Angular Dependence of Cosmic Muon Flux - Experimental Measurement and Simulation

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INTRODUCTION

Being the most abundant cosmic particle at sea level, atmospheric muon can easily provide us the information about primary cosmic rays and its interaction with atmosphere. Muons are usually produced as a decay product of pions and kions at high altitude like $\pi^- \rightarrow \mu^- + \bar{\nu_\mu}$. So it also has strong correlation with atmospheric neutrino flux. Muon flux rate have been observed since the late 1940s [1]. Some popular experiments in past shows that the cosmic muon flux distribution follows $\cos^n$ rule with $n \approx 2$. Software packages like Cosmic Ray Shower (CRY)[2] library provide a spatial and temporal variation of cosmic muon flux. However experimental study of cosmic muon flux will improve the accuracy with different variables like lattitude dependent geomagnetic cutoff, environmental changes.
In this study, we have used Resistive plate Chamber(RPC)[3] as it is a robust gaseous detector with excellent time resolution ($\sim$1 ns) and good position resolution. For our measurement, first a RPC has been fabricated and tested thoroughly with two different gas mixtures. Then using the developed RPC and trigger from coincidence of three scintillators, anglar distribution of cosmic muon flux has been measured at Kolkata (22° 36' 6.71" N, 88° 25' 7.89" E) at 8 m elevation. The details of fabrication, test and measurement are presented here.

CONSTRUCTION OF RPC AND WORKING PRINCIPLE

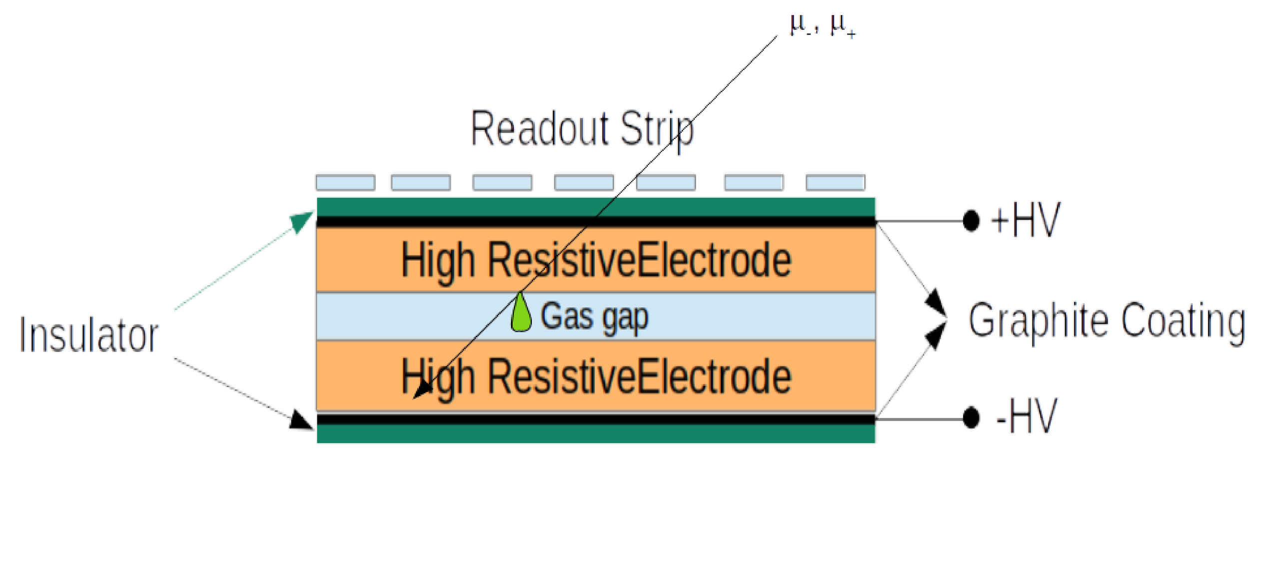
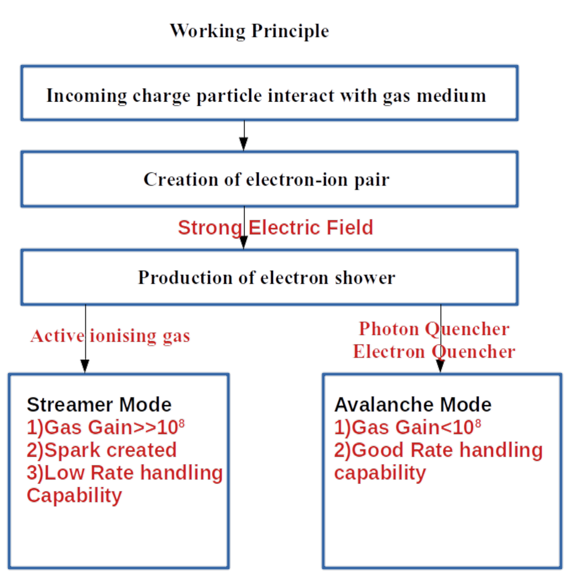


