Operation of Resistive Plate Chamber Detectors with a New Environmentally Friendly Freon

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Abstract

RPC particle gas detectors at CERN provide a vital element to the physics experiments carried out on the LHC. While their current operation and working gas mixtures are successful, environmental and economic factors force a revision of the mixture, specifically the eventual replacement of the current Freon gas R134-a with a newer, less environmentally harmful formulation, namely R1234-yf. The methods and results presented here outline the detector response to the introduction of the new Freon and its behavior under various mixtures. The electronegativity and hence impact on RPC parameters was investigated. It was found that the new Freon gas is indeed electronegative, and suppresses the RPC signal. The mixture was modified to include Argon to increase ionization, and the final results of the operation of the RPC were satisfactory. Further work to refine the mixture for future implementation is necessary.

I. BACKGROUND

A Resistive Plate Chamber (RPC) detector is a particle detector utilizing a constant and uniform electric field produced between two parallel electrode plates, consisting of a material with high bulk resistivity (typically bakelite, a high pressure laminate), in order to localize the charge multiplication inside the detector [1]. The gap between the two electrodes is typically 2mm, constructed of polycarbonate spacers to ensure uniform thickness of the gap. A gas mixture is placed in the gap; typical gases used are Ar, CO_2, R134-a, iC_4H_{10}, and SF_6. When the gas is ionized by a charged particle crossing the chamber, free charge carriers that are deposited in the gas gap trigger avalanches of electrons in the externally applied electric field and originate a signal. The high resistivity of the electrodes confine the drop in the electric field to a limited area where the discharge occurs. A semiconductive layer deposited on the electrodes is transparent to the electric signal produced inside the chamber, and the induced signal is detected by electrically isolated conductive pick up strips allowing a readout.

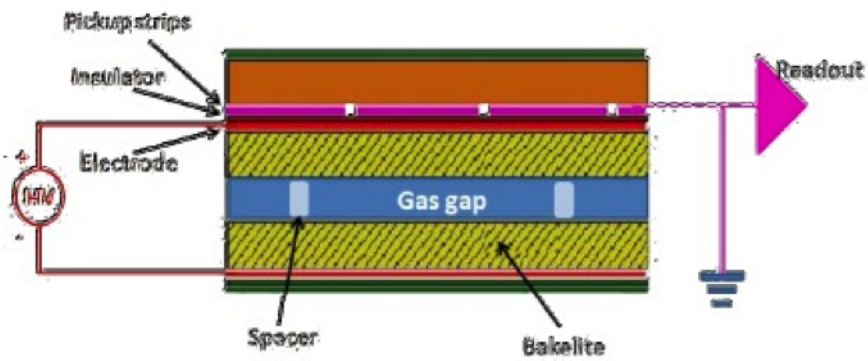

FIG. 1: Schematic view of RPC detector [5]

The physical process of any gas detector is ionization; a charged particle passing through a gas volume produces electron-ion pairs, and with the application a high electric field the primary electrons produce further ionisations [1]. The resulting distribution of free charge in the gas has the characteristic shape of an avalanche. Secondary avalanches can develop due to photons produced in recombination processes during avalanche development. When several of these secondary avalanches are produced, large amounts of free charges in the gas results in the streamer regime [2]. Both the avalanche and streamer regime have the same physical origin and typically both are present. In order to achieve the required rate capability for operation at the LHC, it is desirable to work in the avalanche regime, and suppress the larger, more damaging streamer signals.

The current gas mixture for the RPC operation consists of 94.7% $C_2H_2F_4$ (Freon, also known as R134a)/ 5% iC_4H_{10} (isobutane) / 0.3% SF_6 [3]. Isobutane, being an organic gas, limits the formation of secondary avalanches far from the primary ones by acting as a quencher, absorbing the photons produced from recombination processes. The SF_6 is an electronegative gas, capturing free electrons so limiting the free charges in the gas volume, and so suppressing the onset of streamers.

The Freon constituent of the current gas mixture, Tetraflouroethane CH_2FCF_3, known as R134-a has a high 100 year GWP (global warming potential) rating of 1430. A new type of Freon, Tetraflouopropene $C_3H_2F_4$, known as R1234-yf is a proposed replacement to R134-a, with an extremely low 100 year GWP rating of 4, only four times higher than that of carbon dioxide [4]. This new Freon, while currently expensive, in now being produced in increasing quantities. It is desirable to move to this new Freon not only for environmental reasons, but also for economical reasons as the cost reduces in the near future. An eventual shift to this new Freon is therefore necessary, and the correct gas mixture for optimum RPC operation is required to enable this change.

