SModelS
Interpreting Simplified Models Results

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with Sabine Kraml, Suchita Kulkarni, Andre Lessa, Wolfgang Magerl, Doris Proschofsky, Wolfgang Waltenberger

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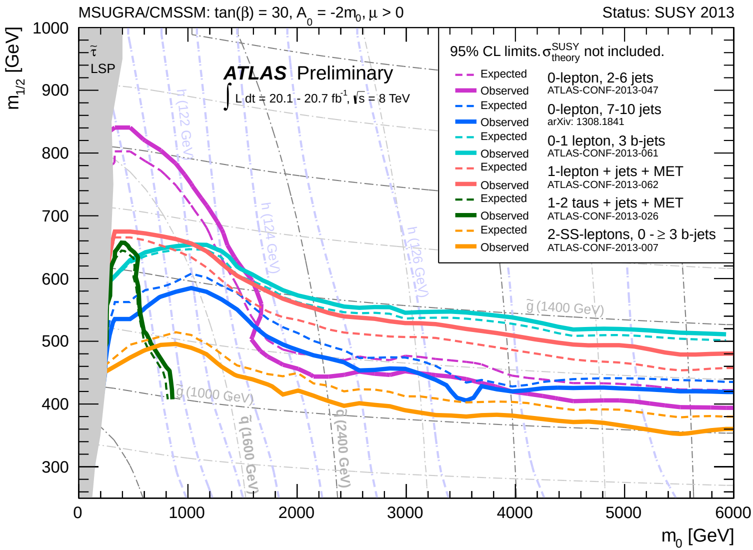
Searching for New Physics

Simple analysis:
Select signal region where a large signal to background ratio is expected, and count the number of observed events

To interpret the result:

- select a theoretical model that should be tested against the experimental result
- for that model: simulate events and reproduce the cuts for the selected signal region to predict the number of expected events
- the observed event count can be compared to the prediction from the theoretical model
- together with knowledge of the expected SM background: likelihood of the theoretical model can be evaluated

Interpretation by ATLAS



Why Simplified Models?

To test a different model: run complete new simulation over its parameter space. (see talks on MadAnalysis5 by E. Conte and G. Chalons)
This is a CPU expensive task, not well suited to scan over large parameter spaces.

Alternative: the experiments do the simulation of events and detector signals for Simplified Models (SMS), and provide upper limits on the SMS cross section instead.

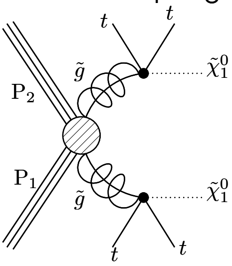
Largely simplifies the task of comparing a theoretical model to those results, we don't need to understand the cuts, efficiencies, ...

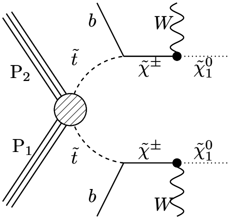
What are Simplified Models?

SMS are an effective-Lagrangian description:

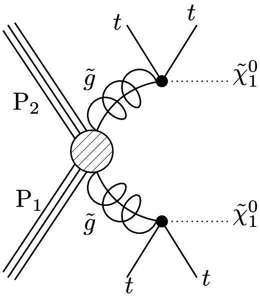
- only a limited number of new particles considered
- only specific decay channels are open
- main parameters are the masses of the new particles

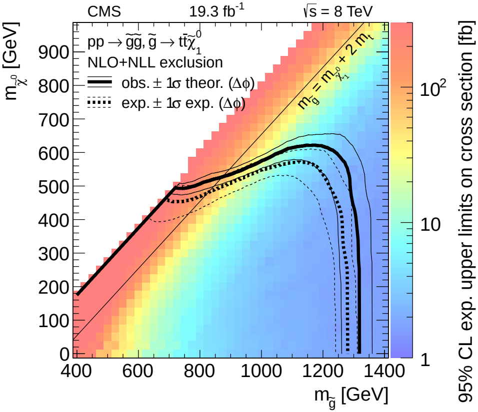
Example:
Search looking for b-jets and leptons plus MET, could arise from different SMS topologies, e.g.





Typical SMS Result





CMS-SUS-13-007

It is very valuable if the experiments publish the digitized plots: makes it easy to include the result in our database

Make use of SMS Results

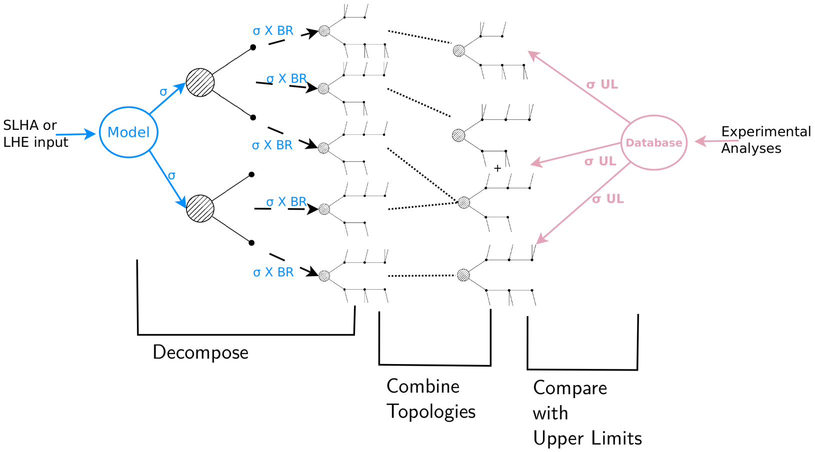
A general model will contain a number of SMS topologies
We want to compare the general model to all applicable SMS results, check if one of them excludes the model

This is not straightforward, we want to do this in an automatised procedure $\rightarrow$ introduce a new framework for that task $\Rightarrow$

SModelS

Decomposes a general model in SMS topologies, matches all applicable experimental results

Working Scheme



SModelS Language

For the matching we introduce a generic language to describe SMS topologies:

- a topology is described by the outgoing SM particles in each vertex
- main information on the BSM states: mass of the particle

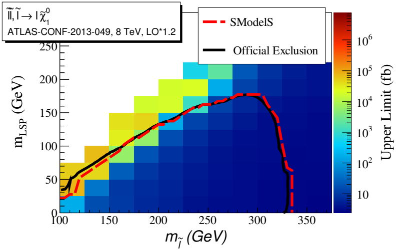
Examples:

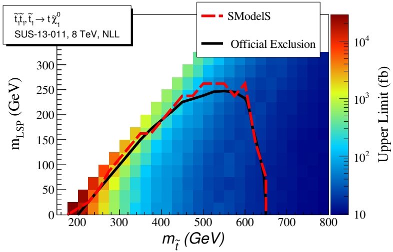
- `[[[t]],[[t]]]` from $\tilde{t}\tilde{t}, \tilde{t} \to t\tilde{\chi}_1^0$
- `[[[b],[W]],[[b],[W]]]` from $\tilde{t}\tilde{t}, \tilde{t} \to b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0$

Plus we can check conditions, such as branching ratios to final states that are summed up

Validation

Idea: use SModelS with the Simplified Model, reproduce exclusion lines





Application to the MSSM

Two random scans over MSSM with 7 and 9 free parameters.
Scan I: light gauginos and sleptons, heavy squarks
Scan II: light squarks but heavy sleptons

Assumptions:

- approximate GUT relation $M_1 : M_2 : M_3 = 1 : 2 : 6$
- common mass parameter for the first two generations of left- and right-handed squarks
- common mass parameter for all three generations of sleptons (left- and right-handed respectively)

Preselection of points: require consistency with Higgs mass, low-energy observables, LEP limits on sparticle masses

Parameter ranges – Scan I

Fixed Parameters:

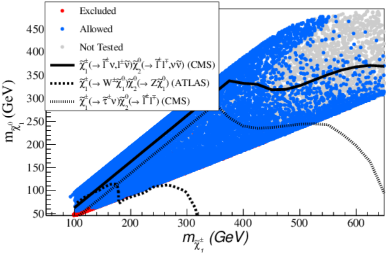
- $m_A = 2$ TeV
- $M_{\tilde{q}} = 5$ TeV
- $M_{\tilde{Q}_3} = 2$ TeV
- $M_{\tilde{U}_3} = 2$ TeV
- $M_{\tilde{D}_3} = 2$ TeV
- $A_b = 0$

Scanned Parameters:

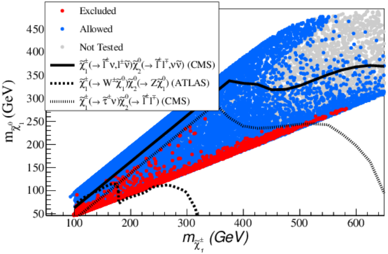
- $M_2 = 0.1 - 1$ TeV
- $\mu = 0.1 - 1$ TeV
- $\tan\beta = 3 - 60$
- $M_{\tilde{L}} = 0.1 - 1$ TeV
- $M_{\tilde{E}} = 0.1 - 1$ TeV
- $A_t = \pm 6$
- $A_\tau = \pm 1$

Results – Scan I

Looking at chargino-LSP masses, what region can be excluded, where do we find excluded points



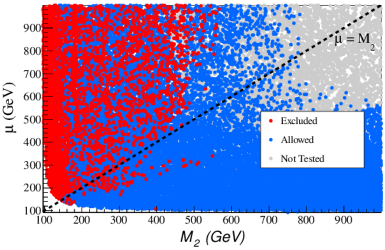
Allowed points plotted on top of excluded points

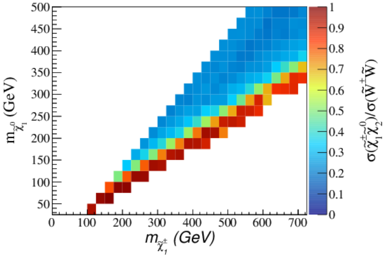


Excluded points plotted on top of allowed points

Results – Scan I

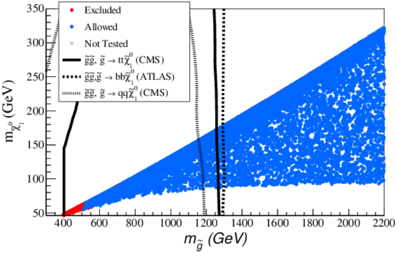
Why are there so many unexcluded points below the official exclusion lines?



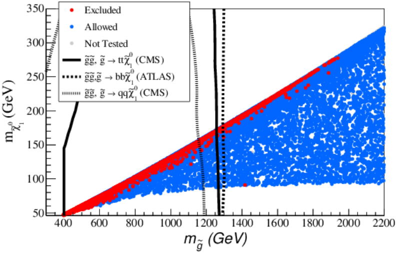


Results – Scan I

A similar picture is found for gluino-LSP masses



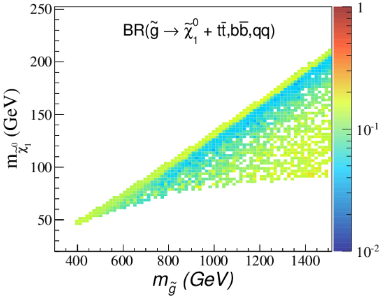
Allowed points plotted on top of excluded points



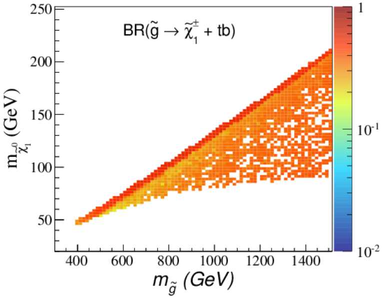
Excluded points plotted on top of allowed points

Results – Scan I

Many points remain unexcluded because of a low branching ratio to SMS topologies considered by the experiments



SMS results available



No SMS results available

Parameter ranges – Scan II

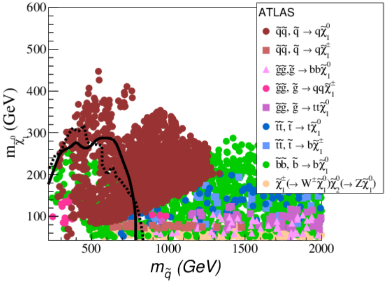
Fixed Parameters:

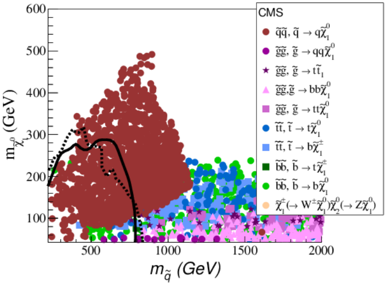
- $m_A = 2$ TeV
- $M_{\tilde{L}} = 5$ TeV
- $M_{\tilde{E}} = 5$ TeV
- $A_\tau = 0$

Scanned Parameters:

- $M_2 = 0.1 - 1$ TeV
- $\mu = 0.1 - 1$ TeV
- $\tan\beta = 3 - 60$
- $M_{\tilde{q}} = 0.1 - 5$ TeV
- $M_{\tilde{Q}_3} = 0 - 2$ TeV
- $M_{\tilde{U}_3} = 0 - 2$ TeV
- $M_{\tilde{D}_3} = 0 - 2$ TeV
- $A_t = [1, 3max(M_{\tilde{Q}_3}, M_{\tilde{U}_3})]$
- $A_b = \pm 1$

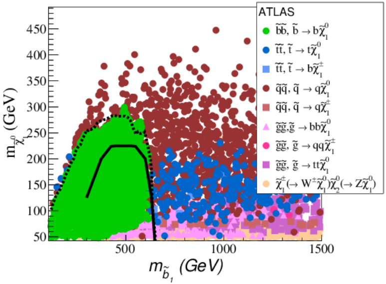
Most constraining SMS topologies in the squark-LSP plane – exclusion from first and second generation squark search results even outside the official exclusion lines

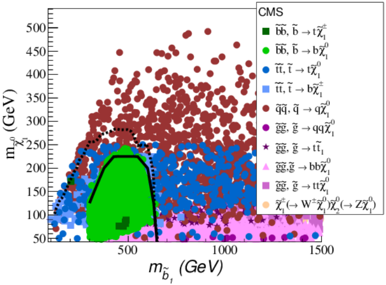




Explanation: the squark production cross section is enhanced if the gluino is not decoupled

Different picture for bottom squarks – results agree very well with the official exclusion lines





Caveats

Some assumptions may not be valid in a general scenario, this should be kept in mind when choosing which analyses may be applied to a given input model

- assumption: signal efficiencies do not depend on details of BSM state, only masses
  - not valid for searches relying on shape distributions
  - might be violated if signal efficiencies depend on spin correlations or the properties of off-shell states in production or decay channels
  - color factor of initial BSM particle influences QCD activity and therefore the signal efficiency

these will be studied to quantify the effect

Attributes

Keeping these caveats in mind, SModelS is a powerful tool for phenomenological studies:

- theory predictions are casted in a model-independent way
  - therefore very general, may be applied to e.g. NMSSM, sneutrino LSP model
  - might also apply to non-SUSY models (e.g. UED)
- decomposition procedure may be used independently to find relevant signatures of an input model
- it is easy to add new experimental results
  - SModelS comes with a large results database
  - the database is regularly updated with the latest results

Fastlim

Similar approach: **Fastlim**
by Papucci, Sakurai, Weiler, Zeune, arXiv:1402.0492

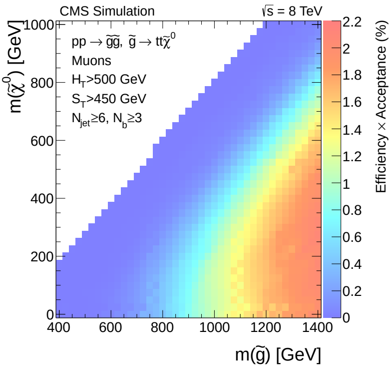
- Fastlim uses efficiency maps, which e.g. allows to combine results from different topologies.
- Currently 11 ATLAS analyses implemented
  (SModelS: more than 40 ATLAS and CMS analyses)
- Detailed SModelS–Fastlim comparison is in progress

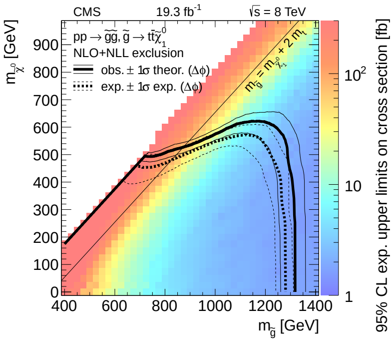
Nb: Efficiency maps are not always available for all SMS results, and developing them oneself based on fast simulation is difficult and time-consuming.

Conclusions

- The two scans presented here demonstrate that SModelS is a powerful tool for phenomenological studies.
- Studies of NMSSM (with U. Ellwanger, C. Hugonie) and sneutrino LSP MSSM (with C. Arina) with SModelS are in progress.
- The publication of the code (+manual) is in preparation.
- SModelS online: http://smodels.hephy.at/online/slha.py
- Next step: include efficiency maps. This will allow us to combine SMS topologies that contribute to the same signal region, and to add SMS topologies not considered by the experiments.

Efficiency map vs. Upper Limit map





from CMS-SUS-13-007

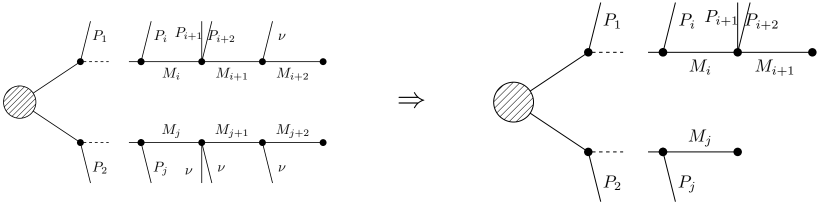
Conditions

Example: direct slepton production (selectron + smuon), decaying to lepton + LSP

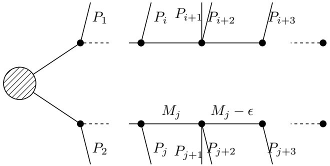
Experimental search is interpreted for the sum of the two topologies, assuming equal contributions from the two flavors
Before applying an experimental result we have to make sure that this assumption is valid for the theory.

Here: μ signal efficiency generally higher than for e, we require that the electron contribution is less than the muon contribution.
This is not a strict condition, we quantify the violation and let the user decide if the result applies or not.

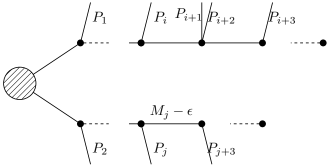
Invisible Compression



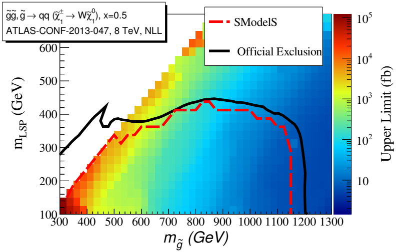
Mass Compression

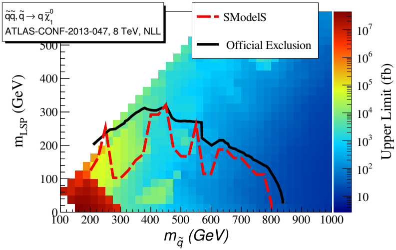


$\Rightarrow$

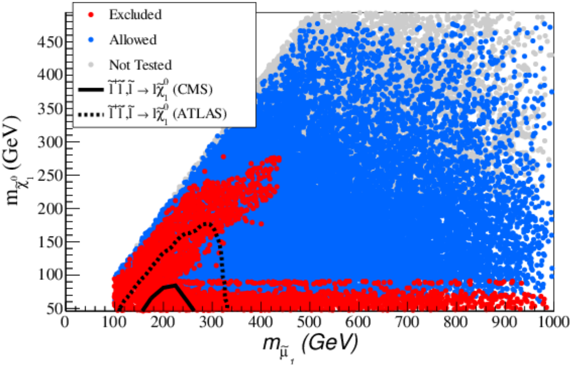


Validation – not always perfect agreement





More Results – Scan I



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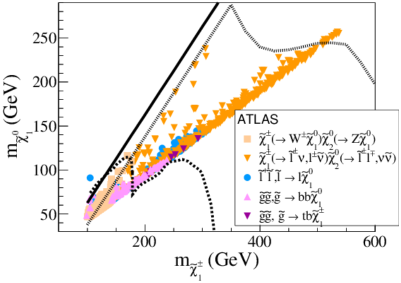
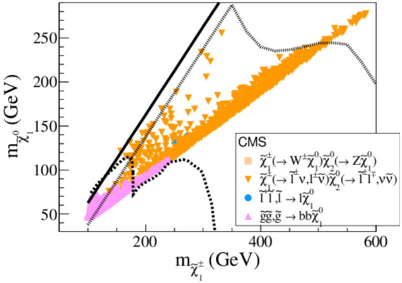
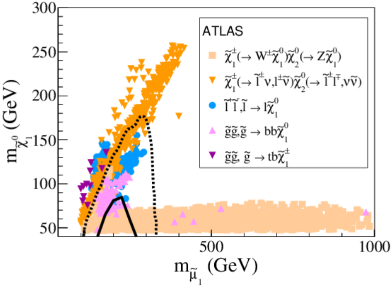


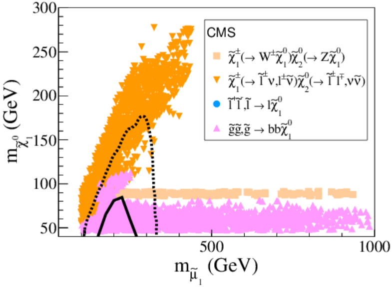
(a)



(b)

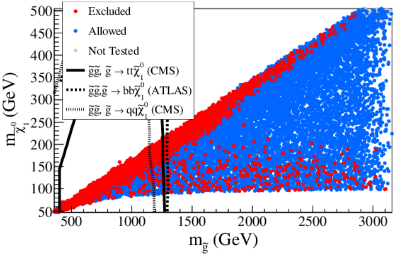


(c)

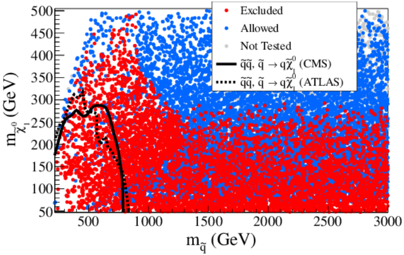


(d)

More Results – Scan II



(a)



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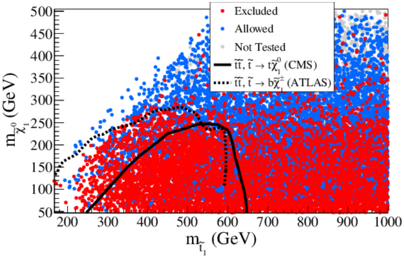

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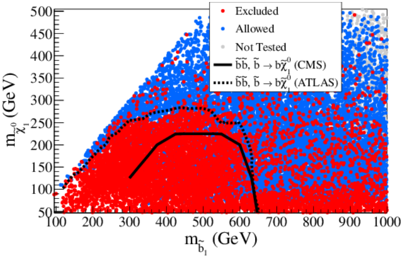

(d)

More Results – Scan II