Whither[†] SUSY?

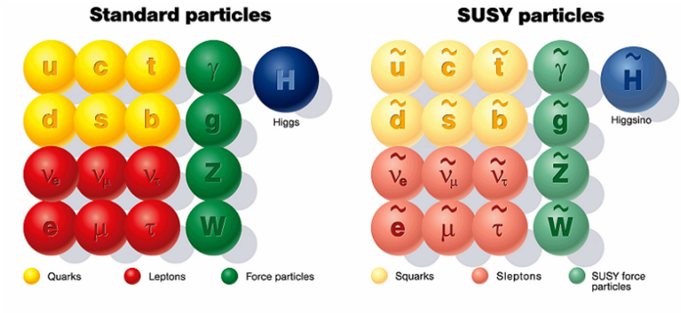
G. Ross, Birmingham, January 2013

†
whither *Archaic or poetic*
adv
1. to what place?
2. to what end or purpose?
conj
to whatever place, purpose, etc.
[Old English *hwider, hwæder;* related to Gothic *hvadrē;* modern English form influenced by HITHER]

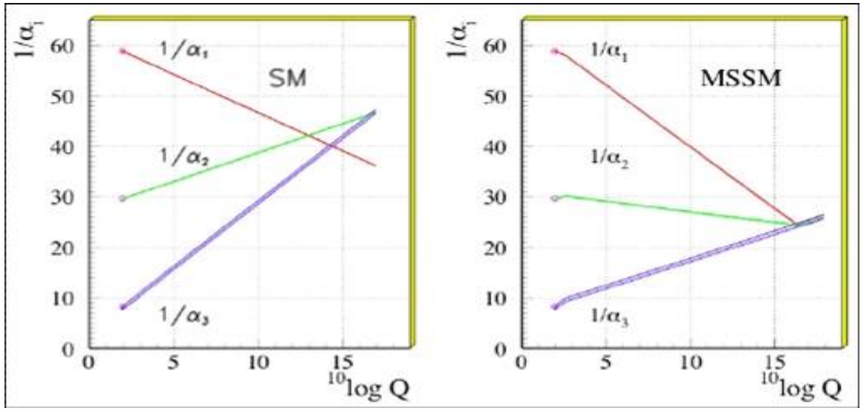
Low energy

SUSY – to what end or purpose?

^



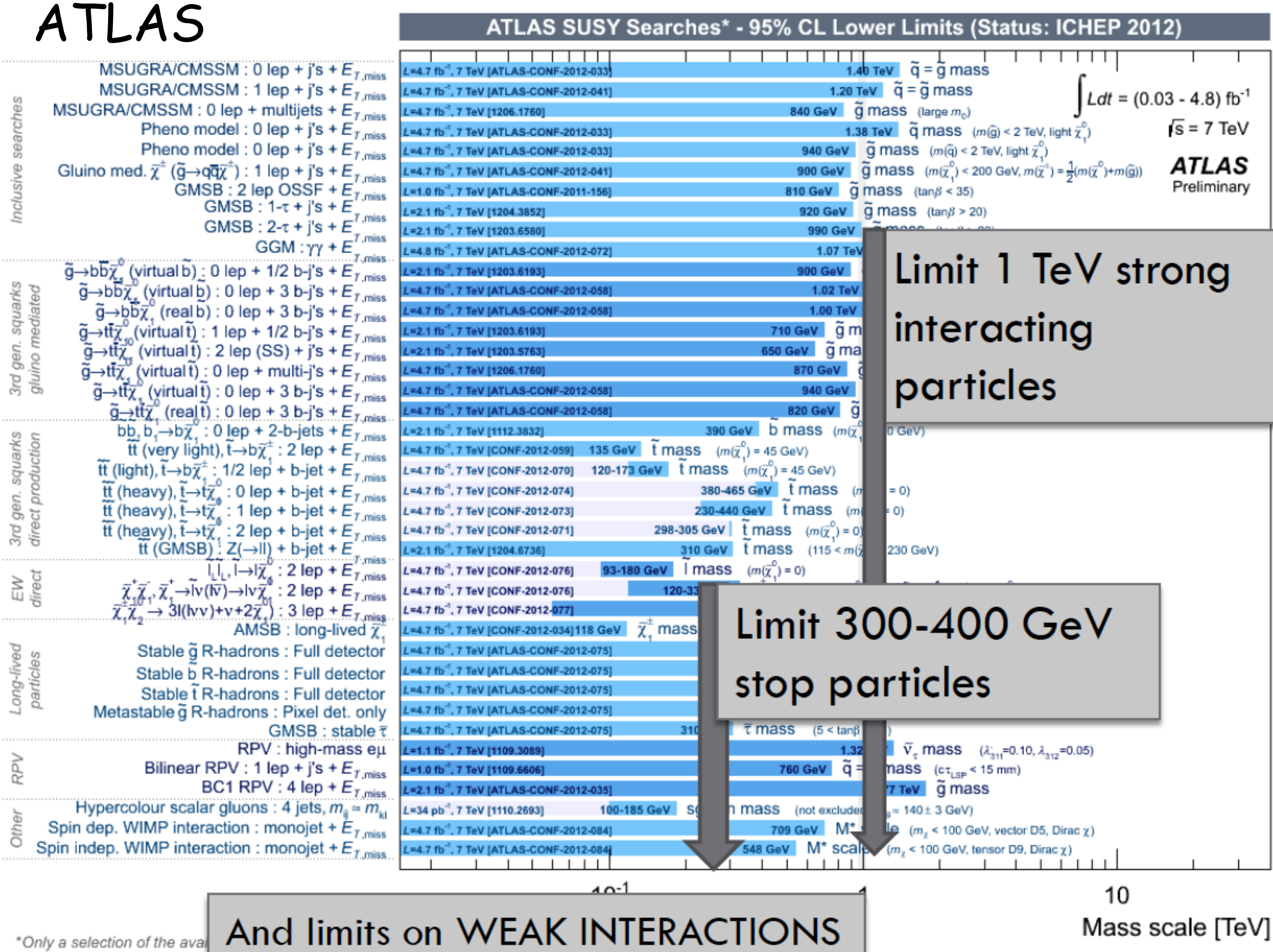
Unification: SU(5), SO(10),...



✔

The hierarchy problem: $M_{Higgs}, M_{W,Z} \ll M_{Planck}, M_{GUT}, ..$ ✔ (?)

ATLAS



Limit 1 TeV strong interacting particles

Limit 300-400 GeV stop particles

And limits on WEAK INTERACTIONS

SUSY - to what place?

Little hierarchy problem

^

MSSM: 105 +(19) Parameters

$$M_Z^2 = \sum_{\tilde{q},\tilde{l}} a_i \widetilde{m}_i^2 + \sum_{\tilde{g},\widetilde{W},\widetilde{B}} \widetilde{M}_i^2 + \ldots$$

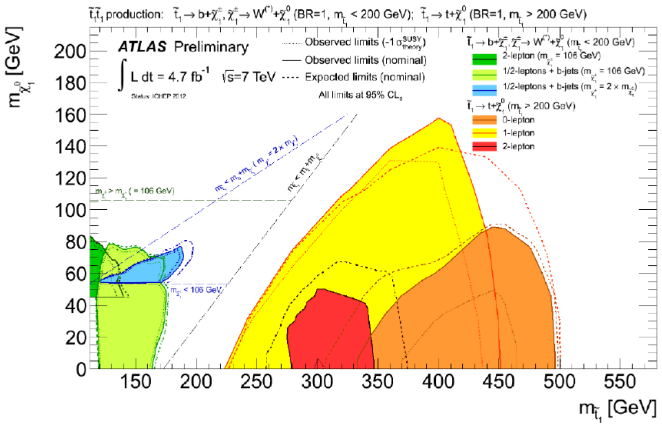
$$m_{\tilde{q}} > 0.6 - 1 TeV \quad \Rightarrow \quad \Delta > a\frac{\widetilde{m}^2}{M_Z^2} \sim 100$$

