Benchmarking the NMSSM with NMSSMTools 2.0

GDR SUSY, Strasbourg April 2008

Cyril Hugonie

Cyril.Hugonie@univ-montp2.fr

LPTA, Montpellier

Why The NMSSM?

- No Higgs observed at LEP $\Rightarrow$ High fine tuning in the MSSM
- μ-problem of the MSSM: $\mu \overset{?}{\sim} M_{\rm susy} \sim M_{\rm weak}$
  - $\mu = 0 \rightsquigarrow$ experimentally excluded
  - $\mu = M_{\rm Pl} \rightsquigarrow$ hierarchy problem

Why The NMSSM?

- No Higgs observed at LEP $\Rightarrow$ High fine tuning in the MSSM
- μ-problem of the MSSM: $\mu \overset{?}{\sim} M_{\rm susy} \sim M_{\rm weak}$
  - $\mu = 0 \rightsquigarrow$ experimentally excluded
  - $\mu = M_{\rm Pl} \rightsquigarrow$ hierarchy problem
- Solution: add a singlet S coupled to H_u, H_d

$$W_{\rm NMSSM} = \cancel{\mu H_u H_d} + \lambda S H_u H_d + \frac{\kappa}{3} S^3 \text{ (+ Yukawas)}$$

After minimisation of the potential: $\mu_{\rm eff} \equiv \lambda \langle S \rangle \sim M_{\rm susy}$

Why The NMSSM?

- No Higgs observed at LEP $\Rightarrow$ High fine tuning in the MSSM
- μ-problem of the MSSM: $\mu \overset{?}{\sim} M_{\rm susy} \sim M_{\rm weak}$
  - $\mu = 0 \rightsquigarrow$ experimentally excluded
  - $\mu = M_{\rm Pl} \rightsquigarrow$ hierarchy problem
- Solution: add a singlet S coupled to H_u, H_d

  $$W_{\rm NMSSM} = \cancel{\mu} H_{\cancel{u}} H_{\cancel{d}} + \lambda S H_u H_d + \frac{\kappa}{3} S^3 \text{ (+ Yukawas)}$$

  After minimisation of the potential: $\mu_{\rm eff} \equiv \lambda \langle S \rangle \sim M_{\rm susy}$
- Simplest SUSY extension of the SM where the EW scale originates from the SUSY breaking scale only
- $\lambda \to 0, \mu_{\rm eff} \neq 0$: MSSM + decoupled singlet sector

  $\Rightarrow$ The parameter space of the NMSSM includes the physics of the MSSM and more

What's the NMSSM?

- Particle content:
  - $\widetilde{S}$: one more neutralino $\leftrightsquigarrow$ $\widetilde{\chi}^0_{i=1..5}$
  - S_R: one more neutral CP even $\leftrightsquigarrow$ $h_{i=1,2,3}$
  - S_I: one more neutral CP odd $\leftrightsquigarrow$ $a_{i=1,2}$

$\Rightarrow$ New Physics beyond the MSSM ($\widetilde{S}$ LSP, light $h \to aa$)

What's the NMSSM?

- Particle content:
  - $\widetilde{S}$: one more neutralino $\leftrightsquigarrow$ $\widetilde{\chi}^0_{i=1..5}$
  - S_R: one more neutral CP even $\leftrightsquigarrow$ $h_{i=1,2,3}$
  - S_I: one more neutral CP odd $\leftrightsquigarrow$ $a_{i=1,2}$

  $\Rightarrow$ New Physics beyond the MSSM ($\widetilde{S}$ LSP, light $h \to aa$)

- Parameters: $V_{\text{Higgs}} = V_F + V_D + V_{\text{soft}}$

$$V_{\text{soft}} = \left(\lambda A_\lambda H_u H_d S + \frac{\kappa}{3} A_\kappa S^3 + \text{h.c.}\right) + m^2_{H_u}|H_u|^2 + m^2_{H_d}|H_d|^2 + m^2_S|S|^2$$

What's the NMSSM?

- Particle content:
  - $\widetilde{S}$: one more neutralino $\leftrightsquigarrow$ $\widetilde{\chi}^0_{i=1..5}$
  - S_R: one more neutral CP even $\leftrightsquigarrow$ $h_{i=1,2,3}$
  - S_I: one more neutral CP odd $\leftrightsquigarrow$ $a_{i=1,2}$

  $\Rightarrow$ New Physics beyond the MSSM ($\widetilde{S}$ LSP, light $h \to aa$)

- Parameters: $V_{\text{Higgs}} = V_F + V_D + V_{\text{soft}}$

$$V_{\text{soft}} = \left(\lambda A_\lambda H_u H_d S + \frac{\kappa}{3} A_\kappa S^3 + \text{h.c.}\right) + m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2$$

+ 3 minimisation conditions:

$$\mu_{\text{eff}} = \lambda \langle S \rangle, \quad \tan\beta = \frac{\langle H_u \rangle}{\langle H_d \rangle}, \quad M_Z^2 = \bar{g}^2 \left(\langle H_u \rangle^2 + \langle H_d \rangle^2 \right)$$

$\Rightarrow$ 6 free parameters: $\lambda, \ \kappa, \ A_\lambda, \ A_\kappa, \ \mu_{\text{eff}}, \ \tan\beta$

Recall: in the MSSM, 2 free parameters $(m_A, \tan\beta)$

Constraining the parameters

- mSUGRA: $M_{1/2}$, m_0, A_0 ($M_{\rm GUT}$), λ, κ, $\tan\beta$, $\mathrm{sgn}(\mu_{\rm eff})$ ($M_{\rm weak}$)?

  $\Longrightarrow$ 1 free parameter ($\mu_{\rm eff}$) for 3 min. conditions at $M_{\rm weak}$

Constraining the parameters

- <u>mSUGRA:</u> $M_{1/2}$, m_0, A_0 ($M_{\rm GUT}$), λ, κ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$ ($M_{\rm weak}$)?
  $\Longrightarrow$ 1 free parameter ($\mu_{\rm eff}$) for 3 min. conditions at $M_{\rm weak}$
  Solution: non-universal singlet soft terms at $M_{\rm GUT}$
  Parameters: λ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$, $M_{1/2}$, m_0, A_0, [A_κ]
  Minimisation conditions $\Longrightarrow$ $\mu_{\rm eff}$, κ, m_S^2 at $M_{\rm weak}$

Constraining the parameters

- mSUGRA: $M_{1/2}$, m_0, A_0 ($M_{\rm GUT}$), λ, κ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$ ($M_{\rm weak}$)?

