A fluorescence-based beam monitor for ultra-high dose rate therapeutical beams

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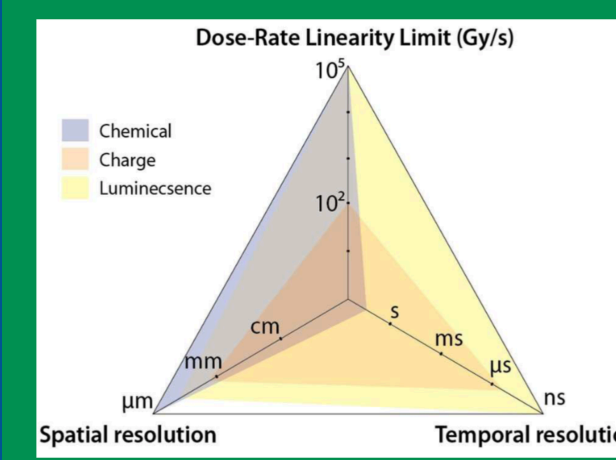
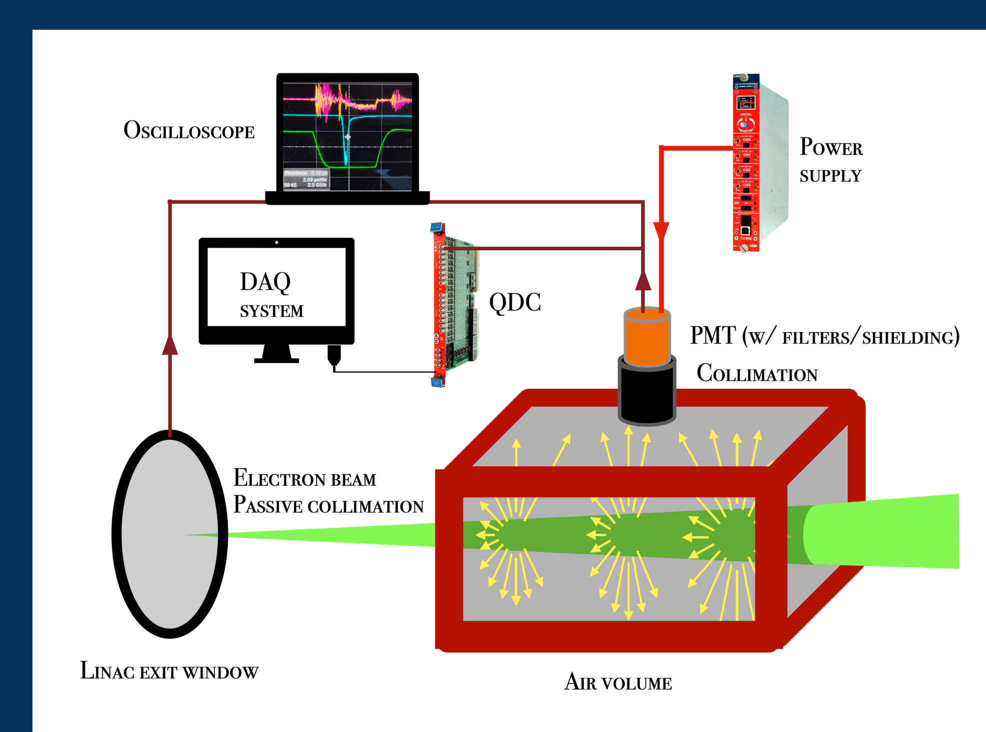
FLASH RADIOTHERAPY

- Radiotherapy consists in delivering a certain amount of dose (energy released per unit of mass) to tumor-affected tissue in order to destroy or reduce the tumor, preserving the surrounding healthy tissues
- FLASH Radiotherapy (FLASH-RT) exploits ultrahigh dose rates delivered in a very very short time, which allows to treat the tumor with a higher (more efficient) dose, keeping an adequate sparing of the healthy tissues (FLASH effect).
- Its biological mechanisms are not yet understood and there is a lot of investigation going on.
- FLASH radiotherapy implementation as a standard procedure in clinical practice cannot disregard a real time monitoring system able to provide accurate information about intensity and direction of the electron beam avoiding saturation and discharges effects as the ones occurring in standard detectors when used in FLASH regimes.

