Florence, 21 September '12

A naive Higgs and no New Physics: Does Nature really care about Naturalness?

In honour of Roberto Casalbuoni
for his 70th Anniversary

Guido Altarelli
Roma Tre/CERN

Prologue

I first met Roberto in Florence in the '60's at the Gatto School.
As he appeared after us I considered him as much younger!

Later we have written a number of papers together
(also with Gatto)

Extended gauge models and precision electroweak data.
Guido Altarelli (CERN), R. Casalbuoni, S. De Curtis (Florence U. & INFN, Florence), N. Di Bartolomeo, Raoul Gatto (Geneva U.), F. Feruglio (Padua U. & INFN, Padua).
Published in Phys.Lett. B318 (1993) 139-147

Improved bounds on extended gauge models from new LEP data.
Guido Altarelli (CERN), R. Casalbuoni (Florence U. & INFN, Florence), S. De Curtis (INFN, Florence), N. Di Bartolomeo, F. Feruglio, Raoul Gatto (Geneva U.).
Published in Phys.Lett. B263 (1991) 459-465

Atomic parity violation in extended gauge models and latest CDF and LEP data.
Guido Altarelli (CERN), R. Casalbuoni (Florence U. & INFN, Florence), S. De Curtis (INFN, Florence), N. Di Bartolomeo, F. Feruglio, Raoul Gatto (Geneva U.).
Published in Phys.Lett. B261 (1991) 146-152

Bounds on extended gauge models from LEP data.
Guido Altarelli (CERN), R. Casalbuoni (Lecce U. & INFN, Lecce), F. Feruglio, Raoul Gatto (Geneva U.)..
Published in Phys.Lett. B245 (1990) 669-680

Testing For Heavier Vector Bosons In E+ E- At Z Peak: A Comparative Study Of Different Models.
Guido Altarelli (CERN), R. Casalbuoni (Lecce U. & INFN, Lecce & Geneva U.), D. Dominici (Camerino U. & INFN, Florence), F. Feruglio, Raoul Gatto (Geneva U.).
Published in Nucl.Phys. B342 (1990) 15-60

Z Width And Branching Ratios In Extended Gauge Models.
Guido Altarelli (CERN), R. Casalbuoni (Lecce U. & INFN, Lecce & Geneva U.), D. Dominici (Camerino U. & INFN, Florence), F. Feruglio, Raoul Gatto (Geneva U.).
Published in Mod.Phys.Lett. A5 (1990) 495

ounds on extended gauge models from LEP data: addendum.
Guido Altarelli (CERN), R. Casalbuoni (Lecce U. & INFN, Lecce), F. Feruglio, Raoul Gatto (Geneva U.).

A 40 years friendship

Now the physics

Before the LHC start many people were ready to bet that:

- strongly interacting new physics particles (gluinos, s-quarks...) would make the first discoveries
- the Higgs was considered more difficult, in particular if light
- the H ---> $\gamma\gamma$ mode was thought to be very difficult and that it would take a long time to get it

Now we know that no new particles were found so far,
that there is evidence for a light Higgs and
that the best signal is from $\gamma\gamma$

The main LHC results so far

- A particle compatible with a Higgs of mass $m_H \sim 126$ GeV has been observed (5.9σ ATLAS $\underbrace{+\ 5.0\sigma \text{ CMS} + \sim 3\sigma \text{ Tevatron}}_{\sim 8\,\sigma}$) decaying in $\gamma\gamma$, ZZ^*, WW^*, bb, $\tau\tau$

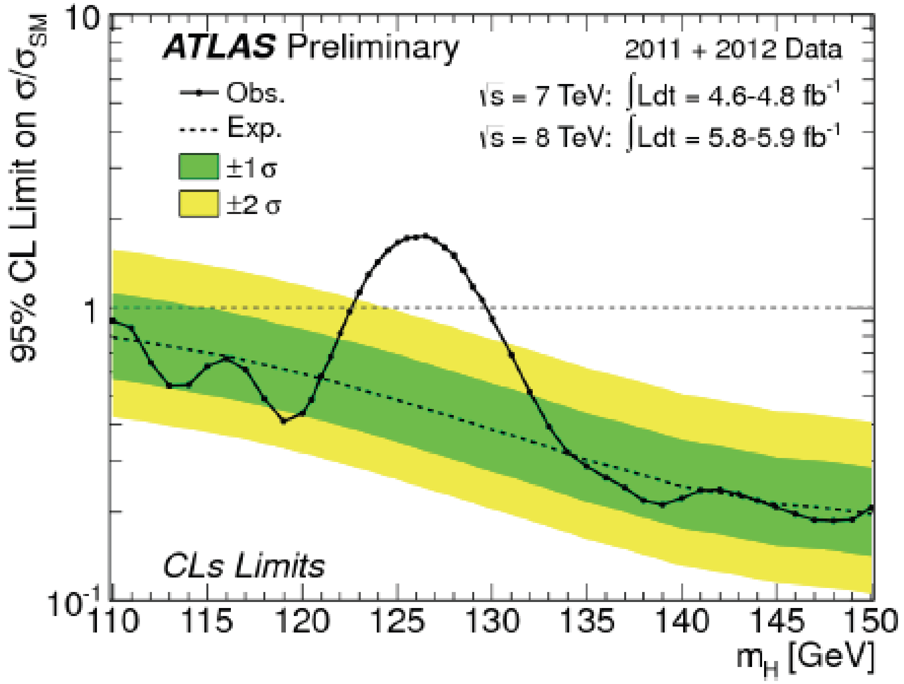
A really big step forward in particle physics!

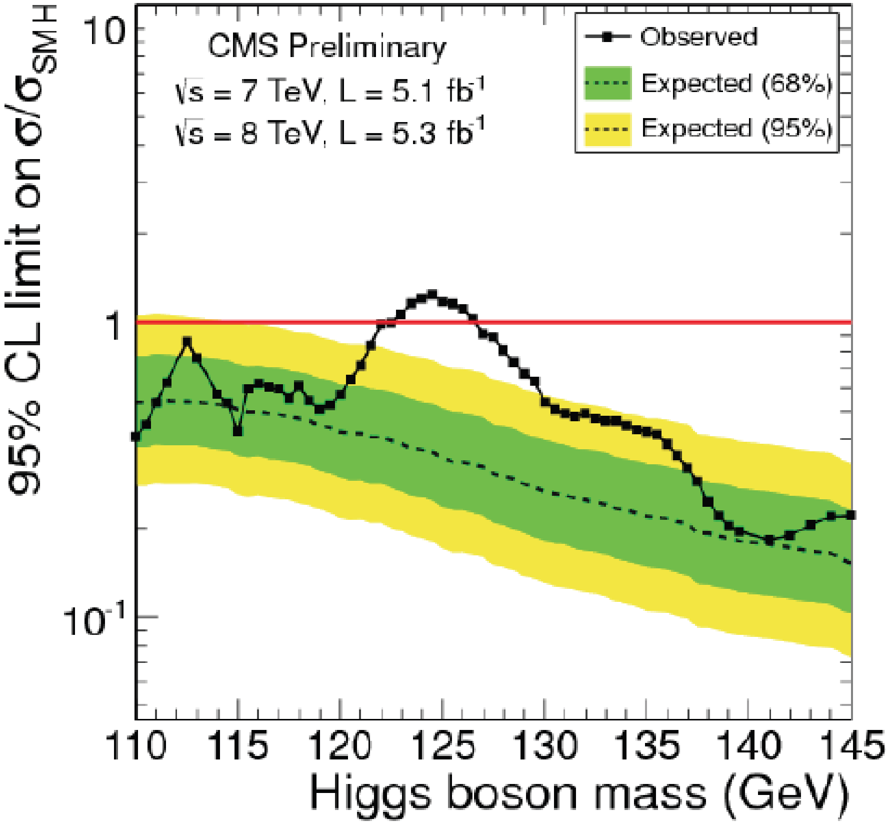
- No other Higgs candidate is present with $m_H < \sim 600$ GeV

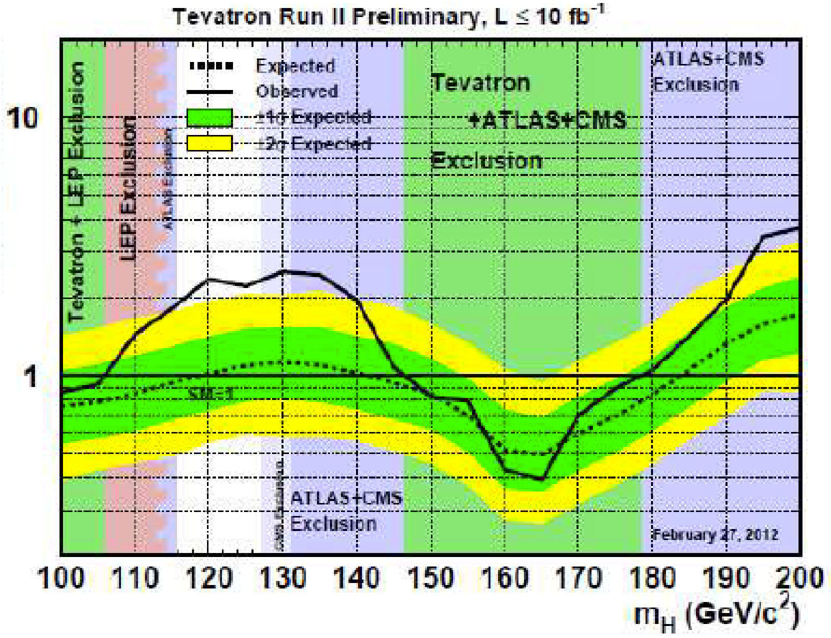
- No evidence of new physics, although a big chunk of new territory has been explored

- Important results on B and D decays from LHCb (also ATLAS&CMS) [e.g. $B_s \to J/\Psi\phi$, $B_s \to \mu\mu$, ... CP viol in D decay]

4th July ‘12







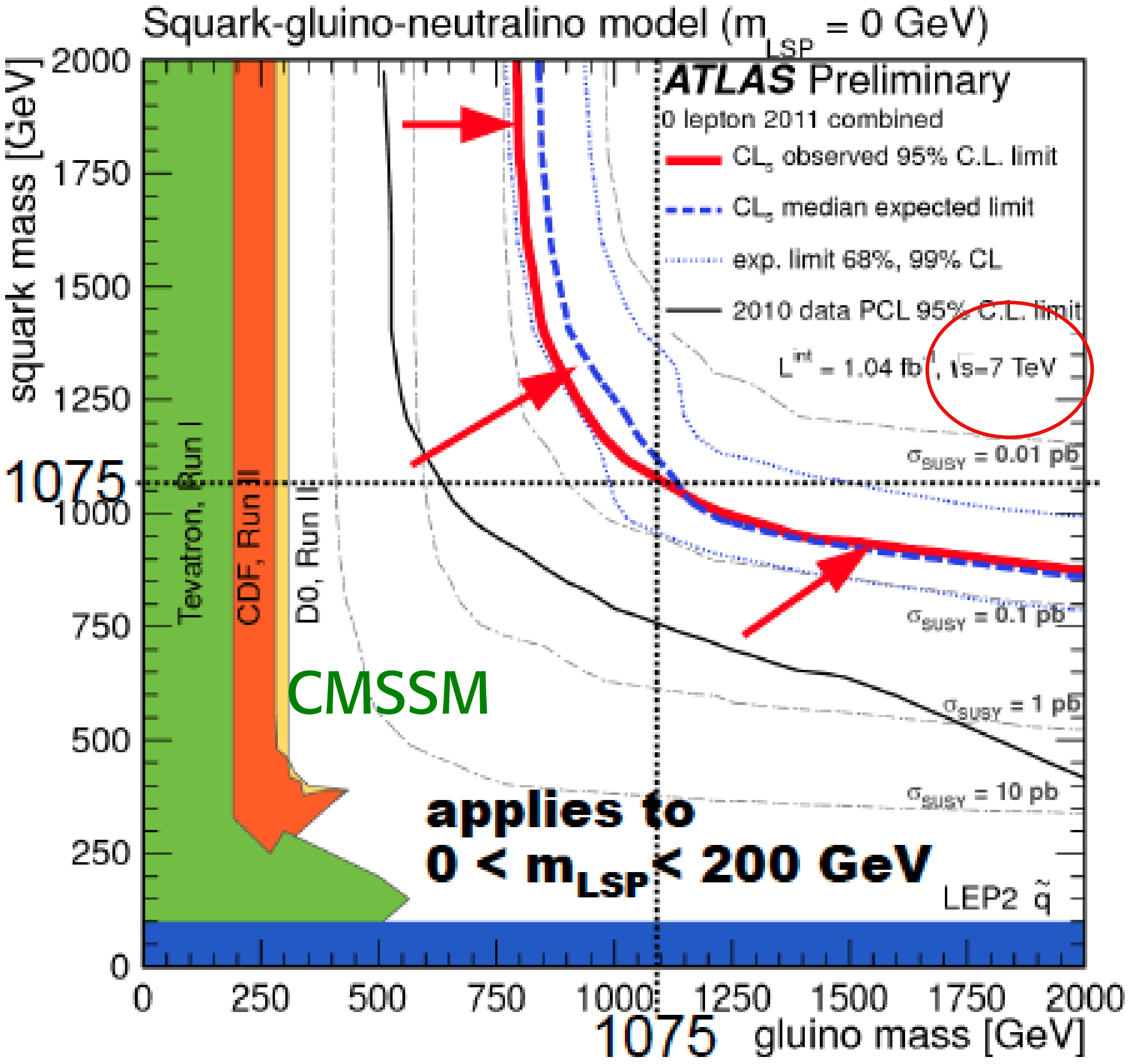
$m_H = 126$ GeV is
a great discovery.
By itself an adequate return
for the LHC investment

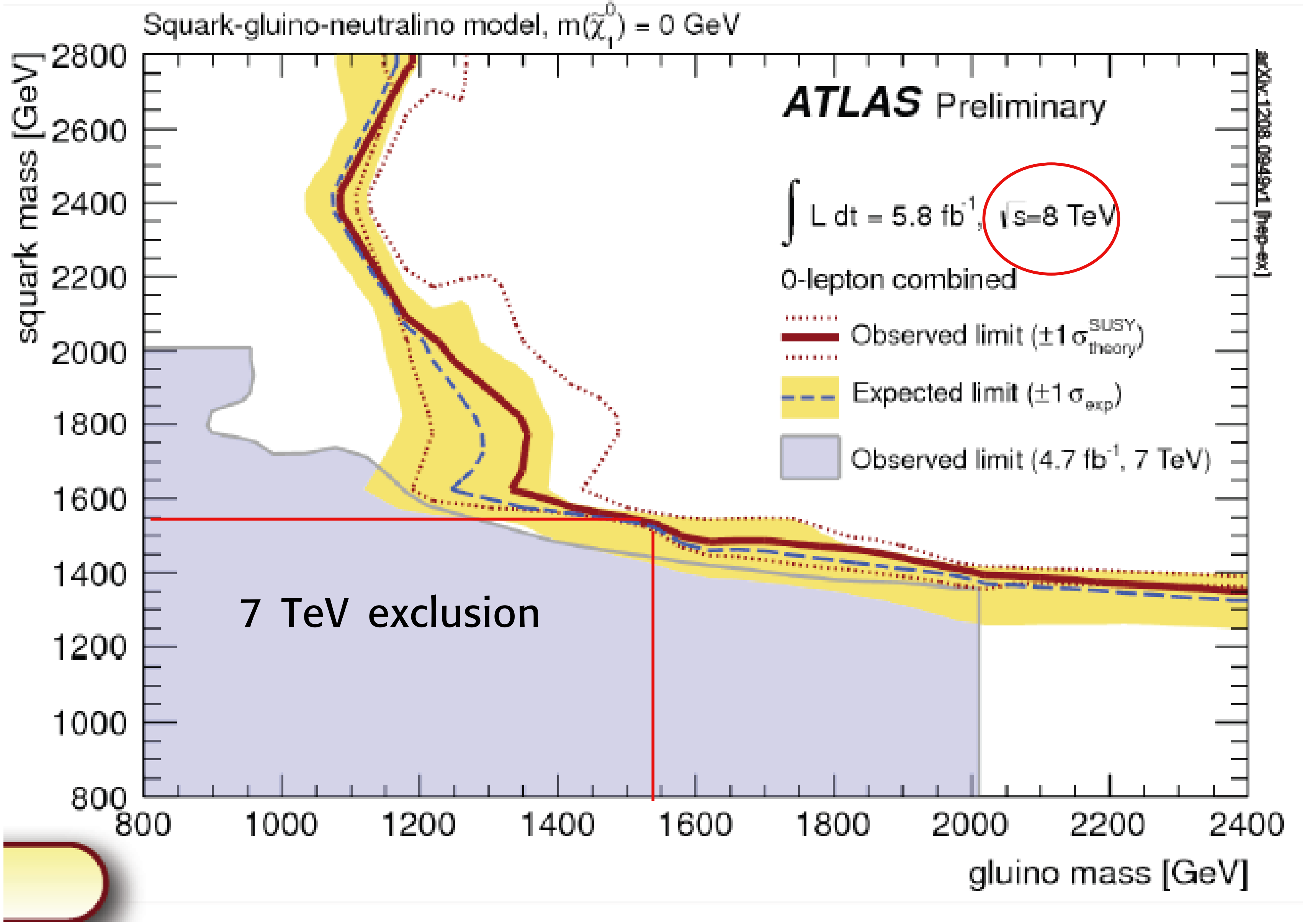
A large new territory has been explored and no new physics

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

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

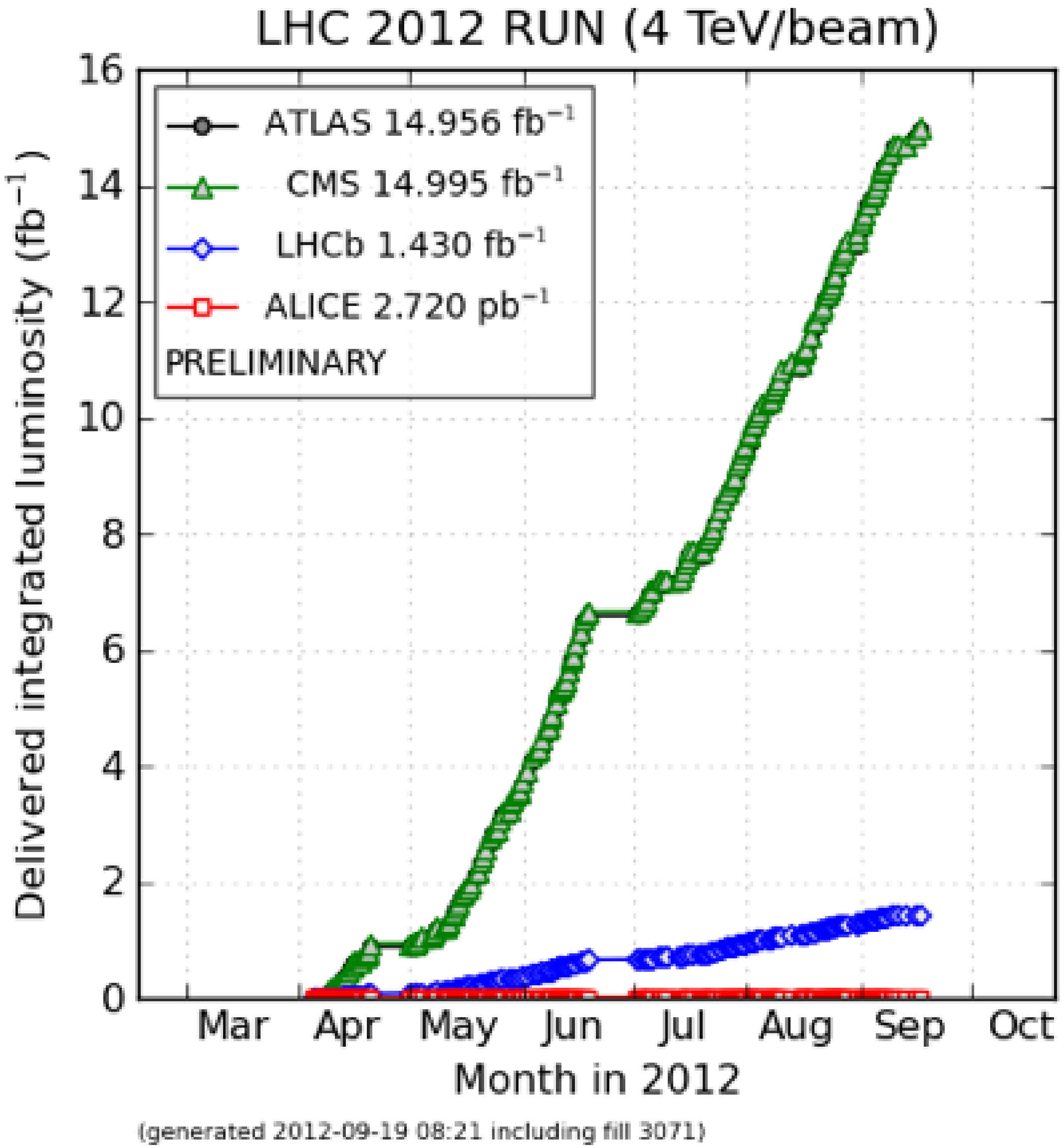
Jets + missing E_T




Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0) = 0$ GeV
ATLAS Preliminary
$\int L\,dt = 5.8\ \mathrm{fb}^{-1}$, $\sqrt{s}$=8 TeV
0-lepton combined
Observed limit ($\pm 1\sigma^{SUSY}_{theory}$)
Expected limit ($\pm 1\sigma_{exp}$)
Observed limit (4.7 fb^{-1}, 7 TeV)
arXiv:1208.0949v1 [hep-ex]
squark mass [GeV]
gluino mass [GeV]
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
800
1000
1200
1400
1600
1800
2000
2200
2400
7 TeV exclusion

~1470

The LHC run continues

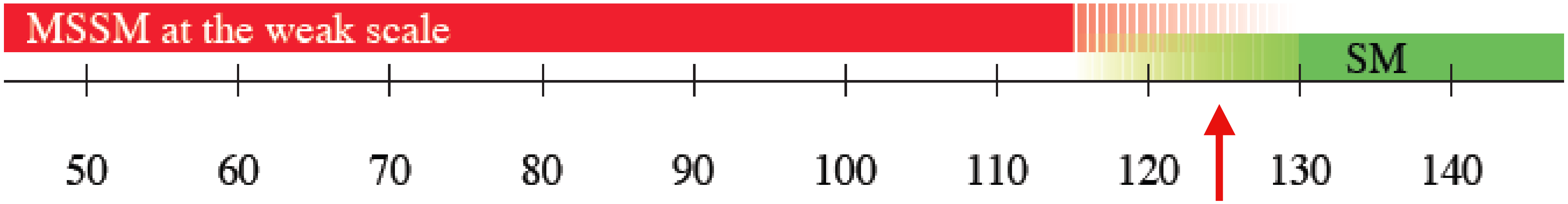


ATLAS&CMS
~ 15 fb^{-1} each

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

A malicious choice!

Strumia



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 Higgs boson?

Spin 0?
Couplings?

The next challenge!

Spin 0?

