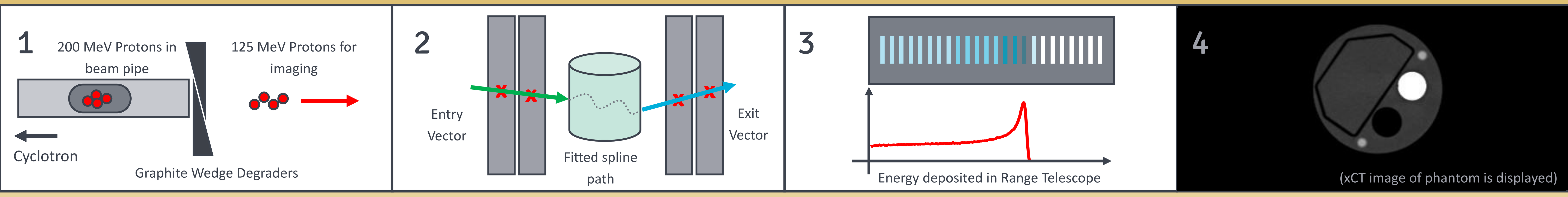
A Phantom for Comparison of Proton CT and X-Ray CT in Proton Therapy Treatment Planning

Sam Manger[1,2], Dr Spyros Manolopoulos[2], Dr Jon Duffy[1], Prof Stuart Green[3], Dr Ben Phoenix[4], Dr Tony Price[4], Chris Waltham[5], Dr Michela Esposito[5], Dr Jon Taylor[6], Dr Gavin Poludniowski[7], Prof Phil Evans[8], Prof Phil Allport[4], Prof David Parker[4], Jaime Nieto-Camero[9], Julyan Symons[9], Prof Nigel Allinson[5]

1) University of Warwick 2) University Hospitals Coventry and Warwickshire 3) University Hospitals Birmingham 4) University of Birmingham 5) University of Lincoln 6) University of Liverpool 7) Karolinska Instituet 8) University of Surrey 9) iThemba Labs, South Africa

X-Ray computed tomography (xCT) introduces a 3% uncertainty in proton range when producing treatment plans for proton therapy due to inaccuracies in the conversion from x-ray Hounsfield Units to proton Stopping Powers [1]. Proton computed tomography (pCT) aims to reduce this range uncertainty by directly measuring the stopping power in-vivo. A phantom has been produced to be imaged with both xCT and pCT that can also measure proton range in the phantom to compare the performance of each imaging modality for proton therapy treatment planning.



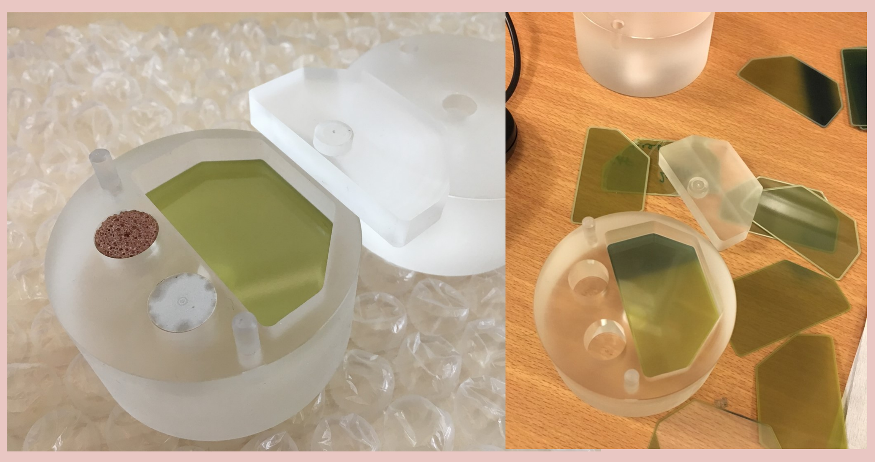
Proton Computed Tomography

1. High energy protons are accelerated to an energy that will pass through the phantom or patient.
2. Two tracker units each side of the phantom provide entry and exit vectors for individual protons, allowing their path through the phantom to be calculated.
3. Residual range of individual protons is measured in a range telescope so that integrated water-equivalent thickness over each proton path can be calculated.
4. Repeating this measurement 2 million times per angle over 180 degrees allows a full tomographic reconstruction of the relative stopping power for each voxel [2].

Phantom Design

The pCT evaluation phantom is designed to work with the PRAVDA prototype proton computed tomography system. It is cylindrical, 75mm tall and 75mm in diameter. There are two 1.5cm diameter recesses for in homogeneities.

A recess for Gafchromic EBT-3 film allows proton range to be measured directly in the phantom. The sensitive region is 35mm long, and is located behind 30mm of polyethylene at the centre. The film has been cut using an computer-controlled vinyl cutter at Queen Elizabeth Hospital, Birmingham for high precision and reproducibility.



Phantom body with LN10 (lung equivalent) and SB5 (cortical bone equivalent) inserts [5].

