PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 69, No. 3
September 2007
pp. 377–386

Background neutron in the endcap and barrel regions of resistive plate chamber for compact muon solenoid/large hadron collider using GEANT4

J T RHEE[1], M JAMIL[1,*], CHRISTOPHER JOEN[2], BINGZHU YIN[3] and Y J JEON[4,*]
[1]Institute for Advanced Physics, Konkuk University, Seoul 143-701, Korea
[2]Faculty of Science and Engineering, Ballarat University, Victoria 3353, Australia
[3]Department of Chemistry, School of Science and Technology, Yanbian University, Yanji 133002, China
[4]Department of Chemistry, Konkuk University, Seoul 143-701, Korea
*Corresponding authors. E-mail: mjamil@konkuk.ac.kr; yjjeon@konkuk.ac.kr

MS received 8 February 2007; accepted 5 July 2007

Abstract. In this study the performance of double gap RPC has been tested by GEANT4 Monte Carlo simulation code. The detector response calculations taken as a function of the neutron energy in the range of 0.01 eV–1 GeV have been simulated through RPC set-up. In order to evaluate the response of detector in the LHC background environment, the neutron spectrum expected in the CMS muon endcap and barrel region were taken into account. A hit rate of about 165.5 Hz cm^{-2}, 34 Hz cm^{-2}, 33.6 Hz cm^{-2}, and 27.0 Hz cm^{-2} due to an isotropic neutron source is calculated using GEANT4 standard electromagnetic package for a 20×20 cm^2 RPC in the ME1, ME2, ME3 and ME4, respectively. While for the same neutron source and using GEANT4 package a hit rate of about 0.42 Hz cm^{-2}, 0.7182 Hz cm^{-2} was measured for the MB1 and MB4 stations respectively. Similar characteristics of hit rates have been observed for GEANT4 low electromagnetic package.

Keywords. Resistive plate chamber; background radiation; Monte Carlo simulation.

PACS Nos 29.40.Gx; 29.40.Cs

1. Introduction

The radiation environment encountered in the large hadron collider (LHC) experiment at CERN will differ [1] completely from standard applications in which existing dosimetric technologies are used. The mixed radiation field in the compact muon solenoid (CMS) experiment will be composed of neutrons, photons and charged hadrons. This complex field, which has been simulated by Monte Carlo codes [2], is due to particles generated by the proton–proton collision and

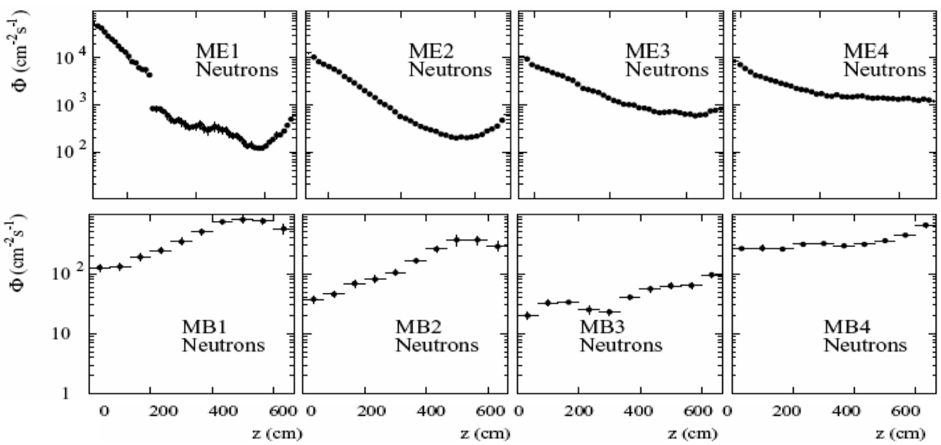

Figure 1. Neutron fluxes in endcap and barrel regions of CMS detector.

reaction products of these particles with the sub-detector material of the experiment itself. The proportion of the different particle species in the field will depend on the distance and on the angle with respect to the interaction point (i.e., radiation environment is unique for each sub-detector constituting CMS).

