Crazy SUSY Scenarios That Just Might Be True

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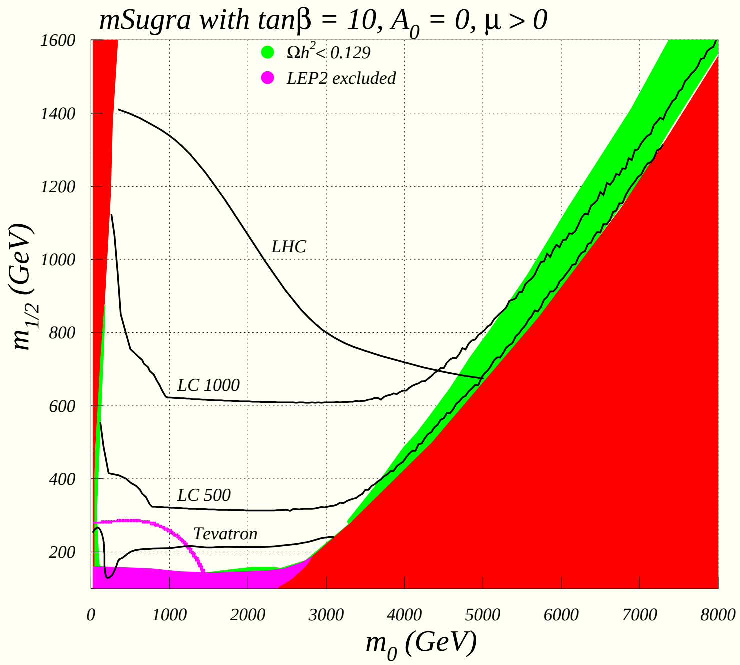
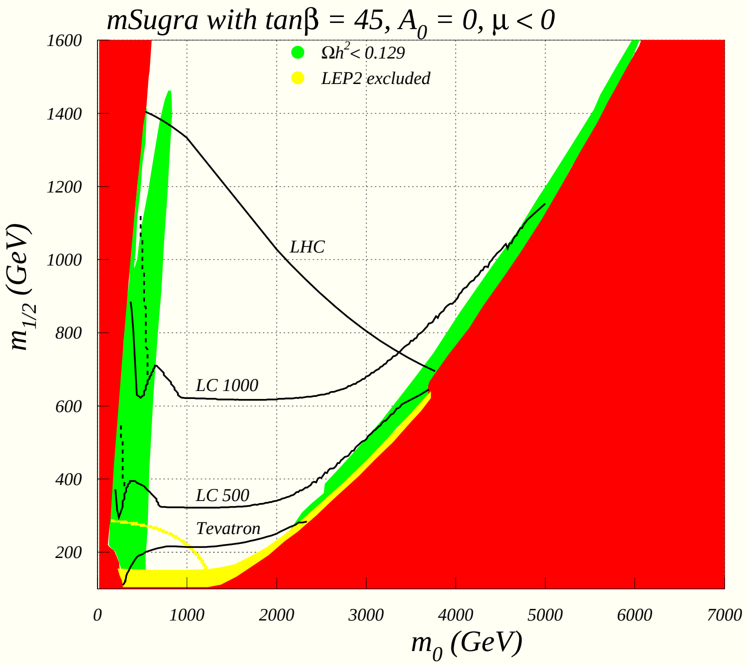
Outline

- ⋆ mSUGRA model and associated myths
- ⋆ NUHM1 model
- ⋆ NUHM2 model
- ⋆ IMH model and Yukawa unification
- ⋆ NMH model

Some standard results from mSUGRA/CMSSM model





- Well known parameter space: $m_0,\ m_{1/2},\ A_0,\ \tan\beta, sign(\mu),\ (m_t)$

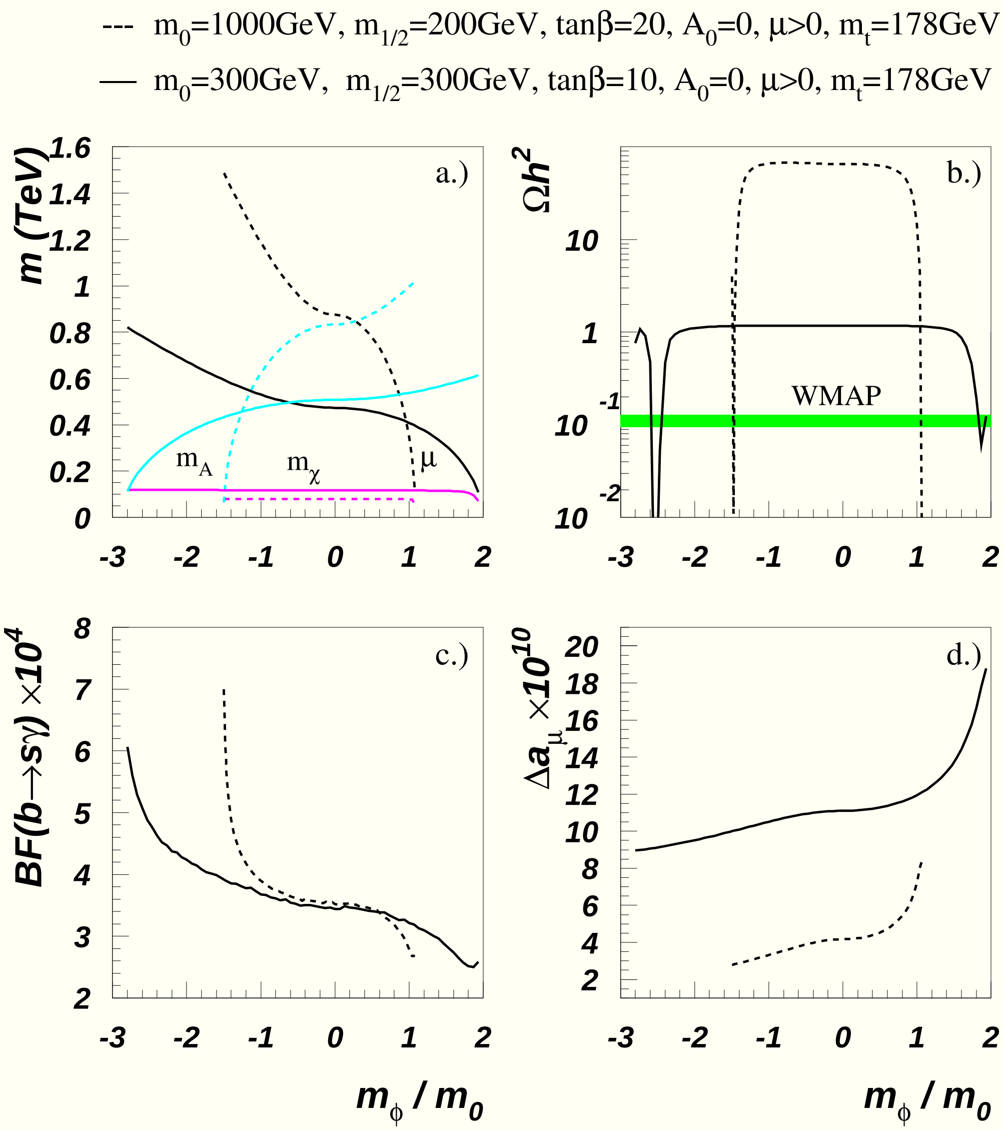
Several myths pertaining to neutralino dark matter

