Enlarging regions of the MSSM parameter space for large $\tan\beta$

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- More than one Higgs doublet are expected in many theories beyond the Standard Model (SM). Ex. Minimal Supersymetric Standard Model (MSSM)
- CP is a good symmetry of the Higgs sector $\rightarrow$ 2 CP even Higgses h and H, 1 CP odd Higgs A and charged Higgs pair $H^{\pm}$.
- Heavier neutral Higgs H, A are being searched for at the LHC via their decay into a pair of tau-leptons. Latest CMS and ATLAS results $\rightarrow m_H \approx m_A > 500$ GeV for $\tan\beta \gtrsim 16$ in the abcense of SUSY decays or similarly for $m_H \approx 500$ GeV, $\tan\beta \lesssim 16$.
- For $\tan\beta \gg 1 \rightarrow$ unification of Yukawa couplings $y_t \approx y_b \approx y_\tau$ and also a somewhat light Higgs sector has better chances of being probed at the LHC
- Furthermore, $\tan\beta \gg 1$ leads to alignment without necessarily decoupling (off-diagonal mass entries in the "Higgs basis" $\propto \sin(2\beta) \approx 2/\tan\beta$).
- Consider SUSY decays into pairs of sbottoms, stops and staus respectively: consequences on electroweak vacuum stability, flavour violating contributions and direct production of these SUSY particles.
- Exploit the chiral coupling of H, A to a pair of down-type sfermions, $g_{A\tilde{d}\tilde{d}} \propto A_{\tilde{f}} \times \tan\beta$.

Model independent bounds

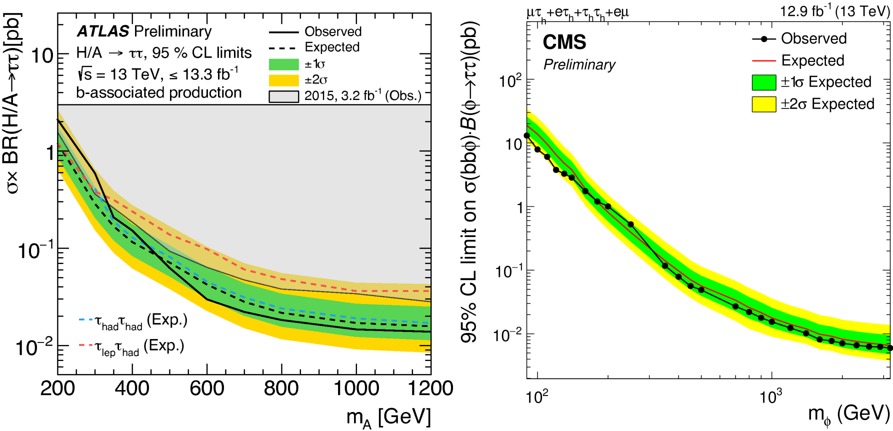

Figure: $\sigma_{bbH} \times Br(H \to \tau\tau)$ [pb] vs m_A [GeV]

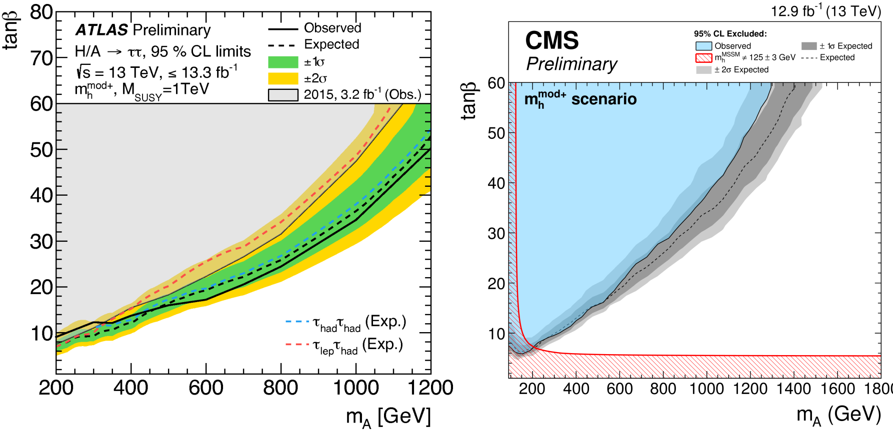

Figure: tan β vs m_A [GeV]

