Medipix for dosimetry and beam characterisation in proton therapy facilities

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Introduction

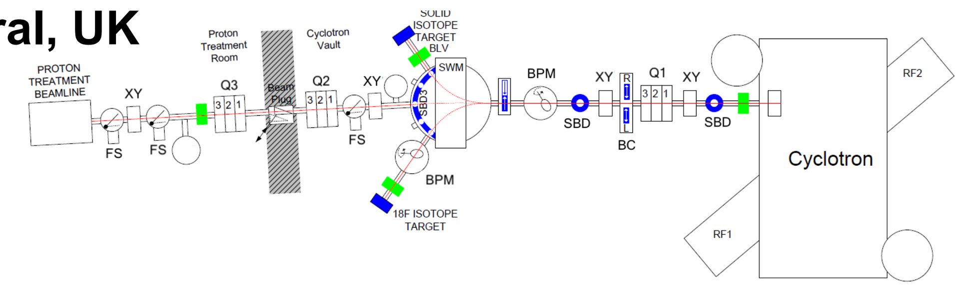
The Medipix detector technology was originally developed for particle tracking at the LHC and then used for radiation imaging and X-ray detection [1]. The newer generations have progressed its specific use for medical applications and suitability for charged particle therapy (CPT) [2, 3].

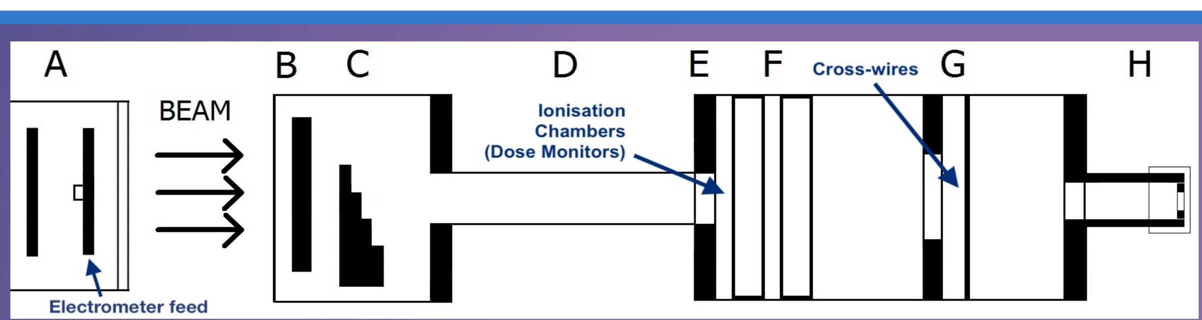
The Medipix3 chip [4, 5] is capable of high flux operation, thus making it appropriate for the characterisation and measurement of ion beams. In this contribution we present test results of the system within a clinical proton beam therapy (PBT) and investigate the potential and applicability of the Medipix3 detector as a tool for dosimetry and monitoring for CPT beams. Further details in Refs. [6, 7].

