Nuclear Physics Mid Term Plan in Italy

LNF – Session

Frascati, December 1st - 2nd 2022

Detectors for medical applications: X-ray and Gamma imaging

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Outline

1. X and γ-ray detection in medical imaging applications

2. X-ray detectors developments and applications @ INFN

   - Photon-counting and spectral imaging: SYRMA3D, KEST, PEPI
   - Next generation hybrid pixel detector: MEDIPIX4
   - Innovative material/sensors: PEROV

3. γ -ray detectors developments and applications @ and around INFN

   - γ and β imaging detectors: synergy with ISOLPHARM
     - ALPIDE – based detector for β-imaging
     - X and γ-ray spectrometer
   - SiPMs for Time of Flight PET @ FBK
   - Radiometabolic therapy and radioguided surgery
     - WIDIMapp: a Wearable Individual Dose Monitoring Apparatus
     - CHIRONE/CHIR2: Beta RadioGuided Surgery with β radiation

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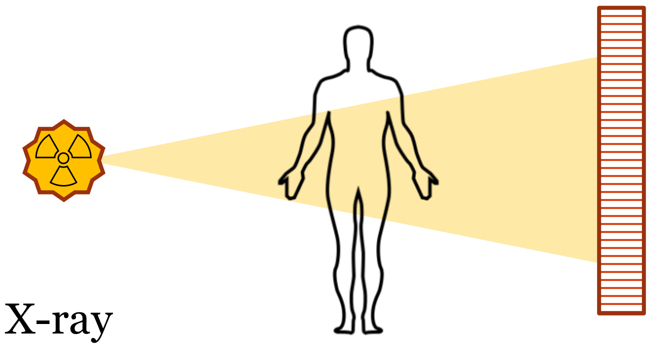
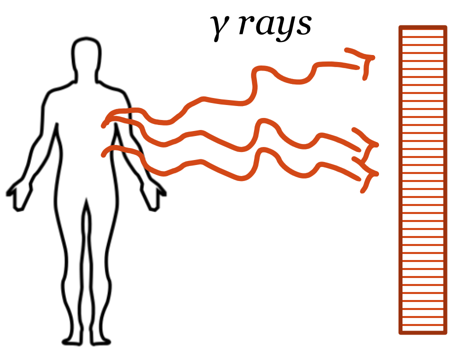
X-ray imaging

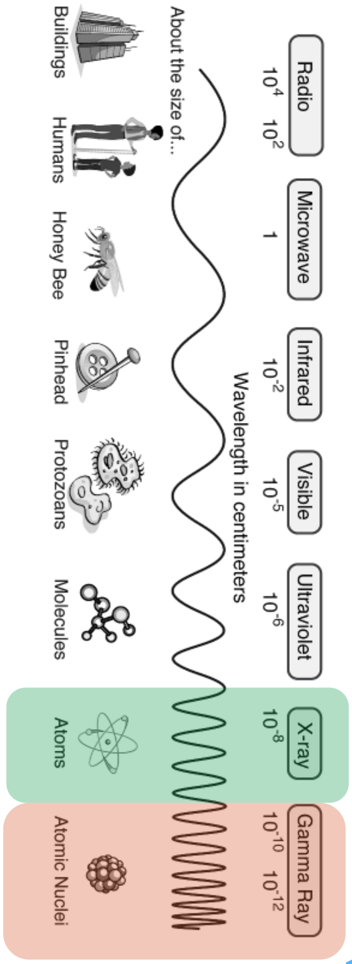


- Planar radiography
- Computed Tomography (CT)
- Fluoroscopy
- …

γ imaging



- Positron Emission Tomography (PET)
- Single Photon Emission Tomography (SPECT)
- …



X-ray imaging detectors

- Energy range → 10 – 150 keV
- High spatial resolution & large FOV → down to 100 μm & several cm^2
- High flux → up to ~10^9 $ph/mm^2/s$ in modern CT
- Photon-counting → Higher soft tissue visibility
- Spectral → Chemical information
- High efficiency → Minimize the patient dose

γ imaging detectors

- Energy range → 100 – 1000 keV
- High efficiency → "Few" events available ~10^2 counts/s
- High efficiency → minimize use of pharmaceuticals
- Time resolution → coincidence imaging in PET
- Low-cost wearable → long time-span measurements

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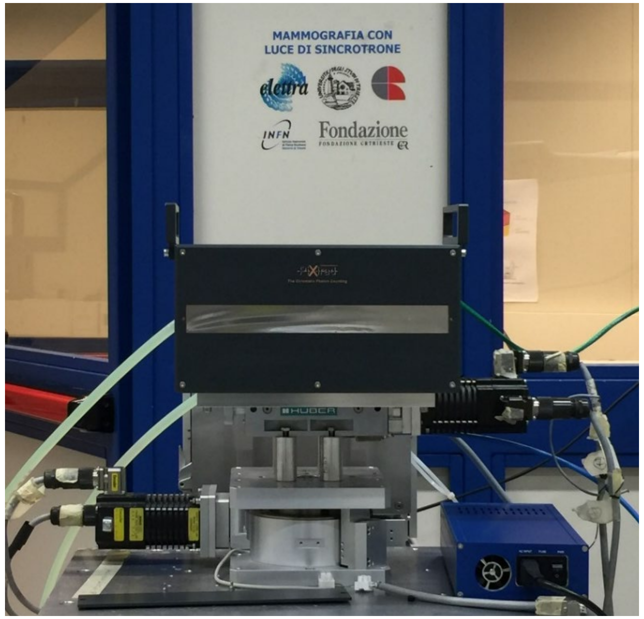
Photon-counting and spectral imaging: SYRMA3D, KEST, PEPI

- PIXIRAD (spinoff INFN-Pisa) developed hybrid detector for X-ray imaging based on PIXIE chip. Sold to PANalytical in 2017.
- Used in several bio-medical imaging applications within INFN-CSN5
  - SYRMA-CT/3D – Syrnchrotron Radiation Mammography
    TS, BO, CA, FE, PI, NA
  - KEST – K-Edge Spectral Tomography
    TS, PI
  - PEPI – Photon-counting Edge-Illumination Phase-contrast Imaging
    TS

SYRMA-CT/3D (2014-2019)

- Development and optimization for phase-contrast breast-CT clinical trial @ Elettra
  - **Large area CdTe single-photon-counting PIXIRAD-8 – PixieII chip**



PROS

- **High efficiency**
- **Large area (25×2.5 cm²)`**
- **Small pixel (60μm pitch)**
- **Dead Time Free Mode**
- **Tunable Threshold**
- **No electronic noise**

CONS

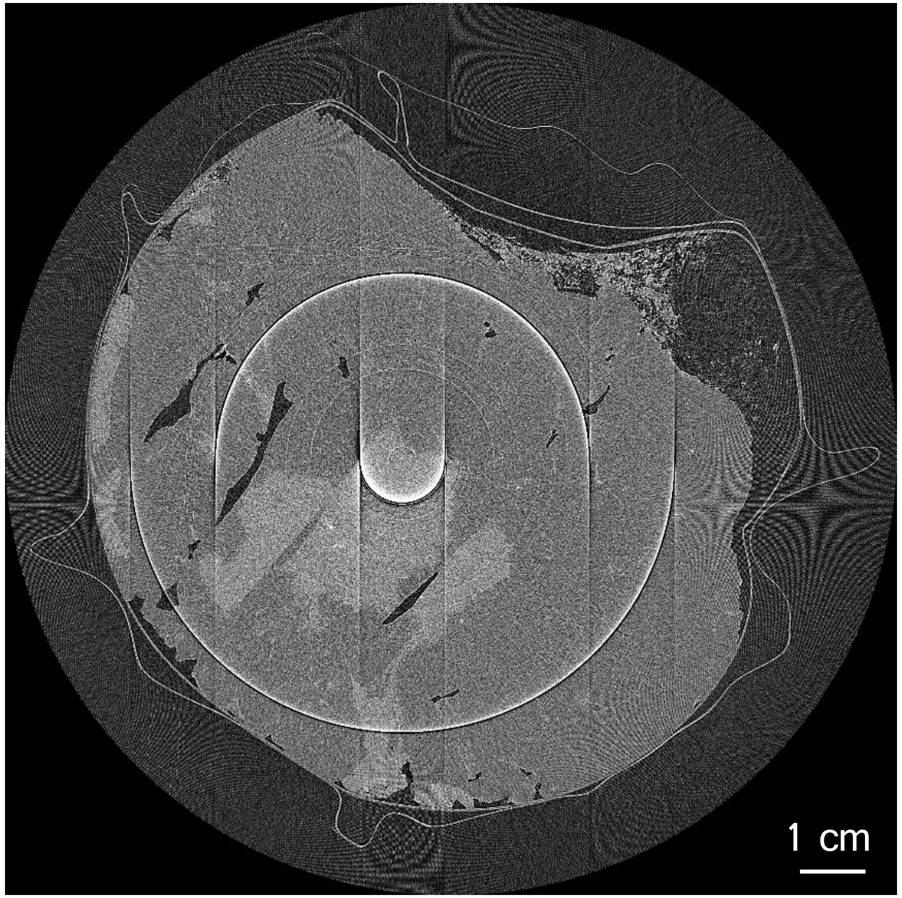
- **3-sides buttable → gap between modules**
- **Time/exposure dependent charge trapping effects**

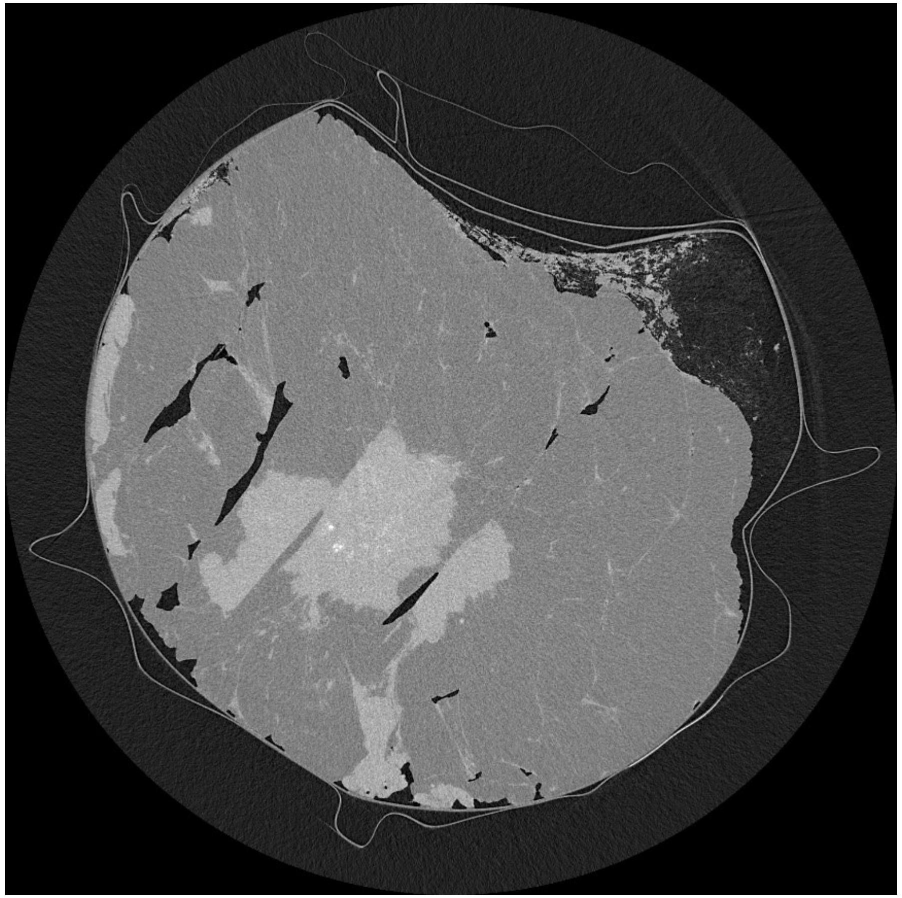
Requires detector-specific pre-processing

Bellazzini, R., et al. JINST 8.02 (2013): C02028.
Delogu, P., et al. JINST 11.01 (2016): P01015.
Delogu, P., et al. JINST 12.11 (2017): C11014.

