LHC Nobel Symposium,15 May ‘13

The Higgs: so simple yet so unnatural

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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 SM experimental validation is now in place

A negative surprise: no production of new particles

No evidence of new physics at ATLAS&CMS although a big chunk of new territory has been explored

No evidence in HF decays (LHCb, …….. B-factories)

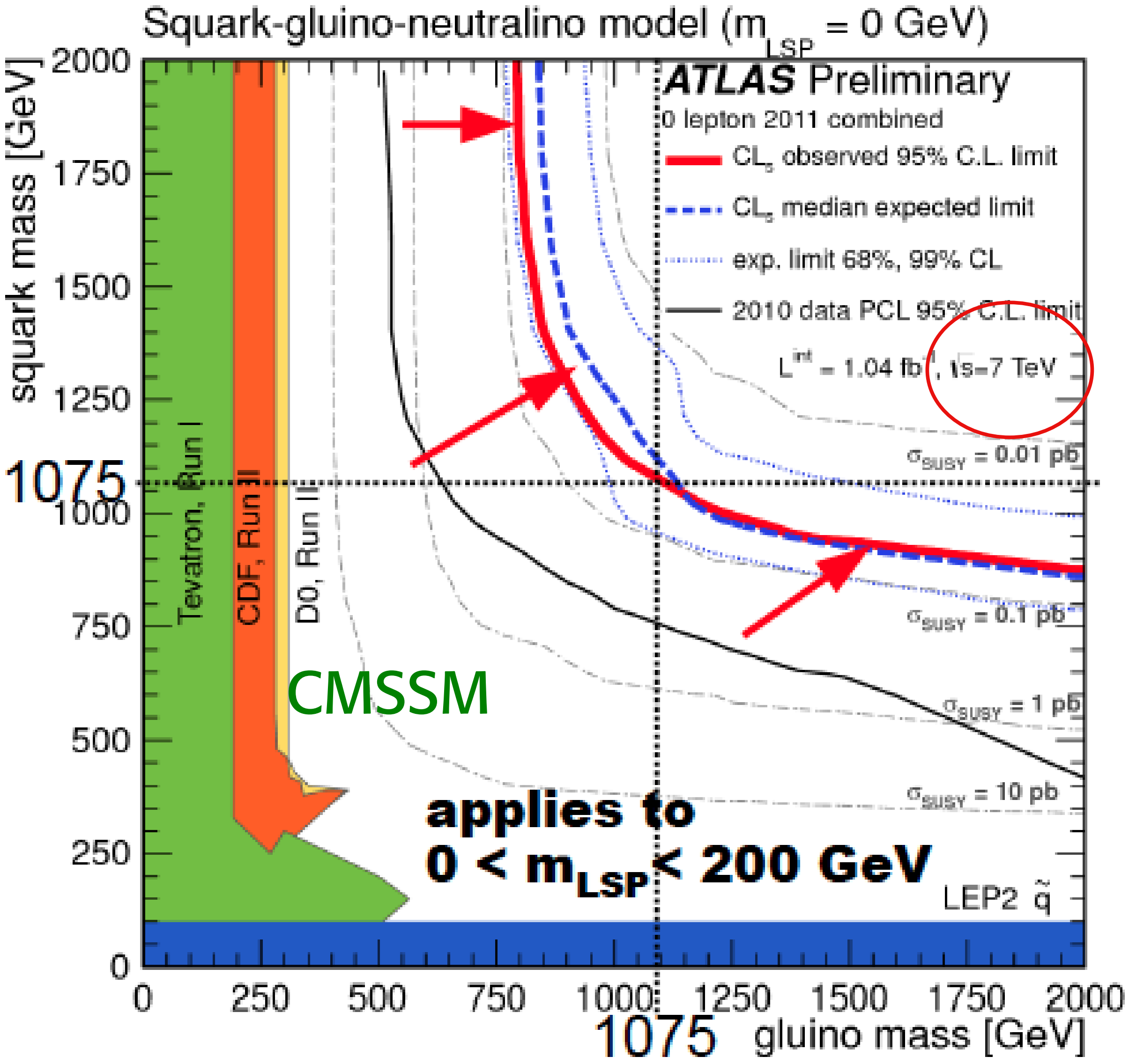
[Nor in $\mu \to e\gamma$ (MEG),…. Perhaps a deviation in $(g-2)_\mu$?]

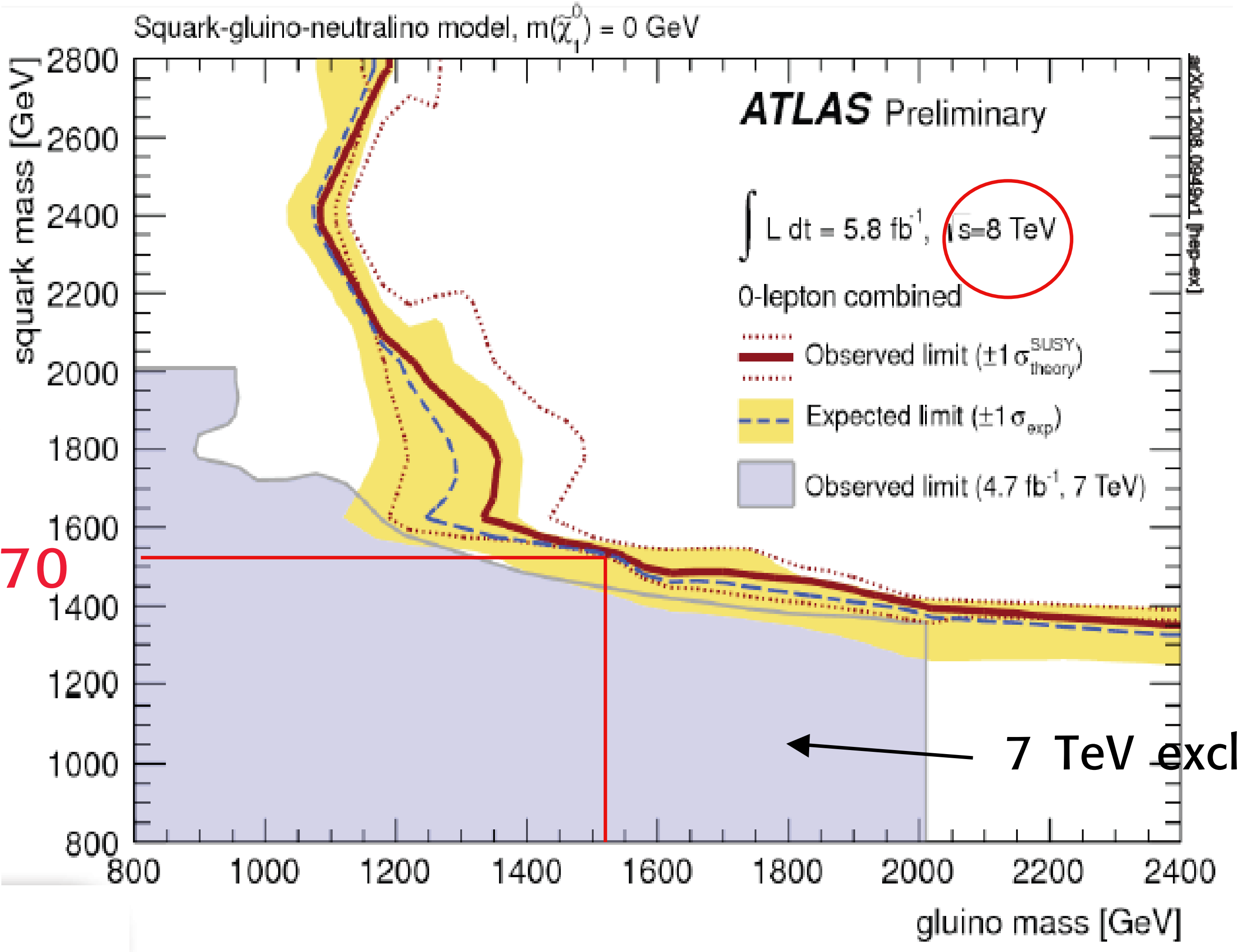
A large new territory explored at the LHC and no new physics

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

Jets + missing E_T





degenerate
s-quarks

~1470

7 TeV exclusion

New physics can appear at any moment but it is now conceivable that no new physics will show up at the LHC

Naturalness? The big question mark!

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

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

Nir
Isidori
.....

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

The SM is very special and if there is New Physics, it must be highly non generic

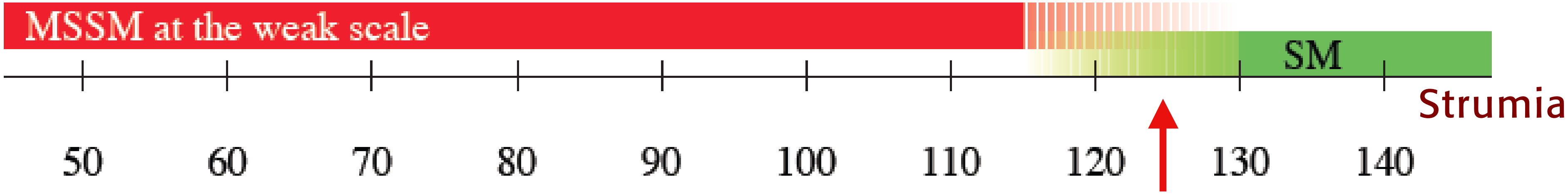
eg in Minimal Flavour Violation (MFV) models

D'Ambrosio, Giudice, Isidori, Strumia'02

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)

Is it really the SM Higgs boson?

Precise measurement of couplings
Confirm $J^{PC}=0^{++}$
Heavier Higgs-like particles? 2HDM, MSSM?

The next challenge!

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

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

H -> $\gamma\gamma$ implies that the H spin cannot be 1 by angular momentum and Bose statistics (s=0,2 can go via s-wave)

With sufficient statistics the spin can be determined by distributions of H - > $\gamma\gamma$ or ZZ*-> 4leptons,
or WW* - > 4leptons

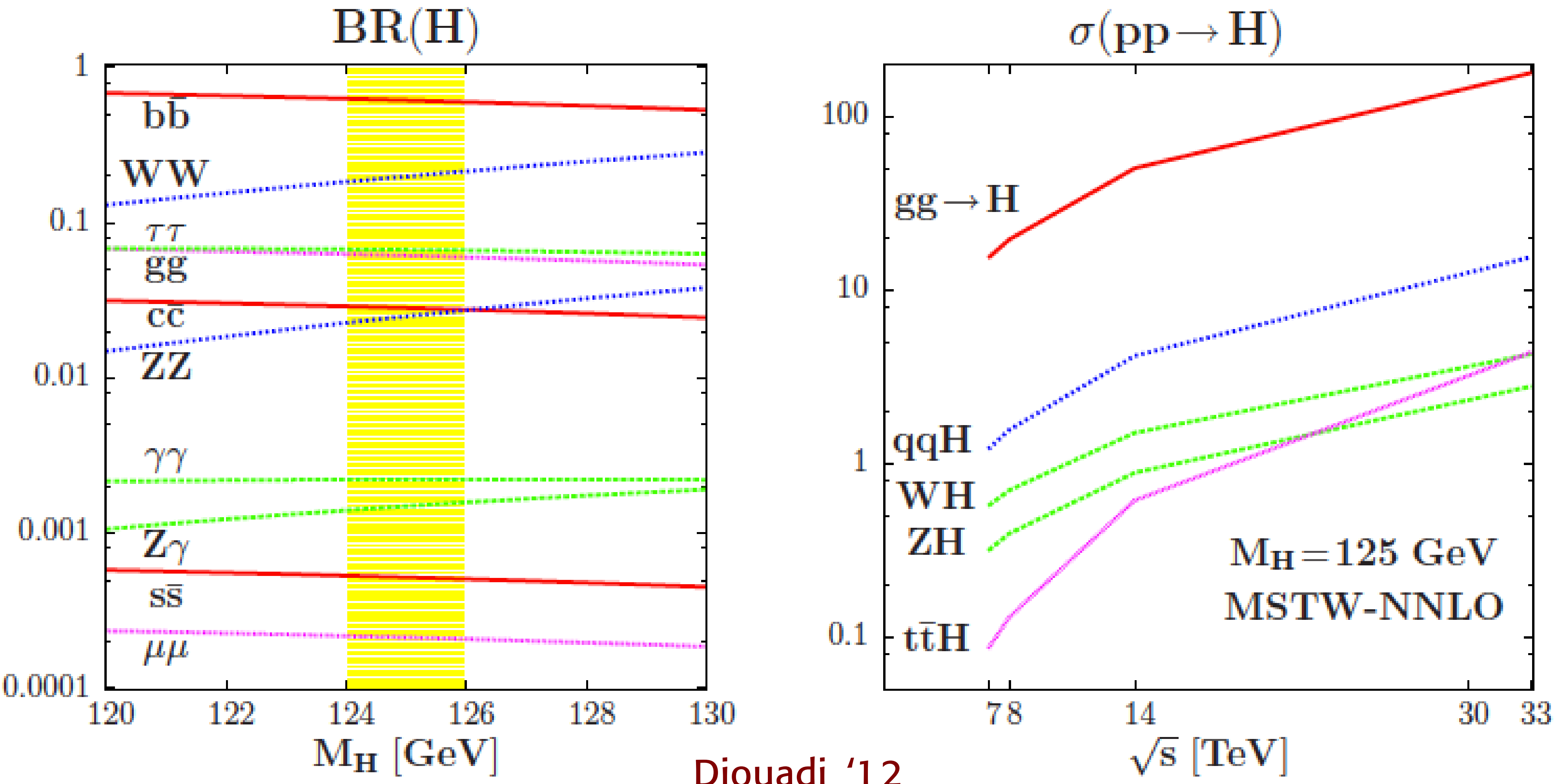
Choi et al '02; De Rujula et al '10; J. Ellis, Hwang'12 ; Djouadi et al '13; De Boer et al '13..........

