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Study of neutron response for two hybrid RPC setups using the GEANT4 MC simulation approach*

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Abstract The present article describes a detailed neutron simulation study in the energy range 10^{-10} MeV to 1.0 GeV for two different RPC configurations. The simulation studies were taken by using the GEANT4 MC code. Aluminum was utilized on the GND and readout strips for the (a) Bakelite-based and (b) glass-based RPCs. For the former type of RPC setup the neutron sensitivity for the isotropic source was $S_{\rm n} = 2.702\times10^{-2}$ at $E_{\rm n} = 1.0$ GeV, while for the latter type of RPC, the neutron sensitivity for the same source was evaluated as $S_{\rm n} = 4.049\times10^{-2}$ at $E_{\rm n} = 1.0$ GeV. These results were further compared with the previous RPC configuration in which copper was used for ground and pickup pads. Additionally Al was employed at (GND+strips) of the phosphate glass RPC setup and compared with the copper-based phosphate glass RPC. Good agreement with sensitivity values was obtained with the current and previous simulation results.

Key words resistive plate chambers, neutron sensitivity, GEANT4, Monte Carlo simulation

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1 Introduction

Resistive plate chambers (RPCs) were developed by Santonico and Cardarelli in the early 1980s[1]. Since then these detectors have been used widely for the detection of high energy charged particles, especially muons with a large-scale spectrometer. The RPC is valued in the domain of high energy physics for its superior time resolution, high efficiency, moderate position resolution and, more importantly, low cost[2]. At the present time, different high-energy particle spectrometers all over the world have been installed with RPCs, using them as a trigger system and/or muon detectors such as BELLE at KEK-B[3, 4], BaBar at SLAC[5], CMS and ATLAS at LHC[6, 7], cosmic ray experiments[8] and BESIII at IHEP of China[9, 10].

The resistive plate chambers can be operated with two modes of operation: (a) streamer mode and (b) avalanche mode. In streamer mode operation of an RPC, the electric field inside the gap is kept intense enough to generate limited discharges localized near the crossing of an ionizing particle. Due to the relatively long relaxation time of the resistive electrode, this mode is suitable for low rate experiments[6]. An RPC is a gas detector, which can achieve time resolution on the nanosecond (10^{-9} s) scale when detecting charged particles in the streamer mode. This number can be lowered to tens of picoseconds if the avalanche mode (i.e. the electric field across the gap is reduced and a robust signal amplification is introduced at the front-end electronics level) has been chosen and a thinner gas layer is used such as a multi-layer resistive plate chamber (MRPC)[11]. Further new developments of the RPC propose that it can serve as a gamma or neutron imaging detector with suitable changes to its structure and materials, for high position resolution has been a new direction of research. However the basis and objectives of RPC studies are still the high position resolution for charged particles[12, 13].

Several studies illustrate that aluminum has been used for ground planes, on pickup strips[14, 15] and as an external frame material[16, 17] of RPC setup, since aluminum is considered cheaper than copper. However, aluminum is much more difficult to weld and

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handle[18]. In the present scenario it is necessary to investigate and understand the characteristics of both aluminum- and copper-based RPC setups. The present studies were performed to estimate the neutron sensitivity response of these resistive plate chamber configurations. The current comparative simulation test was evaluated by the GEANT4 Monte Carlo package.

2 RPC simulation configuration

Our investigated detectors consist of two types of RPC set-ups with a double-gap configuration. The geometrical configuration of a CMS like[1, 14, 15] double gap RPC which has two gas gaps with central common readout strips and the usual RPC gas mixture (3%iC_4H_{10} + 97%$C_2H_2F_4$) was inserted in to the GEANT4 MC code. The MC code GEANT3 was first developed in FORTRAN at CERN to simulate particle-matter interaction[19]. The new GEANT4 project[20] was developed in 1994 to improve the existing GEANT3 program. The GEANT4 package offers an ample set of complementary and alternative physics models based either on theory, on experimental data or on parameterizations. The design choice of GEANT4 was an object-oriented methodology and C++ language in order to provide modular and flexible software. All physical processes, models and visualization modules are entirely accessible to the user. The GEANT4 standard package provides a variety of models based on analytical approaches to describe the interactions of electrons, positrons, photons, and charged hadrons in the energy range between 1.0 keV to 10 PeV[21].

The GEANT4[20] Monte Carlo radiation transport toolkit provides the basic services and infrastructure required for the development of flexible simulation frameworks and applications which have found generalized use in high energy physics, nuclear physics, astrophysics and medical physics. GEANT4 object-oriented design provides the possibility to implement or modify any physics process in GEANT4 without changing the other parts of the software.