  $\Longrightarrow$ 1 free parameter ($\mu_{\rm eff}$) for 3 min. conditions at $M_{\rm weak}$

  Solution: non-universal singlet soft terms at $M_{\rm GUT}$

  Parameters: λ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$, $M_{1/2}$, m_0, A_0, [A_κ]

  Minimisation conditions $\Longrightarrow$ $\mu_{\rm eff}$, κ, m_S^2 at $M_{\rm weak}$

  - Guess $M_{\rm GUT}$ and κ, m_S^2 at this scale
  - Run the RGEs down to $M_{\rm weak}$, compute $\mu_{\rm eff}$, κ, m_S^2
  - Run the RGEs up to $M_{\rm GUT}$, distance from universality

$\Longrightarrow$ For the true CNMSSM see talk by A. Teixeira

Constraining the parameters

- mSUGRA: $M_{1/2}$, m_0, A_0 ($M_{\rm GUT}$), λ, κ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$ ($M_{\rm weak}$)?
  $\Longrightarrow$ 1 free parameter ($\mu_{\rm eff}$) for 3 min. conditions at $M_{\rm weak}$
  Solution: non-universal singlet soft terms at $M_{\rm GUT}$
  Parameters: λ, $\tan\beta$, ${\rm sgn}(\mu_{\rm eff})$, $M_{1/2}$, m_0, A_0, [A_κ]
  Minimisation conditions $\Longrightarrow$ $\mu_{\rm eff}$, κ, m_S^2 at $M_{\rm weak}$
  - Guess $M_{\rm GUT}$ and κ, m_S^2 at this scale
  - Run the RGEs down to $M_{\rm weak}$, compute $\mu_{\rm eff}$, κ, m_S^2
  - Run the RGEs up to $M_{\rm GUT}$, distance from universality

  $\Longrightarrow$ For the true CNMSSM see talk by A. Teixeira

- GMSB: messenger scale $M_{\rm mess}$ and $M_{\rm susy} \equiv m^2/(16\pi^2 M_{\rm mess})$

$$\Delta V_{\rm soft} = \left(\lambda A_\lambda H_u H_d S + \frac{\kappa}{3} A_\kappa S^3 + m_S'^2 S^2 + \xi_S S + {\rm h.c.}\right) + m_S^2 |S|^2$$

$$+\Delta m_{H_U}^2 = \Delta m_{H_D}^2 = -\frac{\lambda^2}{(16\pi^2)^2} \Delta_H M_{\rm susy}^2 \quad \text{and} \quad \Delta W = \mu' S^2 + \xi_F S$$

$\Longrightarrow$ See talk by U. Ellwanger

NMSSMTools 2.0

- Package that contains 3 programs:
  - **NMHDECAY** for general NMSSM
  - **NMSPEC** for mSUGRA (with some non-universality)
  - **NMGMSB** for GMSB (new in **v2.0**)

  each in 3 versions: 1point, random scan, grid scan

NMSSMTools 2.0

- Package that contains 3 programs:
  - **NMHDECAY** for general NMSSM
  - **NMSPEC** for mSUGRA (with some non-universality)
  - **NMGMSB** for GMSB (new in **v2.0**)

  each in 3 versions: 1point, random scan, grid scan

- For a given set of free parameters, it computes:
  - Sparticle/Higgs masses and mixings
  - Higgs decay widths (as in **HDECAY**)
  - DM relic density (using **MicrOMEGAs 2.0**)

    $\Longrightarrow$ See talk by G. Bélanger
  - $b \to s\gamma$, $B_s \to \mu\mu$, $B^+ \to \tau\nu$, Δm_d, Δm_s and a_μ

    $\Longrightarrow$ See talk by F. Domingo

NMSSMTools 2.0

- Package that contains 3 programs:
  - **NMHDECAY** for general NMSSM
  - **NMSPEC** for mSUGRA (with some non-universality)
  - **NMGMSB** for GMSB (new in **v2.0**)

  each in 3 versions: 1point, random scan, grid scan
- For a given set of free parameters, it computes:
  - Sparticle/Higgs masses and mixings
  - Higgs decay widths (as in **HDECAY**)
  - DM relic density (using **MicrOMEGAs 2.0**)

    $\Longrightarrow$ See talk by G. Bélanger
  - $b \to s\gamma$, $B_s \to \mu\mu$, $B^+ \to \tau\nu$, Δm_d, Δm_s and a_μ

    $\Longrightarrow$ See talk by F. Domingo
- I/O files in SLHA2 conventions + script `run PATH/`*`PinpS`*:

  $\Rightarrow$ `PATH/`*`PspectrS`*, *`PdecayS`*, *`PomegaS`* (1point)

  $\Rightarrow$ `PATH/`*`PoutS`*, *`PerrS`* (scan) new in **v2.0**

Input file (1) mSUGRA

```
# INPUT FILE FOR NMSSMTools
# BASED ON SUSY LES HOUCHES ACCORD II

BLOCK MODSEL
        3       1               # NMSSM PARTICLE CONTENT
        1       1               # IMOD (0=general NMSSM, 1=mSUGRA, 2=GMSB)
        10      0               # ISCAN (0=NO SCAN, 1=GRID, 2=RANDOM)
        9       0               # FLAG FOR MICROMEGAS (0=NO, 1=YES)

BLOCK SMINPUTS
        1       127.92D0        # ALPHA_EM^-1(MZ)
        2       1.16639D-5      # GF
        3       .1172D0         # ALPHA_S(MZ)
        4       91.187D0        # MZ
        5       4.214D0         # MB(MB), RUNNING B QUARK MASS
        6       171.4D0         # TOP QUARK POLE MASS
        7       1.777D0         # MTAU

BLOCK MINPAR
#       0       1000.D0         # QSUSY (IF DIFFERENT FROM SQRT(2*MQ1+MU1+MD1)/2)
        1       300.D0          # M0
        2       250.D0          # M12
        3       6.D0            # TB
        4       1.D0            # SIGMU
        5       -900.D0         # A0

BLOCK EXTPAR
        61      .25D0           # L
        64      -150.D0         # AK  (IF DIFFERENT FROM A0)
#       63      -900.D0         # AL  (IF DIFFERENT FROM A0)
#       21      300.D0          # MHDGUT (IF DIFFERENT FROM M0)
#       22      300.D0          # MHUGUT (IF DIFFERENT FROM M0)
#       1       250.D0          # M1  (IF DIFFERENT FROM M12)
#       2       250.D0          # M2  (IF DIFFERENT FROM M12)
#       3       250.D0          # M3  (IF DIFFERENT FROM M12)
```

Input file (2) Grid scan

```
# INPUT FILE FOR NMSSMTools
# BASED ON SUSY LES HOUCHES ACCORD II

BLOCK MODSEL
        3       1               # NMSSM PARTICLE CONTENT
        1       1               # IMOD (0=general NMSSM, 1=mSUGRA, 2=GMSB)
        10      1               # ISCAN (0=NO SCAN, 1=GRID, 2=RANDOM)
        9       1               # FLAG FOR MICROMEGAS (0=NO, 1=YES)

BLOCK SMINPUTS
        1       127.92D0        # ALPHA_EM^-1(MZ)
        2       1.16639D-5      # GF
        3       .1172D0         # ALPHA_S(MZ)
        4       91.187D0        # MZ
        5       4.214D0         # MB(MB), RUNNING B QUARK MASS
        6       171.4D0         # TOP QUARK POLE MASS
        7       1.777D0         # MTAU

BLOCK MINPAR
        4       1.D0            # SIGMU
        17      0.D0            # M0MIN
        18      600.D0          # M0MAX
        27      100.D0          # M12MIN
        28      1100.D0         # M12MAX
        37      10.D0           # TBMIN
        38      10.D0           # TBMAX
        57      -20.D0          # A0MIN
        58      -20.D0          # A0MAX

BLOCK EXTPAR
        617     1.D-2           # LMIN
        618     1.D-2           # LMAX
        647     -50.D0          # AKMIN
        648     -50.D0          # AKMAX

BLOCK STEPS
        19      500             # NM0
        29      500             # NM12
        39      1               # NTB
        59      1               # NA0
        619     1               # NL
        649     1               # NAK
```

