# Effect of Plate Roughness on RPC Performance

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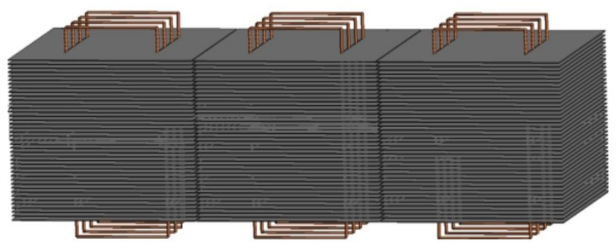
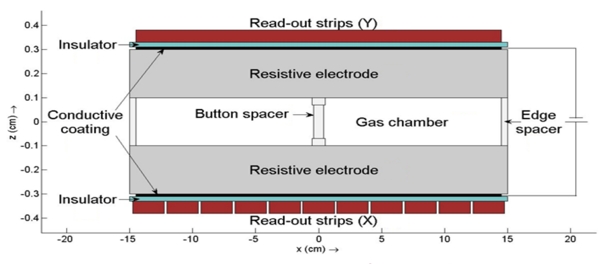
## Introduction

- A large number (~30,000) of Resistive Plate Chambers (RPC) will be used in the Iron CALorimeter (ICAL) detector at India-based Neutrino Observatory (INO) for precise measurement of neutrino oscillation parameters and mass hierarchy.
- The requirement of large area coverage combined with muon detection with good position (< 1cm) and timing resolution (< 1 ns) disapproves non-uniform response from any part of the detector which may affect the overall performance of the setup.
- Long term stability in the detector performance is also an important concern for this experiment.
- This calls for detailed investigation on the detector response and understanding its dependence on device geometry, material grade, gas mixture etc. including environmental parameters.



ICAL modules

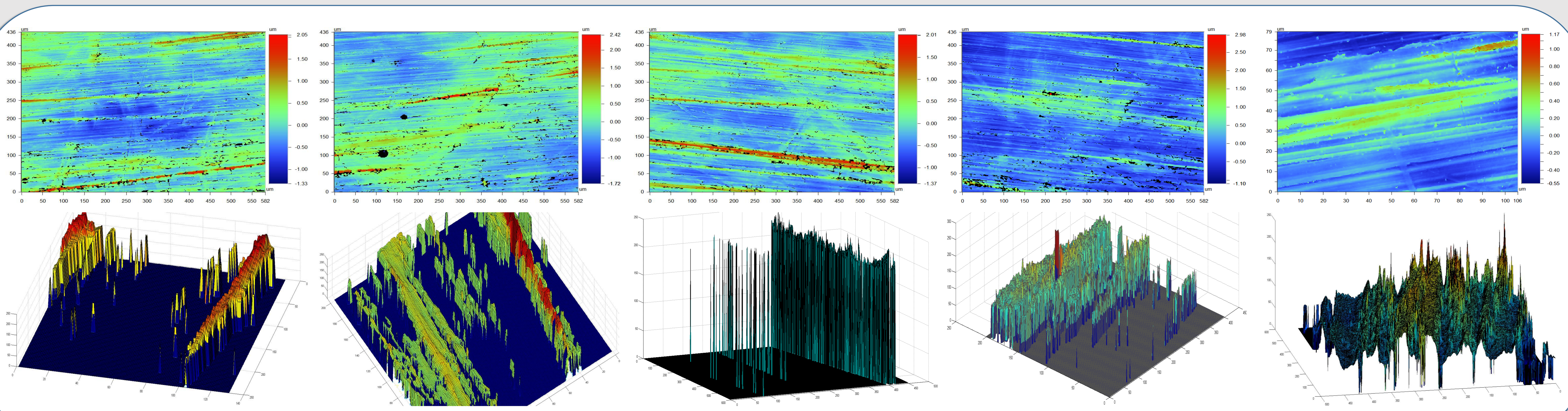



Schematic diagram of an RPC

## Roughness – Measurements

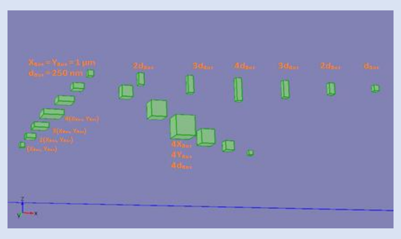
- Surface roughness of the Bakelite/Glass resistive plates in the detectors is one of the major geometrical artifacts that may affect the local electric field leading to spark or instability and gradual degradation of the detector. The production procedure, handling, growth due to ageing are the reasons for formation of these asperities.
- Detailed numerical simulation of the effect of the surface roughness on the electrostatic field of RPC may facilitate its design optimization and prediction and interpretation of experimental data.
- Surface roughness of Bakelite plates measured using **BRUKER ContourGT-K 3D optical microscope**.
- Sample scan size = 640 μm × 480 μm.
  - Average roughness = 200 – 800 nm.
  - Maximum peak-to-valley distance = peak height – valley depth = 2 – 7 μm.