Figure 1: Components of RPC



Type of Gas	Example
Active Ionising Gas	R134a, Ar
Photon Quencher	CH_4 ,iC_4H_10, CO_2
Electron Quencher	SF_6, Freon, R134a

Table 1: different gases and their role

FABRICATION OF BAKELITE RPC AND SPECIFICATIONS

Unlike glass, bakelite is not fragile. Hence testing, handling and shifting of bakelite based modules are much more easier than the glass. The RPC has been developed using P302 (OLTC grade) bakelite sheet[4].

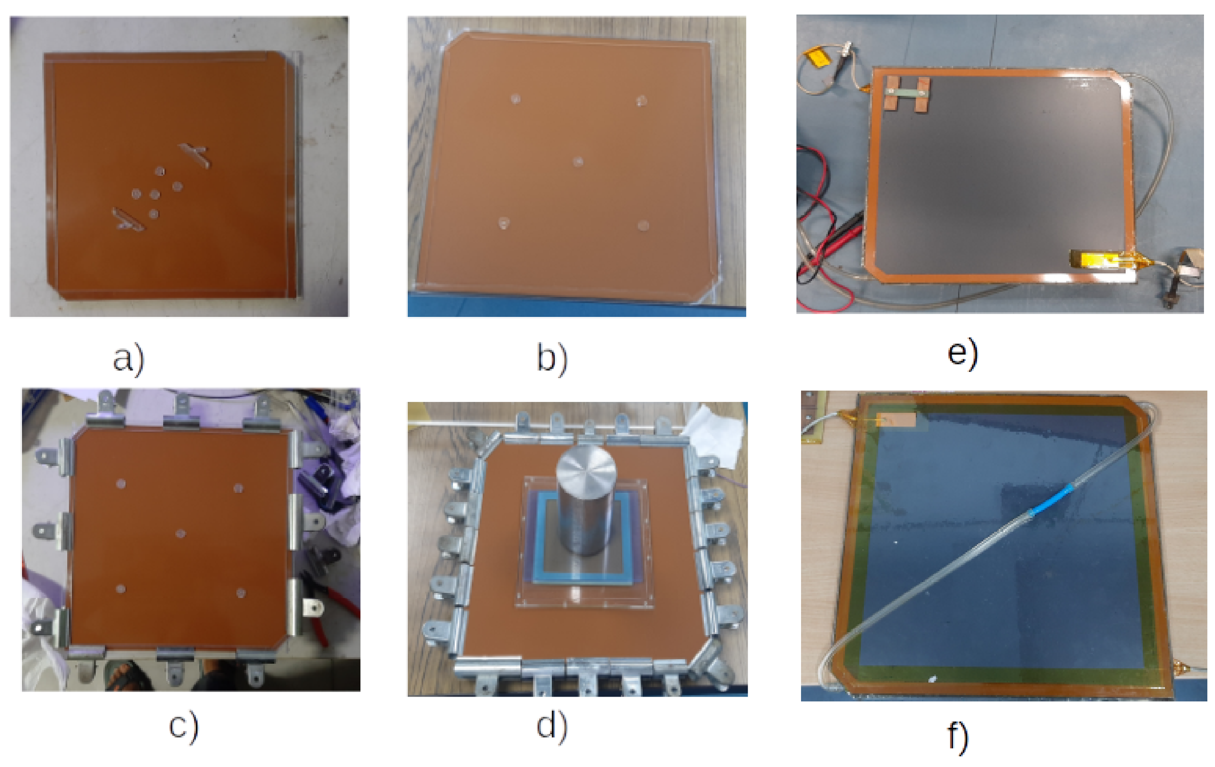


Figure 3: Various steps of Fabrication of RPC: (a) shows 5 button spacer and two gas nozzles have been kept on the inner surface of button electrode (b) shows the button spacers with the gas nozzles has been glued to inner surface of the bottom electrode plate (c) shows the top electrode has been glued with button spacers and side spacers. Metal clips were used for strong attachment (d) shows heavy weights have been placed on the chamber to ensure that uniform gas gap is maintained between the electrodes through button spacers (e) shows good conducting Graphite mixed with special thinner in 1 : 1 ratio and has