SUPERSYMMETRY/THEORY

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Outline

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- Focus points of the MSSM
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  - Gauge mediation
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- Beyond the MSSM
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  - The model
  - The supersymmetric spectrum
  - The EW breaking
- Conclusions

INTRODUCTION

- ATLAS & CMS have discovered a scalar boson with properties consistent with those of the SM Higgs and a mass 125 GeV
- Whether it actually is the SM Higgs depends on possible (future) deviations from the SM predictions in Higgs strengths (e.g. in the $\gamma\gamma$, or any other, channel)
- However the SM suffers (as any effective theory with cutoff $\Lambda \sim M_P$) from a naturalness problem by which the Higgs mass receives huge (quadratic) corrections

$$\Delta m^2 \simeq -\frac{3}{32\pi^2 v^2}\left(m_H^2 + 2m_W^2 + m_Z^2 - 4m_t^2\right)\Lambda^2$$

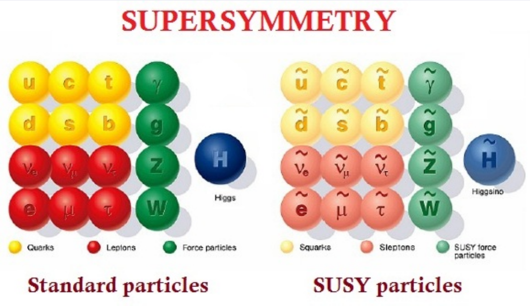
- The paradigmatic solution to the problem of quadratic divergences is supersymmetry by which the previous correction cancels out

IN PARTICULAR THE MINIMAL SUPERSYMMETRIC EXTENSION OF THE SM (MSSM)

- In the MSSM the fields of the SM are duplicated depending on their spins

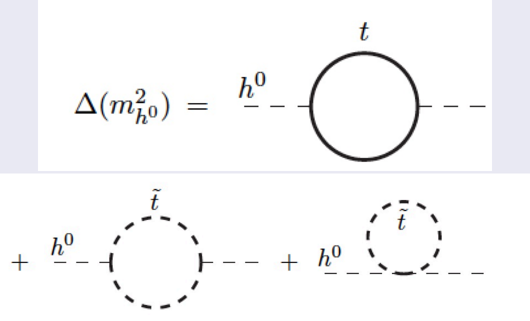
$$\text{SM fermions:} \quad f_{1/2} \to (f, \tilde{f}_0)$$
$$\text{SM gauge bosons: } A_\mu \to (A_\mu, \tilde{A}_{1/2})$$
$$\text{SM Higgs: } H \to (H, \tilde{H}_{1/2})_a \ (a = 1, 2)$$

A cartoon of the MSSM

- 

- The way supersymmetry solves the naturalness problem (sensitivity to UV physics) is by supersymmetric partners canceling the quadratic divergences generated by the SM fields

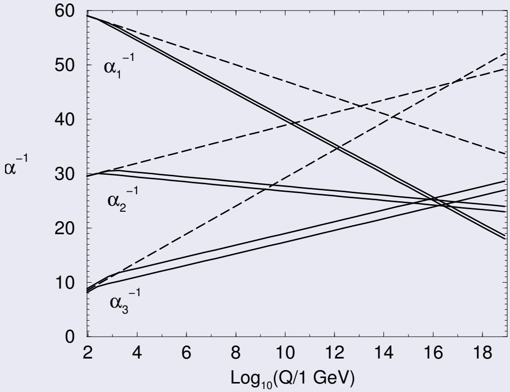
Supersymmetric cancellation



The pros of the MSSM

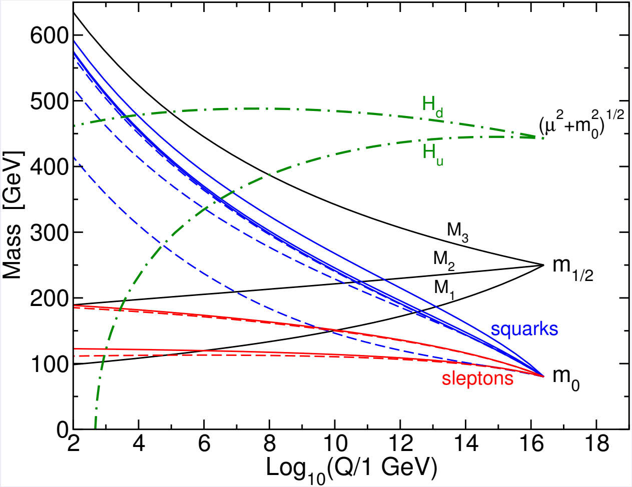
- Supersymmetry is a perturbative theory valid up to the Planck scale
- If superparticles are at $\sim$ TeV scale gauge couplings unify at a scale $M_{GUT} \sim 2 \times 10^{16}$ GeV

Gauge coupling unification in MSSM Vs SM



Triggers naturally electroweak breaking

If soft breaking parameters are generated at M_{GUT} a tachyonic mass can be triggered by RGE at the weak scale



No Stability/triviality problems

- The stability ($\lambda < 0$) and triviality/Landau pole ($\lambda \to \infty$) problems (cf. Hollik's talk) are solved because of the supersymmetric relation

$$\lambda = \frac{1}{8}(g^2 + g'^2)$$

- Because the gauge couplings remain perturbative (and positive) up to M_{GUT} there is no stability and/or triviality problem in the MSSM
- As a consequence: the Higgs mass (unlike in the SM) is NOT a free parameter. For the SM-like Higgs (cf. Slavich's talk)

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3 G_F m_t^4}{\sqrt{2}\pi^2} \left[\log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12 M_S^2} \right) \right]$$

Dark Matter

There is a natural candidate for Cold Dark Mater in the MSSM: the lightest neutralino, provided that R-parity is unbroken

The cons of the MSSM

The MSSM has a number of theoretical drawbacks

- The MSSM has a large number ($\sim 10^2$) of free parameters in the soft supersymmetry breaking sector (many more than the SM). They lower the predictability of the theory
- The supersymmetric parameters are essentially the Yukawa couplings of the SM plus the supersymmetric Higgsino mass μ

The μ-problem

$$W = \mu \widehat{H}_1 \cdot \widehat{H}_2 + \ldots, \quad \mathcal{L}_{soft} = -m_3^2 H_1 \cdot H_2 + h.c.$$

- Why the μ-problem is 'a problem'?

