INO: A National Mega Science and Engineering Project

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Abstract:

The India-based Neutrino Observatory (INO) is a multi-institutional project aimed at building a world-class underground laboratory at the Bodi West Hills near Madurai in Tamil Nadu. The collaboration is deeply engaged in design and construction of a mega science experiment called Iron Calorimeter (ICAL) for studying many key open questions involving the elusive particles called neutrinos. The magnetised ICAL will consist of more than 50, 000 tons of iron plates arranged in stacks with gaps in between where around 30,000 Resistive Plate Chambers (RPCs) would be inserted as active detectors. A total of about 3.6 million ultra-high speed detector signals need to be instrumented in this detector.

A conscious and consistent effort at developing local components and solutions for all the engineering aspects has been undertaken. A large scale detector R&D effort was undertaken to design, develop, characterise and produce RPCs of 2m × 2m in size successfully. Generations of gas systems, including a closed-loop unit were developed and built. The electronics comprising of indigenously developed custom ASICs and high end FPGAs as well as programmable trigger and high speed data acquisition systems are in the advanced stages of development, production and deployment.

Introduction

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. 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 (Figure 1).

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 1.3T, 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. 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 2m × 2m in area.

1. Resistive Plate Chambers (RPCs)

An RPC is a particle detector utilising a constant and uniform electric field produced by two parallel electrode plates, at least one of which is made of a material with high bulk resistivity. A gas mixture with a high absorption coefficient for ultraviolet light is flown through the gap between the electrodes. When the gas is ionised by a charged particle crossing the chamber, free charge carriers that are deposited in the gas gap trigger avalanches of electrons in the externally applied electric field and originate a discharge. Due to the high resistivity of the electrodes, the electric field is suddenly dropped down in a limited area around the point where the discharge occurred. Thus the discharge is prevented from propagating through the whole gas volume. The sensitivity of the counter remains unaffected outside this small area. On the other hand, due to the ultra-violet absorbing component of the gas mixture, the photons produced by the discharge are not allowed to propagate in the gas. This prevents secondary discharges from originating at other points of the detector. The propagation of the growing number of electrons induces a current on external strip electrodes.

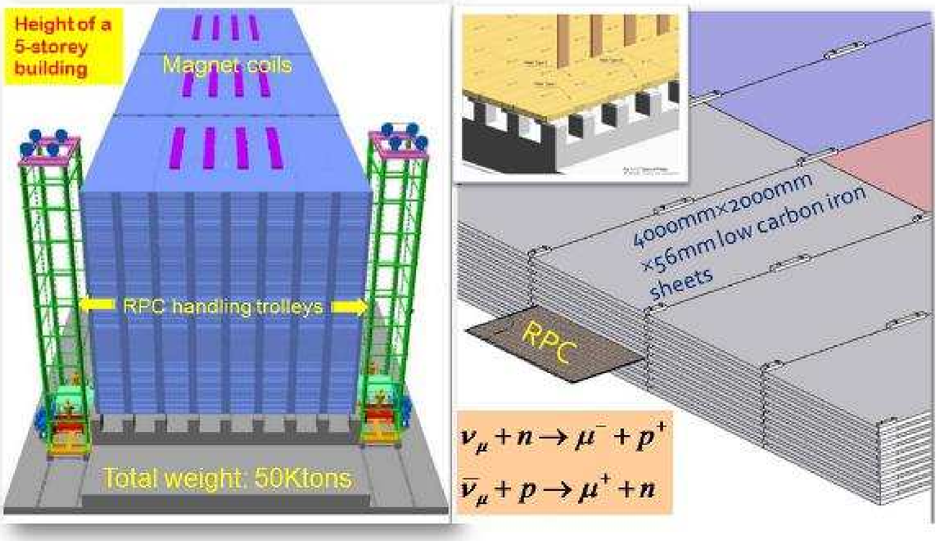

Figure 1: Particles produced in the neutrino interactions pass through alternating layers of iron plates and RPCs, leaving tracks in the latter. Tracks bend as per the charge of the produced particles, due to the ICAL's magnetic field. ICAL will be world's largest electromagnet.

