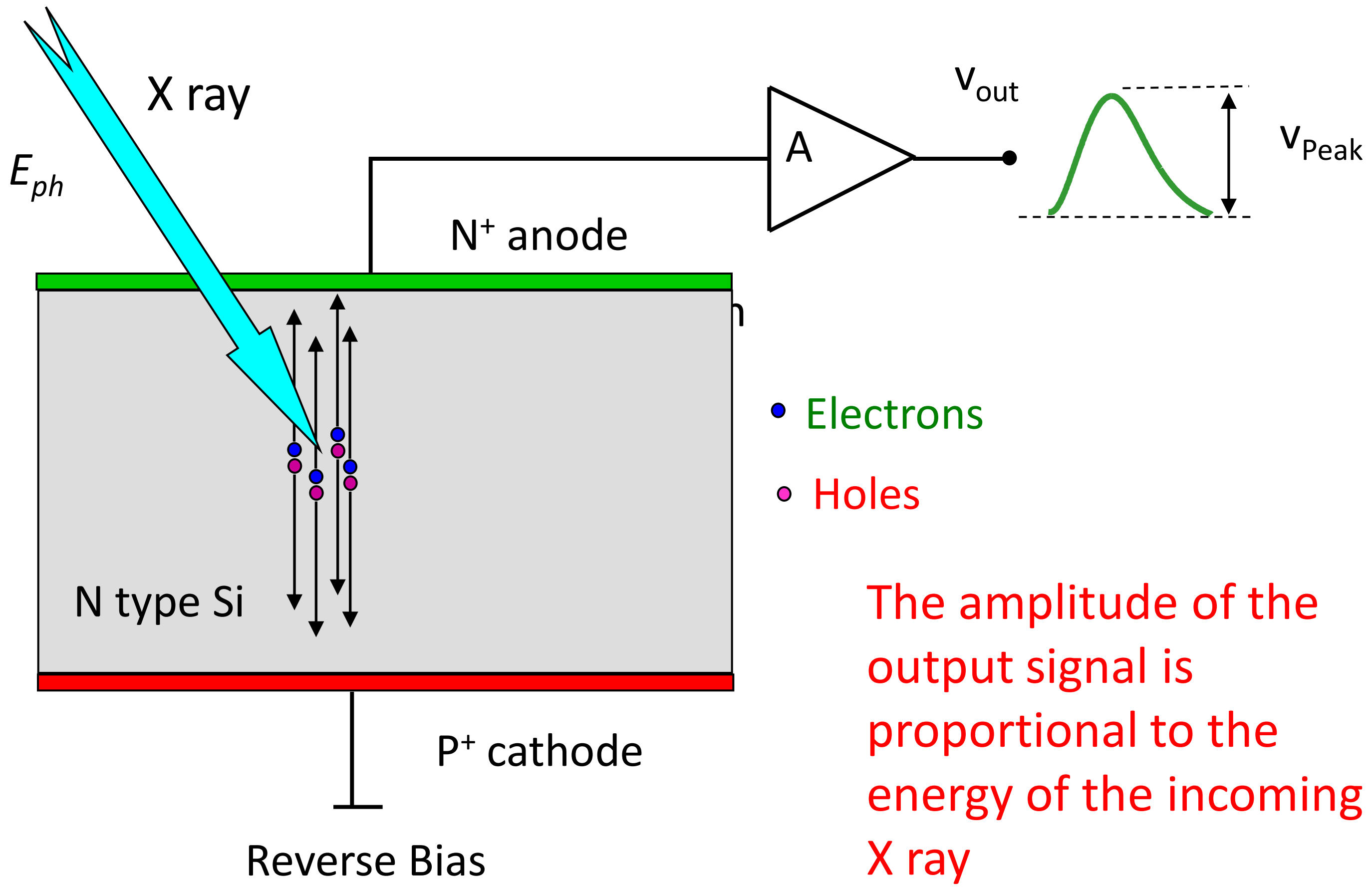
Silicon Drift Detectors for gamma-ray detection: 15 years of research (and collaboration between Politecnico and INAF-Milano)

Outline

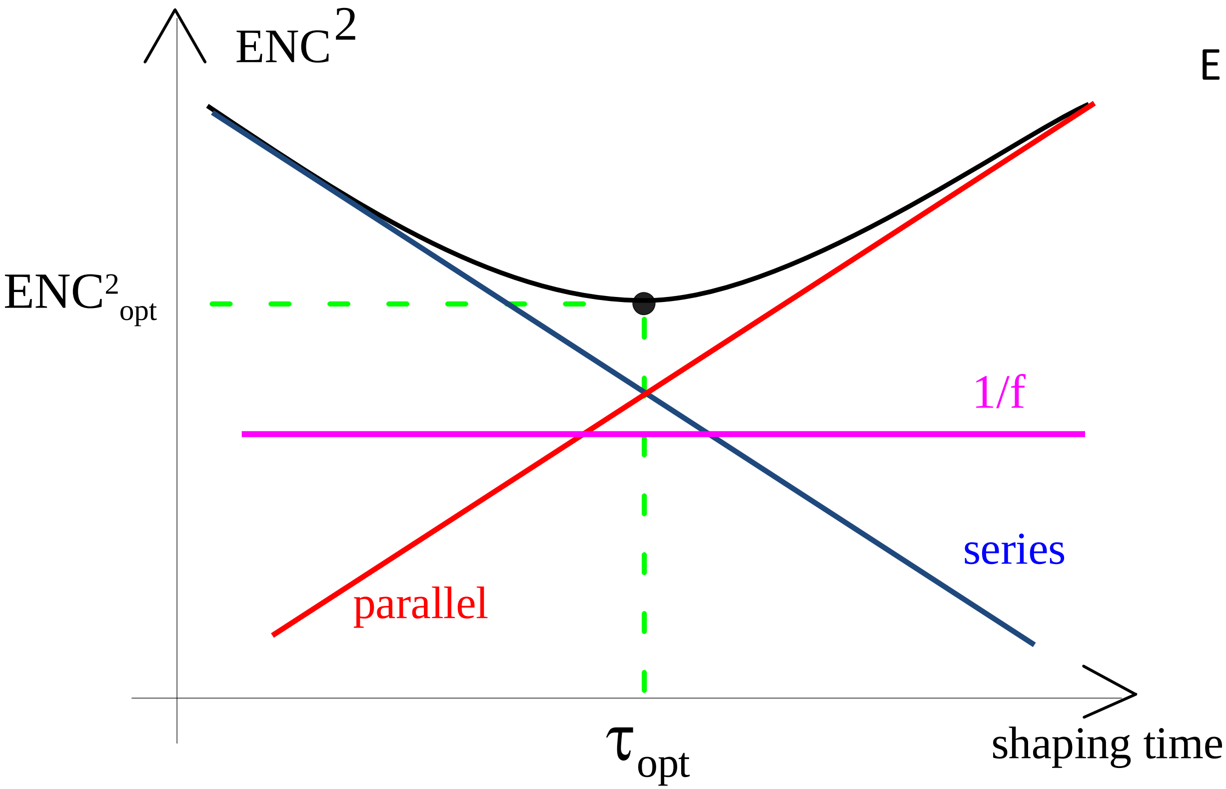
- The Silicon Drift Detector (SDD)
- Gamma-ray detectors based on scintillators and SDDs
- Applications
- Future activities

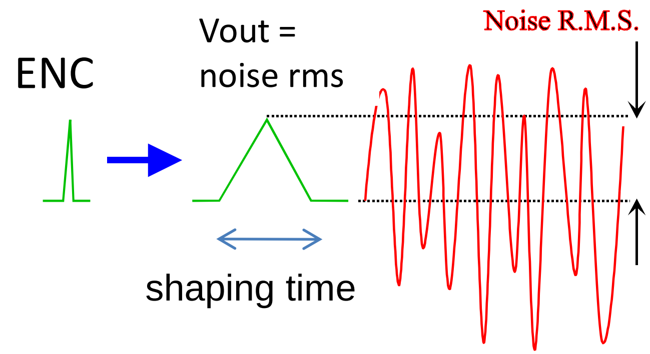
X-ray interaction in a semiconductor detector, generation of the output signal



The amplitude of the output signal is proportional to the energy of the incoming X ray

Equivalent Noise Charge (ENC)

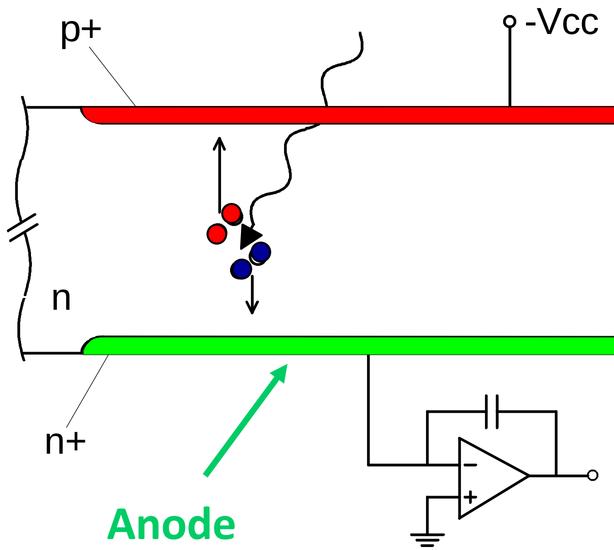




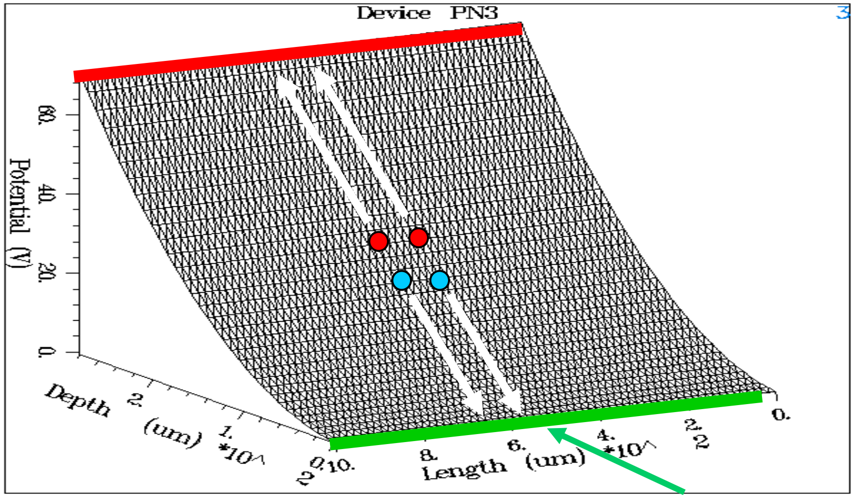
$$ENC^2 = A_1\ 2KT\alpha\ 1/gm\ (C_D + C_i)^2 \frac{1}{\tau} + A_2 q\, I_{leak}\, \tau + A_3 2\pi A_F (C_D + C_i)^2$$

series   parallel   1/f

The classical PIN diode detector



Anode

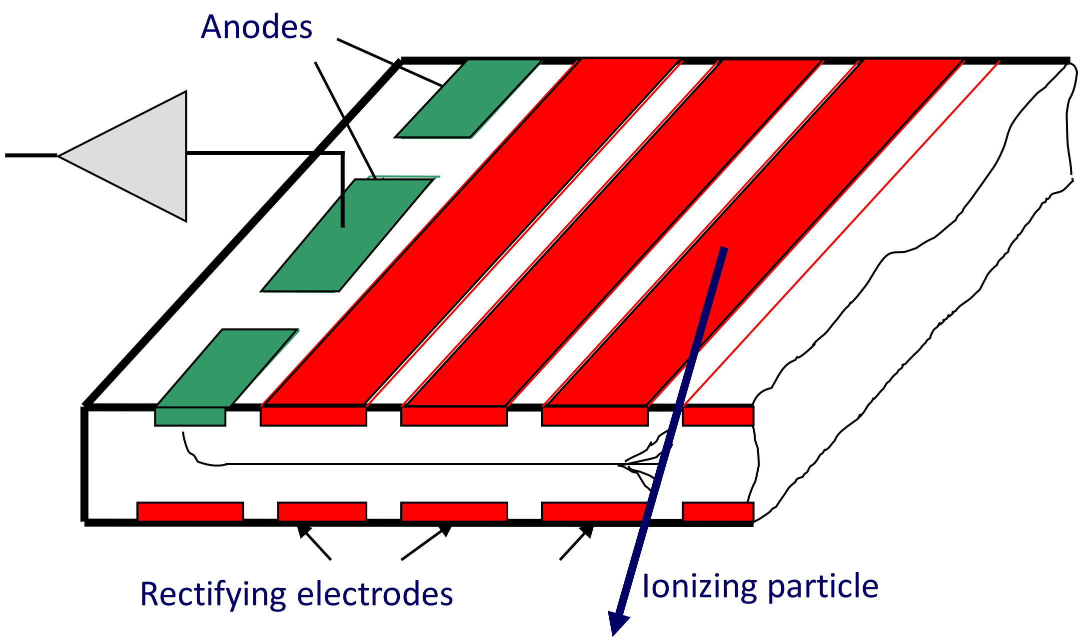


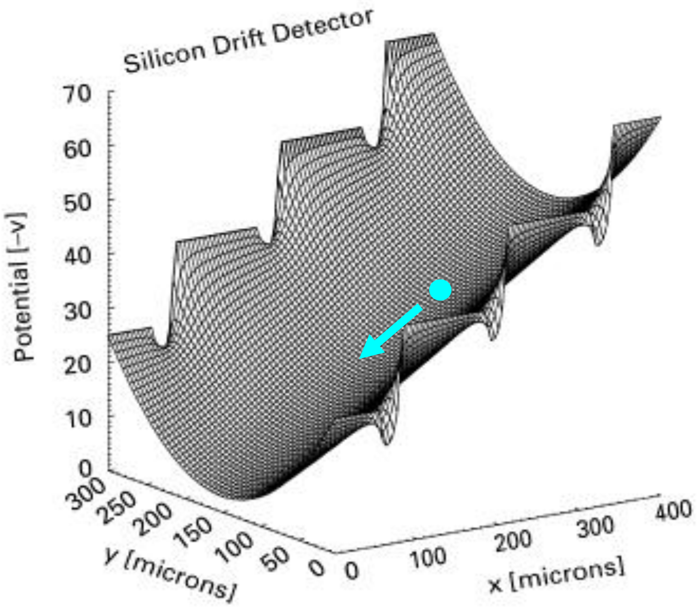
Anode

•The diode is reversely biased in order to fully deplete from free carriers the semiconductor bulk.
•The electrons generated by the X-ray interaction are collected at the anode, the holes at the cathode.

