Low fine tuning in the MSSM with higgsino DM and unification constraints

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Based on

KK, L. Roszkowski, E.M. Sessolo, and S. Trojanowski

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Outline

1. Fine tuning in CMSSM: naturalness vs phenomenology

2. Naturalness with 1TeV higgsino dark matter

   - Non-universal patterns and focus point-like mechanisms

   - The parameter mu

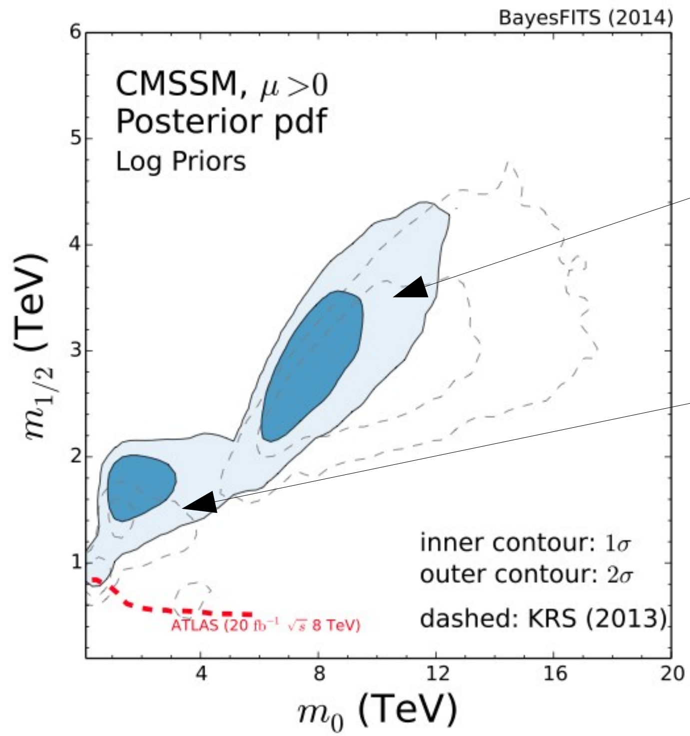
3. Shifting the FT to the high scale

4. Summary

Exp. constraints in GUT-scale SUSY

Likelihood driven scan

Measurement
m_h (by CMS)
$\Omega_\chi h^2$
$\mathrm{BR}\left(\overline{\mathrm{B}} \to \mathrm{X_s}\gamma\right) \times 10^4$
$\mathrm{BR}\left(\mathrm{B_u} \to \tau\nu\right) \times 10^4$
ΔM_{B_s}
$\sin^2\theta_{\mathrm{eff}}$
M_W
$\mathrm{BR}\left(\mathrm{B_s} \to \mu^+\mu^-\right) \times 10^9$
$m_b(m_b)^{\overline{MS}}$
M_t
LUX (2013)

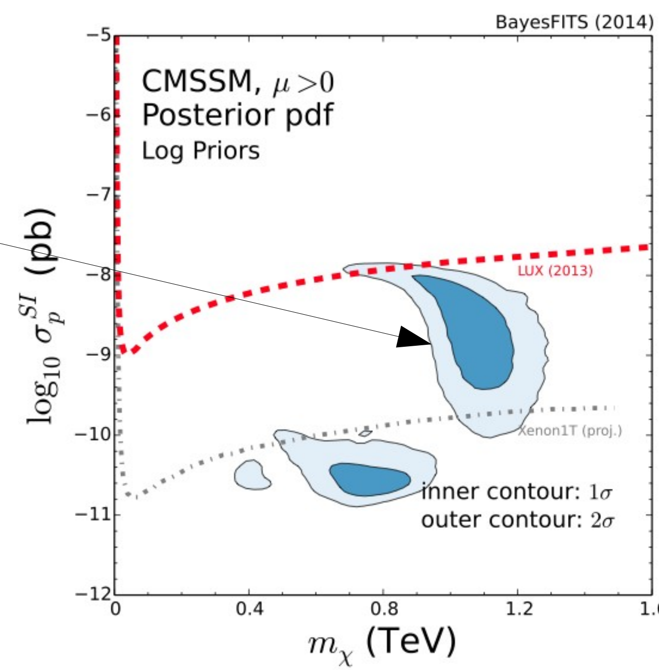


(See parallel talk by A. Williams)

Higgsino dark matter

$$m_\chi \simeq 0.9 - 1.2\ \mathrm{TeV}$$

Bino dark matter, $m_\chi \sim 0.5\, m_{1/2}$



- **1 TeV higgsino excellent prospects at DM detection**
- **Same region also in NUHM, NMSSM, pMSSM**

(Roszkowski *et al* '09, Ross *et al* '13, Profumo,Yaguna '04)

(It's a generic DM solution of MSSM)

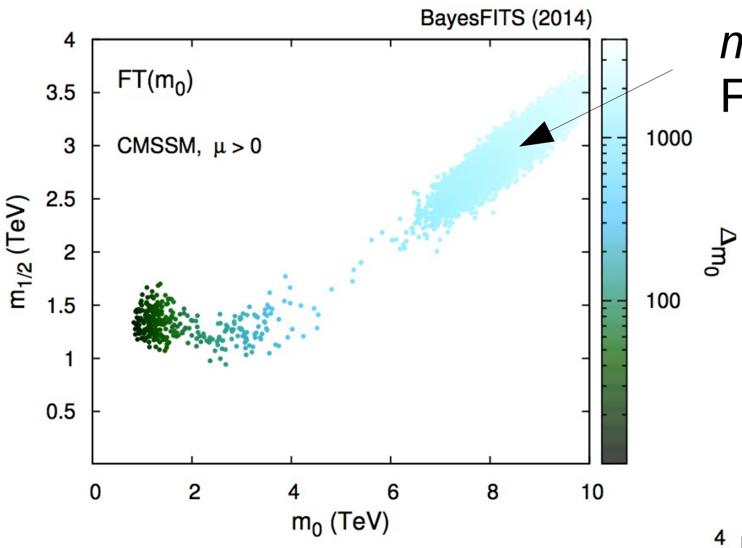
Fine tuning distribution in 1TeV HR

Barbieri-Giudice:

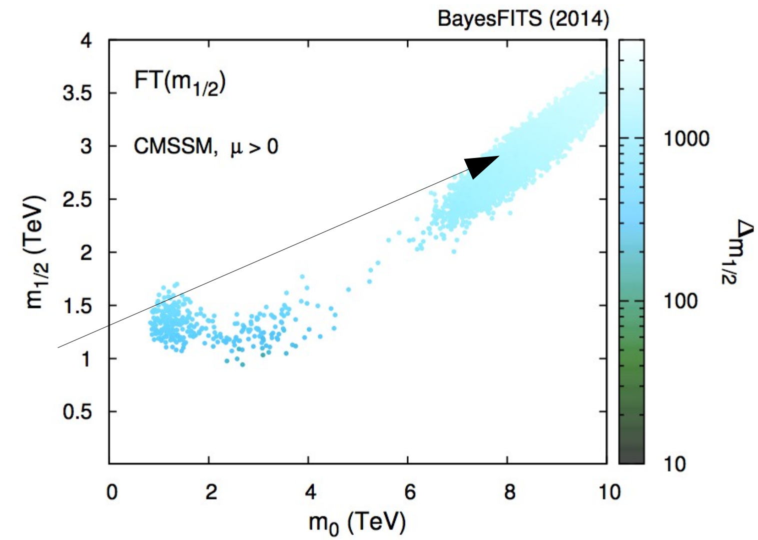
$$\Delta_{p_i} = \left| \frac{\partial \ln M_Z^2}{\partial \ln p_i^2} \right| = \frac{1}{2} \left| \frac{\partial \ln M_Z^2}{\partial \ln p_i} \right|$$