Information also via the HZ inv mass distributions

J. Ellis, Hwang, Sanz, You,'12

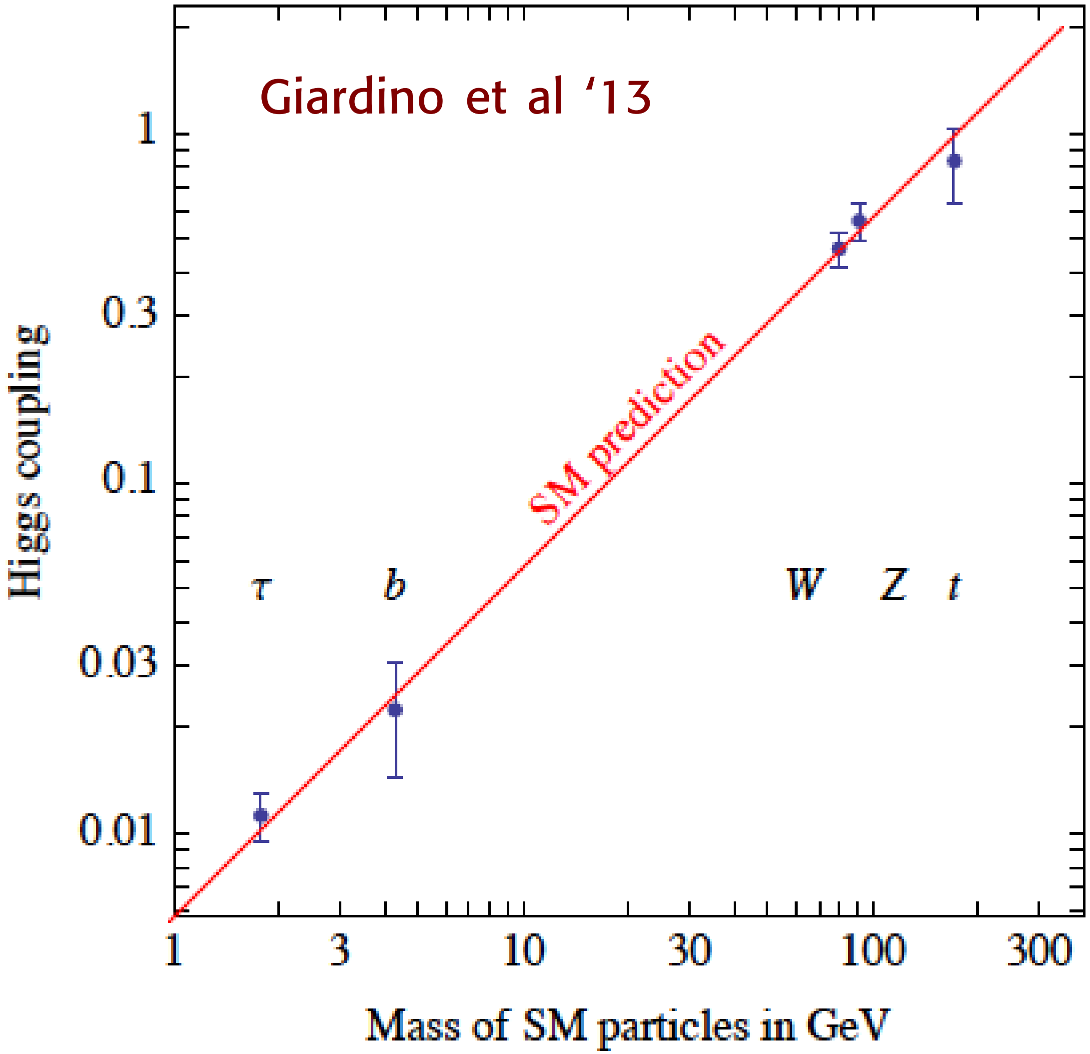
Present data already favour 0^{++}

The SM Higgs: very striking hierarchies of couplings reflected in production crosssections and branching ratios



Djouadi '12

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



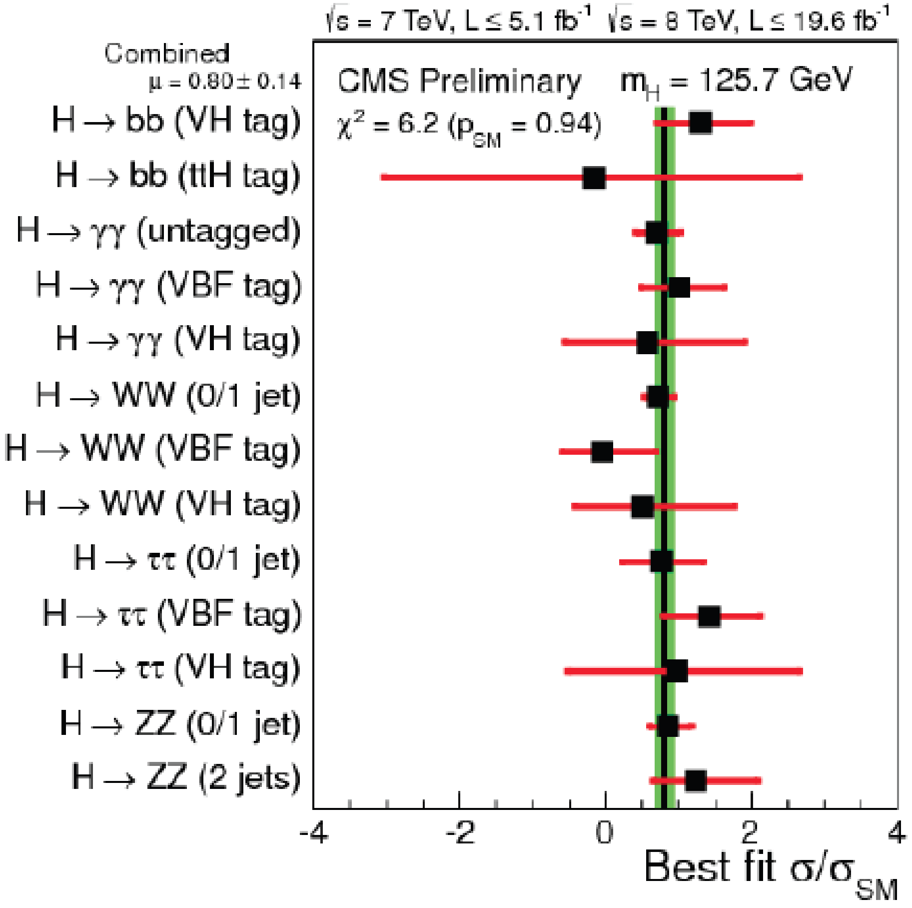
[this is also true for a dilaton-like, but up to a common factor]

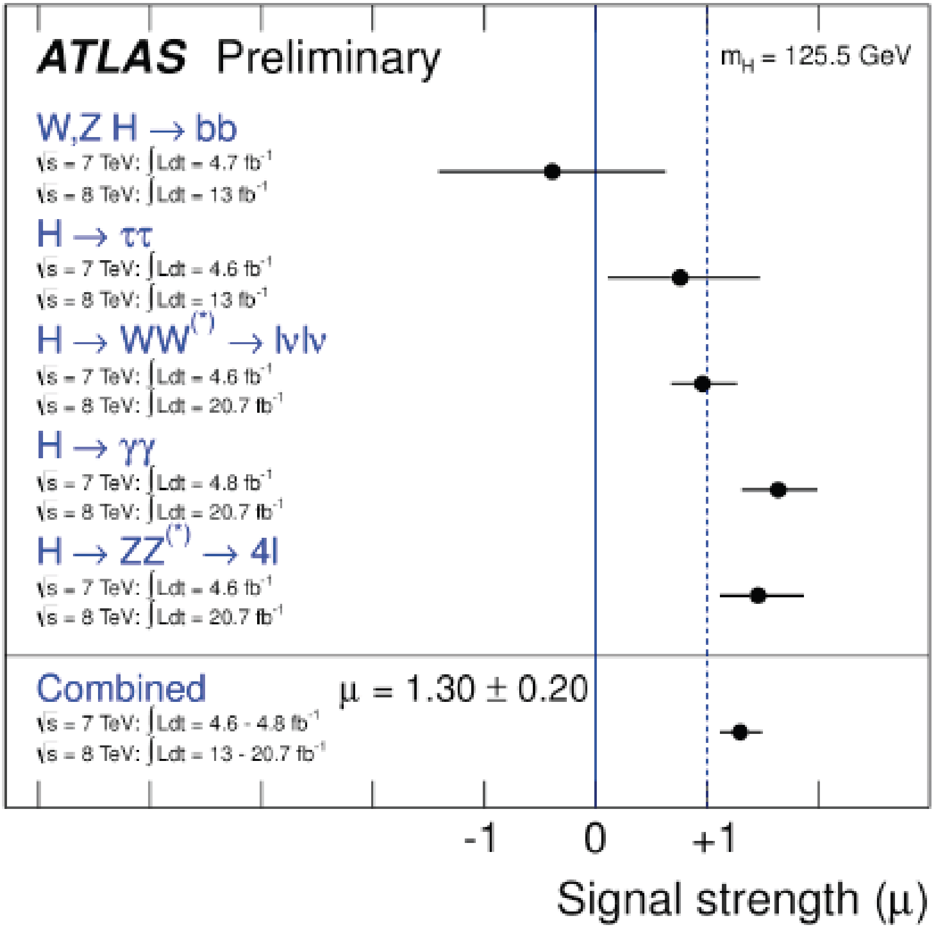
Nearly impossible to reproduce by accident

Agrees with a SM doublet: no Clebsch distortions

Couplings now checked at ~20%

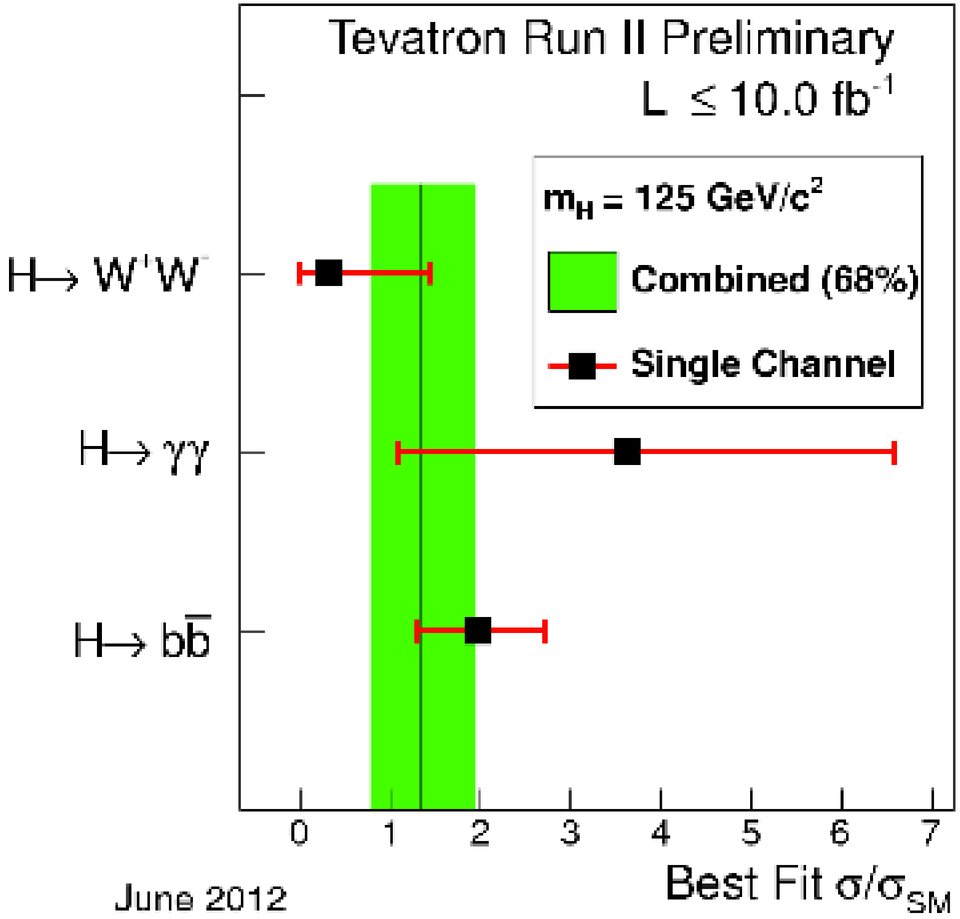
The observed σBr match the predictions within the present accuracy If not the SM Higgs a very close relative!!



