RAPID2021

Workshop on Advanced Radiation Detector and Instrumentation in Nuclear and Particle Physics
Oct 25 - 29, 2021, University of Jammu

Numerical Evaluation of Resistive Plate Chamber (RPC)

Subhendu Das
Saha Institute of Nuclear Physics, Kolkata
Homi Bhabha National Institute, Mumbai

Motivation

- Resistive Plate Chamber is a particle detector with large output signal, good efficiency, time and position resolution.

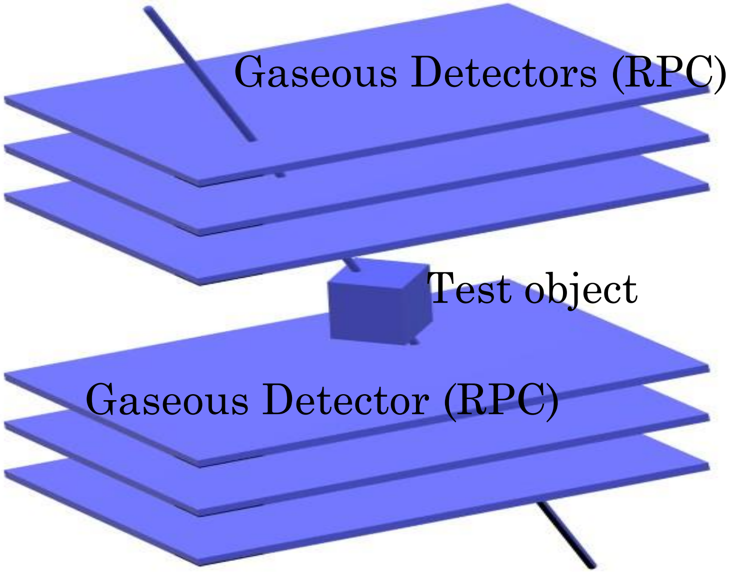
- RPCs are useful in particle tracking, muon tomography, medical imaging and triggering data acquisition.

- A simulation study to identify the appropriate choice of electrode and spacer materials to get an optimal performance of Resistive Plate Chamber (RPC) for muon tomography setup.

Muon Tomography Setup

- Muon tomography is a system to detect material using scattering property of cosmic muon.
- Uses Coulomb scattering of the cosmic ray muons.
- Tracking requires large and multiple detectors (like RPC)
- A multi-parameter data acquisition (DAQ) is required

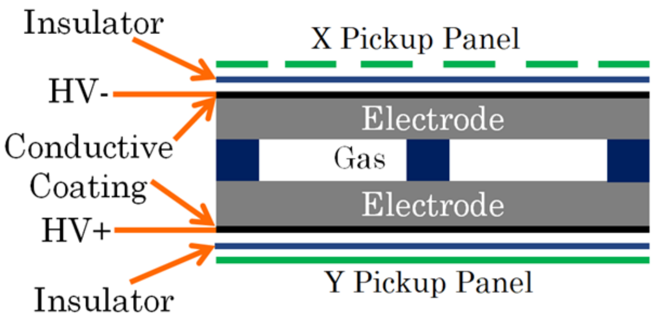
Particle Track

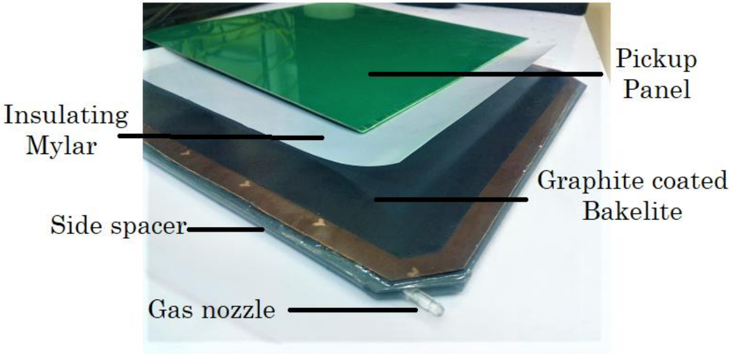


Muon tomography setup

Resistive Plate Chamber (RPC)

- Two parallel plate electrodes of 3mm thick with high bulk resistivity with 2 mm gap.
- Conductive coating on both electrodes for uniform high voltage distribution.
- A suitable gas mixture is flown through the gap between the electrodes.
- Two readout plates are used to collect the signal which are isolated from conductive coating using mica.





