Implications of LHC Higgs results

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ROMA TRE UNIVERSITÀ DEGLI STUDI

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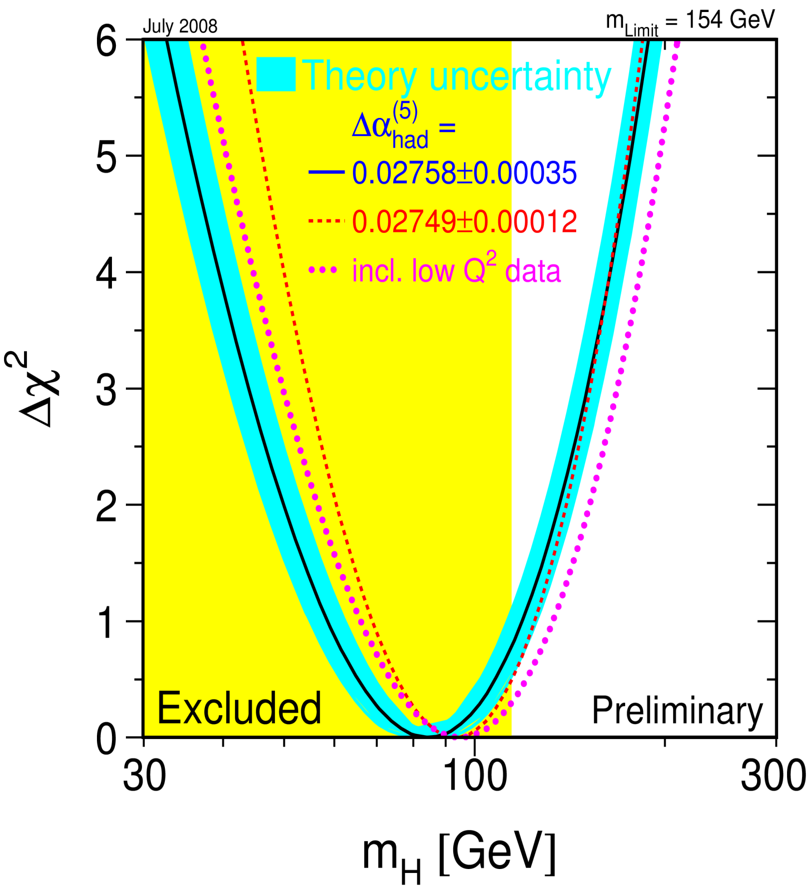
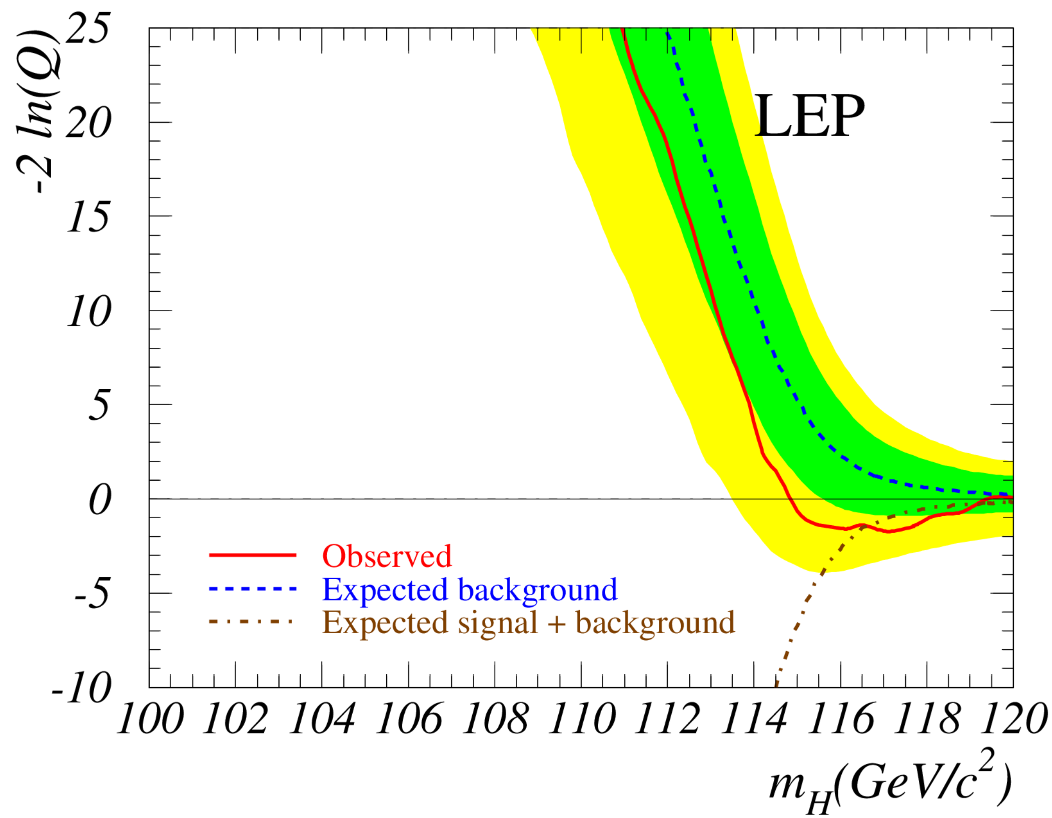
DIPARTIMENTO DI FISICA EDOARDO AMALDI

Outline

- Past and present information on the Higgs boson
- Discussing the hypothesis: $M_h \sim 125$ GeV, $\sigma \sim \sigma_{SM}$ for the SM and the MSSM
- Conclusions

