International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 4 No. 2 Oct. 2013, pp. 424-436

http://www.issr-journals.org/ijias/

Validation of Monte-Carlo Geant4 code for Saturne 43 LINAC

J. EL Bakkali, T. El Bardouni, M. Zoubair, and H. Boukhal

ERSN-LMR, Faculty of Sciences, University Abdelmalek Essaadi, Tetouan, Morocco

ABSTRACT: The aim of this study was to model the 12 MV photon beam from a Saturne 43 LINAC configuring a 10×10 cm^2 radiation field, this by finding the required adjustments to the electron source parameters namely the spot size, shape and energy distribution. The MC simulation tool Geant4 version 4.9.4 was used with rocks clustering software and Geant4 MPI Interface to parallelize our Geant4-based application. In this work, we have developed a user code for Saturne 43 LINAC simulation. This code has the capabilities to run multiple simulations at the same time, perform our own variance reduction techniques, writing and reading phase-space data using IAEA routines, and calculate dose distributions in a water phantom. In aim to speed up the treatment head simulation, we have developed two variance reduction techniques; the first one is based on stacking mechanism and called GAMMATEC, where the second one is a particular implementation of bremsstrahlung splitting and called BREMSPE. The combination of these two techniques can reduce required CPU time about five times. After optimization it was found that the appropriate mean energy, sigma and its full width at half maximum are 11.5 MeV, 0.4 MeV and 1.177 mm.

KEYWORDS: Geant4, LINAC, MPICH2, Rocks Cluster, Monte Carlo.

1 INTRODUCTION

Monte Carlo (MC) [1] is a technique for simulation of the passage of particles through the treatment head of a linear accelerator (LINAC) used in radiotherapy. It is widely accepted that MC simulation of radiation transport is one of the most accurate methods for predicting absorbed dose distributions in radiation therapy. In the past, the major disadvantage of the MC method is principally due to a long computational time and a high cost of powerful computer. But in the present it has become much less severe due to the rapid increase in speed and decrease in cost of computers. There are several general purpose MC codes used for radiation transport simulation such as Electron Gamma Shower Version 4 (EGS4), Monte Carlo N-particle (MCNP), PENELOPE and Geant4.

Geant4 toolkit [2] is a simulation toolkit for the simulation of the passage of particles through matter. Its areas of application include medical and space science, high energy and accelerator physics. The main players in its development are in the discipline of high-energy physics, combining the efforts of more than 100 workers from facilities such as CERN in Europe, KEK in Japan and SLAC in the US. The Geant4 code calculates a physical evolution of each particle step-by-step by Monte-Carlo method. Geant4 has components to model the geometry, the materials involved, the fundamental particles of interest, the generation of primary particles for new events, the tracking of particles through materials and external electromagnetic fields, the physics processes governing particle interactions, the response of sensitive detector components, the generation of event data, the storage of events and tracks, the visualization of the detector and particle trajectories. The verity is, Geant4 is indeed very powerful, but also very complex. The acquisition curve is both steep and long. A superficial knowledge of C++ is insufficient to optimally use the toolkit. Currently Geant4 simulations are painfully slow; it can take up to week on our fastest computer to accurately simulate problems such as patient-dose calculations in radiotherapy.

Geant4 version 4.9.4 has been considered to simulate a Saturne 43 LINAC, used at CEA LIST LNHB for 12 MV photon beam for field size of 10×10 cm^2. In this paper we present in full details the methodology used to find wanted initial electron beam properties, using rocks clustering software [3] to launch multiple simulations at same time. Also we provided the description

Corresponding Author: J. EL Bakkali (bahmedj@gmail.com)

of our own variance reduction methods used to decrease the CPU time consumed by our simulation programs. The MC Geant4 simulation was divided into two parts; the simulation of the LINAC treatment head using our program called ParaSaturne43Writer and the calculation of dose distributions in a homogeneous water phantom using our program called ParaSaturne43Reader.

The accuracy of the calculation of the beam data from MC simulation depends on the accurate input data for modeling the accelerator treatment head. The basic information required for a MC simulation of a treatment head is the specifications of the accelerator geometry such as positions, directions, materials that can be supplied by manufacturer. The least known parameters in a MC simulation of a treatment head are often the properties of the initial electron beam because the manufacturers rarely supply any information for this parameter. Thus, the knowledge of the characteristic of incident electron beam parameters such as the mean energy, sigma and its full width at half maximum is critical to validate Geant4 code for a typical treatment head employed in radiotherapy. In order to compare the calculated data namely percentage depth dose and cross beam profile with measured ones in a homogeneous water phantom (40x40x40 cm^3), the gamma criterion was considered. The tolerance value assigned to relative dose was fixed at 1.5% and the tolerance value for measured positions was considered as 0.1 cm.

2 MATERIALS AND METHODS

2.1 MODELING THE HEAD OF LINAC

2.1.1 SIMULATION PROGRAM

We have developed our own C++ code dedicated to simulate Saturne 43 LINAC treatment head and called ParaSaturne43Writer. This C++ program has the capabilities to:

- Construct model geometry.
- Launch multiple simulations at same time; the parallelization of our program was established using rocks cluster software with Geant4 MPI Interface [4]. Geant4 MPI Interface is a native interface with MPI libraries, with this interface Geant4-based simulation can be parallelized with different MPI compliant libraries, such as LAM/MPI, OpenMPI, and MPICH2. The last one is adopted in our cluster.
- Perform our own reduction variance methods: BREMSPE and GAMMATEC.
- Store the simulation outline in a phase-space file with IAEA format [5], the plane where the particles were stored was located just after jaws components (SSD 50 cm).
- Visualize the whole geometry using the two graphics system namely RayTracer and HeppRep.

