Advancing Radiobiology Technology

IOP Institute of Physics

State of the art: Beam instrumentation

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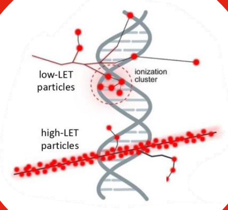
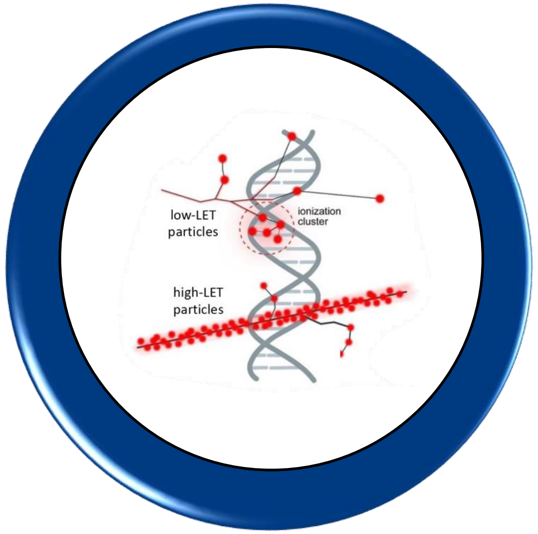
The Cockcroft Institute of Accelerator Science and Technology

QUASAR GROUP



Overview



Motivation and clinical benefits

State of the art

Technology innovations

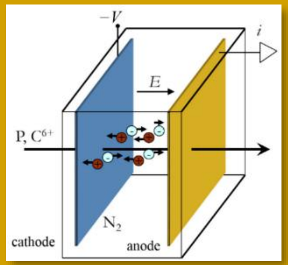
Hadron beam therapy

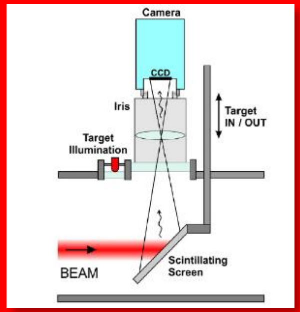
CNAO Synchrotron, image courtesy CNAO.

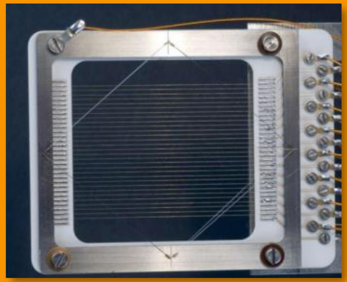
- Significant investment through in the UK and around the world;
- Optimization of Medical Accelerators (OMA) network identified key R&D challenges:
  - Significant time goes into Q&A
  - New technology solutions needed for novel treatment modalities such as FLASH
  - Desirable machine operation modes not currently possible due to lack of non-invasive (online) diagnostics
  - Future facilities (e.g. LhARA) will require different approaches to instrumentation and beam control!

Current diagnostics – established technology

- \+ High resolution
- \+ Reliability
- \+ Validity
- \- Interceptive
- \- Ongoing calibration
- \- Beam perturbation
- \- Limited live feedback







B. Walasek-Höhne, GSI and G. Kube, DESY
S. Giordanengo & M. Donetti, arXiv:1803.00893

Novel diagnostics solution - dosimetry

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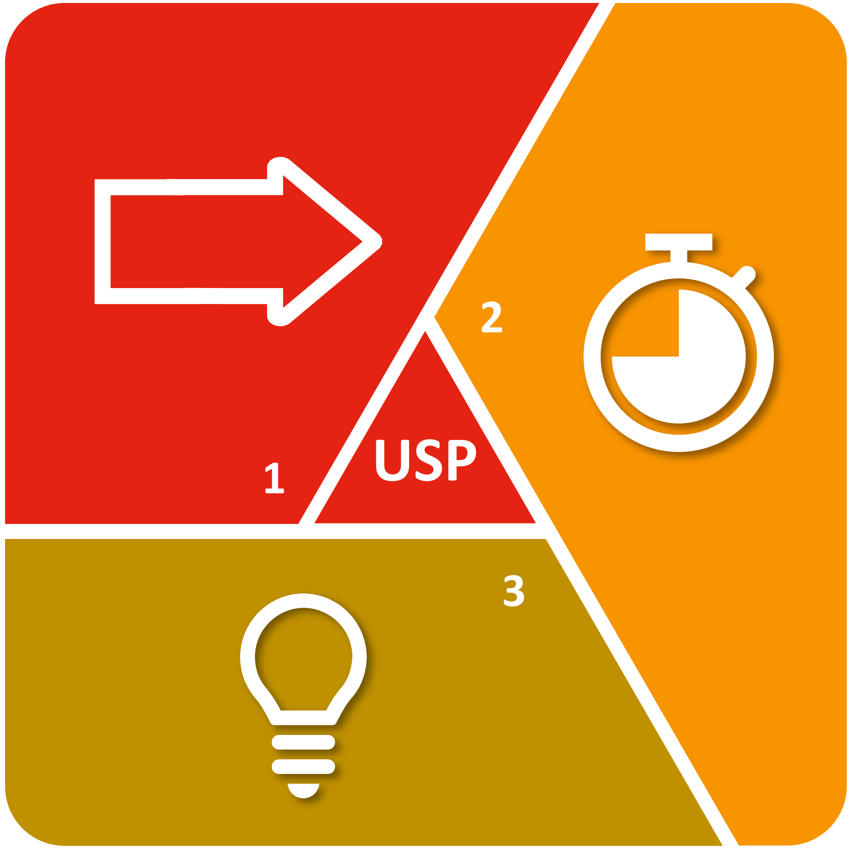
1 Minimally invasive

- ✓ No beam perturbation
- ✓ Online monitoring
- ✓ Superior error detection

3 Novel treatments and improved operation

- ✓ Enabling technology for FLASH and Mini-Beam treatments
- ✓ Active machine regulation based on live feedback becomes feasible



