Implications of the present measurements on theoretical ideas

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French-Italian meeting on the b-Physics

Flavor physics in the light of the recent results at LHC

Outlook

- Anatomy of the Higgs-like resonance
- Impact on popular ideas on BSM Higgs scenarios
- Impact on Fermiophobic-like Higgs models
- Measuring the sign of top-Yukawa coupling
- Higgs-boson imposters
- Conclusions

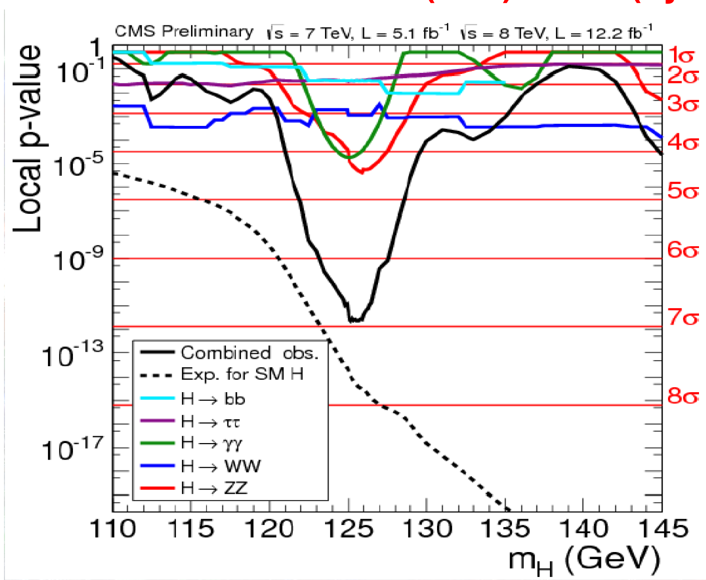
Where are we ?

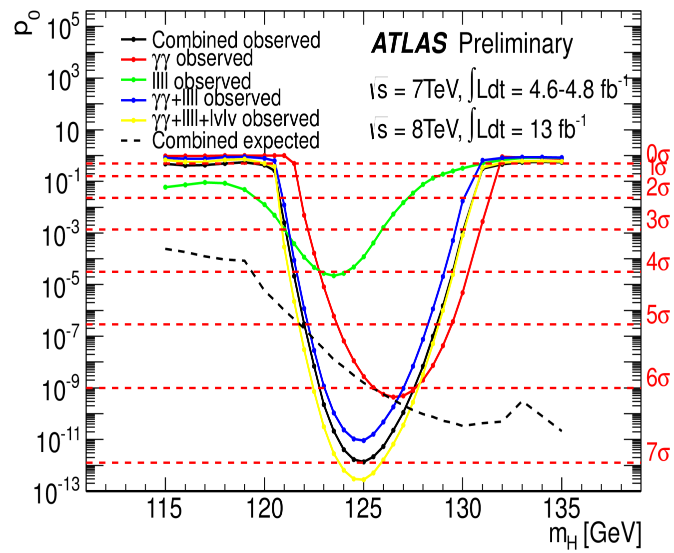
- a new particle (resonance) has been discovered → consistent with the long-awaited SM Higgs boson

- fully confirmed in all its most sensitive channels

CMS mH = 125.8 ± 0.4(stat) ± 0.4 (syst) GeV

ATLAS mH = 126 GeV ± 0.4(stat) ± 0.4 (syst) GeV





- Local probability p for a bckg-only experiment to be more signal like than the observation versus M_H

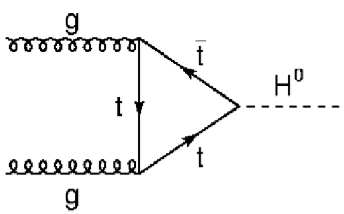
- **Significance:** ATLAS local 7.0 global 5.9 → in 122-131 GeV ($p = 1.7 \times 10^{-9}$)
  CMS local 6.9

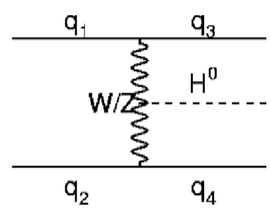
- H→ γγ rules out spin-1. While spin-0 and spin-2 viable

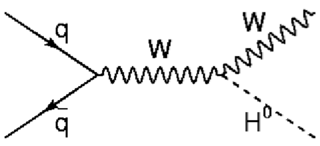
Anatomy of the 125 GeV resonance

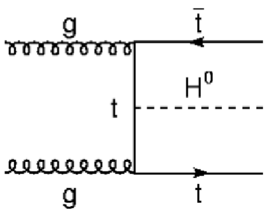
- assuming this is a SM Higgs-like boson
- main production mechanisms are (in order of relevance)
  - Gluon-gluon fusion — ggH → loop
  - Vector Boson Fusion (VBF) — qqH → tree-level
  - W,Z associated production — VH → tree-level
- Crucial to measure Higgs couplings to W,Z, b, t, τ !
- tags are needed to isolate the production mechanisms
  - ggH → gives indirect informations on colored particles running in the loop, as well as on top-Yukawa coupling
  - VBF, VH , H → VV → informations on Higgs coupling to W and Z

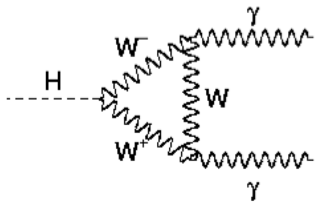
CMS tag analysis Nov 2012

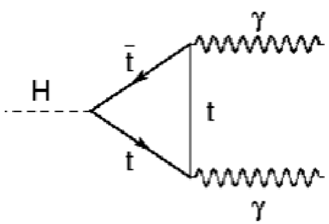








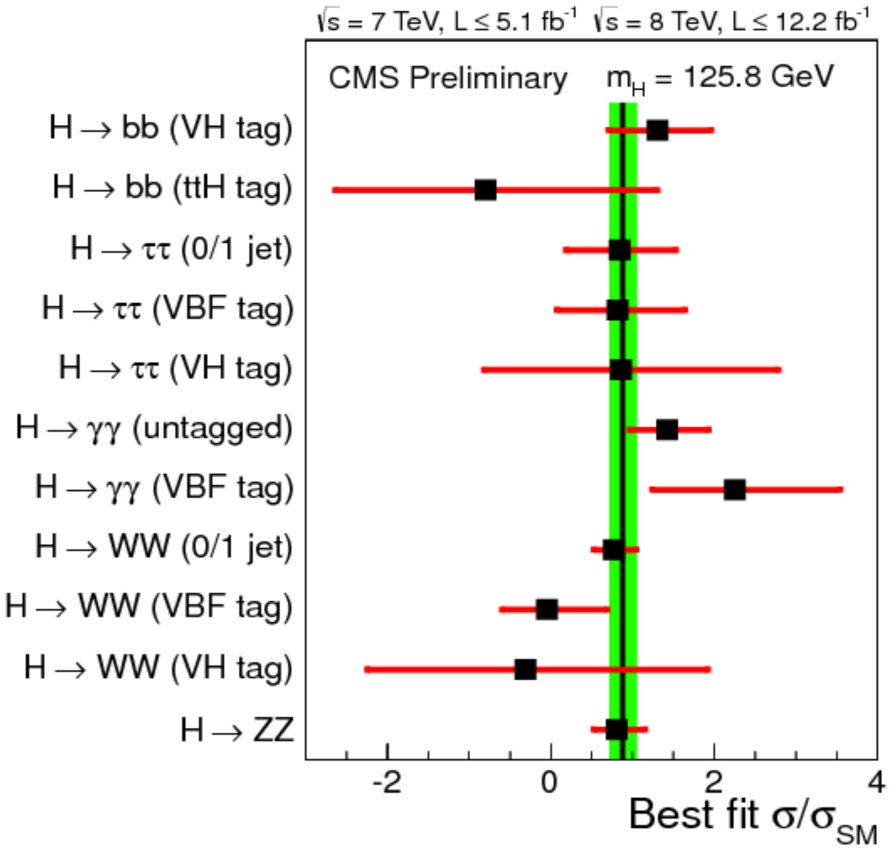




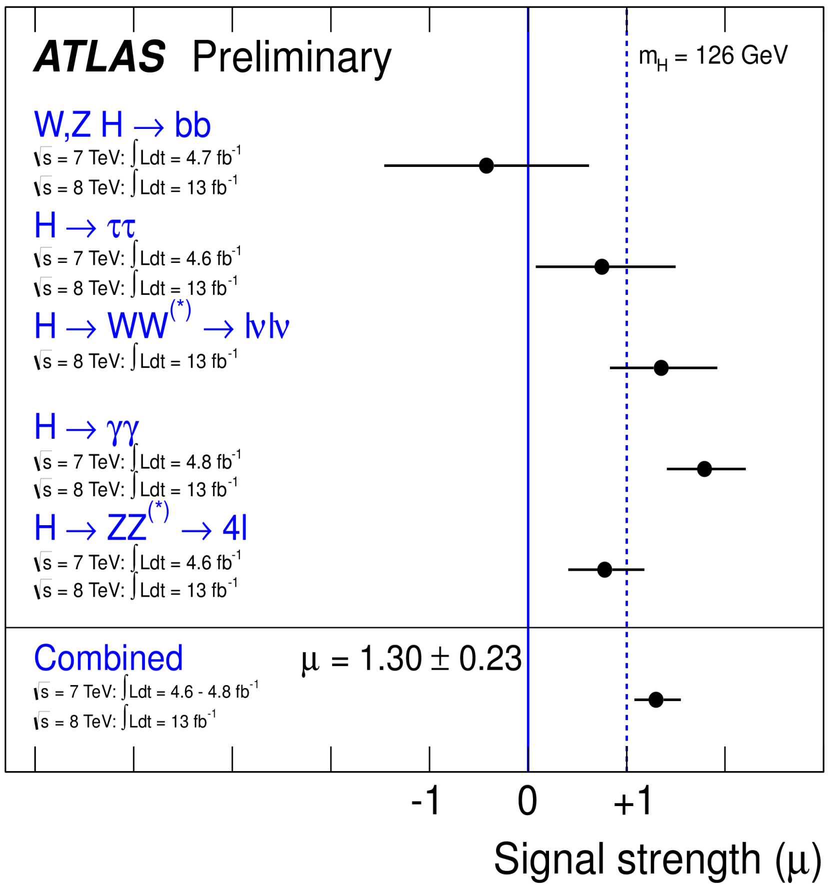
	Untagged	VBF-tag	VH-tag	ttH-tag
$H \rightarrow \gamma\gamma$	✔	✔		
$H \rightarrow bb$			✔	✔
$H \rightarrow \tau\tau$	✔	✔	✔	
$H \rightarrow WW$	✔	✔	✔	
$H \rightarrow ZZ$	✔			

Compatibility with SM Higgs hypothesis

CMS-HIG-12-045



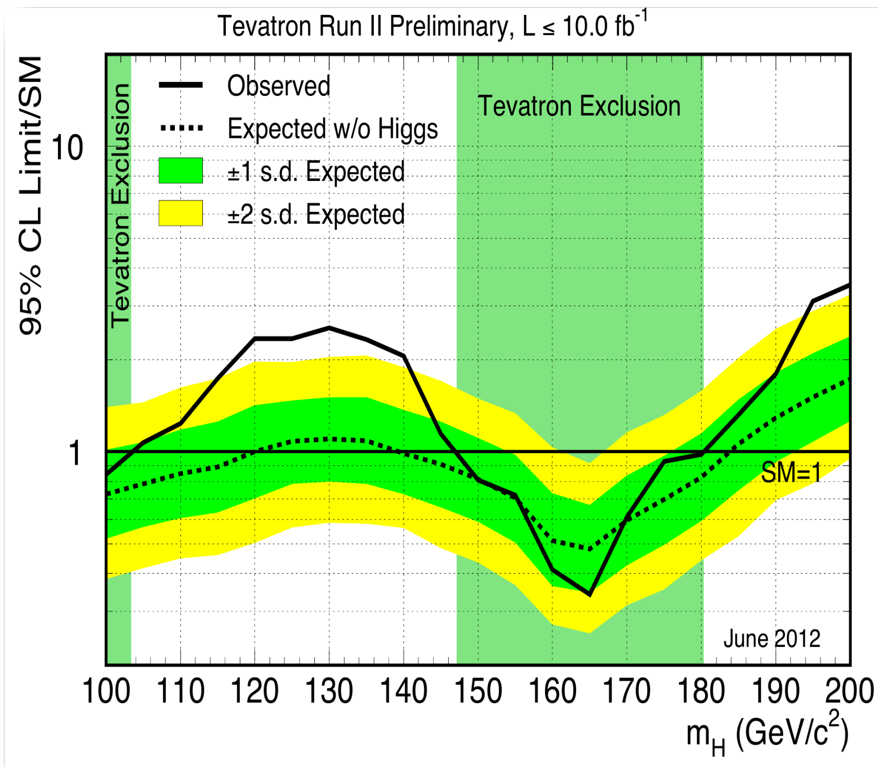
ATLAS-CONF-2012-170

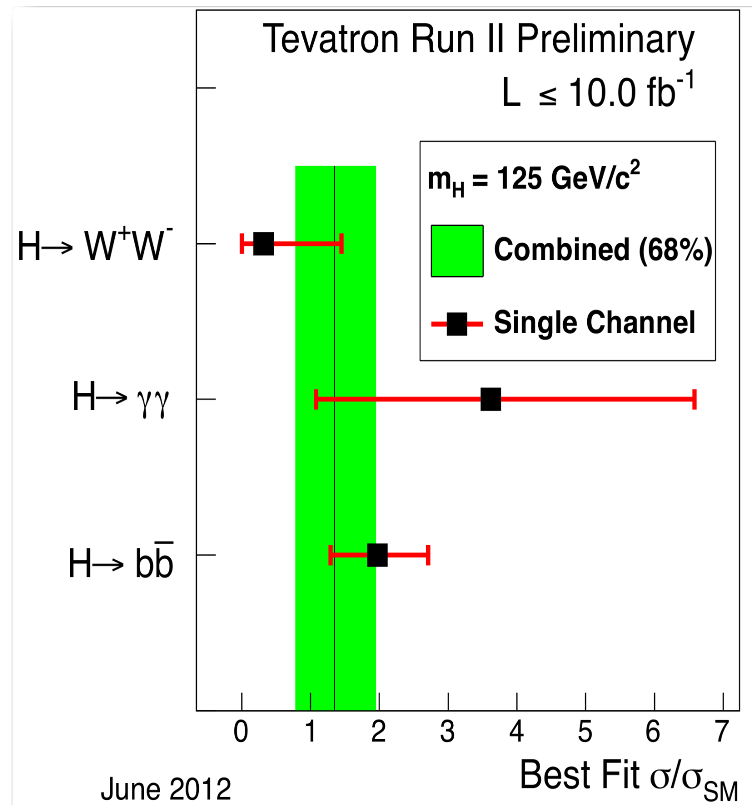


- **overall signal strength normalized to SM**
  CMS = 0.88 ± 0.21   ATLAS = 1.4 ± 0.23
- **di-photon rate enhancement is more pronounced in VBF**

Higgs searches from Tevatron

Combination of searches for H → WW and H → bb shows a clear excess in the 115 GeV - 135 GeV mass region



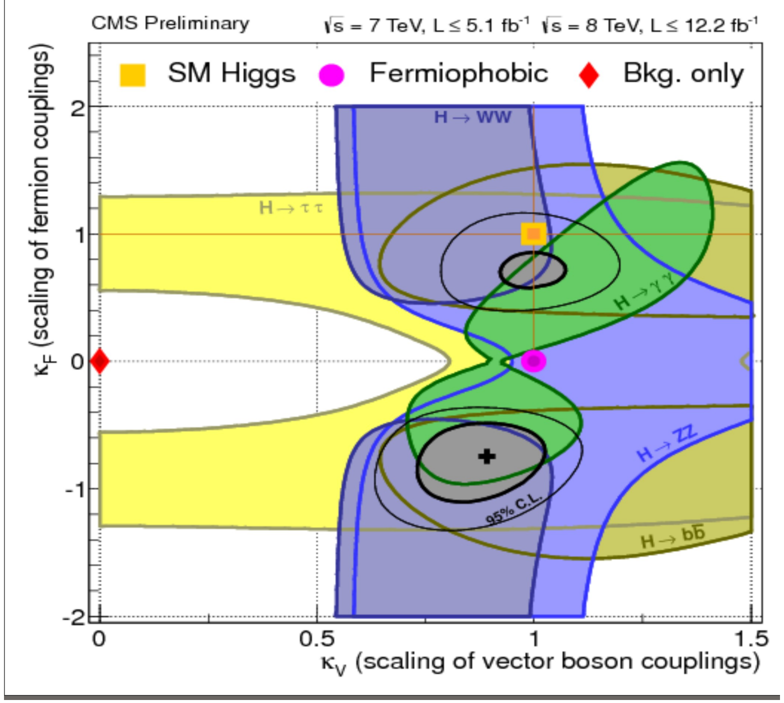


Combined production rates are consistent within 1σ with a Higgs mass of 125 GeV. However, bb and γγ rates appear enhanced !

