Effect of geometry on RPC characteristics

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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 $|\Delta m_{31}^2|$, $\sin^2 2\theta_{23}$, $\theta_{13}$ and also will find out mass hierarchy (sign of $\delta_{32}$).

![Schematic diagram of an RPC](image-url)
INO Iron CALorimeter (ICAL)

- Three modules each of lateral size 16.2m × 16m and height 14.5m weighing about 50 kTon in total.
- Each module contains 150 layers of RPCs (1.95m × 1.91m) interleaved with magnetized (∼1.3 T) iron plates.
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.
- 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 × 30cm RPC.
- Field solvers used:
- 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: ±5 kV.
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

Garfield

Field map

Gas, pressure, temperature

MagBoltz

Field map

neBEM/COMSOL

Geometry, Boundary conditions

Gas parameters

Drift & diffusion of Electrons, Avalanche

Signal from RPC

Gas, particle type, energy

HEED/Geant4

Primary ionization
**Importance:**

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

\[ i(t) = q \vec{v}(t) \cdot \vec{W}(\vec{x}(t)) \]

\( \vec{v}(t) \rightarrow \) Instantaneous velocity of the charge q.

\( \vec{W}(\vec{x}(t)) \rightarrow \) 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.

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

Calculation of weighting field for strip 2
Weighting field: Analytic Method


Weighting field,

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

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

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

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

**Numerical method**

(a)

**Analytic method**

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

- Weighting field from MATLAB
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 Boltzmann 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.
Gas mixture used $\rightarrow$ Freon (134A) : Isobutane = 95 : 5 (in %).

Variation of Townsend coefficient ($\alpha$) with applied field (E) from MagBoltz.
Signal calculation II

V-I plot from experiment:

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

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

- At low voltage: \( R_{\text{gap}} = \infty \).
- At high voltage (After gas breakdown): \( R_{\text{gap}} = 0 \).
**Signal calculation III**

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

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

**Muon track**

**Electron drift lines**

**Ionisation**

**attachment.**

Interaction of electrons while drifting
Signal calculation IV

- Typical RPC signal from simulation.
- Ion-pulse not considered.
- Long tail is not visible.

RPC signal as seen on Oscilloscope.
Experimental progress

- Two Bakelite RPCs of dimension $30 \text{ cm} \times 30 \text{ cm}$ have been fabricated, one ($\text{B1+}$) with silicon oil coating on its inner surface and another ($\text{B2-}$) without the coating.
- $\text{B1+}$ 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.
[1] India-based Neutrino Observatory.
http://www.ino.tifr.res.in/ino/

Cosmic ray test of INO RPC stack.

http://www.comsol.co.in

Simulation of 3D electrostatic configuration in gaseous detectors.
2007 _JINST_ 2 P09006.

http://garfield.web.cern.ch/garfield
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