The implementation of radioluminescent GaN probes for medical physics applications

P. Pittet,
Journées thématiques du Réseau Semi-conducteurs
June 2-3 2022

From detector to Medical Physics applications

Semiconductor based detectors

- **Indirect Gap electrical readout**: Diode, MOSFET, Diamant, EPID
- **Direct Gap optical readout**: GaN, ZnSe, CdTe, CdZnTe

Scintillators (optical readout)

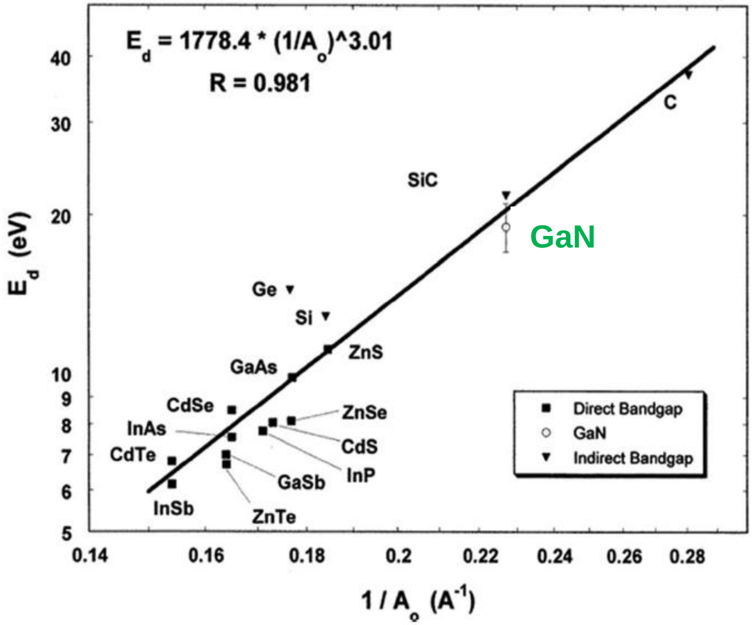
- **OSL**: Al2O3:C, BeO
- **TLD**: LiF, CaF2
- **Inorganic scintillators**: BGO, LYSO, Ruby
- **Organic plastic scintillators**: PVT, PS, Anthracene

	TLD	Diode	MOSFET	Alanine	RL	PSD	ISD
Size	+	+/−	+/++	−	++	++	++
Sensitivity	+	++	+	−	++	+/++	++
Energy dependence	+	−	−	+	−	++	-
Angular dependence	++	−	+	+	++	++	++
Dynamic range	++	++	+	−	++	++	+/++
Calibration procedures, QA, stability, robustness, size of system, ease of operation	+	++	++	−	−/+	+/++	-/+
Commercial availability	++	++	++	++	−	+	-
Online dosimetry	−	++	+	−	++	++	++

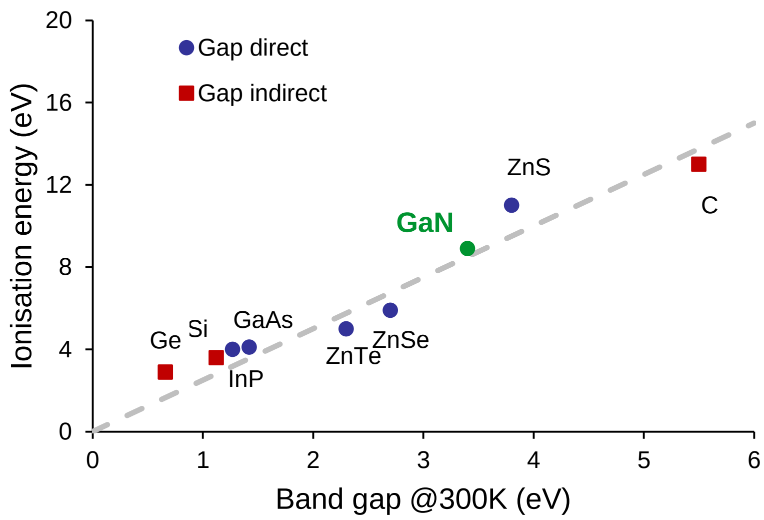
K. Tanderup et al., Medical Physics, 2013

S. Beddar ESTRO38

GaN detector



Good radiation hardness (small lattice constance)

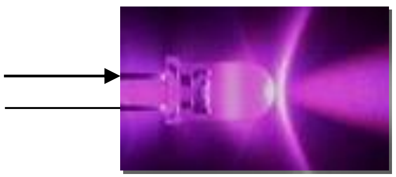


Ionisation energy of 8.9eV

Direct gap semiconductors

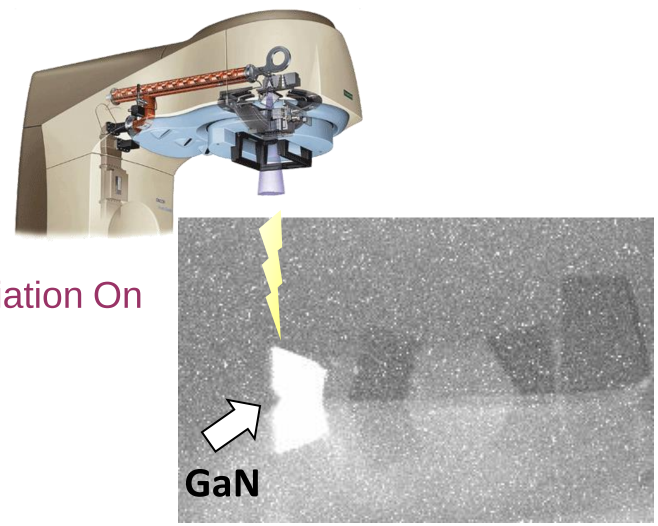
GaN Radioluminescence

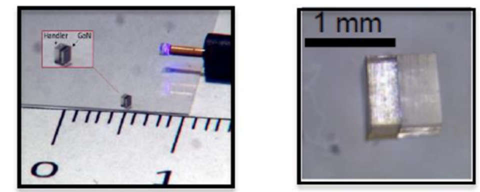
Current On



Electroluminescence

Irradiation On



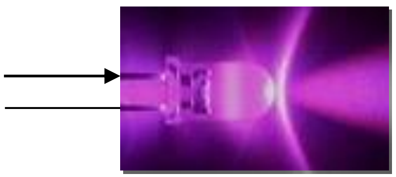


GaN bulk RL transducer with 300 nm Al backside reflector and a 500 micrometer handler (resin).

Direct gap semiconductors

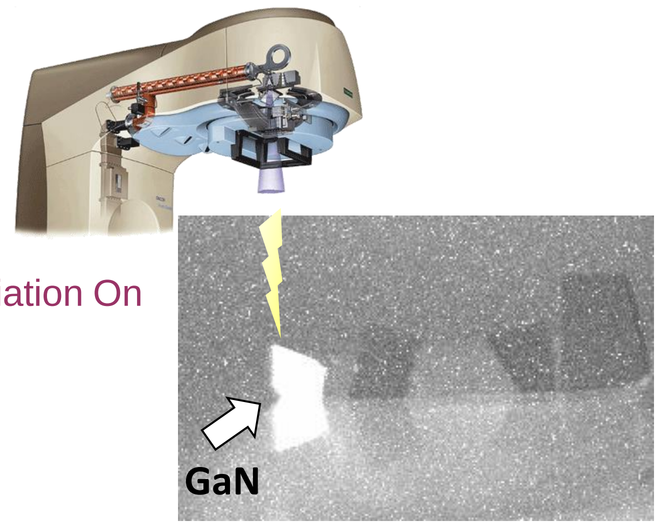
GaN Radioluminescence

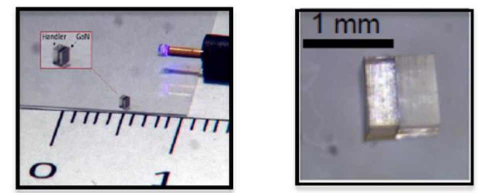
Current On



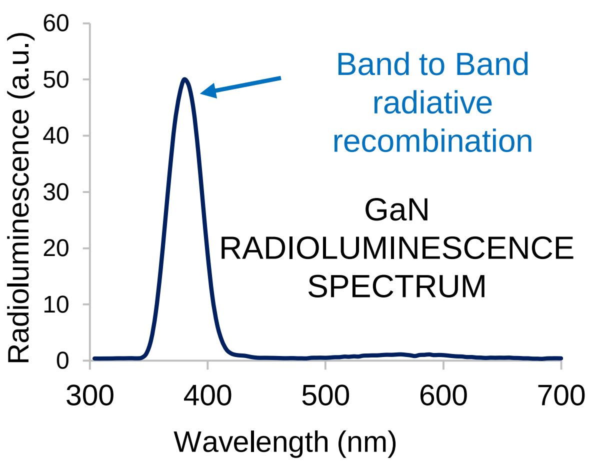
Electroluminescence

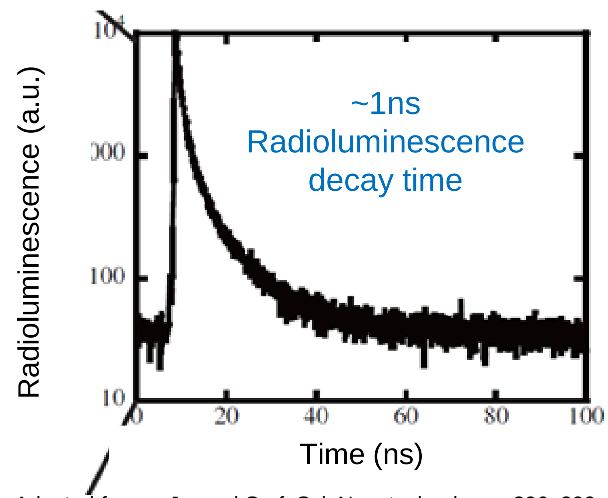
Irradiation On





GaN bulk RL transducer with 300 nm Al backside reflector and a 500 micrometer handler (resin).

