bbll$, $\tau\tau ll$
$H^\pm \to AW$	56.3	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$

- **BP3**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	500 GeV	200 GeV	525 GeV	1	1.6	0 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$H \to AA$	31.4	ggF	$bbbb$, $\tau\tau bb$, $\tau\tau\tau\tau$, $\gamma\gamma bb$
$H \to AZ$	55.0	ggF	$bbll$, $\tau\tau ll$
$H^\pm \to AW$	75.3	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$

Benchmarks

A in the final states

- **BP4**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	350 GeV	70 GeV	400 GeV	1	2	100 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$H \to AA$	48.2	ggF	$bbbb$, $\tau\tau bb$, $\tau\tau\tau\tau$, $\gamma\gamma bb$
$H \to AZ$	51.3	ggF	$bbll$, $\tau\tau ll$
$H^\pm \to AW$	81.6	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$

- **BP5**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	150 GeV	70 GeV	160 GeV	1	2	0 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$H \to AA$	96.7	ggF	$bbbb$, $\tau\tau bb$, $\tau\tau\tau\tau$, $\gamma\gamma bb$
$H^\pm \to AW$	96.5	$tt \to tH^\pm b$	$bbbbWW$, $\tau\tau bbWW$, $\tau\tau bWj$

Benchmarks

$H^{\pm}$ in the final states

- **BP6** similar to Haber/Stal D2.2 (short cascade)

m_h	m_H	m_A	$m_{H^{\pm}}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	300 GeV	300 GeV	200 GeV	1	2	0 GeV	✓	✗

Channel	BR (%)	Production	Possible Final States
$H \to H^{\pm}W^{\mp}$	96.0	ggF	$tbl\nu$
$A \to H^{\pm}W^{\mp}$	95.5	ggF	$tbl\nu$

- **BP7**

m_h	m_H	m_A	$m_{H^{\pm}}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	225 GeV	300 GeV	200 GeV	1	10	70 GeV	✓	✗

Channel	BR (%)	Production	Possible Final States
$A \to H^{\pm}W^{\mp}$	50.4	ggF	$tbl\nu$, $\tau\nu l\nu$

Channel	BR (%)	Channel	BR (%)
$H^{\pm} \to tb$	52.2	$H^{\pm} \to \tau\nu$	46.7

Benchmarks

H± in the final states

- **BP8**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	450 GeV	250 GeV	200 GeV	1	2	0 GeV	✓	✗

Channel	BR (%)	Production	Possible Final States
$H \to H^\pm W^\mp$	53	ggF	$tbl\nu$
$H \to H^+H^-$	26	ggF	$ttbb$
$H \to AZ$	14	ggF	$bbll$, $\tau\tau ll$

similar to Haber/Stal D2.3 (short cascade)

Benchmarks

h in the final states

- **BP9: non-alignment**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
125 GeV	300 GeV	300 GeV	400 GeV	0.6	2	100 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$A \to hZ$	98.4	ggF	$bbll$, $\tau\tau ll$, $ZZll$, $\gamma\gamma ll$
$H \to hh$	15.7	ggF	$bbbb$, $\tau\tau bb$, $llllbb$, $\gamma\gamma bb$
$H^\pm \to hW$	66	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$, $llllbbWW$, $\gamma\gamma bbWW$

- **similar to Haber/Stal A2.1, A2.2 (non-alignment)**

Scenario A (non-alignment)

	m_h (GeV)	m_H (GeV)	$c_{\beta-\alpha}$	Z_4	Z_5	Z_7	$\tan\beta$	Type
A1.1	125	150 ... 600	0.1	−2	−2	0	1 ... 50	I
A1.2	125	150 ... 600	$0.1 \times \left(\frac{150\text{ GeV}}{m_H}\right)^2$	−2	−2	0	1 ... 50	I
A2.1	125	150 ... 600	0.01	−2	−2	0	1 ... 50	II
A2.2	125	150 ... 600	$0.01 \times \left(\frac{150\text{ GeV}}{m_H}\right)^2$	−2	−2	0	1 ... 50	II

Benchmarks

H as 125 SM-like Higgs

- **BP10**

m_h	m_H	m_A	$m_{H^\pm}$	$\sin(\beta-\alpha)$	$\tan\beta$	m_{12}	$\Delta\rho$	Flavor
70 GeV	125 GeV	300 GeV	350 GeV	0	2	0 GeV	✓	✓

Channel	BR (%)	Production	Possible Final States
$A \to hZ$	99.4	ggF	$bbll$, $\tau\tau ll$, $ZZll$, $\gamma\gamma ll$
$H^\pm \to hW$	77.9	$H^\pm tb$-ass.	$bbbbWW$, $\tau\tau bbWW$, $llllbbWW$, $\gamma\gamma bbWW$

- **similar to Haber/Stal B2, low m_H**

Scenario B (low-m_H)	m_h (GeV)	m_H (GeV)	$c_{\beta-\alpha}$	Z_4	Z_5	Z_7	$\tan\beta$	Type
B1.1	65 . . . 120	125	1.0	−5	−5	0	1.5	I
B1.2	80 . . . 120	125	0.9	−5	−5	0	1.5	I
B2	65 . . . 120	125	1.0	−5	−5	0	1.5	II

Summary

BP	1	2	3	4	5	6	7	8	9	10
$H \to AZ$		✓	✓	✓				✓		
$A \to HZ$	✓									
$A \to hZ$									✓	✓
$H \to AA$			✓	✓	✓					
$H \to hh$									✓	
$H \to H^{\pm}W$						✓		✓		
$A \to H^{\pm}W$						✓	✓			
$H \to H^{+}H^{-}$								✓		
$H^{\pm} \to HW$	✓									
$H^{\pm} \to AW$		✓	✓	✓	✓					
$H^{\pm} \to hW$									✓	✓

H **A** **H±** **Non-alignment** **H-125**

Summary

BP	1	2	3	4	5	6	7	8	9	10
$H \to AZ$		✓	✓	✓				✓		
$A \to HZ$	✓									
$A \to hZ$									✓	✓
$H \to AA$			✓	✓	✓					
$H \to hh$									✓	
$H \to H^{\pm}W$						✓		✓		
$A \to H^{\pm}W$						✓	✓			
$H \to H^{+}H^{-}$								✓		
$H^{\pm} \to HW$	✓									
$H^{\pm} \to AW$		✓	✓	✓	✓					
$H^{\pm} \to hW$									✓	✓
	H		**A**				**H±**		**Non-alignment**	**H-125**