# Abstract

The discovery of the 125 GeV neutral boson in 2012 at the LHC is off course the most awaited event of this decade in the area of Particle Physics. This milestone discovery declares the Standard Model (SM) as the most successful theory till date with respect to many experimental evidences which meet the predictions made by it. But at the same time, the SM has some inadequacies such as the explanation for origin of neutrino mass, dark matter and matter-antimatter asymmetry. Such phenomena build the primary motivation to look for other avenues beyond the SM (BSM). It will be compelling enough if these three problems can be addressed within a same framework. The BSM scenarios are generally constructed with the extension of SM particle sector, scalar and/or fermions. Inclusion of fermions and/or Higgs triplet have become an essential criteria in order to explain neutrino mass via the various seesaw mechanisms. Apart offering neutrino mass these seesaw mechanisms also have some role to play in modern cosmology due to the presence of these additional particles. As pointed out by Fukugita and Yanagida these right handed neutrinos can play a vital role in leptogenesis through the CP violating decay of the singlet fermion. This fact allows us to study leptogenesis through which baryogenesis can be realized. On the other hand extension of the scalar sector permits us to explore the possibility of establishing one of the extra scalars as a potential particle dark matter (DM) candidate. This thesis has been dedicated for a motivation addressing the above mentioned issues.

As discovery of the neutrino oscillation confirms about the mass of the neutrinos, study of neutrino mass and mixing have become a very contextual subject in the culture of particle physics. The existence of this particle *neutrino* was first proposed by an Austrian physicist Wolfgang Pauli in 1930, in order to preserve

energy-momentum conservation in nuclear $\beta$ decay. It is good to start with some properties of this new particle called neutrino e.g. it is an electrically neutral fermion, its mass was long thought to be zero, but later on the neutrino oscillation phenomenon along with robust experimental evidences have confirmed the existence of their tiny but nonzero mass. The oscillation phenomenon is realized in the form of oscillation probability which is a function of several parameters termed as neutrino oscillation parameters. These parameters play the key role in the phenomenon of neutrino oscillation. There has been several exercises extensively performed in order to be precisely familiar with these oscillation parameters. With this motivation several BSM scenarios have been proposed which although explain the existence of nonzero neutrino mass, but could not address many long sought queries regarding the oscillation parameters. Among the oscillation parameters are three mixing angles, one phase, two mass squared differences. Depending on various possible values of mixing angles there have been a class of mixing patterns, proposed till date. Three mixing angles constitute, solar, atmospheric and reactor mixing angle, the third of which was thought to be zero till 2011. Then some dedicated experiments e.g. CHOOZ, Daya Bay and RENO revealed that the reactor angle is very small but non-vanishing. Then, some of the queries, that any model in the neutrino sector requires to answer are the exact values of the three phases, which hierarchy the neutrino mass follow, the octant of the atmospheric mixing angle etc. It has now become a tradition to realize the neutrino mass and its mixing considering the discrete flavor symmetry groups due to the fact that the underlying symmetry and their product rules can beautifully offer the existing neutrino mixing patterns. Keeping this in mind we also exercise model building paradigms considering the discrete flavor symmetry groups, specially $S_4$ and $A_4$ in our work and within the same frame we try to address some cosmological consequences of the same. We are particularly interested in finding a common platform for exploring the neutrino phenomenology, origin of matter-antimatter asymmetry and Dark Matter. Here, this thesis, therefore is an attempt in this direction.

In **Chapter 1** we first aim at presenting a literature survey of the present updates on neutrino oscillation parameters, what we have with how much accuracy. Then we briefly discuss the Standard Model of particle physics and its inadequacy in realizing some observed phenomena. Here we also discuss the neutrino oscillation phenomena and the class of seesaw scenarios in short with the motivation of going beyond the Standard Model for explaining light neutrino mass via the inclusion of heavy right handed neutrinos. The seesaw models considered for this task correspond to high energy scale and some other, relatively low energy scale. We keep a section for detailed discussion on matter-antimatter asymmetry of the universe. We also have dedicated one section for Dark Matter history. Finally we end up with a section discussing the non-Abelian discrete flavor symmetries like $S_4$ and $A_4$ which have extensively been used in model building purpose in this thesis.