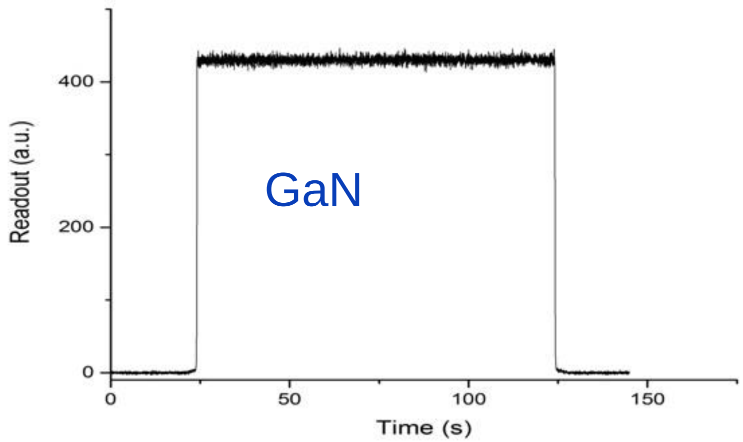




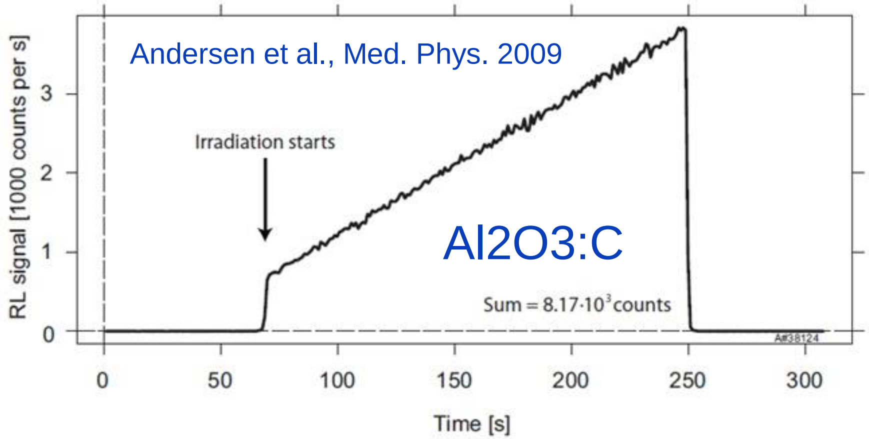
Adapted from e-Journal Surf. Sci. Nanotechnol., pp. 396–399, 2014

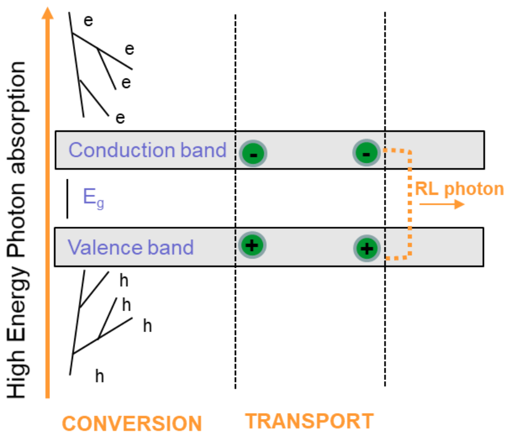
Direct gap semiconductors

Ir-192 afterloaded

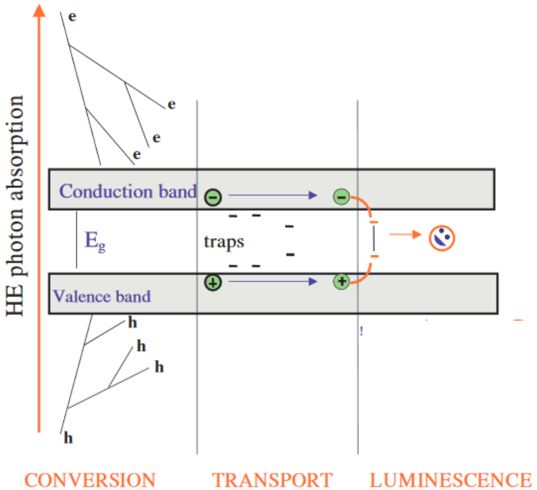


Ir-192 afterloaded





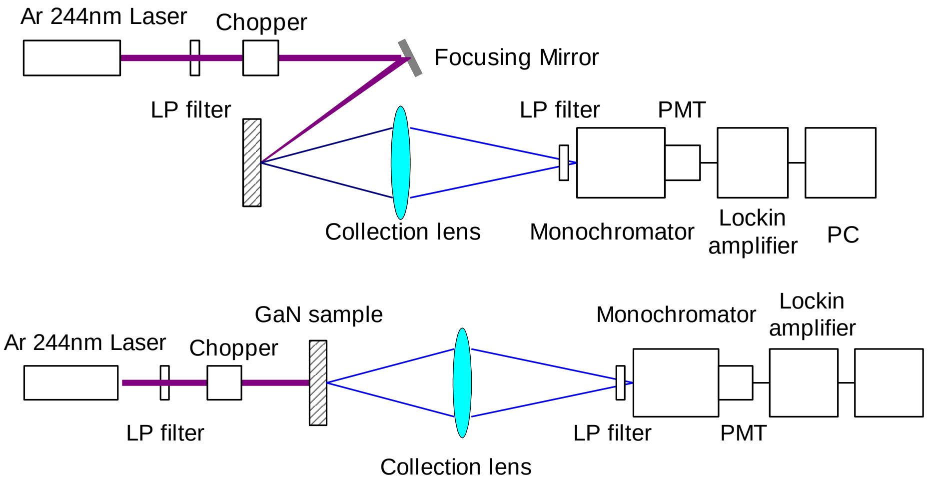
Adapted from Meas. Sci. Technol. **17** (2006) R37–R54