2. Basic principle of operation of RPC

The RPC detector in its simplest configuration is shown in Figure 2. Two planar electrodes made out of a resistive material (typically glass or bakelite) having bulk resistivity of 10^{10} – 10^{12} Ω-cm are spaced by a few mm. The electrodes are connected to a high voltage power supply in order to create a uniform and intense electric field (about 5 kV/mm) in the gap between them. A thin layer of graphite is coated over the external surface of the electrodes to permit uniform application of the high voltage. The electrodes are kept apart by means of small polycarbonate cylindrical spacers having a diameter of 11mm and a bulk resistivity greater than 10^{13} Ω-cm. A gas mixture could consist of Argon, Isobutane and an electronegative gas like Freon (R134a). Argon acts as target for ionising particles while Isobutane, being an organic gas, helps to absorb the photons that result from recombination processes thus limiting the formation of secondary avalanches far from the primary ones. An electronegative gas may serve the purpose of limiting the amount of free charge in the gas. This type of gas mixture is particularly important when one wants to avoid the onset of streamers. The surface resistivity of the graphite coating is high enough to render it *transparent* to the electric pulses generated by the charge displacement in the gas gap. For this reason electric signals can be induced on metallic strips capacitively coupled to the gap. The strips are mounted on the external surface of the gap from which they are separated by a layer of mylar insulator. Two different sets of strips oriented in orthogonal directions may be arranged on both sides of the detector to obtain measurements in both planes. The strips behave like transmission lines with typical characteristic impedance of about 50Ω.

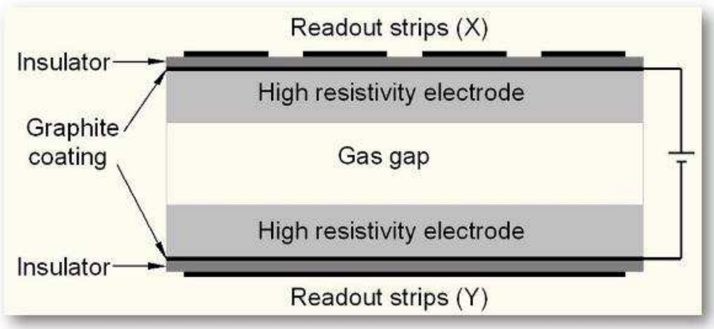

Figure 2: Constructional schematic of a basic Resistive Plate Chamber

High resistivity of the electrodes prevents high voltage supply from providing the electric charge that would be necessary to maintain the discharge between the electrodes. Therefore the electric field drops drastically in the region of the discharge causing it to extinguish.

3. Large area RPC development and characterisation

Having learnt the science and technology of RPC design through fabrication and characterisation of small prototype chambers, we have taken the next logical step to develop larger area RPCs of 1m × 1m in dimensions. We used 3 mm thick float glass sheets which were procured locally. The glass sheets were coated with the special paint that we had developed and applied using the automatic plant. The polycarbonate spacers, buttons and gas nozzles were used for the assembly of the gas gap, which was set in place by using the vacuum jig. Machined plastic honeycomb panels mounted orthogonally on either side of the gas gap, were used for signal pickup. Finally the chamber was packed inside a case made of aluminum honeycomb panels. We have built 12 chambers of this type and individually characterised them in a cosmic ray test stand. These chambers were arranged in a detector stack and is in continuous operation now for several years tracking cosmic ray muons (Figure 3).