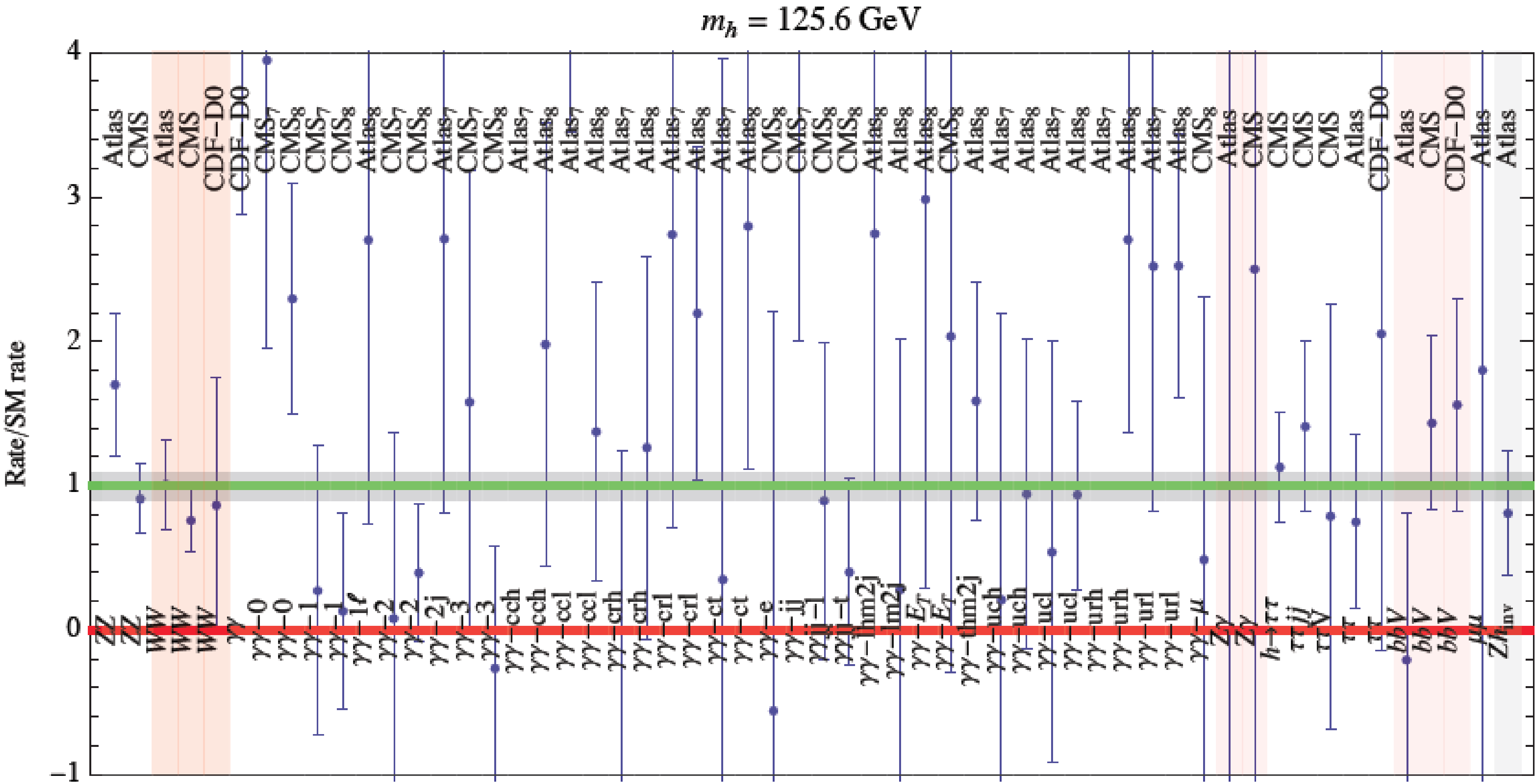


$\mu = 0.80 \pm 0.14$ $\mu = 1.30 \pm 0.20$

The Tevatron confirms the bb channel



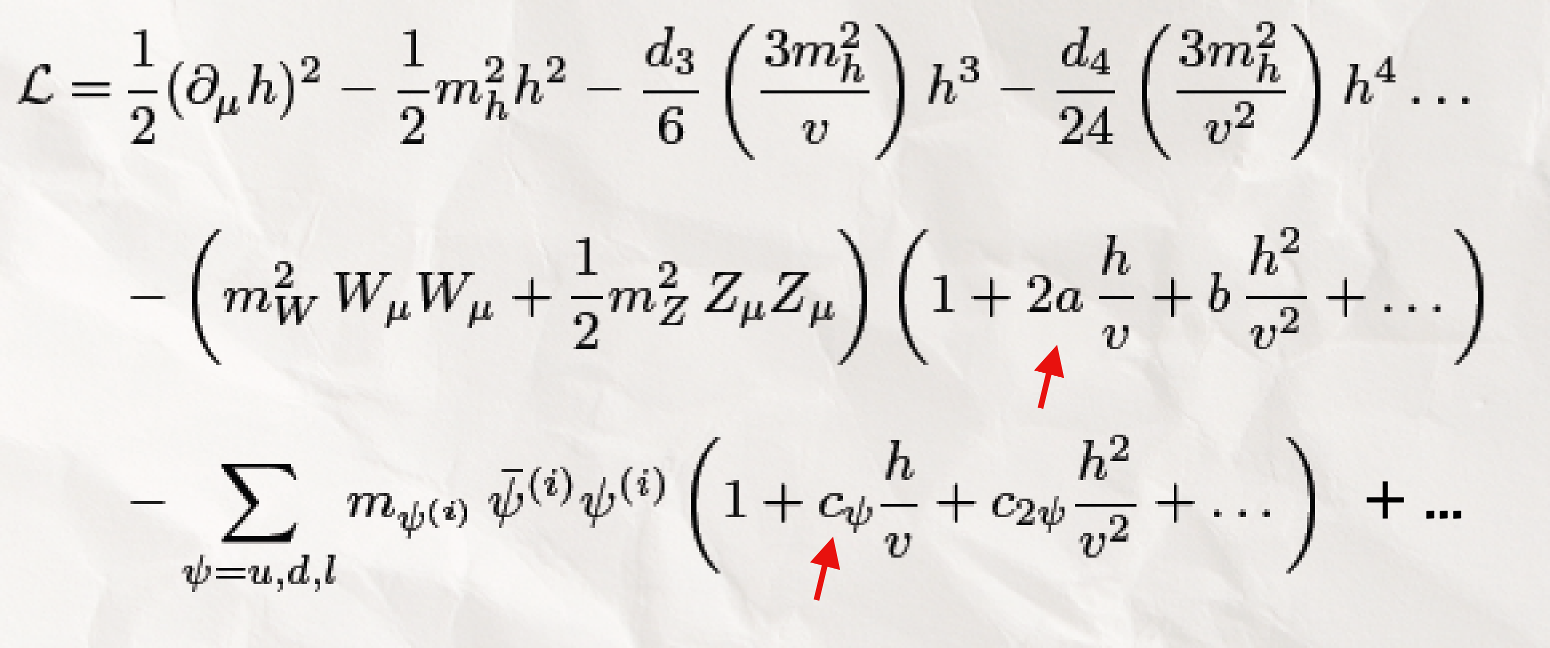
Giardino et al, ‘13



ZZ WW γγ Zγ ff

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

Contino



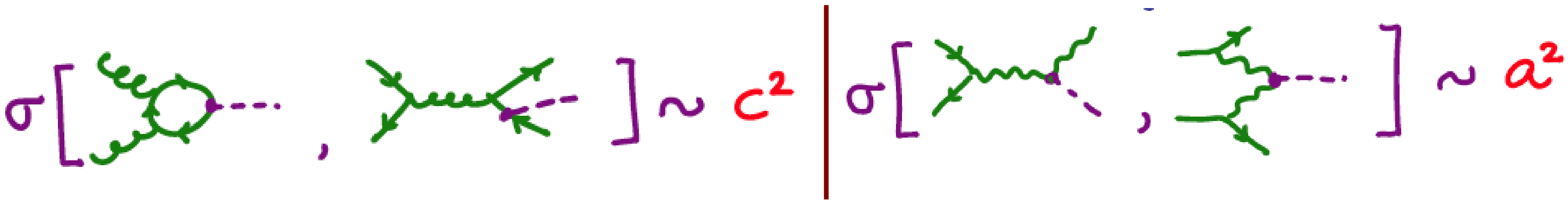
$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots$$

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

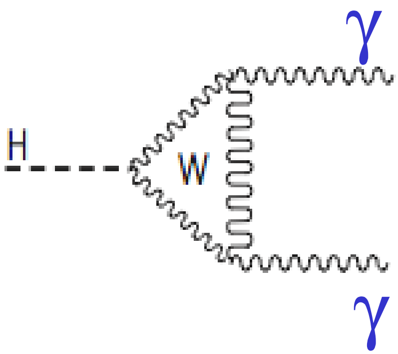
$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi \frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \ldots\right) + \ldots$$

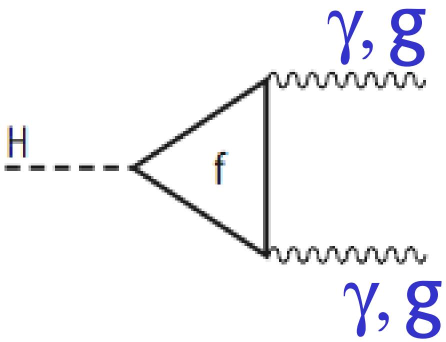
a ~ hVV
c ~ hff

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



Espinosa





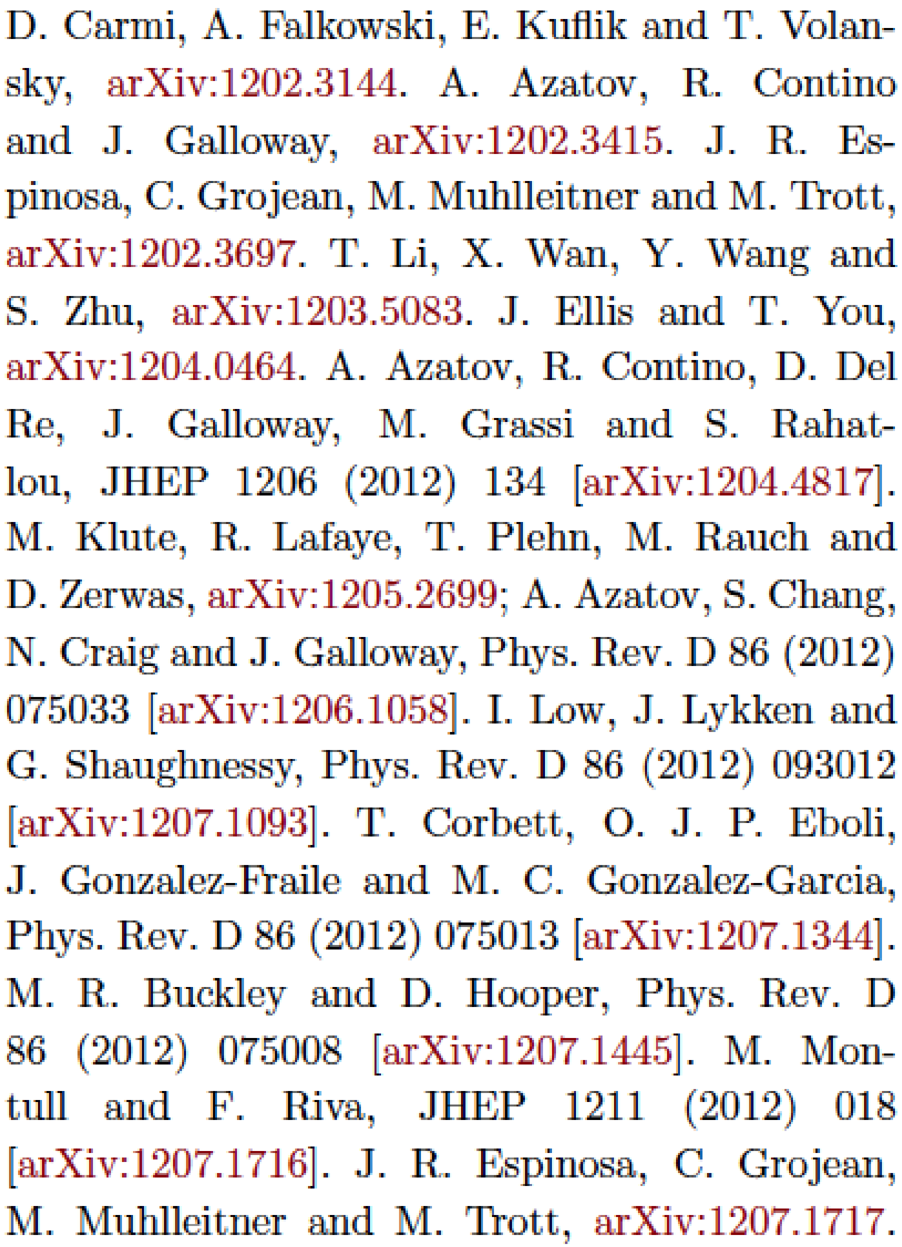
$$\Gamma(H \to \gamma\gamma) = \frac{G_F \alpha^2 m_H^3}{128\pi^3\sqrt{2}} |A_W(\tau_W) + \sum_f N_C Q_f^2 A_f(\tau_f)|^2 \qquad \tau_i = m_H^2/4m_i^2$$

Hγγ amplitude

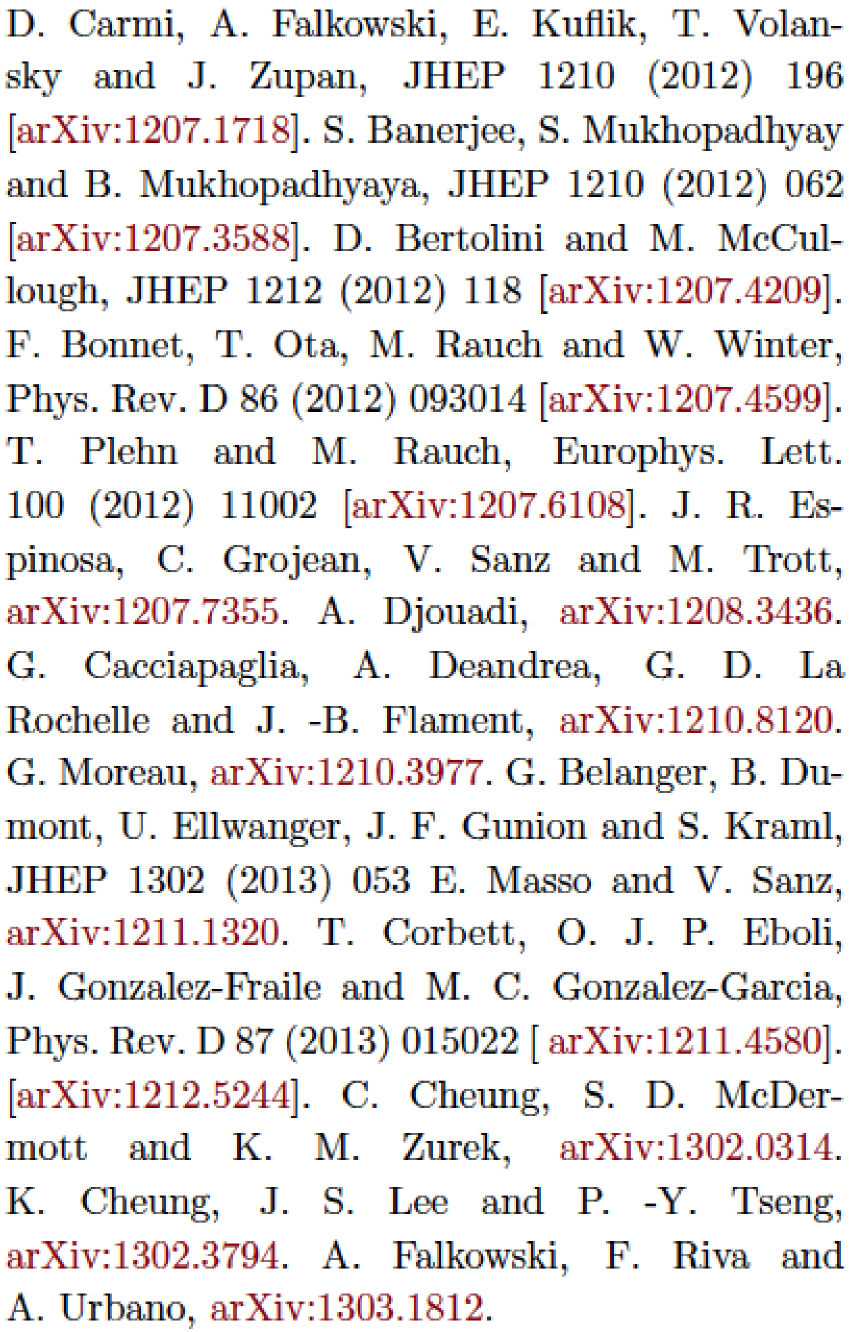
~ $|1.26a-0.26c|^2$

$$\Gamma(H \to gg) = \frac{G_F \alpha_s^2 m_H^3}{64\pi^3\sqrt{2}} |\sum_{f=Q} A_f(\tau_f)|^2$$

