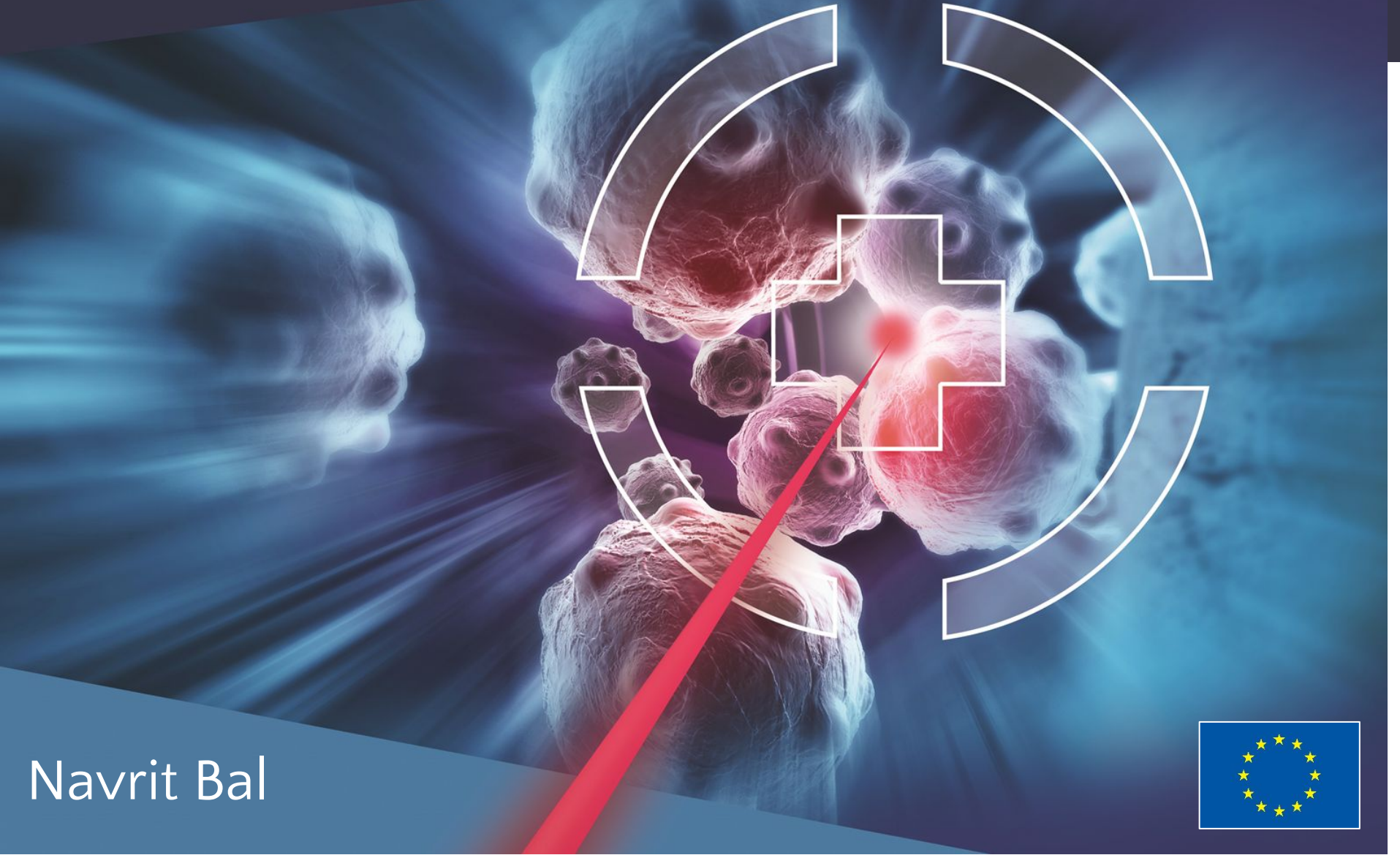


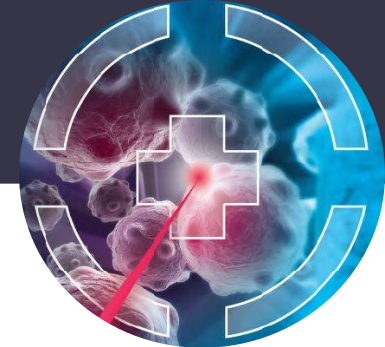


Beam and detector characterisation using Medipix3 at
MedAustron IR1 using protons and carbon ions at
clinical flux rates and full energy range

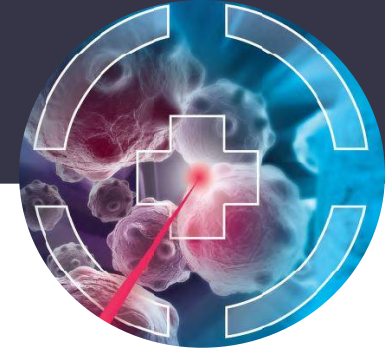


Navrit Bal





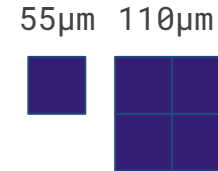
Medipix3 for beam instrumentation and diagnostics?



Can be adapted for various sensor materials:

- Silicon
- GaAs
- Diamond
- Ge
- CdTe
- CZT
- Various gas mixtures
- MCP stack with doped scintillators

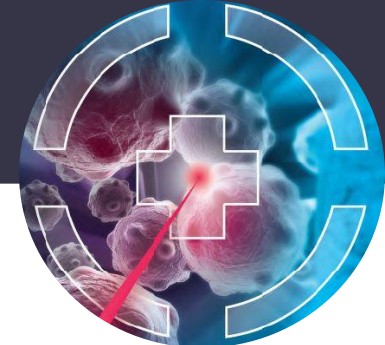
High spatial resolution:
55 or 110 μm pixel pitch



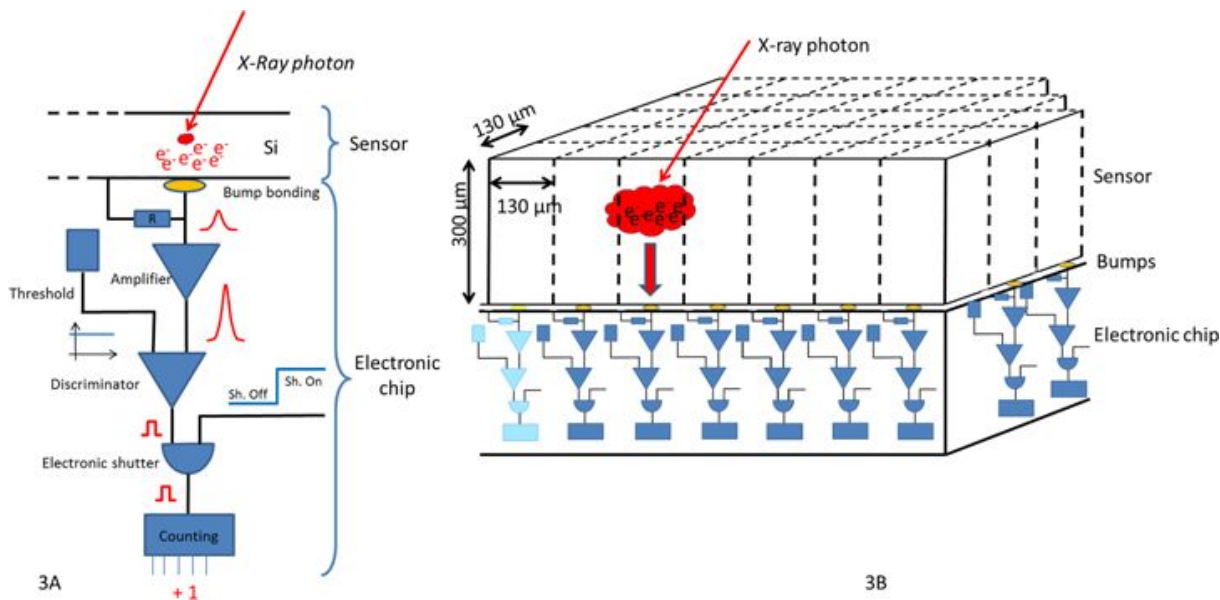
Hybrid pixel detector

The chip is not application specific:

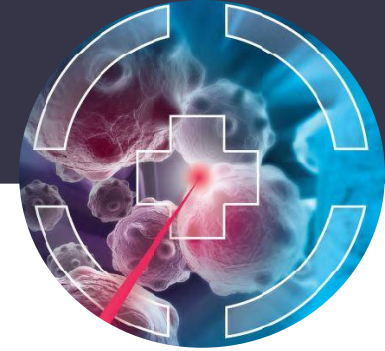
- X-ray photons
- Protons
- Ions
- Electrons
- Neutrons
- Etc.



