Performance study of Glass RPC detector with low Global Warming Potential gases

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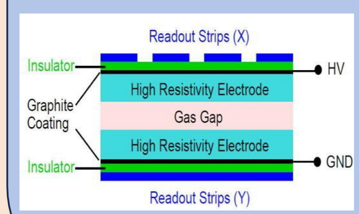
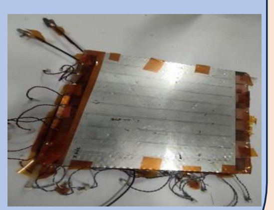
ABSTRACT

Resistive Plate Chambers (RPCs) are widely employed in high-energy physics experiments due to their excellent timing and efficiency capabilities. However, the conventional freon-based gas mixtures employed in RPCs contribute significantly to greenhouse gas emissions due to their high Global Warming Potential (GWP). This study examines the performance of a single-gap glass RPC detector (30 cm x 30 cm) with the standard gas mixture ($C_2H_2F_4$ 95%, i-C_4H_{10} 4.5%, SF_6 0.5%) and eco-friendly alternatives based on CO_2 and HFO gases. The detector was tested using cosmic muons, and its performance in terms of efficiency, time resolution, and charge distribution has been evaluated under these gas configurations. The results provide valuable insight into the feasibility of adapting environmentally sustainable gas mixtures without compromising the operational performance of RPC detectors. This study contributes to a larger effort to operate gaseous detectors in particle physics experiments in an environmentally responsible manner.

INTRODUCTION

- Resistive Plate Chambers (RPCs) are widely used for charged particle detection in high-energy physics experiments.
- They provide large-area coverage with excellent timing performance and high detection efficiency at relatively low cost.
- RPCs employ a parallel-plate geometry with a gas gap between resistive electrodes.
- Stable and efficient RPC operation conventionally relies on freon-based gas mixtures.





RESEARCH MOTIVATION

- Conventional RPC operation relies on freon-based gas mixtures (e.g. $C_2H_2F_4$, GWP ≈ 1430), raising serious environmental concerns.
- Large-scale and long-term use of RPC detectors leads to significant greenhouse gas emissions.
- Eco-friendly alternatives such as CO_2 (GWP = 1) and HFO gases (GWP ≈ 4) offer a strong motivation to develop low-GWP RPC gas mixtures without compromising detector performance.

OBJECTIVE

- To study the performance of a single-gap glass RPC detector using standard and eco-friendly gas mixtures.
- To investigate the feasibility of CO_2- and HFO-based gas mixtures as low-GWP alternatives.
- To compare detector performance in terms of efficiency, time resolution, and leakage current under different gas compositions.

Measurement Methodology

Gas Preparation:

•Standard RPC gas mixture and modified mixture with **10% HFO** were prepared using calibrated MFCs.
•Gas composition was verified using **Gas Chromatography (GC)**.

Trigger & Readout:

•Cosmic muons were selected using plastic and finger scintillators.

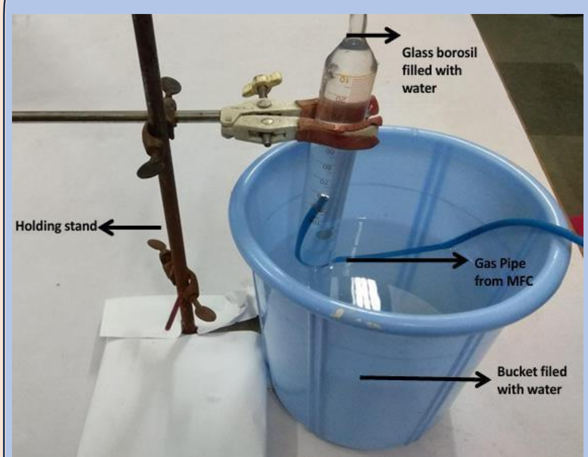
Efficiency Measurement:

•Event counts for different coincidence conditions were recorded using a **VME scaler**.
•Detector efficiency was calculated as the ratio of 4-fold to 3-fold coincidence counts.

Timing Measurement:

- Scintillator trigger was used as START and RPC signal as STOP.
- Time difference was recorded using a TDC.
- Timing resolution was extracted from Gaussian fits to the time spectra.