This feature makes GEANT4 open to the extension of its physics modeling capabilities and to the implementation of alternative physics models. Additional factors responsible for the increasing use of GEANT4 are its modularity, a flexible infrastructure and the Low Energy Electromagnetic Physics Processes category, which provide alternative models for electron and photon transport down to 250 eV[22]. In the present study, both of the RPCs with their materials and configurations which are seen in Fig. 1 were simulated.

In the first RPC setup aluminum was employed for GND plates and for central readout strips, while in the second RPC setup copper was utilized for GND plates and strips. This was performed as the density of copper is higher than aluminum, and according to physics requirements, a similar thickness of copper is used in the configuration of the second setup. Two RPC configurations of size 20 cm × 20 cm were studied. The details of detector composition in terms of material and relative thickness are described in Table 1. The thickness of the gas volume was kept at 2 mm for each gas gap. Two kinds of neutron sources were chosen: (1) The isotropic incident source of neutrons, evenly distributed on the chamber surface, (2) a parallel beam, perpendicularly impinging on the whole RPC surface.

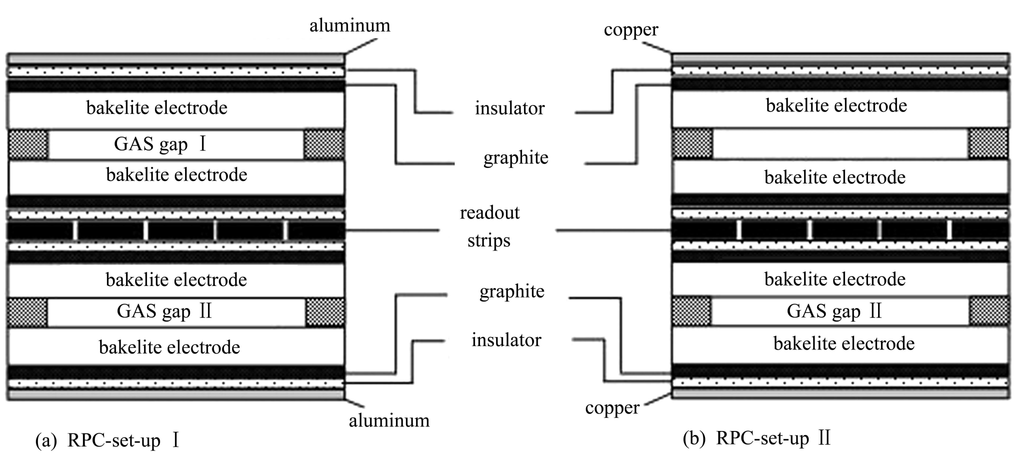

Fig. 1. Two types of RPC detectors: (a) Aluminum-based (GND+ Strips) RPC, and (b) Copper (GND+ Strips) based.

Both of the RPC configurations were simulated for the neutron source in the energy range 10^{-10} MeV to 1.0 GeV. The sensitivity was evaluated at 15 points: namely, 10^{-10}, 10^{-7}, 10^{-6}, 10^{-4}, 10^{-2}, 1, 2, 5, 10, 25, 50, 100, 250, 500, and 1000 MeV. In this simulation work, the range threshold for secondary particles (i.e., for gamma, e^-, and e^+) production in electromagnetic processes was set to 1 μm, 1 nm, and 1 μm respectively.

3 Simulation results and discussion

The experimental set-up (Table 1) has been simulated using the GEANT4 MC code with its standard package for the simulation of low and high energy neutron interactions in the range 10^{-10} MeV to 1.0 GeV. It is important to note that simulations of all the material surrounding both the RPC and the source are necessary in order to take into account the effects of the neutron interactions within these materials[16]. These effects are of particular importance in the neutron sector due to scattering, radiative captures and other inelastic processes depending on the neutron energies[23].

The sensitivity in our GEANT4 MC code is defined as: sens = $N_{\rm I}/N_0$, where $N_{\rm I}$ is the number of charged particles arriving at any of the two gas gaps and N_0 is the number of original primary particles impinging upon the RPC chamber. It is important to notice that in the present work only signals due to neutrons that enter the detector contribute to the neutron sensitivity. The secondary gamma contribution, due to neutron interactions in the RPC volume, has been also treated in this simulation study.

Table 1. The two RPC material thicknesses employed in the present simulation work.