In **Chapter 2** we present a TeV scale seesaw mechanism for exploring the dark matter and neutrino phenomenology in the light of recent neutrino and cosmology data. A different realization of the Inverse seesaw (ISS) mechanism with $A_4$ flavor symmetry is being implemented as a leading contribution to the light neutrino mass matrix which usually gives rise to vanishing reactor mixing angle $\theta_{13}$. Using a non-diagonal form of Dirac neutrino mass matrix and $3\sigma$ values of mass square differences we parameterize the neutrino mass matrix in terms of Dirac Yukawa coupling "$y$". We then use type II seesaw as a perturbation which turns out to be active to have a non-vanishing reactor mixing angle without much disturbing the other neutrino oscillation parameters. Then we constrain a common parameter space satisfying the non-zero $\theta_{13}$, Yukawa coupling and the relic abundance of dark matter. Contributions of neutrinoless double beta decay are also included for standard interaction.

In **Chapter 3** we study an inverse seesaw model of neutrino mass within the framework of $S_4$ flavour symmetry from the requirement of generating non-zero reactor mixing angle $\theta_{13}$ along with correct dark matter relic abundance. The leading order $S_4$ model gives rise to tri-bimaximal type leptonic mixing resulting in $\theta_{13} = 0$. Non-zero $\theta_{13}$ is generated at one loop level by extending the model with additional scalar and fermion fields which take part in the loop correction. The particles going inside the loop are odd under an in-built $Z_2^{\text{Dark}}$ symmetry such that the lightest $Z_2^{\text{Dark}}$ odd particle can be a dark matter candidate. Correct neutrino and dark matter phenomenology can be achieved for such one loop corrections either to the light neutrino mass matrix or to the charged lepton mass matrix although the latter case is found to be more predictive. The predictions for neutrinoless double beta decay is also discussed and inverted hierarchy in the charged lepton correction case is found to be disfavoured by the latest KamLAND-Zen data.

In **Chapter 4** we study the possibility of generating non-zero reactor mixing angle $\theta_{13}$ and baryon asymmetry of the Universe within the framework of an $A_4$ flavour symmetric model. Using the conventional type I seesaw mechanism, we construct the Dirac and Majorana mass matrices which give rise to the correct light neutrino mass matrix. Keeping the right handed neutrino mass matrix structure trivial so that it gives rise to a (quasi) degenerate spectrum of heavy neutrinos suitable for resonant leptogenesis at TeV scale, we generate the non-trivial structure of Dirac neutrino mass matrix that can lead to the light neutrino mixing through type I seesaw formula. Interestingly, such a setup naturally leads to non-zero $\theta_{13}$ due to the existence of anti-symmetric contraction of the product of two triplet representations of $A_4$. Such antisymmetric part of triplet products usually vanish for right handed neutrino Majorana mass terms, leading to $\mu - \tau$ symmetric scenarios in the most economical setups. We constrain the model parameters from the requirement of producing the correct neutrino data as well as baryon asymmetry of the Universe for right handed neutrino mass scale around TeV. The $A_4$ symmetry is augmented by additional $Z_3 \times Z_2$ symmetry to make sure that the splitting between right handed neutrinos required for resonant leptogenesis is generated only by next to leading order terms, making it naturally small. We find that the inverted hierarchical light neutrino masses give more allowed parameter space consistent with neutrino and baryon asymmetry data.

In **Chapter 5** we have exercised an Inverse seesaw model based on the $S_4$ flavor symmetry with an adaptation of type II seesaw mechanism. The leading order neutrino mass is explained under the scheme of ISS, which is later on accompanied by the type II seesaw mechanism in order to reproduce non-zero reactor mixing angle. The type II seesaw perturbation at the same time yields the other oscillation parameters undeviated from their correct $3\sigma$ range. A detailed analysis has been performed by varying the Dirac Yukawa coupling and type II seesaw strength which together play a crucial role in obtaining the oscillation parameters in agreement with the recent experiments. We calculate the contribution to the effective mass governing $0\nu\beta\beta$ decay assuming it to take place through the exchange of light neutrinos.

In **Chapter 6** we discuss the overall conclusions and summary of the work carried out in this thesis. Finally, we end up with the future plan of the research in the field of neutrino physics.