The Higgs to di-photon rate as a probe of Supersymmetry

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Florence,
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Outline

1. Introduction: the discovery of a new boson

2. The Higgs to di- photon rate & Supersymmetry

- The Higgs gamma gamma rate in the MSSM (stops, staus and mixing effects)
- Going beyond the MSSM

3. Phenomenology of the light stau model

- Constraints (EWPTs, DM abundance, vacuum stability)
- (g-2)
- Direct production of light staus at the LHC

Some references

„A 125 GeV SM-like Higgs in the MSSM and the γγ rate "
Carena, Gori, Shah, Wagner arXiv: 1112.3336, JHEP 1203 (2012) 014

„Light Stau Phenomenology and the γγ Higgs Rate"
Carena, Gori, Shah, Wagner, Wang, arXiv: 1205.5842, JHEP 1207 (2012) 175

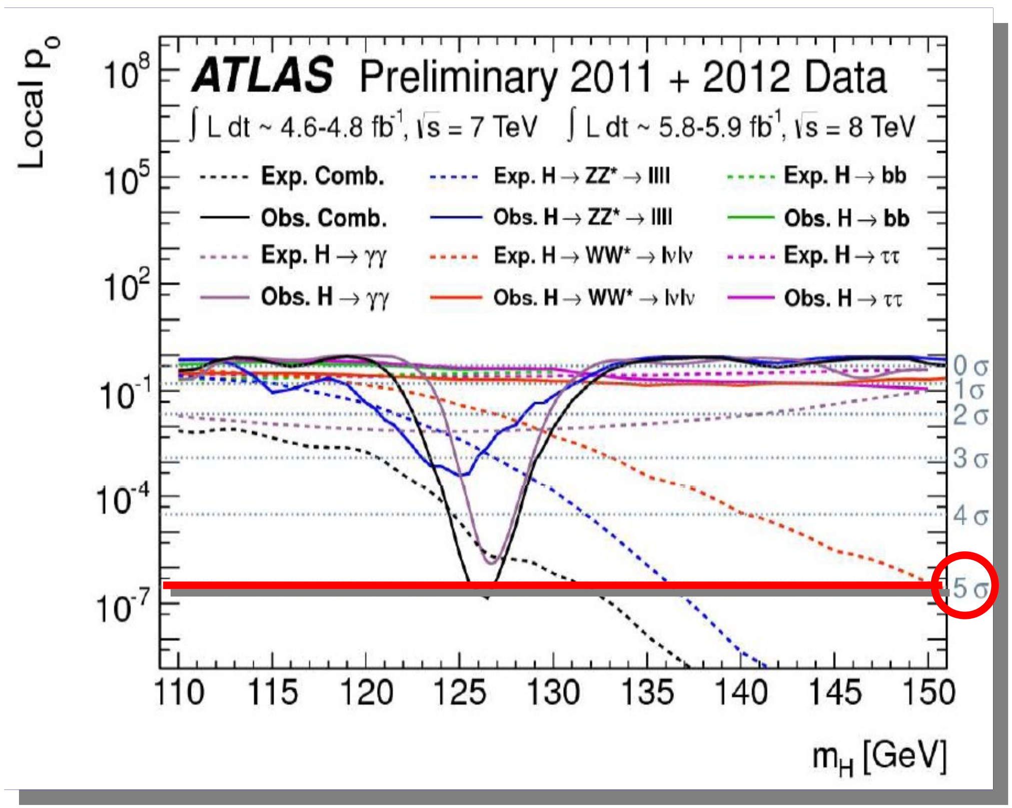
\+ Work in progress
\+ Ian Low

We have a new boson!

July 4th, 2012: Both ATLAS and CMS: „We have observed a new boson"

ATLAS

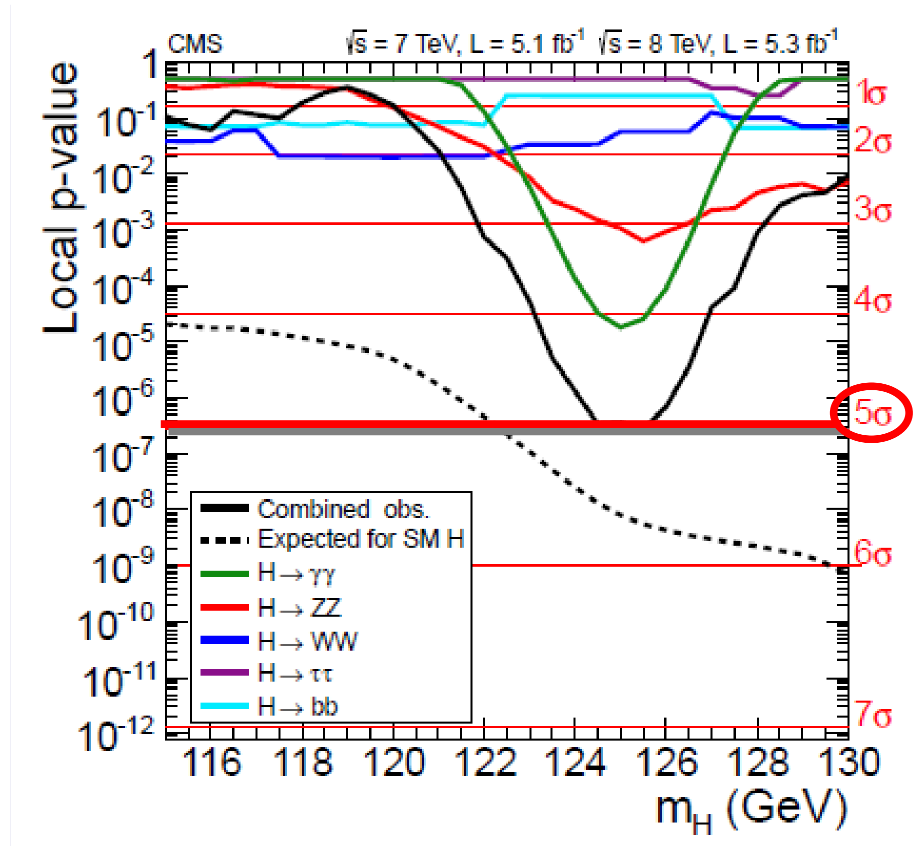
1207.7214



M_h = (126 ± 0.4 (stat) ± 0.4 (syst)) GeV

CMS

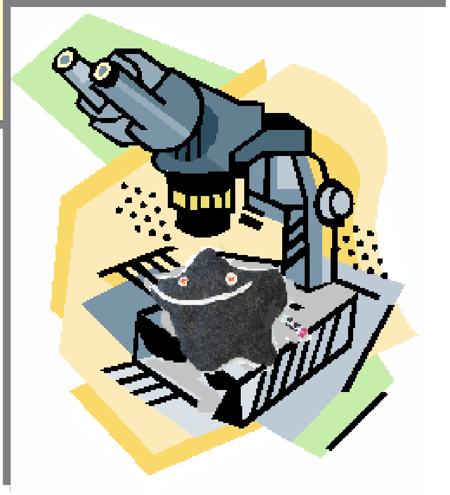
1207.7235



M_h = (125.3 ± 0.4 (stat) ± 0.5 (syst)) GeV

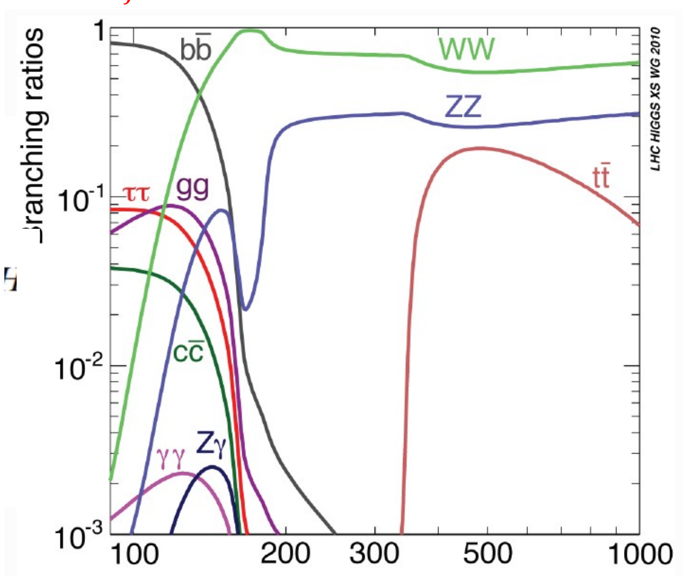
Only the beginning of a new era

A **completely new sector** is started to be probed: the sector of electroweak symmetry breaking



The interactions of this Higgs are still largely unknown

A. Djouadi, 0503172



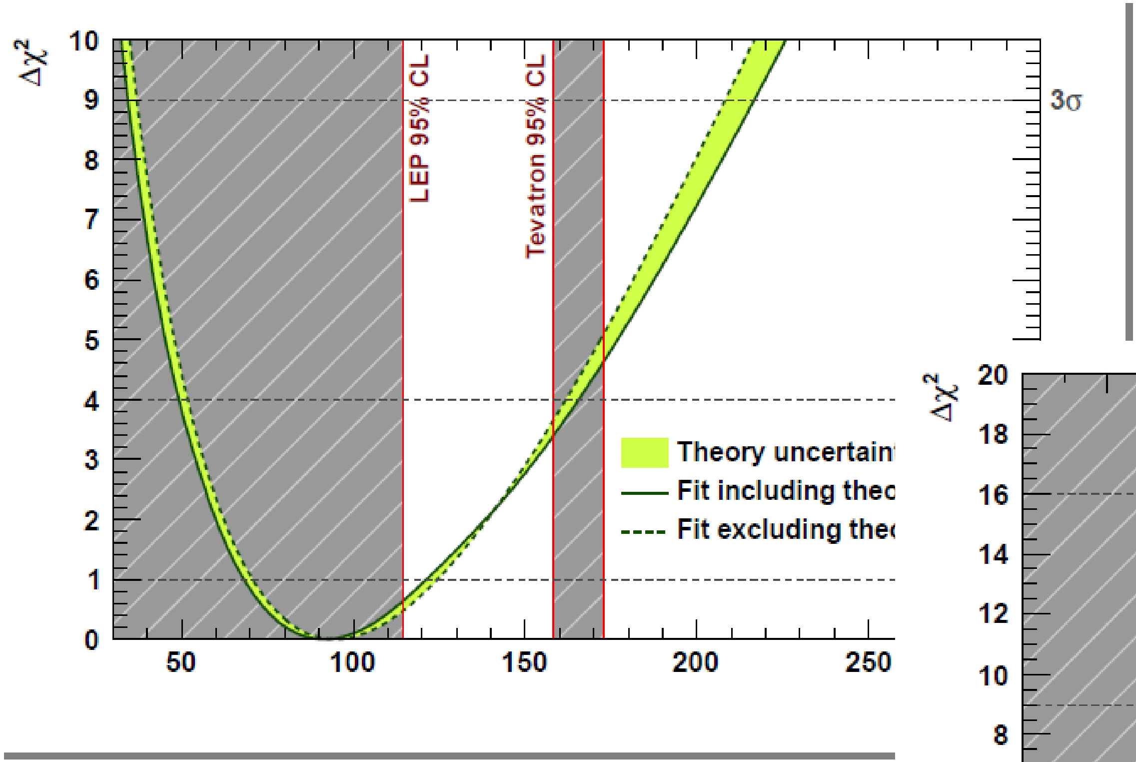
125 GeV: A good mass for experimentalists

Several decay modes will be measured at the LHC!

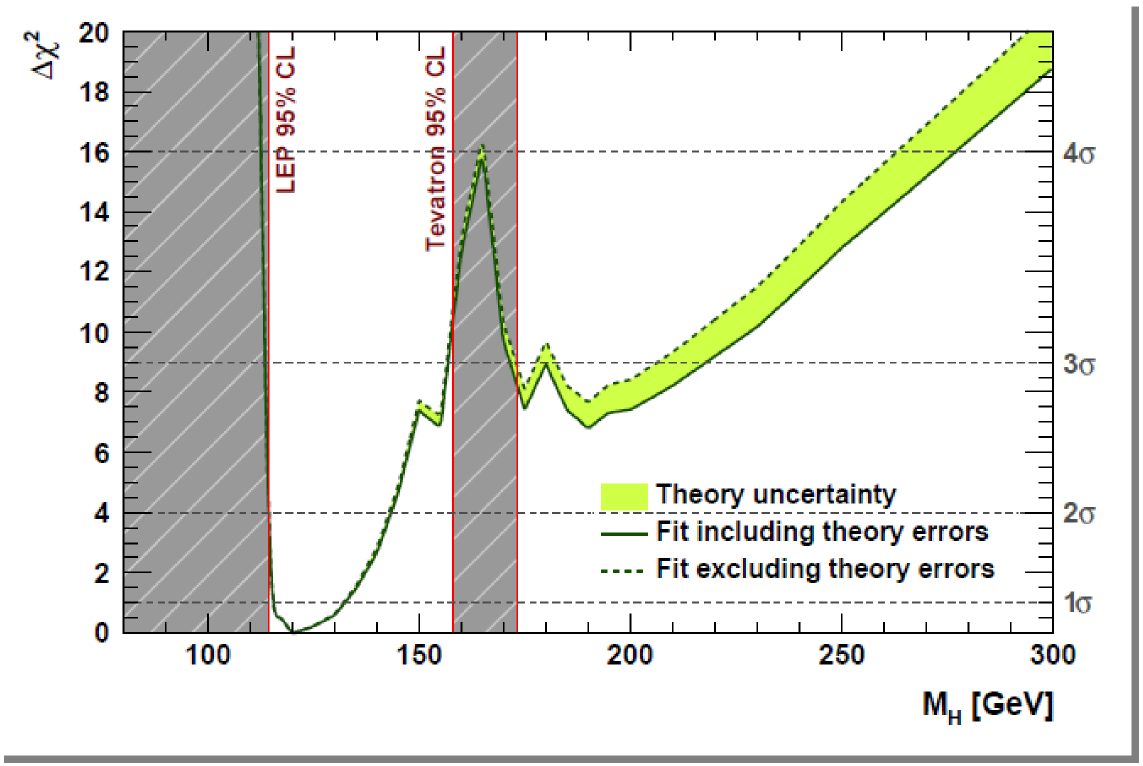
$$\begin{aligned} BR(h \to b\bar{b}) &= 58\%,\ BR(h \to ZZ^*) = 2.7\%, \\ BR(h \to WW^*) &= 21.6\%,\ BR(h \to \tau\bar{\tau}) = 6.4\%, \\ BR(h \to \gamma\gamma) &= 0.22\%,\ BR(h \to \gamma Z) = 0.16\% \end{aligned}$$

The mass of the Higgs

A mass that one could have expected?



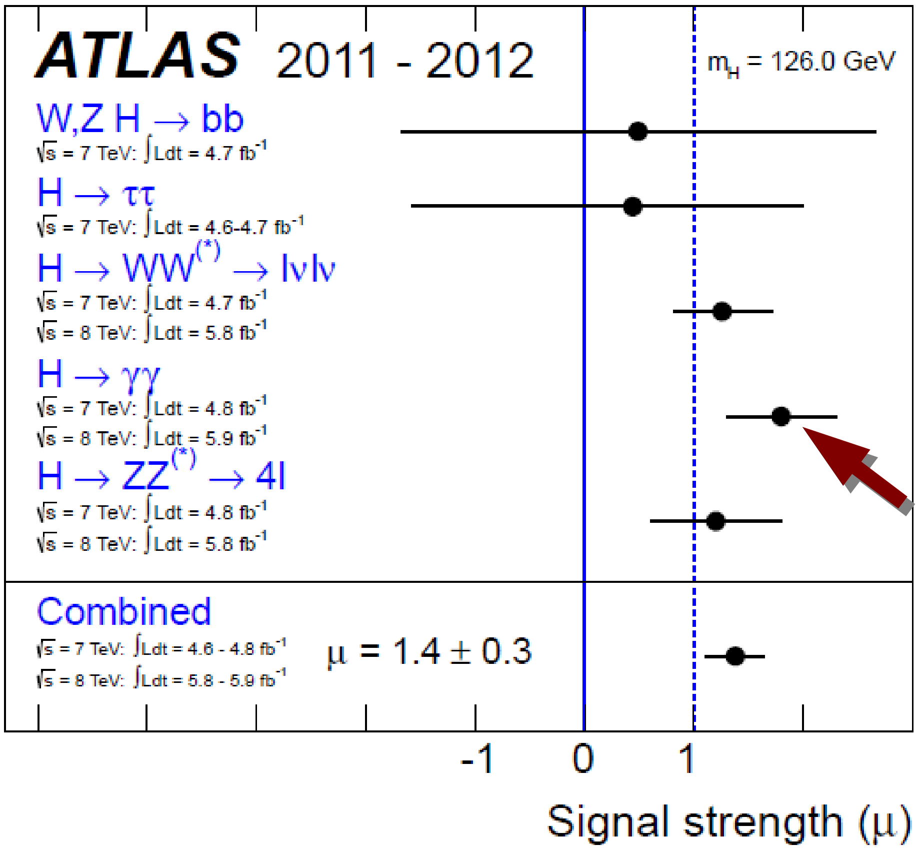
Gfitters, 1107.0975



The Higgs of the SM?

