

BSM Higgses

Current and Future



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NOPP

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Outline

- BSM Higgs searches (Neutral Higgs, Charge Higgs)
 - Conventional Channels
 - Exotic channels
 - Not included in this talk: h_{125} exotic decay, connection to dark matter, ...
- Current results are already very useful — complementarity
 - Indirect vs. direct searches
 - Conventional channels and exotic channels
- Would be nice to have ...

BSM Higgs Sector

Models with extended Higgs sector: arise in natural theories of EWSB

- Higgs sector of MSSM/NMSSM
 - Generic 2HDM
 - Little Higgs, twin Higgs ...
 - Composite Higgs models ...
- neutral Higgs
 - CP-even Higgses
 - CP-odd Higgs
 - mixed CP states
 - Charged Higgses: $H^\pm$
 - Doubly charged Higgses: $H^{\pm\pm}, \dots$
- SM+singlet: parametrized by a simple mixing parameter
 - 2HDM: covers board class of known models
 - Allow for convenient parametrization
 - Many features shared by many extended EWSB sectors

Higgs Couplings

• h/H VV coupling

$$g_{H^0 VV} = \frac{m_V^2}{v} \cos(\beta - \alpha), \quad g_{h^0 VV} = \frac{m_V^2}{v} \sin(\beta - \alpha)$$

Alignment limit: h 125 GeV, $\cos(\beta - \alpha) \sim 0$

LEP limit: no $e^+e^- \rightarrow Z^* \rightarrow ZH$, H could still be light.

• Higgs-Higgs-V coupling

$$g_{AH^0 Z} = -\frac{q \sin(\beta - \alpha)}{2 \cos \theta_w} (p_{H^0} - p_A)^\mu, \quad g_{Ah^0 Z} = \frac{g \cos(\beta - \alpha)}{2 \cos \theta_w} (p_{h^0} - p_A)^\mu,$$

$$g_{H^\pm H^0 W^\mp} = -\frac{q \sin(\beta - \alpha)}{2} (p_{H^0} - p_{H^\pm})^\mu, \quad g_{H^\pm h^0 W^\mp} = \frac{g \cos(\beta - \alpha)}{2} (p_{h^0} - p_{H^\pm})^\mu,$$

$$g_{H^\pm A W^\mp} = \frac{g}{2} (p_A - p_{H^\pm})^\mu,$$

Two non-SM like Higgses have unsuppressed couplings to gauge boson.

LEP limit: $e^+e^- \rightarrow Z^* \rightarrow AH$, $m_H + m_A > E_{\text{cm}}$

Higgs Couplings

Yukawa couplings

	ϕ_1	ϕ_2
Type I		u, d, l
Type II	d, l	u
Type L	l	u, d
Type F	d	u, l

	ξ_H^u	ξ_H^d	ξ_H^ℓ	ξ_A^u	ξ_A^d	ξ_A^ℓ
Type-I	$\cot \beta$	$\cot \beta$	$\cot \beta$	$\cot \beta$	$-\cot \beta$	$-\cot \beta$
Type-II	$\cot \beta$	$-\tan \beta$	$-\tan \beta$	$\cot \beta$	$\tan \beta$	$\tan \beta$
Type-L	$\cot \beta$	$\cot \beta$	$-\tan \beta$	$\cot \beta$	$-\cot \beta$	$\tan \beta$
Type-F	$\cot \beta$	$-\tan \beta$	$\cot \beta$	$\cot \beta$	$\tan \beta$	$-\cot \beta$

Alignment limit: hff, hVV coupling $\Rightarrow$ SM

tri-Higgs couplings

Alignment limit: no $H \rightarrow AA, H \rightarrow hh$

unsuppressed: $h \rightarrow AA$

BSM Higgs Searches

- ◎ Search for extra Higgses
 - ➡ Precision Higgs study: couplings of the SM-like Higgs
 - ➡ Direct search of extra Higgses: direct evidence for BSM new physics
- ◎ Conventional search channel (even for non-SM Higgs):
 $\gamma\gamma$, ZZ , WW , $\tau\tau$, bb , $\mu\mu$, tt
- ◎ Charged Higgs is challenge!
- ◎ Exotic Higgs decay modes open for BSM Higgs
 - ➡ relax the current search bounds
 - ➡ offer new discovery channels

BSM Neutral Higgs Searches:

Conventional Modes

$\gamma\gamma$, ZZ , WW , $\tau\tau$, bb , $\mu\mu$,

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$\gamma\gamma, ZZ, WW, \tau\tau, bb, \mu\mu,$


small Br

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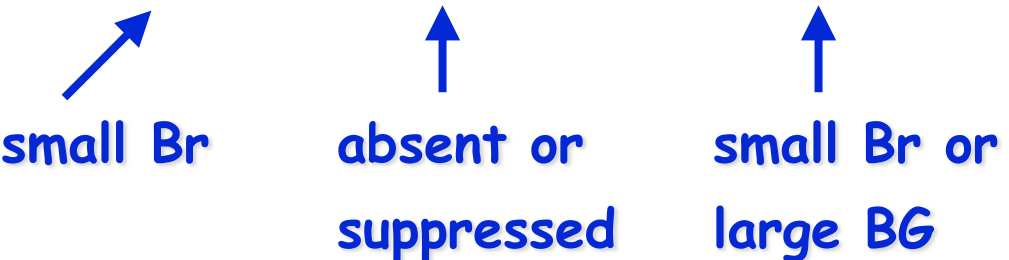

small Br


absent or
suppressed

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small Br absent or suppressed small Br or large BG

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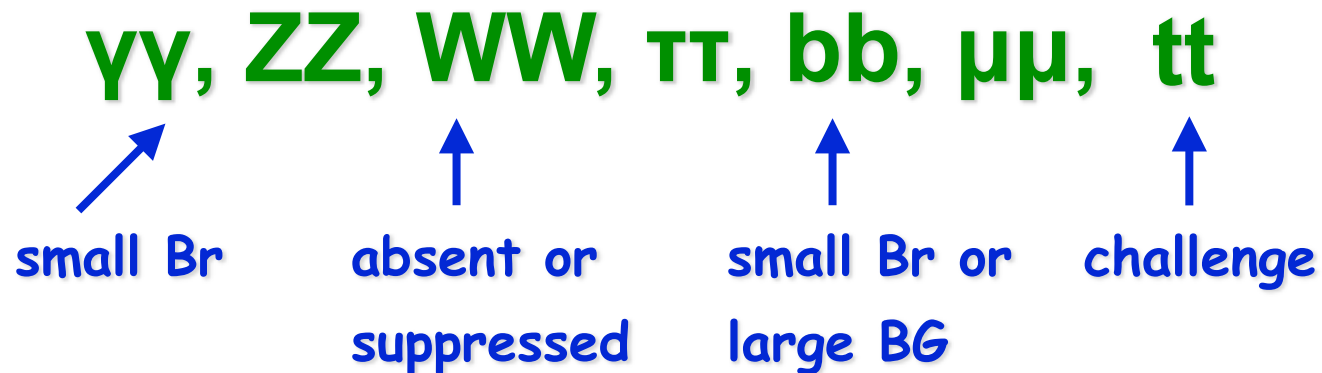

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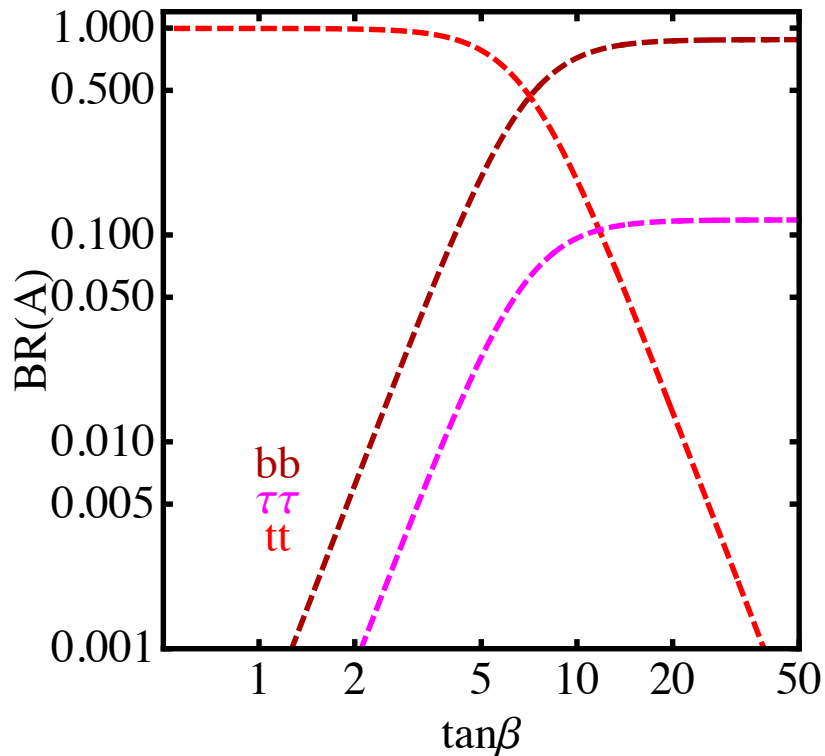
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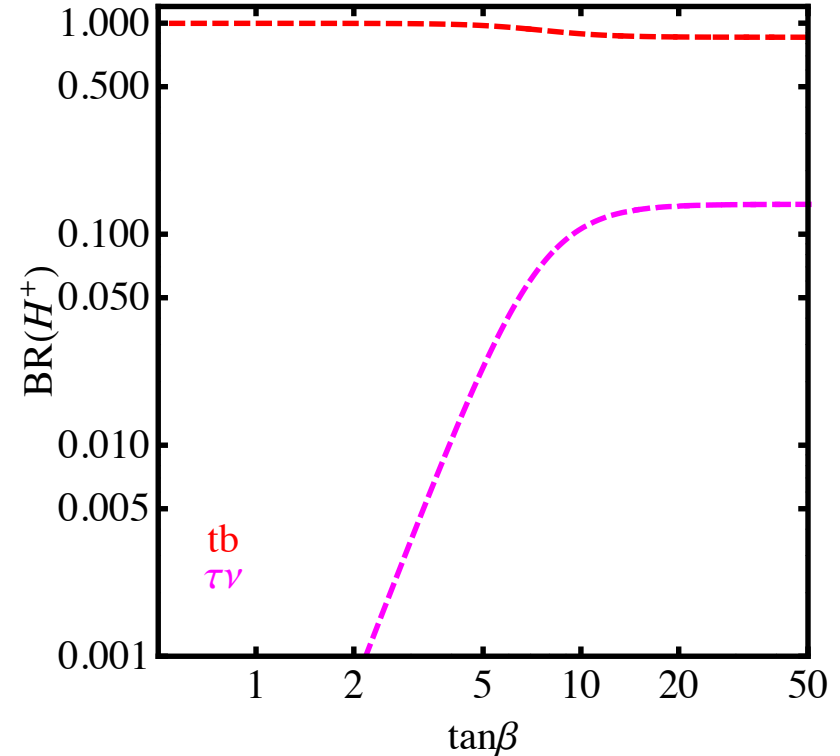


Searching for Other Higgses

⊙ **A/H decay**



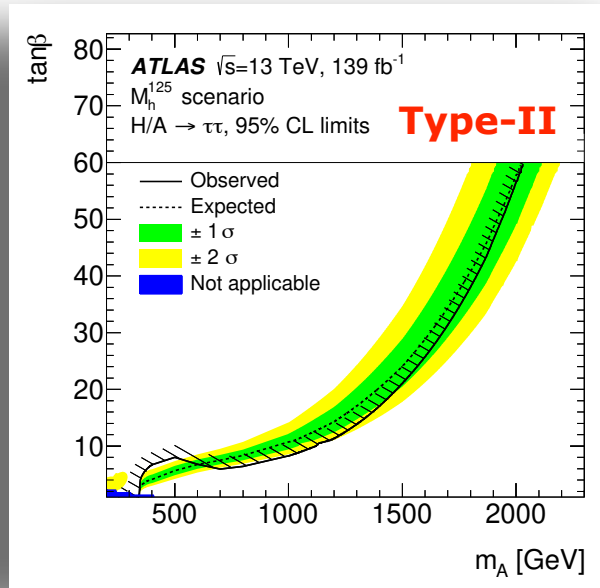
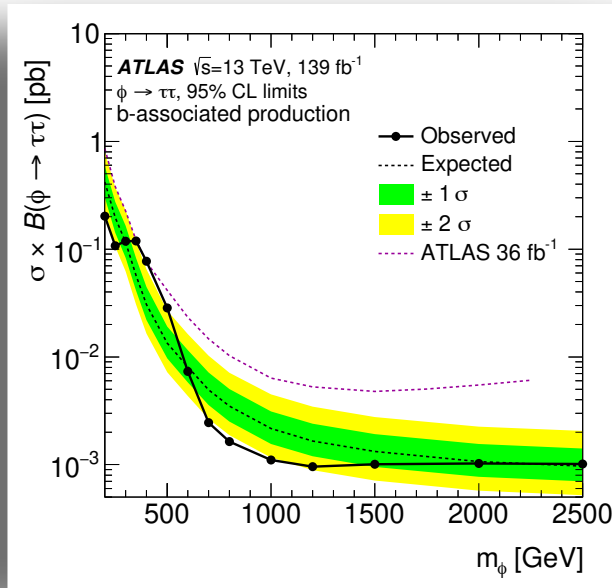
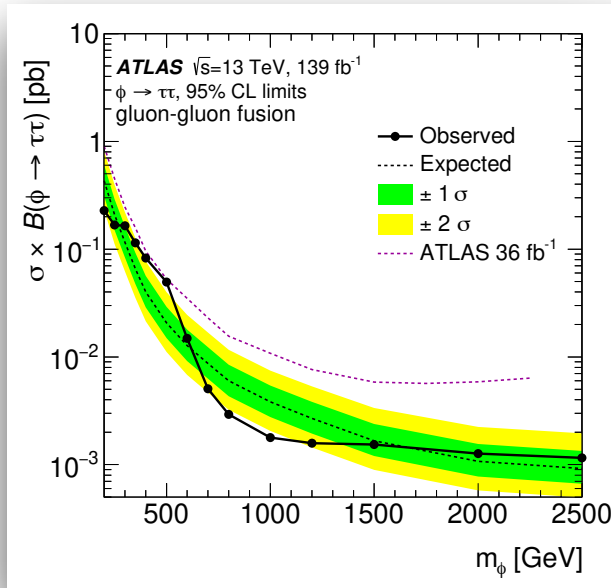
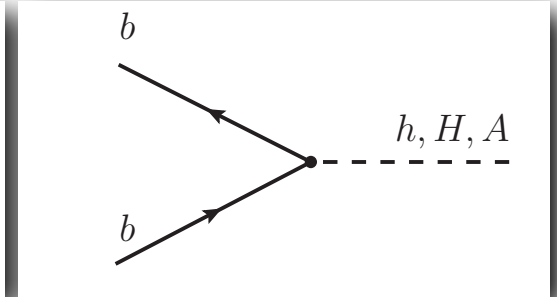
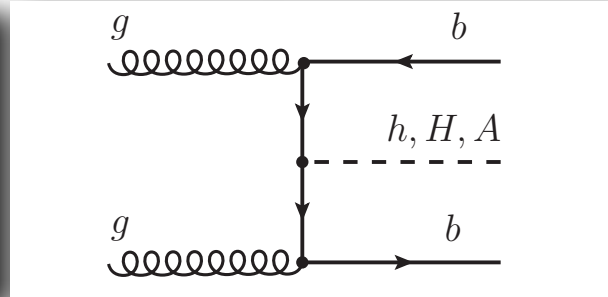
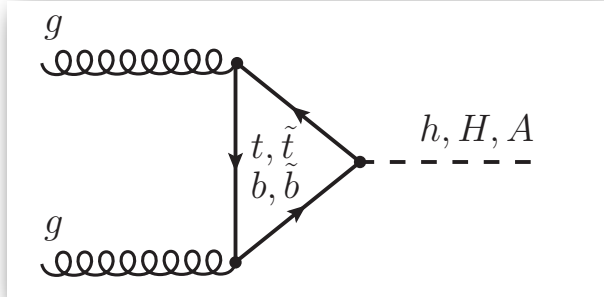
⊙ **$H^\pm$ decay**



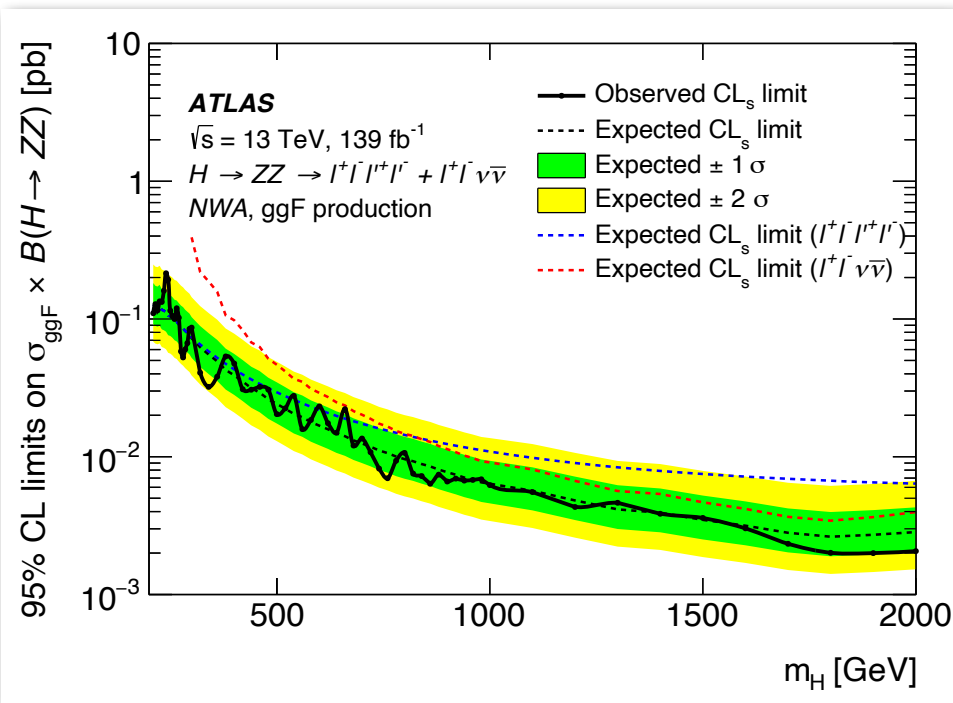
Type-II 2HDM

500 GeV parent particle

H/A $\rightarrow \tau\tau$

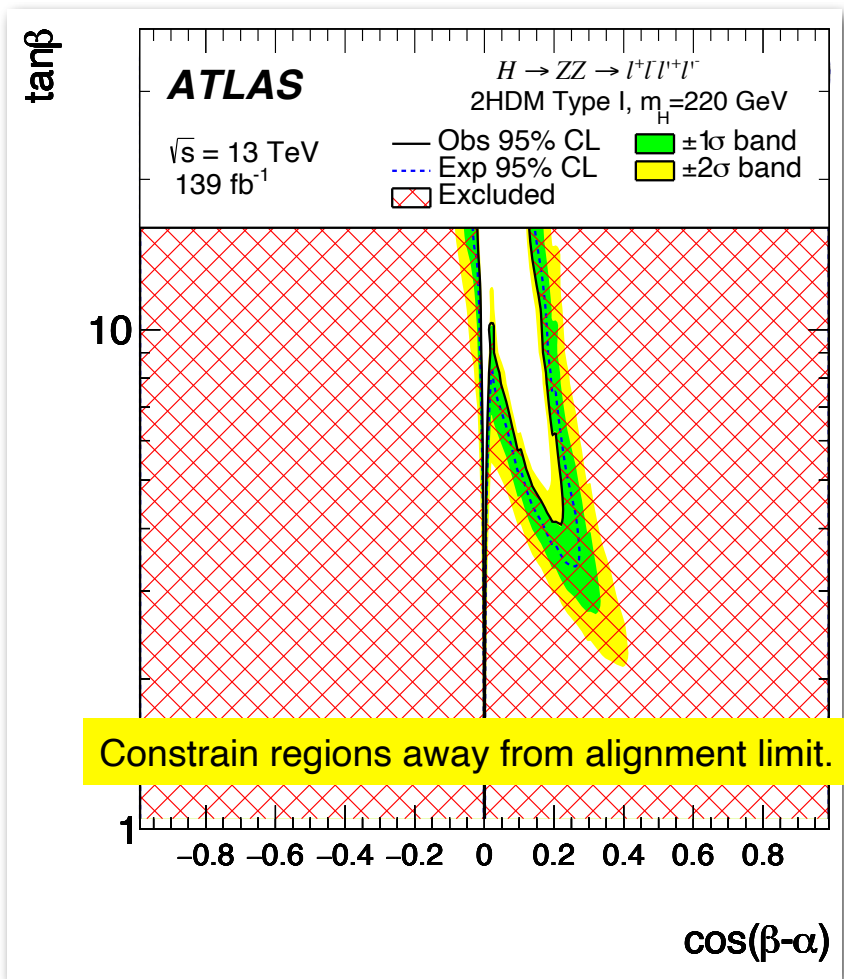


H → ZZ



ATLAS, EPJC 81 (2021) 332

S. Su



BSM Higgs Searches:

Exotic Modes

Exotic Decay

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	$(bb/\tau\tau/WW/ZZ/\gamma\gamma)(bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$h_{SM} \rightarrow AA,$ $H \rightarrow h_{SM} h_{SM},$ $H \rightarrow AA,$
	H^+H^- type	$(\tau\nu/tb)(\tau\nu/tb)$	$H \rightarrow H^+H^-$
	$WH^\pm$ type	$(l\nu/qq')(\tau\nu/tb)$	$H/A \rightarrow WH^\pm$
	ZH type	$(ll/qq/\nu\nu)(tt/bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$H \rightarrow ZA,$ $A \rightarrow ZH, Zh$
charge Higgs	WH type	$(l\nu/qq')(bb/\tau\tau)$	$tH^\pm$ production, $H^\pm \rightarrow WH$ $H^\pm \rightarrow WA$

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Exotic Decay

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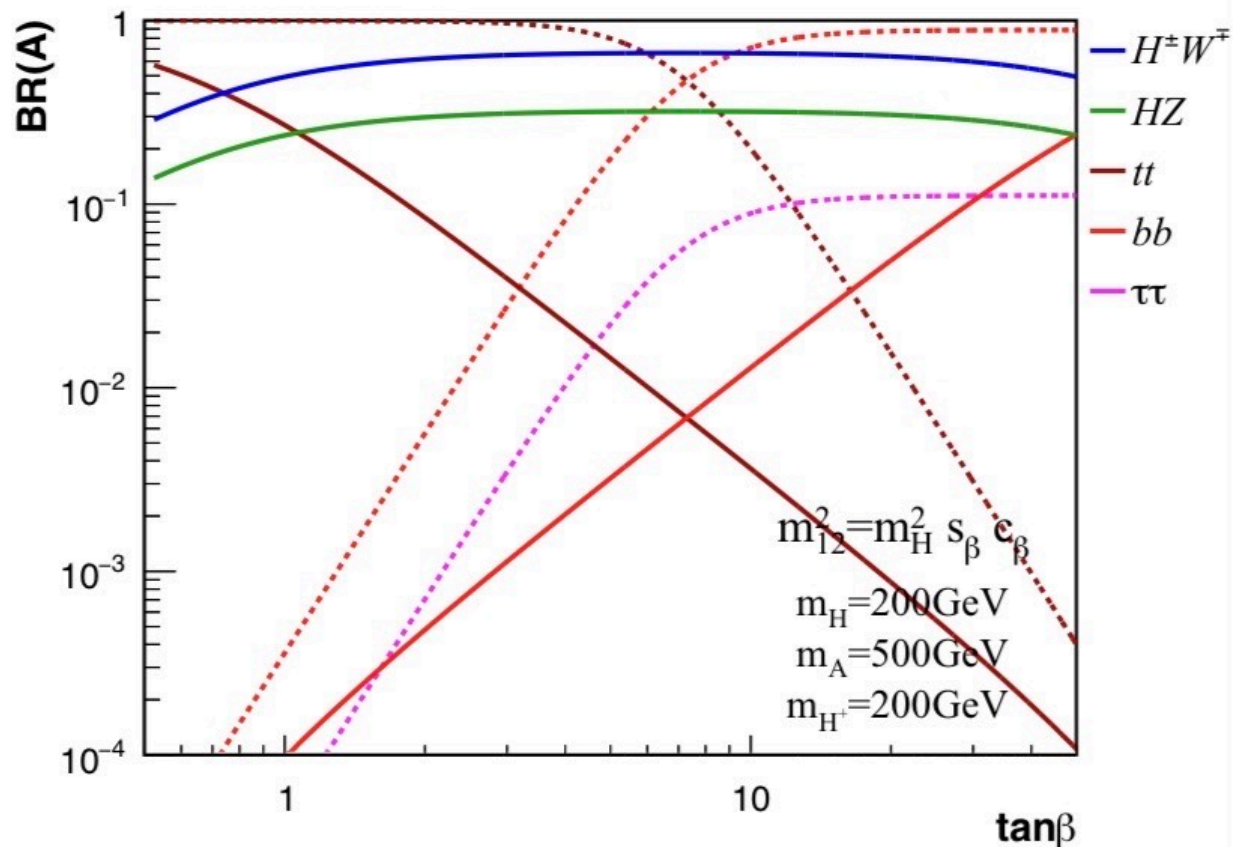
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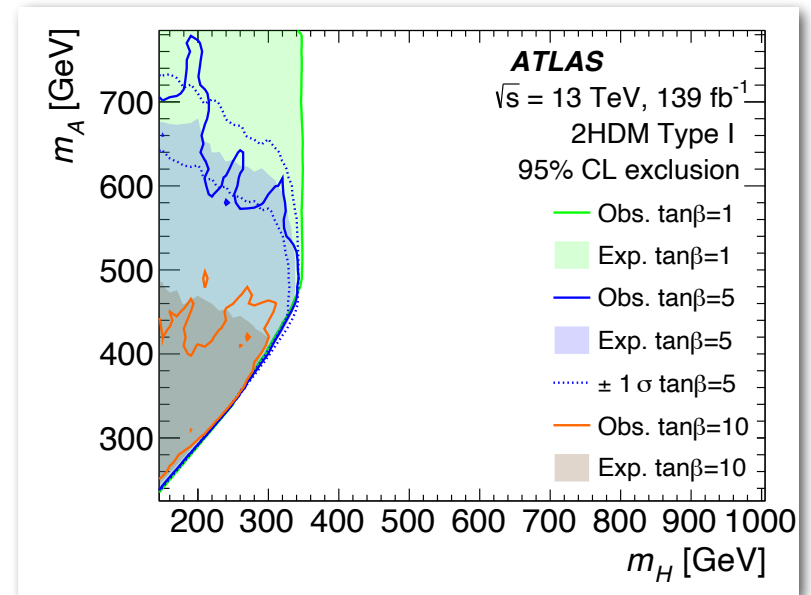
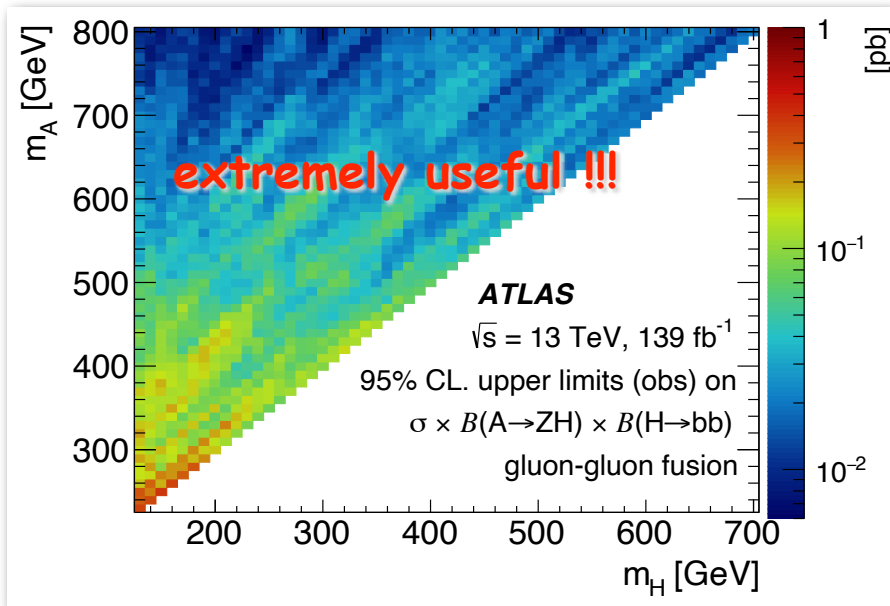
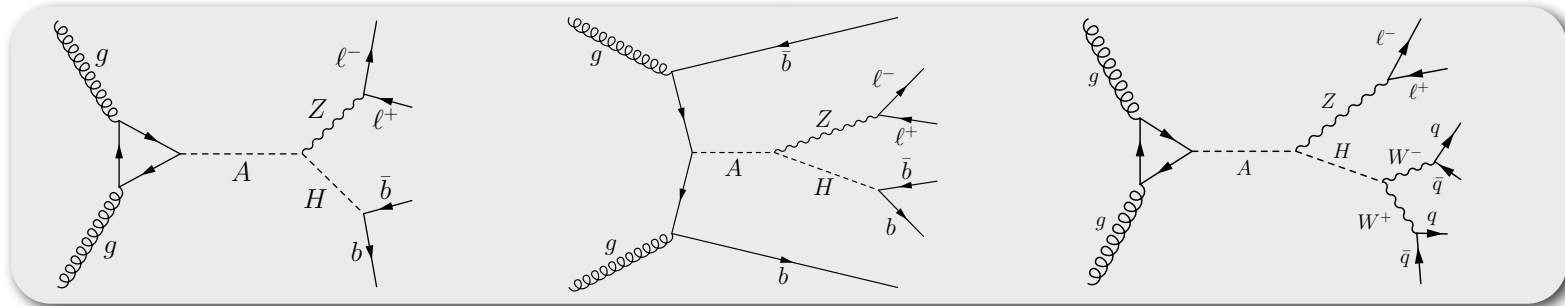
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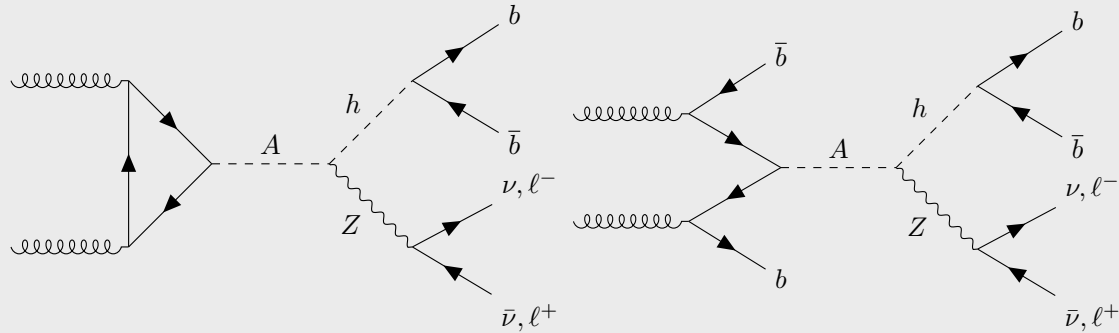


$A \rightarrow HZ$

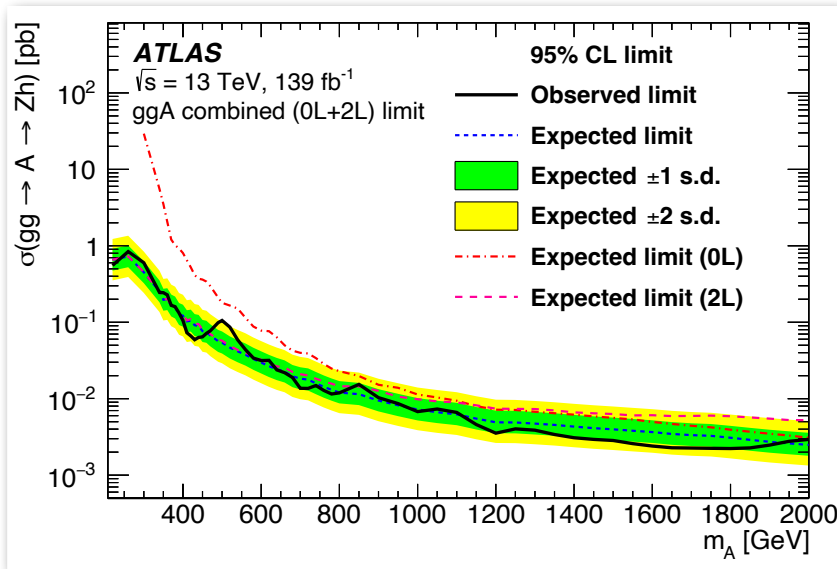


unsuppressed at the alignment limit.

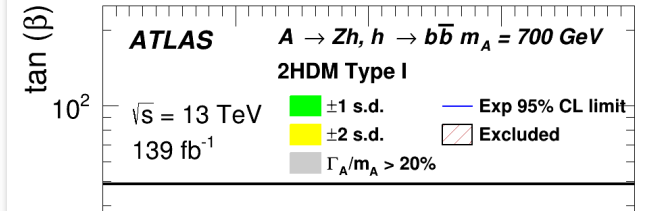
$A \rightarrow Z h_{125}$



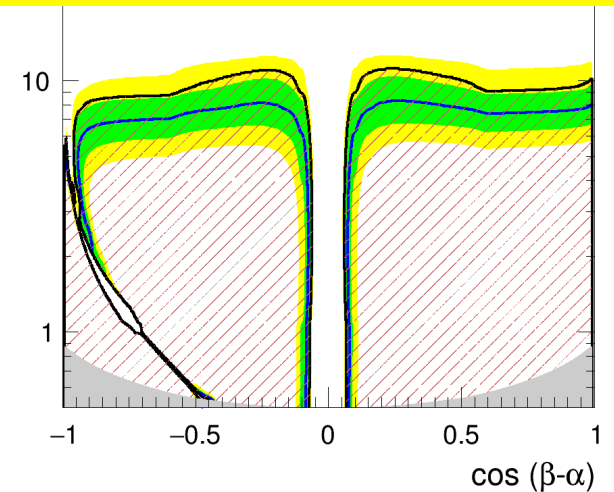
suppressed at the alignment limit.



ATLAS, JHEP 06 (2023) 016



Constrain regions away from alignment limit.