CMS [3] and a toroidal for LHC apparatus (ATLAS) [4] have shown that the RPCs and other detectors at the LHC will operate in an intense radiation background mostly made of photons, neutrons and charged hadrons. RPCs and other detectors in the CMS experiment, will work in a hostile environment rich in neutrons and gamma rays. The maximum expected fluxes (figure 1) in the muon detector for neutrons and gammas are around 5×10^4 and 1×10^4 $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, respectively, for the CMS ME1 station (endcap region), while fluxes one order of magnitude lower are expected in the MB1 station (barrel region).

These kinds of background radiation environments represent a danger to all exposed detectors and electronic components. Due to radiation damage via ionizing energy losses, non-ionizing energy losses, and various other ageing radiation effects [5], the detectors will suffer a loss of performance over time. For this reason these simulations are performed to find the spectra and intensity of background particles in order to propose shielding to improve the signal-to-noise ratio. In addition, the risk of accidental radiation burst due to beam loss or bad beam-tuning should also be taken into account. For these reasons it is important to constantly monitor the radiation level. In the CMS muon system, RPC chambers are located in the barrel and in the endcap regions. In the barrel region, the RPC strips run parallel to the beam and in the endcap they are in radial direction [6].

In order to understand how these kinds of background could affect the detector functionality, we need to know the detector sensitivity to these kinds of radiation. The motivation of our studies is to estimate the hit rate for the neutron background expected in the CMS muon endcap and barrel regions. Neutrons were simulated in the RPC double-gap tri-dimensional geometry by means of GEANT4 Monte Carlo code.

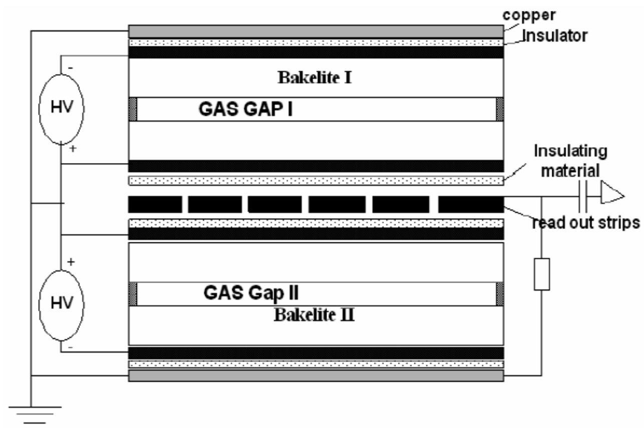

Figure 2. Basic RPC configuration used in the simulation.

2. Resistive plate chamber and its working principle

A double-gap RPC detector has good time resolution and high detection efficiency. It is low cost and can be segmented if needed. Figure 2 shows the structure of a double gap RPC detector. The double gap RPC consists of a stack of resistive bakelite plates, spaced one from the other with spacers of equal thickness creating a series of gas gaps (two gas gaps of about 0.2 mm). The outer surfaces of resistive material are coated with conductive graphite paint to form the HV and ground electrodes. Non-flammable gas mixture which contains 97% tetrafluoroethane and 3% isobutane is used. A charged particle passing through the chamber generates avalanches in the gas gaps. The induced signal is about the average of signals of the two gas gaps. Signals are read out from the copper pickup pads. The operation of resistive plate chamber (RPC) is easy to explain and further readings can be done in ref. [7].

3. Description of GEANT4 Monte Carlo packages

GEANT4 offers an ample set of complementary and alternative physics models based either on theory, on experimental data or on parameterizations. In particular, GEANT4 provides packages specialized for modeling both electromagnetic and hadronic physics interactions [8].

