METROLOGY FOR ADVANCED RADIOTHERAPY USING PARTICLE BEAMS WITH ULTRA-HIGH PULSE DOSE: TEST IN FLASH-LIKE ELECTRON BEAM AT MICROTRON MT 25

Ambrožová I.[1], Chvátil D.[2], Cimmino A.[3], Motta S.[3], Oancea C.[4], Olšanský V.[2], Olšovcová V.[3], Pivec J.[4], Šolc J.[5], Versaci R.[3]

[1] Department of Radiation Dosimetry, Nuclear Physics Institute of the Czech Academy of Sciences, Prague, Czech Republic

[2] Department of Accelerators, Nuclear Physics Institute of the Czech Academy of Sciences, Řež, Czech Republic

[3] ELI Beamlines Centre, Institute of Physics of the Czech Academy of Sciences, Dolní Břežany, Czech Republic

[4] ADVACAM s.r.o., Prague, Czech Republic

[5] Czech Metrology Institute, Prague, Czech Republic

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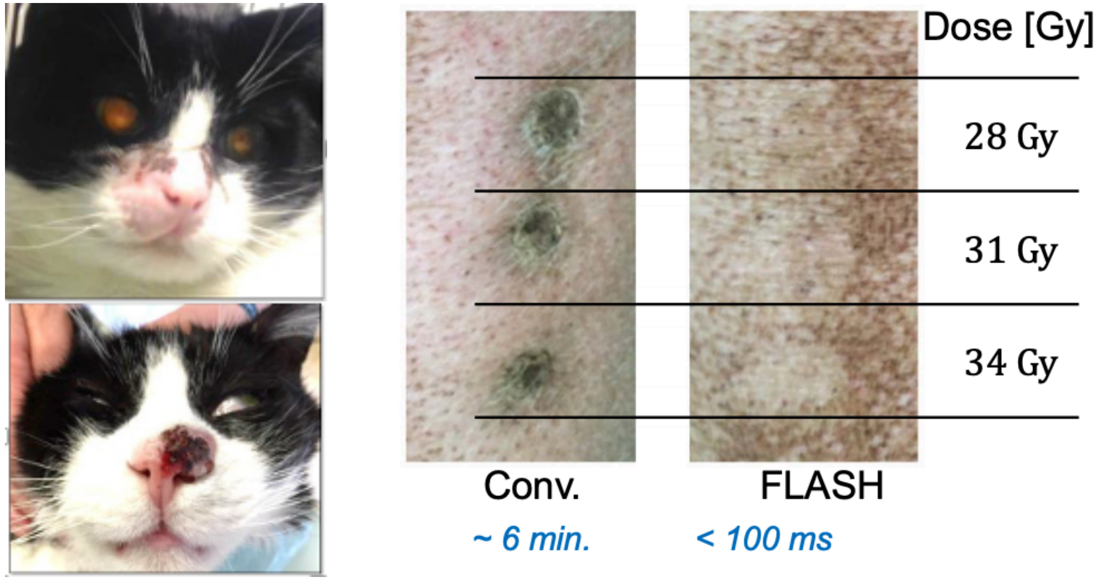
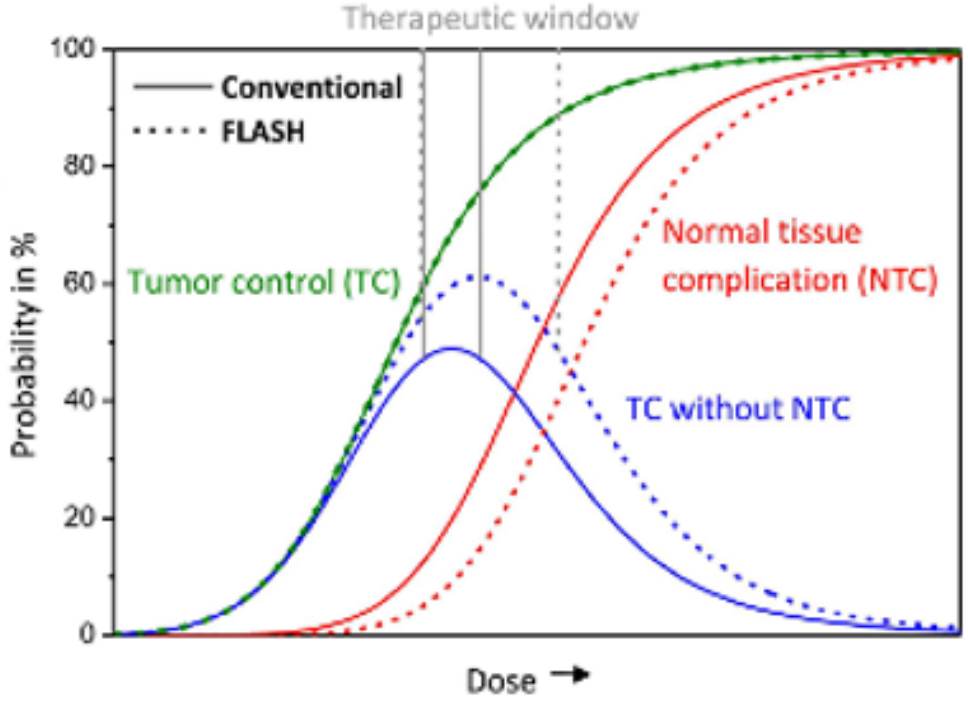
FLASH therapy

- therapeutic resistance to radiation -> innovative radiotherapy strategies
- ultra-high pulse dose-rates (UHPDR) may dramatically reduce adverse side effects, while preserving the required tumour control

