New discovery modes for a light charged Higgs boson at the LHC

Abdesslam Arhrib

Faculté des Sciences et Techniques Tangier, Morocco

Based on A.A, R. Benbrik, M. Krab, S. Moretti, Y. Wang and Q. S. Yan, "New discovery modes for a light charged Higgs boson at the LHC," JHEP **10** (2021) and JHEP **12** (2021)

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Outlines

- Introduction
- Two Higgs doublet model (2HDM)
- Constraining 2HDM using $H_{125} \to AA \to 4\gamma$
- Bosonic decays of charged Higgs: $H^{\pm} \to W^{\pm}h^0/W^{\pm}A^0$
- $W4\gamma$, $W4b$, $W2b2\tau$ signatures for a light $H^{\pm}$ at the LHC.
- Conclusions

Introduction:

After the Higgs-like discovery at $7 \oplus 8 \oplus 13$ TeV LHC, the mission of the LHC run at 13.6 TeV is:

- The improvement of the Higgs-like mass and Higgs-like coupling measurements.
- Find a clear hint of new physics beyond SM

Introduction:

After the Higgs-like discovery at $7 \oplus 8 \oplus 13$ TeV LHC, the mission of the LHC run at 13.6 TeV is:

- The improvement of the Higgs-like mass and Higgs-like coupling measurements.
- Find a clear hint of new physics beyond SM
- Accurate measurements of the Higgs-like couplings to SM particles would help to determine if the Higgs-like particle is the SM Higgs or a Higgs that belongs to a higher representations
- Most of the High representations predicts: singly and/or doubly charged Higgs

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1^0 + i a_1) \end{pmatrix}; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2^0 + i a_2) \end{pmatrix}.$$

The most general potential for 2HDM:

$$\begin{aligned} V(\Phi_1,\Phi_2) &= m_1^2 \Phi_1^\dagger \Phi_1 + m_2^2 \Phi_2^\dagger \Phi_2 + (m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c}) \\ &+ \frac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 + \frac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 \\ &+ \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\ &+ \frac{1}{2}[\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + (\lambda_6 \Phi_1^\dagger \Phi_1 + \lambda_7 \Phi_2^\dagger \Phi_2)\Phi_1^\dagger \Phi_2 + \text{h.c.}], \end{aligned}$$

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- $\mathbb{Z}_2$: $\Phi_i \to -\Phi_i \Leftrightarrow \lambda_{6,7} = 0$
- No explicit CP violation: $Im(m_{12}^2 \lambda_{5,6,7}) = 0$

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}\left(v_1 + \phi_1^0 + i a_1\right) \end{pmatrix} ; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}\left(v_2 + \phi_2^0 + i a_2\right) \end{pmatrix} .$$

$$-\mathcal{L}_Y = \sum_{a=1,2} \left[\bar{Q}_L \, Y_d^a \, \Phi_a d_R + \bar{Q}_L \, Y_u^a \, \tilde{\Phi}_a u_R + \bar{L}_L \, Y_\ell^a \, \Phi_a \ell_R + \text{h.c.} \right] ,$$

leads to FCNCs at tree level.

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• Classification of 2HDMs satisfying the Glashow-Weinberg condition which guarantees the absence of tree-level FCNC.

Type-I	$Y^1_{u,d} = 0, Y^1_\ell = 0$
Type-II	$Y^1_u = Y^2_{d,\ell} = 0$
Type-III (X)	$Y^1_{u,d} = Y^2_\ell = 0$
Type-IV (Y)	$Y^1_{u,\ell} = Y^2_d = 0$

CP conserving 2HDM: CP-even h,H, CP-odd A and $H^{\pm}$

The Yukawa Lagrangian:

$$-\mathcal{L}_{Yuk} = \sum_{\psi=u,d,l} \left(\frac{m_\psi}{v} \kappa_\psi^h \bar{\psi}\psi h^0 + \frac{m_\psi}{v} \kappa_\psi^H \bar{\psi}\psi H^0 - i \frac{m_\psi}{v} \kappa_\psi^A \bar{\psi}\gamma_5 \psi A^0 \right) +$$
$$\left(\frac{V_{ud}}{\sqrt{2}v} \bar{u}(m_u \kappa_u^A P_L + m_d \kappa_d^A P_R) d H^+ + \frac{m_l \kappa_l^A}{\sqrt{2}v} \bar{\nu}_L l_R H^+ + H.c. \right)$$

	κ_u^h	κ_d^h	κ_l^h	κ_u^A	κ_d^A	κ_l^A
Type-I	c_α/s_β	c_α/s_β	c_α/s_β	$\cot\beta$	$-\cot\beta$	$-\cot\beta$
Type-II	c_α/s_β	$-s_\alpha/c_\beta$	$-s_\alpha/c_\beta$	$\cot\beta$	$\tan\beta$	$\tan\beta$
Type-III	c_α/s_β	c_α/s_β	$-s_\alpha/c_\beta$	$\cot\beta$	$-\cot\beta$	$\tan\beta$
Type-IV	c_α/s_β	$-s_\alpha/c_\beta$	c_α/s_β	$\cot\beta$	$\tan\beta$	$-\cot\beta$

Constraints

- Stability of the 2HDM potential requires that it should be bounded from below, [Deshpande and E. Ma, PRD18'1978]

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

- Perturbative unitarity: $V_L^+ V_L^- \to V_L^+ V_L^-$, $h_i\ h_j \to h_i\ h_j$ ...

  [A.A et al PLB490 (2000), S. Kanemura PLB313 (1993)]
- Electroweak precision constraints through S, T, and U

  [W. Grimus et al. JPG35 (2008); PLB801 (2008)]
- B-physic constraints: 2HDM-Calculator linked to SuperIso

  [N. Mahmoudi CPC180 (2009)]
- In 2HDM-II and IV: $m_{H^\pm} > 800$ GeV for any $\tan\beta > 1$

  [Misiak et al EPJC'2017, JHEP'20]
- In 2HDM-I there is no limit on $H^\pm$ for $\tan\beta \geq 2$
- HiggsBounds and HiggsSignals

  [P. Bechtle et al CPC181 (2010)] [P. Bechtle et al Eur.Phys.J.C 74]

Charged Higgs production

(See "Prospects for charged Higgs searches at the LHC," arXiv:1607.01320: A. Akeroyd et al)

- Light charged Higgs, i.e, with $m_{H^\pm} \leq m_t - m_b$: are copiously produced from $t\bar{t}$ production $pp \to t\bar{t} \to t\bar{b}H^- + \text{c.c.}$

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- various direct production modes:
  QCD: $gb \to tH^-$ and $gg \to t\bar{b}H^-$,
  $gg \to W^\pm H^\mp$ (loop), , $gg \to H^+H^-$(loop)
  $b\bar{b} \to W^\pm H^\mp$
  $q\bar{q} \to \gamma, Z \to H^+H^-$,
  $q\bar{q}' \to W^* \to \phi H^\pm$ where $\phi = h^0, H^0, A^0$,
- W-Higgs fusion : $qb \to q'H^+b$
- light $H^\pm$: $\sigma(pp \to t\bar{t} \to t\bar{b}H^-)$ vs $\sigma(q\bar{q} \to \gamma, Z \to H^+H^-)$, $\sigma(q\bar{q}' \to W^* \to \phi H^\pm)$ where $\phi = h^0, A^0$

Charged Higgs decays

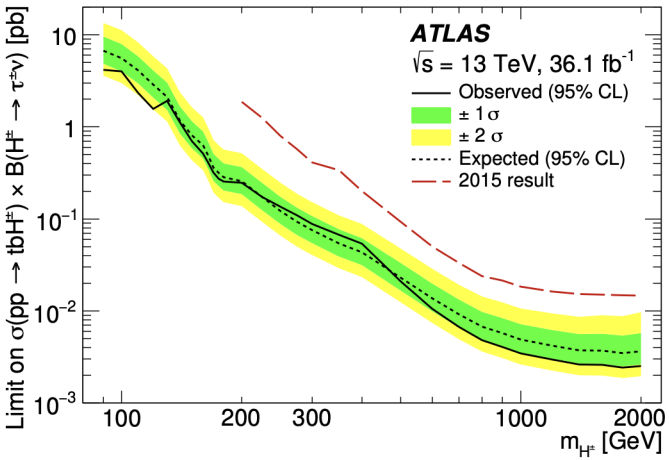
Fermionic decays

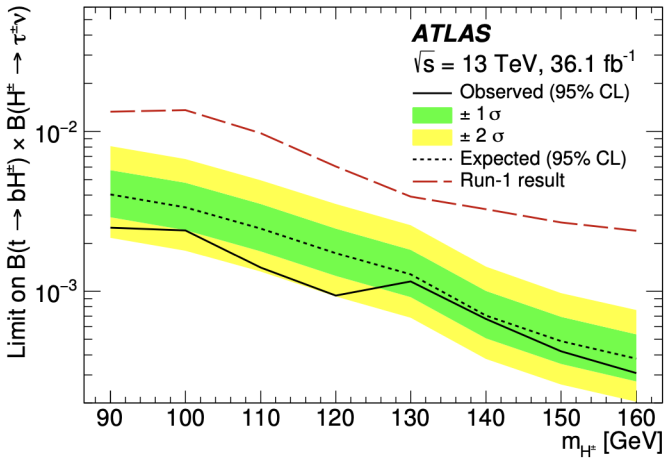
- $H^{\pm} \to \tau\nu \quad , \quad cs \quad , \quad cb$
- $H^{\pm} \to tb$