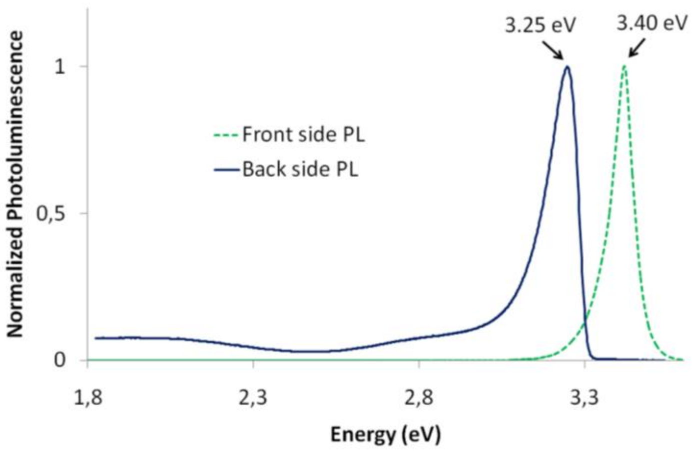


Meas. Sci. Technol. **17** (2006) R37–R54

Direct gap semiconductors

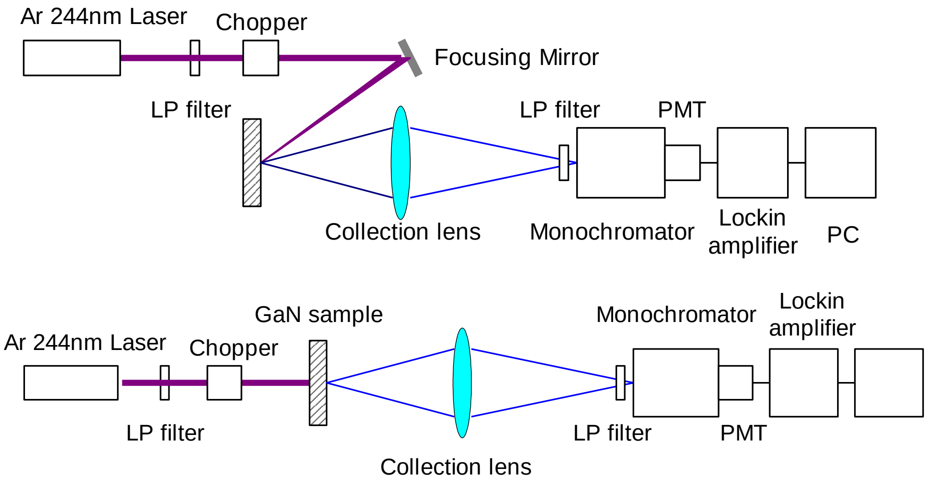
Auto-absorption

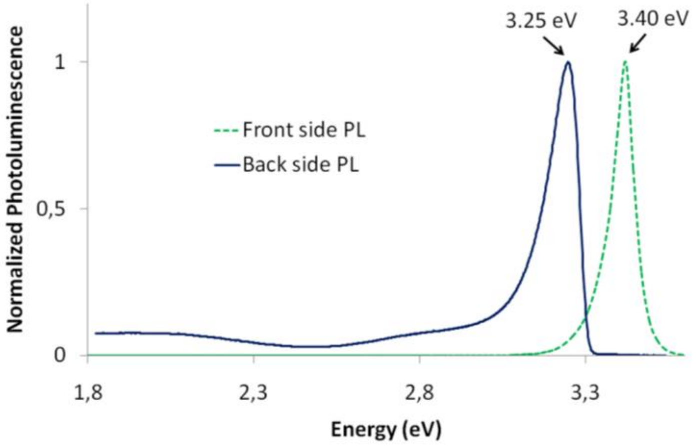


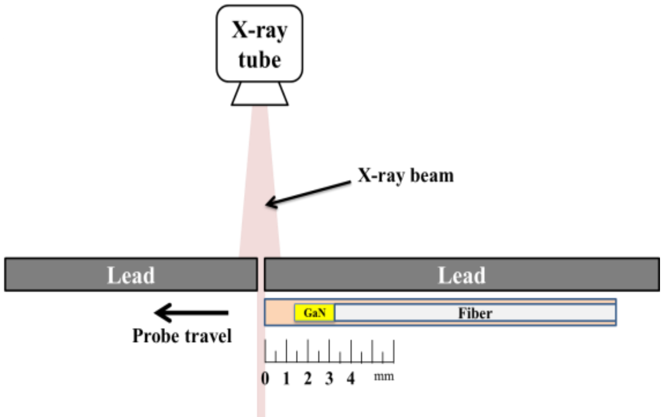


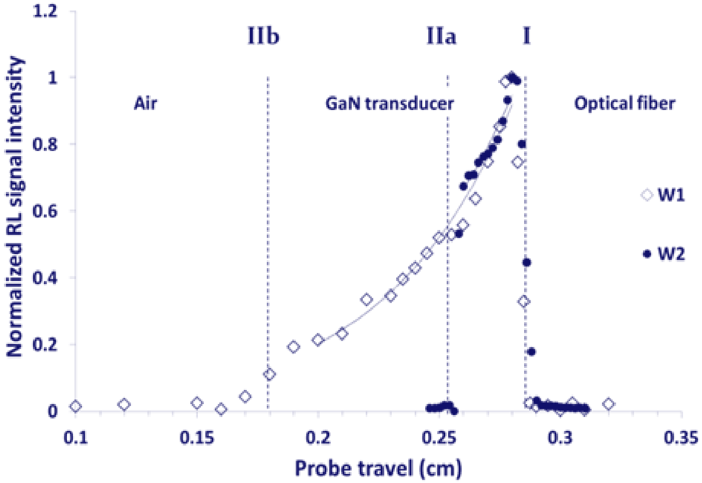
Direct gap semiconductors

Auto-absorption

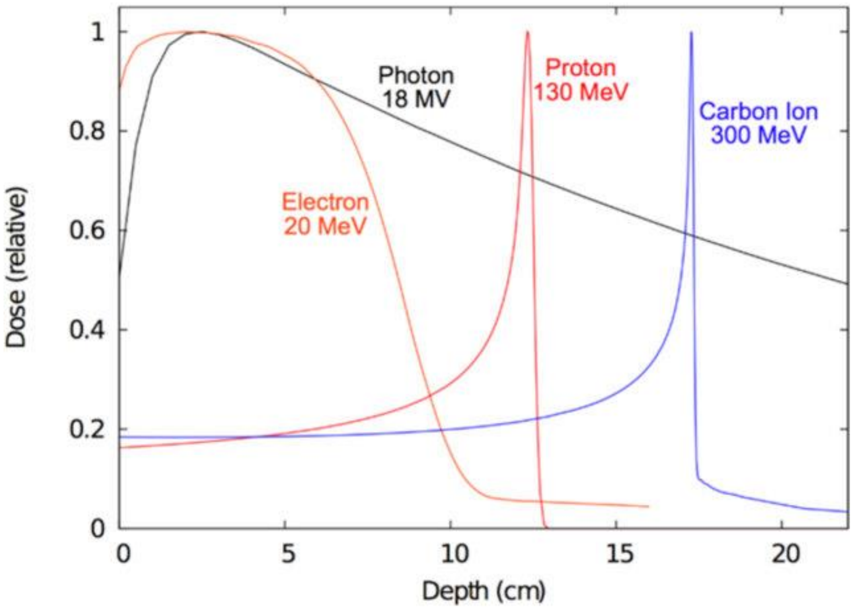






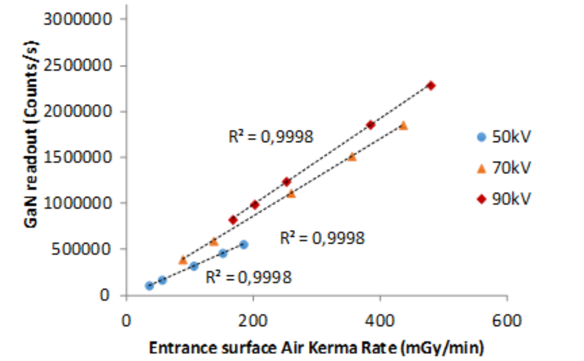


GaN-based dosimetric probe

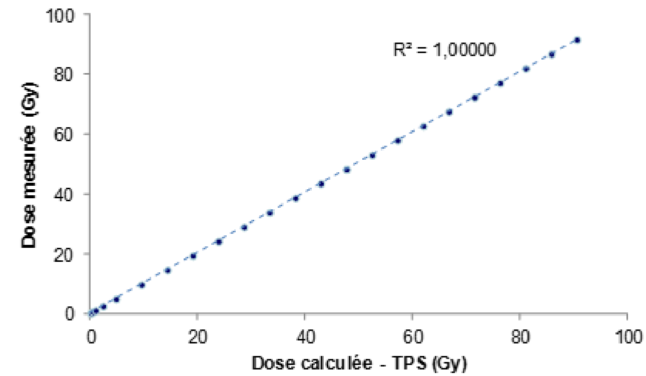


GaN-based dosimetric probe

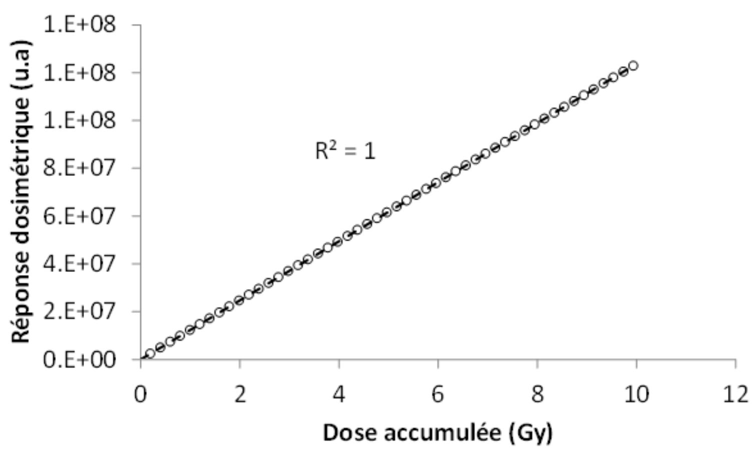
Radiologic X-rays (kV)



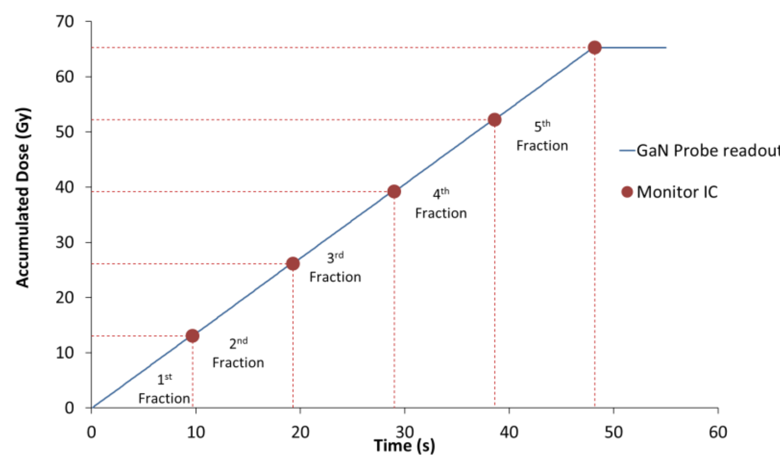
Therapeutic X-rays (6 MV)



Therapeutic Gamma-rays (^{192}Ir)

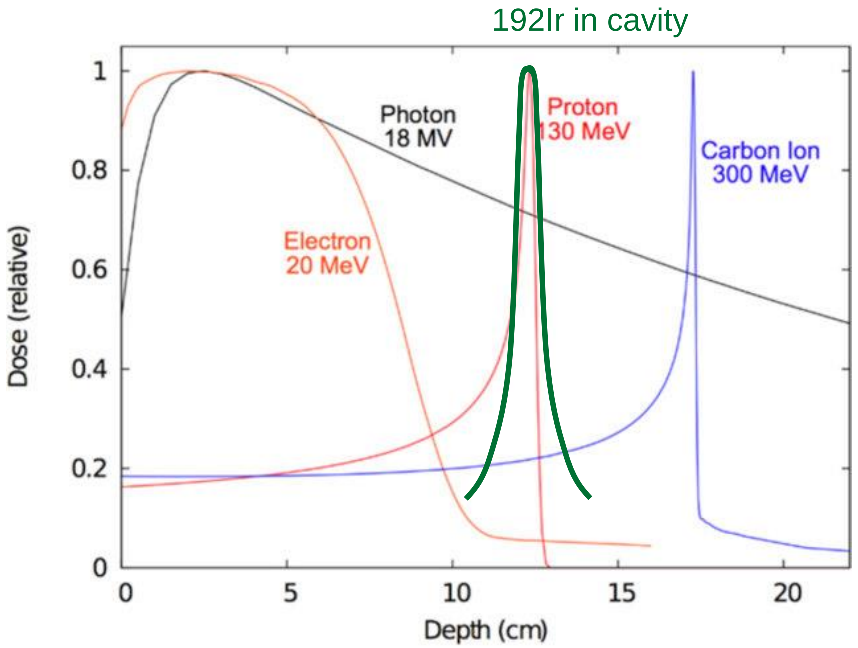


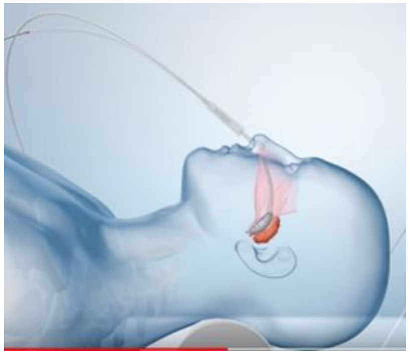
Therapeutic Protons (65 MeV)



GaN tranducer gives a linear dosimetric response with no dependence on the accumulated dose

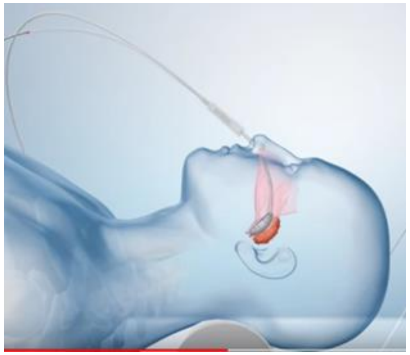
Brachytherapy context of QA and IVD

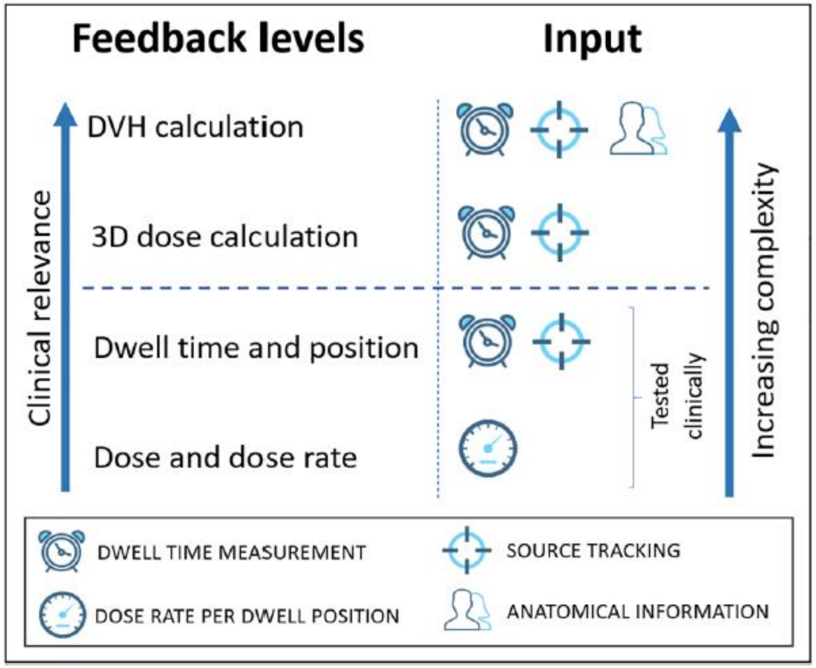




Brachytherapy context of QA and IVD

PDR / HDR afterloader



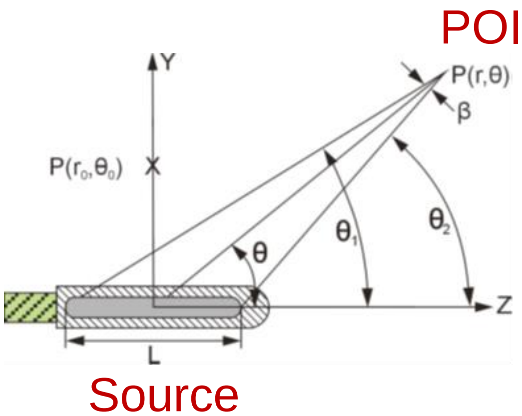


Gabriel P. Fonseca et al., "In vivo dosimetry in brachytherapy: Requirements and future directions for research, development, and clinical practice", *Physics and Imaging in Radiation Oncology,*16, 2020,

GaN detector probe for brachytherapy

DOSE RATE PER DWELL POSITION

Dose rate in water at any POI can be calculated by TG-43U1 formalism



$$\dot{D}(r,\theta) = S_k \Lambda \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} g_L(r) F(r,\theta)$$

S_k Air-kerma strength
Λ Dose rate constant in water
$G_L(r,\theta)$ Geometry function
$g_L(r)$ Radial dose function
$F(r,\theta)$ 2D anisotropy function

