Simulation study on gamma-ray sensitivity of low-resistivity phosphate glass electrode RPC using GEANT4 MC

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Abstract

The phosphate glass used as electrode in the configuration of resistive plate *chamber* (RPC) and it improves the rate characteristics of the detec tor. In the present study, we describe the performance of such type of RPC. For the detector a simulation test is performed with a Monte Carlo si mulator based on GEANT4. Gamma rays in the energy range 0.1 MeV to 1.0 GeV were inserted on the detector surface and their simulation respo nse is reported. The sensitivity results both for single and double-gap phosphate glass RPC's are summarized. As an example, the obtained simul ation results are applied to CMS barrel regions. Also in those regions total sensitivities and hit rates for those regions are evaluated. The simulat ed results are compared with the available bakelite-RPC results, which were found consistent with our studies.

1. Introduction

Resistive Plate Chambers (RPC's) are widely used in many High Energy Physics experiments [1]. They have also been chosen for the muon trigger for both (Large Hadron collider) LHC detectors, i.e CMS (Compact Muon Solenoid) [2] and a Toroidal at LHC Apparatus (ATLAS)[3].

•Resistive plate chambers have a lot of advantages, such as simple design, absence of wire technology, low cost, good time resolution and high gas gain.

•However the designs used for an RPC in those experiments have a rather low rate capability (10^4 Hz/cm^2 in avalanche mode), and poor spatial resolution (several cm). These detectors operate with an efficiency close to 100% only in a few selective gas mixtures [4].

•The main objective of this study is to improve the main characteristics of glass RPC rate capabilities, to find new materials and new approaches for building glass-RPC setups.

•Simulation tests performed in our laboratory, on the phosphate-glass RPC have shown that such type of RPC detector works for neutrons and e+/e- well with a good efficiency [5]. The use of low resistive glasses with bulk resistivities, 10^8–10^{11} Ωcm [6] could be a good choice, as it has lower resistivty and can be used in high rate environment.

•Our latest results will be presented in this article, which were taken for gamma rays simulation for the phosphate- glass RPC in the energy range from 0.1 MeV to 1.0 GeV.

•Gamma rays were transported by GEANT4 Monte Carlo code, and the sensitivity was estimated. The present simulation results were compared with the conventional glass-built RPC results which were reported elsewhere [7, 8].

2. Low-resistive electrode RPC

In order to check the detector response for phosphate-glass RPC, for the γ-rays in the energy range 0.1 MeV- 1.0 GeV, we developed a new gamma ray simulation code in GEANT4 [9, 10] simulation package.

Our set up consists of phosphate glass-RPC chamber of area 20x20 cm^2. The design configuration of the RPC is presented schematically in Fig.1, which is utilized in this work.

The detector is a parallel plate chamber, with the anode made of phosphate glass (with resistivity 10^8–10^{11} Ωcm) and the cathode made from copper .

The gas gap between the two electrodes was taken as 2 mm. Phosphate-glass, 2 mm thick, was covered by insulator strips, 1mm at the upper and lower ends of the double-gap RPC geometry. For detecting signals in the two gas gaps, copper strips were utilized. Similar configuration with only one gas gap set-up was used for single gap RPC. For the present RPC configuration a usual gas mixture of (3%i C_4H_{10}+ 97% $C_2H_2F_4$) was used in both RPC configurations [11].

Monte Carlo simulations are a well-proven technique to verify the performance of a detection system. For the current simulation studies, the geometry and tracking code, GEANT 4 [9, 10] was utilized. This open source package has proven to produce quite accurate results over a large energy ranges with all common nuclear reactions and particles included in it.

Two different kinds of gamma sources were chosen for this simulation study:
(i) An isotropic source of gamma, evenly distributed on the phosphate glass-RPC detector surface, and (ii) A parallel source of gamma's, perpendicularly impinging on the RPC's surface. For each source configuration, the sensitivity was evaluated at 15 different energies: 0.1, 0.2, 0.4, 0.662, 1, 2, 5, 10, 25, 50, 100, 250, 500, 700, and 1000 MeV.

3. Simulation results for single-gap phosphate glass RPC

During the first simulation test, gamma rays were transported by both GEANT4 standard [9, 10] and low [12, 13, 14] packages onto the single-gap phosphate glass PRC.

Charged particles produces were counted, which were generated as a results for low resistive glass-RPC of gamma's insertion on detector's surface.

These particles were produced by different physical processes, like photoelectric effect, Compton affect and pair production, depending on the gamma's energy [15, 16].

The charged particles were detetected by the strips made of copper and counted by the MC code. According to the simulation results found, it was observed that the low-resistive single gap glass RPC works efficiently in detection of the charged particle that were generated due to gamma rays passage through the gas gaps of the chamber.

