Numerical study on the effect of design parameters and spacers on RPC time resolution

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Outline

Outline

Motivation

Figure: Bodi west hill: the proposed site for INO

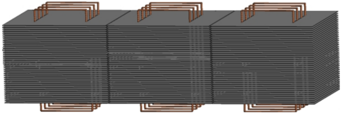


Figure: ICAL modules consisting of alternate layers of RPCs and iron plates

- A large number ($\sim$ 30,000) of Resistive Plate Chambers (RPC) will be deployed in the ICAL setup of India-based Neutrino Observatory.
- Understanding the detail physics behind the operation of RPC will help understanding its behavior at different conditions as well as interpreting the result and optimizing the detector parameters to improve its performance.

Motivation (cont.)

- The response from an RPC is not uniform over its whole area.
- The presence of different geometrical components affect the RPC response.
- Possible reasons may be the field at those regions and the gas flow scheme.
- Keeping uniform gas mixture over the whole chamber, the effect of these components on the electrostatic field map has been investigated.
- Also the effect on the amplitude of RPC signal and its timing properties has been found out.

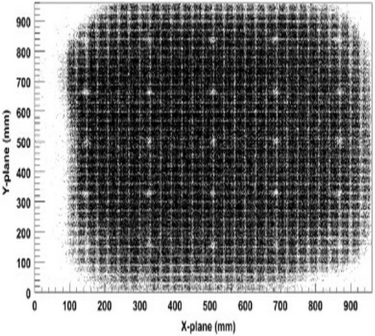


Figure: Variation in RPC response near edges, corners and spacers (figure from *NIM A 661 (2012) S68*).

Outline

Experimental Setup

- One Bakelite RPC of dimension 30 cm $\times$ 30 cm has been operated with a pre-mixed gas mixture R-134A : Isobutane = 95 : 5.
- One finger scintillator along with two paddle scintillators formed a telescope to select muon events passing through the RPC.
- Environmental condition during the experiment -
  Room temperature = 21 - 23 $^{\circ}$C,
  Relative Humidity = 43 - 54 %

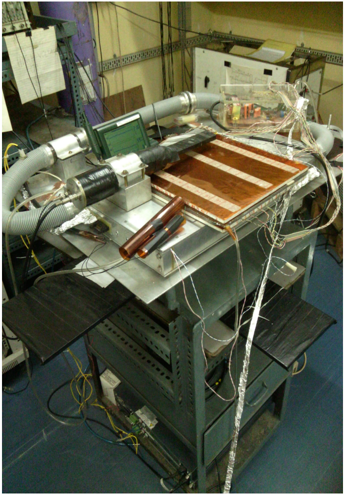


Figure: Experimental setup

TDC measurement

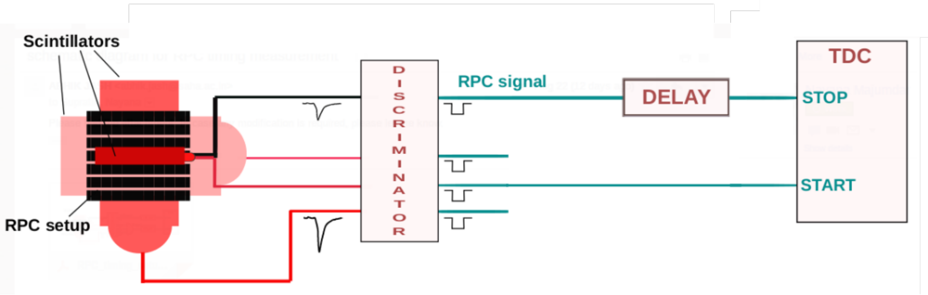
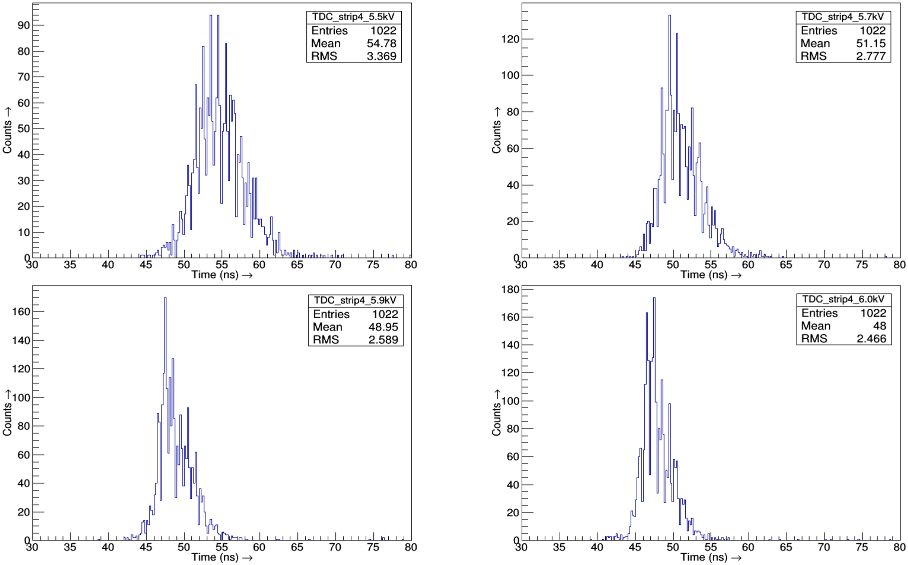


