Cosmology of long-lived stau scenarios in the light of the LHC results

Jan Heisig

Hamburg University

SUSY 2013, ICTP, Trieste

August 30, 2013

Introduction

- If supersymmetry fundamental symmetry: supergravity
  $\rightarrow$ gravitino $\widetilde{G}$

- Production of $\widetilde{G}$ in the early universe $\Omega_{\widetilde{G}} \sim \frac{T_{\mathrm{R}}}{m_{\widetilde{G}}}$

  [Bolz, Buchmüller, Plümacher '98; Bolz, Brandenburg, Buchmüller '00; Pradler, Steffen '07]

- Accommodate Leptogenesis: $T_{\mathrm{R}} \gtrsim 10^9\,\mathrm{GeV}$

  [Davidson, Ibarra '02; Buchmüller, Di Bari, and Plümacher '04]

- Link Leptogenesis $\Leftrightarrow$ Supersymmetry

- Via two cosmological observations
  - BBN predictions
  - DM abundance

The gravitino puzzle

- Phenomenological $m_{\widetilde{G}}$ wide range
- $\Omega_{\widetilde{G}} \sim \frac{T_{\mathrm{R}}}{m_{\widetilde{G}}}$
- Decays of $\widetilde{G} \to \widetilde{X} X$ or $\widetilde{X} \to \widetilde{G} X$ suppressed, long-lived

	$m_{\widetilde{G}} = \mathrm{DM}$	Leptogenesis
$m_{\widetilde{G}} > 2\,\mathrm{keV}$	✓	×
$m_{\widetilde{G}} \lesssim m_{\mathrm{soft}}$	✓	?
$m_{\widetilde{G}} \gtrsim m_{\mathrm{soft}}$	×	×
$m_{\widetilde{G}} \gg m_{\mathrm{soft}}$	×	✓

The gravitino puzzle

- Phenomenological $m_{\widetilde{G}}$ wide range
- $\Omega_{\widetilde{G}} \sim \frac{T_{\mathrm{R}}}{m_{\widetilde{G}}}$
- Decays of $\widetilde{G} \to \widetilde{X} X$ or $\widetilde{X} \to \widetilde{G} X$ suppressed, long-lived

	$m_{\widetilde{G}} = \mathrm{DM}$	Leptogenesis
$m_{\widetilde{G}} \gtrsim 2\,\mathrm{keV}$	✓	×
$m_{\widetilde{G}} \lesssim m_{\mathrm{soft}}$	✓	?
$m_{\widetilde{G}} \gtrsim m_{\mathrm{soft}}$	×	×
$m_{\widetilde{G}} \gg m_{\mathrm{soft}}$	×	✓

To avoid BBN constraints → small NLSP freeze-out abundance

$$Y = \frac{n}{s} \simeq 3.7 \times 10^{-9}\, \Omega h^2 \,\frac{\mathrm{GeV}}{m}$$

Looking for small NLSP yields

- Consider NLSP $= \widetilde{\tau}_1$
- Possible values for $Y_{\widetilde{\tau}_1}$ in MSSM?
- Implications from LHC for $Y_{\widetilde{\tau}_1}$
  - Higgs around 125 GeV
  - Direct SUSY searches:

    Long-lived $\widetilde{\tau}_1 \quad \Rightarrow \quad$ HSCP searches
    Completely different signatures!

pMSSM Monte Carlo scan

- Monte Carlo scan over 17-dim. pMSSM
  A_t, A_b, A_τ; μ, $\tan\beta$, m_A; M_1, M_2, M_3; $\theta_{\widetilde{\tau}}$, $m_{\widetilde{\tau}_1}$; $\theta_{\widetilde{t}}$, $m_{\widetilde{t}_1}$, $m_{\widetilde{b}_1}$;
  $m_{\widetilde{L}_{1,2}}$, $m_{\widetilde{e}_{1,2}}$, $m_{\widetilde{Q}_{1,2}} = m_{\widetilde{u}_{1,2}} = m_{\widetilde{d}_{1,2}}$
- Interprete Higgs discovery in MSSM:

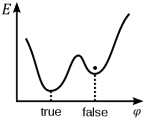
$$123\,\mathrm{GeV} < m_{h/H} < 128\,\mathrm{GeV}$$

[ATLAS, CMS '12]

- Used tools:
  - Spectrum, Higgs decays and precision observables: SuSpect, FeynHiggs
  - Decay tables: SDecay, Whizard
  - Cross sections: Fast XS estimation based on Prospino and NLL Fast, Whizard
  - Stau yield and flavor observables: micrOMEGAs

pMSSM scan – constraints

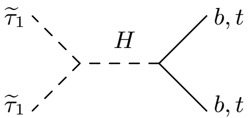
- Interpretation of the HSCP search at the 7 and 8 TeV LHC
  - Consider all SUSY xs (also $pp \to h/H \to \widetilde{\tau}_1 \widetilde{\tau}_1$)
  - Estimated $\sigma^{\text{obs}}_{\text{limit}}$ for each point from [CMS Collaboration '13]
- MSSM Higgs searches at the LHC, Tevatron and LEP via HiggsBounds 4.0.0
- Flavor and precision observables
  - $M_W = 80.385 \pm 0.060\,\text{GeV}$ @ 95% C.L. (Exp.+Theo. error) [TEW Group '12; Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein Zeune '12]
  - $\text{BR}(B \to X_s \gamma) = (3.43 \pm 0.56) \times 10^{-4}$ @ 95% C.L. [Heavy Flavor Averaging Group '12]
  - $\text{BR}(B^0_s \to \mu^+ \mu^-) = (3.2^{+3.2}_{-2.1}) \times 10^{-9}$ @ 95% C.L. [LHCb Collaboration '12]
- Constraints from vacuum (meta-)stability (CCB)
  - Constraints on $|\mu \tan \beta|$ [Kitahara, Yoshinaga '13]
  - Constraints on A_τ, A_b, A_t [Casas, Lleyda, Muñoz '96]



pMSSM scan – dedicated regions

- Dedicated scan
- Systematically look at combinations of:
  - Co-annihilation regions
  - Resonances (with H)
  - Large Higgs-sfermion couplings

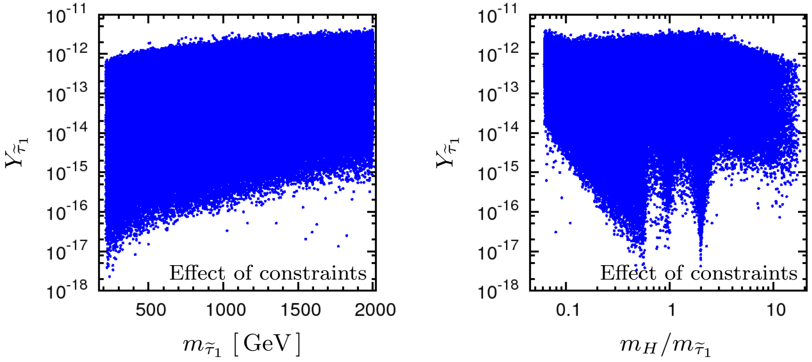
H-resonance:



$$m_H \simeq 2m_{\widetilde{\tau}_1}$$

[Ratz, Schmidt-Hoberg, Winkler '08; Pradler, Steffen '08]