Experimental setup

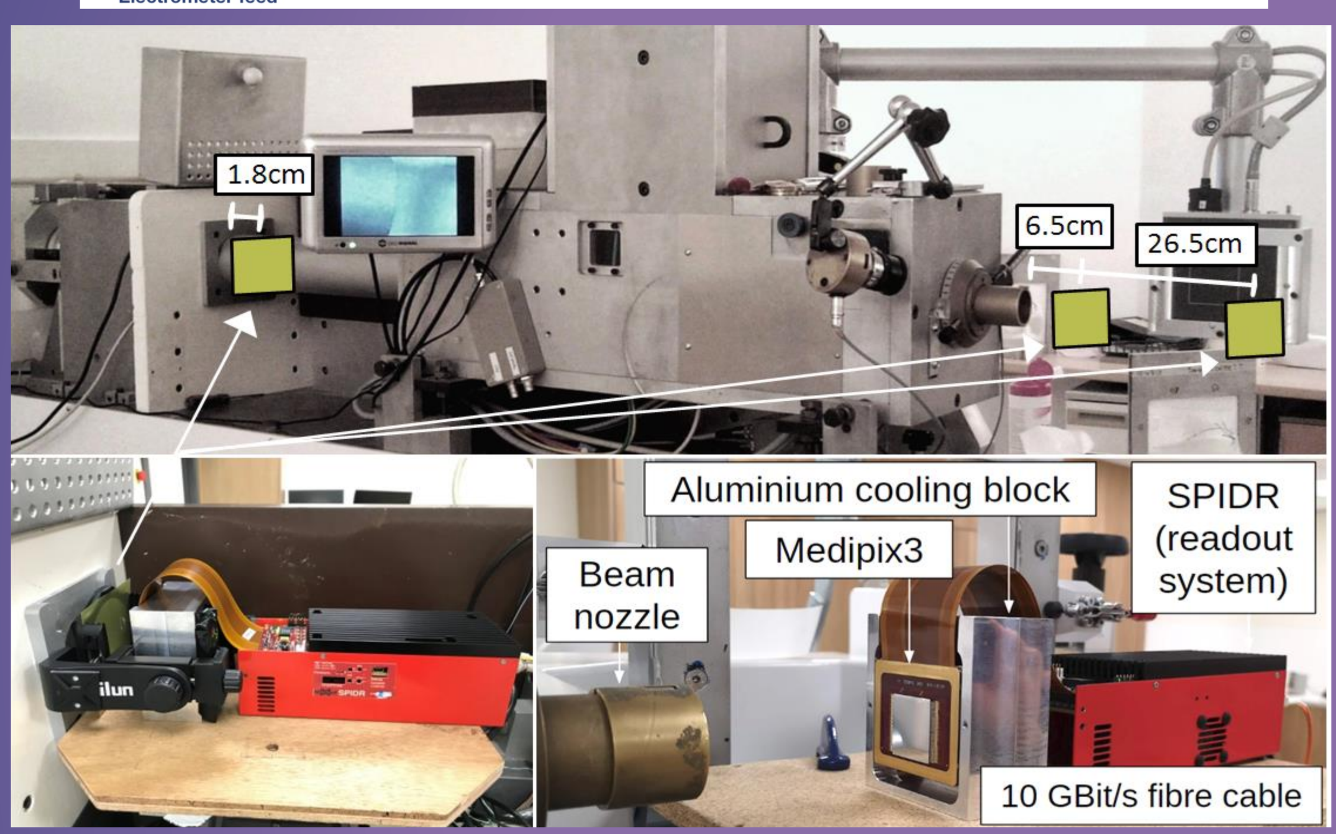
Clatterbridge Cancer Centre (CCC), Wirral, UK

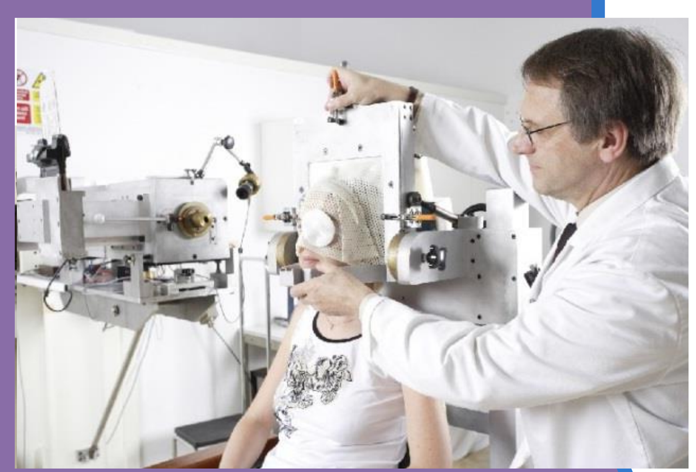
- 60 MeV proton beam
- Passive scanning beam system
- First PBT treatment facility in the UK
- Treated >2830 eye cancer patients since 1989