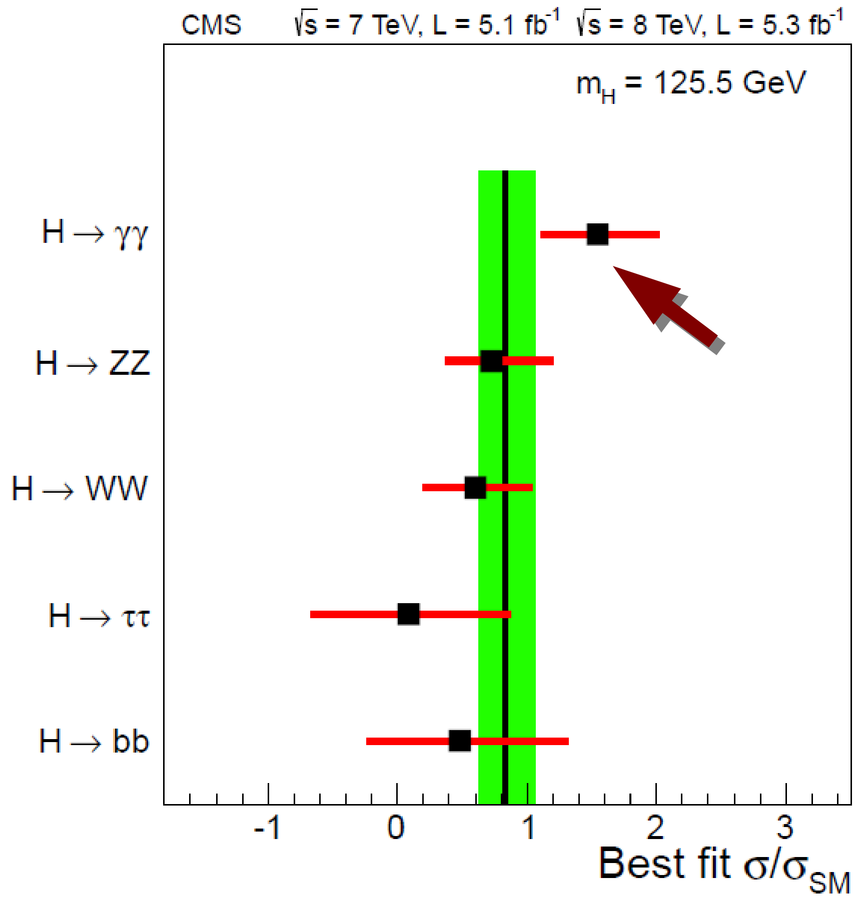
ATLAS

arXiv:1207.7214



CMS

arXiv:1207.7235



SM-like but still large room for **surprises**

What about the **γγ rate**?

The Higgs of the SM?

ATLAS

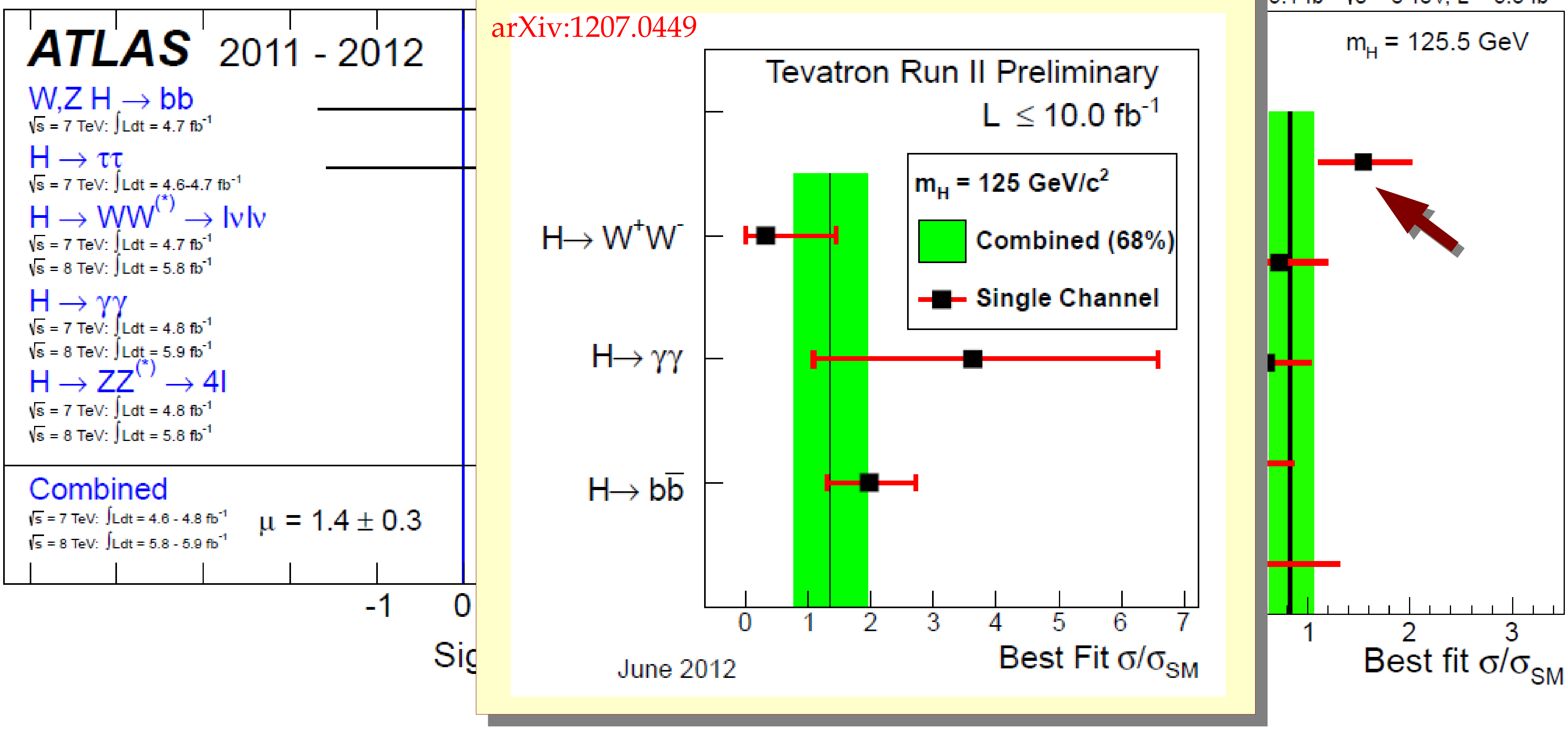
arXiv:1207.7214

CMS

arXiv:1207.7235

...and Tevatron

arXiv:1207.0449

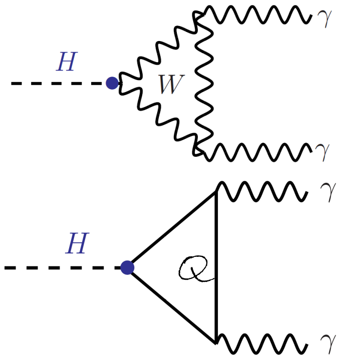


SM-like but still large room for **surprises**

What about the $\gamma\gamma$ rate?

LHC golden channel: γγ

For the SM Higgs:

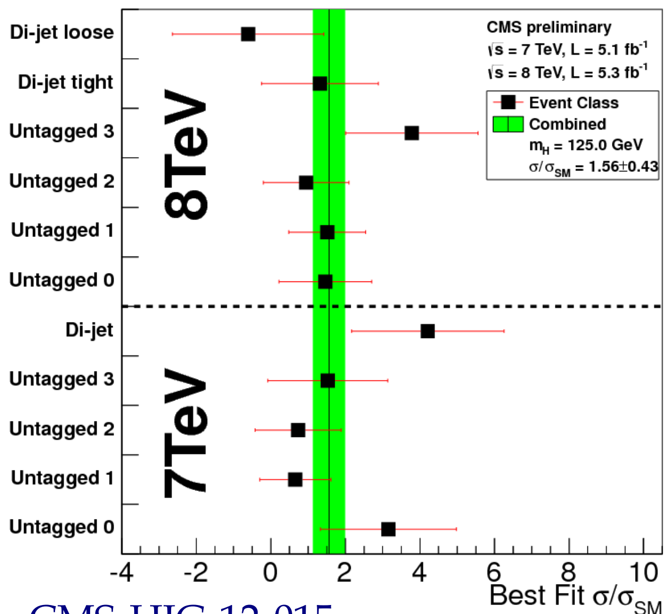


$$\Gamma(h\to\gamma\gamma)^{\rm LO}_{\rm SM}\simeq\frac{\alpha^2 m_h^3}{1024\pi^3}\left|\frac{g_{hWW}}{m_W^2}A_1(\tau_W)-2\sum_f\frac{g_{hf\bar f}}{m_f}N_c^f Q_t^2 A_{1/2}(\tau_f)\right|^2$$

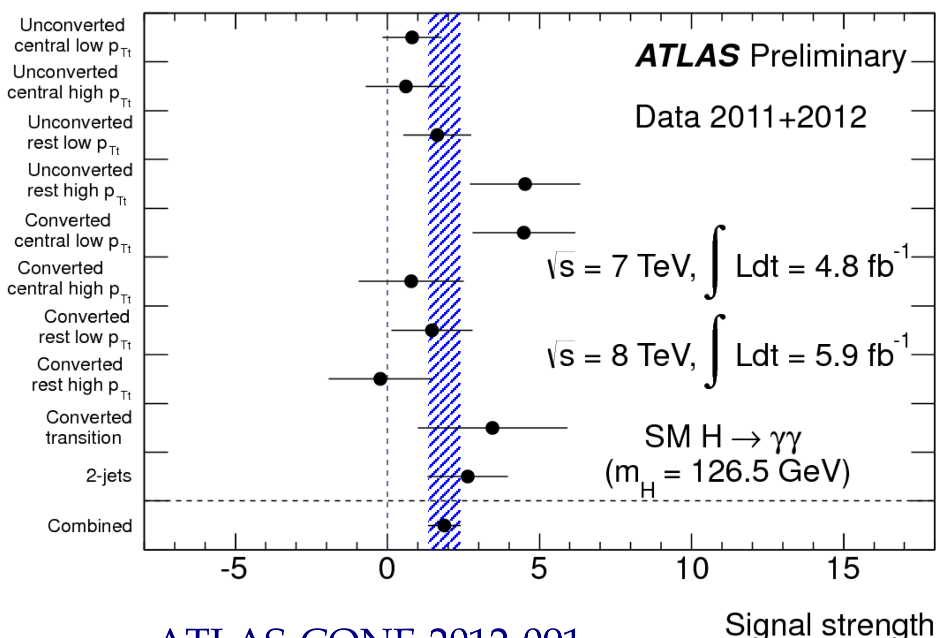
Opposite sign contributions

$$\hat\sigma(\hat s)^{\rm LO}_{(gg\to h)_{\rm SM}}=\frac{\alpha_s^2 m_h^2}{9216\pi}\left|\sum\frac{g_{hf\bar f}}{m_f}N_c^f A_{1/2}(\tau_f)\right|^2\delta(\hat s-m_h^2)$$

Status of the LHC searches:



CMS-HIG-12-015



ATLAS-CONF-2012-091

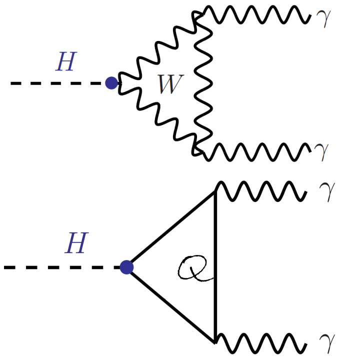
LHC golden channel: γγ

For the SM Higgs:

$$\Gamma(h\to\gamma\gamma)^{\rm LO}_{\rm SM} \simeq \frac{\alpha^2 m_h^3}{1024\pi^3}\left|\frac{g_{hWW}}{m_W^2}A_1(\tau_W) - 2\sum_f \frac{g_{hf\bar f}}{m_f}N_c^f Q_t^2 A_{1/2}(\tau_f)\right|^2$$

Opposite sign contributions

$$\hat\sigma(\hat s)^{\rm LO}_{(gg\to h)_{\rm SM}} = \frac{\alpha_s^2 m_h^2}{9216\pi}\left|\sum \frac{g_{hf\bar f}}{m_f}N_c^f A_{1/2}(\tau_f)\right|^2 \delta(\hat s - m_h^2)$$



Status of the LHC searches:

$$R^{7,\,\rm ATLAS}_{\gamma\gamma} = 2.0 \pm 0.9$$
$$R^{7,\,\rm CMS}_{\gamma\gamma} = 2.1 \pm 0.6$$

$$R^{\rm ATLAS}_{\gamma\gamma} = 1.9 \pm 0.5$$
$$R^{\rm CMS}_{\gamma\gamma} = 1.56 \pm 0.43$$
$$R^{\rm CMS+ATLAS}_{\gamma\gamma} = 1.71 \pm 0.33$$

First (long awaited) signal for beyond the SM physics at the LHC?

Or statistical fluctuation,
Or underestimation of the QCD uncertainties?

Baglio, Djouadi, Godbole, 1207.1451

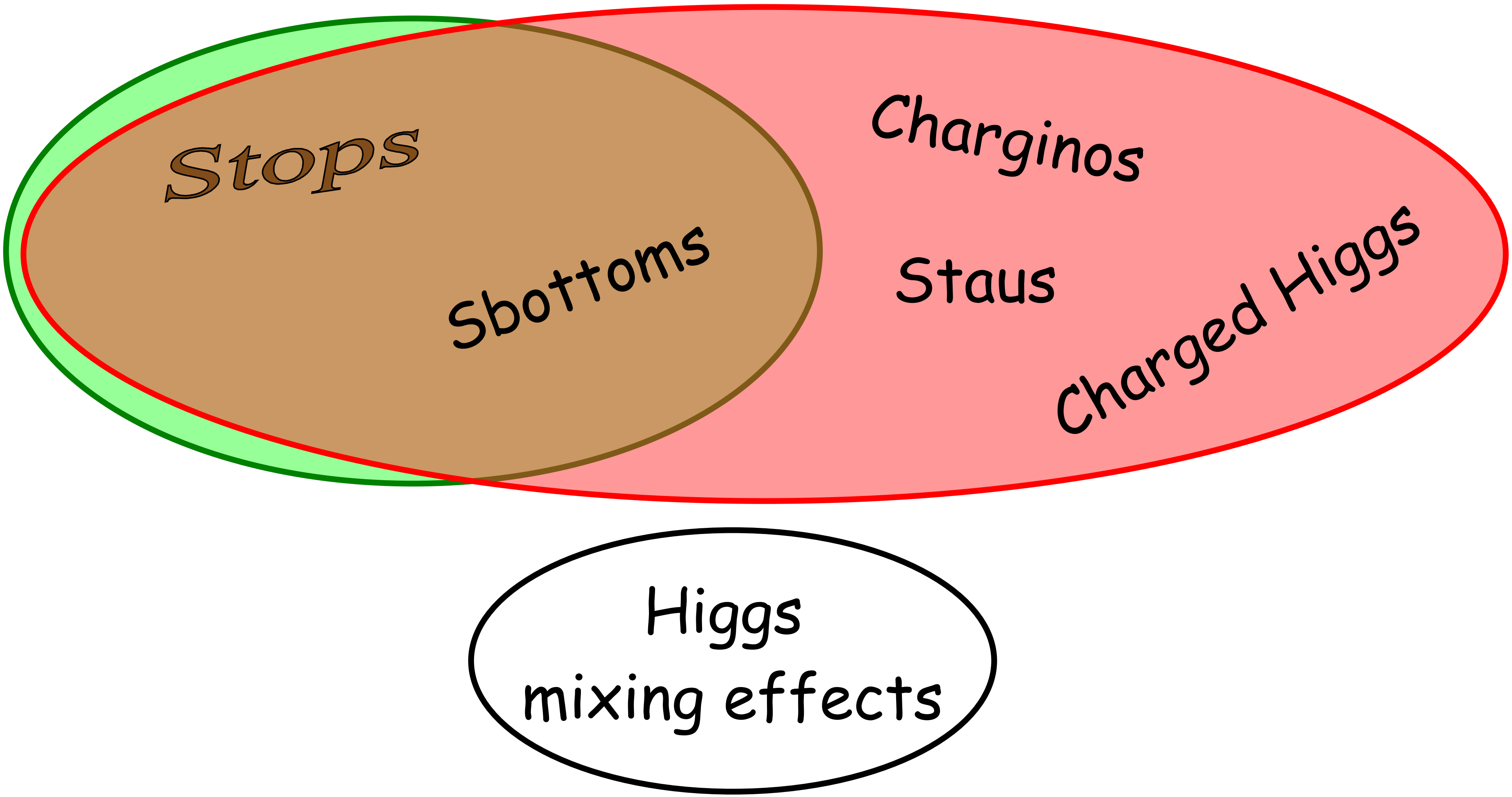
Naturalness and the Higgs rates

- New (light) particles introduced in models to address the **gauge hierarchy problem** also enter in the gluon fusion Higgs production cross section and diphoton rate

- Higgs rates may be **the best route to new physics**

MSSM NP effects in the γγ rate

$$\sigma(pp \to h \to \gamma\gamma) = \sigma(pp \to h)\frac{\Gamma(h \to \gamma\gamma)}{\Gamma_{\rm tot}}$$