$\mu = \mathcal{O}(v), \quad m_3^2 = \mathcal{O}(v^2)$

Only $\mu = 0$ (if forbidden by a symmetry) or $\mu = \mathcal{O}(M_P)$, the cutoff of the theory, are natural

Uncertainty in the mechanism of supersymmetry breaking:

- Gravity mediation (cf. Uranga's talk):
  - Universal mechanism solving the μ problem (Giudice-Masiero)
  - Its minimal version reduces the number of free parameters to $\mathcal{O}$(few)
  - So-called supergravity models (minimal sugra)
- Gauge mediation
  - It is flavor blind
  - It has a μ problem and $A_t = 0$ (at one-loop)
  - Gravitino is the LSP
- Anomaly mediation
  - Tachyonic sleptons

Supersymmetric flavor problem

- Supersymmetric partners can create FCNC and CP violating operators
- Gravity mediation has to be subdominant ($\sim 0.1\%$ of gauge mediation): unless specific UV boundary conditions! (cf. Uranga's talk)

Little hierarchy problem

- The (running) Higgs mass is logarithmically sensitive to the stop mass (cf. Slavich's talk)

$$\Delta m_H^2 \propto L\, m_t^2 \log(m_{\tilde{t}}^2/m_t^2), \quad L = \text{loop factor}$$

- As $(m_H)^0 \lesssim m_Z$ and $(m_H)^{exp} = 125$ GeV, heavy stops are required

- However, when the stops decouple they leave threshold effects which are quadratically sensitive to the stop mass [1] and destabilize the SM vacuum (unless a fine-tuning is performed)

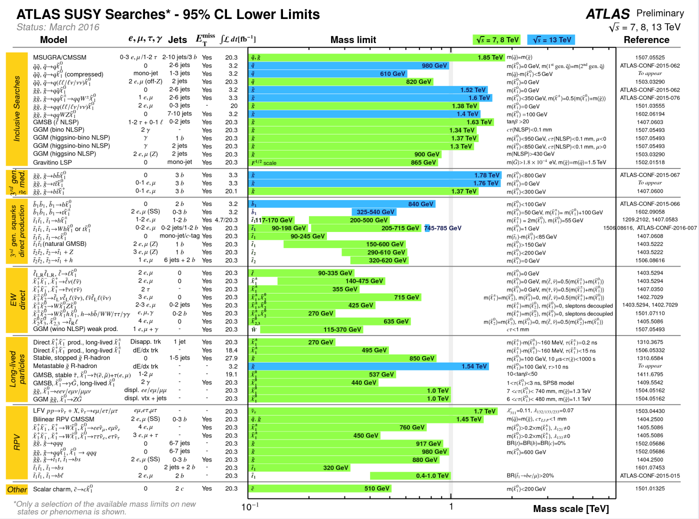
$$\lambda \Delta(v^2) \propto L\, y_t^2 m_{\tilde{t}}^2$$

The tension between the physical Higgs mass and the quadratic correction to the Higgs mass term is dubbed: little hierarchy problem

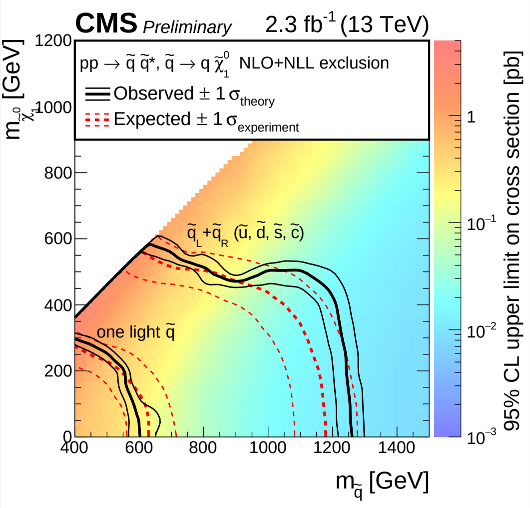
[1] I. Masina, G. Nardini and M. Q., "Electroweak vacuum stability and finite quadratic radiative corrections," arXiv:1502.06525 [hep-ph].

Still the main cons are: the absence of evidence from experimental data!

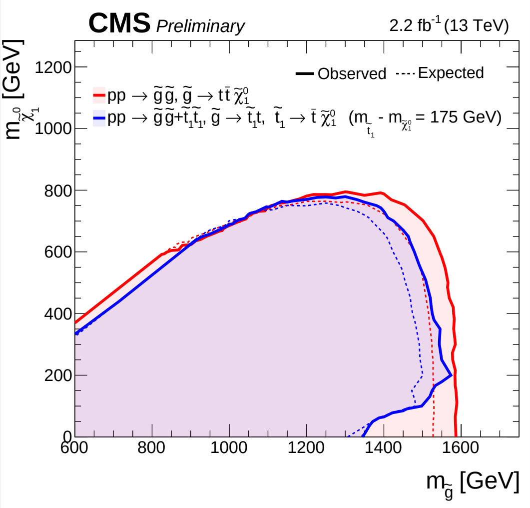
Summary of ATLAS results (cf. Juste's talk)



CMS results (squarks)



CMS results (gluinos)



