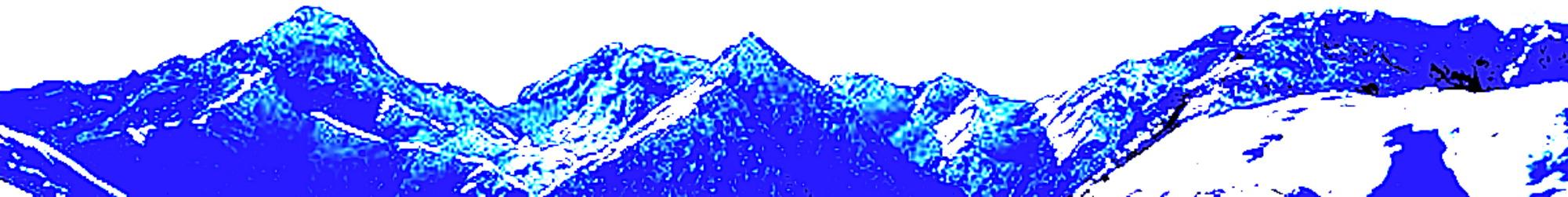
Moriond 2014

Gravitino DM and Leptogenesis after the first LHC results

Jan Heisig, RWTH Aachen University



Introduction

- R-parity conserving Supersymmetry well motivated (DM, stability of EW scale, gauge unification)
- SUSY does not address baryon asymmetry
  $\frac{n_B}{n_\gamma} \simeq \frac{n_B - n_{\bar{B}}}{n_\gamma} \simeq 6 \times 10^{-10}$
- Attractive: Thermal Leptogenesis [Fukugita, Yanagida '86]
- Leptogenesis requires: $T_R \gtrsim 10^9\,\text{GeV}$

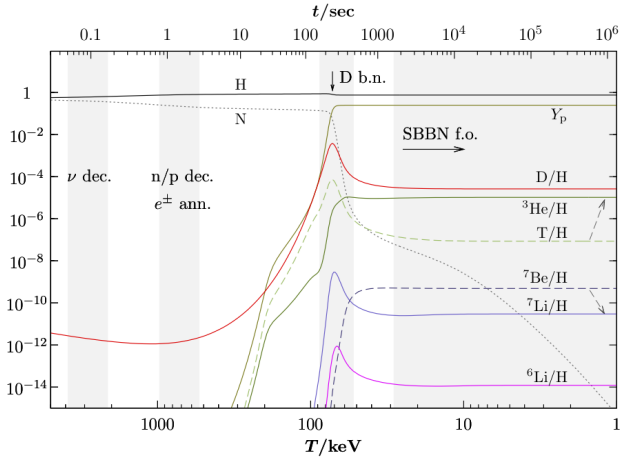
  [Davidson, Ibarra '02; Buchmüller, Di Bari, and Plümacher '04]
- Production of $\widetilde{G}$ in the early universe $\Omega_{\widetilde{G}} \sim \frac{T_R}{m_{\widetilde{G}}}$

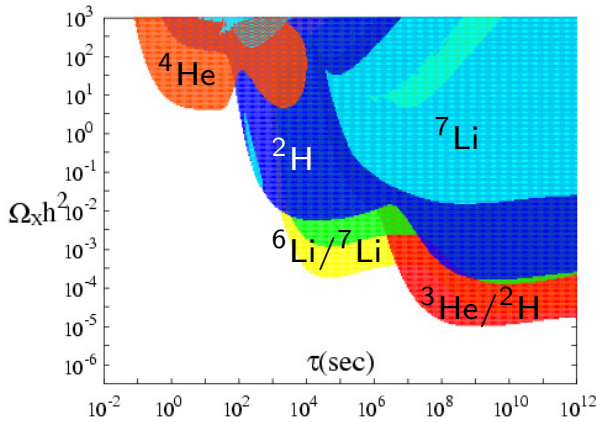
  [Bolz, Buchmüller, Plümacher '98; Bolz, Brandenburg, Buchmüller '00; Pradler, Steffen '07]
- Leptogenesis and Supersymmetry: Gravitino Problem

The Gravitino Problem

- Neutralino LSP ($m_{\widetilde{G}} \sim m_{\text{soft}}$):
  - Decays $\widetilde{G} \to \text{LSP} + X$ suppressed, $\widetilde{G}$ long-lived
  - Decay during/after BBN distorts predictions
  - $\Omega_{\widetilde{G}} \sim \frac{T_R}{m_{\widetilde{G}}} \to$ no Leptogenesis!