The detector capacitance CD is proportional to the active area

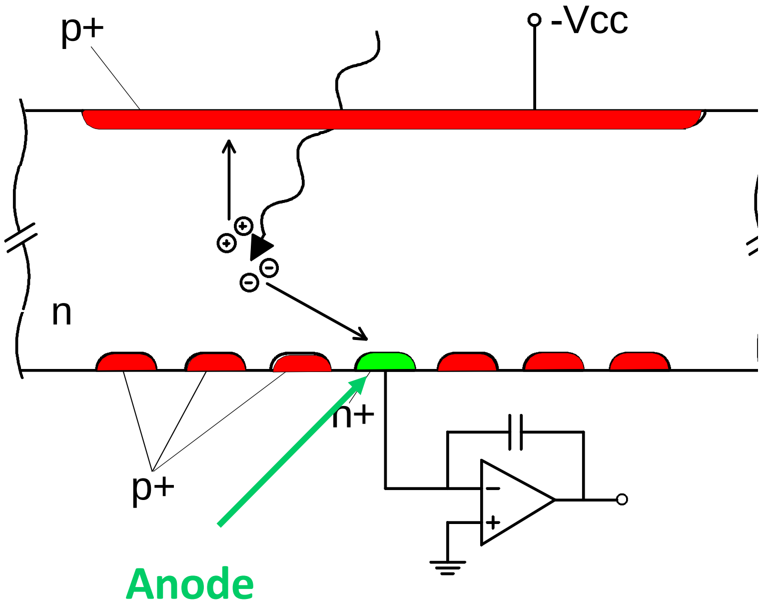
The Silicon Drift Detector (SDD)

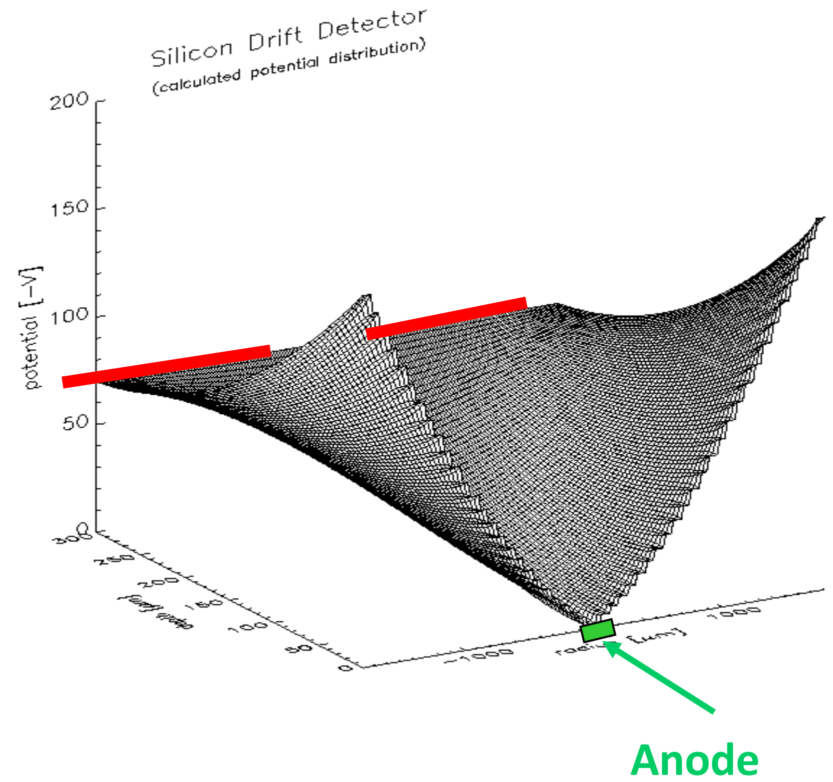




The concept of the SDD has been introduced by E.Gatti (Politecnico di Milano) and P.Rehak (Brookhaven National Laboratory) in 1983

The SDD for X-ray spectroscopy





The electrons are collected by the small anode,characterised by a **low output capacitance,** whose value is independent on the active area of the detector.

Observed energy dependence of Fano factor in silicon at hard X-ray energies

F. Perotti[a,*], C. Fiorini[b]

[a] Istituto di Fisica Cosmica e Tecnologie Relative, C.N.R., via Bassini 15, 20133 Milano, Italy
[b] Politecnico di Milano, Dipartimento di Elettronica e Informazione, Piazza L. da Vinci 32, 20133 Milano, Italy

Received 29 July 1998; received in revised form 15 September 1998

N_e: numero di elettroni generati da un evento ionizzante

$N_e = E/\varepsilon$ con E=energia, ε =3.6eV in Silicio

σ_{Ne}^2: varianza

$\sigma_{Ne}^2 = N_e \cdot F$

F: fattore di Fano (ca. 0.12 in Si)

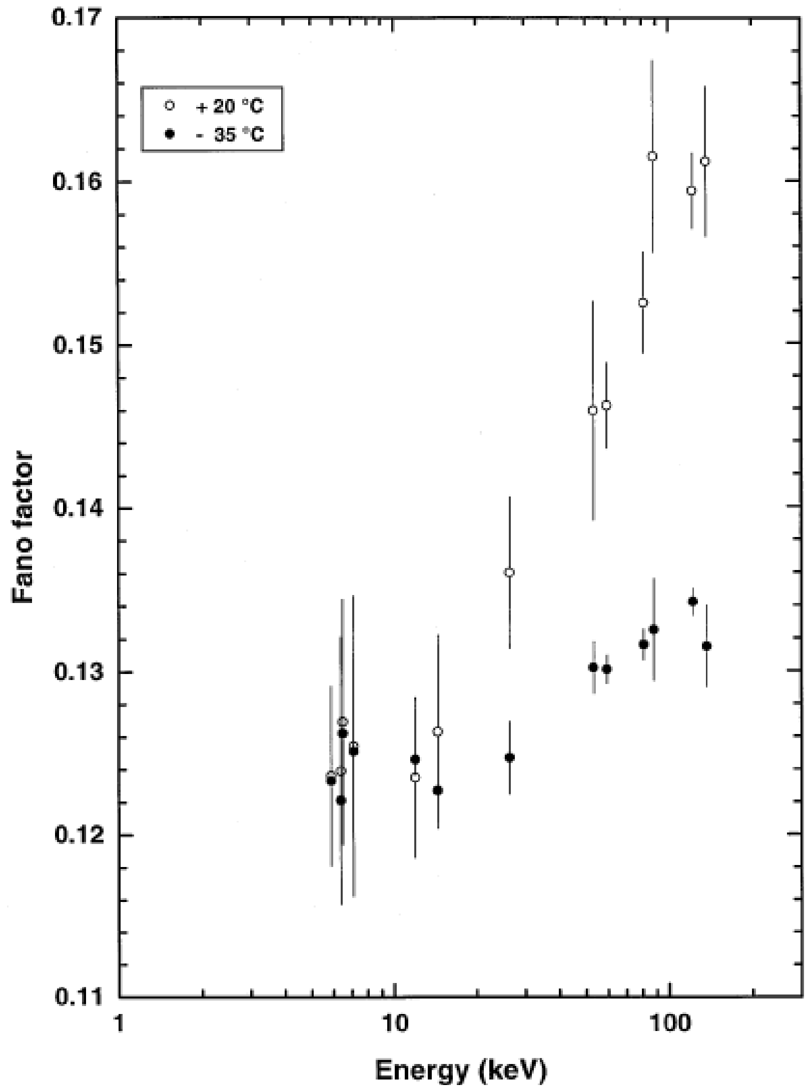
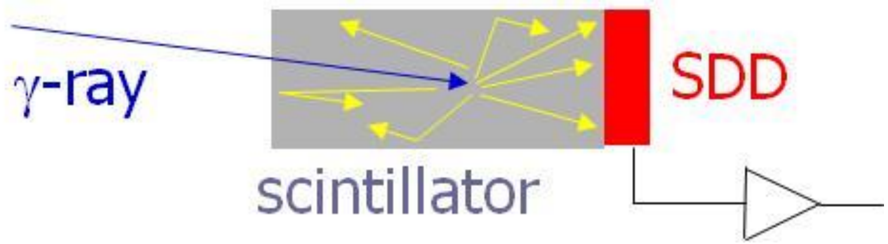
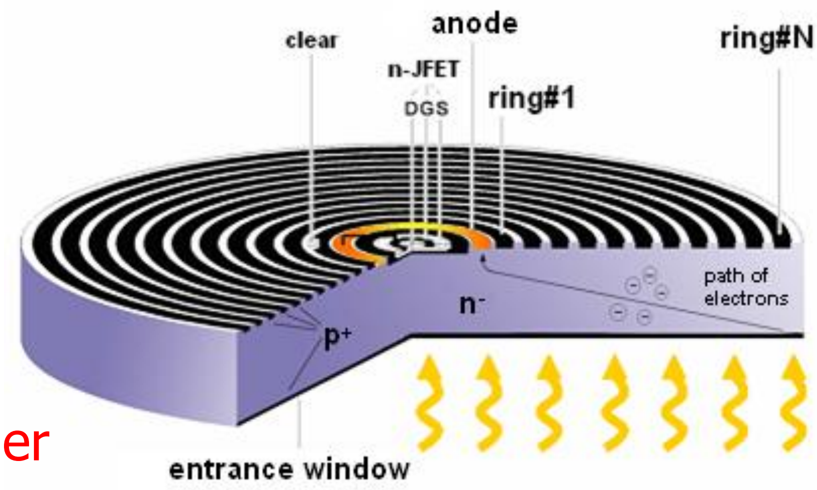


Fig. 7. Fano factor evaluated at room temperature and at −35°C as a function of the energy of the X-ray detected photons.