Bosonic decays

- $H^{\pm} \to W^{\pm}\phi^0 \quad , \quad \phi^0 = h^0, H^0, A^0$
- $H^{\pm} \to W^{\pm}\gamma, W^{\pm}Z$: small (loop mediated)

ATLAS and CMS Limit on $H^{\pm}$: low mass

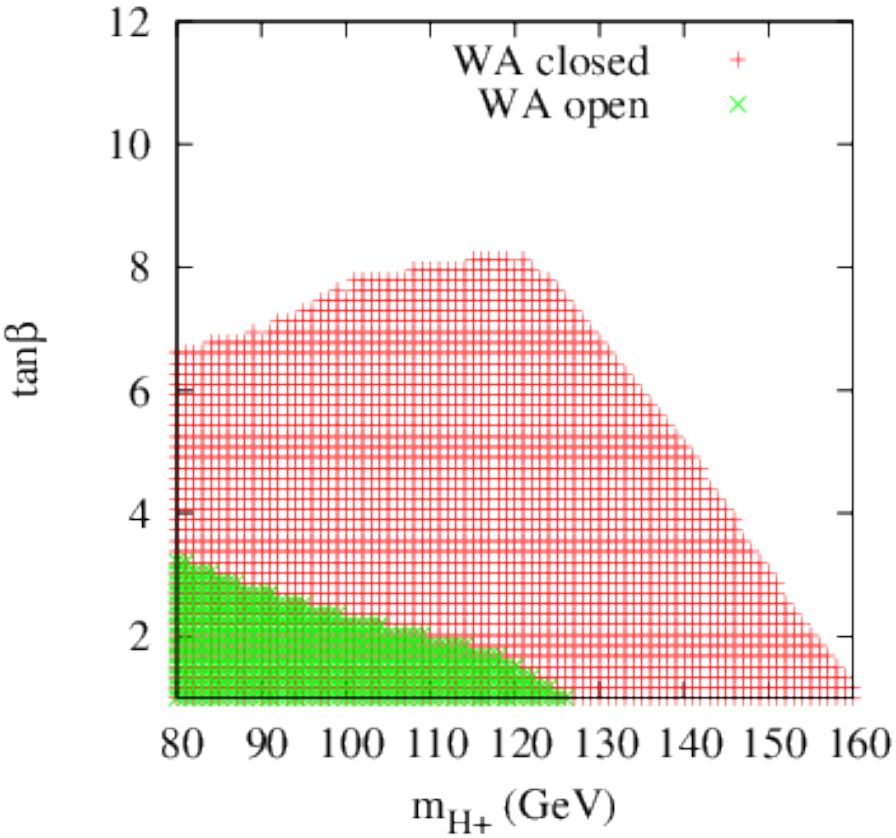




ATLAS and CMS Limits from $H^{\pm} \to c\bar{s}$ are weaker.

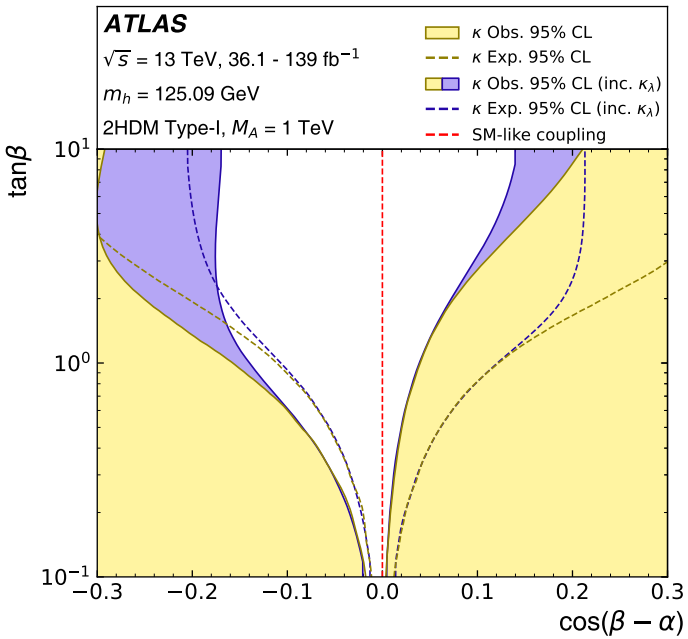
$Br(t \to bH^{+}) = \frac{\Gamma(t \to bH^{+})}{\Gamma(t \to bH^{+}) + \Gamma(t \to bW)}$: depends only on $(\tan\beta, m_{H^{\pm}})$

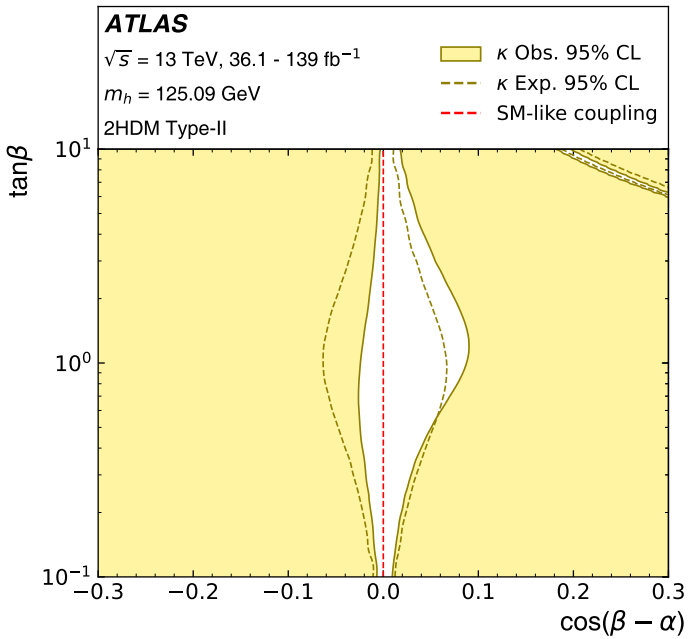
Implication for 2HDM-I for $m_A = 40$ GeV



The opening of $H^+ \to WA$ invalidate the limit from $H^+ \to \tau\nu$

CP conserving 2HDM





- 2 alignment limits:
  - h=125 GeV SM-like: $\sin_{\beta-\alpha} = 1$ (Decoupling limit)
  - $h < H$=125 GeV SM-like: $\cos_{\beta-\alpha} = 1$:

H^0-SM like ; $m_h < m_H = 125$ GeV

In the alignment limit $\cos(\beta-\alpha) \approx 1$, the heavy CP-even Higgs H^0 completely mimics the SM Higgs:

$$\begin{aligned} H^0 f\bar{f} &= \frac{\sin\alpha}{\sin\beta} \approx 1 \quad , \quad h^0 f\bar{f} = \frac{\cos\alpha}{\sin\beta} \\ H^0 VV &= \cos(\beta-\alpha) \approx 1 \quad , \quad h^0 VV = \sin(\beta-\alpha) \approx 0 \end{aligned} \tag{1}$$

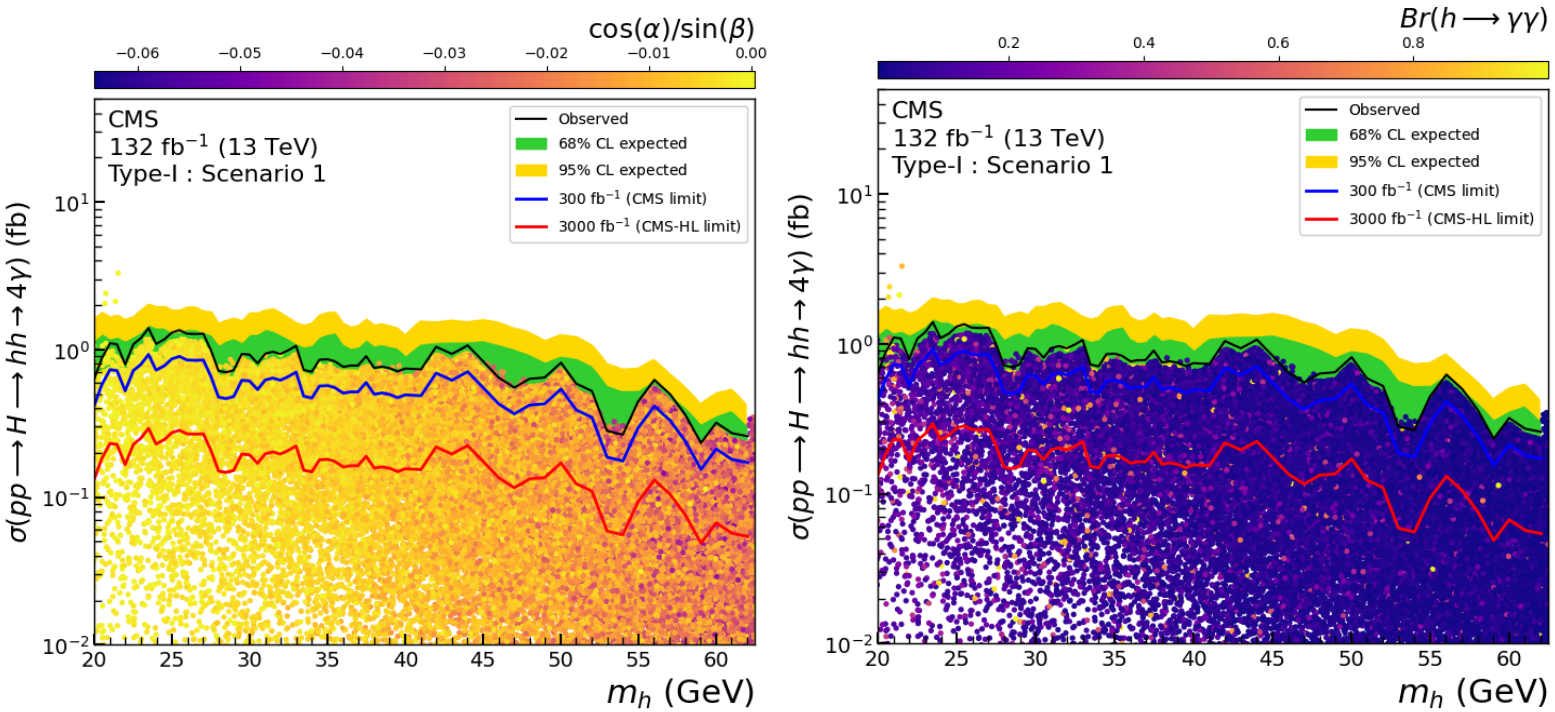
- $m_h \leq m_H = 125$ GeV: $H^0 \to h^0 h^0; A^0 A^0; ZA^0$ might be open: $Br(H^0 \to h^0 h^0) + Br(H^0 \to A^0 A^0) + Br(H^0 \to ZA^0) \leq 10\%$
- if h^0 and A^0 too light: $Z \to h^0 A^0 \propto \cos^2(\beta-\alpha)$
- For $m_h \leq 125$ GeV and $m_H = 125$ GeV: EWPT imply that $H^\pm$ and A^0 would be also light.