The past: LEP

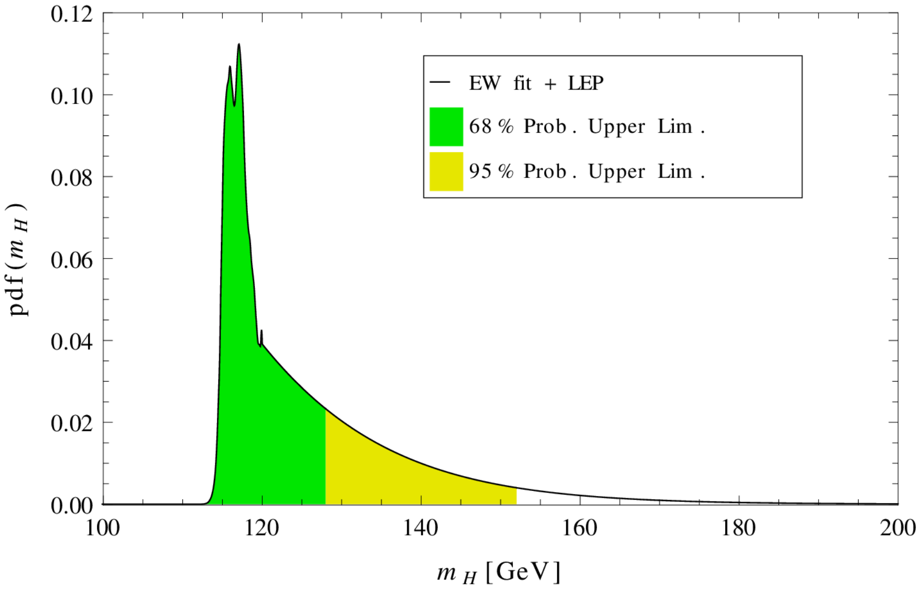


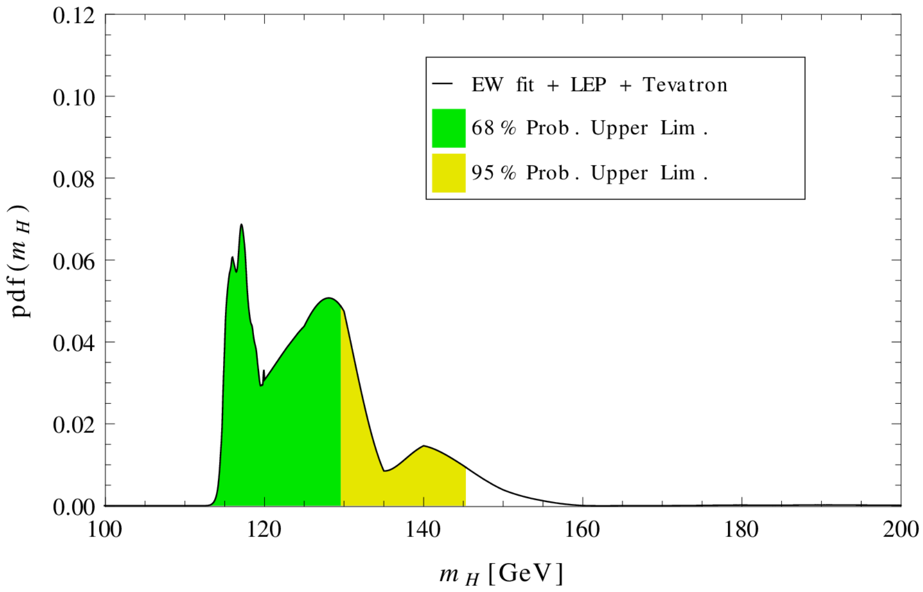


$$Q = \frac{\mathcal{L}(s+b)}{\mathcal{L}(b)}$$

The past: LEP +Tevatron

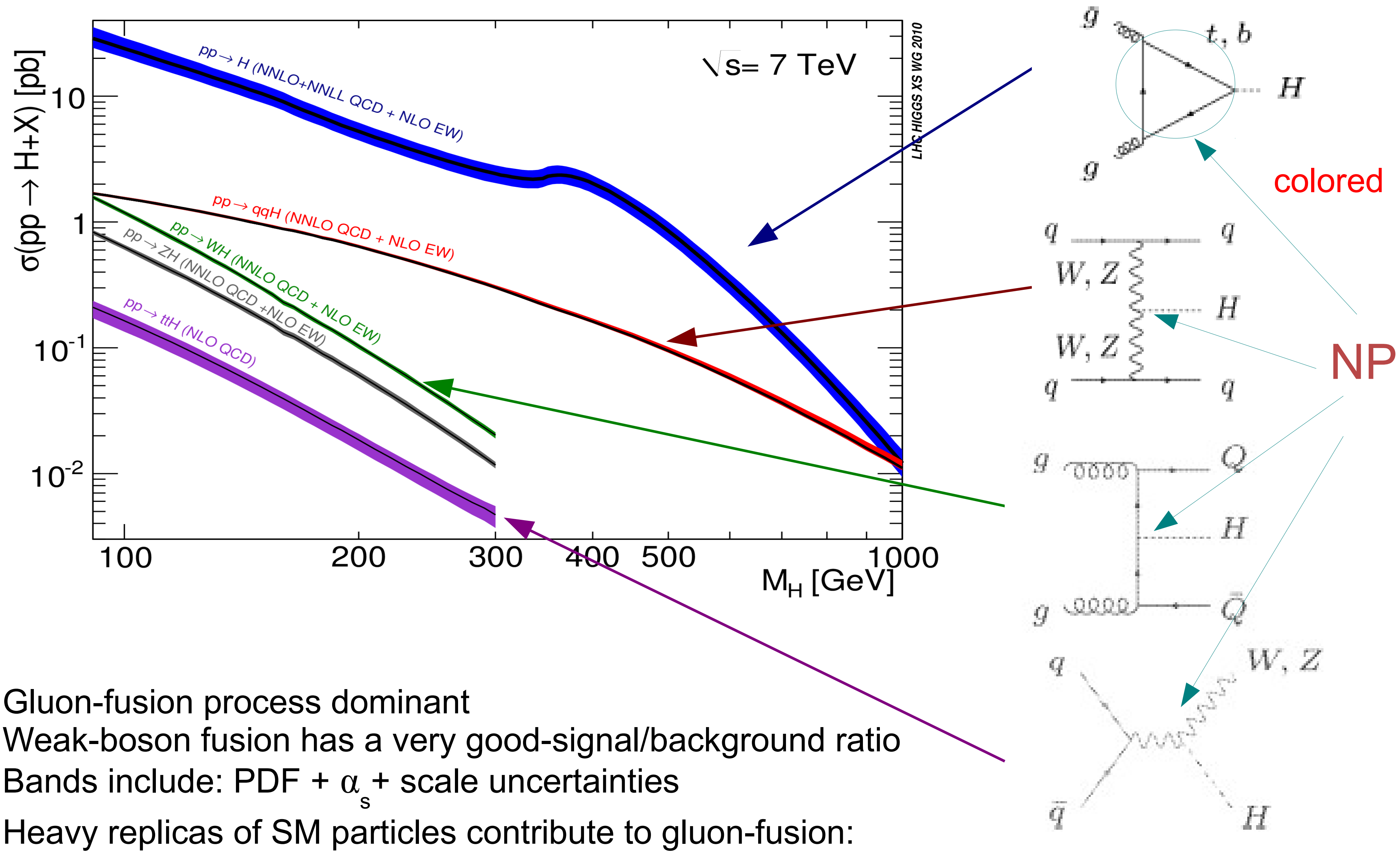
Combining direct and indirect information:





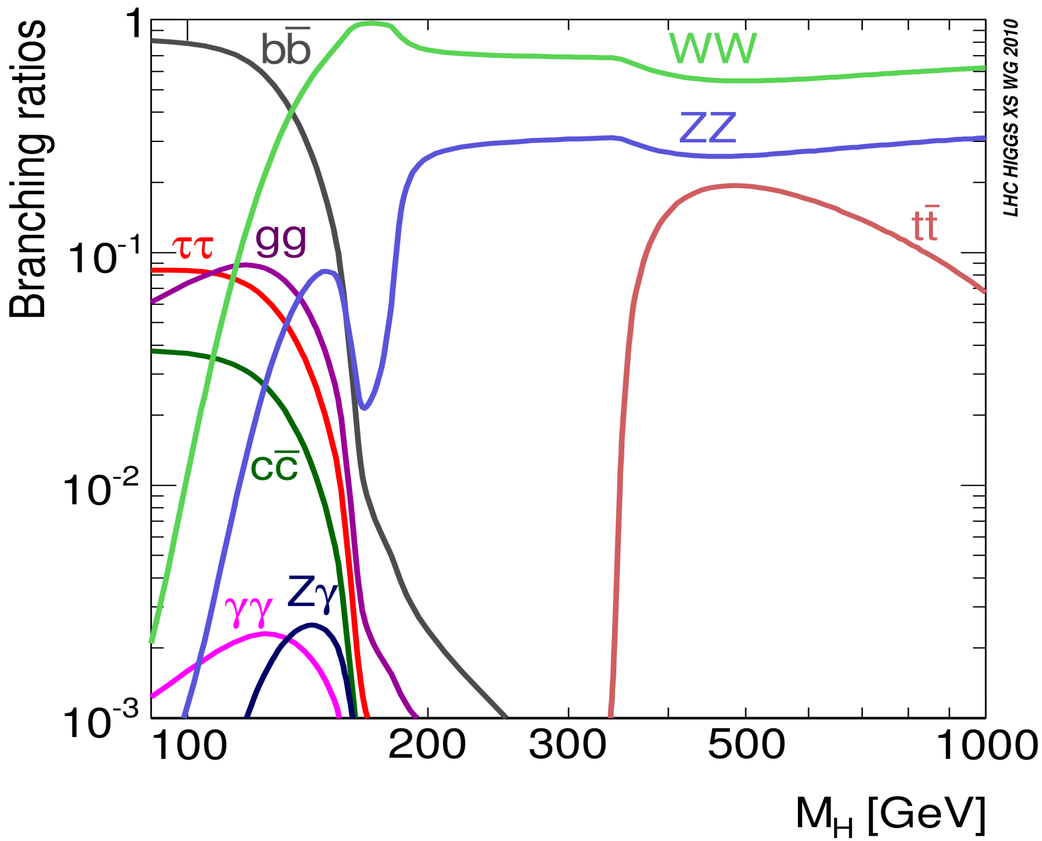
courtesy of S. Di Vita

The present: LHC, Higgs Production

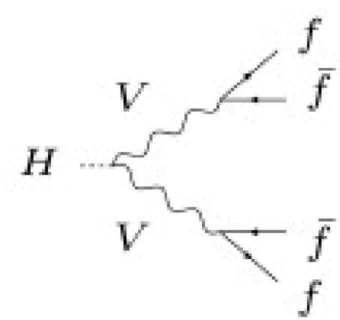


Gluon-fusion process dominant
Weak-boson fusion has a very good-signal/background ratio
Bands include: PDF + α_s + scale uncertainties
Heavy replicas of SM particles contribute to gluon-fusion: ex. 4[th] generation

The present: LHC, Higgs Decays



Golden Channel V=Z

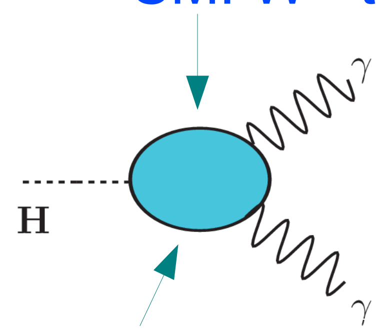


A NP increase in gluon-fusion X-sect. often corresponds to a decrease of BR$(H \to \gamma\gamma)$