been applied to both electrodes to apply voltage uniformly all over the outer surfaces. (f) The outer surfaces of the electrodes have been cover with polyester film, mylar to keep separated the readout plate from high voltage electrodes

Total area of the RPC	$\sim$ 31 cm × 31 cm
Active area of the RPC	$\sim$ 30 cm × 30 cm
Number of electrodes	2
Dimensions of the electrodes	$\sim$ 31 cm × 31 cm × 0.30 cm
Thickness of each button spacer	$\sim$ 0.2 cm
Thickness of the side spacer frame	0.2 cm
Total number of gas nozzles	2
Thickness of gas gap	$\sim$ 0.2 cm

Table 2: Specifications of the RPC.

Gas Composition	R134a : iC_4H_10:SF_6:: 95: 4.5 : 0.5
Gas Flow Rate	$\sim$ 0.65 litre/hour

Table 3: Gas used during test.

TEST RESULTS

CHARACTERIZATION OF RPC

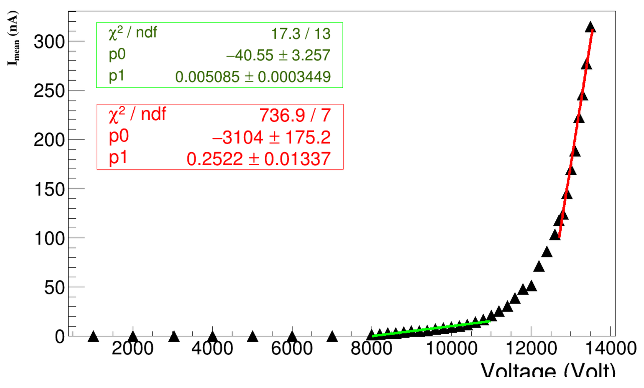


Figure 4: I-V Plot for Gas mixture ratio of 95:4.5:0.5(R134a:iC_4H_10:SF_6) $R_{spacer} = 197 G\Omega$, $R_{electrode} = 4 G\Omega$

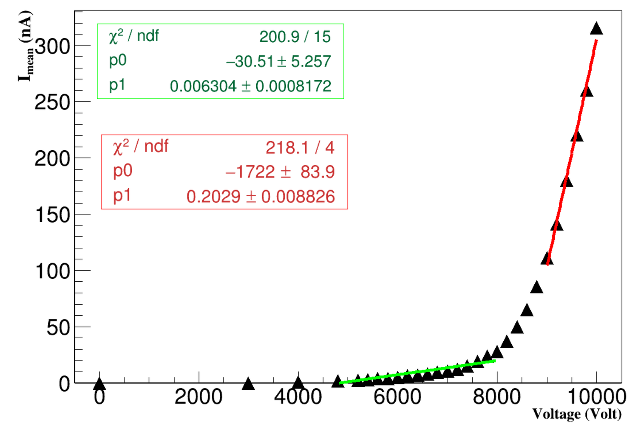


Figure 5: I-V Plot for Gas mixture ratio of 95:4.5:0.5(R134a:iC_4H_10:SF_6) $R_{spacer} = 158 G\Omega$ $R_{electrode} = 4.9 G\Omega$