EWSB condition at large $\tan\beta$

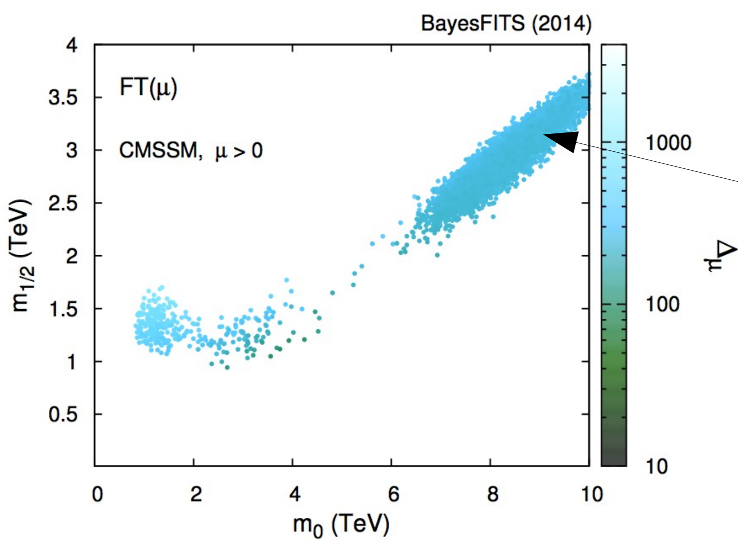
$$\frac{M_Z^2}{2} \approx -\mu^2 - m_{H_u}^2 - \Sigma_u^u + \mathcal{O}(m_{H_d}^2/\tan^2\beta)$$



m0
FT >1000-2000



m1/2
FT >1000-2000



Reminds of Focus Point!

(Chan, Chattopadhay, Nath '98
Feng, Matchev, Moroi '99)

Stable $\Delta_\mu \simeq 250$

The idea of RGE ``focusing”

$$\frac{M_Z^2}{2} \approx -\mu^2 - m_{H_u}^2 - \Sigma_u^u + \mathcal{O}(m_{H_d}^2/\tan^2\beta)$$

$m_{H_u}^2$ at *MSUSY* stable under variations of GUT init. cond.

Integrate 2-loop RGEs / Dependence on init. cond.

$$\begin{aligned} m_{H_u}^2(M_{\rm SUSY}) = &\ 0.645 m_{H_u}^2 + 0.028 m_{H_d}^2 - 0.024 m_{\tilde{Q}_1}^2 - 0.024 m_{\tilde{Q}_2}^2 - 0.328 m_{\tilde{Q}_3}^2 \\ &+ 0.049 m_{\tilde{u}_1}^2 + 0.049 m_{\tilde{u}_2}^2 - 0.251 m_{\tilde{u}_3}^2 - 0.024 m_{\tilde{d}_1}^2 - 0.024 m_{\tilde{d}_2}^2 - 0.019 m_{\tilde{d}_3}^2 \\ &+ 0.024 m_{\tilde{L}_1}^2 + 0.024 m_{\tilde{L}_2}^2 + 0.024 m_{\tilde{L}_3}^2 - 0.025 m_{\tilde{e}_1}^2 - 0.025 m_{\tilde{e}_2}^2 - 0.025 m_{\tilde{e}_3}^2 \\ &+ 0.014 M_1^2 + 0.210 M_2^2 - 1.097 M_3^2 + 0.001 M_1 M_2 - 0.047 M_1 M_3 - 0.089 M_2 M_3 \\ &- 0.113 A_t^2 + 0.010 A_b^2 + 0.006 A_\tau^2 + 0.008 A_t A_b + 0.005 A_t A_\tau + 0.004 A_b A_\tau \\ &+ M_1(0.007 A_t - 0.005 A_b - 0.004 A_\tau) + M_2(0.062 A_t - 0.009 A_b + 0.005 A_\tau) \\ &+ M_3(0.295 A_t + 0.024 A_b + 0.030 A_\tau) \end{aligned}$$

GUT-scale init. cond.

The idea of RGE ``focusing”

$$\frac{M_Z^2}{2} \approx -\mu^2 - m_{H_u}^2 - \Sigma_u^u + \mathcal{O}(m_{H_d}^2/\tan^2\beta)$$

$m_{H_u}^2$ at *MSUSY* stable under variations of GUT init. cond.

Some parameters enter strongly

$$\begin{aligned} m_{H_u}^2(M_{\rm SUSY}) = {} & 0.645 m_{H_u}^2 + 0.028 m_{H_d}^2 - 0.024 m_{\tilde{Q}_1}^2 - 0.024 m_{\tilde{Q}_2}^2 - 0.328 m_{\tilde{Q}_3}^2 \\ & + 0.049 m_{\tilde{u}_1}^2 + 0.049 m_{\tilde{u}_2}^2 - 0.251 m_{\tilde{u}_3}^2 - 0.024 m_{\tilde{d}_1}^2 - 0.024 m_{\tilde{d}_2}^2 - 0.019 m_{\tilde{d}_3}^2 \\ & + 0.024 m_{\tilde{L}_1}^2 + 0.024 m_{\tilde{L}_2}^2 + 0.024 m_{\tilde{L}_3}^2 - 0.025 m_{\tilde{e}_1}^2 - 0.025 m_{\tilde{e}_2}^2 - 0.025 m_{\tilde{e}_3}^2 \\ & + 0.014 M_1^2 + 0.210 M_2^2 - 1.097 M_3^2 + 0.001 M_1 M_2 - 0.047 M_1 M_3 - 0.089 M_2 M_3 \\ & - 0.113 A_t^2 + 0.010 A_b^2 + 0.006 A_\tau^2 + 0.008 A_t A_b + 0.005 A_t A_\tau + 0.004 A_b A_\tau \\ & + M_1(0.007 A_t - 0.005 A_b - 0.004 A_\tau) + M_2(0.062 A_t - 0.009 A_b + 0.005 A_\tau) \\ & + M_3(0.295 A_t + 0.024 A_b + 0.030 A_\tau) \end{aligned}$$

But contributions can correlate:

$m_{H_U}^2, m_{\tilde{Q}_3}^2, m_{\tilde{u}3}^2$ almost cancel if all $= m_0^2$

$$m_{H_u}^2(M_{\rm SUSY}) = 0.074 m_0^2 - 1.008 m_{1/2}^2 - 0.080 A_0^2 + 0.406 m_{1/2} A_0$$