The BR $(H \to \gamma\gamma)$ can increase if NP reduces the other BR's

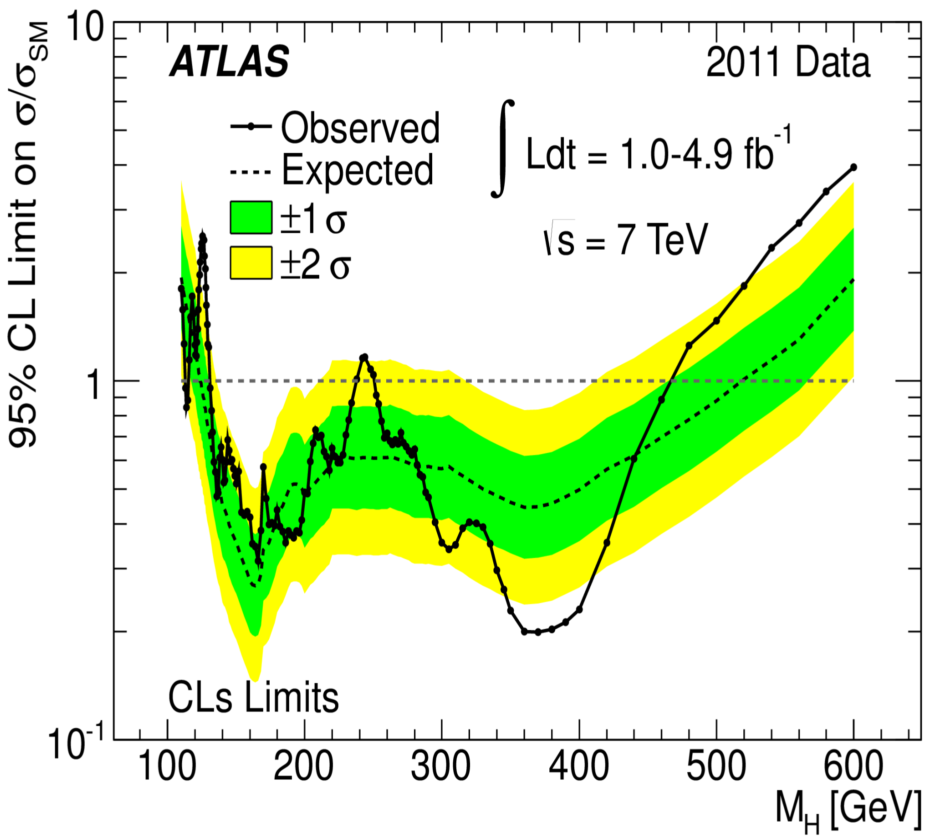
Low Higgs mass

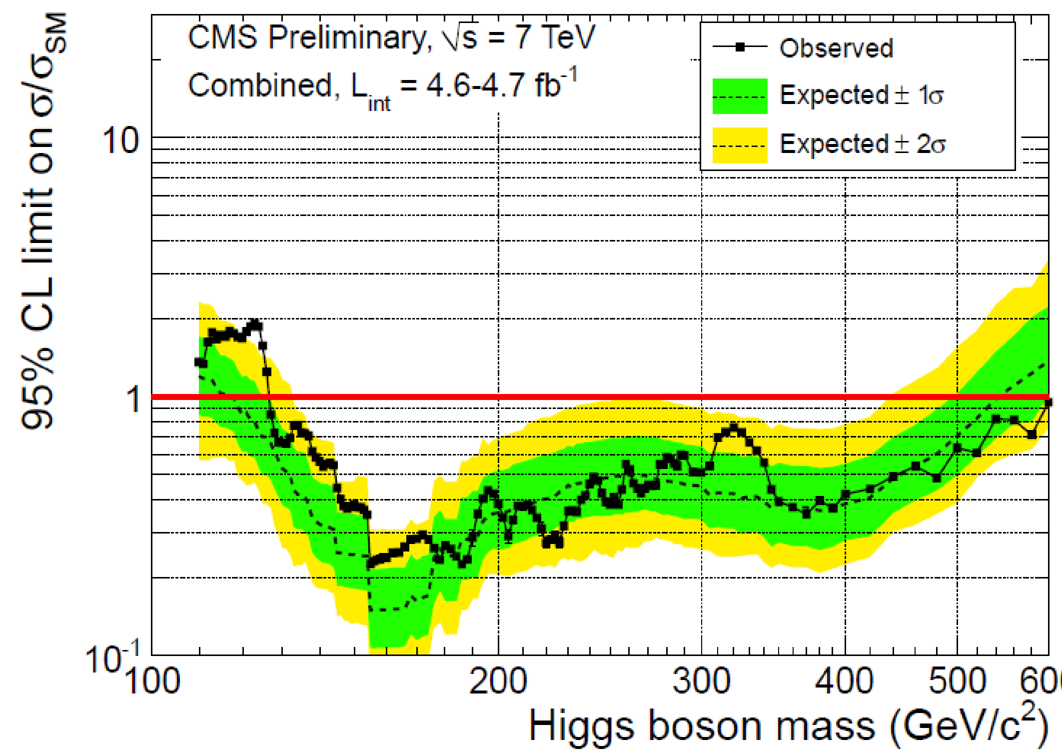
SM: W - t



NP: white + colored

The present: LHC, results





Excess of events in $H \to \gamma\gamma, H \to ZZ$

ATLAS near $M_H \sim$ 126 GeV
and near $M_H \sim$ 245 GeV

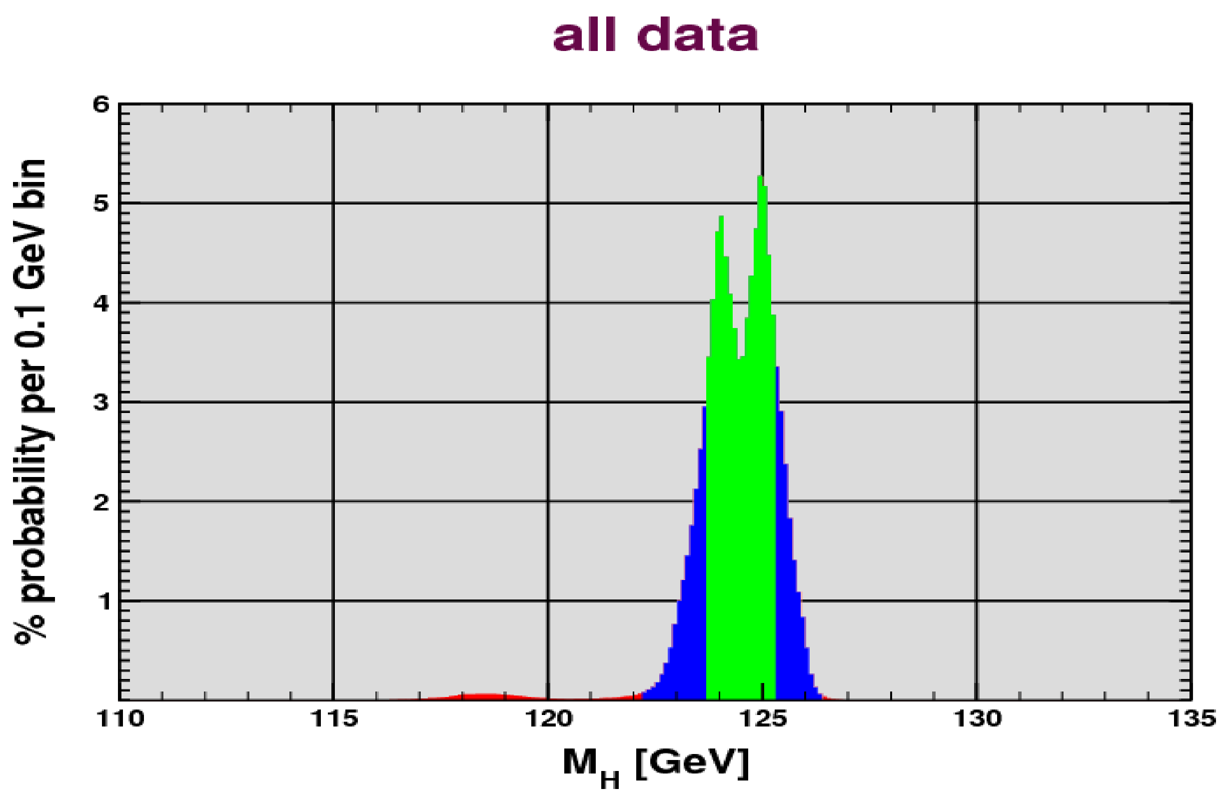
CMS near $M_H \sim$ 124 GeV
and near $M_H \sim$ 119.5 GeV

Supported by a broad excess in $H \to WW$

The present: LHC

This plot should be taken as qualitative.