Complementarity

Constraints

Neutral scalars

- theoretical constraints

vacuum stability/Unitarity/perturbativity/... $m_{12}^2 = m_H^2 \sin\beta \cos\beta$

- Precision Higgs measurements (μ , Γ_h)

- Conventional channels: $\gamma\gamma$, ZZ , WW , $\tau\tau$, $\mu\mu$, bb , tt

- Exotic decay into h : $A \rightarrow hZ$, $H \rightarrow hh$

- Exotic decay of h_{SM} : $h \rightarrow AA$, $h \rightarrow HH$

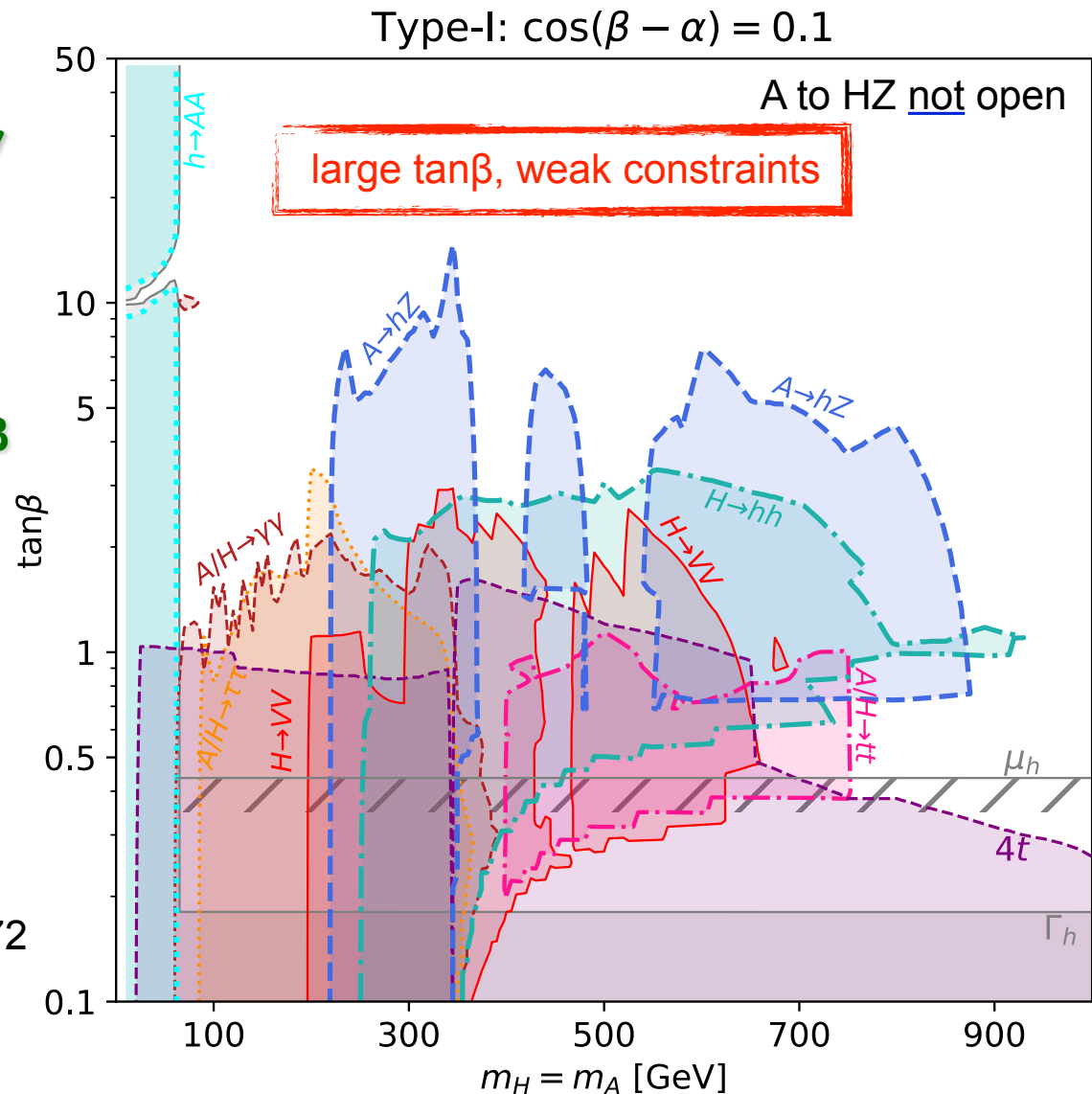
- Exotic decay of BSM sector: $A \rightarrow HZ$, $H \rightarrow AZ$

- LEP searches: $e^+e^- \rightarrow Z \rightarrow HA$, $e^+e^- \rightarrow Z \rightarrow ZH$

- SM non-resonant processes: ttZ , $tttt$

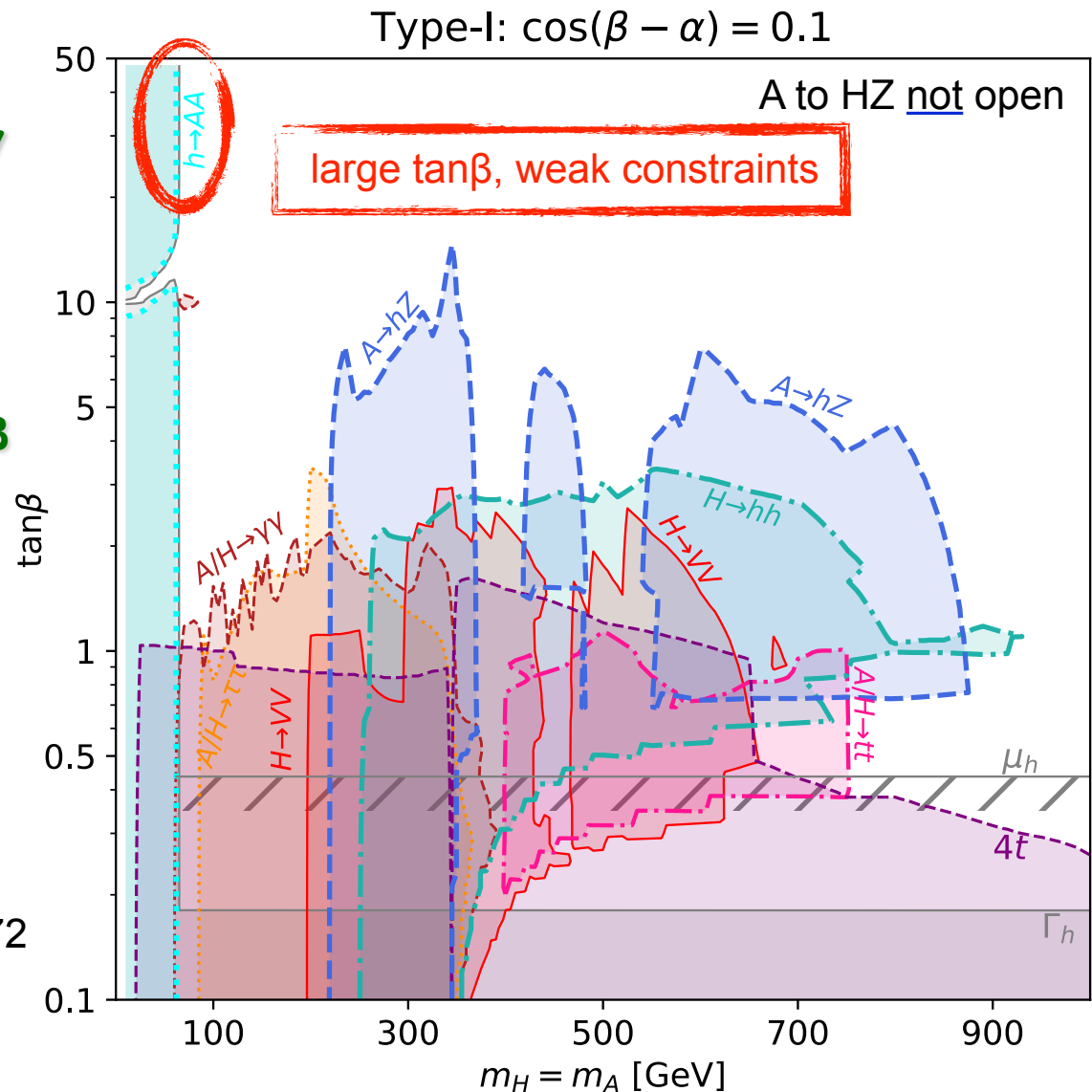
Degenerate Case: Type I

- **degenerate:** $m_{H_{pm}} = m_H = m_A$
no BSM sector exotic decay
allow $A \rightarrow Zh$, $H \rightarrow hh$, $H \rightarrow VV$
(away from alignment)
- **Type I:** ϕ_2 , u/d/l
BSM Higgs Yukawa $\sim 1/\tan \beta$



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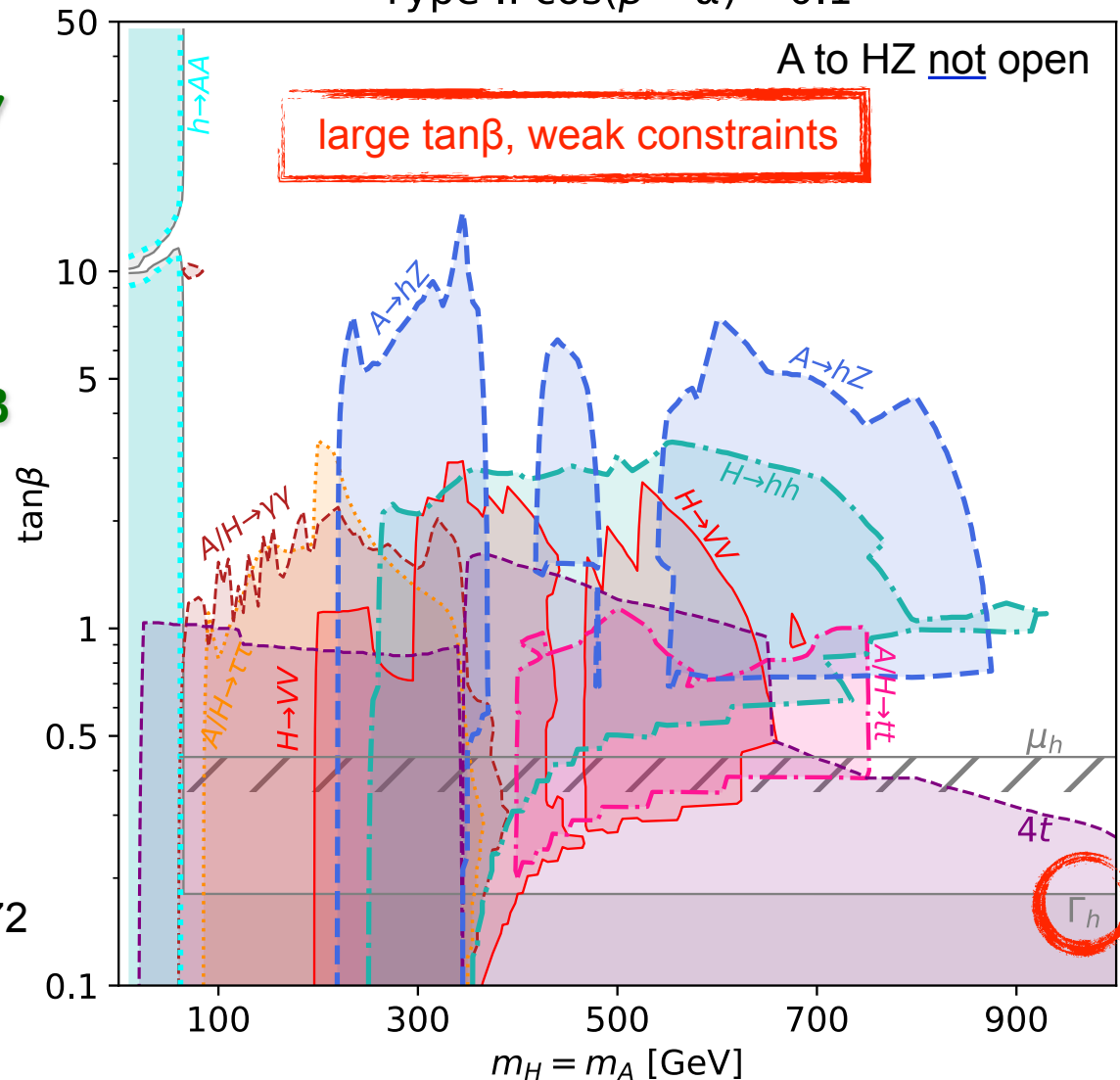
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Type-I: $\cos(\beta - \alpha) = 0.1$

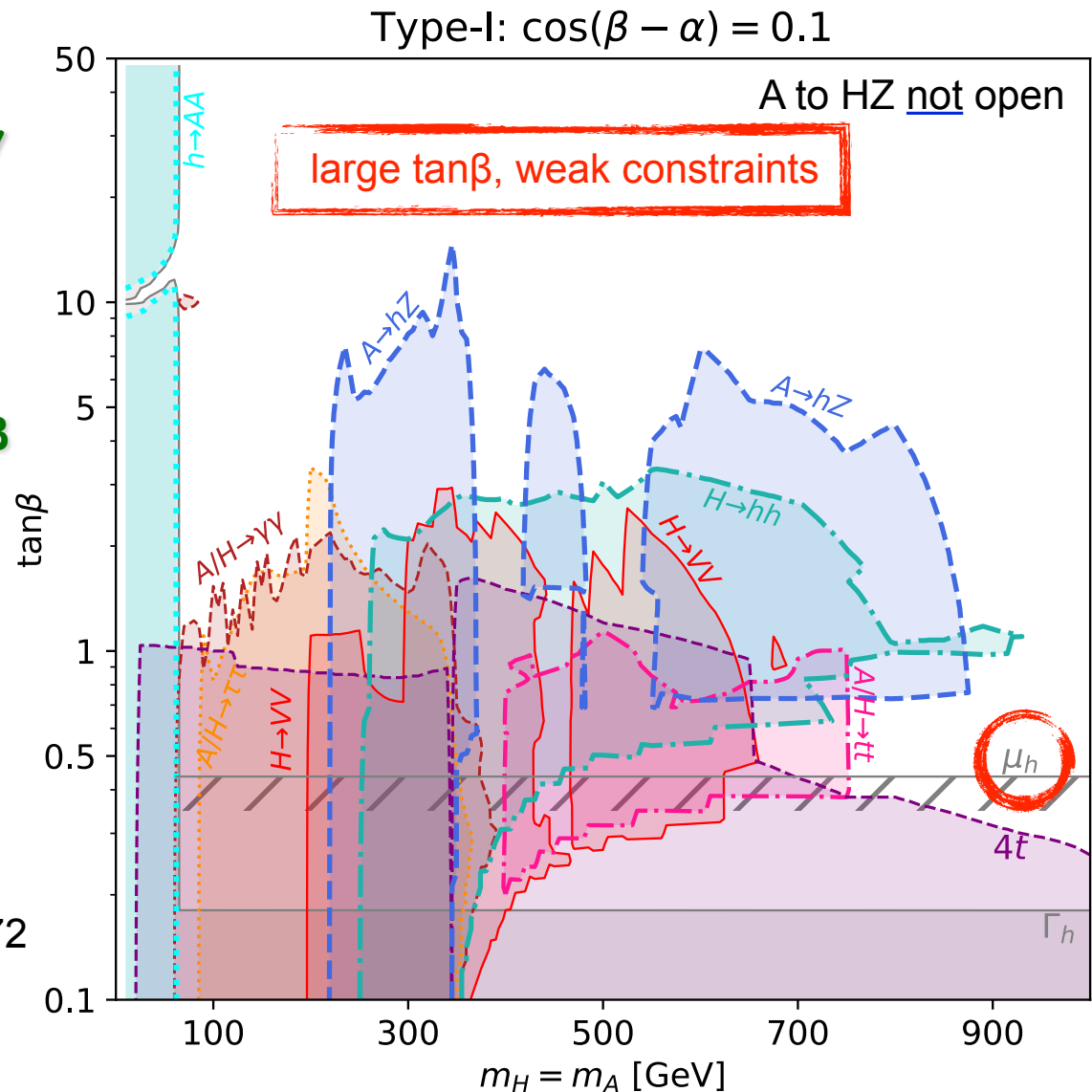
A to HZ not open

large $\tan \beta$, weak constraints

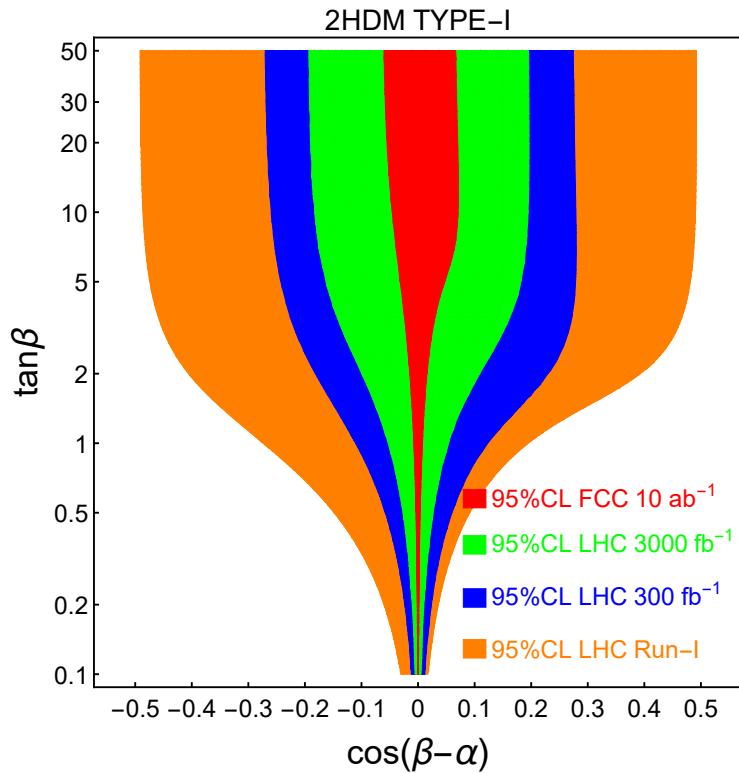


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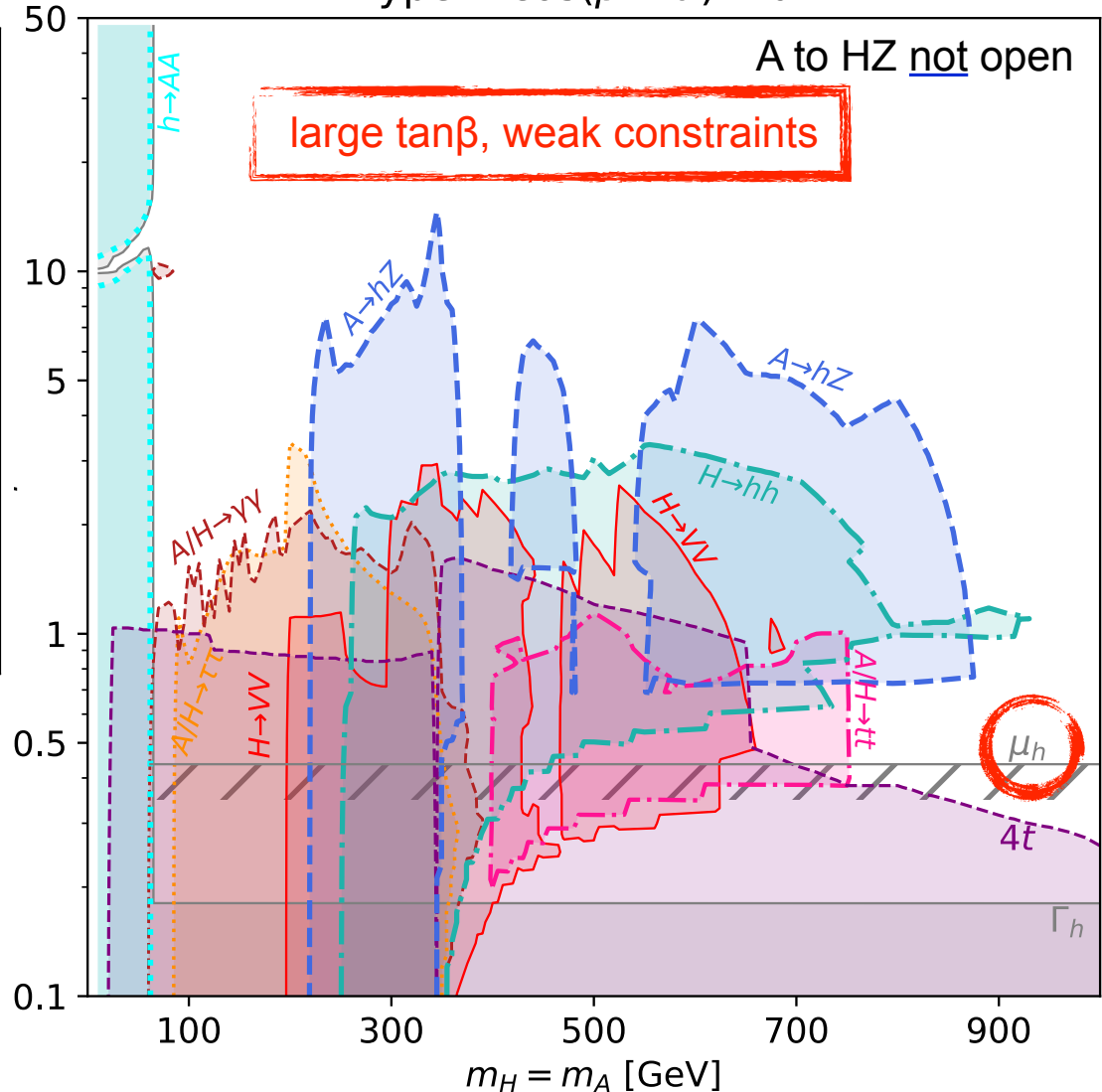
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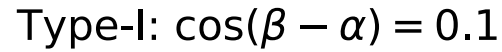


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F. Kling, S. Su, W. Su, 2004.04172

- **Type I: ϕ_2 , u/d/l**



A to HZ not open

large $\tan\beta$, weak constraints

 $\tan\beta$

50

10

5

1

0.5

0.1

100

300

500

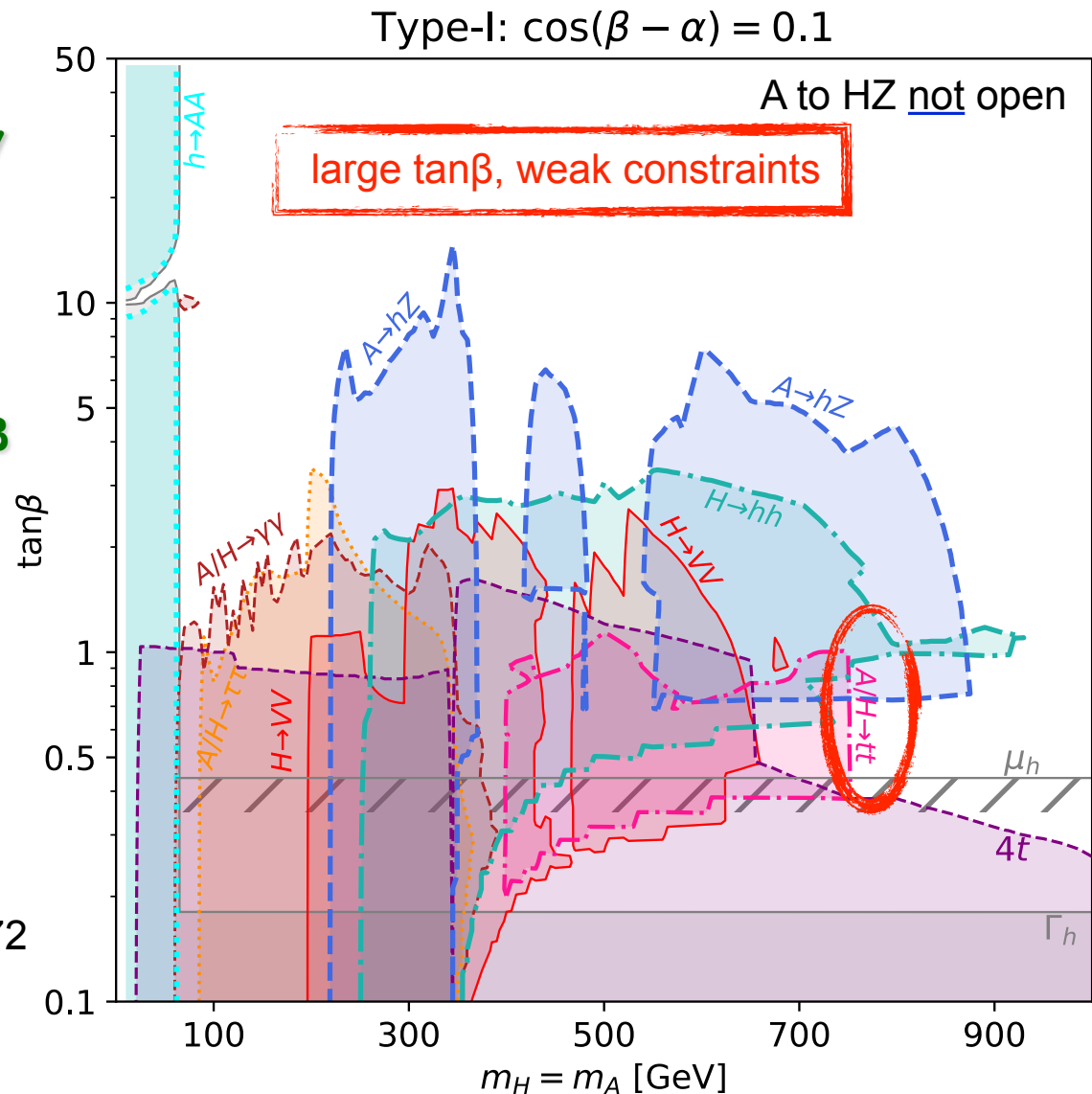
700

900

$$m_H = m_A \text{ [GeV]}$$
$$\mu_h$$
 $\hat{4f^-}$ h

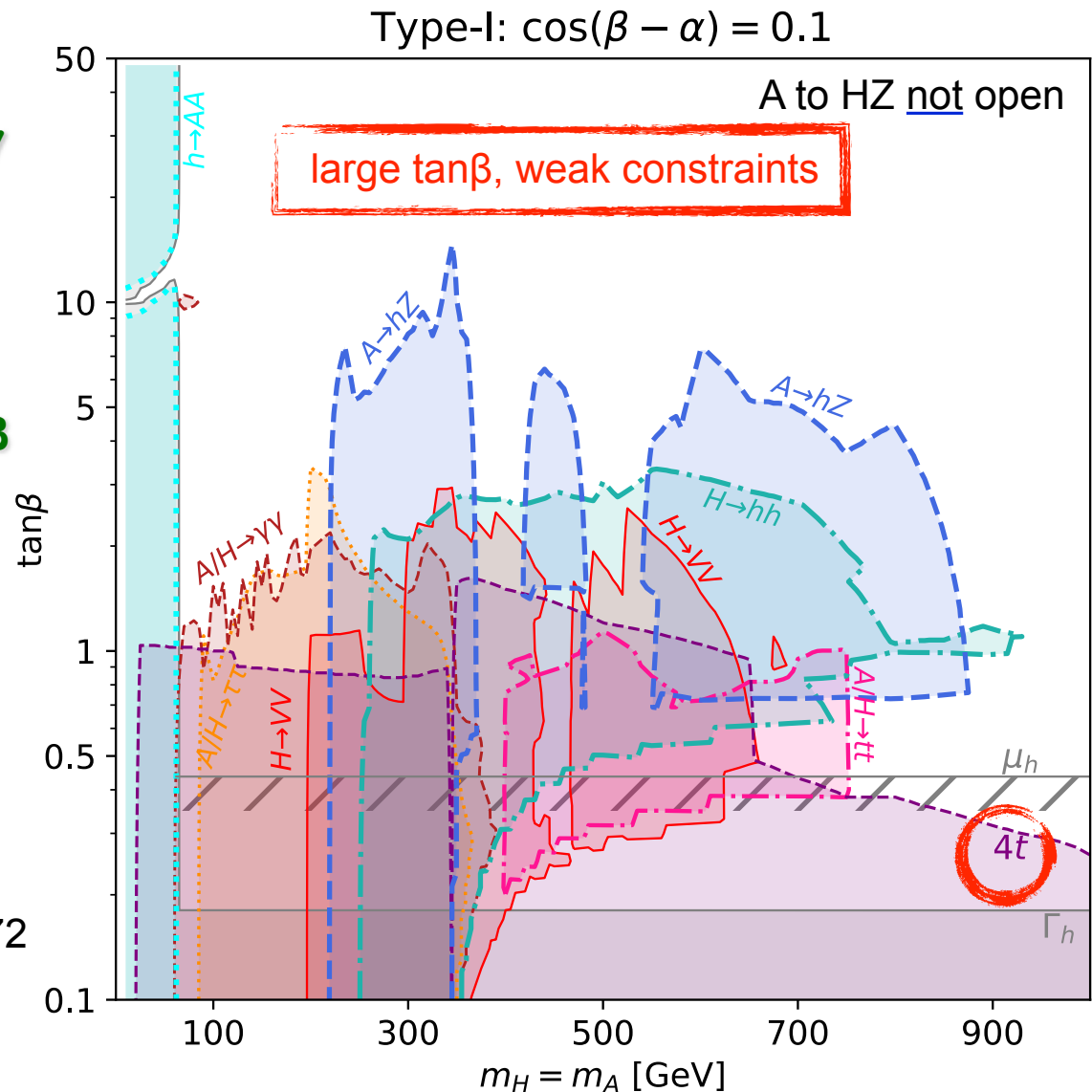
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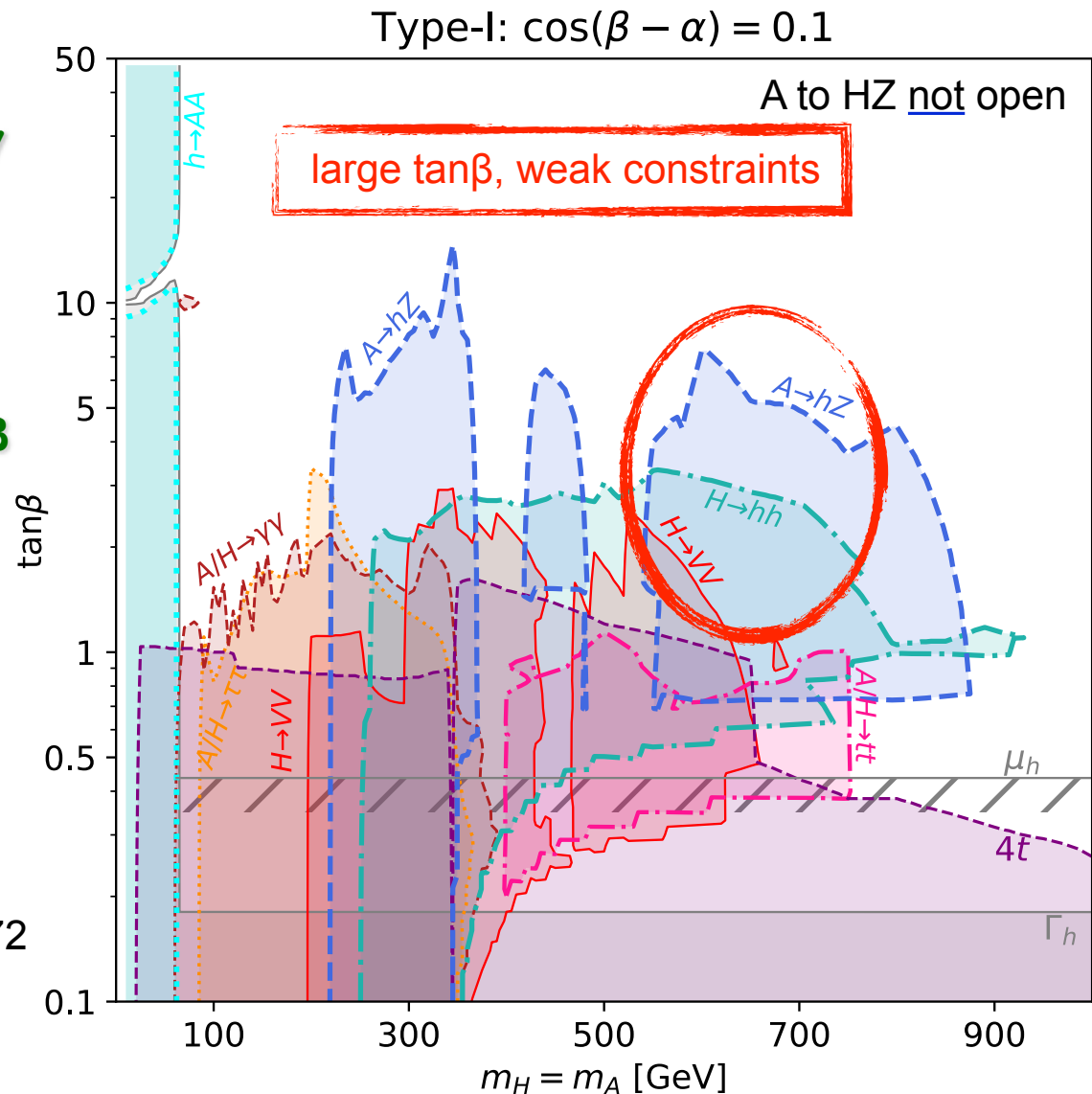
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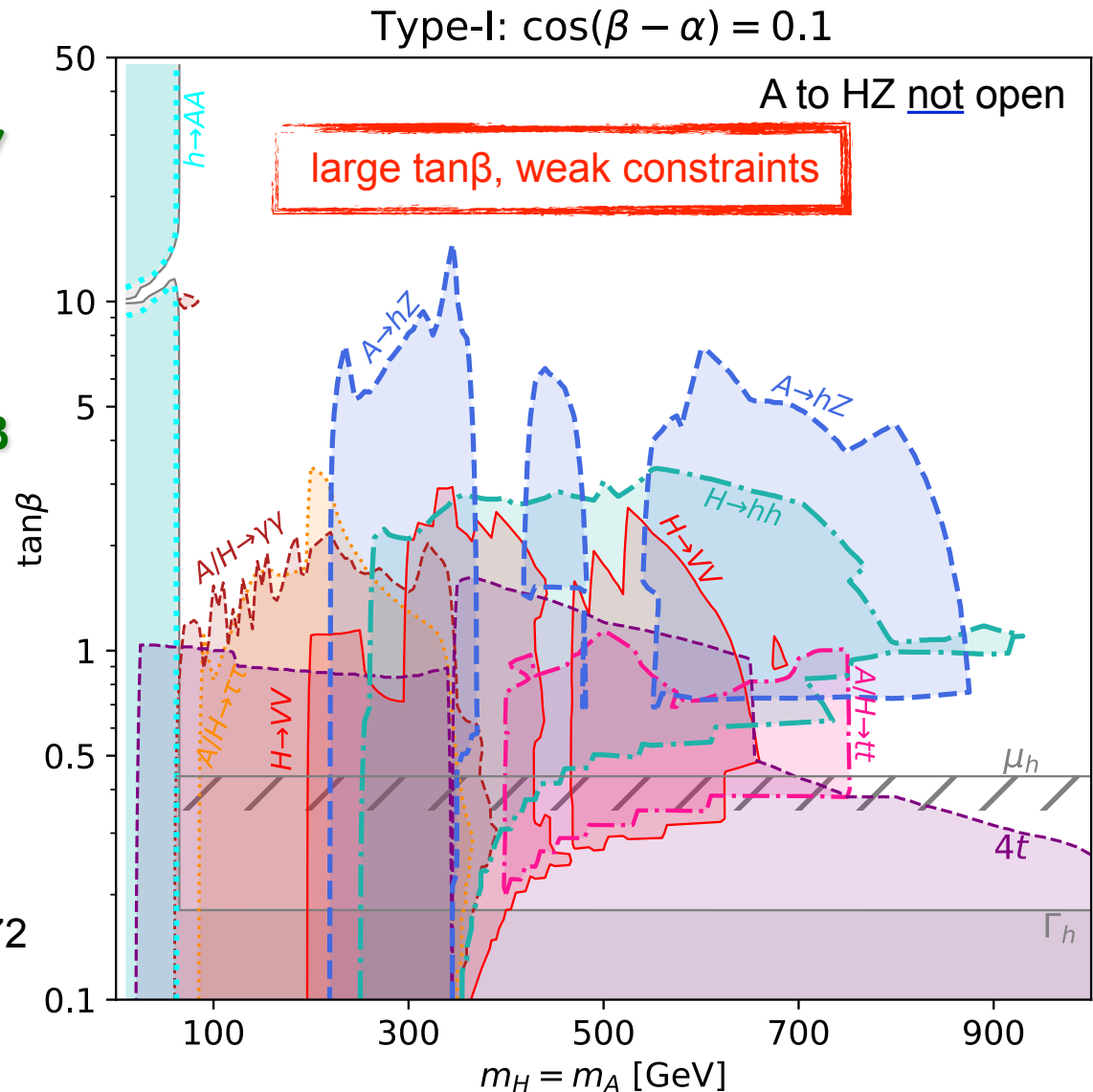
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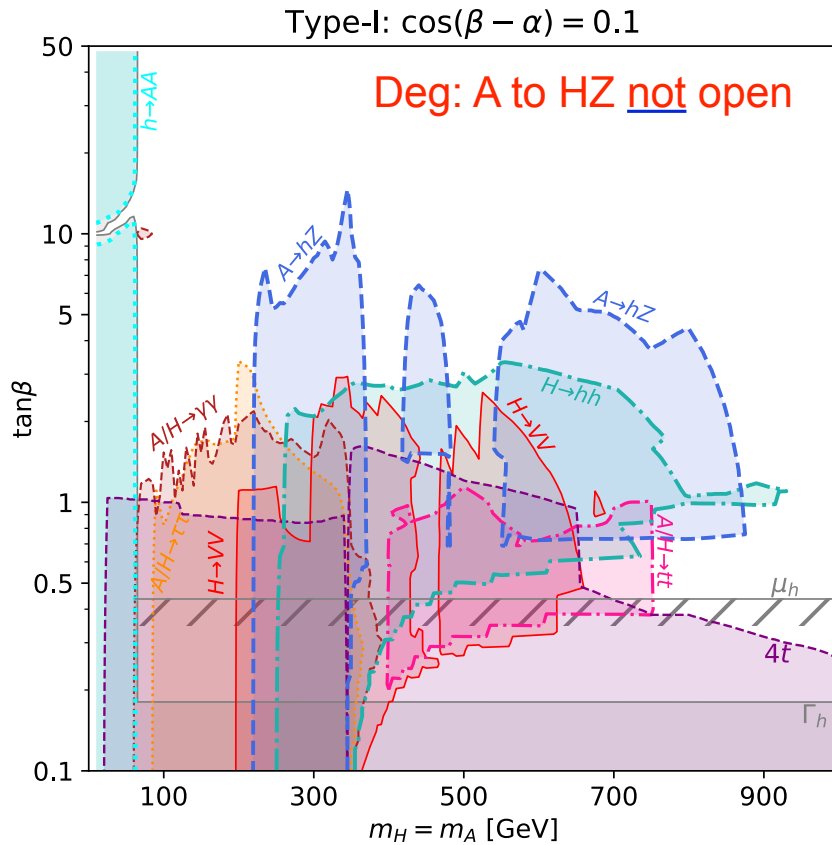
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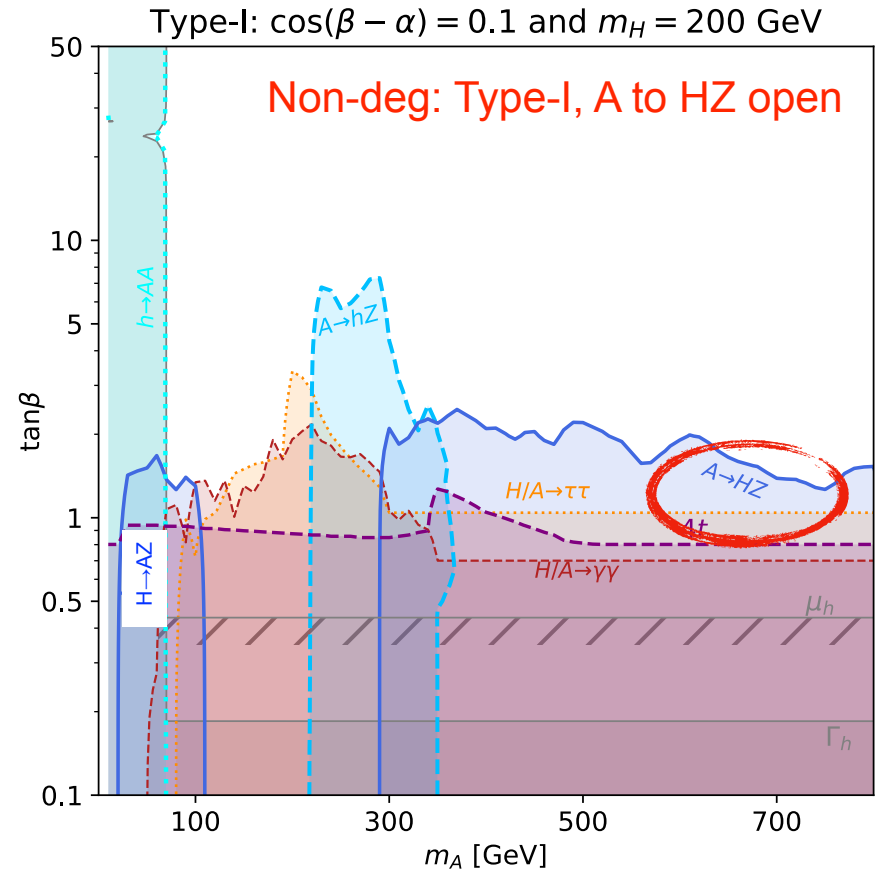


