Discriminating between SUSY and Non-SUSY Higgs Sectors through the Ratio $H \to b\bar{b}/H \to \tau\bar{\tau}$

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June, 22nd 2015

References

Work in collaboration with **Jaume Guasch**, **Wolfgang Hollik** and **Siannah Peñaranda**, based on:

- E. A., J. Guasch, W. Hollik and S. Peñaranda, "Discriminating between SUSY and Non-SUSY Higgs Sectors through the Ratio $H \to b\bar{b}/H \to \tau\bar{\tau}$ with a Higgs boson of 125 GeV", work in progress.

Outline

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2.- Introduction

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Motivation

Is there new physics (NP) behind the Higgs boson?

- New scalar particle discovered at the LHC with mass $m_H = 125.09 \pm 0.21$ (stat.) $\pm\, 0.11$ (syst.) GeV [ATLAS+CMS, 2015] seems to behave as SM Higgs boson.
- Many SM extensions enlarge Higgs sector, including a SM-like Higgs boson.
- In Two-Higgs-Doublet models (2HDM) there are 5 physical states: 2 charged ($H^{\pm}$) and 3 neutral (h, H, A).
- MSSM also contains 2 Higgs doublets with a light neutral scalar (h) compatible with discovered SM-like Higgs boson.

Possibility of probing (non-)SUSY nature of Higgs bosons at the LHC through the observable $R = \frac{\mathrm{BR}(H \to b\bar{b})}{\mathrm{BR}(H \to \tau\bar{\tau})}$.

Introduction

- R receives large renormalization-scheme independent radiative corrections in SUSY models at large $\tan\beta$, absent in the SM or 2HDM: discriminant quantity between SUSY and non-SUSY models [Guasch *et al.*, 2001].
- Leading radiative corrections to R summarized in Δm_b and Δm_τ [Hall *et al.*, 1993; Carena *et al.*, 1994]:

$$h_{b,\tau} = \frac{m_{b,\tau}(Q)}{v\cos\beta}\frac{1}{1+\Delta m_{b,\tau}}\,.$$

- Experimentally: clean observable, measurable at present colliders, main systematic errors cancel (except τ- and b-tagging).
- Theoretically: independent of Higgs production mechanism and of the total width; insensitive to NP effects and unknown high-order QCD corrections to Higgs x-section production; only depends on the ratio of the masses.

R in the MSSM

$$\frac{R^{\rm MSSM}(h)}{R^{\rm SM}} = \frac{(1+\Delta m_\tau)^2\,(-\cot\alpha\Delta m_b+\tan\beta)^2}{(1+\Delta m_b)^2\,(-\cot\alpha\Delta m_\tau+\tan\beta)^2}\,,$$
$$\frac{R^{\rm MSSM}(H)}{R^{\rm SM}} = \frac{(1+\Delta m_\tau)^2\,(\tan\alpha\Delta m_b+\tan\beta)^2}{(1+\Delta m_b)^2\,(\tan\alpha\Delta m_\tau+\tan\beta)^2}\,,$$
$$\frac{R^{\rm MSSM}(A)}{R^{\rm SM}} = \frac{(1+\Delta m_\tau)^2\,(\tan\beta^2-\Delta m_b)^2}{(1+\Delta m_b)^2\,(\tan\beta^2-\Delta m_\tau)^2}\,.$$

- Normalized $R^{\rm MSSM}(\phi)/R^{\rm SM}$ dependent only on $\tan\beta$, $\tan\alpha$, Δm_b and Δm_τ, encoding all the genuine SUSY corrections.
- Δm_b and Δm_τ independent of the SUSY mass scale $M_{\rm SUSY}$, only depend on $\tan\beta$ and the ratio $A_t/M_{\rm SUSY}$.

Sensitivity to SUSY nature of Higgs sector through the analysis of R is independent of SUSY scale.

