



UNIVERSITÀ DEGLI STUDI DI MILANO  
DIPARTIMENTO DI FISICA

# Recent progresses in scintillating optical fiber dosimeters

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CONGRESSO DEL DIPARTIMENTO DI FISICA



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# Main partners of the research

## Scientific collaboration involving:



Department of Physics



Department of Materials Science  
Prof. Anna Vedda and colleagues



Department of Medical Physics



# Background

## Dosimetry needs in the modern X-rays radiation therapy

New irradiation technologies with some common features:

- beam modulation (i.e. Volumetric Modulated Arc Therapy, VMAT)
- small fields (Stereotactic Body Radiation Therapy - SBRT)
- dose conformation → dose escalation + hypofractionation

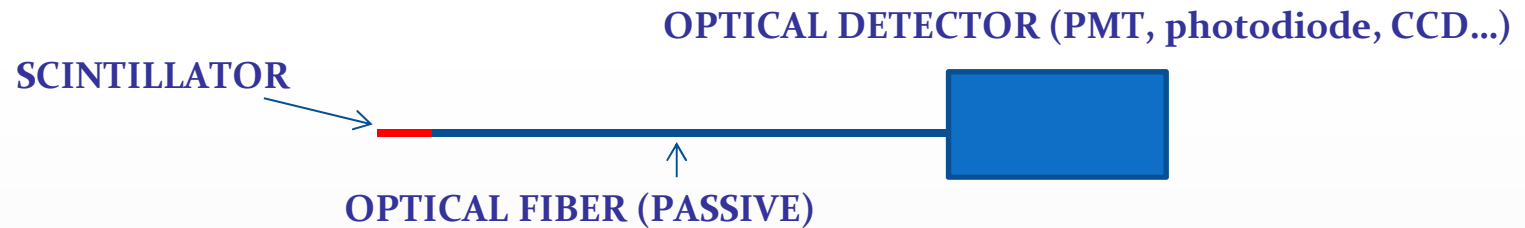
New needs in dosimetry for:

- Commissioning of the innovative machines
- QC of the radiation beams
- QA of the individual treatment plan in phantoms (check of the dose distribution)
- In-vivo dosimetry



# Background

## Scintillating optical fiber dosimeter



Advantages:

- small dimensions (point measurement, small field dosimetry)
- real time measurement of the dose/dose rate
- do not need HV (in-vivo dosimetry)
- unaffected by magnetic fields (ideal for the new Hibrid MRI-LINAC systems)

Major Challenge:

- Stem effect (Cerenkov light and scintillation of the passive fiber)

**Cerenkov light generated in optical fibres and other light pipes irradiated by electron beams**

Phys. Med. Biol., 1992, Vol. 37, No 4, 925-935.

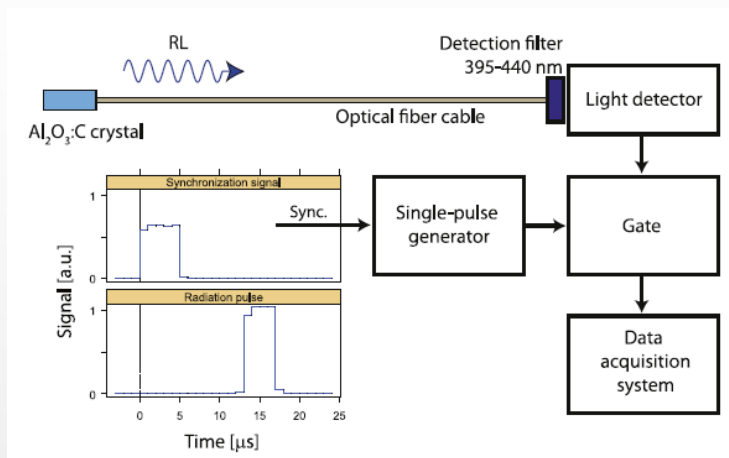
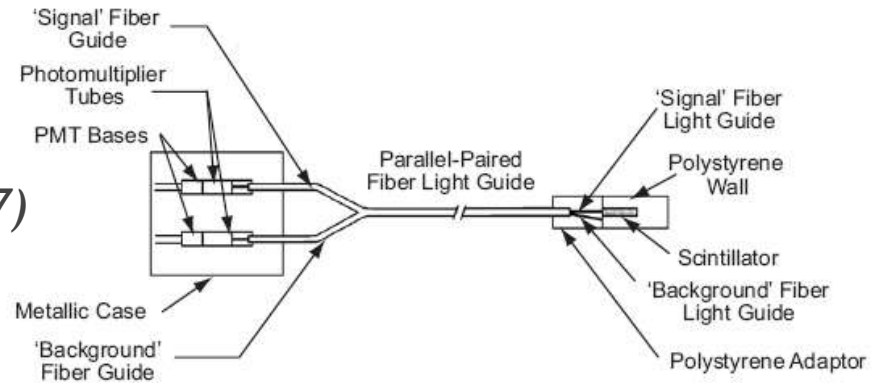
**1992** A S Beddar†, T R Mackie and F H Attix  
Department of Medical Physics, University of Wisconsin Medical School, Madison,  
WI 53706, USA

...~20 years later

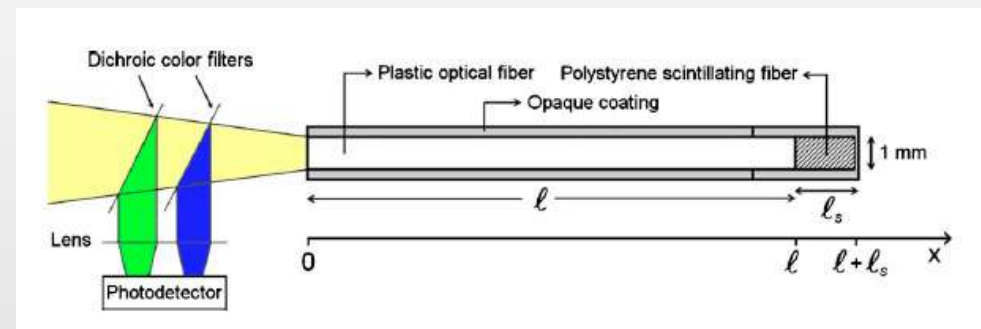


# The Stem Effect

- **Second (reference) fibre**  
(Beddar, *Radiat. Meas.* 41, 2007)



