FLASH range QA measurements with the Quality Assurance Range Calorimeter

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Motivation

Proton Beam Therapy (PBT) offers a highly localised depth-dose distribution, due to the well-defined range of protons in matter for a given beam energy.

Early preclinical evidence suggests FLASH radiotherapy offers additional healthy tissue sparing effects with complete dose delivery in less than 100 ms. For FLASH proton therapy, this corresponds to average currents of at least 600 nA to the patient, compared to current clinical standard of 1–10 nA [1].

To ensure accurate dose delivery in PBT, daily Quality Assurance (QA) measurements of the proton range are required. In addition to the time consuming setup and measurement for accurate range determination, existing detectors are unable to accommodate the 100-fold increase in beam current. We present a detector capable of measuring **proton range in real-time to sub-millimetre accuracy at both clinical and FLASH dose rates.**

Detector Principle

- Stack of optically isolated polystyrene-based plastic scintillator sheets of 105x105x3 mm that **sample proton energy deposition** [2].
- Each sheet is coupled to a photodiode to **measure light output**, which is proportional to proton energy (with quenching corrections).
- Photodiodes coupled to modular ADC converters capable of **zero-deadtime measurements at over 5kHz**, read-out by an FPGA.
- Analytical model [3] deployed to **fit depth-light curve to reconstruct Bragg curve** and recover proton range in **real-time.**

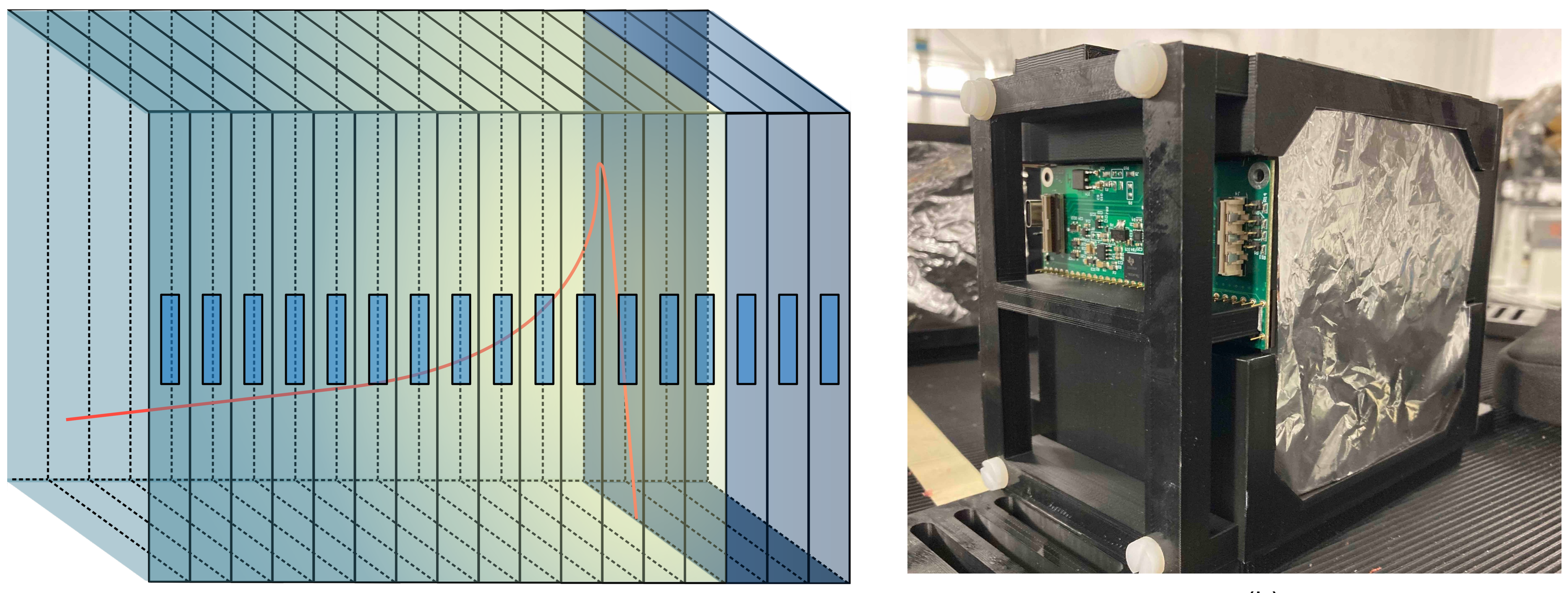

Fig 1. (a) Schematic of the scintillator stack showing the detector principle. The red curve shows a typical proton depth-energy relation. (b) Single detector module of 32 sheets and mounted photodiode circuit board. Each scintillator sheet is optically isolated using sheets of mylar foil.