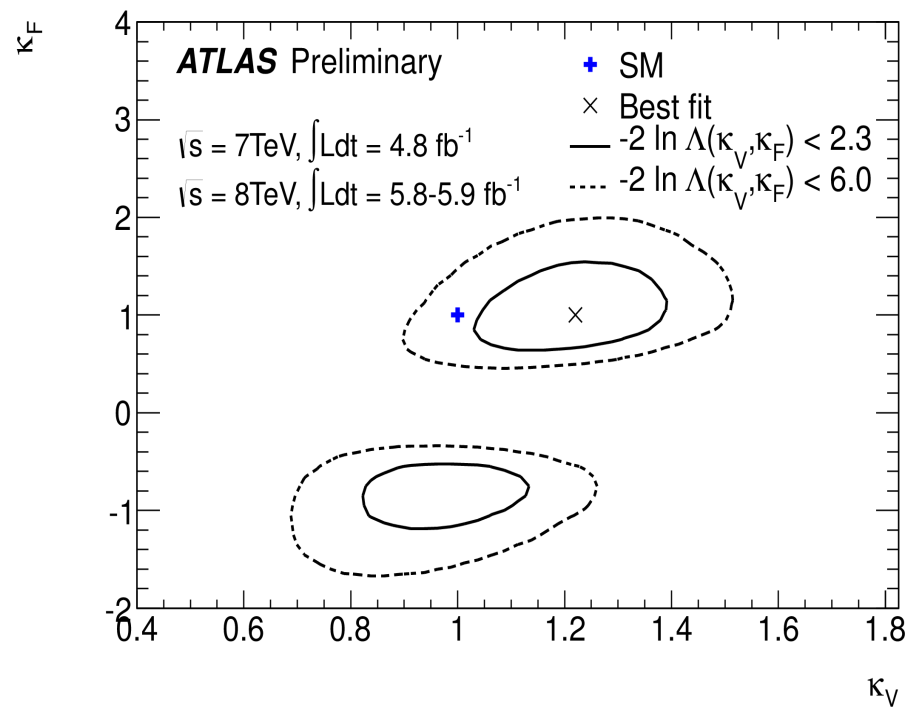
Combination of couplings

Assuming K_F scaling of all fermion couplings and K_V scaling of all vector boson couplings

CMS-HIG-12-045



ATLAS CONF-2012-127

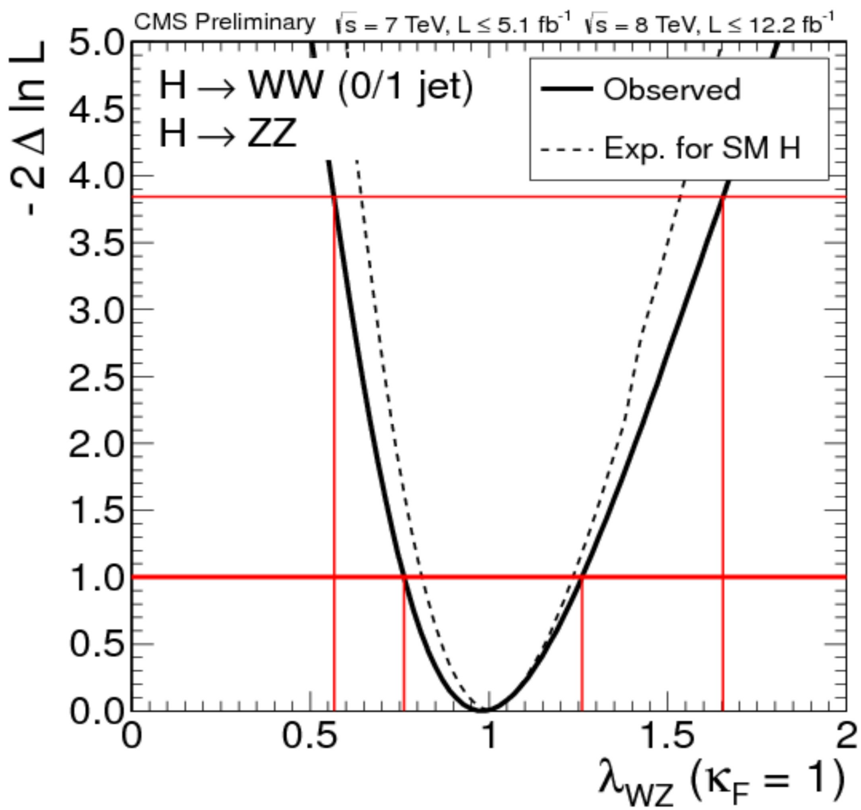


- **positive Yukawa → SM solution is out of 1σ region**
- **negative Yukawa → far from SM solution → dramatic implications for EWSB (see next slides)**

Test of Custodial Symmetry

- parametrization $\lambda_{WZ} = K_W / K_Z$ scaling of vector boson couplings
- results well consistent with SM
- $\lambda_{WZ} \in$ CMS: [0.57 – 1.65] ATLAS: [0.65 – 2] @ 95 % CL

CMS-HIG-12-045



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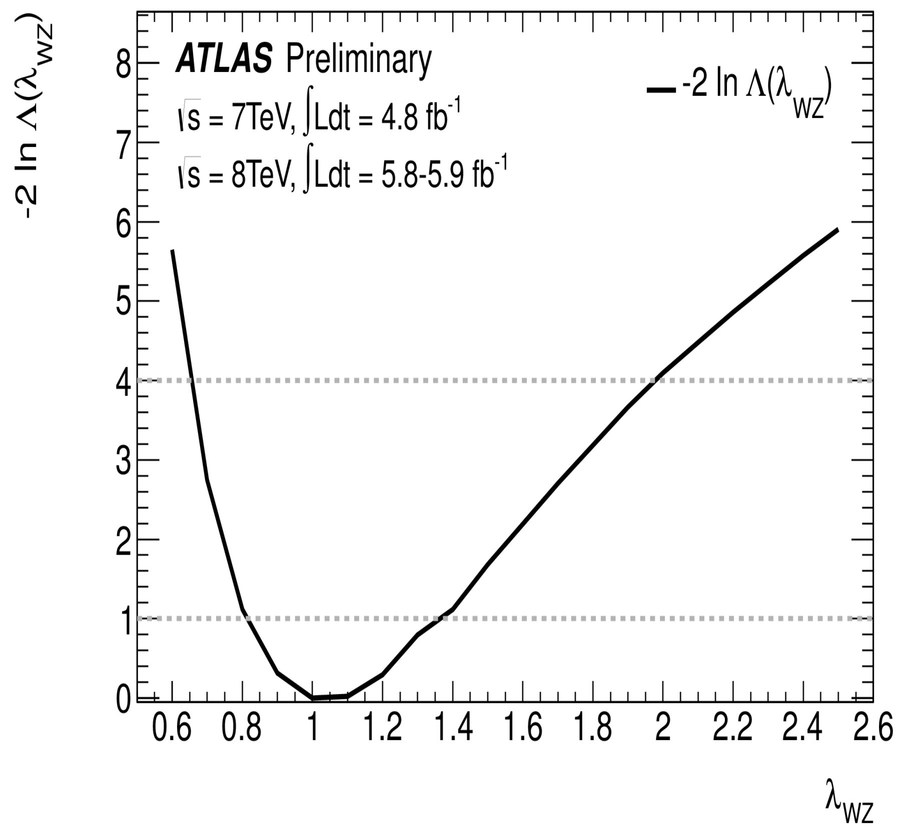
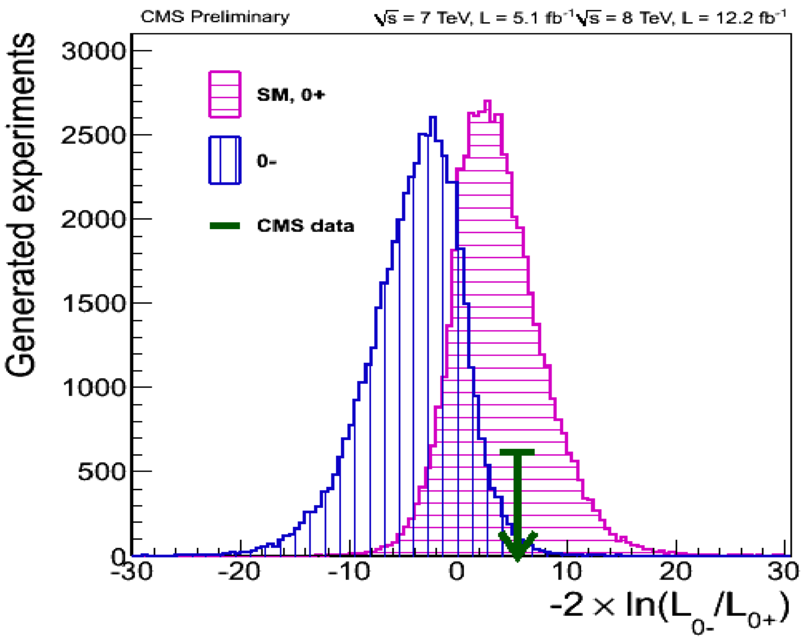


Main properties: spin and CP

- couplings to photons → spin 0 or 2
- leptons kinematic distributions in $H \rightarrow ZZ \rightarrow 4l$ decay used to discriminate $J^{PC} = 0^-$ and $J^{PC} = 2^+$ from $J^{PC} = 0^+$

CMS-HIG-12-045



- Expected distribution of the test statistics comparing the signal J^P hypotheses: 0^- vs 0^+.
  Observed value indicated by the arrow

- data disfavor pseudoscalar hypothesis (with a CL_s of 2.4 %)

What did we learn so far ?

- a new particle (elementary ?) with mass 125 GeV exists
- it is consistent with SM Higgs boson, considering its main decay channels $H \to WW$, $H \to ZZ$, $H \to \gamma\gamma$, $H \to \tau\tau$
- observed decay $H \to \gamma\gamma$ rules out the spin-1 hypothesis
- spin 0 or 2 allowed → pseudoscalar disfavored
- decay $H \to \gamma\gamma$ looks higher then SM → hint of new physics ?
- more statistics is needed in order to assess a non-zero measurement of $H \to bb$ and $H \to \tau\tau$
- Tevatron sees a 2.9σ excess in bb production, compatible with presence of $H \to bb$ with mass in the range 120 – 139 GeV

Why not being happy with SM Higgs boson?

- **mass is in the favored Higgs mass range of EWPT**
- **σ x BRs well consistent with SM predictions !!!**
- **SM is a renormalizable theory in principle valid up to Planck mass M_p**

Theoretical arguments in favor of New Physics

- **quantum instability of Higgs mass** $\rightarrow$ sensitivity to (UV cutoff $)^2$
  (cutoff scale is identified with mass of heavy particles coupled to Higgs)
- **this is at the origin of what we call the fine-tuning problem**
- **Cosmological constant problem is similar (but worst)**
- **Solving the fine-tuning problem has been the guide for BSM theories**
- **But...maybe the fine-tuning problem is a ill-defined problem ?**

- **Phenomenological arguments in favor of NP BSM:**
  - → huge hierarchy of fermion masses and mixing (origin of Yukawa couplings ?) → **flavor hierarchy problem**
  - → missing Dark matter candidate (as WIMP) in the SM
  - → not enough $\not{CP}$ source for matter-antimatter asymmetry of Universe

- **BSM theories aim to solve the Higgs fine-tuning problem**

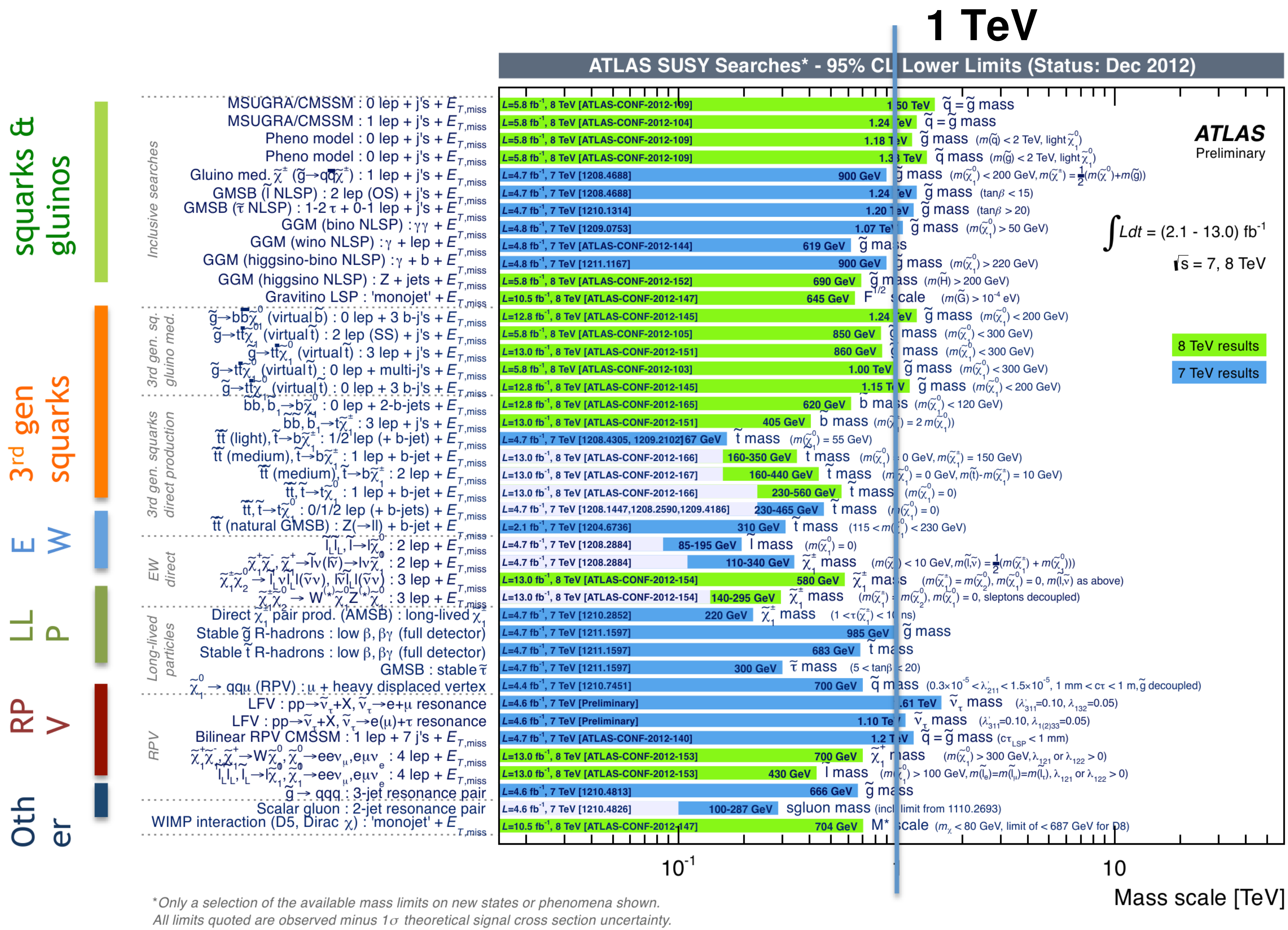
main approaches proposed so far:

