THE DEVELOPMENT AND CHARACTERIZATION OF 2m X 2m GLASS RESISTIVE PLATE CHAMBERS

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The Resistive Plate Chamber (RPC) is a type of spark chamber with resistive electrodes. It is a main class of devices used for tracking high energy (charged particles). An RPC is basically a gaseous detector which works on the principle of ionization of the gas filled inside it, by a charged particle passing through it. RPCs are preferred to scintillators due to the following reasons:

1: Provide good position resolution and good detection efficiency.

2: Can be made to have a large area at minimal cost.

3: Easy to assemble and have simple read-out electronics

4: Better time resolution than scintillators and have long time stability.

5: Since such a detector has very good timing (1-2 ns) and spatial resolution, it is well suited for a fast tracking calorimeter.

Glass RPCs have been proposed as the active element in the iron calorimeter detector for India Based Neutrino Observatory. Single and double gap RPCs are used in cosmic ray experiments, in high energy experiments as well as in astroparticle physics.

Principle of working

The glass RPC is a gaseous detector composed of two parallel electrodes made of commercially available 2 mm thick float glass .The bulk resistivity of glass is about 10^{12}- cm. The glass plates are separated by suitable button spacers epoxied to both plates at regular intervals in such a way that they channel the gas flow through the chamber uniformly. Additional T-shaped spacers are epoxied at the edges of the glass plates to make the whole module gas tight. To distribute high voltage on the glass uniformly, the outer surfaces of the glass plates are coated with a thin layer of graphite paint. The expected surface resistivity of the graphite coated surface is $100-200k\Omega cm^{-2}$ and an electric field ~ 4-5 kV/mm is applied between the two plates.

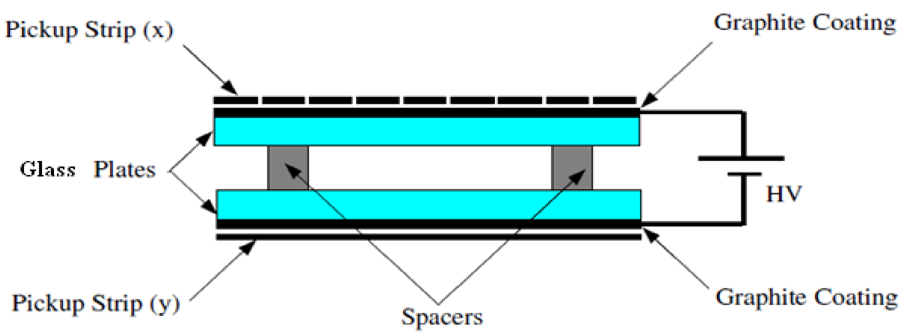

Fig.1. Structure of an a single gap glass RPC

The RPCs described here are dc operated particle detectors whose sensitive element is a 2mm thick layer the mixture of gases Freon (134A), isobutane and SF_6 at normal pressure, under a uniform steady electric field of (4.5-5)kV/mm generated by two parallel electrode plates of Asahi float glass with a volume resistivity of $10^{12}\Omega$cm.When an ionizing particle crosses the gas layer, the liberated electrons suddenly initiate an electric discharge which is quenched by the following mechanisms:

1. Prompt switching off of the field around the discharge point, due to the large electrode resistivity.
2. UV photon absorption by the quencher preventing secondary discharges from photo ionization of gases.
3. Capture of outer electrons of the discharge using a gas with high electron affinity, which reduces the size of the discharge and possibly its transversal dimensions.

The duration of the discharge is typically of the order of ns. The relaxation time of the resistive electrodes plate is τ=2s.The large difference between these two characteristic times ensures that during the discharge the electrode plates behave like insulators, so that only a limited area of ~0.1cm^2 around the discharge point remains inactive for the dead time of the detector. Graphite painted high-voltage electrodes of surface resistivity 200-300kΩ/ cm^2, transparent to the electrical pulse originated in the gas; allow a capacitive readout through external pick up electrodes made of copper strips about 3cm wide, facing the glass electrode (with thin mylar sheets in between for insulation against the high voltage).

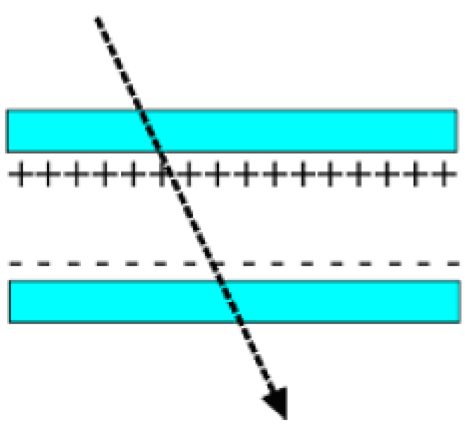

Fig.2.a.(Before) A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally (r~0.1cm^2) available charge is consumed.

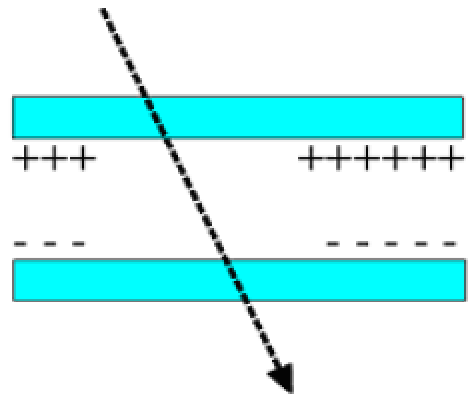

Fig.2.b. (After)The electric field drops only around the streamer location, for a time proportional to the electrode resistivity. The discharged area recharges slowly through the high-resistivity glass plates.

Modes of operation : RPCs can be operated in two different modes called a)avalanche mode and b)streamer mode based on the voltage of operation and the gas composition used.

1. Avalanche Mode

Charged particles passing through the gaseous medium produce primary ionization. These ionized particles are accelerated by the electric field and produce secondary ionization by colliding with the gas molecules. Since the external electric field opposes the electric field of this cluster, the multiplication process stops after sometime. The charges then drift towards the electrodes from where they are collected. This mode operates at a low voltage and the gain is also less. Typical pulse amplitudes are of the order of a few mV.