Tree-level couplings and decay rates

- Decay rates and couplings of $\Phi = H, A$

$$\Gamma(\Phi \to \bar{d}d) = N_c \frac{G_F M_\Phi}{4\sqrt{2}\pi} m_d^2 g_{\Phi\bar{d}d}^2 (1 - 4m_d^2/M_\Phi^2)^{p/2}$$

where N_c is the color factor, $p = 3, 1$ for CP-even or odd Higgs bosons and $g_{A\bar{d}d} = \tan\beta$, $g_{H\bar{d}d} = (\cos\alpha/\cos\beta) \to \tan\beta$ for $\tan\beta \gg 1$. For only SM decays, $Br(H, A \to \bar{\tau}\tau) \sim 0.1$ and $\sigma_{H,A} \times \mathrm{Br}(H, A \to \bar{\tau}\tau) \propto \tan^2\beta$.

- The decay rate into sfermions is,

$$\Gamma(\Phi \to \tilde{f}_i \tilde{f}_j) = N_c \frac{G_F}{2\sqrt{2}\pi M_\Phi} \lambda^{1/2}_{\tilde{f}_i \tilde{f}_j \Phi} g^2_{\Phi \tilde{f}_i \tilde{f}_j}$$

with $g_{\Phi\tilde{f}_i\tilde{f}_j} = \sum_{\alpha,\beta=L,R} T_{ij\alpha\beta} g_{\Phi\tilde{f}_\alpha\tilde{f}_\beta}$ and $i = 1, 2$. The mixed-chirality couplings,

$$g_{A\tilde{d}_L\tilde{d}_R} = -\frac{1}{2} m_d \left[\mu + A_d \tan\beta\right], \qquad g_{H\tilde{d}_L\tilde{d}_R} = -\frac{1}{2} m_d \left[-\mu + A_d \tan\beta\right]$$

$$g_{A\tilde{u}_L\tilde{u}_R} = -\frac{1}{2} m_u \left[\mu - \frac{1}{\tan\beta} A_u\right], \qquad g_{H\tilde{u}_L\tilde{u}_R} = -\frac{1}{2} m_u \left[\mu - A_u \frac{1}{\tan\beta}\right]$$

- Important loop-level corrections which modify the relation between down-type Yukawas and running masses,

$$y_b = \frac{m_b}{v\cos\beta(1+\Delta_b)}, \qquad y_\tau = \frac{m_\tau}{v\cos\beta(1+\Delta_\tau)}$$

  where Δ_b is dominated by sbottom-gluino and stop-chargino loop, whereas Δ_τ is dominated by stau-neutralino and sneutrino-chargino loop.
- Maximal contribution from L-R coupling $\rightarrow$ soft breaking masses of the same order ($m_{Q_3} \sim m_{D_3}$ or $m_{L_3} \sim m_{E_3}$).
- We expect $m_{\tilde{b}_2} \gtrsim m_{\tilde{b}_1}$ and $m_{\tilde{\tau}_2} \gtrsim m_{\tilde{\tau}_1}$.
- For stops different story: m_{U_3} or m_{Q_3} must be of the order of $A_t \simeq 2$ TeV to get a 125 GeV light Higgs $\rightarrow m_{\tilde{t}_2} \sim$ few TeV.
- $m_{\tilde{t}_1} < m_H/2 \rightarrow$ much more split spectrum than for sbottoms and staus.
- Though mixing is not maximal still have stops can contribute to the total decay width enough to suppress Br($\Phi \rightarrow \bar{\tau}\tau$).

- Numerical simulation of production of H, A via gluon fusion and in association with $b\bar{b}$ (dominant at large $\tan\beta$) using SusHi 1.6.1 using the MMHT 2014 pdf's set via LHAPDF 6.1.6.
- SUSY particle spectrum, cross sections and decays calculated with SARAH 4.11.0 and SPheno 3.3.8.
- Flavour observables calculated with flavio and FlavorKit.
- Stability of the EW vacuum investigated using Vevacious 1.2.02.
- *Natural* spectrum due to lack of SUSY signals at the LHC,

$$m_{\tilde{e}_j} = m_{\tilde{L}_j} = m_{\tilde{u}_i} = m_{\tilde{d}_i} = m_{\tilde{Q}_i} = M_2 = M_3 = 2.2\ \mathrm{TeV}$$

with vanishing A-terms. 3rd-generation potentially light. $|\mu|, M_1 \ll M_2, M_3, m_{\tilde{f}_{1,2}}, \therefore$ $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$ and $\tilde{\chi}_1^\pm$ light as well.