Degenerate vs. non-Deg: Type I

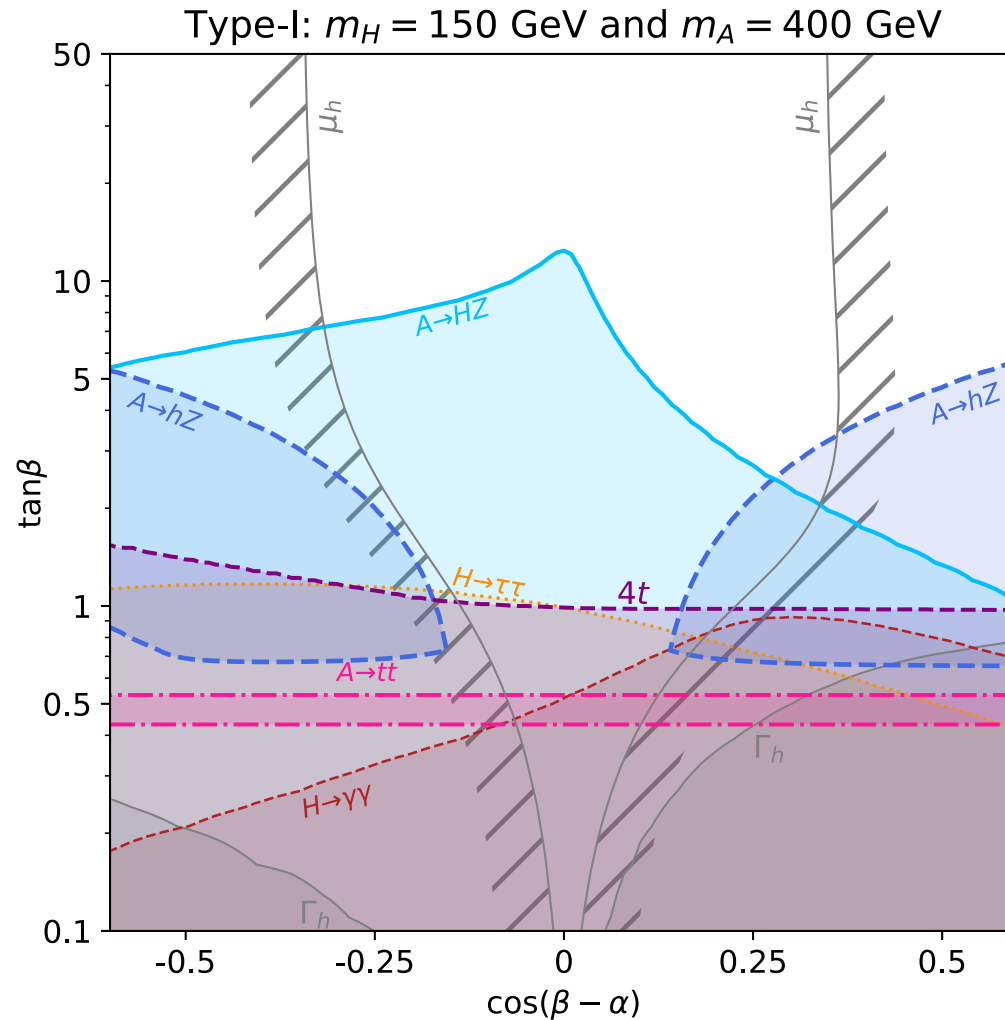
m_A vs. $\tan\beta$



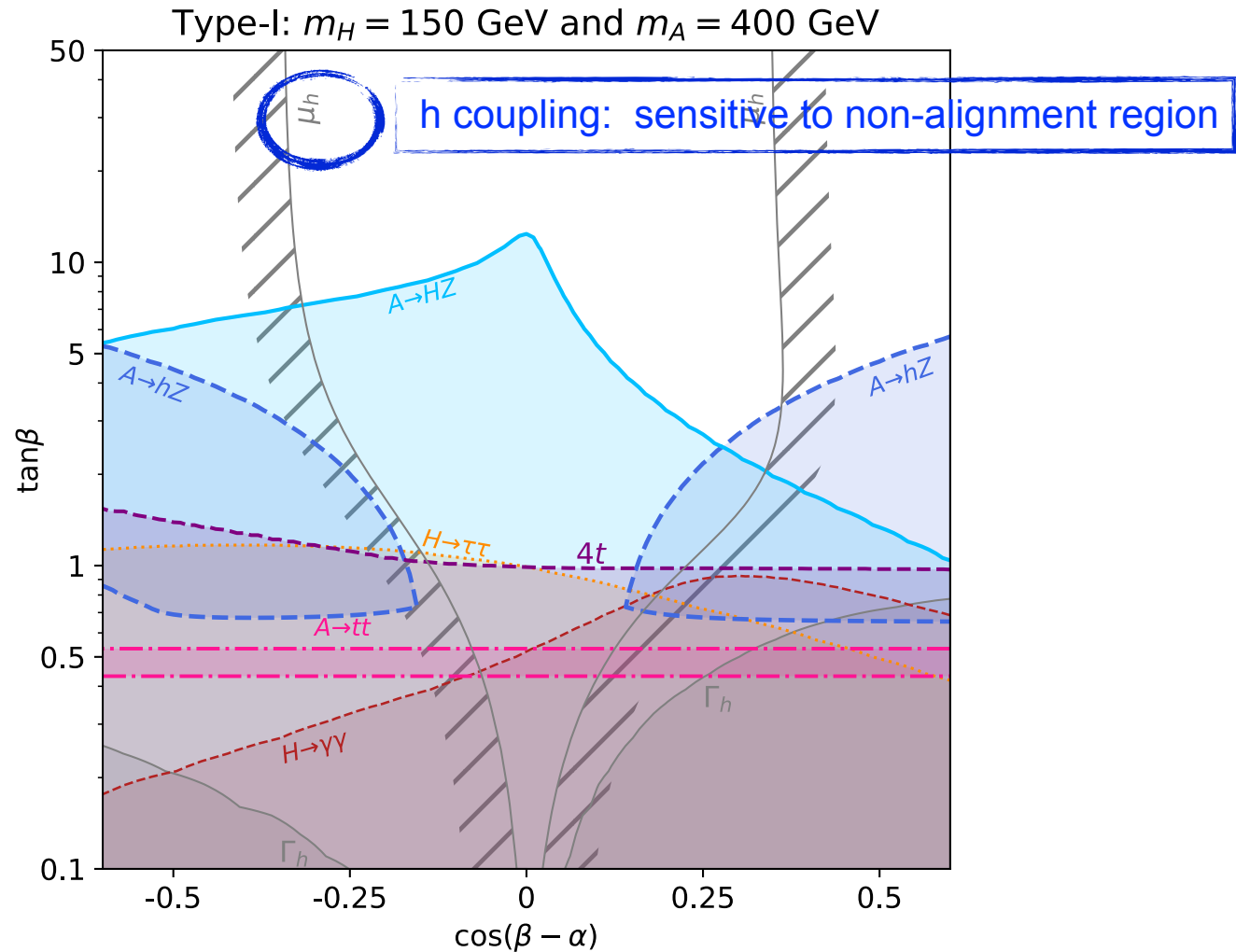
F. Kling, S. Su, W. Su, 2004.04172



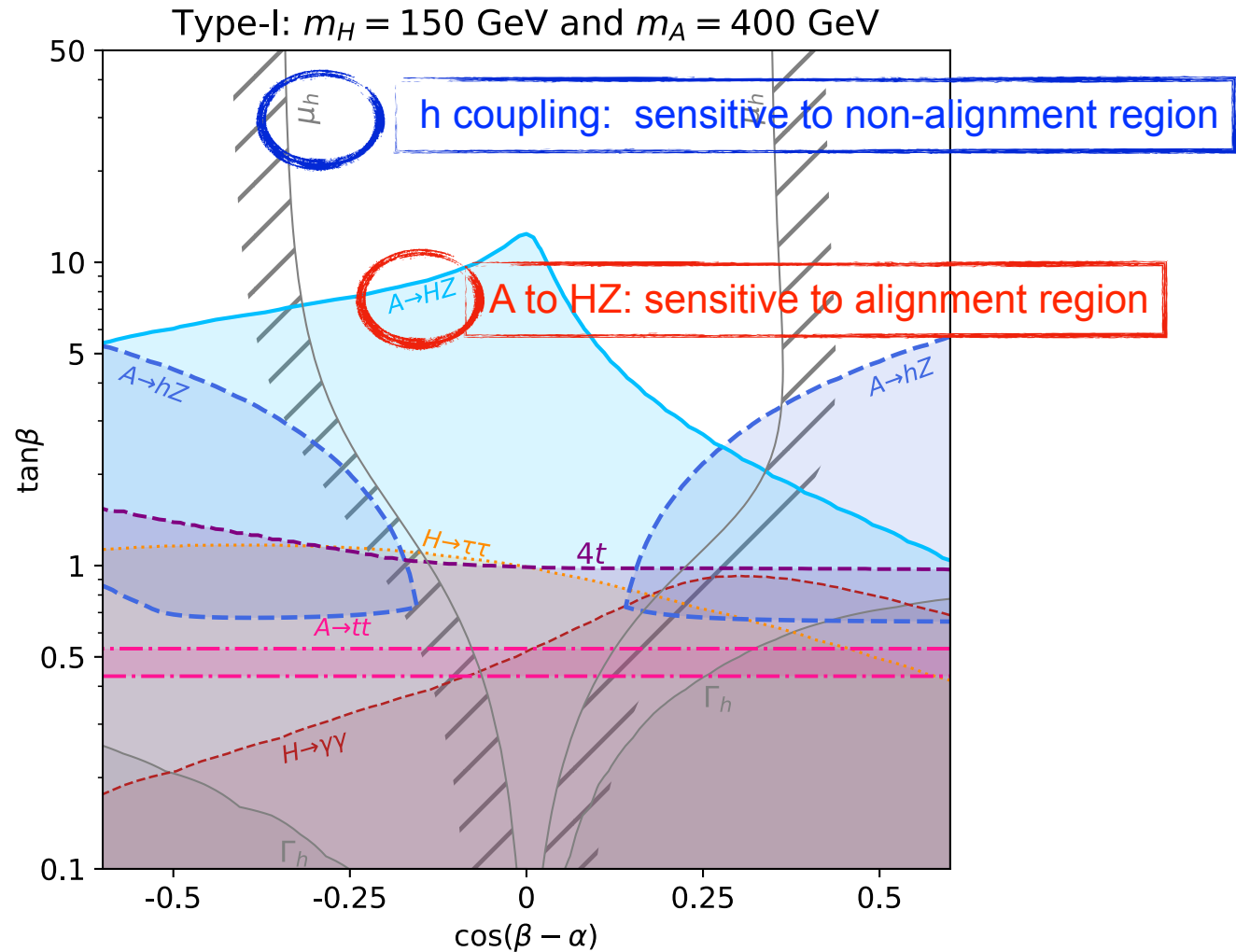
2HDM Neutral Scalars @ LHC



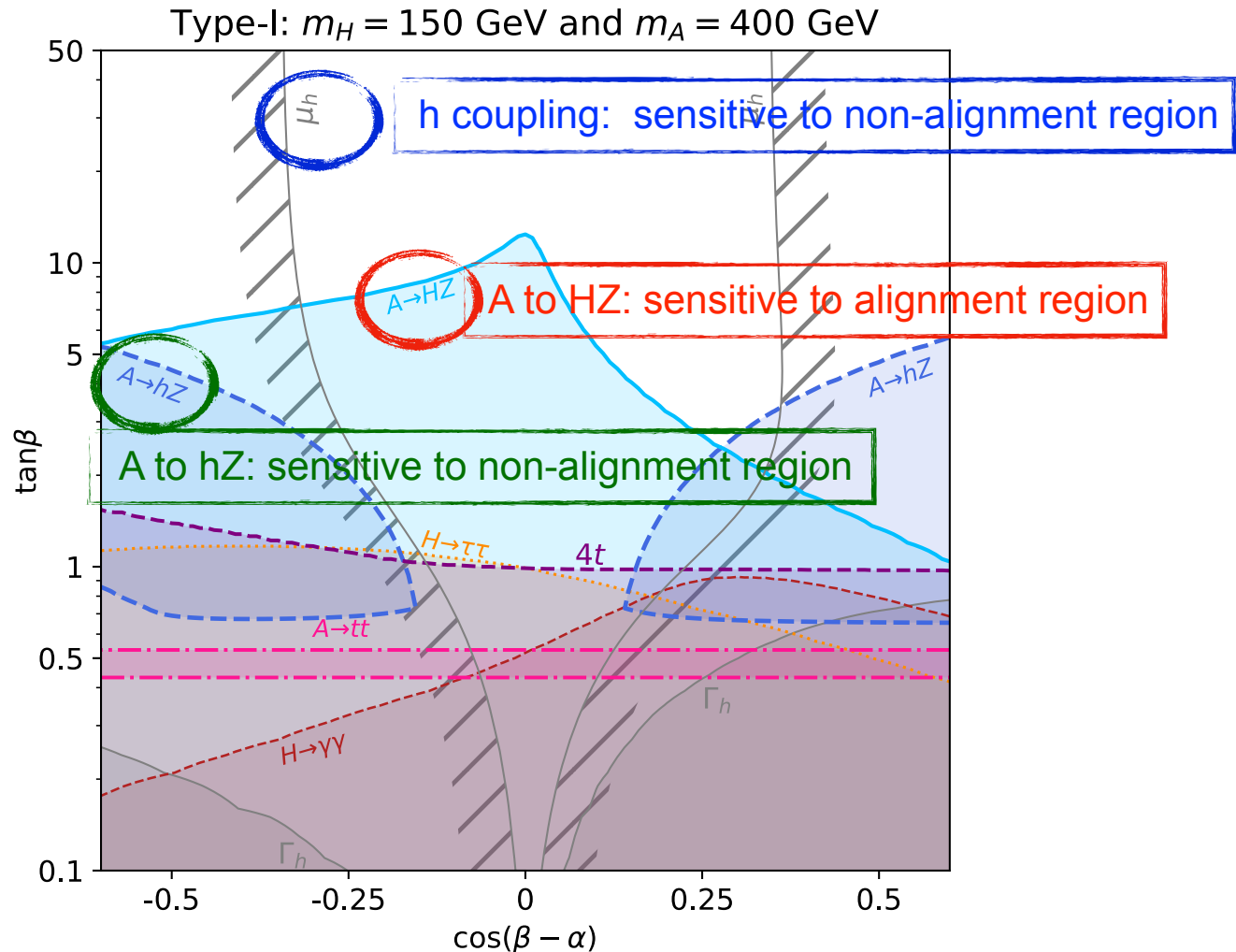
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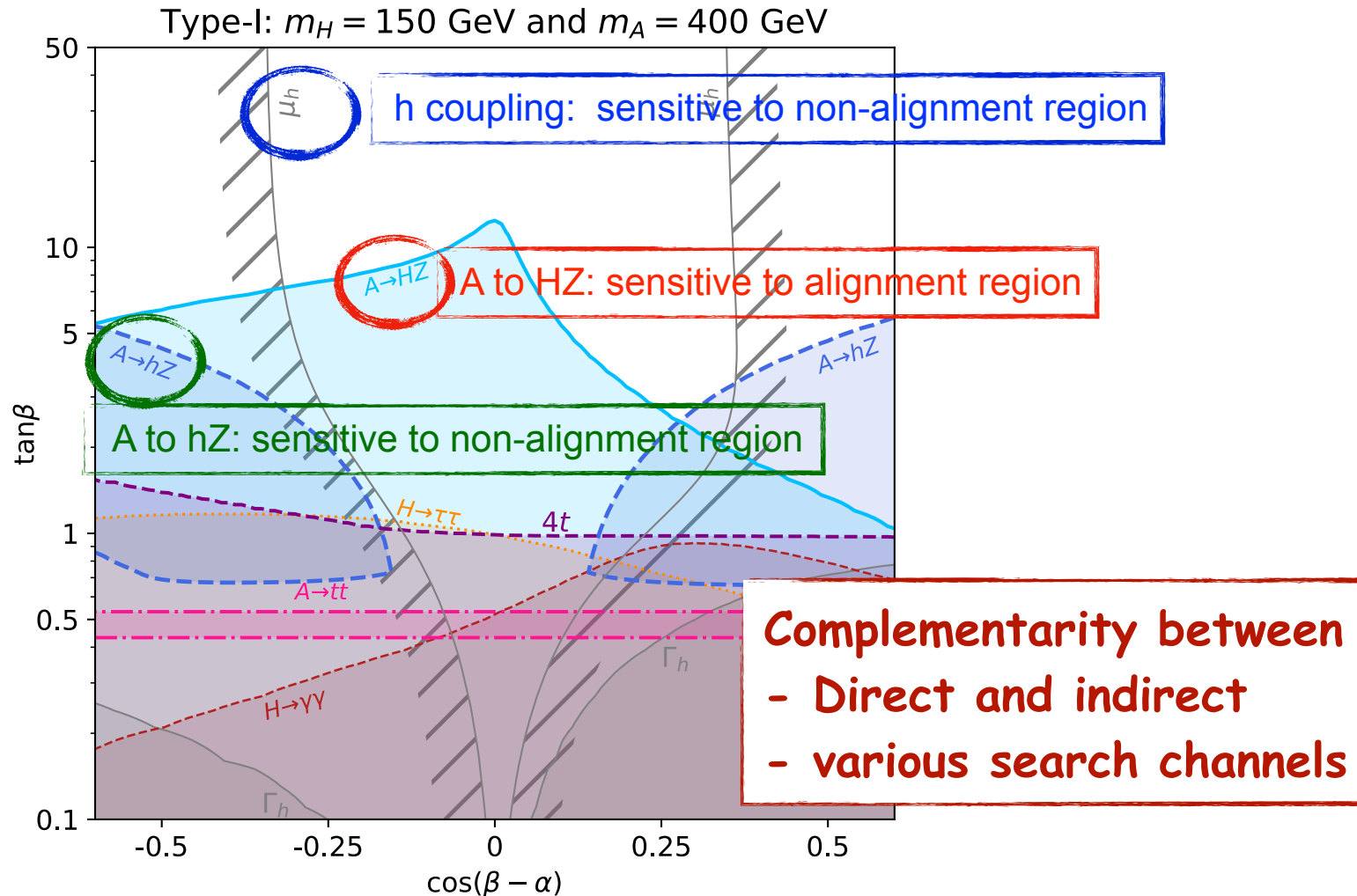
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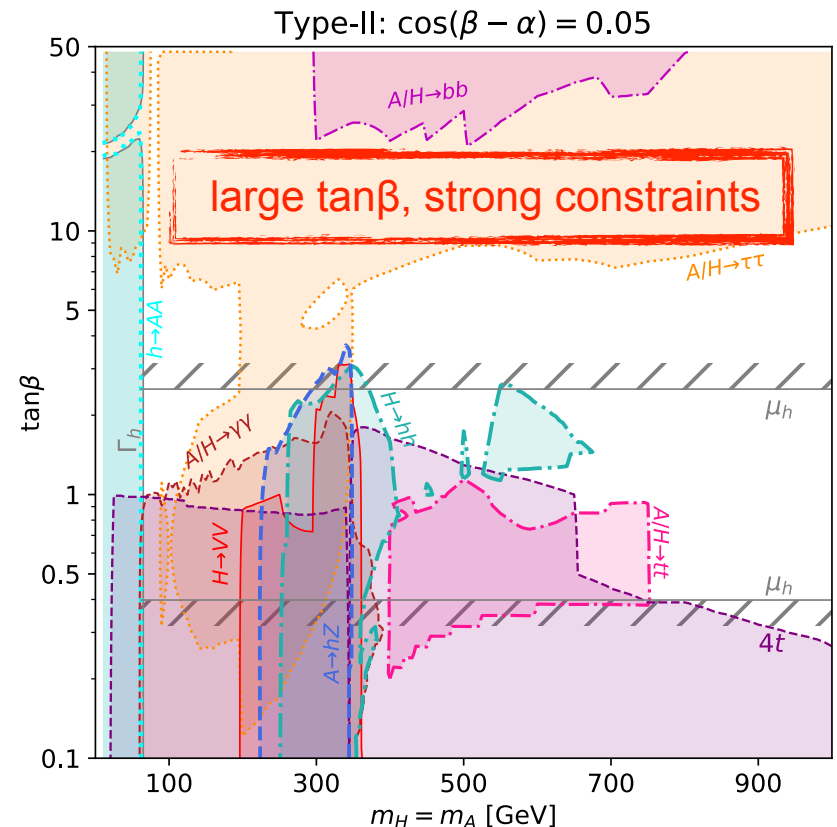
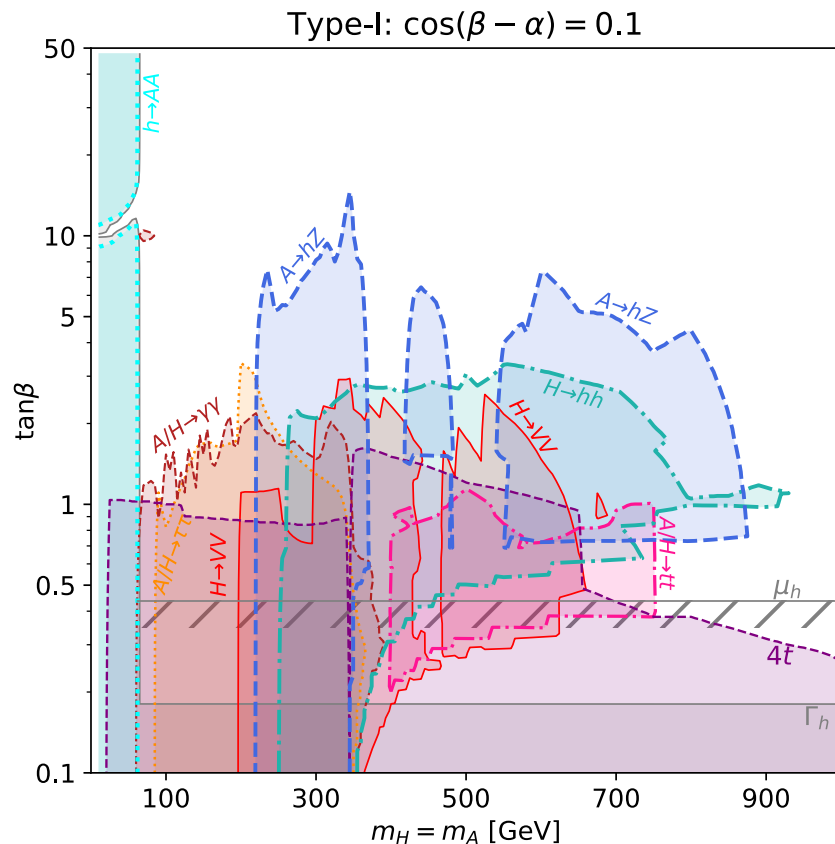
2HDM Neutral Scalars @ LHC



● **Type II** $\phi_{1,u}; \phi_{2,d/l}$

BSM Higgs Yukawa $\sim 1/\tan \beta$

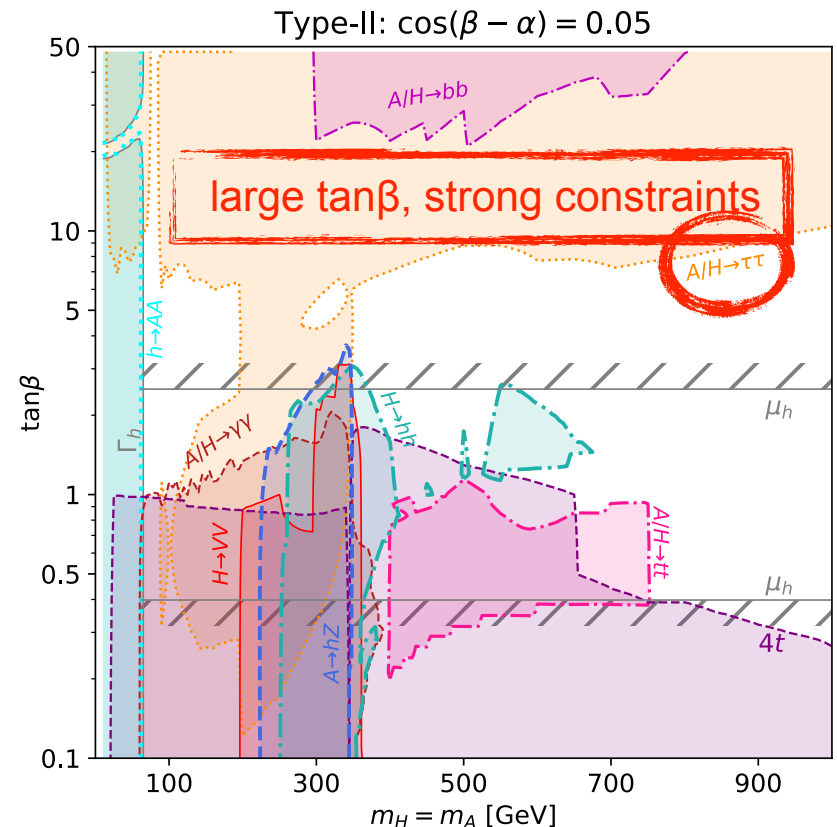
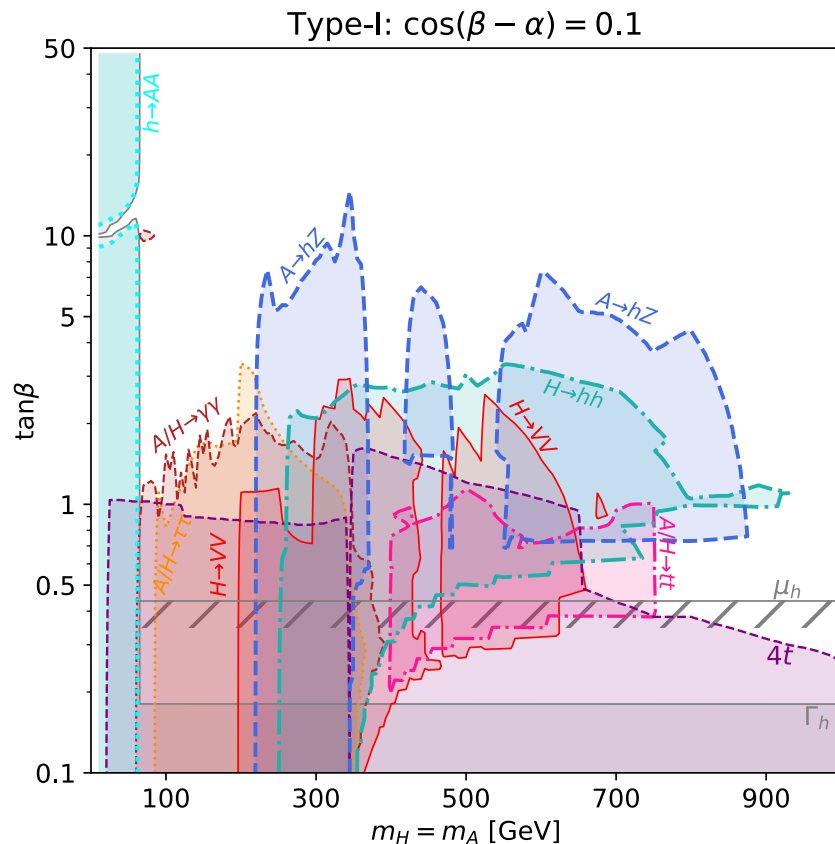
BSM $H/A_u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



● **Type II** $\phi_{1,u}; \phi_{2,d/l}$

BSM Higgs Yukawa $\sim 1/\tan \beta$

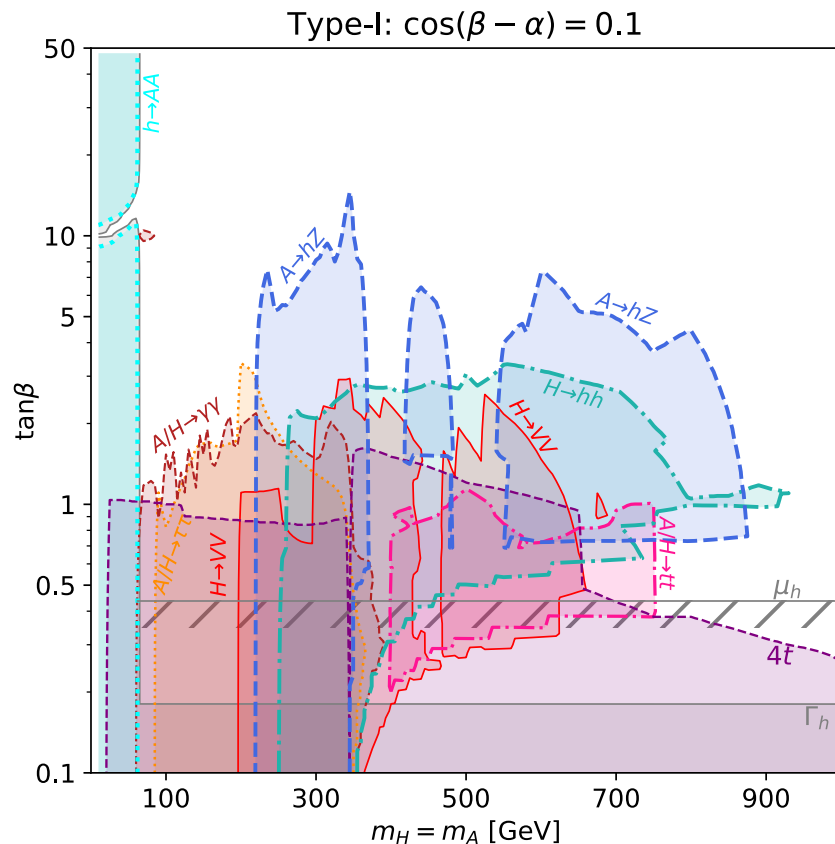
BSM $H/A_u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Degenerate Case: Type I & Type II

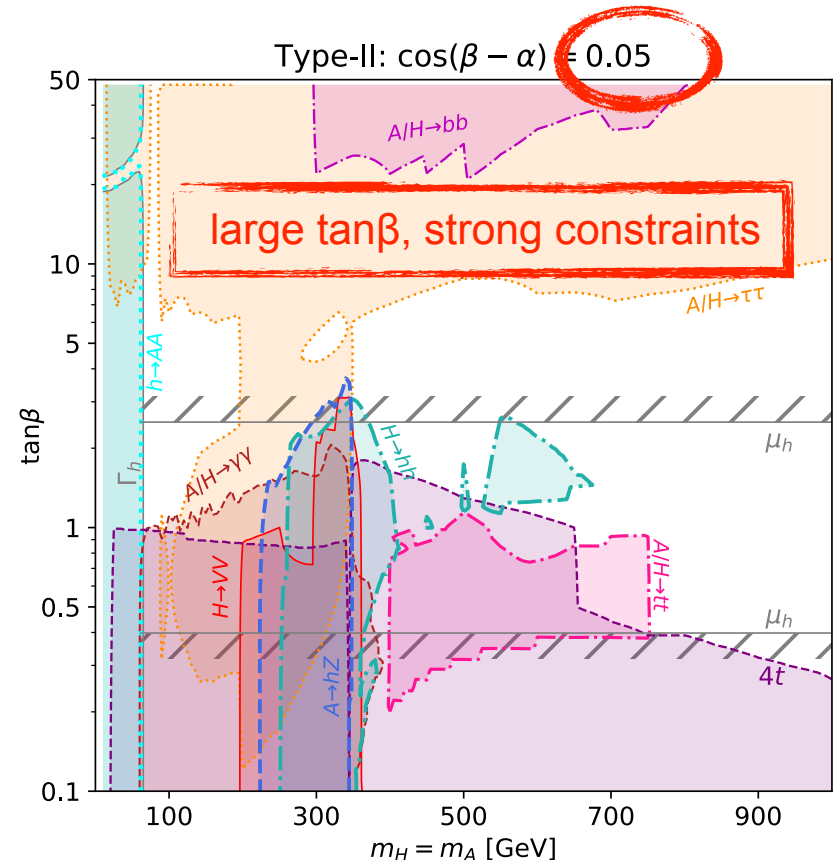
● Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan \beta$



● Type II $\phi_1, u; \phi_2, d/l$

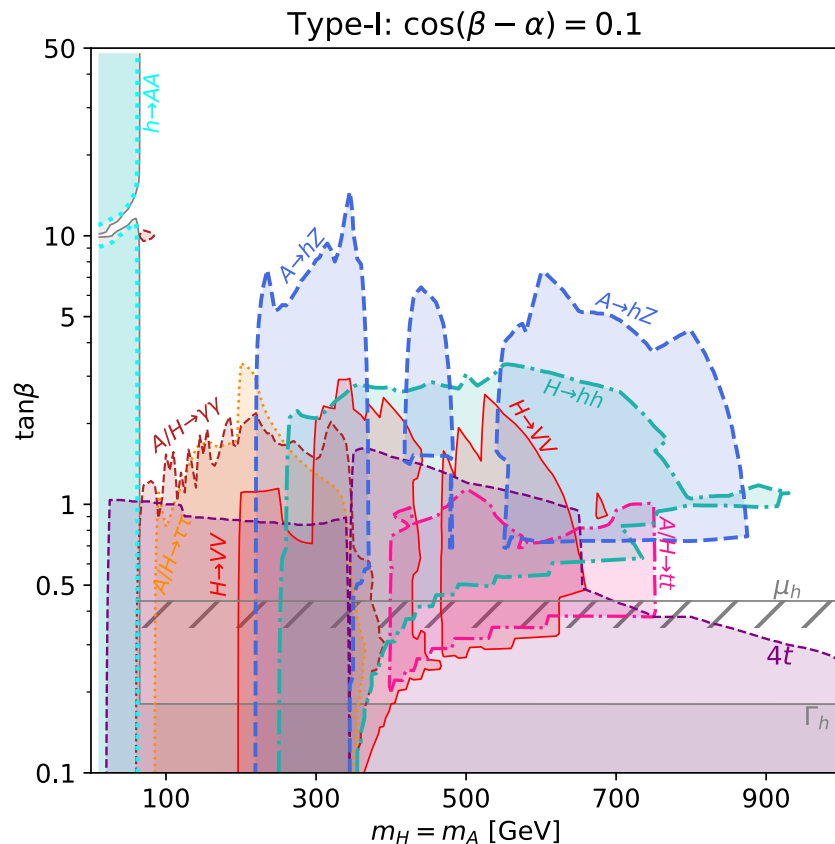
BSM $H/A, u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Degenerate Case: Type I & Type II

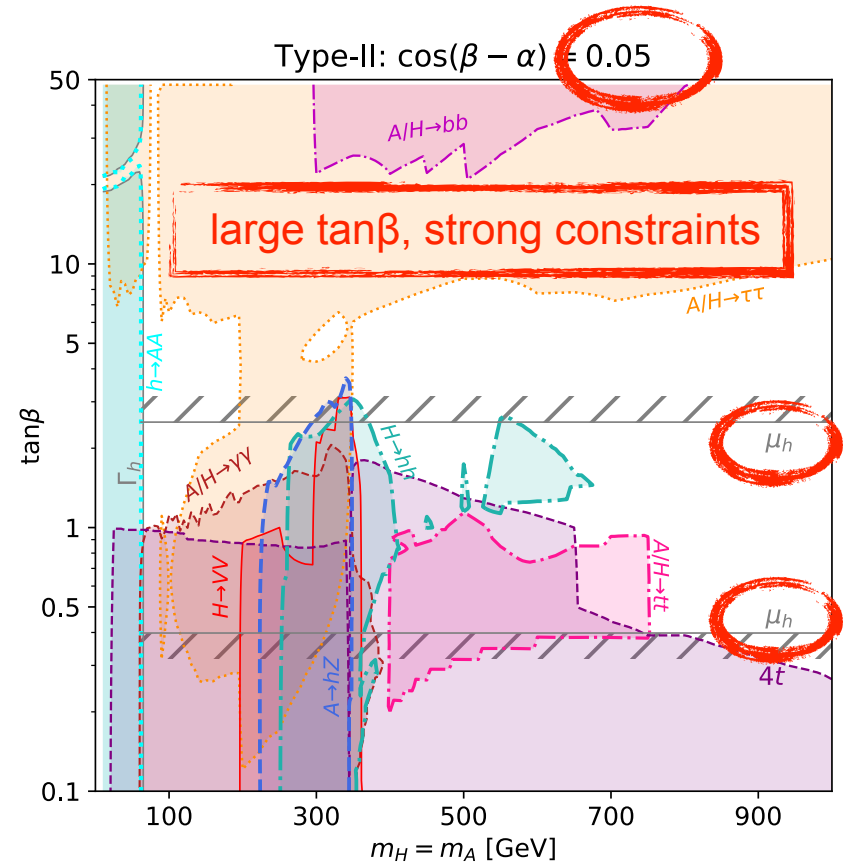
● Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan \beta$