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)

Observation of H -> bb and of $\tau\tau$ then favours $s = 0$ (can go via s-wave decay)

So the spin is probably 0

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

Choi et al ’02
De Rujula et al ‘10

see e.g J. Ellis, Hwang’12

Information also via the HZ inv mass distributions

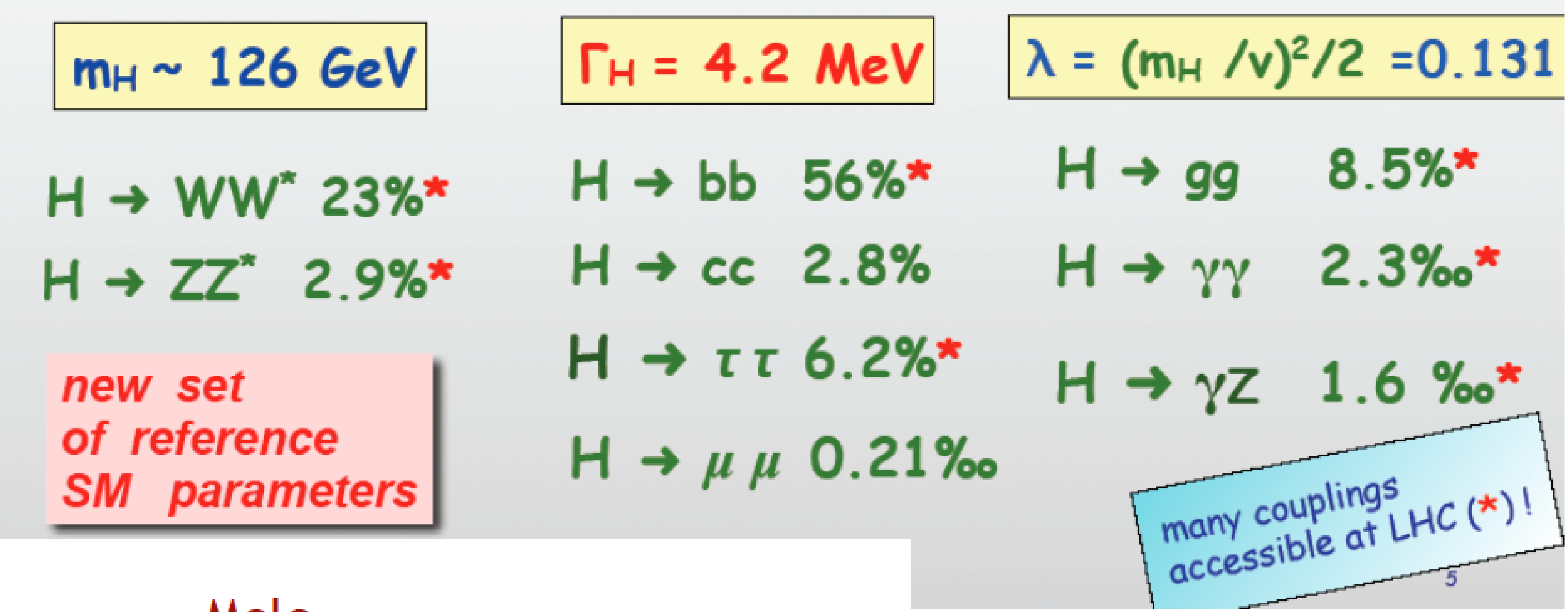
J. Ellis, Hwang, Sanz, You,’12

The Higgs: mass combination

ATLAS $m_H = 126.0 \pm 0.4\ (\mathrm{stat}) \pm 0.4\ (\mathrm{syst})$ GeV
CMS $m_H = 125.3 \pm 0.4\ (\mathrm{stat}) \pm 0.5\ (\mathrm{syst})$ GeV

$$\boxed{m_H = 125.7 \pm 0.4\ \mathrm{GeV}}$$

Main parameters



$m_H \sim 126$ GeV

H → WW^* 23%*
H → ZZ^* 2.9%*

new set of reference SM parameters

$\Gamma_H = 4.2$ MeV

H → bb 56%*
H → cc 2.8%
H → ττ 6.2%*
H → μμ 0.21‰

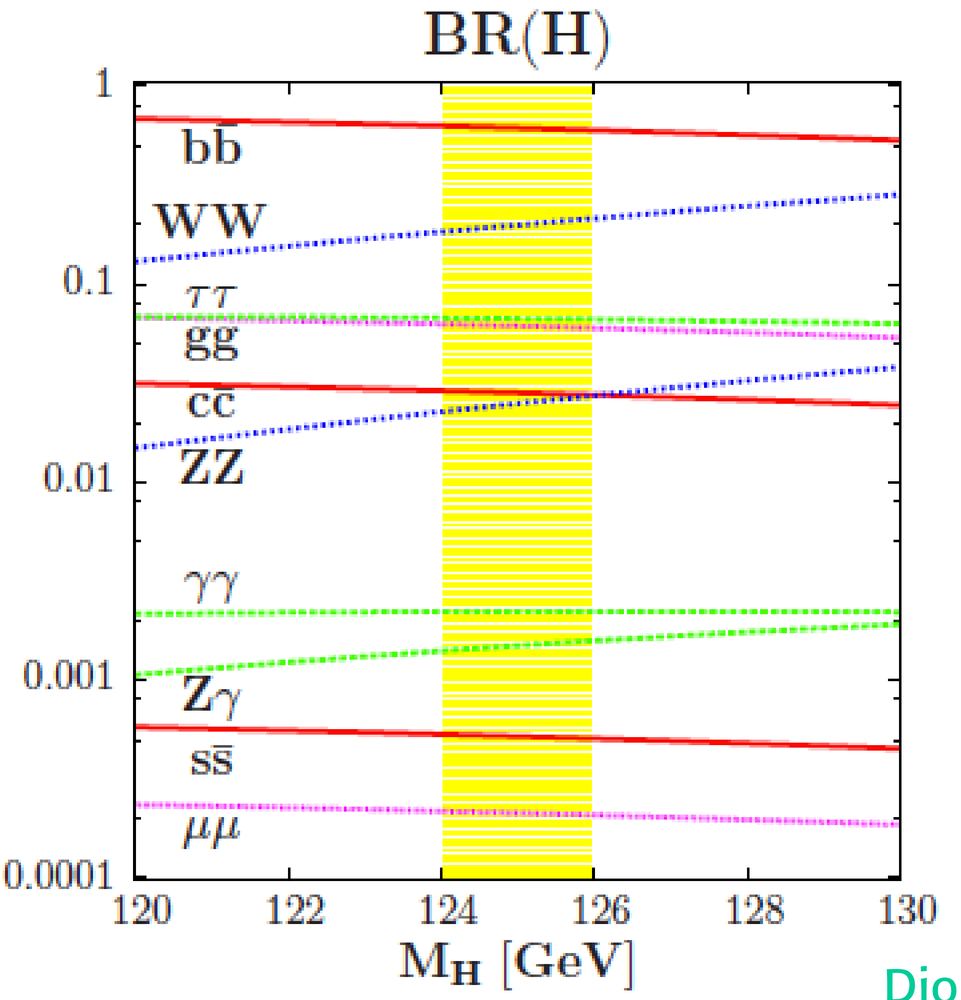
$\lambda = (m_H/v)^2/2 = 0.131$

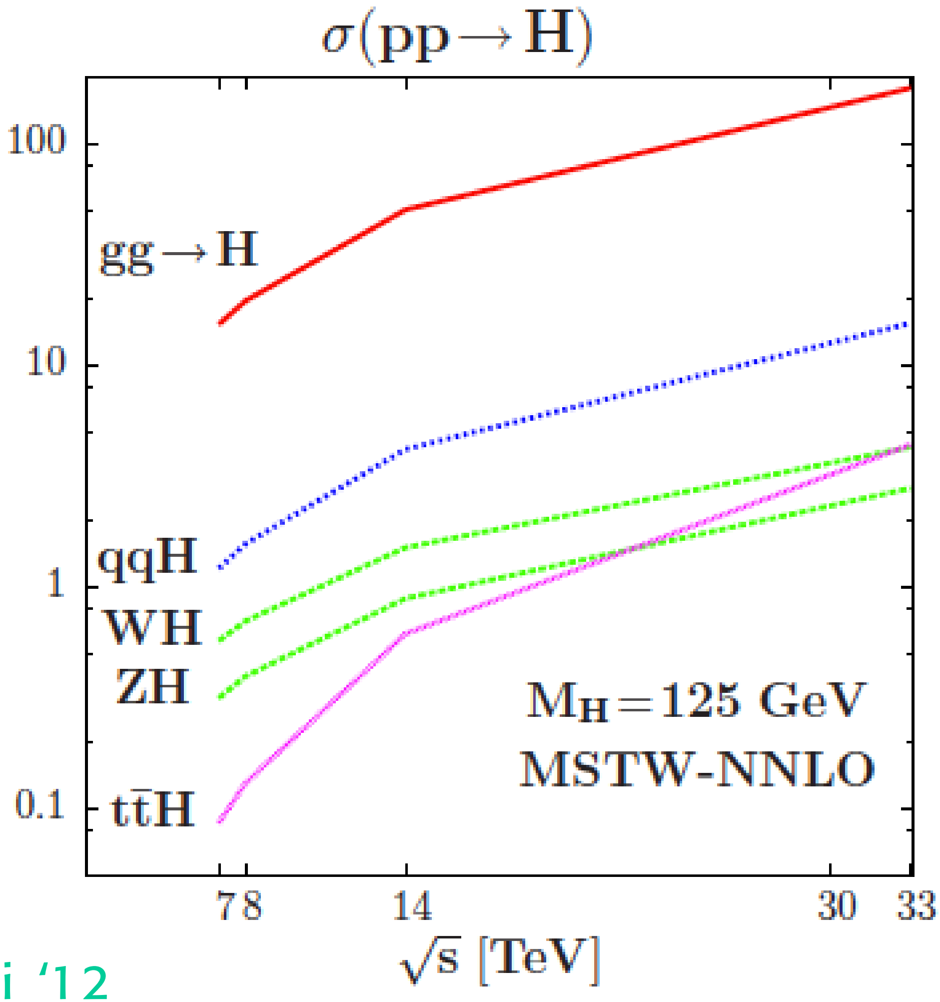
H → gg 8.5%*
H → γγ 2.3‰*
H → γZ 1.6 ‰*

many couplings accessible at LHC (*)!

Mele

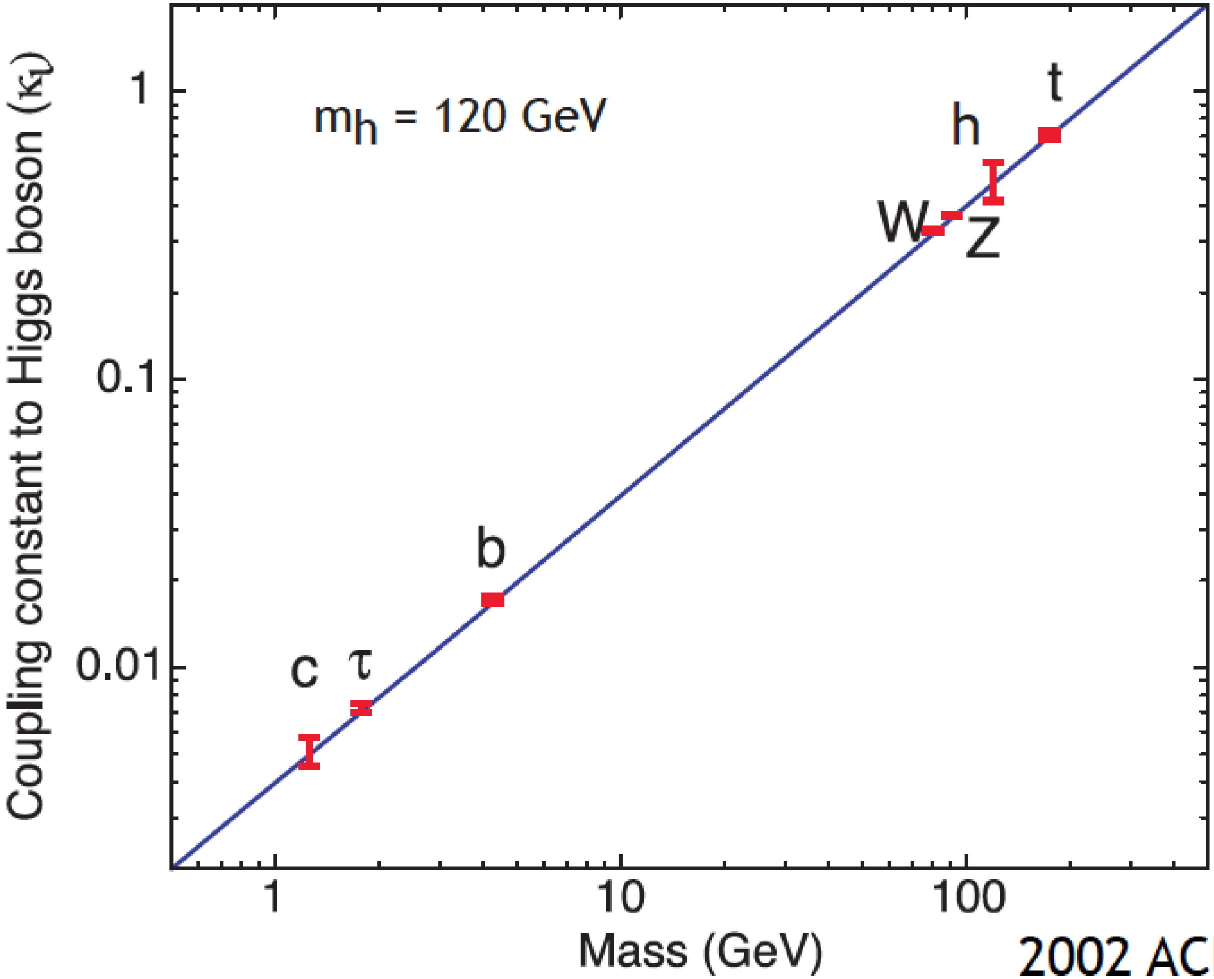
The SM Higgs: very striking hierarchies of couplings reflected in production crosssections and branching ratios





Djouadi '12

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



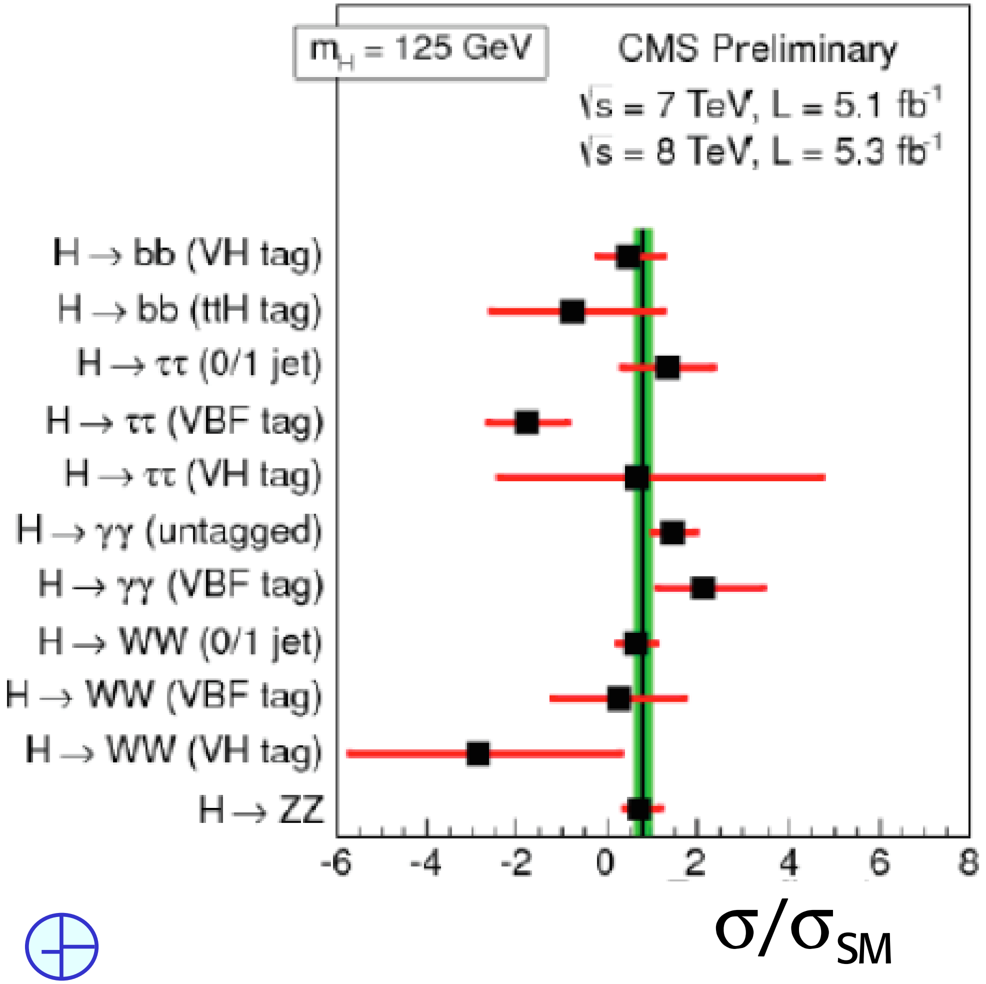
2002 ACFA LC study

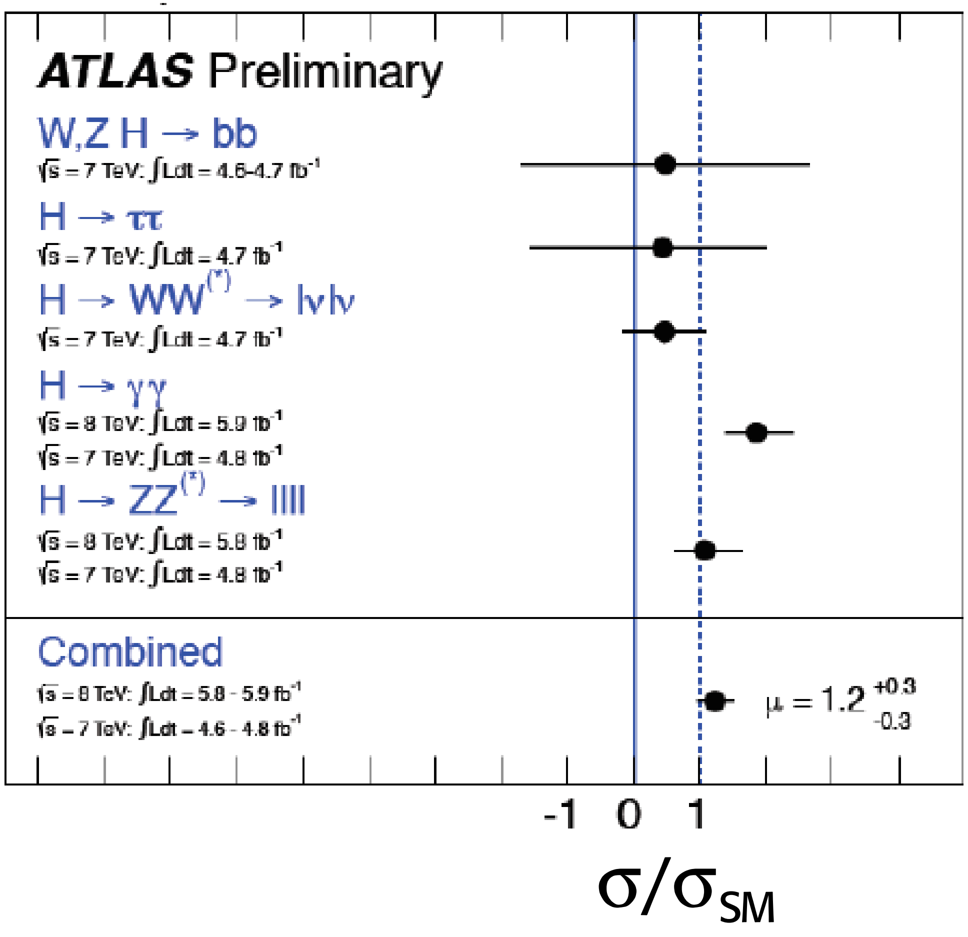
[this is also true for a dilaton, but up to a common factor]

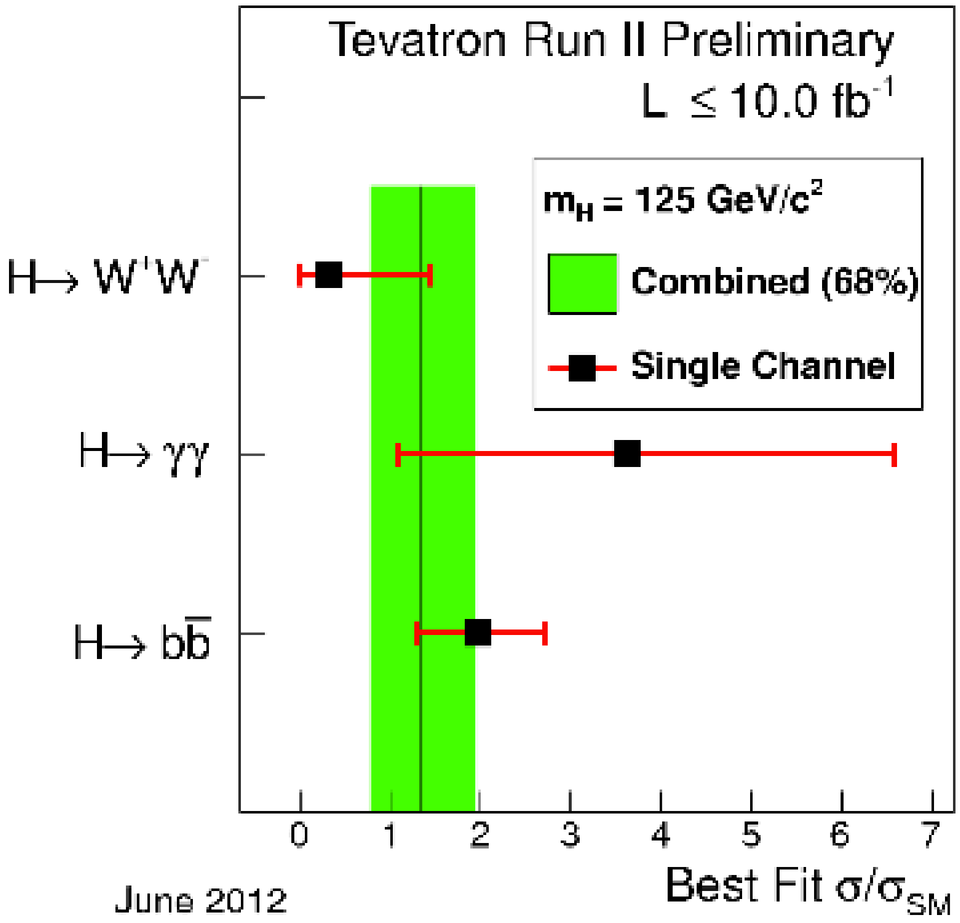
Nearly impossible to reproduce by accident

The observed σBr match the predictions within the present accuracy

If not the SM Higgs a very close relative!!