- In the scan with light sbottoms, we fixed

$$M_1 = 200 \text{ GeV} \qquad M_{\tilde{u}_3} = 2845 \text{ GeV} . \tag{1}$$

and varied the remaining parameters, $\tan\beta$, μ, B_μ, $m_{\tilde{Q}_3}$, $m_{\tilde{d}_3}$, and A_t

$$\begin{aligned} &\tan\beta \in [25, 60] \qquad m_{\tilde{Q}_3} \in [300, 800] \text{ GeV} \qquad m_{\tilde{d}_3} \in [300, 800] \text{ GeV} \\ &\mu \in \pm[200, 400] \text{ GeV} \quad m_A(\text{tree}) \in [500, 1600] \text{ GeV} \quad A_t = \pm m_{\tilde{u}_3} . \end{aligned} \tag{2}$$

We afterwards increase M_1.
- Impose that h satisfies the 125 GeV LHC signal's strengths $b\bar{b}$, WW^*, ZZ^*, $\tau\tau$ and $\gamma\gamma$ at the 2-σ level.
- Discard $m_{\tilde{b}_1} < 300$ GeV from mono-jet searches at 3.2 fb^{-1} and impose the latest 13 TeV CSM direct sbottom and stop pair production searches with $\mathcal{L} = 36.1$ fb^{-1}.
- $\sigma_{bbH} \times \text{Br}(H \to \tau\tau)$ and $\sigma_{ggH} \times \text{Br}(H \to \tau\tau)$ satisfy ATLAS and CMS studies at 13 TeV, $\mathcal{L} = 13.3$ fb^{-1}.

Flavour

- We satisfy all flavour observable constraints ($B_s \to \mu^+\mu^-$, $B \to \tau\nu$, etc) at the 2σ level, except for $B \to X_s\gamma$, for which the stop-chargino loop contribution can be significant, whereas the charged Higgs contributions seems to be subdominant
- Within MFV paradigm studies show that we need for $A_t > 0$, $\mu \gtrsim 800$ GeV or $M_{Q_3} \gtrsim 1.3$ TeV and for $A_t < 0$, $M_{Q_3} \gtrsim 1.5$ TeV Altmannshofer et al. 2012. Taking $\mu > 800$ GeV should not affect the main conclusion of our work.
- Beyond the MFV paradigm, there are in particular possible additional diagrams involving gluinos $\tilde{g}$ and $\tilde{b} - \tilde{s}$ mixing, which may be able to cancel the chargino-stop contributions Altmannshofer et al. 2012, Arana-Catania 2013.
  $\therefore$ We do not impose the constraints from $B \to X_s\gamma$.

Results

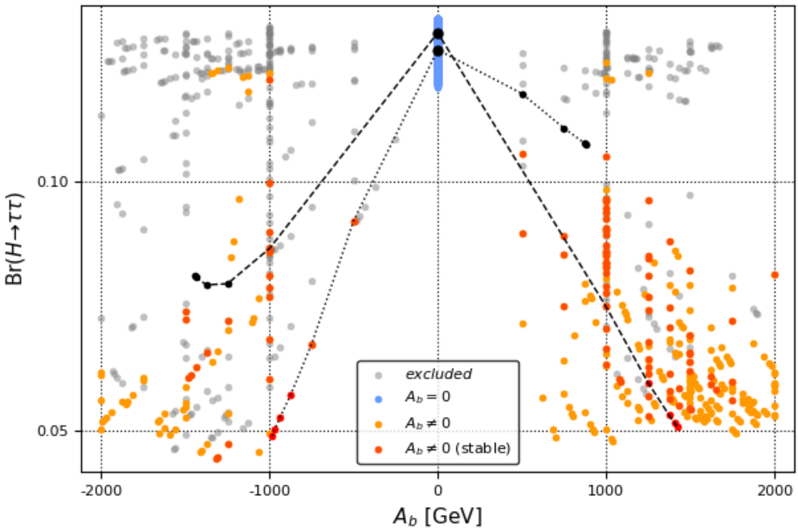

Figure: Br($H \to \tau\tau$) vs A_b [GeV].

