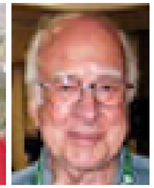
The Higgs Centre, Edinburgh, 8 January '14

The HIGGS and the EXCESSIVE success of the SM

Guido Altarelli
Roma Tre/CERN

LHC 7-8 TeV

A great triumph: the 126 GeV Higgs discovery

A particle apparently just as predicted by the SM theory

The main missing block for the experimental validation of the SM is now in place

A negative surprise: no production of new particles, no evidence of new physics which was expected on theoretical grounds

Not in ATLAS&CMS

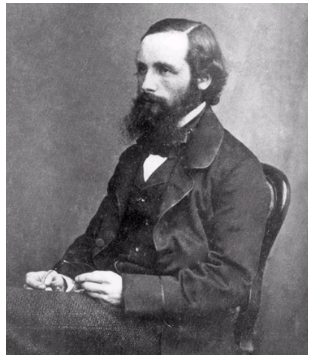
Not in Heavy Flavour decays (LHCb, ... B-factories)

Not in $\mu \to e\gamma$ (MEG) $\mathcal{B} < 5.7 \times 10^{-13}$

Not in the EDM of the electron (ACME) $|d_e| < 8.7 \times 10^{-29}\ e\ \mathrm{cm}$

........[Perhaps a deviation in $(g-2)_\mu$?]

The Higgs discovery is a milestone in the long history of building up a field theory of fundamental interactions (apart from quantum gravity)



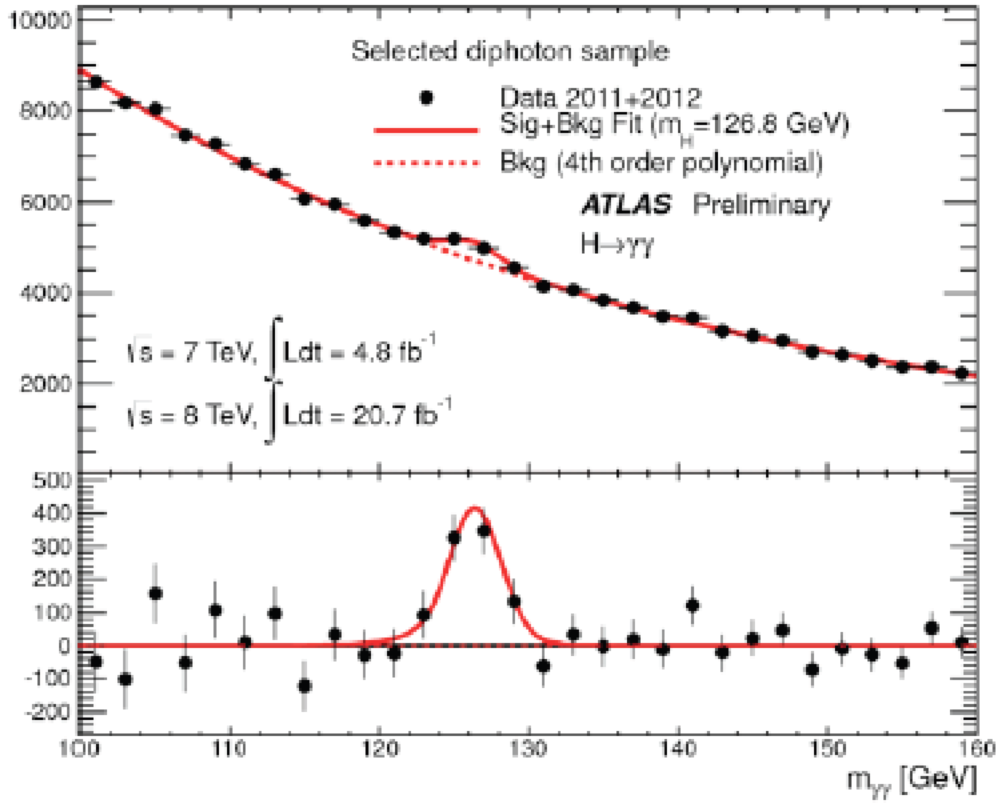
- Maxwell equations of classical Electrodynamics
- Relativity
- Quantum Mechanics
- Quantum Electrodynamics
- The gauge part of the Standard Model
- The EW symmetry breaking sector of the SM

Englert-Brout-Higgs 1964
(50th anniversary!)

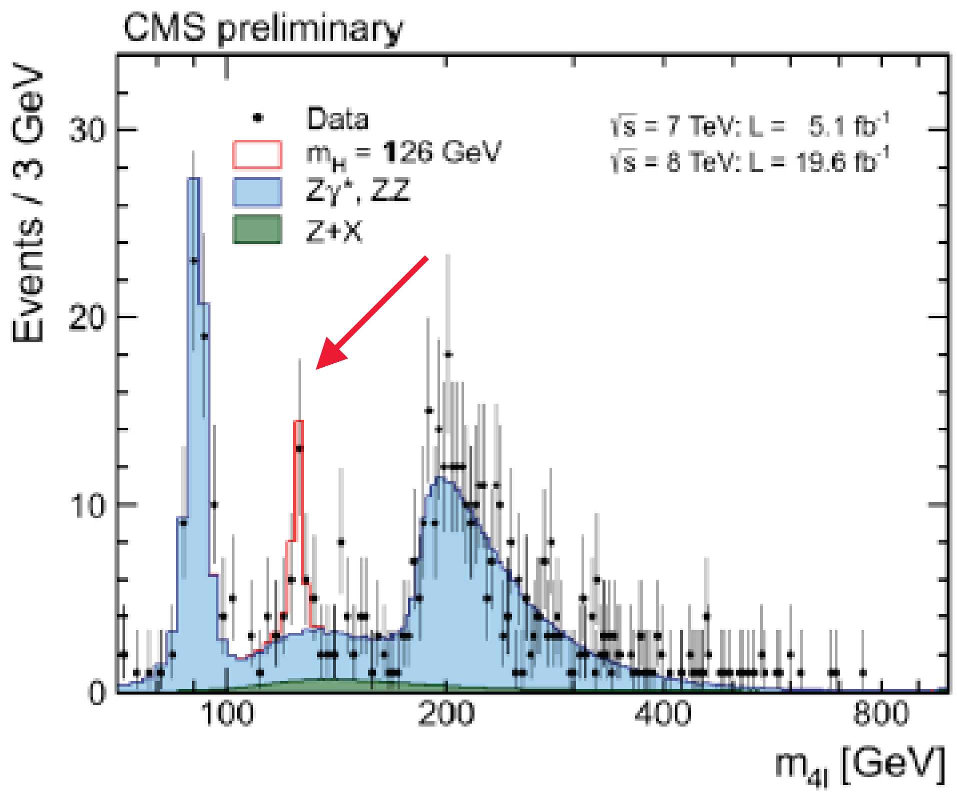

~140 years of theoretical physics

A SM Higgs (or a good approximation to it) of mass m_H ~ 126 GeV has been observed decaying in $\gamma\gamma$, ZZ^*, WW^*, bb, $\tau\tau$

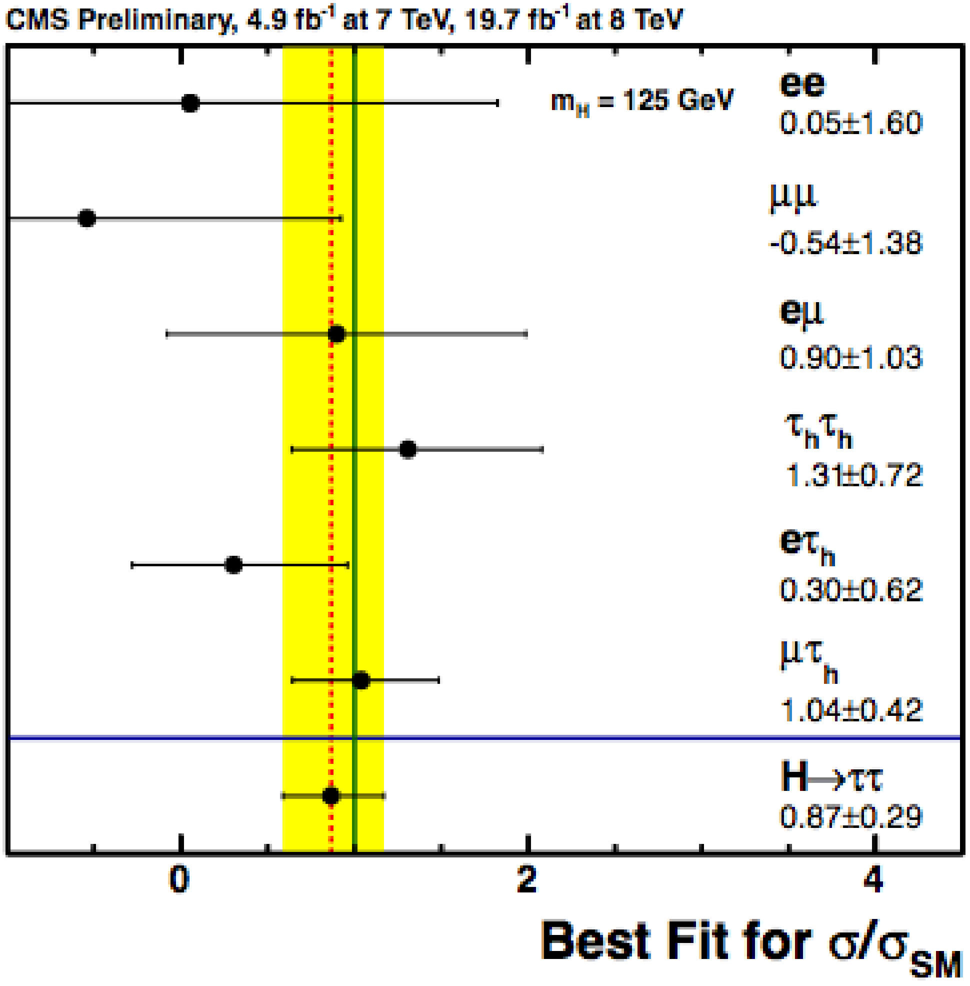
ATLAS $\gamma\gamma$

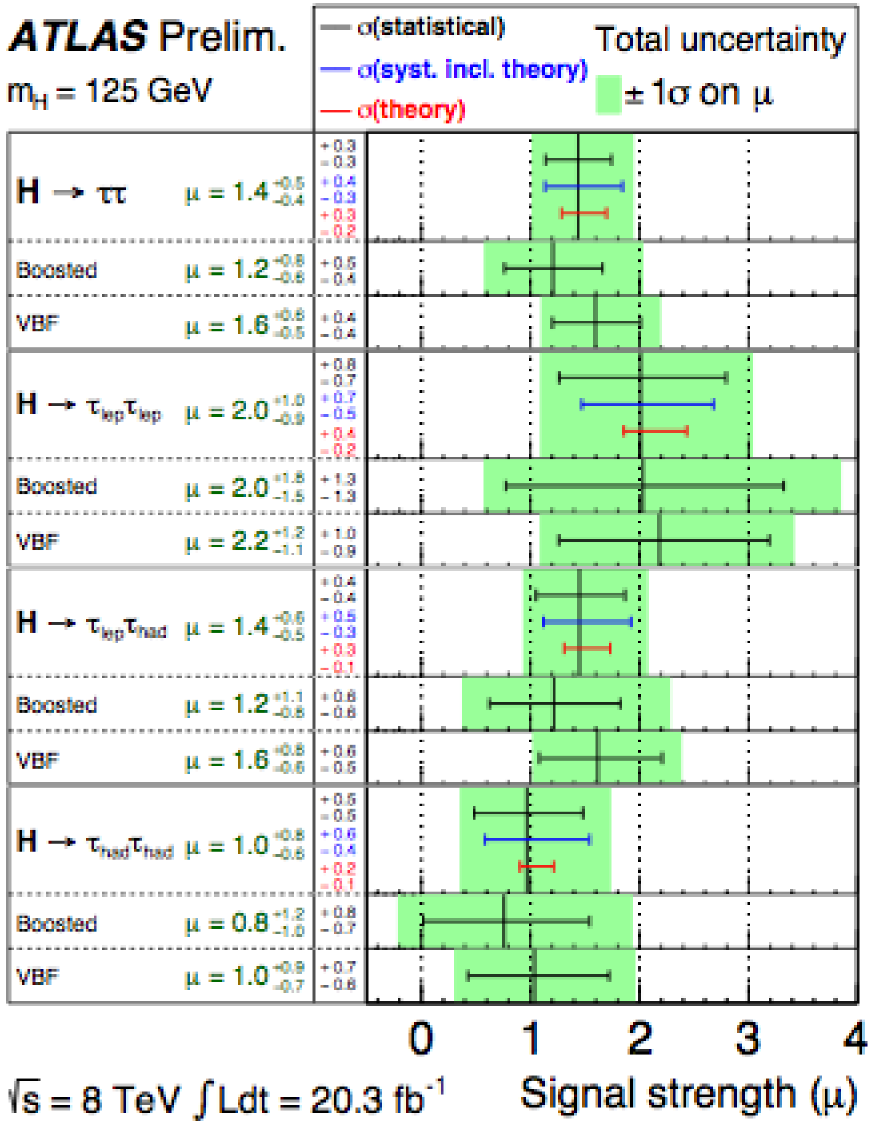


CMS ZZ*



Recently the $\tau\tau$ channel was also measured





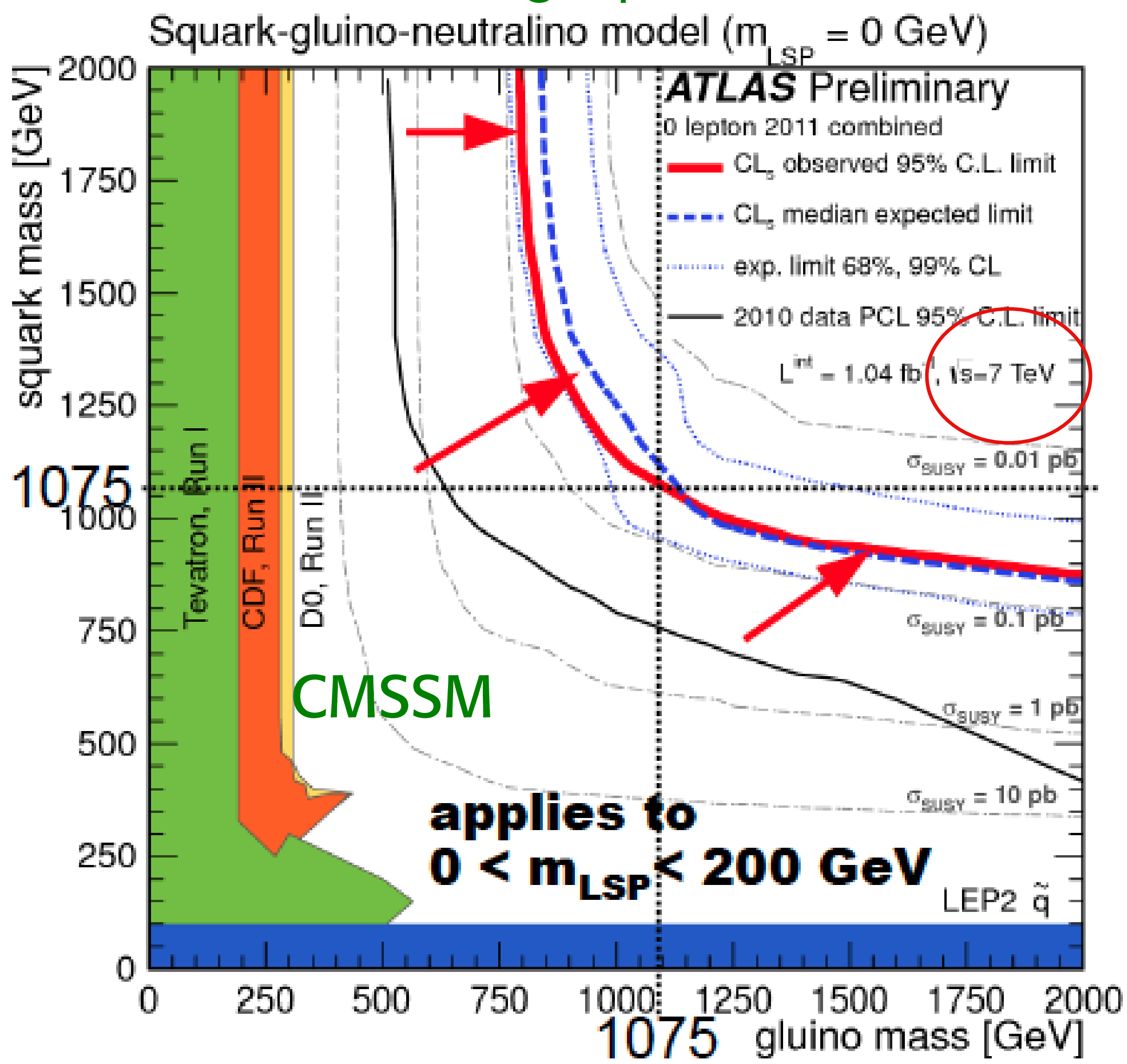
A large new territory explored at the LHC and no new physics

A big step from the
Tevatron 2 TeV
up to LHC 7-8 TeV
(-> 13-14 TeV)

This negative result
is perhaps depressing
but certainly brings
a very important input
to our field

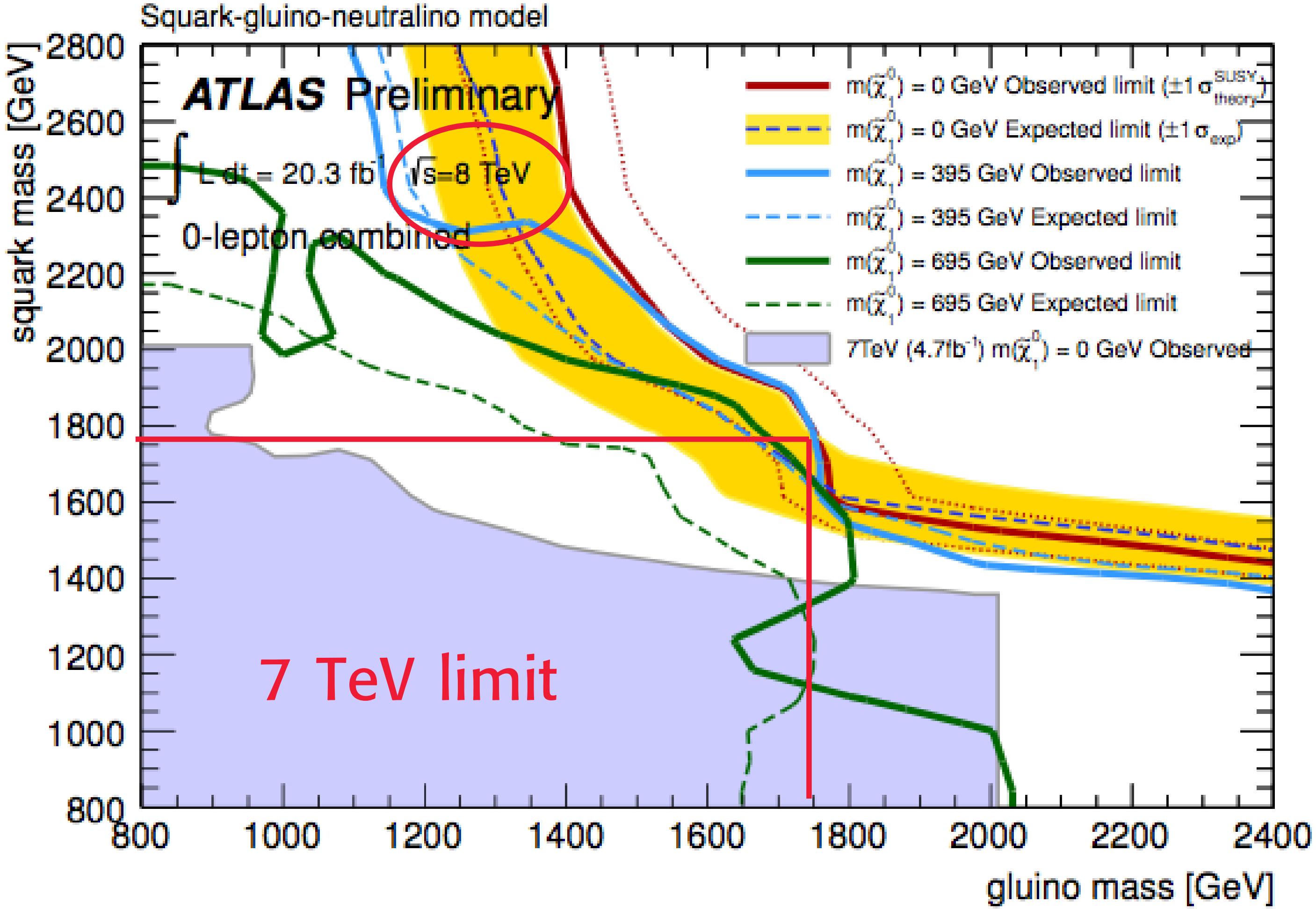
→ a big change
in perspective

Jets + missing E_T



degenerate squarks

~ 1700 GeV



New physics can appear at 14 TeV (we hope) but it is by now conceivable that no new physics will show up at the LHC

Naturalness? The big question mark!

Flavour is also very stringent (great new results from LHCb, CMS...)

