Simplfied Models for Exotic BSM Searches

[based on arXiv:1509.00473 (accepted by JHEP); JH, Andre Lessa, Loic Quertenmont]

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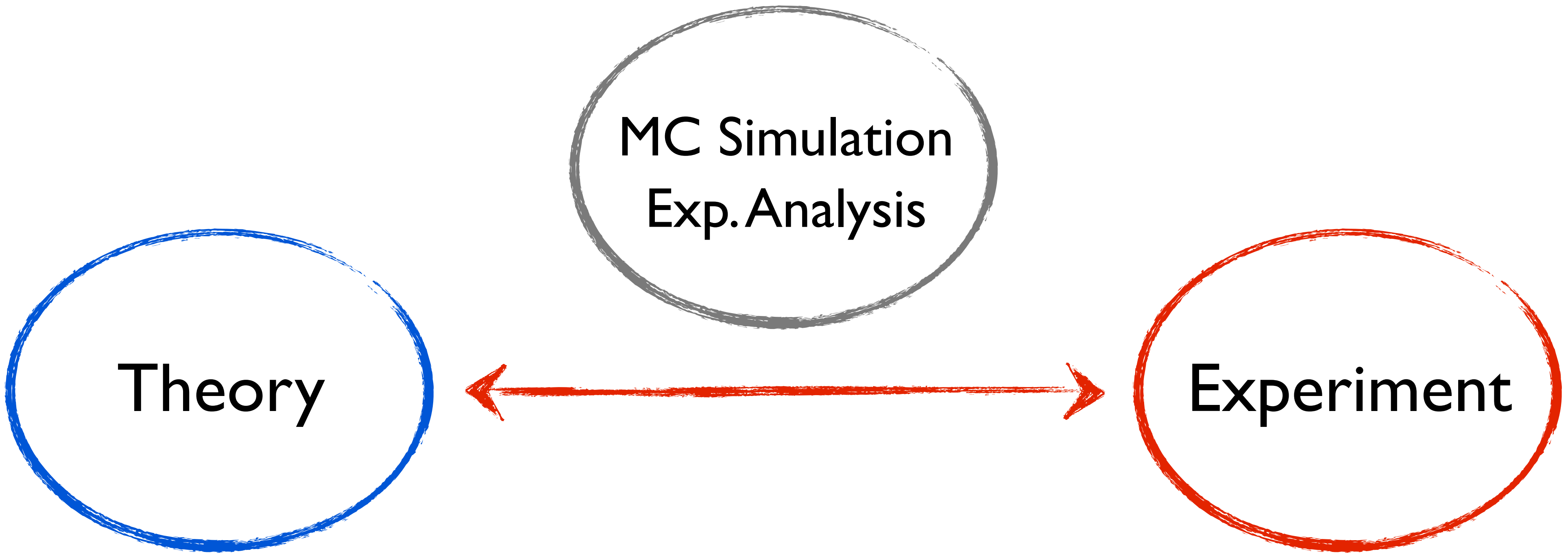
PHYSICS AT THE TERA SCALE Helmholtz Alliance

9th Annual Meeting of the Helmholtz Alliance "Physics at the Terascale"
DESY, Hamburg, November 17th 2015

Why Simplified Models?



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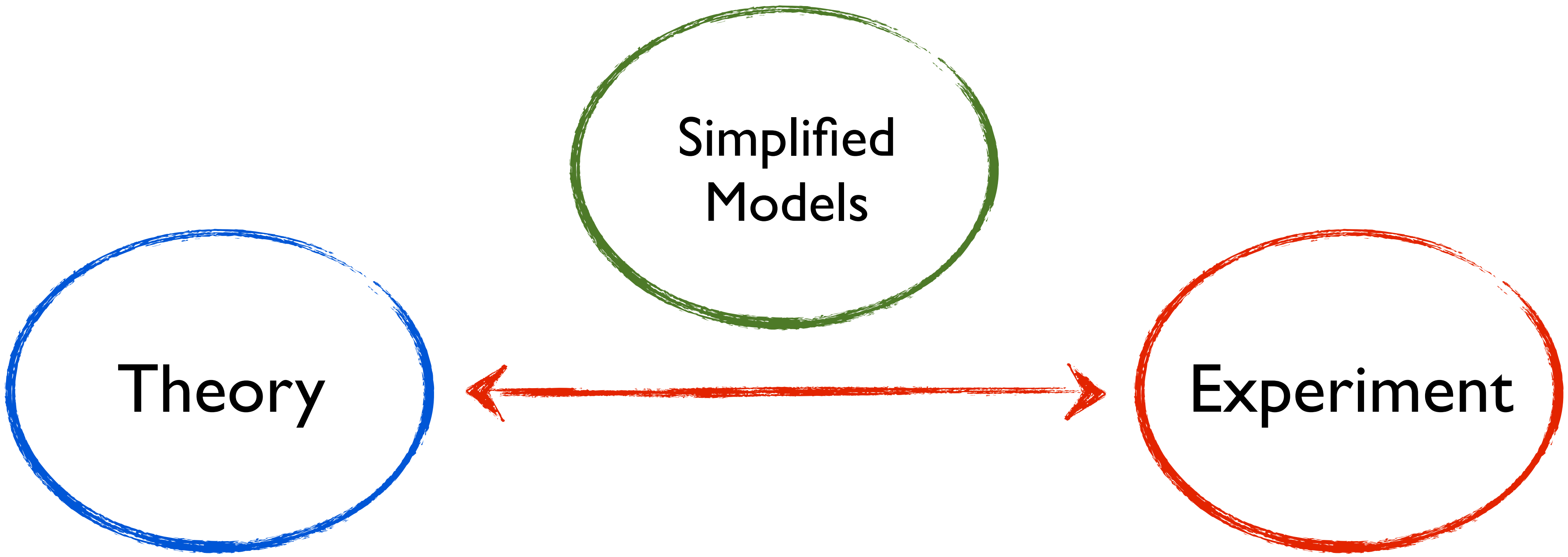

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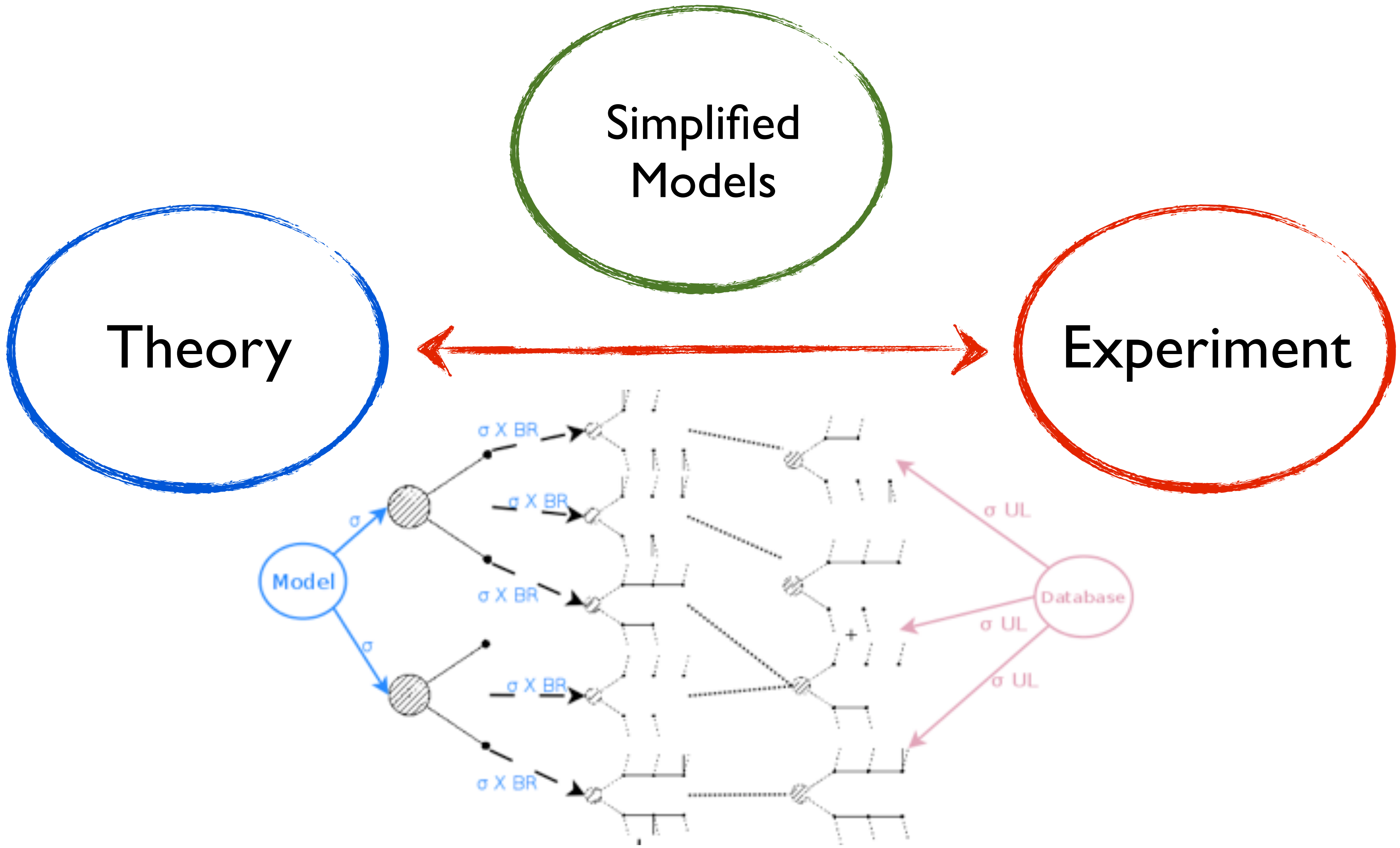

