Current status of MSSM Higgs sector with LHC 13 TeV data

Arghya Choudhury

Consortium for Fundamental Physics
Department of Physics and Astronomy
University of Sheffield, UK

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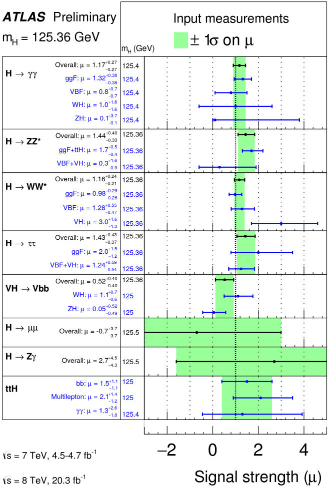
The University Of Sheffield.

Plan of the Talk :

- Brief introduction to MSSM Higgs Sector.
- Global analysis and available pMSSM parameter space.
- Present status of MSSM from LHC Run-I & RUN-II data.
- Conclusions.

Talk based on: R. K. Barman, B. Bhattacherjee, A. Choudhury, D. Chowdhury, J. Lahiri, S. Ray [arXiv:1608.02573].



- Data consistent with SM hypothesis.
- This 125 GeV Higgs → SM Higgs ?????
- Room for New Physics → Still 10 - 20 % deviation of Higgs coupling from SM is allowed.

Higgs sector of Minimal Supersymmetric SM (MSSM):

$$\mathcal{W}_{MSSM} = \widehat{U}^c Y_u \widehat{Q}\widehat{H}_u - \widehat{D}^c Y_d \widehat{Q}\widehat{H}_d - \widehat{E}^c Y_e \widehat{L}\widehat{H}_d + \mu \widehat{H}_d \widehat{H}_u .$$

Superfield	$SU(3)$	$SU(2)_L$	$U(1)_Y$	Particles
$\widehat{H}_d$	1	2	$-\frac{1}{2}$	$(H_d, \widetilde{H}_d)$
$\widehat{H}_u$	1	2	$\frac{1}{2}$	$(H_u, \widetilde{H}_u)$

$$H_d = \begin{pmatrix} h_d^0 \\ h_d^- \end{pmatrix}, \quad \text{and} \quad H_u = \begin{pmatrix} h_u^+ \\ h_u^0 \end{pmatrix},$$

$$\widetilde{H}_d = \begin{pmatrix} \widetilde{h}_d^0 \\ \widetilde{h}_d^- \end{pmatrix}, \quad \text{and} \quad \widetilde{H}_u = \begin{pmatrix} \widetilde{h}_u^+ \\ \widetilde{h}_u^0 \end{pmatrix}.$$

- minimality signifies that this model contains only SM particles with their superpartners and the minimum number (two) of Higgs doublets.
- Higgsinos are chiral fermions. Second Higgs superfield with opposite hypercharge is needed to make the theory anomaly free.
- After the EW symmetry breaking $\rightarrow$ We are left with **5** physical Higgs bosons:
  - Two charged Higgs bosons : $H^{\pm}$,
  - Two CP-even Higgs bosons : h^0 (lighter) and H^0 (heavier),
  - One CP-odd Higgs boson : A^0.

MSSM Higgs sector:

At the tree level, the Higgs sector of MSSM is described by two parameters :

- α and β
  - $\alpha \rightarrow$ mixing angle in the neutral CP even sector.
  - $\tan\beta \rightarrow$ ratio of the vacuum expectation values.
- Or by pseudoscalar mass M_A and $\tan\beta$.
- $tan2\alpha = \frac{M_h^2+M_H^2}{M_A^2-M_Z^2} tan2\beta$

MSSM Higgs sector:

- Tree level parameters: (α and $\tan\beta$) $\rightarrow$ (M_A and $\tan\beta$).
- Related By: $tan2\alpha = \frac{M_h^2+M_H^2}{M_A^2-M_Z^2} tan2\beta$
- Radiative corrections to the Higgs boson mass matrix involving various SUSY parameters can modify the tree level value of α significantly.
- $\tan 2\alpha = \frac{M_A^2+M_Z^2}{M_A^2-M_Z^2+\epsilon/\cos 2\beta}\ \tan 2\beta$, where $\epsilon = \frac{3G_F}{\sqrt{2}\pi^2}\frac{m_t^4}{\sin^2\beta}\ \log\left[1+\frac{{M_S}^2}{m_t^2}\right]$ (corrections in the leading ${m_t}^4$ - one-loop approximation)
- Global fit analysis considering various Higgs coupling measurements may constrain the MSSM parameter space.