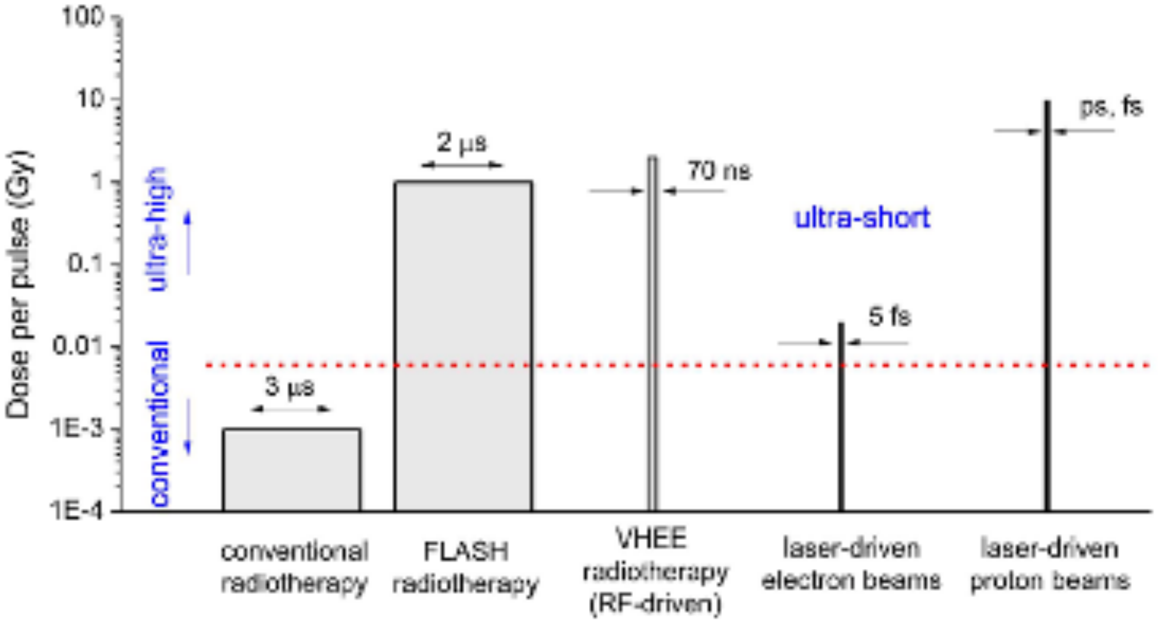


Vozenin et al., Clin Cancer Res 25 (2019) 35; DOI: 10.1158/1078-0432.CCR-17-3375



UHPDR beams

- new generation of proton accelerators, development of alternative irradiation modalities (e.g. VHEE), novel pulsed sources (laser-driven electron or proton beams)
- metrological challenges -> new dosimetry tools and methods needed



	FLASH	conventional
dose per pulse	1 – 10 Gy	0.3 mGy
pulse width	1 -2 us	3 us
dose rate during pulse	10^6 Gy/s	10^2 Gy/s
pulse repetition frequency	10 – 100 Hz	200 Hz
mean dose rate	40 – 1000 Gy/s	0.05 Gy/s
time for dose delivery	**100 ms**	**4 min**

UHDpulse project

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

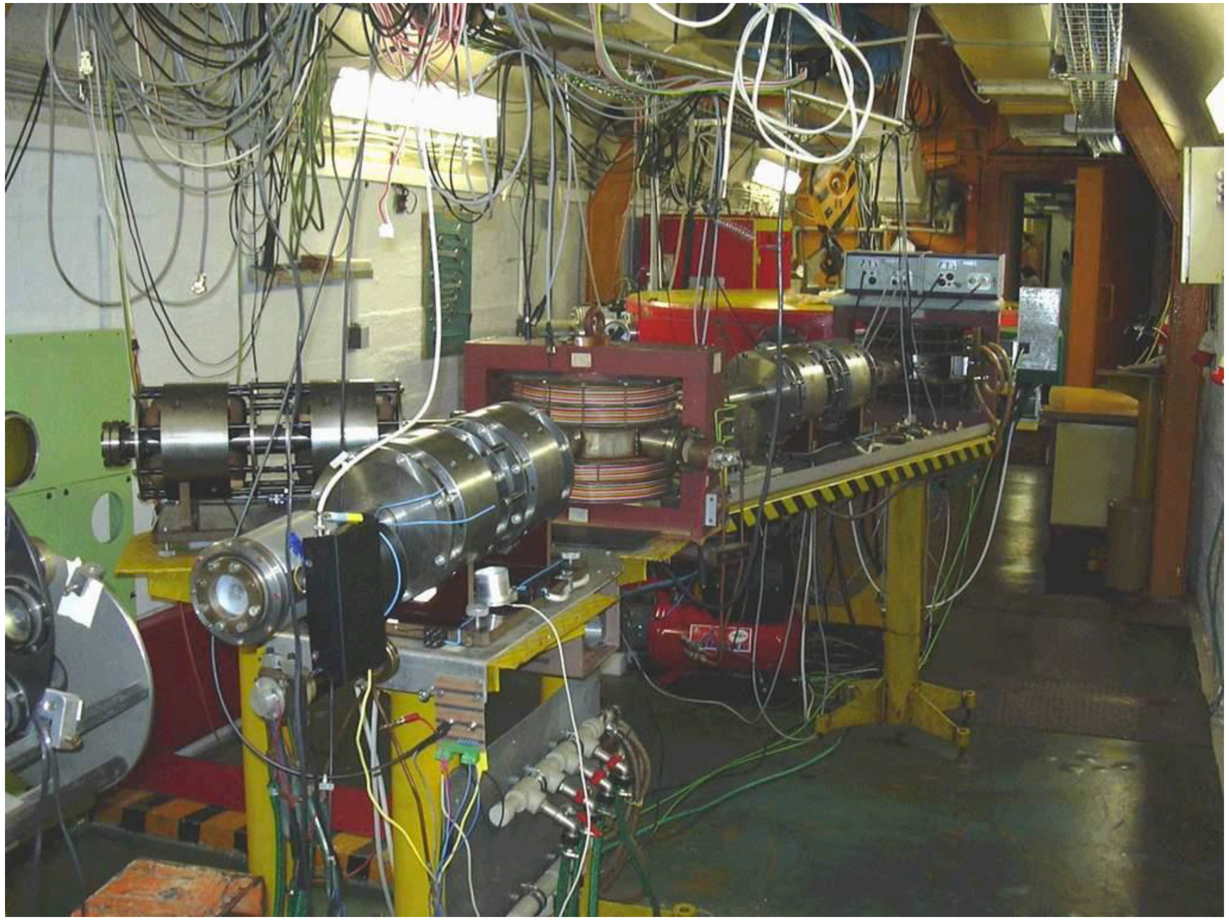
- joint research project within EMPIR (European Metrology Programme for Innovation and Research), coordinated by the National Metrology Institute of Germany, PTB
- http://uhdpulse-empir.eu/
- Sep 2019 – Feb 2023
- to provide the metrological tools needed to establish traceability in absorbed dose measurements of particle beams with ultra-high pulse dose rates (UHPDR), i.e. with ultra-high dose per pulse or with ultrashort pulse duration.