The constraints on NP from flavour are extremely demanding: adding effective operators to SM generally leads to very large Λ

$$M(B_d\text{-}\bar{B}_d) \sim \frac{(y_t V_{tb}{}^* V_{td})^2}{16\,\pi^2 M_W{}^2} + c_{NP}\frac{1}{\Lambda^2}$$

Isidori

c_{NP}:

- ~ 1 $\xrightarrow{\text{tree/strong + generic flavour}}$ $\Lambda \gtrsim 2\times10^4$ TeV [K]
- $\sim 1/(16\,\pi^2)$ $\xrightarrow{\text{loop + generic flavour}}$ $\Lambda \gtrsim 2\times10^3$ TeV [K]
- $\sim (y_t V_{ti}{}^* V_{tj})^2$ $\xrightarrow{\text{tree/strong + MFV}}$ $\Lambda \gtrsim 5$ TeV [K & B]
- $\sim (y_t V_{ti}{}^* V_{tj})^2/(16\,\pi^2)$ $\xrightarrow{\text{loop + MFV}}$ $\Lambda \gtrsim 0.5$ TeV [K & B]

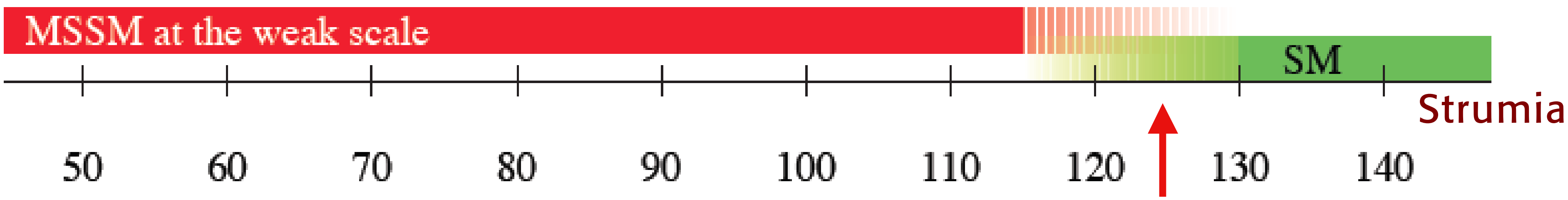
The SM is very special and if there is New Physics, it must be highly non generic eg in Minimal Flavour Violation (MFV) models

The Higgs epochal discovery

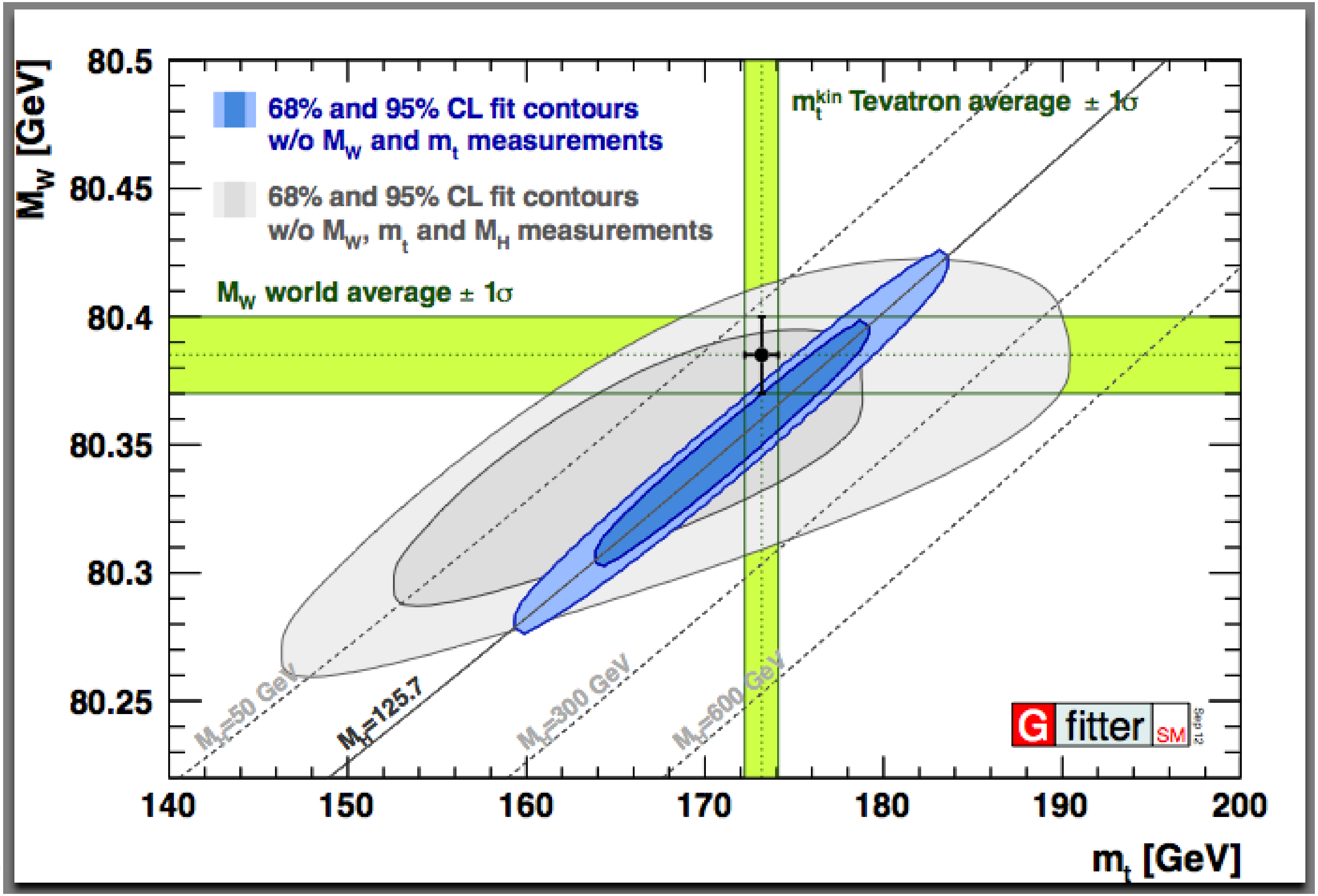
m_H ~ 126 GeV is compatible with the SM and also with the SUSY extensions of the SM

$m_H = 125.6 \pm 0.4$ GeV

A malicious choice!



m_H ~126 GeV is what you expect from a direct interpretation of EW precision tests: no fancy conspiracy with new physics to fake a light Higgs while the real one is heavy
(in fact no "conspirators" have been spotted: no new physics)



80.5
80.45
80.4
80.35
80.3
80.25
M_W [GeV]
140
150
160
170
180
190
200
m_t [GeV]
68% and 95% CL fit contours
w/o M_W and m_t measurements
68% and 95% CL fit contours
w/o M_W, m_t and M_H measurements
M_W world average ± 1σ
m_t^{kin} Tevatron average ± 1σ
M_H=50 GeV
M_H=125.7
M_H=300 GeV
M_H=600 GeV
G fitter SM
Sep 12

The next challenge

Is it really the SM Higgs boson?

Are there non SM admixtures?

- Confirm $J^{PC}=0^{++}$
- Precise measurement of couplings

Are there heavier Higgs-like particles?

extra doublet(s)? 2HDM, MSSM

extra singlet(s)? NMSSM

$J^{PC}=0^{++}$?

Important to check directly, but other choices would change the interaction vertices and heavily affect rates

Present data already strongly favour 0^{++}

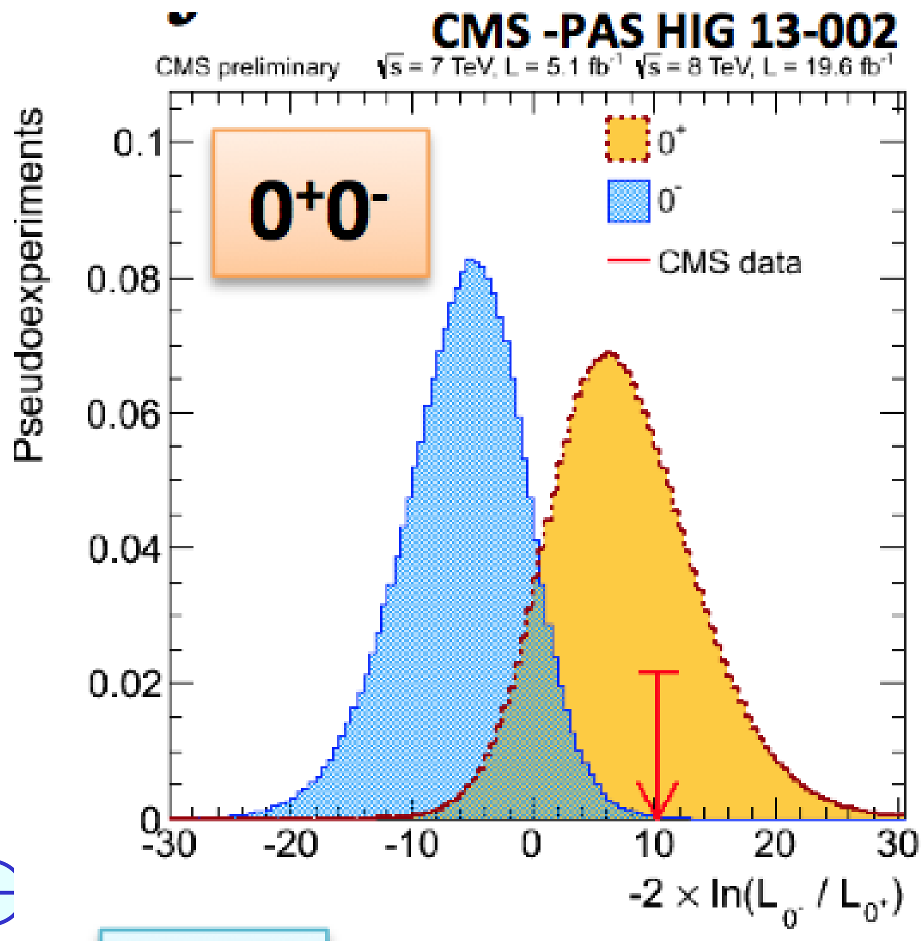
CP-odd component? CP violating decays?
An open challenge for more statistics

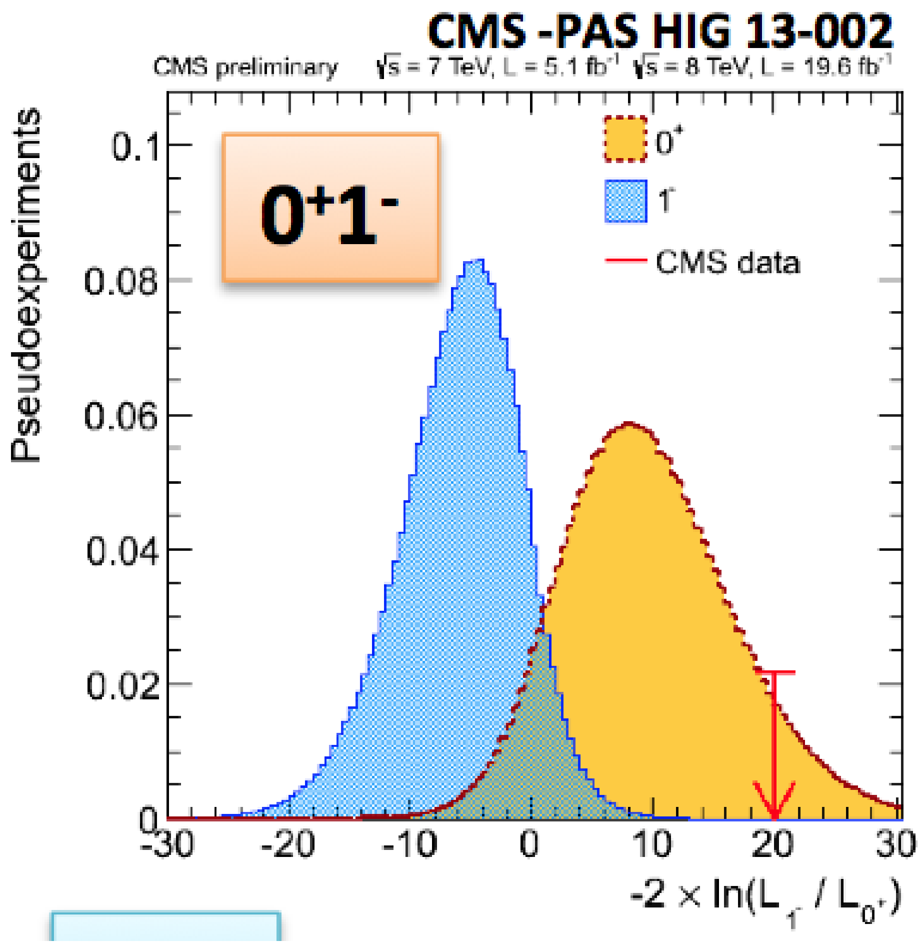
Soni; Freitas; Godbole, Hagiwara......

For example

$H \to ZZ^* \to 4l$

- Data prefers $J^P = 0^+$
- $J^P = 0^-, 1^+, 1^-, 2^+_{mgg}, 2^+_{mqq}$ excluded at >95% CL

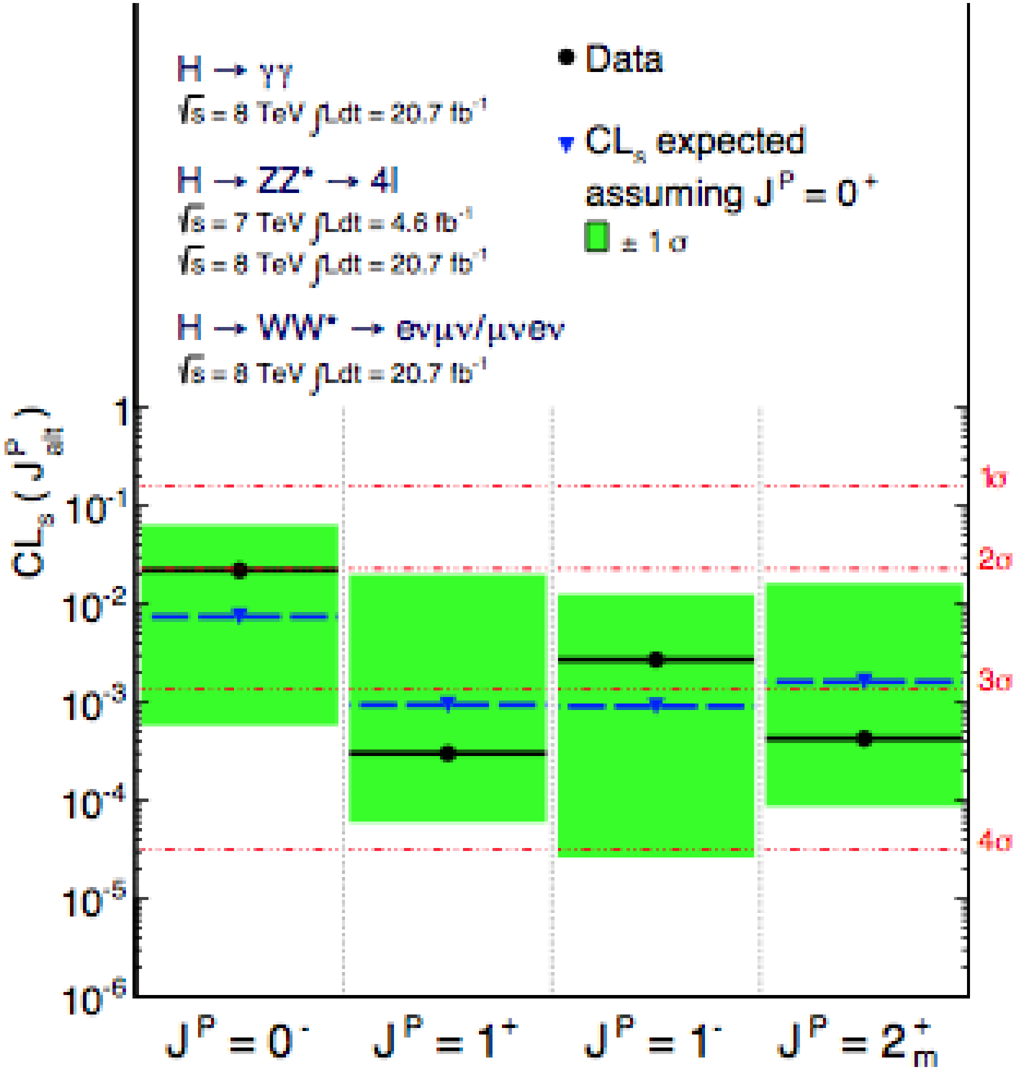




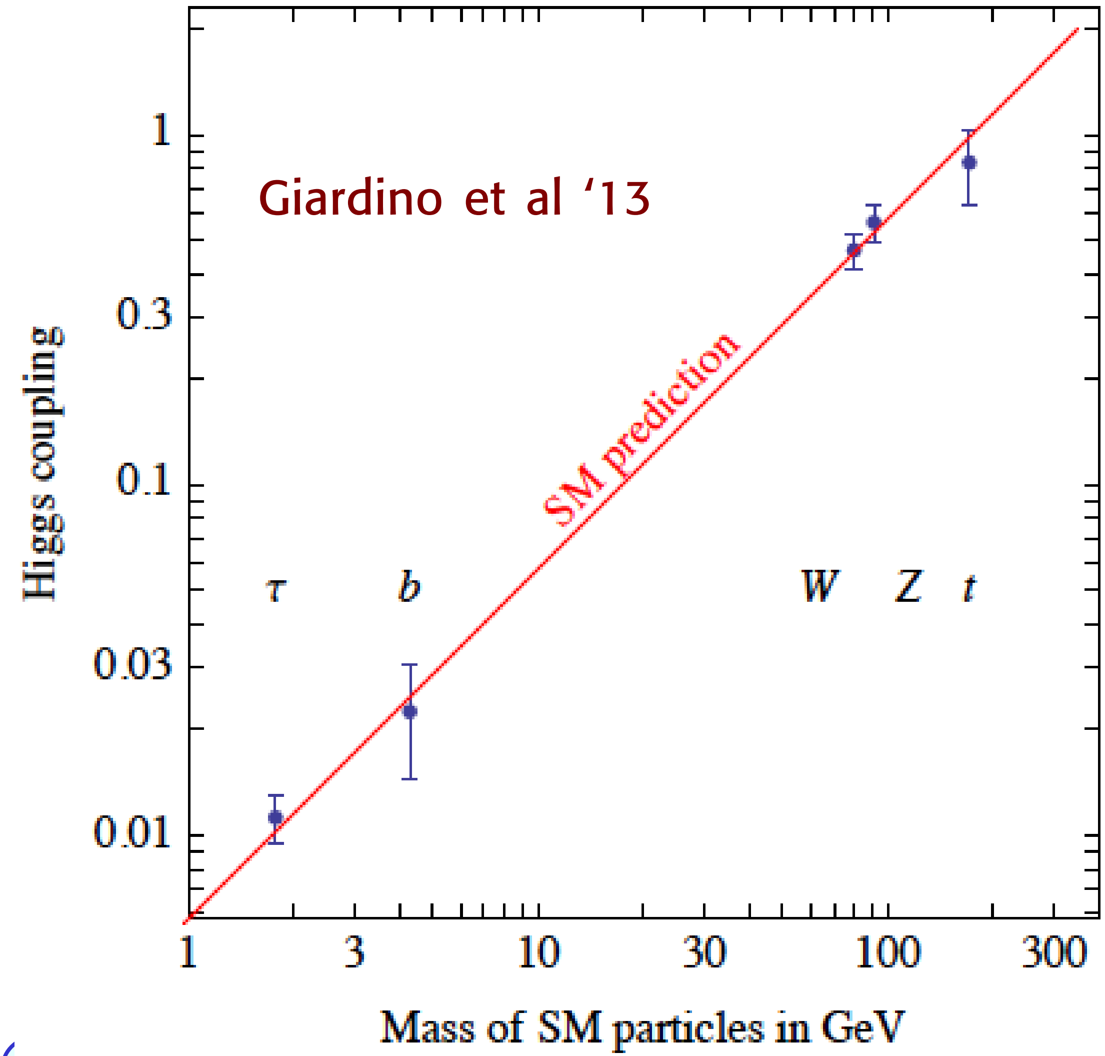
Non SM J^P assignments disfavoured

(at ~2-3 σ)

ATLAS



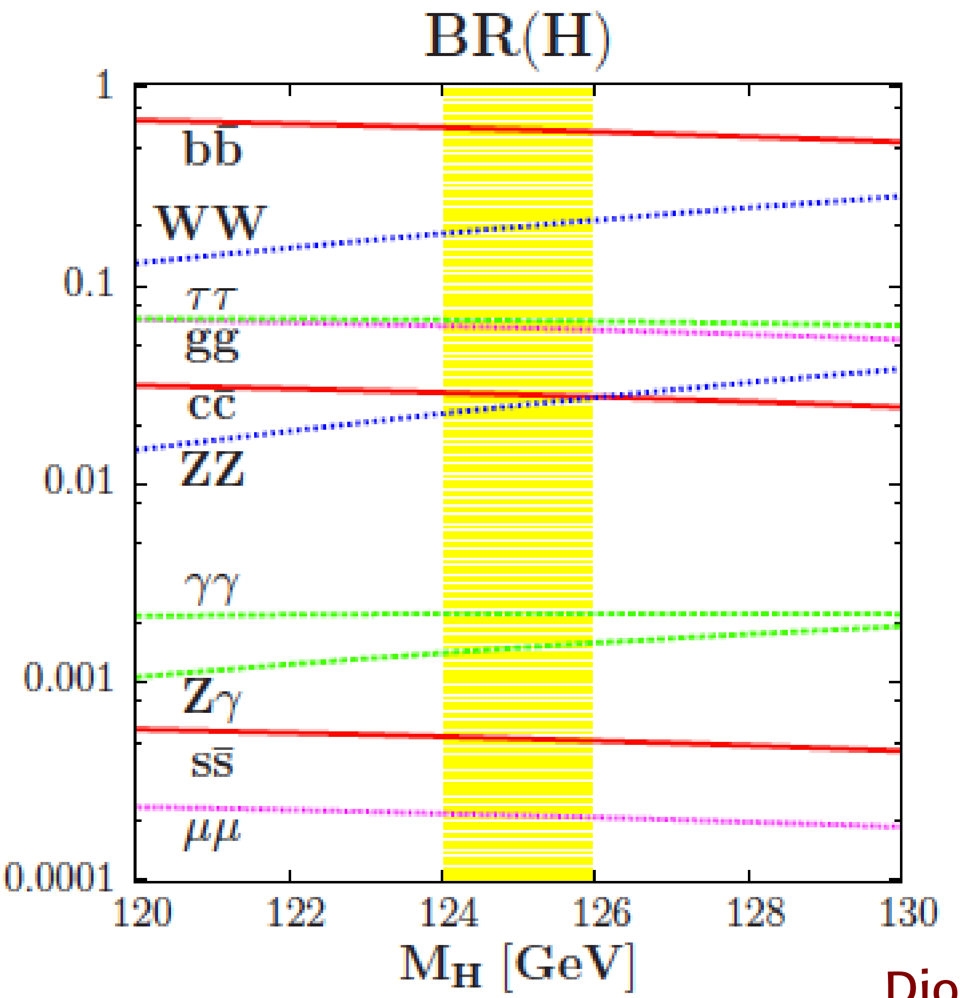
The Higgs couplings are in proportion to masses: a striking signature [plus specified, gg, γγ, Zγ eff. couplings]