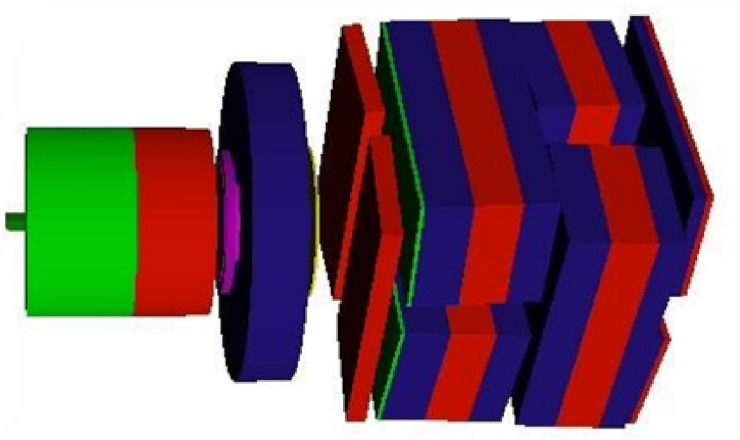

Fig. 1. Illustrating head Geometry using RayTracer

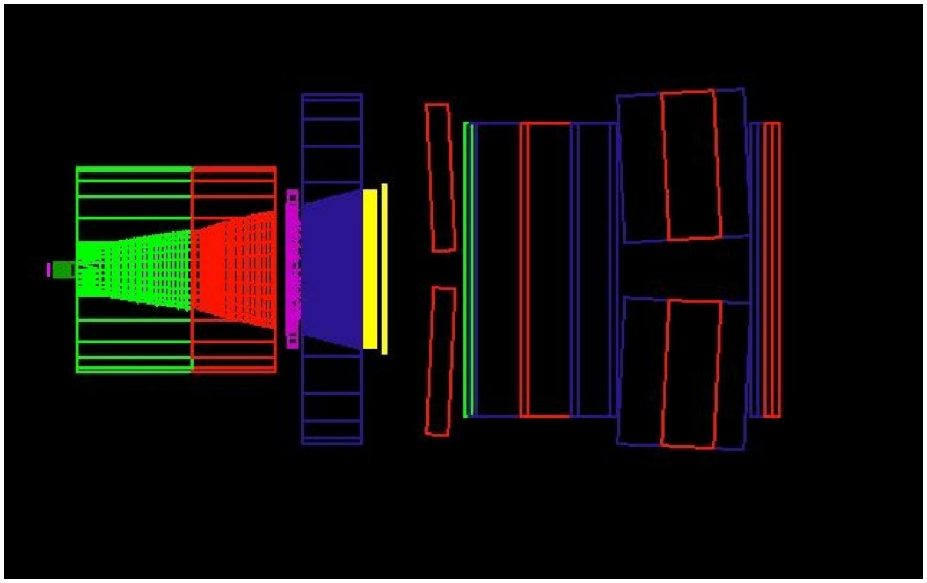

Fig. 2. Illustrating head Geometry using HeppRep

The accelerator head shown in Figure 1 and 2 with different system of visualizations consists of the following elements:

1. A Titanium window.
2. A target.
3. A primary collimator.
4. A secondary collimator.
5. A flattening filter.
6. An ionization chamber.
7. An aluminum plaque.
8. Secondary movable collimators (jaws).

Since the contents of main() program will vary according to the necessity of a given simulation application and must supplied by the user. Thus, we have created our own implementation of main() program that required to build a simulation which able to do the parallelization of independent runs and the Geant4 MPI Interface library was included to build this parallelization. We present now an extract of our code that describes the implementation of our main() program which provides a parallelization of independent runs:

```
G4String command = "/control/execute ";
G4String fileName ;
G4int rank= G4MPImanager::GetManager()-> GetRank();
if (rank==0) {fileName="12.3-0.56-0.5";}
if (rank==1) {fileName="12.2-0.54-0.5";}
if (rank==2) {fileName="12.1-0.52-0.5";}
if (rank==3) {fileName="12-0.50-0.5";}
if (rank==4) {fileName="11.9-0.48-0.5";}
if (rank==5) {fileName="11.8-0.46-0.5";}
if (rank==6) {fileName="11.7-0.44-0.5";}
if (rank==7) {fileName="11.6-0.42-0.5";}
if (rank==8) {fileName="11.5-0.40-0.5";}
if (rank==9) {fileName="11.4-0.38-0.5";}
if (rank==10){fileName="11.3-0.36-0.5";}
 UImanager->ApplyCommand(command+fileName+".mac");
```

2.1.2 CHOOSING PRIMARY INCIDENT GENERATOR

As known modeling sources in realistic setup soon required relatively more complex sources, G4ParticleGun cannot be used in this case. The general particle source (GPS) offers as predefined many common options for particle generation (energy, angular distribution, and spatial distribution). GPS is a concrete implementation of G4VPrimaryGenerator as G4ParticleGun but more advanced. As we can see in below example, how it is easy to fill parameters related to electron beam proprieties using GPS generator:

```
/gps/particle e-
/gps/direction 0 0 1
/gps/pos/type Beam
/gps/pos/centre 0. 0. -28 cm
/gps/pos/halfx 0 mm
/gps/pos/halfy 0 mm
/gps/pos/sigma_x 0.5 mm
/gps/pos/sigma_y  0.5 mm
/gps/ene/type Gauss
/gps/ene/mono 11.5 MeV
/gps/ene/sigma  0.4 MeV
```

Note that Geant4 code uses the sigma parameter instead of FWHM parameter for Gaussian spatial and Gaussian energy distributions.