Global χ^2 - Experimental inputs from LHC RUN-I:

Decay channel	Production Mode	ATLAS	Production Mode	CMS
$\gamma\gamma$	ggF	$1.32^{+0.38}_{-0.38}$ [58]	ggF	$1.12^{+0.37}_{-0.32}$ [59]
	VBF	$0.8^{+0.7}_{-0.7}$ [58]	VBF	$1.58^{+0.77}_{-0.68}$ [59]
	Wh	$1.0^{+1.60}_{-1.60}$ [58]	Wh	$-0.16^{+1.16}_{-0.79}$ [59]
	$t\bar{t}h$	$1.60^{+2.70}_{-1.80}$ [58]	$t\bar{t}h$	$2.69^{+2.51}_{-1.81}$ [59]
	Zh	$0.1^{+3.70}_{-0.10}$ [58]	-	-
ZZ	$VBF+Vh$	$0.26^{+1.64}_{-0.94}$ [60]	$VBF+Vh$	$1.70^{+2.2}_{-2.1}$ [61]
	$ggF+t\bar{t}h+b\bar{b}h$	$1.66^{+0.51}_{-0.44}$ [60]	$ggF+t\bar{t}h$	$0.80^{+0.46}_{-0.36}$ [61]
W^+W^-	ggF	$1.02^{+0.29}_{-0.26}$ [62]	$0/1$ jet (97% ggF, 3% VBF)	$0.74^{+0.22}_{-0.20}$ [63]
	VBF	$1.27^{+0.53}_{-0.45}$ [62]	VBF tagged (17% ggF, 83% VBF)	$0.60^{+0.57}_{-0.46}$ [63]
	Vh	$3.0^{+1.64}_{-1.30}$ [64]	Vh tagged	$0.39^{+1.97}_{-1.87}$ [63]
	-	-	Wh tagged	$0.56^{+1.27}_{-0.95}$ [63]
$b\bar{b}$	Vh	$0.51^{+0.40}_{-0.37}$ [65]	Vh	$1.0^{+0.5}_{-0.5}$ [66]
$\tau^+\tau^-$	ggF	$1.93^{+1.45}_{-1.15}$ [67]	0 jet (96.9% ggF, 1% VBF, 2.1% Vh)	$0.34^{+1.09}_{-1.09}$ [68]
	$VBF(60\%)+Vh(40\%)$	$1.24^{+0.58}_{-0.54}$ [67]	1 jet (75.7% ggF, 14% VBF, 10.3% Vh)	$1.07^{+0.46}_{-0.46}$ [68]
	-	-	VBF tagged (19.6% ggF, 80.4% VBF)	$0.94^{+0.41}_{-0.41}$ [68]
	-	-	Vh tagged	$-0.33^{+1.02}_{-1.02}$ [68]

- Signal strength $\mu_i^f = \frac{\sigma_i \cdot B^f}{\sigma_{i_{SM}} \cdot B^f_{SM}}$
- i stands for production modes
- f stands for decay modes

Inputs for Global χ^2 analysis:

- **Experimental inputs from LHC RUN-II**

Decay channel	Production Mode	ATLAS	Production Mode	CMS
$\gamma\gamma$	ggF	$0.62^{+0.30}_{-0.29}$[69]	ggF	$0.77^{+0.25}_{-0.23}$[70]
	VBF	$2.25^{+0.75}_{-0.75}$[69]	VBF	$1.61^{+0.90}_{-0.80}$[70]
	$t\bar{t}h$	$-0.22^{+1.18}_{-0.88}$[69]	$t\bar{t}h$	$1.91^{+1.5}_{-1.2}$[70]
	Vh	$0.30^{+1.21}_{-1.12}$[69]	-	-
ZZ	ggF	$1.34^{+0.39}_{-0.33}$[69]	ggF	$0.96^{+0.40}_{-0.33}$[71]
	VBF	$3.8^{+2.8}_{-2.2}$[69]	VBF	$0.67^{+1.61}_{-0.67}$[71]
	-	-	Vh	$1.84^{+6.36}_{-1.84}$[71]
	-	-	$t\bar{t}h$	$8.41^{+13.07}_{-8.15}$[71]
$b\bar{b}$	VBF	$-3.9^{+2.8}_{-2.9}$ [72]	VBF	$-3.7^{+2.4}_{-2.5}$ [73]
	$t\bar{t}h$	$2.1^{+1.0}_{-0.9}$ [74]	$t\bar{t}h$	$-2.0^{+1.8}_{-1.8}$ [75]
	Vh	$0.21^{+0.51}_{-0.50}$ [76]	-	-

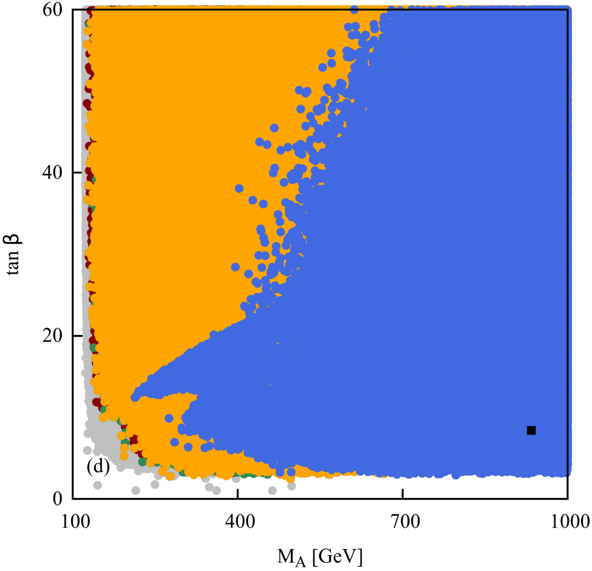
- **Flavour physics constraints:**
  - $\mathrm{Br}(B \to X_s\gamma)_{\mathrm{exp.}} = (3.32 \pm 0.15) \times 10^{-4}$
  - $\mathrm{Br}(B_s \to \mu^+\mu^-)_{\mathrm{exp.}} = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$
  - $\mathrm{Br}(B^+ \to \tau^+\nu_\tau)_{\mathrm{exp}} = (1.06 \pm 0.19) \times 10^{-4}$