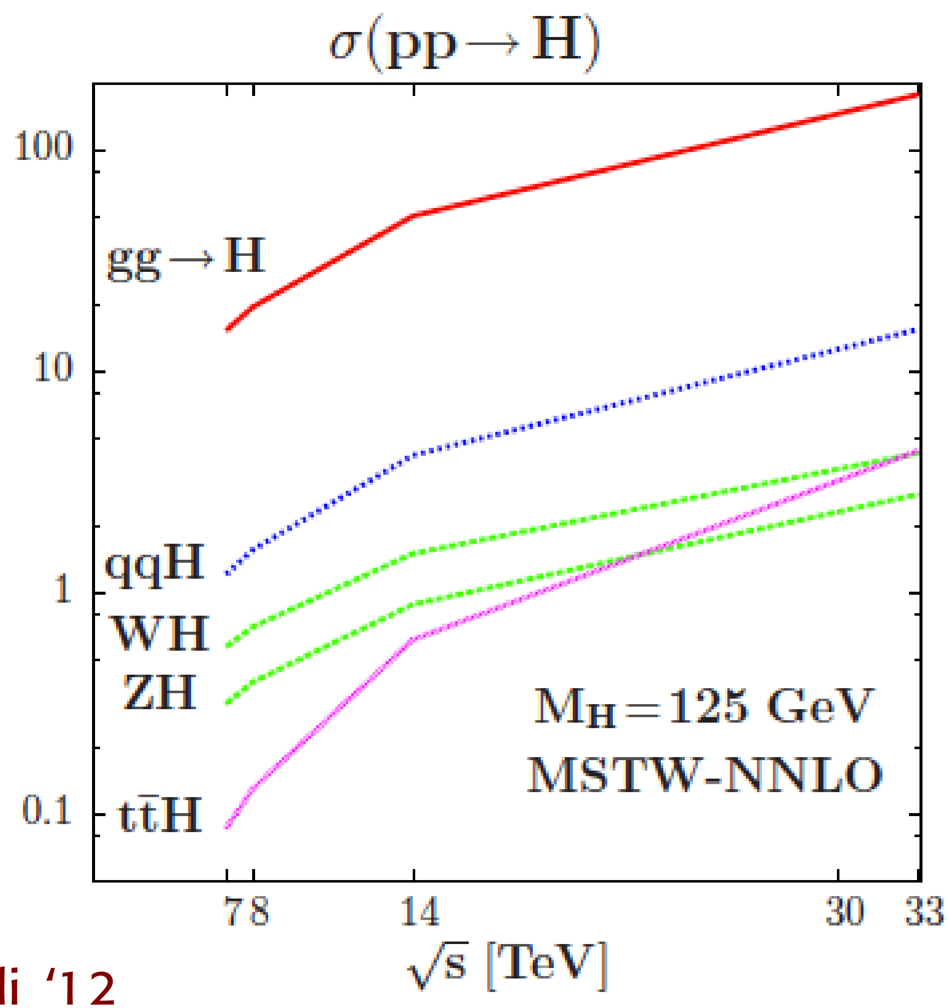


Nearly impossible to reproduce by accident

Agrees with a SM doublet: no Clebsch or mixing distortions

The SM Higgs: striking hierarchy of couplings reflected in production cross-sections and branching ratios

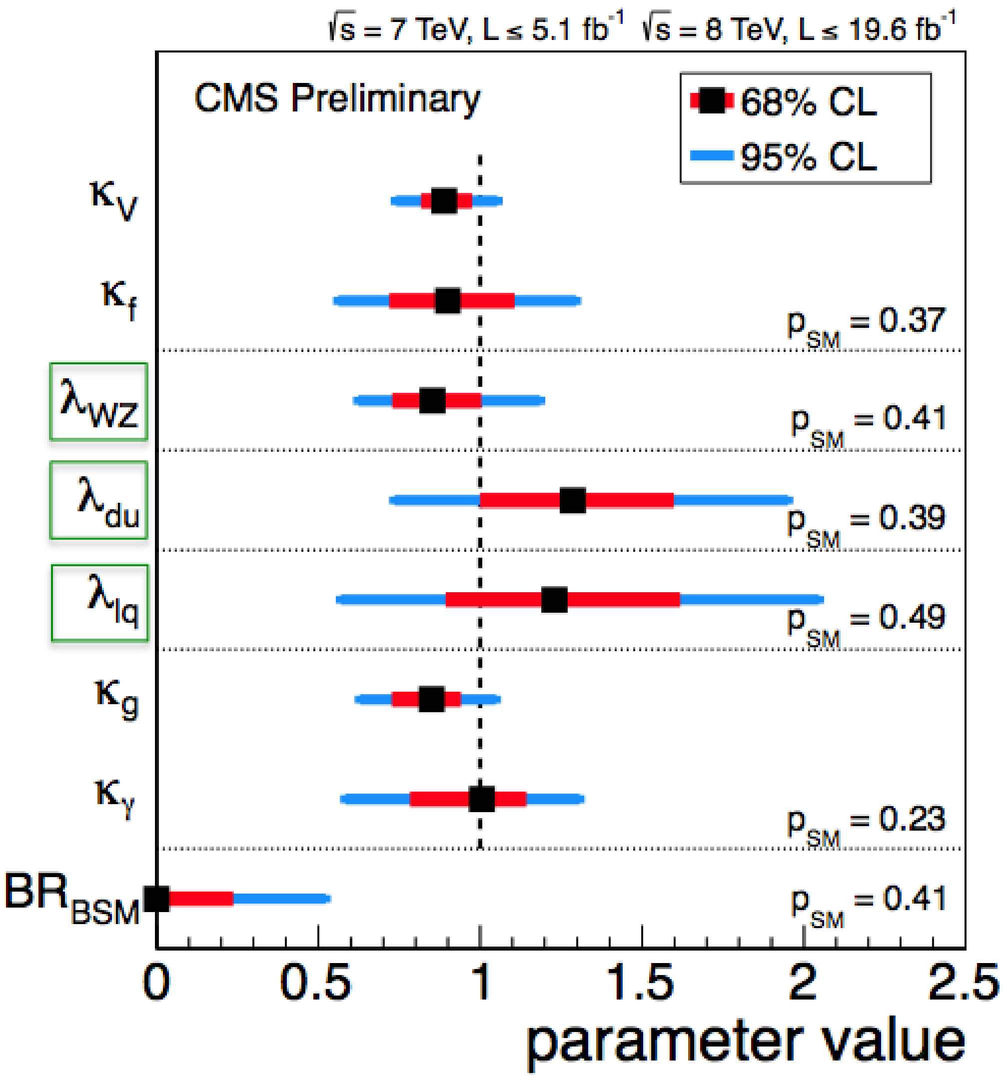


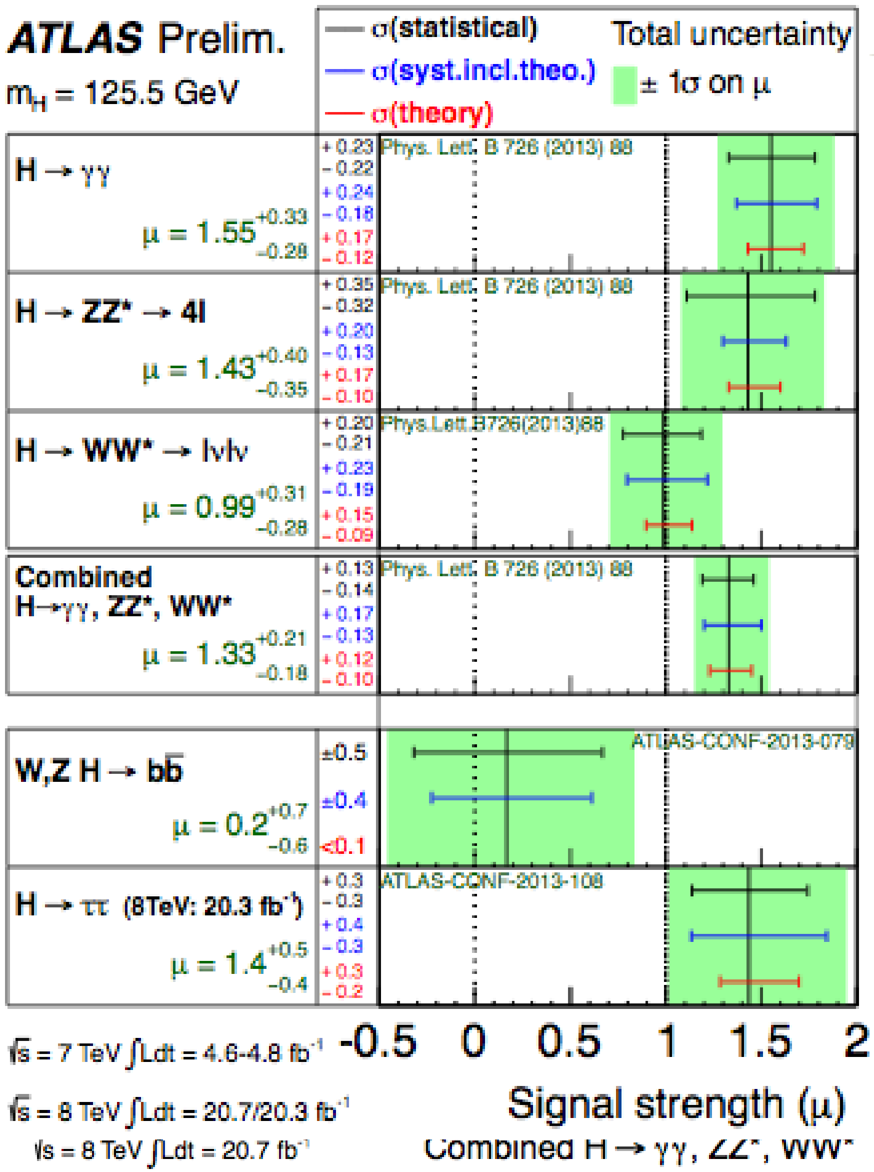


Djouadi '12

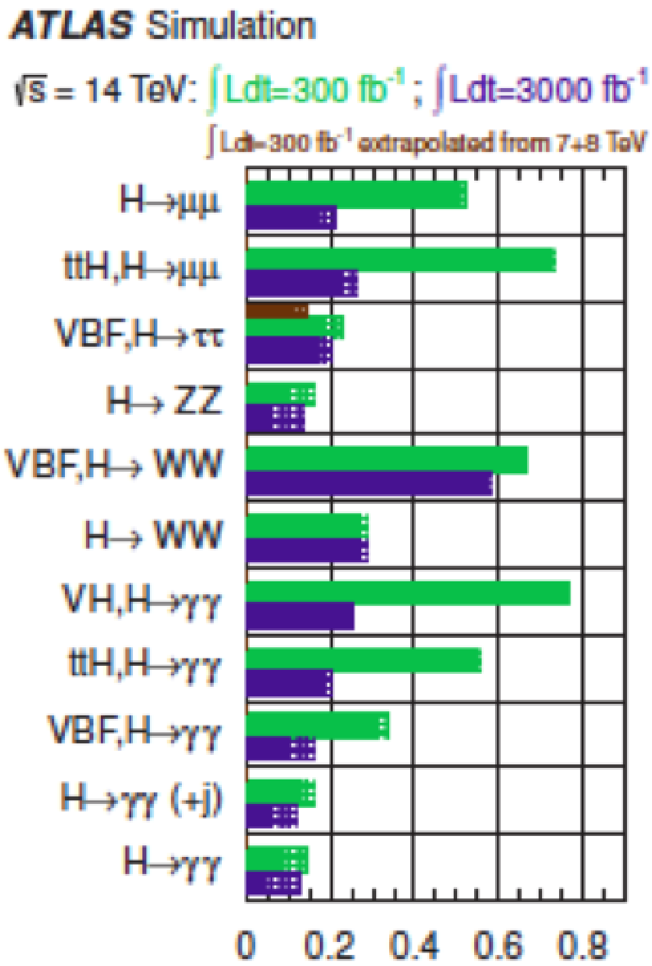
The observed σBr match the predictions within the present accuracy **If not the SM Higgs a very close relative!!**

Couplings now checked at ~20%

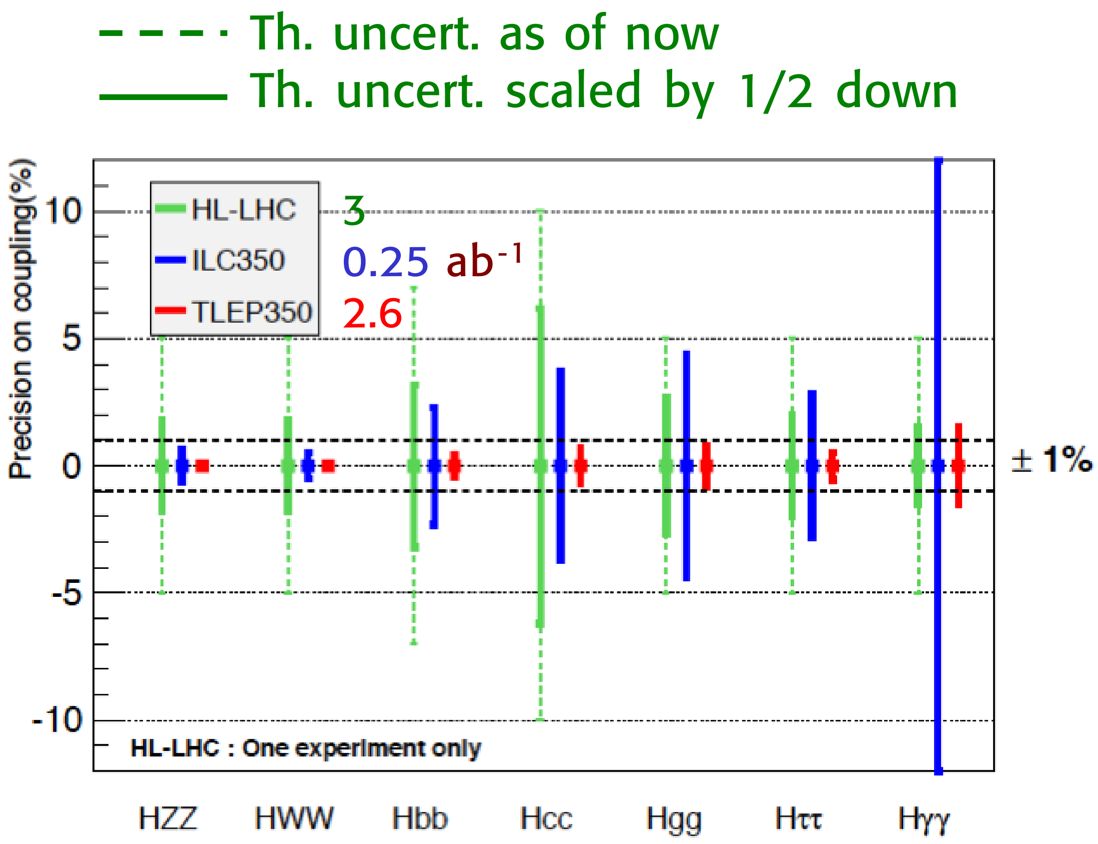




Prospects of coupling measurements at LHC14 and in the future



ArXiv:1307.7292



M. Bicer et al '13

The precise measurements of Higgs couplings are crucial to determine to what extent it is SM

It would really be astonishing if no deviation from the SM is seen!

General effective lagrangians are being studied

eg Alonso et al
Giudice et al
Csaki et al
Contino
Keren-zur et al
Falkowski et al
Elias-Miro et al
Pomarol, Riva.....

But within the present limited statistics it is usual to introduce a universal rescaling of couplings to fermions or to VV=WW,ZZ

Contino

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \dots$$

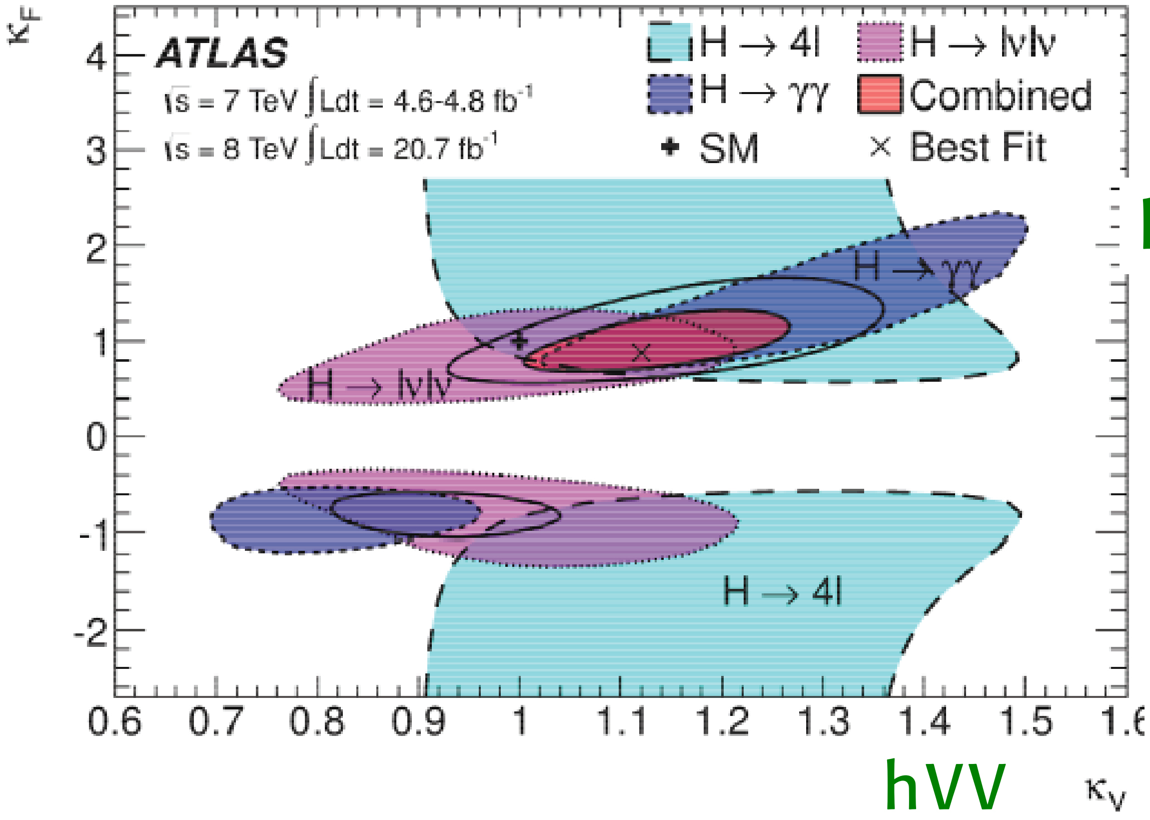
$$- \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \dots\right)$$

