LHC: Theoretical Perspectives

LHC France 2013

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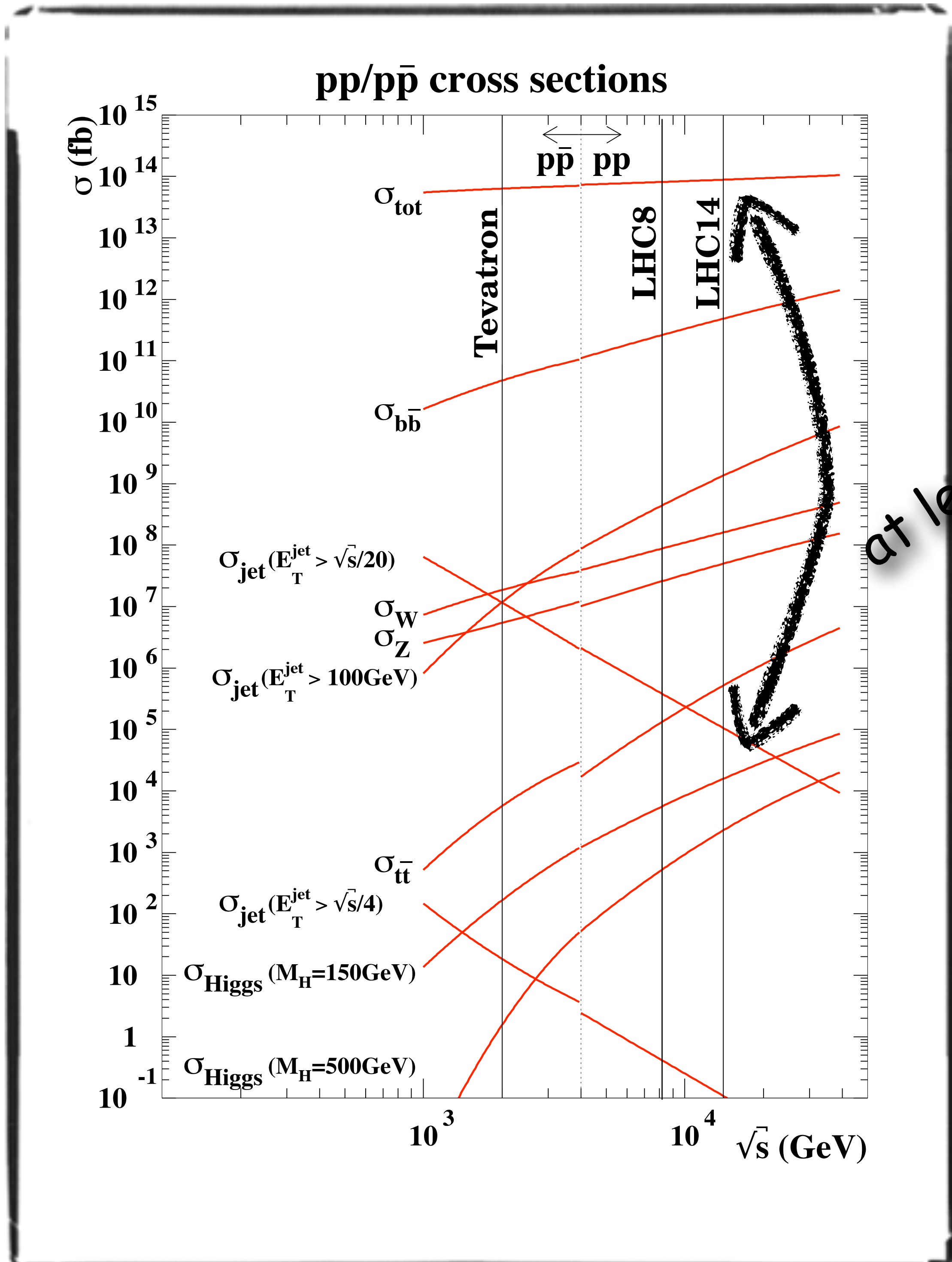
INSTITUCIÓ CATALANA DE RECERCA I ESTUDIS AVANÇATS

We are living a privileged moment in the history of HEP

(picture: courtesy of A. Hoecker]

SM Higgs @ LHC

The production of a Higgs is wiped out by QCD background



at least 10 orders of magnitude

only 1 out of 100 billions events are "interesting"

(for comparison, Shakespeare's 43 works contain only 884,429 words in total)

furthermore many of the background events furiously look like signal events

SM Higgs @ LHC

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only 1 out of 100 billions events are "interesting"

(for comparison, Shakespeare's 43 works contain only 884,429 words in total)

furthermore many of the background events furiously look like signal events

... like finding the paper you are looking for in 10^8 John Ellis' offices

Where are we?

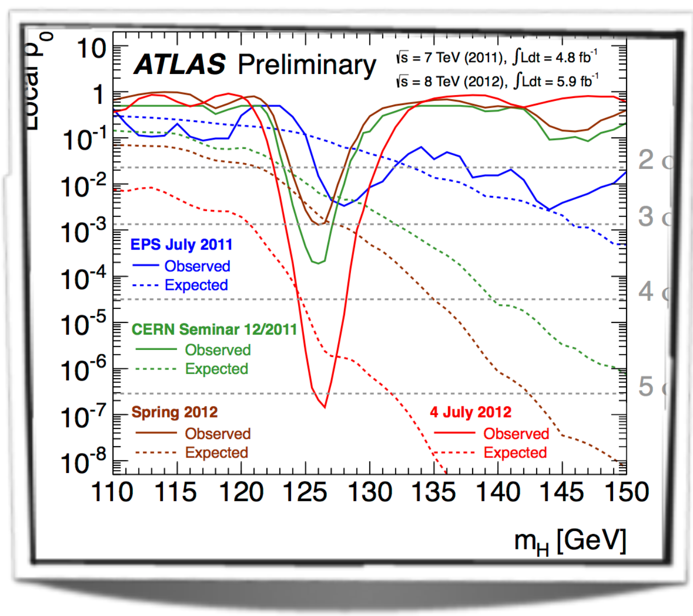
we are living a privileged moment in the history of HEP

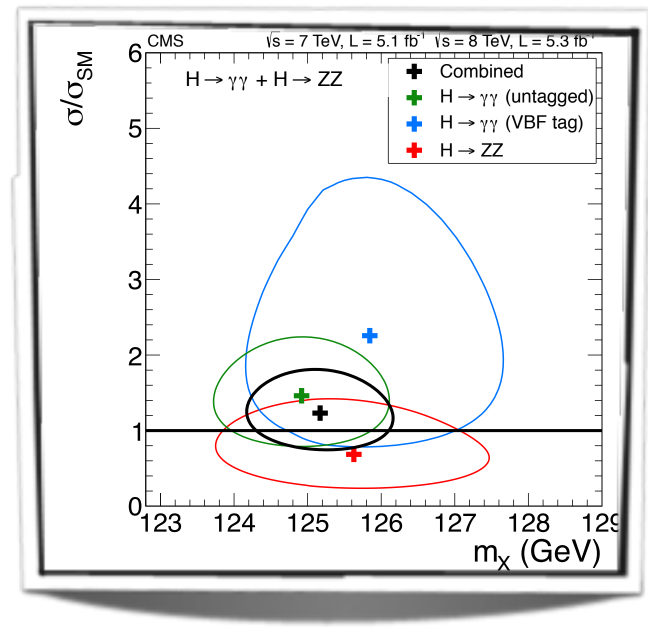
"We have found a new particle" CMS

Where are we? What's next?

we are living a privileged moment in the history of HEP

"We have found a new particle" CMS





"this discovery came at half the LHC design energy, much more severe pileup, and one-third of the integrated luminosity that was originally judged necessary" ATLAS

Higgs is the most exotic particle of the SM

its discovery has profound implications

- Spin 0? Against naturalness: small mass only if protected by symmetry
- Couplings not dictated by gauge symmetry? Against gauge principle (elegance, predictivity, robustness, variety) which used to rule the world (gravity, QCD, QED, weak interactions)
- Triumph of QM+SR that predict (anti)particles of spin 0, 1/2, 1, (3/2 ?), 2

Now what?

"The experiment worked better than expected and the analysis uncovered a very difficult to find signal"

the words of a string theorist

but the experimentalists haven't found what the theorists told them they will find in addition to the Higgs boson:
no susy, no BH, no extra dimensions, nothing ...

Have the theorists been lying for so many years?

Have the exp's been too naive to believe the th's?

Why should you listen to the rest of this talk?

What does come with the Higgs?

We know that the Higgs is not the end of the story

- dark matter
- matter antimatter asymmetry
- hierarchy/naturalness problem
- ...

All these point towards an extended EW/Higgs sector

but so far this extension has been very elusive

- Direct searches @ LHC: M_{new} >~ O(500 GeV) unless reduced couplings to fermions
- EW precision data: M_{new} >~ O(TeV) unless some selection rules (eg R-parity)
- Flavor data: M_{new} >~ O(1000 TeV) unless some protection (eg MVF...)
- ...

HEP future:

exploration/discovery era or consolidation/measurement era?

let's use what we have at our disposal (the Higgs) to explore BSM sector

Now what? What's next?

" With great power comes great responsibility "

Voltaire & Spider-Man

which, in particle physics, really means

" With great discoveries come great measurements "

BSMers desperately looking for anomalies
(true credit: F. Maltoni
actually, first google hit gives a link to an article of
the Guardian on... the Higgs boson!)

1

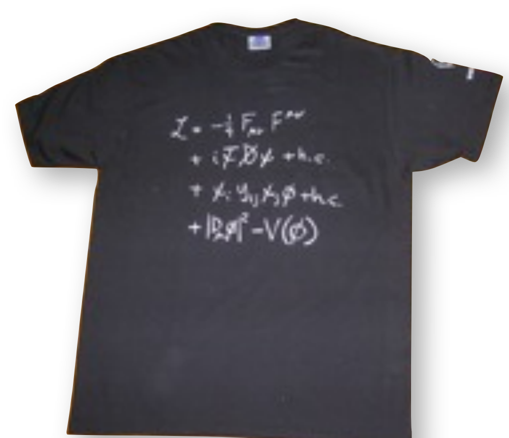
Higgs properties

J^{PC}

Important & nice to see progresses but
"this question carries a similar potential
for surprise as a football game between
Brazil and Tonga" Resonaances

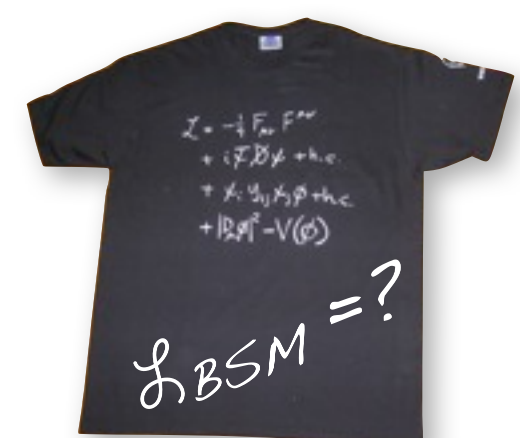
2

Higgs couplings



3

BSM implications



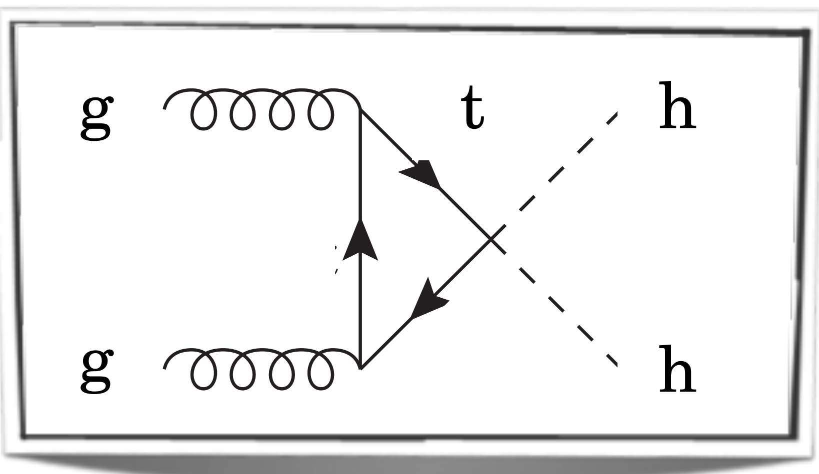
The 2 questions about the Nature of the Higgs

1. Is the Higgs part of an SU(2) doublet? Does New Physics flow towards the SM in the IR?

production and decay rates in agreement with SM is a good hint
but can never exclude a malicious conspiracy
and the SU(2)xU(1) quantum # of the Higgs cannot be measured in single higgs processes

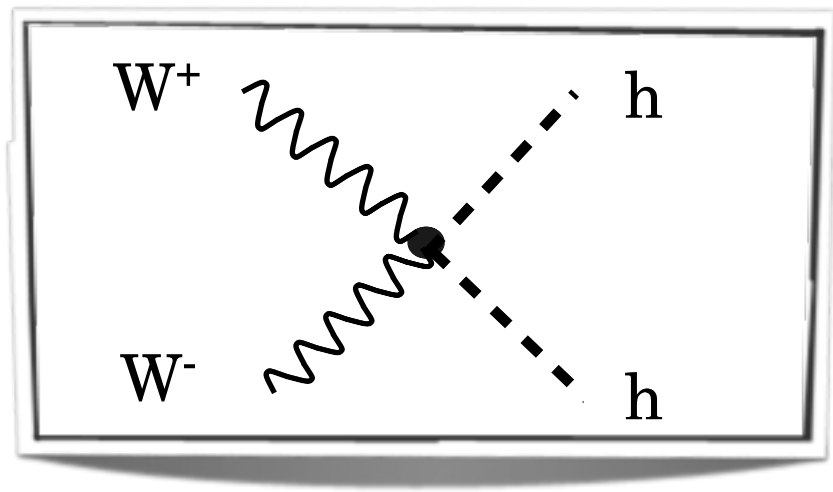
Higgs doublet?

not an easy question at the LHC since we need multi-Higgs couplings



Gröber, Mühlleitner '10
Contino et al '12
Gillioz et al '12

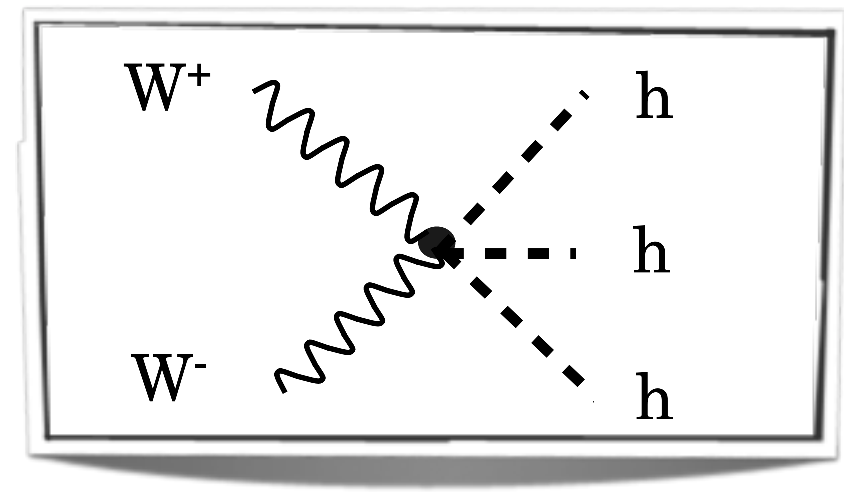
$\sigma^{SM}_{14\mathrm{TeV}} \approx 20\,\mathrm{fb}$



Contino, Grojean,
Moretti, Piccinini, Rattazzi '10

$b_V - 1 = 2(c_V^2-1)+O(c_V^2-1)^2$

$\sigma^{SM}_{14\mathrm{TeV}} \approx 0.5\,\mathrm{fb}$



Contino, Grojean, Pappadopoulo,
Rattazzi, Thamm 'to appear

$3b_{3V} = 4\, c_V(b_V - c_V^2)+O(c_V^2-1)^2$

$\sigma^{SM}_{14\mathrm{TeV}} < 1\,\mathrm{ab}$

(single Higgs production by gluon fusion: $\sigma^{SM}_{14\mathrm{TeV}} \approx 50\,\mathrm{pb}$)