Gas Flow Calibration



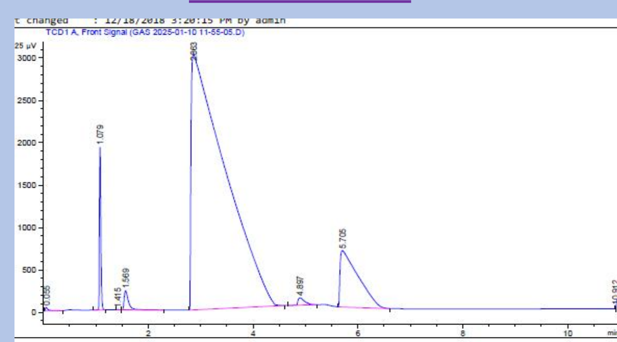
Experimental set-up of the water displacement method employed for the calibration of different gases and MFCs.

Three gas mixtures were calibrated and studied:

- Standard RPC gas mixture: ($C_2H_2F_4$ 95%, i-C_4H_{10} 4.5%, SF_6 0.5%)
- Standard gas mixture with HFO addition: ($C_2H_2F_4$85%, i-C_4H_{10}4.5%, SF_6 0.5%, HFO10%)
- Standard gas mixture with CO_2 addition:
- (CO_2 10%, i-C_4H_{10} 4.5%, SF_6 0.5%, $C_2H_2F_4$ 85%)
- The prepared gas mixtures were independently verified using **Gas Chromatography (GC)**.

Agilent 7890B GC system used for the study. The gas chromatograph separates and quantifies gas mixture components with sensitivity in ~ ppm.

Validation

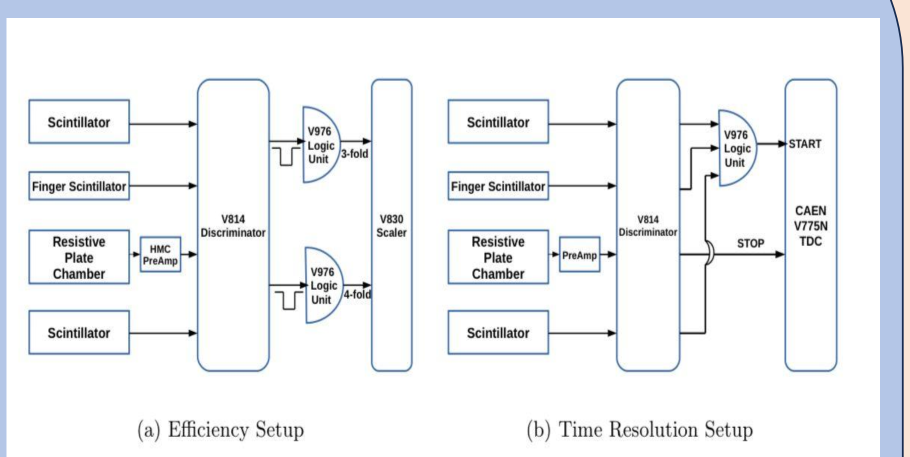


Signal 1: TCD1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [25 µV*s]	Height [25 µV]	Area %
1	0.055	BB	0.0546	158.28564	41.37396	0.10027
2	1.079	BB	0.0282	3493.90186	1925.67078	2.21323
3	1.415	BB	0.0252	5.26219	3.19120	0.00333
4	1.569	BB	0.0836	1272.44897	226.17003	0.80604
5	2.863	BB	0.5478	1.36131e5	3015.05347	86.23279
6	4.897	BB	0.1277	755.03339	87.50880	0.47828
7	5.705	BB	0.3023	1.60273e4	666.98169	10.15259
8	10.912	BB	0.0121	21.27371	30.63018	0.01348

GC spectra confirm the expected gas components, with **additional peaks observed for the HFO-added mixture**, validating the presence of HFO in the gas composition.

EXPERIMENTAL SETUP



•Detector efficiency was determined using a **cosmic muon telescope** with scintillator-based triggering.

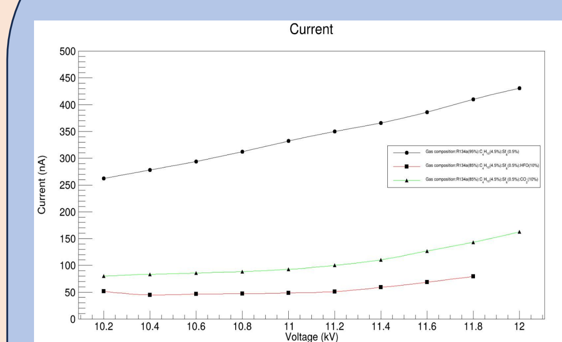
•A **3-fold coincidence** among scintillators was used to define the reference trigger.

