The hMSSM approach:

Orsay+ Rome collaboration:

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- **The hMSSM in one slide**
- **The three basic assumptions:**
  - **– Conventional mass matrix for the CP Higgses**
  - **– Dominance of the leading radiative correction**
  - **– No impact of direct corrections to the couplings**
- **Conclusions**

1. The hMSSM in one slide

MSSM Higgs sector simple at tree level: only two basic inputs, $\tan\beta, M_A$

Radiative corrections make it complicated as $RC = f(M_S, X_t, X_b, \mu, M_i ...)$

Ex: $M_h^2 \xrightarrow{M_A \gg M_Z} M_Z^2 |\cos^2 2\beta| + \frac{3\bar{m}_t^4}{2\pi^2 v^2 \sin^2\beta}\left[\log\frac{M_S^2}{\bar{m}_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12 M_S^2}\right)\right]$

Only information so far on the MSSM from the LHC $\Rightarrow \begin{cases} M_h = 125 \text{ GeV} \\ M_S \gtrsim 1 \text{ TeV} \end{cases}$

hMSSM: trade the value $M_h = 125 \text{ GeV}$ against the radiative corrections.

Back to tree-level: only two inputs for Higgs sector and no SUSY parameters.

$$M_H^2 = \frac{(M_A^2 + M_Z^2 - M_h^2)(M_Z^2 c_\beta^2 + M_A^2 s_\beta^2) - M_A^2 M_Z^2 c_{2\beta}^2}{M_Z^2 c_\beta^2 + M_A^2 s_\beta^2 - M_h^2}$$

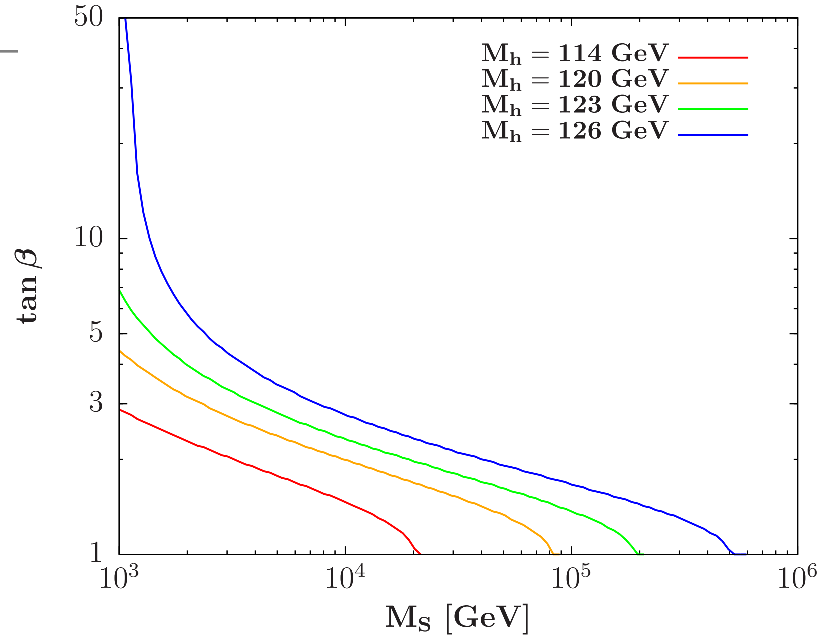
$$\alpha = -\arctan\left(\frac{(M_Z^2 + M_A^2) c_\beta s_\beta}{M_Z^2 c_\beta^2 + M_A^2 s_\beta^2 - M_h^2}\right)$$

