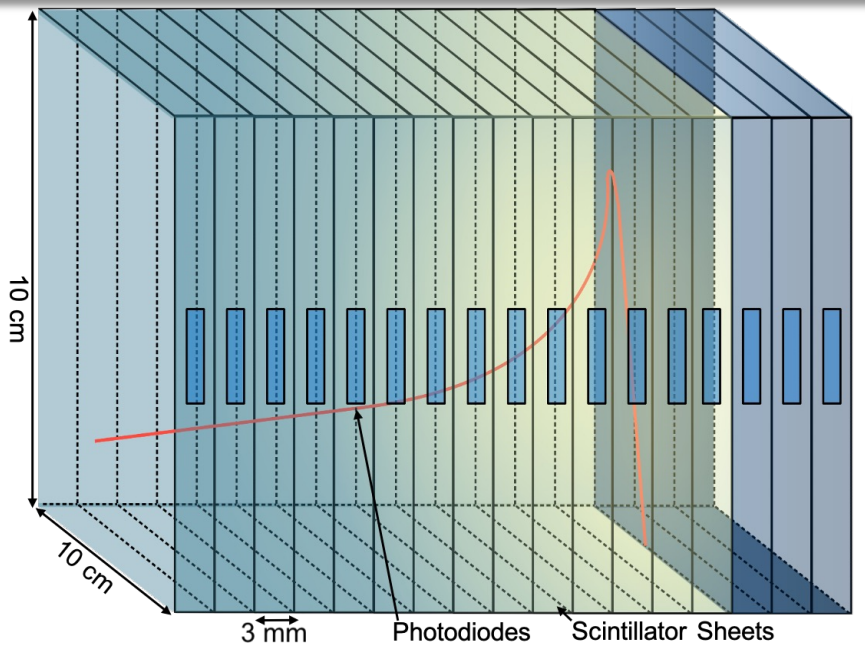
Proton Range Verification

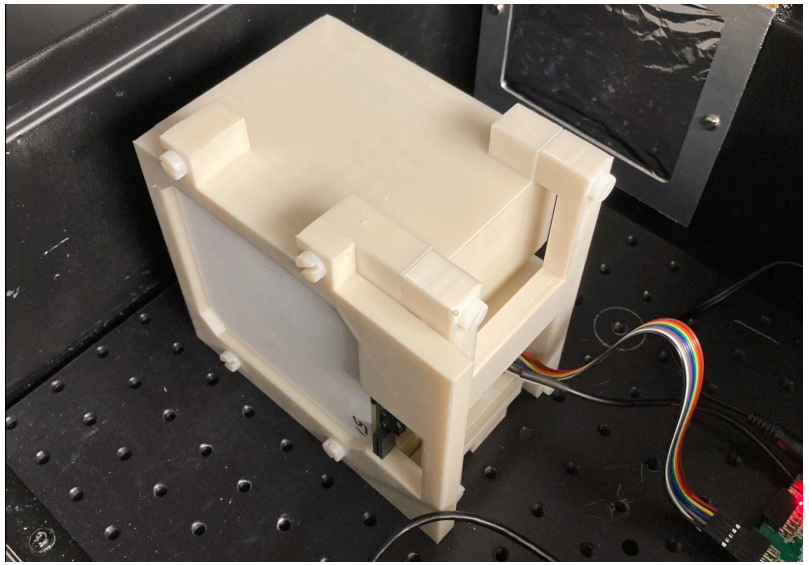
Raffaella Radogna for the INFN Bari group.

Existing collaboration with University College London
Simon Jolly, Saad Shaikh

Quality Assurance Range Calorimeter (QuARC)

- Measure proton range using a series of optically isolated polystyrene scintillator sheets of size: 10 cm × 10 cm × 3 mm.
- Photodiodes coupled to fast, modular ADC electronics read light levels at over 5 kHz.
- Light output of each sheet proportional to proton energy deposition, with some quenching effects.
- Measure depth-*light* curve & reconstruct Bragg depth-*dose* curve to measure proton range [1].