- **Temporal gating**  
(Andersen et al. *Radiat. Meas.* 46, 2011)



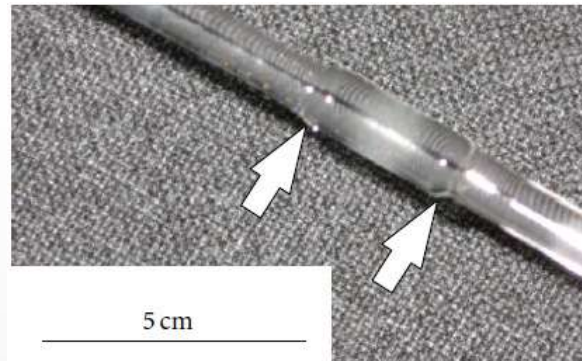
- **Spectral method**  
(Guillot et al. *Med. Phys.* 38, 2011)

Research of a scintillator free from any spectral superposition with the stem effect



# Rare earth-doped silica optical fibers

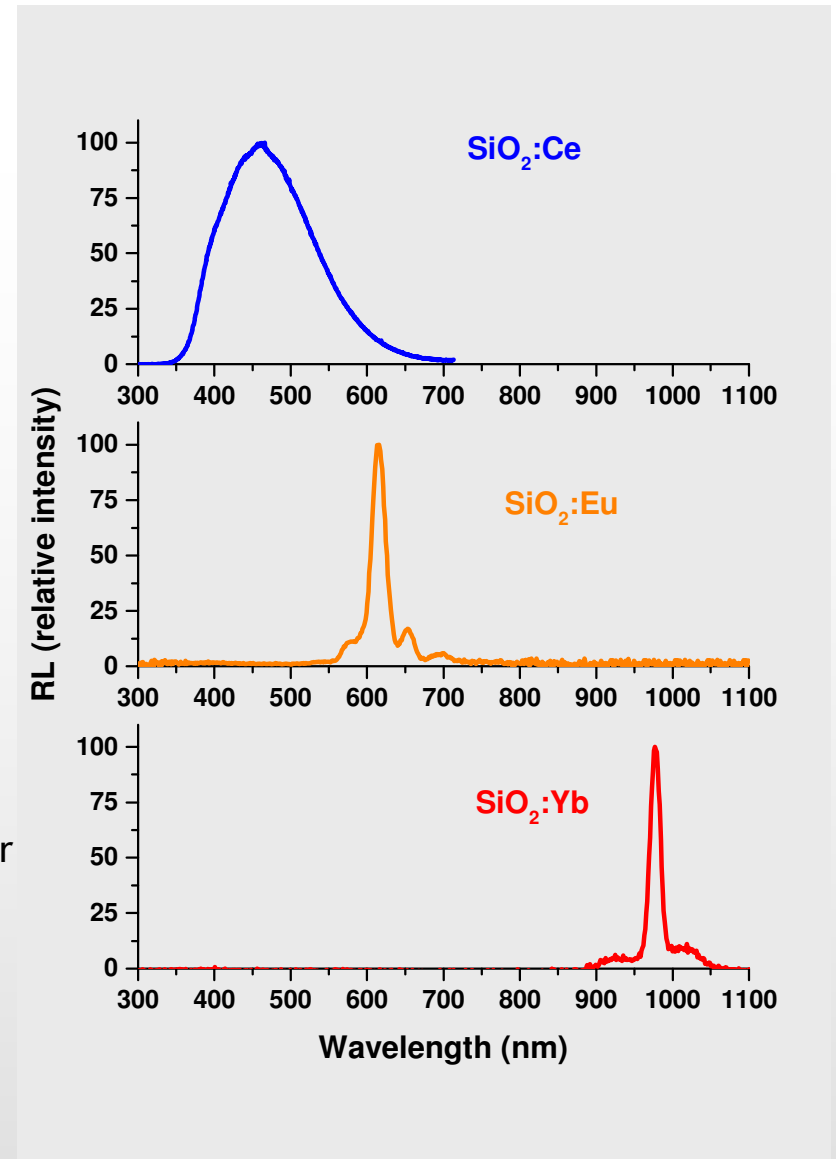
SOL-GEL + «rod in tube» method



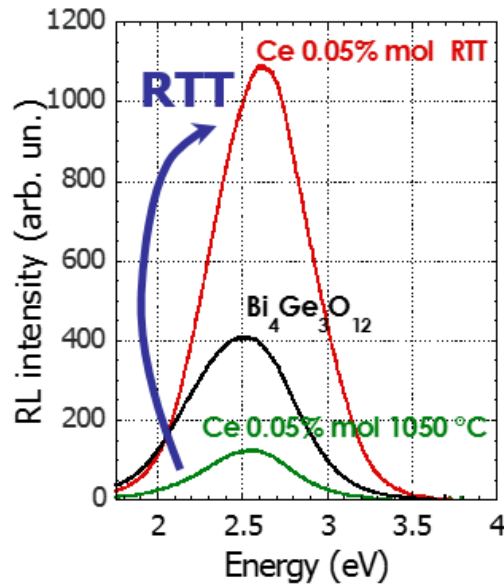
$\mu$  -ionization chamber  
Doped fibre Diode



