Understanding the Impact of a collimated Proton beam on a skeleton utilizing Monte-Carlo simulation (Geant4)

Abstract
This effort is intended to understand the impact of collimated proton beam, when the position of the proton beam is uniformly randomized, on a skeleton as a high dose of radiation is applied to cancer tissues. Proton Beam Therapy (PBT) has been an effective tool utilized to treat cancer cells. Firstly, a Monte Carlo experiment is constructed using Geant4 simulating a collimated proton beam traveling through a controlled environment resembling a human skeleton. The human skeleton is a trapezoid with thickness of 5 mm to 3.5 mm. The Cerebrospinal fluid (CSF) is a slab of 1 mm made of water. The position of the proton beam is uniformly randomized to simulate collimation. The energy deposited in the bone and the cancer tissue are tabulated when the incident protons beam has kinetic energy of 25 MeV to 75 MeV. This study demonstrates that the colimitation has a significant impact due to the energy deposited in skeleton. It also shows the complex material like the normal tissue is also impacted due to reduced energy deposited. In conclusion, the reduced deposited energy (due to uniform randomized position) in the Skelton is significant. Furthermore, additional simulation must be carried out to understand the impact of proton beam when the momentum, direction, and kinetic energy is randomized.

Purpose
The cancer treatment based on Proton Beam Therapy (PBT) is fundamentally implement by shooting proton particles to reduce the impact on the surrounding normal tissues while focusing the deposited energy to the tumors only. The undesired impact is reduced throughout the surrounding normal tissues since the radiation instantly disappears after the "Bragg Peak". Consequently, the normal tissues surrounding the targeted cancer tissues are exposed to reduced radiation. The proton Beam simulation usually assumes a focused pencil beam that is monoenergetic. Furthermore, the simulation usually assumes the target is of a simple material like water for simplicity. This effort is focused in collimating the proton beam and using multiple layered material for the target of PBT simulation. Consequently, it produces a realistic simulation and introduces additional questions to be answered.

Tools and Methods
Geant4 simulation tool was used in this effort. Example B1 was the starting point, since it provided all the components required to set up a basic Monte Carlo example [1]. The Geant4 introduces G4NistManager which is used to provide objects like "G4_A-150_TISSUE", "G4_AIR", "G4_WATER" and "G4_BONE_COMPACT_ICRU". It provides solids like "G4Box", "G4Cons", "G4Trd". Finally, it provided objects like "G4LogicalVolume". The combination of these libraries allowed for a simple construction to simulate a human skeleton. The human skeleton is a trapezoid with thickness of 5 mm to 3.5 mm. The Cerebrospinal fluid (CSF) is a slab of 1 mm made of water; the cancer tumor is a trapezoid of material type tissue. Geant4 provides a comprehensive physics list including "G4EmStandardPhysics", "G4DecayPhsyics", "G4EmExtraPhysics", "G4HadronElasticPhysics" and "G4hadronPhysicsFtFP_BERT". These libraries provide the interaction of proton with mater. Geant4 provides particle libraries such as "G4ParticleGun", "G4ParticleTable", "SetParticlePosition" and "SetParticleMomentumDirection" to set the characteristics of incident proton.

Results
A parameter sweep of 10 Proton is conducted. The position of the protons is uniform random distribution along x and y axis. The Cumulated energy deposited per run in tissue (cancer) and cumulated energy deposited per run in the bone are in table below.

Energy proton	(Tumor/cancer)	(bone)
75 MeV	571.856 MeV	132.661 MeV
70 MeV	500.06 MeV	150.289 MeV
65 MeV	428.831 MeV	164.921 MeV
60 MeV	345.294 MeV	188.8 MeV
55 MeV	251.97 MeV	216.882 MeV
50 MeV	196.354 MeV	202.004 MeV
45 MeV	67.9157 MeV	277.191 MeV
40 MeV	26.251 MeV	294.961 MeV
35 MeV	0 eV	315.01 MeV