Photon-counting specific pre-preprocessing

Without pre-processing → **With pre-processing**





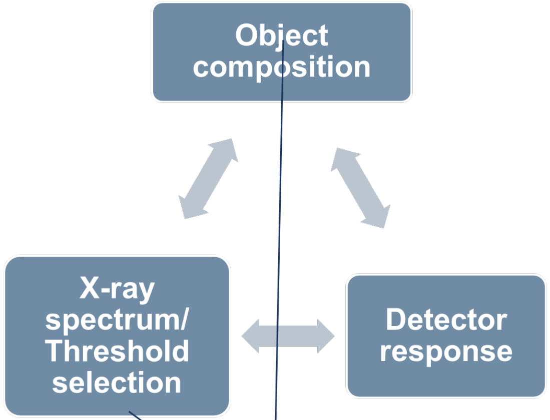
- CT scan on a breast tissue surgical specimen @ Elettra
- 1200 angular vies projections
- X-ray energy: 32 keV
- Dose 20 mGy

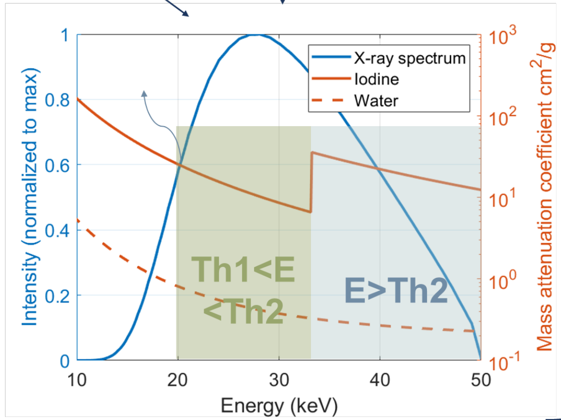
Brombal, L., et al. *Journal of synchrotron radiation* 25.4 (2018): 1068-1077.

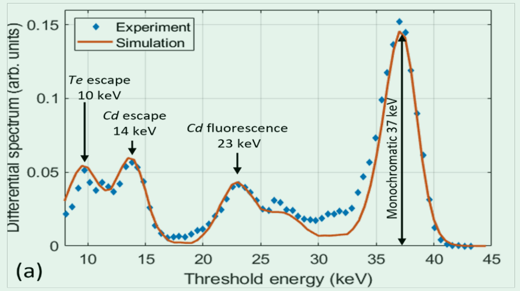
KEST (2017-2018) PEPI (2021 - 2022)

Detector **characterization is critical in spectral imaging**

PIXIRAD1 – PixieIII chip

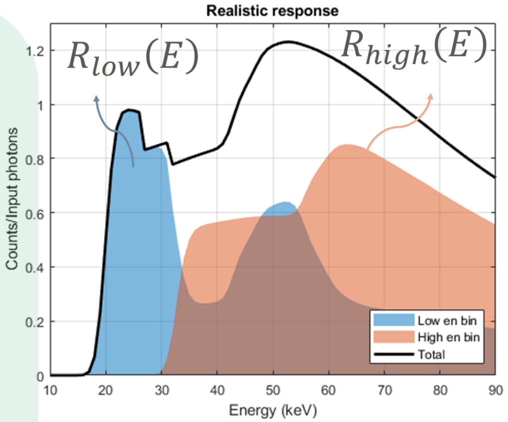




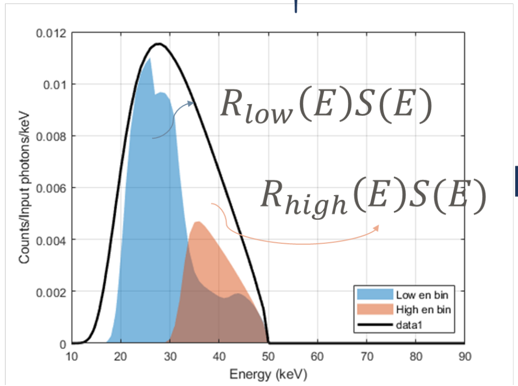


***Pixirad1-PixieIII, NPISUM mode**: Differential threshold scan with 33 keV monochromatic X-ray @ SYRMEP*

E [keV]	FWHM [keV]	ΔE/E
26	3.4 ± 0.4	(13 ± 2)%
33	3.6 ± 0.4	(11 ± 1)%
37	3.7 ± 0.4	(10 ± 1)%
50	4.1 ± 0.4	(8.2 ± 0.8)%



Brombal, L., et al. JINST 17.01 (2022): C01043.
Di Trapani, V., et al. NIM-A 955 (2020): 163220.



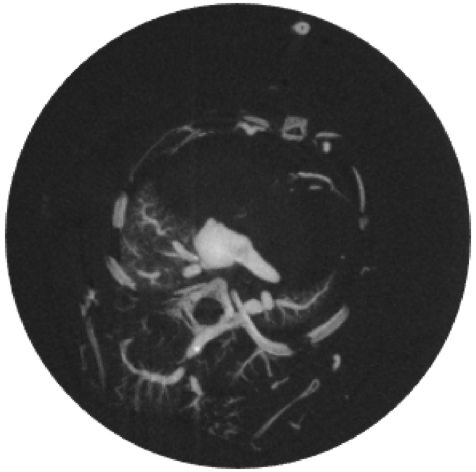
Material decomposition matrix

$$A_i^j = \frac{\int S(E) R_i(E) \mu/\rho_j(E) dE}{\int S(E) R_i(E) dE}$$

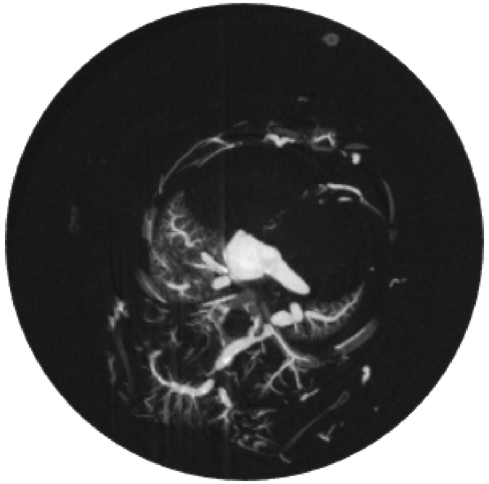
Di Trapani, V., et al. *Optics Express* 30.24 (2022): 42995-43011.
Brombal, L., et al. *JINST* 17.01 (2022): C01043.

KEST (2017-2019) PEPI (2021 - 2022)

Bin1 [27, 33] keV

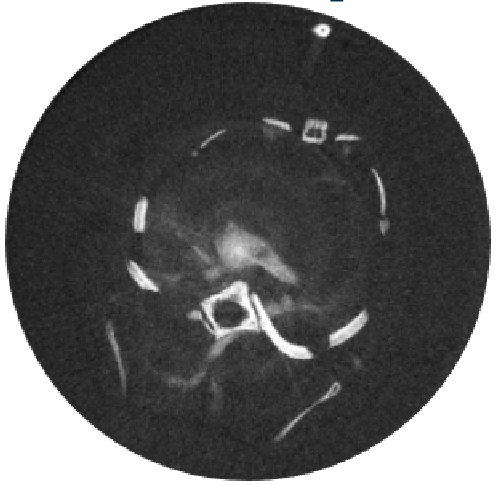


Bin2 >33 keV

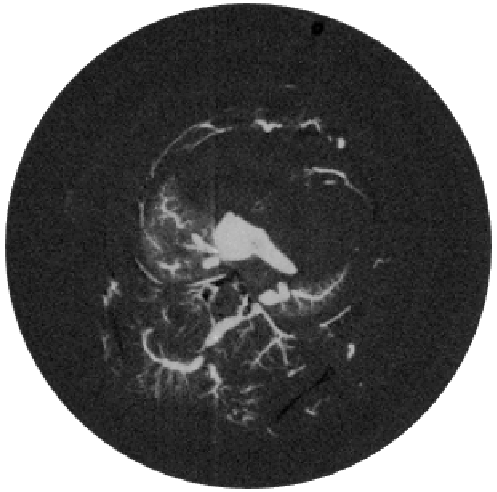


1 cm

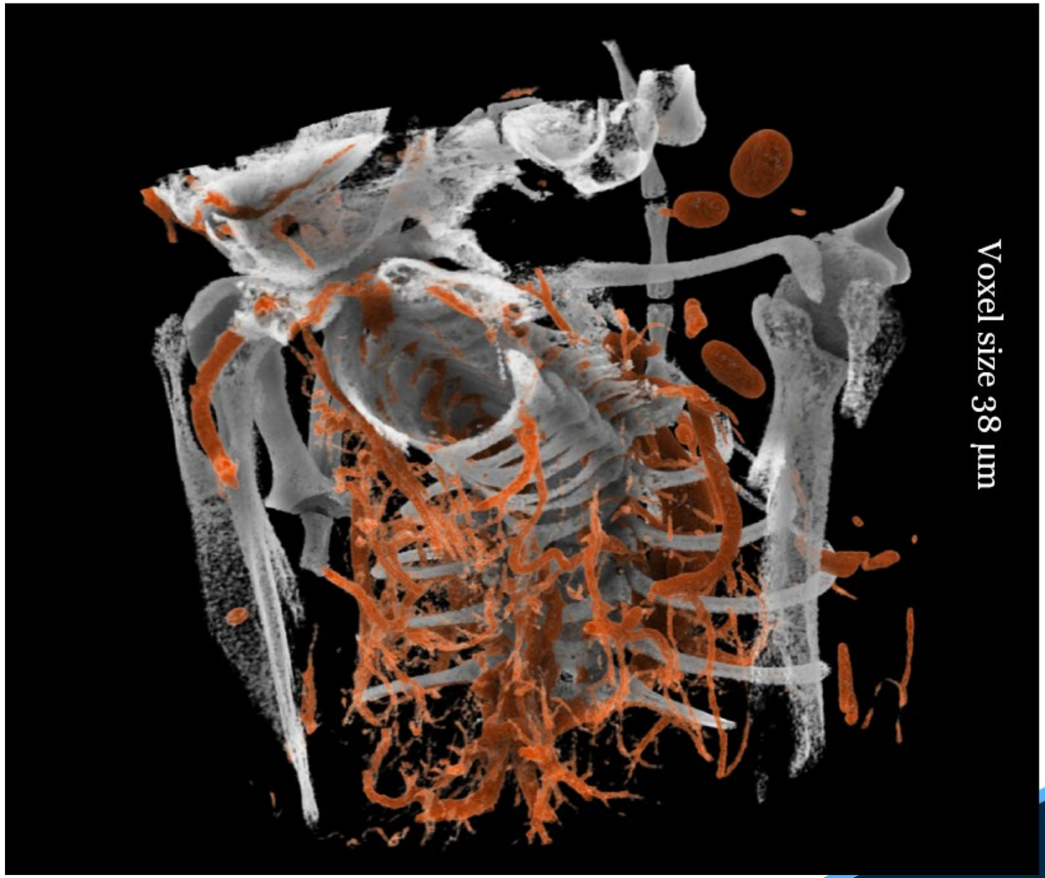
Bone map



Iodine map



VIDEO IN THE ORIGINAL PRESENTATION



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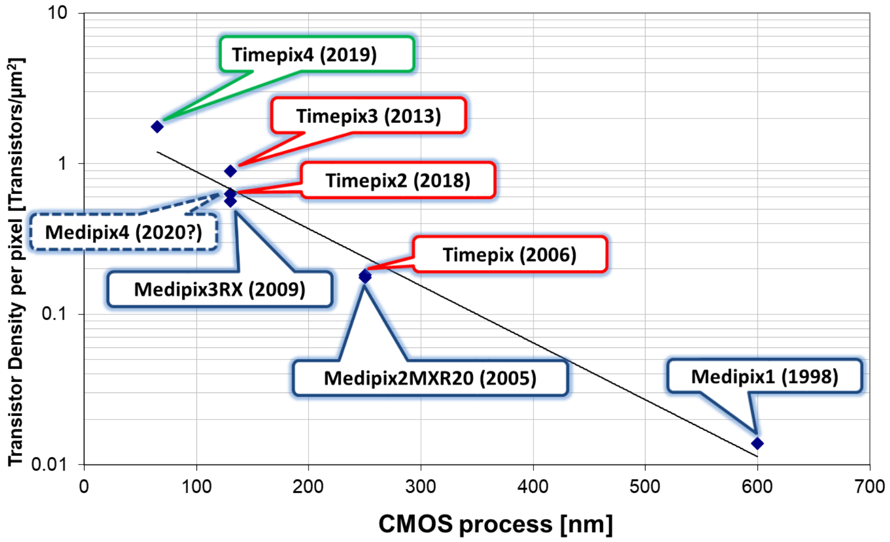
Medipix 4 collaboration

