Development of Resistive Plate Chambers using Bakelite

Saikat Biswas
Variable Energy Cyclotron Centre

Plan

- Physics motivations for INO
- INO Detector (ICAL)
- Resistive plate chamber (RPC) for ICAL
- RPC in a nutshell
- Test results of Chinese RPC
- Development of RPC from local material
- Future Plans

Physics Motivations for INO

- It is a neutrino oscillation experiment.
- To reconfirm the oscillation through appearance and disappearance of neutrinos.
- To measure the neutrino oscillation parameters $|\Delta m^2_{31}|$, $\sin^2 2\theta_{23}$, θ_{13} more precisely.
- To determine neutrino mass hierarchy, whether normal ($m^2_3 > m^2_1$) or inverted ($m^2_3 < m^2_1$).

India-based Neutrino Observatory (INO)

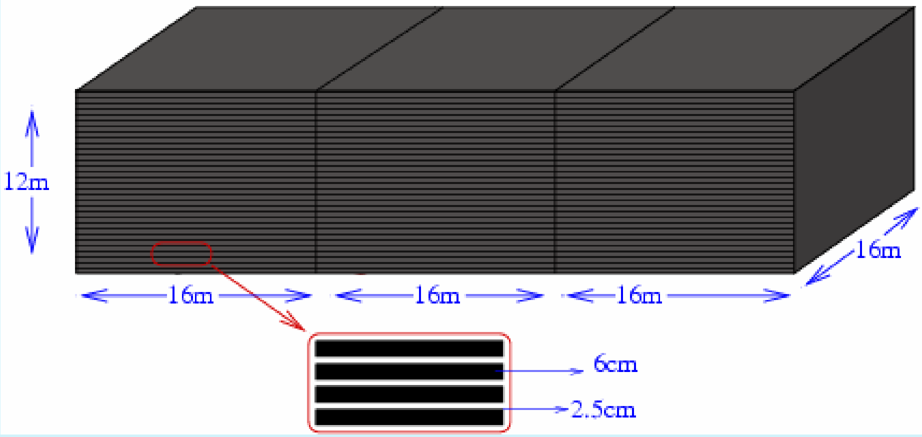
- A underground facility at PUSHEP in Masinaguri, Tamil Nadu in Southern India, about 90 km from Mysore.
- A single 22 m wide, 120 m long and 30 m in height experimental hall will be constructed at the end of a 1.5 km long tunnel.
- At least 1 km of rock overburden in all directions.
- INO will have 50 kiloton Iron CALorimeter (ICAL) capable of detecting atmospheric ν_μ and $\bar{\nu}_\mu$ interactions.
- May also host some other experiments (e.g neutrinoless double beta decay searches) which require low cosmic ray background environment.

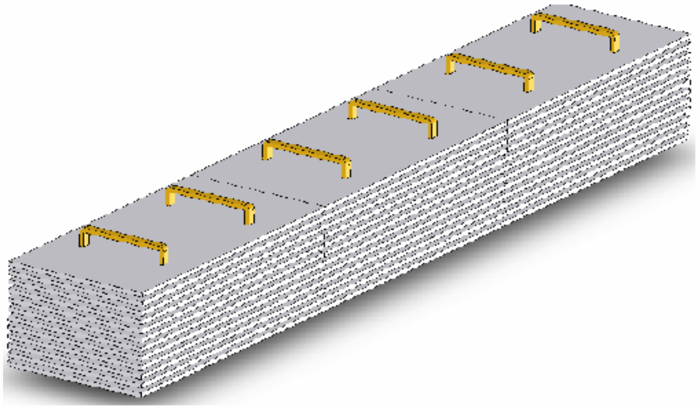
INO Detector :

A Magnetized Iron CALorimeter (ICAL):

- Three modules, each of the size 16m × 16m × 12m and of mass 17 kilotons each.
- In each module 140 layers of iron plates for magnet and RPC.
- 6 cm thick iron plates separated by 2.5 cm, with Resistive Plate Chambers (RPCs) as active element.
- Total mass of 51 kilotons.
- Magnetic field ~1 Tesla allows the determination of muon charge so that ν_μ and $\bar{\nu}_\mu$ can be studied separately.
- For better determination of other track parameters.

Iron CALorimeter
(A detector for INO)





Mass : 51 kilo ton

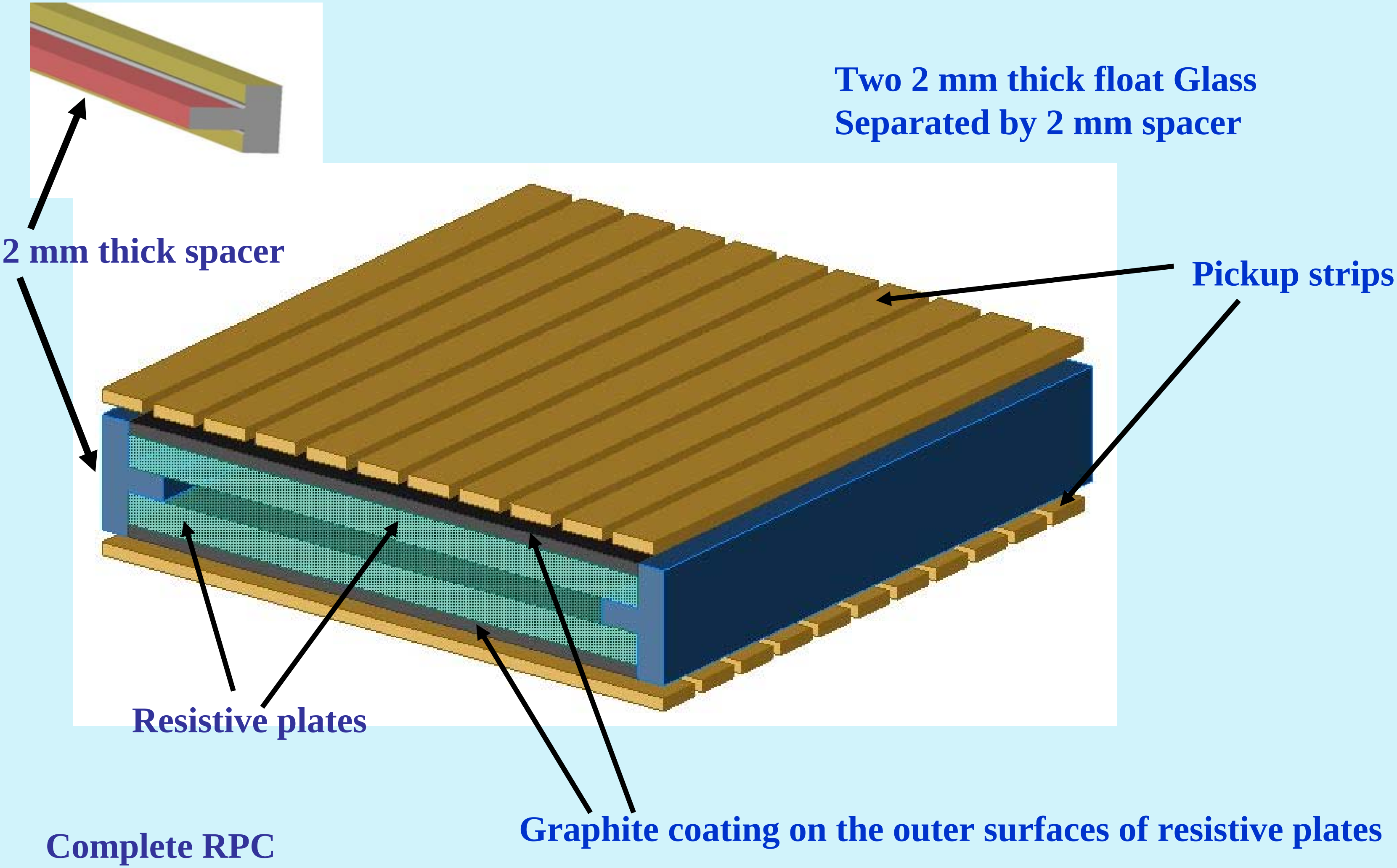
Magnetic field ~ 1 Tesla

Dimension :48m × 16m × 12m

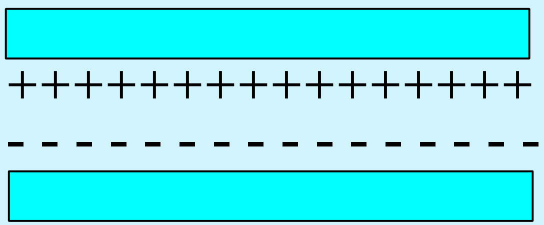
140 layers of iron plates.

Total number of RPC ~ 27000 of dimension 2m × 2m.