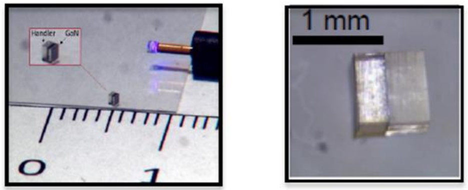
GaN detector probe for brachytherapy

ANR SECURIDOSE

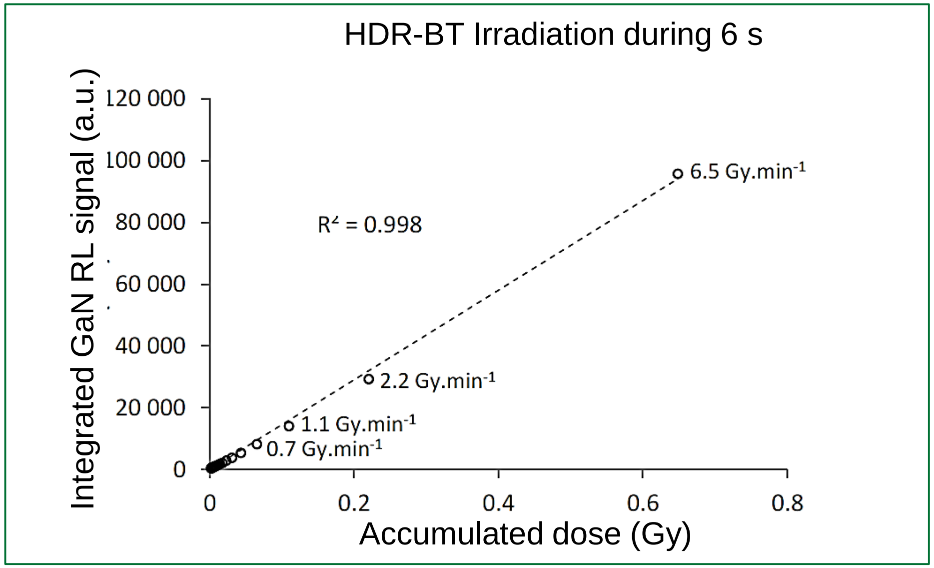
Steep dose gradient ➔ ☺ small size

Time resolved measurements ➔ ☺ direct gap SC

No dose rate dependence of its linear dosimetric respond

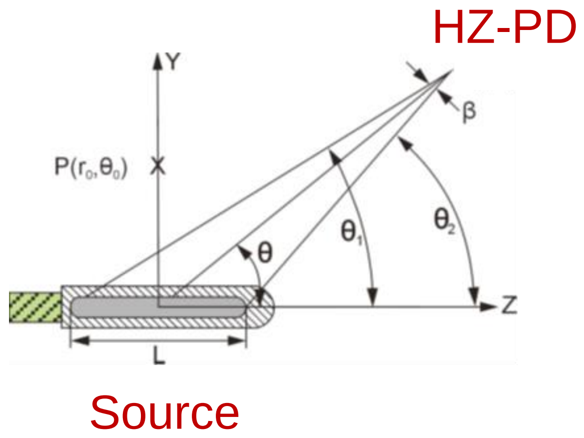


GaN bulk RL transducer with 300 nm Al backside reflector and a 500 micrometer handler (resin).



GaN detector probe for brachytherapy

Source position determination in the case of "High Z" point detectors (HZ-PD)



Extended TG43 formalism

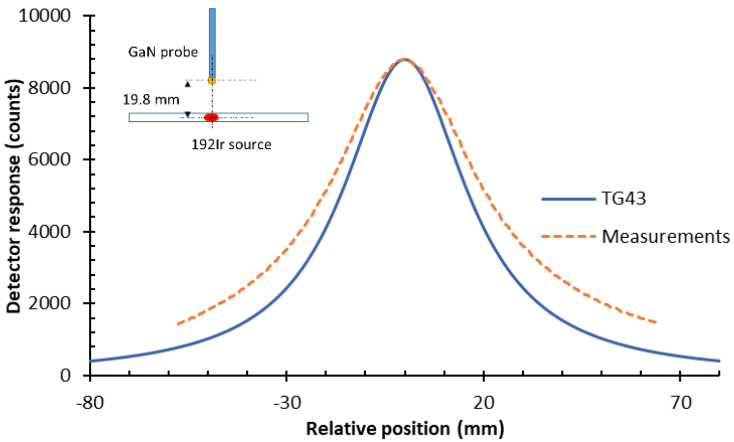
$$\dot{R}(r,\theta) = S_k \Lambda \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} \boldsymbol{g'_L(r)} F(r,\theta) \boldsymbol{F'(r,\theta)}$$

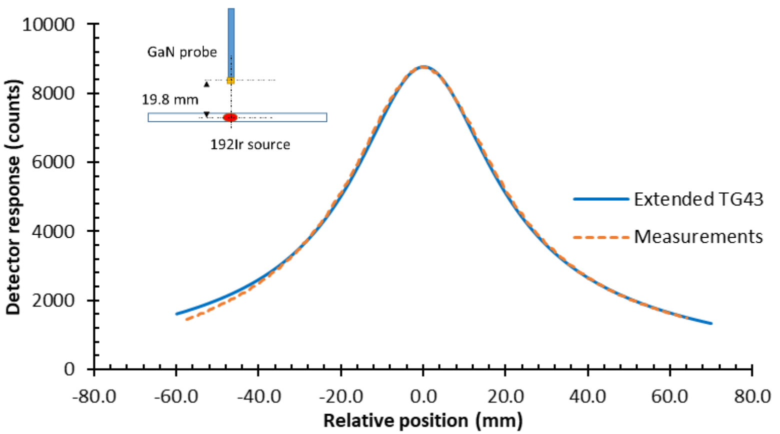
$\boldsymbol{g'_L(r)}$ extended radial dose function

accounts for the High Z of the detector

$\boldsymbol{F'(r,\theta)}$ detector anisotropy function

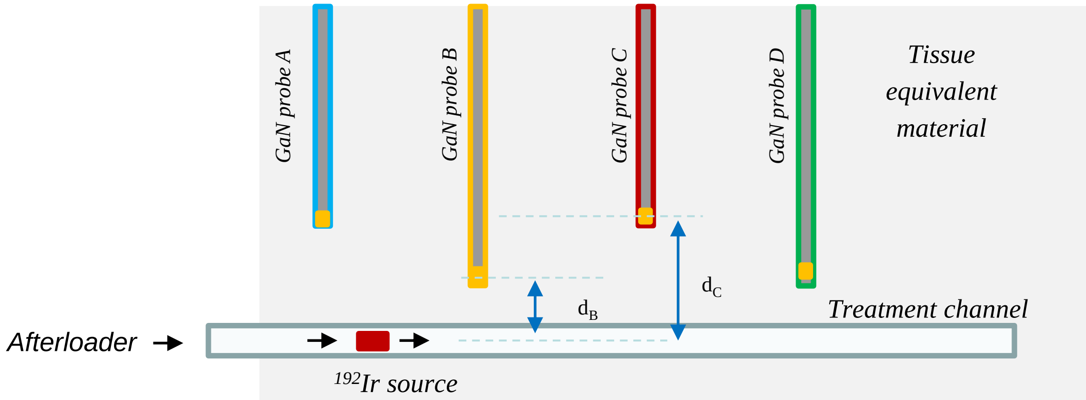
accounts for the anisotropy of the detector and for stem effect

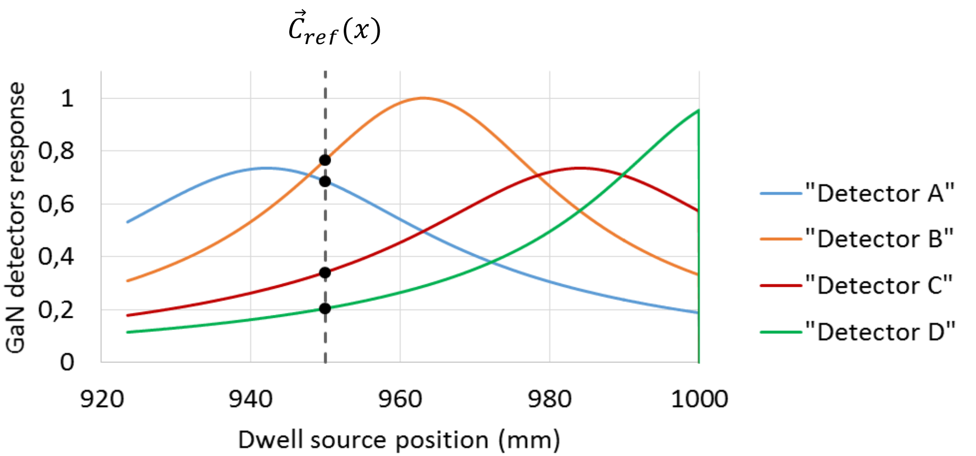




GaN detector probe for brachytherapy

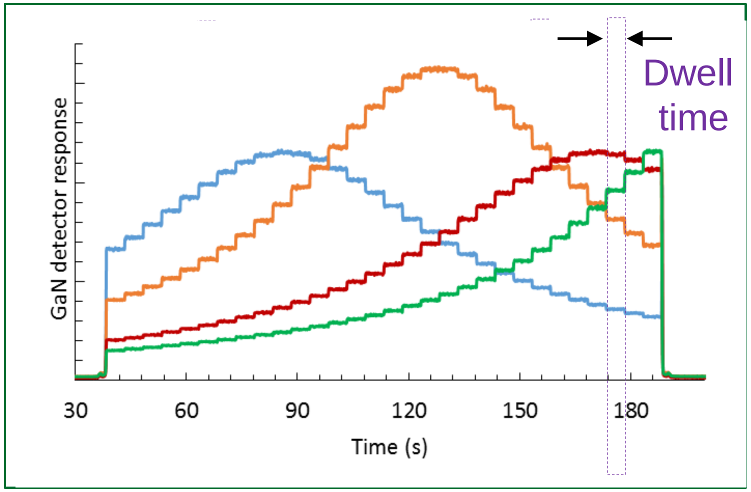
Extended TG43 is used to calculate the response of 4 GaN-based detectors distributed along the treatment channels



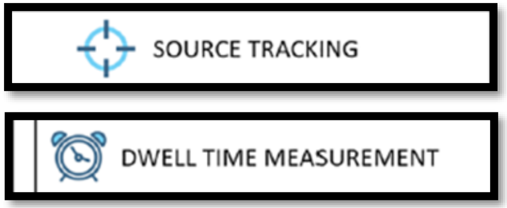


GaN detector probe for brachytherapy

Time-resolved dose rate measurements with 4 GaN detectors are used for both dwell time and position determination



