Solving the μ problem with a heavy Higgs boson

arXiv:1005.1070 with Stefania Gori

Roberto Franceschini

EPFL Lausanne

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Outline

SUSY means a light Higgs(?)

MSSM

$m_h^2 < m_Z^2 \cos^2 2\beta$

- no contribution from the superpotential
- only some of the couplings of the general 2HDM are non-vanishing

large corrections

LO contribution to the rest of the potential at one loop

$\delta m_h^2 \sim \frac{m_{top}^4}{v^2} \log \frac{m_{stop}^2}{m_{top}^2}$

superpotential contributions: NMSSM

$W = \lambda S H_u \cdot H_d + \ldots$

- $m_h^2 < m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$
- $\frac{d\lambda}{d \log \mu} \sim \lambda^2 (\lambda - g)$

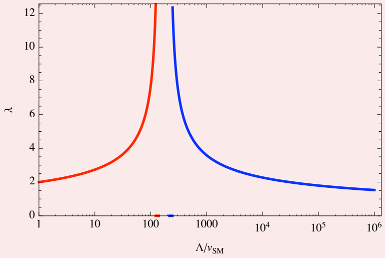
playing with the evolution of g

- $\lambda \sim 0.7$ at the Fermi scale still allows *perturbative* unification of the couplings.
- $m_h^{max} \simeq 150$ GeV

$m_h > 114$ GeV: a not so weak self coupling

$\lambda = 2$: let it go strong

- $m_h^2 \sim \lambda_{SM} v^2$
- λ_{SM} grows in the UV



- at some scale one or more Higgs bosons will reveal their composite nature

- below the strong coupling scale this looks like SUSY with a heavy Higgs boson

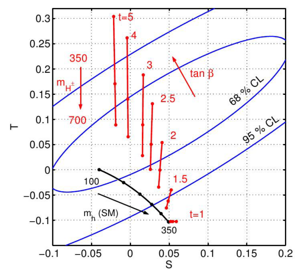
Unifcation can be preserved

$$W = \lambda S H_u H_d + f(S)$$

Harnik, Kribs, Larson, Murayama - PRD 70, Chang, Kilic, Mahbubani - PRD 71, Birkedal, Chacko, Nomura - PRD 71

λSUSY: a Heavy supersymmetric Higgs boson

- LEP prefers a light Higgs



Barbieri, Hall, Nomura, Rychkov - PRD 75

- Higgsinons contribute to T
- the heavy Higgs contributes to S

heavy Higgs:

- less FT
- no need for a special 3rd gen

- more space for heavy 1st,2nd generation

Barbieri, Bertuzzo, Farina, Lodone, Pappadopulo - 1004.2256

$W = \lambda S H_u H_d + \frac{k}{3} S^3$ with large λ

- dynamical generation of μ
- naturalness
- experimental constraints

Generation of $\mu = \lambda s$ and the soft terms

- $4k^2 s^3 - 2Gks^2 + 2s\left(\lambda^2 v^2 + v^2 \lambda k \sin 2\beta + \mu_S^2\right) - Av^2 \lambda \sin 2\beta = 0$
- $\mu_S^2 s^2 + k^2 s^4 - 2G\frac{k}{3}s^3 - \frac{\lambda^2}{4} v^4 \sin^2 2\beta - \frac{m_Z^2}{4} v^2 \cos^2 2\beta < 0$
- $2Gs(A - ks) - 3A\lambda v^2 \sin 2\beta > 0$

small λ : $v/s \ll 1$

$$s \simeq \frac{1}{4k}\left(G + \sqrt{G - 8\mu_S}\right)$$

EWSB triggered by $V_G = -\frac{k}{3} GS^3$

$$\mu_S^2 \simeq -O(v^2)\,(1 - O(v/s))$$

$\lambda \gg 1$: $s \lesssim v$

$$s \simeq \frac{A \sin 2\beta}{2\,(\lambda + k \sin 2\beta)}$$

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$$\mu_S^2 \simeq ks\,(G - 2ks)$$

