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New discovery channels for the fermiophobic Higgs in type-I 2HDM with high cutoff scales

> Jeonghyeon Song (Konkuk University, Korea)

w/ J. Kim, S. Lee, P. Sanyal, D. Wang [2202.05467]

Longing for **BSN**, but

The same sentence repeated in the experimental papers at the LHC

Search for new physics in the τ lepton plus missing transverse momentum final state in proton-proton collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration

Abstract

A search for physics beyond the standard model (SM) in the final state with a hadronically decaying tau lepton and a neutrino is presented. This analysis is based on data recorded by the CMS experiment from proton-proton collisions at a center-ofmass energy of 13 TeV at the LHC, corresponding to a total integrated luminosity of 138 fb⁻¹. The transverse mass spectrum is analyzed for the presence of new physics. No significant deviation from the SM prediction is observed. Limits are set on the production cross section of a W' boson decaying into a tau lepton and a neutrino.

Spirit of invincibility!

Let's check every loophole.

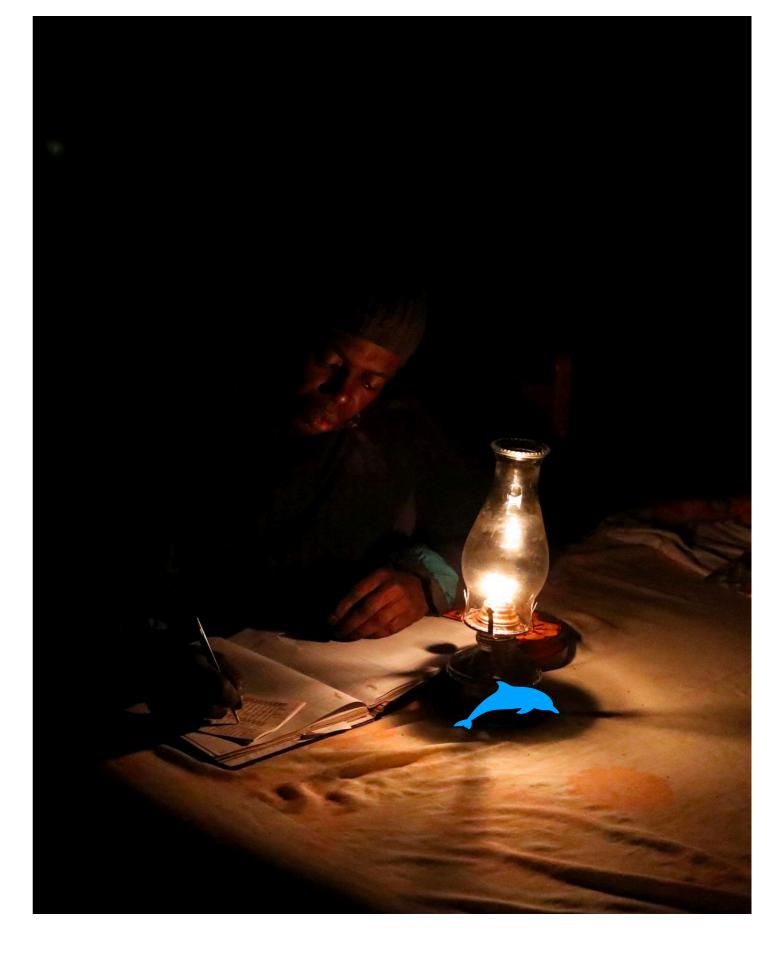
What if we may miss the signal?

It is dark under the lamp.



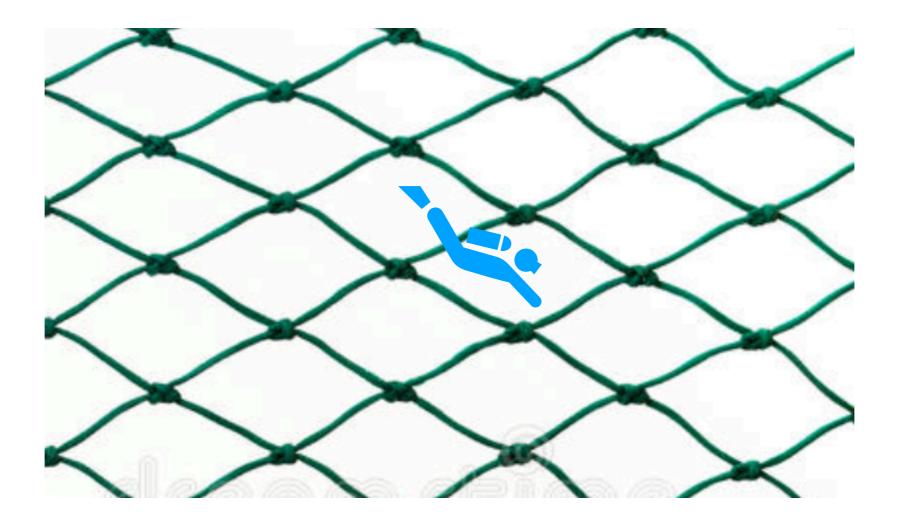
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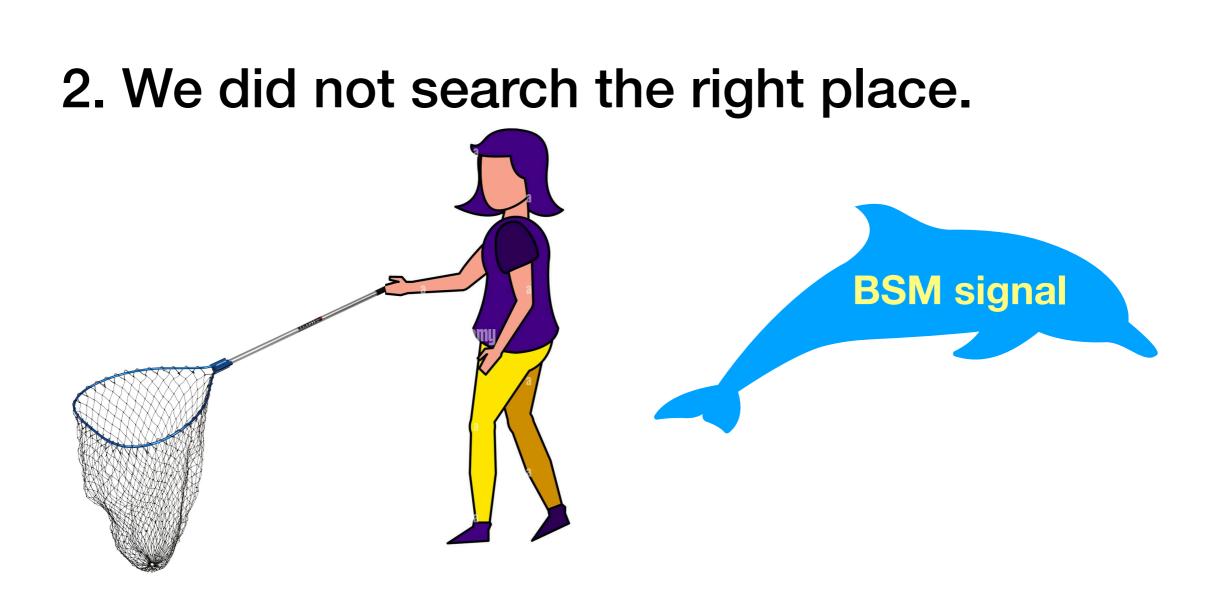
It is dark under the lamp.



Two explanations

1. The new particle is generically elusive at the LHC.





A well-motivated BSM model which satisfy two cases:

Fermiophobic Higgs boson in type-I 2HDM with a high cutoff scale

- 1. Fermiophobic Higgs boson in Type-I 2HDM
- 2. RGE
- 3. Big impacts on the fermiophobic type-I from the high cutoff scale
- 4. Characteristics of the parameters with high cutoff scale
- 5. Golden channel 1: $\tau^{\pm}\nu\gamma\gamma$
- 6. Golden channel 2: $\ell \pm \ell \pm \gamma \gamma + X$
- 7. Conclusions

1. Fermiophobic Higgs boson in Type-I 2HDM

Basic theory setup

$$\Phi_i = \begin{pmatrix} w_i^+ \\ \frac{v_i + h_i + i\eta_i}{\sqrt{2}} \end{pmatrix}, \quad i = 1, 2,$$

where $v = \sqrt{v_1^2 + v_2^2} = 246 \text{ GeV}.$

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• Discrete Z₂ symmetry to avoid tree-level FCNC

$$\Phi_1 \to \Phi_1, \quad \Phi_2 \to -\Phi_1$$

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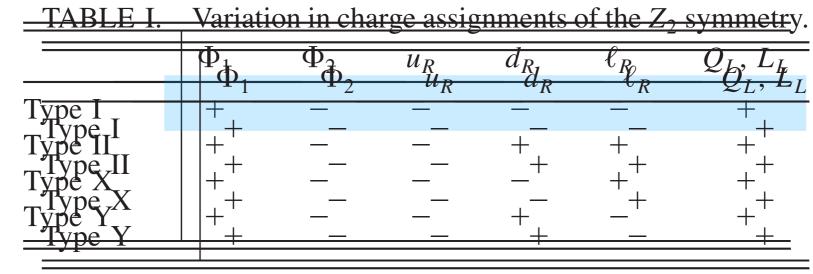
Scalar potential with CP-invariance

 $V_{\Phi} = m_{11}^{2} \Phi_{1}^{\dagger} \Phi_{1} + m_{22}^{2} \Phi_{2}^{\dagger} \Phi_{2} - m_{12}^{2} (\Phi_{1}^{\dagger} \Phi_{2} + \text{H.c.})$ Soft braking of Z2 + $\frac{1}{2} \lambda_{1} (\Phi_{1}^{\dagger} \Phi_{1})^{2} + \frac{1}{2} \lambda_{2} (\Phi_{2}^{\dagger} \Phi_{2})^{2} + \lambda_{3} (\Phi_{1}^{\dagger} \Phi_{1}) (\Phi_{2}^{\dagger} \Phi_{2}) + \lambda_{4} (\Phi_{1}^{\dagger} \Phi_{2}) (\Phi_{2}^{\dagger} \Phi_{1})$ + $\frac{1}{2} \lambda_{5} \left[(\Phi_{1}^{\dagger} \Phi_{2})^{2} + \text{H.c.} \right],$ • Four types

				\square		
	Φ_1	Φ_2	u_R	d_R	ℓ_R	Q_L, L_L
Туре І	+	_	_	_		+
Type II	+	—	—	+	+	+
Туре Х	+	—	—	-	+	+
Type Y	+			+	—	+

$-\mathcal{L}_{\text{Yukawa}} = Y_{u2} \overline{Q}_L \tilde{\Phi}_2 u_R + Y_{d2} \overline{Q}_L \Phi_2 d_R + Y_{\ell 1} \overline{L}_L \Phi_1 e_R + \text{h.c.}$

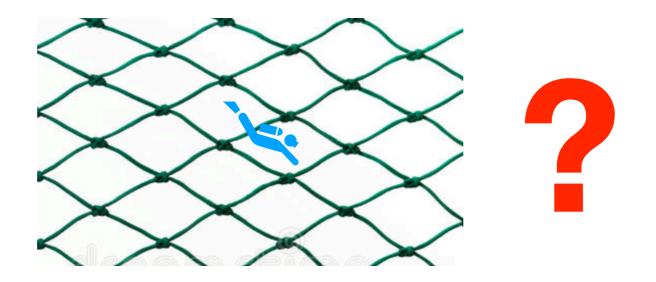
ons. We also discuss the ged Higgs sector from $u\bar{v}v$ [24] and the muon z_{6} . Four types by of discriminating beactions at the LHC and collider phenomenology extra Higgs boson scee results in the MSSM he signal of neutral and type-X Yukawa interaction (all quarks couple to Φ_2 while

