Search for a lighter Higgs in Two Higgs Doublet Models

Solène Le Corre[1]

In collaboration with Giacomo Cacciapaglia[1], Aldo Deandrea[1], Suzanne Gascon-Shotkin[1], Morgan Lethuillier[1], Junquan Tao[2]

GDR Terascale @ Nantes - 24 may, 2016

[1] Institut de Physique Nucléaire de Lyon - Université Claude Bernard Lyon 1
[2] Institute of High Energy Physics, Chinese Academy of Sciences

Motivations

- A Higgs boson discovered at LHC;
- Maybe other scalars waiting to be discovered;
- Two Higgs Doublet Model (2HDM): larger scalar sector than SM.

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The Two Higgs Doublet Model

How does it work ?

Reminder

- Two doublets: ϕ_1, ϕ_2, with vev v_1, v_2;
- Angle β: $\tan\beta = \frac{v_2}{v_1}$;
- Mass eigenstates $\Rightarrow$ angle α.

Physical scalars

- Two scalars: h, H;
- A pseudoscalar: A;
- Two charged higgs: $H^{\pm}$.

Parameters in the physical basis

$$m_h,\ m_H = 125\ GeV,\ m_A,\ m_{H^{\pm}},\ \tan\beta,\ \sin(\beta-\alpha),\ m_{12}$$

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The Two Higgs Doublet Model

The different types of 2HDM

Different ways to couple ϕ_1, ϕ_2 to fermions:

	Type			
	I	II	Flipped	Lepton-specific
Up-type quarks	ϕ_2	ϕ_2	ϕ_2	ϕ_1
Down-type quarks	ϕ_2	ϕ_1	ϕ_1	ϕ_2
Leptons	ϕ_2	ϕ_1	ϕ_2	ϕ_1

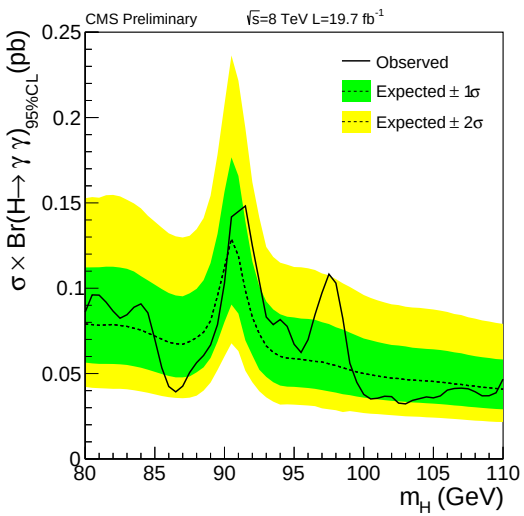
Here, we will focus on Type I only.

The Two Higgs Doublet Model

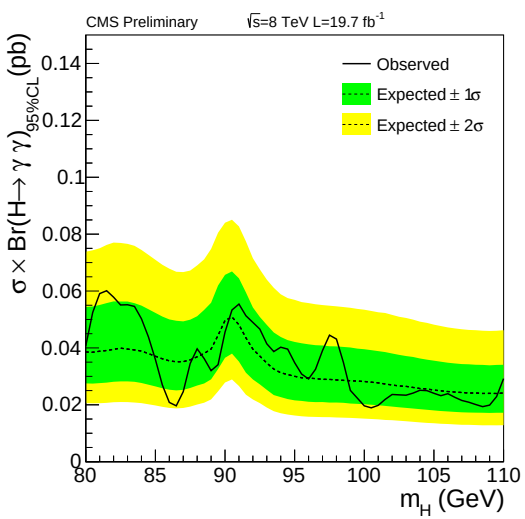
CMS limits on a lighter Higgs

- **Goal:** is LHC Run I at 8 TeV sensitive to a lighter Higgs ?
- **Channel of interest:** $h \to \gamma\gamma$ for $m_h \in [80; 110]$ GeV.

$\sigma_{gg \to h} \times BR_{h \to \gamma\gamma}$



$\sigma_{VBF/VH \to h} \times BR_{h \to \gamma\gamma}$



cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-037/index.html, [CMS-PAS-HIG-14-037]

The Two Higgs Doublet Model

Computation of the $\sigma \times BR_{h\to\gamma\gamma}$

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- **Branching ratios and widths:** computed with **2HDMC**.
  [Eriksson, Rathsmann, Stal; arXiv:0902.0851v2]
- **Cross sections:** computed with the "kappa trick".
  [Cacciapaglia, Deandrea, Drieu La Rochelle, Flament; arXiv:1311.5132v2]

$$\sigma^{2HDM}_{ggh} \simeq \kappa_g^2 \times \sigma^{SM}_{ggh}, \qquad \kappa_g^2 = \frac{\Gamma^{2HDM}_{ggh}}{\Gamma^{SM}_{ggh}}$$

$$\sigma^{2HDM}_{VBF+VH} \simeq \kappa_V^2 \times \sigma^{SM}_{VBF+VH}, \qquad \kappa_V^2 = \frac{\Gamma^{2HDM}_{WW}}{\Gamma^{SM}_{WW}} = \sin(\beta-\alpha)^2$$

SM cross section taken from LHCHXSWG [CERN-2013-004], [arXiv:1307.1347].

Is it coherent with SusHi calculation ?