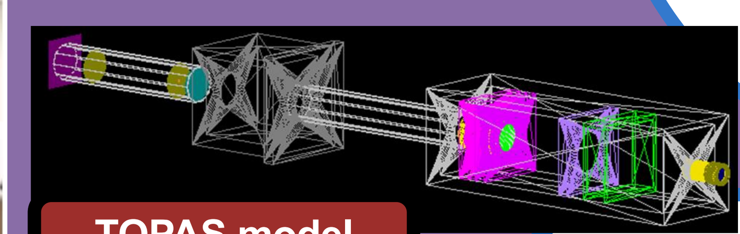




CCC treatment beamline



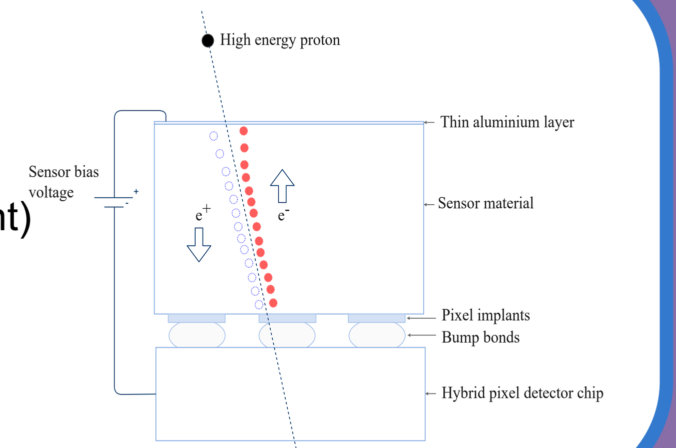




TOPAS model

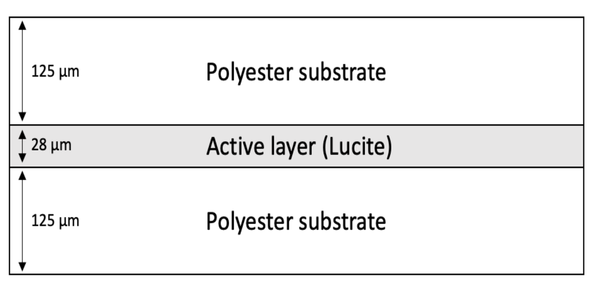
Medipix3

- Hybrid pixel application specific integrated circuit (ASIC)
- ASIC bump-bonded to a 500 µm Si sensor
- Configurable pixel pitch between 55 µm and 110 µm
- Detector made of four 55 x 55 µm² chips (2 x 2 arrangement)
- Each chip consists of 256 x 256 = 65,536 pixels
- 4 chips, active area 28 x 28 mm²
- Count rates of up to ~ 100 kHz per pixel
- SPIDR readout system from Nikhef [8]



EBT3 GAFchromic film

- Standard radiochromic film dosimeter
- Commonly used for quality assurance in radiation therapy
- Analysis of geometrical beam characteristics
- Measurement of 2D or 3D dose distribution
- For hadron therapy the use of EBT3 film is limited due to quenching effects and saturation



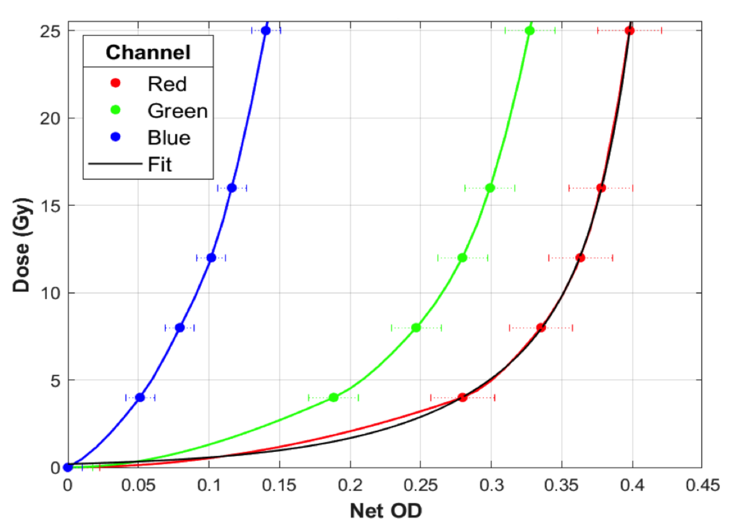
Film calibration and image analysis

The calibration curve is obtained by evaluating the net *OD* values [9] across the full dose range:

$$\text{net } OD = OD_{\text{exp}} - OD_{\text{unexp}} = \log_{10}\left(\frac{I_{\text{unexp}} - I_{\text{bckg}}}{I_{\text{exp}} - I_{\text{bckg}}}\right)$$

A calibration curve for each colour channel is obtained and given standard protocol, only the red channel is considered for this case

A curve fit was applied which enables the grey values from the irradiated films to be converted to dose and plotted against position to obtain transverse beam distributions



