List of Figures

1.1 The elementary particles in standard model (SM). 2

1.2 Oscillation probability as a function of neutrino energy for fixed value of $\Delta m^2 L$ and $\sin^2 2\theta$=1. (Figure adopted from Ref. [8]) 5

1.3 Neutrino mass eighenstates (1,2,3) as a combination of flavour states (e, μ, τ) and the schematic of normal and inverted hierarchies. 7

1.4 Feynman diagrams representing the neutrino interactions inside matter. Left picture shows CC interactions whereas right picture depicts NC processes. 9

1.5 Ratio of the $\bar{\nu}_e$ flux to the expected flux measured by the KamLand with no oscillation, at different L/E values.(Figure adopted from Ref. [8]) . . 12

1.6 ν_μ and ν_e fluxes measured by the Super-Kamiokande experiment. Solid lines are for the 'no oscillation' prediction and the dashed line passing through the data points are the best-fit oscillation prediction.(Figure adopted from Ref. [8]) 13

1.7 Constraints on $\sin^2 \theta_{13}$ from different parts of the global data [33](adopted from Ref [37]). 15

1.8 The τ event observed in OPERA experiment, adopted from Ref. [45]. . 18

1.9 Schematic of the atmospheric neutrino production above the Earth's surface and production of muons after ν_μ interaction inside the ICAL detector. 20

2.1 Schematic view of the 50 kTon iron calorimeter consisting of 3 modules, each having 140 layers of iron plates. 27

2.2 The contours at 90% and 99% CL for 5 years fully-contained events from ICAL simulation with $\Delta m^2 = 2.3 \times 10^{-3}\text{eV}^2$ and comparison with the contours obtained from other experiments (adopted from Ref. [53]). . . 30

2.3 Total number of μ^+ and μ^- events in presence of vacuum and matter at different distances (L) for a positive Δm^2_{32}, taken from [46]. 31

2.4 Schematic showing the up-coming and down-going neutrino directions and the path length L associated with the zenith angle θ_z. 32

2.5 The ratio of the up-coming and down-going neutrino events as a function of L/E obtained from the ICAL simulation, for 5 years of FC events with $\Delta m^2 = 2.3 \times 10^{-3}\text{eV}^2$ (taken from Ref [46]). 34

2.6 Schematic showing the placement of RPCs inside the ICAL detector, taken from Ref [46]. 35

2.7 The internal structure of a RPC module. 36

2.8 The avalanche growth inside RPC is shown schematically. E_0 is the applied electric field across the electrodes. (1)When a charged particle passes through the detector, primary ionization occurs, (2)Avalanche multiplication of the primary electrons and the avalanche electrons affect the electric field E_0, (3) The electrons reach the anode much faster than the ions as ions have much slower drift velocity, and (4) Finally the ions reach the cathode. So the charges in the resistive layers influence the electric field around the small area where the avalanche was developed. 38

2.9 The schematic of the development of streamer inside a RPC. (1)The avalanche formation as discussed in figure 2.8, (2) a large gas gain or avalanche deteriorates the field E_0 and photons start to contribute to the avalanche and streamers are created, (3) a weak spark may be generated and a small area over the electrodes get discharged, (4) the electric field surrounding the avalanche is decreased drastically and the certain portion of the detector remains dead for each incident particle. 40

2.10 The schematic representing the structure of a single gap trigger RPC. . 41

3.1 Left Panel: The INO iron calorimeter prototype detector at VECC. Right Panel: Six RPCs placed inside the iron layers, four of them are glass RPCs and other two are bakelite RPCs. 44

3.2 The schematic showing the coil carrying current to magnetize the iron layers inside the prototype detector volume. 45

3.3 The RPCs and electronics stack in the prototype Lab. 46

3.4 Cosmic muon track for Run No. 2008 and Event No.203. X & Y views of the hits as recorded by strips are shown. 47

3.5 Cosmic muon track for Run No. 2008 and Event No.296. 48

3.6 Geometry of the simulated prototype detector volume. 50

3.7 Simulated prototype detector response while muon passing through it. . 52

3.8 Opposite bending of μ^+ and μ^- events of different energy inside the detector magnetized with 1 T field. 52

3.9 Energy distribution of cosmic muon flux on the Earth surface. 53

3.10 Energy dependence of hit multiplicity of the incident muons. As muons affect mostly one layer, number of hits in this figure represents number of layers muons pass through before getting stopped completely or escaping the prototype detector. Bars represent the RMS of the distribution and at higher energies bars are inside the symbol. 54

3.11 The distribution of energy deposition by muons in 12 RPC layers. The energy deposition spectrum is fitted with the Landau distribution function. 55

3.12 Spectra of energy deposition at different RPC layers for 1GeV muons. . 56

3.13 Average energy deposited by the cosmic muons at 12 RPC layers. Layer number 1 represents the layer at the bottom and this is the 1st layer hit by incident muon. Bars represent the RMS of the distribution. 56

3.14 Mean energy deposited inside 12 RPC layers by muons of varying energy. In this figure mean represents the mean of the Landau distribution and the bars represent the spread of the distribution. 57

3.15 Distribution for average number of hits left by 1GeV muons and 1GeV pions at different RPC layers. Bars represent the RMS of the distribution. 58

4.1 Architecture of the artificial neural network as implemented. 65

4.2 Top Panel: Particle multiplicity distribution as provided by NUANCE event generator due to CC interaction of neutrino events. Bottom Panel: Energy distributions of parent neutrinos and their product muons, and pions as simulated from NUANCE. 69

