European Organization for Nuclear Research

Compact Linear Collider (CLIC)

Summer Student Report

Simulation of the Final Focus and Collimator of the Electron Beam for VHEE Therapy (50-200 MeV) with Geant4 / TOPAS

Student:
El Mehdi ESSAIDI

Supervisor:
Manjit Dosanjh
Alexander Gerbershagen
Walter Wuensch
Andrea Latina

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1 Abstract

As a summer student at CERN, I have been working in the compact Linear Collider group for 8 weeks. I worked with the Geant4 / TOPAS Monte Carlo simulation code. The Compact Linear Collider (CLIC) is a future electron-positron collider under study. It foresees e+e- collisions at center-of-mass energies ranging from a few hundred GeV up to 3 TeV. The CLIC study is an international collaboration hosted by CERN. In this paper, I will report the simulation of the final focus and collimator of the electron beam for VHEE Therapy, which could also be applicable to FLASH methodologies, which might be a major breakthrough in RT. Functional specifications include dose rates from 2 Gy/min to 100 Gy/sec, beam sizes with diameters from 0.5 mm to $\geq 10cm$. High energies ($> 140MeV$) would also be needed for therapy.

2 Introduction

The must widely used accelerator for Radiation Therapy is the conventional linear accelerator delivering 6-23 MV photons beams and proportion, 6-20 MeV electrons. Higher photon energies (e.g. up to 20 MV) are or have been in use for deep clinical targets, but their application is being reduced in particular for the associated neutron production and for an increased interest of short low-energy linacs delivering full rotational techniques with sharp lateral penumbra. The main limitation of RT is the maximum dose that could be tolerated by the surrounding normal tissues. Conventional photon RT is characterized by almost exponential attenuation and absorption; hence the maximum energy is delivered 1-2.5 cm below the beam entrance, continuing to deposit energy at distances beyond the target volumes (Figure 1). To compensate for this, multiple beams angles with static or dynamic techniques are used. Another possibility to overcome the limitations of photons is to use RT with particles (proton or light ions), since this deposit more of their energy at the end of the energy range (Bragg peak). The use of protons has grown

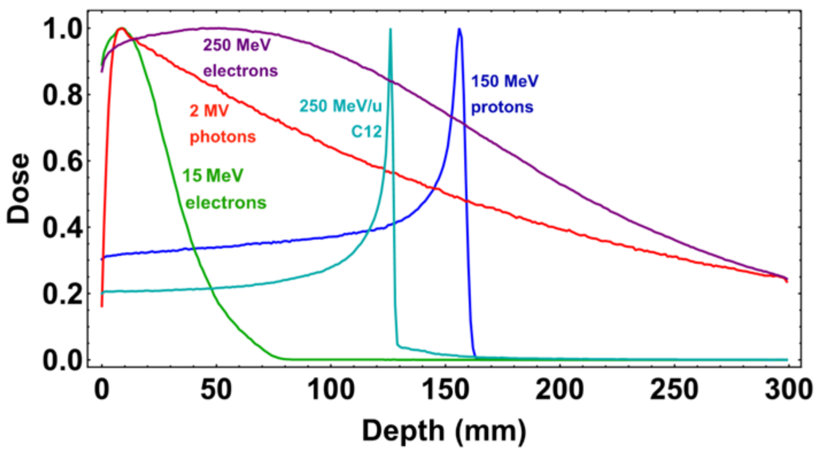

Fig 1: Dose profile for various particle beams in water (beam widths r=0.5 cm), [1].

over the last 20 years, exploiting the ballistic advantage of protons to limit the doses outside of the target volumes in a superior way compared to photons. The major drawbacks of proton RT are the higher technical complexity, the management of uncertainties, an inferior image guidance compared to the last generation of photon RT infrastructure and the high price of both the installation as the operation. A challenge thereby is to make particle RT accelerators as cheap as photon RT facilities. For this, we explore as possible alternative the use of VHEE electrons.

6-20 MeV electrons are classically used in the clinic but, due to their physical energy deposition profile, their use is restricted to treat superficial tumors. Increasing the energy above 50 MeV (VHEE) will overcome these limitations and, in addition, present the following advantages: 1) The penetration becomes deeper and the transverse penumbra sharper thus allowing a more precise treatment of deeper tumors 2) The small diameter VHEE beams can be scanned avoiding mechanical solutions such as the multileaf collimator 3) A rather smaller sensitivity to tissue heterogeneity can be achieved with VHEE beams under certain conditions [1] 4) VHEE accelerators may be constructed at significantly lower cost than current proton facilities. Currently, there is a growing interest in the biomedical community for VHEE beams ranging from 50 to 200 MeV [2-3] and, before an eventual integration of VHEE therapy in the clinic, some mechanistic and preclinical studies are required.

