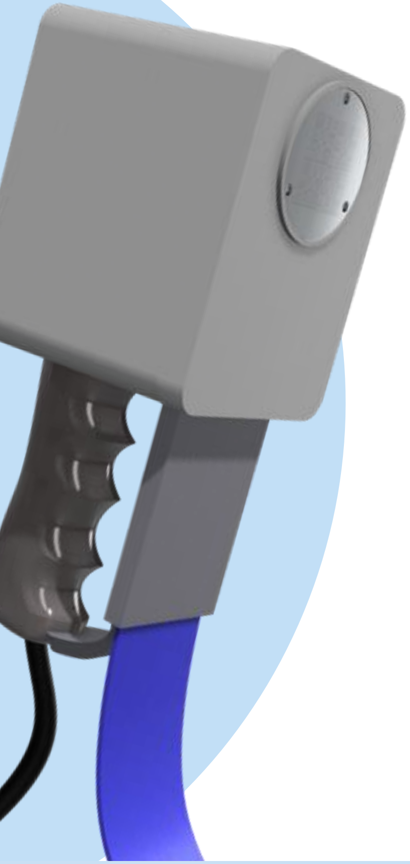
Geant4 Monte Carlo simulations for the design of new imaging devices: MediPROBE4 and T4-QCT



Laura Antonia Cerbone[1,2,5], A.Sarno[1,2], M. Fiorini[3,4], N. V. Biezus[3,4], R. Bolzonella[3,4], G. Mettivier[1,2], P. Russo[1,2]

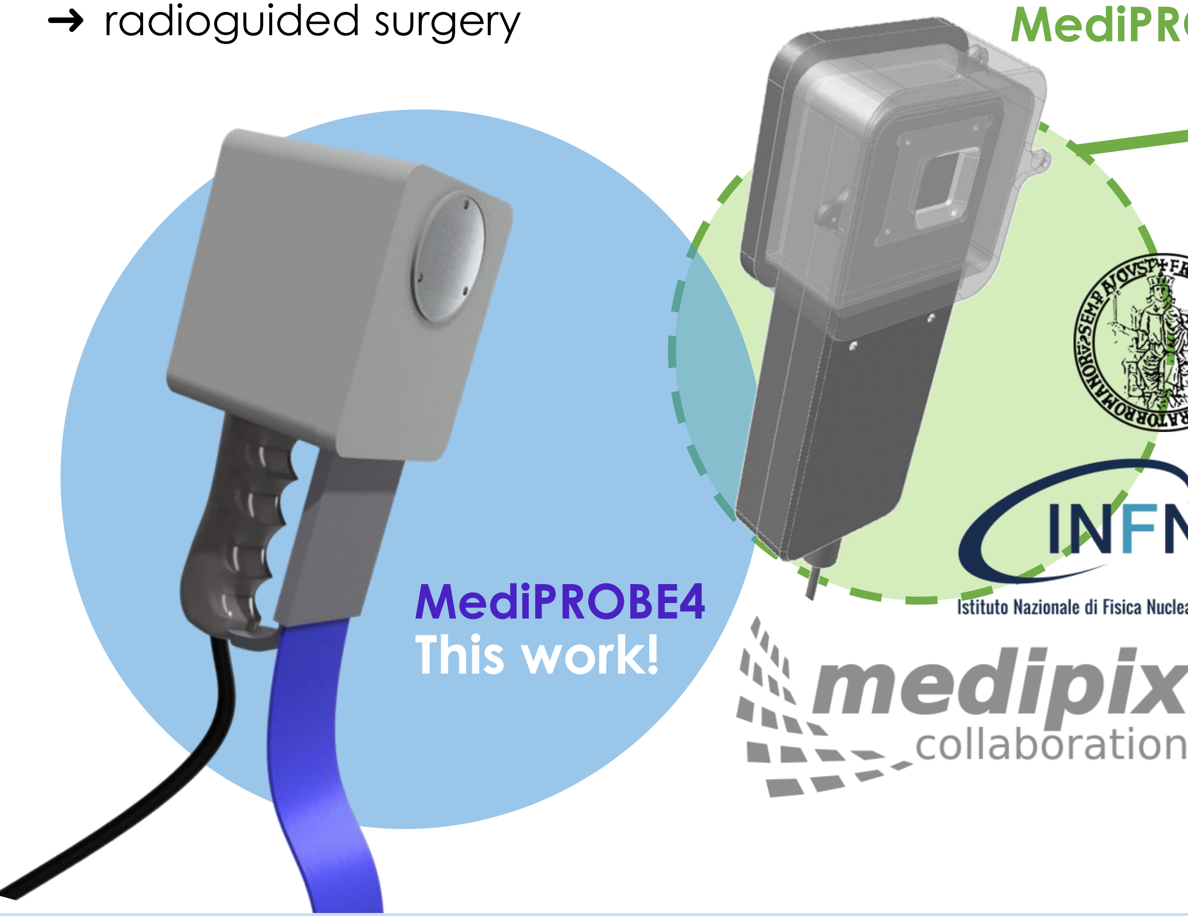
1. Dipartimento Pancini", Università di Napoli Federico II
2. Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Napoli
3. Dipatimento di Fisica e Scienze della Terra, Università di Ferrara
4. Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Ferrara
5. Scuola Superiore Meridionale, Napolidi Fisica “Ettore

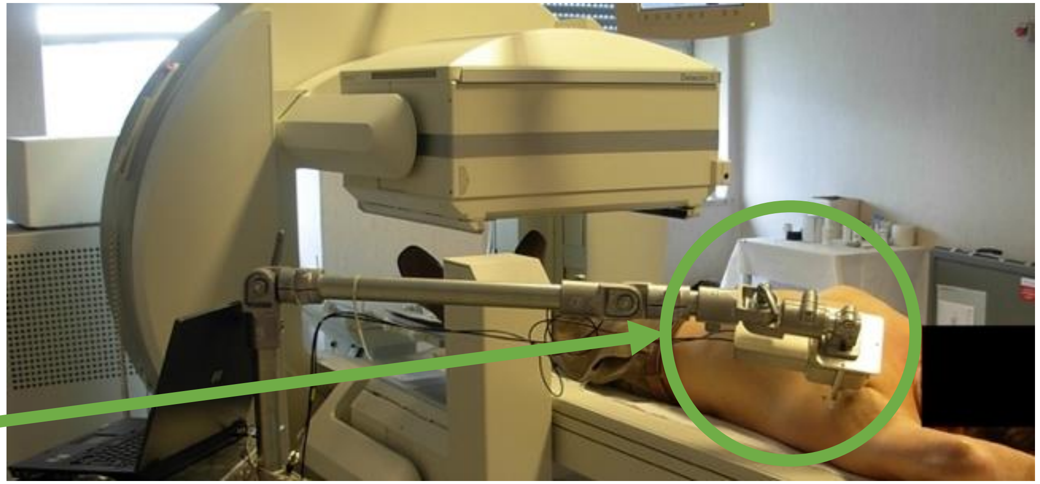
Geant4 based optimization for semiconductor hybrid pixel detector for nuclear medicine imaging

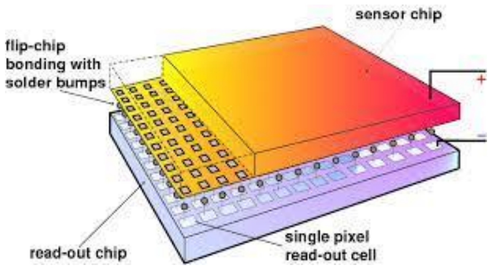
A **portable gamma camera** is a small, light-weight gamma ray detector that can be used for pre- and intra-operative clinical procedures, tipically with Tc-99m radiotracers

➜ sentinel lymph node scintigraphy

➜ radioguided surgery







Hybrid pixel detectors
Semiconductor sensor bump-bonded to a readout chip.

