Simulation of Resistive Plate Chamber RPC Detector Using Garfield++

Thiago de Andrade Rangel Monteiro[1], Eliza Melo da Costa[1], Gilvan Augusto Alves[2] , Callum Lima Rodgers[2] Victor Ferreti[3]

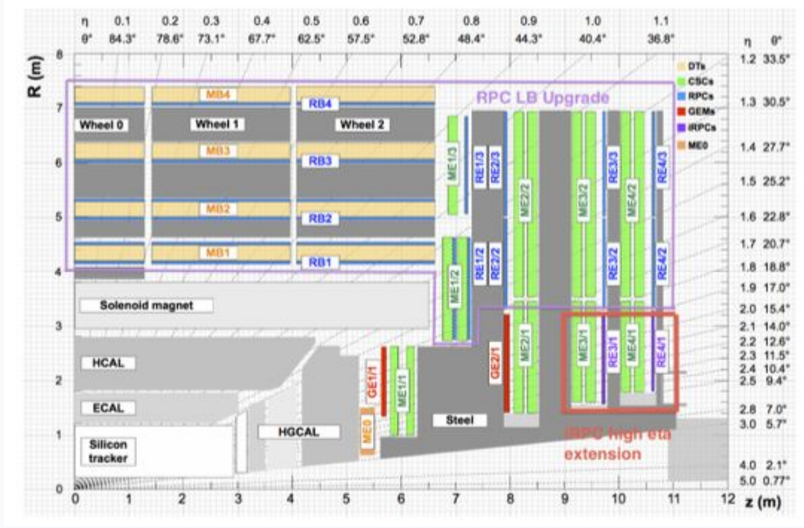
[1]Universidade do Estado do Rio de Janeiro (UERJ), [2]Centro Brasileiro de Pesquisas Físicas (CBPF), [3]Universidade Federal Fluminense (UFF)

Abstract

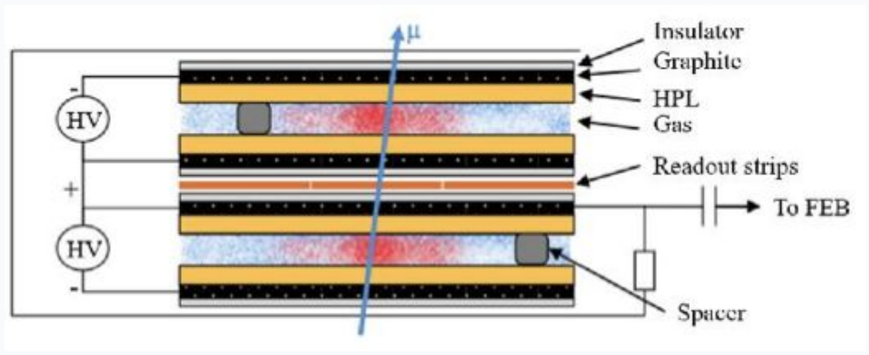
In this work, we investigate the performance of Resistive Plate Chambers (RPC) using Garfield++. RPCs detectors are commonly operated with a freon-based gas mixture containing $C_2H_2F_4$ and SF_6, both with a very high global warming potential. The present work aims at contributing to the search for alternative gas mixtures for RPCs detectors. Based on the studies presented by [1], some alternatives to $C_2H_2F_4$ are tested in simulations, such as CO_2. The RPC performance is evaluated by calculating the efficiency of the detector.

Abstract

In view of the High-Luminosity LHC (HL-LHC) and the new European regulations on greenhouse gas emissions, the development of the iRPC (improved Resistive Plate Chamber)[2] addresses both extreme collision rates and critical environmental constraints.



The RPC operates by ionizing a specialized gas mixture between two parallel high-resistivity plates subjected to an intense electric field (~50 kV/cm), where a passing charged particle liberates electrons that rapidly accelerate into an exponential Townsend avalanche; this charge cloud induces a fast electrical pulse on external readout strips, while the high bulk resistivity of the plates immediately drops the local electric field at the discharge point.