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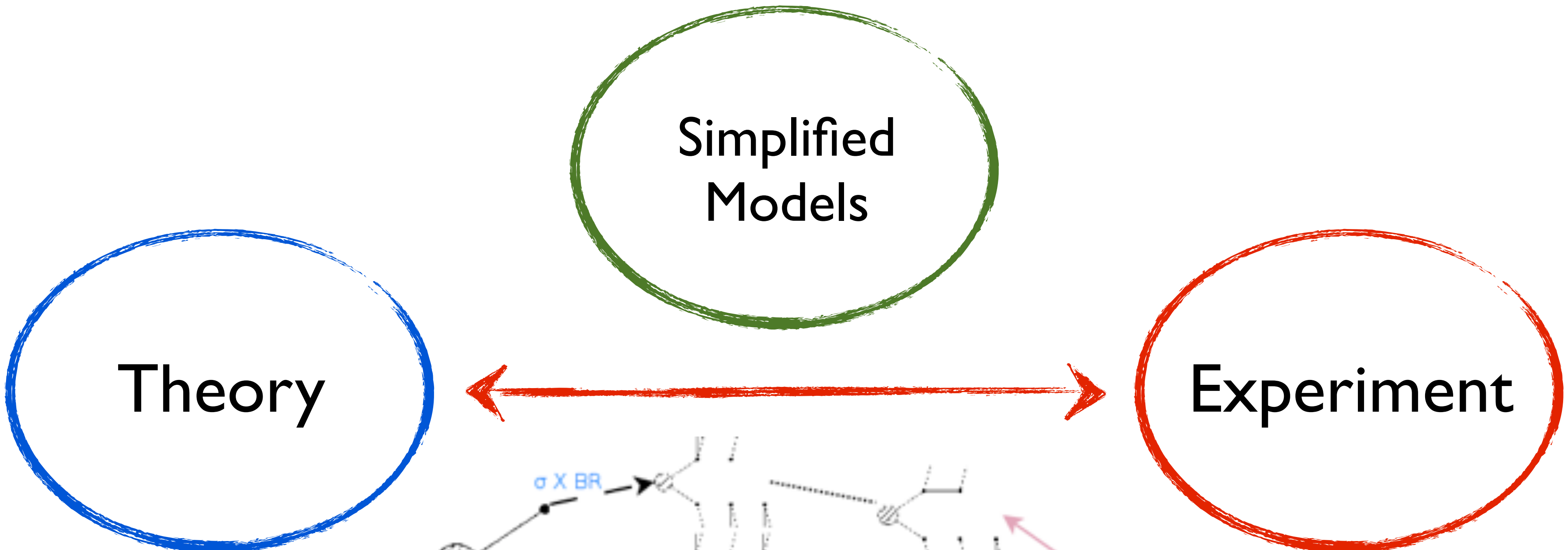

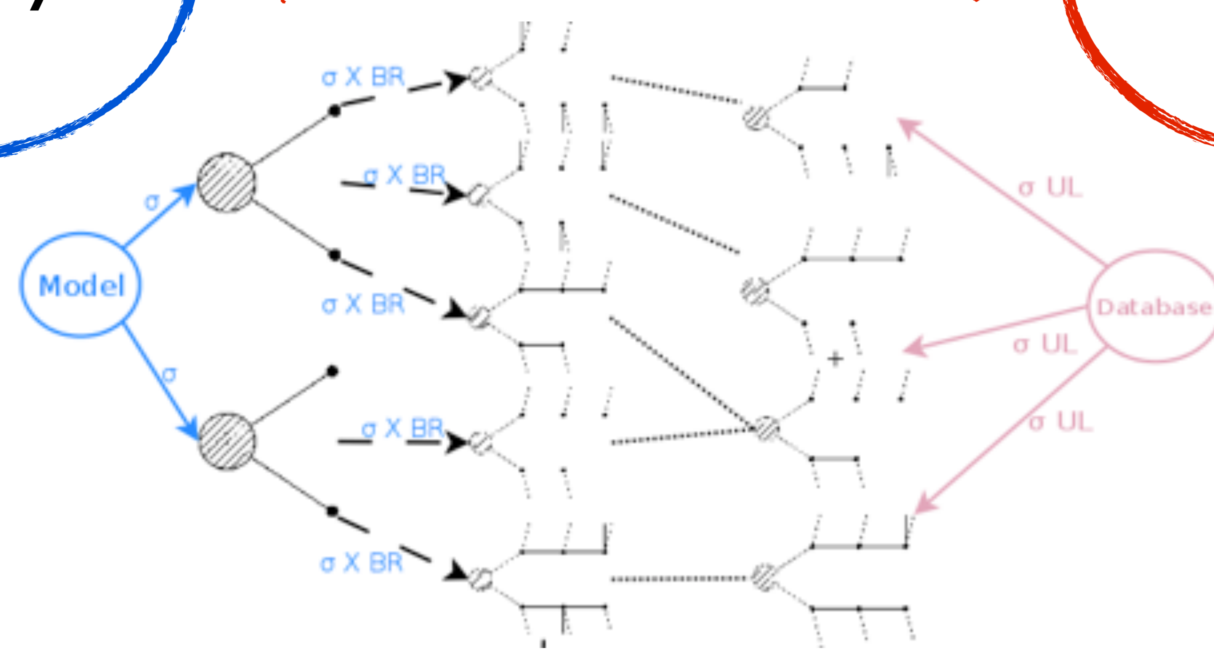

Pros:

- Applicable to any BSM model
- No MC simu → Fast!
- Tools avaibale

Cons:

- Limited by database
- Uses approximations (only masses, topologies)
  [see e.g. Edelhäuser et al. 1410.0965, 1501.03942]

[SModelS: Kraml, Kulkarni, Laa, Lessa, Magerl, Proschofsky, Waltenberger, 1312.4175]
[Fastlim: Papucci, Sakurai, Weiler, and Zeune, 1402.0492]

Simplified Models

- So far: Missing Transverse Energy (MET) searches only
- But: more exotic signatures can be important!

  → Heavy Stable charged particles (HSCP)

This work:

Implement HSCP searches into SModelS

Outline: Motivation > Implementation > Application

Motivation

Why Heavy stable charged particles (HSCP)?

- DM motivated BSM: Lightest Z_2-odd particle stable+neutral
- Heavier Z_2-odd particles can be charged...

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I. Suppressed coupling of lightest Z_2-odd particle

- SUSY: Axino/gravitino LSP → NLSP long-lived

II. Decay of a heavier Z_2-odd particle is kinematically suppressed

- SUSY: Wino/Higgsino-LSP [e.g. Bomark, Kvellestad, Lola, Osland, Raklev, 1310.2788]
- Extra Dimensions [Byrne, hep-ph/0311160]
- SUSY: Stau-neutralino degeneracy
  [e.g. Jittoh, Sato, Shimomura, Yamanaka, hep-ph/0512197]

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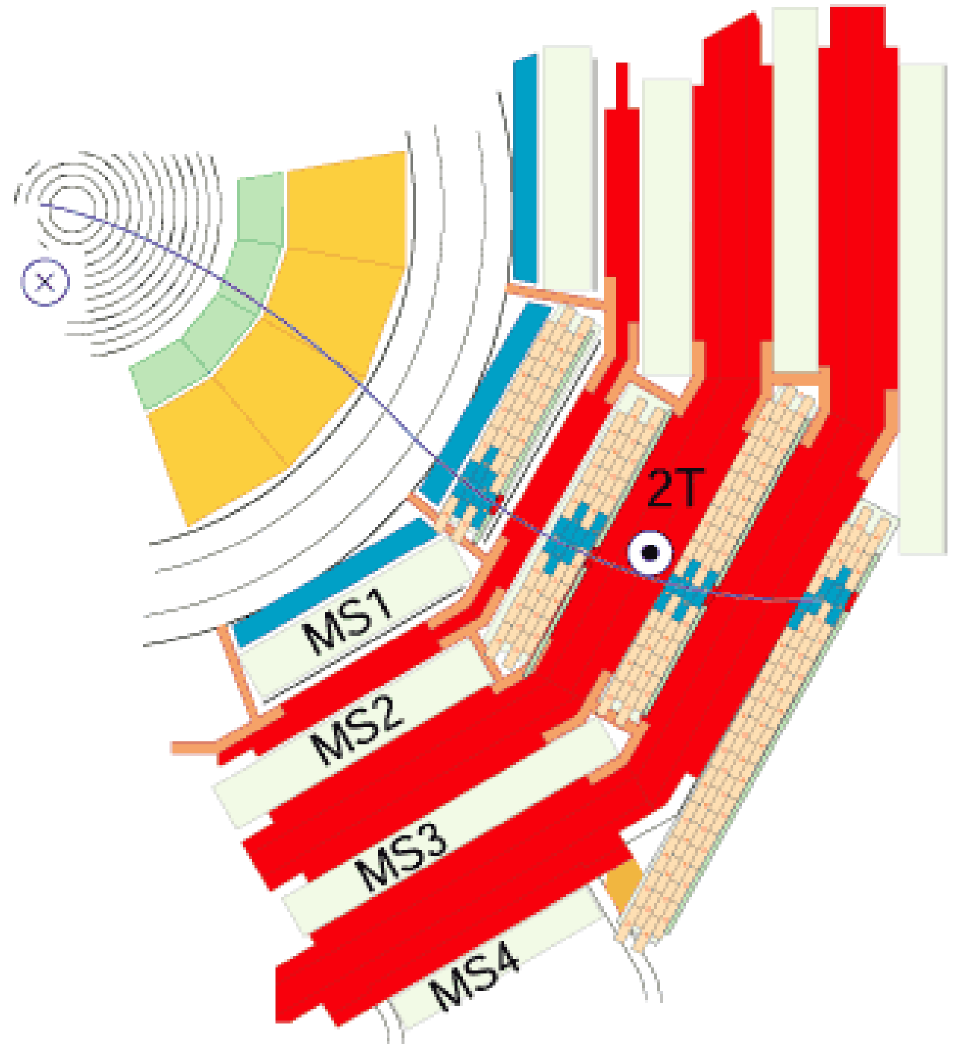
HSCP at the LHC: a prominent signature