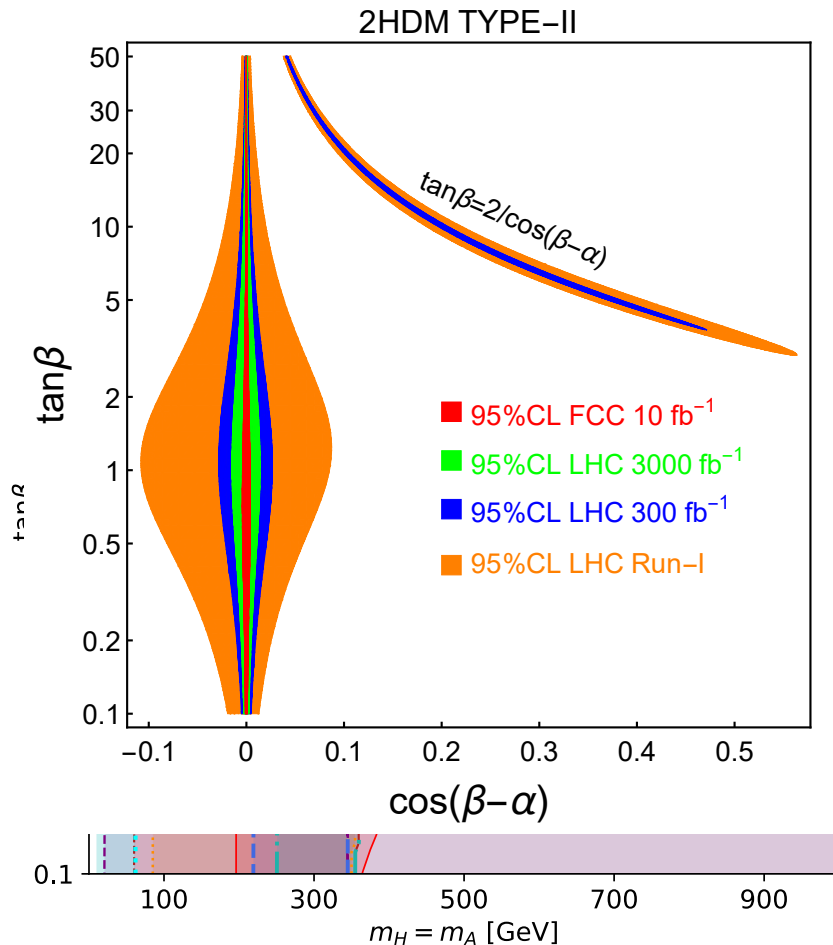
● Type II $\phi_1, u; \phi_2, d/l$

BSM H/A, u $\sim 1/\tan \beta$; d/l $\sim \tan \beta$



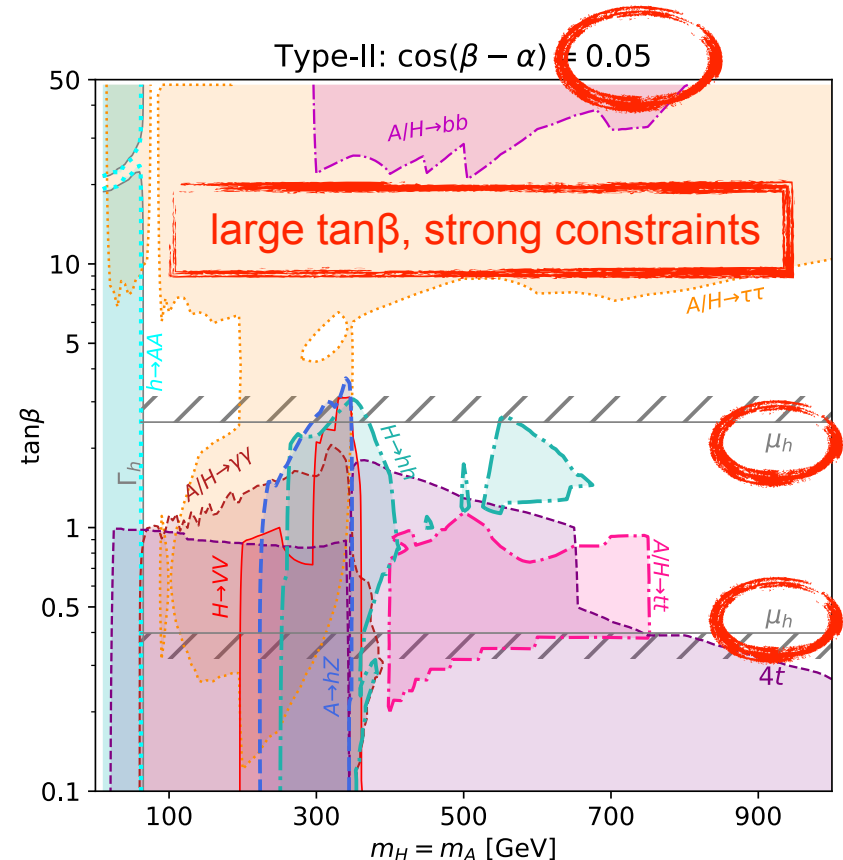
Degenerate Case: Type I & Type II

● Type I: $\phi_1, u/d/l$



● Type II $\phi_1, u; \phi_2, d/l$

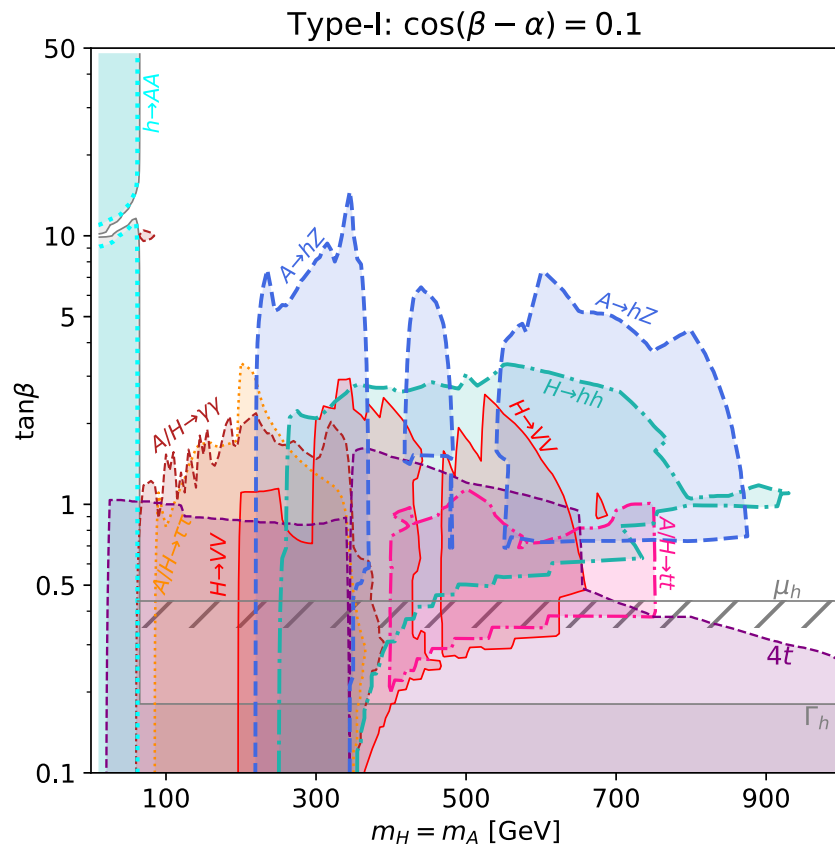
BSM $H/A, u \sim 1/\tan\beta$; $d/l \sim \tan\beta$



Degenerate Case: Type I & Type II

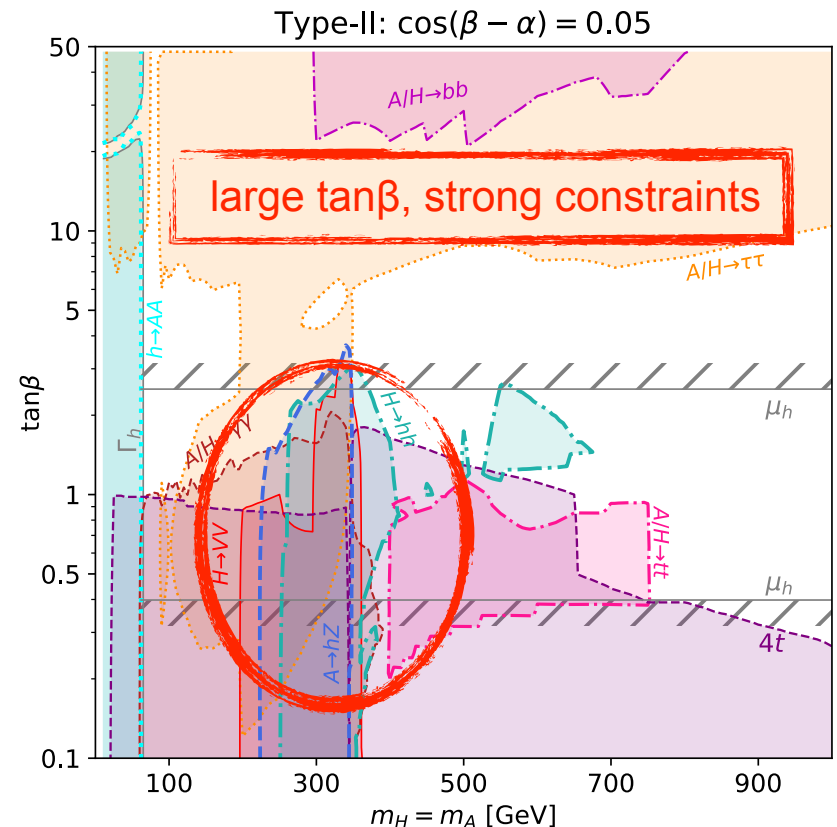
● Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan \beta$



● Type II $\phi_1, u; \phi_2, d/l$

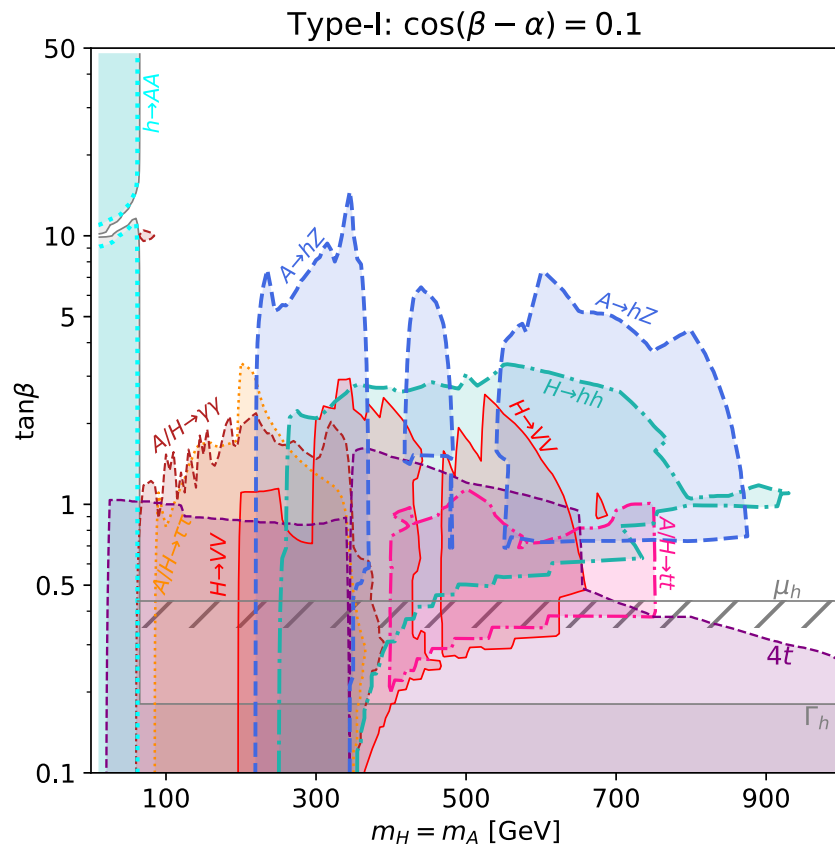
BSM $H/A, u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Degenerate Case: Type I & Type II

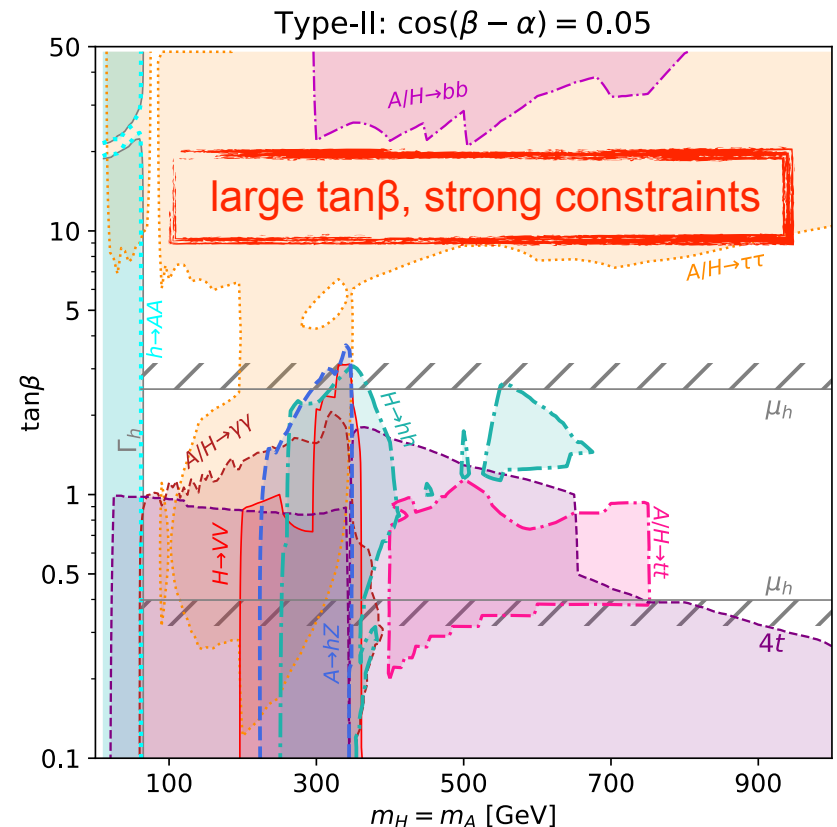
● Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan \beta$



● Type II $\phi_1, u; \phi_2, d/l$

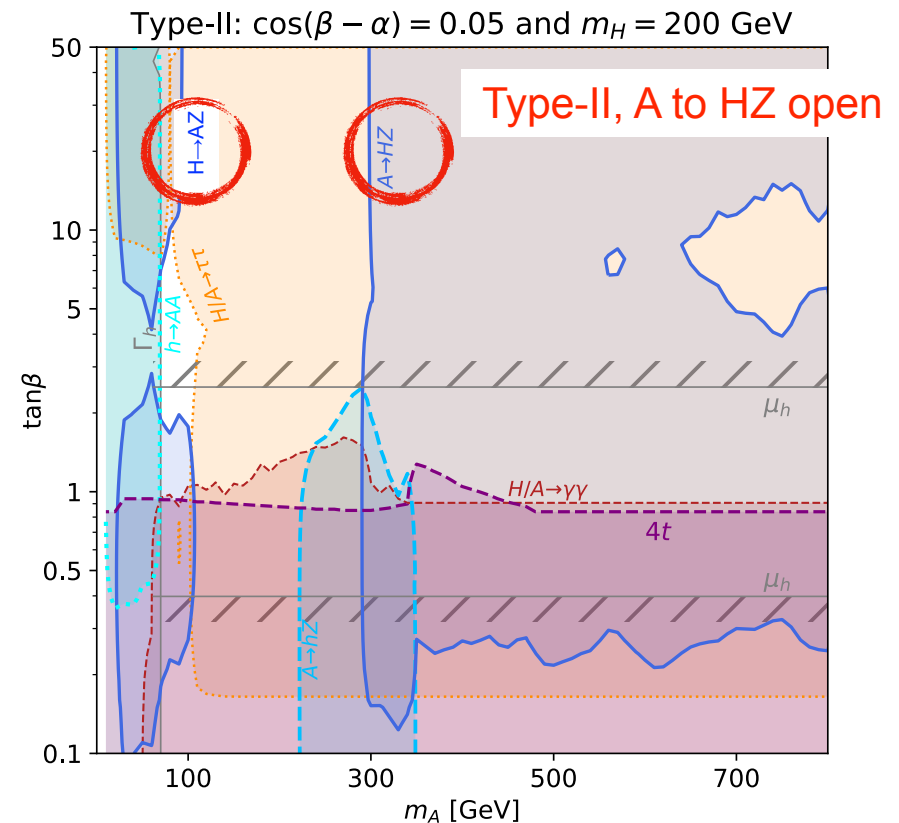
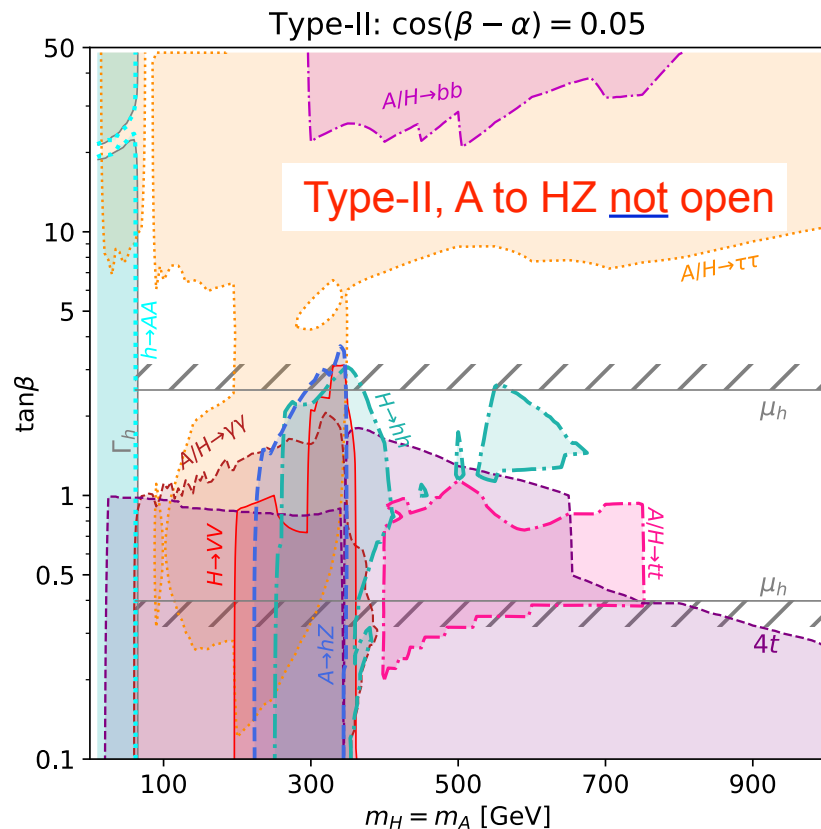
BSM $H/A, u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Non-Degenerate Case: Type II

Type II: ϕ_1 , down-type, leptons; ϕ_2 , up-type

BSM Higgs Yukawa couplings up-type: $\sim 1/\tan \beta$, down-type/lepton: $\sim \tan \beta$,

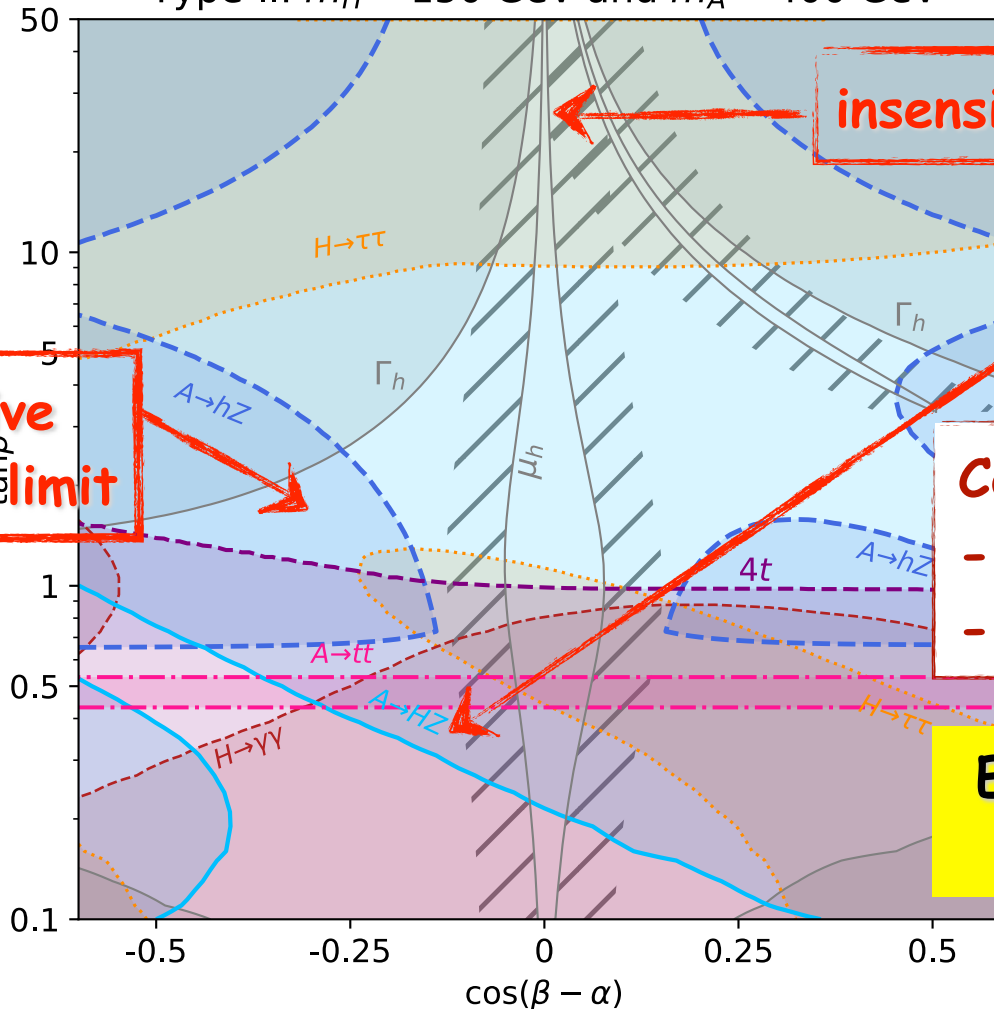


Non-Degenerate Case: Type II

● Non-degenerate: $A \rightarrow ZH$, $H \rightarrow ZA$

$\cos(\beta - \alpha)$ vs. $\tan\beta$

Type-II: $m_H = 150$ GeV and $m_A = 400$ GeV



insensitive to align limit

sensitive to align limit

insensitive to align limit

Complementarity between
- Direct and indirect
- various search channels

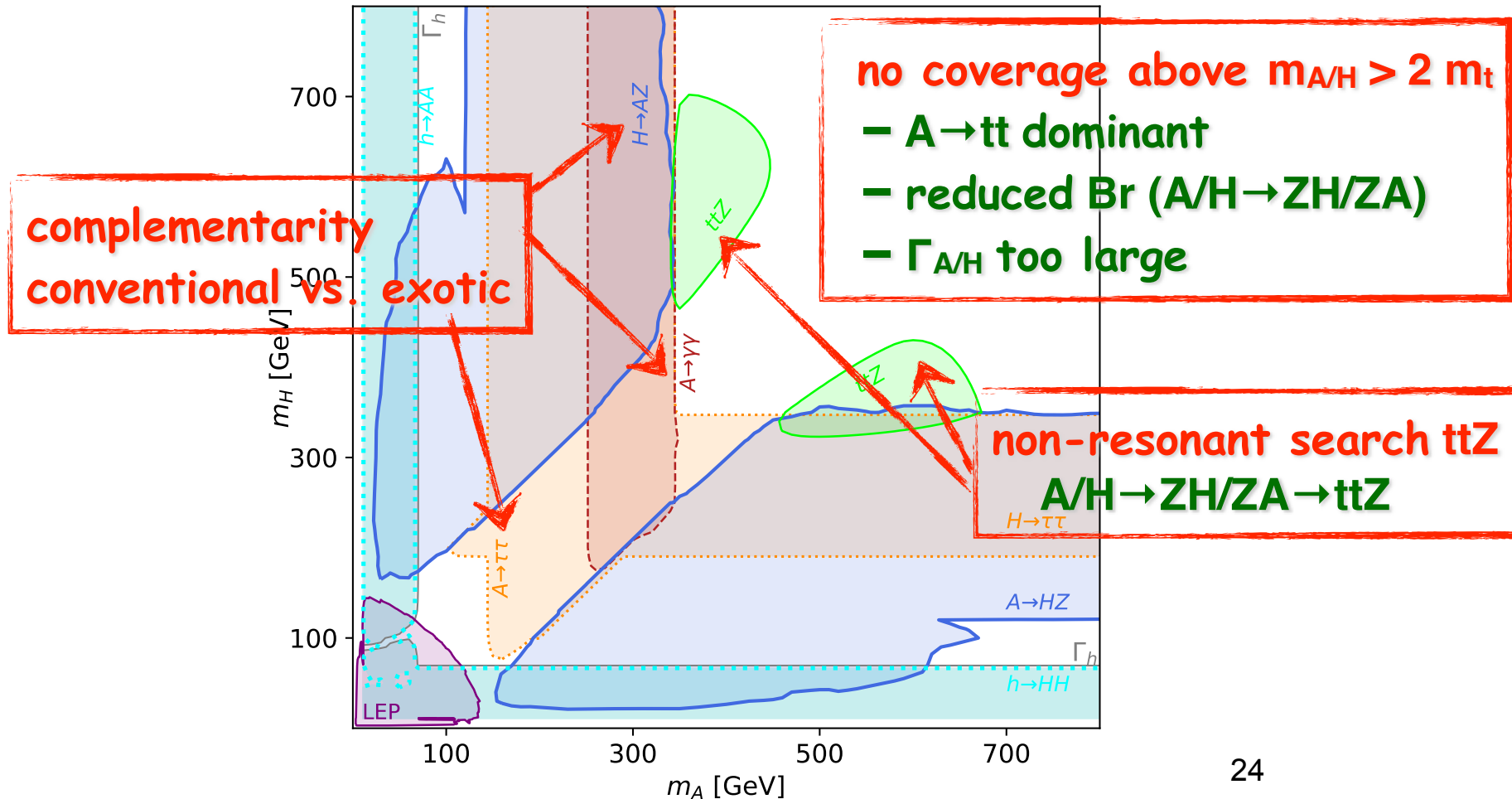
Entire parameter region covered!

Non-Degenerate Case: Type II

Non-degenerate: $A \rightarrow ZH$, $H \rightarrow ZA$

m_A vs. m_H

Type-II: $\cos(\beta - \alpha) = 0$ and $\tan\beta = 1.5$



Charged Higgs: challenge!

Conclusion

- ◉ BSM with extended Higgs sector: BSM Higgses
- ◉ Current search for BSM neutral Higgses: conventional channel
- ◉ Current search for charged Higgs: challenge
- ◉ Exotic Higgs decay modes open:
 - dominant, relax existing limits, new discovery channel
 - ⇒ $Higgs \rightarrow \text{light Higgs} + \text{gauge boson}$
 - ⇒ $Higgs \rightarrow \text{two light Higgses}$
- ◉ Exotic decay complementary to
 - ⇒ Higgs precision: insensitive to alignment limit
 - ⇒ conventional channels
 - ⇒ $A \rightarrow Zh, H \rightarrow hh, H \rightarrow VV$: vanish under the alignment limit

Conclusion

- ◎ We can already do a lot with existing data. **THANK YOU!**
- ◎ Would be nice to have updated results with more data available.
- ◎ Would be nice to add more channels
 - ➔ $H \rightarrow H^+H^-$, $H/A \rightarrow WH^\pm$
 - could be new channels for charged Higgs production/discovery
- ◎ Would be nice to map all mass region instead of a few benchmarks.
 - ➔ $m_{H^\pm}$ vs $m_{A/H}$
- ◎ Continuum search could also be useful for BSM Higgs with large width
 - ➔ ttZ , $tttt$, $ttbb$

An exciting journey ahead of us!

Charged Higgs Challenge

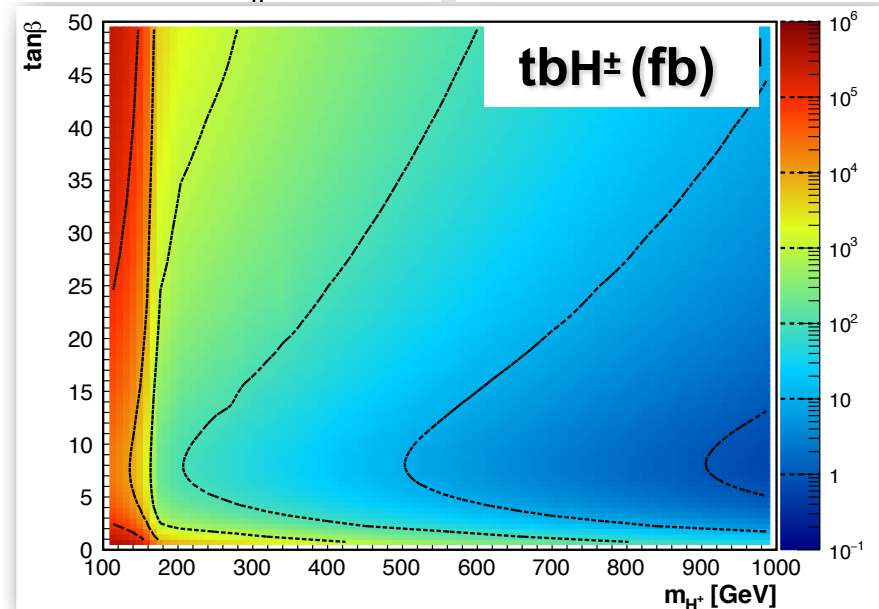
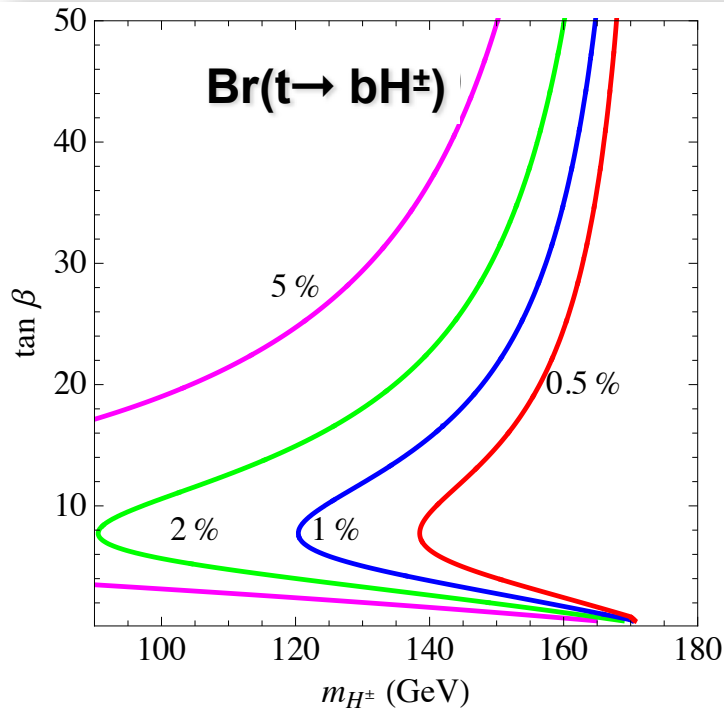
Charged Higgs is challenge for discovery

$m_{H^\pm} < m_t$:

$t\bar{t}$ production with
 $t \rightarrow bH^\pm$, $H^\pm \rightarrow \tau\nu$ or $c s$

$m_{H^\pm} > m_t$: $tbH^\pm$ production (small)

- $H^\pm \rightarrow tb$, large BG
- $H^\pm \rightarrow \tau\nu$ or $c s$, suppressed Br.