3 Materials and Methods

3.1 Monte Carlo simulation

TOPAS (TOol for PArticle Simulation) is a particle simulation code recently developed with the specific aim of making Monte Carlo simulations user-friendly for research and clinical physicists in the particle therapy community. The authors present a thorough and extensive experimental validation of Monte Carlo simulations performed with TOPAS in a variety of setups relevant for proton therapy applications. The set of validation measurements performed in this work represents an overall end-to-end testing strategy recommended for all clinical centers planning to rely on TOPAS for quality assurance or patient dose calculation and, more generally, for all the institutions using passive-scattering proton therapy systems [4].

This paper intends to present a general methodology for simulation of the final focus and collimator of the electron beam for VHEE therapy (50-200 MeV) using Geant4/TOPAS. The new set of tools specically oriented toward radiation therapy simulations has been assessed by simulation of the final focus and collimator of the Electron Beam with beam size 10 cm, incident particle 10e5 and modify the energy of the electron beam to 50 MeV, 80 MeV, 140 MeV, 180 MeV, 200 MeV and set the energy to 140 MeV and modify the thickness of the tungsten plate to 1 cm, 3 cm, 5 cm, 7 cm, 10 cm and set the energy to 140 MeV and modify the material of the collimator from tungsten to copper, aluminium and lead.

The phantom was simulated by defining its dimensions (303030 cm3) and materials. The surface of water was positioned at the isocenter to make sure that SSD=100 cm.

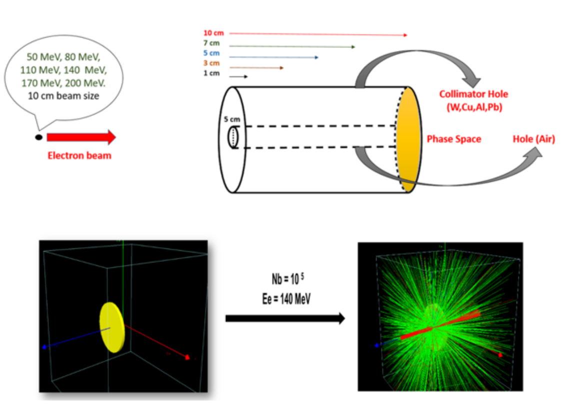

Fig 2. view of the geometry simulated VHEE in Flat (50 - 200 MeV) with phase space using the Geant4 / TOPAS

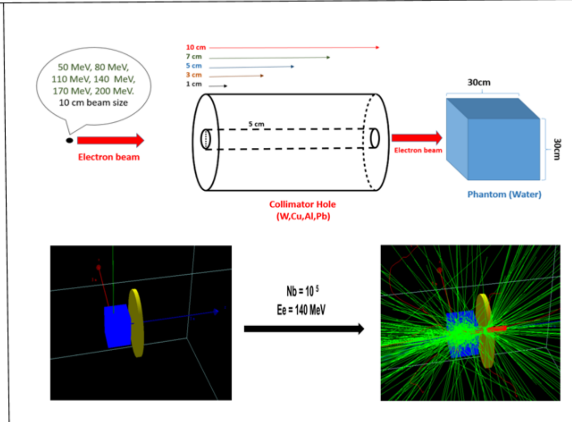

Fig 3. view of the geometry simulated VHEE in Flat (50 - 200 MeV) with phantom using the Geant4 / TOPAS

4 Results and discussion

4.1 Primary electron beam parameters .

The simulated beam has a Flat distribution in the X-Y plane, with beam angular cut of (fX =0, fY =0). Phase-space files recorded all information of secondary particles produced. These files at the surface of the collimator hole were used as sources to obtain the photon and electron fluence per incident electron, and energy deposit in XY plane. The results for a Fig 4) 5) are shown that if you increase the thickness collimator they increase also the number of particles in XY plane with energy maximum in the collimator center, and regarding electron fluence by energy 140 MeV, is more important in thickness collimator 5 cm and 10 cm. and for fig 6) 7) are shown electron fluence by energy 140 MeV, is more important versus 50 MeV with more the number of particles in XY plane, and same for fig 8) 9) in tungsten with more important of the photon compared copper.