The 2 questions about the Nature of the Higgs

2. Is the Higgs elementary or composite?

single Higgs production

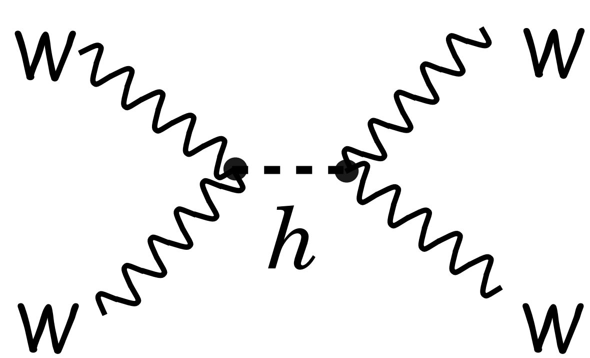
deviations in Higgs couplings can be due either to
1. weakly coupled light states
2. strongly coupled heavy states

$$\frac{\delta g_h}{g_h} \sim \frac{g_*^2}{g_{SM}^2} \frac{m_W^2}{M^2}$$

observing deviations of order δ_h and no new states up to M
would be an indication of Higgs compositeness

$$g_* > \sqrt{\delta_h}\ M/v$$

WW scattering



$$\mathcal{A} \sim \delta_h \frac{s}{v^2} \equiv g_*^2(E)$$

an excess δ_{hh} @ energy E
also gives a lower bound on g*

$$g_*(E) > \sqrt{\delta_{hh}}\ E/v$$

would be a direct evidence of Higgs compositeness

Precision Higgs Physics @ LHC

Chiral Lagrangian for a light Higgs-like scalar

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

$$-\left(m_W^2\, W_\mu W^\mu + \frac{1}{2}m_Z^2\, Z_\mu Z^\mu\right)\left(1 + 2c_V\frac{h}{v} + b_V\frac{h^2}{v^2} + \dots\right)$$

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

$$+\frac{\alpha_{em}}{8\pi}\left(2\,c_{WW}\,W^+_{\mu\nu}W^{-\,\mu\nu} + c_{ZZ}\,Z_{\mu\nu}Z^{\mu\nu} + 2\,c_{Z\gamma}\,Z_{\mu\nu}\gamma^{\mu\nu} + c_{\gamma\gamma}\,\gamma_{\mu\nu}\gamma^{\mu\nu}\right)\frac{h}{v}$$

$$+\frac{\alpha_s}{8\pi}\,c_{gg}\,G^a_{\mu\nu}G^{a\,\mu\nu}\,\frac{h}{v}$$

$$+c_W\left(W^-_\nu D_\mu W^{+\,\mu\nu} + W^+_\nu D_\mu W^{-\,\mu\nu}\right)\frac{h}{v} + c_Z\,Z_\nu\partial_\mu Z^{\mu\nu}\,\frac{h}{v}$$

$$\underbrace{+\left(\frac{c_W}{\sin\theta_W\cos\theta_W} - \frac{c_Z}{\tan\theta_W}\right)Z_\nu\partial_\mu\gamma^{\mu\nu}\,\frac{h}{v}}_{O(p^4)}$$

$$+\mathcal{O}(p^6)$$

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

SM

$$a = b = c = d_3 = d_4 = 1$$

$$c_{2\psi} = c_{WW} = c_{ZZ} = c_{Z\gamma} = c_{\gamma\gamma} = \dots = 0$$

A few (reasonable) assumptions:

- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$
  - ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC (generalization of Glashow-Weinberg th.)
  - ↖ Flavor

Chiral Lagrangian for a light Higgs-like scalar

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

$$-\left(m_W^2\, W_\mu W^\mu + \frac{1}{2}m_Z^2\, Z_\mu Z^\mu\right)\left(1 + \ldots\right)$$

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

$$+\frac{\alpha_{em}}{8\pi}\left(2\, c_{WW}\, W^+_{\mu\nu}W^{-\,\mu\nu} + c_{ZZ}\, Z_{\mu\nu}Z^{\mu\nu} + 2\, c_{Z\gamma}\, Z_{\mu\nu}\gamma^{\mu\nu} + c_{\gamma\gamma}\, \gamma_{\mu\nu}\gamma^{\mu\nu}\right)\frac{h}{v}$$

still large LO parameter space

$\Downarrow \quad \Downarrow \quad \Downarrow$

4 operators @ $O(p^2)$: c_V, c_t, c_b, c_T

2 operators @ $O(p^4)$: c_g c_γ

(contribute to the same order as $O(p^2)$ to $gg \to h$ and $h \to \gamma\gamma$)

Not enough data/sensitivity to determine all these parameters

$\Downarrow \quad \Downarrow \quad \Downarrow$

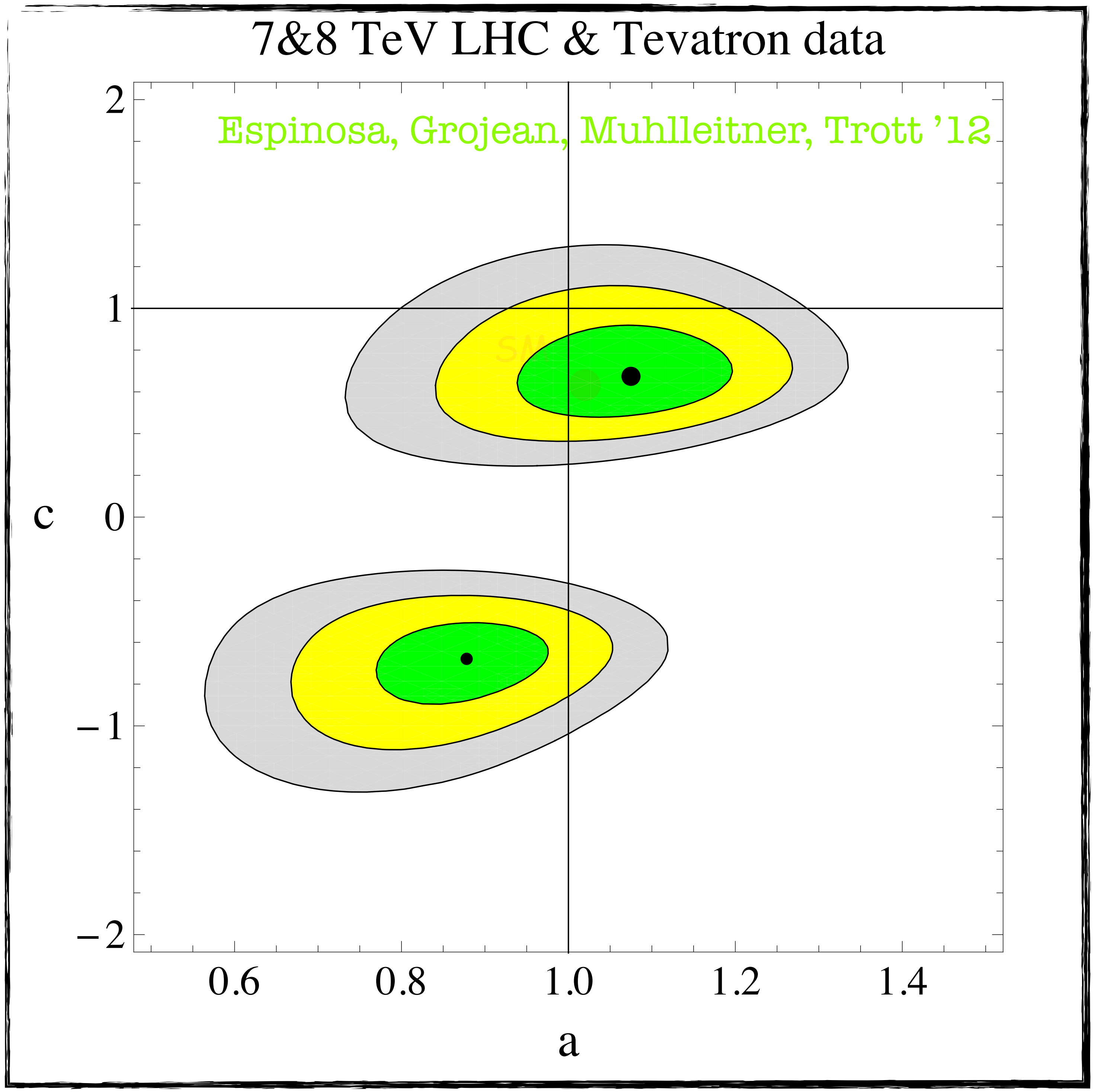
But we can put some of the SM structures under probation

assumptions:

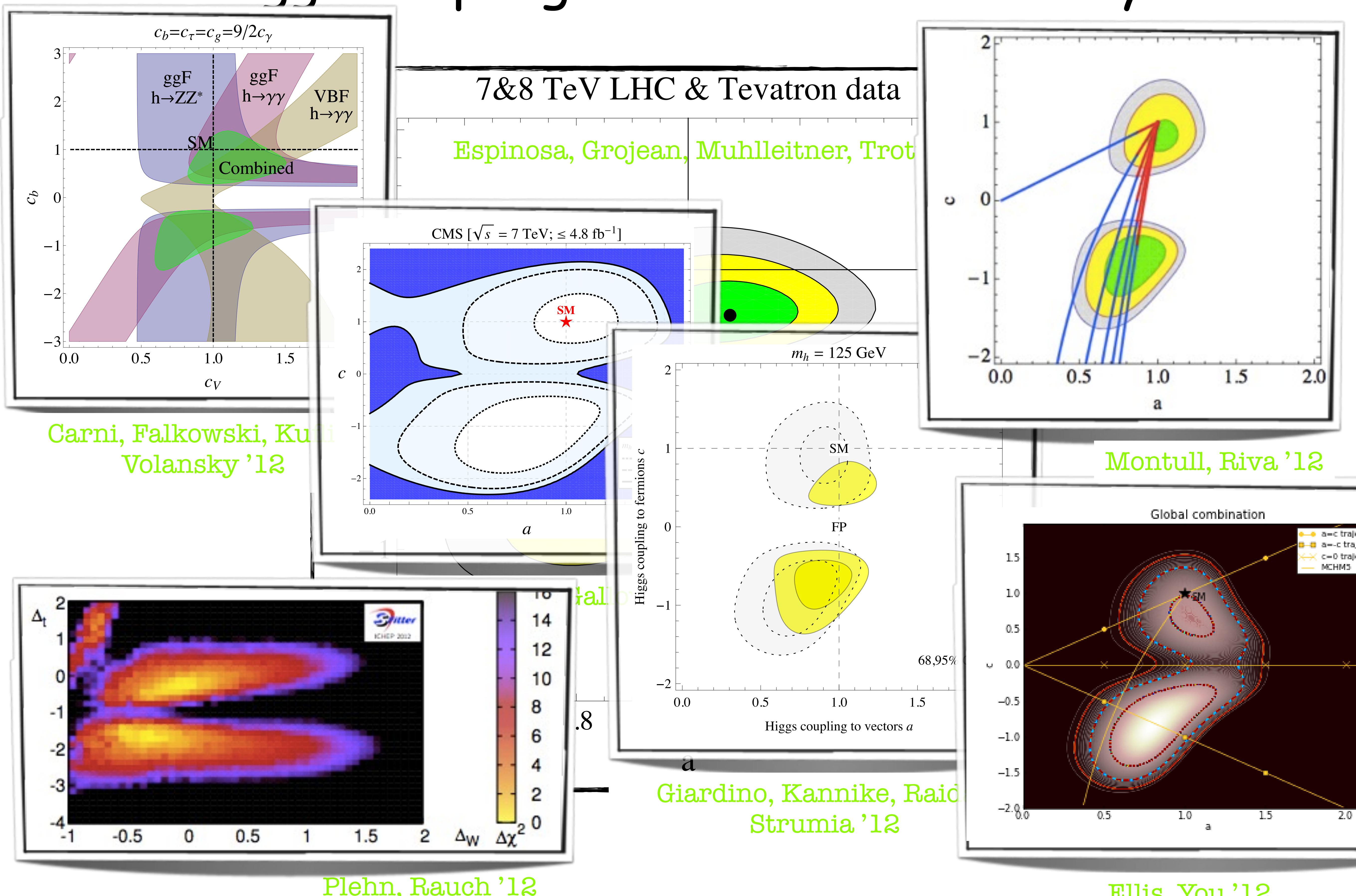
- ☑ spin-0 & CP-even
  - ↖ $\gamma\gamma$ ↖ WW & ZZ
- ☑ custodial symmetry
  - ↖ EWPD
- ☑ no Higgs FCNC (generalization of Glashow-Weinberg th.)
  - ↖ Flavor

