Tomographic dosimetry for small field QA based on the LHCb SciFi detector:
principle, implementation and results

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On the behalf of QASys project consortium (INL, HCL, TIMC, CREATIS, EPFL)
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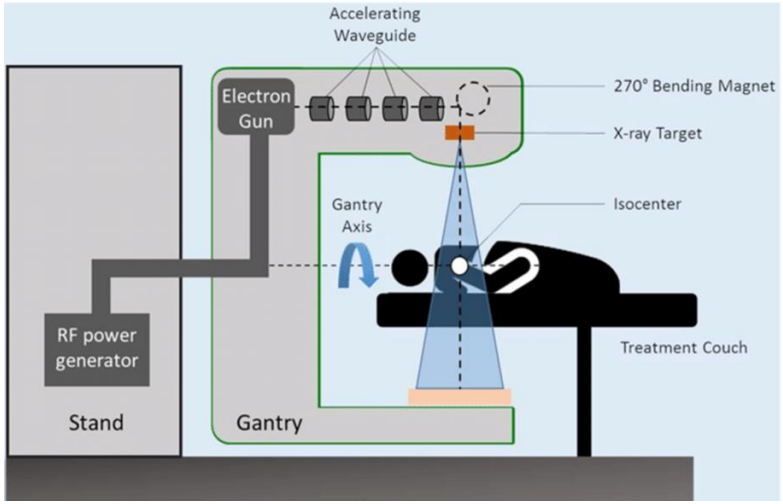
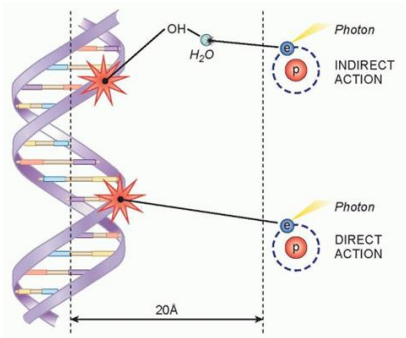
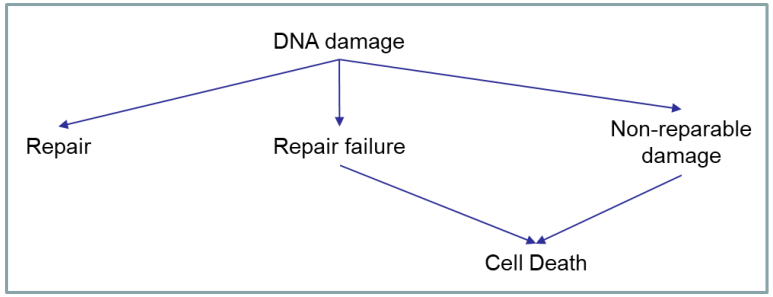
External Beam Radiotherapy:

- ✓ one of the main types of cancer treatment.
- ✓ ionizing radiation used to destroy cancer cells and limit their growth.







Treatment: *Absorbed dose - DNA damage (direct/indirect) without repair or with repair failure*

Efficiency: *RBE – PTV*

Safety: *Acceptable dose on healthy tissues (OAR)*

External Beam Radiotherapy QA:

Motorized 3D water phantom equipped with IC or diodes system for dose distribution measurement

Delta4 phantom instrumented with 4040 diodes (5mm resolution at isocenter)

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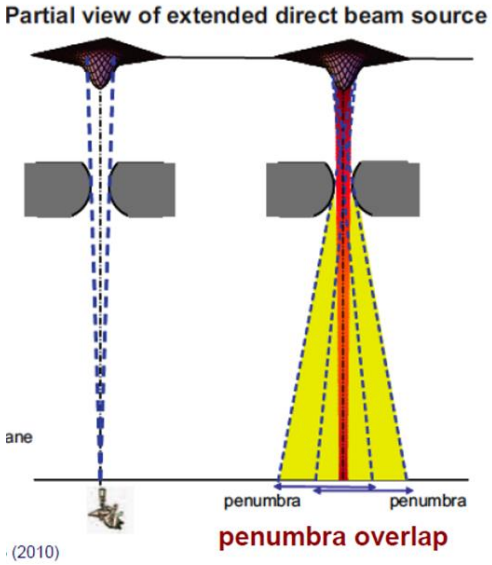
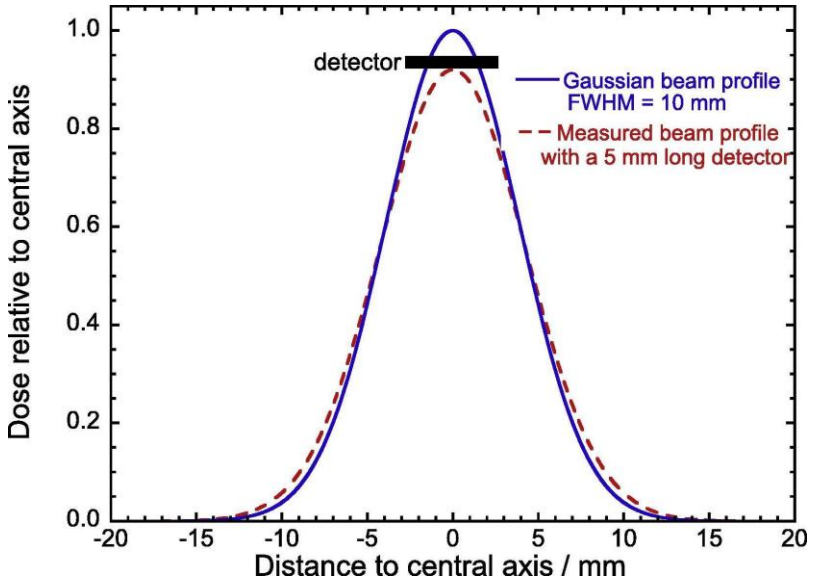
But small field QA remains challenging