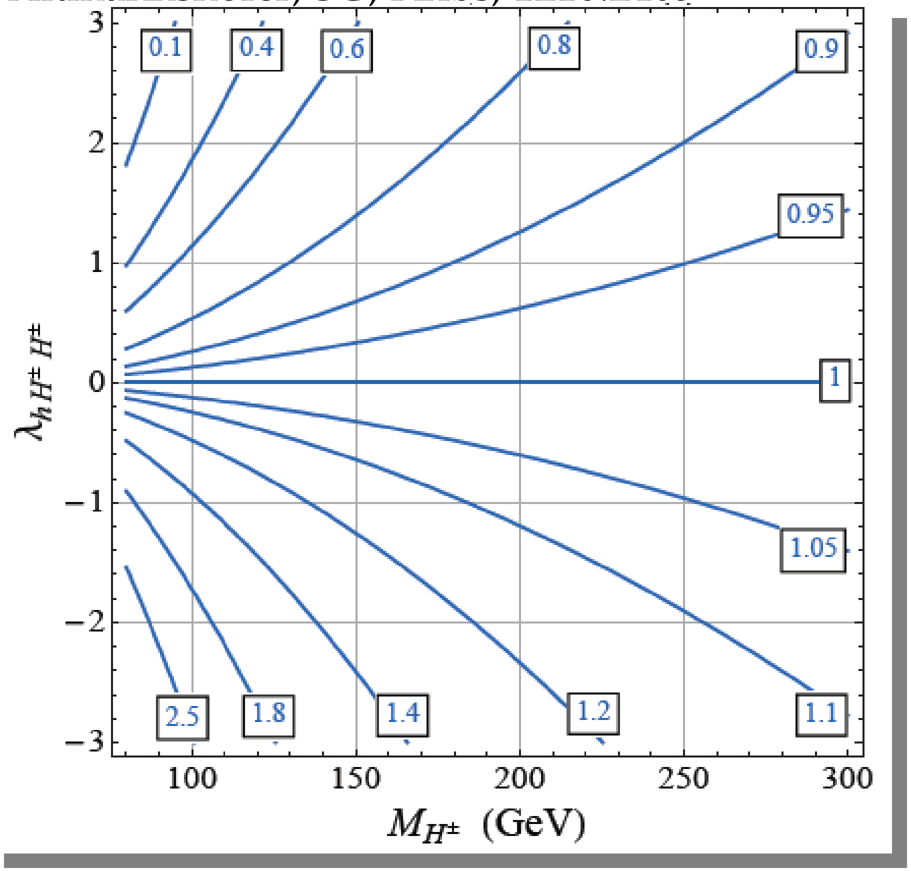


Charged Higgs contributions

$$\sigma(pp \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm tot}}$$

$$\Gamma(h \to \gamma\gamma) \sim \frac{\alpha^2 m_h^3}{1024\pi^3}\left|\frac{g_{hWW}}{m_W^2}A_1(x_W) - N_c Q_t^2 \frac{2g_{ht\bar t}}{m_t}A_{1/2}(x_t) + \frac{\lambda_{hH^\pm H^\pm} v}{m_{H^\pm}^2}A_0(x_{H^\pm})\right|^2$$

Altmannshofer, SG, Kribs, 1210.2465



Maximized at very small tanβ

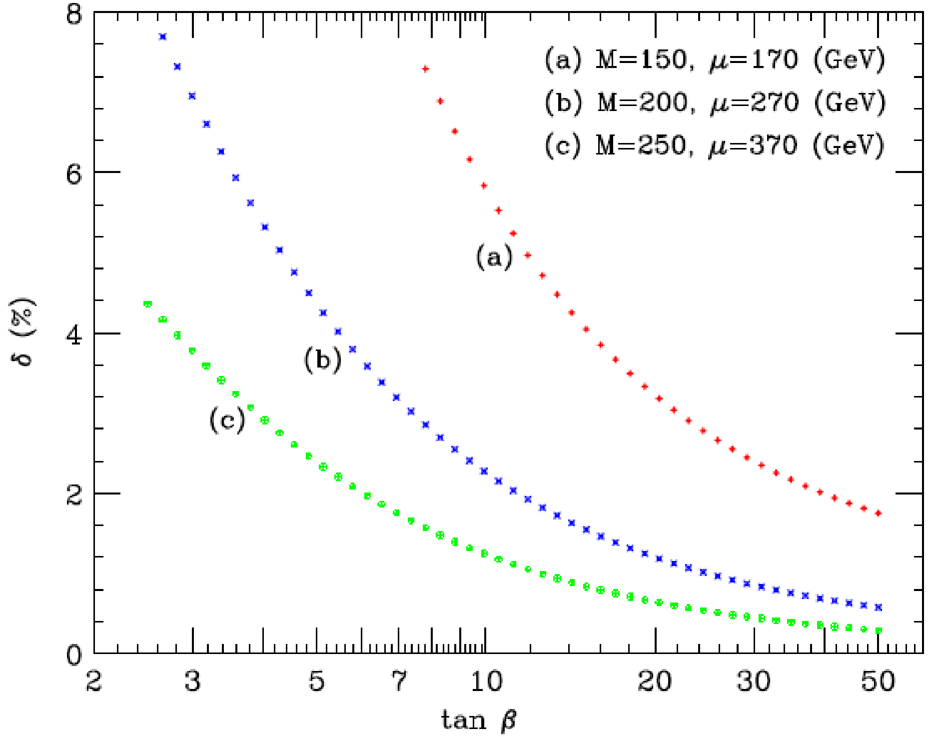
$$\left|\lambda^{\rm MSSM}_{hH^\pm H^\pm}\right| \lesssim \frac{g^2}{2} \sim 0.21$$

Quartic couplings in the MSSM are dictated by the gauge couplings

Too small NP effects coming from the MSSM charged Higgs

Chargino contributions

Diaz, Perez, 0412066



$$\Delta A_{\gamma\gamma} \propto -\frac{m_W^2 s_\beta c_\beta}{M_2 \mu}$$

The parameter dependence can be understood by

the low energy theorem:

Ellis, Gaillard, Nanopoulos, 1976

In presence of heavy charged particles

$$\Delta A^F_{\gamma\gamma} \propto b^F \times \frac{\partial \log(\det \mathcal{M}(v)\mathcal{M}^\dagger(v))}{\partial \log v}$$ for fermions in the loop

$$\Delta A^B_{\gamma\gamma} \propto b^B \times \frac{\partial \log(\det \mathcal{M}^2(v))}{\partial \log v}$$ for bosons in the loop

See also Belanger, Boudjema, Donato, Godbole, Rosier-Lees, 0002039
Blum, D'Agnolo, Fan, 1206.5303

$$\mathcal{M}_{\chi^\pm} = \begin{pmatrix} M_2 & gv\sin\beta \\ gv\cos\beta & \mu \end{pmatrix}$$

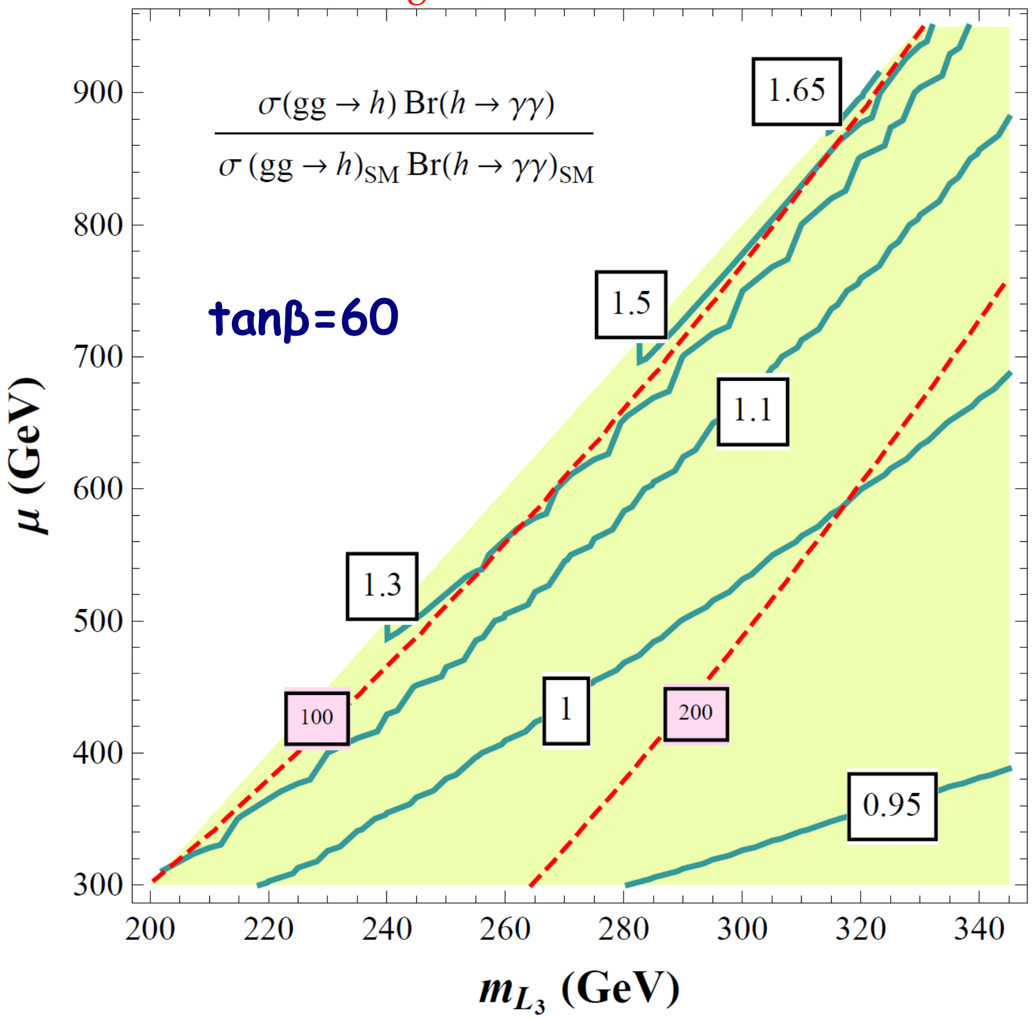
Corrections to the γγ rate are smaller than ~15% and arise only at very small tanβ

Stau contributions

$$\Delta A_{\gamma\gamma} \propto -\frac{(\mu\tan\beta)^2 m_\tau^2}{m_{L3}^2 m_{e3}^2 - m_\tau^2(\mu\tan\beta)^2} \sim -\frac{m_{\tilde{\tau}_2}^2}{m_{\tilde{\tau}_1}^2}\left(1-\frac{m_{\tilde{\tau}_1}^2}{m_{\tilde{\tau}_2}^2}\right)^2$$

For degenerate stau soft masses

Carena, S.G., Shah, Wagner, 1112.3336



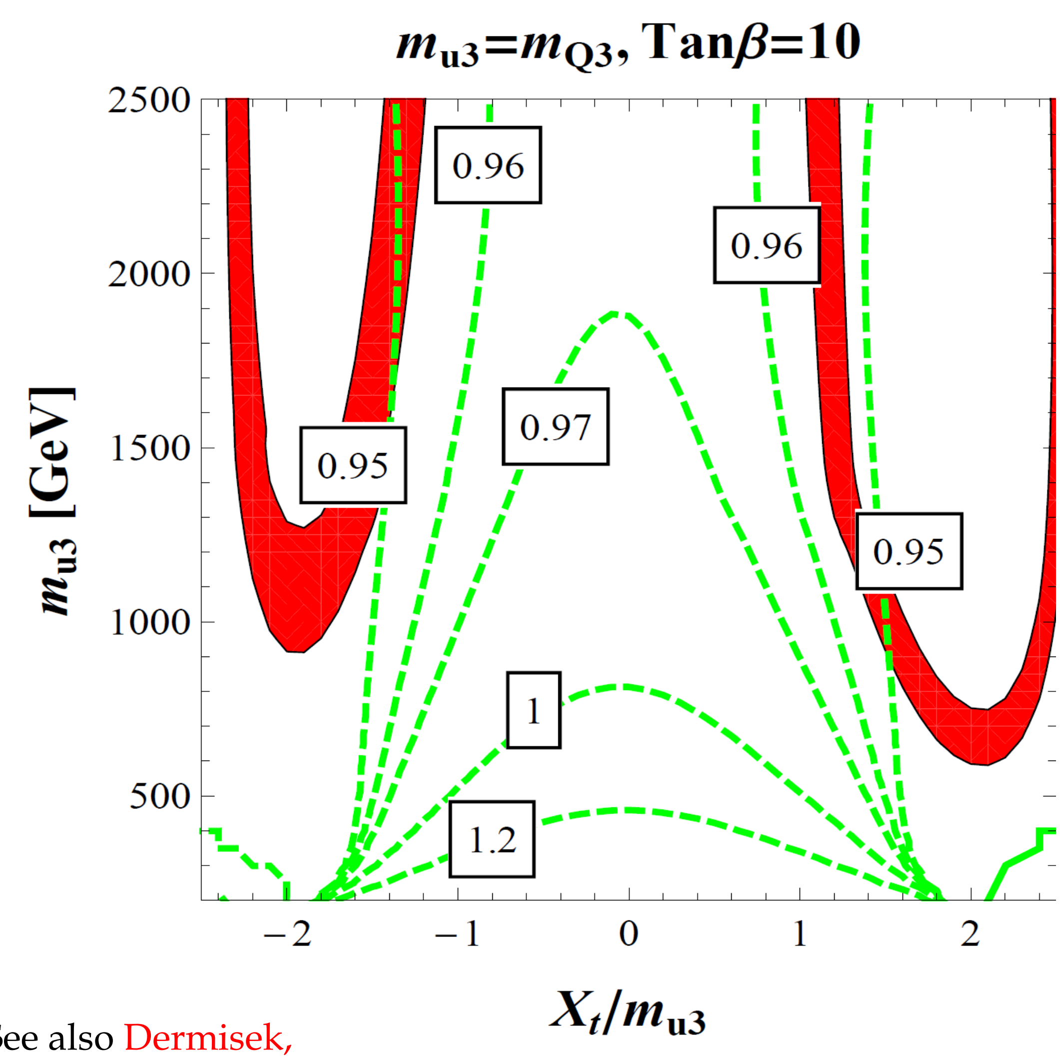
$$\mathcal{M}_{\tilde{\tau}}^2 \simeq \begin{pmatrix} m_{L_3}^2 + m_\tau^2 + D_L^\tau & m_\tau(A_\tau - \mu\tan\beta) \\ m_\tau(A_\tau - \mu\tan\beta) & m_{E_3}^2 + m_\tau^2 + D_R^\tau \end{pmatrix}$$

Heavily mixed light (LEP bound ~95GeV) staus can lead to sizable effect in the γγ rate

Stop contributions

First case: large mixing and comparable stop masses

$$\sigma(pp \to h \to \gamma\gamma) = \sigma(pp \to h)\frac{\Gamma(h \to \gamma\gamma)}{\Gamma_{tot}}$$



- Competing effects in gg fusion and in the γγ partial width
- Both effects are rather small in the region reproducing the correct Higgs mass
- Overall **small suppression** of the γγ rate coming from stops in this region

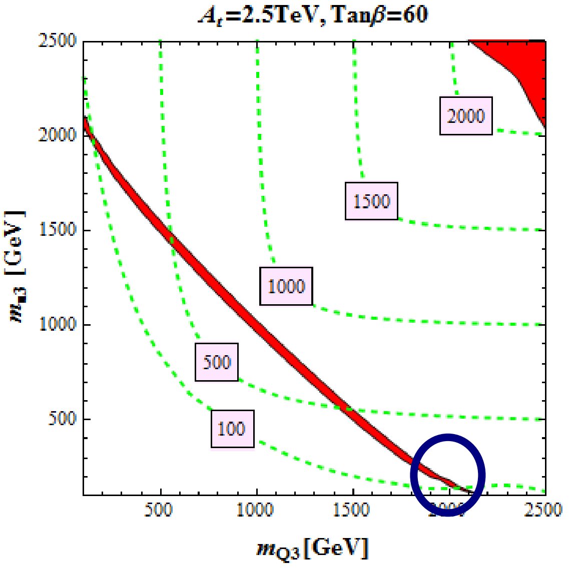
See also Dermisek, Low, 0701235

$$\mathcal{M}^2_{stop} = \begin{pmatrix} m^2_{Q_3} + m^2_t + D_L & m_t X_t \\ m_t X_t & m^2_{u_3} + m^2_t + D_R \end{pmatrix}$$

Stop contributions

Second case: very large splitting between the two stops

Reminder:

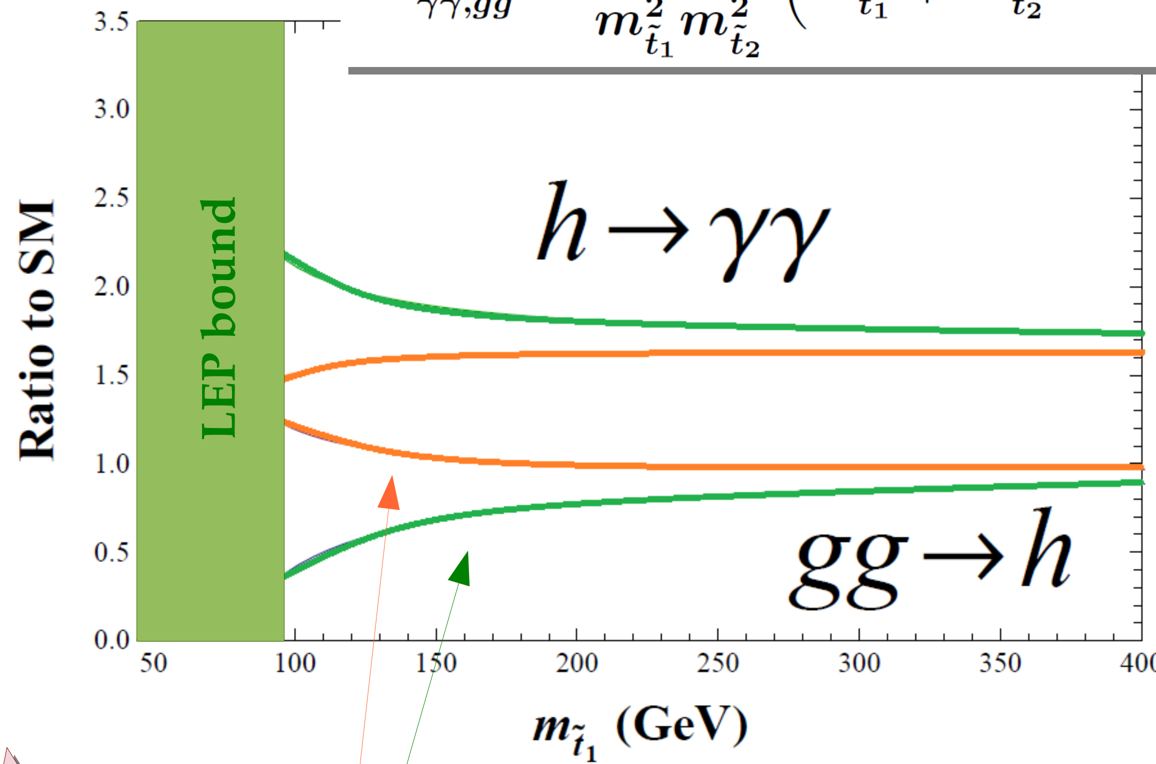


$$m_h^2 \sim m_Z^2 \cos^2(2\beta) + \frac{3}{8\pi^2}\frac{m_t^4}{v^2}\tilde{X}_t$$

$$\tilde{X}_t = \frac{2X_t^2}{M_{\rm Susy}^2}\left(1 - \frac{X_t^2}{12M_{\rm Susy}^2}\right)$$

valid for $m_{Q3} >> m_{u3}$

$$\delta A^{\tilde{t}}_{\gamma\gamma,gg} \propto \frac{m_t^2}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}\left(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 - X_t^2\right)$$



Two solutions for X_t leading to the same Higgs mass

Higgs mixing effects

$$\begin{pmatrix} h & H \end{pmatrix} \begin{bmatrix} m_A^2 s_\beta^2 + M_Z^2 c_\beta^2 & -(m_A^2 + M_Z^2) s_\beta c_\beta + \text{Loop}_{12} \\ \star & m_A^2 c_\beta^2 + M_Z^2 s_\beta^2 \end{bmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

- In the decoupling limit: $m_A \gg M_Z$

  The lightest Higgs couplings are SM-like

- Introducing some mixing between the two Higgs bosons:

$$\begin{cases} \xi_d^h = \xi_\ell^h = -\dfrac{\sin\alpha}{\cos\beta} \\ \xi_u^h = \dfrac{\cos\alpha}{\sin\beta} \\ \xi_V^h = \sin(\beta-\alpha) \end{cases}$$

For generic mixings, the coupling with bottom quarks would be highly non-SM-like

The Higgs width would be very different from the one of the SM

It does not seem to be hinted by the data
(still it is a viable possibility)

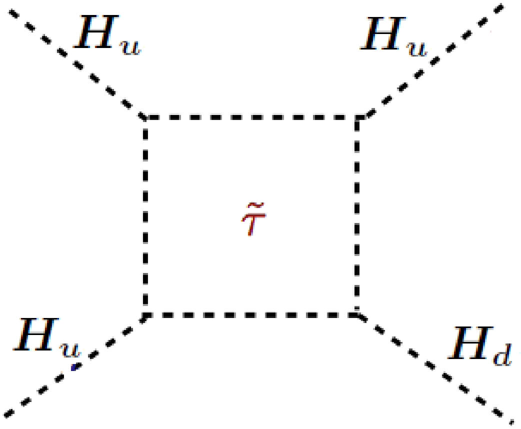
Higgs mixing effects

$$\sigma(pp \to h)\frac{\Gamma(h \to X_{\rm SM})}{\Gamma_{\rm tot}}$$

$m_A \gg M_Z$

$$\begin{pmatrix} h & H \end{pmatrix} \begin{bmatrix} m_A^2 s_\beta^2 + M_Z^2 c_\beta^2 & -(m_A^2 + M_Z^2) s_\beta c_\beta + \text{Loop}_{12} \\ \star & m_A^2 c_\beta^2 + M_Z^2 s_\beta^2 \end{bmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$

$$\text{Loop}_{12} = \frac{m_\tau^4}{12\pi^2 v^2} \frac{\tan^4\beta}{\sin^2\beta} \frac{\mu^3 A_\tau}{M_{\tilde\tau}^4} + \cdots$$



Coupling of the lightest Higgs with b-quarks (at tree level):

$$\xi_d^h = -\frac{\sin\alpha}{\cos\beta}$$

In the exact decoupling limit: $\xi_d^h = 1$

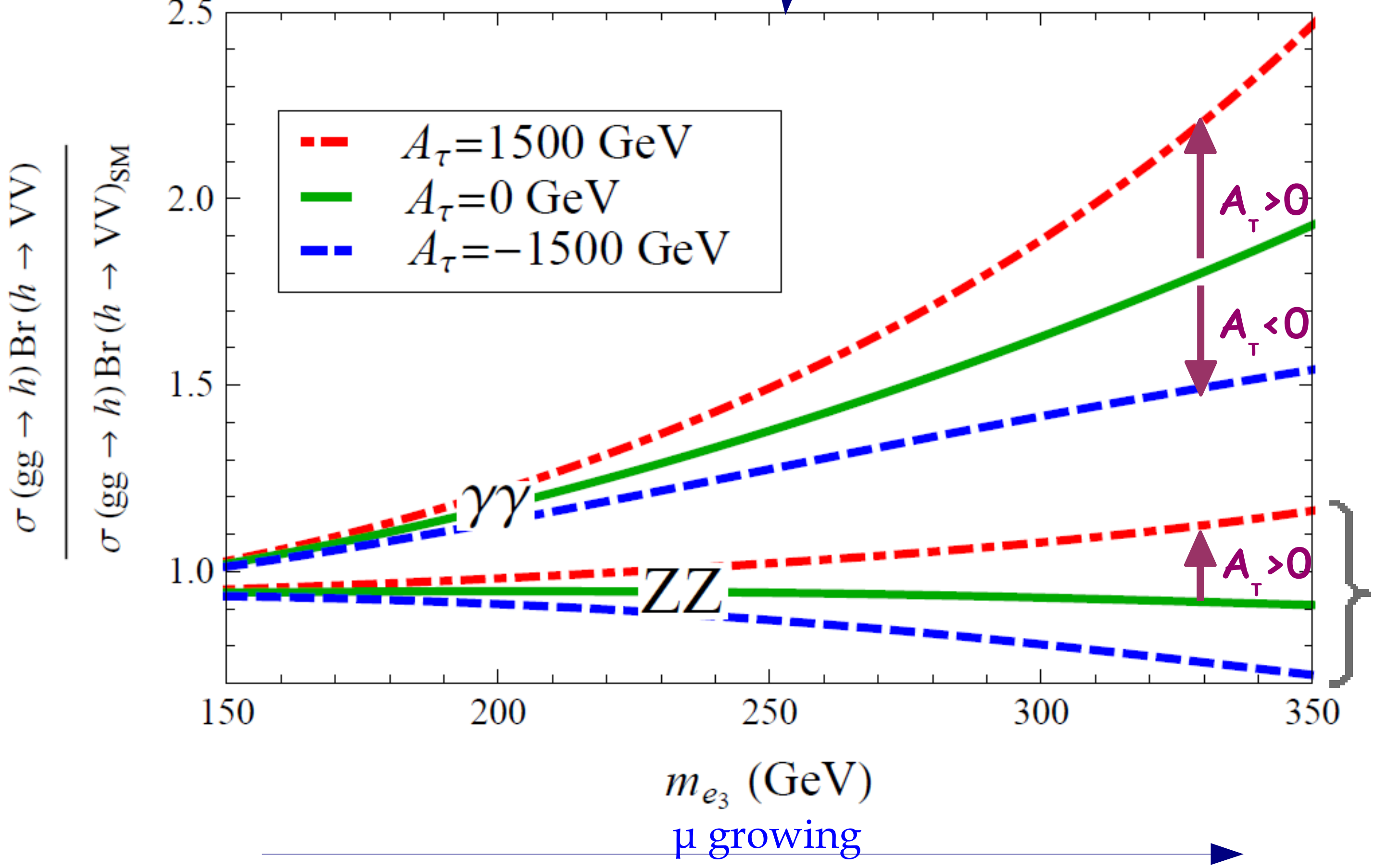
At large μ, A_τ, tanβ we can have $|\xi_d^h| < 1$ (if $\text{Loop}_{12}>0$) or $|\xi_d^h| > 1$ (if $\text{Loop}_{12}<0$)

Γ_{bb} is suppressed Γ_{bb} is enhanced

Higgs mixing effects

At around this point the Higgs-stau potential has a problem of vacuum stability

(see later)



Also the other modes are affected in the same way

(we keep the stau mass constant (~90 GeV))

The effects on the branching ratio into two b-quarks is small (≤ 5-10%)
The bb mode is basically SM-like

Higgs mass in the MSSM

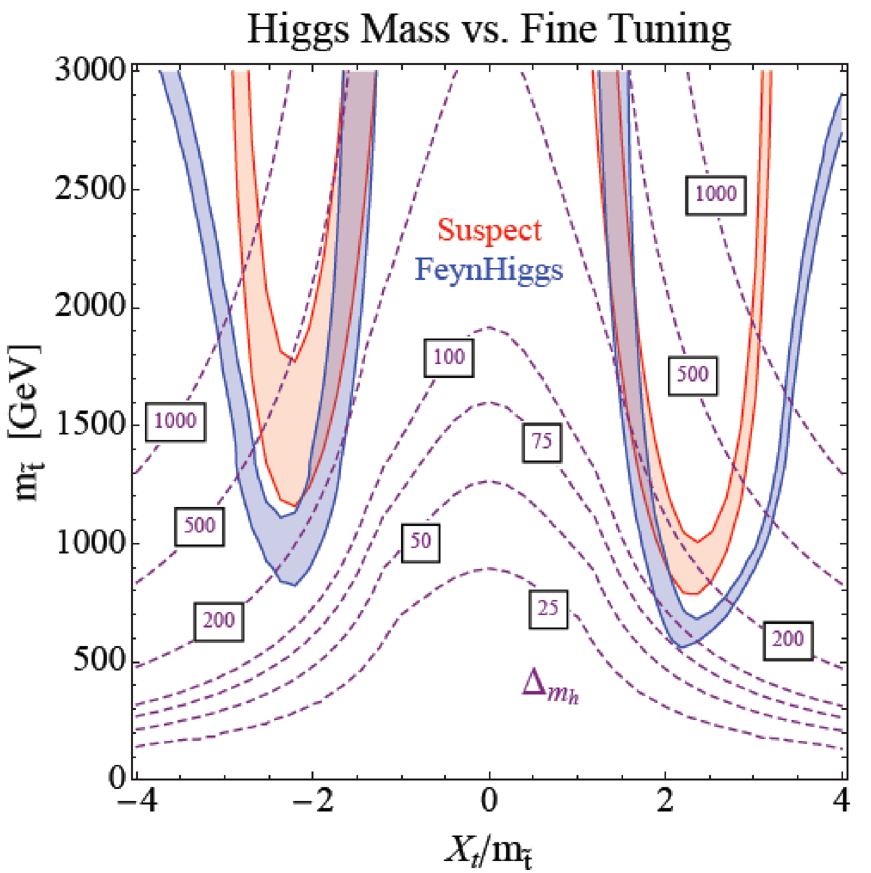
In the „quasi decoupling limit“: ($m_A \gg \lambda v$)

$$\mathcal{M}^2_{stop} = \begin{pmatrix} m^2_{Q_3} + m_t^2 + D_L & m_t X_t \\ m_t X_t & m^2_{u_3} + m_t^2 + D_R \end{pmatrix}$$

$$m_h^2 \sim m_Z^2 \cos^2(2\beta) + \underbrace{\frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left(\frac{\tilde{X}_t}{2} + \log\frac{M^2_{\rm Susy}}{m_t^2}\right)}_{\text{Stop loop contributions}}$$

Valid in the approximation $m_{Q3} \sim m_{u3}$

$$\tilde{X}_t = \frac{2X_t^2}{M^2_{\rm Susy}}\left(1 - \frac{X_t^2}{12 M^2_{\rm Susy}}\right)$$



Hall, Pinner, Ruderman, 1112.2703

Higgs mass in the MSSM

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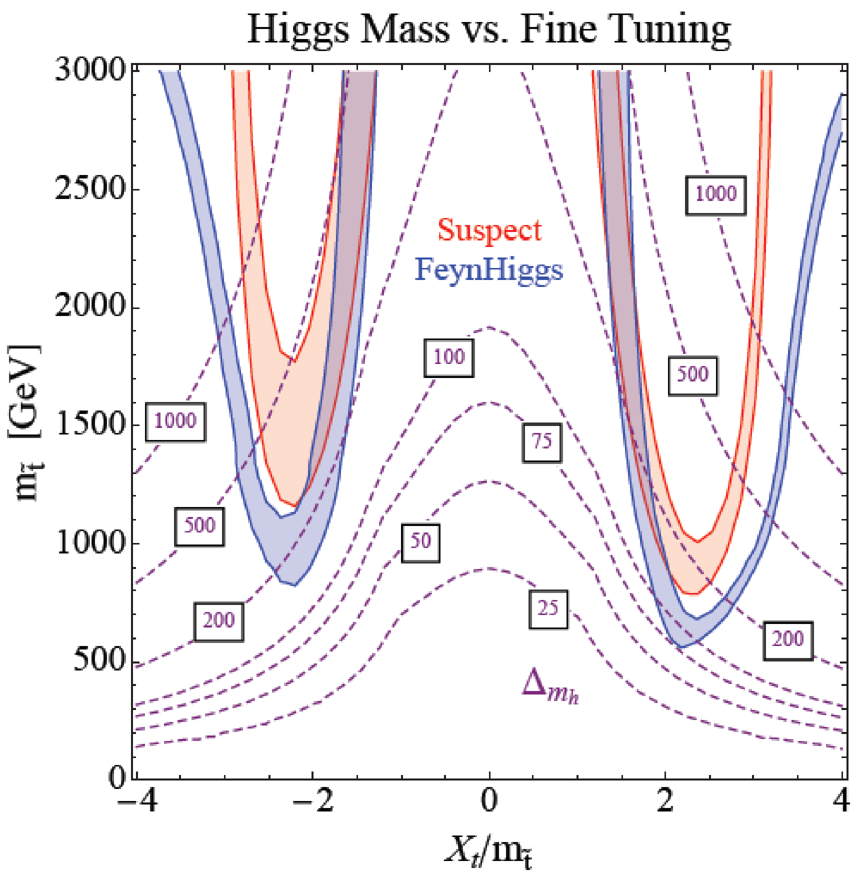
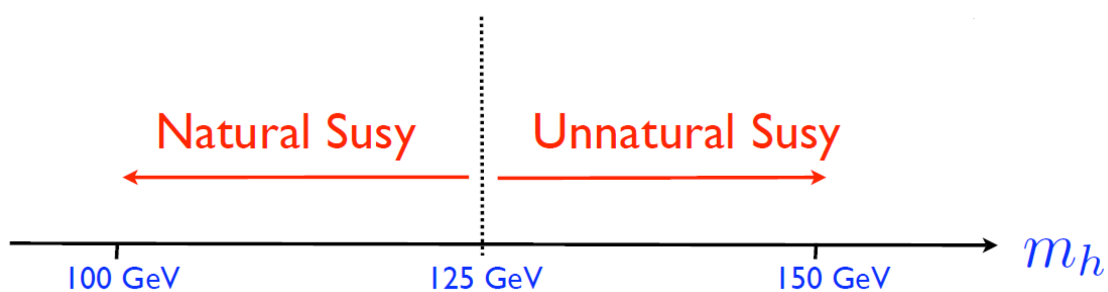


Hall, Pinner, Ruderman, 1112.2703

Take your favorite:



Higgs mass in the MSSM

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$$m_h^2 \sim m_Z^2 \cos^2(2\beta) + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left(\frac{\tilde{X}_t}{2} + \log\frac{M^2_{\rm Susy}}{m_t^2}\right)$$