2 Significantly reduced calibration time

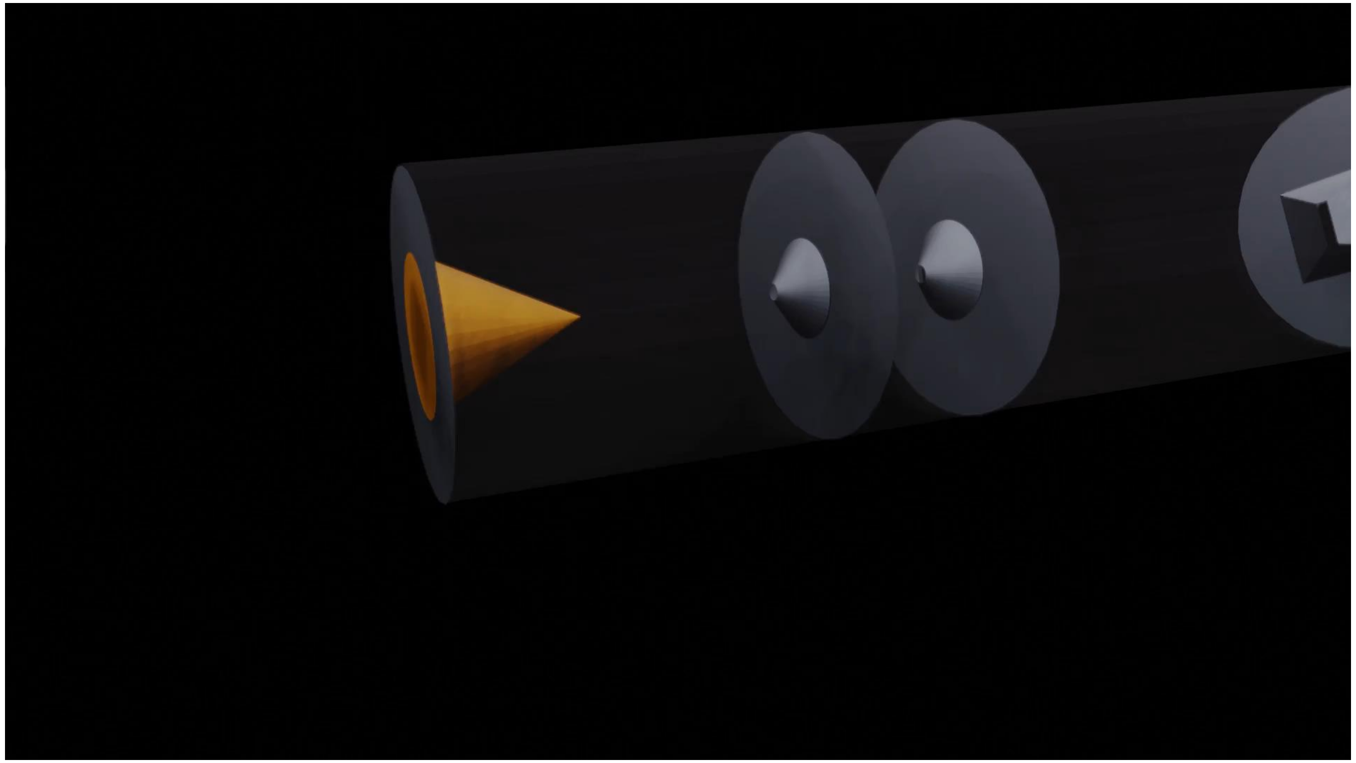
- ✓ No mechanical parts interact with the beam
- ✓ All key parameters monitored remotely
- ✓ Significantly reduced maintenance

N. Kumar, C.P. Welsch, et. al, Physica Medica 73, p 173-178 (2020).

S. Jolly, C.P. Welsch, et al., *"Technical challenges for FLASH proton therapy"*, Phys Med 2020 – Galileo Galilei Award, best paper in 2020

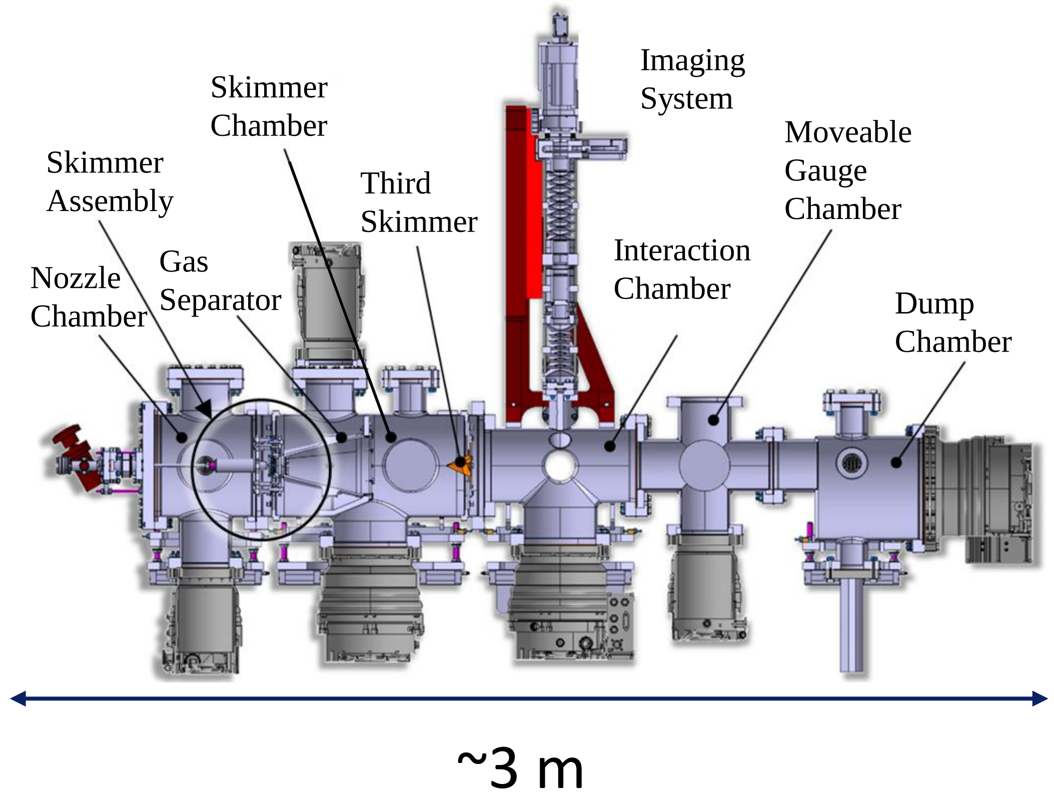
"Non-Invasive Gas Jet In-Vivo Dosimetry for Particle Beam Therapy", contributed talk at IPAC21