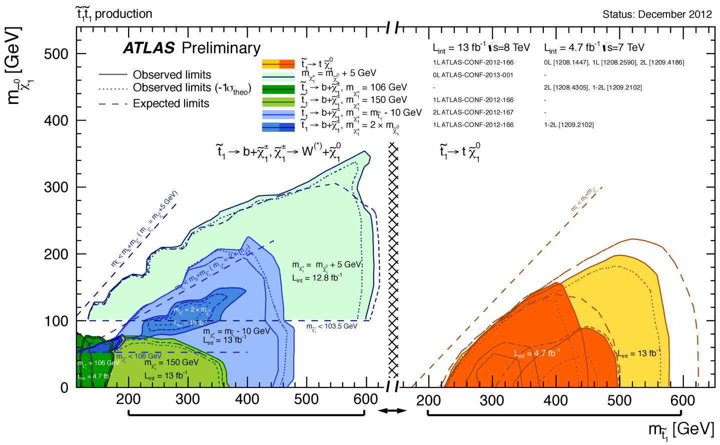
An exception: "Natural" SUSY

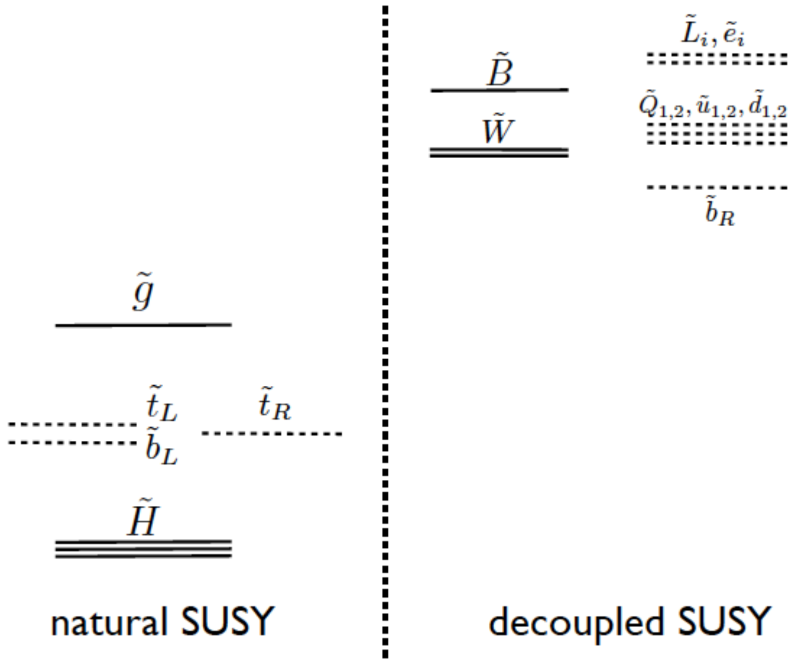
light stop $m_{\tilde{t},LHC} > 250\ GeV$

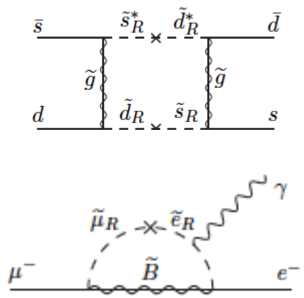
FCNC: 1,2 sgenerations heavy

Hierarchy problem: 3rd sgeneration light









The Higgs mass in SUSY ?

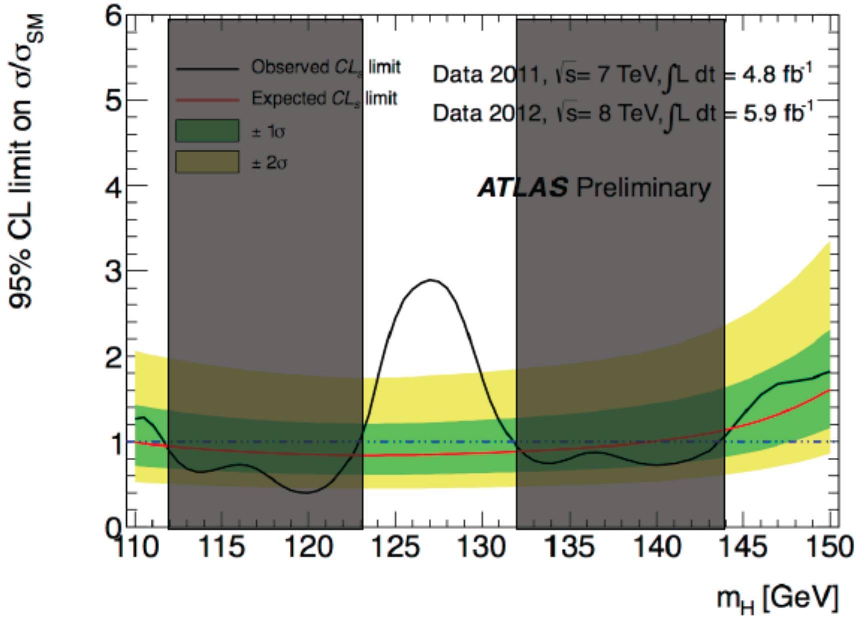
$$M_S^2 = m_{q_3} m_{U_3} \geq (900GeV)^2$$

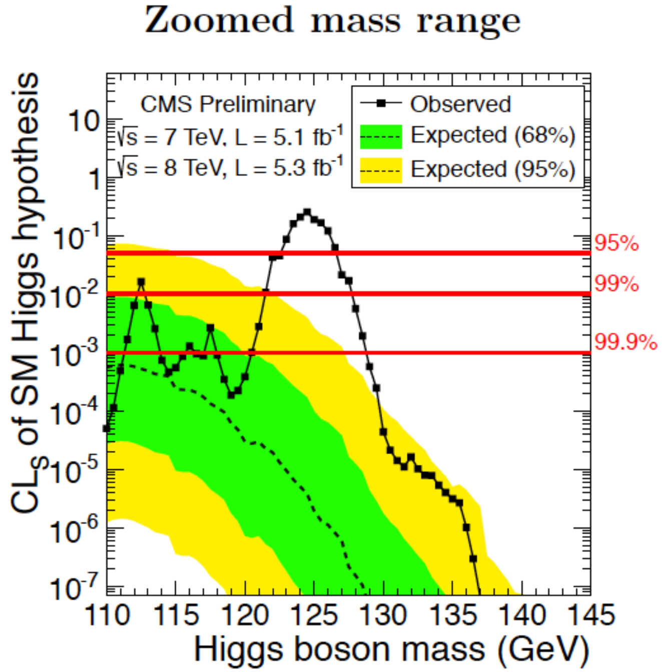
$$M_{h^0}^2 = M_Z^2 \cos^2 2\beta + \frac{3M_t^2 h_t^2}{4\pi^2}\left(\ln(\frac{M_S^2}{M_t^2}) + \delta_t\right) + \cdots \qquad \simeq 125GeV(LHC)$$

Atlas

CMS

- LHC July 2012





126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

at

5σ significance

125.3±0.6 GeV

at

4.9σ significance!

SUSY - to what place?

Little hierarchy problem $\Rightarrow$ definite SUSY structure
breaking ^

MSSM: 105 +(19) Parameters

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$$m_{\tilde{q}} > 0.6 - 1TeV \quad \Rightarrow \quad \Delta > a\frac{\widetilde{m}^2}{M_Z^2} \sim 100$$

$\Rightarrow$ Correlations between SUSY breaking parameters and/or additional low-scale states

SUSY searches - significance

SUSY parameters

$$L(\text{data}|\gamma_i^0) = \frac{1}{\Delta_q} L(\text{data}|\gamma_i; v_0, \beta, \tilde{y}_t(\beta), \tilde{y}_b(\beta))\Big|_{\beta=\beta_0(\gamma_i);\gamma_i=\gamma_i^0}$$

Likelihood

$$\delta\left(\mathrm{v}_0 - \left(-\frac{m^2(\gamma_i)}{\lambda(\gamma_i)} \right)^{1/2} \right)$$

Ghilencea, GGr

$$\Delta_q = \left(\sum_i \left| \frac{\gamma_i}{M_Z} \frac{\partial M_Z}{\partial \gamma_i} \right|^2 \right)^{1/2}$$

Ellis, Enquist, Nanopoulos, Zwirner

Barbieri, Giudice

Fine tuning measure

$$\Delta_q = 100, \quad \delta\chi^2 \sim 9, \quad \delta\chi^2 / d.o.f. \sim 1$$

Outline

I. The CMSSM

Scalar focus point

II. Reduced fine tuning

(G)NMSSM

Gaugino focus point

Natural SUSY

R-parity breaking

Supersoft SUSY breaking

Compressed spectrum

III. Implications of 125 GeV Higgs

I. The CMSSM

$\mu_0, m_0, m_{1/2}, A_0, B_0$

assume correlation between SUSY breaking parameters

$$v^2 = \frac{m^2}{\lambda}$$

$$\boxed{\Delta \equiv \max \left|\Delta_p\right|_{p=\{\mu_0^2, m_0^2, m_{1/2}^2, A_0^2, B_0^2\}}, \qquad \Delta_p \equiv \frac{\partial \ln v^2}{\partial \ln p}}$$