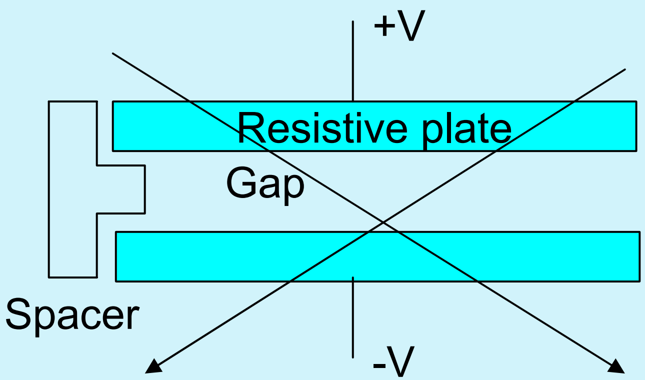
RPC for INO


Two 2 mm thick float Glass
Separated by 2 mm spacer
2 mm thick spacer
Pickup strips
Resistive plates
Graphite coating on the outer surfaces of resistive plates
Complete RPC

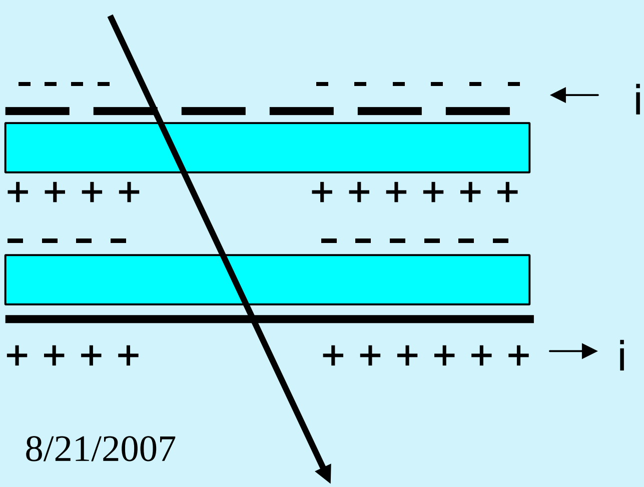
RPC in a nutshell



Surface of resistive electrodes are charged from power supply. Charge-up process is slow due to high resistivity of the material.



A passing charged particle induces an avalanche, which develops into a spark. The discharge stops when local charge is used up. This region is dead until re-charged through the bulk resistivity of the plates (10^{11} Ω-cm.)



When readout strip are placed, charge is either drawn in or drawn out from the readout board, generating voltage signals of opposite polarities.

Charge-up time after each discharge:

$\tau = R_{plate} C \cong (\rho_{plate} d_{plate} / A) (\kappa_{gas} \varepsilon_0 A / d_{gas}) = \rho_{plate} \kappa_{gas} \varepsilon_0$

where

R_{plate} - Resistance of the electrode plate

C - Chamber capacitance

ρ_{plate} - Bulk resistivity of the material of the plate

d_{plate} - Thickness of the plate

A - Area of the chamber

κ_{gas} - Dielectric constant of the gas

ε_0 - Permittivity of the free space

$\tau \cong (5 \times 10^{10}\ \Omega.\ m) . (\sim 4) . (8.85 \times 10^{-12}\ F\ m^{-1}) \cong 2$ sec

Each discharge is localized to ~ 0.1 cm^2

Why RPC ?

- Built from simple and common materials.
- Low fabrication cost per unit area.
- Easy to construct and operate.
- Simple signal pick up and readout system.
- Large detector area coverage .
- High efficiency (>90%) and time resolution (~2ns).
- Particle tracking capability and good position resolution.
- Two dimensional (x and y) readout from the same chamber.
- Long term stability.

Why Bakelite RPC ?

- Surface smoothness of glossy-finish melamine coated bakelite sheet is comparable to glass.
- Bakelite sheet is more flexible than glass and it is unbreakable.
- Bakelite sheet can be made 1.2 m in width and any size in length.
- Bulk resistivity of bakelite can be controlled adjusting the ratio of the phenol and melamine.

Chronology of activity so far

2005-2006

- Obtained 4 bakelite RPC modules from China
- Set up lab at SINP
- Tested 30 cm × 30 cm Chinese RPC at SINP lab
- Developed RPC using bakelite from local market

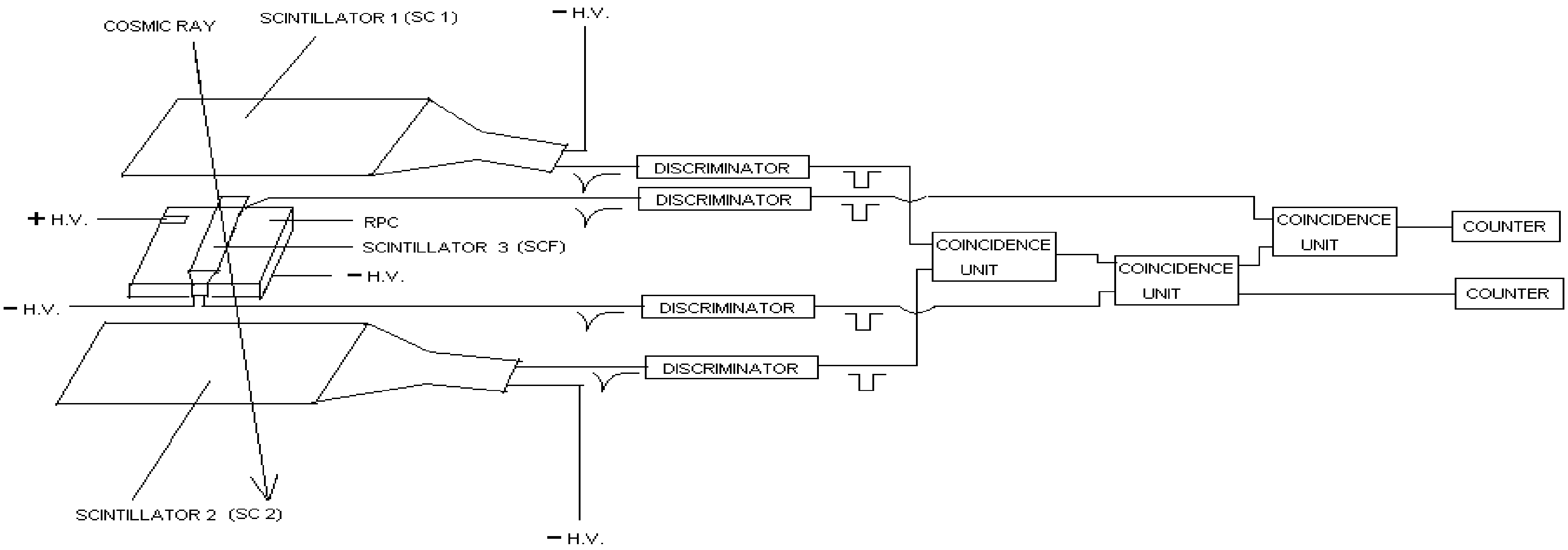
2006-2007

- Testing of local RPCs
- Problems & Identification & Issues
- Improved design
- Visit to Institute of High Energy Physics, China to learn about bakelite RPC

Chinese Bakelite RPC

- This RPC brought from China and tested in SINP.
- Dimension of the RPC : 30cm × 30cm.
- Thickness of each plate : 2mm
- Gas gap between two plates : 2mm