Q is guessed.
Experiments do not provide likelihoods



Erler, 2012

Working hypothesis: $M_H \sim 125$ GeV, $\sigma \sim \sigma_{SM}$

but data still allow $M_H > 600$ GeV although this region is cut by EWPT

Reversing the heavy Higgs argument

Specific type of NP could allow a heavy Higgs in the EW fit ("conspiracy").
Take

$$\sin^2\theta_{eff}^{lept} \sim \frac{1}{2}\left\{1-\left[1-\frac{4A^2}{M_Z^2\,\hat\rho\,(1-\Delta\hat r_W)}\right]^{1/2}\right\}$$

$$\hat\rho = \rho_0+\delta\rho\,(\rho_0^{\rm SM}=1,\delta\rho\leftrightarrow(\epsilon_1,\,T))$$

$$\Delta\hat r_W \leftrightarrow (\epsilon_3,\,S)$$

$$c_i>0 \qquad \sim (\sin^2\theta_{eff}^{lept})^\circ + c_1\ln\left(\frac{M_H}{M_H^\circ}\right)+c_2\left[\frac{(\Delta\alpha)_h}{(\Delta\alpha)_h^\circ}-1\right]-c_3\left[\left(\frac{M_t}{M_t^\circ}\right)^2-1\right]+\ldots$$

To increase the fitted M_H: $\left\{\begin{array}{l}\hat\rho>1\rightarrow \left\{\begin{array}{l}\rho_0>1 \\ \delta\rho>0\end{array}\right. \\ \Delta\hat r_W<0\end{array}\right.$

- $\rho_0>1$ ← Extra Z
- $\delta\rho>0$ ← Isosplitt (s)fermions, Multi Higgs models,
- $\Delta\hat r_W<0$ ← Light sleptons

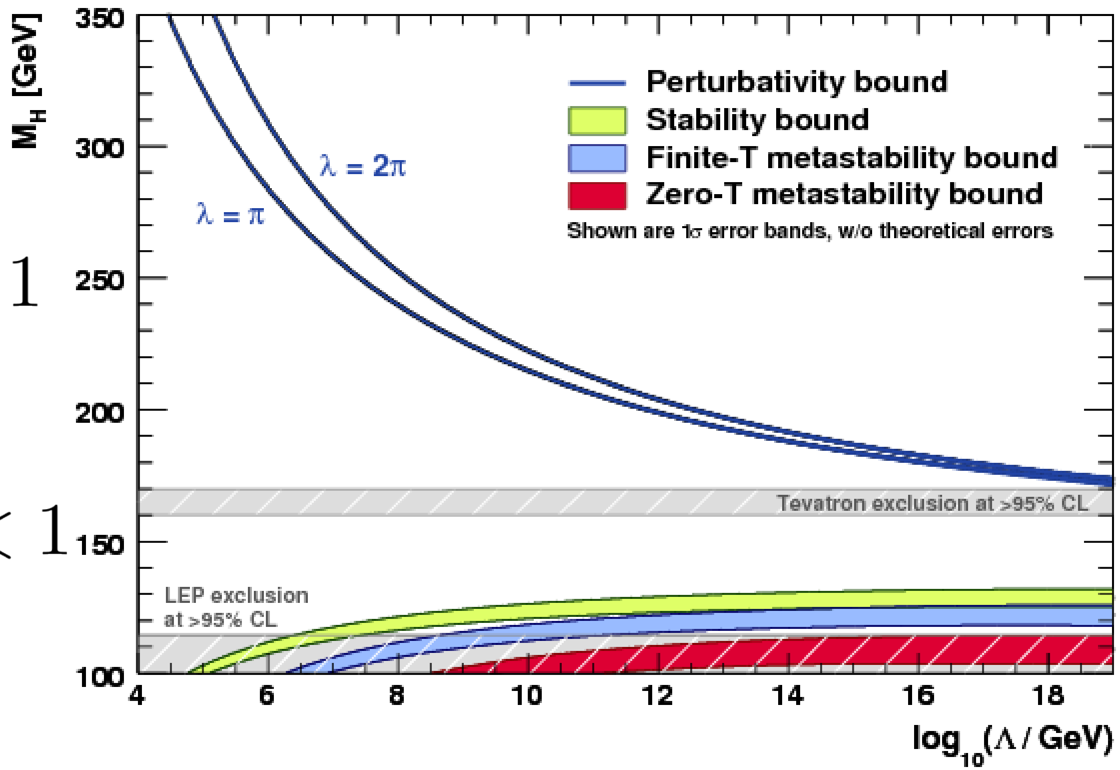
NP (if there) seems to be of the decoupling type
n.b. M_H > 600 GeV would point to the conspiracy

Theoretical bounds on the Higgs mass in the SM

$$V_{\rm Higgs} \approx \frac{\lambda}{4} h^4$$

M_H large $\lambda(m_t) \to \lambda(\Lambda) \gg 1$
non-perturbative regime

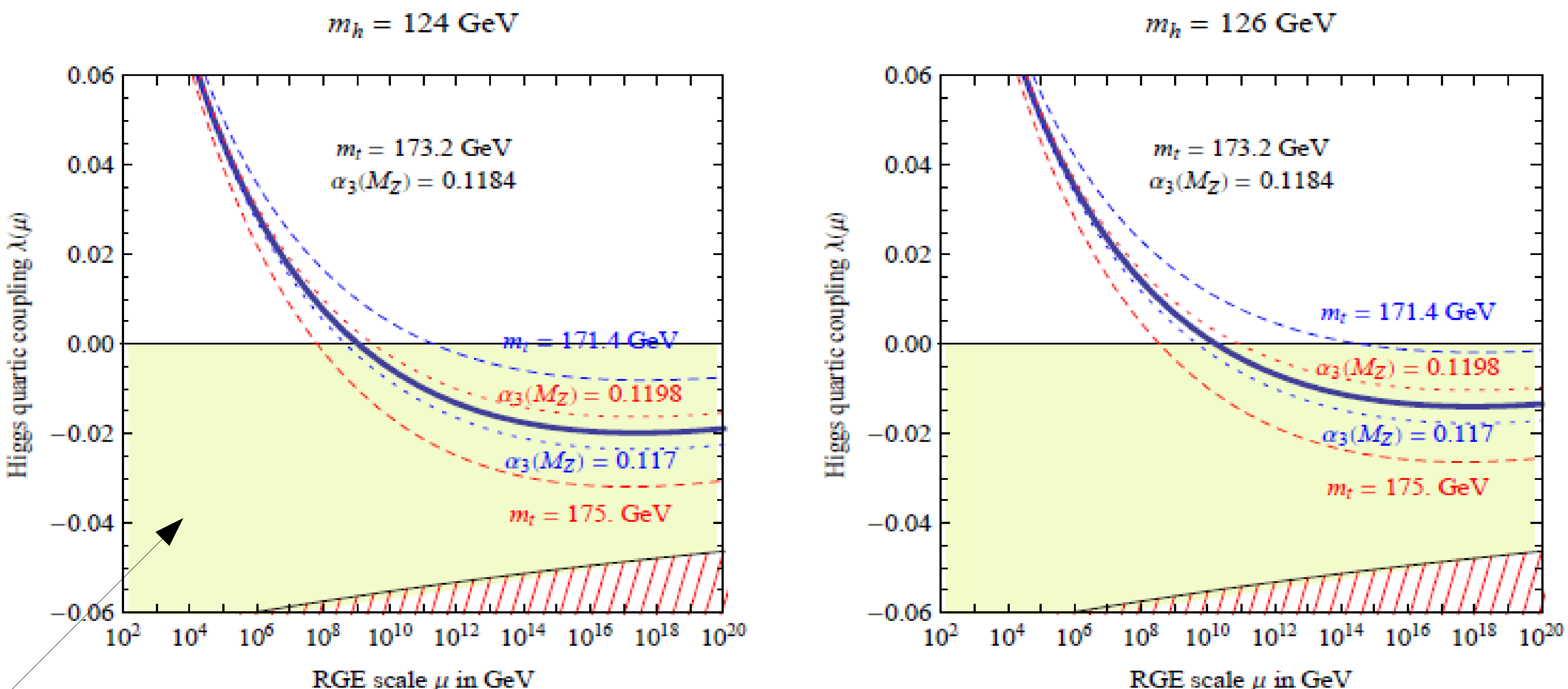
M_H small $\lambda(m_t) \to \lambda(\Lambda) \ll 1$
vacuum (meta)stability



Ellis et al. 2009

Running depends on $m_t,\ \alpha_s, \ldots$

$M_H \sim$ 125 GeV, no problem with the Landau pole, perturbativity up to the Planck scale



Elias-Miro' et al. 2011

Metastability region

Full stability is at the border. Universe becomes metastable at $\Lambda \sim 10^{10}$ GeV.
λ never becomes too negative, small probability of quantum tunneling.
Lifetime of the EW vacuum longer than the age of the Universe.
SM ok up to Planck mass.

