Investigating the importance of device geometry in RPC response

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on behalf of
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Outline

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Motivation

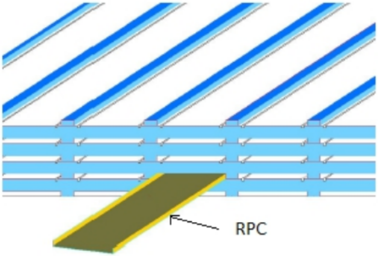
Resistive Plate Chamber (RPC) is a robust and affordable gaseous detector having simple signal pick-up and read-out system, which is extensively used in many HEP and astro-particle experiments due to some unique characteristics :

- Built from simple and common materials, so can be fabricated to have large coverage area at low cost.
- They are easy to stack one above the other to have 3D spatial information with spatial resolution less than 1 cm.
- Very good time resolution (few ns) and detection efficiency ($> 90\%$).
- They have long term stability.
- RPC is the active detector element for INO-ICAL detector, which will study atmospheric neutrinos to make precise measurement of the neutrino oscillation parameters $\left|\Delta m^2_{31}\right|$, $\sin^2 2\theta_{23}$ and also will shed light on neutrino mass hierarchy (sign of δ_{32}).

Motivation (cont.)

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.
- The energy and direction of the muons produced by the interaction of neutrinos with the iron nuclei will be found out from the hit and timing information from RPCs.

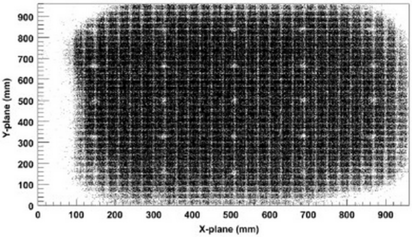


RPC for INO-ICAL detector

$$\nu_\mu + n \rightarrow p + \mu^-$$
$$\overline{\nu}_\mu + p \rightarrow n + \mu^+$$

Motivation (cont.)

- We are trying to understand the detailed physics behind the operation of RPC which will help in optimizing the detector parameters and interpreting the result.
- At present, aim is to find out effect of geometrical artifacts, gas flow scheme etc on RPC response.
- Early r&d works on the INO-ICAL prototype have shown reduced response from RPC near edges, corners and button spacers than a regular point.
- Physical field, gas flow scheme may be the possible reasons.



Dead space near Edge, corner and spacers (fig. from [1]

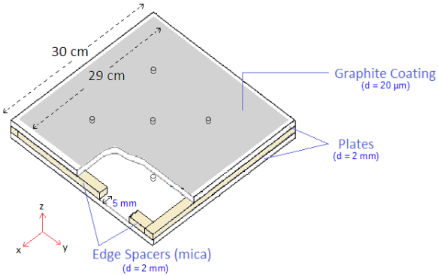
- Presence of uniform gas mixture all over the gas chamber has been assumed.

[1] **M. Bhuyan et al.**, Cosmic ray test of INO RPC stack, *Nucl. Instrum. Meth. A* 661 (2012) S68.

Outline

Field map within RPC

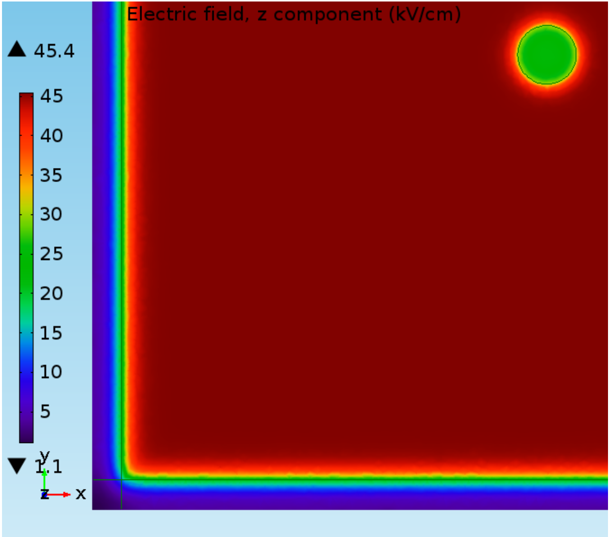
- RPC dimension: 30cm$\times$30cm.
- Field solvers used :
  COMSOL v5.0 : Based on Finite Element Method (FEM).
  neBEM v1.8.16 : Based on Boundary Element Method (BEM), interfaced with Garfield.



RPC model used for field calculation.