Small field QA issues:





Palmans et al. "Dosimetry of small static fields used in external photon beam radiotherapy: Summary of TRS-483, the IAEA-AAPM international Code of Practice for reference and relative dose determination." Medical physics vol. 45,11 (2018)

1. **Energy spectrum variations** between penumbra and in-field regions
2. **Steep dose gradients** (placement errors of point detectors, volume average effect)

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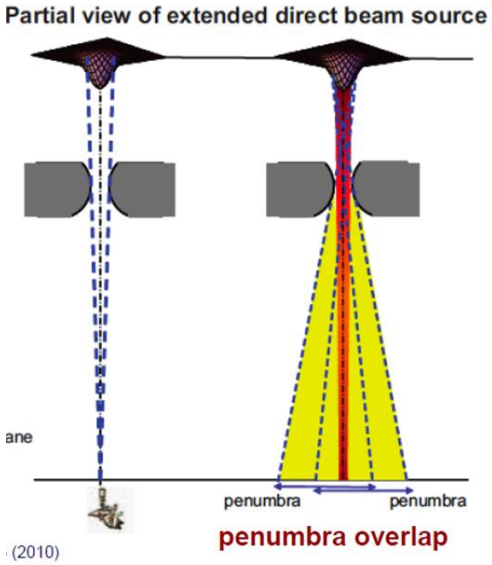

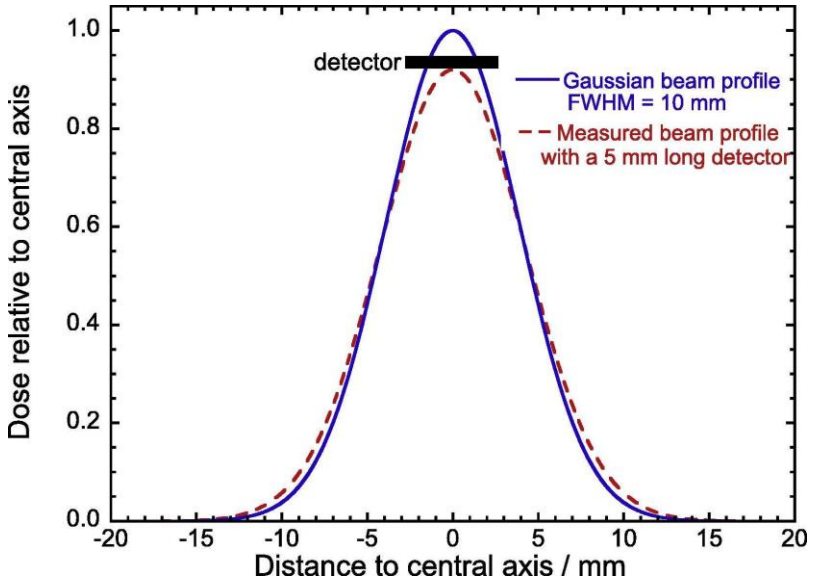

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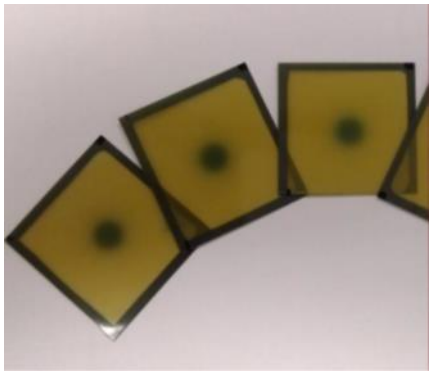
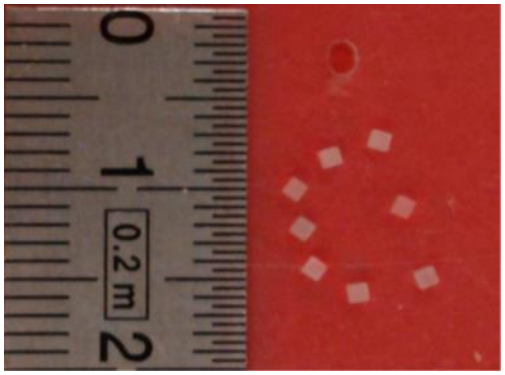
2. **Steep dose gradients** (placement errors of point detectors, volume average effect)

Small field QA requires small size (sub-millimeter) and tissue equivalent detector

Film-based and TLD–based methods [Bassinet et al. *Med. Phys., 2013*]

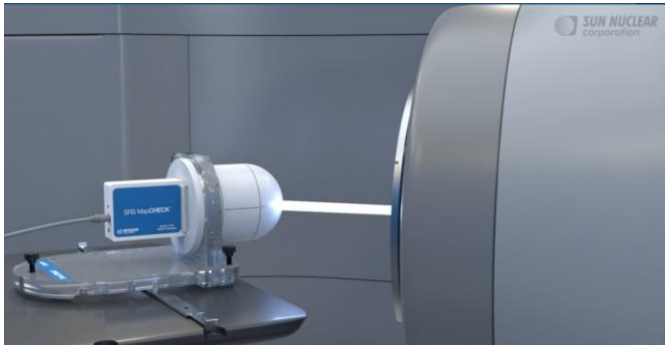


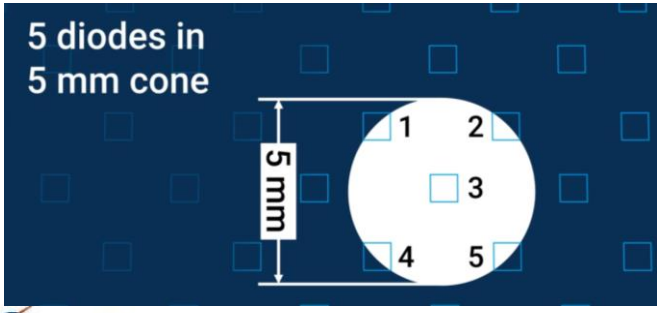


IRSN protocol (standard in France) : EBT3 radiochromic film + 1mm² Thermoluminescent Dosimeters
Institute for Radiological Protection and Nuclear Safety (IRSN) – Rapport N° PSE-SANTE/SDOS/2018-00035 -

Suitable for commissioning but not for daily QA procedures (time consuming and not real time).