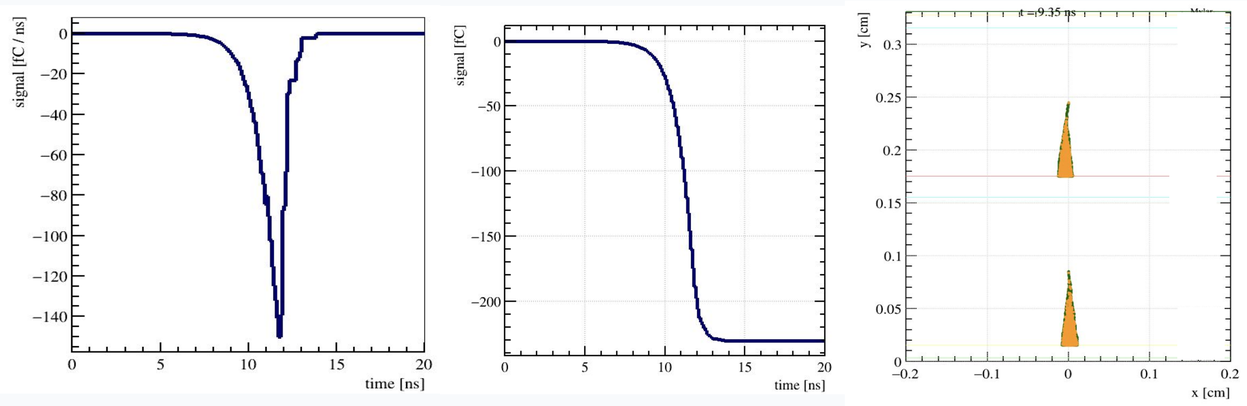


Detector Simulation

The standard gas mixture used in the detector has some functions and operating in avalanche mode: R-134a acts as the primary ionizing medium with high dielectric strength to generate the primary electron-ion pairs; isobutane serves as a photon quencher to prevent secondary avalanches and SF_6 provide strong electron capture due to its high electronegativity prevents destructive transitions into sparks or streamers; and a controlled fraction of water vapor (~40–50% relative humidity) stabilizes the internal resistivity of the bakelite plates, protecting them from drying out and generating spurious dark currents.

Gas components (%)	$C_2H_2F_4$	CO_2	i-C_4H_{10}	SF_6	GWP*$_{MIX}$
GWP	1430	1	3	22800	
Density (g/L)	4.7	1.98	2.7	6.61	
STD	95.2	0	4.5	0.3	1486
30% CO_2 + 1.0 % SF_6	64	30	5	1	1529
30% CO_2 + 0.5 % SF_6	64.5	30	5	0.5	1337
40% CO_2 + 1.0 % SF_6	54.5	40	5	1	1353

Adding CO_2 reduces the mixtures Global Warming Potential (GWP) and operating voltage, though excessive amounts lower dielectric strength and increase streamer probability. To systematically optimize these alternative mixtures we will use Garfield++ (coupled with Magboltz)[3,4] to simulate electron transport parameters, such as drift velocity, Townsend ionization, and attachment coefficients predicting detector efficiency.



