DEPARTMENT OF MEDICAL PHYSICS & BIOMEDICAL ENGINEERING

UCL

Integr8: Towards a clinical prototype scintillator-based proton radiography system

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Overview

- Objective: develop a detector for integrated mode proton radiography capable of real-time tracking lung breathing motion.
- Aim: address significant source of proton range uncertainty in the treatment of lung cancer, unlocking possibility for dose-escalation and improved patient outcomes[1].
- Part 1: preliminary lung motion tracking results with V1 prototype detector.
- Part 2: discuss challenges and showcase V2 of integrated mode proton radiography detector.

[1]Landau et al. (2016) *IDEAL-CRT: A Phase 1/2 Trial of Isotoxic Dose-Escalated Radiation Therapy and Concurrent Chemotherapy in Patients With Stage II/III Non-Small Cell Lung Cancer.* DOI: 10.1016/j.ijrobp.2016.03.031

Imaging lung tumor motion using integrated-mode proton radiography - A phantom study towards tumor tracking in proton radiotherapy

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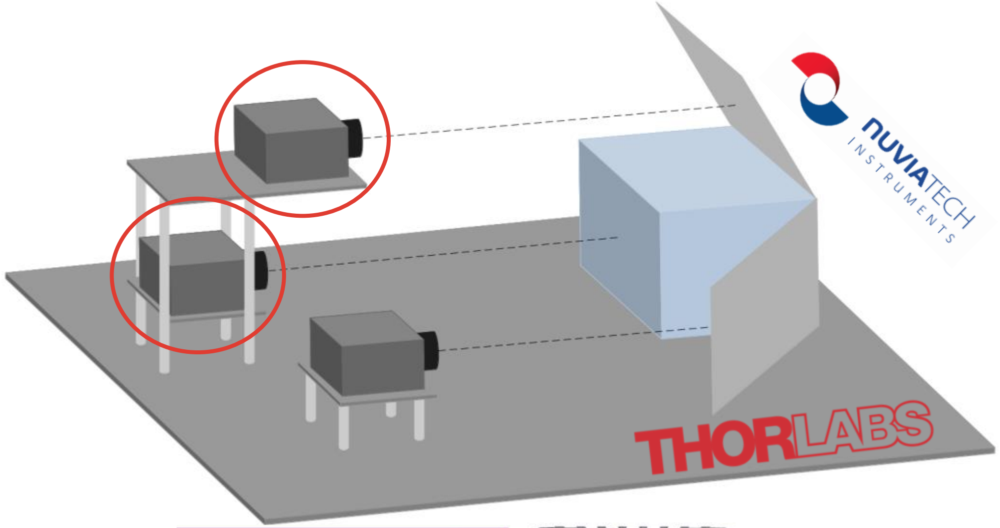
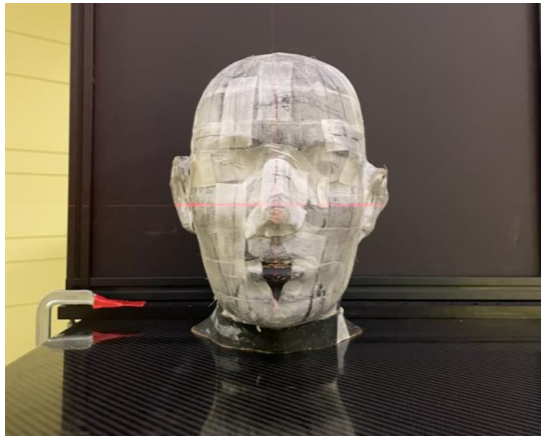
Detector for Integrated Proton Imaging



- Monolithic polystyrene scintillator block imaged with 3 CCD cameras:
  - Scintillator: 20 x 20 x 25 cm, 1.03 g/cm^3 density, 2.5 ns response time, 1.043 RSP.
  - Cameras: 3x FLIR ORYX-10G-51S5M working distance 42.5 cm, 333 FPS.
  - ThorLabs optical breadboard enclosure.