In the present studies, we present the results concerning the following GEANT4 electromagnetic packages:

1. Standard package
2. Low energy package, based on Livermore data libraries [9–11].

3.1 *GEANT4 standard package*

The standard package [8] provides a variety of models based on analytical approach to describe the interactions of electrons, positrons, photons and charged hadrons in

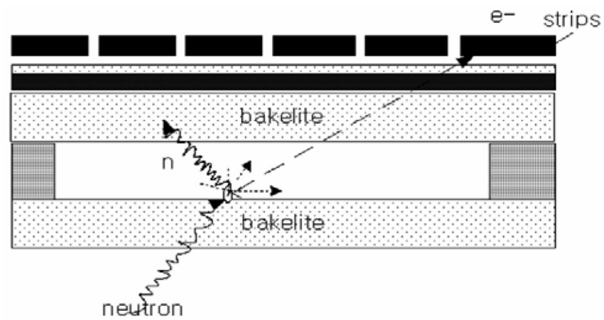

Figure 3. Sample event view at the double gap RPC, where an incoming neutron impinges on the bakelite, charged particles are emitted, and the recoil electron either deposits its full energy in one of the gas gaps or it escapes.

the energy range of 1.0 keV to 100 TeV. The GEANT4 standard package is mainly addressed to the high energy physics domain.

3.2 *GEANT4 low energy package*

The low energy package [8,12] extends the range of accuracy of electromagnetic interactions down to lower energy than the GEANT4 standard package. This low energy package approach exploits evaluated data libraries (EPDL97 [9], EEDL [10] and EADL [11]) which provide data for the calculation of the cross-sections and, the sampling of the final state for the modeling of photon and electron interactions with matter. The current implementation of low energy electron processes can be used down to 250 eV. This package handles the ionization by hadrons and ions [13,14].

By employing this package, we activated the processes which are low energy, Rayleigh scattering, photoelectric effect, Compton effect, gamma conversion, ionization and Bremstrahlung. In addition, it is important to follow low energy electrons, because very low energy electrons (down to 1 eV, for instance) which arrive in the gas gap of an RPC can be easily detected by this package.

4. RPC's configuration

The basic structure and the configuration of the current CMS-like double gap RPC [3] were input to the GEANT4 code [8]. The standard double gap geometry was employed with the strip plane sandwiched between the two gas gaps. The thickness of gas volume (2 mm for each gap) was maintained. 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's surface.

For our source configuration, the sensitivity was evaluated at 18 points: namely, 10^{-8}, 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 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.

5. Double gap RPC sensitivities

Two kinds of GEANT4 Monte Carlo code packages, i.e., GEANT4 standard and low electromagnetic packages were used for the present neutron simulation studies. The signals in the RPCs exposed to neutrons are expected to be generated by a variety of nuclear processes: elastic scattering, in-elastic scattering, radiative neutron capture and so on [15], depending on the neutron energies. A schematic view of the process when a neutron interacts in the bakelite plates, is somehow scattered and generates a secondary electron which crosses the RPC gas gap is reported in figure 3. Two physics lists which involve hadronic physics evaluation were used in the present work. The two patches used for neutron interaction cross-section estimation are LHEP_PRECO_HP and G4NDL3.5. Point-wise evaluated cross-section data are used to model neutron interactions from thermal energies to ~20 MeV. This applies to capture, elastic scattering, fission and inelastic scattering.

The RPC sensitivity is a well-known function of the incoming particle energies since at different energies different processes are responsible for the production of secondary particles. In order to obtain the sensitivity to neutrons in the RPC chamber, we applied the same upper limit assumption as [16,17], namely that each produced charged particle generates a signal into the read-out strips on arriving at the RPC gas gap; if more than one charged particle reaches the gas gap, only the first one is assumed to produce a signal. Double-gap RPC sensitivity in our code is defined as

$$\text{sens} = N_I/N_0, \tag{1}$$

where N_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 neutron sensitivity. Secondary gamma contribution, due to neutron interactions in the RPC volume have been treated in this simulation studies as well. The obtained neutron sensitivity results at neutron energies (10^{-8} eV–1 GeV) are taken from our previous work reported in [18] shown in table 1, which were obtained by applying the above condition on the 20 × 20 cm^2 RPC set-up.

6. Monte Carlo simulation results and discussion

Considering the complexity of GEANT321 [17,19] simulation program for neutron source, we developed a new application code for the neutron simulation through the RPC detector in our laboratory. By applying this RPC neutron simulation code,

Table 1. RPC detector's mean sensitivities and their variances of GEANT4 standard and low processes.

