Multi-photons signatures at the LHC

Abdesslam Arhrib

Faculté des Sciences et Techniques Tangier, Morocco

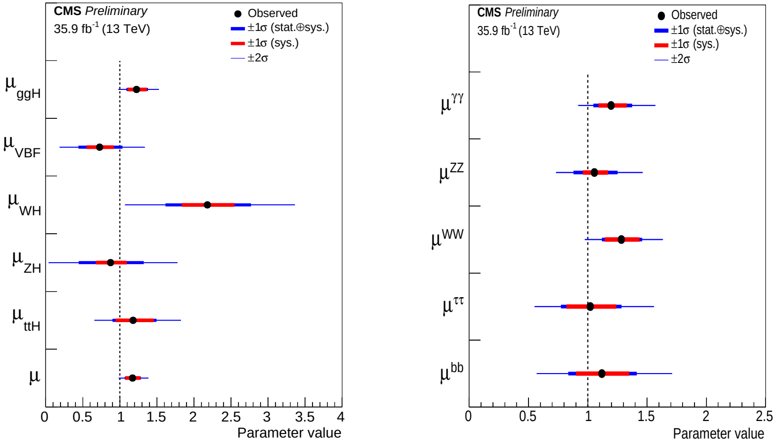
Based on: A, Benbrik, Moretti, Rouchad, Q.S. Yan and X. Zhang, JHEP'18

and work in progress with R. Benbrik, J. ElFalaki, M. Sampaio and R. Santos

H2020 meeting , Lisboa 3th September 2018

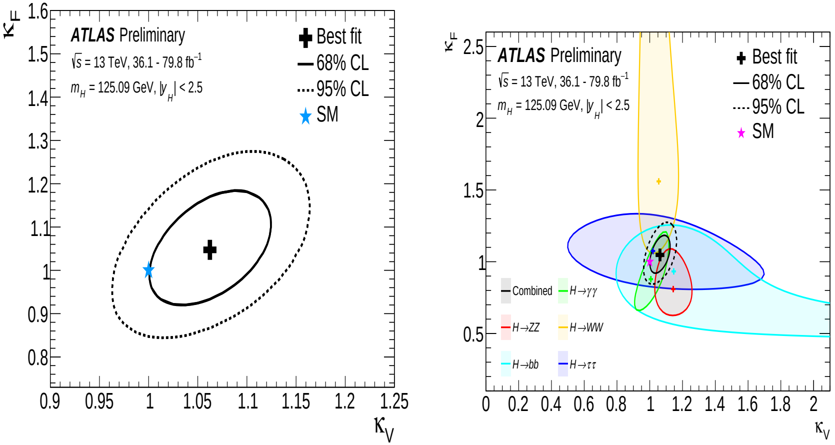
Outlines

- Introduction: Higgs at LHC
- The Two Higgs Doublet Model (2HDM)
- Implications for 2HDM
- Multi-photons signature at 2HDM-I:
  i) quasi-Fermiophobic light Higgs in the 2HDM-I
  ii) $pp \to H_{125} \to hh \to 4\gamma$
- Search for $A^0 \to \gamma\gamma, ZZ, WW$ in the 2HDM, 2HDM+VLQ
- Conclusions

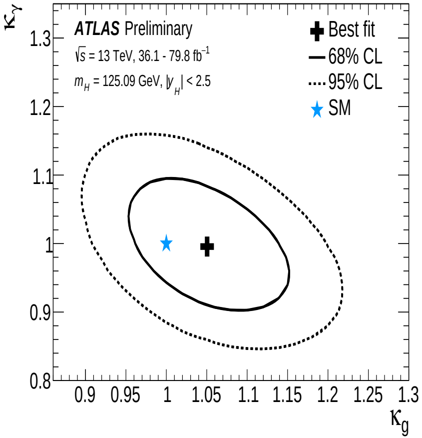


Plot of the fit to the production mode (left) and decay mode (right) signal strength μ_i.

Higgs at LHC



Observed contours at 68% and 95% CL



Observed contours at 68% and 95% CL

What do we learn from Higgs discovery?

1. The Higgs mechanism is operating: from $\Phi\Phi VV$ we get HVV.
2. Observation of bosonic decays: $H \to \gamma\gamma, ZZ, WW$
   Observation of Yuhawa interactions: $H \to \tau^+\tau^-, t\bar{t}$ and $b\bar{b}$

   Still missing $H \to \gamma Z, \mu^+\mu^-$ and triple and quartic couplings hhh, hhhh

What do we learn from Higgs discovery?