Results

- Tested 128 scintillator sheets (4 modules) with proton beams between 70-245 MeV with clinical and FLASH beams using the Varian system at The Christie Hospital at Manchester.
- Fit analytical model [3] to depth-light data and reconstruct Bragg curve. The reconstructed range is **accurate to within 0.5 mm** of the reference data, as shown in Fig.3.

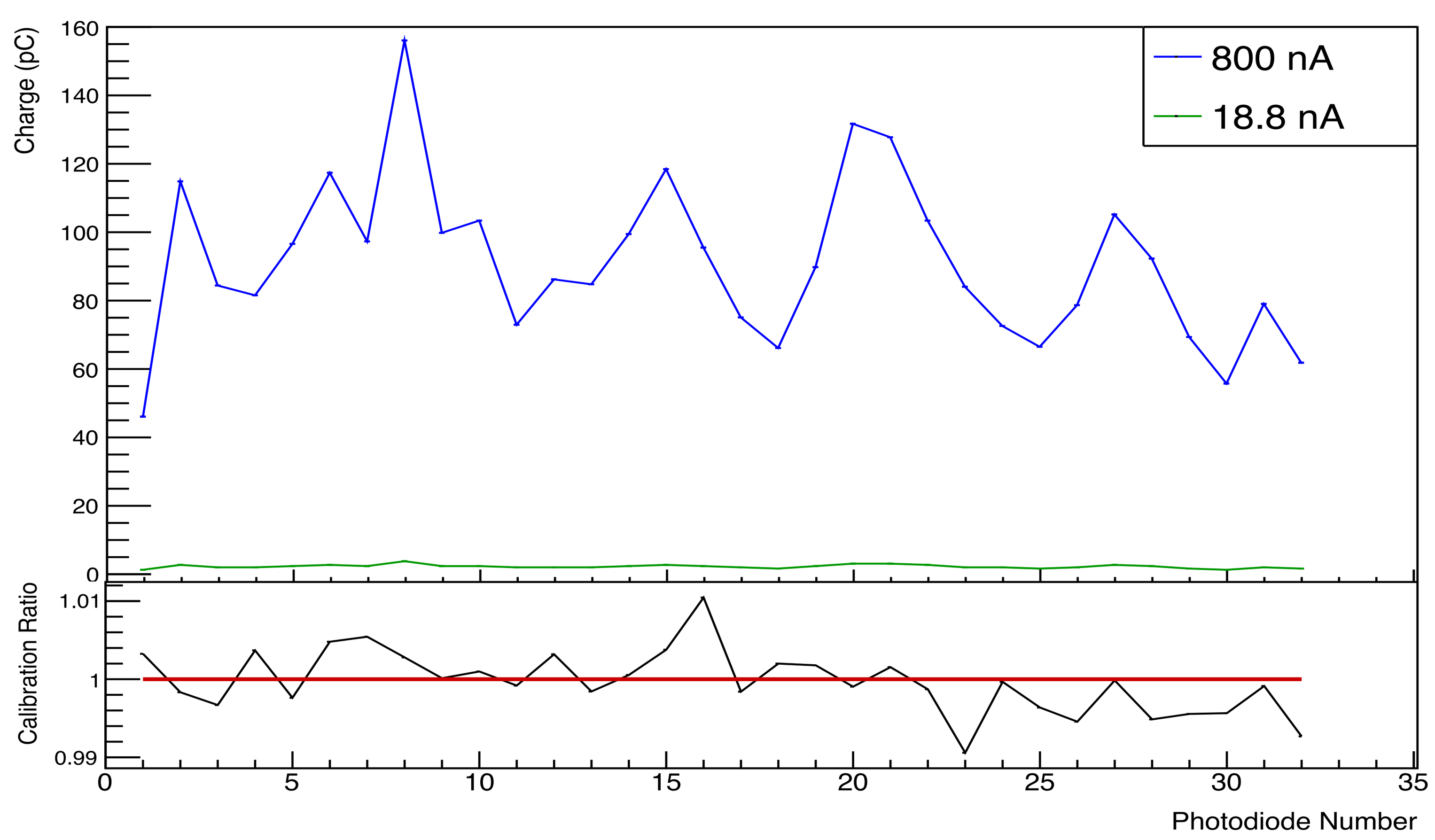

Fig 2. Comparison of the integrated photodiode charge for clinical (18.8 nA) and FLASH (800 nA) currents for a 245 MeV proton beam. The normalised calibration ratio shows that the light output is within 1% of each other.