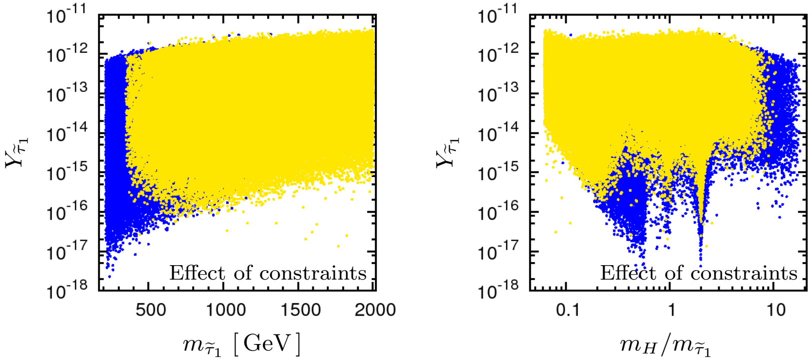
Results – stau yield after LHC 7/8



[JH Thesis '13; JH, J. Kersten, B. Panes, T. Robens, in preparation]

no constraints

Results – stau yield after LHC 7/8

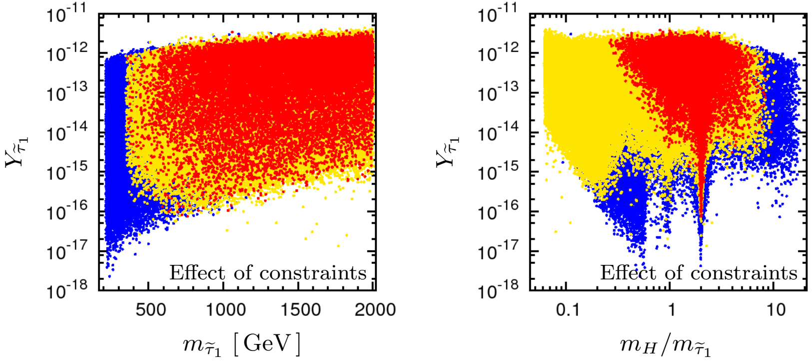


[JH Thesis '13; JH, J. Kersten, B. Panes, T. Robens, in preparation]

no constraints

passed HSCP search

Results – stau yield after LHC 7/8



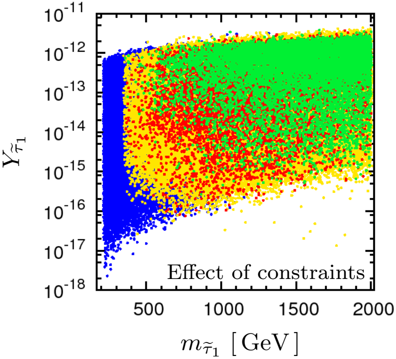
[JH Thesis '13; JH, J. Kersten, B. Panes, T. Robens, in preparation]

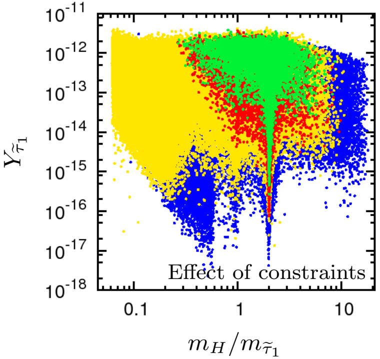
no constraints

(additionally) passed FP+HB

passed HSCP search

Results – stau yield after LHC 7/8





[JH Thesis '13; JH, J. Kersten, B. Panes, T. Robens, in preparation]

- no constraints
- (additionally) passed FP+HB
- passed HSCP search
- (additionally) passed CCB bounds

Search for low stau yields

- Yields $Y \lesssim 10^{-14}$ only close to a resonant pole $m_A \simeq 2m_{\widetilde{\tau}_1}$
- No stau left-right mixing:
  - Stop/sbottom co-annihilation: $Y \simeq 10^{-14}$
  - EWino co-annihilation: $Y \simeq 5 \times 10^{-15}$
- Stau left-right mixing: $Y \simeq 2 \times 10^{-16}$

What about Leptogenesis?