Experimental constraints

For each point in the parameter space, **NMSSMTools** checks:

- $\tilde{\chi}_1^0$ is the LSP
- LEP limits on $\tilde{\chi}^{\pm}$'s and $\tilde{\chi}^0$'s (direct search + $\Gamma_{\rm inv}(Z)$)
- Tevatron + LEP constraints on squarks/gluino
- LEP limit on the charged Higgs mass $m_{h^\pm} > 78.6$ GeV
- LEP constraints from neutral Higgs searches:
  - $e^+e^- \to hZ$ with $h \to b\bar{b}$, $\tau^+\tau^-$, jj, $\gamma\gamma$, invisible, "any"
  - $e^+e^- \to hZ$ with $h \to aa$ and $a \to b\bar{b}$ or $\tau^+\tau^-$
  - $e^+e^- \to ha$ with $h/a \to b\bar{b}$ or $\tau^+\tau^-$
  - $e^+e^- \to ha$ with $h \to aa$ and $a \to b\bar{b}$ or $\tau^+\tau^-$
- WMAP constraints: $.094 < \Omega h^2 < .136$
- BABAR and BELLE limits on B physics
- BNL constraints on a_μ from e^+e^- data (3σ from SM)

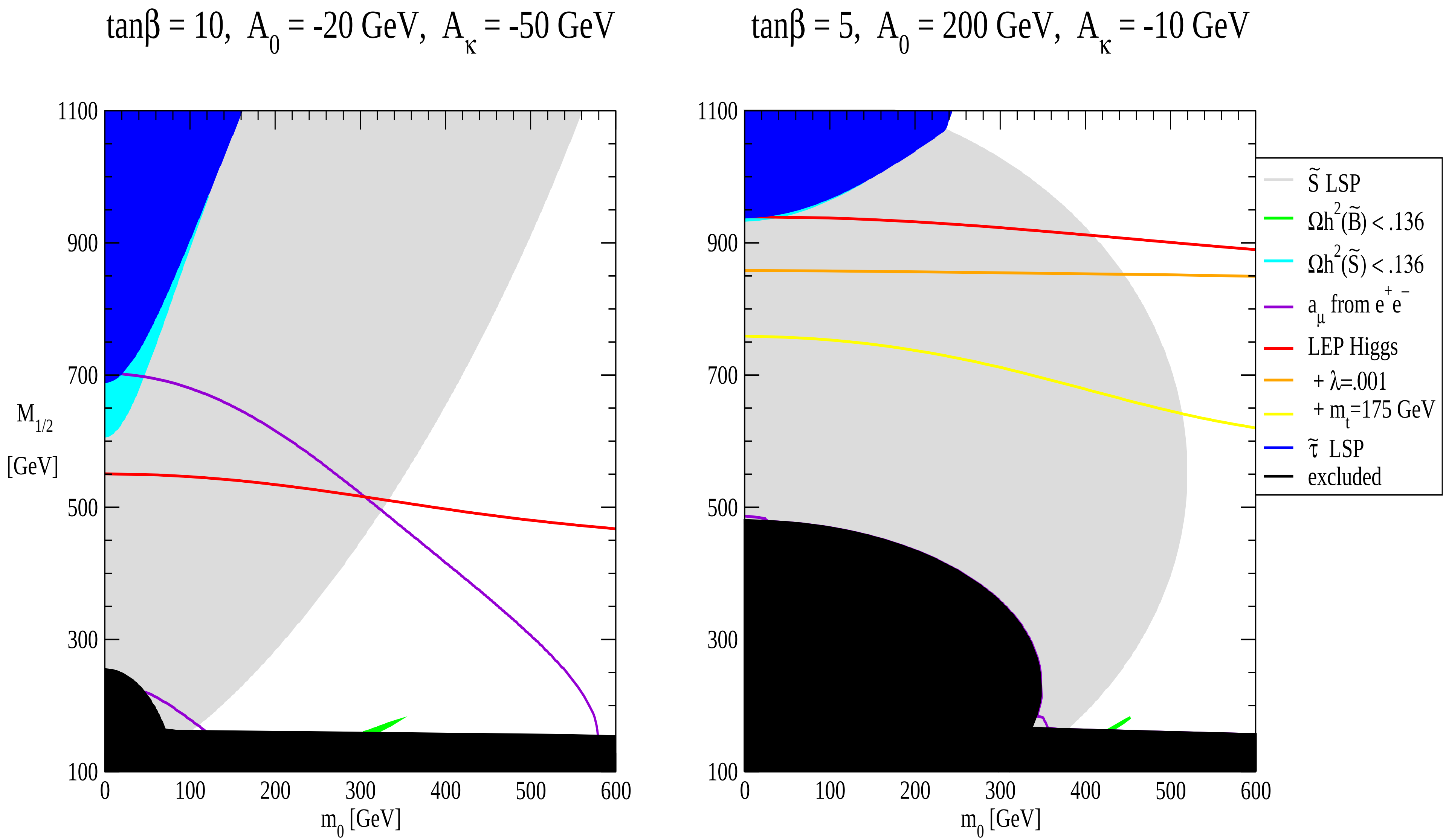
Results with semi-universality

- If $\lambda \ll 1$, $\widetilde{S}$ can be the LSP $\Longrightarrow$ additional cascades at LHC
  Can this scenario be compatible with WMAP? **YES!**
  ... modulo some fine tuning ($m_{\widetilde{S}} - m_{\rm NSLP} \lesssim 1\,{\rm GeV}$)

Results with semi-universality

- If $\lambda \ll 1$, $\widetilde{S}$ can be the LSP $\Longrightarrow$ additional cascades at LHC
  Can this scenario be compatible with WMAP? **YES!**
  ... modulo some fine tuning ($m_{\widetilde{S}} - m_{\mathrm{NSLP}} \lesssim 1\,\mathrm{GeV}$)
  - $\mu A_\kappa < 0$: singlet masses $\nearrow$ with m_0 and/or $M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for small values of m_0 and/or $M_{1/2}$