Couplings and masses evaluated to two loop (leading log) order

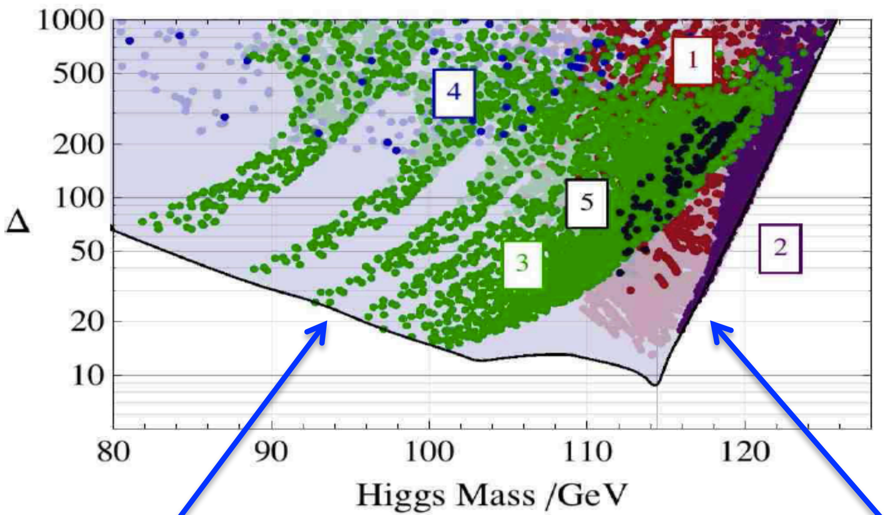
…enhanced sensitivity due to small tree-level $\lambda = \frac{1}{8}\left(g_1^2 + g_2^2\right)\cos^2 2\beta$

Cassel, Ghilencea, GGR
c.f. earlier work : Dimopoulos, Giudice
Chankowski, Ellis, Olechowski, Pokorski

e.g. CMSSM

$$\gamma_i \equiv \mu_0, m_0, m_{1/2}, A_0, B_0$$

Pre-LHC



Relic density restricted

1 h^0 resonant annihilation

2 $\tilde{h}$ t-channel exchange

3 $\tilde{\tau}$ co-annihilation

4 $\tilde{t}$ co-annihilation

• 5 A^0 / H^0 resonant annihilation

Within 3σ WMAP:

$\Delta_{Min} = 15, \quad m_h = 114.7 \pm 2GeV$

$<$ 3σ WMAP:

$\Delta_{Min} = 18, \quad m_h = 115.9 \pm 2GeV$

Cassel, Ghilencea, GGR

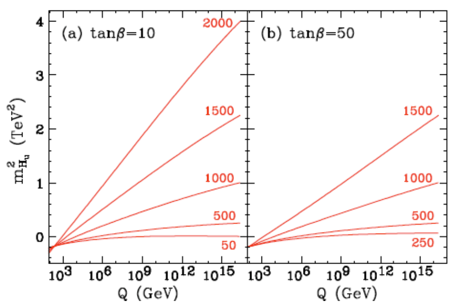
λ increases with m_H

$$v^2 = \frac{m^2}{\lambda}$$

Limit of RGE focus point

-natural cancellation of terms for

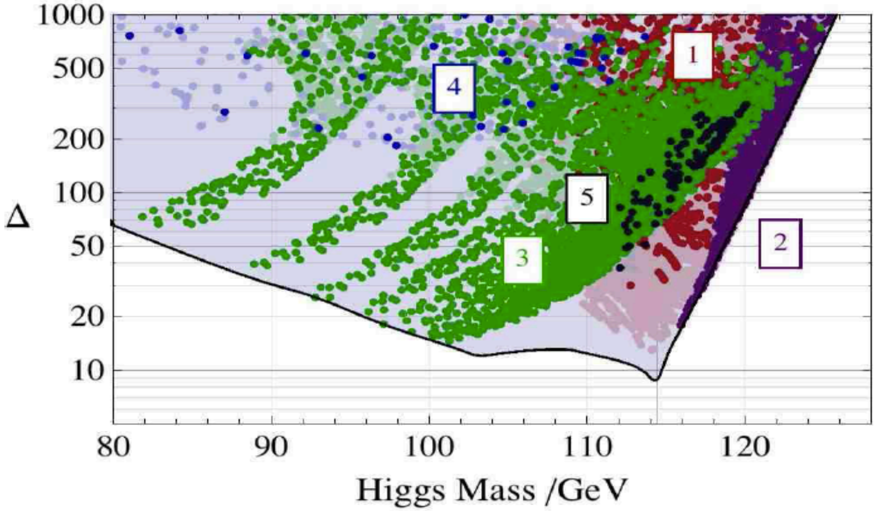
$$m_{H_U}(M_X) = m_{\tilde{t}_R}(M_X) = m_{\tilde{t}_L}(M_X) = m_0$$



$$m^2_{H_u}(Q^2) = m^2_{H_u}(M_P^2) + \frac{1}{2}\left(m^2_{H_u}(M_P^2) + m^2_{Q_3}(M_P^2) + m^2_{\bar{u}_3}(M_P^2)\right)\left[\left(\frac{Q^2}{M_P^2}\right)^{\frac{3y_t^2}{4\pi^2}} - 1\right]$$

e.g. CMSSM

$$\gamma_i \equiv \mu_0, m_0, m_{1/2}, A_0, B_0$$



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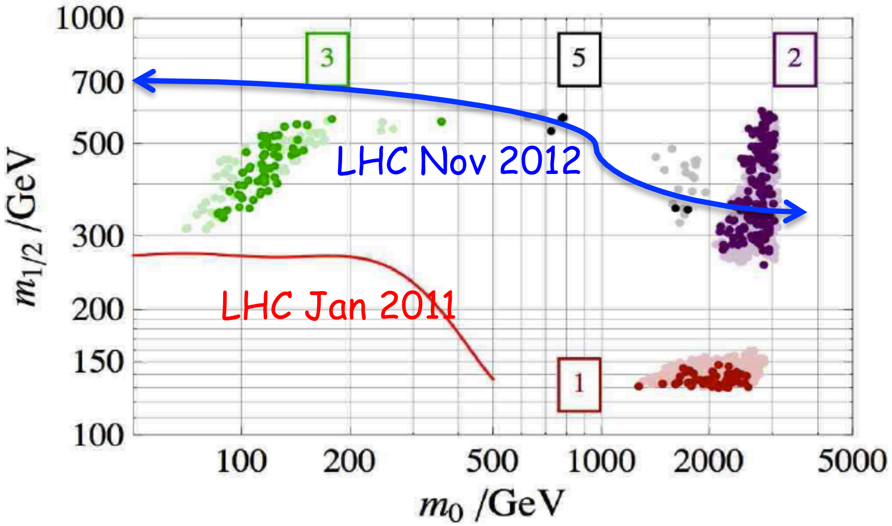
Direct SUSY searches:



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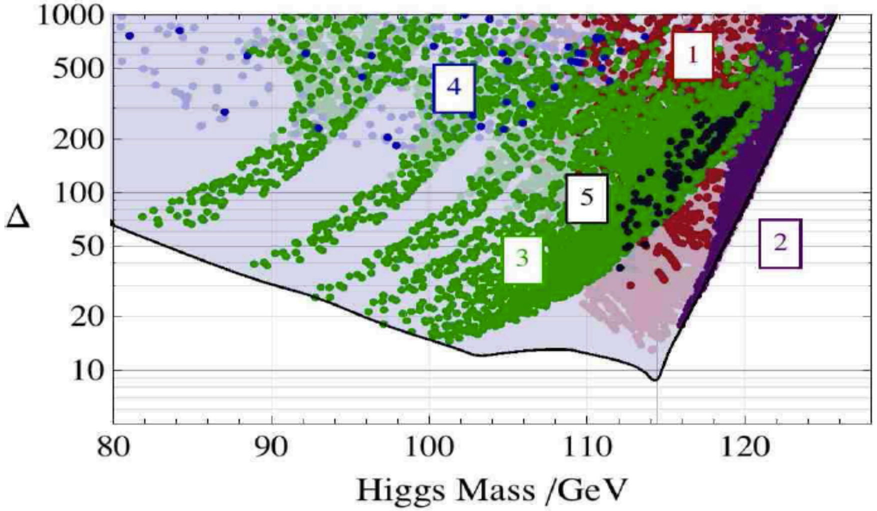