Focus point in the MSSM

- Present exp. bounds are already a naturalness hazard
- In view of future stronger bounds people are re-analyzing and trying to improve naturalness in the MSSM (and minimal extensions)
- One idea to alleviate the fine-tuning is if the high supersymmetry scale is the Focus Point (FP) of the RGE [2] for large $\tan\beta$
- As experimental data suggest that gluinos and sfermion masses may be much larger than the weak scale these particles would decouple at some scale $\mathcal{Q}_0 \gg \mathcal{Q}_{EW}$, and therefore the matching should be performed at the scale $\mathcal{Q}_0$
- The matching condition yields a relationship between the SM Higgs boson potential parameters

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

where $m^2(\mathcal{Q}_{EW}) = \frac{1}{2}m_H^2$, and the supersymmetric parameters at $\mathcal{Q}_0$

[2] J. L. Feng, K. T. Matchev and T. Moroi, hep-ph/9909334

Matching conditions

$$m_H^2/2 = \frac{m_{H_1}^2(\mathcal{Q}_0) - m_{H_2}^2(\mathcal{Q}_0)}{\tan^2\beta - 1} - m_{H_2}^2(\mathcal{Q}_0) - |\mu(\mathcal{Q}_0)|^2$$

$$\lambda = \frac{1}{4}(g_1^2 + g_2^2)\cos^2 2\beta + \frac{3h_t^4}{8\pi^2}X_t^2\left(1 - \frac{X_t^2}{12}\right), \quad X_t = \frac{(A_t - \mu/\tan\beta)}{\mathcal{Q}_0}$$

- For a heavy supersymmetric spectrum, i.e. large soft-breaking terms $a \equiv (m_Q^2,\, m_U^2,\, m_{H_2}^2,\, M_a)$ at the high scale M (messenger scale) at which they are generated, one expects $m_{H_2}^2(\mathcal{Q}_0)$ to be large, thus triggering a huge fine-tuning in matching equation

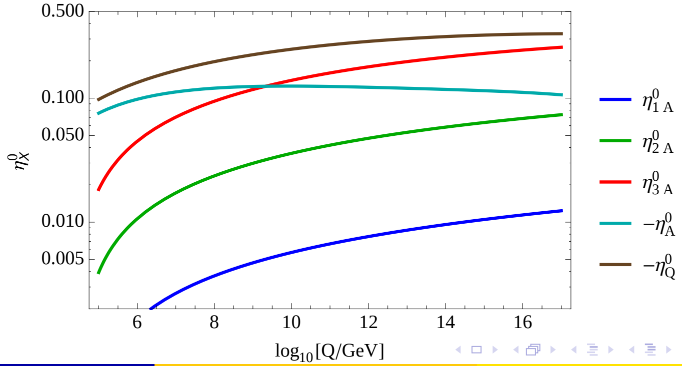
Sensitivity

$$\Delta = \max_a\{\Delta_a\}, \quad \Delta_a = \left|\frac{\partial \log m_H^2}{\partial \log a}\right|$$

The naturalness problem in MSSM thus translates into sensitivity w.r.t. $(m_Q^2,\, m_U^2,\, m_{H_2}^2,\, M_a)$ at the high scale M

- The value of $m^2_{H_2}$ at the scale $\mathcal{Q}_0$ can then be computed on general grounds as

$$m^2_{H_2}(\mathcal{Q}_0) = m^2_{H_2} + \eta^0_Q(M)(m^2_Q + m^2_U + m^2_{H_2}) + \sum_a \eta^0_a(M) M^2_a$$
$$+ \sum_{a \neq b} \eta^0_{ab}(M) M_a M_b + \sum_a \eta^0_{aA}(M) M_a A_t + \eta^0_A(M) A^2_t$$



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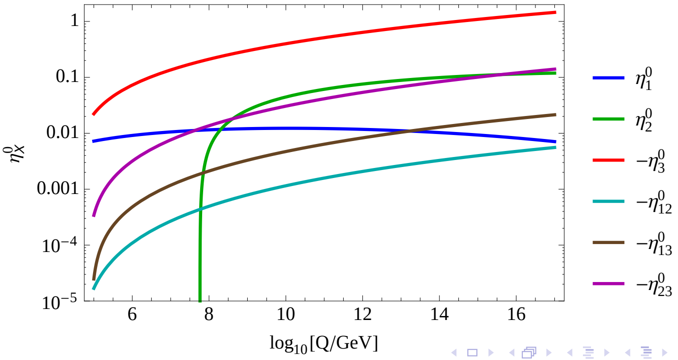
$$+ \sum_{a \neq b} \eta^0_{ab}(M) M_a M_b + \sum_a \eta^0_{aA}(M) M_a A_t + \eta^0_A(M) A^2_t$$



- The FP is defined by

$$m^2_{H_2}(\mathcal{Q}_0) = 0$$

invariant under

$$(m^2_Q,\, m^2_U,\, m^2_{H_2},\, M_a,\, A_t) \to \;(\lambda^2\, m^2_Q,\, \lambda^2\, m^2_U,\, \lambda^2\, m^2_{H_2},\, \lambda\, M_a,\, \lambda\, A_t)$$

- and for large $\tan\beta$ the EOM is

$$\frac{m^2_H}{2} \simeq \frac{m^2_{H_1}(\mathcal{Q}_0)}{\tan^2\beta} - |\mu(\mathcal{Q}_0)|^2, \quad m^2_3 \simeq m^2_{H_1}/\tan\beta$$