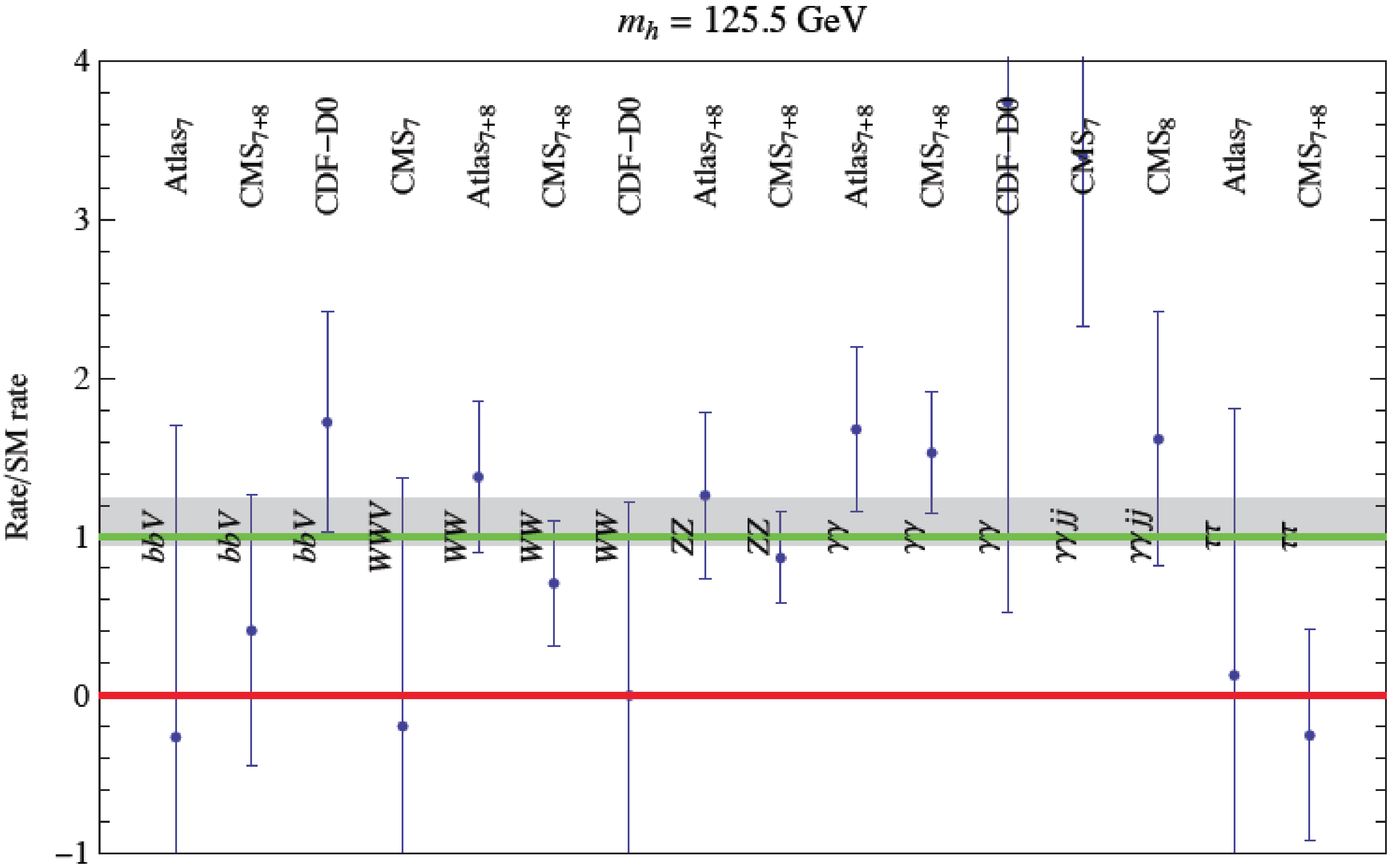






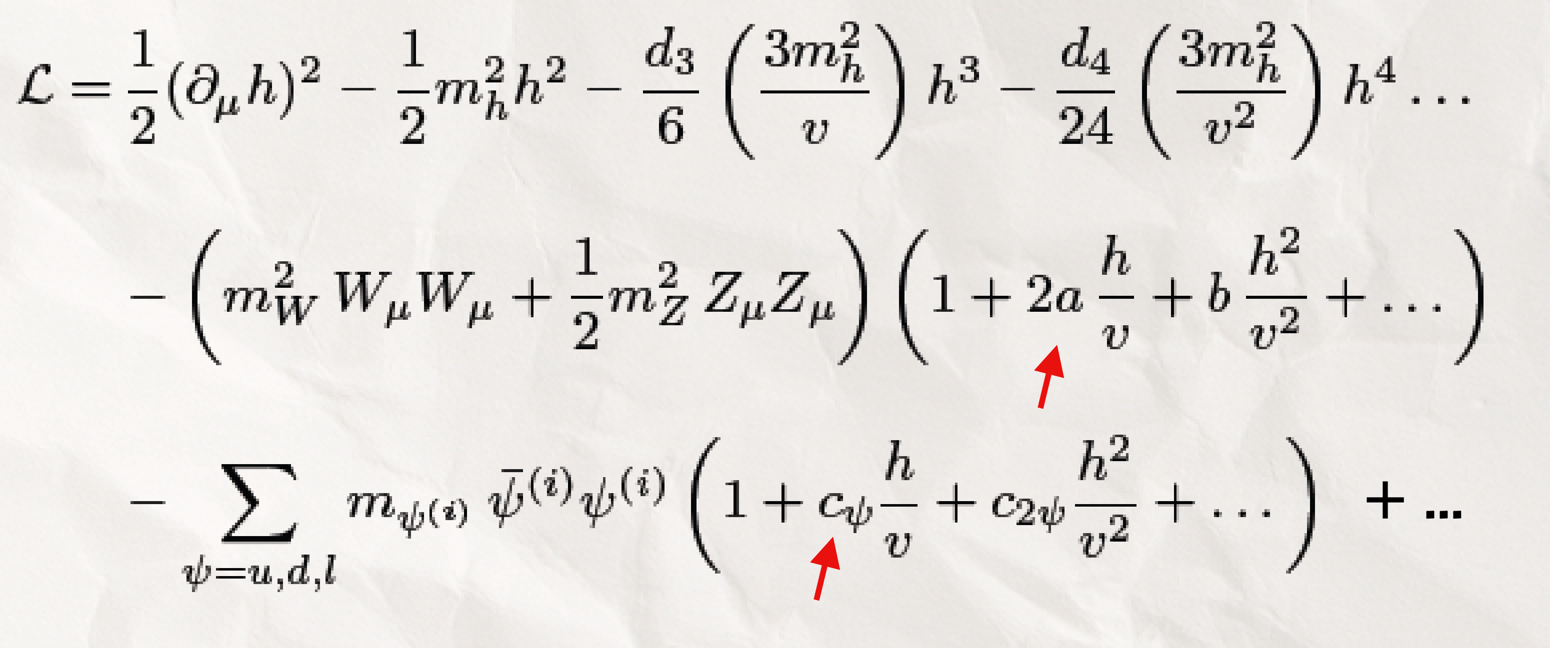
- A lot of attention is being devoted to the (marginal) $\gamma\gamma$ excess and $\tau\tau$ deficit

Giardino et al, ‘12



If the Higgs is confirmed then the precise couplings are crucial in order to determine to what extent it is SM

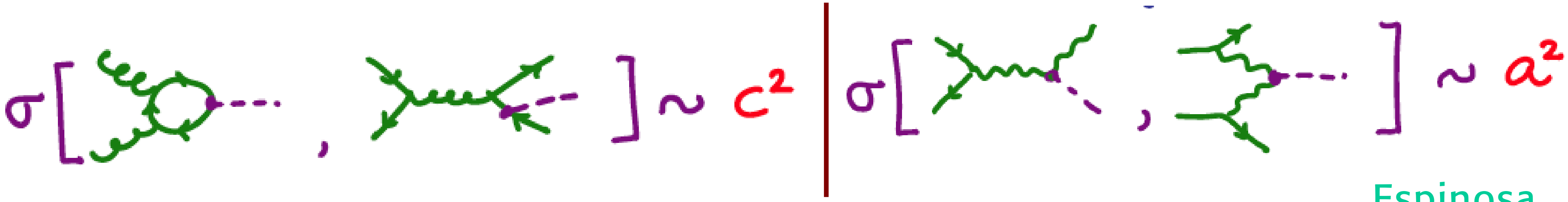
Contino



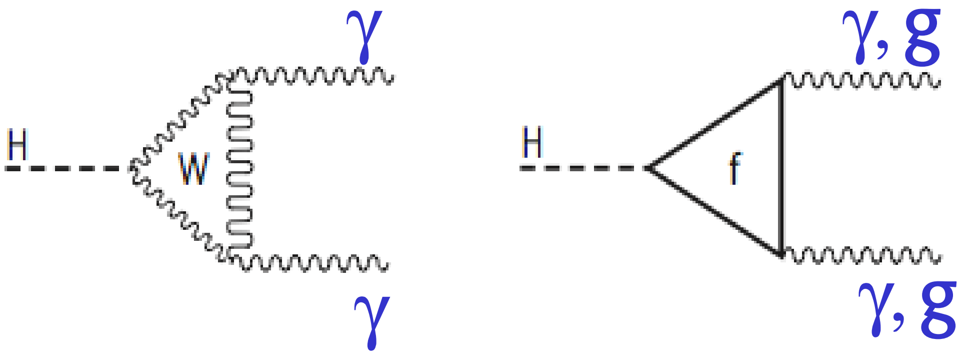
$$\begin{aligned}\mathcal{L} = {} & \frac{1}{2}(\partial_\mu h)^2 - \frac{1}{2}m_h^2 h^2 - \frac{d_3}{6}\left(\frac{3m_h^2}{v}\right)h^3 - \frac{d_4}{24}\left(\frac{3m_h^2}{v^2}\right)h^4 \ldots \\ & - \left(m_W^2\, W_\mu W_\mu + \frac{1}{2}m_Z^2\, Z_\mu Z_\mu\right)\left(1 + \underset{\uparrow}{2a}\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \ldots\right) \\ & - \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)}\left(1 + \underset{\uparrow}{c_\psi}\frac{h}{v} + c_{2\psi}\frac{h^2}{v^2} + \ldots\right) + \ldots\end{aligned}$$

a ~ hVV
c ~ hff

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



Espinosa

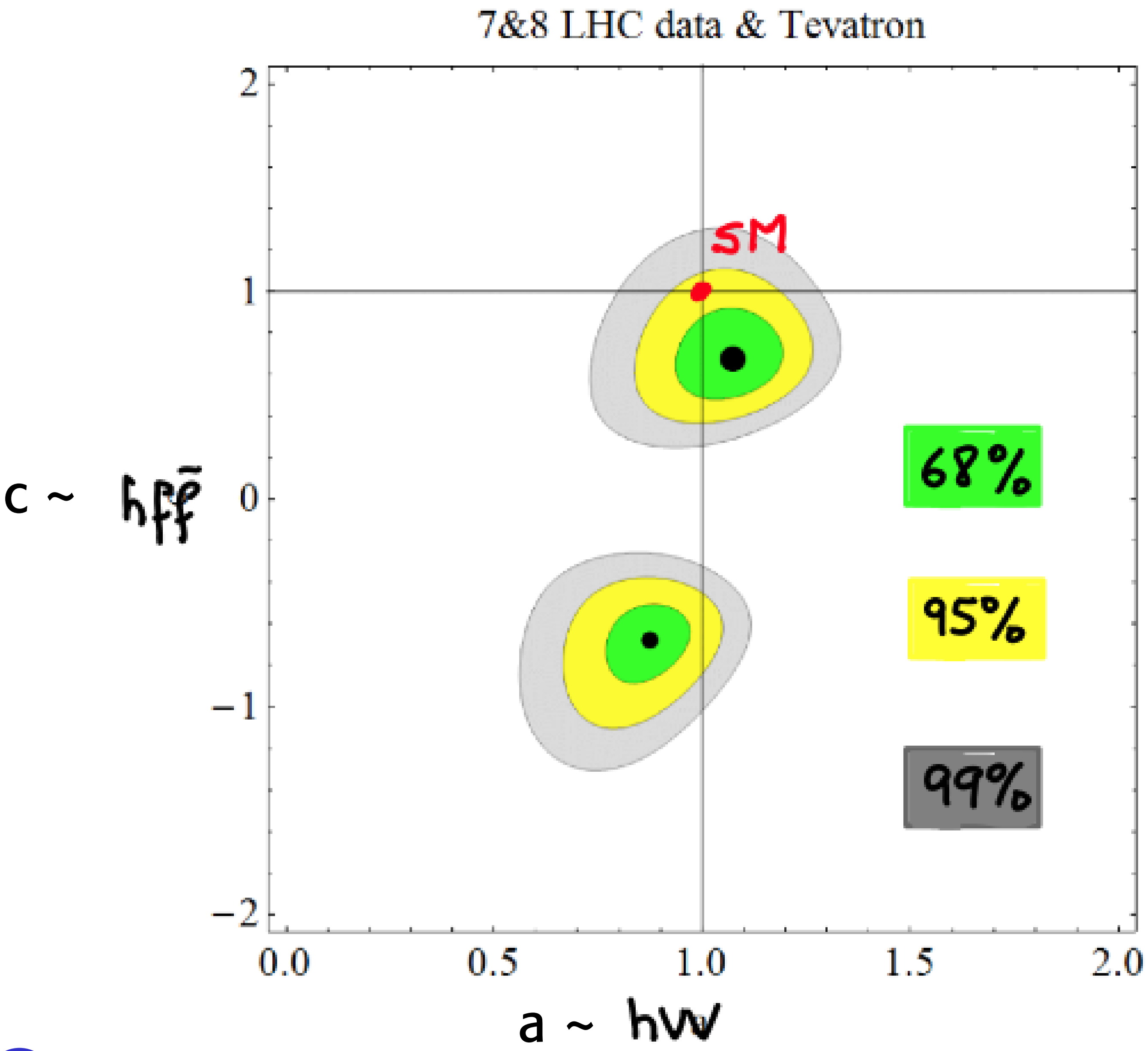


$$\Gamma(H \to \gamma\gamma) = \frac{G_F \alpha^2 m_H^3}{128\pi^3\sqrt{2}} |A_W(\tau_W) + \sum_f N_C Q_f^2 A_f(\tau_f)|^2 \qquad \tau_i = m_H^2/4m_i^2$$

Hγγ amplitude

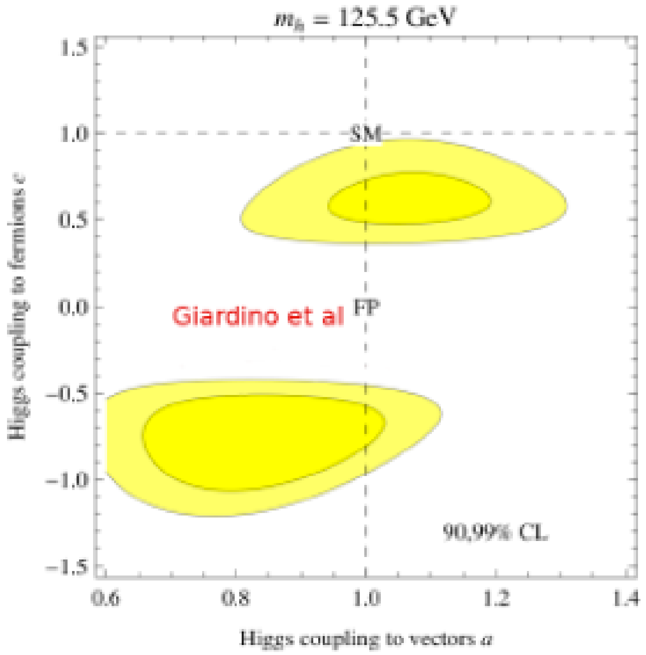
~ $|1.26a-0.26c|^2$

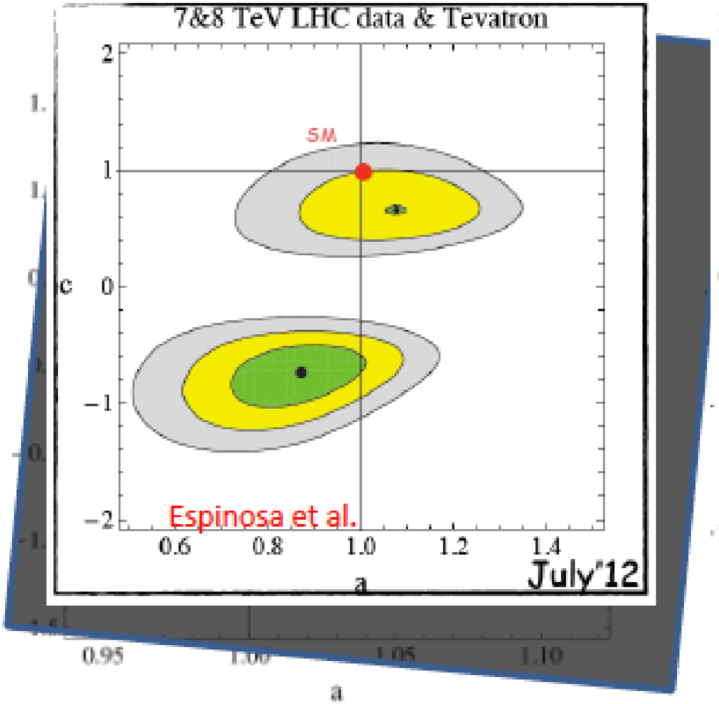
$$\Gamma(H \to gg) = \frac{G_F \alpha_s^2 m_H^3}{64\pi^3\sqrt{2}} |\sum_{f=Q} A_f(\tau_f)|^2$$

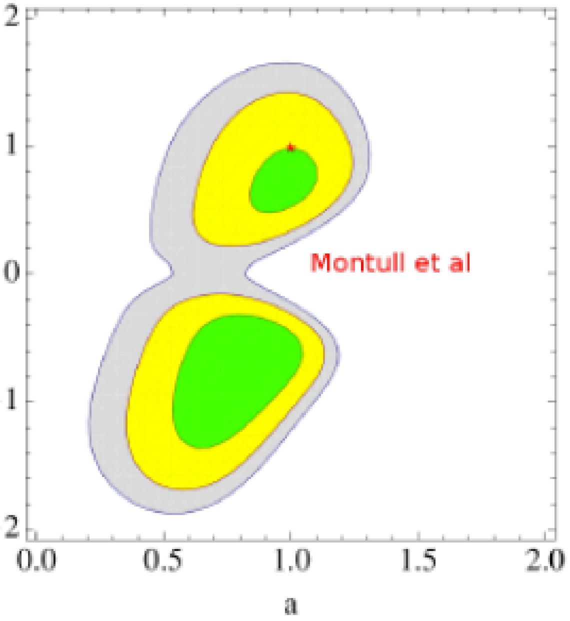


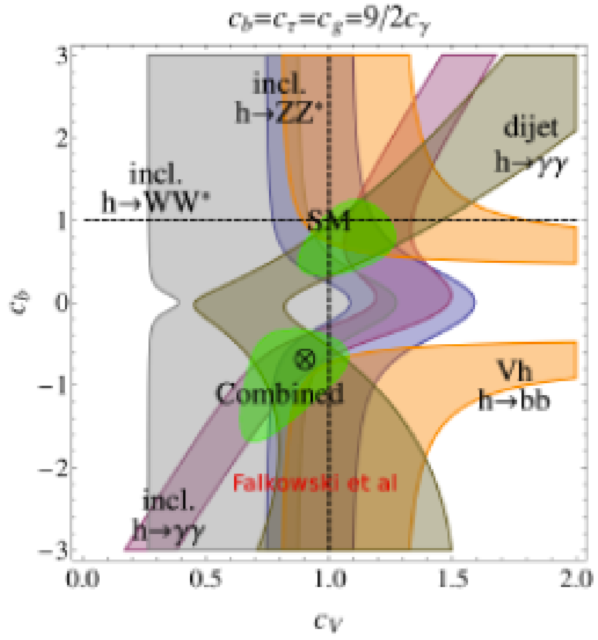
Best fit:
$a > 1$, $c < 1$

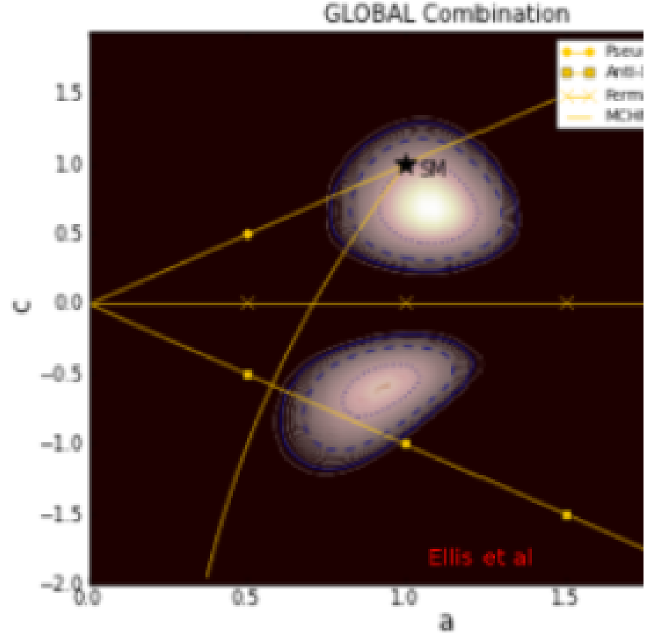
$H\gamma\gamma$ amplitude
$\sim |1.26a-0.26c|^2$





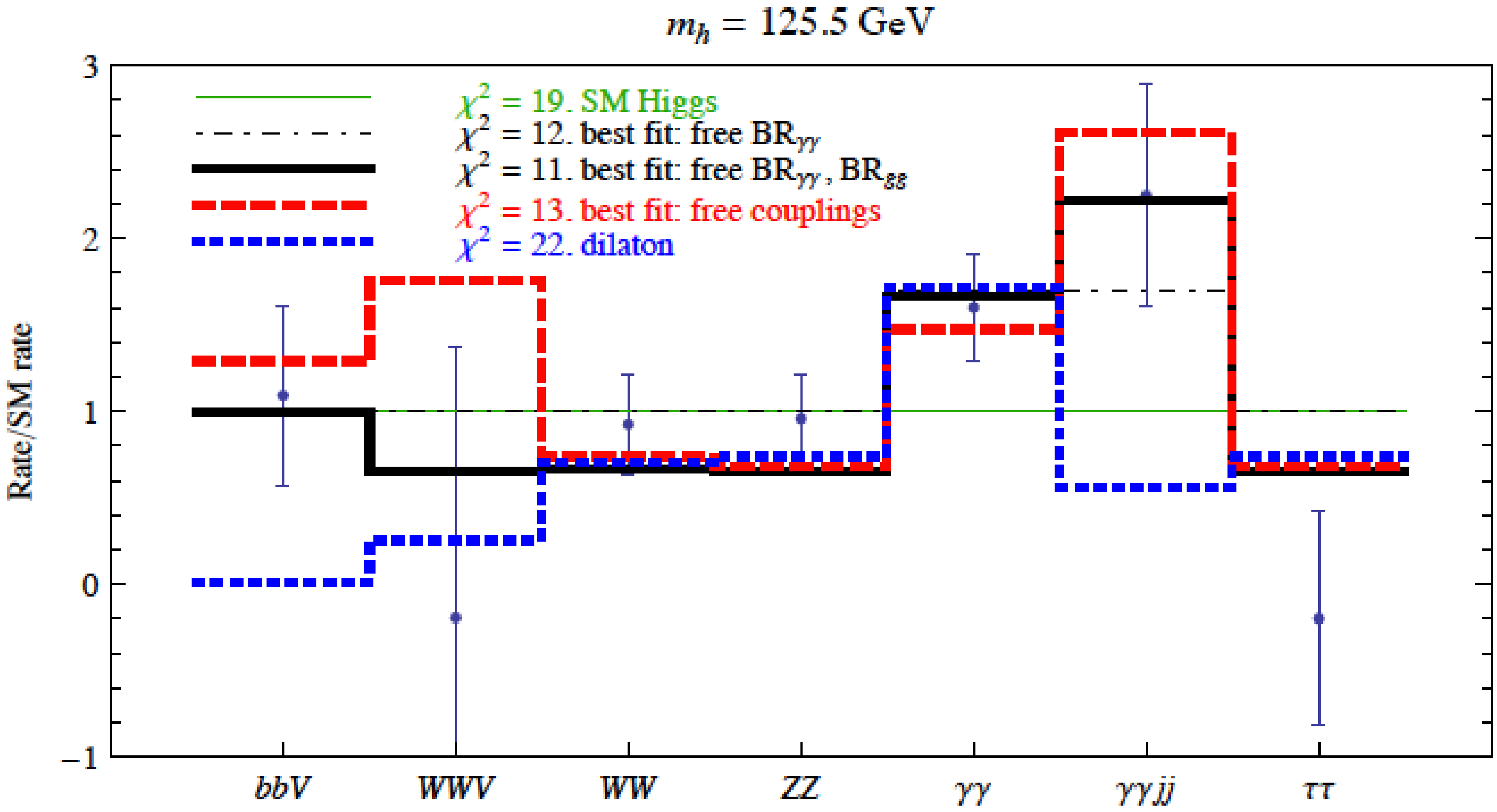


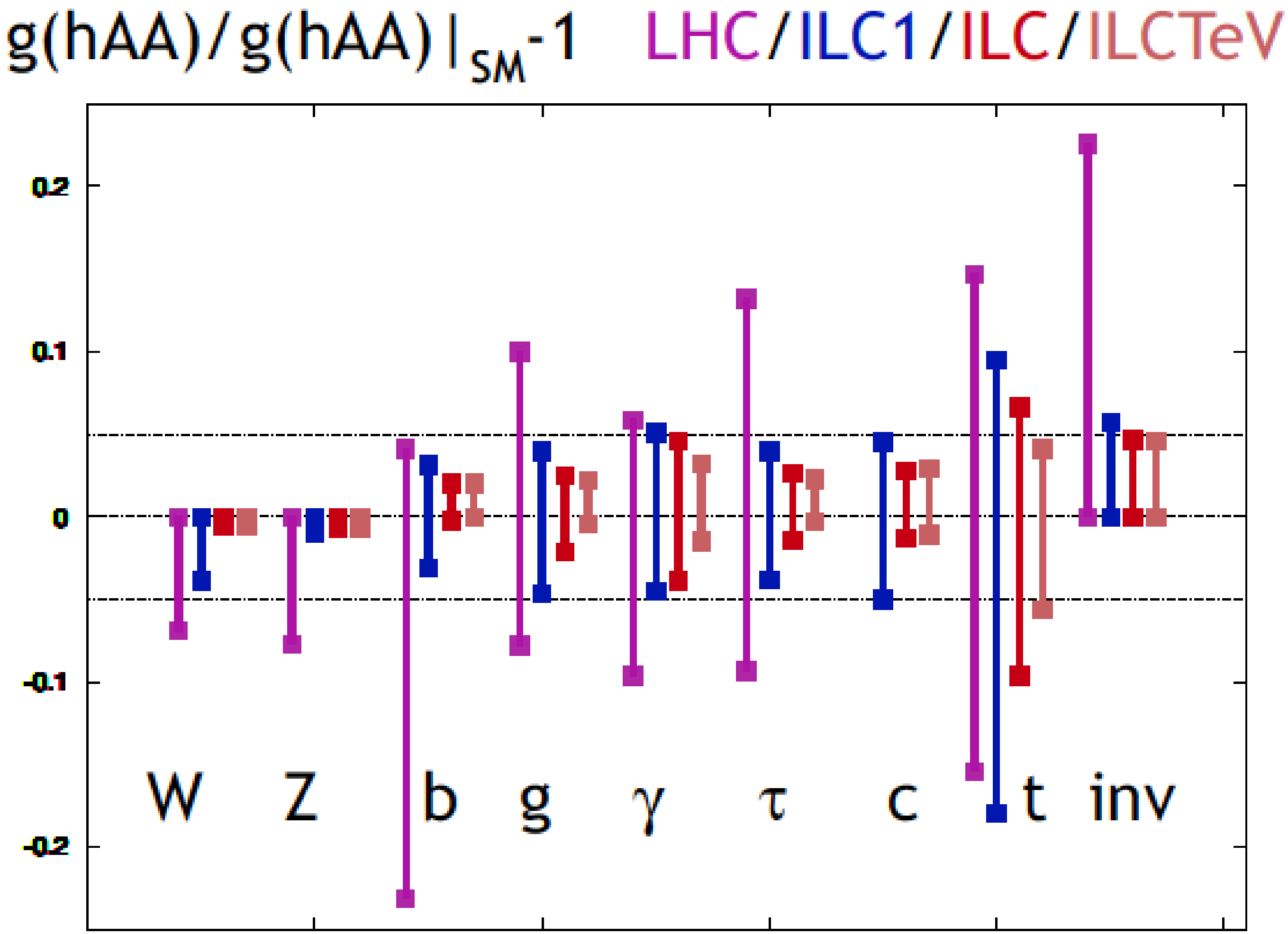




General agreement among different groups

Giardino et al, ‘12





Peskin '12

LHC 14 TeV,
300 fb^{-1}
5-10%

ILC/CLIC
2-5%

Figure 2: Comparison of the capabilities of LHC and ILC for model-independent measurements of Higgs boson couplings. The plot shows (from left to right in each set of error bars) 1 σ confidence intervals for LHC at 14 TeV with 300 fb^{-1}, for ILC at 250 GeV and 250 fb^{-1} ('ILC1'), for the full ILC program up to 500 GeV with 500 fb^{-1} ('ILC'), and for a program with 1000 fb^{-1} for an upgraded ILC at 1 TeV ('ILCTeV'). The marked horizontal band represents a 5% deviation from the Standard Model prediction for the coupling.