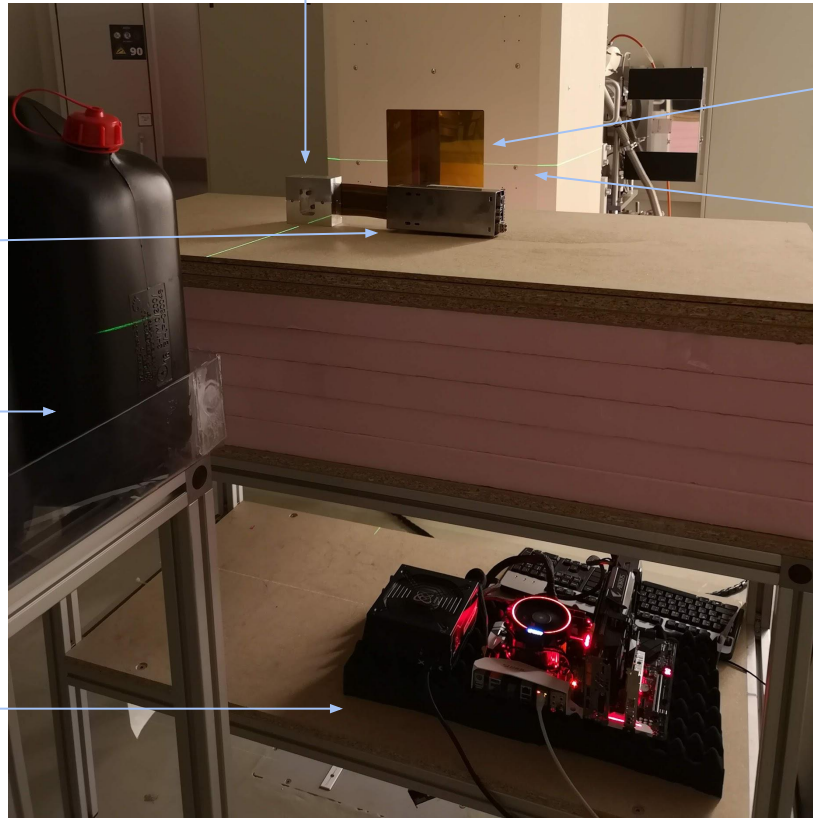
Hybrid pixel detector



Allé, P., Wenger, E., Dahaoui, S., Schaniel, D., & Lecomte, C. (2016, May 3). Comparison of CCD, CMOS and Hybrid Pixel x-ray detectors: Detection principle and data quality. *Physica Scripta*. Institute of Physics Publishing.
<https://doi.org/10.1088/0031-8949/91/6/063001>



Fine pitch Medipix3 300 μ m
Si sensor with Al heatsink



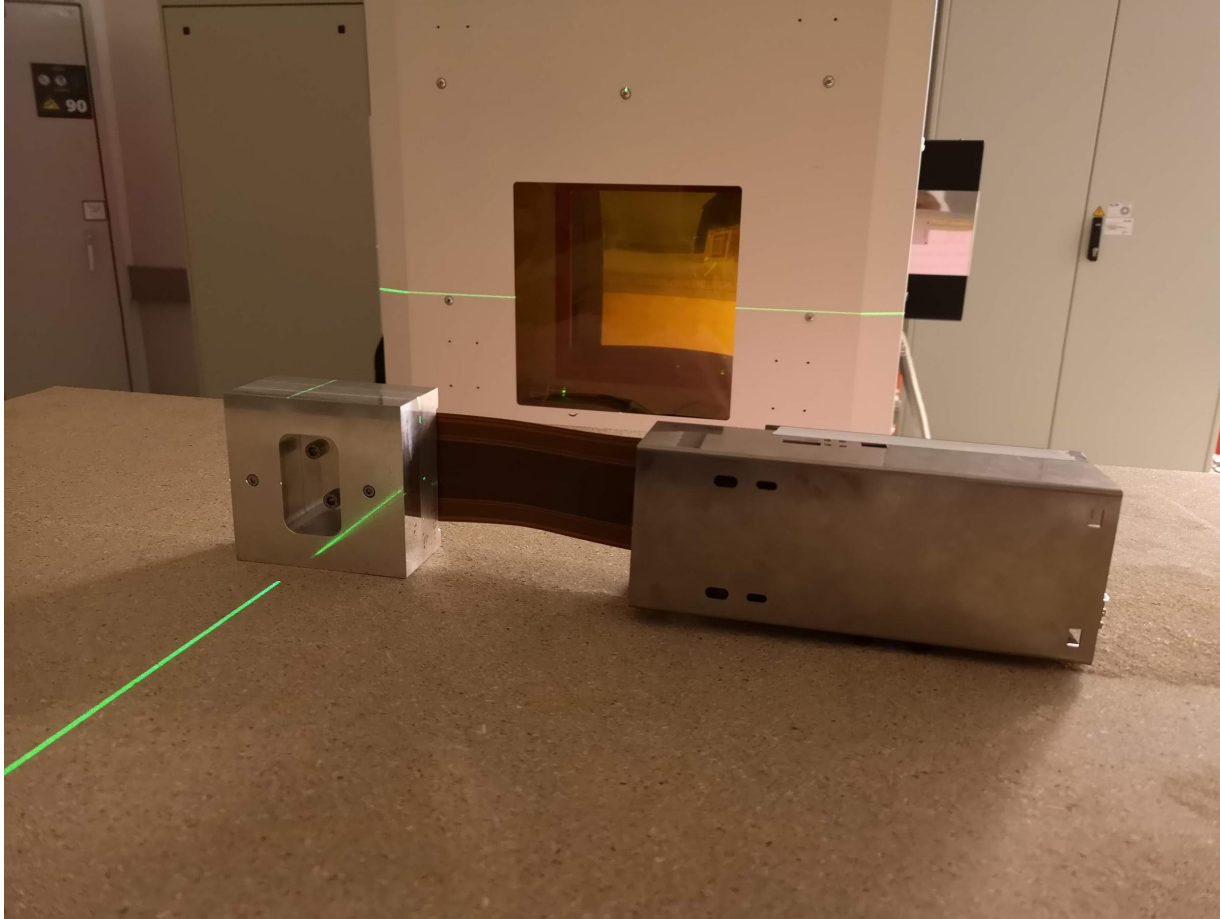
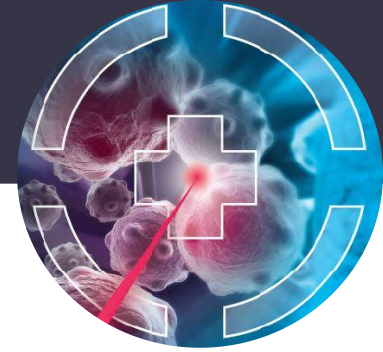
SPIDR v3.5

Water bottles
(~2m depth)

My computer

Beam nozzle

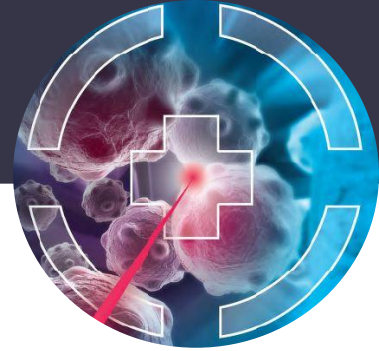
Alignment line lasers

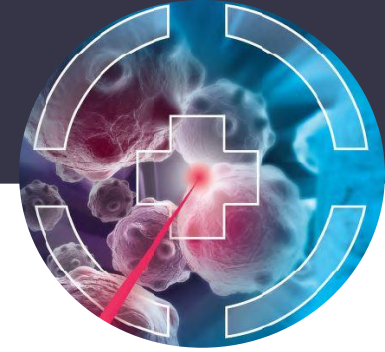


Same as before but closer

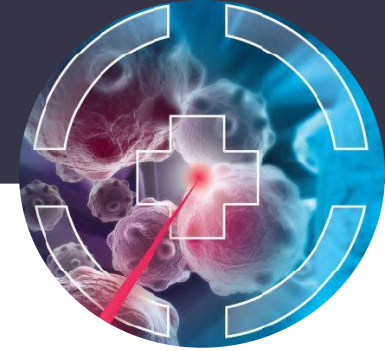


Beam-time starting at 5am...