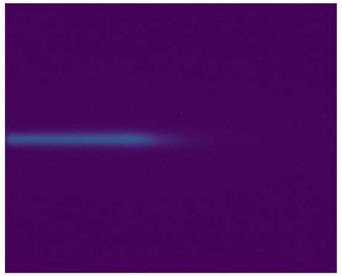
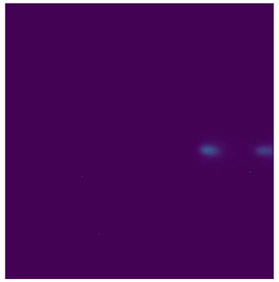
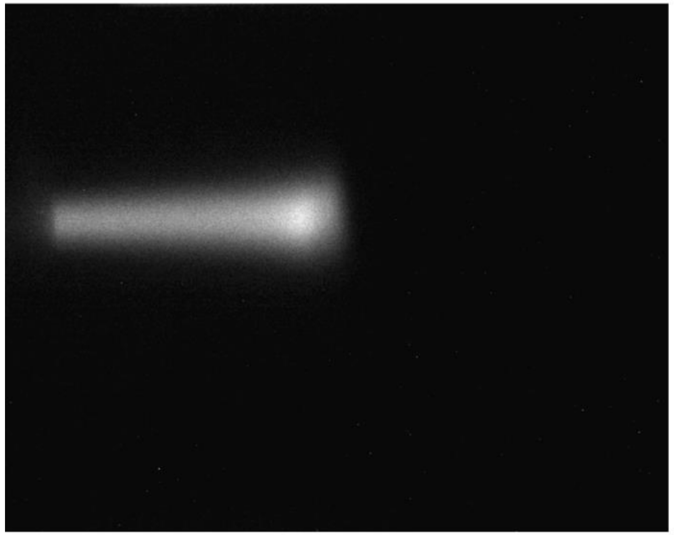




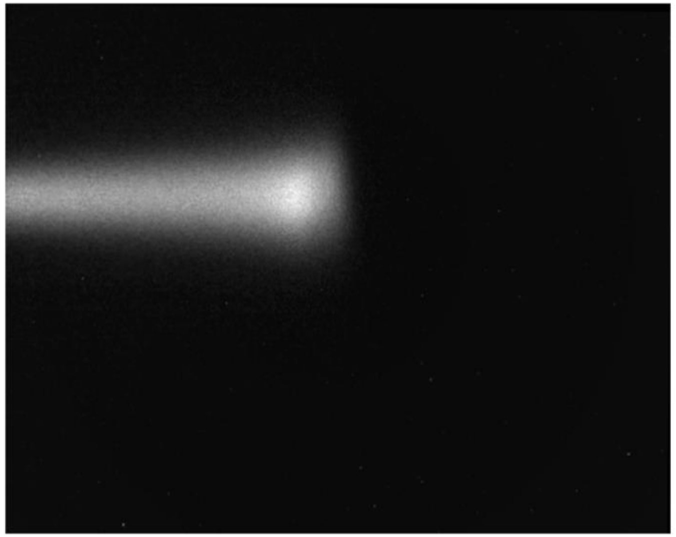
Image Processing

- Measure scintillator depth-light distribution.
- Need to correct optical artefacts in image[2]:
  1. Background subtraction
  2. Stray radiation removal
  3. Lens vignetting correction
  4. Lens distortion correction
  5. Refraction and Perspective Correction
- Perform physics-based so-called "back projection" to map beam onto incident scintillator surface of camera[3].