- The HB/FP (focus point) region occurs at $m_0 \sim$TeV
- The A-annihilation funnel occurs at large $\tan\beta$
- The "bulk" region is excluded
- Squarks are too heavy to be seen at the ILC
- The lightest slepton is right-handed

Simplest extension of parameter space: NUHM1 model

- Non-universal Higgs mass: 1 parameter extension
- $m_\phi = sign(m_{H_u}^2)\cdot\sqrt{|m_{H_u}^2|} = sign(m_{H_d}^2)\cdot\sqrt{|m_{H_d}^2|} \neq m_0$
- Motivated by $SO(10)$ SUSY GUTS since $\hat{H}_u, \hat{H}_d \in \hat{\phi}(10)$; matter superfields $\in \hat{\psi}(16)$
- m_ϕ can be > 0 or < 0: (recall $m_{H_u}^2$ driven "-" in RG running to yield REWSB
- GUT stability constraint: $m_{H_{u,d}}^2 + \mu^2 > 0$ at $Q = M_{GUT}$ (?)
- HB, Belyaev, Mustafayev, Profumo and Tata

NUHM1 model:



--- m0=1000GeV, m1/2=200GeV, tanβ=20, A0=0, μ>0, mt=178GeV
— m0=300GeV, m1/2=300GeV, tanβ=10, A0=0, μ>0, mt=178GeV
m (TeV)
a.)
mA
mχ
μ
Ωh2
b.)
WMAP
BF(b→sγ) ×10^4
c.)
Δaμ ×10^10
d.)
mφ / m0
mφ / m0

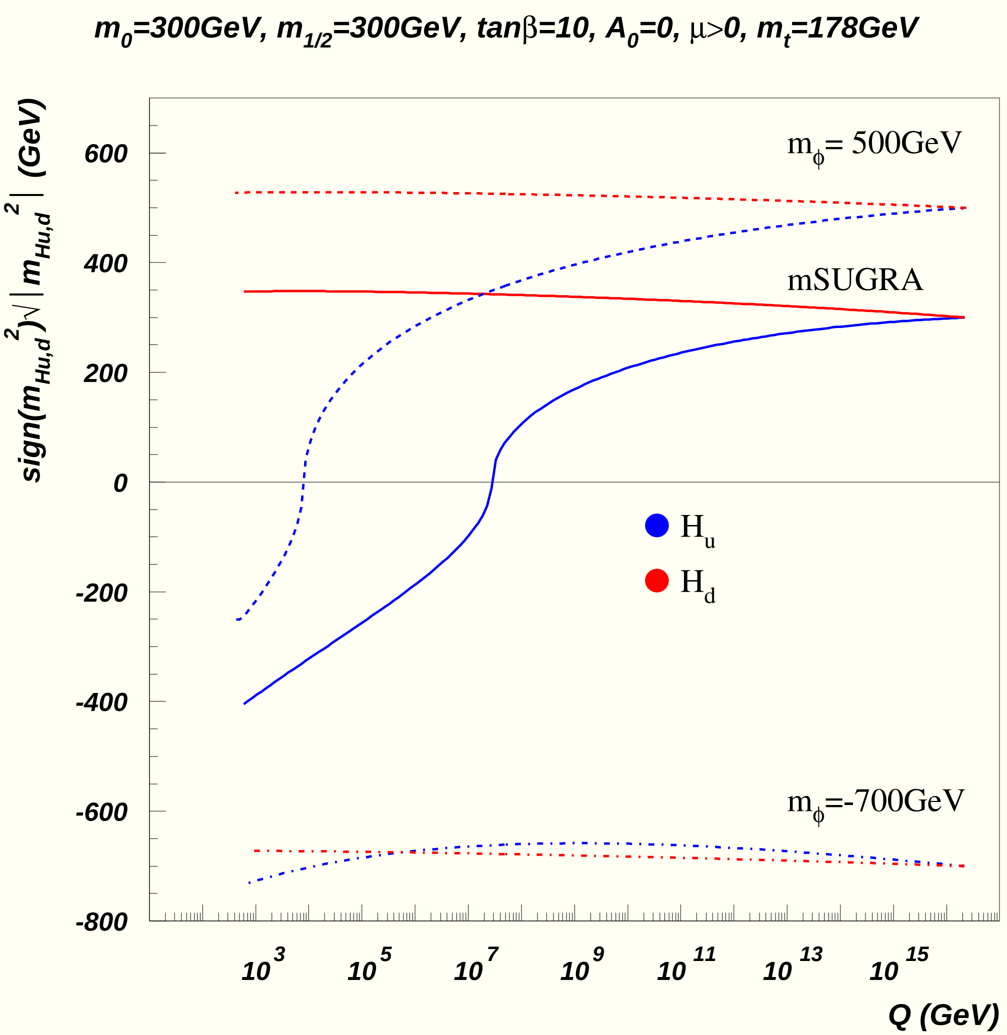
Higgs soft mass running in NUHM1 case:

- $\frac{dm^2_{H_u}}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2 M_1^2 - 3g_2^2 M_2^2 + \frac{3}{10}g_1^2 S + 3f_t^2 X_t\right)$
- $\frac{dm^2_{H_d}}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2 M_1^2 - 3g_2^2 M_2^2 - \frac{3}{10}g_1^2 S + 3f_b^2 X_b + f_\tau^2 X_\tau\right)$
- $X_t = m^2_{Q_3} + m^2_{\tilde{t}_R} + m^2_{H_u} + A_t^2$

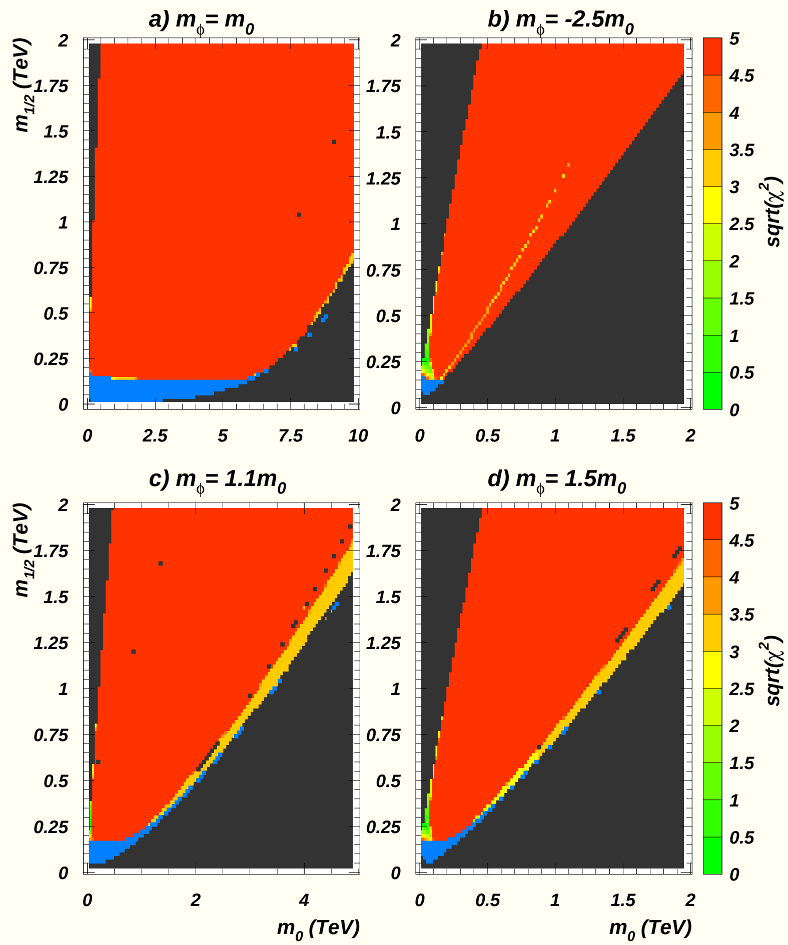
⋆ Tree-level minimization condition

- $\mu^2 = \frac{m^2_{H_d} - m^2_{H_u}\tan^2\beta}{(\tan^2\beta - 1} - \frac{M_Z^2}{2}$
- at moderate to large $\tan\beta$: $\mu^2 \sim -m^2_{H_u}$
- $m_A^2 = m^2_{H_u} + m^2_{H_d} + 2\mu^2 \simeq m^2_{H_d} - m^2_{H_u}$