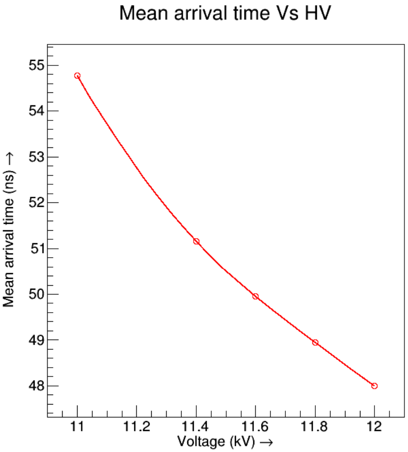
Figure: Schematic diagram of the setup for TDC measurement

- START : finger scintillator.
- STOP : RPC strip.
- Data acquisition using LAMPS.
- TDC calibration : 1 channel = 0.1 ns.

TDC measurement (cont.)



TDC measurement (cont.)



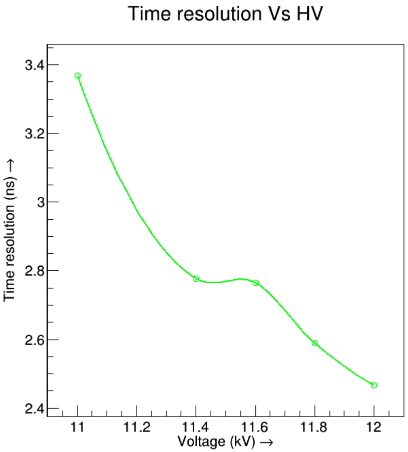


Figure: Variation of mean arrival time and time resolution with applied voltage from experiment.

Outline

Electrostatic field map

- 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.

Model specifications :

- RPC plates : Bakelite ($\epsilon_r = 5.4$).
- Edge spacers, Button spacers : Mica ($\epsilon_r = 5.4$).
- Gas : air ($\epsilon_r = 1.0013$).
- Conductive coating : Graphite ($\epsilon_r = 12$).
- Insulating layer : Mylar ($\epsilon_r = 3.2$).
- H.V. applied : $\pm$6 kV.

Electrostatic field map (cont.)

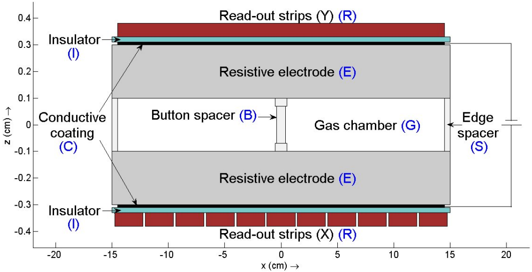


Figure: Schematic diagram of a complete RPC with a button spacer at the center.

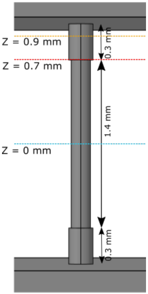


Figure: Schematic diagram of a button spacer used in RPC fabrication.