MSSM scenarios

- $\mu < 0$ $A_t > 0$ scenario [Guasch *et al.*, 2001]:
  $m_{\tilde{g}} = M_{\tilde{b}_1} = M_{\tilde{t}_1} = M_{\tilde{\tau}_1} = M_2 = |\mu| = A_b = A_\tau = |A_t| = 1.5$ TeV.
- Benchmark scenarios [Carena *et al.*, 2013]:
  $M_{\tilde{t}_L} = M_{\tilde{b}_L} = M_{\tilde{t}_R} = M_{\tilde{b}_R} = M_{\rm SUSY}$; $M_1 = \frac{5}{3}\frac{s_W^2}{c_W^2} M_2$;
  $M_{\tilde{q}_{1,2}} = 1500$ GeV, $M_{\tilde{l}_{1,2}} = 500$ GeV; $A_f = 0$ $(f = c, s, d, u, \mu, e)$.

Parameter	$m_h^{\rm mod+}$	$m_h^{\rm mod-}$	light-stop	light-stau
$M_{\rm SUSY}$	1000 GeV	1000 GeV	500 GeV	1000 GeV
μ	200 GeV	200 GeV	350 GeV	500 GeV
M_2	200 GeV	200 GeV	350 GeV	200 GeV
X_t	1.6 $M_{\rm SUSY}$	-1.9 $M_{\rm SUSY}$	2 $M_{\rm SUSY}$	1.6 $M_{\rm SUSY}$
A_b	$= A_\tau = A_t$	$= A_\tau = A_t$	$= A_\tau = A_t$	$= A_t,\ A_\tau = 0$
$m_{\tilde{g}}$	1500 GeV	1500 GeV	1500 GeV	1500 GeV
$M_{\tilde{l}_3}$	1000 GeV	1000 GeV	1000 GeV	245 GeV

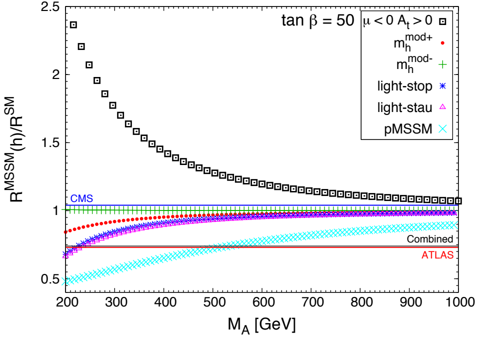
- pMSSM 2392587 [Cahill-Rowley *et al.*, 2013]:
  $\mu = 3955$ GeV, $M_2 = 1606$ GeV, $M3 = 313$ GeV, $M_{\tilde{t}_L} = 2493$ GeV, $M_{\tilde{t}_R} = 2154$ GeV, $M_{\tilde{b}_R} = 2009$ GeV, $A_b = 2067$ GeV, $A_t = -3905$ GeV, $M_{\tilde{\tau}_L} = 3167$ GeV, $M_{\tilde{\tau}_R} = 2319$ GeV, $A_\tau = 2223$ GeV.

LHC data and constraints

ATLAS and CMS generic fits to Higgs coupling ratios

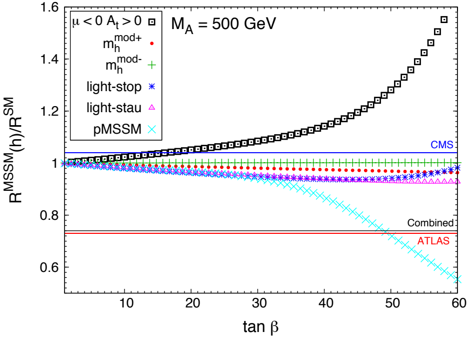
- CMS: $\lambda_{bZ}^{\rm CMS} = 0.59^{+0.22}_{-0.23}$, $\lambda_{\tau Z}^{\rm CMS} = 0.79^{+0.19}_{-0.17}$ [CMS, 2014] $\Rightarrow$ $R^{\rm CMS} = 0.56^{+0.48}_{-0.52}$.
- ATLAS: $\lambda_{bZ}^{\rm ATLAS} = 0.60 \pm 0.27$, $\lambda_{\tau Z}^{\rm ATLAS} = 0.99^{+0.23}_{-0.19}$ [ATLAS, 2015] $\Rightarrow$ $R^{\rm ATLAS} = 0.37^{+0.36}_{-0.37}$.
- Combined [Barlow, 2004]: $\lambda_{bZ} = 0.59 \pm 0.17$, $\lambda_{\tau Z} = 0.89^{+0.14}_{-0.13}$ $\Rightarrow$ $R^{\rm Combined} = R^{\rm exp}/R^{\rm SM} = 0.45^{+0.29}_{-0.30}$

