Abstract

The Standard Model (SM) of particle physics is very successful, yet it leaves many basic questions unanswered. This thesis is focused on some of these open problems. The aim of this study is to explore and exploit the origins of the matter-antimatter asymmetry in the Universe and the origins of dark matter (DM). Baryogenesis, the creation of the baryon asymmetry in the Universe, is a long-standing problem in cosmology. Sakharov formulated his well-known conditions for baryogenesis: baryon number violation, C and CP violation, and a departure from thermal equilibrium. Among the many particle physics scenarios that have been proposed in the past decades, electroweak baryogenesis is interesting. It has become apparent that the SM of electroweak interactions is unable to account for the observed magnitude of the BAU for at least two reasons. Firstly, the electroweak phase transition is not strongly first-order and therefore, any baryon asymmetry created during the transition would subsequently be washed out by unsuppressed baryon violating processes in the broken phase. Secondly, there is not enough CP violation from the CKM matrix to generate the baryon asymmetry.

With the motivation of investigating these problems, we extend the SM by a neutral complex scalar singlet, and a pair of heavy iso-doublet vector quarks (VQ). We consider the potential with a softly broken global U(1) symmetry, which we call the Constrained SM+CS model (cSMCS). Assuming nonzero vacuum expectation value for the complex singlet, we analyze the physical conditions for spontaneous CP violation. The mixing of SM quarks with heavy VQ pairs result in the appearance of additional CP violation. This model provides the strong enough first order EW phase transition and leads to a proper description of baryogenesis. The scalar spectrum of the cSMCS includes three neutral Higgs particles with the lightest one considered to be the 125 GeV SM-like Higgs boson found in 2012 at the LHC. In the considered model, the SM-like Higgs boson comes mostly from the SM-like SU(2) doublet, with a small correction from the singlet.

We present a prediction of the production rates of the cSMCS model Higgs bosons at the LHC, using a conventional effective LO QCD framework and the unintegrated parton distribution functions (UPDF) of Kimber-Martin-Ryskin (KMR). We first compute the SM Higgs production cross-section and compare the results to the existing calculations from different frameworks as well as to the experimental data from the CMS and ATLAS collaborations. It is shown that our framework is capable of producing sound predictions in this case. Therefore we use it for calculation of the cSMCS predictions for the Higgs boson production at the LHC. These predictions for yet undetected Higgs bosons of the cSMCS model may provide some clues for the future discovery.

On the other hand, the gravitational effects of DM have been observed in galaxies, clusters of galaxies, the large-scale structure of the Universe and the Cosmic Microwave Background Radiation. Since none of the particles in the cSMCS model satisfies these conditions, we introduce, in addition a SU(2) doublet with zero vacuum expectation value (The Inert Doublet). This model, that we call cIDMS has an exact Z_2 symmetry and provides correct relic density of DM while fulfilling direct and indirect DM detection limits and simultaneously agree with the LHC results.

The last part of this thesis is devoted to the applying Veltman condition in the Two Higgs Double Model (2HDM) in order to find the masses of the heavy scalars. The 2HDM is one of the simplest extensions of the SM, providing rich phenomenology. It contains an extended scalar sector which instead of one complex $SU(2)$ doublet presence in the SM contains two of the doublets, with weak hypercharges equal to 1. We analyze the soft Z_2 symmetry breaking version of the 2HDM with non-zero vacuum expectation values for both Higgs doublets (Mixed vacuum). We assume that CP is conserved in the scalar sector. In the particle spectrum of this model, there are two neutral CP-even scalars h and H, h being lighter than H. These scalars are two possible candidates for the SM-like Higgs boson, forming two possible scenarios. In the model, there are also a CP-even scalar (pseudoscalar) A and the charged Higgs bosons $H^{\pm}$. The results are constrained by comparing the properties of the light Higgs particle with the corresponding LHC data. We have found that the consistent solution exists only for the SM-like h scenario, with properties in agreement with the recent experimental data.