Real-Time Dosimetry and Beam Monitoring for UHDR VHEE Beams for FLASH RT

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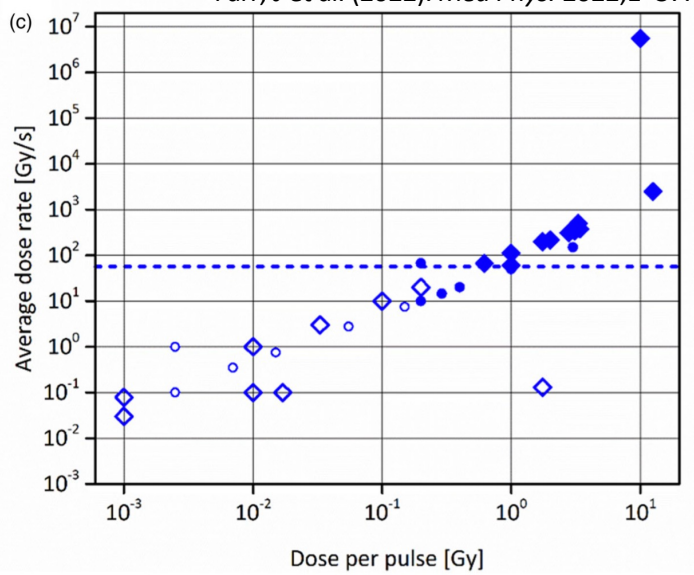
VHEE (*the beam*) and FLASH (*the dream*)

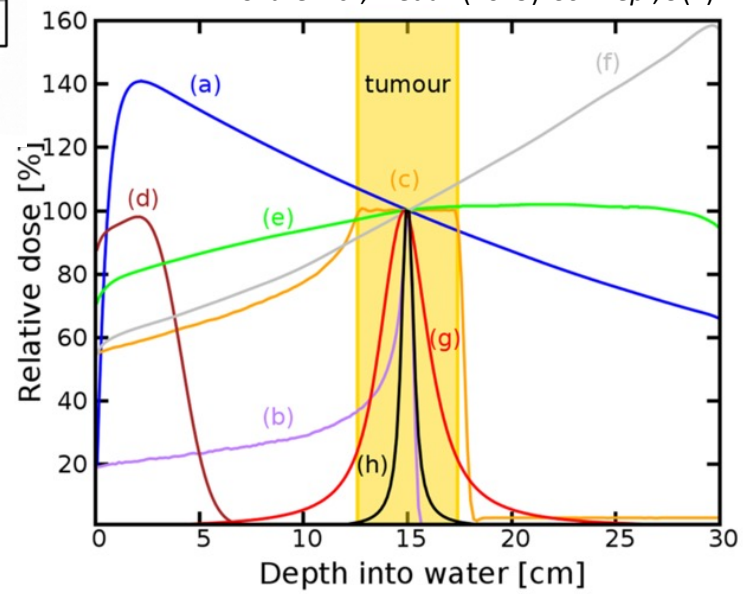
- FLASH effect – healthy tissue sparing observed at >40 Gy/s.
- Demonstrated for low energy electrons, protons and photons.
- Very High Energy Electrons (VHEE) of 100 – 250 MeV could be a promising option for FLASH RT with deep-seated tumours.

Farr, J et al. (2022). *Med Phys.* 2022;1–37.