RPC config.I	thickness/cm	RPC config.II	thickness/cm
aluminum(GND)	0.06	copper (GND)	0.001
polyethylene	0.01	polyethylene	0.01
graphite	0.002	graphite	0.002
Bakelite	0.2	glass electrode	0.2
gas gap 1	0.2	gas gap 1	0.2
Bakelite	0.2	glass electrode	0.2
graphite	0.002	graphite	0.002
polyethylene	0.01	polyethylene	0.01
aluminum(strips)	0.01	copper (strips)	0.001
polyethylene	0.01	polyethylene	0.01
graphite	0.002	graphite	0.002
Bakelite	0.2	glass electrode	0.2
gas gap 2	0.2	gas gap 2	0.2
Bakelite	0.2	glass electrode	0.2
graphite	0.002	graphite	0.002
polyethylene	0.001	polyethylene	0.001
aluminum(GND)	0.06	copper (GND)	0.001

The simulated results of the neutron sensitivity taken by the aluminum-based double-gap RPC are shown in Fig. 2, and are compared with the previous simulation results[24], obtained by copper built RPCs. Similarly we simulated and compared aluminum-based glass RPC neutron sensitivity with copper-based glass RPC sensitivity[24, 25]. In case of the Al-based Bakelite double-gap RPC the sensitivity for isotropic neutron source is $E_{\rm n} = 2.702\times10^{-2}$ at 1.0 GeV, for the same source and energy the sensitivity is $E_{\rm n} = 4.049\times10^{-2}$ using the Al-based glass

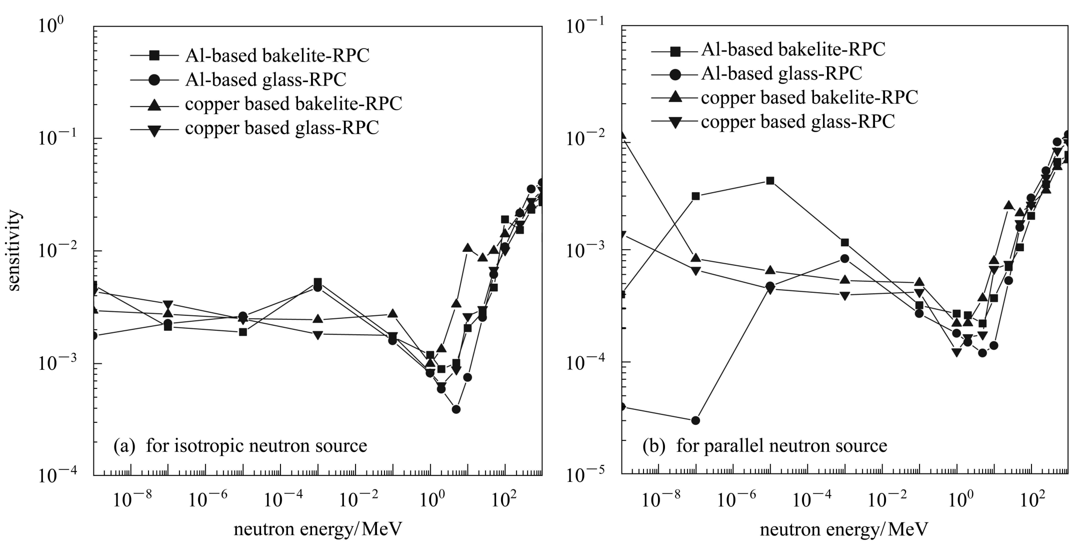

Fig. 2. Two types of double-gap RPCs sensitivities vs. $E_{\rm n}$. (a) Aluminum-based (GND+Strips) RPC and (b) Copper (GND+Strips) based RPC.

double-gap RPC. It is evident from the results that the sensitivity of neutrons below $E_n<10^{-2}$ MeV dominates for both Al and copper-based-Bakelite RPC setups, while for neutrons at higher energy $E_n>10^{-2}$ MeV the sensitivity evaluated is higher for both Al and copper-based-glass RPC setups.

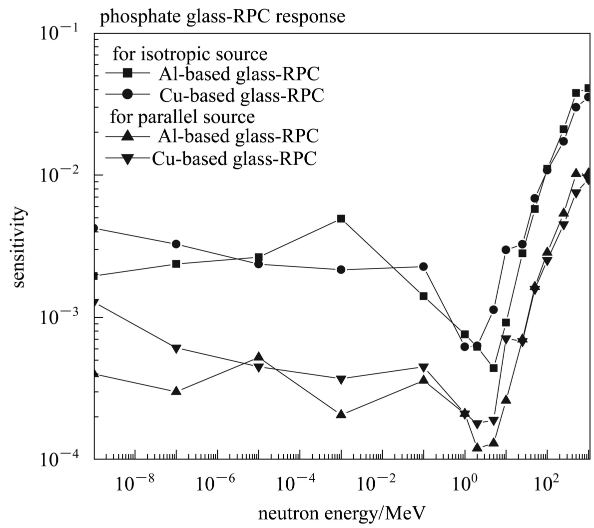

Fig. 3. RPC neutron sensitivity: Comparison between aluminum-based phosphate glass RPC vs. copper-based phosphate glass RPC.

