List of Figures

1.1	Possible hierarchy pattern of neutrino mass, we call them normal	
	(left) and inverted (right) hierarchies [36]. The colors represent	
	the flavor composition of each of the physical neutrinos: red for	
	$ u_e$, green for $ u_\mu$ and blue for $ u_ au$	15
1.2	Schematic representation of type I, type II and type III seesaw	
	mechanism	18
1.3	Schematic representation of inverse seesaw mechanism	21
1.4	Decay modes of right handed neutrinos taking part in leptogenesis	27
2.1	Feynman diagram representing $0\nu\beta\beta$ Decay because of light neu-	
	trino exchanges	54
2.2	Feynman diagram showing the scattering of η_2 and η_3	56
2.3	Self annihilation of η_2 and η_3 into SM fermions (conventions are	
	followed from [41])	57
2.4	Variation of relic abundance with Yukawa coupling	59
2.5	Generation of non-zero $sin^2\theta_{13}$ varying the type II strength for	
	best fit values	65
2.6	Generation of non-zero $sin^2\theta_{13}$, varying the type II strength us-	
	ing upper bound (left panel) and lower bound (right panel) of 3σ	
	deviations	65
2.7	Variation of $sin^2\theta_{12}$, $sin^2\theta_{23}$, Δm_{23}^2 and Δm_{21}^2 with $sin^2\theta_{13}$ with	
	best fit value	66
2.8	Variation of $sin^2\theta_{12}$, $sin^2\theta_{23}$, Δm_{23}^2 and Δm_{21}^2 with $sin^2\theta_{13}$ with	
	upper bound of 3σ deviation	66
2.9	Variation of $sin^2\theta_{12}$, $sin^2\theta_{23}$, Δm_{23}^2 and Δm_{21}^2 with $sin^2\theta_{13}$ with	
	lower bound of 3σ deviation	67

2.10	Variation of effective mass m_{ν}^{ee} (in eV) with type II seesaw strength	
	using bfp	67
2.11	Variation of effective mass m_{ν}^{ee} (in eV) with the lightest neutrino	
	mass using bfp	68
2.12	Variation of effective mass m_{ν}^{ee} (in eV) with type II seesaw strength	
	and the m_3 for upper and lower 3σ bounds	68
3.1	Radiative generation of non-zero θ_{13} from the light neutrino sector	85
3.2	Radiative generation of non-zero θ_{13} from the light neutrino sector	
	(left panel) and charged lepton sector (right panel) $\dots \dots$	88
3.3	Feynman diagram contributing to neutrinoless double beta decay	
	due to light Majorana neutrino exchanges [14]	92
3.4	Model parameter as a function of the lightest neutrino mass and	
	Majorana phase α	96
3.5	Model parameters as a function of the lightest neutrino mass and	
	the atmospheric mixing angle θ_{23}	96
3.6	Corrections parameter(correction to neutrino mass matrix) as a	
	function of lightest neutrino mass and Majorana phase $\alpha.$	97
3.7	Corrections parameter(correction to neutrino mass matrix) as a	
	function of lightest neutrino mass and Majorana phase ζ	97
3.8	Corrections parameter(correction to neutrino mass matrix) as a	
	function of lightest neutrino mass and Majorana phase $\alpha.$	98
3.9	Correction parameters as a function of Majorana and Dirac phases	
	while giving correction to the charged lepton mass matrix	99
3.10	Correction parameters as a function of Majorana and Dirac phases	
	while giving correction to the charged lepton mass matrix	99
3.11	Variation of effective neutrino mass with the lightest neutrino mass	
	in the model with neutrino mass correction. The purple line indi-	
	cates the PLANCK bound on the sum of absolute neutrino masses.	
	The green band shows the KamLAND-ZEN upper bound [63] on	
	the effective neutrino mass	100

