Constraining Long-Lived Sparticles Using Simplified Models

André Lessa
UFABC - Santo André

Program on Particle Physics
ICTP-SAIFR - October 29th, 2015

*Work done in collaboration with J. Heisig and L. Quertenmoint

Outline

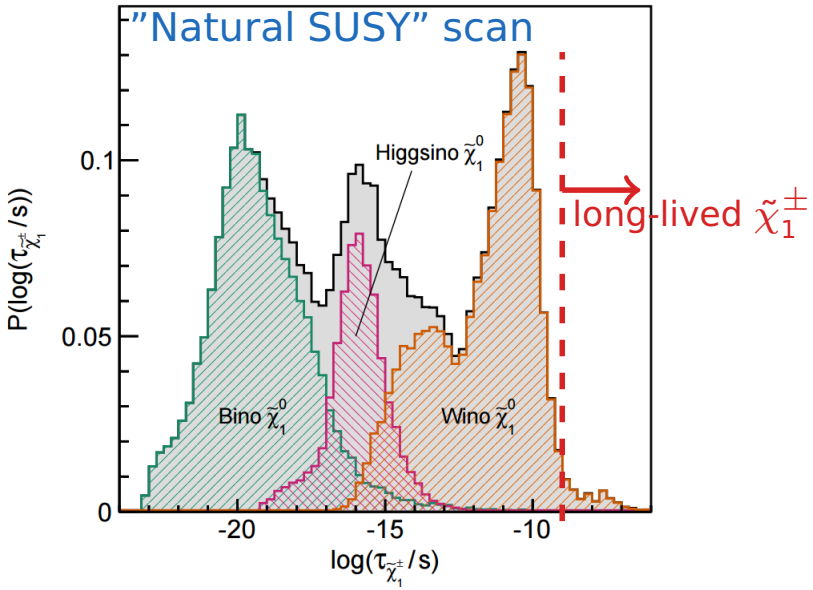
- Why long-lived charged sparticles?
  - Cosmological constraints and motivations
- Overview of experimental searches (CMS)
- Simplified models for HSCPs
- Application to the CMSSM
- Conclusions

Why Long-Lived Charged (S)Particles?

- In SUSY, heavy stable charged particles (HSCPs) typically appear when:

$$m_{NLSP} \simeq m_{LSP}$$

(degenerate spectra)



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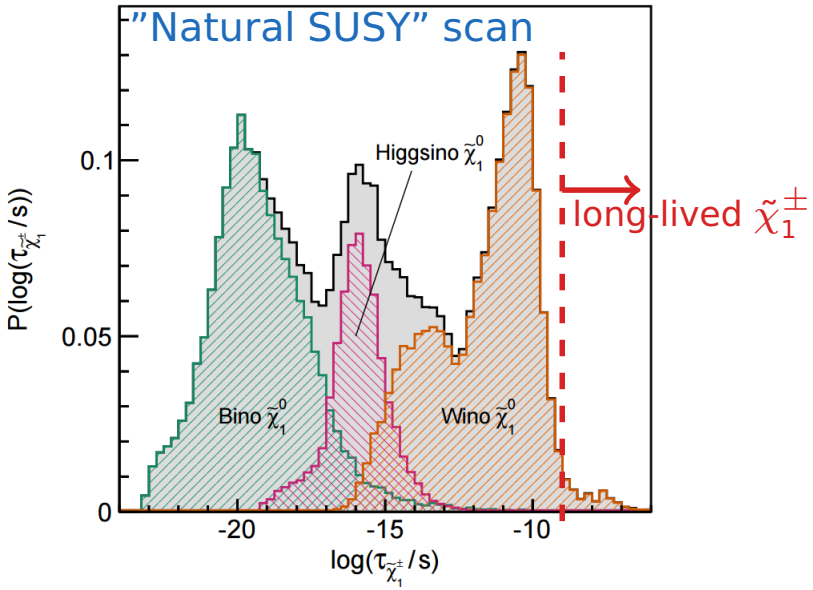

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Suppressed couplings

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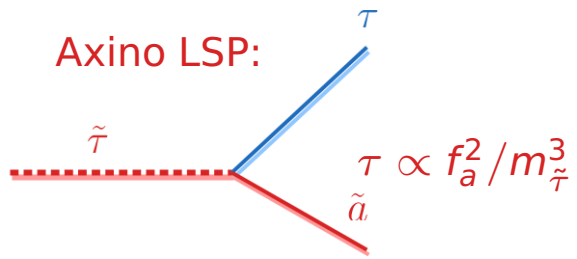
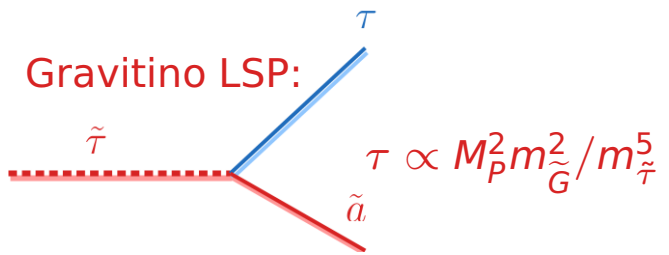


Gravitino LSP:



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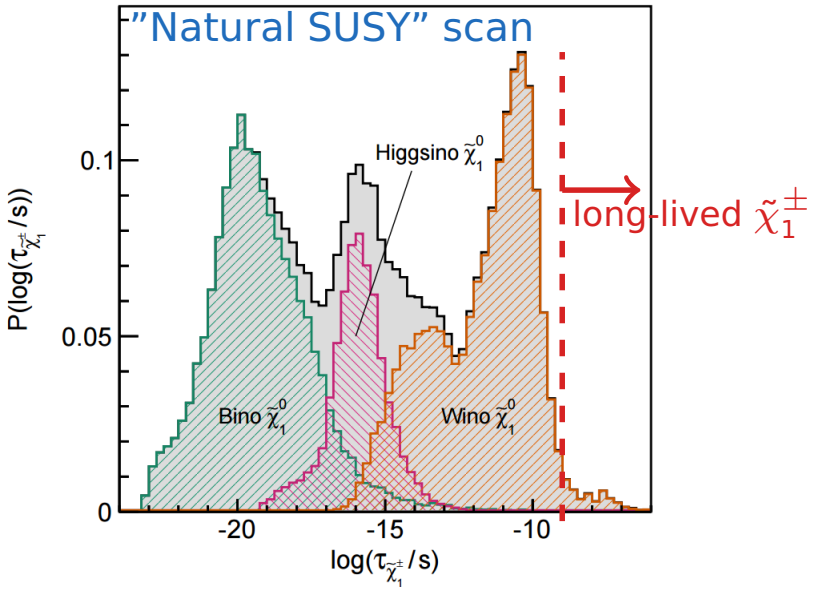

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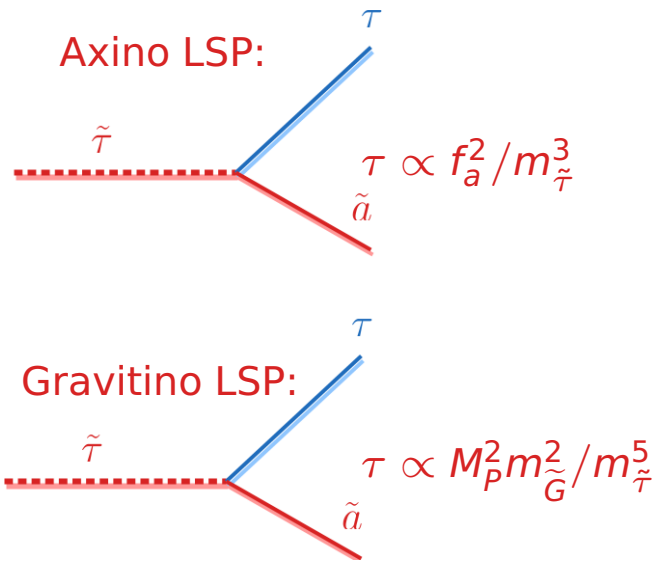

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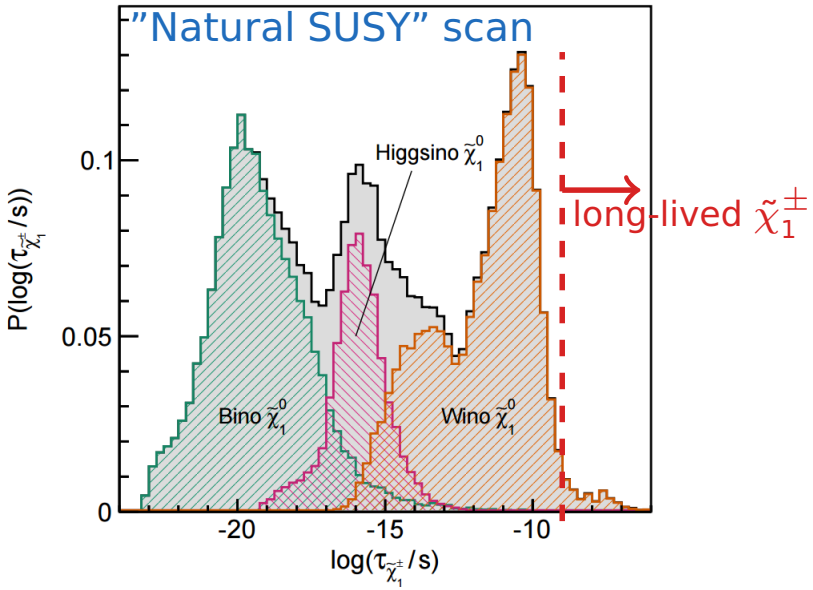

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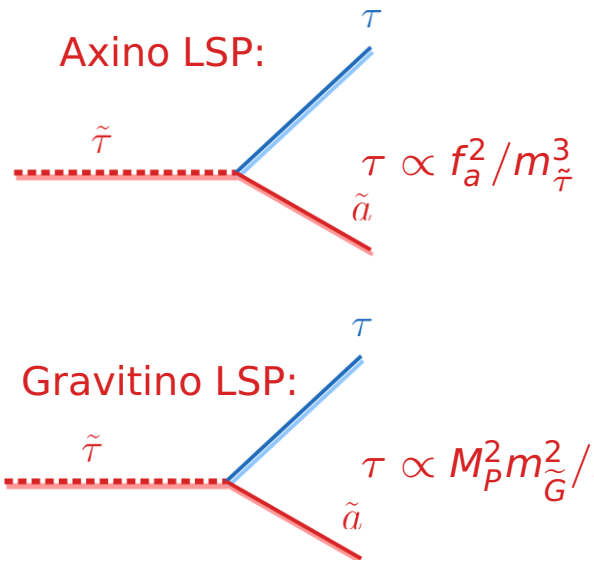
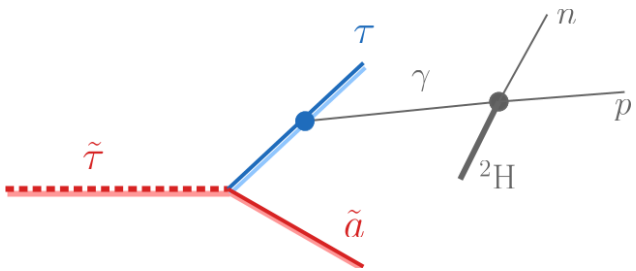


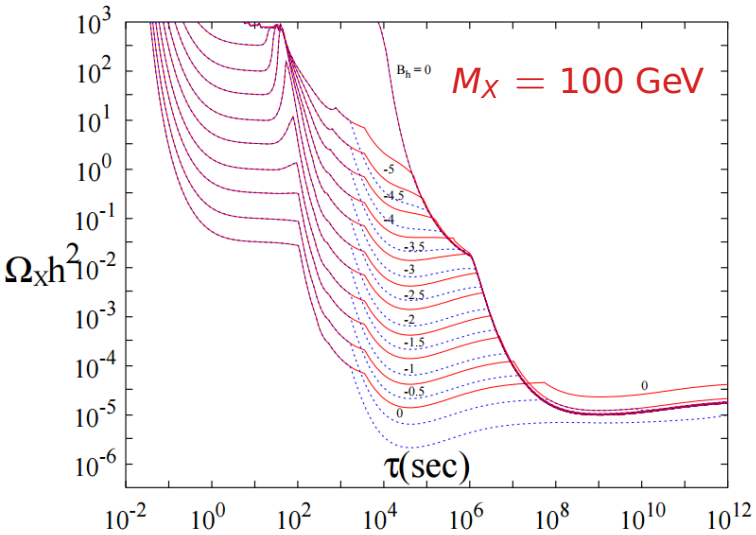
- *Most of these scenarios are DM-motivated*
- $\tau \gtrsim 1 - 10$ ns $\rightarrow$ long-lived

HSCPs and Cosmology: Big-Bang Nucleosynthesis

- BBN constraints:



(Depletion of light elements)



K. Jedamzik, Phys. Rev. D74, 103509, 2006

$\rightarrow \tau_{HSCP} < 0.01 - 1$ s

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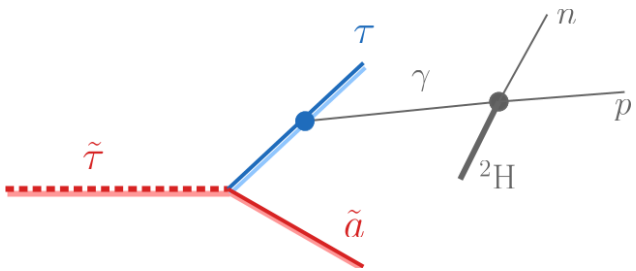

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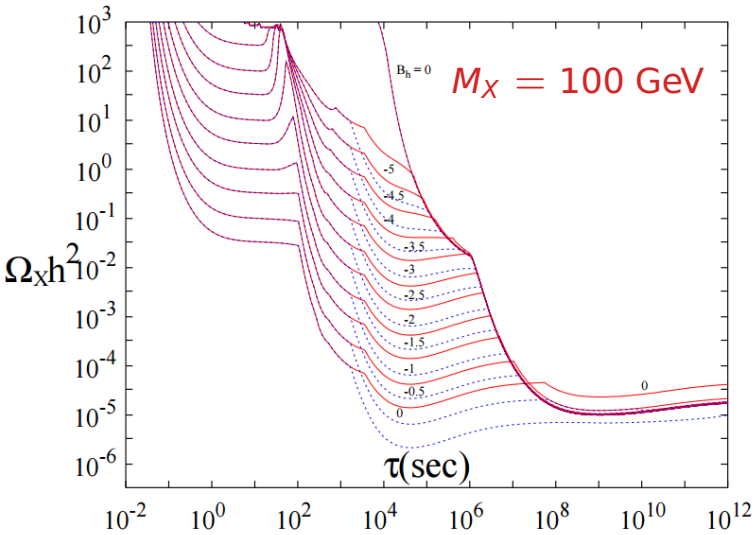

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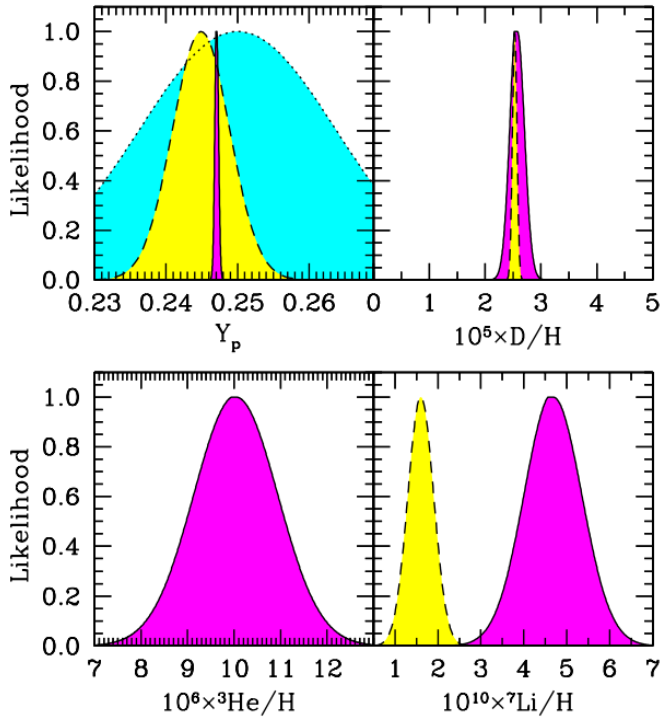
- SBBN predictions:



B. Cyburt, B. Fields, K. Olive and T.-H. Yeh , arXiv:1505.01076 (2015)

$$\left(\frac{^7\text{Li}}{\text{H}}\right)_{\text{theo}} = (4.68 \pm 0.67) \times 10^{-10}$$

$$\left(\frac{\text{Li}}{\text{H}}\right)_{\text{exp}} = (1.6 \pm 0.3) \times 10^{-10}$$

HSCPs and Cosmology: ^{7}Li Problem

How to deplete the primordial Lithium abundance?

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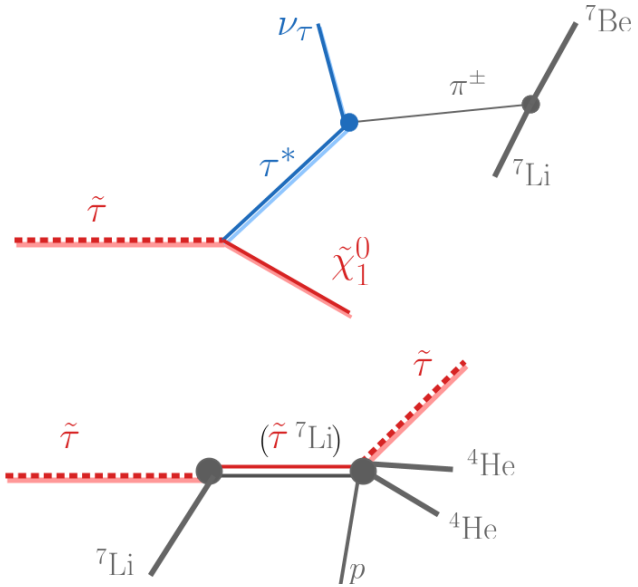
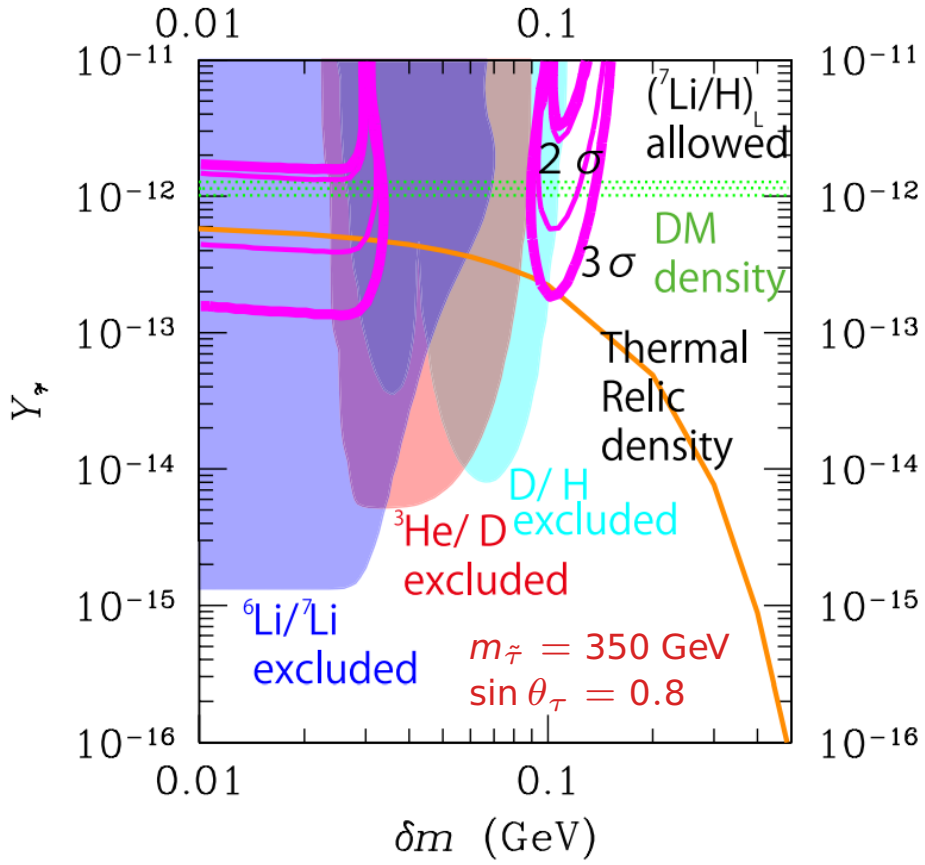
- ^{7}Li depletion with long-lived $\tilde{\tau}$:



- A solution is possible with:
  - $Y_{\tilde{\tau}} > 10^{-13}$
  - $\tau_{\tilde{\tau}} > 1 - 100s$



T. Jittoh et al., Phys.Rev. D84 035008 (2011)

LHC Searches for HSCPs

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- For $\tau > 10^{-8}$s $\rightarrow$ charged tracks
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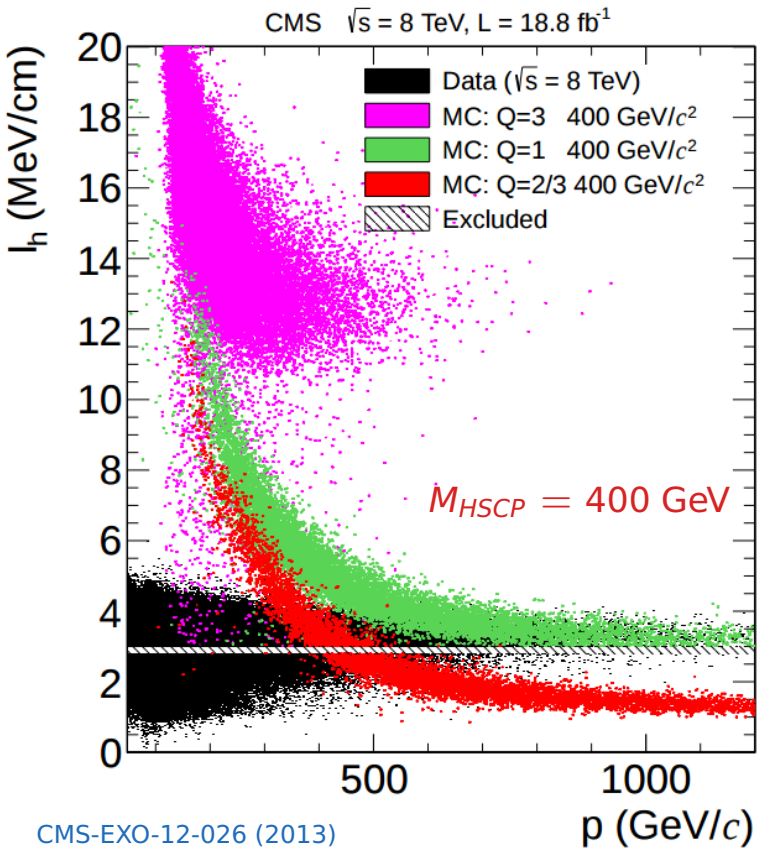

CMS-EXO-12-026 (2013)

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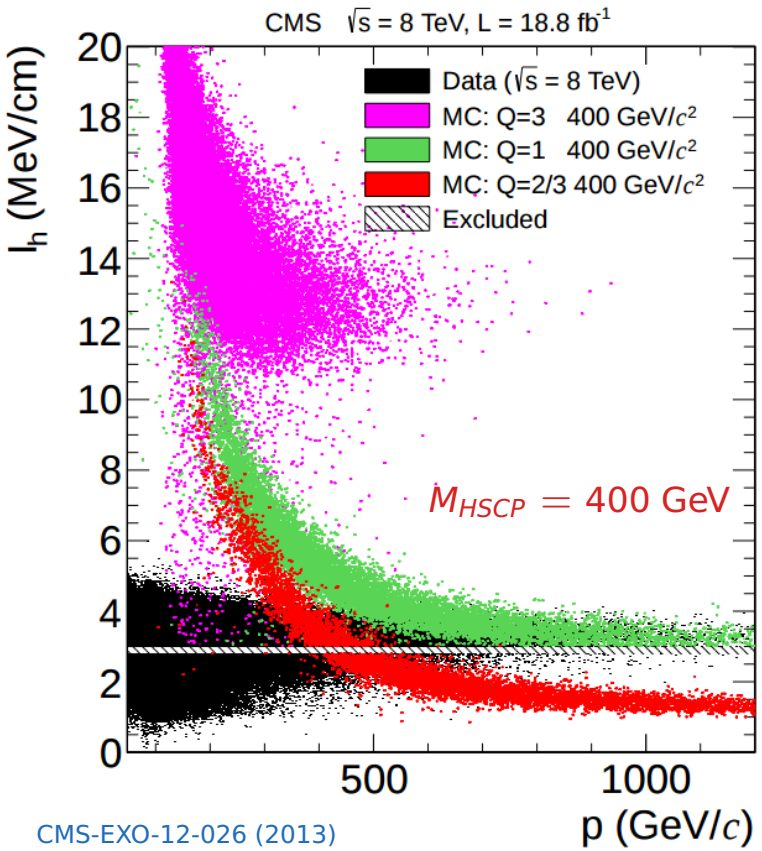


CMS-EXO-12-026 (2013)

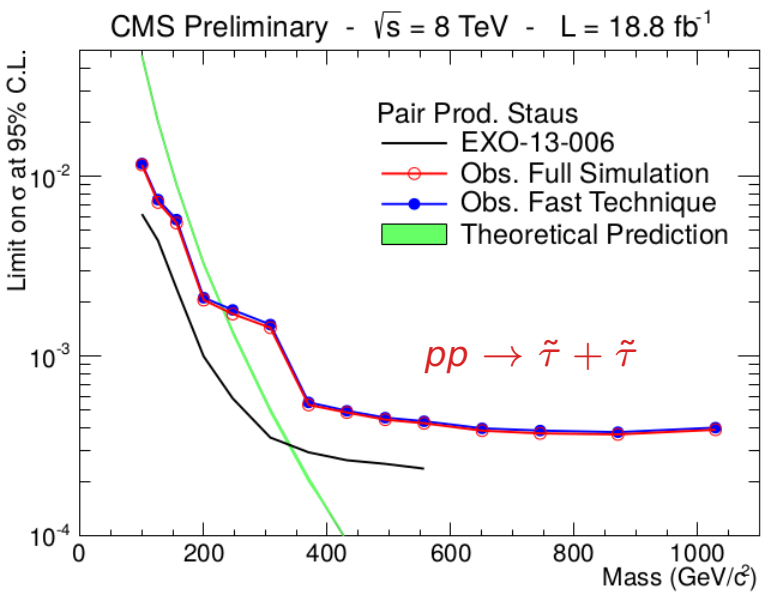
- Highly boosted (with $Q = 1$) $\rightarrow$ fake μ
- CMS Event selection:
  - Charged track
  - $|\eta| < 2.1$, $p_T > 45$ GeV
  - Energy deposit ($I_h > 3$ MeV)
  - Isolation (in $\Delta R < 0.3$):

    Charged particles: $\left(\sum p_T\right) < 50$GeV

    Visible particles: $\left(\sum \frac{E}{|\vec{p}|}\right) < 0.3$
- *Partial efficiencies are provided as a function of p_{HSCP}*

CMS Search for HSCPs

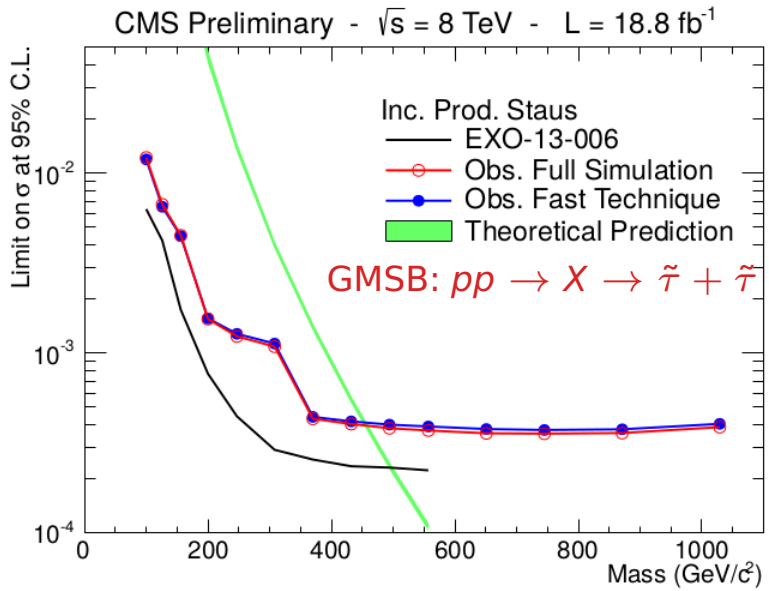
- CMS results (EXO-13-006):



Exclusive production:

$m_{\tilde{\tau}} > 300$ GeV

$\sim$ Model independent



Inclusive production:

$m_{\tilde{\tau}} > 450$ GeV

Model dependent

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  - HSCP mass and lifetime
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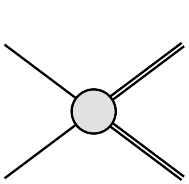
  $\rightarrow$ Simplified Models

Simplified Models for HSCPs

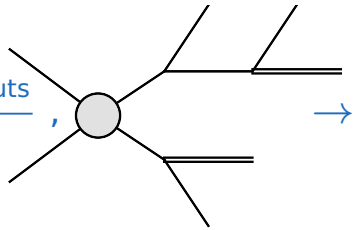
- Basic idea:

1. Compute efficiencies for classes of simplified models (SMS)

   $\rightarrow$ efficiencies database



$\rightarrow \epsilon_1(m_{\text{HSCP}}) = \frac{\sigma^{\text{after cuts}}}{\sigma^{\text{total}}}$,



$\rightarrow \epsilon_2\,(m_{\text{prod}}, m_{\text{int}}, m_{\text{HSCP}})\ldots$

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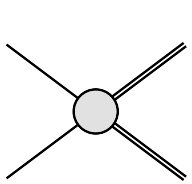

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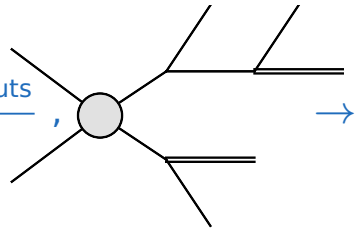

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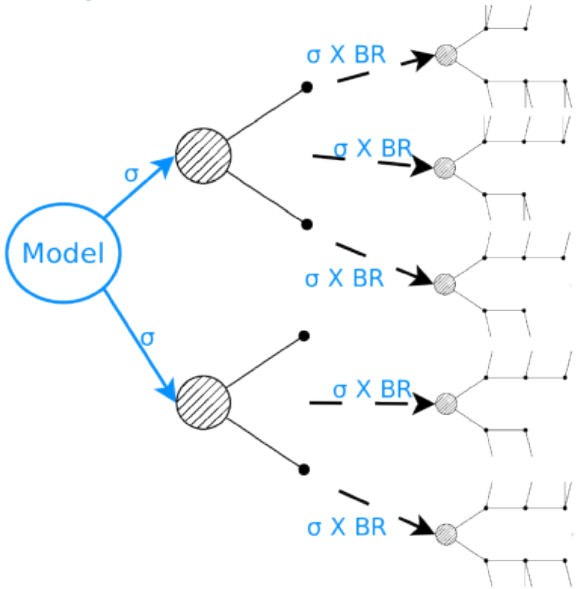
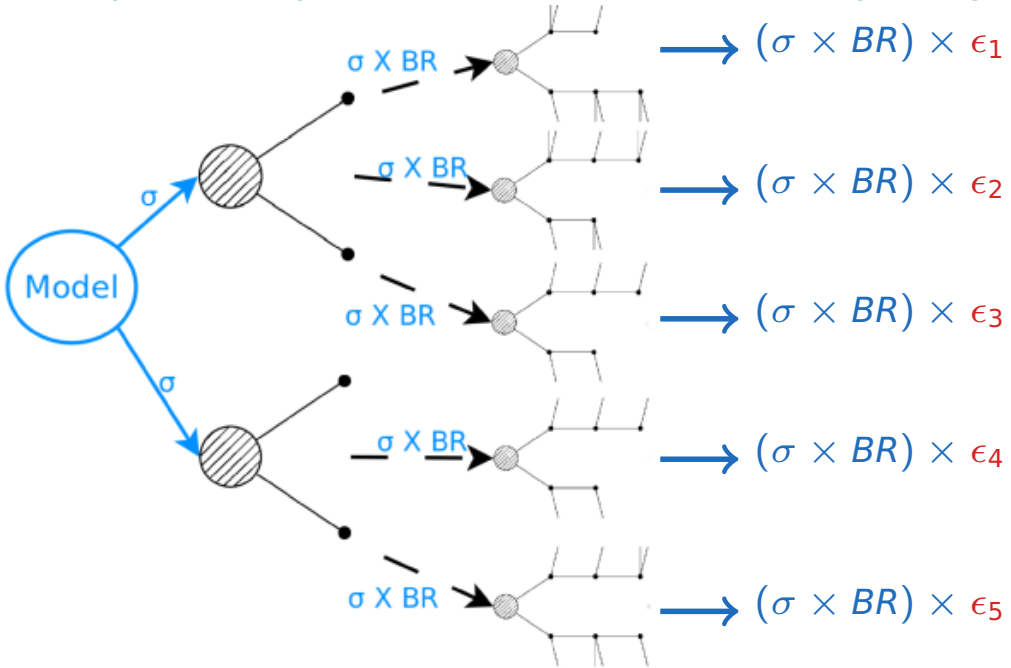
2. Decompose the full model in a coherent sum of SMS



Simplified Models for HSCPs

- Basic idea:

  3. Use the pre-computed efficiencies to compute your full model signal



$$\longrightarrow (\sigma \times BR) \times \epsilon_1$$

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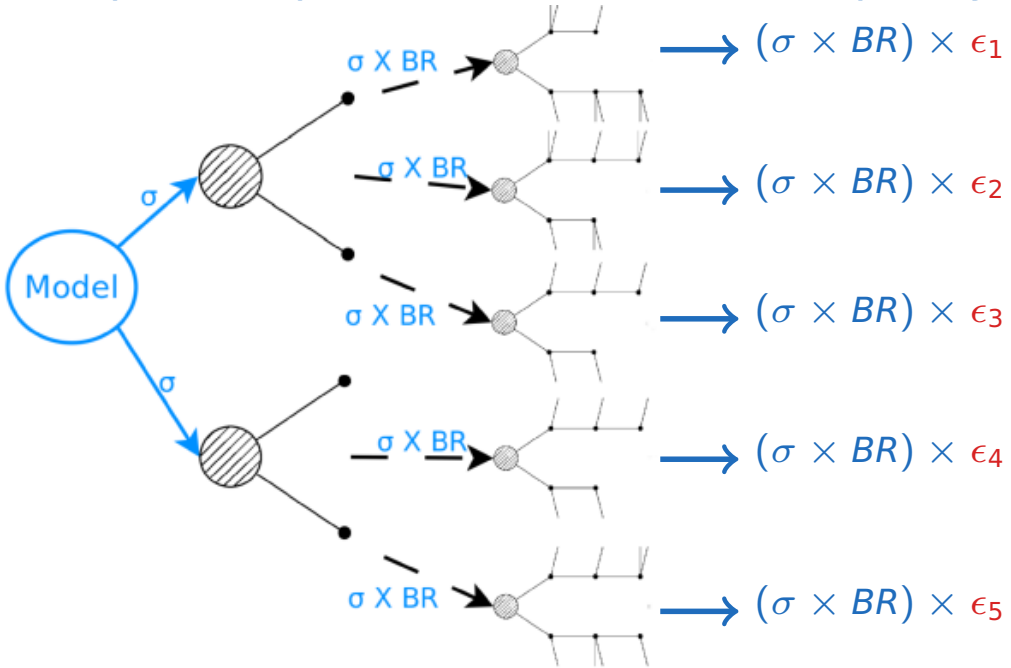

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$\longrightarrow (\sigma \times BR) \times \epsilon_5$

4. Compare to the experimental UL:

$\sigma_{eff} > \sigma_{UL} \rightarrow$ the model is excluded

Simplified Models for HSCPs

- Basic idea:
  1. Compute efficiencies for classes of simplified models (SMS)
  2. Decompose the full model in a coherent sum of SMS
  3. Use the pre-computed efficiencies to compute your full model signal
  4. Compare to the experimental UL

- Pros:
  - Can be applied to any model
  - No MC simulation needed
  - Very fast
  - Decomposition tools available:

    SModelS

- Cons:
  - Neglects specific model dynamics:
    $\epsilon \simeq \epsilon(masses, topology)$
  - Limited by the simplified models used to compute ϵ
  - Decomposition can be slow in special cases

Simplified Models for HSCPs

Computing efficiencies...

(MadGraph + Pythia + CMS probabilities)

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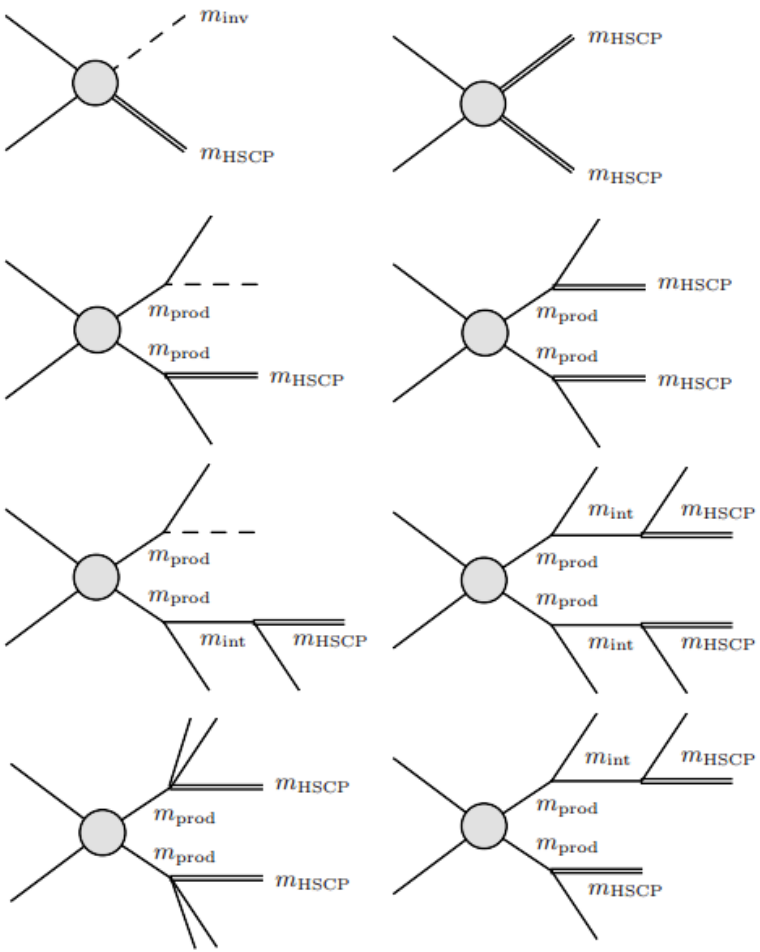
- Simplified Models:



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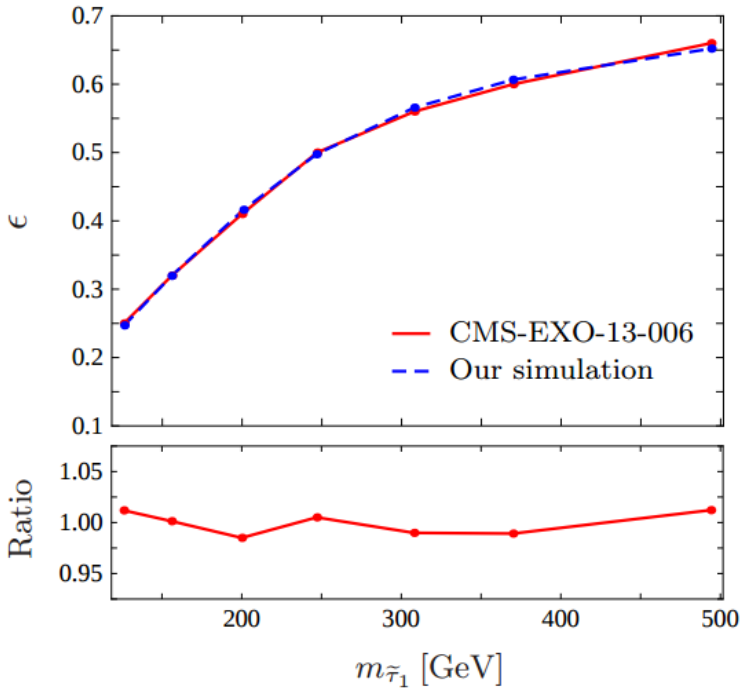
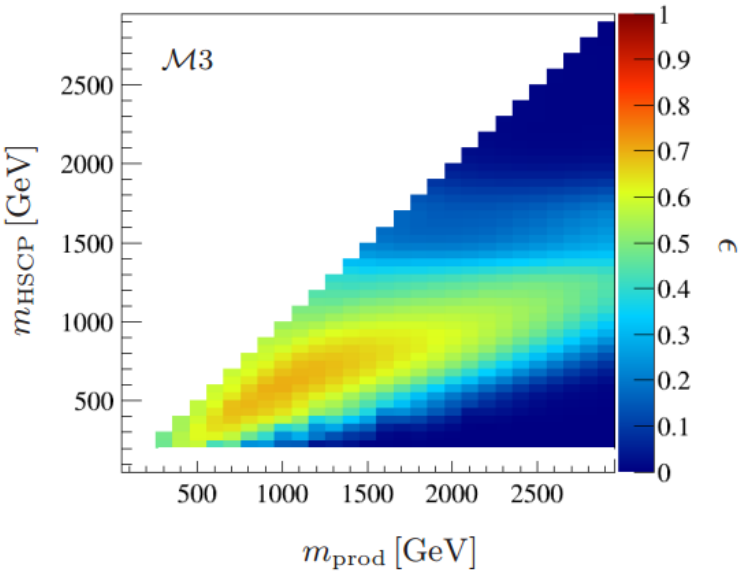
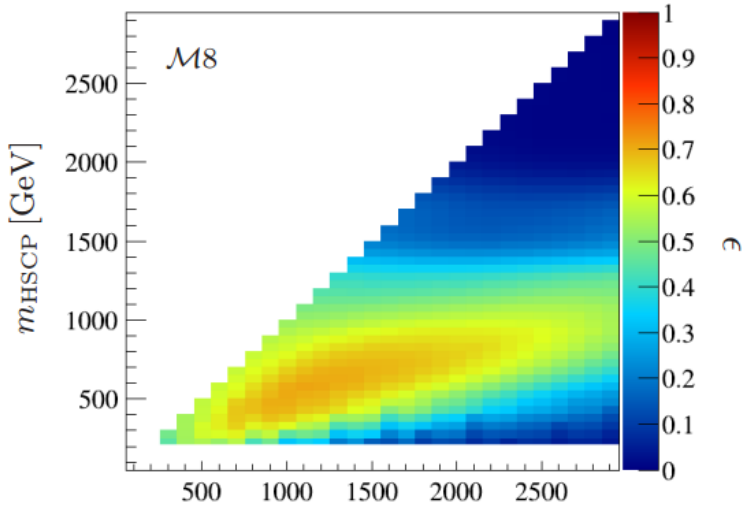
- Validation:



agreement within $\lesssim 5\%$

- Results for ϵ:





CMSSM with long-lived $\tilde{\tau}$s

- Application to the CMSSM

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- Application to the CMSSM+ Solution to the Lithium-7 Problem:
  - Neutralino LSP, stau NLSP
  - $Y_{\tilde{\tau}} > 10^{-13}$
  - $\tau_{\tilde{\tau}} > 1s\ (m_{\tilde{\tau}} - m_{N1} < m_{\tau})$
  - $\tan\beta = 10$

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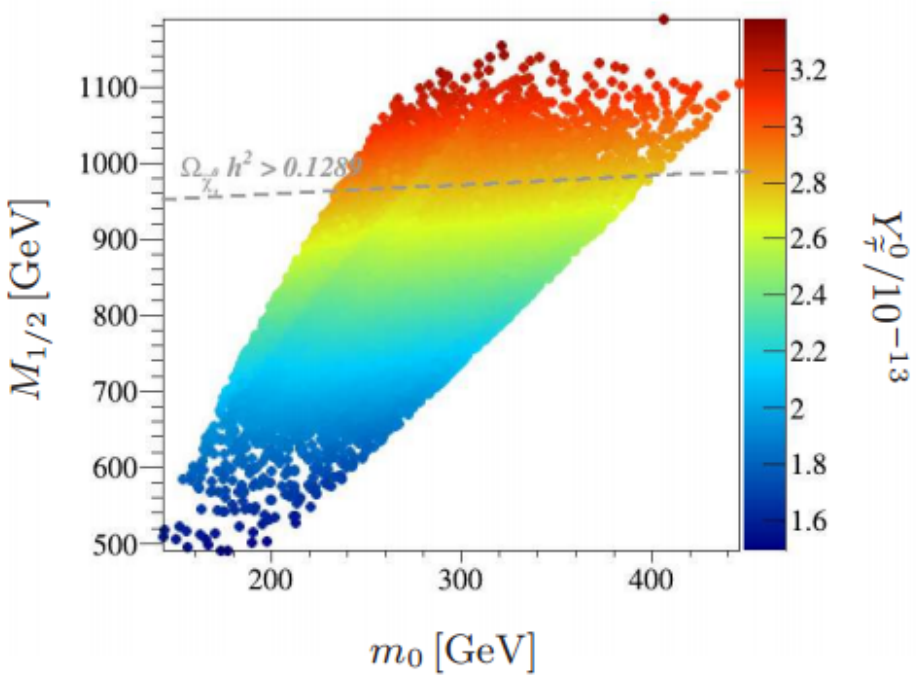
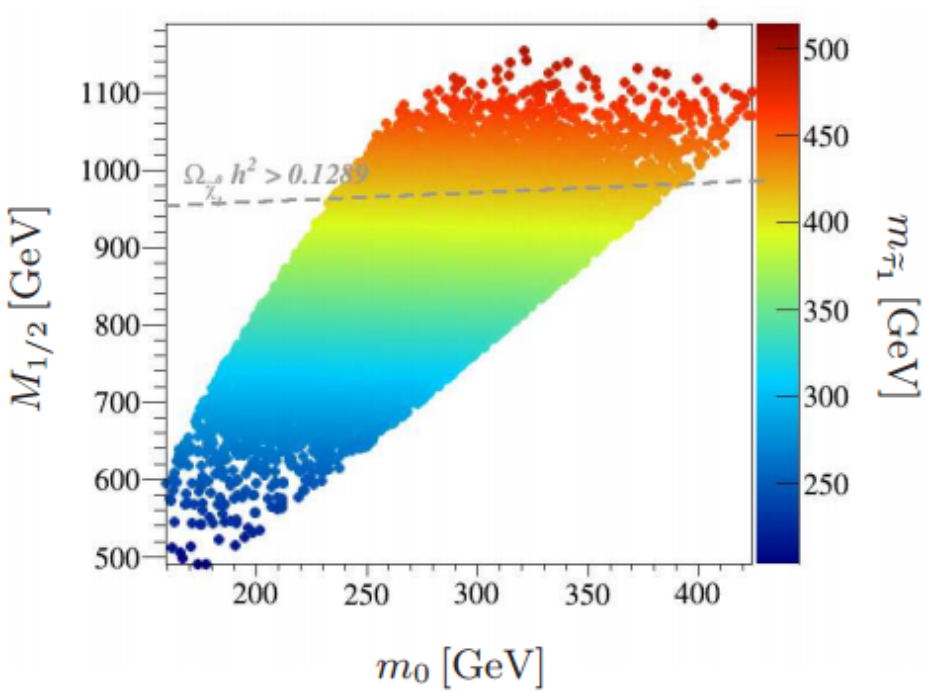
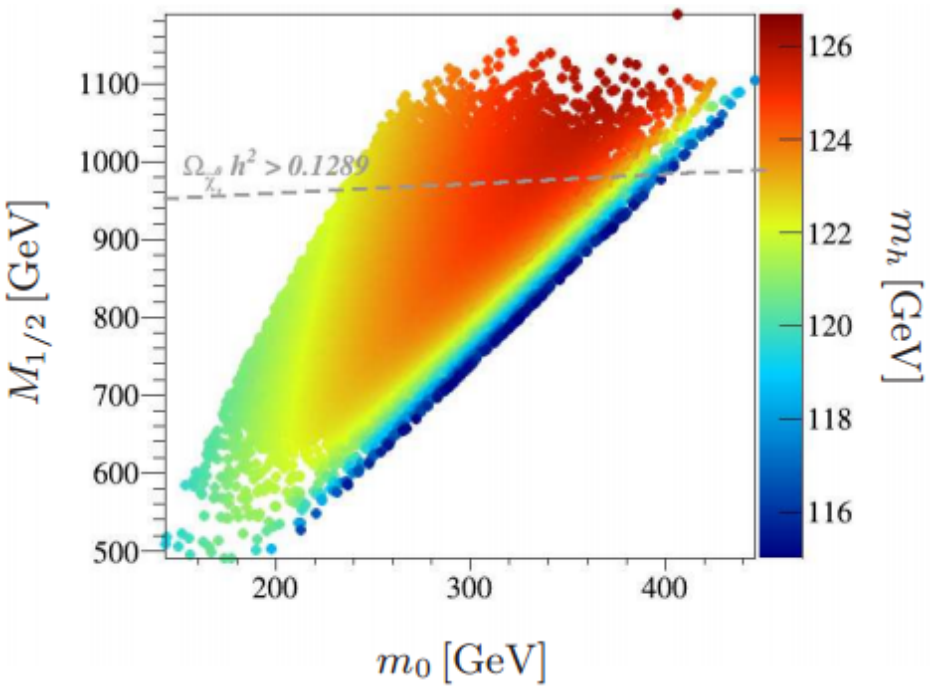
- Scan over m_0, $M_{1/2}$, A_0 $(\mu > 0)$:

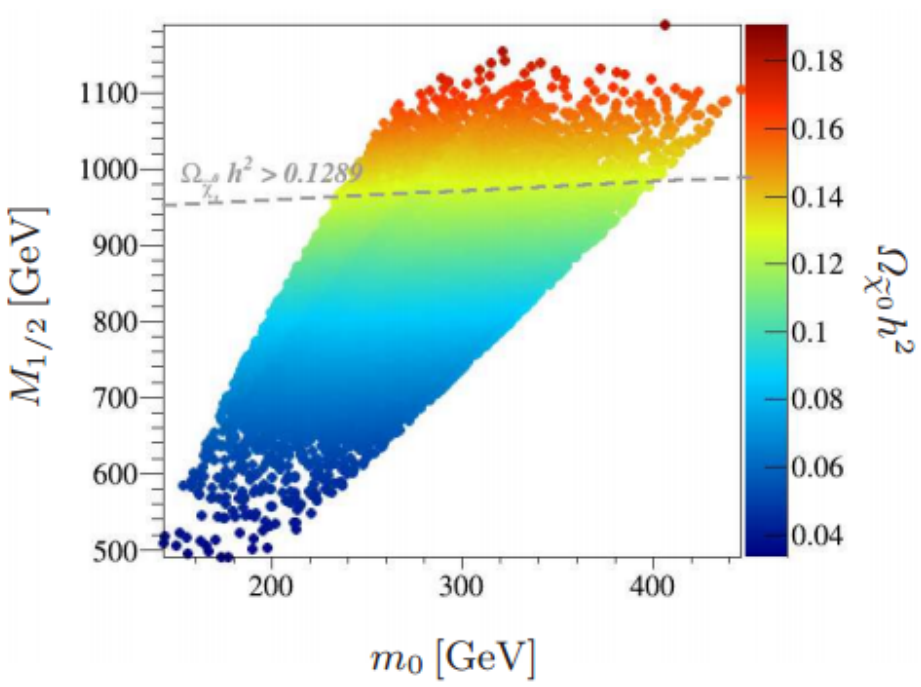




CMSSM with long-lived $\tilde{\tau}$s

- Higgs and Dark Matter constraints:





- We require:
  - $120 \text{ GeV} < m_h < 130 \text{ GeV}$

CMSSM with long-lived $\tilde{\tau}$s: LHC Constraints

- LHC Constraints:
  - MET signatures: $\tilde{q} + \tilde{q} \to qq + \tilde{\chi}_1^0 + \tilde{\chi}_1^0 \sim 70\%$
  - HSCP signatures: $\tilde{\chi}_1^\pm + \tilde{\chi}_1^\pm \to \nu_\tau + \tilde{\tau}_1^\pm + \nu_\tau + \tilde{\tau}_1^\pm \sim 10\%$
  - Mixed signatures: $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \to \nu_\tau + \tilde{\tau}_1^\pm + Z + \tilde{\chi}_1^0 \sim 20\%$

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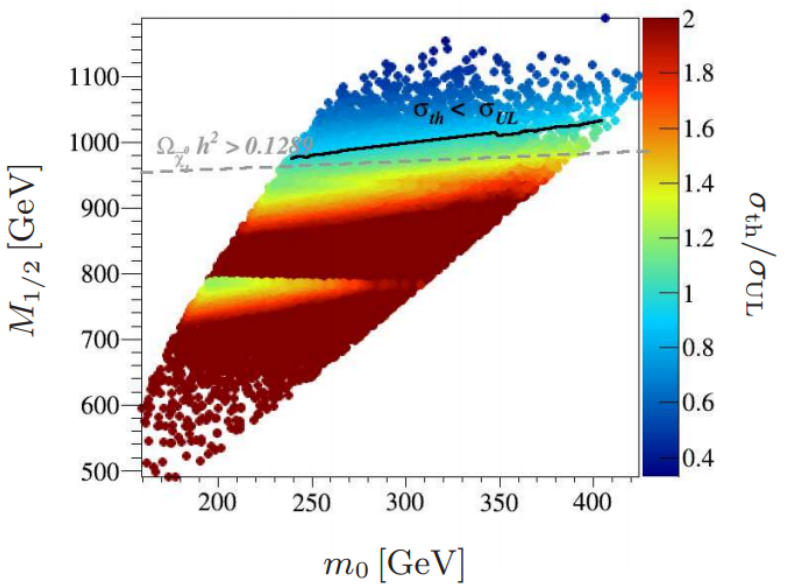

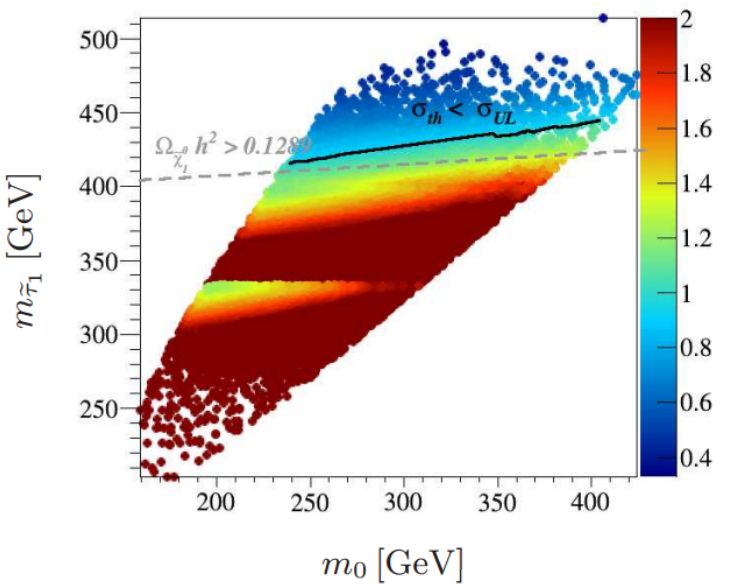

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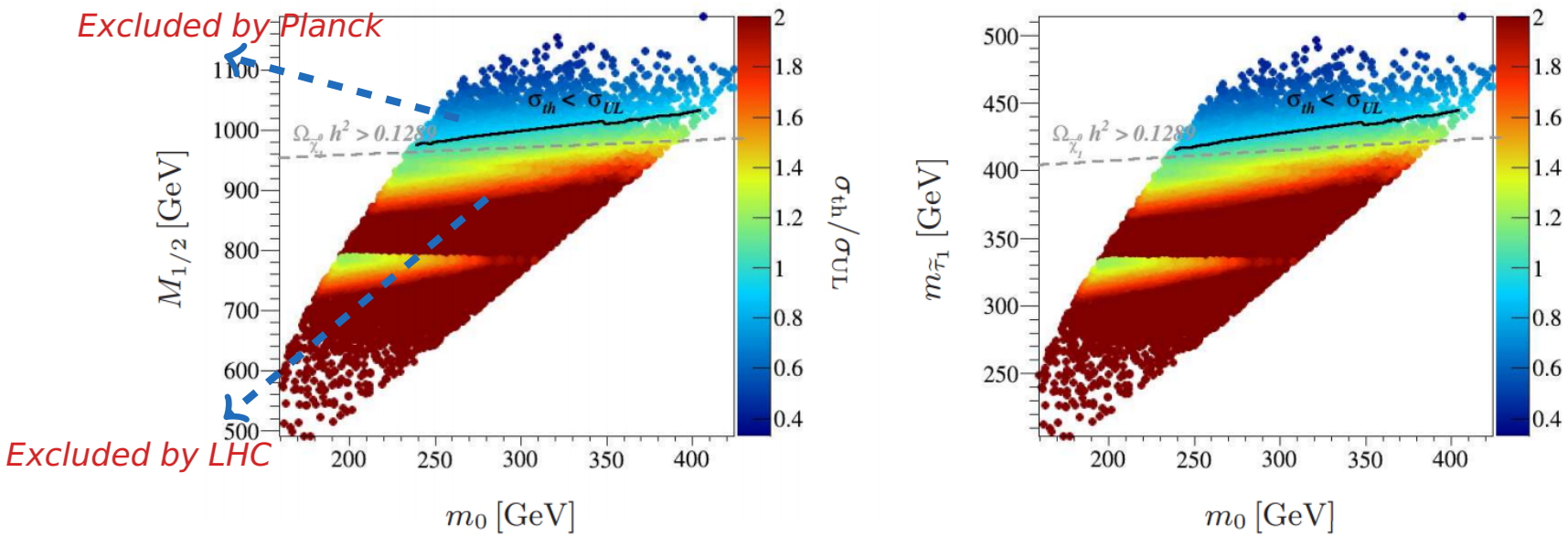
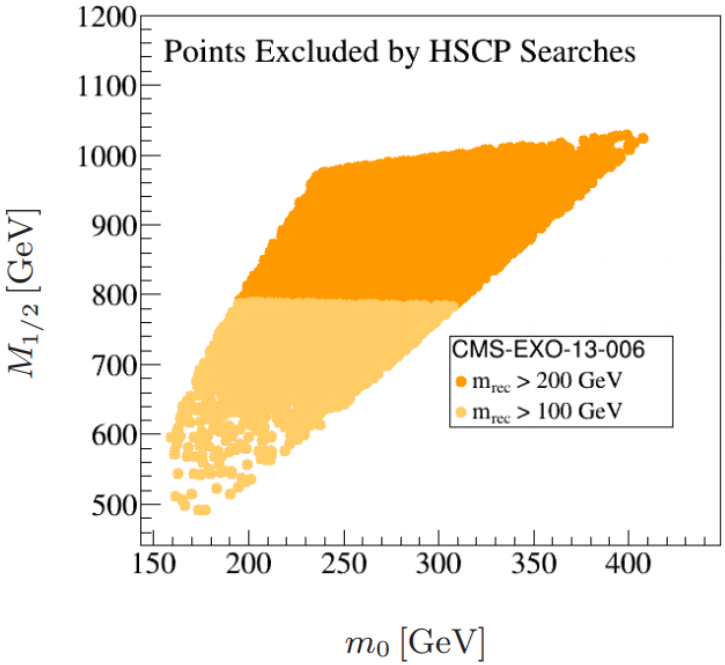
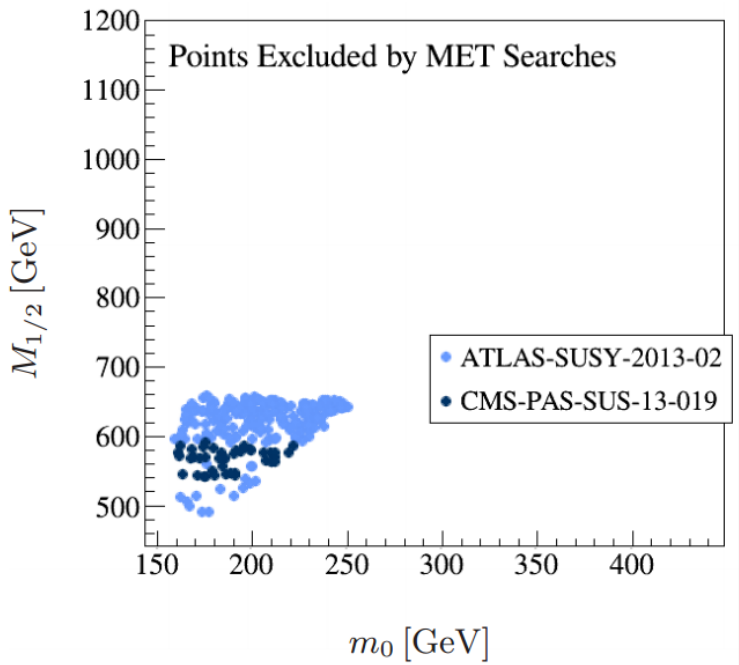
  - MET signatures: $\tilde{q} + \tilde{q} \to qq + \tilde{\chi}_1^0 + \tilde{\chi}_1^0 \sim 70\%$
  - HSCP signatures: $\tilde{\chi}_1^\pm + \tilde{\chi}_1^\pm \to \nu_\tau + \tilde{\tau}_1^\pm + \nu_\tau + \tilde{\tau}_1^\pm \sim 10\%$
  - Mixed signatures: $\tilde{\chi}_1^\pm + \tilde{\chi}_2^0 \to \nu_\tau + \tilde{\tau}_1^\pm + Z + \tilde{\chi}_1^0 \sim 20\%$
- For HSCP and mixed $\to$ use efficiencies database
- For MET $\to$ apply UL to single SMS (SModelS)
- Results:



CMSSM with long-lived $\tilde{\tau}$s: LHC Constraints

- Results: MET vs HSCP

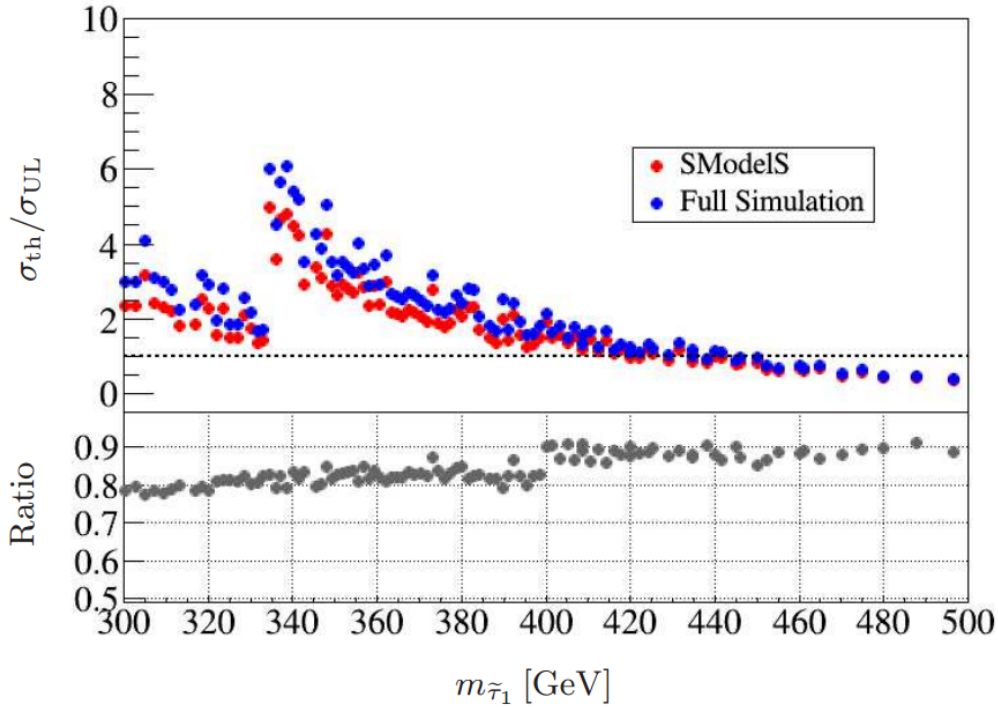




- HSCP constraints dominate
  (even though the HSCP signal is only $\sim 30\%$)
- MET constraints are smaller than in the usual CMSSM
  (MET signal $\sim 70\%$)

CMSSM with long-lived $\tilde{\tau}$s: LHC Constraints

- How does SMS + efficiencies compare with the full sim?



$\rightarrow$ Signal coverage $\sim$ 90%

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Thanks!