Chapter 7

Summary and Conclusions

The phenomena of neutrino oscillation, the explanation of which needs neutrino to have a non-zero mass takes us beyond the standard model. The neutrino physics therefore has opened up a new horizon with a series of new and exciting possibilities. Even though, over the years by a series of challenging experiments, the existence of neutrino oscillation is established beyond doubt, however mapping the exciting world of neutrino physics requires the precision measurements of different landmarks in the neutrino mass matrix e.g., three mixing angles and two mass-squared differences apart from the exotica like fourth family of neutrino.

A series of new experiments are planned, which will take data with different neutrino sources e.g., atmospheric neutrino, accelerator neutrino etc. One such planned experimental effort is the India-based Neutrino Observatory (INO), which is likely to begin data taking in few years. INO will take data with atmospheric neutrinos in the first phase and plans to accept neutrino beams from CERN at a later stage. The physics agenda for INO includes (a) demonstration of neutrino oscillation pattern by disappearance and appearance of ν_μ through the measurement of the variation of the ratio of up-going and down-going neutrinos with L/E, (b) precise measurement of $|\Delta m^2_{23}|$ and θ_{23}.

The considerations of (i) precise measurement of neutrino energy (E) and neutrino path length (L) before interaction, (ii) charge identification of muons, (iii) separation of up going and down going neutrinos and (iv) large neutrino events statistics in a reasonable time led to the design of a 50 kTon magnetized iron calorimeter consisting of 140 iron layers. For design development, production and installation of such a large detector system, we need to have a detailed simulation and data reconstruction framework. As a first step towards realization of the project, a prototype has been installed at VECC with a scaled down geometrical configuration. This thesis deals with the topics towards achieving the overall goal of making a framework for ICAL, taking ICAL prototype as a first case. Following topics are covered in this thesis:

1. Simulation by GEANT4: Detailed simulation has been performed for the ICAL prototype in GEANT4 framework. Energy deposition, hits distribution for muons and hadrons have been studied. Even though a GEANT3-based simulation framework exists as a central INO tool, but present work will enable us to keep an alternative and make use of GEANT4 where GEANT3 based description is not adequate e.g., interactions of pions in iron.

2. Event Reconstruction: Reconstruction of a neutrino events has been dealt in two steps (a) discrimination of hadrons and muons hits on every layer by using the Artificial Neural Network (ANN). For events containing both muons and hadrons e.g., CC events, the hadrons traverse few layers after the vertex layers before getting stopped completely, however muons continue to travel for a longer distance, therefore making the first few layers tp contain hits from both types of particles. This property has been utilized in a feed-forward ANN framework,

where training has been performed by using single particle events and interacting neutrino events from NUANCE model. The separation of "muon only events" from CC type events could be achieved upto 98% efficiency with 10% background fraction. The corresponding numbers for isolating hits in first few layers worsens to 67% efficiency and 40% background fraction. The discrimination performance of hits from subsequent layers is considerably improved. (b) The hits identified as muon hits on various layers are then connected to form muon tracks. Charge and momentum of the tracks are to be determined with good precision, as they form important physics variables. We therefore apply a recursive track fitting algorithm known as Kalman Filter (KF) towards achieving this goal. KF is an iterative procedure where measured hits are included at steps for precise determination of the track parameters. The track parameters are described by a state vector, defined as a column matrix containing (x, y, dx/dz, dy/dz, q/p) as elements. Well defined procedures are adopted to propagate the track from one layer to other thereby updating the track parameters by including new measurements. The procedure has the provision to include process and measurement noise while updating the state vector. The momentum of a track can be determined by the optimized q/p parameter at the first layer considered as vertex. We have applied the method to reconstruct tracks from the simulated hits by cosmic muons on ICAL prototype. We have seen that for fully contained tracks, a momentum resolution of 15% and a linearity between incident and reconstructed track momenta have been achieved. This procedure can be adopted to full scale ICAL data analysis as an extension of the algorithm.

3. Response simulation of the active detectors: The simulation based on GEANT provides energy deposition in the active layers' gas volume as signal. However for a complete response simulation work, one needs to simulate the signal-generation

by active detector layers. In our case, therefore the generation of induced current/charge on RPC-strips needs to be simulated. We have developed a Monte Carlo technique for performing the job. For a 0.3 mm single gap timing RPC, primary ionization and electron generation have been performed using HEED. The formation and propagation of avalanche in presence of the electric field have been simulated, using a formalism based on first the Townsend coefficient, the attachment coefficient, and the saturation due to space charge. Induction and charge collection have been separately formulated. As a result of the implementation of the processes, we obtained time resolution and efficiency of the timing RPC which match with the earlier calculations and measurements. Additionally, we have implemented the roughness of the electrode surfaces in a scale of 1 μm and studied the effect on time resolution and efficiency of the detector. The implementation of the surface roughness was motivated by a measurement of the surface profile of different grades of bakelite, used to built RPCs for ICAL prototype. The long range surface profile follows a Gaussian distribution. After considering the RMS of the distribution as the measure of the roughness, we have introduced different roughness by Gaussian random numbers with varying widths. The final effect on time resolution and efficiency of the roughness shows that the time resolution deteriorates by 30% for a roughness of 4%, while efficiency remains unchanged upto 20% change in roughness and then decreases gradually.

In summary, we have discussed various steps of simulation and reconstruction procedures towards design and data analysis of the ICAL detector in the proposed INO experiment. Different steps are developed independently either for working with ICAL prototype or for ICAL, however these procedures can be seamlessly put together for building a self consistent package for ICAL.