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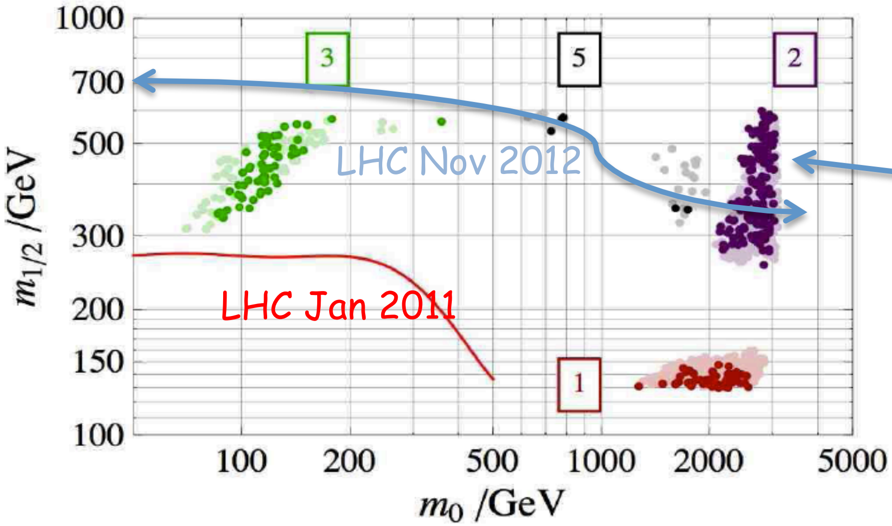
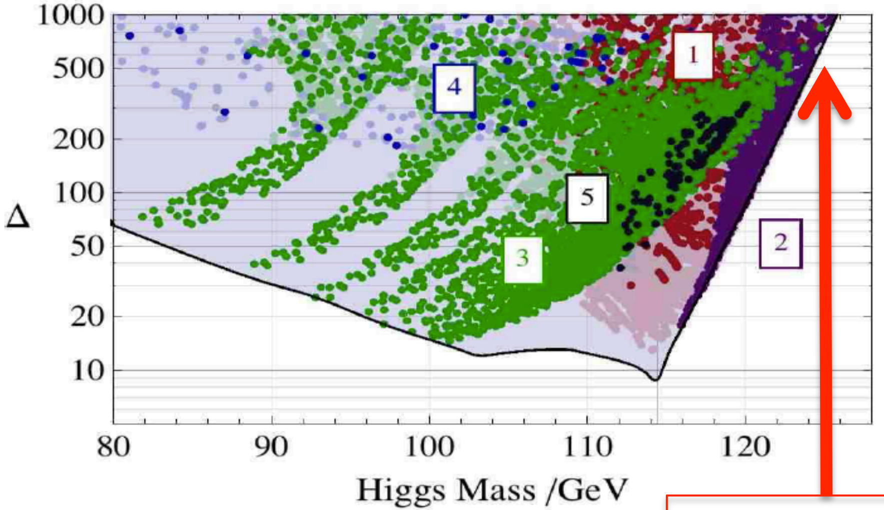


Significant Higgsino LSP component
-now excluded by XENON 100

e.g. CMSSM

$\gamma_i \equiv \mu_0, m_0, m_{1/2}, A_0, B_0$



$m_H > 125 GeV$

$\Delta > 300$

Relic density restricted

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Within 3σ WMAP:

$\Delta_{Min} = 15, \quad m_h = 114.7 \pm 2 GeV$

$< 3\sigma$ WMAP:

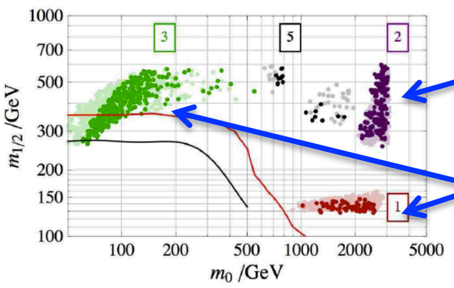
$\Delta_{Min} = 18, \quad m_h = 115.9 \pm 2 GeV$

CMSSM summary:

- Minimises MSSM fine tuning (focus point) (c.f. gauge mediation $\Delta >> \Delta_{CMSSM}$)

$$Max\left[\Delta_{EW}, \Delta_{\Omega}\right] = 15(29), \quad m_h = 114(116) \pm 2GeV$$

- Complementary DM & LHC searches



(a) $m_h > 111$ GeV

DM $\Delta \leq 100$ Sensitivity $\times (10-100)$ (Now achieved!)

LHC $\left(\text{Full region } LHC \ 14TeV \ 10 fb^{-1}\right)$

- *BUT* $\Delta > 300$ for $m_H = 126GeV$

(If give up on unification of soft parameters fine tuning reduced by factor ~ 10)

II. Reduced fine tuning :

…more correlations between parameters…later

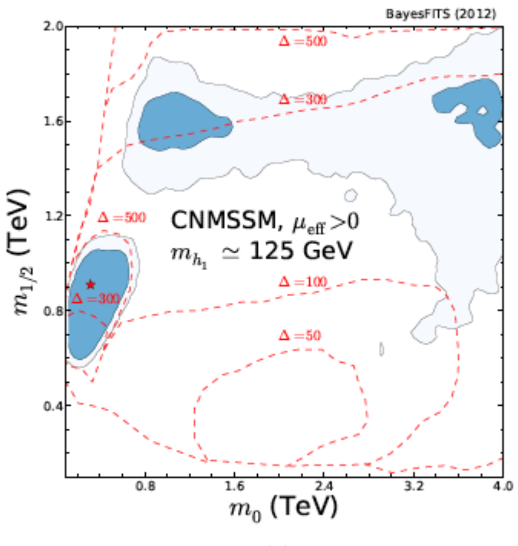
…beyond the MSSM

e.g. singlet extensions – the NMSSM

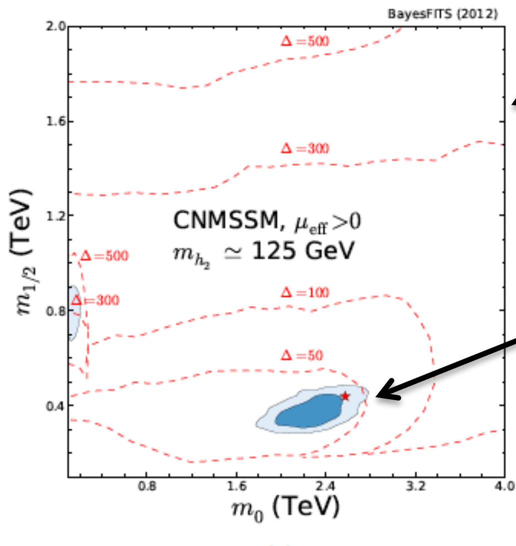
$$W = W_{\text{Yukawa}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$$

Additional quartic interaction $\delta V = \left|\lambda H_u H_d\right|^2$

Fine tuning in the NMSSM $(\lambda \leq 0.7^{\dagger})$



(a)

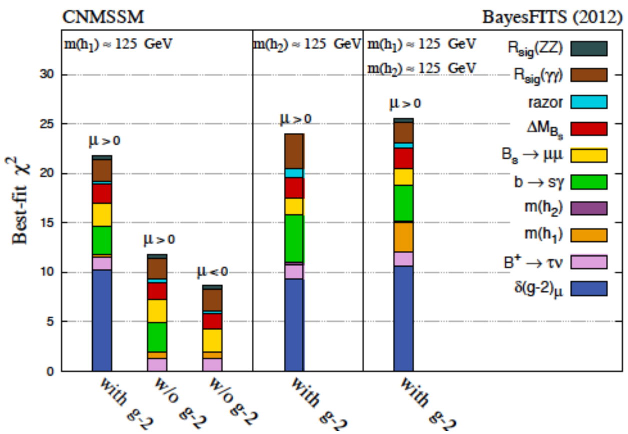


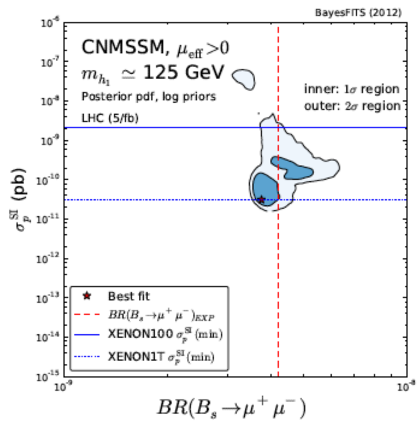
(b)

Higgs not lightest scalar

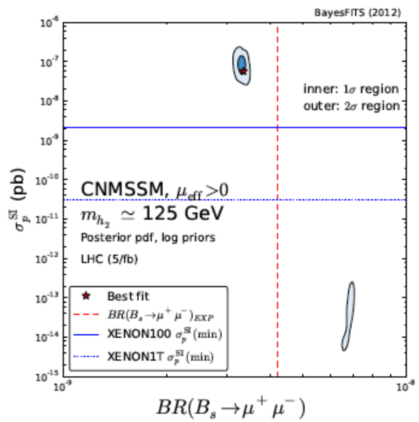
Focus-point; DM exclusion

$(\Delta_{h_t}$ not included)





(a)



(b)

Kowalska, Munir, Roszkowski, Sessolo, Trojanowski, Tsai

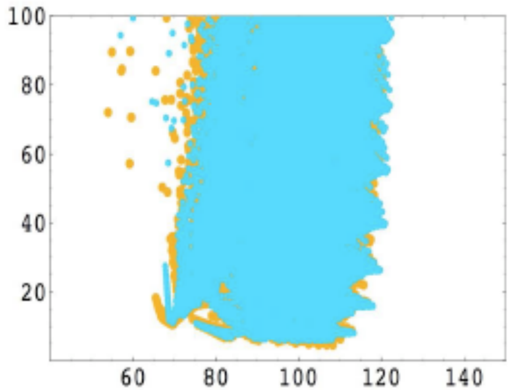
Reduced fine tuning : BMSSM - General Operator analysis

$$\delta L = \int d^2\theta \frac{1}{M_*}(\mu_0 + c_0 S)(H_1 H_2)^2 , \quad S = m_0 \theta\theta$$

