# Development of linseed oil-free Bakelite Resistive Plate Chambers

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## Introduction

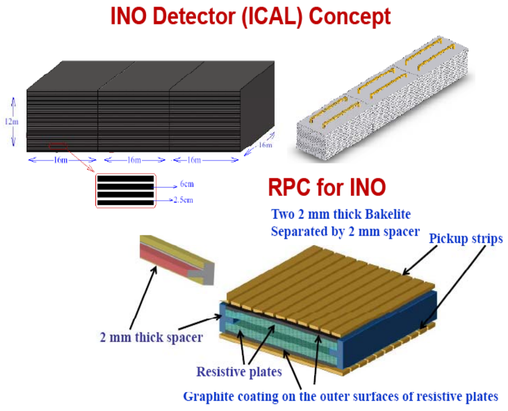
**The active detector in INO → RPC**

- 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.

## Main goal of the study

To construct large bakelite RPC without linseed oil coating for the experiment at India based Neutrino Observatory (INO)

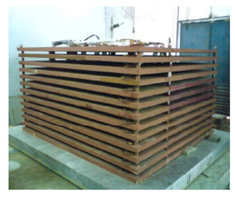
## INO Detector (ICAL) Concept




## ICAL Detector Specifications

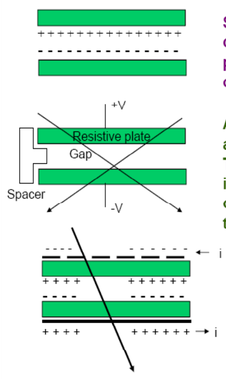
| | |
|---|---|
| *No of modules* | *3* |
| *Module dimension* | *16 m X 16 m X 12 m* |
| *Detector dimension* | *48 m X 16 m X 12 m* |
| *No of layers* | *140* |
| *Iron plate thickness* | *6 cm* |
| *Gap for RPC trays* | *2.5 cm* |
| *Magnetic field* | *1.5 Tesla* |
| *RPC unit dimension* | *2 m X 2 m* |
| *Readout strip width* | *2 cm* |
| *No. of RPCs/Road/Layer* | *8* |
| *No. of Roads/Layer/Module* | *8* |
| *No. of RPC units/Layer* | *192* |
| *Total no of RPC units* | *27000* |
| *No of Electronic channels* | *3.6 X $10^6$* |

## ICAL prototype at VECC



- 5 cm thick iron plates separated by 5 cm, with Resistive Plate Chambers (RPCs) as active element
- Total mass ~ 30 Ton
- Magnetic field ~1.25 Tesla
- 12 RPCs of dimension 1m × 1m will be used

## Basic principle of RPC




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.)

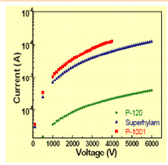
When readout strip are placed, charge is either drawn in or drawn out from the readout board, generating voltage signals of opposite polarities.

## Why Bakelite RPC ?

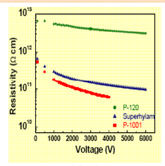
- Bulk resistivity of bakelite is comparable to that of glass.
- Surface smoothness of glossy-finish melamine coated bakelite sheet is comparable to glass.
- Bulk resistivity of bakelite can be controlled adjusting the ratio of the phenol and melamine.
- Bakelite sheet is less breakable than glass.
- Easy to handle.
- Bakelite sheet can be made 1.2 m in width and any size in length.
- Some samples can be used for high voltage operation in humid condition.
- Low cost material.