Contino, Grojean, Moretti, Piccinini, Rattazzi '10

Higgs coupling fits: test of unitarity

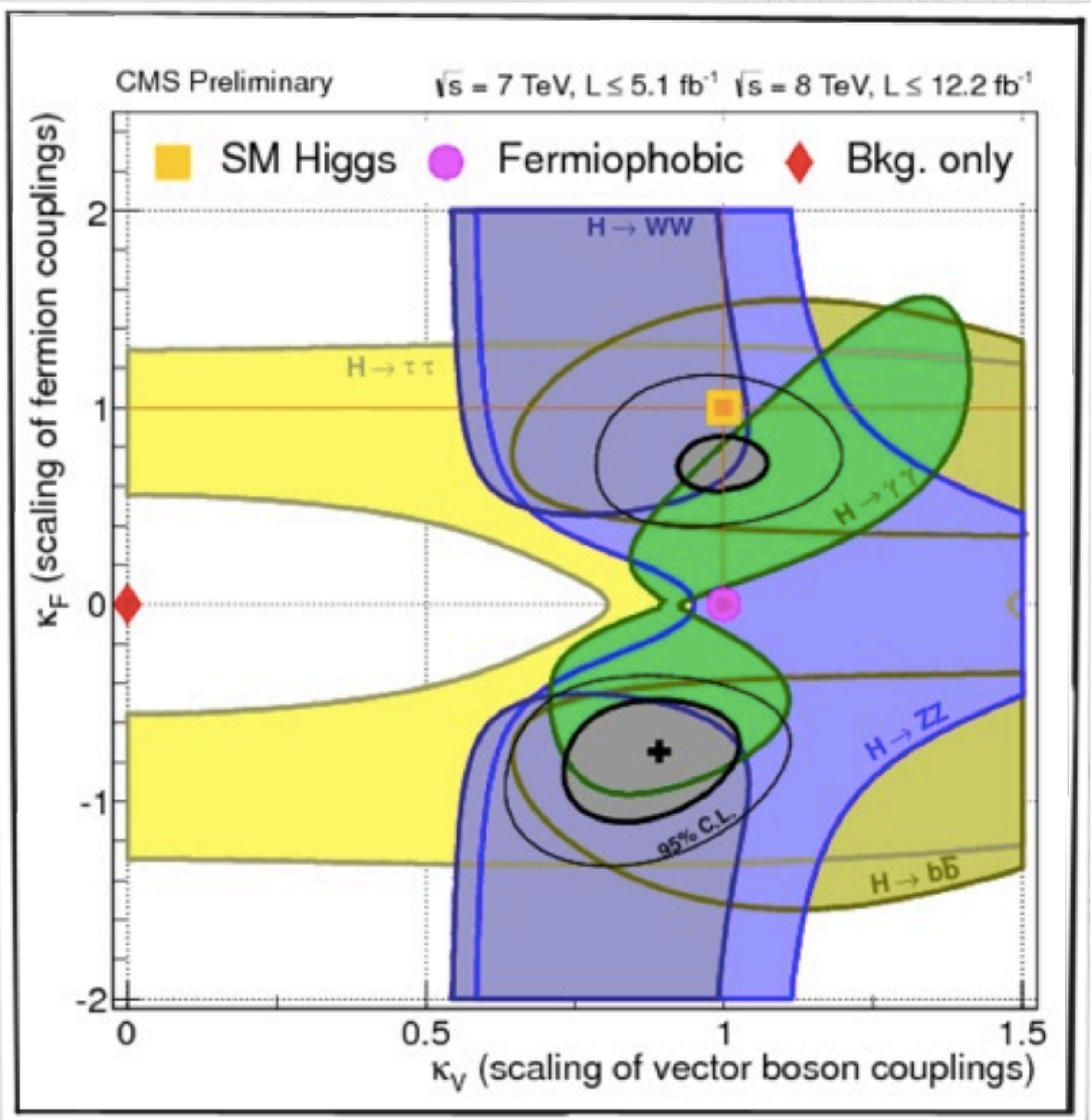


Higgs coupling fits: test of unitarity

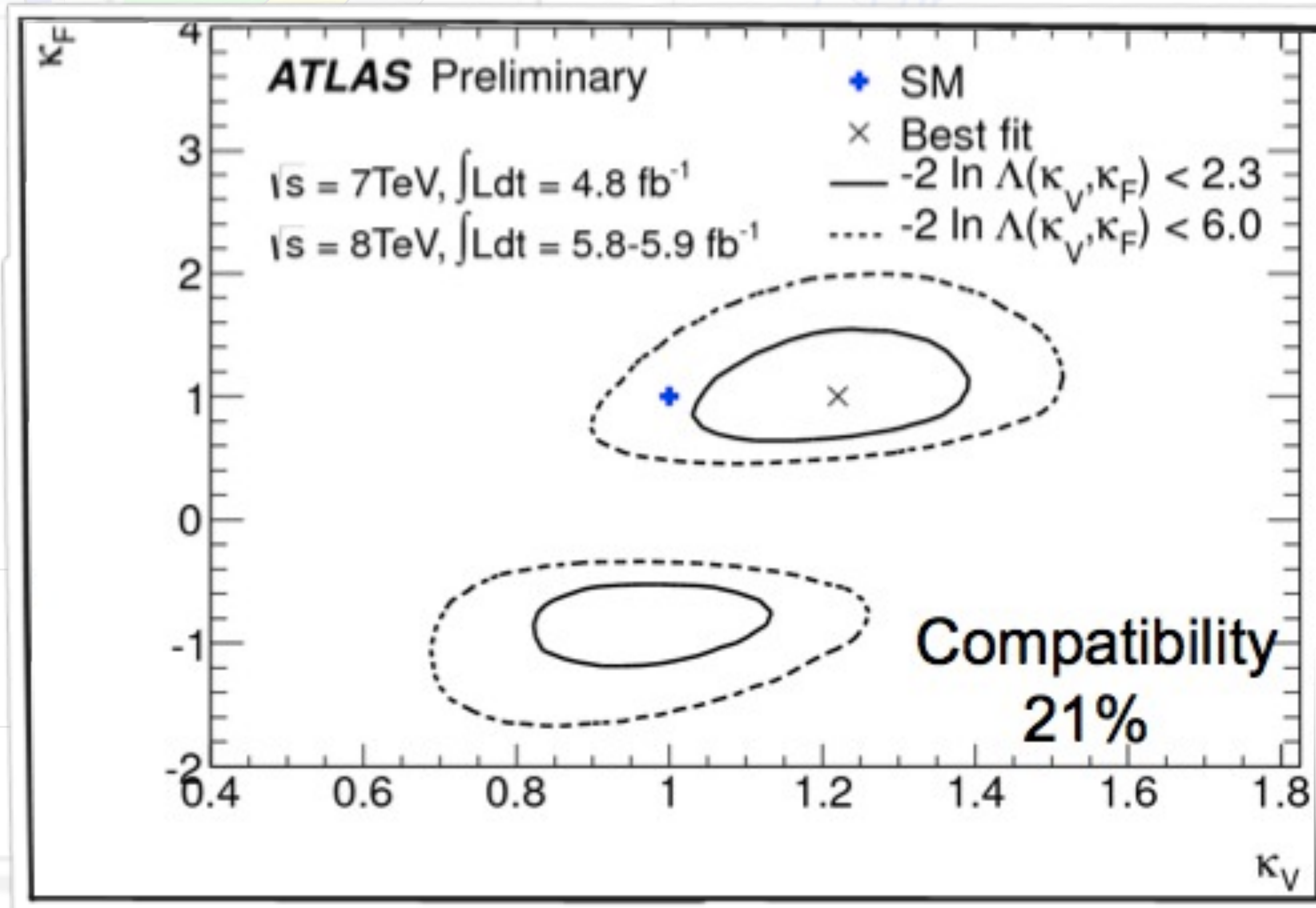


Higgs coupling fits: test of unitarity

don't leave it in the hands of theorists!



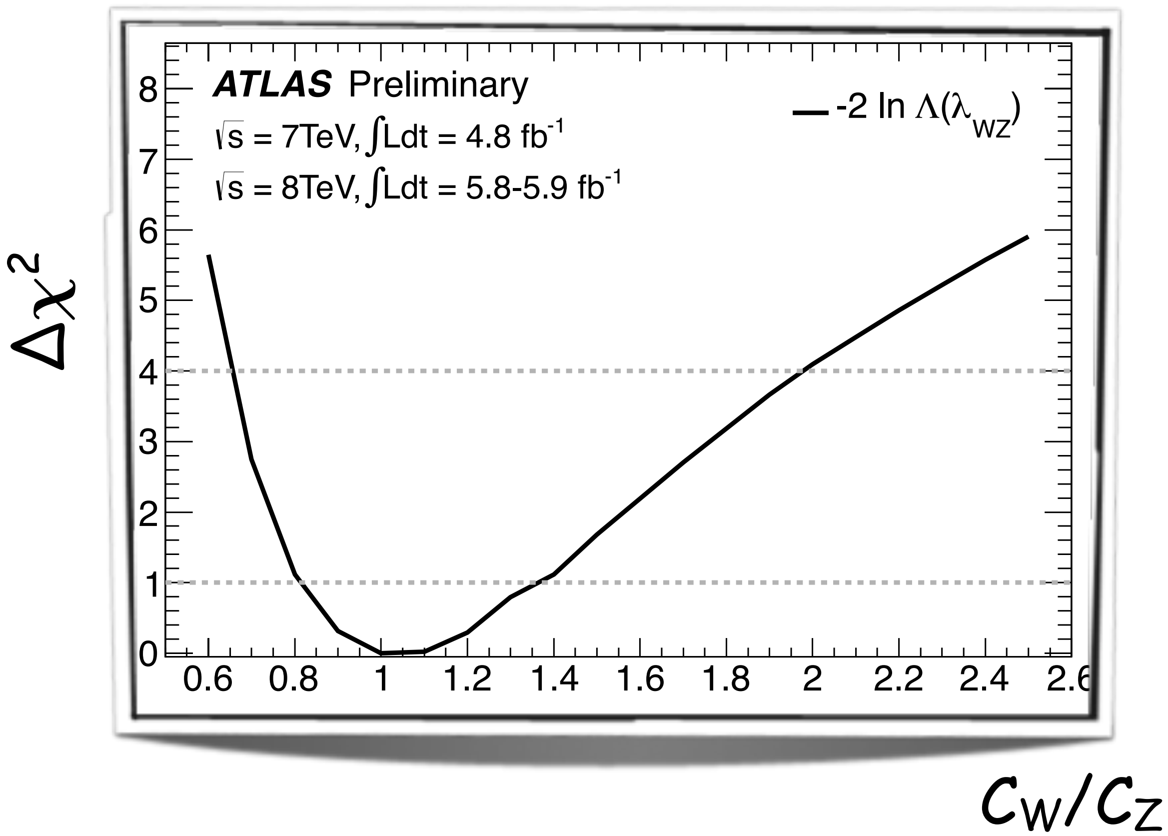
CMS

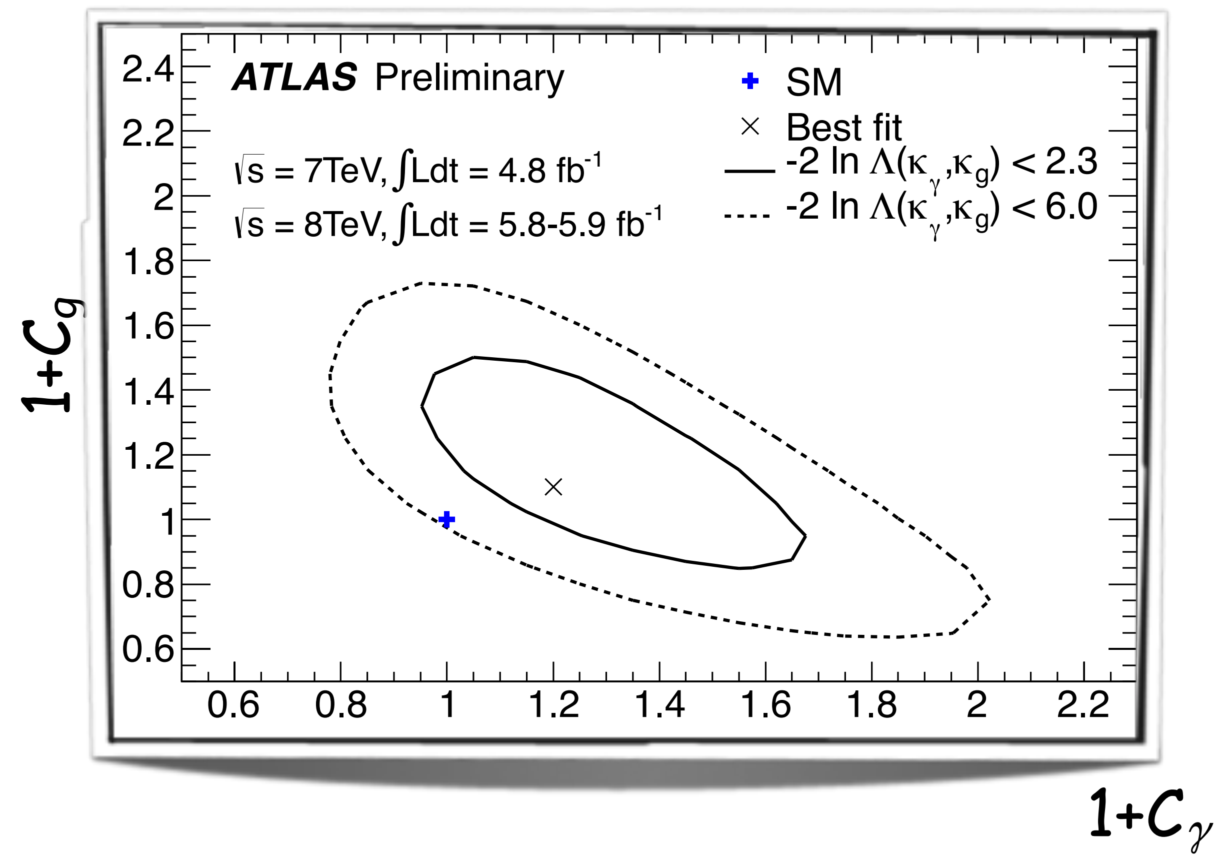


ATLAS

χ^2 fit: other tests of the SM structures

- custodial symmetry: $C_W=C_Z$?
- probing the weak isospin symmetry: $C_u=C_d$?
- quark and lepton symmetry: $C_q=C_l$?
- new non-SM particle contribution: BR_{inv}? $C_g=C_\gamma=0$?





ATLAS-CONF-2012-127

Some tensions
but no statistically significant deviations from the SM structure

Higgs power counting

Giudice, Grojean, Pomarol, Rattazzi '07

- extra Higgs leg: H/f
- extra derivative: ∂/m_ρ

- **Genuine strong operators** (sensitive to the scale f)

$$\frac{c_H}{2f^2}\left(\partial^\mu |H|^2\right)^2 \qquad \frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)^2 \qquad \frac{c_y y_f}{f^2}|H|^2 \bar{f}_L H f_R + \text{h.c.} \qquad \frac{c_6 \lambda}{f^2}|H|^6$$

custodial breaking

- **Form factor operators** (sensitive to the scale $m_\rho = g_\rho f$) (g_{SM} factors in V)

$$\frac{ic_W}{2m_\rho^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i \qquad \frac{ic_B}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)(\partial^\nu B_{\mu\nu})$$

$$\frac{ic_{HW}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} \qquad \frac{ic_{HB}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$

minimal coupling: $h \to \gamma Z$

loop-suppressed strong dynamics

$$\frac{c_\gamma}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{g^2}{g_\rho^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} \qquad \frac{c_g}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{y_t^2}{g_\rho^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}$$

Goldstone sym.
(PGB Higgs)

Higgs power counting: SUSY vs Composite

generic new physics

$$\bar{c}_H, \bar{c}_T, \bar{c}_6, \bar{c}_y \sim O\left(\frac{v^2}{f^2}\right), \quad \bar{c}_W, \bar{c}_B \sim O\left(\frac{m_W^2}{M^2}\right), \quad \bar{c}_{HW}, \bar{c}_{HB}, \bar{c}_\gamma, \bar{c}_g \sim O\left(\frac{g^2}{16\pi^2}\,\frac{v^2}{f^2}\right)$$

weakly coupled NP

$g_* \sim g_{SM}$ ie $f \sim M$

MSSM in the decoupling limit

$$\bar{c}_H \sim \cancel{O\left(\frac{v^2}{f^2}\right)} + O\left(\frac{\alpha_{SM}}{4\pi}\frac{m_W^2}{M^2}\right)$$

$1 - \sin(\beta - \alpha)$

$$\bar{c}_u \sim 1 - \frac{\cos\alpha}{\sin\beta} \sim \frac{m_Z^2}{M_H^2}\frac{1}{\tan^2\beta}$$

$$\bar{c}_d \sim 1 + \frac{\sin\alpha}{\cos\beta} \sim \frac{m_Z^2}{M_H^2}$$

$$\bar{c}_g \sim \bar{c}_\gamma \sim O\left(\frac{g_*^2}{16\pi^2}\frac{m_W^2}{m_{\tilde{t}}^2}\right)$$

M_H heavy CP$^+$ Higgs $\quad m_{\tilde{t}}$ stop mass

strongly coupled NP

$g_* \gg g_{SM}$ ie $f \ll M$

composite Higgs models

$$\bar{c}_{H,y} \sim O\left(\frac{v^2}{f^2}\right)$$

$$\vee\!\!\vee$$

$$\bar{c}_{W,B} \sim O\left(\frac{g^2}{g_*^2}\frac{v^2}{f^2}\right)$$

$$\vee\!\!\vee$$

$$\bar{c}_{HW,HB} \sim O\left(\frac{g^2}{16\pi^2}\frac{v^2}{f^2}\right)$$

$$\vee\!\!\vee$$

$$\bar{c}_{\gamma,g} \sim O\left(\frac{g^2}{16\pi^2}\frac{g^2}{g_*^2}\frac{v^2}{f^2}\right)$$