Dimension 5

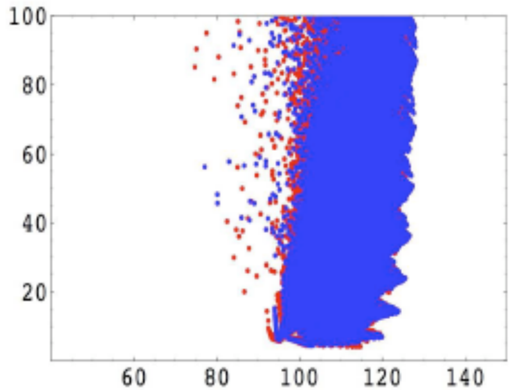
$$\delta V = \varsigma_1 \left(|h_1|^2 + |h_2|^2\right) h_1 h_2 + \varsigma_2 (h_1 h_2)^2 ; \quad \varsigma_1 = \frac{\mu_0}{M_*}, \ \varsigma_2 = \frac{c_0 m_0}{M_*}$$

Δ



m_h

MSSM



m_h

+ dim 5 operators

Cassel, Ghilencea, GGR
Casas, Espinosa, Hidalgo
Dine, Seiberg, Thomas
Batra, Delgardo, Tait
Kaplan,

…effect mainly comes from $\varsigma_1 |h_1|^2 h_1 h_2$ term … origin?

Reduced fine tuning : singlet extensions

$$W = W_{\text{Yukawa}} + (\mu + \lambda S) H_u H_d + \frac{\mu_S}{2} S^2 + \frac{\kappa}{3} S^3 + \xi S$$ GNMSSM

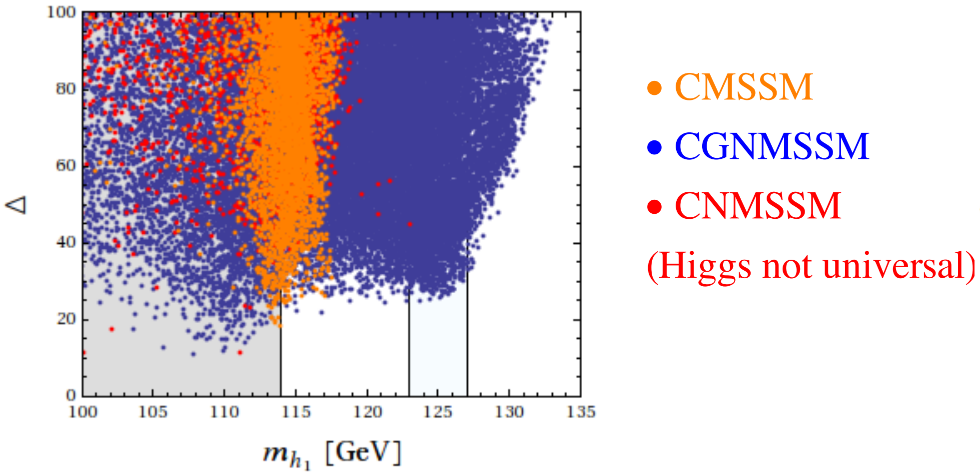
$\mu_S >> m_{3/2}$

$W_{eff}^{GNMSSM} = (H_u H_d)^2 / \mu_s + \mu H_u H_d$

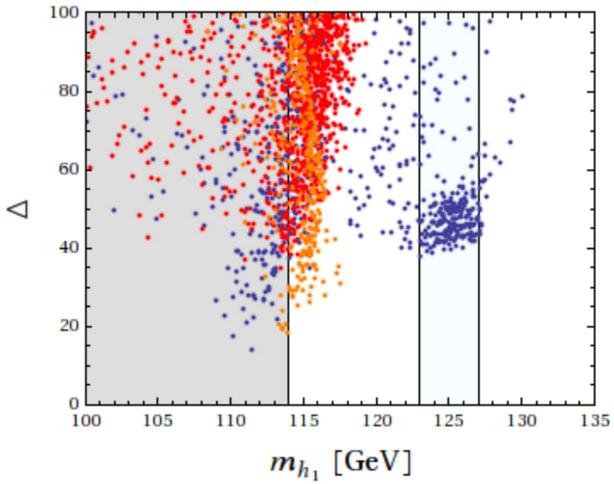
c.f. $W = W_{\text{Yukawa}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$ NMSSM

$\frac{\mu}{\mu_S}\left(|H_u|^2 + |H_d|^2\right) H_u H_d \longrightarrow v^2 = -\frac{m^2}{\lambda}$

Reduced fine tuning mainly for GNMSSM



LHC constraints applied



LHC +DM constraints applied

GGR, Schmidt-Hoberg , Staub

† c.f. Hall, Pinner, Ruderman

GNMSSM

$$W = W_{\text{Yukawa}} + (\mu + \lambda S)H_u H_d + \frac{\mu_S}{2}S^2 + \frac{\kappa}{3}S^3 + \xi S$$

R-symmetry ensures Singlet extensions natural

GNMSSM

$$W = W_{\text{Yukawa}} + (\mu + \lambda S)H_u H_d + \frac{\mu_S}{2}S^2 + \frac{\kappa}{3}S^3 + \xi S$$

NMSSM spectrum
No perturbative μ term
Commutes with SO(10)
Anomaly cancellation

N	q_{10}	$q_{\bar{5}}$	q_{H_u}	q_{H_d}	q_S
4	1	1	0	0	2
8	1	5	0	4	6

R-symmetry ensures singlets light

D=5 operators

up and down Yukawas allowed

$$3q_{10} + q_{\bar{5}} + q_{H_u} + q_{H_d} = 4 \quad \text{Mod N} \quad \Rightarrow \quad 3q_{10} + q_{\bar{5}} = 0 \quad \text{Mod N} \quad \Rightarrow \quad \frac{1}{M}\cancel{QQQL} \qquad \frac{1}{M}LLH_uH_u$$

Weinberg operator

SUSY breaking

$\langle W\rangle, \langle\lambda\lambda\rangle$ R=2 non=perturbative breaking

$Z^R_{4,8} \rightarrow Z^R_2 \quad R-parity$

Domain walls and tadpoles safe   Abel

$\mu \sim m_{3/2}, \quad O(\frac{m_{3/2}}{M^2}QQQL)$

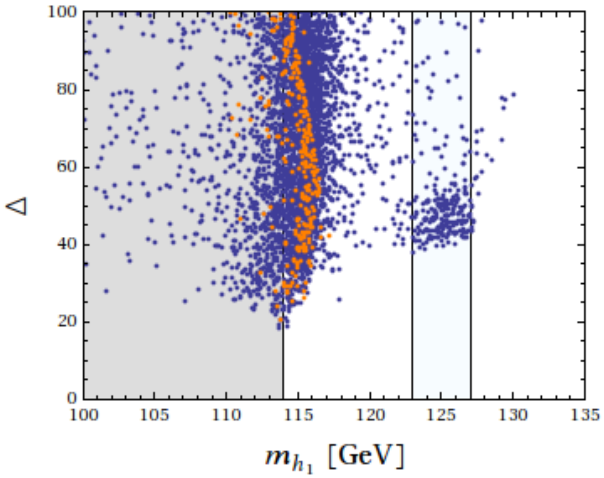
$$\boxed{\begin{aligned} W &= W_{MSSM} + \lambda S H_u H_d + \kappa S^3 + \Delta W \\ \Delta W_{Z_4^R} &\sim m_{3/2} H_u H_d + m_{3/2}^2 S + m_{3/2} S^2 \\ \Delta W_{Z_8^R} &\sim m_{3/2}^2 S \end{aligned}}$$

$\longleftarrow$ μ term and mass terms “natural”

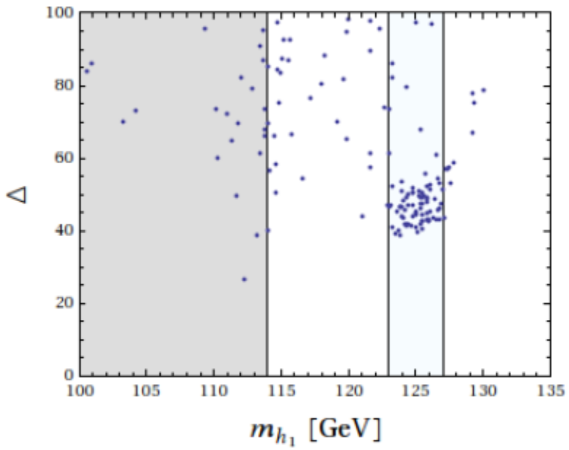
GNMSSM (c.f. NMSSM)

