MSSM with Heavy Scalars

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Outline

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Susy with light scalars: MSSM

SUSY with light (scalar and fermionic) superpartners provides a technical solution to the electroweak hierarchy problem (why is $m_H^2 \sim 10^{-32} M_P^2$???)

- Two bonuses come with light fermionic superpartners:
  - ✔ Improved gauge coupling unification.
  - ✔ The lightest neutralino is a natural candidate for DM.
- ...but light scalar superpartners bring along several problems:
  - ✘ Quite light Higgs boson mass (tension with LEP searches).
  - ✘ New sources of flavour and CP violation.
  - ✘ ...

Also, hierarchy and fine tuning don't want to go away: the cosmological constant problem still has to be solved (why is $\Lambda \sim 10^{-120} M_P^4$???)

Outline

Susy with heavy scalars

➡ With Heavy scalars we lose the solution of the hierachy problem.

- Maybe the electroweak hierarchy problem is solved by a similar way that the cosmological constant one, and we do not need to worry about the fine tuning in the Higgs mass
- Scalar superpartners are needed to be light only to avoid fine tuning. If we accept them to be heavy, we can retain the advantages of weak-scale SUSY and get rid of all its disadvantages

In this model all the scalars but the SM Higgs are much heavier than the weak scale ($M_S = 10^4 - 10^{13}$ GeV), while gaugino and higgsino masses are protected by symmetries and are of $\mathcal{O}(10^2 - 10^3 \text{ GeV})$

But another fine-tunning for the SM-like Higgs boson, and another scale (M_S) entres in the game...

The effective lagrangian

$$\begin{aligned}
\mathcal{L} \quad = \quad & m^2 H^\dagger H - \frac{\lambda}{2}\left(H^\dagger H\right)^2 - \Big[h^u_{ij}\bar{q}_j u_i \epsilon H^* + h^d_{ij}\bar{q}_j d_i H + h^e_{ij}\bar{\ell}_j e_i H \\
& + \frac{M_3}{2}\tilde{g}^A\tilde{g}^A + \frac{M_2}{2}\tilde{W}^a\tilde{W}^a + \frac{M_1}{2}\tilde{B}\tilde{B} + \mu\tilde{H}_u^T\epsilon\tilde{H}_d \\
& + \frac{H^\dagger}{\sqrt{2}}\left(\tilde{g}_u\sigma^a\tilde{W}^a + \tilde{g}'_u\tilde{B}\right)\tilde{H}_u + \frac{H^T\epsilon}{\sqrt{2}}\left(-\tilde{g}_d\sigma^a\tilde{W}^a + \tilde{g}'_d\tilde{B}\right)\tilde{H}_d + \text{h.c.}\Big]
\end{aligned}$$

Finely tuned SM-like Higgs doublet

$$H = -\cos\beta\epsilon H_d^* + \sin\beta H_u$$

Boundary conditions at the scale M_S

$$\lambda(M_S) = \frac{1}{4}\left[g^2(M_S) + g'^2(M_S)\right]\cos^2 2\beta$$

$$h^u_{ij}(M_S) = \lambda^{u*}_{ij}(M_S)\sin\beta, h^{d,e}_{ij}(M_S) = \lambda^{d,e*}_{ij}(M_S)\cos\beta$$

$$\tilde{g}_u(M_S) = g(M_S)\sin\beta,\ \tilde{g}_d(M_S) = g(M_S)\cos\beta,\ \tilde{g}'_u(M_S) = g'(M_S)\sin\beta,\ \tilde{g}'_d(M_S) = g'(M_S)\cos\beta$$

Charginos and Neutralinos

The mass matrices depend on the effective Higgs–higgsino–gaugino couplings:

$$M_C = \begin{pmatrix} M_2 & \tilde{g}_u v \\ \tilde{g}_d v & \mu \end{pmatrix} \quad M_N = \begin{pmatrix} M_1 & 0 & -\tilde{g}'_d v/\sqrt{2} & \tilde{g}'_u v/\sqrt{2} \\ 0 & M_2 & \tilde{g}_d v/\sqrt{2} & -\tilde{g}_u v/\sqrt{2} \\ -\tilde{g}'_d v/\sqrt{2} & \tilde{g}_d v/\sqrt{2} & 0 & -\mu \\ \tilde{g}'_u v/\sqrt{2} & -\tilde{g}_u v/\sqrt{2} & -\mu & 0 \end{pmatrix}$$

- The lightest neutralino remains a viable candidate for Dark Matter
- Include RC to chargino and neutralino masses

Coupling Higgs - neutralino

$$g_{\chi_1^0 \chi_1^0 h} = N_{13}(\tilde{g}_d N_{12} - \tilde{g}'_d N_{11}) - N_{14}(\tilde{g}_u N_{12} - \tilde{g}'_u N_{11})$$

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Fortran Code

Subroutine of the program Suspect (J.L. Kneur et al.)