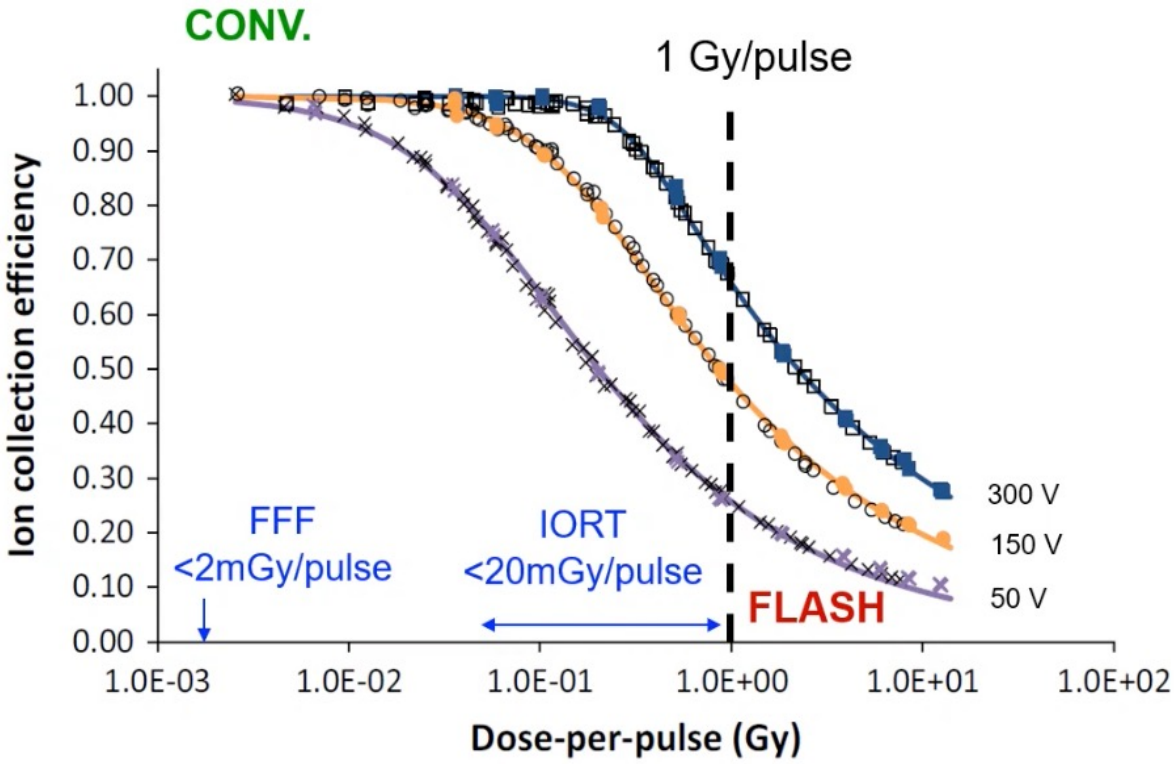
a) Photon
b) Proton
c) SOBP
d) 20 MeV e-
e) 200 MeV VHEE
f) 1 GeV VHEE
g) Focussed VHEE
h) Focussed VHEE

Kokurewicz, K et al. (2019). *Sci. Rep.*, *9*(1).



Challenge for Dosimetry of UHDR Beams

- Ionisation chambers saturate in UHDR conditions required for FLASH.
- Correction factors can account for decrease in ion collection efficiency at UHDR but introduce large uncertainties.
- Collection time of transmission ICs too slow for FLASH beam monitoring.



Petersson et al., Med Phys 44 (2017) 1157

Requirements for UHDR Dose Monitor

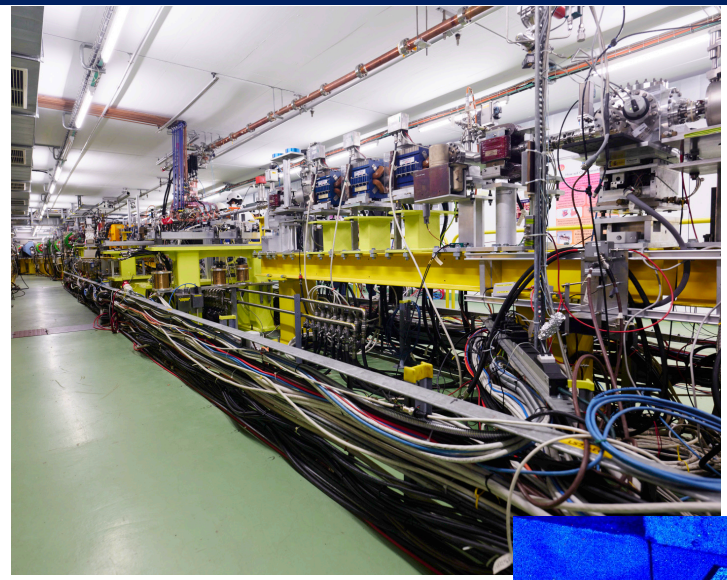
1. A response the does not saturate at the FLASH dose rates.
2. High temporal resolution.
3. High spatial resolution.
4. High level of beam transparency.
5. Large area to cover entire beam.