MSSM parameter space scan:

$$
\begin{gathered}
600 \text{ GeV} < M_1 < 5 \text{ TeV}, \quad 600 \text{ GeV} < M_2 < 5 \text{ TeV}, \quad 500 \text{ GeV} < M_3 < 5 \text{ TeV} \\
1 < \tan\beta < 60, \quad 100 \text{ GeV} < M_A < 1 \text{ TeV}, \quad 100 \text{ GeV} < \mu < 5 \text{ TeV}, \\
600 \text{ GeV} < M_{\tilde{Q}_1} < 5 \text{ TeV}, \quad 600 \text{ GeV} < M_{\tilde{u}_1} < 5 \text{ TeV}, \\
600 \text{ GeV} < M_{\tilde{d}_1} < 5 \text{ TeV}, \; M_{\tilde{Q}_2} = M_{\tilde{Q}_1}, \; M_{\tilde{u}_2} = M_{\tilde{u}_1}, \; M_{\tilde{d}_2} = M_{\tilde{d}_1}, \\
A_{e,\mu,\tau} = A_{u,d,c,s} = 0, \quad -10 \text{ TeV} < A_{b,t} < 10 \text{ TeV}, \\
200 \text{ GeV} < M_{\tilde{Q}_3,\tilde{u}_3,\tilde{d}_3} < 10 \text{ TeV}.
\end{gathered}
$$

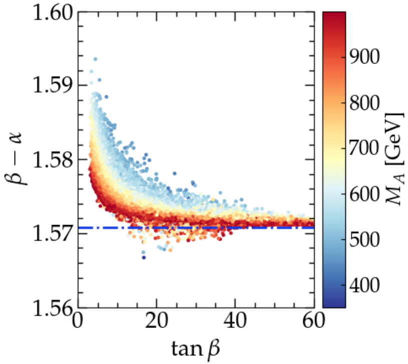
- we compute χ^2 for all the scanned points, defined as: $\chi^2 = \sum_i \frac{(\overline{\mu}_i - \mu_i)^2}{\Delta\mu_i^2}$
- μ_i ($\overline{\mu}_i$) experimentally observed signal strength (MSSM) for a particular production/decay mode i. $\Delta\mu_i \to$ experimental error.
- contribution originating from different production mode: $\overline{\mu}_i = \sum T_i^j \widehat{\mu}_j$
- Consider altogether 49 data points.
- A random scan for approximately 100 million points.

Parameter space allowed in M_A - tanβ plane:



- Orange points → Global fit without flavour physics constraints.
- Blue points → Global fit with flavour physics constraints.

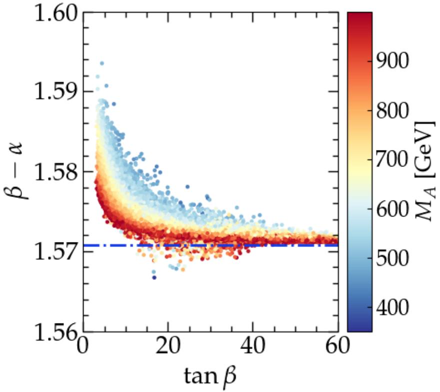
Alignment without decoupling:



Couplings (tree level) of the Higgs bosons (h, H):

$$g_{hVV} = \sin(\beta-\alpha)\ g_V$$
$$g_{HVV} = \cos(\beta-\alpha)\ g_V$$
$$g_{hdd} = -(\sin\alpha/\cos\beta)g_f = (\sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha))\ g_f$$
$$g_{huu} = -(\cos\alpha/\sin\beta)g_f = (\sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha))\ g_f$$
$$g_{Hdd} = -(\cos\alpha/\cos\beta)g_f = (\cos(\beta-\alpha) + \tan\beta\sin(\beta-\alpha))\ g_f$$
$$g_{Huu} = -(\sin\alpha/\sin\beta)g_f = (\cos(\beta-\alpha) - \cot\beta\sin(\beta-\alpha))\ g_f$$

Alignment without decoupling:



- Alignment Limit : h is SM like i.e., $g_{hVV} \sim 1$ and $g_{HVV} \sim 0$.
- Heavier CP even Higgs boson couplings become highly suppressed.
- In decoupling region, $M_A >> M_Z$, $(\beta - \alpha) \sim \pi/2$

- Regions with light M_A ($\leq$ 400 GeV) close to the alignment limit is perfectly allowed by the current data.

