Numerical evaluation of electric field and dark current of Resistive Plate Chamber

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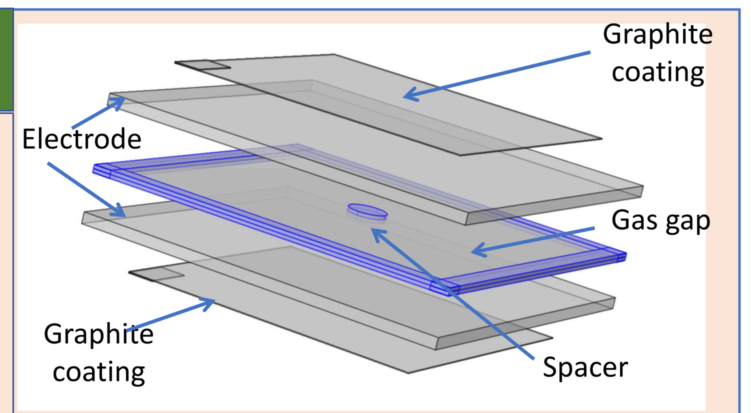
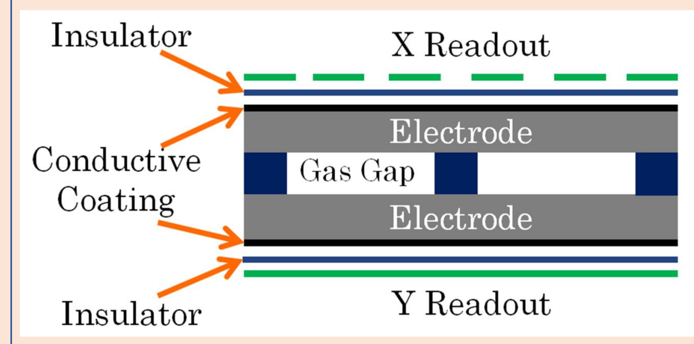
Motivation

- Resistive Plate Chamber (RPC) utilizes a constant and uniform electric field across a gas volume produced by two parallel electrode plates to detect particles from their ionizing interaction with the gas molecules followed by growth of electronic charges under the action of the electric field. RPC provides large output signal with excellent time and position resolutions. It is an efficient, low-cost, robust detector with simple design and fabrication process.
- RPCs are useful in various types of application, like particle tracking and triggering data acquisition in particle physics experiments, and some societal fields, such as muon tomography, medical imaging etc. We are in the process of developing a muon tomography setup using RPC detectors as muon trackers for imaging large civil structures.
- In this poster we attempt to discuss the important designing aspects of the RPC for achieving uniform performance over a large detection area, necessary for building the tomography setup. Using Comsol Multiphysics software we simulate the dark current and electric field distribution inside gas gap for various combination of electrode and spacer materials for design optimization.

Construction of Resistive Plate Chamber

- Two parallel resistive electrodes are placed across a gas gap. Uniformity of gap is maintained by spacers.
- Conductive (graphite) coating is applied on both electrodes for uniform distribution of high voltage.
- A suitable gas mixture is flown through the gap enclosed by side spacers.
- Two readout plates are placed outside and isolated from graphite coating using mica.





Simulation Software for Analyzing Surface Resistivity, Current and Field Configuration

- 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:

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

- A model of RPC of dimension 10 cm X 10 cm with 3 mm thick electrodes and 2 mm gas gap has been used in the simulation. The side spacers of width 5 mm and thickness 2 mm and a central spacer of diameter 10 mm and thickness 2 mm have been considered.

High Voltage Distribution on Electrodes

- High voltage supplied through thin copper strip.
- Suitable surface resistivity (500 K-1 MΩ/□)
- Low surface resistivity causes attenuation of output signal

