Preface

The standard model of elementary particles is one of the most successful scientifical theories elaborated by mankind. Throughout the past century, its predictions have been confirmed with astonishing precision by numerous experiments, in conceptually distant fields and with a variety of experimental techniques. Its theoretical foundations, though, depended on a particle which had not been discovered.

The mass of the Higgs boson is not constrained by the theory, and is allowed to vary in a wide range. Numerous experiments have unsuccessfully pursued its search, but have been able only to exclude its existence in certain mass ranges. The analyses conducted at the detectors operating at the LEP collider at CERN have set a lower bound of 114.4 GeV, whereas the searches performed at the Tevatron at Fermilab have excluded the 156–177 GeV range.

The Large Hadron Collider (LHC) is the particle accelerator which has been built with the aim of producing definitive proof regarding the Higgs boson's existence. It is a superconducting proton collider, with a center of mass energy of 7 TeV. It has the capability of spanning a wide energy range, up to the TeV scale.

The Compact Muon Solenoid (CMS) is one of the four main experiments which analyzes the collisions produced at the LHC. It is a general-purpose detector which has been designed in order to maximize its performance in Higgs boson searches.

The discovery of a Higgs boson depends on its decay products, as it is an unstable particle. If its mass is large enough, the decay to pairs of electroweak vector bosons dominates the particle's decay channels. The production of a Z boson pair, in particular, constitutes the most promising final state in search-oriented analyses. The requirement that at least one of the two Z bosons decays to a light charged lepton pair, in fact, significantly reduces the possible sources of background at a hadron collider.

On July 4, 2012, the CMS and ATLAS experiments have both reported evidence for a narrow resonance with mass close to 125 GeV, with properties compatible with those of a Higgs boson. A crucial role in this discovery was played by the fully leptonic decay channel $\mathrm{H} \rightarrow \mathrm{ZZ} \rightarrow 4\ell$.

In this thesis, we have conducted a search for a heavy Higgs boson in the $\mathrm{H} \rightarrow \mathrm{ZZ} \rightarrow \ell^+\ell^-\mathrm{q}\overline{\mathrm{q}}$ decay channel, with 4.6 fb^{-1} of data collected by the Compact Muon Experiment. The presence of jets in the final state poses a series of challenges to the experimenter: both from a technical point of view, as jets are complex objects and necessitate of ad hoc reconstruction techniques, and from an analytical one, as backgrounds with jets are copious at hadron colliders; therefore, analyses must obtain high degrees of background rejection in order to achieve competitive sensitivity.

The first chapter of this thesis offers a brief introduction to the theoretical foundations of the standard model and the reasons which conjure to the postulate of the existence of the Higgs boson. It further offers an overview of the constrains on the Higgs boson mass before the LHC era, both on an experimental and on a theoretical point of views. It then inspects how Higgs boson searches may be conducted at the LHC, offering an overview of the most promising high-mass analyses and describing the $H \to ZZ \to \ell^+\ell^- q\overline{q}$ channel in more detail, highlighting its main aspects.

Chapter 2 offers a detailed description of the experimental apparatus. The LHC is introduced, and the Compact Muon Experiment is described in its various subdetectors. Particular emphasis is given to the electron and muon reconstruction algorithms.

The challenges posed by jet reconstruction are faced in Chap. 3. After an overview on the general aspects of jet reconstruction, we will give insight on the jet calibration scheme employed at CMS, and show how photon+jet events can be successfully used to measure jet reconstruction performance and resolution on data. More detail is given on the full event reconstruction technique employed at CMS, known as the 'Particle Flow', which allows a significant improvement in jet reconstruction performance over more traditional, calorimeter-based approaches.

The analysis event selection is presented in Chap. 4 , which includes a detailed account of the analyzed data samples, the trigger, and preselection requirements. The analysis, as will be shown, will be split into different categories based on jet flavor tagging information, and an optimization will be performed in each category. The main tool of background discrimination is provided by an angular likelihood discriminant, capable of selecting events likely to originate from the decay of a scalar boson, and discriminate nonresonant backgrounds. The chapter also details the strategy for evaluating the background directly on the data.

Possible sources of systematic uncertainties are investigated in Chap. 5. A number of different effects are scrutinized, ranging from trigger to object reconstruction, from theoretical uncertainties to those related to the quality of the simulation modeling.

In Chap. 6, the events passing the selection requirements in 4.6 fb^{-1} of data collected by the CMS detector are examined, in the search of a possible signal compatible with the decay of a heavy Higgs boson, the modeling of which is shown in detail. We further describe the statistical tools which are adopted to perform such an analysis, and provide the results.

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