FlashDC project: development of a beam monitor for Flash radiotherapy

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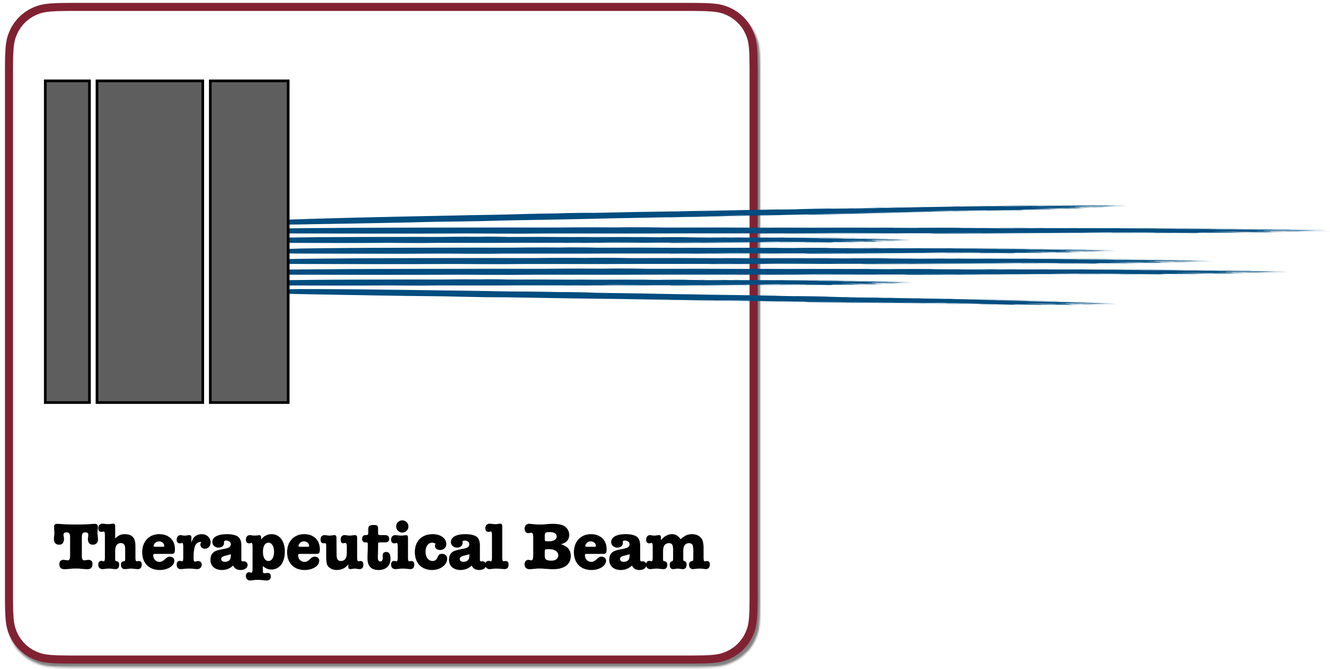
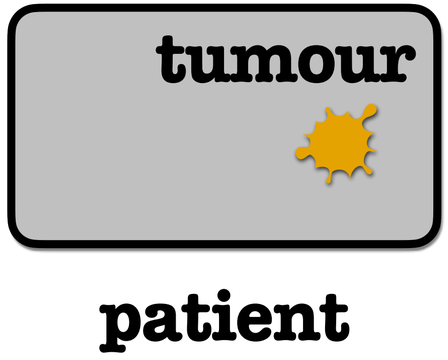
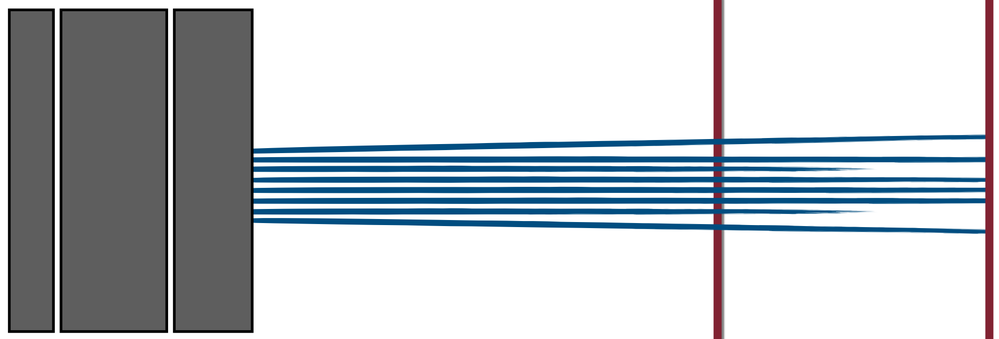
Particle Therapy and Beam Monitoring





Therapeutical beam (photons, electrons and light ions) release energy in the patient (dose) in an optimised way such as the dose distribution maximise the damage on the tumour preserving the healthy tissues. Over the past decades, research in radiotherapy has been focused on the goal to enhance the therapeutic ratio by maximising the tumour control while minimising damage to the healthy tissue.

Particle Therapy and Beam



Therapeutical Beam

Recent advances in RT with electrons with ultra-high dose rate (>40 Gy/s) delivered in a short treatment time (<500 ms) through narrow (order of μs), high dose (~1Gy) pulses, have shown a new potential way to increase the therapeutic ratio, that is a reduction in healthy tissue damage while preserving tumour control.