2. Streamer Mode

In this mode the secondary ionization continues until there is a breakdown of the gas and a continuous discharge takes place. This mode operates at a voltage higher than that of the avalanche mode and has a high gain. Signal generated will be large and typical pulse amplitudes are ~100-200mV.

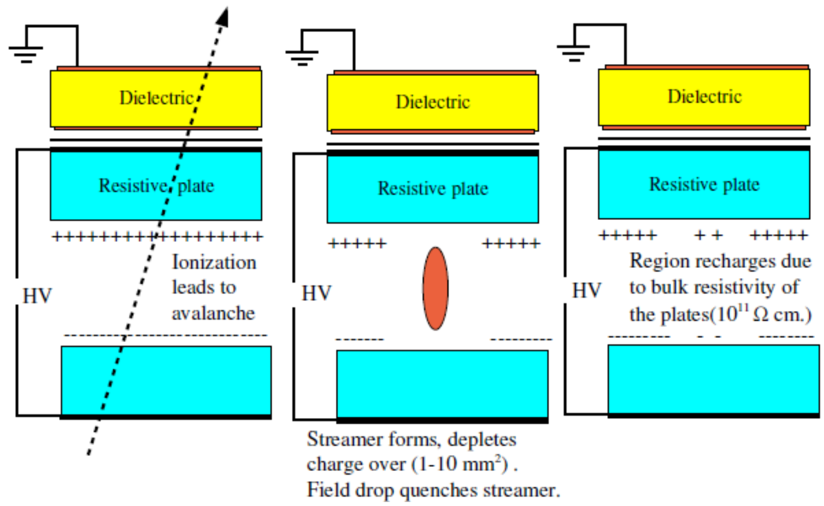

Fig.3. Streamer formation.

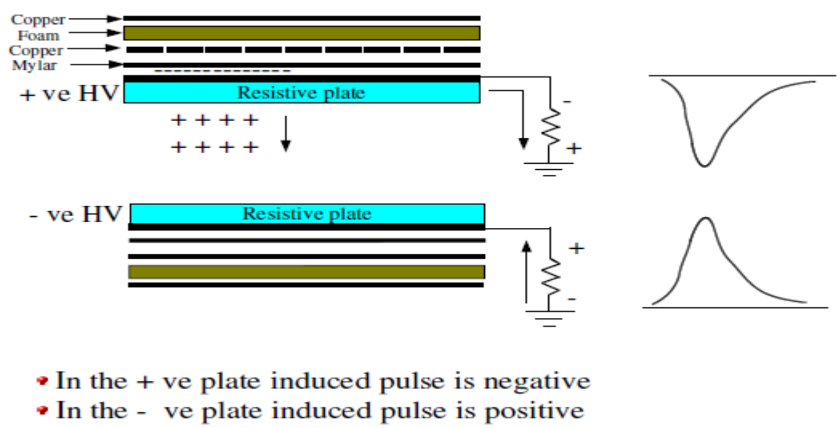

Fig.4. Pulse formation in RPC

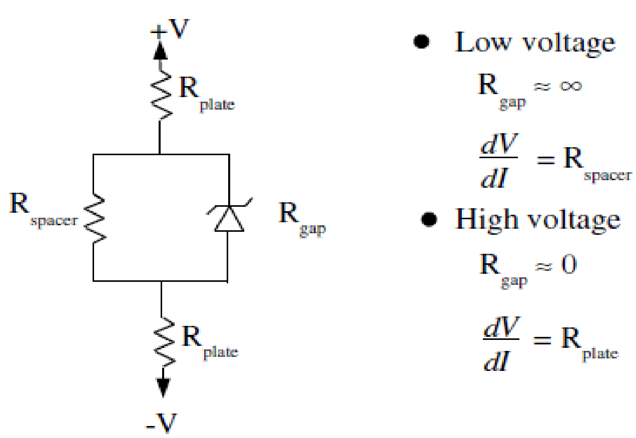

Fig.5.Electrical circuit representation of RPC.

Fabrication of a 2m X 2m RPC:

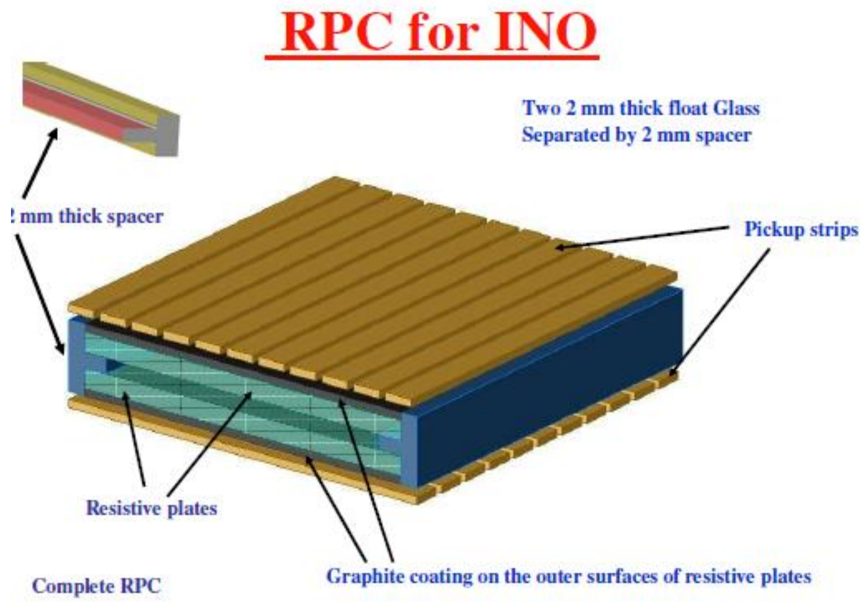

Fig.6.Glass RPC for INO

Many processes are involved in the making of a 2m X 2m RPC. They are the following:

1) Glass cutting and cleaning
2) Conductive coating
3) Gluing of glass
4) Gas leak test
5) High voltage cables and
6) Pick up strips

Glass cutting and cleaning: The Asahi float glasses (each 2mm thick) procured by local vendors are cut by diamond cutter to the appropriate size and the four corner edges are chamfered by a jig of right dimension to make a correct 450 angle. The glasses are thoroughly cleaned with alcohol followed by labolene and distilled water. After that the edge spacers, corner spacers (which are connected to the gas nozzle) and polycarbonate button spacers are also cleaned with alcohol. The glass edges are taped over with masking tape with 1.5-2 cm being masked or taped off on each side so as to prevent the conductive coating to be painted right up to the edge of the glass so that leakage of high voltage does not take place through the edge spacers.

