A simulation study of the e^+/e^- sensitivity of a low resistive phosphate glass electrode in a RPC using GEANT MC*

M. Jamil[1,2] J. T. Rhee[1;1)] Y. J. Jeon[2;2)]

[1] Institute for Advanced Physics, Department of Physics, Konkuk University, Seoul 143-701, Korea
[2] Liquid Crystal Research Center, Konkuk University, Seoul 143-701, Korea

Abstract The resistivity of conventional glass is quite high and is unacceptable in a high rate environment. Low resistive glass-electrodes could be a solution for this problem. The present study reports the e^+/e^- simulation results of an RPC detector made from low resistive phosphate glass electrodes. The detailed geometrical configuration of the content materials which are the essential components of the glass of the RPC detector have been created with the GEANT4 simulation code. Two different types of particle sources, i.e. for e^+/e^-, have been located on the detectors surface to evaluate the performance of the phosphate glass RPC. Both of the particles have been simulated as a function of their respective energies in the range of 0.1 MeV – 1.0 GeV. The present simulation work has shown that the resistive electrode plays an important role for the particle production in the RPC configuration.

Key words Monte Carlo simulation, resistive plate chamber, GEANT4 simulation

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1 Introduction

Resistive Plate Chambers (known as RPCs) were developed at the beginning of 1980's by the physics research group of the University of Rome [1]. These detectors have been widely used in high energy physics experiments both at accelerator and cosmic rays facilities. The main advantage of using this type of detector has been to serve as a low cost tracker to identify muons and provide a rough estimate of their momenta.

Many studies have shown that the glass electrode RPCs have many advantages [2] over bakelite RPCs such as: (i) high electrode planarity (float glass), (ii) good stability of the electrode resistivity (electronic conductivity), (iii) relatively inexpensive and commercially available, and (iv) successful application on a large scale (~2000 m^2) at the BELLE [3] collider experiment. As compared to bakelite, float glass turns out to be a competitive material for the RPC electrodes configuration. Glass- electrodes are relatively inexpensive, their bulk resistivity has a well known temperature behavior and are stable over a large integrated charge [4]. Moreover, due to its intrinsic qualities of homogeneity and planarity, a glass electrode does not need surface treatments like a bakelite electrode (i.e. linseed oil). On the other hand, the float glass has a relatively high bulk resistivity (10^{12}–10^{13} Ωcm) which can be a limitation for the streamer mode operation in high particle rate applications.

However, as the resistivity of conventional glass (10^{13} Ωcm) results in rate capability of the RPC as low as several hundred Hz/cm^2, it is unacceptable for high energy physics experimental environments. The usage of low-resistive glass with resistivity of 10^{10}–10^{11} Ωcm is an attractive way of improving the RPC rate capability [5]. In order to improve the RPC's electrode, we have inserted a promising material, i.e phosphate as a semiconductive glass, which has a relatively low bulk resistivity of 10^8–10^{11} Ωcm. In order

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* Supported by Konkuk University KU- Brain Pool Project in 2009
1) E-mail: jtrhee@konkuk.ac.kr
2) E-mail: yjjeon@konkuk.ac.kr
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to understand how the electrode resistivity and configuration can affect the efficiency of the double-gap low-resisitive phosphate glass RPC, we have tested the sensitivity to e^+/e^-'s in the energy range from 0.1 MeV to 1.0 GeV. These particles were simulated by means of the GEANT4 [6] Monte Carlo code. In this article, we have investigated some properties of glass electrodes for an RPC and the features of their behavior under e^+/e^- irradiation are discussed.

2 Low-resistive electrode RPC configuration set-up

We built a double-gap RPC detector with phosphate glass electrode with a thickness of 2 mm for our simulation test. This type of RPC detector configuration has been developed in C^{++} for the GEANT4 MC to simulate the response to e^+/e^- particles. The unique feature of this code is that all the individual components of the detector response function are specifically defined and produced in it. Fig. 1 shows a schematic image of the setup of the double-gap glass-RPCs with a size of 20 cm×20 cm used in this simulation study. For this simulation test, two types of e^+/e^- sources were chosen: (i) an isotropic source evenly distributed on the entering surface of the chamber, (ii) a e^+/e^- beam impinging normally on the chamber. For these source particles the sensitivity was evaluated at an energy range from 0.1 MeV to 1.0 GeV.

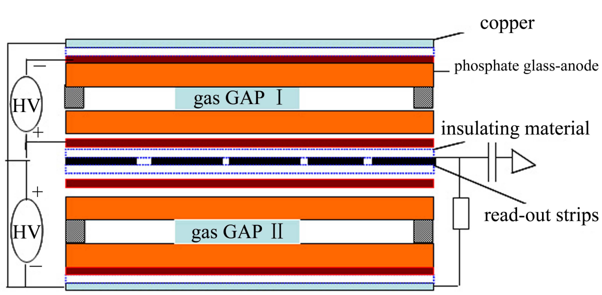

Fig. 1. Schematic view of the RPC with electrodes made from low resistive phosphate glass.

