Highlights of development and deployment of RPC detectors in India

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RPC development centres in India

AMU

BARC

BHU

Bose Institute

CUK

DU

IISER

IITB

IITM

KU

NISER

PU

SINP

TIFR

TKMCAS

TU

VECC

AMU

Aligarh

BARC

Mumbai

BHU

Varanasi

Bose Institute

Kolkata

CUK

Kalaburagi

DU

Delhi

IISER

Mohali

IITB

Mumbai

IITM

Chennai

KU

Kashmir

NISER

Bhubaneswar

PU

Chandigarh

SINP

Kolkata

TIFR

Mumbai

TKMCAS

Kollam

TU

Tejpur

VECC

Kolkata

Date: 28/09/2001

Thickness measurements were done for 14.5 Modi glass
2mm (EX) using ultra sound gauge.
Mean = 2.017 and RMS = 0.1247 (Entries = 27)
( mm )

Date:

Resistance measurement of Modi glass (2mm) done
as follows:

Typical resistance measured was 10^12 

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DAE-BRNS High Energy Physics Symposium, IIT Madras

December 10-14, 2018
Schematic of a basic SRPC

 Resistive materials like glass or bakelite for electrodes
 Special paint mixture (developed locally) for semi-resistive coating
 Plastic honey-comb laminations used as readout panel
 Special plastic films for insulating the readout panels from high voltages
 Two modes of operation: Avalanche (R134a:Isobutane:SF\textsubscript{6} ::95.5:4.2:0.3) and Streamer (R134a:Isobutane:Ar::56:7:37)
Studies on electrode characteristics

30 cm x 30 cm, 3mm thick float glass
Due to manufacturing process, glass surfaces are lot smoother compared to that of bakelite.
Bulk and surface resistivities

**Glass**

**Bakelite**

Surface resistivity in $10^{11} \, \Omega/\square$

Surface resistivity in $10^5 \, \Omega/\square$
Glass characterisation studies

PIXE Spectrum of bakelite sample

PIXE Spectrum of glass sample

Cross-talk
Paint conductivity and charge profile

SINP, Kolkata

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We obtained a position resolution of $0.98 \pm 0.11$ mm using panels made of 5 mm wide strips while it was $0.57 \pm 0.21$ mm with panels made of 3 mm wide strips.
Studies on moister contamination

- Voltage vs. Efficiency for RPC1 and RPC2
- Time vs. Efficiency for RPC1 and RPC2
- Time vs. Efficiency for 20 SCCM, 30 SCCM, 40 SCCM, and 50 SCCM
- Time vs. Current for RPC1 and RPC2

IIT Madras

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Automated leak test system

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Optimising operating gas mixtures

Time Resolution (ns)

Voltage (kV)

Efficiency (%)

Timing Resolution (ns)

Voltage (kV)
Role of SF$_6$ in the RPC gas mixture

### Graphical Data

- **SF$_6$ concentration** vs. **Efficiency (%)**
  - SF$_6$ : 0.1%
  - SF$_6$ : 0.2%
  - SF$_6$ : 0.3%
  - SF$_6$ : 0.4%

### Table Data

<table>
<thead>
<tr>
<th>SF$_6$ (%)</th>
<th>DAQ Mean</th>
<th>DAQ Events</th>
<th>Simulated Mean</th>
<th>Simulated Events</th>
<th>CRO Mean</th>
<th>CRO Events</th>
<th>Simulated Mean</th>
<th>Simulated Events</th>
<th>Simulated Mean</th>
<th>Simulated Events</th>
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</table>
Studies on alternate gas mixtures

Electric field: 50 KV/cm and gas mixture Ar:CO$_2$:N$_2$ :: 5:65:30
Charge identification efficiency (distinguishing up-going/down-going $\mu^+/\mu^-$) of proposed ICAL setup depends on timing properties of RPC.

Experimental and numerical studies on a RPC and calculation of timing properties and efficiency of the detector at various operating conditions.

In this connection, the electric field map of RPC was studied in detail as it is one of the crucial factors for RPC operation. Effect of design components and imperfections (surface roughness) on the detector properties.
RPC timing properties for ICAL

- The RPC is slower near its edge and button spacer (affected region is ~6 mm).
- Reduction of RPC gas gap and using more than one gas gap (Multi-gap RPC configuration) were found to improve timing properties significantly (1ns $\rightarrow$ 50ps).

Variation of (left) average signal generation time and (right) intrinsic time resolution of RPC with distance from a button spacer for different applied fields and gas mixtures.