Singlino LSP (1) $\lambda = .01, \mu A_\kappa < 0$

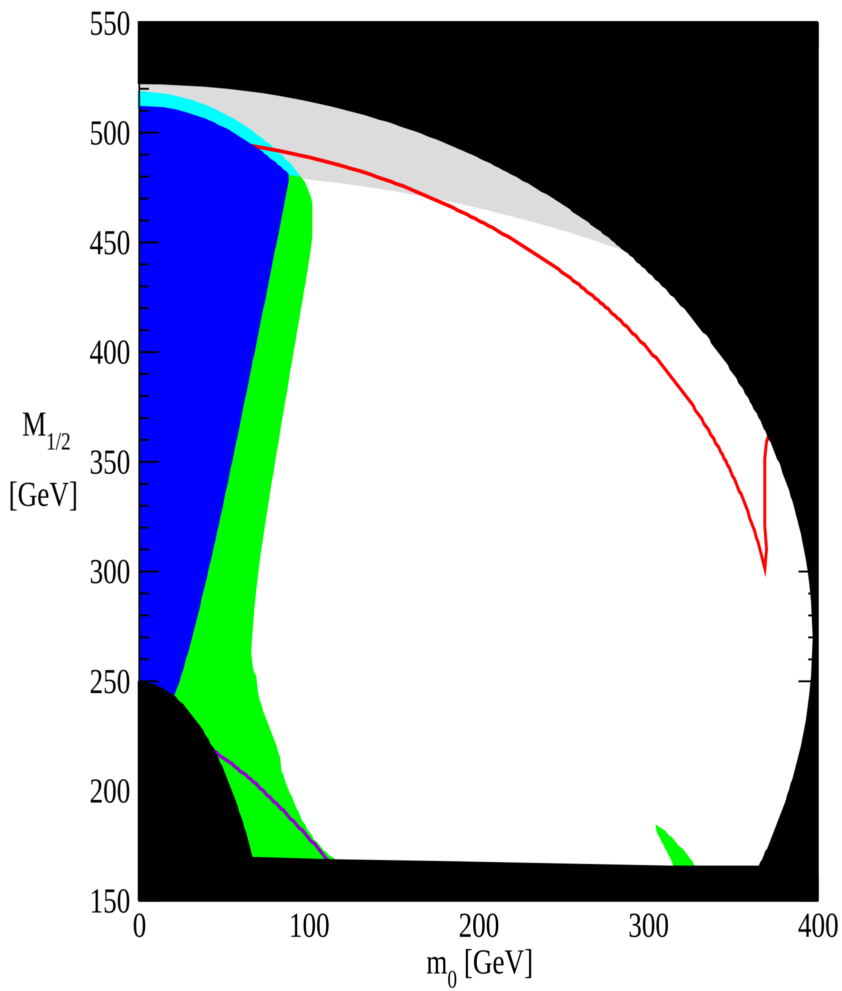


Results with semi-universality

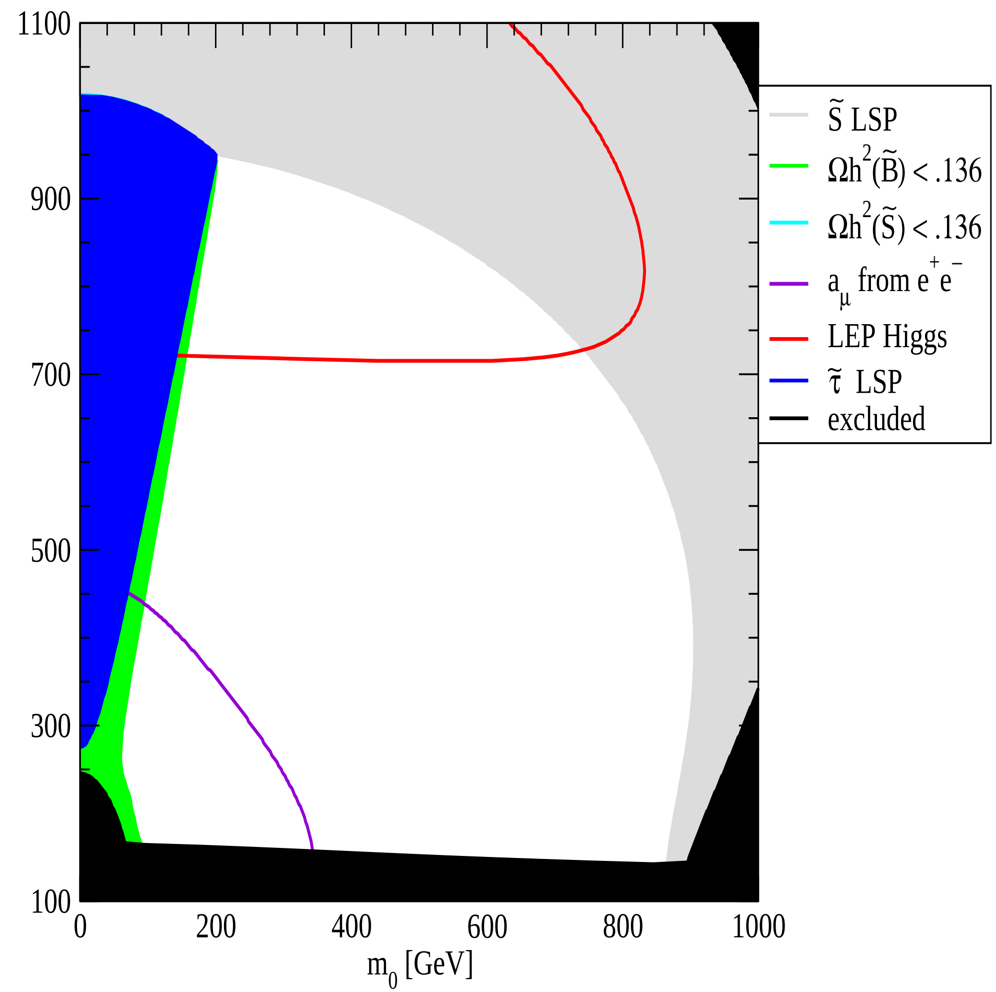
- If $\lambda \ll 1$, $\widetilde{S}$ can be the LSP $\Longrightarrow$ additional cascades at LHC
  Can this scenario be compatible with WMAP? **YES!**
  ... modulo some fine tuning ($m_{\widetilde{S}} - m_{\rm NSLP} \lesssim 1\,{\rm GeV}$)
  - $\mu A_\kappa < 0$: singlet masses $\nearrow$ with m_0 and/or $M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for small values of m_0 and/or $M_{1/2}$
  - $\mu A_\kappa > 0$: singlet masses $\searrow$ with m_0 and $M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for large values of m_0 and $M_{1/2}$

