Development of a GEANT4 Simulation for Varian ProBeam Compact Single-Room Proton Therapy System

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INTRODUCTION

Proton therapy is a growing treatment option for cancer patients. The first the first clinical ProBeam Compact^{TM} was recently commissioned at the South Florida Proton Therapy institute. Monte Carlo simulations are the most accurate way to model a proton beam.

AIM

The aim of this project is to create a simulation model of the Varian ProBeam Compact Single-Room Proton Therapy System using the GEANT4 Monte Carlo simulation tool kit. This basic simulation will be used to simulate depth dose and lateral dose distribution.

METHOD

- Integrated Depth Dose (IDD) curve were experimentally measured at SFPTI using the first clinical ProBeam Compact^{TM} for energy range 70 – 220 MeV with increment at 10 MeV. Approximately, the same experimental setup was modeled suing GEANT4 for simulating the IDD curves and beam spots.
- Points on an IDD curve are described by the percentage of the beam's maximum dose, with "a" and "b" signifying shallower or deeper than the maximum dose, respectively. For example, $R_{a80}$is the proximal 80% point and R_{b20} is the distal 20% point as shown in Figure 2.
- Clinical proton beams are not mono-energetic. The energies of the beam are described by Gaussian distributions. This energy standard deviation (σ_E) is important for the width of the Bragg peak, which is measured from R_{b80} - R_{a80}. The nominal energy of the beam is defined by R_{b80}.
- The beam spot or lateral dose fluence also follows a Gaussian distribution. The beam spot sigma (σ_B) is used to describe the width of the beam
- To match the IDD curves a trial and error approach was taken. Simulations were run with nominal beam energies from 70 MeV to 220 MeV in water. Two variables were changed: the average energy and the σ_E. R_{b80} is matched by changing the average energy of the beam. To increase the depth of R_{b80} the average energy must be increased. To increase R_{b80} - R_{a80}, the Bragg peak width, the σ_E must be increased.
- Lateral dose distribution was found by a similar, trial-and-error method. The command /gps/pos/sigma_r sets standard deviation in radial direction of the beam y-z profile. The command /gps/pos/sigma_r sets standard deviation in radial direction of the beam y-z profile. Sigma_r was used to match the simulated σ_S to the experimental σ_S. A higher sigma_r will result in a higher σ_S.
- The IDD curves were compared using clinically relevant quantities: R_{b80}, Bragg peak width (R_{b80} - R_{a80}), range (R_{b90}), and R_{b20}. Linear interpolation was used to find the points compared. The γ index was used to find how well the simulation matched to the experimental data in the beam direction. The minimum radial distance between the measurement point and the calculation points (expressed as a surface in the dose–distance space) is termed the γ index. Each measured point is evaluated to determine if both the dose difference and distance-to-agreement (DTA) exceed the selected tolerances[1].
- The 2%/2mm was chosen because these are the values Varian uses for the accuracy of their dose models in homogeneous material, such as water.
- The σ_S were compared using percent deviation.

RESULTS

Figure 1 shows the ProBeam Compact beam line on top and the simulated beam line below that. The 170 MeV IDD comparison in **Figure 2** is an example showing how well the simulations model the experimental data. The graph is a 170 MeV beam in a water phantom normalized to 1 at the maximum dose. The experimental data is in blue while the simulated is in red. Important points are shown with black dots. One million protons were simulated to get these results. **Figure 3** shows the inputs changed to matched simulated IDD curves to experimental data. The energy difference shows simulation input energy minus experimental nominal energy, simulated energies were higher than experimental for all nominal energies, but highest for lower energies. The energy standard deviation shows experimental σ_E in red and simulation input σ_E in blue. **Figure 4** shows the passing rate and statistics for each energy's IDD curve using a 2%/2mm gamma test. Most energies had 100% of points passing the test, but a few of the lower energies were in the high 90s with the lowest agreement being 98.1%. The statistics show minimum, average, and maximum gamma values. **Figure 5** is a comparison of experimental and simulated σ_S. Experimental data are in blue and simulated is shown in red, the blue dashed line shows $\pm$ 5% of the experimental data. The simulated data agrees with the experimental data within 3%. **Table 1** shows the simulation input sigma_r used to match simulated beam spot size to experimental data.