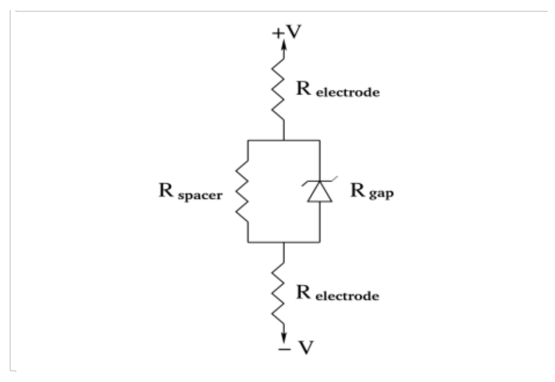


Figure 6: Electronic equivalent Circuit: below discharge region slope of I-V represents $\frac{1}{R_{spacer}}$.Whereas, at very high voltage region i.e voltages above discharge, the gas gap behaves as a conductor($R_{gasgap} = 0$) and slope of I-V represents $\frac{1}{R_{electrode}}$)

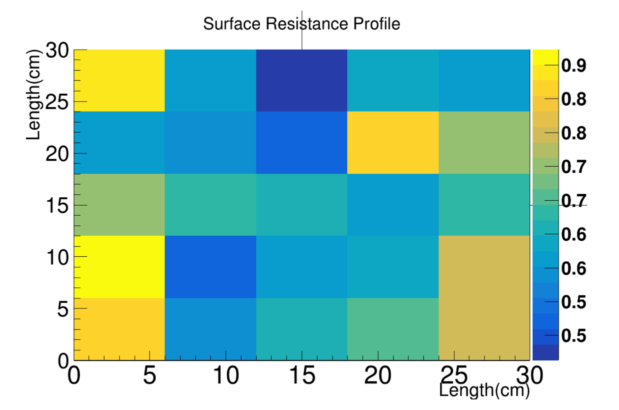


Figure 7: Surface Resistivity of Side-1

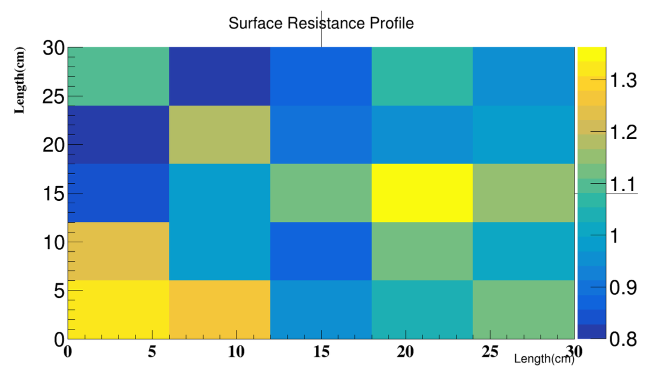


Figure 8: Surface Resistivity of Side-2

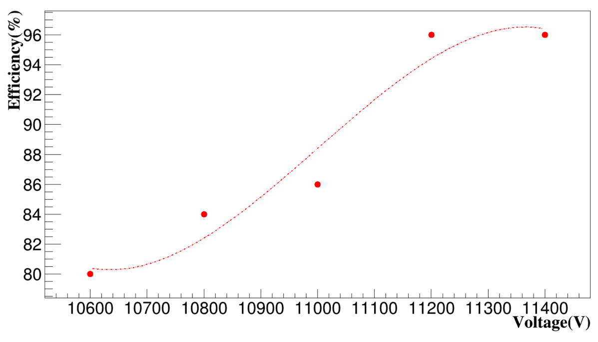


Figure 9: Voltage scan was done and efficiency plateau was observed above 11400V

EXPERIMENTAL SET-UP AND ELECTRONICS

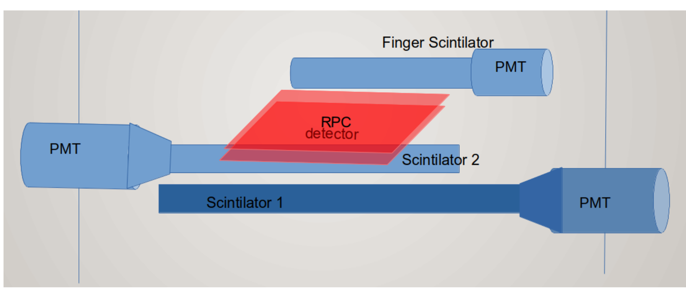


Figure 10: Schematic views of Experimental Set-Up

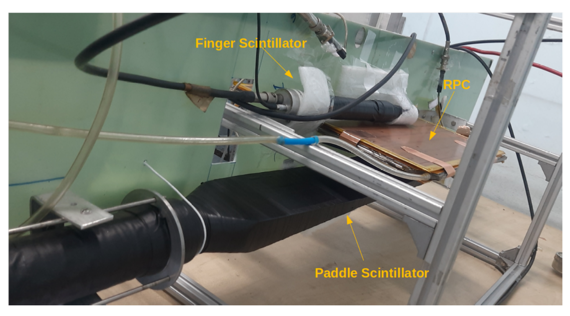


Figure 12: Experimental set-up in our Lab (Side Views For 0° cosmic muon flux measurement)