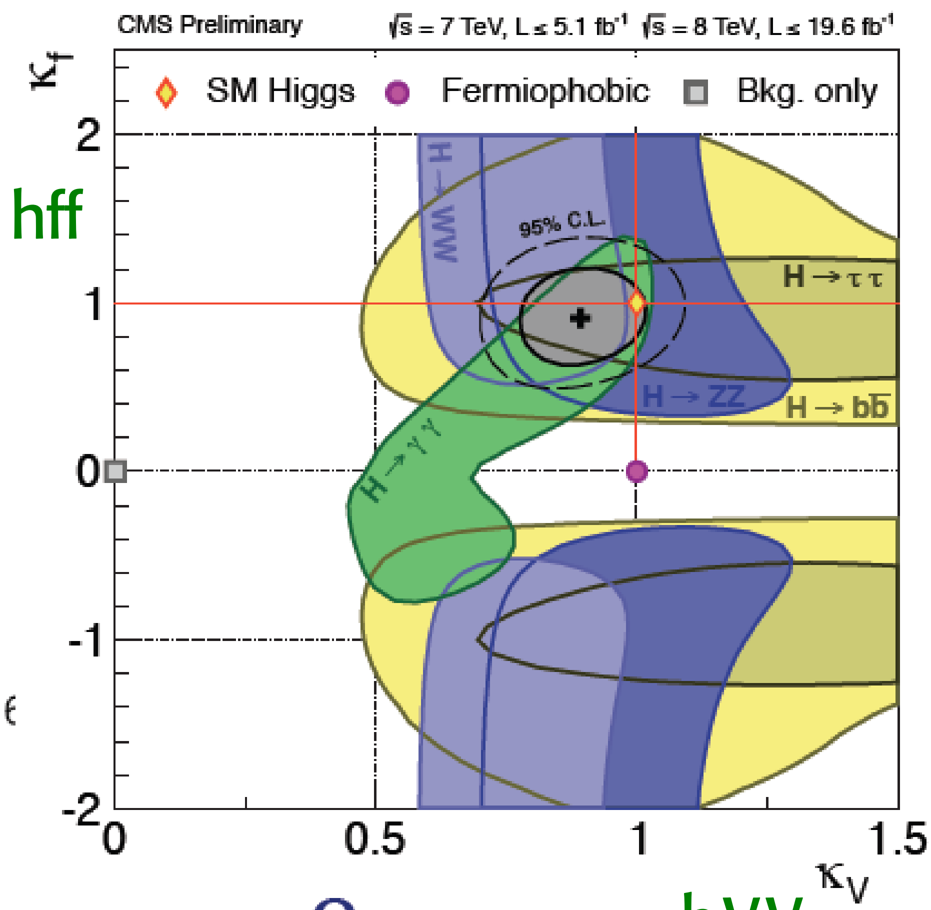
$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \dots\right) \quad + \dots$$

a ~ hVV
c ~ hff

SM:
a = c = 1

Each experiment fits the couplings from their data





$\mu = 1.33 \pm 0.20$

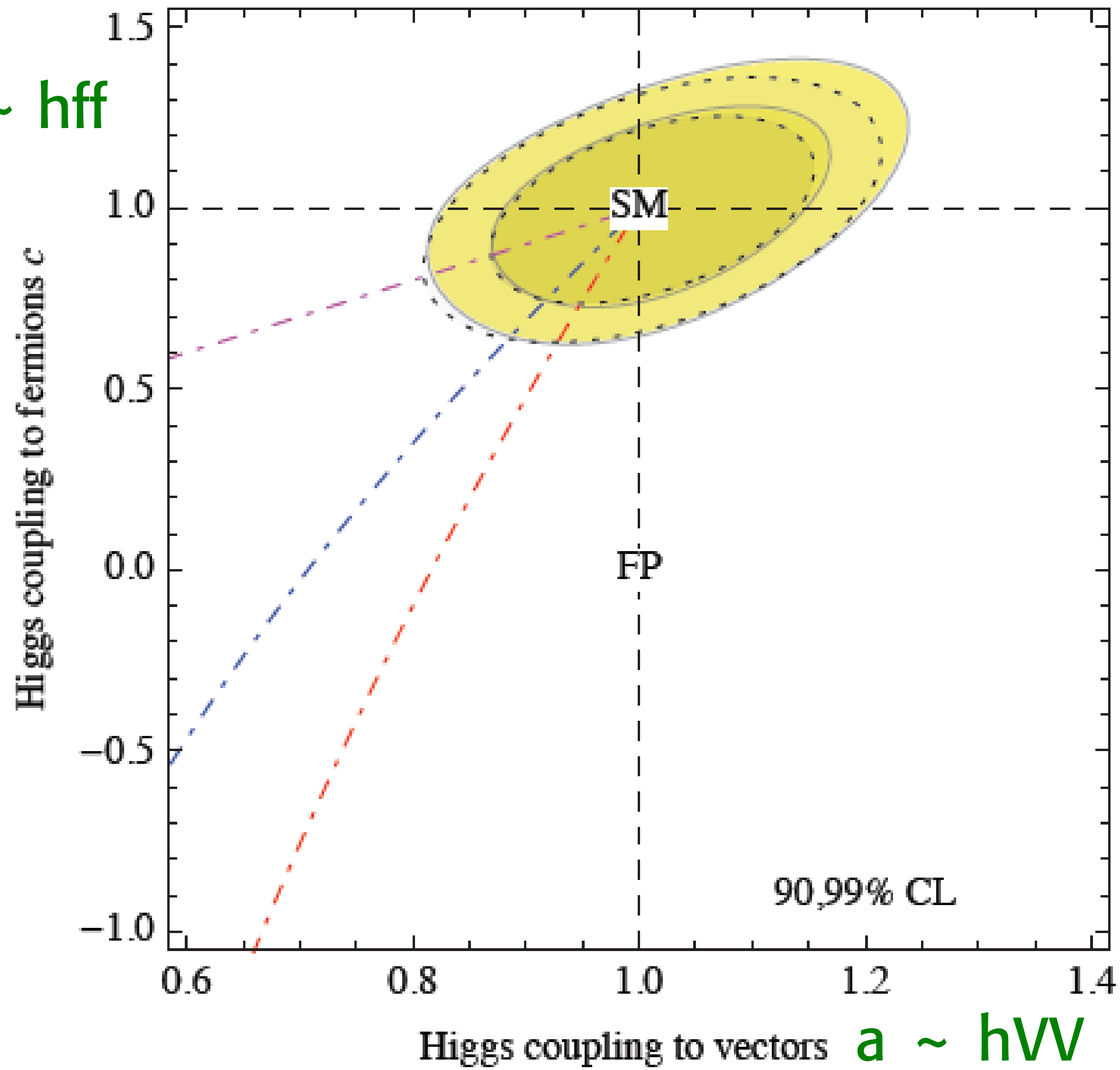
$\mu = 0.80 \pm 0.14$

μ = observed signal/SM prediction

Theorists informal and abusive combination of ATLAS&CMS data

Giardino et al '13

c ~ hff

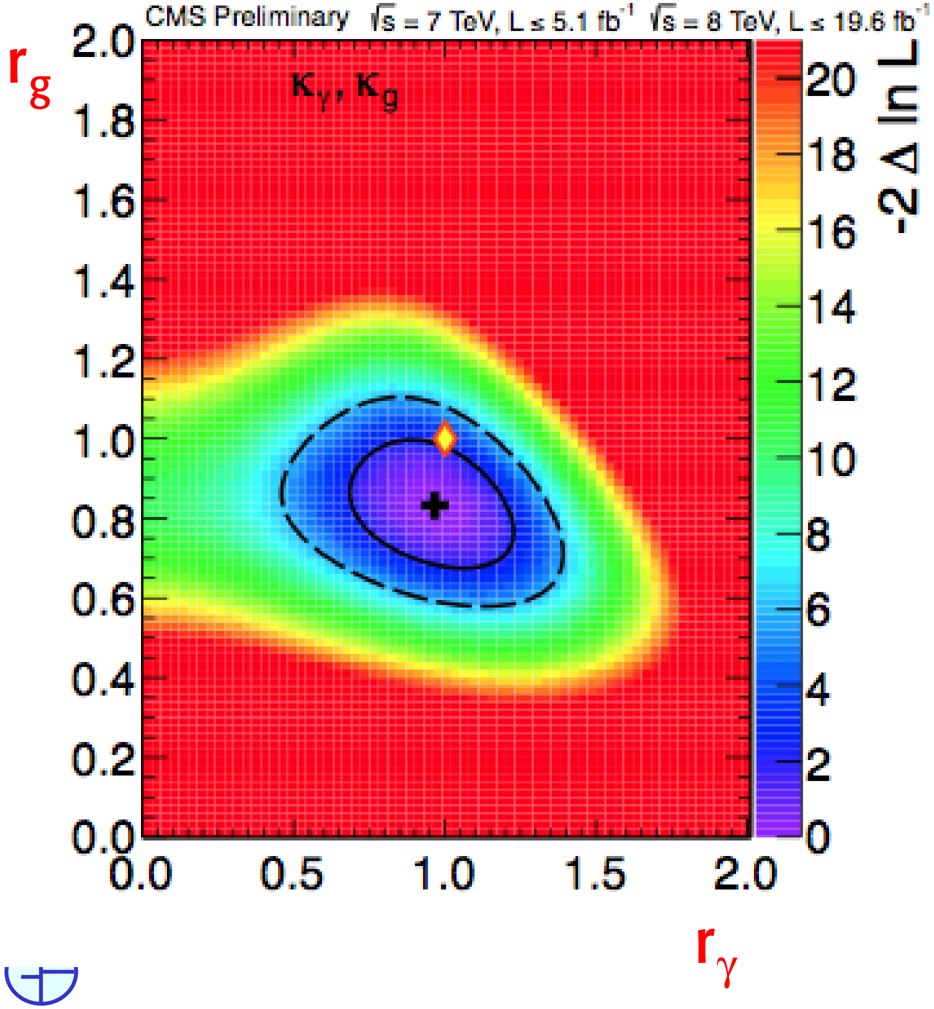


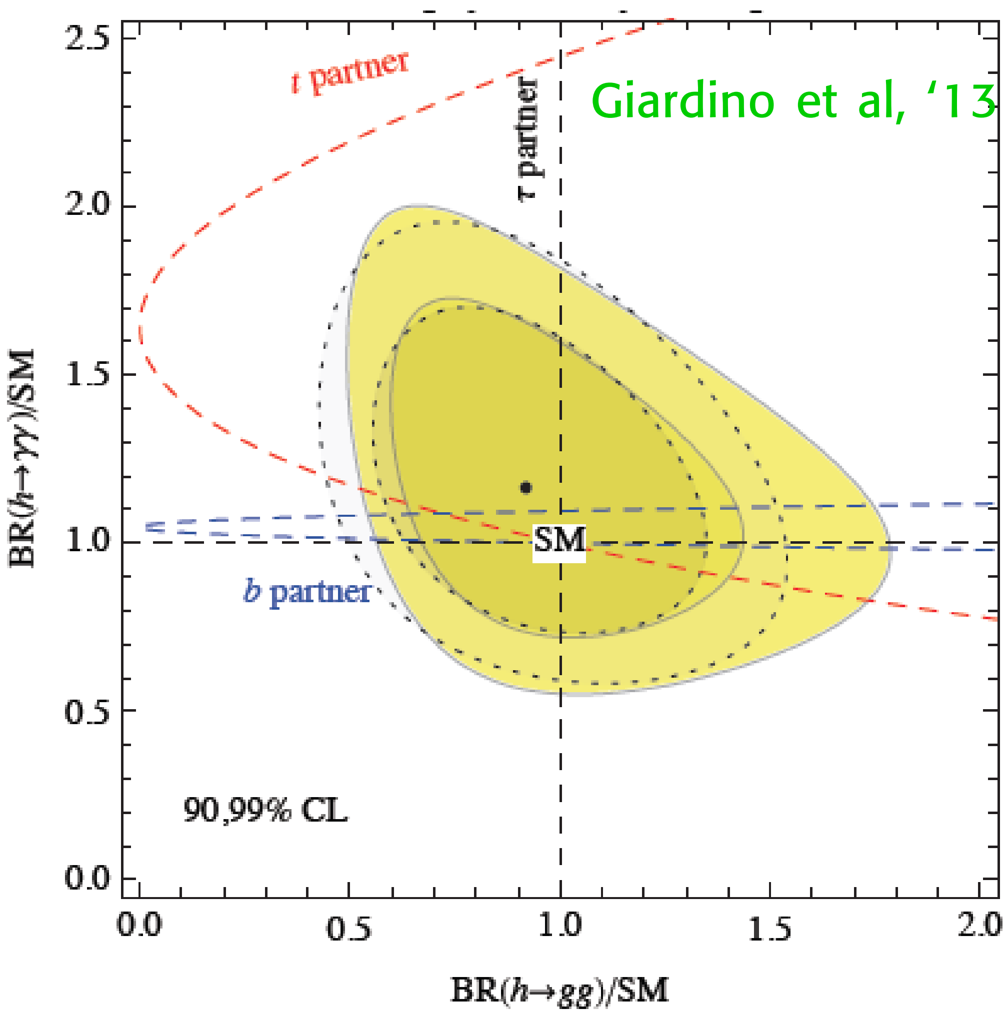
a ~ hVV

New Physics in loops?

$$\Delta L = r_\gamma c_{\rm SM}^{\gamma\gamma} \frac{\alpha}{\pi V} h F_{\mu\nu} F_{\mu\nu} + r_g c_{\rm SM}^{gg} \frac{\alpha_s}{12\pi V} h G^a_{\mu\nu} G^a_{\mu\nu}$$

CMS





A 7 parameter fit from a more general effective lagrangian

Falkowski

$$c_V = 1.04^{+0.03}_{-0.03}$$

$$c_u = 0.55^{+0.66}_{-1.72}$$

$$c_d = 1.03^{+0.26}_{-0.20}$$

$$c_l = 1.04^{+0.21}_{-0.21}$$

$$c_{gg} = 0.005^{+0.022}_{-0.031}$$

$$c_{\gamma\gamma} = 0.0001^{+0.0018}_{-0.0021}$$

$$c_{Z\gamma} = 0.006^{+0.015}_{-0.028}$$

$\Delta\chi^2 = \chi^2_{SM} - \chi^2_{min} = 4.9$, with 7 d.o.f.

the SM hypothesis is a perfect fit :-(((

→ here $c_{gg} = r_g - 1$

For example:

MSSM: separate u and d couplings and | a| < 1

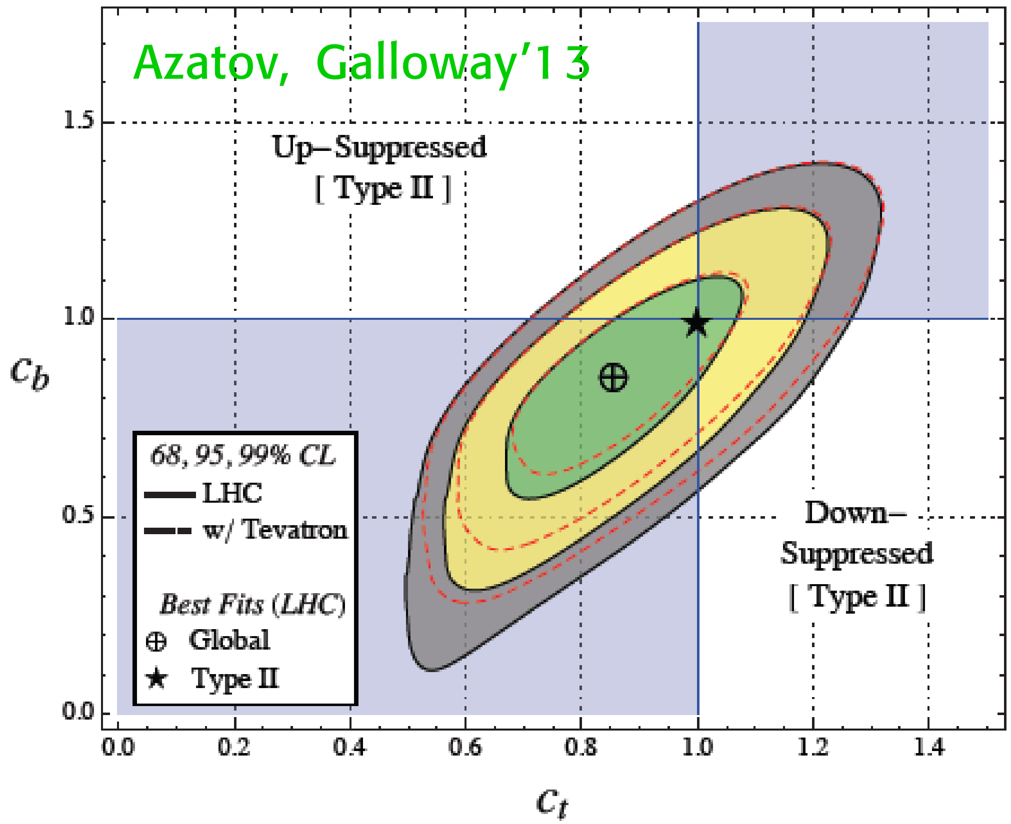
Tree level formulae
Radiative corrections
important

$$\tan 2\alpha = \tan 2\beta \frac{m_A^2 - m_Z^2}{m_A^2 + m_Z^2}$$

$$a = hVV = \sin(\beta - \alpha)$$

$$c_u = huu = \frac{\cos\alpha}{\sin\beta}$$

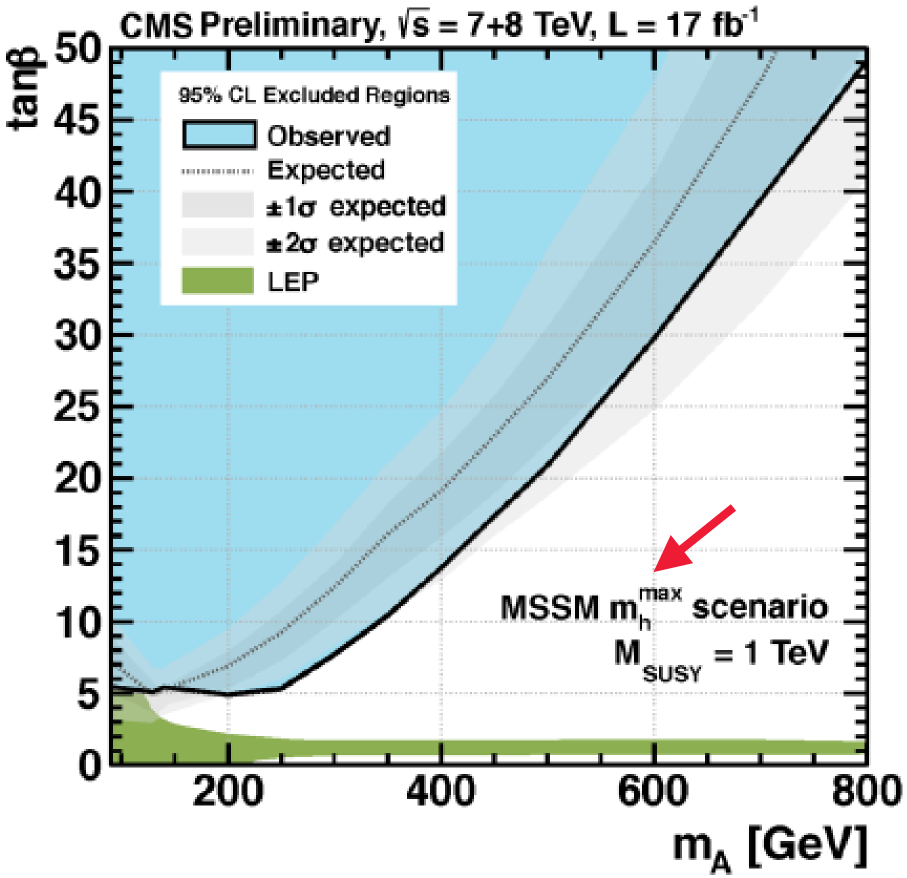
$$c_d = hdd = -\frac{\sin\alpha}{\cos\beta}$$



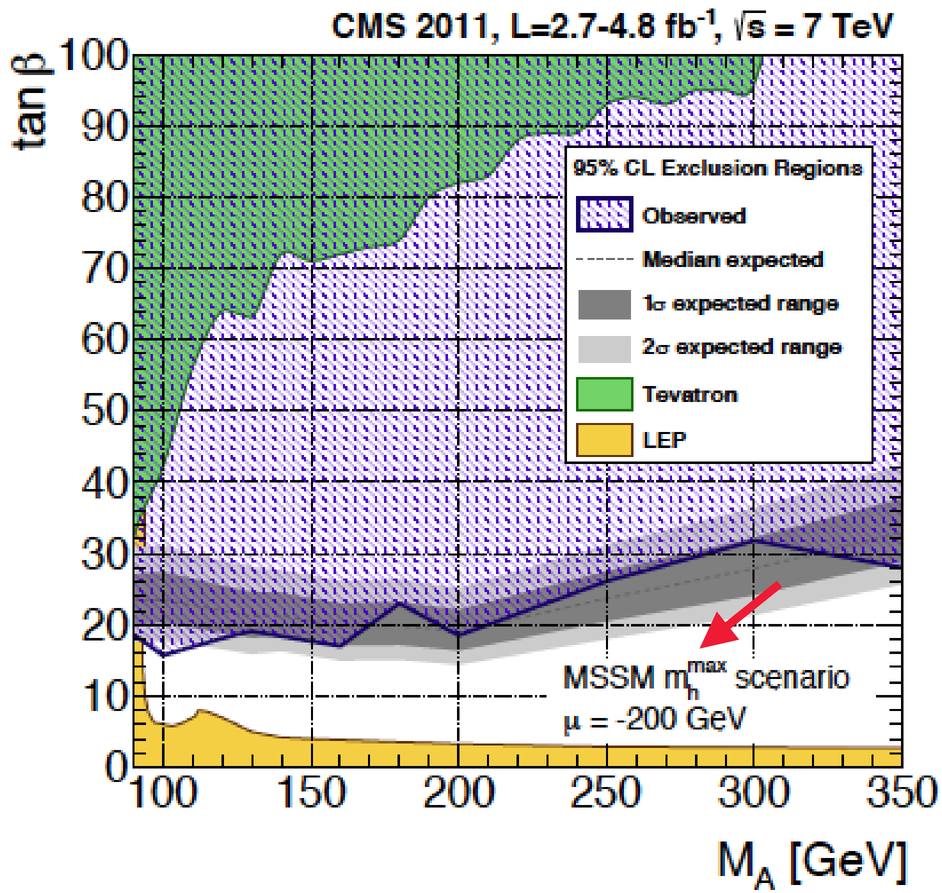
If $c_u > 1$ then $c_d < 1$
and viceversa

A very important open question:
Are there more Higgs particles? Focus on MSSM

Limits (with some assumptions: m_h^{max} scenario)