RG-improved Higgs physics

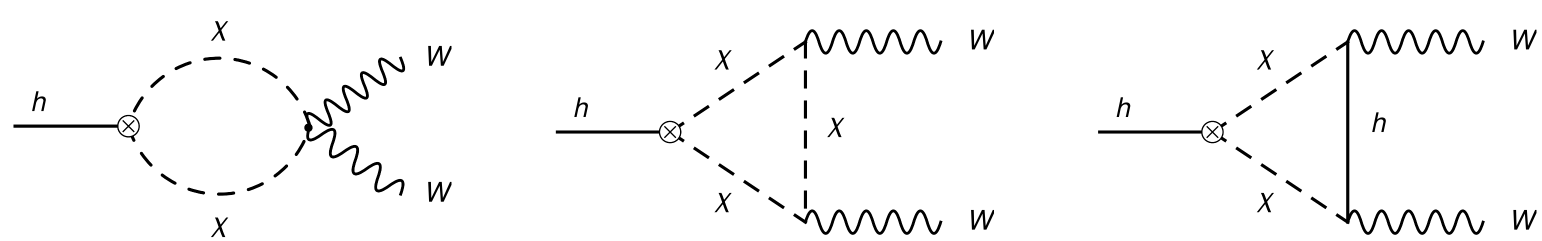
Grojean, Jenkins, Manohar, Trott '13

the previous estimates were based on the values of the Wilson coefficients @ NP scale
RG effects can change the picture

$$\bar{c}_i(\mu) \simeq \left(\delta_{ij} + \gamma_{ij}^{(0)} \frac{\alpha}{8\pi} \log\left(\frac{\mu^2}{M^2}\right)\right) \bar{c}_j(M)$$

anomalous dimensions

dominant effects: loops of Goldstone bosons (couplings g_*)



$$\mu \frac{d}{d\mu} \begin{pmatrix} c_H \\ c_W + c_B \\ c_{HW} + c_{HB} \end{pmatrix} = \frac{\alpha}{8\pi} \gamma \begin{pmatrix} c_H \\ c_W + c_B \\ c_{HW} + c_{HB} \end{pmatrix} \qquad \gamma_{ij}^{(0)} = \begin{pmatrix} 0 & 0 & 0 \\ \text{-1/6} & 0 & 0 \\ ?? & 0 & 0 \end{pmatrix}$$

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anomalous dimensions

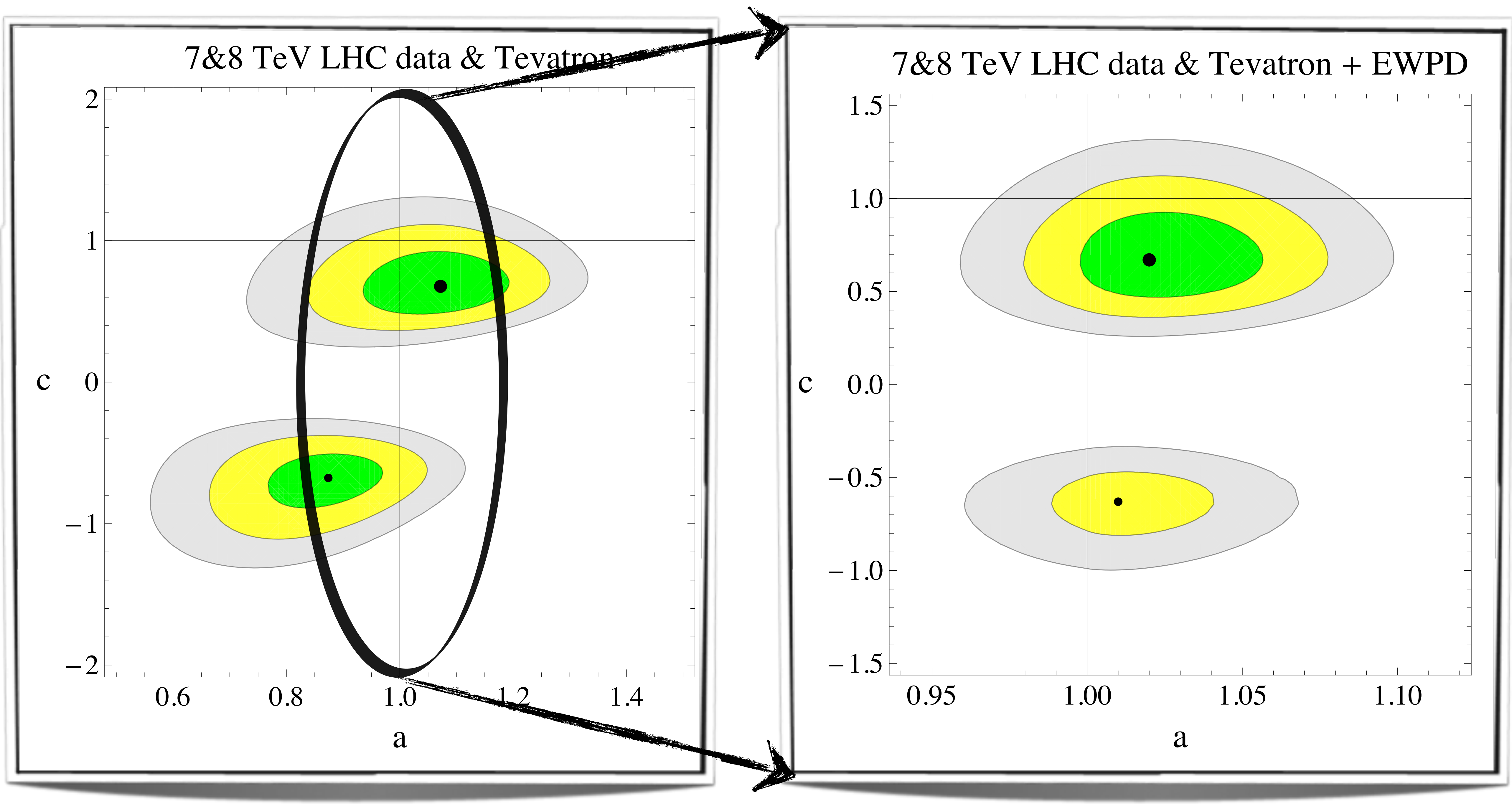
dominant effects: loops of Goldstone bosons (couplings g_*)

$$\bar{c}_{W+B}(\mu) = \underbrace{\bar{c}_{W+B}(M)}_{\frac{m_W^2}{M^2}} + \# \frac{g^2}{16\pi^2} \underbrace{\log\left(\frac{\mu^2}{M^2}\right) \bar{c}_H(M)}_{}$$

$$\frac{m_W^2}{M^2} \gg \frac{g^2}{16\pi^2}\frac{v^2}{f^2} = \frac{g_*^2}{16\pi^2}\frac{m_W^2}{M^2} \times \text{Log}$$

RG-Higgs physics: Don't forget LEP!

Espinosa, Grojean, Muhlleitner, Trott '12



EW data prefer value of 'a' close to 1

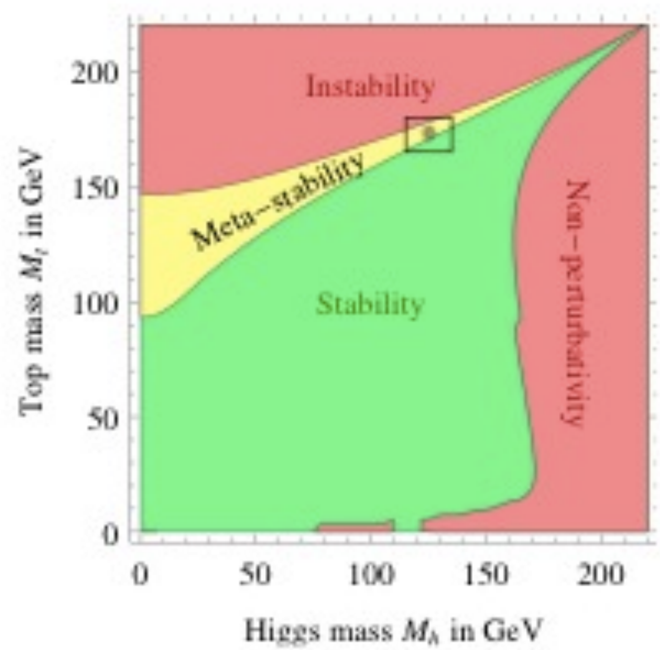
Early Universe Implications

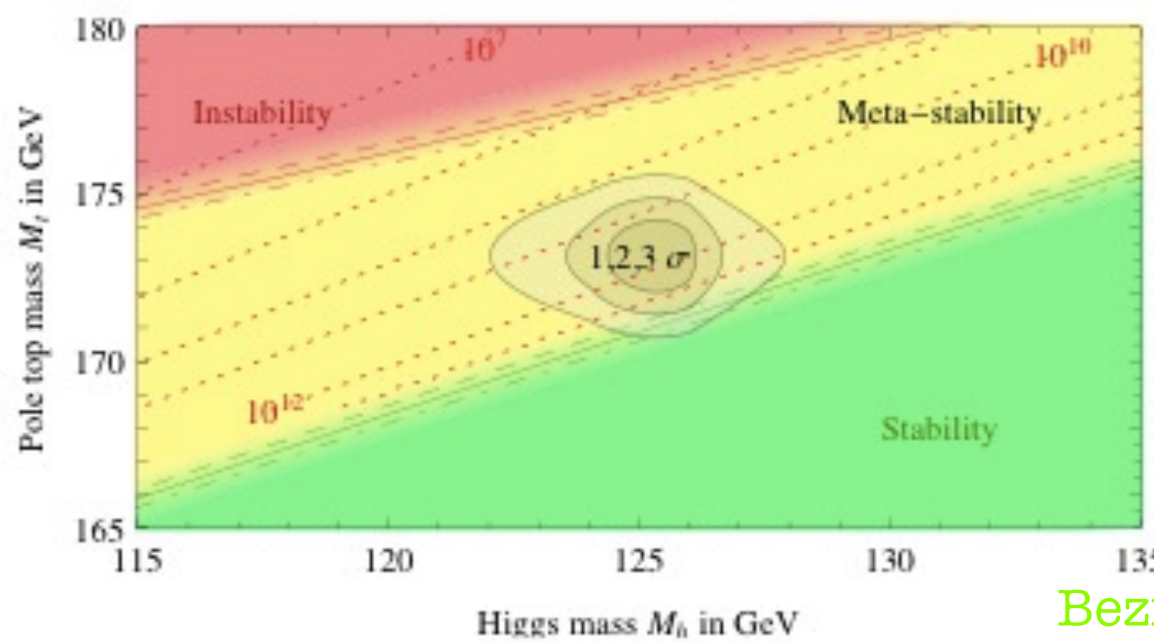
The fate of the EW vacuum

Many of my theory colleagues also started wild speculations/extrapolations

the SM vacuum is stable/metastable

and the validity of the SM can be extended up to the Planck scale!





Bezrukov et al '12
Degrassi et al '12

It is almost certain (>4σ) that $m_H > M_{\text{mestability}}$ and totally certain that $m_H < M^{h^3}_{\text{Landau}}$

(even though this certainty might by questioned by threshold effects at the Planck scale Holthausen, Lim and Lindner '12)

Not totally clear yet if m_H is above $M_{\text{stability}}$, but rather important question since

- ☑ if $m_H > M_{\text{stability}}$, the Higgs could serve as an inflaton
- ☑ if $m_H = M_{\text{stability}}$ the SM is asymptotically safe, ie consistent up to arbitrary high energy

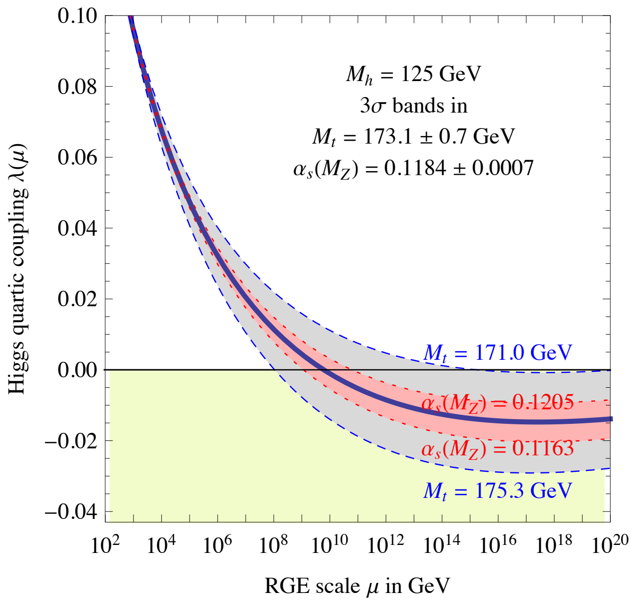
Bezrukov et al '12

need precise Higgs&top mass/couplings (and α_s) measurements (ILC, μ coll.)

and better understanding of pole vs MS top mass Alekhin, Djouadi, Moch '12

From the EW scale to M_{Pl}... and return

Many of my theory colleagues started wild speculations/extrapolations



$$\lambda(M_{\rm Pl}) = -0.0144 + 0.0028\left(\frac{M_h}{\rm GeV} - 125\right) \pm 0.0047_{M_t} \pm 0.0018_{\alpha_s} \pm 0.0028_{\rm th}$$

Degrassi et al '12

is the Higgs potential vanishing potential at M_{Pl}?

Froggatt, Nielsen, Takanishi '01
Arkani-Hamed et al '08
Shaposhnikov, Wetterich '09

EWSB determined by Planck physics? M_{Pl} calculable from weak scale non-gravitational quantities?
absence of new energy scale between the Fermi and the Planck scale?
Anthropic vs. natural EWSB...

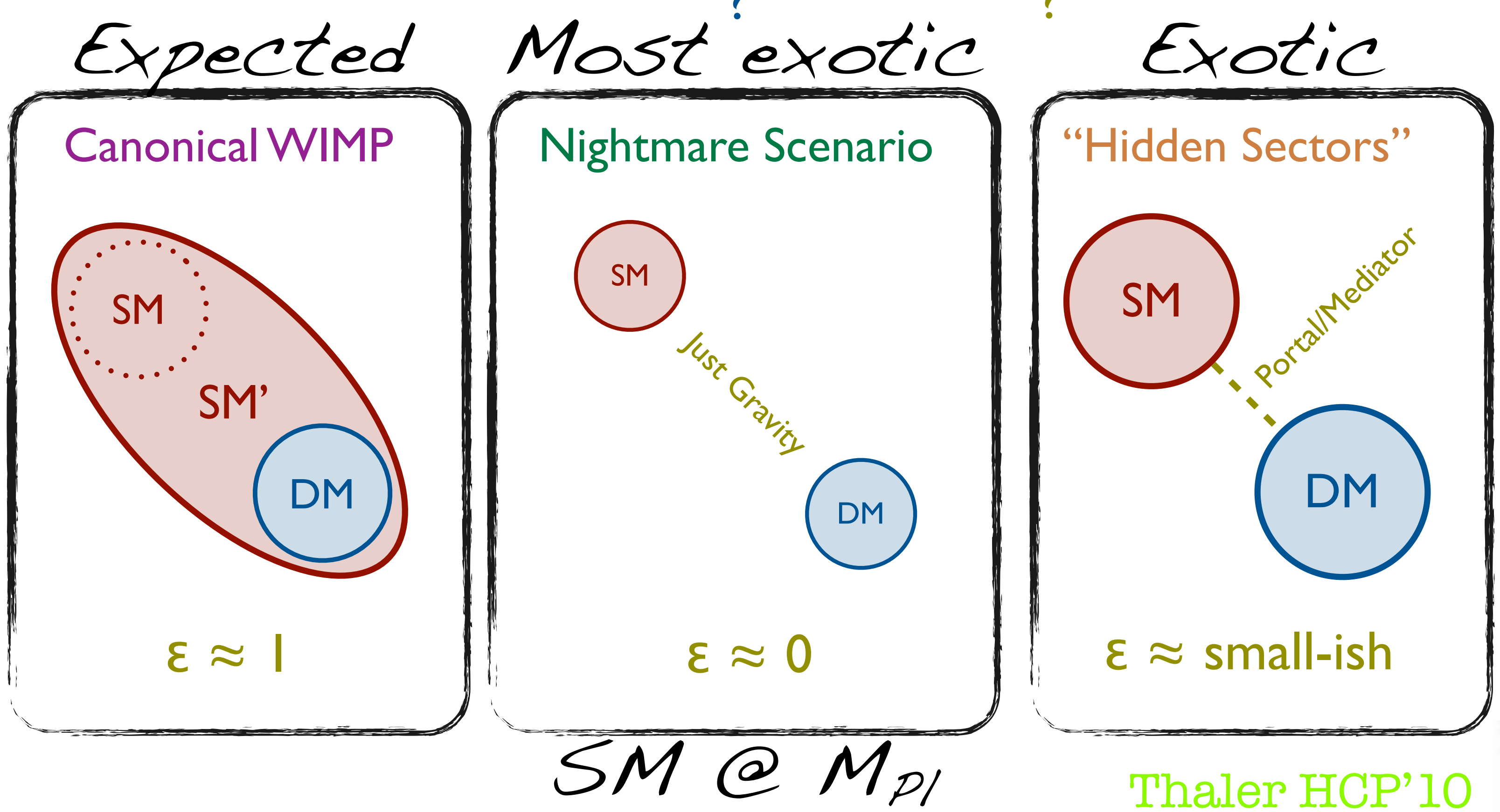
But these implications are based on the assumptions
(1) that the 126 GeV particle observed is *exactly* the SM Higgs
(2) that the Dark Matter sector is decoupled from the weak sector