[1] Wilson JD, Hammond EM, Higgins GS and Petersson K (2020) Ultra-High Dose Rate (FLASH) Radiotherapy: Silver Bullet or Fool's Gold? Front. Oncol. 9:1563. https://doi.org/10.3389/fonc.2019.01563

This new effect has been named FLASH effect.

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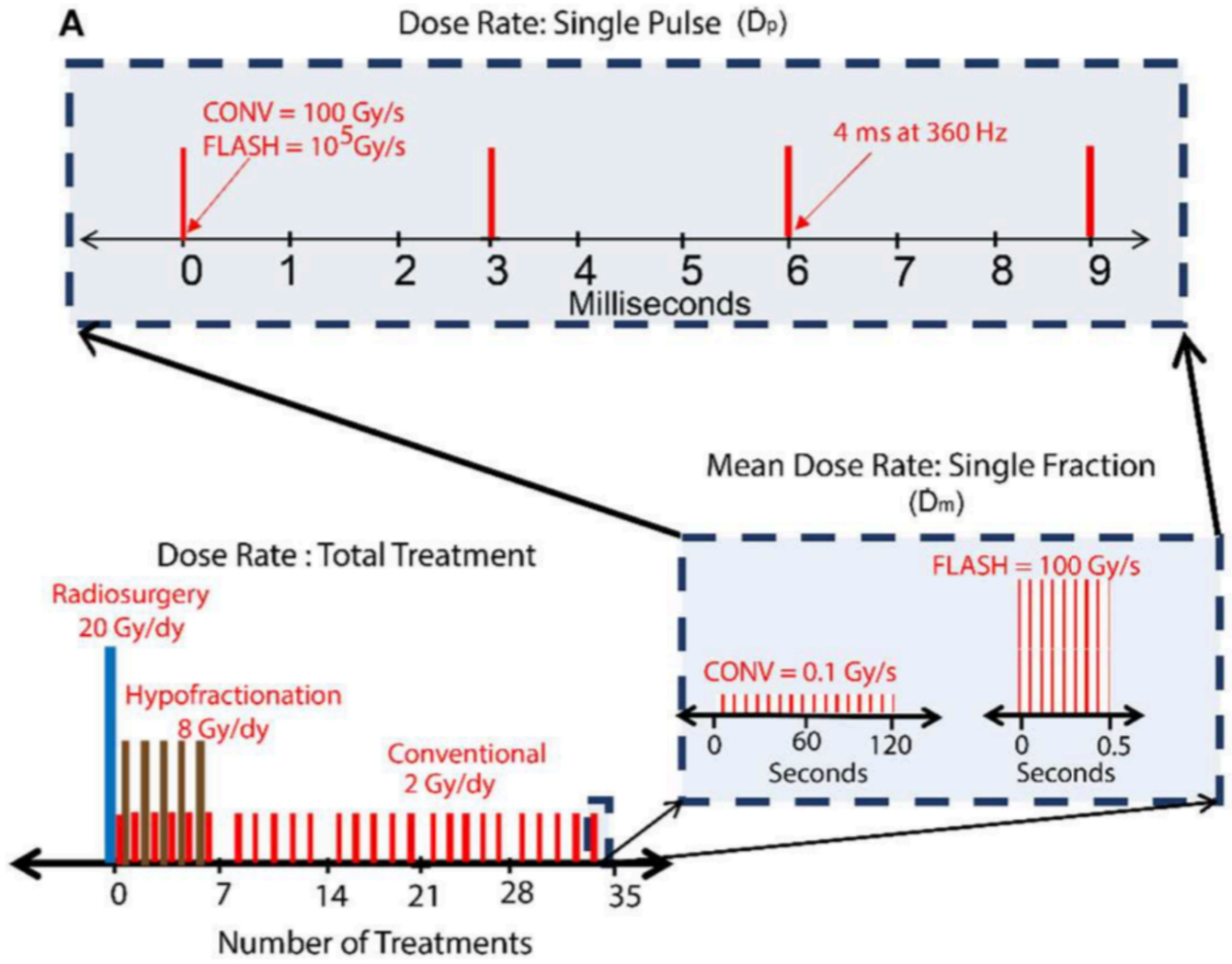
Flash Effect and Beam Monitoring

While the FLASH effect is empirically observed, and from a biological perspective is not yet understood, from a physical point of view it is a phenomenon dependent on a threshold effect on both the average delivered dose-rate and the instantaneous dose-rate. This means that in order to be sure that the observed empirical effect is correlated to such a threshold effect, the number of beam particles per pulse has to be properly measured, real-time, and position-by-position, developing a new beam monitor able to characterise the FLASH beams.

Until now: no available technologies fully meet the needed requirements.

=> FLASH beam monitor able to measure the rate of impinging particles per pulse is urgently needed and a crucial step to validate the FLASH effect.