A long list of References



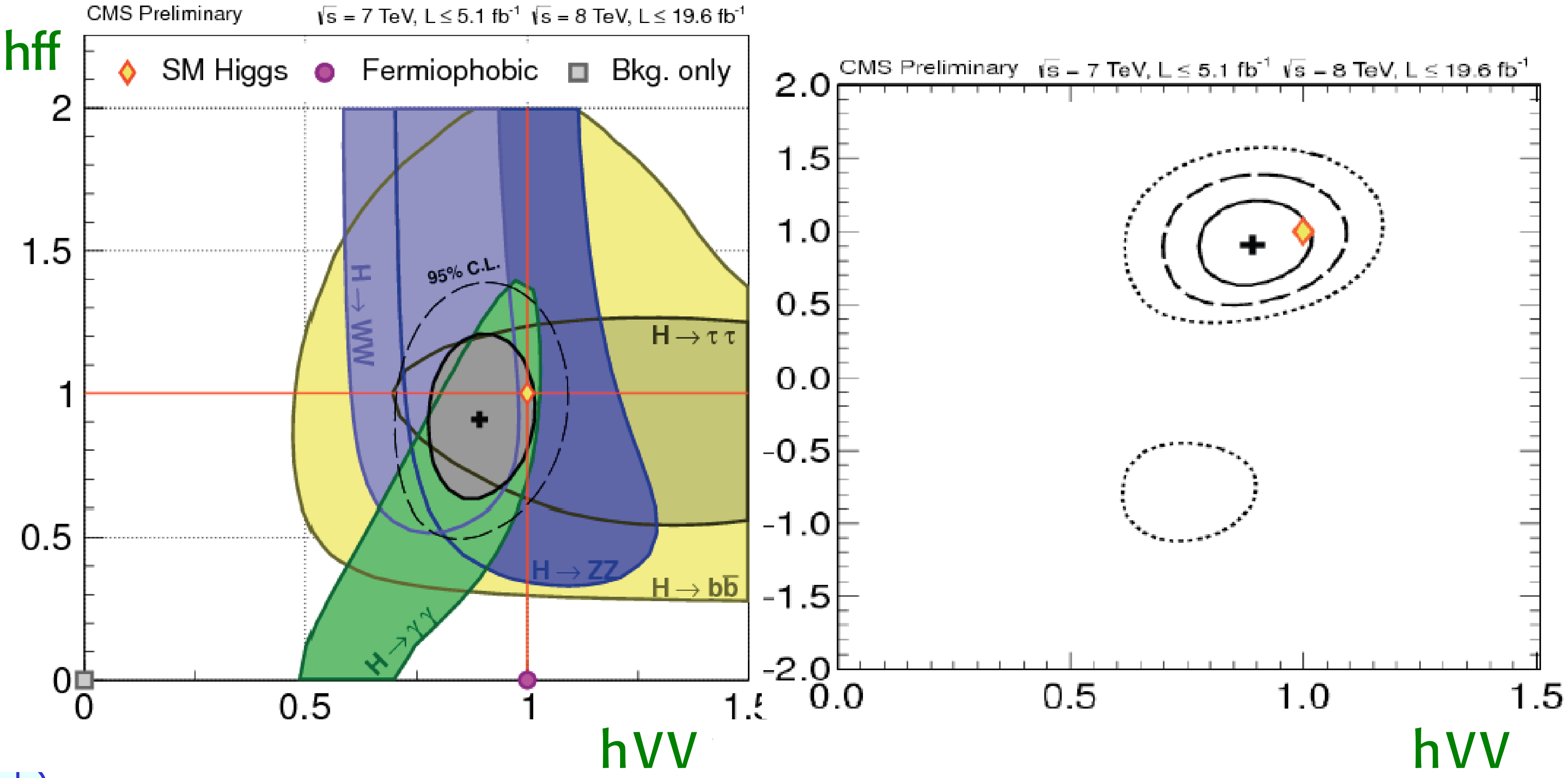
D. Carmi, A. Falkowski, E. Kuflik and T. Volansky, arXiv:1202.3144. A. Azatov, R. Contino and J. Galloway, arXiv:1202.3415. J. R. Espinosa, C. Grojean, M. Muhlleitner and M. Trott, arXiv:1202.3697. T. Li, X. Wan, Y. Wang and S. Zhu, arXiv:1203.5083. J. Ellis and T. You, arXiv:1204.0464. A. Azatov, R. Contino, D. Del Re, J. Galloway, M. Grassi and S. Rahatlou, JHEP 1206 (2012) 134 [arXiv:1204.4817]. M. Klute, R. Lafaye, T. Plehn, M. Rauch and D. Zerwas, arXiv:1205.2699; A. Azatov, S. Chang, N. Craig and J. Galloway, Phys. Rev. D 86 (2012) 075033 [arXiv:1206.1058]. I. Low, J. Lykken and G. Shaughnessy, Phys. Rev. D 86 (2012) 093012 [arXiv:1207.1093]. T. Corbett, O. J. P. Eboli, J. Gonzalez-Fraile and M. C. Gonzalez-Garcia, Phys. Rev. D 86 (2012) 075013 [arXiv:1207.1344]. M. R. Buckley and D. Hooper, Phys. Rev. D 86 (2012) 075008 [arXiv:1207.1445]. M. Montull and F. Riva, JHEP 1211 (2012) 018 [arXiv:1207.1716]. J. R. Espinosa, C. Grojean, M. Muhlleitner and M. Trott, arXiv:1207.1717.



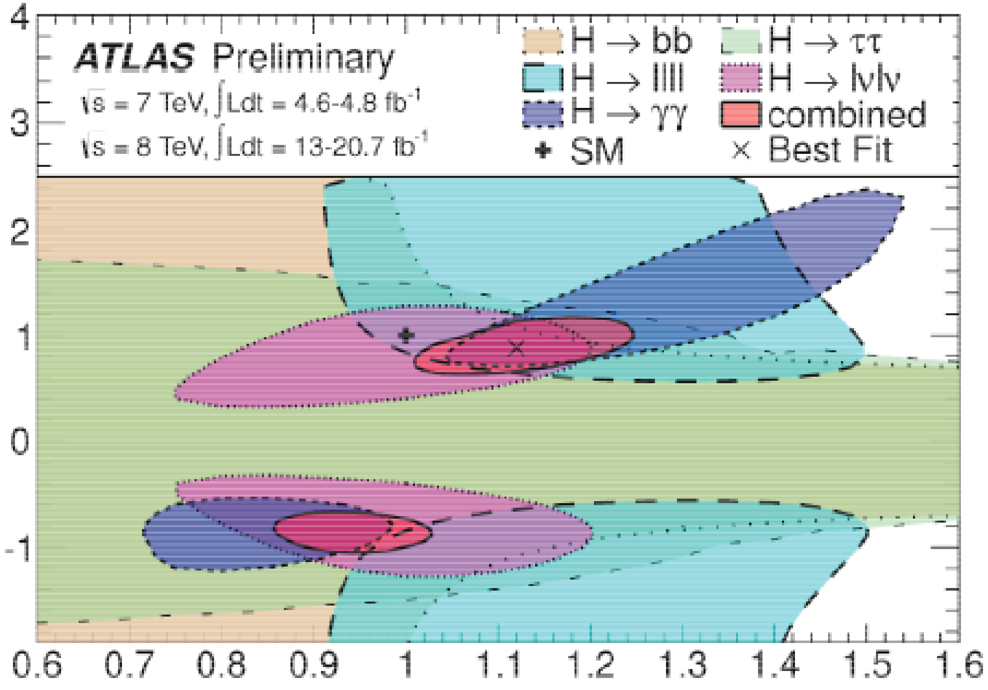
D. Carmi, A. Falkowski, E. Kuflik, T. Volansky and J. Zupan, JHEP 1210 (2012) 196 [arXiv:1207.1718]. S. Banerjee, S. Mukhopadhyay and B. Mukhopadhyaya, JHEP 1210 (2012) 062 [arXiv:1207.3588]. D. Bertolini and M. McCullough, JHEP 1212 (2012) 118 [arXiv:1207.4209]. F. Bonnet, T. Ota, M. Rauch and W. Winter, Phys. Rev. D 86 (2012) 093014 [arXiv:1207.4599]. T. Plehn and M. Rauch, Europhys. Lett. 100 (2012) 11002 [arXiv:1207.6108]. J. R. Espinosa, C. Grojean, V. Sanz and M. Trott, arXiv:1207.7355. A. Djouadi, arXiv:1208.3436. G. Cacciapaglia, A. Deandrea, G. D. La Rochelle and J. -B. Flament, arXiv:1210.8120. G. Moreau, arXiv:1210.3977. G. Belanger, B. Dumont, U. Ellwanger, J. F. Gunion and S. Kraml, JHEP 1302 (2013) 053 E. Masso and V. Sanz, arXiv:1211.1320. T. Corbett, O. J. P. Eboli, J. Gonzalez-Fraile and M. C. Gonzalez-Garcia, Phys. Rev. D 87 (2013) 015022 [arXiv:1211.4580]. [arXiv:1212.5244]. C. Cheung, S. D. McDermott and K. M. Zurek, arXiv:1302.0314. K. Cheung, J. S. Lee and P. -Y. Tseng, arXiv:1302.3794. A. Falkowski, F. Riva and A. Urbano, arXiv:1303.1812.

Each experiment fits the couplings from their data

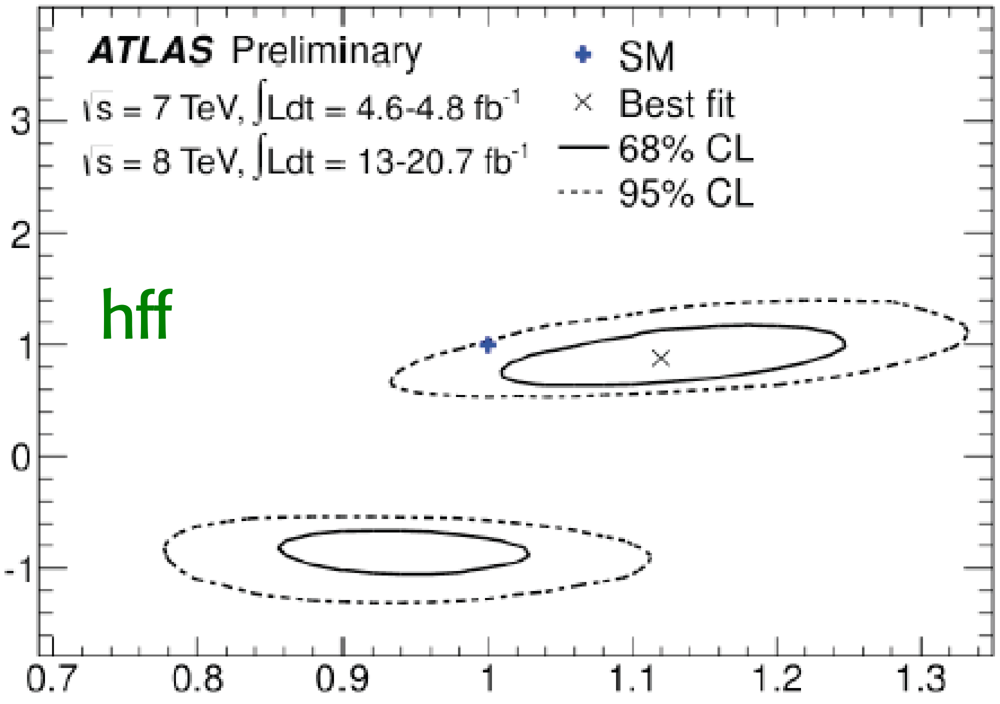
CMS



ATLAS



hVV

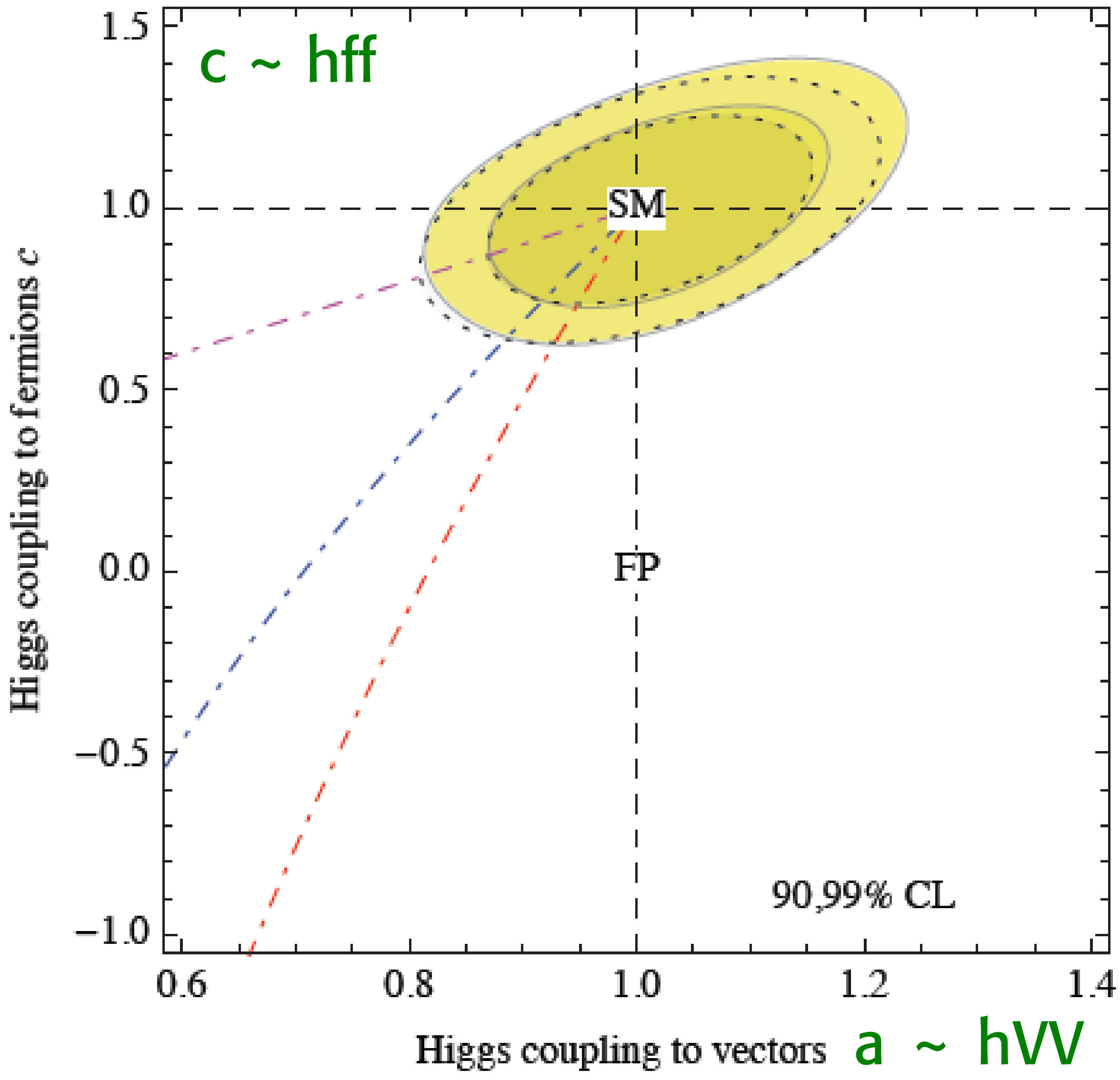


hff

hVV

Theorists informal and abusive combination of ATLAS&CMS data

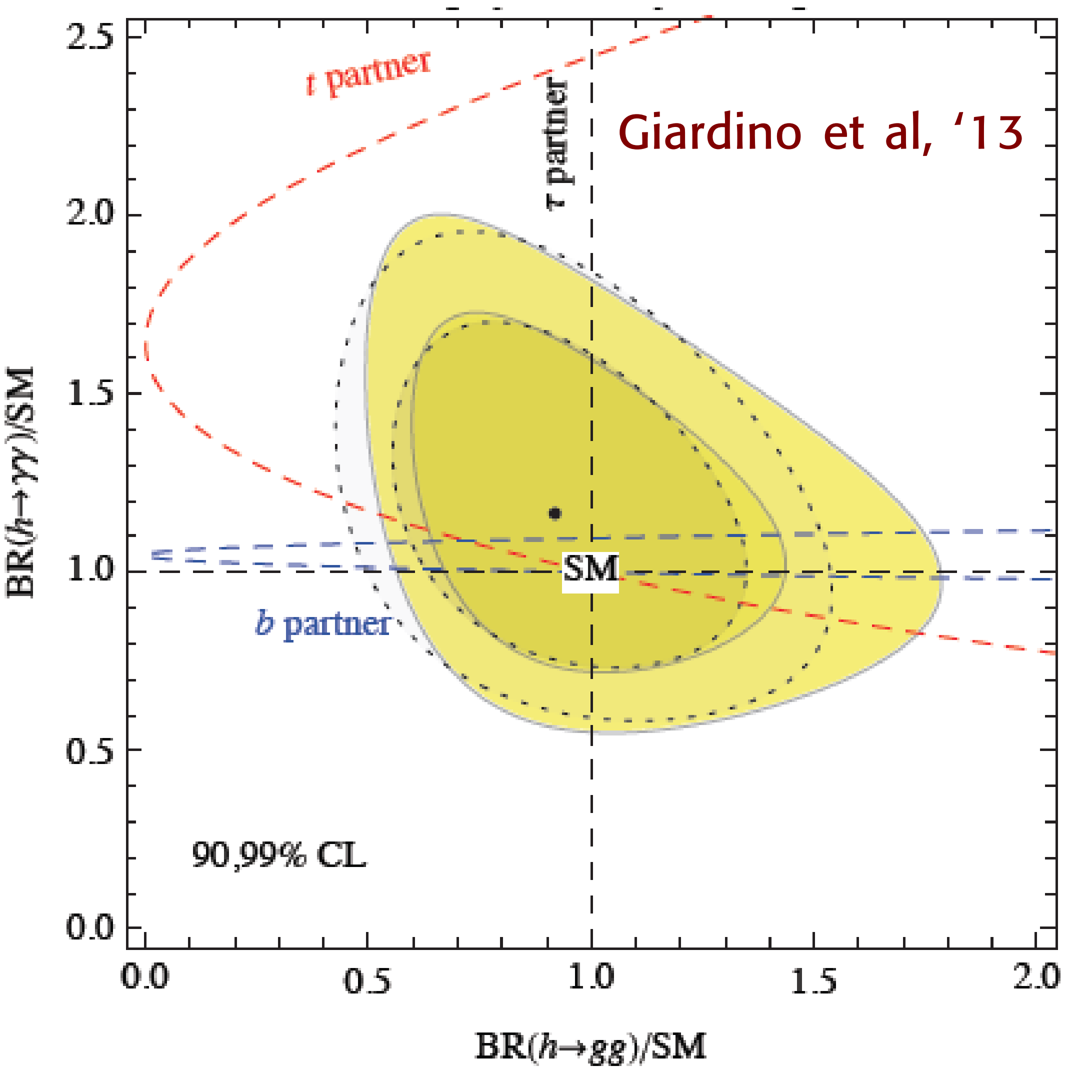
Giardino et al ‘13



a ~ hVV

New Physics in loops?