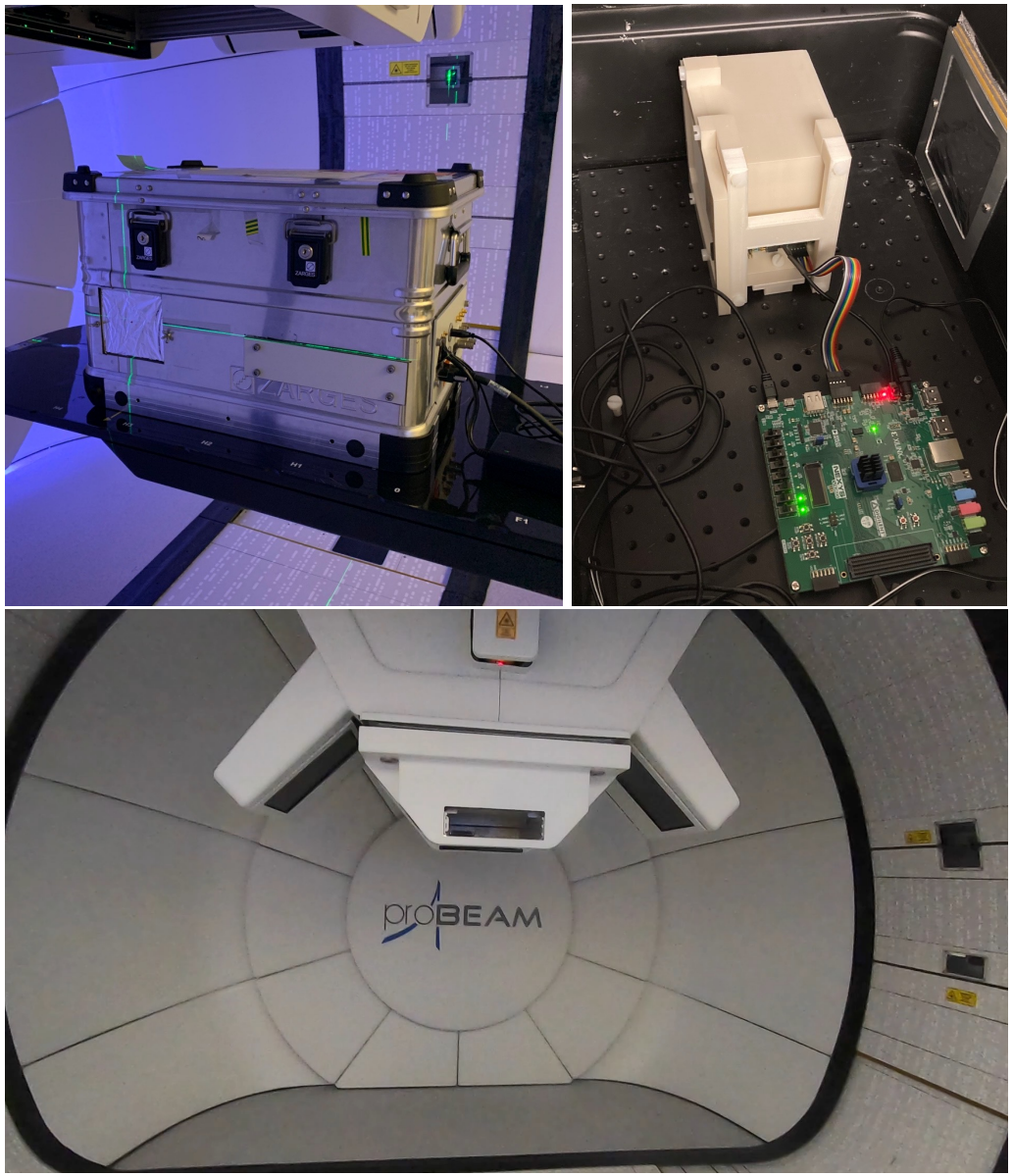




- **Key benefits:**
  - **Plastic scintillator inexpensive and water-equivalent.**
  - **Range reconstructed with single beam delivery.**
  - **Easy detector setup and no optical artefacts.**
  - **Light output dose-rate independent [2].**