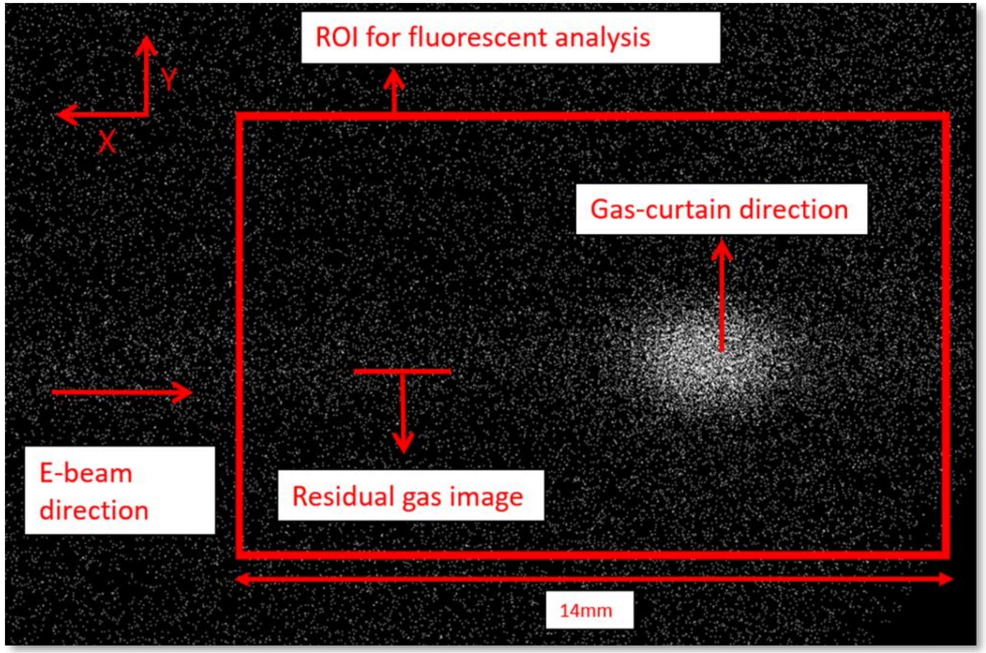
Building up on HL-LHC technology



Gas jet shaping

Building up on HL-LHC technology





"Gas jet monitor R&D is world leading" – CI SAC (2019)

Different setups at the Cockcroft Institute

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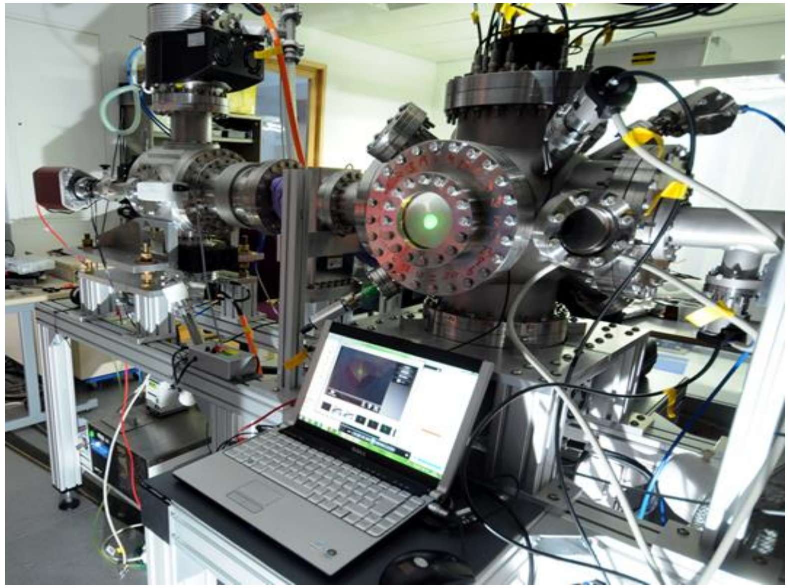
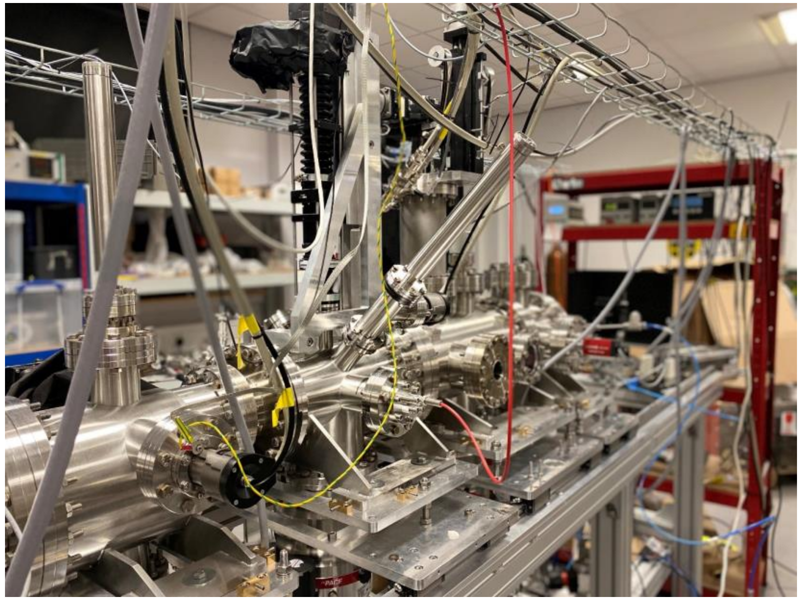
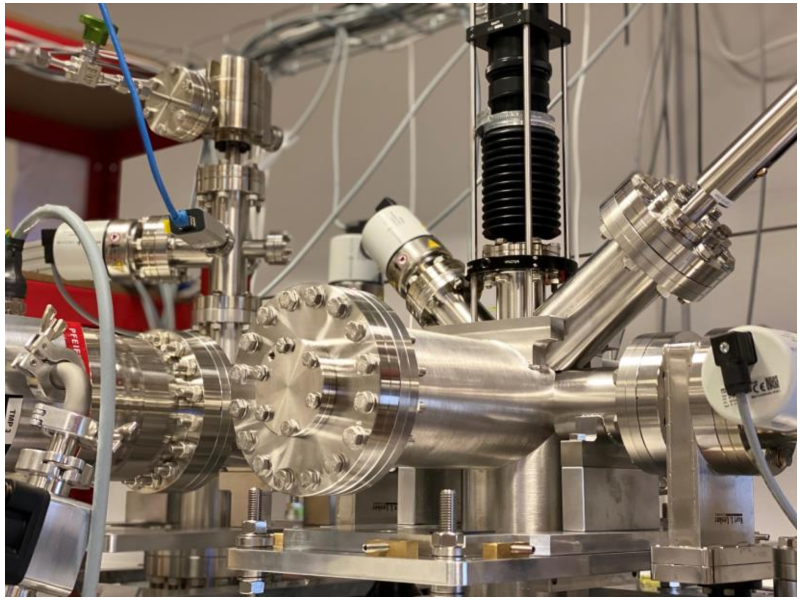