MediPROBE2 (2011)

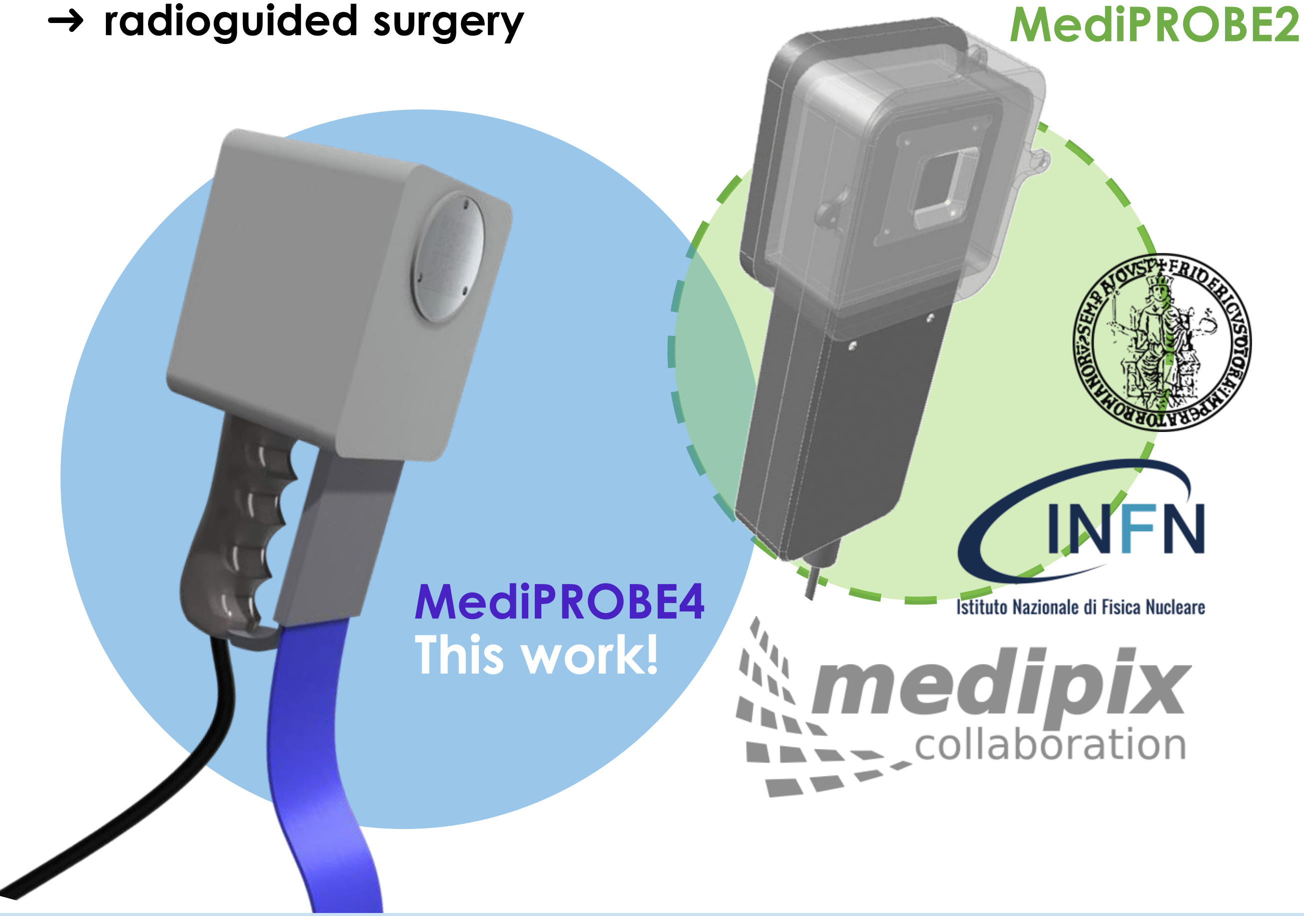
Medipix2 ASIC (256 x 256 pixels, 55 μm pitch).
1-mm-thick CdTe sensor (sensitive area 1.98 cm^2).
Readout mode: frame based (Imaging).
FOV: 40 x 40 mm^2 at 50-mm skin-to-collimator distance.
Spatial Resolution: 5.5 mm FWHM (0.94 mm pinhole) at 50-mm skin-to-collimator distance.

Geant4 based optimization for semiconductor hybrid pixel detector for nuclear medicine imaging

A **portable gamma camera** is a small, light-weight gamma ray detector that can be used for pre- and intra-operative clinical procedures, tipically with Tc-99m radiotracers