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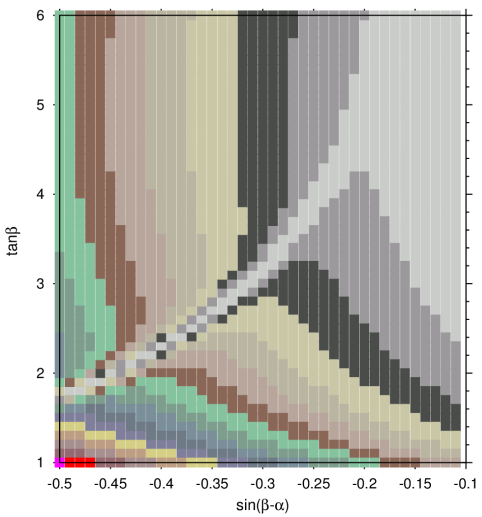
The Two Higgs Doublet Model

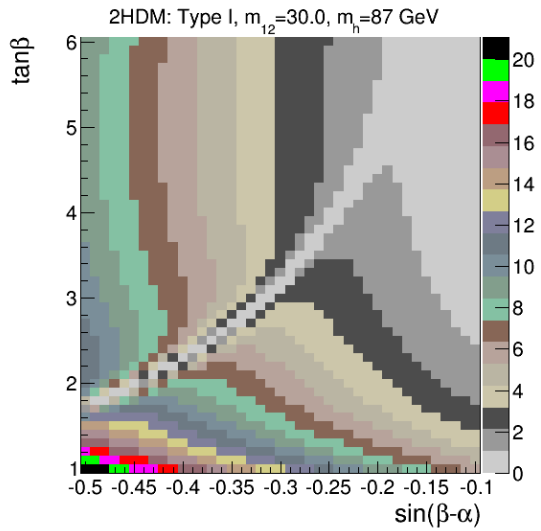
Comparison with SusHi for $gg \to h$ production mode

Inputs

$m_h = 87\ GeV, \quad m_{12} = 30\ GeV, \quad m_H = 125\ GeV, \quad m_A, m_{H^+} = 80\ GeV$
$\tan\beta : 1 - 6, 0.1/step, \quad \sin(\beta - \alpha) : -0.5\ \ -0.1, 0.01/step.$



$\sigma_{gg\to h} \times BR_{h\to\gamma\gamma}$ with "kappa trick".



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- Good agreement for $gg \to h$ production mode;
- SusHi: only ggh and bbh production;
- We assume "kappa trick" can be used for VBF/VH production mode.

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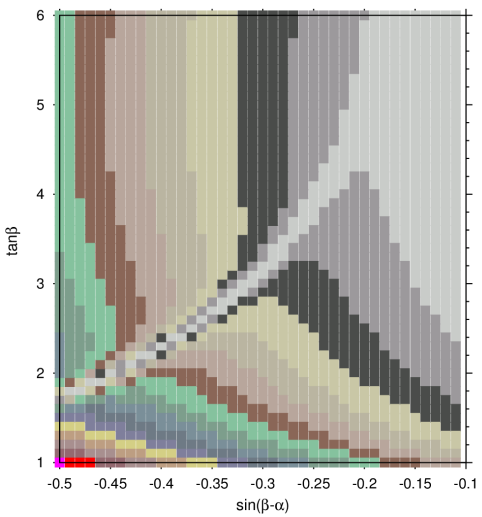

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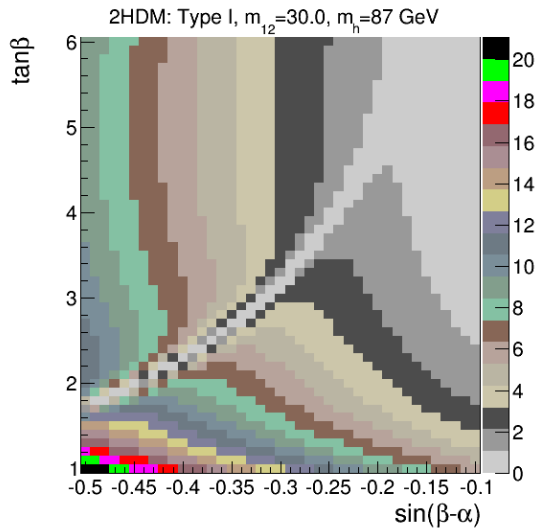

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Constraints

Inputs

$$m_h \in [80;110]\ GeV,\ m_H = 125\ GeV,\ m_A \in [80;1000]\ GeV,\ m_{H^\pm} \in [80;1000]\ GeV,$$
$$\tan\beta \in [1/50;50], \qquad \sin(\beta-\alpha) \in [-1;1], \qquad m_{12} = 30\ GeV$$

- **"Theoretical" constraints:**
  - Electroweak precision tests (S, T, U parameters);
  - Stability, unitarity and perturbativity constraints;
  - Flavor constraints ($B \to X_s\gamma$, $B_s \to \mu\mu$, $\Delta_0(B \to K^*\gamma)$, ΔMd).
- **LEP constraints** (HiggsBounds *[Bechtle et al., arXiv:0811.4169]*)
- **LHC constraints** on the 125 GeV Higgs boson (Run I Legacy combination). *[ATLAS-CONF-2015-044; CMS-PAS-HIG-15-002], [arXiv:1504.07919]*

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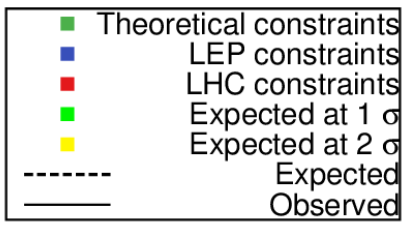

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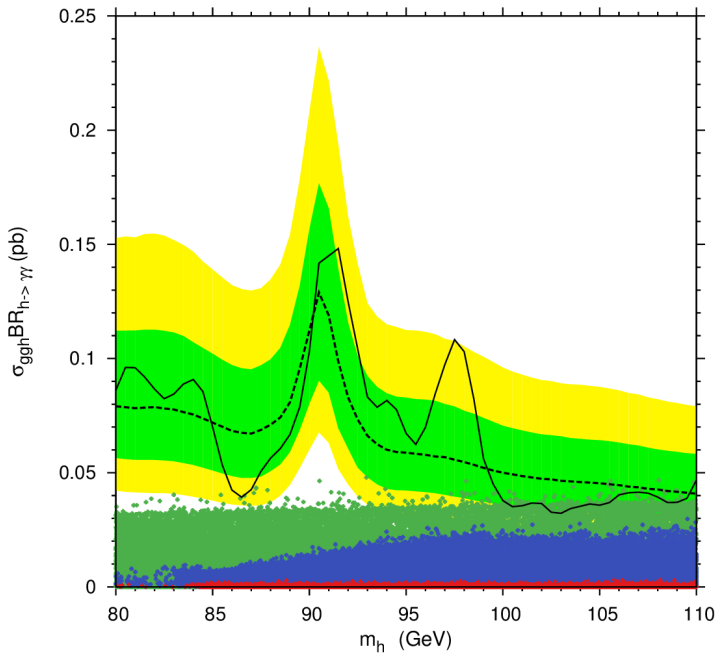

