QuARC – A Quality Assurance Range Calorimeter for Proton Therapy

Saad Shaikh[1], Raffaella Radogna, Fern Pannell, Ruben Saakyan, Spyros Manolopoulos, Derek Attree, Connor Godden, Simon Jolly
University College London

Email:[1]saad.shaikh.15@ucl.ac.uk
University College London | Department of Physics & Astronomy |
Gower Street | London | WC1E 6BT | United Kingdom

UCL

Motivation

Proton Beam Therapy (PBT) offers significant advantages over conventional radiotherapy due to the highly localised dose delivered by protons. This is largely due to the well-defined range of protons in matter for a given beam energy, where the majority of dose is deposited at the end of the proton path. To optimise patient safety, the range of protons must be known accurately, which is measured as part of facility daily quality assurance. However, current methods of range measurement often choose between speed and accuracy. We present a detector capable of fast **real-time range measurements** without compromising accuracy.

Detector Principle

- Stack of inexpensive optically-isolated polystyrene plastic scintillator sheets [1] that **sample proton energy deposition** along path length and are **water-equivalent**.
- Each sheet is coupled to a photodiode to **measure light output of each sheet**, which is proportional to proton energy (with quenching corrections).
- Photodiodes coupled to modular 32-channel analogue-to-digital converters (ADCs) capable of **zero-deadtime measurements at over 5 kHz**, read-out by an FPGA.
- Analytical model [2] deployed to **fit depth-light curve to reconstruct Bragg curve** (red curve in Fig. 1) and recover proton range.

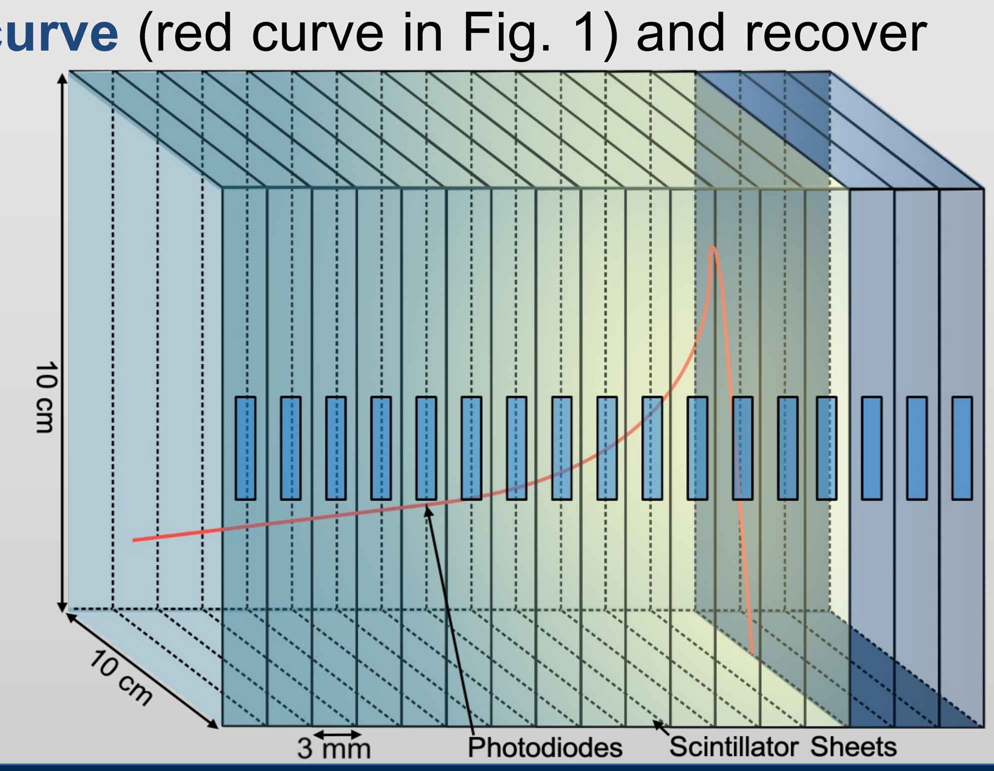

Fig 1. Schematic of the scintillator stack showing the detector principle. Protons enter the stack from the left and the red curve shows example proton depth-energy relation that is recovered from fitting photodiode data.