Stereotactic collimator

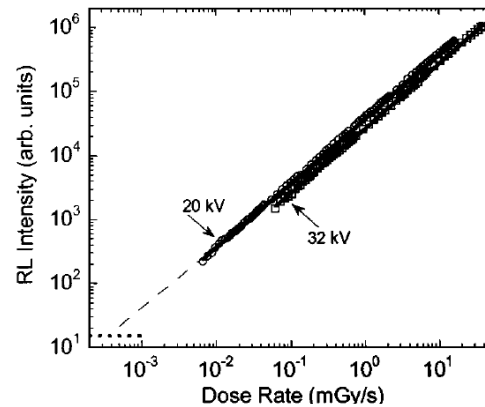


# Ce-doped silica optical fibers



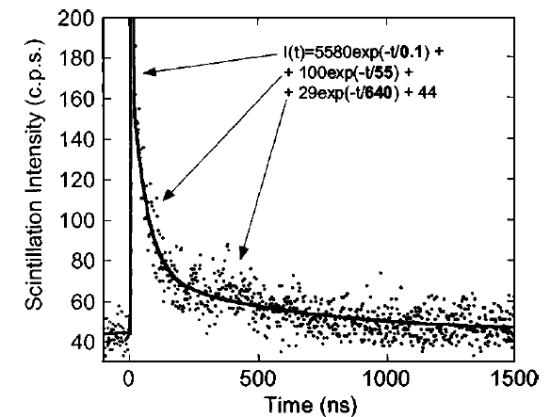
Advances in Optics, 2014

- High RL efficiency
- minimum detectable dose rate  $\ll 10^{-2}$  mGy/s



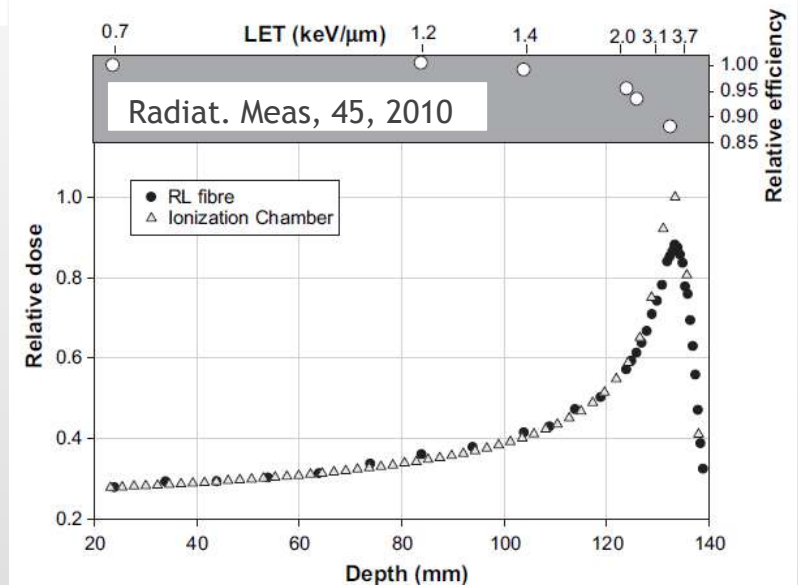
Appl. Phys. Lett. 85, 2004

- Fast: main scintillating time  $\sim 55$  ns ( $5d \rightarrow 4f$   $Ce^{3+}$ )

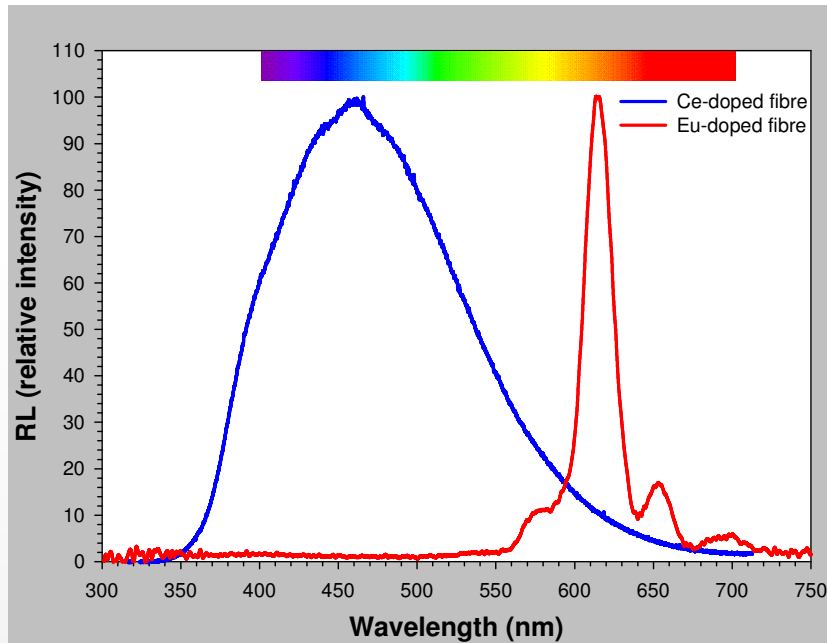


## Applications:

- Dosimetry/QA in diagnostic examinations, brachytherapy and pre-clinical RT studies  
→ stem effect not relevant
- Ion/Proton beams monitoring (dosimetry impaired by quenching of the RL)



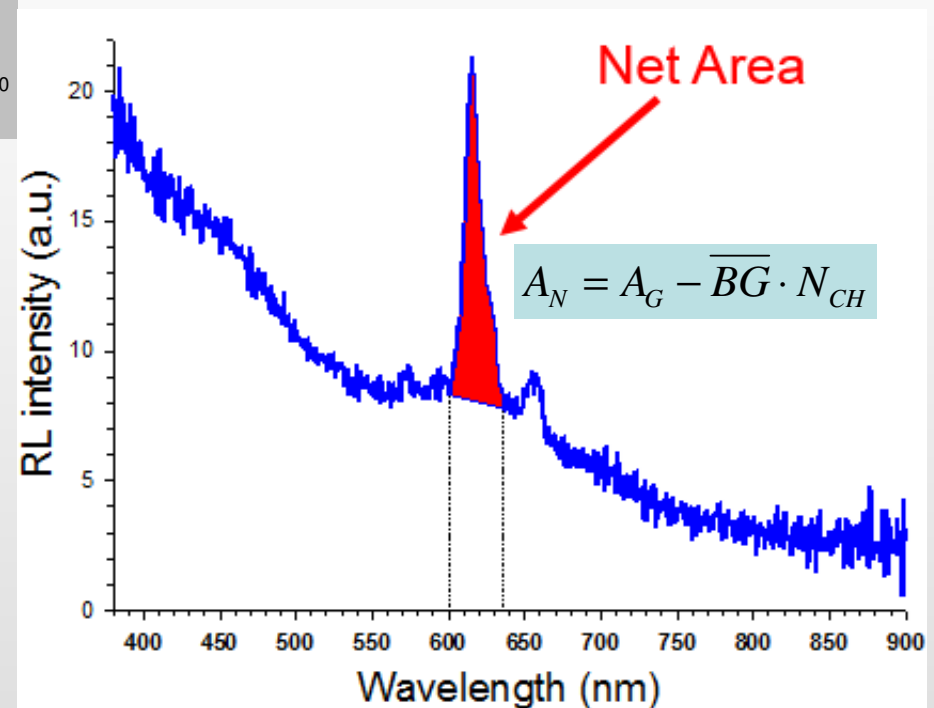
# Eu-doped silica optical fibers



- Narrow emission at ~ 620 nm related to the  $^5D_0 - ^7F_2$  transition of  $\text{Eu}^{3+}$
- Spectral region still interested by the stem effect in unlucky irradiation conditions

