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Performance study of glass RPC detectors for INO-ICAL experiment

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ABSTRACT

Resistive plate chamber (RPC) detectors are known for their excellent timing and good spatial resolution which make them favorable candidate for tracking and triggering in many high energy physics experiments. The Iron Calorimeter (ICAL) detector at India-based Neutrino Observatory (INO) is one such experiment which will use RPCs as an active detector element. The ICAL experiment is designed to study atmospheric neutrinos and various issues related with neutrino physics. The INO-ICAL has geometry that utilizes about 29,000 RPCs of 2×2 m^2 in size, interleaved between thick iron plates, producing muons via the interaction of atmospheric neutrinos with iron. The tracking information of the muons will be extracted from the two-dimensional readout of the RPCs and its position in respective layers along with the upward and downward directionality determined from the timing information. As a result, a precise measurement of timing response of these RPC detectors is quite important. Furthermore, to design readout system for the ICAL detector, induced signal study and charge information is needed as well. In this paper, we present a detailed timing and charge spectra study for various glass RPC candidates. We also report the effect of various gas compositions on the timing and charge spectra of these RPC detectors.

1. Introduction

Neutrinos are fundamental particles, belonging to the lepton family in the Standard Model of Particle Physics. According to the standard model neutrinos come in 3 flavors (ν_e, ν_μ and ν_τ), and are massless. Recent searches [1–6] however, showed that neutrinos have non-zero mass and also oscillate from one flavor to another as they travel. Although a number of discoveries have already been made in neutrino physics, but still there are several unresolved issues that need to be explained. The determination of right order of neutrino mass hierarchy, whether normal or inverted, octant of atmospheric neutrino mixing angle θ_{23} and the value of CP violating phase δ_{CP} are the open questions in neutrino physics [7].

Neutrino feebly interact with matter having an extremely small cross-section of about 10^{-43} cm^2, which makes their detection quite difficult. In view of this, a detector with a large detection area having substantial target material is required to accomplish statistically significant neutrino interaction events in a suitable time frame. Likewise, neutrinos and anti-neutrinos interact distinctively with matter, so it is also necessary that the detector can distinguish them with good resolution. A 50 kt massive magnetized ICAL detector with passive iron target and RPCs as active detector elements will be able to satisfy these essential criteria for neutrino detection. However, before embarking upon the construction of such a large number of RPC detectors for ICAL, it is highly essential to perform a thorough *R&D* to optimize the various detector design and operational parameters in order to improve the physics output. In this paper, we present an extensive study of different materials as an appropriate electrode for RPC detectors, and of the performance of detectors made from these electrodes. We also present a detailed timing and charge spectra study for various glass RPCs and the effect of varying gas composition on the timing and charge spectra of these RPC detectors.

2. The INO-ICAL experiment

The India-based Neutrino Observatory (INO) [8] is a multi-institutional collaboration, aiming to build an underground laboratory consisting of interconnecting caverns, about 1300 m deep under a mountain peak in the West Bodi hills near Madurai, Tamil Nadu. The experimental hall will be constructed at the end of a 2 km long tunnel with about 1 km rock overburden for reducing cosmic rays background. It will be a multi-experiment facility and one of the experiments will be ICAL. The ICAL detector is a sampling calorimeter which consist of three modules, each module having the dimension $16 \times 16 \times 4.5$ m^3. Each of these modules will have an alternating structure of 150 layers of Iron, made up of low-carbon steel as target mass, and about 29,000 single-gap Resistive Plate Chambers (RPCs) of about 2×2 m^2 in size sandwiched

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between them. The ICAL RPCs consist of a 2-dimensional structure providing 64 positive polarity signals from one plane and an equal number of negative polarity signals from the other plane. In total about 3.6 million channels will be instrumented for the complete readout of each ICAL module. The ICAL detector will be magnetized up to a field of about 1.5 T, which allows the charge discrimination of the muons produced by the interaction of muon neutrinos and anti-neutrinos with the ICAL target. This neutrino segregation ability of ICAL will be of extraordinary use to explain unanswered questions and issues in neutrino physics. The ICAL detector is designed in such a way that a long muon track created inside the calorimeter will be useful in achieving better energy and angular resolutions for ν events. In this way, the oscillation probability of atmospheric neutrinos traversing a distance L before interaction and the energy E of the interacting neutrino event can be measured with higher accuracy. However, before final installation and commissioning of the full ICAL detector, a smaller module known as ICAL "*engineering module*" is being built. This module will be of dimensions $8 \times 8 \times 2$ m^3, having 20 layers of RPCs sandwiched between the alternating iron plates. Each RPC layer consists of 16 RPC units. Thus a total of 320 RPCs will be utilized by the engineering module. This module will serve as a precursor to the final ICAL detector and will be used to validate the different subsystems like RPCs, gas unit, magnet etc. The INO project is supposed to be completed within three phases. The just finished first phase mainly comprised detector design and electronics readiness. The ongoing phase two is commencing with tunnel digging and preparing the surface facility. The estimated time span for completion of this project is about 5–6 years.