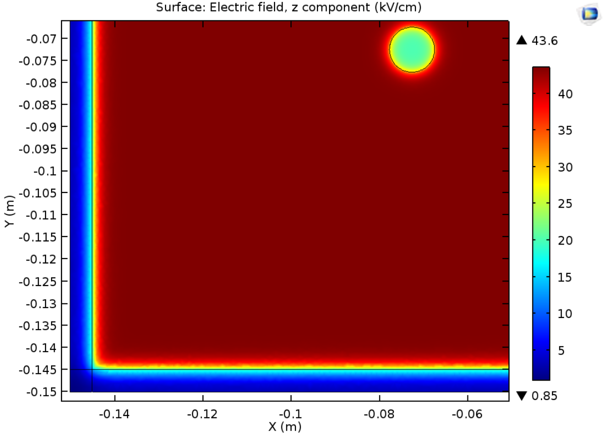


Figure: Surface map of E_z at $z = 0$ plane showing the effect of edge spacers and button spacer.

Electrostatic field map (cont.)

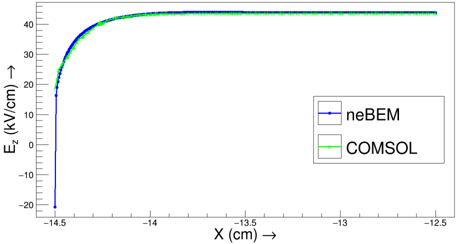


Figure: Effect of edge spacer in physical electric field.

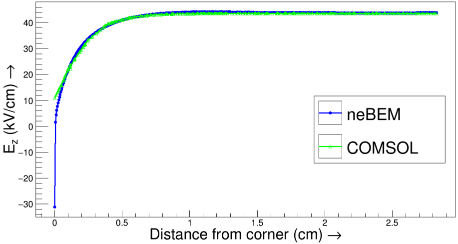


Figure: Effect of corner in physical electric field.

Electrostatic field map (cont.)

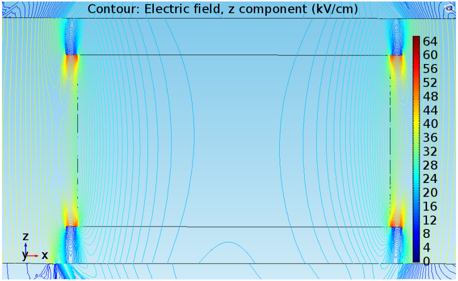


Figure: Contour plot of E_z around button spacer of typical shape from COMSOL.

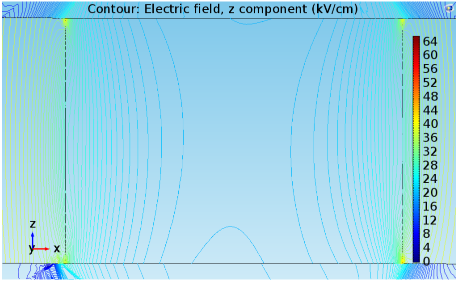


Figure: Contour plot of E_z around uniform cylindrical button spacer from COMSOL.

RPC signal amplitude

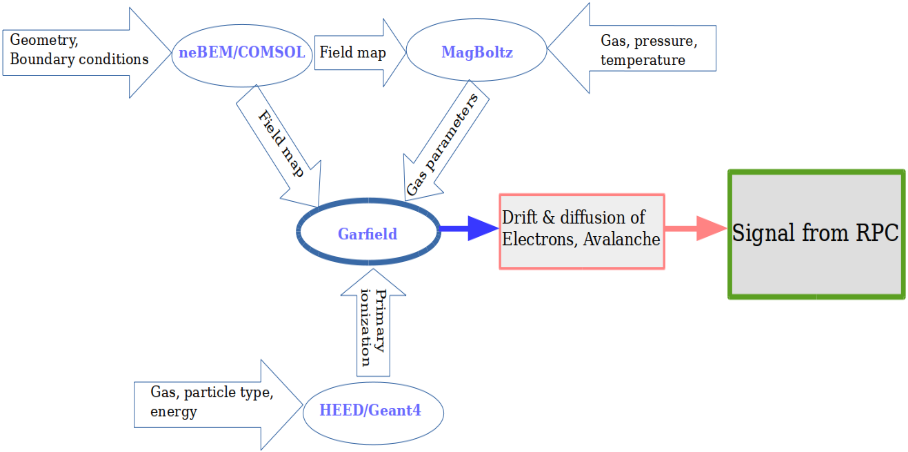


Figure: Garfield framework to simulate RPC signal.