Simulation Software

- COMSOL Multiphysics is a cross-platform finite element analysis, solver and multiphysics simulation software.

- Electric Currents module is used to find current and field configuration by solving three equations.

$$\vec{\nabla} \cdot \vec{J} = Q_{j,v} \qquad \vec{J} = \sigma \vec{E} + \vec{J}_e \qquad E = -\vec{\nabla} V$$

Here,

$V \longrightarrow$ potential,

$E \longrightarrow$ electric field,

$J \longrightarrow$ current density,

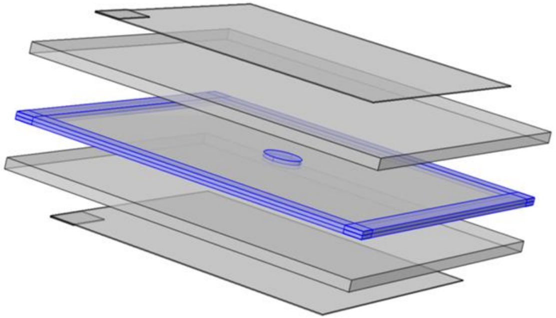
$\sigma \longrightarrow$ electrical conductivity

$J_e \longrightarrow$ external current density

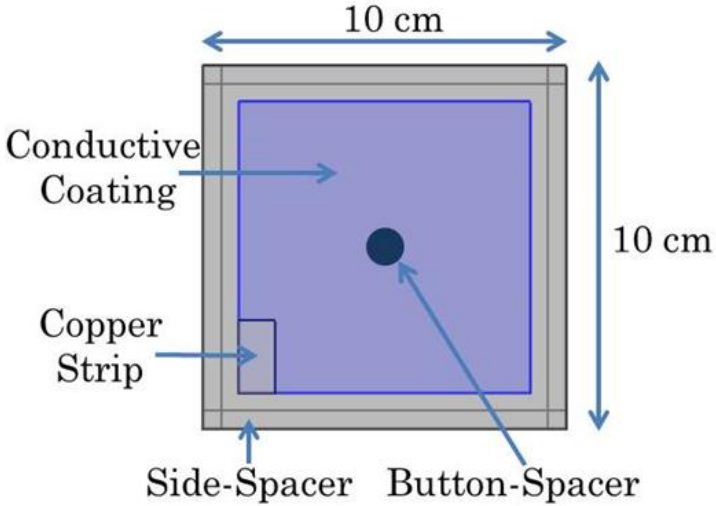
$Q_{j,v} \longrightarrow$ rate of change in volume charge density

Simulation Model

- A 3D-model RPC of dimension 10 cm × 10 cm
- Electrode thickness 3 mm and gas-gap 2 mm
- Width of Side-spacers 5 and thickness 2 mm
- Diameter of button-spacer 10 mm and thickness 2 mm
- Conductive coated area 8 cm x 8 cm



RPC

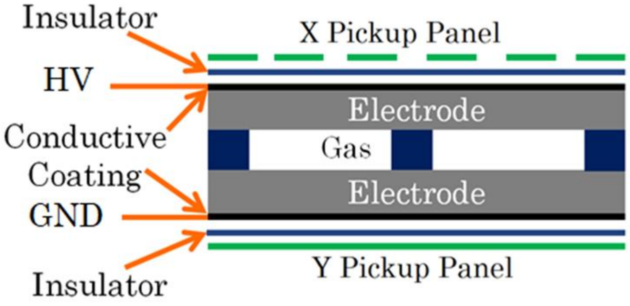


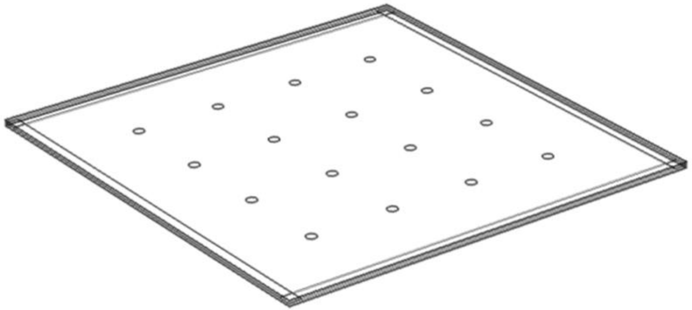
Top View

Comparison with others results

Section of RPC	Calculated current (nA)	Simulated current (nA)
Spacers	0.22	0.15
Frame	2.29	2.32
Insulation film	66.63	66.67
Gas	0.09	0.09