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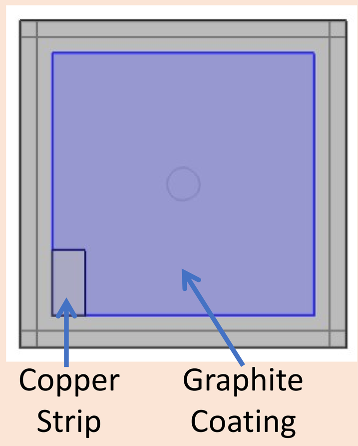
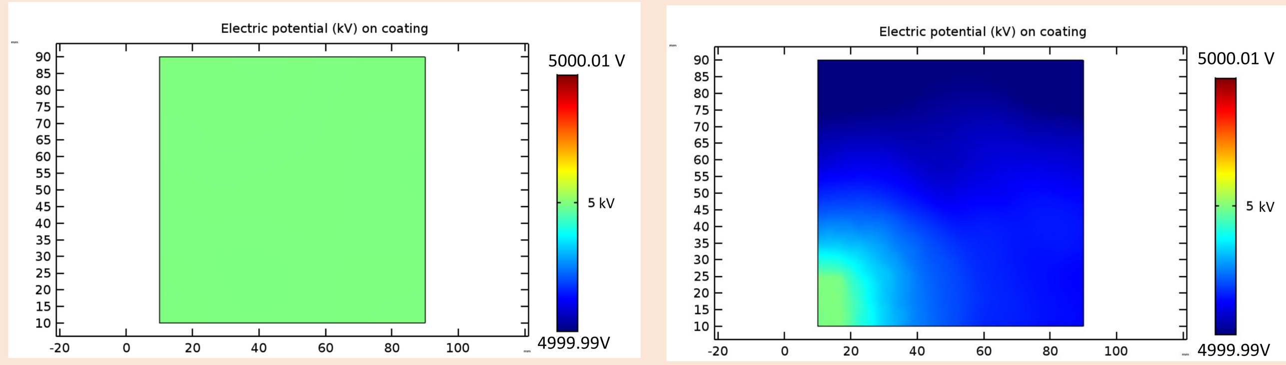
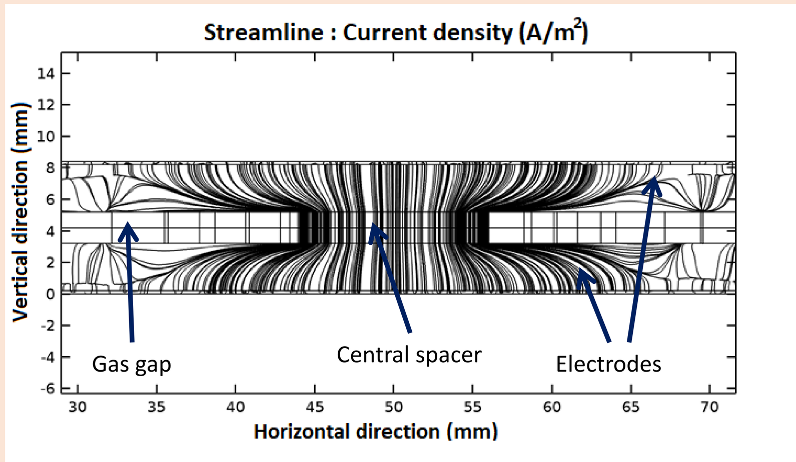