Stop loop contributions

Valid in the approximation $m_{Q3} \sim m_{u3}$

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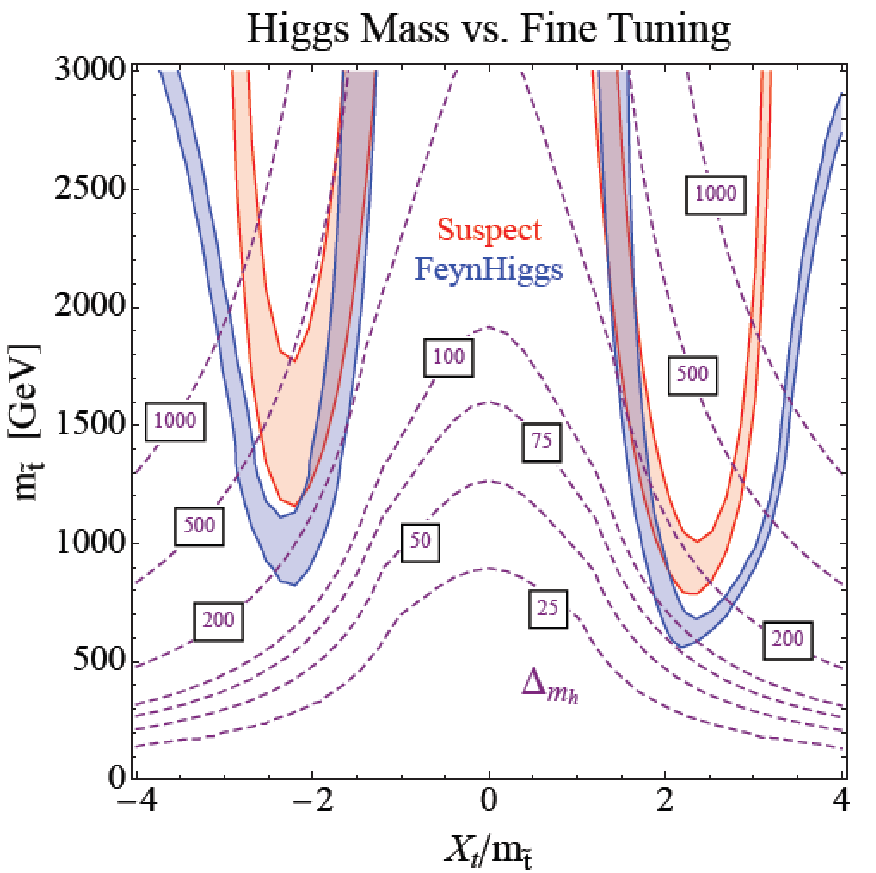
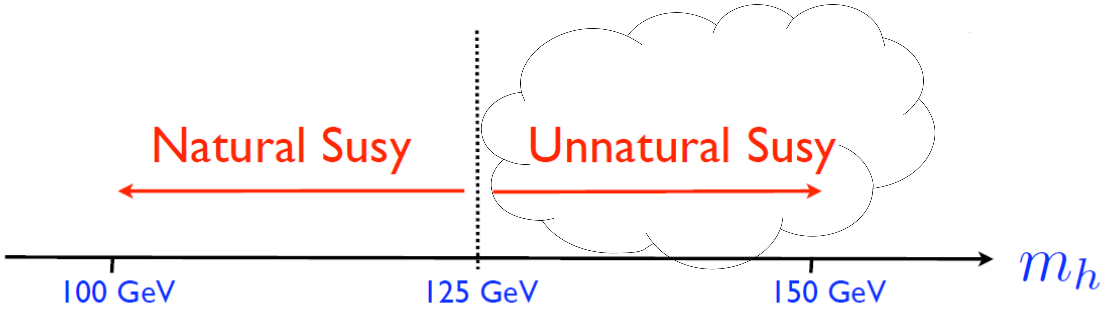


Hall, Pinner, Ruderman, 1112.2703

Take your favorite:



Higgs to di-photon rate beyond the MSSM

An (incomplete) list of references:

1112.2703, Hall, Pinner, Ruderman
λsusy, enhancement of the di-photon rate through the suppression of the bb width
(sizable mixing between the two Higgs doublets)

1112.3548, Ellwanger
1203.3446, Vasquez, Belanger, Böhm, Da Silva, Richardson, Wymant
1203.5048, Ellwanger
1210.1976, Belanger, Ellwanger, Gunion, Jiang, Kraml
NMSSM with h ~ H2, enhancement of the di-photon rate through the suppression of the bb width
(sizable singlet component of the Higgs)

1207.1545: Gunion, Jiang, Kraml
NMSSM: enhancement of the di-photon rate since coming from two degenerate Higgs bosons

1207.2473: An, Liu, Wang
MSSM+ gauged U(1) symmetry: enhancement of the di-photon rate through loops of the fermions curing the gauge anomaly

1207.6596, Delgado, Nardini, Quiros
MSSM+Higgs triplet of SU(2): enhancement of the di-photon rate through chargino loops

1208.1683: Schmidt, Staub
NMSSM+R-symmetry: enhancement of the di-photon rate through chargino, charged Higgs loops

• • •

Phenomenology of the light stau model

EWPTs
Vacuum stability
Dark matter constraints } Constraints

$(g-2)_\mu$ } Predictions

How to look for these light staus: direct searches

It is noteworthy that in spite LHC is pushing higher and higher the bound on the mass of gluinos and squarks of the first two generations, models with electroweakinos (sleptons, charginos) at ~ 100 GeV are still consistent with the data!

Electroweak Precision Tests

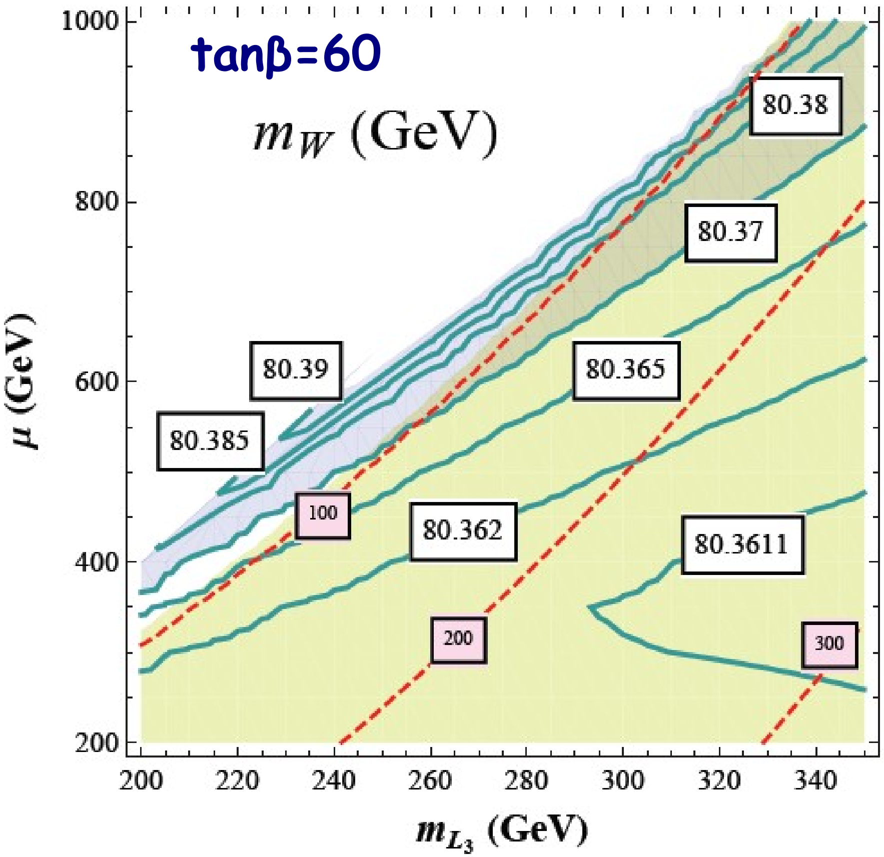
Staus: very light NP states charged under SU(2) x U(1)

→ too large contribution to EWPTs?

New measurement of M_W:

$$(80.385 \pm 0.015)\text{MeV}$$

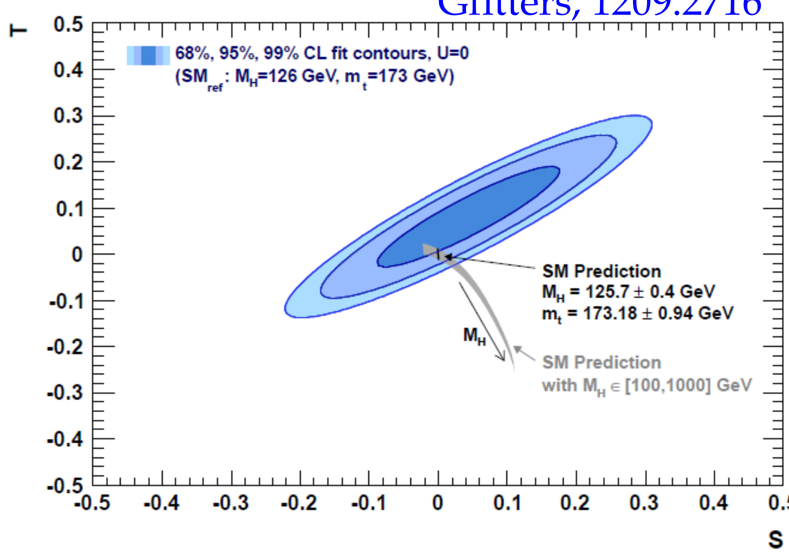
FERMILAB-TM-2532-E, 2012



$$\Delta M_W \simeq \frac{M_W}{2}\frac{\cos^2\theta_W}{\cos^2\theta_W - \sin^2\theta_W}\alpha\,\Delta T$$

Heinemeyer, Hollik, Weiglein, 0412214

Gfitters, 1209.2716



It corresponds to a contribution of (at most)

$$\Delta T \lesssim 0.1$$

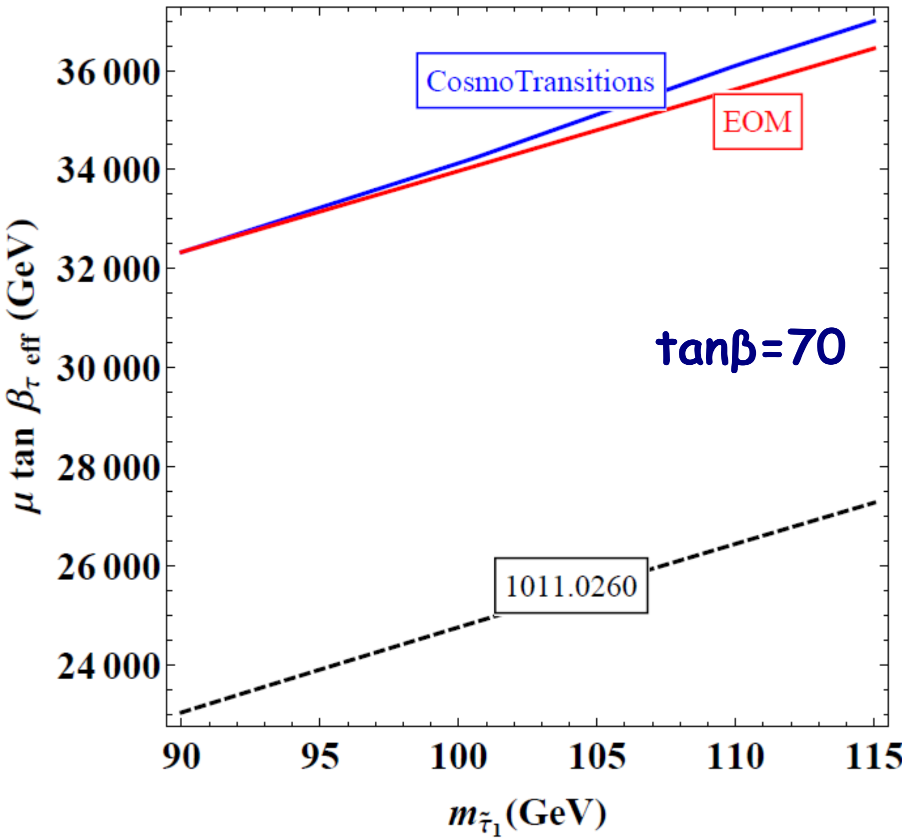
Vacuum stability

Possible instability in the Higgs-staus potential:

$$V \supset -2 y_\tau \mu \tilde{L} \tilde{\tau} \phi_u + \tilde{L}^2 \tilde{\tau}^2 \left(y_\tau^2 - \frac{g_1^2}{2} \right)$$

At the tree level: $y_\tau \mu = \sqrt{2} \frac{m_\tau}{v \cos\beta} \mu \sim \sqrt{2} \frac{m_\tau}{v} \mu \tan\beta$

Carena, SG, Low, Shah, Wagner, to appear



Bound in Hisano, Sugiyama, 1011.0260

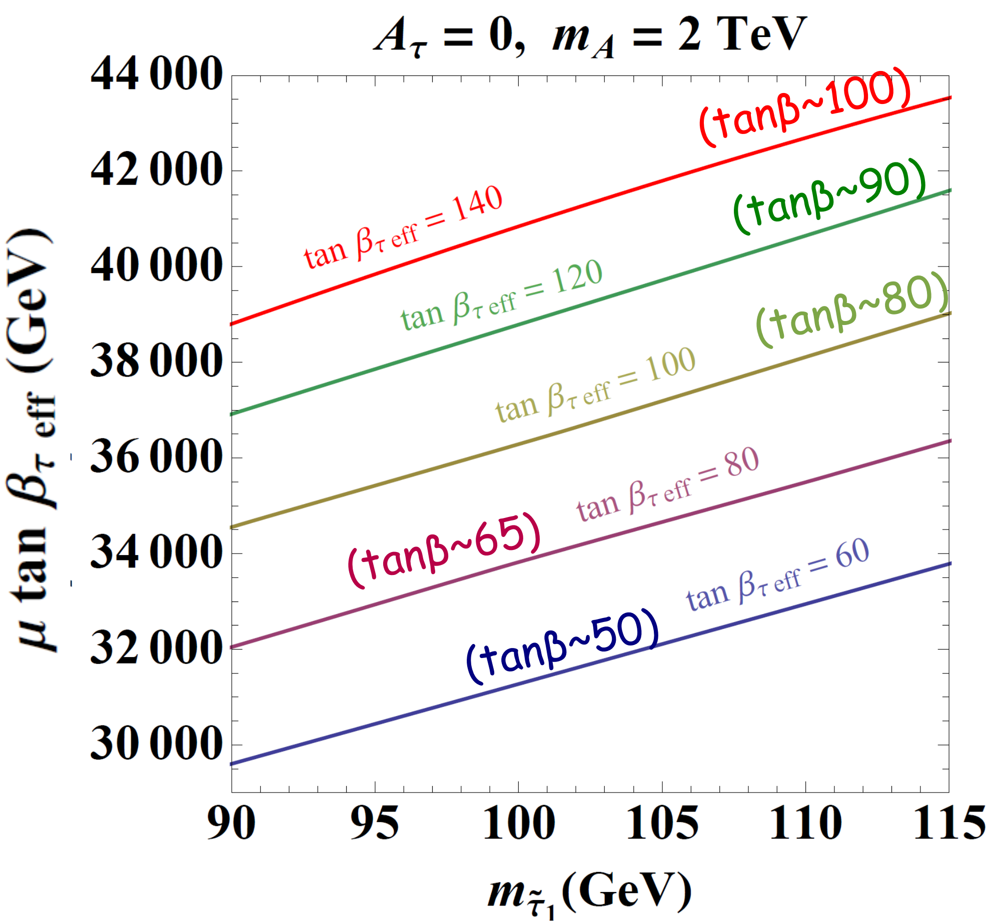
$$|\mu \tan\beta| < 76.9 \sqrt{m_{L_3} m_{E_3}} + \\ + 38.7 (m_{L_3} + m_{E_3}) - 1.04 \times 10^4 \text{ GeV}$$

Kitahara, 1208.4752: with this bound enhancement of the γγ rate larger than ~ 30% are not possible

Vacuum stability

However this does not take into account the tanβ dependence

At very large values of tanβ, the bound can be relaxed



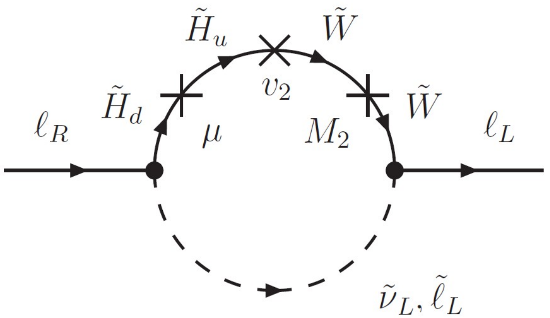
Carena, SG, Low, Shah, Wagner, to appear

Note:

including loop corrections

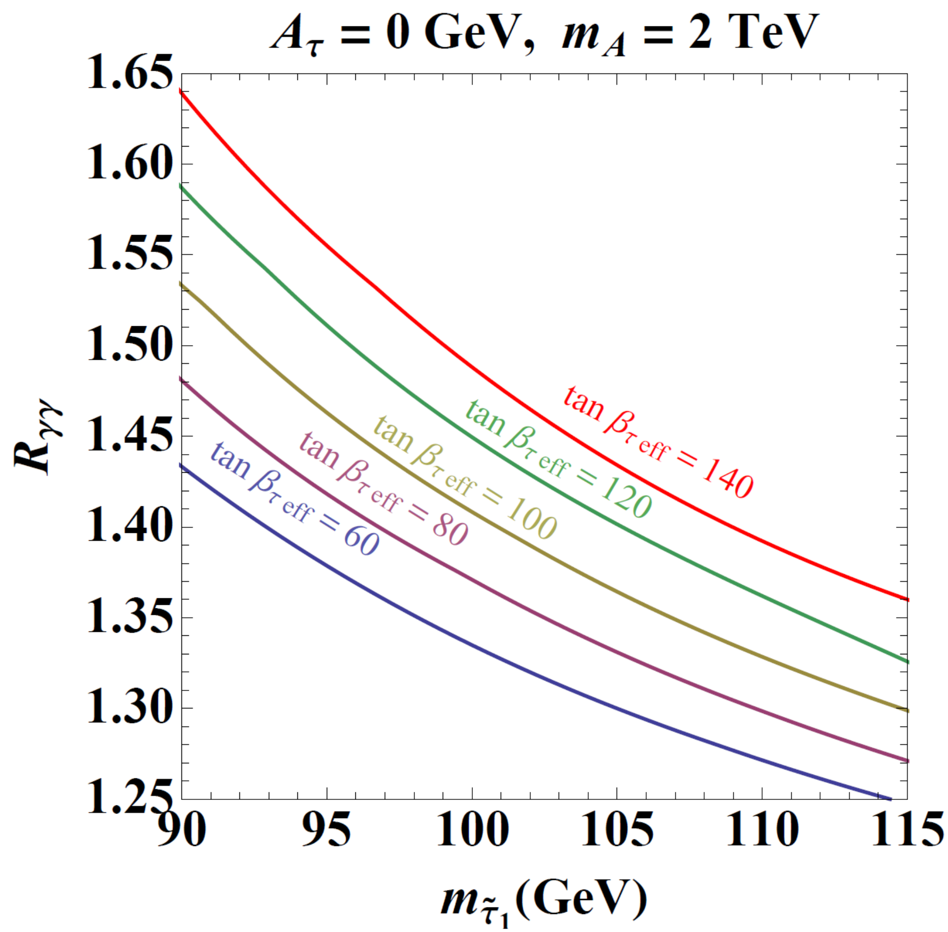
$$y_\tau = \sqrt{2}\frac{m_\tau}{v}\frac{\tan\beta}{1+\Delta_\tau} \equiv \sqrt{2}\frac{m_\tau}{v}\tan\beta_{\tau\ \rm eff}$$