Table 1: Current comparison with Ammosov et al [NIMA 401 (1997) 217-228]

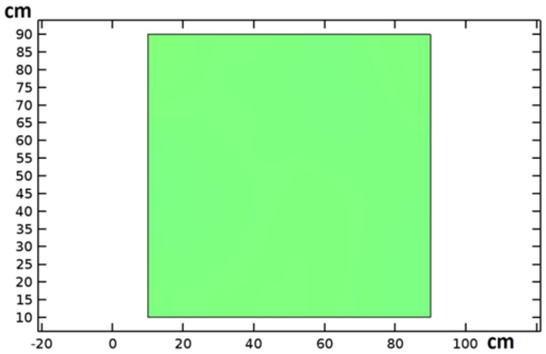




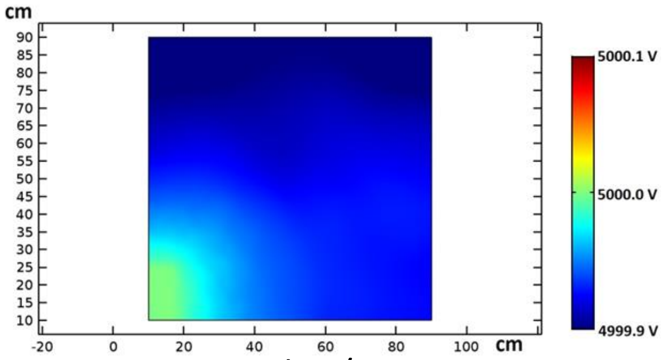
Variant A (whole plane is covered with graphite)

- RPC dimension 50cm x 50cm
- 16 button spacers with diameter 13 mm, frame width 15 mm ($\rho = 10^{12}$ Ω-cm, $\varepsilon = 4$).
- Bakelite thickness 1.6 mm , $\rho = 10^{12}$ Ω-cm, $\varepsilon = 4$.
- Insulation film thickness = 0.6 mm, $\rho = 5 \times 10^{15}$ Ω-cm, $\varepsilon = 3$.
- Gas gap = 2.0 mm, $\rho = 10^{18}$ Ω-cm, $\varepsilon = 1$.
- Applied HV = 8 kV

