Nuclear Inst. and Methods in Physics Research, A 877 (2018) 246–251

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

# Timing and charge measurement of single gap resistive plate chamber detectors for INO—ICAL experiment

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ARTICLE INFO

*Keywords:*
ICAL
Timing
Gaseous detector
RPC

ABSTRACT

The recently approved India-based Neutrino Observatory will use the world's largest magnet to study atmospheric muon neutrinos. The 50 kiloton Iron Calorimeter consists of iron alternating with single-gap resistive plate chambers. A uniform magnetic field of ∼1.5 T is produced in the iron using toroidal-shaped copper coils. Muon neutrinos interact with the iron target to produce charged muons, which are detected by the resistive plate chambers, and tracked using orthogonal pick up strips. Timing information for each layer is used to discriminate between upward and downward traveling muons. The design of the readout electronics for the detector depends critically on an accurate model of the charge induced by the muons, and the dependence on bias voltages. In this paper, we present timing and charge response measurements using prototype detectors under different operating conditions. We also report the effect of varying gas mixture, particularly $SF_6$, on the timing response.



## 1. Introduction

In the Standard Model of particle physics, neutrinos are leptons with zero-charge, so they do not participate in either electromagnetic or strong interactions. As leptons, they have spin one-half, and come in three flavors (electron, muon, or tau) named after the charged-lepton flavor with which they partake in weak interactions. Once assumed to have zero-mass, the observation of neutrino flavor-oscillation revealed that at least some flavors of neutrino must have a tiny, but non-zero mass. A concerted worldwide effort to study neutrino oscillations and their masses [1–7] has made tremendous progress unraveling the properties of these most elusive of particles. However, there remain many unresolved questions about the nature of neutrinos. The Indian physics community is considering the construction of a world-class underground neutrino facility, the India-based Neutrino Observatory (INO) [8], in order to answer some of the most important questions about the nature of neutrinos including their mass hierarchy, the extent of CP violation in their interactions, and whether or not they are Majorana particles (i.e. their own anti-particles).

The INO facility will host multiple experiments including the Iron Calorimeter (ICAL) detector, which is optimized for the study of atmospheric neutrinos. The ICAL detector, will consist of three 17 kt modules each measuring 16 m × 16 m × 14.5 m and containing 151 iron plates, 56 mm each, interleaved with Resistive Plate Chambers (RPCs).

The iron plates provide sufficient mass to cause passing atmospheric neutrinos to interact, while the RPC detectors provide tracking and fast timing measurements. The excellent timing and spatial resolution [9–13] of RPC detectors allows for highly accurate time of flight measurement [14,15]. The ICAL detector will distinguish between upward and downward traveling muon neutrinos in order to enhance the sensitivity of its physics program. As neutrinos travel at close to the speed of light, a timing resolution of the order of a few tens of nanoseconds is needed to infer the direction of travel from the arrival time at opposite ends of the ICAL detector. In addition to the timing performance, an accurate model for the charge content of pulses in the ICAL detector is needed to design the readout electronics. In this paper, we report on both the timing resolution and charge measurements on prototypes of the ICAL RPC detectors under a variety of operating conditions.

## 2. The ICAL RPC detector

RPC detectors are characterized by a high efficiency and a fast response time, achieved at relatively low construction cost. Each RPC consists of two resistive plates, an anode and a cathode, typically fabricated from either bakelite or glass, separated by a gap filled with a gaseous mixture. During operation, a high voltage applied across the electrodes induces an electric field within the gaseous volume. Charged

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https://doi.org/10.1016/j.nima.2017.09.056
Received 23 February 2017; Received in revised form 19 September 2017; Accepted 21 September 2017
Available online 4 October 2017

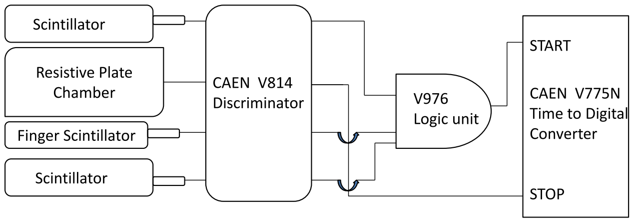


**Fig. 1.** Schematic diagram of the experimental set-up used for timing response measurements.

particles traversing the gap ionize the gas, producing electron–ion pairs along their trajectory. The electron–ion pairs accelerate, in opposite directions, under the influence of the electric field, reaching sufficient kinetic energy to further ionize the gas. At a sufficiently high voltage this process produces an avalanche which significantly amplifies the charge that eventually reaches the resistive plates. The readout electronics converts the charge that reaches each plate into electrical signals which encode the time and charge distribution of each pulse. More details on the operation of RPC detectors can be found in [9], while the detailed geometry and construction procedures are in [16–18].

The massive 50 kt ICAL sampling Calorimeter requires 28,000 RPC detectors, the surface of which is $2\ \mathrm{m} \times 2\ \mathrm{m}$. These RPCs are constructed with 3 mm float glass and read out by 2.8 cm wide strip, made up of copper. For efficient and reliable operation of the RPCs under a variety of environmental conditions, a dedicated *R&D* effort is crucial for optimizing the operating parameters. In this study, we examine the effect of operational parameters on the timing resolution and charge spectra. The performance study of RPCs have also been carried out under different gaseous mixtures, details of which are provided in Section 4.