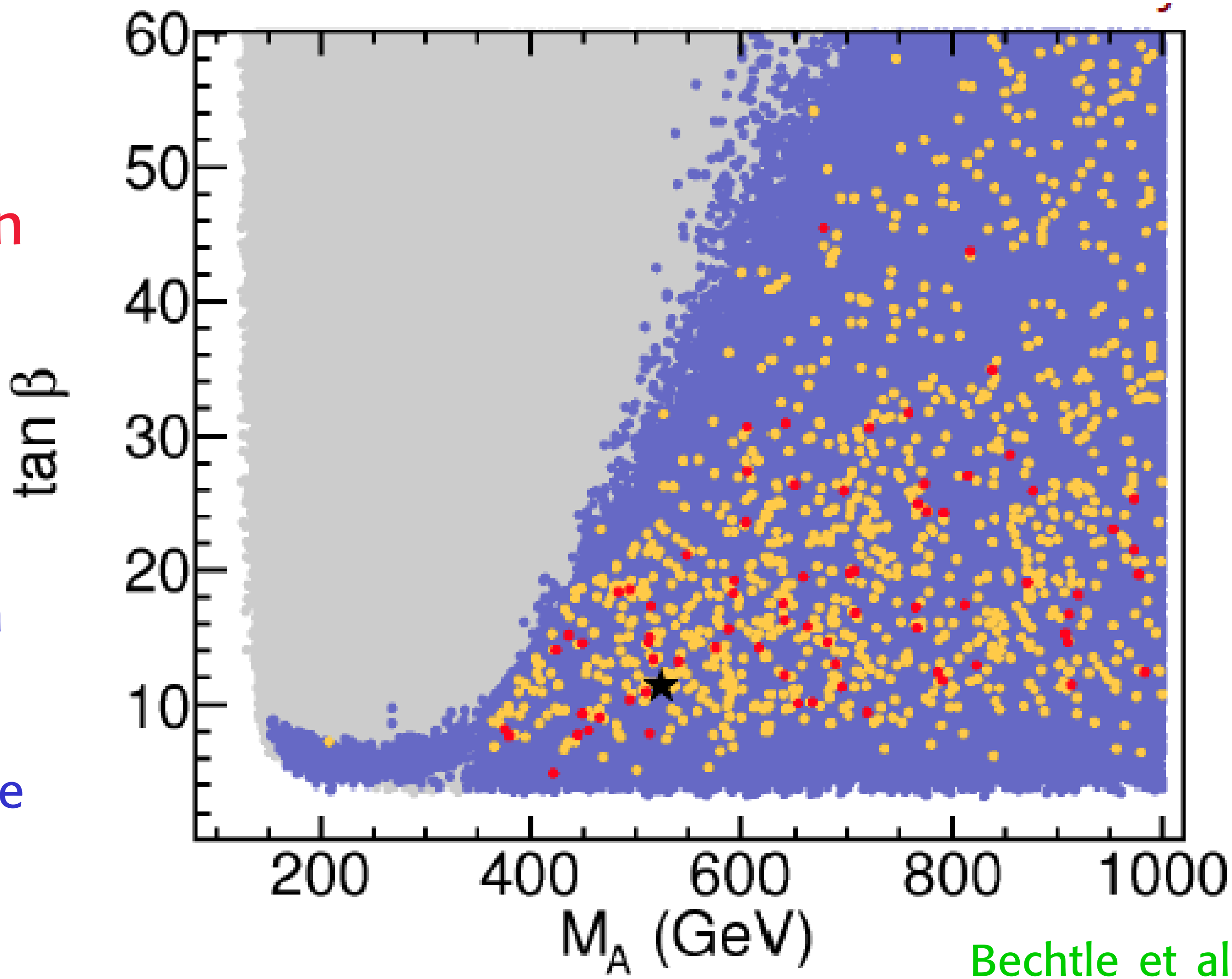
ττ



bb

Dots indicate points (red: smallest χ^2) where the experimental m_h value is reproduced, dep. on the top mixing value X_t , m_t .....

pMSSM scan
8 param.'s



Zeune

Bechtle et al

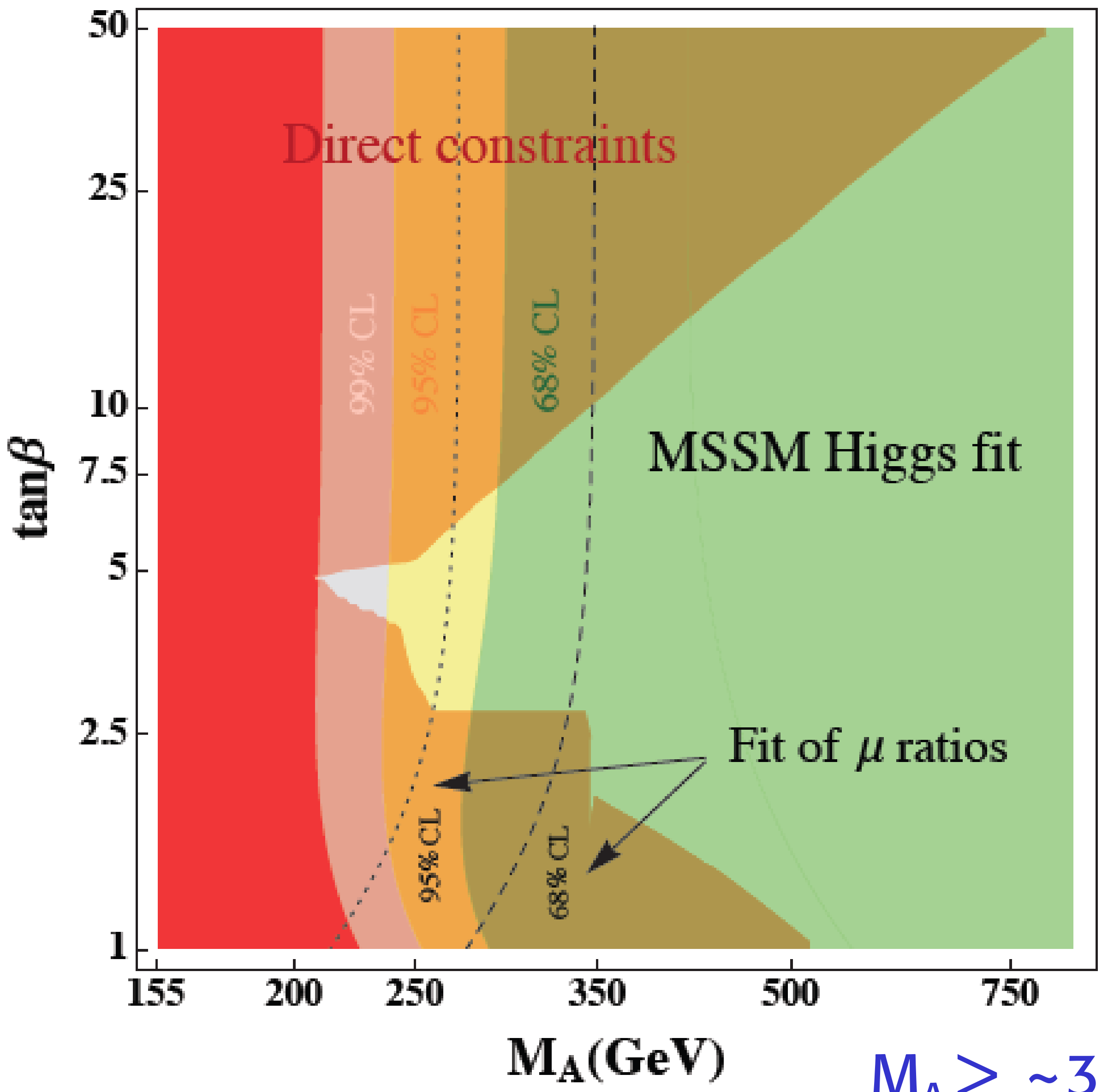
also precision tests
and flavour constraints are imposed

- $(g_\mu - 2)$ differs by more than 3 σ

$M_A >$ ~350 GeV

Djouadi et al '13

A summary plot including the observed signal rates and the limits from direct searches



Bottom line:

The issue of extra Higgs (doublets and/or singlets) is a clear priority

$M_A > \sim 350$ GeV

Impact of the Higgs discovery

The minimal SM Higgs:
is the simplest possible form of spont. EW symmetry breaking.

What was considered by many theorists just as a toy model,
a temporary addendum to the gauge part of the SM,
is now promoted to the real thing!

The only known example in physics of a fundamental,
weakly coupled, scalar particle with VEV

→ e.g. the quartic coupling is perturbative:

$$V = -\mu^2 \phi^\dagger \phi + \tfrac{1}{2}\lambda(\phi^\dagger \phi)^2 \qquad \phi \to v + \frac{H}{\sqrt{2}} \qquad v = 174.1 GeV$$

$$m_H{}^2 = 2\mu^2 = 2\lambda v^2 \longrightarrow \tfrac{1}{2}\lambda \sim 0.13$$

Higgs, unitarity and naturalness in the SM

In the SM the Higgs provides a solution to the occurrence of unitarity violations in some amplitudes (W_L, Z_L scattering)

To avoid these violations one needed either one or more Higgs particles or some new states (e.g. new vector bosons)

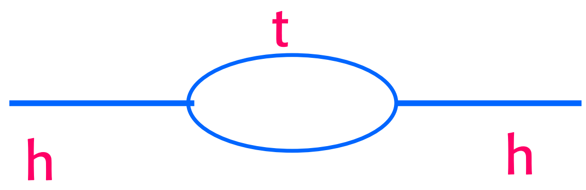
Something had to happen at the few TeV scale!!

While this is a theorem, once there is the Higgs, the necessity of new physics on the basis of naturalness is not a theorem but still a well motivated demand

The absence of accompanying new physics puts the issue of the relevance of our concept of naturalness at the forefront

The naturalness argument for new physics at the EW scale is not a theorem but still is a valid conceptual demand

$$\delta m^2_{h|top} = -\frac{3G_F}{2\sqrt{2}\pi^2} m_t^2 \Lambda^2 \sim -(0.2\Lambda)^2$$



If we see Λ as the scale where new physics occurs that solves the fine tuning problem, then the strong indication that Λ must be nearby follows

However, it is true that the SM theory is renormalizable. and completely finite and predictive

If you do not care about this miraculous fine tuning you are not punished, you find no catastrophe!!

The naturalness principle

Has been and is the main motivation for new physics at the weak scale

But at present our confidence on naturalness as a guiding principle is being more and more challenged

No indirect evidence of new physics (is g-2 really solid?)
No direct evidence of new physics at the LHC

Manifestly some amount of fine tuning is imposed on us by the data. More so now after the LHC7-8 results

Does Nature really care about our concept of Naturalness? Apparently not much!
Which form of Naturalness is Natural?

Is naturalness relevant? The multiverse alternative

- The empirical value of the cosmological constant Λ_{cosmo} poses a tremendous, unsolved naturalness problem

While natural extensions of the SM exist, no natural explanation of the value of Λ_{cosmo} is known

- Yet the value of Λ_{cosmo} is close to the Weinberg upper bound for galaxy formation
- Possibly our Universe is just one of infinitely many continuously created from the vacuum by quantum fluctuations
- Different physics in different Universes according to the multitude of string theory solutions ($\sim 10^{500}$)

Perhaps we live in a very unlikely Universe but one that allows our existence

Given the stubborn refusal of the SM to step aside many have turned to the anthropic philosophy also for the SM

Actually applying the anthropic principle to the SM hierarchy problem is not terribly convincing

After all, we can find plenty of models that reduce the fine tuning from 10^{14} to 10^{2}. And the added ingredients do not appear to make our existence more impossible. So why make our Universe so terribly unlikely?

But there is some similarity

Λ_{cosmo} - > a vacuum energy density in all points of space

v -> a vacuum expectation value in all points of space

With larger Λ_{cosmo} no galaxies, with larger v no nuclear physics

- The anthropic way is now being kept in mind as a possibility

A revival of models that ignore the fine tuning problem

The absence of new physics appears as a paradox to us

Still the picture suggested by the last 20 years of data is simple and clear

Take the SM, extended to include Majorana neutrinos, perhaps axions, as the theory valid up to very high energy

- Neutrino masses? See-Saw mechanism
- Baryogenesis? Thru leptogenesis
- Dark Matter? Axions
- Coupling Unification? SO(10) with an intermediate scale GA, Meloni '13

Possibly Nature has a way, hidden to us, to realize a deeper form of naturalness at a more fundamental level

Dark Matter is the most compelling argument for New Physics

WIMP's still are optimal candidates:
Weakly Interacting Massive Particle with m ~ 10^1-10^3 GeV

LHC can reach any kind of WIMP

For WIMP's in thermal equilibrium after inflation the density is:

$$\Omega_\chi h^2 \simeq const. \cdot \frac{T_0^3}{M_{\rm Pl}^3 \langle \sigma_A v \rangle} \simeq \frac{0.1 \ {\rm pb} \cdot c}{\langle \sigma_A v \rangle}$$

can work for typical weak cross-sections!!!

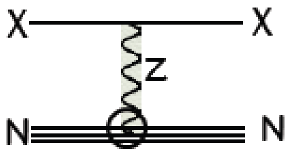
This "coincidence" is a good indication in favour of a WIMP explanation of Dark Matter

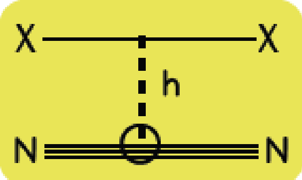
DM searches and the Higgs boson

$$\chi N \to \chi N$$

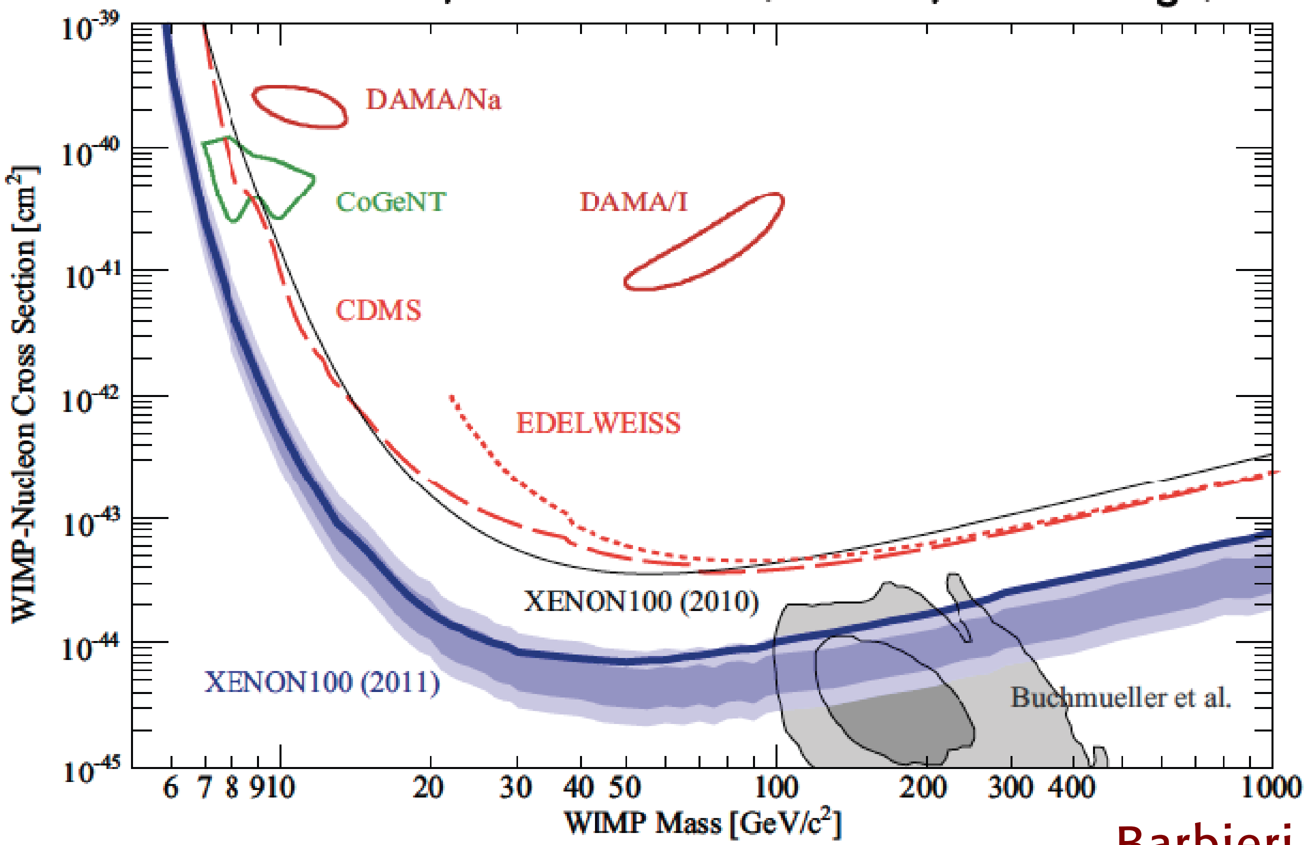
3 events/1.8 backgd

$\sigma_Z(\chi N)$ spin indep. excluded since long time





exclusion by XENON100 (100 days x 48 kgs)



Barbieri

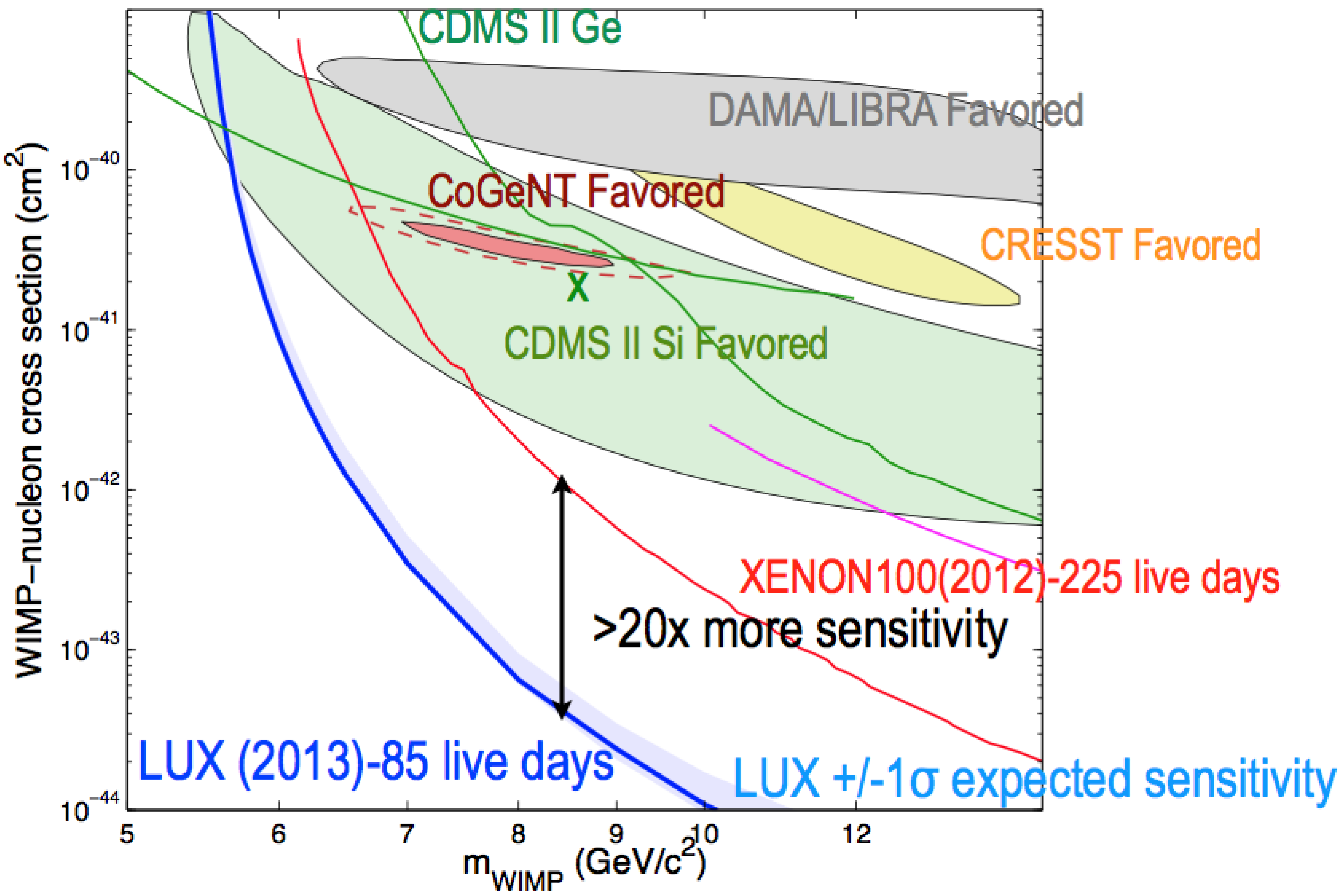
Higgs boson exchange being probed now for $m_h = 125\ GeV$

$$\sigma_h(\chi N) \approx 10^{-43} cm^2\ (\frac{\lambda}{0.1})^2 (\frac{100 GeV}{m_\chi})^2 (\frac{100 GeV}{m_h})^4$$

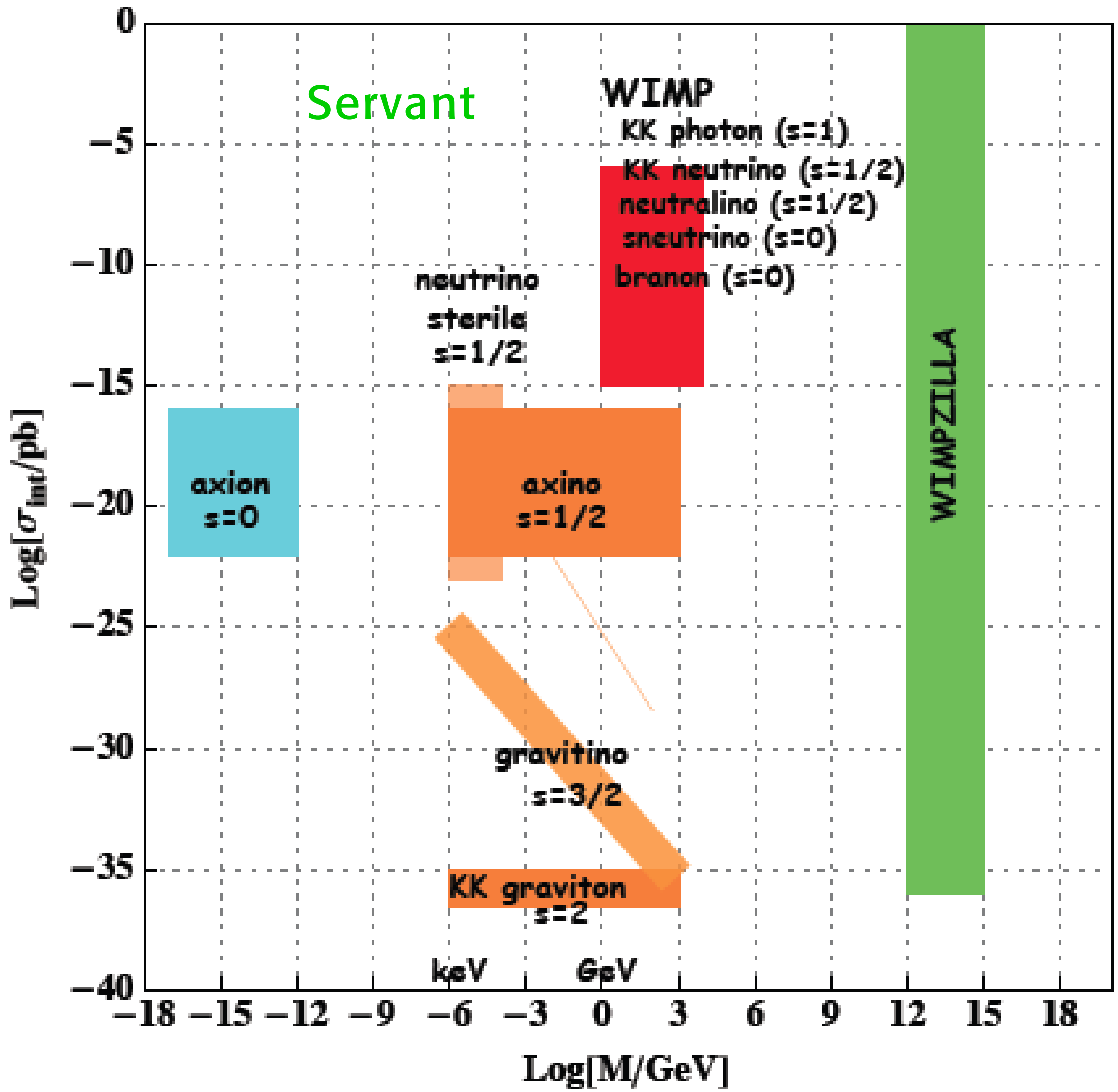
CDMS-Si ArXiv :1304.4279 3 events in the signal region

Possible evidence for low mass ~10 GeV WIMPS?