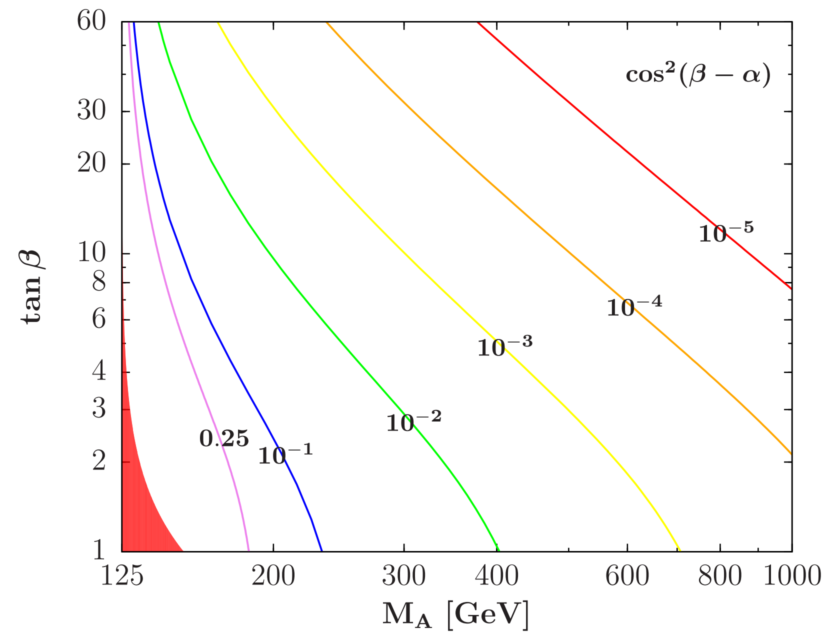
One also has the relation $M_{H^\pm}^2 \simeq M_A^2 + M_W^2$ which is more general...

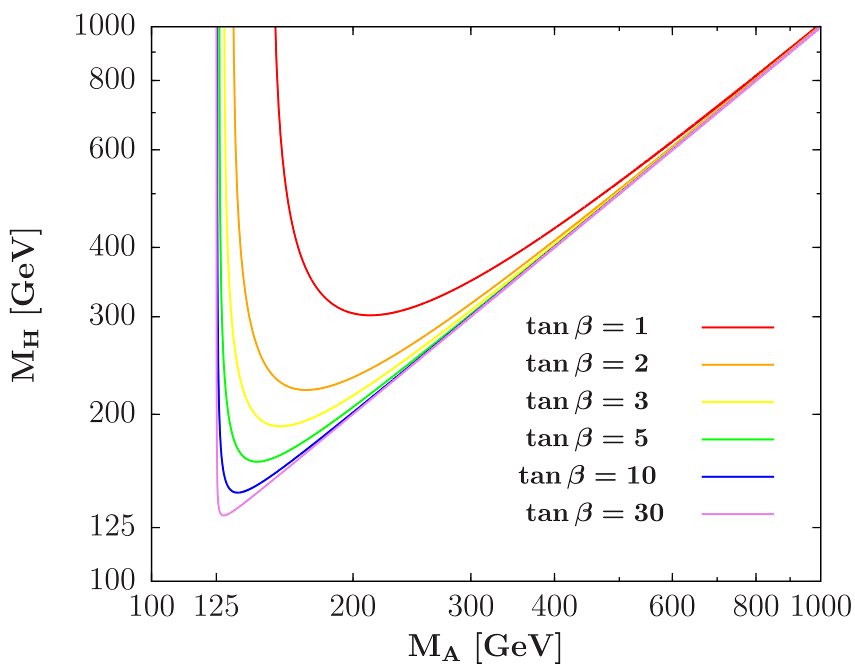
Effective and "model-independent" approach of the MSSM Higgs sector:

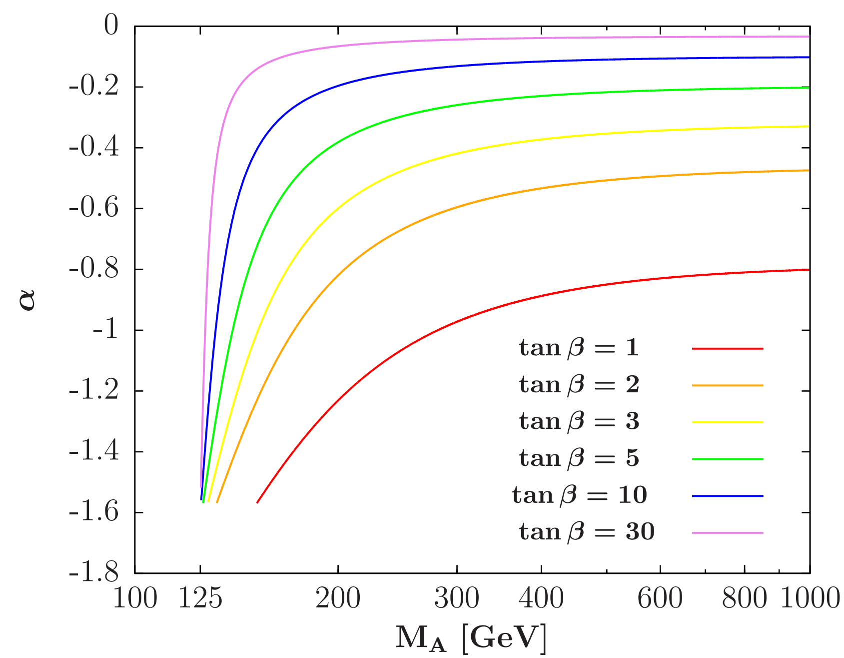
- **good: very simple, economical, .. and opens the possibility of low tanβ**
- **bad: requires large M_S at low tanβ; not defined at very low M_A, ...?**
- **ugly: needs large fine-tuning (but theory already fined-tuned anyway..).**