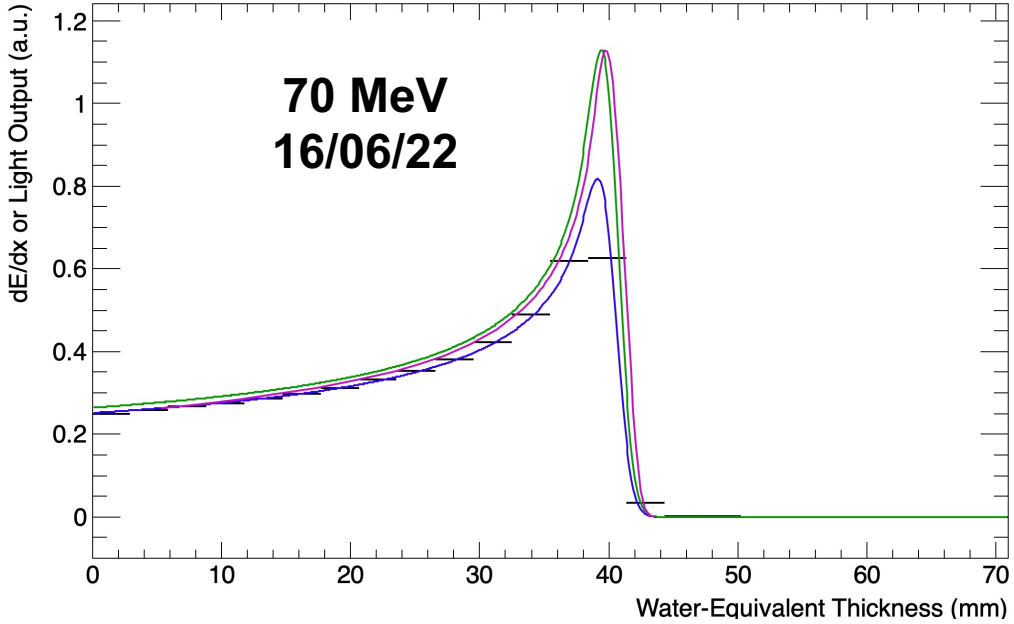
Latest Beam Tests using protons

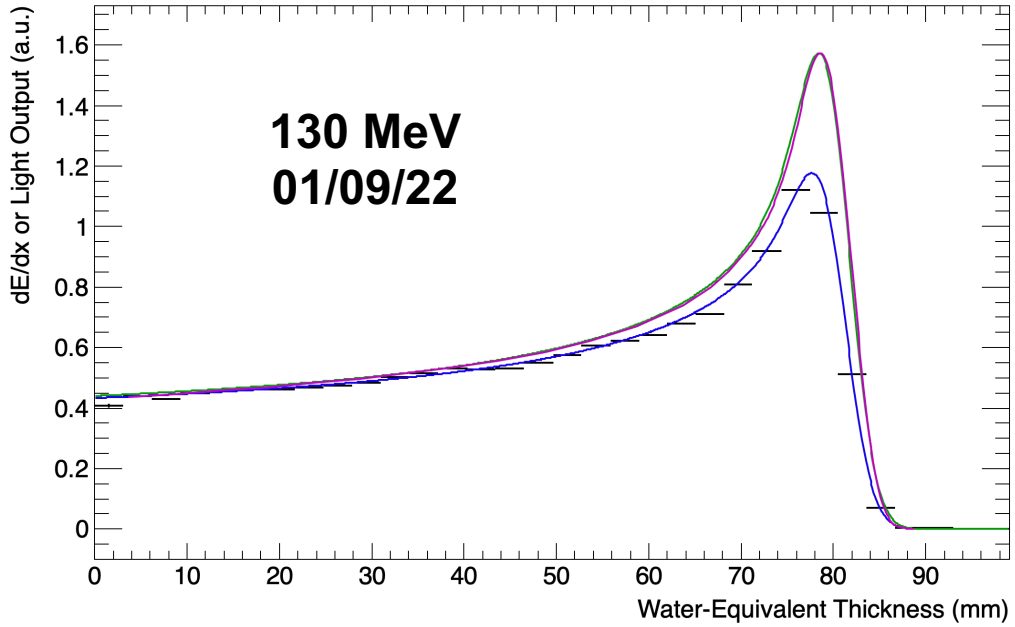
- Beam tests at University College London Hospital on 16th Jun and 1st Sep 2022 to evaluate photodiode performance with clinical beams.
- One detector module (32 sheets, 96 mm total depth) to test pencil beam energies between 70-130 MeV.
- Determine range reconstruction accuracy and demonstrate fast live range reconstruction capabilities.



