Effect of geometry on RPC characteristics

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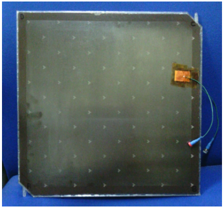
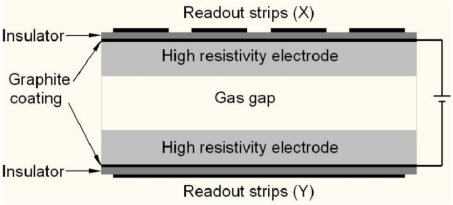


Outline

Motivation I

- Resistive Plate Chambers (RPC) are fast ($\sigma \sim 2$ ns) gaseous detectors constructed from simple and common materials having simple signal pick-up and read-out system.
- They have Good efficiency ($> 90\%$) and long term stability.
- RPC is the active detector element for INO-ICAL [1] detector, which will study atmospheric neutrinos to make precise measurement of the neutrino oscillation parameters $\left|\Delta m^2_{31}\right|$, $\sin^2 2\theta_{23}$, θ_{13} and also will find out mass hierarchy (sign of δ_{32}).

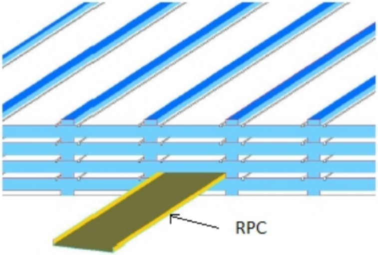


Schematic diagram of an RPC

Motivation II

INO Iron CALorimeter (ICAL)

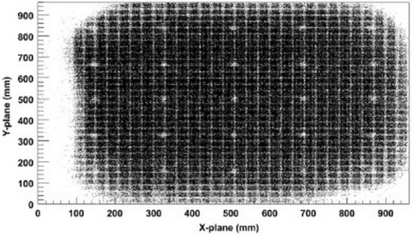
- Three modules each of lateral size 16.2m$\times$16m and height 14.5m weighing about 50 kTon in total.
- Each module contains 150 layers of RPCs (1.95m$\times$1.91m) interleaved with magnetized ($\sim$1.3 T) iron plates.



RPC for INO-ICAL detector

Motivation III

- Early r&d works [2] on the INO-ICAL prototype have shown reduced response near edges, corners and button spacers than a regular point.
- We are looking for the possible reasons which may cause this kind of variation of response from RPC.
- Physical field, gas flow scheme can be the possible reasons.
- Detail field map within RPC has been generated.
- Presence of uniform gas mixture all over the gas chamber has been assumed.

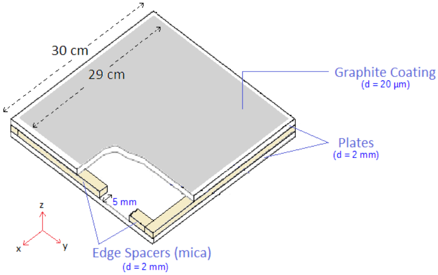


Dead space near Edge, corner and spacers

- The signal from different parts of the geometry is in progress.
- Experimental measurements are in progress.