Setup

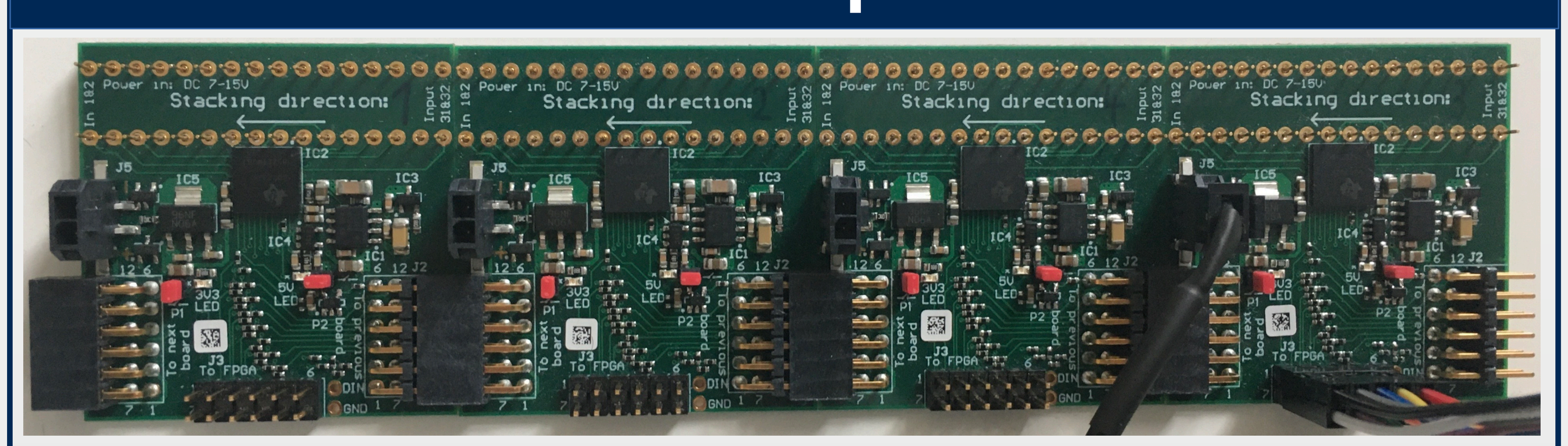

Fig 2. Custom modular circuit board designed by CosyLab housing a Texas Instruments DDC232 ADC. Each of the 4 boards are connected to 16 photodiodes. DDC232 has 8 different dynamic ranges (12.5 pC – 350 pC) to choose from, depending on amount of light in detector.