Uncorrected



Corrected

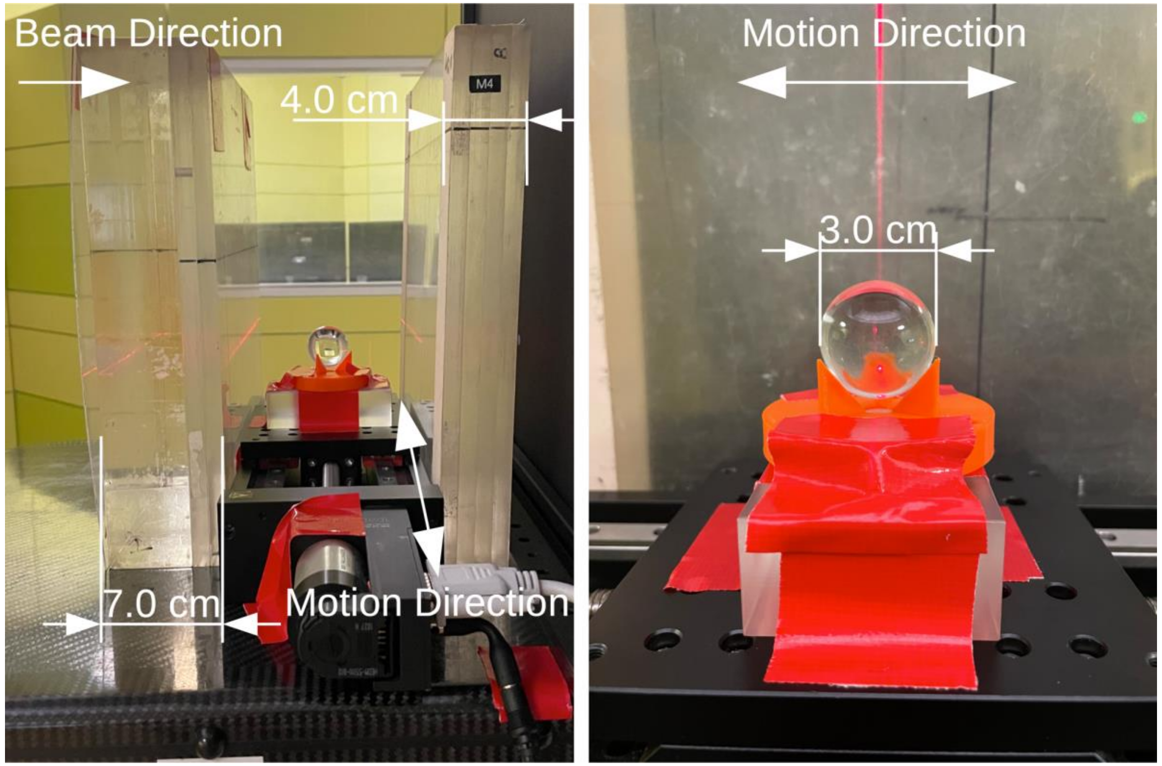


[2]Robertson et al. (2013) *Optical artefact characterization and correction in volumetric scintillation dosimetry.* DOI: 10.1088/0031-9155/59/1/23

[3]Simard et al. (2024) *Integrated-mode proton radiography with 2D lateral projections.* DOI: 10.1088/1361-6560/ad209d

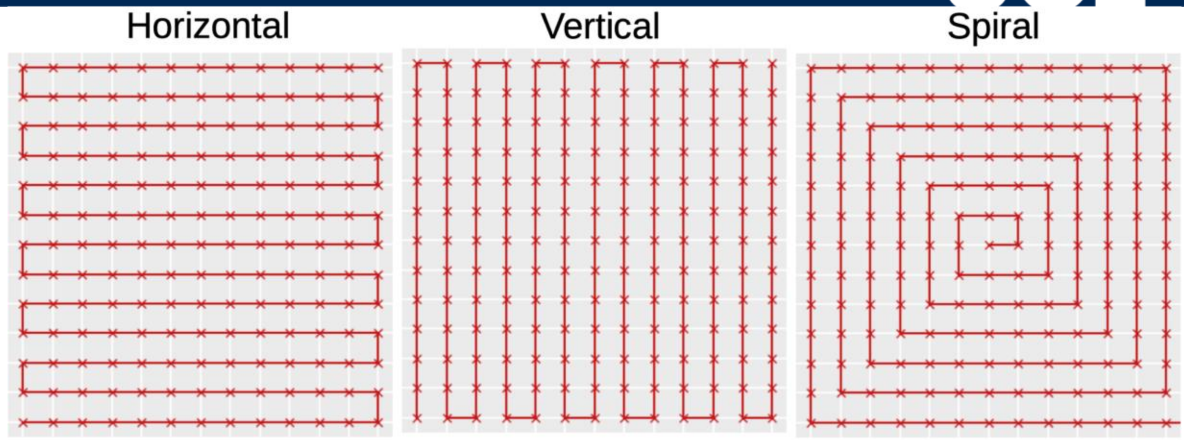
Experimental Setup – MIT

- Experiment at Marburger Ionenstrahl-Therapiezentrum using Siemens synchrotron at 180 MeV and 9.3 mm FWHM.
- Investigate effect of beam scanning pattern on interplay artefacts in radiographs of objects in motion.
- Cameras synchronised to beam spots.
- Simplified lung geometry: PMMA sphere on motorised platform (4 s period) between two PMMA slabs.