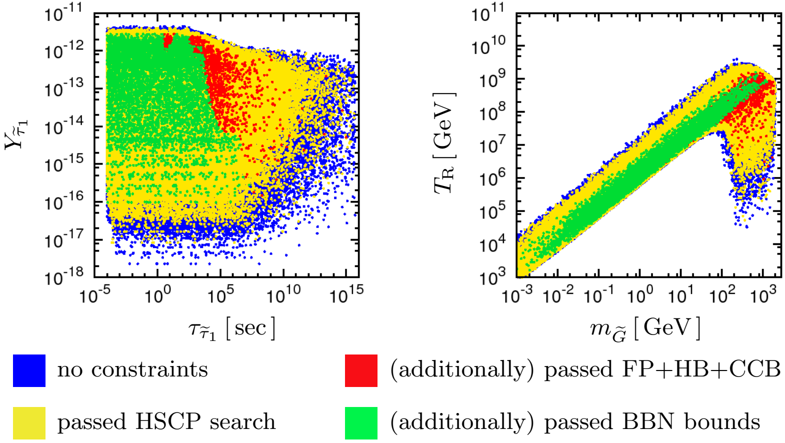
	$m_{\widetilde{G}} = \mathrm{DM}$	Leptogenesis
$m_{\widetilde{G}} > 2\,\mathrm{keV}$	✓	×
$m_{\widetilde{G}} \lesssim m_{\mathrm{soft}}$	✓	?
$m_{\widetilde{G}} \gtrsim m_{\mathrm{soft}}$	×	×
$m_{\widetilde{G}} \gg m_{\mathrm{soft}}$	×	✓

- So far independent of LSP
- Clarify the ? $\rightarrow$ specify LSP $= \widetilde{G}$

Implications for T_R

- Extend param. space by $m_{\widetilde{G}}$ $\rightarrow$ (17+1)-dim. pMSSM scan
- Compute $\tau_{\widetilde{\tau}_1}$, BRs, apply BBN bounds [Jedamzik '08]
- Require $\Omega_{\widetilde{G}} = \Omega_{\mathrm{DM}}^{\mathrm{Planck}}$

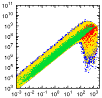
[JH Thesis '13]



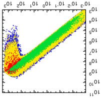
Conclusion

- Supersymmetry <u>and</u> Thermal leptogenesis $\rightarrow$ Puzzle
- Gravitino DM well motivated
- Long-lived stau NLSP phenomenologically interesting
- Low-energy approach: pMSSM scan
- Stau yields $Y_{\widetilde{\tau}_1} \lesssim 10^{-14}$ only close to a resonant pole $m_A \simeq 2m_{\widetilde{\tau}_1}$ (w/ or w/o co-annihilation)
  Smallest yields: $Y_{\widetilde{\tau}_1} \simeq 2 \times 10^{-16}$
- Leptogenesis ?

Conclusion

- Supersymmetry <u>and</u> Thermal leptogenesis $\rightarrow$ Puzzle
- Gravitino DM well motivated
- Long-lived stau NLSP phenomenologically interesting
- Low-energy approach: pMSSM scan
- Stau yields $Y_{\widetilde{\tau}_1} \lesssim 10^{-14}$ only close to a resonant pole $m_A \simeq 2m_{\widetilde{\tau}_1}$ (w/ or w/o co-annihilation)
  Smallest yields: $Y_{\widetilde{\tau}_1} \simeq 2 \times 10^{-16}$
- Leptogenesis 

Conclusion

- Supersymmetry <u>and</u> Thermal leptogenesis $\rightarrow$ Puzzle
- Gravitino DM well motivated
- Long-lived stau NLSP phenomenologically interesting
- Low-energy approach: pMSSM scan
- Stau yields $Y_{\widetilde{\tau}_1} \lesssim 10^{-14}$ only close to a resonant pole $m_A \simeq 2m_{\widetilde{\tau}_1}$ (w/ or w/o co-annihilation)
  Smallest yields: $Y_{\widetilde{\tau}_1} \simeq 2 \times 10^{-16}$
- Leptogenesis 

Thank you for your attention!