1. The Higgs mechanism is operating: from $\Phi\Phi VV$ we get HVV.
2. Observation of bosonic decays: $H \to \gamma\gamma, ZZ, WW$
   Observation of Yuhawa interactions: $H \to \tau^+\tau^-, t\bar{t}$ and $b\bar{b}$

   Still missing $H \to \gamma Z, \mu^+\mu^-$ and triple and quartic couplings hhh, hhhh
3. The Higgs vev is full strength, HWW, HZZ are SM-like (BUT; data has large errors and it may be possible the vev strength is shared by other Higgs like in Multi-Higgs models, SUSY). More data are needed.

Future LHC-HL/ FCC / ILC

The mission of the future LHC run is:

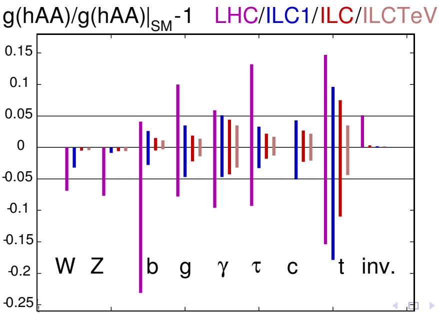
- Accurate measurements of the scalar boson couplings to SM particles would help to determine if the Higgs-like particle is the SM Higgs or a Higgs that belongs to a higher representations:
  more doublets, doublet & triplets, doublet & singlets
- Find a clear hint of new physics beyond SM

Future LHC-HL/ FCC / ILC

The mission of the future LHC run is:

- Accurate measurements of the scalar boson 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: *more doublets, doublet & triplets, doublet & singlets*
- Find a clear hint of new physics beyond SM

LHC & ILC complementarity; M. Peskin, hep-ph/1207.2516



2HDM: G. Branco et al Phys rep'2012

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}\left(v_1 + \phi_1^0 + ia_1\right) \end{pmatrix} ; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}\left(v_2 + \phi_2^0 + ia_2\right) \end{pmatrix} .$$

The most general potential for 2HDM:

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

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1^0 + ia_1) \end{pmatrix} ; \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2^0 + ia_2) \end{pmatrix} .$$

The most general potential for 2HDM:

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

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

2HDM

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

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

leads to FCNCs at tree level.

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

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

leads to FCNCs at tree level.

• 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:

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

	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	$\cot\beta$	$\tan\beta$	$-\cot\beta$

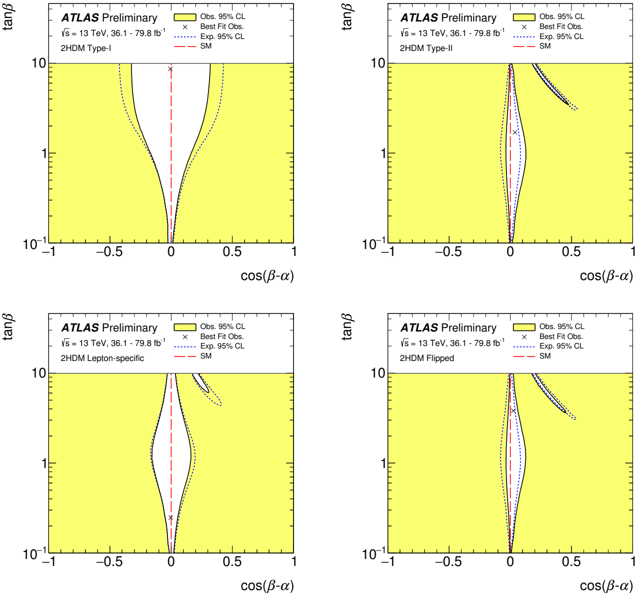
CP conserving 2HDM: CP-even: $h < H$, CP-odd A and $H^{\pm}$

- Couplings:

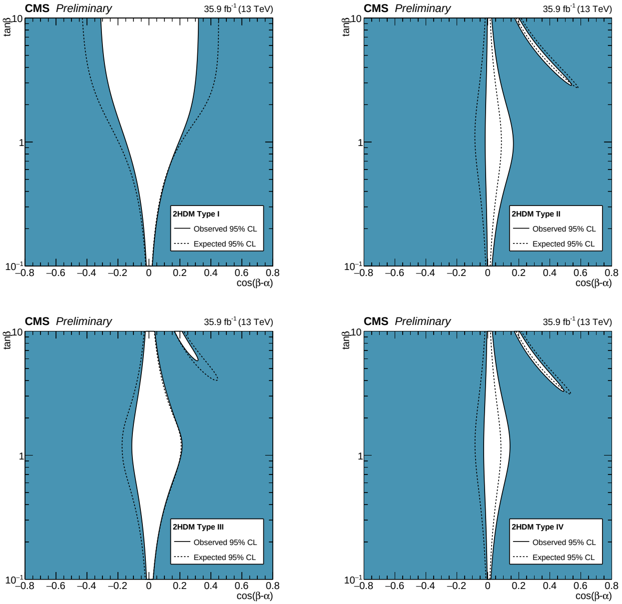
$$hVV \propto \sin_{\beta-\alpha} \quad , \quad HVV \propto \cos_{\beta-\alpha} \quad , \quad AVV = 0$$
$$hH^{\pm}W^{\mp} \propto \cos_{\beta-\alpha} \quad , \quad HH^{\pm}W^{\mp} \propto \sin_{\beta-\alpha} \quad , \quad AH^{\pm}W^{\mp} \propto \frac{g}{2}$$
$$H^{\pm}W^{\mp}\gamma = 0 \ (e.m\ inv) \quad , \quad H^{\pm}W^{\mp}Z = 0 \quad but \quad loop\ mediated$$