Constraining 2HDM using $H_{125} \to AA \to 4\gamma$

Can h^0 be Fermiophobic ?

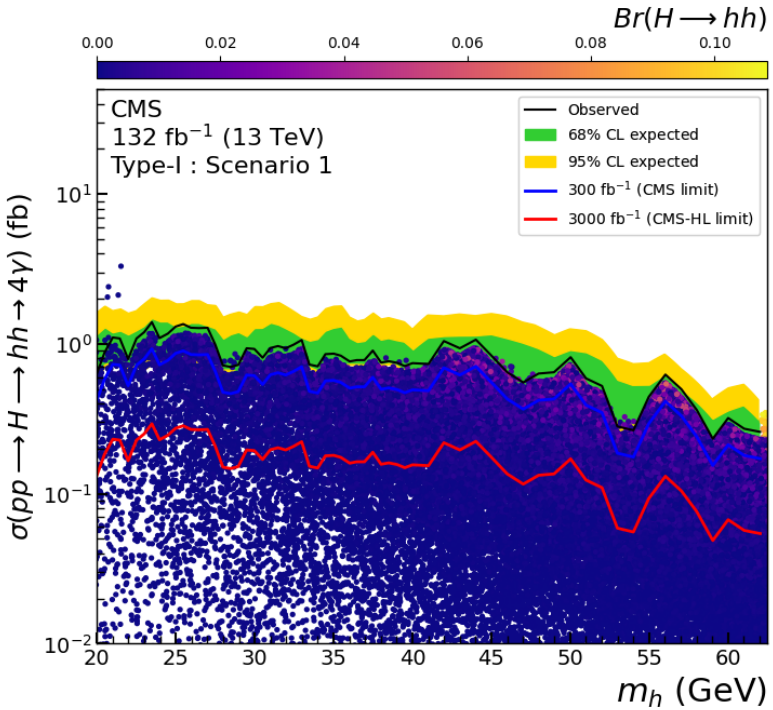
- In 2HDM-I, $h^0 f\bar{f} \propto \frac{\cos\alpha}{\sin\beta} = \sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)$
  For negative $\sin(\beta-\alpha)$ and positive $\cos(\beta-\alpha)$,
  it is clear that $\cos\alpha \to 0$. h^0 becomes fermiophobic.
- $h^0 VV \propto \sin_{\beta-\alpha} \approx 0$; $h^0 \to \{VV^*, V^*V^*\}$ very suppressed;
  $h^0 \to \gamma\gamma$ could reach 100%
- both CMS and ATLAS searches for 4γ events are motivated by light axion particles: $gg \to H \to AA \to 4\gamma$ CMS JHEP 07 (2023), ATLAS Eur.Phys.J.C 84 (2024) 7, 742
- $gg \to H \to hh \to 4\gamma$ and $gg \to H \to AA \to 4\gamma$ have the same differential cross section,

Constraining 2HDM using $H_{125} \to AA \to 4gamma$



CMS $H \to AA \to 4\gamma$: JHEP 07 (2023).

Constraining 2HDM using $H_{125} \to AA \to 4\gamma$

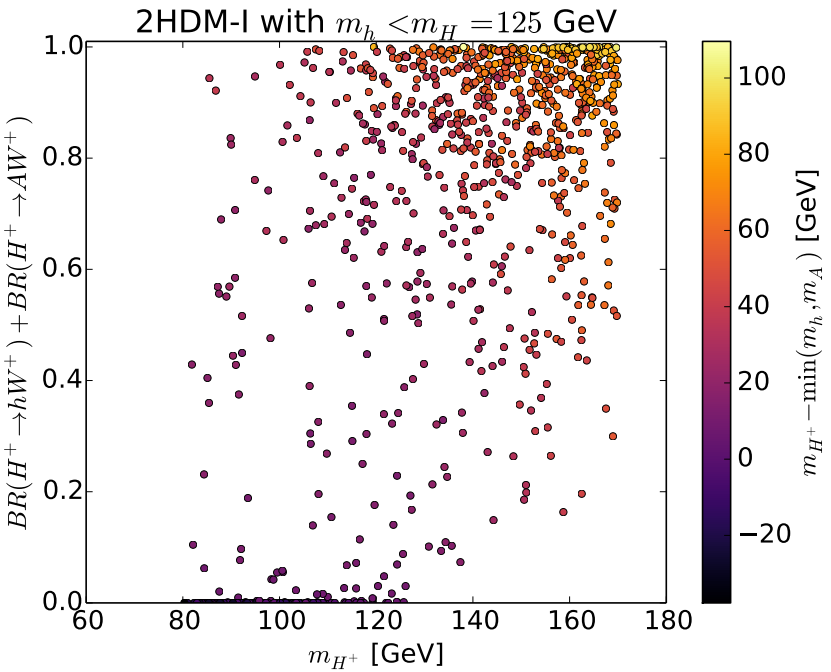


Bosonic decay: $H^{\pm} \to Wh^0$

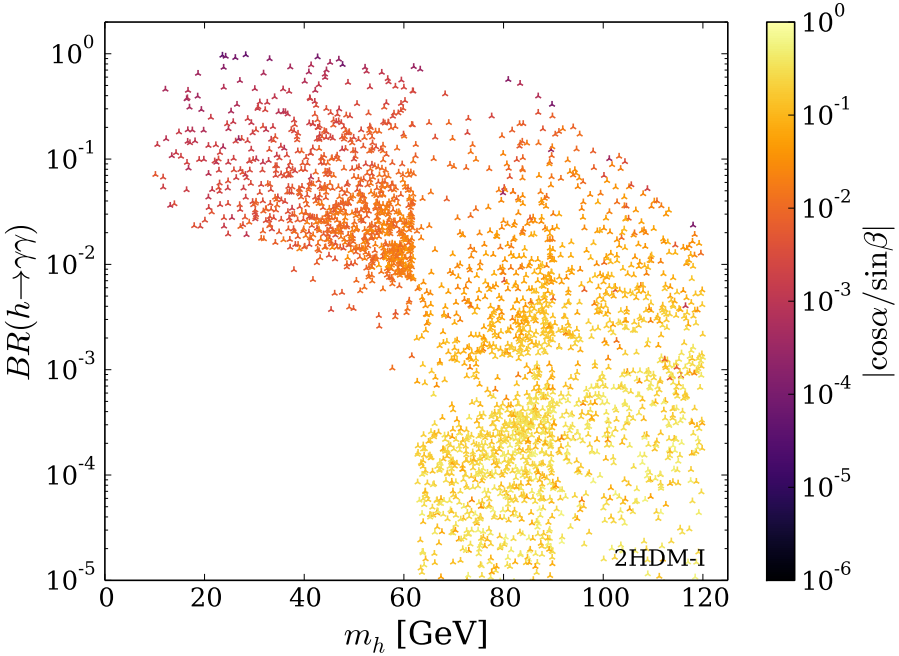
- $H^{\pm}W^{\mp}h^0 \propto \cos(\beta - \alpha) \approx 1$
- light $H^{\pm}$ can be produced from $t\bar{t}$ events with $t \to bH^+$
- also $pp \to W^* \to \{H^{\pm}h^0, H^{\pm}A^0\}$; $pp \to \gamma^*, Z^* \to H^{\pm}H^{\mp}$
- with h^0 close to fermiophobic:
  $pp \to t\bar{t} \to bWbH^+ \to 2b2Wh^0 \to 2b + 2W + 2\gamma$;