M_H ~ 125 GeV and the MSSM

$$\beta,\ \alpha$$

Higgs sector: $H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix},\quad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} \Longrightarrow h, H, A, H^\pm$

Higgs masses: predicted at the tree level in terms of M_A, tan β, $M_h < M_Z$

Including radiative corrections: dependence on all SUSY(-breaking) parameters

$$(A_t, A_b, \mu \ldots)$$

$$M_h \lesssim 135\,\mathrm{GeV}$$

$$M_{A,H,H^\pm} \sim 100 \ldots \mathrm{TeV}$$

decoupling → h SM-like

$$M_A \sim M_H \sim M_H^\pm > \mathcal{O}(200\mathrm{GeV})$$

ϕ	$g^\phi_{u\bar{u}}$	$g^\phi_{d\bar{d}}$	g^ϕ_{VV}
h	$\cos\alpha\,/\sin\beta \to 1$	$-\sin\alpha\,/\cos\beta \to 1$	$\sin(\beta-\alpha) \to 1$
H	$\sin\alpha\,/\sin\beta \to 1/\tan\beta$	$\cos\alpha\,/\cos\beta \to \tan\beta$	$\cos(\beta-\alpha) \to 0$
A	$1/\tan\beta$	$\tan\beta$	0

Large tanβ

$g^\phi_{d\bar{d}}$ ↑

decoupling

$$g^\phi_{d\bar{d}} \to \frac{0}{0}$$

delayed decoupling

How easy is to get M_H ~ 125 GeV in the MSSM ?

$$M_h^2 \simeq M_z c_{2\beta}^2 + \frac{3\, m_t^4}{4\,\pi^2 v^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12\, M_S^2}\right)\right] + \dots$$

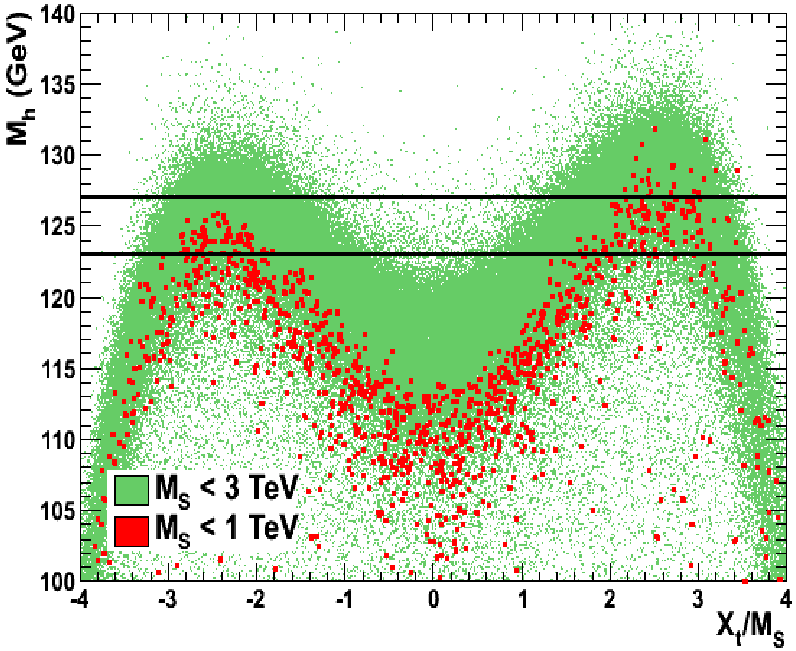
SUSY breaking parameters

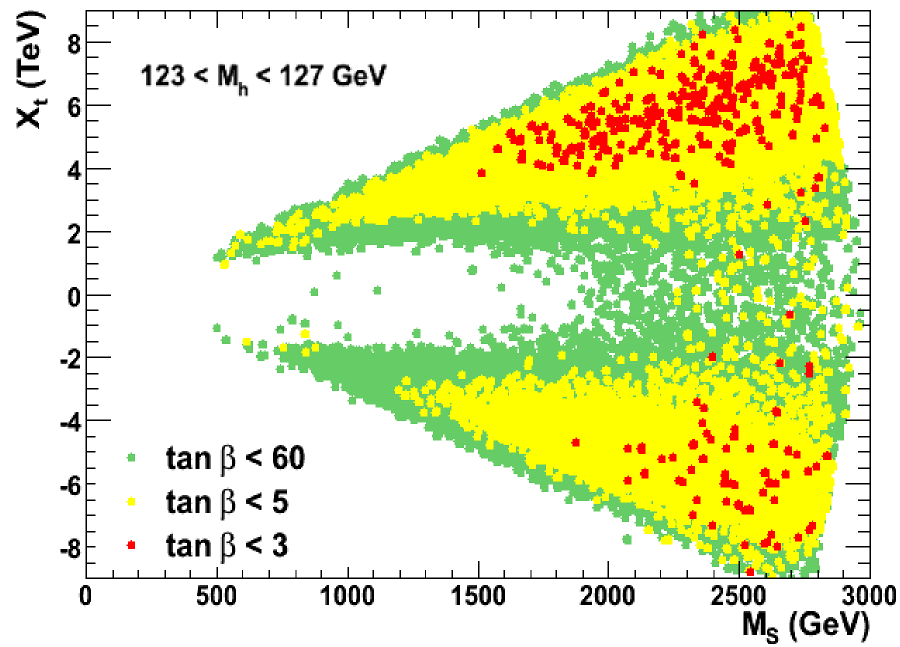
$$X_t = A_t - \mu \cot\beta,\;\; M_S = \sqrt{M_{\tilde{t}_1} M_{\tilde{t}_2}})$$

To get M_H ~ 125 GeV:

- Large tan β, tan β > 10 (increase the tree-level)
- Heavy stops, i.e. large M_S (increase the ln)
- Large stop mixing, i.e. large X_t

The more assumptions we take on the mechanism of SUSY-breaking, the more difficult becomes to get M_H ~ 125 GeV pMSSM: minimal assumptions on SUSY-breaking parameters





Arbey et al., 2011

22 input parameters varying in the domains:

$$1 \leq \tan\beta \leq 60\,,\;\; 50\text{ GeV} \leq M_A \leq 3\text{ TeV}\,,\;\; -9\text{ TeV} \leq A_f \leq 9\text{ TeV}\,,$$
$$50\text{ GeV} \leq m_{\tilde{f}_L}, m_{\tilde{f}_R}, M_3 \leq 3\text{ TeV}\,,\;\; 50\text{ GeV} \leq M_1, M_2, |\mu| \leq 1.5\text{ TeV}.$$

Costrained scenarios:

(no) GMSB:

$\tan\beta,\ sign(\mu),\ M_{mess},\ N_{mess}, \Lambda$

(no) AMSB:

$\tan\beta,\ sign(\mu),\ m_0,\ m_{3/2}$

(yes) MSUGRA:

$\tan\beta,\ sign(\mu),\ m_0,\ m_{1/2},\ A_0$

(no) no-scale:

$m_0 \approx A_0 \approx 0$

(yes) VCMSSM :

