Abstract

The Standard Model (SM) of elementary particles has been able to accomodate almost every observed quantum physical process within a single theoretical framework. However, it is widely believed that the SM does not explain a complete picture as it fails to answer many fundamental problems such as the incorporation of fourth fundamental force i.e. gravitational force, absence of dark matter candidate, unification of the gauge couplings at high energies, and the origin of mass. In order to incorporate these aspects, New Physics models like Supersymmetry (SUSY), Extra-Dimensions, Grand Unified Theory (GUT), etc. have evolved over the time. The SM and these new models predict the existence of a particle called, the Higgs boson, which is supposed to be responsible for providing mass to all the fundamental particles. Many extensions of the SM also predict the existence of new heavy gauge bosons. Among these a simplest extension is the one that involves an additional $U(1)$ gauge group with an associated neutral gauge boson, usually labeled as $Z'$. A common one among such extensions is called Sequential Standard Model (SSM) that includes a neutral gauge boson $Z'_{SSM}$ with the same couplings to quarks and leptons as the Standard Model $Z$ boson. Although this model is not gauge invariant but it has been traditionally considered by experiments studying high-mass resonances. Other models, such as the superstring-inspired $E_6$ model, has more complex gauge group structure, $E_6 \rightarrow SO(10) \times U(1)_c$, with a corresponding neutral gauge boson denoted as $Z'_c$. Most of the studies performed in this subject assumed generation-independent gauge couplings for $Z'$ gauge bosons, but models also exist in which $Z'$ couples preferentially to the third generation fermions. In such non-universal scenarios, the sensitivity of the traditional searches for $Z'$ production using $e^+e^-$ and $\mu^+\mu^-$ final decay states may be substantially reduced, motivating the exploration of $\tau^+\tau^-$ decay states. Hence, the search in $Z' \rightarrow \tau^+\tau^-$ final states helps not only in testing the universality of the couplings but it will also help to establish the branching ratio of $Z' \rightarrow \tau^+\tau^-$ relative to $Z' \rightarrow e^+e^-/\mu^+\mu^-$ final states. The Large Hadron Collider (LHC) at CERN has been built to discover the Higgs boson and to probe such New Physics scenarios.
In this thesis, we report the results from the search of new heavy neutral gauge bosons, \(Z'\), using proton-proton collision data at center-of-mass energy \(\sqrt{s} = 7\) TeV and 8 TeV collected with CMS detector during LHC Runs in Years 2010, 2011, and 2012 respectively. The combined search comprises of four dominant decay channels of \(Z' \rightarrow \tau^+\tau^-\) production: \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_b\tau_b\), \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_\mu\tau_\mu\), \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_\tau\tau_\tau\), and \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_\tau\). where \(\tau\) and \(\tau_\mu\) refer to leptonically \((e, \mu)\) decaying tau-lepton while \(\tau_b\) refers to hadronically decaying tau-lepton. For LHC data of Run 2010 and Run 2011, the analyses performed in fully hadronic tau final state i.e. \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_b\tau_b\) have been presented in details while collision data of Run 2012 is used to perform analysis in \(Z' \rightarrow \tau^+\tau^- \rightarrow \tau_\mu\tau_\mu\) final state. The collision data for Run 2010 and Run 2011 corresponds to an integrated luminosity of 36.1 ±1.4 pb\(^{-1}\) and 4.94 ±0.11 fb\(^{-1}\), respectively. The studies performed with 2012 data corresponds to an integrated luminosity of 5.10±0.22 fb\(^{-1}\). The potential backgrounds are estimated mostly using data-driven techniques and excess of events above the Standard Model background predictions is looked for. To quantify the significance of any possible excess of observed events or to set an upper limit on the \(Z' \rightarrow \tau^+\tau^-\) production rate, we perform a fit of the invariant mass distribution of the two taus and employ Bayesian technique to interpret the results in terms of the upper 95% confidence level limits. The combined limit takes into account the correlation of systematic uncertainties within and across all the four decay channels.

The search performed with 2010 data did not reveal any excess of observed events over the Standard Model background predictions, hence, we excluded a \(Z'_{SSM}\) decaying to \(\tau^+\tau^-\) below mass 468 GeV/c\(^2\) which exceeded the previous best limit \((M_{Z'_{SSM};\tau^+\tau^-} > 399\) GeV/c\(^2\)) set by Tevatron experiments at Fermilab [1]. The search performed with higher statistics of 2011 data again showed no excess of observed events, enabling us to exclude a \(Z'_{SSM}\) decaying to \(\tau^+\tau^-\) below mass 1.4 TeV and \(E_\text{h}\) model \(Z'_{h}\) decaying to \(\tau^+\tau^-\) with mass less than 1.1 TeV. The details of the studies performed with 5.10 ± 0.22 fb\(^{-1}\) of 8 TeV data of LHC Run 2012 are also presented in this thesis. A similar search performed by ATLAS experiment with 4.7 fb\(^{-1}\) of 7 TeV data of LHC Run 2011, excluded \(Z'_{SSM} \rightarrow \tau^+\tau^-\) below mass 1.3 TeV [2].