2.1.3 CHOOSING APPROPRIATE PHYSICS LIST

Geant4 provides several physics lists, from geant4/source/physics_lists/builders we can found six model. The Table 1 shows the use case [6] of each model. emstandard_opt2 has been chosen as default physics model, which have been optimized to model transport of photons and charged particles for radiotherapy applications. In order to enhance bremsstrahlung photons, we have implemented our own bremsstrahlung splitting method, called BREMSPE, the description of this method can be found in “reduction variance methods” section.

Table 1. Physics model and their use case

model	Description
emstandard_opt0	recommended standard EM physics for LHC.
emstandard_opt1	best CPU performance standard physics for LHC.
emstandard_opt2	recommended for precision medical electron accelerator studies
emstandard_opt3	best current advanced EM options.
emlivermore	low-energy EM physics using Livermore data.
empenelope	low-energy EM physics implementing Penelope models.

2.1.4 CUT PRODUCTION ADJUSTMENT

Each kind of particle has a suggested production threshold or cut, the cut value defines the extent to which a particle is tracked, below production cut no secondary particle is produced but the energy loss is computed as deposited energy at the end of the step. In Geant4 the production threshold is defined in distance converted into energy based on the material. Two different cuts may be set: one for gammas that affects the bremsstrahlung process and one for electrons that affects the ionization process. The global photon cutoff energy was set as 10 KeV; this energy was used as the bremsstrahlung creation threshold and photon transport cutoff. While the energy cutoff for electron transport was set as 183 KeV.

The Table 2 describes the cut values in distance range assigned to all relevant materials composed the treatment head.

Table 2. Cut value for all materials used in treatment head

Material	production threshold (mm)	
	electron/positron	gamma
XC10	0.068	0.25
WNICU	0.0412	0.0185
Tungsten	0.037	0.0148
Titanium	0.067	0.339
Stainless_steel	0.0675	0.252
Pb	0.0652	0.0212
Kapton	0.28	21.6
Al	0.172	2.2

2.1.5 REDUCTION VARIANCE METHODS

Variance reduction techniques (VRTs) are used to reduce computing time taken to calculate a result with a given variance. Since for Geant4 code the user is free to implement their own biasing techniques; we have implemented our own reduction variance methods used to decrease CPU time consuming by treatment head simulation. We discuss in this section these two powerful methods used to tune our simulation. Thus, we can save a lot of CPU time by not tracking the particles that are not going to contribute to the results. We have defined in a clear way which is the results we don't want to change when applied this two methods; the number of particles reaching a scoring region was considered as observer.

BREMSPE (Bremsstrahlung **S**plitting for **P**rimary **E**lectron)

The implementation of this method is based on the class BremSplitting from HandOn5 [7] example. The bremsstrahlung splitting process has been established just for secondary photons resulting from only primary electrons bremsstrahlung interactions and our simulation efficiency was improved considerably when this technique was applied. On the other hand, we have done some changes in physics list, particularly in the implementation of emstandard_opt2 model, in order to make the bremsstrahlung splitting process possible. Our interest was to enhance photon production by applying splitting when a bremsstrahlung interaction occurs, but as mentioned above the splitting process will be take only secondary photons created when the bremsstrahlung process is invoked by primary electrons.

Al thought the number of splitting is a essential parameter which affect the simulation efficiency. Thus, we have doing many simulations where the number of bremsstrahlung splitting was the parameter to be evaluate. We have found that if the photons was split up 60 times, the simulation efficiency increases approximately two times.

GAMMATHEC (**GAMMA THE**TA **C**UTOFF)

We have developed this technique which based on stacking mechanism; the purpose was to manage the behavior of the stacks by implementing a G4UserStackingAction class. Secondary particles are created as G4Track objects and they are pushed on the stack using C++ standard containers. We can define the track not to be stacked so to be killed. Proper selection of tracks with well designed stack management provides significant efficiency increase of the entire simulation. This technique takes the action required to kill inutile photons according to their angles, this action not will take all photons who participated in our simulation but only photons those leaving target and not reaching (or their chance to reach this plane are considerably low) the scoring plane located just after jaws (at SSD 50 cm); an angle threshold has been assigned to photons those leaving the target. Although our interests was to study the impact of applying photons angle threshold in the speed of our treatment head simulation, since we have do an analysis to see a spectrum that describes the gamma angular distribution below jaws (at SSD 50 cm) as shown in Figure 3.