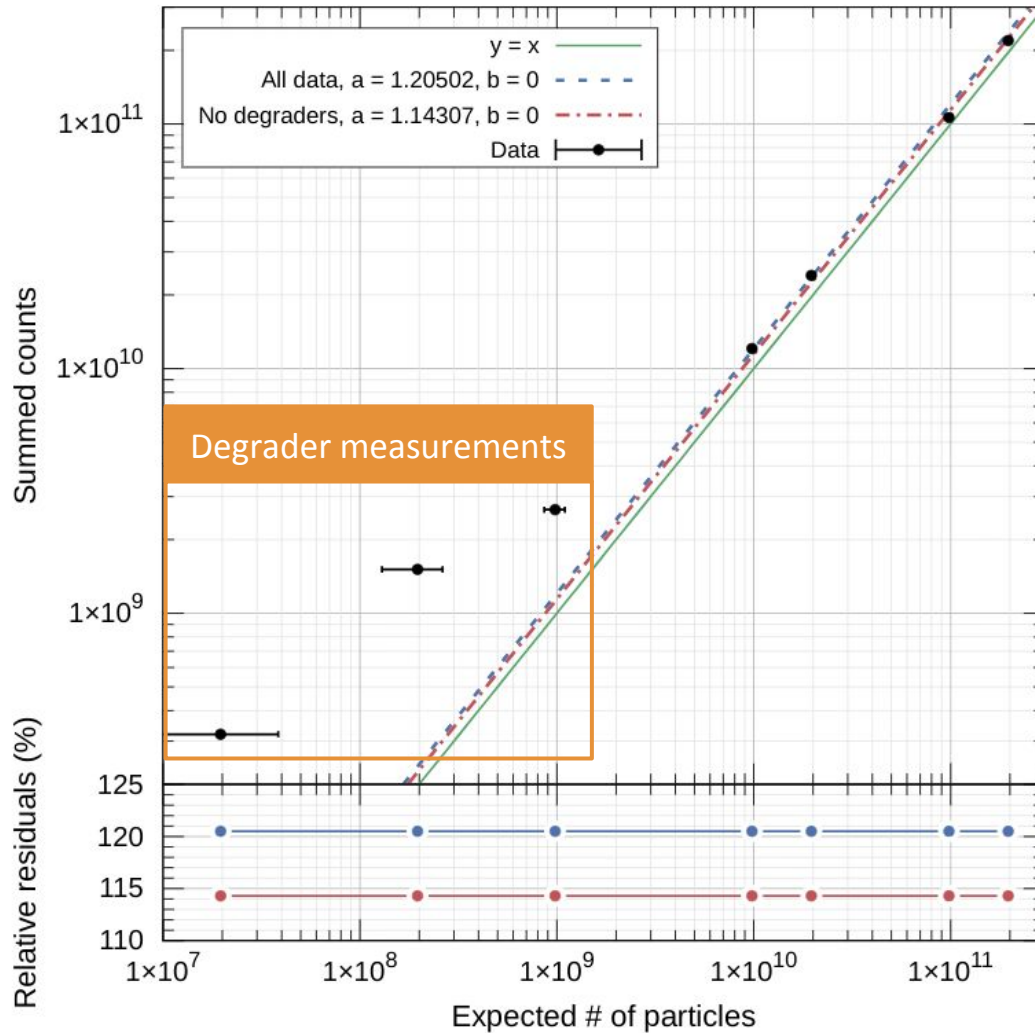
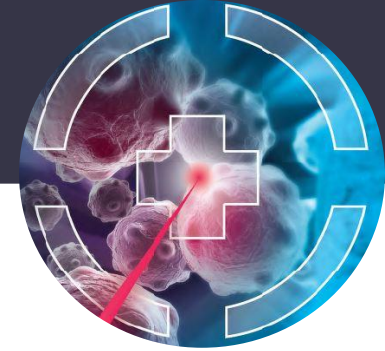




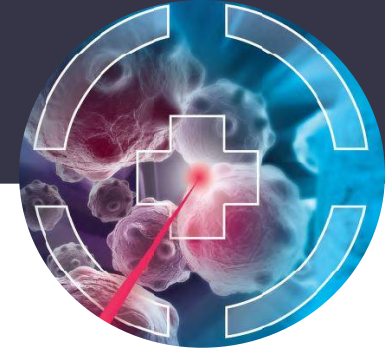
11 hours & ~350 GB later



- Protons, carbon ions
 - Minimum to maximum deliverable flux
 - 10^3 to 10^9 particles per second over the whole detector
 - Minimum to maximum energies
 - Protons - 62, 148, 252, 800 MeV
 - Carbon ions - 120, 260, 400 MeV/A
 - Count rate linearity using degrader plates
 - 62 & 800 MeV protons
 - Proton 800 MeV consistency
- # of dead/unresponsive pixels over time
 - # of noisy pixels over time
 - Radiation damage
 - Short term
 - Beam intensity temporal variations
 - Interesting frequency components



- Count rate linearity of all pixels integrated over all frames for that measurement using **62.4 MeV protons**.
- Ideally, this would be $y = x$
- $\chi^2 = 91$ with all data
- $\chi^2 = 4.6$ without degraders



800 MeV protons

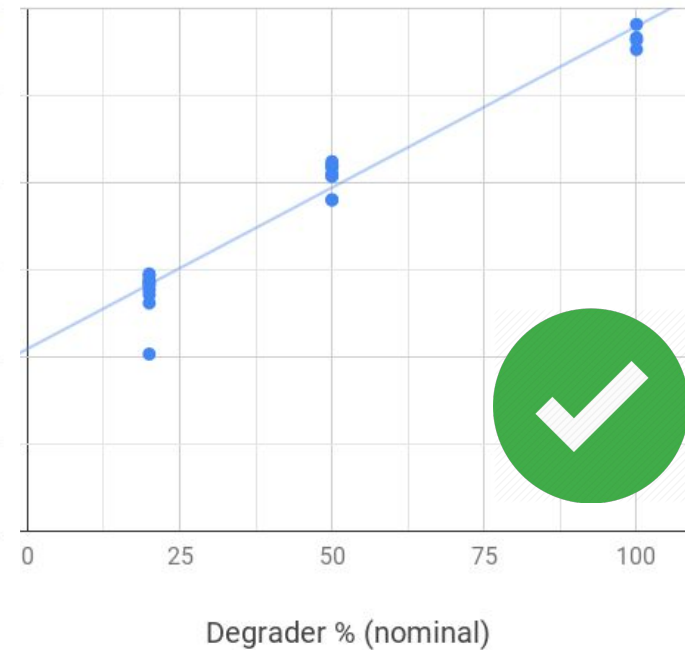
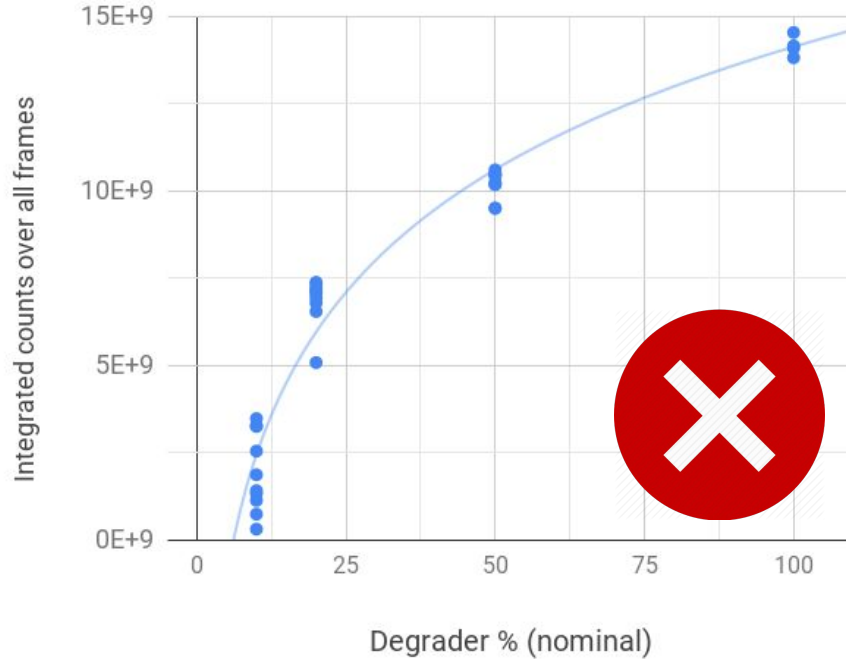
All data, **logarithmic fit**