UHDpulse project

- Specific objectives
  - To develop a metrological framework, including SI-traceable primary and secondary reference standards and validated reference methods for dosimetry measurements for particle beams with ultra-high pulse dose rates
  - To characterise the response of available detector systems in particle beams with ultra-high dose per pulse or with ultrashort pulse duration
  - To develop traceable and validated methods for relative dosimetry and for the characterisation of stray radiation outside the primary pulsed particle beams
  - To provide the input data for Codes of Practice for absolute dose measurements in particle beams with ultra-high pulse dose rates
  - To facilitate the uptake of the project’s achievements by the measurement supply chain, standards developing organisations and end users
- 4 technical work packages (WP)
  - WP1: SI-traceable primary standards for absorbed dose measurements – towards the development of primary standard
  - WP2: Secondary standards and reference methods for reference and relative dosimetry
  - **WP3: Detector systems for measurements in the primary beam**
  - **WP4: Detector systems and methods for dosimetry outside primary beam – stray radiation**

Microtron MT25

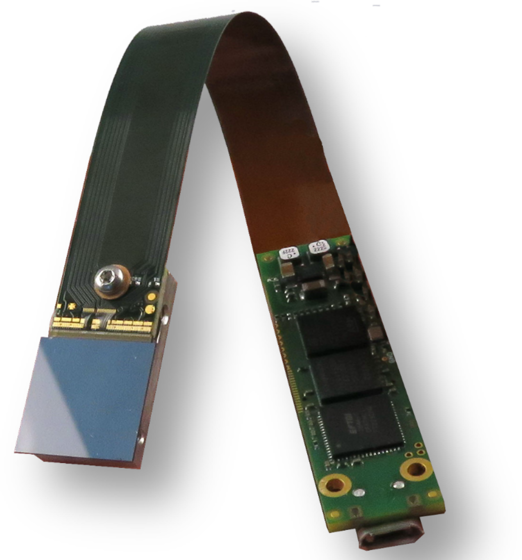
- behavior of the detectors in a conventional radiation field -> characterization in pulsed mixed radiation fields
- several irradiation campaigns
- circular electron accelerator
- monoenergetic electrons (6–24 MeV)
- pulse length 3.5 μs, repetition rate 423 Hz
- mean current 0.5–20 μA



Detectors

- ionization chamber to monitor the beam
- **luminescent detectors**
  - thermoluminescent detectors ($CaSO_4$:Dy, LiF)
  - optically stimulated luminescent detectors
- plastic nuclear track detectors (PNTD)
- GAFchromic films
- **pixel semiconductor detector Timepix3**
  - Silicon sensor, thickness 500 μm
  - 256 x 256 pixels (1px = 55 μm)
  - visualization of individual charged particle tracks -> possibility to distinguish and characterize radiation components of mixed time-dependent stray radiation fields

MiniPIX TimePIX3



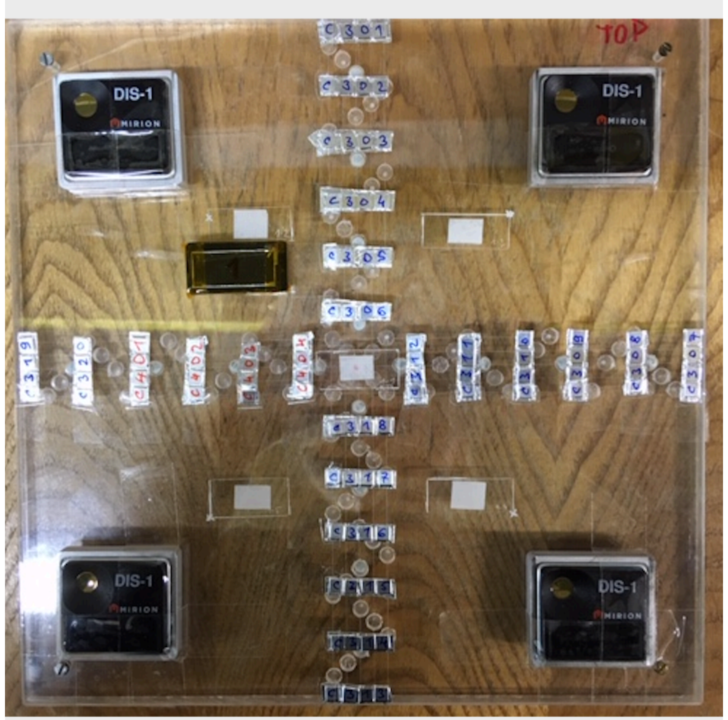
Optimized UHDPulse detector
FLEX MiniPIX TimePIX3

