PhD Thesis Title: Characterisation Studies of Proton Beamlines for Medical Applications and Beam Diagnostics Integration

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ABSTRACT:

Recent advancements in accelerator technology and increasing experience with utilising charged particle beams for medical applications have supported the growing presence of ion beam therapy worldwide. The advantageous dosimetric properties enable high amounts of radiation to be precisely shaped and delivered to target sites while sparing surrounding healthy tissues. Accelerators, beam transport and delivery systems are designed to deliver the beam optimally and safely according to the prescribed treatment. This is maintained by beam instrumentation devices however limitations are seen with conventional tools. Therefore, advanced diagnostics are needed to fully exploit fundamental benefits, for enhanced functionality and to accommodate new developments in particle therapy. A novel online beam monitor based on LHCb VELO detector technology is being developed, capable of providing non-interceptive, active measurements of the beam halo. It was optimised for the 60 MeV ocular proton beamline at the Clatterbridge Cancer Centre (CCC), UK. The facility offers a unique environment to assess the viability of the detectors; however, in order to integrate the system, the propagation and behaviour of the beam must be well understood. Several computational tools were developed to precisely model and completely characterise the facility. Simulation studies were performed using a GEANT4 model of the treatment line to generate transverse beam distributions which showed minimal impact of the sensors on the beam whilst revealing a dependency on the input beam parameters. Experimental measurements were performed using EBT3 film and benchmarked with a Medipix3 detector to verify the model and test for the first time, its performance and applicability in a clinical proton environment. An alternative approach was necessary to resolve beam information upstream and an extensive review was required to overcome facility related limitations to determine the fundamental beamline parameters. An optical lattice was defined in MAD-X and BDSIM, enabling the possibility of end-to-end modelling and yielding parameters ($\sigma_{x,y}$ = 6.89, 2.14 mm, $\beta_{x,y}$ = 9.52, 4.59 m and $D_{x,y}$ = 0.01, 0.00 m) which were used to define the treatment beam. This was utilized in a redeveloped TOPAS model of the CCC delivery system which also incorporated the progress made with multiple codes, providing a single platform for future use. Simulations of the dose deposition, transverse beam profiles and linear energy transfer were achieved. Measurements were also performed with a MiniPIX-Timepix detector to experimentally verify the model for correlation with radiobiological applications. These methods provide a basis to reproduce the physical properties of the beam given the present state of the Clatterbridge facility. This approach was also applied for proof of concept measurements performed at the University of Birmingham. Several uncertainties and improvements were discussed; however, the achieved results demonstrated the possibilities of the adapted VELO sensors as a beam monitoring system. This thesis combines computational modelling, experimental studies and accelerator concepts to establish a framework to characterise, optimise and realistically simulate medical proton beamlines. The application of this work supports the development and integration of novel diagnostics explored at existing facilities for improvements in the delivery and outcomes of proton therapy.

References to author publications that relate specifically to the dissertation:

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