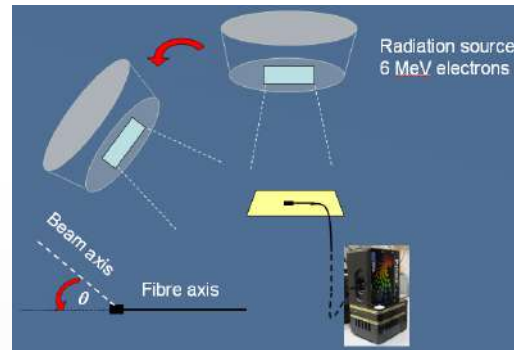
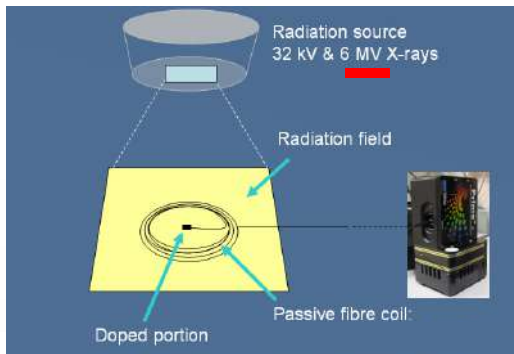
An effective method for removing the stem effect was implemented, but of difficult implementation in the clinical practice

- J Phys D 46, 2013
- Radiat Meas 56, 2013





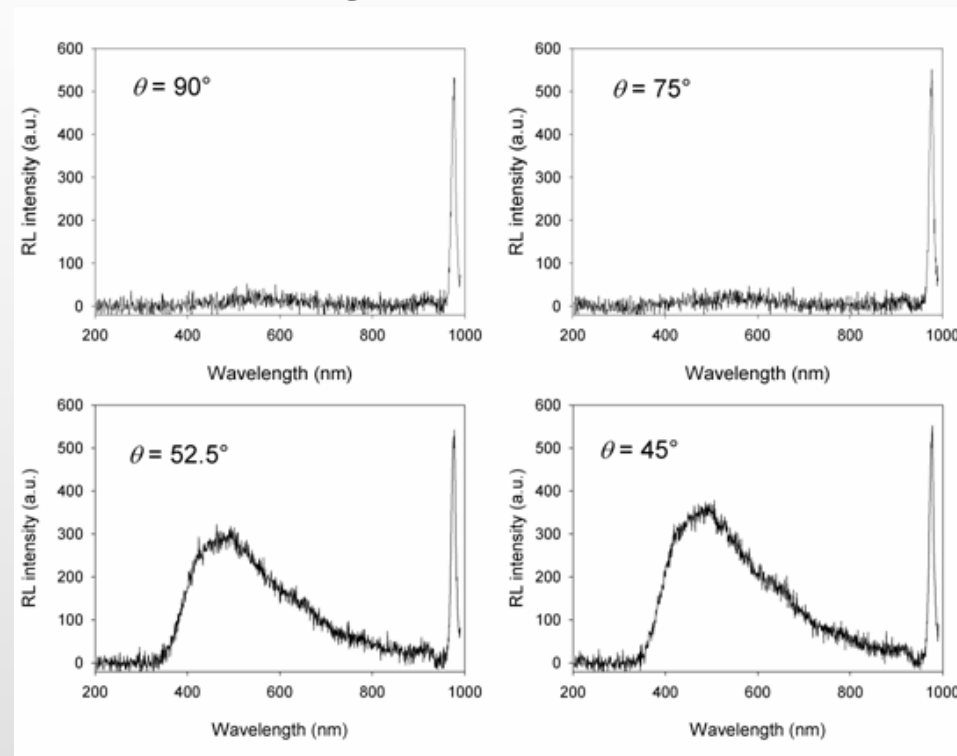
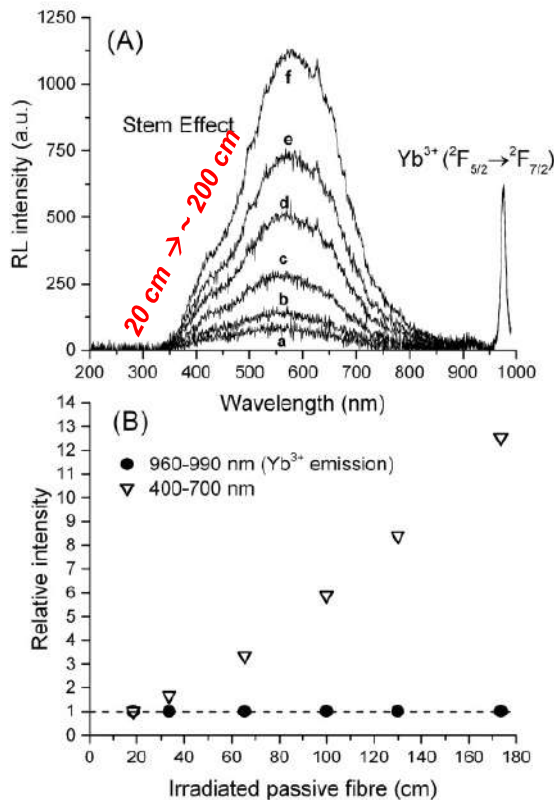
# Yb-doped silica optical fibers



Spectral measurements confirmed the Yb RL independence of:

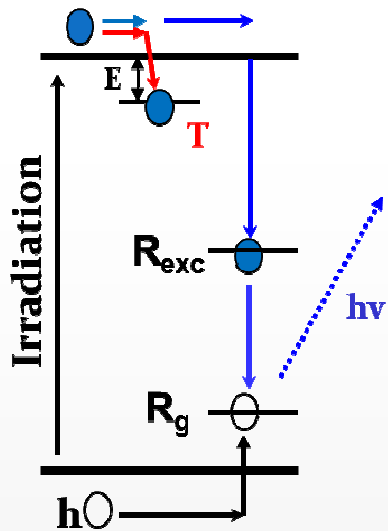
- the beam direction
- the length of irradiated passive fibre