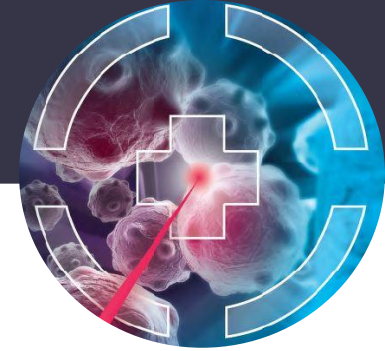


Removed degrader 10 measurements, **linear fit**

● — $-9.25E+09 + 5.08E+09 \ln x$ $R^2 = 0.949$

● — $9.25E+07 * x + 5.22E+09$ $R^2 = 0.952$

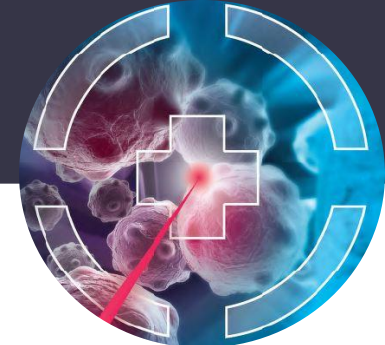




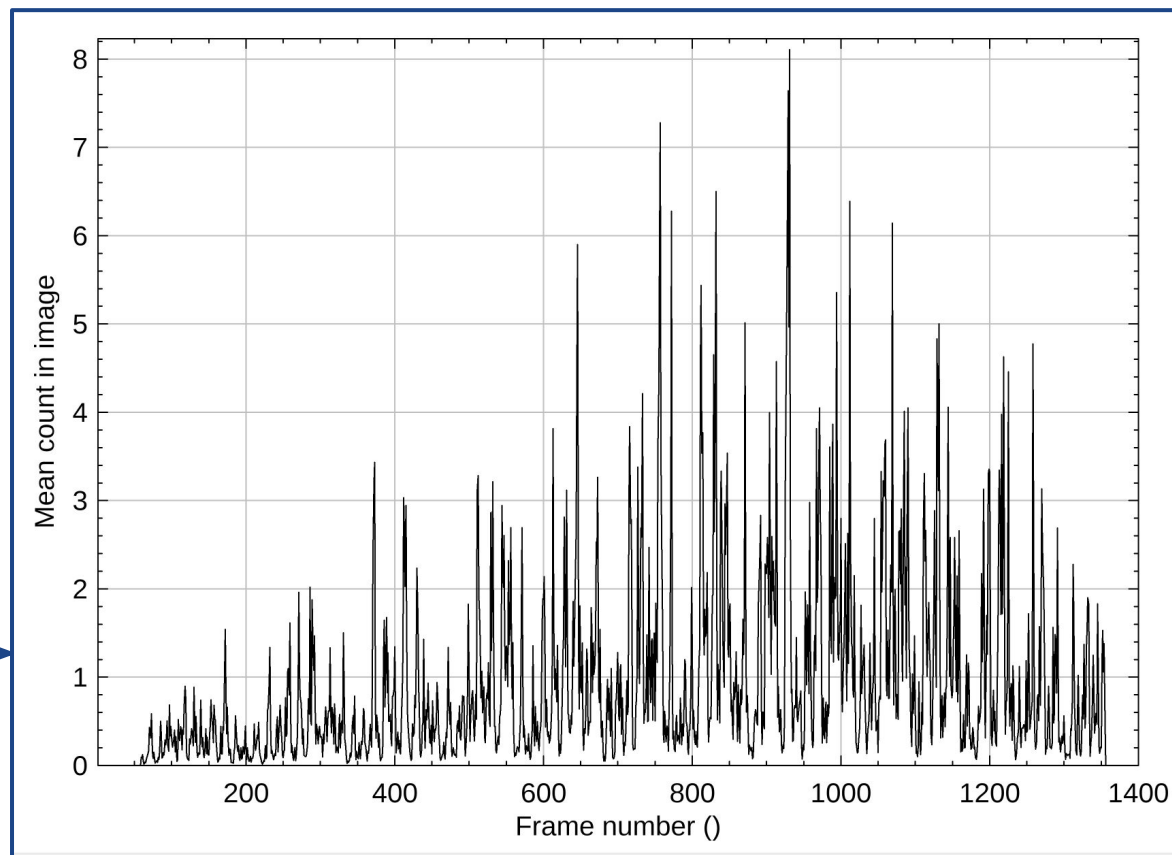
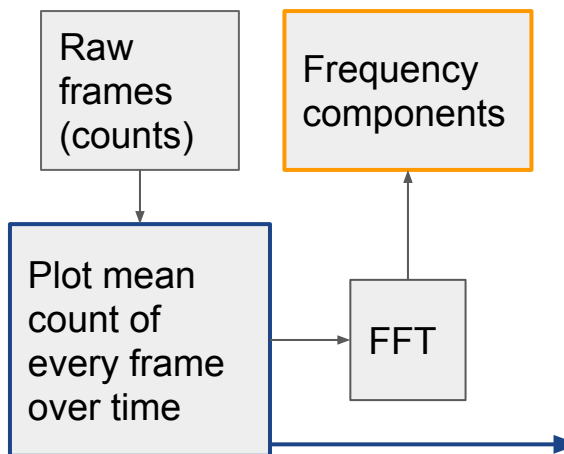
	Degrader (%)	Deviation from mean (%)
<p>Expected to be bad by Claus.</p> <p>(based on other measurements)</p>	10	84 55 without test runs
	20	26 7, 1 outlier removed
	50	8 2, 2 outliers removed
	100	2.5