Negative in our model



However this does not take into account the tanβ dependence

At very large values of tanβ, the bound can be relaxed



Carena, SG, Low, Shah, Wagner, to appear

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$$y_\tau = \sqrt{2}\frac{m_\tau}{v}\frac{\tan\beta}{1+\Delta_\tau} \equiv \sqrt{2}\frac{m_\tau}{v}\tan\beta_{\tau\,\mathrm{eff}}$$

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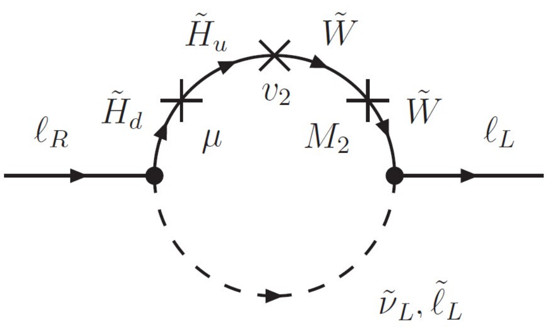
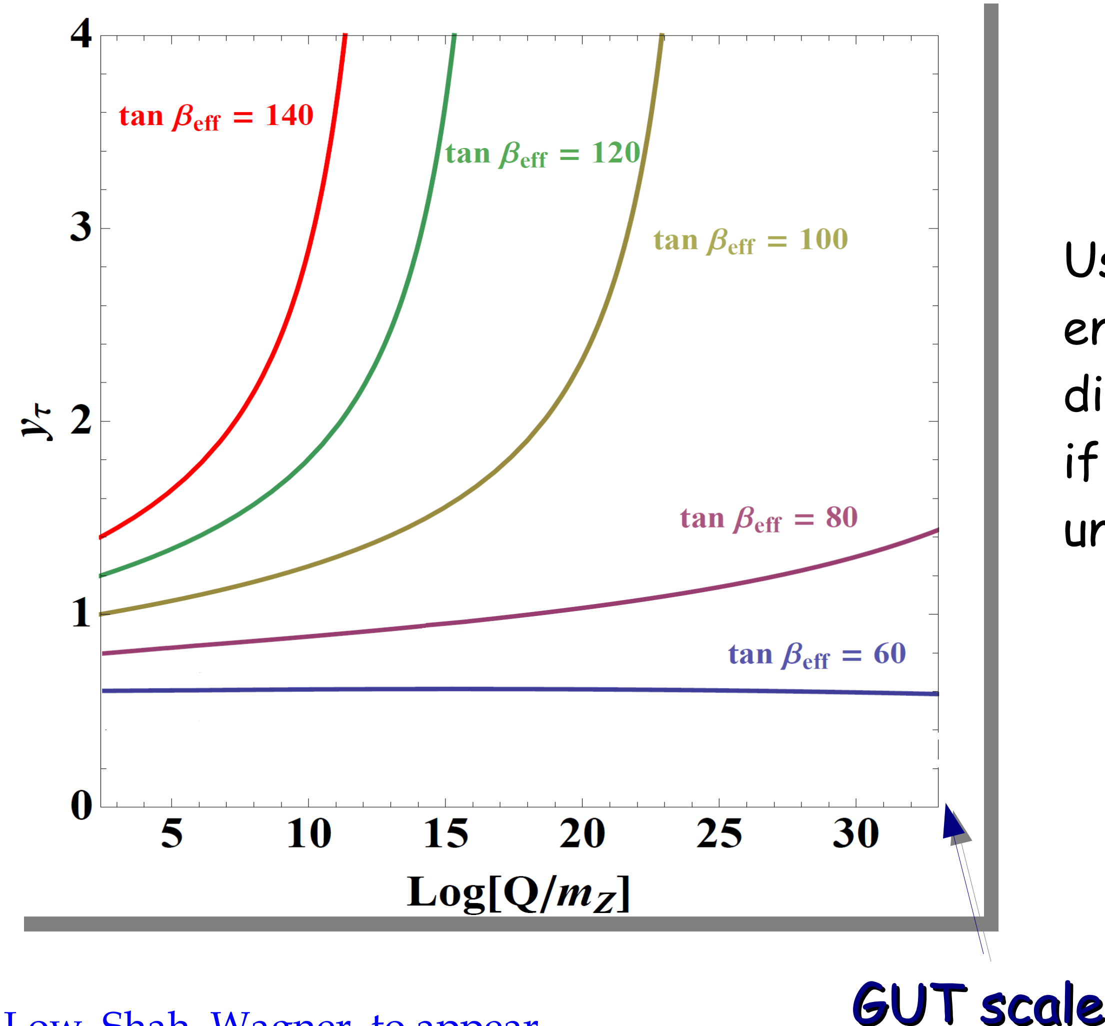


What if a larger di-photon enhancement?

This result would univocally point towards
the existence of a NP scale of the physics beyond the MSSM

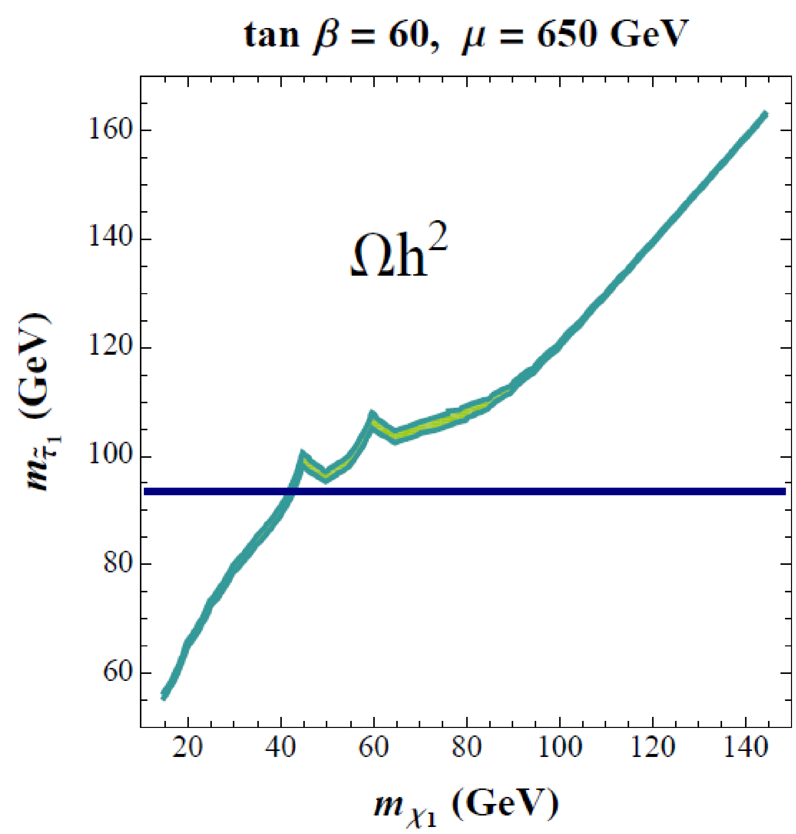


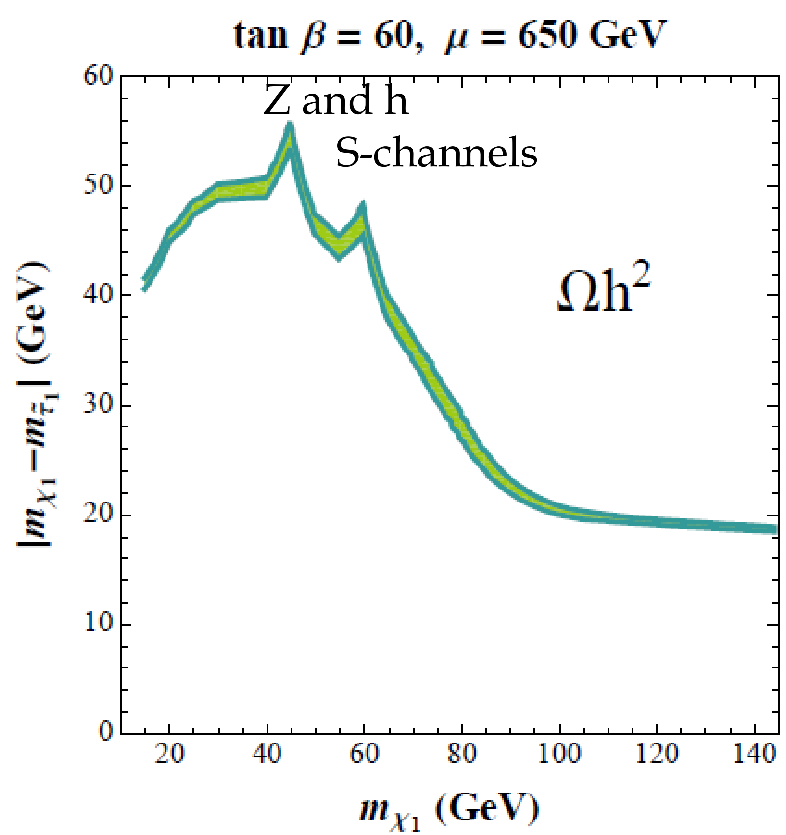
Using light staus, „only" 50-60% enhancements of the di-photon rate are feasable if the MSSM is perturbative until the GUT scale

Carena, SG, Low, Shah, Wagner, to appear

Some handle from Dark Matter?

Carena, Gori, Shah, Wagner, Wang, 1205.5842





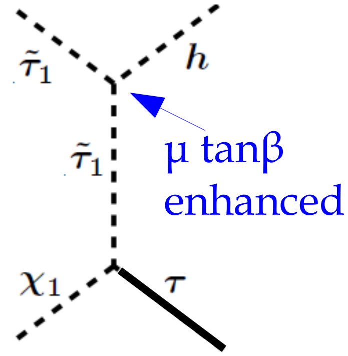
LSP= lightest neutralino (mainly bino)

Main coannihilation channel:

$$\chi_1 \tilde{\tau}_1 \to h\tau$$

In the region of interest:

$$m_{\chi_1} \sim 30 - 40\,\mathrm{GeV}$$

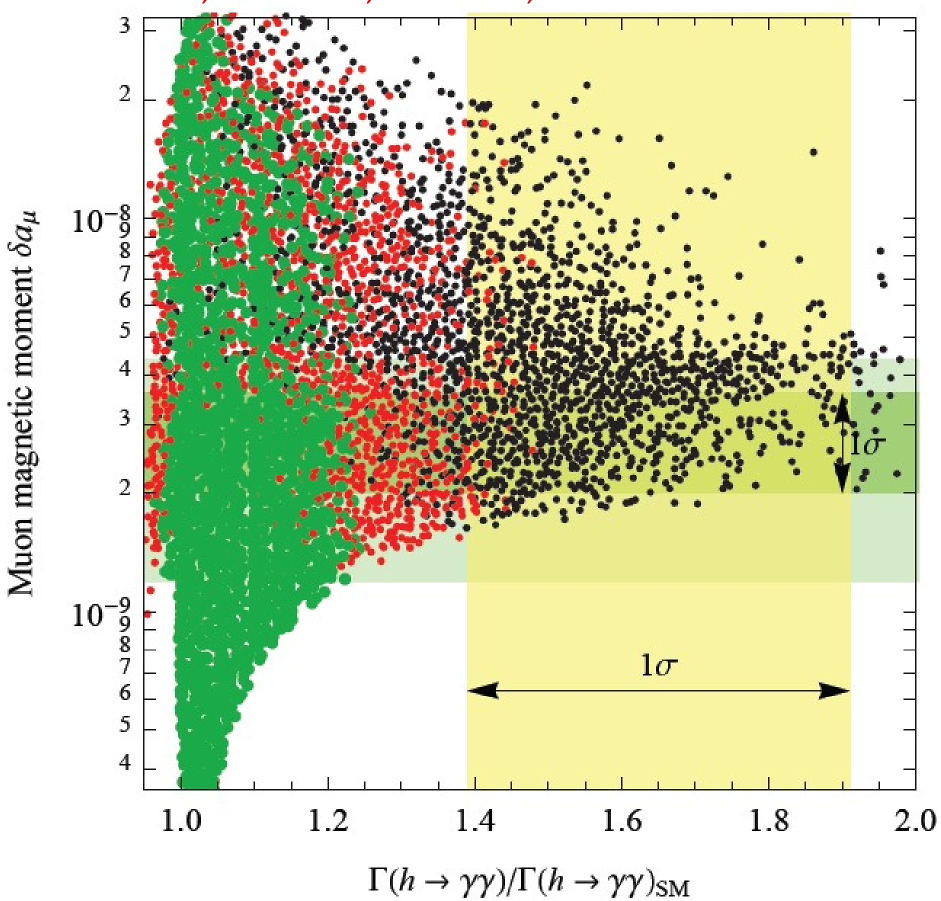


See also Belanger, Biswas, Böhm, Mukhopadhyaya, 1206.5404

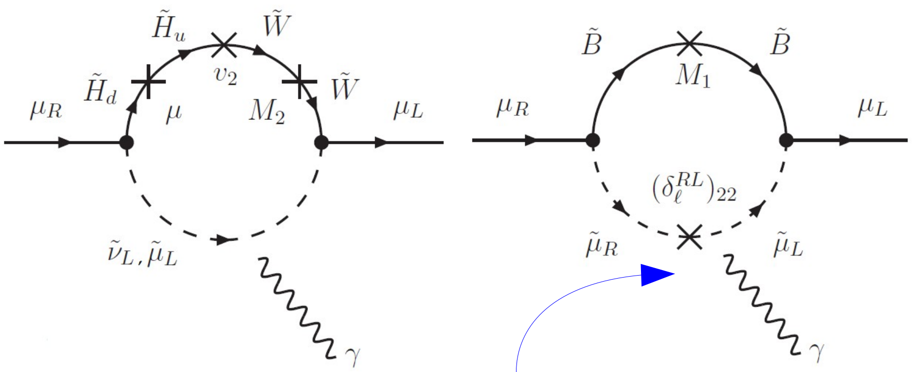
$(g-2)_\mu$

$$\delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (2.8 \pm 0.8) 10^{-9}$$

Giudice, Paradisi, Strumia, 1207.6393



$m_{\tilde{\tau}_1} > 100$ GeV, $m_{\tilde{\tau}_1} > 80$ GeV



Correlation arising in the hypothesis of

- degenerate slepton soft masses at the EW scale
- M1 scanned in such a way that the LSP is neutral and the stau is the NLSP
- Slepton soft masses below the TeV

Staus direct searches

- LEP bound on the stau mass: Aleph, 0112011
  (85-90) GeV in the case of no degeneracy with the lightest neutralino

- CMS bound on long lived staus: 223 GeV
  1205.0272

  Not applicable to our model since our staus are proptly decaying

- CMS & ATLAS multilepton searches
  3 or more leptons final states
  1204.5341, 1208.3144

  $$\tilde{\chi}^{\pm} \to \tilde{\chi}^{0} W, \ell\tilde{\nu}, \tilde{\ell}\nu, \quad \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z, \ell\tilde{\ell}$$

  And also limits on sleptons produced in cascade decays

- ATLAS: searches for staus NLSP produced from gluino & squark cascade decays.
  Up to 4 leptons, jets and missing energy signature. ATLAS-CONF-2012-112

  The limits are model dependent and not applicable if squarks and gluinos are heavy

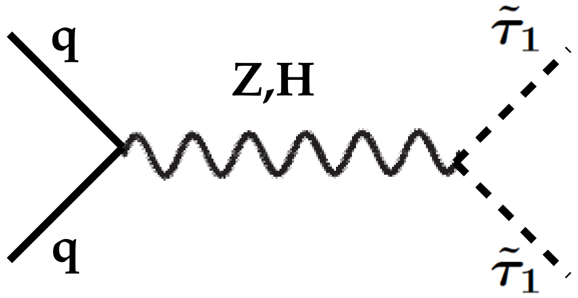
Improved strategies to look for our light staus?