Filmless patient QA based on diodes array





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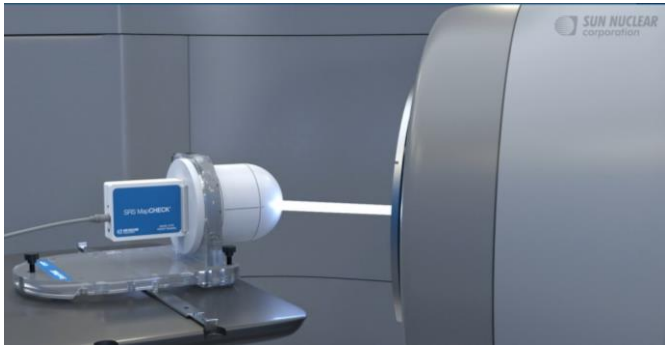
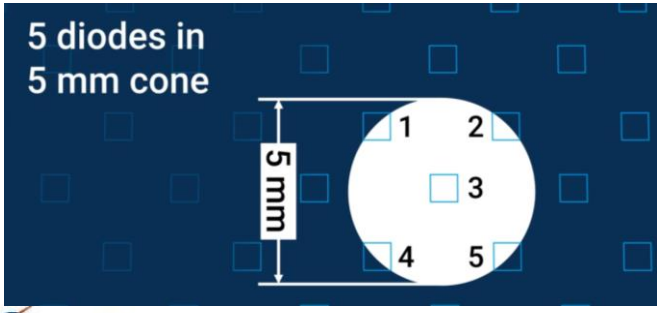
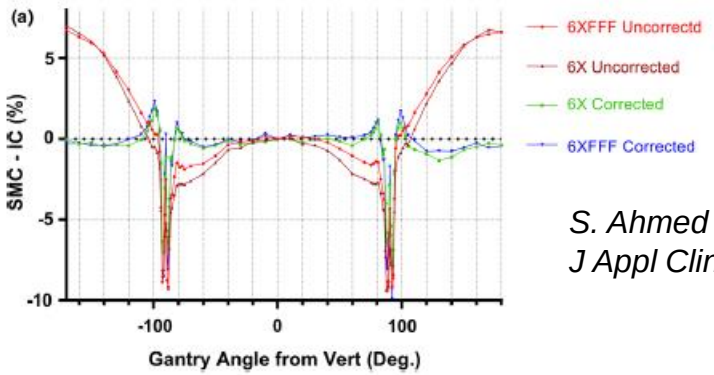




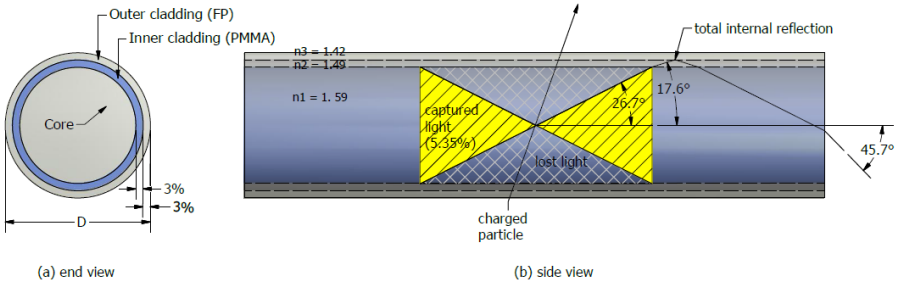
Diodes are not tissue equivalent (Z_{si}=14):

- 😐 compensation factor
- 😐 Limited resolution (spacing of 2.47mm)
- 😐 Angular dependence



S. Ahmed et al.
J Appl Clin Med Phys 2019

Plastic scintillating fiber



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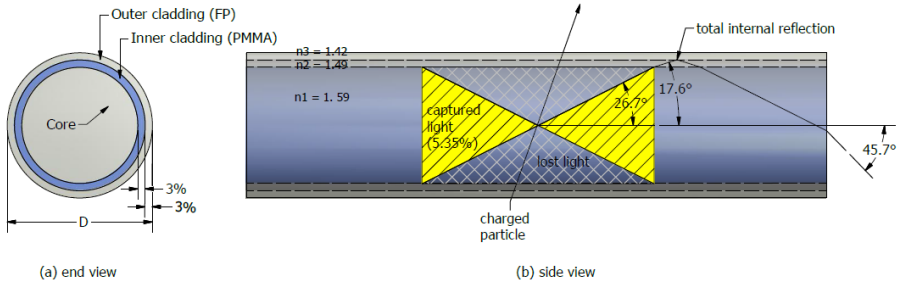
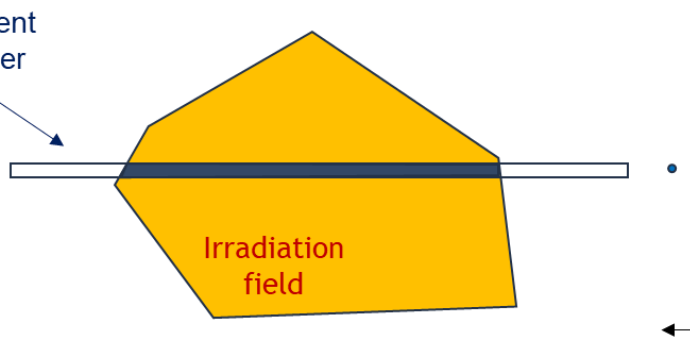


tissue-equivalent scintillating fiber



Signal is proportional to the dose integrated over the irradiated segment of fiber