Good candidates as real time dosimeters



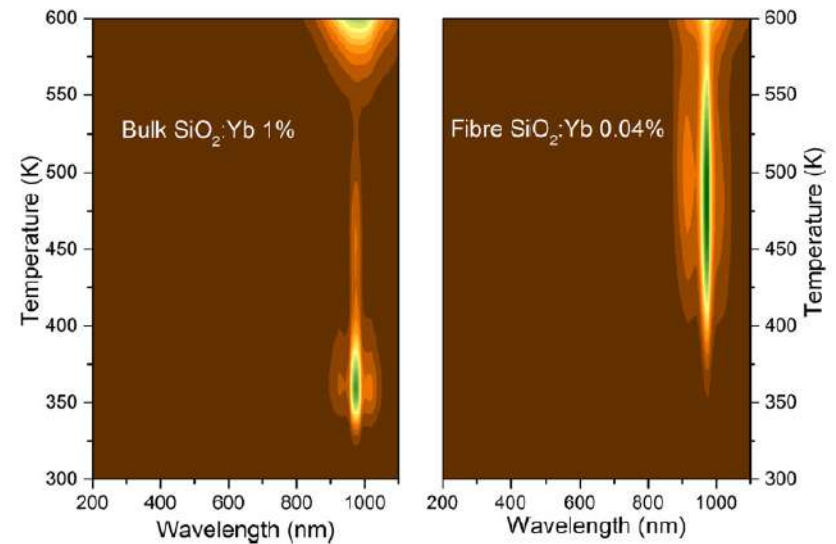
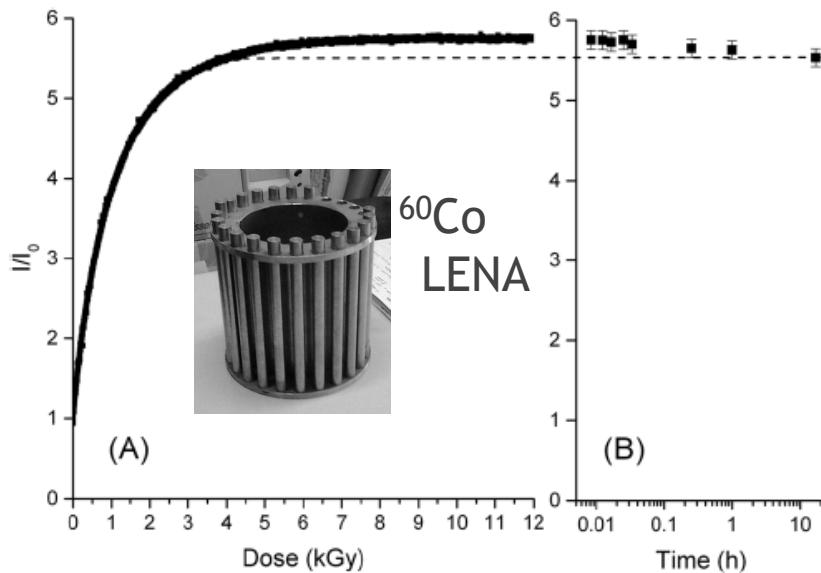
Spectra not corrected for the spectral response of the system

# Yb-doped silica optical fibers



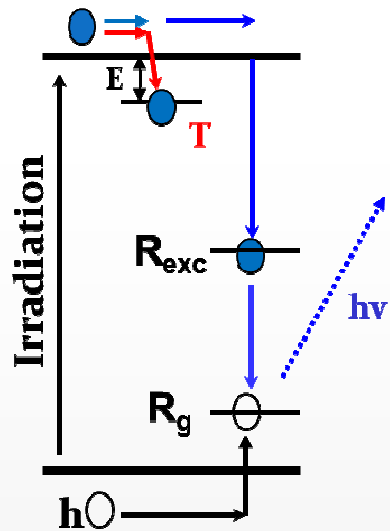
Prerequisite: stability/reproducibility of the RL signal

- Yb-doped optical fibers suffer of «hystereris effect»: increase of the RL efficiency with increasing the cumulated dose
- Defects of the silica matrix acting as competitive traps
- Competitive traps are deep enough to remain filled at room temperature, enabling stability of the RL over the time



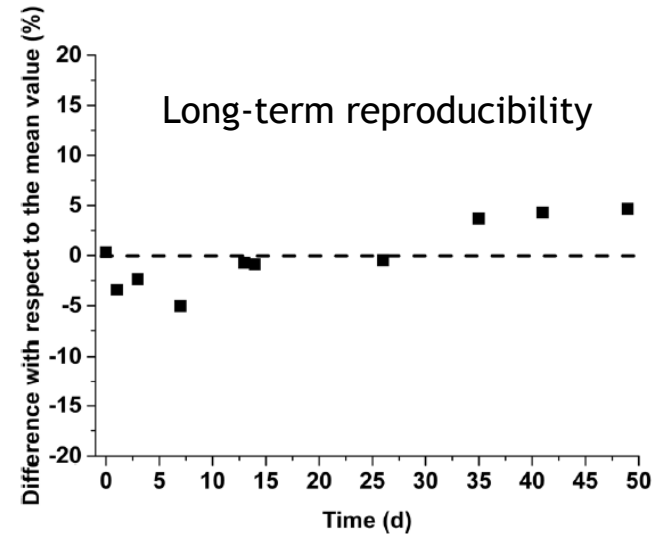
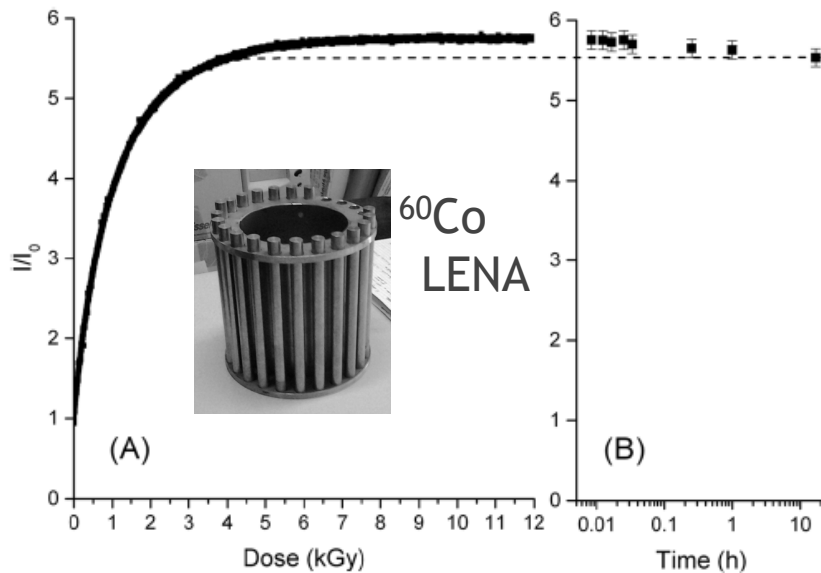
J.Phys.Chem.C. 119, 2015