From the EW scale to M_{Pl}... and return

Many of my theory colleagues started wild speculations/extrapolations

SM/DM Couplings

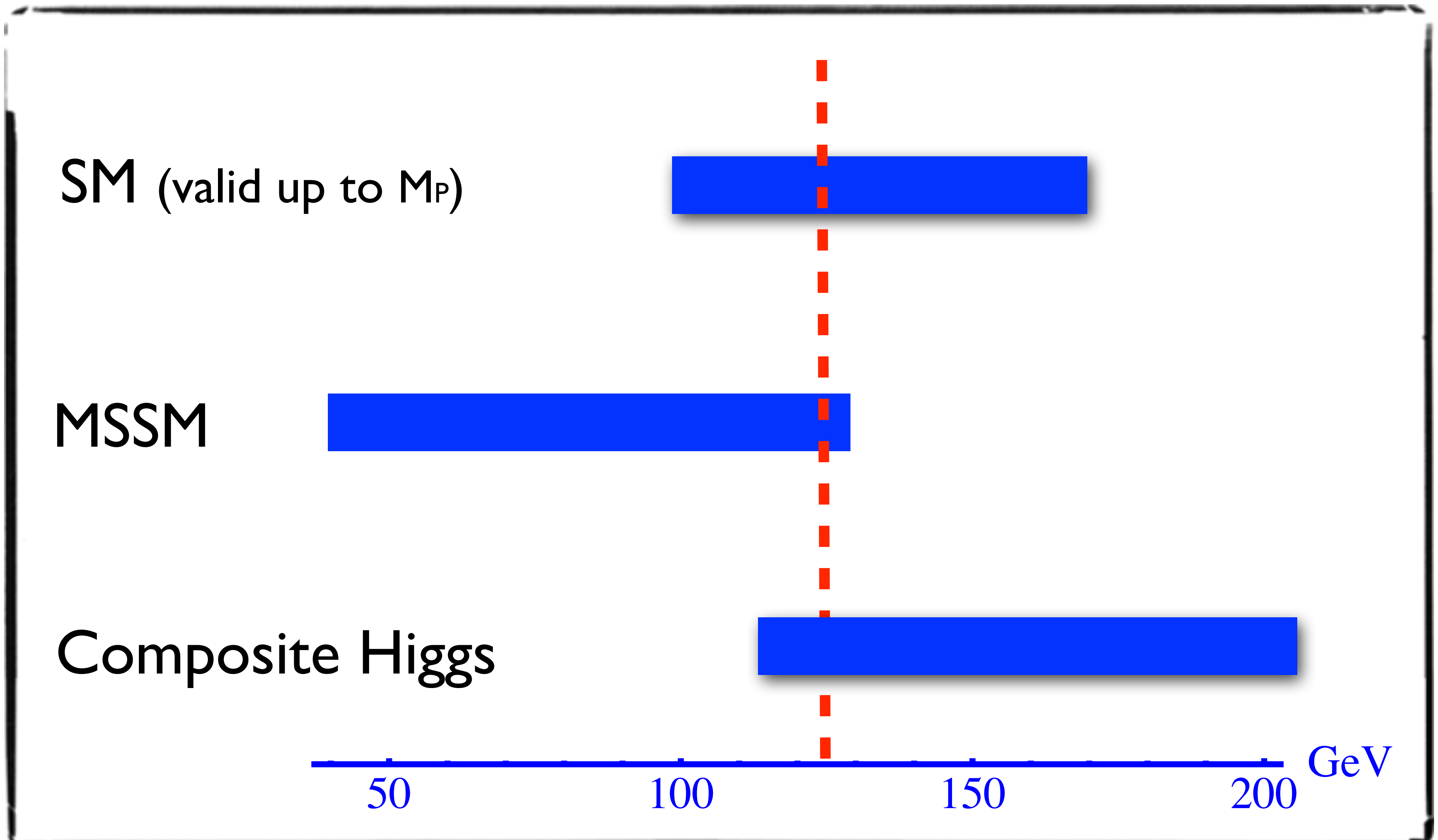
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \underbrace{\mathcal{L}_{\rm DM}}_{?} + \overbrace{\epsilon}^{?}\, \underbrace{\mathcal{O}_{\rm SM}\,\mathcal{O}_{\rm DM}}_{?}$$



Thaler HCP'10

125 GeV Higgs = Exotic BSM?

I want to argue that the value of the Higgs mass
together with the absence of any additional new physics so far
restrict any BSM model to exotic corners of its parameter space



Pomarol ICHEP'12

disclaimer

the notion of "exotic" has to be understood on a statistical basis, ie it depends on our culture (=what we are used to) and there will always be someone to claim that his/her model is the most natural one

Weakly coupled models

Higgs & SUSY/MSSM

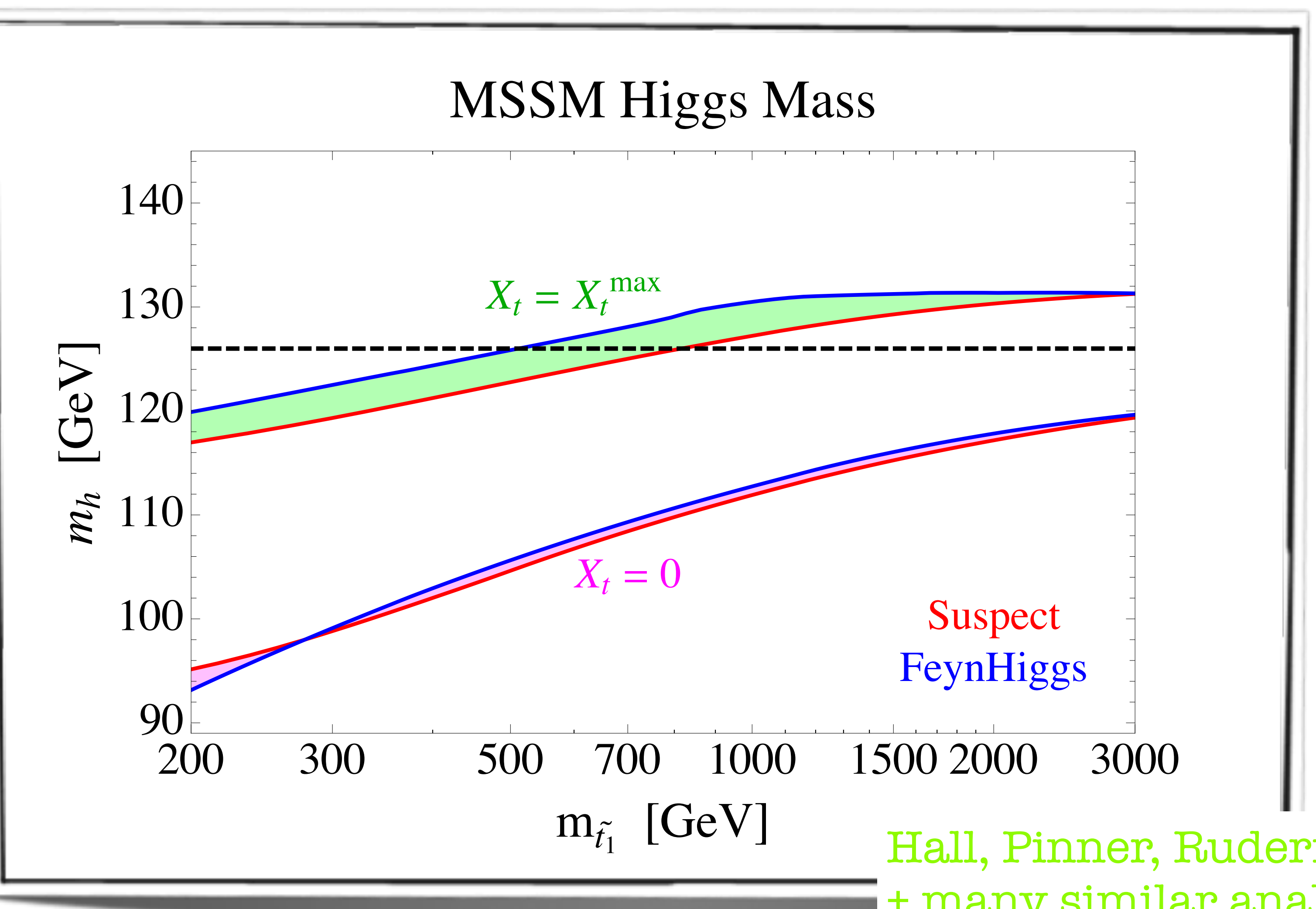
no new super-particles ⇢ decoupling limit?

high Higgs mass
implies
susy is badly broken

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

$(125\ \text{GeV})^2$ $\qquad\qquad$ $(\gtrsim 87\text{GeV})^2$

substantial loop contribution
from stops



Hall, Pinner, Ruderman '11
+ many similar analysse

large mixing
heavy stops

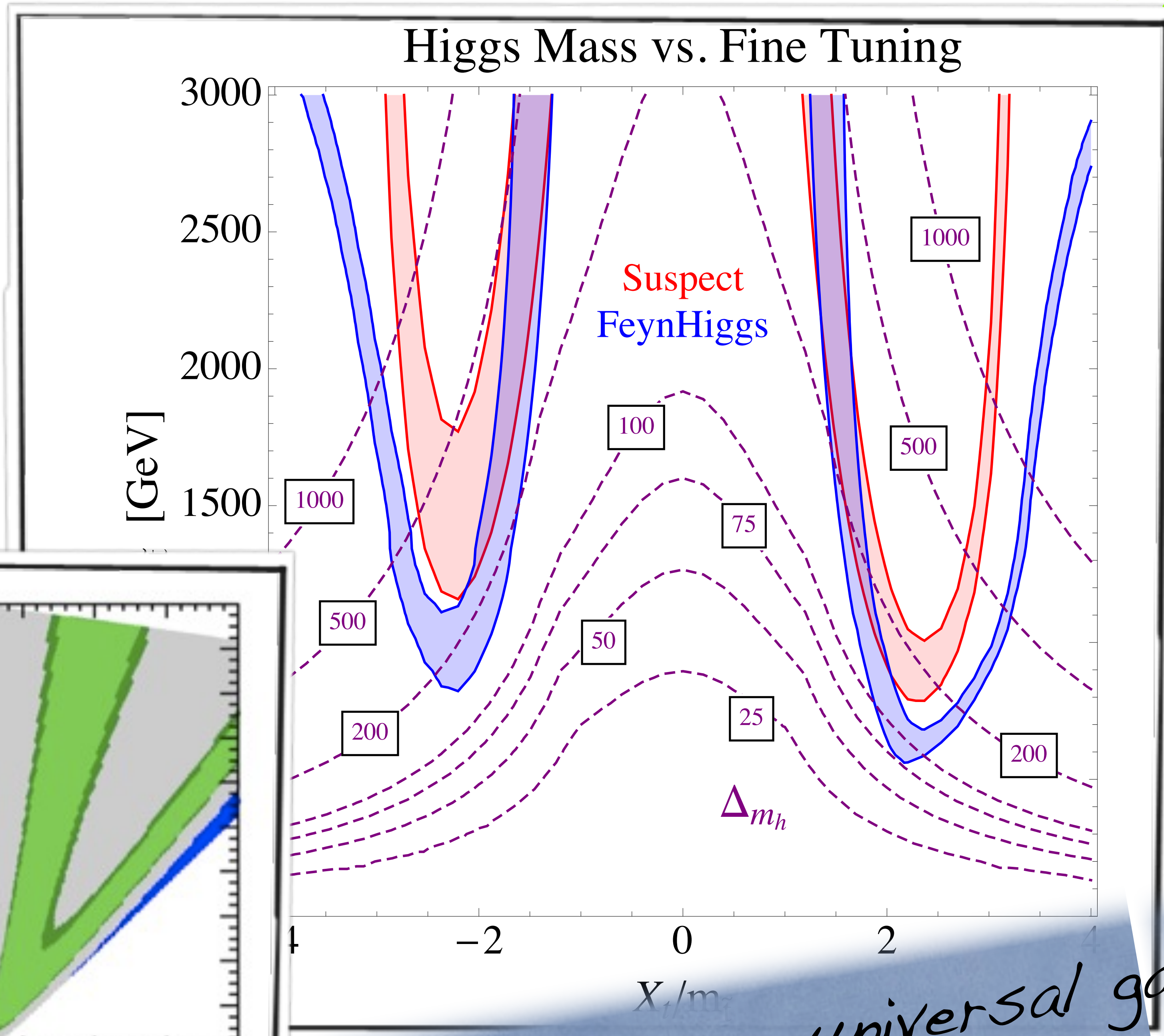
$$\sqrt{m_{Q_3} m_{u_3}} \gtrsim 700\ \text{GeV}$$

$\Downarrow \qquad \Downarrow$

irreducible
fine-tuning ~ O(1%)

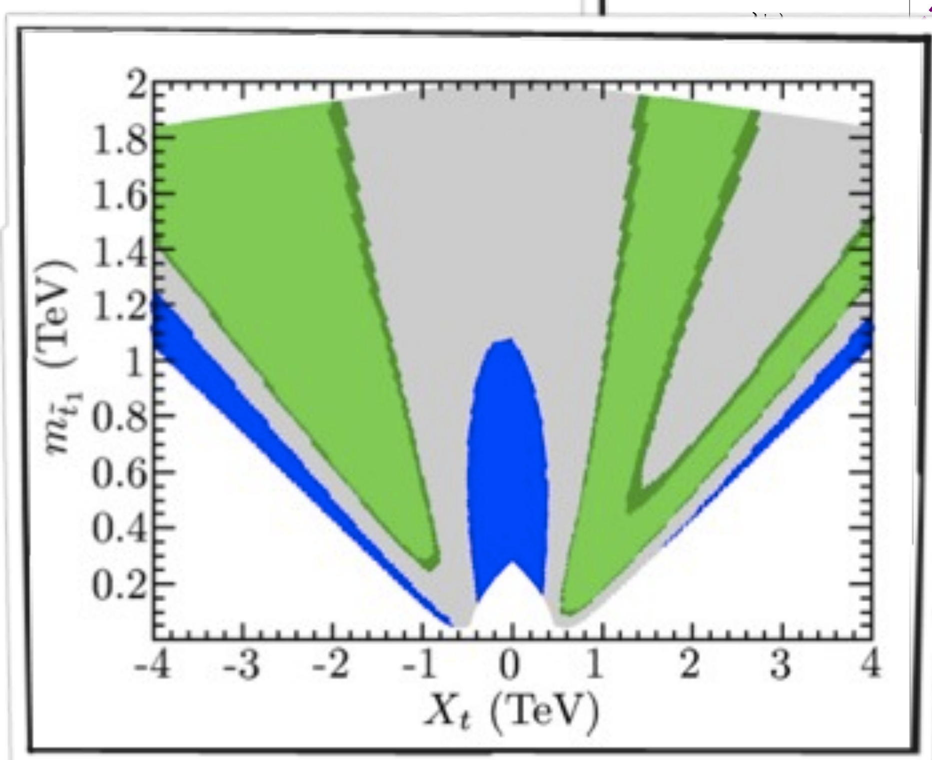
MSSM fine-tuning

Hall, Pinner, Ruderman '11



with larger TH uncertainties, the lower bound can go down:

S. Heinemeyer et al '11



call for non-universal gaugino masses?

maximal mixing requires tricky engineering

$$m_{\tilde{t}}^2(M_Z) \simeq 5.0 M_3^2(M_G) + 0.6 m_{\tilde{t}}^2(M_G)$$

$$A_t(M_Z) \simeq -2.3 M_3(M_G) + 0.2 A_t(M_G)$$

⋯→ generically $|A_t/m_{\tilde{t}}| \leq 1$

Dermisek, Kim '06

Saving SUSY

SUSY is Natural
but not plain vanilla

- ~~CMSSM~~
- pMSSM
- NMSSM
- Hide SUSY
  - reduce production (eg. split families)
  - reduce MET (e.g. ~~R-parity~~, compressed spectrum)

Mahbubani et al

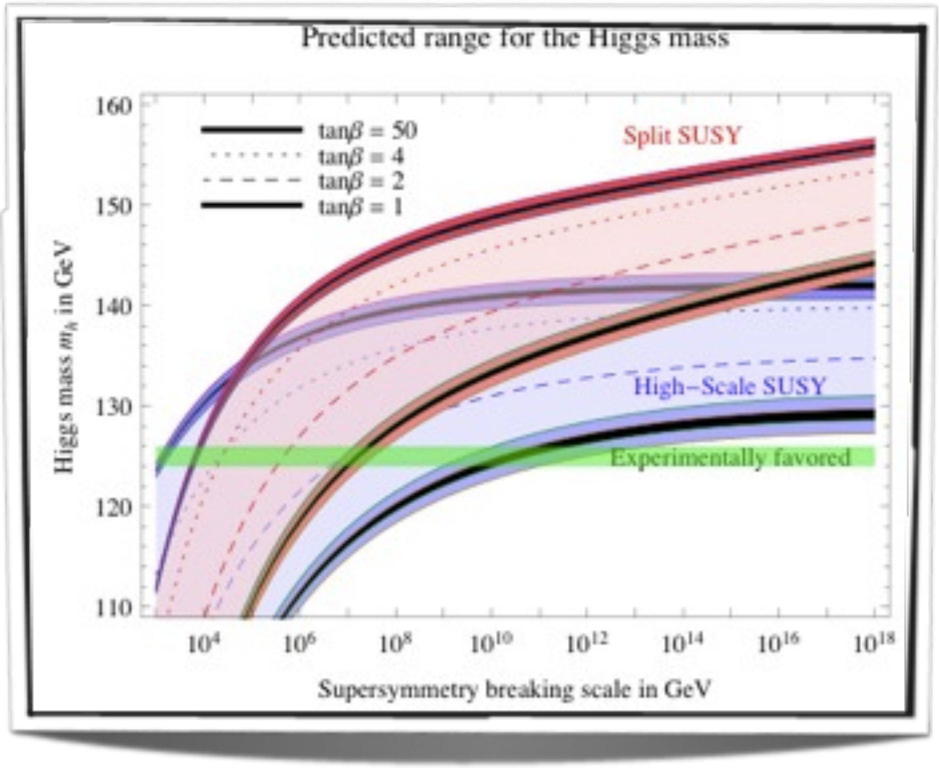
is the SM minimal?

why susy should be minimal?

unification etc...

string etc...

SUSY solves the big hierarchy
(or not even that)
but not the little hierarchy



- Split SUSY: Giudice, Strumia '11
  - susy scalars @ m_{susy}, susy fermions @ m_Z
- high scale SUSY:
  - susy scalars & susy fermions @ m_{susy}

Non Standard SUSY=Higgsinoless MSSM

The Higgs could actually be the first supersymmetric particle discovered!

$$\tilde{H} = \begin{pmatrix} h^0 \\ h^- \end{pmatrix} = (1,2)_{1/2}$$

$$L = \begin{pmatrix} \nu \\ e^- \end{pmatrix} = (1,2)_{1/2}$$

"the superpartner of the Higgs is a neutrino"

Fayet '76

Biggio, Pomarol, Riva '12

	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_R$
Q	$(3,2)_{\frac{1}{6}}$	$1+B$
U	$(\bar{3},1)_{-\frac{2}{3}}$	$1-B$
D	$(\bar{3},1)_{\frac{1}{3}}$	$1-B$
$L_{1,2}$	$(1,2)_{-\frac{1}{2}}$	$1-L$
$E_{1,2}$	$(1,1)_1$	$1+L$
$H \equiv L_3$	$(1,2)_{-\frac{1}{2}}$	0
E_3	$(1,1)_1$	2
W_a^α	$(8,1)_0 + (1,3)_0 + (1,1)_0$	1
Φ_a	$(8,1)_0 + (1,3)_0 + (1,1)_0$	0
$X \equiv \theta^2 F$	$(1,1)_0$	2

X: spurion superfield to give mass to up quarks

Φ_a adjoint chiral superfields to marry to gauginos and generate Dirac masses

- no second higgs doublet so no μ-problem
- lepton # = R-symmetry
  - ☑ B≠L, no proton decay
  - ☑ L≠1, LLE and QLD are not allowed in superpot.
  - ☑ L≠0, neutrino masses are protected and naturally of the order of the gravitino mass
- up quark masses generated by susy breaking

$\Downarrow \quad \Downarrow$

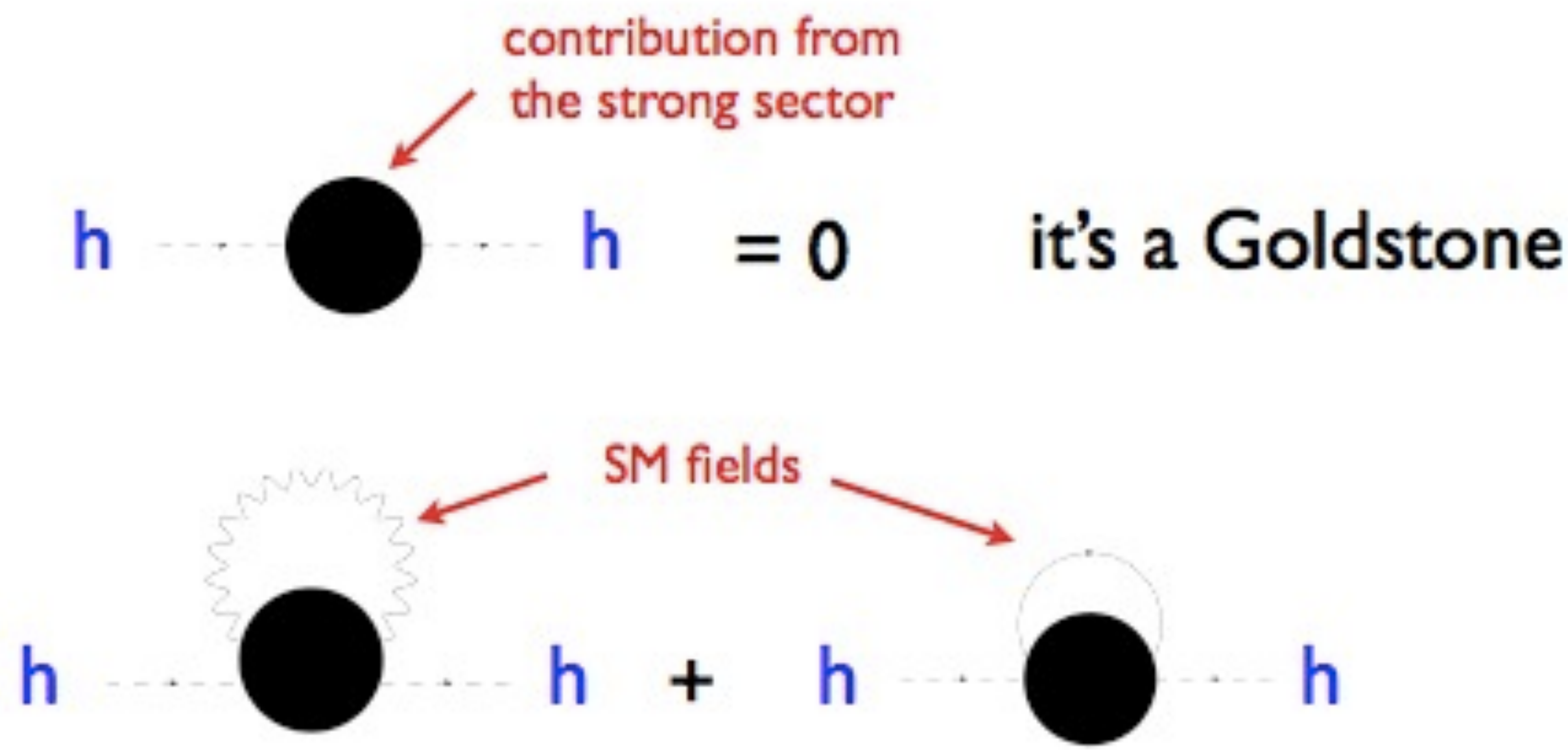
the model is not UV complete as is

so nice features of MSSM like unification have to be readdressed

Strongly coupled models

Light composite Higgs from "light" resonances

The interactions between the strong sector and the SM generate a potential for the Higgs



Impossible to compute the details of the potential from first principles
but using general properties on the asymptotic behavior of correlators
(saturation of Weinberg sum rules with the first few lightest resonances)
it is possible to estimate the Higgs mass

Pomarol, Riva '12   Marzocca, Serone, Shu '12

$$m_h^2 \approx \frac{3}{\pi^2}\frac{m_t^2 m_Q^2}{f_{G/H}^2}$$

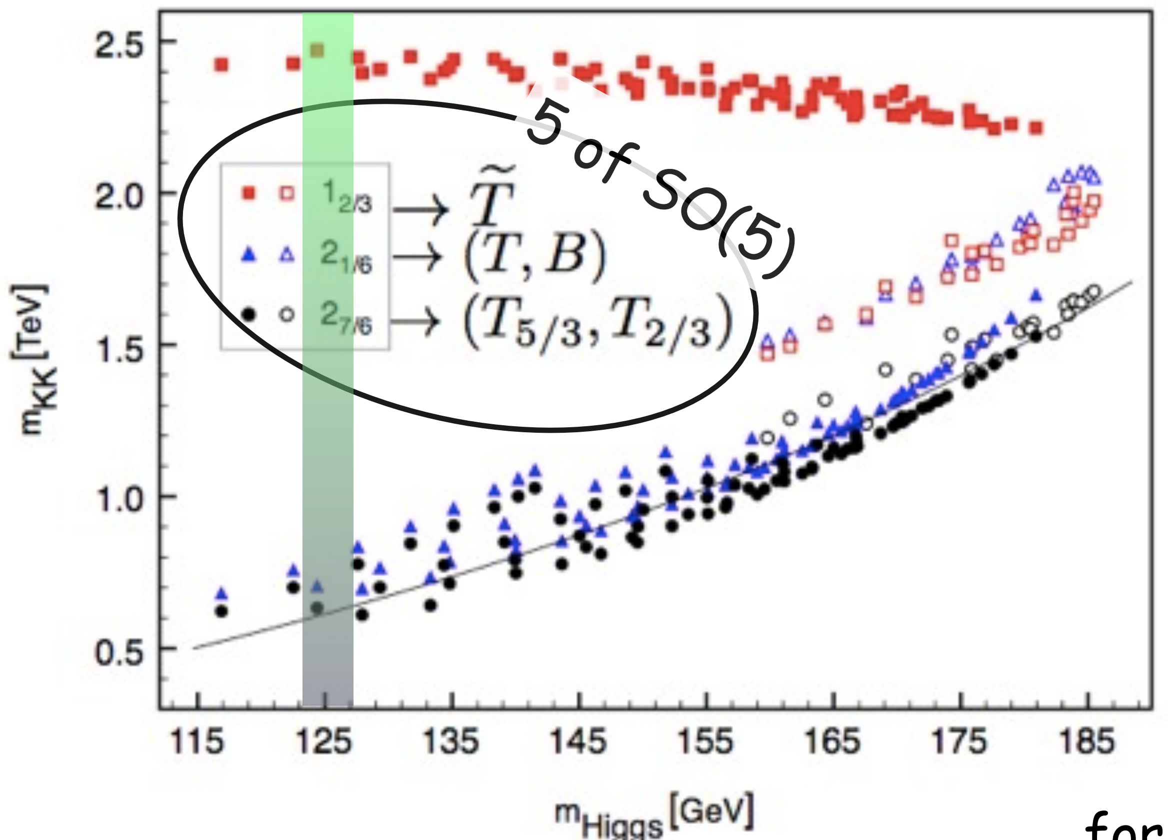
$$m_Q \lesssim 700\ \mathrm{GeV}\left(\frac{m_h}{125\ \mathrm{GeV}}\right)\left(\frac{160\ \mathrm{GeV}}{m_t}\right)\left(\frac{f}{500\ \mathrm{GeV}}\right)$$

fermionic resonances below ~ 1 TeV
vector resonances ~ few TeV (EW precision constraints)
~ for a natural (<20% fine-tuning) set-up ~

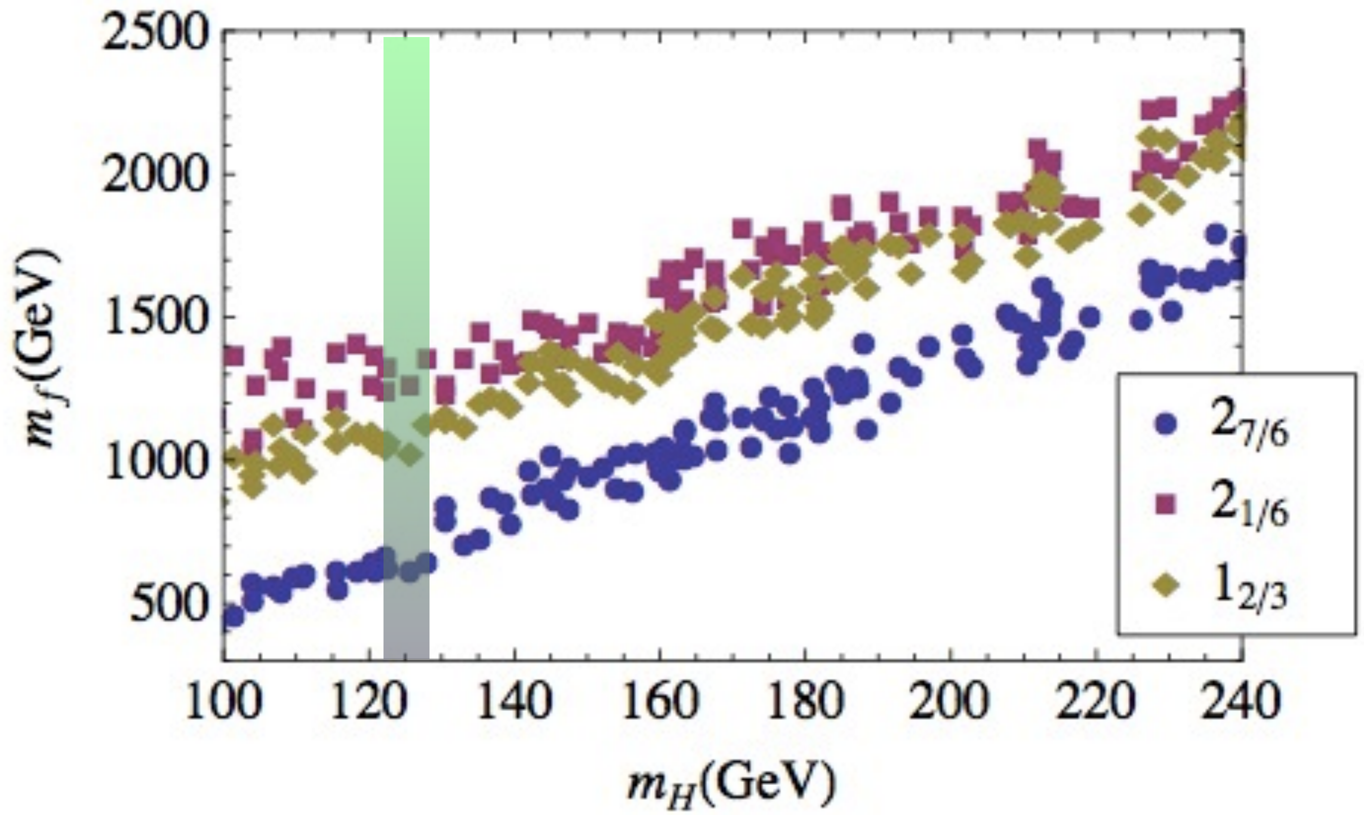
Light composite Higgs from "light" resonances