[Pospelov, Pradler '10]





[Jedamzik '06]

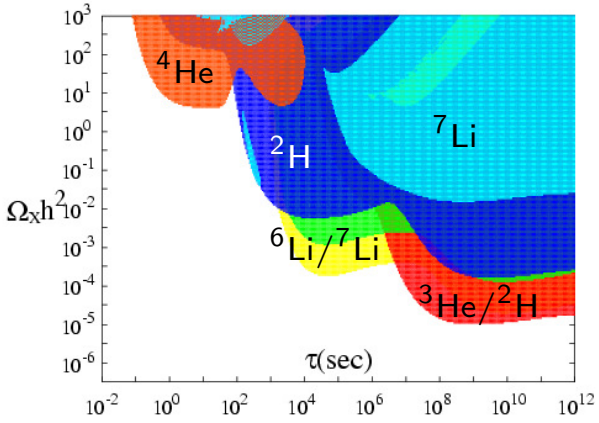
The Gravitino Problem

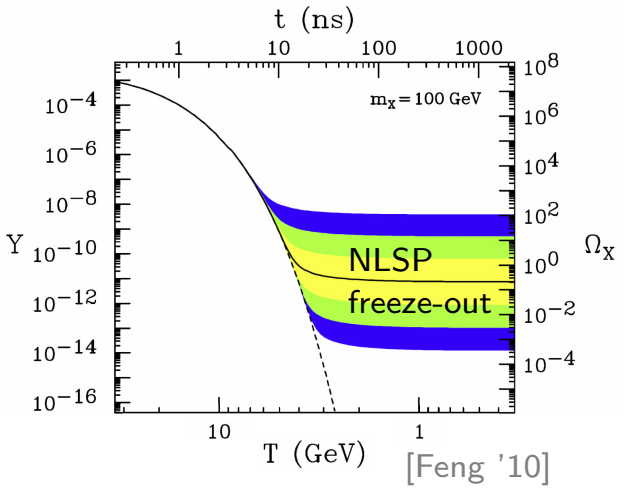
- Gravitino LSP:
  - Gravitino stable
  - NLSP $\to \widetilde{G} + X$ suppressed:

$$\tau_{\text{NLSP}} \sim \frac{M_{\text{Pl}}^2 m_{\widetilde{G}}^2}{m_{\widetilde{\tau}_1}^5}$$

  - Gravitino DM: $\Omega_{\widetilde{G}} \stackrel{!}{=} \Omega_{\text{DM}}$
    $\Omega_{\widetilde{G}} \sim \frac{T_{\text{R}}}{m_{\widetilde{G}}} + (\text{non-therm. contr.})$
  - If NLSP $\in$ MSSM: freeze-out!
  - Consider yield $Y = n/s \sim \Omega/m$

[Jedamzik '06]





[Feng '10]

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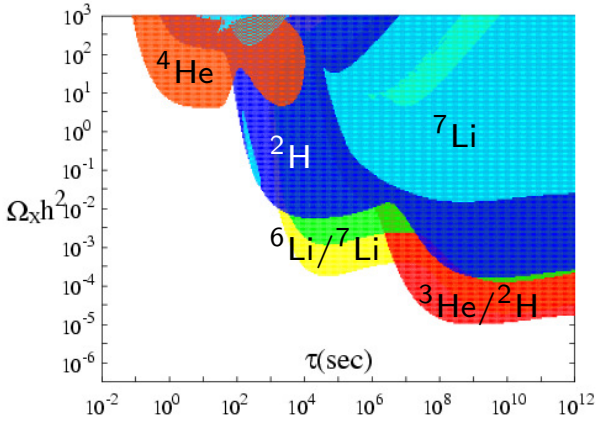
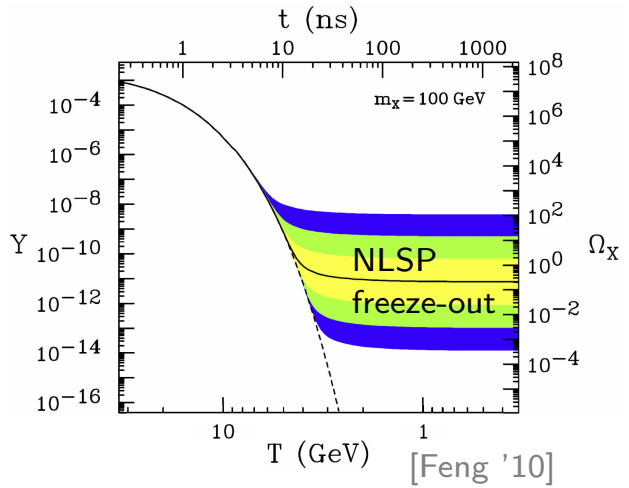
$\to$ Implications from LHC 7/8 and other recent experiments?