→ **sentinel lymph node scintigraphy**

→ **radioguided surgery**



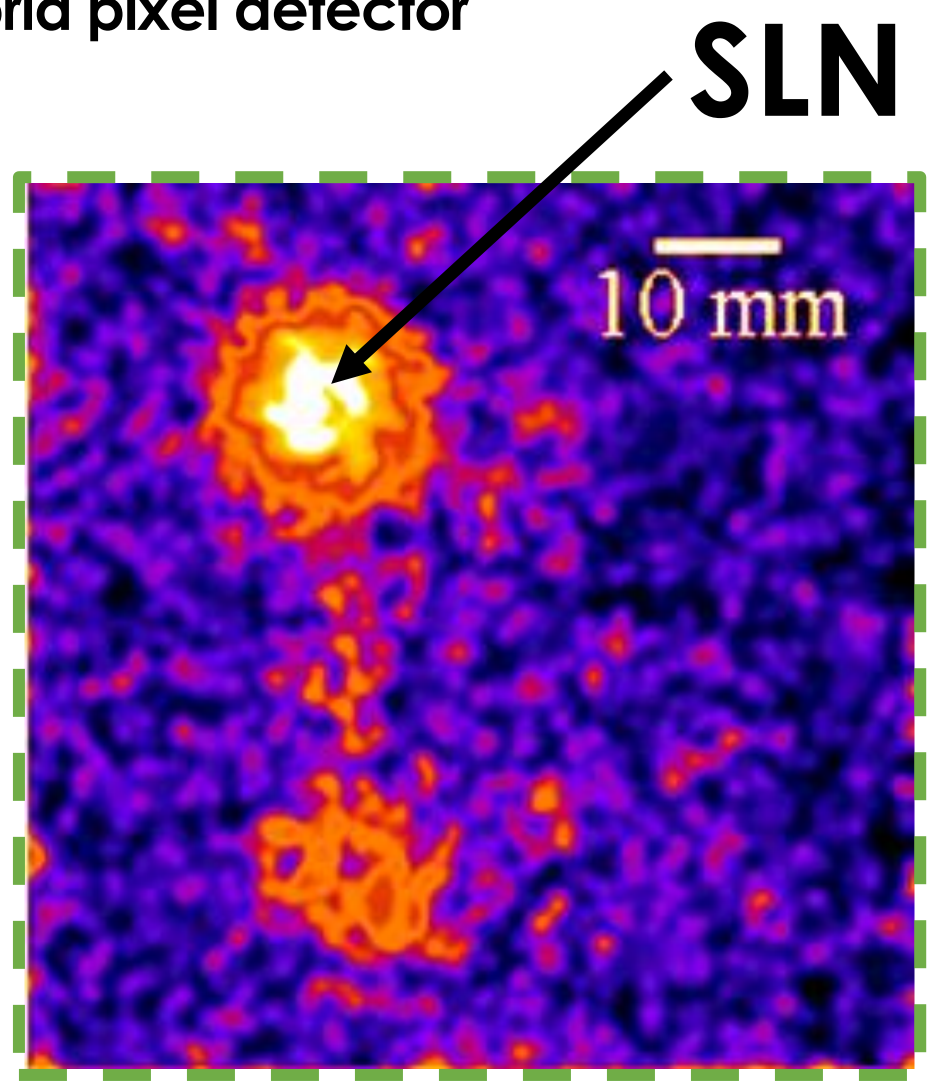


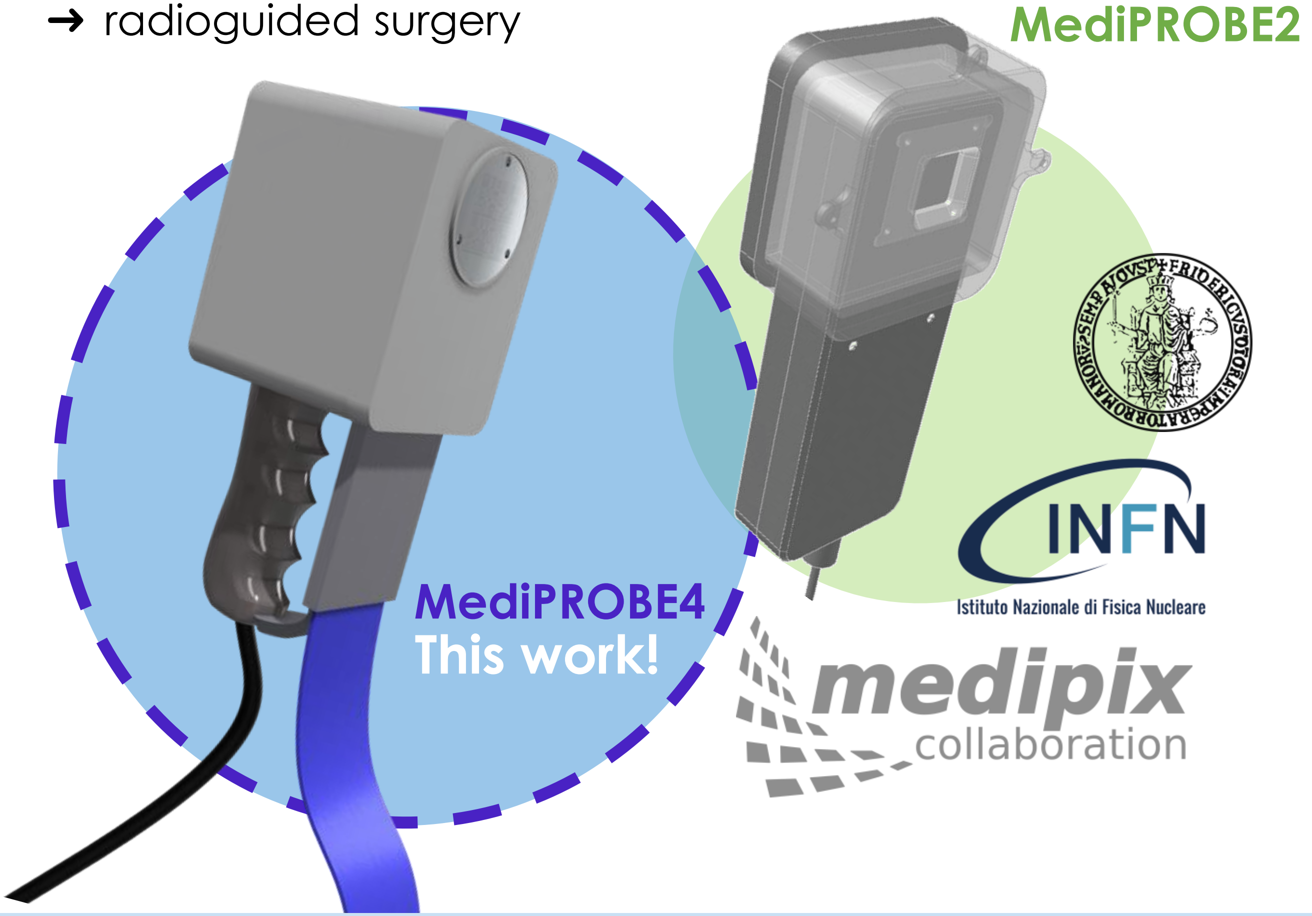
Image of two lymph nodes acquired with MediPROBE2 (pinhole 0.94 mm aperture)

Geant4 based optimization for semiconductor hybrid pixel detector for nuclear medicine imaging

A **portable gamma camera** is a small, light-weight gamma ray detector that can be used for pre- and intra-operative clinical procedures, tipically with Tc-99m radiotracers