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

Status of the 2HDM, h^0 SM-like Higgs



Status of the 2HDM: h^0 SM-like Higgs



Alignment limit: H^0-SM like

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

$$H^0 f\bar{f} = \frac{\sin\alpha}{\sin\beta} \approx 1 \qquad , \qquad H^0 VV = \cos(\beta-\alpha) \approx 1$$

Alignment limit: H^0-SM like

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

$$H^0 f\bar{f} \;=\; \frac{\sin\alpha}{\sin\beta}\approx 1 \qquad , \qquad H^0 VV = \cos(\beta-\alpha)\approx 1$$

- $m_h \leq m_H = 125$ GeV: $H^0 \to h^0 h^0$ and/or $H^0 \to A^0 A^0$ might be open: $Br(H^0 \to h^0 h^0) + Br(H^0 \to A^0 A^0) \leq 20-30\%$
- For $m_h \leq 125$ GeV and $m_H = 125$ GeV: EWPT imply that $H^\pm$ and A^0 would be also light.

Alignment limit: H^0-SM like

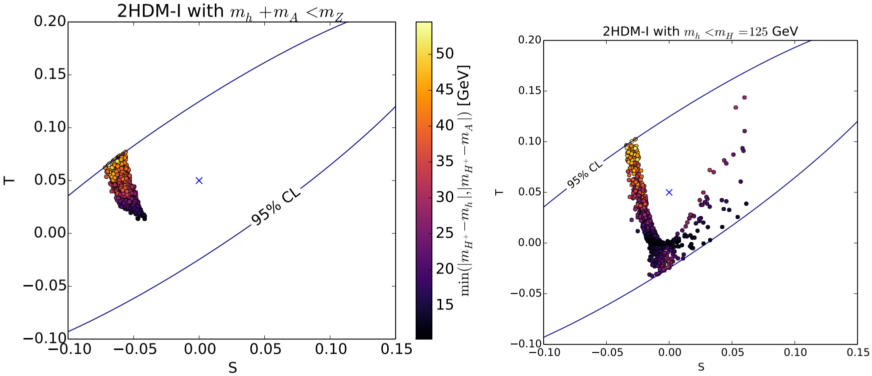
In the alignment limit $\cos(\beta-\alpha)\approx 1$, the heavy CP-even Higgs H^0 mimics the SM Higgs:

$$H^0 f\bar{f} \;=\; \frac{\sin\alpha}{\sin\beta}\approx 1 \qquad , \qquad H^0 VV = \cos(\beta-\alpha)\approx 1$$

- $m_h \leq m_H = 125$ GeV: $H^0 \to h^0 h^0$ and/or $H^0 \to A^0 A^0$ might be open: $Br(H^0 \to h^0 h^0) + Br(H^0 \to A^0 A^0) \leq 20-30\%$
- For $m_h \leq 125$ GeV and $m_H = 125$ GeV: EWPT imply that $H^\pm$ and A^0 would be also light.

Parameter	Scanned range
m_h (GeV)	(10, 120)
m_A (GeV)	(10, 500)
$m_{H^\pm}$ (GeV)	(80, 170)
$\sin(\beta-\alpha)$	$(-1, 1)$
m_{12}^2 (GeV ^{2})	$(0,\ m_A^2 \sin\beta\cos\beta)$
$\tan\beta$	(2, 25)

EWPT: S and T



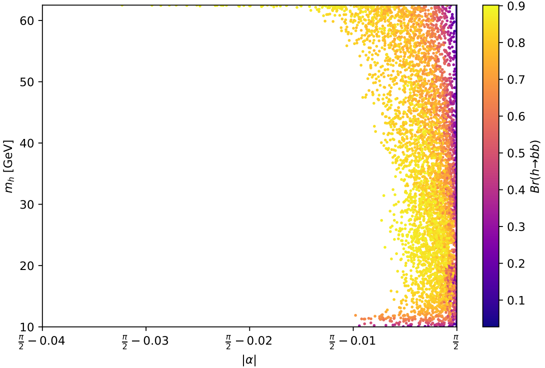
A.A, R. Benbrik, R. Enberg, W. Klemm, S. Moretti and S. Munir, PLB'17