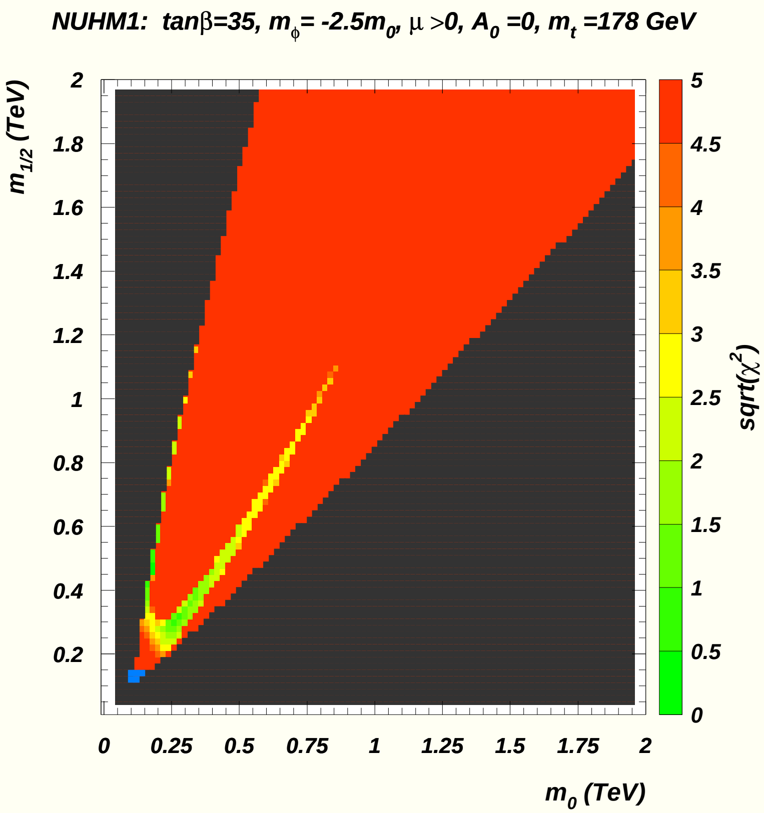
Running of $m^2_{H_u}$ and $m^2_{H_d}$



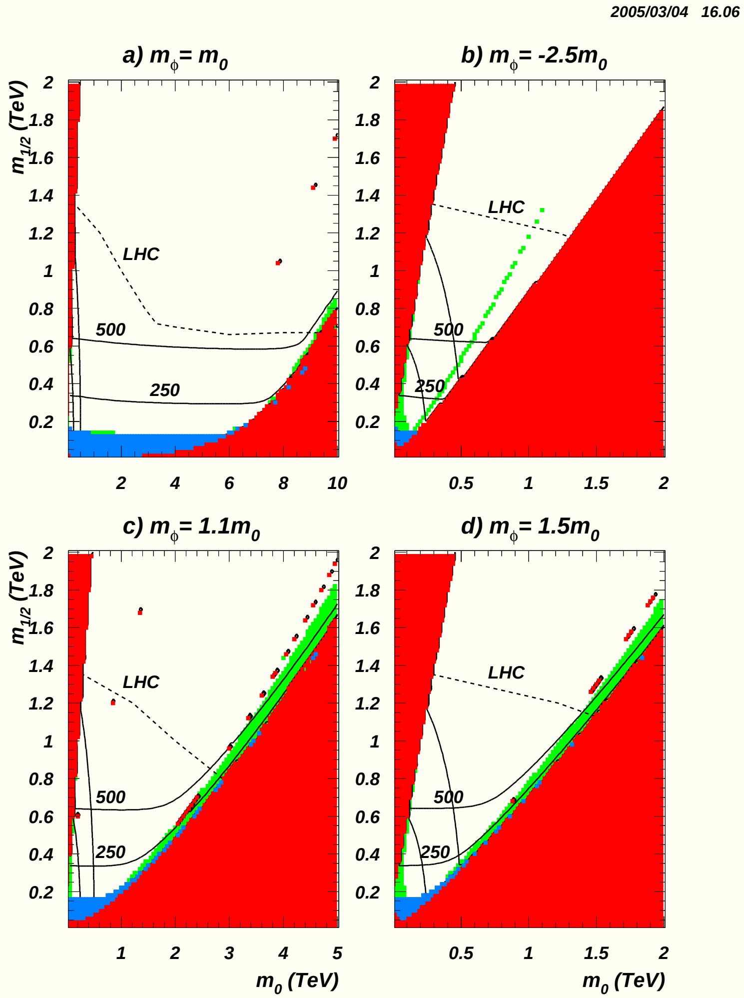
χ^2 evaluation of NUHM1 model for various m_ϕ