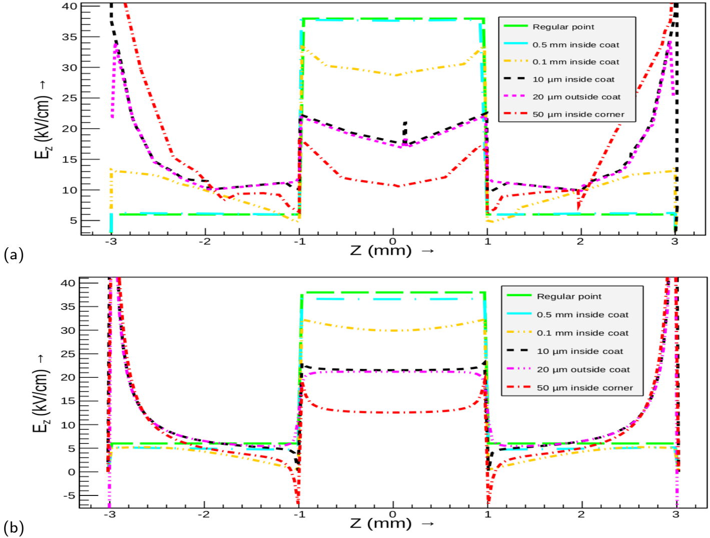
Field map within RPC I

- Simulation of electric field for a 30cm$\times$30cm RPC.
- Field solvers used :
  COMSOL [3] v4.4 : Based on Finite Element Method (FEM).
  neBEM [4] v1.8.16 : Based on Boundary Element Method (BEM), interfaced with Garfield [5].
- Model specifications :
  RPC plates : Bakelite ($\epsilon = 6.4$).
  Edge spacers : Mica ($\epsilon = 5.4$).
  Gas : air ($\epsilon = 1.0013$).
  Conductive coating : Graphite.
  H.V. applied : $\pm$5 kV.



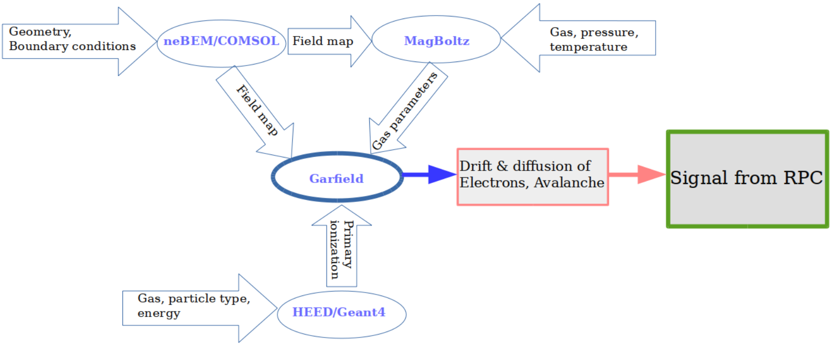
RPC model used in simulation studies

Field map within RPC II



Effect of edge and corner on RPC field, as computed by (a) COMSOL, (b) neBEM.

Signal calculation : simulation scheme



Garfield framework to simulate RPC signal

Signal calculation : weighting field

Importance :

Signal induced on RPC pickup strip due to movement of charge in gas chamber is given by **Shockley-Ramo theorem** -

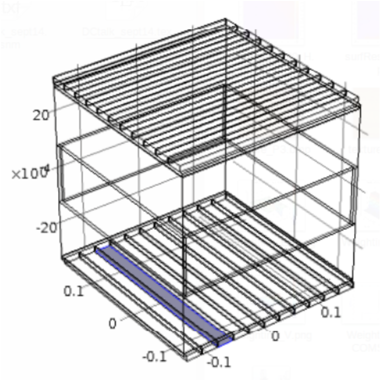
$$i(t) = q\overrightarrow{v}(t).\overrightarrow{W}(\overrightarrow{x}(t))$$

$\overrightarrow{v}(t) \rightarrow$ Instantaneous velocity of the charge q.
$\overrightarrow{W}(\overrightarrow{x}(t)) \rightarrow$ Weighting field associated with the electrode under study. It is the field produced when the electrode under study is at unit potential and all other electrodes are at ground potential.

- Calculated both Numerically and Analytically.

Weighting field : Numerical Method

- Calculated for all the pickup strips of RPC.
- Both COMSOL and neBEM is used.



Calculation of weighting field for strip 2

- Graphite coat considered as dielectric ($\epsilon = 12.0$).
- Strip of interest is at value 1.
- All other strips are at value 0.