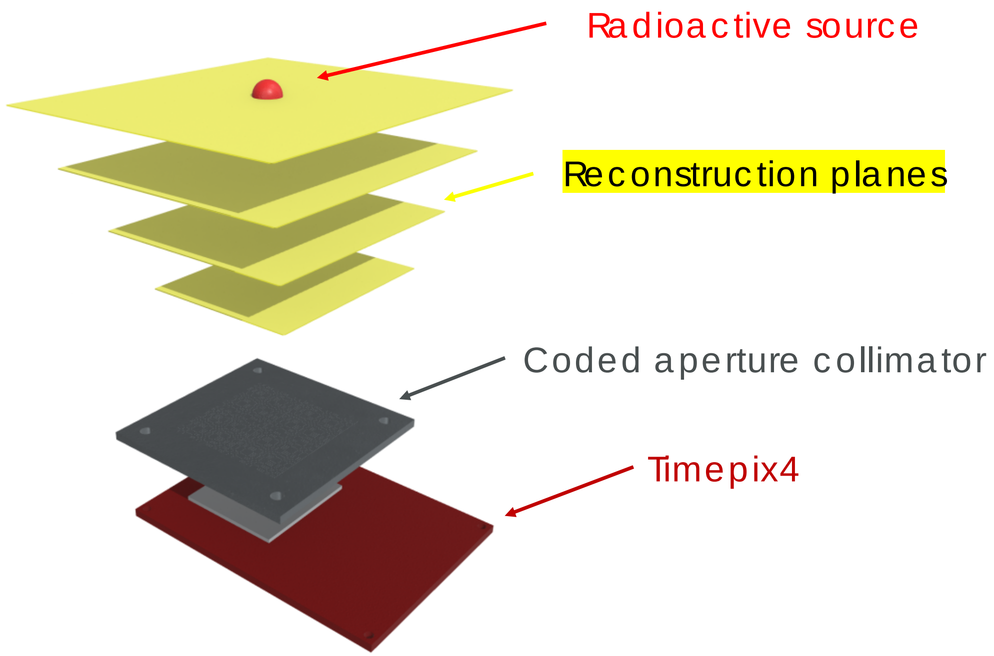
➜ sentinel lymph node scintigraphy

➜ radioguided surgery



MediPROBE4 (2022) with Timepix4

Timepix4 ASIC (448 x 512 pixels, 55 μm pitch).
0.3-mm-thick Si sensor (sensitive area 6.93 cm^2).
Readout modes: Frame based + Data Driven (tracking).
Coupled to a Coded Aperture (CA) collimator.



With CA mask, from 2D data, one can obtain a 3D reconstruction of the emitting object (through a deconvolution algorithm).

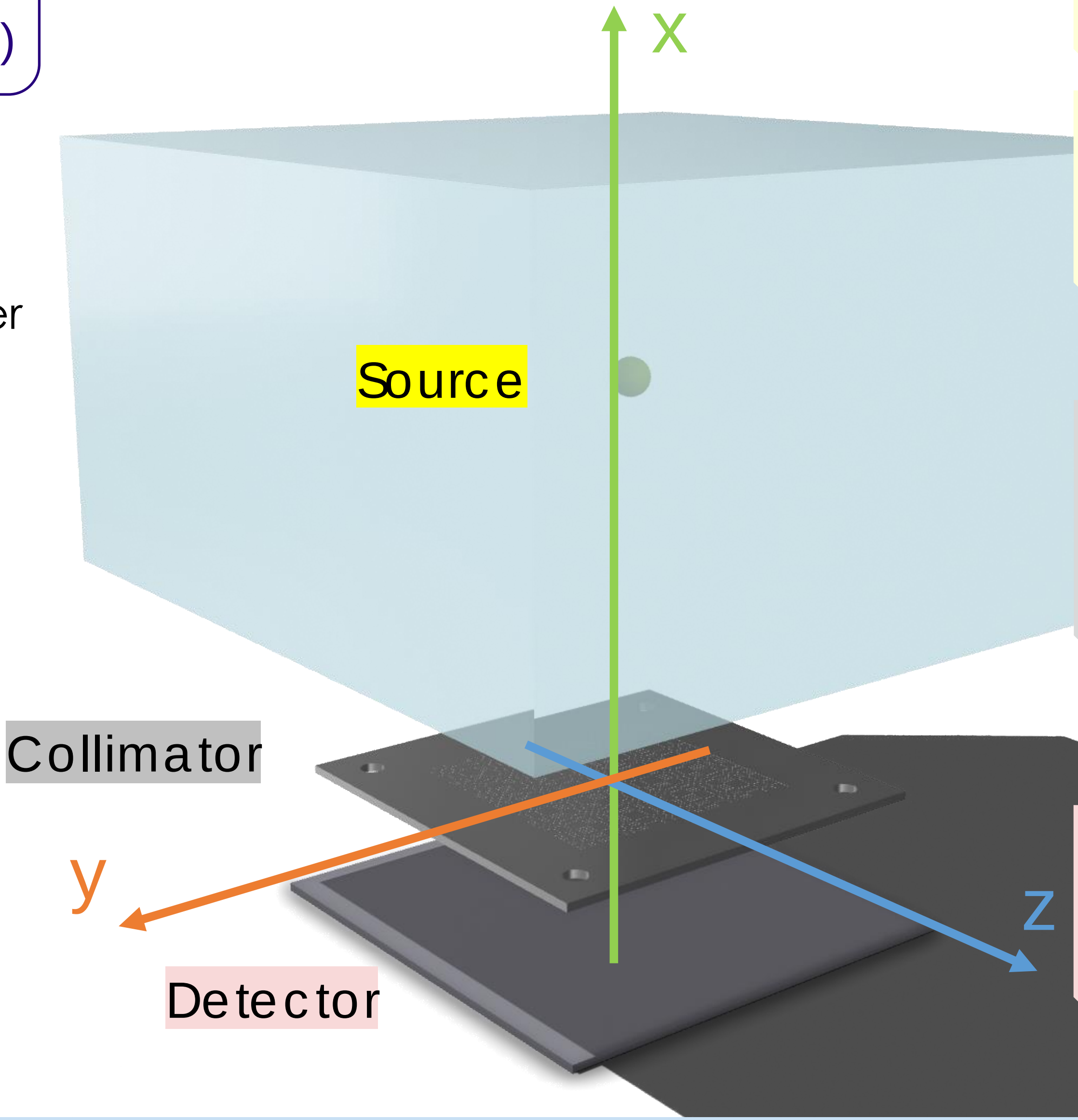
Monte Carlo simulations with Geant4

Version 10.6
PhysicsListStdOpt4()

Simulated processes
- Photoelectric absorption
- Coherent and incoherent scatter
- Deexitations processes

Electron range cut-off: 1 μm

We used Geant4 MC simulation to **simulate images acquired by our imaging system** to later decode them using a deconvolution algorithm and study them.



Geometry
- Planar round source
- Spherical source

Photon energy
- Monoenergetic
- Radioactive sources spectra (Tc99m, Ba133, Am241)

Coded Aperture Collimator
Interactions with the collimator were simulated, as well as with the interposed material (e.g. water phantom simulating tissue)

Detector
CdTe (1 or 2 mm thick) or Si sensor (300 μm thick) (55μm x 55μm pixel)