High voltage testing of Chinese Bakelite RPC using Cosmic Ray at SINP/VECC



Schematic representation of cosmic ray setup

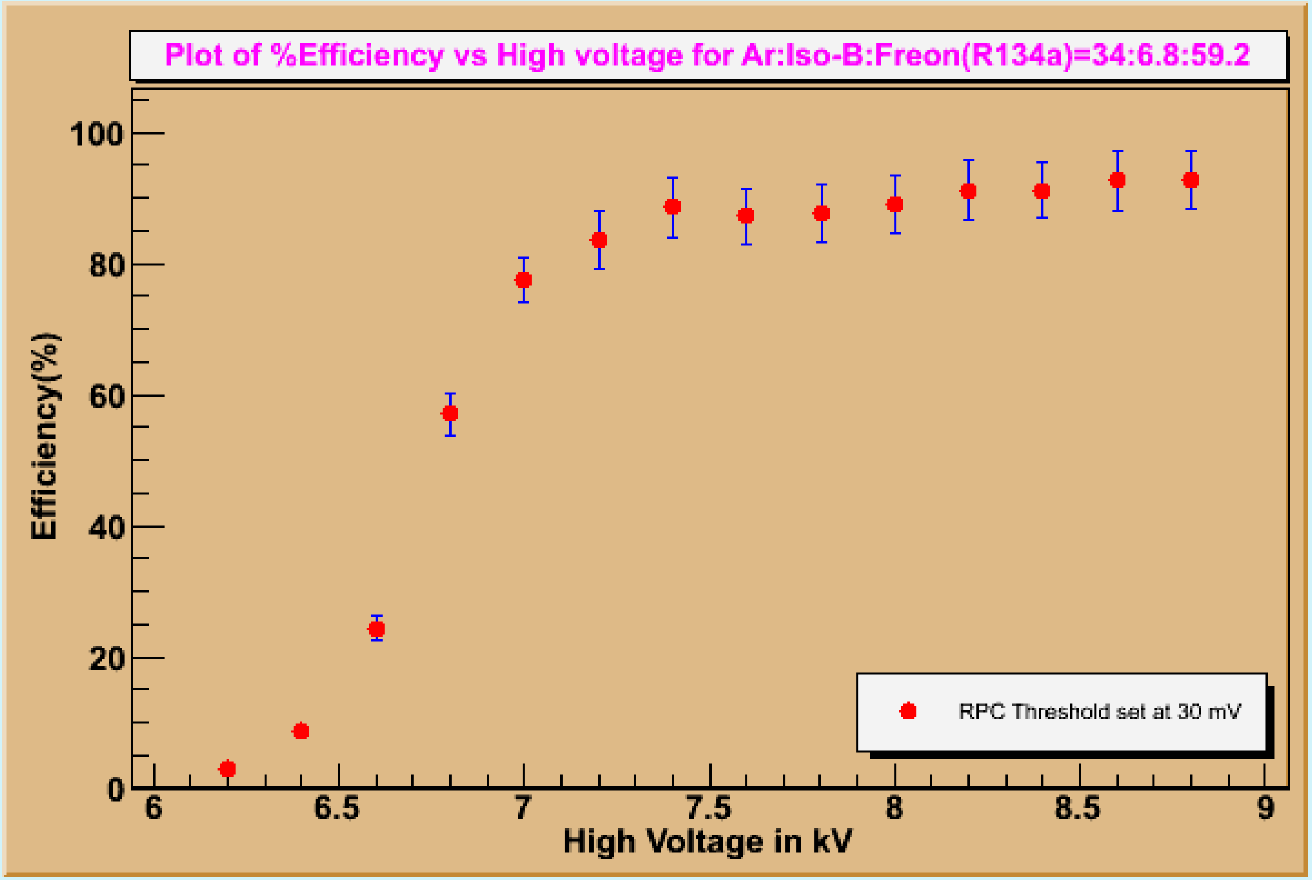
- Trigger signal = SC1 .AND. SC2 .AND. SCF

- Efficiency = $\dfrac{\text{(RPC count with signal in coincidence with trigger)}}{\text{(Trigger count)}}$

Gas Mixture

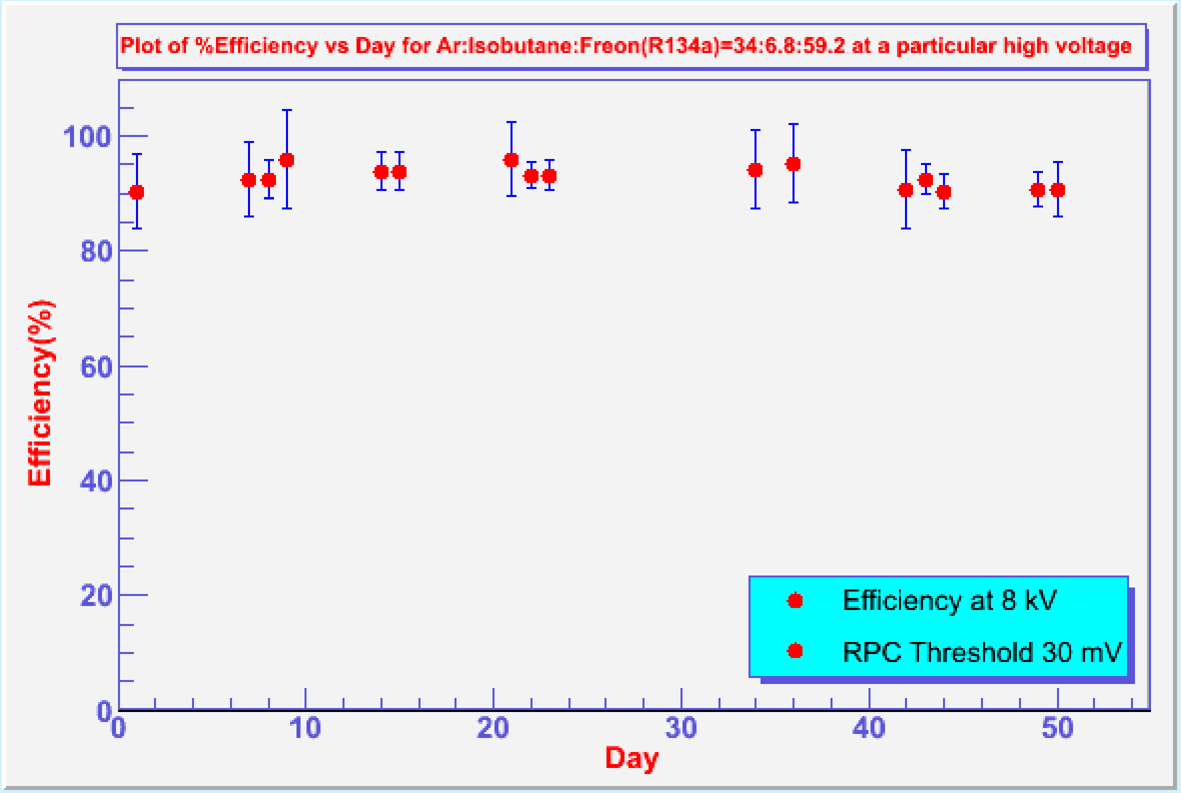
- Argon : To provide the efficient gas amplification.
- Isobutane : To absorb UV photon. It is the “photon quench gas”.
- Freon (R134a) : To control charge and physical size of streamer. It is the “electron quench gas”.

Efficiency curve for RPC



- The RPC is tested in streamer mode using premixed gas.
- The Trigger rate is around $0.31/cm^2/min$.
- Plateau region has been found from voltage 7.5 KV onwards at efficiency 91% .

Test of stability for Chinese RPC



- Curve is showing the constancy of the efficiency at a particular high voltage.

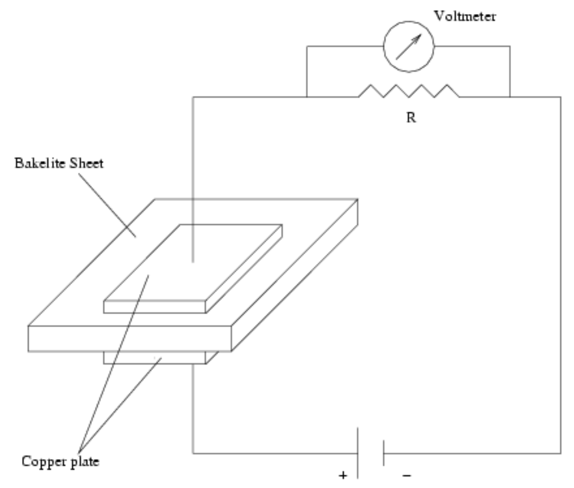
- Average efficiency (92.7 ± 1.9)% have been observed.

Fabrication of RPC using local Bakelite sheet

Fabrication Procedure (at VECC PMD lab)

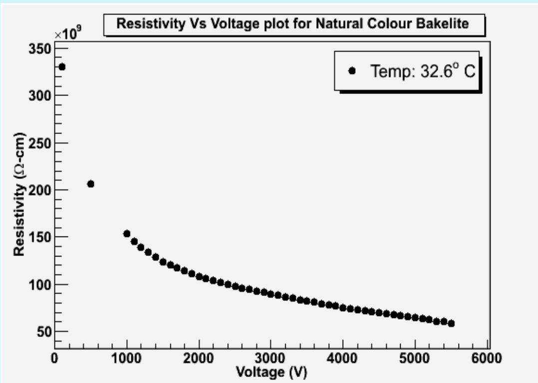
- Measure the bulk resistivity of the bakelite sample.
- Cut the bakelite in proper dimension from large sheet.
- Clean bakelite plates few times with alcohol. Then dry.
- Make the edge-spacers and button spacers using polycarbonate sheets.
- Glue both types of spacers on one of bakelite sheet. Dry for one day. Glue other bakelite plate on it and gas gap is ready.
- Put weights along the glue joints and leave overnight.
- Coat partially conducting graphite layer on the outer side of the RPC. (Thickness adjusted based on surface resistivity)
- Attach electrical leads using conducting copper tape.