## Surface Morphology



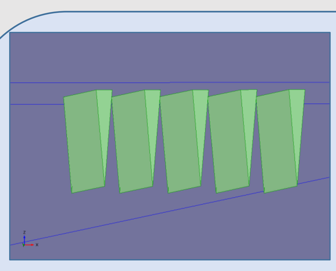
## Roughness – Analysis and Numerical Modelling

- The surface maps are analysed using **MATLAB** to get specific information about the different building blocks.
- The surface contains distribution of ridges, spikes and trenches.
  - Spikes of pyramidal or box shape having height 1 – 5 μm.
  - Ridge like structures with height ~ 2 μm with different directionality.
  - Mainly all the spikes and ridges are sitting on a wavy profile which has an amplitude of ~ 1 μm.
  - Occasional presence of very tall ridges, and spikes has also been observed.
- Three different models have been used to showcase the effect of different shapes of the surface asperities.
- Asperities are of dimension few μm whereas RPC dimension ~ 30 cm. A simplified model of an RPC has been solved keeping in mind computational resources.
- The change in local electric field due to these asperities has been found out using Finite Element Method (**COMSOL**®) and Boundary Element Method (**neBEM** interfaced with Garfield).
  - COMSOL- the geometry is meshed using free tetrahedral elements. The potential is calculated at the nodal points. The field is calculated by differentiating the shape function used for solving the problem.
  - neBEM- the surfaces have been discretized using rectangular/triangular elements. The charge distribution on the elements has been calculated from the supplied boundary conditions using Green's function technique. The potential and field at any point are calculated using the same Green's function method from this charge distribution.

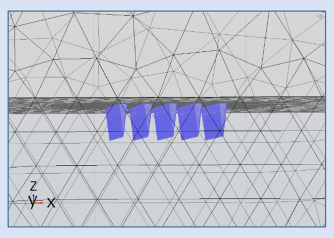


Distribution of boxes of different heights forming the rough surface

- Increase in height along X axis, in multiple of the height of smallest box.
- Increase in width along Y axis.
- Increase in height and width along diagonal direction.
- Space between edge of any two blocks = 8 μm.

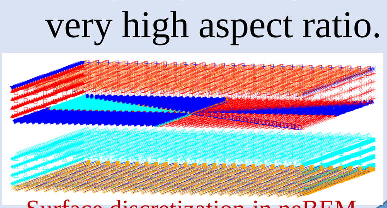


Roughness in shape of ridges

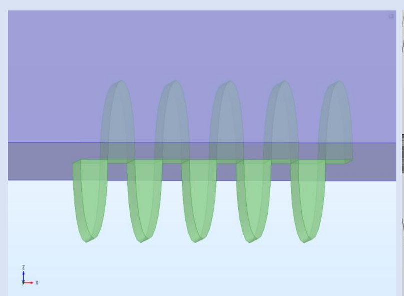


Volume meshing in COMSOL

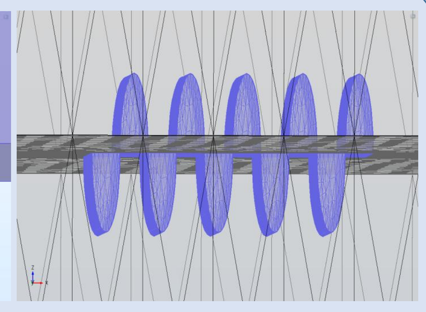
- Ridge-like structures (base width = 25 μm, height = 5 μm). Space between any two ridges = 50 μm.
- Difficulty – Very sharp edge along with very high aspect ratio.