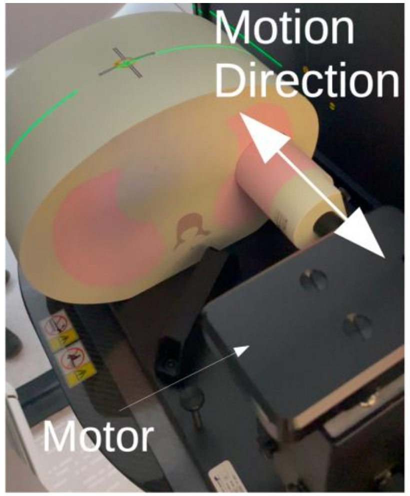
Results – MIT

- Investigate 3 scanning patterns: horizontal, vertical and spiral.
- After each frame, direction of scanning is reversed.
- Horizontal scan skews object diagonally in direction of motion.
- Vertical scan shrinks or elongates object depending on motion.
- Spiral scan significantly distorts image.
- Best image comes from fastest field delivery!



Experimental Setup – UCLH

- Experiment at UCLH to determine lung motion tracking accuracy.
  - CIRS anthropomorphic thorax phantom, with motorised insert (sinusoidal motion).
  - Can investigate several parameters:
    - Insert size (diameter)
    - Amplitude of motion
    - Speed of motion
  - Varian ProBeam system operated at 230 MeV with 5 mm spot spacing.
  - System presents challenges:

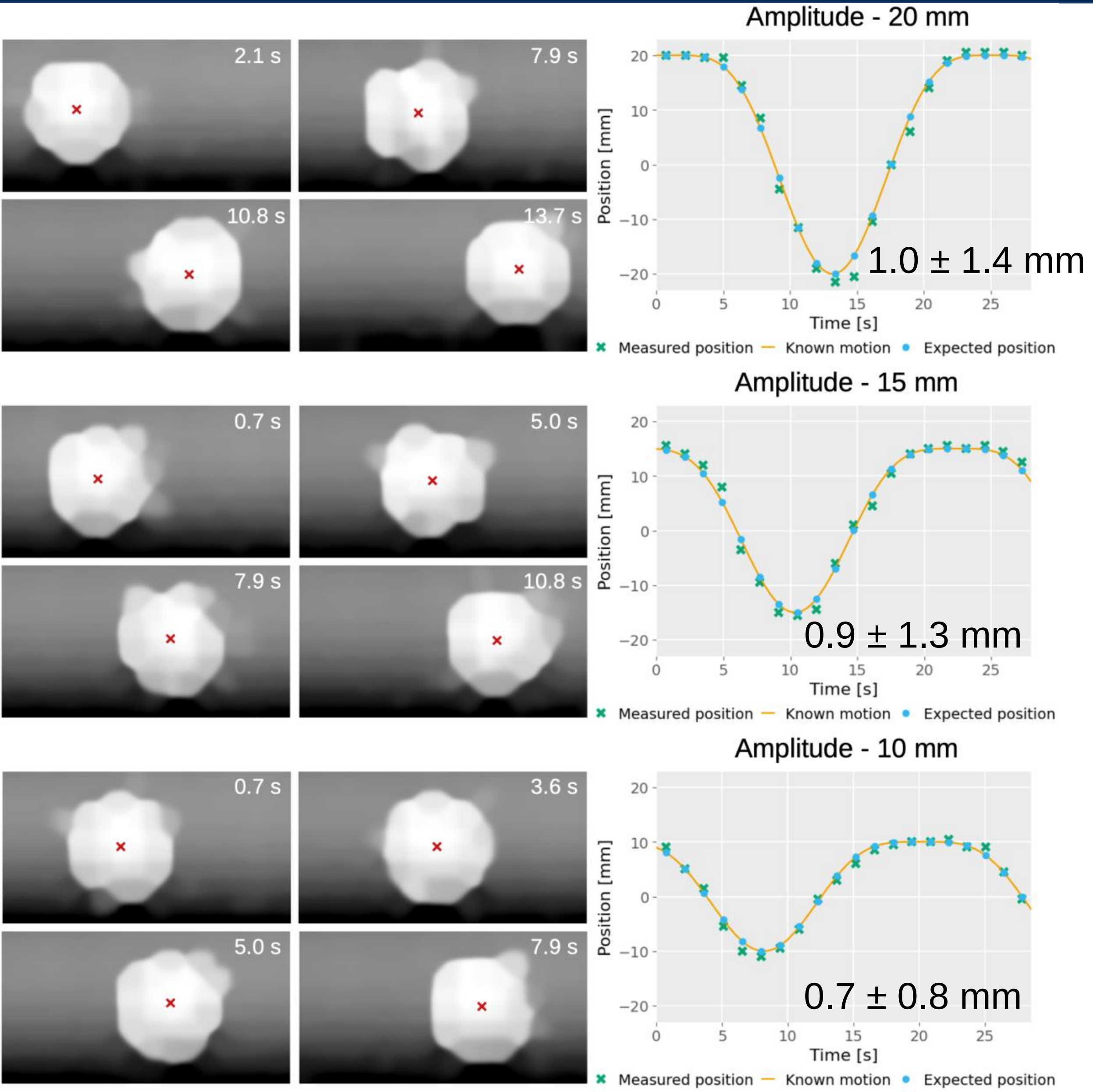


    - No beam trigger signal externally accessible.
    - Therefore, use photodiode to trigger camera image capture.
    - Continuously scanned beam however *does not switch off* between spots!
    - Workaround by forcing beam to skip spot positions and resample skipped spots.
    - **Takes longer to deliver field but slowed down insert motion to compensate**.