Laboratory tests with Timepix4

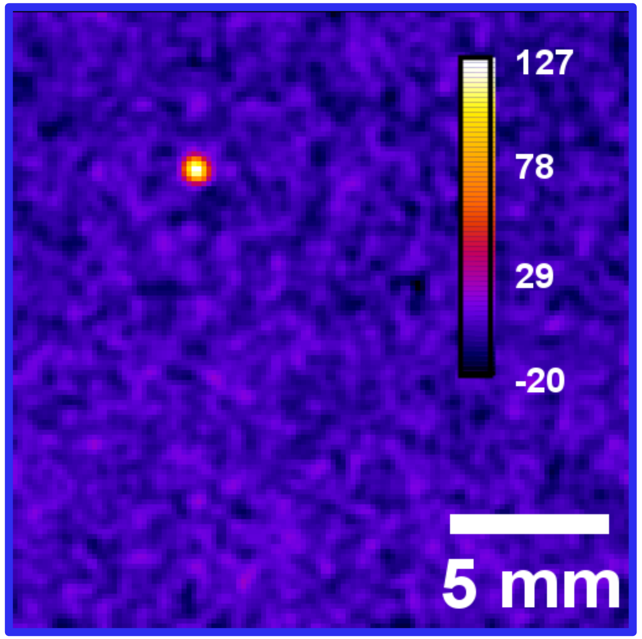
Spectral imaging of radioactive sources
(Timepix4 coupled to a coded aperture collimator)

- Timepix4v1 bump bonded with a **300 μm Silicon** sensor
- Spidr4 hardware and in-house software (Nikhef)
- Coded aperture collimator physically available at the lab (NTHN MURA mask, rank 31, **0.08 mm holes, 0.110 mm** thickness)
- Radioactive source: Ba-133 (0.6 mm diameter)

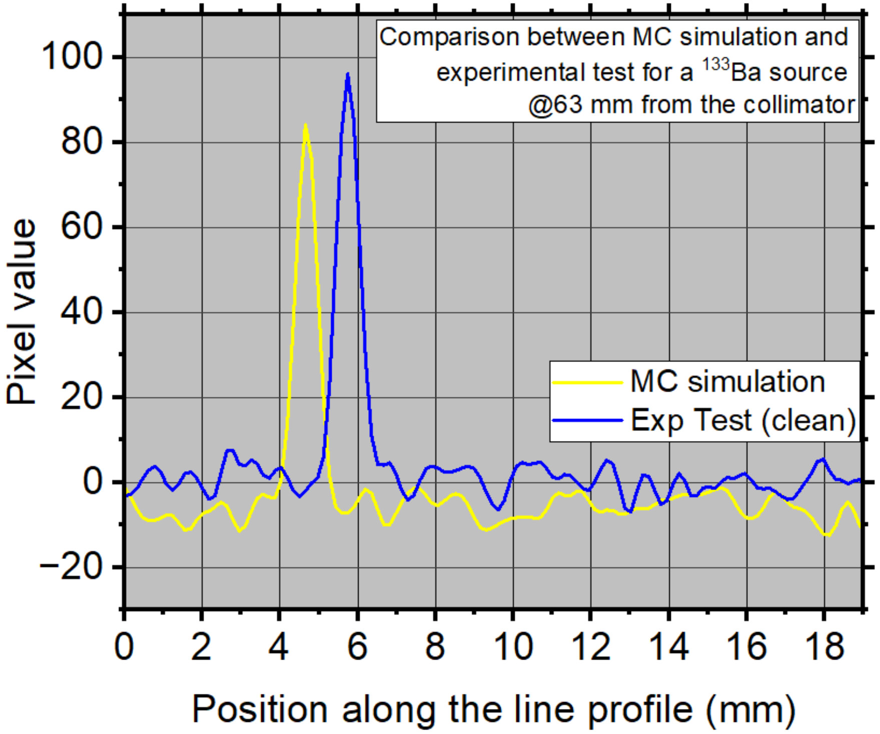
Geant4 simulations

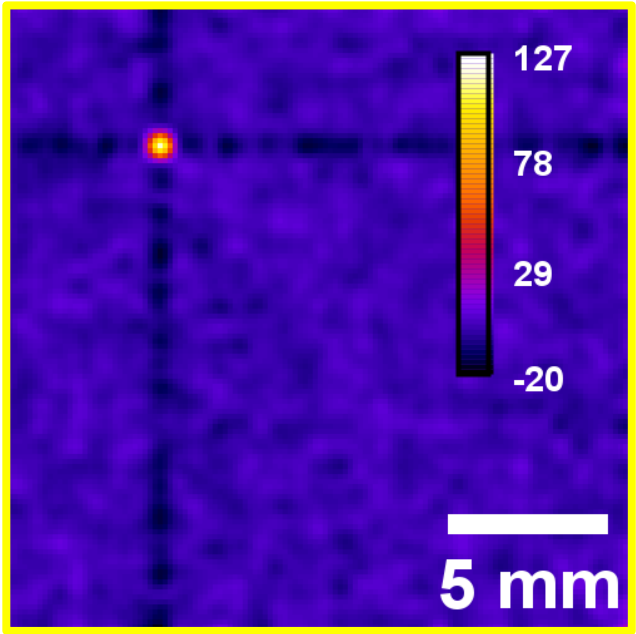
Imaging of a monoenergetic source taking into account interactions inside the sensor.

- **300 μm Silicon** sensor (energy deposition in the sensor are computed each 10μm along the ionization track)
- Coded aperture collimator (NTHN MURA mask, rank 31, **0.08 mm holes, 0.110 mm** thickness)
- Monoenergetic source 30.85 keV (planar round source, 0.6 mm, placed at 5mm from the FOV center)