true spectrum in explicit realizations

Contino, Da Rold, Pomarol '06



De Curtis, Redi, Tesi '11



for similar results, see also

Matsedonskyi, Panico, Wulzer '12 & Marzocca, Serone, Shu '12

Nice AdS/CFT interpretation

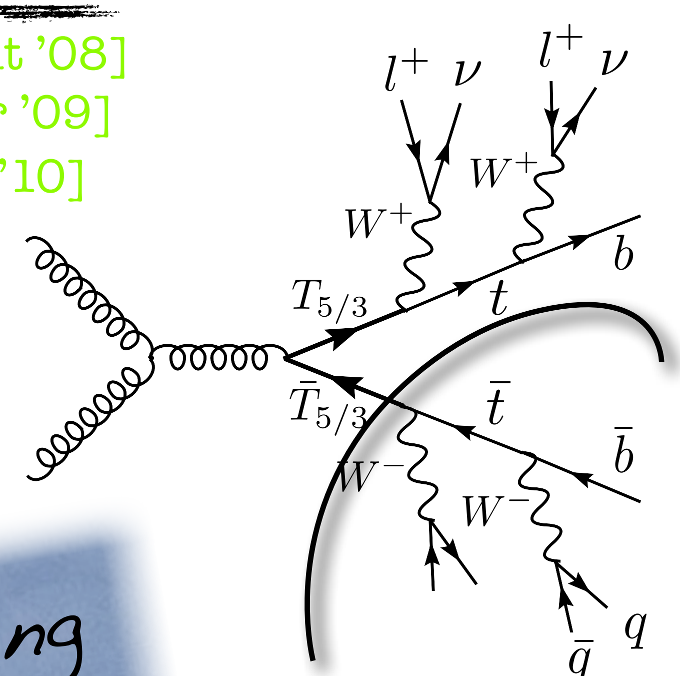
$$\mathrm{Dim}[\mathcal{O}_\Psi] = \frac{3}{2} + |M_\Psi + \frac{1}{2}|$$

$$M_\Psi = 1/2 \leftrightarrow \dim[\mathcal{O}_\Psi] = 3/2 \leftrightarrow \text{light free field decoupled from CFT}$$

Rich phenomenology of the top partners

Search in same-sign di-lepton events

[Contino, Servant '08]
[Mrazek, Wulzer '09]
[Dissertori et al '10]

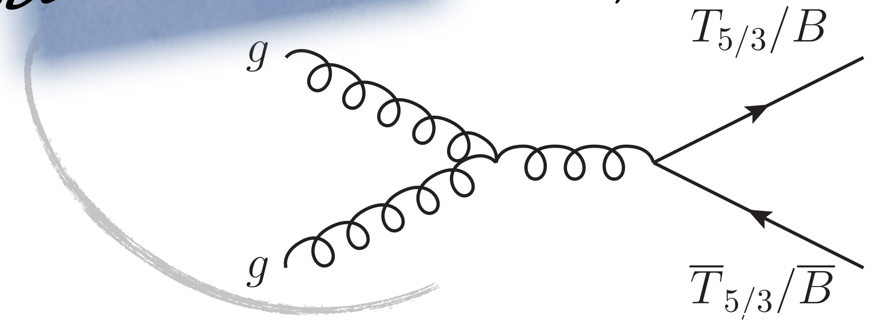


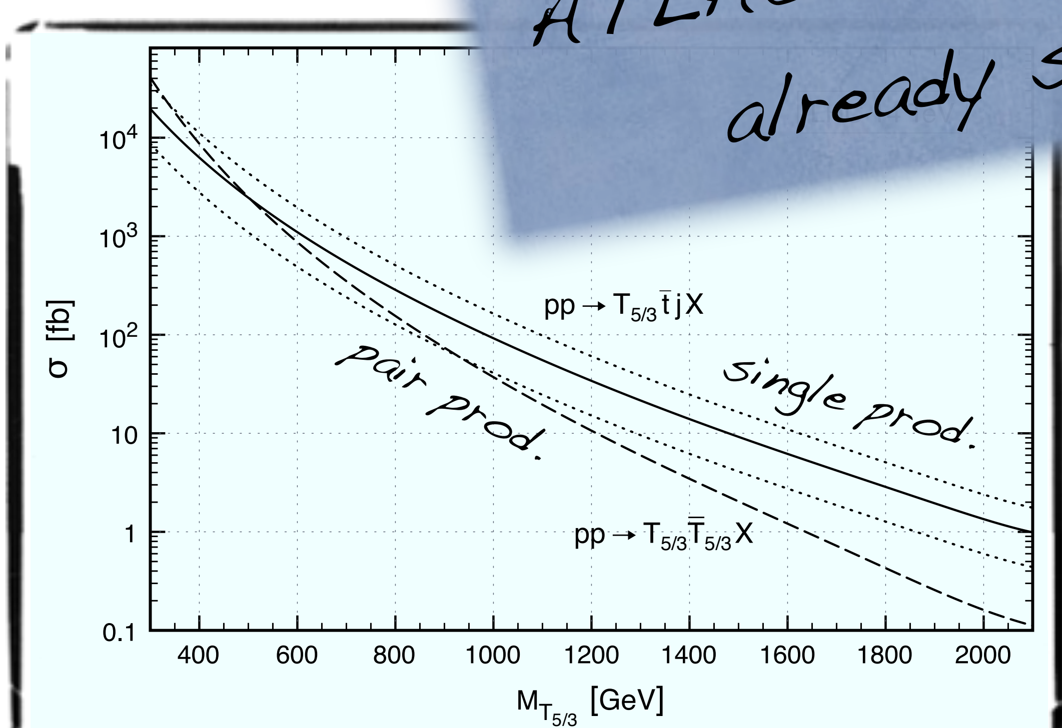
- $t\bar{t}$+jets is not a background [except for charge mis-ID and fake e$^-$]
- the resonant (tW) invariant mass can be reconstructed

discovery potential (LHC$_{14\text{TeV}}$)
$M_{5/3}$=500 GeV (σxBR≈100/fb) → 56 pb^{-1}
$M_{5/3}$=1 TeV (σxBR≈2/fb) → 15 fb^{-1}

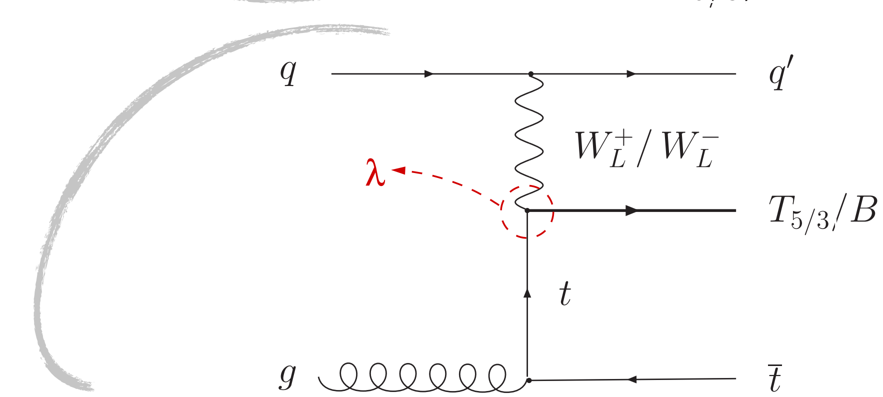
ATLAS & CMS searches ongoing
already stringent bounds

Pair production (model independent)





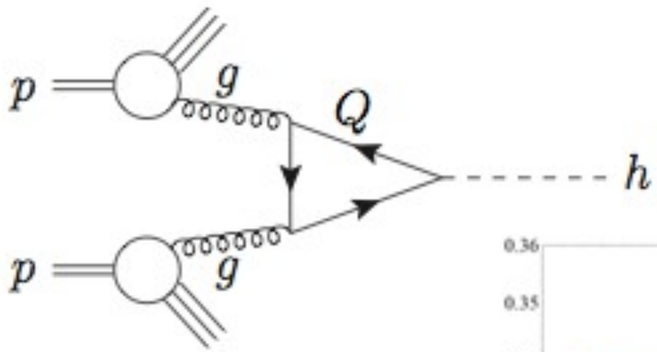
[Contino, Servant '08]



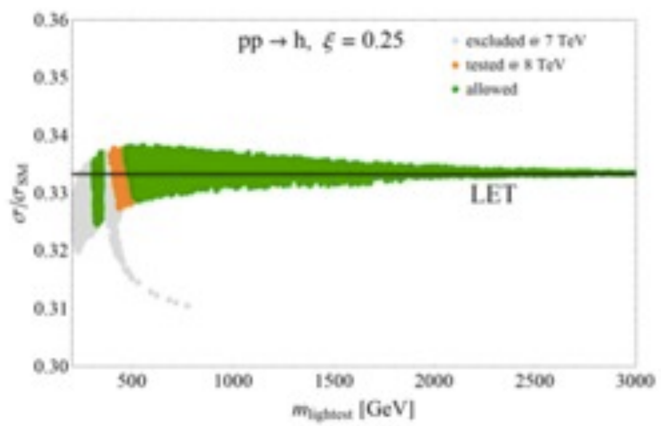
Single production (model dependent)

Top partners & Higgs physics

~ current single higgs processes are insensitive to top partners ~



$\sigma^{SM}_{14\mathrm{TeV}} \approx 50$ pb



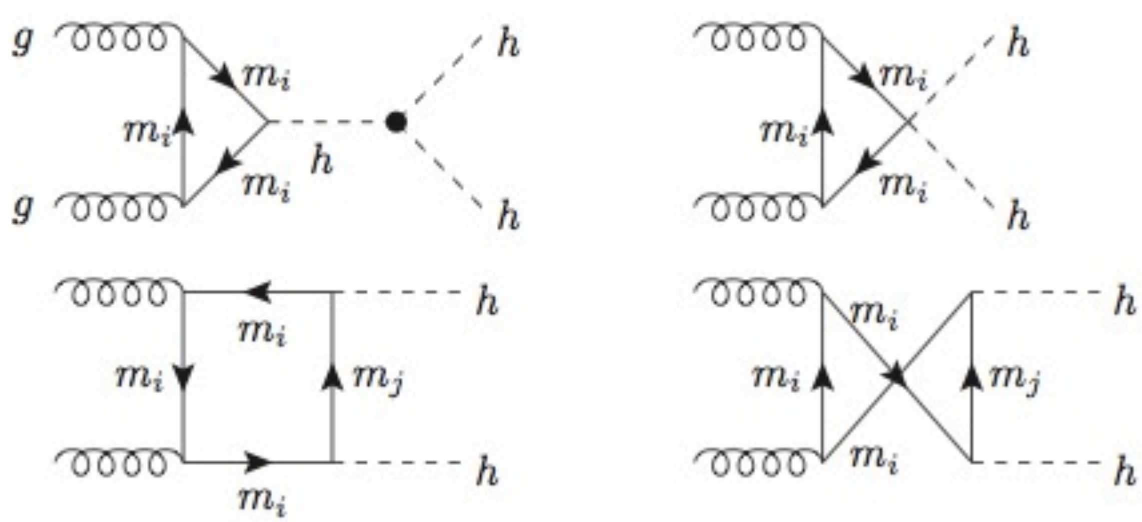
two competing effects that cancel:

- ☑ T's run in the loops
- ☑ T's modify top Yukawa coupling

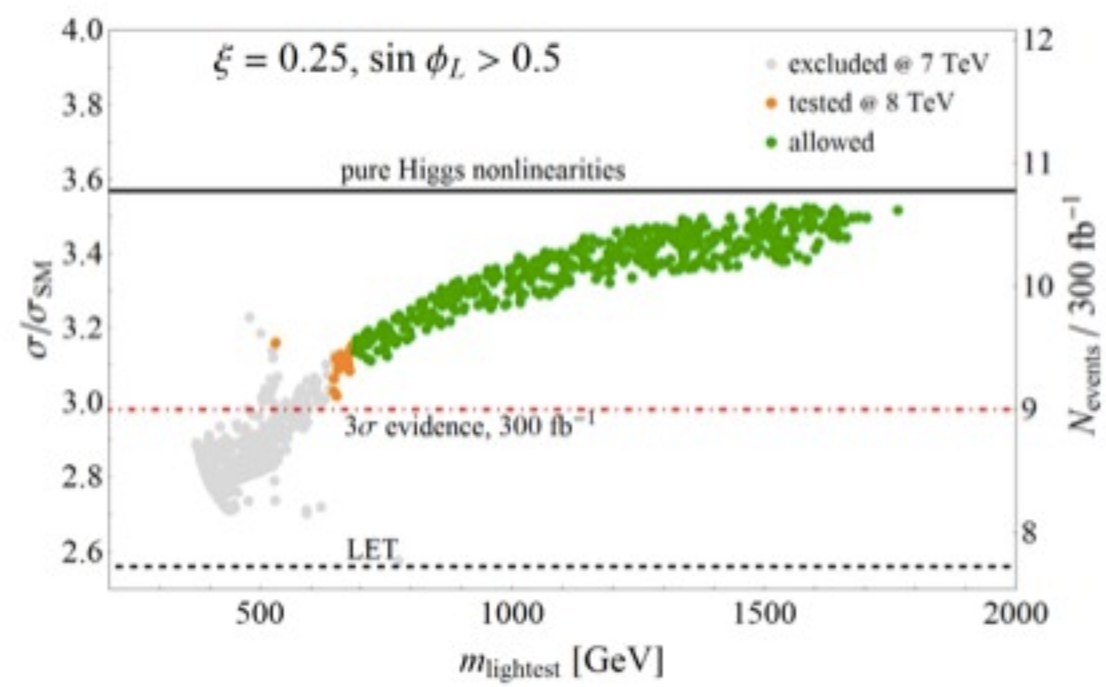
Falkowski '07
Azatov, Galloway '11
Delaunay, Grojean, Perez, '13

~ sensitivity in double Higgs production ~

Gillioz, Grober, Grojean, Muhlleitner, Salvioni '12



$\sigma^{SM}_{14\mathrm{TeV}} = 17.9$fb



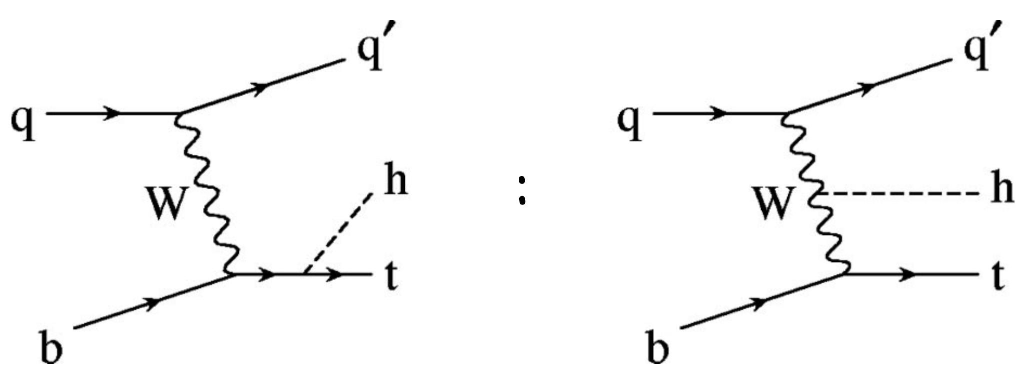
Top partners & Higgs physics

direct measurement of top-higgs coupling

htt is important but challenging channel

may be easier channel to look at

qb→q'th



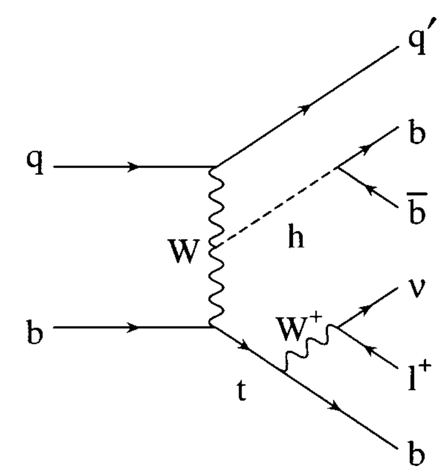
@m_H=125GeV $$\frac{|\mathcal{A}_W - \mathcal{A}_t|^2}{|\mathcal{A}_W + \mathcal{A}_t|^2} \approx 13$$