Singlino LSP (2) $\lambda = .01, \mu A_\kappa > 0$

tanβ = 10, A_0 = 250 GeV, A_κ = 270 GeV



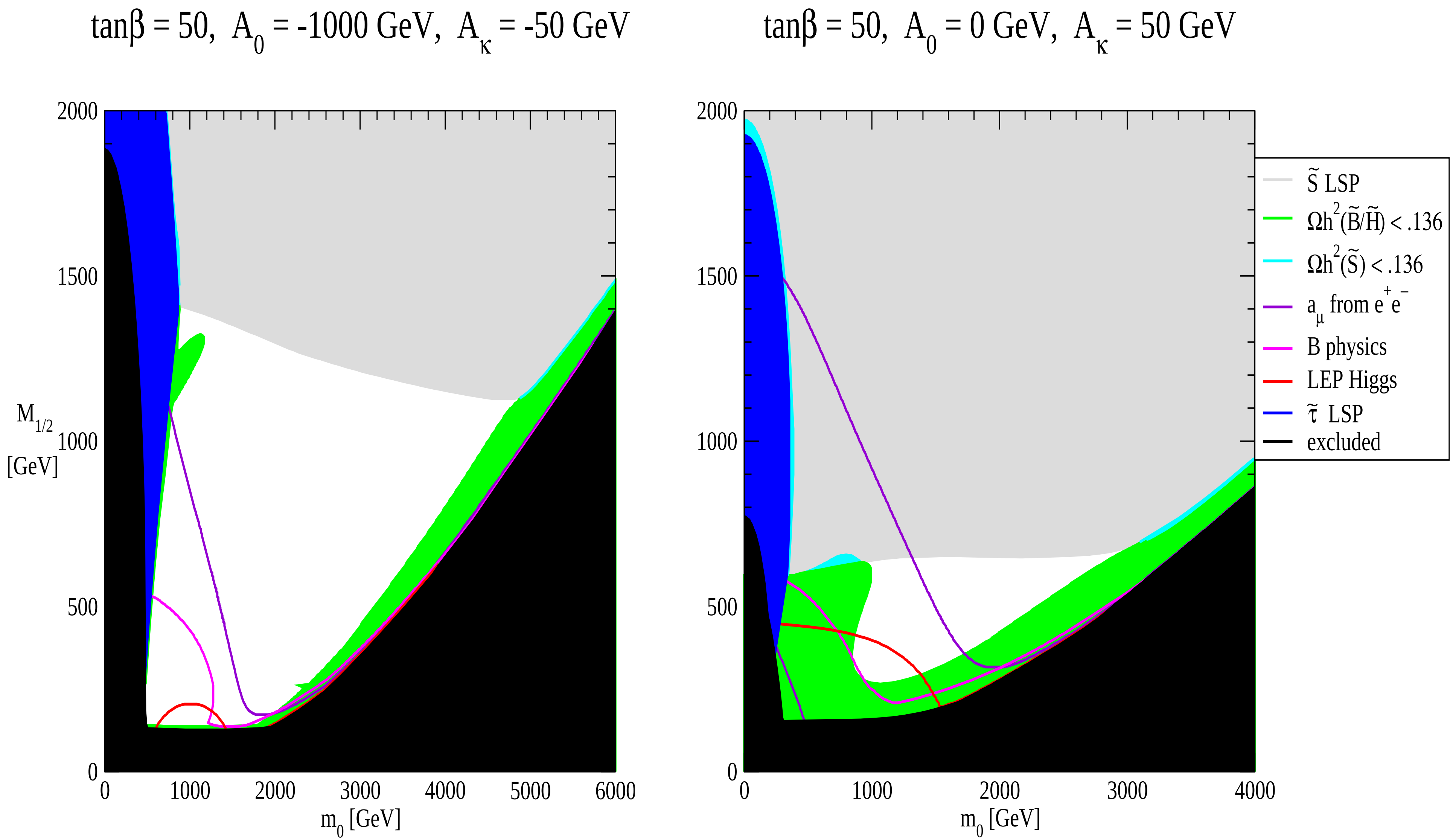
tanβ = 5, A_0 = 750 GeV, A_κ = 10 GeV



Results with semi-universality

- If $\lambda \ll 1$, $\widetilde{S}$ can be the LSP $\Longrightarrow$ additional cascades at LHC
  Can this scenario be compatible with WMAP? **YES!**
  ... modulo some fine tuning ($m_{\widetilde{S}} - m_{\text{NSLP}} \lesssim 1\,\text{GeV}$)
  - $\mu A_\kappa < 0$: singlet masses $\nearrow$ with m_0 and/or $M_{1/2}$
    $\Longrightarrow \widetilde{S}$ LSP for small values of m_0 and/or $M_{1/2}$
  - $\mu A_\kappa > 0$: singlet masses $\searrow$ with m_0 and $M_{1/2}$
    $\Longrightarrow \widetilde{S}$ LSP for large values of m_0 and $M_{1/2}$
  - large $\tan\beta$: singlet masses independent of $m_0, M_{1/2}$
    $\Longrightarrow \widetilde{S}$ LSP for large values of $M_{1/2}$ (where $\widetilde{B}$ is heavy)

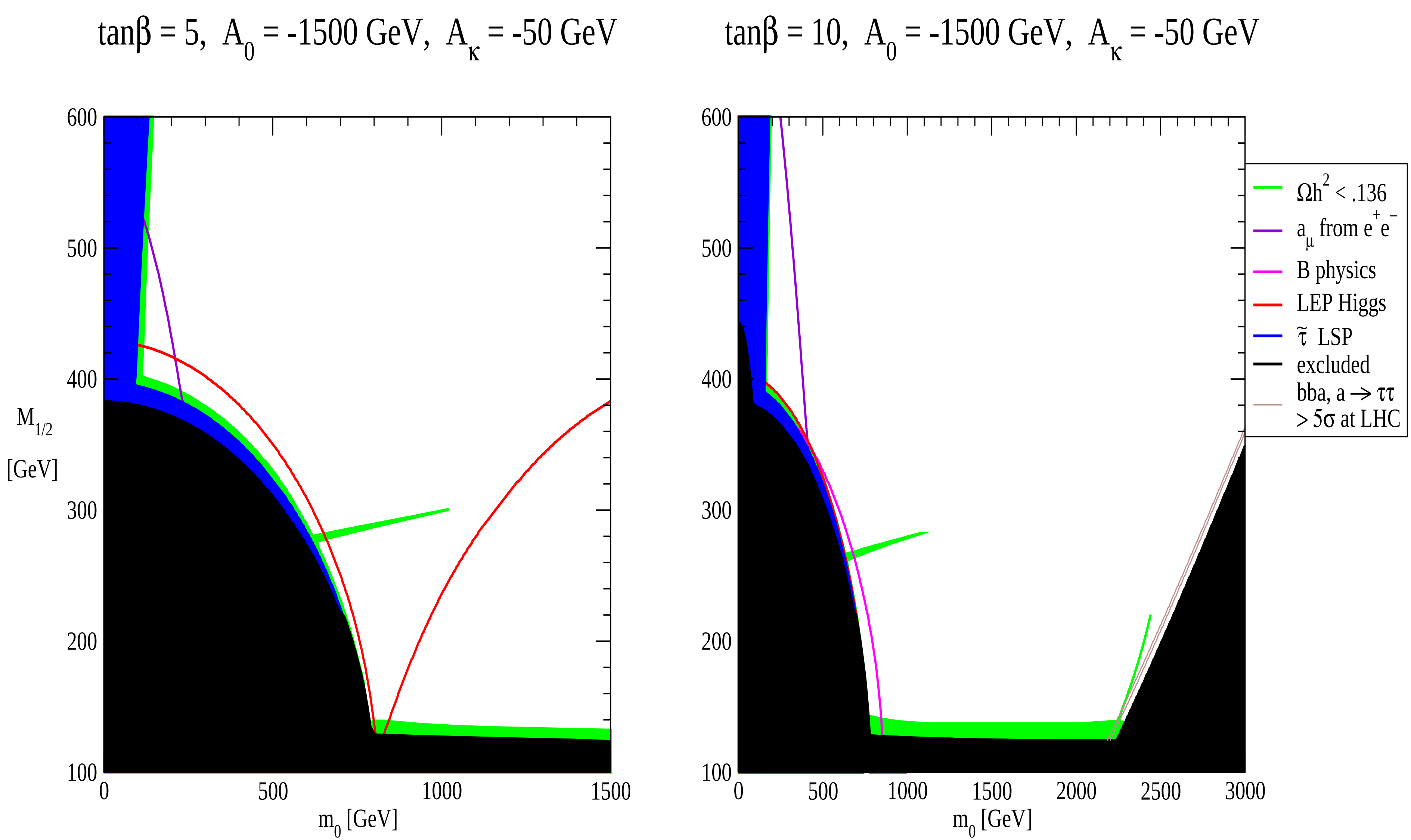
Singlino LSP (3) $\lambda = .01$, large $\tan\beta$