Monitor for keV beams

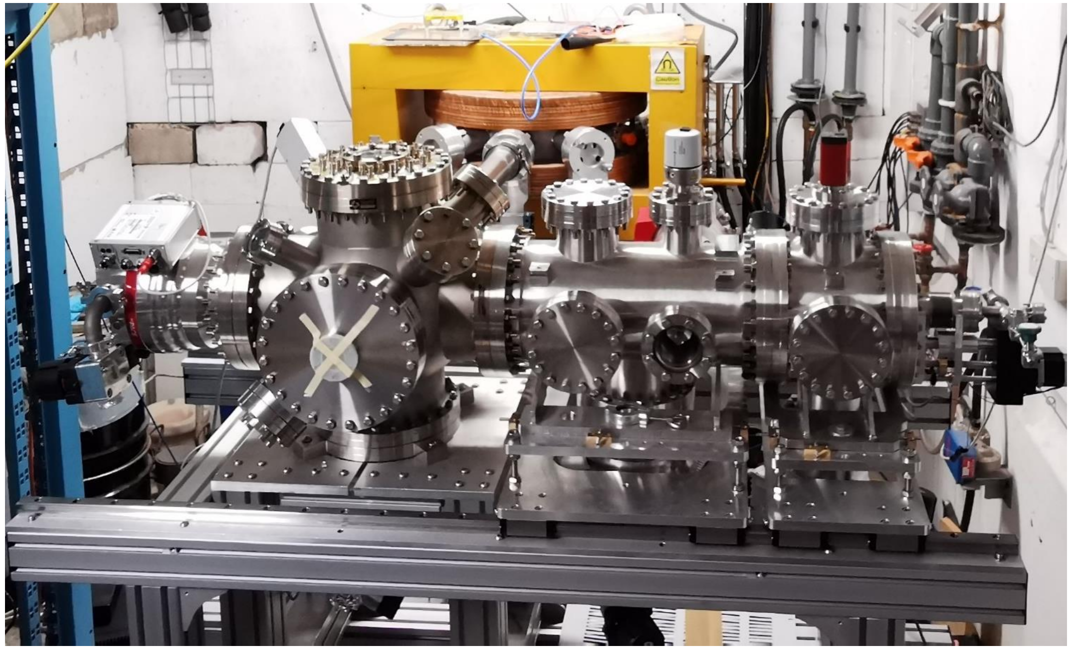


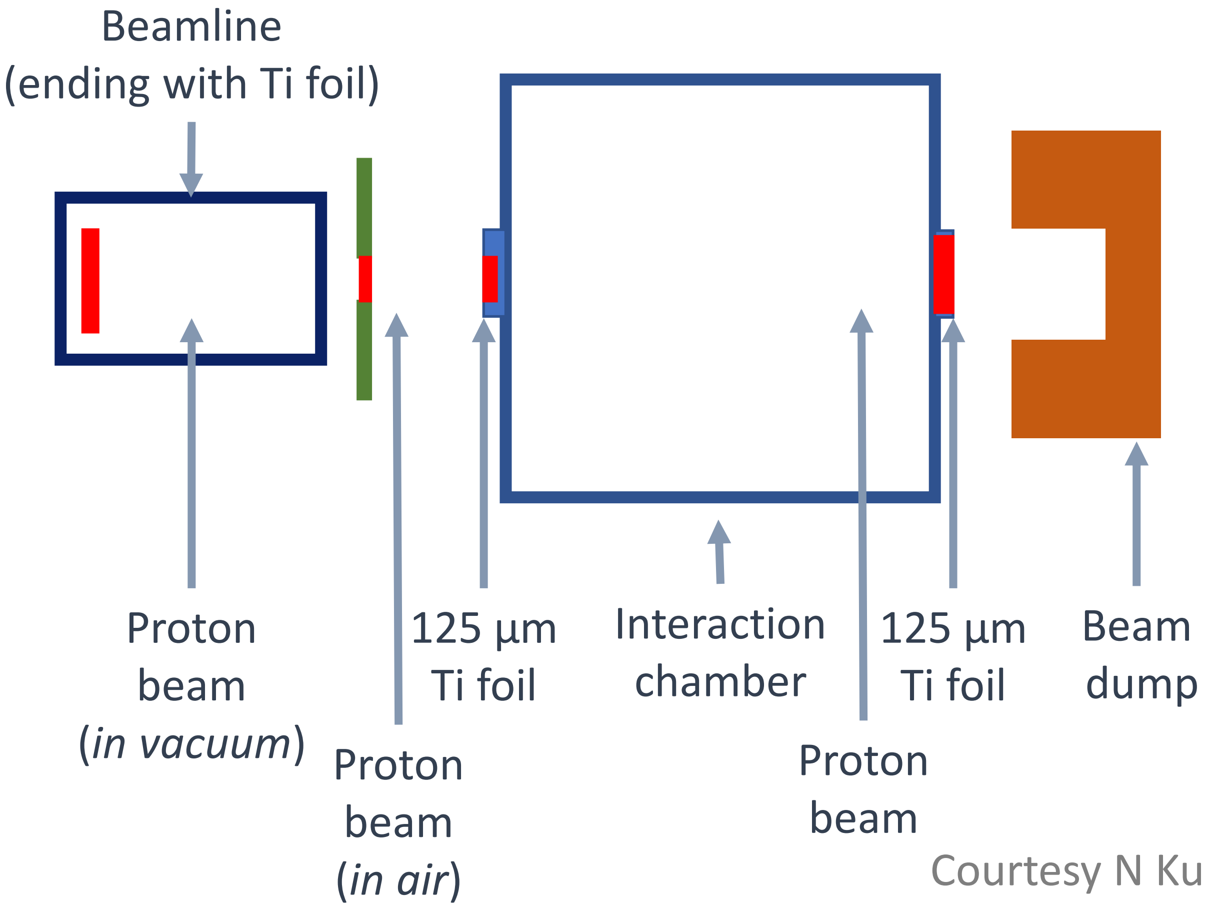
HL-LHC prototype



HL-LHC working instrument

Measurements @ UoB MC40 cyclotron



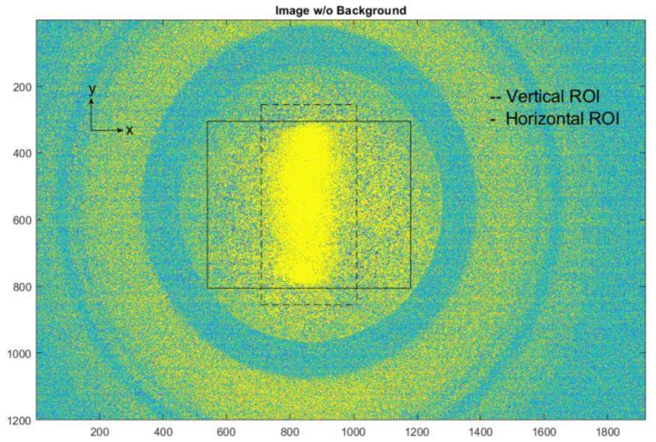


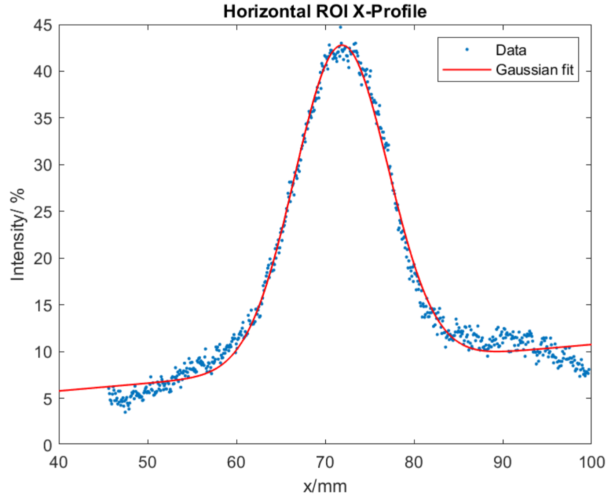
Courtesy N Kumar, ULIV

Beam Parameters

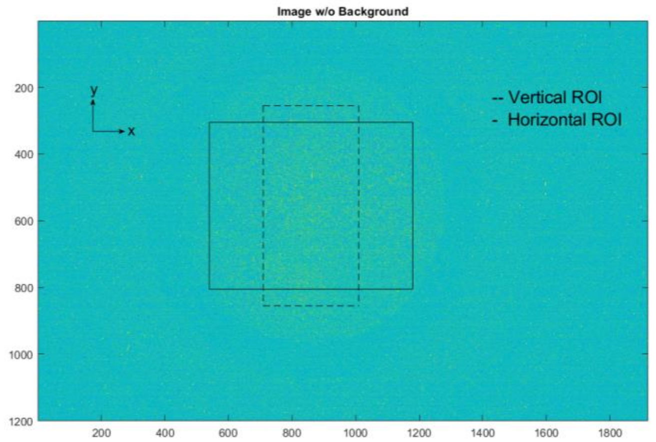
Beam Species:	***Protons***
Beam Energy:	***28 MeV***
Beam Current:	***150-750 nA (on FC1)***
Beam Collimator Area:	***4-100 mm²***

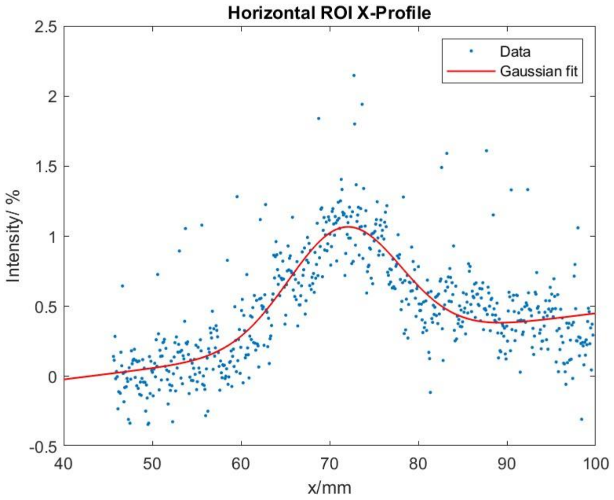
Measurements @ UoB MC40 cyclotron





Beam collimator Area= 100 mm^2
Integration time = 1 s
Gas Pressure in Interaction chamber = 1.2 $\times 10^{-5}$ mbar
σ = 5.4 mm
Beam current at FC_1= 150 nA





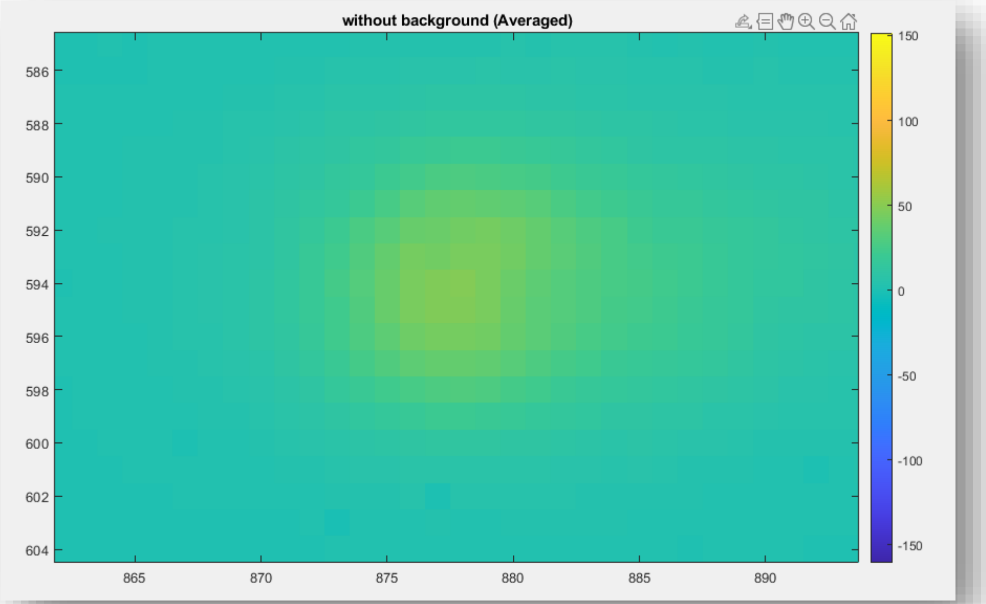
Beam collimator Area= 4 mm^2
Integration time = 20 s