RPC signal amplitude (cont.)

- Gas mixture used $\rightarrow$ R-134A : Isobutane = 95 : 5 (in %).
- Applied voltage for simulation: $\pm$6 kV (E_z= 43.6 kV/cm).
- Passage of 2 GeV muon through RPC gas chamber, 5 $^\circ$ inclination with z axis.
- Signal from lower read-out strip of width 2.5 cm (towards the side of Anode).

RPC signal amplitude (cont.)

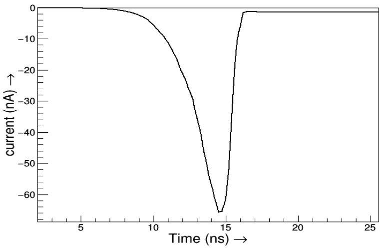


Figure: Typical RPC signal from simulation (averaged over 50 events).

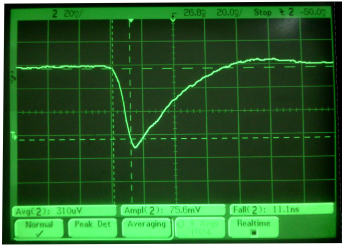


Figure: RPC signal as seen on Oscilloscope.

- A constant value of ion-mobility considered but effect of the external electronic circuit is not considered in calculation $\rightarrow$ modification in falling edge.

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

RPC signal amplitude (cont.)

- Muons of energy 2 GeV are passed through RPC in X-Z plane making an angle 5° with the Z axis.
- One muon 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.

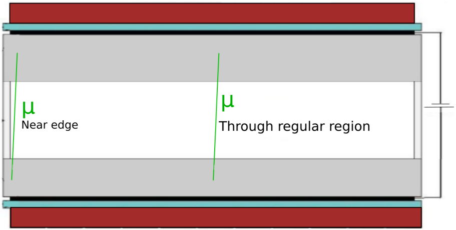


Figure: Passage of muon through different regions of an RPC.

RPC signal amplitude (cont.)

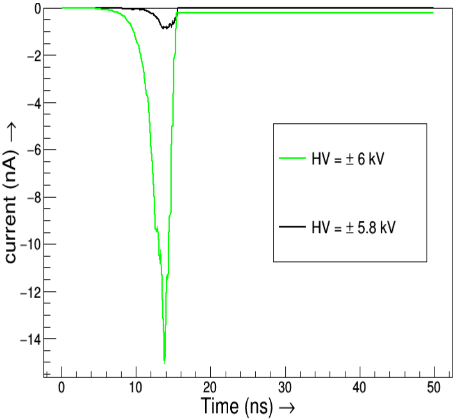


Figure: Signal induced due to passage of a 2 GeV muon through a regular region.

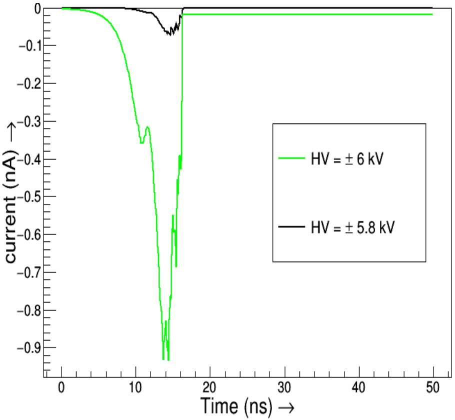


Figure: Signal induced due to passage of a 2 GeV muon through a region near edge.

RPC time resolution

- Cluster positions in the gas chamber due to passage of 2 GeV muon - HEED.
- Electrons are drifted from the cluster positions following Monte-Carlo method taking care of Townsend and attachment co-efficients and diffusion of electron.
- Time taken by the fastest electron is stored as arrival time.
- The process is repeated for many tracks (fixed θ, $\phi = 1$ - 360°) and a distribution of arrival time obtained.
- Mean of the distribution → Average arrival time.
  RMS of the distribution → Time resolution.