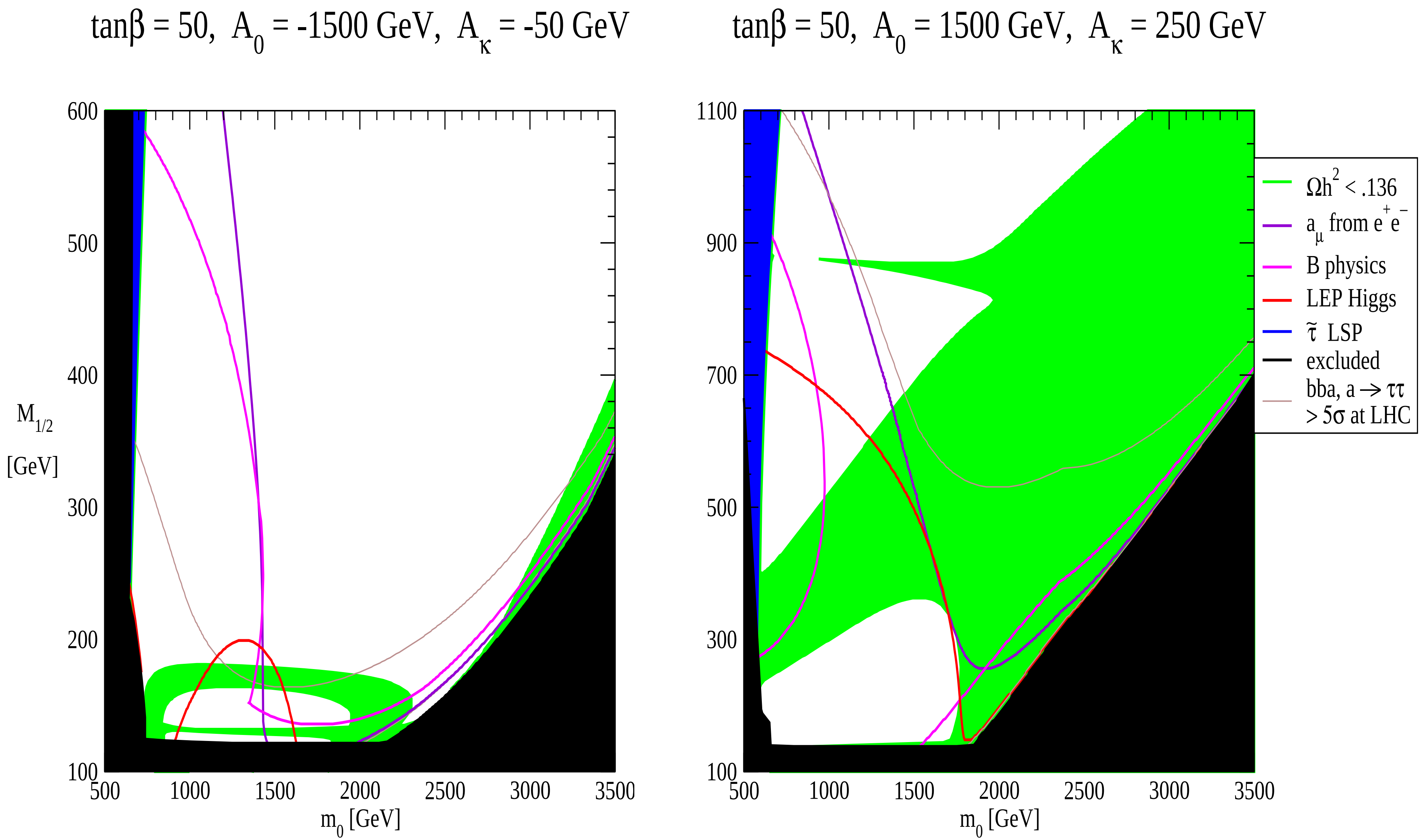
Results with semi-universality

- If $\lambda \ll 1$, $\widetilde{S}$ can be the LSP $\Longrightarrow$ additional cascades at LHC
  Can this scenario be compatible with WMAP? **YES!**
  ... modulo some fine tuning ($m_{\widetilde{S}} - m_{\mathrm{NSLP}} \lesssim 1\,\mathrm{GeV}$)
  - $\mu A_\kappa < 0$: singlet masses $\nearrow$ with m_0 and/or $M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for small values of m_0 and/or $M_{1/2}$
  - $\mu A_\kappa > 0$: singlet masses $\searrow$ with m_0 and $M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for large values of m_0 and $M_{1/2}$
  - large $\tan\beta$: singlet masses independent of $m_0, M_{1/2}$
    $\Longrightarrow$ $\widetilde{S}$ LSP for large values of $M_{1/2}$ (where $\widetilde{B}$ is heavy)
- If $\lambda \sim .1$: the pseudoscalar singlet a could be responsible
  for the ($\widetilde{B}$) LSP annihilation through $\widetilde{B}\widetilde{B} \to a$ resonance
  Would this a be visible at the LHC? **YES... if $\tan\beta$ is large**

Extra resonance (1) $\lambda = .1, \tan\beta = 5 - 10$



Extra resonance (2) $\lambda = .1, \tan\beta = 50$



Large λ (1) Small $\tan\beta$

Large values of $\lambda \Rightarrow$ light h

(from singlet/doublet mixing)