E.g., the CMSSM

$$m_{H_u}^2(M_{\mathrm{SUSY}}) = 0.074 m_0^2 - 1.008 m_{1/2}^2 - 0.080 A_0^2 + 0.406 m_{1/2} A_0$$

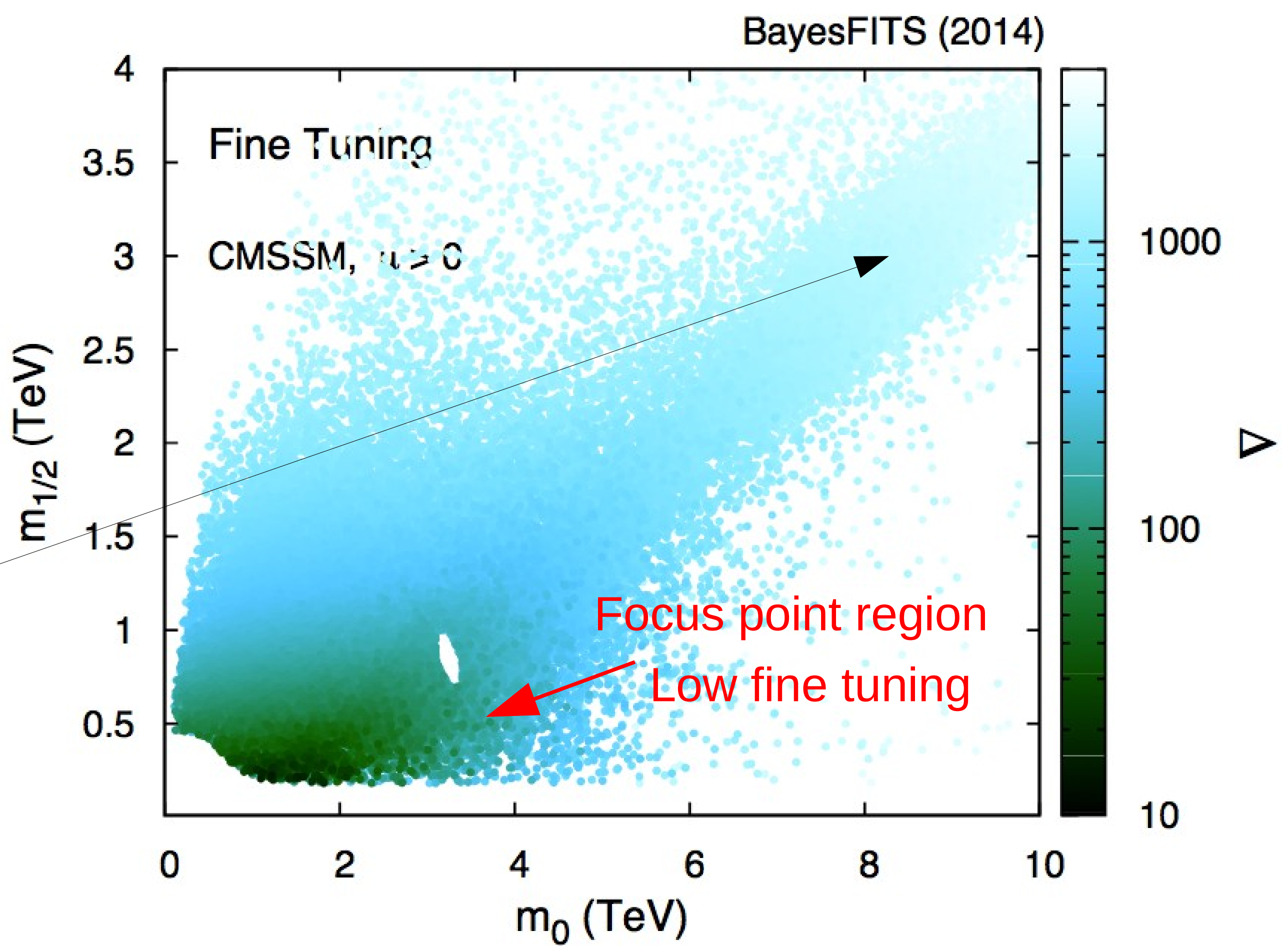
If $m_{1/2}, |A_0| < 1\ \mathrm{TeV}$

low fine tuning even for

quite large m_0!

GUT bound.cond. that lead to efficient ``focus point” in ~1TeV higgsino region?

(clearly not the CMSSM)



- Good Higgs mass
- Good relic density
- Just in reach of LUX
- Just outside LHC

Non-universal Higgs mass

$$m_{H_u}^2(M_{\rm SUSY}) = 0.074m_0^2 - 1.008m_{1/2}^2 - 0.080A_0^2 + 0.406m_{1/2}A_0$$