Crucial Parameters for Beam Monitoring



Studies suggest instantaneous dose rate could play a determining role in FLASH effect

Beam Characteristics	CONV	FLASH
Dose Per Pulse D_p	~0.4 mGy	~1 Gy
Dose Rate: Single Pulse $\dot{D}_p$	~100 Gy/s	~10^5 Gy/s
Mean Dose Rate: Single Fraction $\dot{D}_m$	~0.1 Gy/s	~ 100 Gy/s
Total Treatment Time T	~days/minutes	< 500 ms

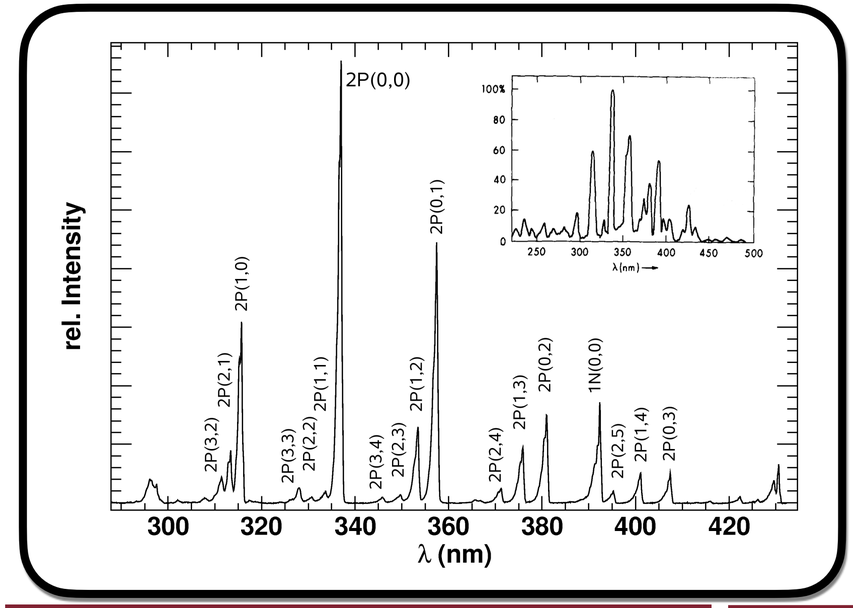
[3] Wilson JD et al, doi:10.3389/fonc.2020.00210)

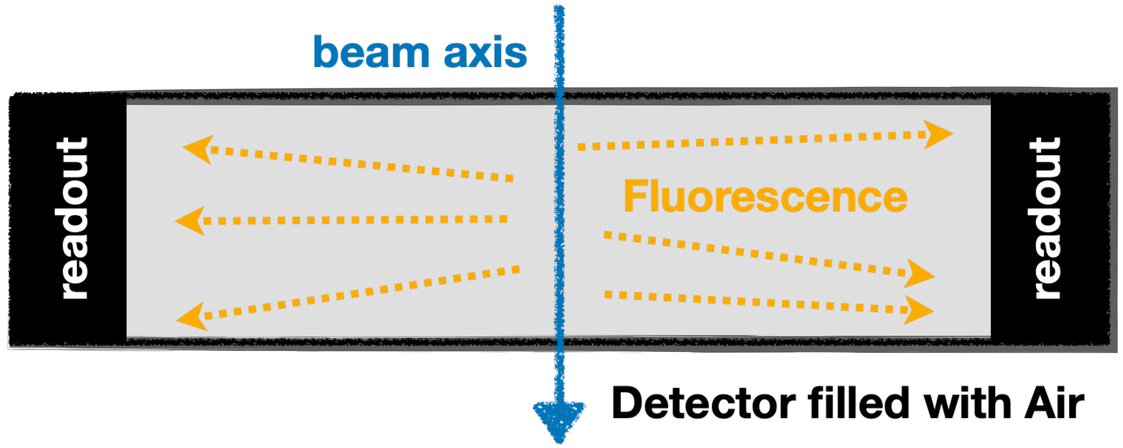
FlashDC

The FlashDC project has the purpose of developing a monitor for FLASH-RT capable at the same time to provide online the number of particles per pulse and beam real-time monitoring with a wide dynamic range able to fit different kinds of FLASH-beams depending on the type of used particle, accelerator and FLASH treatment.

Fluorescence is a form of luminescence

- It is the emission of light from an excited atom or molecule, with a lifetime of the excited state ~ 10^{-8} s
- In air, the fluorescence occurs on the nitrogen molecule and it is excited via electron impact
- An electron crossing air produces about 4ph./m