- **Elementary Higgs boson → symmetry that cancels Λ^2 terms** (SUSY models, Lee-Wick SM (SM replica with massive ghosts))

- **Elementary Higgs boson → UV scale lowered at TeV scale** (quantum gravity models in large extra-dimensions)

- **Composite Higgs boson → strongly coupled NP sector,** (Technicolor, composite Higgs boson as pNGB)

Current status of SUSY searches



Higgs mass impact on SUSY models (MSSM)

$$m_h^2 = M_Z^2 \cos^2 2\beta + \delta_t^2$$

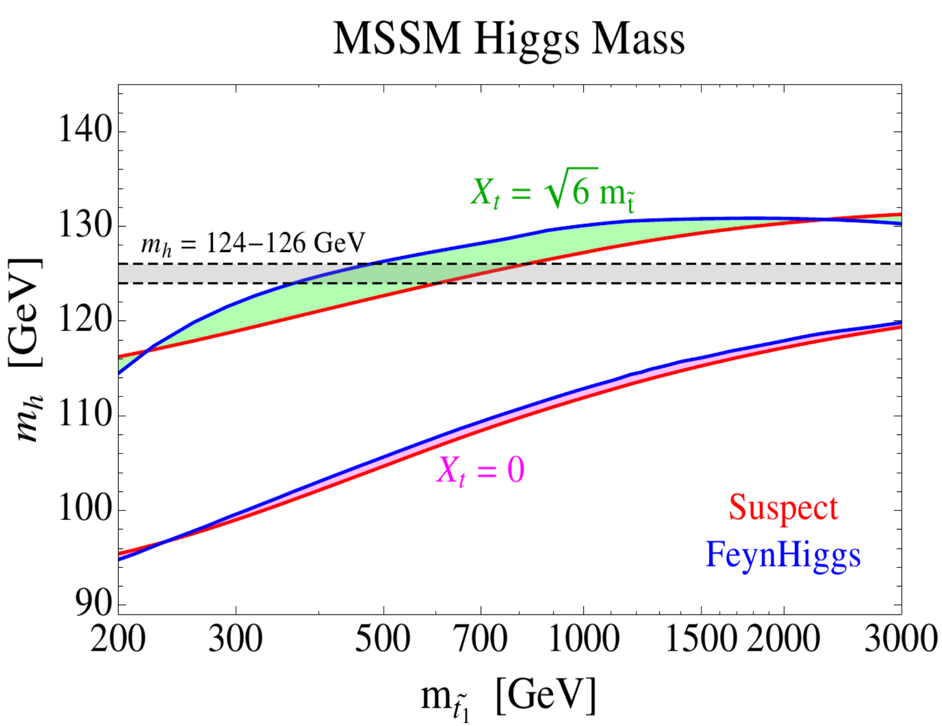
~ 85 GeV

large Higgs mass implies SUSY badly broken

at large tanβ→

$$\delta_t \approx \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde t}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde t}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde t}^2}\right)\right]$$

M_H=125 GeV requires heavy squarks



Large mixing → heavy stops

$$\sqrt{m_{Q_3} m_{u_3}} \gtrsim 700 \text{ GeV}$$

→ fine-tuning O(1%) on EWSB condition

$$-\frac{m_Z^2}{2} = |\mu|^2 + m_{H_u}^2$$

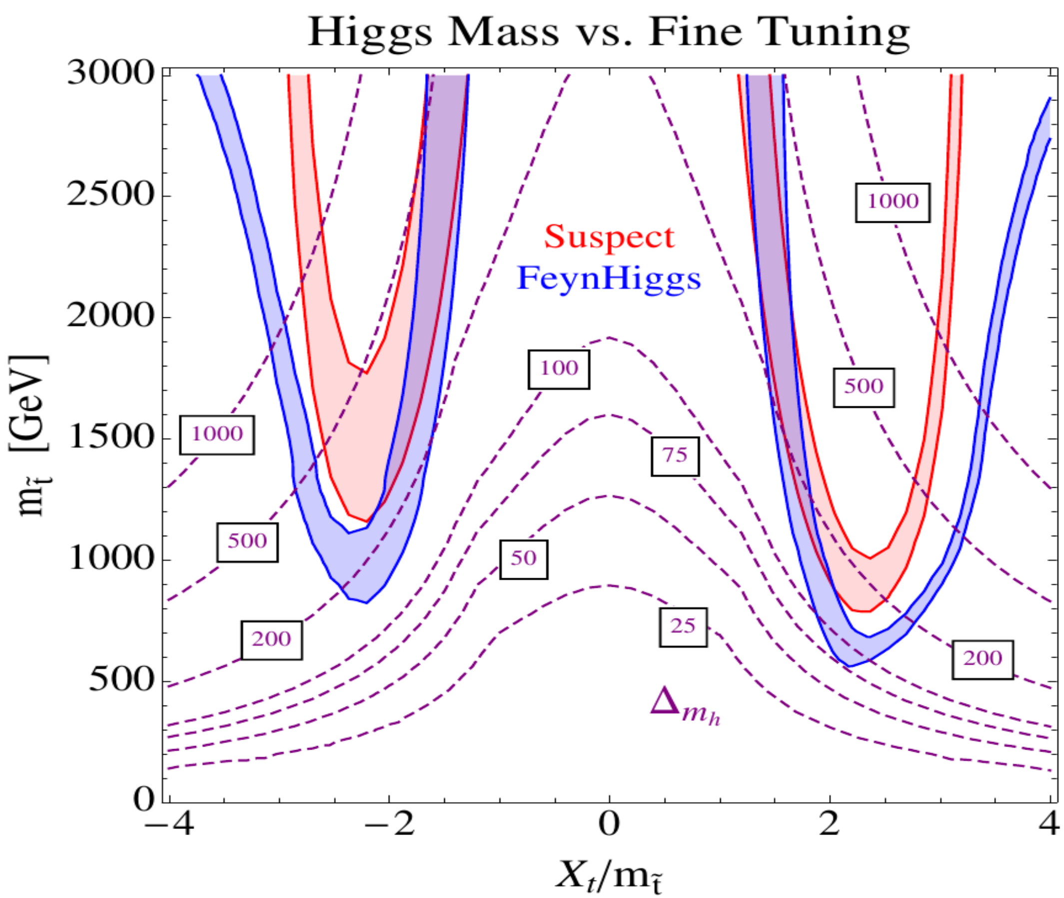
MSSM fine tuning

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2\right)\ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

Λ scale of SUSY breaking

- for large squarks $\delta m_{H_u}^2$ becomes too large
- fine tuning is needed to achieve EWSB

$$\Delta_{m_h} = \max_i \left|\frac{\partial \ln m_h^2}{\partial \ln p_i}\right|$$



Hall, Pinner, Ruderman JHEP 1204 (2012)

- maximal mixing required to avoid multi TeV stops
- difficult to achieve in SUSY breaking scenarios
- Δ_m > 75 (100) in order to achieve M_H =124 (126) GeV for Λ = 10 TeV
- fine-tuning much worst for higher Λ scales

Natural SUSY with M_H=125 GeV

Why SUSY should be simple MSSM ?

NMSSM → additional new singlet S → μ-term naturally generated by <S>

$$W \rightarrow \lambda S H_u H_d$$

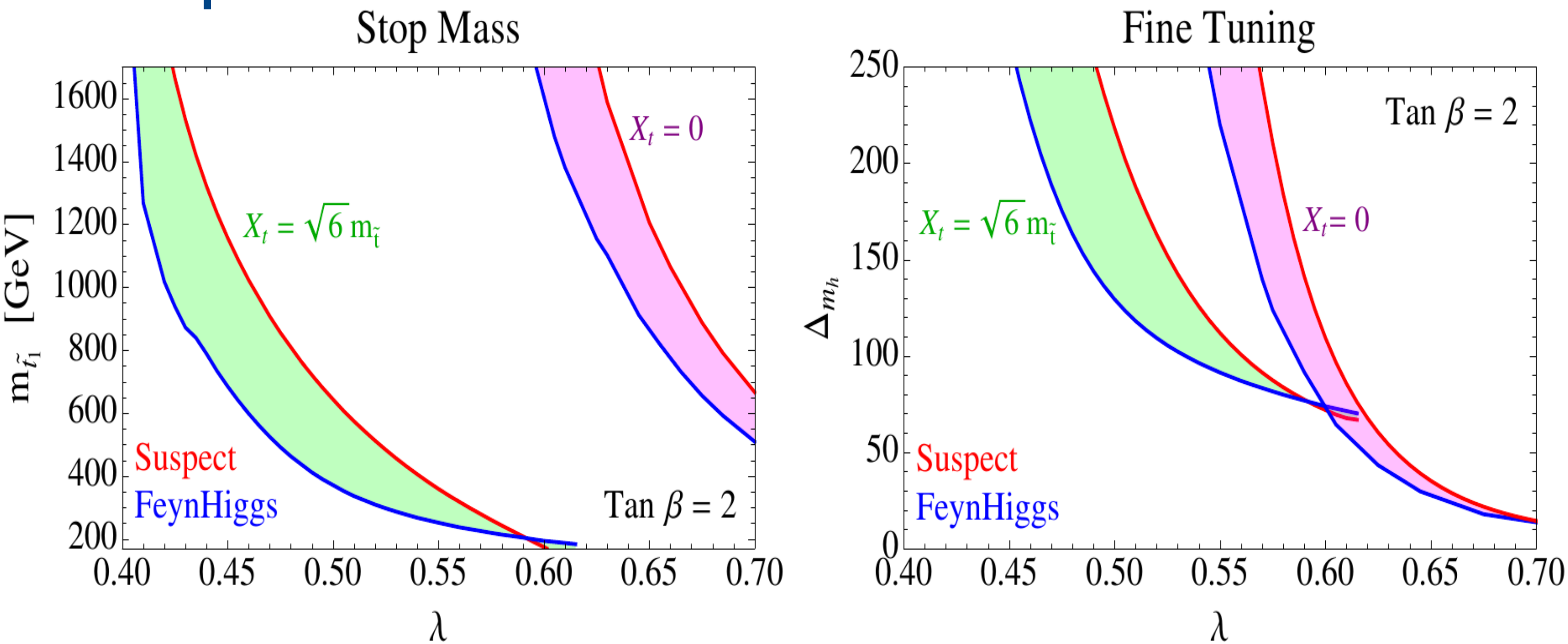
no dimensionfull terms in the W superpotential

$$(m_h{}^2)_{\text{tree}} \leq m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$$

- potentially reducing the fine-tuning problem
- however for large values of $\lambda > 0.7$ the theory becomes non-perturbative
- for $\lambda < 0.7$ theory is perturbative up to GUT scale

NMSSM perturbative

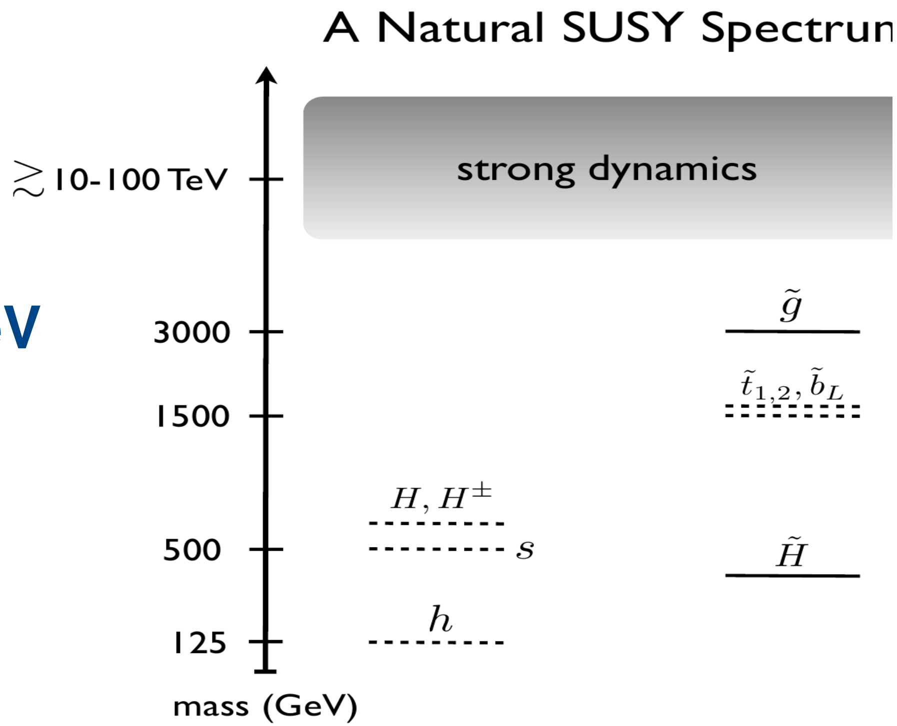
Hall, Pinner, Ruderman JHEP 1204 (2012)



- **large values of λ allow for lighter stops and much less fine tuning**
- **only 5 – 10 % tuning if mediation scale of SUSY breaking is low and stop mixing is non-maximal**
- **achieved with tanβ ~ 2 and λ ~ 0.7, but very close to the edge of perturbative regime**

Naturalness in large λ–SUSY scenario

- Higgs mass can be still 125 GeV with $\lambda > 2$ but strong dynamics expected at 10-100 TeV
- stops mass can be ~ 1.5 TeV
- gluino as heavy as 3 TeV

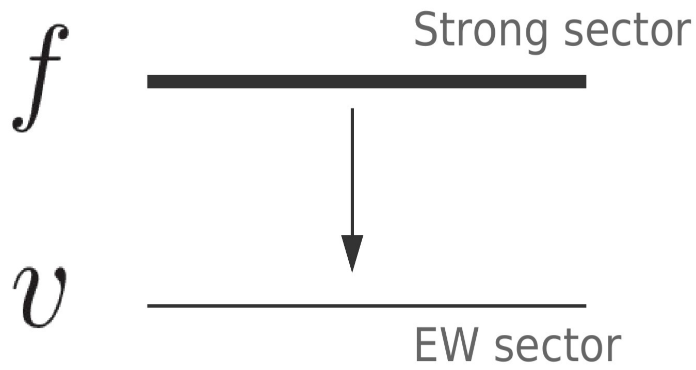


Hall, Pinner, Ruderman JHEP 1204 (2012)

- **Interesting non-decoupling effects among Higgs-doublets:**
  - suppresses the coupling of light Higgs to b-quarks
  - enhancing rates of γγ and **WW** and depleting rates of **bb** and ττ

Composite Higgs models

$$\xi = \frac{v^2}{f^2} < 1$$



Higgs boson is a bound state of a new strongly interacting sector → Pseudo Nambu-Goldstone Boson

Mass protected by its PNGB nature

Strongly Interacting Light Higgs (SILH)

- **Light composite Higgs as PNGB from strongly interacting sector (SIS)**

- **Higgs mass is acquired by interactions of SIS with SM fields**

- **Various realizations in specific models (**Holographic Higgs as PNGB, Little Higgs, etc**)** Harkani-Hamed, Cohen, Georgi (2001), Harkani-Hamed, Cohen, Katz, Nelson (2002), Contino, Nomura, Pomarol (2003)

- **Low energy effective Lagrangian parametrization in terms of two parameters:** coupling g_ρ and mass m_ρ of the strongly interacting sector Giudice, Grojean, Pomarol, Rattazzi JHEP 0706 (2007)

- $$m_\rho = g_\rho f$$
  Characteristic parameters
  f = scale of sigma-model
  $$\xi \equiv \frac{v^2}{f^2}, \quad v = \left(\sqrt{2}G_F\right)^{-1/2} = 246\,\mathrm{GeV}$$

- Expected small modifications to the SM Higgs couplings
- New operators in Higgs self-coupling suppressed by $1/m_\rho$
- Expected violation of unitarity in VV → VV scattering

$$
\begin{aligned}
g_{hWW} &= g m_W \left[1 - \frac{c_H}{2}\xi\right] , \\
g_{hff} &= \frac{g m_f}{2 m_W} \left[1 - \xi \left(\frac{c_H}{2} + c_y\right)\right] , \\
g_{hhh} &= \frac{g m_H^2}{4 m_W} \left[1 + \xi \left(c_6 - \frac{3 c_H}{2}\right)\right]
\end{aligned}
$$