Quasi-fermiophobic h^0 in 2HDM type I

- $h^0 f\bar{f} \propto \frac{\cos\alpha}{\sin\beta} \to 0$ for $\alpha \to \pi/2$, h^0 becomes fermiophobic.
- $h^0 VV \propto \sin_{\beta-\alpha} \approx 0$; $h^0 \to \{VV^*, V^*V^*\}$ very suppressed;

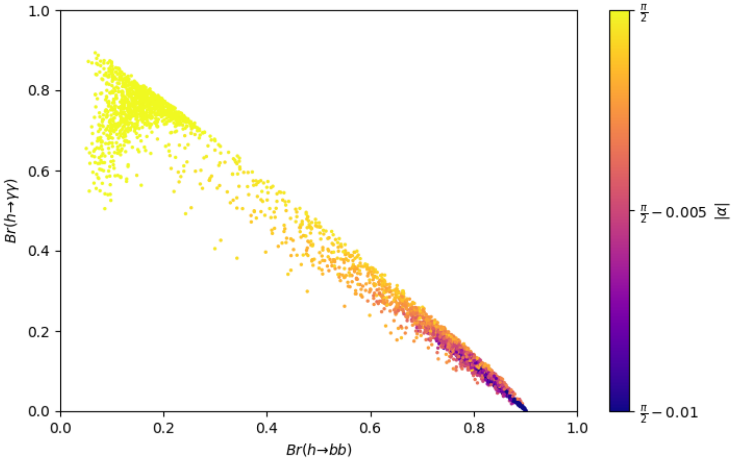
Quasi-fermiophobic h^0 in 2HDM type I

- $h^0 f\bar{f} \propto \frac{\cos\alpha}{\sin\beta} \to 0$ for $\alpha \to \pi/2$, h^0 becomes fermiophobic.
- $h^0 VV \propto \sin_{\beta-\alpha} \approx 0$; $h^0 \to \{VV^*, V^*V^*\}$ very suppressed;
- $h^0 \to \gamma\gamma$ mediated by $H^\pm/W^\pm$ loops could reach 100%
- in the fermiophobic limit $h^0 \to b\bar{b}$, $h^0 \to s\bar{b}$ would compete with $h^0 \to \gamma\gamma$: Barroso, Brucher, Santos PRD'99, A.A PLB'05



Quasi-fermiophobic h^0 in 2HDM type I

- $h^0 \to \gamma\gamma$ vs $h^0 \to b\bar{b}$ at one-loop:



Fermiophobic Higgs searches: LEP and Tevatron

- At LEP-II: $\sigma(e^+e^- \to Zh^0) \propto \sin^2_{\beta-\alpha}$,
  If $\sin(\beta-\alpha) \approx 1$; $m_h < 104$ GeV is excluded.

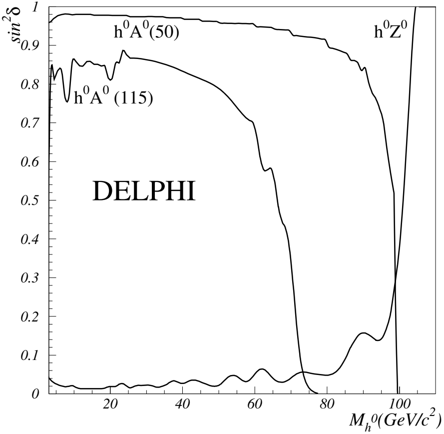
  DELPHI: hep-ex/0406012 EPJC'2004

  In our case $\sin(\beta-\alpha) \approx 0$

- At tevatron, similar limit from $p\bar{p} \to Wh^0 \propto \sin^2_{\beta-\alpha}$ and $p\bar{p} \to W^* \to qq'h^0 \propto \sin^2_{\beta-\alpha}$.

  D0: hep-ex/0803.1514, PRL'2008

- At LEP-II: DELPHI looks to:
  $\sigma(e^+e^- \to A^0h^0 \to A2\gamma) \propto \cos^2_{\beta-\alpha}$; $A^0 \to b\bar{b}, Zh$



$\sin^2\delta = \sin^2(\beta - \alpha)$

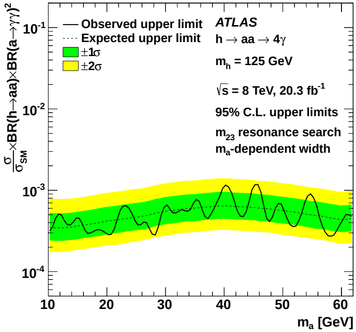
Excluded: above Zh^0 and below A^0h^0

$gg \to H \to hh \to \gamma\gamma\gamma\gamma$

- The search channel that mostly enabled Higgs discovery was $gg \to H \to \gamma\gamma$ decay.
- Because photons final states are clean at hadronic environment LHC
- Also because of sharp resolution in the di-photon invariant mass achievable by the LHC detectors
- knowledge of $m_H = 125$ GeV, one can enforce $m_{4\gamma} = m_H$
- One can reconstruct in each event photon pairs: $m_{\gamma\gamma} = m'_{\gamma\gamma}$

ATLAS study

- G. Aad *et al.* [ATLAS Collaboration], "*Search for new phenomena in events with at least three photons collected in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector,*" EPJC**76**(2016)
- ATLAS study was motivated and applied to the Next-MSSM case with light CP-odd $gg \to H \to a_1 a_1 \to \gamma\gamma\gamma\gamma$.