Temporal beam variations

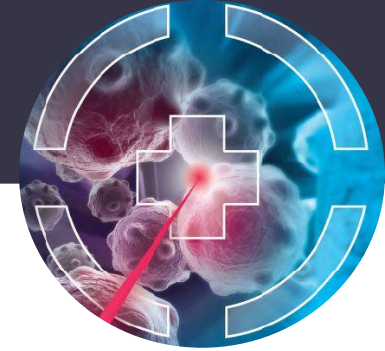


Input data for next plots



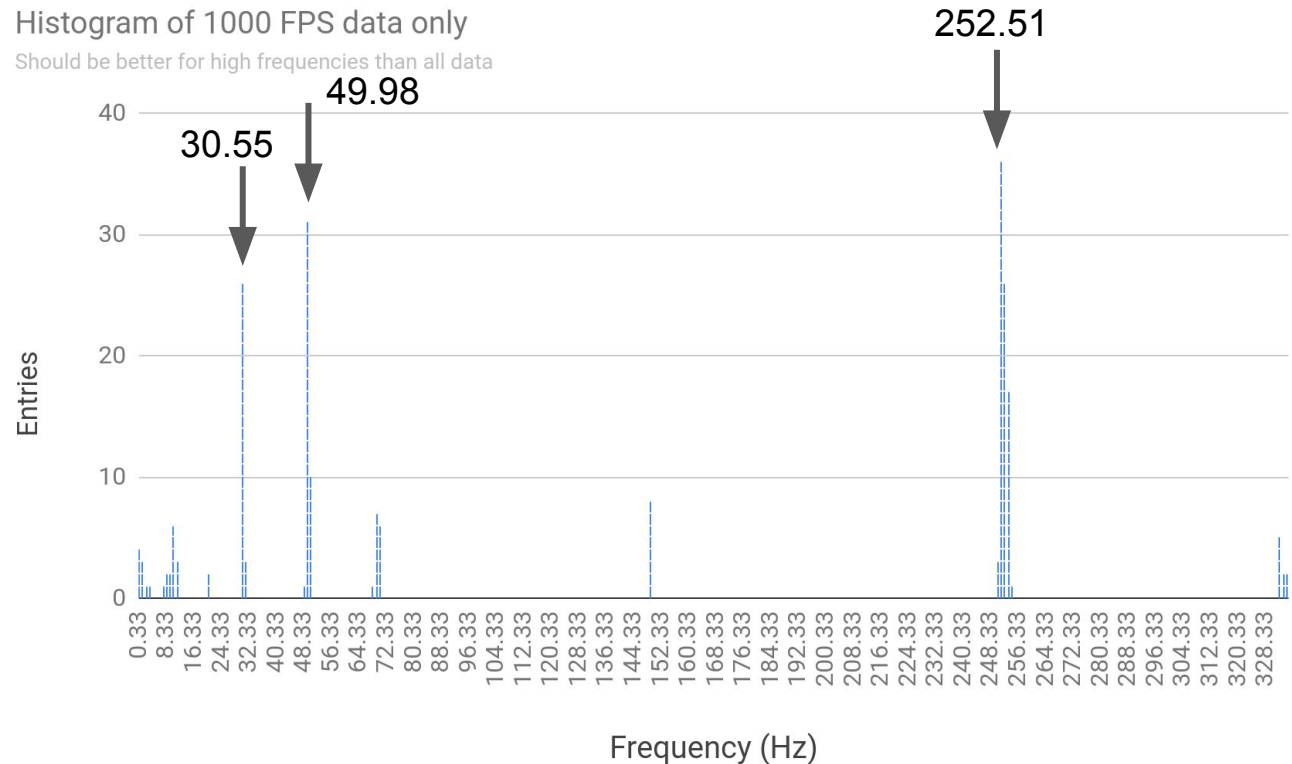


Temporal beam variations



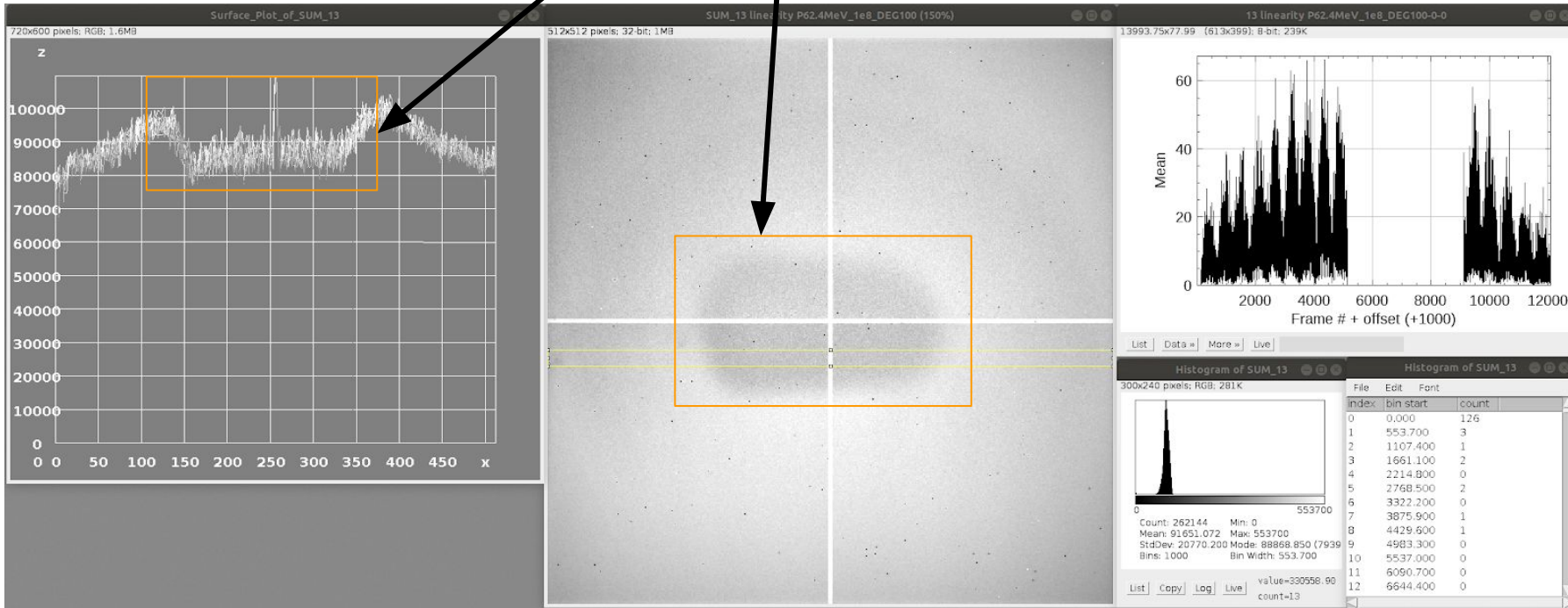
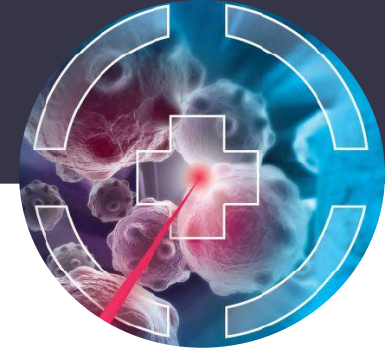
- 252.51 Hz
 - $\sigma = 0.83$
- 49.98 Hz
 - AC mains
 - $\sigma = 0.29$
- 30.55 Hz
 - $\sigma = 0.55$
- What causes these oscillations?

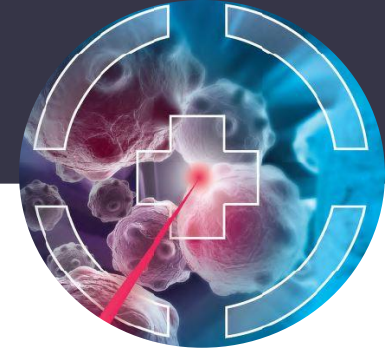
Histogram of 1000 FPS data only
Should be better for high frequencies than all data





Radiation damage





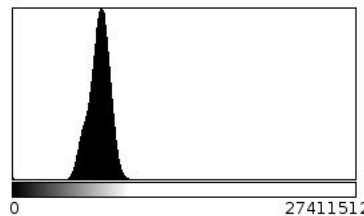
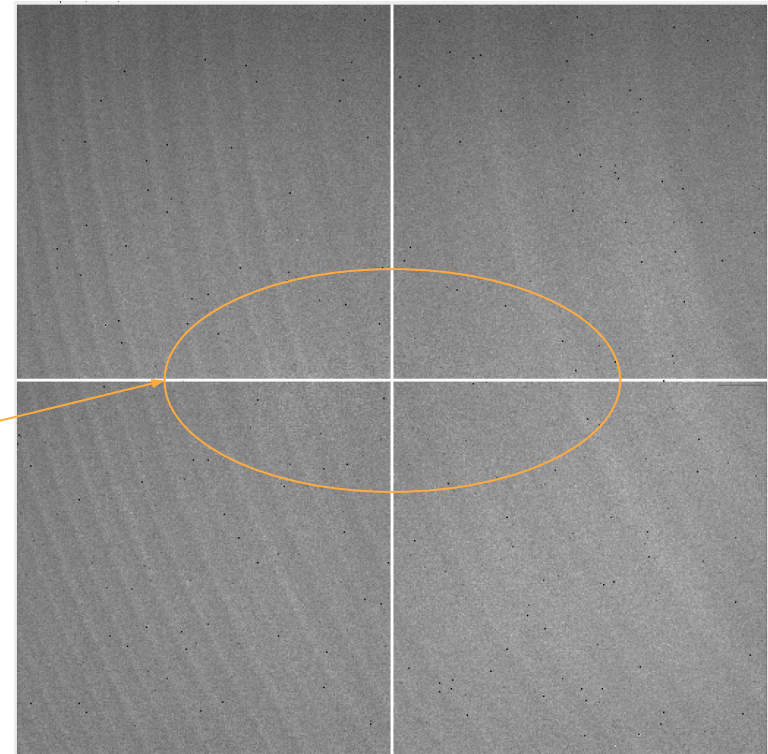
X-ray test - 50 kVp 0.92mA 5 mins:

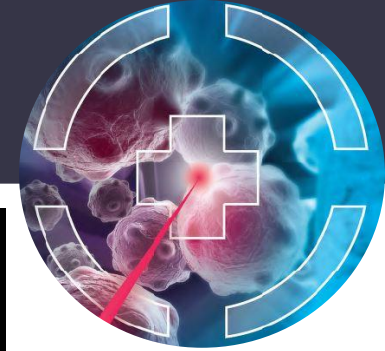
Dead pixels = 123 (0.04% of total) ✓

Detector uniformity → 95% of counts within 19% of the mean, averaged over the 4 chips, excluding the cross. ✓