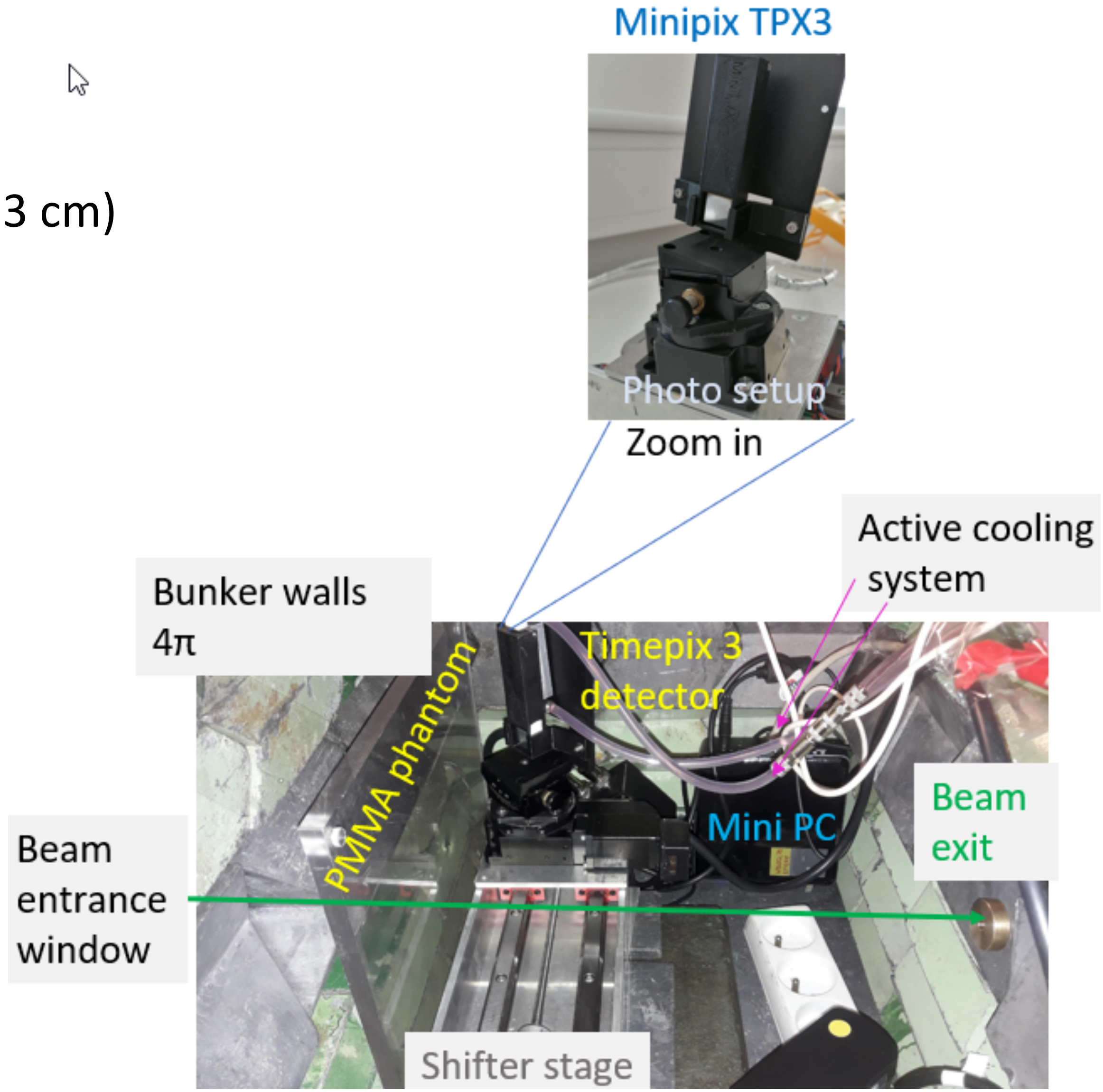
Experimental set-up

- electron beam 23 MeV
- lead bunker to shield background radiation
- dose rate 2–44 Gy/s
- PE moderator (8 cm thick)

Experimental set-up

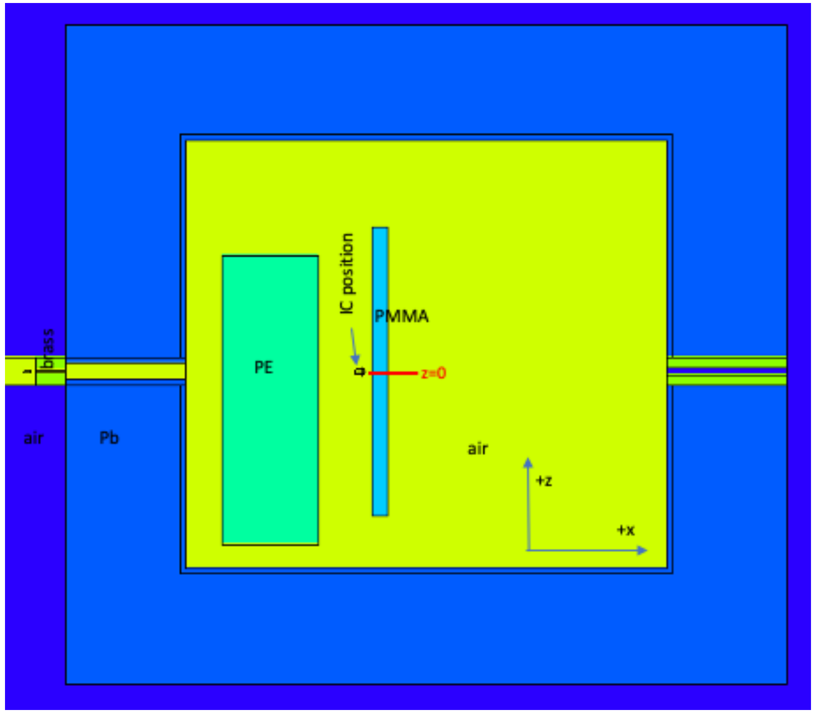
- PMMA plate with passive detectors (25 x 25 x 1.3 cm)
- shifter stage with Timepix 3

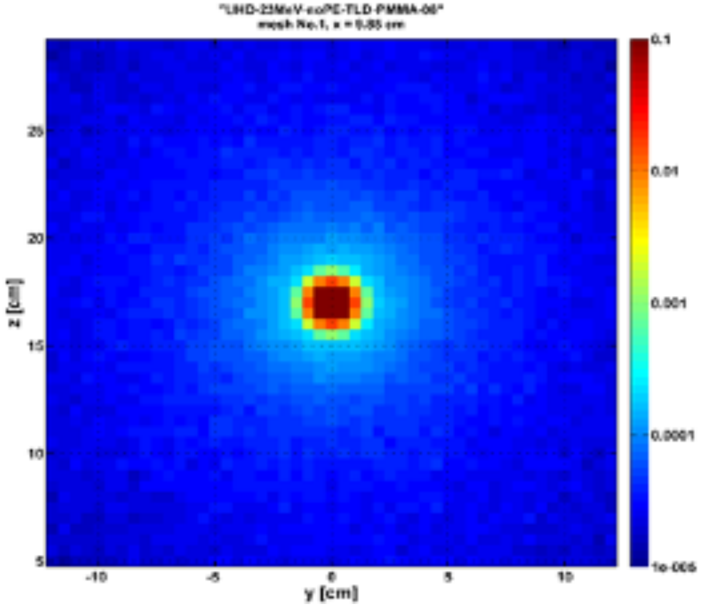


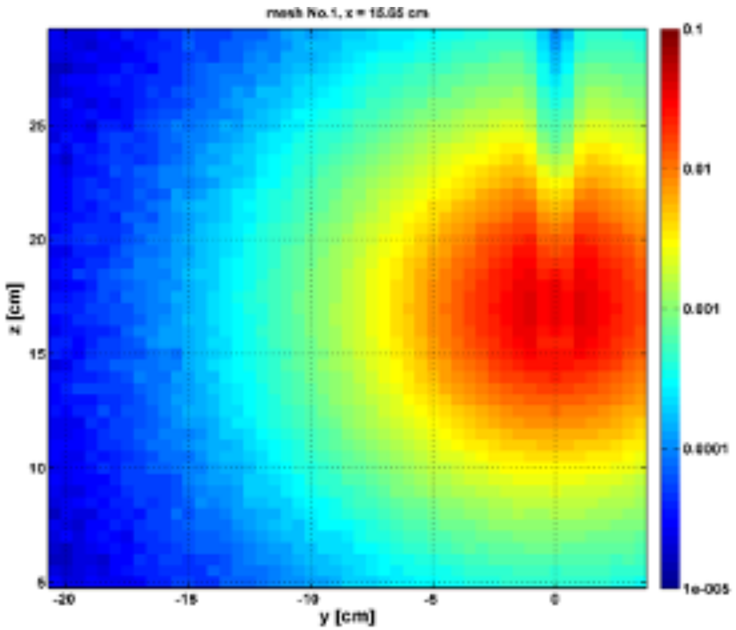


Results

- measurements supported by Monte Carlo simulations of particle energy spectra, fluence and dose distributions inside the bunker, and ionization chamber response