Gas Pressure in Interaction chamber = 1.2 $\times 10^{-5}$ mbar
σ = 6.4 mm
Beam current at FC_1= 150 nA

Courtesy N Kumar, ULIV

Measurements at DCF, Whitehaven

Carbon beam energies: 16 MeV, 20 MeV (Nitrogen) and 12 MeV, 16 MeV, 20 MeV, 24 MeV (Argon).

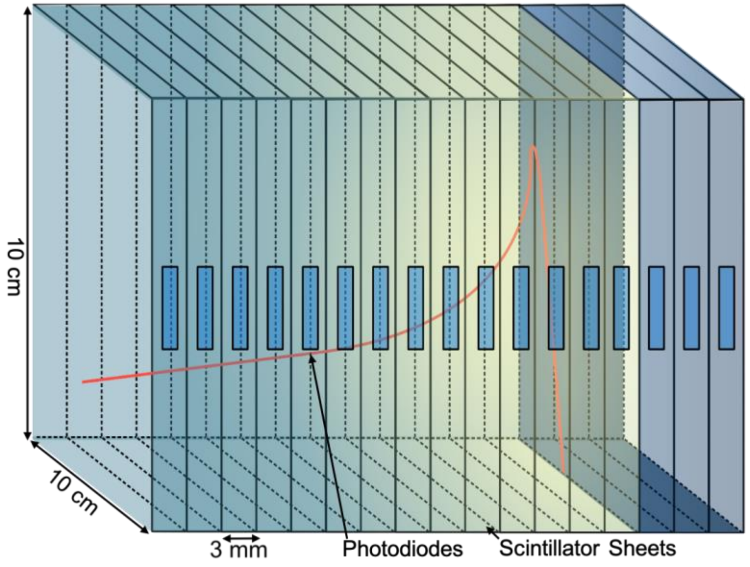
- 100nA (3.25×10^{10} – 8.125×10^{10} Carbon Ions/Sec) with/without gas jet –Exposure times: 1 s, 300 ms, 100 ms
- 100nA (3.25×10^{10} – 8.125×10^{10} Carbon Ions/Sec) with/without gas jet size 2 –Exposure times: 1 s, 300 ms, 100 ms
- 100nA (3.25×10^{10} – 8.125×10^{10} Carbon Ions/Sec) with/without gas jet size 3 –Exposure times: 1 s, 300 ms, 100 ms
- 10nA (3.25×10^{9} – 8.125×10^{9} Carbon Ions/Sec) with/without gas jet –Exposure times: 1 s, 2 s
- 1nA (3.25×10^{8} – 8.125×10^{8} Carbon Ions/Sec) with/without gas jet –Exposure times: 1 s, 2 s