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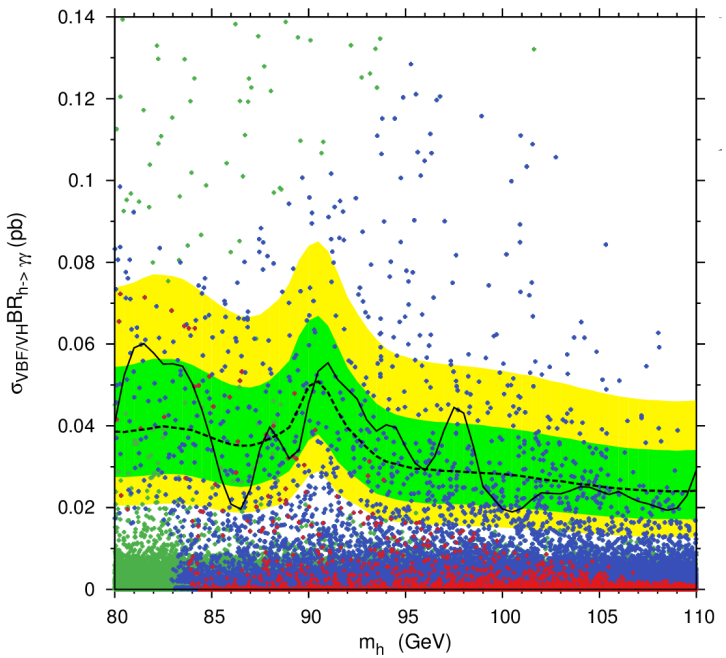

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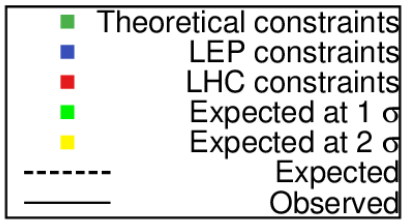

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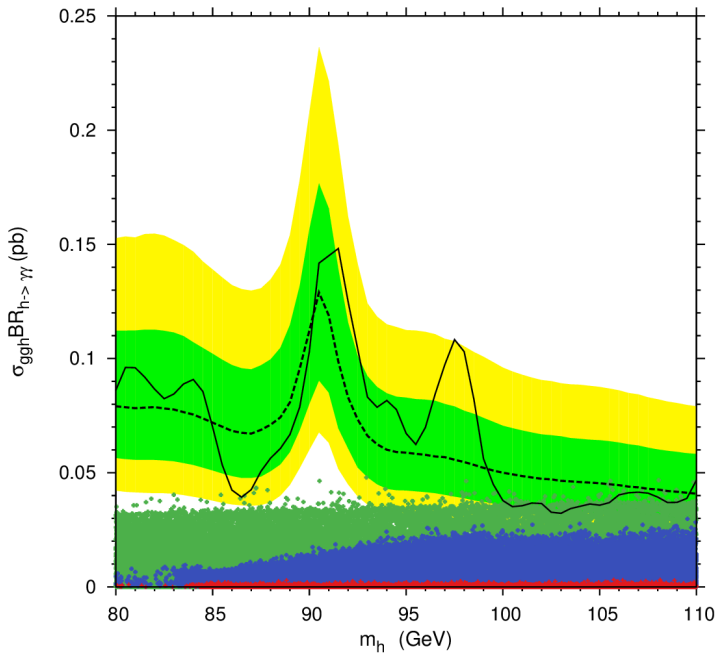

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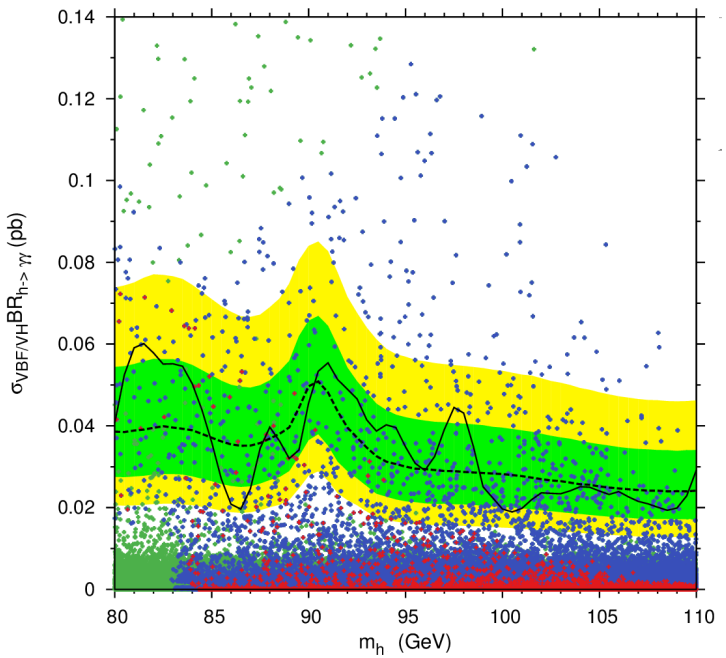

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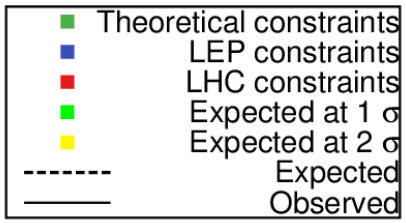