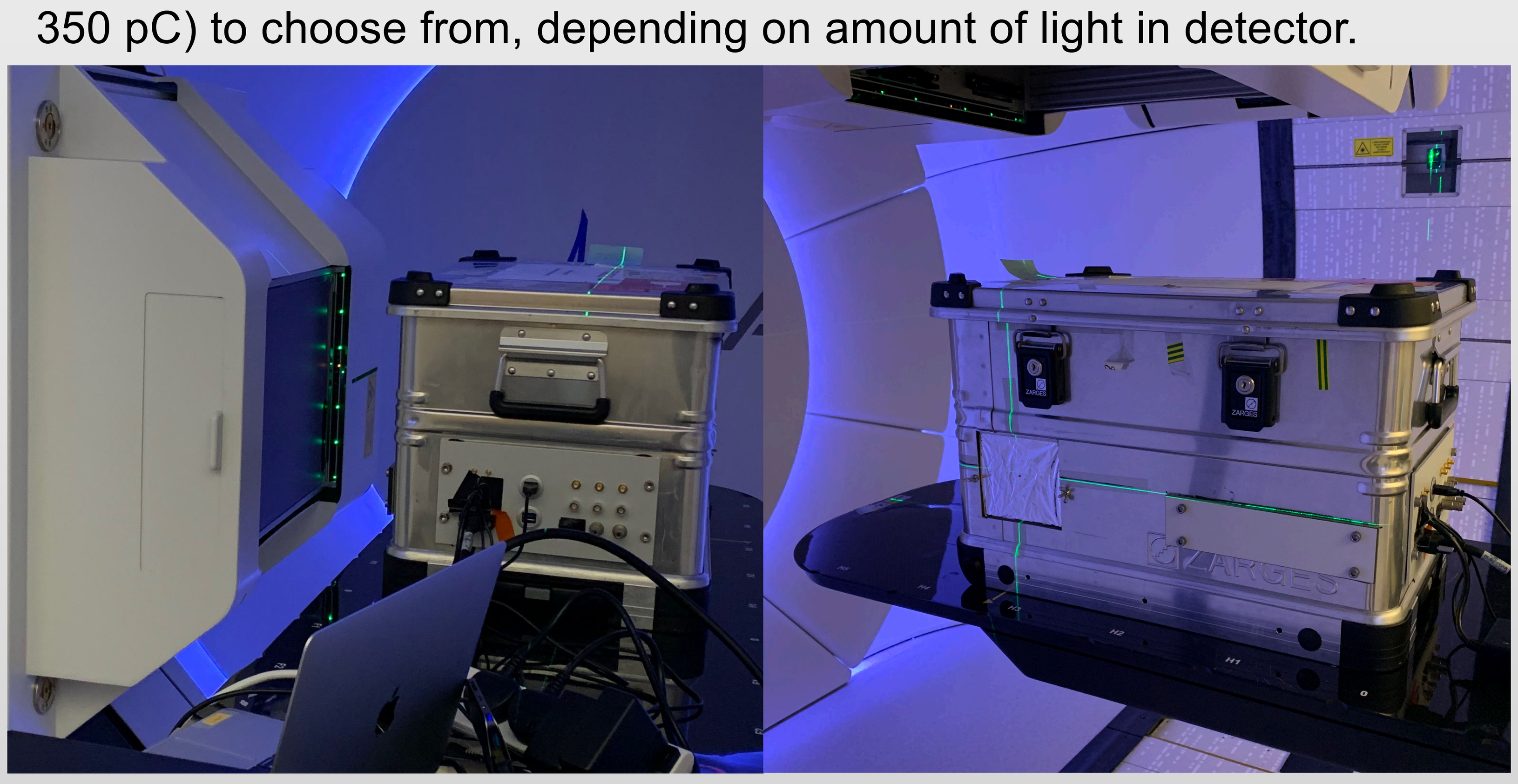

Fig 3. Set-up at UCLH PBT facility. *Left:* beam nozzle adjacent to the detector housing, containing the scintillator stack and readout electronics. *Right:* mylar foil beam entrance window and laser-guided alignment system. The first scintillator sheet is placed approximately at the beam iso-centre and an additional window located behind the stack.

UCLH Test Beam Results

- Tested 32 scintillator sheets (2 ADC modules) with proton beams between 70-110 MeV (upwards of 10^{10} protons/s).
- Fit analytical model using the ROOT data analysis framework to depth-light data and reconstruct Bragg curve for comparison against the facility reference curve.