No response variation observed in the centre at all, damage was expected. ✓

No significant change in noise from the equalisation procedure. ✓

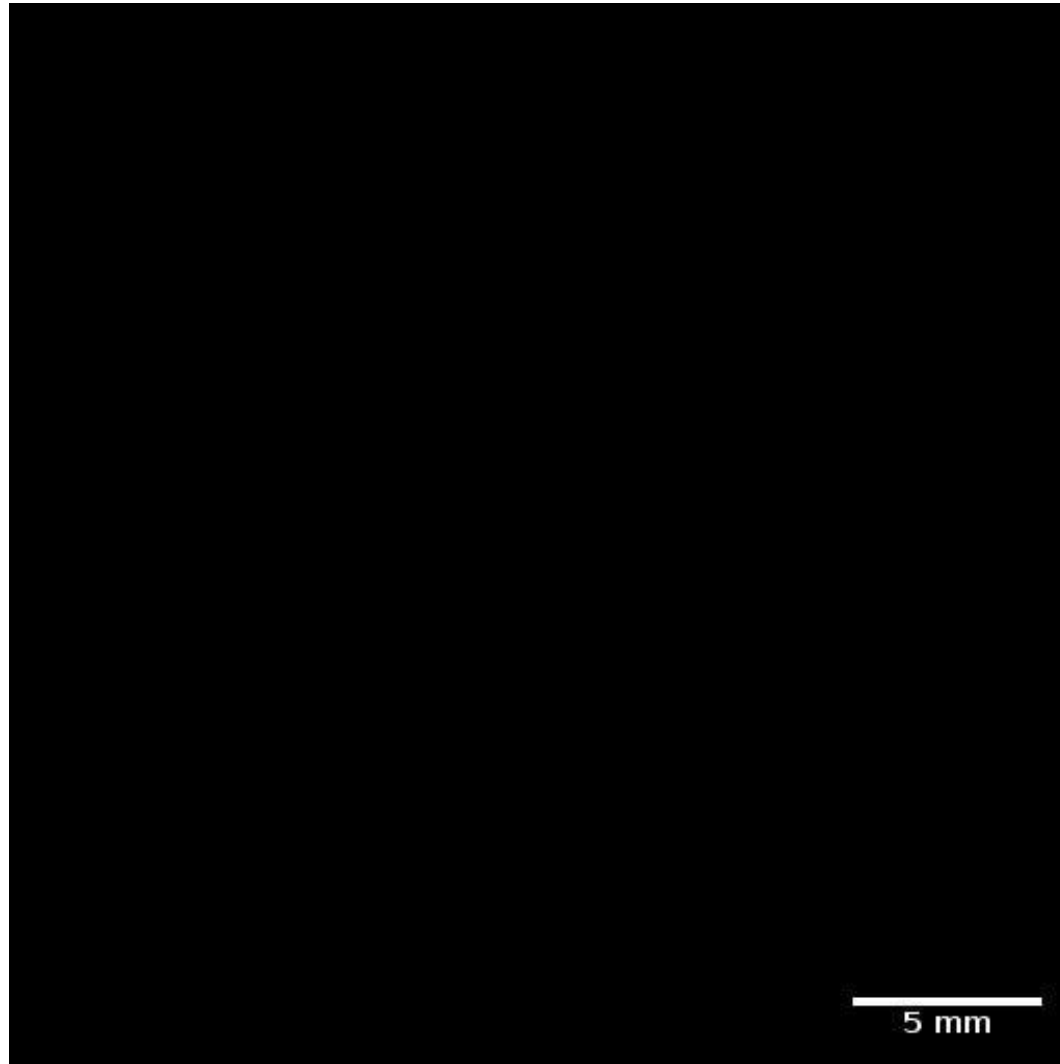




Real time

X1000 data FPS

Heavily
compressed
video

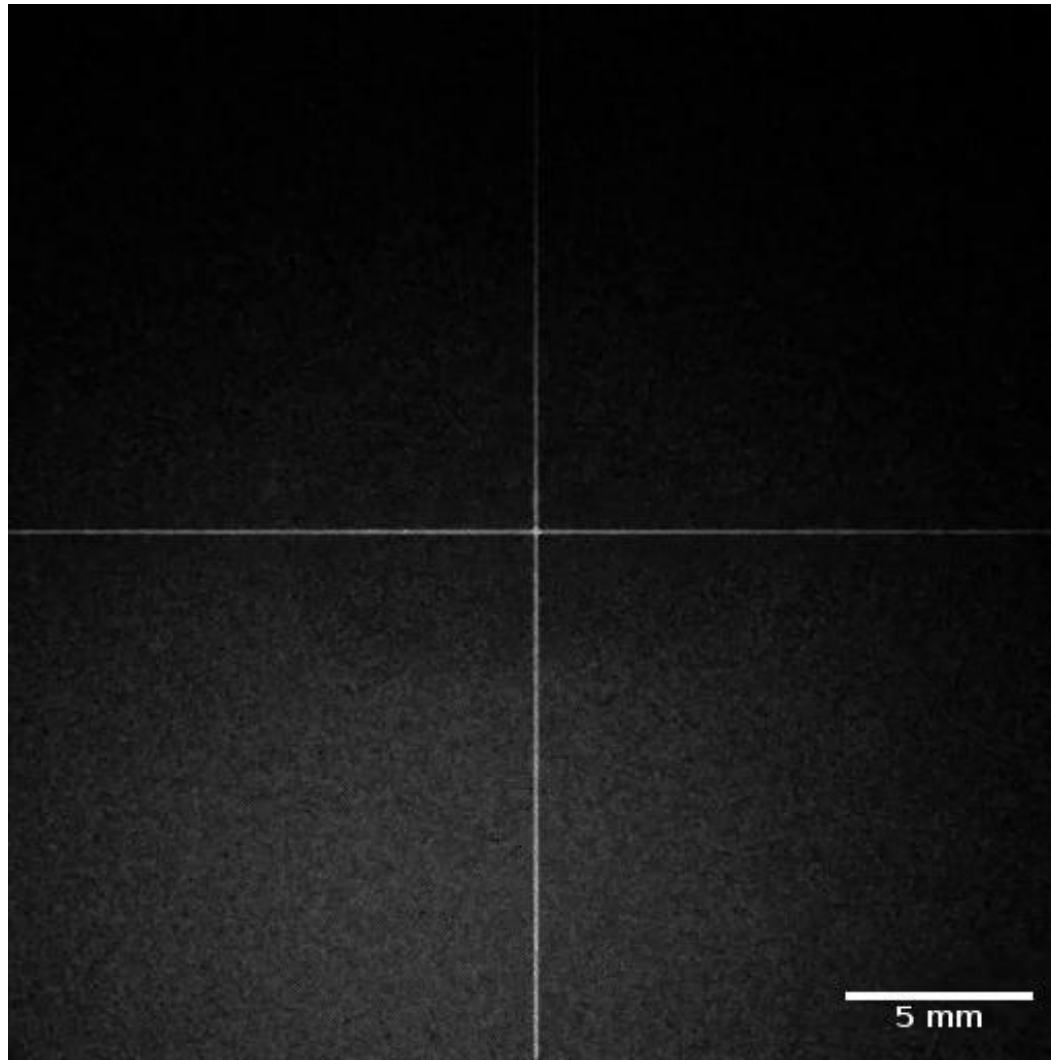


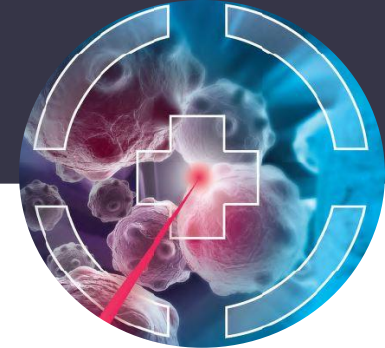


1% real time

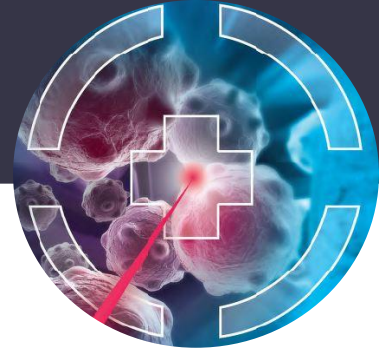
x10 data FPS

Small
subsection of
data





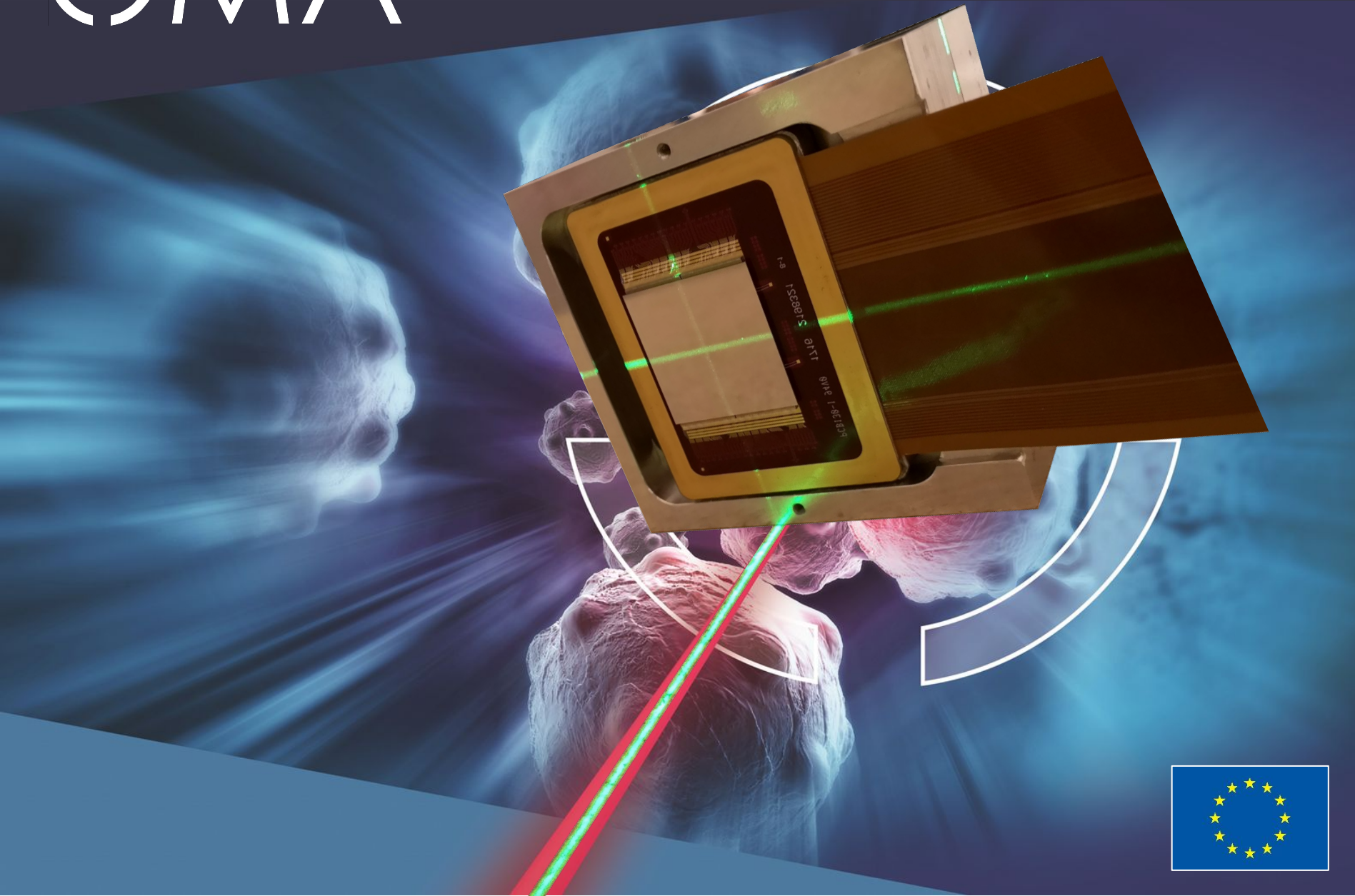
Beam intensity is not measurable at kHz frame rates with 55 μm pixels & excellent count rate linearity with other detectors

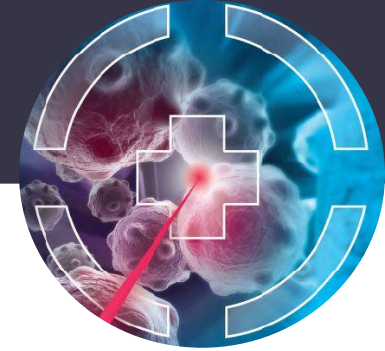


Thanks to Claus and the MedAustron team!