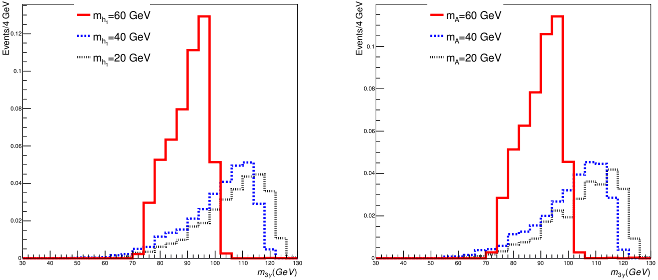


- $gg \to H \to hh \to 4\gamma$ and $gg \to H \to AA \to 4\gamma$ have the same differential cross section,
- The matrix elements can be put as

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

  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.
- $\mid \mathcal{M}^{h,A} \mid^2 \propto \{C^2, D^2\}(k_1.k_2)^2(k_3.k_4)^2$

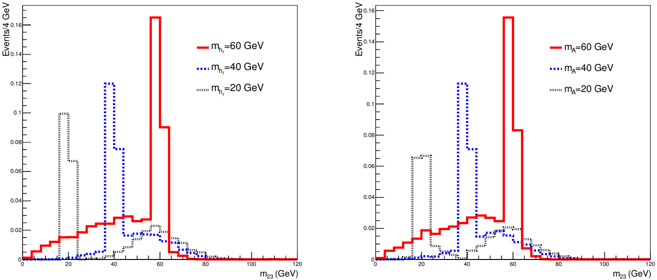
$gg \to H \to hh \to 4\gamma$ vs $gg \to H \to AA \to 4\gamma$



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).

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).
- 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) $\Delta R(\gamma\gamma) > 0.4$.

Our scan

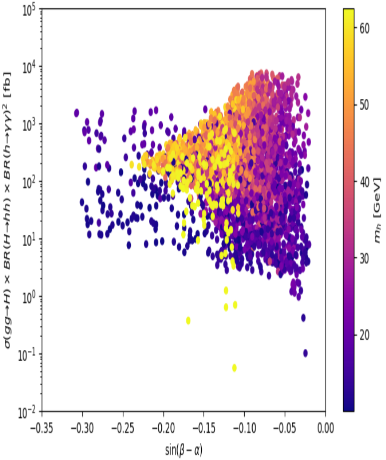
parameters	scan-1	scan-2
m_H (SM-like)	125	125
m_h	$[10, 62.5]$	$[10, 62.5]$
m_A	$[62.5, 200]$	$[10, 200]$
$m_{H^\pm}$	$[100, 170]$	$[100, 170]$
$\tan\beta$	$[2, 50]$	$[2, 50]$
α	$\alpha = \pm\frac{\pi}{2} \mp \delta$	$s_{\beta-\alpha} = [-0.35, 0.0]$
m_{12}^2	$[0, 100]$	$[0, 100]$

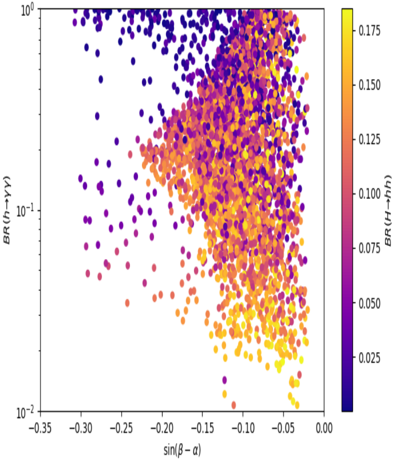
Our scan

parameters	scan-1	scan-2
m_H (SM-like)	125	125
m_h	$[10, 62.5]$	$[10, 62.5]$
m_A	$[62.5, 200]$	$[10, 200]$
$m_{H^\pm}$	$[100, 170]$	$[100, 170]$
$\tan\beta$	$[2, 50]$	$[2, 50]$
α	$\alpha = \pm\frac{\pi}{2} \mp \delta$	$s_{\beta-\alpha} = [-0.35, 0.0]$
m_{12}^2	$[0, 100]$	$[0, 100]$