Application of the SDD in γ-ray spectroscopy and imaging





Advantages of SDDs with respect to other photodetectors:

- high quantum efficiency (~90 %) @ 565nm of CsI(Tl), vs. PMT(~30 % of PMT)
- compact, mechanical robust
- no statistical spread due to multiplication
- low operating voltages
- smaller sensitivity to bias and temperature variations
- insensitivity to magnetic fields

Applications:

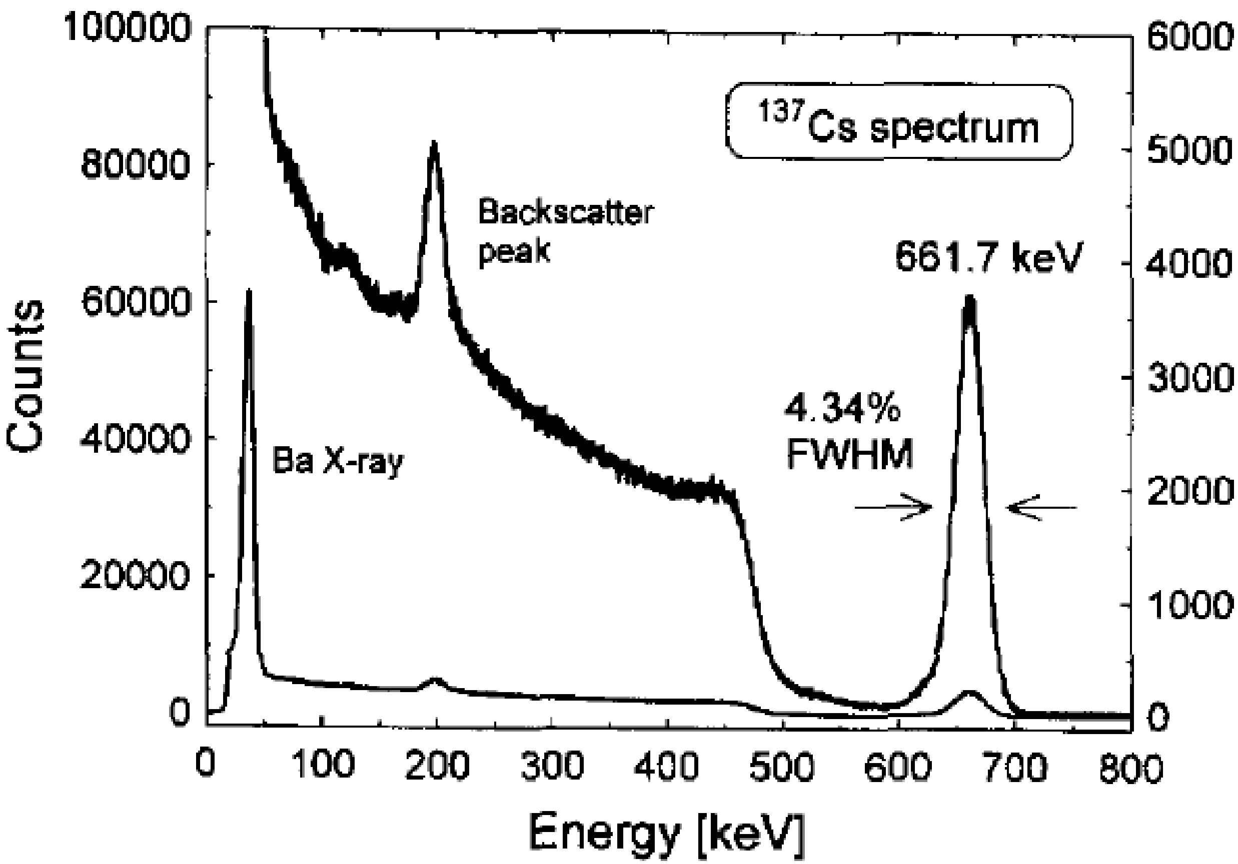
- medical imaging
- gamma-ray astronomy
- homeland security
- nuclear physics experiments

Scintillation detection using a silicon drift chamber with on-chip electronics

C. Fiorini[a,*], F. Perotti[b]

[a] Politecnico di Milano, Dipartimento di Elettronica e Informazione, Piazza L. da Vinci 32, 20133 Milano, Italy
[b] Istituto di Fisica Cosmica e Tecnologie Relative, C.N.R., via Bassini 15, 20133 Milano, Italy

Received 16 June 1997

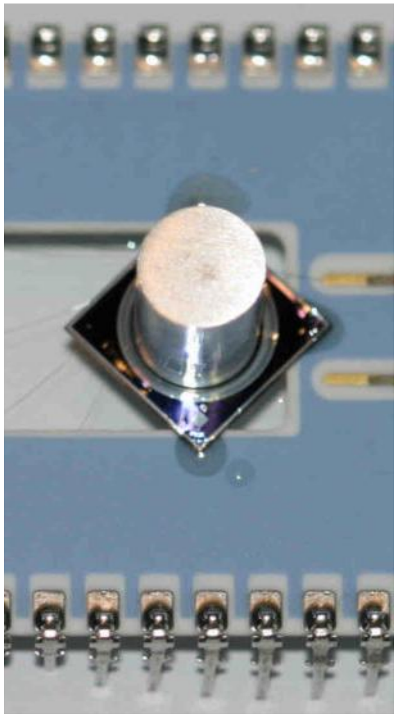


Gamma-ray spectroscopy with a SDD coupled to a CsI(Tl) scintillator

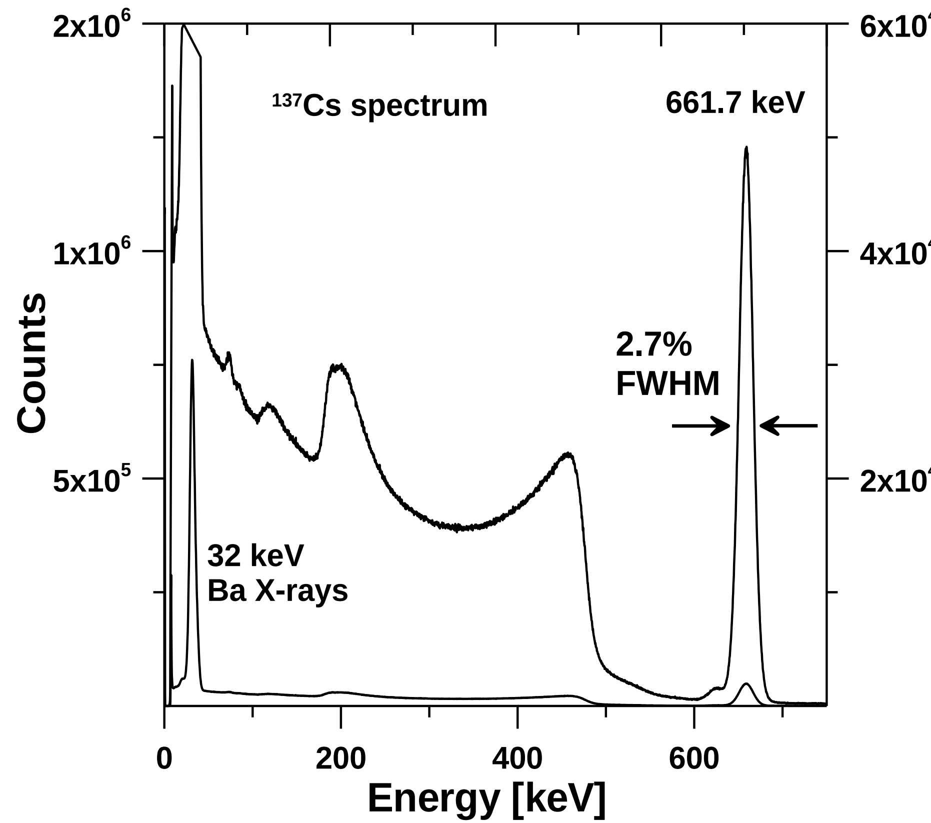
at the time of publication, the world-record energy resolution with a scintillator

Measurement carried out at CNR – Via Bassini – the 31 December 1996

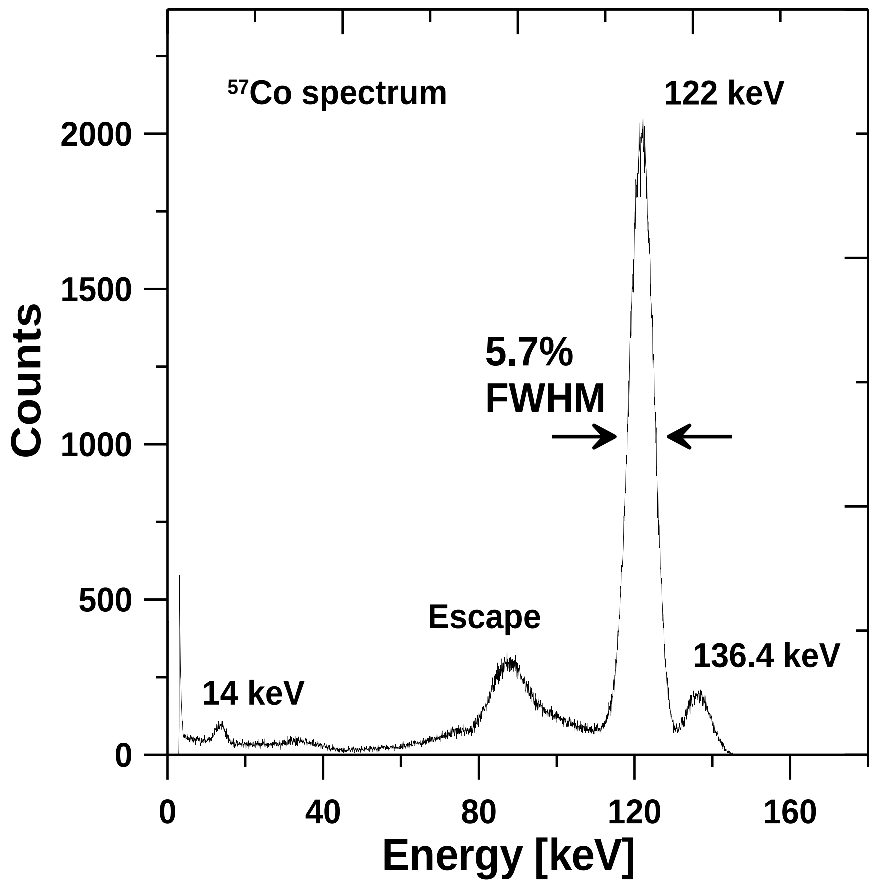
Gamma-ray spectroscopy with an SDD coupled to $LaBr_3$

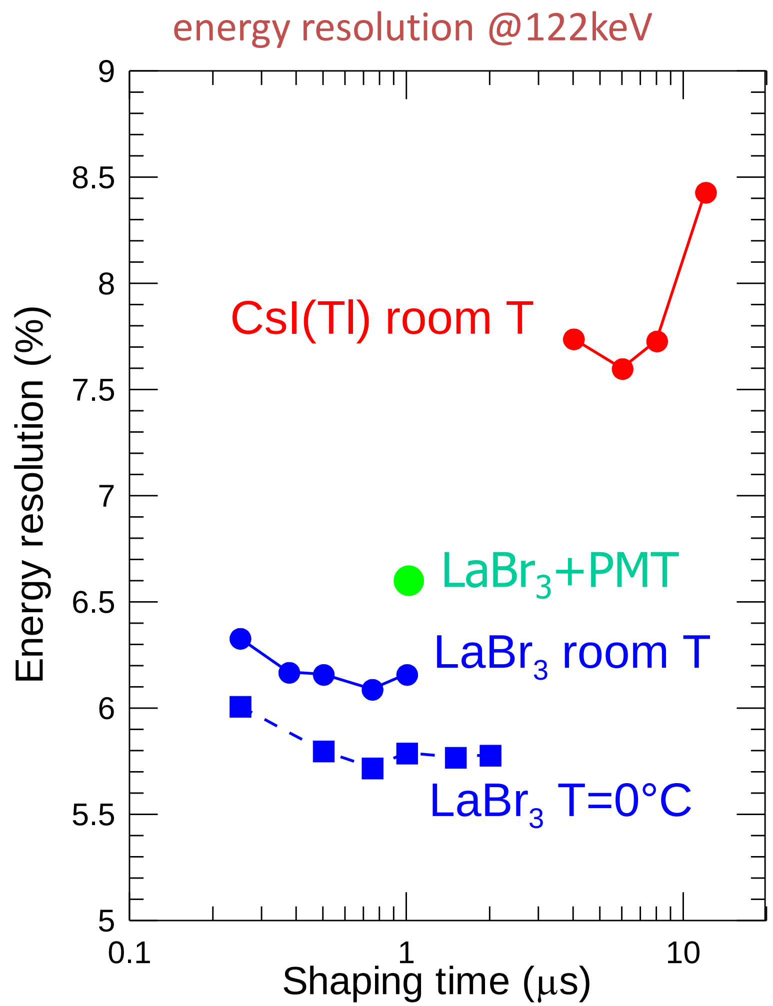


- 30mm² SDD
- Brillance 380
  5mm Ø,
  5mm thick



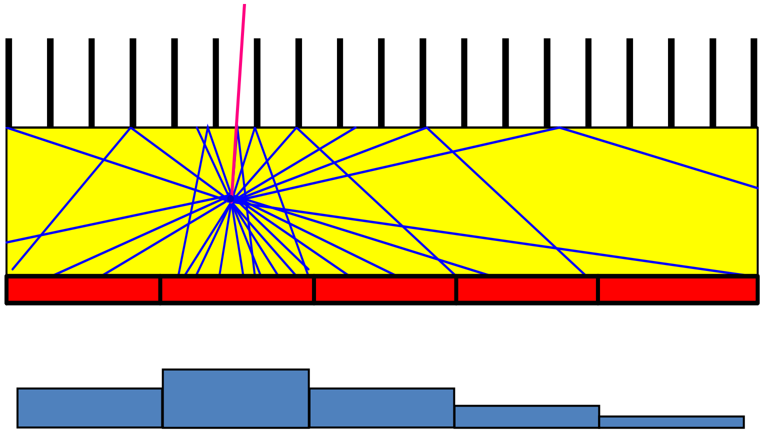
Fiorini, C.; et al. "Gamma-Ray Spectroscopy With LaBr3:Ce Scintillator Readout by a Silicon Drift Detector"; IEEE Transactions on Nuclear Science, Volume 53, Issue 4, Part 2, Aug. 2006 Page(s):2392 – 2397.





world record in energy resolution with a scintillator

Anger Cameras based on SDDs



Main advantages (vs. pixellated detectors, e.g. CdTe or CZT):

• spatial resolution (<mm) achieved with ~ 10 times larger photodetector pixel size