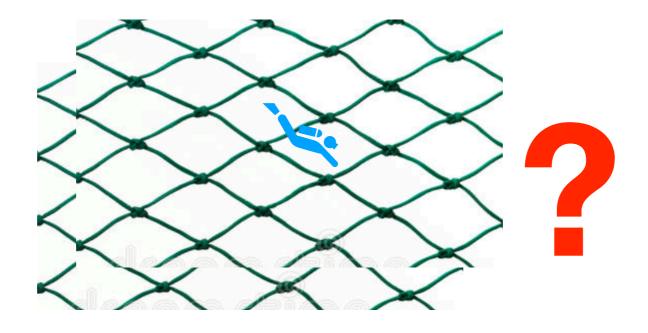


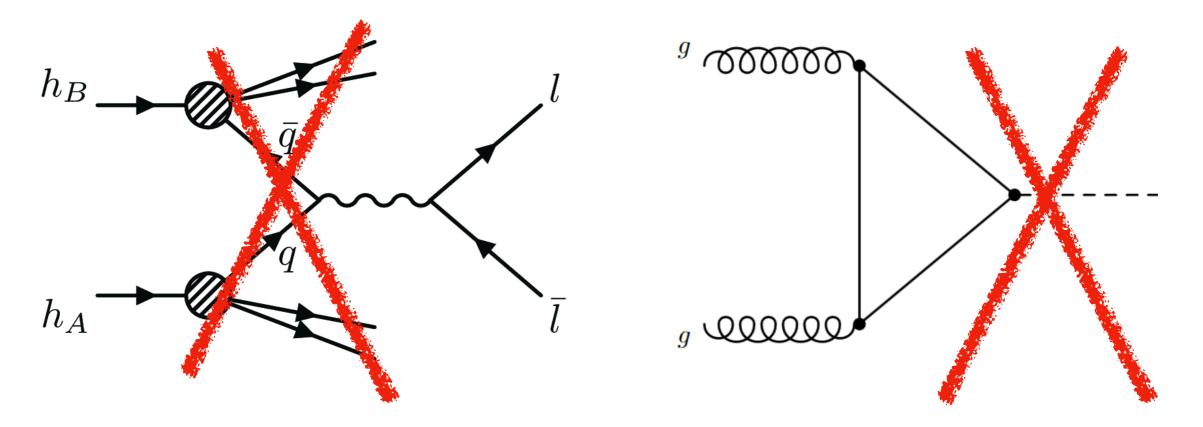
fermiophobic type-I: $M_H = 125 \text{ GeV}, \quad \alpha = \pi/2.$

$$\xi_f^h = \frac{c_0}{s_\beta}, \quad \kappa_f^H = \frac{s_\alpha}{s_\beta}, \quad \xi_t^A = -\xi_b^A = -\xi_\tau^A = \frac{1}{t_\beta}.$$
0

Lighter h_f becomes fermiophobic!



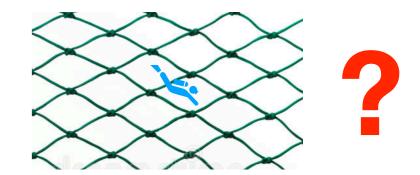




Normal productions are prohibited!

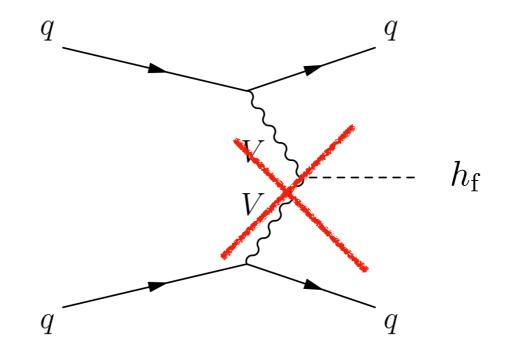
• SM Higgs boson

$$h_{\rm SM} = s_{\beta-\alpha}h + c_{\beta-\alpha}H.$$



• Near the Higgs alignment limit:

$$c_{\beta-\alpha} \simeq 1 \Longrightarrow g_{h_{\rm f}-V-V} \simeq 0$$



2. RGE

Does this model satisfy the theoretical stabilities?

□ Yes. We obtain the viable parameters.

❀ But that's true at the WE scale. The couplings run!

• Running of gauge couplings

$$16\pi^{2}\beta_{g_{3}} = -7g_{3}^{3},$$

$$16\pi^{2}\beta_{g_{2}} = \left(-\frac{10}{3} + \frac{n_{d}}{6}\right)g_{2}^{3} = -3g_{2}^{3},$$

$$16\pi^{2}\beta_{g_{1}} = \left(\frac{20}{3} + \frac{n_{d}}{6}\right) = 7g_{1}^{3},$$

2 in the 2HDM

• Running of Yukawa couplings has two contributions.

$$\beta_Y = \beta_Y^g + \beta_Y^Y$$

$$16\pi^2 \beta_{Y_t}^g = -\left(\frac{17}{12}g_1^2 + \frac{9}{4}g_2^2 + 8g_3^2\right)Y_t,$$

$$16\pi^2 \beta_{Y_\tau}^g = -\left(\frac{15}{4}g_1^2 + \frac{9}{4}g_2^2\right)Y_\tau,$$

$$16\pi^2 \beta_{Y_t}^Y = \left(\frac{3}{2}Y_b^2 + \frac{9}{2}Y_t^2\right) Y_t$$
$$16\pi^2 \beta_{Y_\tau}^Y = \frac{5}{2}Y_\tau^3$$

Running of quartic couplings from bosonic contributions and fermonic contributions

$$\beta_{\lambda} = \beta_{\lambda}^{b} + \beta_{\lambda}^{Y}$$

• In type-X, for example,

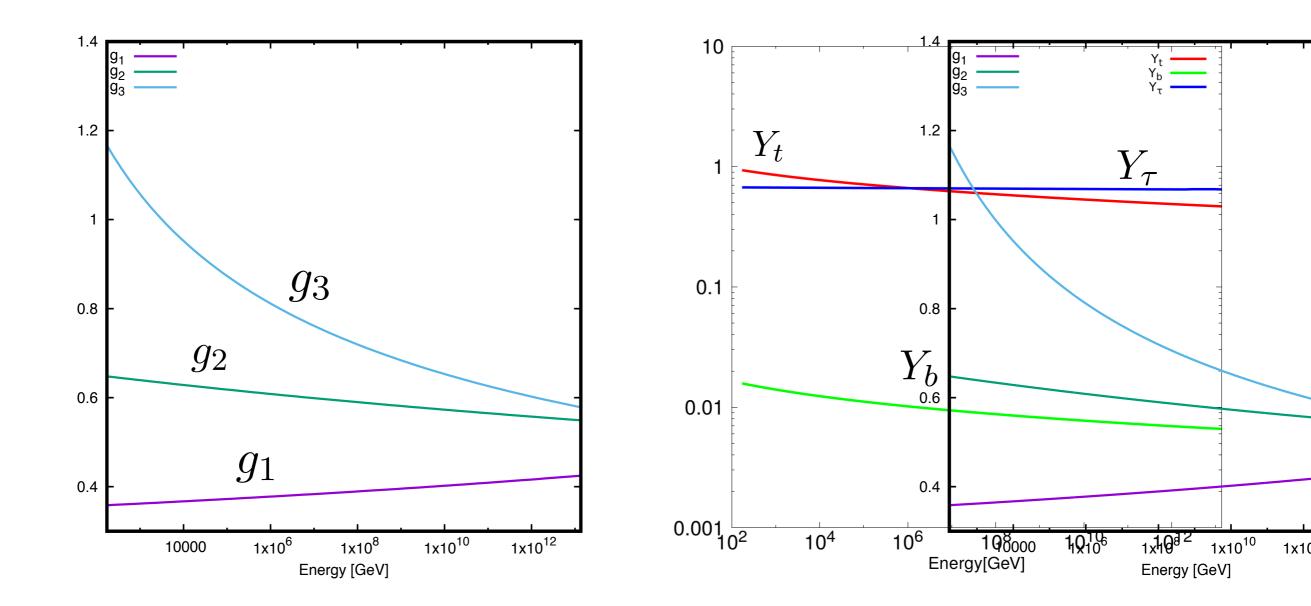
$$\begin{split} 16\pi^2\beta^b_{\lambda_1} = &\frac{3}{4}g_1^4 + \frac{3}{2}g_1^2g_2^2 + \frac{9}{4}g_2^4\\ &- 3g_1^2\lambda_1 - 9g_2^2\lambda_1 + 12\lambda_1^2 + 4\lambda_3^2 + 4\lambda_3\lambda_4 + 2\lambda_4^2 + 2\lambda_5^2,\\ 16\pi^2\beta^Y_{\lambda_1} = &- 4Y_\tau^4 + 4Y_\tau^2\lambda_1. \end{split}$$

Enverence in the second of the

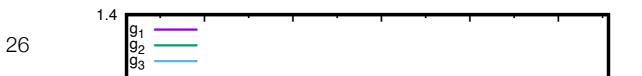
		BI	P1		BP2	BBB	BBP53	BP6
in GeV		M_H 4 i 419	787 7	m_H	In Carl 231	93260737	93560865	121.448
in GeV		M_A in 0	J&I	m_{A}	VIA CASOPON	12476997	15.68.59	63.0
in Gev	V I	$\Lambda_H \pm 453.$	895	M_H	In the set	1331084	1376.0052	139.871
λ_1		0.09	539	2	$\lambda_101099632$	1102963	0.52616	0.082024
λ_2		0,25	788		λ_2 (),25788	002257692	00225673	0.25774
λ_3		6,9	130		λ_3 3 3 3 9 9 6 8	0.3.369668	00589359	0.38712
λ_4		-\$43	549		λ_4 -3.848783	-0.4.54783	-00456724	-0.33662
λ_5		3,23	062		λ5 BAZ2B62	0.1.3899453	0013249953	0.177861
$n { m GeV}$	2 n	$n_{12}^2 26960$	238	\mathfrak{F}_1^2	ip 16982288 9	3939292785	3953.22262715	204.844987
${ m an}eta$		tan5	30	t	ant/ 327/31 /54	5227 0.54	26700	72.00
$\beta - \alpha)$		$\sin(\emptyset.9$	986)	\sin	sin 0,09.9996 3 -	0.00999183	0.00999996	-0.02828
$\ln(\beta - \epsilon)$	$\alpha) y_h^\ell$	$\times 1sih20$	954		0\$\$\$12603361 00.	1.1.328293566	10182049553	-1.036145

Table 1. Ben Tabler & po Barbien 25 & Brank Speints if on Scenario 2.