Charged Higgs

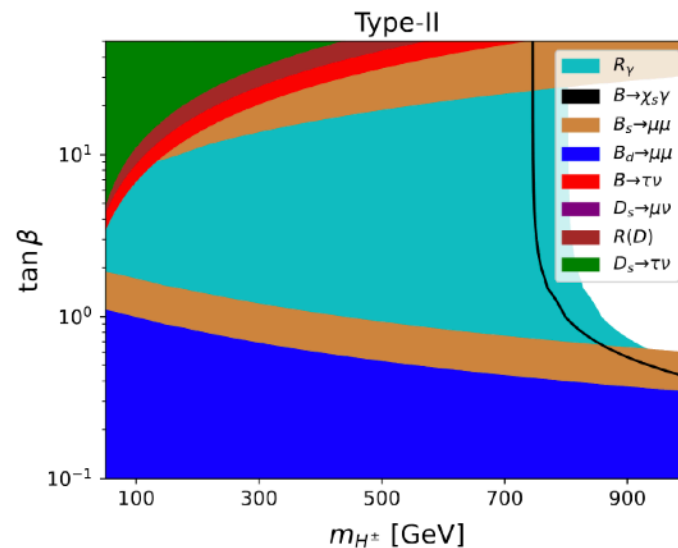
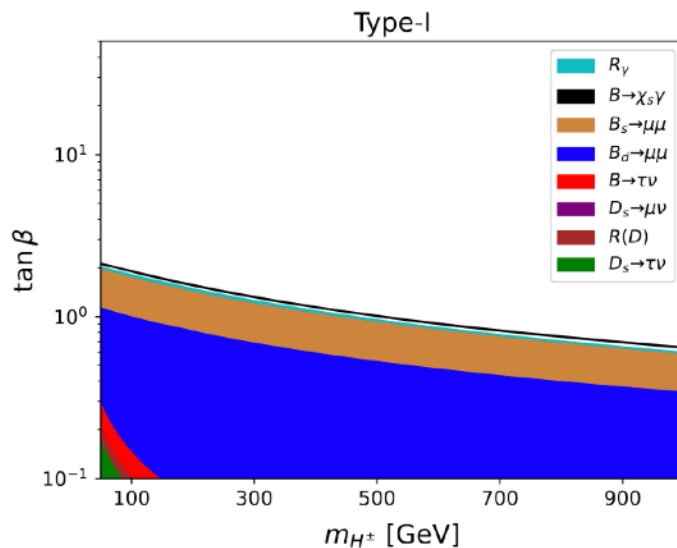
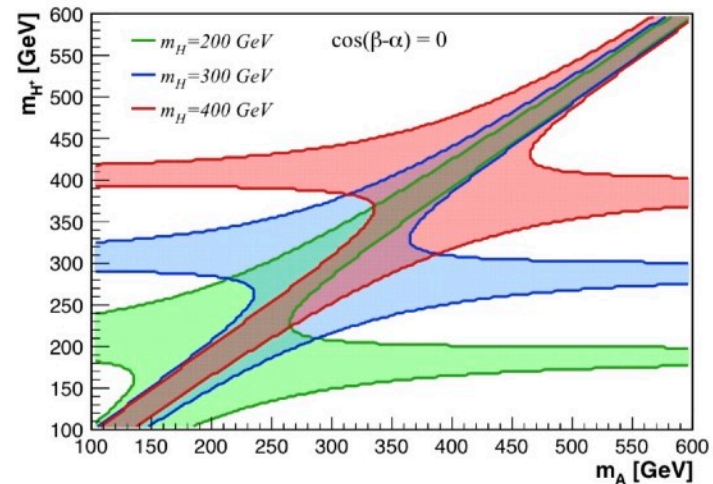
- EW precision constraints

$$m_{Hpm} \sim m_H, m_A, m_h$$

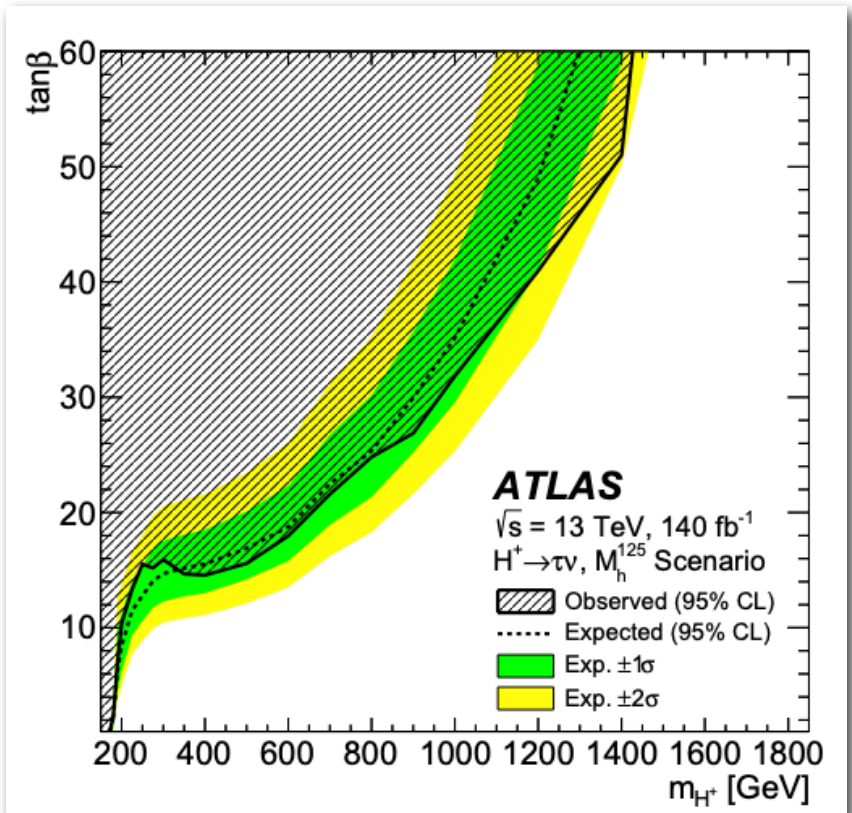
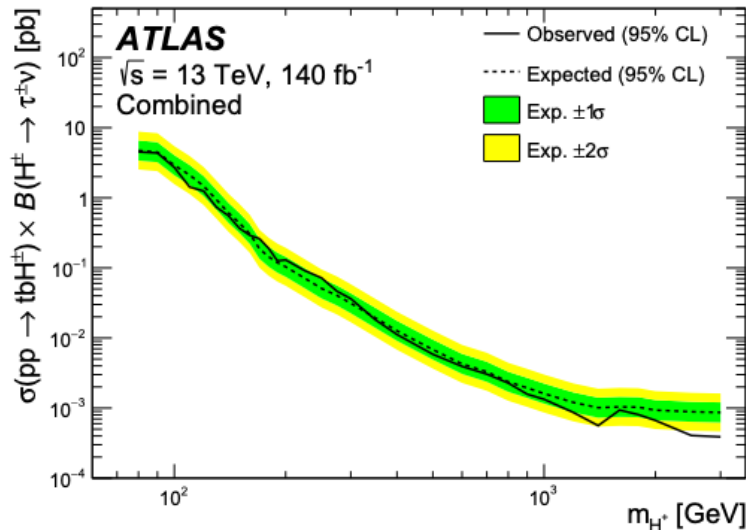
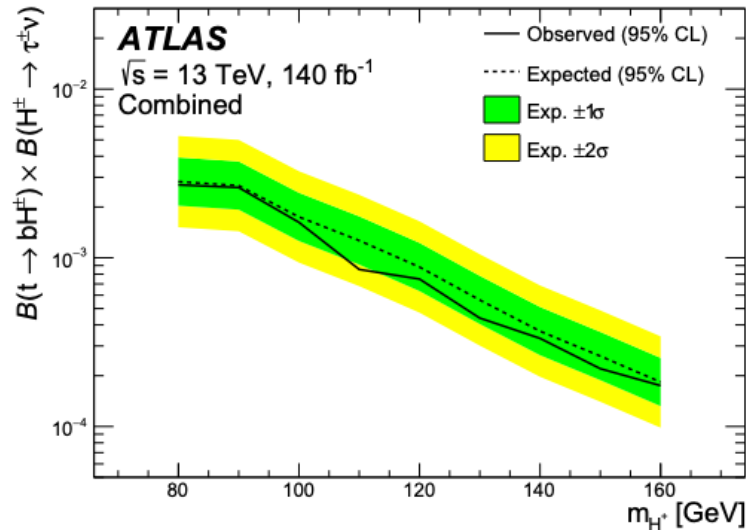
- direct searches

$$H^\pm \rightarrow cs, cb, \tau\nu, tb$$

- flavor constraints

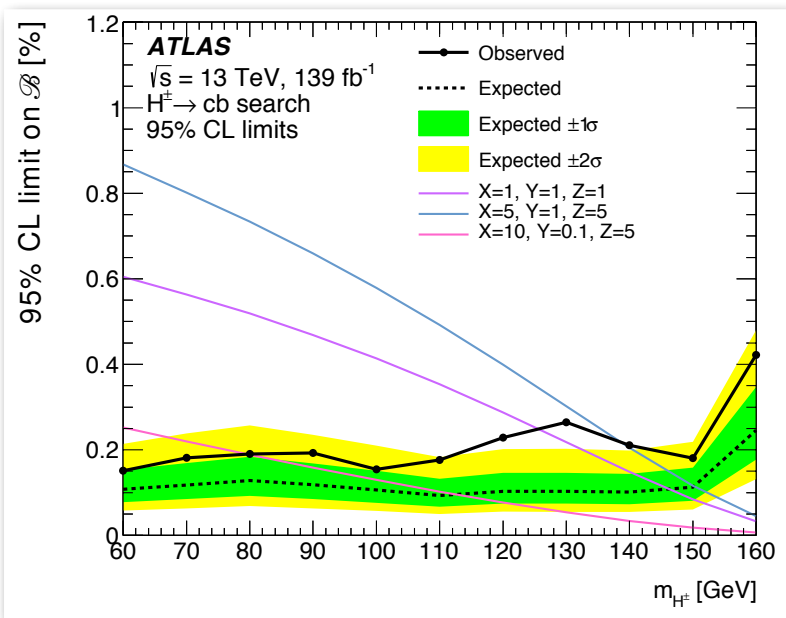
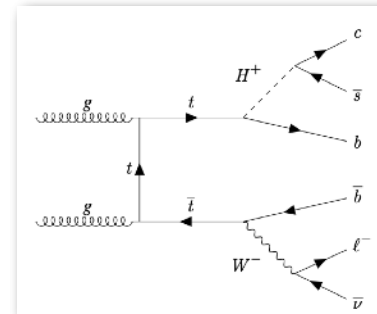
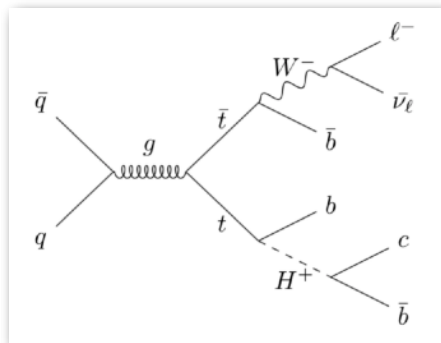


$$H^\pm \rightarrow \tau\nu$$

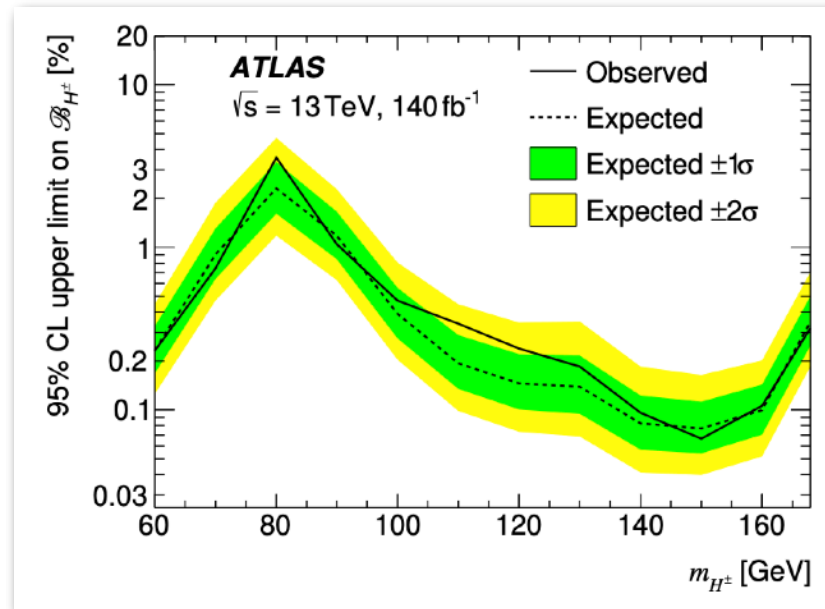


ATLAS, 2412.17584

Light $H^\pm \rightarrow cs, cb$

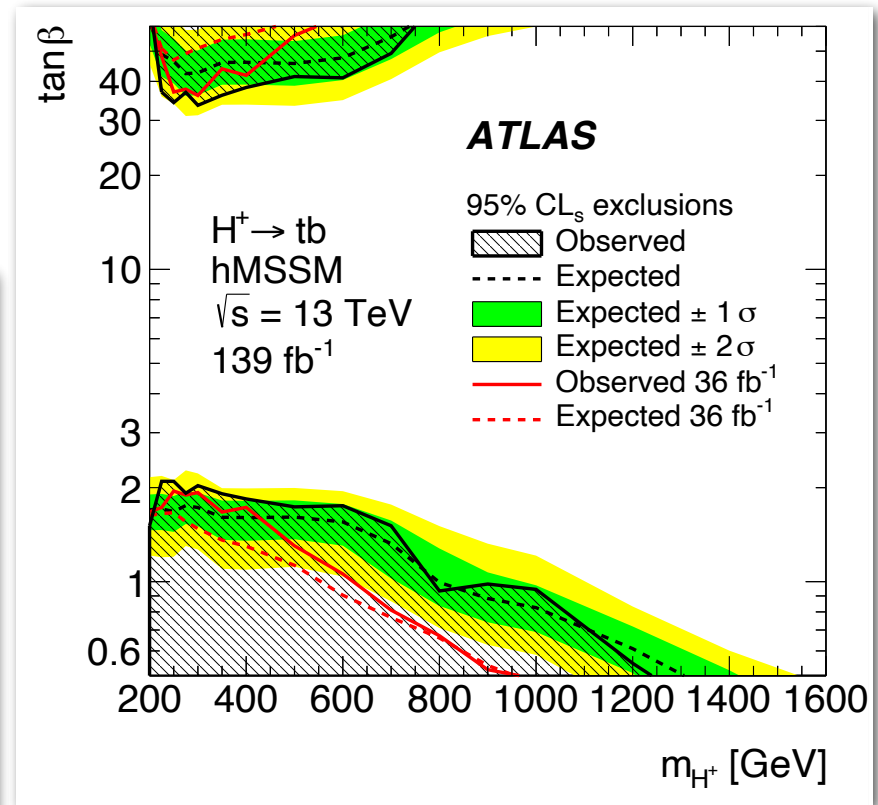
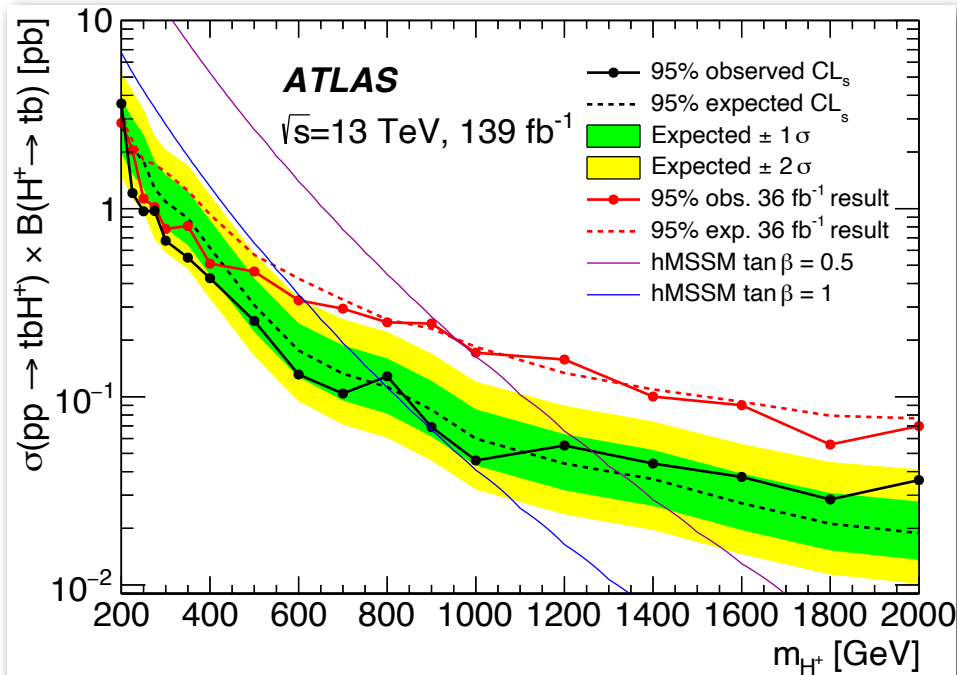
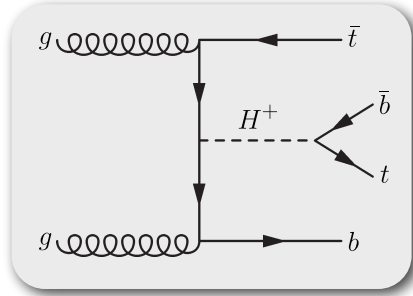


ATLAS, 2302.11739, JHEP 09 (2023) 004



ATLAS 2407.10096, EPJC 85 (2025) 153

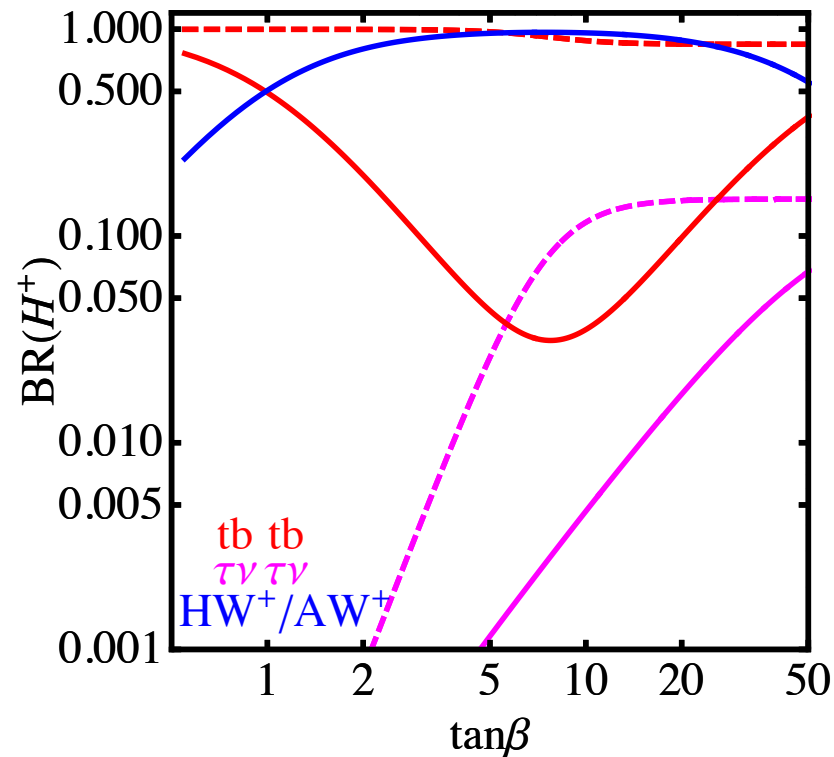
Heavy $H^\pm \rightarrow tb$



ATLAS, 2102.10076 JHEP 06 (2021) 145

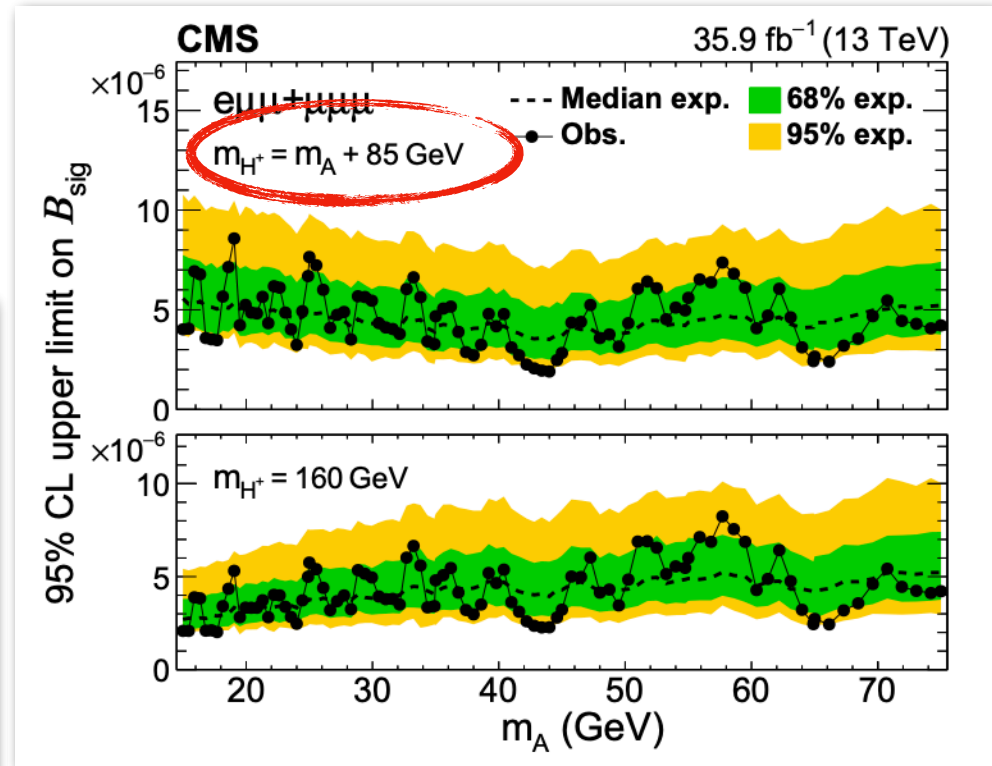
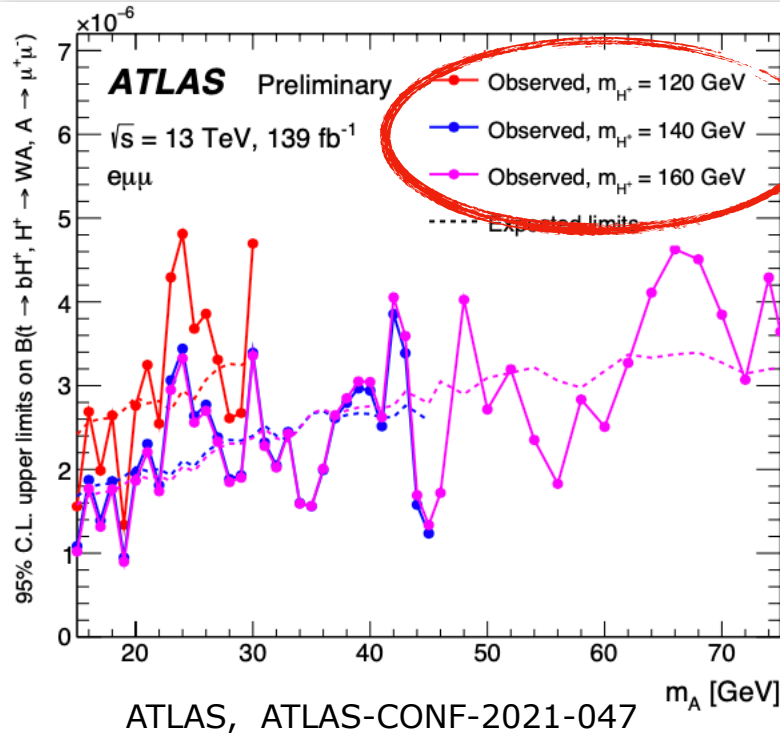
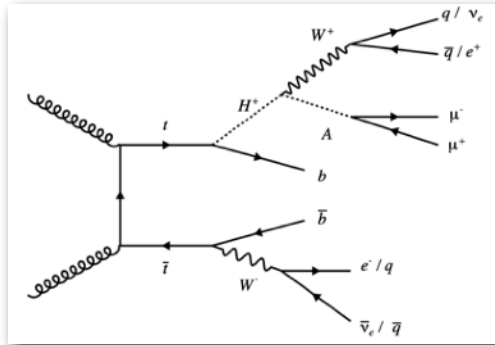
Charged Higgs Challenge

- New decay mode for $H^\pm$: $H^\pm \rightarrow AW/HW$



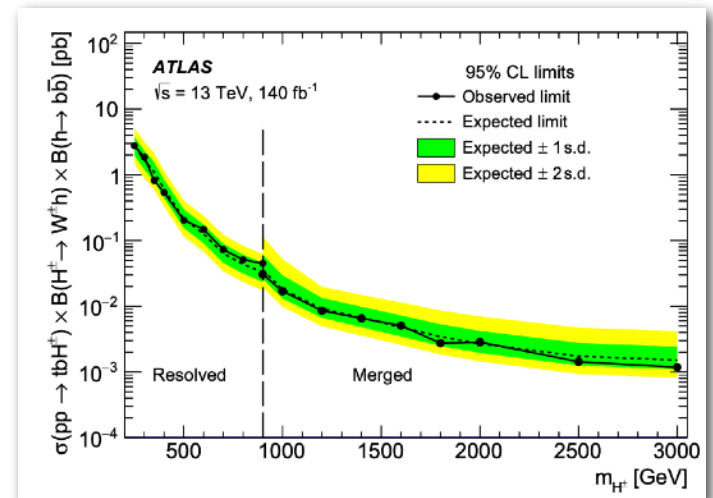
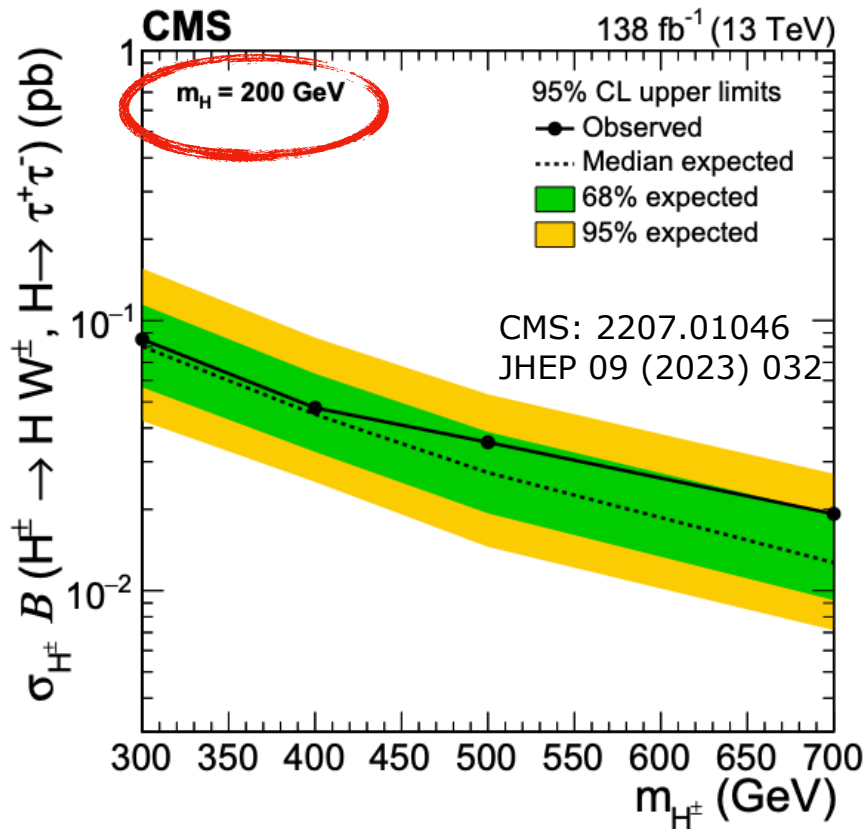
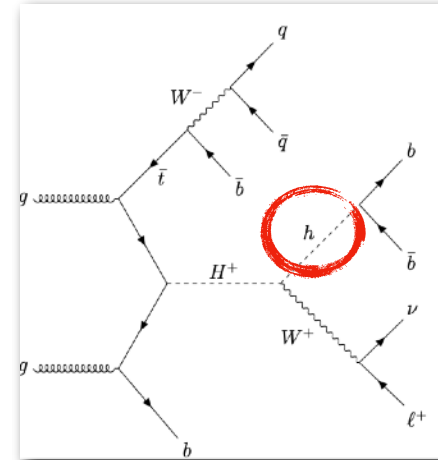
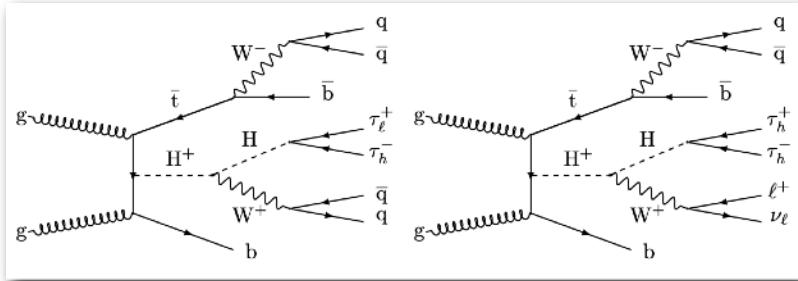
500 GeV parent particle
200 GeV daughter particle

Light $H^\pm \rightarrow AW/HW$



CMS, 1905.07453, PRL 123, 131802 (2019)

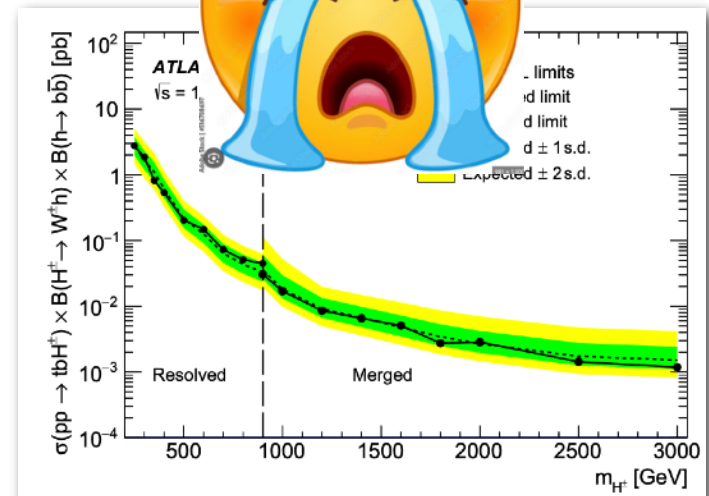
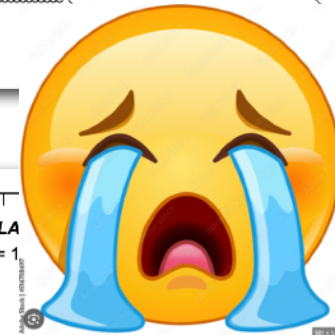
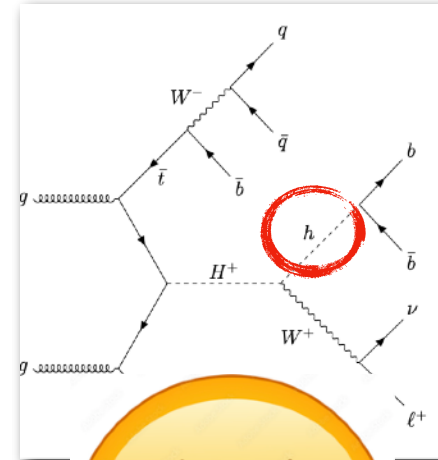
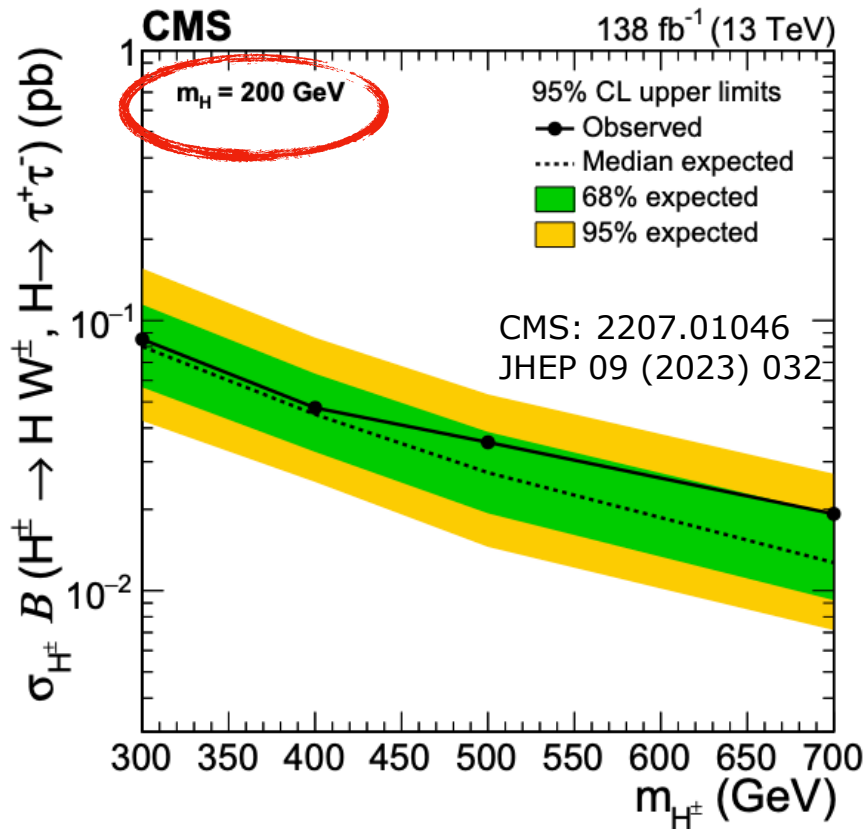
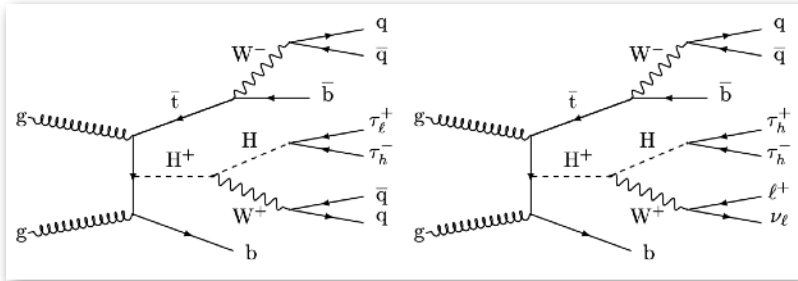
Heavy $H^\pm \rightarrow AW/HW$



ATLAS: 2411.03969

35

Heavy $H^\pm \rightarrow AW/HW$



ATLAS: 2411.03969

35

Complementarity

Channels

Charged scalars

- theoretical constraints

vacuum stability/Unitarity/perturbativity/... $m_{12}^2 = m_H^2 \sin\beta \cos\beta$

- H_{pm} width measurements ($\Gamma_{H_{\text{pm}}}$)

- Conventional channels: $\tau\nu$, cs , cb , tb

- Exotic decay of BSM sector: $H^\pm \rightarrow AW/HW/hW$

- LEP searches: $e^+e^- \rightarrow Z \rightarrow H^+H^-$

- SM non-resonant processes: $ttbb$, constrain $tbH^\pm(>tb)$

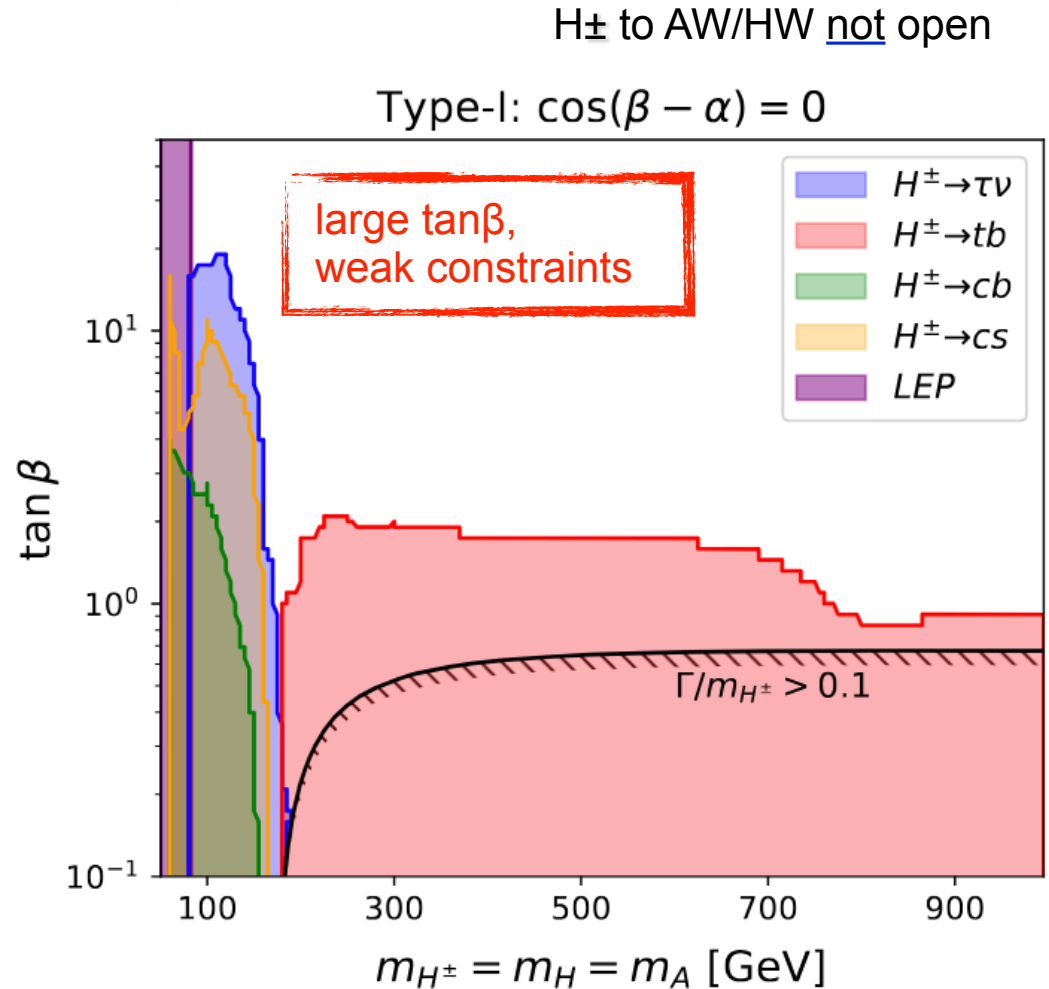
involve fiducial phase space with nontrivial cuts.

