Strong supersymmetry: A search for squarks and gluinos in hadronic channels using the ATLAS detector
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High energy physics is the branch of science devoted to the study of the smallest, fundamental particles of the universe. The Standard Model of particle physics, constructed in the second half of the 20th century, describes all known fundamental particles and three of the four interactions between them; only gravity is not included. It has been extremely successful in describing physics at the smallest length scales, by making precise, verifiable predictions. Such predictions include the existence of the messenger particles of the weak interaction, the $W^\pm$ and $Z$ bosons, which were discovered in 1983 at CERN in Geneva, and of the heaviest quark, the top quark, discovered in 1995 at Fermilab in the US.

The last missing piece of the Standard Model puzzle was discovered at CERN in 2012: the Higgs boson. Introduced in the theory in the 1960s, it is part of a mechanism breaking the so-called electroweak symmetry, resulting in massive Standard Model particles. With the Higgs particle discovered, and the Standard Model complete, at first glance particle physics seems to have come to its conclusion. However, looking closer, there are several issues with the model.

The astronomical discovery of dark matter, which seems to have no or very weak interactions with ordinary matter except via gravity, has led to the belief that the Standard Model does not describe all the particles in the universe. Only 18% of all matter in the universe is normal Standard Model matter, with dark matter being much more abundant. The accelerating expansion of the universe points to a form of energy which cannot be accounted for by the current physical theories, dubbed dark energy. Furthermore, since if in the early universe equal amounts of matter and anti-matter would have been generated, it would have all annihilated, there must have been a matter-antimatter asymmetry. The current Standard Model does not lead to the required magnitude for the asymmetry.

There is also a theoretical issue with the model. Radiative corrections to the Higgs boson mass raise it to very high scales. The existence of the electroweak scale ($O(100)$ GeV) at which the Higgs boson acts is therefore in some sense unnatural. This scale problem is known as the hierarchy problem.

Many theories have been devised to solve these issues, one of which is supersymmetry, which states that a symmetry exists in nature between fermions, particles with half-integer spin, and bosons, having integer spin. In supersymmetry, each known Standard Model particle has a partner particle with the same properties except for its spin, which differs by half a unit. Since none of these particles have been discovered so far, supersymmetric particles need to be heavier than their partners. This can be achieved by breaking the symmetry. Supersymmetry is currently the most researched
theory providing a solution to the hierarchy problem while being able to provide a candidate for a dark matter particle.

To test the Standard Model, particle accelerators are used, which accelerate particles and collide them at high centre-of-mass energies. From the relationship between energy and mass, \( E = mc^2 \) (made famous by Einstein), it becomes clear that the energy of two particles which collide with high velocity can be transformed into mass of heavier particles. However, the heavier the mass of produced particles, the higher the initial energy needs to be. To search for supersymmetric particles, the Large Hadron Collider (LHC) at CERN is used. The LHC accelerates protons to 99.9999% of the speed of light, and collides them with a centre-of-mass energy of 8 TeV\(^1\). The decays of the particles produced in the collisions are detected by particle detectors, such as the ATLAS detector.

Previous experiments have not found evidence for supersymmetric particles, and set limits on the mass of supersymmetric particles. However, with the high collision energies achieved at the LHC the searches for these particles have entered a new realm of possibilities. This thesis describes a search for supersymmetry with the ATLAS detector. We search for supersymmetry by studying discrepancies from the Standard Model in data recorded by ATLAS.

**Thesis outline**

This thesis is organised as follows: a theoretical foundation is provided in chapter 1, which covers the theory of the Standard Model of particle physics in short, and subsequently describes several of its shortcomings. The second half of the chapter discusses the theory and phenomenology of supersymmetry, motivating the search for supersymmetry in LHC collisions. Chapter 2 describes the design and performance of the LHC and the ATLAS detector. The operating performance of the semiconductor tracker, one of the tracking components of ATLAS for which I was responsible for monitoring the efficiency, is treated in greater detail.

The rate of supersymmetric particle production is given by the production cross section, which is computed numerically with inputs from analytical calculations and experimental results, such as parton distribution functions. Both these components have uncertainties, which need to be propagated to uncertainties on the cross sections for supersymmetric particle production. I have been responsible for developing a framework to calculate these cross sections and their uncertainties for SUSY signal processes. This framework is used by the SUSY working group in ATLAS, and is described in chapter 3.

Particles traversing the detector are not observed directly, but need to be reconstructed from electronic detector signals. This event reconstruction is discussed in chapter 4, where also the data simulation using Monte Carlo techniques is described. If strongly interacting supersymmetric particles are present in nature with masses around 1 TeV, they should be abundantly produced in LHC collisions and subsequently decay into highly energetic quarks, possible leptons and undetectable stable particles.

\(^1\) TeV is equivalent to the energy of a flying mosquito, which consists of the order of \(10^{23}\) atoms.
Therefore, we use the reconstructed events to search for these types of supersymmetric particles in events with energetic jets and high missing transverse momentum without electrons or muons. This search, using 5.8 fb$^{-1}$ of $\sqrt{s} = 8$ TeV data, is discussed in detail in chapter 5. I have been working on this analysis and its predecessor, conducted on $\sqrt{s} = 7$ TeV data, since 2011. Within the group of ATLAS physicists collaborating on this analysis, I have been in charge of defining the analysis for certain supersymmetric scenarios with small mass differences between the supersymmetric particles, including the signal grid definition, analysis optimisation and setting the exclusion limits. Furthermore, I have worked on other areas of the analysis, such as the background estimation and the analysis framework development and maintenance.

Finally, in chapter 6 the results and implications of this analysis are discussed, and compared to other SUSY analyses done by ATLAS.