3 Detector response

The response of low-resistive phosphate glass RPC to e^+/e^- has been studied by means of the GEANT4 MC simulation code. All the material compositions of the current RPC detector were taken into account in order to observe the effects of the positron and electron interactions within the detector configuration. For the current simulation studies the RPC's gas gap was taken as the sensitive detector inside the GEANT4 MC code, as it is important to take into account the physics of the ionization and electron multiplication in the gas for these charged (e^+'s and e^-'s) particles. For both of the particle sources the simulation results are shown in Fig. 2(a) and (b), which were obtained by comparative simulation studies undertaken with the GEANT4 Standard [6] and GEANT4 Low [7, 8] packages. A closer inspection of these results reveals that for both sources at ∼2 MeV the sensitivity does not depend on the type of the source particles type. However above that energy (5 MeV up to 100 MeV onward) the sensitivity is higher for an isotropic particle source than for the parallel particle source. The sensitivity is defined as: $s = N_{\mathrm{IorII}}/N_{\mathrm{o}}$, where N_{IorII} is the number of charged particles reaching any of the two gas gaps and N_{o} is the number of original primary particles impinging the chamber.

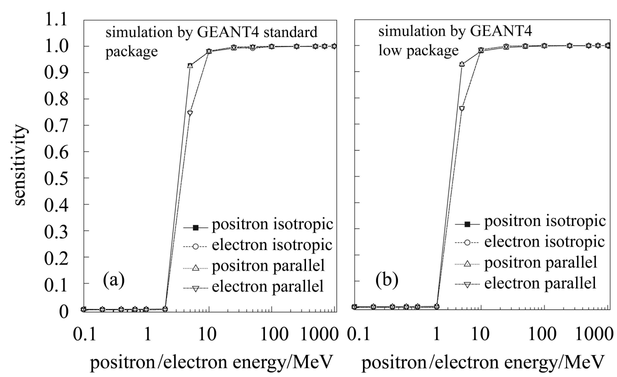

Fig. 2. Low-phosphate glass RPC's sensitivity for e^+/e^- particles for both, isotropic and parallel particles sources; the sensitivity values are evaluated from 0.1 MeV to 1.0 GeV.

According to these results the RPC detector sensitivity for electron is $s \approx 0.7489$ and $s \approx 0.75956$ for $E < 5.0$ MeV using the GEANT4 Standard and Low packages respectively. In case of positrons using the same energy domains the RPC sensitivity is $s \approx 0.92687$ and $s \approx 0.92736$ employing the GEANT4 Standard and Low packages respectively. The sensitivity for both the sources reaches values of 0.999, which is due to the fact that both e^+/e^- are charged particles and on reaching the gas gaps of the RPCs set-up they produce a detectable signal that is detected on the strips. In the present work, the charged particle signal is evaluated and summed up in the MC simulation code. It can clearly be concluded that the positron sensitivity is a little higher than the electron sensitivity. This behavior can be explained by the higher interaction cross-section. Therefore its sensitivity response is higher. Table 1 and Table 2 gives

Table 1. Electron simulation response for conventional glass RPCs Vs. low phosphate glass RPCs.

particles source	energy/MeV	conventional glass-RPC			phosphate glass-RPC	
		GEANT3.21	GEANT4 Standard	GEANT4 Low	GEANT4 Standard	GEANT4 Low
electron	0.1	0.0	0.0	0.0	0.0	0.0
isotropic	0.2	0.0	0.0000019	0.000001	0.0	0.0
	0.4	0.00001	0.0000019	0.000016	0.00003	0.0
	0.662	0.00003	0.004396	0.000026	0.00004	0.00001
	1	0.03110	0.00011	0.000028	0.00003	0.00001
	2	0.23684	0.005526	0.000136	0.00014	0.00016
	5	0.64121	0.77816	0.79827	0.74891	0.75956
	10	0.82459	0.98345	0.98510	0.98154	0.98401
	25	0.83285	0.99751	0.99779	0.99701	0.99771
	50	0.83067	0.99911	0.99922	0.99150	0.99905
	100	0.82900	0.99966	0.99949	0.99965	0.99965
electron	0.1	0.0	0.0	0.0	0.0	0.0
parallel	0.2	0.0	0.0	0.0	0.0	0.0
	0.4	0.0	0.000026	0.000026	0.00003	0.00002
	0.662	0.0	0.000021	0.000022	0.00002	0.00005
	1	0.0	0.000023	0.000032	0.00002	0.00003
	2	0.0446	0.00019	0.000128	0.0001	0.00011
	5	0.66028	0.77813	0.78853	0.74686	0.76135
	10	0.80603	0.98331	0.98513	0.98196	0.98490
	25	0.79584	0.99749	0.99778	0.99710	0.99743
	50	0.79665	0.99909	0.99915	0.99907	0.99915
	100	0.79441	0.99936	0.99966	0.99959	0.99977

Table 2. Positron simulation response for conventional glass RPCs Vs. low phosphate glass RPCs.