Surface discretization in neBEM



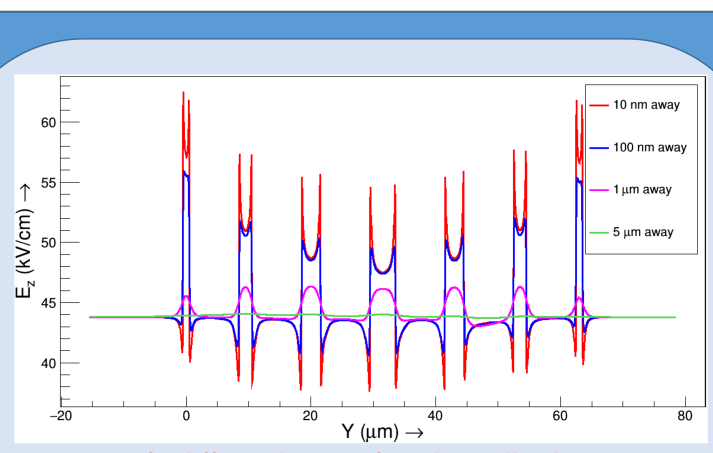
Roughness in shape of a wave



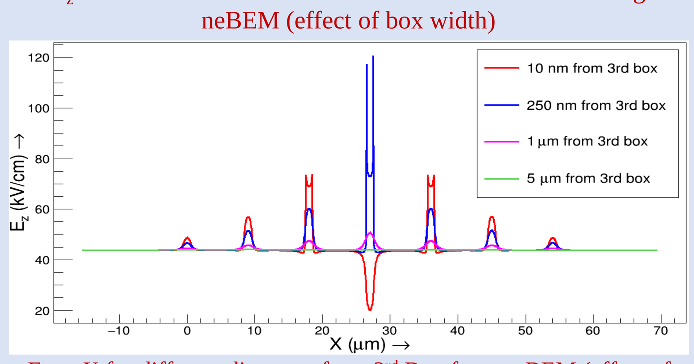
Meshing in COMSOL

- Wave shaped profile with base = 20 μm, height = depth = 10 μm, pitch = 20 μm.
- Difficulty - Very high aspect ratio.

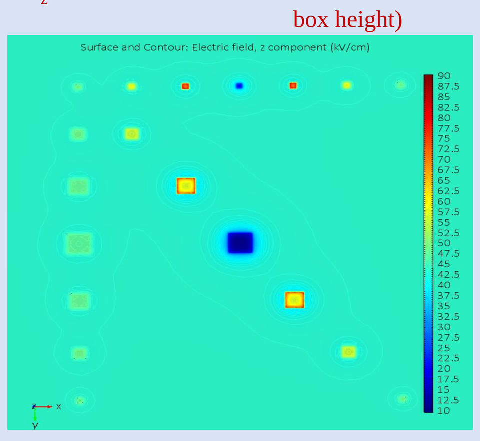
## Results



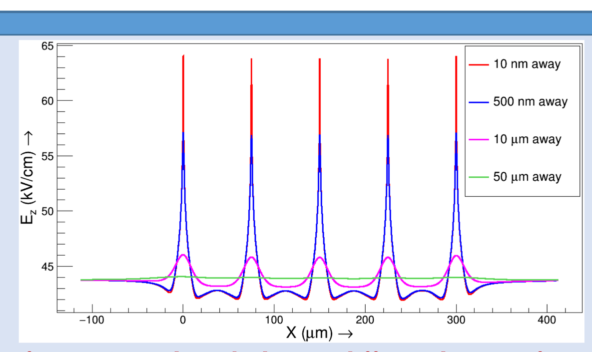

$E_z$ Vs Y for different distances from the smallest box using neBEM (effect of box width)



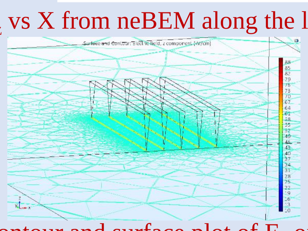

$E_z$ vs X for different distances from 3rd Box from neBEM (effect of box height)



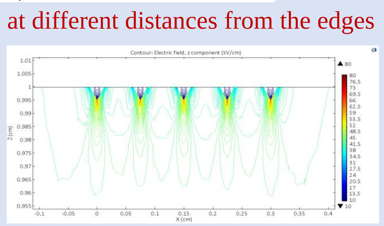
Contour-surface plot of $E_z$ on XY plane – 10 nm from 3rd Box ( COMSOL)