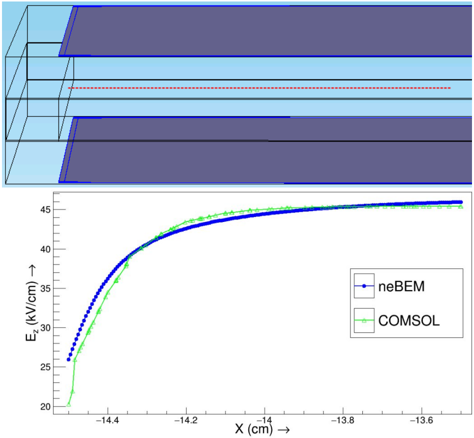
Model specifications :
RPC plates : Bakelite ($\epsilon_r = 6.4$).
Edge spacers, Button spacers : Mica ($\epsilon_r = 5.4$).
Gas : air ($\epsilon_r = 1.0013$).
Conductive coating : Graphite ($\epsilon_r = 12$, for signal calculation).
H.V. applied : $\pm$6 kV.
Insulating layer : Mylar ($\epsilon_r = 3.2$) $\rightarrow$ For signal calculation.

Field map within RPC (cont.)

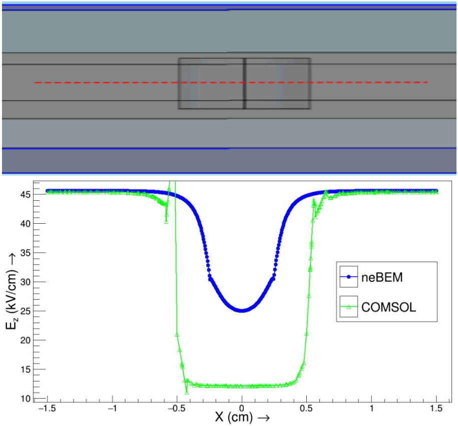


Surface map of E_z showing the effect of edge spacers and button spacers

Field map within RPC (cont.)



(a)

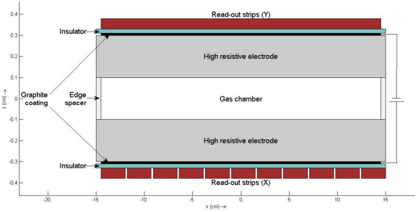


(b)

Effect of (a) side spacer and (b) button spacer in physical electric field as computed from COMSOL and neBEM

RPC signal

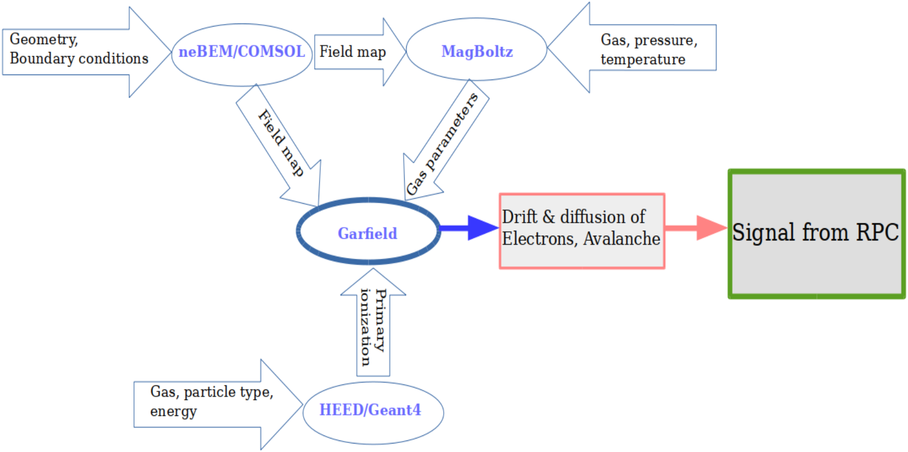
- Electric field map within the chamber : neBEM/COMSOL.
- Calculation of gas transport properties (Townsend coefficient, attachment coefficient, longitudinal and transverse diffusion coefficients and drift velocity of electrons) : MagBoltz $\rightarrow$ Solves the Boltzman transport equations for electrons in arbitrary gas mixtures.
- Interaction of relativistic charged particle with the gas medium and their energy loss : HEED/Geant4.



Schematic diagram of a complete RPC

- Garfield framework has been used to calculate the signal induced on the RPC pick-up strip.

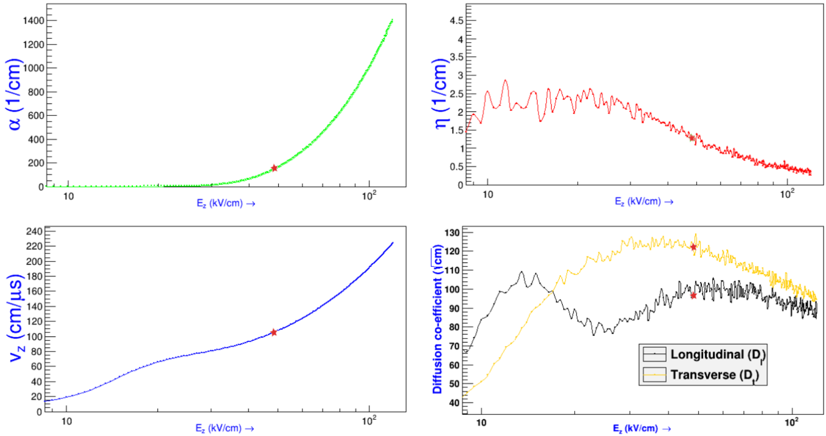
RPC signal (cont.)