## Properties of Indian bakelite

| Trade Name | BS-2572 Grade | Density (g/cc) | Electrical strength (kV/mm) | Surface finish | Measured bulk resistivity (Ω cm) |
|---|---|---|---|---|---|
| P-1001 | P1 | 1.38 | 3.5 | Matt | $6.13 \times 10^{10}$ |
| Superhylam | P2 | 1.72 | 9.5 | Glossy | $1.25 \times 10^{11}$ |
| P-120 | P3 | 1.22 | 9.5 | Matt | $3.67 \times 10^{12}$ |




I-V plot

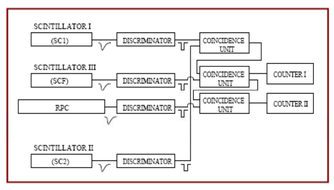



ρ-V plot

## Fabrication Procedure

- Bulk resistivity measurement
- Cut in proper dimension
- Making of polycarbonate
  - Edge spacers
  - Button spacers
  - Gas nozzles
- Gluing and silicone coating
- Partially conducting graphite coating on the outer sides
- Surface resistivity measurement
- Electrical leads connection
- Leak test using Argon and Helium sniffer probes


## Schematic representation of cosmic ray setup



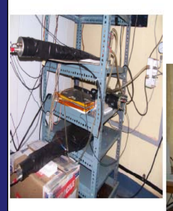

Complete RPC

All RPCs are tested in streamer mode.
Discriminator threshold for the RPC signal is set at -40 mV.

**Master trigger signal = SC1 .AND. SC2 .AND. SCF**

**Efficiency = (RPC signal in coincidence with master trigger) / (Master trigger count)**

## Cosmic ray test bench



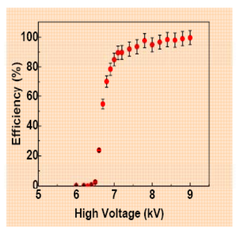
Arrangement of the scintillators and the RPC

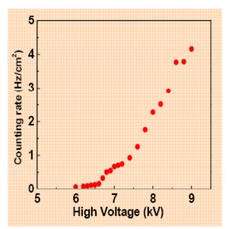
Power supply, front-end electronics and DAQ

- Used gas: Argon, Iso-butane, R-134a (34:7:59).
- Flow rate: 0.4 ml/min (3 detector volume/day)

4 gas mixing unit

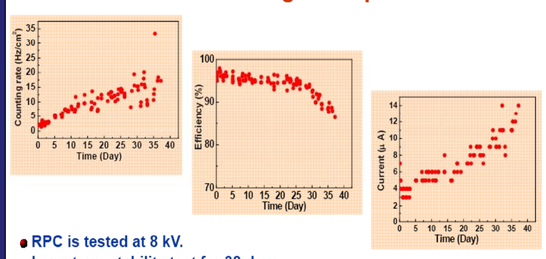
## Characteristics of Superhylam grade bakelite RPC



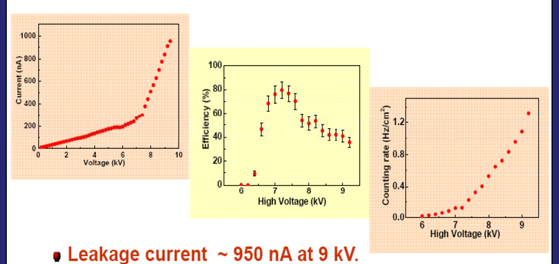

- The RPC is tested in streamer mode using premixed gas.
- The Trigger rate is around 0.005 Hz/cm$^2$.
- Plateau region has been found from voltage 7.5 kV onwards at efficiency >95%.
- At 9 kV leakage current of the RPC ~ 5 μA.

## Problems in long term operation




- RPC is tested at 8 kV.
- Long term stability test for 38 days.
- Counting rate increases with time.
- RPC operated continuously for 25 days without change in efficiency.
- Efficiency decreases from a value ~ 95% to 85% within next 13 days.
- Current increases with time.
- Retested after 2 months. Efficiency saturates at ~ 82%.

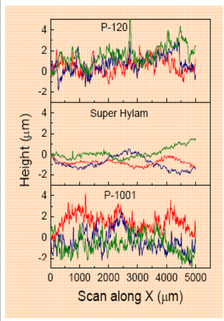
## Characteristics of P-120 grade bakelite RPC




- Leakage current ~ 950 nA at 9 kV.
- Efficiency starts to decrease from a HV ~ 7.5 kV.
- Conditioned for a few days with HV.
- No improvement is observed.