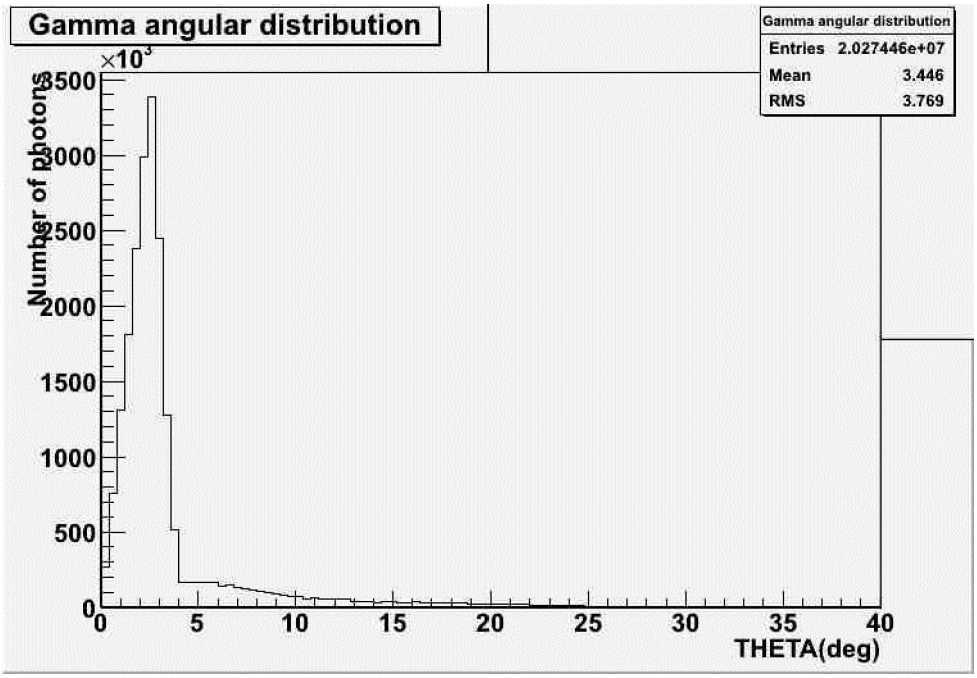

Fig. 3. Gamma angular distribution below Jaws (SSD 50cm)

The main purpose of this technique is to kill inutile tracks (photons originally created in the W-Target) those establish one of the following conditions:

A) If the track is created in W-Target and propagates in the negative z direction.

B) If the track has an angle greater than the angle threshold. The value of this threshold can be retrieved from Figure 3 which it provides a spectrum of gamma angular distribution below jaws; we can assume that the threshold angle is nearly equal to 22 degree. After applying this technique, the computing time taken by treatment head simulation was decreased about two times.

In the Table 3 we resume the set of parameters used for the treatment head simulation.

Table 3. Parameters used for the treatment head simulation

Parameter	value
Physics list	emstandard_opt2
Electron/Positron cut	10.058 KeV
Photon cut	183.6 KeV
BREMSPE, Split number	60
GAMMATHEC, Angle threshold	22 degree

2.2 CALCULATION OF THE DOSE DELIVERED IN THE PHANTOM

2.2.1 PHANTOM GEOMETRY

The Figure 4 shows the geometry of a homogeneous water phantom (40x40x40 cm^3) using HeppRep visualization system. The thickness of PMMA crossed by the beam is 4 mm (15 mm for the all other walls of the phantom). The distance from the top of the target to the external entrance window of the water phantom is 90 cm. The depth in water is expressed from the external side of the entrance window of the phantom. Thus, a measurement of 10 cm depth means 4 mm of PMMA plus 9.6 cm of water. The data used for comparison were the central axis percentage depth dose (The ratio of the dose at a given

point on the central axis of an electron beam to the maximum dose on the central axis multiplied by 100) and the cross beam profile at 10 cm depth.

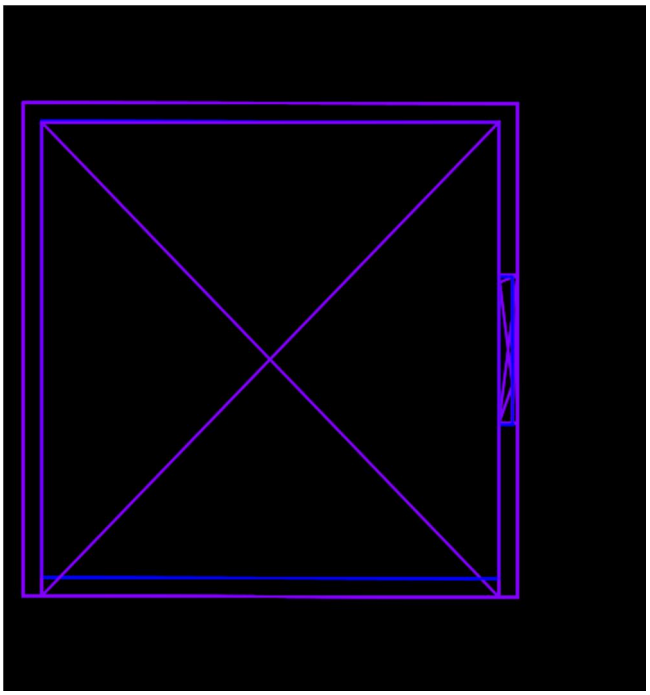

Fig. 4. Illustrating phantom Geometry using HeppRepp

2.2.2 SIMULATION PROGRAM

We have created our own simulation program called Parasaturne43Reader, this program has the Capabilities to:

- Simulate doses deposition in water phantom.
- Run multiple simulation at time (eleven independent runs), the parallelization of our program was established by using rocks cluster software with GEANT4 MPI interface.
- Read phase-space files using IAEA routines, the obtained phase-space files were used as an input to the Monte Carlo dose calculations.
- Generate the beam data of 12 MV photon beams, i.e. the central axis percentage depth doses, cross beam profiles.
- Visualize the whole geometry using HeppRep graphics system.

