SModelS: A Tool for Making Systematic Use of Simplified Models Results

Wolfgang Waltenberger (on behalf of the SModelS group)

Institute for High Energy Physics, Austrian Academy of Sciences, Nikolsdorfergasse 18, 1050 Wien, Austria
E-mail: walten@teilchen.at

Abstract. We present an automated software tool "SModelS" to systematically confront theories Beyond the Standard Model (BSM) with experimental data. The tool consists of a general procedure to decompose such BSM theories into their Simplified Models Spectra (SMS). In addition, SModelS features a database containing the majority of the published SMS results of CMS and ATLAS. These results consist of the 95% confidence level upper limits on signal production cross sections. The two components together allow us to quickly confront any BSM model with LHC results. As a show-case example we will briefly discuss an application of our procedure to a specific supersymmetric model.

It is one of our ongoing efforts to extend the framework to include also efficiency maps produced either by the experimental collaborations, by efforts performed within the phenomenological groups, or possibly also by ourselves.

While the current implementation can handle null results only, it is our ultimate goal to build the Next Standard Model in a bottom-up fashion from both negative and positive results of several experiments. The implementation is open source, written in python, and available from http://smodels.hephy.at.

1. Introduction

The discovery of a Higgs-like boson [1, 2] has been announced with much fanfare in July 2012, marking the end of a fifty-year old quest to complete the Standard Model. And yet, many questions remain unanswered, notably the question about the particle nature of dark matter, or the puzzle of the stability of the electroweak scale. Many theoretical frameworks have been devised that aim at solving these questions. It is common to many of them that they predict partners of Standard Model particles at energies \( \lesssim 2 \) TeV. No such particles have been discovered to date by the CMS and ATLAS experiments at the LHC, though a whole slew of searches has been conducted [3, 4]. So indeed, the Higgs boson is likely to have been found, but where is the physics that stabilizes its mass?

Simplified Models

It has become common practise to present one’s results of searches for BSM physics in terms of SMSes, quantifying the result as an upper limit on the cross section of the produced BSM particles, as a function of the BSM particles’ masses, see Fig. 1 (left). It is the aim of this work to make maximum usage of the published SMS results, enabling us to take an arbitrary BSM model and quickly compare it against an entire database of SMS results.
2. The Procedure
The SModelS procedure can be split up into a few subtasks, such as:

- the decomposition of the full model into its SMS equivalent “elements”,
- the potential compression of elements,
- the potential combination of elements to match experimental results,
- and finally the comparison of the theoretically predicted cross section with the experimentally given upper limit on that cross section.

In what follows, we shall discuss briefly each step of the procedure.

2.1. Decomposition
The main guiding principle of the SModelS framework is that the signal efficiencies of a given analysis depends mostly on the event kinematics and is not majorly affected by the idiosyncrasies of a particular model. That way, it is possible for us to

- decompose a full model into its Simplified Models Spectrum,
- describe this spectrum in terms of SMS equivalent elements. These elements depend only on the final state SM particles plus a dark matter candidate (DMC), the masses of the BSM particles, and the element’s production cross section times branching ratio.

Fig. 2 shows this description of an element. As a next step, a formalism has been devised that describes our SMS equivalent elements in a single, simple string, by making use of a square bracket notation to distinguish between branches and vertices, respectively, and assigning letters to the SM particles, as can been seen in Fig. 1 (right). In the current implementation, a fundamental $\mathbb{Z}_2$-symmetry is assumed, making it unnecessary to mention the dark matter particle explicitly in our formalism – it is expected to terminate the decay chains of every branch.

2.2. Compression
In case the difference in mass between two subsequent BSM particles in a given decay chain is small, it is assumed that the emergent SM particles are too soft to be detected by the LHC experiments. In that case these soft particles are omitted from the description of the
topology: the topology is “compressed” – see Fig. 3. Likewise, in the case that multiple invisible particles appear at the end of a decay chain – such as a DMC and a neutrino – the particles are experimentally indistinguishable from a single invisible particle of a mass that is the equivalent of the invariant mass of the sum of all invisible particles. In this case, the topology is compressed accordingly: the invisible particles are replaced by a single invisible particle with the corresponding mass.