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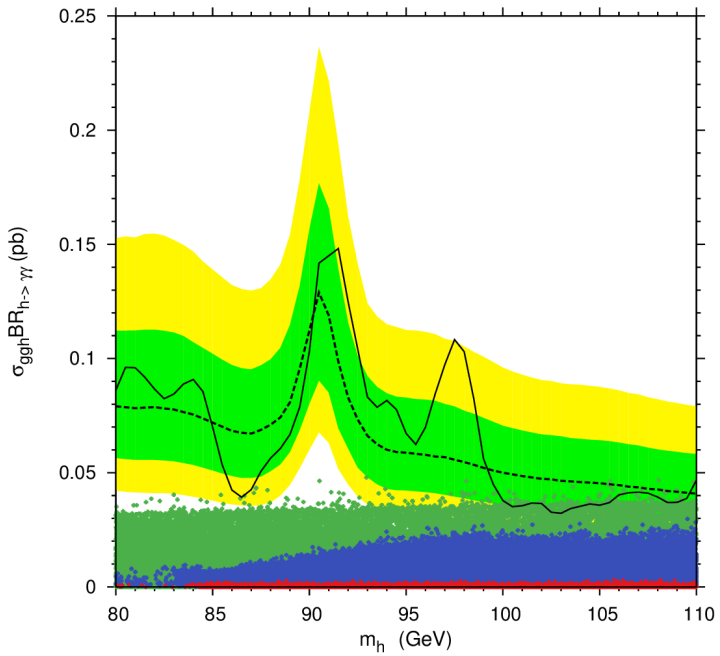

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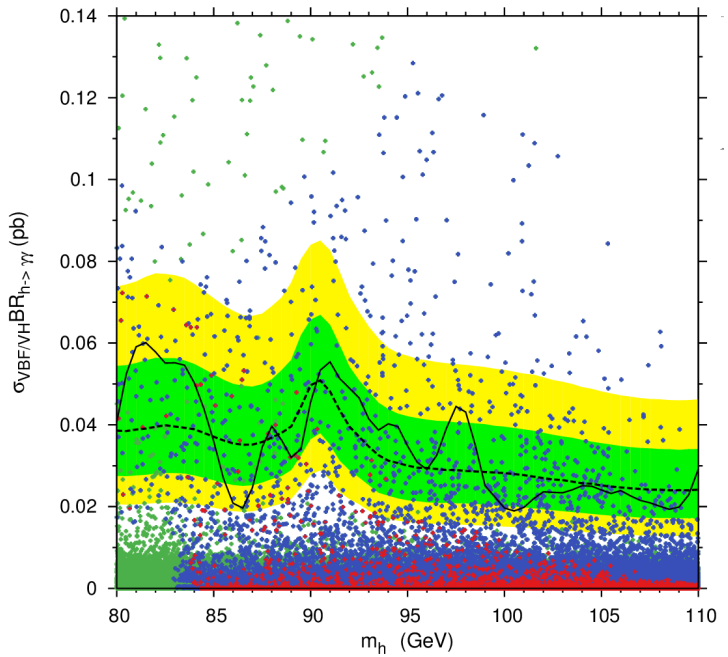

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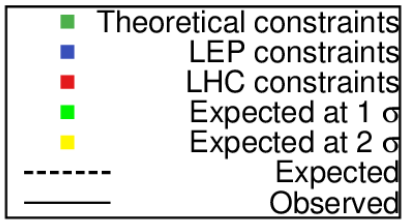

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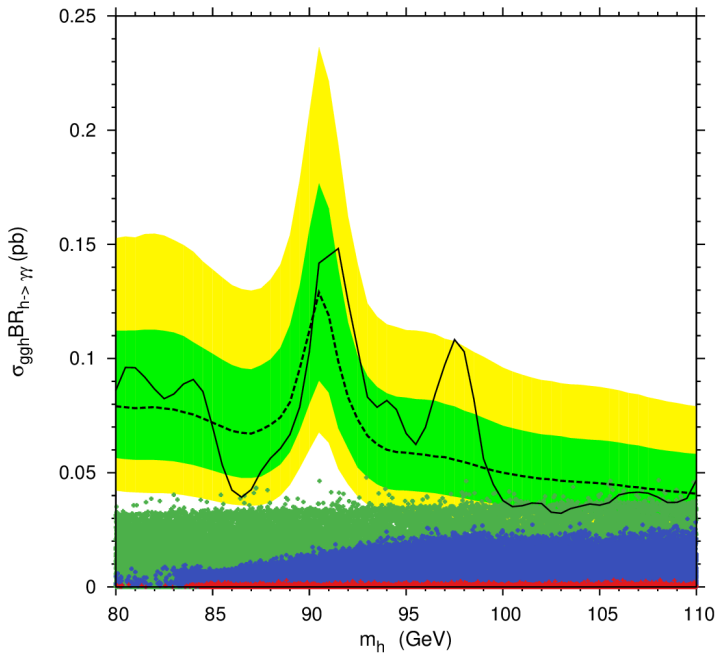