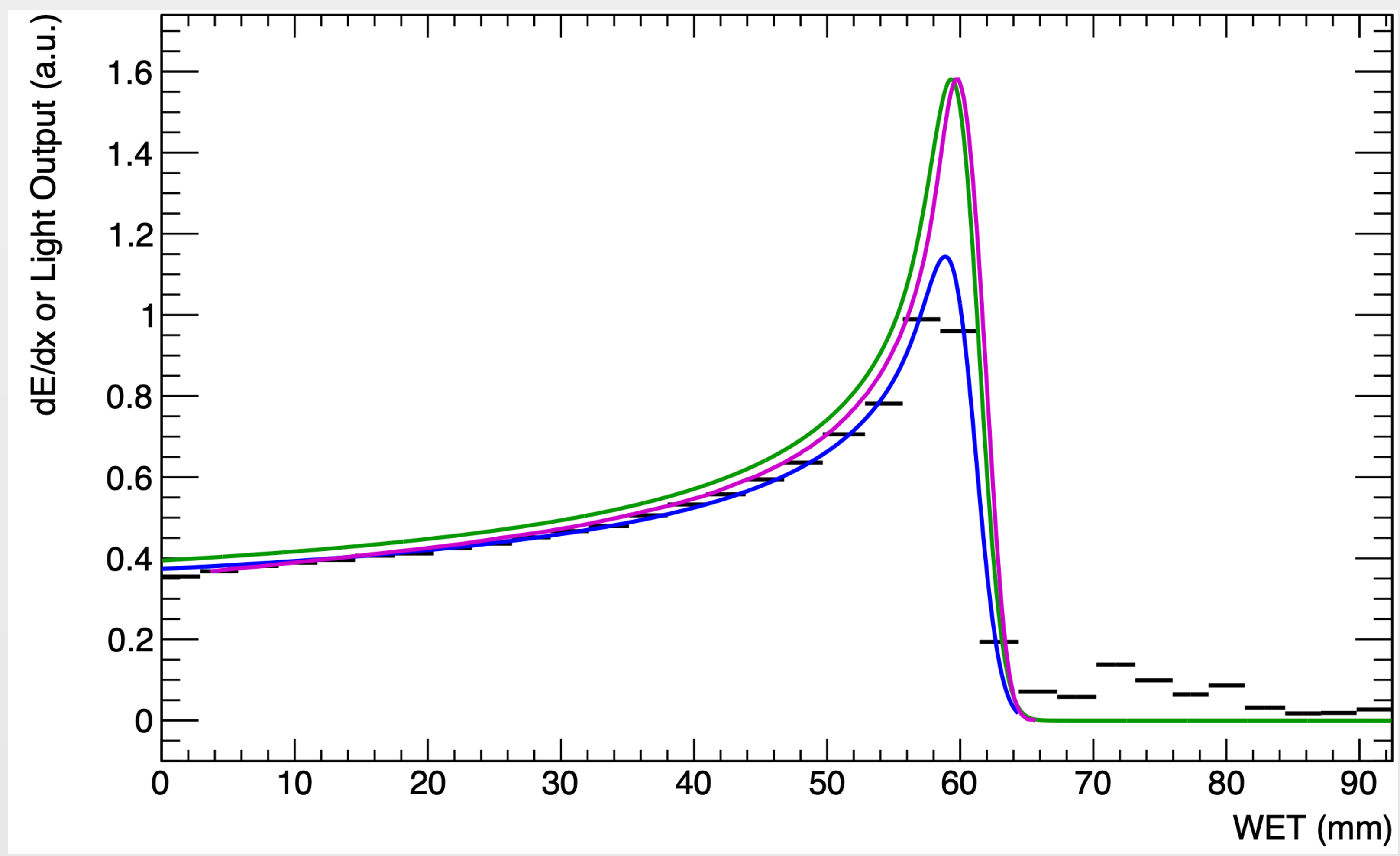

Fig 4. Fit result for 90 MeV proton beam. The black lines show the measured light output from each sheet, the blue curve shows the fitted depth-light curve, the green curve shows the reconstructed Bragg curve, and the magenta curve shows the facility reference curve.

- Good quality of fits despite low light levels (only 1% of total headroom) and electronic background noise beyond the Bragg peak. Systematic underestimation of range by about 0.5 mm.
- **Able to reconstruct range in real-time, as protons are delivered to the detector at up to 40 Hz with 32 sheets.**

