Design and Characterisation Studies of Resistive Plate Chambers

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Important developments have occurred recently in neutrino physics and neutrino astronomy. Oscillations of neutrinos, and the inferred evidence that neutrinos have mass, are likely to have far-reaching consequences. This discovery has come from the study of neutrinos from the Sun and those produced in interactions of cosmic rays with the earth's atmosphere. The pioneering Homestake Mine Neutrino Experiment in the USA, the gigantic Super-Kamiokande detector and the KamLAND detector in Japan, the heavy-water detector at the Sudbury Neutrino Observatory in Canada, and a few other laboratories, together, have contributed in a very fundamental way to our knowledge of neutrino properties and interactions. Impelled by these discoveries and their implications for the future of particle physics, plans have been made world-wide, for new neutrino detectors, neutrino factories and long base-line neutrino experiments.

Indian scientists were pioneers in atmospheric neutrino experiments. In fact, neutrinos produced by cosmic ray interactions in the earth's atmosphere were first detected in the deep mines of the Kolar Gold Fields (KGF) in south India in 1965. In order to revive underground neutrino experiments in India, a multi-institutional collaboration has been formed with the objective of creating an India-based Neutrino Observatory (INO).

Considering the physics possibilities and given the past experience at KGF, the INO collaboration has decided to build a magnetised Iron CALorimeter (ICAL) detector with Resistive Plate Chambers (RPCs) as the active detector elements. In the first phase of its operation, ICAL will be used for atmospheric neutrino physics with the aim of making precision measurements of the parameters related to neutrino oscillations. The detector will be magnetised to a field of about 1.3 T, enabling it to distinguish the positive and negative muons and thus identifying muon-type neutrino and anti-neutrino produced events separately. This will be useful for ICAL to provide an exciting possibility to determine the ordering of the neutrino mass levels. Finally, this detector can also be used as the far-detector of a futuristic long-base-line neutrino experiment using the neutrino beam from a neutrino factory. Good tracking, energy and time resolutions as well as charge identification of the detecting particles are the essential capabilities of this detector. The ICAL experiment will need about 30,000 RPCs each of about 200 cm $\times$ 200 cm in area.

RPCs are fast, planar, rugged and low-cost gas detectors which are being, and will be, used extensively in a number of high energy and astro-particle physics experiments. They find applications for charged particle detection, time of flight, tracking and digital calorimetry due to their large signal amplitudes as well as excellent position and time resolutions. A dedicated R&D programme is currently underway to design, develop and characterise large area RPCs, ultimately leading to their large scale and low-cost production required for the ICAL detector. In essence, this thesis outlines the successful completion of designing, building and characterising large size RPCs, for the first time in India.

To begin with, we developed a large number of single gap glass RPCs of 30 cm $\times$ 30 cm in area, using the glass procured from local market, and studied their operation in the streamer mode (using a gas mixture of R134a : Isobutane : Argon in the ratio of 62 : 8 : 30). The results obtained from the characterisation studies of these chambers were consistent with those reported in the literature. However, we were faced with a serious problem as far as stability of their operation is concerned. They died of sudden aging when operated continuously. In order to understand this problem, we studied extensively the glass, gas and other components of the RPC detector using a number of different techniques. We subsequently fabricated a large number of RPCs of 100 cm $\times$ 100 cm in area and operated them in the avalanche mode (using a gas mixture of R134a : Isobutane : SF_6 in the ratio of 95.15 : 4.51 : 0.34), without facing any aging problems. These chambers show typical efficiencies of over 98% and timing resolutions of about 1 ns.

A sophisticated gas mixing and distribution system, which works on four input gases, has been designed and fabricated as part of this R&D work. It features mass flow controllers to precisely mix the gases to the required proportion and 0.3 mm diameter stainless steel capillaries to control the mixed gas into 16 pneumatically controlled output channels. We have also developed an open loop gas recovery system using fractional condensation technique and studied its performance. We have developed a suitable paint and an automated painting plant for glass electrode coating. We have also indigenously designed and fabricated polycarbonate spacers, buttons and gas nozzles which are needed to fabricate the RPC gas gaps as well as developed appropriate jigs and tools used during the RPC detector assembly and quality control.

We have subsequently designed and built a detector stack of 12 RPCs of 100 cm $\times$ 100 cm in area, along with a state-of-the-art, front-end electronics, trigger, data acquisition, control and monitoring systems. The stack is in un-interrupted operation now for about a couple of years. The stack is currently tracking about 6 cosmic ray muons per second. Some of the parameters that are monitored using this data on day to day basis are the RPC efficiencies using cosmic ray muons, absolute and relative timing resolutions as well as the stability of RPCs based on the monitoring data of the individual strip rates. Apart from studying various characteristics and long-term stability of the RPCs under test, the stack is also being used to study and optimise a number of parameters concerning the RPC gap, chamber design, gas mixture and readout electronics.

The cosmic ray muon tracks are used to build a tomography of the RPCs, which make up the detector stack. Pitch (30 mm) of the pickup strips used for the RPC readout as well as the dead space due to the button-shaped spacers (11 mm in diameter) are accurately mapped using this analysis. We have also studied the distribution of the residuals between the track and hit pick-up strip coordinates as well as the impact position distribution of the cosmic ray muons on both readout planes of RPC detectors. The width of the residual distribution was found to be as expected for pick-up strip widths of 28 mm. The average strip multiplicity for the cosmic ray muon data was also obtained to be a little over 1, again confirming to the expected value. We have also established the up-down tracking capability of the stack for charged particles, using the cosmic ray muon data.

The individual strip counting rates (or noise rates) provide an excellent measure for monitoring the long-term stability of the RPC detectors. We have also shown that the noise rates reflect the effect of 24-hour day-night variations in the ambient conditions faithfully. This opens up the possibility of gain correction of the RPCs using their noise rates.

Finally, we have recently succeeded in fabricating and testing glass RPCs of 200 cm $\times$ 200 cm in area - the designed RPCs for the ICAL detector. All the characterisation studies that we have completed so far - including those on the effect of SF_6 on the RPC performance, have concluded that these chambers are performing excellently and make them a perfect choice as active detector elements for the ICAL experiment.

Keywords: Neutrino physics, INO, ICAL, Particle detectors, Glass Resistive Plate Chambers

Supervisor's Signature