1. The hMSSM in one slide









2. Assumptions: standard mass matrix

The CP-even Higgs sector is usually described by the 2×2 mass matrix :

$$\mathbf{M_\Phi^2} = \mathbf{M_Z^2} \begin{pmatrix} c_\beta^2 & -s_\beta c_\beta \\ -s_\beta c_\beta & s_\beta^2 \end{pmatrix} + \mathbf{M_A^2} \begin{pmatrix} s_\beta^2 & -s_\beta c_\beta \\ -s_\beta c_\beta & c_\beta^2 \end{pmatrix} + \begin{pmatrix} \Delta\mathcal{M}_{11}^2 & \Delta\mathcal{M}_{12}^2 \\ \Delta\mathcal{M}_{12}^2 & \Delta\mathcal{M}_{22}^2 \end{pmatrix}$$

It is by diagonalizing this matrix that one obtains $\mathrm{M_H}, \mathrm{M_h}$ and α:

- tree–level masses are given in terms of $\mathrm{M_A}$ and $\mathrm{M_Z}$ plus the angle β;
- radiative corrections (with the SUSY parameters) appear only in $\mathbf{\Delta\mathcal{M}_{ij}^2}$.

Assumption clearly valid at scales $\mathrm{M_S}$ not far for 1 TeV (common wisdom..

In the hMSSM, we assume that this picture is valid at much higher scales.

We understand that this is the main problem and subject of discussion:

Question 1): how far can we go in $\mathrm{M_S}$ while retaining this simple form?

Question 2): when RGE improving, the matrix has still a convenient form?

Work under way.. Thanks to Carlos, Gabriel, Pietro et al. for the help!

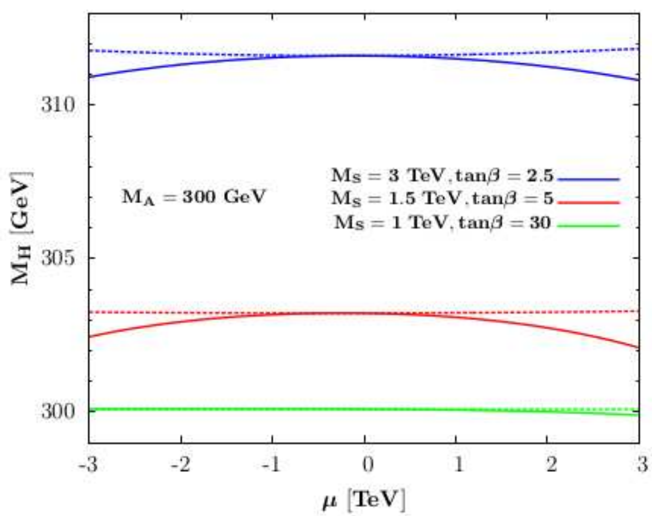
2. Assumptions: dominance of main correction

Dominant correction to $\Delta\mathcal{M}^2$ due to top/stop sector and approximately:

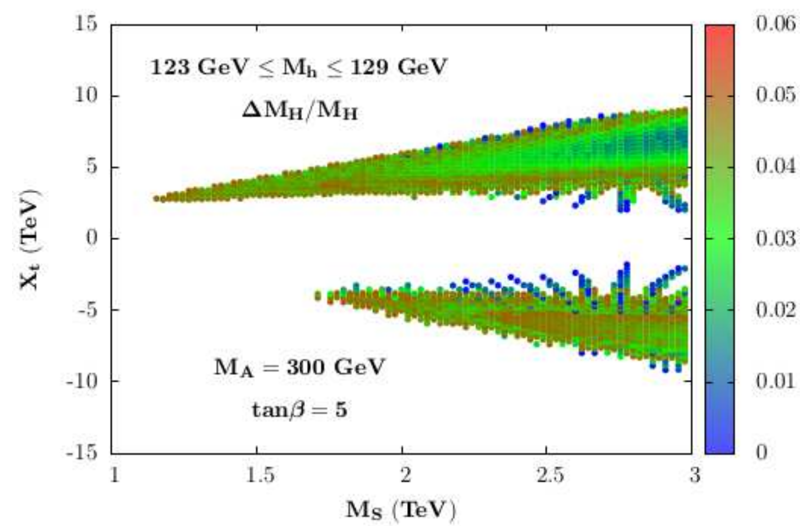
$$\Delta\mathcal{M}^2_{22} \propto \frac{3\bar{m}_t^4}{2\pi^2 v^2 \sin^2\beta}\left[\log\frac{M_S^2}{\bar{m}_t^2}+\frac{\tilde{X}_t^2}{M_S^2}\right]+\cdots \gg \Delta\mathcal{M}^2_{11}, \Delta\mathcal{M}^2_{12}$$

We have checked the approximation in two different configurations:

Include subleading terms in $\Delta\mathcal{M}^2$
(Carena,Wagner,Haber,Hempfling...)
$\lambda_t, \lambda_b, X_t = X_b$ and varying μ
with some choice of $M_S, \tan\beta$.



Scan of the MSSM parameters
with all Higgs rad. corrections
(we use Suspect with BDSZ RC)
and impact of M_S, A_t, μ, A_b



Very good approximation ($\leq$ few percent) for M_H, α for not too large μ.

2. Assumptions: no direct corrections

Higgs couplings given by α and β: no large direct corrections

Higgs couplings to u,d and V:

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$
h	c_α/s_β	s_α/c_β	$s_{\beta-\alpha}$
H	s_α/c_β	c_α/c_β	$c_{\beta-\alpha}$
A	$1/t_\beta$	t_β	0

Higgs self–couplings: Hhh+hhh

$$\lambda_{hhh} = 3c_{2\alpha}s_{\beta+\alpha} + 3dc_\alpha^3/s_\beta$$

$$\lambda_{Hhh} = 3s_{2\alpha}s_{\beta+\alpha} - c_{2\alpha}c_{\beta+\alpha} + 3ds_\alpha c_\alpha^2/s_\beta$$

$$d \simeq \Delta\mathcal{M}_{22}^2/M_Z^2$$

OK, but with one exception: the $\Delta_b \propto \mu\tan\beta/M_S$ correction to $g_{\Phi bb}$

(remark made by Michael Spira when implementing hMSSM in HDECAY).

$g_{Hbb} \approx g_{Abb} = 1/(1+\Delta_b)$ **important in one case:** $pp \to H/A \to \tau\tau$

$$\sigma(pp \to \Phi) \propto (1+\Delta_b)^{-2}$$

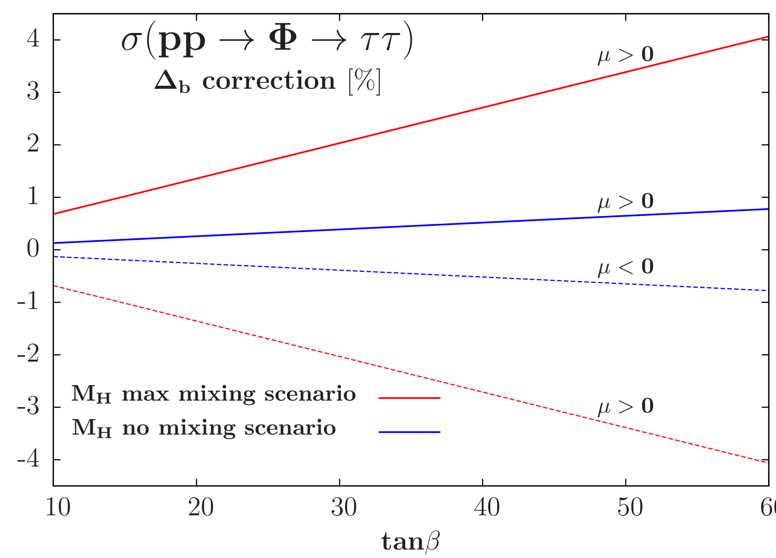
$$BR(\tau\tau) \propto \Gamma_\tau/(\Gamma_\tau + \Gamma_b)$$

