Project Report on

Monte Carlo Simulation of Linear Accelerator for Dosimetry Analysis

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Abstract: Radiation therapy is a type of cancer treatment that uses beams of intense energy to kill cancer cells. The equipment most often used for the procedure is the Linear Accelerator (LINAC), which produces beams of X-rays. It is required to evaluate the dose distribution of the LINAC machine before applying radiation therapy to the human body. This project is aimed at achieving the same. The algorithms to evaluate dose distribution for radiotherapy planning will be based on Monte Carlo methods. In terms of accuracy and providing realistic results, Monte Carlo methods have proven to be promising. The project is in collaboration with MVR Cancer Center at Calicut and aims to simulate an 6Mev Elekta LINAC machine for its dose evaluation.

1 Introduction

Cancer is one of the deadliest diseases in the world today. Cancerous cells are formed when cells in the body fail to die and instead have an abnormal and uncontrollable growth. With over 100 types of cancer reported to date, this disease can affect any part of the body. One of the major techniques for cancer treatment is radiotherapy.

Radiotherapy uses waves of energy, such as light or heat, to treat cancers and other tumours and conditions. The most commonly used machine in radiotherapy is the Linear Accelerator (Linac). A LINAC produces X-rays in the range of 5-30 MeV.

The head of a LINAC consists of a target, primary collimator, flattening filter, ionisation chamber, mirror,MLC- Multi Leaf Collimator and secondary collimator (as in Figure 2). It produces beams of radiation to the affected area of the patient body to kill the cancer cells. Once the cancer is diagnosed, the dose of the radiation will be determined from the CT(Computed Tomography) images taken from the patient as part of the treatment.

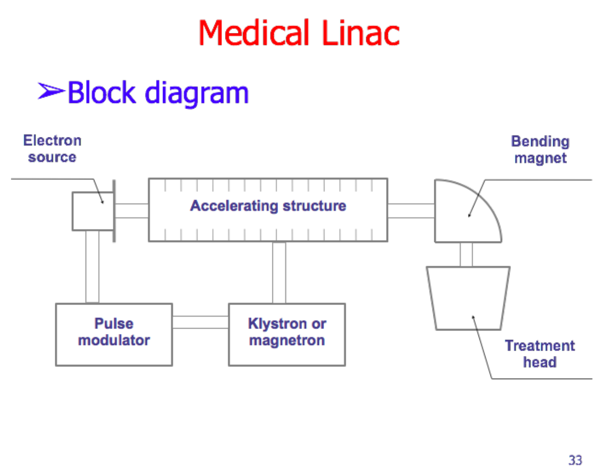

Fig 1: Block Diagram of Medical LINAC electron acceleration structure.

In this project, we initially try to simulate the LINAC head for beam production. For the production of beams, the phase space can be used. The phase space contains information such as energy, position, direction, etc. of millions of particles. In the next stage, the particles which constitute the phase space are transported to the patient or phantom and the dose distribution is calculated.

To calculate the precision of the dose, several methods are used including the use of physical phantoms. We use a software approach for the same by deploying the Monte Carlo (MC) simulation method. This method relies on repeated random sampling to obtain numerical results and can help us to acquire accurate results.

The accuracy depends on the number of histories, and consequently, the simulation time. To reduce the simulation time, parallel computing will have to be used, which can be implemented in Geant4 using suitable libraries.

2 Problem statement

Monte Carlo simulation of a linear accelerator for treatment planning of cancer:

1. Simulation of radiation beam production in LINAC.
2. Simulation of beam transport from LINAC head to phantom.
3. Dosimetry analysis of radiation on phantom.

3 Literature Review

3.1 Background

Presently, there are two major vendors for the LINAC machines - Elekta and Varian (Figure 2), both of which use microwave technology to accelerate electrons in a waveguide. The electron gun attached to the waveguide acts as the electron source. The electrons are accelerated down the structure by pulses of microwave from a magnetron in the case of Elekta or klystron in the case of Varian (Figure 2). The electron beams, on leaving the accelerator tube, are bent by magnetic fields in varying angles depending on the machine vendor. Once the electron beam hits the target, X-ray beams are produced.