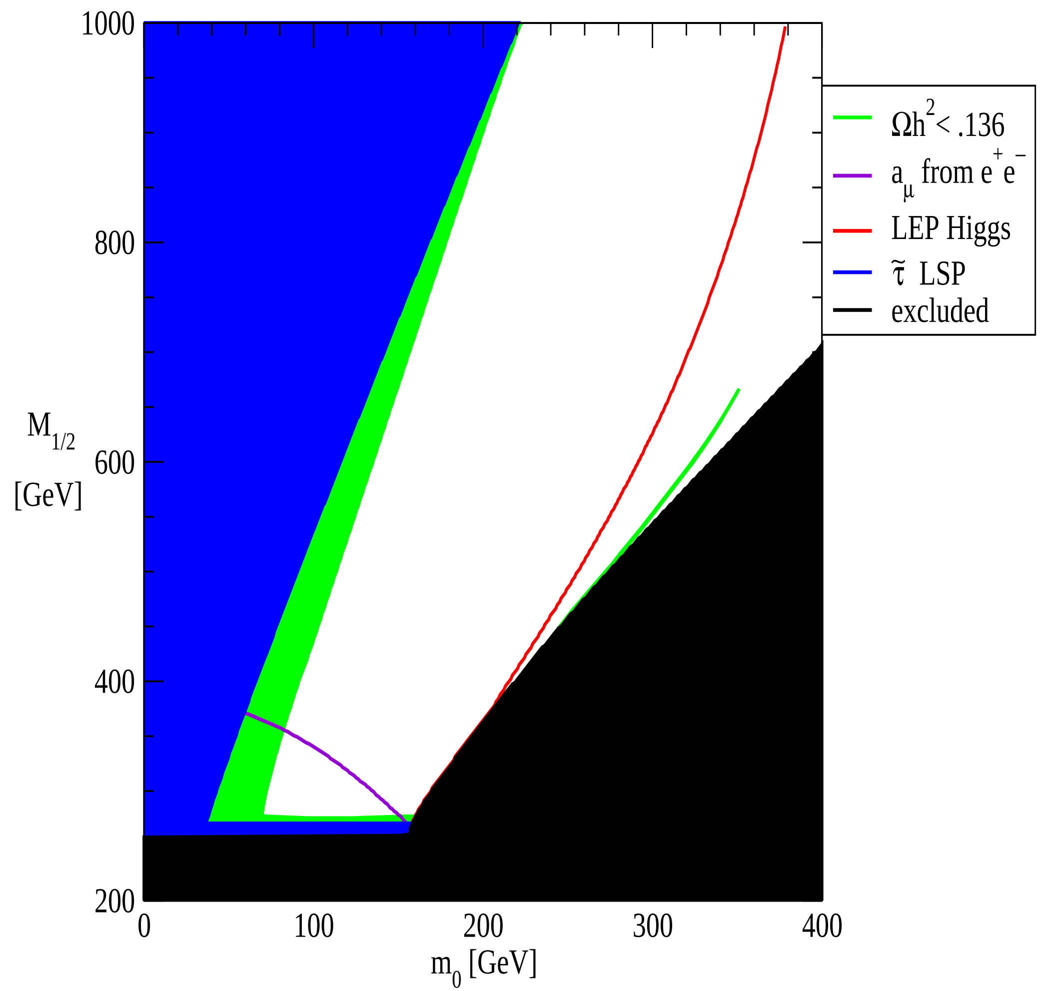
Large λ (1) Small $\tan\beta$

$\lambda = .5,\ \tan\beta = 2,\ A_0 = -1300$ GeV, $A_\kappa = -1400$ GeV

Large values of $\lambda \Rightarrow$ light h

(from singlet/doublet mixing)

- small $\tan\beta$ (max. m_h)



Large λ (1) Small $\tan\beta$

Large values of $\lambda \Rightarrow$ light h

(from singlet/doublet mixing)

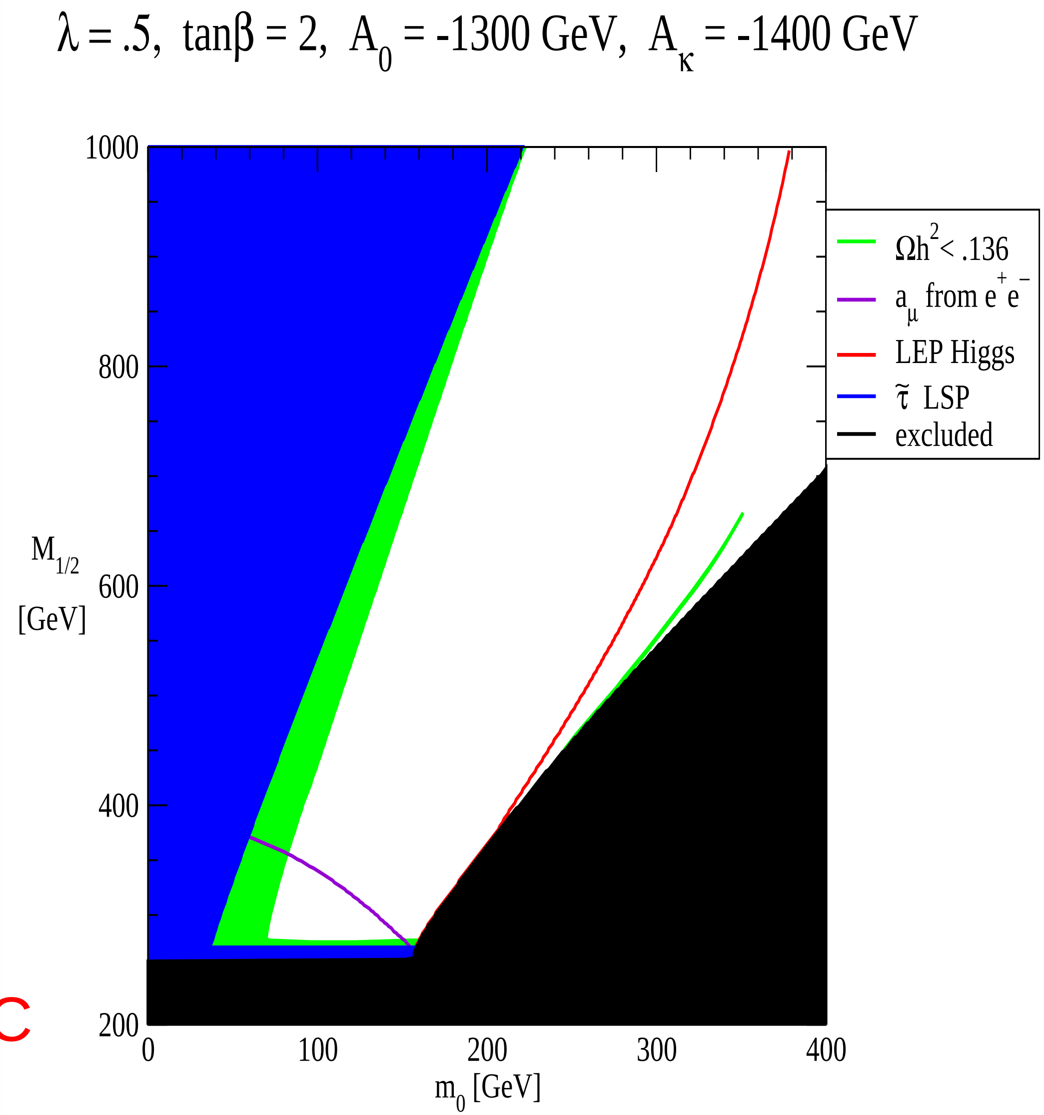
- small $\tan\beta$ (max. m_h)
- A_κ such that $h \to aa$