Experimental test CNR = 36



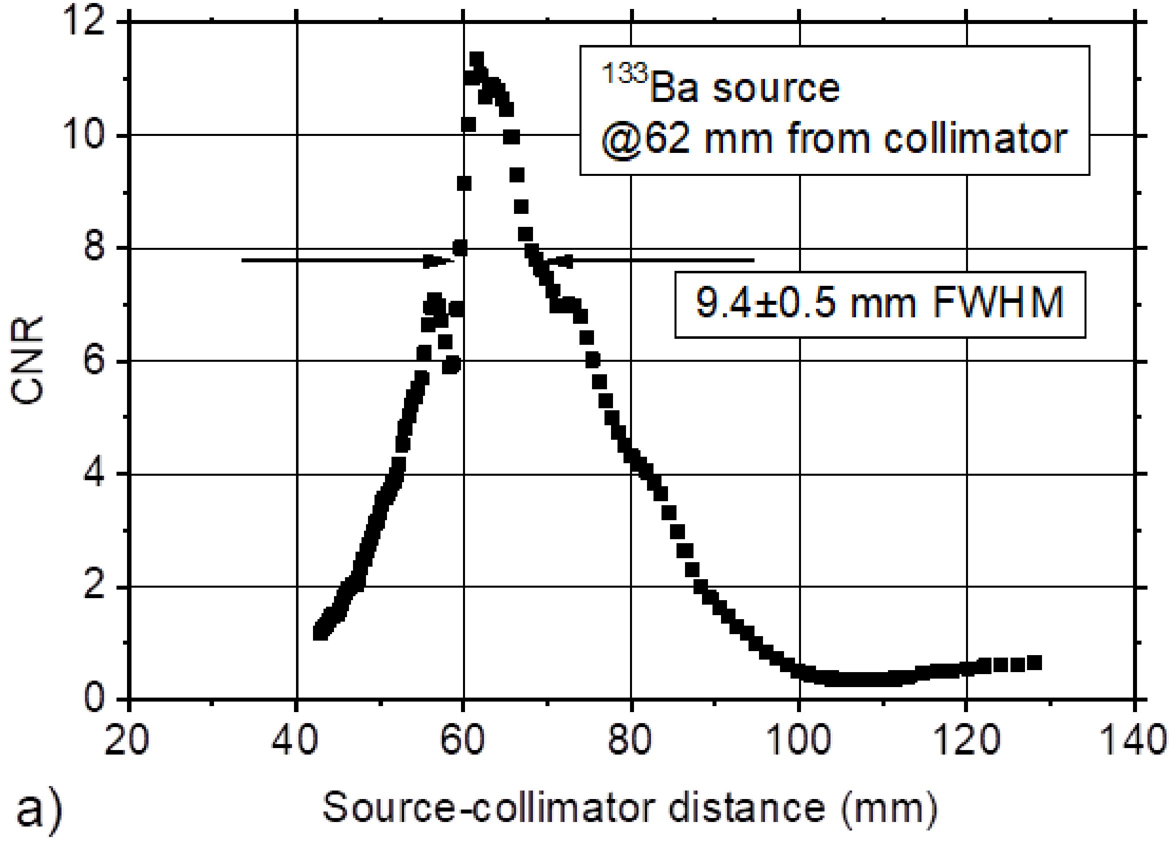


MC simulation CNR = 35

MediPROBE4 axial spatial resolution

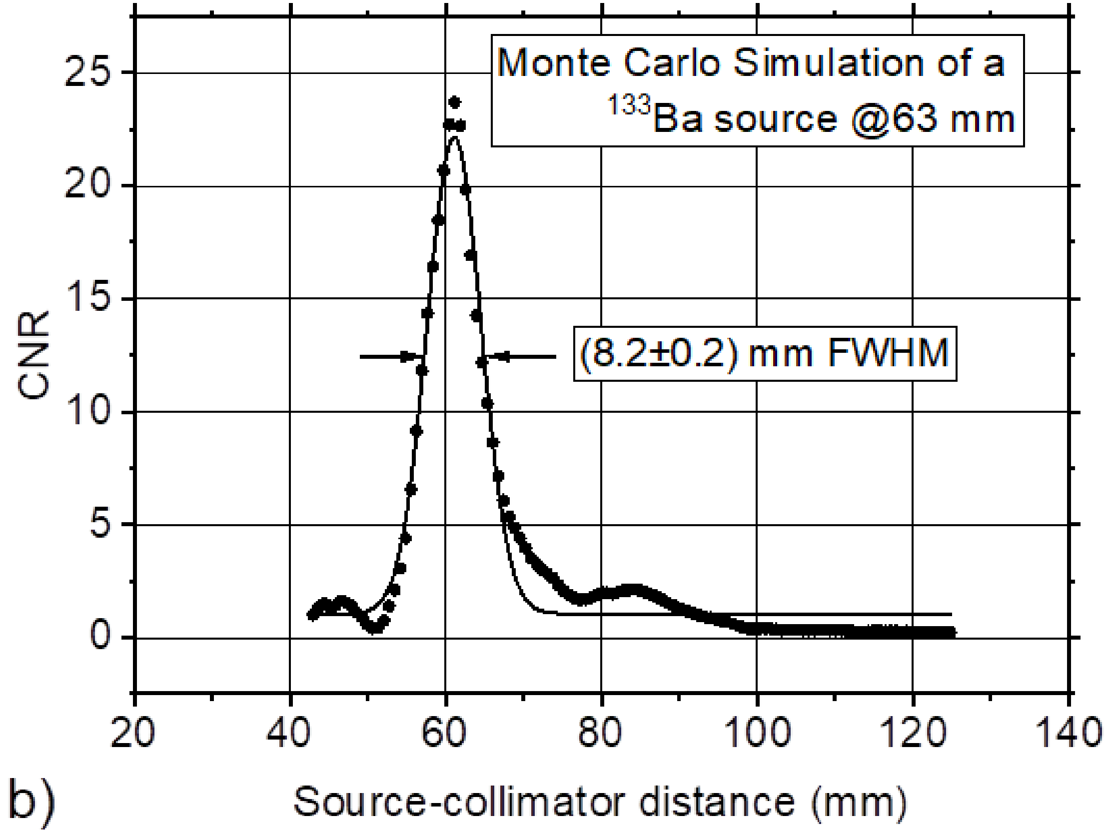
Laboratory tests with Timepix4

Spectral imaging of radioactive sources
(Timepix4 coupled to a coded aperture collimator)



Geant4 simulations

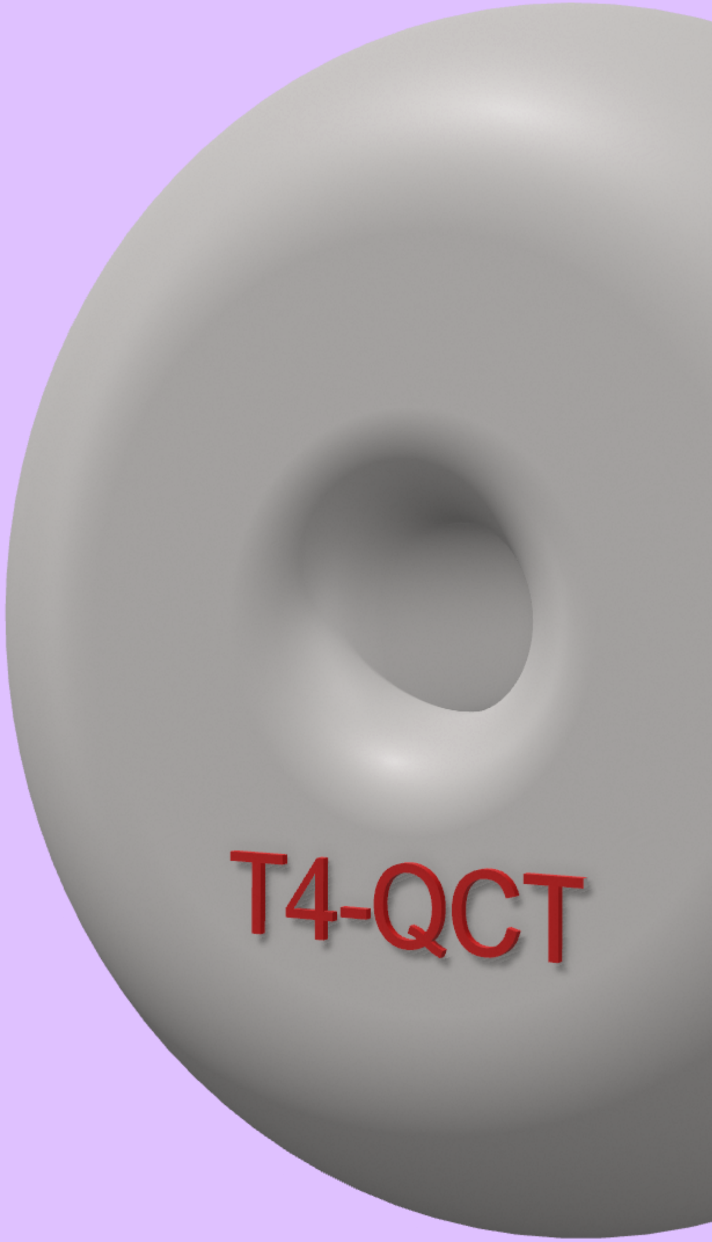
Imaging of a monoenergetic source taking into account interactions inside the sensor.