The main purpose of this program was to simulate energy deposit in a phantom filled with water for a typical LINAC (Saturne 43) used for intensity modulated radiation therapy. The 12 MV dose calculations were performed for field size 10 x 10 cm^2 and the voxel size for the 40 x 40 x 40 cm^3 water phantom was 5 x 5 x 5 mm^3. The simulation was run in parallel on a 11 node Linux cluster. The voxelised phantom size was 11.25 x 11.25 x 11.75 cm^3 and the number of voxels along x, y and z were 45, 45 and 47, respectively.

Useful efficiency improving techniques such as histories recycling is available in G4IAEAPhspReader [5] class, it can improve the efficiency of dose calculations without significantly changing the results. The Table 4 describes the set of parameters used in dose calculations program.

Table 4. Parameters used for dose calculations simulation

Parameter	value
Physics list	emstandard_opt2
Electron/Positron cut	10 KeV
Photon cut	10 KeV
Histories recycling	24 times

2.3 METHODOLOGY OF STUDY

It is well known that the least known parameters in a MC simulation of the treatment head are often the electron source parameters. Thus, our work consist to find required adjustment to this parameters related to the electron spot for a 12 MV photon beam, namely the spot size, shape and energy distribution for a single energy and a single field (12 MV photon; 10x10 cm^2 field at 100 cm from the source; 10 cm depth in water). At the first time we have followed the suggested methodology proposed by Verhaegen and Seuntjens [8], but unfortunately we have not arrived to optimize electron beam proprieties, even so we have advised the following method for selecting the electron beam properties to be evaluated:

1. The electron beam is characterized by a Gaussian-shaped energy spectrum.
2. We started with the following initial electron beam properties: 11.3 MeV as mean energy, sigma equal to 0.36 MeV, and a 2-D Gaussian distribution in the plane XY, with full width at half maximum (FWHM) fixed at 1.177 mm (Standard deviation = 0.5 mm).
3. For each independent run, we increase simultaneously the energy by 0.1 MeV and the sigma by 0.02 MeV. The FWHM value was fixed at 1.177 mm. The rocks clusters software was employed to run multiple simulations at same time and the Geant4 MPI Interface was considered to parallelize our simulation programs.
4. Gamma index program was employed to select the good electron beam proprieties between those suggested in this study.

In Table 5 we show the eleven initial electron beam proprieties used in this study.

Table 5. Properties of the initial electron beams

Gaussian energy parameters		*Gaussian spatial parameters*	
Mean (MeV)	*Sigma (MeV)*	*Mean(mm)*	*FWHM(mm)*
11.3	0.36	0	1.177
11.4	0.38	0	1.177
11.5	0.40	0	1.177
11.6	0.42	0	1.177
11.7	0.44	0	1.177
11.8	0.46	0	1.177
11.9	0.48	0	1.177
12	0.5	0	1.177
12.1	0.52	0	1.177
12.2	0.54	0	1.177
12.3	0.56	0	1.177

3 RESULTS AND DISCUSSION

3.1 LINAC HEAD SIMULATION SPEED UP

As stated in early paragraphs that Geant4 code is painfully slow; it can take up to week on our fastest computer to accurately simulate problems such as patient-dose calculations in radiotherapy. To accelerate the treatment head simulation we have developed the two variance reduction techniques namely BREMSPE, in order to increase the production of photons by the bremsstrahlung process and GAMMATHEC that use the stacking approach. In order to ensure that these two techniques can be safely used without biasing the simulations, we have launched two kinds of simulations with and without VRTs and a comparison between calculated data for these two kinds of simulations has been established. The Figure 5 shows the percentage difference between PDD data points for two kinds of simulations; all data points have a percentage difference less than 0.9%.

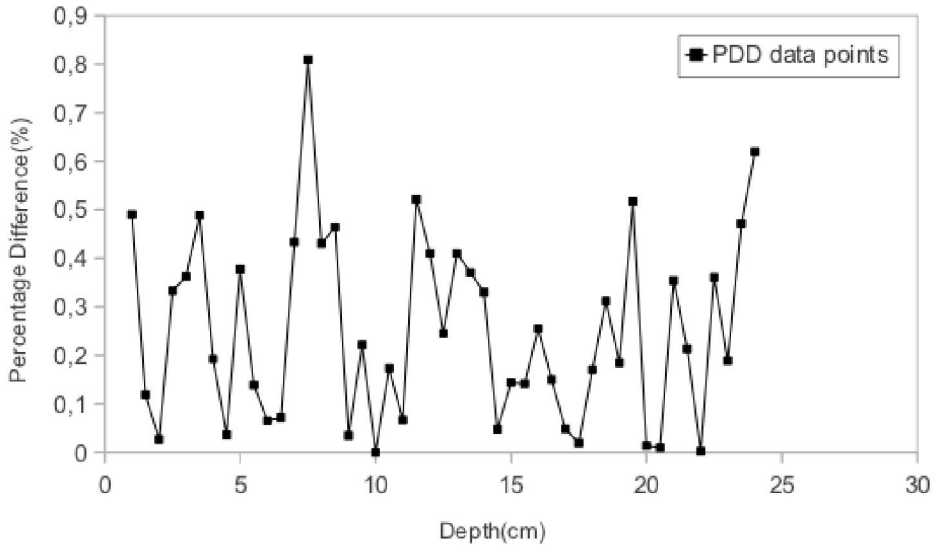

Fig. 5. Comparison between PDD data points for simulation with/without VRTs

Now we will see how these two methods can reduce CPU time required by treatment head simulation. The Table 6 gives such results.