Conductive coating: Conductivity of the glass is increased by coating one side of it with a mixture of dry colloidal graphite and industrial lacquer in a ratio of 1:8 using a spray gun. Once the surface is coated the masking tape is removed and the resistivity of both surfaces is measured using two fixed sizes of copper and brass square (about 17.5 x 17.5 cm2). The graphite layer serves two purposes: it is conductive enough to act as anode/cathode and is resistive enough to prevent itself from conducting away signal from the pickup planes.

Gluing of glass: The glue used is 3M Scotch-weld epoxy adhesive (DP 190) in a duo-pack cartridge. The button spacers (width ~1.8mm) are glued in a square array on top of the glass surface without the graphite coating. The glue comes out through the three holes of the spacers. Then the other glass plate is placed above this array of spacers thus obtaining a gas gap of 2mm. To put a uniform weight throughout the $4m^2$ area the whole set up is wrapped with plastic sheets and the air inside the plastic sheets is sucked slowly to create partial vacuum and a pressure equivalent to 5cm of water column pressure. The set up is left for one day to fix the spacers. The straight edge-spacers are also designed such that the glass sits neatly within. There is a 1mm gap where the glue can be poured. The central protrusion is 2mm, thus supplying the required gap between glass plates. The central hole is where the wedge of the corner spacer fits. It also contains the gas inlet/outlet pipes into which the gas nozzle fits. The glue is poured in the required gap and lead blocks are placed along the 4 sides to put the pressure and whole setup is left for one day, on the next day the same procedure should be followed for the other side of the RPC.

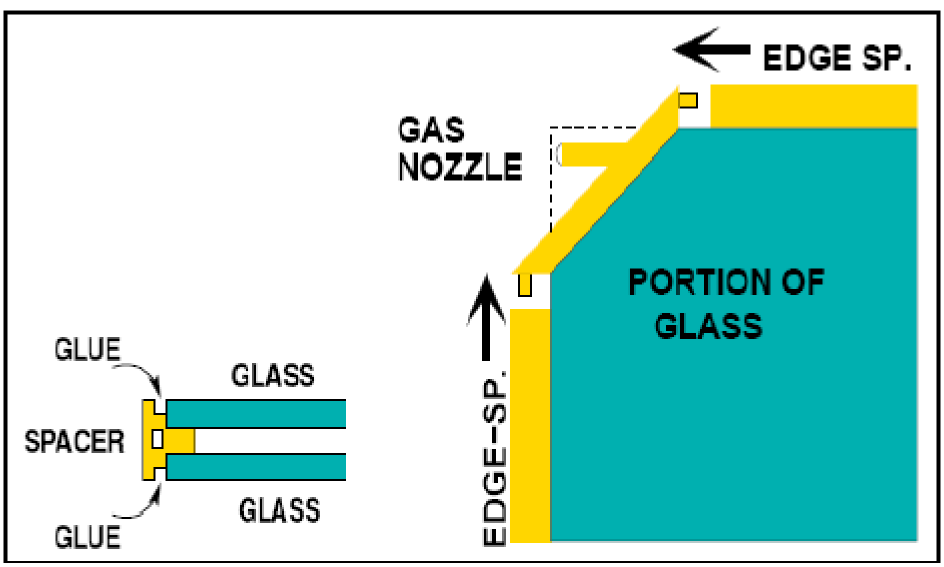

Fig.7.Side and top views of the spacer.

Gas Leak Test: It should be made sure that no gas leak occurs, especially at the glued joints. This is done by flowing Freon gas at atmospheric pressure and leak test is done using a gas sensor FLON GH-202F.

High Voltage Cables: Now the base RPC is ready and it is to be wired for applying high voltage and picking up the signals as charged particles pass through. The high voltage is applied to the graphite layer by sticking on a copper tape and leads are then soldered on to the copper. Positive voltage is applied to one side and a roughly equal and negative voltage to the other side, using a bi-polar high voltage DC supply, so that both see a common ground. The bi-polar connection is better than the unipolar one, since each glass surface sees only half the total voltage, thus decreasing the chances of HV leaks.

Pickup Strips : The RPC is now sandwiched between two honeycomb pickup panels placed orthogonal to each other and then packed in an aluminium case. The pickup panel consists of 64 copper strips on one side and a layer of 5mm of plastic and aluminium on the other side. Each strip is machined to a width 2.8 cm and the gap between two adjacent strips is 0.2cm. Honeycomb panels are lightweight and provide adequate mechanical strength. Each strip is terminated with a 50Ω impedance to match the characteristic impedance of the preamplifier. A layer of mylar of thickness 100µm is placed between the graphite layer and the pickup panel to provide insulation.

GAS FLOW SYSTEM:

The choice of filling gas for RPCs is governed by several factors: low working voltage, high gain, good proportionality and high rate capability. For a minimum working voltage, noble gases are usually chosen since they require the lowest electric field intensities for avalanche formation. The first ionization potential, the first Townsend co-efficient and the electronegative attachment co-efficient determine the avalanche multiplication, the presence and relative importance of photo production, the saturated avalanche range to the streamer mode. The gas mixture fixes the working mode of the RPC in 'avalanche' or in 'streamer' mode, resulting in different characteristics and performances.

Currently the RPCs are being operated in the avalanche mode and hence the main component is an electronegative gas, with high enough primary ionization production but with small free path for electron capture. The high electronegative attachment coefficient limits the avalanche electrons number. Here Freon (eco-friendly R134A) which meets the above requirements, is used. Polyatomic gases, often hydrocarbons, have a high absorption probability for ultra violet photons, produced in electron-ion recombination. This gas is known as quenching gas and limits the lateral charge spread. Here 'Isobutane' is used as the quenching gas. Finally SF6 (Sulphur-hexafluoride) is used to control the excess number of electrons.

Gas composition:

Mixture constituents	Percentage
Freon(R134A)	95.42%
Isobutane	4.21%
SF6	0.37%

The gas mixing system is designed for mixing four gases: Argon, Freon (134A), Isobutane and SF6 by volumetric method.