Moving to a new project…

T4-QCT

A spectral quantitative photon counting CT for the assessment of bone density losses



High-Resolution peripheral quantitative CT (HR-pQCT)

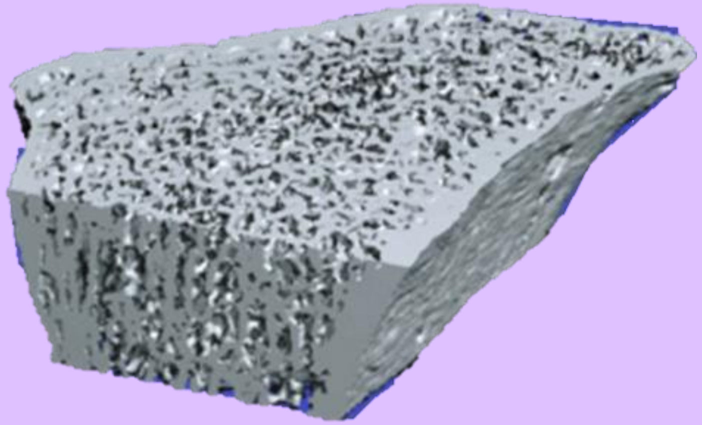
Capable of resolving the micrometric trabecular structure of bones (≈50 μm)

Analyzed anatomical compartments:
- Wrist (Radius)
- Ankle (Tibia)
- Heel

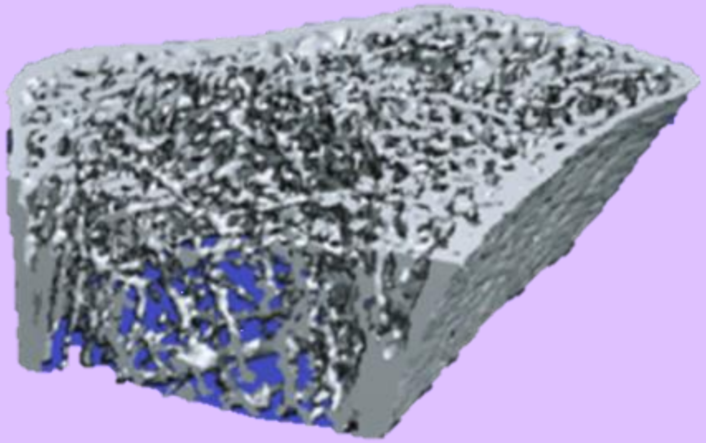
Commercially available HR-pQCT

- Isotropic spatial resolution ≈ 60 μm
- Cone beam (scan time 2-4 minutes)
- **4 μSv effective dose** to patient per scan (9 mm scan lenght, 12 cm FOV)
- ≈ 600 kg (NOT portable, of course)