Impact of the Higgs discovery

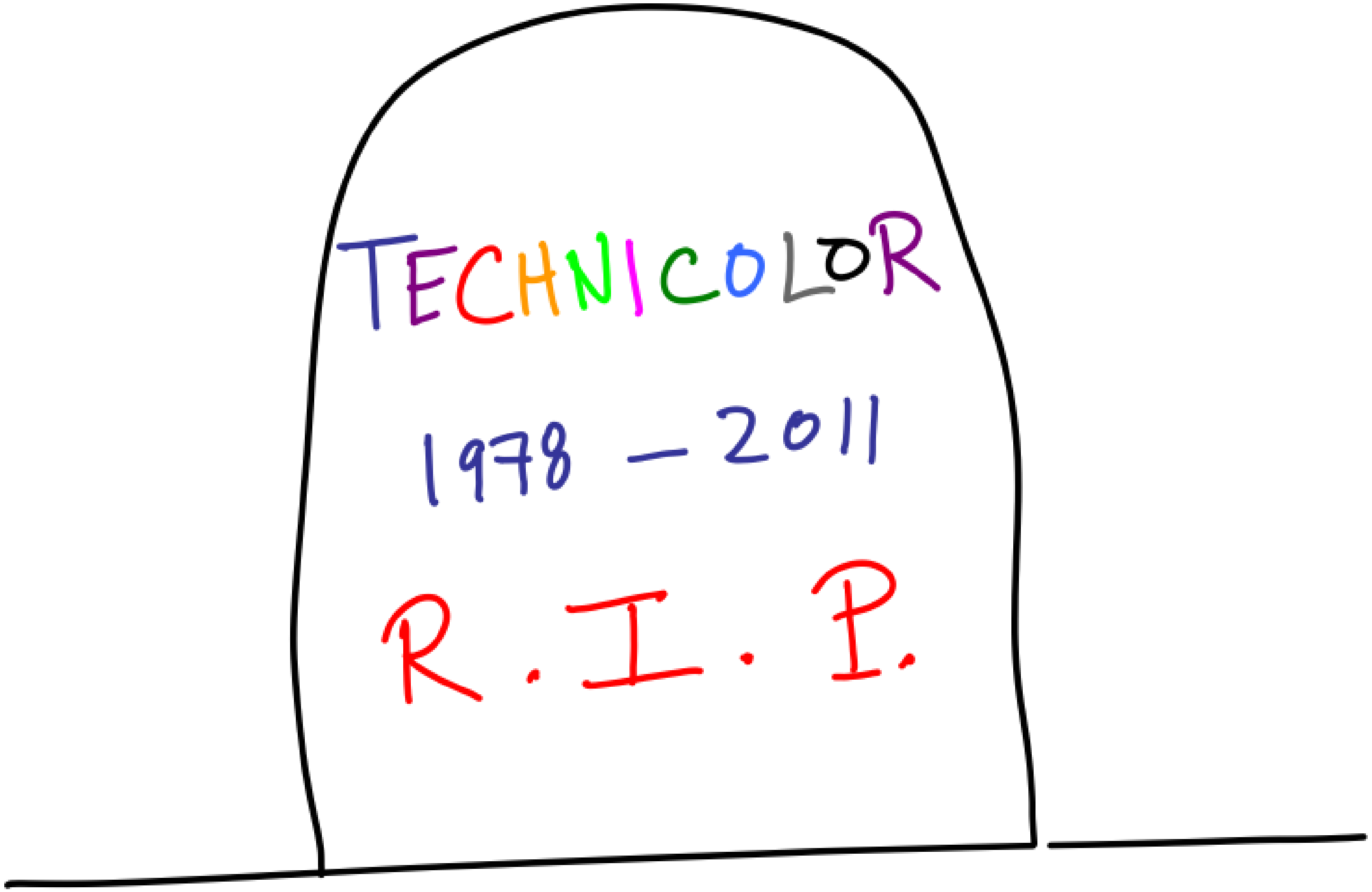
The only known example in physics of a fundamental, weakly coupled, scalar boson with VEV

A death blow not only to Higgsless models, technicolor models.... but also to all models with no 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]

Arkani-Hamed '12

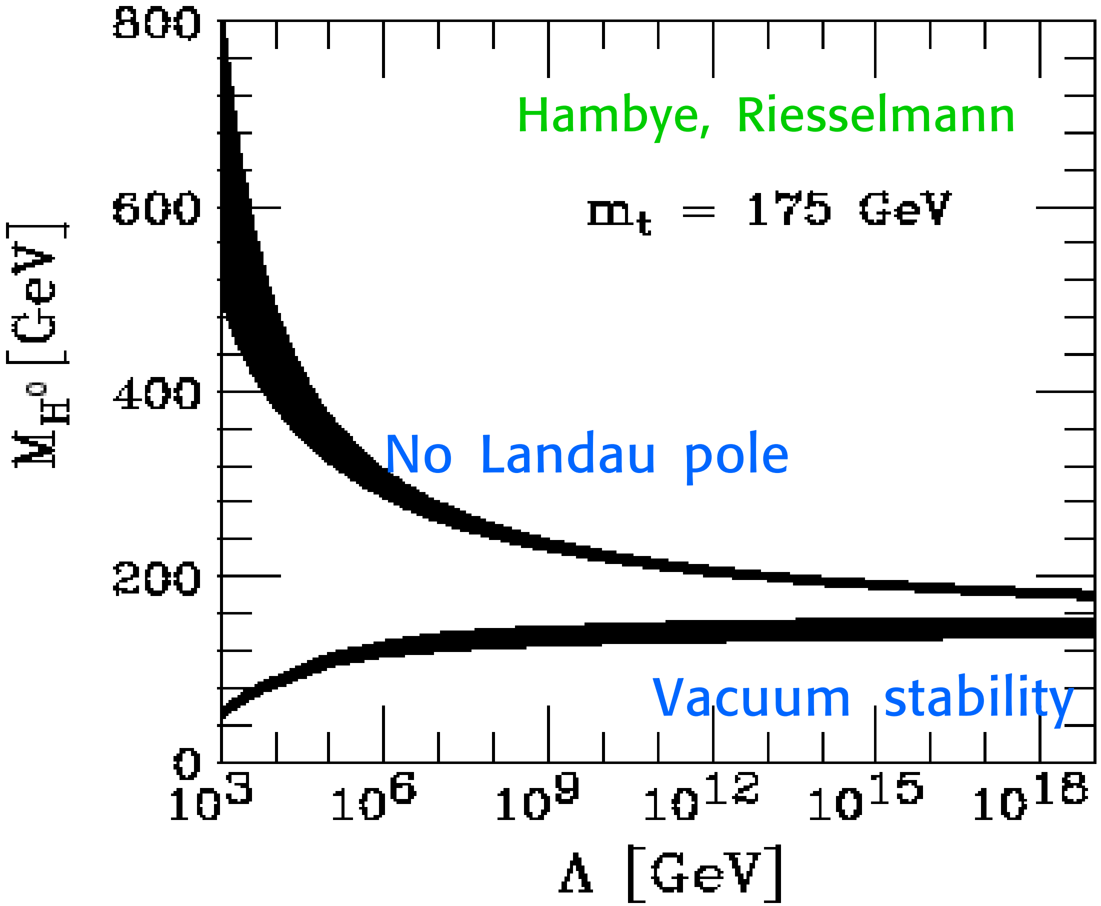
TRIUMPH OF WEAK COUPLING



Theoretical bounds on the SM Higgs mass

Λ: scale of new physics beyond the SM

Upper limit: No Landau pole up to Λ
Lower limit: Vacuum (meta)stability



If the SM would be valid up to M_{GUT}, M_{Pl} with a stable vacuum then m_H would be limited in a small range

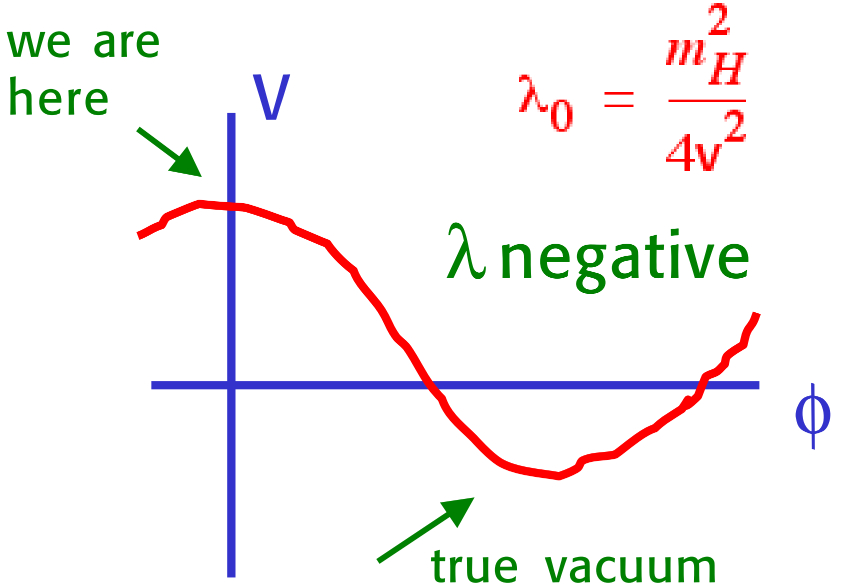
depends on m_t and α_s → 130 GeV < m_H < 180 GeV

Isn't m_H = 126 GeV a bit too light?

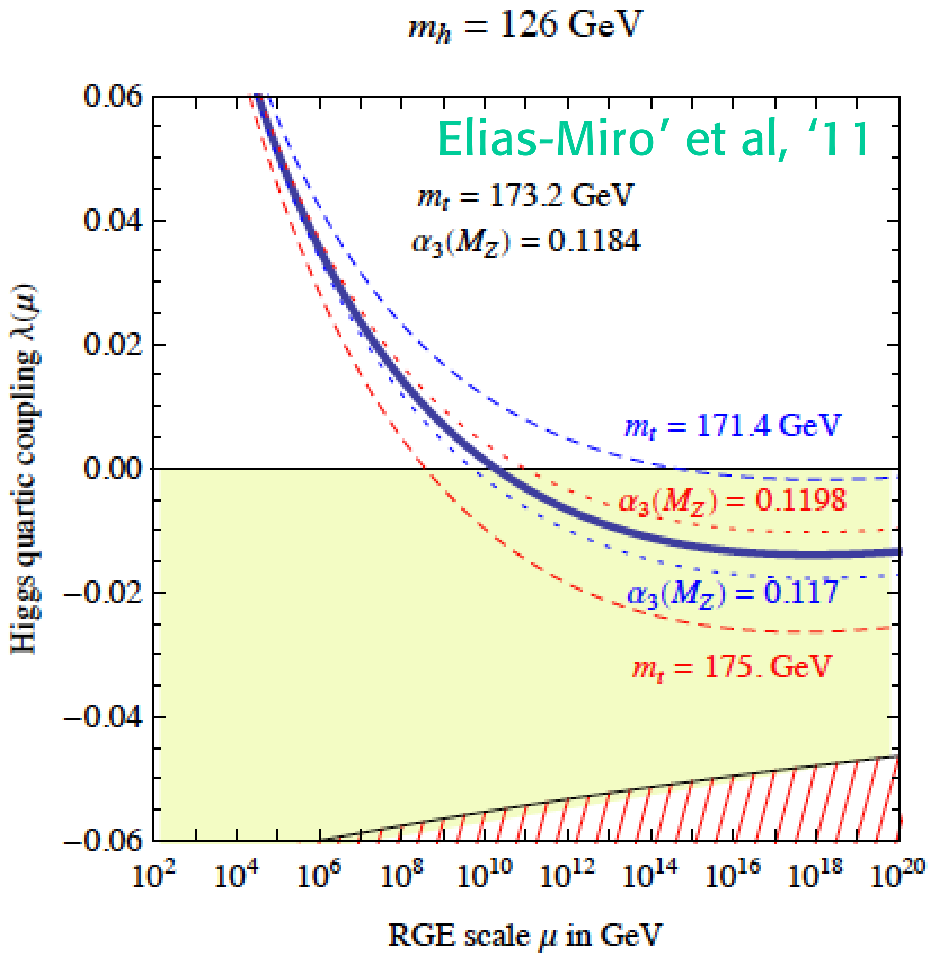
But metastability (with sufficiently long lifetime) is enough!

$$V[\phi] = -\mu^2\phi^2 + \lambda\phi^4$$

$$\lambda_0 = \frac{m_H^2}{4v^2}$$



(something is assumed to stabilize V at ~ M_{Pl})

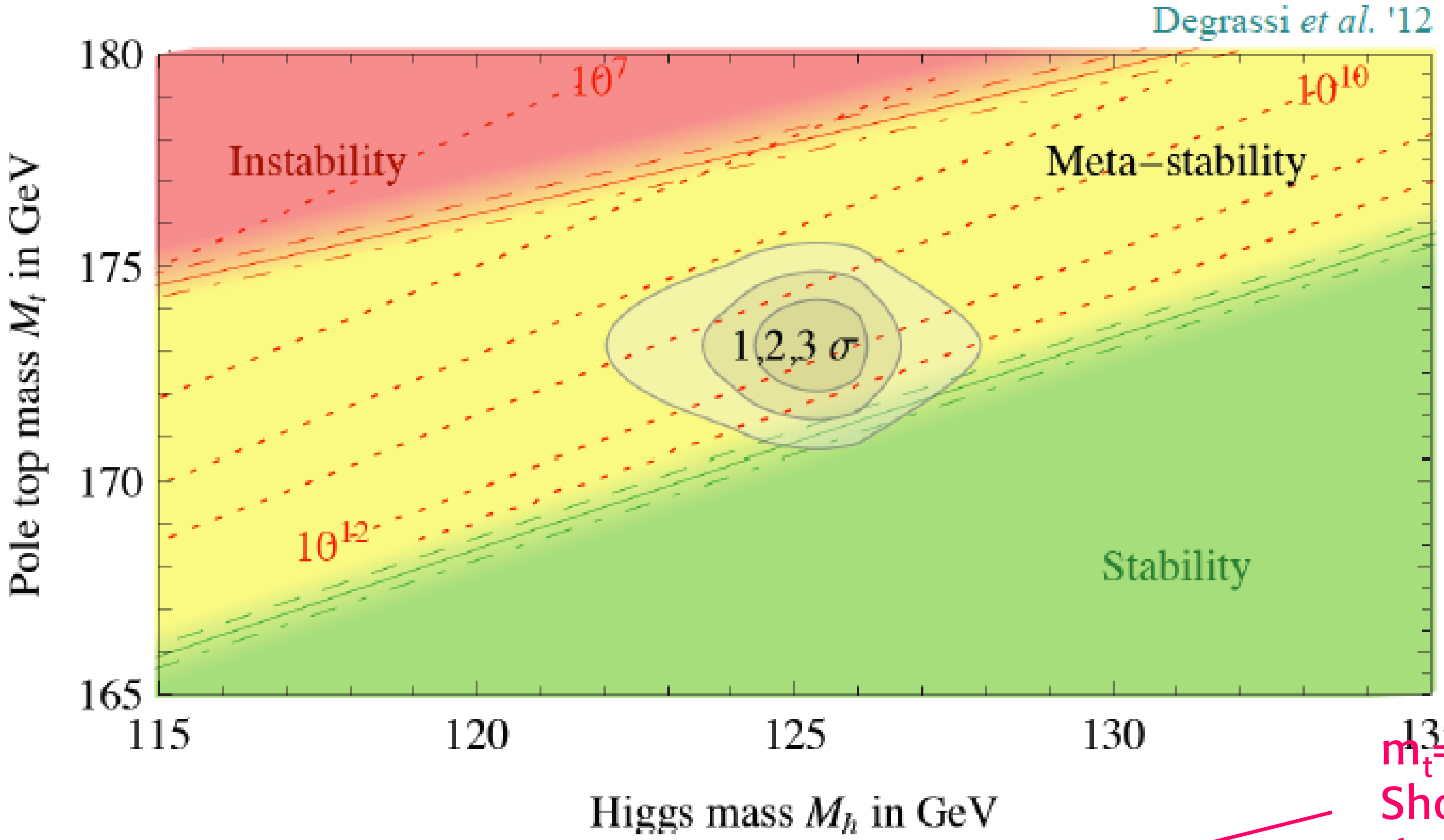


Elias-Miro' et al, '11

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

But the SM remains viable up to M_{Pl} (Early universe implications)

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

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

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

see e.g. Shaposhnikov; Wetterich '10

Higgs, unitarity and naturalness in the SM

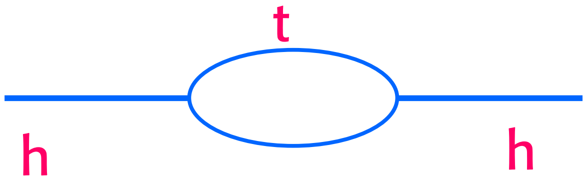
In the SM the Higgs provides a solution to the occurrence of unitarity violations in some amplitudes (W_L, Z_L scattering)

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



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

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

  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

except this!

Quo Vadis SUSY?

J. Ellis

Quo Vadis SUSY?

J. Ellis

Years ago, after LEP2, in a talk I said

"the SUSY train is late"

Today I should say

"perhaps the SUSY train will never arrive at the LHC"

Once the no fine tuning taboo has been infringed
it is not clear where to put the SUSY scale

SUSY: boson fermion symmetry

The hierarchy problem: $\delta m_{h|top}^2 = -\frac{3G_F}{2\sqrt{2}\pi^2} m_t^2 \Lambda^2 \sim -(0.2\Lambda)^2$

In broken SUSY Λ^2 is replaced by $(m_{stop}^2 - m_t^2)\log\Lambda$

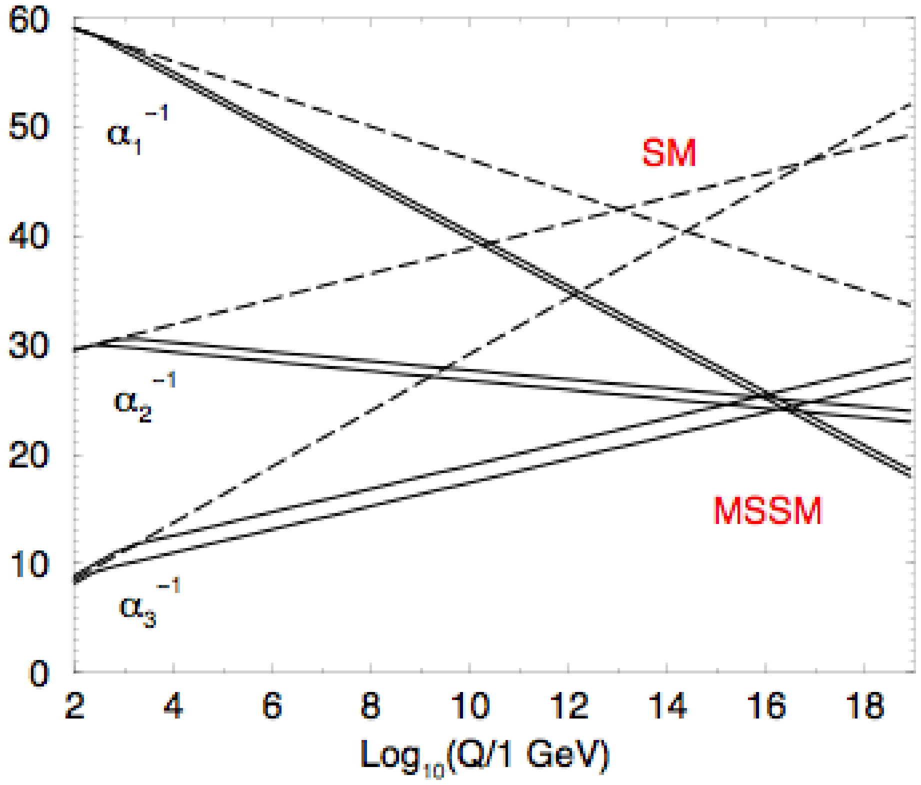
$m_H > 115.5$ GeV, $m_{\chi+} > 100$ GeV, EW precision tests, success of CKM, absence of FCNC, all together, impose sizable Fine Tuning (FT) particularly on minimal realizations (MSSM, CMSSM…).

Yet SUSY is a completely specified, consistent, computable model, perturbative up to M_{Pl} quantitatively in agreement with coupling unification (GUT's)
(unique among NP models)
and has a good DM candidate: the neutralino
(actually more than one).

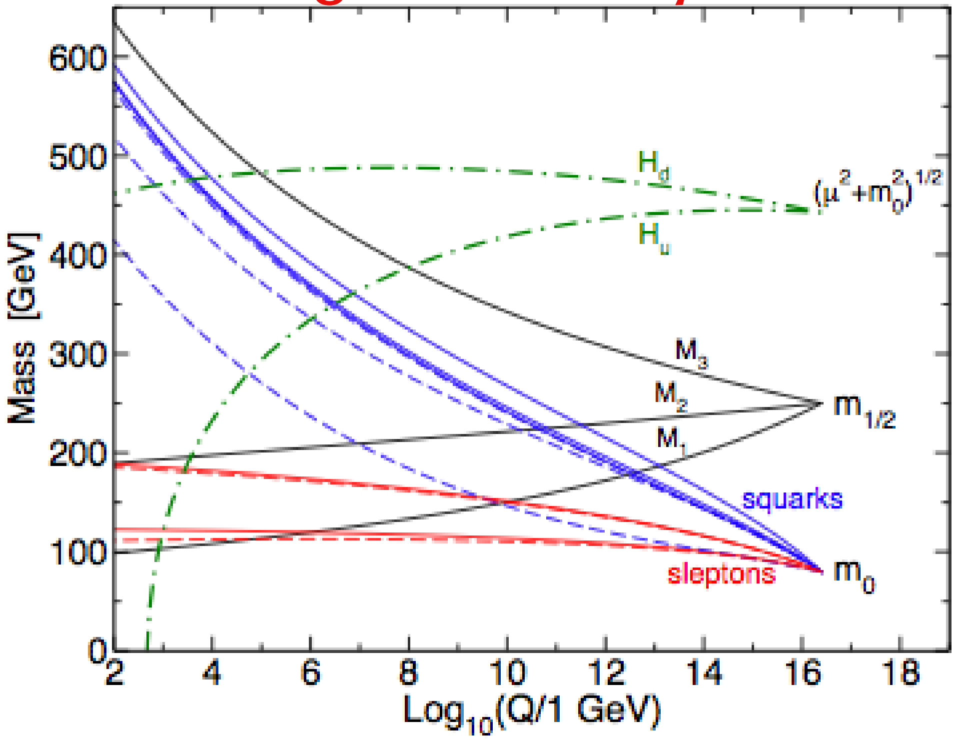
⊕ For a many theorists remains the reference model for NP

Beyond the SM SUSY is unique in providing a perturbative theory up to the GUT/Planck scale

Coupling unification improved



EW symmetry breaking emerges naturally



Other BSM models (little Higgs, composite Higgs, ...) all become strongly interacting and non perturbative at a multi-TeV scale

The general MSSM has > 100 parameters

Simplified versions with a drastic reduction of parameters are used for practical reasons, e.g.