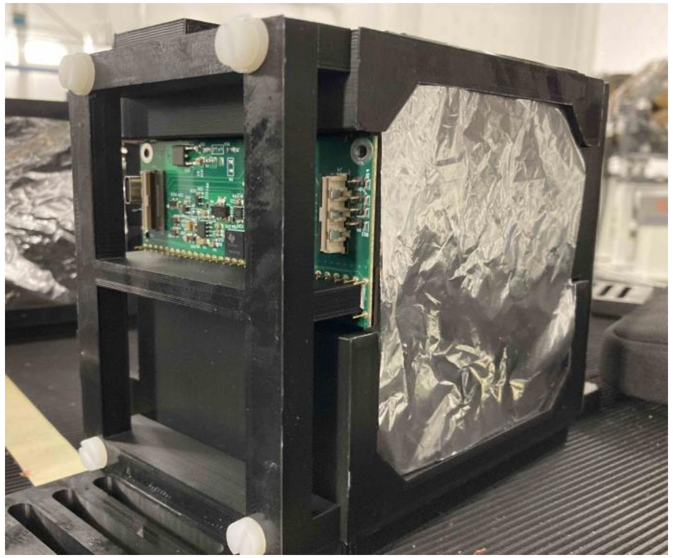


Courtesy N Kumar, ULIV

Quality Assurance Range Calorimeter (QuARC)

- Optically-isolated polystyrene scintillator sheets in a segmented design.
- Photodiodes coupled to fast, modular electronics and FPGA to read light levels at 6 kHz.
- Light output nonlinear to LET due to quenching effects described by Birks' law.
  - Fit light output using analytical depth-light model.



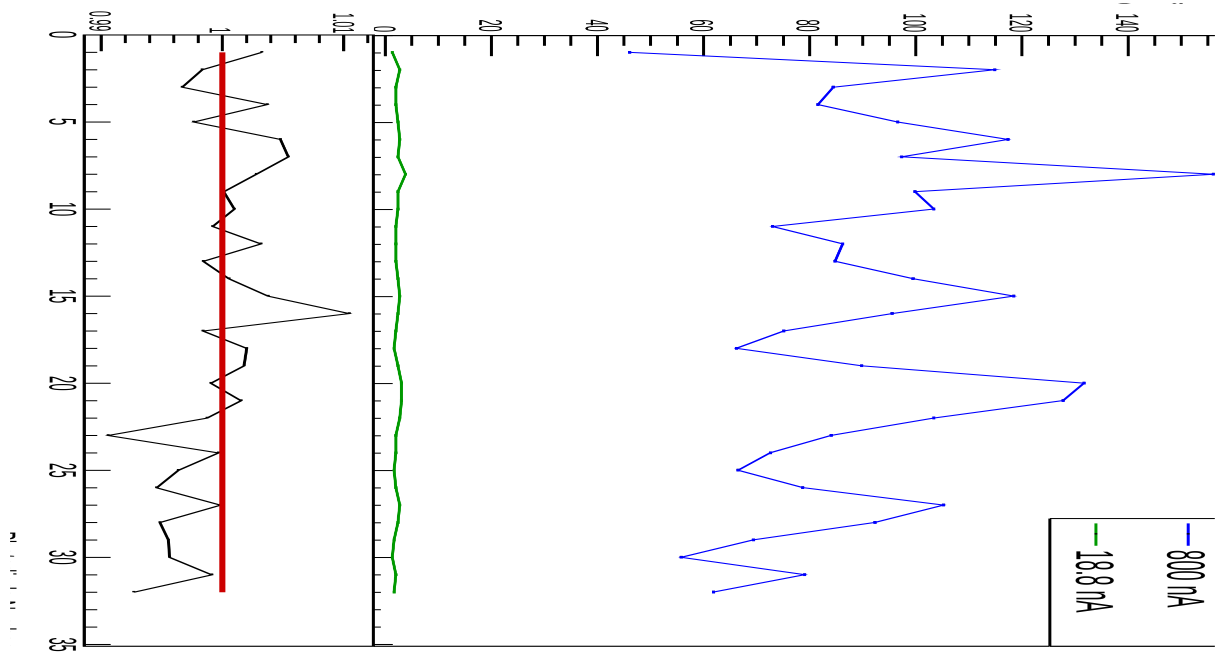


S Jolly, S Shaikh, S E Rodriguez, C Godden, M Warren, D Attree, R Saakyan (all UCL), R Radogna (U Bari), L Kelleter (DKFZ)

Courtesy S Jolly , UCL

The Christie Beam Test

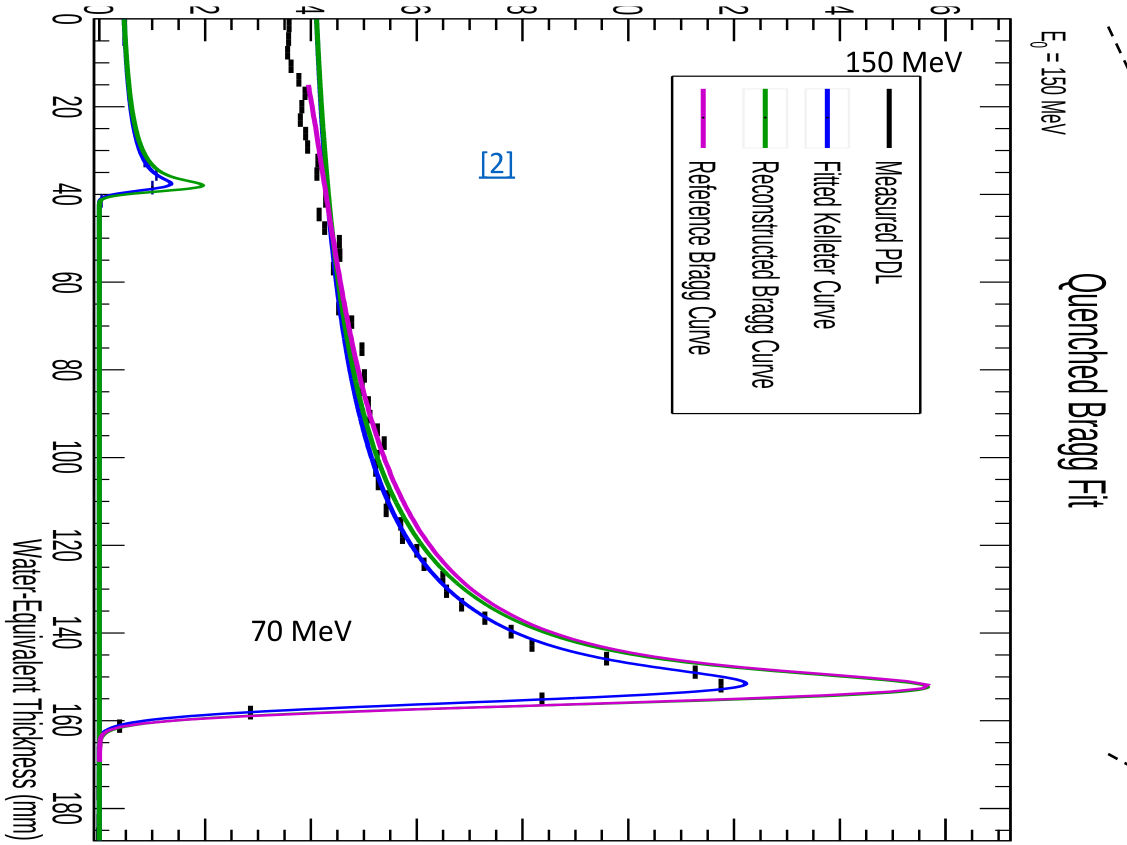
- Four 32-sheet detector modules (40 cm WET) to test energies between 70 - 245 MeV at clinical current;
- 245 MeV FLASH beam available at 800 nA ion-source current (~ 7% transmission).