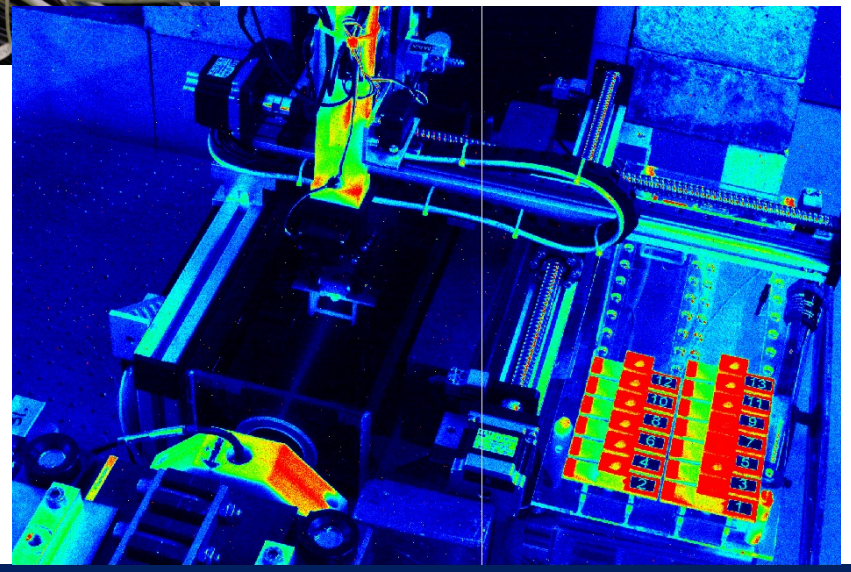
Potential Options for UHDR Dosimetry

- Modified ionisation chamber geometry and design, e.g., ultra-thin plane parallel ion chambers
- Solid-state detectors e.g., diamond detectors, Si detectors
- Scintillators
- Accelerator Beam Instrumentation - current transformers, pick-up monitors etc.

CLEAR Accelerator (*the beam that could make or break my dreams*)

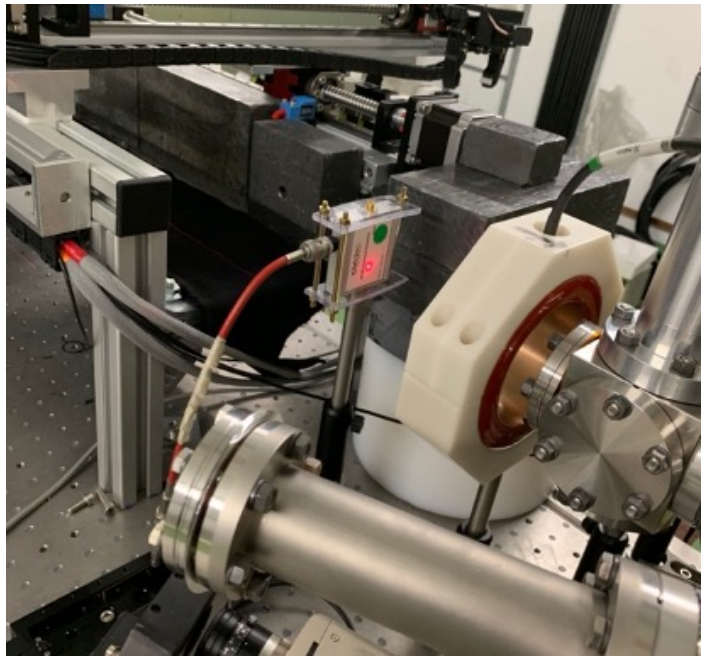
- CERN Linear Electron Accelerator for Research
- 60 – 220 MeV electron beam.
- Used for accelerator and component R&D, electronics irradiations and medical applications.
- Significant focus on UHDR VHEE RT research.