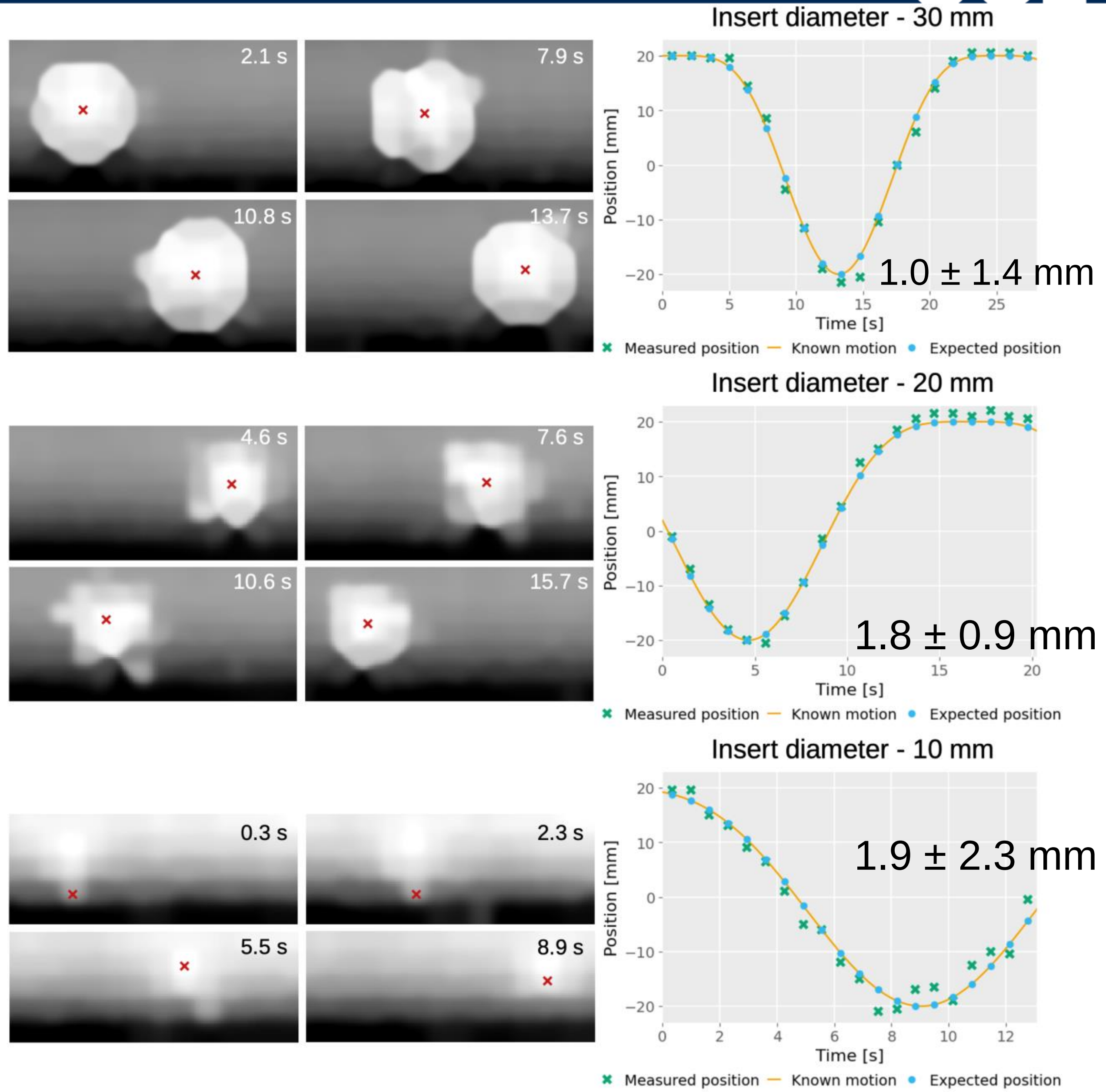
Results – UCLH

- Deliver fields to encompass full object range of motion + 1 cm margin.
- Determine centroid of object in each frame.
- **Better accuracy with larger, slower objects undergoing smaller range of motion.**
- Accuracy generally between 1-3 mm.

Insert Diameter (mm)	Motion Amplitude (mm)	Motion Period (s)	Field Size (cm^2)	Frame Acquisition Time (s)	Mean Absolute Error (mm)
30	20	6	9x5	1.4	3.1 ± 4.5
30	20	12	9x5	1.4	2.2 ± 2.9
30	20	24	9x5	1.4	1.0 ± 1.4
30	15	24	9x5	1.4	0.9 ± 1.3
30	10	24	9x5	1.4	0.7 ± 0.8
20	20	24	8x4	1.0	1.8 ± 0.9
10	20	24	7x3	0.7	1.9 ± 2.3