Figure 3: RPC test stands built at various INO labs and being operated round the clock for several years

4. Development of RPCs for ICAL detector

The ICAL detector proposes to use about 30,000 RPCs of 2m × 2m in dimensions. Therefore, our final aim was to build RPCs of this size and study their performance and long-term stability in operation, so that they can be successfully produced in large numbers and used in the ICAL detector. These RPCs are comparable to some of the largest area chambers in the world. We essentially followed the same procedure which we have streamlined for the fabrication of gas gaps earlier. However, RPCs of this large area had required design of and development of special handling system and jigs for their assembly and handling. We have successfully designed and developed this infrastructure. Now large number of 2m x 2m RPCs are being produced in many Indian industries.

5. Closed loop gas system

Pilot unit of a closed loop gas mixing and distribution system (schematic of which is shown in Figure 4) for the INO project was designed and is being operated with 2m x 2m RPCs for many years. A number of studies on controlling the flow and optimisation of the gas mixture through the RPC stack were carried out. The gas system essentially measures and attempts to maintain absolute pressure inside the RPC gas volume. During typical Mumbai monsoon seasons, the barometric pressure changes rather rapidly, due to which the gas system fails to maintain the set differential pressure between the ambience and the RPC gas volume. As the safety bubblers on the RPC gas input lines are set to work on fixed pressure differentials, the ambient pressure changes lead to either venting out and thus wasting gas through safety bubblers or over pressuring the RPC's gas volume and thus degrading its performance. The above problem also leads to gas mixture contamination through minute leaks in gas gap. The problem stated above was solved by including the ambient barometric pressure as an input parameter in the closed loop. Using this, it is now possible to maintain any set differential pressure between the ambience and RPC gas volumes between 0 to 20mm of water column, thus always ensuring a positive pressure inside the RPC gas volume with respect to the ambience. This has resulted in improved performance of the gas system by maintaining the constant gas flow and reducing the gas toping up frequency.