CMSSM, mSUGRA : universal gaugino and scalar soft terms at GUT scale $m_{1/2}$, m_0, A_0, tgβ, sign(μ)

NUHM1,2: different than m_0 masses for H_u, H_d (1 or 2 masses)

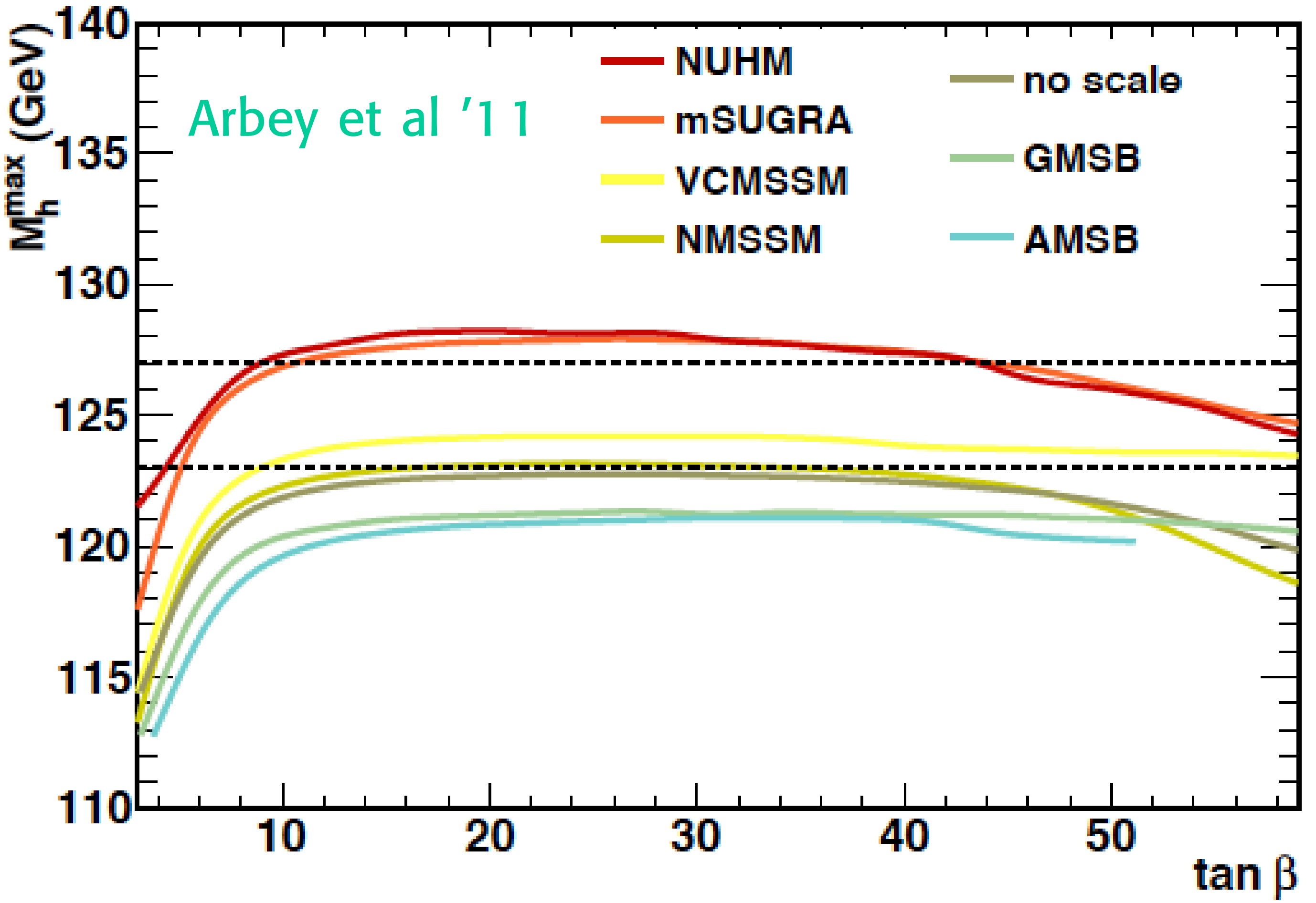
It is only these oversimplified models that are now cornered

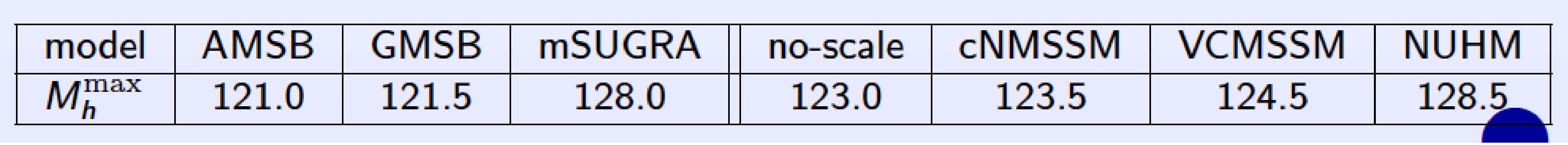
CMSSM, mSUGRA, NUHM1,2 need squarks heavy, A_t large and lead to tension with g-2 (that wants light SUSY)

Arbey et al'11 ,Akura et al; Baer et al; Battaglia et al; Buchmuller et al, Kadastik et al; Strege et al; '11

$m_H = 126$ GeV plus new bounds from negative searches disfavour simplest versions of SUSY

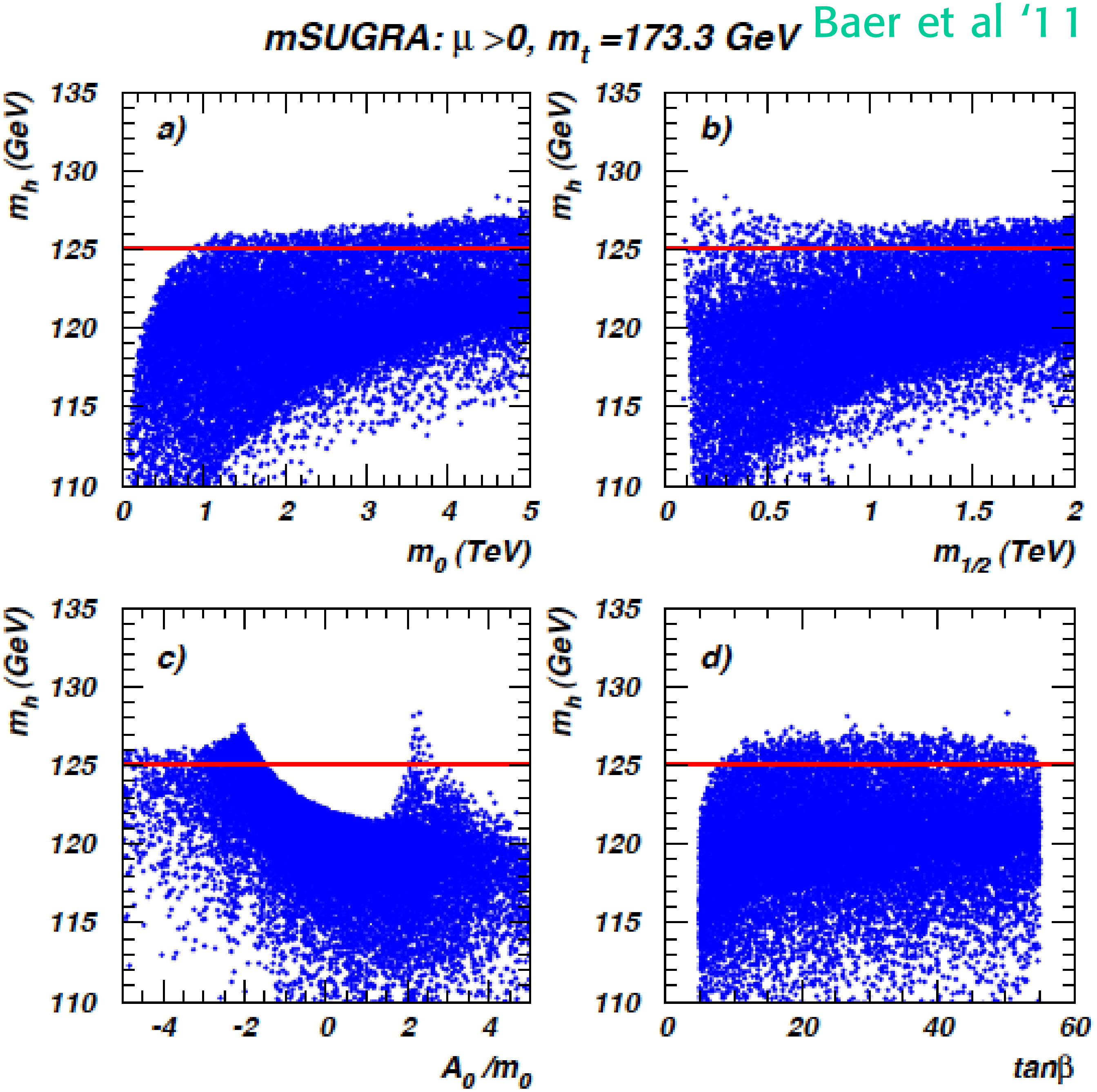
Mahmoudi


Arbey et al ’11



model	AMSB	GMSB	mSUGRA	no-scale	cNMSSM	VCMSSM	NUHM
M_h^{max}	121.0	121.5	128.0	123.0	123.5	124.5	128.5

M_H ~125 GeV makes CMSSM/mSUGRA marginal



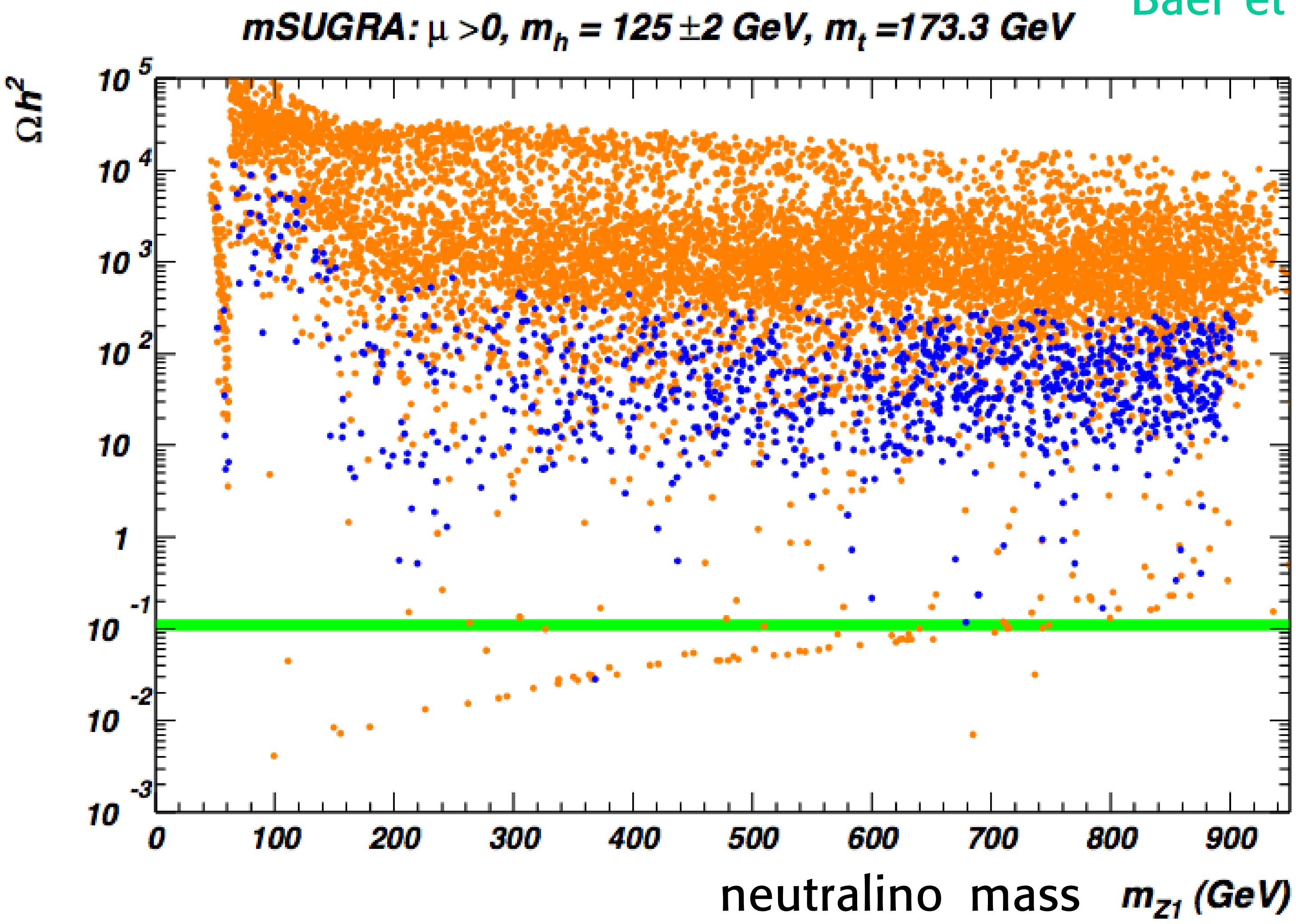
Baer et al '11

Terrible fine tuning

Ghilencea et al '12

Dark Matter in mSUGRA: normally too much is predicted for m_H = 125 GeV

Baer et al ‘12



neutralino mass

blue:

$m_0 < 5$ TeV

orange:

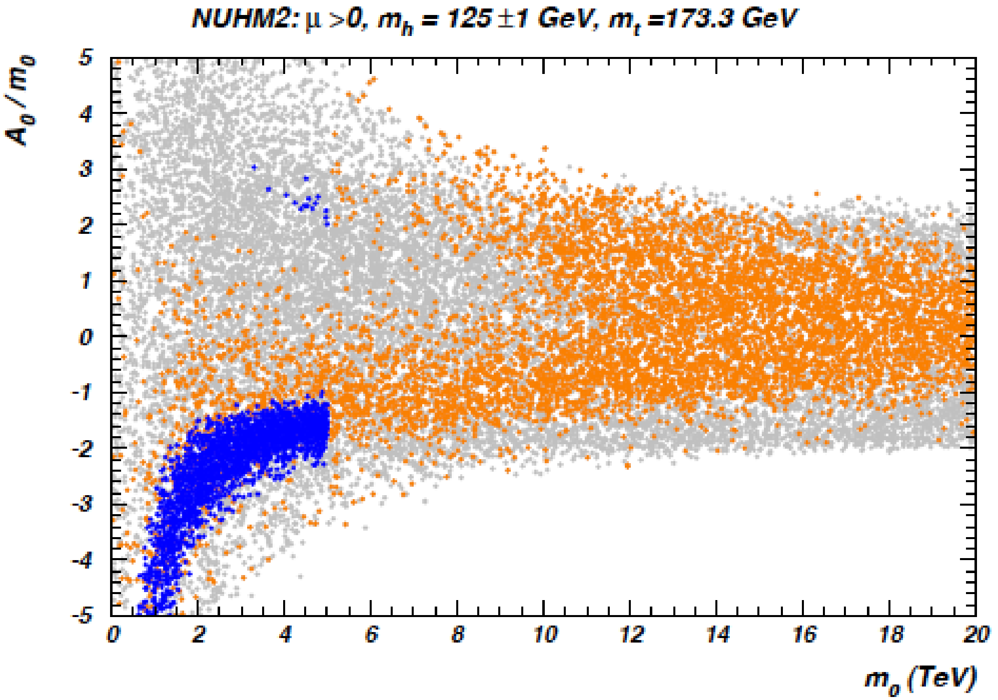
$5 < m_0 < 20$ TeV

Exp

Baer et al ‘11

NUHM1,2

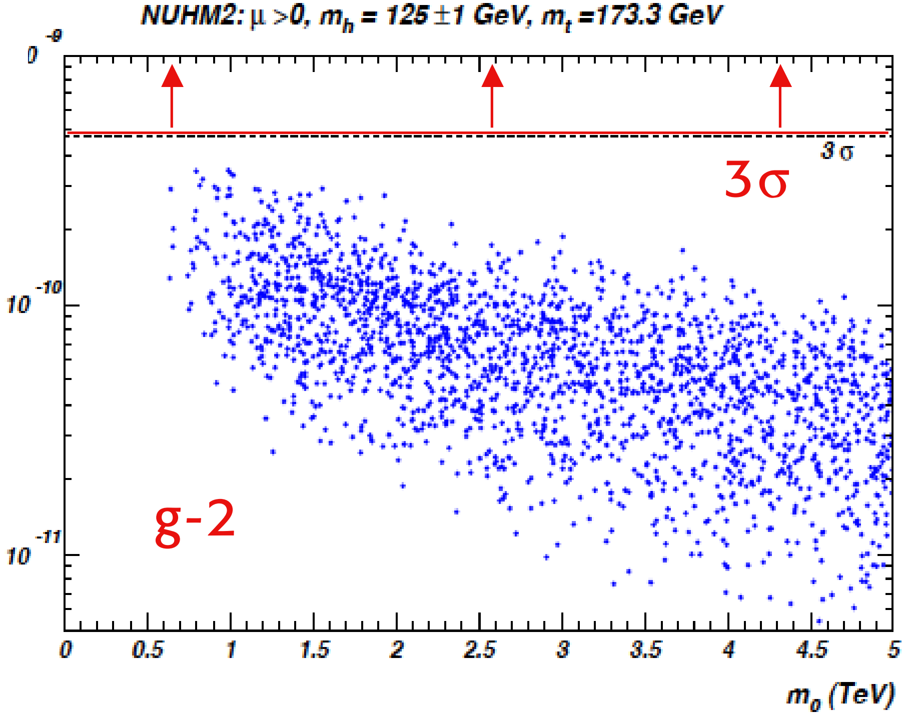
add 1 or 2 separate mass parameters for Hu, Hd



blue: m_H ~125 GeV

note A_0 large and negative

inconsistent with g-2 →



3σ

g-2

Muon g-2

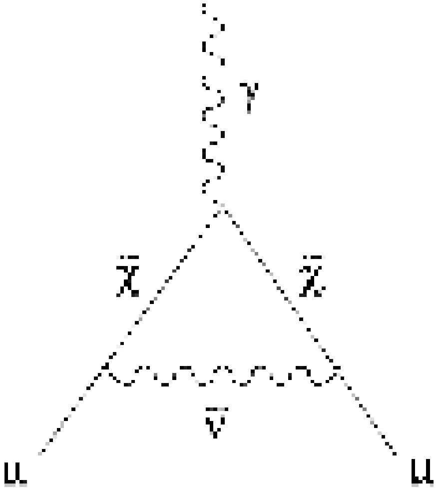
a_μ is a plausible location for a new physics signal!!

eg could be light SUSY (tension with m_H ~ 126 GeV and LHC7 limits)

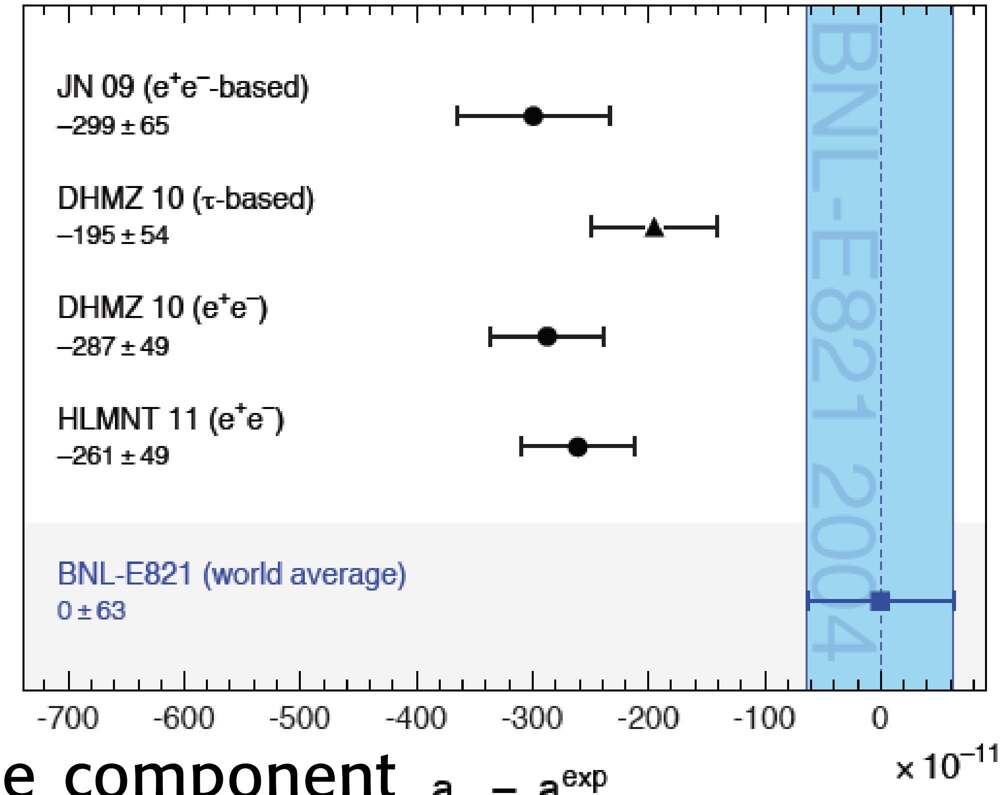
$$a_\mu^{\,exp} - a_\mu^{\,SM} = (28.7 \pm 8.0) \times 10^{-10}$$

- 3.6 ”standard deviations“ (e^+e^-)
- 2.4 ”standard deviations“ (τ)

$$\delta a_\mu = 13 \cdot 10^{-10} \left(\frac{100 GeV}{M_{SUSY}} \right)^2 tg\beta$$



Status: summer 2011 (*published results shown only*)