C_i **parameters of order O(1) model dependent**

- **Higgs does not balance completely the VV → VV amplitude**
- **Scale of unitarity breaking higher than in no-Higgs**

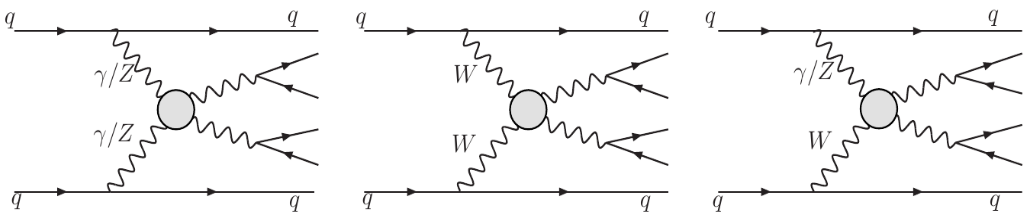
$$\sigma\left(pp \to V_L V_L' X\right)_{c_H} = \left(c_H \xi\right)^2 \sigma\left(pp \to V_L V_L' X\right)_{\not{H}}$$

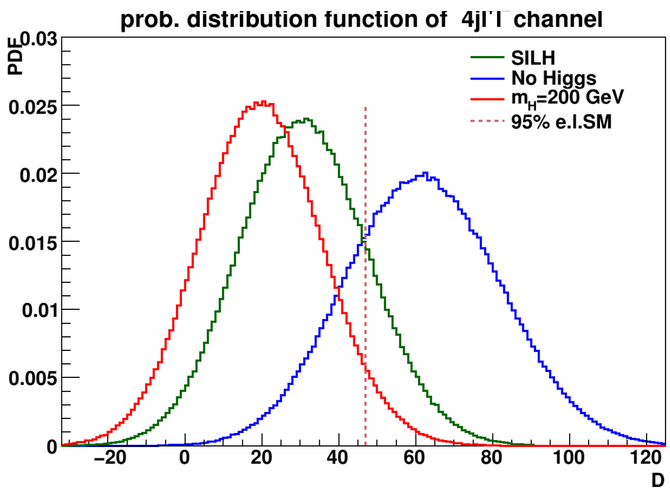
- **Unitarity recovered by exchange of heavy resonances**

- **new resonances are predicted in Composite Higgs models →** heavy vector-resonance ρ like in QCD, composite partners of top

- **rich phenomenology expected at LHC**

- **Possible to distinguish SM Higgs from Higgsless and SILH via VV → VV**





$4jl^+l^-$ channel

SILH with $c_H \xi = 1$

L=200/fb, LHC 14 TeV
sum over ee and μμ final states

Ballestrero et al., JHEP 0911 (2009)

D=actual number of events founds in the peak taking into account stat. fluct, $D = B + S - \overline{B}$

Limits on Higgs compositness

- Limits **from couplings measurement** of low mass Higgs h126

  -> LHC: $4\pi f$ > 5-7 TeV if no deviations observed

  -> ILC: $4\pi f$ > 30 TeV

- Direct analysis of **VV scattering and double Higgs production at LHC:**
  -> $4\pi f$ > 4 TeV (direct probe of SILH scenarios)

- **At LHC direct search of ρ** important at small g_ρ
  -> able to push m_ρ at 1 TeV-2 TeV, ie $4\pi f$ > 3-4 TeV
  but less effective at high g_ρ

- **At ILC the test of aTGC** can constraint m_ρ > 7-8 TeV

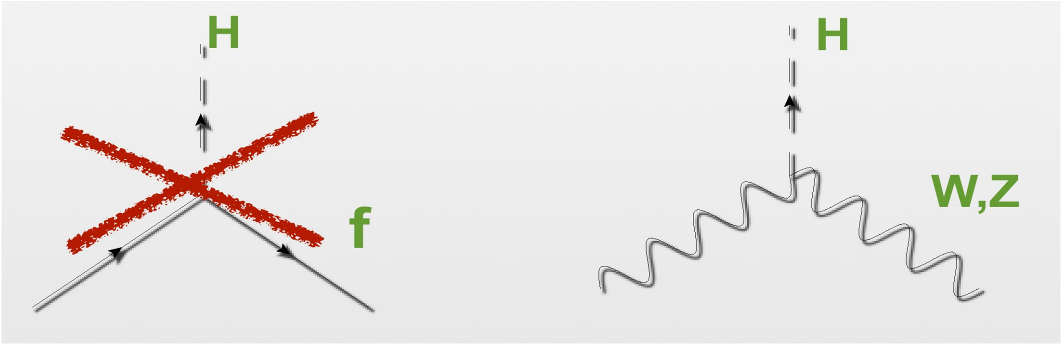
Bolognesi' s talk snowmass 2013

More exotic scenarios

...what if Higgs boson is only responsible for Mw, Mz but not of fermion masses ?

- fermion masses $\neq 0$ → Chiral Symmetry Breaking
- in SM, ChSB and EWSB (M_W , $M_Z \neq 0$) are generated by the Higgs mechanism at the same scale ~ vev = <H>
- not (yet) any direct experimental evidence supporting the existence of tree-level Yukawa couplings Y_f
- present measurements of $H \to bb$ and $H \to \tau\tau$ decays have large errors → still compatible with vanishing Yukawas
- a direct measurement of top quark coupling (tt H) is missing
- ChSB and EWSB can have different mechanisms: ChsB → compositeness, extra-dimensions, technicolor...

Naive Fermio-Phobic Higgs scenario



- **NO** Yukawa couplings at tree-level
- Higgs mechanism gives mainly rise to EWSB and Mw,Mz
- but is not responsible for ChSB and fermion masses

Advantages

- **Fermiophobia lowers the vacuum stability bound on Higgs**
- **M_H= 125 GeV consistent with no NP below Planck scale**

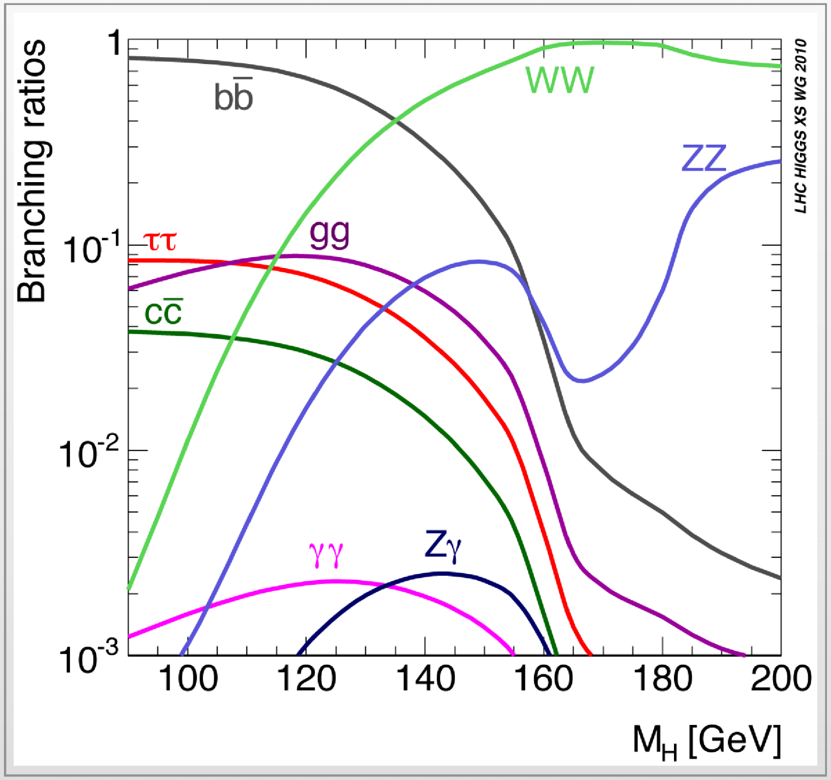
Giardino, Kannike, Raidal, Strumia, PLB 718 (2012)

Higgs decays : FP vs SM

[through W loops (no-top loops)]

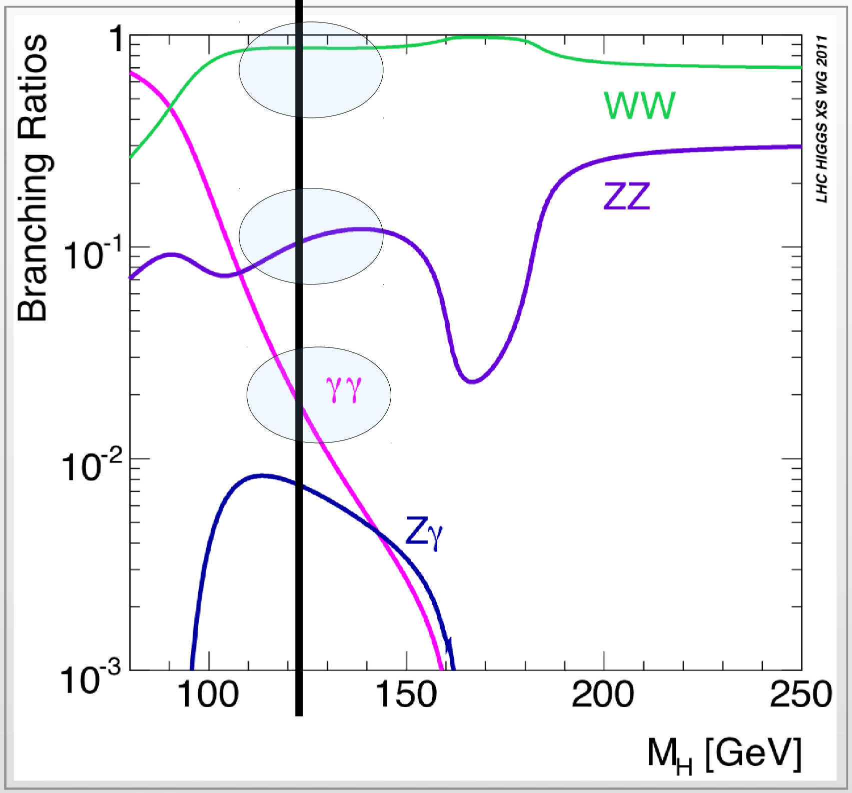
- H → WW, ZZ, γγ, Zγ

SM Higgs



M_H=125 GeV

FP Higgs

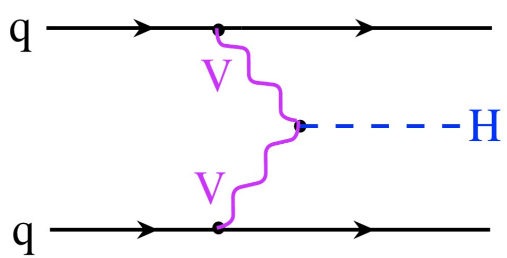


For M_H ~ [100,110,125] GeV :

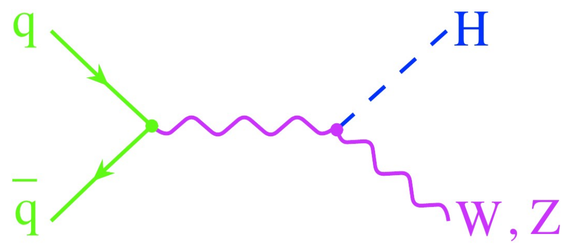
$BR(\gamma\gamma)_{FP}$ ~ [110,30,7] x $BR(\gamma\gamma)_{SM}$

Naive Fermio-Phobic Higgs production mechanisms

VBF



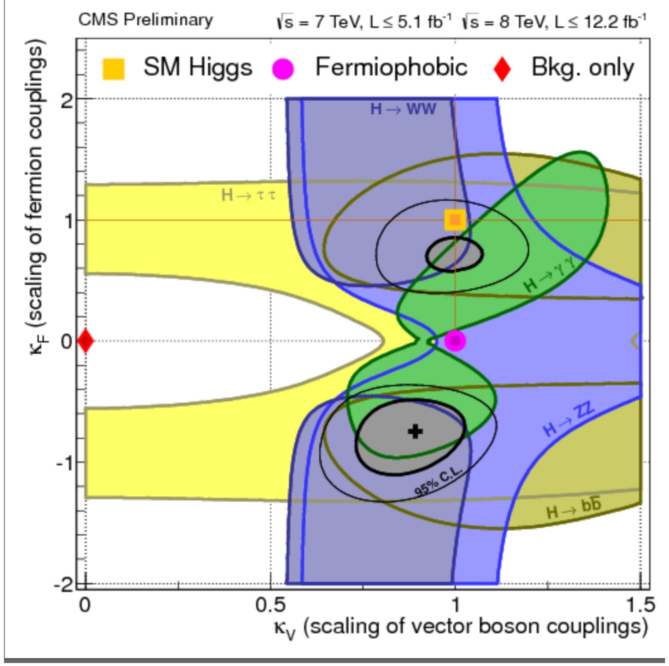
VH



- no gluon-gluon fusion
- VBF fusion dominant mechanism
- harder pT spectrum → better S/B !

Naive FP Higgs with M_H=125 GeV excluded at 99 % CL

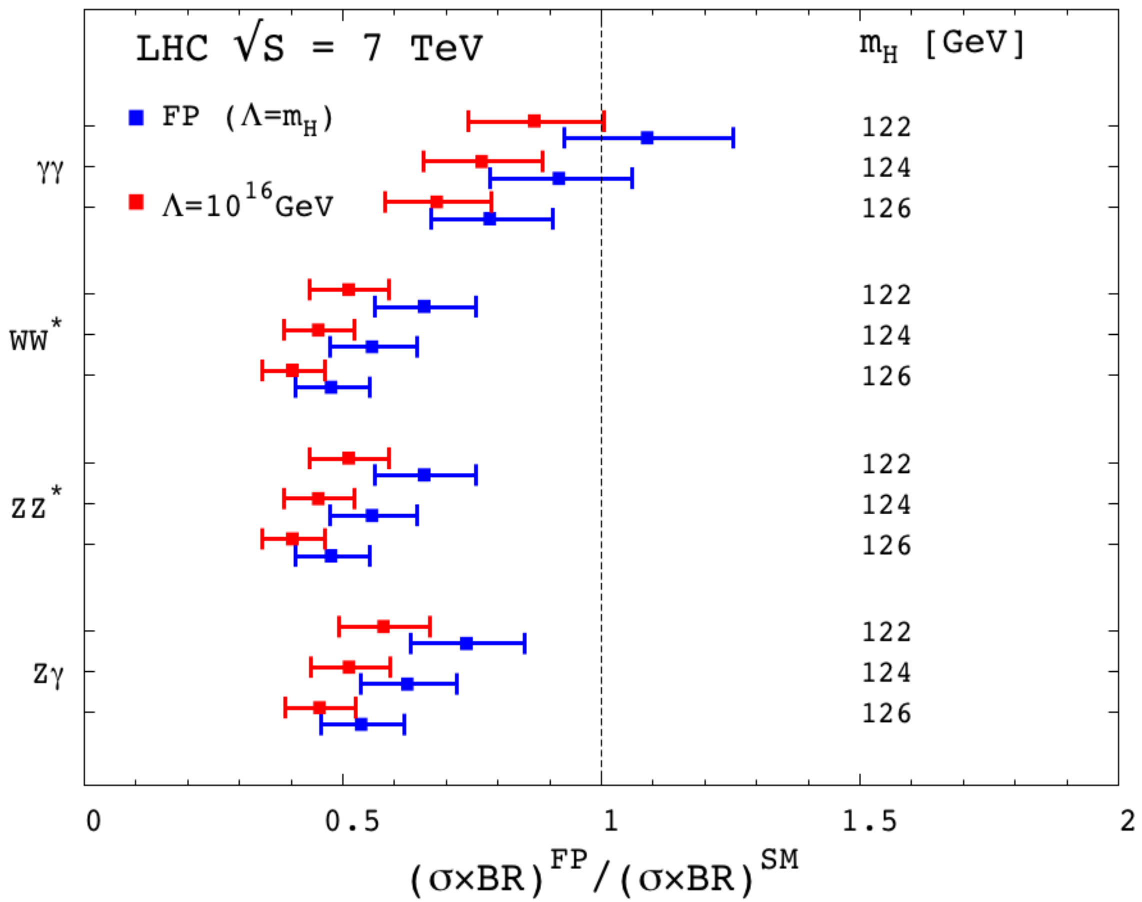
CMS-HIG-12-045



- **NFP Higgs predicts μ=1 @ M_H=123 GeV**
- **higher μ predicted in WW, ZZ , $\gamma\gamma$ when VBF and VH tagging are applied**
- **observed rates in VBF and VH are much smaller.**