Need detail collide analyses to reinterpret

- Flavor

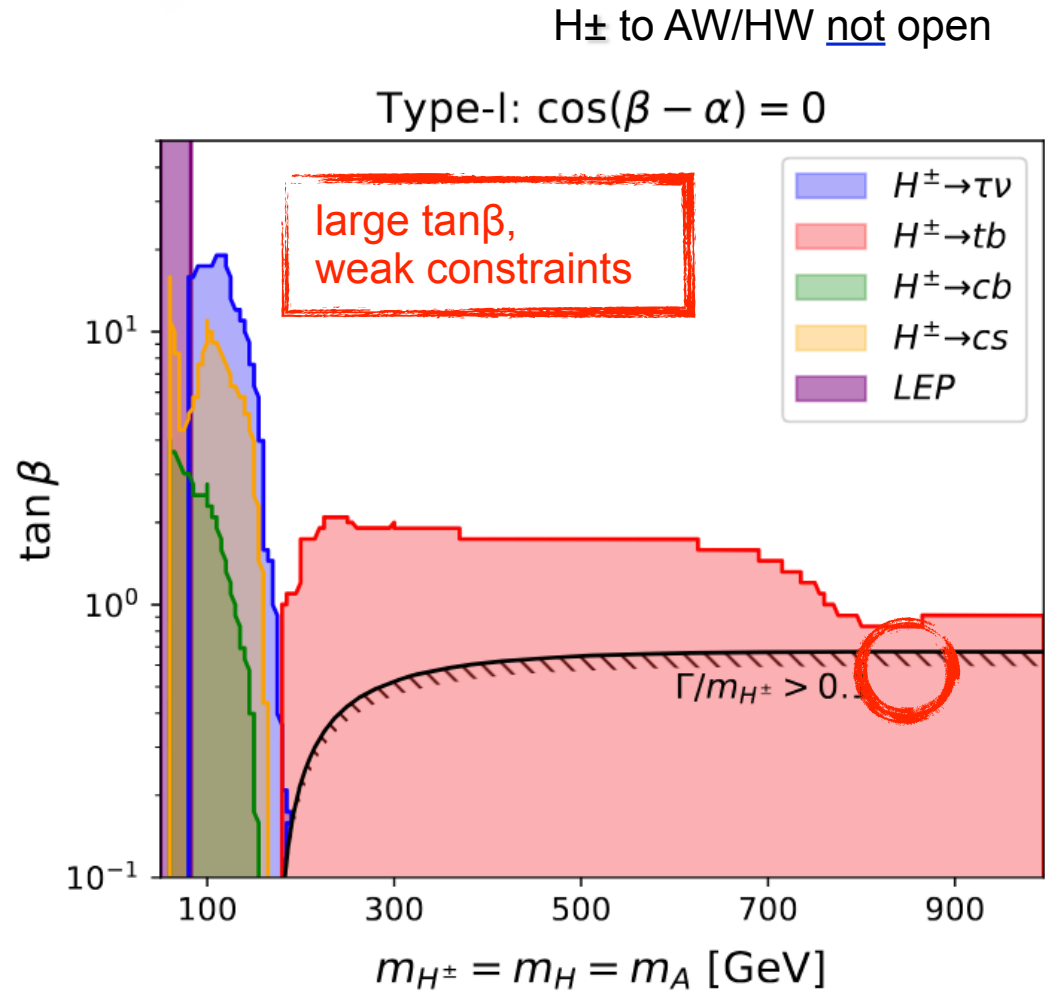
Degenerate Case: Type I

- **degenerate:** $m_{H^\pm} = m_H = m_A$
no BSM sector exotic decay
- **Type I:** $\phi_2, u/d/l$
BSM Higgs Yukawa $\sim 1/\tan \beta$



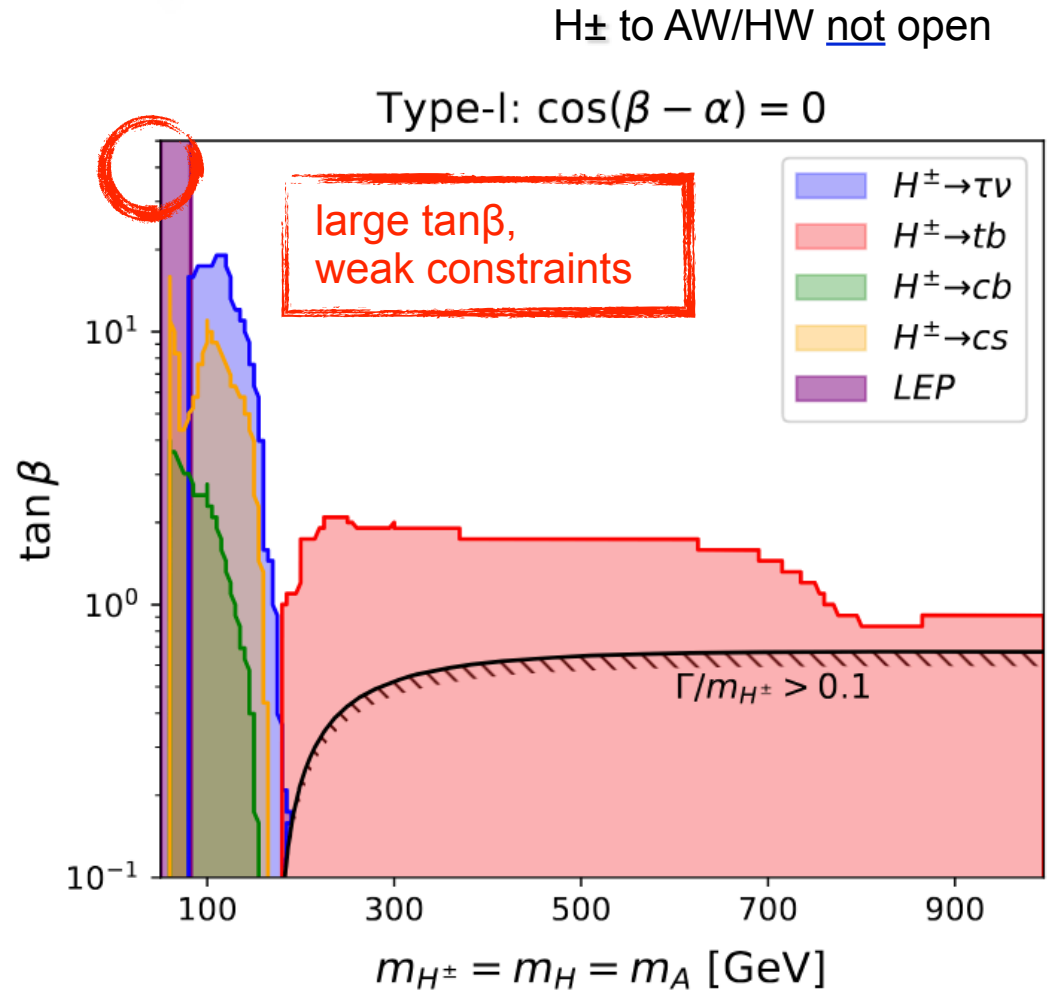
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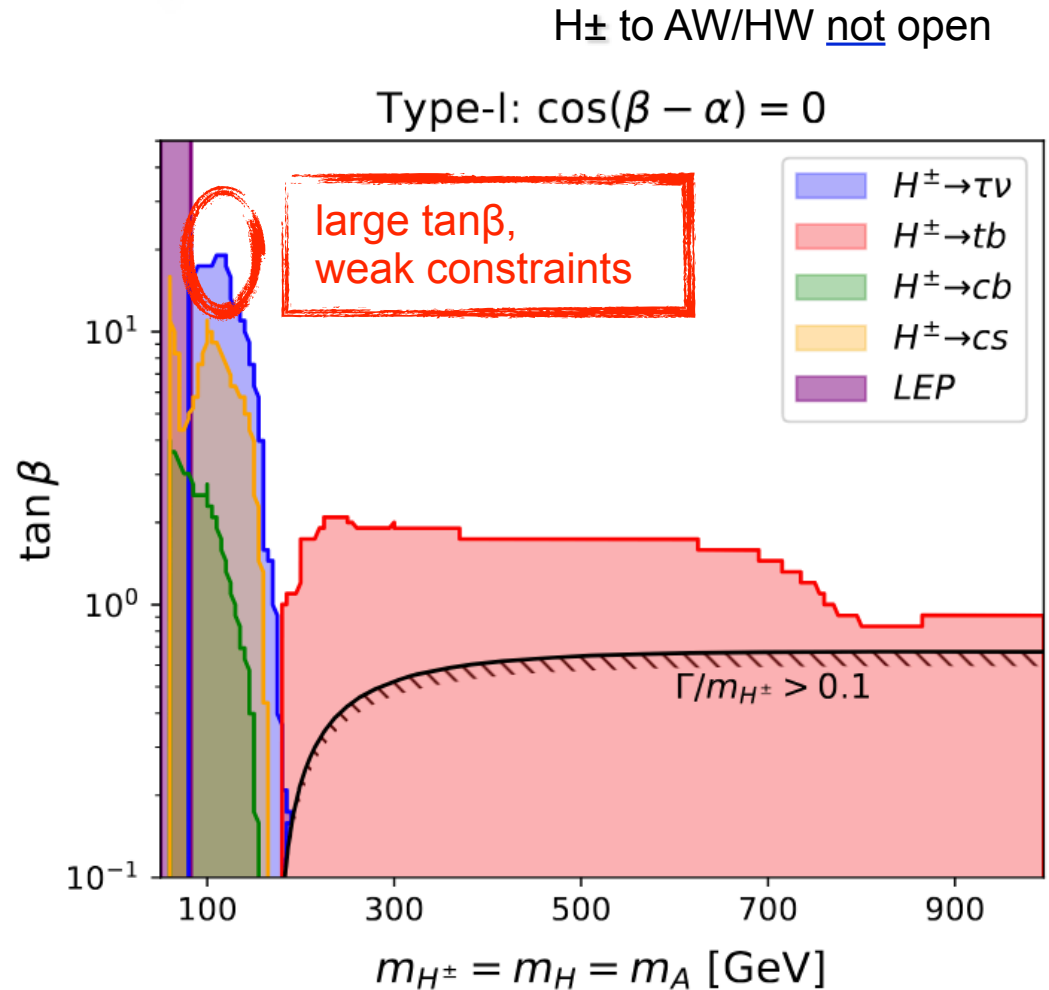
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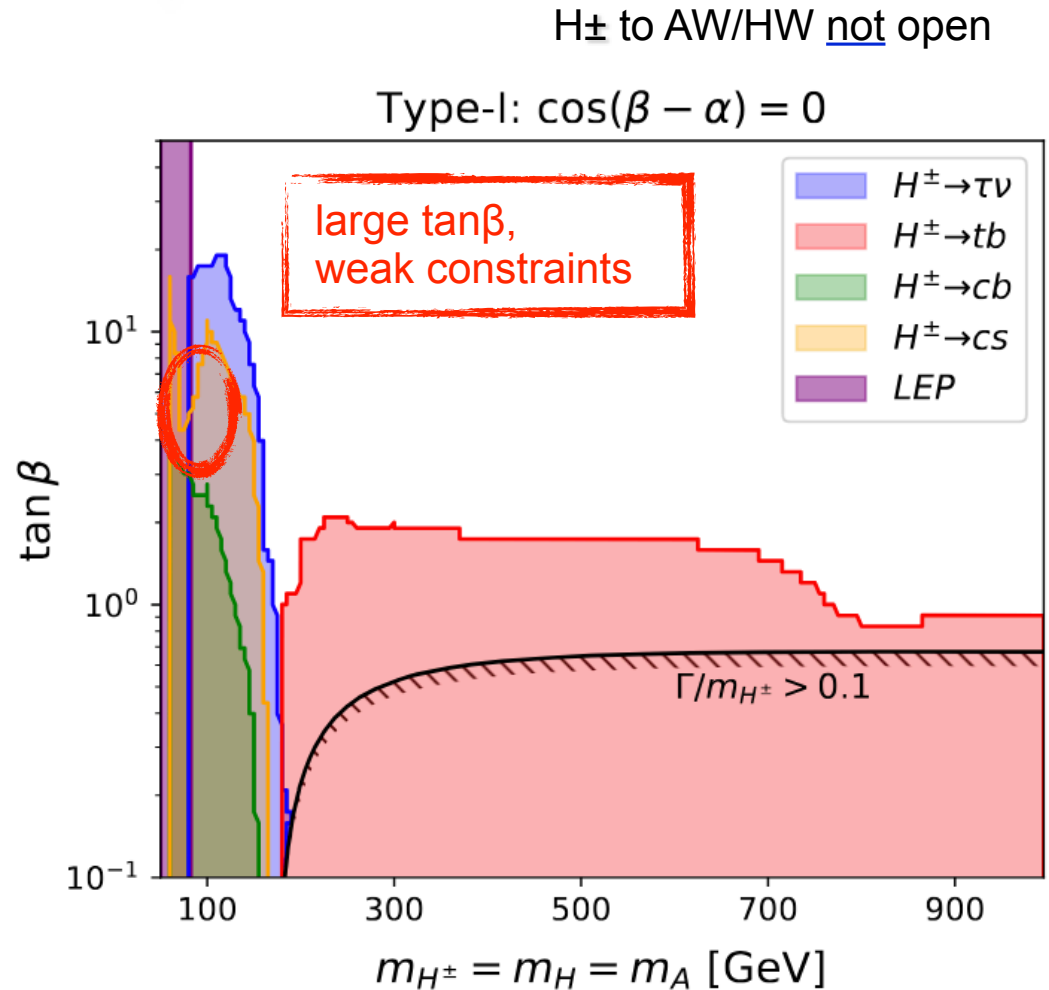
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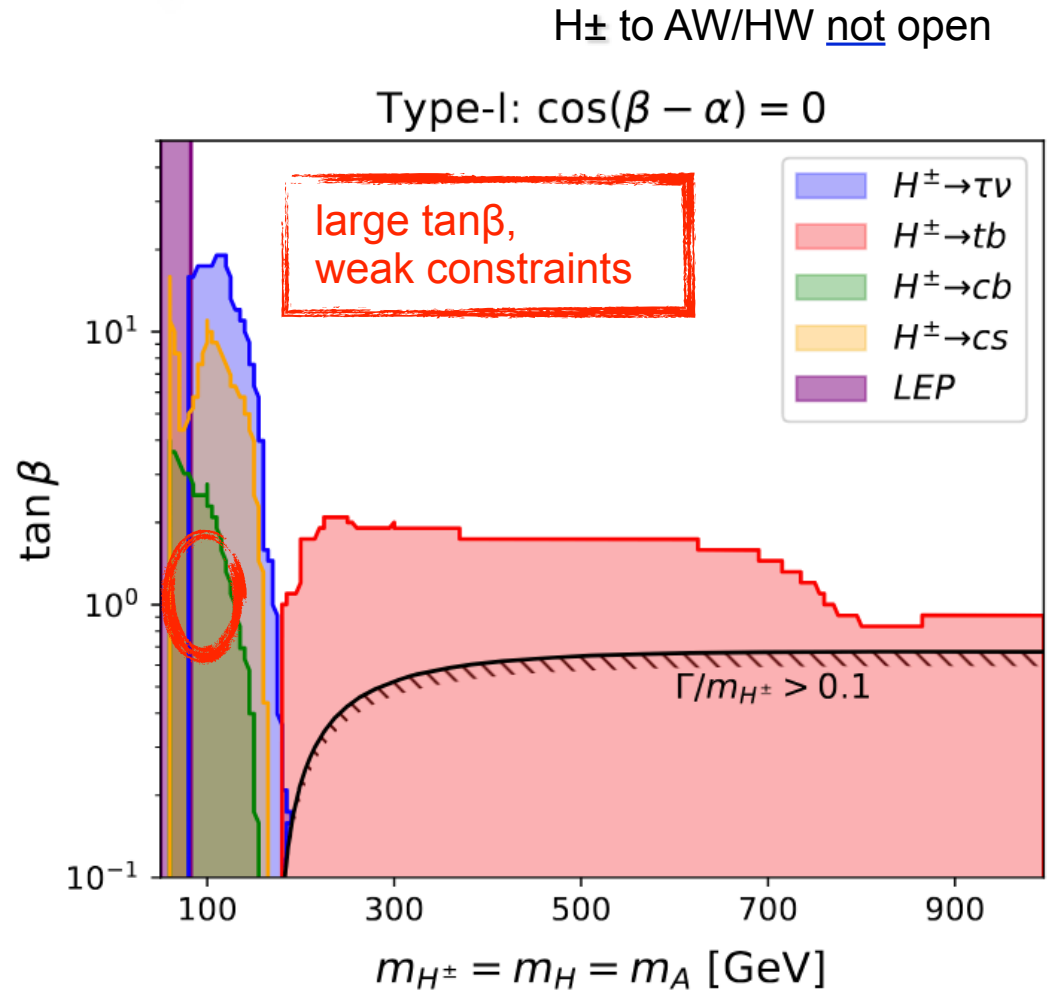
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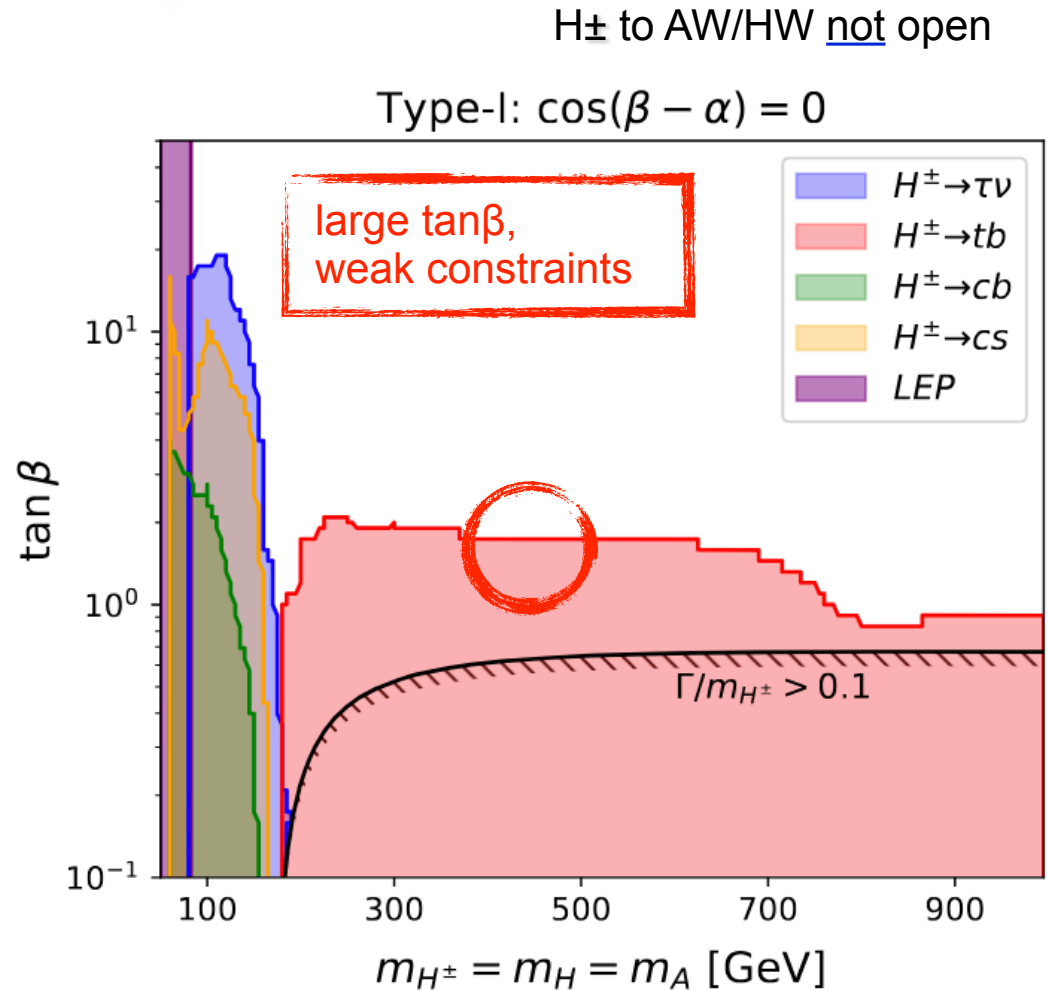
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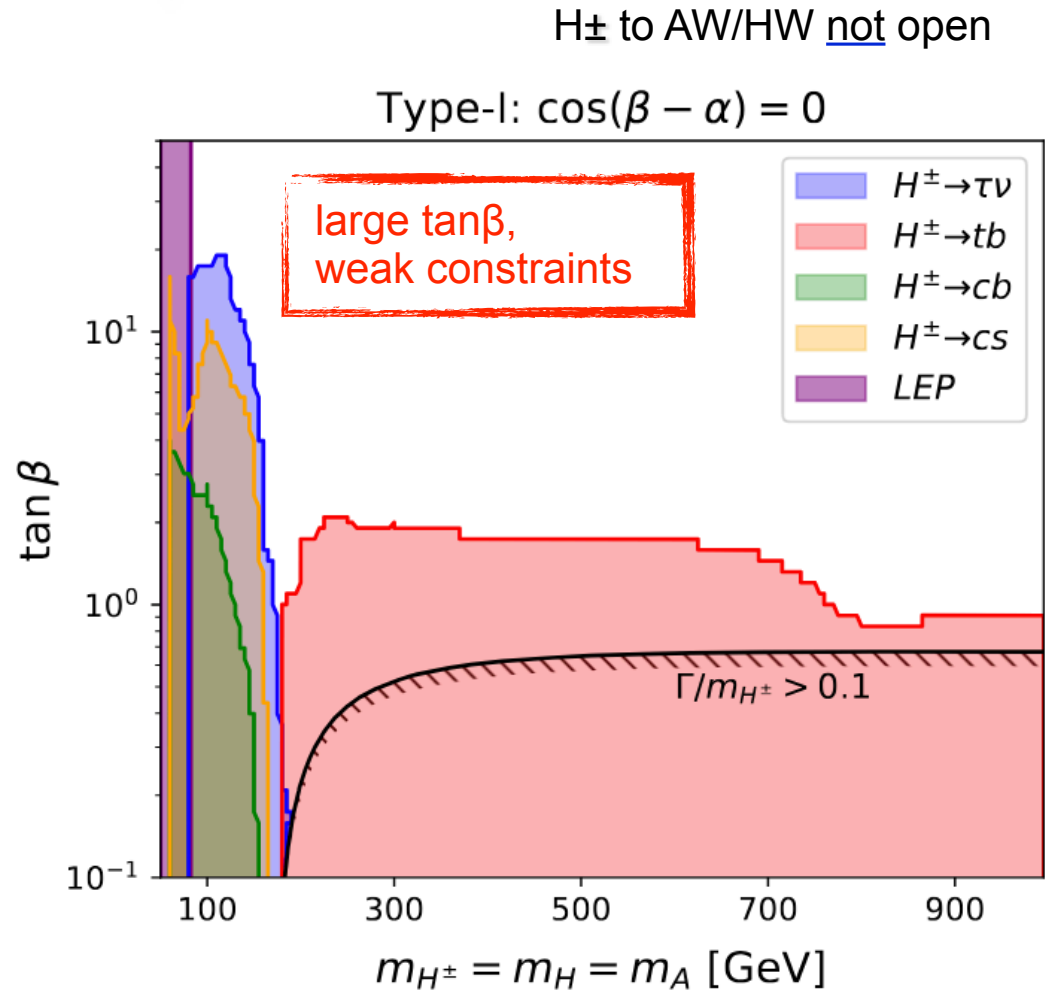
Degenerate Case: Type I

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Degenerate Case: Type I

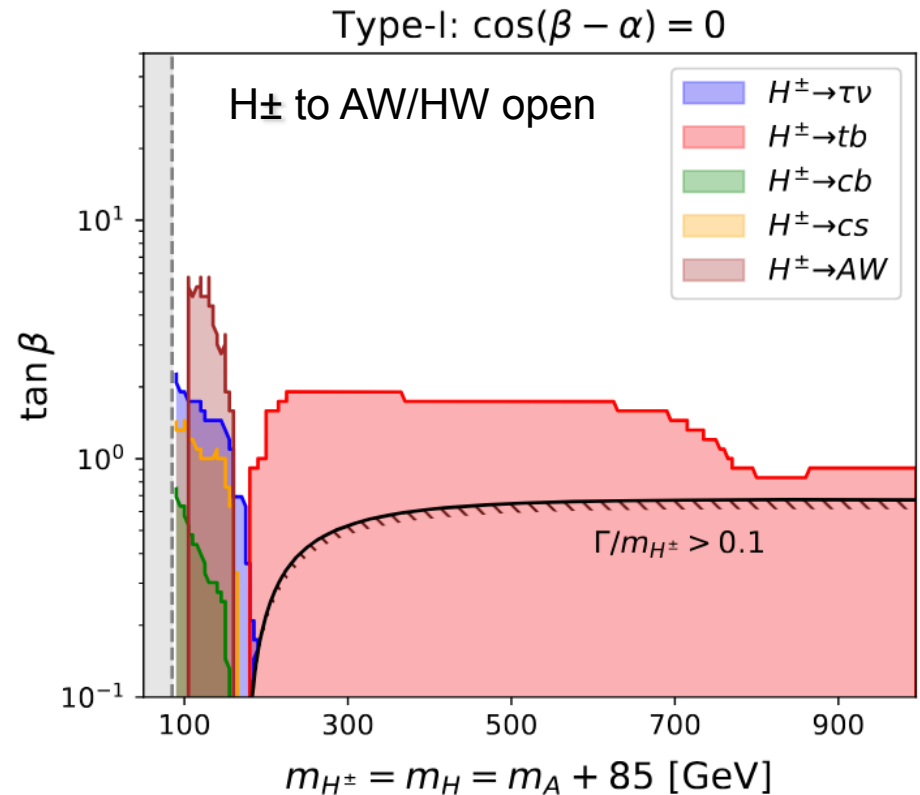
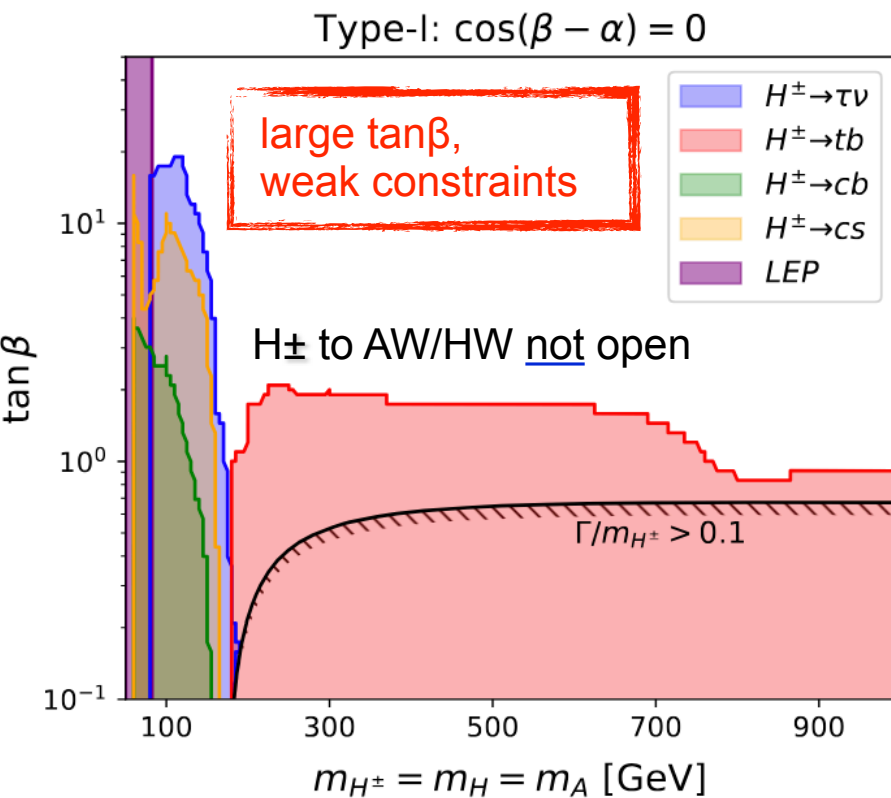
- **degenerate:** $m_{H^\pm} = m_H = m_A$
no BSM sector exotic decay
- **Type I:** $\phi_2, u/d/l$
BSM Higgs Yukawa $\sim 1/\tan \beta$



Non-degenerate Case: Type I

● Type I: ϕ_1 , u/d/l

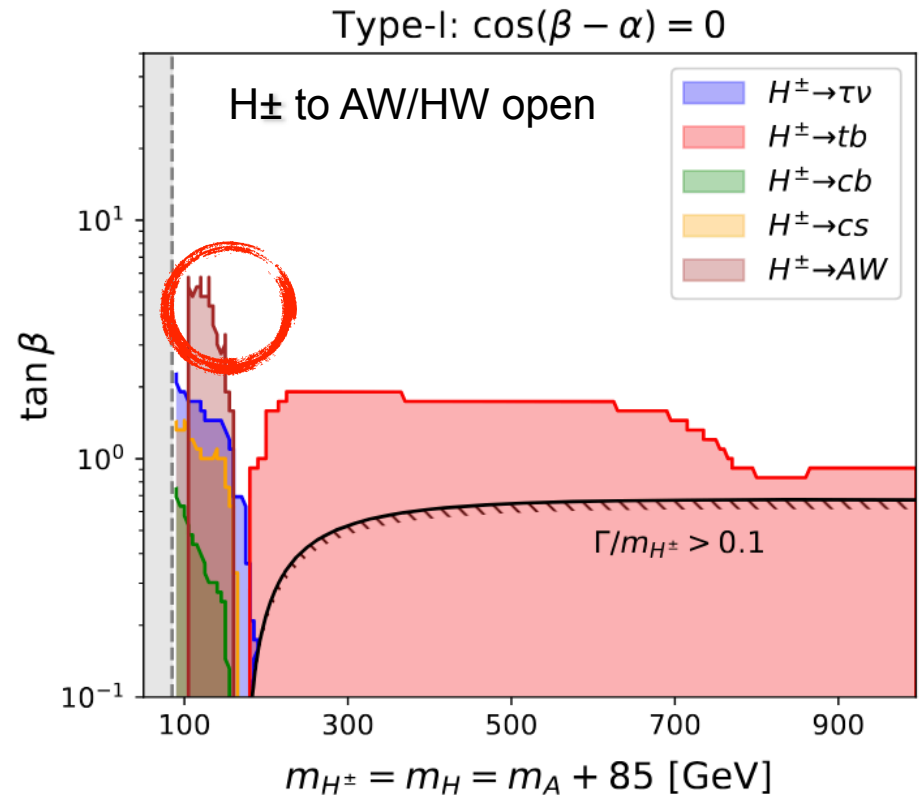
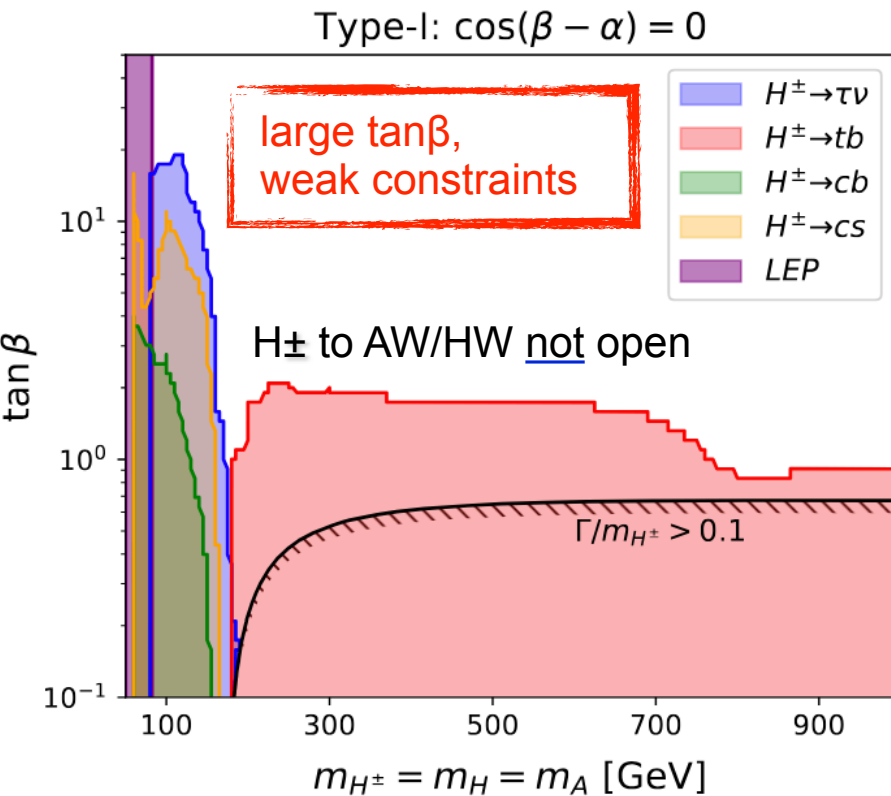
BSM Higgs Yukawa $\sim 1/\tan\beta$



Non-degenerate Case: Type I

• Type I: ϕ_1 , u/d/l

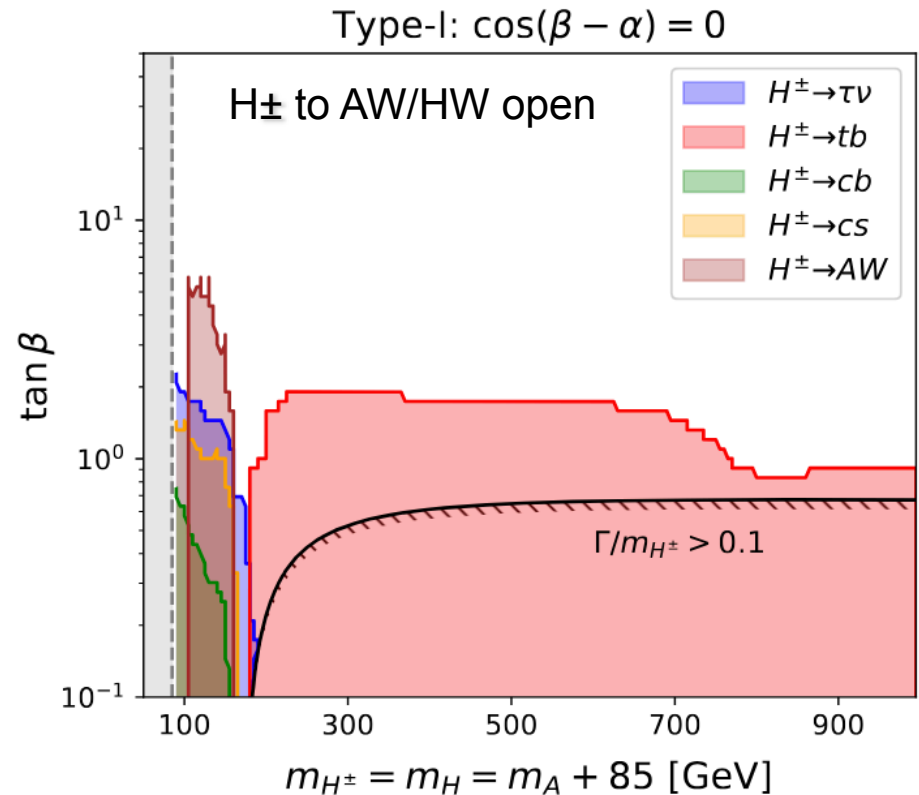
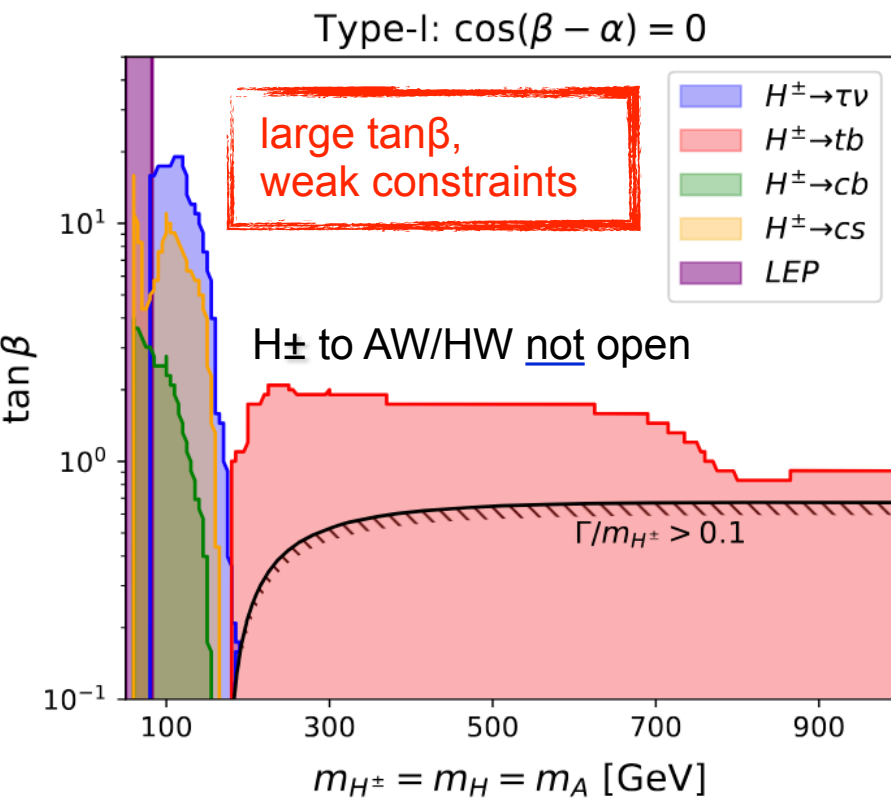
BSM Higgs Yukawa $\sim 1/\tan\beta$