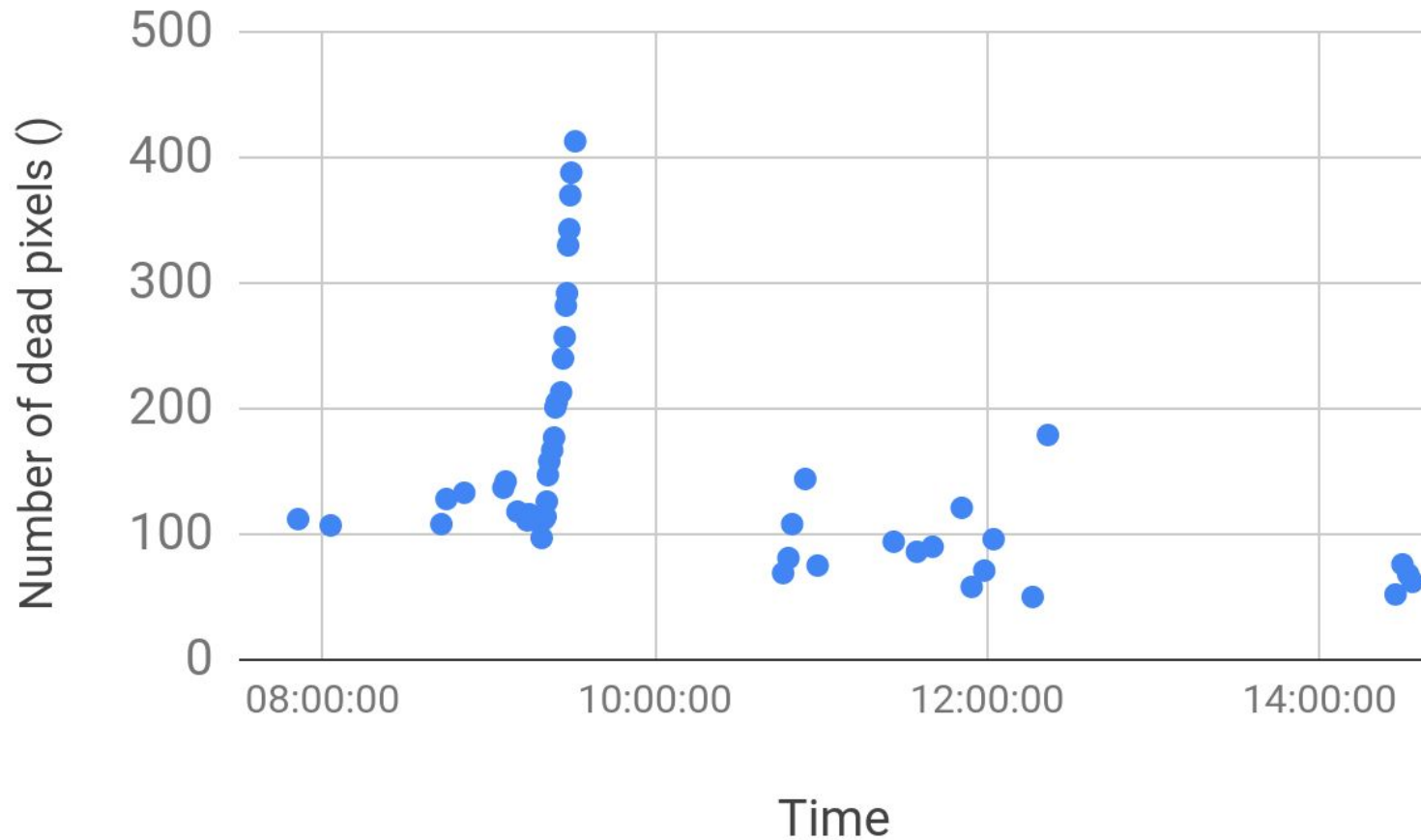
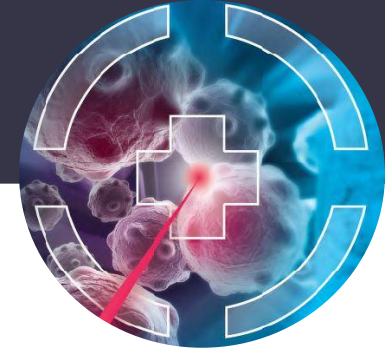


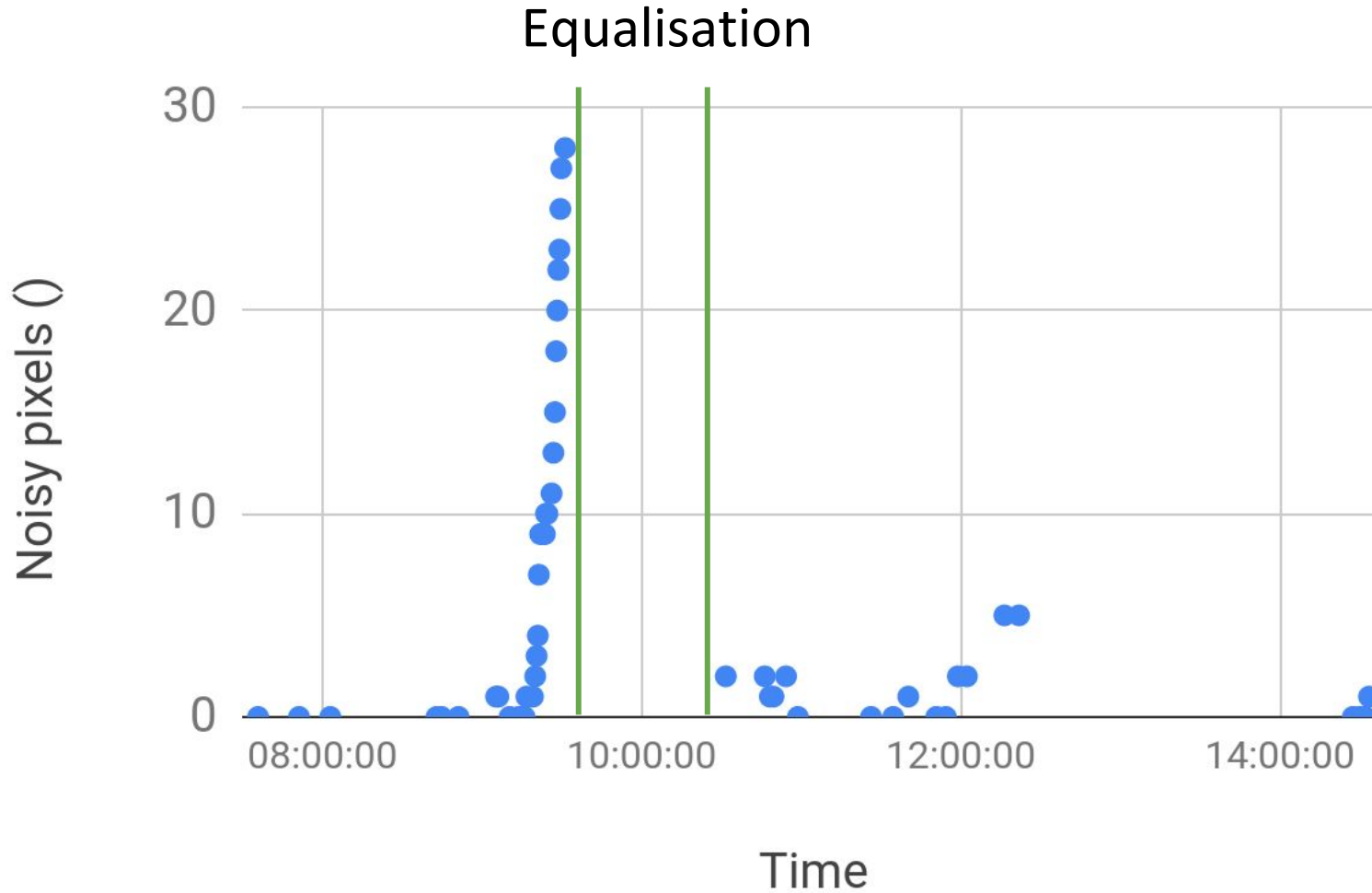
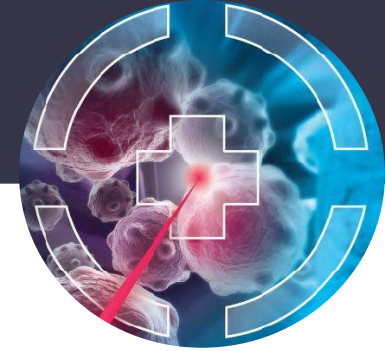
Thank you for listening!