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$$\mu_S^2 \simeq ks\left(G - 2ks\right)$$

$$V(vev) \simeq -\frac{\lambda^2}{4}v^4 \sin^2 2\beta + -k^2 s^4 + \frac{1}{3}kGs^3 < 0$$

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$$G/s < O(\lambda^2/k)$$

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$$Gs/v^2 > O(\lambda)$$

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$$\mu_S^2 \simeq ks\left(G - 2ks\right)$$

$$G/A < O(\lambda/k)$$

$$GA > O(\lambda^2 v^2)$$

$$A > \lambda v$$

a heavy Higgs boson: $m_h \sim \lambda v \sim \mu$

Parameters: μ, m_{H^+}

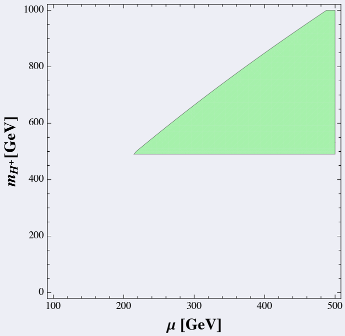
$$\mu \equiv \lambda s\,, \quad m_{H^+}^2 = \frac{2\mu(A - \frac{k}{\lambda}\mu)}{\sin 2\beta} - \lambda^2 v^2 + mW^2$$

$$G = A$$

$$m_{H^+}^2 > 2\lambda^2 v^2 + m_W^2$$

$$m_{H^+}^2 < 4\frac{\mu^2}{\sin^2 2\beta} + m_W^2 + \frac{m_Z^2}{\tan^2 2\beta} + O\left(\frac{1}{\lambda}\right)$$

$\lambda = 2$, $k = 1.2$, $\tan\beta = 1.5$



$\mu \sim m_h$

$$\frac{\lambda v}{\sqrt{2}} \sin 2\beta < \mu < \frac{3}{2}\lambda v \sin 2\beta$$

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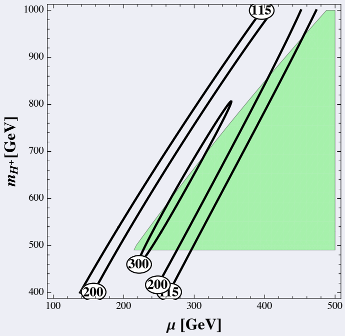

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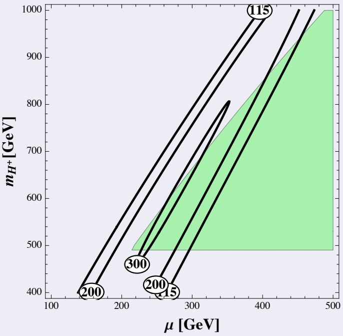

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- $\mu / m_Z \gtrsim 1$
- Higgs and Chargino not at LEP

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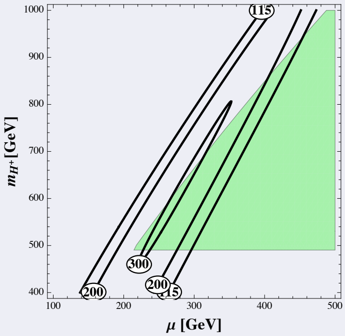


- $\mu / m_Z \gtrsim 1$
- Higgs and Chargino not at LEP

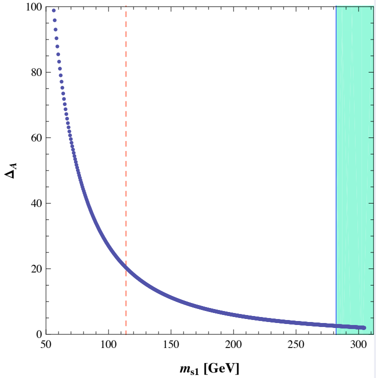
the heavier the Higgs the better

$$\lambda^2 v^2 = \frac{2s\lambda(A-ks)}{\sin 2\beta} + \frac{m_1^2 - m_2^2}{\cos 2\beta} + m_Z^2$$