Non-degenerate Case: Type I

● Type I: ϕ_1 , u/d/l

BSM Higgs Yukawa $\sim 1/\tan\beta$

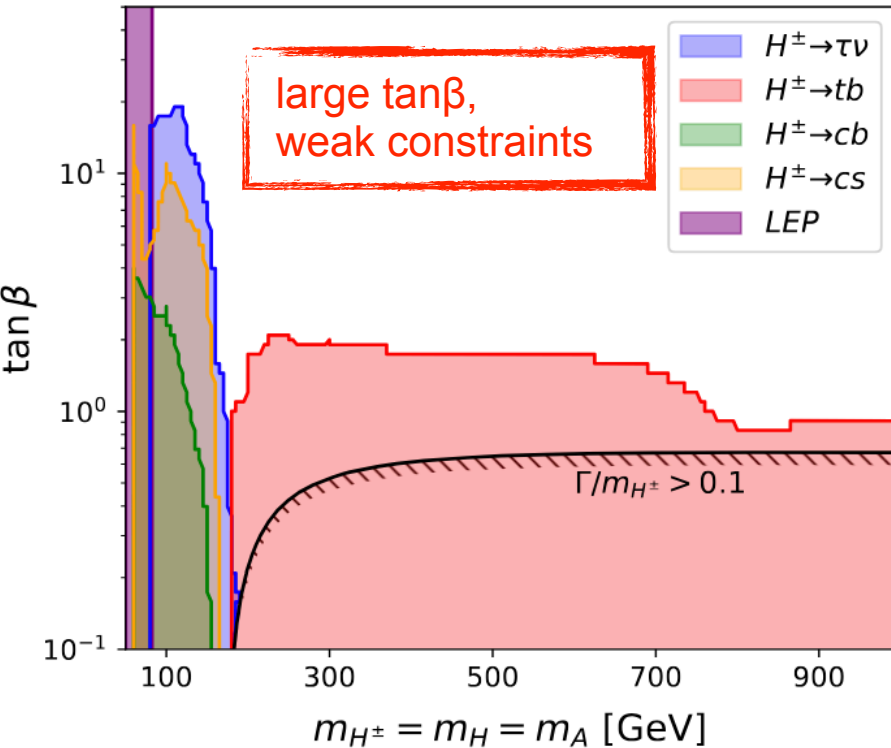


Degenerate Case: Type I/II

• Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan\beta$

Type-I: $\cos(\beta - \alpha) = 0$

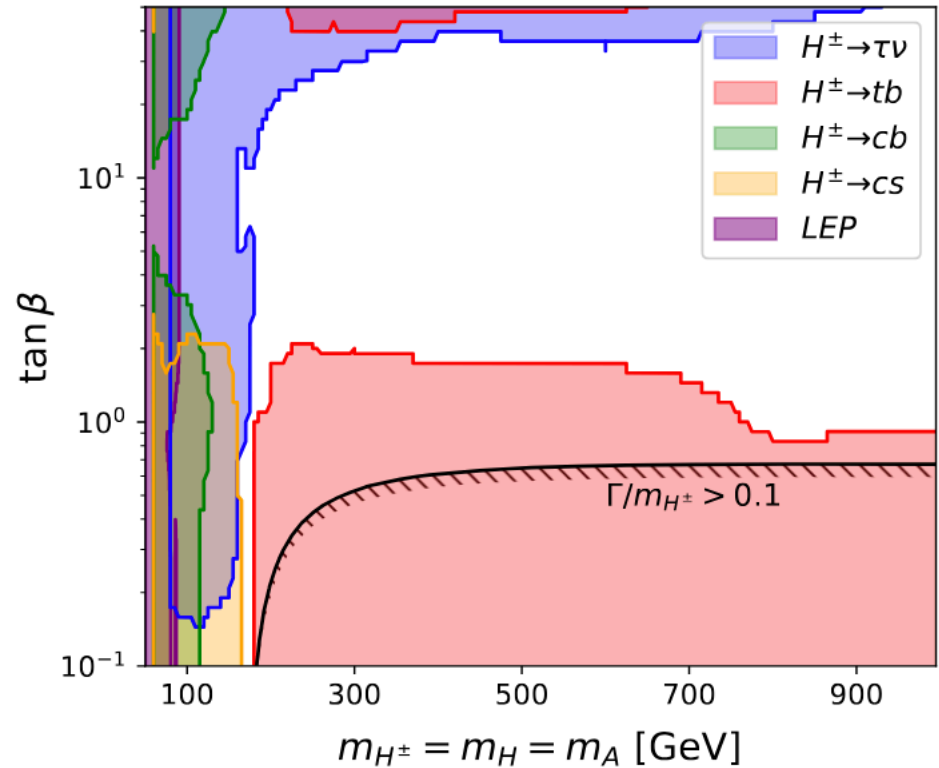


$H^\pm$ to AW/HW not open

• Type II $\phi_1, u; \phi_2, d/l$

BSM $u \sim 1/\tan\beta$; $d/l \sim \tan\beta$

Type-II: $\cos(\beta - \alpha) = 0$

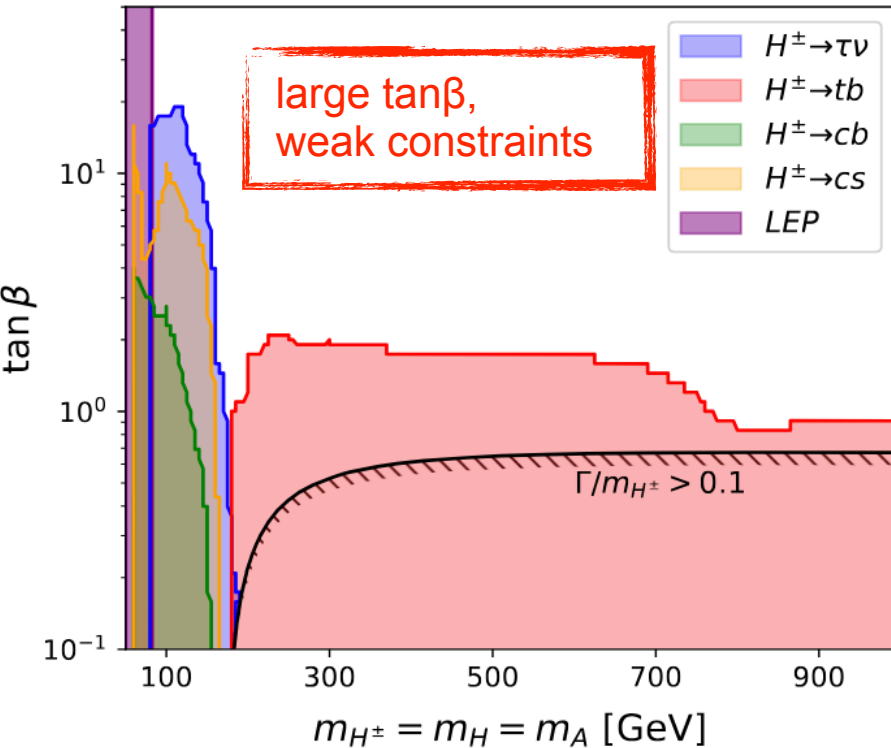


Degenerate Case: Type I/II

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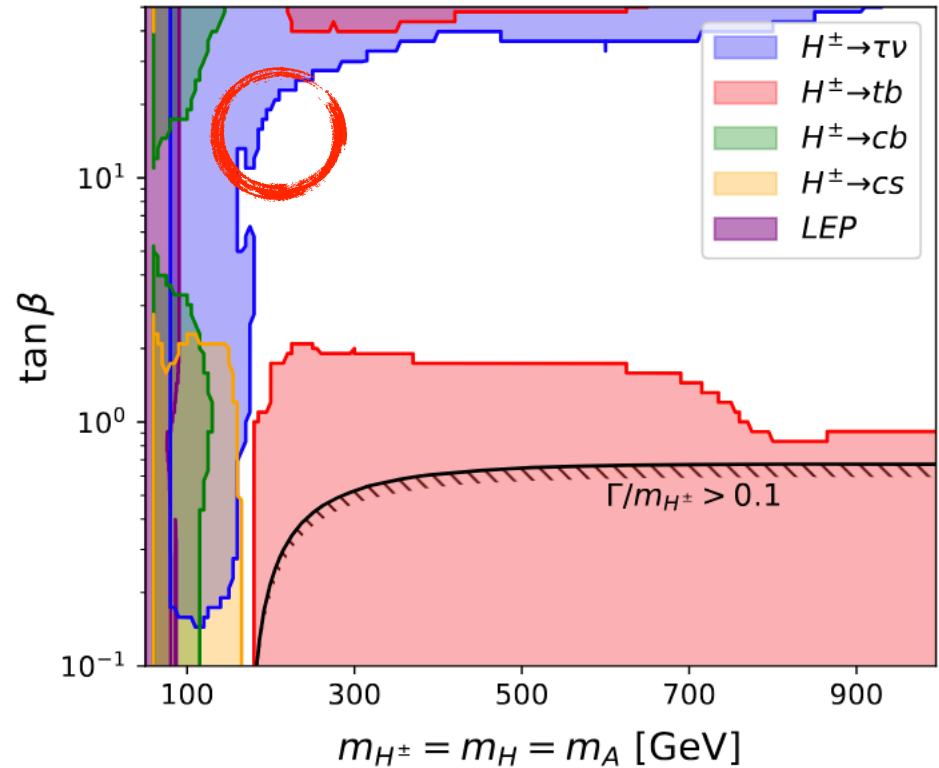


$H^\pm$ to AW/HW not open

• Type II $\phi_1, u; \phi_2, d/l$

BSM $u \sim 1/\tan\beta$; $d/l \sim \tan\beta$

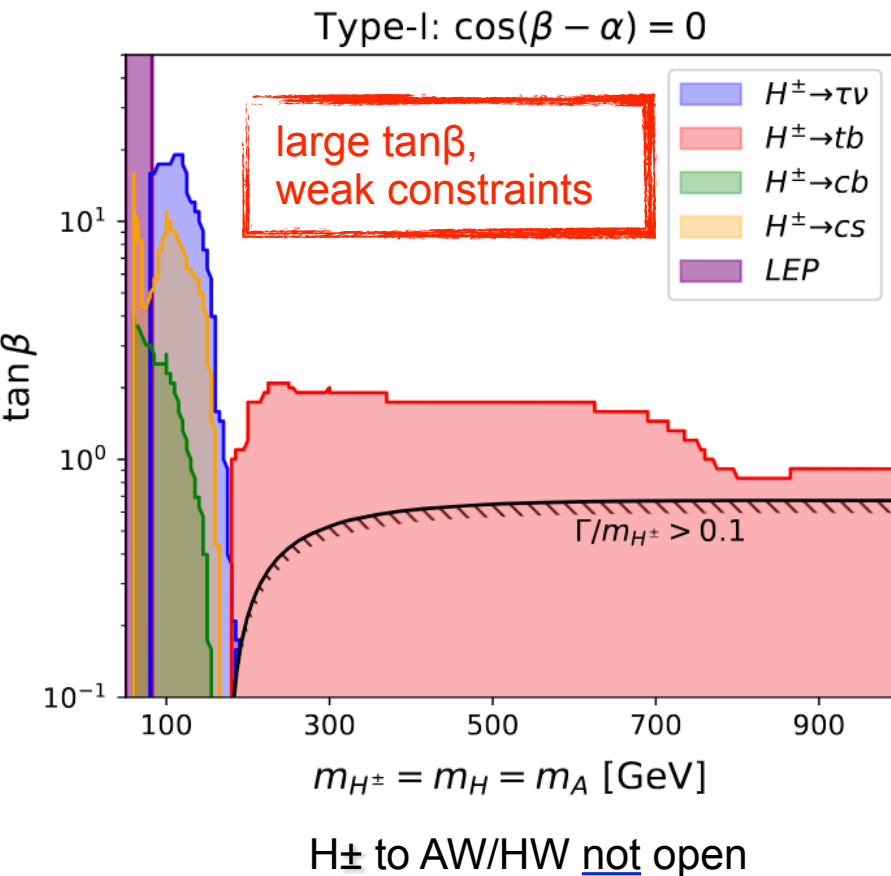
Type-II: $\cos(\beta - \alpha) = 0$



Degenerate Case: Type I/II

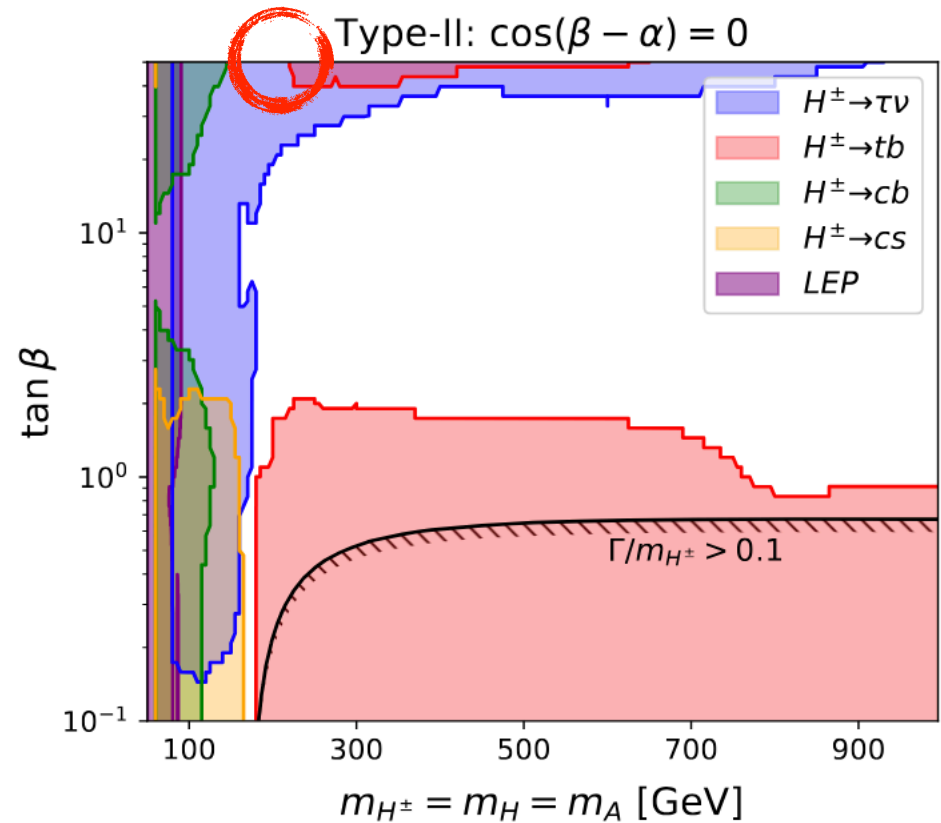
• Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan\beta$



• Type II $\phi_1, u; \phi_2, d/l$

BSM $u \sim 1/\tan\beta$; $d/l \sim \tan\beta$

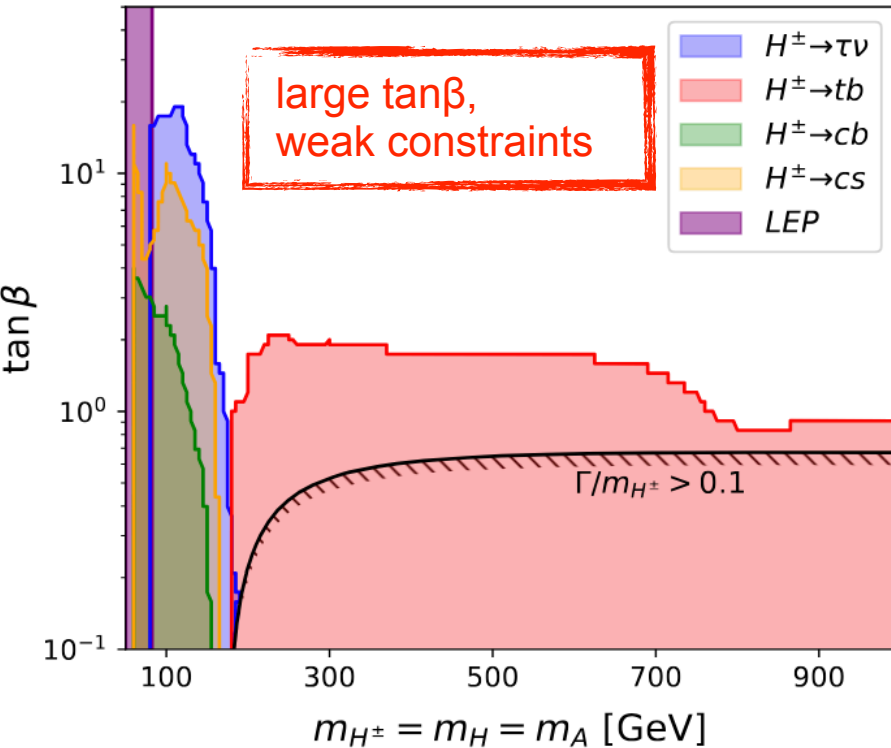


Degenerate Case: Type I/II

• Type I: $\phi_1, u/d/l$

BSM Higgs Yukawa $\sim 1/\tan\beta$

Type-I: $\cos(\beta - \alpha) = 0$

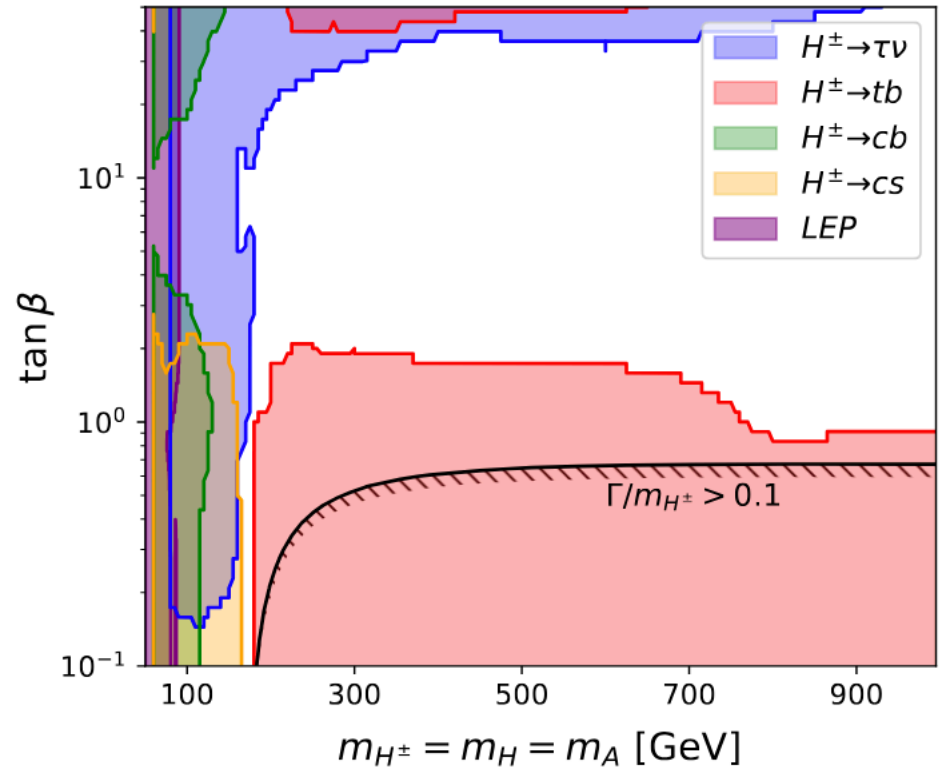


$H^\pm$ to AW/HW not open

• Type II $\phi_1, u; \phi_2, d/l$

BSM $u \sim 1/\tan\beta$; $d/l \sim \tan\beta$

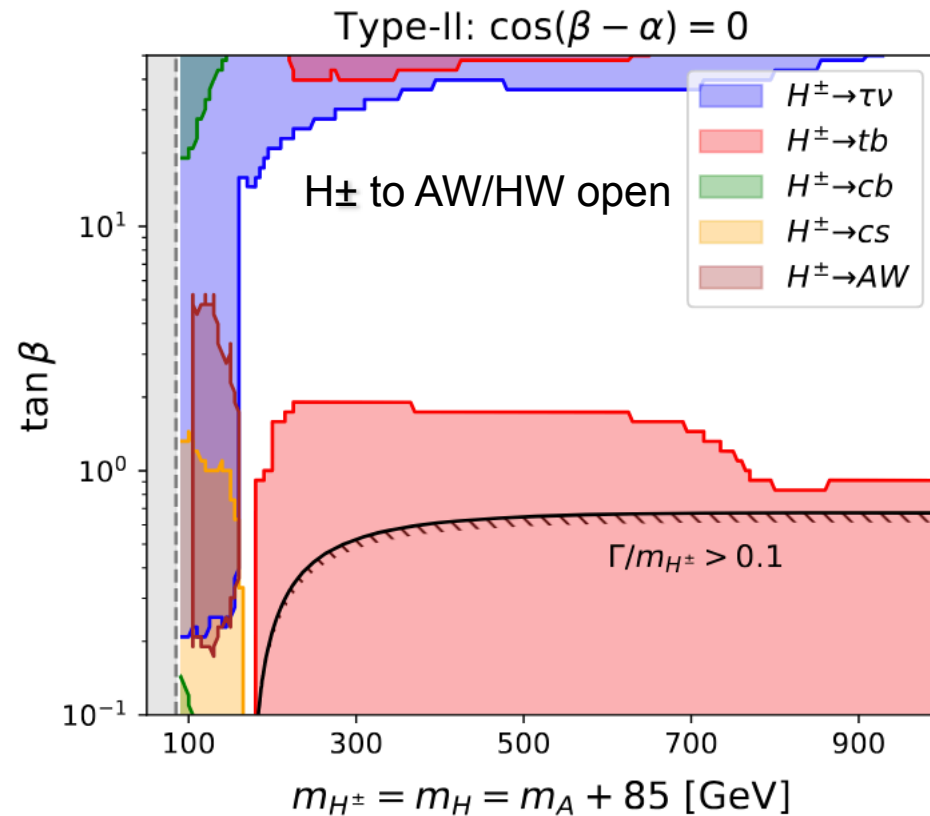
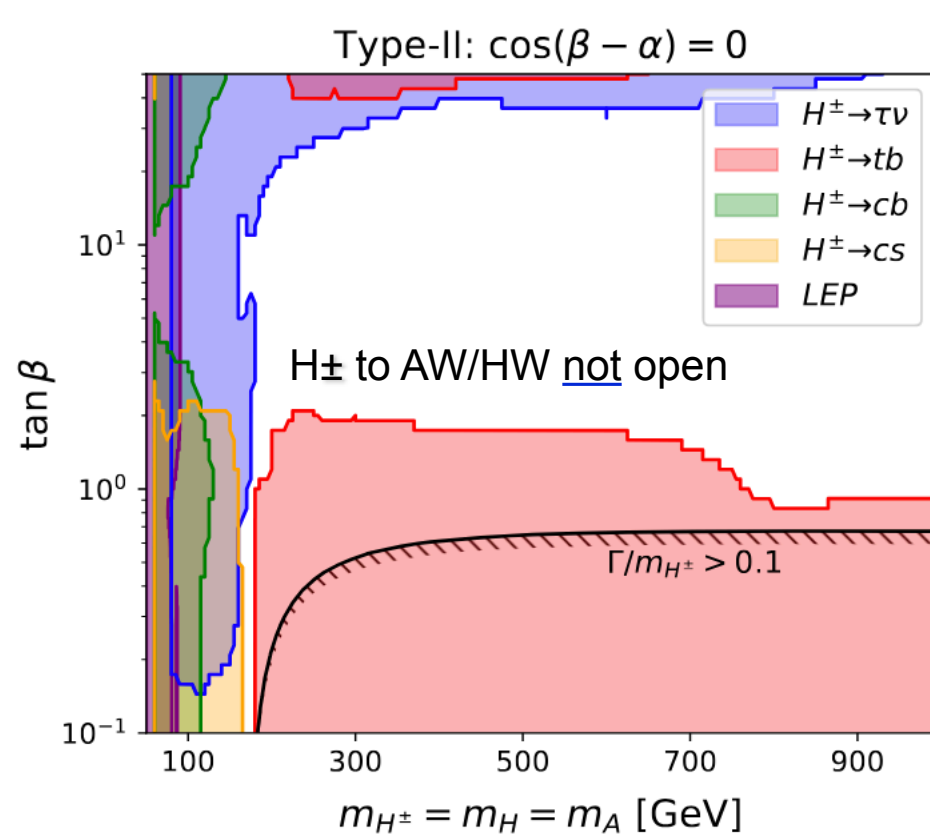
Type-II: $\cos(\beta - \alpha) = 0$



Non-Degenerate Case: Type II

● Type II $\phi_{1,u}; \phi_{2,d/l}$

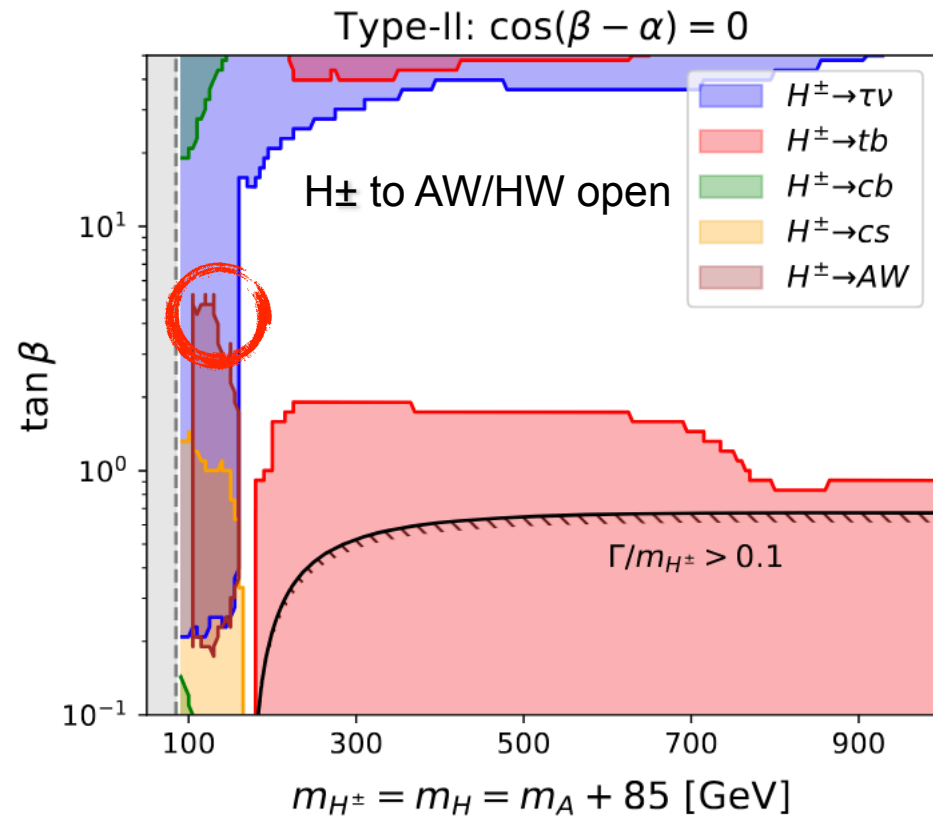
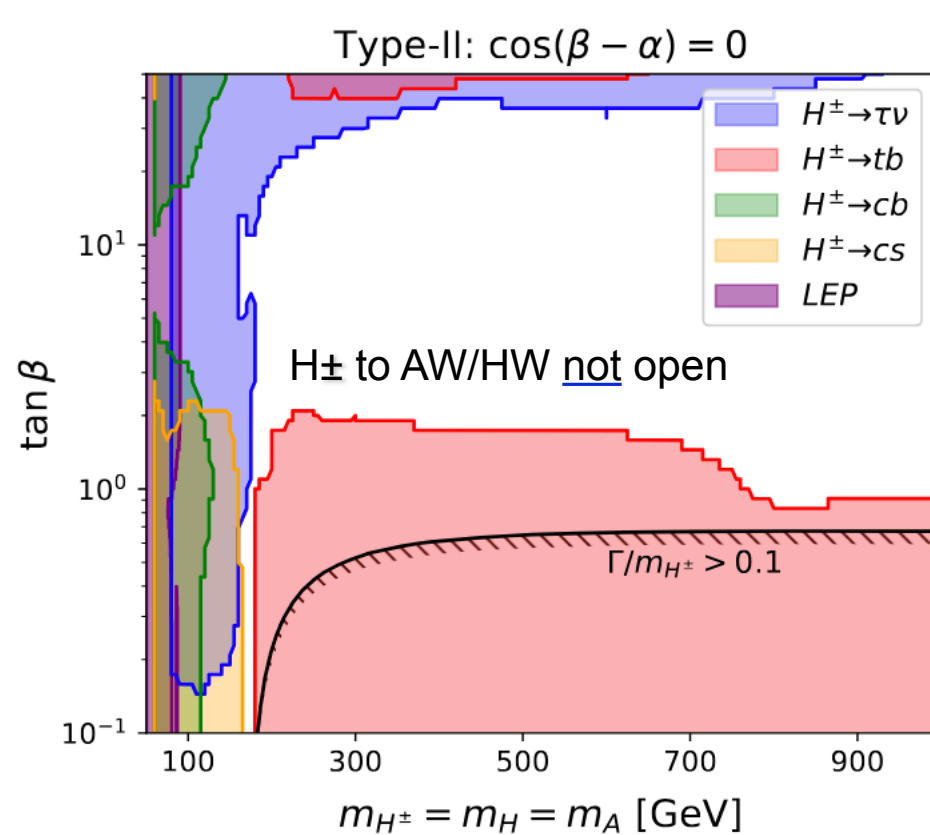
BSM $u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Non-Degenerate Case: Type II

● **Type II** $\phi_{1,u}; \phi_{2,d/l}$

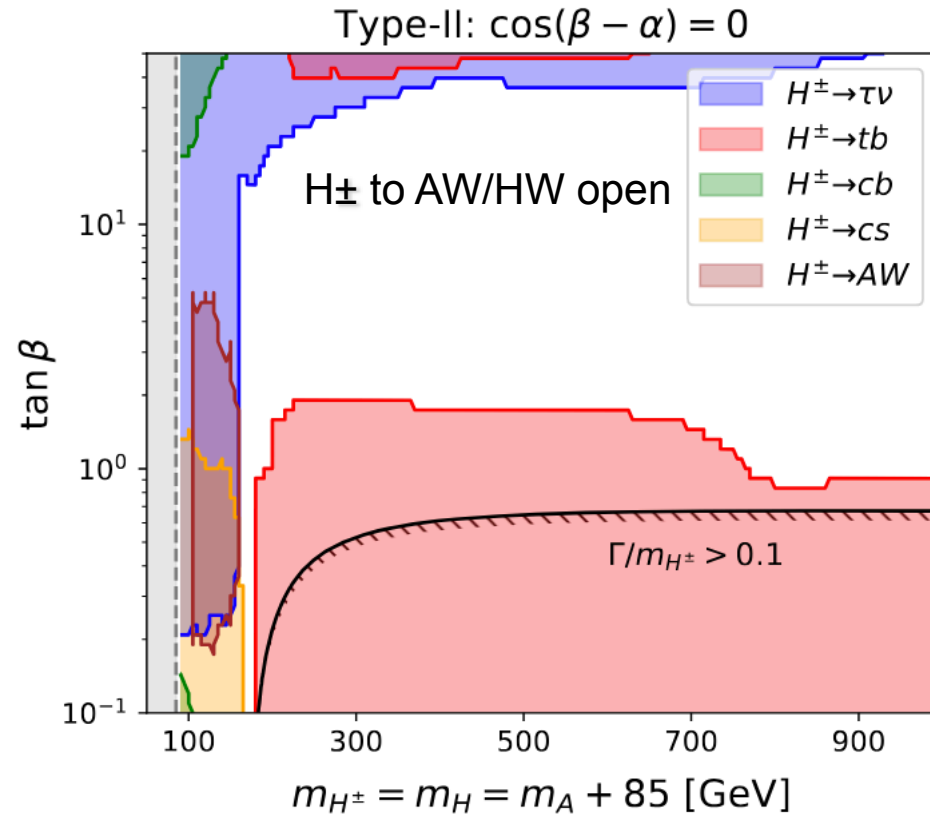
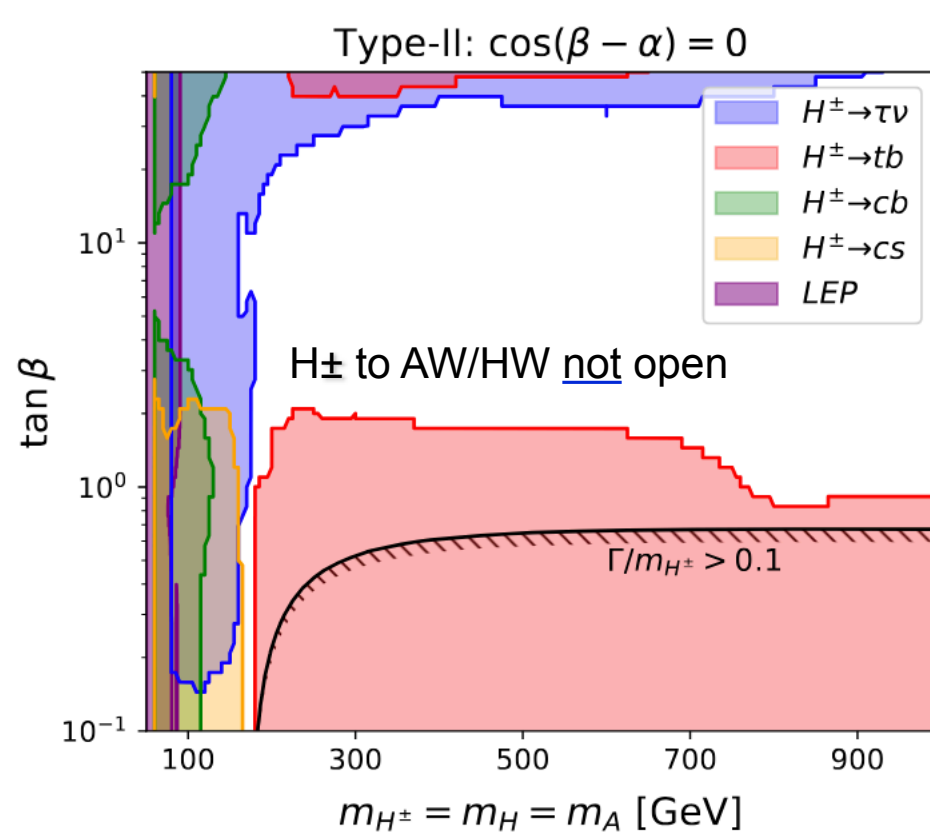
BSM $u \sim 1/\tan \beta$; $d/l \sim \tan \beta$



Non-Degenerate Case: Type II

● **Type II** $\phi_{1,u}; \phi_{2,d/l}$

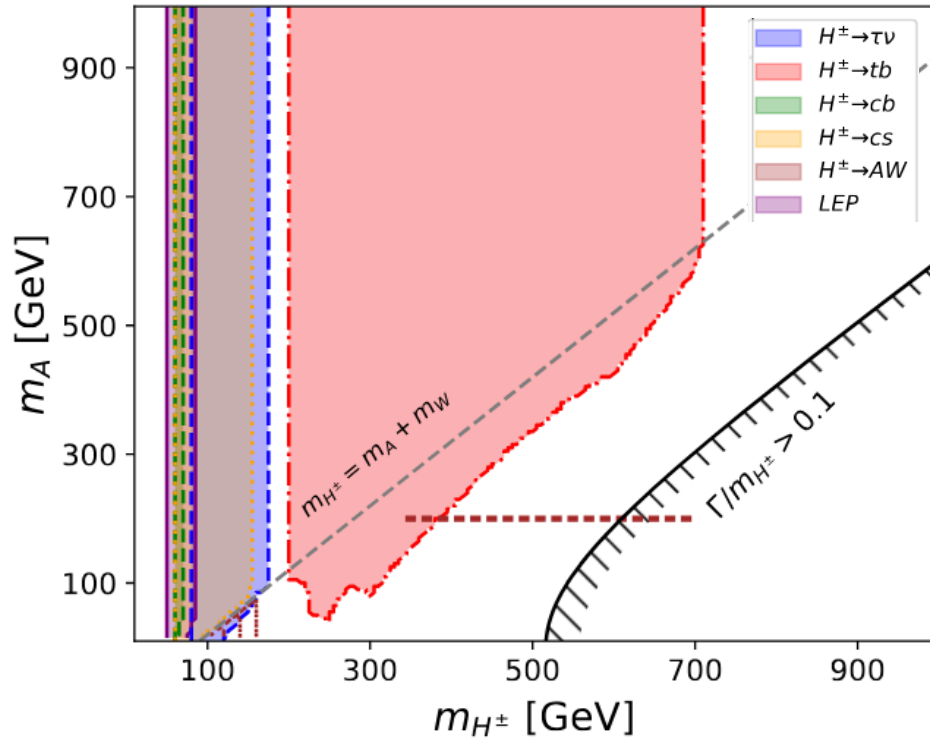
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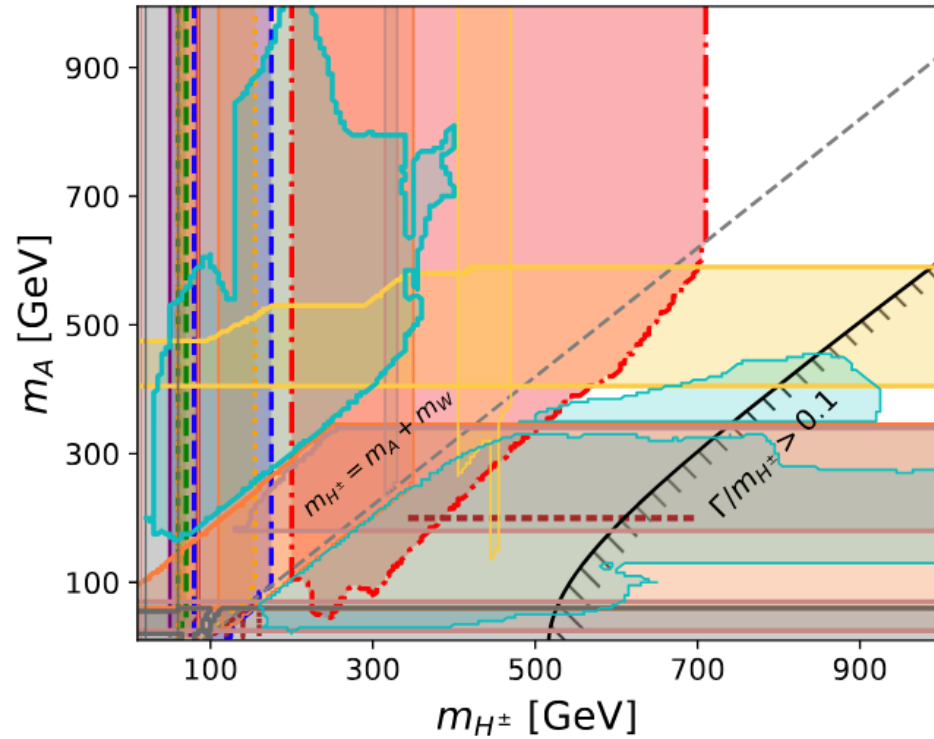
Type L: Neutral + Charge

- $H^\pm \rightarrow \tau\nu$
- $H^\pm \rightarrow tb$
- $H^\pm \rightarrow cb$
- $H^\pm \rightarrow cs$
- $H^\pm \rightarrow AW$
- $A/H \rightarrow \tau\tau$
- $A/H \rightarrow \gamma\gamma$
- $A/H \rightarrow tt$
- $h \rightarrow AA/HH$
- $A/H \rightarrow ZH/ZA$
- LEP