$m_0 \approx -A_0$

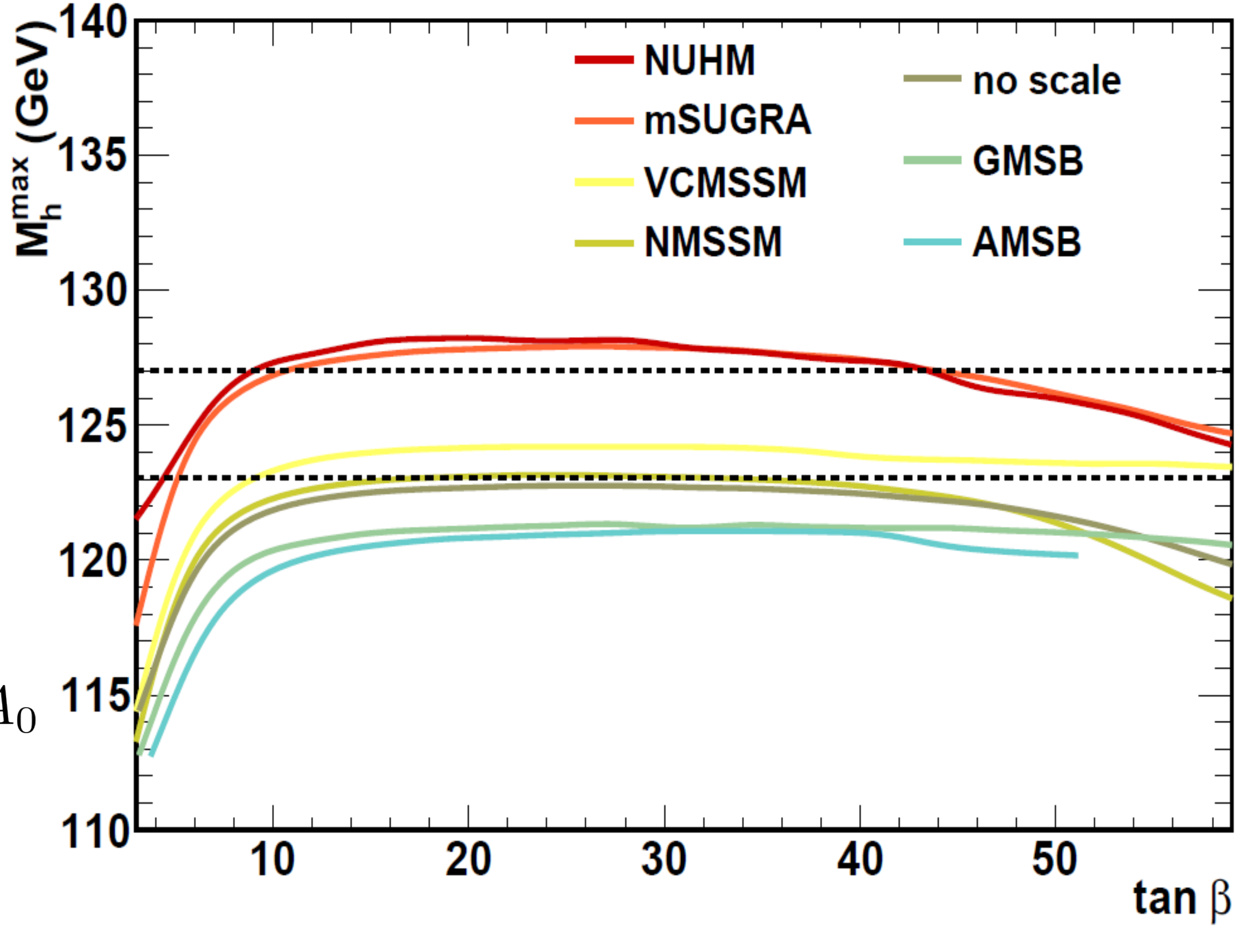
(no) NMSSM :

$m_0 \approx 0,$

$A_0 \approx -1/4 m_{1/2}$

(yes) NUHM:

non universal m_0



Arbey et al., 2011

mSUGRA:	$50\ \text{GeV} \le m_0 \le 3\ \text{TeV}$,	$50\ \text{GeV} \le m_{1/2} \le 3\ \text{TeV}$,	$\lvert A_0\rvert \le 9\ \text{TeV}$;
GMSB:	$10\ \text{TeV} \le \Lambda \le 1000\ \text{TeV}$,	$1 \le M_{\text{mess}}/\Lambda \le 10^{11}$,	$N_{\text{mess}} = 1$;
AMSB:	$1\ \text{TeV} \le m_{3/2} \le 100\ \text{TeV}$,	$50\ \text{GeV} \le m_0 \le 3\ \text{TeV}$.	

$\sigma \sim \sigma_{SM}$ and the MSSM

- Squarks and gluinos contribute to the loop-induced gluon fusion production cross section
- $\sigma(g\,g \rightarrow h)$ is fully known at NLO QCD (standard + SUSY contributions)
- $\sigma(g\,g \rightarrow h)$ implemented in the event generator POWHEG.

E. Bagnaschi, P. Slavich, A. Vicini,G.D. (11)

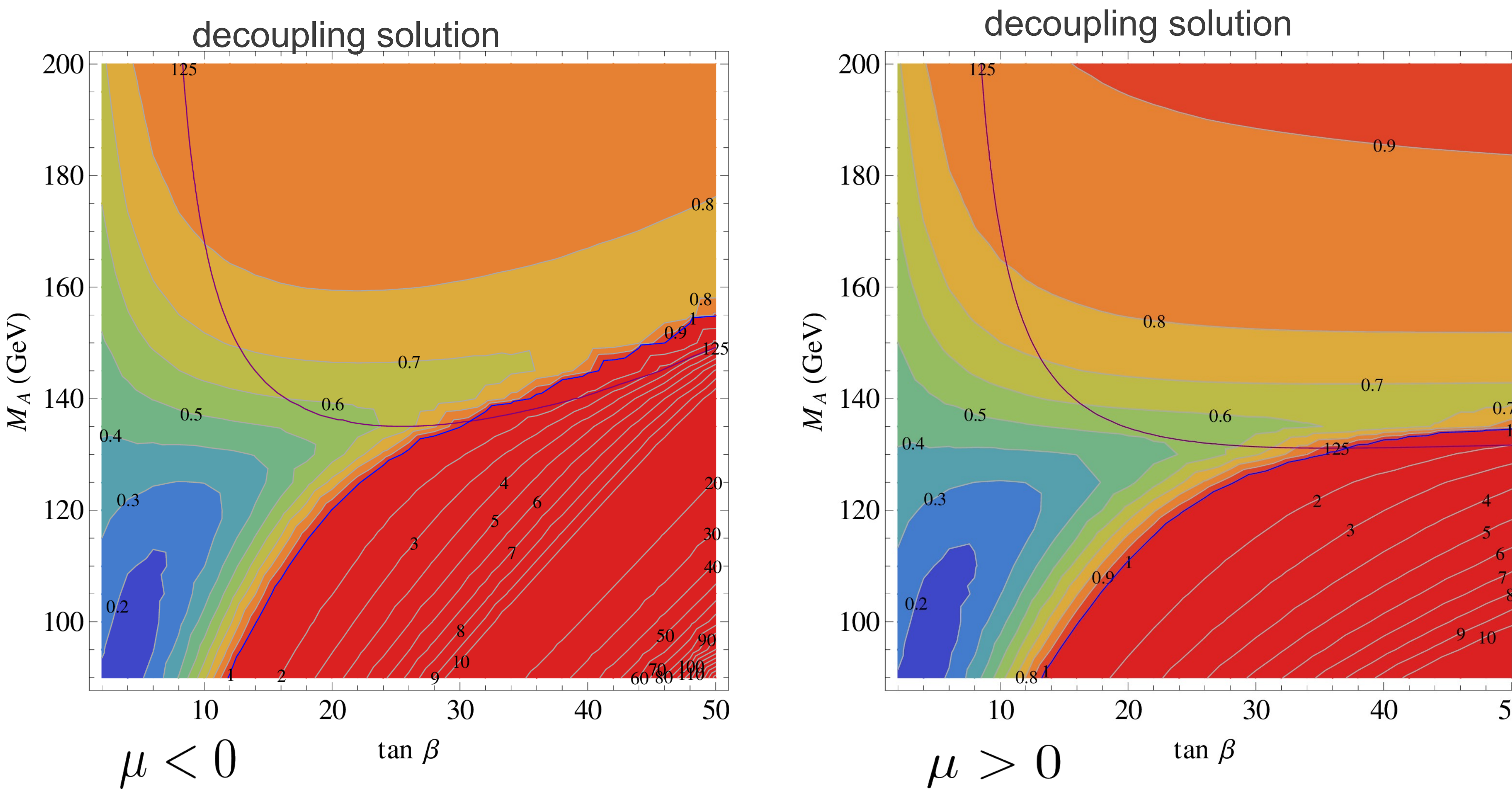
a) Interface POWHEG with a mass spectrum generator that provides Higgs masses and couplings.
b) Rescale the SM contribution.
c) insert the SUSY correction

PO(sitive)W(eight)H(ardest)E(mission)G(enerator)

Nason et al. (04--)

- Matching NLO-QCD matrix elements with Parton Showers
- Generate the hardest emission first, with NLO accuracy, independently of the PS
- Can be interfaces to several SMC programs (HERWIG/PHYTIA)
- Generate events with positive weights
- NLO accuracy of the total cross-section preserved