$$v \sim m_{soft}/\lambda$$

$$FT \sim 1/m_{s_1}$$

FT



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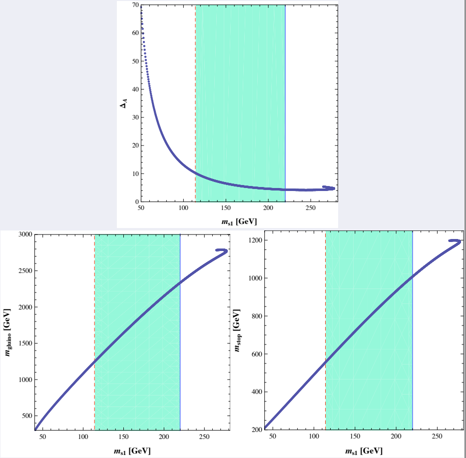
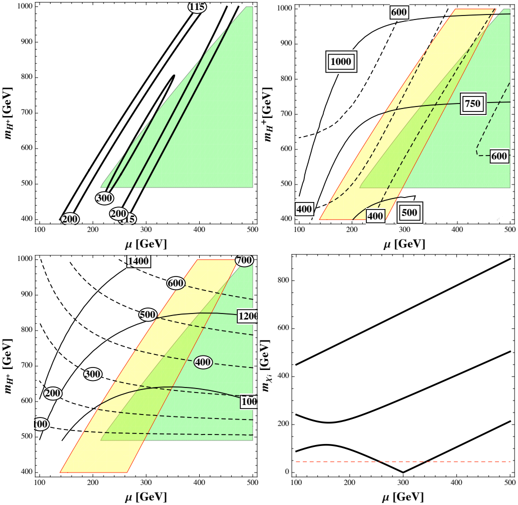
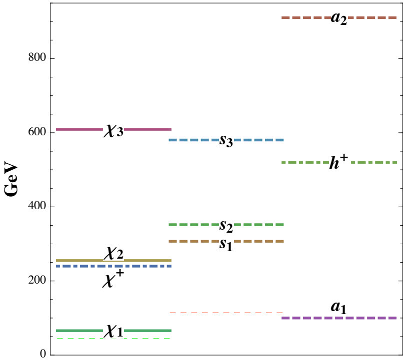
FT and Naturalness bounds



see also Barbieri, Bertuzzo, Farina, Lodone, Pappadopulo - 1004.2256

a rather heavy SUSY spectrum

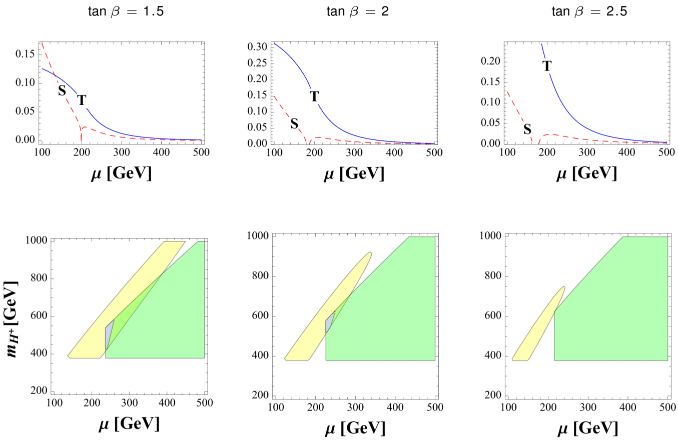




- s_1, χ^+, h^+ tipically above LEP reach
- χ_1^0 excluded by LEP in some region
- a_1 is typically light