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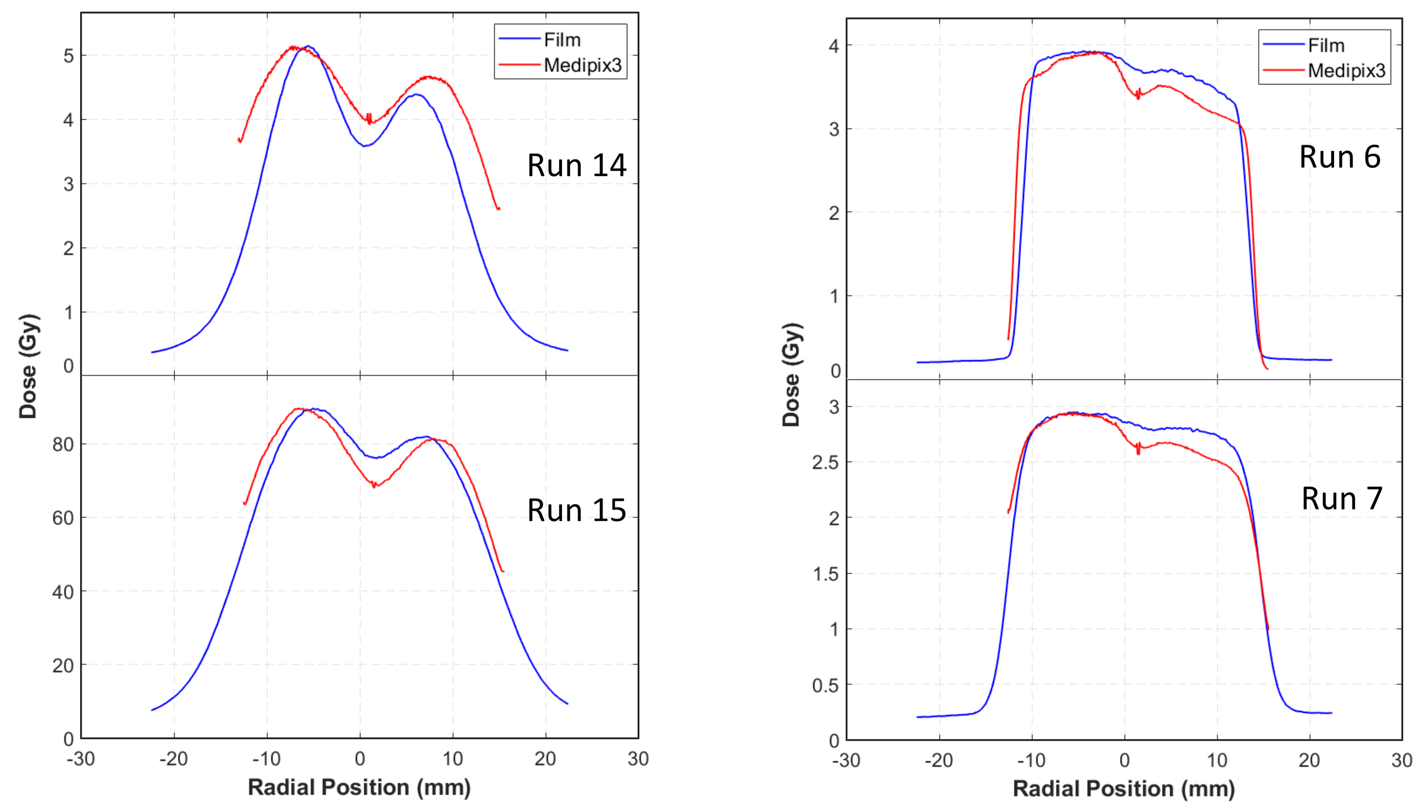
Measurements and Results

Beam profiles

Comparison between EBT3 films and Medipix3 measurements

Run (#)	Beam current (nA)	Time (s)	Distance from nozzle (cm)
2	0.012	97.2	9.5
3	0.052	99.8	9.5
4	0.35	49.8	9.5
5	0.69	44.9	9.5
6	0.27	32.6	9.5
7	0.27	29.5	30.0
8	1.35	75.0	30.0
9	1.35	68.9	9.5
10	1.97	66.4	9.5
11	0	9.0	9.5
14	2.2	103.0	Integration zone
15	2.1	285.3	Integration zone



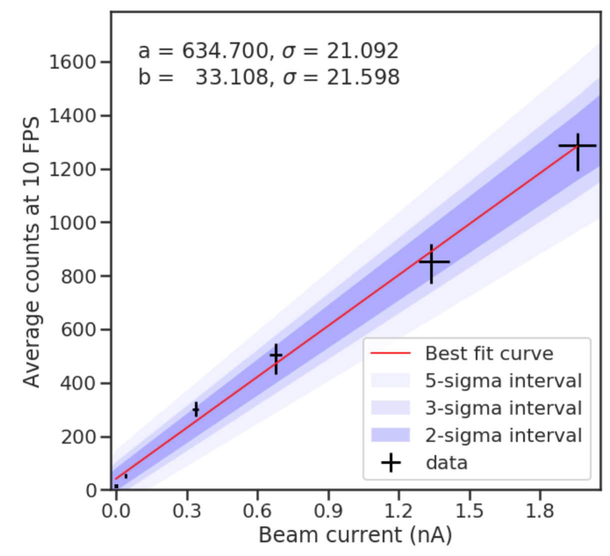
There is observable agreement between the distributions and any variances can be related to the image analysis uncertainties as well as fundamental differences between the detection processes. Most of the profiles do not extend completely across as high doses are detected right through to the edges of the sensor