The gas mixing system consists of the following components:

Purifier Column : It contains Molecular sieve used to absorb moisture and purify it.

Mixing Unit : Based on Mass Flow Controllers (MFC) and the flow of the gas is displayed in Standard Cubic Centimeter per Minute (SCCM).

Distribution Pane l : 16 RPC's can be connected in parallel, which is achieved by “Flow resistors” viz. Capillaries which are 2m long and 200μ in diameter. These offers a resistance of 1/14th of a bar to the gas flow when the flow is about 6SCCM.

Safety Bubbler's : To take care of the back pressure exerted and protect the RPC's from over pressurizing.

Isolation Bubbler's : It prevents back diffusion of air into the RPC and also the indicate the flow of the gas.

Exhaust Manifold : All the gas to be vented is collected in this manifold and a single output is provided to vent the used gas into the atmosphere. This manifold has a pressure sensor to indicate the pressure with respect to the room pressure.

Moisture Meter: Microprocessor based SHAW sensor meter to monitor the moisture content in the mixed gas.

The pressure of the gases to be mixed are controlled by at the output of the cylinder itself by using two stage pressure regulators. The pressure set is 0.5 to 1 Kg/cm2 but as Freon(134A) and Iso-Butane gases are in liquid form low pressure input regulator of the order of 0 to 5 Kg/cm2 to be used, while for Argon and SF6 the pressure is of the order of 2000Kg/cm2**.**

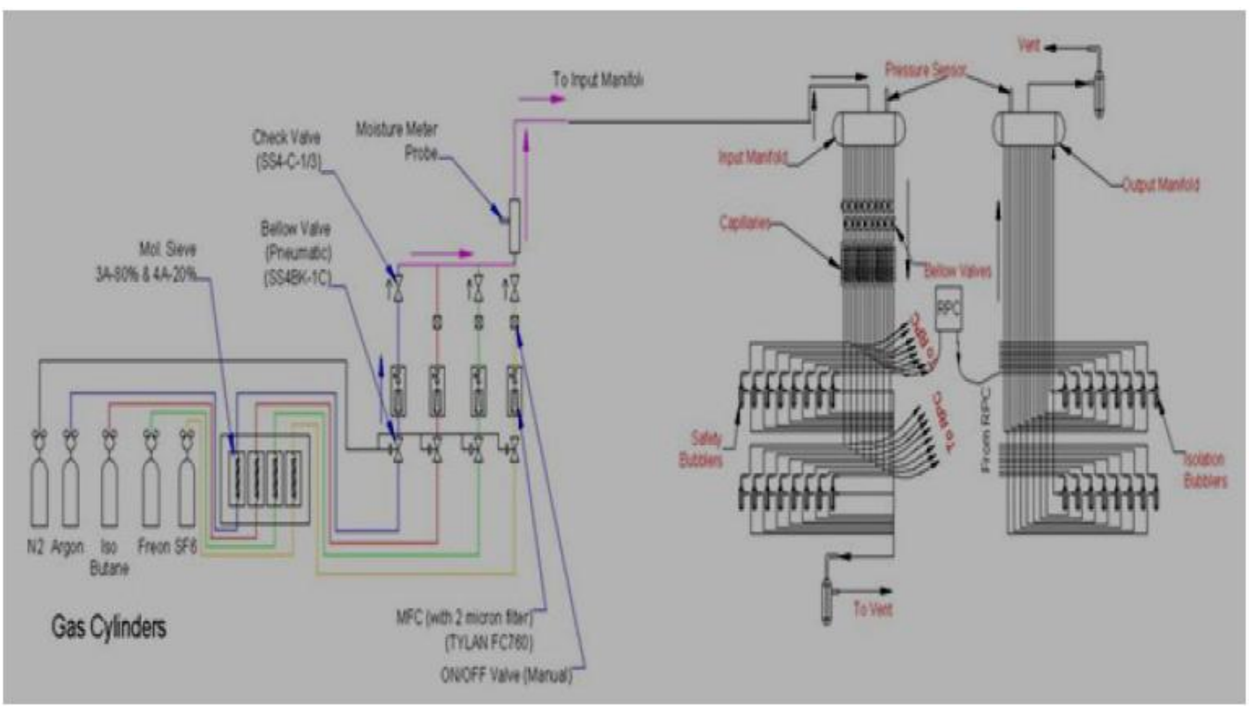

Fig.8. Block diagram of gas flow system.

Gas constituents	Gas Flow (in SCCM)
Freon(R134A)	17.9
Isobutane	0.79
SF_6	0.07

On the display unit of the MFC.

There are two RPC's connected so each is getting 9.38 SCCM of total gas mixture.

Alignment of RPC in the laboratory:

To measure the efficiency of the RPC, firstly we ensure that the trigger pulse generated is solely due to the atmospheric muons. Four scintillator paddles are used to set up a coincident circuit for this purpose, i.e a cosmic ray telescope with these scintillators. There are 4 trigger paddlesP3, P4, P1 & P2. The area of these scintillators are 2 cm X 30 cm, 3cm X 30cm, 20 cm X 40 cm and 20cm X 40cm respectively. These paddles produce a signal when a cosmic ray muon or other charged particle passes through them. The geometry of the telescope using these paddles is set up such that a window of 2cm X 30cm is available for the cosmic ray muons to pass through the telescope as well as through the pick up strips of the RPC under test. Narrow paddles are used to define the telescope geometry precisely. The data from the RPC pickup strip is recorded whenever a cosmic muon generates a trigger signal through the logic $P_1 .P_2.P_3.P_4$ i.e., a trigger is formed when a muon passes through the paddles P_1, P_2, P_3 and P_4.