Weighting field : Analytic Method

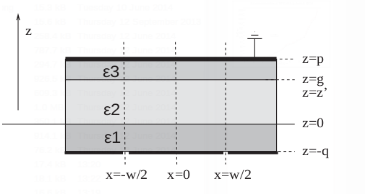
- Calculated based on the paper: Th Heubrandtner, B Schnizer, C Lippmann, W Riegler - Nucl. Instr. and Meth., 489 (2002), p. 439.
  Weighting field,

$$\boxed{E_z(x,z) = V_1\epsilon_1\frac{2}{\pi} \times \int_0^\infty dk\cos(kx)\sin(k\frac{w}{2})F_2(k,z)}$$

with, $F_2(k,z) = -\frac{2}{D(k)}[(\epsilon_2+\epsilon_3)(e^{-k(q+z)} + e^{-k(2p+q-z)}) - (\epsilon_2 - \epsilon_3)(e^{-k(q+2g-z)} + e^{-k(2p+q-2g+z)})]$

and

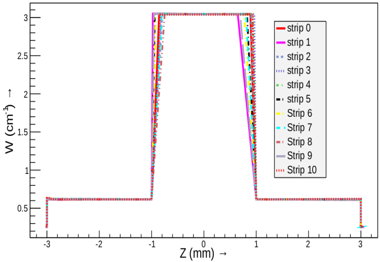
$D(k) = (\epsilon_1+\epsilon_2)(\epsilon_2+\epsilon_3)(1-e^{-2k(p+q)}) - (\epsilon_1-\epsilon_2)(\epsilon_2+\epsilon_3)(e^{-2kp} - e^{-2kq}) - (\epsilon_1+\epsilon_2)(\epsilon_2-\epsilon_3)(e^{-2k(p-g)} - e^{-2k(q+g)}) + (\epsilon_1-\epsilon_2)(\epsilon_2\epsilon_3)(e^{-2kg} - e^{-2k(p+q-g)})$



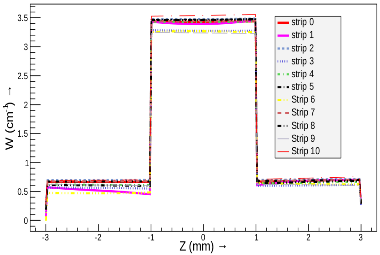
Geometry to calculate Weighting field for RPC

- Electrodes have infinite dimension along y-direction.
- There is no gap between the strips.
- MATLAB has been used.

Numerical method

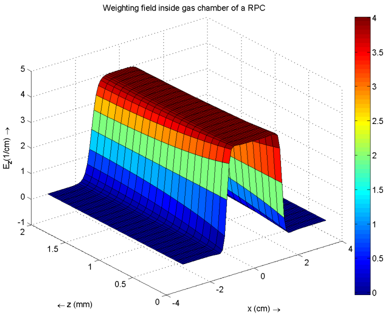


(a)



(b)

Analytic method



Weighting field from MATLAB

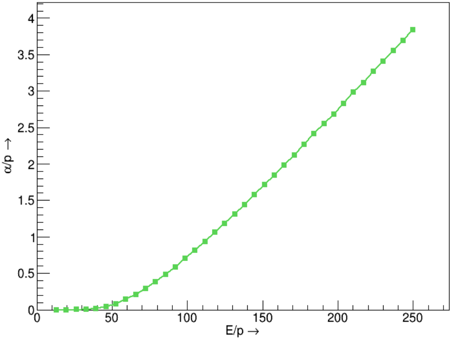
Weighting field using (a) COMSOL, (b) neBEM

Signal calculation

- Electric field map within the chamber : neBEM/COMSOL.
- Calculation of gas properties (Townsend coefficient, attachment coefficient, longitudinal and transverse drift velocity of electrons) : MagBoltz → Solves the Boltzman transport equations for electrons in arbitrary gas mixtures.
- Interaction of relativistic charged particle with the gas medium and their energy loss : HEED/Geant4.
- Garfield framework has been used to calculate the signal induced on the RPC pick-up strip.

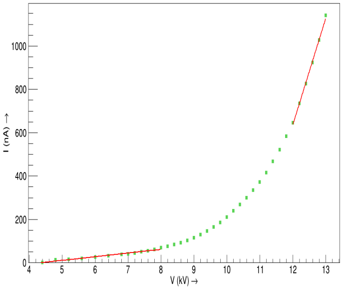
Signal calculation I

- Gas mixture used → Freon (134A) : Isobutane = 95 : 5 (in %).