Moreover, for the same source and energy scales the sensitivities were $E_n = 3.142\times10^{-2}$ and $E_n = 3.491\times10^{-2}$ using the copper built Bakelite RPC and copper built glass RPC respectively. Similarly the results for the parallel neutron source response are given in detail in Fig. 3 along with those for the isotropic neutron source. Evidently, from the results of Al- and Cu- based Bakelite RPCs, the neutron sensitivity shows a similar behavior, while for both of the glass based RPC configurations, the sensitivity is rather lower at low neutron energies and at the higher energies $E_n = 1.0$ GeV, sensitivities are higher than the former type RPC setup. This could be because that of glass density is higher than Bakelite electrodes thus at low energies neutrons could not pass through them, which results in lower sensitivities, while at higher energies neutrons pass easily through glass materials and produce large number of charged particles as they pass through bulky glass electrodes, which results in a higher sensitivity response.

It is clear from Fig. 2(a) and (b) results that sensitivity values rise in the low energy region ($E_n<1\times10^{-5}$ MeV) mostly due to γ's coming from the (n,γ) capture reaction whose cross section increases with the decrease in neutron energy as $\sigma \propto 1/\sqrt{E_n}$. For all such configurations of RPCs at $E_n>1$ MeV, the sensitivity is evaluated higher for an isotropic source than for a parallel source. This dependence is due to the fact that the isotropic neutron source takes a wider path when it passes through either a Bakelite or glass electrode RPC surface. Eventually such a neutron source produces more charged particles which contribute to sensitivity. The increasing behavior of neutron sensitivity with neutron energy is in agreement with previous studies[14]. At higher energies ($E_n>1.0$ MeV), the sensitivity rises rapidly and reaches a maximum as a consequence of protons produced by elastic scattering on H and by (n,p) reactions on C, O and Al.

In order to further investigate the behavior of Al- and Cu-based RPC for neutrons, we simulated Al- based phosphate glass RPCs and compared it with Cu-based phosphate glass RPC results[26]. From the obtained results, it can be seen that both at low and high neutron energies Al-based phosphate glass RPC gives higher sensitivities than Cu-based phosphate glass RPC. The results are shown in Fig. 3. The present simulated results are further compared with the available experimental results[16, 27, 28], which show a close agreement with each other (Table 2). According to these values both aluminum and copper can be utilized for the GND and pickup strip materials.

Table 2. A summary of the neutron sensitivity results the experimental results are compared with an Al-based RPC, and with a copper-based RPC.

particles	energy/MeV	double-gap RPC sensitivity				
		experimental results	Al(GND+strips)		Cu (GND+strips)	
			Bakelite-built RPC	Glass-built RPC	Bakelite-built RPC	Glass-built RPC
neutron	1.0	2.0×10^{-3}	1.19×10^{-3}	8.2×10^{-4}	1.263×10^{-3}	8.42×10^{-4}
	2.0	$(6.3\pm0.02)\times10^{-4}$	8.4×10^{-4}	5.9×10^{-4}	9.6×10^{-4}	6.38×10^{-4}
	20.0	$(5.3\pm0.5)\times10^{-3}$	2.92×10^{-3}	2.05×10^{-3}	5.88×10^{-3}	1.29×10^{-3}
	50.0	$<7-8\times10^{-3}$	4.72×10^{-3}	6.16×10^{-3}	8.574×10^{-3}	6.79×10^{-3}

4 Summary and concluding remarks

Neutron simulation sensitivity has been performed at two different types (i.e for (a) Al-based bakelite RPCs and (b) Cu-based RPCs) of RPC configurations. These simulations were conducted by the GEANT4 MC simulation package and the obtained results are shown in Fig. 1 and Fig. 2. Although two different setup materials were utilized for RPC simulation, the sensitivity results shown in Fig. 2 are in close agreement with each other. Moreover, such materials were further employed on glass-based and phosphate glass built RPC setups, and neutron sensitivity results predicted similar behavior. Our neutron sensitivity results propose that both aluminum and copper can be utilized for RPC configuration both on GND and on pickup pads.

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