Web GUI

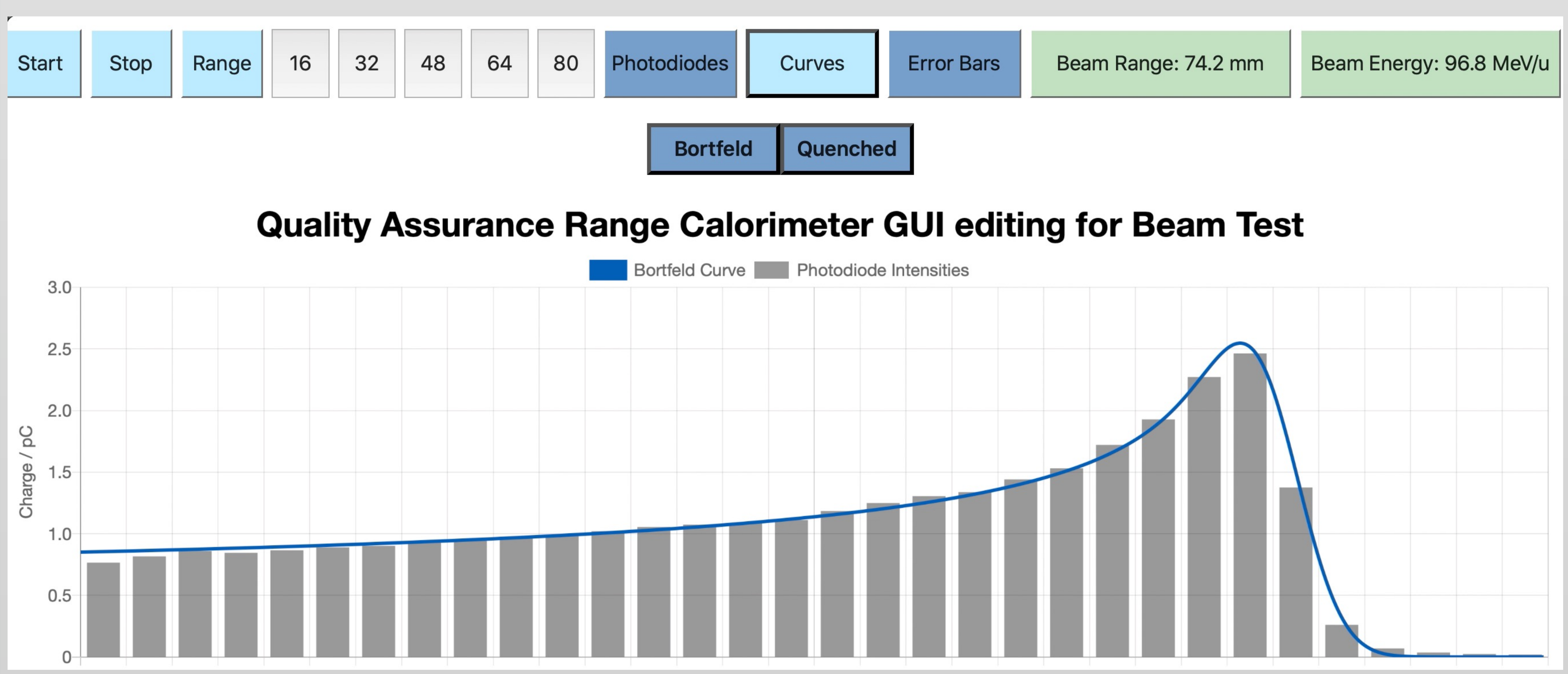

Fig 5. Web-based GUI developed in JavaScript to display fit results without ROOT. Detector hosts webpage on local area network to allow any device (phone, tablet, computer) on hospital network to access results without dedicated software. GUI developed by Fern Pannell.

Future Work

- Final detector will have 128 3 mm scintillator sheets coupled to 4 DDC232s to cover full clinical beam range.
- Test new DDC232 circuit board prototype, with 32 diodes per board and improvements to noise-shielding and daisy-chaining.
- Investigation of generic non-ROOT-based C++ fitting algorithm for faster range reconstruction, possibly deployed on FPGA using Vivado High-Level-Synthesis.
- Additional beam tests to further characterise detector systematics and optimise light output.
- Detector simulation in Geant4 for comparison against experimental results.
- Detector control to be integrated into web-based GUI.

Science & Technology Facilities Council

[1] L. Kelleter et al. “A Scintillator-based Range Telescope for Particle Therapy”. In: Physics in Medicine & Biology 65.16 (Aug. 2020). doi: 10.1088/1361-6560/ab9415.
[2] L. Kelleter and S. Jolly. “A Mathematical Expression for Depth-Light Curves of Therapeutic Proton Beams in a Quenching Scintillator”. In: Medical Physics 47.5 (Feb. 2020), pp. 2300–2308. doi: 10. 1002/mp.14099.

COSYLAB