II. EXPERIMENTAL SET UP

To explore the effect of introducing the new Freon into the RPC gas mixture, two standard HPL RPCs were used, labeled RPC0 and RPC1 both with a gas gap of 2 mm and surface area 80 x 100 cm^2. One readout section was used per RPC, each with 7 readout strips. The RPC detection of cosmic muons was triggered by a scintillator system, outlined in FIG.2.

Two scintillators SC0 and SC1, are used to trigger the signal acquisition as the cosmic muon intersects the scintillators and RPCs. SC0 was placed above the RPCs and SC1 below. The data acquisition was performed using two CAEN module V1720 digitizers connected via a V1718 VME Bridge, allowing the full range of channels for both RPCs. Channel 0 for each digitizer was dedicated to the trigger enabled by the coincidence of the scintillator output, while channels 1-7 for each digitizer formed the input for the 7 strips for each RPC respectively. The stored RPC signal in the digitizer is in the form of ADC units as a function

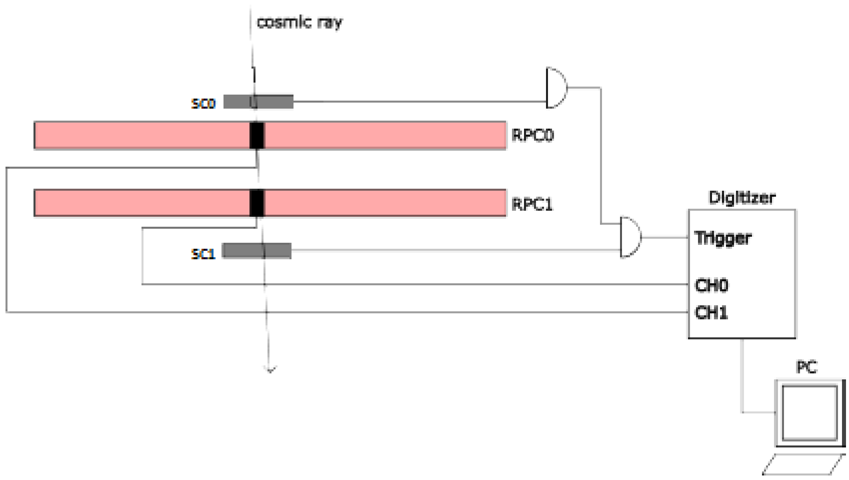

FIG. 2: Schematic of RPC trigger system (Adapted from [3])

of time, each acquisition being 4096 time units corresponding to 10 μs, with a 12 bit ADC resolution and $\pm$1.25 Volt range. A calibration of the voltage scale in this case resulted in 1 ADC unit corresponding to 0.5 mV. Following the trigger signal, the data were recorded on the PC via a CAEN WaveDump, run separately for each RPC.

To perform data analysis, a baseline calculation removing fluctuations of the acquired signal is performed to neglect any overshoot of the signal, and the data is cut at -2.5 mV to discriminate the signal from background noise.

III. RESULTS AND DISCUSSION

Several mixtures were tested and comparisons made between the performance of mixtures with the old and new Freon types. Measurements for each gas mixture were taken for different high voltages. To analyse the RPC signal, several histograms were plotted for each run; pulse height, pulse integrated charge, event time, cluster size (amount of strips firing for each signal) and a baseline width (providing information regarding the baseline calculation). From this information, the efficiency of the RPC, avalanche and streamer signal frequency, and average pulse charge can be extracted. Initially, a mixture consisting of approximately 95% R134a, 5% iC_4H_{10} and varying small introductions of R1234yf was tested, and compared to older data from the same RPCs consisting of approximately 95% R134a, 5% iC_4H_{10} and varying amounts of SF_6. This comparison allows a deduction of the electronegativity of the new Freon, using that of SF_6 as a reference. The results were found to be comparable; the new data is illustrated in terms of RPC efficiency in FIG.3. For further detail regarding the old data (not included here for brevity) please refer to [3].