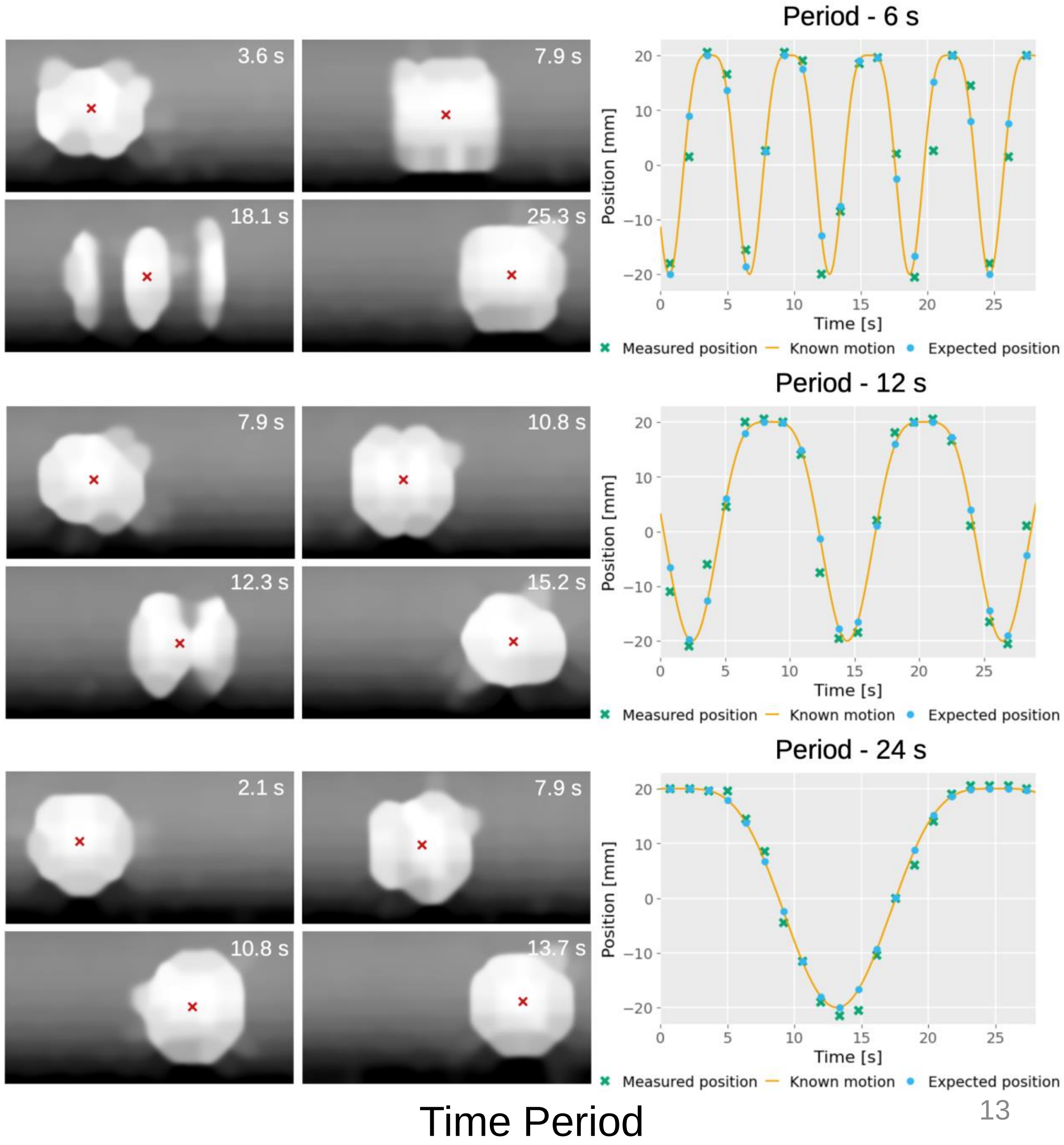
Amplitude



Insert Diameter

Results – UCLH

- Better accuracy with slower motion: MAE (mm): 6s = 3.1 ± 4.5; 12s = 2.2 ± 2.9; 24s = 1.0 ± 1.4
- Realistic breathing cycle ~6s.
- **Interplay effect can be reduced by delivering full-speed fields!**
- Normal fields delivered 2.5-3x faster than those used in test.
- With faster acquisition, could get ~1.0 mm accuracy with 6s cycle.

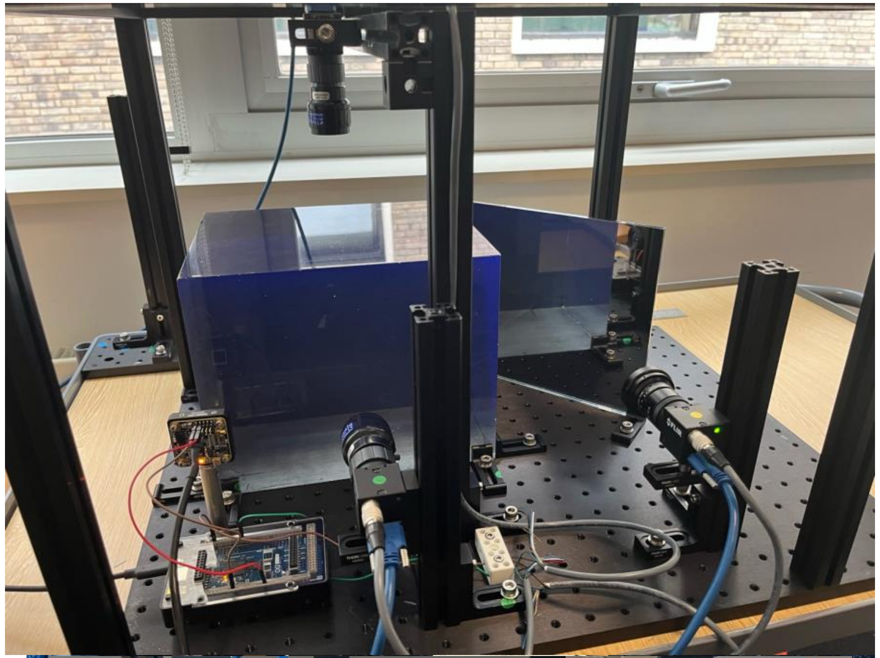


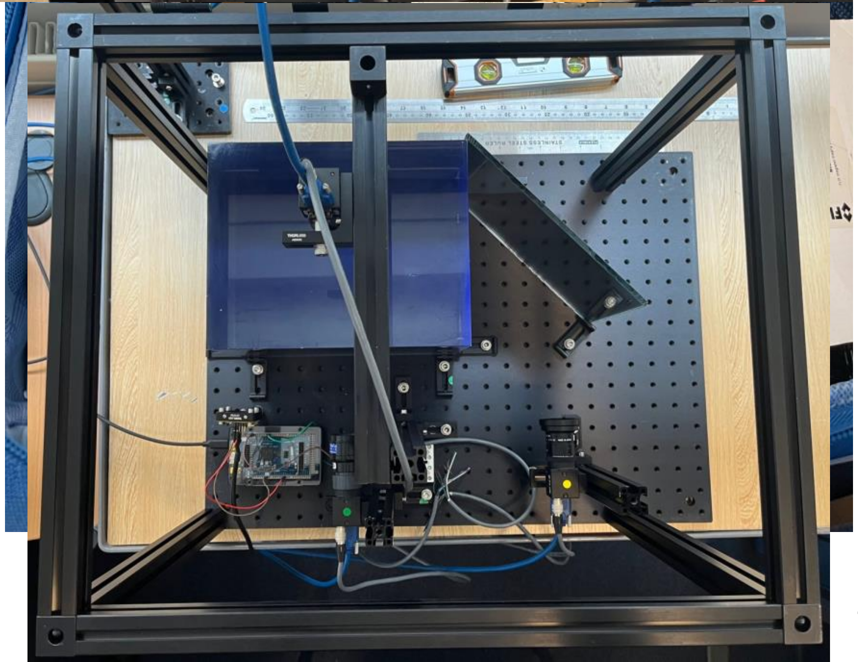
What have we learned?