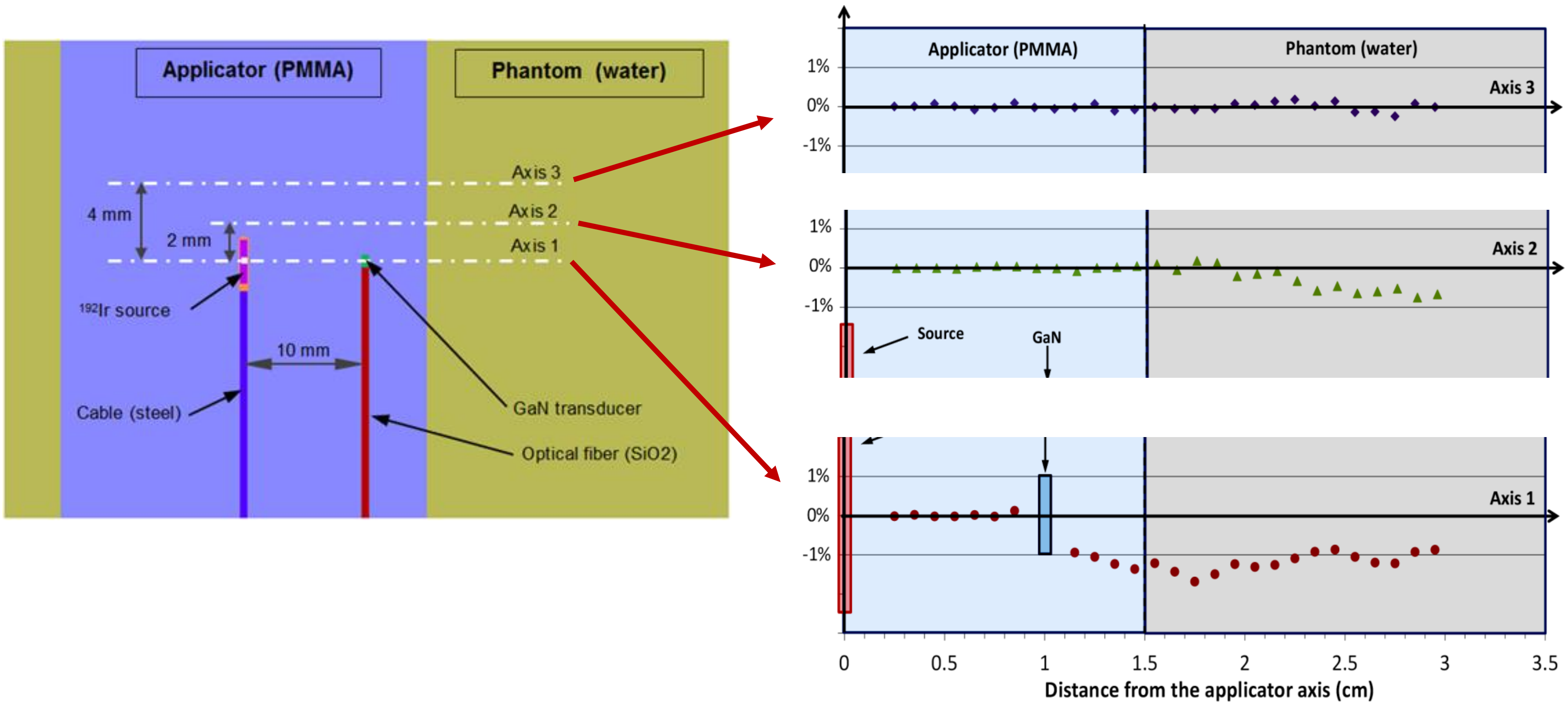
Dwell position ➔
Correlation (set meas., set TG43ext resp)



P. Guiral et al., Medical Physics, 43, 2016.

GaN detector probe for brachytherapy

Dose perturbation due to GaN transducers (MC simulations)

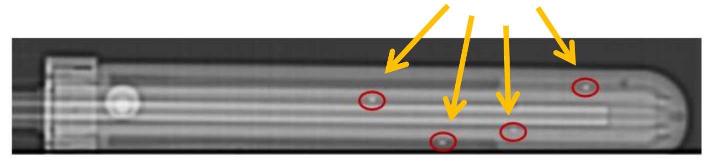


Limited dose perturbations (~1%) behind the GaN detector on the Source-detector axis

GaN detector probe for brachytherapy

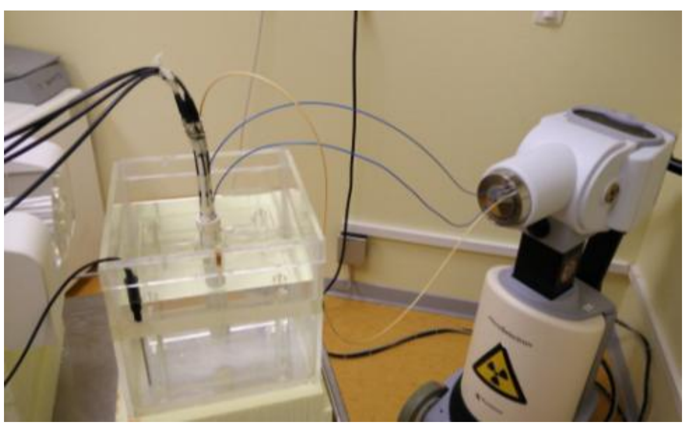
- Gynecological applicator instrumented with 4 GaN-based detector for in-vivo quality control

4 GaN-based detectors



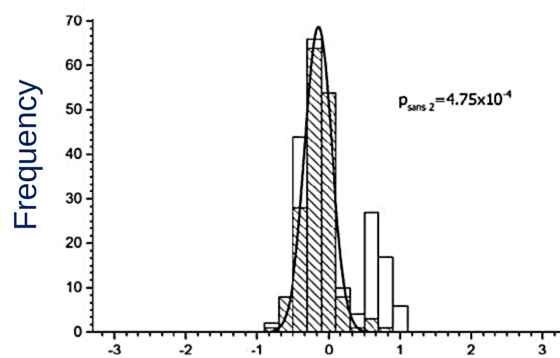
SOURCE TRACKING

DWELL TIME MEASUREMENT



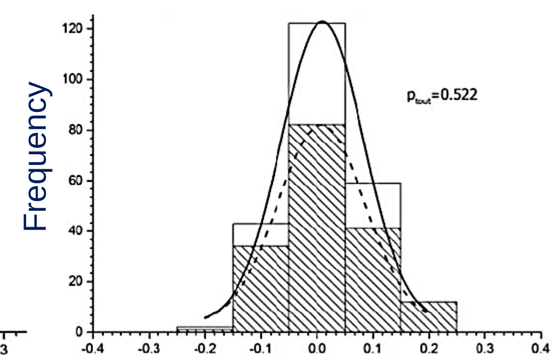
P. Guiral et al., Medical Physics, 2016.

Mean deviation -0,42mm
Standard deviation 0,01 mm



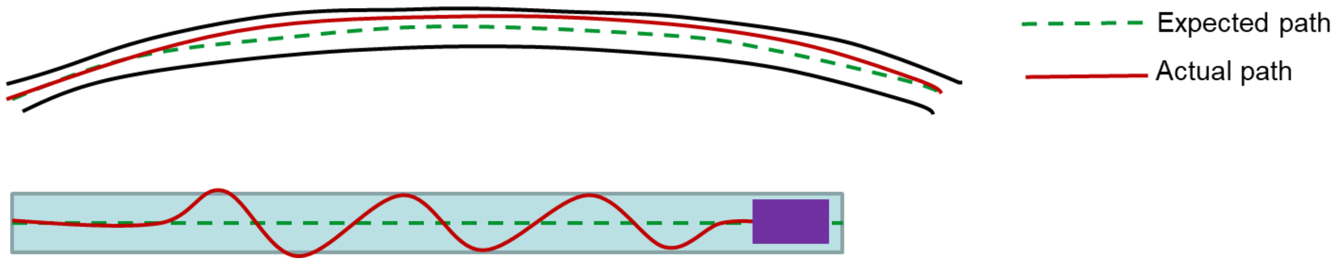
Dwell position deviations (mm)

Mean deviation 0,08 s
Standard deviation 0,02 mm

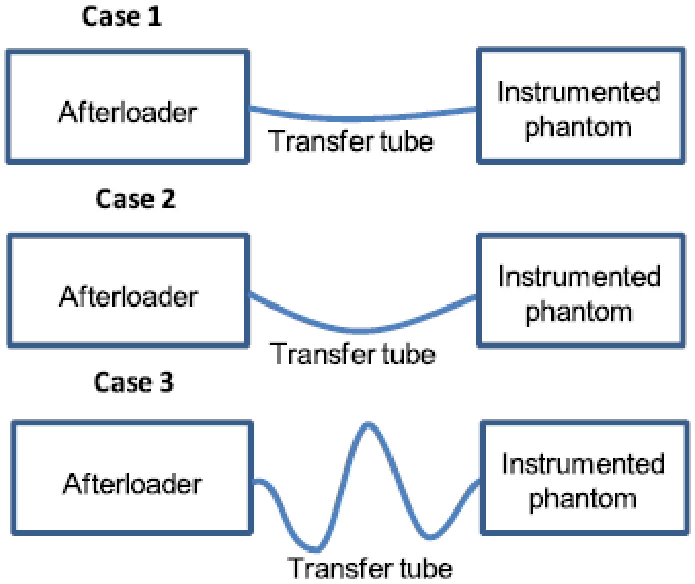


Dwell time deviations (s)

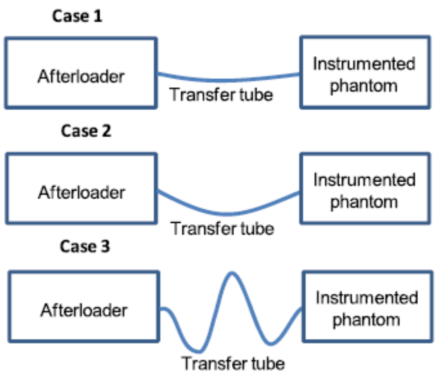
Path deviation and snaking effect in bended transfer tube

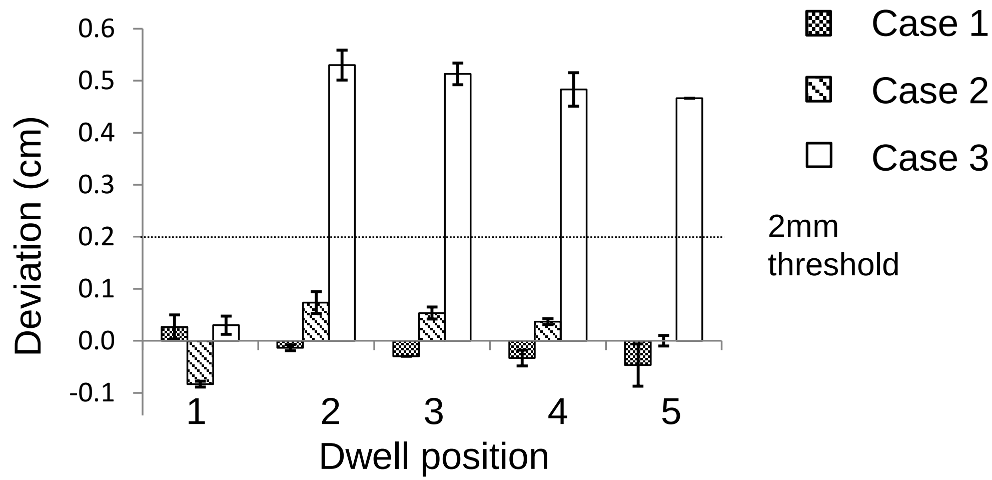


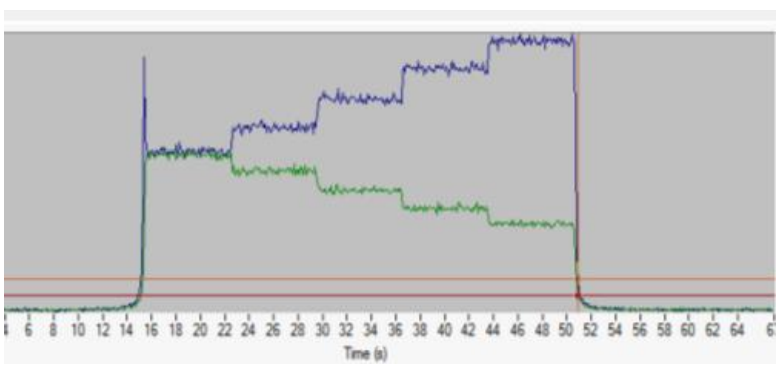
(Eckert & Ziegler BEBIG Co-60 source)



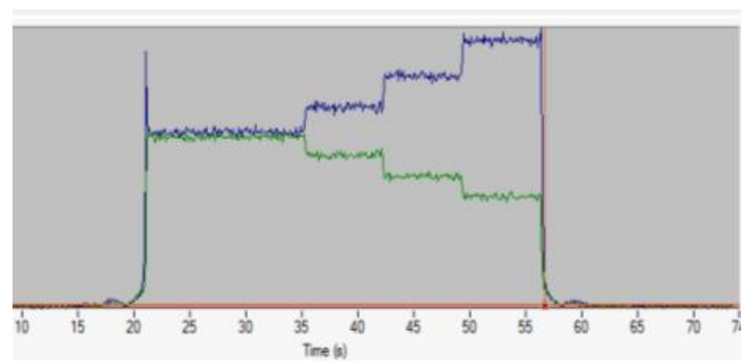
Path deviation and snaking effect in bended transfer tube