3. RPC electrodes characterization and performance study

The Resistive Plate Chamber [9] was introduced as a practical alternative to the localized discharge spark chamber. It comprises two planar electrodes with a high bulk resistivity of the order $10^{10}-10^{12}\ \Omega$ cm, which are separated by a gas gap of a few millimeters. The outer surfaces of these electrodes are coated with a conductive layer in order to apply a high voltage, which produces a uniform electric field across the electrodes. Careful selection of an appropriate electrode material plays a significant role in improving several detector performance parameters. The high bulk resistivity profoundly affects the particle rate handling capacity and ensures that the generated discharge is confined to an area around the primary avalanche, consequently ensuring also that other active areas remain sensitive to charged particles. A high surface uniformity is required to avoid both the localization of excess charges as well as to achieve a highly uniform electric field configuration. In our earlier studies [10], we have performed bulk and surface resistivity measurements of different glass electrodes, namely Asahi, Saint Gobain, and Modi.

The bulk resistivity measurements were done using a small sample from the electrode, sandwiched between two copper plates which are connected to a variable high voltage power supply. An appropriate bias voltage was applied across the plates and the leakage current was measured. The corresponding bulk resistivity was calculated for each applied bias voltage. It was found that among all the electrodes materials we have studied Saint Gobain glass has the highest bulk resistivity of the order $5 \times 10^{12}\ \Omega$ cm on average.

For measuring the surface resistivity, two conductive brass bar jigs have been used. The setup was placed over the sample and a DC voltage was applied between the brass jigs. The surface resistivity of Asahi glass is in the order of $2 \times 10^{11}\ \Omega/\square$ (where $\square$ denotes the unit surface area in cm^2), which is slightly greater compared to that of Saint Gobain glass. Fig. 1 shows the surface

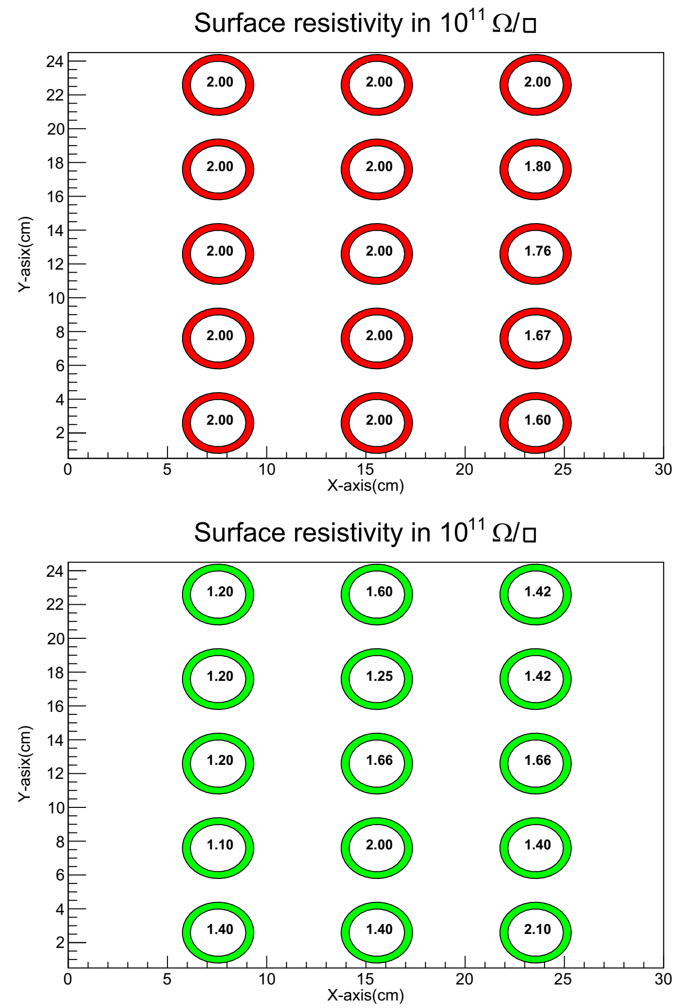

Fig. 1. Surface resistivity of Asahi (*top*) and Saint Gobain (*bottom*) glass in $10^{11}\ \Omega/\square$.

resistivity variation for different glass electrodes. Using these electrodes, we first fabricated small prototype RPCs of dimension 30×30 cm^2 and later of larger size 1×1 m^2. These prototypes were tested for their performance under different gas compositions and environmental dependencies [11–13], in particular they were tested for an efficiency better than 95%. The Saint Gobain GRPC (Glass RPC) showed the lowest count rate among all gas compositions we have used.

4. Timing and charge measurements

We have chosen Asahi and Saint Gobain GRPCs for the timing and charge spectra studies. Various previous studies [14–16] have shown that the gaseous composition plays a significant role in the timing and charge response of these RPC's. The timing resolution is defined as to distinguish two closely occurring events on the basis of their timing information. In general, the timing resolution results from the timing variation ("time walk") that is caused by fluctuations of the position of primary ionization clusters. In any detector, apart from identification of radiation, spatial and timing information, as well as detailed knowledge of the released charges plays a vital role in detector physics and in designing their electronics readout. Fig. 2 shows the experimental set-up for the timing and charge studies which we have performed under a $CH_2FCF_3/C_4H_{10}/SF_6$ (95%/4%/1%) gas composition with applied bias voltages ranging from 9.8 kV to 11 kV.