# Yb-doped silica optical fibers



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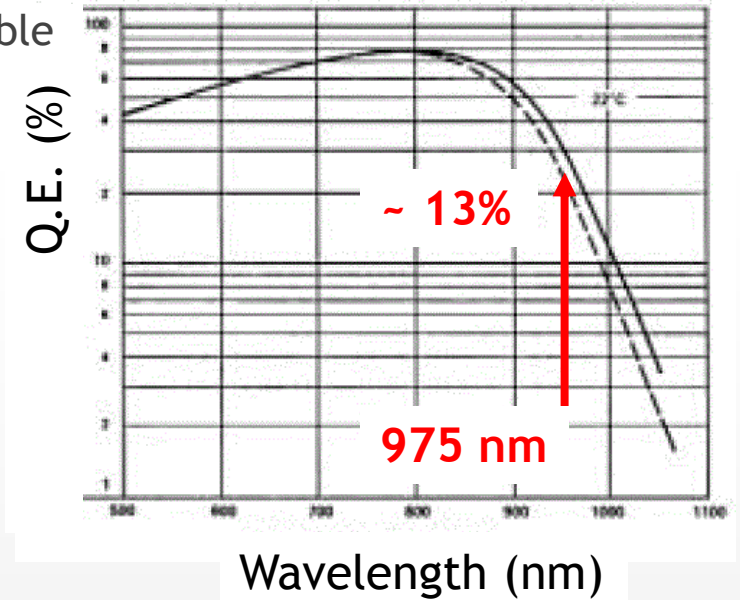
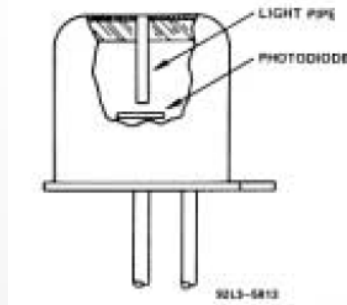
Appl. Phys. Lett 105, 2014

# Yb-doped silica optical fibers: the reader

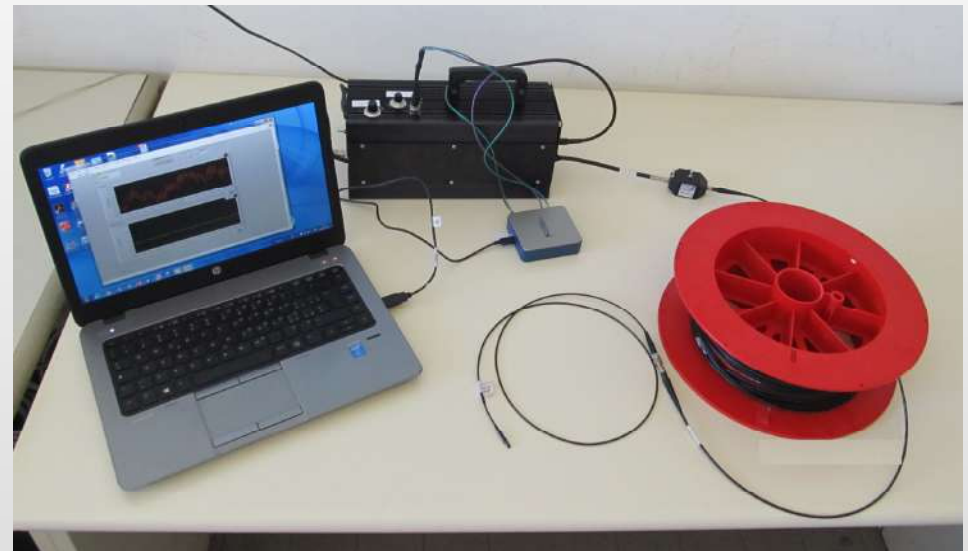
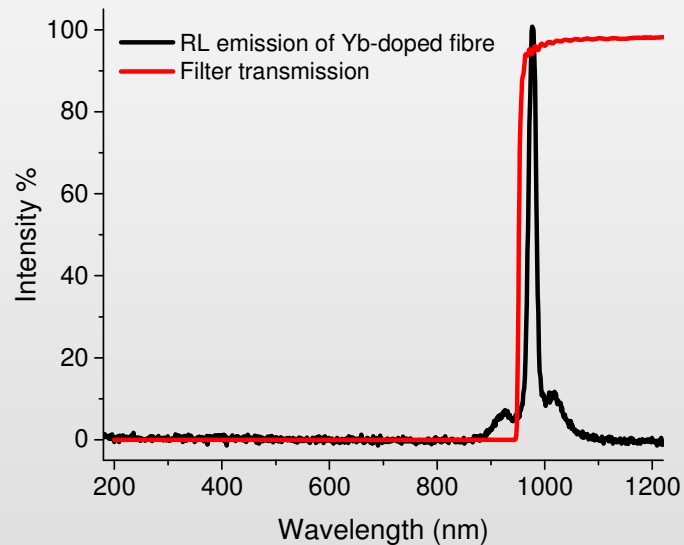
Design and implementation of an efficient and portable optical detector for real-time measurements of the emission of  $\text{Yb}^{3+}$



APD (Geiger Mode)

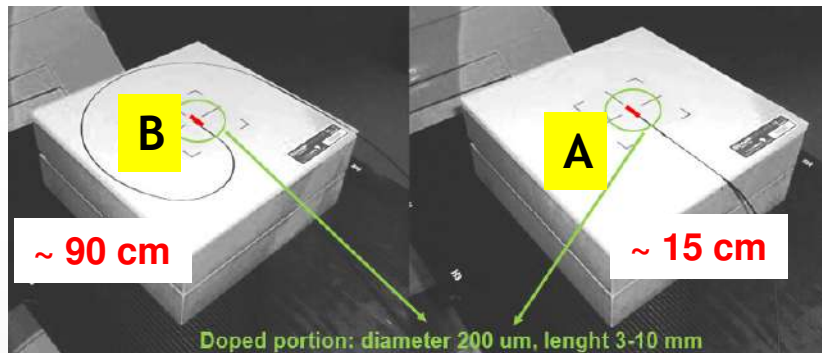


Long-pass filters (cut-on wavelength: 950 nm)