- We can perform proton radiography of static objects to sub–mm accuracy ***directly with the therapeutic source.***
- We now have promising indications of imaging performance for objects in motion using scanned beams.
- Biggest technical limitation is acquisition speed: faster imaging means fewer artefacts and better accuracy.
- Several practical aspects to consider for clinical implementation:
  - Detector size
  - Mechanical stability
  - Data acquisition framework -> real-time image processing?

Integr8 Detector 2.0 (beta)

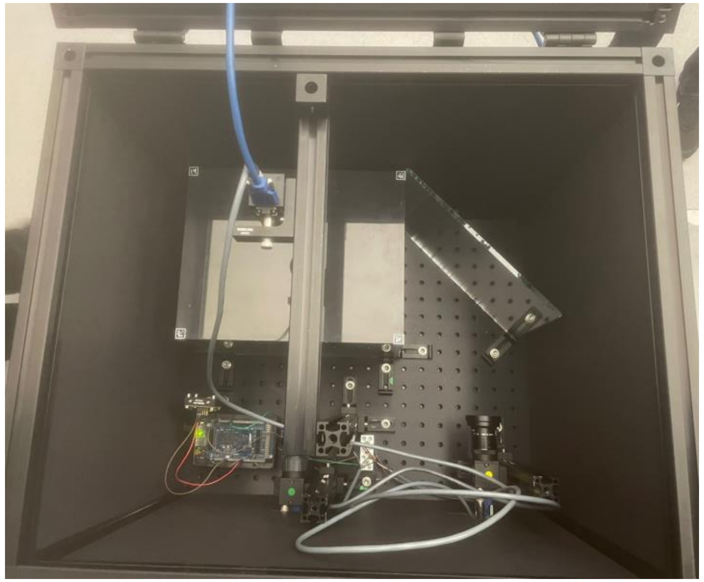
- Joined Integr8 in May 2024 to take over detector design and construction.
- Detector was safely and securely stored for handover…
- New cameras: FLIR Blackfly S USB3
  - Tiny and USB-powered with 522 FPS!
- New lenses: 1.7mm focal length
  - Reduces working distance from 42.5cm to 10cm.
- New ThorLabs enclosure design
  - Less than 50% overall size & removed 1 mirror.
- New data acquisition code in C++
  - Simpler and easier image acquisition and storage.





Next Steps

- Beam tests at UCLH!
  - Verified functionality of new data acquisition software.
  - Currently optimising image acquisition speed and baseline camera properties.
  - Also improving camera alignment methods.
- Track continuously scanned beams at full speed and reevaluate interplay effects.
- Develop real-time image processing framework.



Thanks for Listening!

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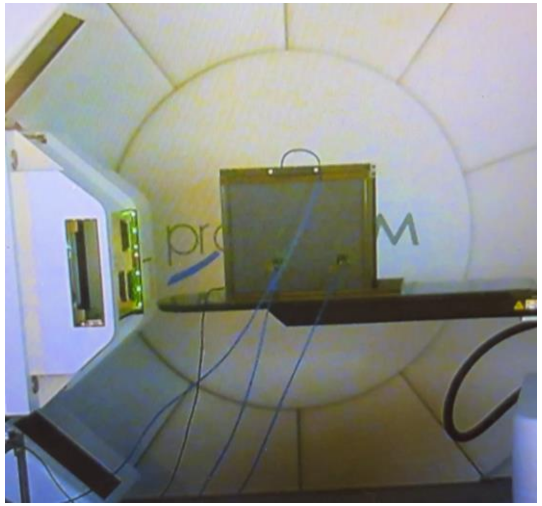
  - Yannick Senger @ MIT

Integr8

We’re always watching



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