Table 6. The numbers of bremsstrahlung photons per incident electron, the simulation times, and and the rates of photons reaching the scoring plan below jaws

Number of events processed: 10000	Photons /incident e-	CPU time /incident e-	Photons /second	Efficiency increase
Referenced simulation	0.0042	0.000457	9.19	1
BREMSPE	0.0883	0.00511	17.279	1.88
GAMMATHEC	0.0046	0.000262	17.55	1.91
BREMSPE+*GAMMATHEC*	0.083	0.001823	45.529	4.95

As we can conclude; that this two methods able to reduce the CPU time taken to simulate Linac treatment head and the simulation efficiency was found to be five times higher when using these two techniques.

3.2 PHOTON ENERGY SPECTRA

The MC method is a convenient and accurate tool allowing the calculation of spectra possessing the essential features of real spectra. Photon energy spectra of Saturne 43 treatment head was calculated with Geant4 (version 4.9.4), using GPS generator. The X-ray energy spectrum used was obtained after a 12 MV Gaussian electrons hit with the tungsten target.

The Figure 6 shows the results obtained for energy dependent flux of a 12 MV photon beam at 90 cm SSD. The X-ray energy spectrum was created by simulating 10^9 photons. The Energy bins have an homogeneous width of 0.1 MeV.

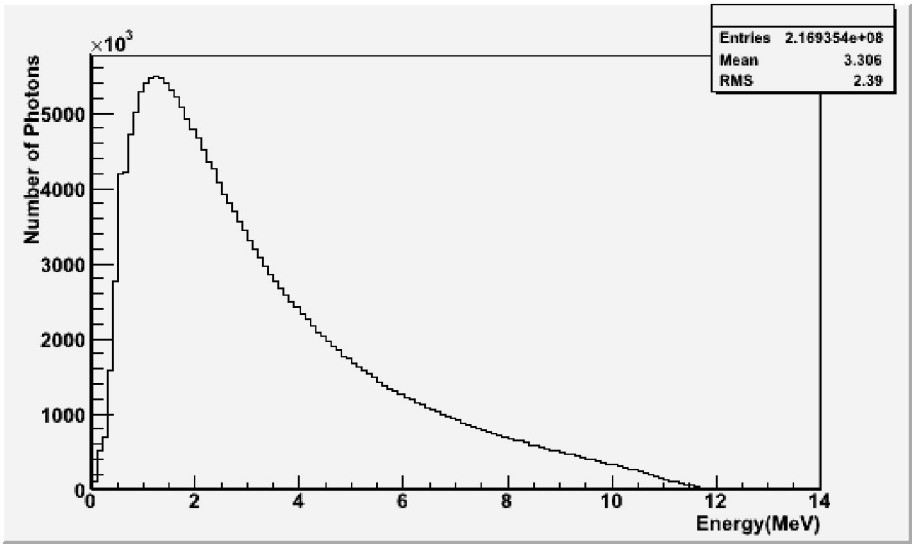

Fig. 6. Monte Carlo calculated spectrum photon energy spectrum at SSD 90 cm for 12 MV photon beam

The weighted mean energy of photon spectrum is 3.30 MeV which is comparable to the value 3.29 MeV published by M.Zoubair [9] and the value 3.24 MeV published by Blazy et al. [10] for a similar Linac.

3.3 COMPARISON BETWEEN SIMULATED DATA AND MEASURED ONES

The determination of absorbed dose within a patient is based on the measurement of absorbed dose in water, since mean electron density of soft tissues is close to that of water. The correction factor is given in the dosimetric code of practice and is based on the value of a beam quality index (QI). QI is defined for a fixed source-to-skin distance, SSD, of 100 cm, with the surface field size defined at 10×10 cm^2. The quality index for this definition is the ratio of depth doses on the central axis, at 20 cm and 10 cm, respectively (D20/D10) [11]. As mentioned in early paragraphs, the adjustment was performed by comparing our simulated data calculated in a homogeneous water phantom (40x40x40 cm^3) with the experimentally measured cross beam profile and the percentage depth dose (PDD) curves for a 10x10 cm^2 field. These data are provided by LNHB. In order to compare the results and to select the requested parameters (energy spectrum etc), the gamma criterion was used.

We have suggested our methodology to establish the electron beam tuning stage; the results of our study for selected electron beams proprieties are plain explained in the Table 7 where the tolerance value assigned to relative dose was fixed at 1.5% and the tolerance value for measured positions was considered as 0.1 cm.

Each phase-space file generated by ParaSaturne43Writer program for each electron beam proprieties announced in Table 5, contains in average about 4.5 millions particles as a consequence of simulation of 25 millions histories where the bremsstrahlung photon was split up 60 times. The average CPU time consuming by the ParaSaturne43Writer program was about two days. The Table 7 resumes the outputs obtained from ParaSaturne43Reader program where the number of histories was fixed at 5.10^8 particles, each one was recycled 24 times, the simulation average CPU time consuming by ParaSaturne43Reader program was about six days and the average statical uncertainly were less than 0.2% for PDD and less than 0.8% for cross beam profile. Parasaturne43Reader generate at the end of simulation two text files contains information about simulated data, one for percentage depth dose and one for cross beam profile.