Surface Resistivity

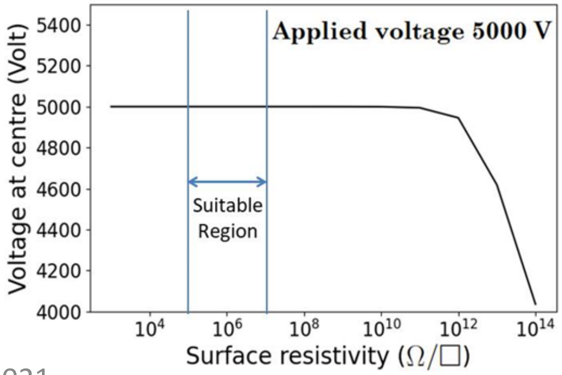


1 M Ohm/square

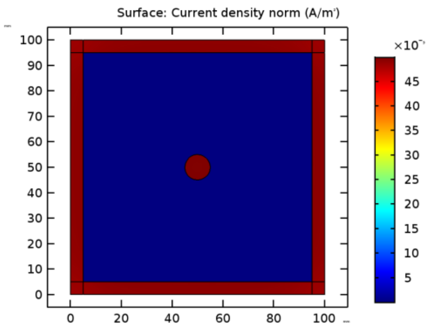


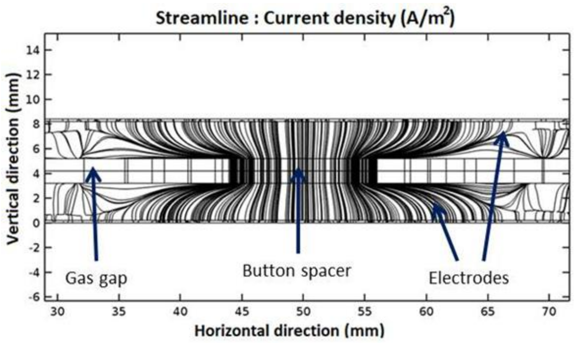
10 G Ohm/square

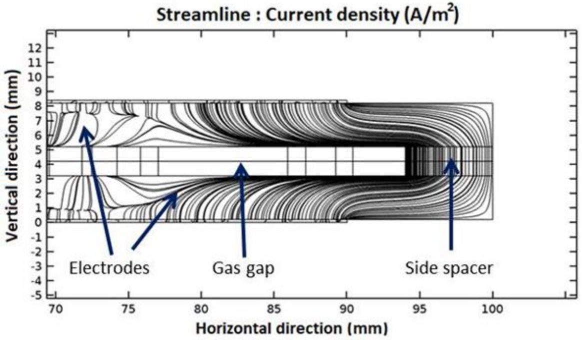
- Suitable surface resistivity range from 100K to few M Ohm/square)
- Low surface resistivity causes attenuation of output signal.

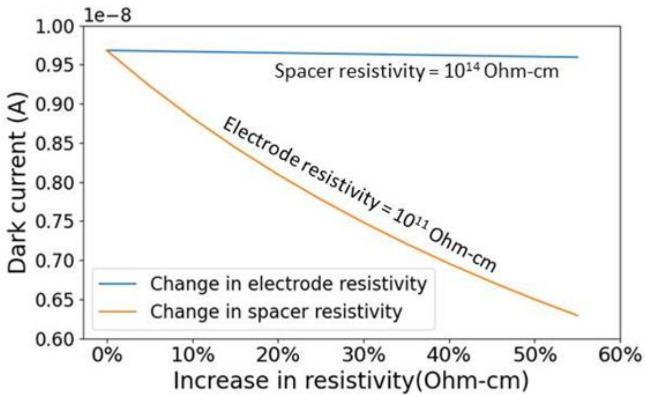


Dark Current



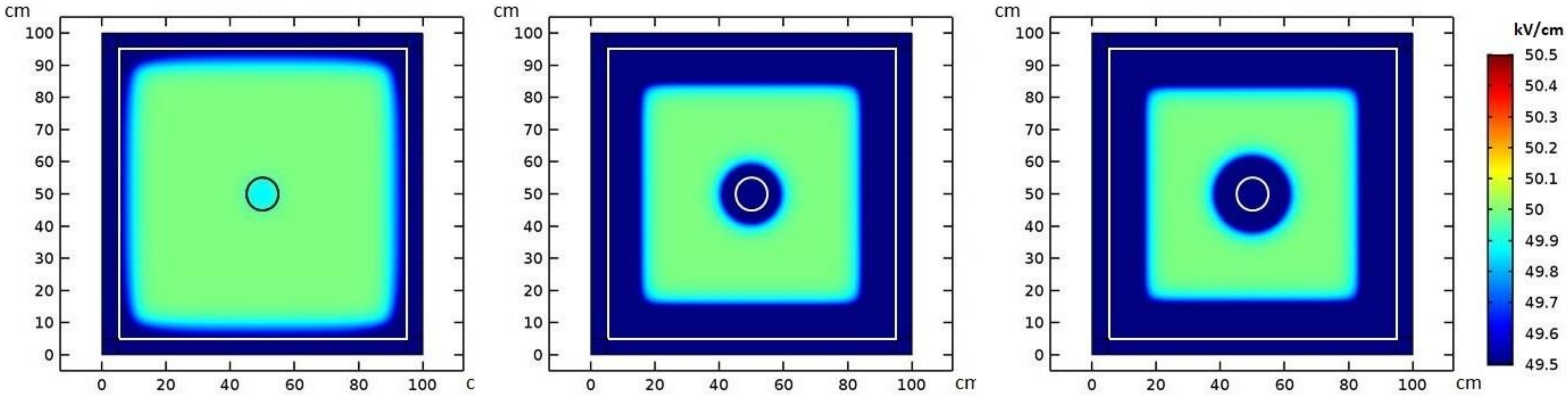






- Maximum dark current flows through the side and button spacers
- Dark current depends on spacer resistivity rather than electrode resistivity.