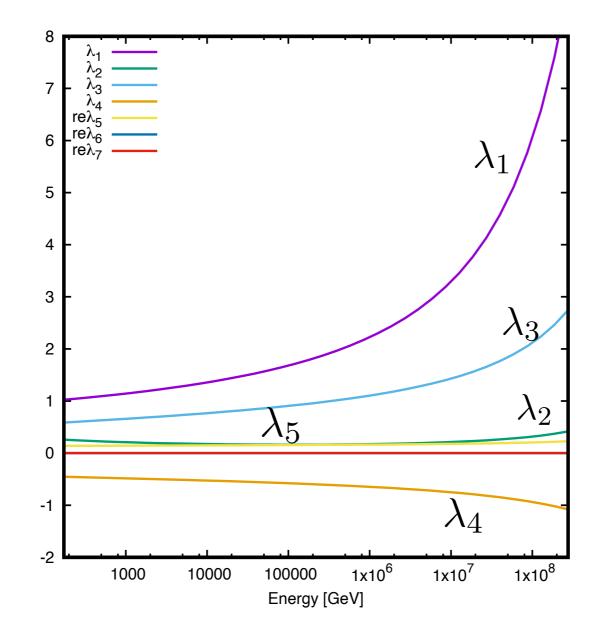
BP-IS



• No dramatic changes



BP-IS





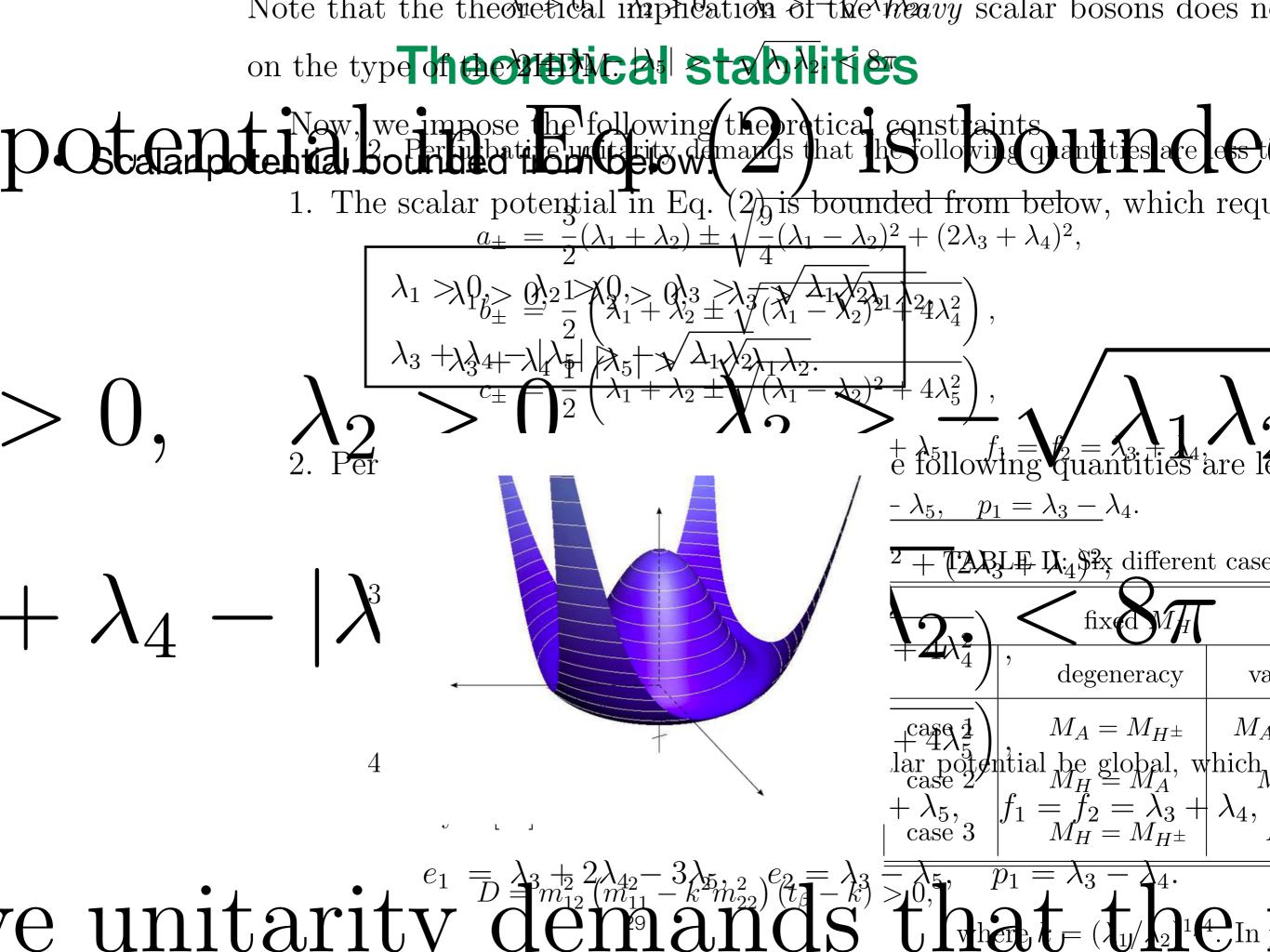
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- Why is the large quartic coupling a problem?
- It can threaten the theoretical stabilities.



Theoretical stabilities

1. Scalar potential bounded from below:

$$\lambda_1 > 0, \quad \lambda_2 > 0, \quad \lambda_3 > -\sqrt{\lambda_1 \lambda_2},$$
$$\lambda_3 + \lambda_4 - |\lambda_5| > -\sqrt{\lambda_1 \lambda_2}.$$

2. Perturbative unitarity of scalar-scalar scattering at tree level

$$\begin{aligned} a_{\pm} &= \frac{3}{2} (\lambda_1 + \lambda_2) \pm \sqrt{\frac{9}{4} (\lambda_1 - \lambda_2)^2 + (2\lambda_3 + \lambda_4)^2}, \\ b_{\pm} &= \frac{1}{2} \left(\lambda_1 + \lambda_2 \pm \sqrt{(\lambda_1 - \lambda_2)^2 + 4\lambda_4^2} \right), \\ c_{\pm} &= \frac{1}{2} \left(\lambda_1 + \lambda_2 \pm \sqrt{(\lambda_1 - \lambda_2)^2 + 4\lambda_5^2} \right), \\ f_{+} &= \lambda_3 + 2\lambda_4 + 3\lambda_5, \quad f_{-} = \lambda_3 + \lambda_5, \quad f_{1} = f_{2} = \lambda_3 + \lambda_4, \\ e_{1} &= \lambda_3 + 2\lambda_4 - 3\lambda_5, \quad e_{2} = \lambda_3 - \lambda_5, \quad p_{1} = \lambda_3 - \lambda_4. \end{aligned}$$

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 $< 8\pi$

3. Vacuum stability

$$D = m_{12}^2 \left(m_{11}^2 - k^2 m_{22}^2 \right) \left(t_\beta - k \right) > 0,$$

$$k = (\lambda_1 / \lambda_2)^{1/4}$$

BP-IS $\beta_{\lambda} = \beta_{\lambda}^{b} + \beta_{\lambda}^{Y}$ (5.5)

8 One should note, since the Yukawa couplings depend on the specific kinds of 2HDM, it is 7 Divious that their evolution as well as those of the quartic couplings are model-dependent. (5.5) 7 This is obvious from Equations. 5.2 and 5.1. One floot note, since the Yukawa couplings depend on the specific kinds of 2HDM, it is obvious that their evolution is the state of the quarter of the specific kinds of 2HDM, it is obvious that their evolution is the state of the specific kinds of 2HDM, it is obvious that their evolution is the specific kinds of 2HDM, it is obvious that their evolution is the specific kinds of 2HDM, it is obvious that their evolution is the specific kinds of 2HDM, it is obvious that their evolution of the quartic couplings is the one of the quarter of the difference of the quarter of the difference of the quarter of the specific kinds of 2HDM, it is obvious that their evolution is the specific coupling is the former of the difference of the quarter of the difference of t

Based and the Weishing second with a second problem of the problem of the second problem in the second problem in the second problem of the second proble

$$\beta_{\lambda} = \beta_{\lambda}^{b} + \beta_{\lambda}^{Y} \tag{5.5}$$

One should note, s**BR-tS** Yukawa couplings depend on the specific kinds of 2HDM, it is by the quartic couplings are model-dependent. $\beta_{\lambda} = \beta_{\lambda} + \beta_{\lambda}$ for the quartic couplings are model-dependent. $\beta_{\lambda} = \beta_{\lambda} + \beta_{\lambda}$ for $\beta_{\lambda} = \beta_{\lambda} + \beta_{\lambda}$ ld note, since she Yakawa couplings depend on the specific skinds of 2HDM, it is at the solution of the stand in continues depend on the specific kinds of 2HDM, it is ings depend on the specific kinds 57^{2} HDM, it is One should note, since the Yukawa coup well as those of the quartic coupling oby Gussilia to their evolution arrively as these of the curric Roupling protocold dependent few rem Equations by fands offication, for chrosings hose vellance vescaletly. uctophing rate of and there ^{3⁴} subsection, we will present here the full twotogettegylte Herrouninenetinario pointer Hings will thosphysbeauchinar terane consistent with and the since an experimental and the side of the side of the second shortly. soni that cin Scenario Initia de cant la terre and la terre and the terre ter Alerie puis of the second dependent of the second with the RS to veoter intervel where the ward of the two WS and Barand B Brand B B equice and subsection, constraints in BP12 correspondent on Wheregon and within gconstant sole addited to offestion to WS region with and at the BR2 Hour spania BRF WS hegion and

- RGE analysis to calculate the cutoff scale
 - 1. Run each parameter point to the next high energy scale via the RGEs.
 - 2. Check three conditions—unitarity, perturbativity, and vacuum stability.
 - 3. If any condition is broken at a particular energy scale, we stop the evolution and record the energy scale as the cutoff scale.

$$g_s, g, g', \lambda_{1,\dots,5}, \xi_f^{h,H,A}, m_{ij}^2, v_i, (i = 1, 2).$$

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3. Big impacts on the fermiophobic type-I from the high cutoff scale

Kim, Lee, Sanyal, Song [2207.05104] PLB 2022 • Scanning

For $m_{h_{\rm f}} = 20, 30, 40, 60, 96 \,{\rm GeV},$

 $M_{A/H^{\pm}} \in [80, 900] \text{ GeV},$ $t_{\beta} \in [1, 100], \qquad m_{12}^2 \in [0, 15000] \text{ GeV}^2.$ • Scanning steps

Step A Theoretical requirements and the low energy data

- 1. Higgs potential being bounded from below;
- 2. Perturbative unitarity of the scattering amplitudes;
- 3. Perturbativity of the quartic couplings;
- 4. Vacuum stability;
- 5. FCNC observables.

Step B High energy collider data

- 1. Higgs precision data via HIGGSSIGNALS;
- 2. direct searches at high energy collider via HIGGSBOUNDS.