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Fluorescence

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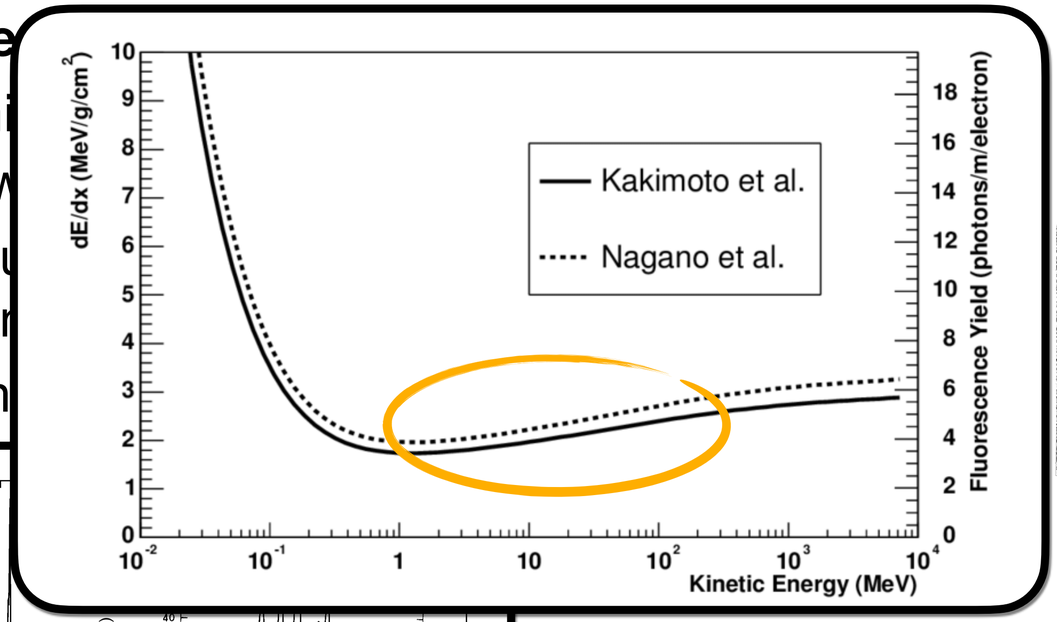
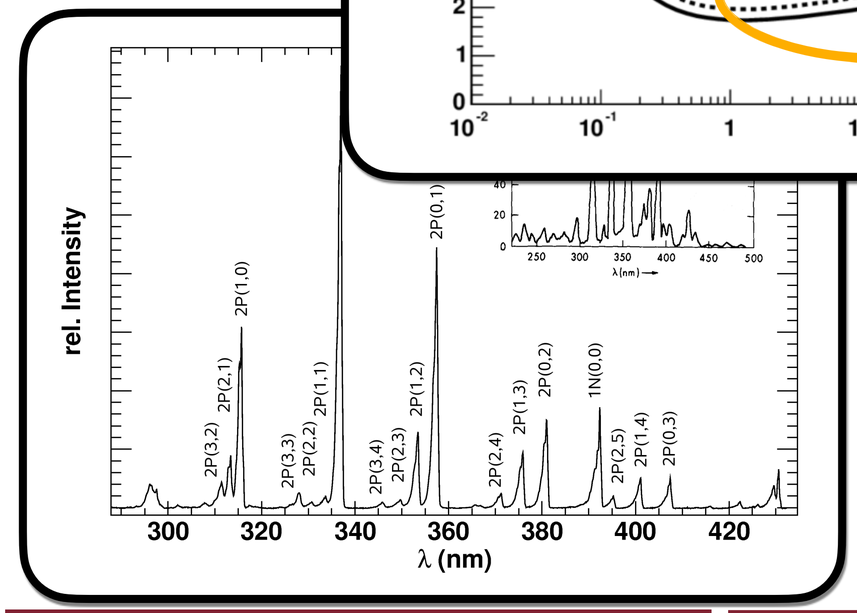
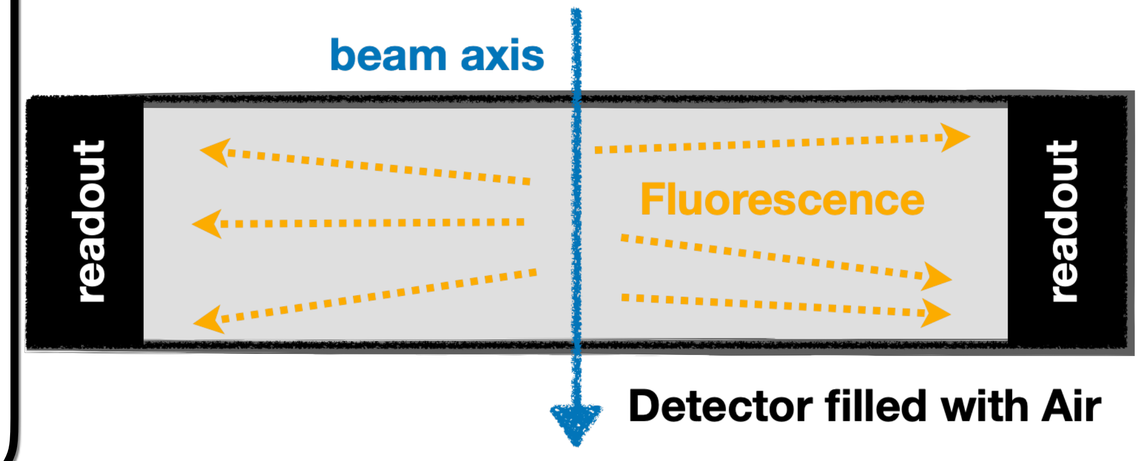
- An electron