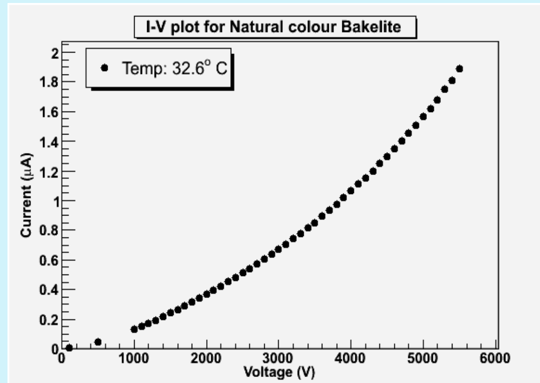
Measurement of bakelite resistivity



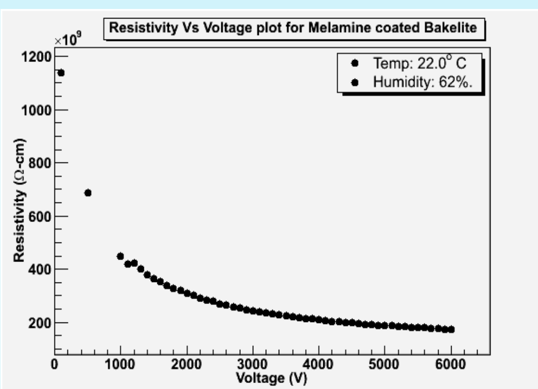
Schematic diagram of resistivity measurement set up

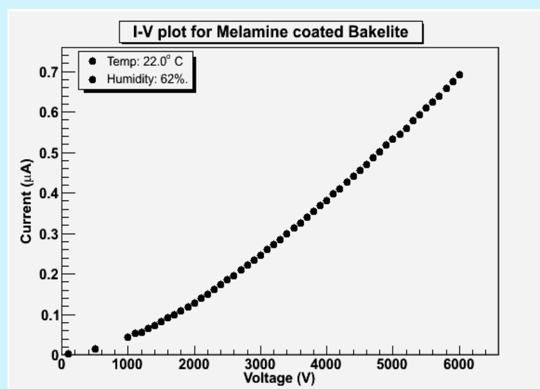
Characteristics of Bakelite Sheet (Grade P-1001 and Superhylam)





Resistivity Vs Voltage Current Vs Voltage
For Grade P-1001

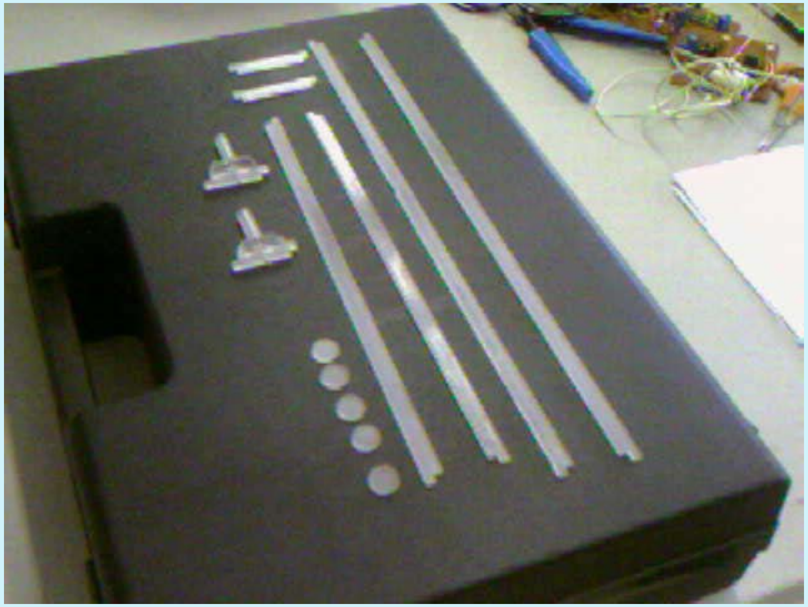




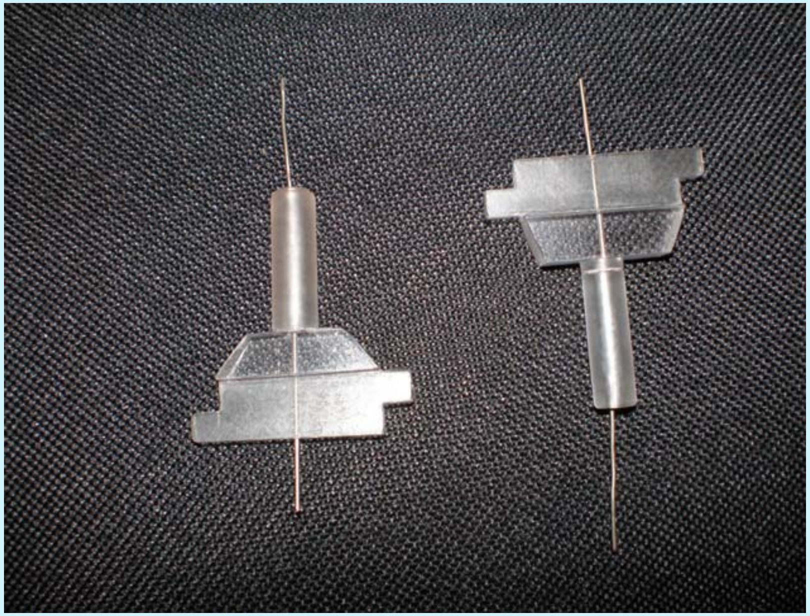
Resistivity Vs Voltage Current Vs Voltage
For Superhylam

- Available in Kolkata.
- Resistivity varies from 1.5×10^{11} Ω-cm to 5.8×10^{10} Ω-cm with voltage for P-1001.
- Superhylam is a melamine coated Bakelite.
- For Superhylam $\rho \sim 2 \times 10^{11}$ Ω – cm at 6 KV.

Figure of polycarbonate spacers and Gas nozzles



Edge spacers and button spacers made in VECC PMD lab.

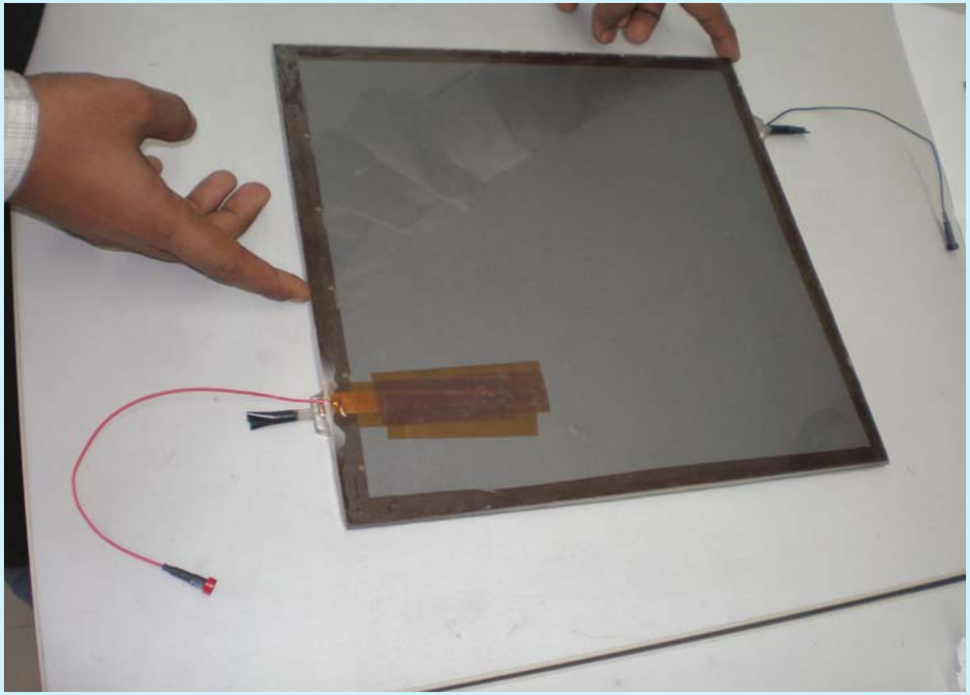


Polycarbonate gas nozzles made in SINP workshop.

