EXPERIMENTAL AND MONTE CARLO DOSIMETRY OF A DYNAMIC COLLIMATION SYSTEM PROTOTYPE

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PURPOSE

It was the purpose of this work to build an experimental dynamic collimation system (DCS) prototype and experimentally benchmark two Monte Carlo models that are currently used to study dynamic collimation in pencil beam scanning (PBS).

BACKGROUND

Figure 1: Illustration of the DCS [1].

The DCS is an emerging low-energy PBS collimator that provides energy-specific collimation through the sequenced motion of four collimation trimmer blades, illustrated in Figure 1 [1]. Recent treatment planning studies have indicated that the DCS can reduce the dose delivered to the nearby healthy tissues [2-4]. However, these studies rely on theoretical Monte Carlo models that lack rigorous experimental benchmarking.

PROTOTYPE DCS & SETUP

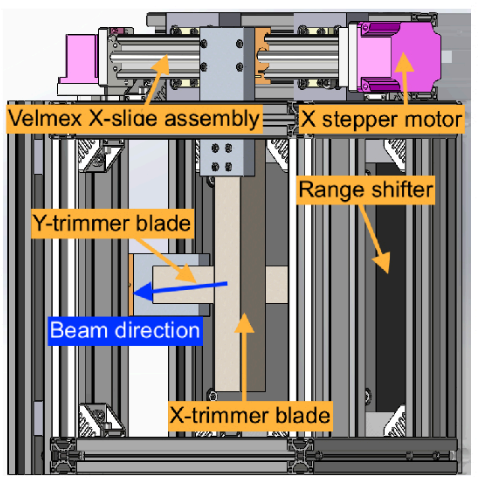

Figure 2: SolidWorks™ visual rendering of the experimental DCS prototype. The features of the experimental design were:

1. Lightweight and compact collimator design
2. Inexpensive component cost and construction
3. Reproducible and repeatable collimator translation
4. Remotely operable
5. Well-defined simulation geometry and alignment
6. Compatibility with commerical dosimeters

The experimental prototype, shown in Figure 2, was modeled to closely mimic the Monte Carlo geometry initially used to study PBS collimation by Hyer et al. [1] and Gelover et al. [4]. A set of trimmer blades were machined from a nickel alloy and mounted to high-precision stepper motors with a removable, experimental range shifter fabricated from iso-molded graphite.

Integral depth dose and lateral profile measurements of beamlets collimated by a DCS were performed using the PBS-enabled, horizontal beamline fitted with the IBA Universal Nozzle at the Northwestern Proton Center. The collimators were aligned perpendicularly to the scanning of the beam and offset upstream from the isocenter. The trimmer translational axes and beam scanning system were aligned by centering the trimmer in a uniformly irradiated field.

MEASURED AND SIMULATED PROFILE RESULTS

Integral depth dose (IDD), Figure 3, and lateral profile, Figure 4, measurements were acquired as a basis to evaluate Monte Carlo models of the DCS prototype. The consistency between the Monte Carlo models to predict changes in profiles due to the influences of scatter off the trimmer blades were assessed on and off the central axis.

- IDD profiles were measured through the wall of an IBA Blue Phantom[2] 3D Scanning water tank with an IBA StringRay chamber
- Lateral profile measurements were acquired using the IBA Lynx scintillator, which was also benchmarked with EBT3 film
- Agreement between the measured and Monte Carlo-simulated profiles were evaluated using a 1 % / 1 mm gamma criteria.
- MCNP6 resulted in an elevated percent IDD within the plateau region and a larger percent increase in the absolute dose value than Geant4