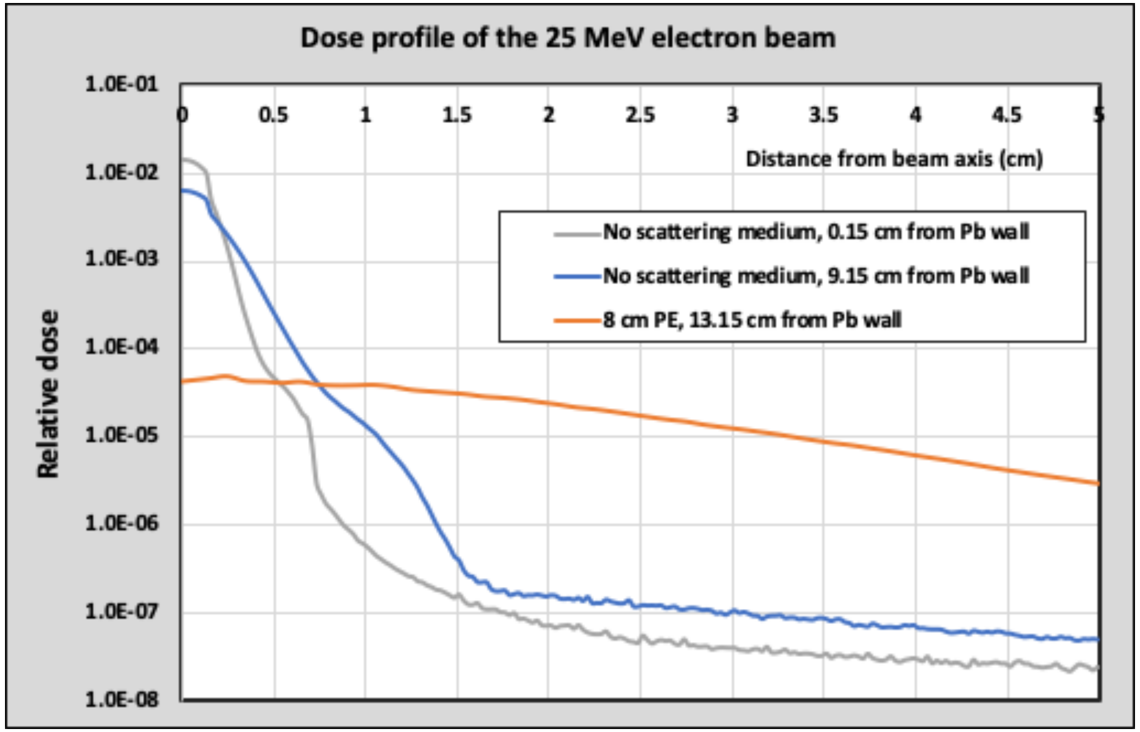




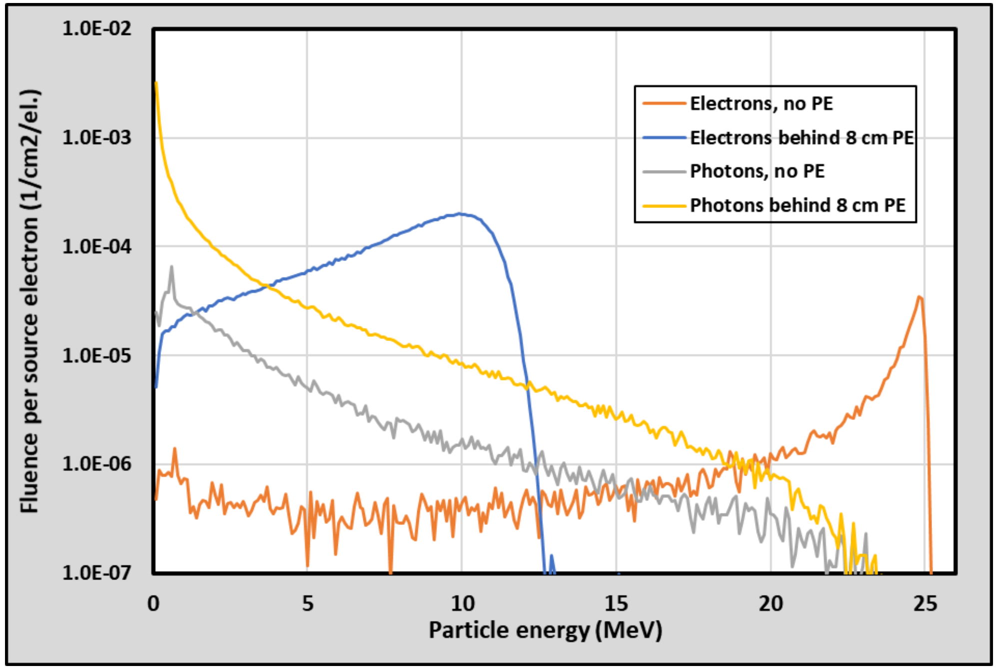


Results

- simulated dose profile and fluence spectra of electrons and photons

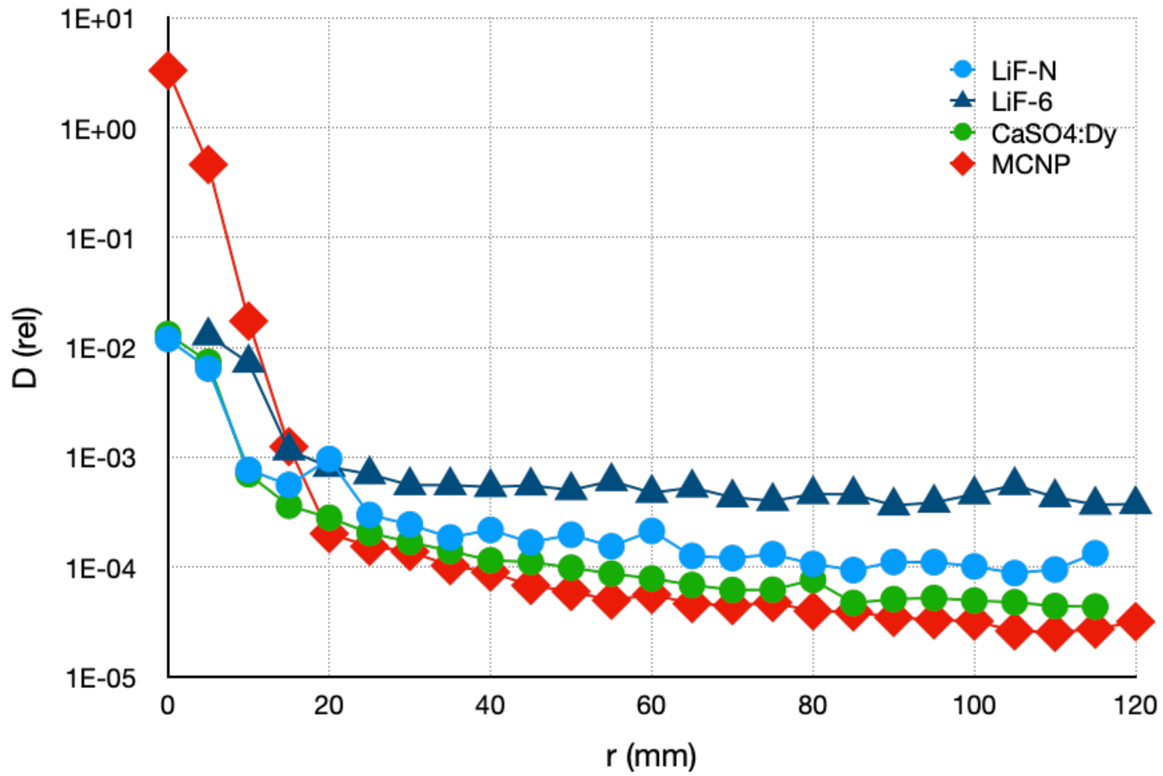


*Fluence spectra of electrons and photons **2 cm off** the 25 MeV electron beam axis, behind 8 cm thick PE and without PE*



Results

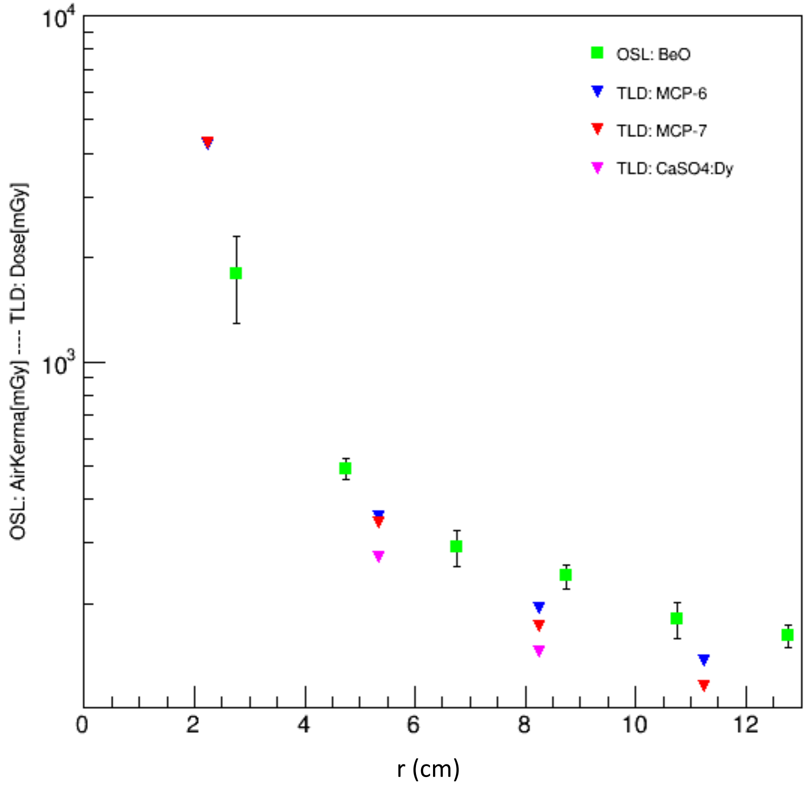