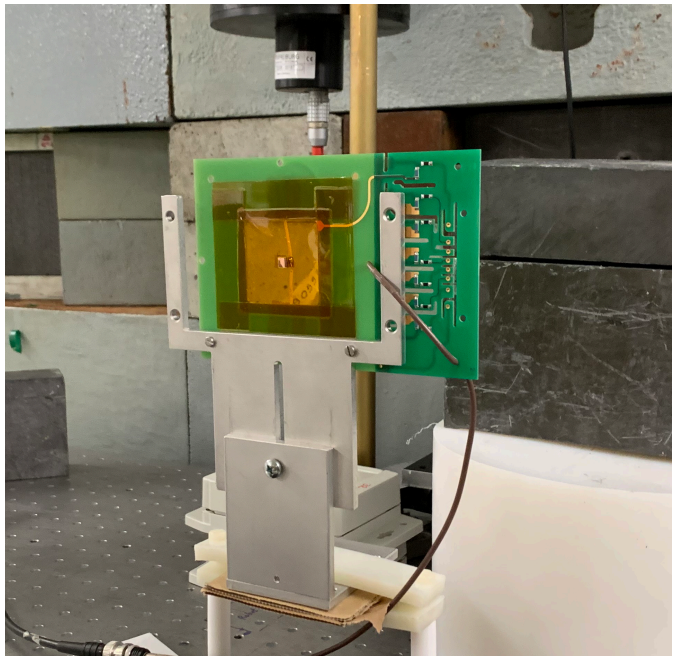


Initial Detector Experiments at CLEAR

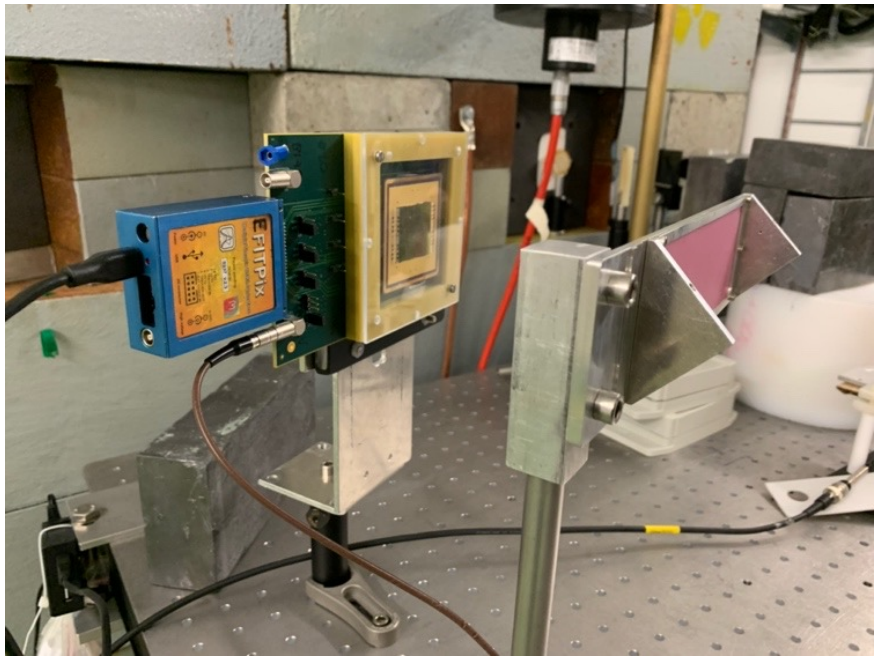
pCVD Diamond Detector



GEM Foil Detector

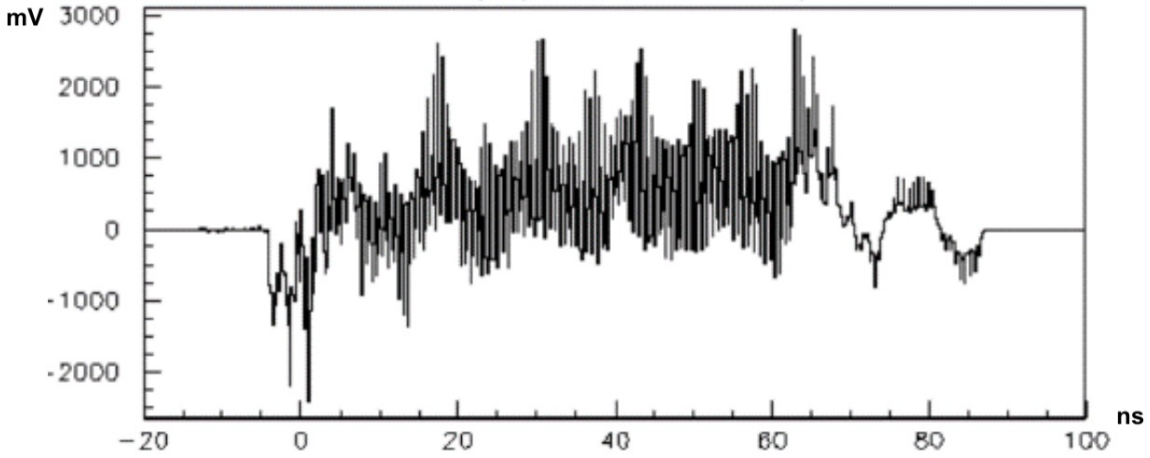


Timepix3 ASIC