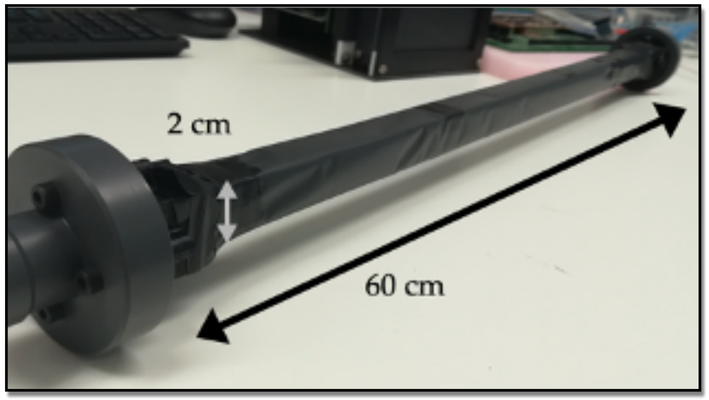


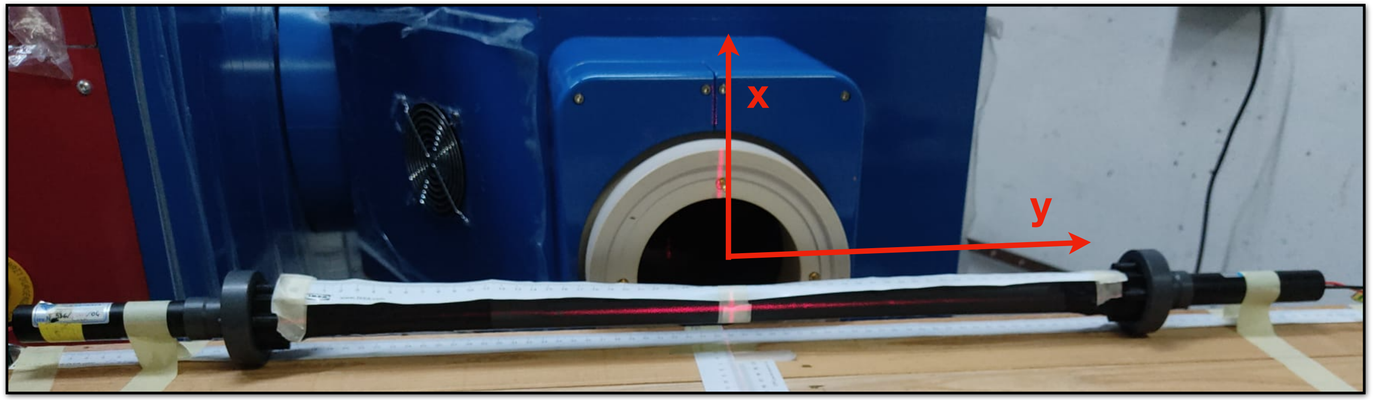
- ☑ **The impact of the detector on the beam line is minimised: about 5μm of Tedlar (PVC)**
- ☑ Fluorescence is almost independent from the beam energy
- ☑ Pressure and temperature dependencies are already present in literature. The detector can be calibrated.

FlashDC

The monitor is based on the physical phenomenon of air fluorescence: this has the great advantage of not depending on an energy threshold and to have a much simpler light collection system due to the isotropically emission of fluorescence light.

Emission of light through fluorescence has typical times of the order of 10^{-8} s, sufficient to unfold typical FLASH pulses of duration of the order of 1-10 μs emitted with repetition rate of the order of 1 Hz-1kHz, giving the chance to develop in this way an object capable of performing pulse by pulse treatment acting as an online beam monitor.





Several prototypes of the monitor have been developed. The one shown in consists of a PVC box 2 x 2 x 60 cm^3 (a tube with a squared section and black walls), filled with air, to be set orthogonally to the beam with light sensors to the two opposite edges. The 60 cm length and the large number of fluorescence photons expected (fluorescence yield ~4 ph/m, with a pulse of 10^{10} particles in the case of electrons) allow to use the comparison of the charge measured at the two monitor edges to reconstruct the beam position.

FlashDC

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Preliminary measurements have been performed at SIT-Sordina (Aprilia, Italy) with LIAC and Electron Flash.

- ☑ **Test of the detector response as a function of position (x, y) and intensity (current). The results are promising.**
- ☑ **Updated prototypes (with optimised geometry and readout) and more accurate measurements are planned for 2022.**