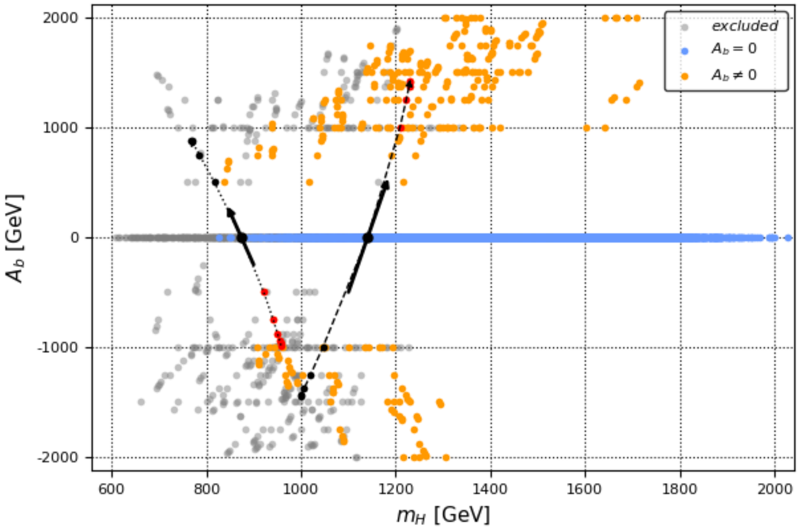

Figure: A_b [GeV] vs m_H [GeV].

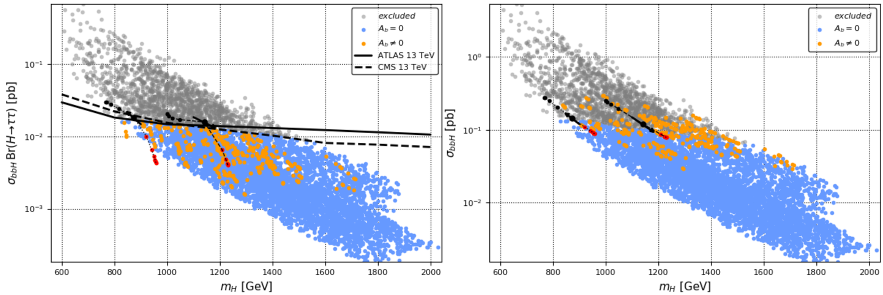

Figure: $\sigma_{bbH} \times \mathrm{Br}(H \to \tau\tau)$ [pb] vs m_H [GeV] and σ_{bbH} [pb] vs m_H [GeV].

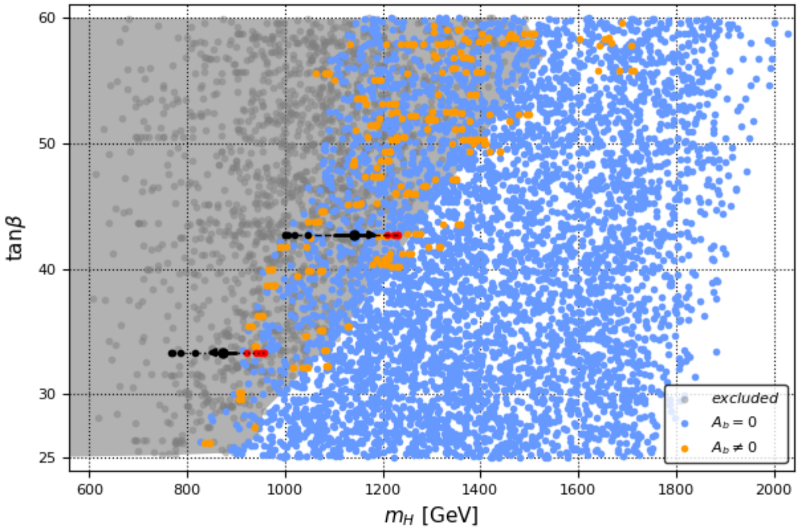

Figure: Tan β vs m_H [GeV]..

Conclusions

- We study the possibility of enlarging the MSSM large $\tan\beta$ regions currently strongly constrained by $H, A \to \tau\bar{\tau}$ by allowing SUSY decays into sbottoms.
- We show that this is indeed possible satisfying all current experimental constraints and by possibly allowing for deviations from the MFV paradigm.
- The appearance of charge/color breaking vevs implies an upper bound on $A_b \to$ lower bound on $Br(H \to \tilde{b}\tilde{b}^*)$.
- These additional SUSY decays can be particular relevant in the near future when searches from the $H, A \to \tau\bar{\tau}$ may put further constraints on the $m_H - \tan\beta$ plane.