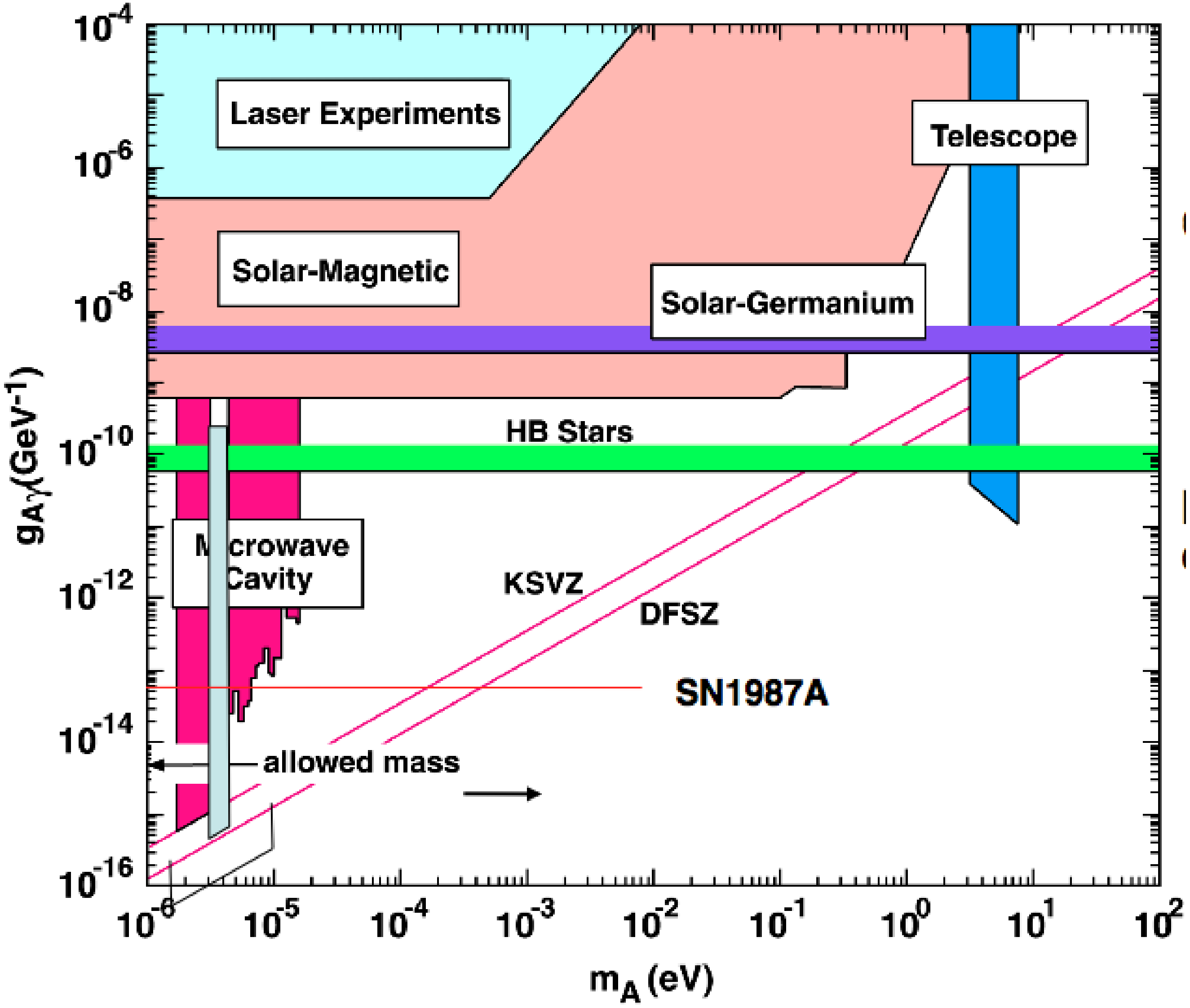
Now excluded by LUX ArXiv:1310.8214



Of all DM candidates the axion is the closest to the SM

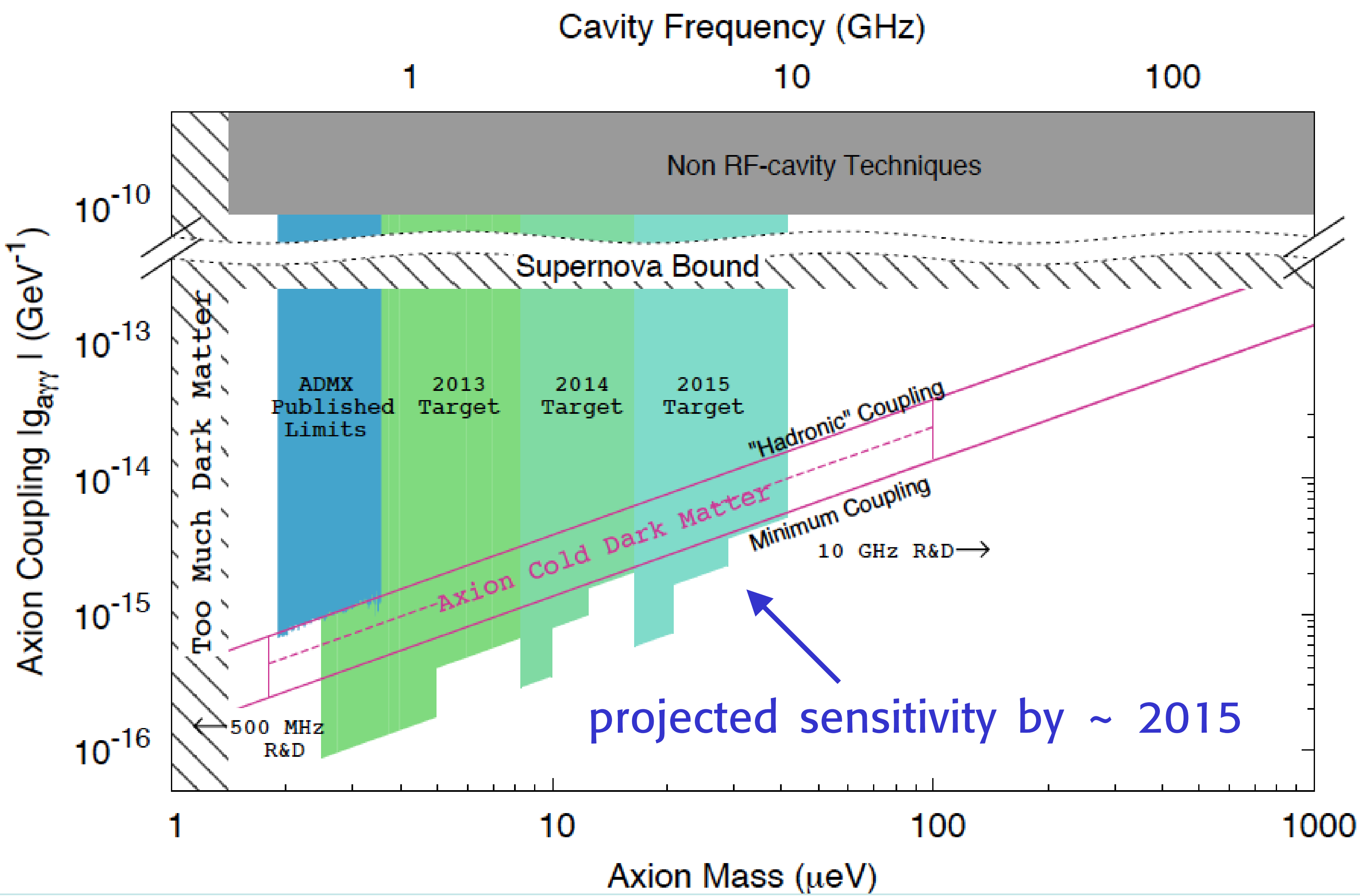


Axion searches are very important



ADMX: the Axion Dark Matter Experiment

University of Washington at Seattle



A revival of models that ignore the fine tuning problem

Examples:

Split SUSY

heavy scalars, light gauginos and higgsinos (DM and Unification)

High scale SUSY

all sparticles heavy

λh^4 fixed by gauge

Non SUSY GUT's

Unificaxion

Giudice, Rattazzi, Strumia

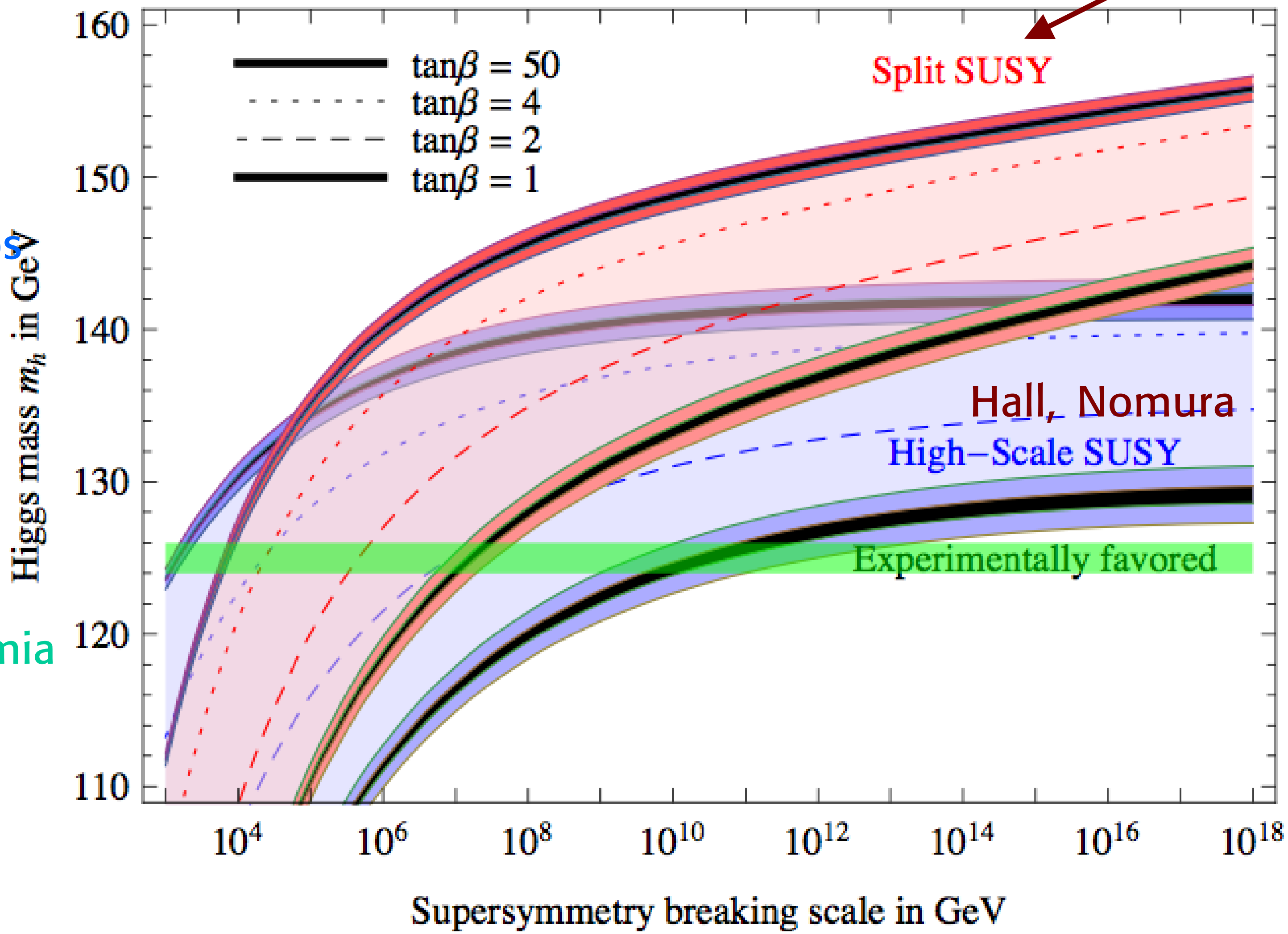
Non SUSY SO(10)

GA, Meloni

••••••••

Giudice, Strumia

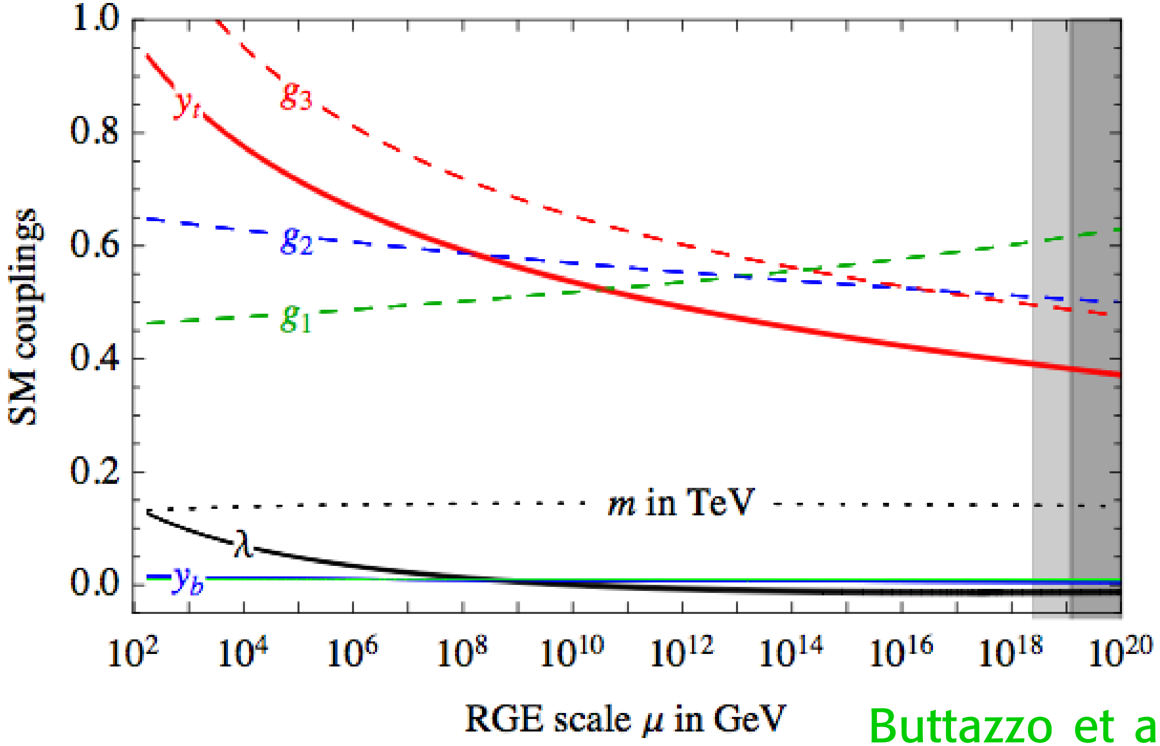
Arkani-Amed,Dimopoulos
Giudice, Romanino



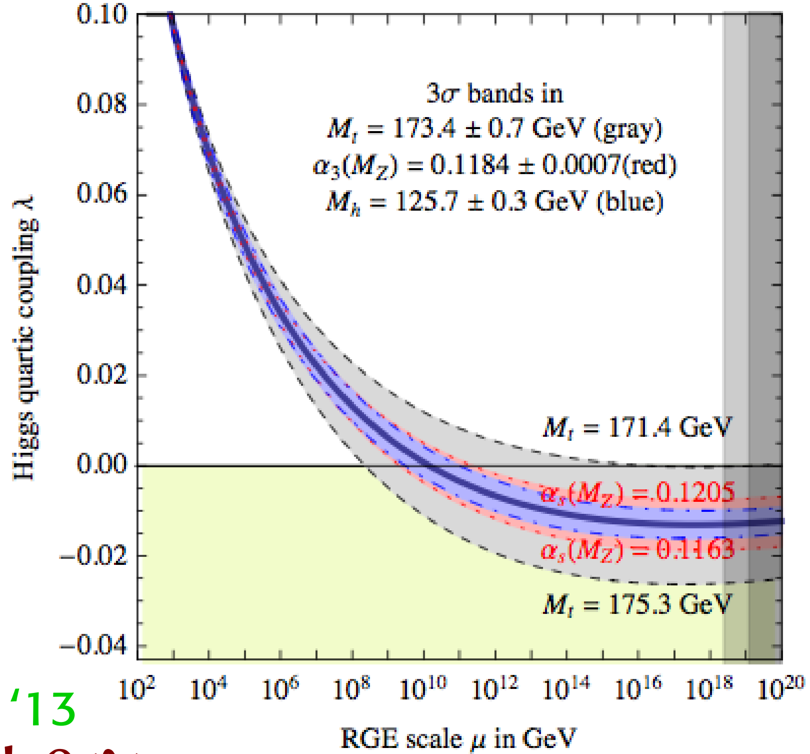
State of the art coupling evolution in SM (3 loops, thresholds)

In the absence of new physics, for m_H ~ 126 GeV, the Universe becomes metastable at a scale Λ ~ $10^{10\text{-}12}$ GeV

But metastability (with sufficiently long lifetime) is enough and the SM remains viable up to M_{Pl} (Early universe implications)