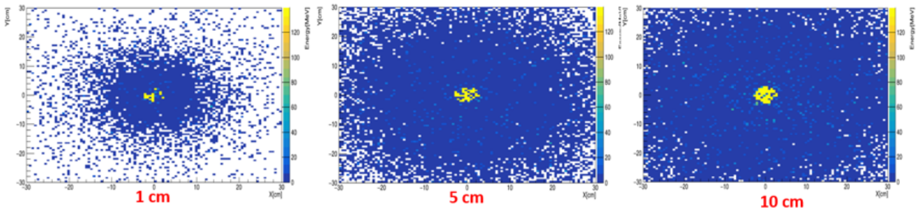

Fig 4. Energy deposit in XY plane the energy 140 MeV versus the thickness of the tungsten plate 1 cm, 5 cm, 10 cm.

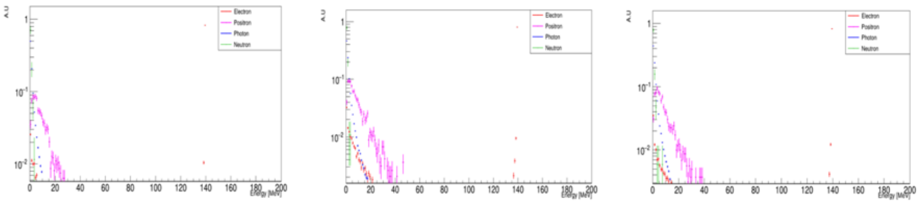

Fig 5. Electron fluence per energy 140 MeV versus the thickness of the tungsten plate 1 cm, 5 cm, 10 cm.

Fig 6. Energy deposit in XY plane versus the energy of the electron beam to 50 MeV, 140 MeV.

Fig 7. Electron fluence per energy versus the energy of the electron beam to 50 MeV, 140 MeV.

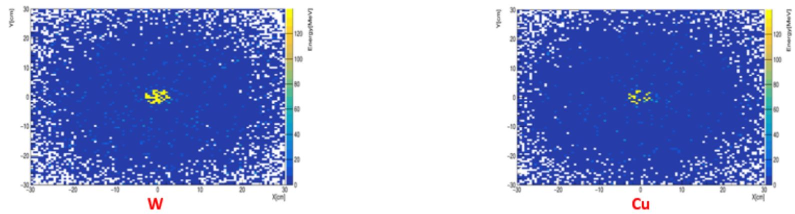

Fig 8. Energy deposit in XY plane versus the material of the collimator from tungsten to copper.

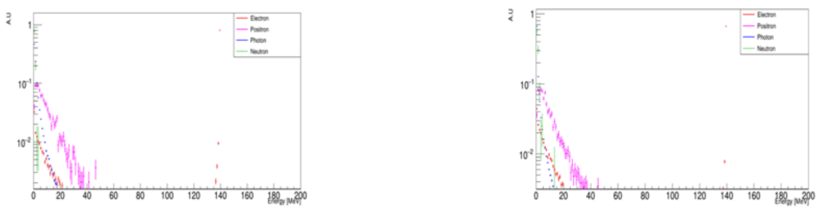

Fig 9. Electron fluence per energy versus the material of the collimator from tungsten to copper.

4.2 Depth dose

Electrons generated in the source cell were accelerated to the collimator hole by moving in the air and X- rays were produced. The X-rays were shaped in the collimator hole and measured in the water phantom. The electrons have a very fast absorption and only allow rather superficial irradiation. The results for a dose depth are shown: figure (a), in dose depth was high by increasing electron energy. figure (b), in dose depth, was high by increasing the collimator hole radius. figure (c), in dose depth, was high by decreasing the thickness collimator. figure (d), in dose depth, was high in material tungsten versus in material copper. With a note that the dose rate in-depth in a water medium depends on three parameters: Region 1: dose increase or buildup. Region 2: maximum dose. Region 3: exponential attenuation of the dose as a function of depth.