- Inputs: M_S, $\mu(M_Z)$, $M_{1/2}(M_{GUT})$, $tan(\beta)(M_S)$ & SM inputs
- Evolution:

M_{EW}		M_S
g_1, g_2, g_3 h^t, h^b, h^τ μ	$\leftsquigarrow$ RGE $\rightsquigarrow$ 1-loop threshold corrections	$\tilde{g}_u, \tilde{g}_d, \tilde{g}'_u, \tilde{g}'_d$ M_1, M_2, M_3 λ

... and obtain running masses of: M_h, M_{χ^0}, M_{χ^+}, $M_{\tilde{g}}$.

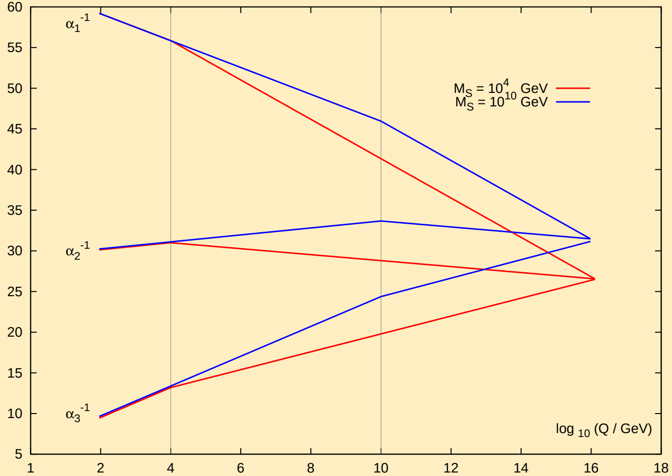
- Computation of the pole masses of the Higgs boson and charginos, neutralinos & gluinos

+ Interface with : $\begin{cases} \text{Hdecay: Higgs Decay} \\ \text{Sdecay: } \chi^0, \chi^+, \tilde{g} \\ \text{'omega' subroutine (M. Drees).} \quad \text{with} \quad h \to WW^* \to Wff \end{cases}$

Outline

Plots

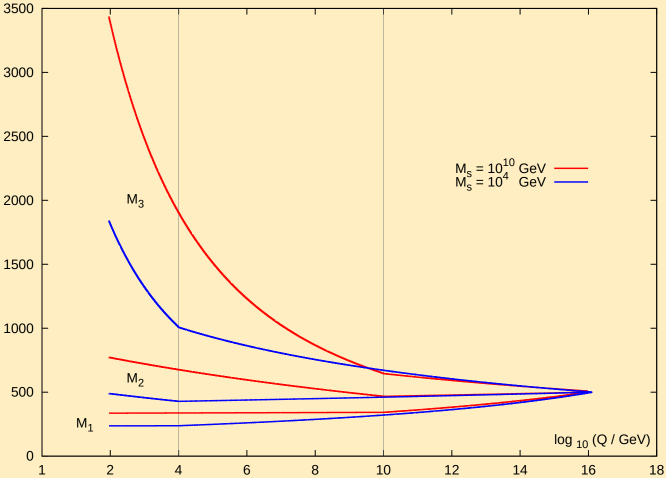
Unification of gauge couplings



$\mu = M_{1/2} = 500\ GeV,\ tan(\beta) = 30$

Plots

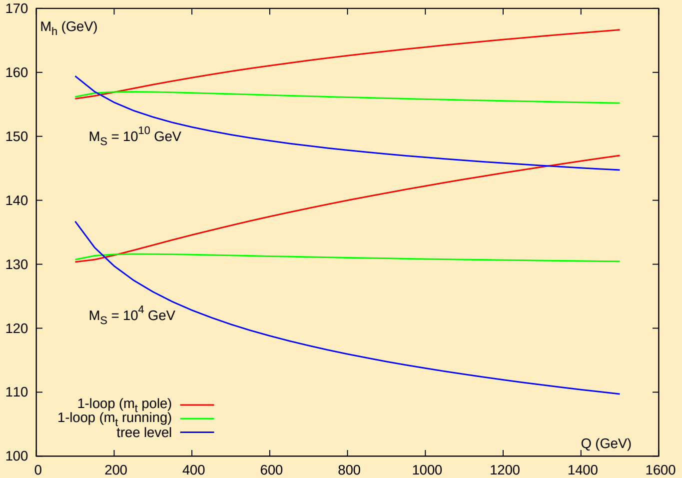
Unification of gaugino masses



$$\mu = M_{1/2} = 500\ GeV,\ tan(\beta) = 30$$

Plots

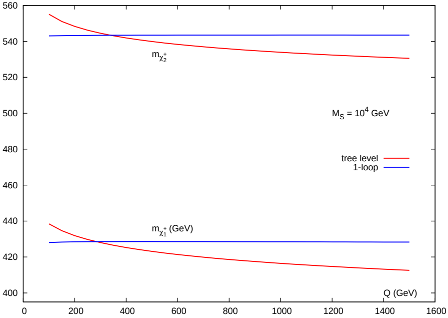
Prediction for the light Higgs boson mass