- So that for

$$m_{H_1} \simeq \tan\beta m_H, \quad \mu \simeq m_H$$

fine-tuning is minimized

- A scatter plot of the sensitivity Δ with respect to the soft-breaking parameters $(m_Q^2,\, m_U^2,\, m_{H_2}^2,\, M_a)$ at the messenger scale M would show, for large $\tan\beta$, a minimum fine-tuning for configurations of $(m_Q^2,\, m_U^2,\, m_{H_2}^2,\, M_a)$ such that there is the FP at the scale $\mathcal{Q}_0$

$$m_{H_2}^2(\mathcal{Q}_0) = 0$$

- For a given messenger scale M the configuration which provides minimum fine-tuning in solving the EOM has a fixed relationship between the different parameters $(m_Q^2,\, m_U^2,\, m_{H_2}^2,\, M_a)$
- This relationship has to be provided by the theory at the scale M
- If we consider a particular theory of supersymmetry breaking

THERE IS A HIDDEN FINE-TUNING WE ARE NOT CONSIDERING

- or perhaps it is

IMPLEMENTED BY THE SYMMETRIES OF THE UV THEORY

- In the absence of a particular theory of supersymmetry breaking at the scale M

THE HIDDEN FINE-TUNING IS UNCOMPUTABLE

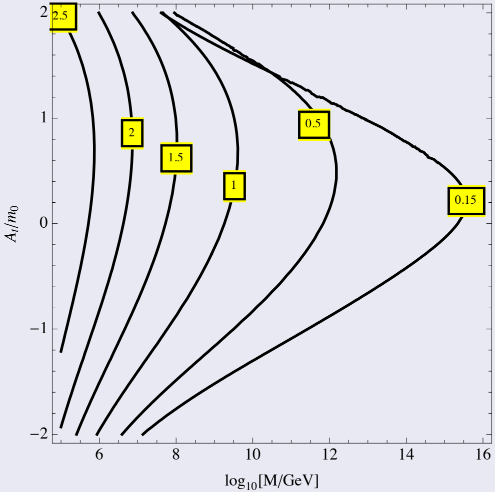
- Instead of making a scatter plot of sensitivity we can study the existence of FP's for different models of boundary condition. In particular [3]

- CMSSM MODELS
- GAUGE MEDIATION MODELS
- MIRAGE MEDIATION=GRAVITY MEDIATION+ANOMALY MEDIATION MODELS

[3] A. Delgado, M. Q., C. Wagner, arXiv:1402.1735

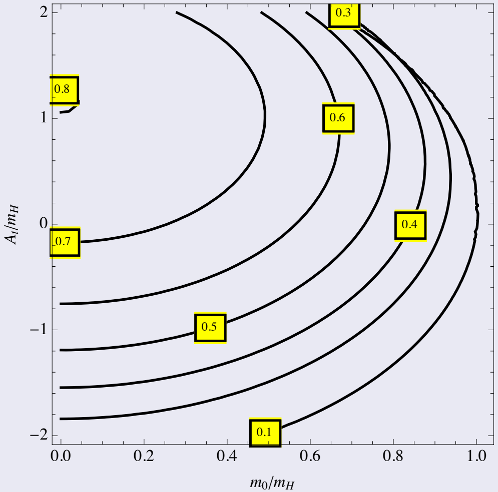
UNIVERSAL BOUNDARY CONDITIONS

$m_Q = m_U = m_{H_2} \equiv m_0, \quad M_a \equiv m_{1/2}$ (contours of fixed $m_{1/2}/m_0$)



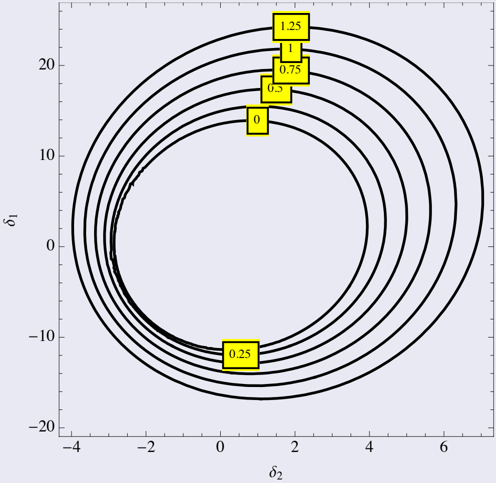
non-universal Higgses: $M = 10^{16}$ GeV

$m_Q = m_U \equiv m_0, \quad m_{H_2} = m_{H_1} \equiv m_H, \quad M_a \equiv m_{1/2}$ (fixed $m_{1/2}/m_H$)



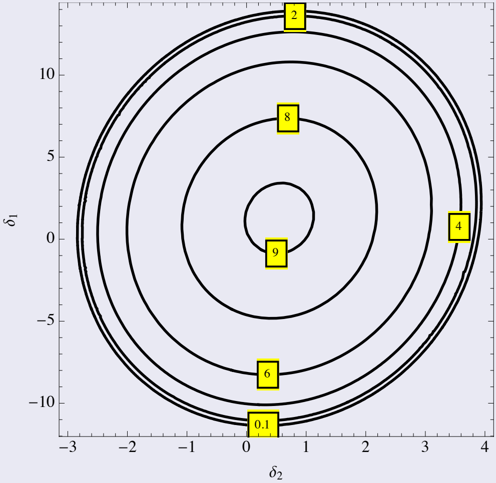
NON-UNIVERSAL GAUGINOS: $M = 10^{16}$ GeV

$m_Q = m_U = m_{H_2} \equiv m_0, \quad M_a \equiv \delta_a m_{1/2}, \; A_t = -2.5 m_0$ (fixed $m_{1/2}/m_0$)



NON-UNIVERSAL GAUGINOS: $M = 10^{16}$ GeV

$m_Q = m_U = m_{H_U} \equiv m_0, \quad M_a \equiv \delta_a m_{1/2}, \; A_t = 0$ (fixed $m_{1/2}/m_0$)



Gauge mediation

- Supersymmetry is broken in a hidden sector by fields

$$X = M + F\theta^2$$

- It is communicated to the messenger fields by superpotential couplings

$$W = \Phi^I X \overline{\Phi}_I + \lambda_U H_2 \mathcal{O}_D + \lambda_D H_1 \mathcal{O}_U$$