FlashDC

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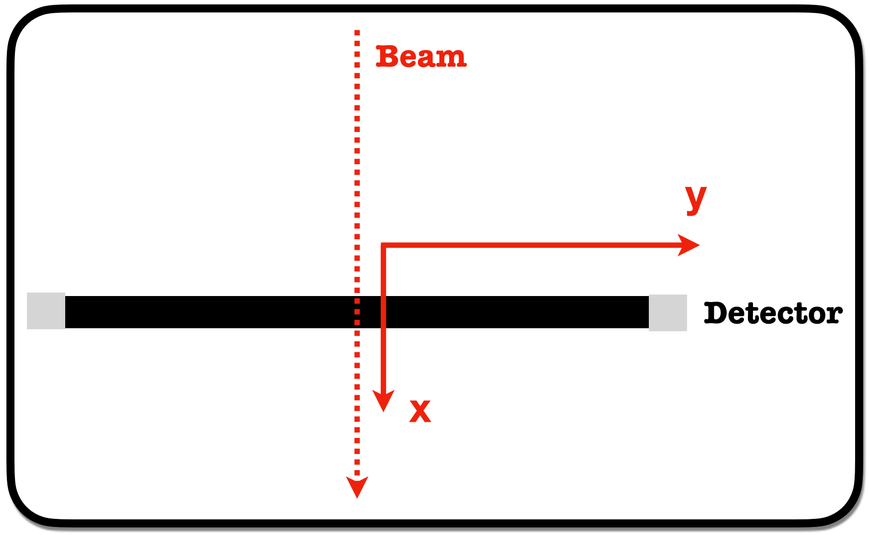
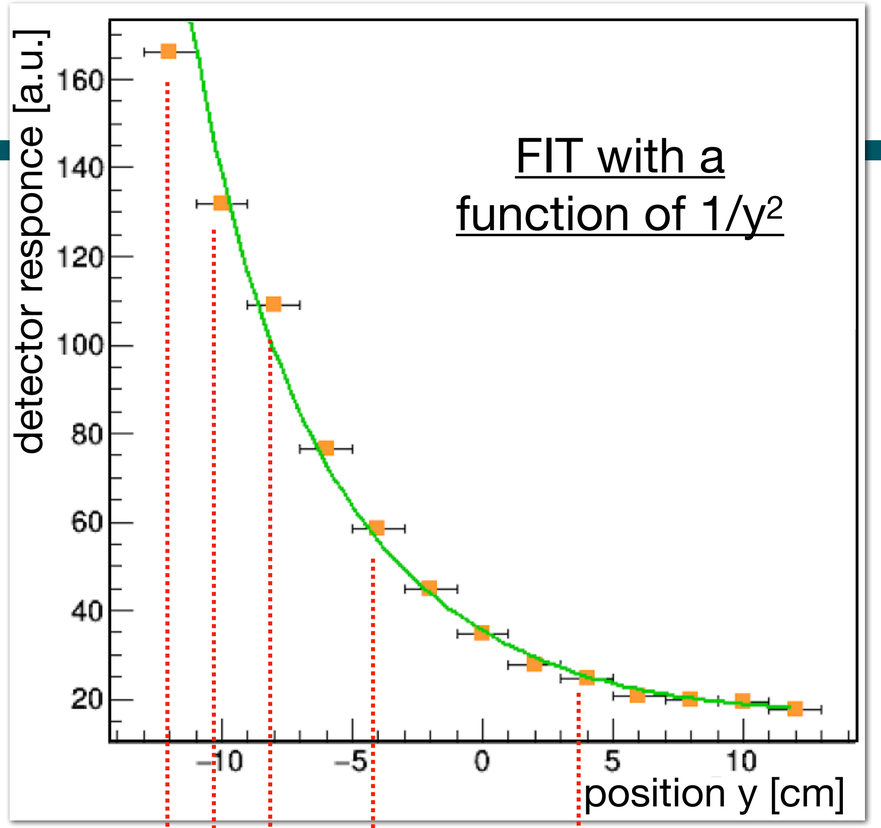
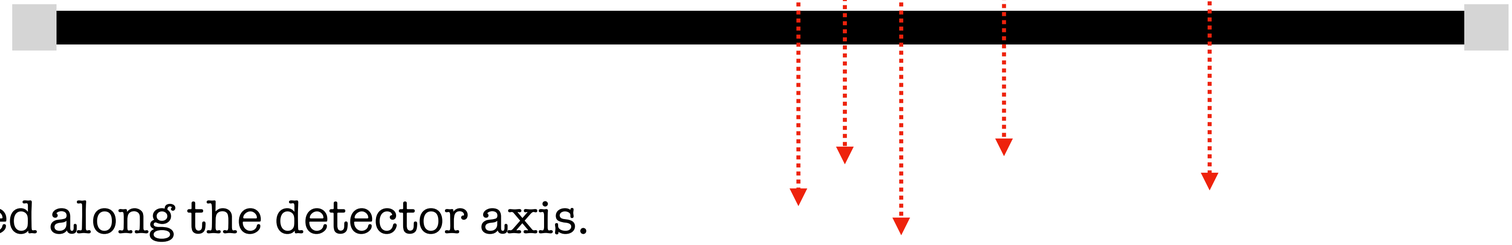
- ☑ **Test of the detector response as a function of position (x, y)**







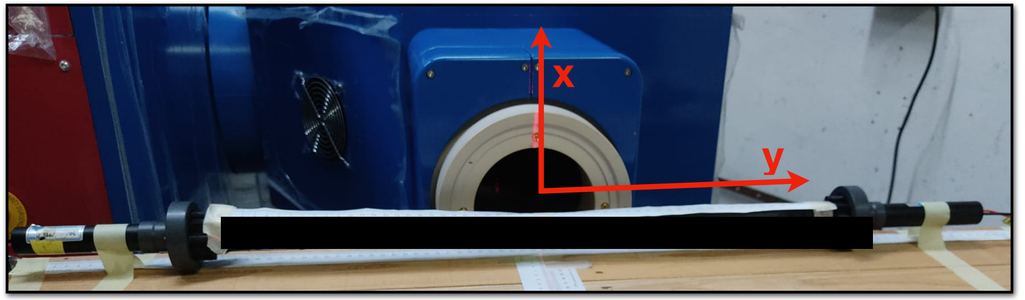
The beam entrance has been moved along the detector axis.
The response is function of the solid angle, as expected.