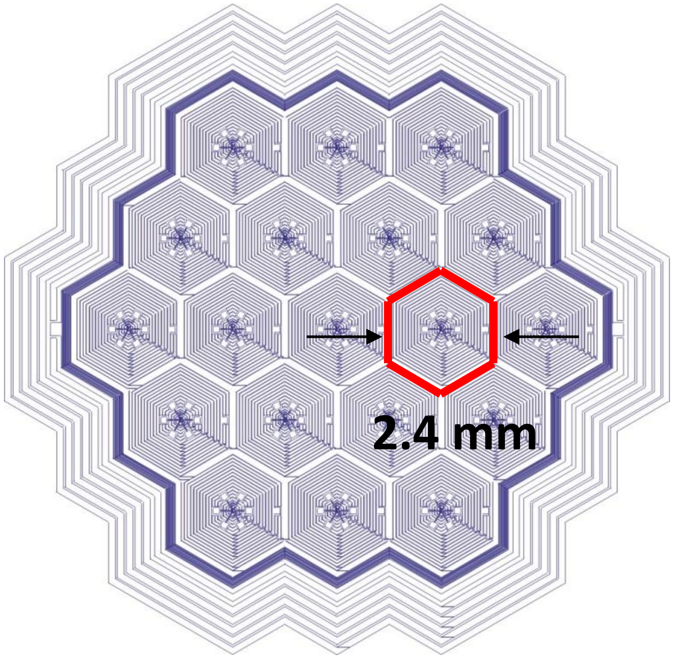
⇒1/100 readout channels needed for a given spatial resolution

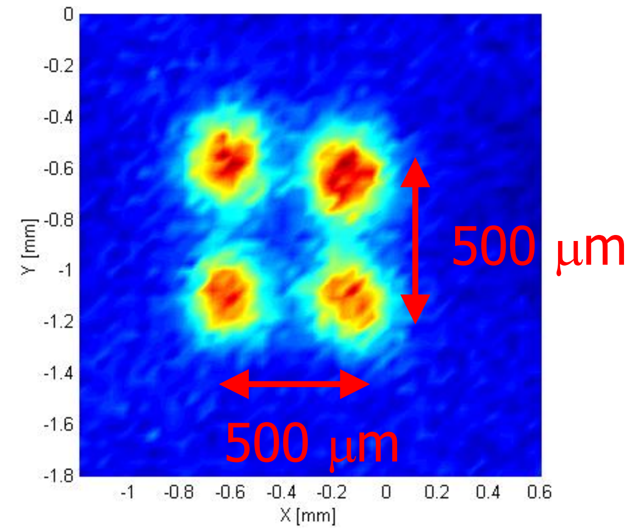
• good detection efficiency, adjustable vs. energy with scintillator thickness

Main disadvantage

Poorer energy resolution, especially at low energy, due to the scintillator conversion (although new scintillators like $LaBr_3$ are reducing this gap) and to the electronics noise added by the several photodetectors used for the light readout

Small prototype of SDD - CsI(Tl) Anger camera





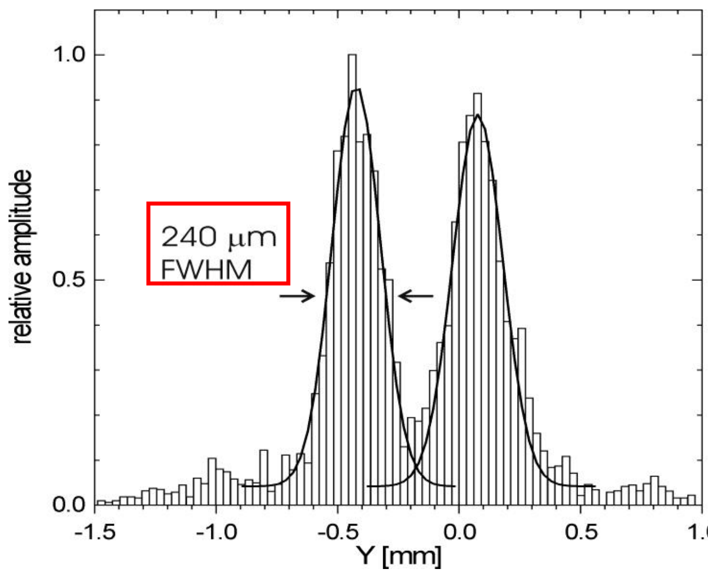
Total area = 5 mm^2×19 ~ 1cm^2

CsI(Tl) thickness = 3 mm

T = -10°C

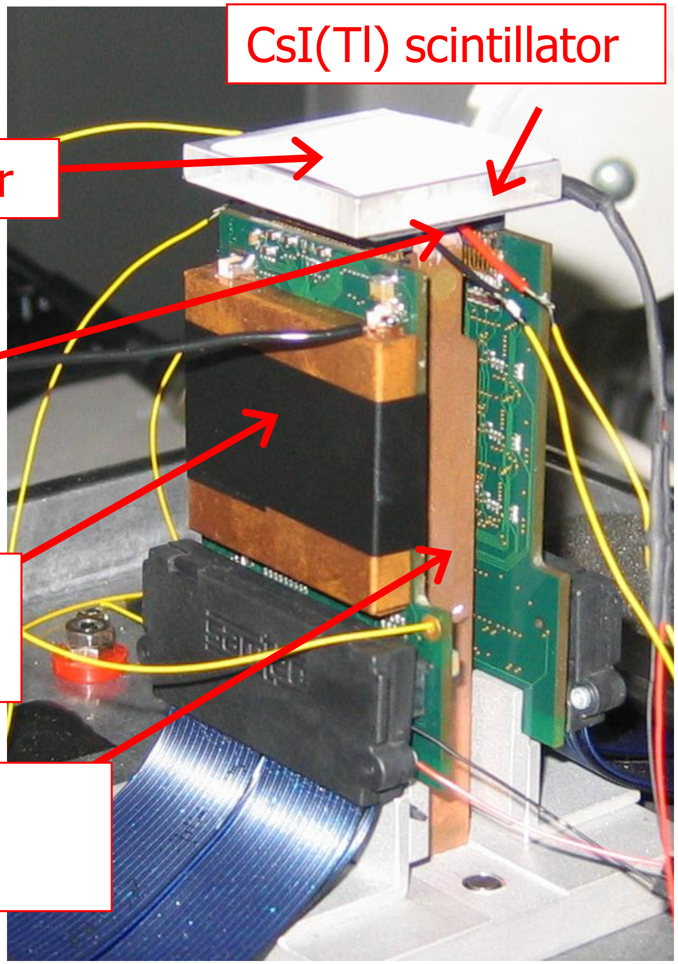
E = 122 keV (^{57}Co)

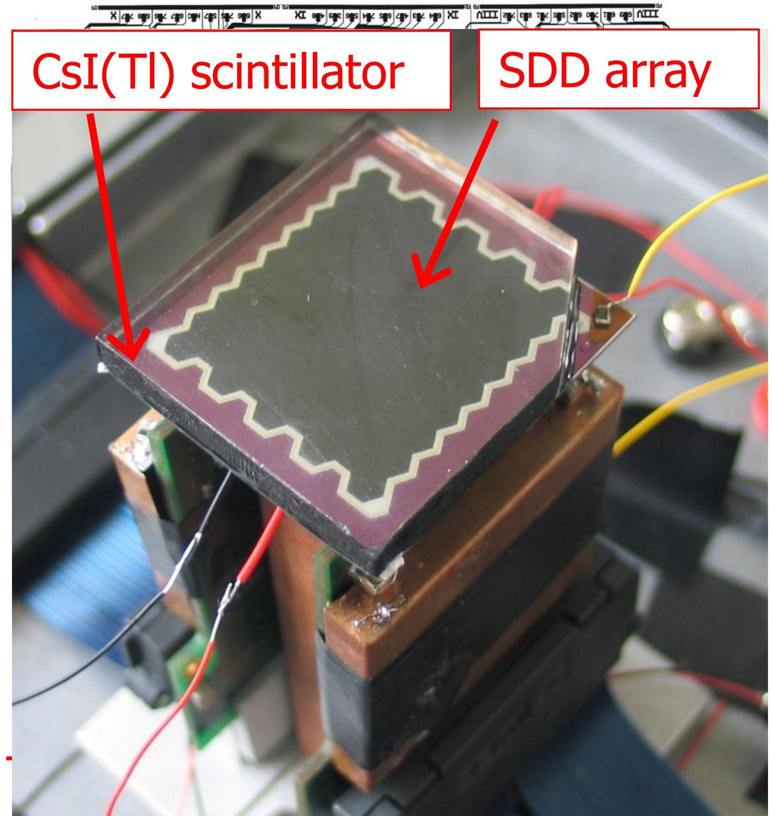
ø $_{collimator}$ ~ 180 μm



160 μm intrinsic resolution

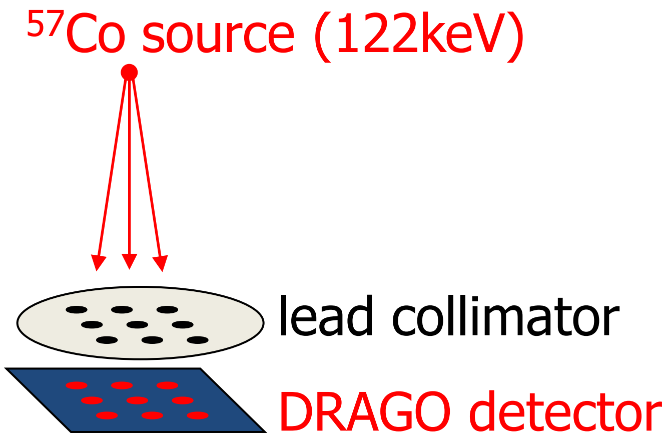
The DRAGO Gamma Camera
(DRift detector Array-based Gamma camera for Oncology)

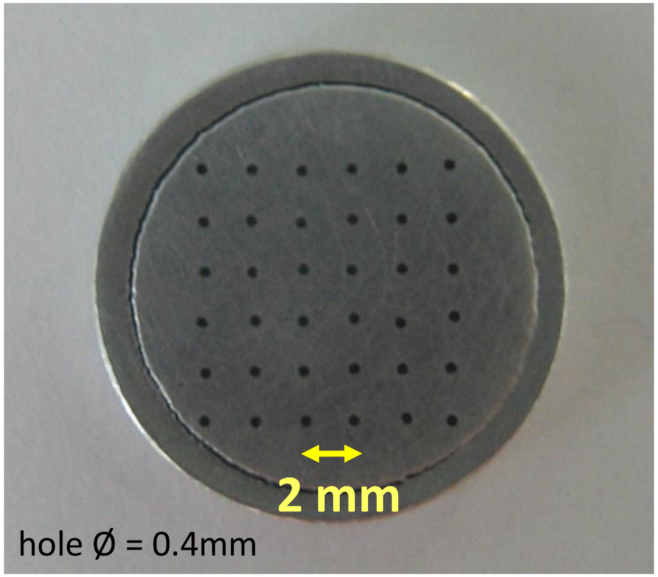


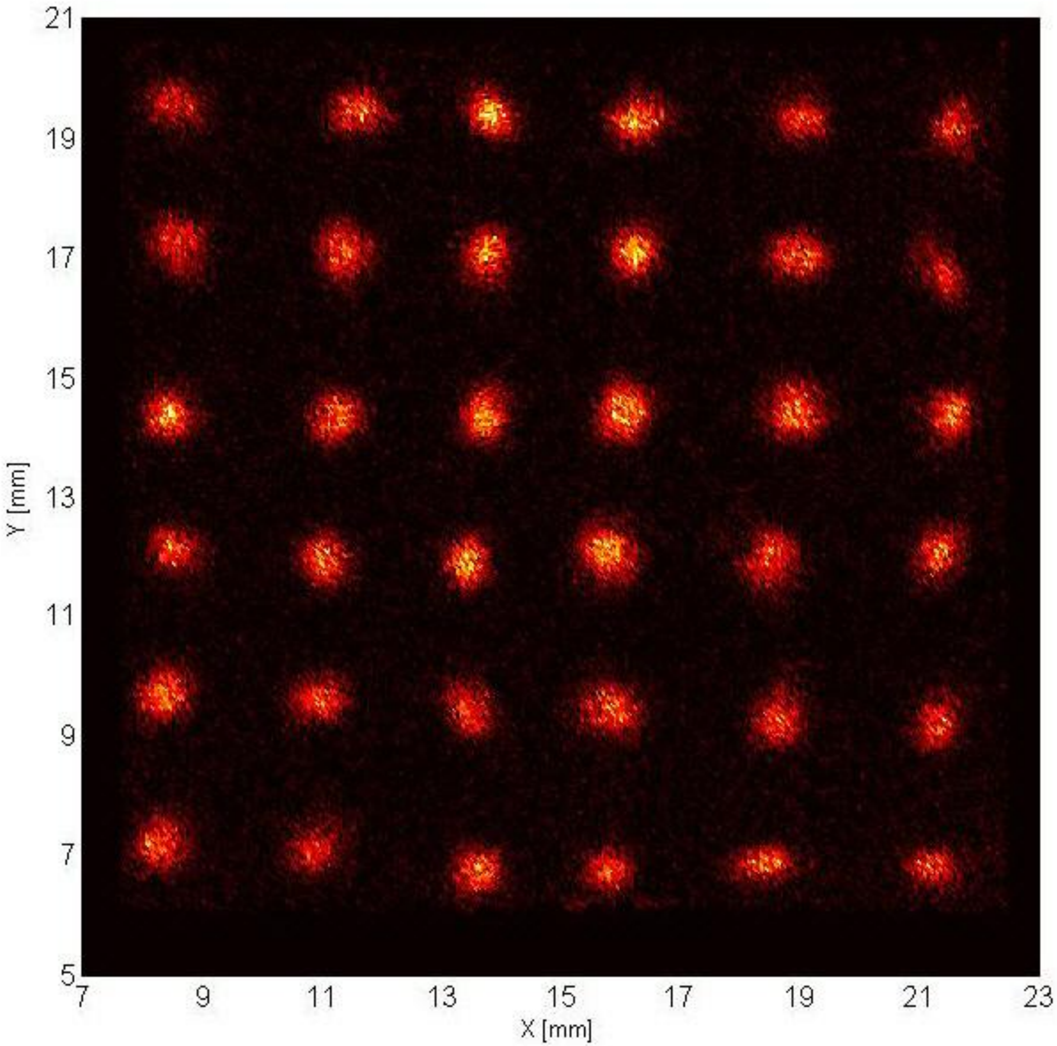


- tot. active area = 6.7cm²
- leakage current ~ 300pA/cm² @RT
- QE ~ 90% @ 565nm of CsI(Tl)
- CsI(Tl) thickness = 5mm (~80%@140keV)