Case 1
(reference)



Case 3

GaN probe for low dose guide wire tracking ANR Newloc

Interventional radiology

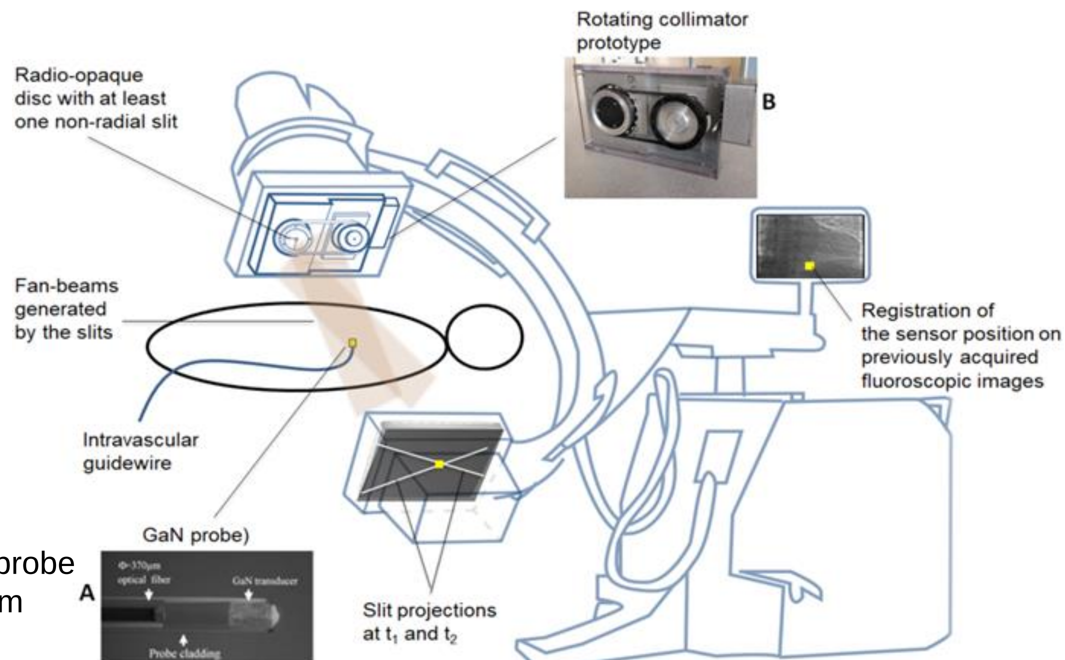
GaN probe for low dose guide wire tracking

Interventional radiology

Principle of virtual fluoroscopy for low dose tracking

Guiral P, Pittet P, Grondin Y, Jalade P, Galvan JM, Lu GN, Desbat L, Cinquin P. Fan-Beam Based Virtual Fluoroscopy for Navigated Catheterization in Interventional Radiology. Stud Health Technol Inform. 2019 Aug 21;264:74-78.

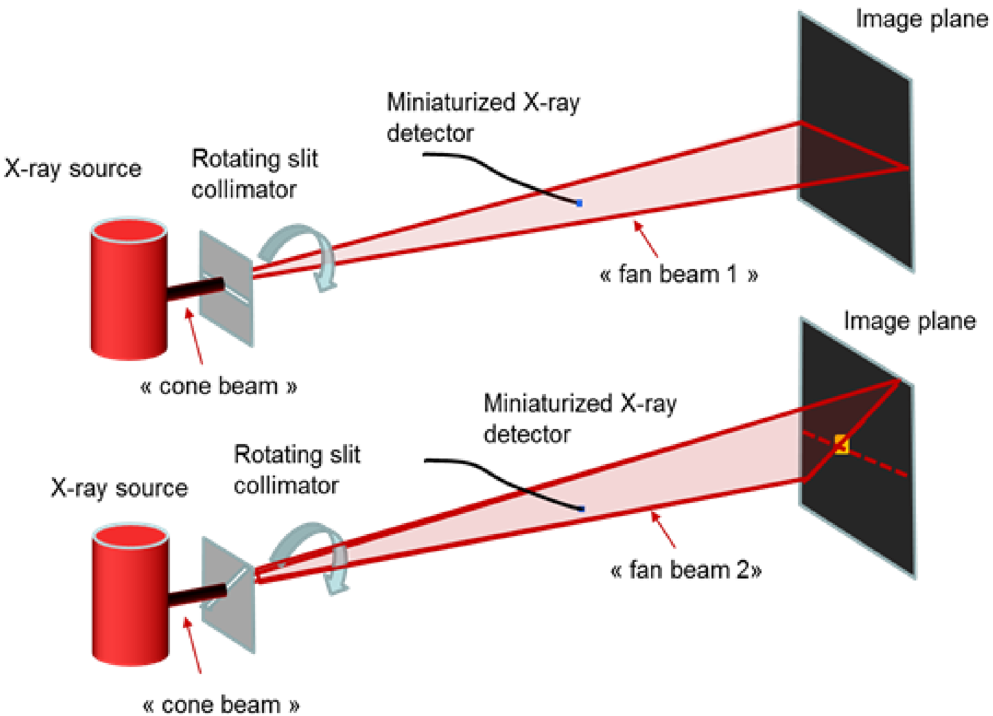
Detector probe
Φ < 800µm

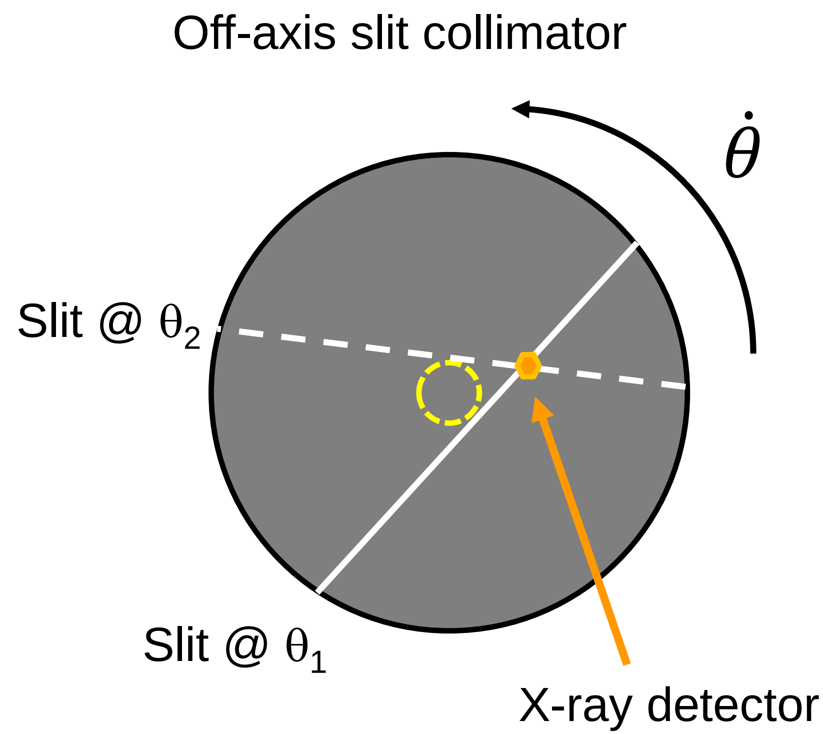


GaN probe for low dose guide wire tracking

Principle of virtual fluoroscopy for low-dose tracking

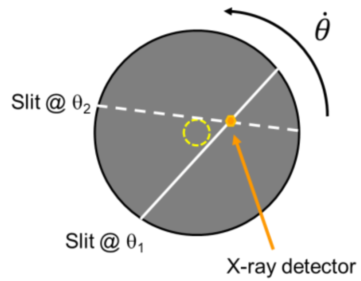
ANR Newloc





GaN probe for low dose guide wire tracking

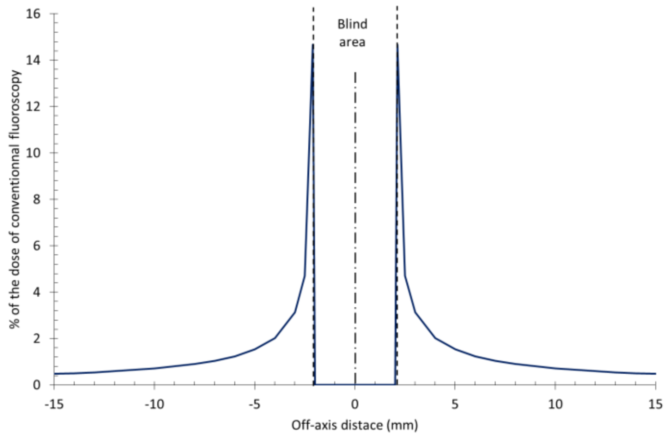
Dose reduction



$$\overline{D_{FB}} = D_{CB}\frac{S_{slit}}{S_{coli}}$$

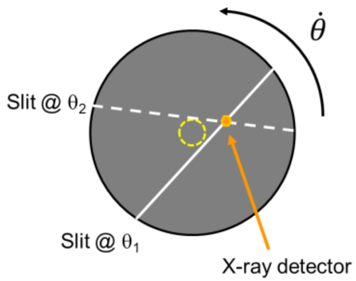
$$\begin{cases} D_{FB}(r) \sim D_{CB}\dfrac{\cos^{-1}\left(\frac{R-0.5w}{r}\right)-\cos^{-1}\left(\frac{R+0.5w}{r}\right)}{\pi}\ for\ r > R \\ D_{FB}(r) = 0\ for\ r \leq R \end{cases}$$

where w is the width of the slit.