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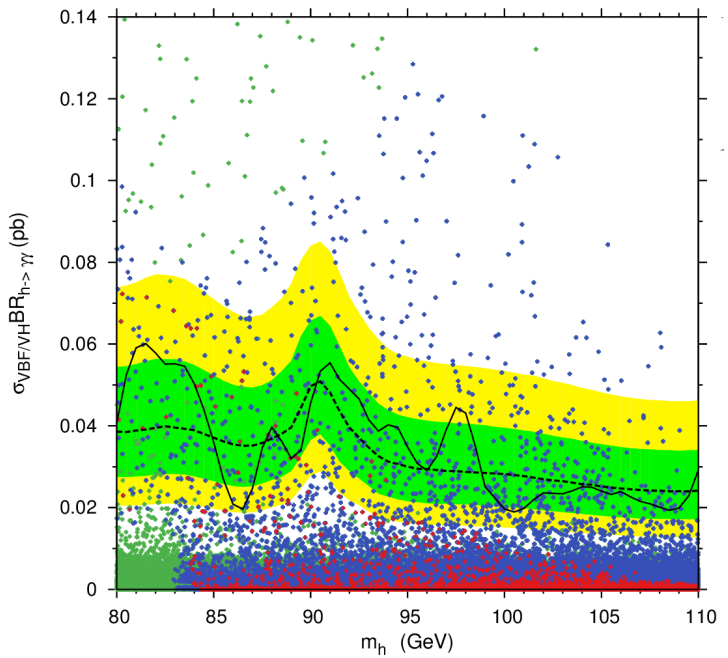
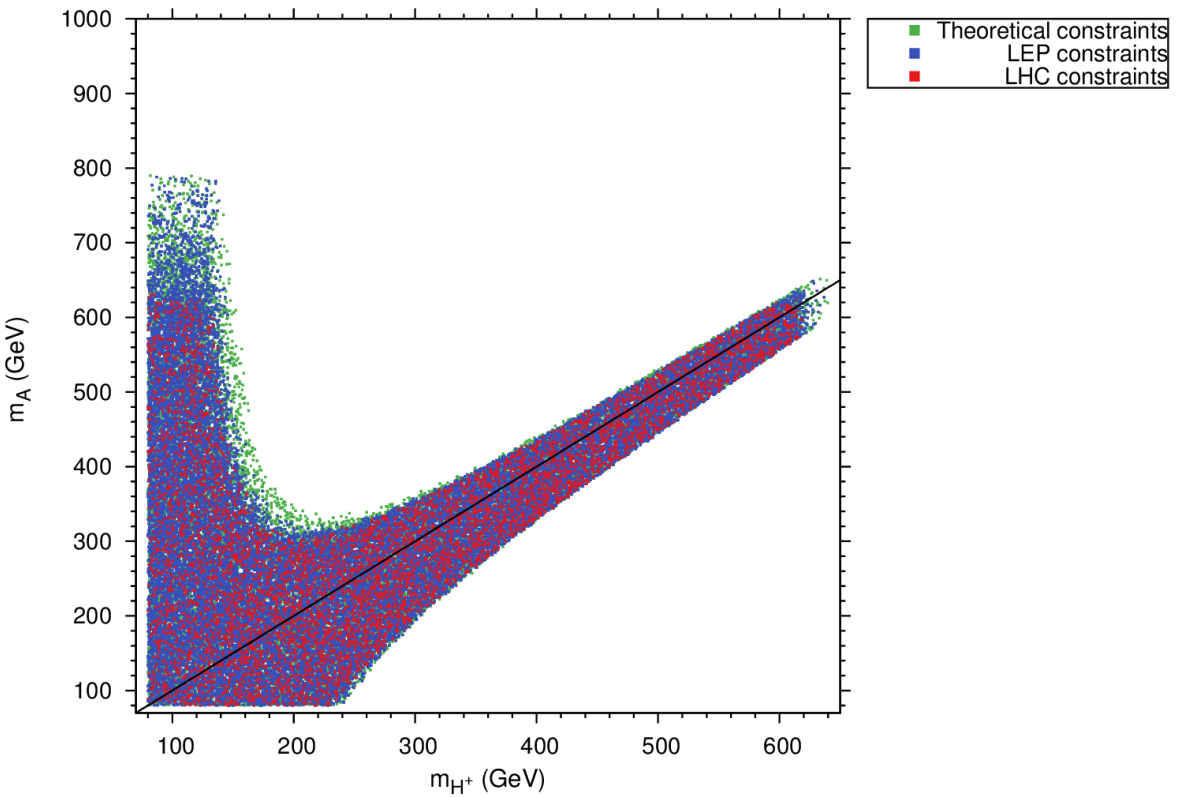


Constraints on the free parameters

m_A and $m_{H^\pm}$

- Strong correlation (due to T parameter)
- High mass limit: m_A, $m_{H^\pm} < 630$ GeV.