Particle source	Energy (MeV)	By GEANT4 packages Standard ε ($\pm\sigma$)	Low ε ($\pm\sigma$)
Isotropic neutron	10^{-8}	$5.334(\pm 0.000178)\times 10^{-3}$	$6.064(\pm 0.000169)\times 10^{-3}$
	10^{-7}	$4.224(\pm 0.000186)\times 10^{-3}$	$4.545(\pm 0.000268)\times 10^{-3}$
	10^{-6}	$2.744(\pm 0.000141)\times 10^{-3}$	$2.927(\pm 0.000134)\times 10^{-3}$
	10^{-4}	$2.505(\pm 0.000127)\times 10^{-3}$	$2.48(\pm 0.000240)\times 10^{-3}$
	10^{-2}	$2.44(\pm 0.000129)\ \times 10^{-3}$	$2.442(\pm 0.000145)\times 10^{-3}$
	10^{-1}	$2.738(\pm 0.000155)\times 10^{-3}$	$2.720(\pm 0.000150)\times 10^{-3}$
	1.0	$1.263(\pm 0.000178)\times 10^{-3}$	$1.045(\pm 0.003110)\times 10^{-3}$
	2.0	$9.96(\pm 0.000297)\times 10^{-4}$	$1.032(\pm 0.002457)\times 10^{-3}$
	5.0	$1.34(\pm 0.000781)\times 10^{-3}$	$1.573(\pm 0.000161)\times 10^{-3}$
	10.0	$3.353(\pm 0.000148)\times 10^{-2}$	$3.771(\pm 0.000087)\times 10^{-3}$
	25.0	$1.048(\pm 0.000389)\times 10^{-2}$	$1.054(\pm 0.004710)\times 10^{-2}$
	50.0	$8.574(\pm 0.000354)\times 10^{-3}$	$8.069(\pm 0.000336)\times 10^{-2}$
	100.0	$1.004(\pm 0.000142)\times 10^{-2}$	$1.012(\pm 0.003060)\times 10^{-2}$
	250.0	$1.409(\pm 0.000223)\times 10^{-2}$	$1.405(\pm 0.000502)\times 10^{-2}$
	500.0	$2.168(\pm 0.006800)\times 10^{-2}$	$2.190(\pm 0.000354)\times 10^{-2}$
	1000.0	$2.547(\pm 0.004596)\times 10^{-2}$	$2.557(\pm 0.000435)\times 10^{-2}$
Parallel neutron	10^{-8}	$1.119(\pm 0.000084)\times 10^{-3}$	$1.263(0.000181)\times 10^{-2}$
	10^{-7}	$8.30(\pm 0.000065)\times 10^{-4}$	$9.360(0.000990)\times 10^{-4}$
	10^{-6}	$6.450(\pm 0.000800)\times 10^{-4}$	$6.440(0.000060)\times 10^{-4}$
	10^{-4}	$5.310(\pm 0.000082)\times 10^{-4}$	$5.440(0.000094)\times 10^{-4}$
	10^{-2}	$5.07(\pm(0.000008)\times 10^{-4}$	$4.820(0.000059)\times 10^{-4}$
	10^{-1}	$6.150(\pm 0.001915)\times 10^{-4}$	$5.940(0.000093)\times 10^{-4}$
	1.0	$2.20(\pm 0.000000)\times 10^{-4}$	$2.430(0.000044)\times 10^{-4}$
	2.0	$2.22(\pm 0.000052)\times 10^{-4}$	$2.340(0.00000)\times 10^{-4}$
	5.0	$3.70(\pm 0.000043)\times 10^{-4}$	$3.950(0.000057)\times 10^{-4}$
	10.0	$7.950(\pm 0.000064)\times 10^{-4}$	$8.880(0.000107)\times 10^{-4}$
	25.0	$2.448(\pm 0.000126)\times 10^{-3}$	$2.510(0.000196)\times 10^{-3}$
	50.0	$2.118(\pm 0.000148)\times 10^{-3}$	$2.109(0.000100)\times 10^{-3}$
	100.0	$2.537(\pm 0.000927)\times 10^{-3}$	$2.470(0.000105)\times 10^{-3}$
	250.0	$3.378(\pm 0.000189)\times 10^{-3}$	$3.551(0.000291)\times 10^{-3}$
	500.0	$5.458(\pm 0.000210)\times 10^{-3}$	$5.359(0.000160)\times 10^{-3}$
	1000	$6.368(\pm 0.000263)\times 10^{-3}$	$6.496(0.000181)\times 10^{-3}$