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



MSSM: separate u and d couplings

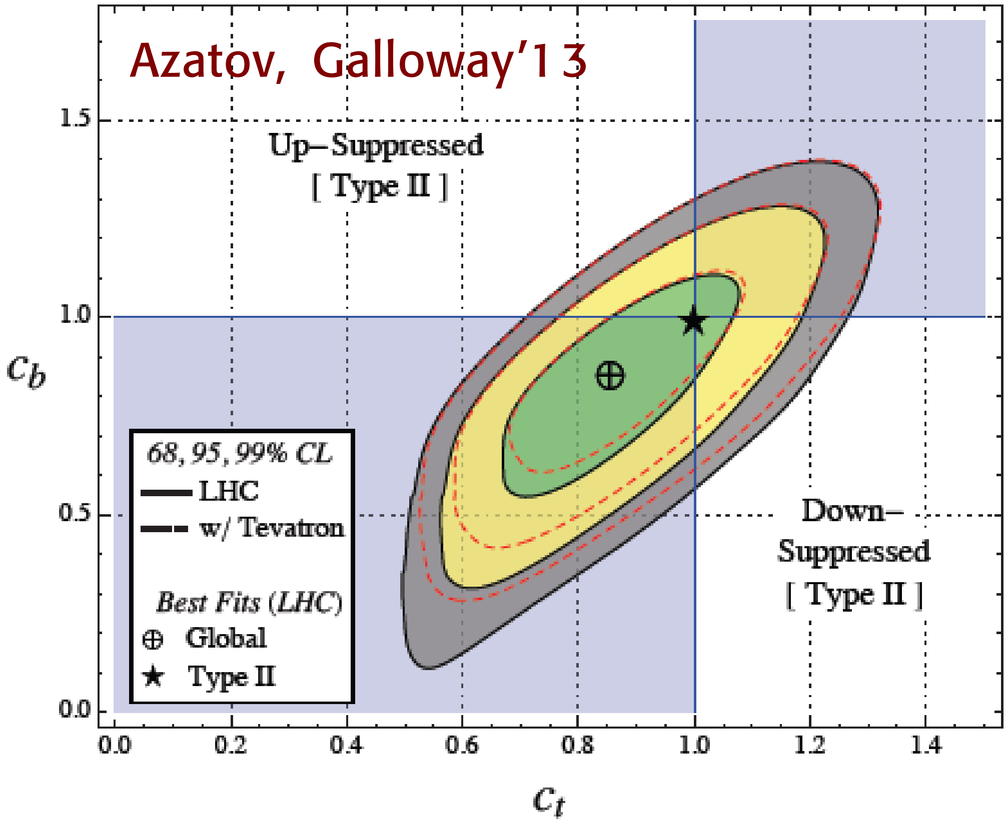
$$a = hVV = \sin(\beta - \alpha)$$

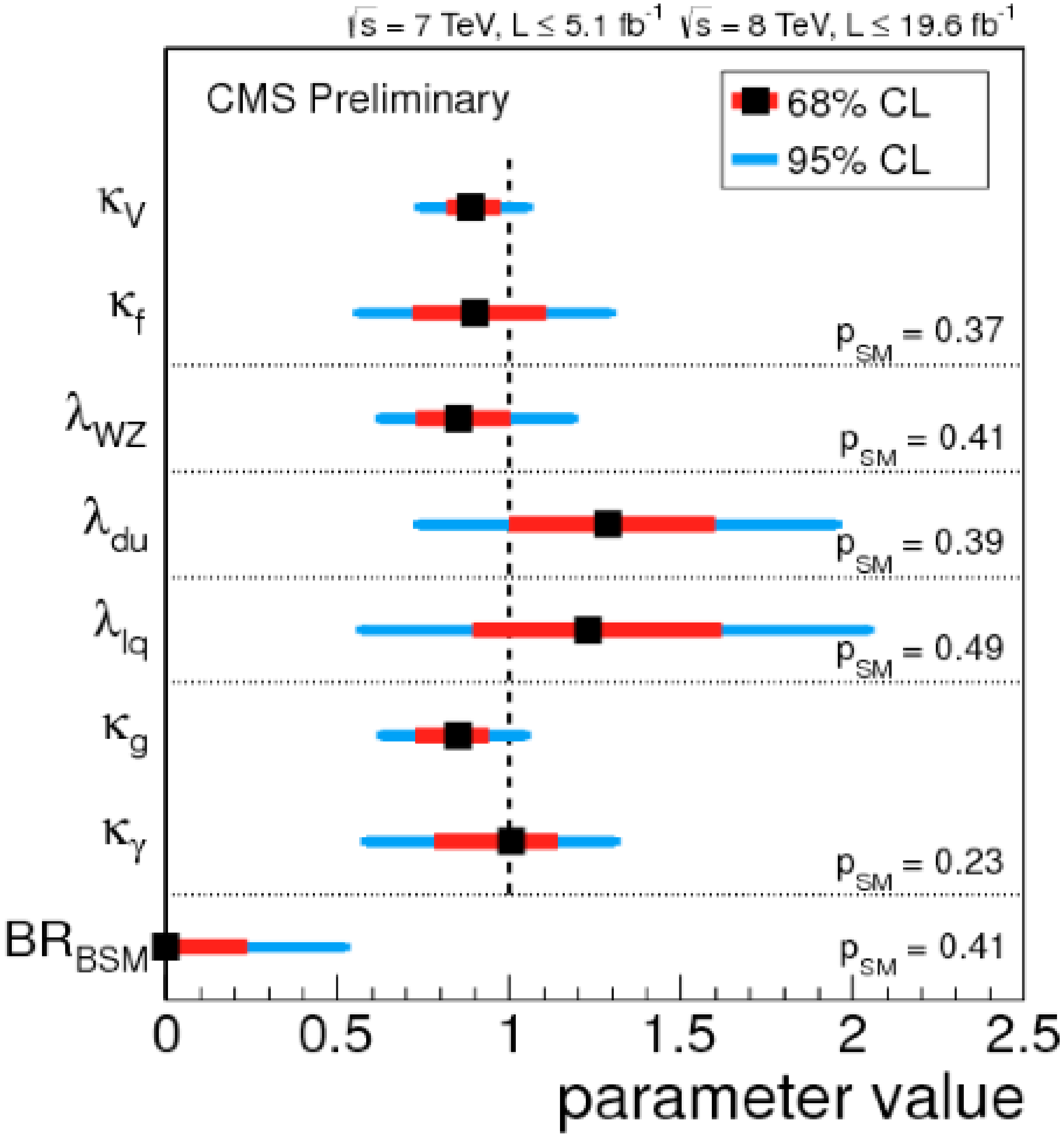
$$c_u = huu = \frac{\cos\alpha}{\sin\beta}$$

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

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

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




√s = 7 TeV, L ≤ 5.1 fb⁻¹ √s = 8 TeV, L ≤ 19.6 fb⁻¹
CMS Preliminary
68% CL
95% CL
κ_V
κ_f
p_SM = 0.37
λ_WZ
p_SM = 0.41
λ_du
p_SM = 0.39
λ_lq
p_SM = 0.49
κ_g
κ_γ
p_SM = 0.23
BR_BSM
p_SM = 0.41
0
0.5
1
1.5
2
2.5
parameter value

Impact of the Higgs discovery

The minimal SM Higgs: what was considered 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 boson with VEV

A death blow not only to Higgsless models, technicolor models.... but also a threat to all models with no fast enough decoupling

[If new physics comes in a model with decoupling the absence of new particles at the LHC implies small corrections to the H couplings]

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

Higgs, unitarity and naturalness in the SM

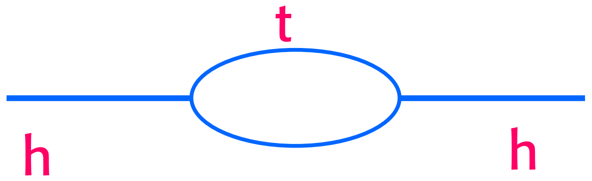
In the SM the Higgs provides a solution to the occurrence of unitarity violations in some amplitudes (W_L, Z_L scattering)

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 was based on a theorem, once there is the Higgs, the necessity of new physics on the basis of naturalness is not a theorem

Higgs light + quadratic divergences ---> cutoff (new physics) nearby



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

The SM as an effective theory

With new physics at Λ the low en. th. is an effective theory.

After integration of the heavy d.o.f.:

$\mathcal{L}_i$: operator of dim i

$$\mathcal{L} = \underbrace{o(\Lambda^4) + o(\Lambda^2)\mathcal{L}_2 + o(\Lambda)\mathcal{L}_3 + o(1)\mathcal{L}_4}_{\text{Renorm.ble part}} + \underbrace{o(1/\Lambda)\mathcal{L}_5 + o(1/\Lambda^2)\mathcal{L}_6 + \ldots}_{\text{Non renorm.ble part}}$$

In absence of special symmetries or selection rules, by dimensions $c_i\mathcal{L}_i \sim o(\Lambda^{4-i})\mathcal{L}_i$

$\mathcal{L}_2$: Boson masses ϕ^2. In the SM the mass in the Higgs potential is unprotected: $c_2 \sim o(\Lambda^2)$

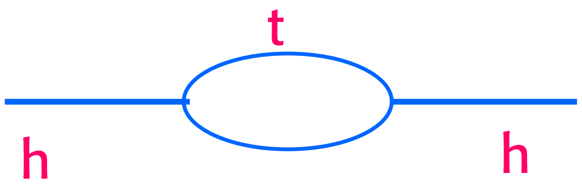
$\mathcal{L}_3$: Fermion masses $\bar{\psi}\psi$. Protected by chiral symmetry and SU(2)xU(1): $\Lambda \to m\log\Lambda$

$\mathcal{L}_4$: Renorm.ble interactions, e.g. $\bar{\psi}\gamma^\mu\psi A_\mu$

$\mathcal{L}_{i>4}$: Non renorm.ble: suppressed by $1/\Lambda^{i-4}$ e.g. $1/\Lambda^2\bar{\psi}\gamma^\mu\psi\bar{\psi}\gamma^\mu\psi$

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

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



It is true that the SM theory is renormalizable.
Thus if one ignores the hierarchy problem it is completely finite and predictive
If you do not care about fine tuning you are not punished

Only if we see the cutoff as the scale where new physics occurs that solves the infinities problem, then the strong indication that Λ must be nearby follows

The crisis of 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 (g-2?)
No direct evidence of new physics at the LHC

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

Does Nature really care about our concept of Naturalness?
Which form of Naturalness is Natural?

Solutions to the hierarchy problem

- Supersymmetry: boson-fermion symm.

  The most ambitious and widely accepted
  Simplest versions now marginal
  Plenty of viable alternatives

- Strong EWSB: Technicolor

  Strongly disfavoured by LEP. Coming back in new forms

  Composite Higgs

  Higgs as PG Boson, Little Higgs models……

- Extra spacetime dim's that somehow "bring" M_{Pl} down to o(1TeV) [large ED, warped ED, ……]. Holographic composite H

  Exciting. Many facets. Rich potentiality. No baseline model emerged so far

- Ignore the problem: invoke the anthropic principle

  Extreme, but not excluded by the data

Solutions to the hierarchy problem

- Supersymmetry: boson-fermion symm.

  The most ambitious and widely accepted
  Simplest versions now marginal
  Plenty of viable alternatives

All more or less
in trouble....

- Strong EWSB: Technicolor

  Strongly disfavoured by LEP. Coming back in new forms

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- Extra spacetime dim's that somehow "bring" M_{Pl} down to o(1TeV) [large ED, warped ED, ...]. Holographic composite H

  Exciting. Many facets. Rich potentiality. No baseline model emerged so far

- Ignore the problem: invoke the anthropic principle

  Extreme, but not excluded by the data

now boosted!

Two main directions

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

SUSY

For an orderly retreat
simplest new ingredients are

- 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.

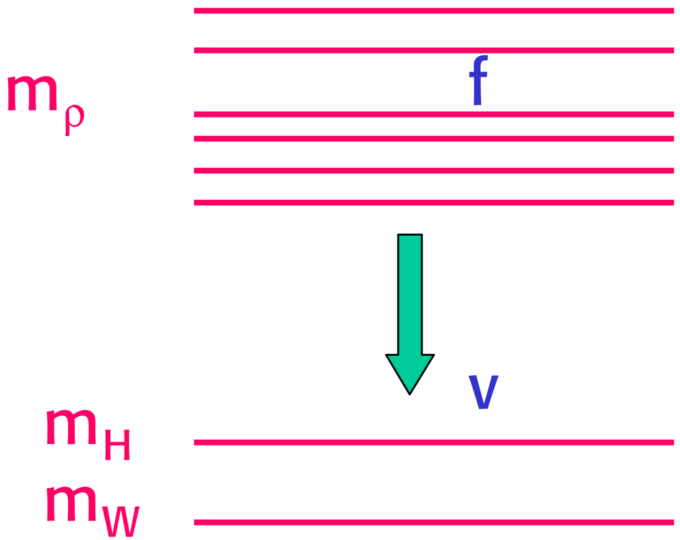
Key role of light top partners

- Large Fine-Tuning models: disregard the naturalness principle in part or even completely and explore possible, viable models (wrt Dark Matter, ν masses, Baryogenesis...)

- **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.
Pseudo-Goldstone boson of an enlarged symmetry.
eg. SO(5)/SO(4). Can be set up in a holographic ED context.