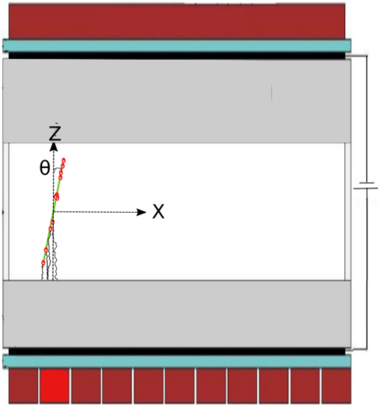


Figure: Calculation of average arrival time and time resolution.

RPC time resolution (cont.)

- Step length for the Monte-Carlo drift of electrons = 2 μm.
- Gas mixtures used:
  R-134A : Isobutane = 95 : 5.
  SF_6 of 0.1%, 0.2%, 0.5% used replacing same amount of Isobutane.
- Variation of Average arrival time with the applied voltage as well as SF_6 % has been calculated.

RPC time resolution (cont.)

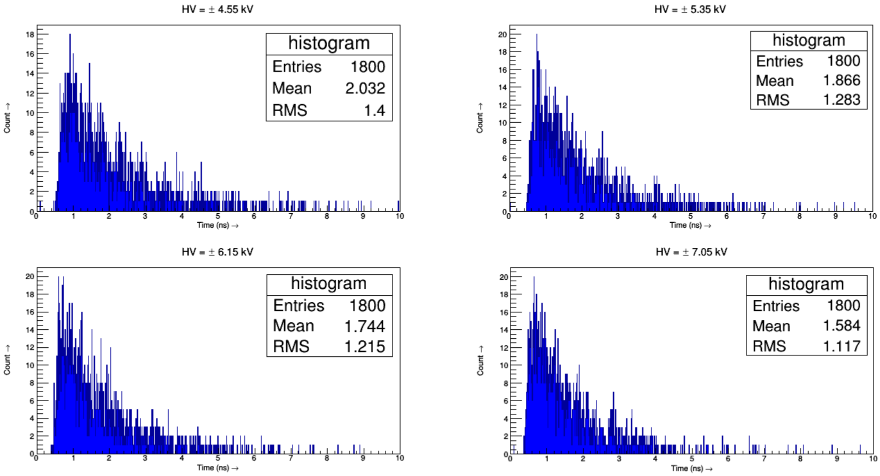
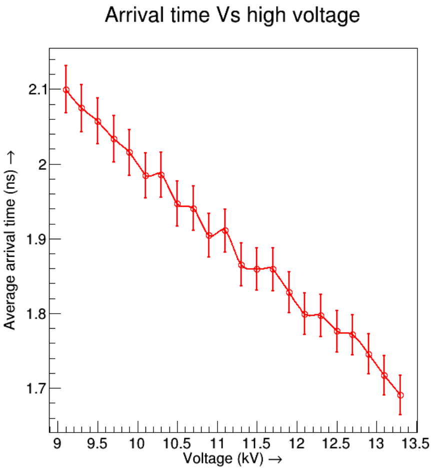


Figure: Histogram of electron arrival time at different voltages for R-134A : Isobutane = 95 : 5.

RPC time resolution (cont.)



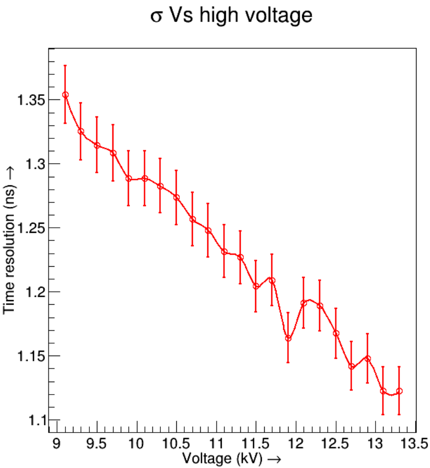


Figure: Variation of average arrival time and fluctuation in its value with the applied voltage for R-134A : Isobutane = 95 : 5.

RPC time resolution (cont.)

- Increase in applied voltage

  $\Rightarrow$ increase in electron drift velocity.

  $\Rightarrow$ **decrease in average arrival time**.

  $\Rightarrow$ decrease in transverse diffusion co-efficient.