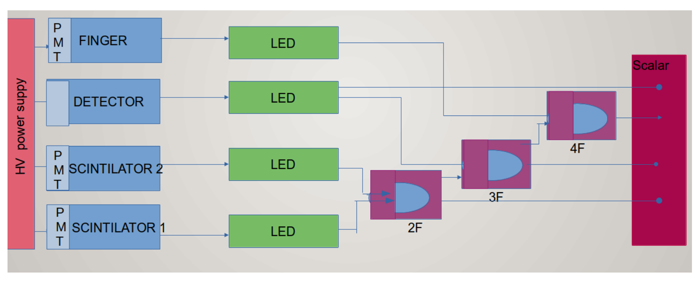


Figure 11: Electronic Circuit Diagram: NIM High Voltage Module N471A(CAEN), Quad-Scalar N1146(CAEN), Co-incidence module N455(CAEN), discriminator LED N841 and LEMO connector were used for signal processing and data acquisition.

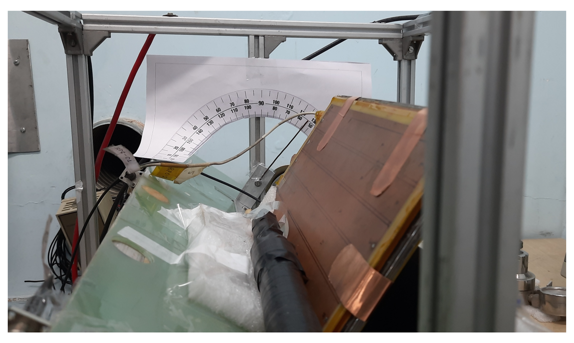


Figure 13: Experimental set-up in our Lab (Side Views For 50° cosmic muon flux measurement)

- Data was taken from Dec. 2021 to April 2022 at VECC, Kolkata.
- RPC high voltage was maintained above 11400 V for more than 90 % efficiency.
- Room temprature was maintained around 22° Celsius.
- Humidity(RH) was maintained around 40 %.
- The cosmic-muon flux scan was done along North-South direction and to do this a rotating frame was developed.
- Keeping the axis of rotation along East-west direction, rotating frame was rotated along clockwise and anti-clockwise direction with an interval of 10°.