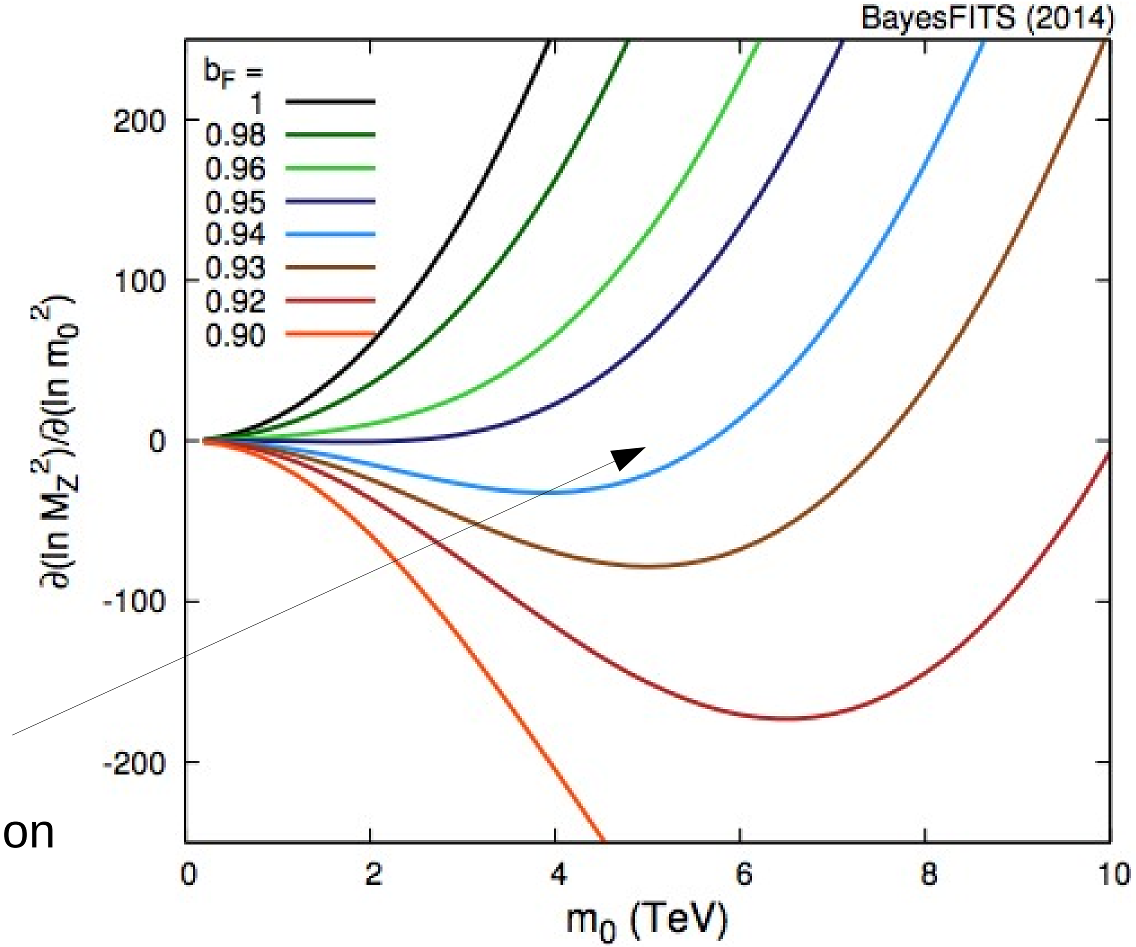
Make it smaller =>> larger *m_0*

Parametrize with

$$b_F = \left|\frac{m_{H_u}(GUT)}{m_0}\right|$$

b_F = 0.92 -- 0.94

Optimal for large *m_0*
typical of 1TeV higgsino region



Non-universal gaugino models

(Kane, King '98
Abe *et al.* '07
Horton, Ross '09, ...)

$$m_{H_u}^2(M_{\rm SUSY}) = 0.074m_0^2 - 1.008m_{1/2}^2 - 0.080A_0^2 + 0.406m_{1/2}A_0$$

Naturally emerge in Supergravity with GUTs

(J.Ellis *et al.* '84-85, Drees '85, ...)

$$\mathcal{L} \sim \frac{F_{ab}}{M_{Pl}}\lambda_a\lambda_b$$

$$F_{ab} \in \mathbf{24}\times\mathbf{24},$$
$$\mathbf{45}\times\mathbf{45},\ldots\ (\mathrm{sym})$$

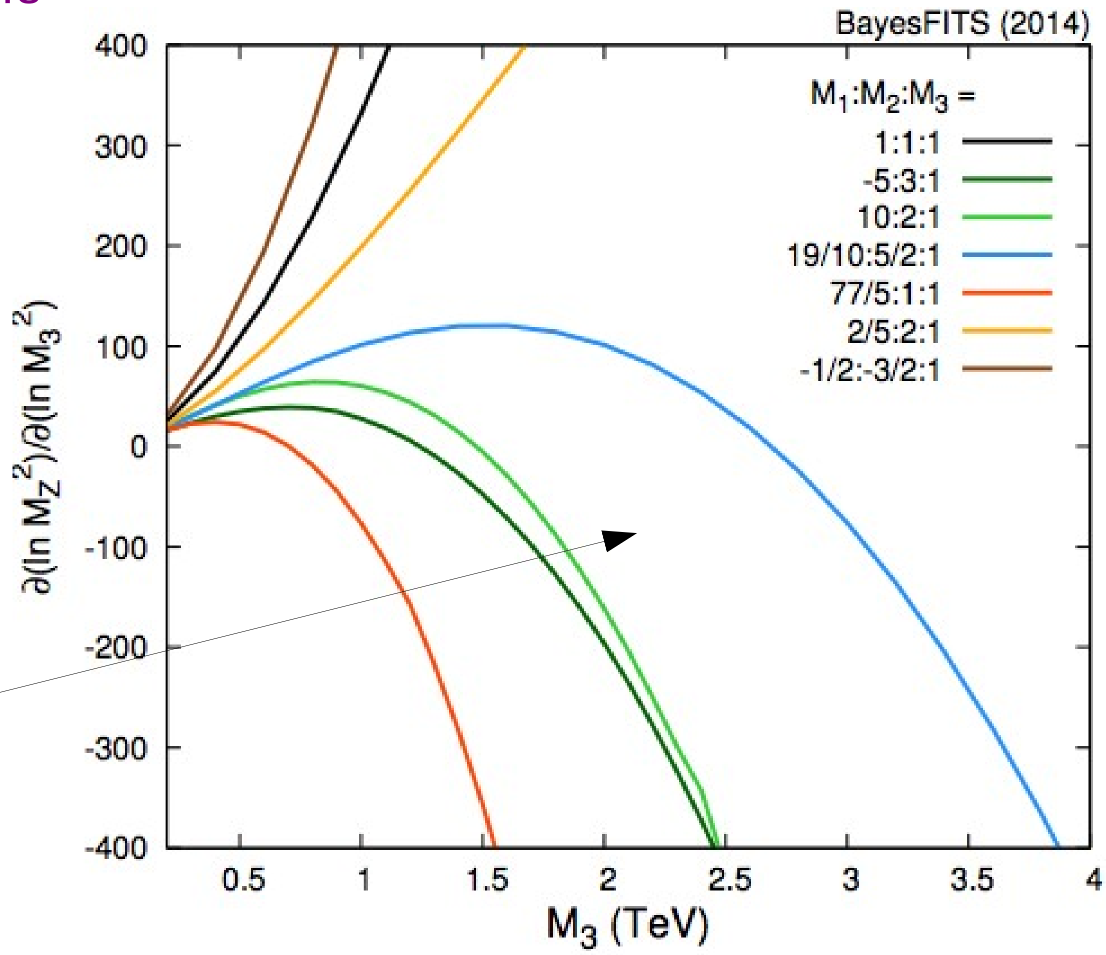
Group theory gives
($M_1 : M_2 : M_3$)

(-5 : 3 : 1), (10 : 2 : 1) in *SU(5)*

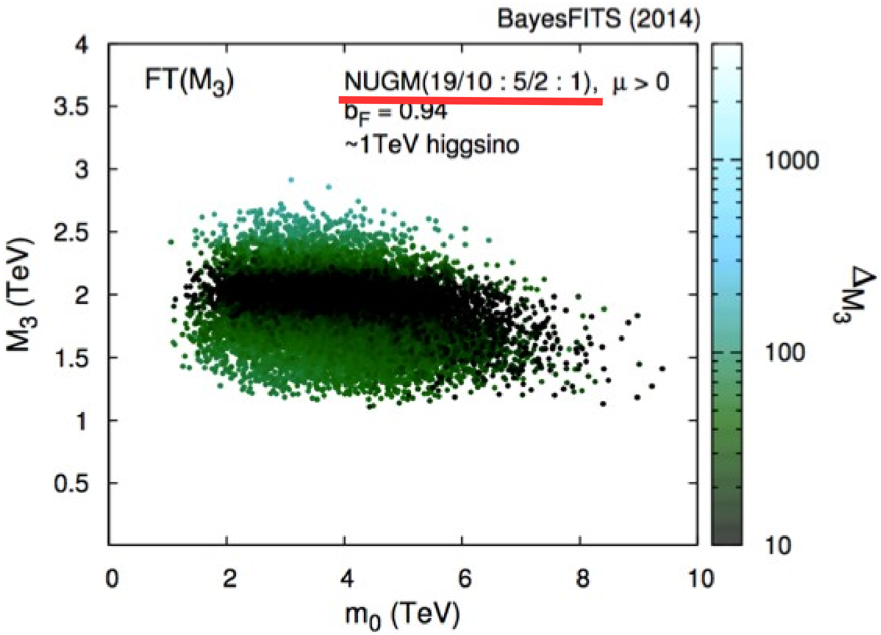
(19/10 : 5/2 : 1) in *SO(10)*...