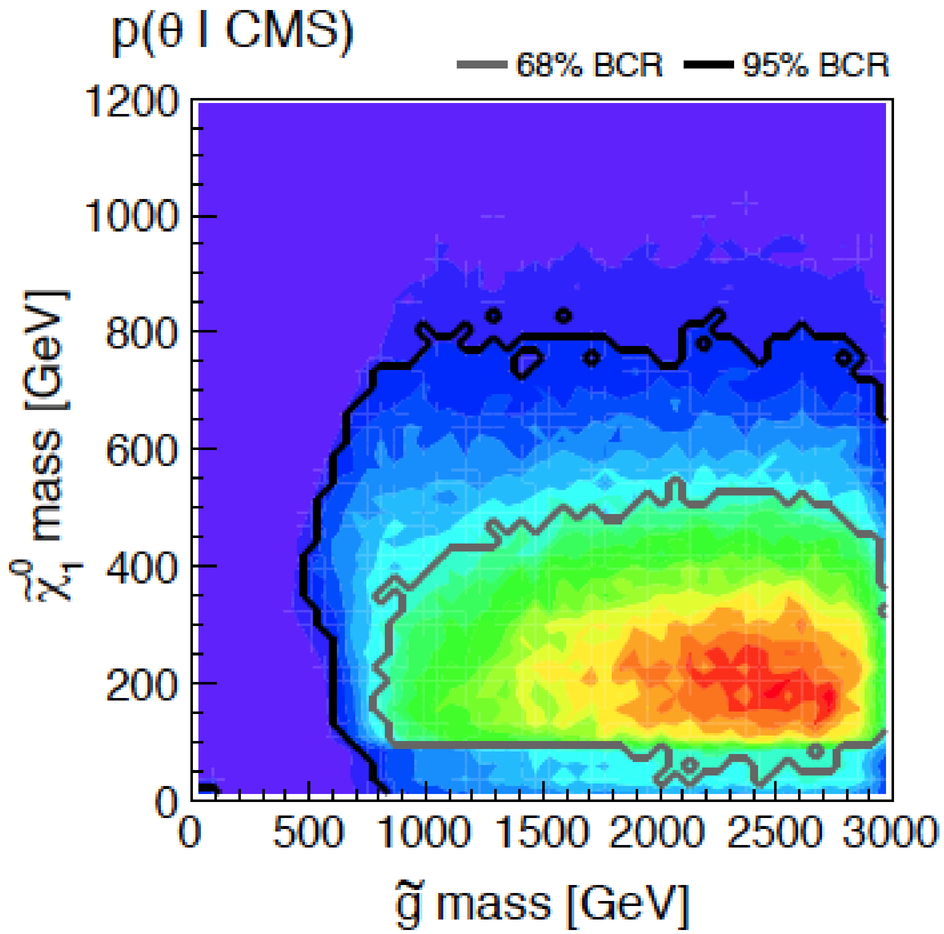


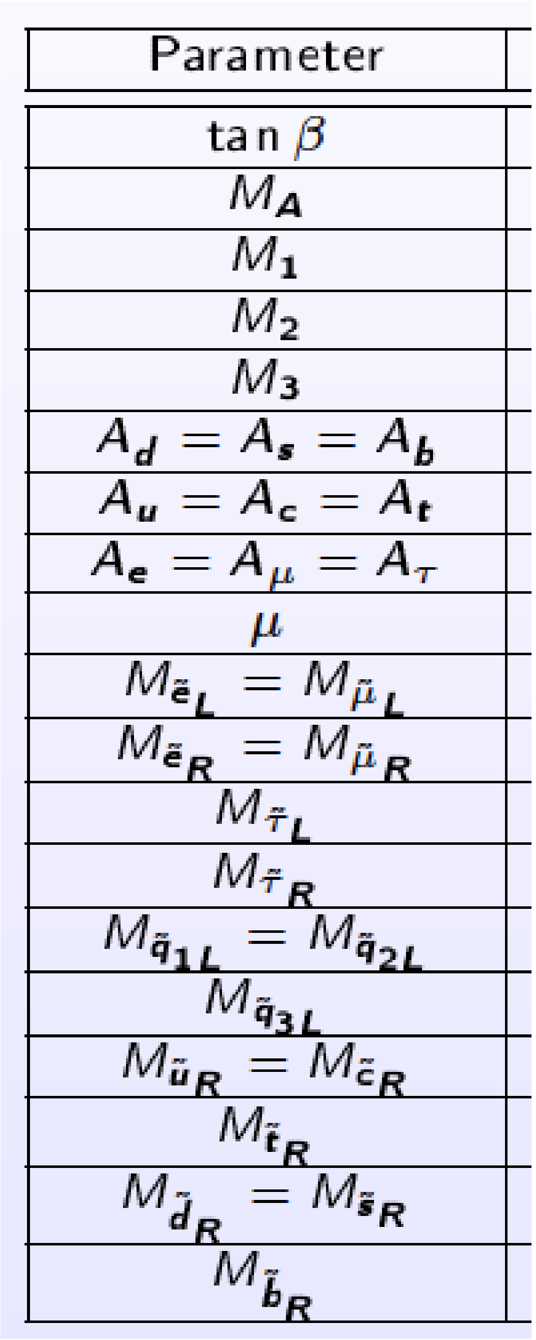
- Th error from γ–γ is a large component

A more flexible setup is the MSSM with CP and R conservation and 19 parameters (pMSSM)

recently studied in several works

Arbey et al ‘11, ‘12





Parameter
$\tan\beta$
M_A
M_1
M_2
M_3
$A_d = A_s = A_b$
$A_u = A_c = A_t$
$A_e = A_\mu = A_\tau$
μ
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$
$M_{\tilde{\tau}_L}$
$M_{\tilde{\tau}_R}$
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$
$M_{\tilde{q}_{3L}}$
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$
$M_{\tilde{t}_R}$
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$
$M_{\tilde{b}_R}$

As a comparison, the upper limit on m_h is larger in the pMSSM

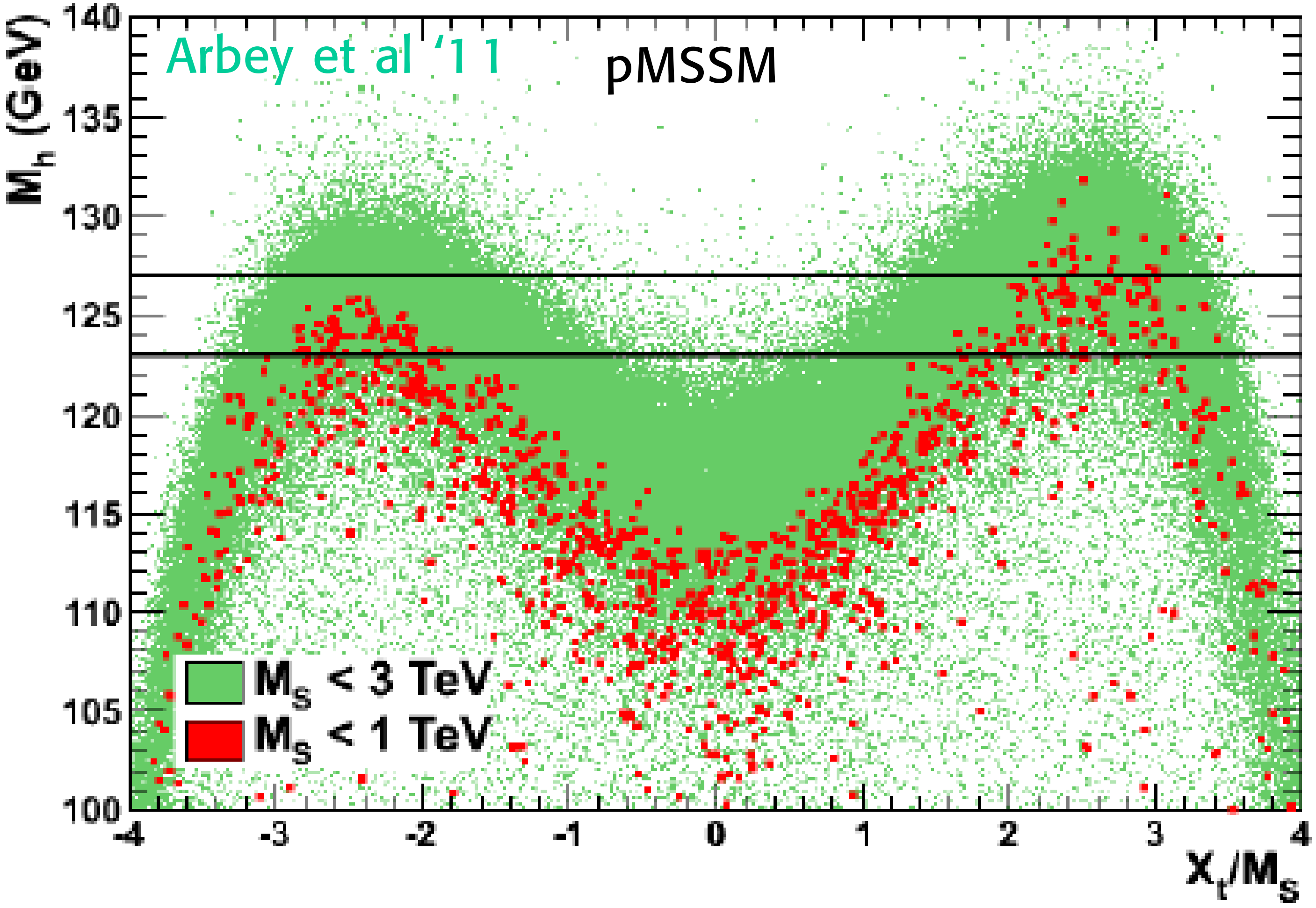
$m_h^2 = m_Z^2 |\cos 2\beta|^2 + \delta m_h^2$

$$\delta m_h^2 = \frac{3G_F}{\sqrt{2}\pi^2} m_t^4 \left(\log\left(\frac{\overline{m}_{\tilde t}^2}{m_t^2} \right) + \frac{X_t^2}{\overline{m}_{\tilde t}^2} \left(1 - \frac{X_t^2}{12\overline{m}_{\tilde t}^2} \right) \right)$$

$125^2 = 91^2 + 86^2$

Mahmoudi

$X_t = A_t - \mu \cot\beta$



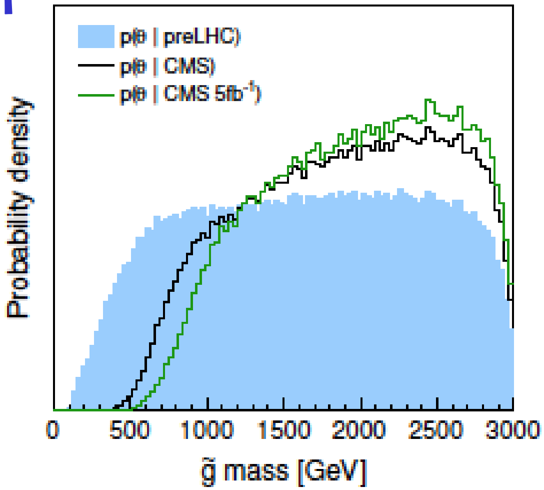
large M_S
large X_t
needed

gluinos and 1-2 gen s-quarks are mostly affected by LHC not EW-inos and stops

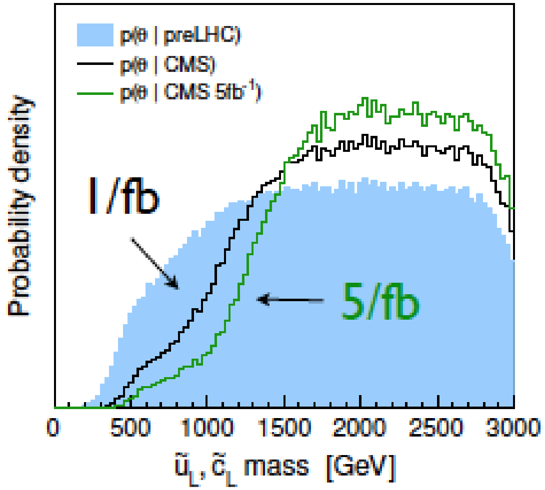
Sekmen et al '11

pMSSM

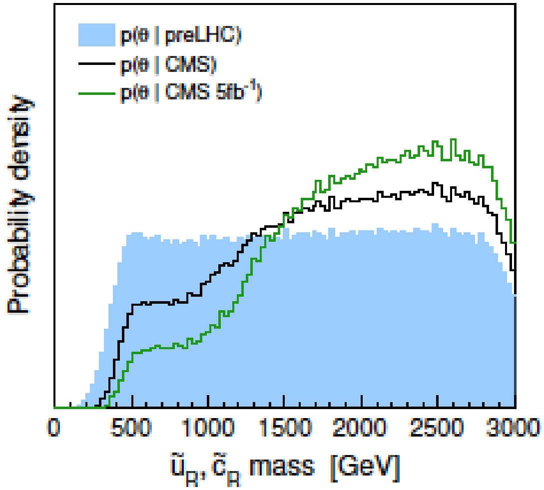
gluino

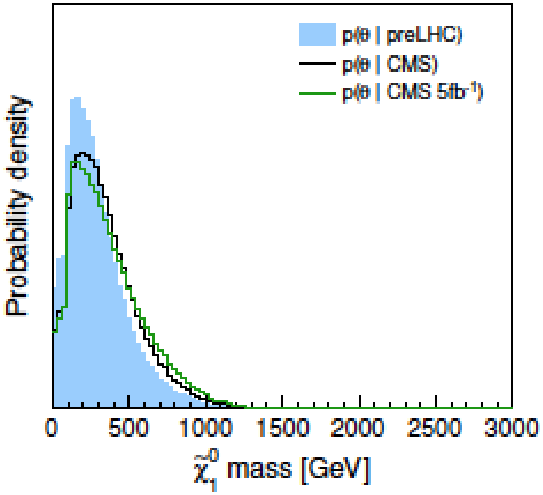


left squark

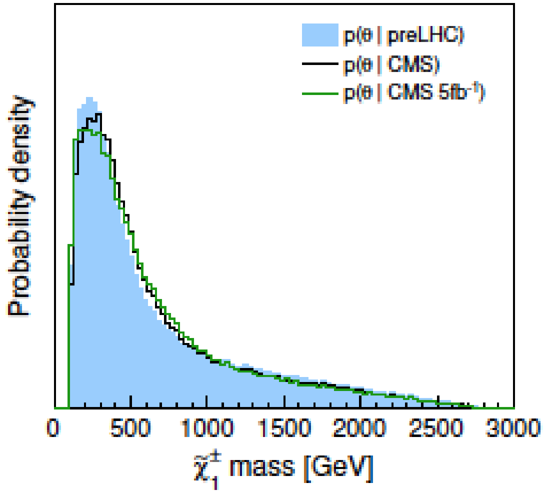


right squark

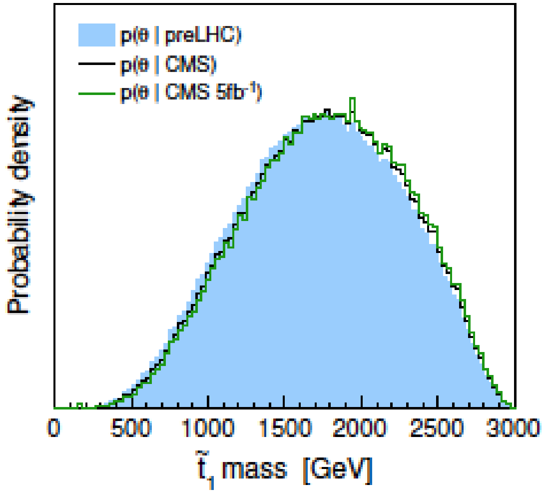




neutralino



chargino



stop

One must go beyond the CMSSM, mSUGRA, NUHM1,2

There is plenty of room for more sophisticated versions of SUSY as a solution to the hierarchy problem

The pMSSM shows that SUSY is alive

For an orderly retreat

Simplest new ingredients

- Heavy first 2 generations
- NMSSM
- λ SUSY

} an extra Higgs singlet

The last trench of natural SUSY!

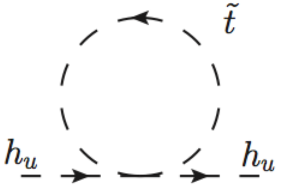
For MSSM to be natural

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

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

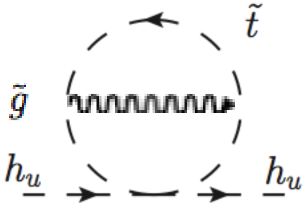
Tree level
$\sin^2 2\beta << 1$
(no extra singlet in MSSM)

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

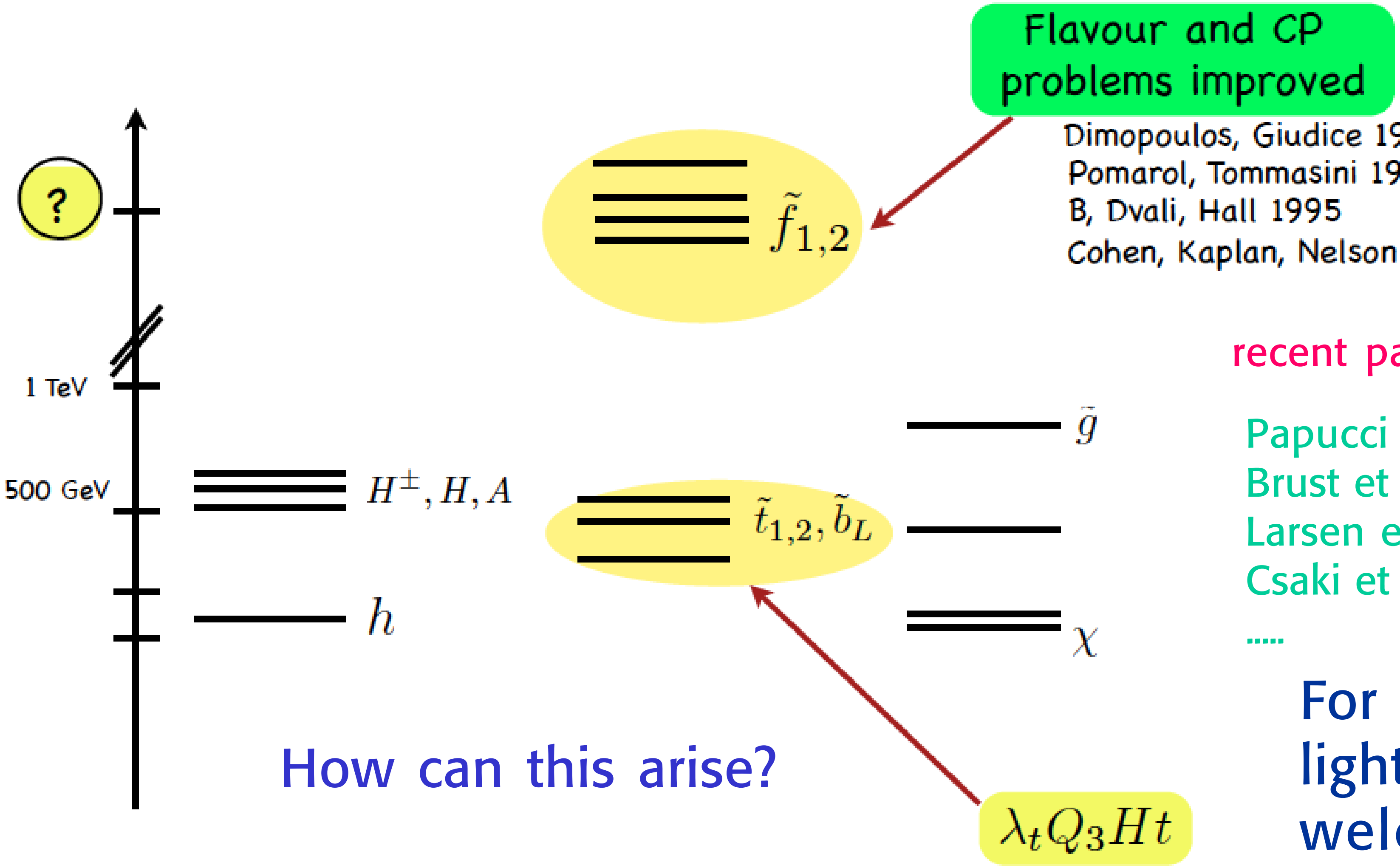


$$\delta m_{H_u}^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2 \left(\frac{\Lambda}{\text{TeV}} \right)$$

Beyond the CMSSM, mSugra, NUHM1,2

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

$\lambda_t Q_3 H t$

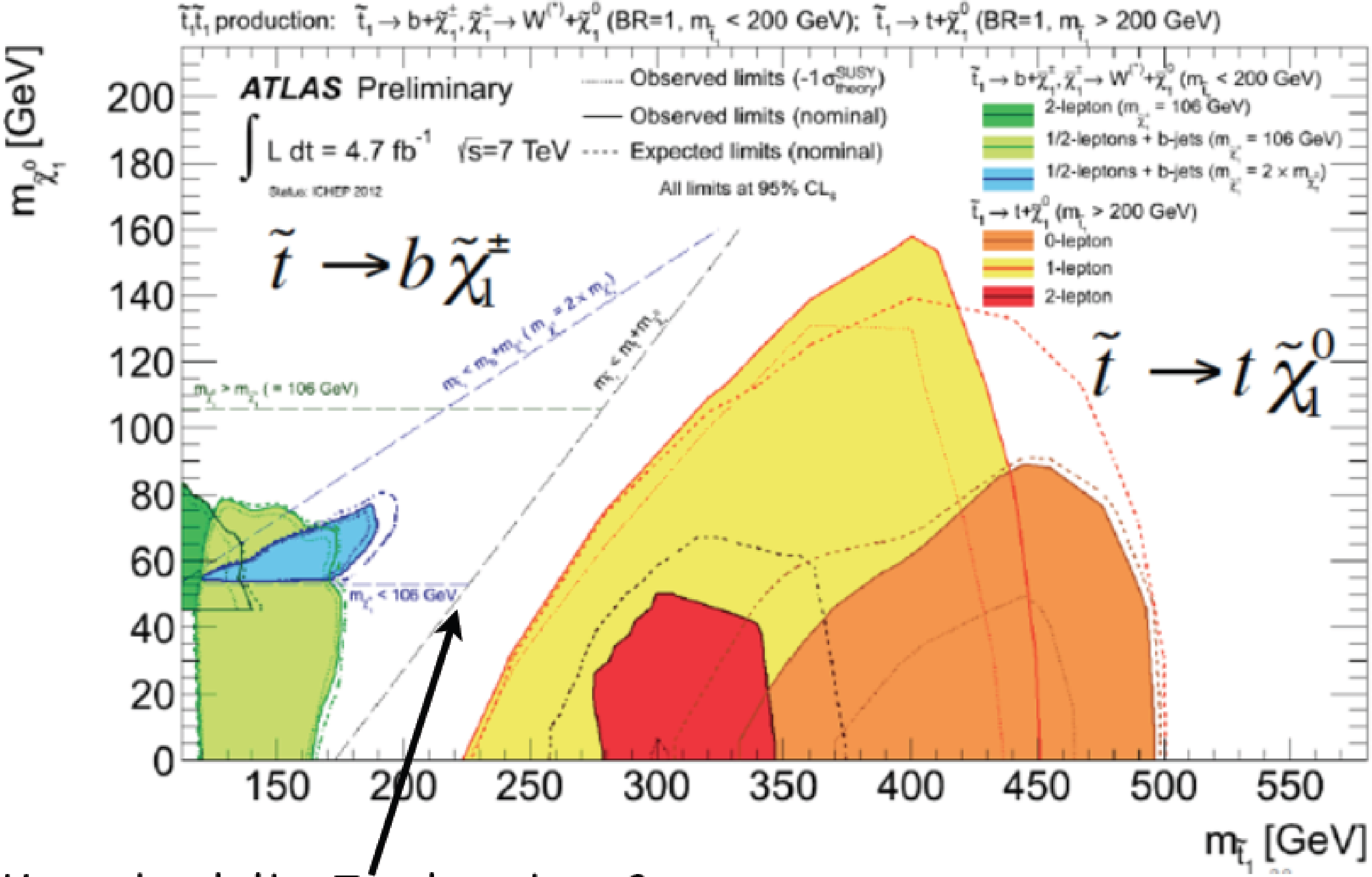
How can this arise?

recent papers, e.g.

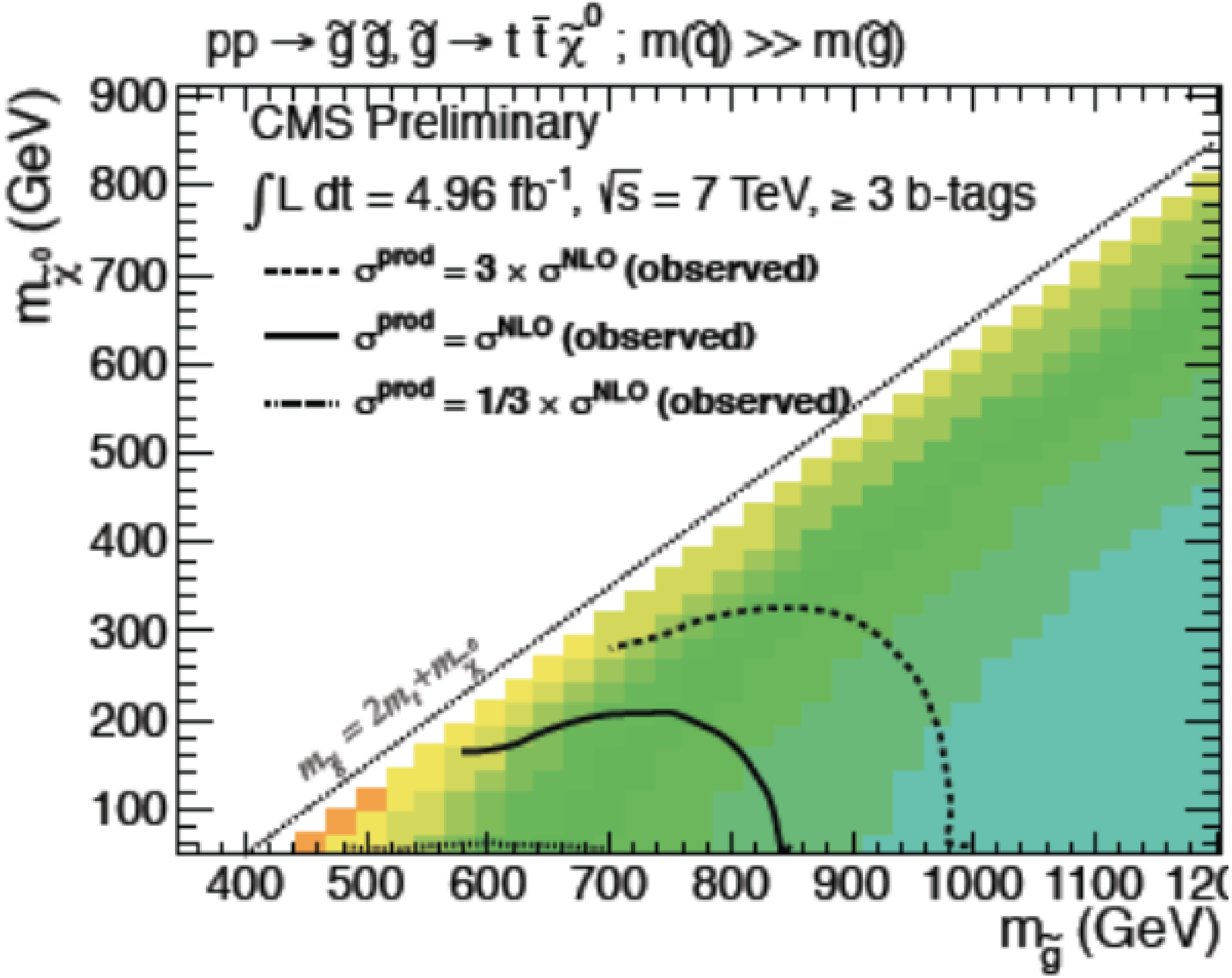
Papucci et al ‘11
Brust et al ‘11
Larsen et al ‘12
Csaki et al ‘12
.....