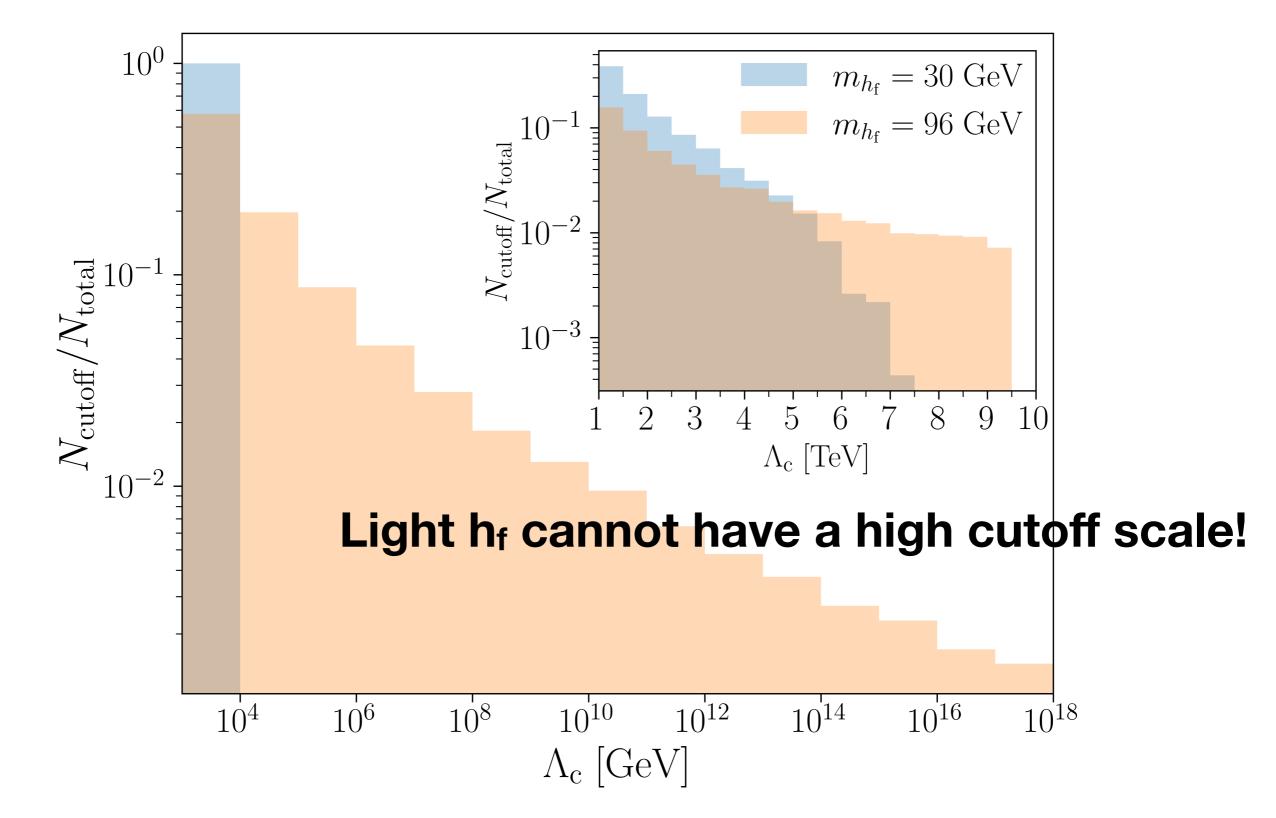
• Model survives at the EW scale, except for m_{hf} =60 GeV.

	Survival probabilities								
$m_{h_{\rm f}} [{\rm GeV}]$	20	96							
Step- $B(2)$	1.10%	0.27%	0.13~%	0.026~%	25.7%				
Step- $B(3)$	0.207%	0.048%	0.011%	0.000%	25.7%				

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$m_{h_{\rm f}}$ [GeV] 20 30 40 60 Step-B(2) 1.10% 0.27% 0.13% 0.026%						
Step-B(2) 1.10% 0.27% 0.13% 0.026%	96	60	40	30	20	$m_{h_{\rm f}} [{\rm GeV}]$
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Step-B(3) 0.207% 0.048% 0.011% 0.000%	25.7%	0.000%	0.011%	0.048%	0.207%	Step- $B(3)$

Different high-energy scale behaviors, according to m_{hf}

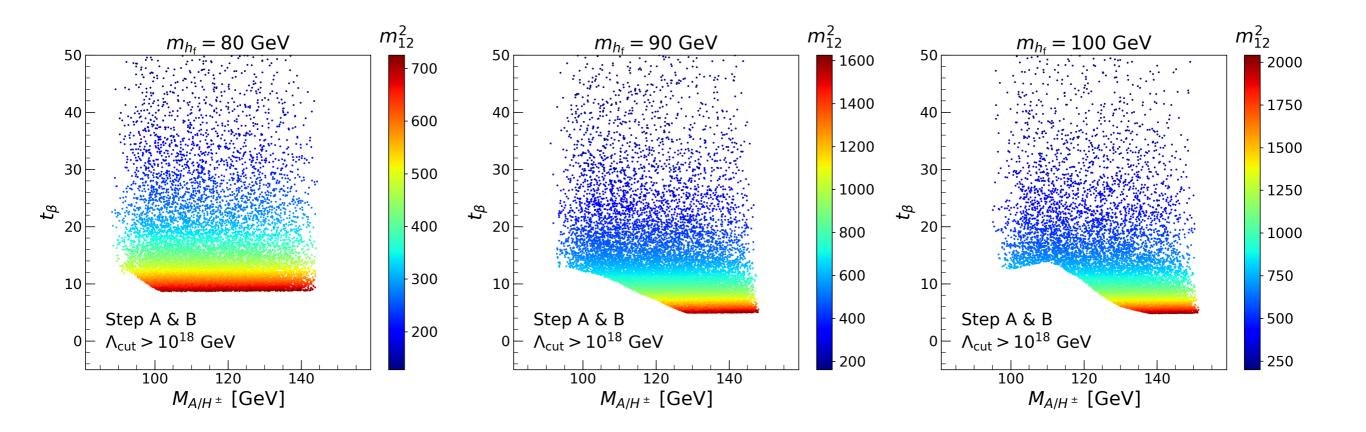


4. Characteristics of the parameters with high cutoff scale

Let's focus on the fermiophobic Higgs boson which can accommodate high Λ .

$$m_{h_{\rm f}} = 80, \ 90, \ 100 \ {\rm GeV}.$$

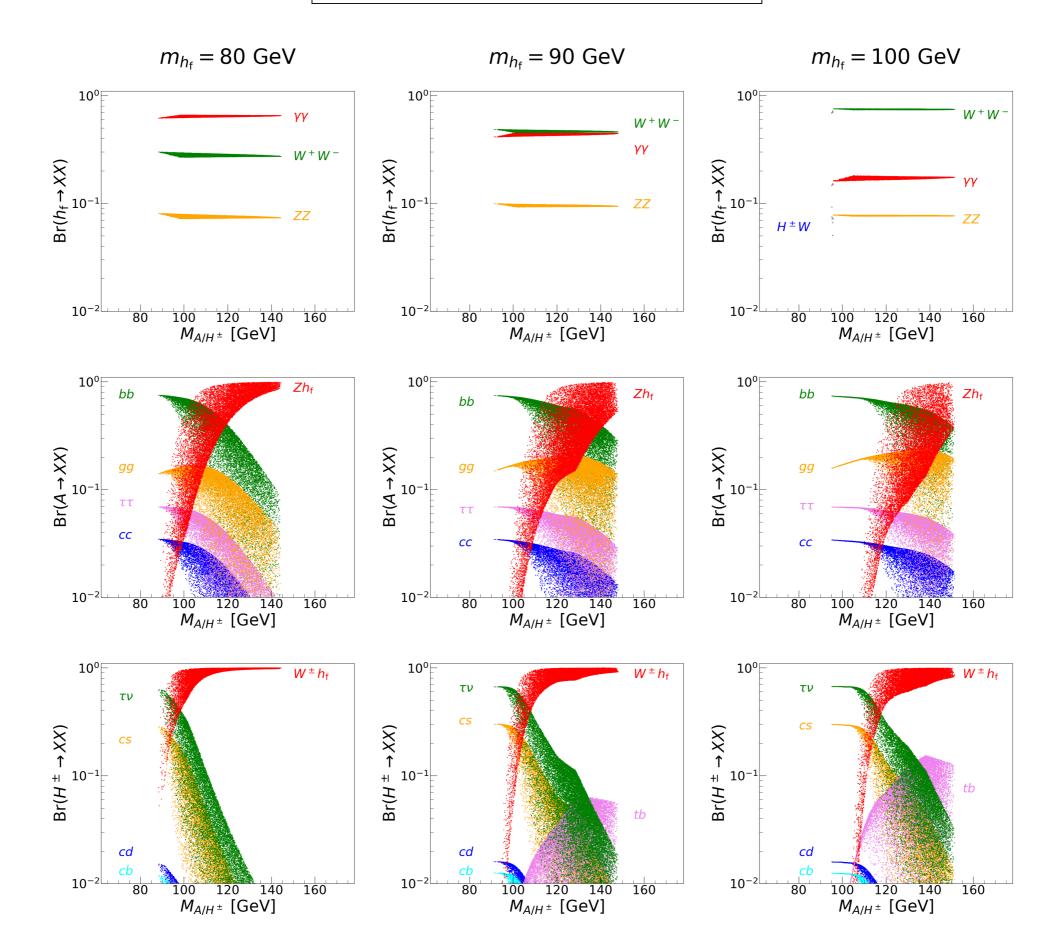
Viable parameter points with $\Lambda > 10^{18}$ GeV

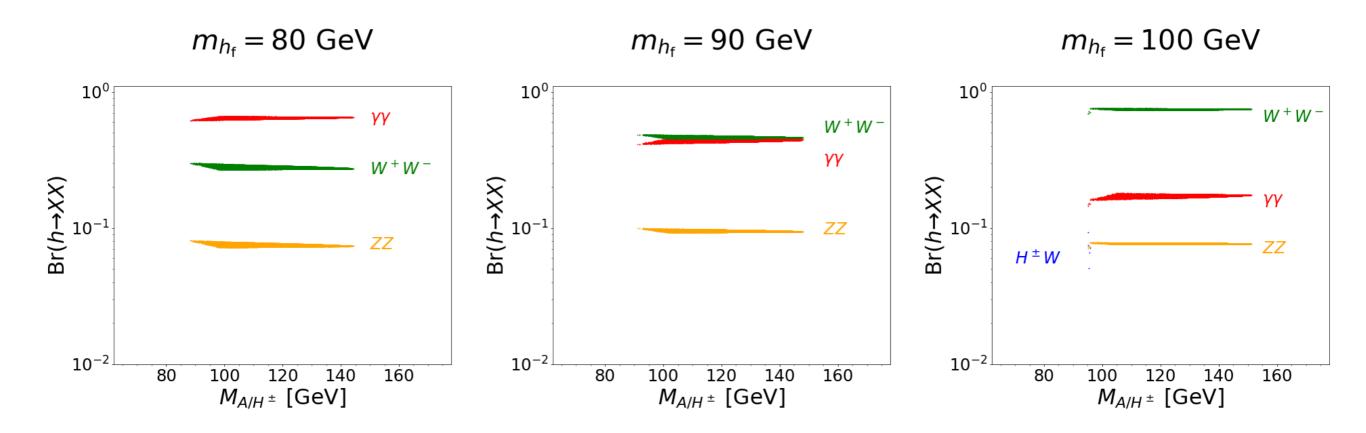


• Light masses for the other BSM Higgs bosons

- $\tan \beta > 6$
- m_{12}^2 is small.

Step A & B, $\Lambda_{cut} > 10^{18}$ GeV





- h_f decays into a photon pair, but not dominantly.
- WW (3-body and 4-body) is also sizable.