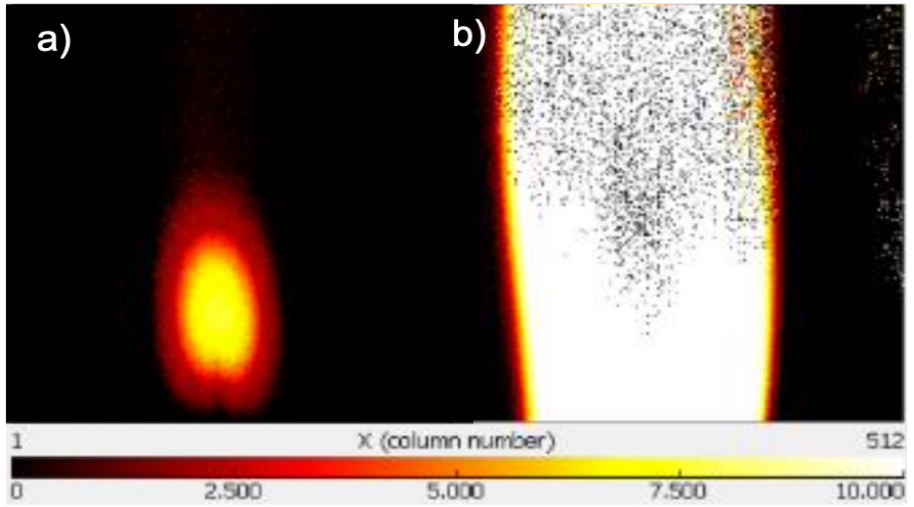


Detector Experiments at CLEAR

1. pCVD B2-HV Diamond Detector – saturated at 1.6 Gy/s.
2. Timepix3 ASIC – saturated at 5 Gy/s.
3. GEM foil – did not saturate up to 200 Gy/s and high temporal resolution.