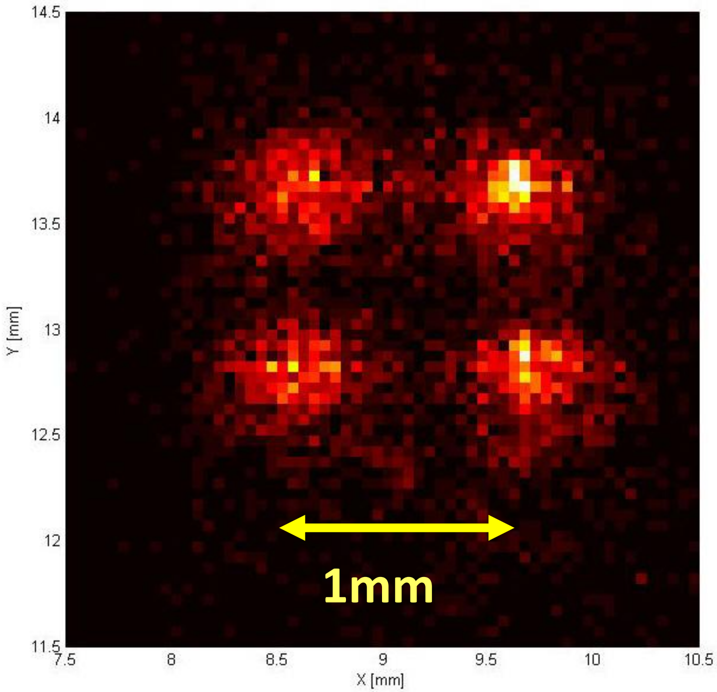
γ-ray measurements

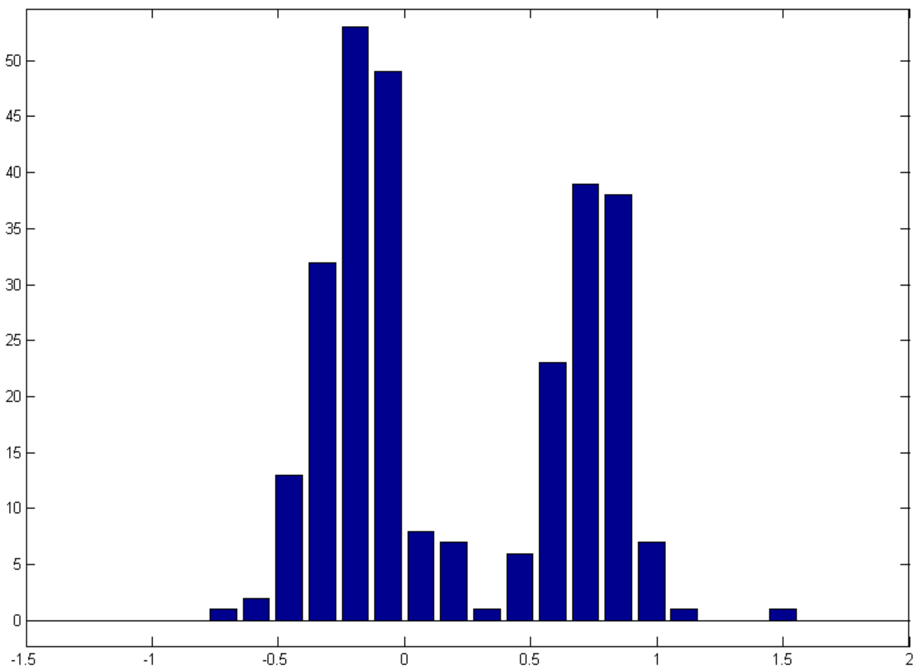






Spatial resolution



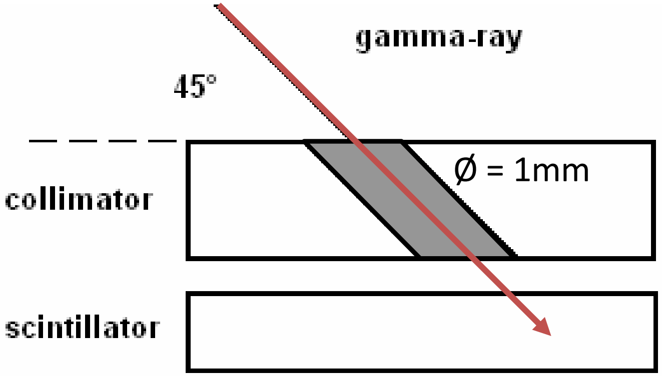


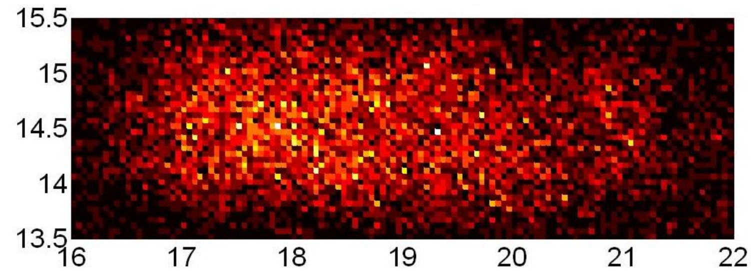
Ø collimator ~ 0.2 mm

Spatial resolution = 0.25 – 0.50 mm

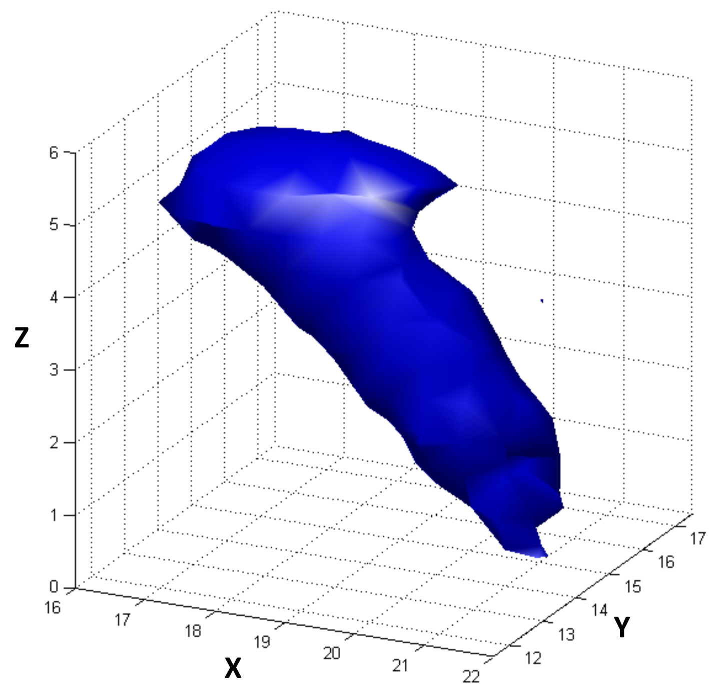
(ref: 3.2mm SDD pixel size)