- absorbed dose as a function of distance from the beam axis measured with different types of TLD and simulated with MCNP
- total air kerma at the beam axis 31 Gy (standard uncertainty estimated to 20%)



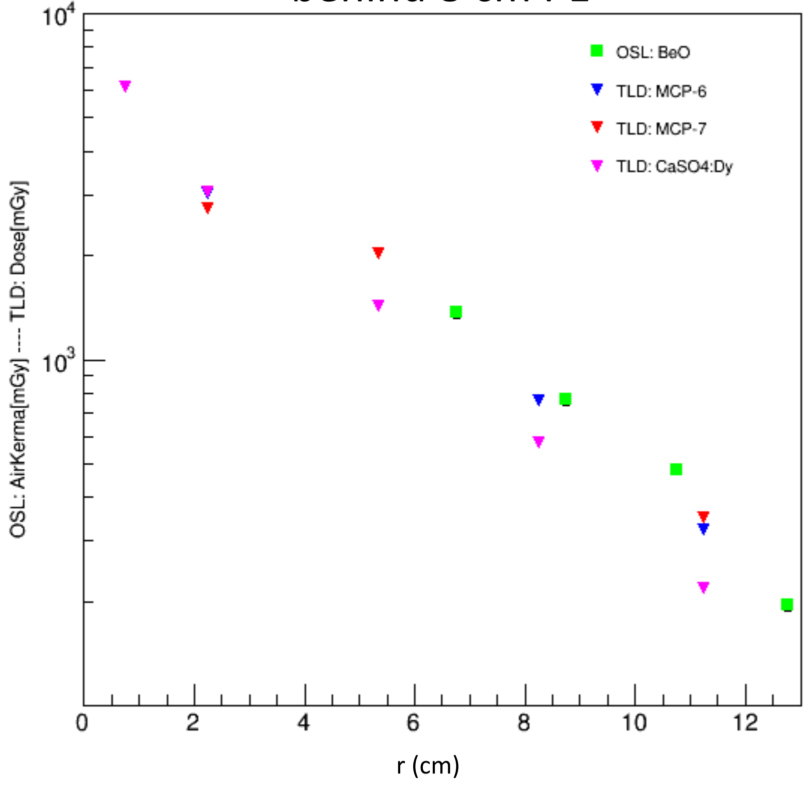
Results

- absorbed dose in water/air kerma as a function of distance from the beam axis measured with different types of TLD and OSLD