• Existing searches for the fermiophobic Higgs boson

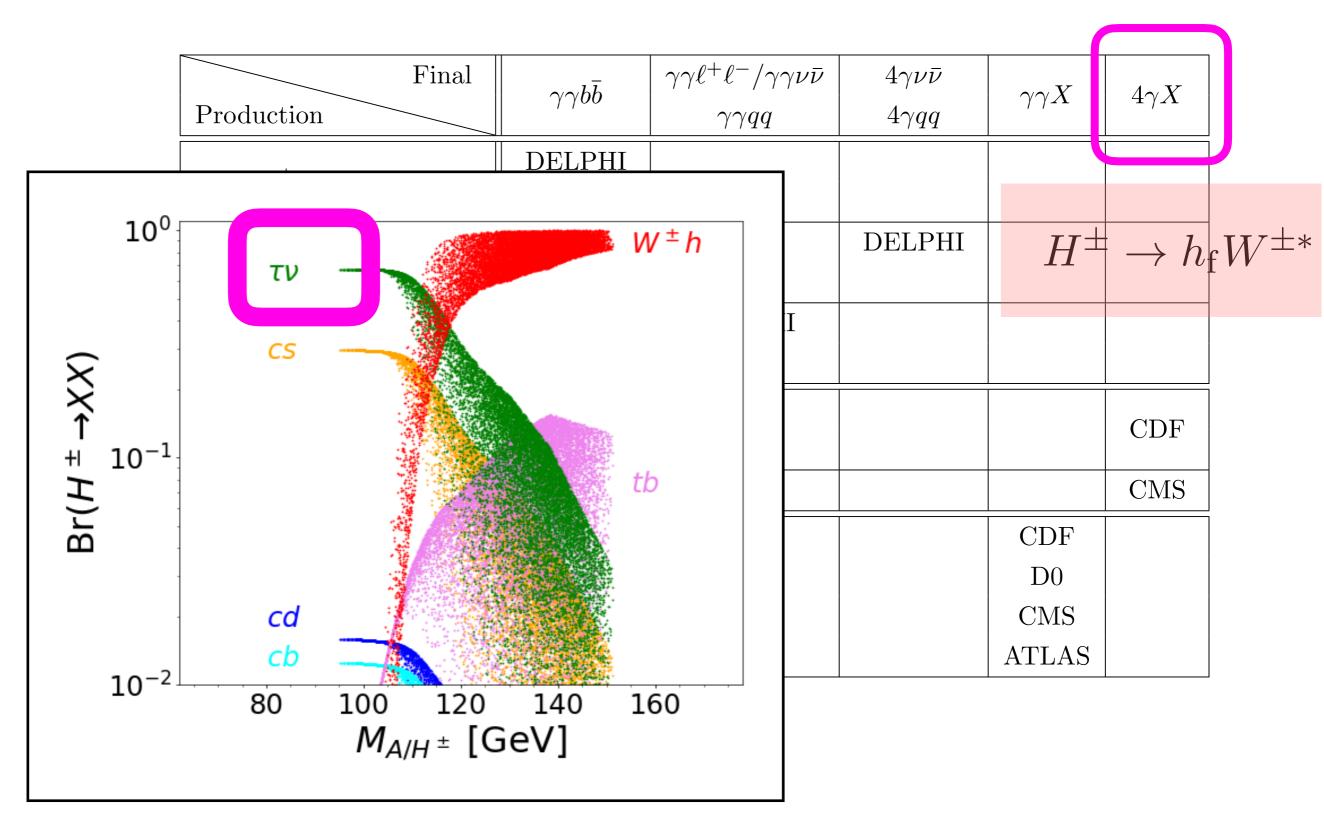
Final Production	$\gamma\gamma b\overline{b}$	$\begin{array}{c} \gamma\gamma\ell^+\ell^-/\gamma\gamma\nu\bar{\nu}\\ \gamma\gamma qq \end{array}$	$\begin{array}{c} 4\gamma\nu\bar{\nu}\\ 4\gamma qq \end{array}$	$\gamma\gamma X$	$4\gamma X$
$e^+e^- \rightarrow h_{\rm f}A$	DELPHI				
$e^+e^- \to h_{\rm f}A$			DELPHI		
$\rightarrow h_{\rm f} h_{\rm f} Z$					
$e^+e^- \to h_{\rm f} Z~(\mathbf{X})$		DELPHI			
$p\bar{p} \rightarrow h_{\rm f} H^{\pm}$					CDF
$\rightarrow h_{\rm f} h_{\rm f} W^{(*)}$					
$pp \to h_{\rm SM} \to h_{\rm f} h_{\rm f}$					CMS
				CDF	
$pp/p\bar{p} \rightarrow h_{\rm f} V/h_{\rm f} jj~(\textbf{X})$				D0	
				CMS	
				ATLAS	

• All rely on $h_f \rightarrow \gamma \gamma$ or $h_f h_f \rightarrow \gamma \gamma \gamma \gamma \gamma$

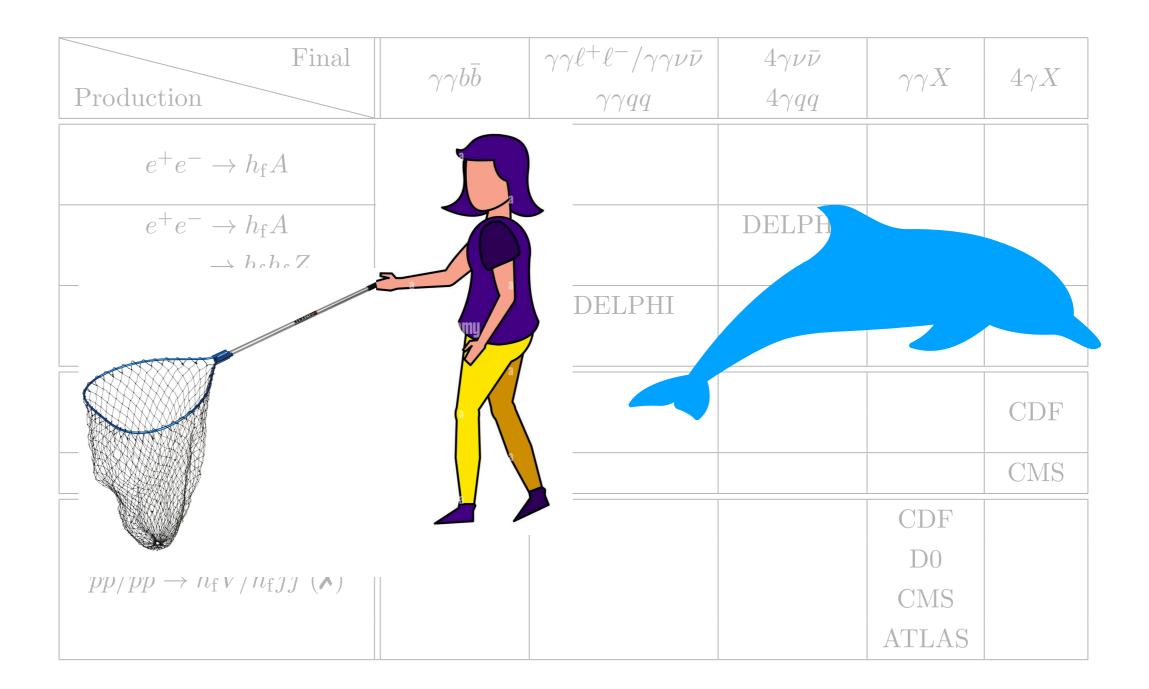
- Single h_f decay mode: a photon pair.
- BUT $h_f h_f$ can have another efficient mode, $\gamma\gamma$ WW.

$$\begin{split} m_{h_{\rm f}} &= 80 \; {\rm GeV}: & {\rm Br}(h_{\rm f}h_{\rm f} \to \gamma\gamma WW) \simeq 36\%, & {\rm Br}(h_{\rm f} \to \gamma\gamma)^2 \simeq 35\%, \\ m_{h_{\rm f}} &= 90 \; {\rm GeV}: & {\rm Br}(h_{\rm f}h_{\rm f} \to \gamma\gamma WW) \simeq 40\%, & {\rm Br}(h_{\rm f} \to \gamma\gamma)^2 \simeq 20\%, \\ m_{h_{\rm f}} &= 100 \; {\rm GeV}: & {\rm Br}(h_{\rm f}h_{\rm f} \to \gamma\gamma WW) \simeq 30\%, & {\rm Br}(h_{\rm f} \to \gamma\gamma)^2 \simeq 4\%, \end{split}$$