3.12	Variation of effective neutrino mass with the lightest neutrino mass
	in the model with charged lepton correction. The purple line indi-
	cates the PLANCK bound on the sum of absolute neutrino masses.
	The green band shows the KamLAND-ZEN upper bound [63] on
	the effective neutrino mass
3.13	Variation of effective neutrino mass with the lightest neutrino mass
	in the model with charged lepton correction
3.14	Dark matter mass as a function of Yukawa coupling keeping the
	mediator mass fixed for each plots, such that the constraints on
	the DM relic abundance is satisfied
4.1	Decay modes of right handed neutrino in type I seesaw
4.2	Correlation between different model parameters for NH. The label
	Gen refers to the most general structure of the mass matrix discussed. 123
4.3	Model parameters as a function of the lightest neutrino mass for
	NH. The label Gen refers to the most general structure of the mass
	matrix discussed
4.4	Correlation between different model parameters for IH. The label
	Gen refers to the most general structure of the mass matrix discussed. 124
4.5	Model parameters as a function of the lightest neutrino mass for
	IH. The label Gen refers to the most general structure of the mass
	matrix discussed
4.6	Model parameters as a function of one of the Majorana phases α
	for IH. The label Gen refers to the most general structure of the
	mass matrix discussed
4.7	Real and imaginary parts of the model parameters for NH with
	the most general structure of the mass matrix discussed in the text.126
4.8	Real and imaginary parts of the model parameters for IH with the
	most general structure of the mass matrix discussed in the text 126
4.9	Baryon asymmetry as a function of model parameters for NH with
	a horizontal pink line corresponding to the Planck bound $\eta_B =$
	$6.04 \pm 0.08 \times 10^{-10}$ [9]

4.10	Baryon asymmetry as a function of model parameters for IH with	
	a horizontal pink line corresponding to the Planck bound $\eta_B =$	
	$6.04 \pm 0.08 \times 10^{-10}$ [9]	127
4.11	Baryon asymmetry as a function of Dirac CP phase for NH and	
	IH with a horizontal pink line corresponding to the Planck bound	
	$\eta_B = 6.04 \pm 0.08 \times 10^{-10} [9]. \dots \dots \dots \dots \dots \dots \dots$	128
4.12	Baryon asymmetry as a function of Majorana CP phases for NH	
	and IH with a horizontal pink line corresponding to the Planck	
	bound $\eta_B = 6.04 \pm 0.08 \times 10^{-10}$ [9]	128
5.1	Generation of non-zero $sin^2\theta_{13}$, varying the type II strength for	
	best fit mass squared splittings for NH (left panel) and IH (right	
	panel) case	154
5.2	Generation of non-zero $sin^2\theta_{13}$, varying the type II strength using	
	lower and upper bound of 3σ deviations	154
5.3	Variation of $sin^2\theta_{12}, sin^2\theta_{23}, \Delta m_{31}^2$ and Δm_{21}^2 with $sin^2\theta_{13}$ for NH	
	case with best fit values	155
5.4	Variation of $sin^2\theta_{12}, sin^2\theta_{23}, \Delta m_{31}^2$ and Δm_{21}^2 with $sin^2\theta_{13}$ for NH	
	case with lower bound of 3σ deviation	155
5.5	Variation of $sin^2\theta_{12},sin^2\theta_{23}$, Δm^2_{31} and Δm^2_{21} with $sin^2\theta_{13}$ for NH	
	case with with upper bound of 3σ deviation	156
5.6	Variation of $sin^2\theta_{12}, sin^2\theta_{23}, \Delta m_{23}^2$ and Δm_{21}^2 with $sin^2\theta_{13}$ for IH	
	case with best fit value	156
5.7	Variation of $sin^2\theta_{12}, sin^2\theta_{23}$, Δm^2_{23} and Δm^2_{21} with $sin^2\theta_{13}$ for IH	
	case with lower bound of 3σ deviation	157
5.8	Variation of $sin^2\theta_{12}, sin^2\theta_{23}$, Δm^2_{23} and Δm^2_{21} with $sin^2\theta_{13}$ for IH	
	case with upper bound of 3σ deviation	157
5.9	Variation of effective mass $ M_{ee} $ (in eV) for the standard and non-	
	standard contribution to $0\nu\beta\beta$ decay due to light neutrino ex-	
	changes [27]	158