GENERAL-NMSSM PHENOMENOLOGY

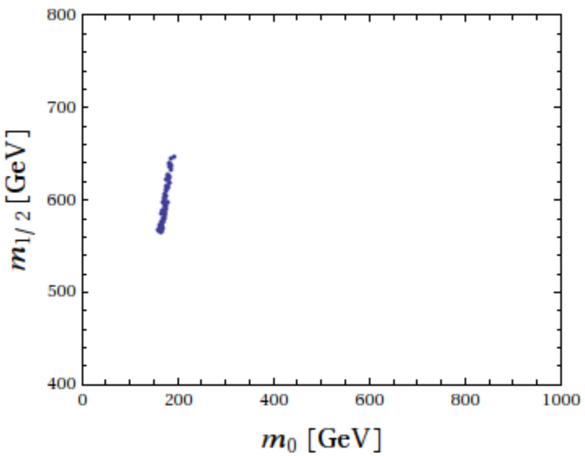
Dark Matter structure



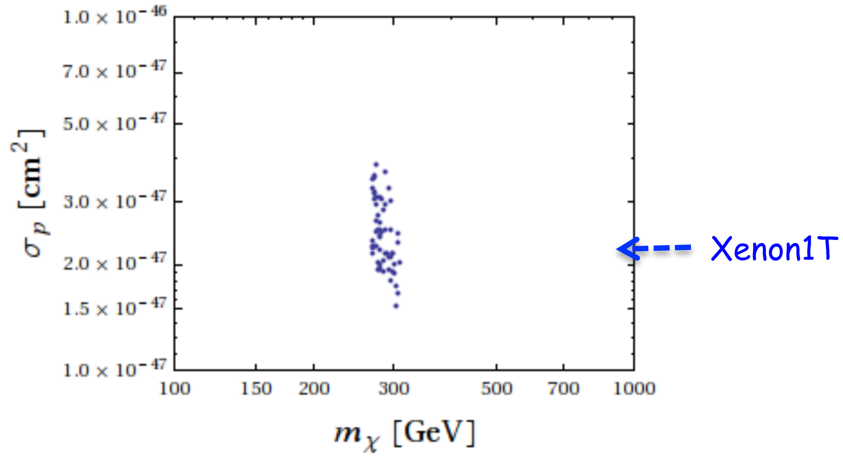
$(\rho_{LSP} \leq \rho_{DM})$



$(\rho_{LSP} \approx \rho_{DM})$



Stau co-annihilation



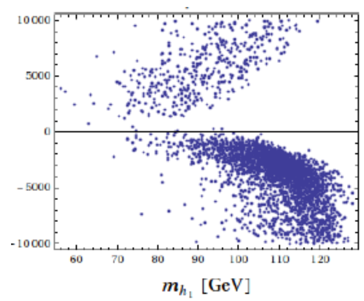
DM searches insensitive

GENERAL-NMSSM PHENOMENOLOGY

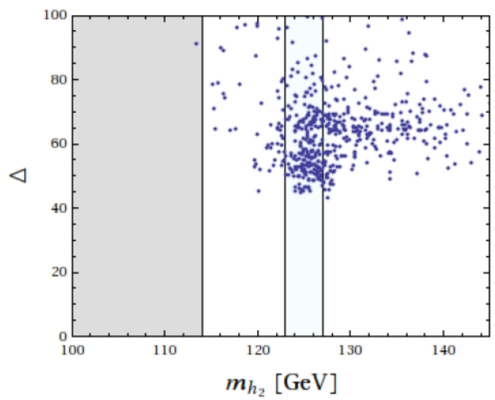
Higgs structure $\quad (h_u, h_d, s)$

- $\mu_s \gg \mu$ MSSM SUSY structure with heavy Higgs

- $\mu_s, m_s, b_s \sim \mu$ $\quad h_1 \simeq H_{u,d} + \varepsilon S, \quad h_2 = S - \varepsilon H_{u,d}$



$\ldots h_2$ may be lighter than LEP bound



m_{h_1} v/s Δ for the case $m_{h_2} < m_{h_1}$

GENERAL-NMSSM PHENOMENOLOGY

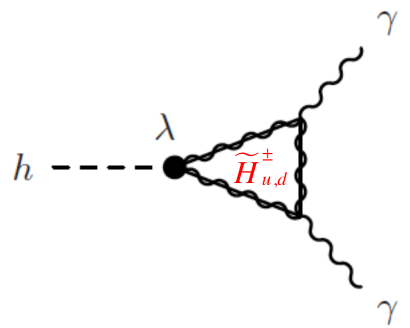
Higgs structure (h_u, h_d, s)

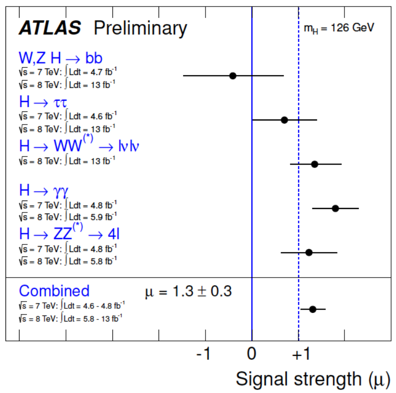
- $\mu_s \gg \mu$ MSSM SUSY structure with heavy Higgs

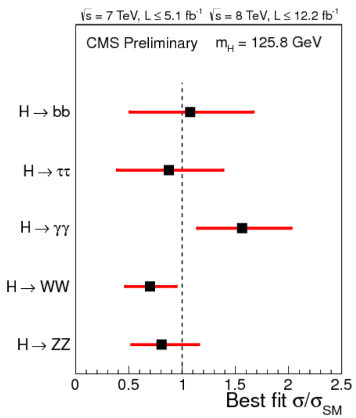
- $\mu_s, m_s, b_s \sim \mu$ $h_1 \simeq H_{u,d} + \varepsilon S, \quad h_2 = S - \varepsilon H_{u,d}$

...h_2 may be lighter than LEP bound

...h_1 may have enhanced $\gamma\gamma$ rate







Schmidt-Hoberg, Staub

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- $\mu_s \gg \mu$ MSSM SUSY structure with heavy Higgs

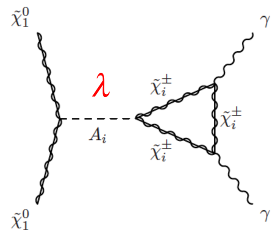
- $\mu_s, m_s, b_s \sim \mu$ $\qquad h_1 \simeq H_{u,d} + \varepsilon S, \quad h_2 = S - \varepsilon H_{u,d}$

...h_2 may be lighter than LEP bound

...h_1 may have enhanced $\gamma\gamma$ rate

...h_1 may have enhanced LSP annihilation rate to photons..?

$$\langle \sigma v \rangle_{\gamma\gamma} \simeq (6 \cdot 10^{-28}\ \mathrm{cm}^3\ \mathrm{s}^{-1}) \cdot \lambda^2 \kappa^2 \left(\frac{(100\ \mathrm{GeV})^2}{4\, m_{\tilde{\chi}_1^0}^2 - m_{A_1}^2} \right)^2 \left(\frac{m_{\tilde{\chi}_1^0}}{130\ \mathrm{GeV}} \right)^2$$