- above results do not take into account effect of **Radiative Corrections**
- **RC** can suppress BRs of **H → $\gamma\gamma$, WW,ZZ** (depending on the NP scale Λ where Yukawa' s are assumed to be vanishing)
- Yukawa couplings cannot be kept vanishing at any scale
- fermion masses ⇒ Yukawa radiatively generated **EG , Mele, PRD 82 (2010)**

Inclusive production



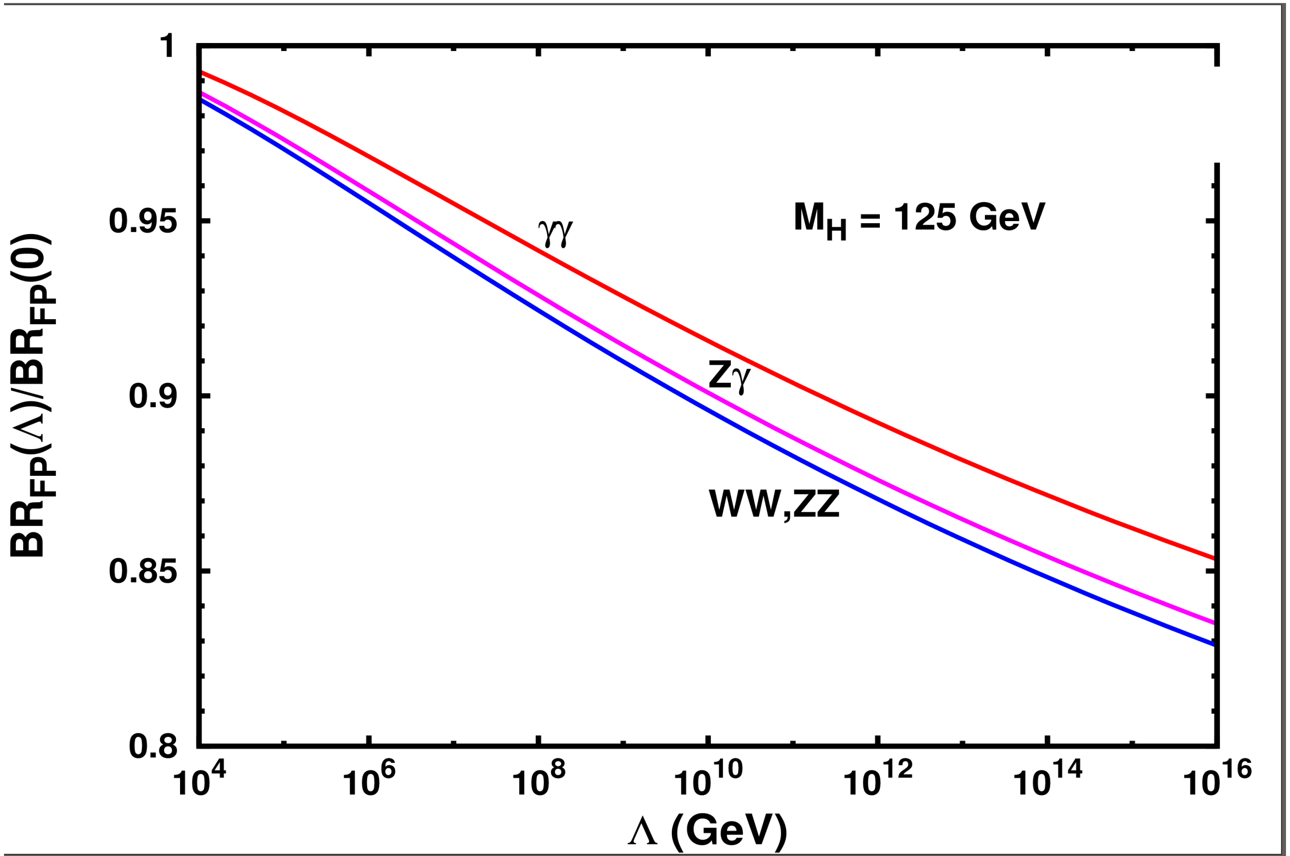
EG,B.Mele,M.Raidal PLB 716 (2012)

Naïve FP predicts $\mu = 1$ @ M_H=123 GeV, while RC can reduce it

Λ → scale where Yukawa couplings are vanishing

Effects of radiative corrections on

$BR_{FP}(\Lambda)$ / $BR_{FP}(0)$: M_H=125 GeV



reduction < 10 – 20% for $\Lambda \sim 10^{10}$ – 10^{16} GeV

EG,Mele,Raidal PLB 716 (2012)

Can SUSY be ruled out if we find that Yukawa couplings are vanishing at tree-level ?

- Vanishing Yukawa's in MSSM

  → impact on MSSM would be dramatic

  → whole MSSM strongly disfavored !
  vanishing Yukawas ⇒ $M_H < M_Z$

- switching off Yukawa couplings in MSSM is not as smooth as in SM

- supersymmetry as an effective low energy theory → NMSSM viable (but not renormalizable)

Failure of MSSM in the FP limit

Fermiophobic limit: $y_t \to 0$

$$\Delta M_h^2 = -\frac{3v^2 \sin^2\beta}{2\pi^2}\frac{a_t^4}{48 M_S^4} < 0$$

- we cannot get mH > mZ and even more ~125 GeV
- mH < mZ ⟶ MSSM is ruled out
- FP Higgs if SUSY → cannot be just MSSM-like

Advantages of SUSY Fermiophobia

- Fermiophobic Higgs can cure some SUSY problems

- fine-tuning problem of SUSY induced only by gauge couplings → fine-tuning improved by a factor

$$N_c y_t^4 / g^4 \sim 25.$$

- removes little SUSY hierarchy problem

- squarks and sleptons masses of 2-3 TeV become now completely Natural

- FCNC and CP problems automatically solved

- SUSY effects in FCNC processes much suppressed

Fermiophobic NMSSM viable

EG, Kannike, Mele, Racioppi, Raidal, PRD 86 (2012)

Z_3 symmetric FP NMSSM superpotential

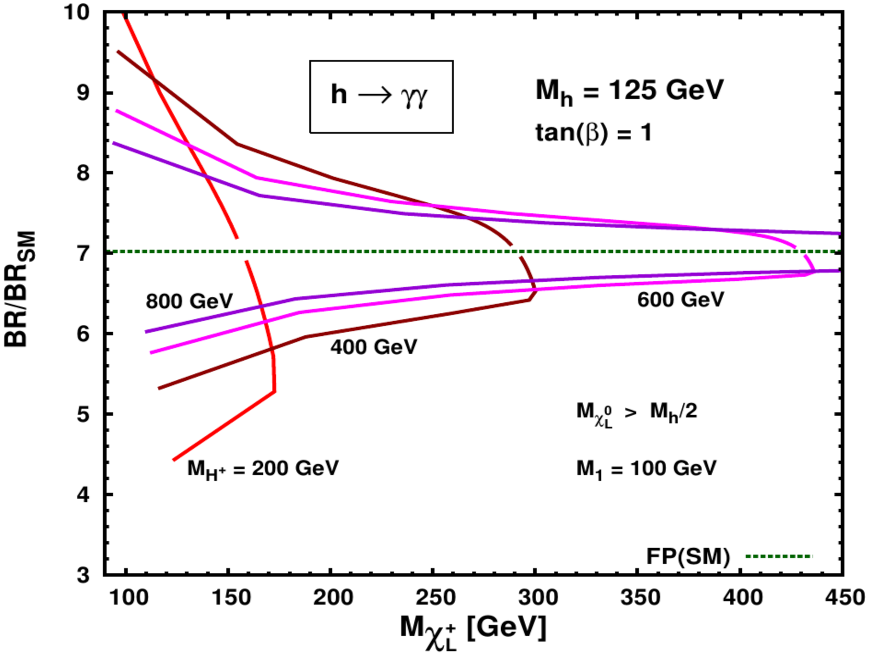
$$\mathcal{W} = \lambda S H_u H_d + \frac{k}{3} S^3$$

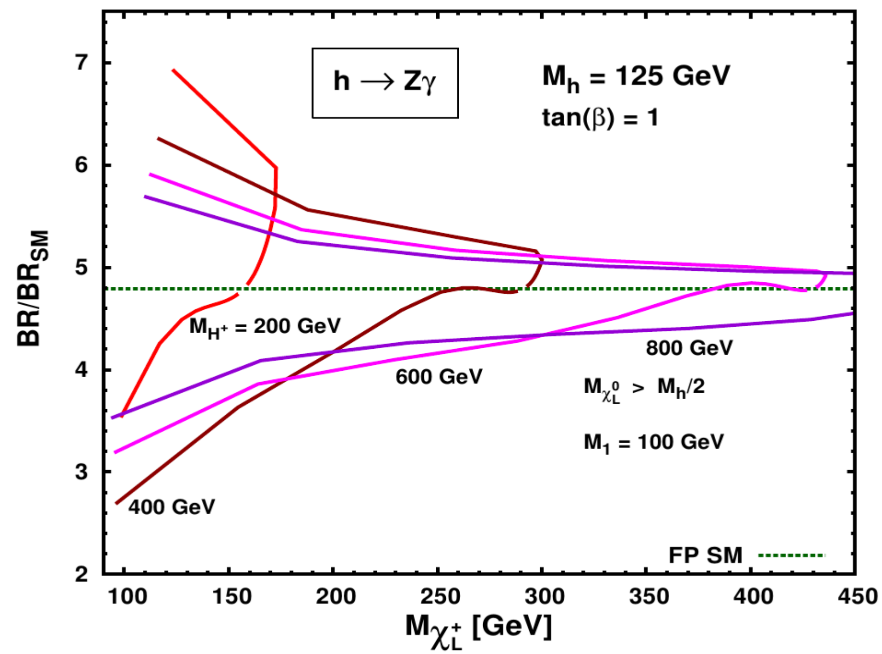
and S, H_u, H_d soft terms

$$\mathcal{L}_{\rm soft}^{S,H} = -\left(m_{h_u}^2 h_u^\dagger h_u + m_{h_d}^2 h_d^\dagger h_d + m_s^2 s^\dagger s\right) - \left(a_\lambda s h_u h_d + \frac{1}{3} a_k s^3 + h.c.\right)$$

where

- s is the scalar component of S
- Z_3 is also used in order to get fermiophobia
- $X_{H_u} = X_{H_d} = X_S = 1$ and $X_f = 0 \Rightarrow \boxed{y_f, a_f = 0}$
  But also other possible configurations (see 1204.0080)





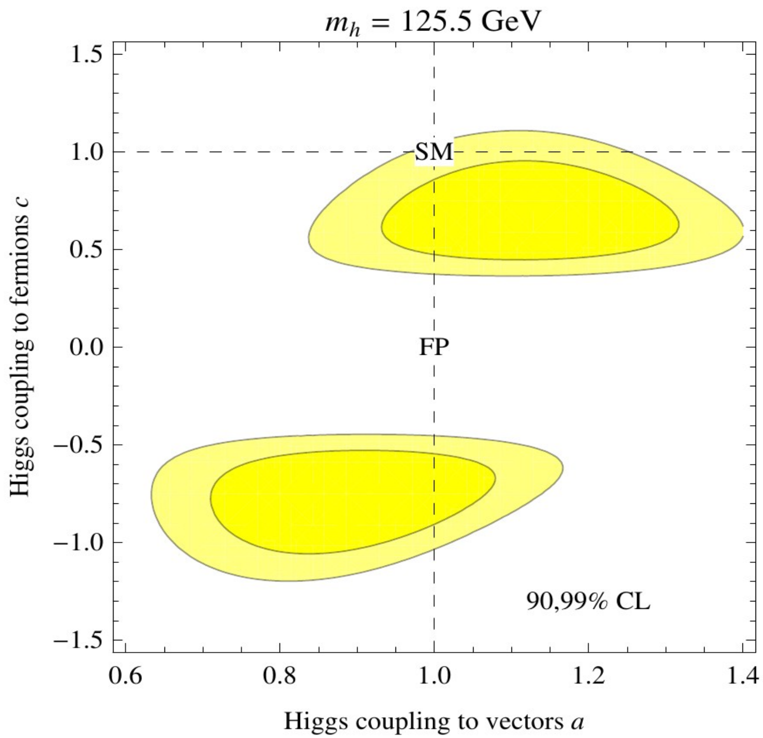
- BR(H → γγ) can be decreased → reducing the tension in VBFxBR(γγ) rates
- but without ggH coupling the FB NMSSM is disfavored by observed inclusive production rates of H → γγ (which requires a ggH coupling)
- but ggH coupling can be generated by loop of squarks alone !
- This requires large A-terms if Yukawa couplings are vanishing

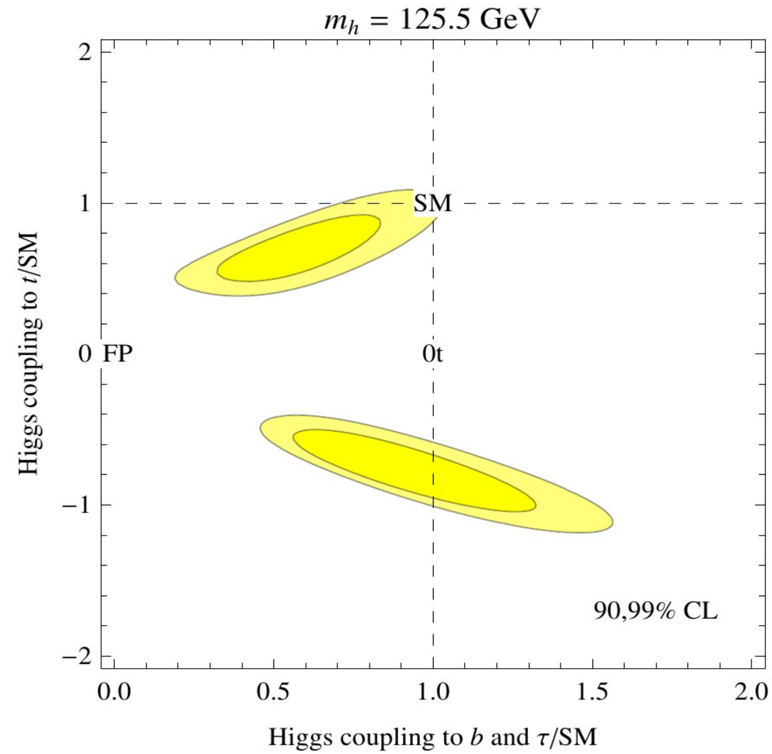
(EG, Racioppi work in progress)

- FP NMSSM would require a completely new strategy search at LHC

Wrong sign in Yukawa couplings: **$Yf \rightarrow -Yf$**
(suggested by the fits)

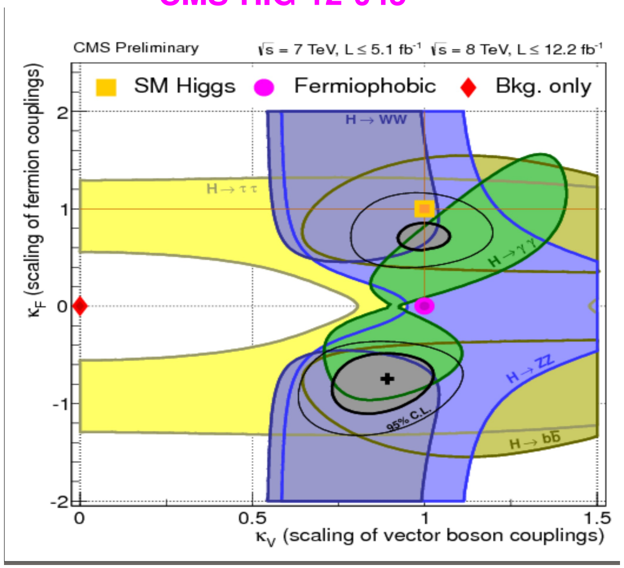
cure: **requires new physics at TeV scale**