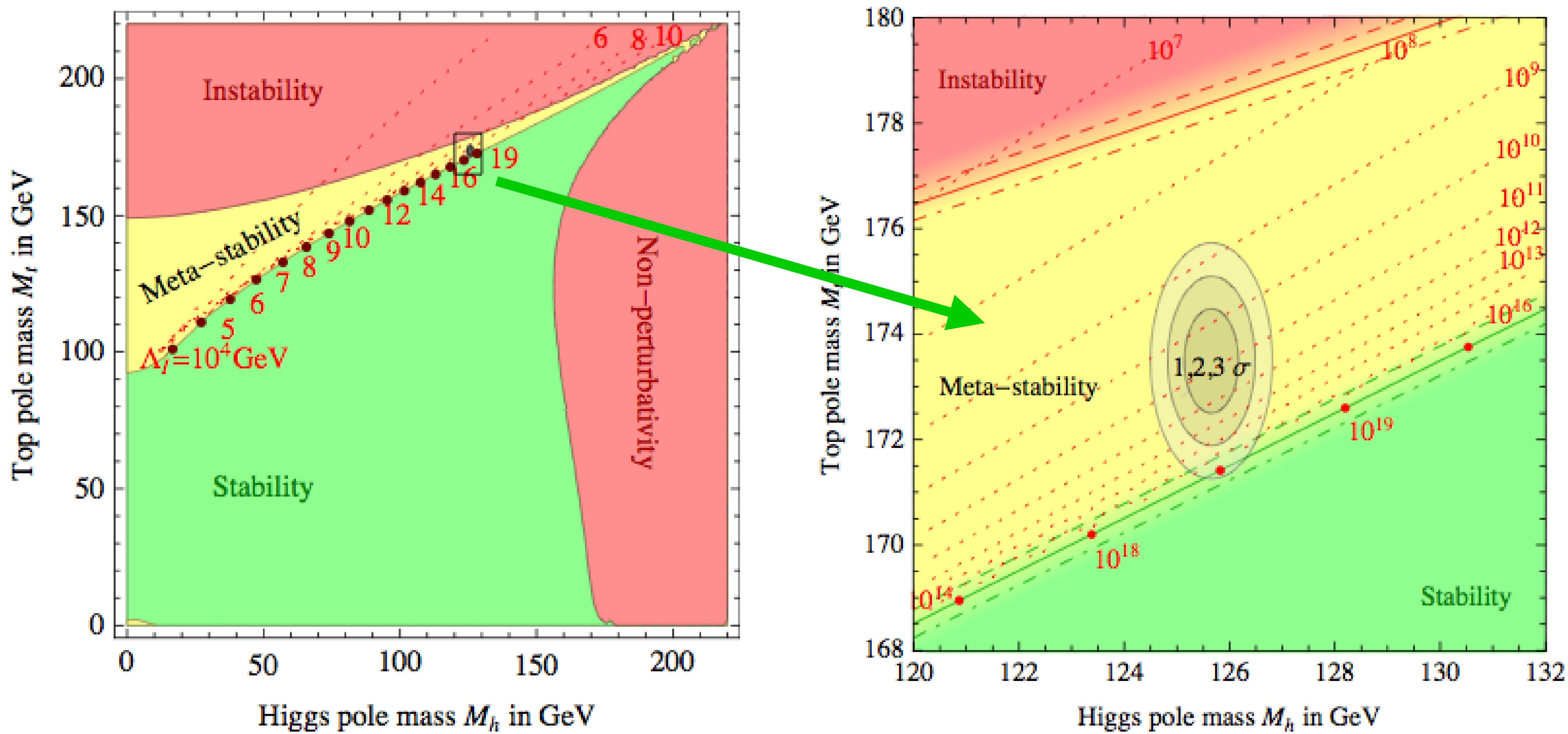


Buttazzo et al '13



For the measured values both λ and $\beta(\lambda)$ vanish near M_{Pl}

see e.g. Shaposhnikov; Wetterich '10



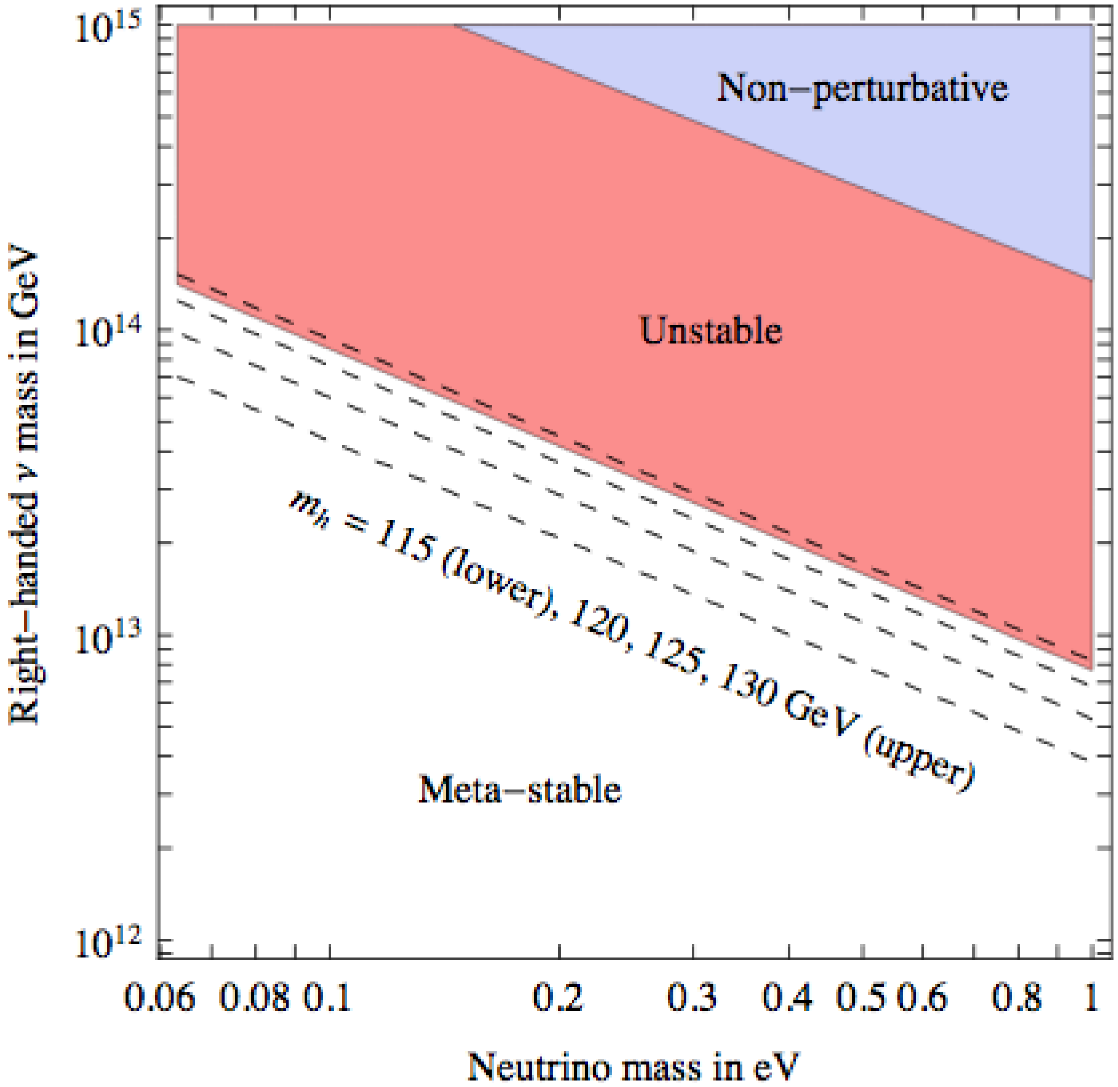
Absolute stability condition

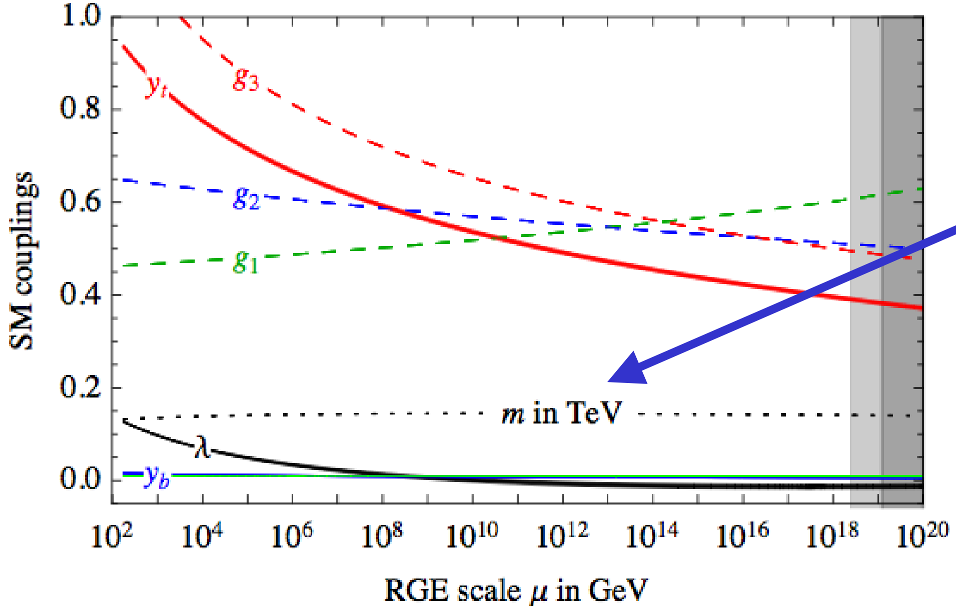
$$M_h > 129.6\,\text{GeV} + 2.0(M_t - 173.35\,\text{GeV}) - 0.5\,\text{GeV}\,\frac{\alpha_3(M_Z) - 0.1184}{0.0007} \pm 0.3\,\text{GeV}$$

The SM evolution up to M_{Pl} leads to a narrow critical wedge: a hidden message?

For M < 10^{14} GeV RH neutrinos do not make the vacuum unstable

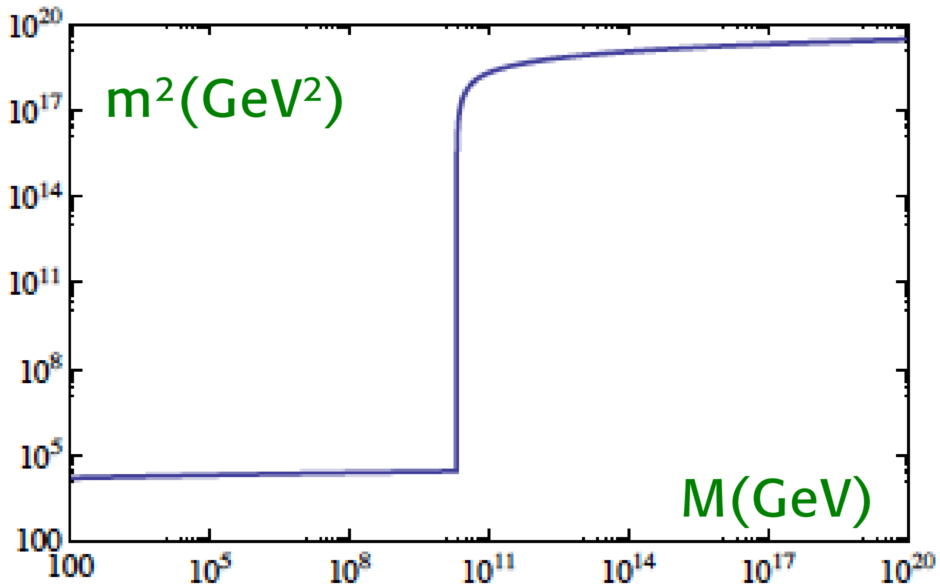
J. Elias-Miro' et al '11





In the absence of a threshold the Higgs mass evolves logaritmically

Barbieri



In the presence of a threshold at M for a heavy particle coupled to the Higgs, the quadratic sensitivity produces a jump in the running mass

$M \sim 10^{10}$ GeV, $\lambda_H \sim 1$, jump $\sim (\lambda_H M)^2/(16\pi^2)$

Fine tuning is needed to explain the small value of m at low energy

A drastic conjecture

No new thresholds between m_W and M_{Pl}?

Shaposhnikov

And hope that gravity will somehow fix the problem of fine tuning related to the M_{Pl} threshold (with many thresholds it would be more difficult for gravity to arrange the fine tuning)

For this, one would need to solve all problems like Dark Matter, neutrino masses, baryogenesis.... at the EW scale

In particular no GUT's below M_{Pl}

The νMSM

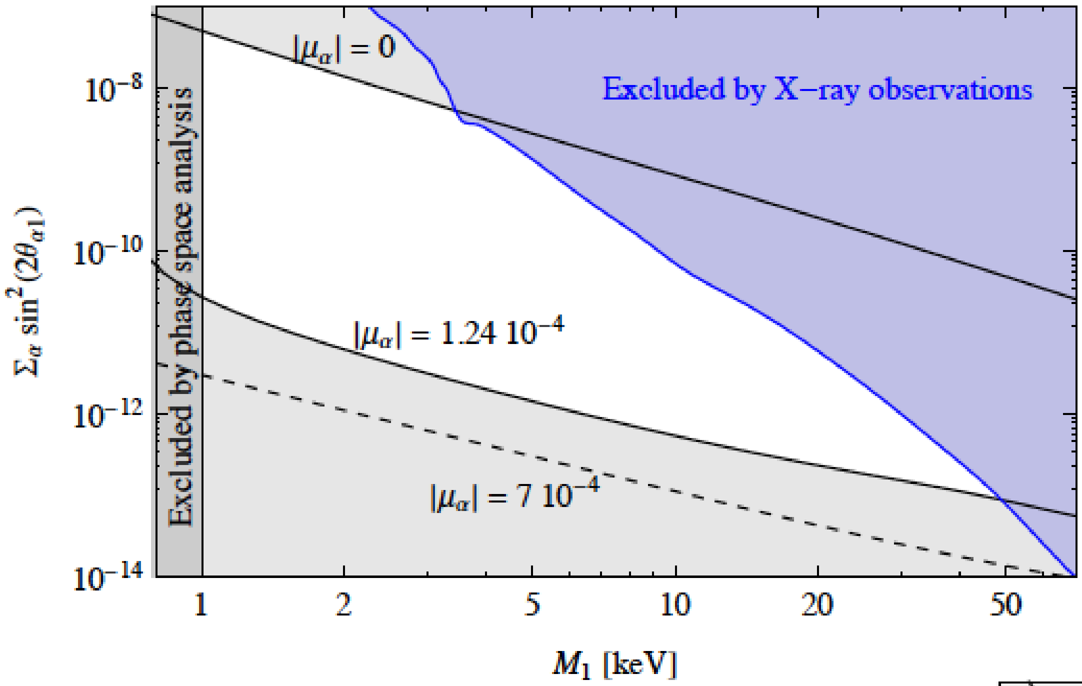
Shaposhnikov et al

There are 3 RH ν's: N_1, N_2, N_3 and the see-saw mechanism
But the N_i masses are all below the EW scale
Actually N_1 ~ o(1-10) keV, and $N_{2,3}$ ~ GeV with eV splitting
Very small Yukawa couplings are assumed to explain the small active ν masses

$$m_\nu = \frac{y_\nu^2 v^2}{M_N}$$

The phenomenology of ν oscillations can be reproduced
N_1 can explain (warm) DM
$N_{2,3}$ can explain the Baryon Asymmetry in the Universe

N_1 decay produces a distinct X-ray line
$N_{2,3}$ could be detected by dedicated accelerator experiments (eg in B decays, Br ~ 10^{-10})
A LOI for the CERN SPS has been presented
Bonivento et al, ArXiv:1310.1762

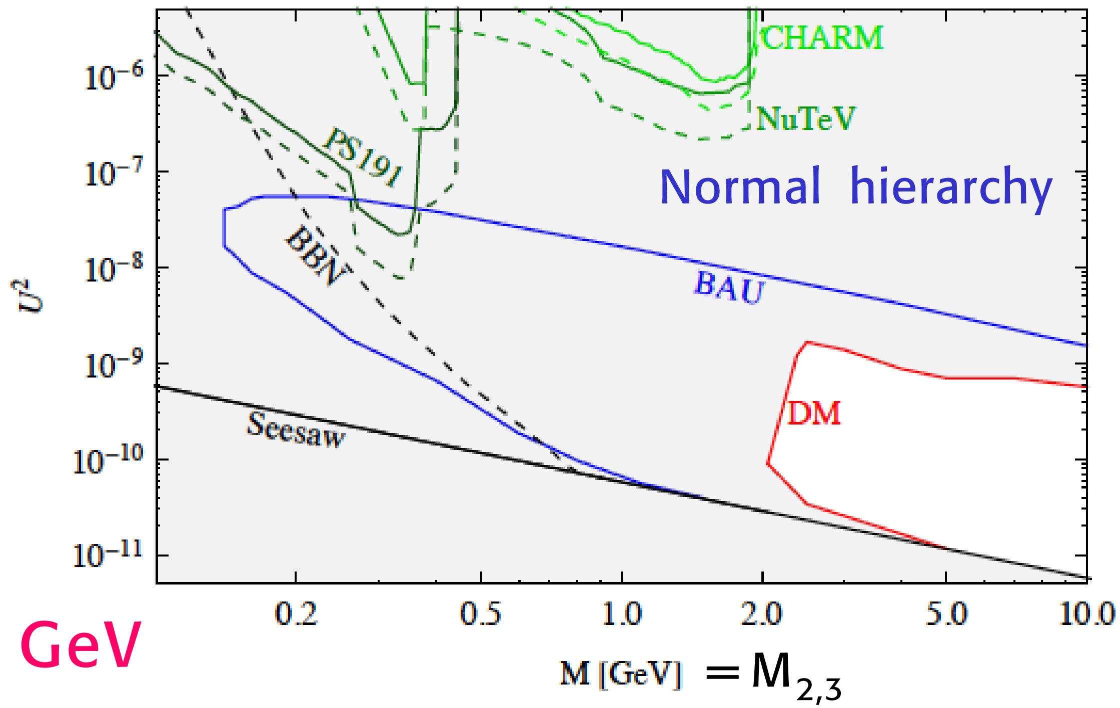


Canetti et al '12

The claim is that all constraints can be satisfied

keV

No explanation of the mass splitting



GeV

The other main side: stay natural and minimize the FT

- "Stealth" Naturalness: build models where naturalness is restored not too far from the weak scale but the related NP is arranged to be not visible so far

Fine-tuning the fine-tuning-suppression mechanism?

Two main directions

SUSY ← → Composite Higgs

SUSY

For an orderly retreat
simplest new ingredients are

- Compressed spectra
- Heavy first 2 generations
- NMSSM (an extra Higgs singlet)

The last trench of natural SUSY!

Composite Higgs

H as PGB of extended symm.
q and l mix with comp. ferm.

Key role of light top partners

Going beyond the MSSM: an extra singlet Higgs

In a promising class of models a singlet Higgs S is added and the μ term arises from the S VEV (the μ problem is solved)

λSH_uH_d

additional term

$$m_h^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \delta_t^2$$

Mixing with S can modify the Higgs mass and couplings at tree level

Hall et al '11, King et al '12, Barbieri et al '13.....

NMSSM: $\lambda <\sim 0.7$ the theory remains perturbative up to M_{GUT}
(no need of large stop mixing, less fine tuning)

λ SUSY: $\lambda \sim 1 - 2$ for $\lambda > 2$ theory non pert. at ~10 TeV

It is not completely excluded that at 126 GeV the second heaviest is seen while the lightest escaped detection at LEP

Ellwanger '11, Belanger et al '12

- Going beyond the MSSM: Natural SUSY

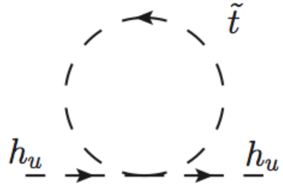
For MSSM to be natural

$m_{\tilde{g}}, m_{\tilde{t}}, m_{\tilde{b}}, m_{\tilde{h}}$ < ~1 TeV

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

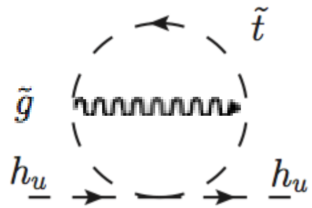
Tree level $\sin^2 2\beta << 1$
(no extra singlet in MSSM)

μ related to lightest Higgsino mass



$$\delta m_{H_u}^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 + |A_t|^2\right) \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

largest radiative corrections involve s-top and gluinos



$$\delta m_{H_u}^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

Beyond the CMSSM, mSugra, NUHM1,2 that are under stress

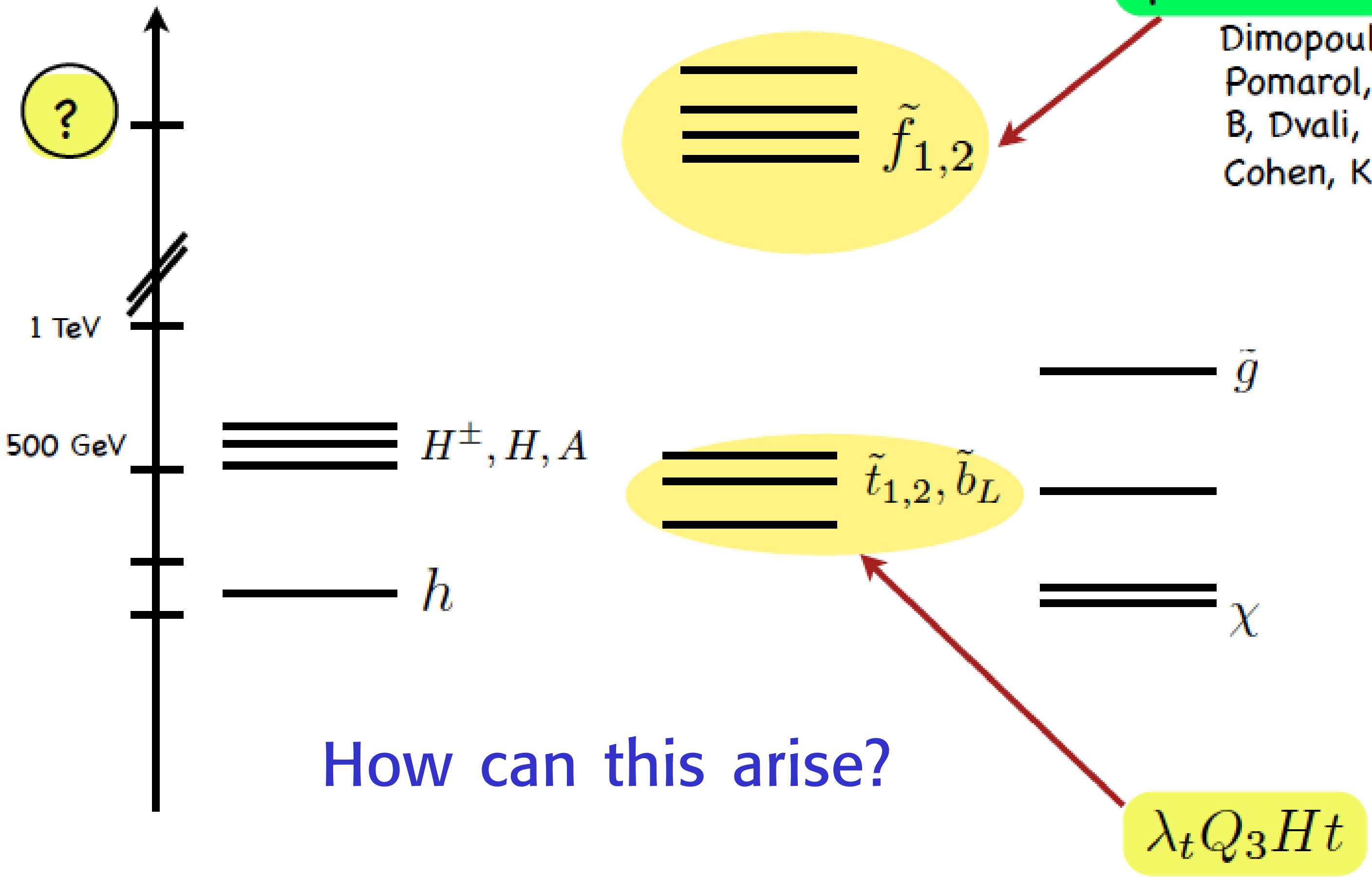
Heavy 1st, 2nd generations

Barbieri

Flavour and CP problems improved

Dimopoulos, Giudice 1995
Pomarol, Tommasini 1995
B, Dvali, Hall 1995
Cohen, Kaplan, Nelson 1996

pioneer papers



How can this arise?

recent papers, e.g.

Papucci et al '11
Brust et al '11
Essig et al '11
Katz et al '11
Larsen et al '12
Csaki et al '12
.....