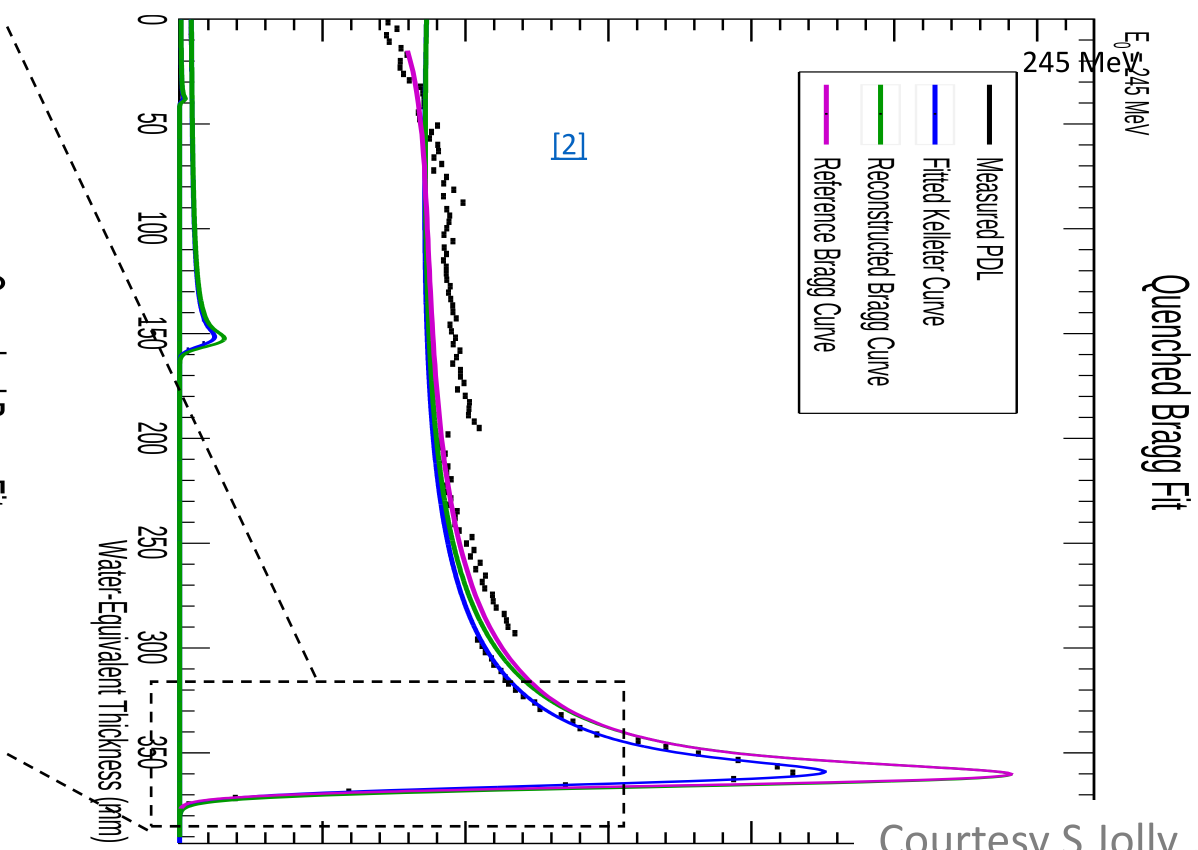


Courtesy S Jolly , UCL

The Christie Beam Test: Results

	70 MeV	150 MeV	245 MeV
Reference range (mm)	38.67	154.79	363.89
Fitted range(mm)	38.87	154.99	364.27

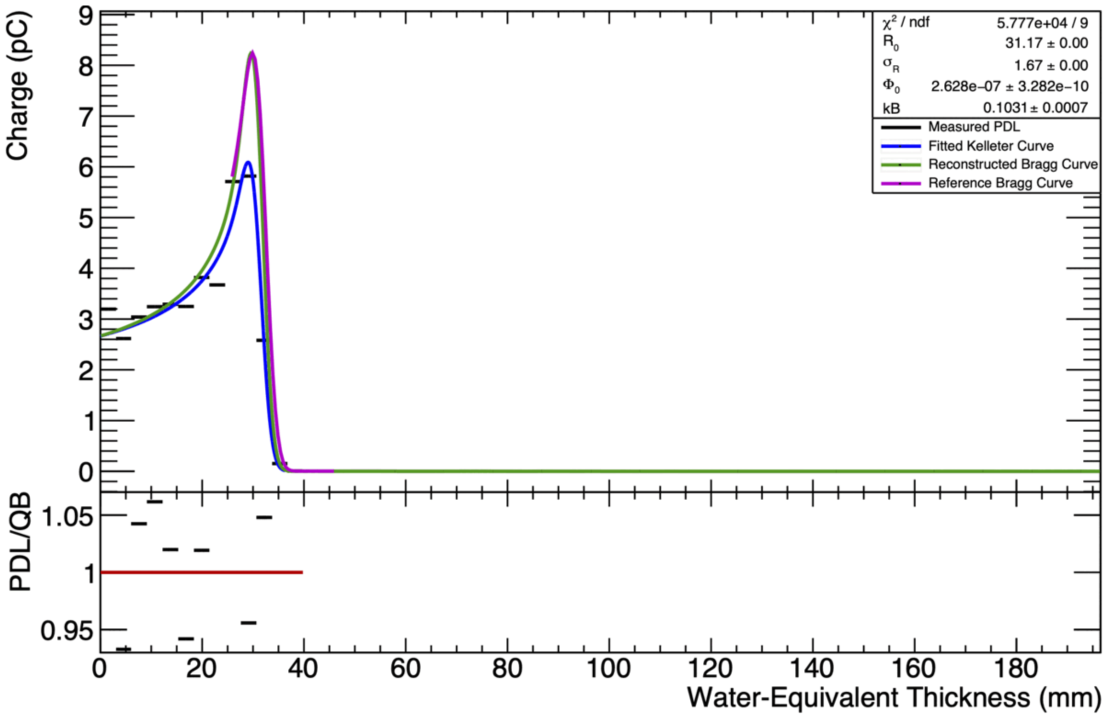




Courtesy S Jolly , UCL

PARTREC Beam Test

- Tested currents up to 50 nA and energies up to 150 MeV.
- Push the detector to its limit in terms of beam current/scintillator light output.
- 2 detector modules tested.