- See Talk "Alignment in extended Higgs models" by Howard Haber.

Bounds on heavy Higgses from LHC direct searches:

- Neutral Higgs boson searches:
  - Search for H with $\gamma\gamma$ final states.
  - Search for H with WW, ZZ final state.
  - Search for H with hh ($b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\tau$) final states.
  - Search for $H/A \to \tau^+\tau^-$ final states.
  - Search for A with Zh final states.

- Charged Higgs boson searches
  - Search for $H^\pm$ with $\tau\nu$, $c\bar{s}$ final states.
  - Search for $H^\pm$ with $t\bar{b}$ final states.

- Bounds set by the ATLAS and CMS collaborations on the masses and BRs of the neutral and charged Higgs bosons from 8/13 TeV data.

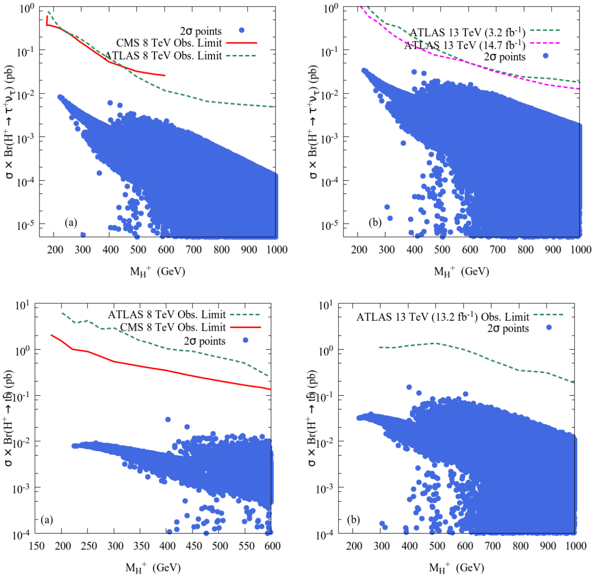
Bounds on heavy Higgses from LHC direct searches:

Channel	Experiment	Mass range (GeV)	Luminosity
$gg \to H/A \to \tau^+\tau^-$	ATLAS 8 TeV [78]	90-1000	19.5-20.3 fb^{-1}
	CMS 8 TeV [79]	90-1000	19.7 fb^{-1}
	ATLAS 13 TeV [80]	200-1200	3.2 fb^{-1}
	CMS 13 TeV [81]	100-3000	2.3 fb^{-1}
$b\bar{b} \to H/A \to \tau^+\tau^-$	ATLAS 8 TeV [78]	90-1000	19.5-20.3 fb^{-1}
	CMS 8 TeV [79]	90-1000	19.7 fb^{-1}
	ATLAS 13 TeV [80]	200-1200	3.2 fb^{-1}
	CMS 13 TeV [81]	100-3000	2.3 fb^{-1}
$gg \to H/A \to \gamma\gamma$	ATLAS 8 TeV [82]	65-600	20.3 fb^{-1}
	CMS 8+13 TeV [83]	500-4000	19.7+3.3 fb^{-1}
	ATLAS 13 TeV [84]	200-2000	3.2 fb^{-1}
$pp \to bH/A(H/A \to b\bar{b})$	CMS 8 TeV [85]	100-900	19.7 fb^{-1}
$gg \to H \to W^+W^-$	ATLAS 8 TeV [86]	300-1500	20.3 fb^{-1}
	ATLAS 13 TeV [87]	500-3000	3.2 fb^{-1}
$W^+W^-/ZZ \to H \to W^+W^-$	ATLAS 8 TeV [86]	300-1500	20.3 fb^{-1}
	ATLAS 13 TeV[87]	500-3000	3.2 fb^{-1}
$gg \to H \to ZZ$	ATLAS 8 TeV [88]	160-1000	20.3 fb^{-1}
$gg \to H \to ZZ \to (\ell\ell)(qq)$	ATLAS 13 TeV [89]	300-1000	3.2 fb^{-1}
$gg \to H \to ZZ \to (\ell\ell)(\nu\nu)$	ATLAS 13 TeV [90]	300-1000	3.2 fb^{-1}
$pp \to H \to Z\gamma$	ATLAS 13 TeV [91]	250-2750	3.2 fb^{-1}
$W^+W^-/ZZ \to H \to ZZ$	ATLAS 8 TeV [88]	160-1000	20.3 fb^{-1}
$pp \to H \to ZZ$	CMS 8 TeV [92]	150-1000	5.1 fb^{-1}
$pp \to H \to W^+W^-$	CMS 8 TeV [92]	150-1000	5.1 fb^{-1}
$gg \to H \to hh$	ATLAS 8 TeV [93]	260-1000	20.3 fb^{-1}
$pp \to H \to hh \to (b\bar{b})(b\bar{b})$	ATLAS 13 TeV [94]	500-3000	3.2 fb^{-1}
$pp \to H \to hh \to (\gamma\gamma)(b\bar{b})$	CMS 8 TeV [95]	250-1100	19.7 fb^{-1}
$pp \to H \to hh \to (b\bar{b})(b\bar{b})$	CMS 8 TeV [96]	270-1100	17.9 fb^{-1}
$gg \to H \to hh \to (b\bar{b})(\tau^+\tau^-)$	CMS 8 TeV [97]	260-350	19.7 fb^{-1}
$gg \to A \to Zh \to (\tau^+\tau^-)(\ell\ell)$	CMS 8 TeV [97]	220-350	19.7 fb^{-1}
$gg \to A \to Zh \to (b\bar{b})(\ell\ell)$	CMS 8 TeV [98]	225-600	19.7 fb^{-1}
$gg \to A \to Zh \to Z(\tau^+\tau^-)$	ATLAS 8 TeV [99]	220-1000	20.3 fb^{-1}
$gg \to A \to Zh \to Z(b\bar{b})$	ATLAS 8 TeV [99]	220-1000	20.3 fb^{-1}
	ATLAS 13 TeV [100]	200-2000	3.2 fb^{-1}
$pp \to Ab\bar{b} \to Zhb\bar{b} \to Z(b\bar{b})(b\bar{b})$	ATLAS 13 TeV [100]	200-1000	3.2 fb^{-1}
$pp \to tH^\pm(H^\pm \to \tau^\pm\nu) + X$	ATLAS 8 TeV [101]	180-1000	19.5 fb^{-1}
$pp \to tbH^\pm(H^\pm \to \tau^\pm\nu)$	ATLAS 13 TeV [102]	200-2000	3.2 fb^{-1}
	CMS 8 TeV [103]	200-600	19.7 ± 0.5 fb^{-1}
$gb \to tH^\pm(H^\pm \to tb)$	ATLAS 8 TeV [104]	200-600	20.3 fb^{-1}
$qq' \to H^\pm(H^\pm \to tb) \to (l + \text{jets})$	ATLAS 8 TeV [104]	400-2000	20.3 fb^{-1}
$qq' \to H^\pm(H^\pm \to tb) \to (\text{all had.})$	ATLAS 8 TeV [104]	400-2000	20.3 fb^{-1}
$pp \to \bar{t}bH^\pm(H^\pm \to tb)$	CMS 8 TeV [103]	200-600	19.7 ± 0.5 fb^{-1}