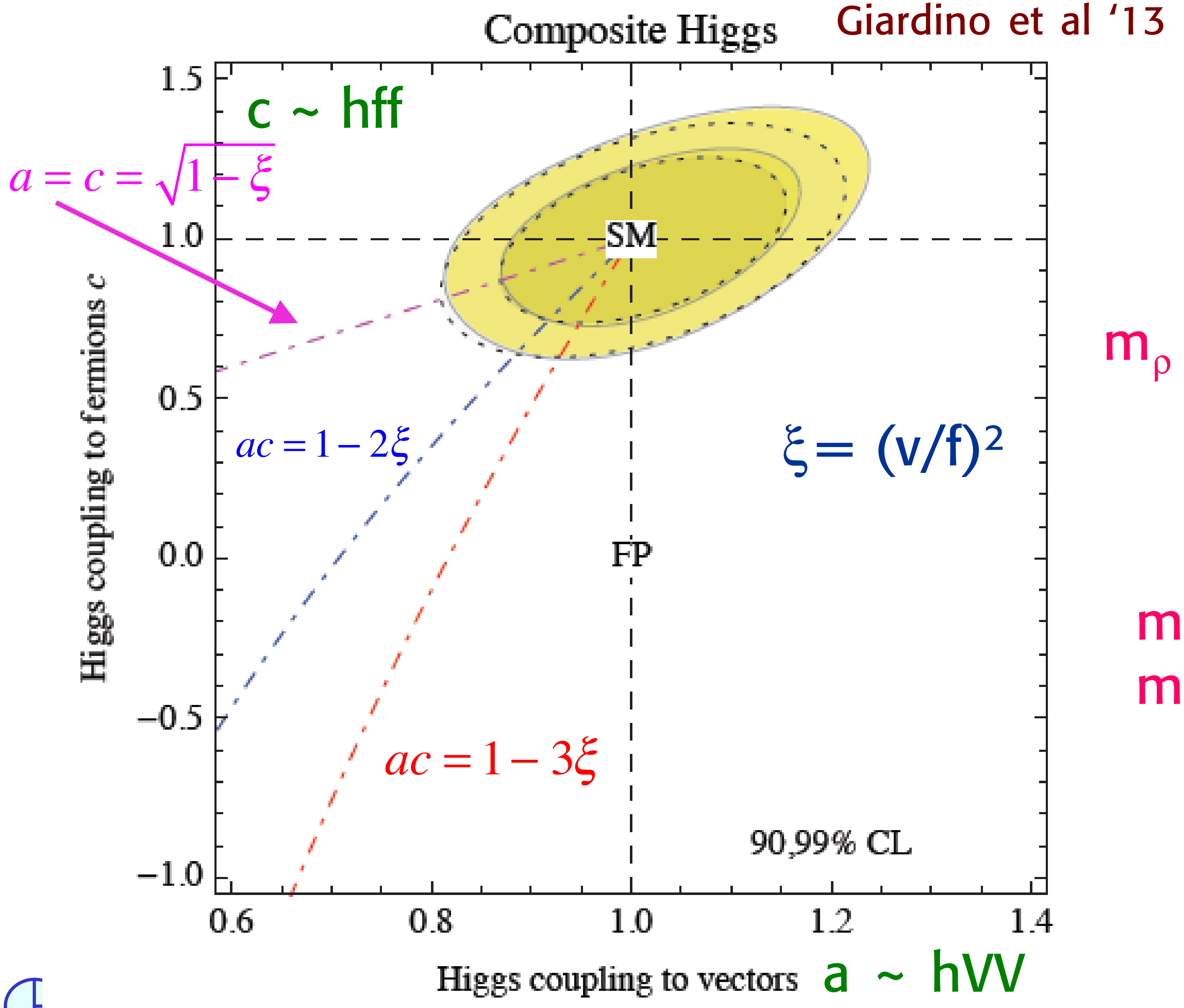
v ~ EW scale   f ~ SI scale

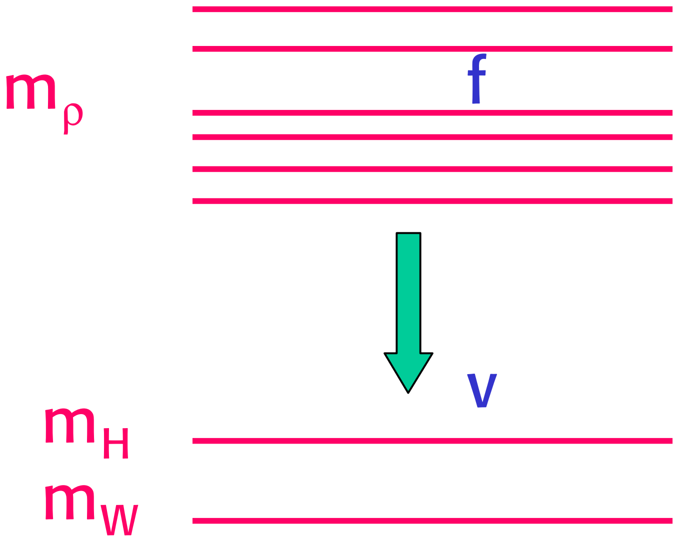
$\sim f < m_\rho <\sim 4\pi f$

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

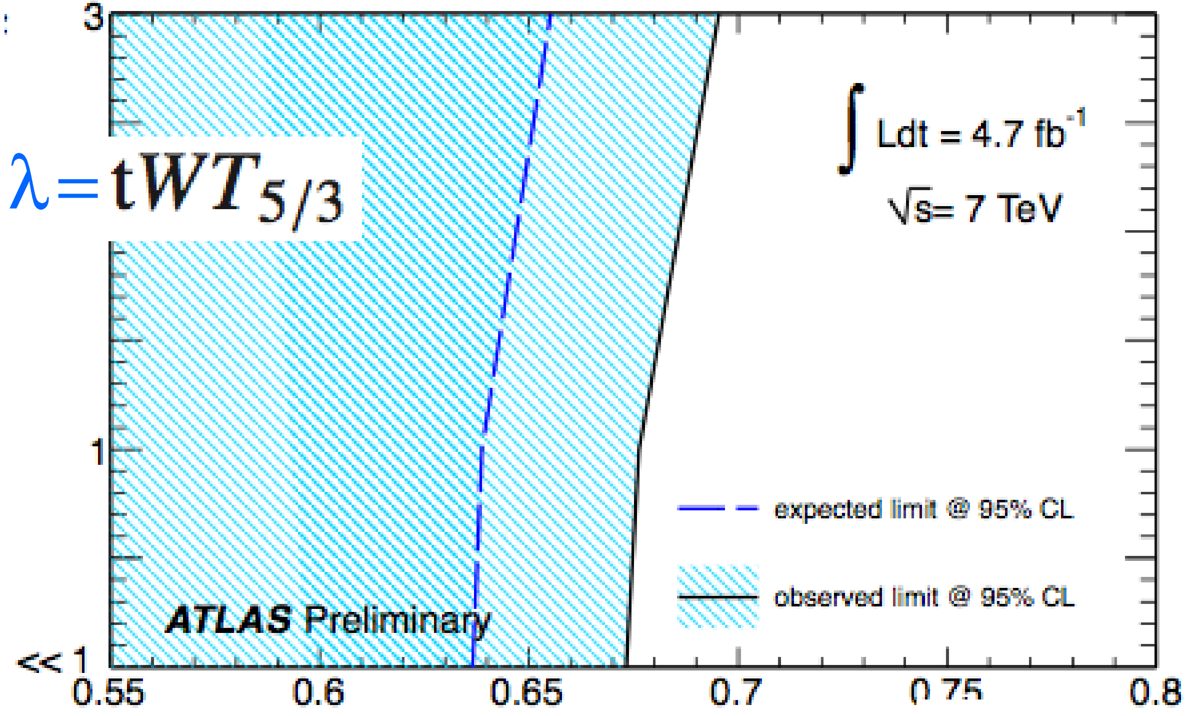
ξ interpolates between SM [$\xi \sim 0$]
and some degree of compositeness
$\xi \sim 1$ similar to Technicolor
[ξ limited by precision EW tests $\xi < \sim 0.2$]

Giardino et al '13



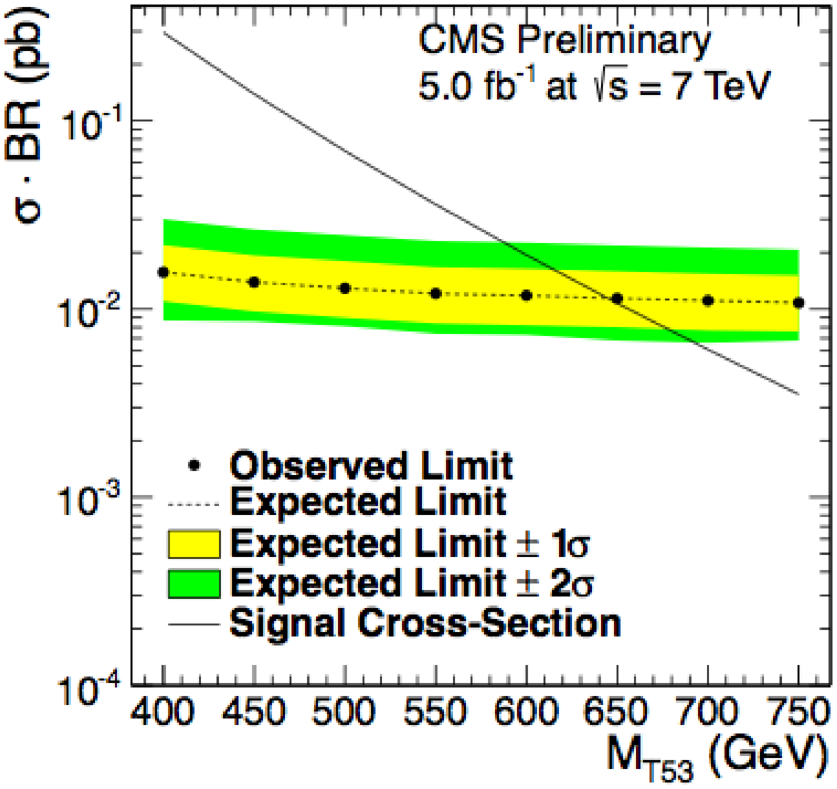


Searches for t partners



$\lambda = tWT_{5/3}$

$m_{T\ 5/3}$ TeV



- Natural SUSY

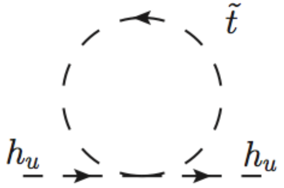
For MSSM to be natural

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

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

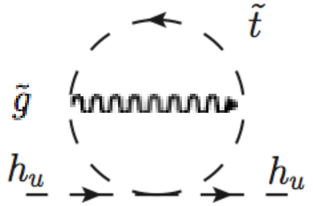
Tree level $\sin^2 2\beta << 1$
(no extra singlet in MSSM)

μ related to
lightest Higgsino
mass



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

largest radiative corrections
involve s-top and gluinos

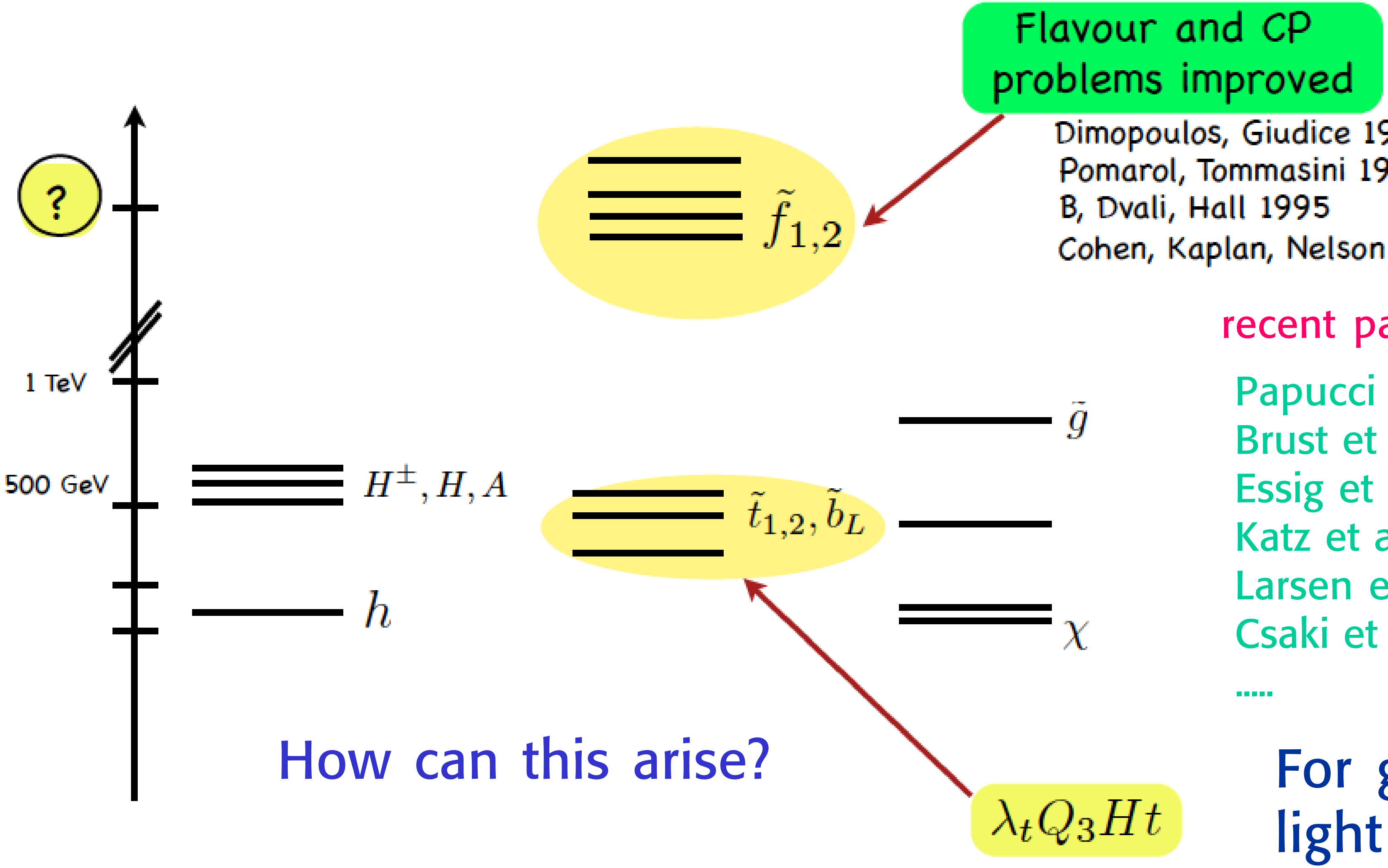


$$\delta m_{H_u}^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\mathrm{TeV}}\right)$$

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

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
.....