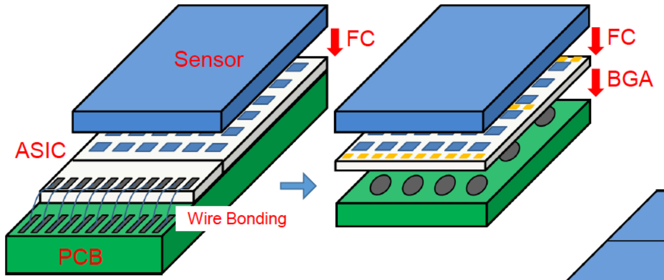
- INFN became official member of the Medipix4 Collaboration in November 2020
- Collaboration based at CERN with 18 members
- Two new ASICs produced:
  - **Timepix4**
    4-side buttable large single-threshold particle tracking detector chip with improved energy and time resolution and with high-rate imaging capabilities
  - **Medipix4**
    Will target spectroscopic X-ray imaging at rates compatible with medical CT scans

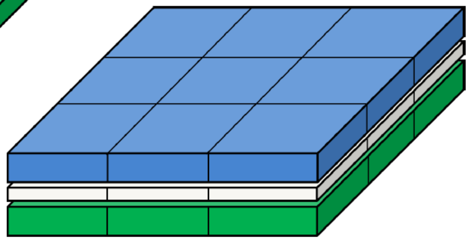


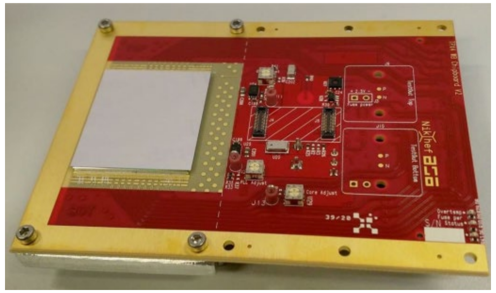
Courtesy of M. Fiorini

Timepix4 ASIC specifications

- 4-side buttable pixel arrangement
- Target to build large area detectors by combining smaller modules
- The **Through-Silicon Vias (TSVs)** is the key technology for this paradigm shift







			Timepix3 (2013)	Timepix4 (2019)
Technology			130nm – 8 metal	65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448 **3.5x**
Sensitive area			1.98 cm^2	**6.94 cm^2**
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	TOT and TOA
		Event Packet	48-bit	64-bit **33%**
		Max rate	0.43×10^6 hits/mm^2/s	**3.58×10^6 hits/mm^2/s** **8x**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)
		Max count rate	~0.82×10^9 hits/mm^2/s	~5×10^9 hits/mm^2/s **5x**
TOT energy resolution			< 2KeV	**< 1Kev** **2x**
TOA binning resolution			1.56ns	**195ps** **8x**
TOA dynamic range			409.6 µs (14-bits @ 40MHz)	**1.6384 ms** (16-bits @ 40MHz) **4x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps** (16x @10.24 Gbps) **32x**
Target global minimum threshold			<500 e^-	<500 e^-

Courtesy of M. Fiorini

MEDIPIX4 – CSN5 (2021-2023)

aimed at the exploitation of the family of application-specific integrated circuits (ASICs) developed by the Medipix4 Collaboration at CERN

5 INFN Division involved (FE, LNS, NA, PI, TS), National Resp: M. Fiorini (Ferrara University and INFN)

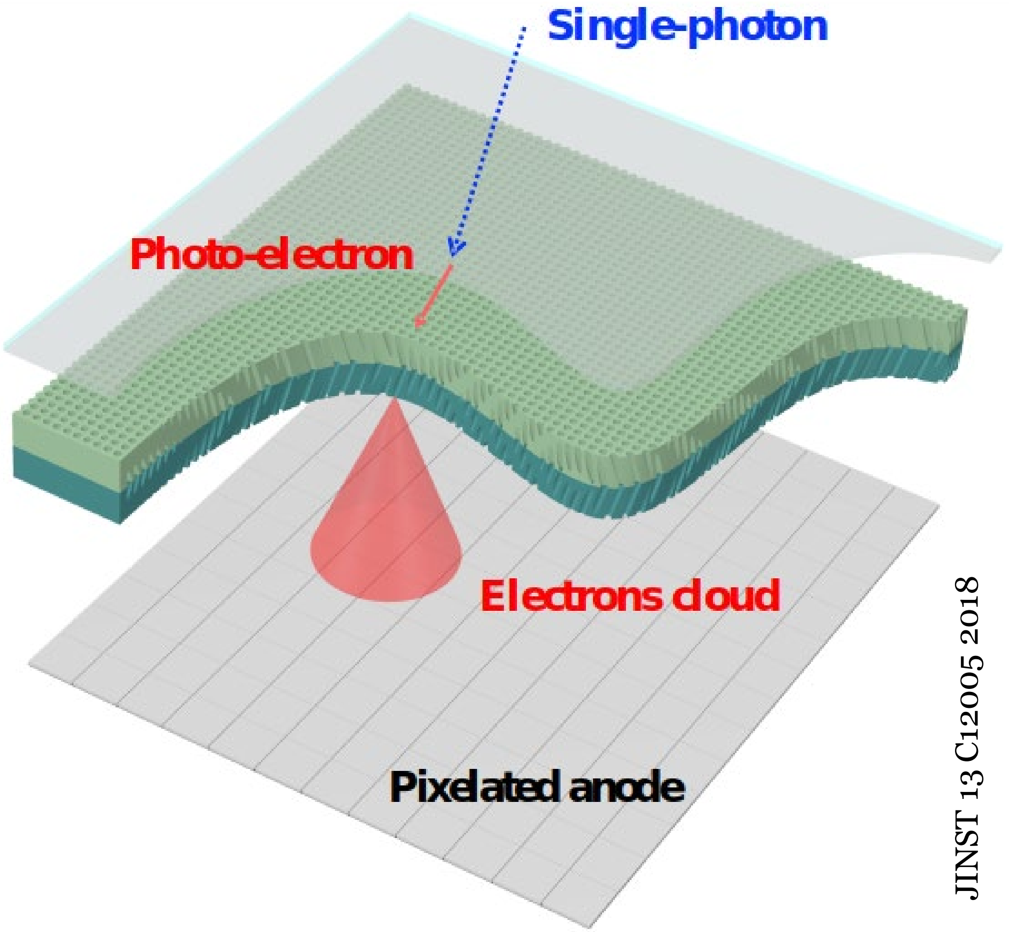
- **WP1: Electronics/software/cooling** (WP Leader: FE; Participating Groups: NA,PI)
- **WP2: New sensors development** (SiC, UV) (WP Leader: LNS; Participating Groups: Ferrara, LNS, Napoli) → see Giada Petringa's talk
- **WP3: Dosimetry and Nuclear Medicine** (WP Leader: NA, Participating Group: PI, LNS)
  - Nuclear Medicine - Compact gamma camera (NA)
  - Dosimetry - Gamma-ray detector for dosimetry and MV X-rays (NA), Diagnostic X-ray beams (PI), charged particles (LNS)
- **WP4: X-ray imaging** (WP Leader: Pisa; Participating Groups: FE, NA, PI and TS)
  - Spectral imaging (TS, PI, FE)
  - Phase Contrast Imaging (TS, NA)

Courtesy of M. Fiorini

Hybrid MCP development

- Hybrid vacuum photo-detector development
  - photocathode + MCP multiplication + Timepix4 anode in vacuum tube
  - **Funded by ERC: 4DPHOTON** (INFN, CERN, UniFE)

- **Synergies with MEDIPIX4** CSN5 project:
  - Development of FPGA-based read-out electronics for the Timepix4 ASIC
  - Development of open-source control and data acquisition software
  - Strong expertise available to the INFN community

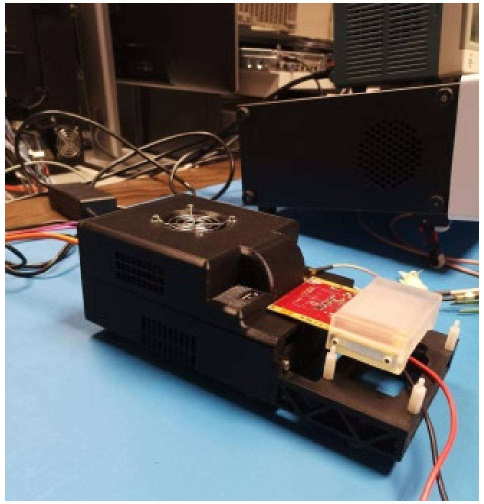


JINST 13 C12005 2018

Courtesy of M. Fiorini

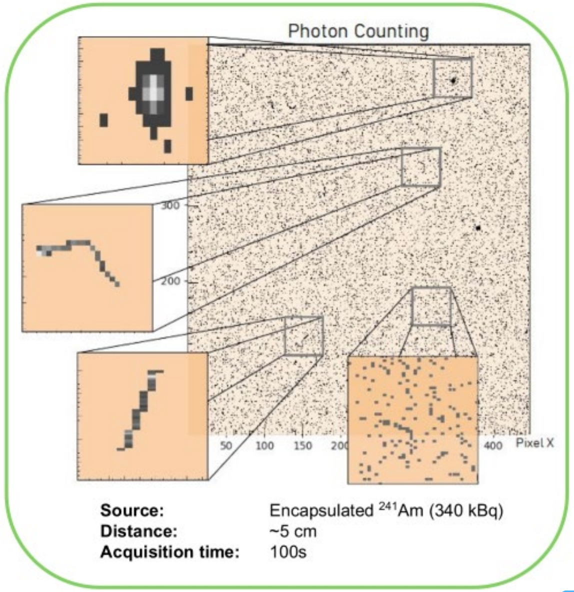
Current status

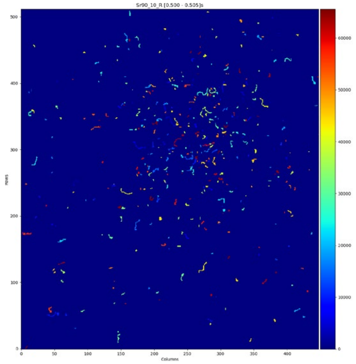
- First Timepix4_v2 bump-bonded assemblies (300 µm Si sensors, Advacam) available September 2022 and currently under test in Ferrara
- Software for slow-control and fast readout of Timepix4 under development in Ferrara, first release ready soon
- Production of assemblies with 0.5-2.0 mm CdTe sensors will be launched at the beginning of 2023



Future activities

- 2022 Medipix4 chip produced
- 2023 test of Timepix4 Si assembly + procurement of CdTe assembly
- Medipix4 assemblies production planned 2023





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PEROV (2020-2023)

- R&D for photodetectors based on Organo-Metal Halide Perovskite (OMHP) materials

- Involving LNF-INFN, INFN-Roma1, Universita' di Roma "La Sapienza", UniRoma2, UniMI, CNR

OMHP are class of hybrid organic-inorganic semiconductor materials with a perovskite unit-cell structure ABX3 with:

- A = CH3NH3+, B = metallic cation (PB2+), X =halide anions (Cl-, Br-, I-)

Organic semiconductors:

- Disordered system
- Localized electronic states
- Hopping transport ⇒ low mobility
- **Low cost, low temperature processing**
- **Can be solution processed**
- **Scalable to large area**

Inorganic semiconductors:

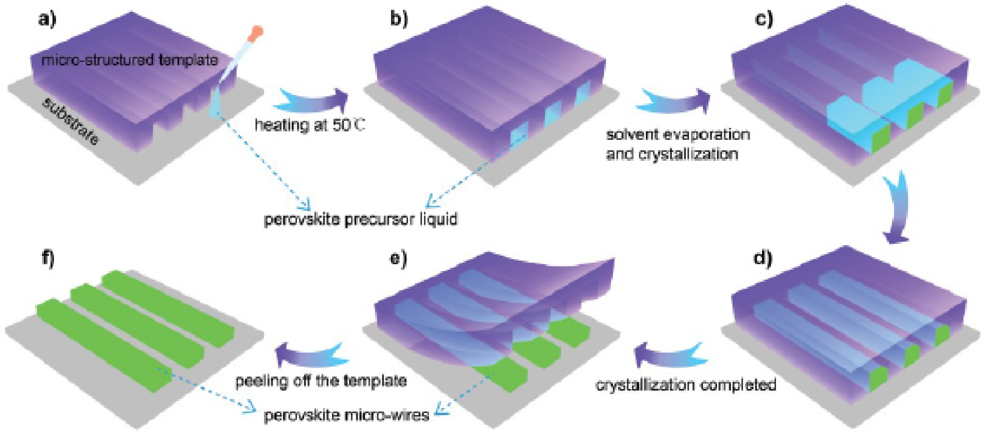
- **Ordered periodic crystal ⇒ band structure**
- **Delocalized Bloch states**
- **band transport ⇒ high mobility**
- Usually wafer based technology
- Costly, high temperature processes

		Silicon	$CH_3NH_3Pb(I,Br)_3$
Density		2.33 g/cm^3	4.15 g/cm^3
Band gap (eV)		1.12 (indirect)	1.5-1.6 / 2.24 (direct)
Mobility (cm^2/Vs)	electrons	1400	< 70/190
	holes	450	< 160/220
Absorption (cm^{-1})		< 10^4	> $4x10^4$
Threshold energy for impact ionization (eV)		1.2	~2 / 2.5 (estimated)
Mean free path (nm)		≤ 100	~100 (theory)

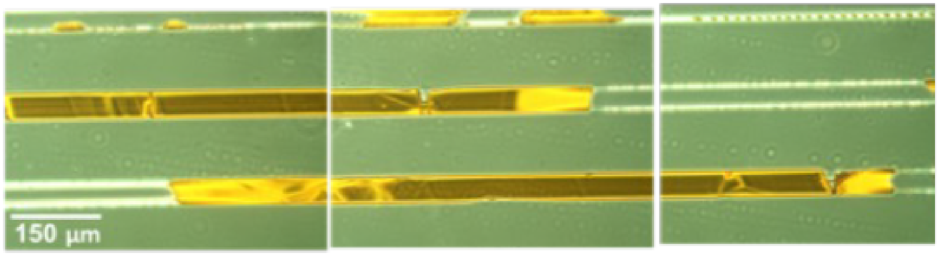
- OHMP band gap tunable changing halide (I,Br,Cl) 🙂
- OMHP contain highly mobile defects and have instabilities issues ☹️

Courtesy of M. Testa – INFN LNF

Micro-fluidics for perovskite crystals production:



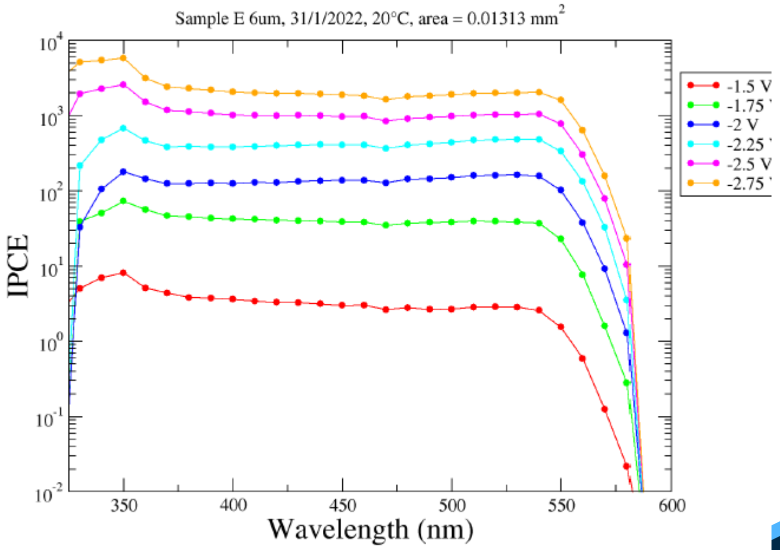
Typical dimension: W x L x H = 150 µm x 500 µm x 6(2) µm
Production by CNR - Nanotec



- Device realized with CH_3NH_3PbBr deposition on **patterned** Indium Tin Oxide/ $CH_3NH_3PbBr_3$ and Au evaporation
  - Innovative technique
  - *Deposited patent (INFN + CNR)* 102022000010469 (*)
- Gain observed at larger bias for thickness of 2 and 6 um

Pro:
- **large flexibility in dimension**
- **moderate area**
- **pixelization**
- **flexible substrate**
- **Deposited directly on substrate**

Contra:
- **need high optimization of parameters (pressure, temperature,..)**



(*) M. Testa, I. Viola, L.De Marco, M. Auf der Maur, F. Matteocci

Courtesy of M. Testa – INFN LNF

- Goal: the feasibility of a hybrid X-ray detector structure combining a perovskite absorption layer and a CMOS silicon active layer
    - Principle: X-ray-generated electrons in the perovskite layer are transferred to silicon and collected by low-capacitance sensing sites coupled to in-pixel readout electronics
- The CMOS chips with an area of the order of $1 cm^2$ are available from ARCADIA INFN project

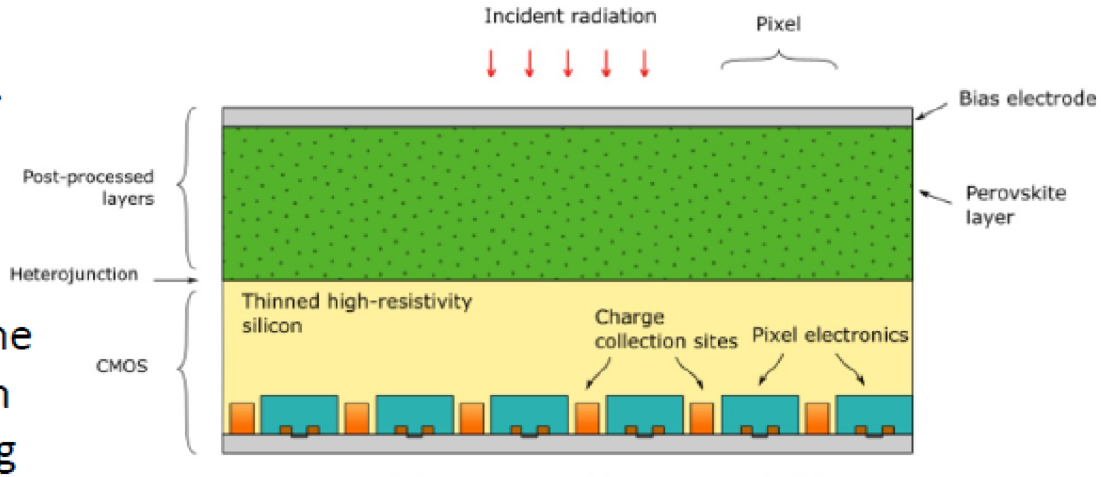
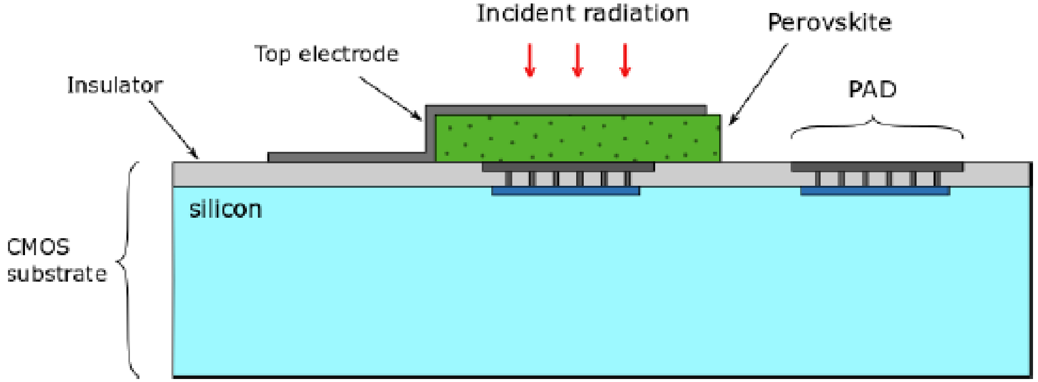


Figure 1. Simplified cross section of the proposed hybrid detector

PRIN 2022 project proposal
L.Pancheri, M. Testa, I.Viola

- On going activity:
    - Test on deposition of perovskite micro-channels through microfluidics technique on CMOS substrates with aluminium pads, used as passive substrates



Courtesy of M. Testa – INFN LNF

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ISOLPHARM

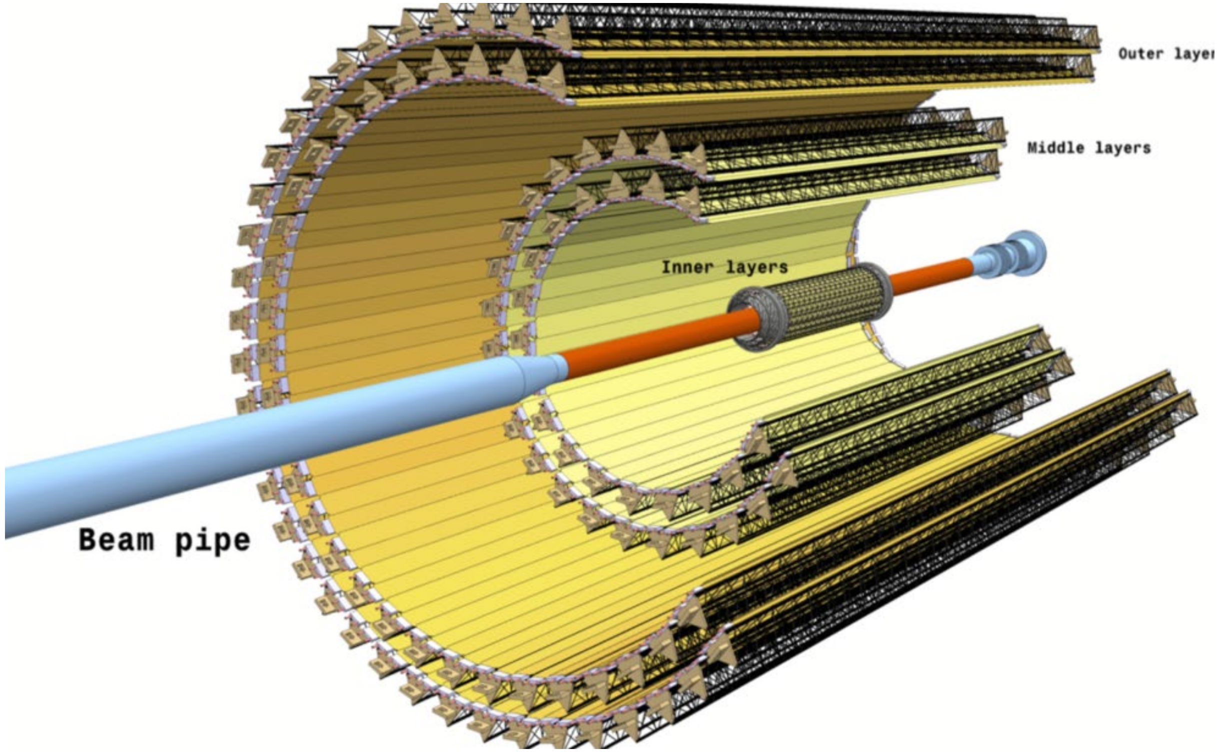
- Aims at the production of wide set of high-purity radionuclides for diagnosis and therapy
- Uses the Isotope Separation On-Line (ISOL) technique @ LNL

- Many partners involved:
  - Within INFN: LNL, TIFPA, PD, PV, LNS, BO, PI

- Many activities including detector development:
  - Beta imaging (e.g. microscopy applications)
  - Gamma imaging (e.g., high-energy gamma camera)

High energy physics → Biomedical application

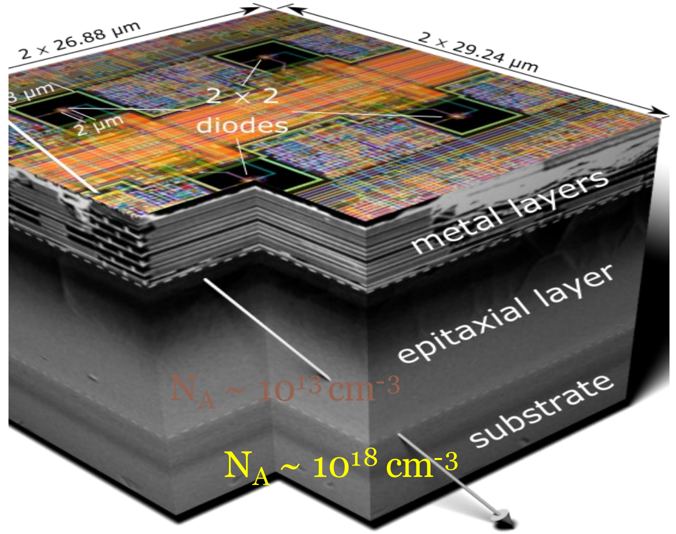
ALICE Inner Tracking System



Mager, M., and ALICE collaboration. *NIMA* 824 (2016): 434-438.