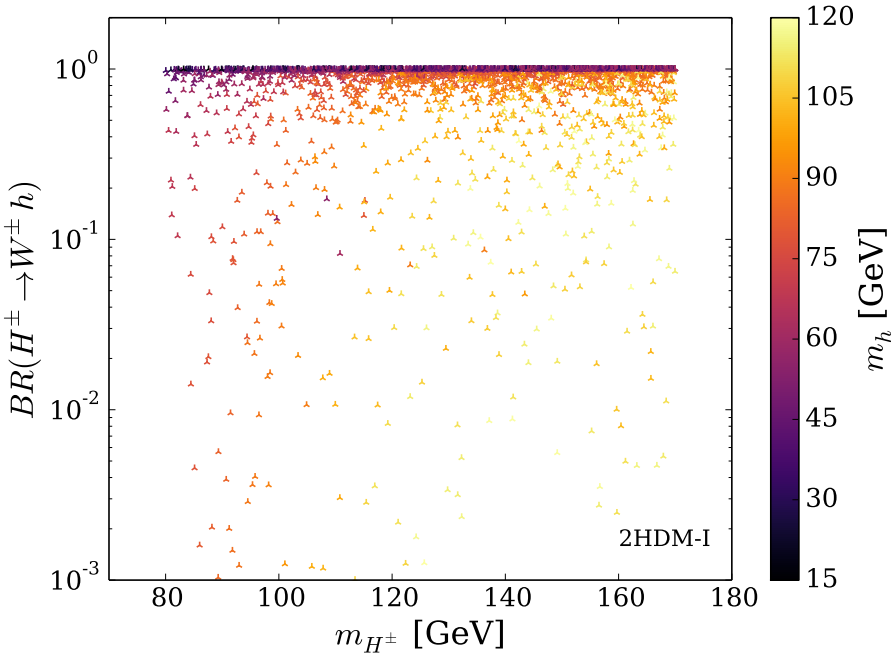
$pp \to H^{\pm}h^0 \to Wh^0h^0 \to 4\gamma + W$

Br($H^{\pm} \to W^{\pm} S$)

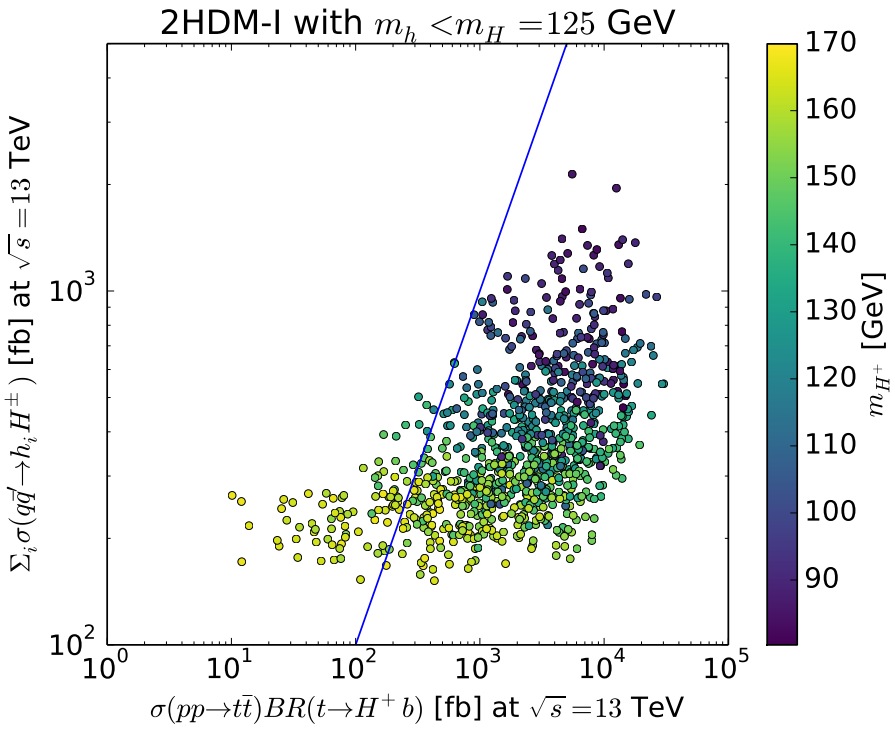


Br($h^0 \to \gamma\gamma$) and Br($H^\pm \to W^\pm h^0$)



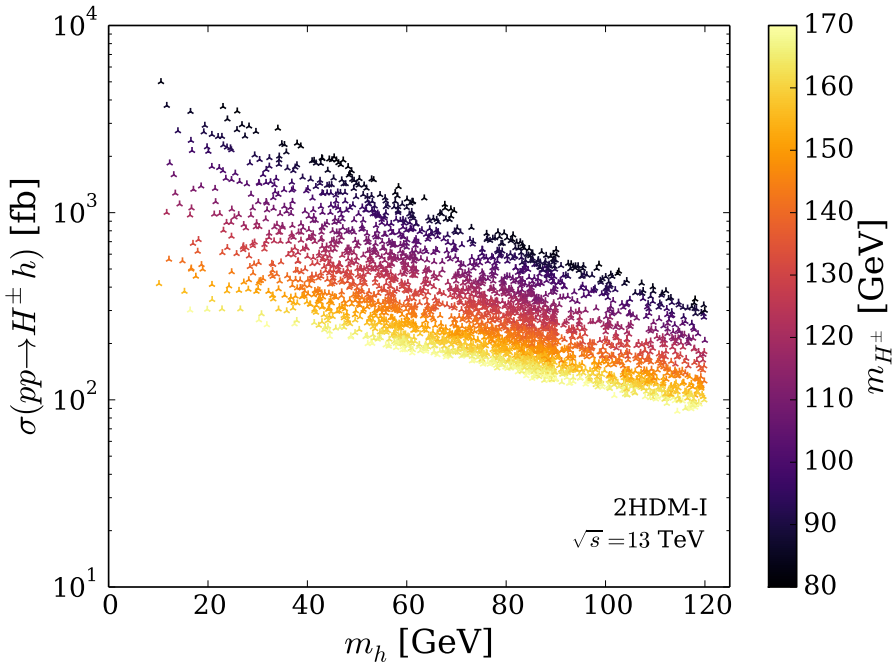


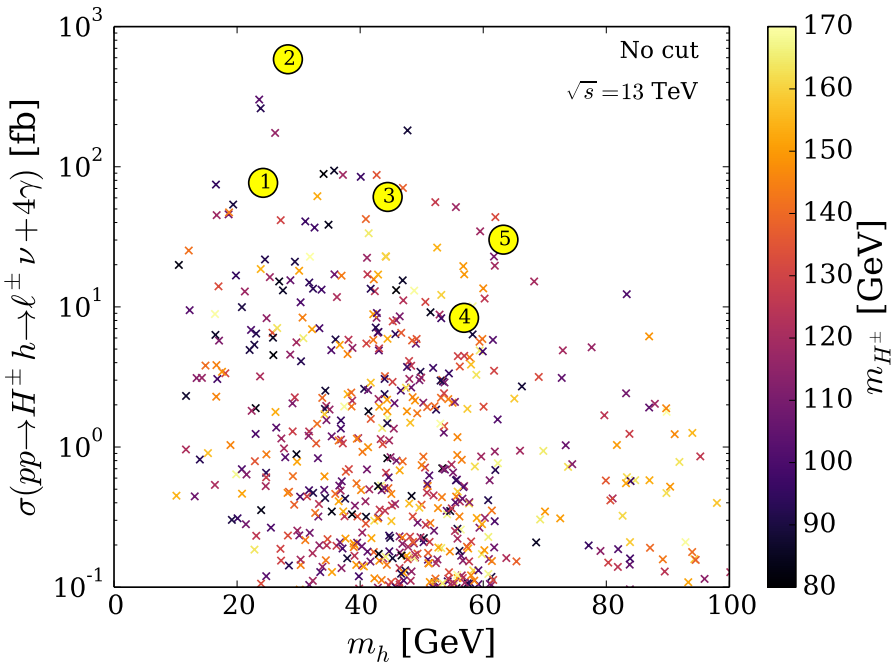
Comparison: $\sigma(pp \to t\bar{t}) \times BR(t \to H^+ b)$ vs. $\Sigma_i \sigma(q\bar{q}' \to H^\pm h_i)$



$\sigma(q\bar{q}' \to H^{\pm}h^0)$; $\sigma(q\bar{q}' \to l\nu 4\gamma)$

BP	m_h	$m_{H^{\pm}}$	m_A	$\sin_{\beta-\alpha}$	$\tan\beta$	$\sigma_{W^{\pm}4\gamma}$[fb]	Br($h^0 \to \gamma\gamma$)
1	24.2	152.2	111.1	-0.048	20.9	359	0.94
2	28.3	83.7	109.1	-0.050	20.2	2740	0.97
3	44.5	123.1	119.9	-0.090	10.9	285	0.70
4	56.9	97.0	120.3	-0.174	5.9	39	0.22
5	63.3	148.0	129.2	-0.049	20.7	141	0.71





Cuts and selection efficiencies

We require pseudorapidity $|\eta| < 2.5$ for the lepton and photons, and an isolation $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 0.4$ for all objects.

(i) all photons: $p_T^\gamma > 10\,\text{GeV}$; charged lepton: $p_T^\ell > 20\,\text{GeV}$,

(ii) imposes that $p_T^\gamma > 20\,\text{GeV}$ and $p_T^\ell > 10\,\text{GeV}$.