Goulet M et al., " High resolution 2D dose measurement device based on a few long scintillating fibers and tomographic reconstruction", Med Phys. 2012

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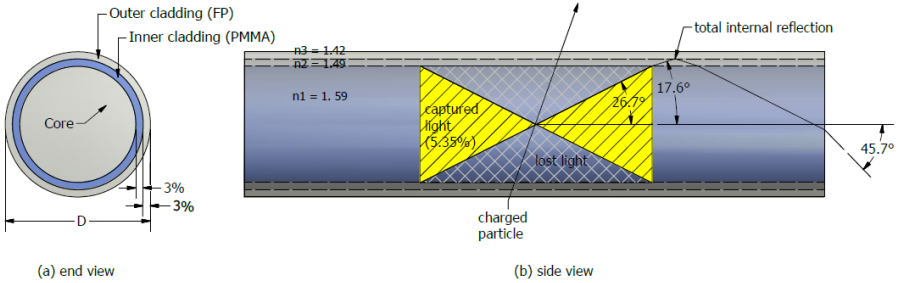

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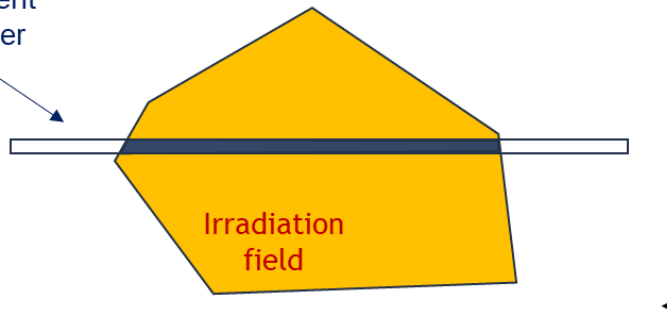

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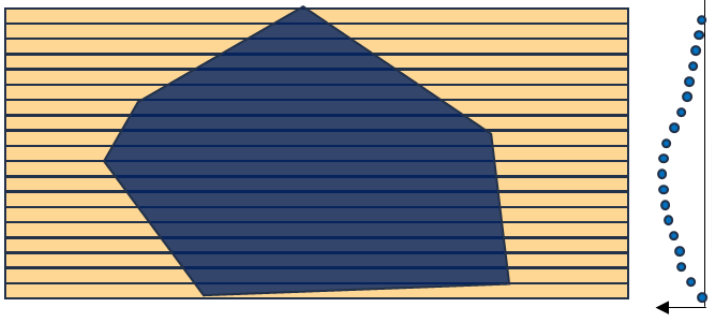
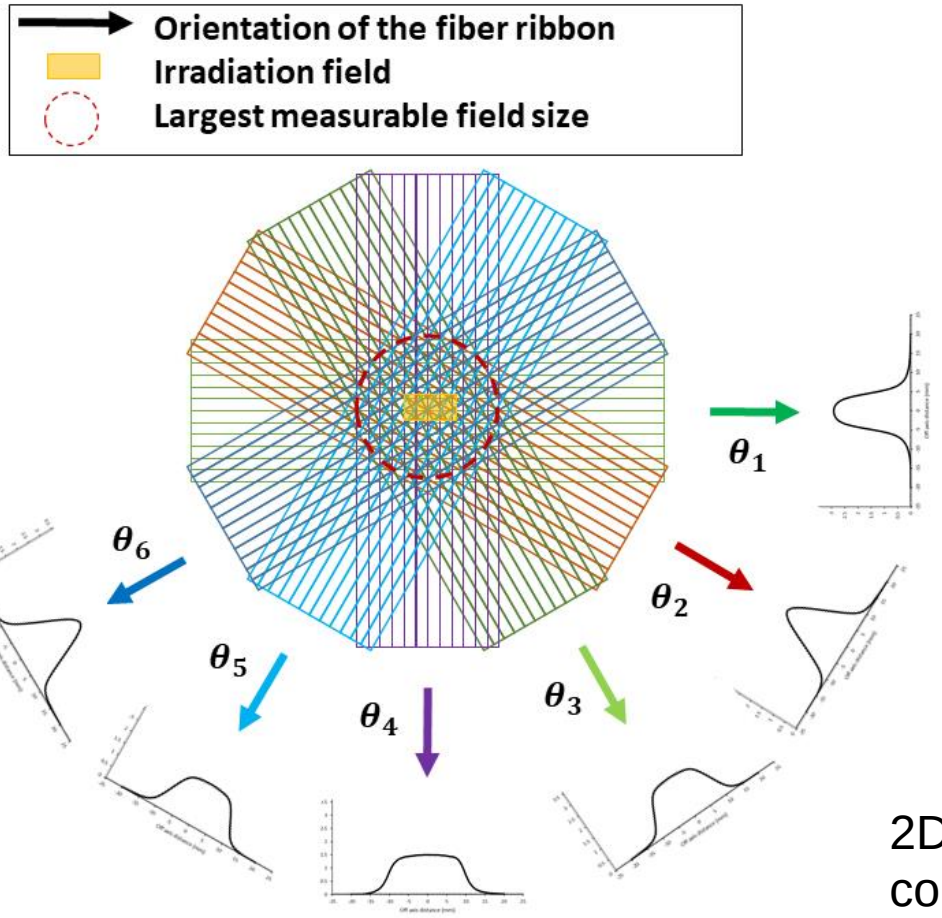
tissue-equivalent scintillating fiber ribbon