Picture (1) presents shape 1 which is the Skelton with the thickness of 5 mm to 3.5 mm, shape 3 which is the CSF with the thickness of 1 mm and shape 2 which is the tumor (cancer).
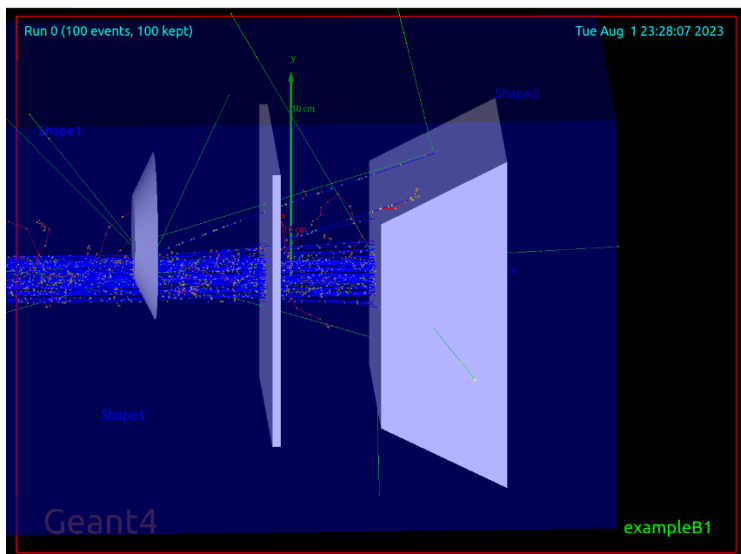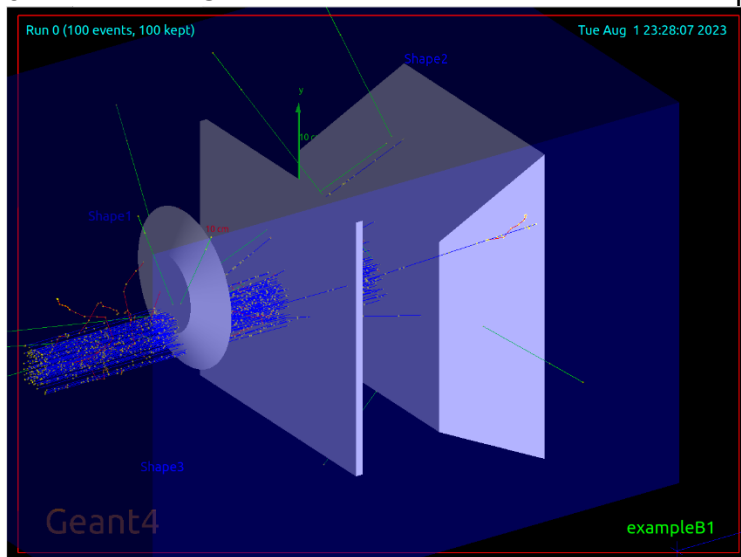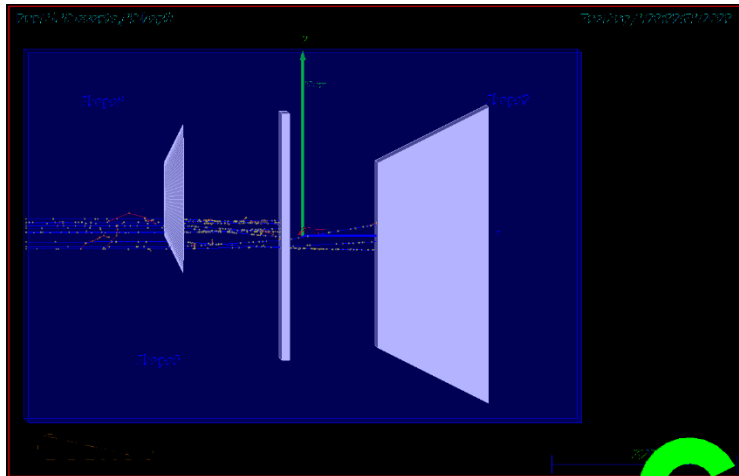
Table (1) presents the amount of the total kinetic energy divided between the normal skeleton and cancer tissue. At kinetic energy of 75 MeV most of the kinetic energy is deposited in the cancer tissue. At kinetic energy of 35 MeV all the energy is deposited in the Skelton. This result of the study shows that additional measure must be taken to reduce the negative impact of the proton therapy. For instance, the collimating precision must be improved to focus the proton beam on the target. Additional simulation must be conducted to understand the impact of proton beam when the momentum, direction, and kinetic energy is randomized. This additional simulation will help with the collimating precision.

Conclusion
In conclusion, additional study must be carried out to understand the impact of proton beam when the incident proton's momentum, direction, and kinetic energy are randomized. This is important since these parameters have a direct impact on the colimitation technology. Furthermore, this effort has provided Montecarlo truth measuring the impact of having multiple type of tissues before the incident protons have deposited their energy in the tumor. For example, the thickness of the tissues like the skull has an impact on the deposited energy of the incident protons passing though. The healthy skeleton receives substantial amount of radiation even at a reduced rate.

Reference
[1] https://geant4-userdoc.web.cern.ch/Doxygen/examples_doc/html/README_basic.html