Beam characteristics	CONV	UHDR / FLASH-RT
Dose per pulse	~ 0.5 mGy	> 1 Gy
Inst. dose rate (single pulse)	~ 100 Gy/s	> 10^6 Gy/s
Mean dose rate (single fraction)	~ 0.1 Gy/s	> 100 Gy/s
Total fraction time	~ minutes	< 100 ms

BEAM MONITORS



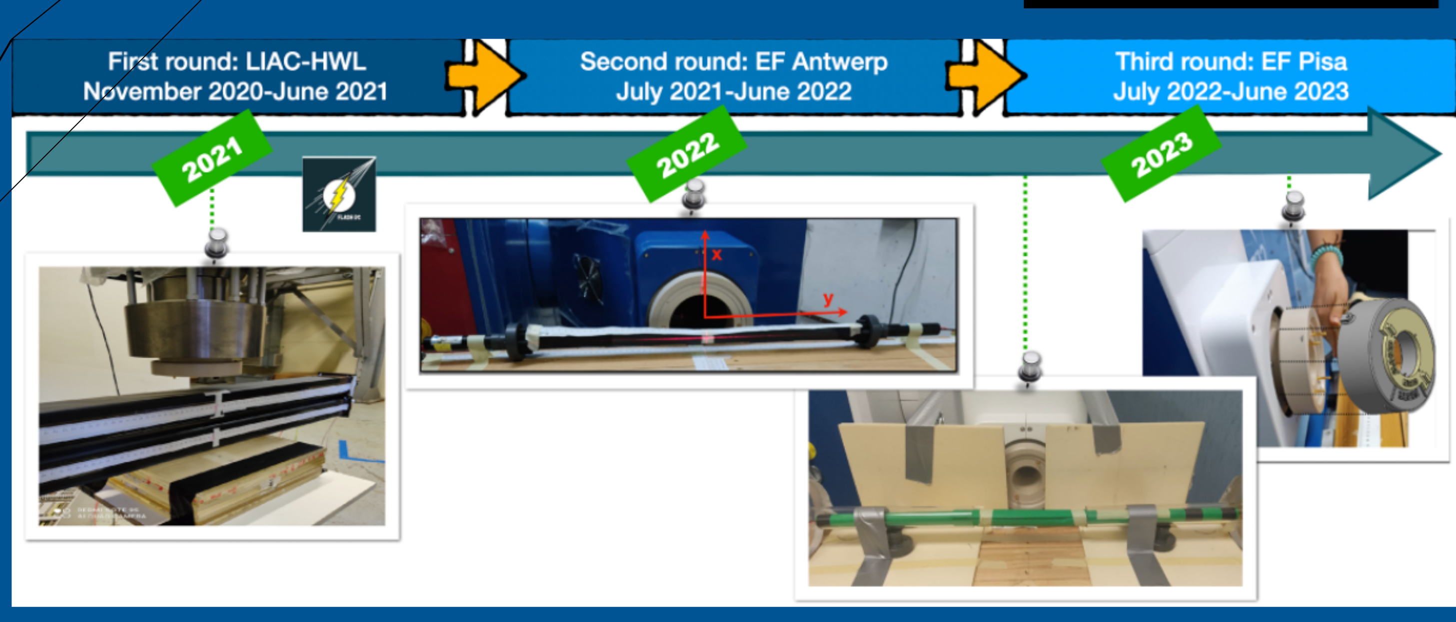


The prototype has been tested with the ElectronFlash experimental machine, provided by the S.I.T. Sordina IORT Technologies S.p.A. (Aprilia, Italy) at different dose rates:

- *Pulse length: 4 μs*
- *10^{12} electrons/pulse*
- *E_k at the linac exit: 7 MeV*
- *Design dose rate: up to 10^4 Gy/s*
- *Dose rate for a single pulse: up to 10^6 Gy/s*
- *Field spread: ≈10 cm*