  $\Rightarrow$ **decrease in fluctuation in electron drift path**

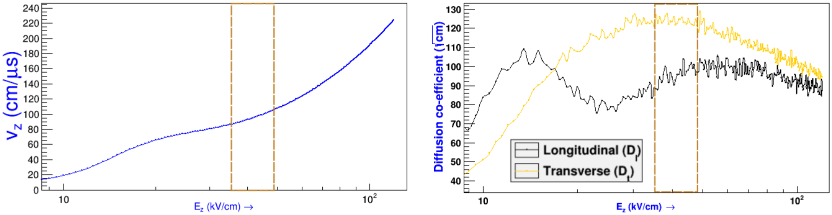


Figure: Variation of electron drift velocity and diffusion co-efficient of the gas mixture R-134A : Isobutane $= 95 : 5$ with E_z.

RPC time resolution (cont.)

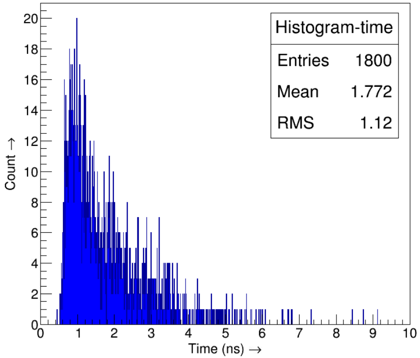


Figure: Arrival time distribution for muons passing through a regular region.

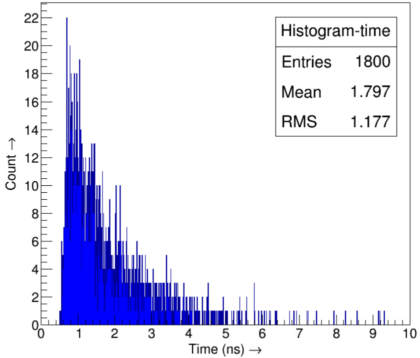


Figure: Arrival time distribution for muons passing through a region near edge (1.25 cm away from edge).

RPC time resolution (cont.)

- Effect of different geometrical components can be found out by releasing electrons to drift from a point -
  - At a regular region.
  - At a point near edge spacer.
  - At a point very near to the edge of the button spacer.
- Fluctuation in arrival time due to the creation of clusters will not be present.

RPC time resolution (cont.)

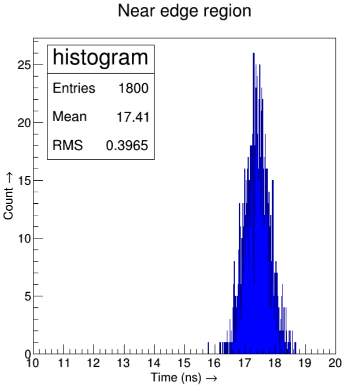


Figure: Near edge spacer.

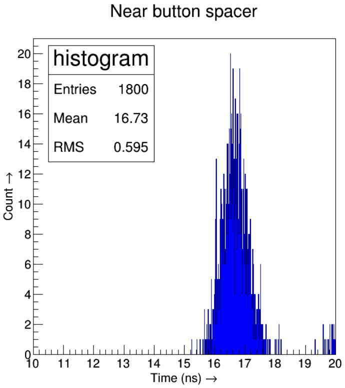


Figure: Near button spacer

RPC time resolution (cont.)