Primary collimators, which are situated right below the target, direct the beam in the direction of the treatment and reduce leakage. At the lower end of the primary collimator is the flattening filter, which reduces the beam intensity in the centre to provide uniform radiation intensity distribution. The beam then enters the ionization chamber, from which measurements of the amount of radiation are taken and uniformity of the beam is controlled.

The backscatter plate (In Elekta Synergy Platform LINAC) avoids backscattered radiation from secondary collimators. The mirror placed on beam central axis shows the position of the radiation beam and enables patient set-up.

The next focus is to target the radiation dose to cancer cells as precisely as possible to minimize side effects and avoid damaging normal cells. Imaging tests are used to contour the shape and location of one's tumour and define its boundaries.

The customized beam is usually shaped by a multileaf collimator (MLC) that is incorporated into the head of the machine. The positioning of the MLC vary for Elekta and Varian Linacs (Figure 2). The patient lies on a moveable treatment couch and lasers are used to make sure the patient is in the proper position. The treatment couch can move in many directions including up, down, right, left, in and out. The beam comes out of a part of the accelerator called a gantry, which can be rotated around the patient. Radiation can be delivered to the tumour from many angles by rotating the gantry and moving the treatment couch.

3.2 Related Works

Several works have been done in the field for the simulation of Linear Accelerators, some of which are briefed below.

In a work done by Kagri Yazgan and Yigit Cecen [1], Monte Carlo N-particle (MCNP) code was used to simulate a medical electron linac gantry. Flux, dose, and spectrum analyses were performed for filtered

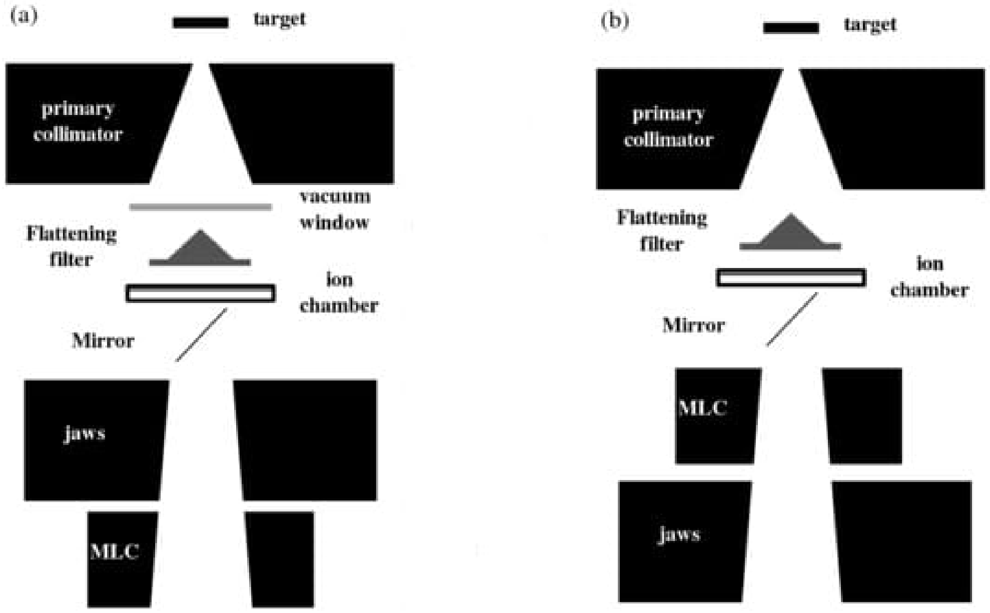

Fig 2: a) Geometry of the VARIAN LINAC b)Geometry of Elekta LINAC

and FFF (Flattening Filter-Free) systems. Monte Carlo simulations were conducted to compare experimental and theoretical values for quality assurance of the model. It was found that the average photon energy was 3.54 times higher in the filtered system than in the FFF systems and the errors in the comparison of simulation-experimental values were only 0.22%. Mohammad Taghi Bahreyni Toossi et al. [2] on the other hand used the MCNP-4C to simulate electron beams from Neptun 10 PC medical linac. They measured and calculated output factors for 6, 8 and 10 MeV electrons by using Wellhofer-Scanditronix dose scanning system.