Making of RPC

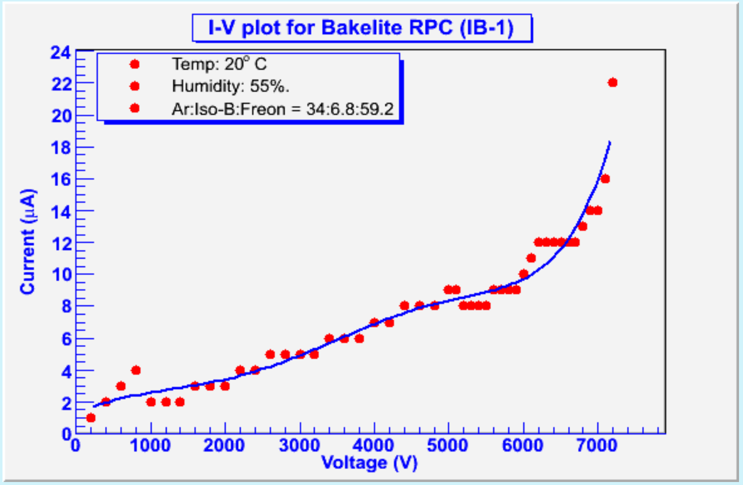
Gluing of spacers and gas nozzles on bakelite plates

Figure of first Indian Bakelite RPC made in VECC

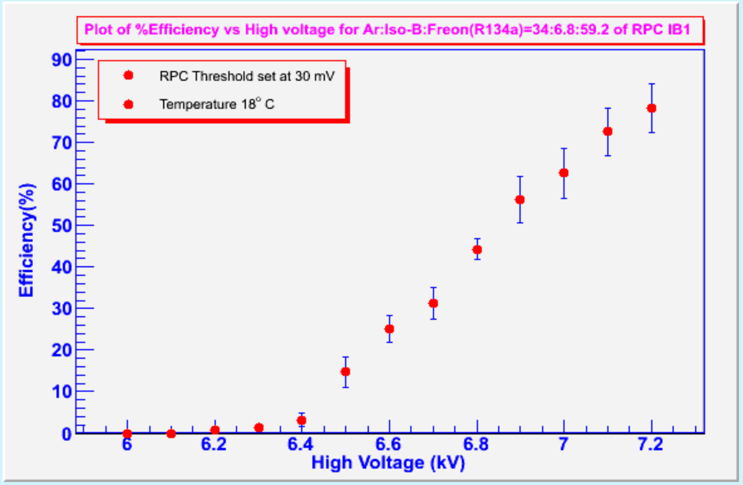


30cm x 30cm Bakelite RPC (IB1) made in VECC.

Test results of local Bakelite (P-1001) RPC IB-1



I-V plot with gas mixture of Argon, Iso-B and Freon



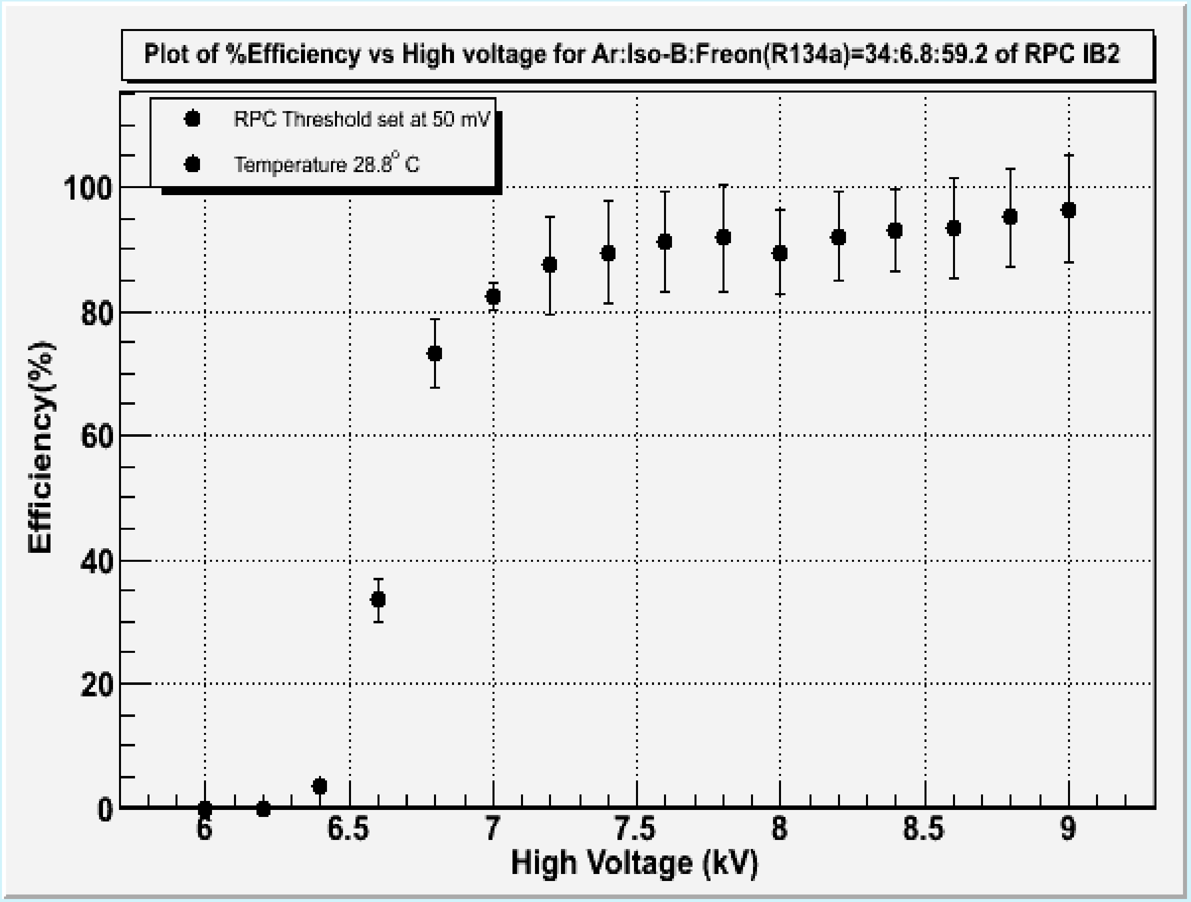
Efficiency Vs High Voltage

- Leakage current increases with applied voltage.
- Leakage current increases with Humidity and Temperature.
- Efficiency increases with applied voltage.
- Leakage current is too high at higher voltage, so voltage has not been increased more than 7.2 KV.
- The Bakelite (Grade P-1001) is not suitable for RPC.
- It is a mechanical grade.

Test of RPC (IB2) made in VECC

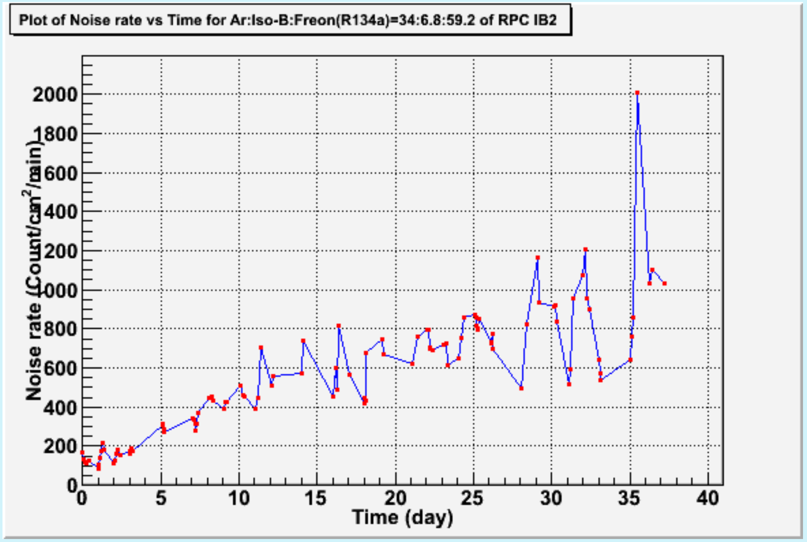
- RPC is made by white melamine coated superhylam bakelite.
- Dimension of the RPC : 30 cm × 30 cm .
- It is tested using premixed gas of Argon, Iso-Butane and R-134a (34:6.8:59.2).
- RPC is operated in Streamer mode.

Efficiency curve for RPC made by Superhylam

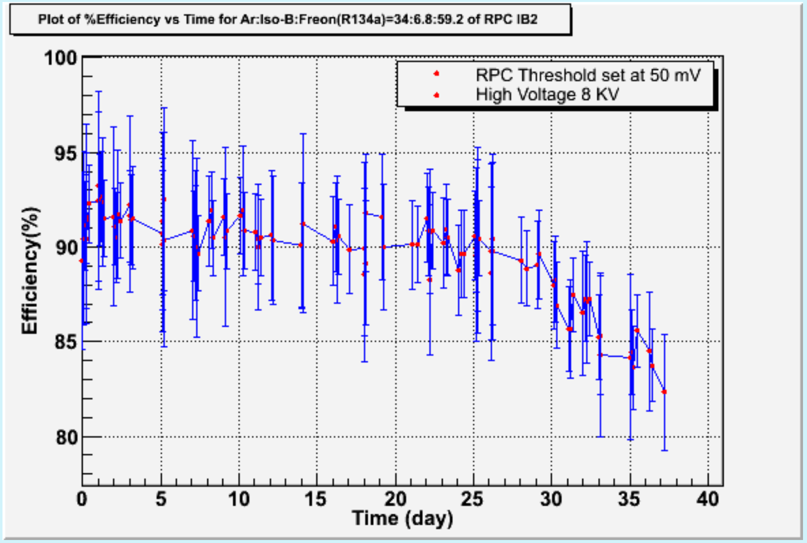


- The Trigger rate is ~0.3/cm^2/min.
- Plateau region has been found from voltage 7.5 KV onwards at efficiency >91%.
- At 9 KV current through the RPC ~5μA.