Proposing new channels

Carena, Gori, Shah, Wagner, Wang, 1205.5842

Direct production of staus/sneutrinos

1) $pp \to \tilde{\tau}_1 \tilde{\tau}_1 \to (\tau\, \mathrm{LSP})(\tau\, \mathrm{LSP})$



Production cross section for staus at ~ 95 GeV:
~55 fb (8TeV), ~130 fb (14TeV)

See also Lindert, D. Steffen, Trenkel, 1106.4005

Main backgrounds: Z+ Z/γ*, WW, W+jets

Veto on the invariant mass close to mZ

Cut on the p_T of the taus > $m_W/2$

Difficult to reduce reasonably: jet rejection factor 20-50 for loose hadronic taus (id~60%)

What about taus decaying leptonically? Work in progress

Talking to experimentalists:

Possible large improvement in the tau identification/jet rejection in the near future

Proposing new channels

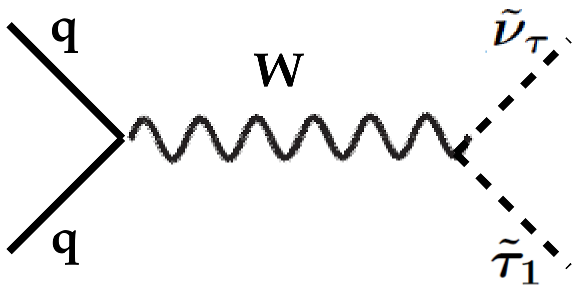
Carena, Gori, Shah, Wagner, Wang, 1205.5842

Direct production of staus/sneutrinos

2) $pp \to \tilde{\tau}_1 \tilde{\nu}_\tau \to \ell \tau \tau \not{E}_T$

$(\tilde{\tau}_1 \to \tau\, \mathrm{LSP}, \tilde{\nu}_\tau \to W \tilde{\tau}_1, W \to \ell \nu)$

Additional lepton: easier search, even if statistically limited



Production cross section for staus at ~ 95 GeV, sneutrino ~ 270 GeV:
~15 fb (8TeV), ~40 fb (14TeV)

Main backgrounds: W+ Z/γ*, W+jets

Proposing new channels

Carena, Gori, Shah, Wagner, Wang, 1205.5842

Direct production of staus/sneutrinos

2) $pp \to \tilde{\tau}_1 \tilde{\nu}_\tau \to \ell \tau \tau \not{E}_T$

	Total (fb)	Basic (fb)	Hard Tau (fb)
Signal	1.6	0.26	0.11
Physical background, $W + Z/\gamma^*$	27	0.32	$\lesssim 10^{-3}$
$W+$ jets background	10^4	39	0.25

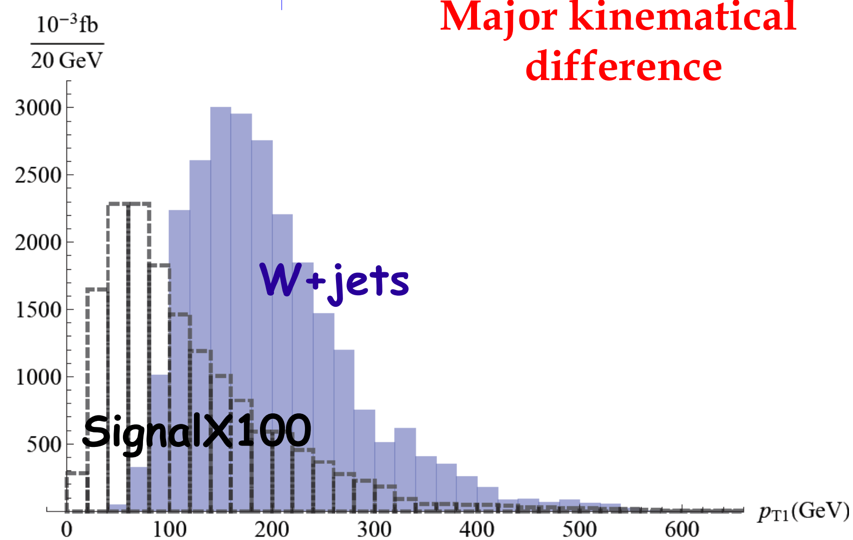
14 TeV

2-loose taus $p_T^\tau > 10$ GeV, $\Delta R > 0.4$	$p_T^\ell > 85$ GeV, $\not{E}_T > 85$ GeV	$p_T^{\tau_1} < 80$ GeV

Estimation at the parton level,
A more careful analysis would be needed

Major kinematical difference

Comparable numbers (after cuts) at the 8 TeV LHC



Motivate experimentalists to perform a dedicated search to validate these results

Conclusions

If LHC will find a Higgs (at ~125 GeV) with enhanced $\gamma\gamma$ rate

→ Light staus with large mixing provide a good candidate to look for

Further enhancement due to Higgs mixing are possible

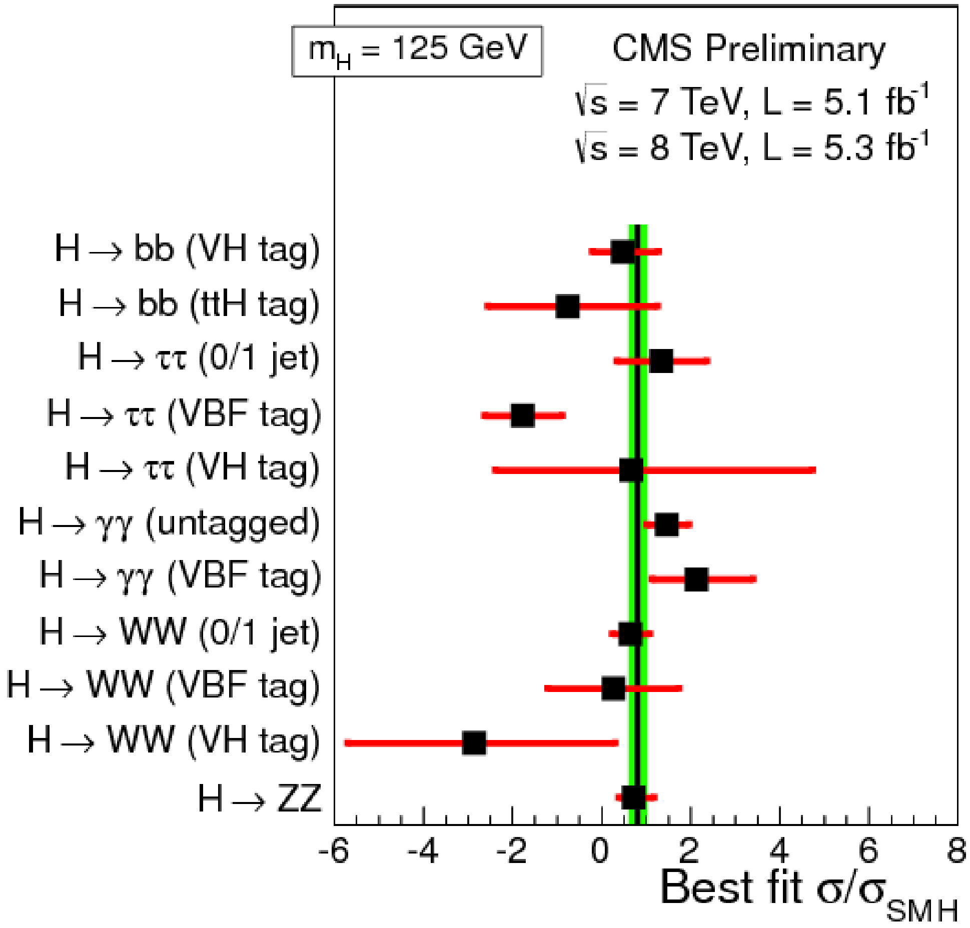
→ Little enhancement also of the other channels (WW, ZZ)

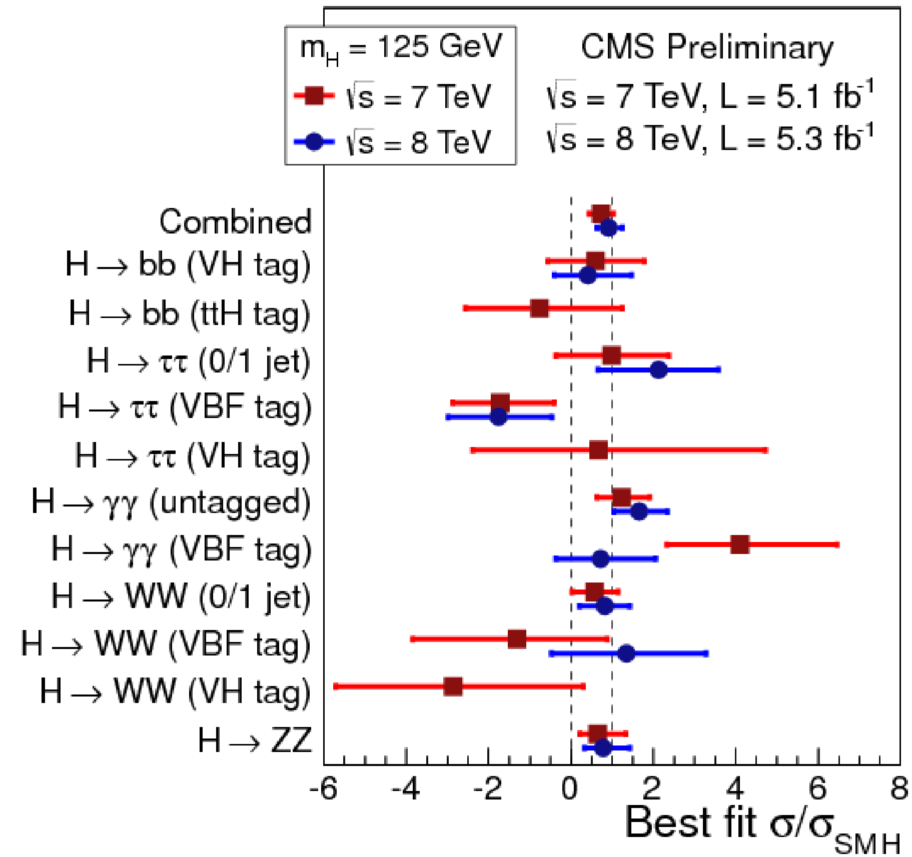
Possible modification of the Higgs production cross section thanks to light stops

Light staus with large mixing:

- Good fit of electroweak precision observables
- Relatively light neutralino LSP to have a good DM candidate
- $(g\text{-}2)_\mu$ in agreement with the experimental measurement (under a reasonable set of assumptions)
- Possibility of discovering them directly at the 14TeV LHC, through weak production, even if all the other scalars of the theory are very heavy (beyond the reach of the LHC)

CMS Higgs results, more detail





Higgs mass in the pMSSM

In the „quasi decoupling limit“: ($m_A \gg \lambda v$)

$$\mathcal{M}^2_{stop} = \begin{pmatrix} m^2_{Q_3} + m_t^2 + D_L & m_t X_t \\ m_t X_t & m^2_{u_3} + m_t^2 + D_R \end{pmatrix}$$

$$m_h^2 \sim m_Z^2 \cos^2(2\beta) + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left(\frac{\tilde{X}_t}{2} + \log\frac{M^2_{\rm Susy}}{m_t^2}\right)$$

Stop loop contributions

$$\begin{cases} \tilde{X}_t = \dfrac{2X_t^2}{M^2_{\rm Susy}}\left(1 - \dfrac{X_t^2}{12M^2_{\rm Susy}}\right) \\ X_t = A_t - \dfrac{\mu}{\tan\beta} \end{cases}$$

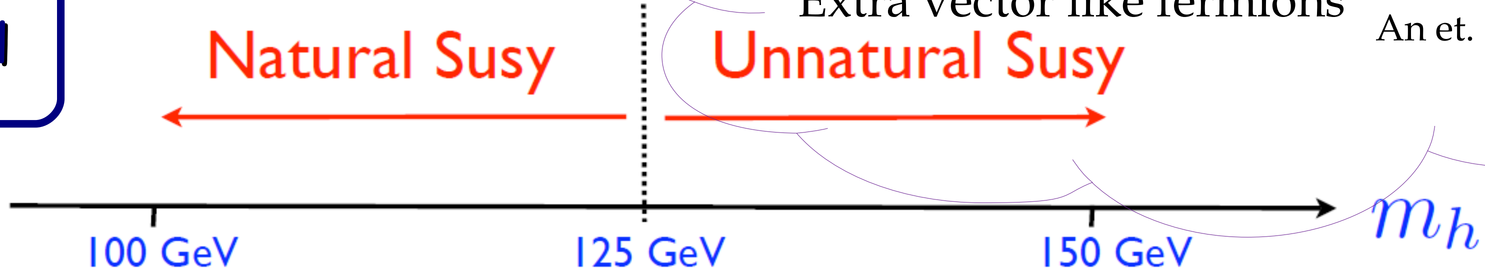
Stop mixing

Valid in the approximation $m_{Q3} \sim m_{u3}$

Extensions of the MSSM:
NMSSM & λSusy
U(1)'
Extra vector like fermions

Hall et. al., 1112.2703
Ellwanger, 1112.3548
Boudjema et. al., 1203.3141
Vasquez et.al., 1203.3446
Lodone, 1203.6227
Benbrik et. al., 1207.1096
An et. al., 1207.2473

L. Hall

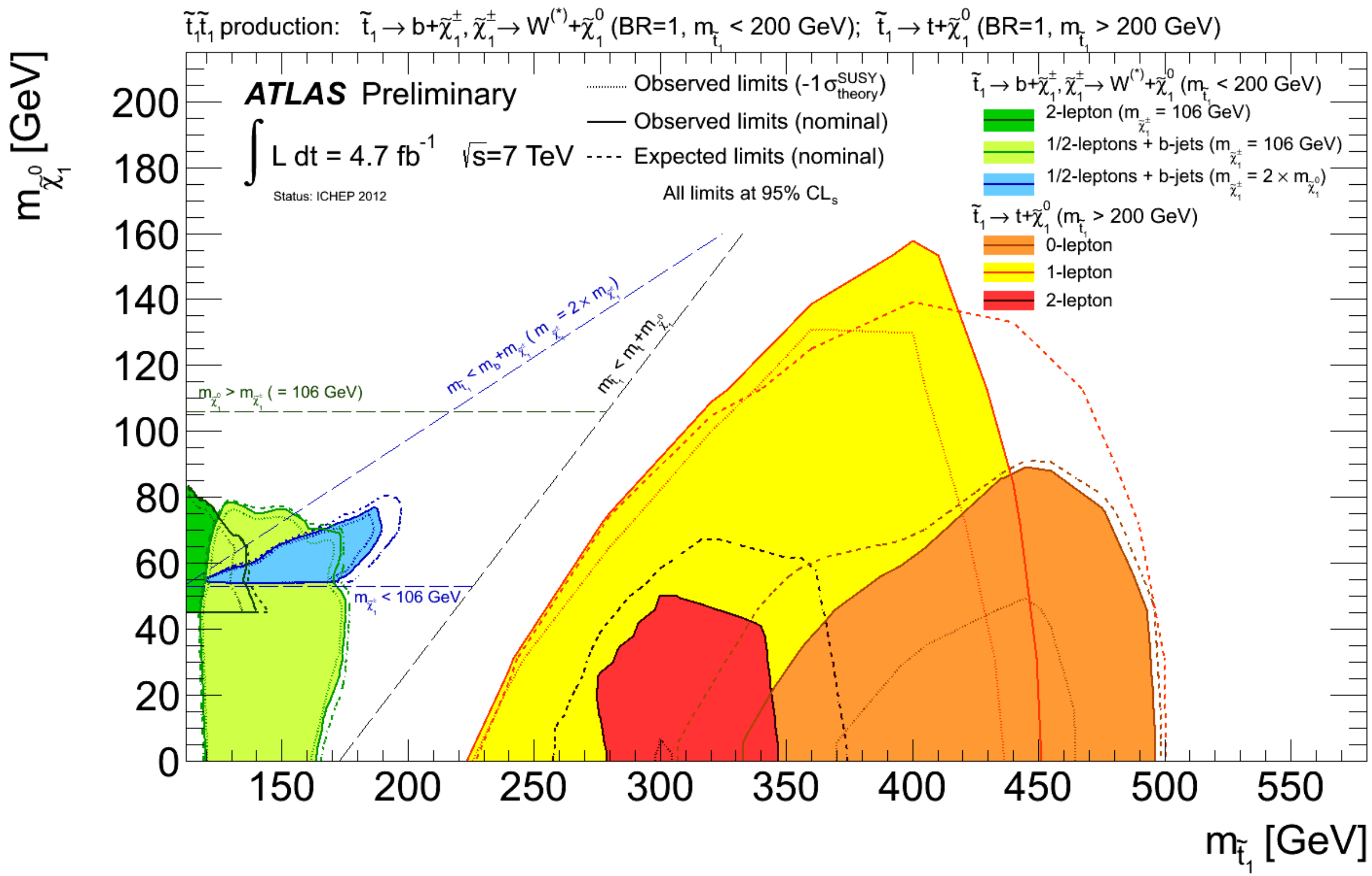


LHC searches for light stops

We have already spoken about the possibility of changing the Higgs production cross section through loops of very light (right handed) stops

Only recently LHC started to probe directly produced stops

Crucial searches if gluinos are heavy ($\gtrsim$ 2TeV)