Sensitivity results are shown in the Table 1.

These results predict that as the density of phosphate glass is higher than the bakelite RPCs, a significant improvement of charged particle production is observed.

As a result such types of RPC have higher response for the inserted gamma rays. A close look to the results reveals that gamma energy till ~ 2 MeV, the sensitivity values increase slowly, but suddenly at E_γ=5 MeV, the sensitivity rises quickly and later it increase smoothly.

Obviously the results prove that as there is only single gap in front of gamma rays, so the sensitivity is half of the double-gap RPC response.

Using GEANT4 standard packages, the single gap sensitivity for an isotropic gamma rayis $s_\gamma = 6.1\times10^{-3}$ at E_γ =2 MeV, which suddenly jumps to $s_\gamma = 2.226\times10^{-2}$ at E_γ =5 MeV, and smoothes down at further increase of energy which reaches to $s_\gamma = 2.2295 \times10^{-2}$ at E_γ =100 MeV.

Similarly with GEANT4 low packages, the response is $s_\gamma = 7.87\times10^{-3}$ at E_γ =2 MeV and $s_\gamma = 2.142\times10^{-2}$ at E_γ =5 MeV, and finally it is obtained as $s_\gamma = 2.145\times10^{-2}$ at E_γ =100 MeV.
Slightly lower sensitivity results for parallel gamma rays are also obtained that are presented in Table 1.

Particle Sources	Energy (MeV)	Conventional-glass RPC double-gap (sensitivity) GEANT4 Standard	Conventional-glass RPC double-gap (sensitivity) GEANT4 Low	Phosphate-glass RPC double-gap (sensitivity) GEANT4 Standard	Phosphate-glass RPC double-gap (sensitivity) GEANT4 Low
γ (Isotropic)	0.1	0.000591	0.000608	0.00065	0.00060
	0.2	0.000755	0.000737	0.00083	0.00076
	0.4	0.001419	0.001511	0.00016	0.00123
	0.662	0.003048	0.003776	0.00315	0.00328
	1.0	0.005623	0.006514	0.00569	0.00654
	2.0	0.01.317	0.01639	0.01352	0.01622
	5.0	0.03802	0.04032	0.03808	0.04019
	10.0	0.06053	0.06003	0.05882	0.06066
	25.0	0.07033	0.06785	0.07297	0.06897
	50.0	0.07557	0.07238	0.07596	0.07515
	100.	0.08207	0.07775	0.08556	0.08130
	250.	0.09079	0.08419	0.0942	0.08809
	500.	0.09615	0.08884	0.09836	0.09313
	700.	0.09815	0.09027	0.10202	0.09273
	1000.	0.09949	0.09121	0.10402	0.09384
γ (Parallel)	0.1	0.0001276	0.000144	0.00013	0.00014
	0.2	0.000171	0.000176	0.00023	0.00017
	0.4	0.000408	0.000371	0.00039	0.00024
	0.662	0.00071	0.000841	0.00072	0.00086
	1.0	0.001336	0.001676	0.00149	0.00173
	2.0	0.003243	0.004089	0.00349	0.00402
	5.0	0.008691	0.01015	0.00947	0.01033
	10.0	0.01568	0.01537	0.01544	0.01593
	25.0	0.01833	0.01769	0.01907	0.01828
	50.0	0.01994	0.01888	0.01944	0.01988
	100.	0.02126	0.02021	0.02201	0.02036
	250.	0.02375	0.02203	0.02406	0.02348
	500.	0.02495	0.02313	0.02610	0.02395
	700.	0.02562	0.02387	0.02633	0.02428
	1000.	0.02624	0.02374	0.02687	0.02554

Table 1 . Phosphate-glass RPC γ –rays sensitivity results, simulated by GEANT4 MC codes.