m_A vs $m_{H^\pm}$

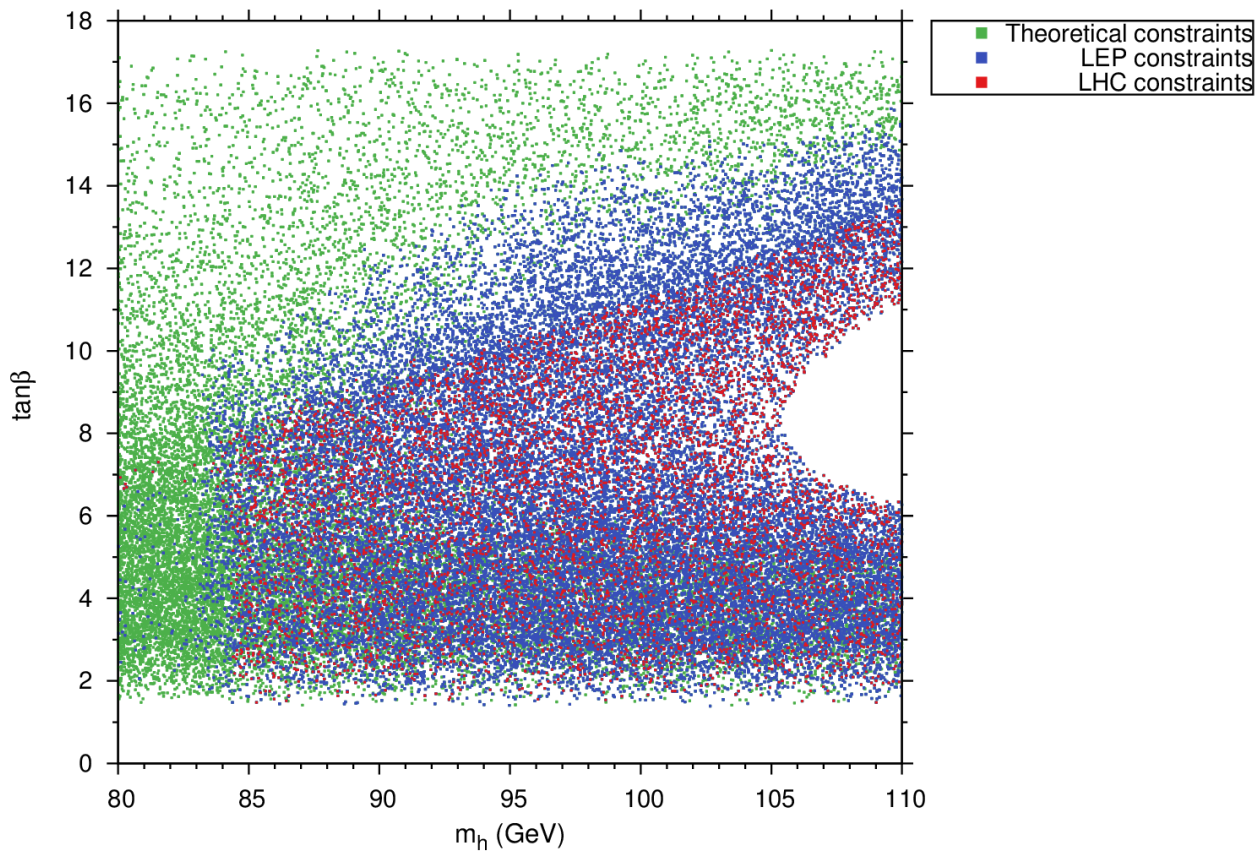


Constraints on the free parameters

tan β

- Higher and lower bounds: $1.5 < \tan\beta < 14$.

tan β vs m_h

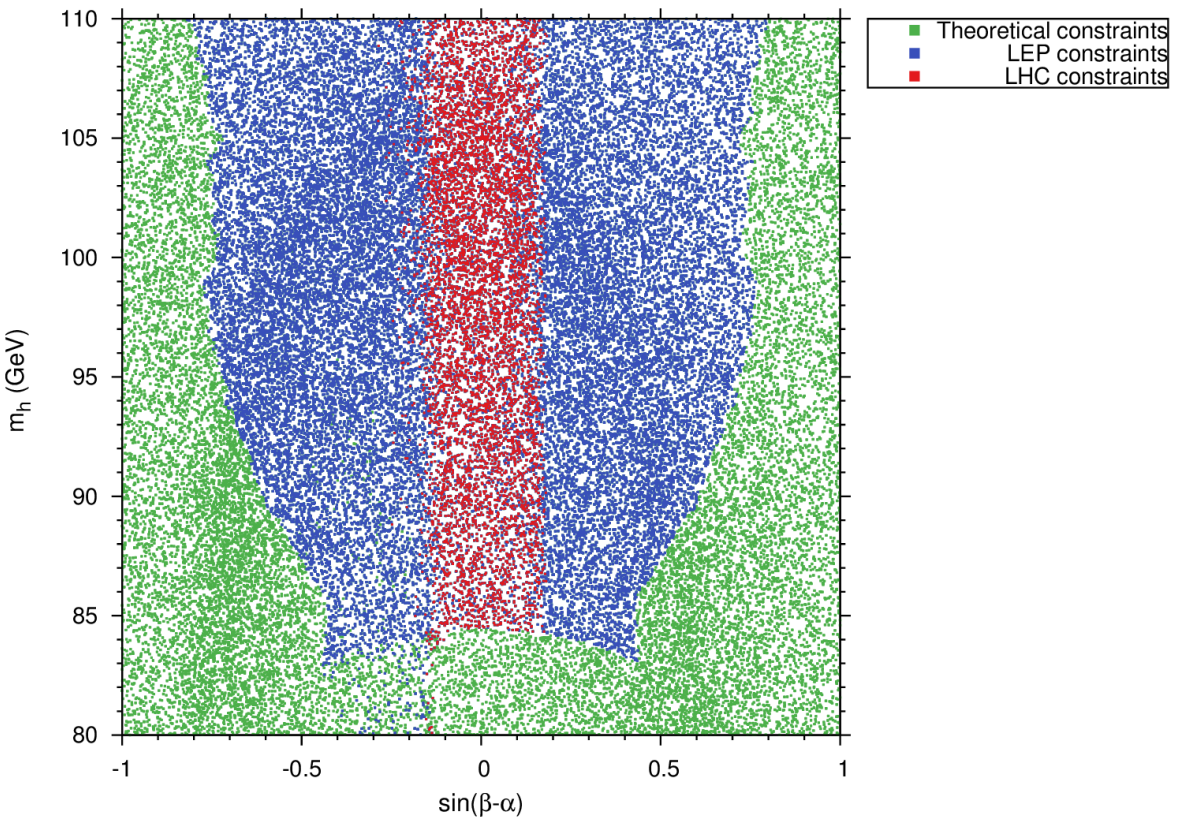


Constraints on the free parameters

m_h and sin$(\beta - \alpha)$

- No lower bound on m_h
- Constraints on sin$(\beta - \alpha)$: -0.3<sin$(\beta - \alpha)$<0.2