Fermi 135GeV line : $\lambda, \kappa \le 1, \quad m_{A_1} \simeq 240 - 280 GeV$

Schmidt-Hoberg, Staub, Winkler

Input			
$\tan\beta$	1.2	v_s [GeV]	-4.0
λ	0.74	A_λ [GeV]	0
κ	1.4	A_κ [GeV]	0
μ_s [GeV]	103.0	b_s [GeV^2]	$3.356 \cdot 10^5$
μ [GeV]	208.0	$b\mu$ [GeV^2]	$2.4 \cdot 10^5$
M_1 [GeV]	1500.0	M_2 [GeV]	193.0
M_3 [GeV]	1500.0	m_{scalar} [GeV]	1500.0
$A_{top}Y_{top}$ [GeV]	1500.0	ξ_S [GeV^3]	0.0
CP even Higgs sector			
m_{h_1} [GeV]	125.7	down fraction h_1	41.5%
m_{h_2} [GeV]	690.1	up fraction h_1	57.8%
m_{h_3} [GeV]	786.8	singlet fraction h_1	0.7%
CP odd Higgs sector			
m_{A_1} [GeV]	247.5	singlet fraction A_1	99.9%
m_{A_2} [GeV]	691.9	up and down fraction A_1	0.1%
Neutralino sector			
$\tilde{\chi}_1^0$ [GeV]	130.0	bino fraction $\tilde{\chi}_1^0$	<0.1%
$\tilde{\chi}_2^0$ [GeV]	156.4	wino fraction $\tilde{\chi}_1^0$	5.1%
$\tilde{\chi}_3^0$ [GeV]	316.2	down-higgsino fraction $\tilde{\chi}_1^0$	0.3%
$\tilde{\chi}_4^0$ [GeV]	331.6	up-higgsino fraction $\tilde{\chi}_1^0$	10.0%
$\tilde{\chi}_5^0$ [GeV]	1497.4	singlet fraction $\tilde{\chi}_1^0$	84.5%
Chargino sector			
$\tilde{\chi}_1^+$ [GeV]	154.8	wino fraction $\tilde{\chi}_1^+$	70.6%
$\tilde{\chi}_2^+$ [GeV]	332.6	higgsino fraction $\tilde{\chi}_1^+$	29.4%
Electroweak observables			
$R_{\gamma\gamma}$	1.2	$R_{b\bar{b}}$	1.0
R_{ZZ}	1.0	$R_{\tau\bar{\tau}}$	1.0
$\mathrm{Br}(b \to s\gamma)$	$3.4 \cdot 10^{-4}$	$\mathrm{Br}(B_s \to \mu\mu)$	$3.7 \cdot 10^{-9}$
Δa_μ	$-1.2 \cdot 10^{-11}$	$\delta\rho$	$4.5 \cdot 10^{-5}$
Dark matter			
Ωh^2	0.1	X_{FO}	24.9
σ_p^{SI} [cm^2]	$2.2 \cdot 10^{-45}$	σ_p^{SD} [cm^2]	$3.8 \cdot 10^{-40}$
$\langle\sigma v\rangle_{\gamma\gamma}$ [cm^3/s]	$0.83 \cdot 10^{-27}$	$\langle\sigma v\rangle_{\gamma Z}$ [cm^3/s]	$0.79 \cdot 10^{-27}$

GNMSSM benchmark point

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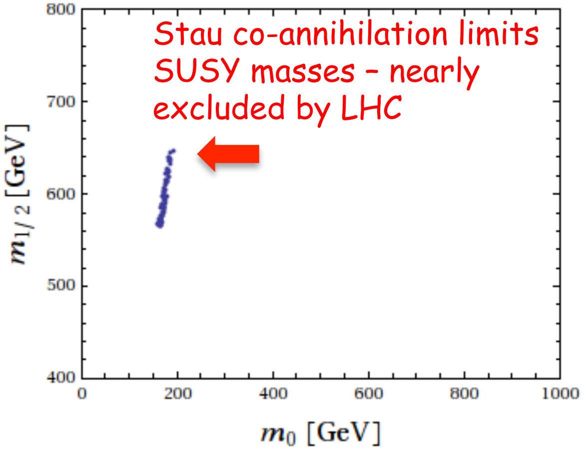
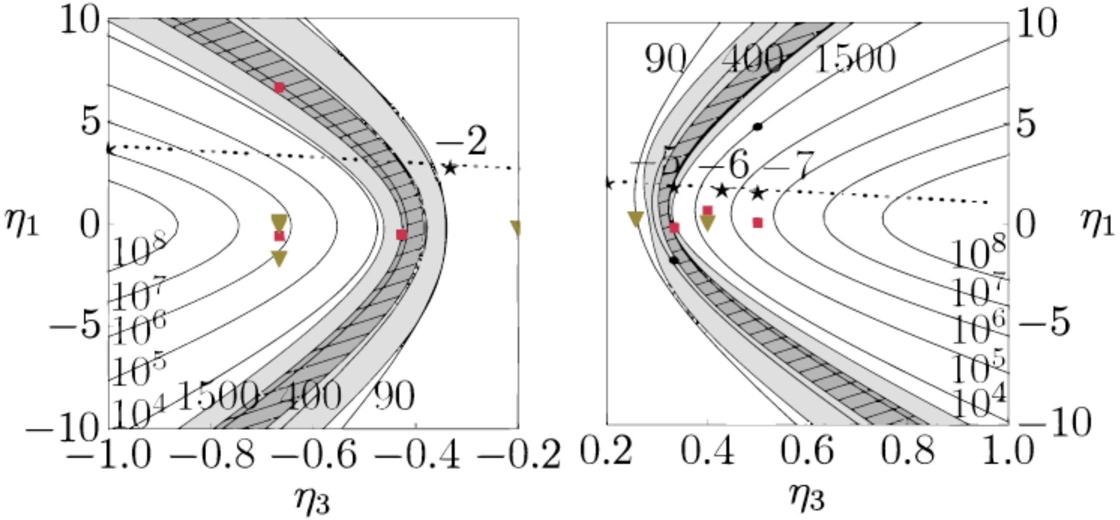
GNMSSM benchmark point



Reduced fine tuning : nonuniversal gaugino masses

$$16\pi^2 \frac{d}{dt} m_{H_u}^2 = 3\left(2\,|\,y_t\,|^2\,(m_{H_u}^2 + m_{Q_3}^2 + m_{\bar{u}_3}^2) + 2\,|\,a_t\,|^2\right) - 6g_2^2\,|\,M_2\,|^2 - \frac{6}{5} g_1^2\,|\,M_1\,|^2$$

New focus point: cancellation between M_3 and M_2 contributions if $|M_2|^2 \simeq |M_3|^2$ at M_{SUSY}



$$M_3 : M_2 : M_1 = \eta_3 : 1 : \eta_1$$

Reduced fine tuning : nonuniversal gaugino masses

$$16\pi^2 \frac{d}{dt} m_{H_u}^2 = 3\left(2\,|\,y_t\,|^2\,(m_{H_u}^2 + m_{Q_3}^2 + m_{\bar{u}3}^2) + 2\,|\,a_t\,|^2\right) - 6g_2^2\,|\,M_2\,|^2 - \frac{6}{5} g_1^2\,|\,M_1\,|^2$$

New focus point: cancellation between M_3 and M_2 contributions if $|M_2|^2 \simeq |M_3|^2$ at M_{SUSY}

Natural ratios? e.g.:

GUT: $SU(5):\quad \Phi^N \subset (24\times 24)_{symm} = 1+24+75+200;\quad SO(10):\quad (45\times 45)_{symm} = 1+54+210+770$

Representation	$M_3 : M_2 : M_1$ at M_{GUT} ($\eta_3 : 1 : \eta_1$)	$M_3 : M_2 : M_1$ at M_{EWSB} ($2.7\eta_3 : 1 : 0.5\eta_1$)
1	1:1:1	6:2:1
24	2:(-3):(-1)	12:(-6):(-1)
75	1:3:(-5)	6:6:(-5)
200	1:2:10	6:4:10

String: $(3+\delta_{GS}):(-1+\delta_{GS}):\left(-\frac{33}{5}+\delta_{GS}\right)$ (OII, also mixed moduli anomaly)

Gaugino focus point - Phenomenology

- Gaugino mass ratios

$$\frac{M_i(Q)}{M_{1/2}} = \eta_i \frac{\alpha_i(Q)}{\alpha_i(M_X)} \quad \Rightarrow \quad \begin{array}{l} \dfrac{M_1(Q)}{M_2(Q)} \approx 0.5\eta_1 \\ M_2(Q) \approx 0.8 M_{1/2} \\ \dfrac{M_3(Q)}{M_2(Q)} \approx 2.7\eta_3 \end{array}$$

.... gauginos can be very heavy

- Light neutralino and 2 charginos nearly degenerate

$$m_{\chi_2^0} - m_{\chi_1^0} = M_Z^2 \left(\frac{s_W^2}{M_1} + \frac{c_W^2}{M_2} \right) + \mathcal{O}(\frac{M_Z^3}{M_2^2})$$

$$m_{\chi_1^\pm} - m_{\chi_1^0} = \frac{1}{2} M_Z^2 \left(\frac{s_W^2}{M_1} + \frac{c_W^2}{M_2} \right) + \frac{1}{2} M_Z^2 \left(\frac{s_W^2}{M_1} - \frac{c_W^2}{M_2} \right) \epsilon \sin 2\beta + \mathcal{O}(\frac{M_Z^3}{M_2^2})$$

$+ \text{ for } |M_1| < \mu,$ Bino or Higgsino LSP candidate

Summary

- CMSSM (and other MSSMs) highly fine tuned

Summary

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- BCMSSM: more correlations or BMSSM