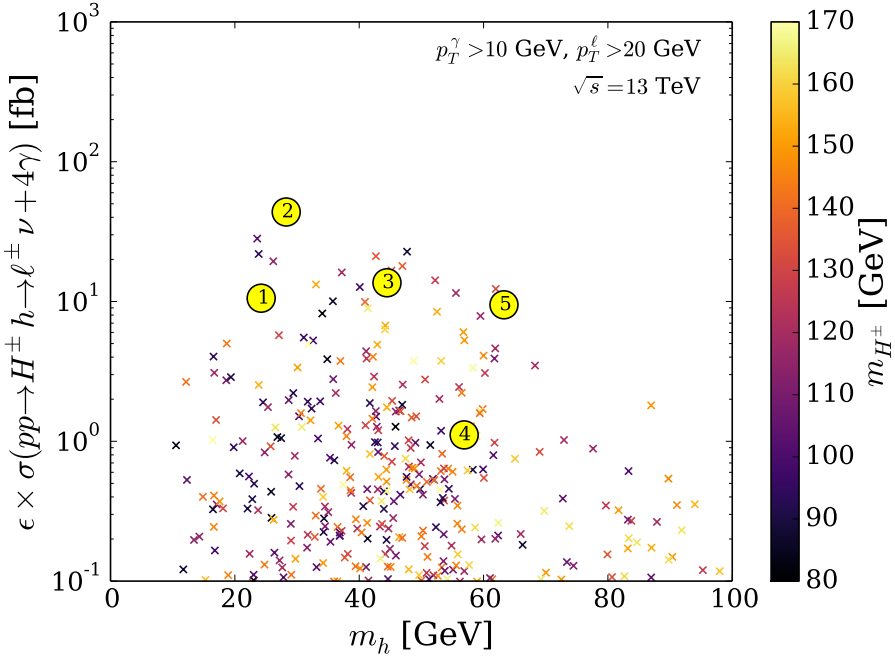
- The irreducible SM W+4γ Background $< 10^{-6}$ pb.

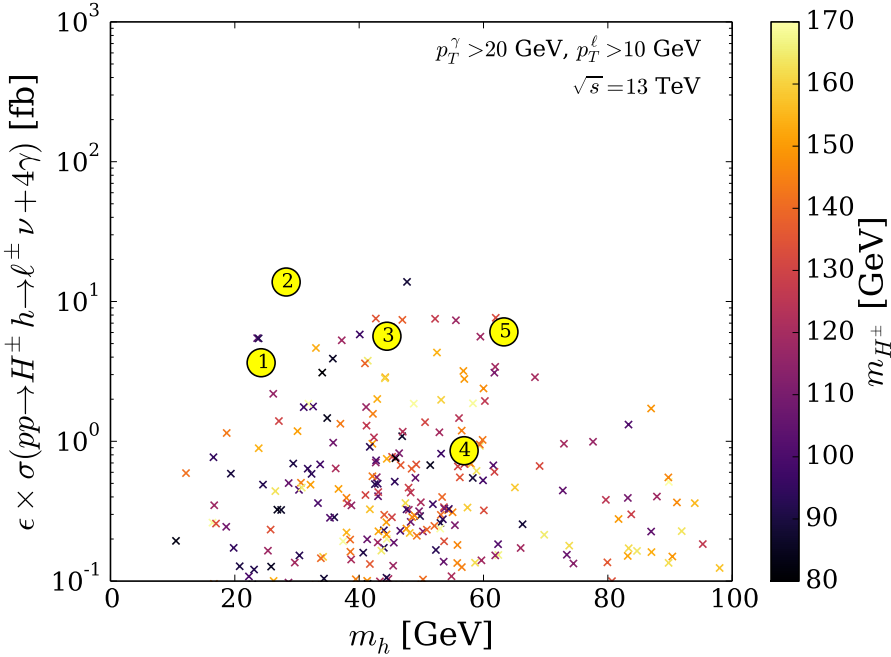
- The selection efficiencies: $\epsilon = \sigma(\text{cuts})/\sigma(\text{no cuts})$.

p_T^γ >10 GeV, p_T^ℓ >20 GeV

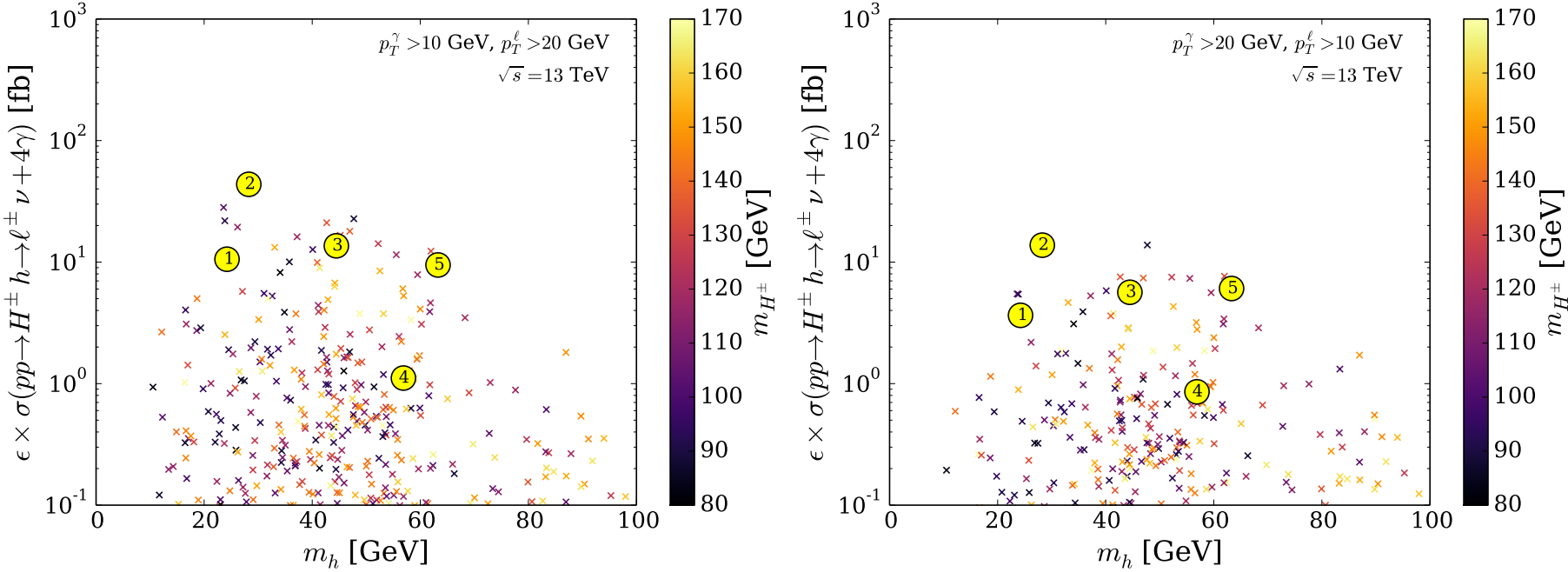
$m_{H^+} \backslash\, m_h$	20	30	40	50	60	70	80	90	100
80	0.04	0.08	0.10	0.08	0.05	<0.01			
90	0.05	0.10	0.13	0.13	0.10	0.06	<0.01		
100	0.05	0.14	0.16	0.16	0.13	0.11	0.06	<0.01	
110	0.06	0.13	0.18	0.19	0.17	0.16	0.13	0.07	<0.01
120	0.07	0.14	0.20	0.22	0.24	0.22	0.17	0.13	0.06
130	0.10	0.16	0.23	0.25	0.28	0.25	0.24	0.20	0.15
140	0.10	0.18	0.23	0.27	0.28	0.31	0.28	0.27	0.21
150	0.11	0.19	0.26	0.31	0.31	0.33	0.32	0.29	0.27
160	0.12	0.21	0.26	0.29	0.34	0.34	0.34	0.30	0.32

$\sigma(q\bar{q}' \to H^{\pm}h \to l\nu + 4\gamma)$ with cuts

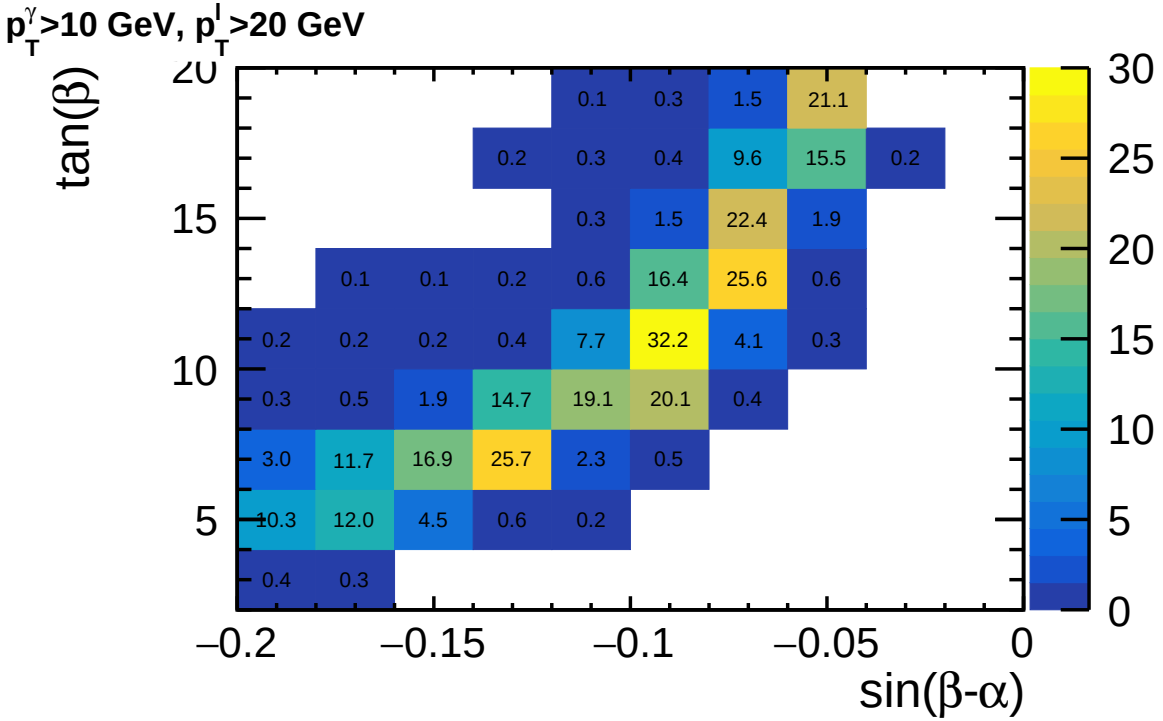




$\sigma(q\bar{q}' \to H^{\pm}h \to l\nu + 4\gamma)$ with cuts



A full Monte Carlo (MC) analysis at the detector level shows that $W4\gamma$ signal is very promising, at the LHC with 300 fb^{-1} luminosity.