χ^2 evaluation of NUHM1 model for $\tan\beta = 35$, $m_\phi = -2.5m_0$



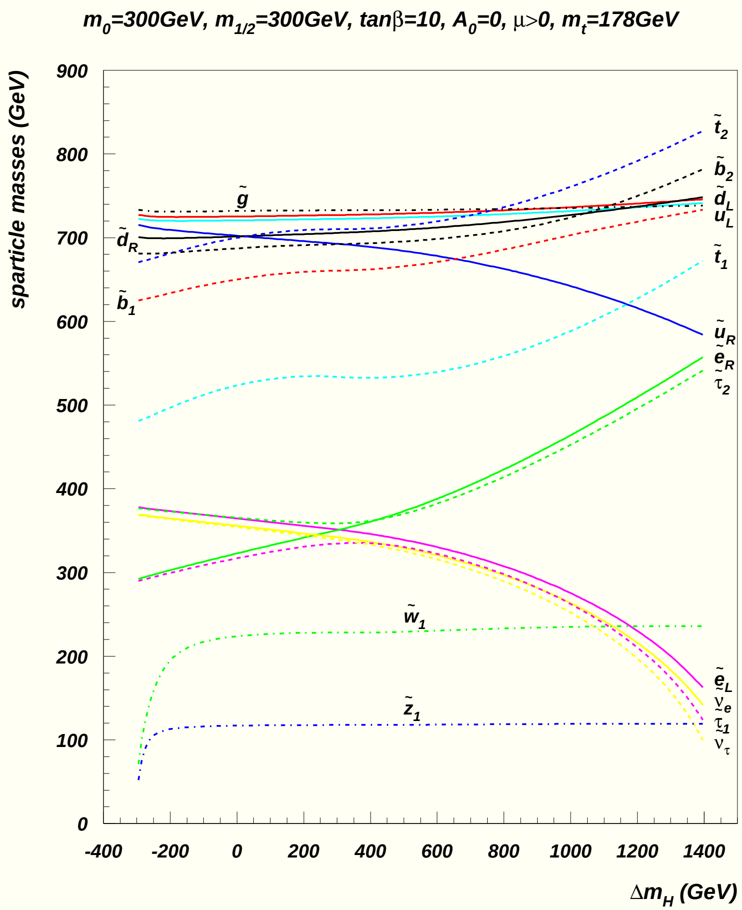
Collider reach for NUHM1 model



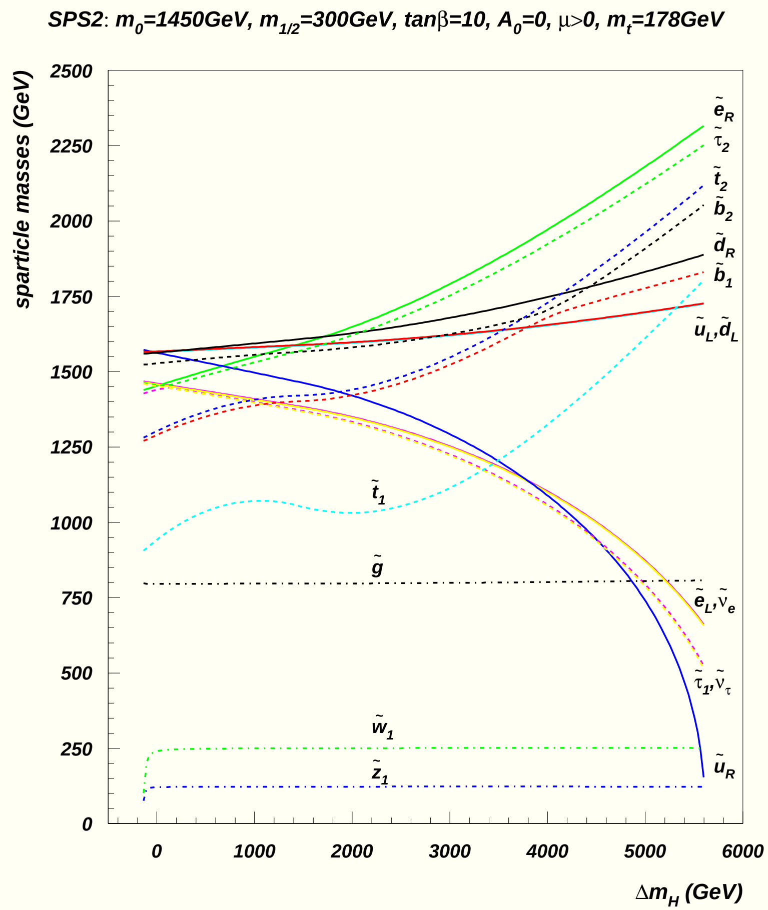
NUHM2 model:

- $m_0,\ m^2_{H_u},\ m^2_{H_d},\ m_{1/2},\ A_0,\ \tan\beta, sign(\mu)$
- REWSB: $m^2_{H_u},\ m^2_{H_d} \leftrightarrow \mu,\ m_A$
- Can always dial parameters so that in A-funnel or higgsino region
- See also Berezinsky et al.; Arnowitt and Nath; Ellis, Olive, Falk, Santoso
- $S = m^2_{H_u} - m^2_{H_d} + Tr[\mathbf{m}^2_Q - \mathbf{m}^2_L - 2\mathbf{m}^2_U + \mathbf{m}^2_D + \mathbf{m}^2_E] = 0$ in mSUGRA and NUHM1 case; $\neq 0$ for NUHM2 model
- For large scalar masses, S can dominate RG running

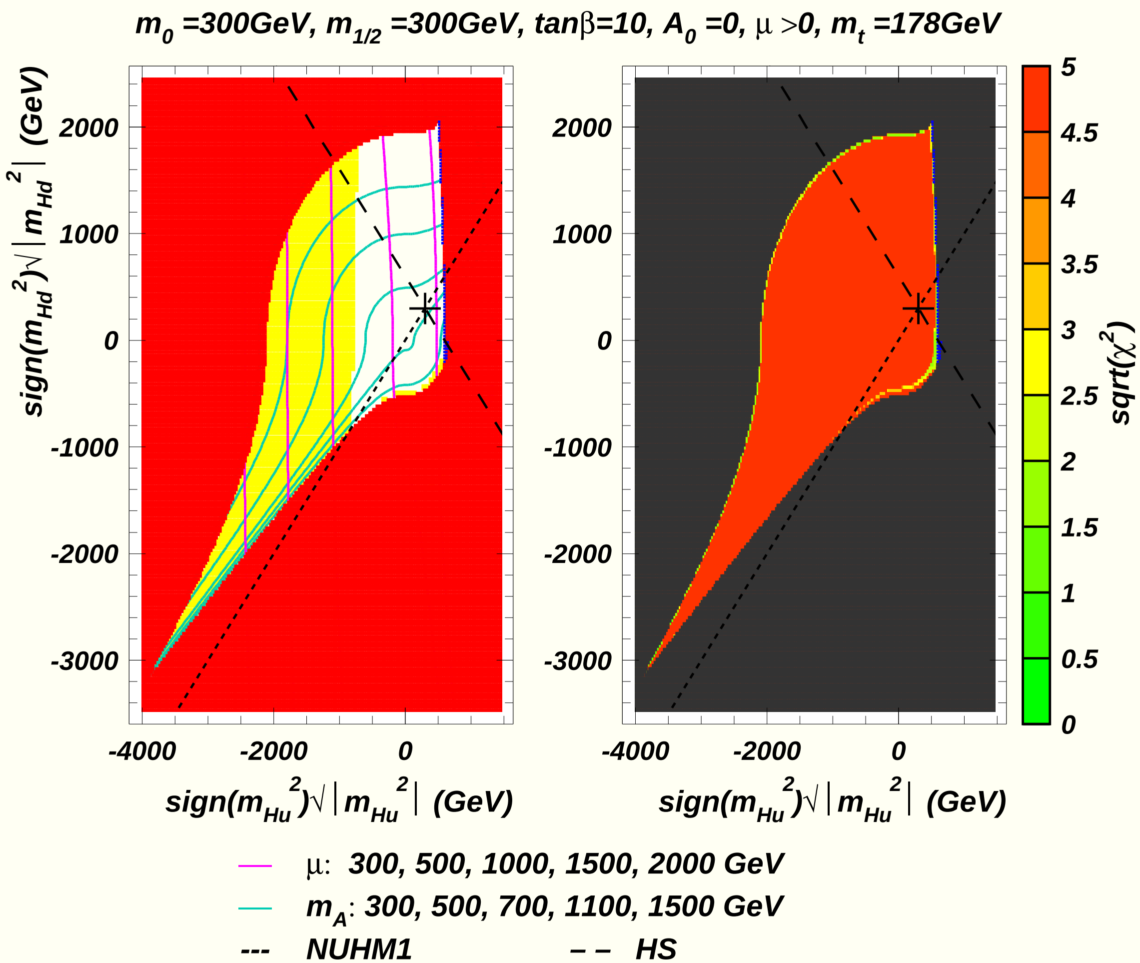
Sparticle masses in NUHM2 model with HS: $m_0 = m_{1/2} = 300$ Ge