without PE

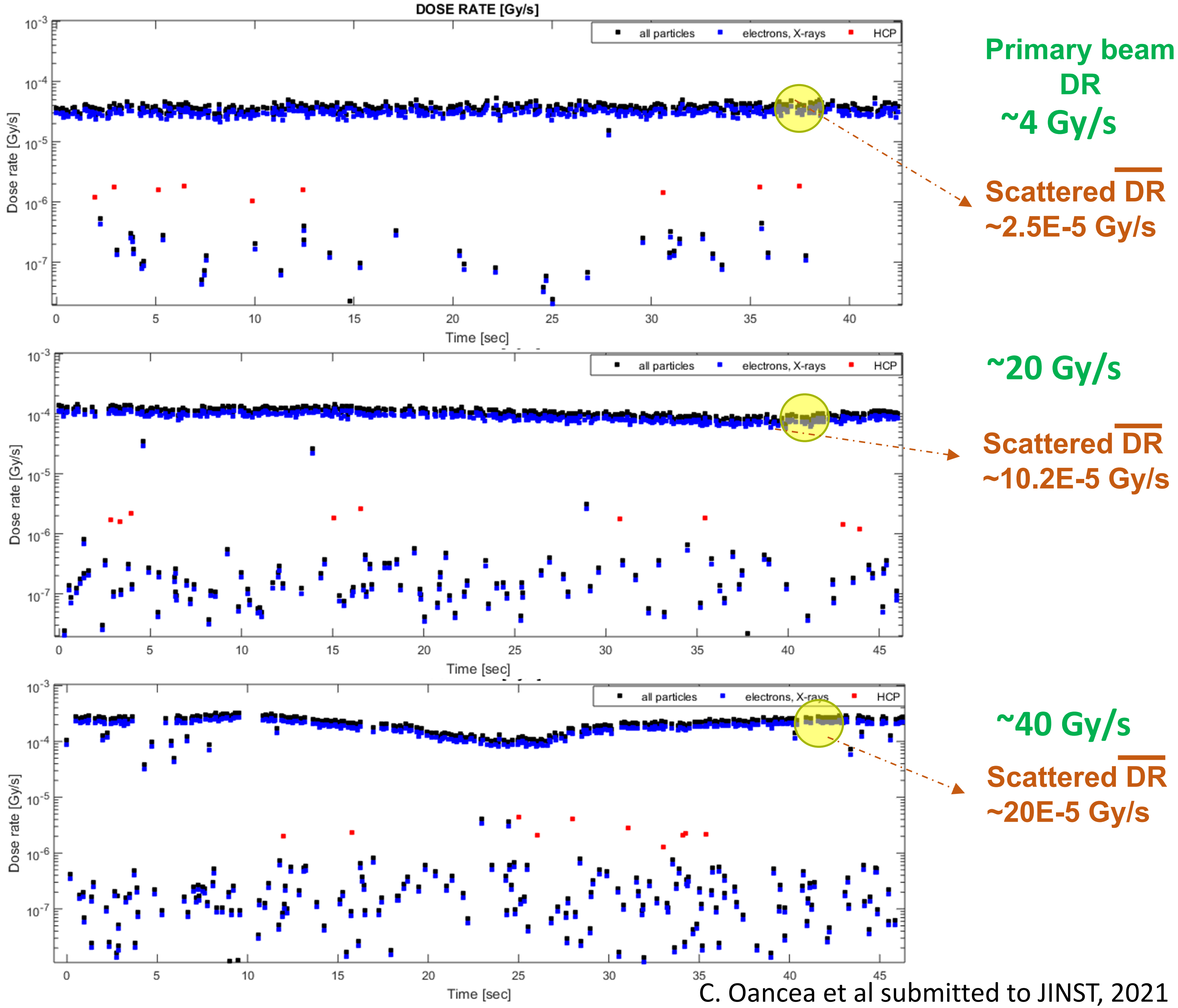


behind 8 cm PE



Results

- dose rate (DR) measurements using Minipix Timepix3
- Bias 120 V, acquisition time ≤ 1ms
- 100 mm distance from the primary beam, behind 1 cm PMMA phantom
- beam intensity ~100-1000nA



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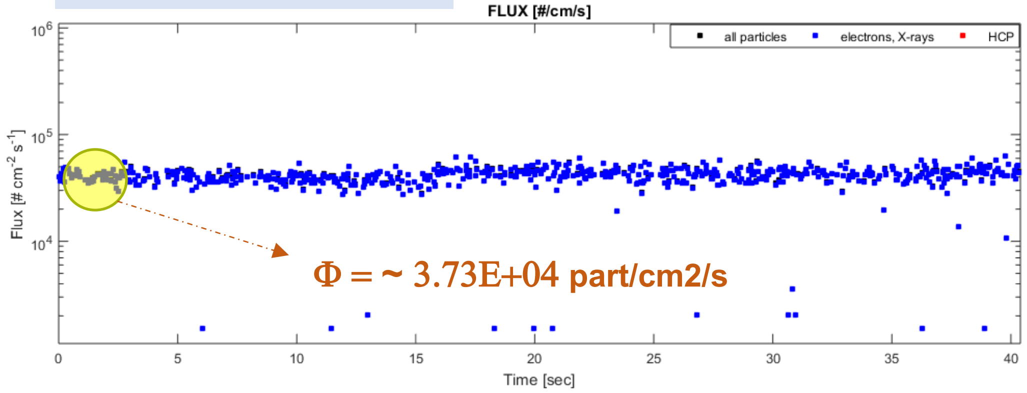
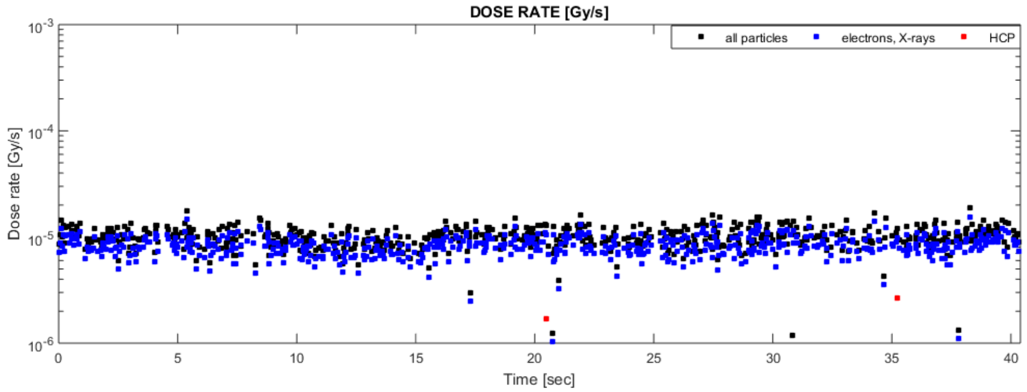
Results