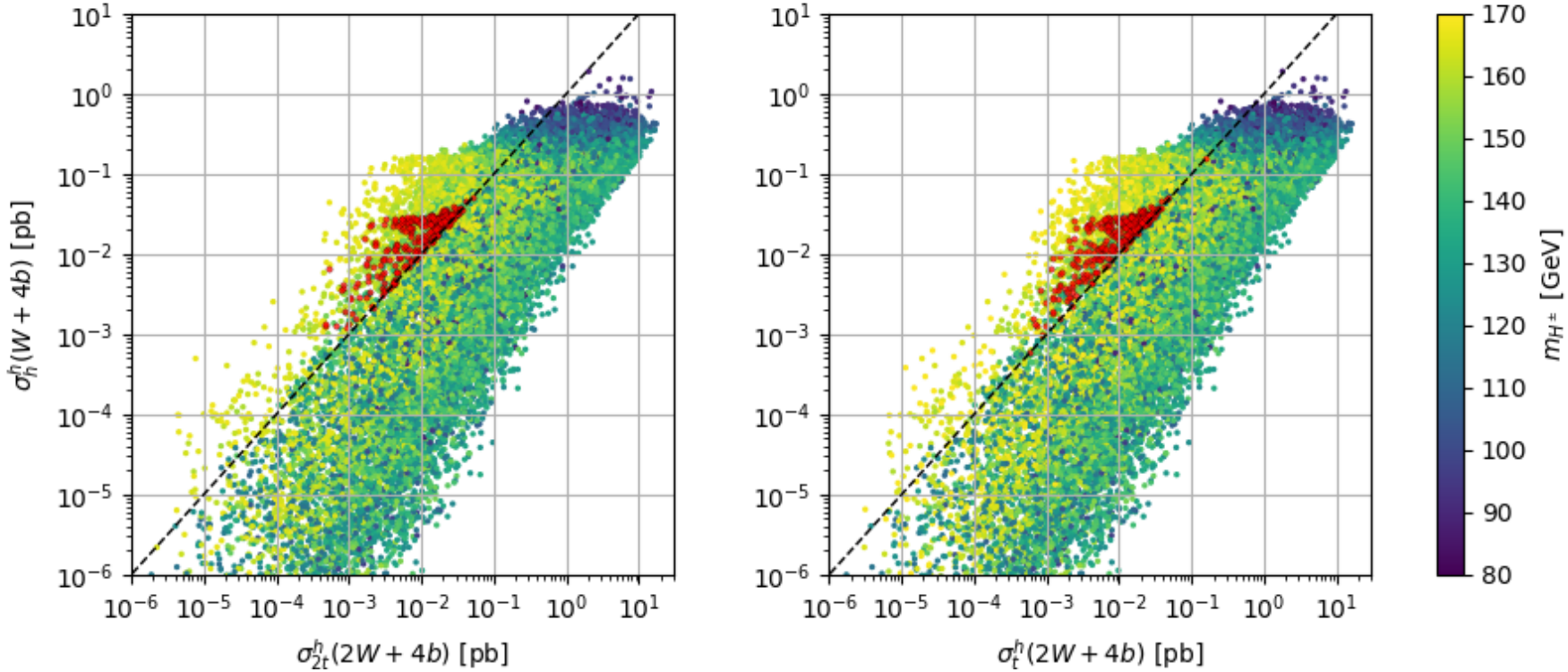
The predicted significances over the $(\sin(\beta-\alpha), \tan\beta)$ plane for $\sqrt{s} = 14$ TeV and $L = 300$ fb^{-1}

fermionic decays of h^0 and A^0

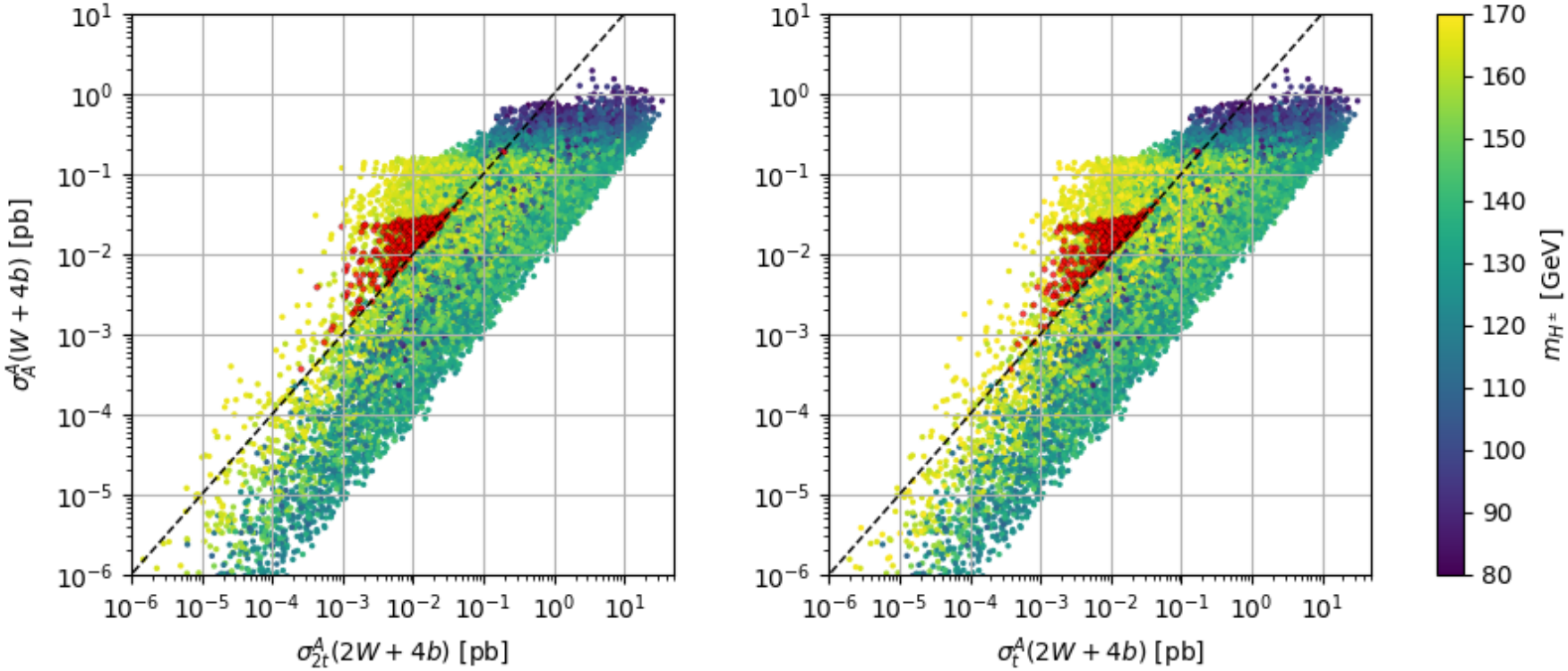
	production and decay chain
$\sigma^{h_i}_{2t}(2W2b2f)$	$2\ \sigma_{t\bar{t}} \times \mathrm{BR}(t \to bH^+) \times \mathrm{BR}(\bar{t} \to \bar{b}W) \times$ $\mathrm{BR}(H^\pm \to Wh_i) \times \mathrm{BR}(h_i \to f\bar{f})$
$\sigma^{h_i}_{t}(2W2b2f)$	$\sigma(pp \to t\bar{b}H^-) \times \mathrm{BR}(t \to bW) \times \mathrm{BR}(H^\pm \to Wh_i) \times$ $\mathrm{BR}(h_i \to f\bar{f})$

	Di-Higgs production and decay chain
$\sigma^{h_i}_{h_j}(2W2f2f')$	$\sigma(H^+H^-) \times \mathrm{BR}(H^\pm \to W^\pm h_i) \times \mathrm{BR}(H^\pm \to W^\pm h_j) \times$ $(\mathrm{BR}(h_i \to f\bar{f}) \times \mathrm{BR}(h_j \to f'\bar{f}') + h_i \longleftrightarrow h_j)\ \frac{1}{1+\delta_{ff'}}$
$\sigma^{h_i}_{h_j}(W2f2f')$	$\frac{1}{1+\delta_{ff'}}\ \sigma(H^\pm h_i) \times \mathrm{BR}(H^\pm \to W^\pm h_j) \times$ $(\mathrm{BR}(h_i \to f\bar{f}) \times \mathrm{BR}(h_j \to f'\bar{f}') + h_i \longleftrightarrow h_j)$