we studied the detector response uniformity by computing each neutron energy efficiency fluctuation around the average. In order to estimate the uncertainties associated to the calculated sensitivity, we simulated ten independent runs (i.e. $m = 10$) of the Monte Carlo simulation code for each source of neutrons at definite energy, where the final calculated sensitivity ε is given by the mean of the sensitivities ε_k calculated for each simulation run at particular energy, and the estimation of the variance of the sensitivity σ is given by the expression [20,21].

$$\varepsilon = 1/m\Sigma\varepsilon_k, \tag{2}$$

Table 2. Summary of the experimental and simulated neutron results.

Particles	Energy (MeV)	Double-gap RPC sensitivity: Experimental results	G4 standard results	G4 low results
Neutrons	1.0	2.0×10^{-3}	1.263×10^{-3}	1.054×10^{-3}
	2.0	$(6.3\pm0.02)\times10^{-4}$	9.6×10^{-4}	1.032×10^{-3}
	20.0	$(5.3\pm0.5)\times10^{-3}$	5.88×10^{-3}	5.62×10^{-3}
	50.0	$<7–80\times10^{-3}$	8.574×10^{-3}	8.60×10^{-3}

Table 3. CMS/RPC endcap region neutron sensitivity* and background hit rates.

By GEANT4 package	Particle	Neutron sensitivity ($\times10^{-3}$)				Hit rate (Hz cm^{-2})			
		ME1	ME2	ME3	ME4	ME1	ME2	ME3	ME4
Standard	Neutron	3.31	3.72	3.36	3.00	165	34.0	33.6	27.0
Low	Neutron	3.39	3.66	3.36	3.06	170	33.0	34.0	27.5

*Sensitivity values are the average values taken for each endcap region, and the neutrons source was taken as isotropic source for calculating those results.

Table 4. CMS/RPC barrel region neutron sensitivity and background hit rates.

By GEANT4 packages	Particle	Types	Neutron sensitivity		Hit rate (Hz cm^{-2})	
			MB1	MB4	MB1	MB4
Standard	Neutron	Isotropic	9.50×10^{-3}	2.9×10^{-3}	1.32	0.72
Low	Neutron	Isotropic	2.56×10^{-3}	2.7×10^{-3}	0.40	0.76

$$\sigma_\varepsilon^2 = 1/(m-1)\Sigma(\varepsilon_k - \varepsilon)^2. \tag{3}$$

Similar simulation studies were performed and results were undertaken using the parallel neutron source and employing both GEANT4 standard/low electromagnetic packages.

By employing GEANT4 standard electromagnetic packages the double-gap RPC sensitivity obtained for an isotropic neutron source is, sn $< 2.547\times10^{-2}$ for $En \approx 1$ GeV. Applying GEANT4 low electromagnetic packages the RPC sensitivity, sn $< 2.557\times10^{-2}$ has been found for the same energy domain. Similarly for the double-gap RPC using parallel neutron source for GEANT4 standard electromagnetic packages the neutron sensitivity sn $< 6.368\times10^{-3}$ has been noted for $En \approx 1$ geV whereas the RPC neutron sensitivity, sn $< 6.496\times10^{-3}$ for the same neutron source, and energies has been obtained using the GEANT4 low electromagnetic packages. The present GEANT4 neutron simulation results are reliable and are in agreement with the experimental results reported in [17,22,23]. A comparison