SIT - LIAC Accelerators at 6 MeV

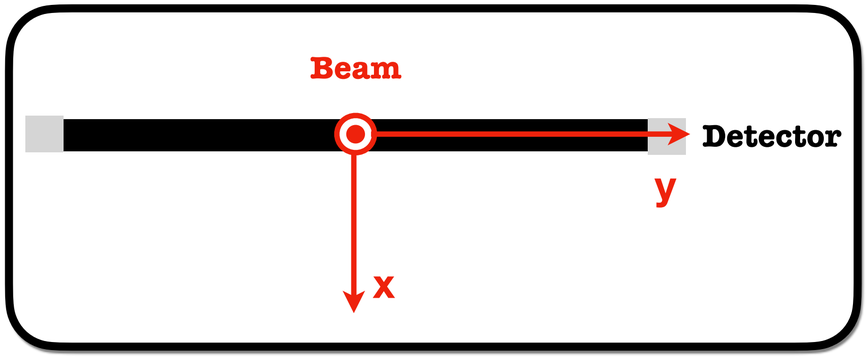
FlashDC

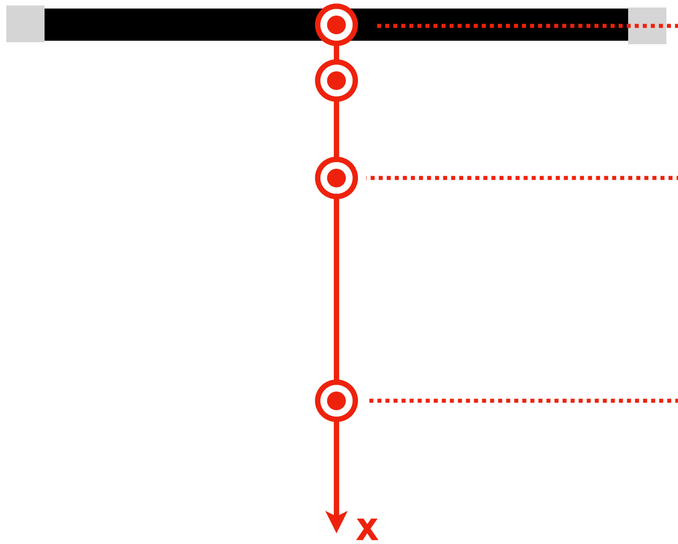
ElectronFlash of SIT at 7 MeV

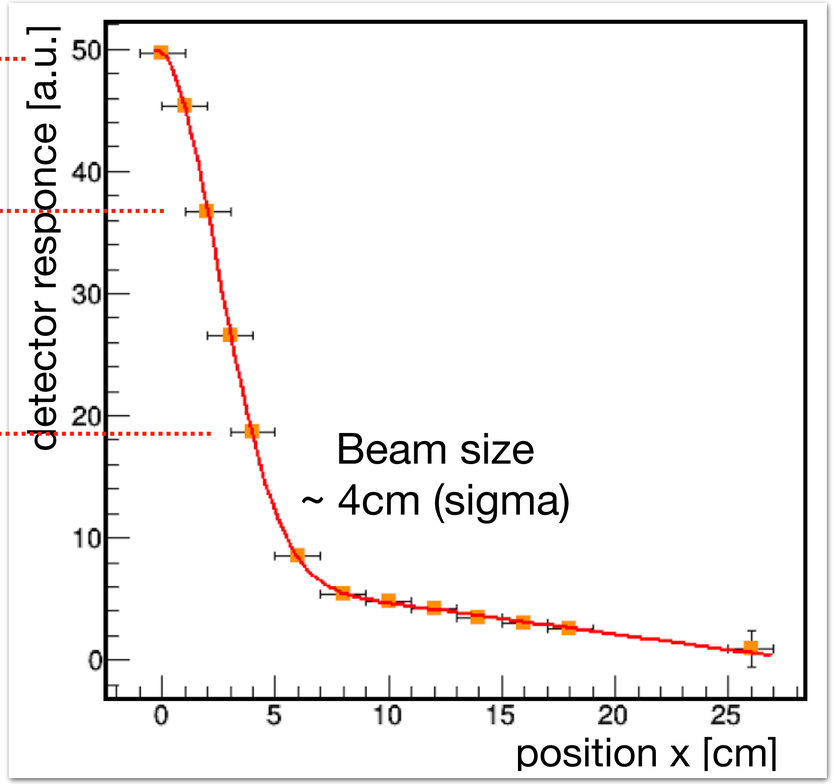
Preliminary measurements have been performed at SIT-Sordina (Aprilia, Italy) with LIAC and Electron Flash.



☑ **Test of the detector response as a function of position (x, y)**







The detector has been moved in and out off beam and the beam shape has been correctly reconstructed