Dependence of $R^{\mathrm{MSSM}}(h)$ with M_A



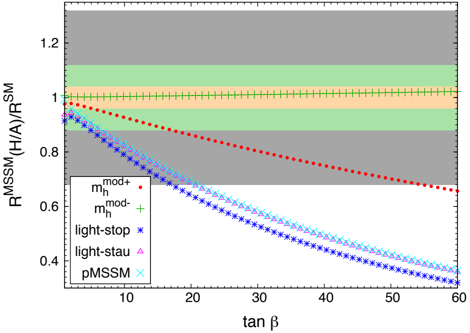
- Decoupling behavior with M_A in all scenarios.
- $\mu < 0$ $A_t > 0$: largest deviations but excluded by ATLAS, CMS, and Combined, and also disfavored by BR($B_s \to \mu^+\mu^-$).
- $m_h^{\text{mod+}}$: allowed by CMS, deviations around 20%.
- $m_h^{\text{mod-}}$: allowed by CMS, indistinguishable from SM.
- light-stop, light-stau: larger deviations up to 40%.
- pMSSM: 50% deviations, allowed by data if $M_A \lesssim 500$ GeV.

Dependence of $R^{\mathrm{MSSM}}(h)$ with $\tan\beta$



- No significant deviations in $m_h^{\mathrm{mod}+}$, $m_h^{\mathrm{mod}\text{-}}$, light-stop, and light-stau scenarios, up to 10%.
- pMSSM: predictions allowed by CMS for any value of $\tan\beta$, and by ATLAS and the combined analysis if $\tan\beta \gtrsim 50$; largest deviation around 50% for $\tan\beta = 60$.

Dependence of $R^{\text{MSSM}}(H/A)$ with $\tan\beta$



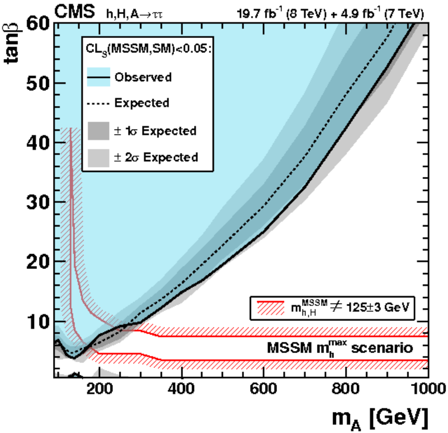
- 32%: $m_h^{\text{mod}+}$ for $\tan\beta \gtrsim 55$, rest of scenarios for $\tan\beta \gtrsim 20$.
- 12%: $m_h^{\text{mod}+}$ for $\tan\beta \gtrsim 20$, rest of scenarios for $\tan\beta \gtrsim 5$.
- 4%: guaranteed for any of these 4 scenarios with $\tan\beta \gtrsim 5$