# Yb-doped silica optical fibers: the stem effect

Figure adapted by Carrasco et al. Med Phys 42, 2015

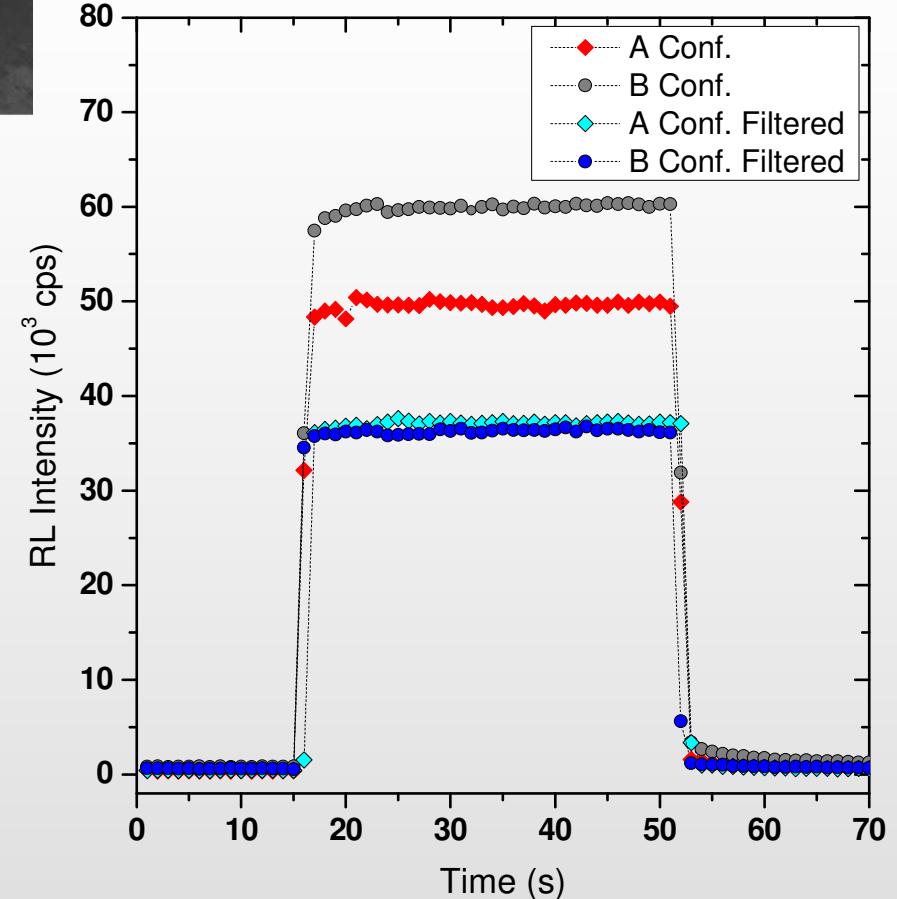


STANDARD IMAGING

6 MV X-rays, 200 MU, 300 MU/min, 30x30 cm<sup>2</sup>

Complete suppression of the stem effect by optical filtering

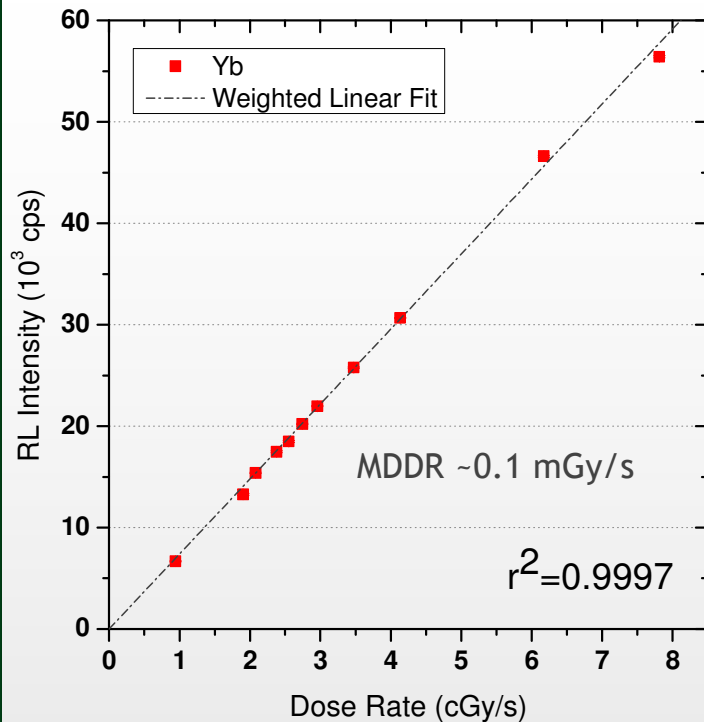
→ No calibration procedures required



# Yb-doped silica optical fibers: dosimetry

Linearity vs. dose rate:

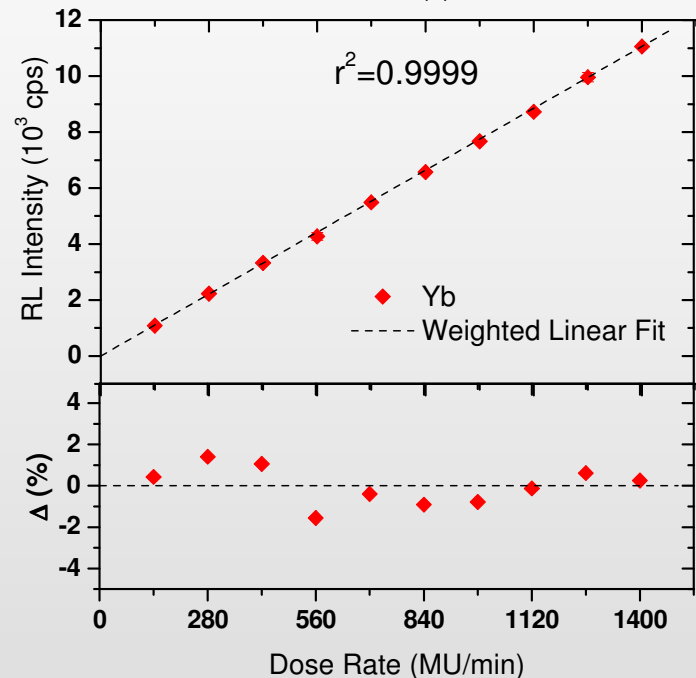
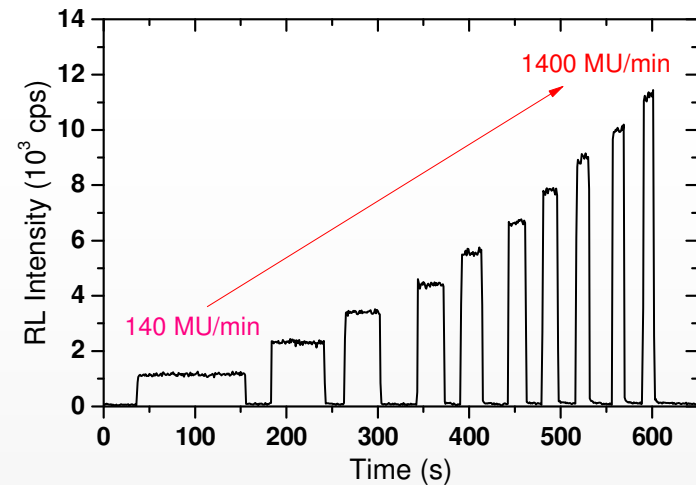
- Change of the source-detector distance