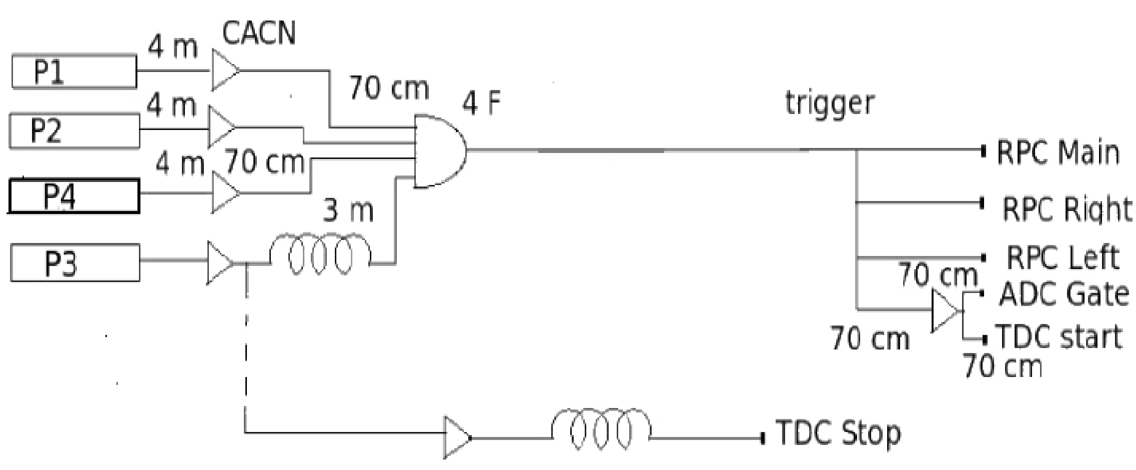

Fig.9.Circuit diagram for trigger logic for RPC

The analog pulses that come from the PMT's are converted to digital pulses through discriminators kept at a threshold of -20mV. P1, P2, P3 and P4 are ANDed to give 4-fold signal. Scalars are added at different stages to monitor counting rates of these signals. The P3 signal is delayed to take care of the jitter from the scintillation paddles which arises due to its finite time

resolution. The pick-up strips of the RPC's are connected to discriminators by twisted pair cables and output is taken to different channels of TDC with some delay. RPC Trigger is taken from the middle strip of RPC(Main #20) and ANDed with 4fold signal to get 4-fold x RPC trigger signal.
Finally this signal is recorded.

Efficiency of RPC is defined as:

$$E = \frac{4F \times RPC}{4F}$$

The RPC pulses are connected to ADC before digitizing and the 4fold signal is given to ADC gate to ensure that when TDC gives a START the ADC gate is also open at the same time.

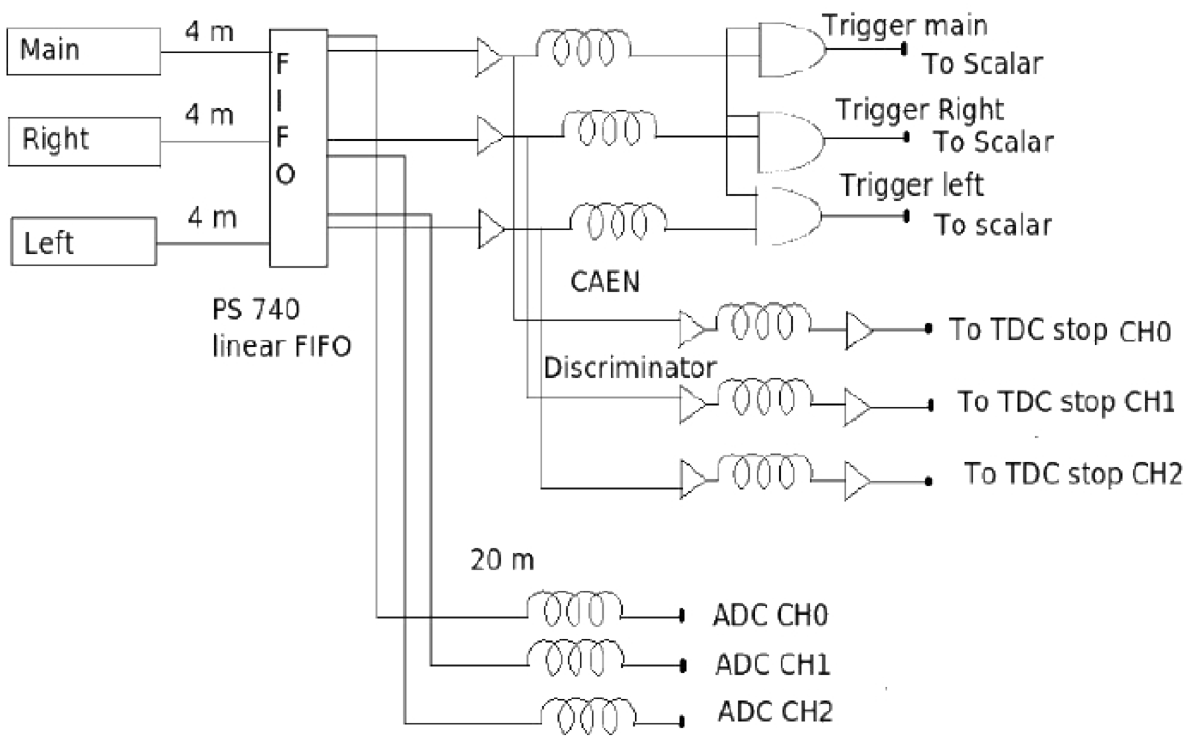

Fig.10. Circuit diagram for efficiency calculation.

Electronic data acquisition system: The entire signal processing and data acquisition system can be divided into the following modules:

a) Front end electronics (16 channel analog front end and 32 channel digital front end).
b) Trigger module.
c) Signal routers (Trigger and TDC Router & Control and data Router).

d)Back end DAQ system (Data and Monitor Control module & Data and Monitor Readout module).