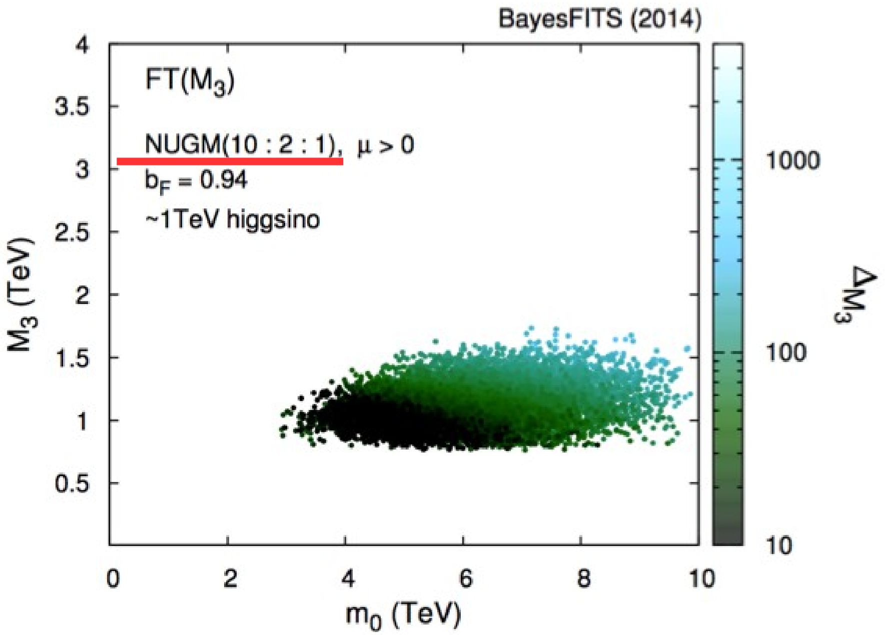
Are good for large M_3!

Make *this* smaller =>> larger $m_{1/2}$

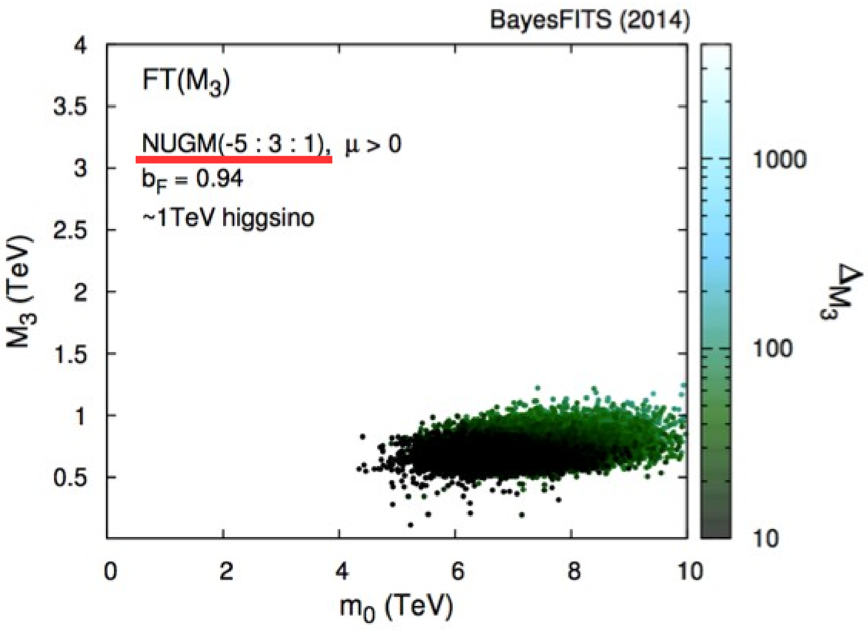


Fine tuning of gauginos/scalars

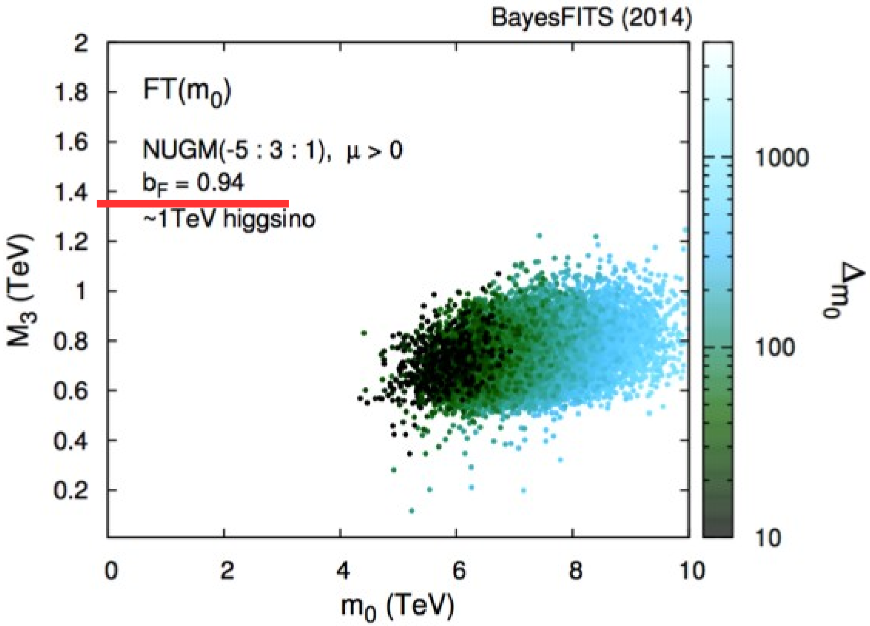


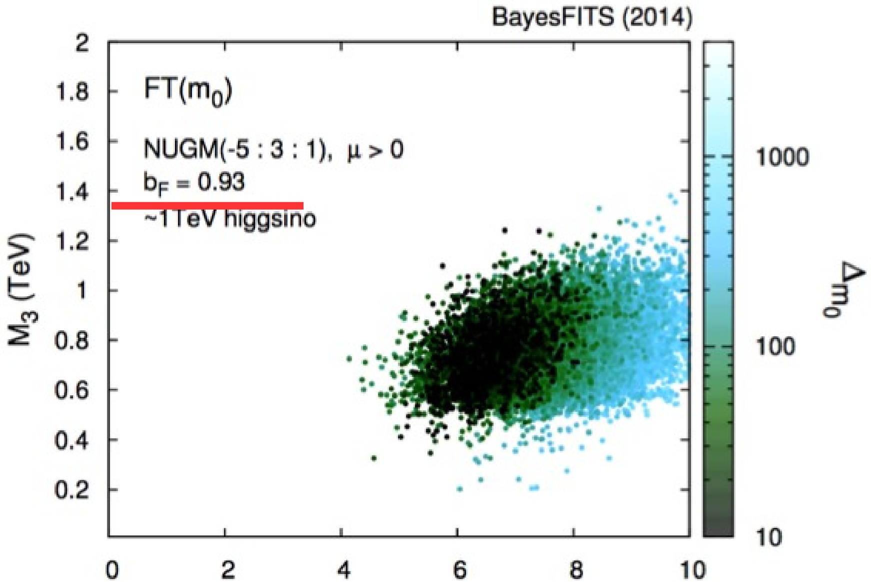


NON-UNIVERSAL GAUGINOS:

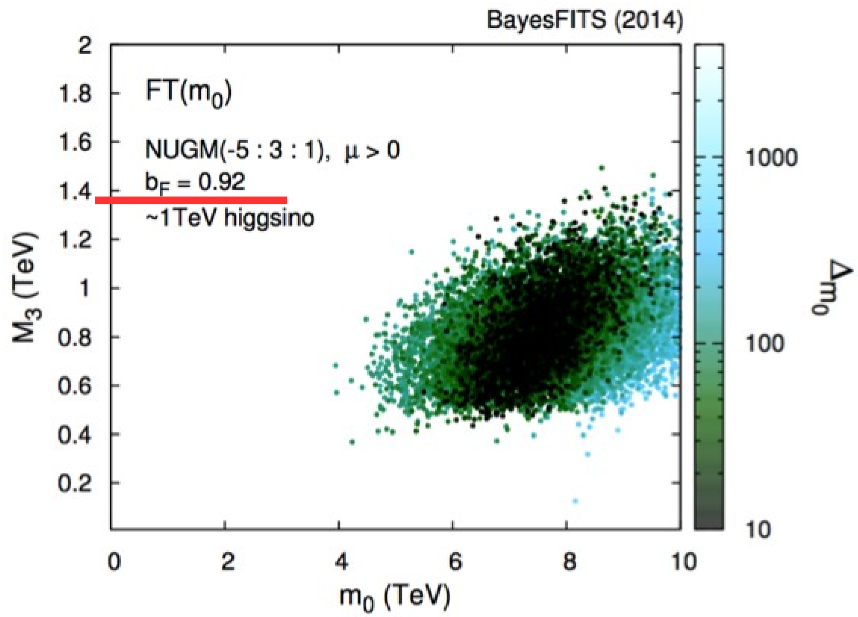


Fine tuning of gauginos/scalars





NON-UNIVERSAL HIGGS/SCALAR:



Including the mu parameter

$$M_Z^2 \approx -2m_{H_u}^2(M_{SUSY}) - 2\mu^2$$
$$\approx (c_0 m_0^2 + c_3 M_3^2) - 2\mu^2$$
$$c_0, c_3 \ll 1$$

- c_0 small because of appropriate ratio $m_{H_u}^2/m_0^2$
- c_3 small thanks to possible *SU(5)* or *SO(10)* symmetry at GUT scale

What about μ?

$\Delta_\mu \simeq 250$ by construction since $\mu \simeq 1$ TeV

Unless.... $\mu = c_H m_0$ ...like in Giudice-Masiero (1988):

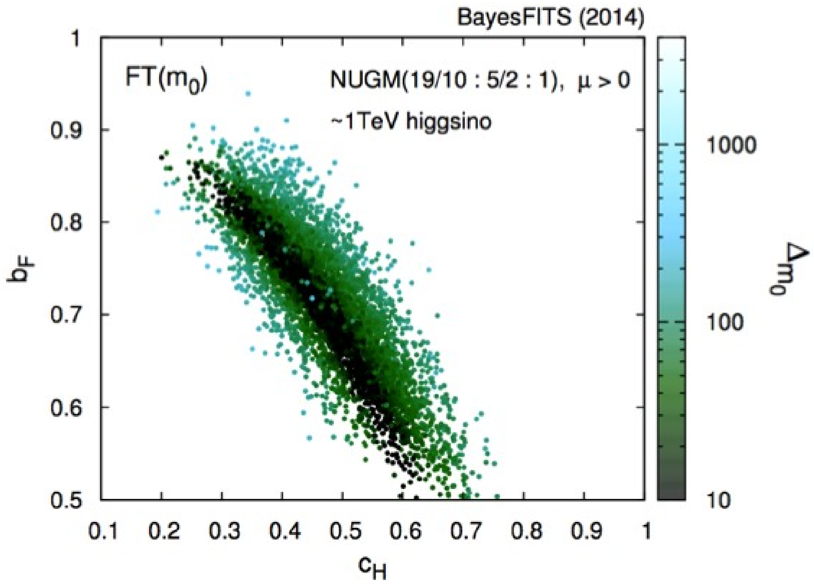
N=1 min. supergravity with extra term in Kahler metric:

$$K(\hat{h}, \hat{h}^\dagger, \hat{C}_i, \hat{C}_i^\dagger) = \hat{h}^\dagger \hat{h} + \sum_i \hat{C}_i^\dagger \hat{C}_i + \frac{\lambda}{M_{\rm Pl}} \hat{h}^\dagger \hat{H}_u \hat{H}_d \longrightarrow \mu_0 \propto \lambda m_{3/2} \Rightarrow \mu = c_H m_0$$

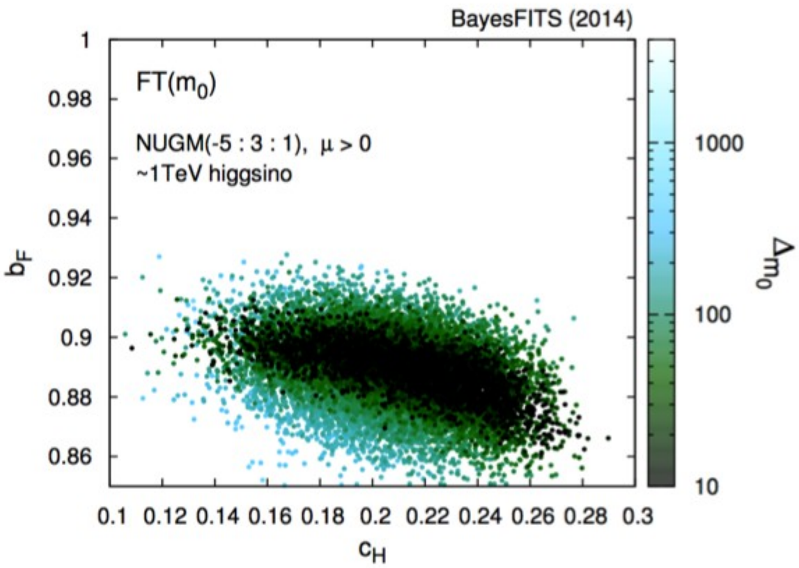
$$\langle \hat{h} \rangle = M_X + \theta^2 F \longrightarrow m_0 \leftrightarrow m_{3/2} \sim e^{K/2} \frac{F}{M_{Pl}}$$