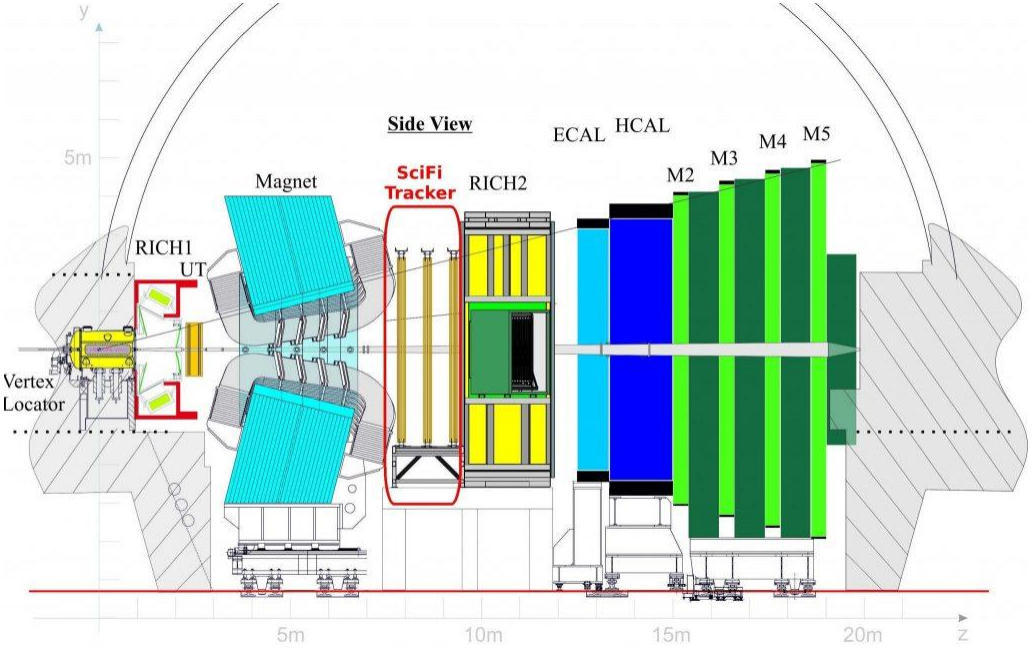


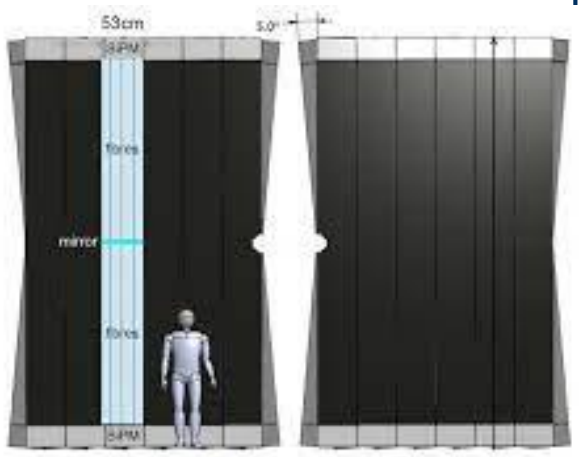
Signal at ribbon output gives the projected profile of the irradiation field



2D dose cartography can be computed from the projected view of the radiation field by tomography