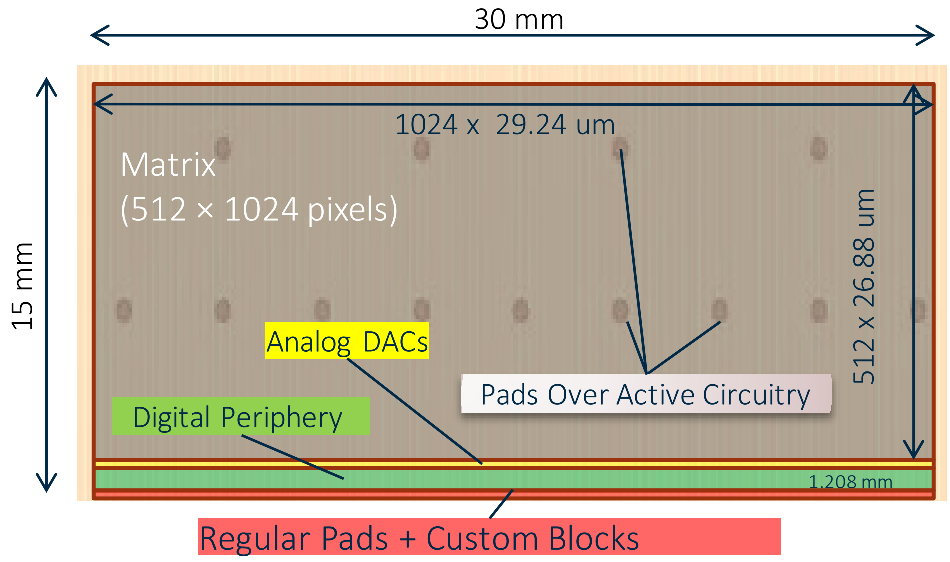
ALPIDE design

Pixel Sensor CMOS 180 nm Imaging Process (TowerJazz) 3 nm thin gate oxide, 6 metal layers

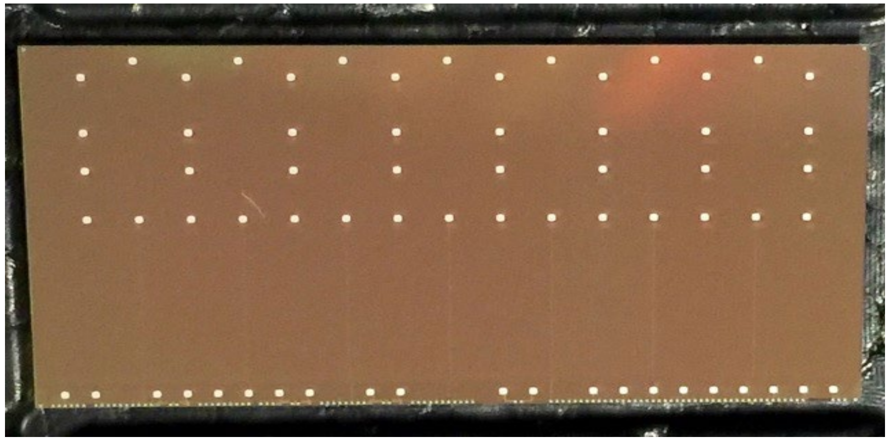


Courtesy of P. Giubilato – INFN LNL

15 x 30 mm^2 area, 100% fill factor, 1-side pads
(or pads over the matrix, but more difficult)



ALPIDE

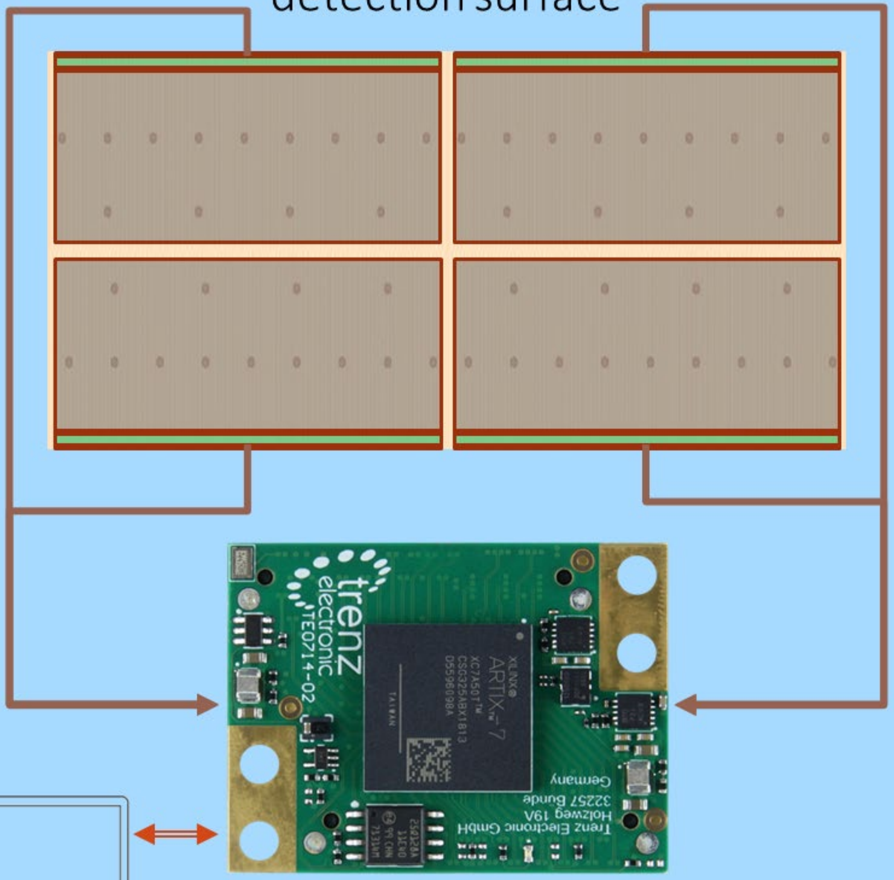


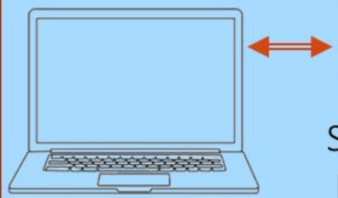
Courtesy of P. Giubilato – INFN LNL

Parameter	ALPIDE
Chip size (mm x mm)	15 x 30
Chip thickness (µm)	50 / 100
Spatial resolution (µm)	5
Detection efficiency	>99%
Fake hit rate	<< 10^{-6} (<10^{-8})
Integration time (µs)	< 6
Power density (mW/cm^2)	~40
Hit rate (cm^{-2})	> 1 MHz

High-rate detection possible thanks to in-sensor data sparsification performed at pixel level

By tiling is possible to create a uniform detection surface

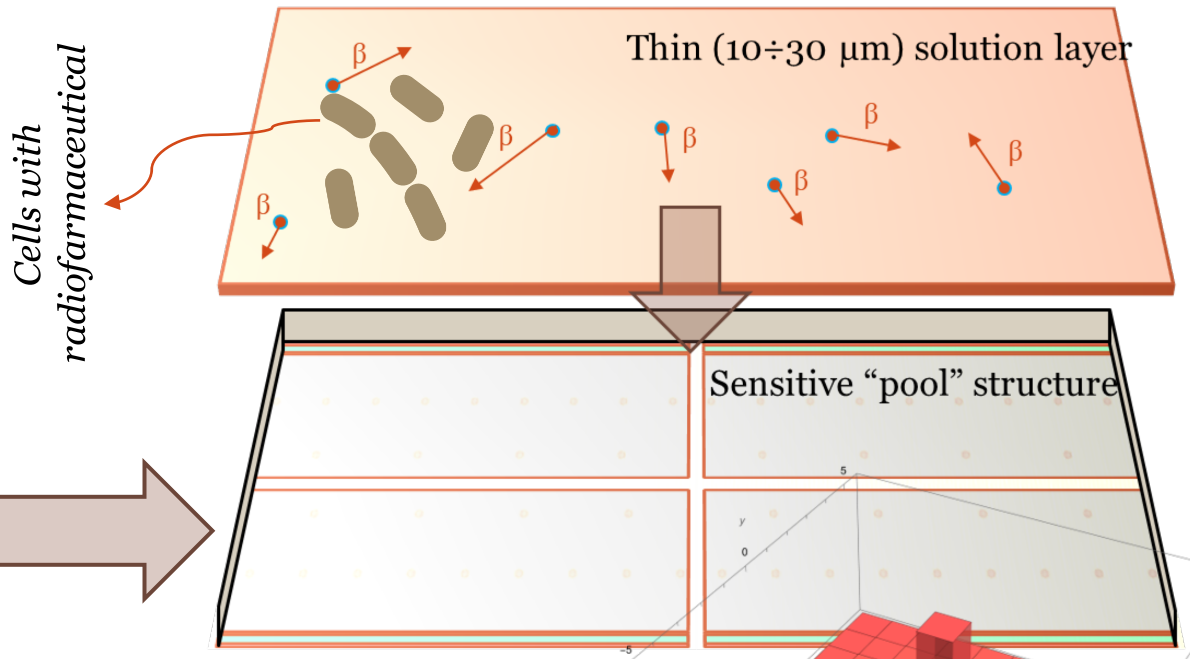




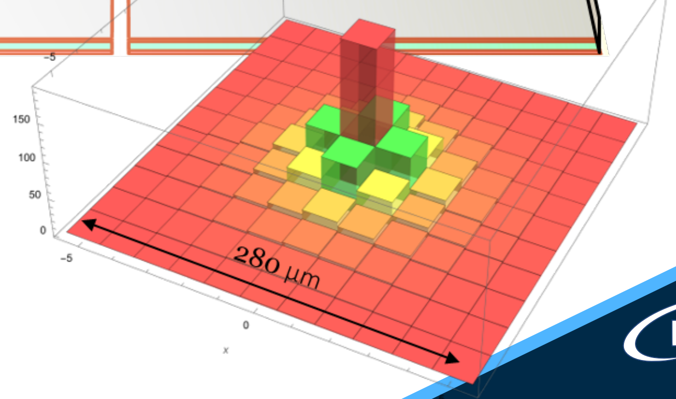
Small, cheap system-on-board FPGA for high-speed readout and sensors management