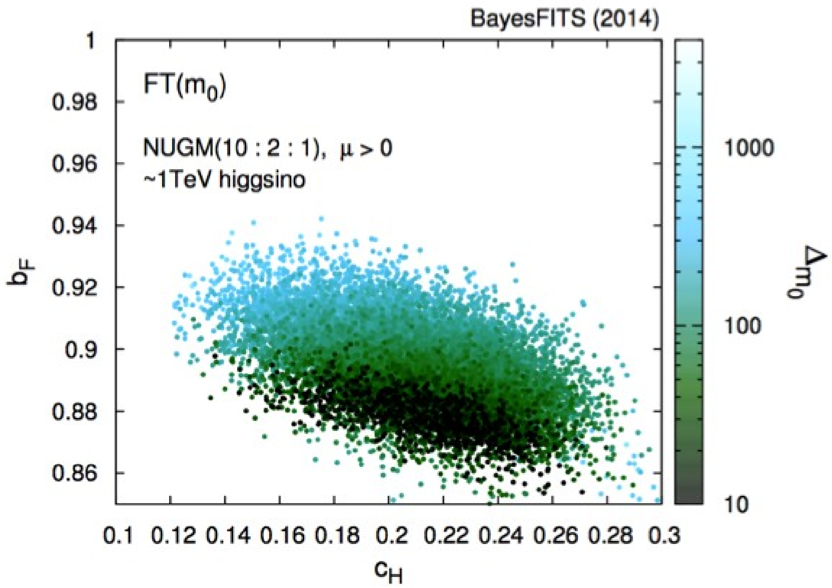
Including the mu parameter

Now m_0 fine tuning parametrized by 2 pars: $c_H = |\mu/m_0|\,,\ b_F = |m_{H_u}/m_0|$



Often, low FT right inside 1 TeV higgsino region!





Including the mu parameter

A possible model for making it work:

A. $m^2_{H_u}, m^2_0$ split at *MGUT* so to give $b_F \neq 1$

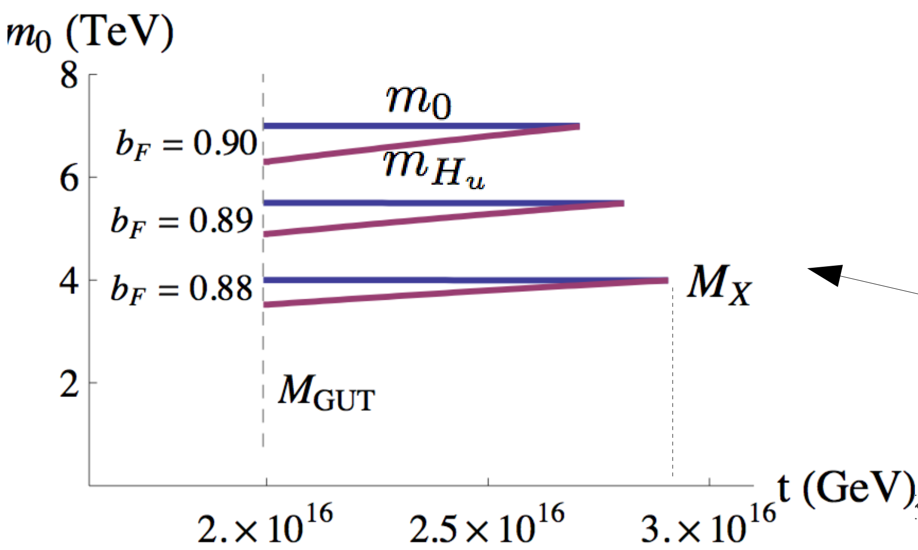
B. Extended gauge group compatible with one gaugino mass pattern

C. Symmetry to forbid the μ term in the superpotential.

$$W_{SU(5)\times U(1)} = \mu_\Sigma \mathrm{tr}\hat{\Sigma}^2 + \frac{1}{6}\lambda_\Sigma \mathrm{tr}\hat{\Sigma}^3 + \lambda_S \hat{S}\hat{\theta}_{50}\hat{\theta}_{\overline{50}} + \lambda_H \hat{h}_5 \hat{\Sigma}\hat{\theta}_{50} + \lambda_{\bar{H}} \hat{h}_{\bar{5}} \hat{\Sigma}\hat{\theta}_{\overline{50}}$$
$$+ \frac{1}{4} Y_U \epsilon_{ijklm} \hat{\psi}^{ij}_{10} \hat{\psi}^{kl}_{10} \hat{h}^m_5 + \sqrt{2} Y_D \hat{\psi}^{ij}_{10} \hat{\phi}_{5i} \hat{h}_{\bar{5}j}, \quad + \mu_H \hat{h}_5 \hat{h}_{\bar{5}}$$

(Berezhiani and Tavartkiladze, 1996)

$$q_{\psi_{10}} = \frac{1}{2}, \quad q_{\phi_5} = \frac{1}{2}, \quad q_{h_5} = -1, \quad q_{h_{\bar{5}}} = -1, \quad q_{\theta_{50}} = 1, \quad q_{\theta_{\overline{50}}} = 1, \quad q_\Sigma = 0, \quad q_S = -2$$



After SUSY breaking at *Mx* :

$$m_0^2 \equiv m_5^2 = m_{10}^2 = \Delta_5^2 = \Delta_{\bar{5}}^2 = \Delta_{50}^2 = \Delta_{\overline{50}}^2 = m_\Sigma^2 = m_S^2$$

$b_F \neq 1$ after RGE run above *MGUT* !