Results

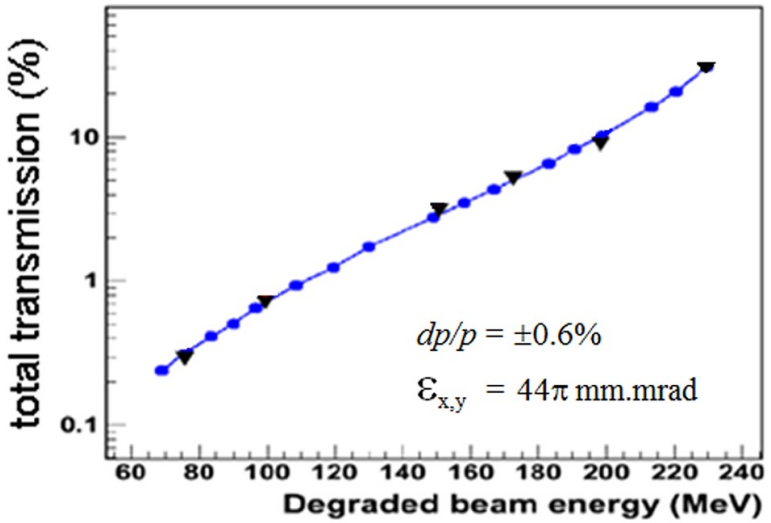
- Legend:
  - Black: Sheet Average Light Output
  - Blue: Fitted Quenched Depth-Light Curve
  - Green: Reconstructed Depth-Dose Curve
  - Magenta: UCLH Reference Dose Curve
- Captures shape of Bragg curve and range accurate within 0.5 mm.
  - Depth calibration is ongoing.
- Latest result accurate to 0.1 mm in only 10 mins – including setup time.
- Reconstructed range well despite poor signal-to-noise ratio.
  - Only using 1% of total headroom.
- Real-time range reconstruction!
  - 6 kHz data-rate, 40 Hz range fitting.

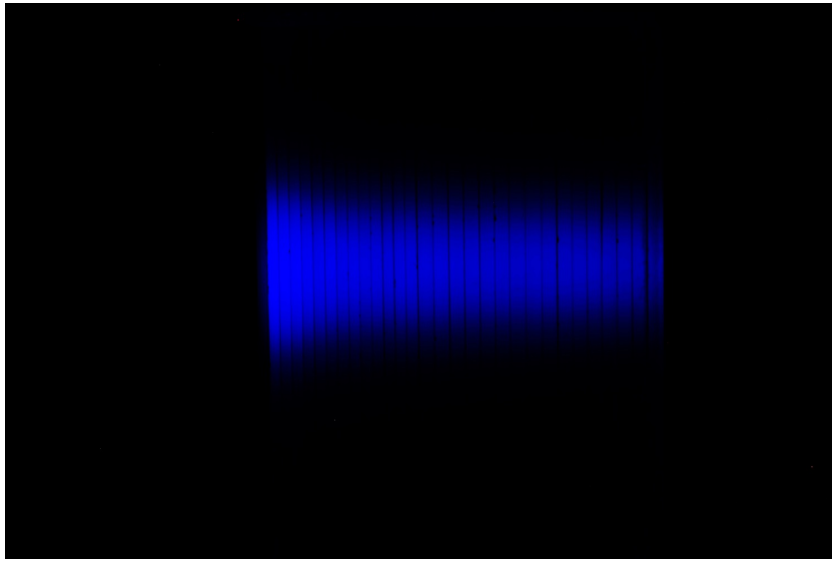




Scaling To FLASH

- Dose-rate for FLASH estimated around 40 Gy/s.
  - Estimated delivery time of 100 ms
  - Corresponds to a current of 600 nA to the patient [3].
- Current detectors used for QA fail at this level.
- However, due to the nanosecond decay time of the plastic scintillator and the large dynamic range of the detector, range measurements are also possible at FLASH dose rates.
  - scintillation light output scales linearly with dose-*rate*.
- Measurements made with clinical beam at UCLH with 300 nA cyclotron current.
  - Approx. 1% transmission ratio to treatment room.
  - Expect 600/(300*1%) = 200 factor increase in light.





FLASH Range Measurements

- **First FLASH measurements planned**
  - The Christie, Manchester (October 2022)
  - UMCG, Groningen (November 2022)

References

References:
1. 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
2. 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.
3. S. Jolly et al. “Technical Challenges for FLASH Proton Therapy”. In Physica Medica 78 (2021). DOI: 10.1016/j.ejmp.2020.08.005