List of Tables

1.1	Charges of the SM particles and the Higgs boson under isospin(I),	
	third component of $isospin(I_3)$, $Hypercharge(Y)$ and $electric charge(Q)$	6)
1.2	Charge assignments of SM particle contents [24]	6
2.1	Particles and their quantum numbers under $SU(2)_L$ symmetry,	
	and A_4 , Z_2 , Z_3 flavour symmetry groups	51
2.2	Neutrino Oscillation data for Normal mass Ordering	58
2.3	Neutrino Oscillation data for Inverted mass Ordering	58
2.4	Values of p, q obtained by solving for IH case with best fit central	
	value of 3σ deviations	61
2.5	Values of p, q obtained by solving for IH case with a upper bound	
	of 3σ deviations	62
2.6	Values of p,q obtained by solving for IH case with an lower bound	
	of 3σ deviations	62
2.7	Comparison of relic abundance Ω with various choices of Yukawa	
	couplings, DM mass, RH neutrino mass	64
2.8	Summary of results obtained from various allowed mass schemes	64
3.1	Fields and their transformation properties under $SU(2)_L$ gauge	
	symmetry as well as the $S_4 \times Z_2 \times Z_3 \times U(1)_L$ symmetry	81
3.2	Fields responsible for generating non-zero θ_{13} as well as dark mat-	
	$ter\ with\ their\ respective\ transformations\ under\ the\ symmetry\ group$	
	of the model	84
3.3	Fields responsible for generating non-zero θ_{13} as well as dark mat-	
	ter with their respective transformations under the symmetry group	
	of the model	86

3.4	Fields responsible for generating non-zero θ_{13} as well as dark mat-
	ter with their respective transformations under the symmetry group
	of the model
3.5	Global fit 3σ values of neutrino oscillation parameters [64]. Here
	$\Delta m_{3l}^2 \equiv \Delta m_{31}^2$ for NH and $\Delta m_{3l}^2 \equiv \Delta m_{32}^2$ for IH
4.1	Global fit 3σ values of neutrino oscillation parameters [7, 8] 112
4.2	Fields and their transformation properties under $SU(2)_L$ gauge
	symmetry as well as the A_4 symmetry
4.3	Fields and their transformation properties under $SU(2)_L$ gauge
	symmetry as well as the A_4 symmetry in the $\mu-\tau$ symmetric limit.132
5.1	Fields and their transformation properties under $SU(2)_L$, the S_4
	flavor symmetry and Z_2 flavor symmetry
5.2	Gobal fit oscillation data from reference [26]
5.3	Values of a, b obtained by solving for NH case with best fit central
	value of 3σ deviations
5.4	Values of a, b obtained by solving for NH case with a upper bound
	of 3σ deviations
5.5	Values of a,b obtained by solving for NH case with an lower bound
	of 3σ deviations
5.6	Values of a, b obtained by solving for IH case with best fit central
	value of 3σ deviations
5.7	Values of a, b obtained by solving for IH case with a upper bound
	of 3σ deviations
5.8	Values of a, b obtained by solving for IH case with an lower bound
	of 3σ deviations
5.9	Summary of results obtained from various allowed mass schemes 159

List of Abbreviations

SM Standard Model

BSM Beyond Standard Model

EWSB Electro Weak Symmetry Breaking

SUSY Supersymmetry

LHC Large Hadron Collider

LEP Large Electron Positron

CERN The European Organization for Nuclear Research

CC Charged Current

NC Neutral Current

PMNS Pontecorvo-Maki-Nakagawa-Sakata

CKM Cabibbo-Kobayashi-Masakawa

GUT Grand Unified Theory

CP Charge-Parity

RENO Reactor Experiment for Neutrino Oscillations

NDBD Neutrinoless Double Beta Decay

BM Bi-Maximal

TBM Tri-bimaximal

HM Hexagonal Mixing

GRM Golden Ratio Mixing

NH Normal Hierarchy

IH Inverted Hierarchy

ISS Inverse seesaw

eV Electron Volt

GeV Giga Electron Volt

TeV Tera Electron Volt

RH Right Handed Neutrino

bfp Best fit point

LH Left handed

B+L Baryon + Lepton

LN Lepton Number

VEV Vacuum Expectation Value

BBN Big Bang Nucleosynthesis

CMBR Cosmic Microwave Background Radiation

WMAP Wilkinson Mass Anisotropy Probe

DM Dark Matter