- Pass the whole detector: muon-like signature
- Two disctinct features



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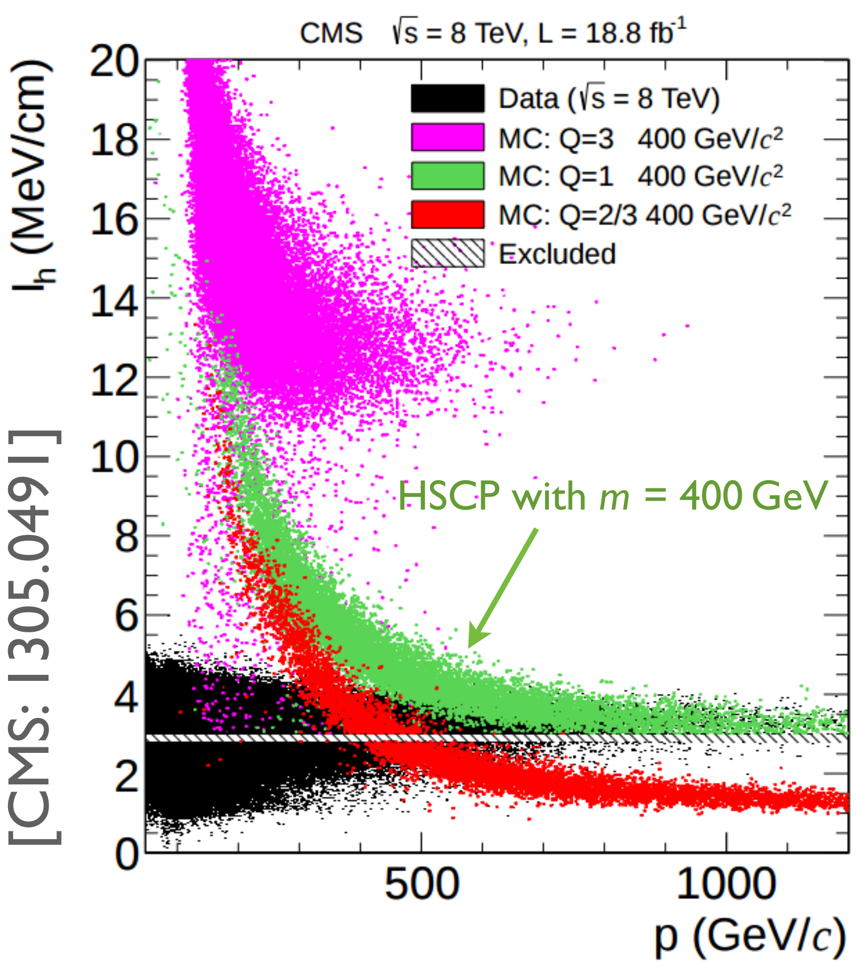
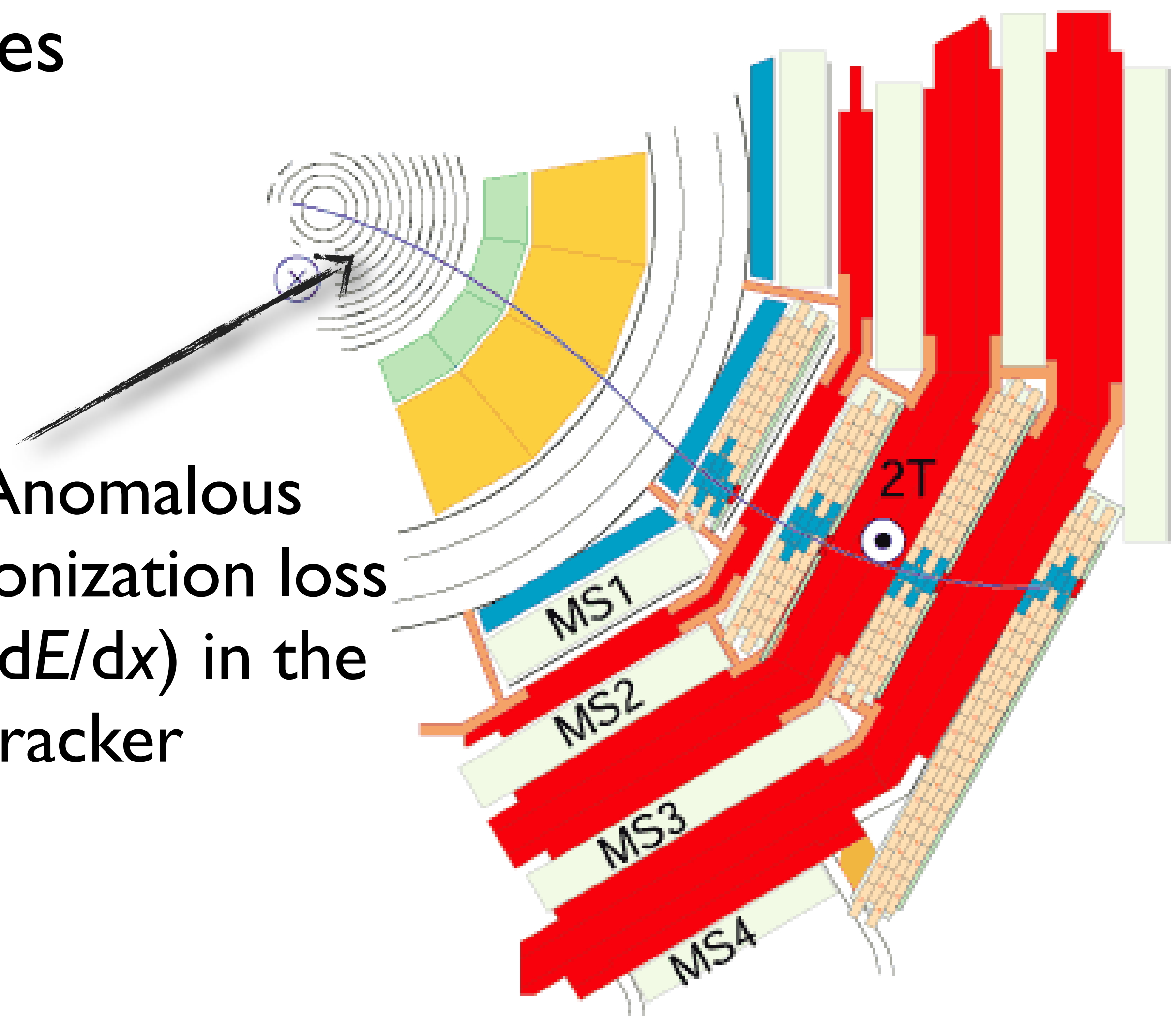


Anomalous ionization loss (dE/dx) in the tracker



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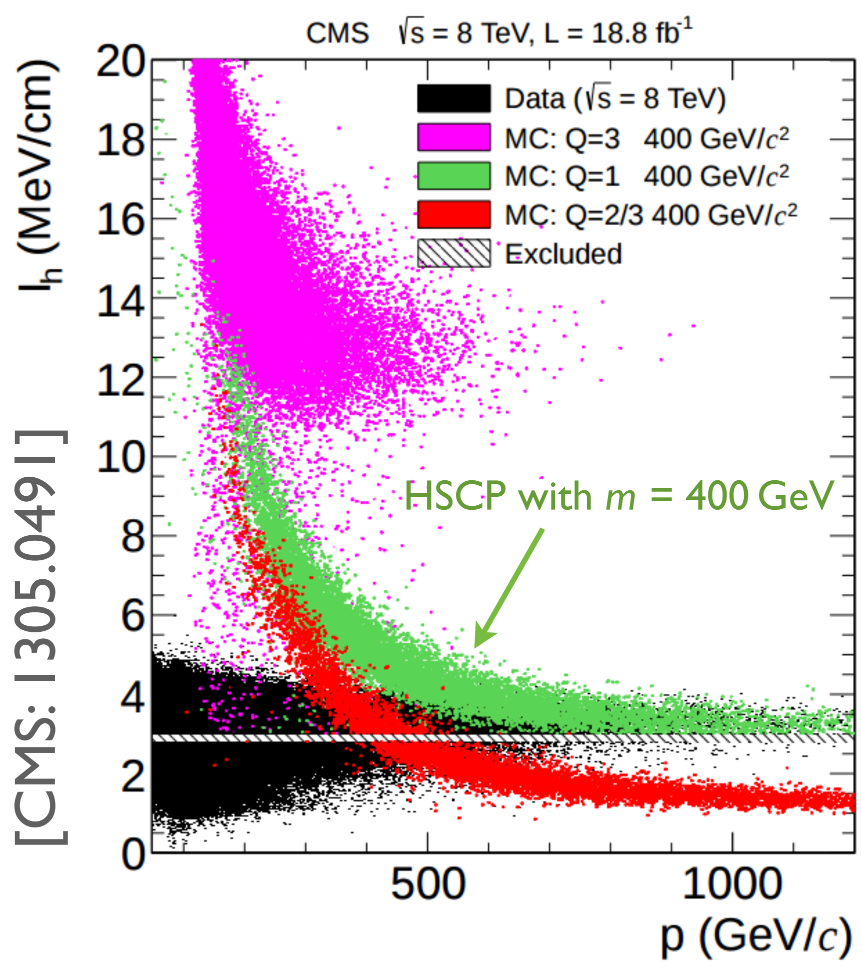

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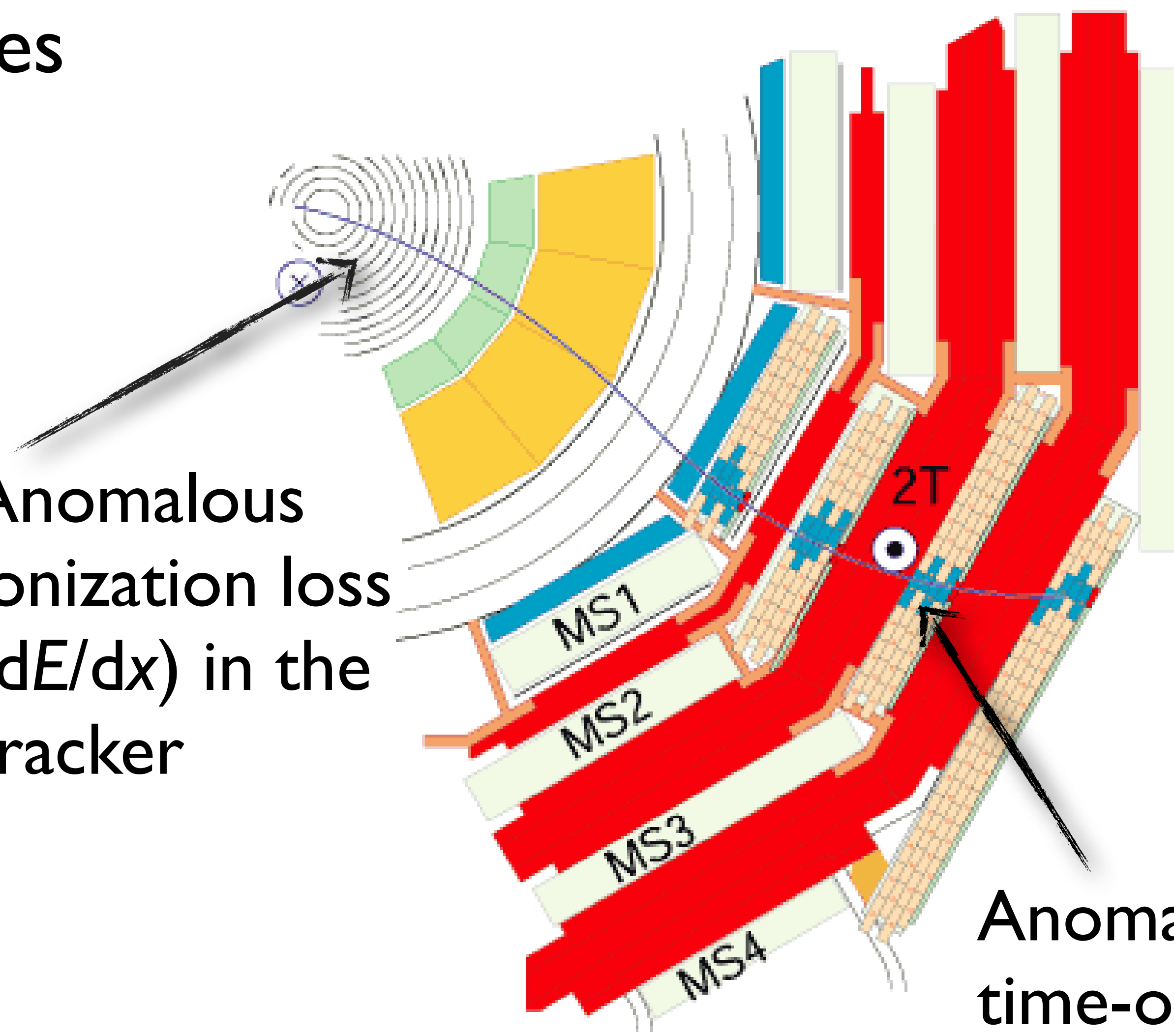