Higgs coupling accuracies

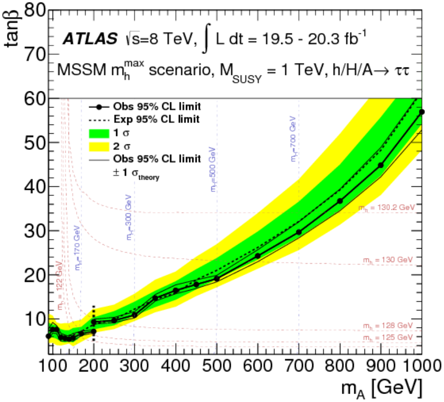
Observable	LHC	HL-LHC	LC	HL-LHC+LC
$Hb\bar{b}$	10-13%	4-7%	0.6%	0.6%
$H\tau\bar{\tau}$	6-8%	2-5%	1.3%	1.2%
R	32-42%	12-24%	4%	3%

Table: Expected accuracy with which fundamental Higgs couplings $Hb\bar{b}$ and $H\tau\bar{\tau}$ and derived $R = \mathrm{BR}(H \to b\bar{b})/\mathrm{BR}(H \to \tau\bar{\tau})$ can be measured at the LHC/HL-LHC, LC and in combined analyses of the HL-LHC and LC [Dawson *et al.*, 2013].

Searches for neutral MSSM Higgs bosons decaying to $\tau\bar{\tau}$

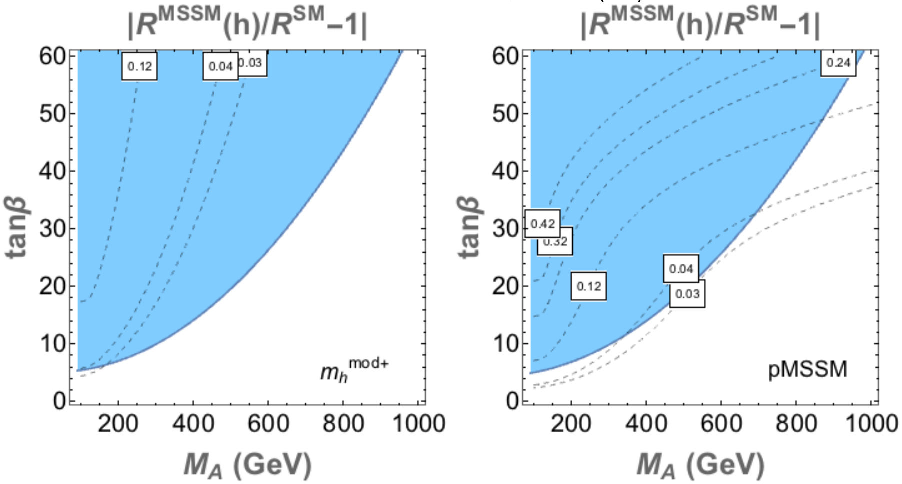


[CMS, 2014]



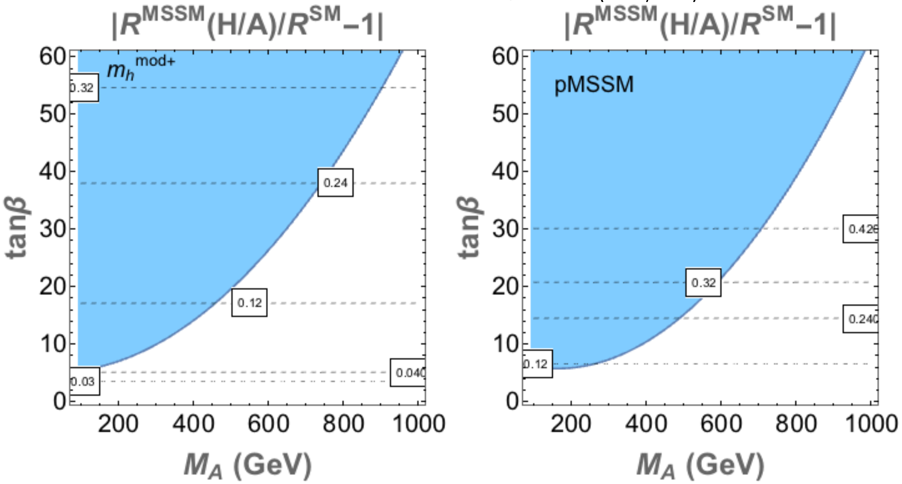
[ATLAS, 2014]

Potential discrimination with $R^{\rm MSSM}(h)$



- HL-LHC only sensitive to SUSY nature of h for large values of M_A and $\tan\beta$.
- LC can probe h SUSY nature for any value of M_A and $\tan\beta$.