SciFi tracker for LHCb experiment implements 250µm fiber ribbons…





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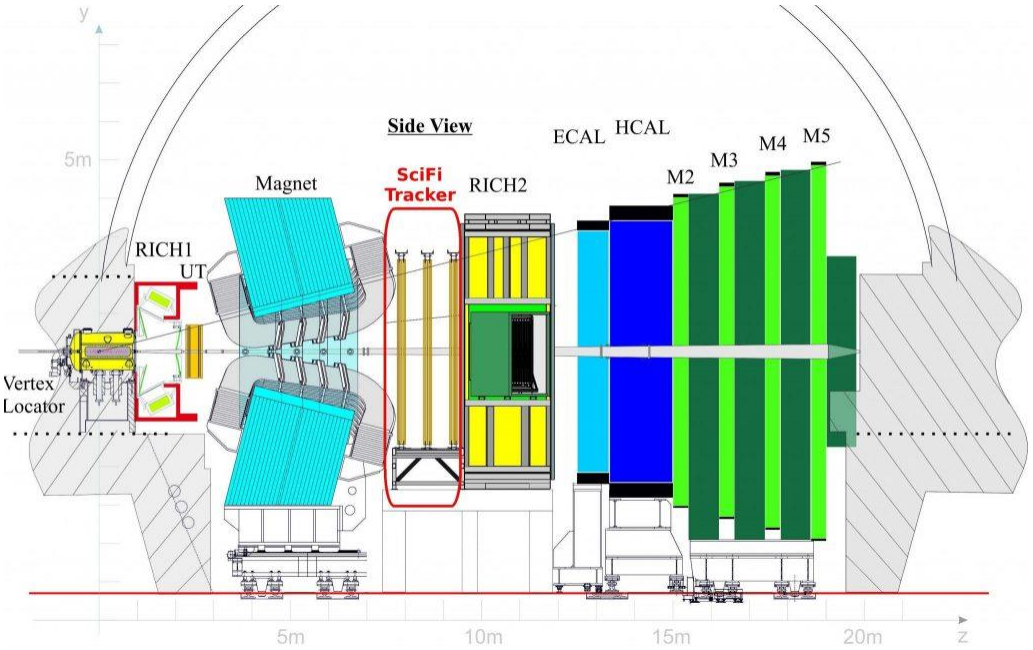
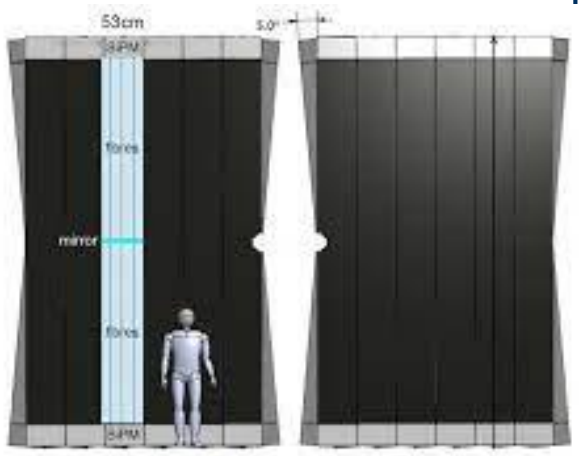
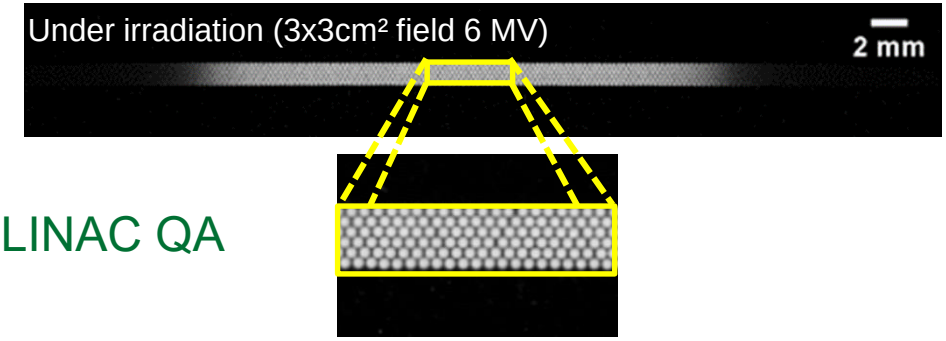
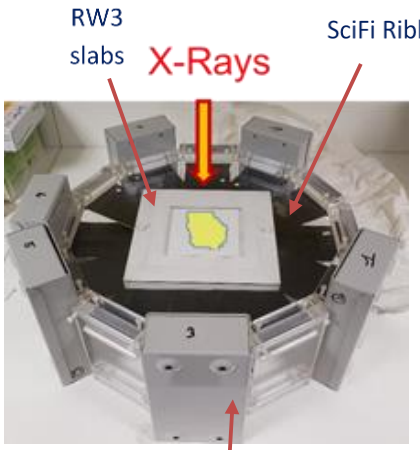
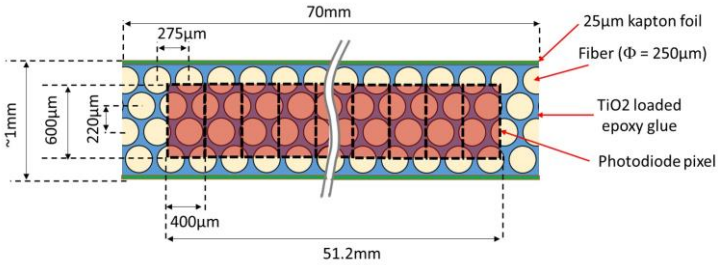






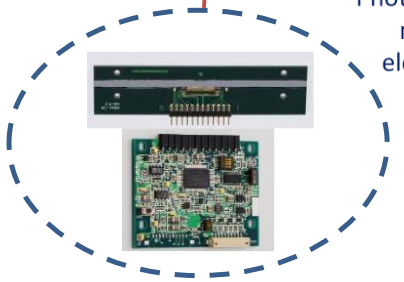
…which can also be used as detector for LINAC QA



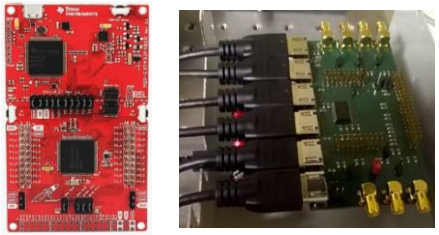


Cross-section of the SciFi ribbon showing the 250 µm scintillating fibers arrangement and the coupling with the photodiode array

b)

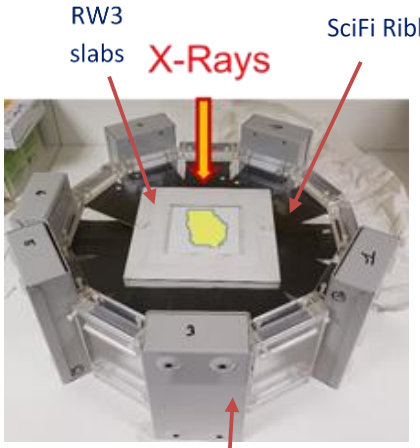


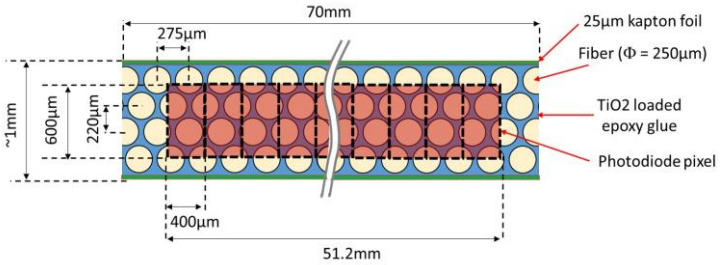
a)