$\Lambda_G = NF/4\pi M, \quad \Lambda_S = \Lambda_G/\sqrt{N}$

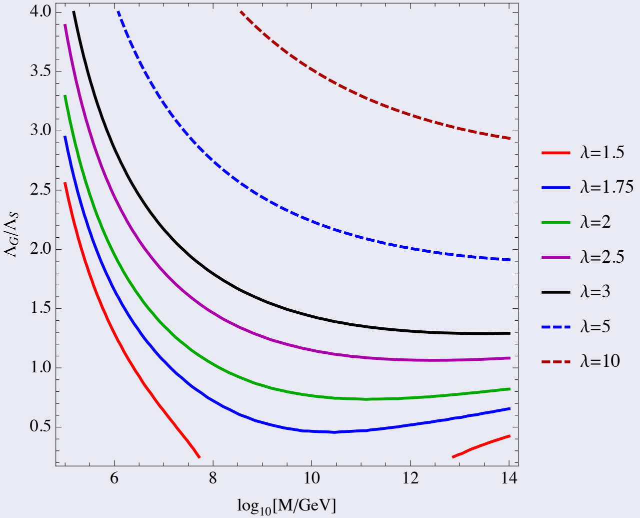
$$m_Q^2 = 2\left(\frac{4}{3}\alpha_3^2 + \frac{3}{4}\alpha_2^2 + \frac{1}{60}\alpha_1^2\right)\Lambda_S^2$$

$$m_U^2 = 2\left(\frac{4}{3}\alpha_3^2 + \frac{4}{15}\alpha_1^2\right)\Lambda_S^2$$

$$m_{H_2}^2 = 2\left(\frac{3}{4}\alpha_2^2 + \frac{3}{20}\alpha_1^2\right)\Lambda_S^2$$

$$M_a = \alpha_a \Lambda_G, \quad A_t = 0, \quad m_{H_2}^2 = (1+\lambda)\, m_L^2, \quad \lambda = \lambda_U^2$$

Lines of constant λ (excluded $\lambda = 0$, i.e. MGM)



Mirage mediation

Mirage mediation assumes that the contributions from gravity and anomaly mediation are comparable in size

$\widetilde{m}_{3/2} = m_{3/2}/4\pi,$ $[+\mathcal{O}(\alpha_1^2)]$

$$m_{H_2}^2 \simeq m_0^2 + \left[3\alpha_t\left(6\alpha_t - \frac{16}{3}\alpha_3 - 3\alpha_2 - \frac{13}{15}\alpha_1\right) - \frac{3}{2}\alpha_2^2 b_2\right]\widetilde{m}_{3/2}^2$$

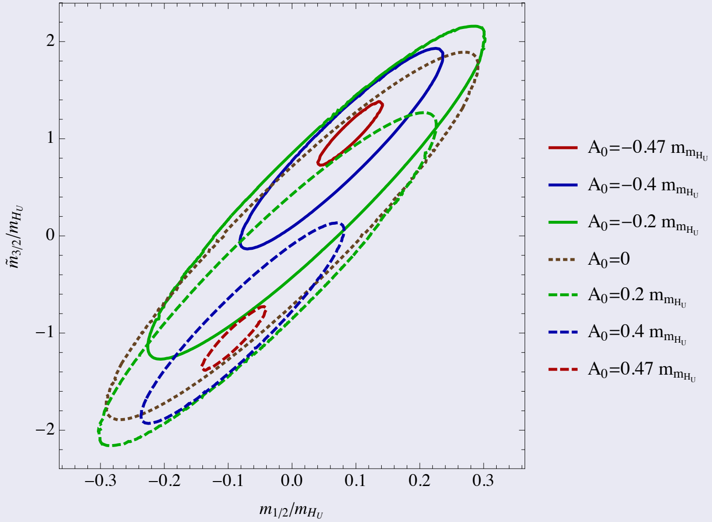
$$m_Q^2 \simeq m_0^2 + \left[\alpha_t\left(6\alpha_t - \frac{16}{3}\alpha_3 - 3\alpha_2 - \frac{13}{15}\alpha_1\right) - \frac{8}{3}\alpha_3^2 b_3 - \frac{3}{2}\alpha_2^2 b_2\right]\widetilde{m}_{3/2}^2$$

$$m_U^2 \simeq m_0^2 + \left[2\alpha_t\left(6\alpha_t - \frac{16}{3}\alpha_3 - 3\alpha_2 - \frac{13}{15}\alpha_1\right) - \frac{8}{3}\alpha_3^2 b_3\right]\widetilde{m}_{3/2}^2$$

$$A_t = A_0 - \left(6\alpha_t - \frac{16}{3}\alpha_3 - 3\alpha_2 - \frac{13}{15}\alpha_1\right)\widetilde{m}_{3/2}$$

$$M_a = m_{1/2} + \alpha_a b_a \widetilde{m}_{3/2}$$

Lines of constant A_0, for $M = 10^{16}$ GeV



Beyond the MSSM

- The experimental value of the Higgs mass (125 GeV) constrains the MSSM parameters (cf. Slavich's talk):