Healthy



Osteoporotic

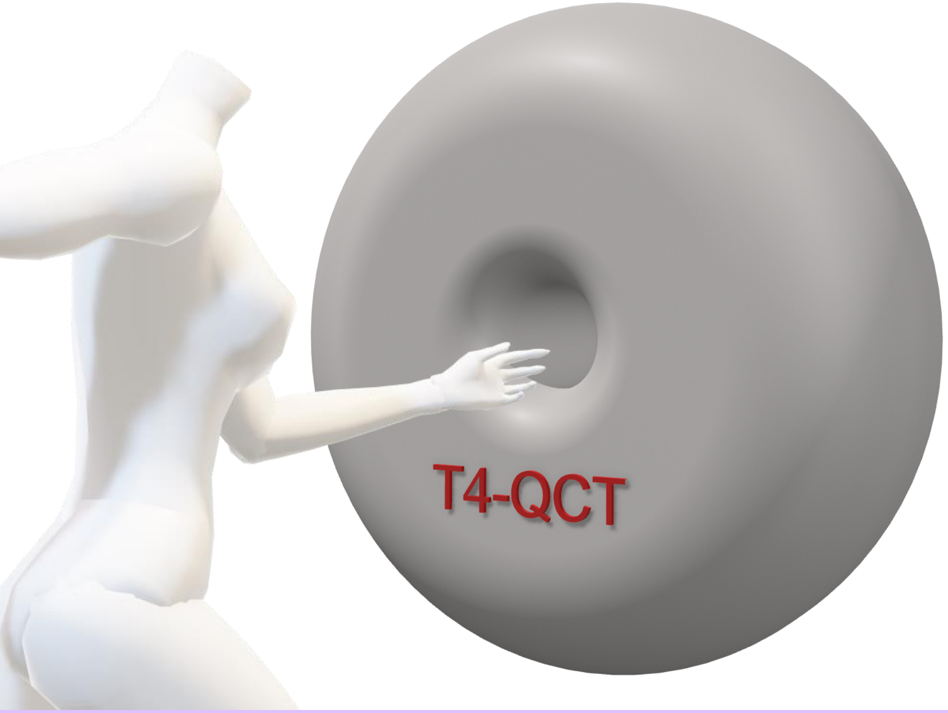


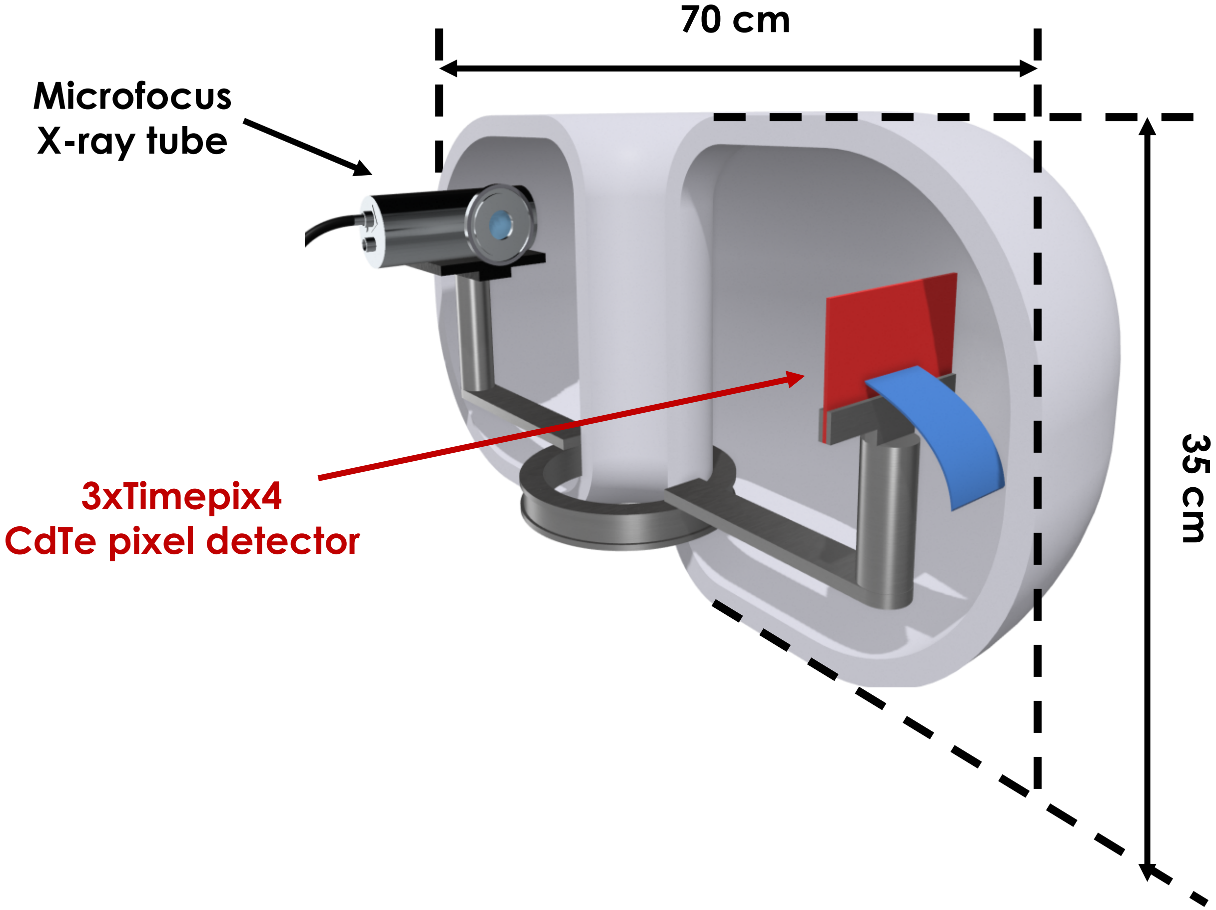
3D image of the radius of a 68 years old patient obtained with a commercial HR-pQCT

Spectral quantitative CT for the assessment of bone density losses

Our purpose is to realize the first prototype of a spectral (color) CT scanner using the Timepix4 read-out ASIC and a microfocus x-tay tube, for bone densitometry by scanning peripheral parts of the body (wrist, tibia, fingers).

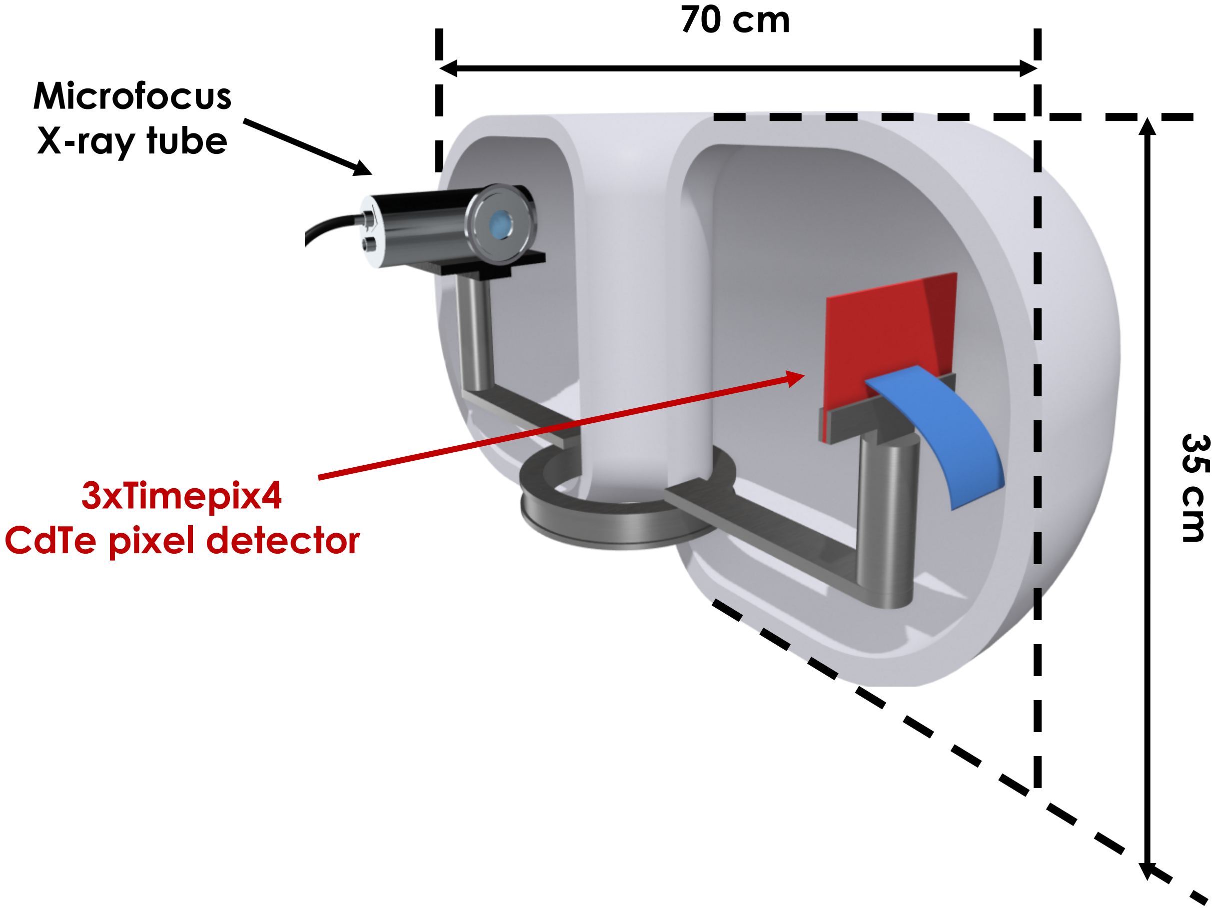
The patient will insert one limb inside the bore using a 3D-printed holder for the forearm or the leg (not shown).





Spectral quantitative CT for the assessment of bone density losses

- Isotropic high spatial resolution (≈ 60 μm)
- Photon counting detector
- Field of View of 10-12 cm at isocenter
- Photon counting & Spectral capabilities → possibility to separate bone from soft tissue without a dual-energy scan
- Expected patient effective dose <10 μSv
- 30% - 60% reduction of radiation dose with respect to energy-integrating CT



Monte Carlo simulations goals

- Reproduce the detection system: the Timepix4 hybrid pixel detector
- Establish which is the optimal geometrical configuration for the system:
    1. Magnification
    2. Extention of the sensible area (trade-off between costs and FOV)
    3. Spatial resolution (must be micrometric to resolve the trabeculae)
- Dose assessment

Thank you
for your attention!

Laura Antonia Cerbone
cerbone@na.infn.it
Lauraantonia.cerbone-ssm@unina.it