Table 7. Comparison between calculated data for different electron beam proprieties used in the study

Beam proprieties			Index of Gamma < 1%		Index of Gamma < 0.5%		$TPR2_{0/10}$	Z_{Dmax} (cm)
Energy (MeV)	Sigma (MeV)	FWHM (mm)	PDD	Profile	PDD	Profile		
Measure	--	--	– –	– –	– --	– –	0.6282	2.5
11.3	**0.36**	**1.17**	97.90%	77.8%	70.2%	66.7%	0.6181	2.0
11.4	**0.38**	**1.17**	97.90%	80.4%	89.40%	58.7%	0.6210	2.5
11.5	**0.40**	**1.17**	97.90%	91.1%	95.7%	77.8%	0.6289	2.5
11.6	**0.42**	**1.17**	100%	73.9%	91.50%	56.5%	0.6236	2.5
11.7	**0.44**	**1.17**	100%	82.2%	91.50%	60.0%	0.6285	2.5
11.8	**0.46**	**1.17**	97.90%	86.7%	95.70%	71.1%	0.6327	2.5
11.9	**0.48**	**1.17**	100%	86.7%	89.40%	68.9%	0.6287	2.5
12	**0.50**	**1.17**	100%	80.0%	97.90%	62.2%	0.6295	2.5
12.1	**0.52**	**1.17**	100%	88.9%	100%	75.6%	0.6268	2.5
12.2	**0.54**	**1.17**	100%	77.8%	100%	53.3%	0.6303	2.5
12.3	**0.56**	**1.17**	100%	80.0%	89.40%	68.9%	0.6355	2.5

From these results one notices that the appropriate mean energy, sigma and its FHWM are 11.5 MeV, 0.4 MeV and 1.177 mm, as we can see for this electron beam proprieties that the simulated data agreed well with measured data, except data points who located in the penumbra region, where the dose profile has a high gradient, after all, 91.1% of the calculated data points seems agree with experience within 1.5% /1 mm. The percent difference in this region was about 6%. The ambiguities may possibly come from inaccuracies in the simulation geometry, the approximation of the initial source configuration or uncertainties in the measured data. The Figure 7 shows the cross beam profiles for measured and calculated data points.

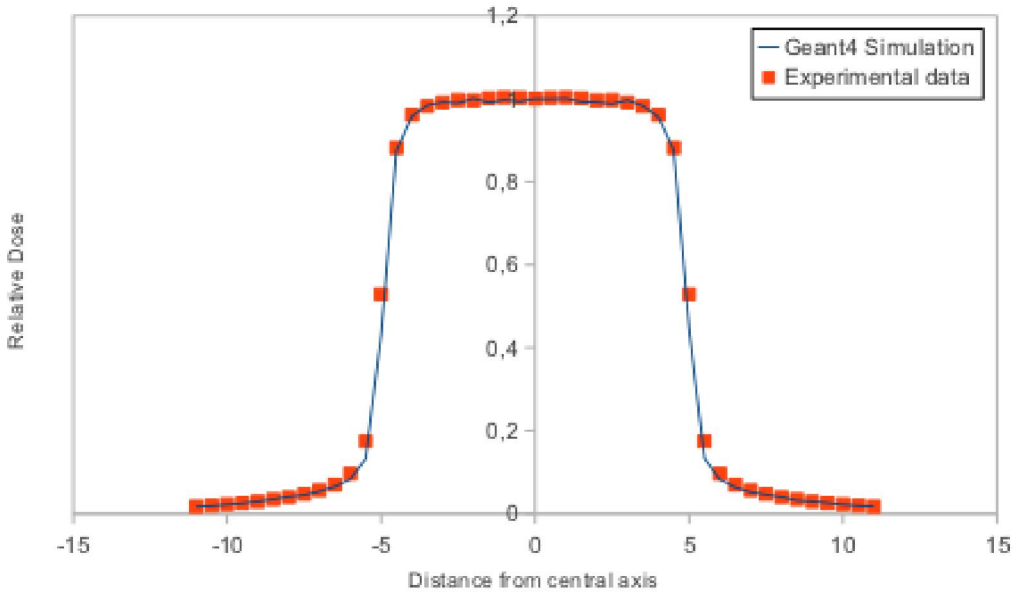

Fig. 7. Comparison of calculated and measured dose profile at the depth of 10 cm due to 12 MV photon beam in homogeneous water phantom, for a 10 × 10 cm^2 field size

For the depth dose curve, it's seems that 97.6% of the calculated data points agree within 1.5% / 1mm with the experimental measurements for depth 10 cm, so except the first data point all others ones were accepted, The ambiguities may possibly caused by inaccuracies in the approximation of the initial source configuration or uncertainties in the measured data. The Figure 8 shows the depth doses curves for measured and calculated data points.