Detector response and activation

The detector has a linear response across the entire tested range of beam currents from 0.012 to 1.97 nA

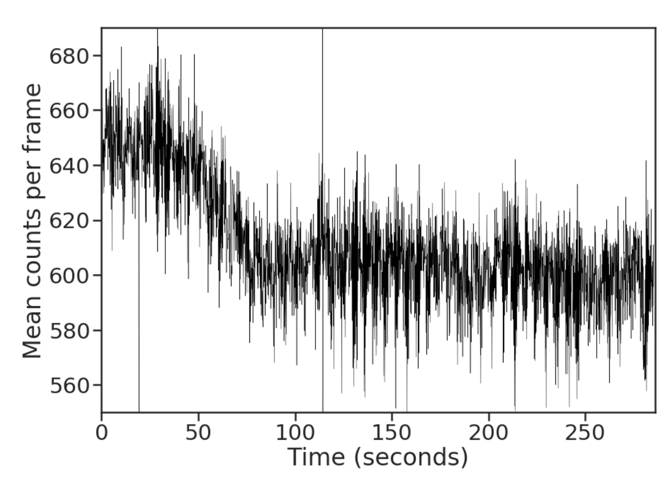
Measurement parameters of detector activation with acquisition times and run ranges

Run (#)	Time (s)	Mean (counts/s)	Standard deviation (counts/s)	Start (counts/s)	End (counts/s)
2–3	50	7.2×10^{-4}	1.3×10^{-3}	9.5×10^{-4}	6.7×10^{-4}
5–6	20	4.4×10^{-2}	2.8×10^{-2}	4.7×10^{-2}	4.0×10^{-2}
8–9	10	6.4×10^{-2}	3.8×10^{-2}	6.7×10^{-2}	6.1×10^{-2}
11	8.3	9.8×10^{-2}	6.4×10^{-2}	9.9×10^{-2}	9.7×10^{-2}
15	0.094	1.3	0.63	1.5	1.2

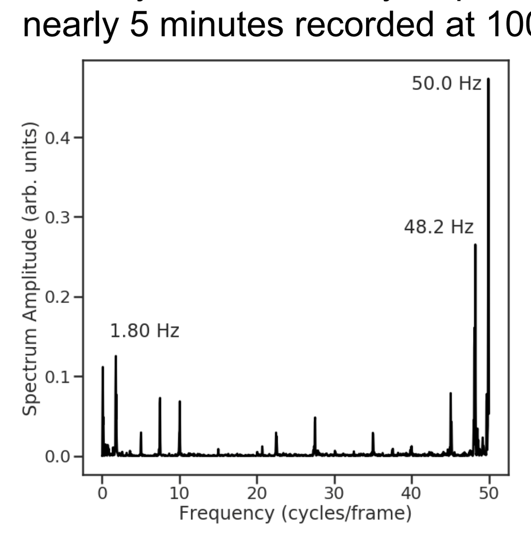


Temporal analysis of the beam

Temporal stability of the beam over all pixels over nearly 5 minutes, recorded at 100 FPS, 26.3 Gy/min in the integration zone



Frequency components of the beam intensity as recorded by all pixels over nearly 5 minutes recorded at 100 FPS



Conclusions

- First set of tests using Medipix3 in a clinical proton beam environment
- Comparison with standard EBT3 film dosimetry methods
- General agreement between both methods
- Medipix3 chip could be optimised significantly for high flux protons (> 60 MeV)
- Promising capabilities and versatility of Medipix3 for clinical proton therapy as a fast and efficient, future tool for routine dosimetry, commissioning and beam monitoring
- To facilitate its progression toward clinical implementation, further testing is recommended to characterise the cluster properties, signal uniformity, sensitivity across the detector, activation levels, dose rate thresholds, energy dependence, stability, special resolution and dosimetric calibration factors

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