• Existing searches for the fermiophobic Higgs boson

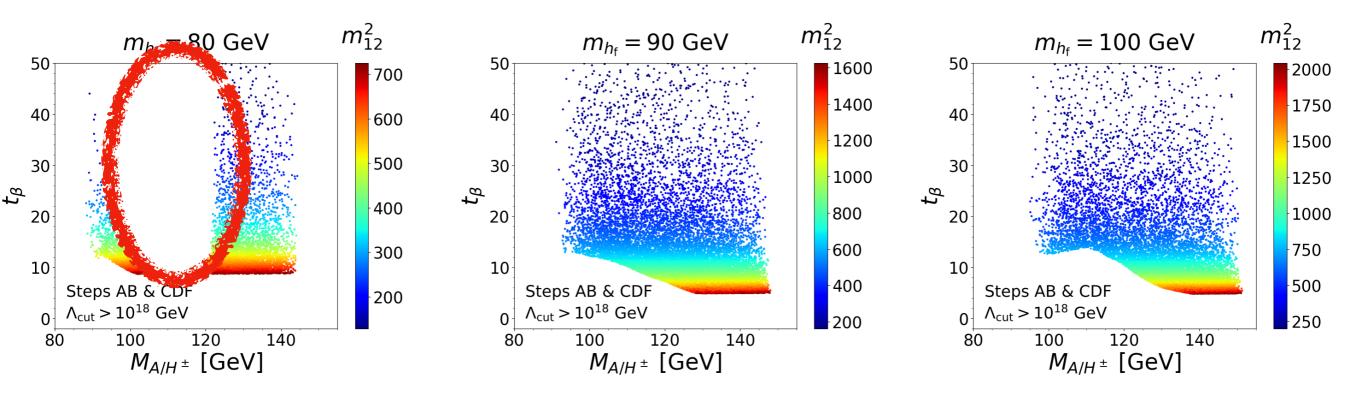


• Existing searches for the fermiophobic Higgs boson



Viable parameter points with Λ >10¹⁸ GeV

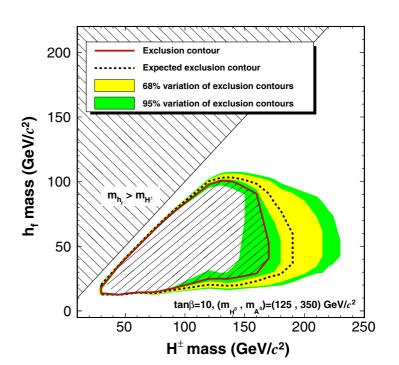
mhf=70 GeV is excluded



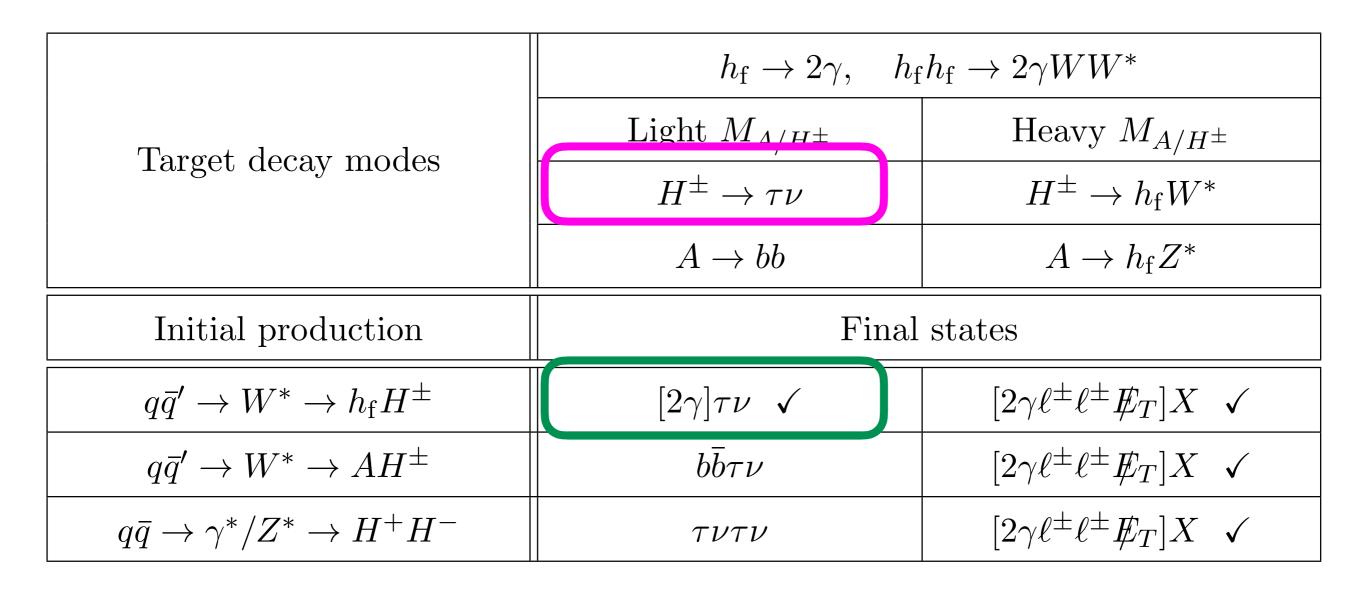
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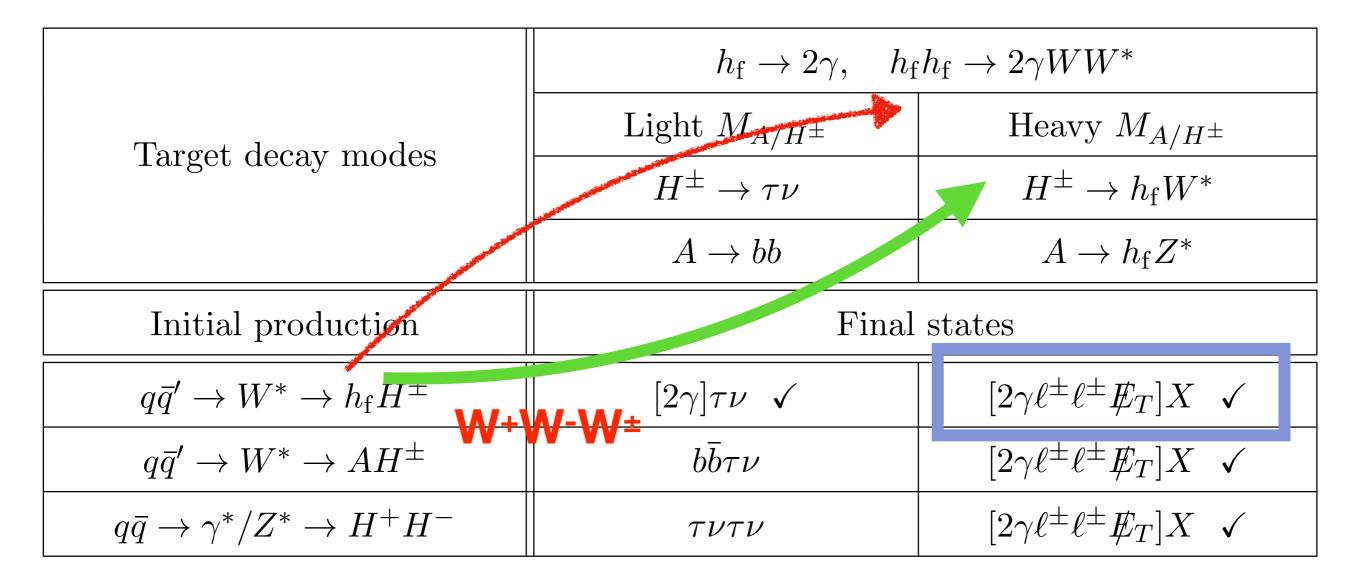
CDF 4γ

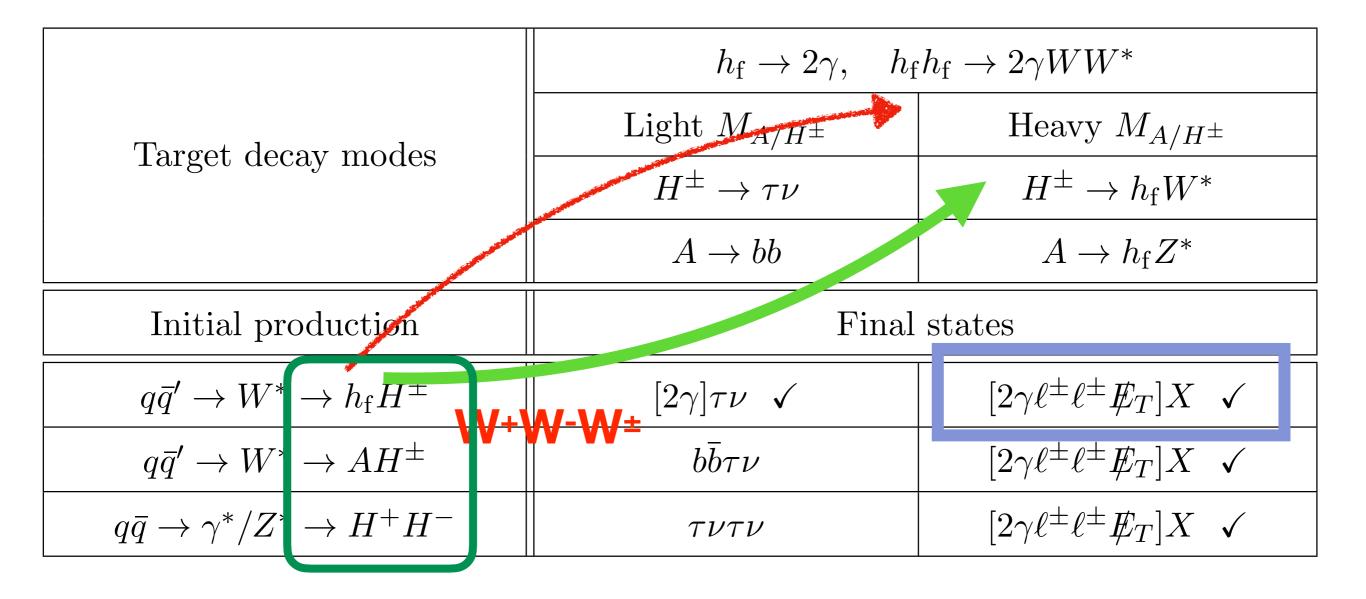
Search for a low-mass neutral Higgs boson with suppressed couplings to fermions using events with multiphoton final states



	$h_{\rm f} \to 2\gamma, h_{\rm f} h_{\rm f} \to 2\gamma W W^*$				
Target decay modes	Light $M_{A/H^{\pm}}$	Heavy $M_{A/H^{\pm}}$			
	$H^{\pm} \to \tau \nu$	$H^{\pm} \to h_{\rm f} W^*$			
	$A \to bb$	$A \rightarrow h_{\rm f} Z^*$			
Initial production	Final	states			
$q\bar{q}' \to W^* \to h_{\rm f} H^{\pm}$	$[2\gamma]\tau\nu \checkmark$	$[2\gamma\ell^{\pm}\ell^{\pm}E_{T}]X \checkmark$			
$q\bar{q}' \to W^* \to AH^{\pm}$	$b\overline{b} au u$	$[2\gamma\ell^{\pm}\ell^{\pm}E_{T}]X \checkmark$			
$q\bar{q} \to \gamma^*/Z^* \to H^+H^-$	τντν	$[2\gamma\ell^{\pm}\ell^{\pm}E_{T}]X \checkmark$			

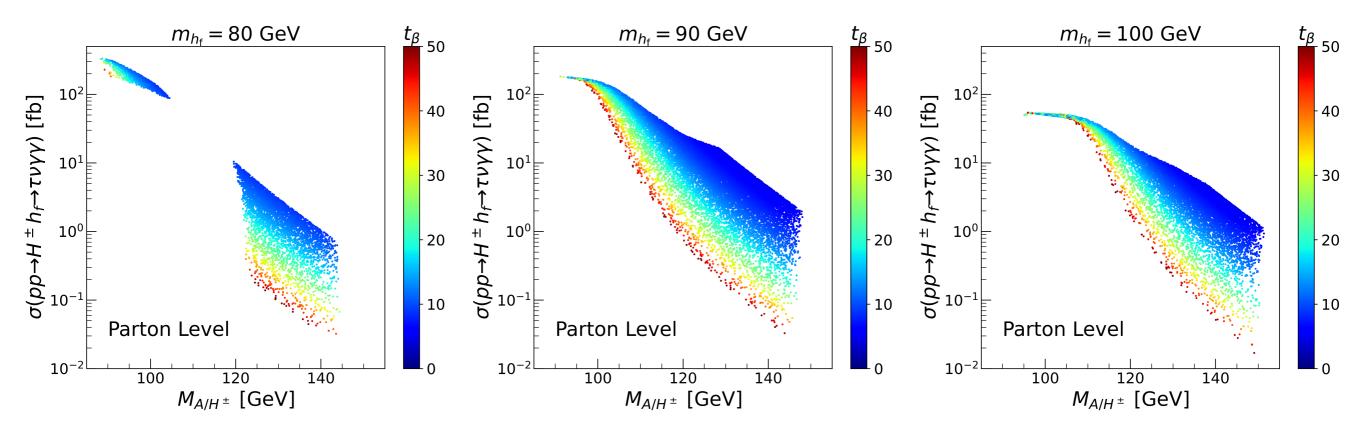






5. The first golden channel: $\tau^{\pm}\nu\gamma\gamma$

Parton-level cross sections



- The larger tan β , the smaller σ .
- The larger MH \pm , the smaller σ .
- The signal rate is sizable, above 100 fb.

Signal-to-Background analysis at the detector level

Final state of $\tau^{\pm}\nu\gamma\gamma$

$$\begin{split} \text{BP-}\tau 1: & m_{h_{\text{f}}} = 80 \text{ GeV}, & M_{A/H^{\pm}} = 95.8 \text{ GeV}, \\ m_{12}^2 = 501.1 \text{ GeV}^2, & t_{\beta} = 12.5, \\ \text{BP-}\tau 2: & m_{h_{\text{f}}} = 90 \text{ GeV}, & M_{A/H^{\pm}} = 100.3 \text{ GeV}, \\ m_{12}^2 = 318.4 \text{ GeV}^2, & t_{\beta} = 25.4, \\ \text{BP-}\tau 3: & m_{h_{\text{f}}} = 100 \text{ GeV}, & M_{A/H^{\pm}} = 106.9 \text{ GeV}, \\ m_{12}^2 = 274.3 \text{ GeV}^2, & t_{\beta} = 36.4. \end{split}$$

Cross sections in units of fb for $\tau^{\pm}\nu\gamma\gamma$								
	BP- $\tau 1$	BP- $\tau 2$	BP- $\tau 3$	$jj\gamma$	$j\gamma\gamma$	$W^{\pm}\gamma\gamma$	$Z\gamma\gamma$	
parton-level with MG	197.2	122.1	43.5	7.73×10^{7}	1.08×10^5	140.3	184.7	
Basic Selection	21.84	14.87	5.89	1.25×10^3	45.25	0.761	0.954	
$p_T^{\gamma_1} > 70 \text{ GeV}$ $p_T^{\gamma_2} > 40 \text{ GeV}$	9.31	7.08	3.11	144.62	28.73	0.205	0.186	
$m_{\gamma_1\gamma_2} \in [62.5, 125] \text{ GeV}$	9.20	6.98	3.08	21.94	4.35	0.023	0.032	
$\not\!$	6.49	4.89	2.16	2.51	0.052	0.007	0.003	
veto jets	4.36	3.18	1.43	0.98	0.011	0.004	0.002	

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For the basic selection

- We select events with at least one $\tau_{\rm h}$ -jet and two leading photons with $p_T > 20$ GeV, $|\eta| < 2.5$, and the angular separation of $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} > 0.4$.