Acquisition module electronics MSP432P401R board with its daughter board for photodetection module interfacing

c)





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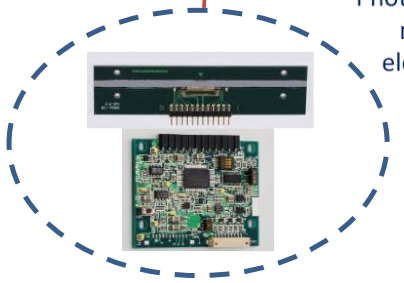

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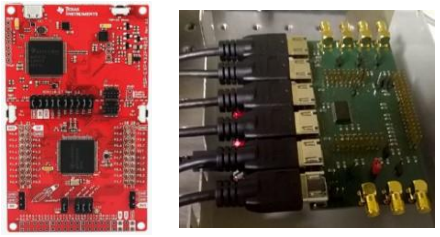


Acquisition module electronics MSP432P401R board with its daughter board for photodetection module interfacing

c)

Number of tissue-equivalent scintillating ribbons	6 (rotated increment of 30°)
Number of scintillating fibers	~6000 (6x1000)
Lateral resolution (pixel pitch of the photodiode arrays)	400 µm
Number of photodetection channels	768 (6x128)
Maximum field size	42 mm in diameter
Detector depth in RW3	1.4 cm

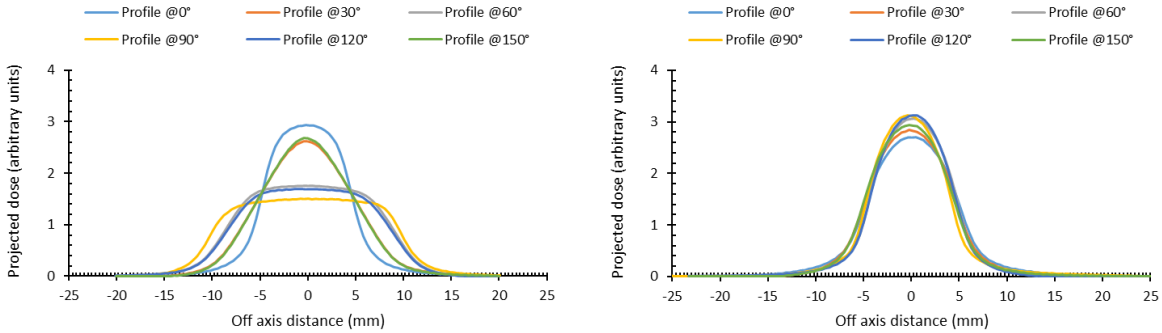
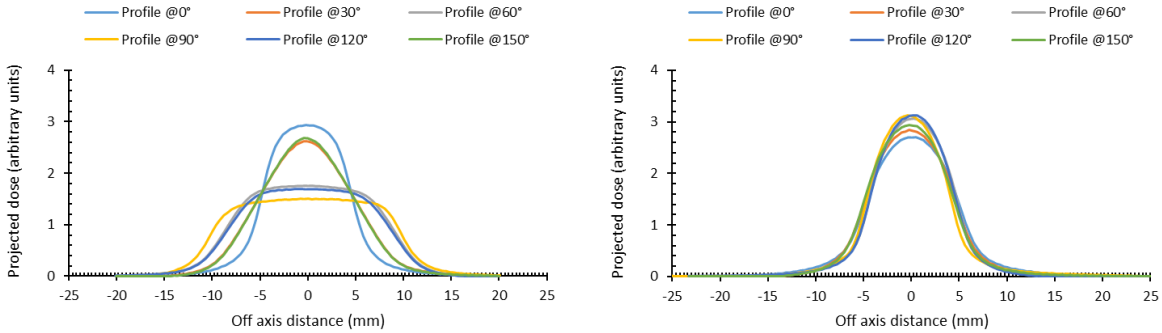


FIG. 7: Measured profiles for a) the 20x10 mm² rectangular and b) the elliptic fields, respectively.

Measurements were carried out at high SNR (in the range [44dB-66dB]) within 2s



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Field profiles are reconstructed with submillimeter resolution

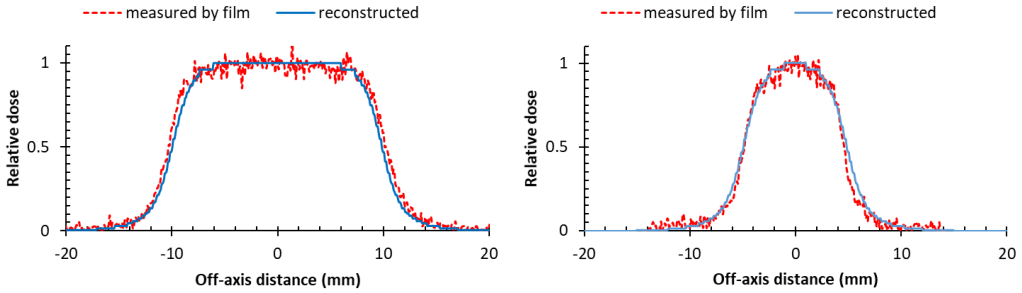

FIG. 10: Dose profile of the 20x10 mm² field obtained by 2-step method reconstruction and EBT3-film measurements: a) X-axis dose profile and b) Y-axis one .