Yahya Tayalatia et. al [4] developed a computational model for 6MV Elekta Synergy Platform linac using GATE Monte Carlo software. The simulation was carried out using v6.2 of GATE (Geant4 Application for Tomographic Emission), built on top of GEANT4 simulation toolkit. The simulated depth dose profiles were in good agreement with the measured ones, with uncertainty less than 1.6%. Alex C. H. Oliveira et al. [8] worked on the evaluation of dose distributions in radiotherapy planning. They aimed at creating a computational model of the head of a 6 MeV Linac using the MC code Geant4 for the generation of phase spaces. They assessed and analyzed the beam quality from the information taken from the phase space.

4 Design

1. Flowchart of Geant4's basic simulation of Linac. Figure 3 corresponds to the basic work flow of the partially simulated medical linac from Geant4 in c++. The main function reads a mac file as input which contains the specifications like the nominal beam energy of linac, type of phantom, dose of radiation etc. provided by the user. The world creation refers to the 3D volume allocated for the construction of simulated accelerator and phantom. The partial simulations of the basic LINAC, Varian LINAC 2100 and Varian Saturn 43, which are obtained from Geant4, are used as references to simulate the Elekta Synergy Linac. The source of particle generation for

radiotherapy can either be from a random generator or from an input file containing the phase space.

An input file of experimental data is provided to compare with the current data, following which the beam actions (understood to be beam generation and transportation) take place. An output file with the dose output in the phantom is produced. As the particle characteristics and geometric positions change (due to linac rotation etc.), the transient information is recorded and the output is obtained either through graphical visualization or through verbose results.

2. Design for simulation of Elekta Linac (Figure 4)

   Using generic assumptions of an Elekta Linac machine's design, the following classes and functionality have been added to the code set.

   For the simulation of Elekta Linac, the fixed specifications of the machine components including the material for construction, dimensions, positioning etc. are hard-coded in the class file ML2Elekta.cc. The components described are as given in Figure 4. The varying input specifications like the nominal beam energy are given as UI input in elekta.mac file. The values are assigned accordingly through ML2ElektaMessenger.cc class file, which serves as the communicator between the UI inputs and the linac component description.

5 Work Plan

5.1 Work done so far

1. Literature Survey: Understood the working and components of a LINAC head.
2. Visited the MVR Cancer Centre: Attended a talk on LINAC and its internals.
3. Installed and configured Geant4 simulation toolkit
4. Studied a simulation of the basic medical LINAC components.
5. Met with Dr.Niyas (Chief Medical Physicist at MVR Cancer Centre) to discuss the LINAC specifications and working.
6. Initiated simulation for a basic Elekta Synergy LINAC.

   The code set obtained from Geant4 contains a partial simulation of basic Varian LINAC. The requirement, as conveyed by Dr.Niyas for MVR Cancer Centre, is that of Elekta Synergy or Elekta Versa HD LINAC. The Elekta machines have several variations from their Varian counterparts. Our approach was to study the differences in detail so as to work on the existing simulated code for Varian. Basic classes, header files, and geometric simulation of basic components of Elekta LINAC have been implemented. The specifications of the machine are yet to be obtained using which the simulation has to be carried forward.

5.2 Work to be done

1. Obtain the specifications of the required Elekta LINAC and complete the simulation.
2. Understand the electron beam behaviour before it hits the target and simulate the components for beam generation if required.
3. Study the role of Monte Carlo methods in the simulations to be done.
4. Simulation of radiation beam transportation from the LINAC treatment head to the phantom.

