Abstract

Introduction

In this thesis, we have presented some interesting and new results on various aspects of lepton masses, mixings and flavor violation in supersymmetric theories. We have focussed on some of the open challenges that the field of high energy physics faces today. Future experiments are very important in the sense that they can probably answer several important questions. Some of them are — is the physics of the dynamics of neutrino mass generation different from that behind the masses of all other known particles, what is the absolute value of the masses of neutrinos, what is the exact nature of the neutrinos (i.e., Dirac or Majorana), do neutrino interactions violate CP, which is the basis for understanding the matter–antimatter asymmetry of the universe, do we and all matter have descended from heavy neutrinos, does non standard interaction (NSI) of the neutrinos exist, is the lepton mixing matrix non unitary, what is the octant of atmospheric angle, and what is the model of beyond Standard Model theories, etc.

First we concentrated on model buildings relevant to neutrino masses and mixings in SO(10) theories using updated values of running quark and lepton masses in a framework of type II seesaw mechanism. Type II Seesaw mechanism mediates through induced scalar triplet vev and can generate neutrino masses in SO(10) model. This model has been used
earlier also, and is quite predictive in the sense that it uses 126 dimensional Higgs vev which relates masses of the Majorana neutrinos to both the Dirac mass as well as charged fermion masses. Our analysis in this work provides a benchmark for future works connected to model building in neutrino physics with a purpose to conceive the dynamical origin of neutrino mass and mixing.

Next we have explored cLFV processes constrained by the recent MEG experiment to test New Physics BSM theories and hence have predicted the masses of new supersymmetric particles, scalars, gauginos, sfermions that could be present at next LHC’s run. It is worth mentioning that detection of new particles at the second run of LHC will help immensely in the construction of beyond Standard Model theories.

Then, in the middle part of the thesis, we have evaluated favored values of leptonic CP violation phase $\delta_{CP}$ in neutrino sector, determined the nature of octant of $\theta_{23}$ and neutrino mass hierarchy in non SUSY SO(10) theory in the context of resolving the entanglement of quadrant of leptonic CPV phase and octant of $\theta_{23}$ at Long Baseline Neutrino Experiments. It may be noted that the above three values (i.e neutrino mass hierarchy, octant of $\theta_{23}$ and leptonic CPV phase $\delta_{CP}$) are still unknown in neutrino sector which needs to be determined precisely. In this regard we will calculate the baryon asymmetry of the Universe via leptogenesis in one flavor regime and predict the favored values of $\delta_{CP}$ consistent with the current BAU of the universe, $5.7 \times 10^{-10} < Y_B < 6.7 \times 10^{-10}$ (BBN).

Unitarity in $U_{PMNS}$ matrix is not yet established, and hence it has left scope for testing non unitarity in the leptonic sector which will result in various implications for New Physics theories in predicting the values of leptonic CPV phase, $\delta_{CP}$, Majorana phases, $\alpha$, $\beta$ and the absolute value of the neutrino masses. The interesting feature of our work is that we have evaluated the absolute value of lightest neutrino mass which is found to be consistent with the cosmological constraints on the sum of the neutrino mass bound, $\sum_i m(\nu_i) < 0.23$ eV from CMB, Planck 2015 data (CMB15+ LRG+ lensing + $H_0$) [37]. We note that absolute value of
lightest neutrino mass is also not known so far, and hence our prediction made here may be tested in future when experiments (including neutrinoless double beta decay experiments) will determine its value.