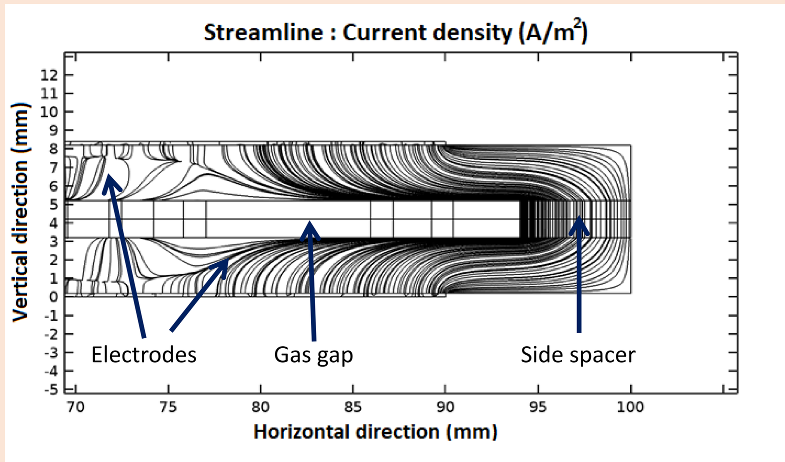


1 MΩ/□ 100 M Ω/□
Voltage distribution on graphite coating for different surface resistivities (Applied voltage 5 kV)

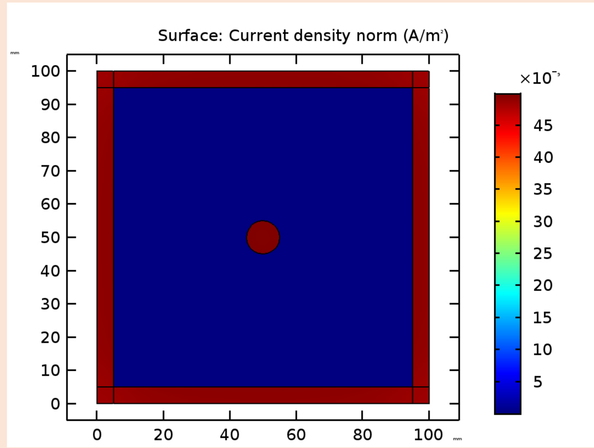
Dark Current Flow Through the Spacers



Current flow through central spacer

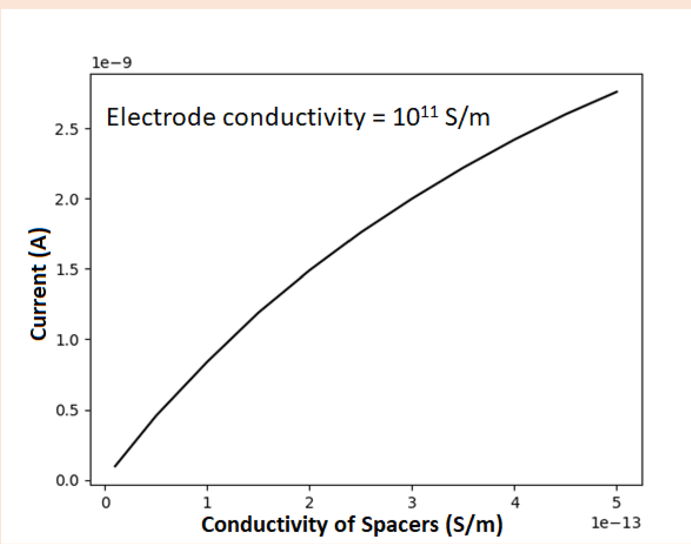


Current flow through side spacer

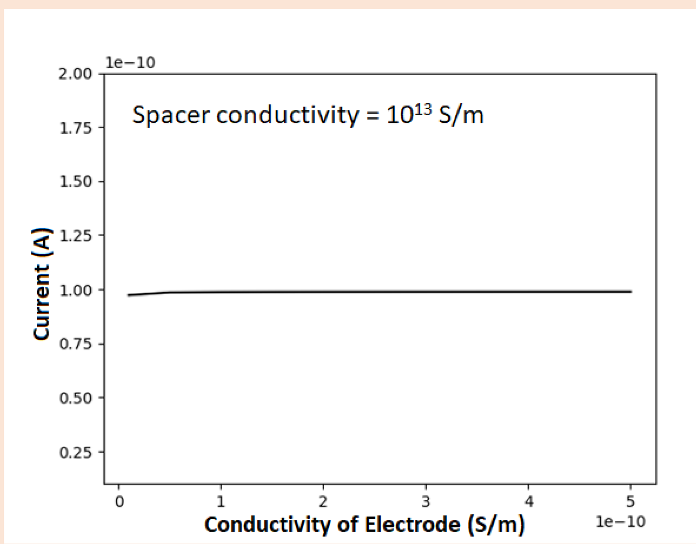


Surface plot of current density

- Maximum current flows through the side and button spacers.
- Amount of dark current is governed by the resistivity of the spacer material.
- The actual current will be slightly higher due to electrical discharge caused by passage of charged particle through the detector.