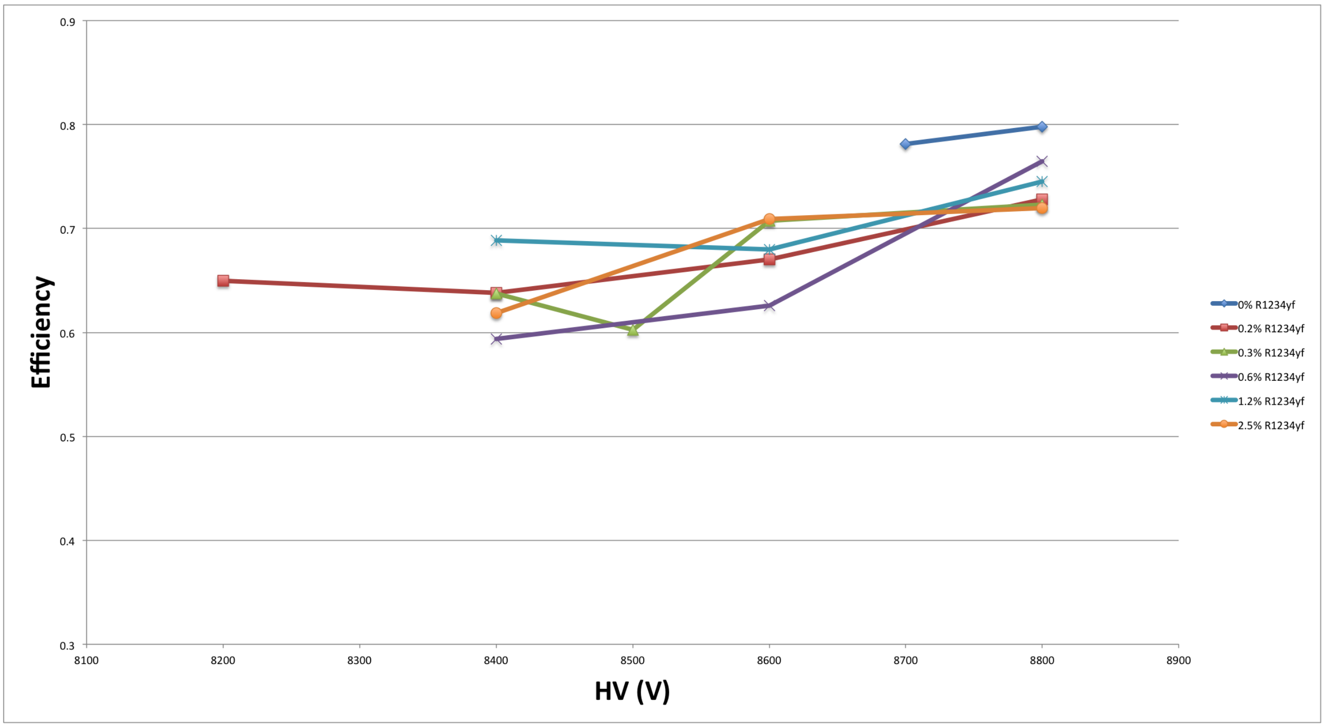

FIG. 3: Efficiency at different high voltages for varying small percentages of R1234-yf addition to mixture based on 95% R134a and 5% iC_4H_{10} (Note: this data at -2 mV cut)

A further comparison was then performed, between the same old SF_6 data at 0% SF_6(hence only R134-a and iC_4H_{10}), and a new mixture consisting of approximately 95% R134-a and 5% R1234-yf. This gives a direct comparison of the potential quenching action of the new freon, in place of isobutane. With few data points for the original data at 0% SF6, this comparison was less conclusive, although indicates no unexpectedly large changes between the two as seen in FIG.4 again in terms of RPC1 efficiency.

Once the potential electronegativity and quenching behaviour of the new freon had been established, the next change was to replace the old freon completely with the new R1234-yf. The new mixture contained approximately 95% R1234-yf and 5% R134-a. The signal was found to be suppressed and it was not possible to operate the detector the necessary efficiency; it was decided to add Argon and a small amount of isobutane to the mixture to trigger avalanches and increase ionisation. The resulting final mixture of R1234-yf, Ar