Anomalous time-of-flight in the muon-system

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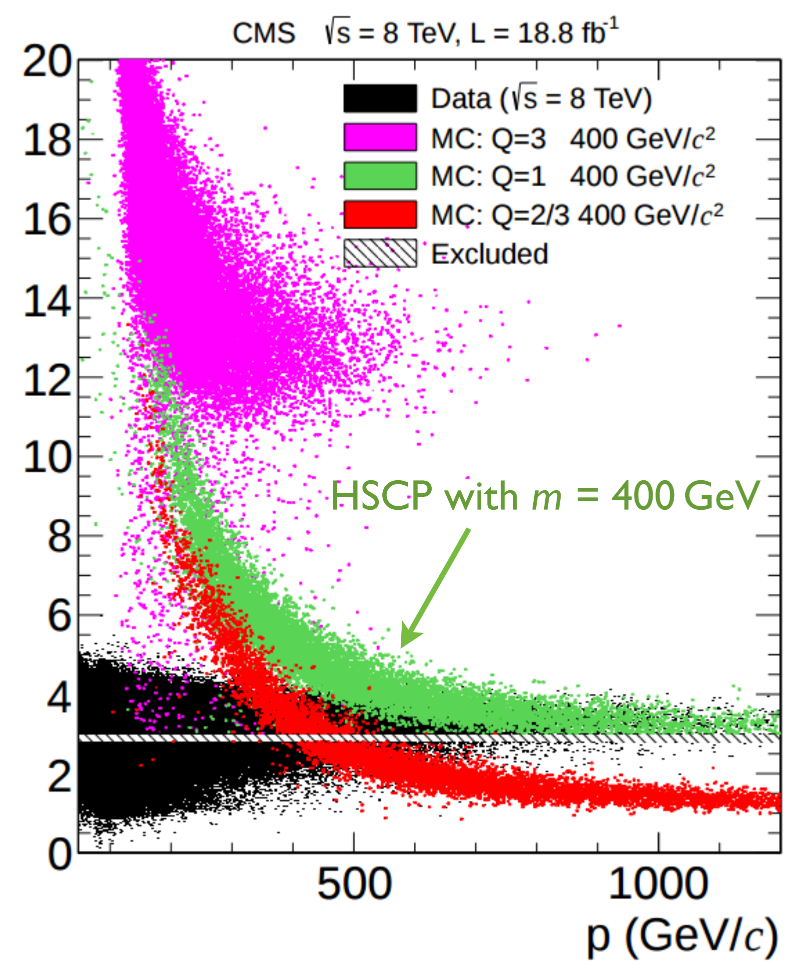

[CMS: 1305.0491]

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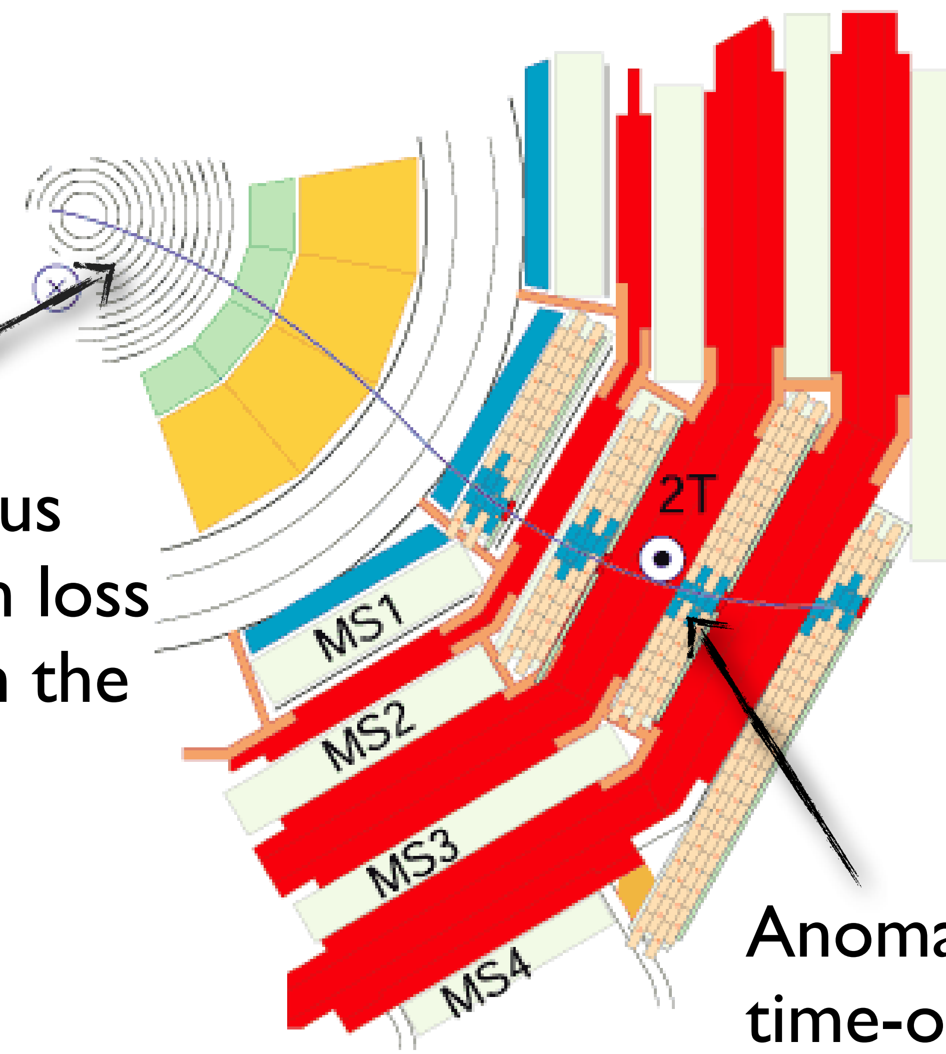


Anomalous time-of-flight in the muon-system

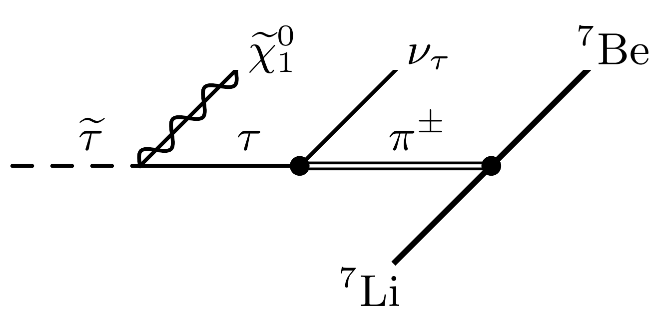
High sensitivity!

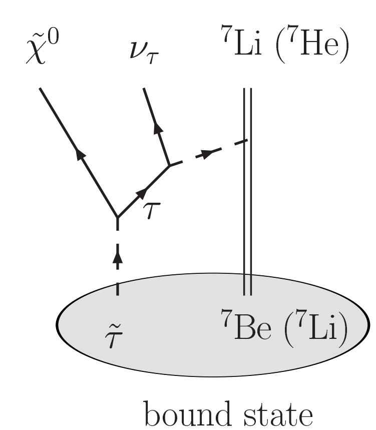
Additional motivation: Cosmology

- Big Bang Nucleosynthesis (BBN): Intriguing test of particle physics at temperatures $T \sim 1\,\mathrm{MeV}$ or times $t \sim 1\,\mathrm{min}$
- SBBN: Consistence for D, ^{3}He, ^{4}He
- But: Significant discrepancy for ^{7}Li:

$$\left(\frac{^7\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{theo}} = (4.68 \pm 0.67) \times 10^{-10}, \quad \left(\frac{\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{exp}} = (1.6 \pm 0.3) \times 10^{-10}\,.$$

- Depletion of ^{7}Li via HSCPs one proposed solution

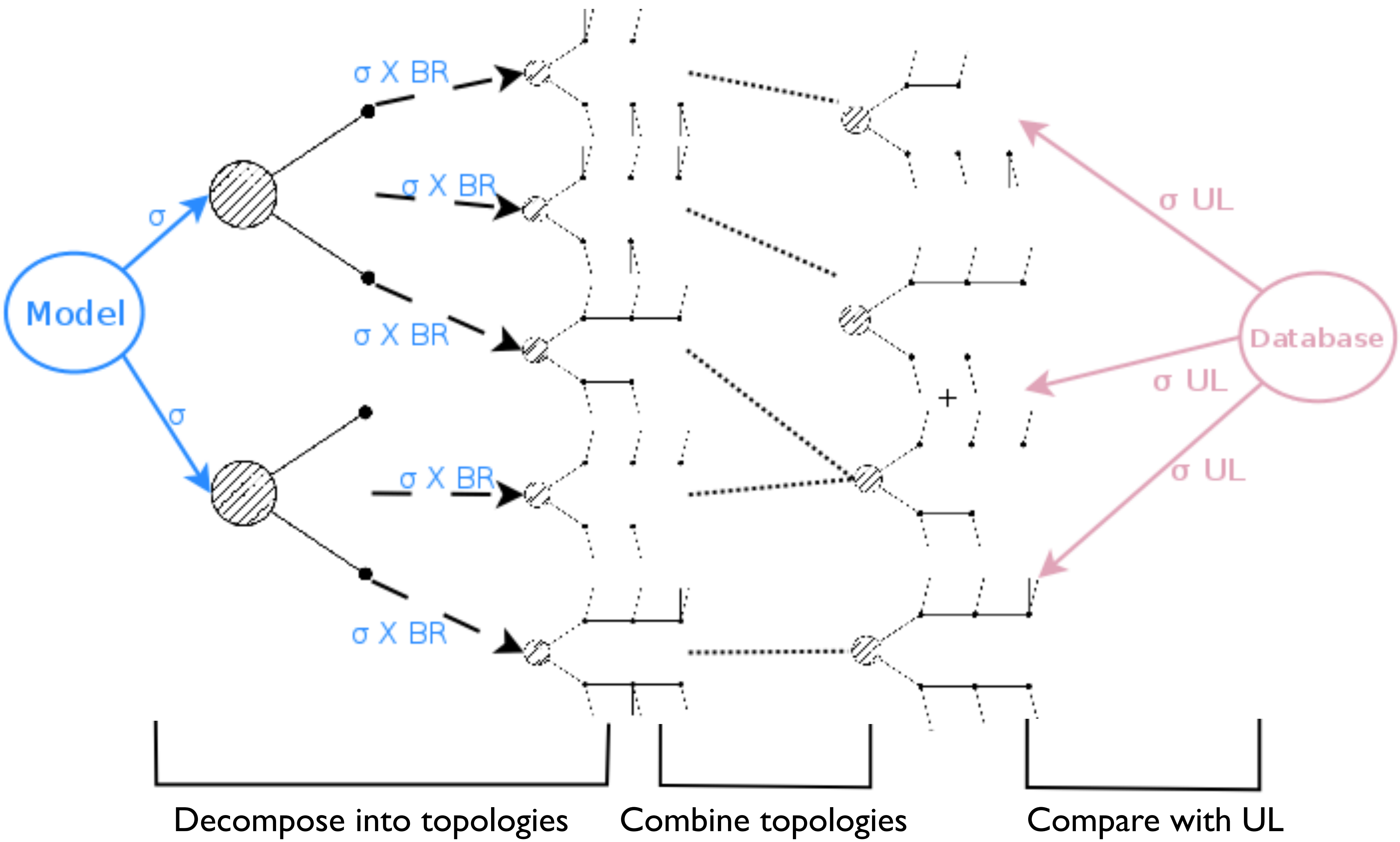




[see e.g. Jittoh, Kohri, Koike, Sato, Shimomura, Yamanaka, 0704.2914]