Phys Med Biol 62, 2017

Total counts (i.e. dose)  
independent of the dose rate

- Change of the LINAC pulse frequency





# Yb-doped silica optical fibers: validation

- Relative dose profiles (OAR, PDD) and Output Factors\* (OF)
  - Varian Trilogy System Linear Accelerator
  - 6 MV X-rays FFF
  - Water phantom (IBA)



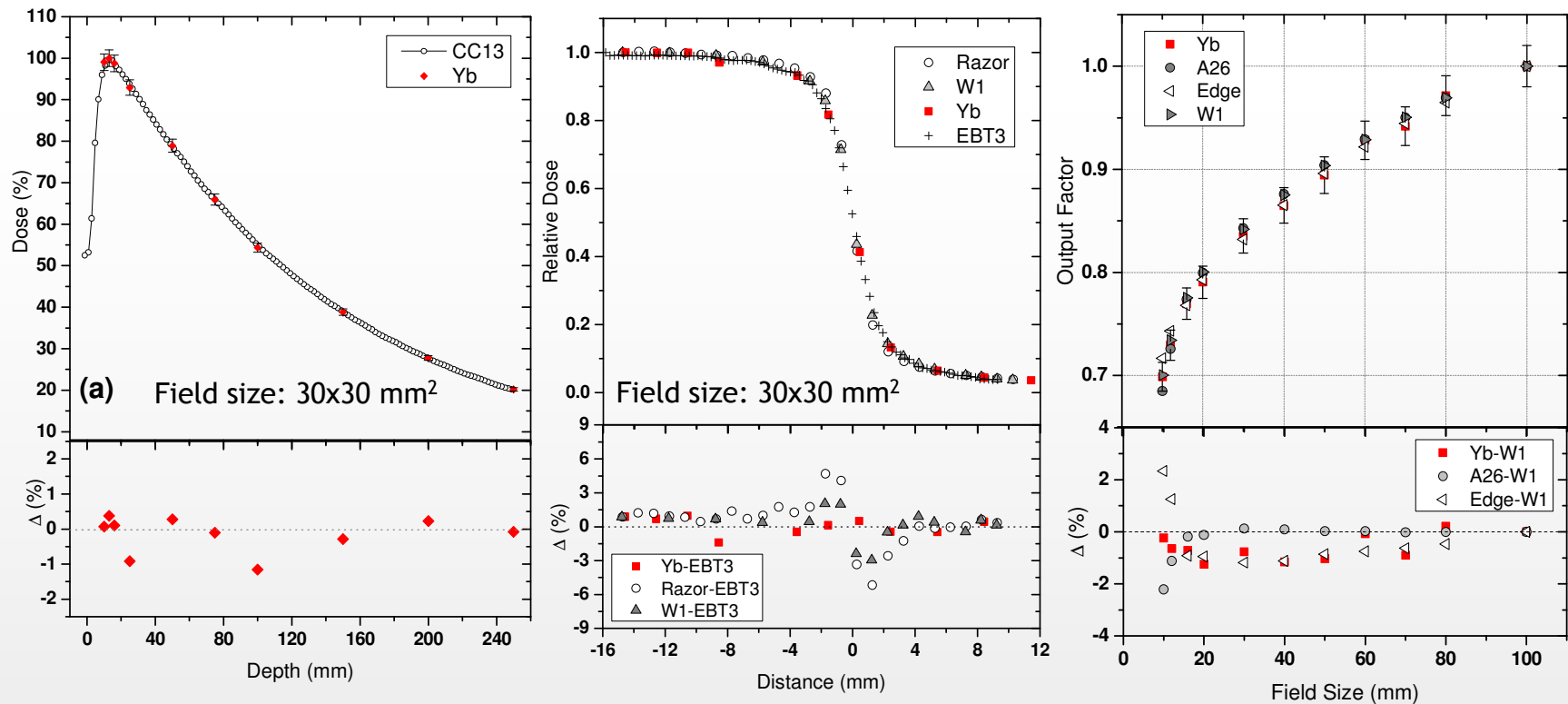
*\*The OF of a generic field with size  $i \times i$  cm<sup>2</sup> is the ratio between the signal produced by this field and the corresponding signal produced by the standard size 10x10 cm<sup>2</sup> field*

Reference detectors:

- Ion chamber (Exradin A26, Standard Imaging; CC13, IBA)
- Diodes (Razor, IBA; EDGE, Sun Nuclear Corporation)
- Scintillator (Exradin W1, Standard Imaging)
- Gafchromics films (EBT3, ISP technologies)

# Yb-doped silica optical fibers: validation

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- Good agreement between the results of the fibre and of other reference detectors
- Effective and practical tool for “small field” dosimetry and promising for in-vivo dosimetry

# Conclusions

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- Rare earth doped silica optical fibers have RL properties that can be exploited in various dosimetry applications, and more in general for ionizing radiation detection and monitoring.
- For some applications connections with industrial partners have been already established, for other applications, including medical dosimetry, contacts are currently in progress.
- Further applications are possible → discussion and new inputs are welcome