$\lambda_t Q_3 H t$

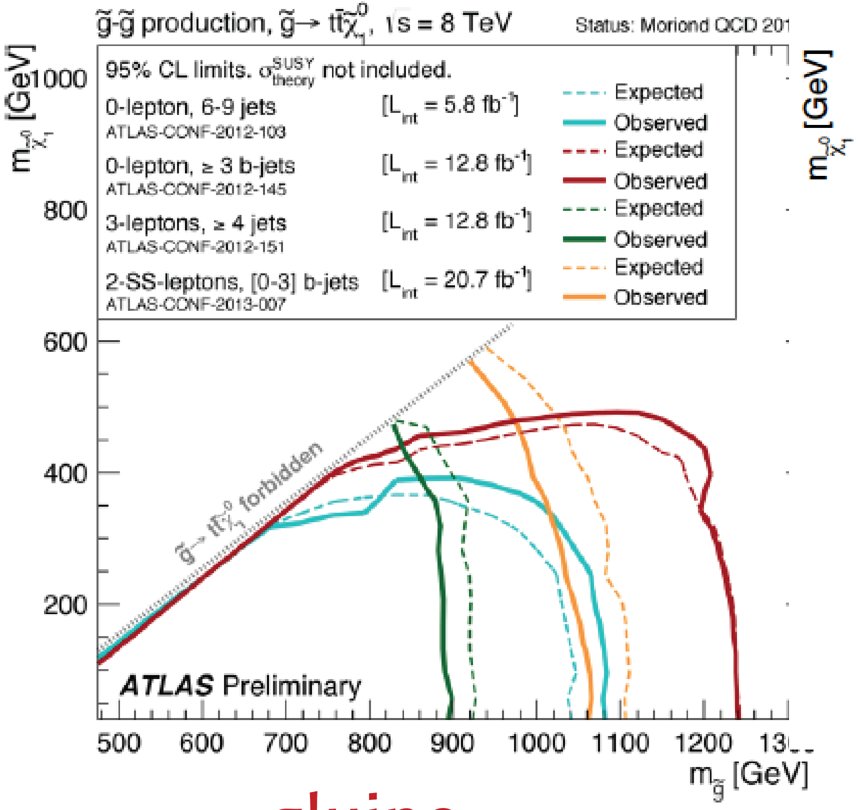
How can this arise?

For g-2
light sleptons
welcome

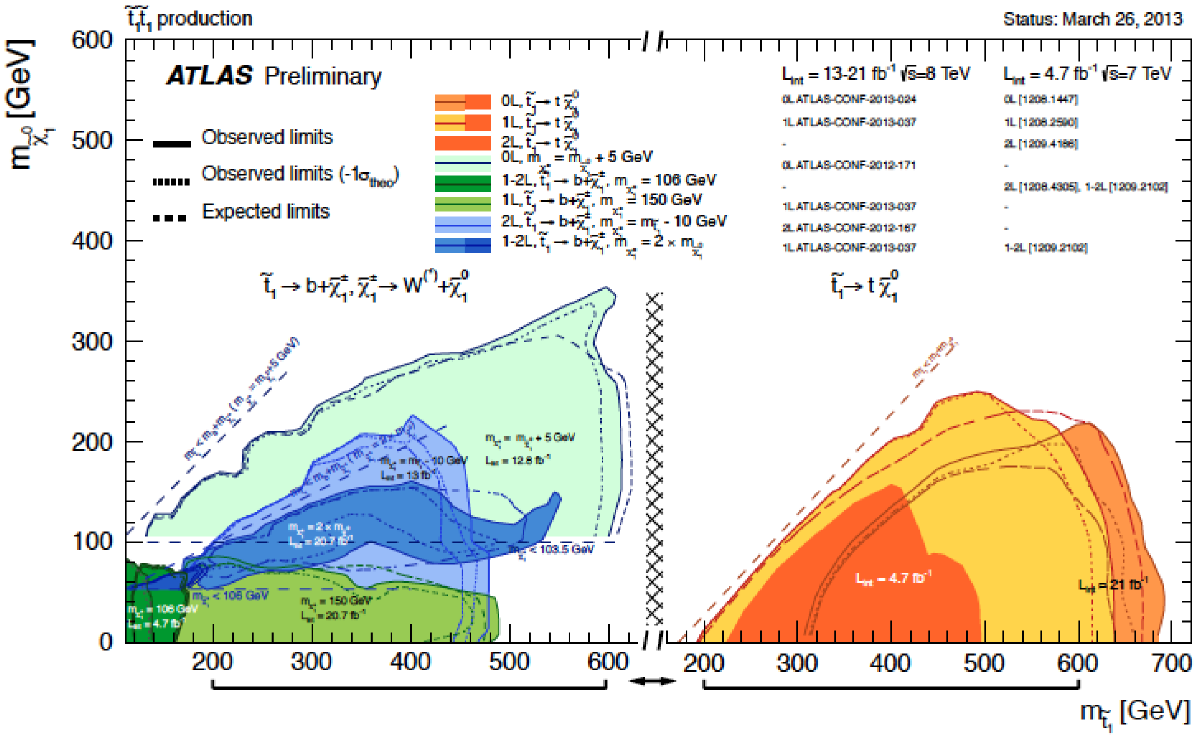
Searches of light gluinos, s-top, s-bottom: already biting hard

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 $t\chi^0$



gluino



s-top

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)

additional term

λSH_uH_d

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

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 excluded that at 126 GeV the second heaviest is seen while the lightest escaped detection at LEP

Ellwanger ‘11, Belanger et al ‘12

Is naturalness relevant? The multiverse alternative

- The empirical value of the cosmological constant Λ poses a tremendous, unsolved naturalness problem

  yet the value of Λ 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 refuse of the SM to step aside, and the terrible unexplained naturalness problem of the cosmological constant, many people have turned to the anthropic philosophy also for the SM

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

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

One can argue that the case of the cosmological constant is a lot different: the context is not as fully specified as the for the SM

A revival of models that ignore the fine tuning problem

Examples:

Split SUSY

heavy scalars, light ferminos

High scale SUSY

all sparticles heavy

λh⁴ fixed by gauge

Non SUSY GUT's

Unificaxion

Giudice, Rattazzi, Strumia

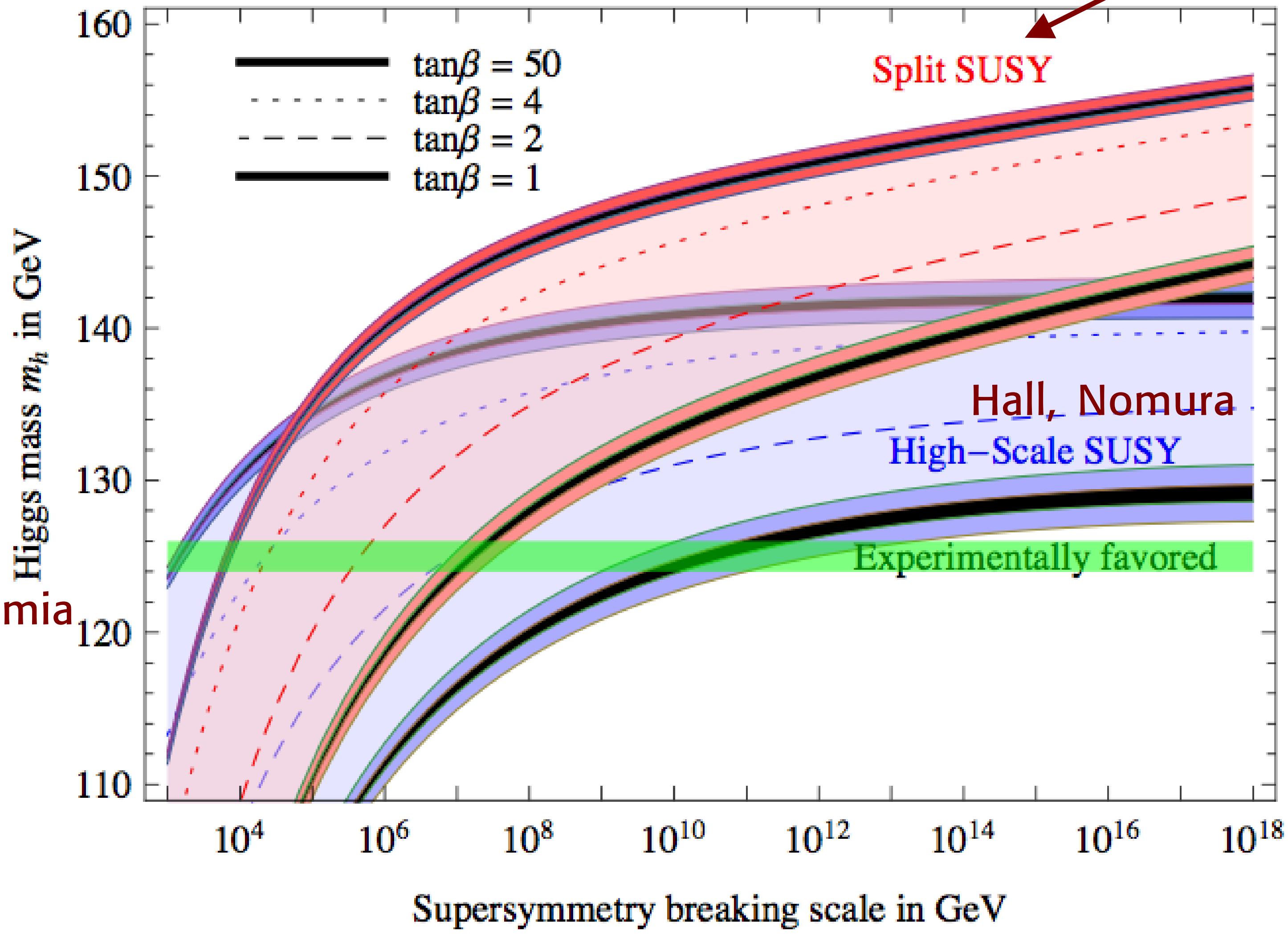
Non SUSY SO(10)

GA, Meloni

••••••••

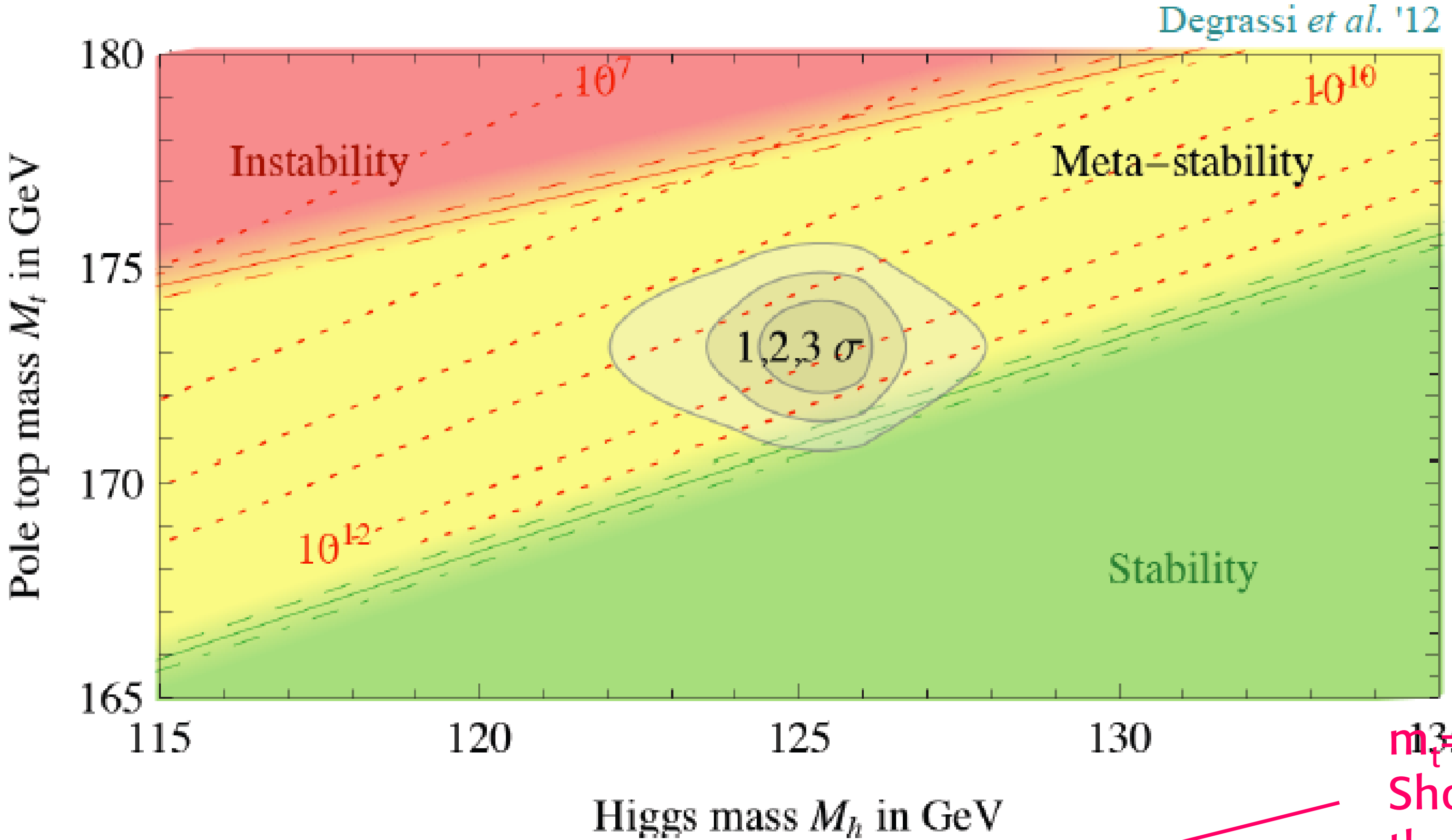
Giudice, Strumia

Arkani-Amed,Dimopoulos
Giudice, Romanino



Hall, Nomura

In the SM for m_H ~ 126 GeV the SM vacuum is metastable



Tevatron
m_t=173.2±0.9 GeV
Should we believe the error?
See Alekhin et al '12

Absolute stability condition

$$M_h\,[\mathrm{GeV}] > 129.4 + 2.0\left(\frac{M_t\,[\mathrm{GeV}] - 173.1}{1.0}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\mathrm{th}}$$

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

see e.g. Shaposhnikov; Wetterich '10

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, as the theory valid up to very high energy

Dark Matter? Axions
Baryogenesis? Thru leptogenesis
Coupling Unification? SO(10) with an intermediate scale

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

An explicit model: GA, Meloni ArXiv:1305.1001

An enlarged SM (to include RH ν's, coupling unification in GUT) valid up to a large scale is an (enormously fine tuned) option

following the anthropic philosophy, the Multiverse, the Landscape

A light Higgs

SO(10) non SUSY GUT

SO(10) breaking down to $SU(4)xSU(2)_L xSU(2)_R$
at an intermediate scale ($\sim 10^{11}$ GeV)
[coupling unification, p-decay OK]

Majorana neutrinos and see-saw (-> $0\nu\beta\beta$)

Baryogenesis thru leptogenesis

Axions as dark matter (axion searches)

recall that $\mu \to e\,\gamma$, edm of neutron.... are not seen!