[Jedamzik '06]





[Feng '10]

Outline

- Implications for possible NLSP yields

  Based on J. Kersten, B. Panes, T. Robens, JH: 1310.2825, acc. by JHEP

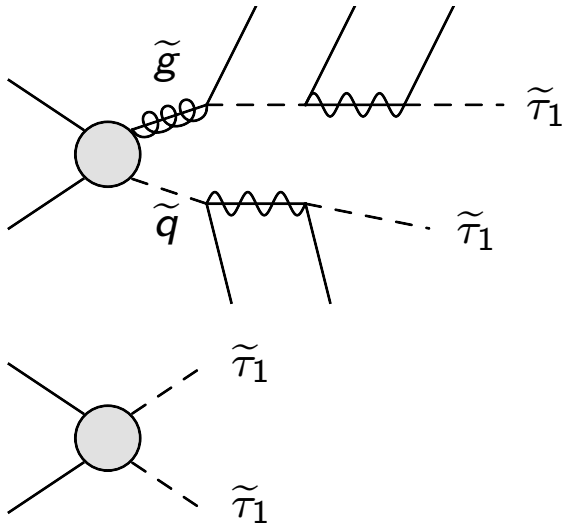
- Implications for the reheating temperature

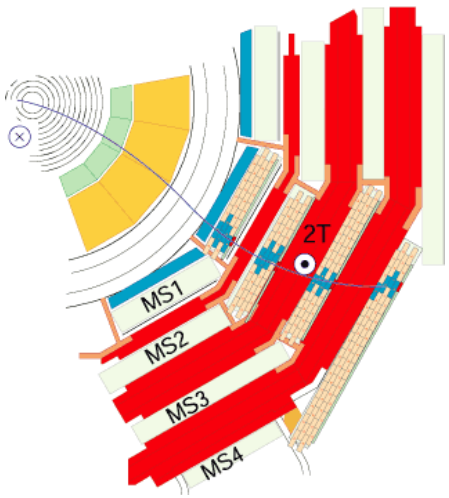
  Based on JH: 1310.6352 sub. to JCAP

Choice of NLSP

Consider NLSP $= \widetilde{\tau}_1$:

- Direct SUSY searches = HSCP searches (no MET!)
- Clean signature $\rightarrow$ high sensitivity
- Robust mass bounds possible
- E.g. $m_{\widetilde{\tau}_1} \gtrsim 340\,\text{GeV}$ [CMS 2013]
- Great prospects for LHC 13/14





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; $\theta_{\tilde{\tau}}$, $m_{\tilde{\tau}_1}$; $\theta_{\tilde{t}}$, $m_{\tilde{t}_1}$, $m_{\tilde{b}_1}$; $m_{\tilde{L}_{1,2}}$, $m_{\tilde{e}_{1,2}}$, $m_{\tilde{Q}_{1,2}} = m_{\tilde{u}_{1,2}} = m_{\tilde{d}_{1,2}}$
- Interprete 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: micrOMEGAs
- No 'blind' scan – systematically scan co-annihilation regions, resonances, larger mixings

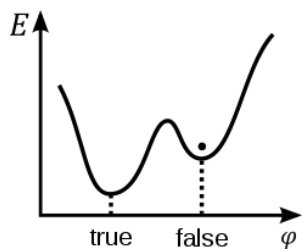
pMSSM scan – constraints

- 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]
  - $\text{BR}(B_s^0 \to \mu^+\mu^-) = (3.2^{+3.2}_{-2.1}) \times 10^{-9}$ @ 95% C.L.

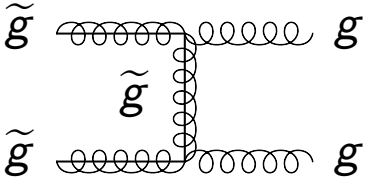
    [LHCb Collaboration '12]
- Constraints from vacuum (meta-)stability (CCB)
  - Constraints on $|\mu \tan\beta|$ [Kitahara, Yoshinaga '13]
  - Constraints on A_τ, A_b, A_t [Casas, Lleyda, Muñoz '96]



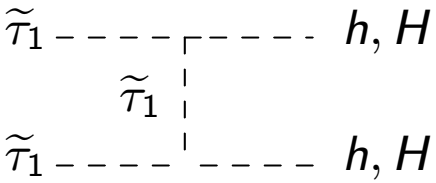
Implications for low stau yields, $Y < 10^{-14}$

Scan exceptional regions [Griest, Seckel '91, Ratz, Schmidt-Hoberg, Winkler '08; Pradler, Steffen '08]

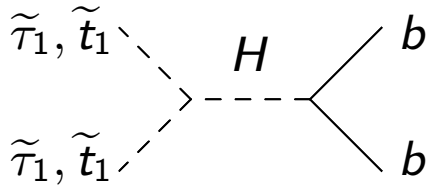
- Co-annihilation with colored sparticles, e.g. $m_{\widetilde{g}} \simeq m_{\widetilde{\tau}_1}$:

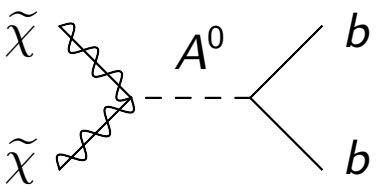


- Enhanced stau-Higgs couplings, large mixing, large tan β



- H/A-resonance, $m_H, m_A \simeq 2m_{\widetilde{\tau}_1}$





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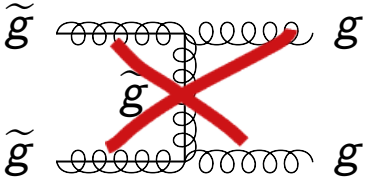
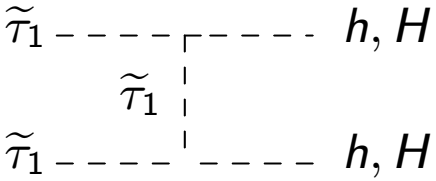


Constrainted by HSCP bounds

- Enhanced stau-Higgs couplings, large mixing, large tan β



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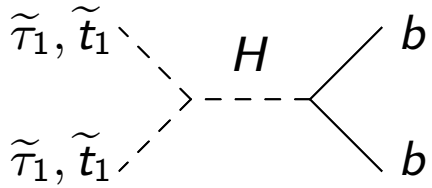

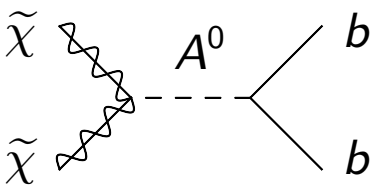

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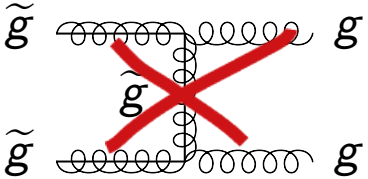

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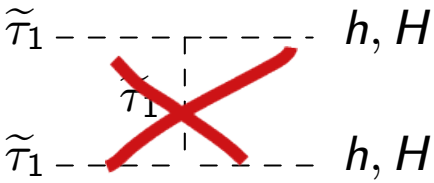

Constrainted by FP bounds
MSSM Higgs searches
CCB bounds

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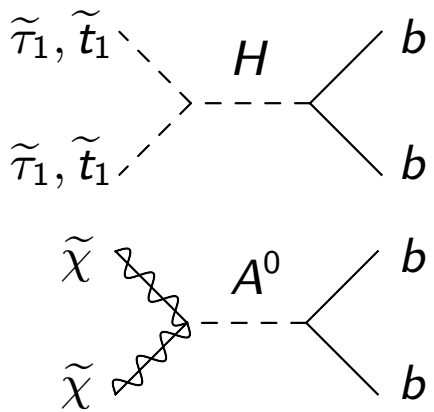

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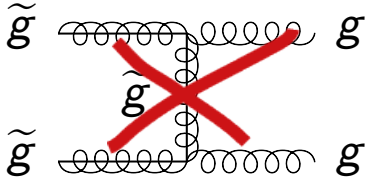

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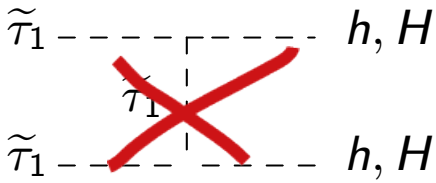

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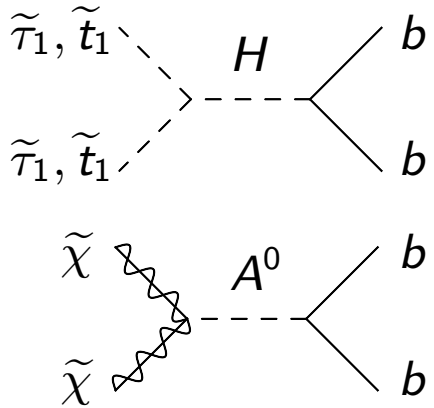
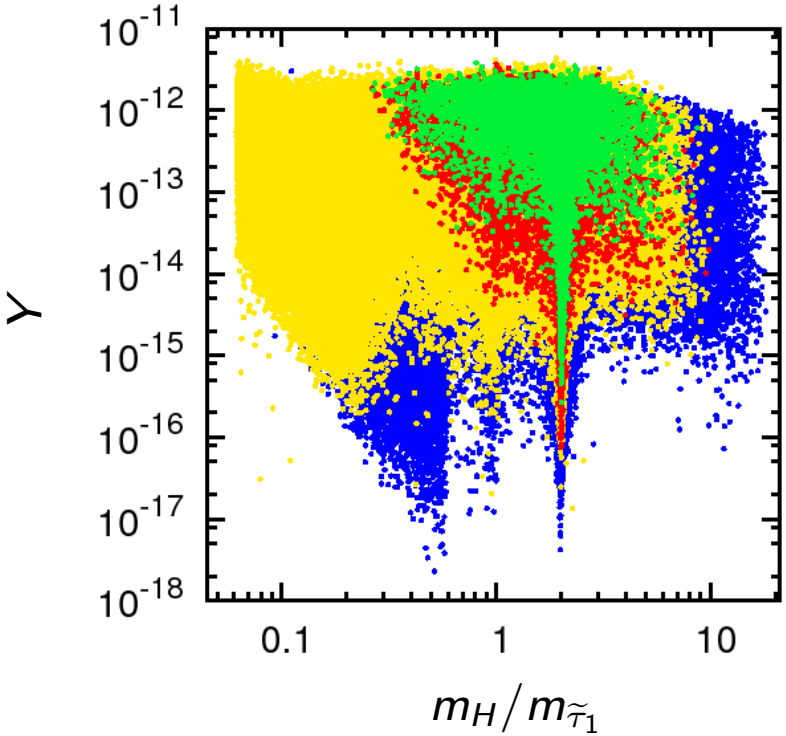
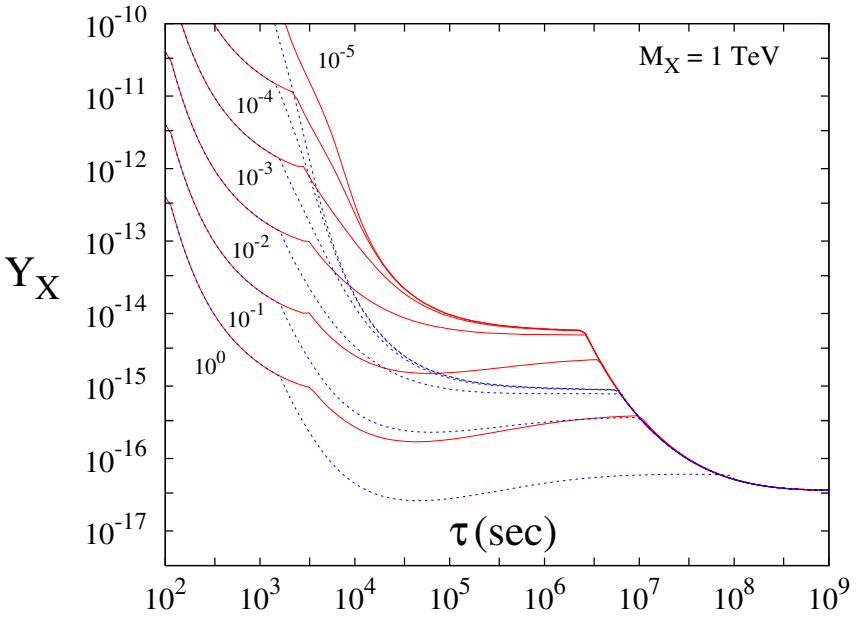


Resonant stau annihilation or
resonant stop/EWino co-annihilation
provides $Y < 10^{-14}$

Implications for the stau yield

[1310.2825]





[Jedamzik '08]

no constraints

passed HSCP search

(additionally) passed FP+HB

(additionally) passed CCB bounds

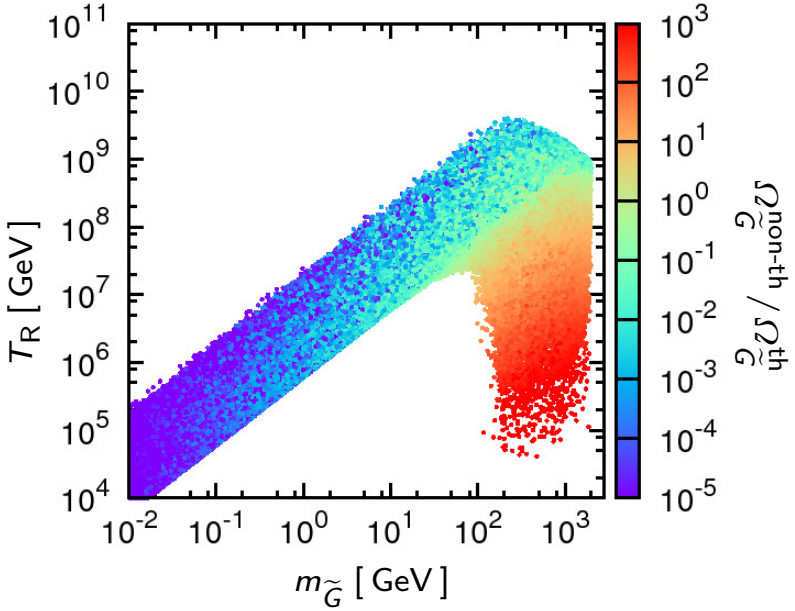
Implications for T_R from Ω_{DM}

- Extend param. space by $m_{\widetilde{G}}$
- Gravitino DM:
  $\Omega_{\widetilde{G}} h^2 \stackrel{!}{=} \Omega_{DM} h^2 = 0.119$ [Planck '13]
  $\Omega_{\widetilde{G}} = \Omega^{th}_{\widetilde{G}} + \Omega^{non\text{-}th}_{\widetilde{G}}$
- Non-thermal production:
  $\Omega^{non\text{-}th}_{\widetilde{G}} \sim Y_{\widetilde{\tau}_1} m_{\widetilde{G}}$
- Thermal production:

$$\Omega^{th}_{\widetilde{G}} \sim \sum_{i=1}^{3} C_i \left(1 + \frac{M_i^2}{3 m^2_{\widetilde{G}}}\right) m_{\widetilde{G}} T_R$$

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

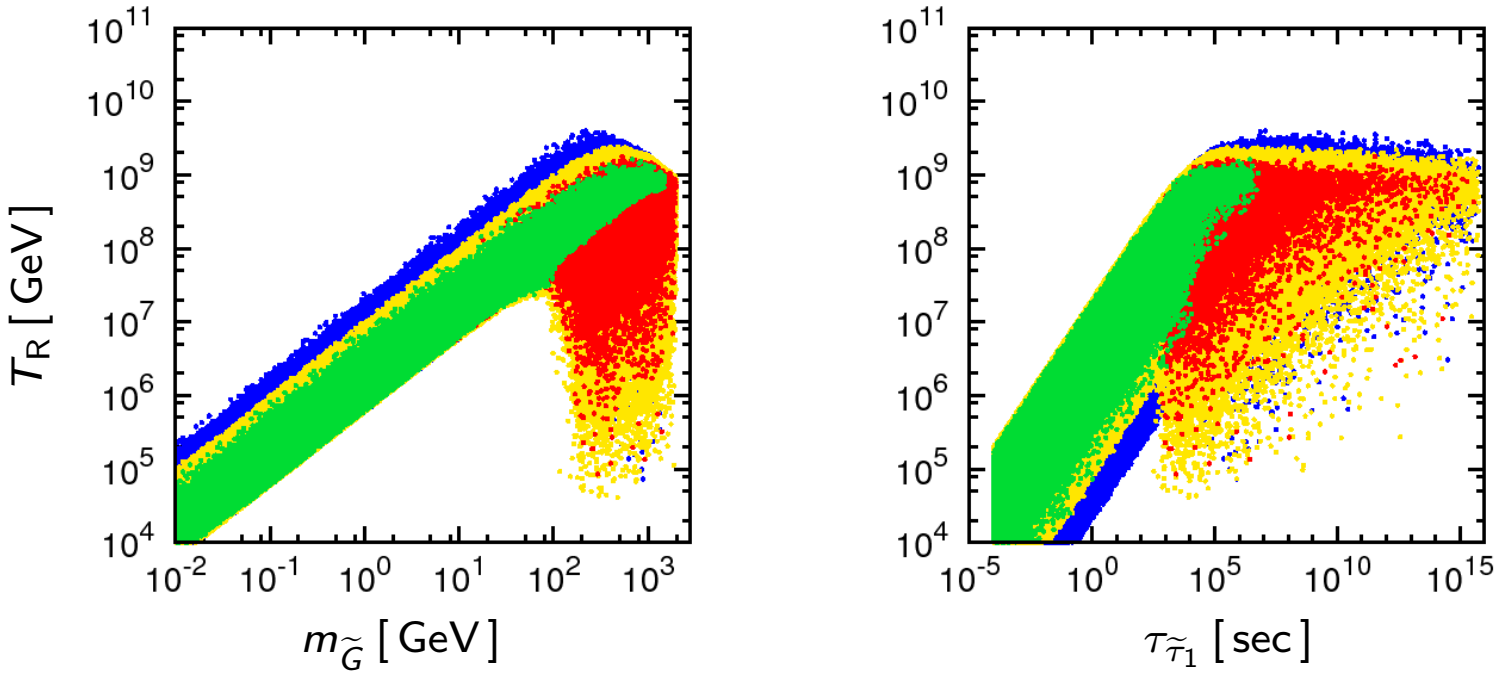
[1310.6352]



Implications for T_R from BBN

- Compute $\tau_{\widetilde{\tau}_1}$, hadronic BRs $\Gamma(\widetilde{\tau}_1 \to \widetilde{G}\tau q\bar{q})$, $\Gamma(\widetilde{\tau}_1 \to \widetilde{G}\nu_\tau q\bar{q}')$
- Apply BBN bounds [Jedamzik '08]

[1310.6352]



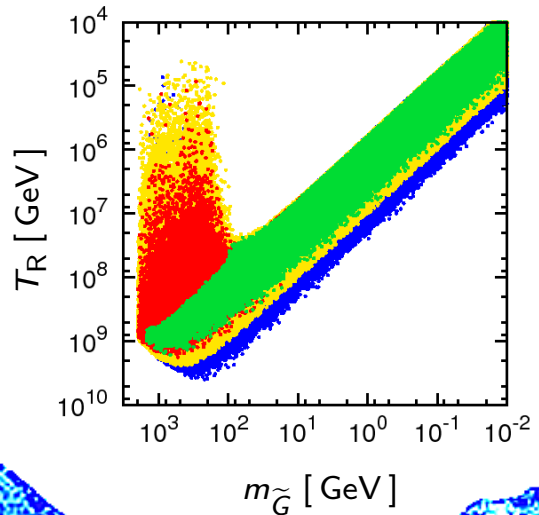
Implications for T_R

Points with $T_R > 10^9\,\text{GeV}$ point to very particular corner:

- Large gravitino masses: $300\,\text{GeV} < m_{\widetilde{G}} < (m_{\widetilde{\tau}_1} - 200\,\text{GeV})$
- Life-times: $10^4\,\text{sec} < \tau_{\widetilde{\tau}_1} < 10^7\,\text{sec}$
- Exceptionally small yields $Y \lesssim 10^{-14}$
- All in H/A resonant region (w EWino/stop or w/o co-ann.)
- Gaugino masses just above exclusion limits, in particular M_2 (running)
- Small stau-gaugino splittings, $m_{\widetilde{\tau}_1} > 800\,GeV$
- 1^{st} and 2^{nd} generation sfermions arbitrary heavy

Conclusions

- SUSY+Leptogenesis $\rightarrow$ Gravitino Problem
- Gravitino-stau scenario: high LHC sensitivity
- Performed bottom-up approach (no high scale model)
- Points with $T_R > 10^9$ GeV are allowed
- Point to very particular corner in parameter space with interesting LHC pheno – testable @ LHC 13/14
- Thermal Leptogenesis:



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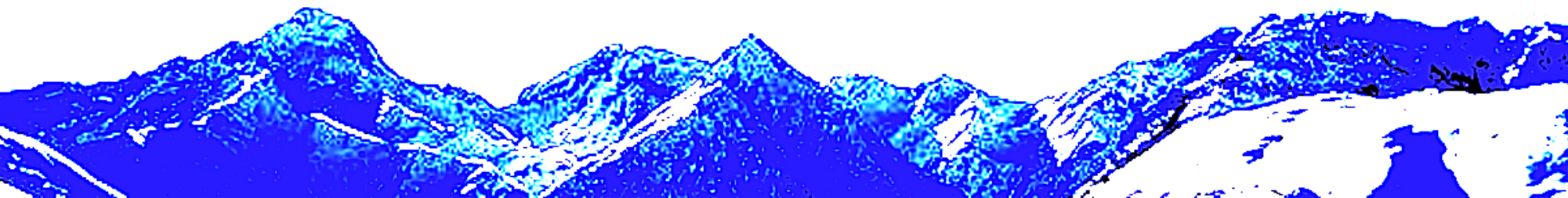


Backup – Prospects for LHC 14

Important channels for points with $T_R > 10^9$ GeV:

- EWino & gluino production
- Resonant production of staus

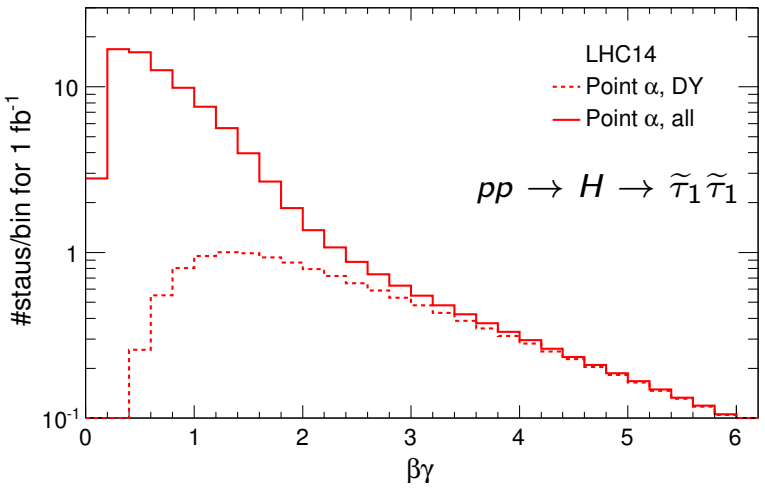
  $\rightarrow$ Extremely slowly moving HSCPs

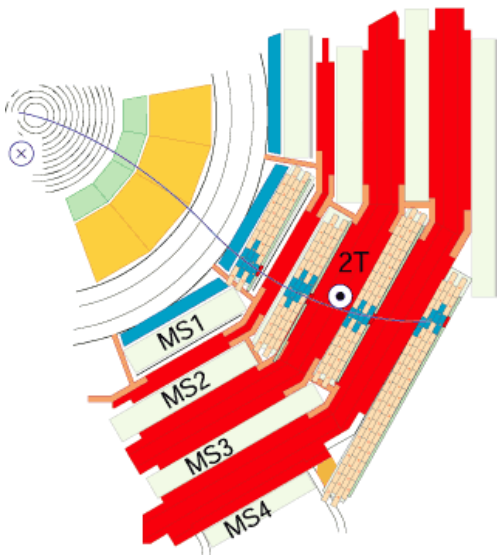
  - Challenging for trigger

    [Kersten, JH; '12]

