

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

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Introduction

- If supersymmetry fundamental symmetry: supergravity
→ gravitino \tilde{G}

- Production of \tilde{G} in the early universe $\Omega_{\tilde{G}} \sim \frac{T_R}{m_{\tilde{G}}}$

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

- Accommodate Leptogenesis: $T_R \gtrsim 10^9 \text{ GeV}$

[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 $m_{\tilde{G}}$ wide range
- $\Omega_{\tilde{G}} \sim \frac{T_R}{m_{\tilde{G}}}$
- Decays of $\tilde{G} \rightarrow \tilde{X}X$ or $\tilde{X} \rightarrow \tilde{G}X$ suppressed, long-lived

	$m_{\tilde{G}} = \text{DM}$	Leptogenesis
$m_{\tilde{G}} > 2 \text{ keV}$	✓	×
$m_{\tilde{G}} \lesssim m_{\text{soft}}$	✓	?
$m_{\tilde{G}} \gtrsim m_{\text{soft}}$	×	×
$m_{\tilde{G}} \gg m_{\text{soft}}$	×	✓

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$m_{\tilde{G}} \gg m_{\text{soft}}$	✗	✓

To avoid BBN constraints \rightarrow small NLSP freeze-out abundance

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

Looking for small NLSP yields

- Consider NLSP = $\tilde{\tau}_1$
- Possible values for $Y_{\tilde{\tau}_1}$ in MSSM?
- Implications from LHC for $Y_{\tilde{\tau}_1}$
 - Higgs around 125 GeV
 - Direct SUSY searches:
Long-lived $\tilde{\tau}_1 \Rightarrow$ HSCP searches
Completely different signatures!

pMSSM Monte Carlo scan

- Monte Carlo scan over 17-dim. pMSSM

$$A_t, A_b, A_\tau; \mu, \tan \beta, m_A; M_1, M_2, M_3; \theta_{\tilde{\tau}}, m_{\tilde{\tau}_1}; \theta_t, m_{\tilde{t}_1}, m_{\tilde{b}_1}; \\ m_{\tilde{L}_{1,2}}, m_{\tilde{e}_{1,2}}, m_{\tilde{Q}_{1,2}} = m_{\tilde{u}_{1,2}} = m_{\tilde{d}_{1,2}}$$

- Interpret Higgs discovery in MSSM:

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

[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: MICROMEAS

pMSSM scan – constraints

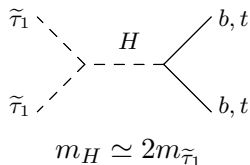
- Interpretation of the HSCP search at the 7 and 8 TeV LHC
 - Consider all SUSY xs (also $pp \rightarrow h/H \rightarrow \tilde{\tau}_1 \tilde{\tau}_1$)
 - Estimated $\sigma_{\text{limit}}^{\text{obs}}$ for each point from [CMS Collaboration '13]
- MSSM Higgs searches at the LHC, Tevatron and LEP via HIGGSBOUNDS 4.0.0
- Flavor and precision observables
 - $M_W = 80.385 \pm 0.060 \text{ GeV} @ 95\% \text{ C.L.}$ (Exp.+Theo. error)
[TEW Group '12; Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein Zeune '12]
 - $\text{BR}(B \rightarrow X_s \gamma) = (3.43 \pm 0.56) \times 10^{-4} @ 95\% \text{ C.L.}$
[Heavy Flavor Averaging Group '12]
 - $\text{BR}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.2_{-2.1}^{+3.2}) \times 10^{-9} @ 95\% \text{ C.L.}$
[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

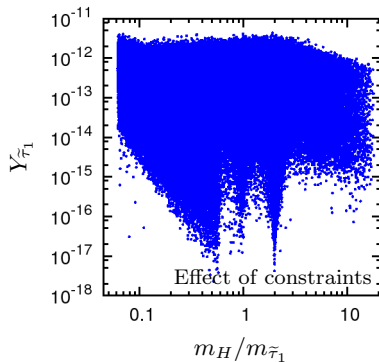
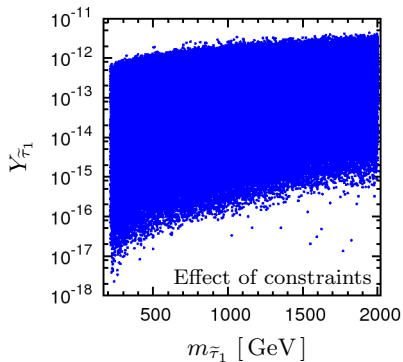
- Dedicated scan
- Systematically look at combinations of:
 - Co-annihilation regions
 - Resonances (with H)
 - Large Higgs-sfermion couplings