For g-2
light sleptons
welcome

Searches of light s-tops



How about the Tevatron here?


$pp \rightarrow \tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}\tilde{\chi}^0$; $m(\tilde{q}) >> m(\tilde{g})$
CMS Preliminary
$\int L\,dt = 4.96\ fb^{-1}$, $\sqrt{s} = 7$ TeV, ≥ 3 b-tags
$\sigma^{prod} = 3 \times \sigma^{NLO}$ (observed)
$\sigma^{prod} = \sigma^{NLO}$ (observed)
$\sigma^{prod} = 1/3 \times \sigma^{NLO}$ (observed)
$m_{\tilde{g}} = 2m_t + m_{\tilde{\chi}^0}$
$m_{\tilde{\chi}^0}$ (GeV)
900
800
700
600
500
400
300
200
100
400
500
600
700
800
900
1000
1100
120
$m_{\tilde{g}}$ (GeV)

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)

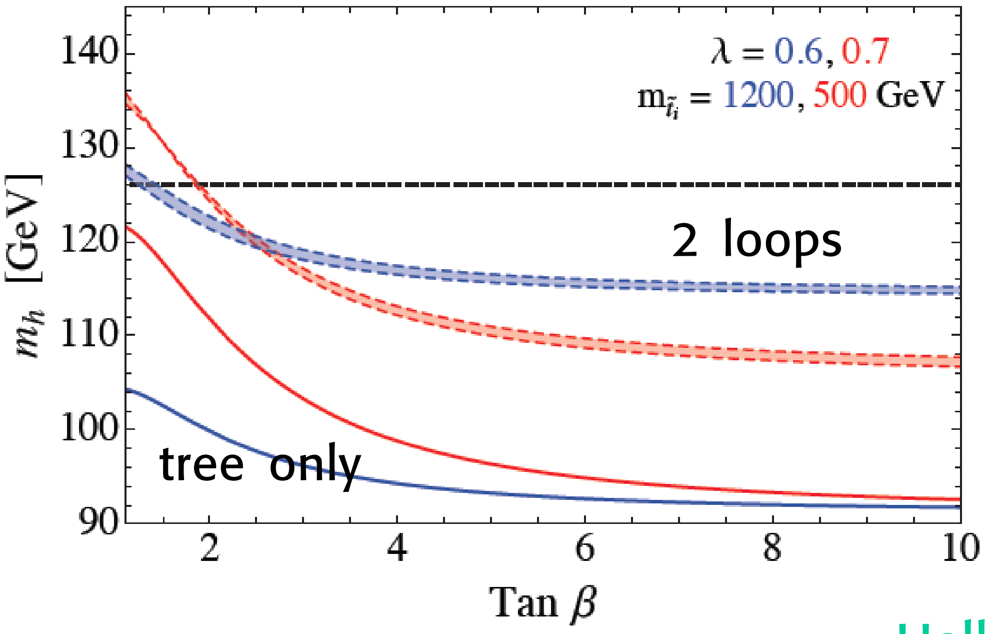
$$\lambda\, S H_u H_d$$

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

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

NMSSM Higgs Mass



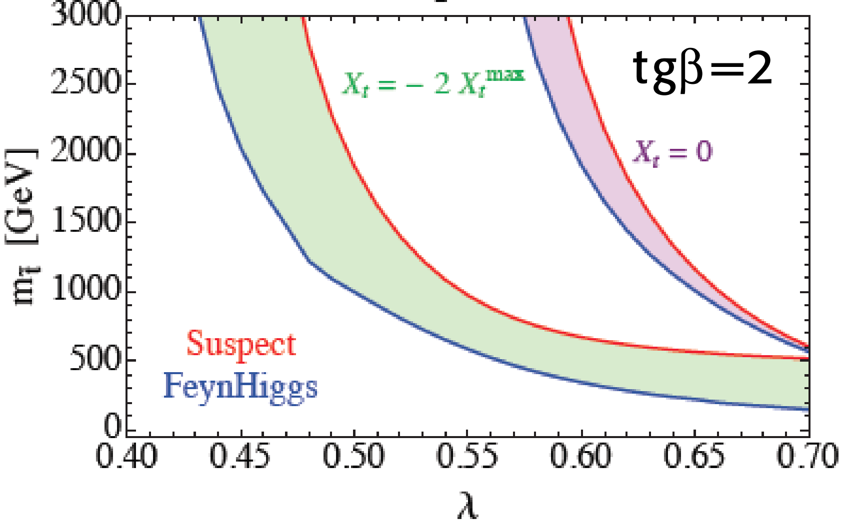
additional term

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

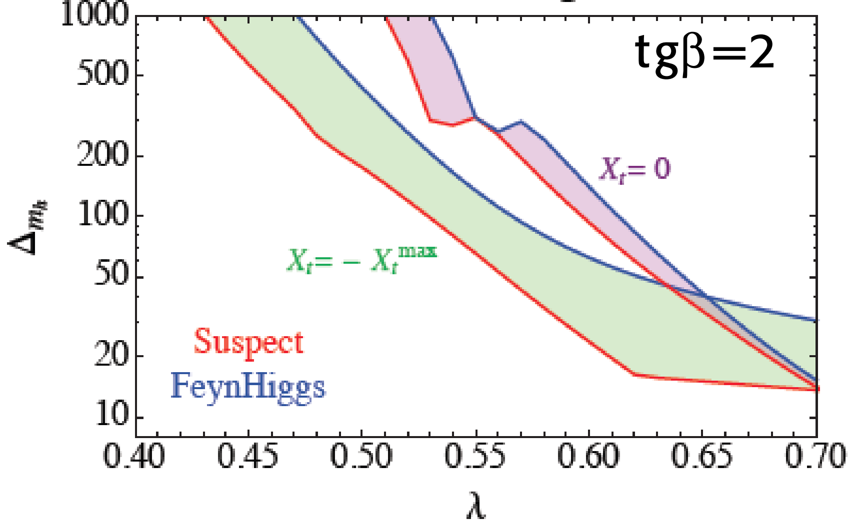
less need of loop terms
-> lighter s-top, less FT

Hall et al '11

Stop Mass

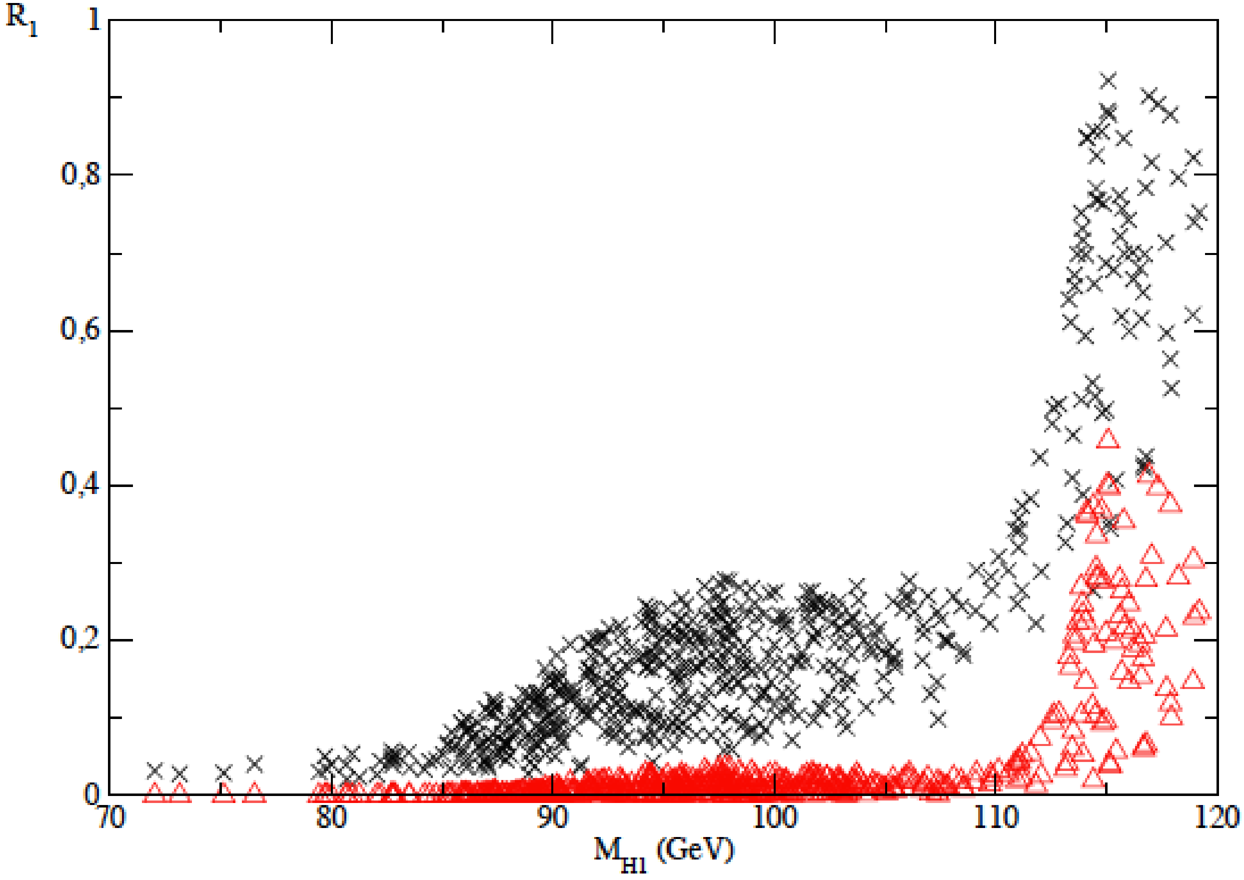


Fine Tuning



It is not excluded that at 125 GeV the heaviest of the two is seen and the lightest escaped detection at LEP

Ellwanger '11



the $\gamma\gamma$ and $\tau\tau$ couplings of the lightest higgs are suppressed

while enhanced for the heavier at 125 GeV

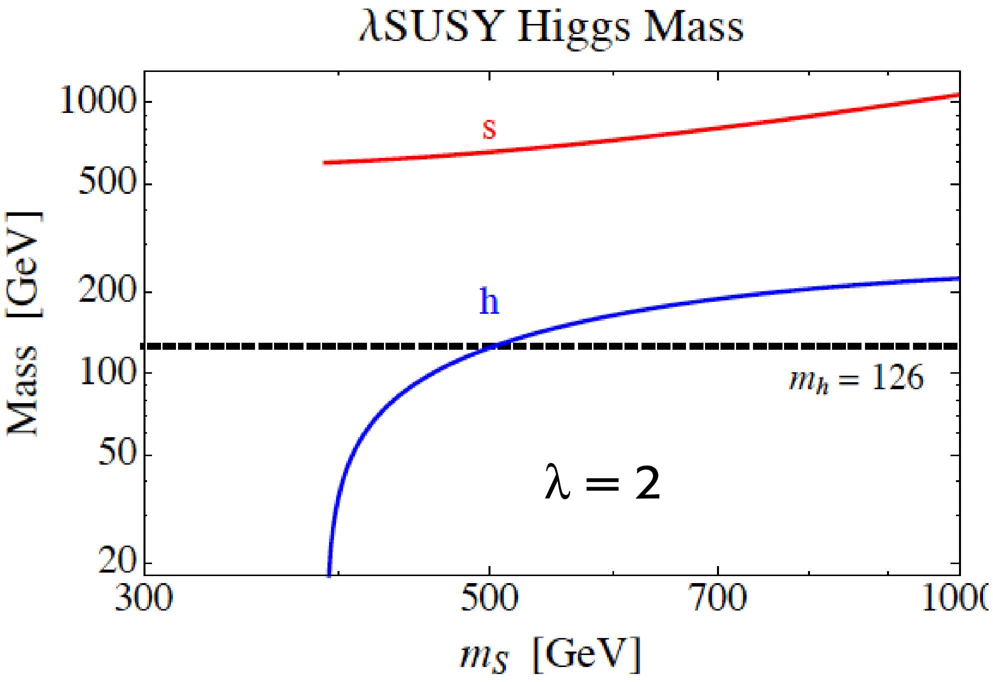
For $\lambda > 0.7$ the full mixing matrix must be considered

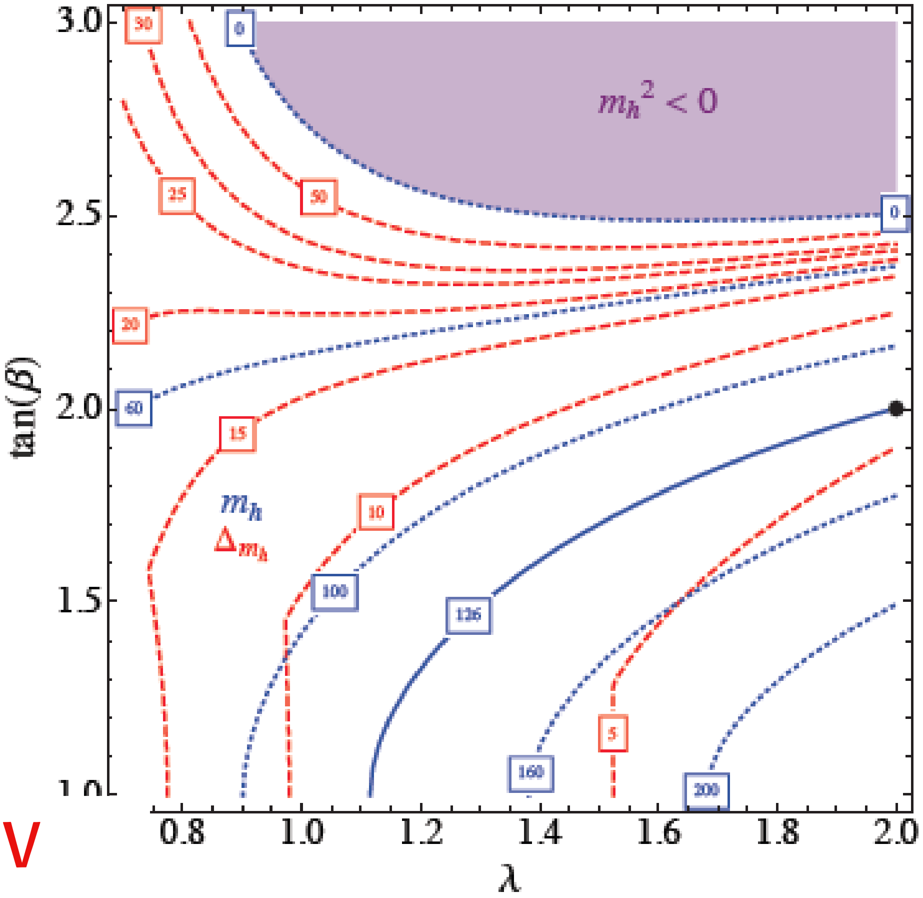
the λ term is too large, but mixing with S pushes H down

Hall et al '11

No need of loops

Fine tuning can be very small





But perturbativity is lost at ~10 TeV

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

I find applying the anthropic principle to the SM hierarchy problem still unmotivated and difficult to understand

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?

The case of the cosmological constant is a lot different: the context is not as fully specified as the for the SM (quantum gravity, string cosmology, branes in extra dims., wormholes thru different Universes....)

A possible anthropic route

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 e.g. $SU(4)xSU(2)_L xSU(2)_R$
at an intermediate scale (10^{11-12})
[coupling unification, p-decay OK]

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

Axions as dark matter

Baryogenesis thru leptogenesis

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

No new physics at the LHC (how sad!) except perhaps a Z'_{B-L} [$(g-2)_\mu$ and other present deviations from SM in colliders should be disposed of]

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 does not look to be a good predictor.

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 the multiverse and the anthropic philosophy are gaining credit and many unnatural models are appearing in the literature

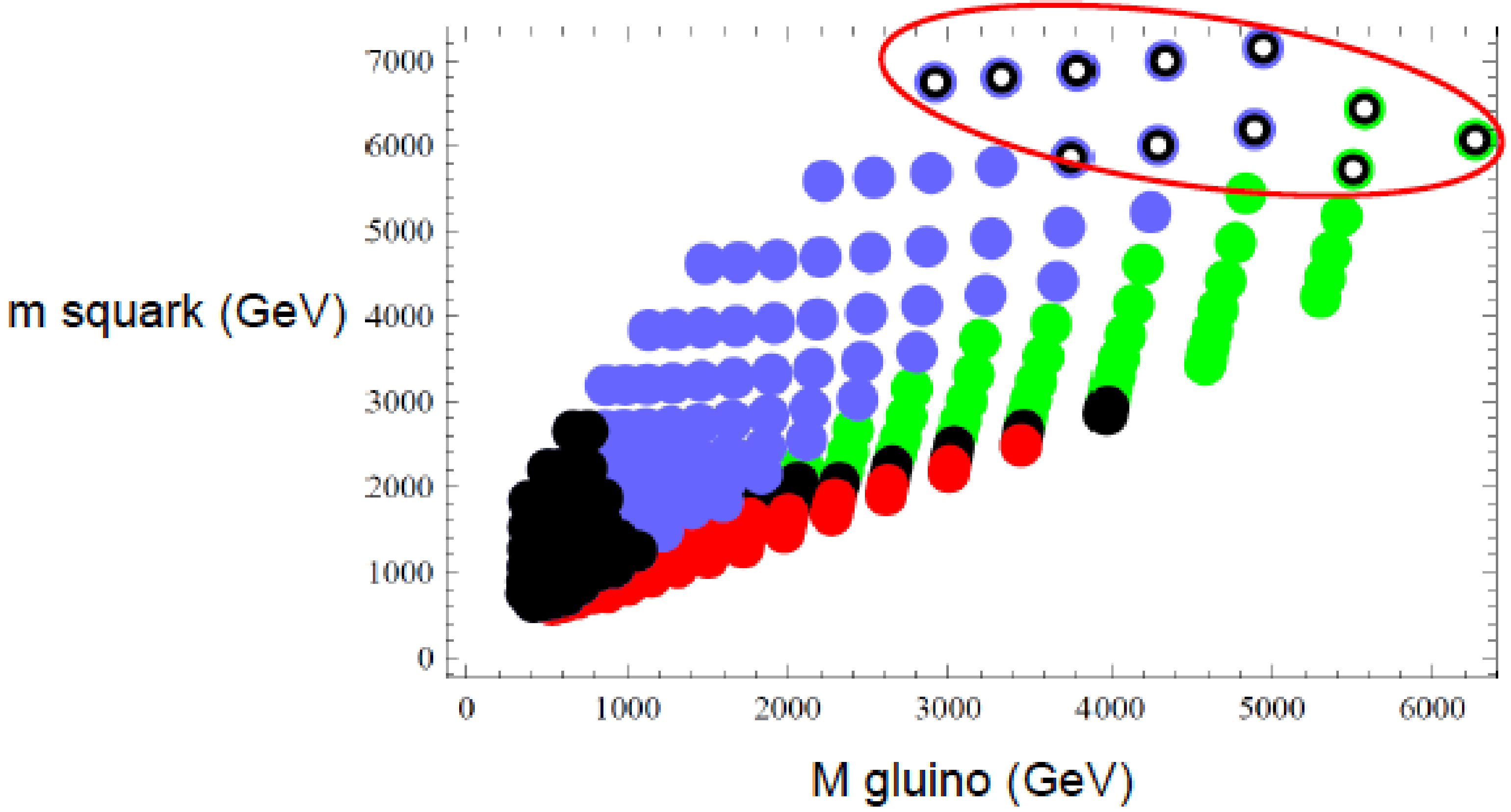
Buon Compleanno Roberto!

Pure GGM @ M=10^8 GeV what's left of…

Khoze

● Excluded by Jets&MET

● 125-127 GeV Higgs world



We are here?

gluino and
s-quarks
at 6-7 TeV!!