Bounds on heavy Higgses from LHC direct searches:

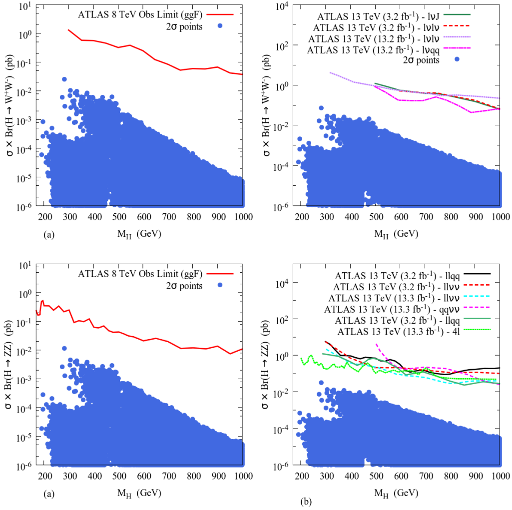
Channel	Experiment	Mass range(GeV)	Luminosity
$gg \to H \to ZZ(\ell\ell\nu\nu)$	ATLAS 13 TeV [105]	300-1000	13.3 fb^{-1}
$gg \to H \to ZZ(\nu\nu qq)$	ATLAS 13 TeV [106]	500-3000	13.2 fb^{-1}
$gg/VV \to H \to ZZ(\ell\ell qq)$	ATLAS 13 TeV [106]	500-3000	13.2 fb^{-1}
$gg/VV \to H \to ZZ(4\ell)$	ATLAS 13 TeV [107]	500-3000	14.8 fb^{-1}
$gg/VV \to H \to W^+W^-(\ell\nu\ell\nu)$	ATLAS 13 TeV [108]	200-3000	13.2 fb^{-1}
$gg \to H \to W^+W^-(\ell\nu qq)$	ATLAS 13 TeV [109]	500-3000	13.2 fb^{-1}
$gg + VV \to H \to W^+W^-(\ell\nu\ell\nu)$	CMS 13 TeV [110]	200-1000	2.3 fb^{-1}
$pp \to H \to \gamma\gamma$	ATLAS 13 TeV [111]	200-2400	15.4 fb^{-1}
$pp \to H \to \gamma\gamma$	CMS 13 TeV [112]	500-4000	12.9 fb^{-1}
$gg/b\bar{b} \to H \to \tau^+\tau^-$	ATLAS 13 TeV [113]	200-1200	13.3 fb^{-1}
$gg/b\bar{b} \to H \to \tau^+\tau^-$	ATLAS 13 TeV [114]	90-3200	12.9 fb^{-1}
$gg/b\bar{b} \to H \to b\bar{b}$	CMS 13 TeV [115]	550-1200	2.7 fb^{-1}
$pp \to H \to hh \to b\bar{b}b\bar{b}$	ATLAS 13 TeV [116]	300-3000	13.3 fb^{-1}
$pp \to H \to hh \to b\bar{b}\tau^+\tau^-$	CMS 13 TeV [117]	250-900	12.9 fb^{-1}
$pp \to tH^\pm(H^\pm \to \tau^\pm\nu) + X$	ATLAS 13 TeV [118]	200-2000	14.7 fb^{-1}
$pp \to tH^\pm(H^\pm \to tb) + X$	CMS 13 TeV [119]	300-1000	13.2 fb^{-1}