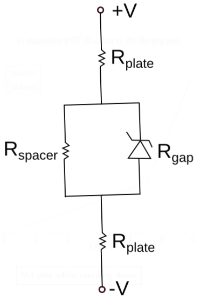


Variation of Townsend coefficient (α) with applied field (E) from MagBoltz.

V-I plot from experiment :



V-I plot of RPC B1+ : straight line fit for two regions.

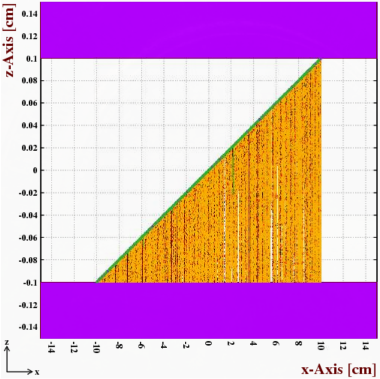


Equivalent circuit of RPC to explain its V-I plot.

- $R_{plate} = 1.02\ G\Omega$
- $R_{spacer} = 58.18\ G\Omega$
- Voltage across gas gap at breakdown = 12 kV

- At low voltage : $R_{gap} = \infty$.
- At high voltage (After gas breakdown) : $R_{gap} = 0$.

- Applied voltage : ± 8 kV across gas gap.
- Incident particle : 1 GeV muon.



Interaction of electrons while drifting

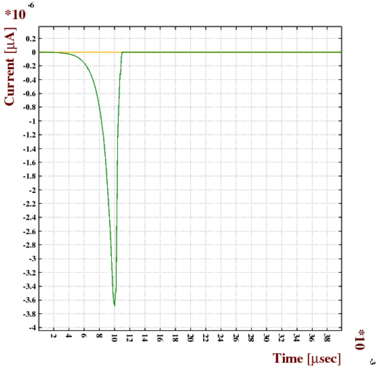
- The picture is just for representation.
- Gain in this voltage = 635.

Muon track

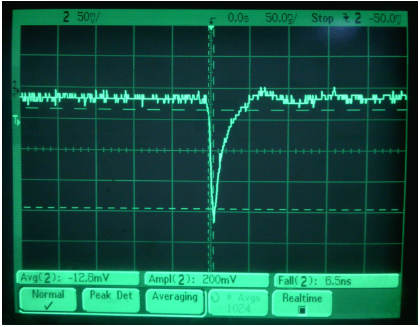
Electron drfit lines

Ionisation

attachment.



Typical RPC signal from simulation.



RPC signal as seen on Oscilloscope.

- Ion-pulse not considered.
- Long tail is not visible.

Experimental progress

- Two Bakelite RPCs of dimension 30 cm$\times$30 cm have been fabricated, one (B1+) with silicon oil coating on its inner surface and another (B2-) without the coating.
- B1+ is tested and characterized.
- Measurements from both will help comparing the effect of surface smoothness on RPC characteristics.
- Measurements at different positions of an RPC will help understanding the effect of geometrical artifacts on RPC characteristics.
- A probe to measure voltage distribution over the graphite coat has been made which will help to see if there is any variation of potential over the surface, which may affect the RPC response.

Future plans

- Calculation of signal induced on different RPC pick-up strips.
- Find out change in RPC response according to strip position and surface smoothness of electrodes, experimentally and numerically.
- Characterization of RPC B2-.
- Charge and timing measurement of the RPCs.
- Simulate the gas flow within RPC gas chamber and find out dead regions and the effect of gas flow scheme on RPC response.

References

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http://www.ino.tifr.res.in/ino/

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Cosmic ray test of INO RPC stack.
Nucl. Instrum. Meth. A 661 (2012) S68.

[3] COMSOL: a multiphysics simulation tool.
http://www.comsol.co.in

[4] N. Majumdar and S. Mukhopadhyay.
Simulation of 3D electrostatic configuration in gaseous detectors.
2007 *JINST* 2 P09006.

[5] Garfield - Rob Veenhof.
http://garfield.web.cern.ch/garfield

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