Aspects of E_6 Inspired Supersymmetric Models

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Thesis submitted for the degree of
Doctor of Philosophy

May 2017

Contents

Abstract

Supersymmetry (SUSY) is currently one of the best motivated extensions of the Standard Model (SM) of particle physics. Softly broken SUSY naturally stabilises the electroweak scale against large quantum corrections, without the unnatural fine tuning required in the SM. However, experimental searches for superpartners and the observed 125 GeV Higgs mass now imply that large corrections again arise in the minimal supersymmetric standard model (MSSM), reintroducing the need for fine tuning.

In this thesis, we study a class of non-minimal E_6 inspired SUSY models that are partially motivated by solving these and other problems of the MSSM. A unified E_6 gauge group at high energies is assumed to lead to a low-energy theory with one or more additional $U(1)$ gauge symmetries and extra matter content compared to the MSSM. To facilitate the study of these and other Beyond the Standard Model theories, we implement several extensions to existing automated tools, significantly improving their capabilities and range of applicability.

In the simplest E_6 inspired models, additional contributions to the Higgs mass reduce the need for large radiative corrections but introduce a new source of fine tuning associated with a massive Z' boson. By considering several such models at low energies, we show that experimental limits on the mass of this state imply a minimal amount of fine tuning is required to reproduce the electroweak scale. The severity of this fine tuning is also shown to depend strongly on the details of the gauge symmetry breaking.

We next consider an alternative E_6 model with a single, exact custodial symmetry. This custodial symmetry, combined with an automatically conserved matter parity, implies the existence of two dark matter candidates in the model. We explore the parameter spaces of constrained versions of this model and the MSSM in which one dark matter candidate is a MSSM-like mixed bino-Higgsino or pure Higgsino state. We find that the dark matter relic density may be reproduced while satisfying experimental constraints, and that light exotics may be discoverable at the Large Hadron Collider. We conclude by investigating the impacts of current and future direct detection searches on the parameter spaces of both models.

Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship

Signed _____ Date _____

Acknowledgements

This thesis would not have come about were it not for the many brilliant people who worked with and supported me. I would like to thank my supervisor Tony Williams, whose guidance and sage advice encompassed day-to-day questions about physics to all things academic, and more besides. Thanks also to my supervisor Martin White for his useful hints and ideas during my candidature. Special thanks are due to my collaborators, from whom I have learned a tremendous amount. To Peter Athron, for his keen insights and for allowing me to work on all sorts of interesting projects. To Roman Nevzorov, for his incredible knowledge and answers to all sorts of questions. Thank you both for your patience, kindness, and for countless enlightening and entertaining discussions. Further afield, thanks also to Alexander Voigt, for sharing his unsurpassed talents in coding and all kinds of awesome suggestions for improvements, new ideas and things to try.

I would also like to thank the staff and students of the CSSM and CoEPP for their help and support, and for the friendly environment in which to work. In particular, thanks to Alex Chambers, Taylor Haar, Filip Rajec, Michael Evans, Jake Forster and my office mates for the many shared laughs, and conversations ranging from the very helpful to the outright random.

During my candidature I was fortunate to be supported by the generosity of Peggy Barker through the Barker Tong Scholarship in Physics. I am very grateful for her support and encouragement, her interest in how our research progressed, and for reminding me to spend time out of the office as well as in it.

For this I can also thank my friends, for barbecues, book suggestions, and, occasionally, just for a much needed distraction.

Finally, thanks to my wonderful family, including my siblings Katie, Jordan and Emily, for always being there, even when I was not. Most especially, thank you to my parents Richard and Julia. Without their hard work and love I would not be where I am today.

List of Publications

The results of the research described in this thesis have appeared in the following publications, with the corresponding chapters also given:

- P. Athron, D. Harries, and A. G. Williams, Phys. Rev. **D91**, 115024 (2015), arXiv:1503.08929 [hep-ph] (Chapter 5)
- P. Athron, D. Harries, R. Nevzorov, and A. G. Williams, Phys. Lett. **B760**, 19 (2016), arXiv:1512.07040 [hep-ph] (Chapter 7)
- F. Staub, P. Athron, L. Basso, M. D. Goodsell, D. Harries, M. E. Krauss, K. Nickel, T. Opferkuch, L. Ubaldi, A. Vicente, and A. Voigt, Eur. Phys. J. **C76**, 516 (2016), arXiv:1602.05581 [hep-ph] (Chapter 4)
- P. Athron, D. Harries, R. Nevzorov, and A. G. Williams, JHEP **12**, 128 (2016), arXiv:1610.03374 [hep-ph] (Chapter 6 and Chapter 7)

Additionally, the work on a semi-analytic boundary value problem solver algorithm described in Chapter 4 forms one part of a major update to the public software package `FlexibleSUSY` (P. Athron, M. Bach, D. Harries, J.-h. Park, D. Stöckinger, A. Voigt, and J. Ziebell, in preparation).

Within the chapters presenting original work carried out during this thesis, the discussion naturally focusses on those parts of the research that I carried out. In particular, in Chapter 4 the generalisation of the semi-analytic boundary value problem solver to generic models and its implementation in `FlexibleSUSY`, along with the implementation of a fixed point root finding algorithm and the implementation of loop induced decays, is my own work. Although together with my co-authors I was also involved in the model validation and the documentation of the additional extensions to `FlexibleSUSY` described in the above publications, detailed discussions of these aspects of the work are omitted. Similarly, the numerical results presented in Chapters 5 and 7 are my own work.