EXPERIMENTAL RESULT AND CRY SIMULATION

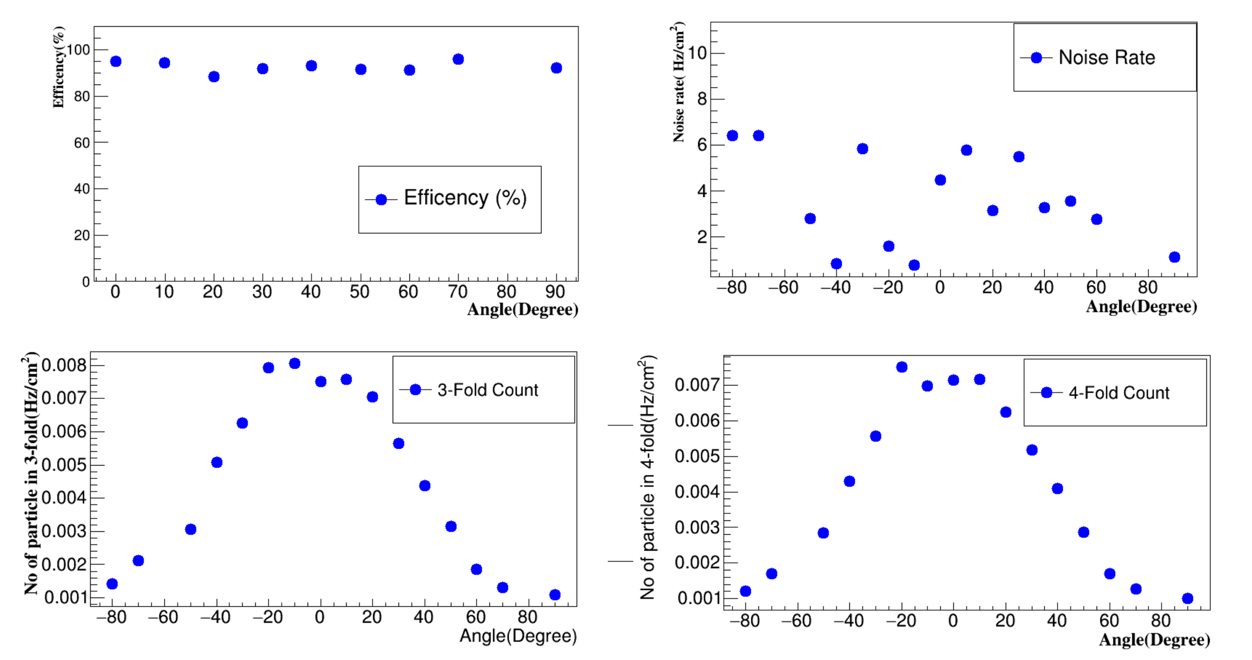


Figure 14: Experimental Result:a) Effcency b) Noise Rate c) 3-Fold count d) 4-Fold count have been shown here w.r.t zenith angle

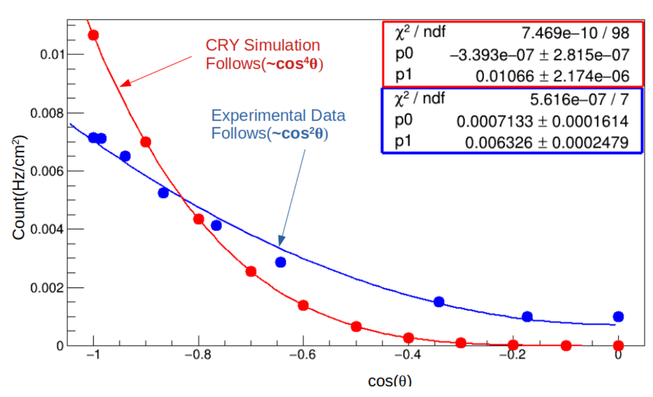


Figure 15: Compare with CRY Simulation

- We have generated cosmic muon flux data for 22° 36' 6.71" latitude at sea level using Cosmic Ray shower(CRY) Library.
- CRY simulation data follows $I \propto \cos^4\theta$ where as our experiment suggest $I \propto \cos^2\theta$

CONCLUSION AND OUTLOOK

- We have successfully developed oil-free bakelite working upto $\sim$99% efficiency. The detectors have been characterized with a gas mixture of R134a:iC_4H_10 : SF_6 :: 95 :4.5 : 0.5 and 90 : 5 :5(by volume).
- Angular distribution Cosmic muon flux follows $\cos^n\theta$ where $n \approx 2$.
- Our experimental study has been compared with CRY simulated data and significant deviation from simulated result was observed.
- As change in geomagnetic cut-off was observed in long-term(1950–2020), cosmic muon fluxs and its angular distribution will be playing an important role to predict this change. This study with good statistics will help us to understand the geomagnetic cut-off and environmental degradation locally.

ACKNOWLEDGEMENT

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