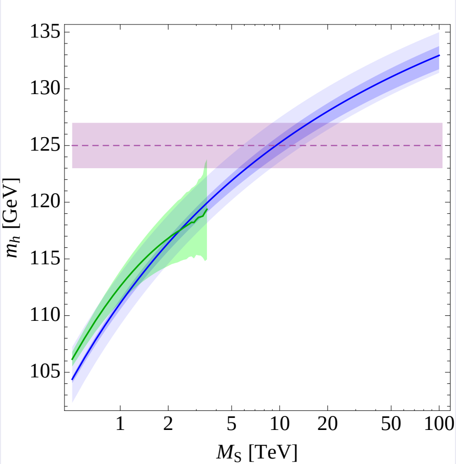
  - Heavy enough stops ($\gtrsim$ TeV)
  - Large values of $\tan\beta \gg 1$, i.e. $v_2 \gg v_1$: it requires the hierarchy $m_1^2 \gg m_3^2$, $m_2^2 \simeq -m_Z^2/2$ from EW minimum
  - Maximum value of LR mixing in stop sector $A_t \simeq \sqrt{6} m_{\tilde{t}}$

  which re-creates a little hierarchy problem $\sim (0.1 - 1)\%$
- Some supersymmetric models are already ruled out by the Higgs discovery at the LHC and by the measurements of Higgs couplings to fermions and gauge bosons

An example is the MSSM from minimal gauge mediation, the paradigmatic mechanism to solve the supersymmetric flavor problem: A_t is generated only at two-loop and very heavy stops are required

GMSB can reproduce the Higgs mass only for superheavy stop masses [4]

Higgs mass for small $A_t \simeq 0$ and $\tan\beta = 30$

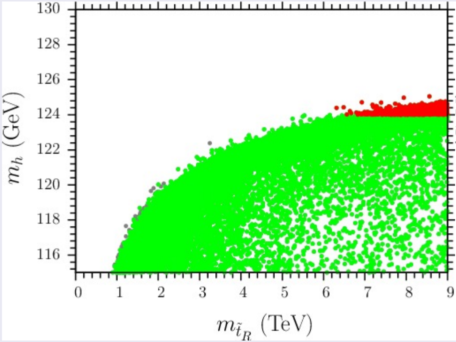


$m_{\tilde{t}} \gtrsim 10$ TeV

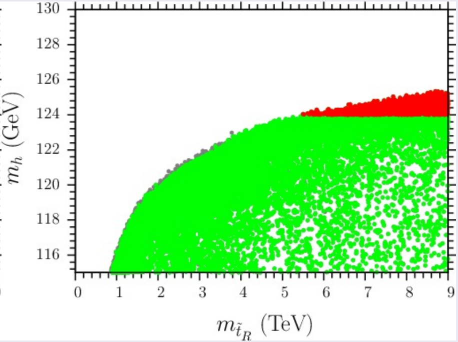
[4] P. Draper, P. Meade, M. Reece and D. Shih, "Implications of a 125 GeV Higgs for the MSSM and Low-Scale SUSY Breaking," arXiv:1112.3068 [hep-ph]

- Within minimal GMSB [5]

GMSB with $n_{5+\bar{5}} = 1$



GMSB with $n_{5+\bar{5}} = 5$



$$m_{\tilde{t}} \gtrsim 10 \text{ TeV}$$

[5] M. A. Ajaib, I. Gogoladze, F. Nasir and Q. Shafi, "Revisiting mGMSB in Light of a 125 GeV Higgs," arXiv:1204.2856 [hep-ph].

An attempt to have a more natural supersymmetric theory and get rid of the little hierarchy problem is going beyond the MSSM (BMSSM) and increasing the tree level Higgs mass by a D-term [6], or an F-term [7]

D-term contribution

- An extra gauge group, on top of the SM one, has to be introduced
- The Higgs sector has to be charged under the extra gauge group
- The D-term contribution easily increases the tree level Higgs mass to cope with experimental values
- The model requires anomaly cancellation

The simplest way, which does not require to enlarge the gauge group, is by an F term which implies enlarging the MSSM Higgs sector

[6] P. Batra, A. Delgado, D. E. Kaplan and T. M. P. Tait, "The Higgs mass bound in gauge extensions of the minimal supersymmetric standard model," hep-ph/0309149

[7] J. R. Espinosa and M. Q., "Gauge unification and the supersymmetric light Higgs mass," Phys. Rev. Lett. **81** (1998) 516 [hep-ph/9804235].

F-term contribution

- The only possibilities are introducing gauge singlets S and/or $SU(2)_L$ triplets T_Y with hypercharge $Y = 0, \pm 1$ which can couple to the Higgs sector as

$$W = \lambda_1 S H_1 \cdot H_2 + \lambda_2 H_1 \cdot T_0 H_2 + \chi_1 H_1 \cdot T_1 H_1 + \chi_2 H_2 \cdot T_{-1} H_2$$

- Singlets and triplets contribute to the tree-level Higgs mass as

$$\frac{m_h^2}{v^2} = \frac{g^2 + g'^2}{2} \cos^2 2\beta + (\lambda_1^2 + \lambda_2^2) \sin^2 2\beta + 4\chi_1^2 \cos^4 \beta + 4\chi_2^2 \sin^4 \beta$$

Of course singlets are the simplest solution (NMSSM) to solve the little hierarchy problem, although they contribute only to the Higgs mass for small values of $\tan\beta$ (cf. Slavich's talk)

- However singlet tadpoles are not protected by any symmetry (once local supersymmetry is broken) and can destabilize the hierarchy when they are coupled to heavy states as Bagger, Poppitz and Randall proved [8] that there are 2-loop divergences

$$\mathcal{L} \propto \frac{1}{(16\pi^2)^2} m_{3/2}^2 M_p Re(S + S^\dagger)$$

- Way out is if tadpoles are protected by residual symmetry, as e.g. $\mathbb{Z}_3$ but then there is a cosmological domain wall problem as Abel, Sarkar and White showed [9]
- There is not an easy solution, as e.g. introducing gauged $U(1)_R$ symmetry [10] which requires anomaly cancellation

[8] J. Bagger, E. Poppitz and L. Randall, hep-ph/9505244
[9] S.A. Abel, S. Sarkar and P.L. White, arXiv:hep-ph/9506359
[10] S.A. Abel, arXiv:hep-ph/9609323