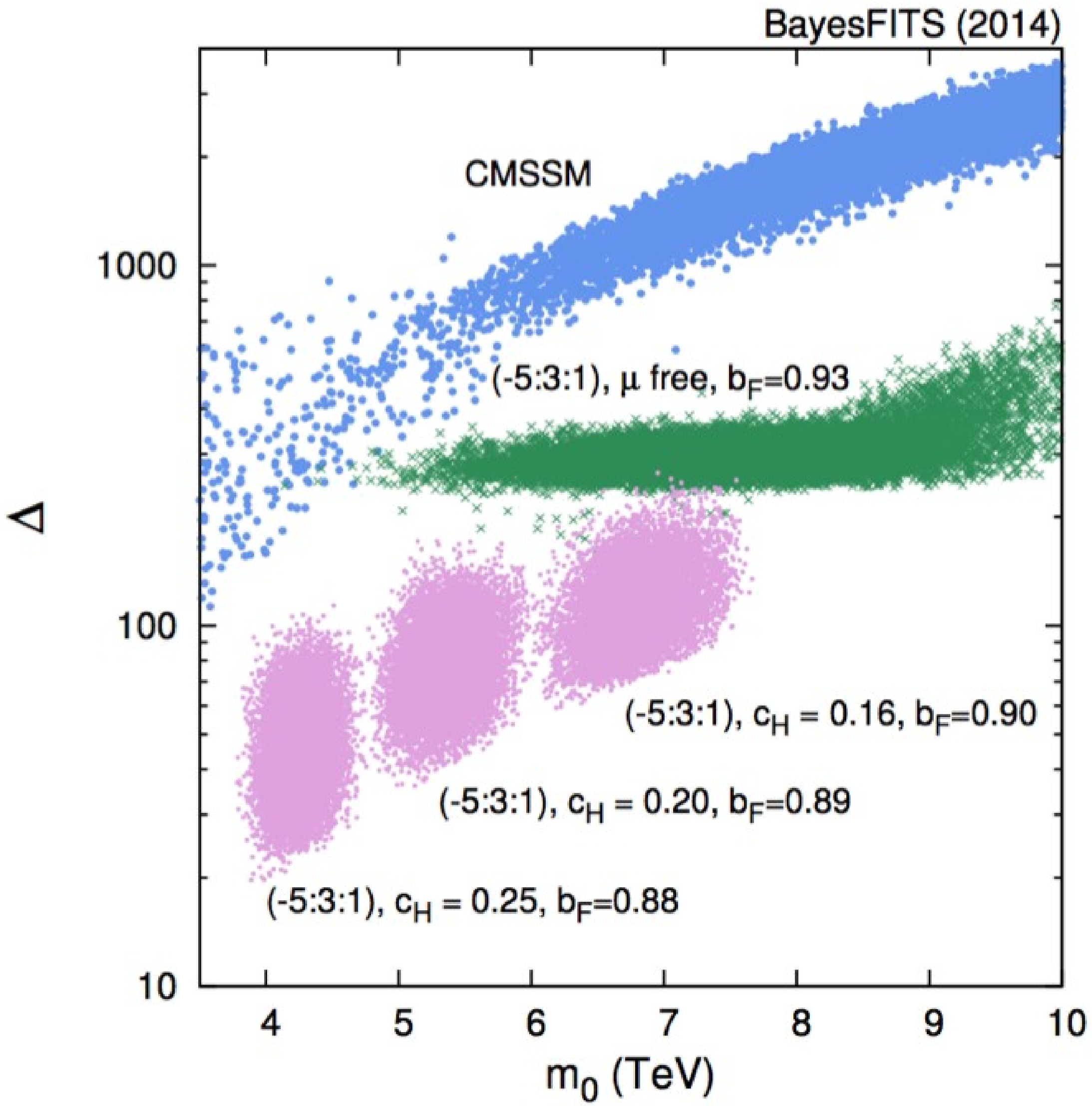
$$\frac{\Delta_{\bar{5}}^2(M_{\mathrm{GUT}})}{m_{10}^2(M_{\mathrm{GUT}})} = F(t, m_0, M_5) \exp\left(\frac{45}{8\pi^2}\lambda_H^2 t\right)$$

Including the mu parameter

Total fine tuning

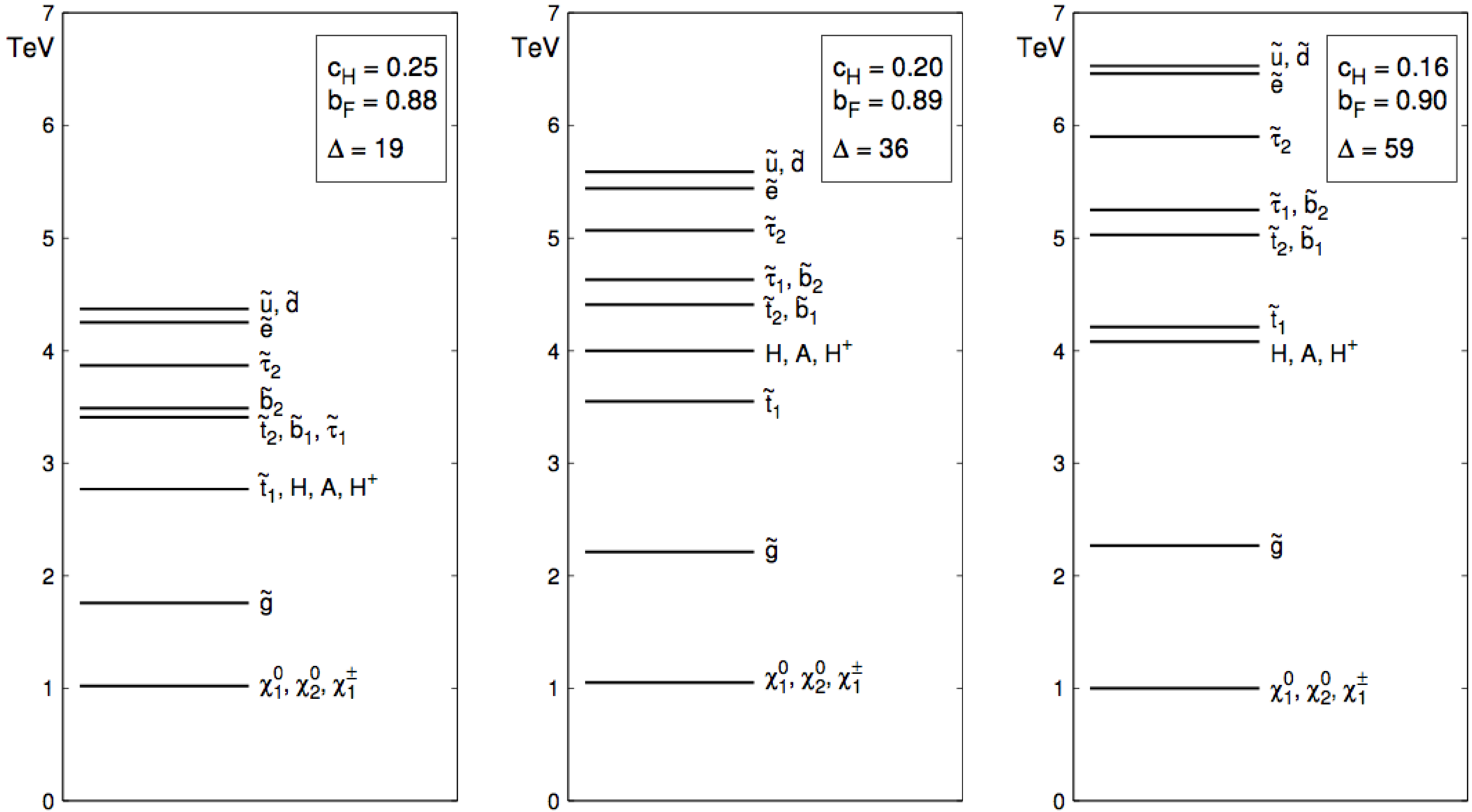
All constraints satisfied

~1 TeV higgsino DM



Including the mu parameter

Typical spectra:



Summary

- Models with universality satisfy constraints but unnatural

  (1TeV higgsino region very favored)

- Non universal conds. at GUT scale can induce focusing
- Must include mu (via Giudice-Masiero?)
- Shifting the burden to the pars. of the high-scale physics
- Spectra in reach of DM searches / LHC.