Type-L: $\cos(\beta - \alpha) = 0, \tan\beta = 1.5$



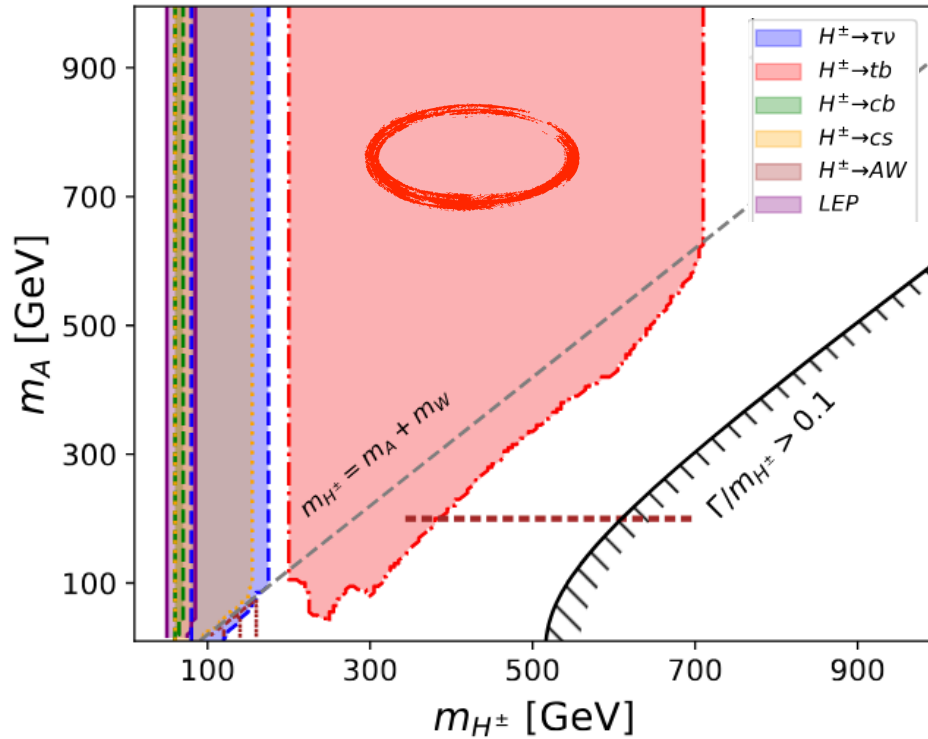
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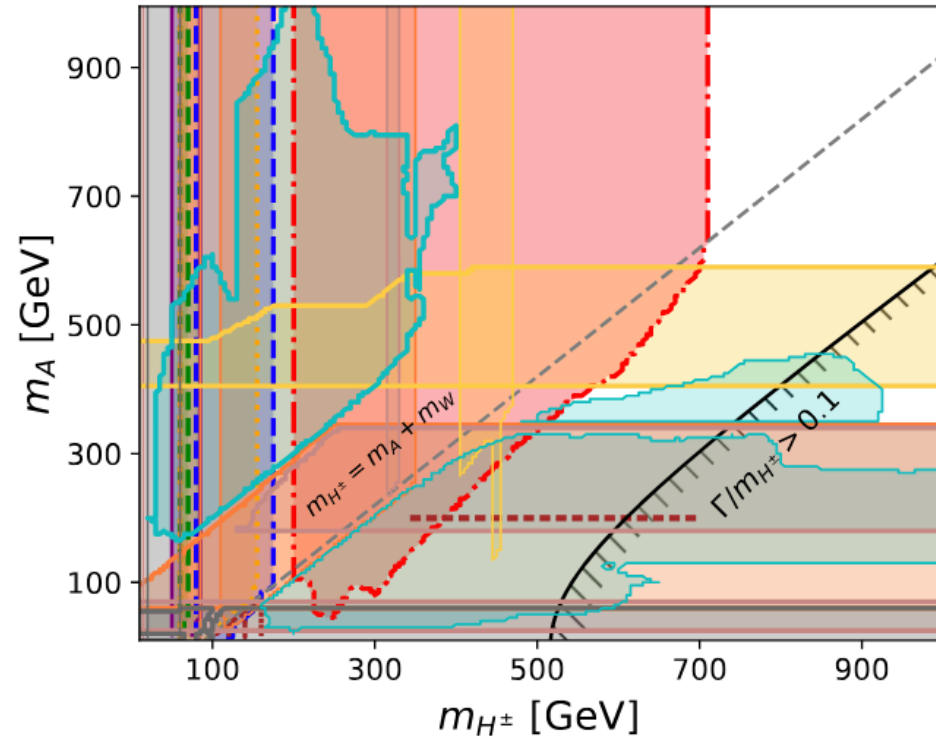
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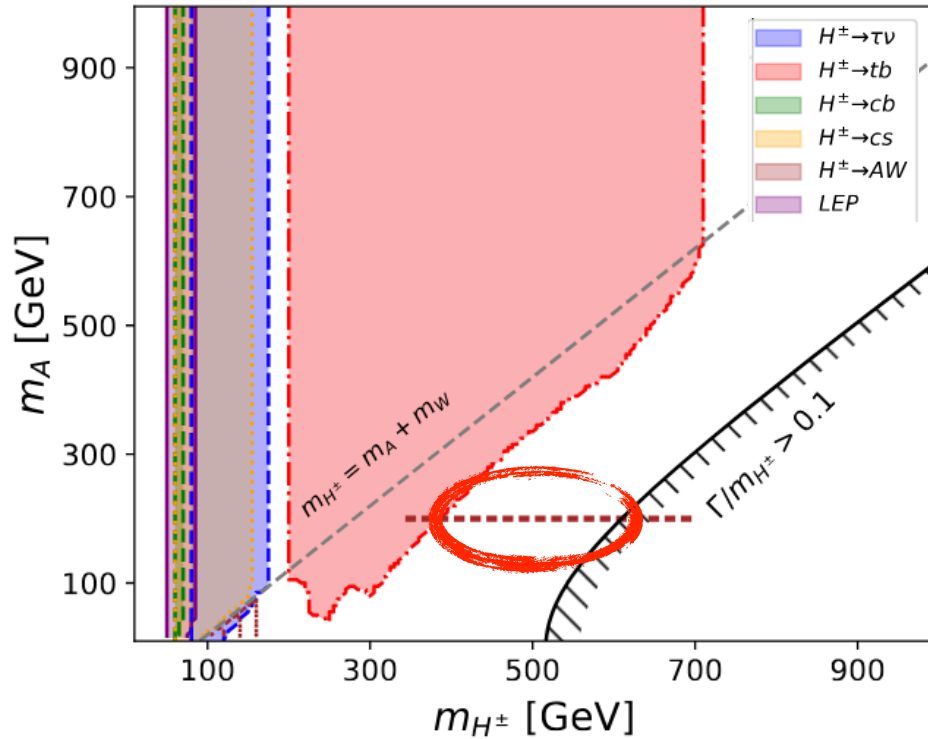
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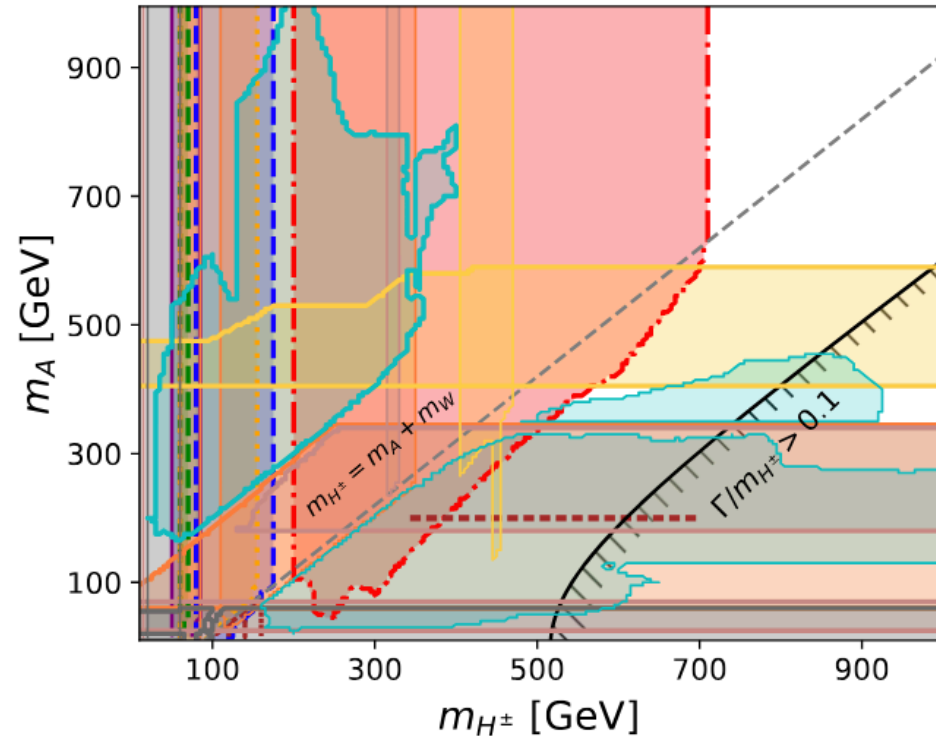
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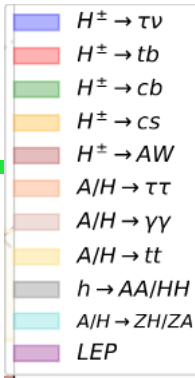
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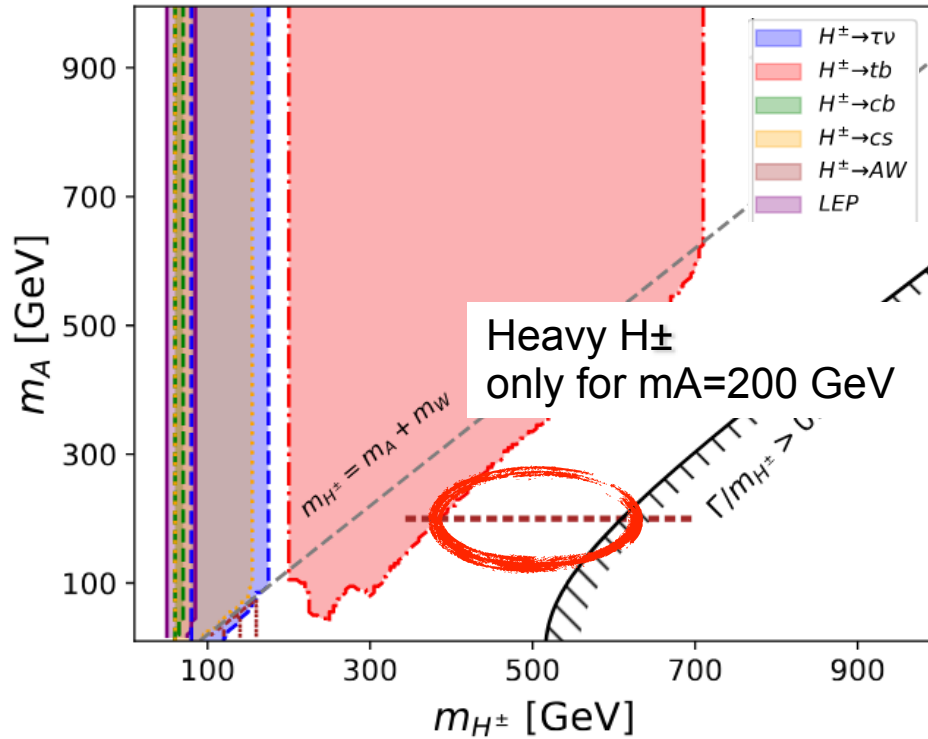
Type-L: $\cos(\beta - \alpha) = 0, \tan\beta = 1.5$



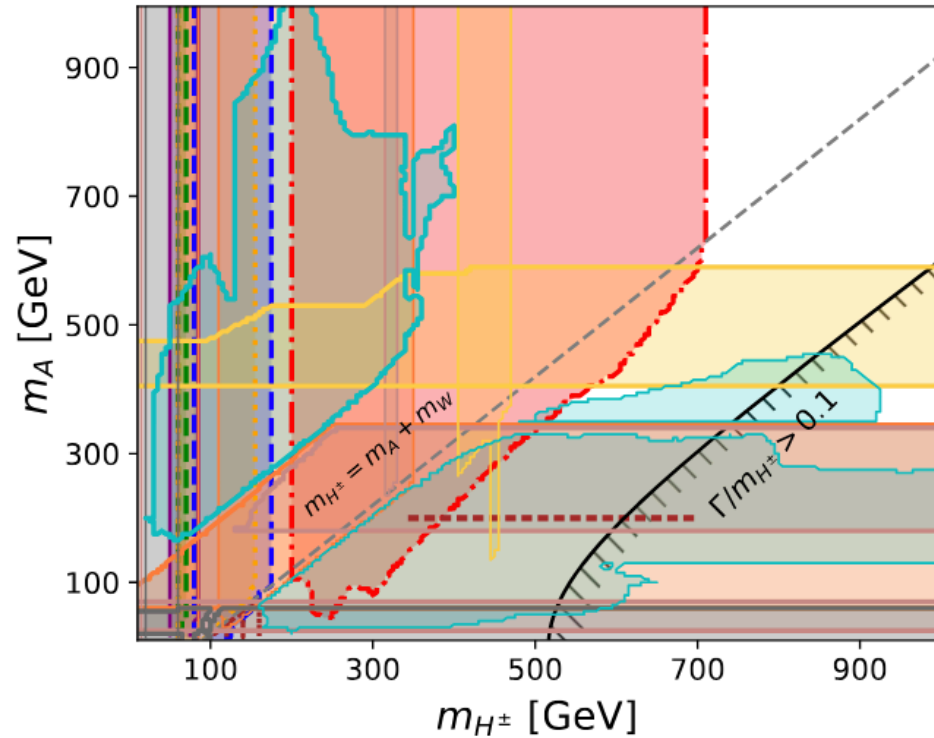
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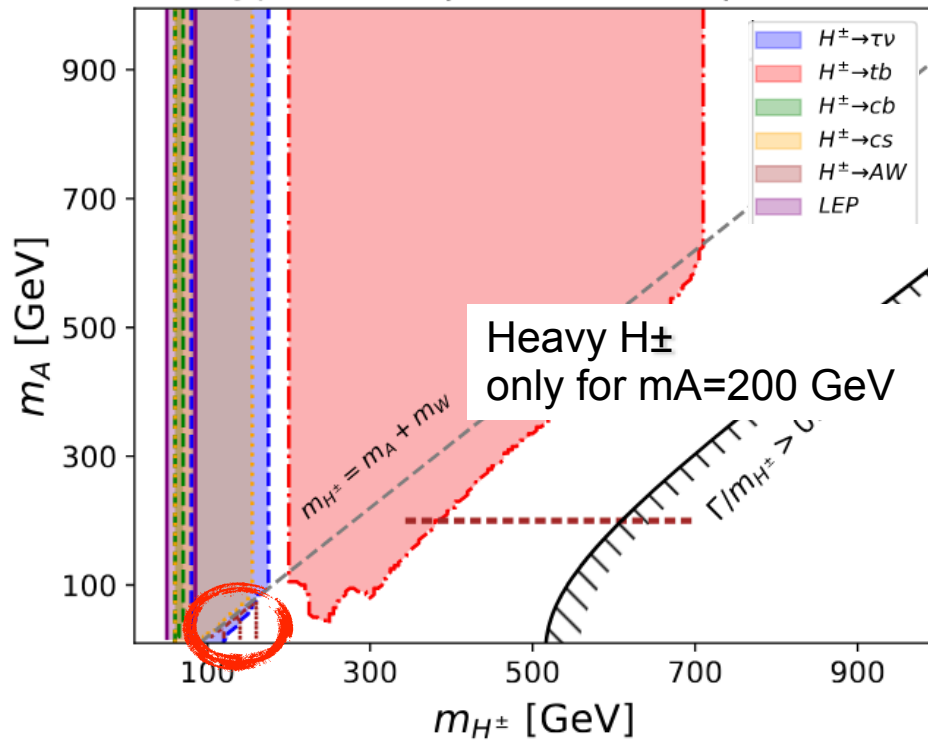
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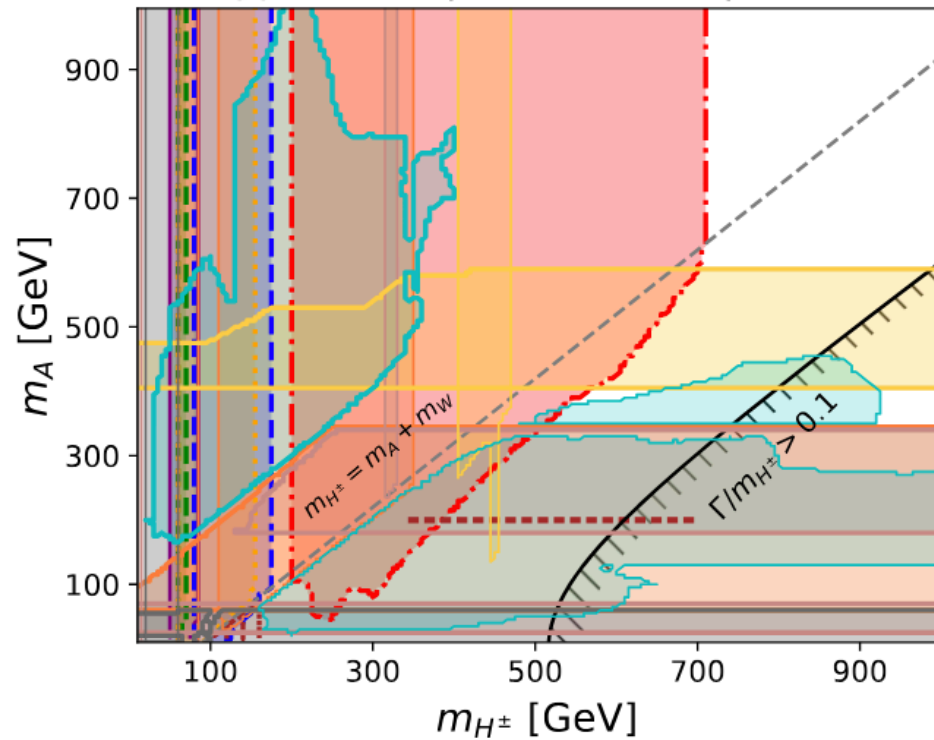
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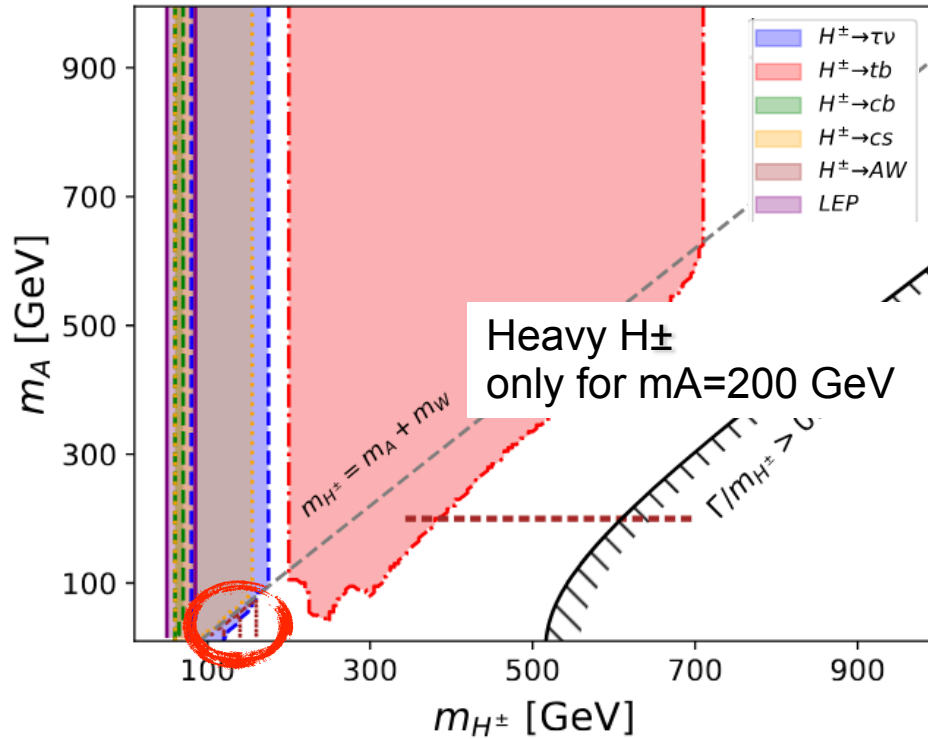
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Type L: Neutral + Charge

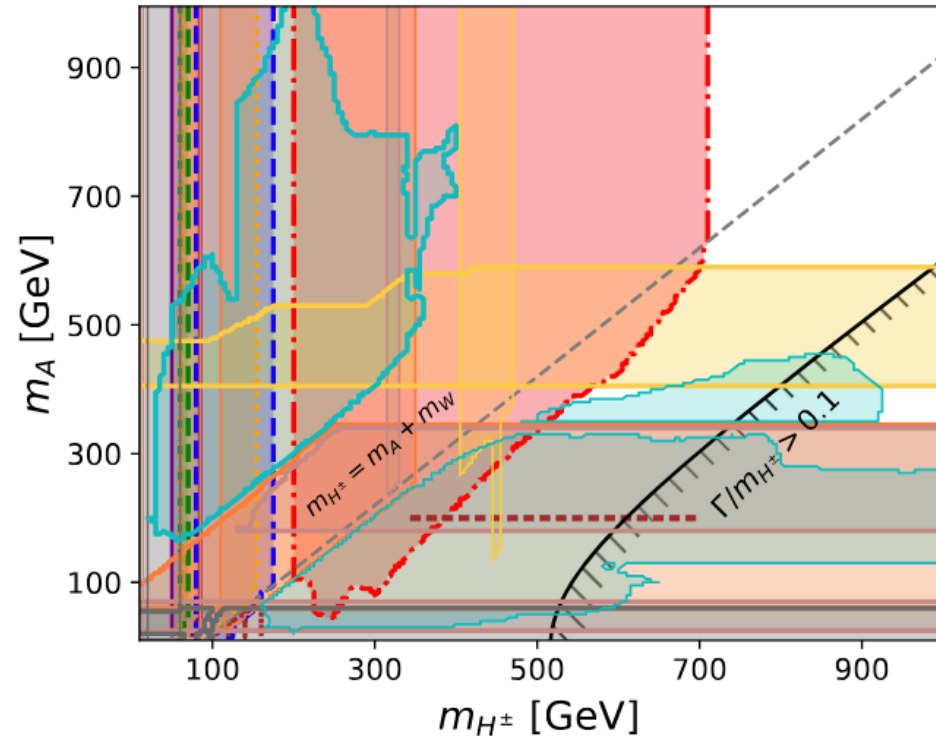
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Light $H^\pm$
only for $m_{H^\pm} = m_A + 85$ GeV
 $m_{H^\pm} = 120, 140, 160$ GeV

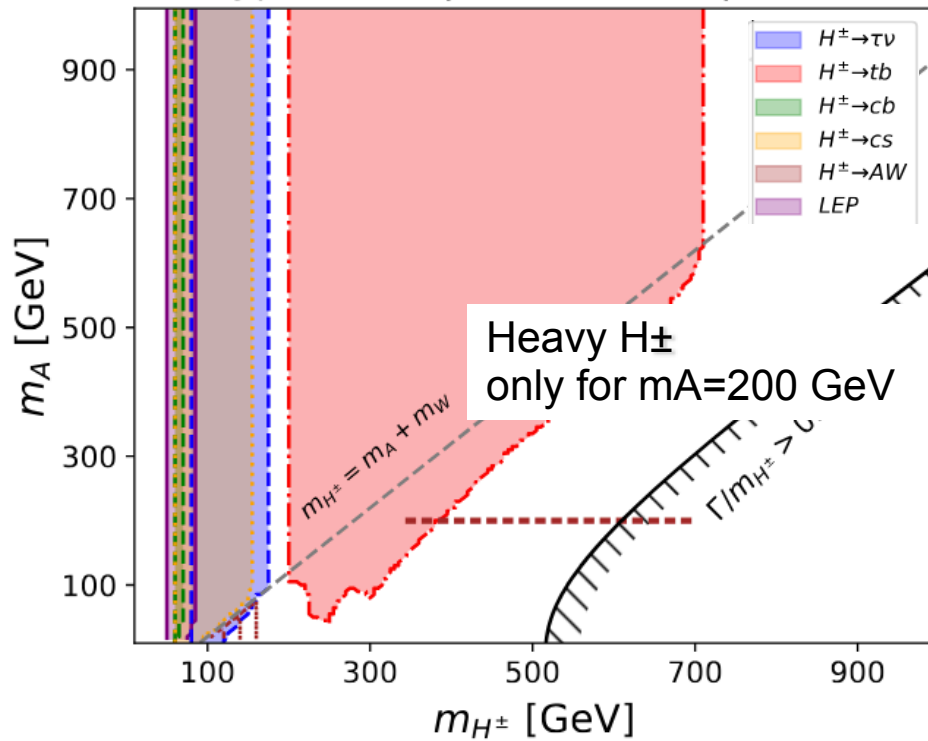
Type-L: $\cos(\beta - \alpha) = 0, \tan \beta = 1.5$



Type L: Neutral + Charge

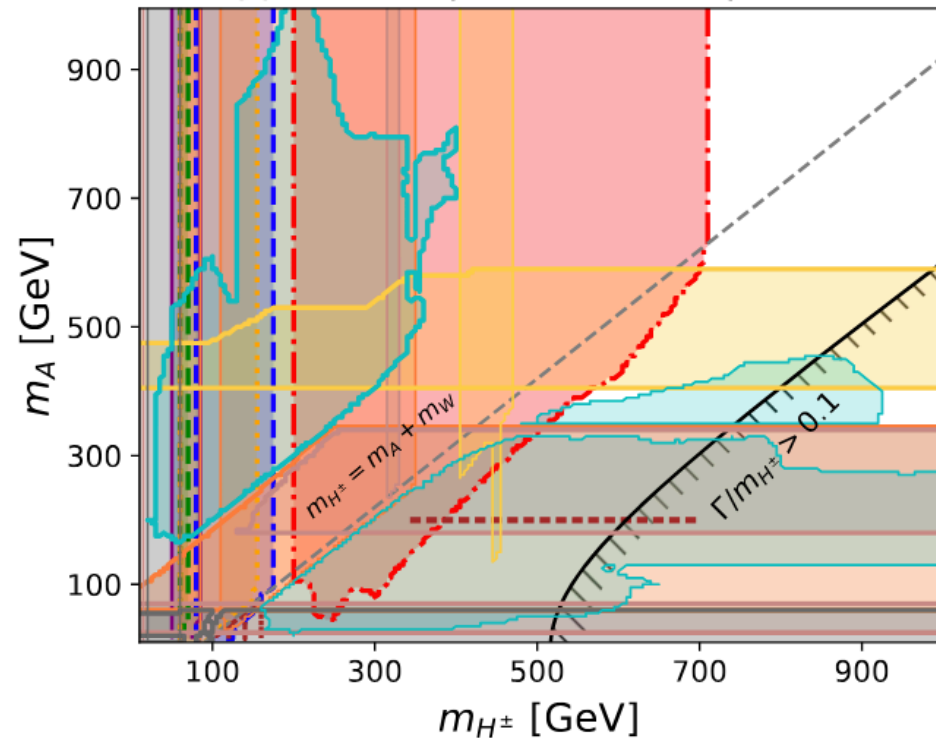
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Light $H^\pm$
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Type-L: $\cos(\beta - \alpha) = 0, \tan\beta = 1.5$



Exotic Decay

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	$(bb/\tau\tau/WW/ZZ/\gamma\gamma)(bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$h_{SM} \rightarrow AA,$ $H \rightarrow h_{SM} h_{SM},$ $H \rightarrow AA,$
	H^+H^- type	$(\tau\nu/tb)(\tau\nu/tb)$	$H \rightarrow H^+H^-$
	$WH^\pm$ type	$(l\nu/qq')(\tau\nu/tb)$	$H/A \rightarrow WH^\pm$
	ZH type	$(ll/qq/\nu\nu)(tt/bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$H \rightarrow ZA,$ $A \rightarrow ZH, Zh$
charge Higgs	WH type	$(l\nu/qq')(bb/\tau\tau)$	$tH^\pm$ production, $H^\pm \rightarrow WH$ $H^\pm \rightarrow WA$

Exotic Decay

New channels open up for non-SM Higgs decay

neutral Higgs	HH type	$(bb/\tau\tau/WW/ZZ/\gamma\gamma)(bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$h_{SM} \rightarrow AA,$ $H \rightarrow h_{SM} h_{SM},$ $H \rightarrow AA,$
	H^+H^- type	$(\tau\nu/tb)(\tau\nu/tb)$	$H \rightarrow H^+H^-$ 
	$WH^\pm$ type	$(l\nu/qq')(\tau\nu/tb)$	$H/A \rightarrow WH^\pm$
	ZH type	$(ll/qq/\nu\nu)(tt/bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$H \rightarrow ZA,$ $A \rightarrow ZH, Zh$
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Exotic Decay

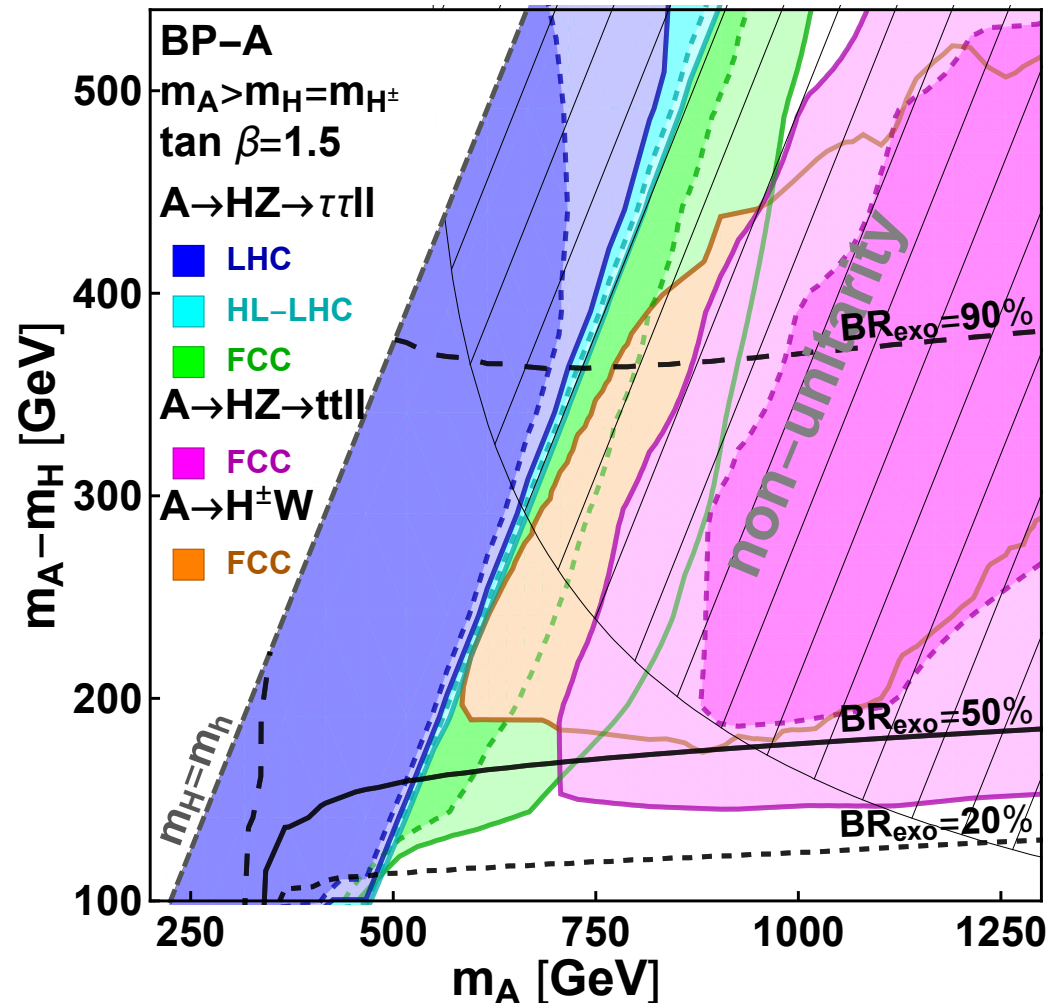
New channels open up for non-SM Higgs decay

neutral Higgs	HH type	$(bb/\tau\tau/WW/ZZ/\gamma\gamma)(bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$h_{SM} \rightarrow AA,$ $H \rightarrow h_{SM} h_{SM},$ $H \rightarrow AA,$	
	H^+H^- type	$(\tau\nu/tb)(\tau\nu/tb)$	$H \rightarrow H^+H^-$	←
	$WH^\pm$ type	$(l\nu/qq')(\tau\nu/tb)$	$H/A \rightarrow WH^\pm$	←
	ZH type	$(ll/qq/\nu\nu)(tt/bb/\tau\tau/WW/ZZ/\gamma\gamma)$	$H \rightarrow ZA,$ $A \rightarrow ZH, Zh$	
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100 TeV pp Reach

BP-A ($m_A > m_{H^\pm} = m_H$)

$A \rightarrow HZ, H^\pm W^\mp$

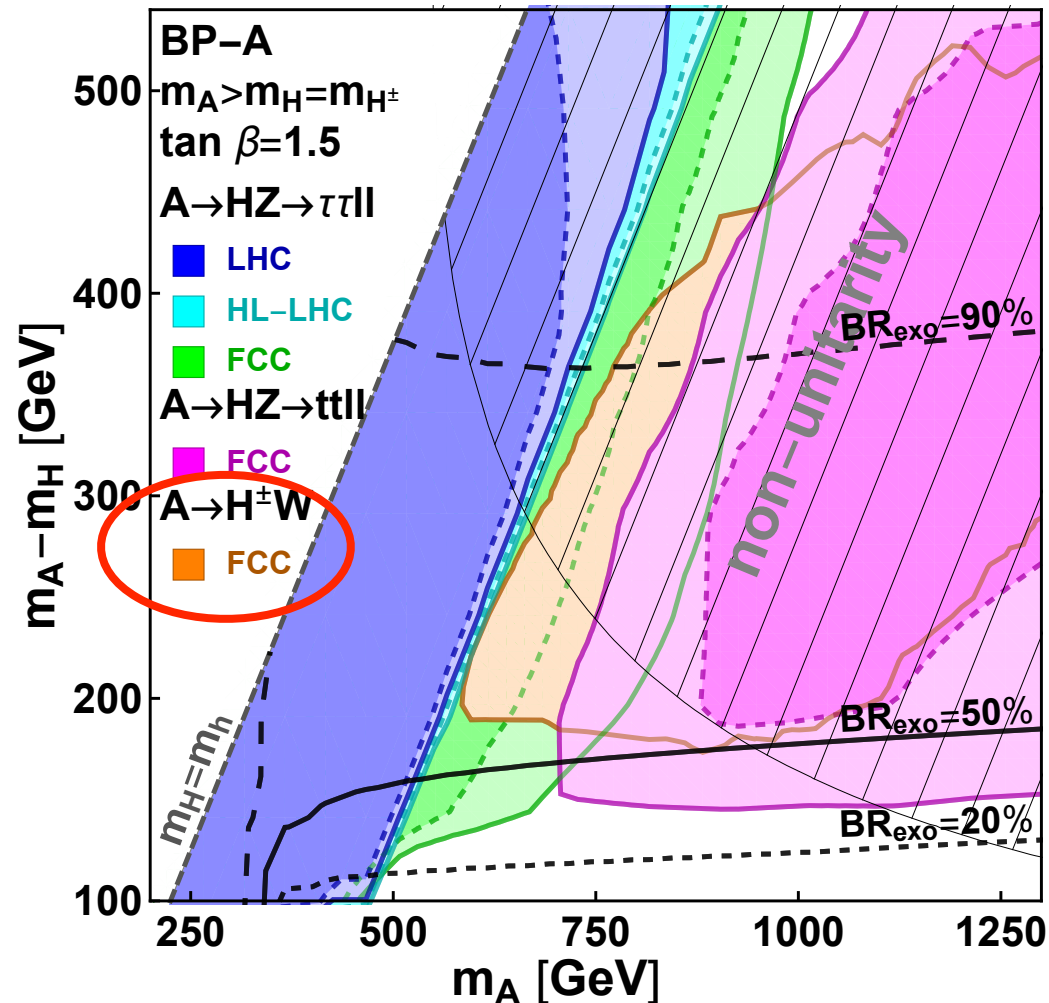


Almost entire parameter space of hierarchical 2HDM can be covered.

100 TeV pp Reach

BP-A ($m_A > m_{H^\pm} = m_H$)

$A \rightarrow HZ, H^\pm W^\mp$



Almost entire parameter space of hierarchical 2HDM can be covered.

Conclusion

- ◉ BSM with extended Higgs sector: BSM Higgses
- ◉ Current search for BSM neutral Higgses: conventional channel
- ◉ Current search for charged Higgs: challenge
- ◉ Exotic Higgs decay modes open:
 - dominant, relax existing limits, new discovery channel
 - ⇒ $Higgs \rightarrow \text{light Higgs} + \text{gauge boson}$
 - ⇒ $Higgs \rightarrow \text{two light Higgses}$
- ◉ Exotic decay complementary to
 - ⇒ Higgs precision: insensitive to alignment limit
 - ⇒ conventional channels
 - ⇒ $A \rightarrow Zh, H \rightarrow hh, H \rightarrow VV$: vanish under the alignment limit

Conclusion

- ◎ We can already do a lot with existing data. **THANK YOU!**
- ◎ Would be nice to have updated results with more data available.
- ◎ Would be nice to add more channels
 - ➔ $H \rightarrow H^+H^-$, $H/A \rightarrow WH^\pm$
 - could be new channels for charged Higgs production/discovery
- ◎ Would be nice to map all mass region instead of a few benchmarks.
 - ➔ $m_{H^\pm}$ vs $m_{A/H}$
- ◎ Continuum search could also be useful for BSM Higgs with large width
 - ➔ ttZ , $tttt$, $ttbb$

An exciting journey ahead of us!