Courtesy S Jolly , UCL

Summary and future plans

- Detector able to reconstruct proton ranges at clinical currents between 70-245 MeV with an accuracy of 0.4 mm.
- Detector can handle up to 50 nA of nozzle current. Non-linearities in charge observed but range consistent.

- Further development of web-based GUI to allow detector control.
- Improve scintillator composition and construction to optimise light output.
- Geant4 simulation to benchmark experimental results and constrain Birks' constant.
- Additional beam tests to optimize light output and characterize detector performance with clinical and FLASH beams.

Courtesy S Jolly , UCL

Virtual diagnostics

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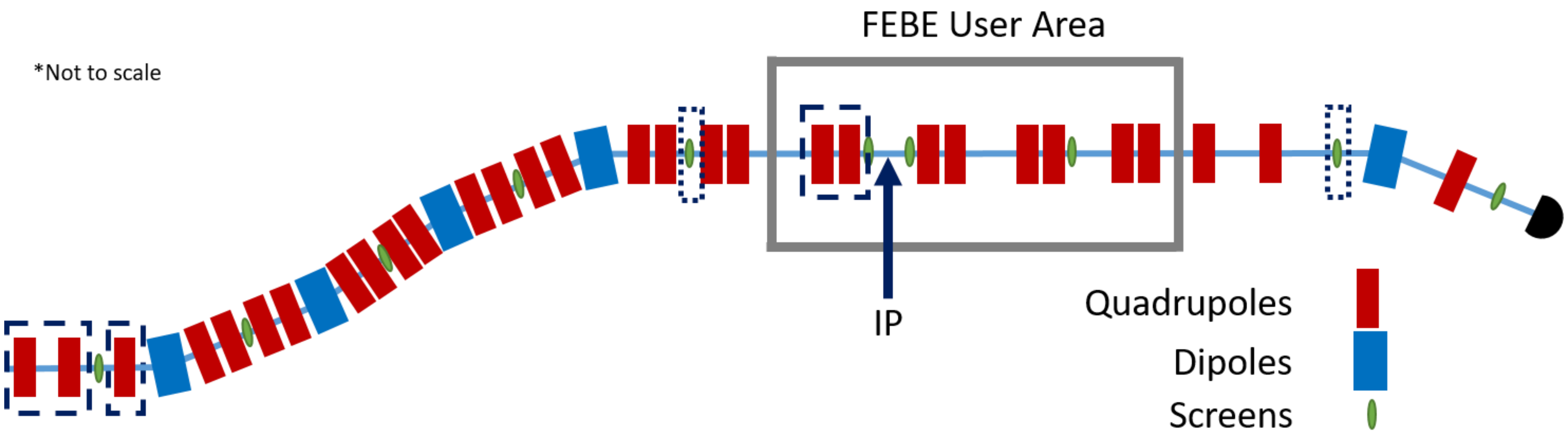
- Beam characteristics crucial in places where measurement difficult, e.g. inside of a plasma cell;
- Virtual diagnostics (VD) can infer properties those locations!

- <u>Case study</u>:
  - Simulation study on profile measurements at FEBE @ CLARA
  - Upstream and downstream X-Y measurements used to infer characteristics

Courtesy J Wolfenden, ULIV

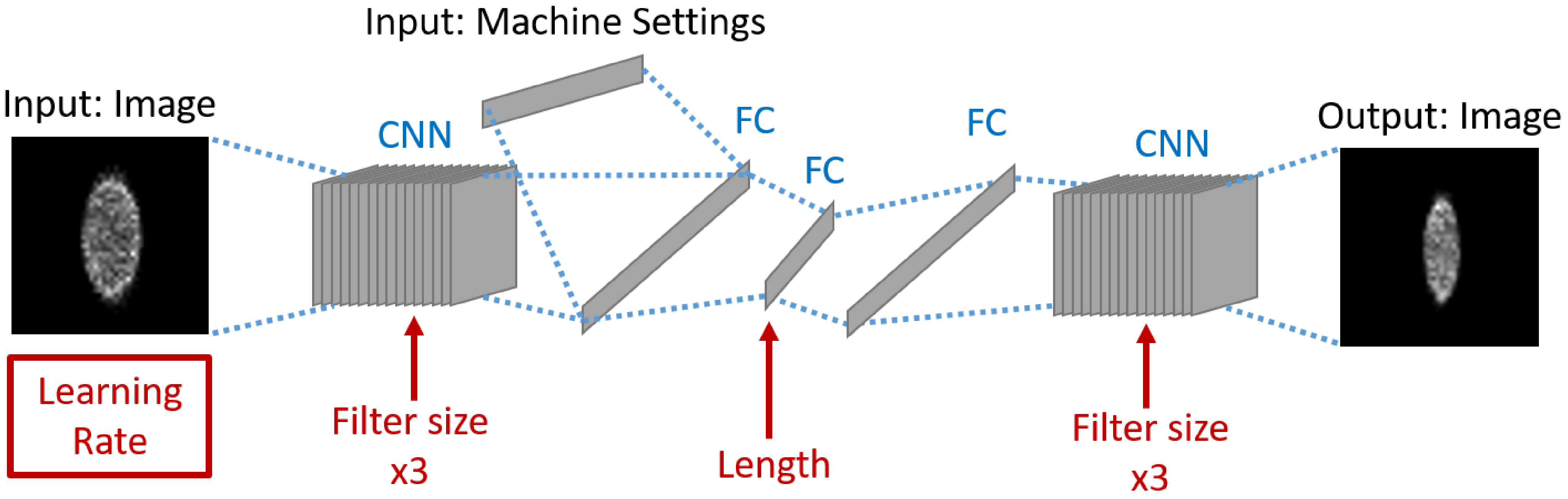
Virtual diagnostics



- Initial simple demonstration - planned profile measurement points could be used
- Highlighted quads were varied and profiles at highlighted screens were simulated

Courtesy J Wolfenden, ULIV

Virtual diagnostics



- Convolutional Neural Network architecture used with tuneable hyper parameters
- Upstream and downstream versions of the diagnostic were tested

Courtesy J Wolfenden, ULIV

Summary

- Wide range of reliable diagnostics available for medical accelerators;
- However, future facilities will require new and different approaches as performance of current monitors no longer sufficient;
- This will require cross-discipline collaboration!
- These technology innovations are expected to also find application outside of medical accelerators.

Thanks for your attention!