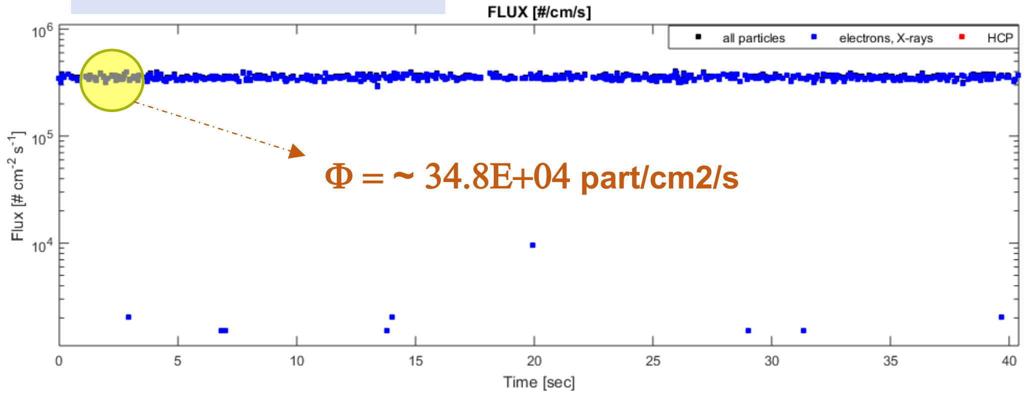
- flux of particles and dose rate measurements using Minipix Timepix3 detector behind 8 cm PE

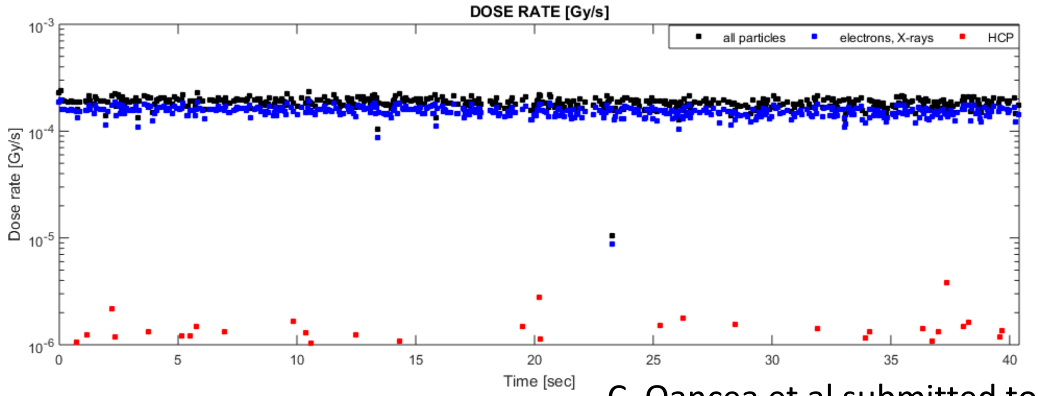
160 mm distance





60 mm distance





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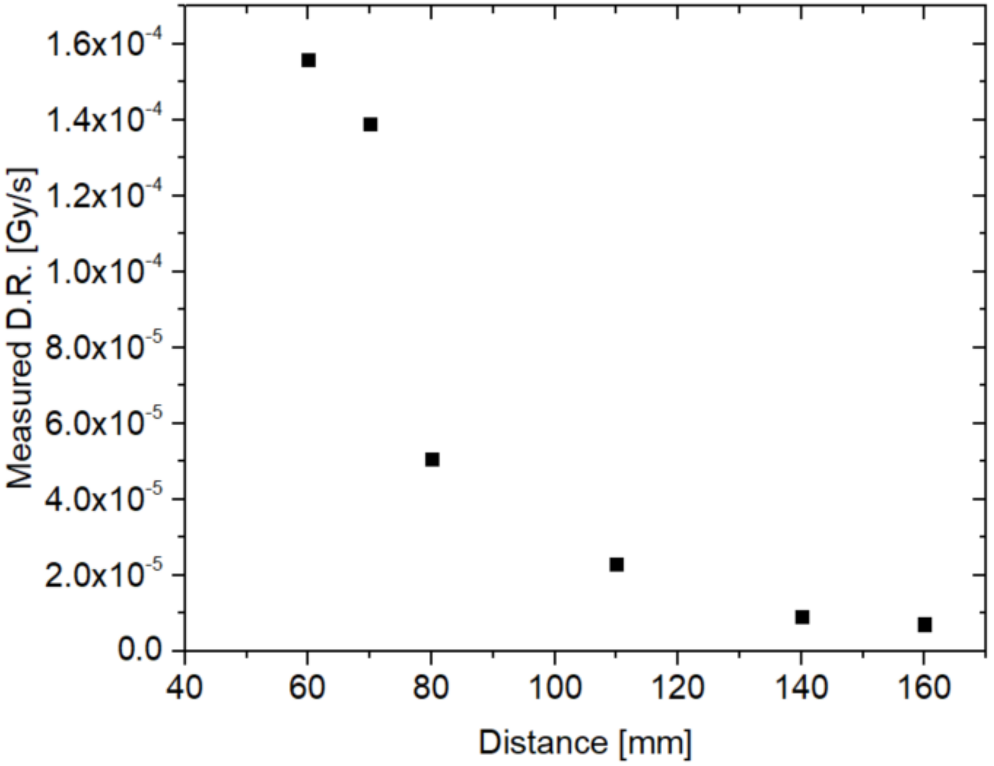
Results

- characterization of stray radiation behind 8 cm PMMA phantom using Minipix Timepix3



Distance	Flux	DR
mm	particles/cm2/s	Gy/s
160	3.73E+04	7.11E-06
140	5.54E+04	9.08E-06
110	8.00E+04	2.30E-05
80	1.32E+05	5.07E-05
70	3.64E+05	1.39E-04
60	3.48E+05	1.56E-04

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Conclusions

- preliminary data from test at electron beam at microtron MT 25 were presented
- various types of TLD with different sensitivity to thermal neutrons
- the active hybrid semiconductor pixel detectors Timepix3 made out of Si sensors are suitable for measuring the stray radiation in electron beams
- within the UHDpulse project a customized waterproof detector for FLASH radiotherapy was developed (all the electronics placed at a distance from the sensor on a flexible cable and no metallic parts close to the sensor)
- the particle flux and dose rate could be measured in data-driven mode up to 50 mm distance from the beam core

Acknowledgement

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