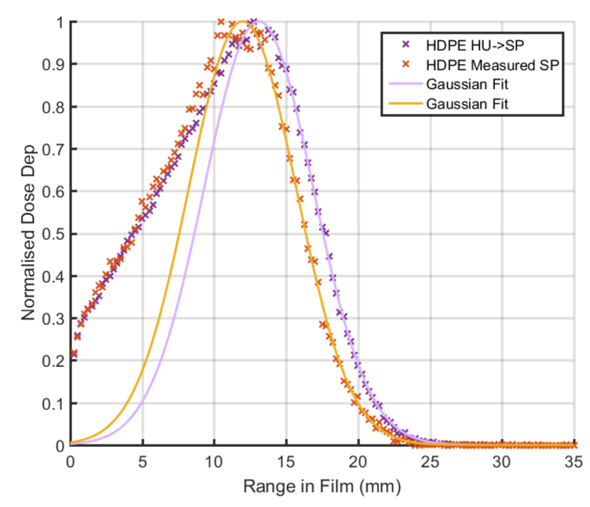
Simulation Studies

A Monte Carlo model of the phantom was built using Gate [3] to evaluate the feasibility of a study on a measured range shift caused by the Hounsfield Unit to Stopping Power conversion using EBT-3 film. The 28 um active region of EBT-3 film was set to record deposited dose. Material stopping powers were manipulated in Gate to replicate those calculated from x-ray CT and also directly measured and reported by Grant et al [4].

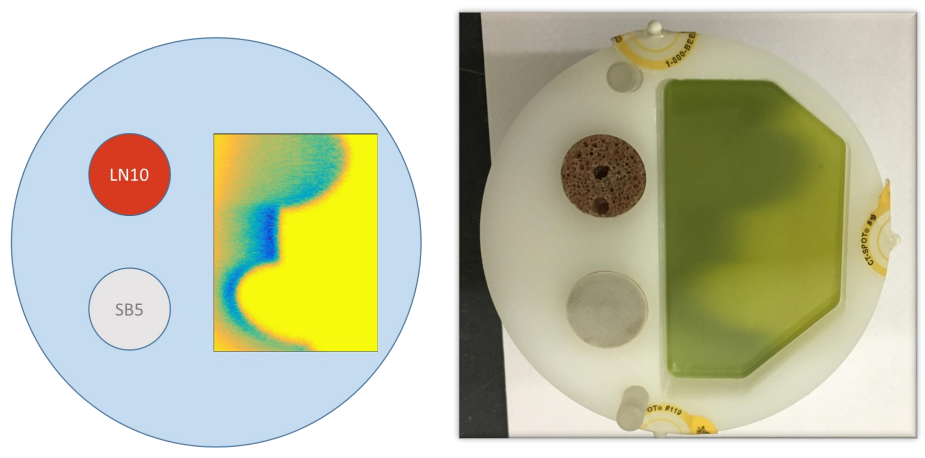
The stopping powers were adjusted by modifying the mean ionisation energy. Rearranging the Bethe-Bloch formula yields

$$I_{modified} = I_{default} \exp\left[\left(1 - \frac{SP_{modified}}{SP_{default}}\right)\left(\ln(2m_e\gamma^2\beta^2) - \ln(I_{default}) - \beta^2\right)\right]$$

Using the reported xCT stopping power value and measured stopping power value of polyethylene from [4], a range difference at R_{80} of 0.79 mm was observed in the centre of the phantom using simulated 80 MeV protons.



80 MeV proton dose deposition along film in simulations based on xCT and directly measured material

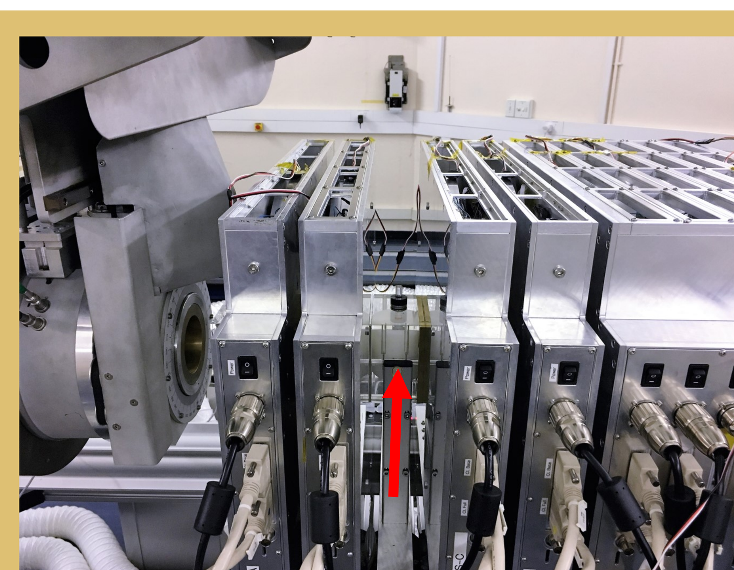


Simulation of film response in polyethylene phantom overlaid on a diagram alongside a measured dose delivery performed at iThemba Labs in November 2016

Progress and Future Work

A proton CT scan of the phantom was taken at iThemba Labs, South Africa on 20/11/2016. However, with a large amount of data to analyse it will be a few weeks before an image is produced. An irradiation of the phantom was also performed using the iThemba beam. Selecting a beam with a range of 45mm in water allows three distinct regions to be observed, as seen in simulation.

The next stages of the experiment entail importing the proton CT image into clinical treatment planning software, and producing a new stoichiometric calibration curve for small phantoms for the xCT scanners at UHCW. Then, an evaluation of calculated proton ranges and a measurement of delivered range may be performed.



Phantom sat between the tracker modules of the Pravda proton CT instrument on the iThemba beam line

Acknowledgements

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References

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