Cross section in units

	Cut					$W^{\pm}Zj$	$W^{\pm}Z\gamma$
	Cross	sections i	fatherfore they are	Ywith MG	801.22	7.80	
	BP- $\tau 1$	BP- $\tau 2$	BP- $ au 3$	Selė́ė́ting ($\pm \ell \pm j \gamma \gamma$	\$\$2.457	$Z\gamma \chi 03$
parton-level with MG	197.2	122.1	43.5	7.73×10^{7}	$\overline{C_{e}^{1.08} \times 10^{5}}$	140.3	184.7
Basic Selection	21.84	14.87	5.89	1.25×10^{3}	45.25	0.0799	0.9 0 404
$p_T^{\gamma_1} > 70 \text{ GeV}$	9.31	7.08	9 11		$\begin{array}{c c} 20 \text{ GeV} \\ \hline 28.72 \end{array}$	0.205	0.196
$p_T^{\gamma_2} > 40 \text{ GeV}$	9.01	1.00	3.11	$\ \eta\ \stackrel{144.62}{<} 2.5, \Delta$	R < 0.4	0.039	0.18621
$m_{\gamma_1\gamma_2} \in [62.5, 125] \text{ GeV}$	9.20	6.98	3.08	21.94	4.35	0.023	0.032
$\not\!$	6.49	4.89	2.16 T	able 35Cut-f	low 0h252 of	the Coos s	ections for
veto jets	4.36	3.18	1.43 T	he ba dleg roun	ds of $M \pm Z\gamma$	$an 01.0004+\ell$	-0i0021de

- Huge backgrounds from $jj\gamma$ and photon as well $j_{s} \neq j_{T} = \frac{5}{20} \& e^{10}$ from $jj\gamma$. probability of the $W^{\pm}Zj$ and $Z\ell^{+}\ell^{-}$ backgrounds
- QCD jets can be mistaggedaasitphotons.gorataparation yield alm
- The contribution from radiation photons is sizable. We can integrated luminosity of 300 fb⁻¹. Considering

the significances are

$$\Delta_{\rm bg} = 0: \qquad \mathcal{S}_{\rm BP-SS1} = 25.5 \qquad \mathcal{S}_{\rm BP}$$

Cross sections in units of fb for $\tau^{\pm}\nu\gamma\gamma$								
	BP- $\tau 1$	BP- $\tau 2$	BP- $\tau 3$	$jj\gamma$	$j\gamma\gamma$	$ W^{\pm} \gamma \gamma$	$Z\gamma\gamma$	
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veto jets	4.36	3.18	1.43	0.98	0.011	0.004	0.002	

Veto jets with $p_T > 20 \text{ GeV}$ and $|\eta| < 2.5$

We can tame the background!

Significance with 300/fb

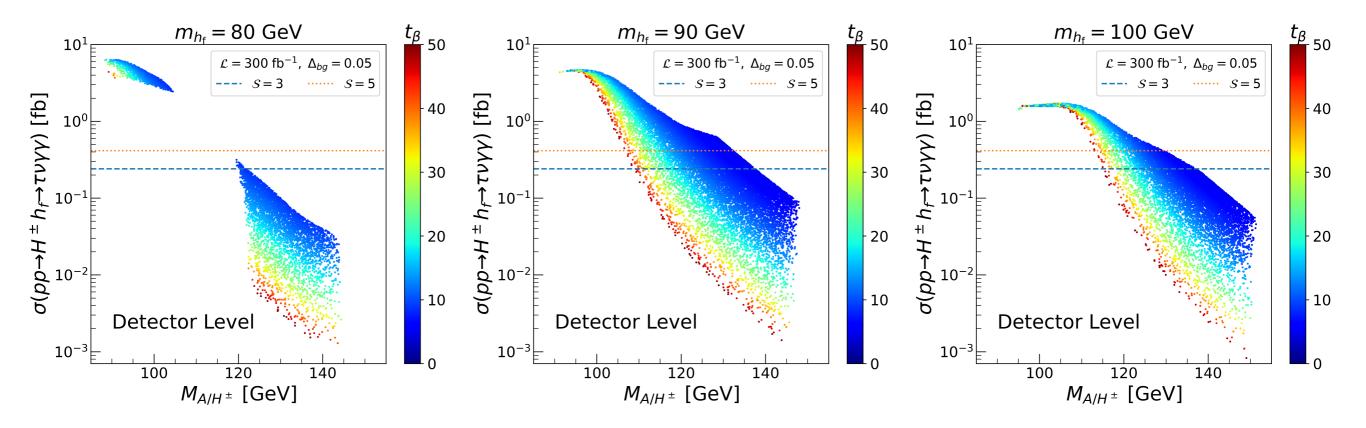
$$\Delta_{\rm bg} = 0: \qquad S_{\rm BP-\tau 1} = 52.8, \qquad S_{\rm BP-\tau 2} = 41.0, \qquad S_{\rm BP-\tau 3} = 20.9,$$

$$\Delta_{\rm bg} = 5\%: \qquad S_{\rm BP-\tau 1} = 34.2, \qquad S_{\rm BP-\tau 2} = 27.3, \qquad S_{\rm BP-\tau 3} = 14.7.$$

Very promising!

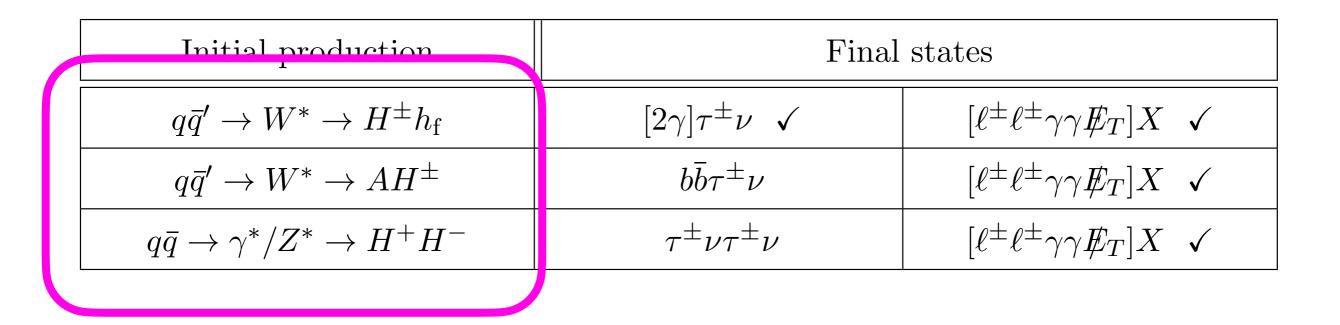
Isn't it cherry-picking? The fancy results are for the BPs.

% What about the other parameters?

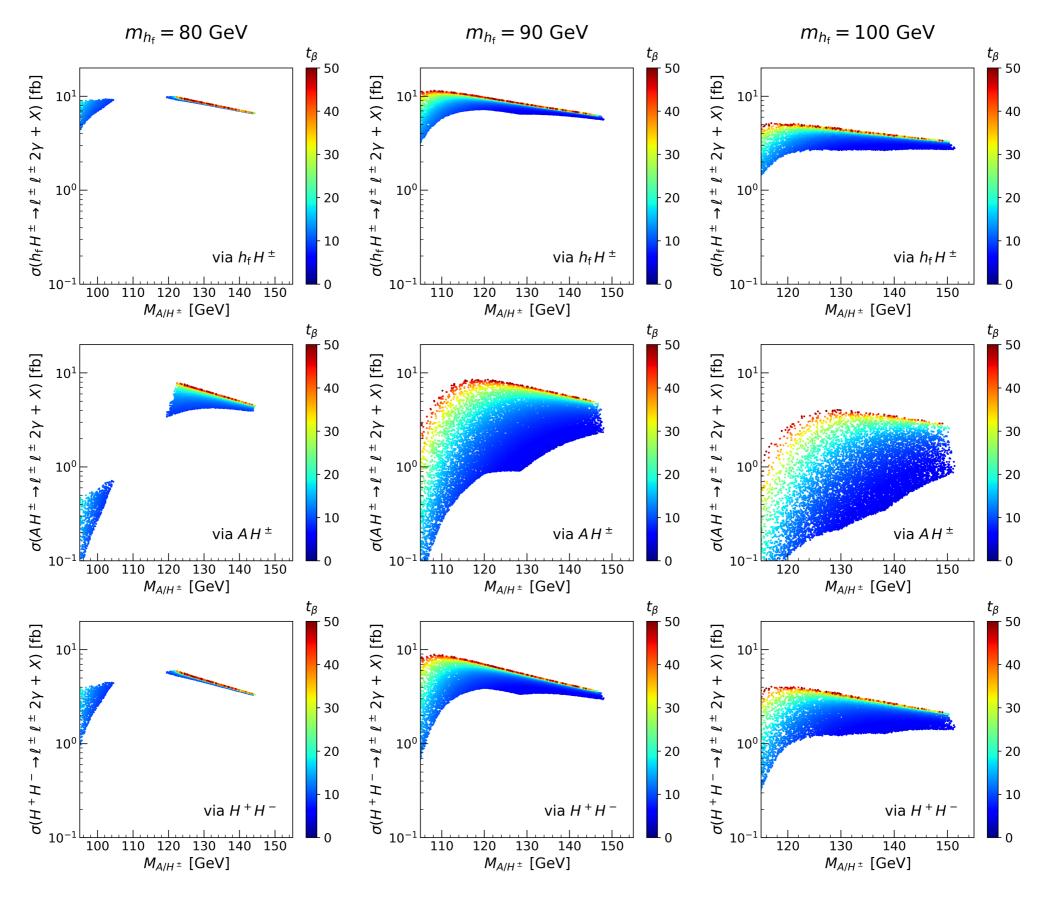


- Most of the parameters with light $M_{H\pm}$ can enjoy the significance larger than 5 with 300/fb.
- The larger tan β , the smaller σ .