Search for $H^{\pm}$ with $\tau\nu$ and $t\bar{b}$ final states:



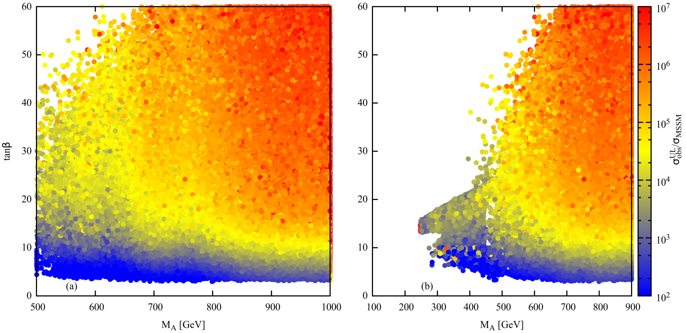
- $g_{H^\pm \bar{u}d} \propto m_d \tan\beta(1+\gamma_5) + m_u \cot\beta(1-\gamma_5)$.
- For small $\tan\beta$, $H^\pm$ exclusively decays to $t\bar{b}$
- For large values of $\tan\beta$, $\mathrm{Br}(H^\pm \to \tau^\pm \nu_\tau) \sim 10\%$.
- Main production mechanism $pp \to tbH^\pm$.

Search for H with WW, ZZ final states.:



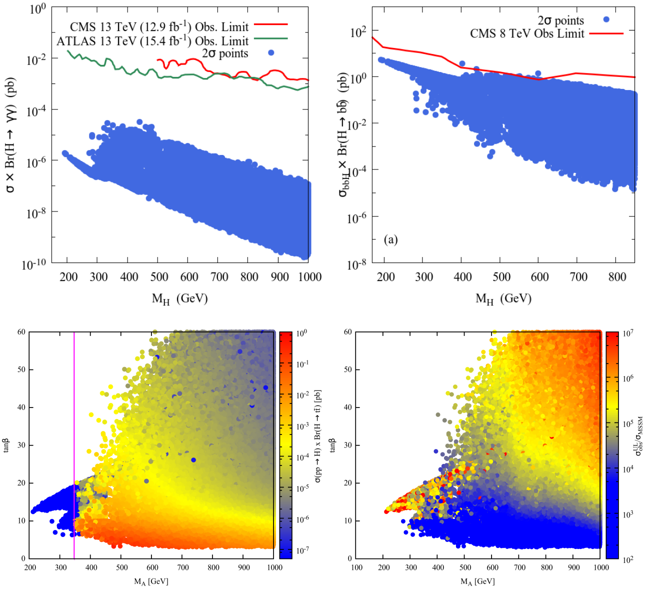
- Due to alignment limit (i.e. $(\beta - \alpha) \sim \frac{\pi}{2}$) $\rightarrow \mathrm{Br(H \rightarrow WW, ZZ)}$ highly suppressed.

Search for H with hh ($b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$) final state:

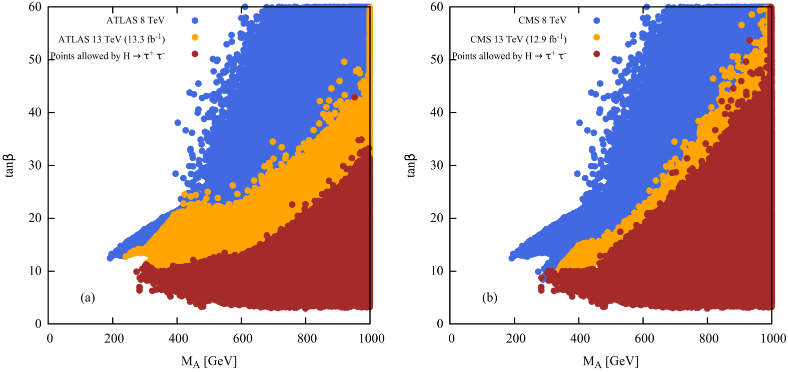


- σ^{UL}_{Obs} $\rightarrow$ the upper limits on $\sigma_H \times \mathrm{Br}(H \rightarrow hh \rightarrow b\bar{b}b\bar{b}/b\bar{b}\tau^+\tau^-)$
- $4b$ final state $\rightarrow$ $11.24 \lesssim \sigma^{UL}_{Obs}/\sigma_{MSSM} \lesssim 7.92 \times 10^7$ (ATLAS 13.3 fb^{-1} data).
- $b\bar{b}\tau^+\tau^-$ final state $\rightarrow$ $13.41 \lesssim \sigma^{UL}_{Obs}/\sigma_{MSSM} \lesssim 1.71 \times 10^8$ (CMS 12.9 fb^{-1} data).
- $\mathrm{Br(H \rightarrow hh)}$ sizeable only for small $\tan\beta$ (≤ 5)
- For $M_A \geq 350$ GeV, $t\bar{t}$ opens up and dominates.
- $b\bar{b}\gamma\gamma$ channel will be effective for HL-LHC.