$$\Rightarrow \sigma \times BR \propto 1 - \Delta_b/5$$

Need very large $\Delta_b \gtrsim 100\%$

to have impact $\Delta^{th}\sigma \approx 25\%$

$\Rightarrow$ **Not so bad!**



3. Conclusions

If you “buy” these three basic assumptions:

- **Conventional mass matrix for CP Higgses**
- **Dominance of leading radiative correction**
- **No impact of direct corrections to couplings**

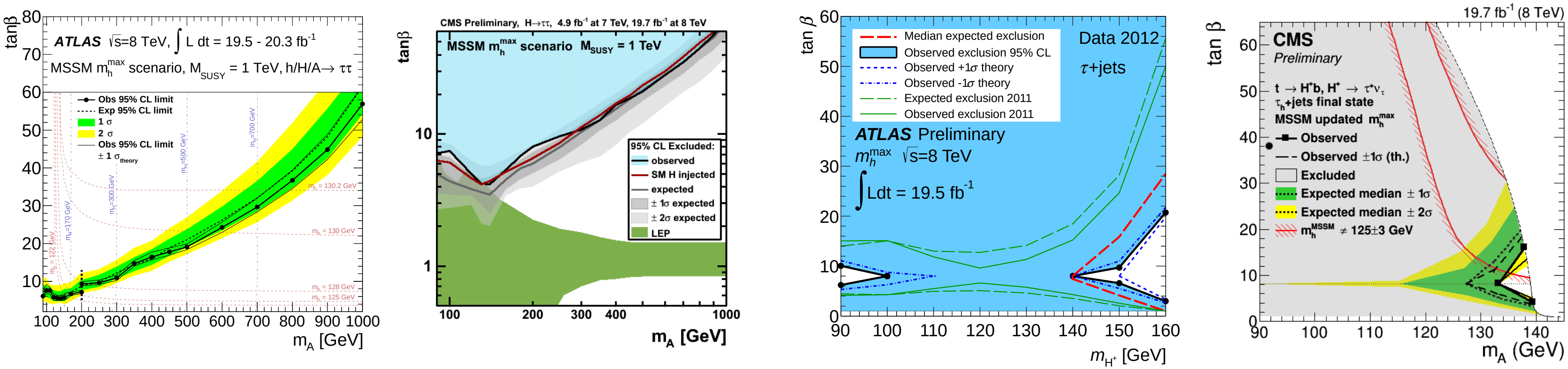
You can take the jackpot...

- **a very simple description of the MSSM space; easy to implement,**
- **again only two inputs, so no scan, no grid, no set of benchmarks...,**
- **very transparent, one can “deconvolute” it in theory/exper. analyses,**
- **it allows the possibility to address low tanβ “model-independently”,**
- **allows more action: plenty of channels to be investigated/interpreted.**

Example of a very preliminary analysis: Rome+Orsay, in progress...

3. Conclusions

Combine ATLAS+CMS $\mathrm{pp} \to \mathrm{H}^{\pm} \to \tau\nu$ and $\mathrm{pp} \to \mathrm{A/H} \to \tau^+\tau^-$



- **From $\mathrm{t} \to \mathrm{bH}^+ \to \mathrm{b}\tau\nu$ search:**
  $\mathrm{M_A} \lesssim 140$ GeV is now excluded;
- **$\mathrm{pp} \to \tau\tau$ sensitive at high $\tan\beta$:**