Esteves et al., Med. Phys. (submitted)

Accuracy and resolution of 2D dose cartography are evaluated in terms of gamma index which quantifies **the difference between measured and reference dose distributions on a point-by-point basis** in terms of both **dose and distance to agreement (DTA) differences**. For any measured position P_i, it is defined as:

$$\gamma(P_i) = \min_k \left(\sqrt{\frac{\left|D_i - D_{ref,k}\right|^2}{\Delta D^2} + \frac{\left|P_i - P_{ref,k}\right|^2}{DTA^2}} \right)$$

where ΔD is the accuracy uncertainty (Dose difference) and DTA, the resolution (Distance to Agreement). The min value is searched over all the points available in the reference dose distribution.

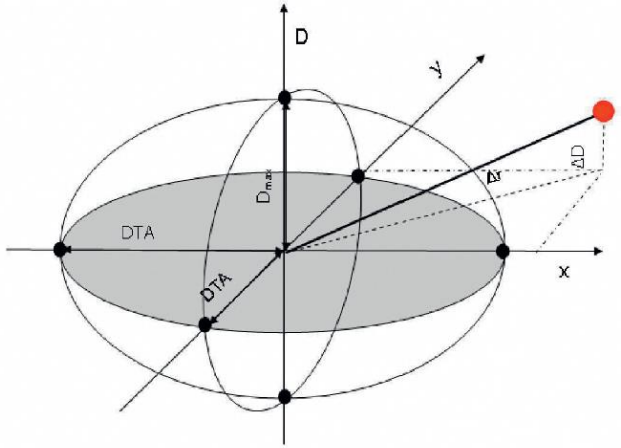

Fig. 3. The concept of gamma verification [5]: x, y, D – spatial and dose dimensions; DTA – distance-to-agreement; D_{max} – max dose deviation; Δr, ΔD – local spatial and dose divergence of the analyzed point

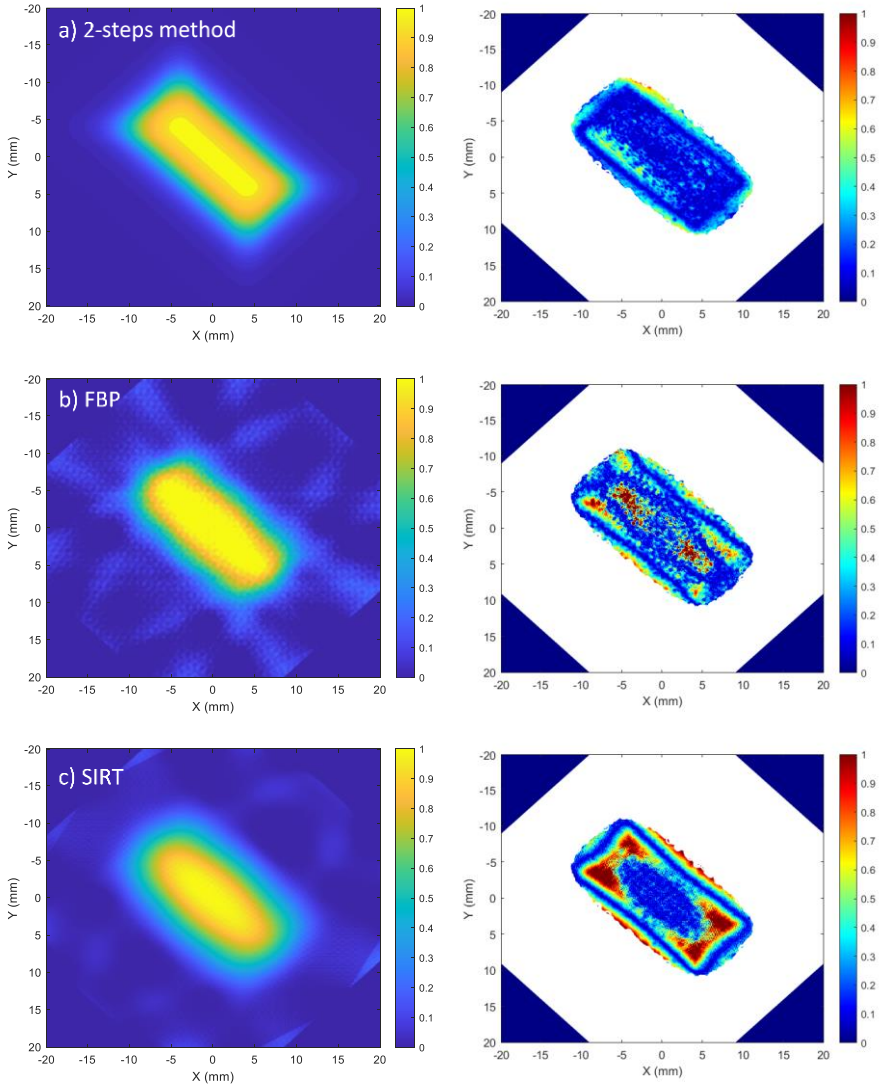

FIG. 9: Dose distributions and 1% DD/1 mm DTA gamma index cartographies obtained with the a) 2-step, b) FBP and c) SIRT reconstruction methods for the 20x10 mm² field.

Esteves et al., Med. Phys. (submitted)

Gamma index analysis for 1% dose-difference of and 1mm distance to agreement

Field	Collimator orientation	2-Step Method	FBP	SIRT
20x10 mm²	0°	99.9	98.2	95.9
	45°	99.8	97.5	92.5
10x10 mm²	0°	99.9	99.4	97.0
	45°	99.6	99.8	97.4
10mm Elliptical field	0°	99.9	96.9	84.9
	45°	99.9	99.0	86.5
Cone 5 mm	0°	99.8	93.4	65.6

- ✓ The system can be used for stereotactic cone radiosurgery (SRS) QA as well as for machine QA.
- ✓ We are currently working on IMRT segment reconstruction to use our system for patient-specific QA.

Thank you for your attention

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P. Jalade, J. Ribouton

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