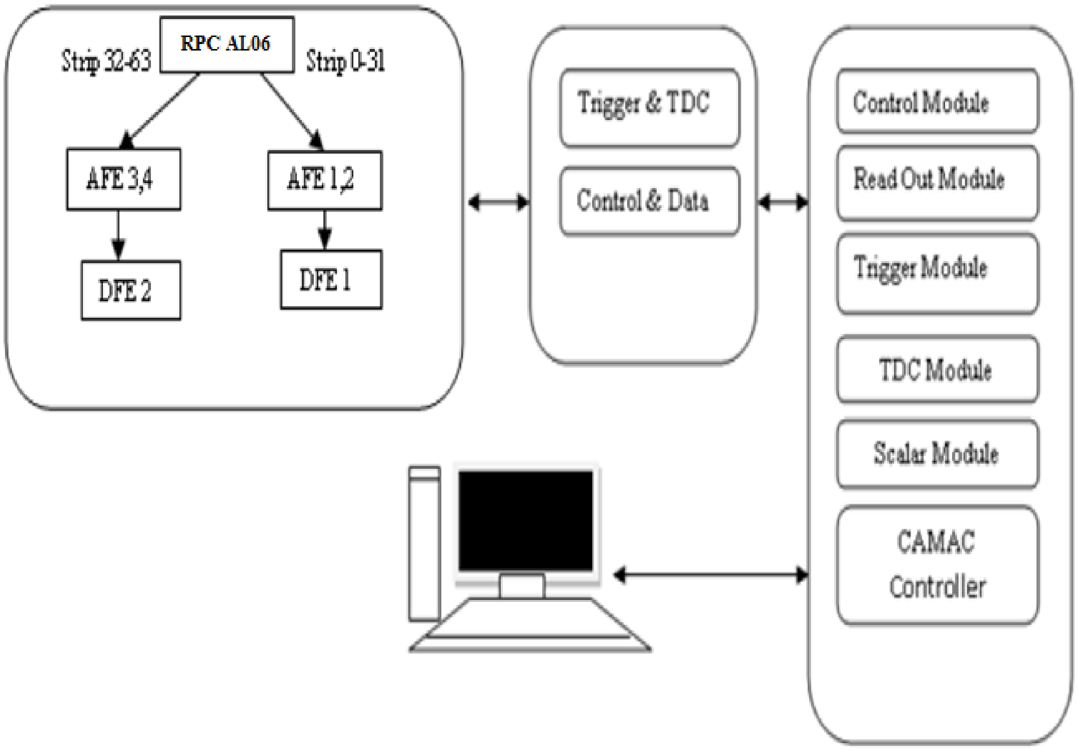

Fig.11.Block diagram for electronics setup.

a) Front End Electronics : The signal from a pickup strip is passed through a pre-amplifier (gain70-80) and the output is fed to four 16 channel discriminator modules(Analog Front End). The signal crossing the set threshold in the discriminator generates differential ECL output. At present, the threshold is kept at -20mV. This section also generates the primitive trigger_0 logic. The discriminator modules are connected to two 32 channel Front End Processing (FEP) module (Digital Front End) which converts the ECL i/p to TTL o/p and also generates trigger_1 signals. Both the DFE's work independently.

b) Trigger logic : The trigger logic picks up the event to be recorded. The basic principle of trigger generation is M × N fold coincidence where M is the layer coincidence of M consecutive signals out of 64 pickup signals and N is the no. of consecutive layers satisfying M fold layer coincidence. The M×N folds implemented are 1×5, 2×4, 3×3, and 4×2. Trigger is implemented in three stages. In the first stage i.e. trigger_0 logic, the shaped discriminator pulses from every 8th channel of 64 channels in the X-plane of RPC are logically ORed to get eight T0 signals. Similar signals are obtained for the Y-plane of each RPC. These eight T0 signals are logically ANDed to achieve the required Mfold triggers (T1 signals – 1F, 2F, 3F, 4F) in each layer. The trigger_1 logic is implemented in the Front End Processing (FEP) module using CPLDs. The M-fold signals (T1) from X-plane of all RPC layers are routed via Trigger and TDC Router module to the Final Trigger module in the CAMAC crate. The M×N coincidence logic (T2 trigger) is implemented in this module using T1 signals. T2 signals from X-plane and Y-plane are logically ORed to get the final trigger output which indicates the valid event to be recorded. The trigger generation rate is monitored with in-built scalars. All the triggers are maskable.

c) Signal Routers : Trigger and TDC router receives the M-fold T1 signals and TDC signals from the FEP modules and routes them to the Final Trigger module and TDC module respectively. Control and Data Router receives control signals from the INO Controller module and routes them towards the FEP modules. It also receives data and feds the same to the Readout module.

d) Data Acquisition : A PC based data acquisition system is built using CAMAC standard modules in the back end which is connected to the front end with a fast serial link. For the purpose of data acquisition. The 64 strip RPC is considered equivalent to two 32 strips RPCs and hence the read out mechanism for 32 strip RPC is employed here also. The two main functions of the DAQ system i.e. Event Data Recording and Monitoring is controlled by the INO Controller module housed in the CAMAC crate. The Front End processing module of X and Y planes of all the RPCs are daisy chained into two groups for event data recording. At present no daisy chains are used for monitoring purpose and hence all the RPCs can be monitored simultaneously. On a final trigger, CAMAC controller invokes an interrupt handler routine where INO controller initiates data transfer from front end modules in a bit serial mode via daisy chain and data is buffered in the Readout module for further CAMAC readout. A set of 40 signals are selected in each monitoring cycle by the INO controller, which invokes interrupt handler at pre-defined monitoring period (10sec) where rates of the selected signals are recorded and the next set of signals are selected for monitoring. The set of signals monitored in each cycle consist of 32 pickup signals of one RPC, 4 fixed frequency signals and 4 M-fold trigger_1 (1F, 2F, 3F, 4F) signals. The next 32 pickup signals of the same RPC are monitored simultaneously through the second DFE. The need is to record the event time, three dimensional interaction tracks and its direction in the detector. The event initiated by the final trigger records the Boolean status information of all pickup channels contributing to the track information. The relative time of interaction of track at each layer is recorded in the TDC which gives the directional information.

Results:

a) **Efficiency:** The efficiency of the right (S20), main (S21) and left (S22) strips is calculated and plotted as a function of voltage applied. The main strip will show the maximum efficiency since the 2cm paddle is kept along the main strip.