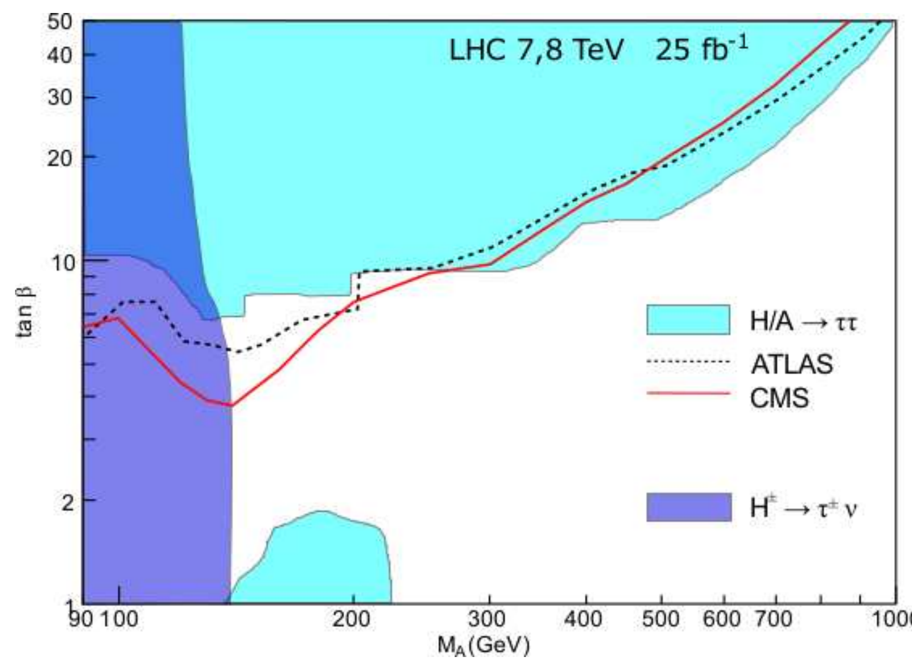
– weaker at low $\mathrm{M_A}$ (no h events)

– stronger at high $\mathrm{M_A}$ (no SUSY).

- **low tanβ can now be considered.**

(A excludes small part of low tanβ)

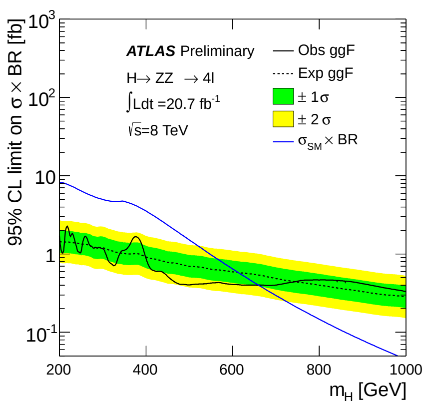
$\Rightarrow$ only tiny forbidden area remains!

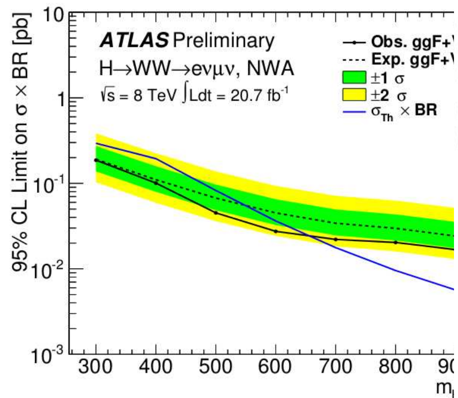


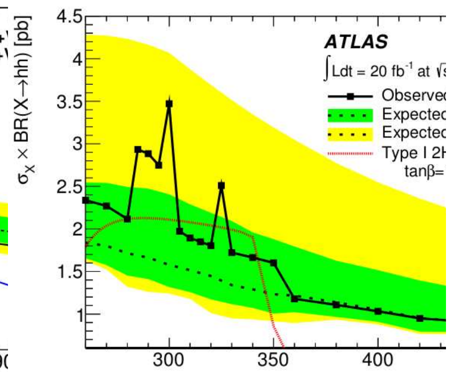
3. Conclusions

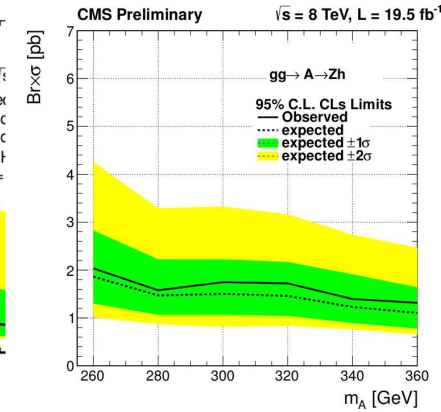
Extend search for heavy SM Higgs for MSSM and consider new channels:

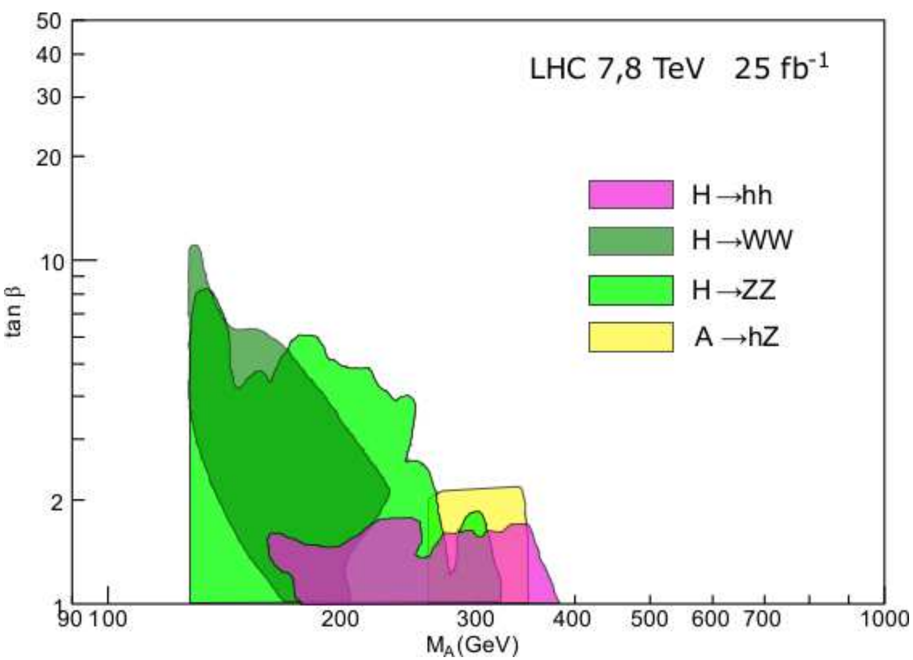
$$pp \to H \to ZZ \quad pp \to H \to WW \quad pp \to H \to hh \quad pp \to A \to hZ$$







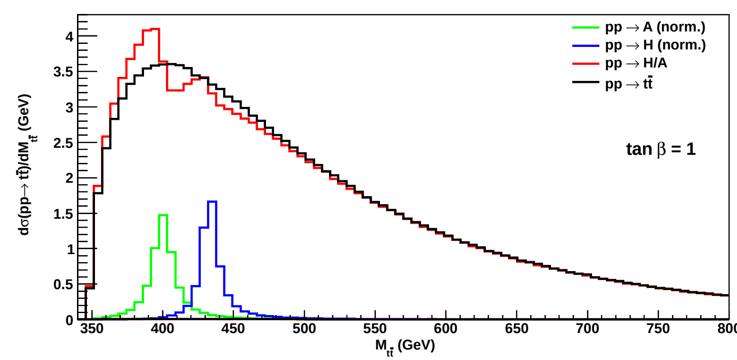




Also consider $pp \to \Phi \to t\bar{t}$

– crucial at low tanβ, high M_A

– very interesting features...