2.3. The Database of SMS Results
Another essential building block of the SModelS framework is its database of experimental results. Taking SMS results like Fig. 1 as the input data, its meta information such as the analysis’ integrated luminosity, its center-of-mass energy, or the analysis “id” (e.g. ATLAS-CONF-2012-105, or SUS-12-005) is stored alongside with the efficiency maps and cross section upper limit maps published by the experiments, see Tab. 1. In addition, the efficiency and upper limit maps are described in the SModelS formalism in the aforementioned table, in a field coined “constraint”, referring to the fact that the label defines what part of a full model is constrained by that experimental result. At times, additional conditions have to be met in order for an experimental result to be applicable to a specific full model. Such conditions are also described in terms of our SMS labeling formalism. The according entry in the database is called “fuzzycondition”. See Ref. [6] for examples of such conditions, and also for a full list of the results that entered the database.

2.4. Putting it All Together
Once a full model is decomposed according to the procedure described in Sec. 2.1, the model is ready to be tested against the database of SMS results. In case an experimental result matches not a single but an entire set of elements (such as is the case for e.g. \([\{l\}, \{l\}, \{l\}, \{l\}\]) – it
matches both the case of electrons and muons), the two elements are combined, which is to say that their cross sections times branching ratios are added up – see Fig. 4. The experimental upper limit on the cross section can then be directly compared against the theoretical prediction, and the full model is either excluded by this specific analysis or not. Finally, the most important elements that are not covered by any analysis are identified; they are dubbed “missing topologies”.

**Figure 4.** The working principle of SModelS

### 3. A Simple Application

SModelS v1.0 has already been applied to a variety of full models (see e.g. Refs. [7–12]); in this document we only exemplarily show one result of a study that targets a low-fine tuning scenario within the pMSSM, see Ref. [12]. The scenario itself has been defined in Ref. [13]. Fig. 5 shows the distribution of the missing topologies, as a function of $m_{\tilde{t}_1}$ and $m_{\tilde{\chi}^0_1}$ (leaving out weakino production): in order to constrain the stop mass in the low-fine tuning scenario, it can be seen that it is beneficial to consider pair-produced stop and sbottom particles with subsequent hadronic decays of SM vector bosons.

**Table 1.** Metadata describing the SMS result in Fig. 1
4. Conclusion

A tool has been presented that allows for an automatic comparison of a full model with SMS results. It is based on a method to decompose a given full model into its SMS topologies, a database of SMS results, a formalism to describe what a certain SMS result constrains, and a framework that finally matches the theoretical predictions of a given SMS topology with experimental results. Support for heavy stable charged particles has already been realized as a patch to SModelS [7]; it will eventually become a part of SModelS proper.

Acknowledgements

We thank the ATLAS and CMS SUSY groups for helpful discussions on their results, and in particular for providing (most of) the SMS cross section upper limits used here in digital format. This work is supported in part by the French ANR project DMASTROLHC, the “New Frontiers” program of the Austrian Academy of Sciences, the “Investissements d’avenir, Labex ENIGMASS”, and by the “Fundação de Amparo à Pesquisa do Estado de São Paulo”.

References

[1] Aad G et al. (ATLAS) 2012 Phys. Lett. B716 1–29 (Preprint 1207.7214)
[2] Chatrchyan S et al. (CMS) 2012 Phys. Lett. B716 30–61 (Preprint 1207.7235)
[3] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
[4] https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
[5] Khachatryan V et al. (CMS) 2014 Eur. Phys. J. C74 3036 (Preprint 1405.7570)
[6] Kraml S, Kulkarni S, Laa U, Lessa A, Magerl W, Proschotko-Spindler D and Waltenberger W 2014 Eur. Phys. J. C74 2868 (Preprint 1312.4175)
[7] Heisig J, Lessa A and Quertenmont L 2015 JHEP 12087 (Preprint 1509.00473)
[8] Belanger G, Drieu La Rochelle G, Dumont B, Godbole R M, Kraml S and Kulkarni S 2013 Phys. Lett. B726 773–780 (Preprint 1308.3735)
[9] Grober R, Mühleitner M, Popenda E and Wlotzka A 2015 Phys. Lett. B747 144–151 (Preprint 1502.05935)
[10] Belanger G, Ghosh D, Godbole R and Kulkarni S 2015 JHEP 09 214 (Preprint 1506.00665)
[11] Barducci D, Belanger G, Hugonie C and Pukhov A 2016 JHEP 01 050 (Preprint 1510.00246)
[12] Magerl V 2015 Master’s thesis TU Wien
[13] Cahill-Rowley M, Hewett J L, Ismail A and Rizzo T G 2013 Community Summer Study 2013: Snowmass on the Mississippi (CSS2013) Minneapolis, MN, USA, July 29-August 6, 2013 (Preprint 1307.8444)