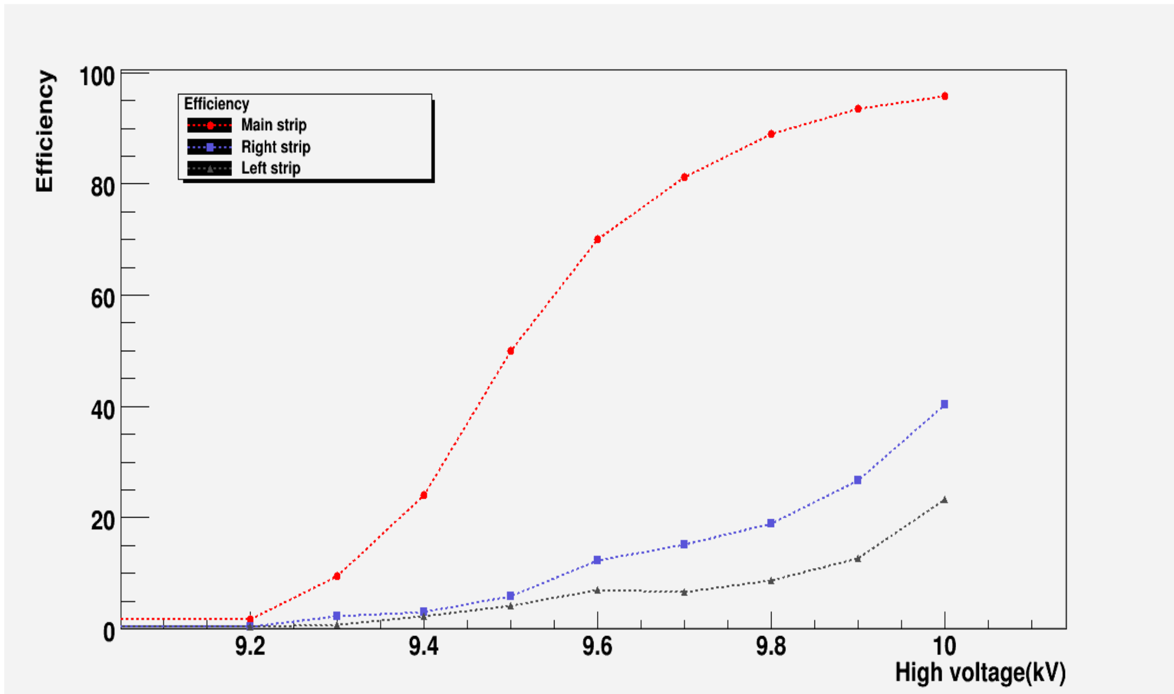

Fig.12.Efficiency in % Vs high voltage in kV.

The plateau region is achieved around 9.7kV (efficiency~81%) for the main strip. From the plot, it is seen that cross-talks become prominent at higher voltages.

b) **Noise Rate:** Noise rate as a function of voltage are plotted.

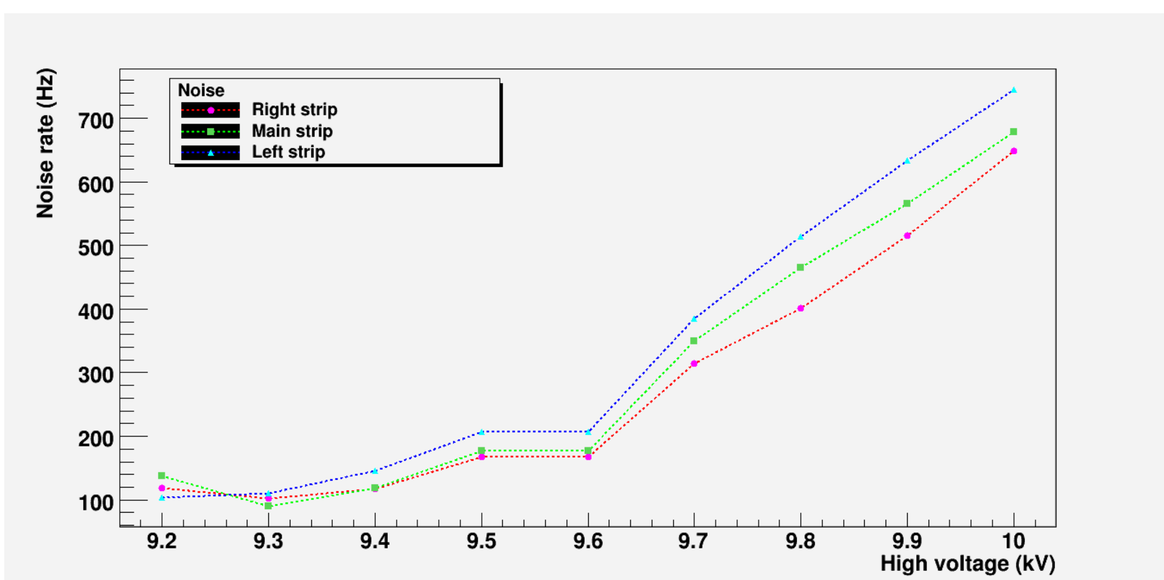

Fig.13. Noise rate in Hz Vs High voltage (kV)

c) **I-V characteristics**: The resistances of the glass and gap can be found from the I-V characteristics.