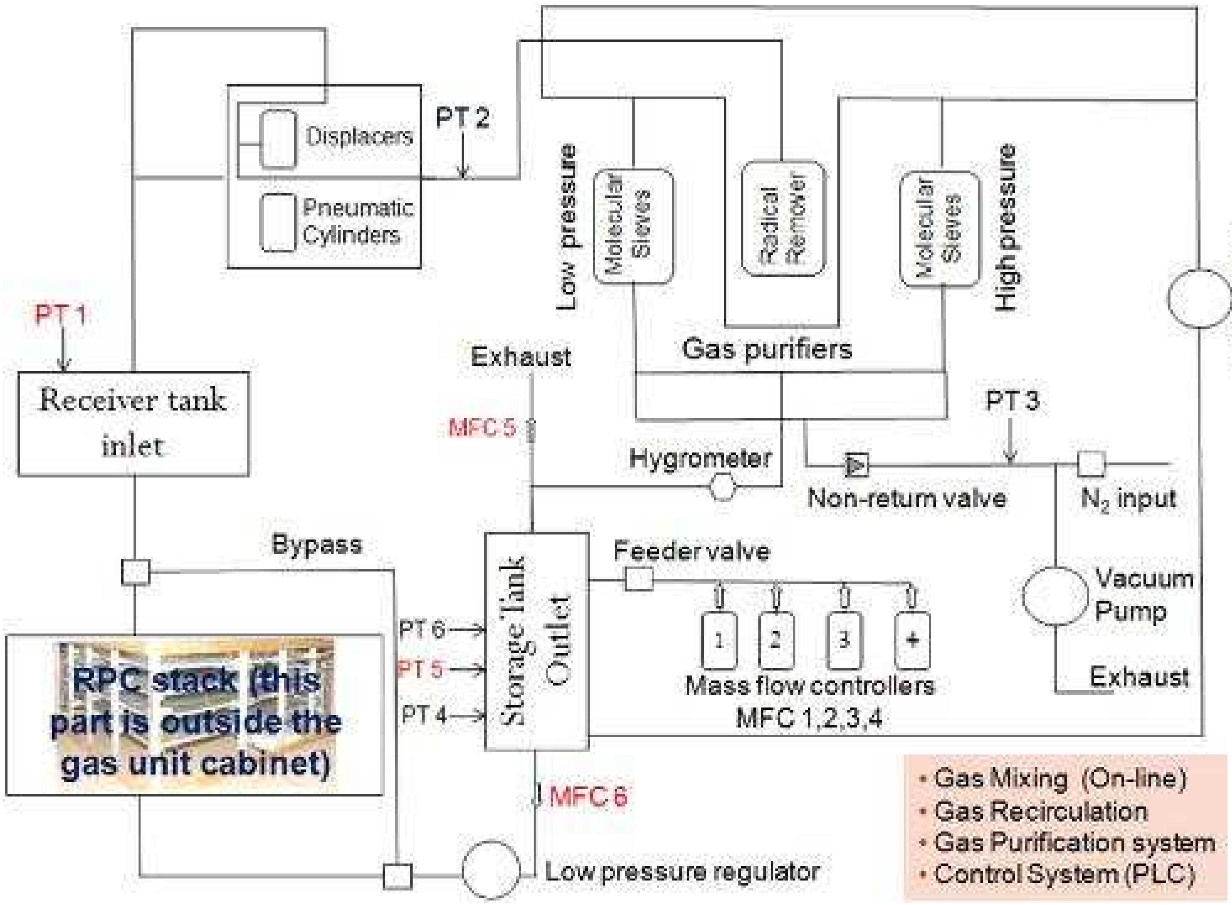

Figure 4: Schematic flow diagram of Closed loop gas system for operating RPC detector stacks

6. ICAL electronics

The ICAL DAQ system performs a large variety of tasks. It identifies physics events in the detector by forming a trigger, tracks the muons formed from the neutrino interactions with iron by storing the detector state during an event and find directionality of neutrinos through tracking and timing. It also monitors health of the RPC detectors by recording their noise rates and chamber currents periodically. Architecture of the ICAL's electronics and DAQ systems (Figure 5) is based on designating the RPC as the minimum standalone unit. Analog front-end (AFE) boards using indigenously designed 4-channel voltage amplifier and 8-channel leading edge discriminator ASICs, are mounted on two orthogonal edges of the RPC unit. The digital front-end (DFE) module is located at one corner of the RPC unit. DFE module comprises of several functional blocks such as an ASIC based Time-to-Digital Converter (TDC), Strip-hit latch, Rate monitor, Pre-trigger generator, ambient parameter monitor and analog front-end (AFE) control. A soft-core processor takes care of all the data acquisition (DAQ) needs, configuration of the front-end components as well as data transfer operations between the RPC unit and the back-end servers. Considerable part of the DFE module's hardware, including the soft-processor is implemented inside a high-end Field Programmable Gate Array (FPGA). Digitised data is transmitted to the back-end using the DFE's network interface. Thus, the entire ICAL detector will function like a large Ethernet LAN, with RPC units as LAN hosts together with the back-end DAQ computers. The DAQ back-end servers receive event and monitor data from the DFE modules, build physics events and archive the same, besides providing all the DAQ services and user interfaces.