•A **4-fold coincidence**, including the RPC signal, was used to measure detector response for efficiency calculation.

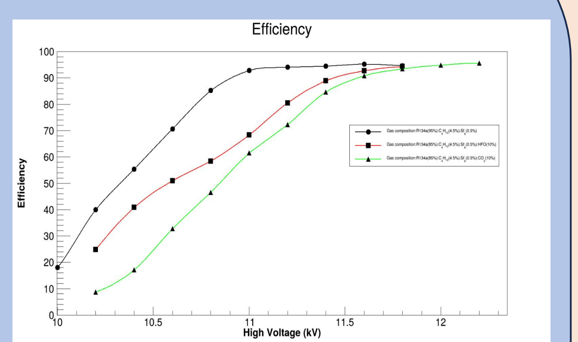
•Timing resolution was measured by recording the **time difference** between the scintillator trigger (START) and the RPC signal (STOP).

•The time difference distribution was used to extract the **timing resolution** of the RPC detector.

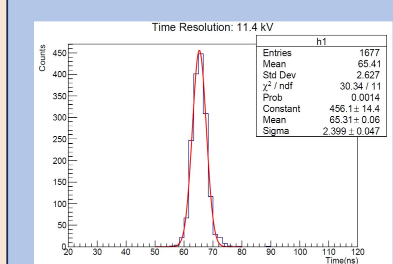
Detector Performance Results



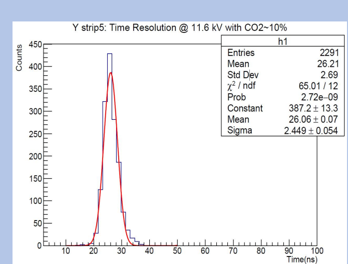
I–V behaviour of the RPC detector operated with standard and eco-friendly gas mixtures.



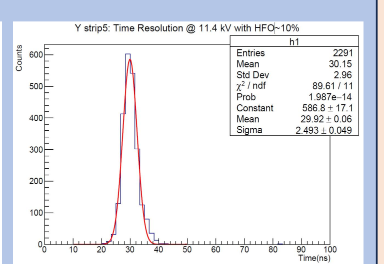
Detection Efficiency as a Function of High Voltage for Different Gas Compositions



TDC Spectrum at 11.4 kV (Standard Gas Mixture)



TDC Spectrum at 11.6 kV (CO_2-based Gas Mixture)



TDC Spectrum at 11.6 kV (HFO-based Gas Mixture)

DISCUSSIONS & CONCLUSIONS

- **Current–Voltage Characteristics**
  - Stable I–V behaviour is observed for all gas compositions.
  - Similar current trends with less leakage current indicate electrically stable RPC operation with eco-gas mixtures.

Detection Efficiency

- All gas compositions show a clear efficiency plateau.
- Comparable maximum efficiencies are achieved for standard and HFO-added mixtures.
- A small shift in operating voltage is observed for eco-friendly gas mixtures.
- Efficiency performance remains stable with HFO addition.

Timing Resolution

- Time difference spectra exhibit well-defined Gaussian distributions.
- Extracted timing resolutions are:

σ = (2.40 ± 0.05) ns for standard gas
σ = (2.45 ± 0.05) ns for CO_2-based gas
σ = (2.49 ± 0.05) ns for 10% HFO-added gas

CONCLUSIONS

- Stable RPC operation is achieved with eco-friendly gas mixtures, including 10% HFO.
- I–V characteristics confirm reliable detector behaviour for all tested compositions.
- High detection efficiency with a clear plateau is maintained with HFO addition.
- Timing resolution shows only a small dependence on gas composition.
- Low-GWP gas mixtures are promising alternatives for environmentally sustainable RPC operation.

FUTURE WORK

•Extension of the study to **timing resolution and charge distribution measurements** using eco-friendly gas mixtures.
•Systematic investigation of RPC performance with **increased HFO fractions** in the gas composition.
•Long-term **stability and ageing studies** under sustained operation with low-GWP gas mixtures.
•Optimization of operating parameters for **environmentally sustainable RPC operation**.

References

1. Search for environment friendly CO_2 gas mixtures for the glass-based RPC detectors, Nucl. Instrum. Methods A, 2024.
2. Refrigerant properties and GWP comparison of R134a and HFO-based gases, ResearchGate, 2018.

ACKNOWLEDGEMENT

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