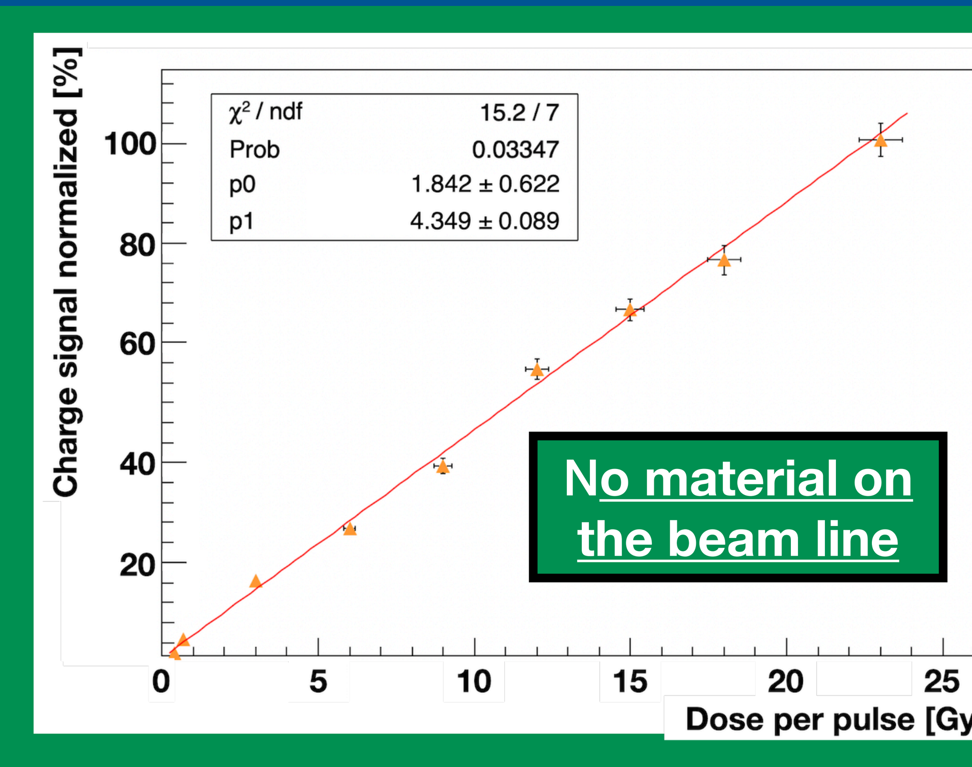
The light response of the detector (collected charge) was evaluated as a function of the beam current intensity, correlated to the number of electrons per pulse (thus also to the amount of dose) and of the detector position.

FLASHDC



The FLASH detector beam counter (FlashDC) is based on the physical principle of air fluorescence of electrons, never exploited before for this application, allowing for an almost constant fluorescence yield (photon production per meter of an electron in air) for a wide range of kinetic energies, (1 MeV-103 MeV, i.e. ≈4-5 photons/m/electron). The first prototype consisted in a volume of 7x7x90 cm^3 of air, enclosed by a thin layer of Teflon sheet, with a PVC supporting structure and two PMTs on the opposite squared faces.

- Advantages: using air as a medium minimizes the impact of the detector on the beam line, preserving the best irradiation conditions for the patient and having a device simple and cheap to produce, with a simple light collection system (photons emitted isotropically) and minimal dependence from the electron energy
- The latest prototype is still an air volume, with smaller dimensions (2x2x60 cm3), with two PMTs on both ends equipped with UV filters, meant for studies on both position and charge sensitivity.
- The response is linear with the beam intensity (values ranging from 70 to 120 mA, thus from 2x1012 to 3x1012 el./pulse). Noise can be successfully subtracted from the signal.
- Background is a sizable portion (~35%) of the total signal. Moreover, the gain of the PMT is still non-optimal for the fluctuations of the signal amplitude.
- The final detector will be able to monitor the instantaneous intensity of typical FLASH pulses making a 2D mapping of the beam with a spatial resolution ≈mm. Monte Carlo simulations will be used to estimate the light output and detection efficiency and finalize the detector layout.



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[1] Trigilio et al. , NIM A 1041 (2022) 167334, DOI: 10.1016/j.nima.2022.167334
[2] Rahman et al., Radiotherapy and Oncology, Volume 175, 2022,Pages 210-221, ISSN 0167-8140,DOI: 10.1016/j.radonc.2022.08.009.