Problems



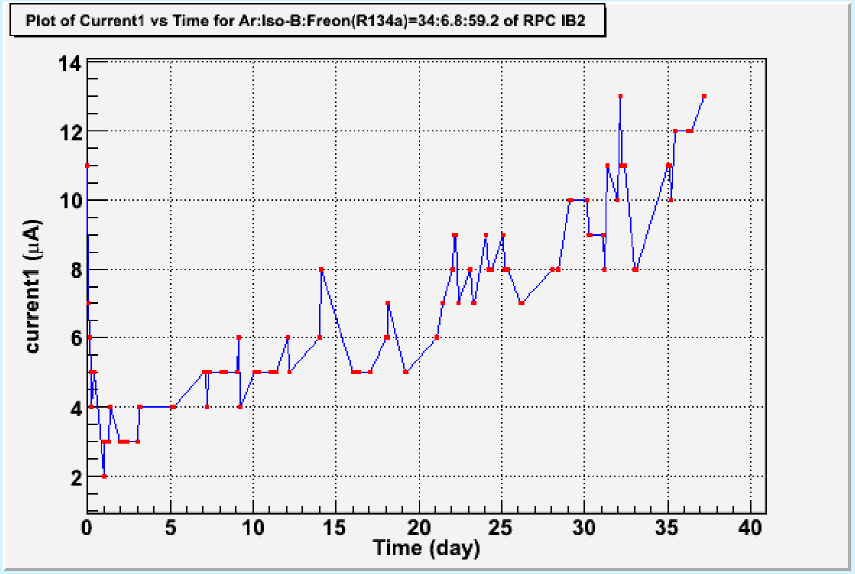
Noise rate Vs Day

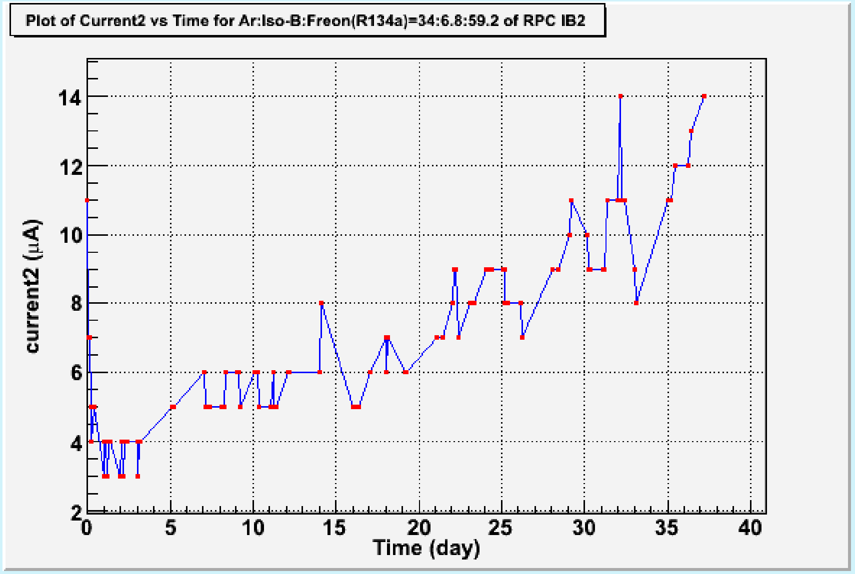


Efficiency Vs Day

- Noise rate increases with time.
- Long term stability test for 38 days.
- RPC is tested at 8 KV.
- RPC operated continuously for 25 days without change in efficiency.
- Efficiency decreases from a value ~92% to 82% within 38 days.

Current in two channels

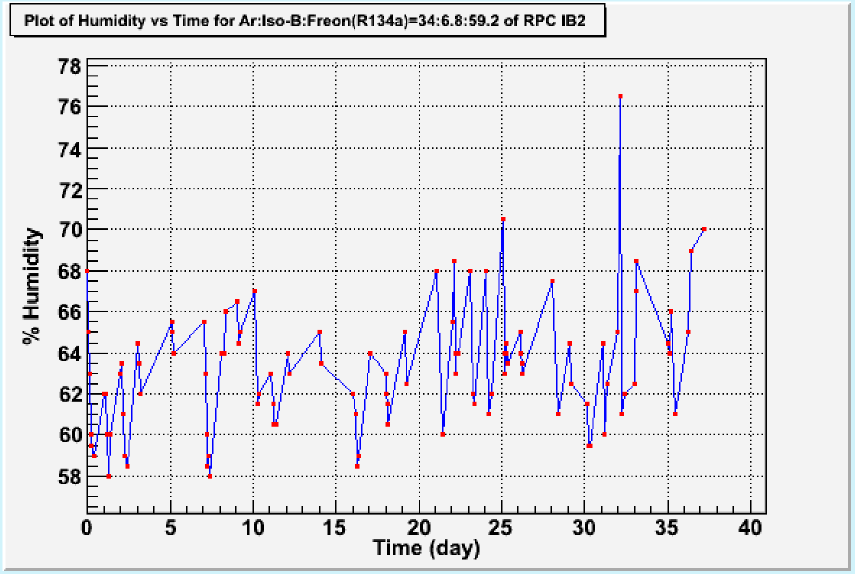


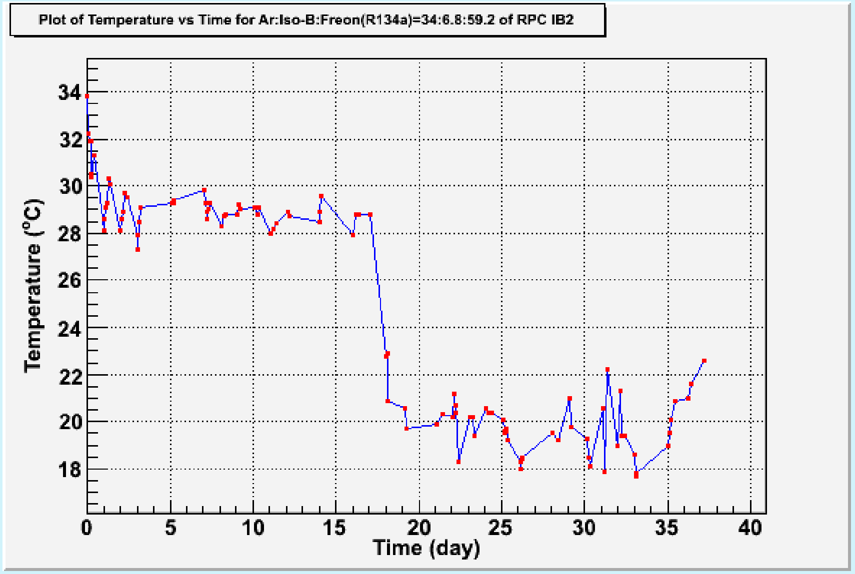


Current in Channel 1

Current in Channel 2

Humidity and Temperature

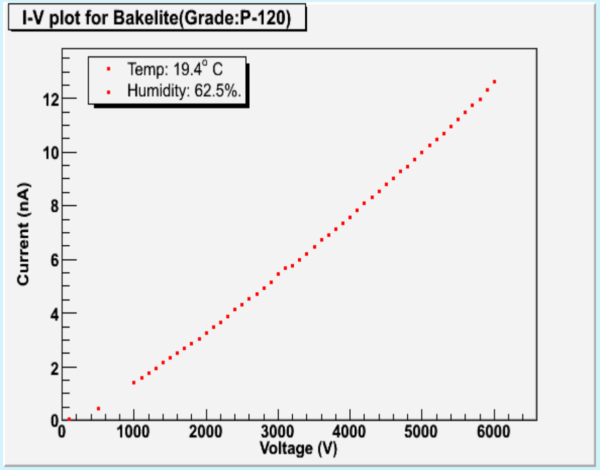




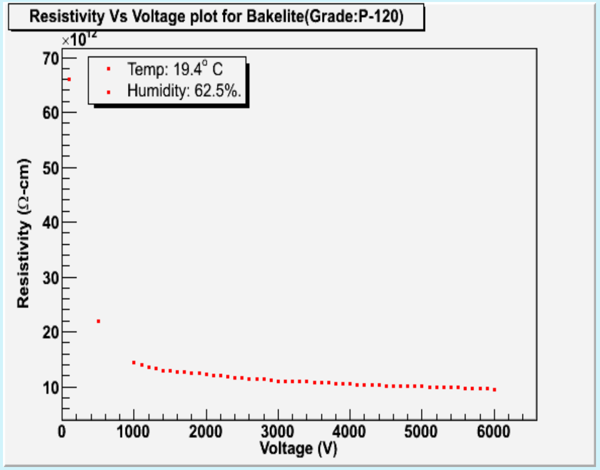
Humidity Vs Day

Temperature Vs Day

Characteristics of Bakelite (P-120)