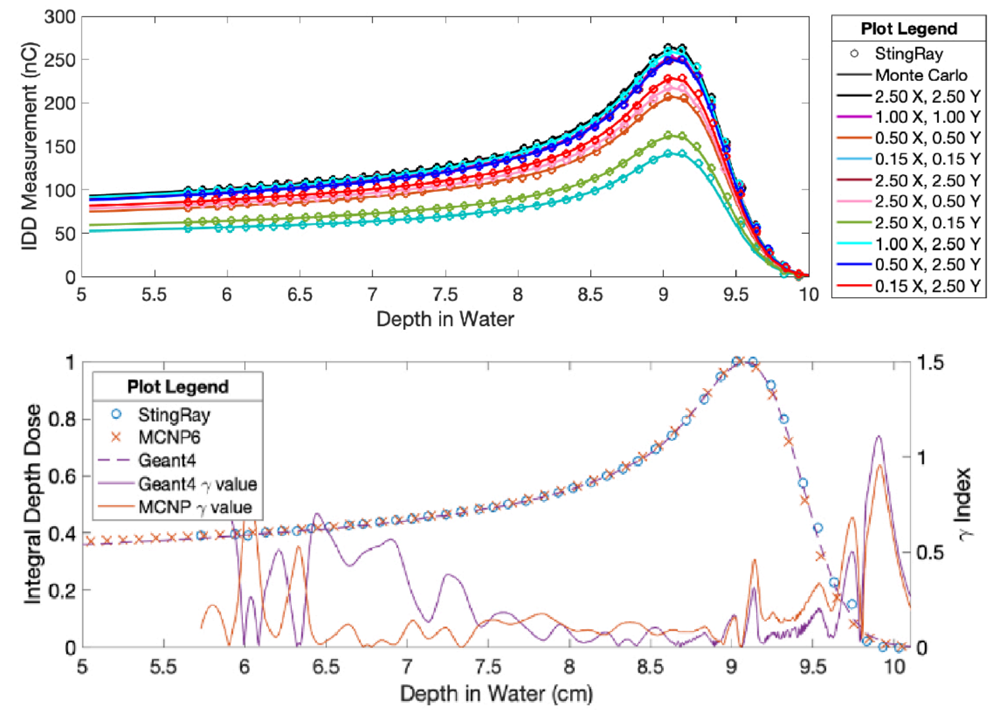

Figure 3: (Top) Measured and MCNP6-simulated IDD profiles from uncollimated and X- and Y-collimated 151.0 MeV proton beamlets color coded by trimmer offsets in cm. (Bottom) A trimmed IDD profile with the X- and Y-collimators positioned 1.5 mm from the central axis of the beamlet. The 1 %/1 mm gamma analysis test is included for each simulation relative to the measured IDD.