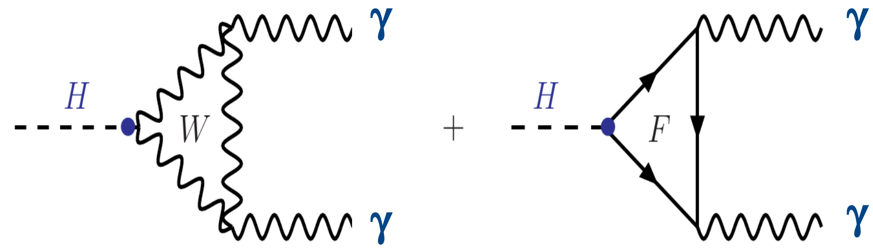




Giardino, Kannike, Raidal, Strumia, PLB 718 (2012)

CMS-HIG-12-045





- Negative solutions for K_F mainly comes from $H \to \gamma\gamma$
- Sign $[A^H_{1/2}$(loop of top)$]$ = - Sign$[A^H_1$(loop of W)$]$

$$\Gamma(H \to \gamma\gamma) = \frac{G_\mu \alpha^2 M_H^3}{128\sqrt{2}\pi^3} \left| \sum_f N_c Q_f^2 A^H_{1/2}(\tau_f) + A^H_1(\tau_W) \right|^2 \qquad \tau_i = M_H^2/4M_i^2$$

- Changing the sign of top-Yukawa coupling improves the fit in $H \to \gamma\gamma$: destructive interferences turn out to be constructive

- **Is any process allowing to directly constrain the sign of top-Yukawa coupling ? → YES**

How to disentangle the sign of top Yukawa coupling

- **Flipping the sign of Yukawa couplings has dramatic consequences for the EWSB**

- **relative sign of Hff and HWW couplings is physical**

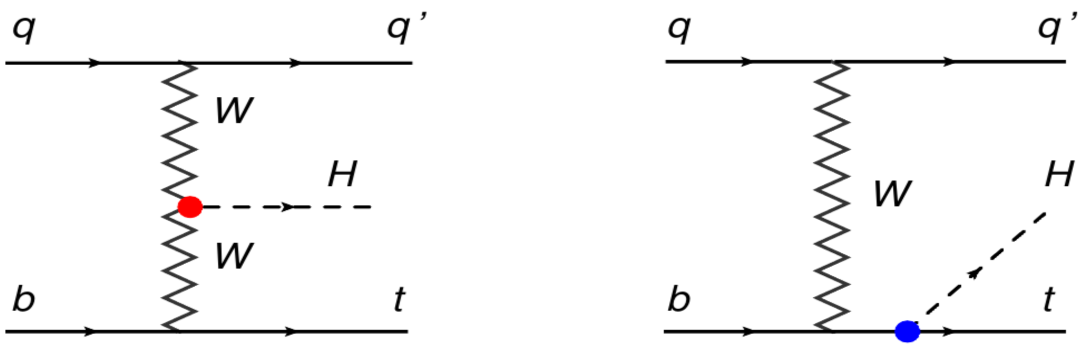
- **unitarity and renormalizability are spoiled**

- **unitarity in $V_L\, V_L \rightarrow f\, f \rightarrow$** recovered by adding new weakly interacting resonances (Higgs-boson-like) or by infinite tower of strongly coupled resonances

- **If the scale of unitarity violation is high enough then the low energy processes should be insensitive to UV-completion**

Sensitive process to the sign of top-Yukawa

Biswas, EG, Mele JHEP 1301 (2013)



$$\boxed{q\, b \to t\, q'\, H} \to t\, q' \gamma\gamma$$ **with signature of H → γγ**

Two scenarios considered

- **Universal Yukawa rescaling** that is assuming just one free parameter $C_f = C_t$ (and $C_V = 1$) both in production and decay amplitudes. $BR_{\gamma\gamma}$ is then a function of C_t, which enters both the $H \to \gamma\gamma$ width and the Higgs total width through C_f;
- **C_t and BR(γγ) as independent parameters** $C_V = 1$), with C_t affecting only production cross sections, and $BR_{\gamma\gamma}$ describing the overall effect of new physics on the Higgs decay rate.

SM total σ x BR (γγ) is small

$$\sigma(q\,b \to t\,q'H)^{SM} \simeq 15.2 \text{ fb} \quad \text{at} \quad \sqrt{s} = 8 \text{ TeV}$$
$$\sigma(q\,b \to t\,q'H)^{SM} \simeq 71.8 \text{ fb} \quad \text{at} \quad \sqrt{s} = 14 \text{ TeV}$$

$$BR_{\gamma\gamma}^{SM} \simeq 2.29 \cdot 10^{-3}$$

- For $C_F < 0 \rightarrow \sigma$ expected to grow up due to unitarity breaking

- BR(γγ) mostly sensitive to a reduction of magnitude $|C_F|$

$$\Lambda = 12\sqrt{2}\pi \frac{v^2}{m_t\,|c_F - c_V|}$$ ~ 9.3 TeV

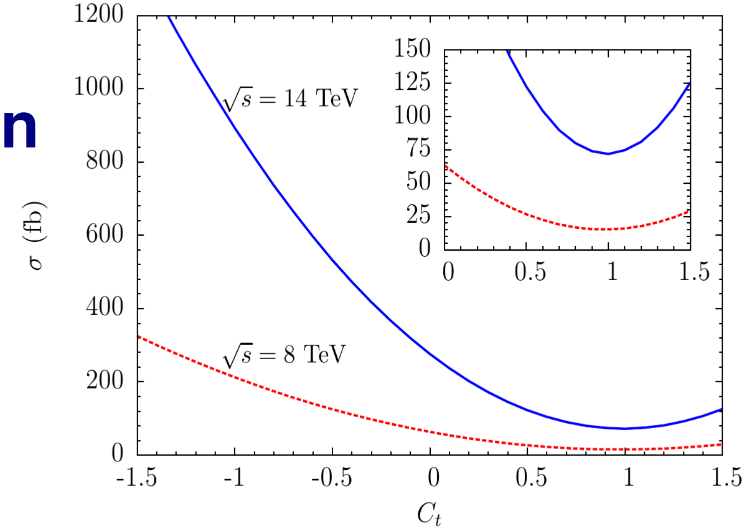
scale of unitarity breaking

Farina, Grojean, Maltoni, Salvioni, Thamm 1211.3736

same process but with H → bb signature

Enhancement factors versus C_t

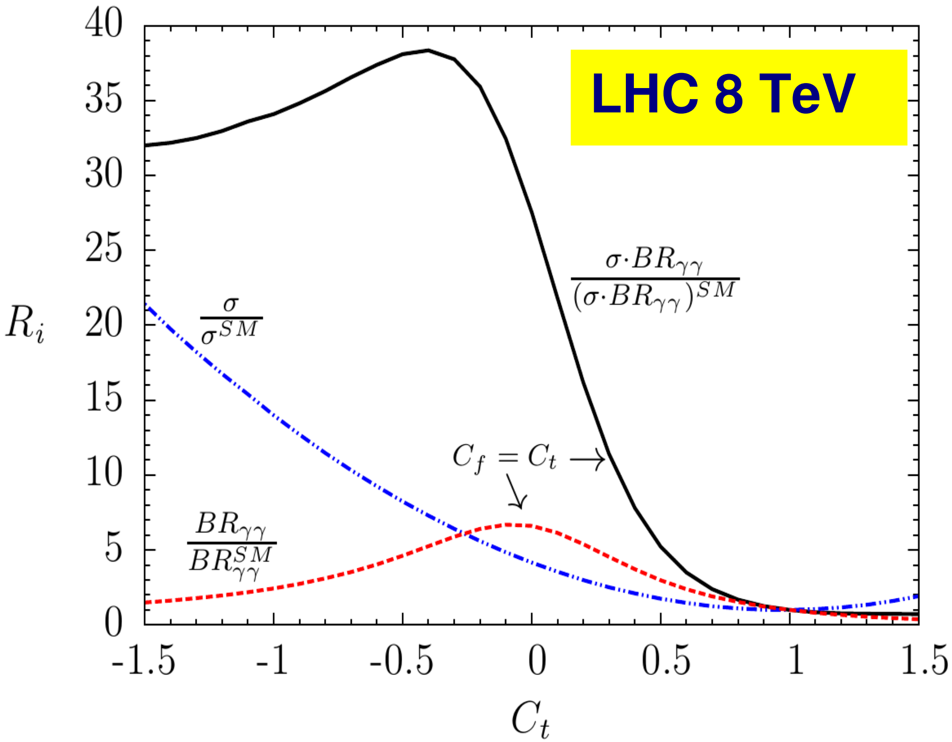
Total cross section
$pp \to t\,q\,H$

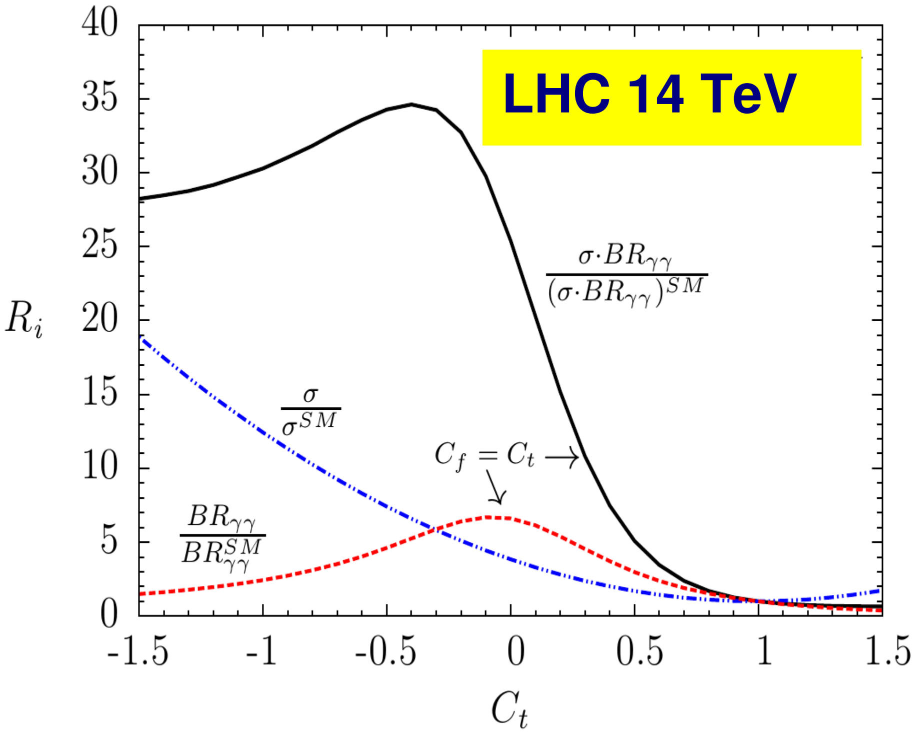


SM → $C_t = 1$

PDF = CTEQ6L1

R_i = Ratios





Irreducible backgrounds for pp → t q H (→ γγ)

- we are looking for top decaying hadronically $t \to b\, q\, q'$
- final state bckg consists of → $2\,\gamma + b\, + (\geq\ 3\, j)$
- irreducibles bckg processes

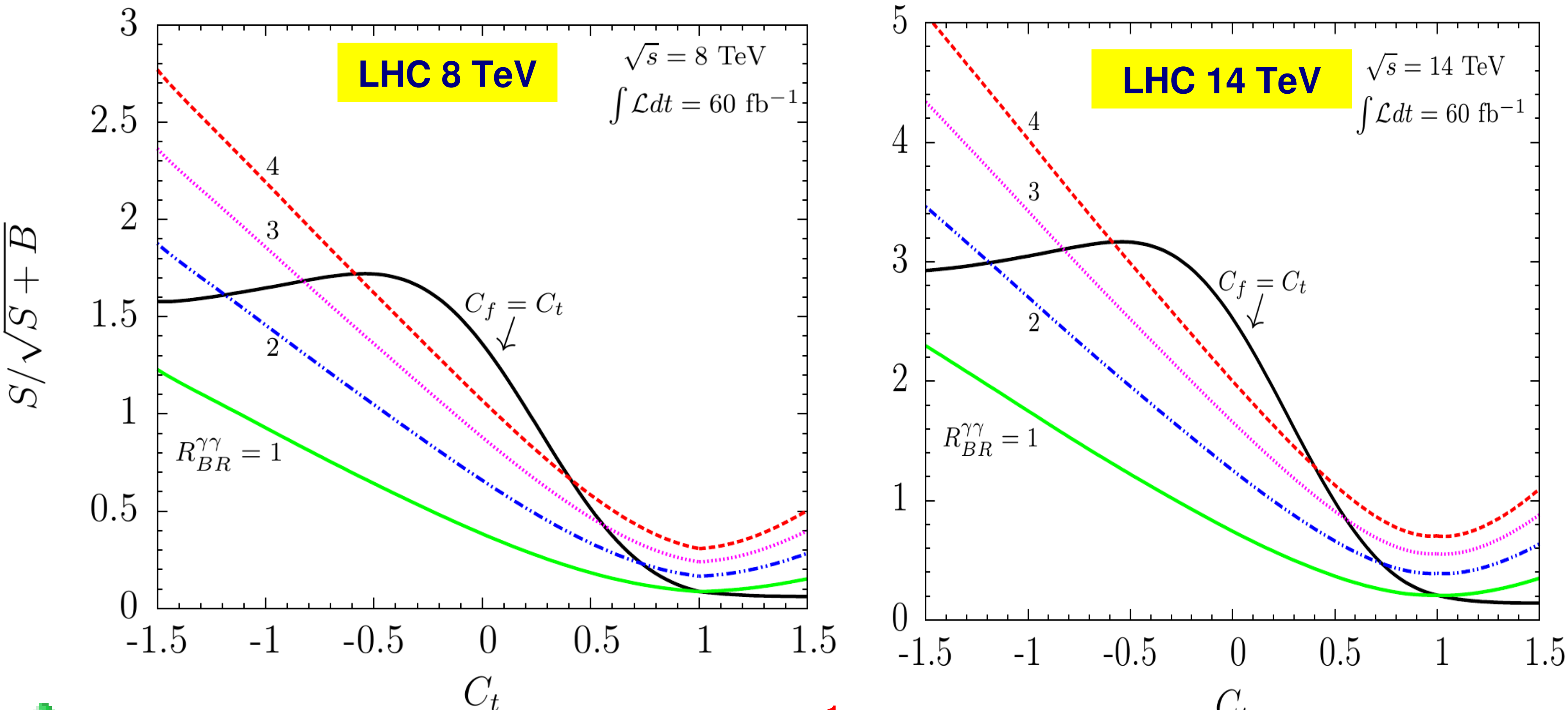
$$
\begin{aligned}
pp &\to 2\,\gamma + t + j\,, \\
pp &\to 2\,\gamma + \bar{t}\, t\,, \\
pp &\to 2\,\gamma + b + 3\, j
\end{aligned}
$$

- optimized selection cuts

$$p_T^{\gamma_1} > 40 \text{ GeV}, \qquad p_T^{\gamma_2} > 30 \text{ GeV}, \qquad p_T^{j,b} > 25 \text{ GeV}, \qquad |\eta_{\gamma,b}| < 2.5, \qquad |\eta_j| < 4.5$$

$$\Delta R_{i,j} = \sqrt{\Delta\eta_{i,j}^2 + \Delta\phi_{i,j}^2} > 0.4$$

- bckg well under control



- an integrated Luminosity of **L = 60 fb^{-1}** would give **10 signal events** versus **0.3 of bckg** overall the negative range **$-1.5 < C_t < 0$**
- **SM would require HL-LHC to reach an observable event statistics**

- Including different decay channels can dramatically improve the significance already with data at 8 TeV (Biswas, Margaroli, Mele, work in progress)

Can be the 125 GeV resonance an Higgs-boson imposter?