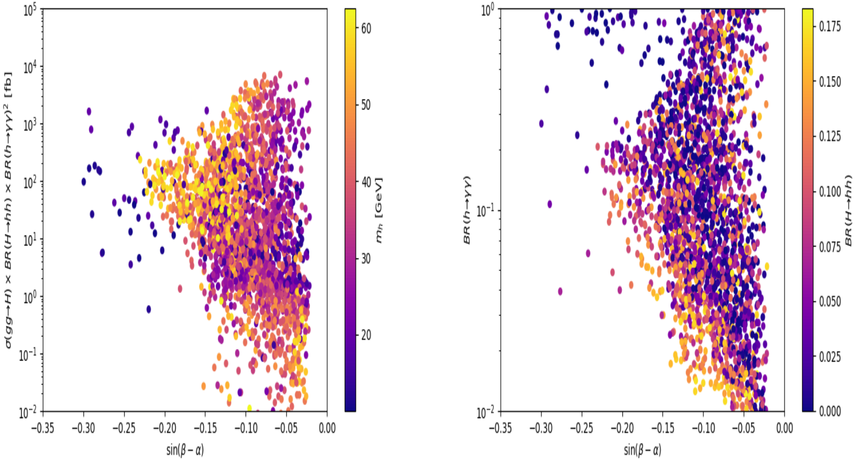
- Evaluate $Br(h \to \gamma\gamma)$ and $BR(H \to hh, AA)$ taking into account all LHC constraints as well as all theoretical constraints
- $\sigma(gg \to H \to hh \to \gamma\gamma\gamma\gamma) = \sigma(gg \to H) BR(H \to hh)(Br(h \to \gamma\gamma))^2$ is evaluated using the narrow width approximation.

$\sigma(gg \to H \to hh \to \gamma\gamma)$ scan-1

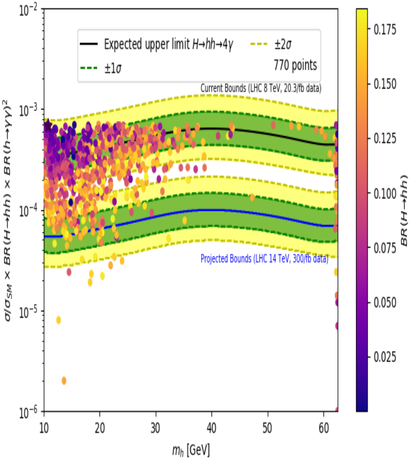


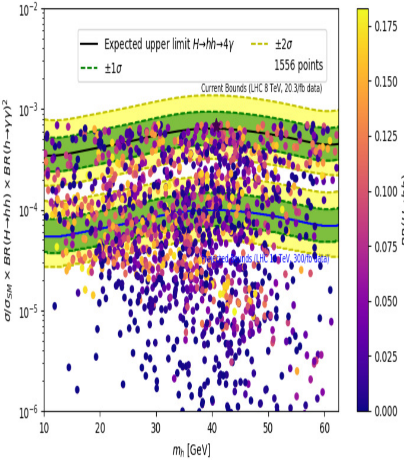


$\sigma(gg \to H \to hh \to \gamma\gamma)$ scan-2



$\sigma(gg \to H \to hh \to \gamma\gamma\gamma\gamma)$





Search for $A^0 \to \gamma\gamma, ZZ, WW$ in 2HDM w/wo VLQ

- $A^0 \to \gamma\gamma, ZZ$ clean final states
- $A^0 \to ZZ$ can be used as a means to search for signals of CPV.
- $A^0 \to \gamma\gamma, ZZ, WW$ are all loop mediated by fermionic loops. Because in the bosonic sector, the EW theory conserves C and P while after adding fermions C and P are separately violated. Therefore, there is no contribution to $A \to VV$ from the SM bosons

  Gunion, Haber, Kao PRD'92

$A \to \gamma\gamma$: 2HDM 8 TeV

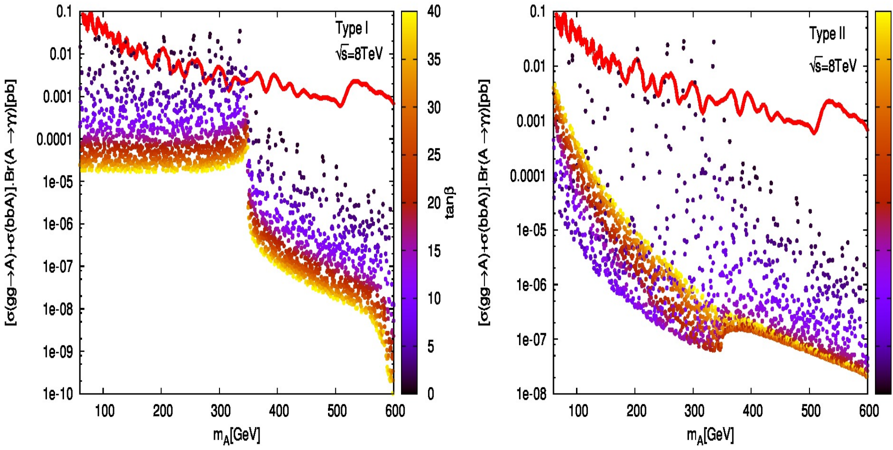


Figure: $\sigma(pp \to A^0) \times Br(A \to \gamma\gamma)$ at $\sqrt{s} = 8\,TeV$ vs m_A and $\tan\beta$.