Verification of DOI capability by measuring a 45° tilted beam

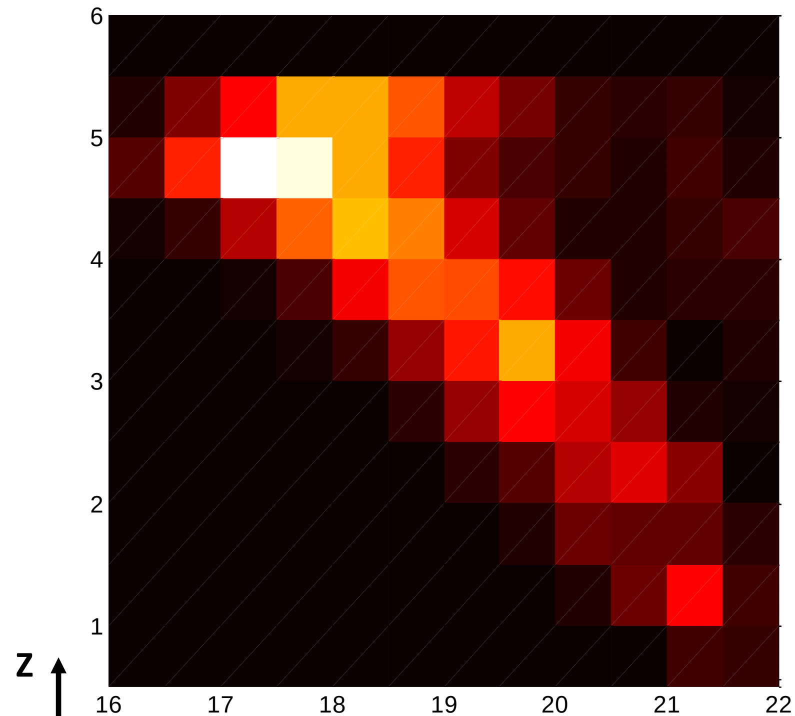




X-Y image

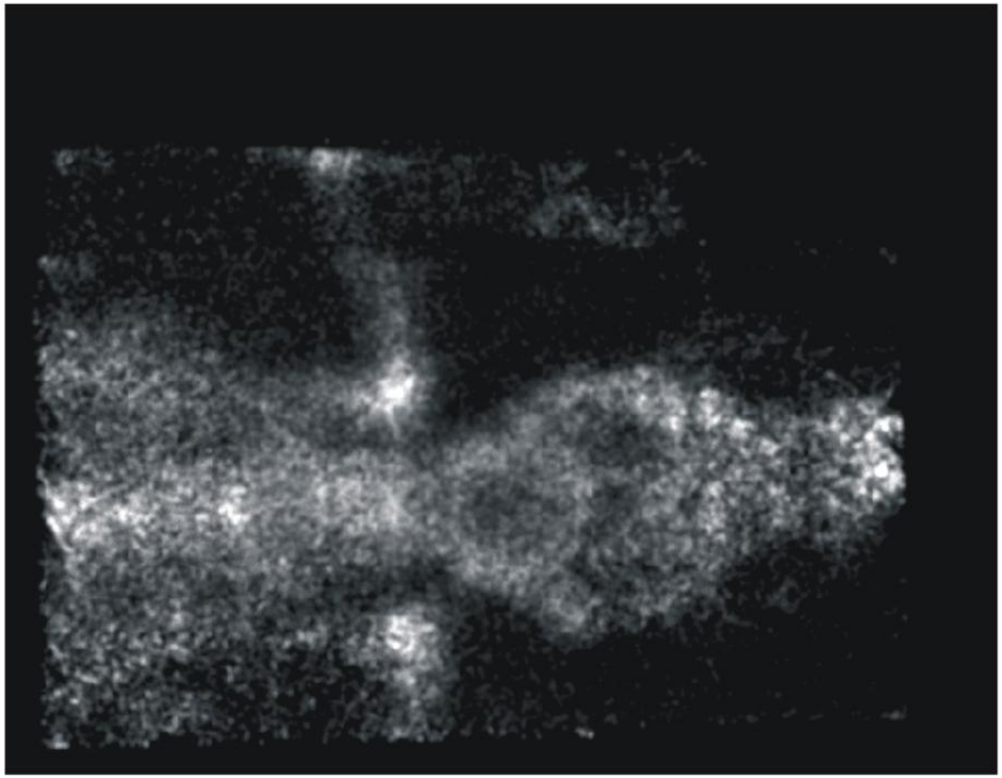


isosurface image

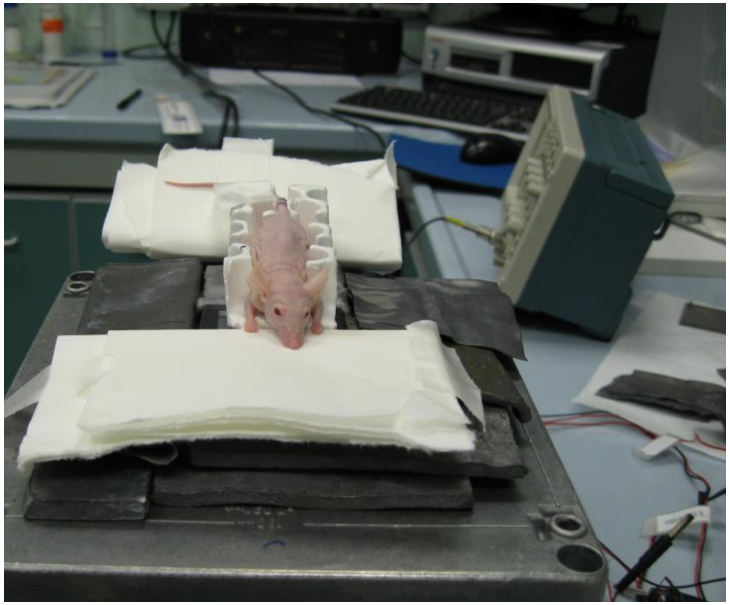


X-Z image

Preliminar *in vivo* planar scintigraphy of a mouse

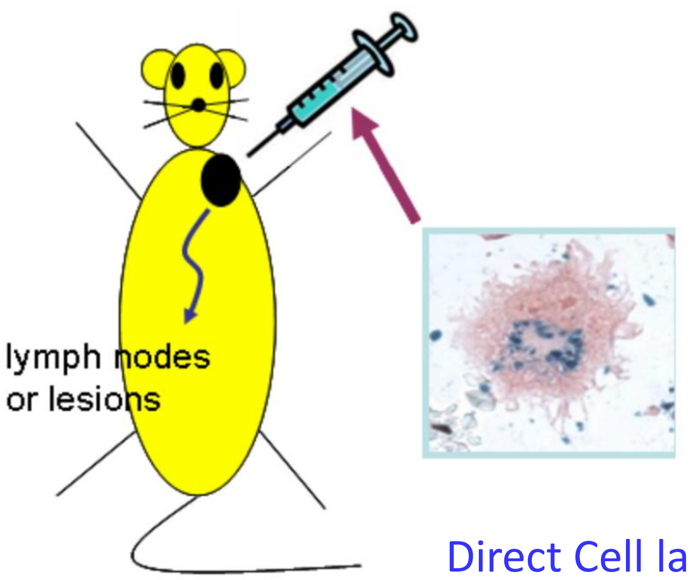


[^{99}Tc] MDP
2.5mCi injected activity
2h. after injection,
10min acquisition time

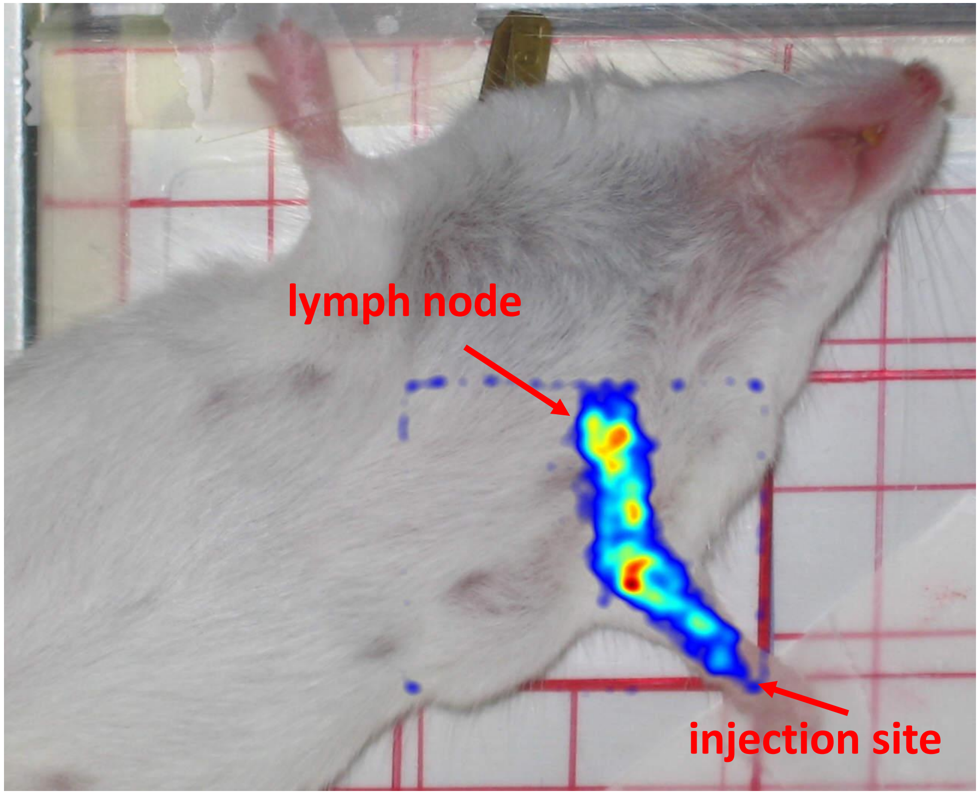


Measurements carried out at
Hospital San Raffaele, Milano, Italy
Hospital San Paolo, Milano, Italy

Preliminar *in vivo* Direct Cell imaging



Direct Cell labeling



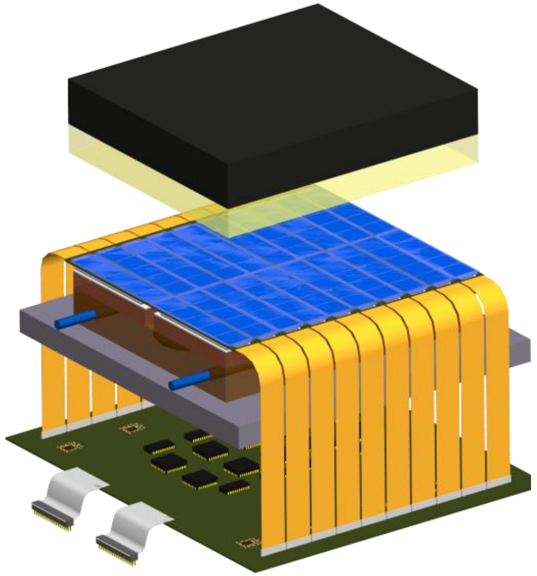
In-vivo dendritic cells tracking by means of the DRAGO camera

Measurements carried out at Hospital San Paolo, Milano, Italy

The HICAM gamma camera (EC contract n. LSHC-CT-2006-037737)

features:

- **10x10cm^2** FOV
- intrinsic resolution **~ 1mm**
- overall resolution ~ 2.5mm @5cm
- energy resolution ~ 10% @140keV
- **compactness**
- compatibility with MRI



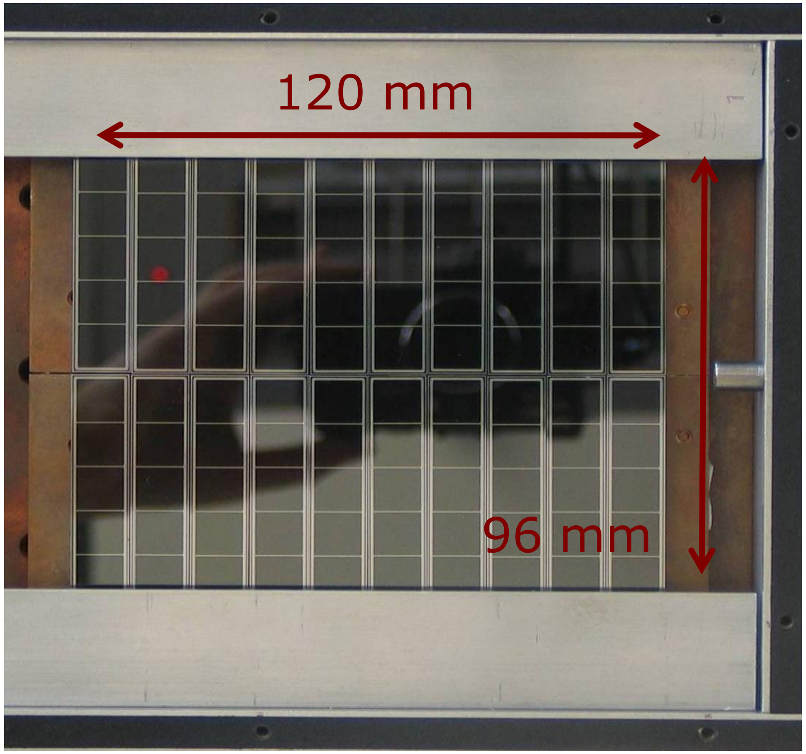
Applications:

- planar clinical studies of spine and small bones
- intra-operative imaging of breast cancer and melanoma
- imaging of parathyroid and thyroid
- SPECT measures in test phantoms
- combined HI-CAM and MRI measures
- small animal imaging

The consortium:

- Politecnico di Milano, Italy
- MPI Halbleiterlabor, Germany
- L'ACN, Italy
- Nuclear Fields Holland
- UCL London, UK
- OORR-Bg, Italy
- Hospital San Pau, Barcelona, Spain
- University of Milan, Italy
- Cf Consulting, Italy

Array of 20 monolithic arrays of 5 SDDs (100cm^2 total area)



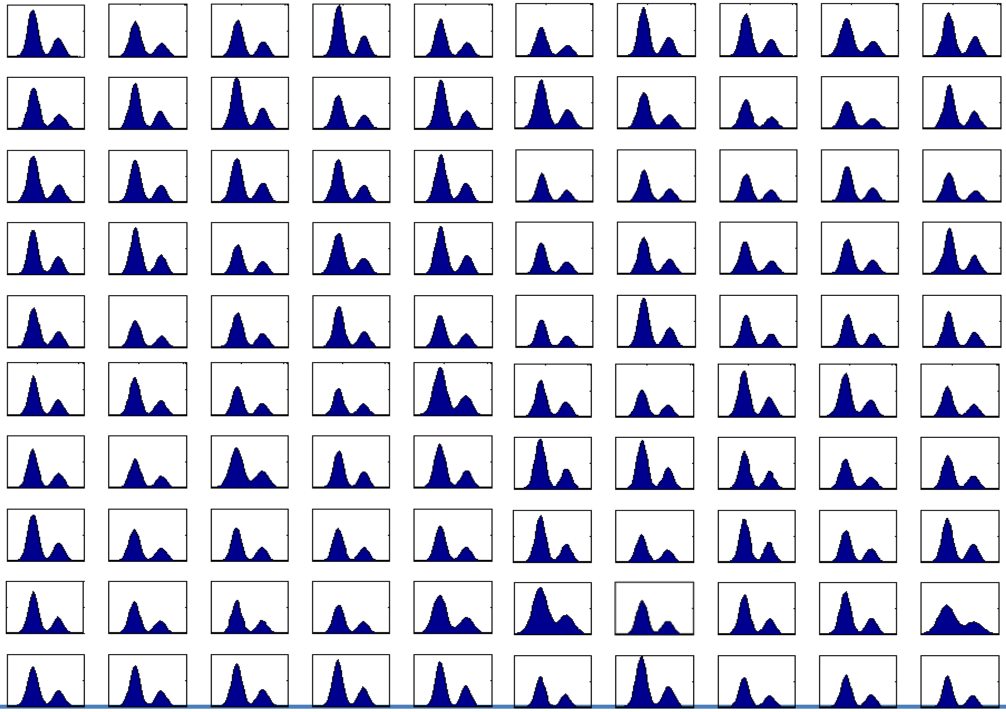
~ 20% dead area

The biggest array of assembled SDDs

Photodetectors qualification:
direct ^{55}Fe irradiation
(without the scintillator)