## Surface profile study

**Surface profile scan by DekTak 117 Profilometer**



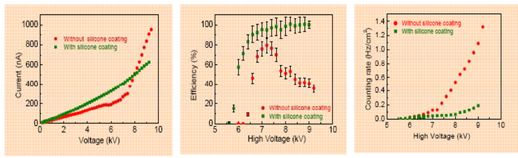

| Grade | Long range variation (μm) | Short range variation (μm) |
|---|---|---|
| P-120 | 0.84 ± 0.12 | 0.64 ± 0.06 |
| Superhylam | 0.49 ± 0.17 | 0.17 ± 0.02 |
| P-1001 | 0.88 ± 0.09 | 0.63 ± 0.13 |

Inner-side of P-120 grade RPC is coated with **silicone** to make the surface smooth.

## Utilities of Silicone

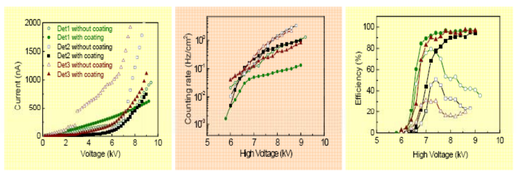
- Very low chemical reactivity with the gas used
- Good thermal stability over a wide temperature range (from -100 to 250°C)
- Electrically insulator
- Low vapour pressure
- High viscosity ~ 5500 cP at 23°C
- Density 1.02 g/cc at 23°C

## After silicone coating




Current reduces | Efficiency plateau obtained | Counting rate decreases

## Repetition of results




**Three small prototypes have been tested.**

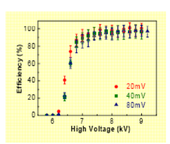
*Without silicone coating*

- Current increases rapidly.
- After a certain voltage efficiency decreases in all cases.

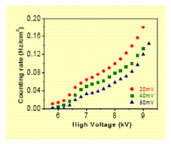
*With silicone coating*

- Efficiency plateau >96% obtained.
- Counting rate decreased.
- Current decreased.

## Effect of RPC threshold

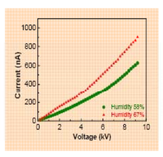



Efficiency curve does not depend on RPC threshold

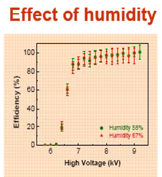



Counting rate is larger for lower RPC threshold

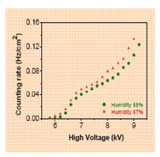
## Effect of humidity




Leakage current is larger in higher humidity

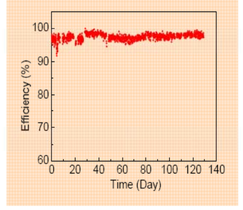


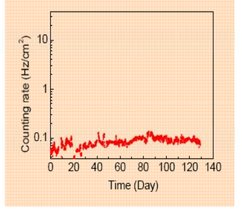

No effect of humidity on efficiency curve




Counting rate is larger in higher humidity

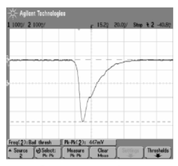
## Results of long term test



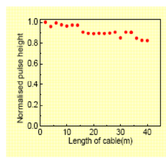



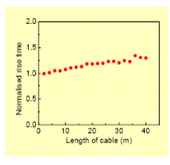

- RPC is tested at 8 kV.
- Efficiency remains constant > 96% for more than 130 days operation.
- Counting rate is constant and ~ 0.1Hz/cm$^2$.
- Current < 600 nA.
- One module is tested at 10 kV to study the effect of damage. An efficiency >96%, with leakage current ~ 2 μA and counting rate ~1.5 Hz/cm$^2$ obtained.