6 Conclusion

Cancer has grown to become the second leading cause of death. Because of the same, radiotherapy's prominence has increased, and with it, the need for proper dosimetry analysis. Using Monte Carlo simulation, dosimetry evaluation can be done with high accuracy. For the process, the simulation of beam production in LINAC and beam transport to the simulated phantom are also to be done. Through this project, we

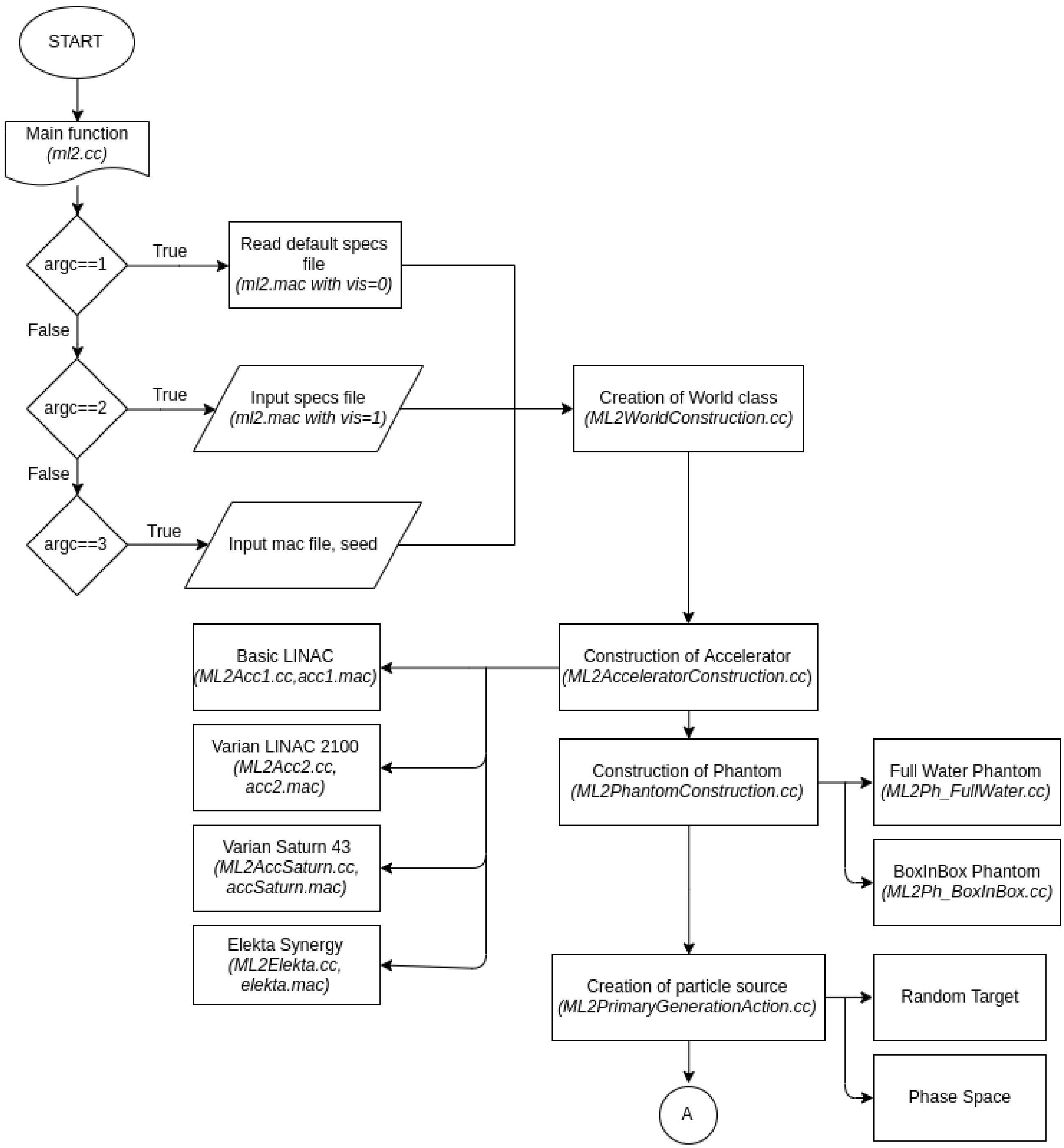

Fig 3 (Part I): Geant4's basic simulation of Linac. The names in italics within brackets refer to the corresponding file names (input/output/executables) in the code set