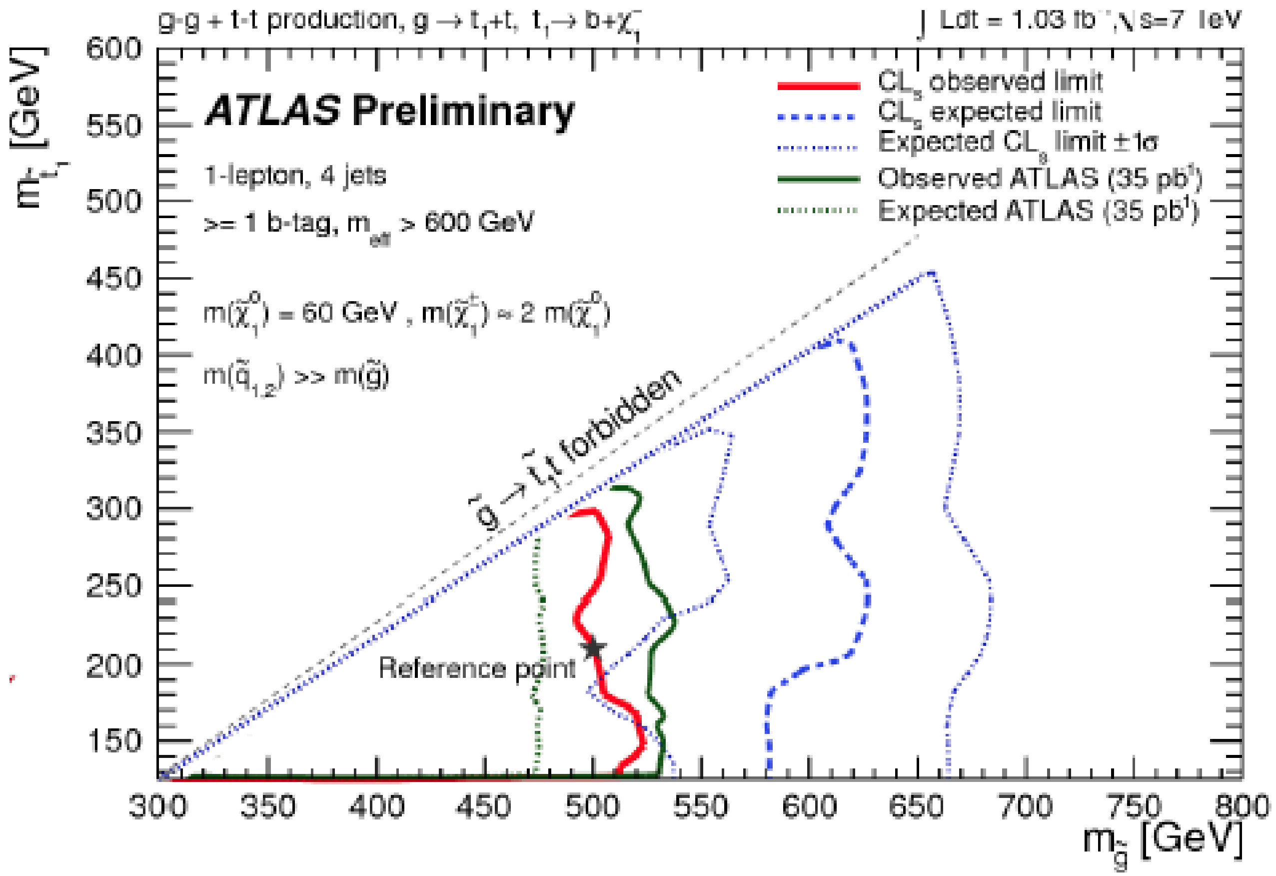
● Excluded 223 GeV stau

● Excluded 314 GeV stau

For example, may be gluinos decay into 3-gen squarks

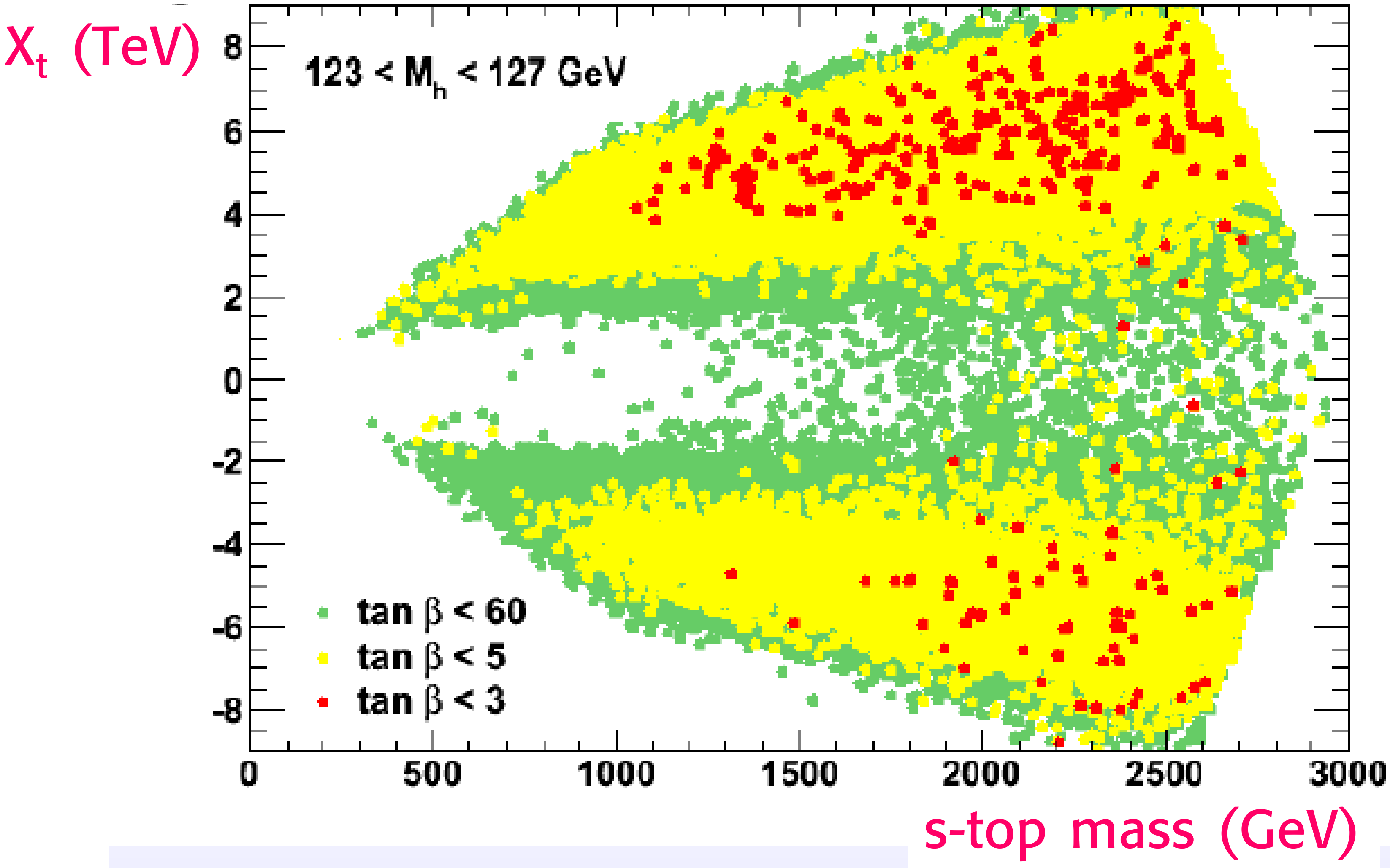
e.g. $\tilde{g} \to \tilde{t}_1 t$; $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$

and $\tilde{\chi}_1^{\pm} \to W^* \tilde{\chi}_1^{0}$



m(gluino) > 500 GeV at 95% C.L. $m_{s\text{-top}}$ >~250 GeV

Arbey et al ‘11

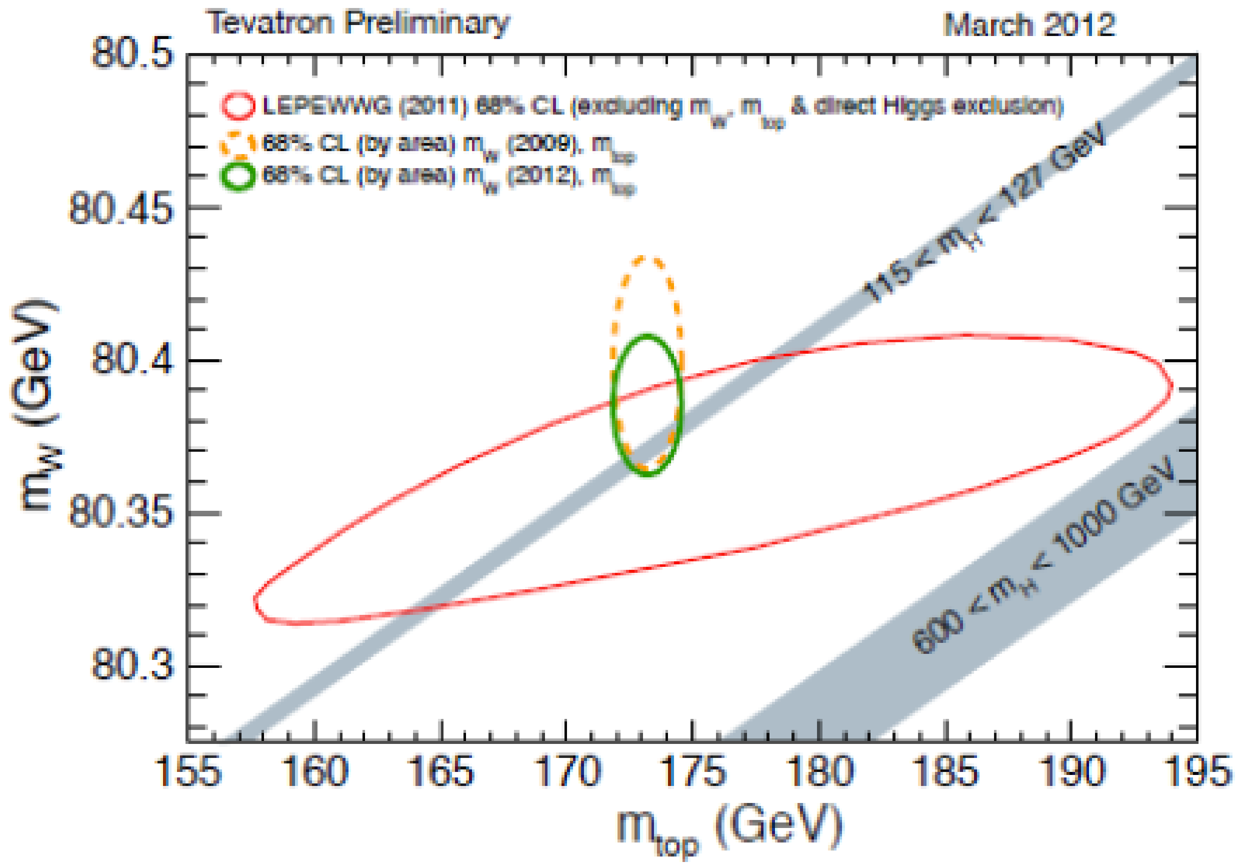


SUSY effects could improve the EW fit

"light SUSY"=
= light s-leptons
and charginos;
s-quarks >~1 TeV

G.A, Caravaglios,
Gambino, Giudice, Ridolfi '01

The same region
as for $(g\text{-}2)_\mu$



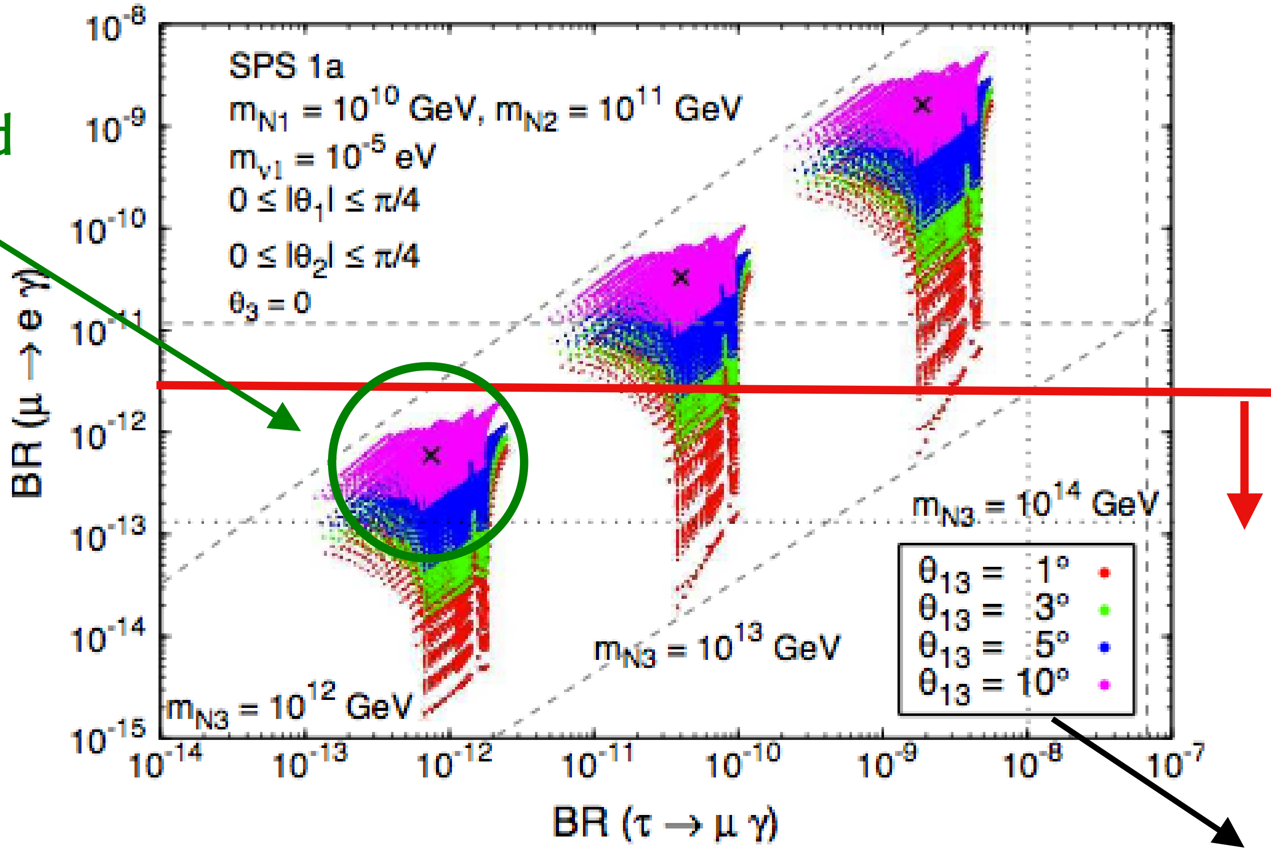
Very important new limit on lepton flavour violation

MEG ‘11 $\mathcal{B}(\mu^+ \to e^+\gamma) < 2.4\times10^{-12}$ (90% C.L.)

SM prediction ~ invisible

Antush et al ‘06

still allowed



SUSY
GUT CMSSM
with see-saw

MEG ‘11

$\theta_{13} \sim 9\pm1^0$

⊕ New Daya Bay, RENO ‘12 measurement of θ_{13} neutrino mixing angle

No neutron electric dipole moment

d_n violates P and T

$$\vec{d}_n = d\vec{\sigma} \qquad \vec{m}_n = \mu\vec{\sigma}$$

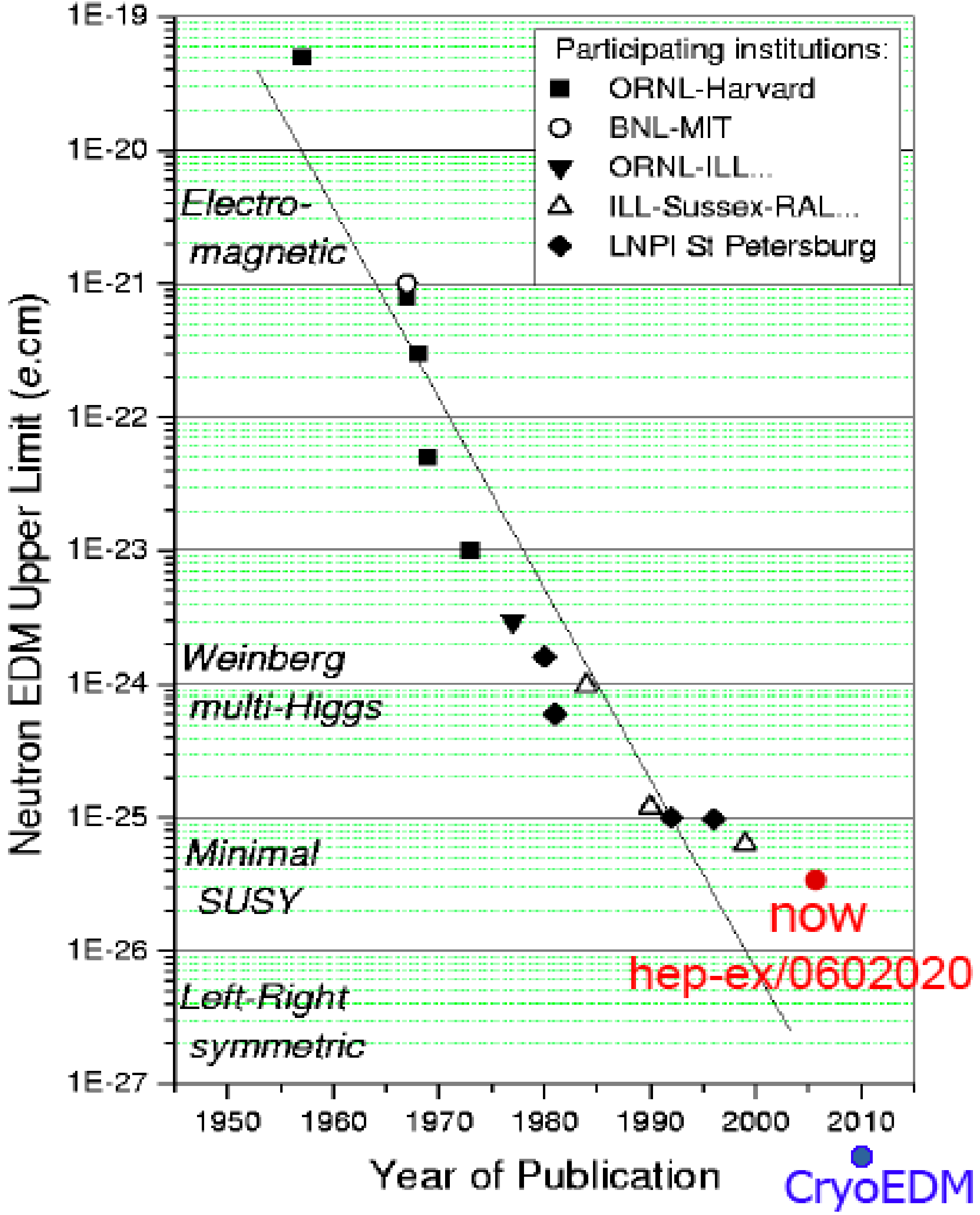
$$H \sim -(\vec{d}_n \cdot \vec{E} + \vec{m}_n \cdot \vec{B}) = -(d\vec{E} + \mu\vec{B}) \cdot \vec{\sigma}$$

E and B have opposite behaviour under P and T

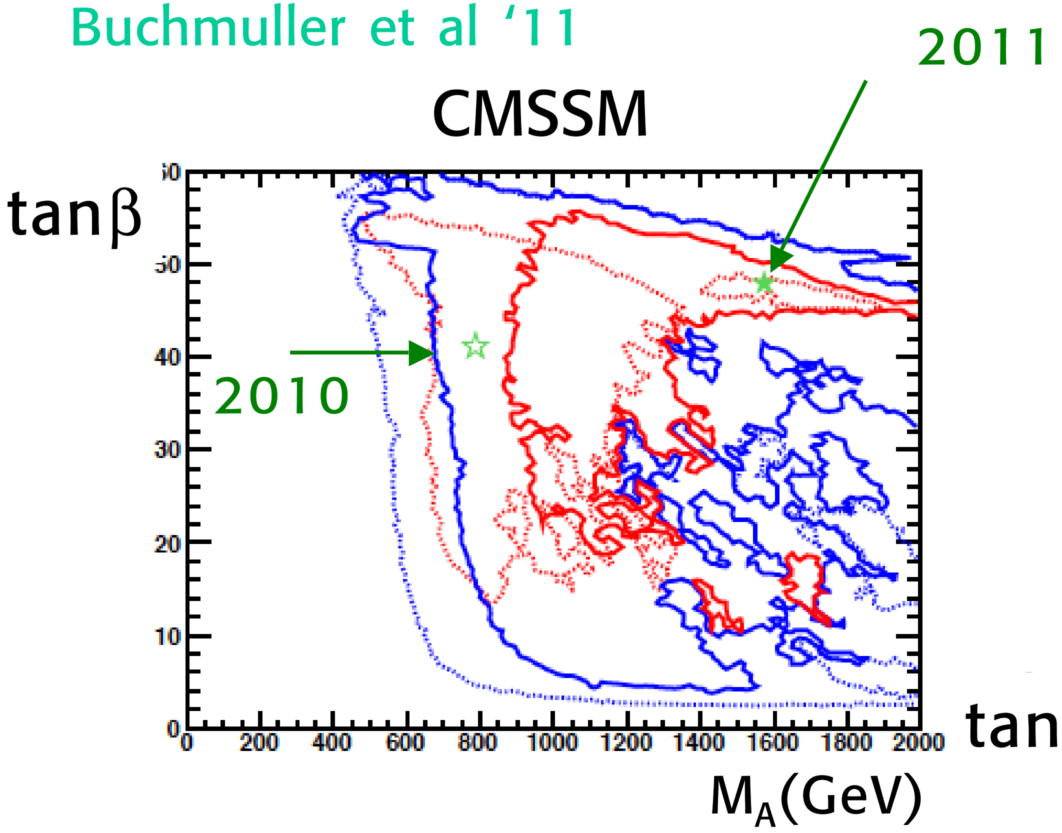
CPT is conserved, so
T violation implies CP violation

Present limit on d_n
from Grenoble

$|d_n| < 3\ 10^{-26}$ e cm (90%cl)



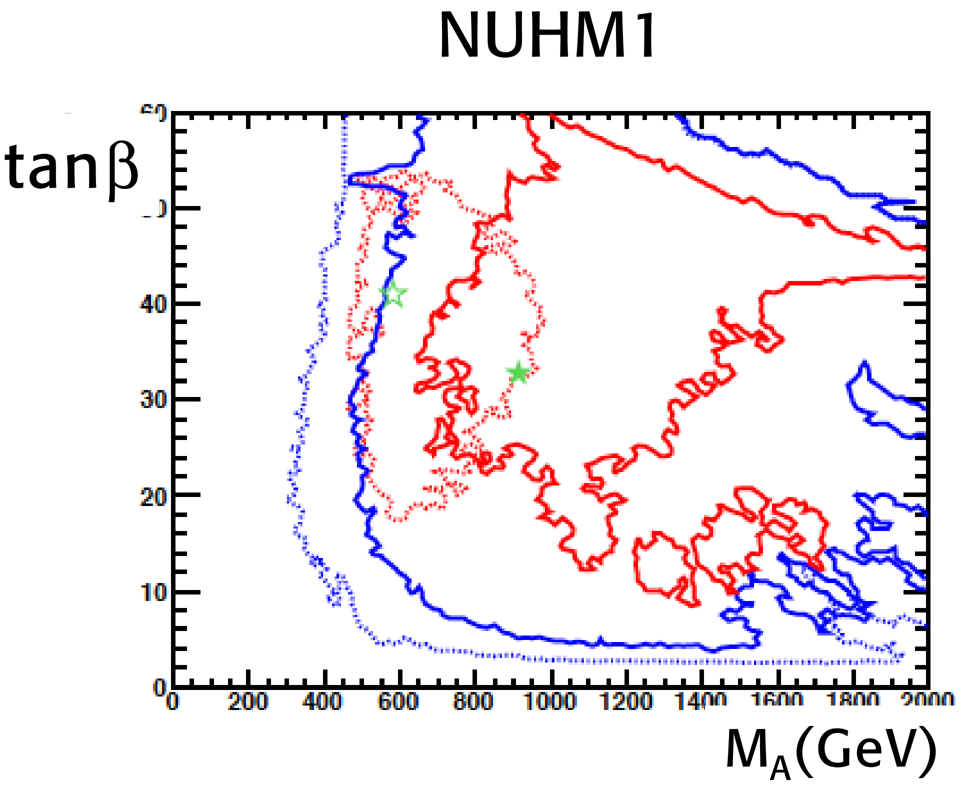
Buchmuller et al ‘11



heavier scalars with new data

g-2 in trouble

with g-2 m_H ~ 119 GeV
without g-2 m_H ~ 125 GeV



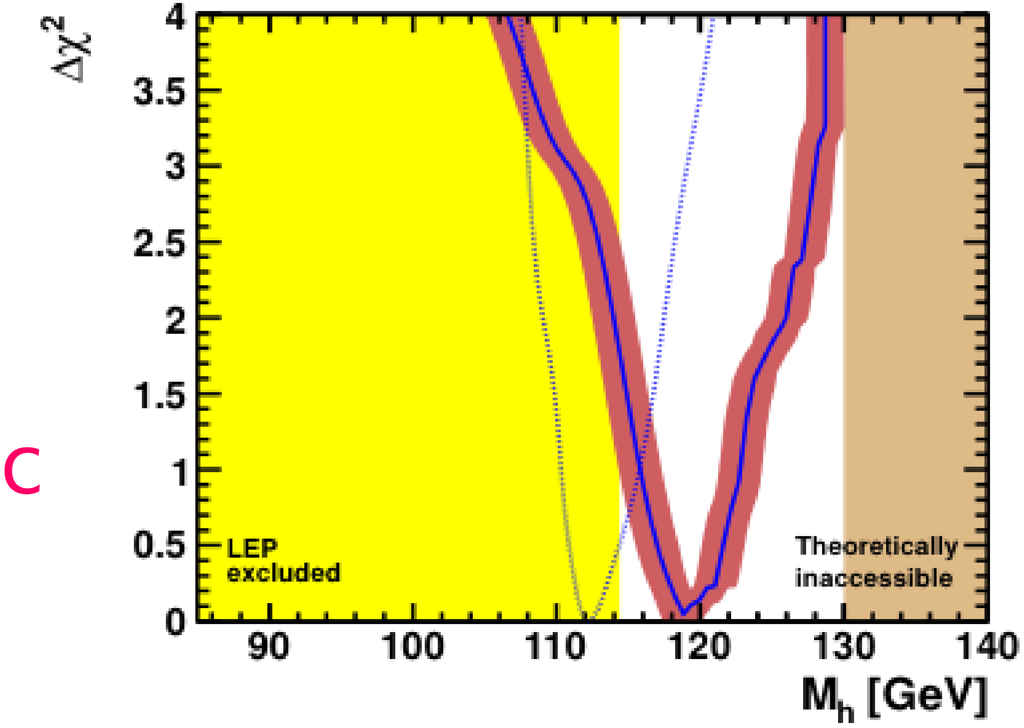
Extended EW precision tests

Before LHC ‘11

O. Buchmuller
et al ’07-’11

- The EW precision tests
- Muon g-2
- Flavour precision observables
- Dark Matter
- Higgs mass constraints and LHC

CMSSM:



⊕ m_h goes up in CMSSM when b->sγ, $(g-2)_\mu$, Ω_{DM} are added

A moderate enhancement of the $\gamma\gamma$ rate may be indicated

Ellwanger '11