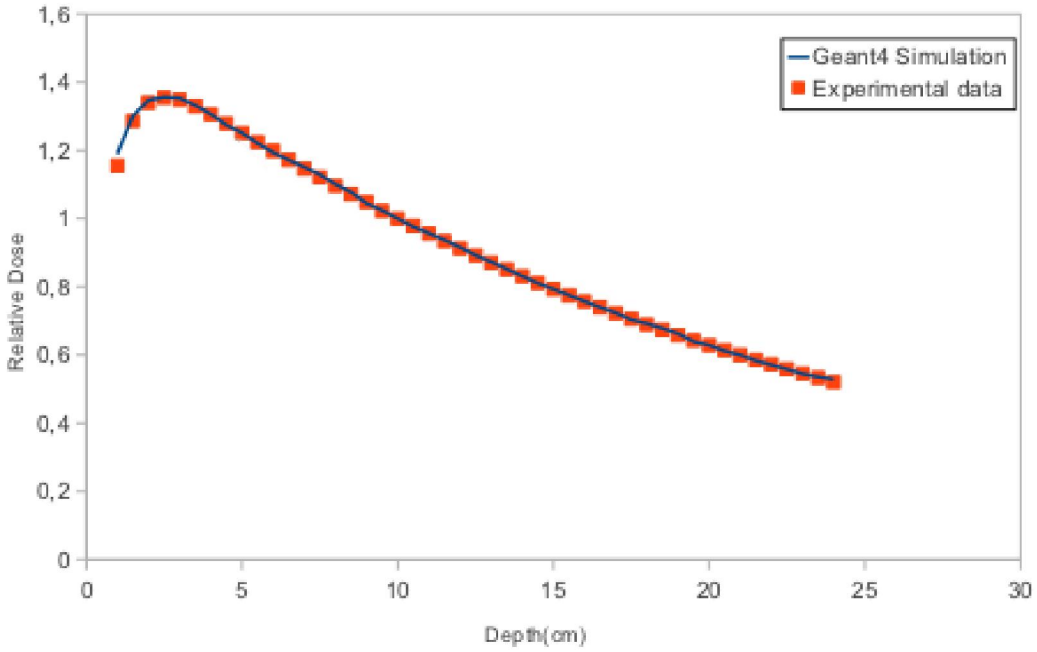

Fig. 8. Comparison of calculated and experimental relative depth dose due to 12 MV photon beam in homogeneous water phantom, for a 10 × 10 cm^2 field size. Results are normalized to the dose at the depth of 10 cm

4 CONCLUSION

This theoretical study has shown that it is possible to use Geant4 to model a typical linear accelerator used in radiotherapy with accuracy within 1.5% / 1mm. The goal was to evaluate and elaborate the ability of Geant4 to model the 12 MV photon beam from a medical linear accelerator Saturne 43 installed at CEA LIST LNHB and configuring a 10×10 cm^2 radiation field. During this work we have observed that MC Geant4 is very slow, even so we have developed two variance reduction techniques namely BREMSPE and GAMMATEC to speed up the treatment head simulation with a factor of five times. The knowledge of the initial electron beam proprieties is crucial to validate such linear accelerator. Thus, the parallelization of our Geant4-based application using rocks clustering software and Geant4 MPI interface has been considered to running multiple simulations at same time; each simulation has a different electron beam proprieties then the appropriate one was selected using gamma criterion.

REFERENCES

[1] D. W. O. Rogers, "Monte Carlo techniques in radiotherapy," *Physics in Canada*, vol. 58, n° 2, p. 63–70, 2002.

[2] S. Agostinelli et al., "Geant4—a simulation toolkit," *Nuclear Instruments and Methods in Physics Research A*, Volume 506, Issue 3, 1 July 2003, Pages 250–303.

[3] Rocks Clusters, *Open-Source Toolkit for Real and Virtual Clusters*, 2013. [Online] Available: http://www.rocksclusters.org/wordpress/ (2013)

[4] K. Murakami, *Geant4 MPI Interface*, European Laboratory for Particle Physics. [Online] Available: http://geant4.web.cern.ch/geant4/geant4_public/source/geant4/ (2013)

[5] M. A. Cortés-Giraldo, J. M. Quesada, M. I. Gallardo and R. Capote, "An implementation to read and write IAEA phase-space files in Geant4based simulations," *International Journal of Radiation Biology*, Jan 2012, Vol. 88, No. 1-2, pp. 200-208.

[6] D Sawkey et al., "Comparison of electron scattering algorithms in Geant4," *Physics in Medicine and Biology*, Volume 57, Number 11, pages 3249, 2012. doi:10.1088/0031-9155/57/11/3249

[7] T. Aso, J. Tinslay, T. Koi, *Hands-on 5 Alternative Physics Lists, Bremsstrahlung Splitting*, SLAC National Accelerator Laboratory, Menlo Park, CA, Stanford University, 2010.
[Online] Available: http://geant4.slac.stanford.edu/PueblaTutorial2010/HandsOn5 (2013)

[8] Verhaegen F. and Seuntjens J, "Monte Carlo modelling of external radiotherapy photon beams," *Physics and Medical Biology*, vol. 48, n° 21, p. 107-164, 2003.

[9] M. Zoubair, T. El Bardouni, O. Allaoui, Y. Boulaich, B. El Bakkari, C. El Younoussi, H. Boukhal, E. Chakir, "BEAM: A Monte Carlo Code to Simulate Radiotherapy Treatment Units," *World Journal of Nuclear Science and Technology*, vol. 3, no. 1, pp. 14-21, 2013.

[10] D. W. O. Rogers, B. A. Faddegon, G. X. Ding, C. M. Ma, J. Wie, and T. R. Mackie, "BEAM: A Monte Carlo Code to Simulate Radiotherapy Treatment Units," *Medical Physics*, vol. 22, no. 5, pp. 503-524, 1995.

[11] IAEA, *Radiation Oncology Physics: A Handbook for Teachers and Students*, International Atomic Energy Agency, 2005.