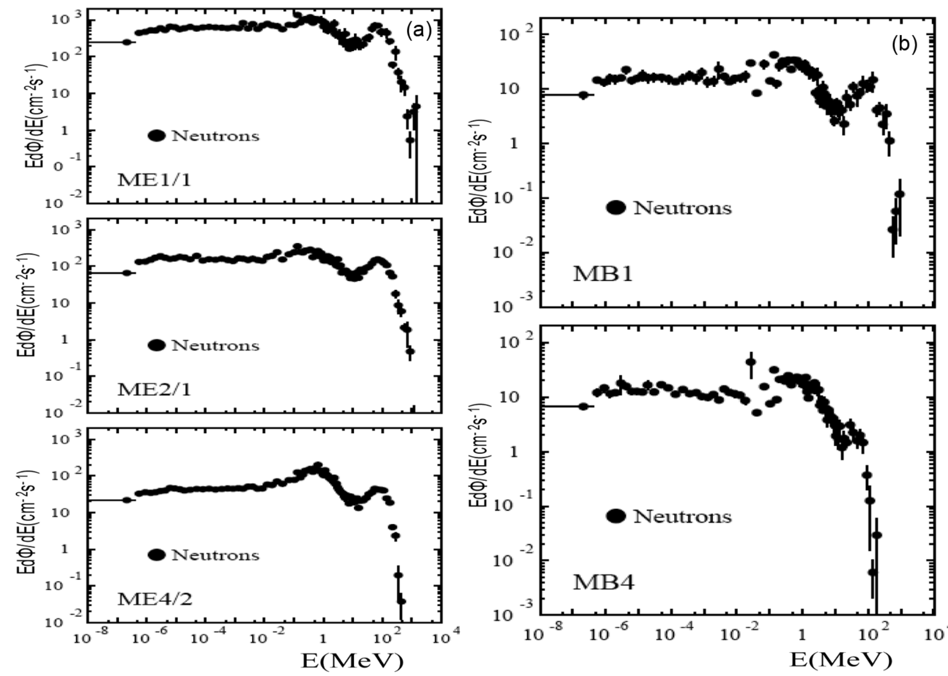

Figure 4. (**a**) Particle spectra in the CSC gas layers of ME1/1, ME2/1 and ME4/2. (**b**) Particle spectra in the drift tube gas layers of MB1 and MB4.

between the simulated and available experimental neutron sensitivity results at low energies can be seen in table 2.

7. Conclusion

In order to simulate the endcap region of the RPC for neutrons, we applied our preliminary results to figure 4a of the CMS muon TDR (CERN/LHCC/97/32), which shows the particle spectra in CSC gas layers of ME1/1, ME2/1 and ME4/2. The assumption that we could employ our simulation results in table 4 to these regions is based on the fact that the CSC and the RPC in the endcap area of CMS have same locations. Similarly, for barrel area hit rate estimation we applied the simulation results to figure 4b, which shows neutrons background spectra in the drift tube gas layers of MB1 and MB4. Hit rate of particles can be found by employing same number of particles impinging in the code and getting the sensitivity values bin by bin of figures 4a and 4b. The sum of all those sensitivity results divided by the total number of neutrons, gives the average sensitivities in those regions, i.e., ME1, ME2, ME3, ME4 and MB1, and MB4 for CMS endcap, and barrel stations. The application of those results (figures 10.6.2/3 of the CMS muon TDR [3]) gives the total hit rate of neutrons in those respective regions. The obtained results are tabulated in table 4, showing the CMS/RPC endcap and barrel neutron background hit rates, which were estimated by using the GEANT4 standard and GEANT4 low electromagnetic package codes for a double-gap RPC.

A simulation study of the RPC's sensitivity for neutrons was done, and the results are applied to the CMS/RPC endcap and barrel regions. The method illustrated here might be used to estimate the sensitivity for different experimental environments using neutron spectra. By observing the present simulation results, we can see that the experimental neutron sensitivity values and the results obtained by GEANT4 low package, seem in agreement at high energies within 89% range, while a comparison of the obtained simulation results evaluated by the GEANT4 standard package and the experimental sensitivity values, at the same energy domains are found in agreement within 87% range. Therefore, one can notice that GEANT4 low energy package works better than the GEANT4 standard package. The obtained results are summarized in tables 1–4, in which the neutrons sensitivities according to their respective energy vs. sensitivity contributions are reported for the RPC detector. According to these numerical values, we can estimate that the CMS endcap ME1, ME2, ME3 and ME4/1 will have a hit rate due to an isotropic neutron source (using GEANT4 standard electromagnetic package) of about 165.5, 34, 33.6 and 27.0 Hz cm^{-2} respectively, while the corresponding rate for the same source using GEANT4 low electromagnetic package would be about 170.0, 33.0, 34.0 and 27.54 Hz cm^{-2} respectively. In the case of isotropic neutron source using GEANT4 standard electromagnetic package for the region of CMS MB1 and MB4, the hit rates would be about 0.42 and 0.7182 Hz cm^{-2}, while for the same source and region using GEANT4 low electromagnetic package, the hit rates would be 0.40 and 0.7678 Hz cm^{-2} respectively.