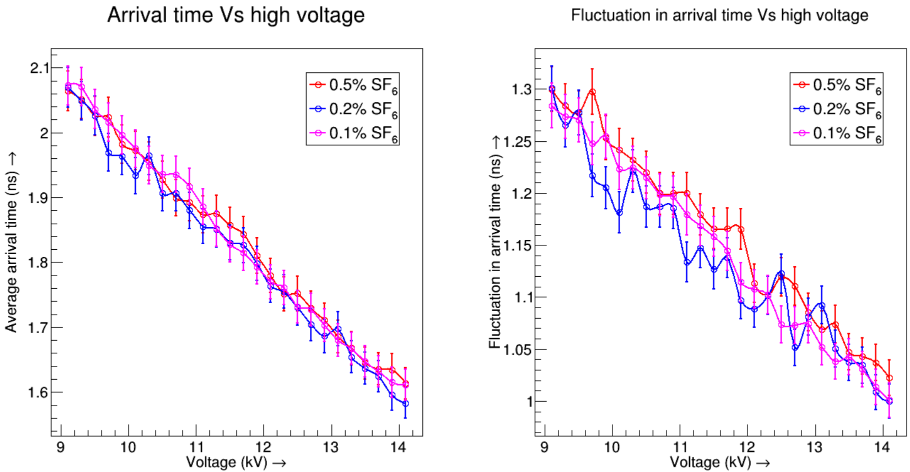


Figure: Variation of average arrival time and fluctuation in its value due to electron drift with the applied voltage for different SF_6 %.

Outline

Conclusion

- The electrostatic field map is affected due to presence of the geometrical components.
- Less amplitude of signal from the regions near edge spacers and corners can lead to loss of efficiency at those places.
- The variation of electron arrival time and fluctuation in that value decrease with the increase in applied voltage as has been observed both experimentally and numerically.
- Preliminary calculations showed an effect of the critical regions on the average arrival time of electrons and the fluctuation in the arrival time.
- Same calculations with higher statistics will help to improve the result.
- Effect of gas mixture on the timing properties will also be found out experimentally.

Acknowledgment

- **Purba Bhattacharya** (NISER) for helping me with the Garfield work.
- Dr. **Saikat Biswas** (NISER), Prof. **Sudeb Bhattacharya** (SINP), **Meghna K. K.** (IMSc) for their help during experimental arrangements.
- **Ganesh Das** (VECC) for helping me fabricating the Bakelite RPC.
- **Deb Sankar Bhattacharya** (SINP), **Rajesh Ganai** (VECC) for all the helpful discussions.
- **INO collaboration** for financial support and suggestions at different stages of my work.

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Thank You

Additional Slides

RPC working principle

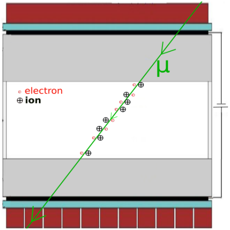

Figure: Primary ionization by the passing radiation

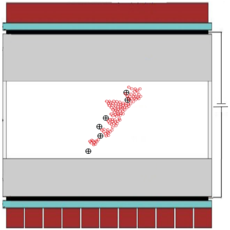

Figure: Further ionization by the moving electrons

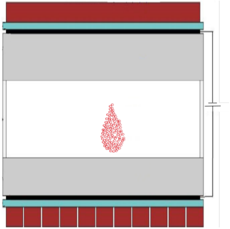

Figure: Induction of signal due to movement of e^- avalanche and ions

- The current induced on a read-out strip due to movement of charge q with velocity $\overrightarrow{v}(t)$ is given by **Shockley-Ramo** theorem :

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

RPC working principle (cont.)

- Value of q depends on the ionizing particle, gas mixture and the electrostatic field.

$$N = N_0 e^{(\alpha-\eta)x}$$

$N_0 \rightarrow$ Primary number of electrons

N $\rightarrow$ Total number of electrons

$\alpha \rightarrow$ Townsend co-efficient

$\eta \rightarrow$ Attachment co-efficient

- Instantaneous velocity of the charge, $\overrightarrow{v}(t)$ depends on the gas mixture as well as on the electrostatic field.

Voltage Vs Current plot

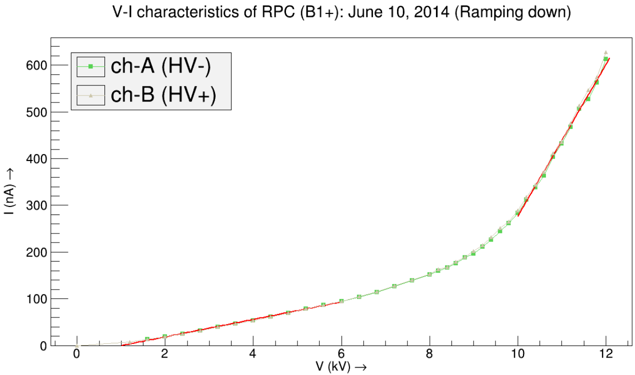

Figure: V-I plot of RPC while ramping down

- Breakdown occurs around 10.2 kV.
- $R_{plate} = 6.16\ G\Omega$.
- $R_{spacer} = 53.4\ G\Omega$.