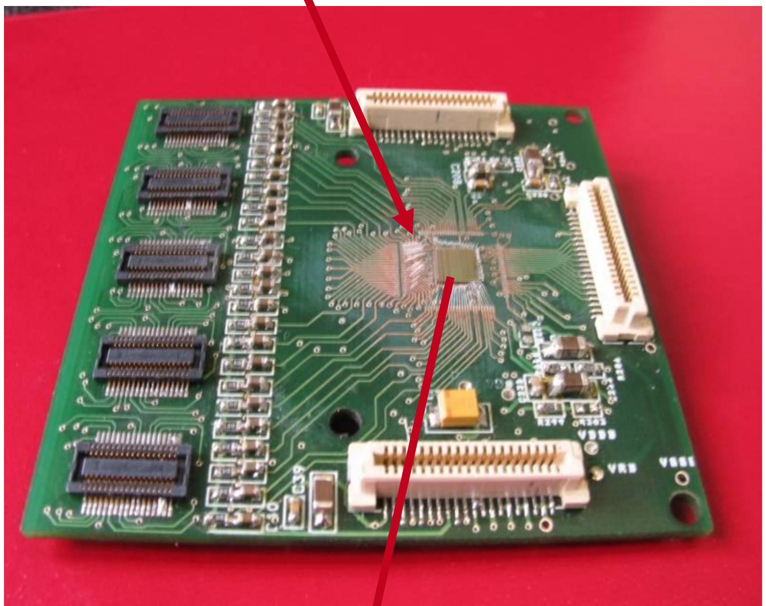
t_{peak}=8.3us

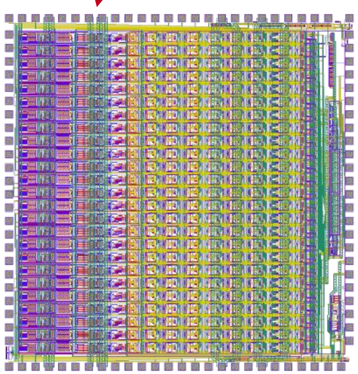
T= - 5°C



Biasing and readout electronics of the camera

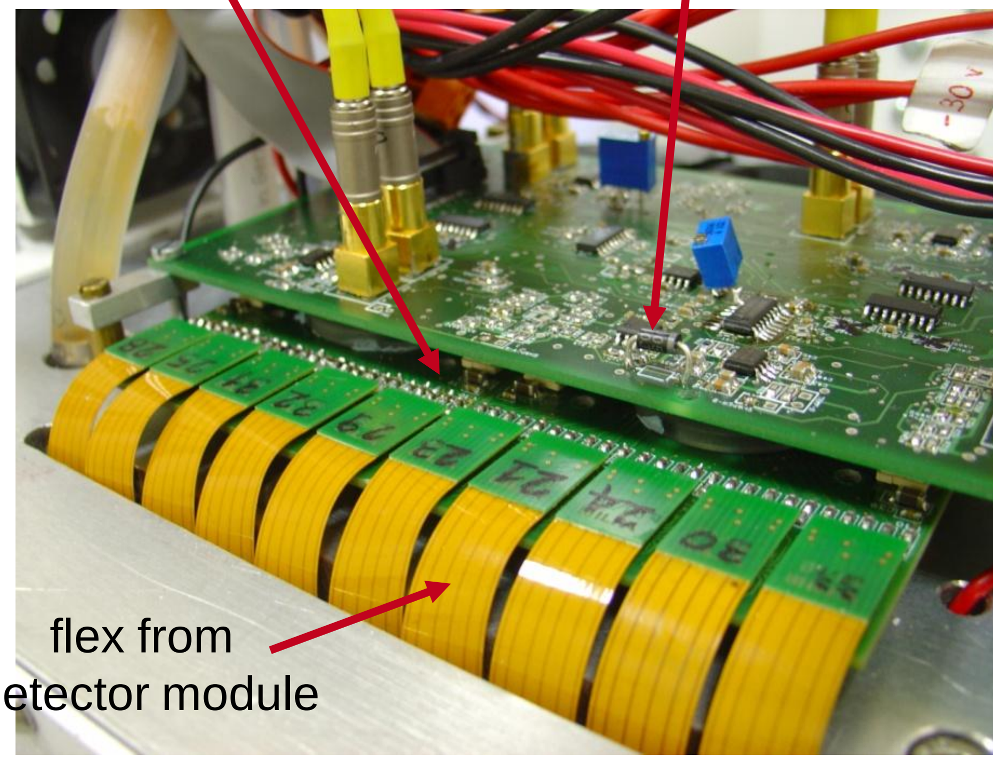
25-channels readout circuit
0.35μm CMOS technology





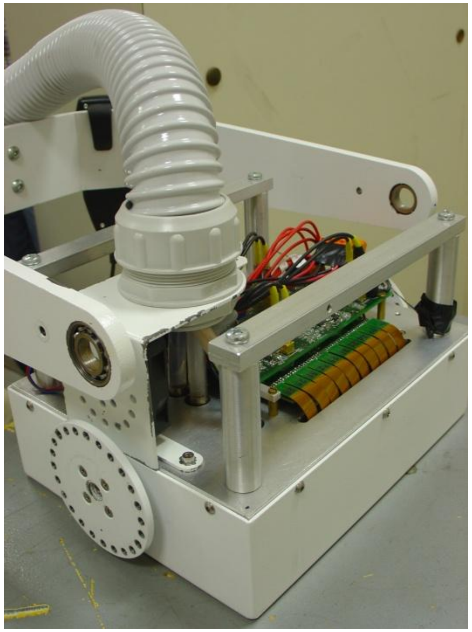
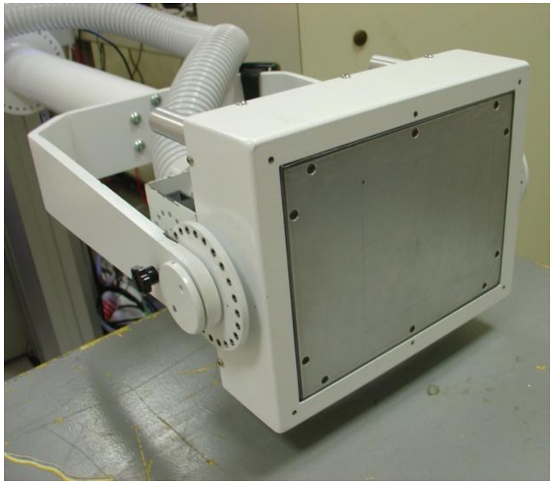
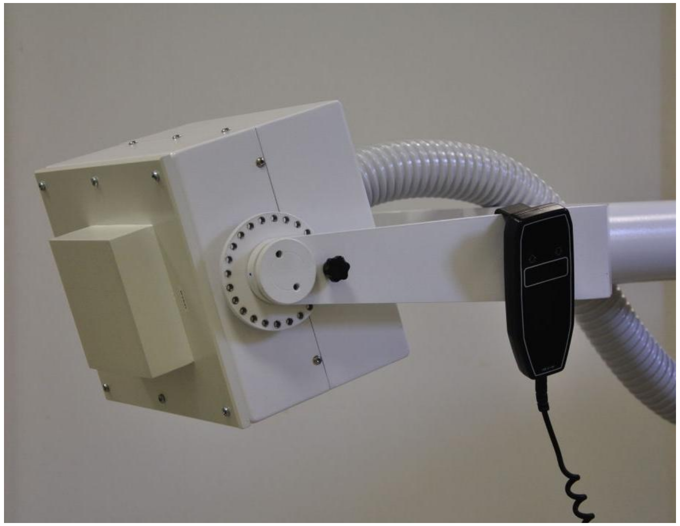
25-channels
readout boards
(x4)

board including biasing
and interface with DAQ
(SPI programming and
data acquisition)

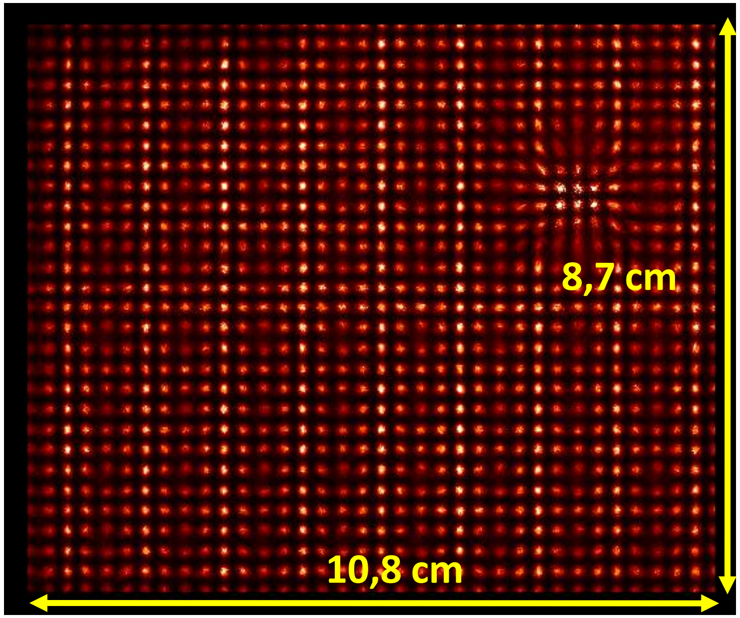


flex from
detector module

Assembly of the camera head

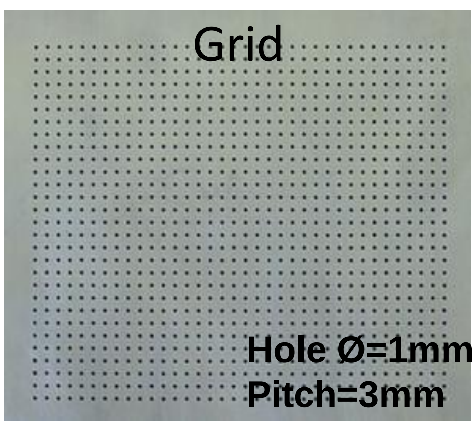




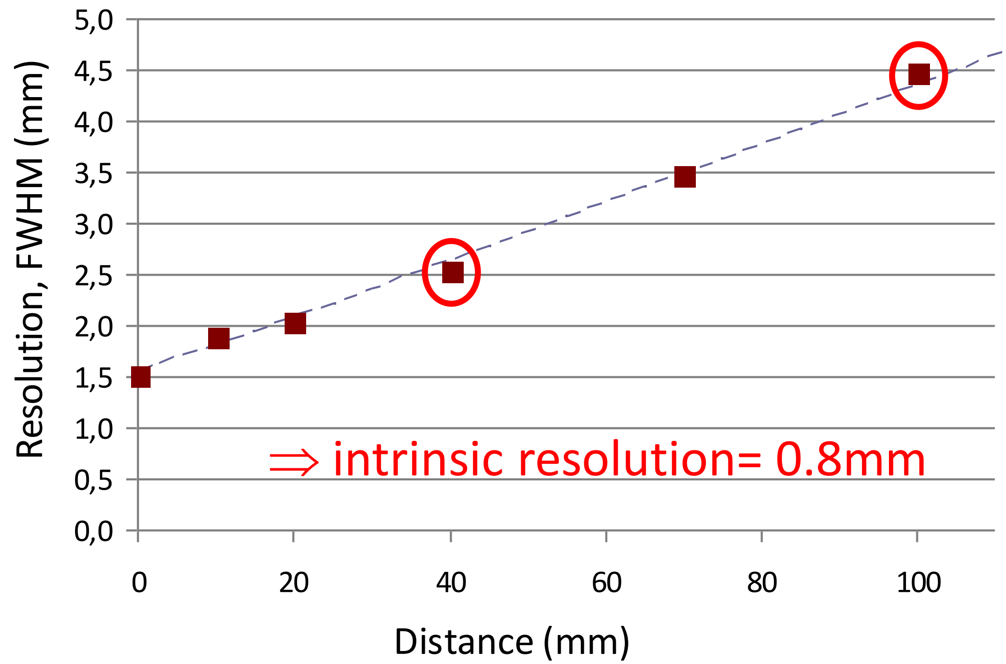
FOV and spatial resolution



corrected for linearity and uniformity

^{99}Tc





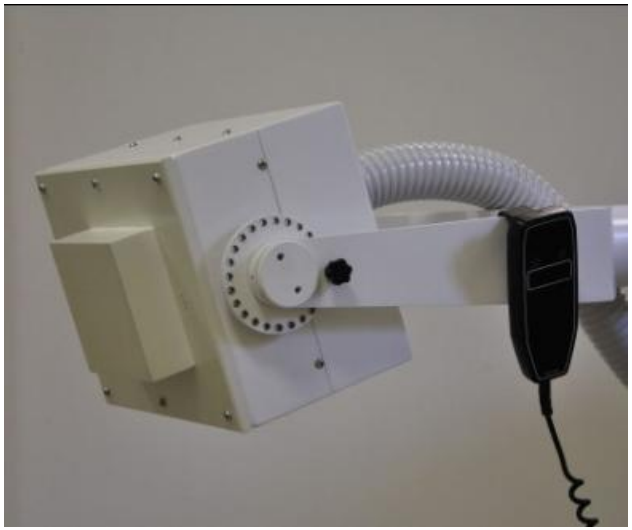
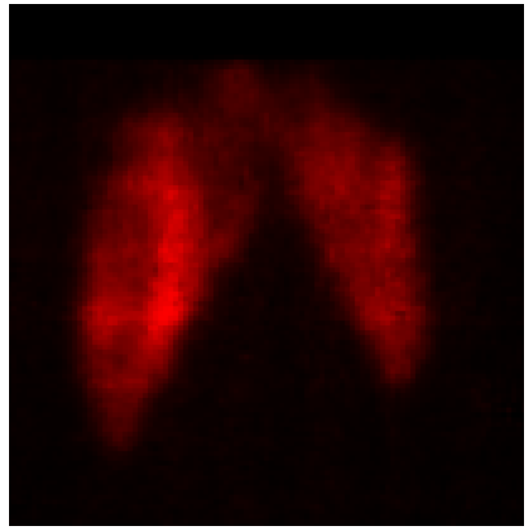
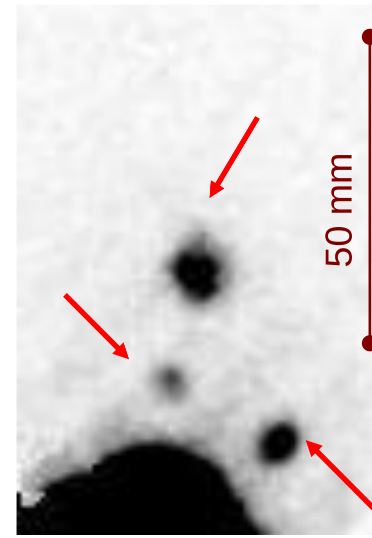
LEUHR parallel hole collimator