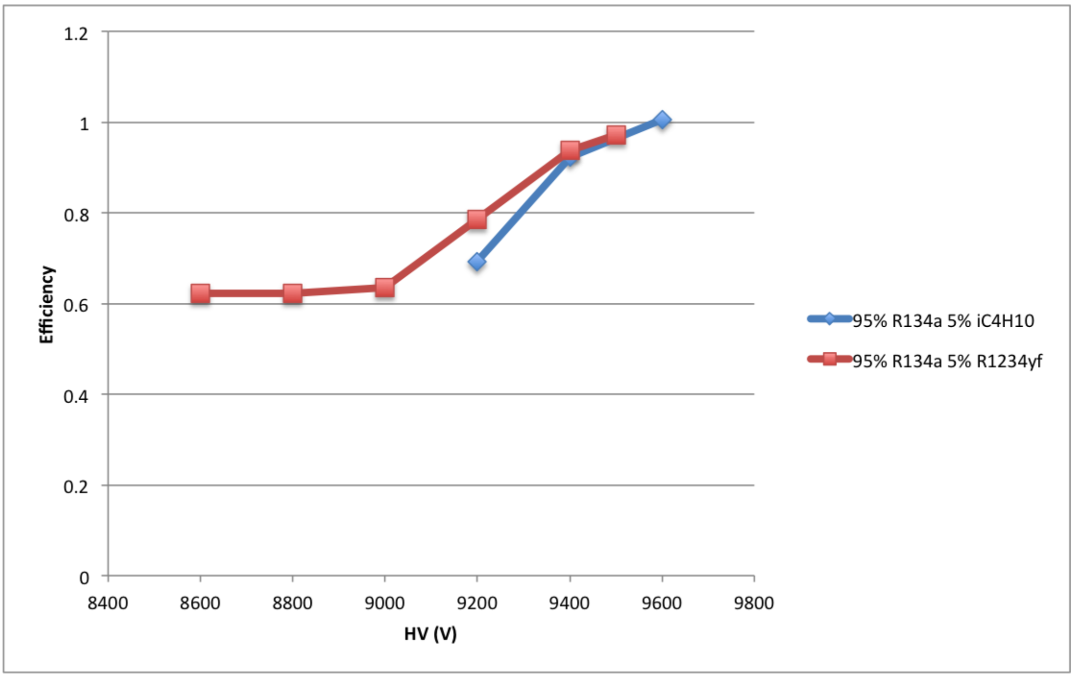

FIG. 4: Comparison of efficiency at different high voltages between two mixtures based on 95% R134a containing 5% iC_4H_{10} and 5% new freon R1234-yf respectively

and iC_4H_{10} was varied between approximately 47.5% R1234-yf 5% iC_4H_{10} 47.5% Argon, reducing to 2/3 the Argon component and then to 1/3 proportionally. The results of this mixture are shown below.

IV. CONCLUSION

The RPC response to the new freon is encouraging; the R1234-yf/Argon mixture produces satisfactory results in terms of detector efficiency with higher percentages of Argon, and other results such as average charge and pulse height, while not included here for brevity, show the RPC to be operating successfully. Further work to investigate the new freon in more detail is necessary, and eventual refinement of the mixture for implementation will take place. This initial data gives some indication of the behaviour of the RPCs with the replacement freon gas, and is hence useful in allowing the investigation to move forward.

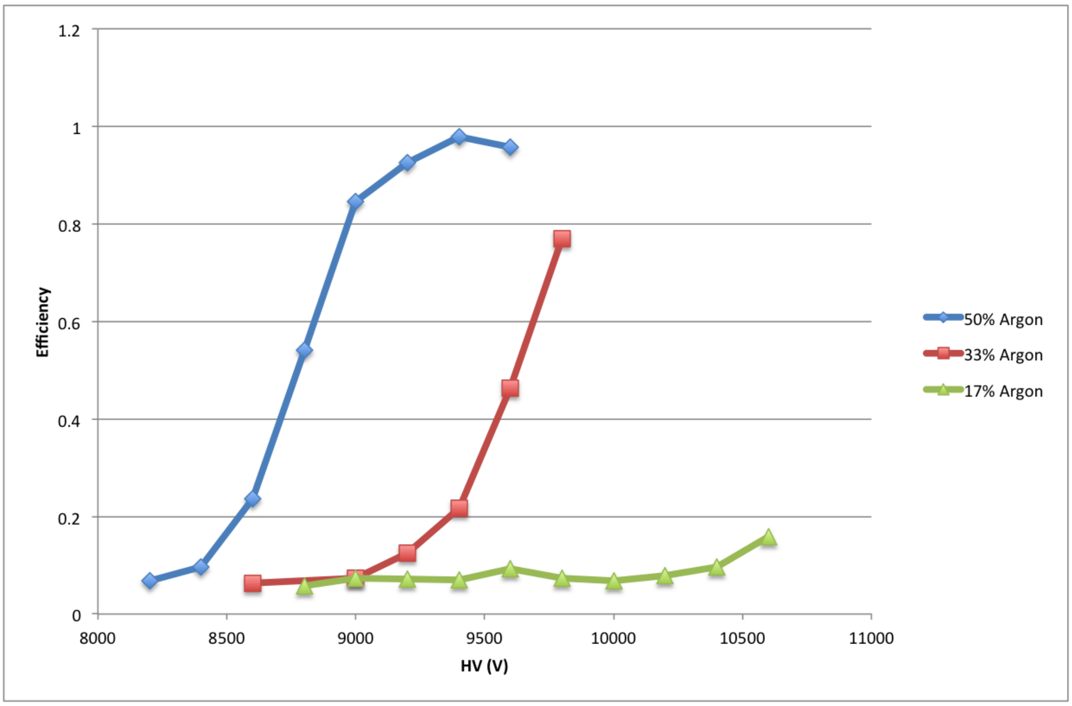

FIG. 5: RPC1 efficiency for R1234-yf with different percentages of Argon

Acknowledgments

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[1] "Techniques for Nuclear and Particle Physics Experiments" WR Leo; 2nd ed. Springer 1994

[2] "Design and Characterisation Studies of Resistive Plate Chambers" S. Bheesette, Thesis 2009

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[4] http://www.linde-gas.com

[5] https://cdsweb.cern.ch/record/1444615