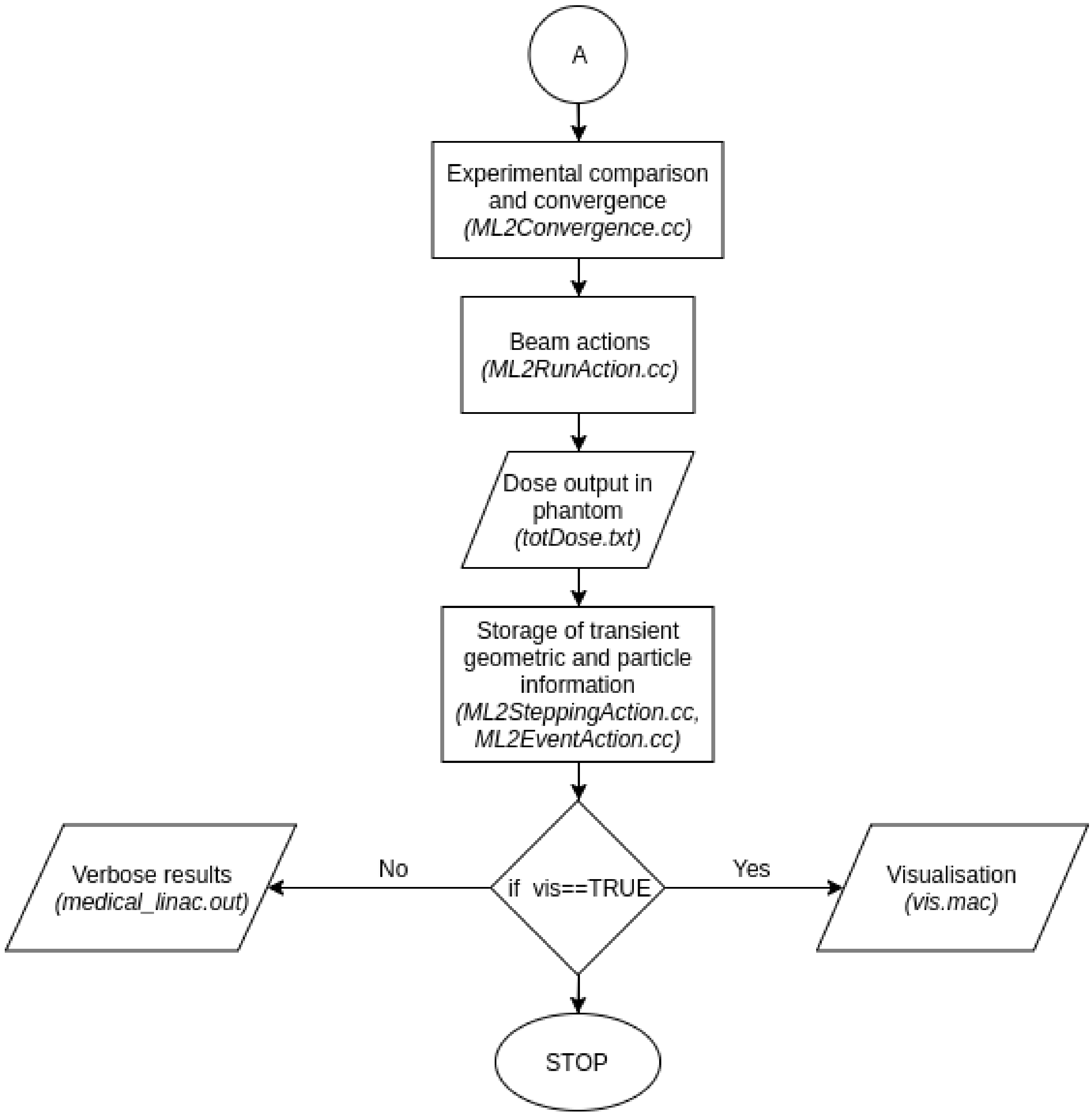

Fig 3 (Part II): Geant4's basic simulation of Linac.

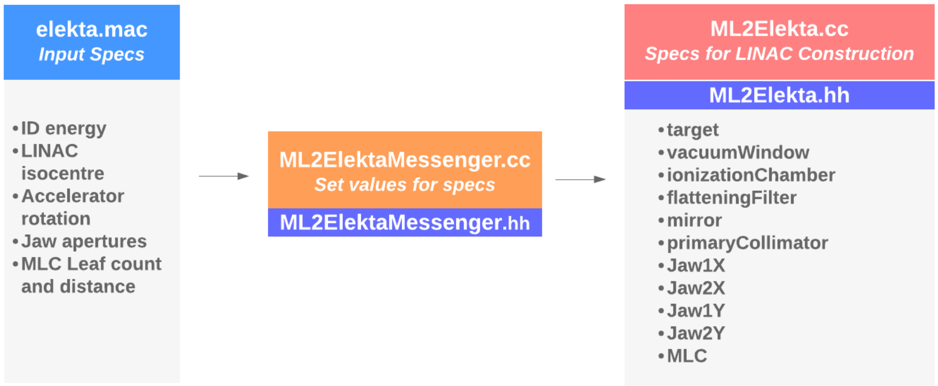

Fig 4: Design for simulation of Elekta Linac.

hope to simulate an Elekta LINAC at MVR Cancer Centre.

References

[1] Yazgan, Çağrı & ÇEÇEN, Yiğit. (2017). Monte Carlo simulation of a medical linear accelerator for filtered and FFF systems. TURKISH JOURNAL OF PHYSICS. 41. 498-506. 10.3906/fiz-1704-30.

[2] Bahreyni Toossi, Mohammad Taghi & Momennezhad, Mehdi & Hashemi, Seyed. (2012). Monte Carlo simulation for Neptun 10 PC medical linear accelerator and calculations of output factor for electron beam. Reports of Practical Oncology & Radiotherapy. 17. 115–118. 10.1016/j.rpor.2012.01.011.

[3] Serrano, Benjamin & Hachem, A & Franchisseur et. al. (2006). Monte Carlo simulation of a medical linear accelerator for radiotherapy use. Radiation protection dosimetry. 119. 506-9. 10.1093/rpd/nci620.

[4] Didi S, Moussa A, Yahya T, Mustafa Z. Simulation of the 6 MV Elekta Synergy Platform linac photon beam using Geant4 Application for Tomographic Emission. J Med Phys 2015;40:136-43

[5] Ji, Hao & Li, Yaohang. (2016). Monte Carlo Methods and Their Applications in Big Data Analysis. 10.1007/978-3-319-25127-1_7.

[6] Agostinelli et. al. (2003). GEANT4-a simulation toolkit. Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment. 506. 250. 10.1016/S0168-9002(03)01368-8.

[7] Amako, K. et. al. (2006). Geant4 Developments and Applications. IEEE Transactions on Nuclear Science. 53. 270-278. 10.1109/TNS.2006.869826.

[8] Oliveira et. al. Monte Carlo Simulation of a Medical Linear Accelerator for Generation of Phase Spaces. International Nuclear Atlantic Conference - INAC (2013).