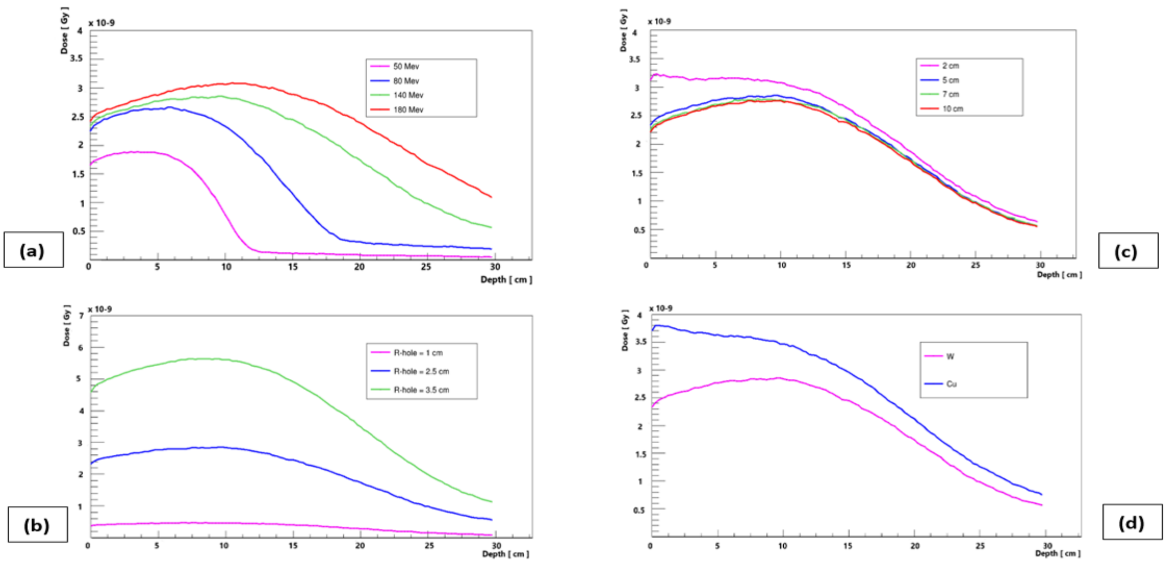

Fig 10. Monte Carlo calculated depth-dose for an electron beam 140 MeV. a) depth-dose curve with different energy and b) depth-dose curve with different radius collimator hole, c) depth-dose curve with different thickness collimator hole and d) depth-dose curve with different material collimator hole, for beam size 10 cm in voxels with dimension of 2.5×2.5×2.5 mm3 at depth of maximum dose.

4.3 Beam profile

The results for a beam profile are shown that have gaussian profile , figure (a), in dose was high er by increasing the collimator radius. figure (b), in dose, was a little high by decreasing the thickness collimator.

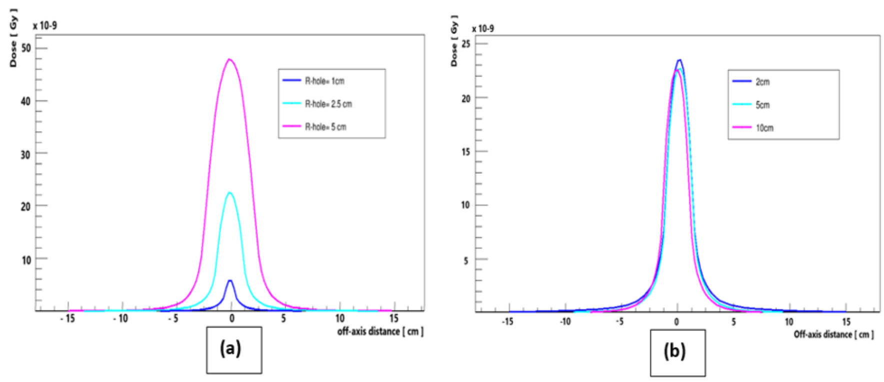

Fig 11. Comparison of Monte Carlo calculated beam profile of 140 MeV. (a) beam profile with different radius collimator hole, (b) beam profile with different thickness collimator.

5 Conclusion

The results of this simulation study several advantages of using VHEE beams for radiotherapy including, improved dose deposition characteristics, increased possible dose rate, ease of beam steering and manipulation and my future work studies will be on radiological biology and secondary particle production (eg . neutron, positron ..). This project can be further extended to explore the energies and beams suitable for FLASH.

6 References

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[4] Testa M, Schümann J, Lu HM, Shin J, Faddegon B, Perl J, Paganetti H. Experimental validation of the TOPAS Monte Carlo system for passive scattering proton therapy. Med Phys. 2013 Dec; 40(12):121719.