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Bench marking of RPC detectors

1m x 1m RPC stack in TIFR

2m x 2m RPC test stand in TIFR

2m x 2m RPC stack in Madurai

1m x 1m RPC stack in VECC
A few results from an RPC stand
Multiple muons in RPC stands

Multi_Event_x_0057_029933_m2

Multi_Event_x_0057_025969_m2

Multi_Event_x_0057_009718_m2

Multi_Event_y_0057_029933_m2

Multi_Event_y_0057_025969_m2

Multi_Event_y_0057_009718_m2
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<th>e-ICAL</th>
<th>m-ICAL</th>
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<td>1</td>
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<td>Module dimensions</td>
<td>16.2m×16m×14.5m</td>
<td>8m×8mx2m (90:1)</td>
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<td>Detector dimensions</td>
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<td>10</td>
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<td>56mm</td>
<td>56mm</td>
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<td>Gap for RPC trays</td>
<td>40mm</td>
<td>40mm</td>
<td>45mm</td>
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<td>RPC dimensions</td>
<td>1,950mm×1,910mm×24mm</td>
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<td>1,950mm×1,910mm×24mm</td>
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<td>No. of RPC units</td>
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<td>320 (1,192m²) (90:1)</td>
<td>20 (74.5m²) (1440:1)</td>
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<td>No. of readout strips</td>
<td>3,686,400</td>
<td>40,960 (90:1)</td>
<td>2,560 (1440:1)</td>
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## Deployment scenario of RPCs

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<tr>
<th>Experiment</th>
<th>Area (m²)</th>
<th>Electrodes</th>
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<th>Mode</th>
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<td>1</td>
<td>Avalanche</td>
<td>Trigger</td>
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</table>
Profile of an ICAL RPC detector

Detector size: 1,950mm × 1,910mm × 24mm
Pickup strips: 128 (64 each of X- & Y-planes)
Materials for gas gap fabrication

Schematic of an assembled gas volume

Edge spacer

Gas nozzle

Glass spacer
Glass spray painting robot
Screen printing on electrodes
Automated resistivity measurement
Automatic RPC gap making
Development of Pickup panels

Honeycomb panel

Foam panel

Polypropylene as well as PVC panels are also developed.

G-10 panel
Development of SFS pickup panel

- Fire proof
- Water proof
- Flexible
- Light weight
- Cost effective
- Strip impedance
- Locally available
- Density ($\rho$): 0.3 - 0.6 g/cm$^3$
- Flexibility: Strong
- Radiation resistance: High
- Melting temperature ($T_m$) 2100°C
Closed loop gas system

About 200,000 litres (60 LPG cylinders) of gas will be circulating in the ICAL detector all the time.

Regenerate, Recycle and Reuse

- Gas Mixing (On-line)
- Gas Recirculation
- Gas Purification system
- Control System (PLC)
ICAL detector holds about 200,000 litres of gas all the time. Gas recycling system ensures that almost no gas is wasted.
ICAL, e-ICAL and m-ICAL

Magnet coils

RPC handling trolleys

Total weight: 50Ktons
A collage of muon tracks in m-ICAL

Event = 376, $p = 0.58$ GeV, $\theta = 148.07^\circ$

Event = 376, $p = 0.58$ GeV, $\theta = 148.07^\circ$

Event = 499, $p = 0.44$ GeV, $\theta = 136.47^\circ$

Event = 499, $p = 0.44$ GeV, $\theta = 136.47^\circ$

Event = 957, $p = 0.70$ GeV, $\theta = 145.19^\circ$

Event = 957, $p = 0.70$ GeV, $\theta = 145.19^\circ$

Event = 632, $p = 0.31$ GeV, $\theta = 109.44^\circ$

Event = 632, $p = 0.31$ GeV, $\theta = 109.44^\circ
Fine tuning RPC operating conditions
Muon life time measurement

\[ \chi^2 / \text{ndf} = 86.53 / 94 \]

Coeff of exp (A) \( \tau_\mu \) (\( \mu s \))

- \( \tau_\mu \) = 2.24 ± 0.08
- Constant (B) = 176.7 ± 1.9

\[ A \cdot \exp\left(-\frac{1}{\tau_\mu} \cdot x\right) + B \]

- Trigger Condition: L9 & L8 & L7 & L6
- This trigger allows to observe for decay of muon in 6 bottom Fe layers.
- Conditions to observe decay signal in any of the 6 bottom layers:
  1. There should be at least one hit in all above layers (muon signal)
  2. There should not be any hit in all the below layers

\[ \chi^2 / \text{ndf} = 95.63 / 93 \]

Coeff of exp (A) \( \tau_\mu \) (\( \mu s \))

- \( \tau_\mu \) = 2.111 ± 0.068
- Constant (B) = 166.2 ± 1.8

\[ A \cdot \exp\left(-\frac{1}{\tau_\mu} \cdot x\right) + B \]
High rate (low gain) RPCs

- The rate handling capability (RC) of the RPC per unit voltage drop is given by:

$$S = \frac{Qd}{\varepsilon_0 V} \quad \text{RC} = \frac{1}{\rho t q_m}$$

where $S$ is the dead area, $Q$ is the total charge, $d$ is gap thickness, $\varepsilon_0$ is the dielectric constant of the gas, $V$ is the applied voltage, $\rho$ is the electrode resistivity, $t$ is the electrode thickness and $q_m$ is the average charge produced per event.