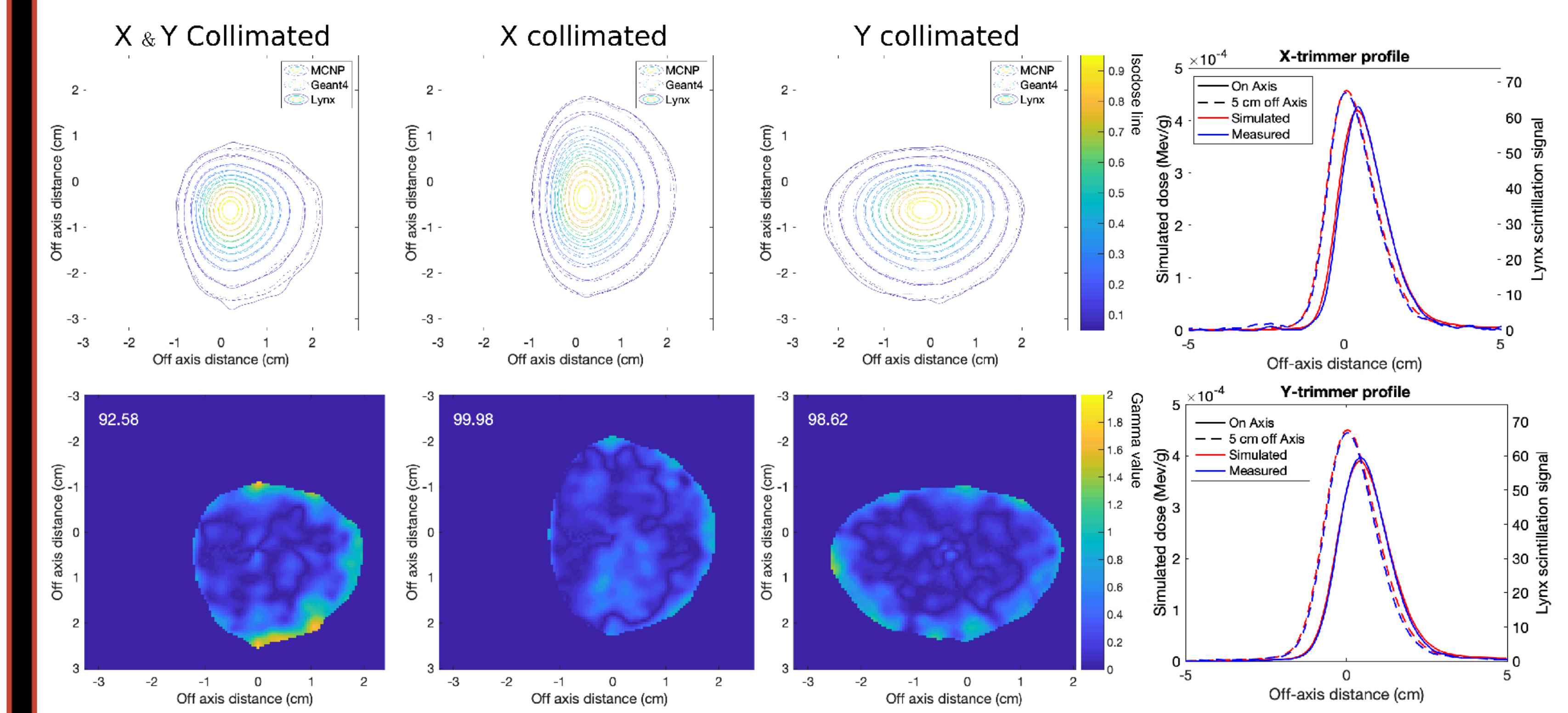

Figure 4: Simulated and measured lateral profiles from a collimated 151.0 MeV proton beamlet. Various combinations of X- and Y-trimmers were used to benchmark the MCNP6 calculations of collimated proton beamlets along the central axis and 5.0 cm off-axis in the x- and y-direction (right-most plots). The Geant4 gamma pass rates for each of the measurements are listed in white for each beamlet and were consistent with the MCNP6 simulation gamma pass rates.

MONTE CARLO MODELING

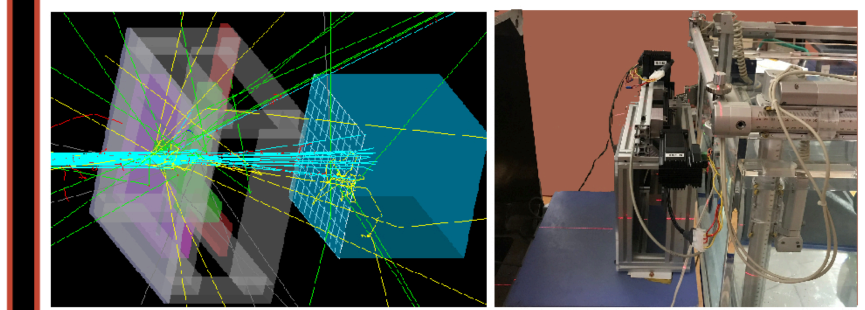

Figure 5: Simulation (left) and experimental (right) setups for lateral and IDD profiles in water.

The Northwestern IBA UN beamline was modeled by projecting the commissioning lateral profiles towards a divergent point source. A Gaussian energy spectrum was fitted across several nominal energies to match their commissioned IDD profiles.

The geometry illustrated in Figure 5 was modeled to reflect the experimental setups for both the IDD and lateral profile measurements in both MCNP6 and Geant4 Monte Carlo codes. MCNP6 transport included Vavilov scattering theory and ion recoil sampling. The Geant4 Monte Carlo model was developed from the Geant4 user base classes and the QGSP_BIC_HP physics list.

CONCLUSIONS

While great agreement was achieved among simulated and measured beamlet profiles, subtle differences were observed between MCNP6 and Geant4 simulations:

- The Rossi approximation (MCNP6) overpredicted penumbra relative to the Highland approximation (Geant4)
- MCNP6 resulted in an elevated plateau IDD from low-energy scatter off the collimation than Geant4.
- A non-focused collimator results in broader off-axis profiles than those delivered on-axis

REFERENCES

1. D. Hyer et al., Medical Physics, 41(9):091701, 2014.
2. A. Moignier et al., Int. J. Rad. Onc., Bio., and Phys., 95(1), 2015.
3. B. Smith et al., Medical Physics, 43(8), 2016.
4. E. Gelove et al., Medical Physics, 42(3), 2015.

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