Garfield framework to simulate RPC signal

RPC signal (cont.)

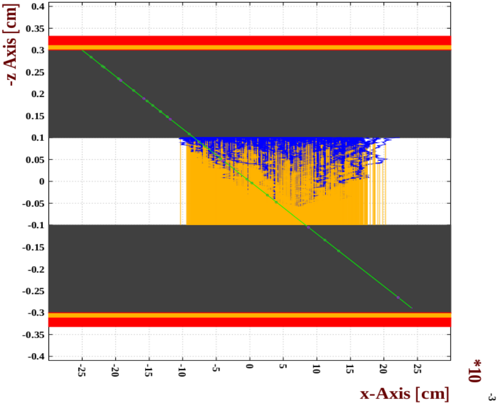
- Gas mixture used → Freon (134A) : Isobutane = 95 : 5 (in %).
- Applied voltage for simulation: ±6 kV (E_z= 46 kV/cm).



Variation of Townsend coefficient (α), attachment coefficient (η), electron drift velocity (V_z) and diffusion coefficients (D_l and D_t) with applied field (E_z) from MagBoltz.

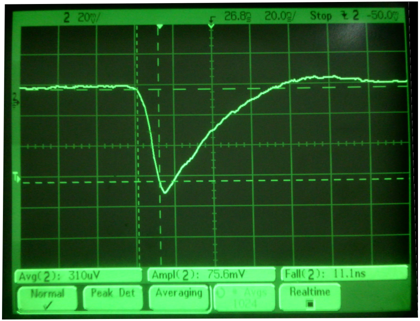
RPC signal (cont.)

- Passage of 1 GeV muon through RPC gas chamber, 5 ° inclination with z axis.
- Pick-up plane is a copper plate (no strip) for simplicity.

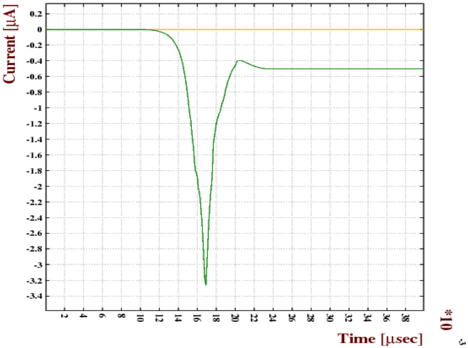


Avalanche produced due to drift of electrons and ions within RPC gas chamber

- Signal from lower pickup panel (towards the side of Anode).
- Appearance of long tail for slow ion movement (ion-mobility $= 1 \times 10^{-6}$ cm$^2/\mu s$V).



RPC signal as seen on Oscilloscope.

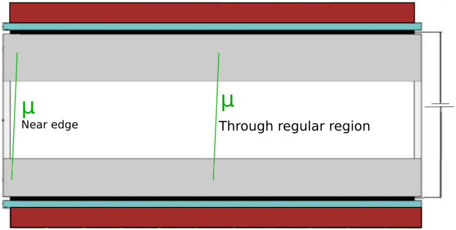


Typical RPC signal from simulation.

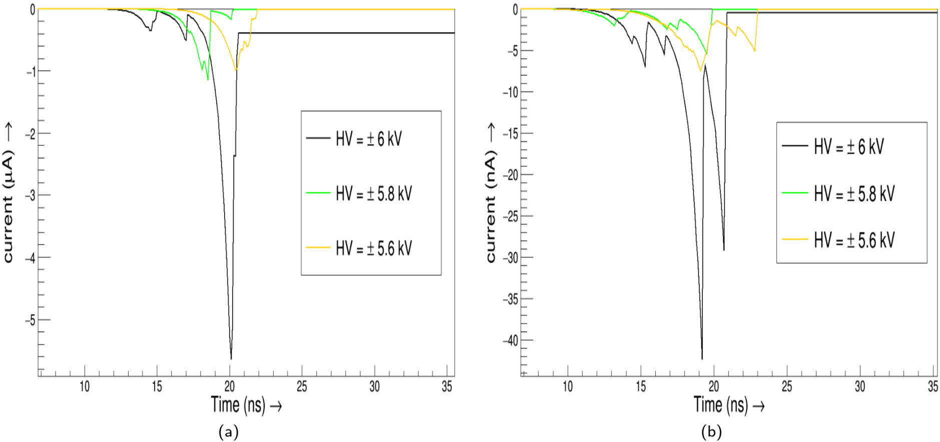
- Rise time of pulse $\sim$ 11 ns.
- Rise time from simulation $=$ 7 ns.