m_h vs sin$(\beta - \alpha)$

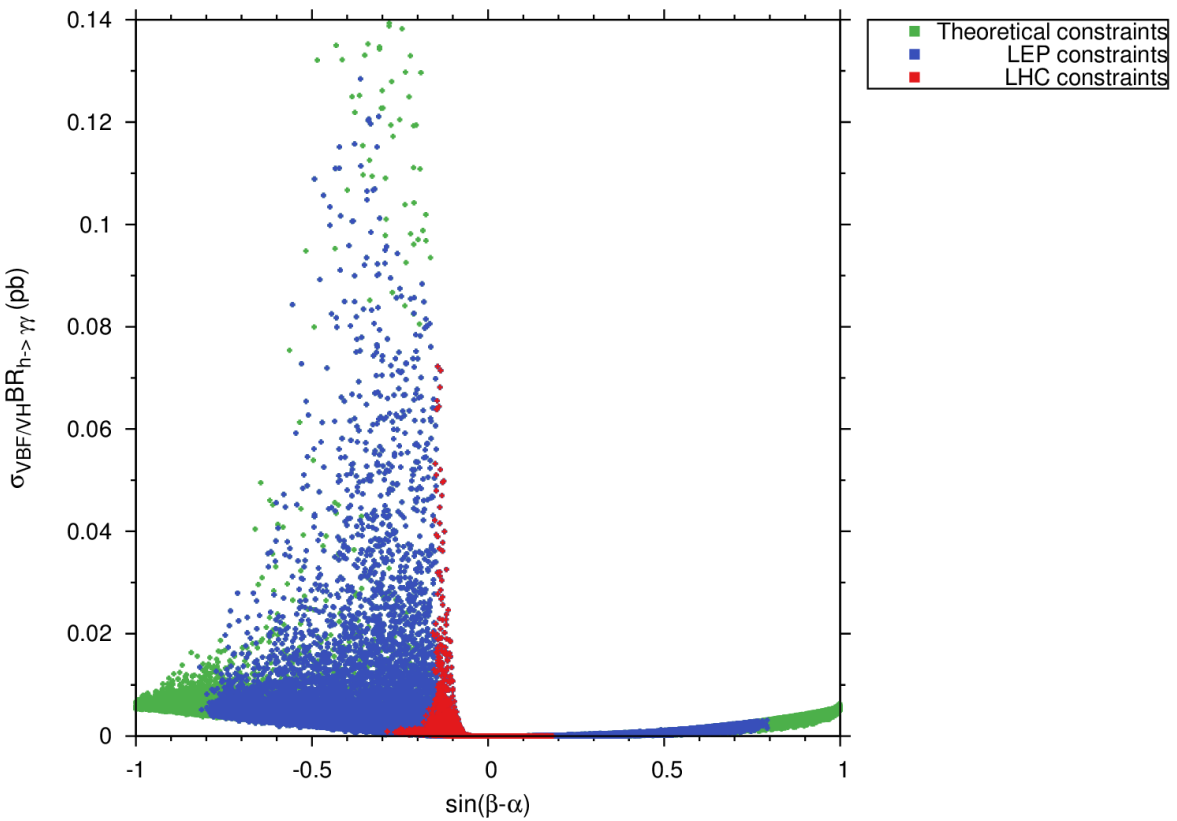


Constraints on the free parameters
$\sin(\beta-\alpha)$

- Restriction to $\sigma\times$BR>0.005 pb;

$\Rightarrow$ Restriction on $\sin(\beta-\alpha)$: -0.2<$\sin(\beta-\alpha)$<0.0

$\sigma_{VBF/VH\to h} \times BR_{h\to\gamma\gamma}$ vs $\sin(\beta-\alpha)$



Constraints on the free parameters

Scans with more statistics

New inputs :

$m_h \in [80; 110]$ *GeV*,
$m_H = 125$ *GeV*,
$m_A \in [80; 630]$ *GeV*,
$m_{H^\pm} \in [80; 630]$ *GeV*,
$\tan\beta \in [1.5; 14]$,
$\sin(\beta-\alpha) \in [-0.2; 0]$,
$m_{12} = 30$ *GeV*

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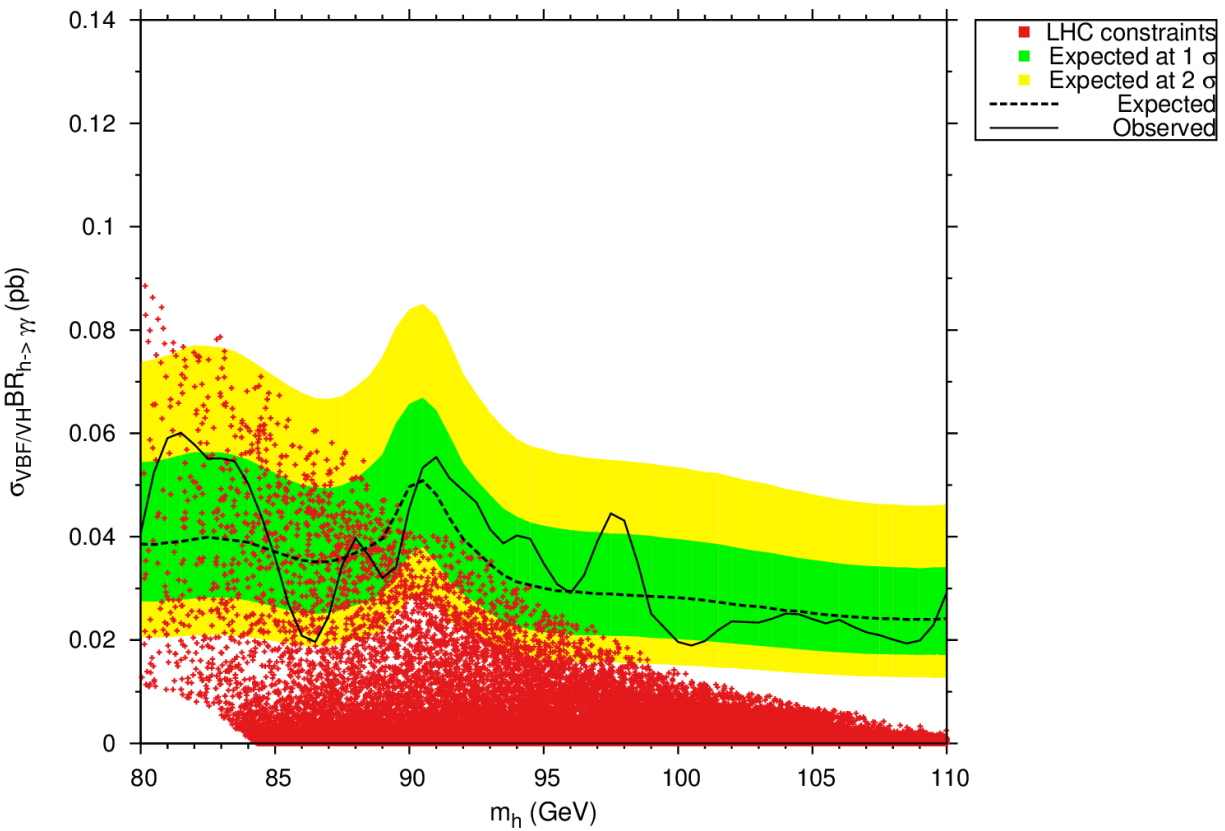