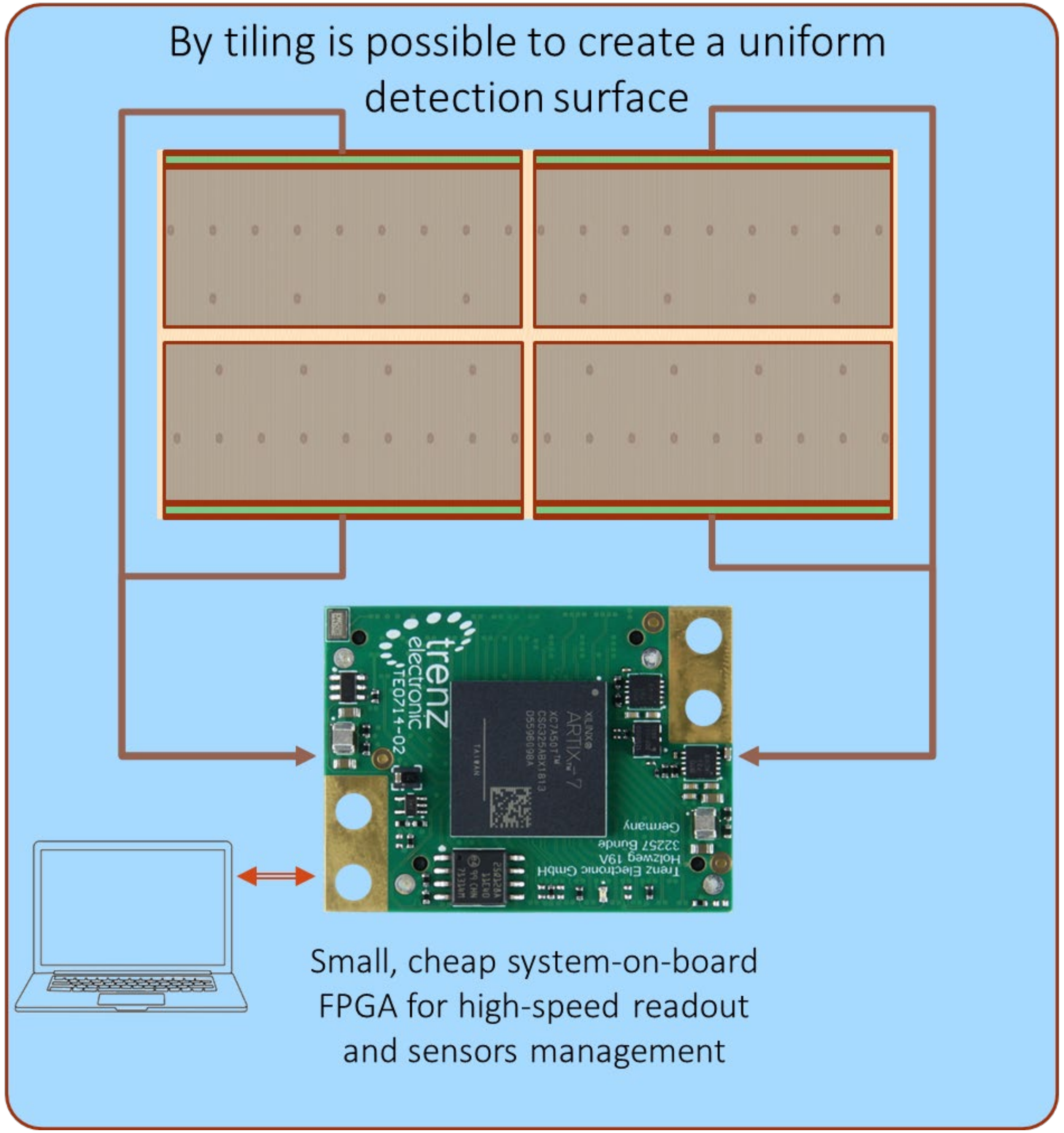
Courtesy of P. Giubilato – INFN LNL

A "detecting pool" allows β detection over a very large area, <u>in parallel</u>, with ≈10 μm resolution (Lambertian)



Lambertian illumination for 4π emission at a distance of 30 um from the sensor (28 μm pixel). The signal remains strongly clustered, allowing precise position determination





Courtesy of P. Giubilato – INFN LNL

Production

Large scalability potential

→ Detector are produced with the same processes as in smartphones sensor
→ Cheap (few USD per cm²)

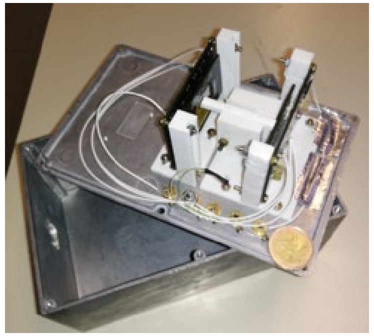
Future

Stacked structure for 3D high granularity sensor for other medical applications

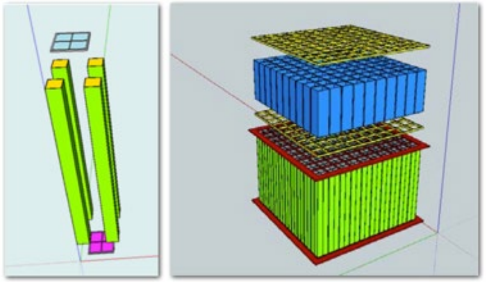
→ X-ray detection
→ Gamma detector (low energy)
→ Sensor for Photo Electron Emission Microscopy (PEEMS)

Compact and modular position-sensitive gamma detectors for medical and space applications

XGS, a compact and modular X and gamma-ray spectrometer with CsI scintillators and double-readout Silicon Drift Detectors with dedicated electronics for the THESEUS mission by ESA.

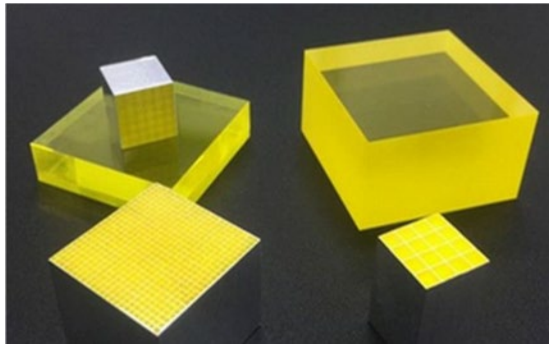


The ProtoXGS-2 prototype. A single 4.5 x 4.5 x 45 mm3 scintillator bar is coupled at both ends with single cell, 5 x 5 cm2 SDDs each with a PA-001 preamplifier.

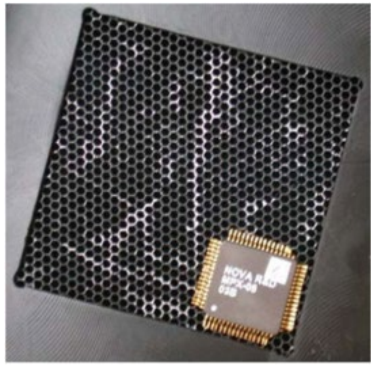


Layout of the XGS module

In the context of the **ISOLPHARM** project, a new gamma camera module optimized for the gamma radiation emitted by Ag-111 (main line 342 keV, 7%) will be developed during the next 3 years.



GAGG scintillators in slab and matrix produced by Epic-Crystal *in the framework of the FAMU experiment.*



It foresees the modern GAGG scintillators already tested in Bologna as part of other projects (ASI HERMES nanosatellites), SiPM and fast readout electronics.

50 × 50 mm2 collimator used in an experimental γ-camera (INFN former Scintirad Project);

G. Baldazzi , INFN-BO

Outline

1. X and γ-ray detection in medical imaging applications

2. X-ray detectors developments and applications @ INFN

   - Photon-counting and spectral imaging: SYRMA3D, KEST, PEPI
   - Next-generation hybrid pixel detector: MEDIPIX4
   - Innovative material/sensors: PEROV

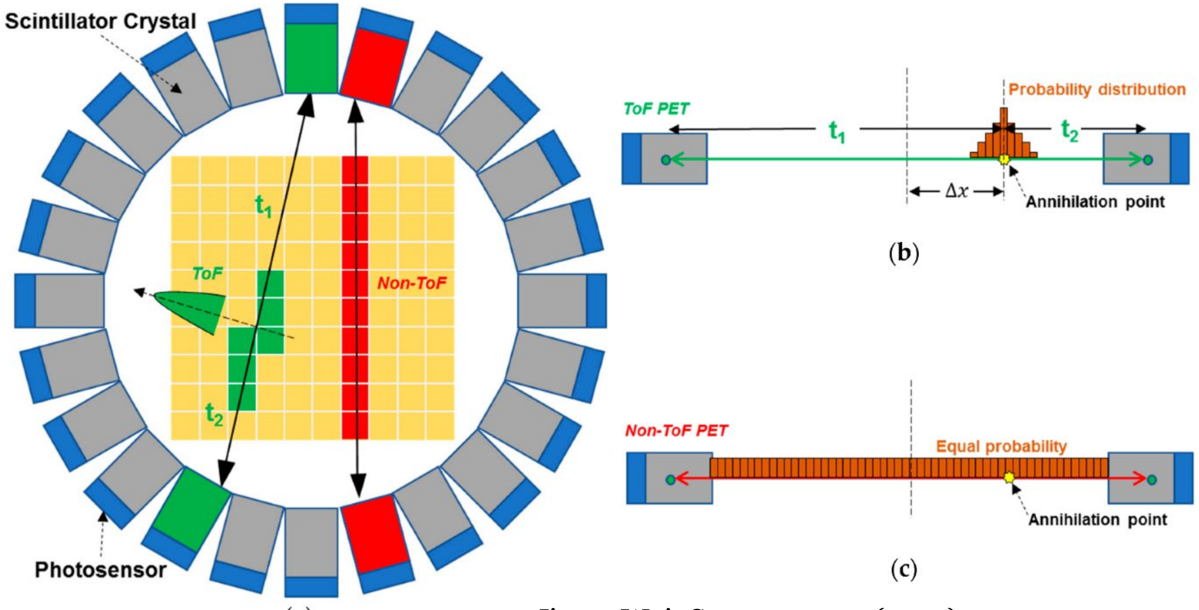
3. **γ -ray detectors developments and applications @ and around INFN**

   - γ and β imaging detectors: synergy with ISOLPHARM
     - ALPIDE – based detector for β-imaging
     - X and γ-ray spectrometer

   - **SiPMs for Time of Flight PET @ FBK**

   - Radiometabolic therapy and radioguided surgery
     - WIDIMapp: a Wearable Individual Dose Monitoring Apparatus
     - CHIRONE/CHIR2: Beta RadioGuided Surgery with β radiation

PET and ToF PET

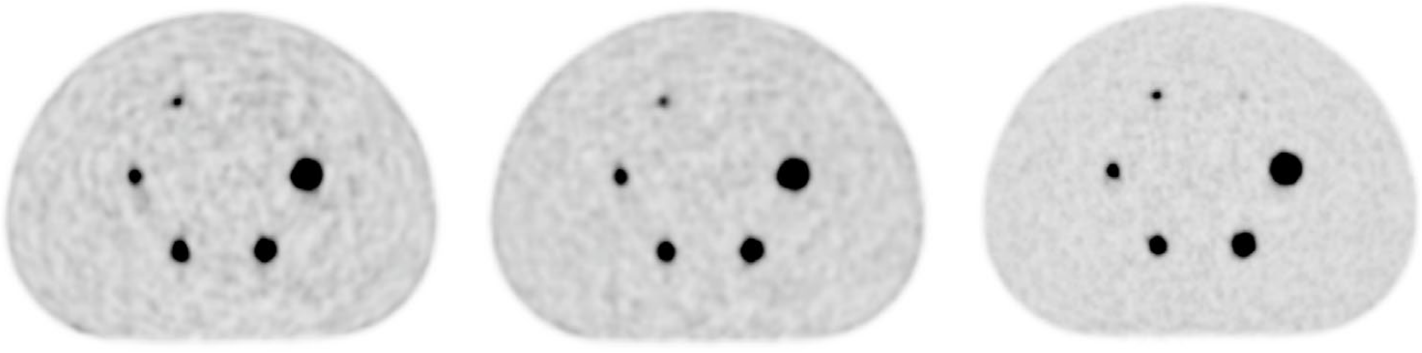


Jiang, Wei, *Sensors* 19.22 (2019): 5019.