Acknowledgements

This paper was supported by the research grant from Konkuk University in 2001.

References

[1] The large hadron collider project webpage, http://cern.ch/lhcXnew X homepage/
[2] M Huhtinen, Radiation environment simulation for the CMS detector, CERN, CMS Tech. Note 95–198 (1995)
[3] CMS, The Muon Project, Technical Design Report, CERN/LHCC/97/32, December 1997
[4] ATLAS, The Muon Project, Technical Design Report, CERN/LHCC/97/22, May (1997)
[5] A G Holmes-Siedel and L Adams, *Handbook of radiation effects*, 2nd ed. (Oxford University Press, Oxford, UK, 2002)
[6] CMS Collaboration: M C Fouz, *Nucl. Phys.* **B120**, 264 (2003)
[7] Libor Dedek *et al*, *Measurement science review* (2001) vol. 1, No. 1
[8] GEANT4 Collaboration: *GEANT4 – a simulation toolkit*, S Agostinelli *et al*, *Nucl. Instrum. Methods* **A506**, 250 (2003)
[9] D Cullen, J H Hubbell and L Kissel, The Evaluated Photon Data Library, 97 version, UCRL-50400, vol. 6, Rev. 5

[10] D E Cullen and S M Seltzer, Tables and graphs of electron interaction cross-sections from 10 eV to 100 GeV derived from the LLNL evaluated electron data library (EEDL), $Z = 1$–100 UCRL-50400, vol. 31
[11] S T Perkins, D E Cullen, M H Chen, J H Hubbell, J Rathkopf and J Scofield, Tables and graphs of atomic subshell and relaxation data derived from the LLNL evaluated atomic data library (EADL), $Z = 1$–100 UCRL-50400, vol. 30
[12] S Chauvie, G Depaola, V Ivanchenko, F Longo, P Nieminen and M G Pia, *GEANT4 Low Energy Electromagnetic Physics Proceedings of CHEP 2001*, Beijing (China), pp. 337–340 (2001)
[13] S Giani *et al*, CERN-OPEN-99-121 and INFN/AE-99/20 (1999)
[14] S Giani *et al*, CERN-OPEN-99-300 and INFN/AE-99/21 (1999)
[15] William R Leo, *Techniques for nuclear and particle physics experiments* (Springer-Verlag, Berlin, Heidelberg, 1987)
[16] S Altieri *et al*, *Nucl. Instrum. Methods* **A461**, 57 (2001)
[17] S P Ratti, Resistive plate chambers in high energy physics experiment, International Conference on High Energy Physics, ICHEP2000, *Proc. of the XXXth Int. Conf. in H.E.P* edited by C S Lim and T Yamanaka (World Scientific, Singapore, 2000) pp. 1261–1263
[18] J T Rhee *et al*, *J. Korean Phys. Soc.* **48**, 33 (2006)
[19] Application Software Group – Computing and Networks Division GEANT – Detector Description and Simulation Tool CERN Program Library Long Writeup W5013 October 94, CERN, Geneva, Switzerland
[20] S Hurtado *et al*, *Nucl. Instrum. Methods* **A518**, 764 (2004)
[21] K Debertin and R G Helmer, *Gamma and X-ray spectrometry with semiconductor detectors* (North-Holland, Amsterdam, 1988)
[22] S P Ratti, RPC sensitivity to low energy neutrons and gamma rays: Preliminary results, *International Euro Physics Conference on High Energy Physics (EPS HEP)*, July 2001, Budapest, Hungary
[23] Marcello Abbrescia *et al*, *Nucl. Instrum. Methods* **A506**, 101 (2003)