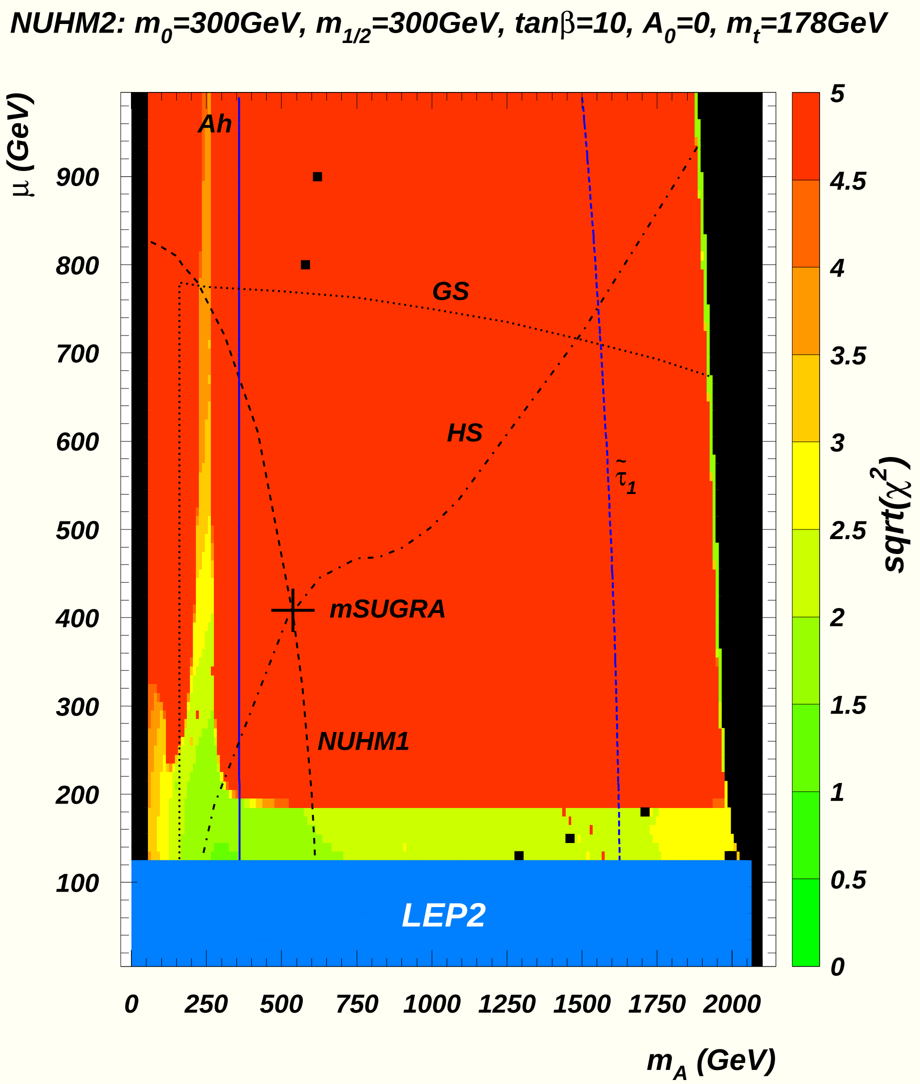
Sparticle masses in NUHM2 model with HS: $m_0 = 1450$ GeV, m_1



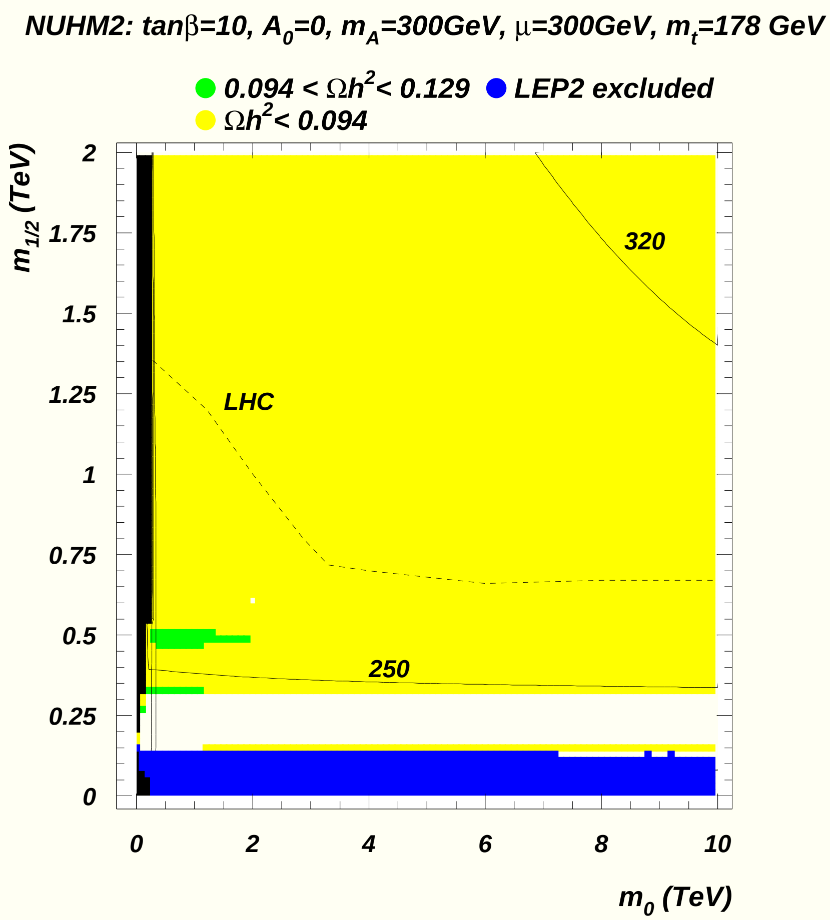
NUHM2 parameter space for $m_0 = m_{1/2} = 300$ GeV