- Sensitivity for masses below 90 GeV;

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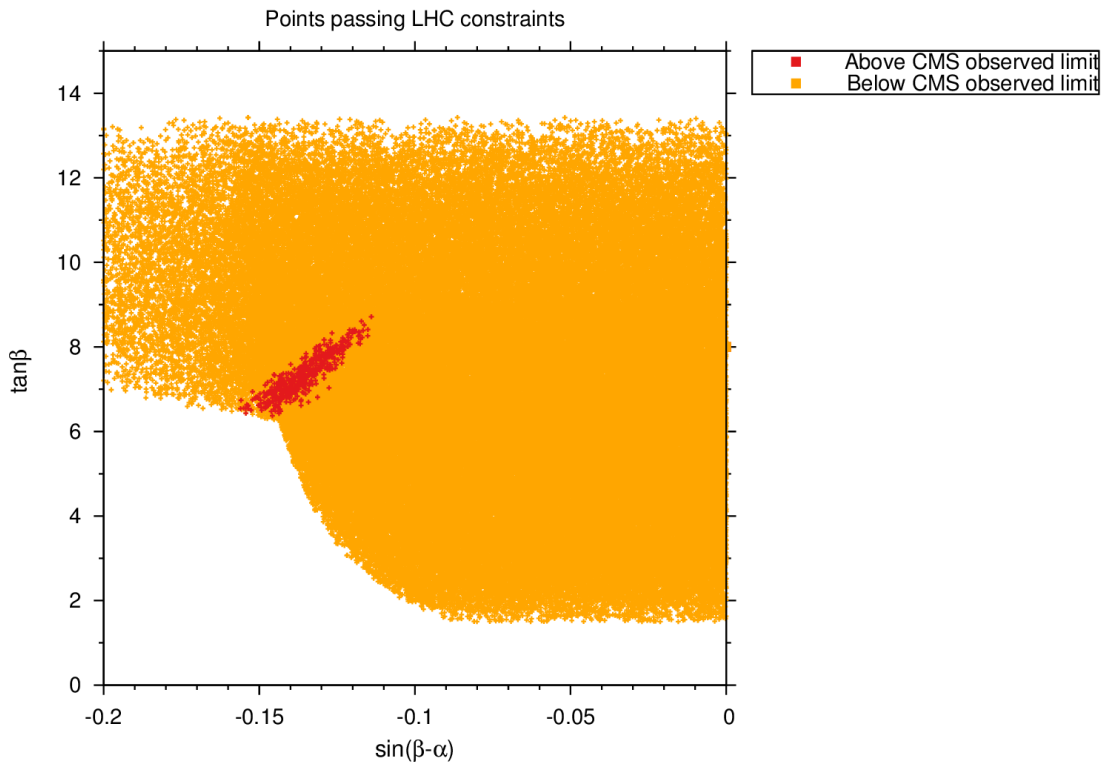
Exclusion from CMS observed exclusion limits (VBF/VH channel) in $\tan\beta$ vs $\sin(\beta-\alpha)$ plane ("LHC points" only)



- CMS observed limit in VBF/VH channel $\Rightarrow$ red areas in parameter space can be excluded.

Conclusion

- We study the 2HDM Type I with $m_H = 125$ GeV, $m_{12} = 30$ GeV;
- Sensitivity in VBF/VH production channel;
- Put some constraints on the free parameters:

$$m_h \in [80; 110]\ GeV,\ m_H = 125\ GeV,\ m_A \in [80; 630]\ GeV,\ m_{H^\pm} \in [80; 630]\ GeV,$$
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- Highest rates in VBF/VH channel for $\sin(\beta-\alpha) \in [-0.2; 0]$;
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Backup

The Two Higgs Doublet Model

How does it work ?

Two doublets: ϕ_1, ϕ_2.

Most general potential:

$$
\begin{aligned}
V =& m_{11}^2 \phi_1^\dagger \phi_1 + m_{22}^2 \phi_2^\dagger \phi_2 - \left(m_{12}^2 \phi_1^\dagger \phi_2 + h.c. \right) + \frac{\lambda_1}{2} \left(\phi_1^\dagger \phi_1 \right)^2 \\
&+ \frac{\lambda_2}{2} \left(\phi_2^\dagger \phi_2 \right)^2 + \lambda_3 \left(\phi_1^\dagger \phi_1 \right) \left(\phi_2^\dagger \phi_2 \right) + \lambda_4 \left(\phi_1^\dagger \phi_2 \right) \left(\phi_2^\dagger \phi_1 \right) \\
&\left\{ + \frac{\lambda_5}{2} \left(\phi_1^\dagger \phi_2 \right)^2 + \left[\lambda_6 \left(\phi_1^\dagger \phi_1 \right) + \lambda_7 \left(\phi_2^\dagger \phi_2 \right) \right] \phi_1^\dagger \phi_2 + h.c. \right\}
\end{aligned}
$$

FCNC $\Rightarrow$ descrete $\mathbb{Z}_2$ symmetry.
$\Rightarrow \lambda_6, \lambda_7 = 0$; $m_{12} \neq 0$ (soft breaking).