- Spin-1 is ruled out while spin-2 case will be tested soon
- Pseudoscalar case disfavored
- Let' s focus on the case of a scalar-like imposter

Low, Lykken, Shaughnessy PRD 86 (2012)

- EW singlet and a custodial singlet → strongly disfavored
  - coupled to operator of dimension 4 (like dilaton, or graviscalar) i.e. to the trace of EMT $T_\mu^{\ \mu} \sim$ masses
  - Coupled to operators of dim. 5, as $\phi\, F_{\mu\nu} F^{\mu\nu} / \Lambda$
- Not an EW singlet but a custodial singlet and neutral member of a custodial 5-plet

  → could belong to an EW triplet of SU(2) (triplet imposter)

Dilaton imposter (χ) $\rightarrow$ same couplings as SM

$$\mathcal{L}_{\chi V_1 V_2} = c_{\chi V}\left(\frac{2m_W^2}{v}\chi W_\mu^+ W^{-\mu} + \frac{m_Z^2}{v}\chi Z_\mu Z^\mu\right) + c_{\chi g}\frac{\alpha_s}{12\pi v}\chi G^a_{\mu\nu}G^{a\,\mu\nu} + c_{\chi\gamma}\frac{\alpha}{8\pi v}\chi F_{\mu\nu}F^{\mu\nu} + c_{\chi Z\gamma}\frac{\alpha}{8\pi v s_w}\chi F_{\mu\nu}Z^{\mu\nu}$$

EW singlet imposter (s)

$$\mathcal{L}_{sV_1V_2} = \kappa_W \frac{\alpha}{8\pi m_s s_w^2} s W^+_{\mu\nu}W^{-\mu\nu} + \left(\kappa_W\frac{c_w^2}{s_w^2} + \kappa_B\frac{s_w^2}{c_w^2}\right)\frac{\alpha}{16\pi m_s} s Z_{\mu\nu}Z^{\mu\nu} + \kappa_g\frac{\alpha_s}{16\pi m_s} s G^a_{\mu\nu}G^{a\,\mu\nu} + (\kappa_W + \kappa_B)\frac{\alpha}{16\pi m_s} s F_{\mu\nu}F^{\mu\nu} + \left(\kappa_W\frac{c_w}{s_w} - \kappa_B\frac{s_w}{c_w}\right)\frac{\alpha}{8\pi m_s} s F_{\mu\nu}Z^{\mu\nu},$$

SZγ coefficient of same order of SZZ and SWW

$$\Gamma_{gg} \gtrsim \Gamma_{\gamma\gamma} \gtrsim \Gamma_{Z\gamma} \gtrsim \Gamma_{WW} \gtrsim \Gamma_{ZZ}$$

$$\Gamma^{(\mathrm{SM})}_{WW} > \Gamma^{(\mathrm{SM})}_{gg} > \Gamma^{(\mathrm{SM})}_{ZZ} > \Gamma^{(\mathrm{SM})}_{\gamma\gamma} > \Gamma^{(\mathrm{SM})}_{Z\gamma}$$

→ @ M_H=125 GeV

Model independent fits

Useful to consider the ratios

$$D_{W/Z} \equiv \frac{B\sigma_{gg}(WW)}{B\sigma_{gg}(ZZ)} = \frac{\Gamma(S \to WW)}{\Gamma(S \to ZZ)}$$

$$D_{\gamma/Z} \equiv \frac{B\sigma_{gg}(\gamma\gamma)}{B\sigma_{gg}(ZZ)} = \frac{\Gamma(S \to \gamma\gamma)}{\Gamma(S \to ZZ)},$$

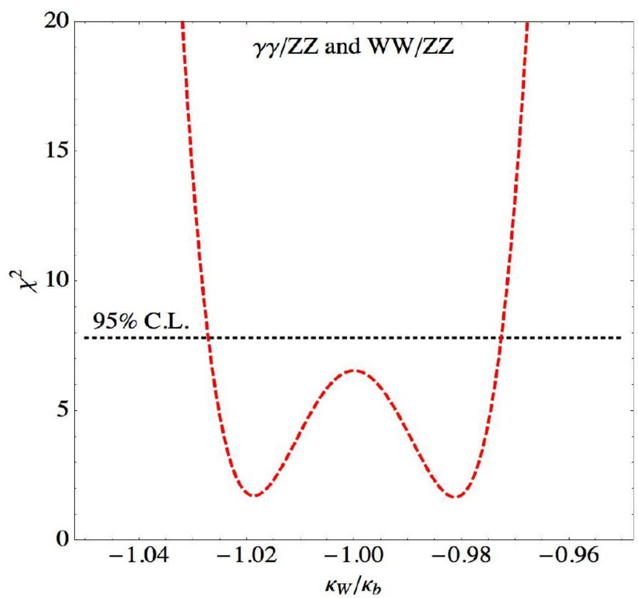
$$D_{Z\gamma/Z} \equiv \frac{B\sigma_{gg}(Z\gamma)}{B\sigma_{gg}(ZZ)} = \frac{\Gamma(S \to Z\gamma)}{\Gamma(S \to ZZ)}.$$

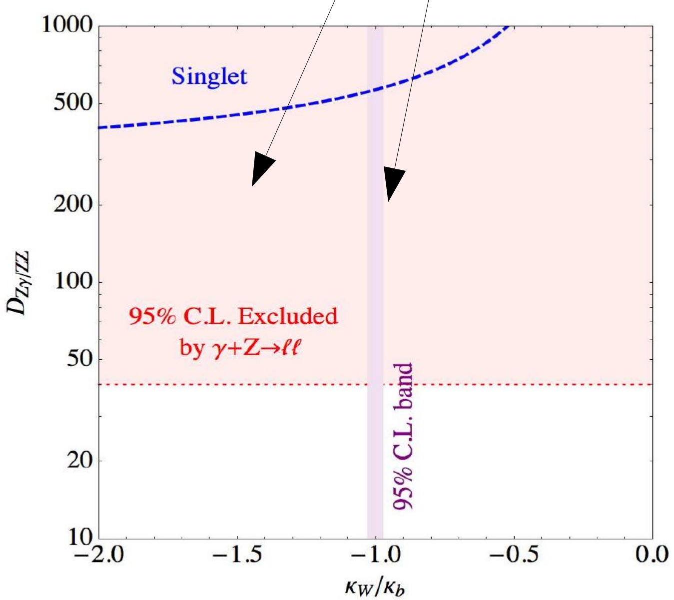
Predicted ratio

$$D_{Z\gamma/Z} \sim 500$$

95% CL excluded by H → Zγ

95%CL band comes from best fit of χ^2

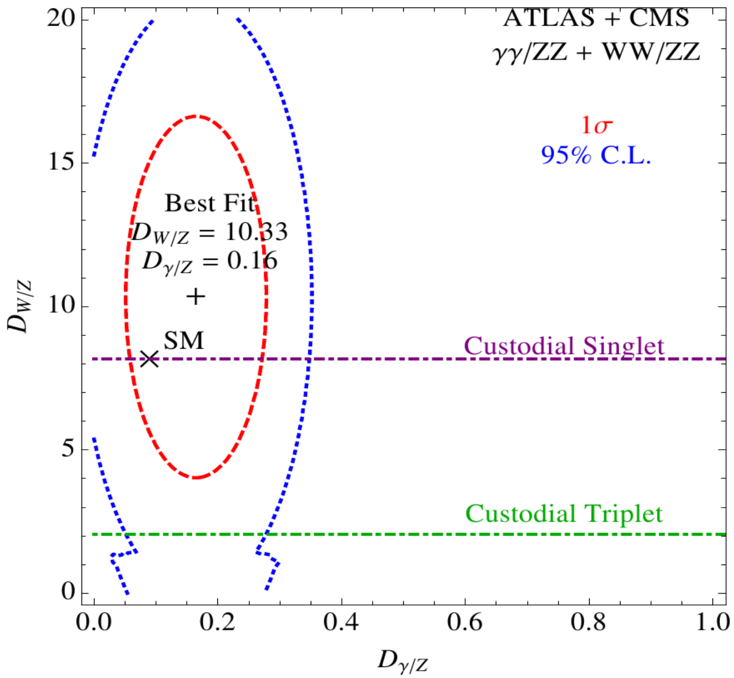


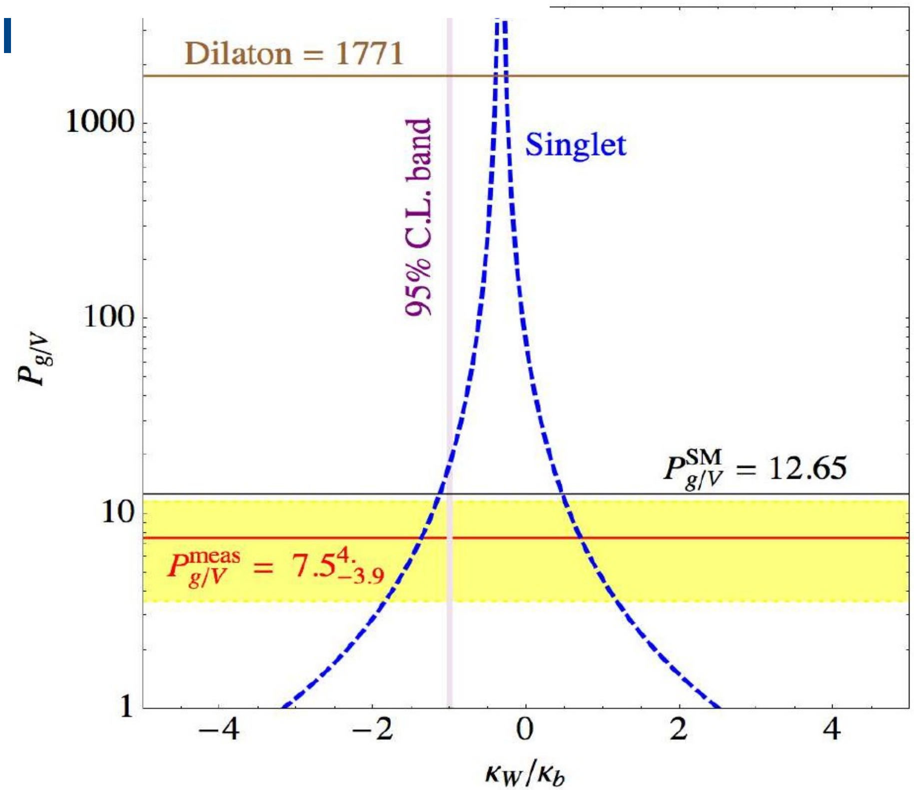


Predictions for NOT EW-singlet but a custodial singlet and 5-plet

$$D^{(h)}_{W/Z} = 8.16\ , \qquad D^{(h_5)}_{W/Z} = \frac{1}{4} D^{(h)}_{W/Z} = 2.04$$

- custodial singlet consistent at 1σ level
- custodial triplet consistent at 2σ level





- **EW-singlet** like Dilaton (including RS radion) imposters are disfavored (observed $P_{g/V}$ is in agreement with SM)

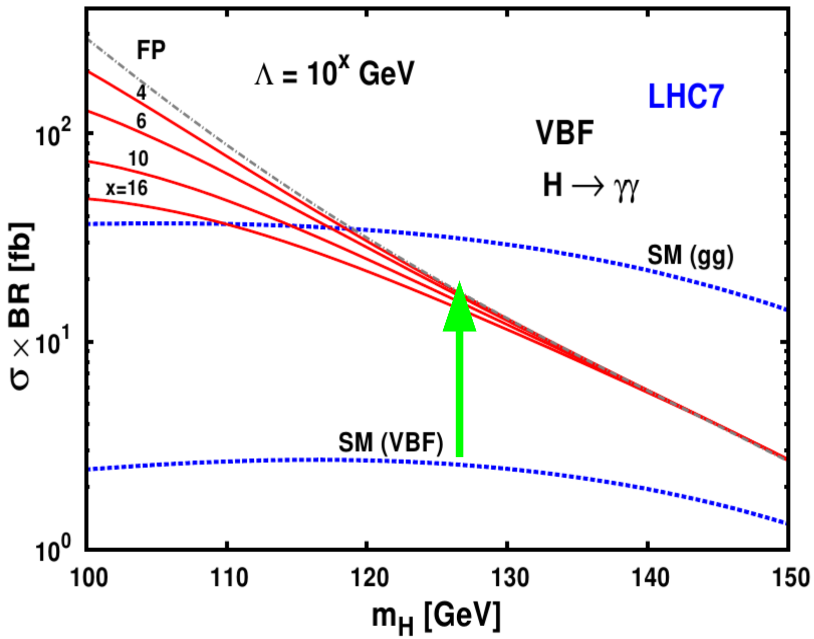
$$P_{g/V} \equiv \frac{B\sigma_{gg}(\gamma\gamma)}{B\sigma_{\rm VBF}(\gamma\gamma)} \qquad P^{(\rm D)}_{g/V} = 140 \times P^{(\rm SM)}_{g/V} \sim 1700$$

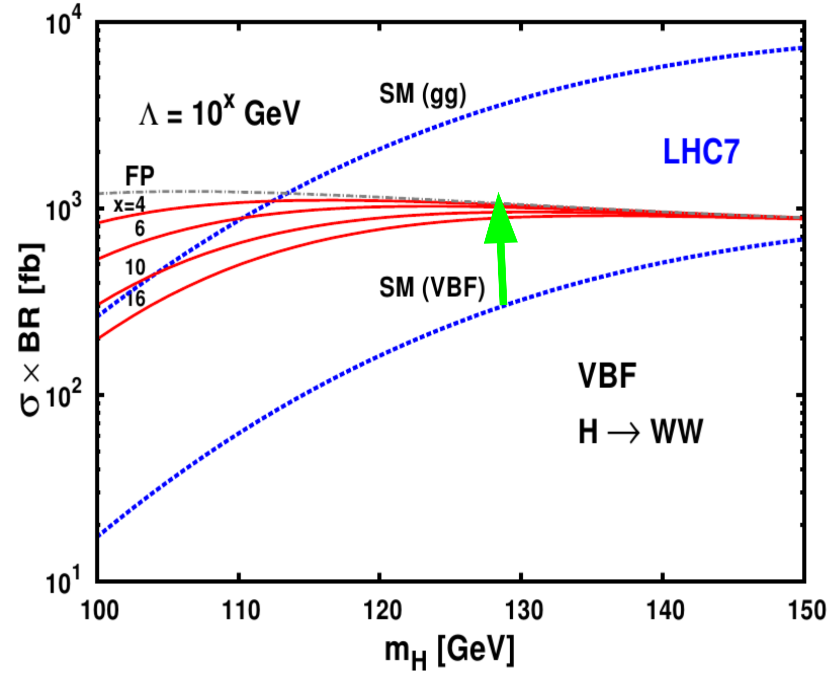
Conclusions

- **A Higgs-like signal has been observed with 125 GeV mass**
- **Good consistency with SM Higgs → dramatic implications for BSM scenarios**
- **MSSM is disfavored → new scenarios like NMSSM seems viable, but large λ couplings needed to ameliorate the SUSY little fine-tuning problem**
- **A composite PNGB Higgs has almost same coupling as SM, more statistics is needed to test this scenario (HL- LHC) or ILC**
- **Precise measurements of Higgs couplings to fermions are crucial for understanding the origin of flavor problem and fermion masses**
- **Fermiophobic naïve Higgs is ruled out for mH=125 GeV → light NP is required to make it viable → dramatic implications for flavor physics if confirmed**
- **sign of Yukawa coupling can be tested soon at LHC via pp → H t q process → dramatic implications for NP at TeV scale if wrong sign would be confirmed**
- **EW singlet Higgs imposters are ruled out, including dilaton and RS radion. NOT-EW singlet Higgs imposters are still viable → more statistics required**