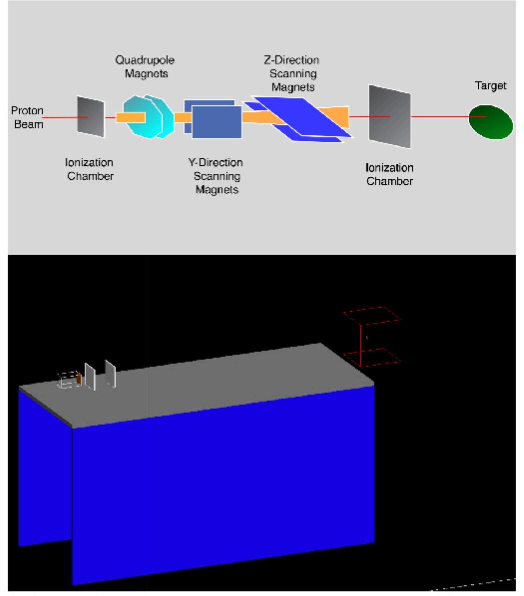

Figure 1

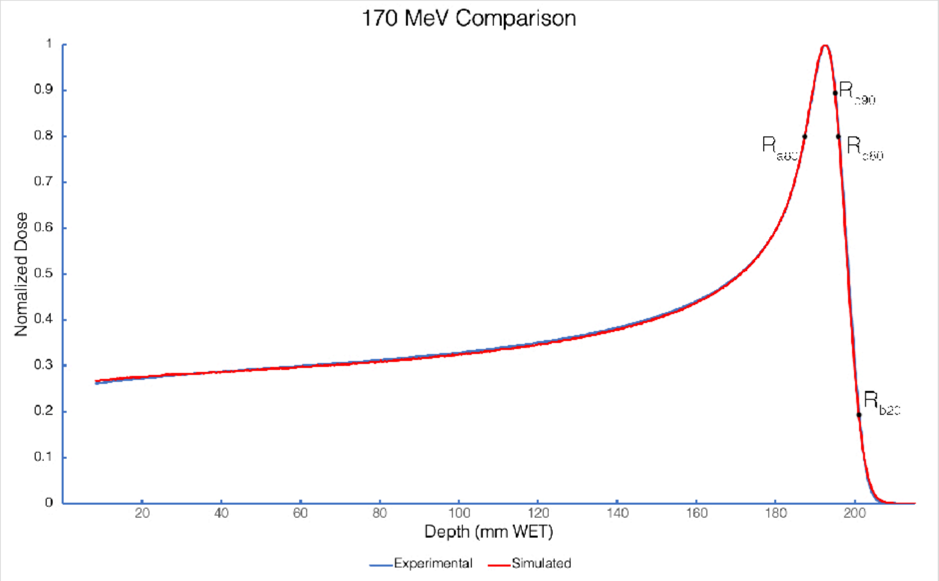

Figure 2

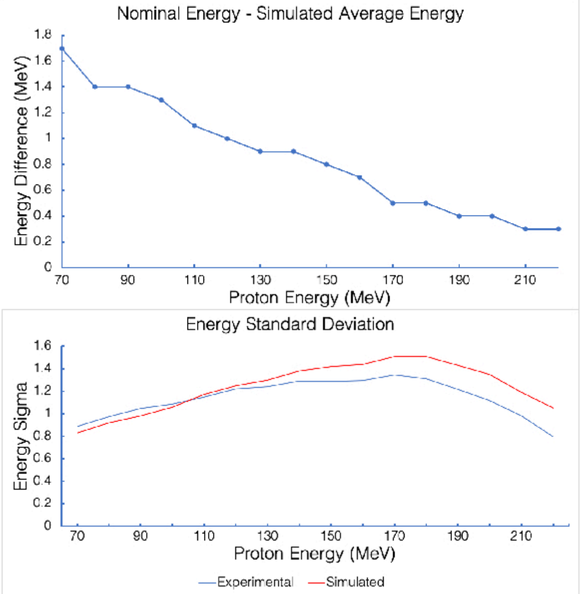

Figure 3

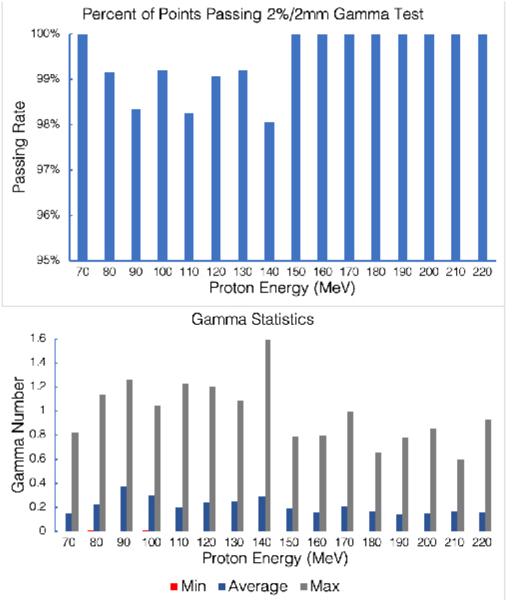

Figure 4

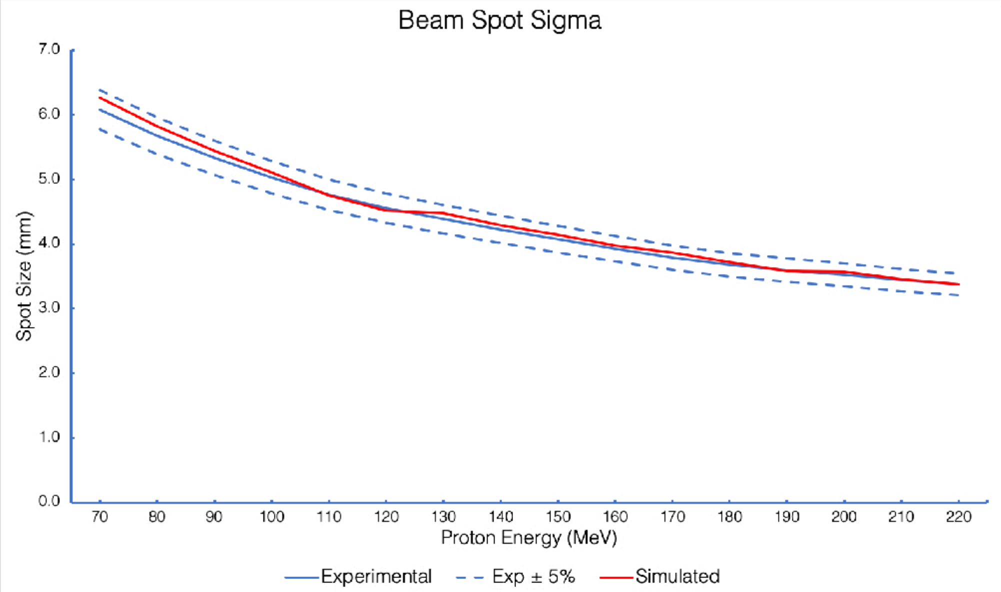

Figure 5

Energy (MeV)	/gps/pos/sigma_r
70	0
80	0
90	0
100	0
110	0
120	1.5
130	1.5
140	1.5
150	1.5
160	1.5
170	1.6
180	1.6
190	1.6
200	1.6
210	1.6
220	1.6

Table 1

CONCLUSION

The agreement between the simulated and experimental data shows that the simulation matches with the actual ProBeam compact closely. The user must input three parameters when looking for an IDD or lateral dose distribution: average energy, σ_E, and sigma_r. GEANT4 is highly configurable which means this simulation can be improved upon in the future. Further work will include addition of focusing and scanning magnets to the beam line and modeling off axis beams.

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REFERENCES

1. Low, D. A., Harms, W. B., Mutic, S., & Purdy, J. A. (1998). A technique for the quantitative evaluation of dose distributions. Medical Physics, 25(5), 656-661. doi:10.1118/1.598248

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