Particle Sources	Energy (MeV)	Single gap RPC GEANT4 Standard	Single gap RPC GEANT4 Low	Double-gap RPC GEANT4 Standard	Double-gap RPC GEANT4 Low
Gamma (Isotropic)	0.1	0.00029	0.00036	0.00065	0.00060
	0.2	0.00043	0.00038	0.00083	0.00076
	0.4	0.00091	0.00087	0.00016	0.00123
	0.662	0.00152	0.00173	0.00315	0.00328
	1	0.00300	0.00286	0.00569	0.00654
	2	0.0061	0.00787	0.01352	0.01622
	5	0.01903	0.01922	0.03808	0.04019
	10	0.02226	0.02142	0.05882	0.06066
	25	0.02099	0.01965	0.07297	0.06897
	50	0.02106	0.02027	0.07596	0.07515
	100	0.02295	0.02145	0.08556	0.08130
	250	0.02529	0.02303	0.0942	0.08809
	500	0.02575	0.0249	0.09836	0.09313
	700	0.02666	0.02406	0.10202	0.09273
	1.0 GeV	0.02750	0.02601	0.10402	0.09384
Gamma (Parallel)	0.1	0.00005	0.00004	0.00013	0.00014
	0.2	0.00009	0.00004	0.00023	0.00017
	0.4	0.00021	0.00011	0.00039	0.00024
	0.662	0.00033	0.00029	0.00072	0.00086
	1	0.00067	0.0008	0.00149	0.00173
	2	0.00177	0.00194	0.00349	0.00402
	5	0.00456	0.00508	0.00947	0.01033
	10	0.01062	0.01053	0.01544	0.01593
	25	0.01822	0.01723	0.01907	0.01828
	50	0.02026	0.01977	0.01944	0.01988
	100	0.02208	0.02035	0.02201	0.02036
	250	0.02402	0.0230	0.02406	0.02348
	500	0.02504	0.02468	0.02610	0.02395
	700	0.02530	0.02513	0.02633	0.02428
	1.0 GeV	0.02570	0.02518	0.02687	0.02554

Table 2. A comparison of the gamma-rays sensitivity, taken for conventional-glass and phosphate-glass double-gap RPC.

Particle Source	RPC set-up	Energy (MeV)	Double-Gap RPC Sensitivity Results: Experiment (bakelite-RPCs) (x 10^{-2})	(Glass-RPC) GEANT 3.21 Isotropic (x 10^{-2})	(Glass-RPC) GEANT 3.21 Parallel (x 10^{-2})	(Phosphate-glass-RPC) GEANT 4 Standard (x 10^{-2})	(Phosphate-glass-RPC) GEANT 4 Low (x 10^{-2})
γ	Single gap	0.9	0.41±0.04	0.445	0.450	0.245	0.279
		1.4	0.69±0.05	0.793	0.787	0.474	0.5345
		1.5	0.80±0.05	0.870	0.837	0.488	0.602
γ	Double gap	0.9	0.72±0.05	0.851	0.877	0.478	0.591
		1.4	1.18±0.05	1.554	1.517	0.835	1.021
		1.5	1.40±0.05	1.704	1.638	0.894	1.216

Table 3. Summary of the experimental and simulated results.

Simulation codes: GEANT4	Simulation codes: Particle	Conventional glass RPC sensitivity MB1	Conventional glass RPC sensitivity MB4	Hit rates (Hz/cm^2) MB1	Hit rates (Hz/cm^2) MB4	Phosphate-glass RPC sensitivity MB1	Phosphate-glass RPC sensitivity MB4	Hit rates (Hz/cm^2) MB1	Hit rates (Hz/cm^2) MB4
Standard	γ- ray	0.0156	0.0078	0.46	1.40	0.11542	0.00786	0.57709	1.4942
Low	γ- ray	0.0184	0.00927	0.47	1.67	0.01120	0.00853	0.560	1.621

Table 4. The results obtained by simulations for the CMS/RPC barrel gamma sensitivity, and their expected hit rates for the low resistive-glass RPCs.

4. Simulation results for double-gap RPC

A second simulation test was performed to check the response of double-gap low resistive glass- RPC for gamma-rays, using the GEANT4 MC codes.
From the simulation, it was observed that as we inserted the two gas gaps geometry before these particles, then the sensitivity of the detector doubled the single-gap response.
This behavior is obvious, as the inserted particles have more thicker and bulky materials, the inserted γ-rays produce twice the charged particles in the two gas gaps caused by avalanche in those gaps. Gamma ray energy sensitivities for double-gap RPC detector with phosphate-glass electrodes are tabulated in Table 1(right hand side).

The present simulation findings are in agreement with the conventional-glass RPC sensitivity results (Ref. [7, 8, 17, 18]), which further validates that the phosphate glass plays a vital role in describing the RPC detector properties. Moreover a relatively higher response for such phosphate glass RPC is obtained. This could be due to the fact that the density of phosphate is higher than the conventional glass electrode.

The sensitivity is defined as the ratio of the count of the secondary electrons that reached the sensitive region of the detector to the count of the γ-rays that enter the RPC chamber. The cut-off energy is set to 1 μm, 1nm, 1μm; which is the energy range where the simulation stops detecting at γ -rays, electrons and positrons in the GEANT4 code. In this simulation work it was assumed that any electrons that reached the gas gap with energy higher than the cut-off energy range are detectable and produce a signal, which is detected and counted in the simulation. Fig. 2(b), shows the results of the simulation taken for isotropic and parallel incident γ-rays inserted on the surface of the phosphate-glass RPC.