Electric Field



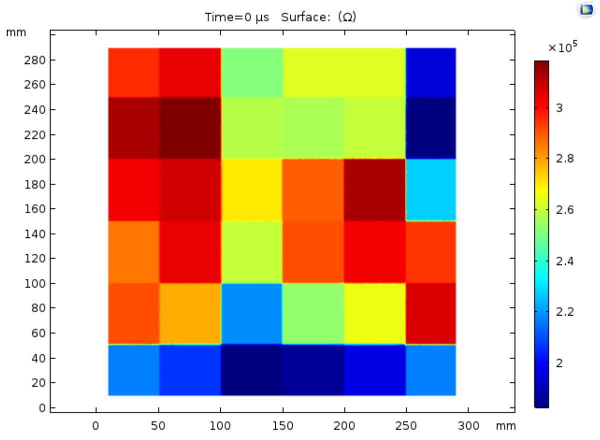
Electrode res. = $10^{11}\Omega$ cm, Spacer res. = $10^{14}\Omega$ cm, Ratio = 10^3

Electrode res. = $10^{13}\Omega$ cm, Spacer res. = $10^{14}\Omega$ cm, Ratio = 10^1

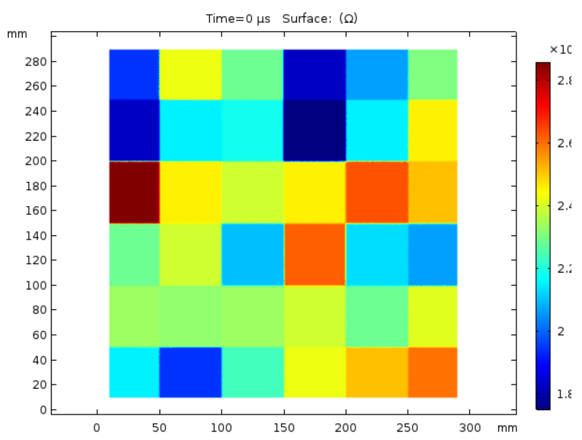
Electrode res. = $10^{13}\Omega$ cm, Spacer res. = $10^{13}\Omega$ cm, Ratio = 1

- Ratio between spacer and electrode resistivity greater than 10^3 provides better field uniformity

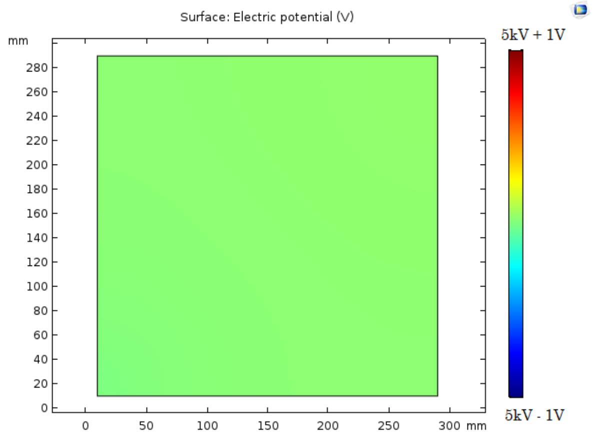
Effect of non-uniform surface resistivity on surface potential



Bottom layer surface resistivity



Top layer surface resistivity



Simulated potential on top graphite layer

- Potential throughout the surface is uniform.

Summary and Future Plans

- Suitable surface resistivity of conductive coating 100k–1M ohm/square.

- Dark current depends on bulk resistivity of the spacer material.

- Ratio between spacer and electrode resistivity greater than 10^3 provides better field uniformity. Suitable resistivity for electrode material 10^{11} to 10^{13} ohm-cm and for spacers 10^{14} to 10^{16} ohm-cm.

- In future, we have plan to perform few experimental measurements to corroborate the simulation results.

- Collaborators
  - Jaydeep Datta
  - Nayana Majumdar
  - Supratik Mukhopadhyay

- Acknowledgements
  - I like to thank the organizers for giving me the opportunity to present my work here.
  - I would like to thank my lab colleagues Sridhar Tripathy, Prasant Kumar Rout, Vishal Kumar, Promita Roy, and Pralay Das for there advice and suggestions.
  - I like to express my gratitude towards SINP and UGC for helping me financially throughout the work.

Thank You