Time-of-Flight (TOF) PET

V

Conventional PET

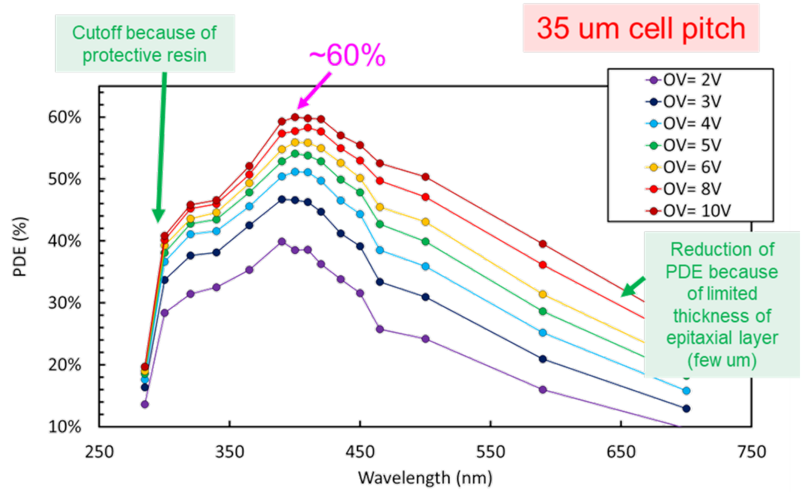


(a) nonTOF **(b)** TOF, 527ps **(c)** TOF, 210ps

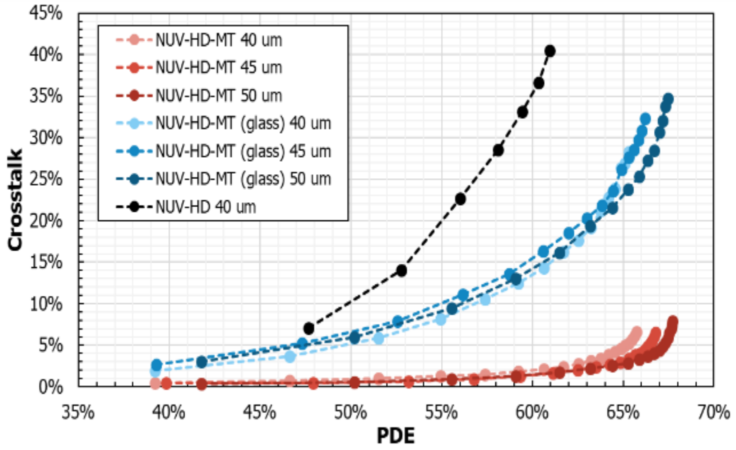
Conti, Maurizio *Clinical and Translational Imaging* 7.2 (2019): 139-147.

SiPMs for PET @ FBK

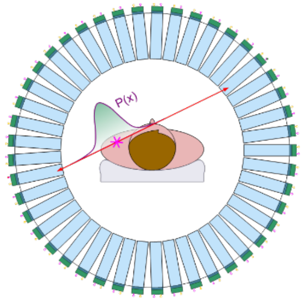
State of the art PDE and noise

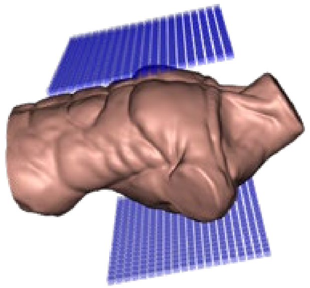


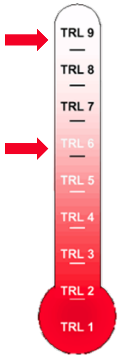
Gola, A et al. (2019). "NUV-Sensitive Silicon Photomultiplier Technologies Developed at Fondazione Bruno Kessler." *Sensors*, *19*(2), 308.



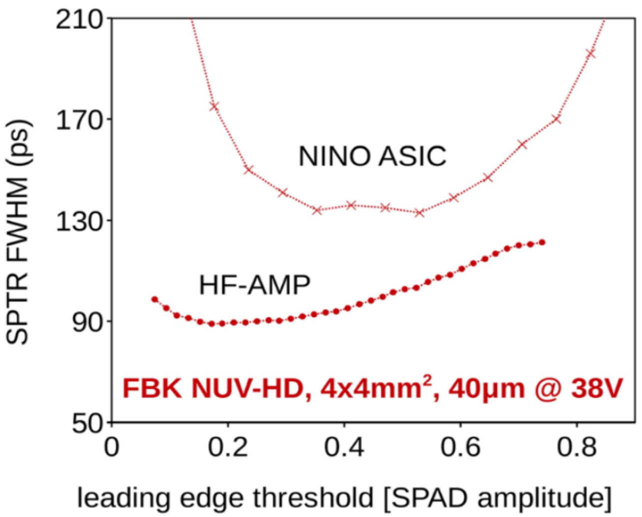
Optical crosstalk vs. PDE at 420 nm measured on NUV-HD-MT technology.

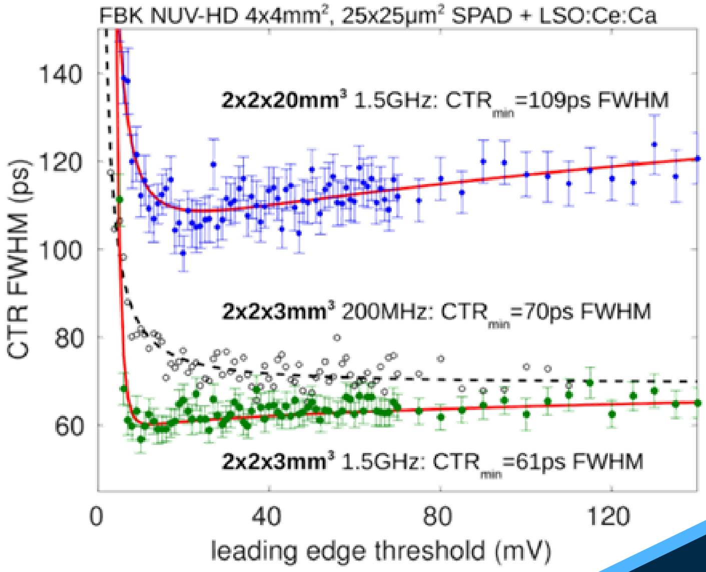






World-leading performance in PET





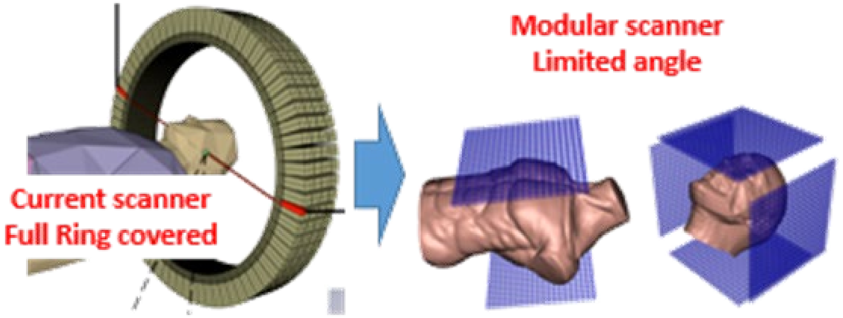
World record timing resolution: Single Photon Time resolution (SPTR, left) and Coincidence Resolving Time (CRT) in LYSO readout (right).

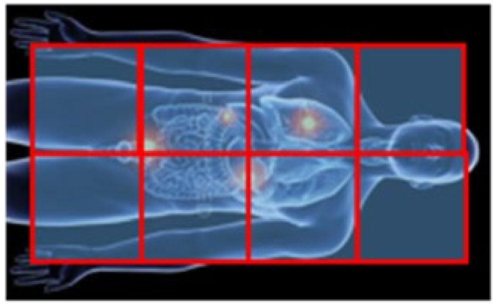
Courtesy of A. Gola– FBK

Development of large ToF-PET panels @ FBK

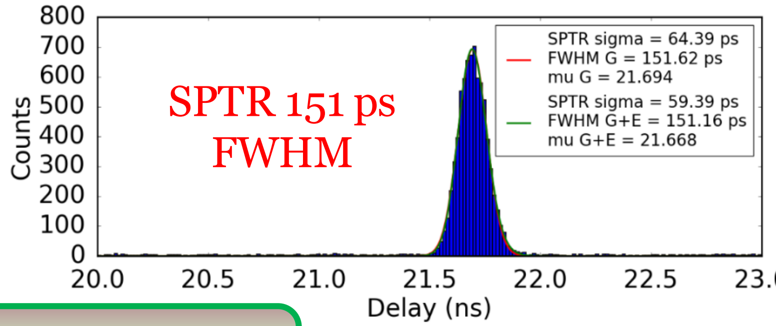
MASSACHUSETTS GENERAL HOSPITAL
ONCO VISION
Jožef Stefan Institute
ICCUB Institut de Ciències del Cosmos

- 3D integration of SiPMs with TSV technology
- Development of 50x50 mm² PDMs to form *30x30 cm² ToF-PET panels*
- Used for limited-angle ToF-PET systems, for brain PET, Cardiac PET and full-body scanners.

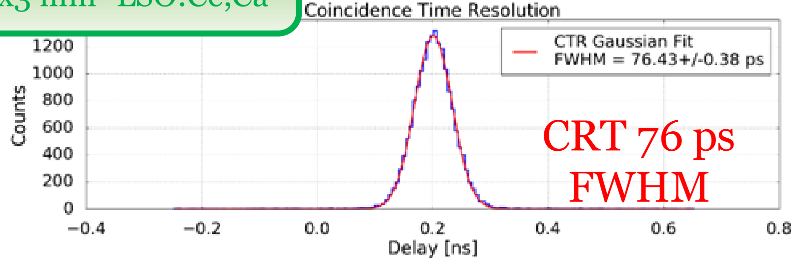


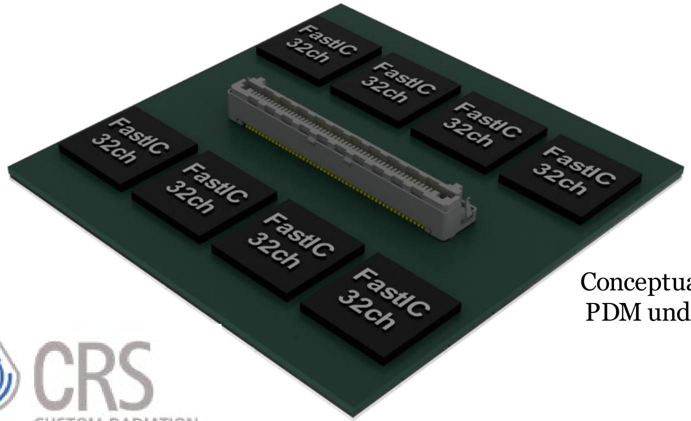


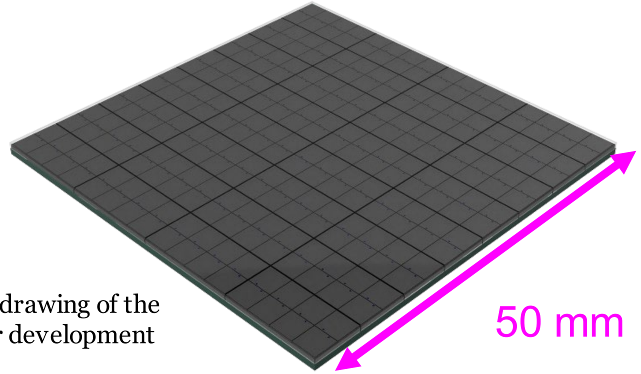
Application of the PDM to build large panes used in new, limted-angle PET applications: Brain Pet, Cardiac PET, while-body PET