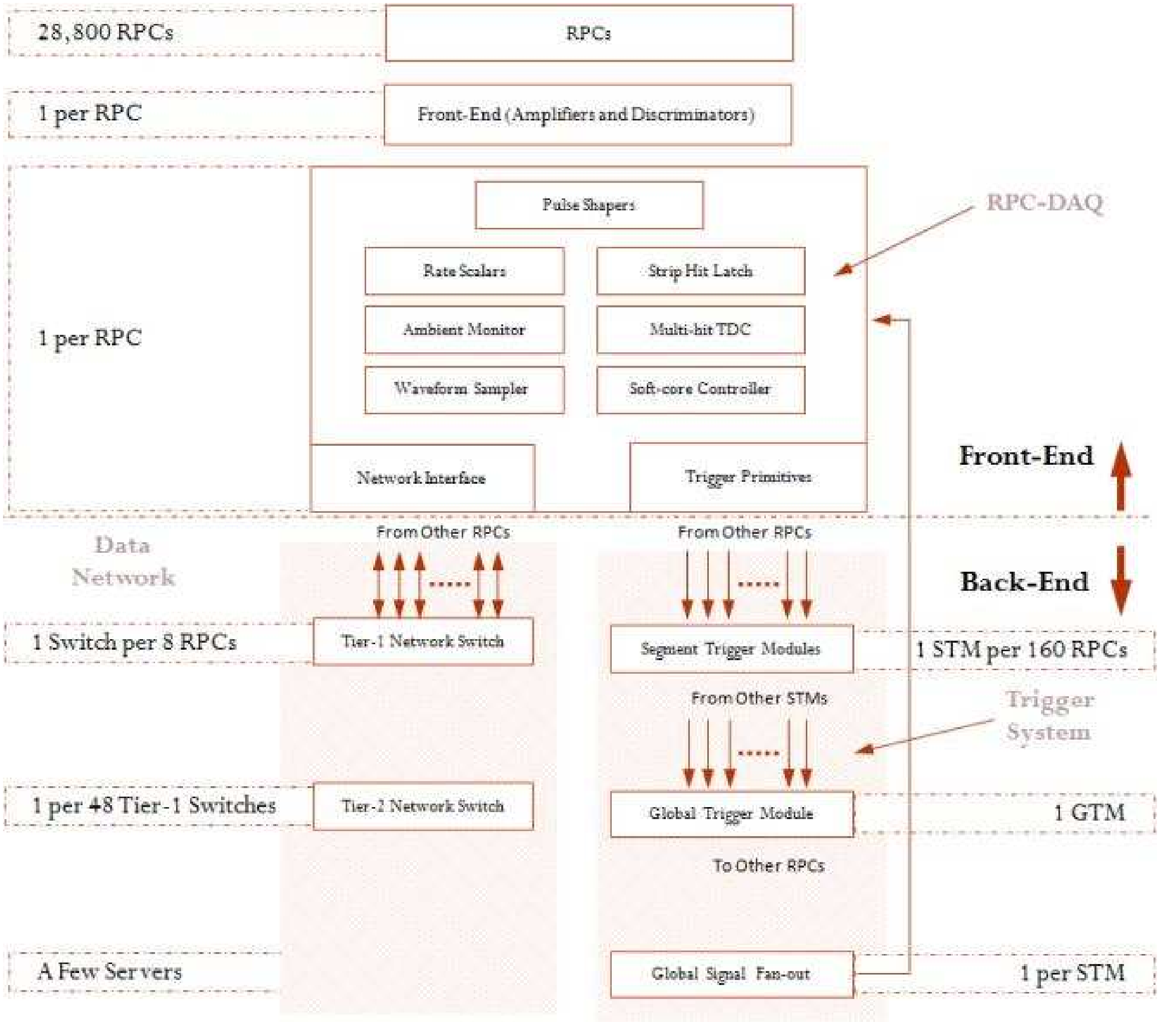

Figure 5: Overall scheme of ICAL electronics

7. Status and outlook

INO project involves merely recording and studying of interactions of neutrinos, which are naturally produced particles. Neutrinos are absolutely harmless to humans and all living organisms. Every second our body receives more than 400 trillion neutrinos from the sun and from other sources. Typically a neutrino has to zip through 10 billion billion people before doing anything. In fact, our body contains about 20mg of 40K which is β radioactive. We emit about 340 million neutrinos/day, which run from our body at the speed of light until the end of the universe! Unfortunately, construction of INO project is delayed due to certain misconceptions among the local people, which are unfortunately planted and propelled by a few activists and politicians. We are currently engaged in an extensive outreach programmes involving young students, local public as well as government officials. Meanwhile, all the requisite approvals and clearances from state and central governments are being obtained.