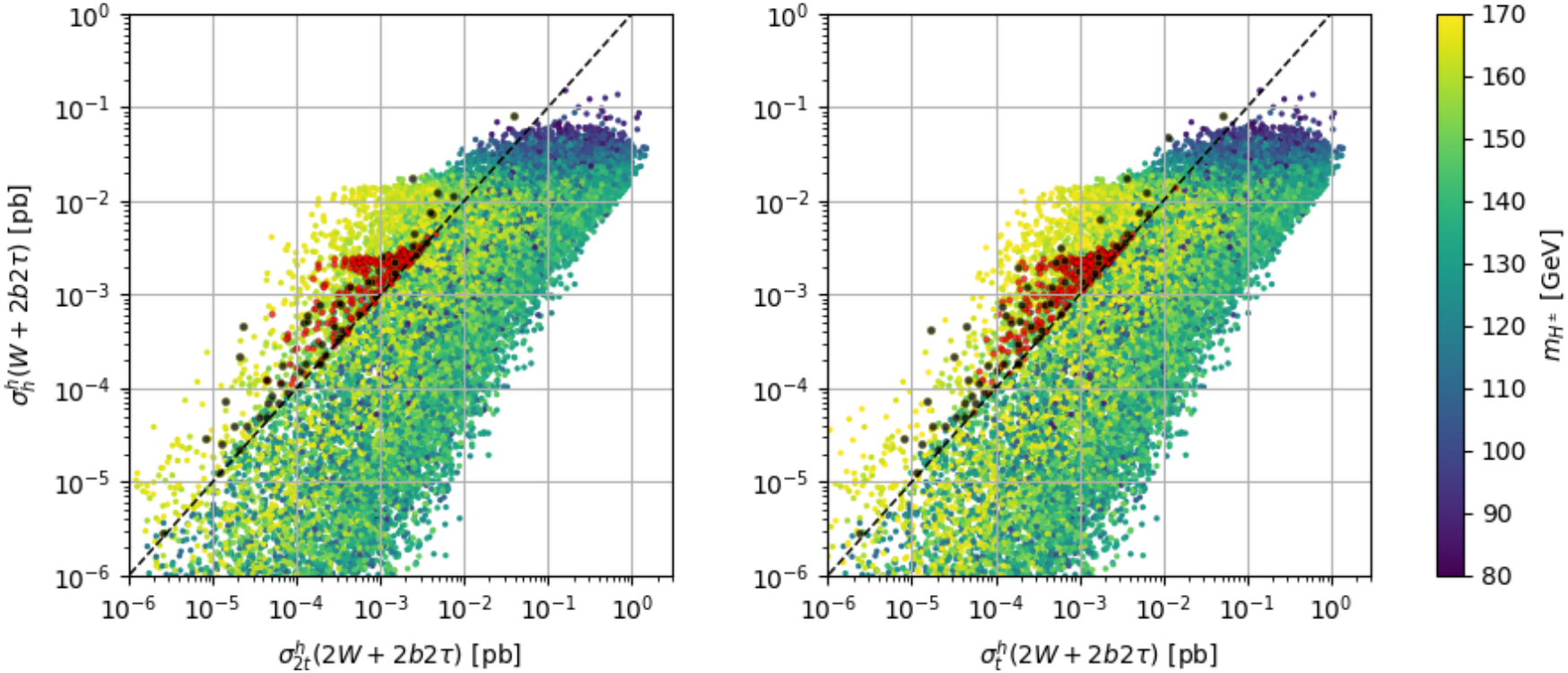
Table: $i, j = 1, 2$ and have $h_1 = h$ and $h_2 = A$; $f(f') = b$ or τ.



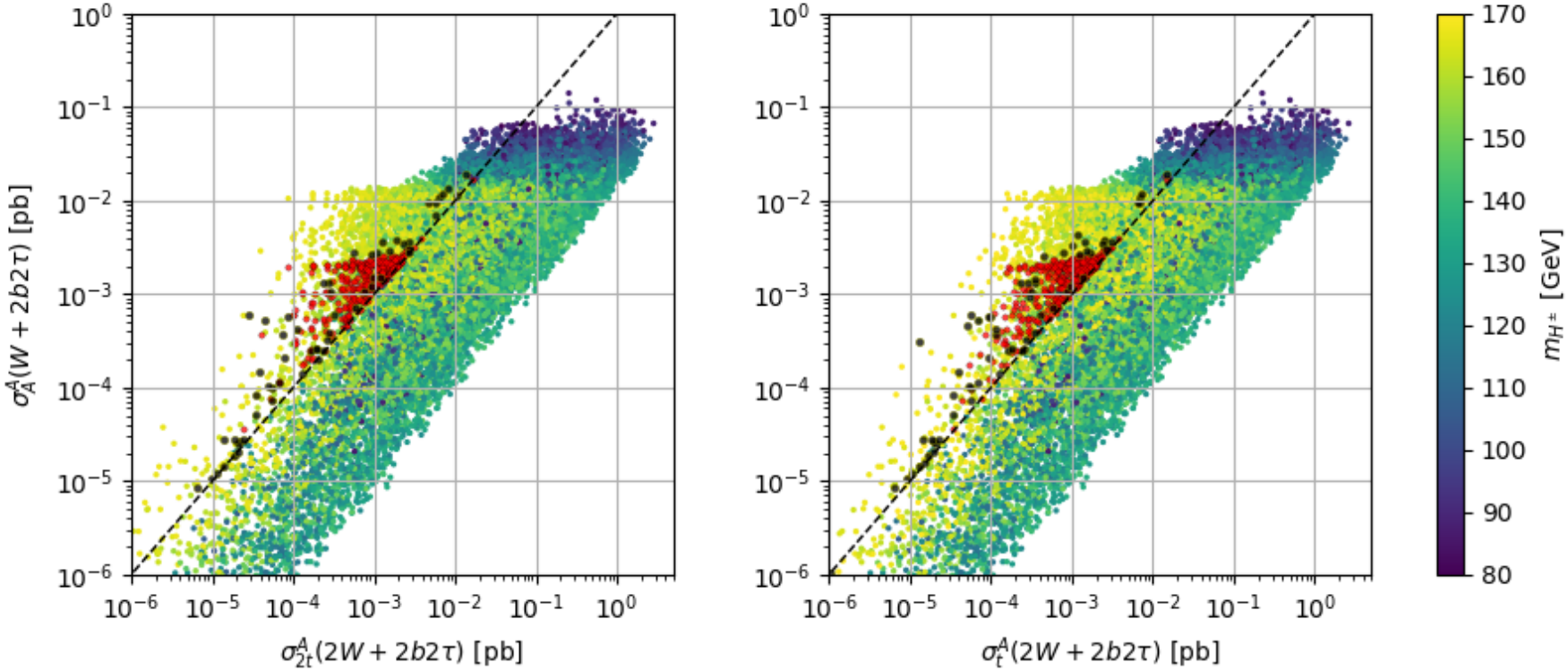
$\sigma(pp \to H^\pm h) \times \mathrm{BR}(H^\pm \to W^\pm h) \times \mathrm{BR}(h \to b\bar{b})^2$ compared to 2 σ_{2t} (left) and σ_t^h (right). Red points identify: $\sigma(H^+H^-) \times \mathrm{BR}(H^\pm \to W^\pm h)^2 \times \mathrm{BR}(h \to b\bar{b})^2$ in 2HDM-I.



$\sigma(pp \to H^\pm A) \times \mathrm{BR}(H^\pm \to W^\pm A) \times \mathrm{BR}(A \to b\bar{b})^2$ compared to σ^A_{2t} (left) and σ^A_t (right). Red points identify: $\sigma(H^+H^-) \times \mathrm{BR}(H^\pm \to W^\pm A)^2 \times \mathrm{BR}(A \to b\bar{b})^2$ in 2HDM-I.



$2\sigma(pp \to H^\pm h) \times \mathrm{BR}(H^\pm \to Wh) \times \mathrm{BR}(h \to b\bar{b}) \times \mathrm{BR}(h \to \tau^+\tau^-)$ compared to σ_{2t}^h (left) and σ_t^h (right). The red points identify $\sigma(H^+H^-)x\mathrm{BR}(H^\pm \to Wh)^2x\mathrm{BR}(h \to b\bar{b})x\mathrm{BR}(h \to \tau^+\tau^-)$ for 2HDM-I while the black points are for 2HDM-X rates: $\sigma(pp \to H^\pm h) \times \mathrm{BR}(H^\pm \to W^\pm h) \times \mathrm{BR}(h \to \tau^+\tau^-) \times \mathrm{BR}(h \to b\bar{b})$.



$2\sigma(pp \to H^\pm A) x \mathrm{BR}(H^\pm \to WA) x \mathrm{BR}(A \to b\bar{b}) x \mathrm{BR}(A \to \tau^+\tau^-)$ compared to σ_{2t}^A (left) and σ_t^A (right). The red points identify $\sigma(H^+H^-) x \mathrm{BR}(H^\pm \to WA)^2 x \mathrm{BR}(A \to b\bar{b}) x \mathrm{BR}(A \to \tau^+\tau^-)$ for 2HDM-I while the black points are for 2HDM-X rates: $\sigma(pp \to H^\pm A) \times \mathrm{BR}(H^\pm \to W^\pm A) \times \mathrm{BR}(A \to \tau^+\tau^-) \times \mathrm{BR}(h \to b\bar{b})$.