A closer look to the obtained results shows that, the dominant interaction process contributing to the γ-rays sensitivity is due to Compton scattering, except that the photoelectric effect dominates in the low energy region below E_γ < 100 keV (see Fig. 2). Pair production becomes comparable to Compton scattering in the high-energy region around 10 MeV; and becomes more dominant at around 20 MeV. It must be noted that there is a small photoelectric effect present at high energies (E_γ > 1 MeV). This could be from the secondary electrons generated by the photoelectric effect when γ-rays after Compton scattering interacted in the glass electrode or gas of the RPC again. The sensitivity has a peak near E_γ = 10 MeV. We point out that there is a little interaction with the gas in the low-energy region and the phosphate-glass in the high-energy region.

The double-gap phosphate-glass RPC sensitivity to γ-rays is well below 9×10^{-2} at E_γ =100 MeV, for both the isotropic and parallel configurations. Using GEANT4 standard packages, the sensitivity for an isotropic gamma rays for low resistive glass-RPC is $s_\gamma = 1.35\times10^{-2}$ at E_γ =2 MeV, at further energy it reaches to $s_\gamma = 3.8\times10^{-2}$ at E_γ =5 MeV, and at E_γ =100 MeV it is $s_\gamma = 8.556\times10^{-2}$. In case of GEANT4 low packages, the response is $s_\gamma = 1.622\times10^{-2}$ at E_γ =2 MeV and $s_\gamma = 4.019\times10^{-2}$ at E_γ =5 MeV, and finally it is obtained as $s_\gamma = 8.130\times10^{-2}$ at E_γ =100 MeV. Similarly a lower sensitivity response is evaluated for parallel gamma rays which can be seen in Table 1. A comparison of the conventional –glass RPC response for γ-rays with phosphate-glass RPC is given in Table 2, which shows phosphate-glass RPC gives higher sensitivity results. Table 3 present a comparison of the bakelite, conventional and phosphate-glass RPC results for gamma rays. It is observed that at low energy photons, the sensitivity of such detector does not affect significantly.

As an example, we utilized the CMS photon spectrum [11] of Fig. 3 to evaluate the phosphate- glass RPC sensitivity with an isotropic source. An expected hit rate in MB1 and MB4 was 0.57 and 1.4 respectively, using GEANT4 standard packages. Similar hit rates were obtained using GEANT low packages shown in Table 4.

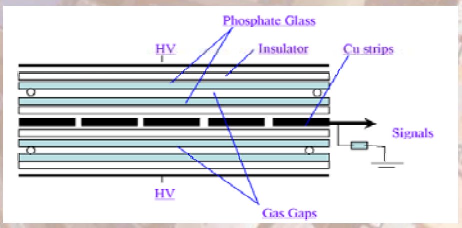

Fig. 1 Schematic drawing of an RPC with electrodes made of phosphate glass.

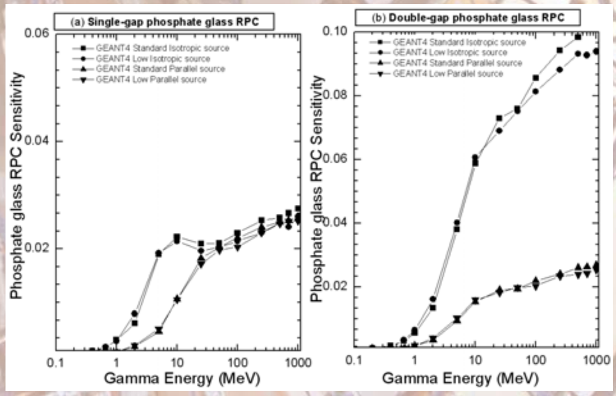

Fig. 2 Gamma rays sensitivity for phosphate glass RPC. (a)left side: Single gap phosphate glass RPC sensitivity for γ-rays (b) right side: Double gap phosphate glass RPC sensitivity for γ-rays.

5. Conclusion

Sensitivity of single- and double-gap phosphate glass RPCs for γ-rays in the energy range from 0.1 MeV to 1.0 GeV have been investigated using GEANT4 MC.

Due to the main advantage of phosphate glass electrode with low resistivity, the employment of such an RPC configuration is considerable compare to conventional RPC with Bakelite electrode.

In fact the low-resistive glass RPC has a good performance in such condition and also it has shown a possibility as a detector for the gamma ray source.

From the results of our current gamma rays simulation, the phosphate-glass RPC setup is proper in the region of high rate particles detection as like in the LHC experiment.