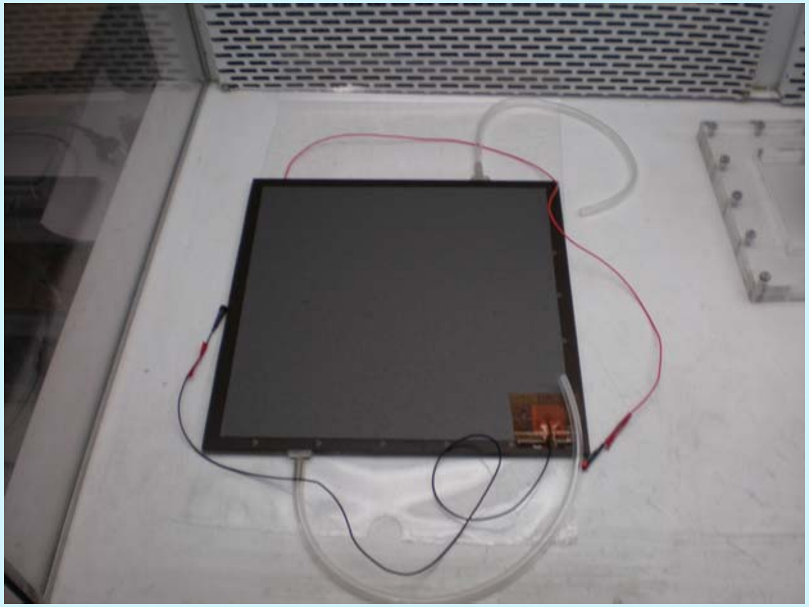


Resistivity Vs Voltage



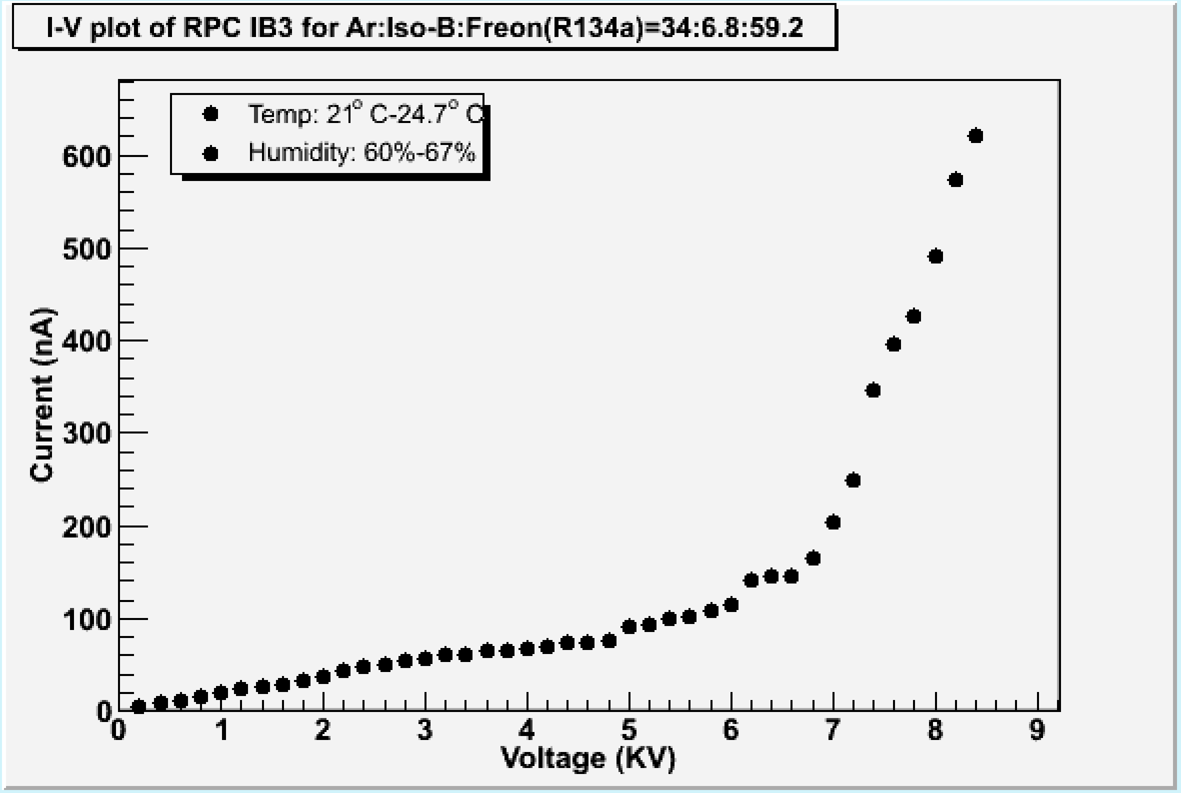
Current Vs Voltage

- $\rho \sim 9 \times 10^{12}$ Ω–cm at 6 KV.
- Origin: Hyderabad factory.
- Thickness: 2 mm
- Natural colour melamine coating bakelite.