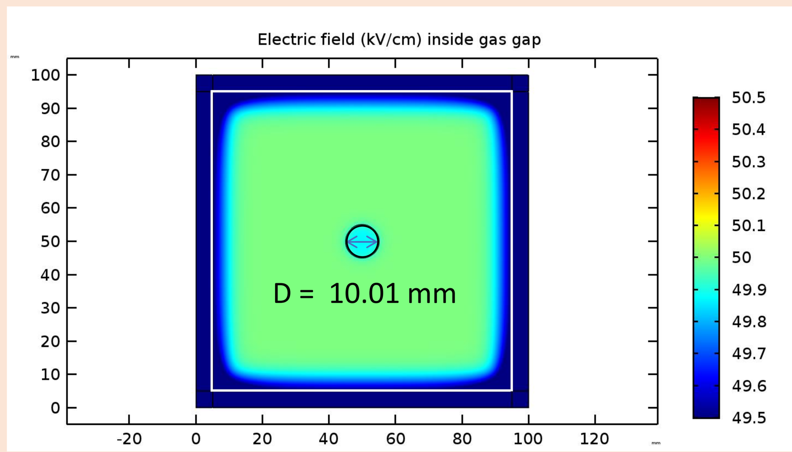


Current with varying spacer conductivity

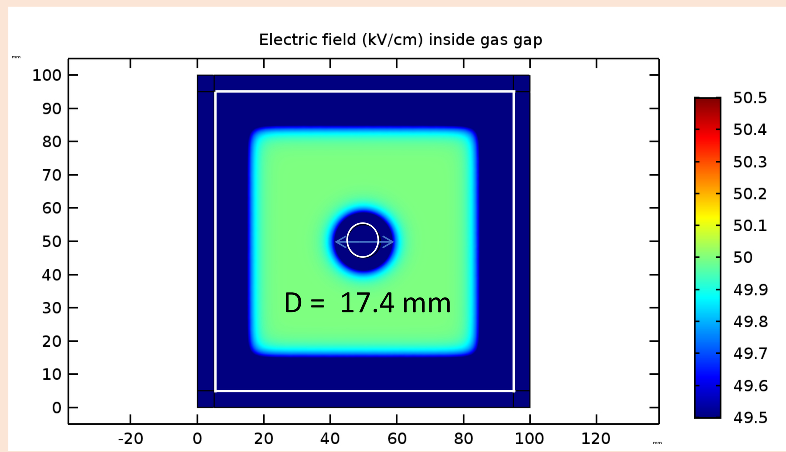


Current with varying electrode conductivity

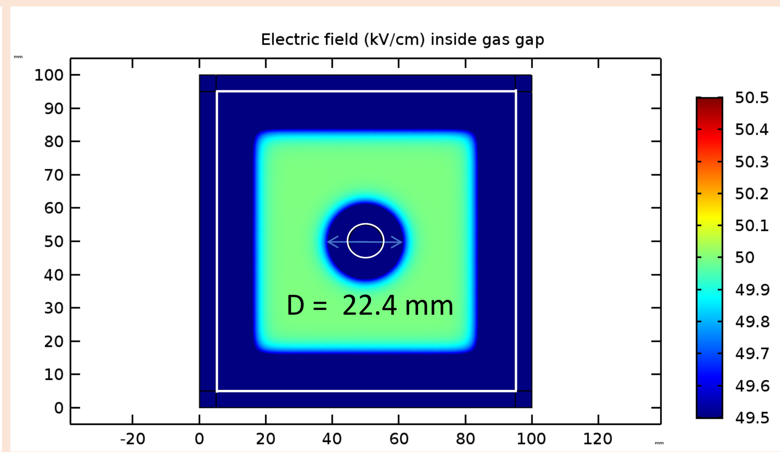
Field Configuration Inside Gas Gap with Different Electrode and Spacer Materials



Bakelite Electrode , PVC spacers



Glass Electrode , PVC spacers



Glass Electrode , Glass spacers

- Resistivity in Ω-cm (bakelite ~ 10^{11} , glass ~ 10^{13} , PVC ~ 10^{14}), diameter of spacer = 10 mm and height = 2 mm
- Potential between two electrodes = 10 kV, expected electric field = 50 kV/cm
- Ratio between spacer and electrode resistivity greater than 10^3 provides better field uniformity (bakelite and PVC combination).

Summary

- Surface resistivity conductive coating 500k–1 MΩ/□ is suitable to achieve uniform distribution of high voltage on the electrodes.
- Amount of dark current is governed by the resistivity of the spacer material.
- Higher resistivity of spacer relative to that of electrode (by 3 order) provides better field uniformity. For example, electrode resistivity 10^{10} to 10^{12} Ω-cm (bakelite, glass), spacer resistivity 10^{14} to 10^{15} Ω-cm (PVC, acrylic plastic) are suitable materials for construction of RPC.
- In future we have plan to study the effect of non-uniform surface resistivity of the graphite coating.

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