## 3. Experimental setup

The performance of a prototype ICAL RPC detector was characterized using cosmic ray muons detected with a plastic scintillator hodoscope. The RPC detector is placed between two large scintillators, each consisting of a polyvinyl toluene (PVT) polymer and instrumented with a Hamamatsu H3178-51 Photomultiplier tube (PMT). An additional thin "finger" scintillator, the size of a single readout strip in the RPC detector allows for more precise location of incoming cosmic ray muons. The analog output pulses from the three scintillators are fed into a CAEN V814 Leading Edge Discriminator with minimum width and pulse heights optimized to reject instrumental noise while maintaining high-efficiency for cosmic ray muons. In the case of the large scintillators, the pulse width is set at 40 ns and the pulse height threshold is set at 25 mV, while for finger scintillator the settings are 40 ns and 50 mV.

The discriminator output corresponding to each scintillator is fed into a CAEN V976 logic unit, where a three-way coincidence provides the trigger signal which is used as a START command for a CAEN V775 time-to-digital converter (TDC). In order to amplify short raw output pulses from the RPC, they are fed into a preamplifier, followed by an amplifier circuit characterized by a bandwidth of 0.1–1 GHz and a gain of ~60. The output pulses from the amplifier are then fed into a CAEN V814 Leading Edge Discriminator, whose output after providing the appropriate delay with respect to the trigger signal is utilized as a common STOP command for the CAEN V775 TDC. The time interval between the START and STOP signal is converted into voltage level using the built-in TAC (time to analog converter) feature of the multichannel TDC module. The output of the TAC sections are multiplexed and subsequently converted by two fast ADC (analog to digital converter) modules. A TDC produces output which is the absolute time difference between the START and STOP and fluctuation in their value provides the estimate of time resolution. The block diagram for the measurement of timing resolution is shown in Fig. 1. We show in Fig. 2, the distribution of the time difference between the START and the STOP signal. The width of this distribution provides an estimate of timing resolution. The development of ionization charge and its amplification within the RPC detector depend, among others, on the composition of the gaseous mixture. In the avalanche mode, typical gases Tetrafluoroethane (TFE), isobutane and sulfur hexaflouride are used, yielding raw signals (without preamplifier) of an amplitude of 2–5 mV under appropriate electric fields. The study of charge development due to ionization, resulting in avalanche, and their nature with respect to applied voltage gives a panoramic view of avalanche to streamer transition. A charge to digital converter (QDC) has been used for the study of charge produced under various operating conditions. The schematic of the setup for charge measurement is shown in Fig. 3. The output pulses (analog) from each scintillator is fed into a CAEN V814 Leading Edge Discriminator for analog to digital conversion. The discriminated outputs of the scintillators are sent to CAEN V976 logic unit to obtain GATE pulse for the CAEN V965A QDC, while the analog output of the RPC after providing the appropriate delay with respect to the trigger signal used as an input for the GATE. Figs. 4 and 5 show an example of charge distribution for with and without $SF_6$ gas mixture and at a particular bias voltage of 10.2 kV.

## 4. Performance study with varying gas mixtures

The RPC detector performance is strongly linked to the gas mixture it uses. It has been shown that the addition of sulfur hexafluoride ($SF_6$) to the mixture in the avalanche mode of operation, results in the reduction of charge produced inside the detector following the passage of charge particle along with the suppression of streamers [19]. Although the exact mechanism is not yet well understood, the electron affinity of

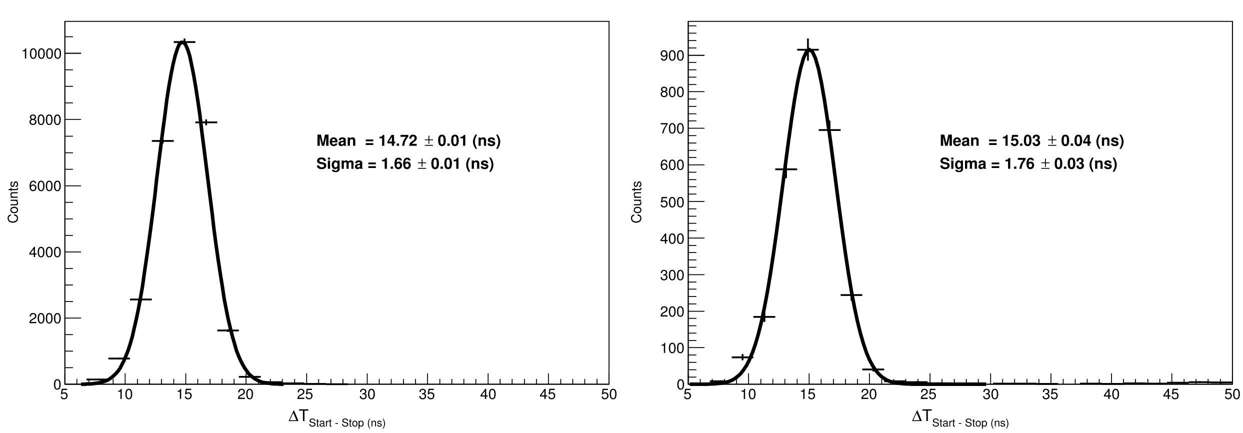


**Fig. 2.** Time distribution for Saint Gobain (left) and Asahi (right) RPC detectors at a bias voltage of 10.6 kV, $SF_6$ concentration of 0.3%, and at discriminator threshold of 50 mV.