No new physics at the LHC
[$(g-2)_\mu$ and other present deviations from SM in colliders should be disposed of]

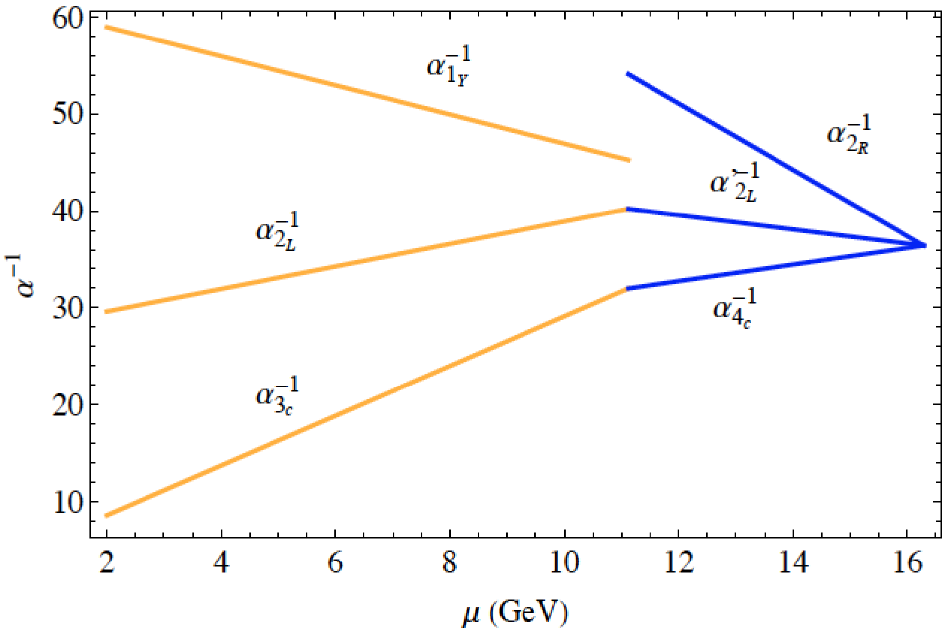
We worked out an explicit model: GA, Meloni ArXiv:1305.1001

$$SO(10) \xrightarrow{M_{GUT}-210_H} 4_C\,2_L\,2_R \xrightarrow{M_I-126_H,45_H} 3_C\,2_L\,1_Y \xrightarrow{M_Z-10_H} 3_C\,1_Y$$

The imposed constraints are sufficiently restrictive that only a particular breaking chain with PS symmetry at M_I works

	210_H	$\overline{126}_H$	45_H	10_H
M_{GUT}	all components	$(6,1,1),(\overline{10},3,1)$	$(1,3,1),(6,2,2),(15,1,1)$	$(6,1,1)$
M_I	–	$(10,1,3),(15,2,2)$	$(1,1,3)$	–
EW	–	–	–	$(1,2,2)$

$$M_I = (1.3 \pm 0.2)\cdot 10^{11}\,\mathrm{GeV} \qquad M_{GUT} = (1.9 \pm 0.6)\cdot 10^{16}\,\mathrm{GeV}$$



obs.	*fit*	*pull*	*obs.*	*fit*	*pull*
m_u(MeV)	0.49	0.03	$\lvert V_{us}\rvert$	0.225	0.038
m_d(MeV)	0.78	0.75	$\lvert V_{cb}\rvert$	0.042	−0.208
m_s(MeV)	32.5	−1.50	$\lvert V_{ub}\rvert$	0.0038	−0.659
m_c(GeV)	0.287	−1.49	J	3.1×10^{-5}	0.589
m_b(GeV)	1.11	−2.77	$\sin^2\theta^l_{12}$	0.318	0.611
m_t(GeV)	71.4	0.70	$\sin^2\theta^l_{23}$	0.353	−1.548
r	0.031	0.10	$\sin^2\theta^l_{13}$	0.0222	−0.758
η_B	5.699×10^{-10}	−0.001			

leptogenesis → η_B

Best fit solutions for the fermion observables at the scale $M_{GUT} = 2 \cdot 10^{16}$ *GeV.*

Predictions

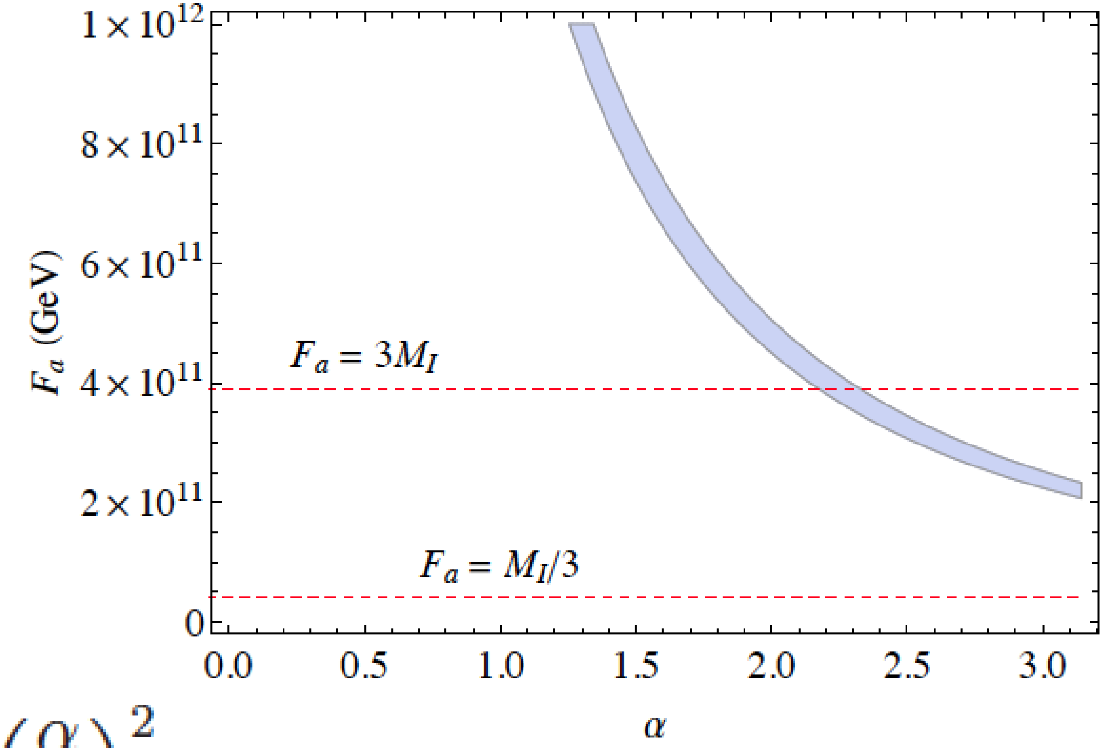
p-decay
$\tau > 10$^36 yrs

$light\ \nu\ masses\ (eV)$	$heavy\ \nu\ masses\ (10^{11}\ GeV)$	$phases\,(^\circ)$	$m_{ee}\ (eV)$
.0046	1.00	$\delta = 88.6$	5×10^{-4}
.0098	1.09	$\phi_1 = -33.2$	
.0504	21.4	$\phi_2 = 15.7$	

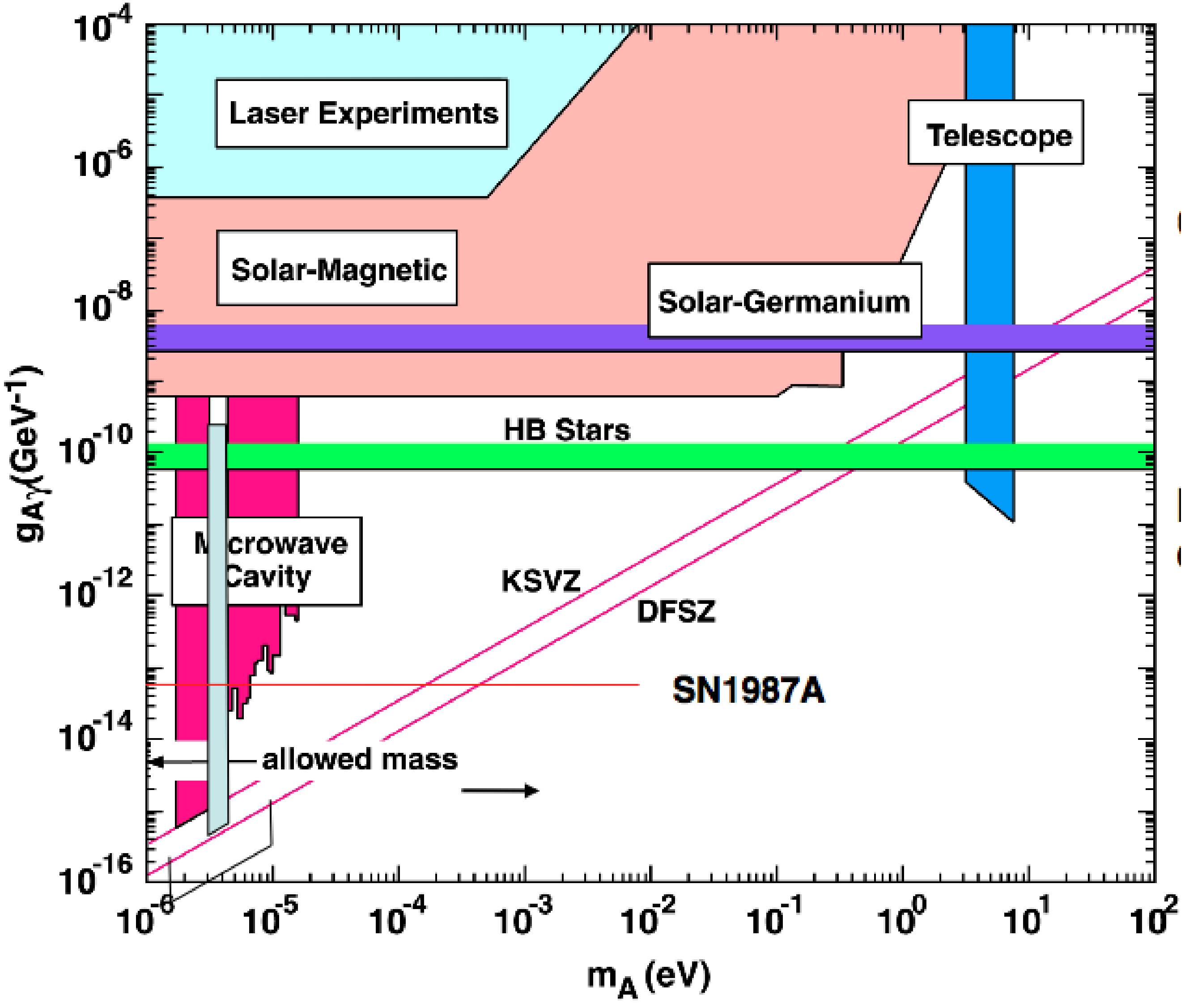
Axions can reproduce the correct amount of DM

$$m_a = \frac{z^{\frac{1}{2}}}{1+z}\,\frac{f_\pi\, m_\pi}{F_a}$$

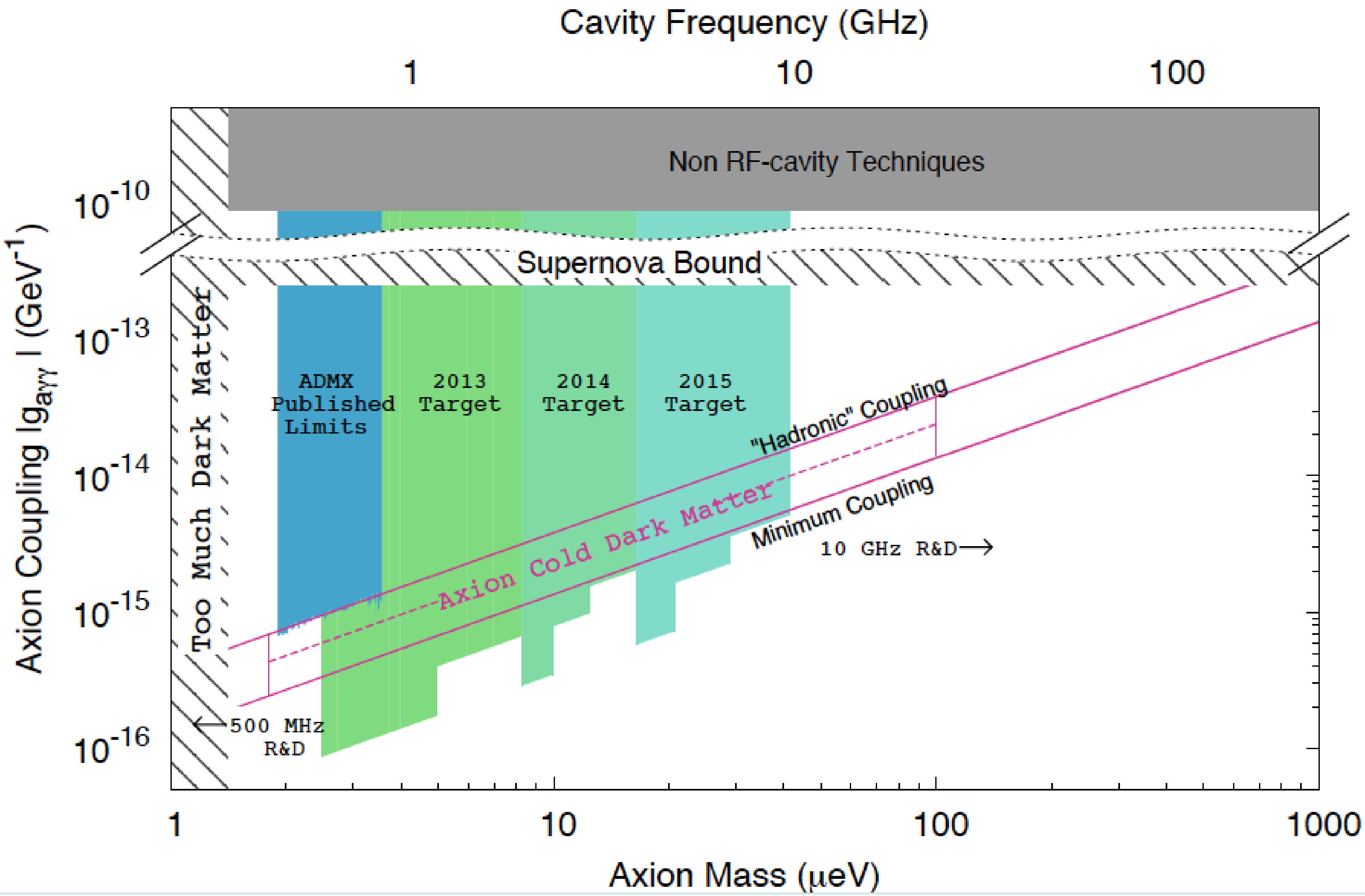
$$\Omega_a h^2 \approx 0.7 \left(\frac{F_a}{10^{12}\,\mathrm{GeV}}\right)^{\frac{7}{6}} \left(\frac{\alpha}{\pi}\right)^2$$



Axion searches are very important



ADMX: an experiment for axion search



Conclusion from the LHC at 7 - 8 TeV

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

No evidence of new physics. Naturalness was not so far a good heuristic guiding principle

Precise tests of the Higgs couplings and further searches for new physics will be done in the next few years at 8 - 14 TeV

Meanwhile many unnatural models are being studied.
Even the Multiverse and the anthropic philosophy are gaining credit

Questions

To which accuracy is the 126 GeV boson the SM Higgs?

Can we hope that a significant precision in the couplings can be reached in the near future? Which accelerator?

The simple naturalness criterium failed

Modify it? How?
Abandon it?

Does Nature really care about our concept of Naturalness?
Which form of Naturalness is Natural?