NUHM2 parameter space for $m_0 = m_{1/2} = 300$ GeV



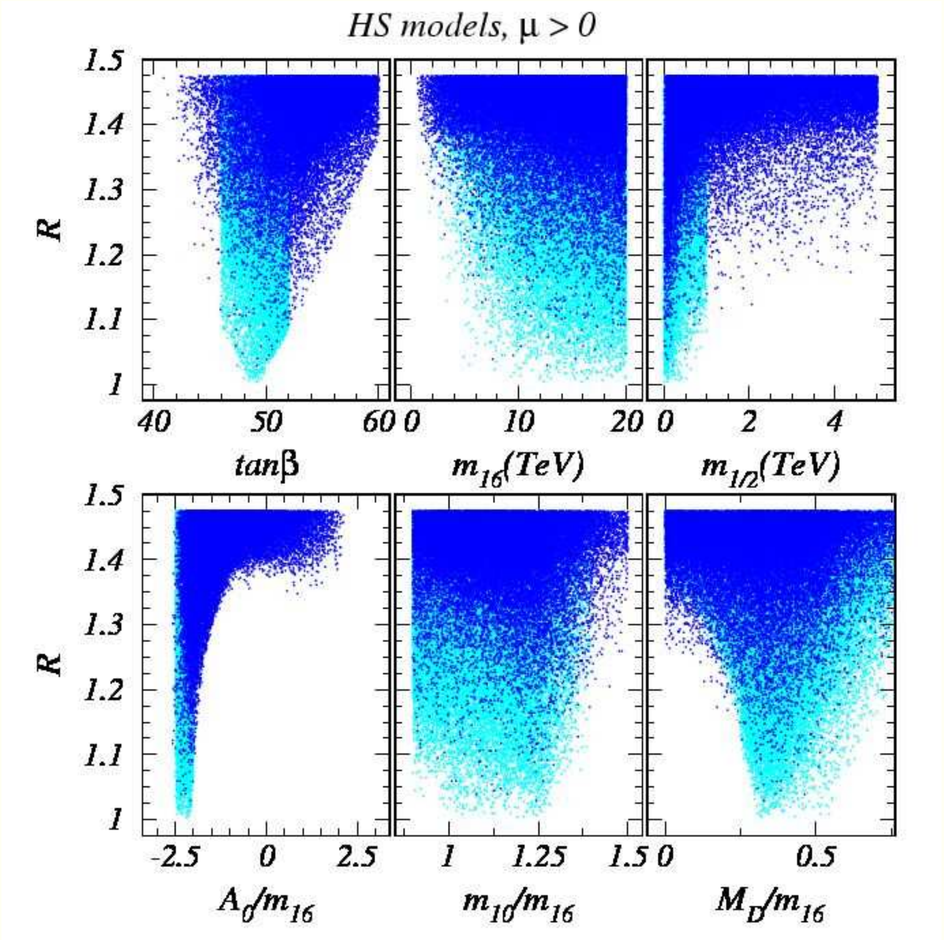
Reach of colliders in NUHM2 model



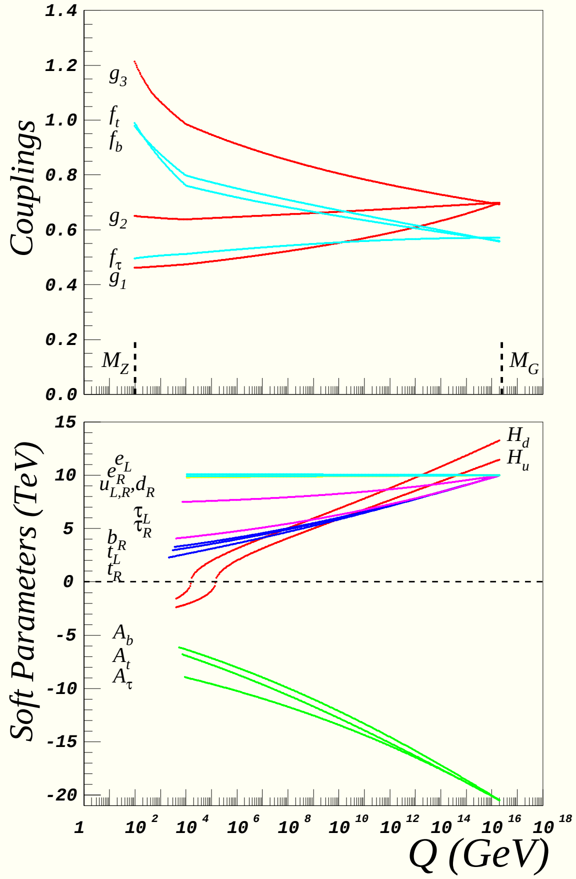
NUHM2: Yukawa coupling unification

- Yukawa coupling unification (YCU) for $t - b - \tau$ predicted in simplest $SO(10)$ SUSY GUTs
- Depends sensitively on t, b, τ self energy graphs, which depend on entire SUSY spectrum
- Good YCU over much of p-space for $\mu < 0$: D-term model (HB, Diaz, Ferrandis, Tata)
- Good YCU for $\mu > 0$ in NUHM2 model but only if $A_0^2 = 2m_{10}^2 = 4m_0^2$ with split Higgs! (Auto, HB, Balazs, Belyaev, Ferrandis, Tata) (Blazek, Dermisek, Raby)
- Boundary conditions originally found by Bagger, Feng, Polonsky, Zhang for radiatively driven Inverted Scalar Mass Hierarchy model