Implementation

Extending SModelS



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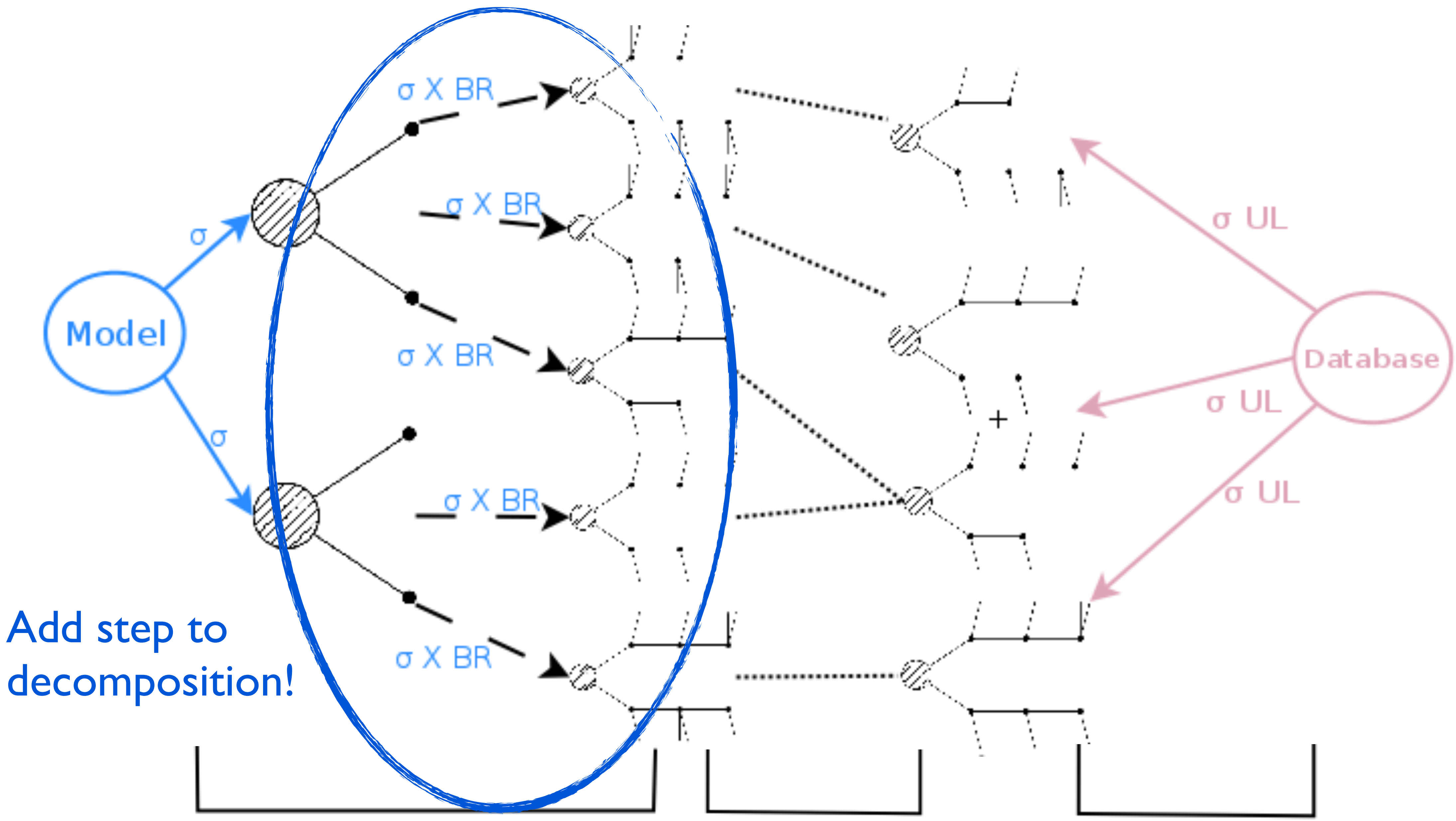
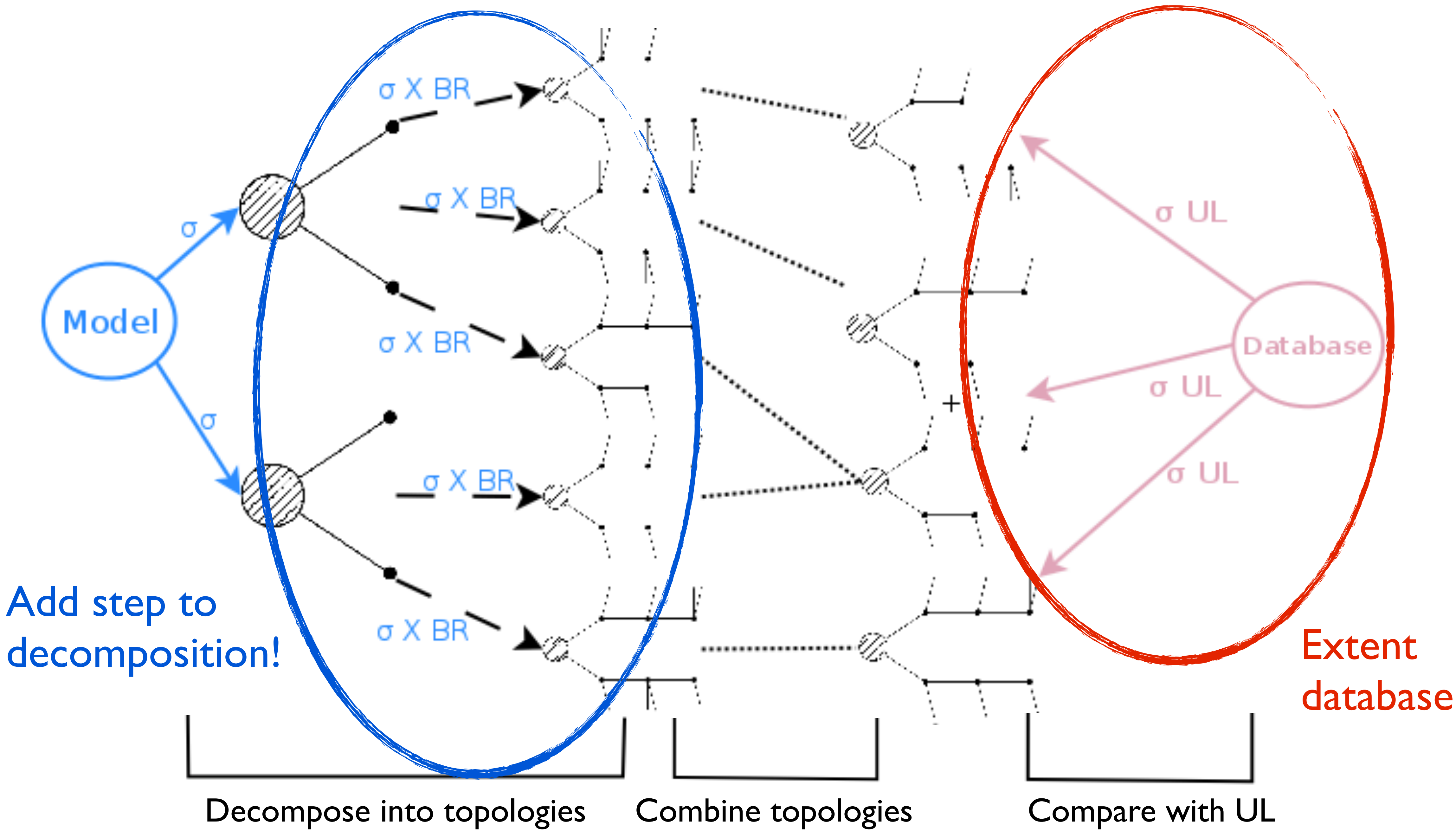


Decompose into topologies

Combine topologies

Compare with UL

Extending SModelS

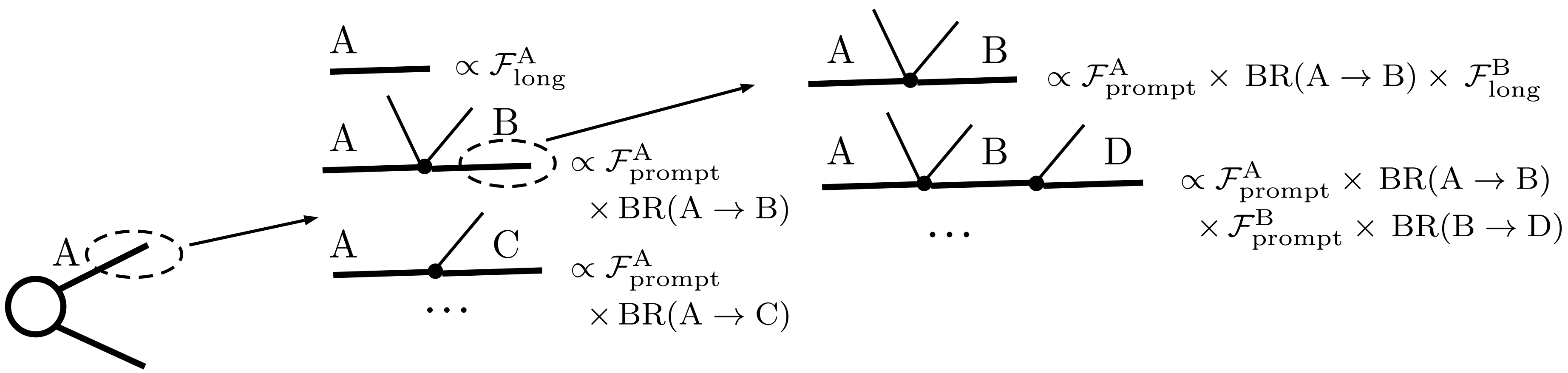


Extending SModelS

- Add step to decomposition:

  Probability to decay prompt: $\mathcal{F}_{\text{prompt}} = 1 - e^{-\Gamma l_{\text{inner}}/(\gamma\beta)}$,

  or appear metastable: $\mathcal{F}_{\text{long}} = e^{-\Gamma l_{\text{outer}}/(\gamma\beta)}$,



- End up with:

  pure MET, mixed MET/HSCP and pure HSCP

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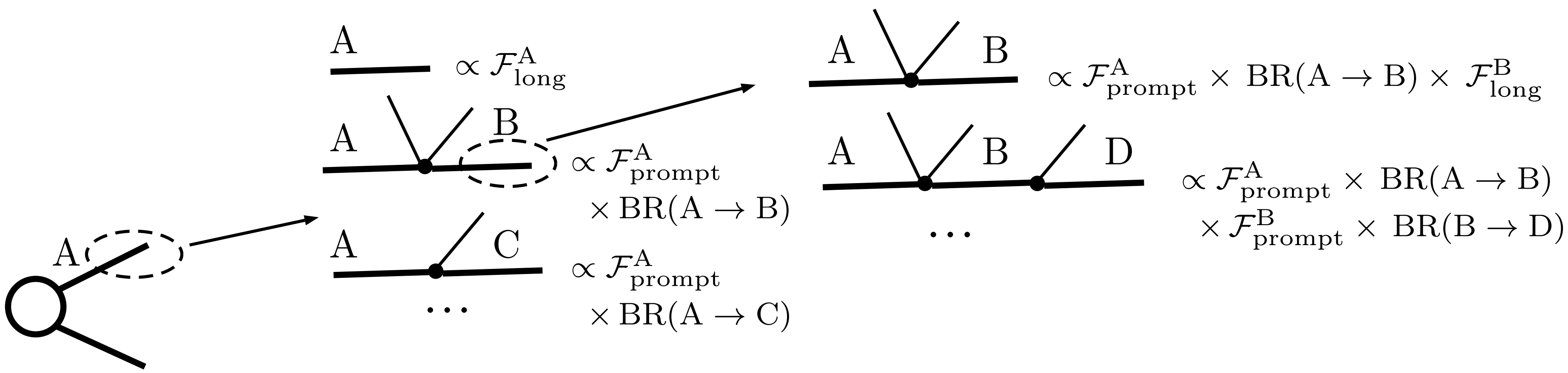

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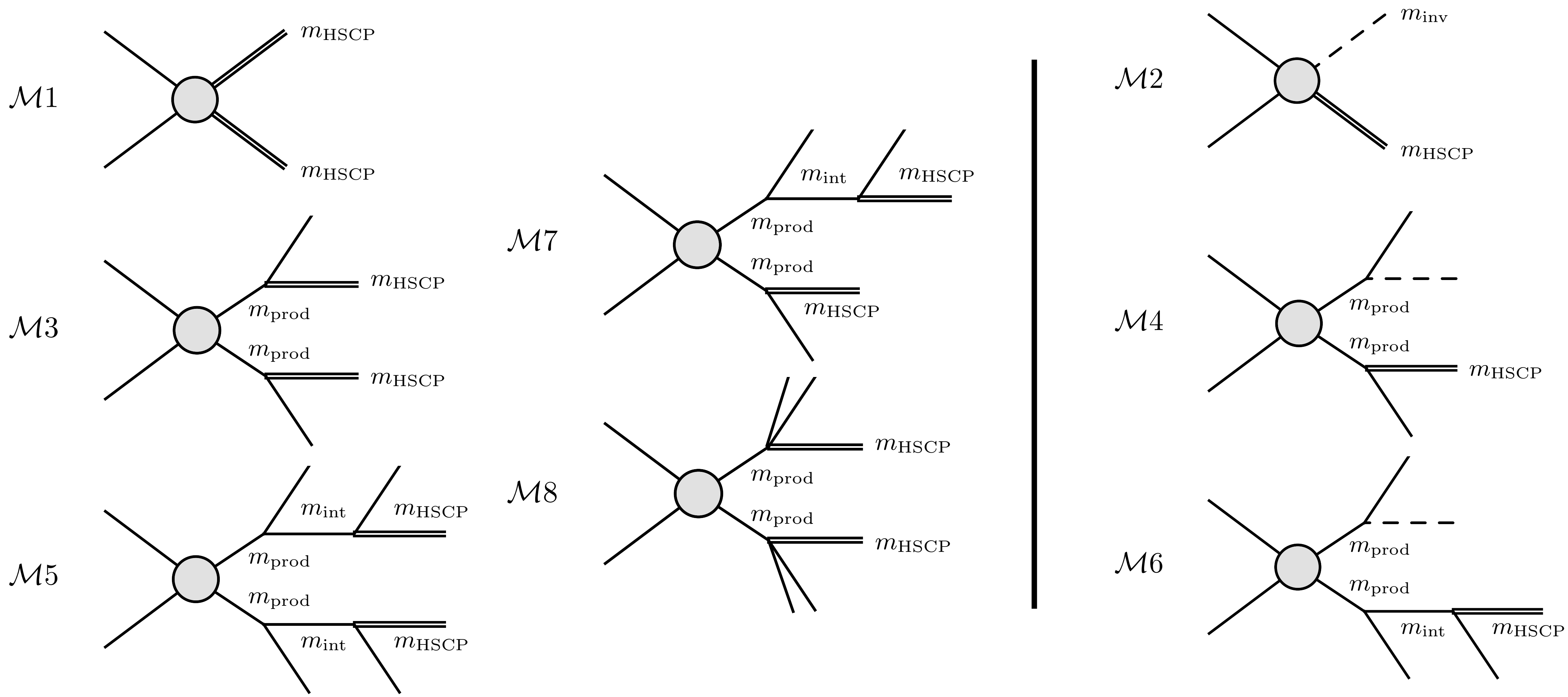
  Extent database!

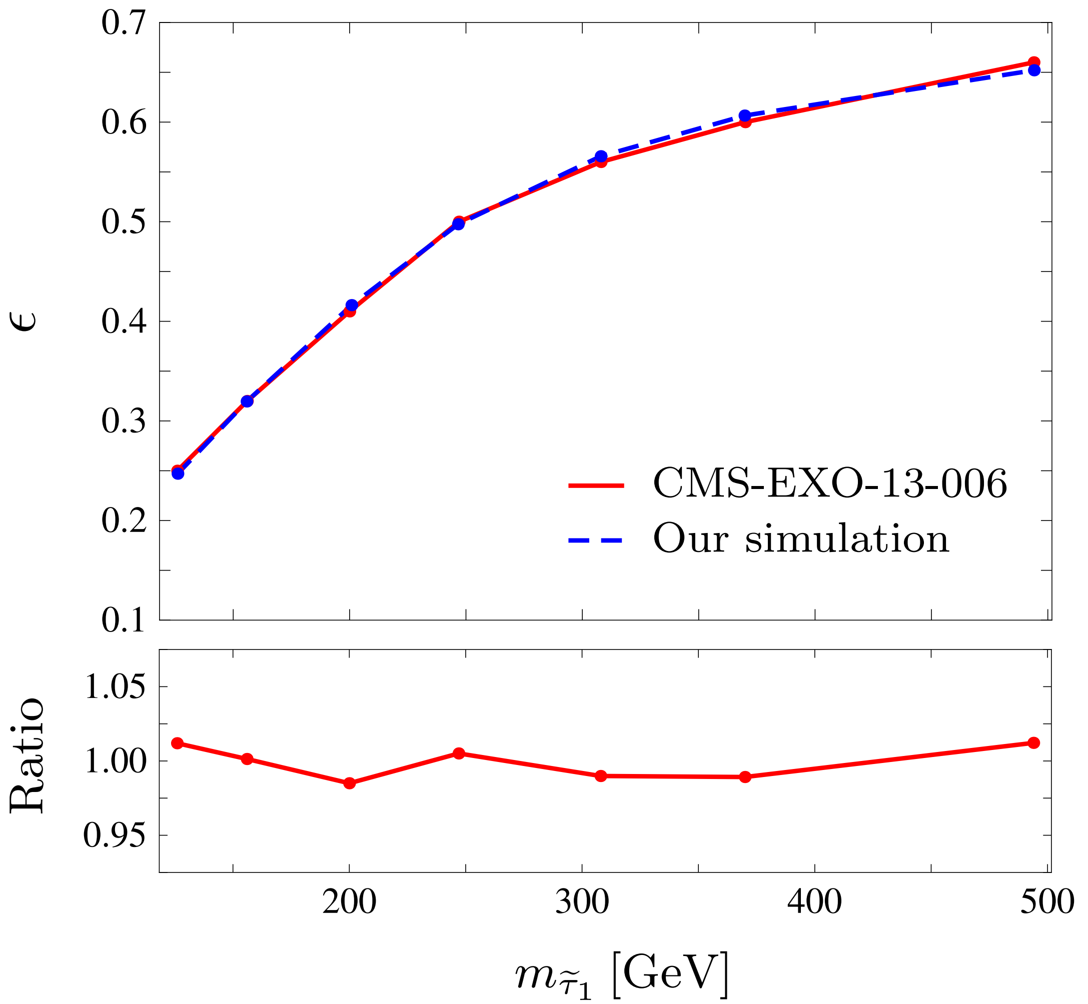
Extending SModelS: Considered Topologies

Pure HSCP: MET/HSCP:



Extending SModelS: Efficiencies

- Extent database:
  Compute efficiencies for 8 topologies
- Simulation: MadGraph/Phythia
- CMS HSCP analysis:
  Novel methode based on probabilities passing cuts
  [CMS: 1502.02522]
- Validation GMSB model →
- Less than 5% deviation



Application

The Tip of the CMSSM Co-annihilation Strip

[see also: Desai, Ellis, Luo, Marrouche, 1404.5061]

- CMSSM with neutralino LSP, stau NLSP
- Require $\delta m = m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} < 0.1\ \mathrm{GeV}$, $\tau_{\tilde{\tau}} \gtrsim 1 - 100s$

  → possible solution to the ^{7}Li-Problem [Konishi et al. 1309.2067]
- Monte Carlo scan over

$$m_0, M_{1/2}, A_0$$

  for fixed $\tan\beta$ and $\mu > 0$
- Stau abundance (before its decay): $Y_{\tilde{\tau}}^0 \gtrsim 10^{-13}$

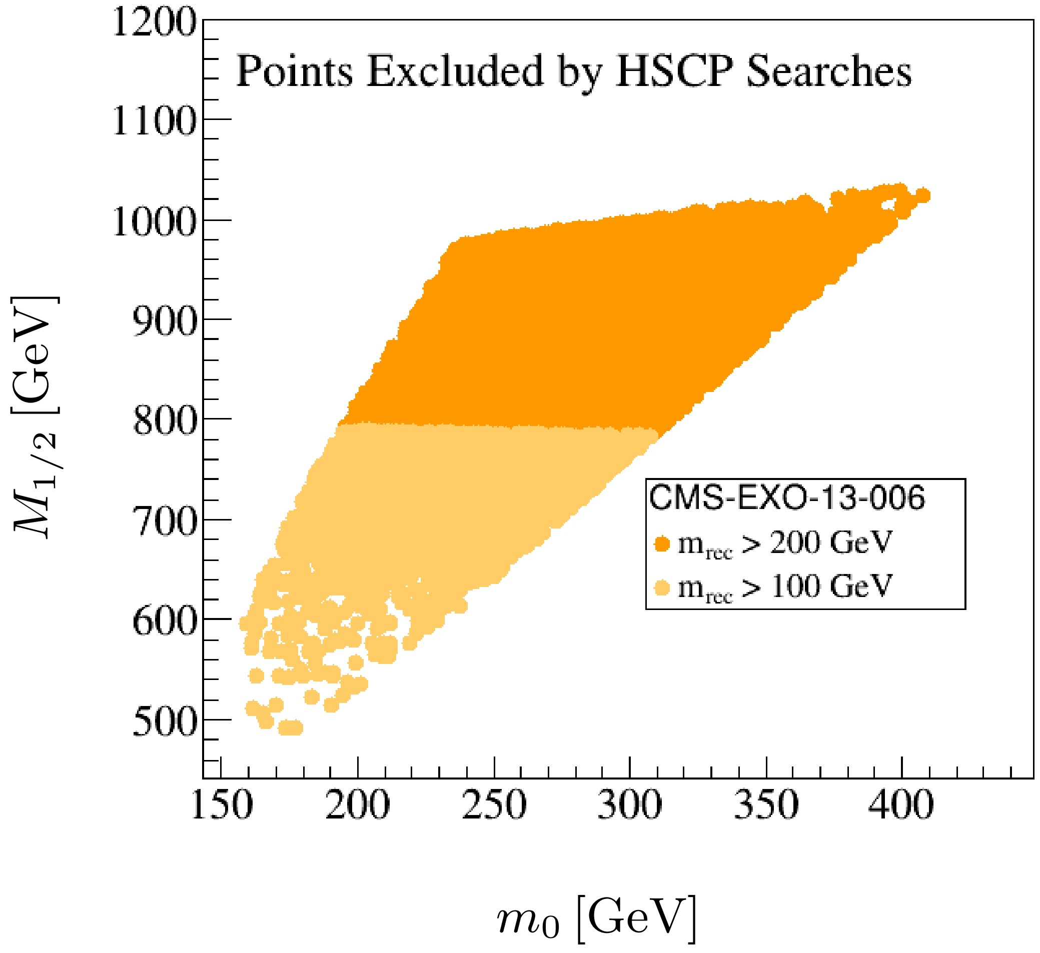
The Tip of the CMSSM Co-annihilation Strip

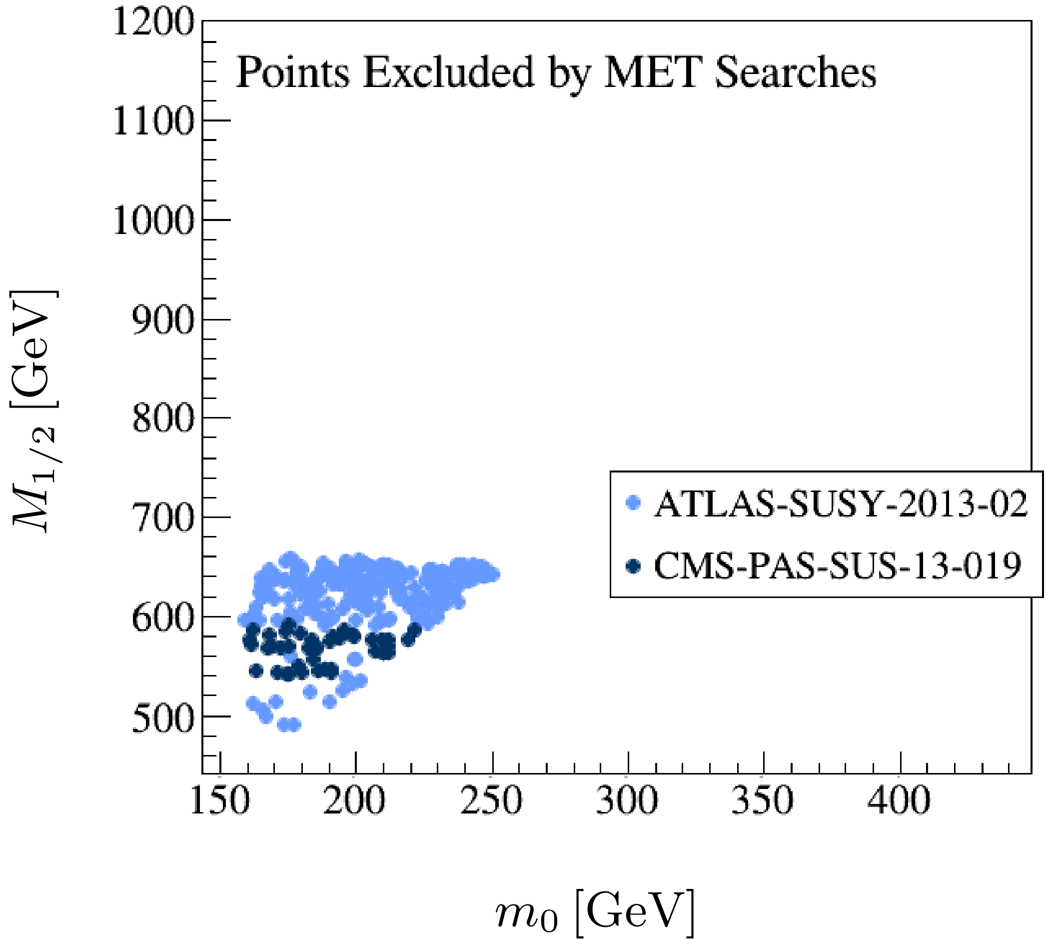
- LHC sensitivity:
  - ~70% signal: MET signatures (dominant $\widetilde{q}\widetilde{q} \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0 + 2j$)
  - ~20% signal: mixed MET/HSCP (dominant $\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0 \to \widetilde{\tau}_1^\pm\widetilde{\chi}_1^0 + \nu_\tau Z$)
  - ~10% signal: pure HSCP (dominant $\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\pm \to \widetilde{\tau}_1^\pm\widetilde{\tau}_1^\pm + 2\nu_\tau$)
- For HSCP and mixed: Efficiency database (8 topologies)
- For pure MET: Apply UL from most sensitive topology from SModelS MET-database

The Tip of the CMSSM Co-annihilation Strip

- LHC: HSCP versus MET sensitivity

[JH, Lessa, Quertenmont, 1509.00473]

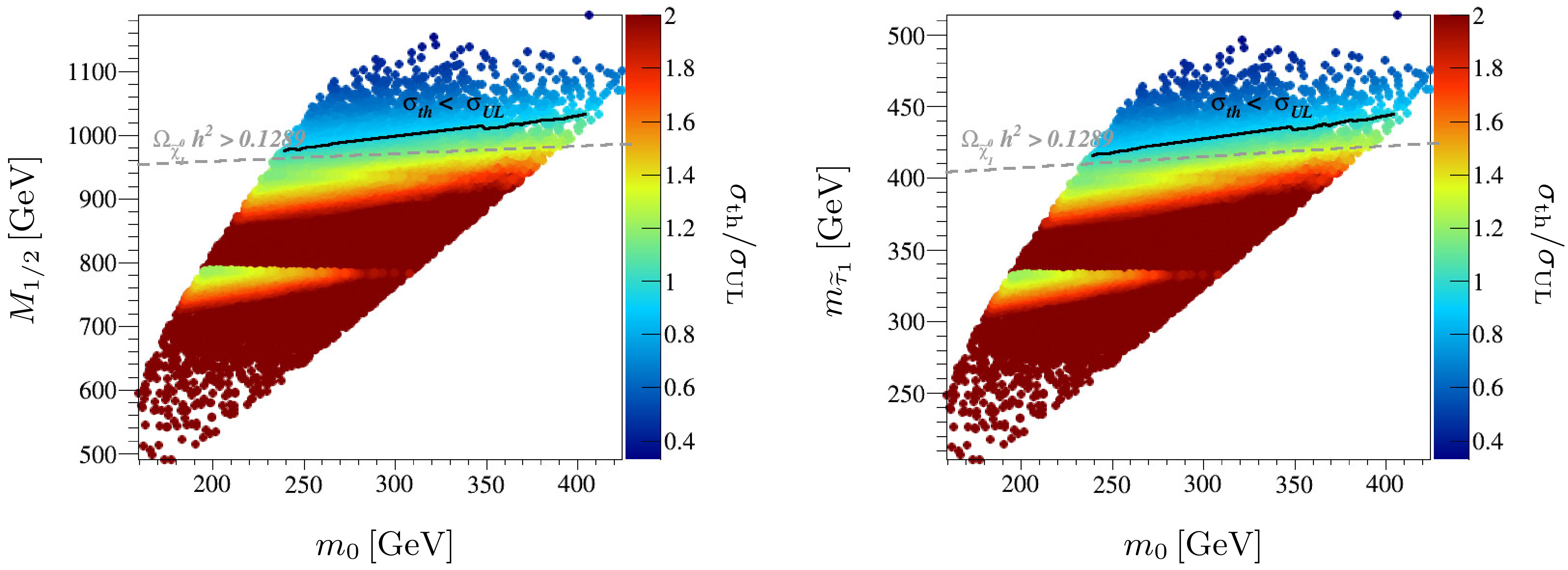




The Tip of the CMSSM Co-annihilation Strip

- LHC sensitivity (for $\tan\beta = 10$):

[JH, Lessa, Quertenmont, 1509.00473]