Efficiency and singles rate

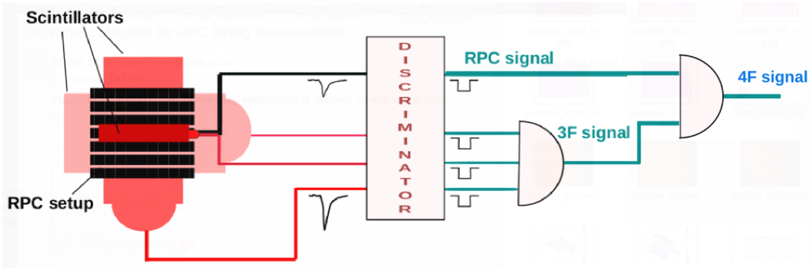

Figure: Schematic diagram of the setup to calculate strip efficiency and singles rate

- Efficiency (%) $= \frac{4F}{3F} \times 100$
  3F = AND of signals from 3 scintillators.
  4F = AND of 3F and RPC strip signal.
- Singles rate$(Hz/cm^2) = \frac{\text{singles count}}{\text{strip area} \times \text{counting time}}$
  singles count = any signal from RPC strip which crosses threshold.

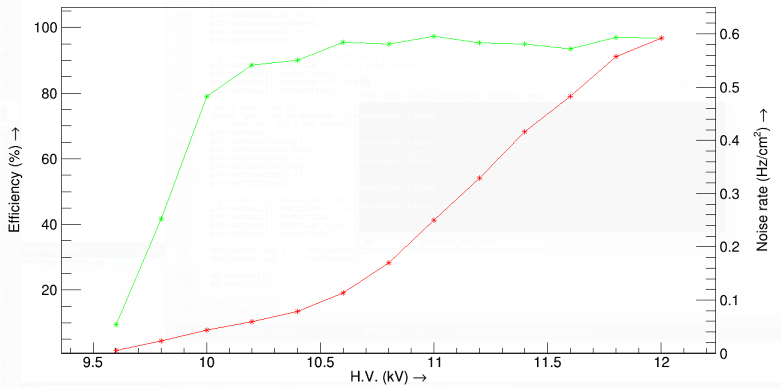

Figure: Variation of efficiency and singles rate of RPC B1+ with H.V.

Effect of shape of button spacer on E_z

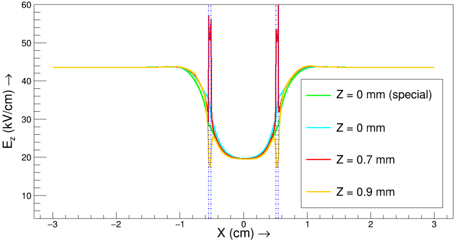

Figure: Variation of E_z along X-direction at different positions near a button spacer - COMSOL.

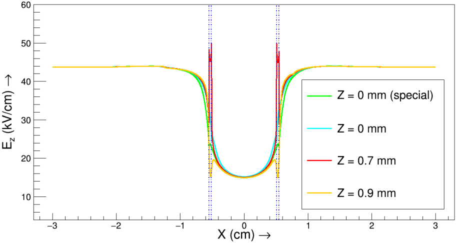

Figure: Variation of E_z along X-direction at different positions near a button spacer - neBEM.

Electron and Ion movement within RPC gas chamber

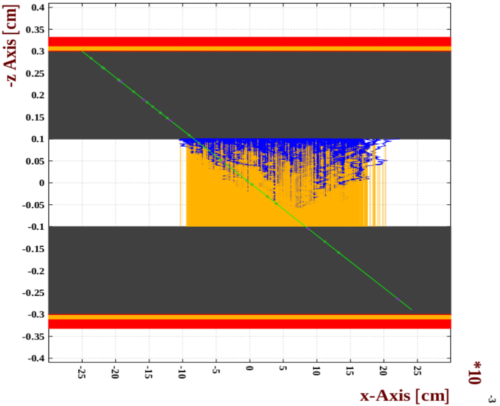

Figure: Avalanche produced due to drift of electrons and ions within RPC gas chamber.