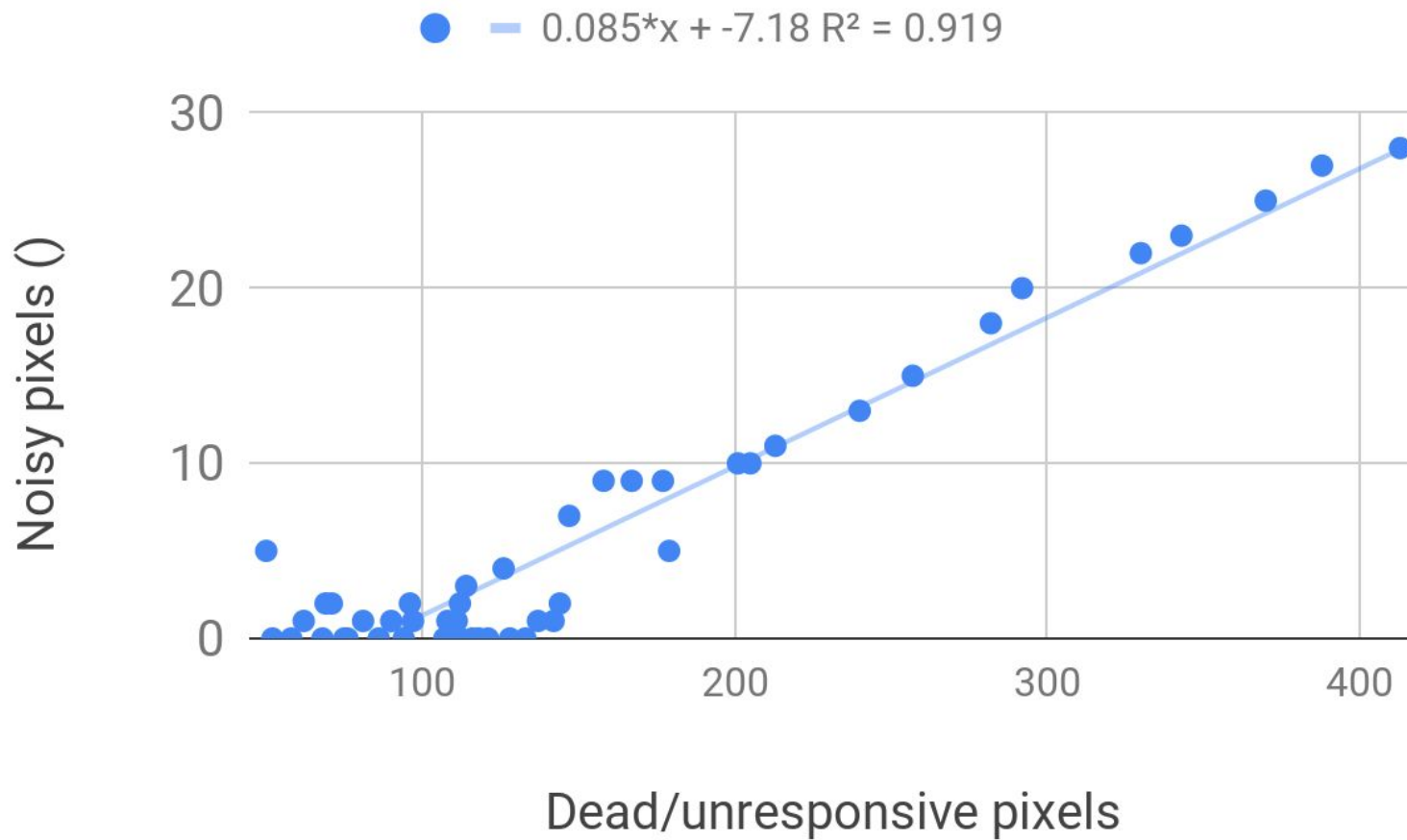
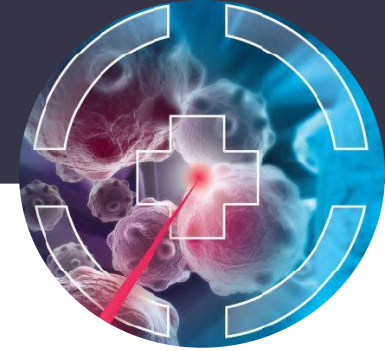
- Detector active area = $28 \times 28 \text{ mm}^2$.
- Sensor material = High resistivity silicon, $300 \mu\text{m}$ thickness.
- Pixel pitch (spatial resolution) = $55 \mu\text{m}$.
- Radiation types: Designed for x-rays and electron detection primarily, works with any ionising radiation depositing $> 5 \text{ keV}$ within a single pixel.
- Frame rate = $0 - 2000 \text{ FPS}$ (Frames Per Second) for 12 bit counter depth (per pixel) in Continuous R/W mode (0 dead time). Other frame rate maximums for different pixel counter depths.
- Detector settings: Highly optimised for x-ray detection between 4-25 keV.
- Particle flux = $10^3 - 10^9$ particles per second over the whole detector.
- Proton energies = 62, 148, 252, 800 MeV.
- Carbon ion energies = 120, 260, 400 MeV/A.
- Detector frame rates used = 50, 100, 1000 FPS in Continuous R/W mode (0 dead time).
- Degradation plates used = 10, 20, 50, 100 %.

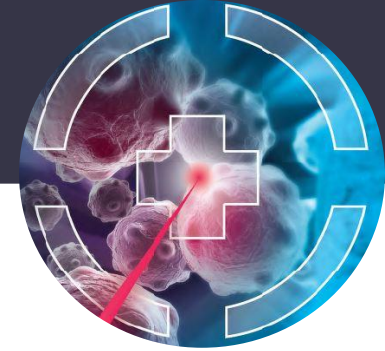






Dead to noisy pixels correlation

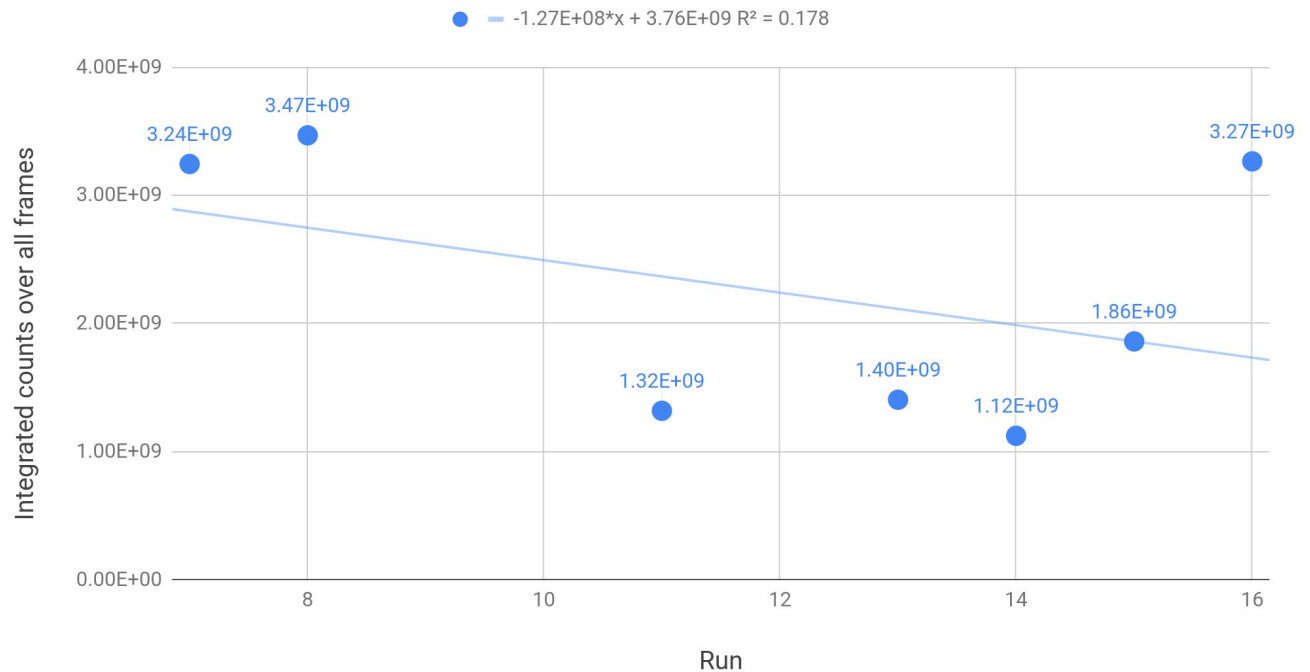


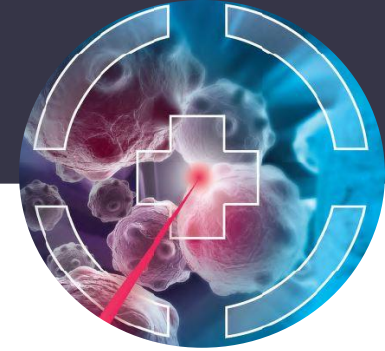


Protons 800 MeV Degradar 10 (try 2)

These should be the same in principle

**+/- 55%
of the
mean**





- Presented at IPAC 2019 - '**Beam Characterisation Using MEDIPIX3 and EBT3 Film at the Clatterbridge Proton Therapy Beamline**', N. J. S. Bal, J. S. L. Yap, A. Kacperek, R. Schnuerer, M. Fransen, F. Linde, J. L. Parsons, J. Resta-Lopez, C.P. Welsch, IPAC 2019 Conference Proceedings, Melbourne, Australia.
DOI:10.18429/JACoW-IPAC2019-THPMP033
- Subsequent paper planned for the above with Jacinta.