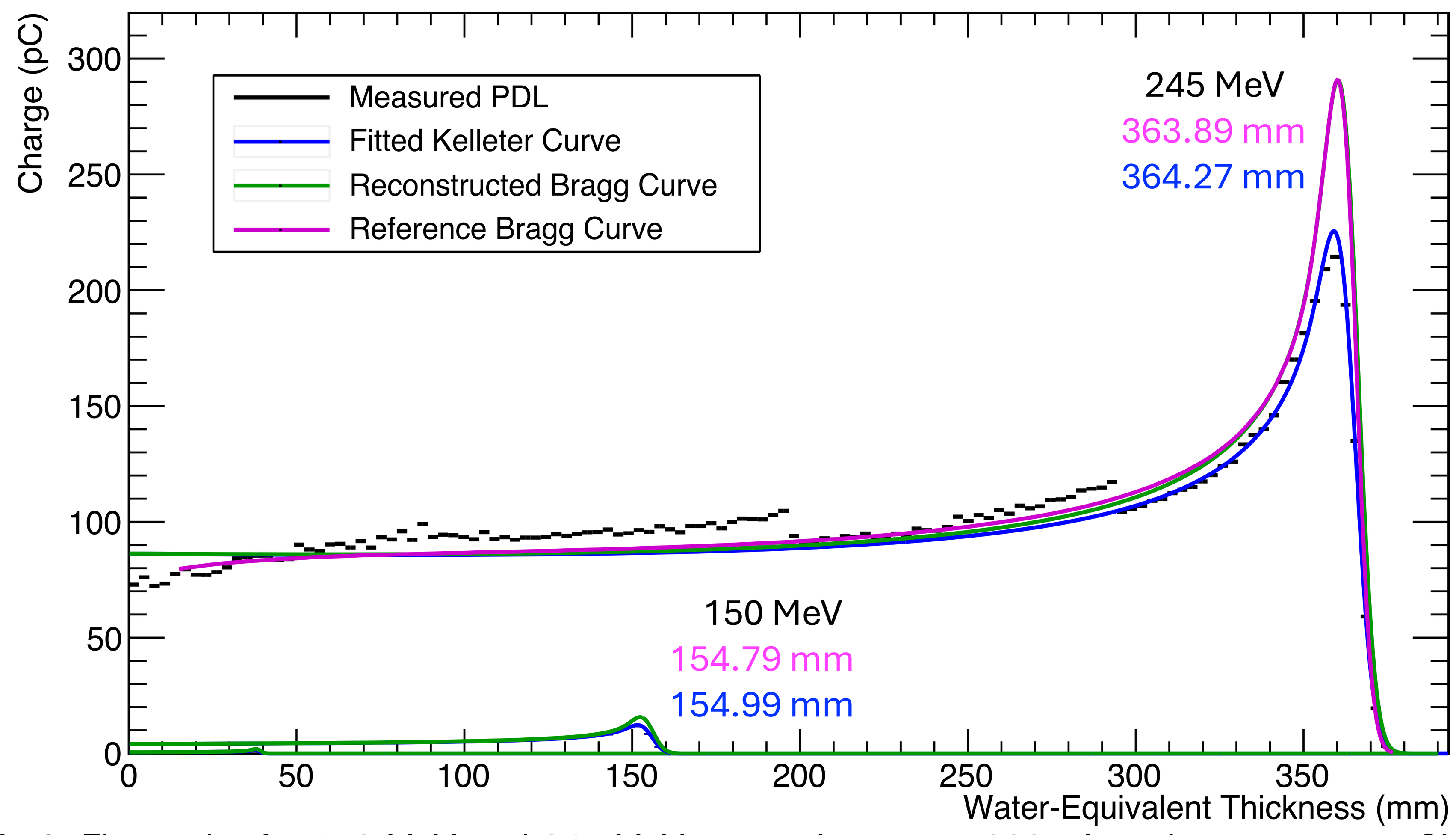

Fig 3. Fit results for 150 MeV and 245 MeV proton beams at 800 nA cyclotron current. Shown is the measured light output (black), fitted depth-light curve (blue), reconstructed Bragg curve (green), and facility reference curve (magenta).

Future Work

- Further development of web-based GUI, hosted by detector, to allow data display and detector control without any specialised software.
- Improve scintillator composition and construction to optimise light output and stabilise cross-module calibration, further improving fit accuracy.
- Deployment of fitting routines onto an FPGA to increase fitting speed.
- Geant4 simulation to benchmark experimental results and constrain Birks' constant.
- Additional beam tests to further characterise detector performance with clinical and FLASH beams.

References

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