

Preface

Concepts of fundamental states or elements have been developed independently by several ancient civilizations several centuries before the Common Era, such as the concept of indestructible particles, which was devised in Greece and India, for example. However, the scientific discipline of particle physics is rather young. The first elementary particle to our current knowledge, the electron, was only discovered at the end of the nineteenth century. The discovery of quantum mechanics and special relativity, around the same time, allowed for the development of theories of the fundamental interactions. The first successful description of interactions between fundamental particles, quantum electrodynamics, was developed only in the 1940s.

During the past century, huge efforts on both theoretical and experimental sides have led to the current description in particle physics, the standard model (SM) of particle physics. It describes, within the common framework of relativistic quantum field theory, the interactions between elementary particles for three out of the four known fundamental forces: the strong force described by quantum chromodynamics, and the weak and electromagnetic forces, described by the electroweak theory. For gravitation, the “oldest” known fundamental force, no successful description at short distances exists. Up to the time of this writing, 17 elementary particles (not counting the antiparticles) have been observed: six quarks, six leptons, four gauge bosons, and a boson, which is likely the Higgs boson.

The observations of a huge amount of experiments have proven the validity of the SM to an extremely high precision for all accessible energy scales. Despite this unprecedented success of the SM, several theoretical indications and experimental measurements clearly point to physics beyond the SM. The observation of neutrino oscillations or the evidence of dark matter find no explanation within the SM. The missing description of quantum gravity, which is important for energies around the Planck scale, $M_{\text{Planck}} \sim 10^{18}$ GeV, requires a new theoretical framework. These and other arguments place the SM as an effective low-energy theory, valid for energies up to the electroweak scale, $v \sim 246$ GeV.

In order to overcome some of the shortcomings of the SM, multiple theories have been developed. One very popular theory is supersymmetry (SUSY). The SM

is extended by an additional symmetry between bosons and fermions: for each elementary particle in the SM, there exists a partner particle, which differs in spin by one half. Because of the breaking of the symmetry, these particles are much heavier than their SM counterparts and have not yet been observed. The model of SUSY provides elegant solutions to multiple problems, for example, the problem of dark matter mentioned above: the lightest new particle within the SUSY framework could be a candidate for the dark matter particle.

Yet, no observation of supersymmetric particles or other evidence for SUSY have been found so far.

With the construction of the Large Hadron Collider (LHC), a new energy regime has been made accessible: the energy frontier has been pushed up to the TeV scale. If supersymmetric particles exist, they will likely have masses around this scale. Therefore, the general purpose detectors at the LHC should be able to discover them.

In this dissertation, a search for supersymmetric particles produced in proton–proton (pp) collisions is presented. The search is performed using data collected by the Compact Muon Solenoid (CMS) experiment at a center of mass energy of $\sqrt{s} = 8$ TeV. The data sample corresponds to an integrated luminosity of 19.5 fb^{-1} . This search uses primarily the kinematic variable M_{T2} for discriminating between new physics candidate events and events from SM processes. This variable is a generalization of the transverse mass to the case of the pair production of two particles, which both decay semi-invisibly.

The variable M_{T2} is also used in a study for evaluating the feasibility of a search for the production of supersymmetric partner particles of the top quark in events containing two charged leptons. In many SUSY scenarios, the supersymmetric top quark partner is the lightest strongly produced supersymmetric particle. Therefore, several dedicated searches for this particle are designed. The study presented here shows the possibility of using various variables to discriminate between the SUSY signal events and events from the main SM background process, $t\bar{t} + \text{jets}$.

It has been decided that the full potential of the LHC will be exploited by an upgrade of the LHC machine around 2022. The upgrade will increase the instantaneous luminosity of the LHC by approximately a factor ten, thus allowing for the collection of pp collision data corresponding to about 3000 fb^{-1} . The upgrade will require also the experiments to be upgraded.

Already before the year 2022, the innermost detector of the CMS experiment, the pixel detector, will have to be replaced because of radiation damages. The replacement will be used to change the pixel detector design. In this dissertation, a study of the physics performance of this upgrade is shown with focus on the capability of tagging jets, which come from b -quark hadronization. The study is performed in the context of SUSY using the event selection of the $M_{T2}b$ search, which was performed during 2011 for the analysis of 7 TeV pp collision data.

It is expected that by 2022, the forward part of the electromagnetic calorimeter of the CMS experiment will also need to be replaced due to high radiation damages. A study of the long-term evolution of the signals produced in this forward part is

presented using in-situ data of the light monitoring system of the calorimeter. Comparisons with laboratory measurements preceding the construction of the CMS experiment are discussed. The correlations between these laboratory measurements and the in-situ data are used to disentangle various components that contribute to the change in signal measurements of the calorimeter.

The thesis is organized as follows: in Chap. 1, the theoretical aspects of the SM relevant for high energy physics are reviewed. Then, in Chaps. 2 and 3, SUSY and consequent signatures at the LHC are introduced. In Chap. 4, the LHC accelerator and CMS detector are described, followed by a description of the reconstruction of basic physics objects in Chap. 5. In Part II of the thesis, the search for SUSY is covered: in Chap. 6, the main search variable, M_{T2} , and its kinematical properties are introduced. This chapter contains also a summary of the SUSY search performed at $\sqrt{s} = 7$ TeV. Chapter 7 is dedicated to the search for SUSY in hadronic final states using the M_{T2} variable with pp collision data collected at $\sqrt{s} = 8$ TeV. In Chap. 8, the feasibility study of a search for the pair production of scalar top quark partners is summarized. In Part III, studies related to the upgrade program of the CMS experiment are presented. After a short review of the upgrade program in Chap. 9, the physics performance study for the pixel detector upgrade is discussed in Chap. 10. Finally, Chap. 11 contains the evolution study of the electromagnetic calorimeter endcap signals. In Chap. 12, a summary is given.

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