H -resonance:




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

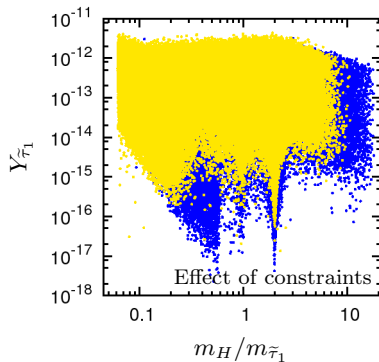
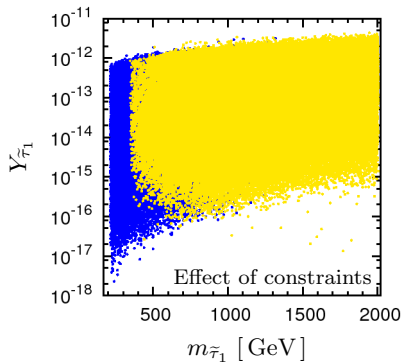
Results – stau yield after LHC 7/8



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

 no constraints

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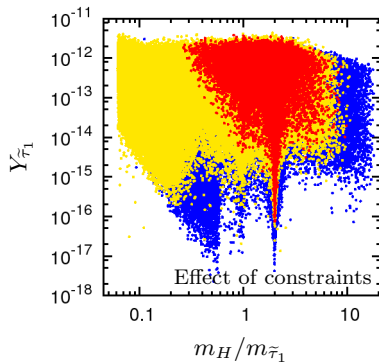
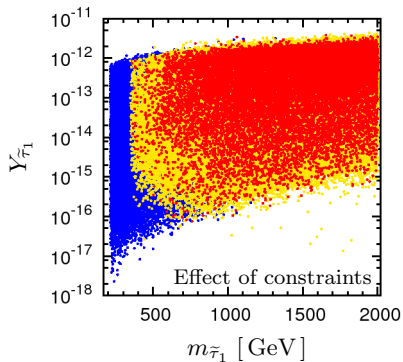


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passed HSCP search

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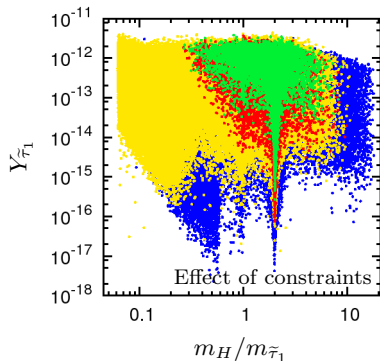
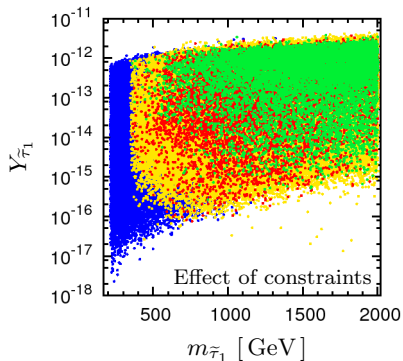


(additionally) passed FP+HB



passed HSCP search

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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 $m_A \simeq 2m_{\tilde{\tau}_1}$
- 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?

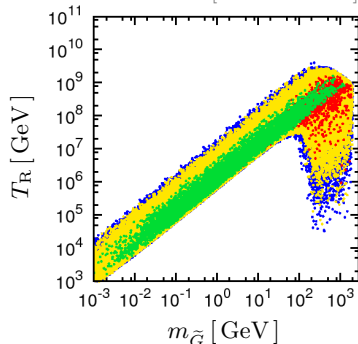
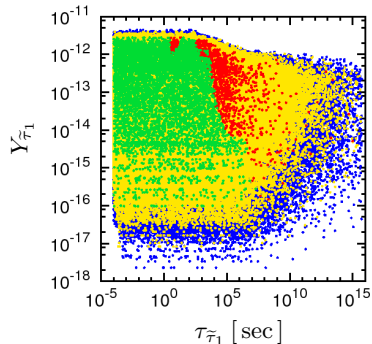
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- So far independent of LSP
- Clarify the ? → specify LSP = \tilde{G}

Implications for T_R

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


[JH Thesis '13]



■ no constraints
■ passed HSCP search

■ (additionally) passed FP+HB+CCB
■ (additionally) passed BBN bounds

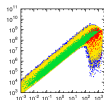
Conclusion

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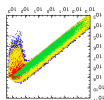
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Thank you for your attention!