- Dropping the existence of singlets, the next solution is adding triplets with $|Y| = 0, 1$ (no tadpoles allowed)
- It is a particularly appealing extension, which includes singly and doubly charged states
- Triplets have (as generic non-doublet representations) the general problem that their VEVs contribute to the ρ parameter at the tree-level, strongly constraining the model, as experimentally we know

$$\rho - 1 = \Delta\rho, \qquad -4 \times 10^{-4} < \Delta\rho < 10^{-3} \quad @ \quad 95\% CL$$

- This constraint translates into a few GeV bound on the triplet VEV
- Or by introducing a custodial symmetry in the model in the context of non-supersymmetric [11] and supersymmetric [12] extensions of the SM

Many problems solved going to X-dim

[11] Georgi-Machacek, NPB **262** (1985) 463; Chanowitz-Golden, PLB **165** (1985) 105; Gunion-Vega-Wudka, PRD **42** (1990) 1673.

[12] L. Cort, M. Garcia-Pepin and M. Q., arXiv:1308.4025 [hep-ph]

An example of focus point BC's: SS breaking

- As we saw, focus point are boundary conditions which satisfy automatically the equations of the EW minimum:

Potential

$$V = m_1^2|H_1^0|^2 + m_2^2|H_2^0|^2 - (m_3^2 H_1^0 H_2^0 + h.c.) + \frac{g^2 + g'^2}{8}(|H_1^0|^2 - |H_2^0|^2)^2$$

EoM

$$\frac{g^2 + g'^2}{4} v^2 = \left[\frac{m_1^2 - m_2^2}{\sqrt{(m_1^2 + m_2^2)^2 - 4m_3^4}} - 1\right](m_1^2 + m_2^2)$$

- The last equation usually requires a fine-tuning (for large values of the parameters) to determine the value of $v = 246$ GeV

The model

- The model is based on a 5D theory compactified on an interval (orbifold): $S^1/\mathbb{Z}_2$, with two 4D branes at the fixed points $y = 0, \pi R$
- Gauge bosons, at least first and second generation matter and the Higgs sector are propagating in the bulk
- In the bulk there is $N = 2$ supersymmetry and matter is in $N = 2$ hypermultiplets, e.g. $\mathbb{H}_a = (H_a, H_a^c, \Psi_a, F_a, F_a^c)$ where Ψ_a are Dirac
- Zero modes have $N = 1$ (orbifold boundary conditions)
- $N = 1$ supersymmetry is broken by twisted (SS) boundary conditions with parameter $0 < \omega < 1/2$

$$\begin{bmatrix} H_1(x,y) & H_1^c(x,y) \\ H_2^c(x,y) & H_2(x,y) \end{bmatrix} =$$

$$e^{i\omega\sigma_2 y} \sum_{n=0}^{\infty} \sqrt{\frac{2}{\pi}} \begin{bmatrix} \cos ny\, H_1^{(n)}(x) & \sin ny\, H_1^{c(n)}(x) \\ \sin ny\, H_2^{c(n)}(x) & \cos ny\, H_2^{(n)}(x) \end{bmatrix} e^{-i\omega\sigma_2 y}$$

The spectrum

- The spectrum is [13] at tree-level
  - For first and second generation matter (and $\tilde{\tau}_R$) and gauginos

$$M_a = m_{\tilde{f}} = \frac{\omega}{R}$$

  - For the Higgs sector

$$m_1^2 = m_2^2 = m_3^2 = \frac{\omega}{R} \quad \Longrightarrow \quad v = 0,\ \tan\beta = 1,\ m_h = 0,\ m_H = \frac{2\omega}{R}$$

- EW symmetry is unbroken at the tree level (it requires radiative breaking) and the Higgs mass is zero at tree level ($\tan\beta = 1$)

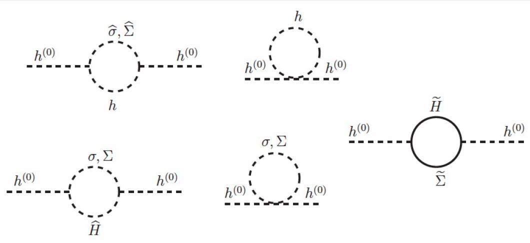
[13] I. Antoniadis, S. Dimopoulos, A. Pomarol and M. Q., hep-ph/9810410
A. Delgado, A. Pomarol and M. Q., [hep-ph/9812489]
S. Dimopoulos, K. Howe and J. March-Russell, arXiv:1404.7554 [hep-ph]
I. G. Garcia, K. Howe and J. March-Russell, arXiv:1510.07045 [hep-ph].

EW BREAKING

- Both problems are fixed by introducing Higgs triplets $\mathcal{T}_a$ in the bulk with $Y = 0$ (which trigger a tree-level Higgs mass F-term at small values of $\tan\beta$) and coupled by a superpotential term

$$W = \left(\widehat{\lambda}_1 \mathcal{H}_1 \cdot \mathcal{T}_1 \mathcal{H}_2 + \widehat{\lambda}_2 \mathcal{H}_1 \cdot \mathcal{T}_2 \mathcal{H}_2\right) \delta(y)$$

