

Aspects of E_6 Inspired Supersymmetric Models

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Contents

| | |
|---|-------------|
| Abstract | vii |
| Statement of Originality | ix |
| Acknowledgements | xi |
| List of Publications | xiii |
| 1 Introduction | 1 |
| 2 The Minimal Supersymmetric Standard Model | 9 |
| 2.1 Field Content and Interactions | 9 |
| 2.2 The Phenomenological MSSM | 13 |
| 2.3 The Constrained MSSM | 16 |
| 2.4 Electroweak Symmetry Breaking | 20 |
| 2.5 The Particle Spectrum of the MSSM | 25 |
| 2.5.1 The MSSM Higgs Sector | 26 |
| 2.5.2 The Neutralino and Chargino Sectors | 28 |
| 2.5.3 The Sfermions | 30 |
| 2.6 Why Might the MSSM not be Enough? | 32 |
| 3 E_6 Inspired Supersymmetric Models | 37 |
| 3.1 $U(1)$ Extensions of the MSSM | 37 |
| 3.2 The Exceptional Supersymmetric Standard Model | 42 |
| 3.3 Gauge Symmetry Breaking in the E_6 SSM | 49 |
| 3.4 The Particle Spectrum of the E_6 SSM | 52 |
| 3.4.1 Exotic States | 54 |
| 3.4.2 The E_6 SSM Higgs Sector | 57 |
| 3.4.3 The Neutralino Sector | 59 |

| | | |
|----------|---|------------|
| 4 | Extensions to Mass Spectrum Generators for BSM Models | 63 |
| 4.1 | Automated Tools for BSM Models: Benefits and Limitations | 63 |
| 4.2 | Semi-analytic RGE Solutions in General Models | 67 |
| 4.2.1 | SUSY Models | 68 |
| 4.2.2 | Non-SUSY Models | 72 |
| 4.3 | The Semi-analytic BVP Solver Algorithm | 74 |
| 4.3.1 | Review of the Two-scale Algorithm | 75 |
| 4.3.2 | Implementation of the Semi-analytic BVP Solver Algorithm | 80 |
| 4.3.3 | Tests and Comparisons of the BVP Solvers | 84 |
| 4.4 | Loop Induced Decays | 90 |
| 5 | Fine Tuning in the E_6SSM | 99 |
| 5.1 | A New Source of Fine Tuning | 99 |
| 5.2 | Measures of Fine Tuning | 101 |
| 5.3 | Calculating Fine Tuning in the E_6 SSM | 106 |
| 5.4 | Naturalness Impact of Z' Limits in the E_6 SSM | 111 |
| 5.4.1 | Stop Mass Fine Tuning | 111 |
| 5.4.2 | Fine Tuning at Low Energies | 113 |
| 5.5 | Benchmark Scenarios | 117 |
| 5.6 | Alternative E_6 Inspired Models | 121 |
| 5.7 | Conclusions | 123 |
| 6 | An E_6 Inspired Model with Exact Custodial Symmetry | 127 |
| 6.1 | An Alternative to the E_6 SSM | 127 |
| 6.2 | The SE_6 SSM and the CSE_6 SSM | 129 |
| 6.3 | Gauge Symmetry Breaking in the SE_6 SSM | 134 |
| 6.4 | Modifications to the Particle Spectrum | 139 |
| 6.4.1 | The Neutralino Sector | 141 |
| 6.4.2 | The Exotic Sector | 143 |
| 6.4.3 | The Higgs Sector | 147 |
| 7 | Dark Matter Scenarios in the CSE_6SSM | 155 |
| 7.1 | Dark Matter in BSM Models | 155 |
| 7.1.1 | Calculation of the Relic Density | 156 |
| 7.1.2 | Direct Detection of Dark Matter | 158 |
| 7.2 | Scanning the CSE_6 SSM Parameter Space | 160 |
| 7.3 | Mixed Bino-Higgsino Dark Matter | 166 |

| | | |
|----------|---|------------|
| 7.4 | Pure Higgsino Dark Matter | 173 |
| 7.5 | Benchmark Scenarios | 177 |
| 7.6 | Impact of Current and Future Searches | 181 |
| 7.7 | Conclusions | 186 |
| 8 | Summary | 189 |
| A | Review of SUSY Model Building | 193 |
| A.1 | The Super-Poincaré Algebra | 193 |
| A.2 | Superspace and Superfields | 196 |
| A.3 | Supersymmetric Lagrangians | 200 |
| B | Approximate RGE Solutions in the MSSM | 205 |
| C | Approximate RGE Solutions in the E_6SSM | 209 |
| D | SE_6SSM RGEs | 235 |
| D.1 | Gauge Couplings | 235 |
| D.2 | Superpotential Trilinear Couplings | 237 |
| D.3 | Superpotential Bilinear and Linear Couplings | 244 |
| D.4 | Gaugino Masses | 245 |
| D.5 | Soft-breaking Trilinear Scalar Couplings | 246 |
| D.6 | Soft-breaking Bilinear and Linear Couplings | 269 |
| D.7 | Soft Scalar Masses | 272 |
| | Bibliography | 309 |

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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Signed

Date

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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.