Yukawa unification in NUHM2 model



Yukawa unification in NUHM2 model



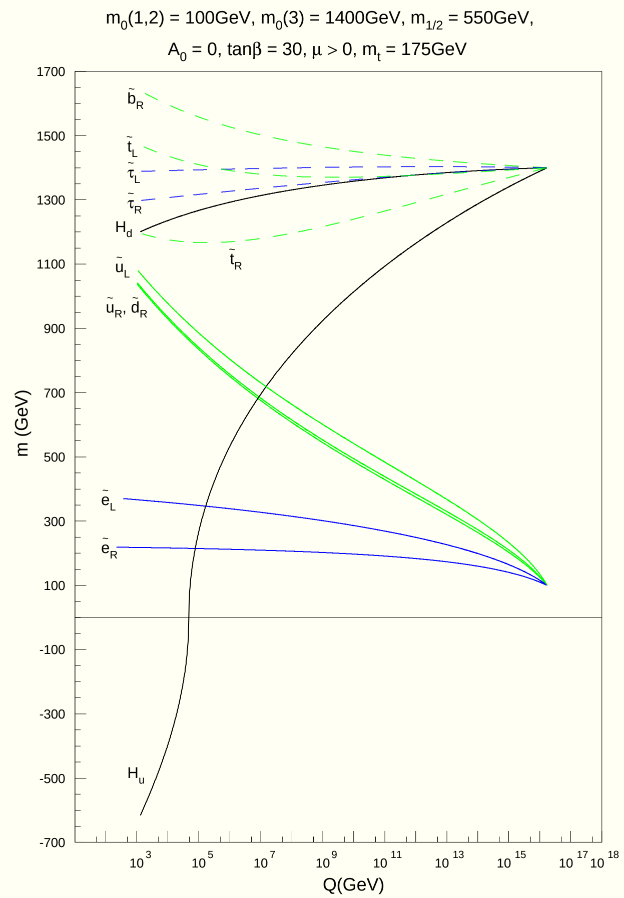
Reconcile YCU with relic density

- Large m_0 values in YCU HS model suppress neutralino annihilation: large relic density is typical
- Dermisek, Raby, Roszkowski, Ruiz de Austri maintain good YCU for low μ, m_A solutions
- Auto, HB, Balazs, Belyaev, Ferrandis, Tata: low μ, m_A solutions $\rightarrow$ lessen unification
- Auto HB, Belyaev, Krupovnickas solution of relic density: light $m_{\tilde{u}_R}$, $m_{\tilde{c}_R}$ reduces relic density while preserving Yukawa unification

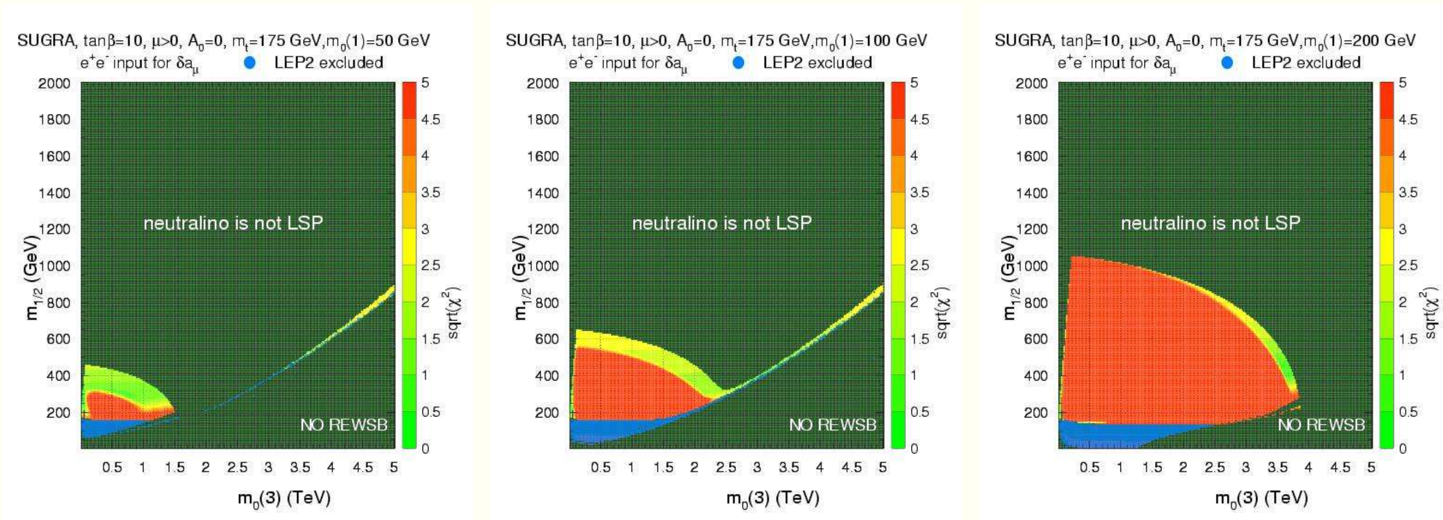
Normal Scalar Mass Hierarchy Case

- In mSUGRA model, WMAP relic density selects preferred regions of parameter space
- Measured $BF(b \to s\gamma)$ close to SM value:
- Measured value of $(g-2)_\mu \to \sim 3\sigma$ deviation: prefer light 2nd gen scalars e.g. $\widetilde{W}_{1,2}\tilde{\nu}_\mu$ loops
- All three can be matched in Normal Scalar Mass Hierarchy model (NMH)
- $m_0(1) \simeq m_0(2) \ll m_0(3) \simeq m_{H_{u,d}},\ m_{1/2},\ A_0,\ \tan\beta,\ sign(\mu)$
- FCNC bounds mainly apply to 1+2 gen; more freedom on splitting 3rd gen.
- HB, Belyaev, Mustafayev, Krupovnickas

NMH model mass evolution



χ^2 fit to NMH model



Conclusions

- ⋆ NUHM1 model:
  - for any $m_0,\ m_{1/2},\ \tan\beta$ value, two solutions of m_ϕ give correct $\Omega_{CDM}h^2$
  - A-funnel or higgsino region
- ⋆ NUHM2 model
  - can dial to low μ, $2m_{\widetilde{Z}_1} \sim m_A$ regions
  - new $\tilde{e}_L$ and $\tilde{u}_R$ co-annihilation regions
- ⋆ Yukawa coupling unification in HS model
  - BFPZ boundary conditions
  - radiatively driven IMH model
  - reconcile with $\Omega_{CDM}h^2$? light squarks?
- ⋆ NMH model
  - light $m_{\tilde{e}_{L,R}}$, $m_{\tilde{\mu}_{L,R}}$ masses