$A \to \gamma\gamma$: 2HDM 14 TeV

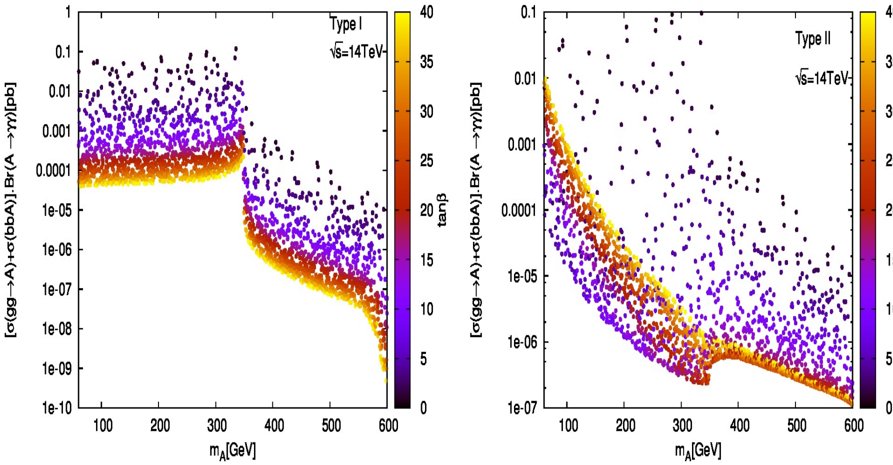


Figure: $\sigma(pp \to A) \times Br(A \to \gamma\gamma)$ at $\sqrt{s} = 14\,TeV$ vs m_A.

$A \to ZZ$: 2HDM

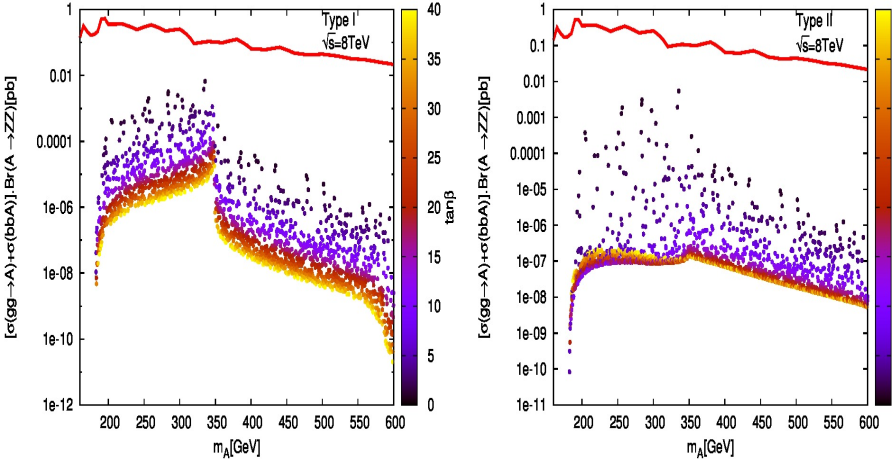


Figure: $\sigma(pp \to A^0) \times Br(A \to ZZ)$ at $\sqrt{s} = 8\,TeV$ vs m_A and $\tan\beta$.

Constraint from T parameter.

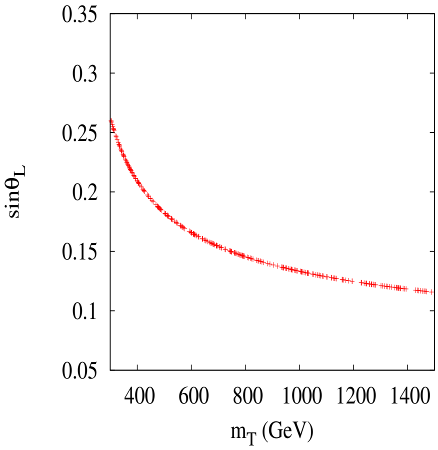


Figure: Upper limit at 95% CL on the mixing angle as a function of the T quark mass in the 2HDM-II with VLT