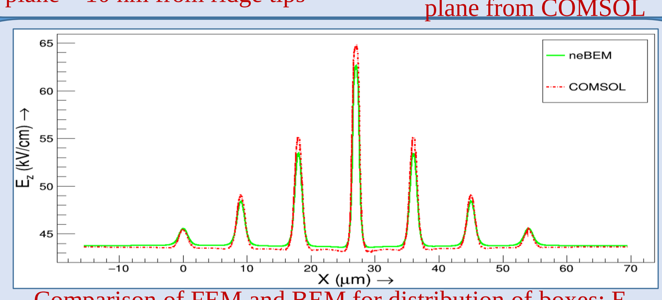

$E_z$ vs X from neBEM along the lines at different distances from the edges



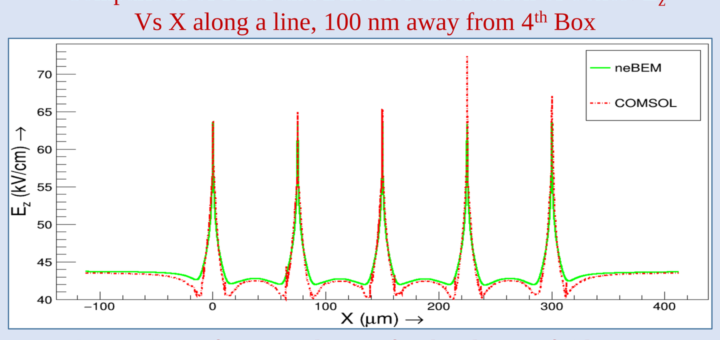
Contour and surface plot of $E_z$ on XY plane – 10 nm from ridge tips



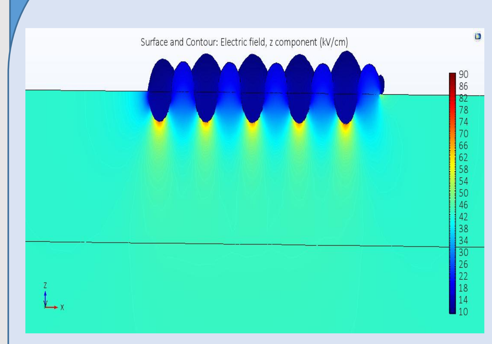
Contour plot of $E_z$ in X-Z plane from COMSOL



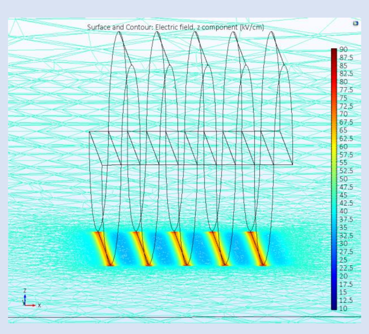

Comparison of FEM and BEM for distribution of boxes: $E_z$ Vs X along a line, 100 nm away from 4th Box



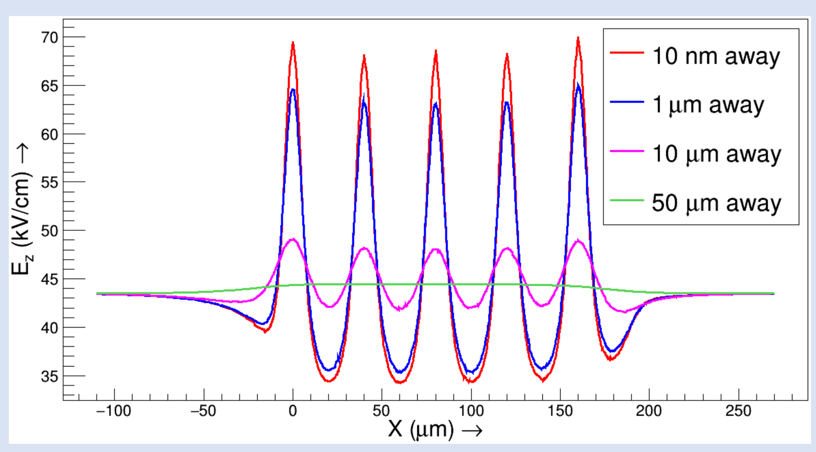

Comparison of FEM and BEM for the cluster of ridges: $E_z$ Vs X along a line, 10 nm away from the tips



Affected area due to wave shaped structure from COMSOL



Contour plot of Ez on the XY plane, 100 nm from wave peaks




Ez vs X from COMSOL along lines at different distances from the peaks of the wave

## Summary

- FEM and BEM solutions show good agreement.

| Solver | Elements | Time | Memory | Error / convergence |
|---|---|---|---|---|
| COMSOL | $2 \times 10^6$ | 15 mins* | ~ 4 GB | $10^{-5}$ in 190 iterations |
| neBEM | $17 \times 10^3$ | 2 hours | ~ 8.8 GB | $R.E\|_{max} = 10^{-4}$ |

*After finding out the proper meshing scheme, which itself is a rigorous process.

- The value of electric field near the sharp structures may become twice or more of the normal value depending on shape and size of it.
- The enhanced field value (60% of the regular value) is confined within a small region (10 – 200 μm) depending on the shape and size of the asperities.
- This may affect the gas transport properties and production of avalanche and may alter the detector behaviour.
- Considering the overall distribution of asperities on the surface, the detector response near the plates may be significantly altered which in turn may affect the physics performance of INO ICAL detector.
- Depending on the results of investigation, RPC plates may be optimised with some surface treatment.

## Acknowledgement

- Purba Bhattacharya (NISER) for her suggestions with the field calculation work using neBEM.
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