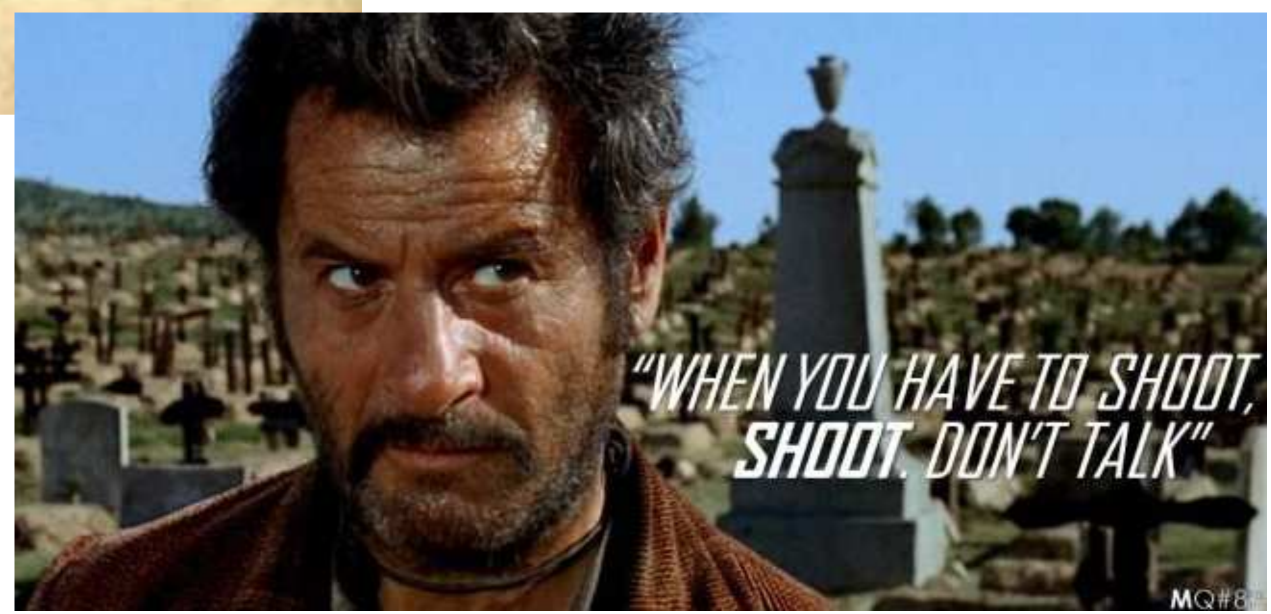
challenging and nice analyses!

3. Conclusions

Now, we are really at the crossroads and there are two options:

Is the hMSSM the good guy?

..... or the ugly one?



Appendix

Leading top/stop sector radiative correction:

(difficult to have tan$\beta \lesssim 4$; talk by Luciano at CERN, 15 May 2013)

$$\Delta\mathcal{M}^2_{22} = \frac{3}{2\pi^2}\frac{m_t^4}{v^2 s_\beta^2}\left[\frac{1}{2}\tilde{X}_t + \ell_S + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_s\right)\left(\tilde{X}_t\ell_S + \ell_S^2\right)\right]$$

$$\ell_S = \log(M_S^2/m_t^2), x_t = X_t/M_S, \tilde{X}_t = 2x_t^2(1 - x_t^2/12)$$

Including subleading radiative corrections involving μ and sbottoms:

(used to have the "blue line" with tanβ=2.5 mentioned by Carlos)

$$\Delta\mathcal{M}^2_{11} = -\frac{v^2\sin^2\beta}{32\pi^2}\bar{\mu}^2\left[x_t^2\lambda_t^4(1 + c_{11}\ell_S) + a_b^2\lambda_b^4(1 + c_{12}\ell_S)\right]$$

$$\Delta\mathcal{M}^2_{12} = -\frac{v^2\sin^2\beta}{32\pi^2}\bar{\mu}\left[x_t\lambda_t^4(6 - x_t a_t)(1 + c_{31}\ell_S) - \bar{\mu}^2 a_b\lambda_b^4(1 + c_{32}\ell_S)\right]$$

$$\Delta\mathcal{M}^2_{22} = \frac{v^2\sin^2\beta}{32\pi^2}\left[6\lambda_t^4\ell_S(2 + c_{21}\ell_S) + x_t a_t\lambda_t^4(12 - x_t a_t)(1 + c_{21}\ell_S)\right.$$
$$\left. - \bar{\mu}^4\lambda_b^4(1 + c_{22}\ell_S)\right]$$

with $\bar{\mu} = \mu/M_S, a_{t,b} = A_{t,b}/M_S$ and for two loops factors c_{ij}.

Carena, Espinosa, Quiros and Wagner, Phys. Lett. B355 (1995) 209;
Haber, Hempfling and Hoang, Z. Phys. C75 (1997) 539;
Carena and Haber, Prog. Part. Nucl. Phys. 50 (2003) 63.