4.3 Schematic illustration of the philosophy of selection of inputs for identifying hits for Category-II inputs. Here the muon hit at layer 1 is the candidate hit i.e., the hit whose neighboring hits distribution is to be studied. A circular region is chosen around the candidate hit for 10 subsequent layers (5 layers are shown in the figure) and hit multiplicities inside the region is taken as the input to the network. The filled circles represent the hadron hits and the triangles represent the muon hits. As shown in this figure the projected circular area from the candidate muon hit on layer 1 consists of two hits (both muon and hadron) for all the successive four layers. 72

4.4 Left panel: Average number of hits (N^m_{hit}) in first 10 layers after the vertex for Category-I input e.g., when 1 GeV muon and 1 GeV hadron events are mixed at the event-level. Right panel: Hits (N^m_{hit}) distribution at different layers for Category-II input e.g., when 1 GeV muon hits and 5 GeV hadron hits are mixed at the hit-level to create a new event. N^m_{hit} is >1 even for muons, because the circular region for obtaining N^m_{hit} contains both types of particles. Here, for muon hits distribution, layer numbers are shifted slightly from the original value for better visualization. The error bars represent the RMS of the N^m_{hit} distribution calculated over a particular layer number. 73

4.5 ANN output spectra for category I (Left Panel) and category II (Right Panel) inputs. Reasonable distinction are seen for two types of particles for category I input. We apply a threshold of 0.5 for obtaining the efficiency and background fraction. For category II inputs, as expected the spectra is not well separated and the threshold need to be adjusted to obtain reasonable muon discrimination efficiency. 74

4.6 Left Panel: Variation of the muon discrimination efficiency and background fraction for category I input at 0.5 threshold, for muon events of varying energies. Right Panel: Variation of efficiency and background fractions with muon energy, for category II input. In this case 0.14 was the threshold value for the discrimination. 75

4.7 Variation of efficiency and background with varying threshold for Category-II, where 1 GeV muon hits and 5 GeV hadron hits are mixed at the hit-level in each event. 76

4.8 Efficiency and background fraction for Category-II input (where 1 GeV muon hits and 5 GeV hadron hits are mixed at the hit-level in each event) at different layers subsequent to the closest to the vertex. 77

4.9 Left Panel: Variation of N^m_{hits} for muon and pion hits from the CC neutrino events generated from NUANCE. Here layer numbers for muon candidate hits are shifted slightly from the original value for better visualization purpose. Right Panel: ANN output spectra of the events containing the muon and pion hits, after training in ANN. 79

5.1 The distribution for interacting neutrinos events and product muons, in absence of oscillation. 82

5.2 Zenith angle distribution for muon neutrino events. The events for $\cos\theta_z > 0.1$, termed as 'up-going' events in NUANCE are depleted when 2-flavour oscillations are turned on. (adopted from Ref. [46]). 83

5.3 The muon events corresponding to the CC interactions of muon neutrinos in figure 5.2. Here also the effect of oscillation is similar to the neutrinos. (adopted from Ref. [46]). 84

5.4 Flowchart to represent the main processes in Kalman Filter method. . . 91

5.5 Comparison of hits from a single muon track before and after propagation. 92

5.6 x,y-pull distributions after track fitting. 94

5.7 Pull of muon tracks momenta after track fitting. 95

5.8 Reconstructed momentum distribution for 1 GeV incident muon events. 95

5.9 Reconstructed momenta for incident muon tracks of varying momentum. 96

5.10 Resolution of the reconstructed momenta. 97

6.1 Cluster size distribution for RPC gas mixture, (adopted from Ref [91]) 101

6.2 Space charge effect is shown schematically. Here E_0 is the applied field across the RPC electrodes and E_1, E_2 and E_3 are the electric field arises due to the accumulation of space charges between the two electrodes. . 105

6.3 The avalanche development inside 0.3 mm gas gap after inclusion of space-charge effect and it is assumed that avalanche saturates when number of avalanche electrons is $\geq 5 \times 10^7$. 106

6.4 The induced current distribution for the single gap RPC, without considering any surface roughness. 107

6.5 The internal structure of a single gap Bakelite RPC, shown schematically. 108

6.6 Charge spectrum for the timing RPC, considering the avalanche saturation at $N(t) \sim 5 \times 10^7$. 109

6.7 The fluctuations in surface heights for three different grades of bakelite materials as measured by a DekTek 117 Profilometer. 111

6.8 The distributions of surface heights for three different grades of bakelite. 112

6.9 Longitudinal (orange line) and transverse (green line) diffusion coefficients calculated by MAGBOLTZ [100] for the given gas mixture. . . . 115

6.10 Townsend and attachment coefficients as obtained from MAGBOLTZ [100] for a mixture of $C_2F_4H_2$, $i-C_4H_{10}$, SF_6 gases in 85 : 5 : 10 ratio. 116

6.11 Variation of drift velocity with electric field as predicted by MAGBOLTZ [100] for $C_2F_4H_2/i-C_4H_{10}/SF_6$ gas mixture in 85/5/10 ratio. . 117

6.12 The variation of efficiency as well as time resolution of the timing RPC due to variation in electric field inside the RPC gas gap, arises due to the fluctuation in surface heights of the RPC electrodes. The simulated values are compared with those of the analytically obtained results from Ref. [102] 120