Outline of the thesis

In chapter 2, we will calculate neutrino masses and mixings at GUT scale, with updated values of running quark and lepton masses in minimal SO(10) Grand Unified Theory using type II Seesaw mechanism. We find that our calculated values of neutrino oscillation parameters agree with latest global fit values of these parameters. In chapter 3, we will study the rare cLFV decay $\mu \rightarrow e\gamma$ in $\mu$-$\tau$ symmetric SUSY SO(10) theories, using type I seesaw mechanism, in mSUGRA, NUHM and NUGM models. We have used the value of Higgs mass as measured at LHC, latest global data on the reactor mixing angle $\theta_{13}$ for neutrinos, and latest constraints of $\text{BR}(\mu \rightarrow e\gamma)$ as projected by MEG. We find that in mSUGRA very heavy $M_{1/2}$ region is allowed by future MEG bound of $\text{BR}(\mu \rightarrow e\gamma)$, though in NUHM case a low $M_{1/2}$ is also allowed. Hence we further studied the non universal gaugino mass model (NUGM). In mSUGRA, the $m_0$ values as allowed by MEG 2013 bound, shifts toward heavier spectrum, as compared to allowed $m_0$ of (which was allowed by a less stringent bound of MEG 2011). As compared to mSUGRA, in NUHM, a wider parameter range is allowed. For Higgs mass central value 125.4 GeV, our analysis allows a slightly lower value of $m_0$, both in mSUGRA and NUHM. We find that NUGM allows in general, a wider parameter space, as compared to both mSUGRA and NUHM. Here $\text{BR}(\mu \rightarrow e\gamma)$ is found to increase with increase in $m_0$ which could be due to particular ratios of gaugino masses. In NUGM, we find that allowed values of $|A|$ are shifted towards heavier side (compared to mSUGRA and NUHM). Hence any observation of heavy particles at next run of LHC, could help us to discriminate among these models, in reference to constraints put by cLFV decays. This in turn could contribute towards a better understanding of theories beyond
standard model (BSM). In Chapter 4, we will discuss, how the earlier study, of improvement of CP violation discovery potential at long baseline neutrino experiments (LBNE/DUNE), by combining with its ND (near detector) and reactor experiments, can be further analysed to resolve entanglement of the quadrant of leptonic CPV phase and Octant of atmospheric mixing angle $\theta_{23}$, at LBNEs. The study will be done for both NH (Normal hierarchy) and IH (Inverted hierarchy), HO (Higher Octant) and LO (Lower Octant). We show how baryogenesis can enhance the effect of resolving the entanglement of octant of $\theta_{23}$ and quadrant of $\delta_{CP}$ present at LBNEs, and how possible values of the leptonic CP-violating phase $\delta_{CP}$ can be predicted in this context. With respect to the latest global fit data of neutrino mixing angles, we predict the values of $\delta_{CP}$ for different cases. In this context we present favored values of $\delta_{CP}$ ($\delta_{CP}$ range at $>2\sigma$ ) constrained by the latest updated BAU range and also confront our predictions of $\delta_{CP}$ with an up-to-date global analysis of neutrino oscillation data. We find that some region of the favored $\delta_{CP}$ parameter space lie within the best fit values around $\delta_{CP} \sim 1.3\pi - 1.4\pi$. A detailed analytic and numerical study of baryogenesis through leptogenesis is performed in this framework within the nonsupersymmetric S0(10) models. In Chapter 5, we will study the effects of non-unitarity parameters from existing experimental constraints, on cLFV decays such as, $\mu \rightarrow e\gamma$, $\mu \rightarrow \tau\gamma$, $\tau \rightarrow e\gamma$. We also study their effects on generation of baryon asymmetry through leptogenesis. Considering flavor effects in leptogenesis, we do a parameter scan of a minimal seesaw model in a type I Seesaw framework satisfying Planck data on baryon to photon ratio of the Universe, which lies in the interval, $5.8 \times 10^{-10} < Y_B < 6.6 \times 10^{-10}$ (BBN). We predict values of lightest neutrino mass, and Dirac and Majorana CP violating phase $\delta_{CP}$, $\alpha$ and $\beta$, for normal hierarchy and inverted hierarchy for one, two and three flavor leptogenesis regimes. It is worth mentioning that all these four quantities are unknown yet, and future experiments will be measuring them.
All the predictions made in the thesis - Beyond standard model theories, new sparticles, Octant of atmospheric mixing angle, mass hierarchy, leptonic CPV phase, non-unitarity of leptonic mixing matrix and absolute mass of light neutrinos, are testable in future.