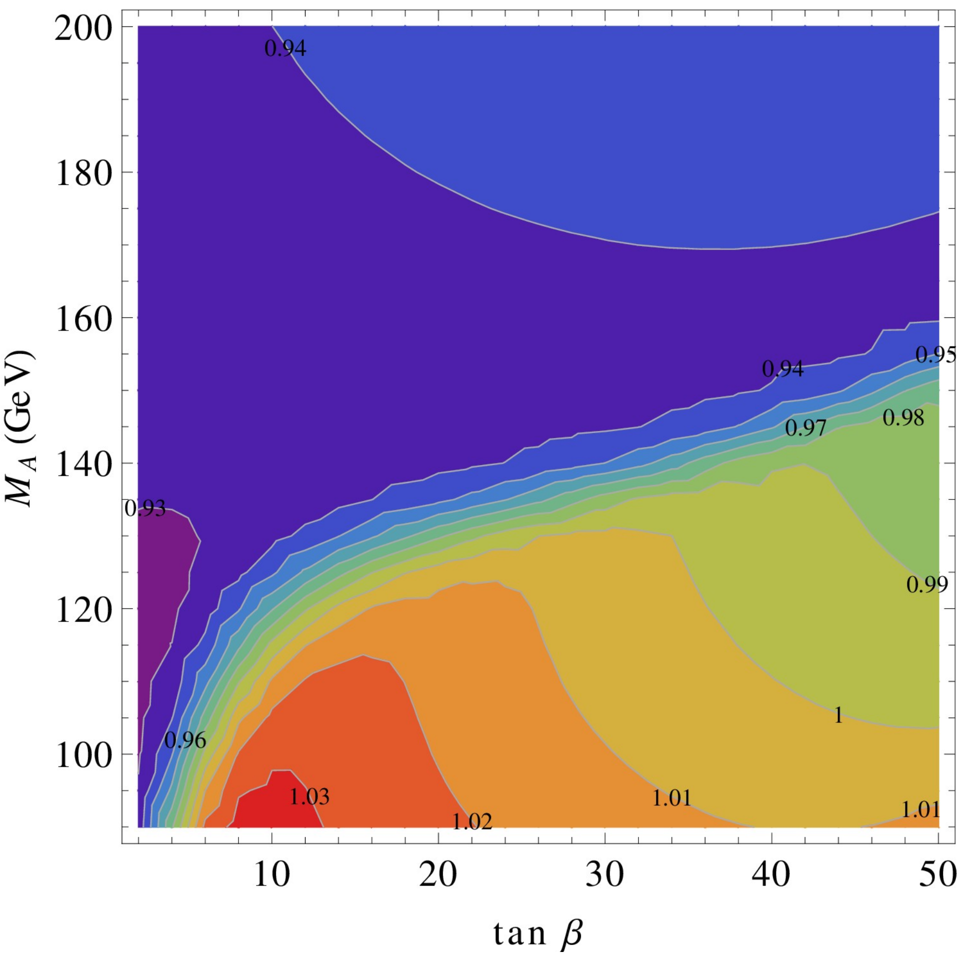
$$\frac{\sigma(g\,g \to h)}{\sigma(g\,g \to h_{SM})}$$



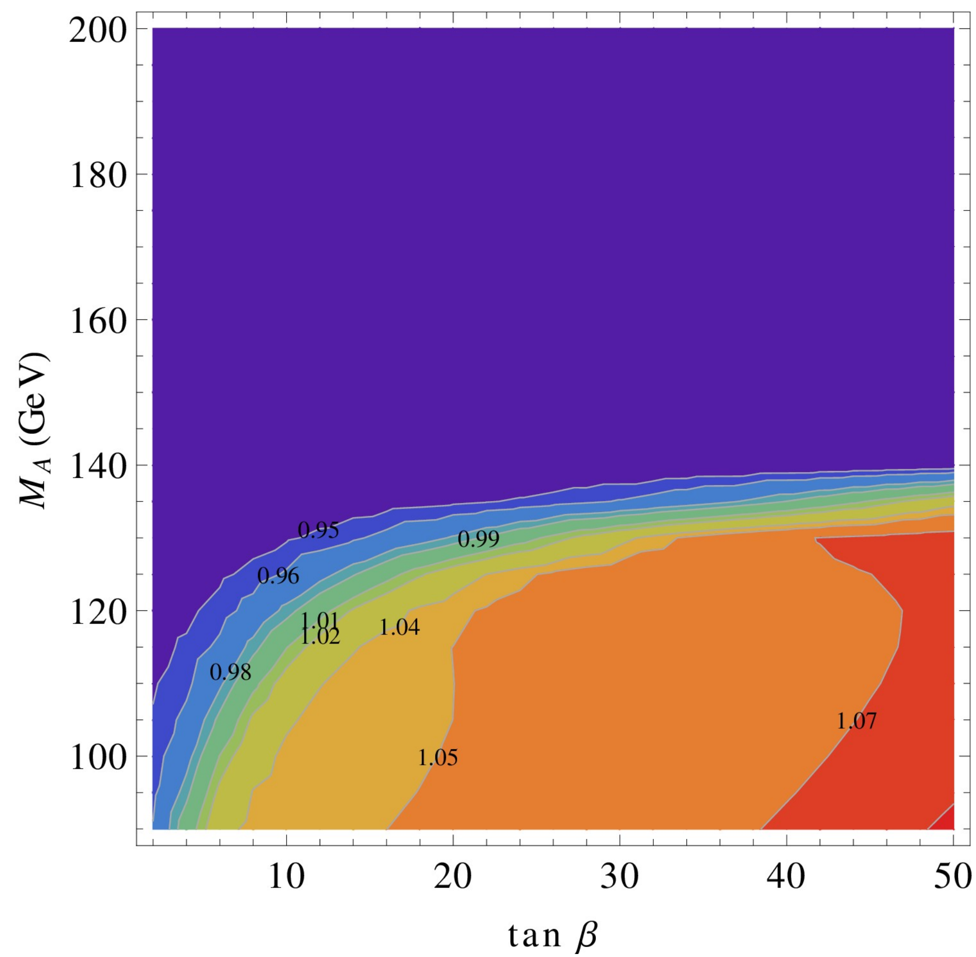
$m_Q=m_U=m_D=$ 1000 GeV, $X_t= A_t-\mu \cot\beta=$2500 GeV, $M_3=$ 800 GeV, $M_2 = 2\,M_1$ =200 GeV, $|\mu|$ = 200 GeV