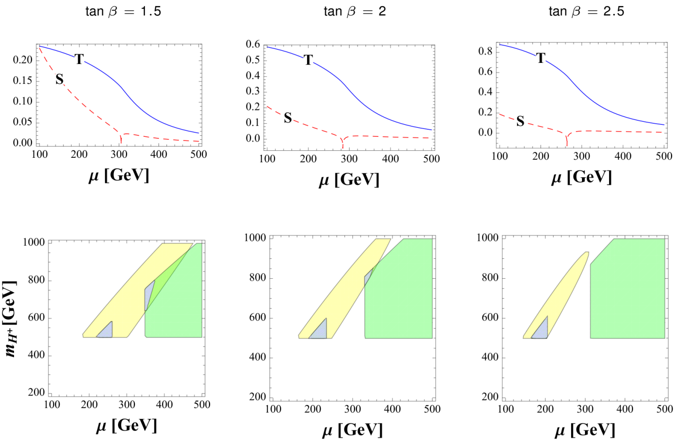
Experimental constraints for $\lambda = 1.5$

- LEP direct serches
- WIMP searches
- EWPT



Experimental constraints for $\lambda = 2$

- LEP direct serches
- WIMP searches
- EWPT



LHC: a strongish self-coupling in the Higgs sector

largish λ and k

$$s_i \to s_j s_k$$

$$s_i \to a_j a_k$$

Cavicchia, Franceschini, Rychkov - PRD 77

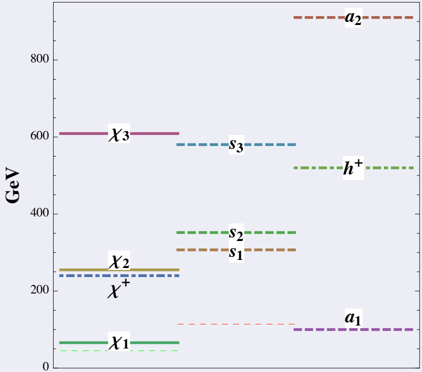
the lightest Higgs state

$$a_1 \to b\bar{b}, \tau^-\tau^+$$

$\lambda \gtrsim k > 1$

- $\Gamma(s_1 \to a_1 a_1) > \Gamma(s_1 \to WW)$
- $gg \to s_n \to a_1 a_1$
- $gg \to s_n \to Za_1$
- $gg \to s_n \to invisible$

$m_{H^+} = 550\ GeV, \mu = 250\ GeV$



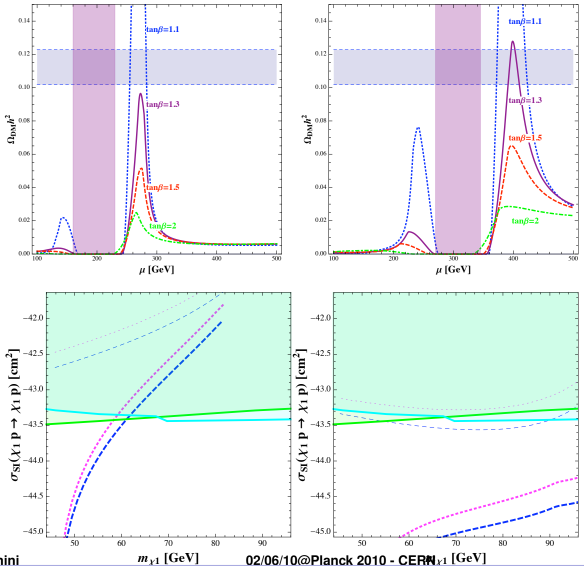
Conclusions

the NMSSM with largish λ ($\lambda \gtrsim k > 1$)

- strong coupling onset in the Higgs sector at 10-100 TeV
- UV completions compatible with gauge coupling unification exist
- $\lambda v \sim m_h$ is the only relevant scale of the model
- μ is dynamically generated: $\mu \sim m_h \sim \lambda v$
- FT is low because $v \sim m_{soft}/\lambda$

- a largish λ gives a spectrum generically beyond LEP reach
- current experimental constraints and Naturalness prefer $\lambda \sim 2$
- testable at LHC in the decays of the Higgs bosons

Dark matter



tanβ=1.1
tanβ=1.3
tanβ=1.5
tanβ=2
Ω_DM h²
μ [GeV]
σ_SI(χ1 p → χ1 p) [cm²]
m_χ1 [GeV]