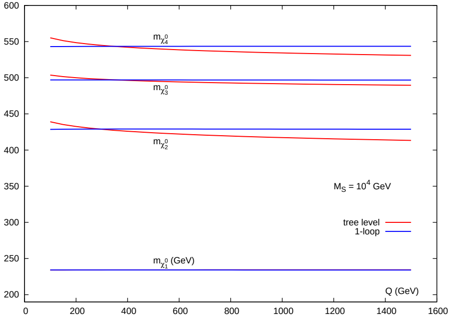


$$\mu = M_{1/2} = 500\ GeV,\ tan(\beta) = 30$$

Plots

Chargino and neutralino masses

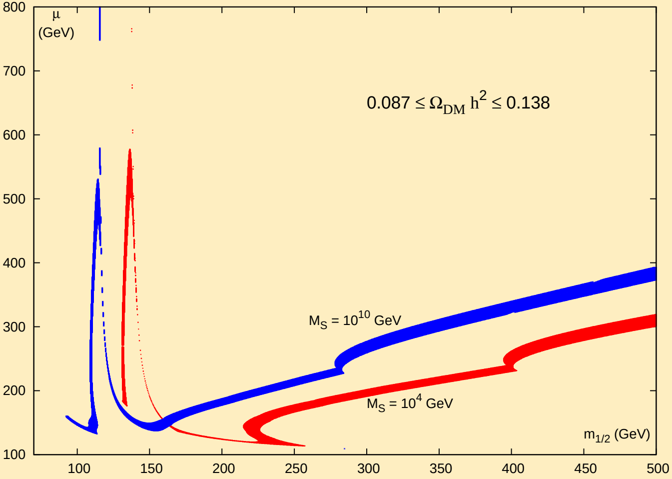




$$\mu = M_{1/2} = 500\ GeV,\ tan(\beta) = 30$$

Plots

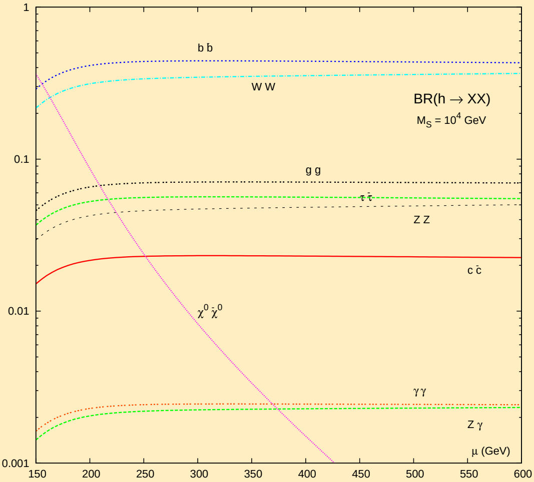
Dark matter constraint



$tan(\beta) = 30$

Higgs

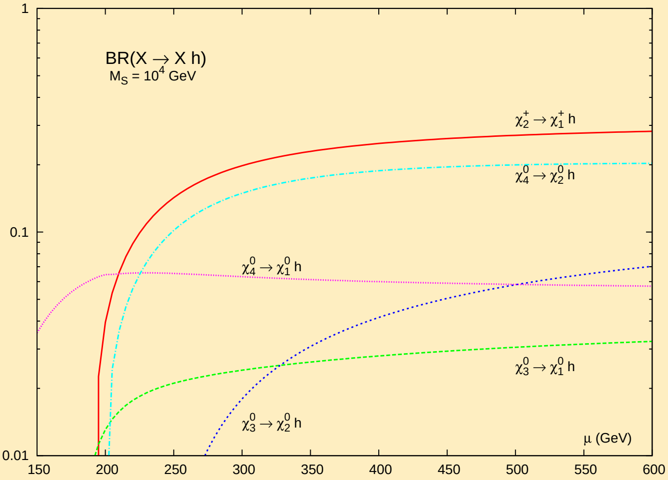
Higgs branching ratio



$tan(\beta) = 30$

Higgs

Decays into a Higgs



$tan(\beta) = 30$

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Conclusions

- At the price of giving up the solution to the electroweak hierarchy problem, Susy with heavy scalars gets rid of the nuisances of the MSSM and retains its advantages

- We have made a detailed study of the spectrum in this scenario.
  - RGE for couplings
  - Include RC to Higgs and neutralinos, charginos & gaugino masses.
  - Dark matter constraint.
- Implementation of this scenario in Suspect.
- Discused the phenomenology related to the Higgs sector.

Conclusions

Merci beaucoup.