  - Many stopped staus

[Lindert, Steffen, Trenkel; '11]





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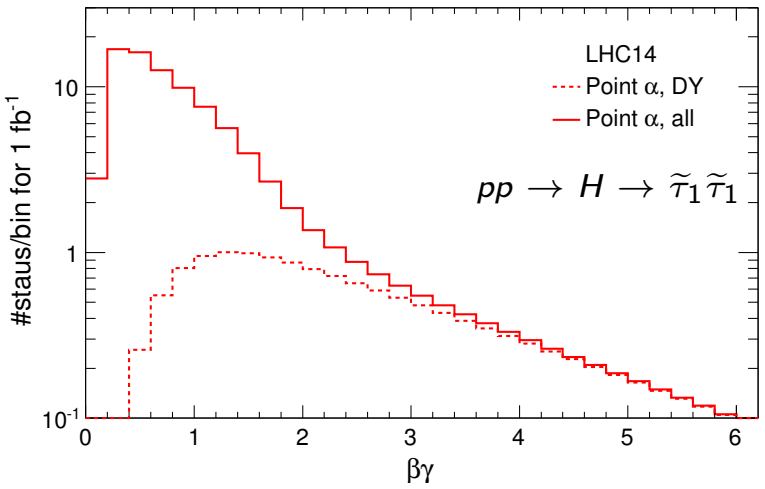
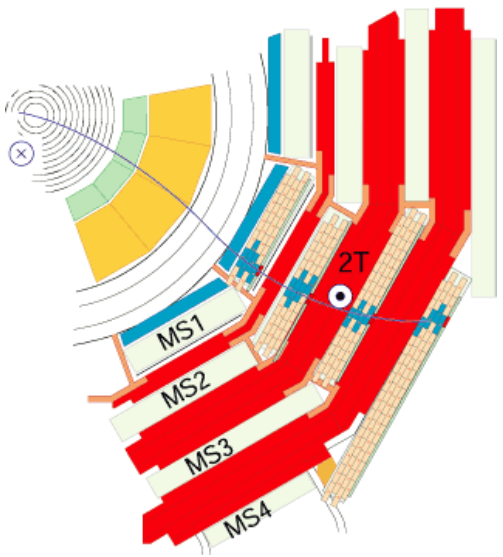


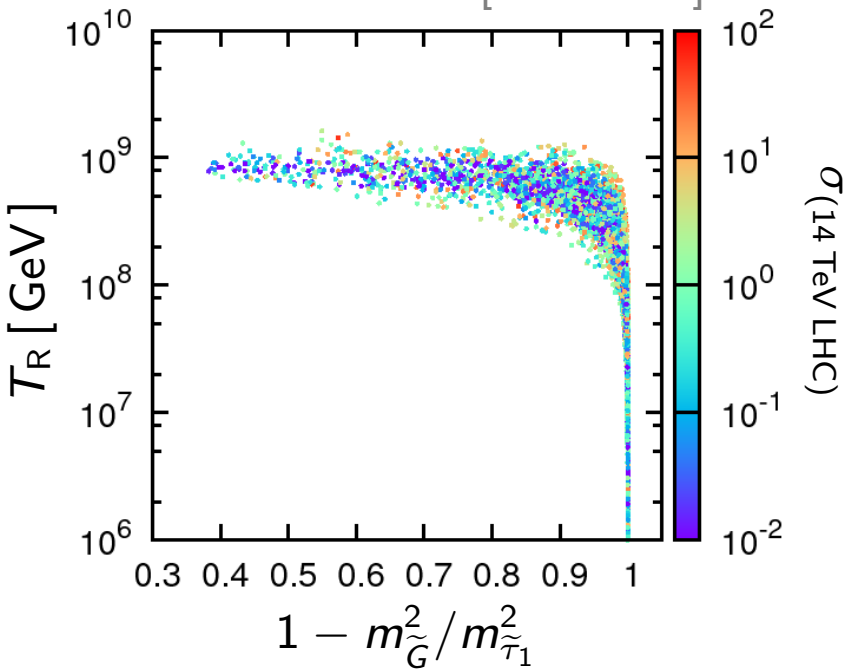


Backup – Prospects for LHC 14: Stopped Staus

Determination of $m_{\widetilde{G}}$ from $\widetilde{\tau}_1 \to \widetilde{G}\tau$ in detector

$$E_\tau \simeq \frac{m_{\widetilde{\tau}_1}}{2}\left(1 - \frac{m^2_{\widetilde{G}}}{m^2_{\widetilde{\tau}_1}}\right)$$

[1310.6352]



$m_{\widetilde{\tau}_1}, m_{\widetilde{G}}, \tau_{\widetilde{\tau}_1} \to$ Probe Supergravity

[Feng, Rajaraman, Takayama '04; W. Buchmüller, Hamaguchi, M. Ratz, and T. Yanagida '04]