Potential discrimination with $R^{\rm MSSM}(H/A)$



- LHC could probe SUSY nature of H/A for $M_A \gtrsim 500$ GeV with $\tan\beta \gtrsim 20$.
- HL-LHC could discriminate between SUSY and non-SUSY models for practically any value of M_A with $\tan\beta \gtrsim 5$.

Conclusions

- Update of the analysis of $R = \text{BR}(H \to b\bar{b})/\text{BR}(H \to \tau\bar{\tau})$ to look for a strong evidence for SUSY nature of Higgs bosons.
- Realistic MSSM scenarios with m_h compatible with $m_{H^{\text{SM}}} \simeq 125$ GeV.
- Taken into account constraints by LHC data on $Hb\bar{b}$ and $H\tau\bar{\tau}$ couplings, and by the ATLAS and CMS searches for heavy neutral MSSM Higgs bosons. Expected accuracy for these couplings at the HL-LHC and the future LC also considered.
- Small region of MSSM parameter space sensitive to SUSY nature of h allowed by present measurements. Not reliable conclusion because a large region of parameter space allowed by CMS experiment, but excluded by ATLAS experiment and our combined result at 68% C.L.
- To be sensitive to SUSY nature of h, a $3-4\%$ measurement required, to be performed at a future LC.

LHC capable of discriminating between SUSY and non-SUSY models if new Higgs boson discovered and its couplings to b quarks and τ leptons measured with moderate level of accuracy.

Bibliography

- G. Aad *et al.* [ATLAS and CMS Collaborations], Phys. Rev. Lett. **114** (2015) 191803 [arXiv:1503.07589 [hep-ex]].
- J. Guasch, W. Hollik and S. Peñaranda, Phys. Lett. B **515** (2001) 367 [hep-ph/0106027].
- L. J. Hall, R. Rattazzi and U. Sarid, Phys. Rev. D **50** (1994) 7048 [hep-ph/9306309, hep-ph/9306309].
- M. Carena, M. Olechowski, S. Pokorski and C. E. M. Wagner, Nucl. Phys. B **426** (1994) 269 [hep-ph/9402253].
- M. Carena, S. Heinemeyer, O. Stl, C. E. M. Wagner and G. Weiglein, Eur. Phys. J. C **73** (2013) 9, 2552 [arXiv:1302.7033 [hep-ph]].
- M. W. Cahill-Rowley, J. L. Hewett, A. Ismail, M. E. Peskin and T. G. Rizzo, arXiv:1305.2419 [hep-ph].
- V. Khachatryan *et al.* [CMS Collaboration], Eur. Phys. J. C **75** (2015) 5, 212 [arXiv:1412.8662 [hep-ex]].
- The ATLAS collaboration, ATLAS-CONF-2015-007, ATLAS-COM-CONF-2015-011.
- R. Barlow, physics/0406120; eConf C **030908** (2003) WEMT002 [physics/0401042 [physics.data-an]]; physics/0306138.
- V. Khachatryan *et al.* [CMS Collaboration], JHEP **1410** (2014) 160 [arXiv:1408.3316 [hep-ex]];
- G. Aad *et al.* [ATLAS Collaboration], JHEP **1411** (2014) 056 [arXiv:1409.6064 [hep-ex]].
- S. Dawson, A. Gritsan, H. Logan, J. Qian, C. Tully, R. Van Kooten, A. Ajaib and A. Anastassov *et al.*, arXiv:1310.8361 [hep-ex];