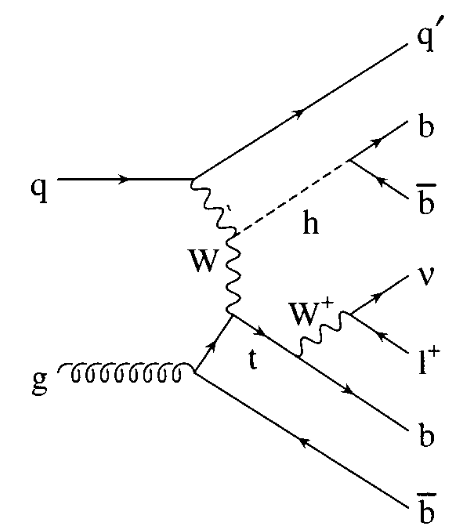
Farina, Grojean, Maltoni, Salvioni, Thamm '12

	$\sigma(pp \to tjh)$ [fb]		$\sigma(pp \to tjh\bar{b})$ [fb]	
	$c_F = 1$	$c_F = -1$	$c_F = 1$	$c_F = -1$
8 TeV	17.3	252.7	12.14	181.4
14 TeV	80.6	1042	59.6	828.5

look at final states:

$3\,b + 1\,\text{fwd jet} + l^{\pm} + \not{p}^T$. $4\,b + 1\,\text{fwd jet} + l^{\pm} + \not{p}^T$.

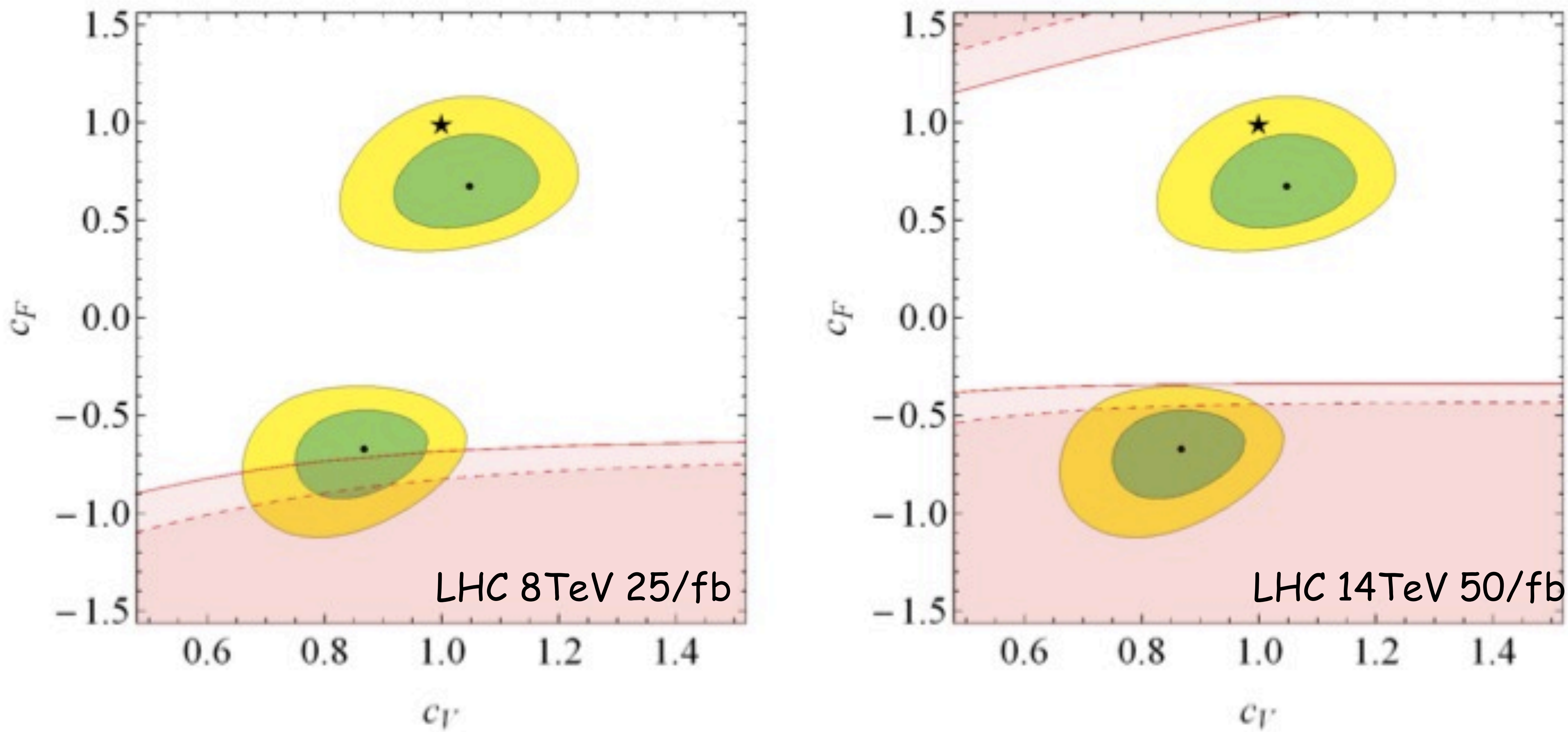




Top partners & Higgs physics

direct measurement of top-higgs coupling

single-top in association with Higgs



68% and 95% CL exclusion region vs current Higgs coupling fit

Farina, Grojean, Maltoni, Salvioni, Thamm '12

Conclusions: Higgs = Person of year?

as of 06/12/12

TIME
Person of the Year

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2012 2011 2010 2009 2008

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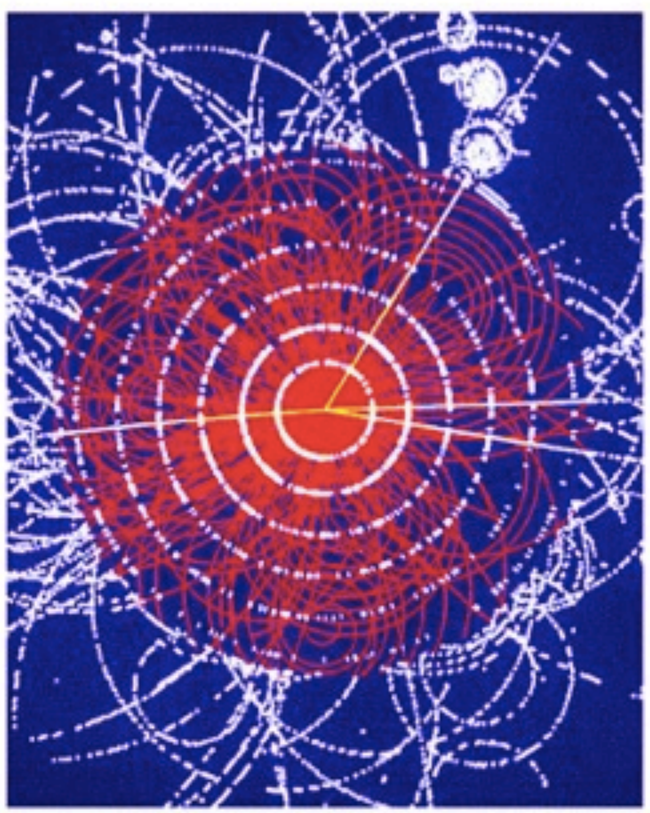
THE CANDIDATES

The Higgs Boson

18 of 40

By Jeffrey Kluger | Monday, Nov. 26, 2012



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Simulation of a Higgs-Boson decaying into four muons, CERN.

What do you think?

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Definitely No Way

VOTE

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Photos: Step inside the Large Hadron Collider.

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2011: The

2009: Ben

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[slide stolen from A. David talk@LHCHXSWG CERN '12]

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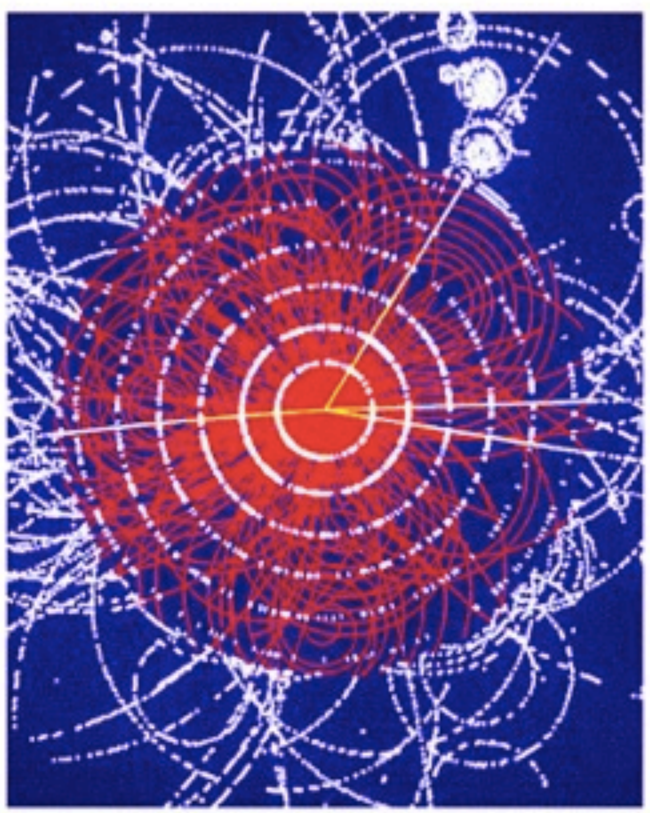

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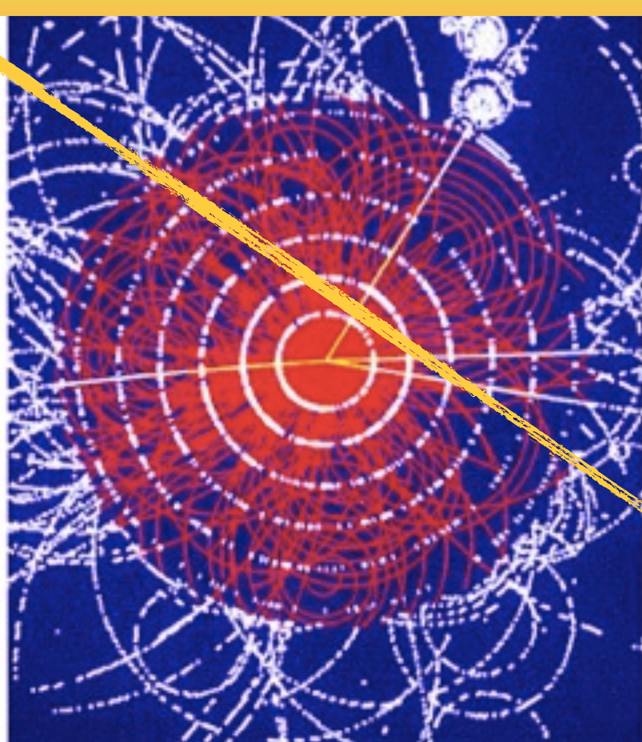

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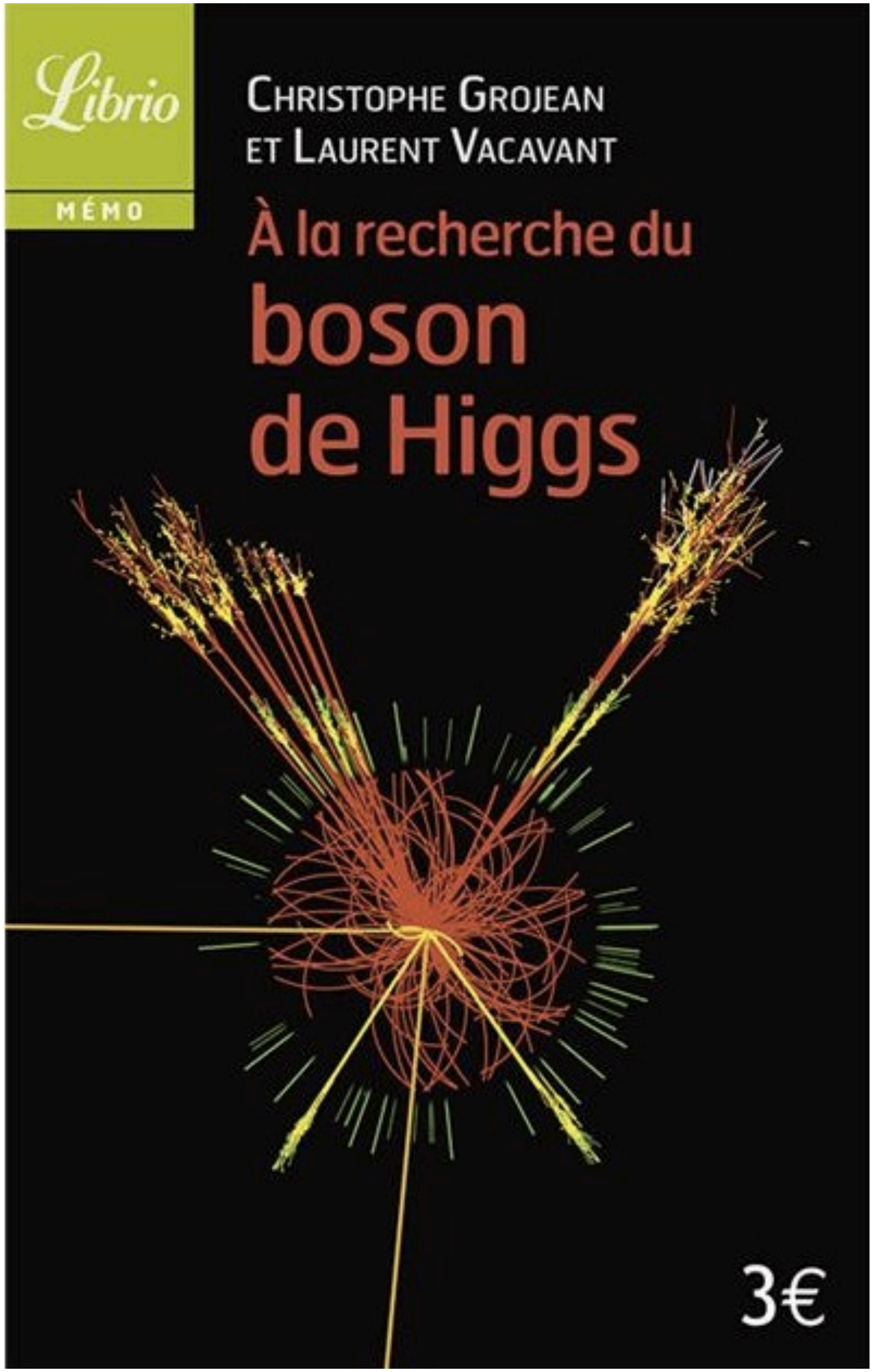
Self promotion



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