2HDM+VLT

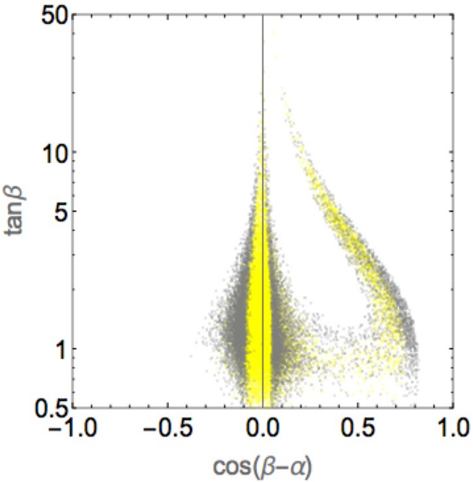


Figure: 95% CL region in the $(\cos(\beta-\alpha), \tan\beta)$ plane. The gray (yellow) regions were obtained using Higgs Run 1(2) data. $|s_L| < 0.20$ and 400$< m_T < 1000$ GeV and set $y_T = 4\pi$.

2HDM+VLT

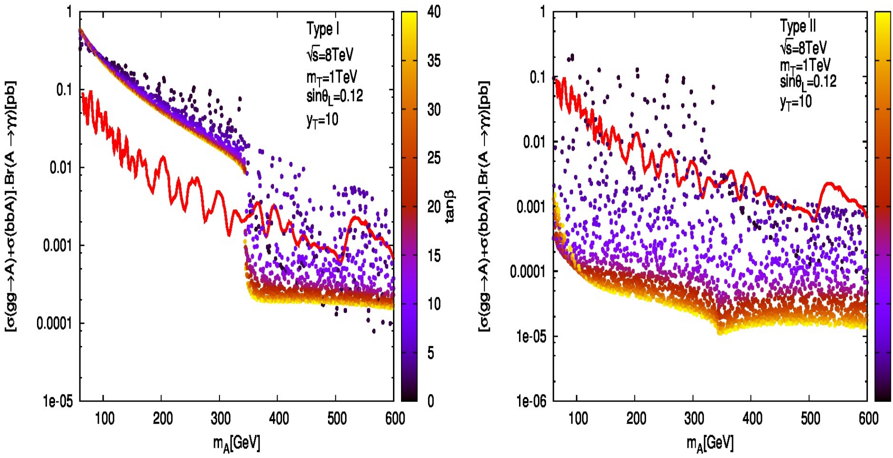


Figure: $\sigma(pp \to A^0) \times Br(A \to \gamma\gamma)$ in the 2HDM+VLT at $\sqrt{s} = 8\,TeV$ vs m_A and tanβ.

2HDM+VLT

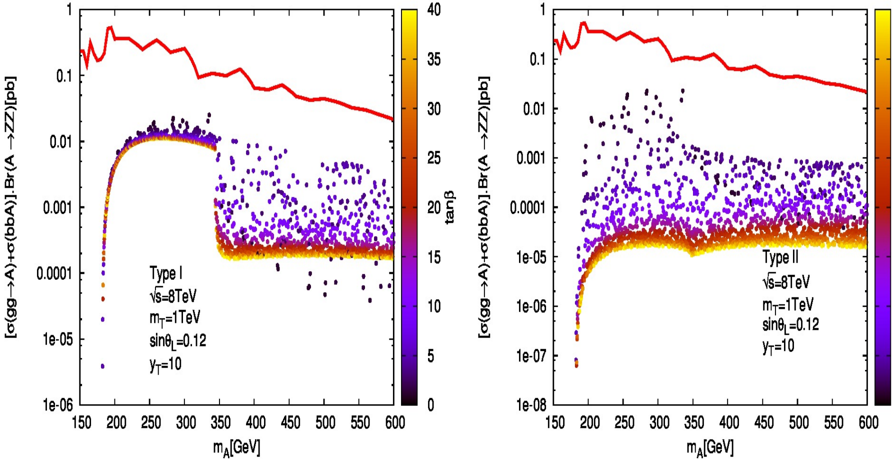


Figure: $\sigma(pp \to A^0) \times Br(A \to ZZ)$ in the 2HDM+VLT at $\sqrt{s} = 8\,TeV$ vs m_A and $\tan\beta$

Conclusions

- In 2HDM-I there is regions of the parameter space compliant with theoretical and experimental constraints yielding substantial $Br(h \to \gamma\gamma)$ as well as $Br(H \to hh)$.
- The cross section for $gg \to H \to hh \to 4\gamma$ is at pb level and is sensitive to ATLAS exclusion.
- We extrapolate our results to a collider energy of 14 TeV and luminosity of 300/fb.
- A small portion of parameter space of the 2HDM has already been probed in $A^0 \to \gamma\gamma$.
- For the case of the final states with two massive gauge bosons we are still at least one order of magnitude away from highest possible rates in the model.