Conclusions

- In 2HDM-I there is regions of the parameter space compliant with all constraints yielding substantial BRs for $H^{\pm} \to W^{\pm *} h / W^{\pm *} A$ in which the $m_{H^{\pm}} < m_t - m_b$.
- $\sigma(pp \to t\bar{t} \to tbH^{+} \to tbWA^{0})$ and/or $pp \to H^{\pm} h / H^{\pm} A / H^{\pm} H^{\mp}$ could be sizeable
- light $H^{\pm}$ in the 80–160 GeV mass range, still being consistent with all LHC, LEP, Tevatron and B-physics data.

Conclusions

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- $\sigma(pp \to t\bar{t} \to tbH^{+} \to tbWA^{0})$ and/or $pp \to H^{\pm} h / H^{\pm} A / H^{\pm} H^{\mp}$ could be sizeable
- light $H^{\pm}$ in the 80–160 GeV mass range, still being consistent with all LHC, LEP, Tevatron and B-physics data.
- $pp \to H^{\pm} h^{0} \to W^{\pm} + 4\gamma$ with significant events.
- $pp \to H^{\pm} h^{0} \to W^{\pm} + 4f$ could be much larger than events from $pp \to t\bar{t}$ or $pp \to tbH^{+}$.

Is $h \to \gamma\gamma$ ruled out?

- ATLAS searched for new phenomena in events with at least three photons at 8 TeV and with an integrated luminosity of 20.3 fb^{-1}. [ATLAS ; hep-ex/1509.05051] based on $pp \to H \to AA \to 4\gamma$
- $pp \to H \to hh \to 4\gamma$: [A.A et al JHEP 07 (2018) 007]

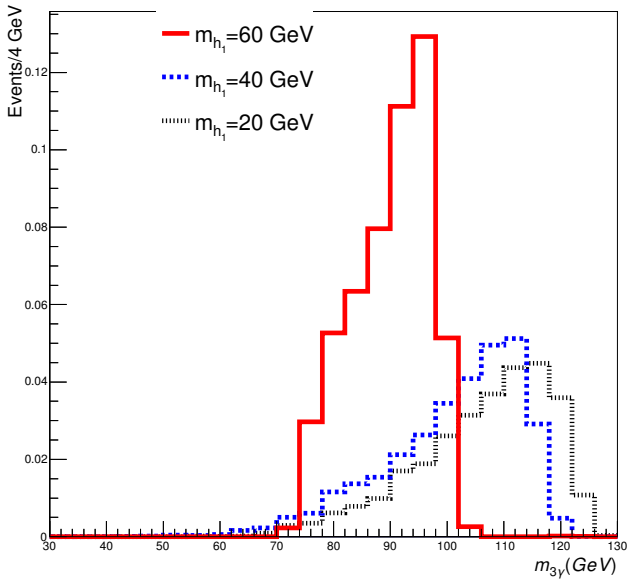
$gg \to H \to hh \to 4\gamma$ vs $gg \to H \to AA \to 4\gamma$

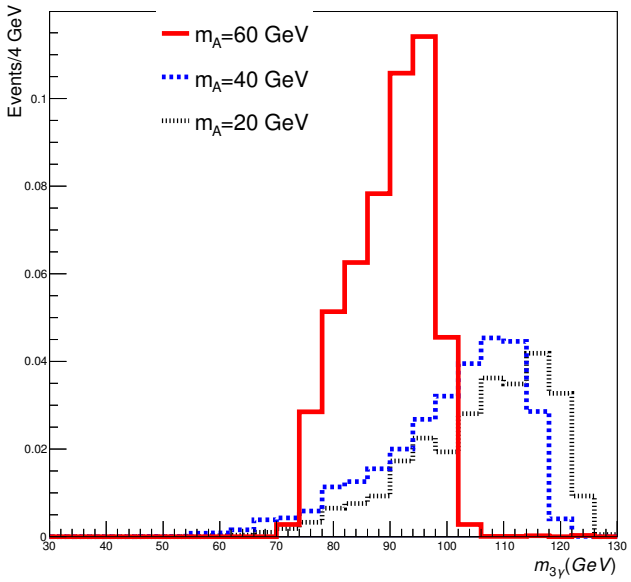
- $gg \to H \to hh \to 4\gamma$ and $gg \to H \to AA \to 4\gamma$ have the same differential cross section,
- The matrix elements can be put as

$$\begin{aligned}
\mathcal{M}^h &= C(k_1 \cdot k_2 \eta^{\mu\nu} - k_2^\mu k_1^\nu)\epsilon_\mu^*(k_1)\epsilon_\nu^*(k_2)(k_3 \cdot k_4 \eta^{\rho\sigma} - k_4^\rho k_3^\sigma) \\
&\quad \times \epsilon_\rho^*(k_3)\epsilon_\sigma^*(k_4)\delta^{ab}\epsilon(p_1)\cdot\epsilon(p_2)\,, \\
\mathcal{M}^A &= D\epsilon_\alpha^*(k_1)\epsilon_\beta^*(k_2)\epsilon^{\alpha\beta\mu\nu}k_\mu^1 k_\nu^2 \epsilon_\rho^*(k_3)\epsilon_\sigma^*(k_4)\epsilon^{\rho\sigma\gamma\delta}k_\gamma^3 k_\delta^4 \delta^{ab}\epsilon_{p_1}.\epsilon_{p_2}
\end{aligned}$$

  p_1 and p_2 is the momentum of the initial gluons, $k_1 - k_4$ are momentum of 4 photons in the final state.
- $|\,\mathcal{M}^{h,A}\,|^2 \propto \{C^2, D^2\}(k_1.k_2)^2(k_3.k_4)^2$

$gg \to H \to hh \to 4\gamma$ vs $gg \to H \to AA \to 4\gamma$

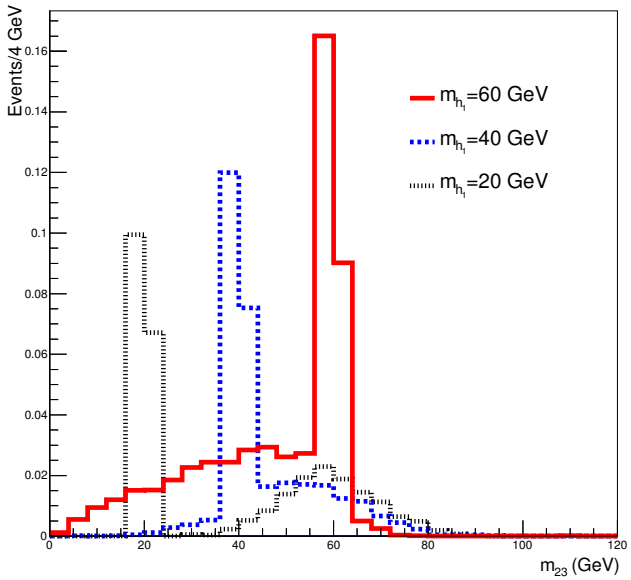


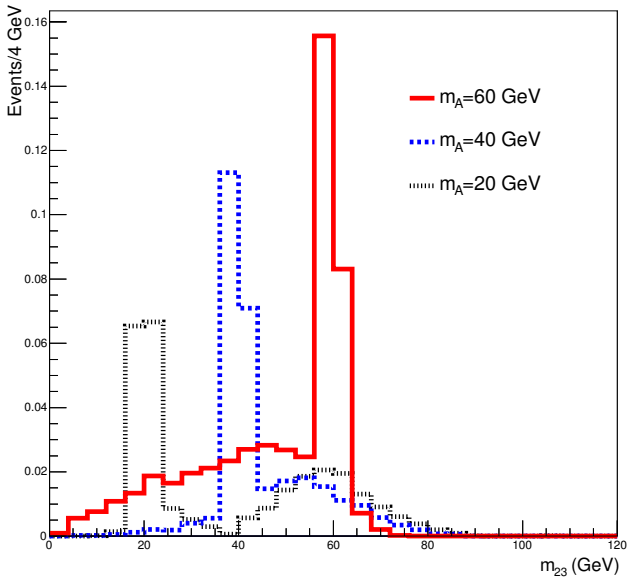


Distributions at detector level: (a) $m_{3\gamma}$ for $gg \to H \to hh \to 4\gamma$, (b) $m_{3\gamma}$ for $gg \to H \to AA \to 4\gamma$,

$m_{3\gamma}$: the invariant mass of the 3 leading P_T-ordered photons

$gg \to H \to hh \to 4\gamma$ vs $gg \to H \to AA \to 4\gamma$





Distributions at detector level: (a) m_{23} for $gg \to H \to hh \to 4\gamma$ and (b) m_{23} for $gg \to H \to AA \to 4\gamma$.

m_{23}: the invariant mass of the 2nd and 3rd P_T-ordered photons.

Projection from 8 TeV to 14 TeV sensitivity

- In order to project the sensitivity of the future LHC run at $\sqrt{s} = 14$ TeV, we have to rescale 8 TeV results.
- The 'boost factors', for both signal and background processes is calculated using MC tools: (MadGraph 5, PYTHIA: simulate showering, hadonisation and decays and PGS to perform the fast detector simulations).

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- we adopt the same selection cuts of the ATLAS collaboration,
  - i) $n_\gamma \geq 3$: we consider inclusive 3 photon events.
  - ii) The two leading photons should have a $P_t(\gamma) > 22$ GeV and the third one should have a $P_t(\gamma) > 17$ GeV
  - iii) The photons should be resolved in the range $|\eta| < 2.37$ and do not fall in the end-cap region $1.37 < |\eta| < 1.52$.
  - iv) $\Delta R(\gamma\gamma) > 0.4$.