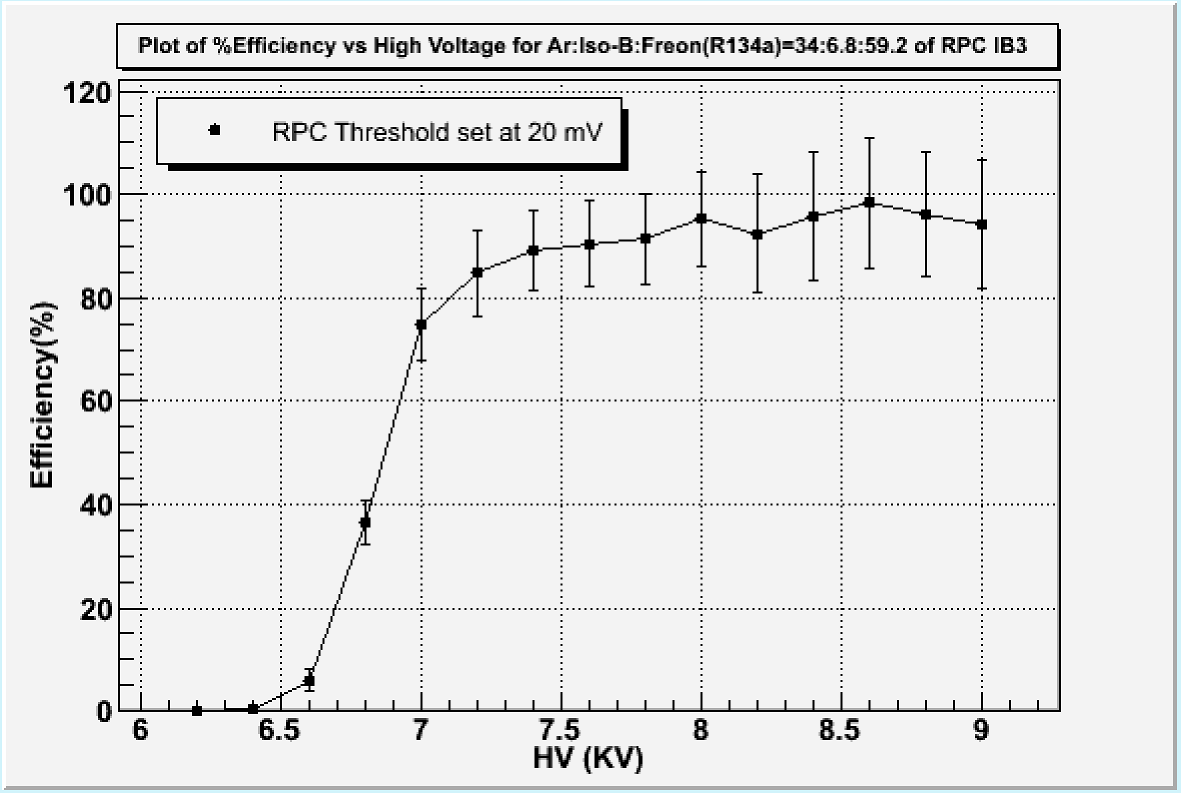
Complete RPC made by P-120

I-V plot for RPC IB3



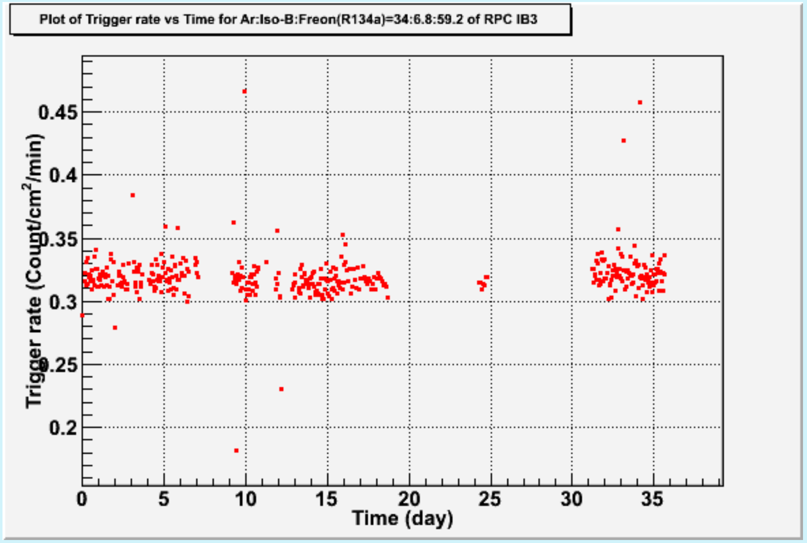
- Current is ~600nA at 9 KV.
- Efficiency starts to decrease after a certain HV.
- Inner side of RPC is coated with silicone oil.

Efficiency plot for IB3

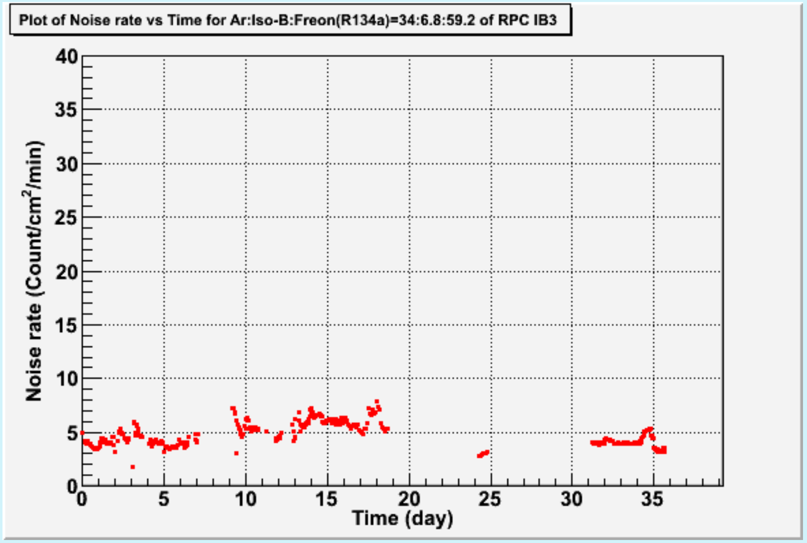


- Efficiency plateau over 90% obtained from 7.5 KV onwards.

Results of long term test



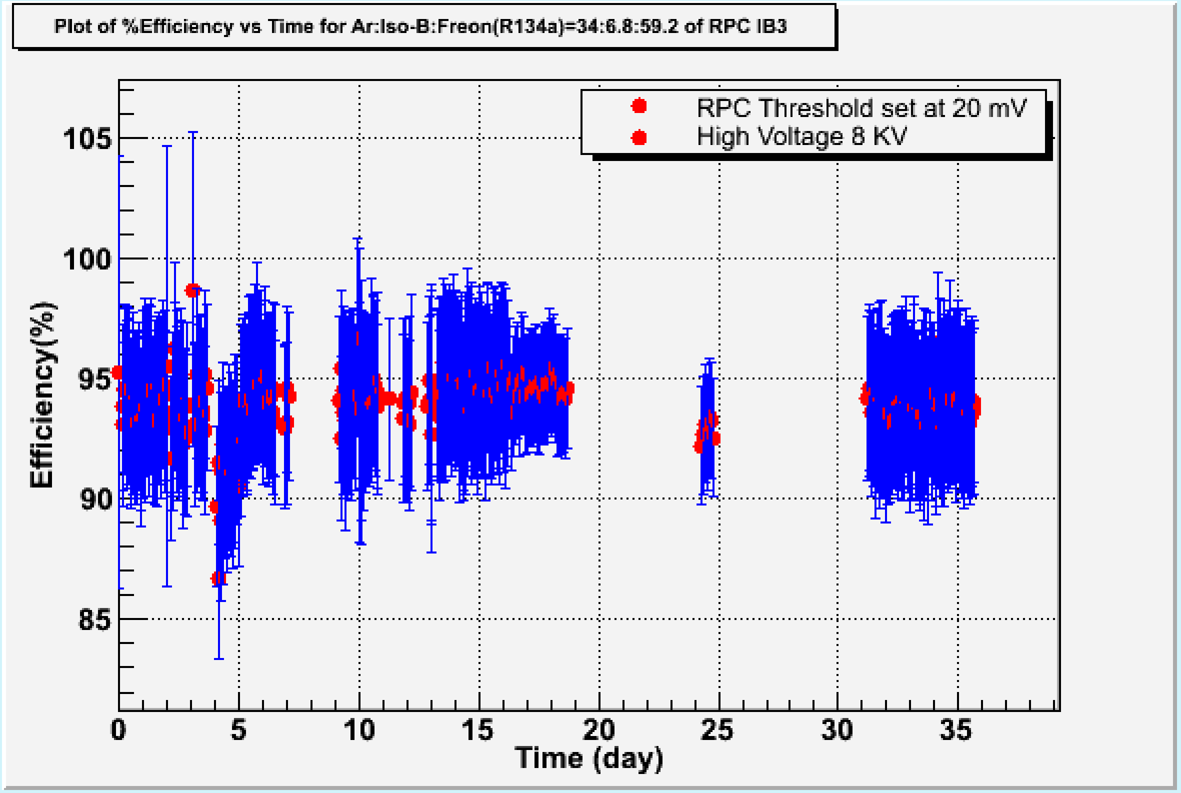
Trigger rate Vs Day



Noise rate Vs Day

- Noise rate is constant and ~5-8/cm^2/min.

Efficiency Vs Day



- Efficiency remains constant ~ 92-95% for 35 days operation.
- Operation had to stop for gas system modification.

DAQ

- Data acquisition using CAMAC has been started.
- Lamps has been installed.
- Scalar and TDC module have been installed.
- Calibration of TDC module has been done.

RPC in Institute of High Energy Physics (China)

1m × 2m bakelite RPC in IHEP

Study of RPC in IHEP

- Linseed oil free bakelite RPC of different sizes are used
- Thickness of each bakelite sheet : 2 ± 0.02 mm
- Bulk resistivity of the plates : 2×10^{11} - 2×10^{13}
- Copper read out strip pasted on G-10 material are being used for signal pick up
- RPCs are used in streamer mode with a gas mixture of Ar:Iso-B:Freon = 50:8:42 at 8 KV
- Threshold of RPC is set at 100 mV
- Average efficiency : 94 - 97%
- Single counting rate : 0.1 Hz/cm^2
- Dark Current: <10 μA/m^2

Summary of bakelite RPC study so far

- Testing setup is operational at SINP lab, it is upgraded with new gas flow system.
- Two Chinese RPCs (30cm x 30cm) tested, and gives stable >90% efficiency.
- One Chinese module dismounted and mounted again with local components (glue etc) and performance is good.
- RPC (IB-1) made by P-1001 grade bakelite shows large leakage current and could not be tested at higher voltage.
- RPC (IB-2) of Super-hylam grade is tested in streamer mode for 38 days. Efficiency decreasing and leakage current and noise rate increasing after 25 days.
- RPC (IB-3) of grade P-120 shows better I-V characteristics, one module is tested for 35 days in streamer mode. Stable efficiency >91%, low leakage current and noise rate obtained. Second module of P-120 is ready for testing.

Future plans

- Fabrication of larger RPC using Indian bakelite.
- Testing of 1m x 1m Chinese bakelite RPC .
- RPC testing using the gas system of VECC.
- Measurement of time resolution of RPC.
- Installation of Lab View and starting on line monitoring.
- Construction of pick up panel using G-10.
- Study of surface quality and material properties of Bakelite.

- **Testing of prototype of ICAL at VECC.**

Acknowledgment

I am grateful to Dr. Subhasis Chattopadhyay, Prof. Satyajit Saha, Prof. Sudeb Bhattacharya and Dr. Manoj Sharan for all kinds of supports, suggestions and discussions.

Thank You