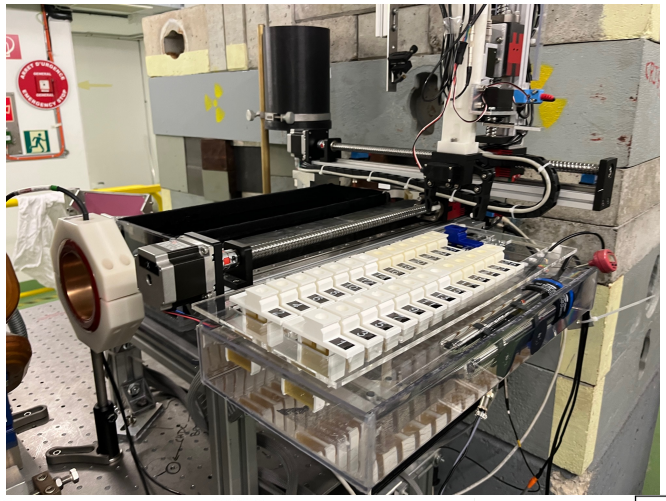
GEM foil response for 10 nC pulse

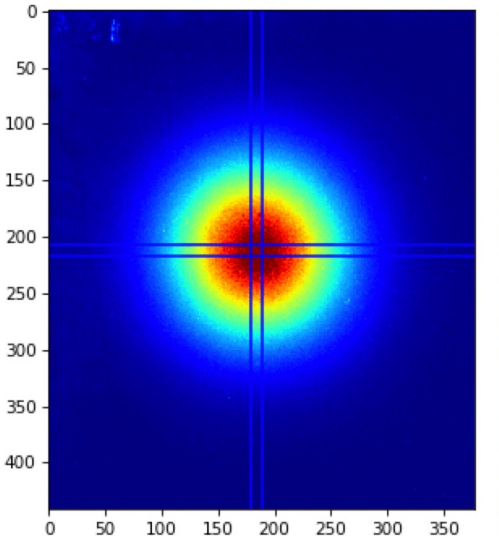


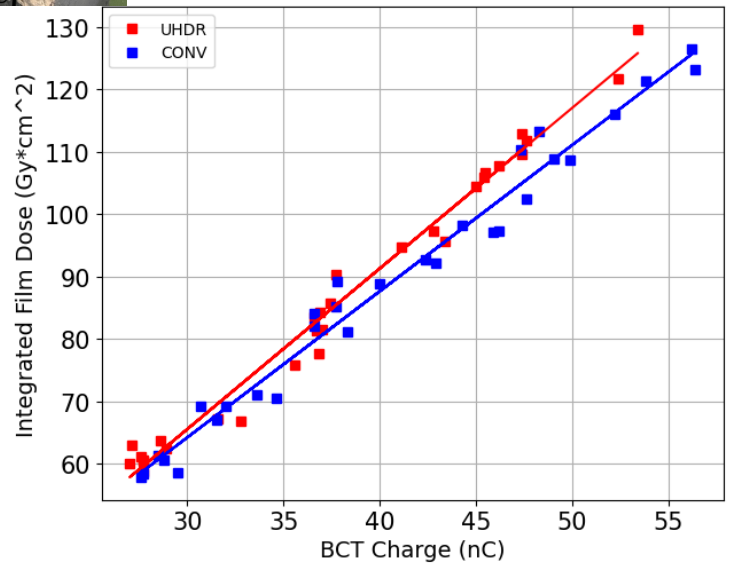
Timepix3 response at a) 100 pC pulse and b) 250 pc pulse

Beam Dosimetry at CLEAR

- Beam Current Transformers (BCTs) provide non-destructive charge measurements.
- Linear response with dose measured on film at a reference position.
- However… beams at CLEAR are not flat and have varying beam size.
- Therefore the area integrated dose is used.

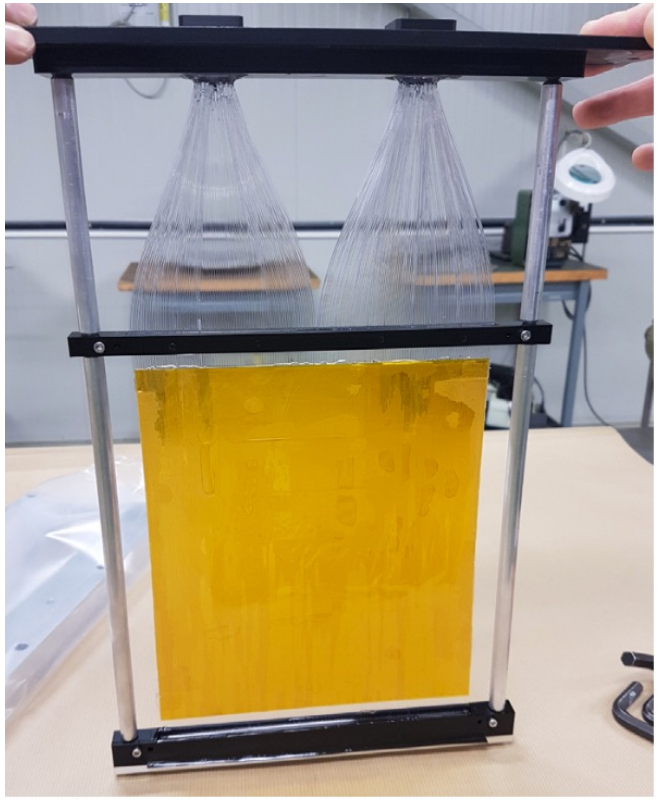






Next steps…

- Existing range of detectors investigate only applicable for small size beams.
- BCTs only capable of providing total charge/dose measurements – no info on flatness, symmetry or beam size.
- Tests on other solid-state detectors.
- Investigate and characterise a number of scintillating/optical fibre arrays.
- Detectors and instrumentation for *in vivo dosimetry.*



Ortega Ruiz, I et al. *Nuclear Inst. and Methods in Physics Research, A 951 (2020)*

Thank you for listening!

Any questions?