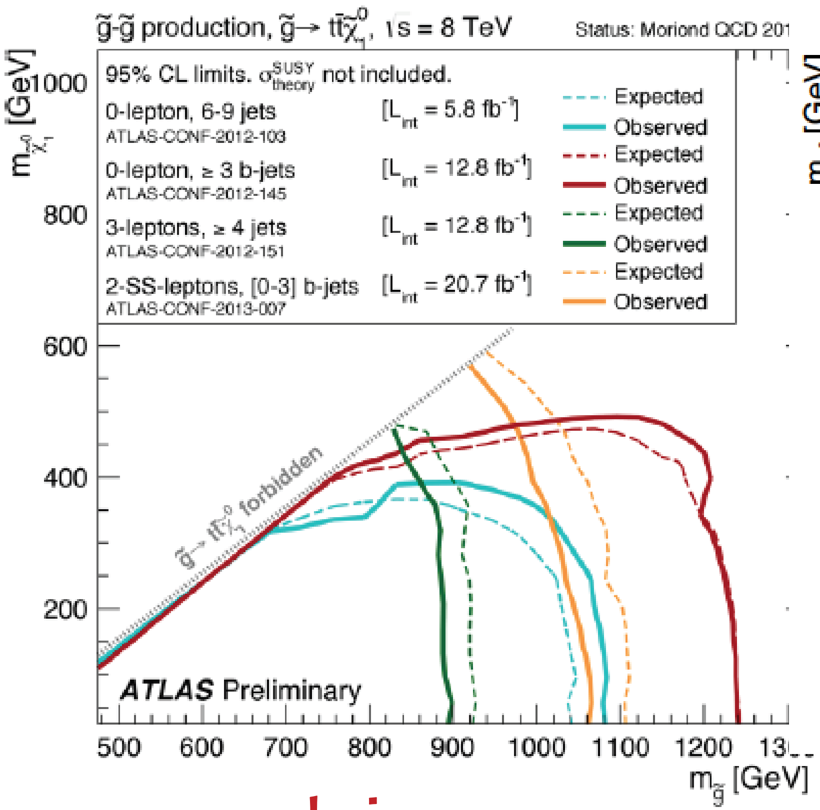
For g-2 light sleptons welcome

Searches of light gluinos, s-top, s-bottom: already biting hard

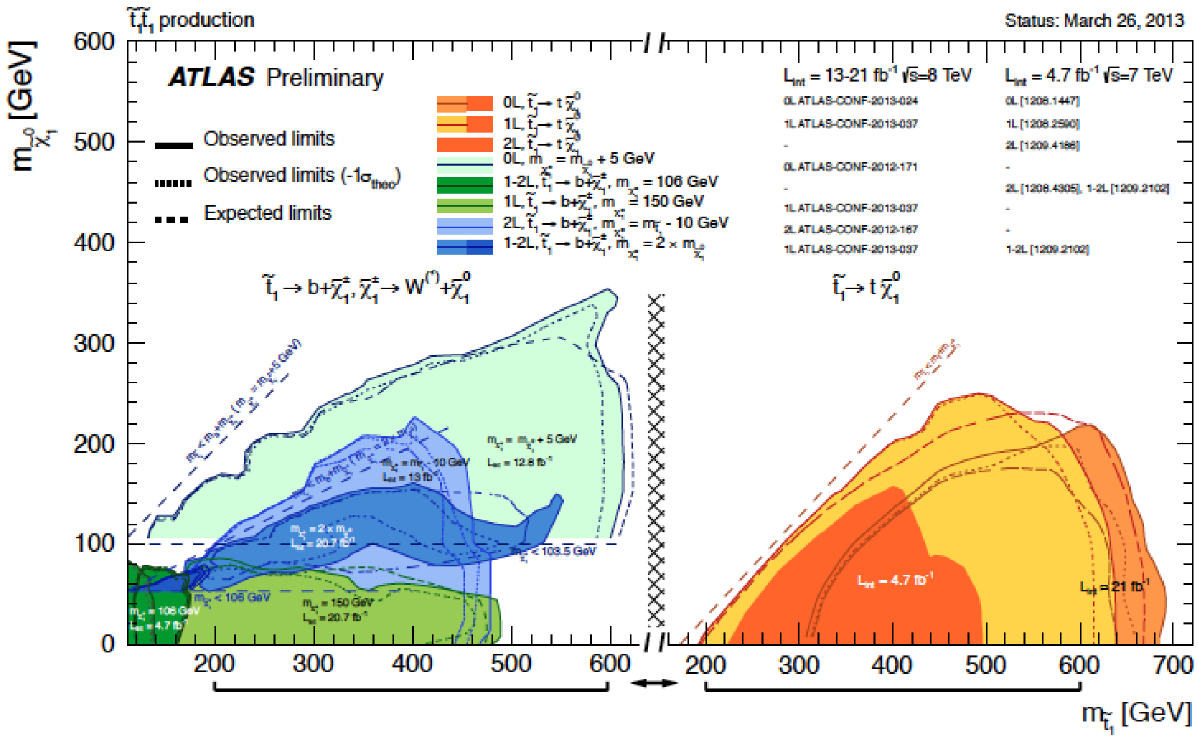
Gluino mediated s-top production: $m_g < 1.2$ TeV excluded under a variety of assumptions

Direct s-top production: $m_{stop} < 0.60$-0.65 TeV excluded assuming 100% BR for either $b\chi^+$ or $t\chi^0$

ATLAS



gluino

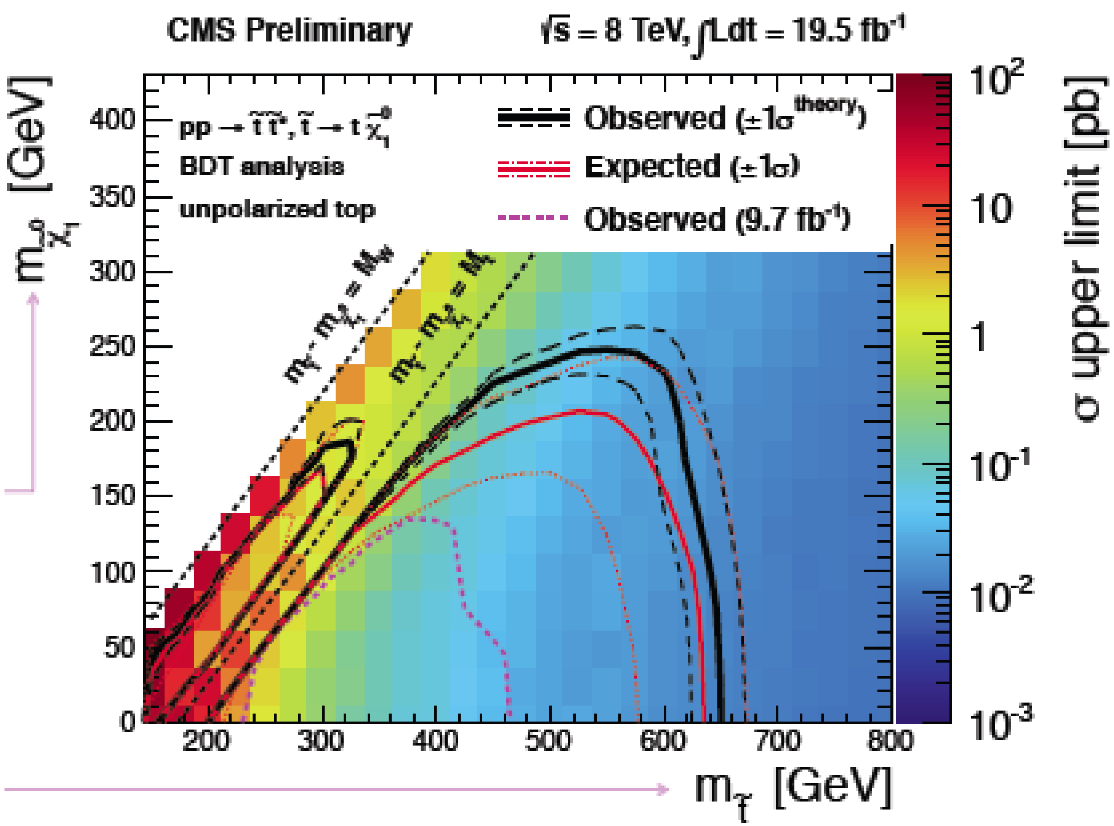


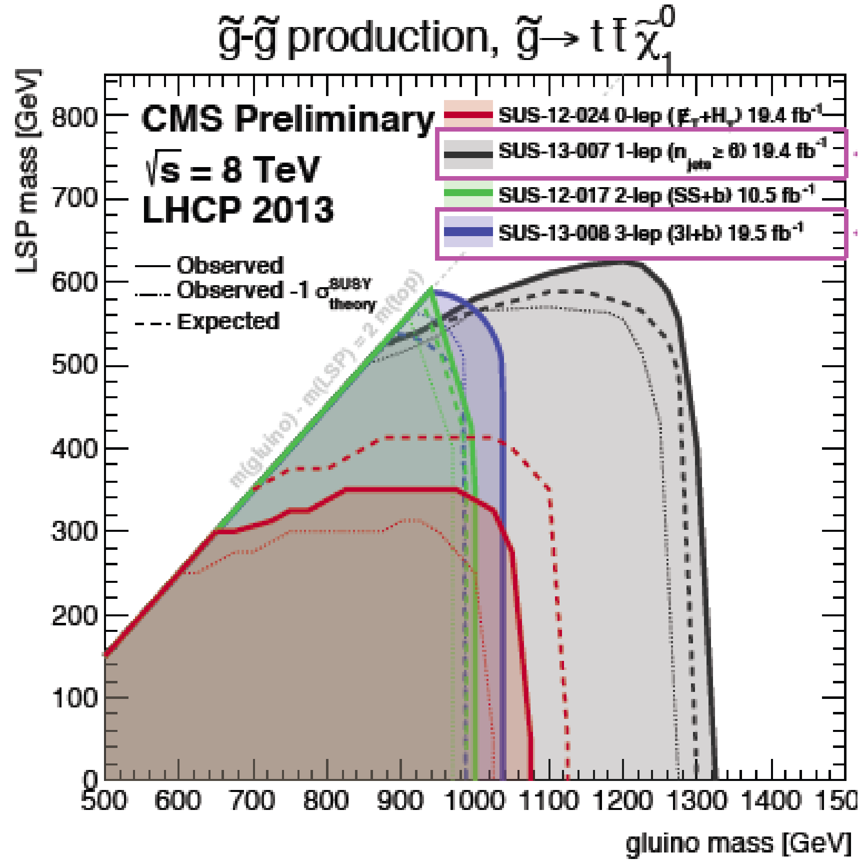
s-top

Searches for stops, gluinos, sbottoms target natural SUSY

- Probe stops up to ~650 GeV
- Probe gluinos up to ~1.3 TeV
- Probe sbottoms up to ~600 GeV

CMS





- **Composite Higgs**

Georgi, Kaplan '84; Kaplan '91; Agashe, Contino, Pomarol '05; Agashe et al '06; Giudice et al '07; Contino et al '07; Csaki, Falkowski, Weiler '08; Contino, Servant '08; Mrazek, Wulzer '10; Panico, Wulzer '11; De Curtis, Redi, Tesi '11;Marzocca, Serone, Shu '12; Pomarol, Riva'12; De Simone et al '12.........

The light Higgs is a bound state of a strongly interacting sector and a pseudo-Goldstone boson of an enlarged symmetry. eg. SO(5)/SO(4). Can be set up in a holographic ED context.

v ~ EW scale   f ~ SI scale

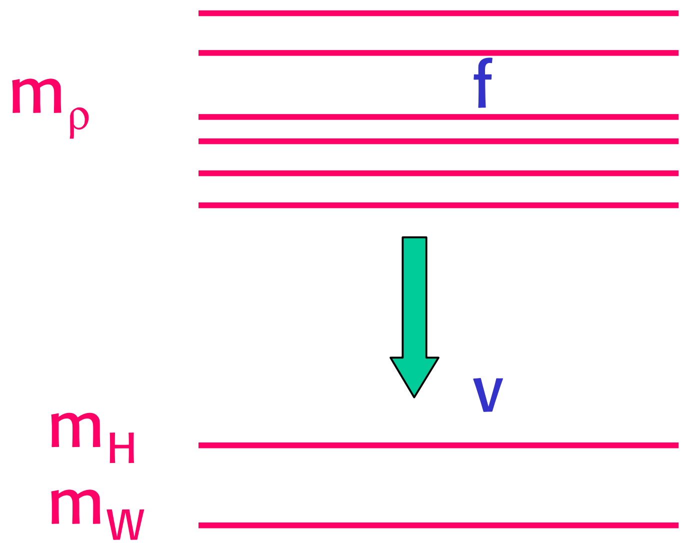
$\sim f < m_\rho <\sim 4\pi f$

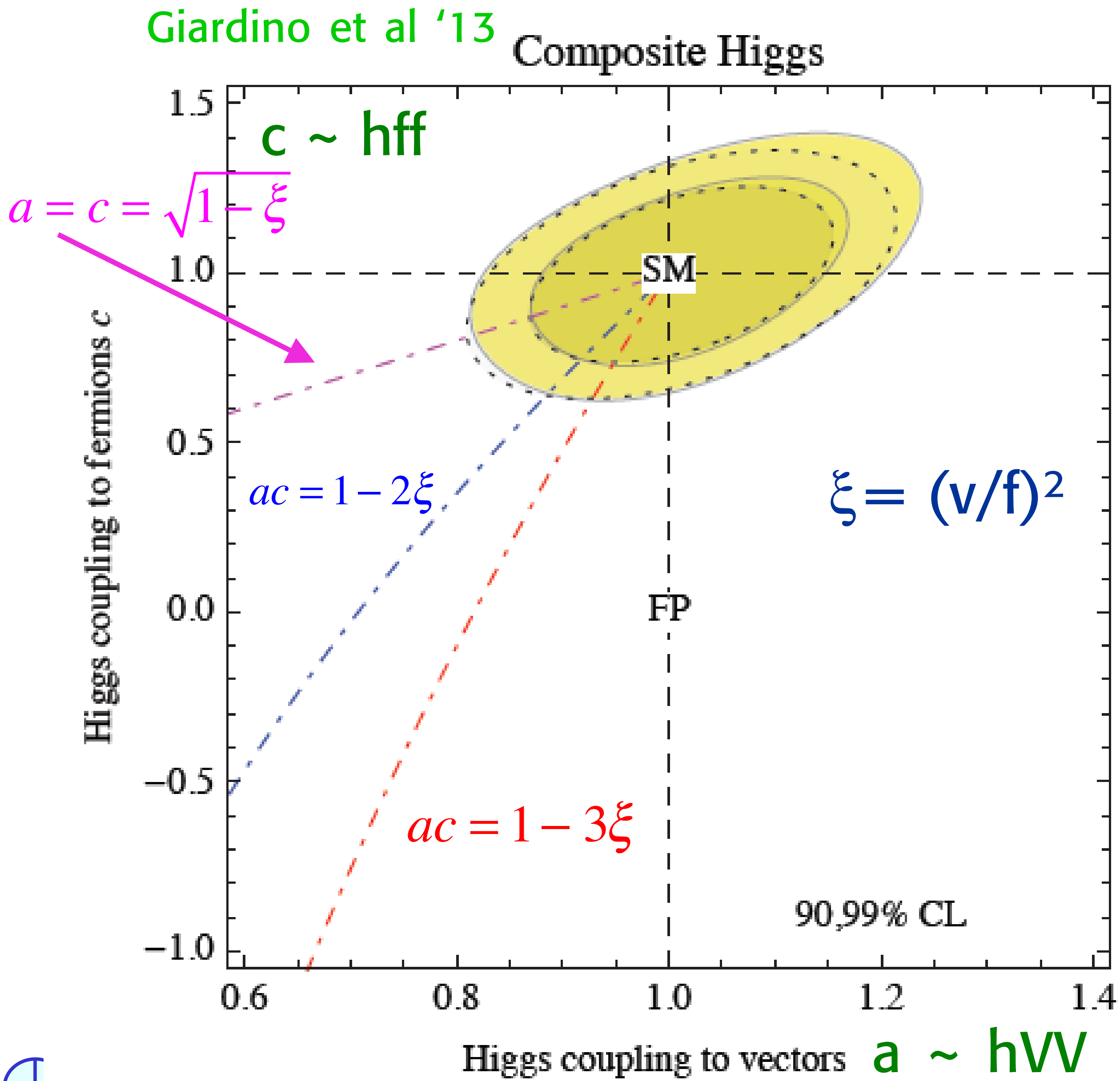
$\xi = (v/f)^2$

ξ interpolates between SM [$\xi \sim 0$] and some degree of compositeness

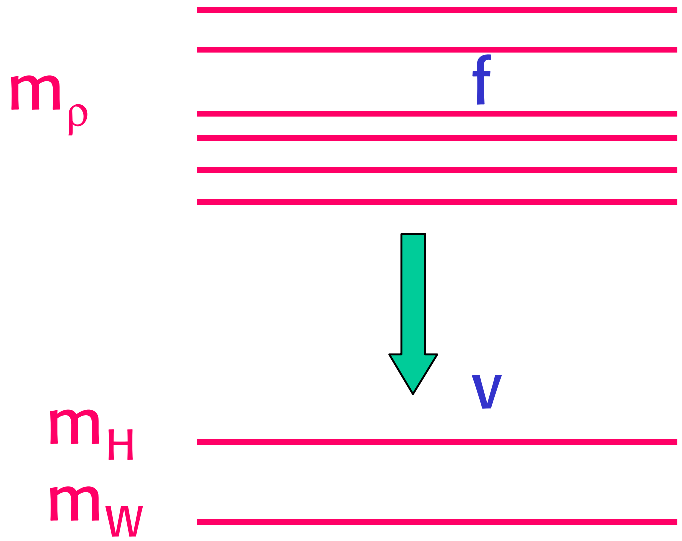
$\xi \sim 1$ similar to Technicolor

[ξ severely limited by precision EW tests $\xi < \sim 0.2$]





ξ severely limited by precision EW tests $\xi < \sim 0.2$



In general composite models are more vulnerable than SUSY from EW precision tests
(for SUSY Higgs couplings are more effective than EWPT)

Composite models can be tested by:

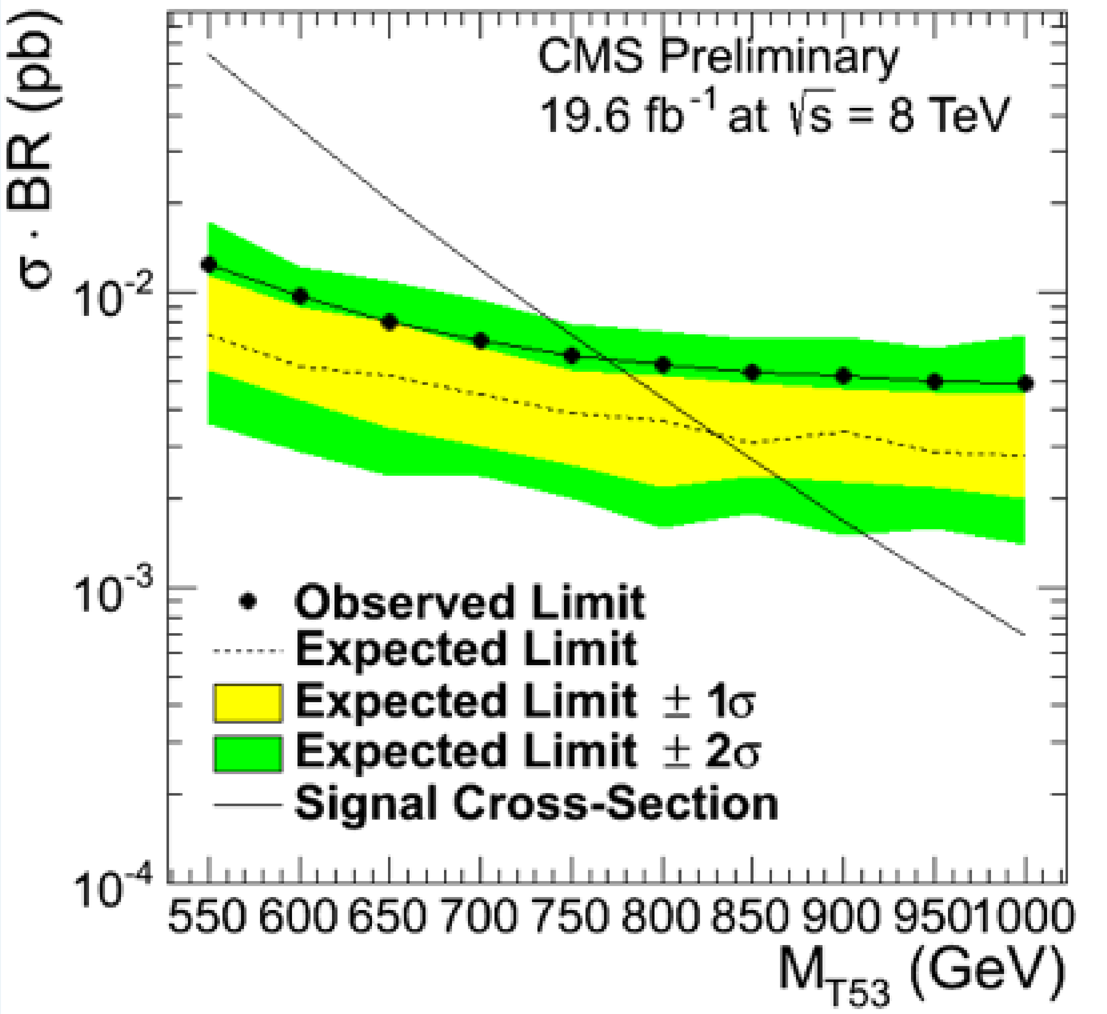
- Searching for fermions of charges 2/3 or 5/3 ... that quench the bad top loop behaviour

- Measurable deviations can be expected in channels
  pp -> tth, gg -> hh and in decays h-> $\mu\mu$, h -> $Z\gamma$

Some recent papers:
Azatov et al '13
Contino et al '13
Jenkins et al '13
Grojean et al '13......

Searches for t partners

In composite models the top loop bad behaviour is quenched by a new fermion



Expected and observed 95% C.L. limits on the $T_{5/3}$ production cross section. The 1-sigma and 2-sigma combined statistical and systematic expected variation is shown as a yellow (light) and green (dark) band, respectively.

A 5/3 charged fermion cannot mix and is not pushed up

Conclusion from the LHC at 7 - 8 TeV

A particle that looks very much like the simplest elementary SM Higgs has been found

The exp. verification of the SM is complete

The first example of a fundamental, weakly coupled, scalar particle with VEV

No evidence of new physics. We expected complexity and we found simplicity
So far naturalness was not a good heuristic guiding principle. But the final outcome is still open

A change of perspective is taking place: many unnatural models are being studied. Even the Multiverse and the anthropic philosophy are gaining credit

Precise tests of the Higgs couplings and further searches for new physics will be done in the next few years at 13-14 TeV