Search for $H \to \gamma\gamma$, $b\bar{b}$, $t\bar{t}$ $A \to Zh$ final states.:

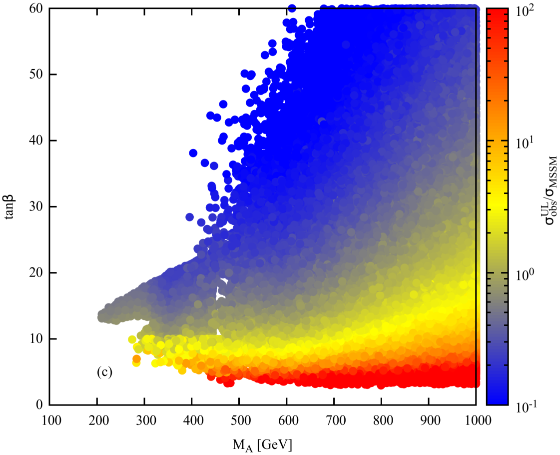


Search for H/A with $\tau^+\tau^-$ final states:



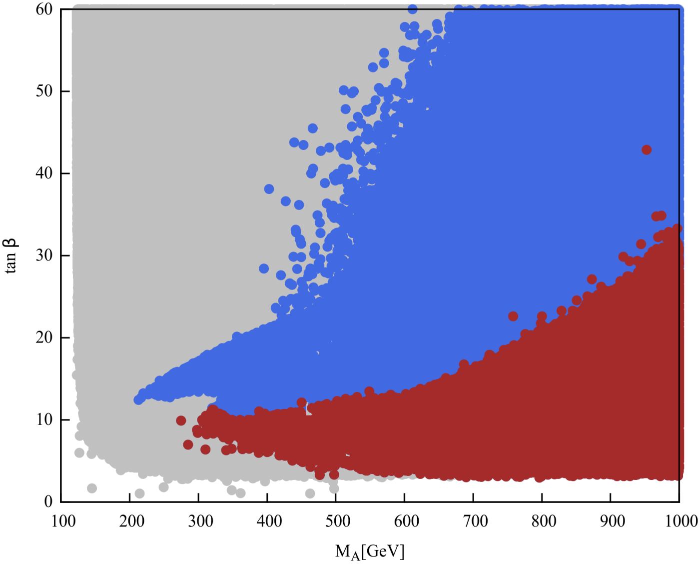
- $g_{Hf_df_d} = -(\cos\alpha/\cos\beta)g_{SM}$; $g_{Af_df_d} = -(\tan\beta)g_{SM}$.
- For fixed α, both the couplings $Hf_d\bar{f}_d$ and $Af_d\bar{f}_d$ increases with $\tan\beta$.
- $\tan\beta \geq 10$, H and A decays to $b\bar{b}$ ($\sim$ 90%) and $\tau^+\tau^-$ ($\sim$ 10%).
- Production of H/A is also primarily controlled by $\tan\beta$.
- Entire regions with $\tan\beta \gtrsim 10$ are excluded for $M_A \lesssim 500$ GeV.

Search for H/A with $\tau^+\tau^-$ final states:



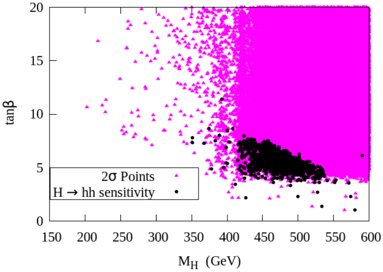
- Most promising channel.
- $0.03 \lesssim \sigma^{UL}_{Obs}(ATLAS\ 13.2\ fb^{-1})/\sigma_{MSSM} \lesssim 2.58 \times 10^3$.

$M_A - \tan\beta$ plane status:



Future prospect for $H \to hh \to b\bar{b}\gamma\gamma$ final states:

- Single H production cross section can be up to two orders of magnitude larger compared to the direct h pair production.
- It can also have non-trivial effects on the self coupling measurement of the 125 GeV Higgs. B. Bhattacherjee, AC, arXiv:1407.6866.



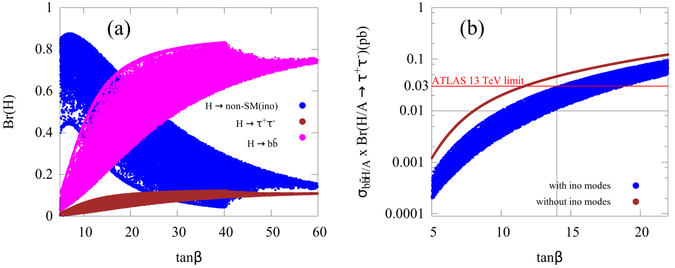
B. Bhattacherjee, A. Chakraborty, AC,

arXiv:1504.04308

- $BR(H \to hh)$ is substantial only for smaller values of $\tan\beta$.
- The most dominant production mechanism $\to$ ggF.
- Events with two b-jets, two photons and no isolated leptons are selected.
- Reconstruct two higgs from $b\bar{b}$ and $\gamma\gamma$.
- $M_{b\bar{b}\gamma\gamma} = M_H \pm 50$ GeV.
- Low $\tan\beta$ (< 10) regions are expected to be probed at the HL-LHC.