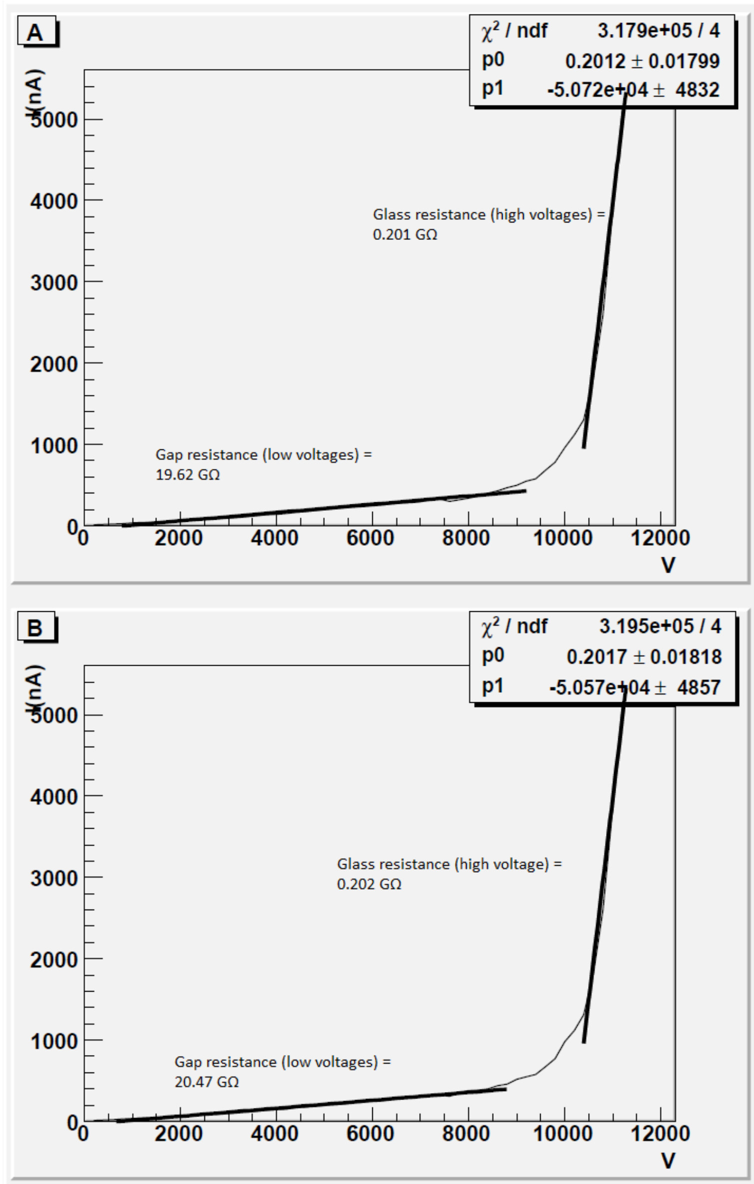

Fig.14: I-V characteristics. Channel A corresponds to the positive voltage side and channel B corresponds to the negative voltage side.

Channel A: Gap resistance (low voltages) =19.62 GΩ
Glass resistance (high voltages) =0.201 GΩ

Channel B: Gap resistance (low voltages) =20.47 GΩ
Glass resistance (high voltage) = 0.202 GΩ

d) **TDC distribution plot**: The time different between the arrival of trigger and firing of RPC, taken for operating voltage 9.7kV are used to plot a histogram and fitted with a Gaussian function.

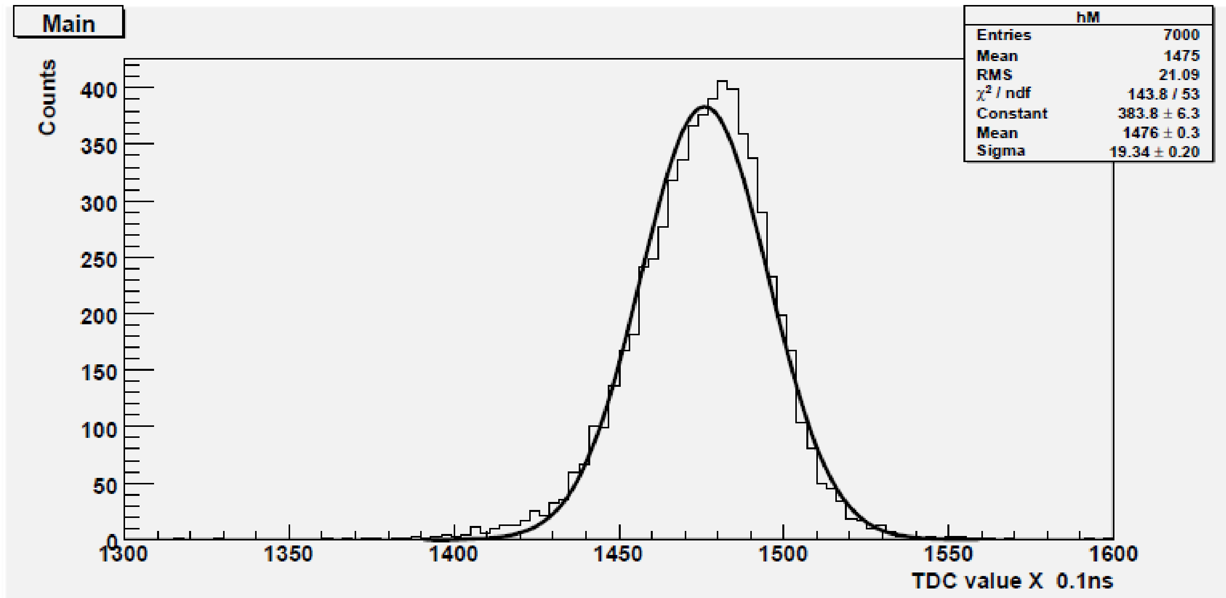

Fig.15: TDC plot for operation at 9.7kV
Time resolution, from the plot = 19.34 X 0.1 ns =1.934ns

Conclusion: The 2m x 2m RPC AL06 is successfully completed and it is operating in the avalanche mode with an efficiency of about 81% at a voltage of 9.7kV.It is characterized and the time and charge distributions are also studied.

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7) My classmates

References:

[1] Yu N.Pestov, G.V.Fedotovich, Preprint IYAP-77-78, Slac Translation, 184 (1978); G. Battistoni et al., Nucl. Instr. and Meth. 152, 423 (1978); G.Battistoni et al., Nucl. Instr. and Meth. 176, 297 (1980)
[2] Daniel Marlow, Princeton University, Seminar at Rice University (1999)
[3] G.Battistoni et al., Nucl. Instr. and Meth. 202, 459 (1982)
[4] M.Anelli, G.Bencivenni, G.Felici, L.Margo, Nucl. Instr. Meth. A 300, 572-574 (1991)
[5] S.S.Upadhya, "Conceptual design of DAQ system for a prototype detector".
[6] S.D.Kalmani, N.K.Mondal, B.Satyanarayana, P.Verma, "Online gas mixing and multi-channel distribution system".

[7] B.Satyanarayana, “ICAL electronics and DAQ schemes”.
[8] B.Satyanarayana, “Electronics for the INO ICAL detector”.
[9] B.Satyanarayana, “Commissioning of ICAL prototype detector electronics”.
[10] S.S.Upadhya, “Electronics and DAQ system for INO prototype detector”.
[11] V.M.Datar, S.Jena, S.D.Kalmani, N.K.Mondal, P.Nagaraj, L.V.Reddy, M.Saraf, B.Satyanarayana, R.R.Shinde, P.Verma, “Development of Glass Resistive Plate Chamber for INO experiment”.
[12] S.Biswas, “Resistive Plate Chambers for experiments at India -based Neutrino Observatory