Backup slides

LHC (VBF) : H → γγ, WW*





- rates of FP/VFB[SM] at mH=125 GeV

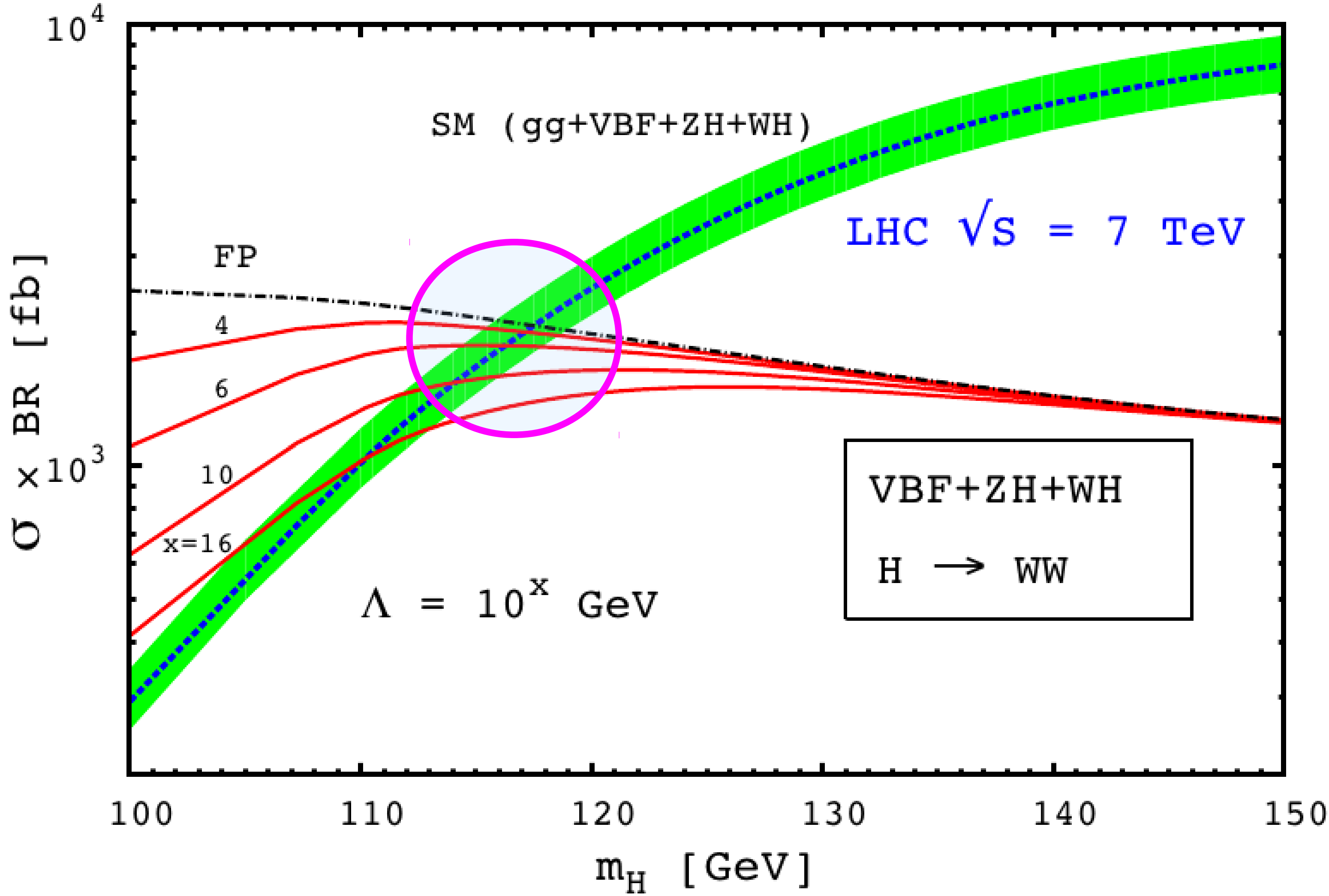
EG, Mele PRD 82 (2010)

→ H → gg   rate[FP] ~ 7 x rate[SM(VBF)]

→ H → WW*   rate[FP] ~ 5 x rate[SM(VBF)]

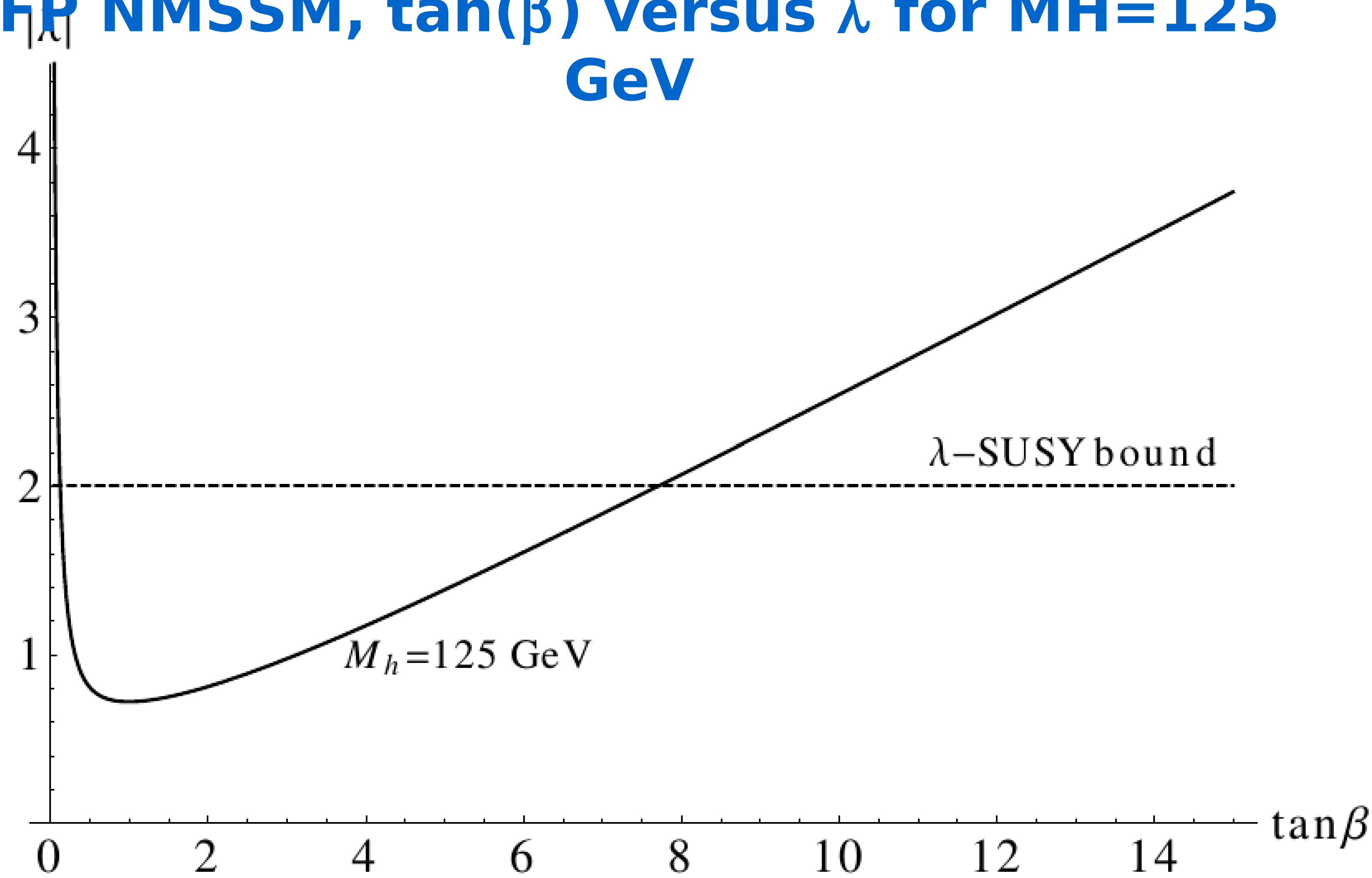
→ H → ZZ*   rate[FP] ~ 5 x rate[SM(VBF)]

FP(VBF+VH) : H → WW*



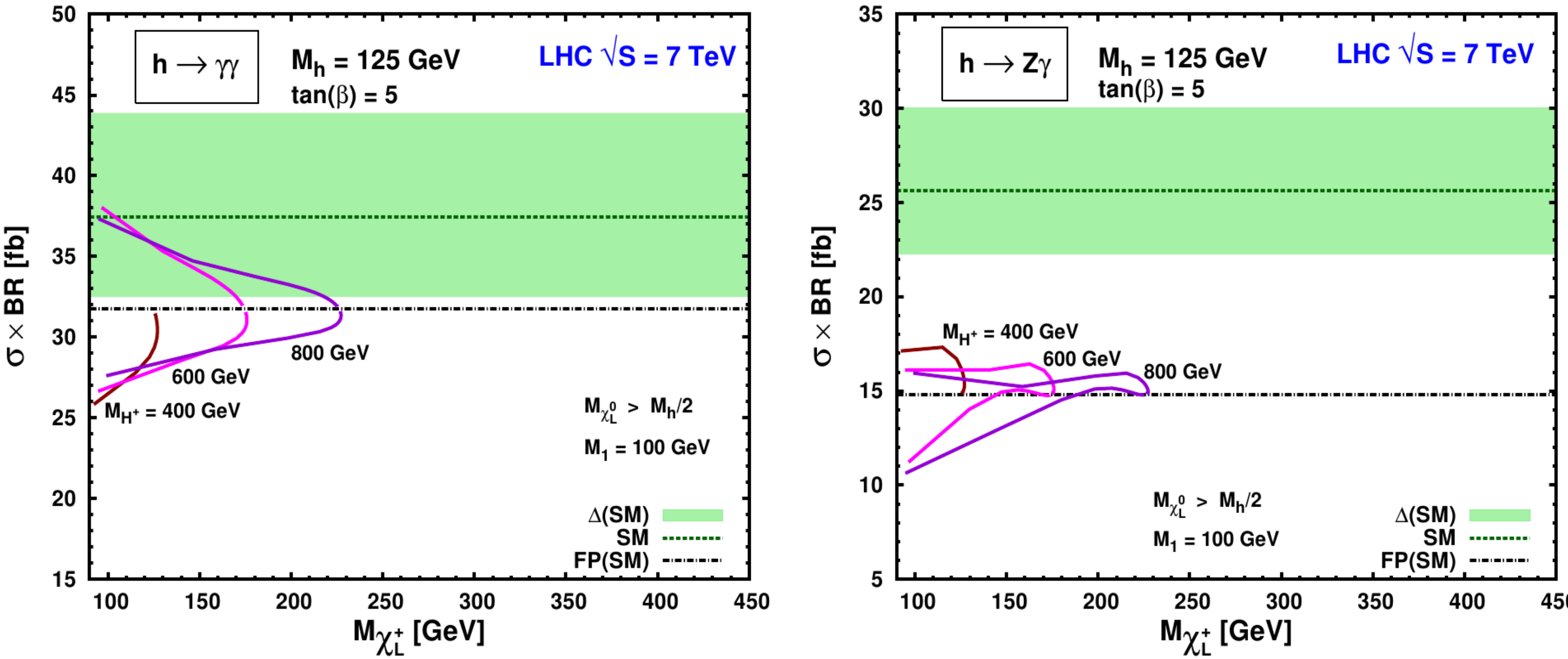
For mH=124-126 GeV, FP Higgs has a smaller inclusive WW* production rate with respect to SM!

FP NMSSM, tan(β) versus λ for MH=125 GeV



Upper bound on tan(β) < 8

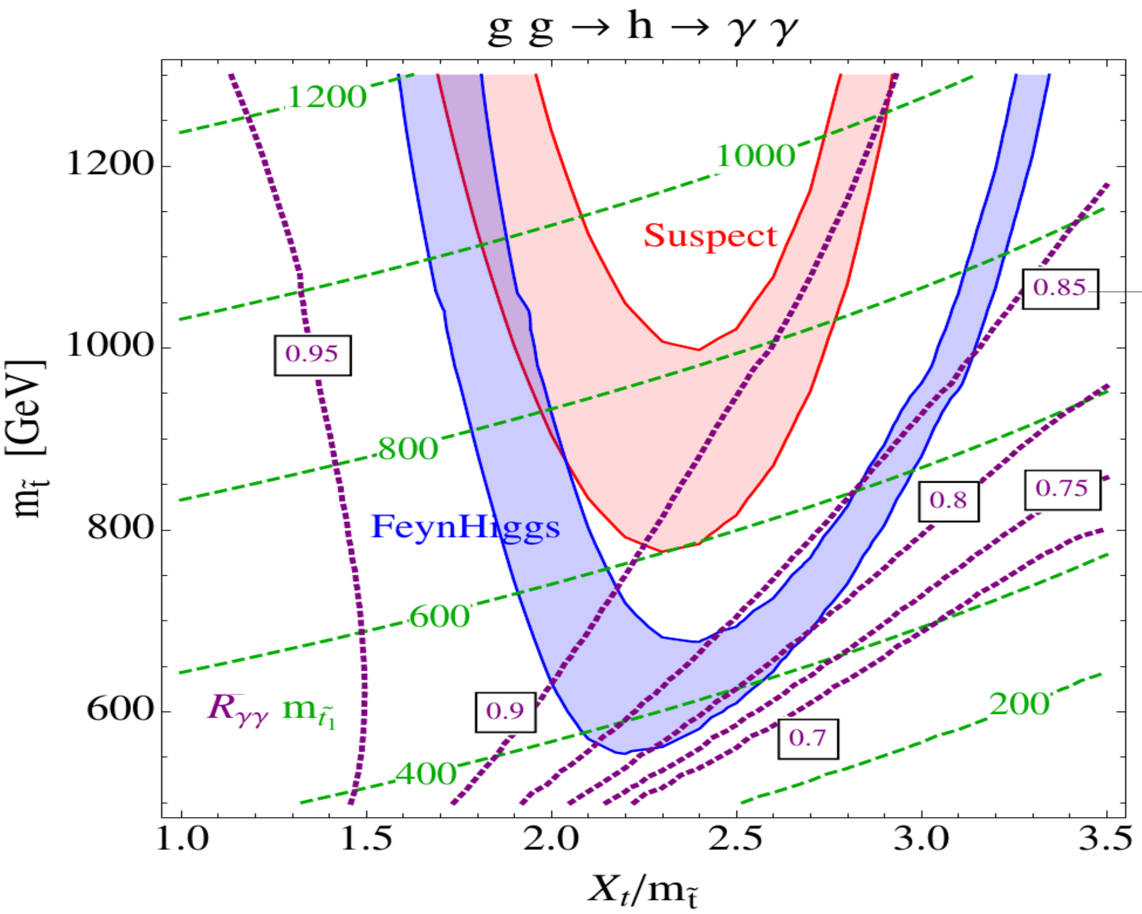
FP NMSSM with tan(β)=5



Increasing tan(b) > 1, deviations from FP SM on BR(H → γγ) and BR(H → Zγ) are reduced

MSSM impact on couplings

Hall, Pinner, Ruderman ' 11



Contour plots at M_H=125 GeV

BR X cross section normalized to SM

Fermiophobic NMSSM

- Minima of V: general case is quite complicated
- there is a choice of parameters that allows no mixing between singlet S and h_u, h_d

$$
\boxed{\begin{aligned} a_\lambda &= 0 \\ k &= \lambda \\ \tan\beta &= 1 \end{aligned}}
$$

- $\tan\beta=1$ is allowed since no low energy constraints come from Yukawa couplings
- we restrict our model to this special set of parameters
  → natural choice → more predictive

Strategy

- $M_h = \frac{|\lambda| v}{\sqrt{2}} = 125$ GeV, $M_1 = 100$ GeV → **fixed-parameters**
- $(M_{H^\pm}, M_{\chi_L^+}) \to (|\mu|, M_2)$ → **free-parameters**
- $M_{\chi_L^0} > M_h/2 \Rightarrow h \nrightarrow \chi_i \chi_j$ → **to require neutralino LSP**

  $\Rightarrow R-\text{parity} \Rightarrow h \nrightarrow \chi_i^* \chi_j, \chi_i^* \chi_j^*$

FP SUSY contributions to h → γγ , γZ