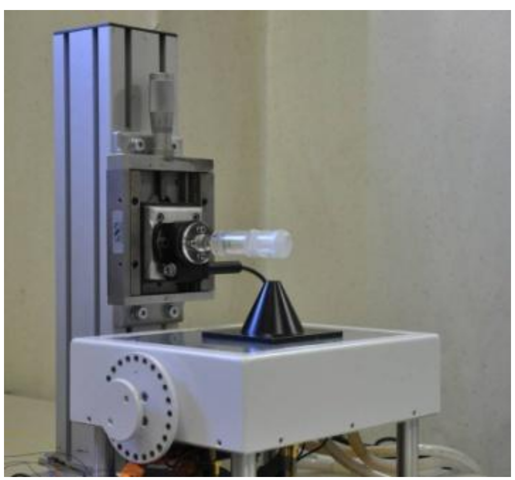
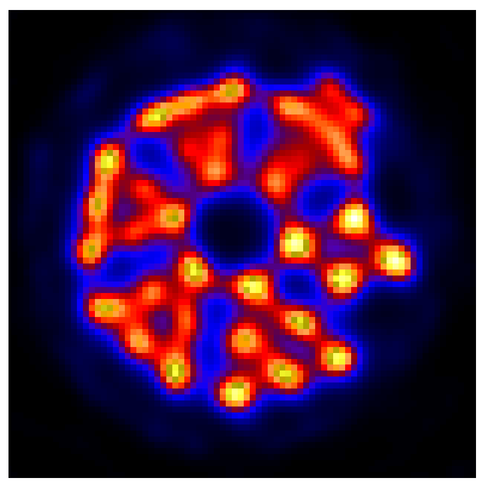
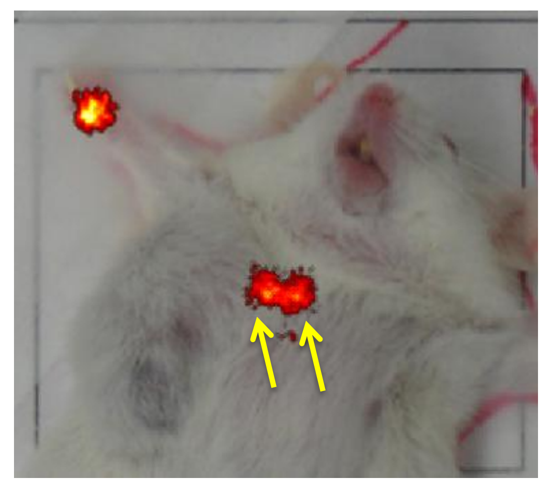
Comparison with a reference camera

E.CAM System Spatial Resolution:

6.3 mm with LEUHR @ 10 cm

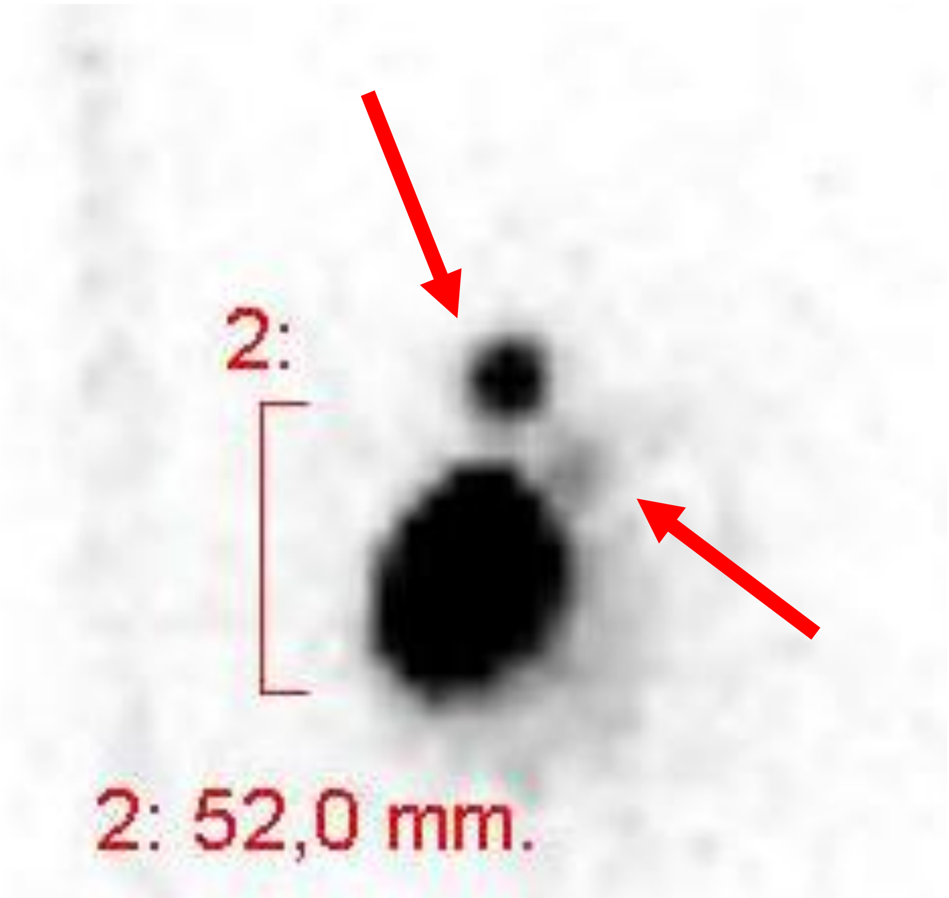
Applications of the HICAM gamma camera

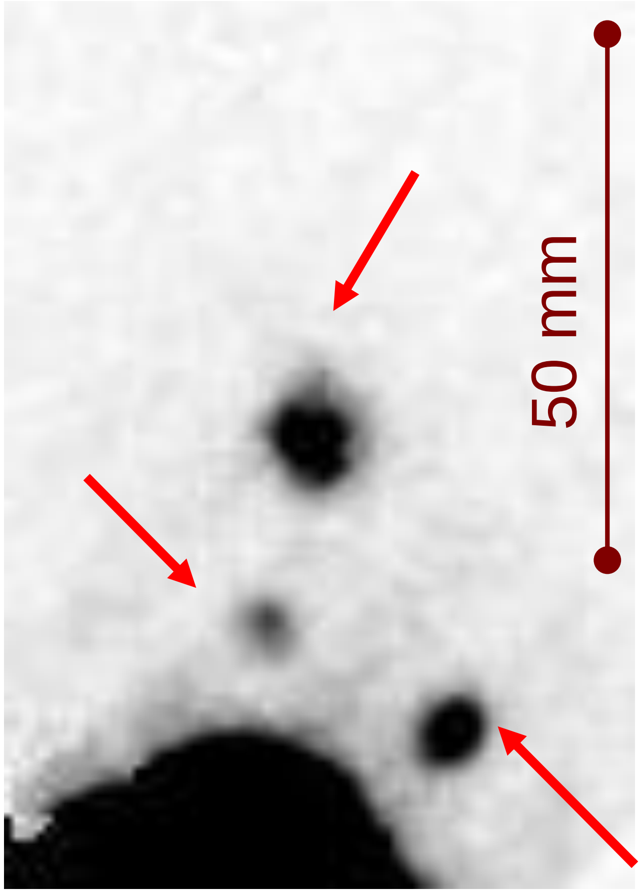




Clinical trial: Lymphoscintigraphy

Lymphoscintigraphy to localize the sentinel node



E-CAM

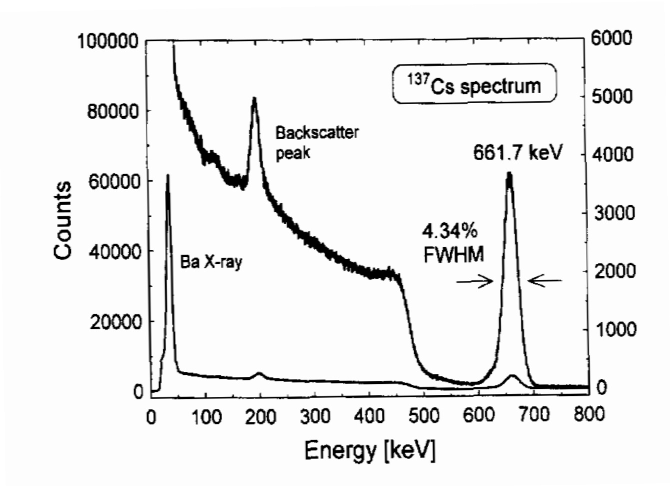


HICAM

Summary: 15 years of research an development

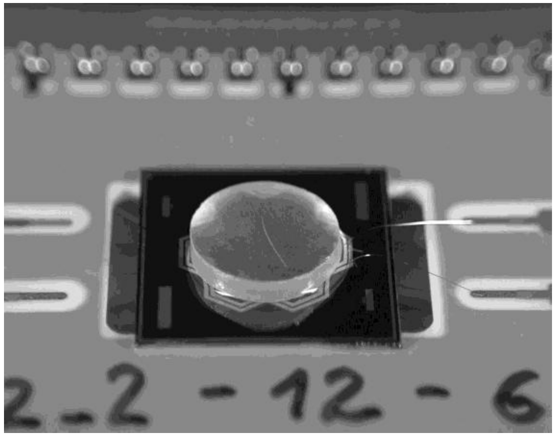
1997

First SDD-scintillator gamma detector
world-record energy resolution
(0.07cm^2)



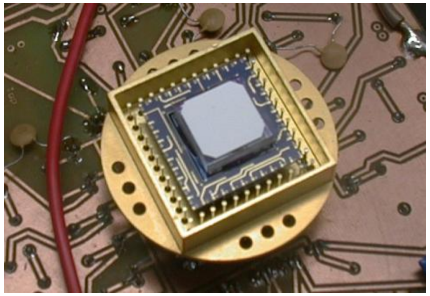
2000

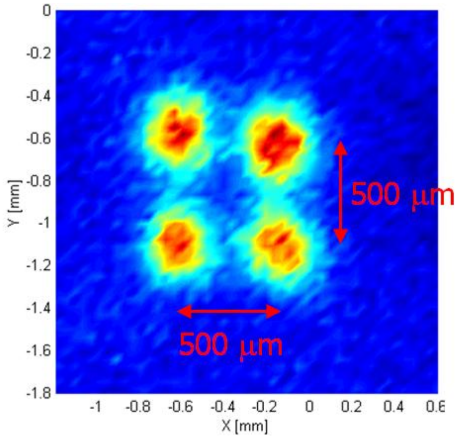
proof of a SDD-based gamma-ray imaging detector
(0.35cm^2)



2004

200μm resolution gamma camera
(1cm^2)

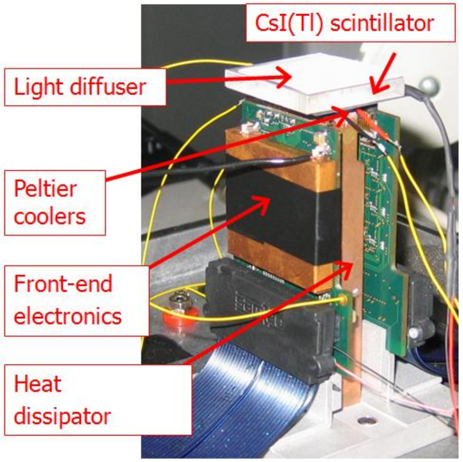


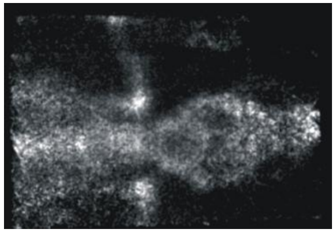


2007

The DRAGO gamma camera

first animal imaging ($7cm^2$)

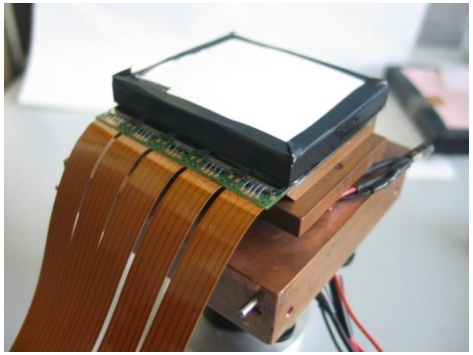


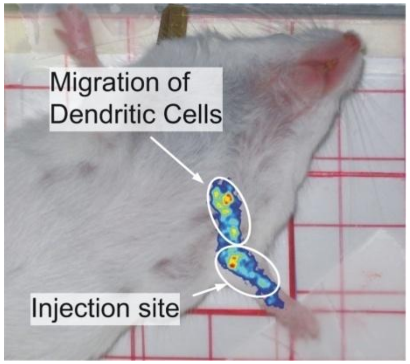


2009

The HICAM gamma camera

first cellular imaging ($25cm^2$)





2010

The large HICAM gamma camera

first clinical imaging ($100cm^2$)