-(G) NMSSM Reduced Δ $\Longrightarrow$ GNMSSM $\Longrightarrow$ Z_{4R}, Z_{8R}

SUSY states can be (slightly)heavier

$m_h \rightarrow 130 GeV$

LHC bounds already severe with conventional cosmology

Summary

- CMSSM (and other MSSMs) highly fine tuned

- BCMSSM: more correlations or BMSSM

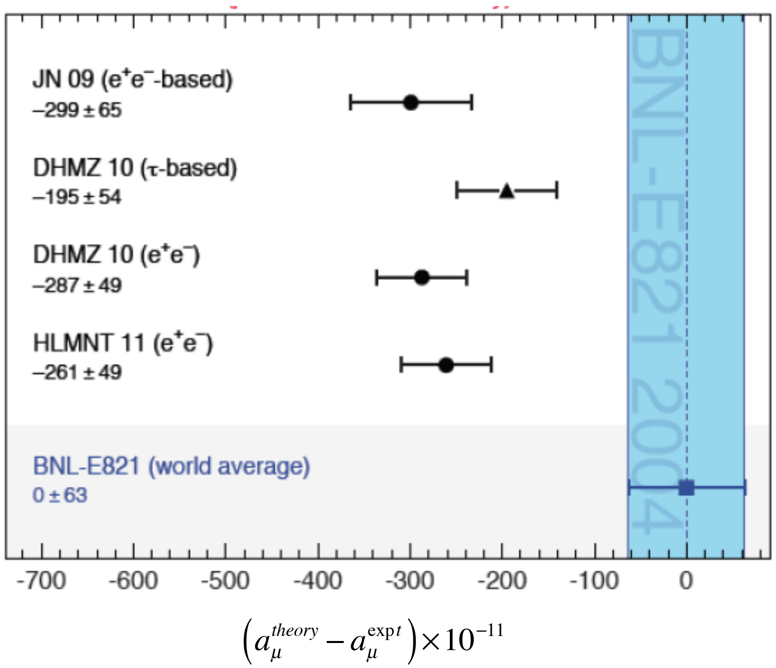
  -GNMSSM + gaugino focus point; SUSY states heavier

  Still room for natural SUSY!

- Indirect hints….g-2, $h \to \gamma\gamma$, Fermi

Muon g-2

$$\boxed{a_\mu^{theory} - a_\mu^{\text{expt}} = -(28.7 \pm 8.0) \times 10^{-10}}$$



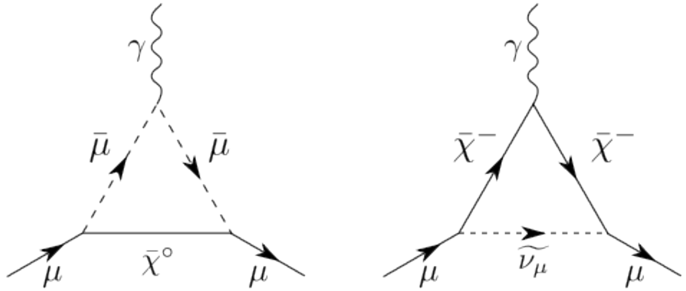
Theory error from hadronic contribution:

$$\delta a_\mu^{e^+e^-} = 3.6\,\sigma$$

$$\delta a_\mu^{\tau} = 2.4\,\sigma$$

SUSY

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



Needs light sleptons – anomaly/mirage spectrum?

With slepton universality – $h \to \gamma\,\gamma$ plausibly correct!

Giudice et al

Summary

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  Still room for natural SUSY!

- Indirect hints....g-2, $h \to \gamma\gamma$, Fermi

- Hidden SUSY

  Natural SUSY

  R-parity breaking

  Supersoft SUSY breaking

  Compressed spectrum

Summary

- CMSSM (and other MSSMs) highly fine tuned

- BCMSSM: more correlations or BMSSM

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- Indirect hints....g-2, $h \to \gamma\gamma$, Fermi

- Hidden SUSY

- Intriguing implications of 125GeV pure SM Higgs

  IRFP?, Higgs inflation?...

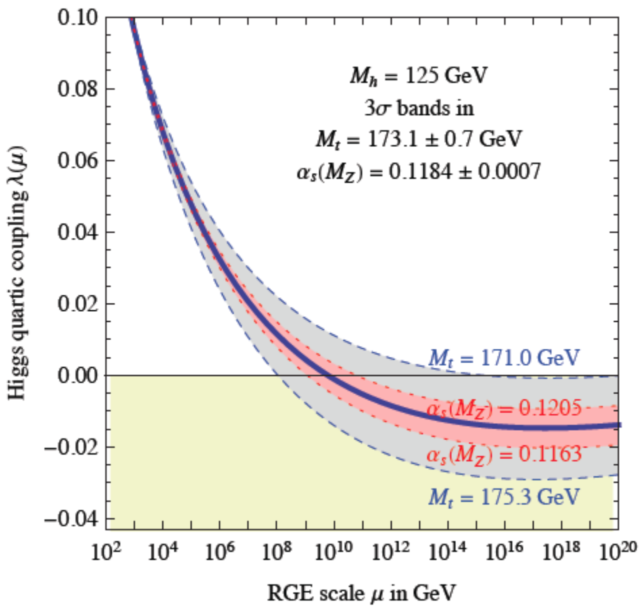
Implications of 125 GeV Higgs – vacuum instability

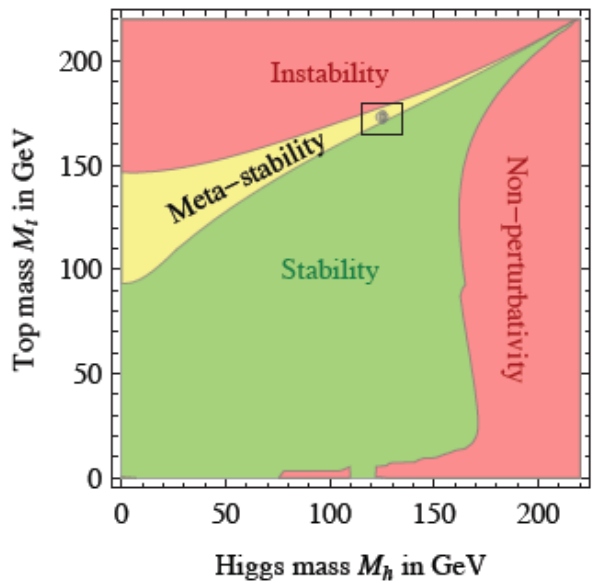
$$V(H) = -\frac{1}{2}M_H^2|H|^2 + \frac{\lambda}{4}|H|^4$$

Tunneling probability: $p = \max_R \frac{V_U}{R^4} \exp\left[-\frac{8\pi^2}{3|\lambda(\mu)|} - \Delta S\right]$

Isidori, Ridolfi, Strumia

λ



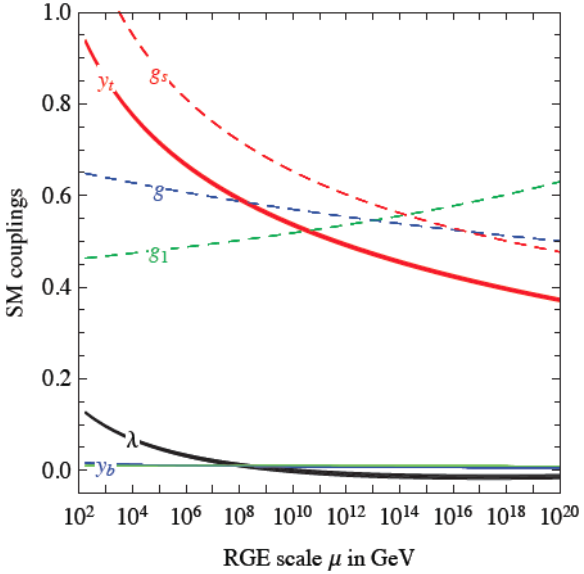


$$M_h\ [\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\mathrm{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\mathrm{th}}$$

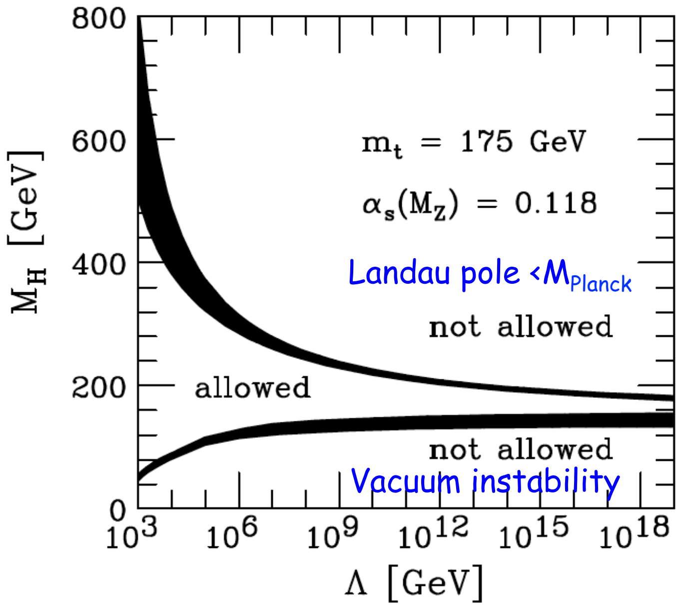
$M_h > 129.4 \pm 1.8\ \ \mathrm{GeV}$ $\quad 2\sigma$ away from stability

De Grassi et al

III. Implications of 125 GeV Higgs



RGE - just the Standard Model



Higgs coupling small

Hambye, Riesselmann