- Next generation collider experiments like HL-LHC-ATLAS, HL-LHC-CMS and CBM-FAIR require detectors with rate capability of ~20KHz/cm².

- If $q_m$ can be reduced to 50fC, rate capability can be increased to 25KHz/cm².

- Experimental and simulation studies on RPC are in progress using cosmic muons to optimize gas mixture, noise threshold, and applied voltage to achieve required rate capability with reasonable efficiency.

SF₆=1.5%, HV=10KV
R&D with bakelite electrodes

P-302 OLTC grade HPL bakelite

Streamer mode with Argon:R134a:Iso-butane:: 34:57:9
Long time operation of bakelite RPC

240cm × 120cm × 0.2cm
Multi-gap Resistive Plate Chamber

Entries = 12783
\( \chi^2 / \text{ndf} = 232 / 135 \)
a0 = -84.65 ± 3.44
a1 = -2.197 ± 0.260
a2 = 397.4 ± 0.5

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Eff. (%)</th>
<th>Time res. (ns)</th>
<th>Noise ((\text{Hz/cm}^2))</th>
<th>I (nA)</th>
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<tr>
<td>I</td>
<td>P1, P2</td>
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<td>1.42</td>
<td>1.5</td>
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<td>II</td>
<td>P1, P2, MRPC</td>
<td>85.9</td>
<td>0.87</td>
<td>2.85</td>
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<td>III</td>
<td>P1, P2, MRPC</td>
<td>87.8</td>
<td>0.85</td>
<td>1.87</td>
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</table>
Feasibility of MRPC for PET

B. Satyanarayana
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Stay tuned for …

- High quality, but low cost RPC detector production by industries for e-ICAL and ICAL.
- Alternate gas mixtures for RPCs
- 3D simulation of multi-component, viscous gas flow through RPC
- Pixel readout techniques for RPCs
- Neural networks and machine learning techniques for efficient track reconstruction
- Muon tomography and cargo scanners
- Prototypes of MRPC based PET devices
- RPC detector technologies for contributing to accelerator and other futuristic experiments
For more details ...

- Effect of the surface resistivity of electrode coating on the space dispersion of induced charge in Resistive Plate Chambers (Shamsul Haque Thoker et al)
- Study of Multigap Resistive Plate Chambers as a potential candidate for development of a PET device (M. Nizam et al)
- A portable Cosmic Muon Tracker using Resistive Plate Chambers (RPCs) for outreach activities (Yuvaraj E. et al)
- Manufacturing, installation commissioning of mini-ICAL magnet: INO project (S. P. Prabhakar et al)
- Mini-ICAL, INO Project: Magnetic field simulation & development of magnetic measurement set up (N. S. Dalal et al)
- Design and assembly of water-cooled coil for prototype mini ICAL magnet at Madurai for INO project (S. K. Thakur et al)
- Electronics and DAQ for the magnetized mini-ICAL detector at IICHEP (Mandar Saraf et al)
- Trigger generation system architecture for INO mini-ICAL system (Shib Shankar Sikder et al)
- RPC and CLS for mini-ICAL detector - Ravindra (R. Shinde et al)
- Optical Communication for RPCDAQ (Abinaya et al)
- RPC-DAQ V3 module for INO’s ICAL detector (Abinaya et al)
- A multi-hit TDC for INO experiment (Chithra et al)
- Database management system for RPC production QC (Pavan Kumar Vengala et al)
- \( \mu \)SR with mini-ICAL (Neha Panchal et al)
- Measurement of azimuthal dependence of Cosmic ray muon flux using 2m x 2m RPC stack at IICHEP Madurai (Pethuraj S et al)
- Muon multiplicity in 2m x 2m RPC and comparison with Corsika simulation (Suryanarayan Mondal et al)
- Update on muon reconstruction for INO-ICAL (A.D.Bhatt et al)
- Muon momentum spectra with mini-ICAL (A.D.Bhatt et al)
- Reconstruction of muon track in presence of noise in ICAL (Moon Moon Devi et al)
- Studies on deep learning technique for track reconstruction for INO (Deepak Samuel et al)
- Simulation studies for a shallow depth ICAL and planned cosmic muon veto detector for mini-ICAL (Neha Panchal et al)