2x2x3 mm³ LSO:Ce,Ca







Conceptual drawing of the PDM under development

SPTR and CRT measured at FBK NUV-HD-SiPMs read by the FastIC ASIC developed by ICCUB.
Sensor: NUV-HD-LFv2 SiPMs, 3x3 mm²
Scintillator: 2x2x3 mm³ LSO:Ce,Ca
Power consumption: 3 mW/ channel

FBK CRS CUSTOM RADIATION SENSORS

Courtesy of A. Gola– FBK

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     - X and γ-ray spectrometer

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   - **Radiometabolic therapy and radioguided surgery**
     - WIDIMapp: a Wearable Individual Dose Monitoring Apparatus
     - CHIRONE/CHIR2: Beta RadioGuided Surgery with β radiation

WIDMApp

- Wearable Individual Dose Monitoring Apparatus
- Rationale
  - Targeted Radionuclide Therapy (TRT) effectiveness is related to reconstruction of absorbed dose in lesions and OARs
- The device
  - Wearable multi-channel sensor for gamma and beta detection
    - Thin, lightweight, robust, biocompatible
- Innovation with respect to state of the art
  - Much high accuracy in dosimetry
  - Real treatment personalization
  - Massive logistical simplification with respect to standard of care
- Possible developments in the next 5 years
  - Tests on patients
  - Detector optimization
  - Detector engineering

By
R. Mirabelli
E. Solfaroli-Camillocci

VIDEO IN THE FINAL PRESENTATION

INFN ROMA
Istituto Nazionale di Fisica Nucleare
Sezione di Roma

WIDMApp

a Wearable Individual Dose Monitoring Apparatus

Received: 11 March 2021 | Revised: 30 September 2021 | Accepted: 11 October 2021
DOI: 10.1002/mp.15311

TECHNICAL NOTE

MEDICAL PHYSICS

Technical note: A wearable radiation measurement system for collection of patient-specific time-activity data in radiopharmaceutical therapy: system design and Monte Carlo simulation results

Silvio Morganti[1] | Francesco Collamati[1] | Riccardo Faccini[1,2] | Giuseppe Iaccarino[3] | Carlo Mancini-Terracciano[1,2] | Riccardo Mirabelli[1,2] | Francesca Nicolanti[1,2] | Massimiliano Pacilio[4] | Antonella Soriani[3] | Elena Solfaroli-Camillocci[1,2,5]

CHIRONE (2014-2016) - CHIR2 (2017-2019)

- CHIRONE and CHIR2 projects involved INFN-RM1, INFN-PG
- Many other partners (also clinical):
  - IIT, Sapienza, ISS, IEO, Carlo Besta …
- Goal:
  - Development of a $\beta-$ detector for radio-guided surgery
- Innovation with respect to state of the art:
  - Much more precise and accurate with respect to gamma-based technique
  - Allows radio guided surgery also in case of elevated background
  - Much handier detector, for example in robotic surgery
- Possible developments in the next 5 years:
  - Detector engineering beyond prototype
  - Extended tests on patients

Beta RadioGuided Surgery with β radiation

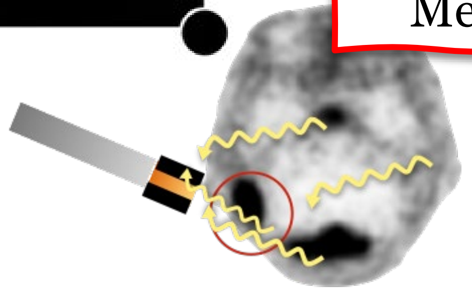
[1] A novel radioguided surgery technique exploiting β– decays, Camillocci ES et al., Sci Rep 2015;4:4401. doi:10.1038/srep04401

- Standard use: γ emitter + γ probe
  - E.g. ^{99}Tc: E_{γ}=140 keV

FACT:

1/3 of these photons traverse more than 8 cm in human tissue

LIMITATIONS:
Healthy organs background
Detector shielding
Medical staff exposure



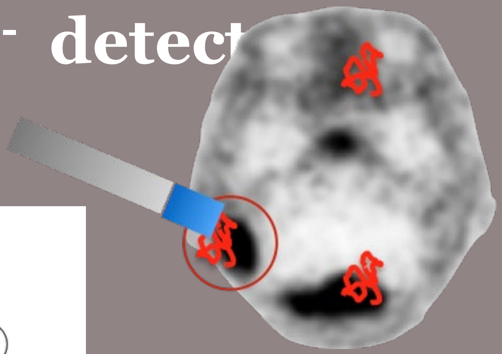
Courtesy of F. Collamati

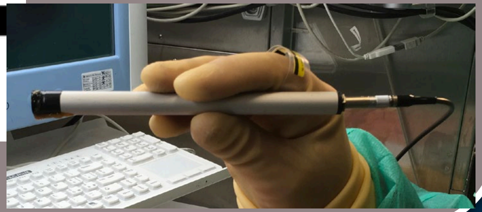
[1]

CHANGE IN PARADIGM: CHIRONE (2014)

β⁻ emitter + β⁻ detect

e.g.: **^{90}Y**, pure β⁻ decay,
2.2MeV ↔ ~mm penetration
68Ga, β⁺ decay,
1.92 MeV





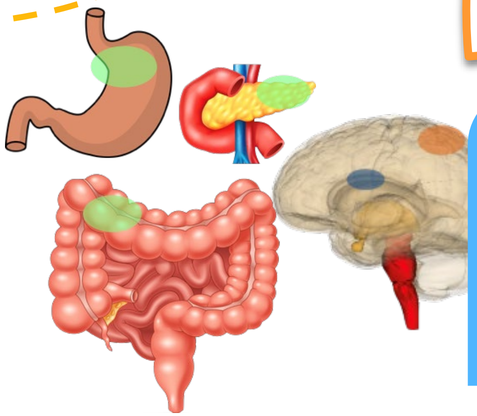
ADVANTAGES:
No background from healthy tissue
Smaller probe
Reduced exposure

Beta RadioGuided Surgery with β radiation

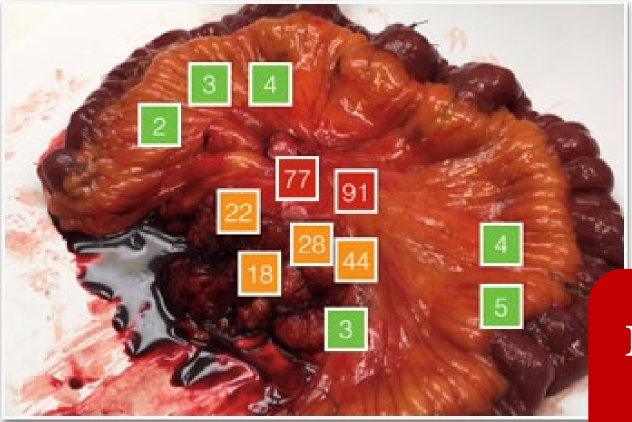
DETECTOR DEVELOPMENT

Scintillating crystal (5mm diam.) of *p-terpheynyl*:
→ High sensitivity to β
→ Transparency to γ

USE CASE IDENTIFICATION

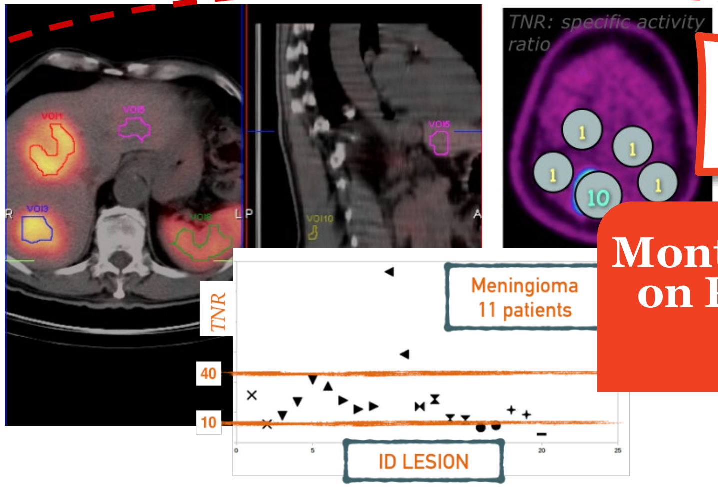


β^- Meningioma, Glioma and NETs, with ^{90}Y-DOTATOC
β^+: NETs with ^{68}Ga-DOTATOC
Prostate Cancer with ^{68}Ga-PSMA



EXPERIMENTAL VALIDATION

Ex-vivo tests on Meningioma and GEP-NET samples @IEO (Milan)



FEASIBILITY STUDIES

Monte Carlo simulations on PET/SPECT patient uptakes

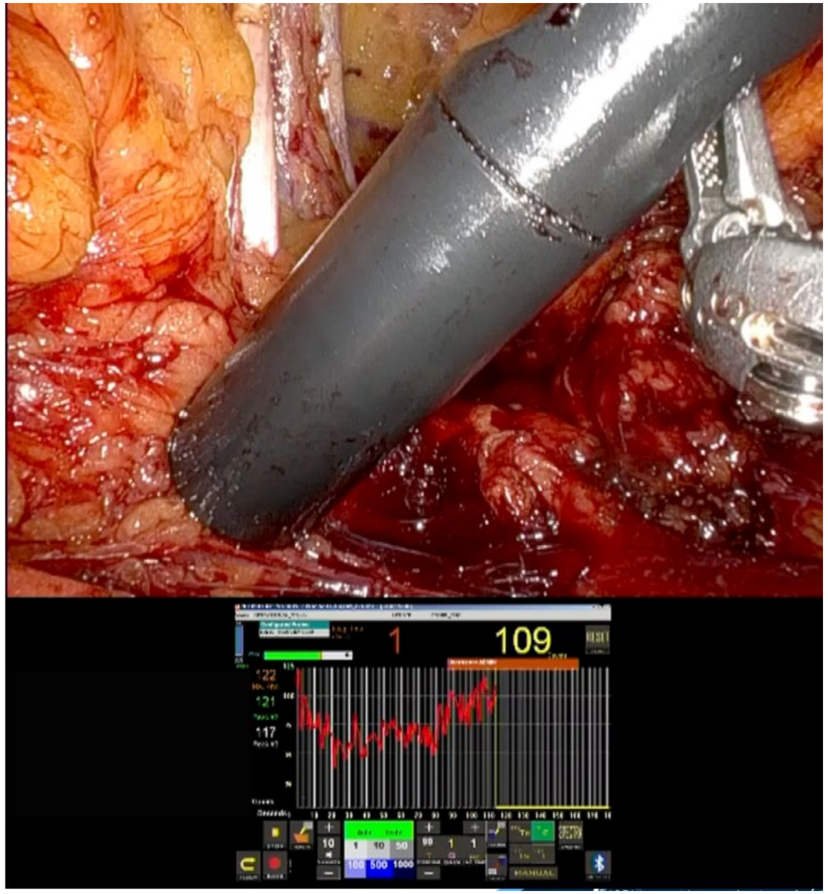
Courtesy of F. Collamati

Beta RadioGuided Surgery with β radiation

Ongoing activities:

- **Feasibility studies** of β-RGS with ^{18}F
  - Cervical Cancer (^{18}F-FDG)
- **Monte Carlo simulations** allowed to foresee probe counting due to signal and background;
- **Experimental Studies** on Detector characterization and optimization for ^{18}F β+ detection (endpoint 633 keV)
- First **in-vivo** tests with ^{68}Ga ongoing *@IEO-Milan*
  - Prostate Cancer *(PSMA)*
  - NETs *(DOTATOC)*
- **Results** are strongly **confirming** not only the technique **capabilities**, but also the **accuracy** of our previous **simulations**!

VIDEO IN THE FINAL PRESENTATION



Courtesy of F. Collamati

Contributors list

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- Francesco Collamati (INFN-Roma1)
- Massimiliano Fiorini (INFN-Ferrara, Università di Ferrara)
- Piero Giubilato (INFN Padova, Università di Padova)
- Alberto Gola (FBK)
- Marcello Lunardon (INFN Padova, Università di Padova)
- Carlo Mancini Terracciano (INFN-Roma1, Università La Sapienza”
- Marianna Testa (INFN-LNS)

Conclusions and summary

That’s not my job, this is the reason why we have conveners!

THANK YOU!