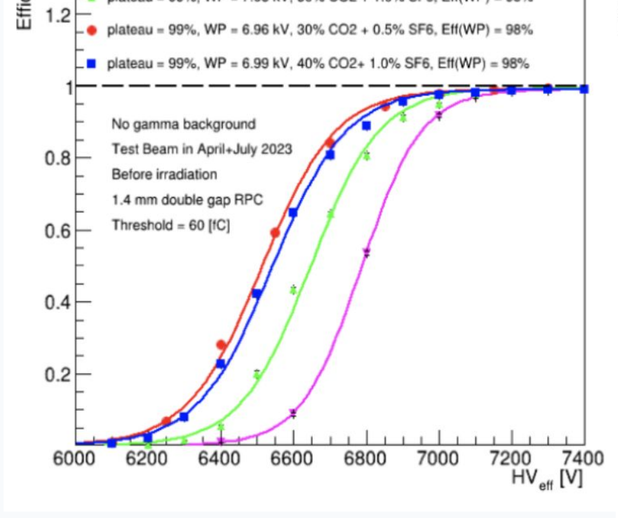
Preliminary Results

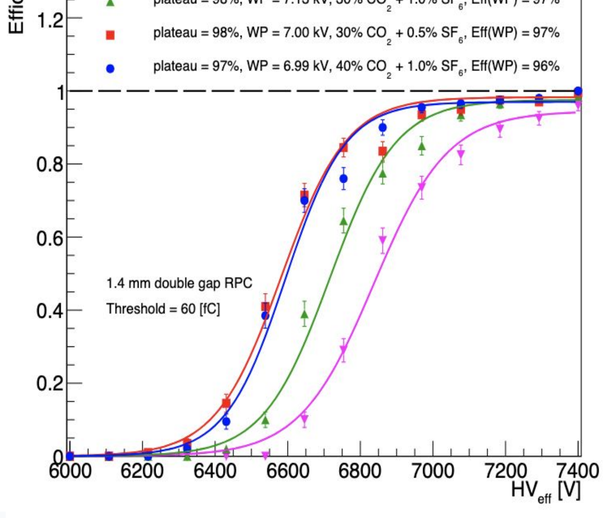
To evaluate the performance of the gas mixtures, tests were conducted both before and after irradiation. Before exposure, the primary figure of merit is the detection efficiency (ε), defined as the fraction of detected events relative to the expected total. The efficiency as a function of the effective high voltage follows a sigmoidal curve, parameterized as:

$$\epsilon = \frac{\epsilon_{\max}}{1 + e^{-\lambda(\mathrm{HV_{eff}} - \mathrm{HV_{50\%}})}}$$

where ε_{max} denotes the maximum efficiency plateau, λ governs the slope of the transition region, and HV50% is the voltage at which the efficiency reaches half of its maximum value. The operational working point (WP) is a critical parameter, standardly defined as the voltage required to achieve 95% of the maximum efficiency plus a safety margin of 150 V. It is determined by:

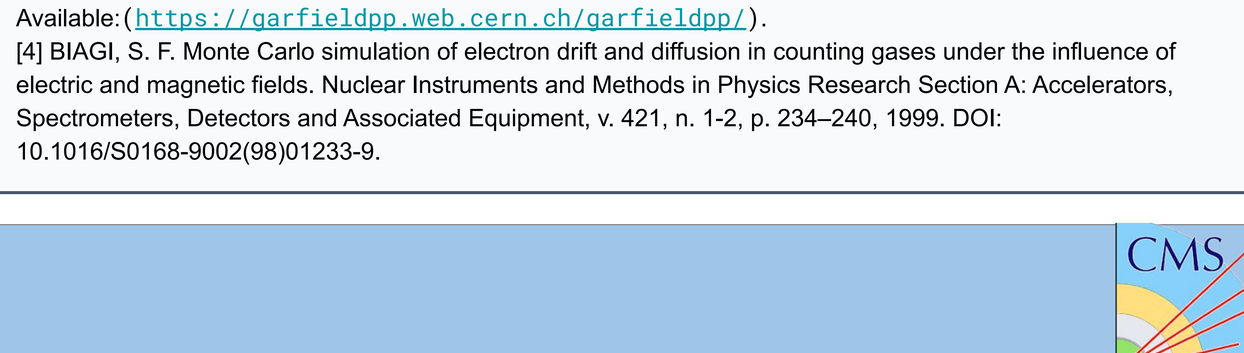
$$\mathrm{WP} = \mathrm{HV_{95\%}} + 150\,\mathrm{V} = \frac{\log 19}{\lambda} + \mathrm{HV_{50\%}} + 150\,\mathrm{V}$$





Next Steps

As a next step, finite element simulations using **Elmer FEM** will be implemented to compute the realistic electric field configuration. This approach will account for edge effects, field distortions around the spacers and frame boundaries, and the impact of the finite resistivity of the coating, allowing for a more accurate modeling of avalanche dynamics and signal induction in Garfield++.



References

[1] T. De Andrade Rangel Monteiro. Performance of CO2 based mixture in CMS Improved Resistive Plate Chambers in HL-LHC, Dec. 2024.

[2] A. Samalan, M. Tytgat, G. Alves, F. Marujo, F. Araujo, E. Da Costa, D. de Jesus Damiao, H. Nogima, A. Santoro, S. Fonseca de Souza, A. Alexandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, M. Shopova, G. Soultanov, M. Bonchev, A. Dimitrov, L. Litov, and I. Crotty. Upgrade of the cms resistive plate chambers for the high luminosity lhc, 09 2021.

[3] H. Schindler, "Garfield++ — simulation of tracking detectors," CERN, Geneva. [Online]. Available: (https://garfieldpp.web.cern.ch/garfieldpp/).

[4] BIAGI, S. F. Monte Carlo simulation of electron drift and diffusion in counting gases under the influence of electric and magnetic fields. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, v. 421, n. 1-2, p. 234–240, 1999. DOI: 10.1016/S0168-9002(98)01233-9.