Heavy Higgs decay to SUSY states:

- Heavy Higgs decaying to Electroweakinos.



- Ino decay modes relax the limit on tanβ.

- Limit on $M_A - \tan\beta$ plane depends on Ino states (especially with the position of NLSP).

- Heavy Higgs to stops/sbottoms $\rightarrow \widetilde{t}_1\widetilde{t}_1$ or $\widetilde{b}_1\widetilde{b}_1$ also could be the dominant decay mode.

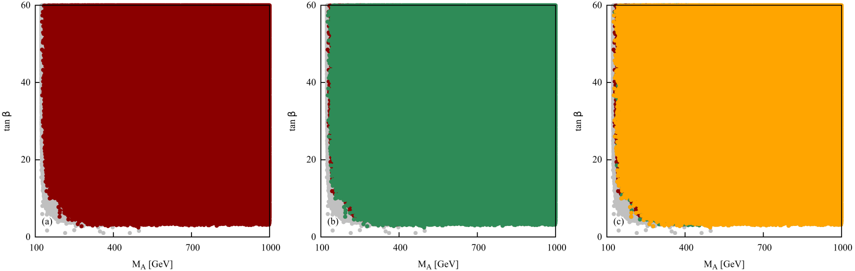
Summary:

- Global fit analysis using LHC 8+13 TeV data and flavour physics constraints.
- Low M_A and high $\tan\beta$ regions are excluded due to $B_s \to \mu^+\mu^-$ $B^+ \to \tau^+\nu_\tau$ constraints.
- The regions with low M_A and low $\tan\beta$ are not favoured by the $\mathrm{Br}(\mathrm{b} \to \mathrm{s}\gamma)$ constraint.
- Signal strength measurements are in favour of the alignment and decoupling limit. Not always forced to be in the decoupling limit.
- 10 - 20% deviations from the SM expectations are also observed for various Higgs signal strength variables.
- The direct searches with $H \to WW, ZZ, \gamma\gamma$ final states are not effective to probe the relevant parameter space.
- Upper bounds derived on $H/A \to \tau^+\tau^-$ are found to impose the most stringent bound.
- Wait for more data !!!

Back Up

Effect of Run-I and Run-II data on global fit:

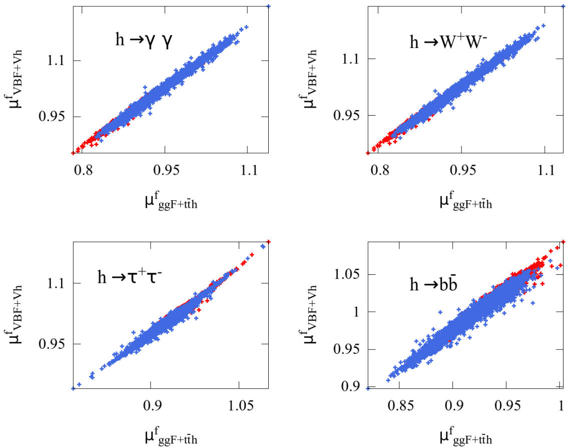
- Without any flavor constraints.



(a) Only 13 TeV data - brown points (left panel).
(b) Only 8 TeV data - green points (middle panel).
(c) 8 + 13 TeV data - orange points (right panel).

For 8+13 TeV data and flavor constraints fit See Page 10

Correlations of various Higgs signal strength variables:



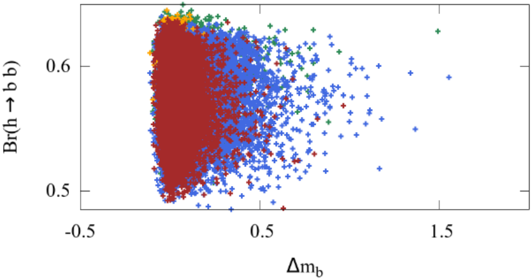
- Red points → Fit with Run-I data
- Blue points → Fit with combined Run-I & Run-II data

SUSY QCD corrections:

- In an effective Lagrangian approach :

$$L_{hb\bar{b}} = -\frac{m_b}{v_{SM}}\left(\frac{1}{1+\Delta_b}\right)\left(-\frac{\sin\alpha}{\cos\beta}\right)\left(1-\frac{\Delta_b}{\tan\beta\tan\alpha}\right)b\bar{b}h$$

- Loop corrections (in powers of $\alpha_s \tan\beta$) involving heavier sparticles can significantly modify the b quark mass and it's Yukawa coupling from its tree level predictions.



Heavy Higgs decay to sbottoms: