



# SModelS v1.1 user manual: Improving simplified model constraints with efficiency maps<sup>☆</sup>

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## ABSTRACT

SModelS is an automatized tool for the interpretation of simplified model results from the LHC. It allows to decompose models of new physics obeying a  $\mathbb{Z}_2$  symmetry into simplified model components, and to compare these against a large database of experimental results. The first release of SModelS, v1.0, used only cross section upper limit maps provided by the experimental collaborations. In this new release, v1.1, we extend the functionality of SModelS to efficiency maps. This increases the constraining power of the software, as efficiency maps allow to combine contributions to the same signal region from different simplified models. Other new features of version 1.1 include likelihood and  $\chi^2$  calculations, extended information on the topology coverage, an extended database of experimental results as well as major speed upgrades for both the code and the database. We describe in detail the concepts and procedures used in SModelS v1.1, explaining in particular how upper limits and efficiency map results are dealt with in parallel. Detailed instructions for code usage are also provided.

### Program summary

*Program Title:* SModelS

*Program Files doi:* <http://dx.doi.org/10.17632/w4nft4459w.1>

*Licensing provisions:* GPLv3

*Programming language:* Python

*Nature of problem:* The results for searches for new physics beyond the Standard Model (BSM) at the Large Hadron Collider are often communicated by the experimental collaborations in terms of constraints on so-called simplified models spectra (SMS). Understanding how SMS constraints impact a realistic new physics model, where possibly a multitude of relevant production channels and decay modes are relevant, is a non-trivial task.

*Solution method:* We exploit the notion of simplified models to constrain full models by “decomposing” them into their SMS components. A database of SMS results obtained from the official results of the ATLAS and CMS collaborations, but in part also from ‘recasting’ the experimental analyses, can be matched against the decomposed model, resulting in a statement to what extent the model at hand is in agreement or contradiction with the experimental results. Further useful information on, e.g., the coverage of the models’ signatures is also provided.

*Additional comments including Restrictions and Unusual features:* At present, the tool is limited to signatures with missing transverse energy, and only models with a  $\mathbb{Z}_2$ -like symmetry can be tested. Each SMS is defined purely by the vertex structure and the SM final state particles; BSM particles are described only by their masses, production cross sections and branching ratios. Possible differences in signal selection efficiencies arising, e.g., from different production mechanisms or from the spin of the BSM particles, are

<sup>☆</sup> This paper and its associated computer program are available via the Computer Physics Communication homepage on ScienceDirect (<http://www.sciencedirect.com/science/journal/00104655>).

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ignored in this approach. Since only part of the full model can be constrained by SMS results, SModelS will always remain more conservative (though orders of magnitude faster) than “full recasting” approaches.  
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## 1. Introduction

The ATLAS and CMS experiments at the Large Hadron Collider (LHC) are searching for new physics beyond the Standard Model (BSM) in many different channels. An important class of these searches considers final states with large missing transverse energy (MET), targeting supersymmetry (SUSY) with R-parity conservation or other models with a new conserved parity. In order to design optimal analyses that look for specific final states and to communicate the results, the concept of simplified models [1–5] has been widely adopted by the experimental collaborations.

While limits in terms of simplified model spectra (SMS) are a convenient way to illustrate and compare the reach of specific analyses, understanding how they constrain a realistic model with a multitude of relevant production channels and decay modes quickly becomes a non-trivial task. To tackle this issue we have created SModelS [6,7], an automatized tool for interpreting simplified model results from the LHC. The principle of SModelS is to decompose BSM collider signatures featuring a  $\mathbb{Z}_2$  symmetry into simplified model topologies, using a generic procedure where each SMS is defined by the vertex structure and the SM final state particles; BSM particles are described only by their masses, production cross sections and branching ratios.

The SModelS decomposition corresponds to an approximate mapping of the original model signatures to a coherent sum of simplified model topologies. The underlying assumption [6] is that differences in the event kinematics (e.g. from different production mechanisms or from the spin of the BSM particle) do not significantly affect the signal selection efficiencies. The tool can then be used for any BSM model with a  $\mathbb{Z}_2$ -like symmetry as long as all heavier R-odd particles (cascade-)decay promptly to the lightest one, which should be electrically and color neutral.<sup>1</sup> Note that due to the  $\mathbb{Z}_2$  symmetry only pair production or associated production of two BSM particles is considered, and MET is always implied in the final state description. Regarding experimental results, the tool contains a large database of SMS results from ATLAS and CMS SUSY searches.

Since the publication of SModelS v1.0 [7] in December 2014, the code base has undergone significant structural changes. Version 1.1 comes with many new features, the most important one being the *extension to efficiency maps*.

The advantage of efficiency maps (EM) over the previously (and still) used cross section upper limit (UL) maps is that they allow to combine contributions from different SMS topologies to the same signal region (SR) of a given experimental analysis. This significantly enhances the coverage and constraining power of the SMS results. Further novelties of this release include:

- a new and more flexible database format;
- extended information on the topology coverage;
- inclusion of likelihood and  $\chi^2$  calculation for EM-type results;
- inclusion of a database browser tool for easy access to the information stored in the database;
- performance improvement for the decomposition of the input model;
- inclusion of new simplified model results to the database, including a few 13 TeV results;
- overall significant speedups of the code and the database.

The purpose of this paper is to present these new features, describing in detail the concepts and procedures used in the code and the database. Particular attention is given to how upper limits and efficiency maps are dealt with simultaneously.

The (re-)interpretation of LHC searches, which is the main goal of SModelS, has recently become a very active field. Several other public tools have been developed by different groups. In particular, FastLim [9] and XQCAT [10] employ pre-computed efficiency maps to constrain, respectively, the minimal supersymmetric standard model (MSSM) and extra heavy quark scenarios. SUSY-AI [11] is a code which has been trained with machine learning techniques to reproduce the ATLAS exclusion for the phenomenological MSSM. Finally, CHECKMATE [12,13], MADANALYSIS5 [14,15], Rivet ( $\geq 2.5$ ) [16] and GAMBIT's ColliderBit [17,18] allow for more general recasting of ATLAS and CMS searches based on Monte Carlo event simulation. Last but not least, Contur [19] aims at constraining BSM scenarios from differential Standard Model measurements based on the Rivet [16] toolkit.

The rest of the paper is organized as follows. We start in Section 2 by explaining the basic concepts of SModelS, including the structure of UL-type and EM-type results and of the database of experimental results. In Section 3, we then discuss in detail the decomposition procedure, the computation of the theory predictions, the comparison of theory predictions against the experimental results, and how missing topologies are identified. How to run SModelS is shown in Section 4. Section 5 contains conclusions and an outlook.

Installation instructions are provided in Appendix A. Appendix B describes some useful SModelS-internal tools, while Appendix C provides information about ‘home-grown’ efficiency maps included in the database. A complete, browsable manual and an extensive code documentation are provided in html format in the ‘docs’ folder of the distribution; they are also available online at [20].

In case of problems using SModelS, we kindly ask the user to contact the authors via `smodels-users@lists.oeaw.ac.at`.

### Note:

When using SModelS v1.1 for scientific work (or any other purposes), please cite this paper as well as the original SModelS publication [6]. In scientific publications, please also cite the programs SModelS v1.1 makes use of: PYTHIA 6.4 [21] and/or PYTHIA 8.2 [21,22], NLLFAST [23–29], and PySLHA [30]. For convenience, these citations are provided as a bibtex file in the SModelS distribution.

We also strongly recommend to cite all the experimental results used; a separate bibtex file is provided to that effect in the SModelS database folder. In case you use the FastLim efficiency maps in SModelS (see ‘adding FastLim data’ in Appendix B), please also properly cite FastLim [9] and the relevant experimental results. These references are also provided in a bibtex file with the distribution.

<sup>1</sup> Charged tracks may also be treated in an SMS context [8] and will be available in future versions of SModelS.

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