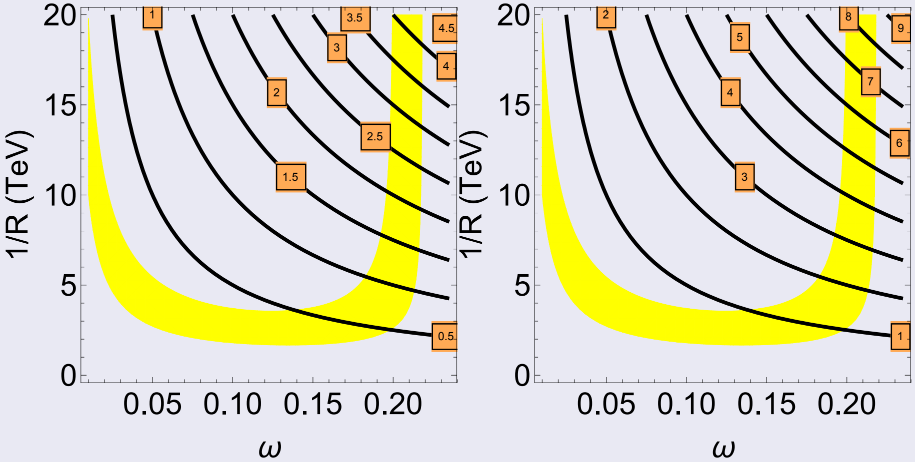
- EW breaking is triggered by one-loop radiative corrections as [14]



[14] A. Delgado, M. Garcia-Pepin, G. Nardini and M. Q., in preparation

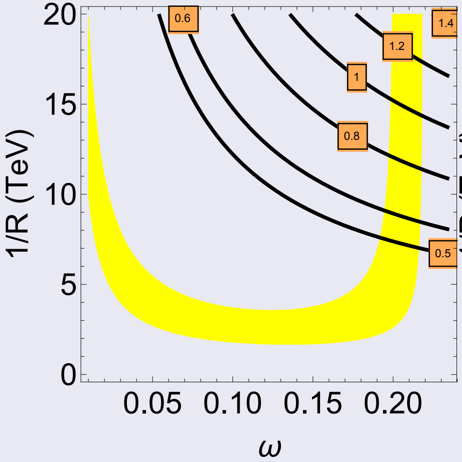
- The region (yellow) of radiative EWSB is shown in the plots

Masses of bulk sfermions and gauginos | **Heavy Higgses**

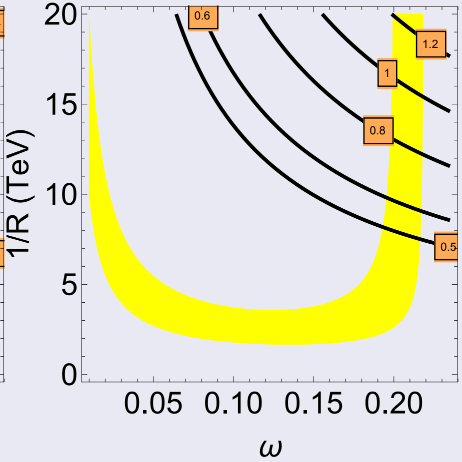


- Third generation matter is localized at the brane $y = 0$
- It is massless at the tree level
- Stops receive a mass from (finite) radiative corrections

Heavier stop

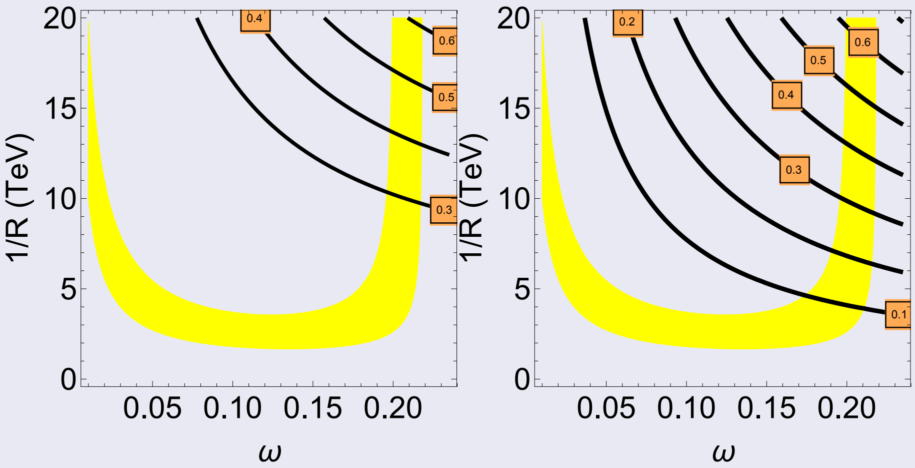


Lighter stop



- As well as the third generation slepton doublet and light triplet

$\tilde{\ell}_3$ | Light triplet



The global picture is

- Above the scale $\mathcal{Q} \sim 1/R$ the theory is 5D
- At the scale $\mathcal{Q} \sim \omega/R$ all KK modes (e.g. gauginos) are integrated out and yield (finite) threshold effects triggering radiative EWSB
- Below the scale $\mathcal{Q} = \omega/R$ the theory is the 4D SM plus the light sector scalars (e.g. stops), with masses at $\lesssim$TeV
- At the scale $m_{\tilde{t}} \simeq 700 - 800$ GeV stops decouple and yield quadratic corrections to the Higgs mass (thresholds)

$$\Delta m_H^2 \simeq \frac{12}{32\pi^2} h_t^2 m_{\tilde{t}}^2 \simeq \left(10^2 \text{ GeV}\right)^2$$

which do not destabilize the EW minimum

- The LSP is the third generation $\tilde{\nu}_L$
- The NLSP is the $\tilde{\tau}_L$
- The phenomenology is to be worked out

Conclusion

- Supersymmetry is a beautiful theory which can explain the big hierarchy problem, with DM candidates
- It has its roots on more fundamental theories as supergravity and superstring theories
- Of course the *devil is in the details* $\equiv$ mechanism of supersymmetry breaking
- The simplest detection is probably on the gluino $\equiv$ a strongly interacting particle with gauge couplings
- Supersymmetry decouples $\Leftrightarrow$ It is impossible to exclude it in an absolute way
- Present bounds are in the 1-2 TeV, but a tuning of 1 part in 10^3 or 10^4 is always much better than one part in 10^{16} (the SM fine tuning)

The last word (for the moment) is in the hands of LHC13!