## Test of signal attenuation



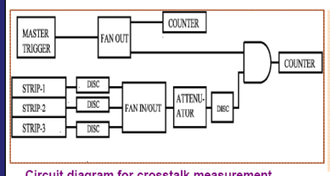
Streamer pulse



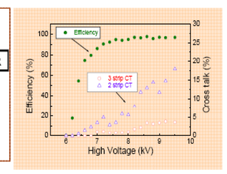




- Typical RPC streamer pulse height: ~ 300 – 500 mV
- Long cable drive has been tested
- Pulse height reduces to ~ 80% of the maximum

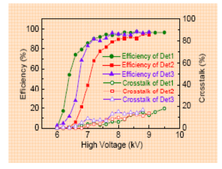
## Crosstalk



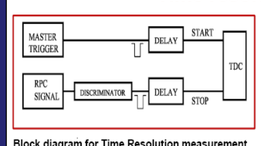

Circuit diagram for crosstalk measurement



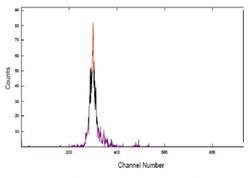

- Foam and G10 based copper pick-up strip has been used
- Crosstalk between two adjacent strip may come from some event
- Crosstalk between two adjacent strips is < 20%
- Crosstalk between three adjacent strips is < 5%




## Time resolution of RPC



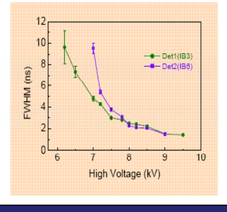

Block diagram for Time Resolution measurement



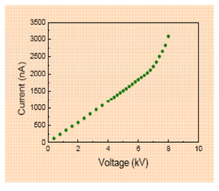

Time spectra of RPC

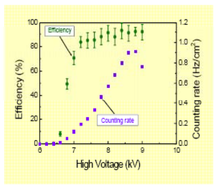
- P/S 7186 TDC is used
- Offset delay ~ 10 ns
- 1 ch of TDC = 0.097 ns
- FWHM$_{SCF}$ = 1.98 ± 0.02 ns

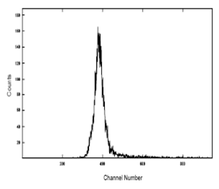
- TDC Start: Master trigger (3 fold scintillator)
- TDC Stop: Signal from RPC
- Time resolution of RPC ~ 2 ns

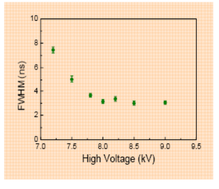



## First result of uncoated P-120 RPC




## Summary and Outlook

- RPC of Superhylam grade is tested in streamer mode for 38 days. **Efficiency decreasing and leakage current and counting rate increasing after 25 days.**
- RPC of grade **P-120** shows better I-V characteristics.
- **Three** modules (with and without **silicone coating**) are tested.
- One silicone coated module is tested for **130 days** in streamer mode. **Stable efficiency >96%, low leakage current (~500 nA) and counting rate (~0.1 Hz/cm$^2$) obtained.**
- Time resolution **~2 ns.**
- Fabrication of **1 m × 1 m** RPC started.
- Performance with multigap design, effect of temperature and humidity etc. will be studied in the future.
- **Testing of 1 m × 1 m RPC in prototype of ICAL at VECC**

**Acknowledgement**

*We acknowledge the service rendered by Mr. Ganesh Das of VECC for meticulously fabricating the detectors and Mr. Avijit Das of SINP for surface profile scans of the bakelite sheets used by us.*

**References**

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[2] S. Biswas et al., arXiv:0802.2766
[3] DAE-BRNS High Energy Physics Symposium, IIT Kharagpur, (2006) 335
[4] DAE-BRNS Symposium on Nuclear Physics, Vol. 52 (2007) 593
[5] S. Biswas, Talk given at IX International Workshop on Resistive Plate Chambers and Related Detectors, Mumbai, February 2008