GaN probe for low dose guide wire tracking

Dose reduction



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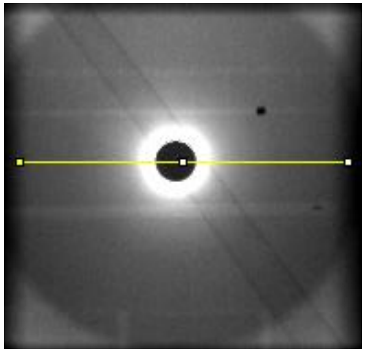
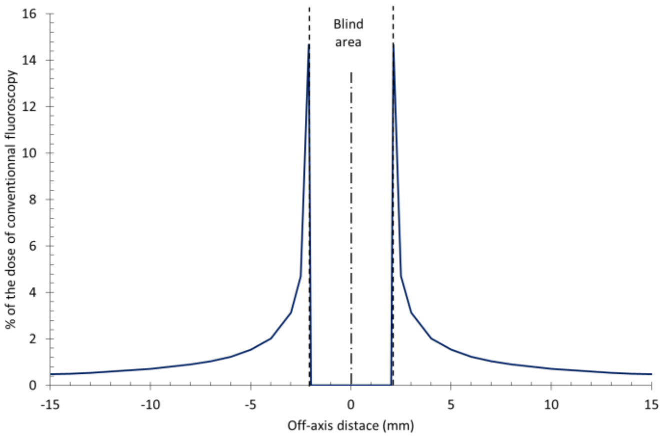
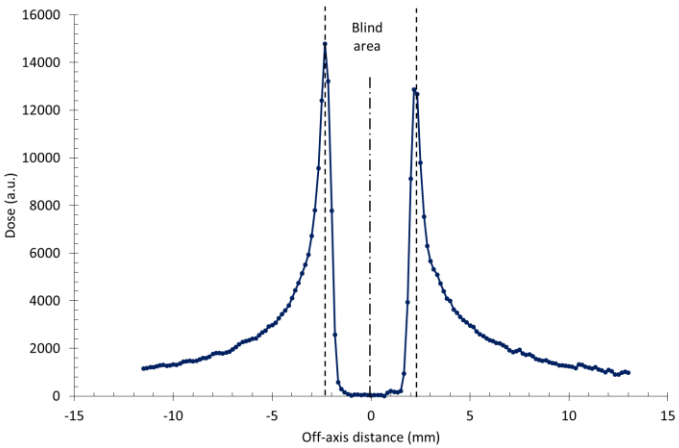
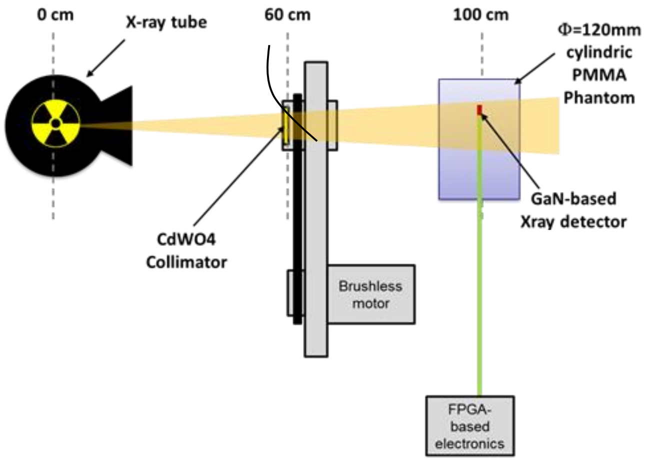
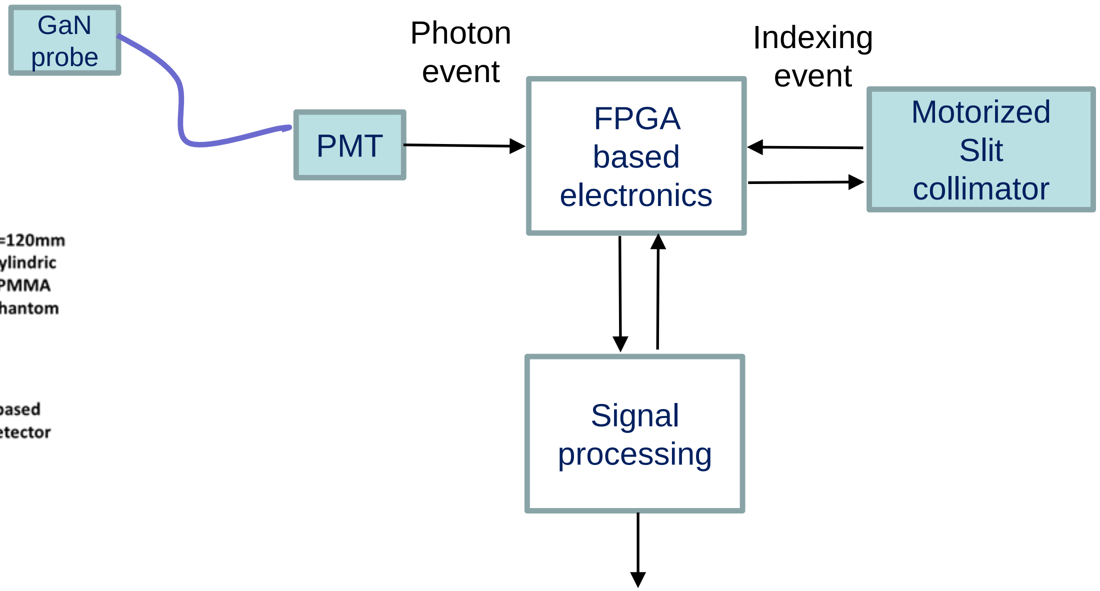






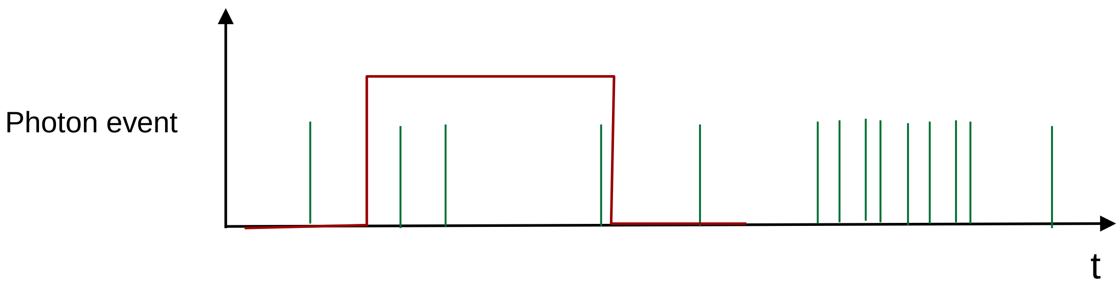
GaN probe for low dose guide wire tracking





Probe position(x_{1i}, x_{2i})
back-projected in preoperative images

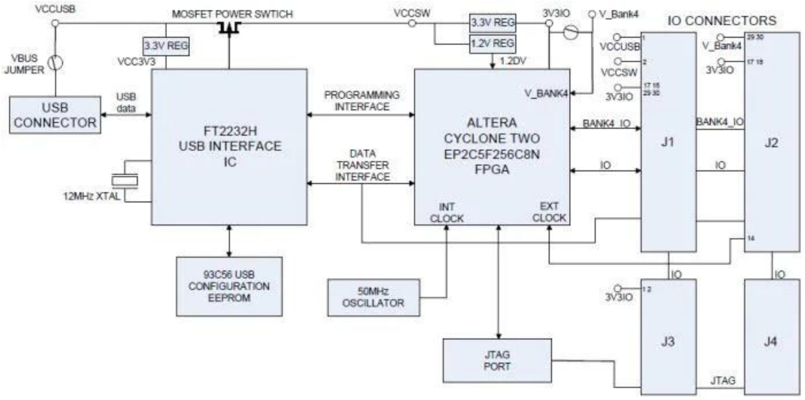
Photon counting over a sliding window providing good timing resolution and low level detection



GaN probe for low dose guide wire tracking

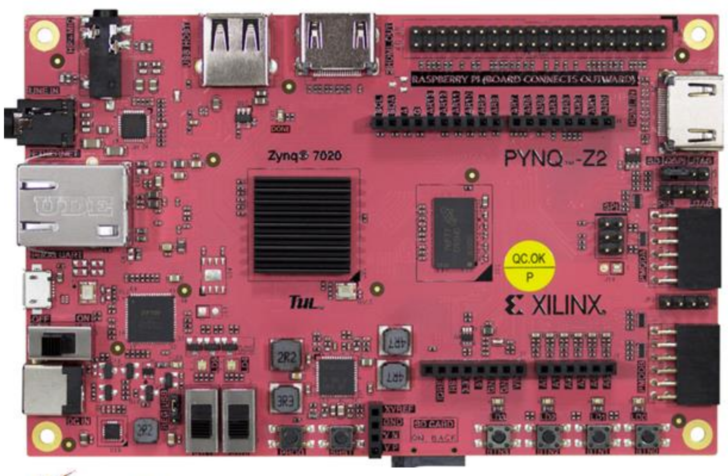
FPGA based electronics: 1st prototype Cyclone II

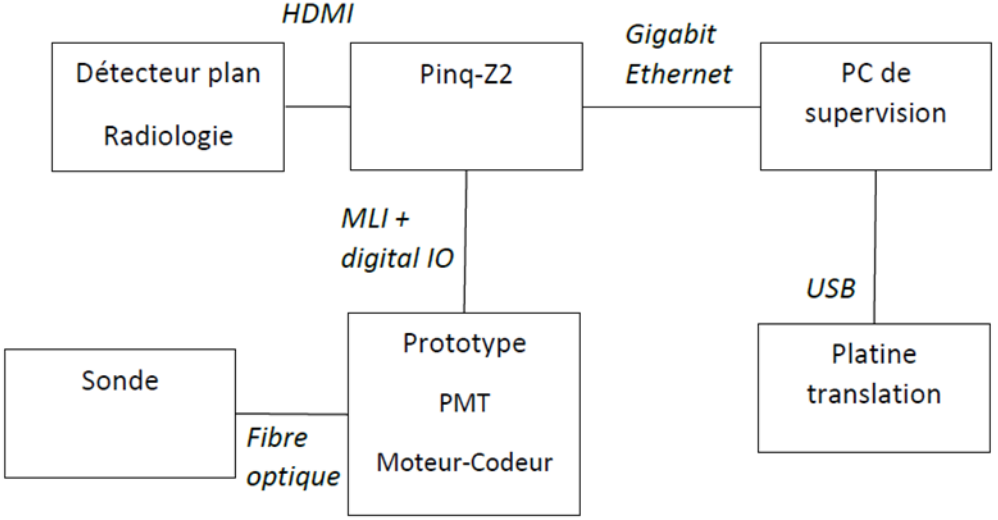
Morphic-IC development board



FPGA based electronics: 2nd prototype Xilinx Zynq XC7Z020 System on Chip (SoC).