  LEP limits:

  if $a \to bb$, $m_h \gtrsim 106$ GeV

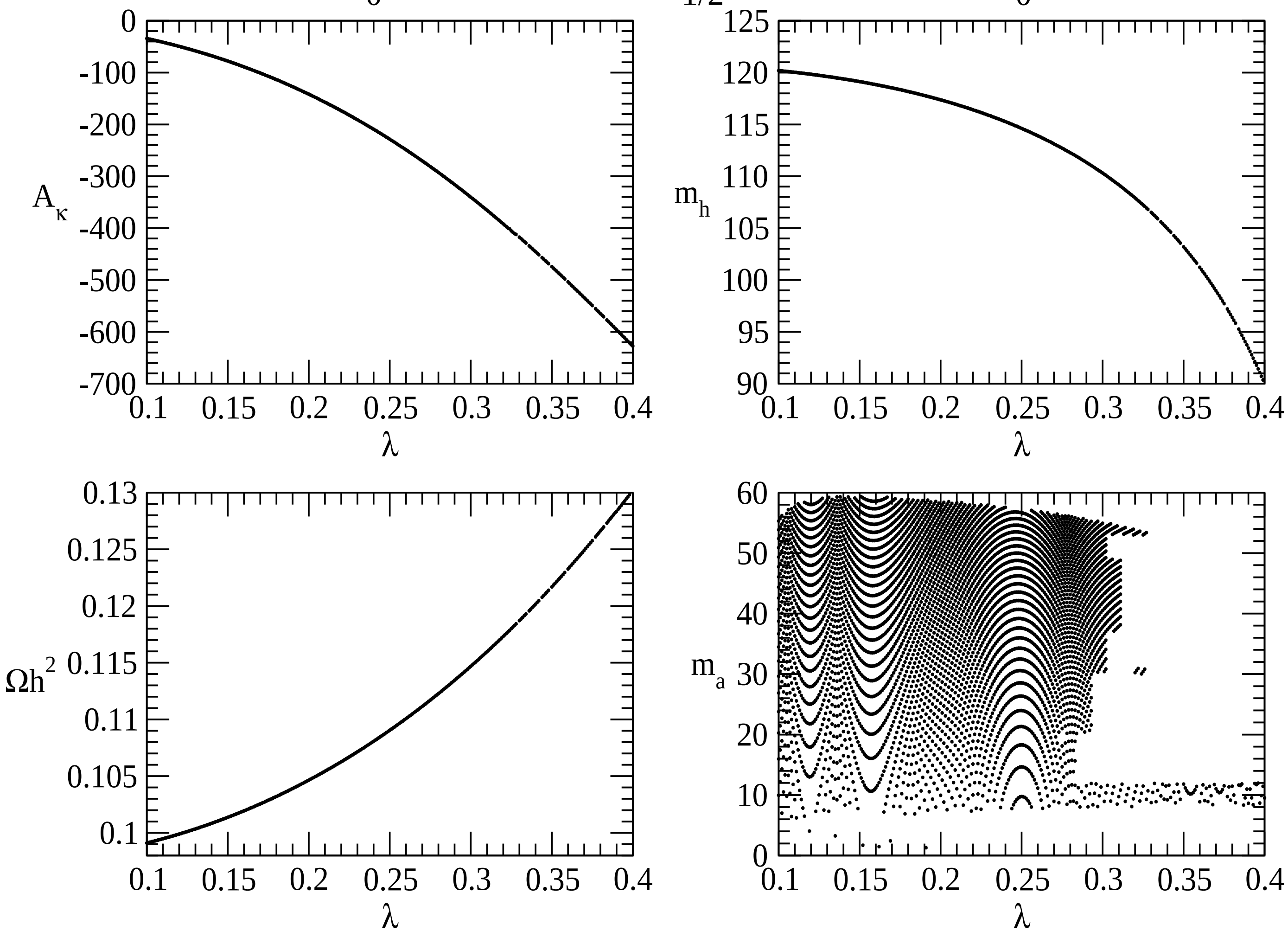
  if $a \to \tau\tau$, $m_h \gtrsim 90$ GeV

  $\Longrightarrow$ difficult to see at LHC



Large λ (2) h → aa

$\tan\beta = 10,\ m_0 = 174$ GeV, $M_{1/2} = 500$ GeV, $A_0 = -1500$ GeV



Benchmark points for the LHC

A. Djouadi & al., arXiv:hep-ph/0801.4321

- **BMP1:** $m_{h_1} = 120$ GeV, $m_{a_1} = 40$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 90\%$, $\mathrm{Br}(a_1 \to bb) = 90\%$
- **BMP2:** $m_{h_1} = 120$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 92\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$
- **BMP3:** $m_{h_1} = 90$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 99.9\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$

BMP1-3: $\widetilde{B}$ LSP coannihilating with $\widetilde{\tau}$ NSLP

Benchmark points for the LHC

A. Djouadi & al., arXiv:hep-ph/0801.4321

- **BMP1:** $m_{h_1} = 120$ GeV, $m_{a_1} = 40$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 90\%$, $\mathrm{Br}(a_1 \to bb) = 90\%$
- **BMP2:** $m_{h_1} = 120$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 92\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$
- **BMP3:** $m_{h_1} = 90$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 99.9\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$

  BMP1-3: $\widetilde{B}$ LSP coannihilating with $\widetilde{\tau}$ NSLP
- **BMP4:** $m_{h_2} = 123$ GeV, $m_{h_1} = 32$ GeV, rest heavy
  $\mathrm{Br}(h_2 \to h_1 h_1) = 88\%$, $\mathrm{Br}(h_1 \to bb) = 92\%$
  Mixed $\widetilde{H}/\widetilde{S}$ LSP annihilating to WW, Zh_1

Benchmark points for the LHC

A. Djouadi & al., arXiv:hep-ph/0801.4321

- **BMP1:** $m_{h_1} = 120$ GeV, $m_{a_1} = 40$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 90\%$, $\mathrm{Br}(a_1 \to bb) = 90\%$
- **BMP2:** $m_{h_1} = 120$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 92\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$
- **BMP3:** $m_{h_1} = 90$ GeV, $m_{a_1} = 9$ GeV, rest heavy
  $\mathrm{Br}(h_1 \to a_1 a_1) = 99.9\%$, $\mathrm{Br}(a_1 \to \tau\tau) = 88\%$

  BMP1-3: $\widetilde{B}$ LSP coannihilating with $\widetilde{\tau}$ NSLP
- **BMP4:** $m_{h_2} = 123$ GeV, $m_{h_1} = 32$ GeV, rest heavy
  $\mathrm{Br}(h_2 \to h_1 h_1) = 88\%$, $\mathrm{Br}(h_1 \to bb) = 92\%$
  Mixed $\widetilde{H}/\widetilde{S}$ LSP annihilating to WW, Zh_1
- **BMP5:** $m_{h_1} = 91$ GeV, $m_{h_2} = 118$ GeV, $m_{h_3} = 174$ GeV,
  $m_{a_1} = 100$ GeV, $m_{a_2} = 170$ GeV, $m_{h^\pm} = 188$ GeV
  $\widetilde{B}$ LSP annihilating through h/a resonances

  BMP4-5: Need non-universal m_{H_u}, m_{H_d} and A_λ

Conclusions

- The NMSSM is a SUSY extension of the SM more general (and more coherent) than the MSSM which phenomenology deserves to be studied (at least) at the same level
- It could be much richer and more complex than the MSSM
  - Singlino LSP giving extra cascades at LHC
  - Pseudoscalar singlet visible at LHC for large $\tan\beta$
  - Light h might escape LHC if it decays through $h \to aa$
- **NMSSMTools 2.0** is a dedicated package to study it

$\Longrightarrow$ KEEP POSTED (AND DOWNLOAD) ON:

`http://www.th.u-psud.fr/NMHDECAY/nmssmtools.html`