Effect of edge on RPC signal

- Muons are passed through RPC in X-Z plane making an angle 5° with the Z axis.
- Keeping all the above same, 100 muons, each of energy 2 GeV are passed through a region away from all imperfections (Regular region) and through a region near edge (2.5 mm from edge spacer) of RPC. The results are compared.



Effect of edge on RPC signal (cont.)

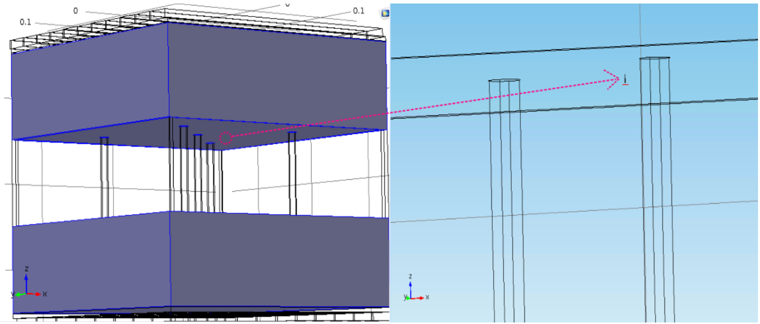


Average RPC signal for different applied voltages when 2 GeV muons are passed through (a) regular region, (b) near edge

Outline

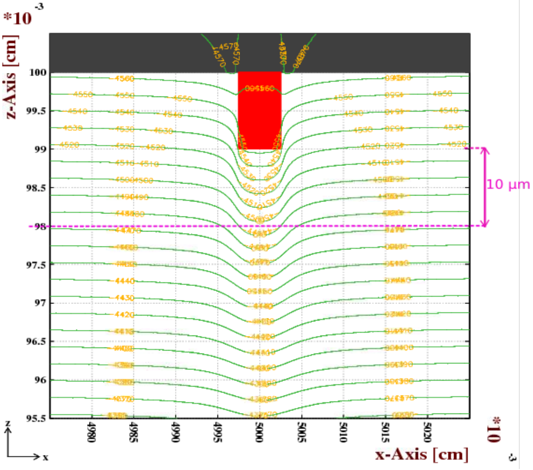
Modeling of rough surface

- Roughness in the form of a block of dimension 50μm $\times$ 50μm and height 10μm is introduced.
- COMSOL and neBEM are used to calculate the field map.



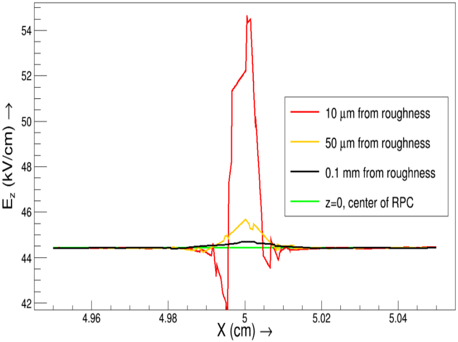
Block-shaped roughness at the inner surface of RPC plate

- Applied voltage $\pm$ 6 kV on the graphite coating.

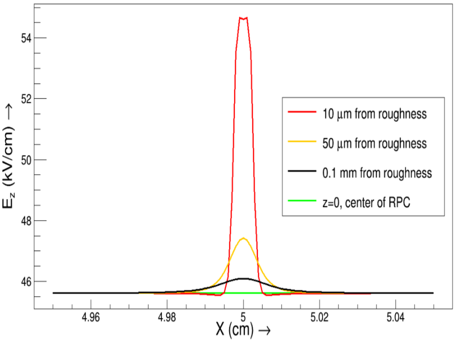


Contour plot of E_z around the block-shaped roughness.

Effect of roughness on E_z (cont.)



(a)



(b)

Variation of E_z with X at different distances from the block-shaped roughness from (a) COMSOL, (b) neBEM.

Outline

1. Motivation
2. Effect of frame and spacers
   - Effect on field
   - Effect on signal
3. Effect of surface roughness
   - Effect on field
4. Further study

Further study

- The effect of surface roughness on the induced signal will be investigated.
- Fine tuning the simulation parameters to approach more realistic condition and verifying it with experimental data.
- Simulate the gas flow within RPC gas chamber and find out dead regions and the effect of gas flow scheme on RPC response.

Acknowledgment

- **Purba Bhattacharya** (SINP) for helping me with Garfield work.
- **Sananda Das** (SINP), **Deb Sankar Bhattacharya** (SINP) for the helpful discussions.
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Thank You