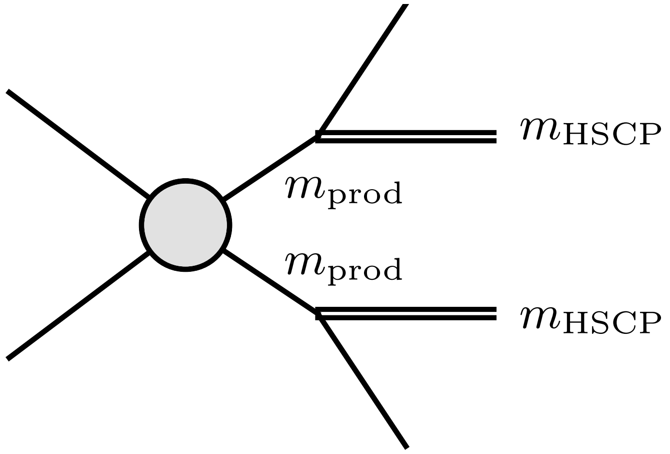
Summary

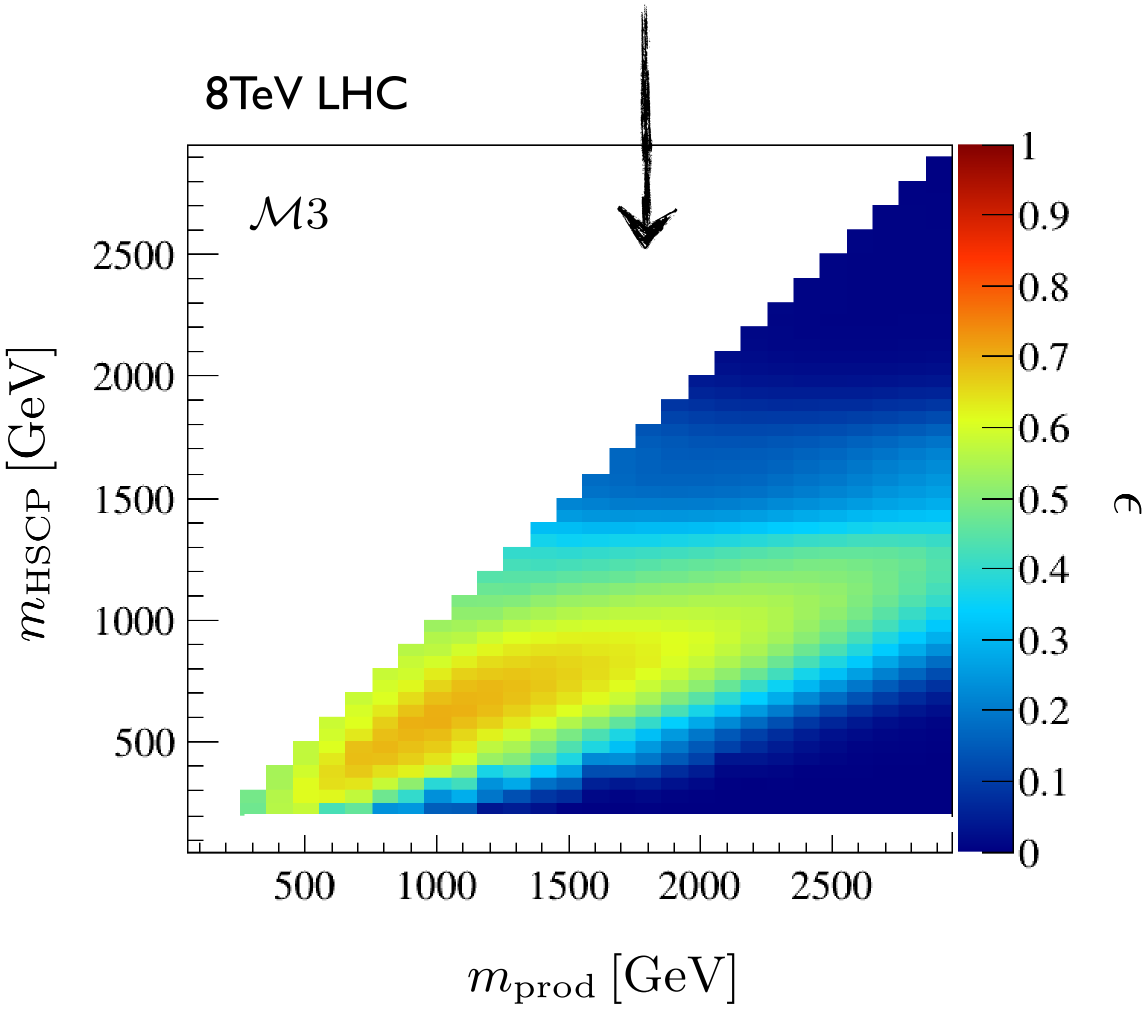
- Heavy stable charged particles (HSCP) occur in
  - co-annihilation scenarios
  - very weakly interacting DM (axinos/gravitinos)
- LHC high sensitivity to HSCPs
- Implementation of HSCP searches into SModelS
- Automatically test appearance of HSCPs
- HSCP highest sensitivity although only ~30% of signal
- Tip of stau-coannihilation strip excluded (from LHC or Planck) for low $\tan\beta$

Thank you for your attention!

Extending SModelS: Efficiencies

Exemplarily for $\mathcal{M}3$





- Signal efficiencies up to 70%
- Efficiencies drop for
  - $\beta \to 1$ (muon-background)
  - $\beta \lesssim 0.45$ (trigger)

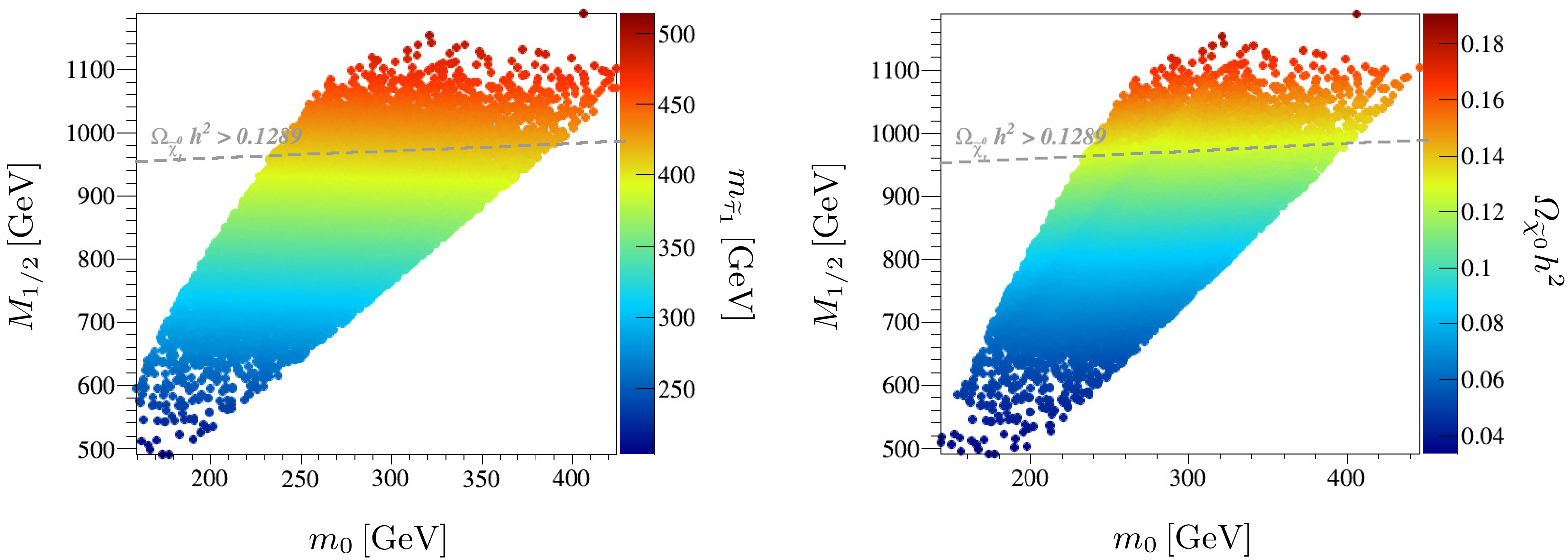
[cf. JH, Kersten, 1203.1581]

→ Use efficiencies for general model

The Tip of the CMSSM Co-annihilation Strip

- Scan (for $\tan\beta = 10$):

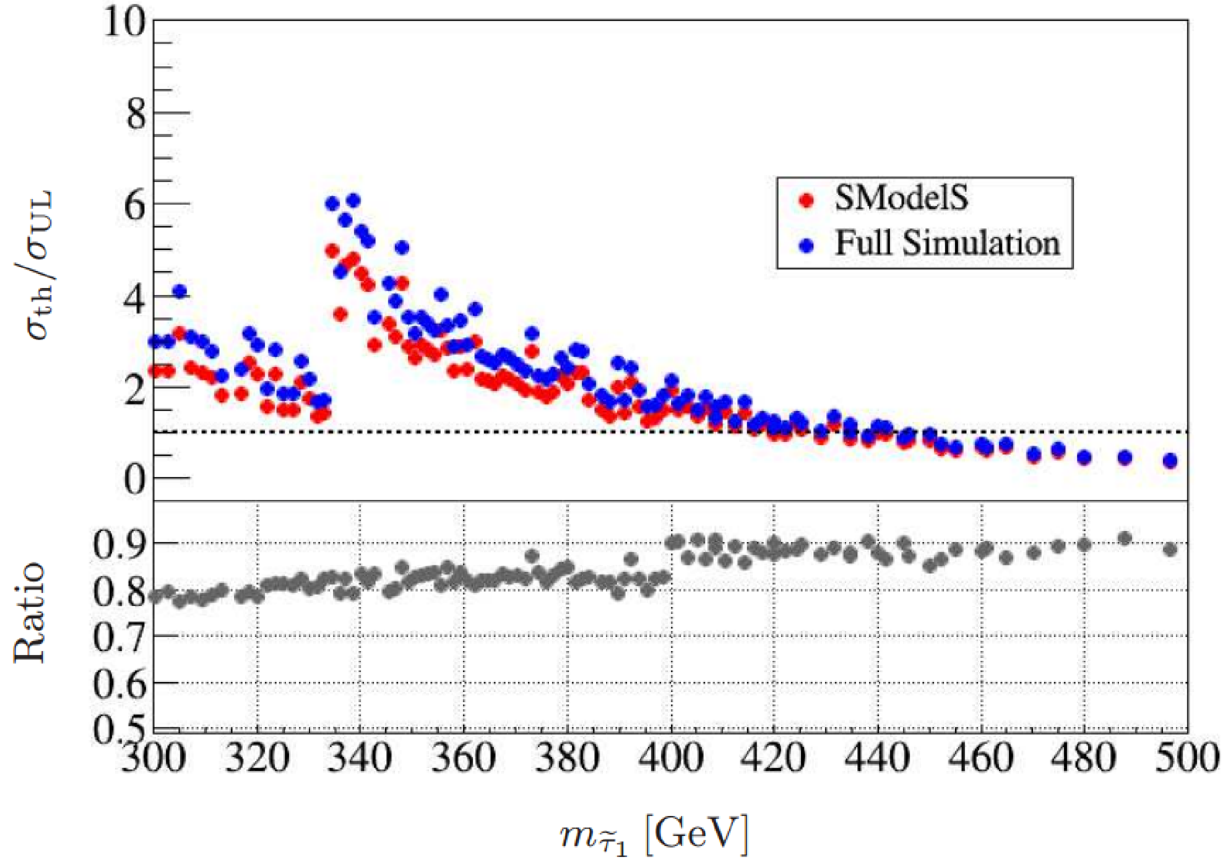
[JH, Lessa, Quertenmont, 1509.00473]



The Tip of the CMSSM Co-annihilation Strip

- Simplified models versus full simulation:

[JH, Lessa, Quertenmont, 1509.00473]



- SModelS conservative
- Signal coverage: ~90%