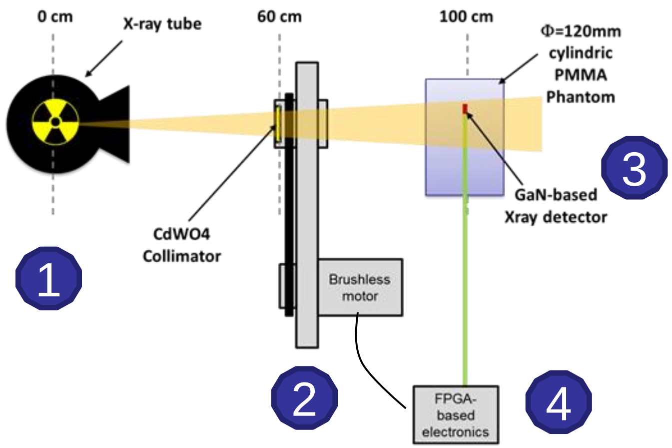
PYNQ-Z2 Development Board



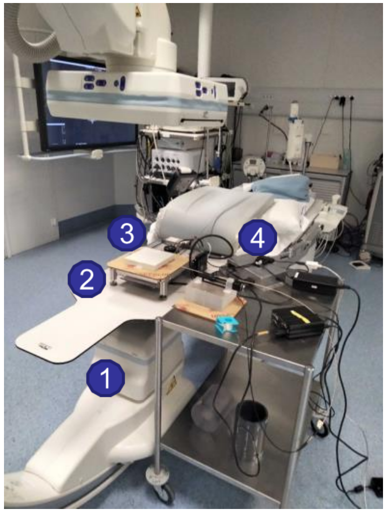


GaN probe for low dose guide wire tracking

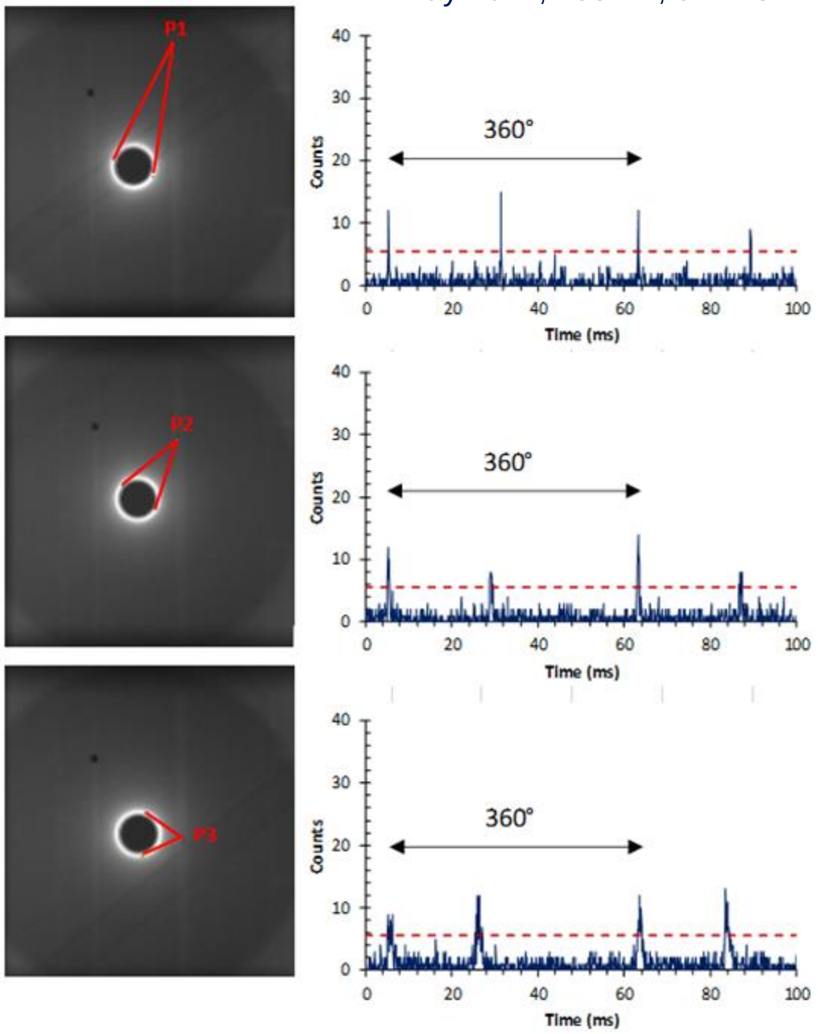
Instrumentation



Experimental setup
for system testing



X-Ray 70kV, 155mA, 644ms



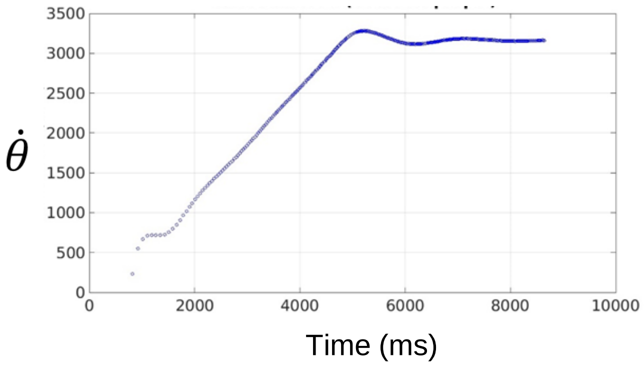
GaN probe for low dose guide wire tracking

- Integration over a sliding window :

High time resolution

but

limited angular resolution due to angular speed variations



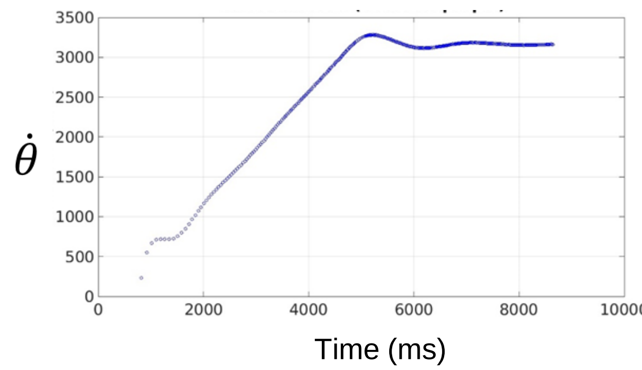
GaN probe for low dose guide wire tracking

- Integration over a sliding window :

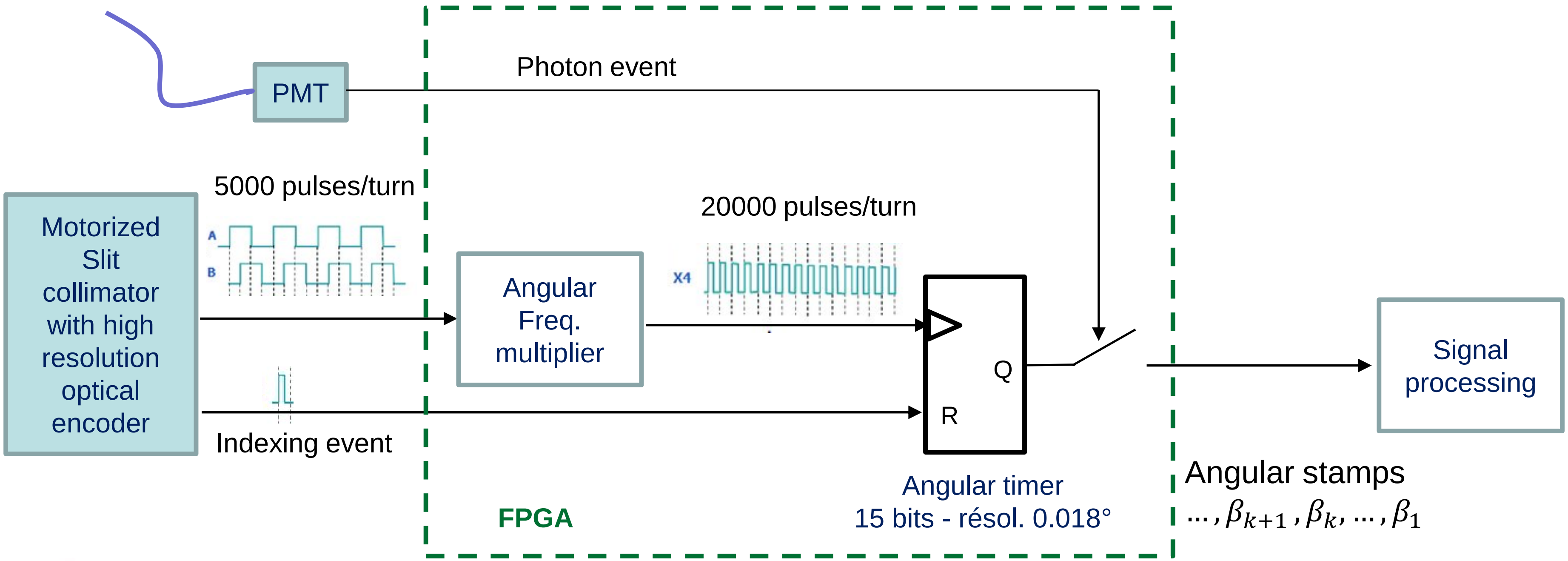
  High time resolution

  but

  limited angular resolution due to angular speed variations

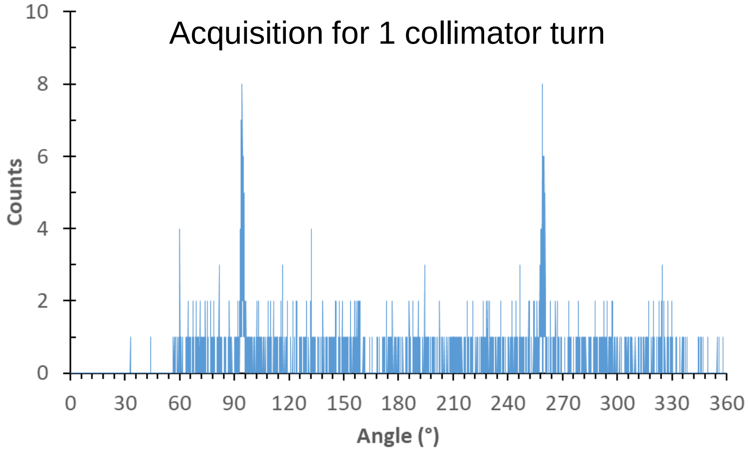


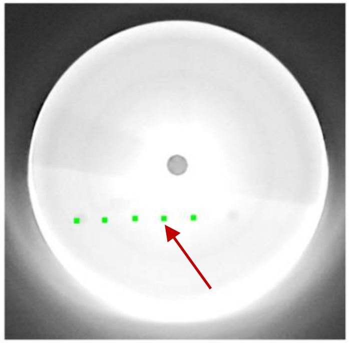
- PMT operated in photocounting mode + photon stamping with its angle of arrival

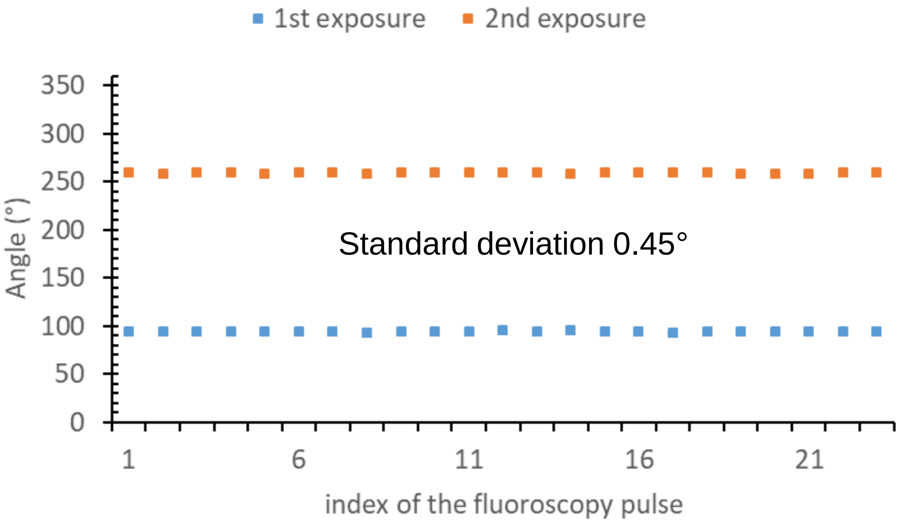


GaN probe for low dose guide wire tracking

Fluoroscopy 107 kV@110.8 mA pulse 20.9 ms (SDD~60cm depth =1.5cm)
Collimator 3500 rpm (17 ms/turn) (2.3mAs - dose reduction ratio ~70)







Thank you for your attention

- ✓ Brachytherapy QA – QC (ANR SECURIDOSE)

P. Pittet, P-Y Guiral, R. Wang, G-N Lu, J-M Galvan

P. Jalade, J. Ribouton

L. Gindraux, A. Rivoire

Guiral, P., Ribouton, J., Jalade, P., Wang, R., Galvan, J.-M., Lu, G.-N., Pittet, P., Rivoire, A. and Gindraux, L., Med. Phys., 43, 2016

- ✓ Low-dose Virtual fluoroscopy (ANR NEWLOC)

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Y. Grondin, P. Augerat, E. Tranchant

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A. Gaudu

Guiral P, Pittet P, Grondin Y, Jalade P, Galvan JM, Lu GN, Desbat L, Cinquin, Stud Health Technol Inform. 2019 Aug 21;264