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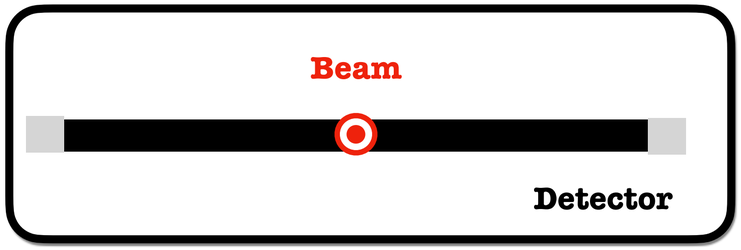
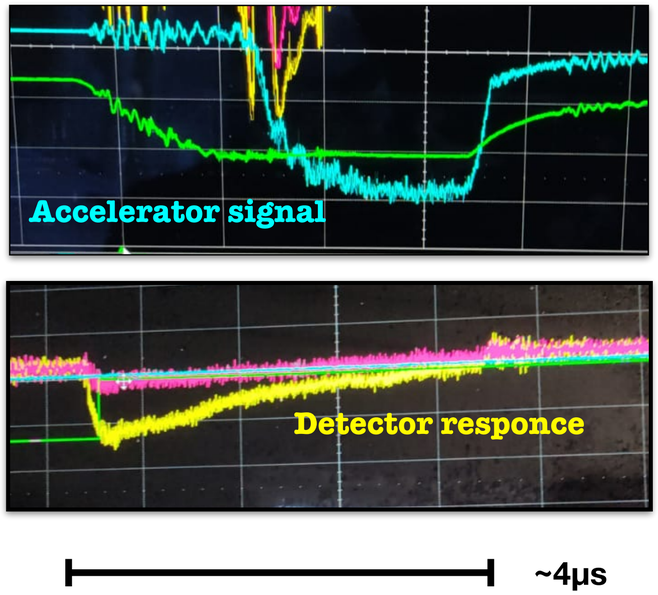
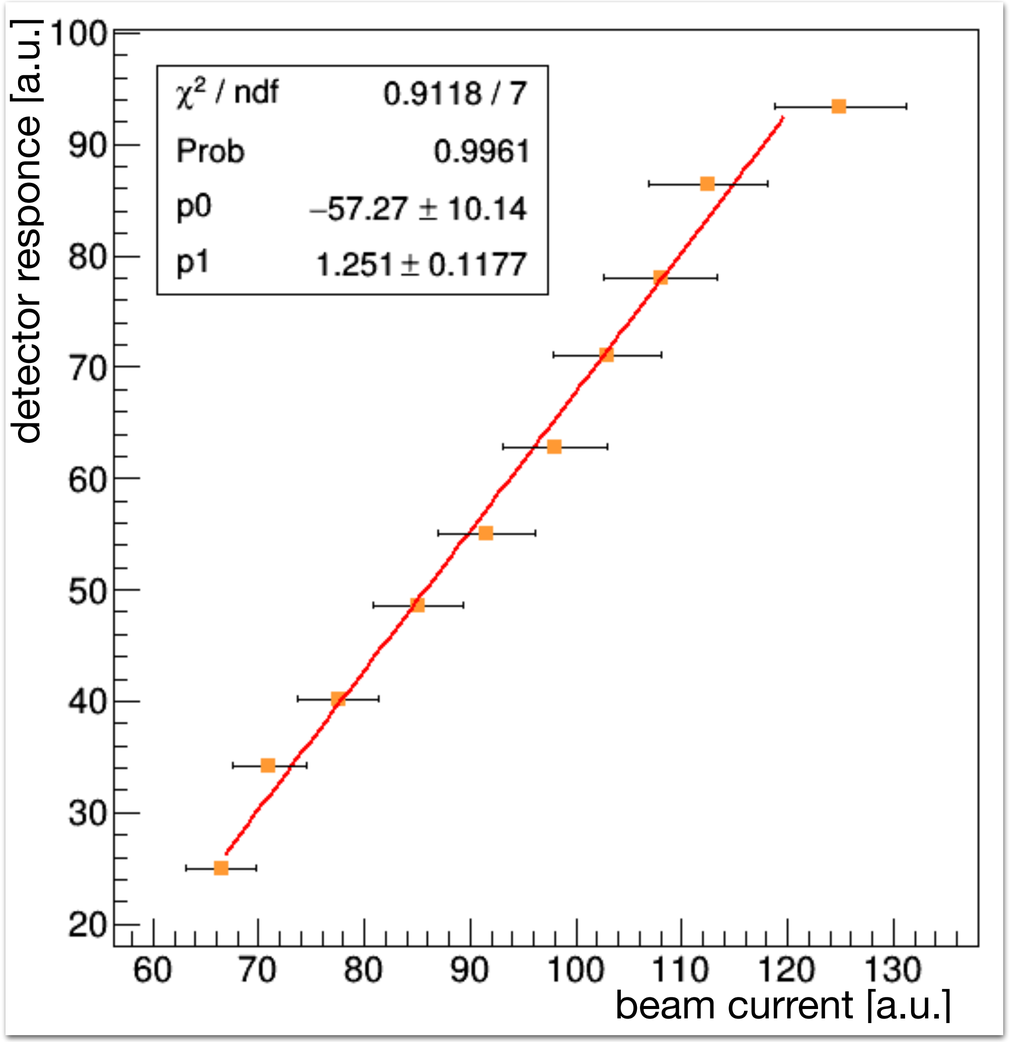
- ☑ **Test of the detector response as a function of position (x, y) and intensity (current). The results are promising.**







The response has been studied as a function of the current

CONCLUSIONS

- Electron fluorescence in air has been proposed as detection technique for Monitor detector for Flash therapeutical Beams
- A set of preliminary measurements with flash electrons beams and the obtained results have demonstrated that such a monitor can fulfill the required performances.
- With the help of a FLUKA MC simulation, a model of the detection technique has been performed.
- Introducing the measured parameters in this model we will able to optimise the geometry and the optical readout system of the monitor in order to project the final device.
- In this contribution the measurements, the results with the monitor prototype have been presented.