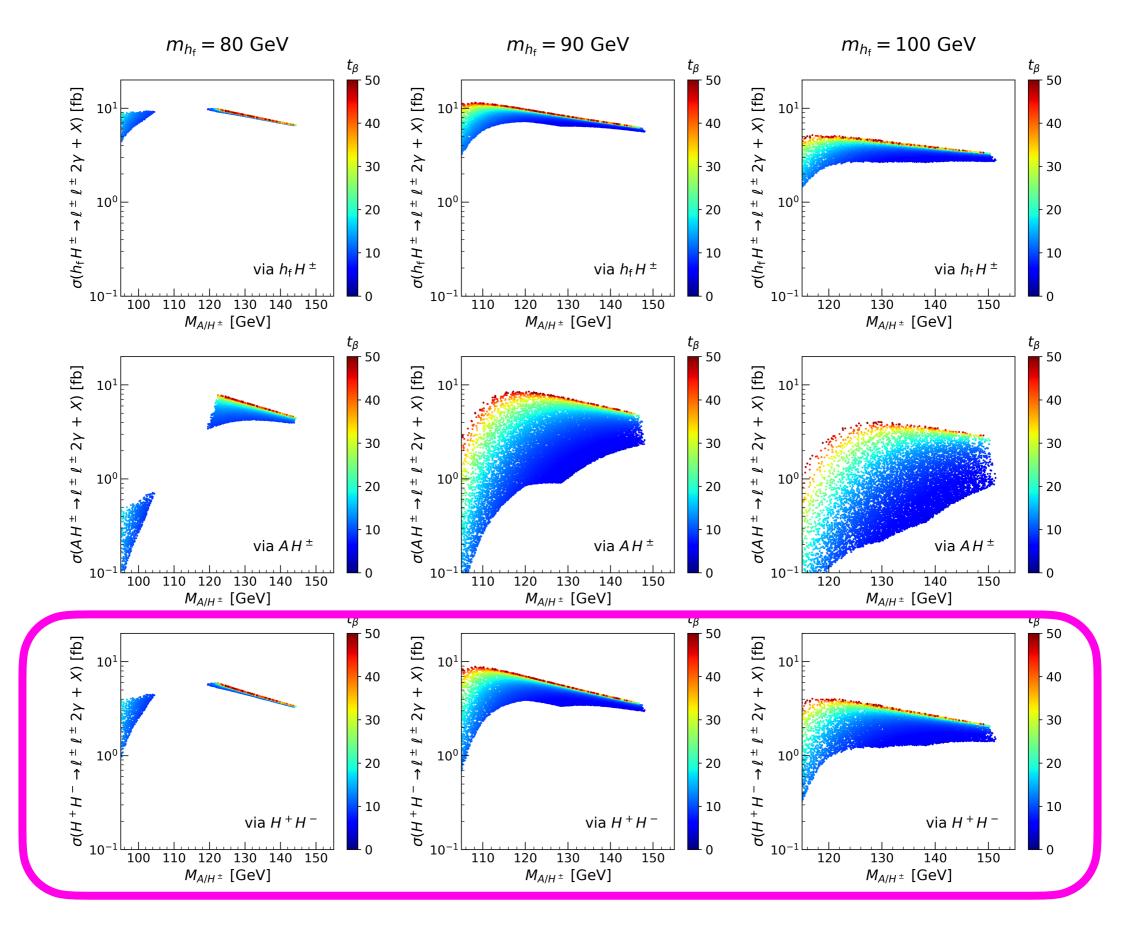
6. The second golden mode: ℓ ± ℓ ± γγ + X



Three channels

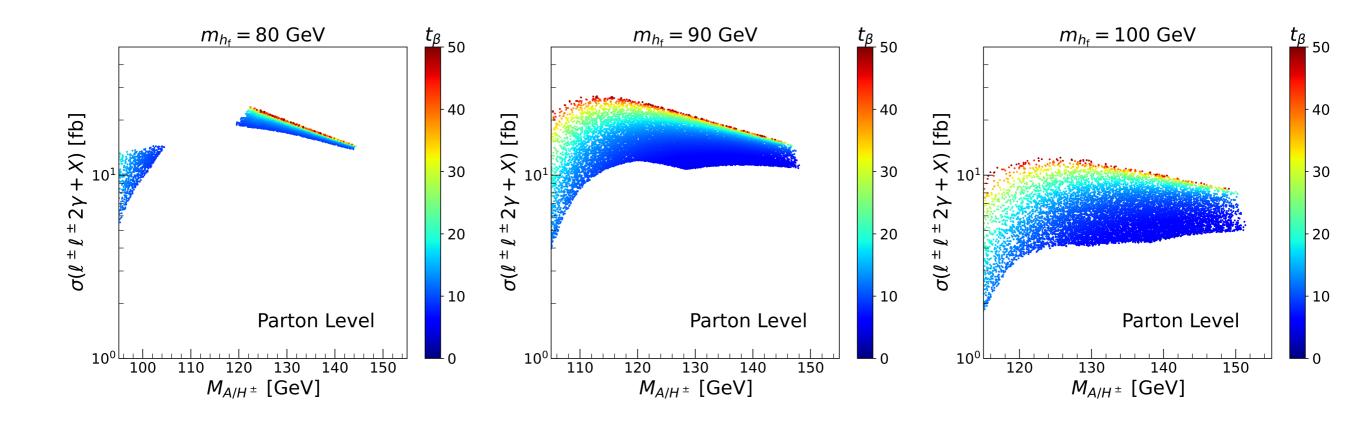


All three channels have compatible σ .



Not considered in the literature.

Inclusive cross sections



- The larger $tan\beta$, the larger σ .
- The signal rate is sizable, above 10 fb.

Signal-to-background analysis at the detector level

BP-SS1:	$m_{h_{\rm f}} = 80 { m ~GeV},$	$M_{A/H^{\pm}} = 122.4 \text{ GeV},$
	$m_{12}^2 = 166.5 \ \mathrm{GeV}^2,$	$t_{\beta} = 38.4,$
BP-SS2:	$m_{h_{\rm f}} = 90 { m ~GeV},$	$M_{A/H^{\pm}} = 112.9 \text{ GeV},$
	$m_{12}^2 = 166.1 \ \mathrm{GeV}^2,$	$t_{\beta} = 48.7,$
BP-SS3:	$m_{h_{\rm f}} = 100 \; {\rm GeV},$	$M_{A/H^{\pm}} = 125.7 \text{ GeV},$
	$m_{12}^2 = 203.5 \ \mathrm{GeV}^2,$	$t_{\beta} = 49.1.$

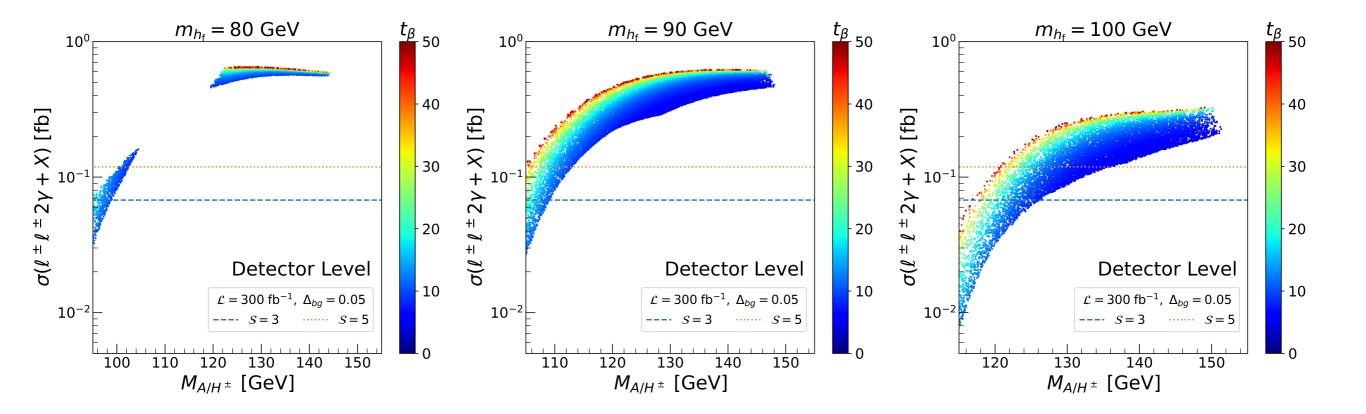
Cross sections in units of fb for $\ell^{\pm}\ell^{\pm}\gamma\gamma \not\!$									
parton-level with MG	23.50	26.95	12.45	1.25×10^3	170.43	7.80			
Selecting $\ell^{\pm}\ell^{\pm}\gamma\gamma$	9.57	9.53	7.50	115.75	22.10	1.03			
$p_T > 20 \text{ GeV},$ $\not\!$	1.50	0.77	0.43	0.164	0.046	0.04			
$ \eta < 2.5, \ \Delta R > 0.4$	0.735	0.354	0.227	0.070	0.027	0.021			

Almost background-free environment with the basic selection

Signal significances with 300/fb

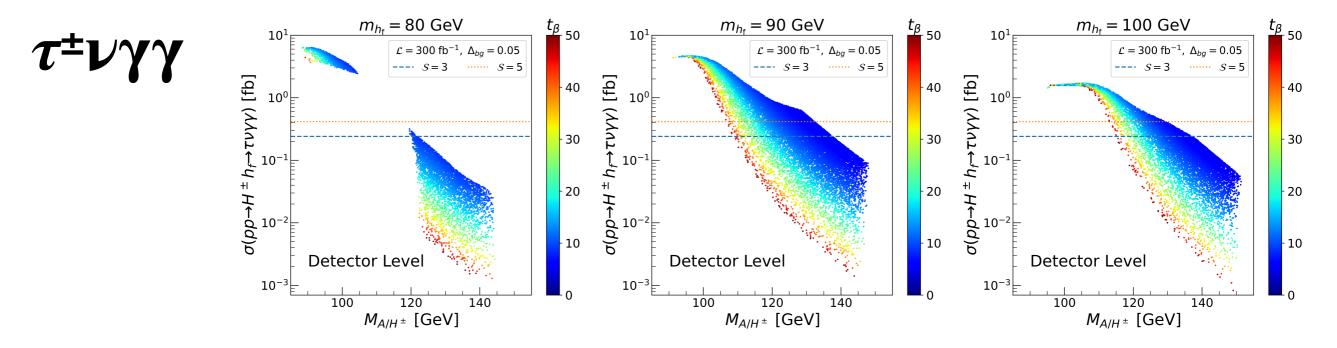
$$\Delta_{\rm bg} = 0: \qquad S_{\rm BP-SS1} = 23.9, \qquad S_{\rm BP-SS2} = 13.4, \qquad S_{\rm BP-SS3} = 9.3, \\ \Delta_{\rm bg} = 5\%: \qquad S_{\rm BP-SS1} = 21.8, \qquad S_{\rm BP-SS2} = 12.5, \qquad S_{\rm BP-SS3} = 8.7.$$

Again very promising!!!

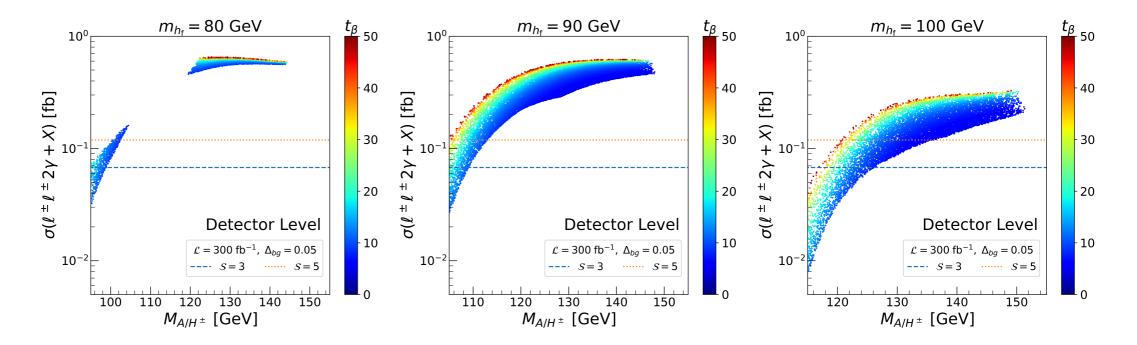


Most parameters with heavy MH± can be probed.

Total complementary between two channels



 $\ell \pm \ell \pm \gamma \gamma + X$



7. Conclusions

- The light fermiophobic Higgs boson model in type-I can retain the cutoff scale all the way up to the Planck scale.
- High cutoff scale requires m_{hf} above 80 GeV and $M_A/M_{H\pm}$ below 142 GeV.
- Two discovery channels, $\tau^{\pm}\nu\gamma\gamma$ and $\ell^{\pm}\ell^{\pm}\gamma\gamma$ + X, can discover the fermiophobic Higgs boson well with 300/fb. .