 S.Gori

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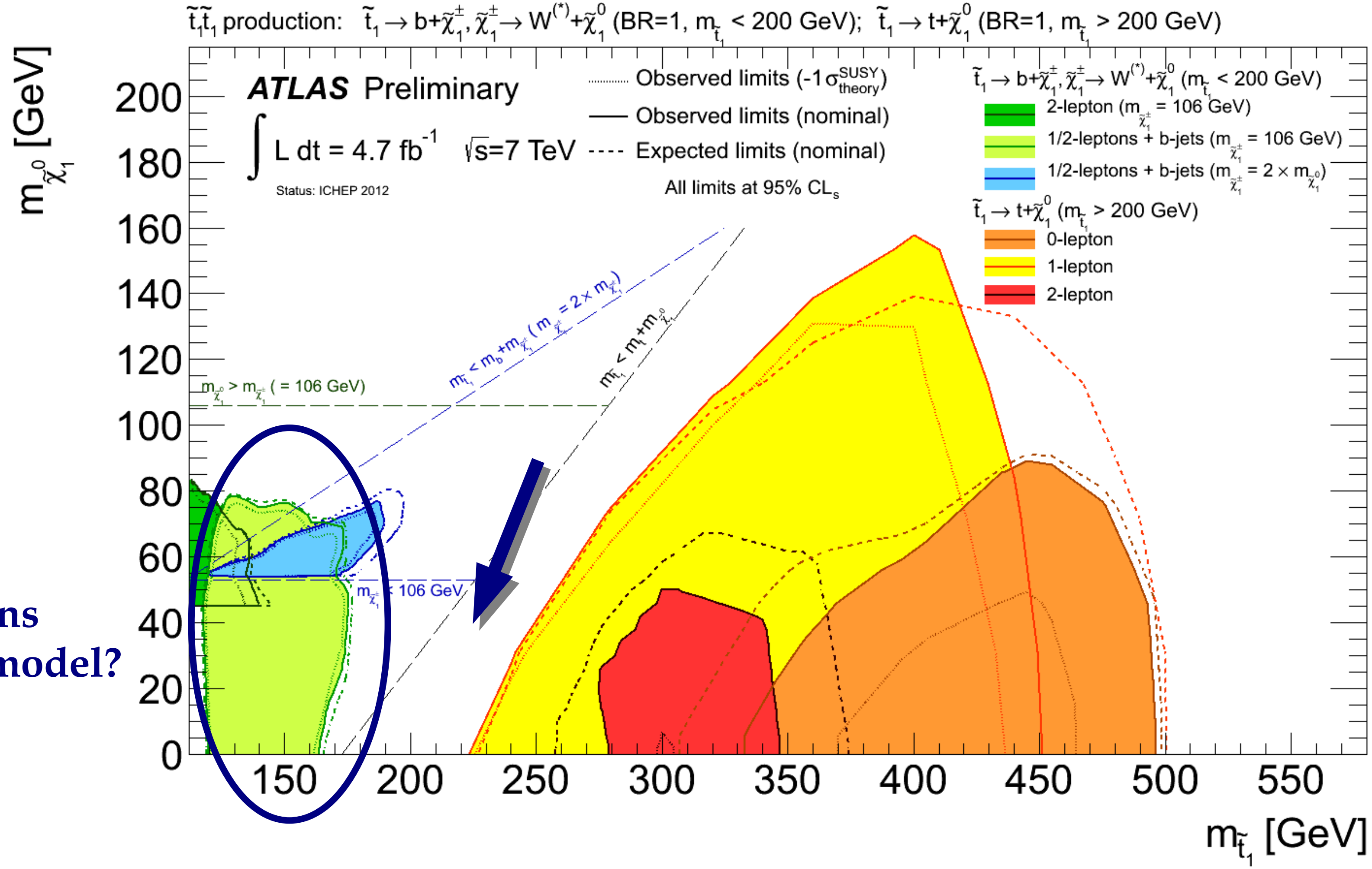

What happens here in our model?

 S.Gori

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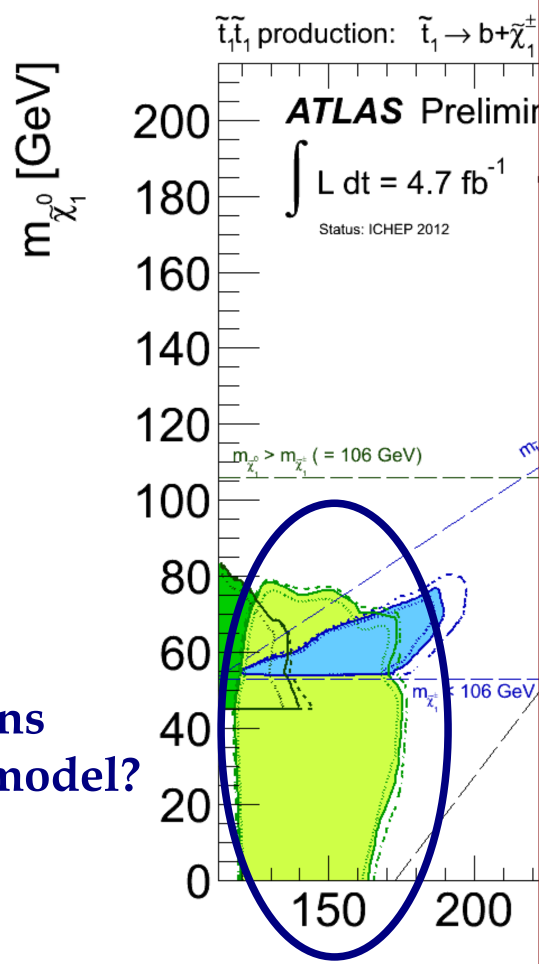


What happens here in our model?

Carena, SG, Shah, Wagner, Wang, work in progress

The decay $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm},\ \tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0$
is usually suppressed

thanks to the opening up of new decay modes

$\tilde{t}_1 \to \tilde{\tau}_1 b\nu_\tau$ To recast multilepton searches

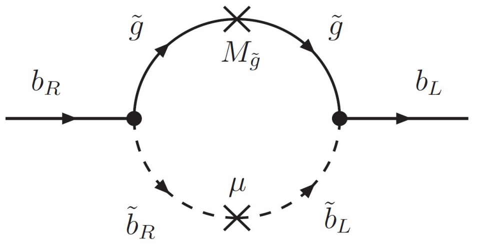
$\tilde{t}_1 \to \tilde{\chi}_1^0 c$ CDF bound: m_{stop}>120 GeV if 100% decaying in this final state and neutralino mass ~30-40 GeV
0707.2567

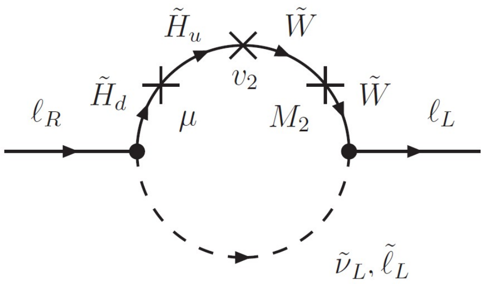
Carena, SG, Shah, Wagner, Wang, work in progress

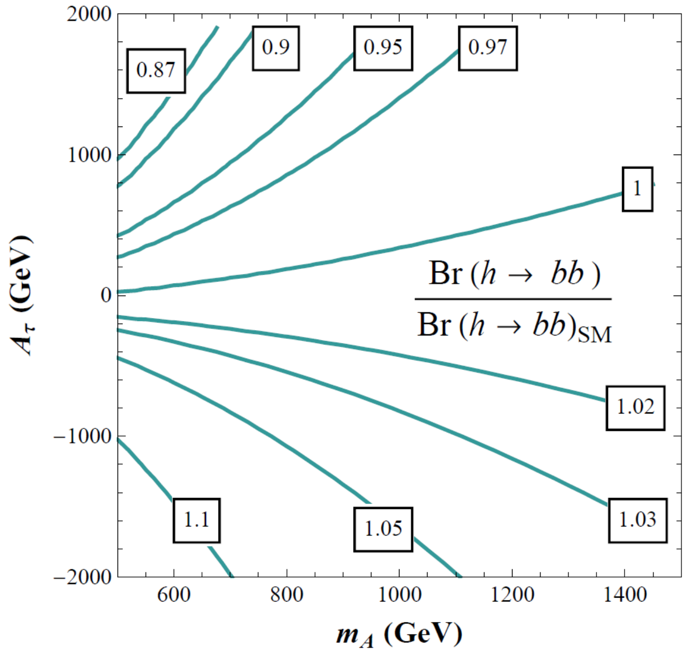
$$g_{hbb,h\tau\tau} = -h_{b,\tau}\sin\alpha + \Delta h_{b,\tau}\cos\alpha$$

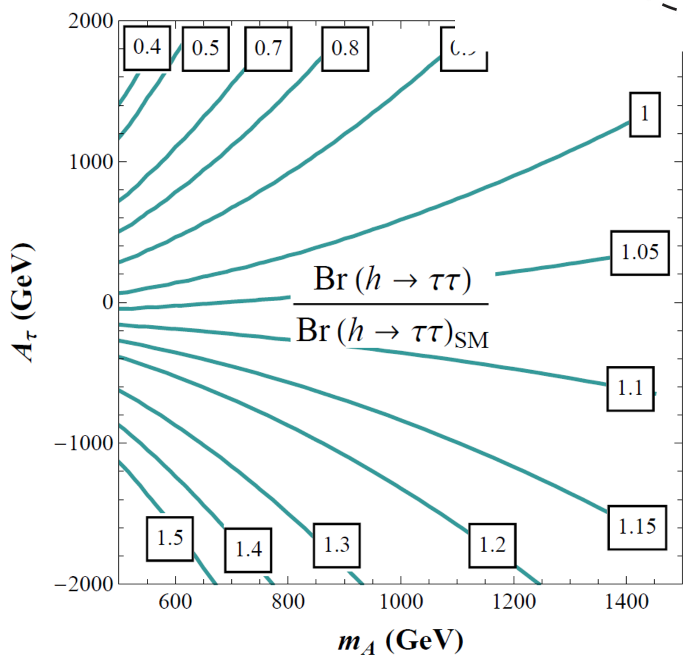
$$g_{hbb,h\tau\tau} = -\frac{m_{b,\tau}\sin\alpha}{v\cos\beta(1+\Delta_{b,\tau})}\left[1-\frac{\Delta_{b,\tau}}{\tan\beta\tan\alpha}\right]$$

$$\frac{g_{hbb}}{g_{h\tau\tau}} = \frac{m_b(1+\Delta_\tau)\left(1-\Delta_b/(\tan\beta\tan\alpha)\right)}{m_\tau(1+\Delta_b)\left(1-\Delta_\tau/(\tan\beta\tan\alpha)\right)}$$









$$A_t = 2\text{TeV},\ m_{Q_3} = 1.65\text{TeV},\ m_{u_3} = 200\text{GeV},\ m_{L_3} = m_{e_3} = 280\text{GeV},\ \tan\beta = 60$$

MSSM Higgs properties

At the tree level

$$\xi_u^h = \frac{\cos\alpha}{\sin\beta}$$

Higgs mixing angle

$$\xi_d^h = \xi_\ell^h = -\frac{\sin\alpha}{\cos\beta}$$

$$\xi_V^h = \sin(\beta-\alpha)$$

Couplings normalized to the SM value

+

Couplings with sparticles and additional Higgs bosons

Giving the effective couplings $\xi_\gamma^h,\ \xi_g^h$

$$\sigma(pp\to h\to X_{\rm SM}) = \sigma(pp\to h)\frac{\Gamma(h\to X_{\rm SM})}{\Gamma_{\rm tot}}$$

Main contribution coming from gluon gluon fusion,

Dominated by Γ_{bb}

Is this the Higgs boson?

New program: Higgs Identification

What makes a Higgs a Higgs?

1) Spin 0 boson
- **Spin 1 is excluded, but spin 2 is hard to exclude**

2) CP even
- **Pure CP odd should be ruled out or in this year**

3) Taking a vev and breaking SU(2)×U(1)

An (incomplete) list

Chivukula et. al.1207.0450
Coleppa et. al. 1208.2692
Bellazzini et. al, 1209.3299
Chacko et. al. 1209.3259, ...

Well motivated „Higgs imposter"

Dilaton (conformal strong dynamics)

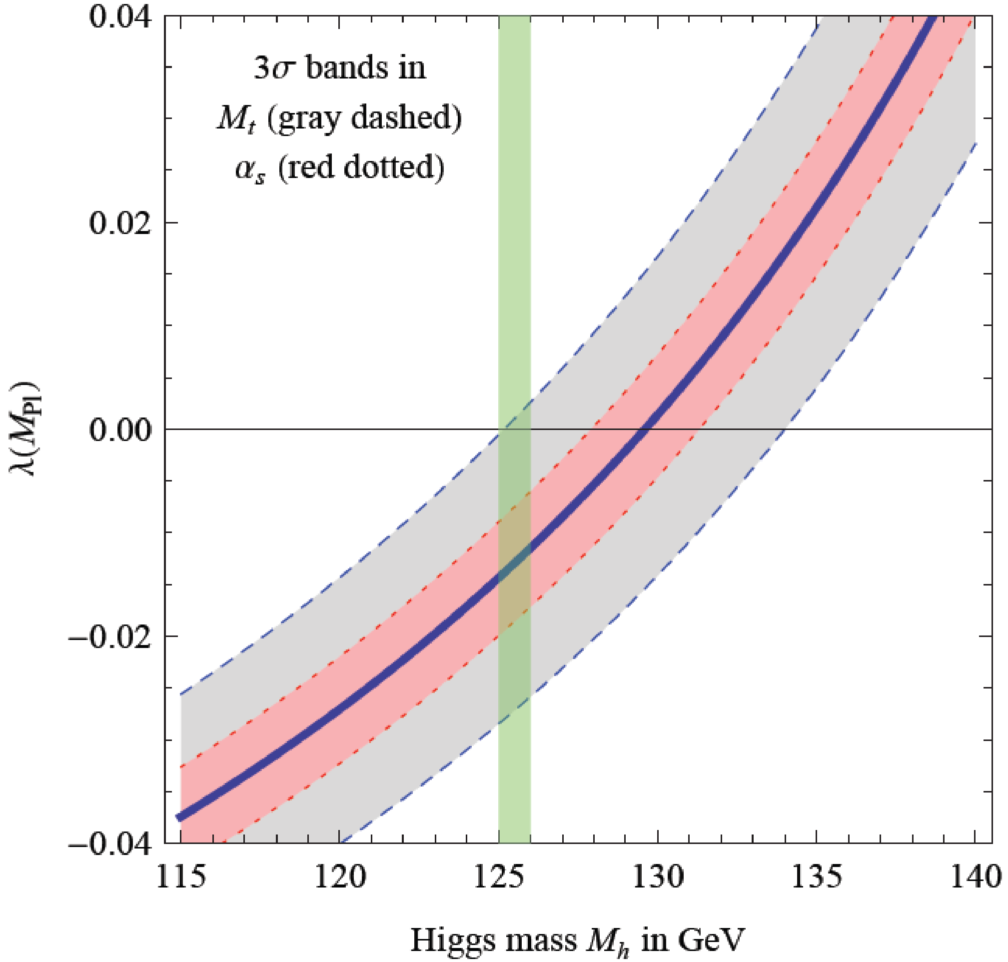
Radion (warped extra dimensional models)

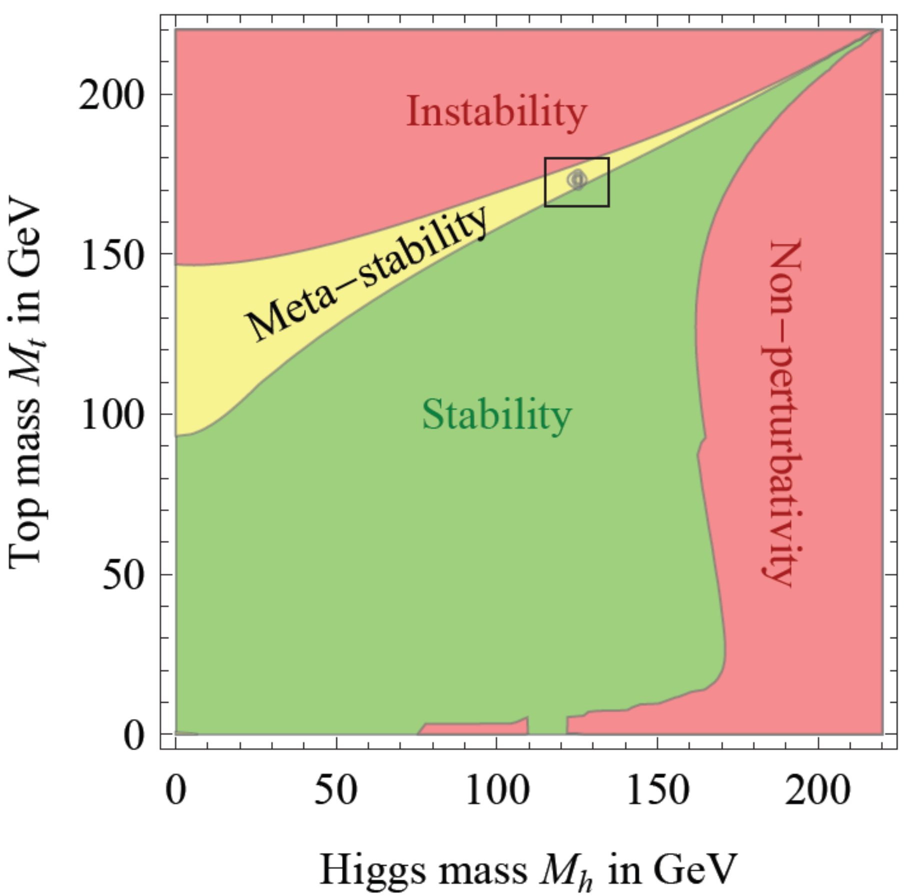
Plain singlets & triplets (extended Higgs sectors)

Low, Lykken, Shaughnessy 1207.1093

Let me call the new boson the Higgs boson

A good mass also for theorists?





Degrassi, Di Vita, Miro, Espinosa, Giudice, Isidori, Strumia,
1205.6497