$$\frac{\sigma(g\,g \to h)}{\sigma(g\,g \to h_{SM})_{\text{rescaled}}}$$

$\mu < 0$

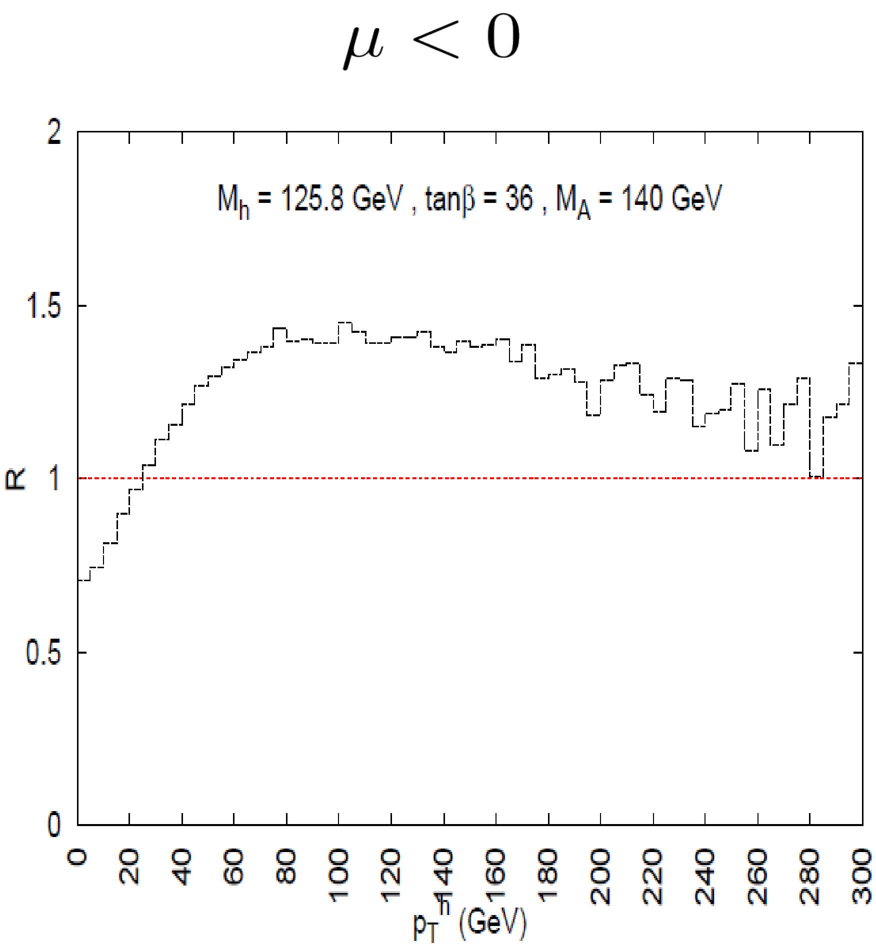


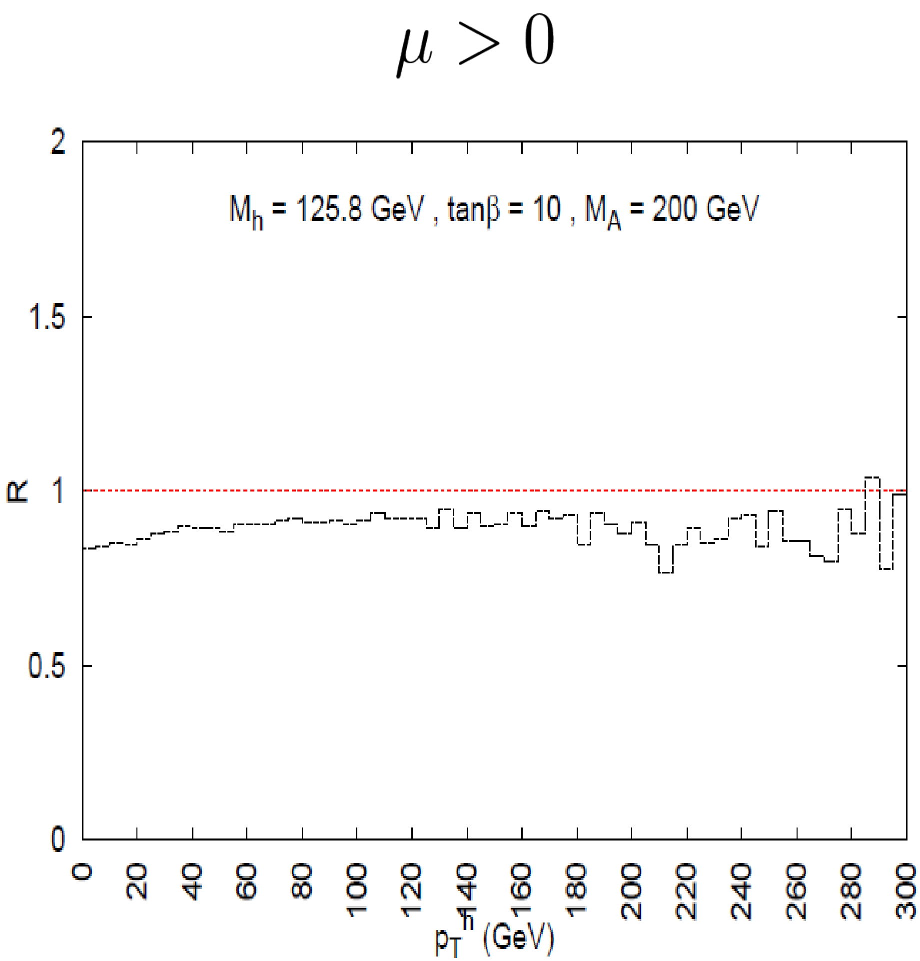
$\mu > 0$



Squarks are heavy: corrections up to 10%

Using the p_t^h to disentangle between SM and MSSM



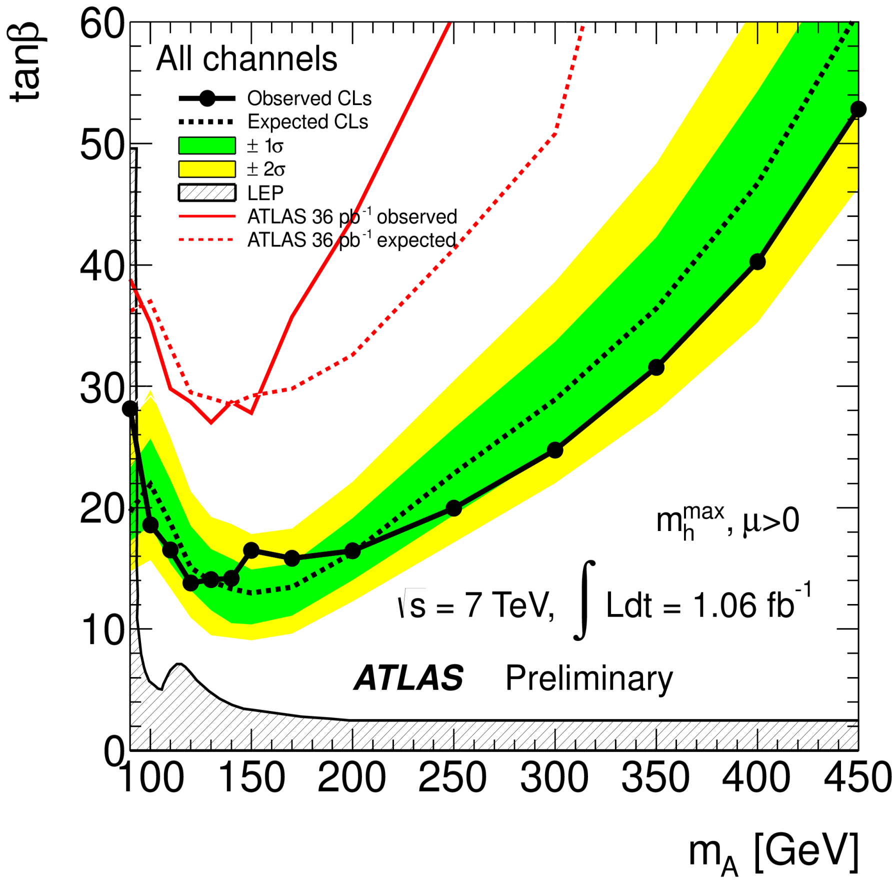


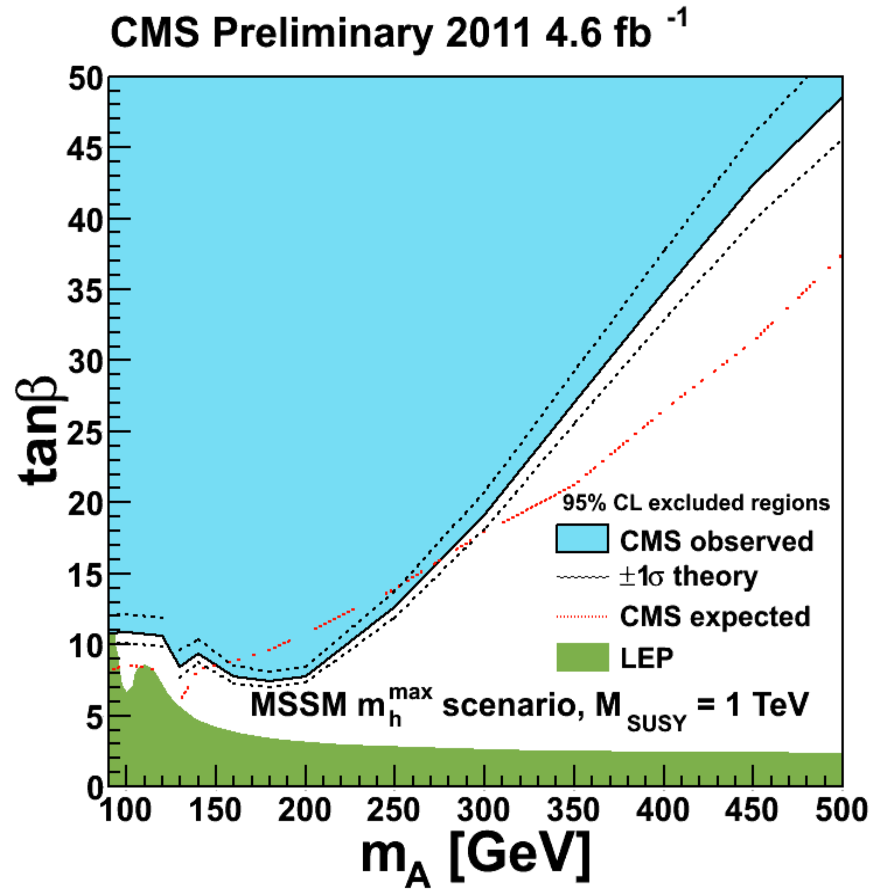
R= ratio $\frac{d\sigma}{d\,p_t^h}$ MSSM over SM

obtained using POWHEG + HERWIG

(Bagnaschi et al.)

$\phi \to \tau\tau\ (\phi = h, H, A)$ kills the non-decoupling solution





The ATLAS, CMS plots represent points in the MSSM parameter space different from ours, the SUSY corrections are not included in these plots, but with these limits ……

M_H ~ 125 GeV: Large M_A , to be in the decoupling regime

Conclusions

- It is too early to make any firm statement.
- Personally, I believe that a Higgs boson is in the mass range 116-126(+2):
  M_h = 121 ± 5 GeV
- The exact value of the Higgs mass is very important.
  A single GeV makes the difference.
- M_h = 125 GeV is a very intriguing value.
  For the SM it is at the “border” of the stability region.
  For the MSSM it is at the ”border” of the mass-predicted region.