Figure 6: Mini-ICAL detector in operation

In order to verify the proof of principles of both physics and engineering of the project, a small - but of identical design, a detector named mini-ICAL was built and is being operated successfully. Apart from producing invaluable physics data, this detector also helps testing various engineering designs and long-term performance of RPC detectors and electronics working under the influence of magnetic field. We hope that all the hurdles will be cleared soon and we will be able to build this dream project of the nation - which will add a science temple to Madurai, without any further delay. It may be noted that several experiments in this cutting-edge area of physics are in operation or being built in many countries. Obviously if commissioning of ICAL detector is delayed, we are going to miss out on an opportunity of potential discoveries. Needless to say that will not be a good message to send out to the world scientific community that Indian scientists and engineers are capable of conceiving and building a world class laboratory and experiment, the project proposal was vetted by the committee of world renowned scientists, but still it couldn't be built only due to some misconceptions.

About the author: Dr. Satyanarayana did his B.Tech in Electronics and Communication Engineering from J.N.T.University, Hyderabad and Ph.D. in Physics from IIT Bombay. He is working in the Department of High Energy Physics, TIFR since 1983 – and is currently a Scientific Officer (H). He is also a Visiting Professor at the Applied Science Department of the American College, Madurai. His areas of interest include 'Detectors and Instrumentation for high energy and nuclear physics experiments'. He worked on many major experiments, including a series of underground experiments at Kolar Gold Fields, D-Zero experiment at Fermilab, Chicago and CMS experiment on LHC at CERN, Geneva. Currently, he is engaged in building a mega science experiment called ICAL at the proposed India-based Neutrino Observatory (INO) near Madurai.

Dr. Satyanarayana is a Fellow of Institution of Electronics and Telecommunication Engineers (IETE) as well as Institute of Engineers (IE). He is a member of the Governing Council of Instrument Society of India as well as a Member of Indian Physics Association. He is a Senior Member of IEEE. He is a member of the Executive Committee and Secretary of the IEEE Bombay Section. He is the Chair of its Signal Processing Society. He is also a Executive Committee member of the IEEE India Council and its Vice Chair (Technical Activities). He won IEEE Bombay Section's Outstanding Volunteer Award for 2014 and IEEE Head Quarter's MGA Achievement Award for 2016.

Dr. Satyanarayana has published about 200 research papers and proceedings in national and international journals and conferences. His very first paper won the best paper award by IETE..

He guided and co-guided a large number of undergraduate, master and doctoral students. He served on many of doctoral and expert committees as well as on college/universities' academic councils, boards of studies and advisory boards. He is on editorial and refereeing teams of several prestigious science and engineering journals.

Centre for Education Growth & Research (CEGR) Recommendation to AICTE

Centre for Education Growth and Research (CEGR) is an independent think tank dedicated towards qualitative, innovative and employability-enhancing education, preparing the next generation as future leaders. The Centre provides a platform for the exchange of dialogue among Academicians, Corporate, media and policy makers and augments educational growth and research.

CEGR requested AICTE through policy recommendation to make it mandatory for all AICTE approved Institutions as faculty members deserves better academic environment.

Minimum one percent of revenue generation of Academic Institution must be spent on the intellectual growth of the faculty members which includes training, research, publication, travel grants, attending seminar, etc.

To download complete policy recommendation to AICTE for approval process handbook, please click on the below link
http://cegr.in/CEGR-Policy-Recommendations.php

India to get 100 Gbps internet before 2019 end: ISRO Chief

ISRO Chairman K Sivan has said that India will get internet speeds of over 100 Gbps before the end of next year. He added that India's GSAT-19, launched in 2017, and the yet-to-be-launched GSAT-11, GSAT-29 and GSAT-20 will together provide high bandwidth connectivity and bridge the digital divide. Sivan was speaking at a convocation event in Hyderabad.