particles source	energy/MeV	conventional glass-RPC			phosphate glass-RPC	
		GEANT3.21	GEANT4 Standard	GEANT4 Low	GEANT4 Standard	GEANT4 Low
positron	0.1	0.00605	0.00213	0.0	0.00202	0.00264
isotropic	0.2	0.00607	0.00212	0.000004	0.00183	0.00236
	0.4	0.00480	0.002114	0.000014	0.00194	0.00231
	0.662	0.00385	0.002124	0.000011	0.00222	0.002760
	1	0.00609	0.00249	0.00003	0.00223	0.00285
	2	0.04340	0.00399	0.00010	0.00357	0.00411
	5	0.63679	0.93467	0.78956	0.92687	0.92736
	10	0.80923	0.98050	0.98535	0.97939	0.97919
	25	0.82439	0.99252	0.99760	0.99256	0.9927
	50	0.82336	0.99609	0.99207	0.99572	0.9957
	100	0.82733	0.99865	0.99968	0.99757	0.99870
positron	0.1	0.00699	0.00198	0.0	0.00218	0.00229
parallel	0.2	0.00635	0.00208	0.0	0.00203	0.00255
	0.4	0.00740	0.00218	0.000028	0.00225	0.00262
	0.662	0.00663	0.00222	0.000024	0.00216	0.00257
	1	0.00740	0.00228	0.000024	0.00214	0.00293
	2	0.05861	0.01110	0.000122	0.00333	0.00404
	5	0.65699	0.93518	0.77819	0.92436	0.92830
	10	0.79481	0.94507	0.98332	0.97967	0.97985
	25	0.78862	0.99255	0.99792	0.99230	0.99214
	50	0.79091	0.98902	0.99916	0.99580	0.99612
	100	0.78999	0.99456	0.99963	0.99771	0.99786

a comparison view of the positron and electron sensitivities for these particles taken by the GEANT3.21 [9] and GEANT4 MC packages.These results shows that except GEANT3.21 (at low energy), both the conventional glass and the low-resistive glass electrodes give similar results.

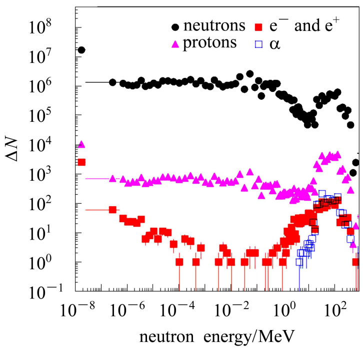

Fig. 3. A schematic view of the CMS Muon Barrel (MB1) e^+/e^- specta, shown as squares (Reproduced from Ref. [10]).

Table 3. RPC sensitivity evaluated for the CMS MB1 e^+/e^- spectrum.

for phosphate glass RPC with an area of 20 cm×20 cm			
particles	obtained results	by GEANT4 Standard package	by GEANT4 Low package
e^+	sensitivity	0.113	0.111
	hit rates	0.045	0.0444
e^-	sensitivity	0.12	0.116
	hit rates	0.048	0.0464

For estimating the actual experimental environments sensitivity to various e^+/e^- spectra for the low-resistive glass RPC, we have used the CMS-MB1 e^+/e^- spectrum of Fig. 3 [10] to estimate the total hit rate and the average sensitivity in that region using isotropic e^+/e^- sources. According to these results, the CMS MB1 chamber will have an average sensitivity of about 0.113 and 0.111 with a hit rate of about 0.045 Hz/cm^2 and 0.0444 Hz/cm^2 due to e^+ using the GEANT4 Standard and Low packages. Similarly the sensitivity for e^- is of 0.12 and 0.116 with a hit rate of 0.048 Hz/cm^2 and 0.0464 Hz/cm^2 (Table 3).

4 Conclusion

A GEANT4 based low-resistive phosphate glass RPC's simulation study has been performed for e^+/e^- particles. It was observed that RPC's sensitivity to both kinds of particles (e^+/e^-) depends mainly on the electrodes configuration and its density. As the density of the electrodes increase, the impinging particle on the RPC's surface generates more ionization, hence the sensitivity increases. The results obtained using simulations are consistent with those reported previously in literature [11]. A rather higher sensitivity and hit rates response were achieved this time. The reason could be that the previous results were evaluated for bakelite built RPCs, while the current results are obtained for phosphate glass RPCs, which have a higher density than bakelite electrodes. Consequently a higher number of charged particles is produced inside the gas gaps, hence the sensitivity values increase.

It is important to note that in previous studies [5] it was observed that the noise rate of the tested MRPC gave an undesirably strong dependence on the high voltage applied. The noise level (of an MRPC efficiency at 5.6 kV) was is about 1 Hz/cm^2. The noise then rapidly increased with increasing HV, surpassed 100 Hz/cm^2 at HV ≈ 6.2 kV, which is considered as an unstable behavior of the chamber.

Although a degradation of the phosphate glass RPC performance at a high rate environment is observed, the current simulation results reported could be a significant step forward in the search for new materials for the RPC detector development especially for the high-rate operations and calls for further R&D.

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