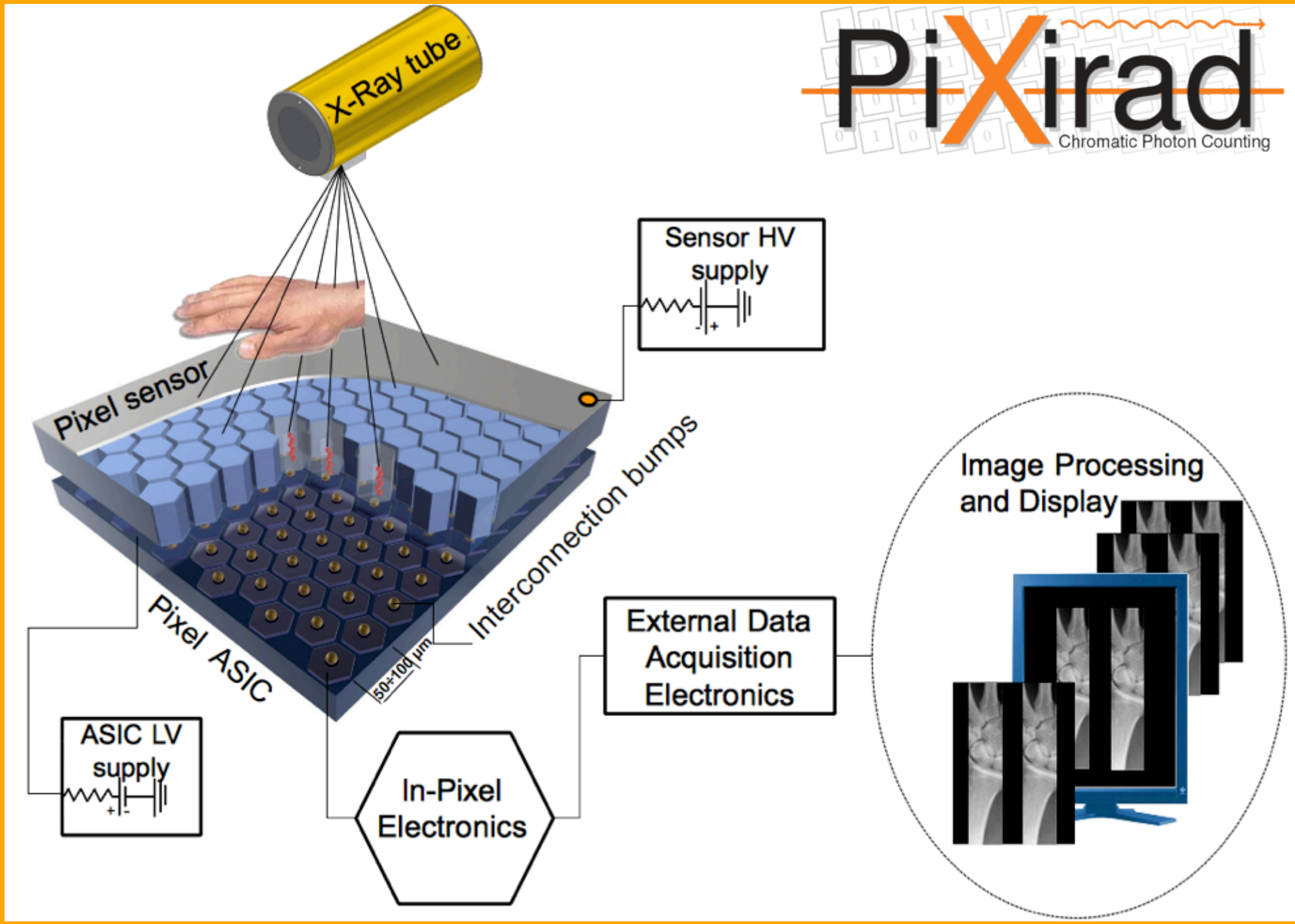
**Comitato Nazionale per il Trasferimento Tecnologico**

# Dal sensore allo *spin-off*

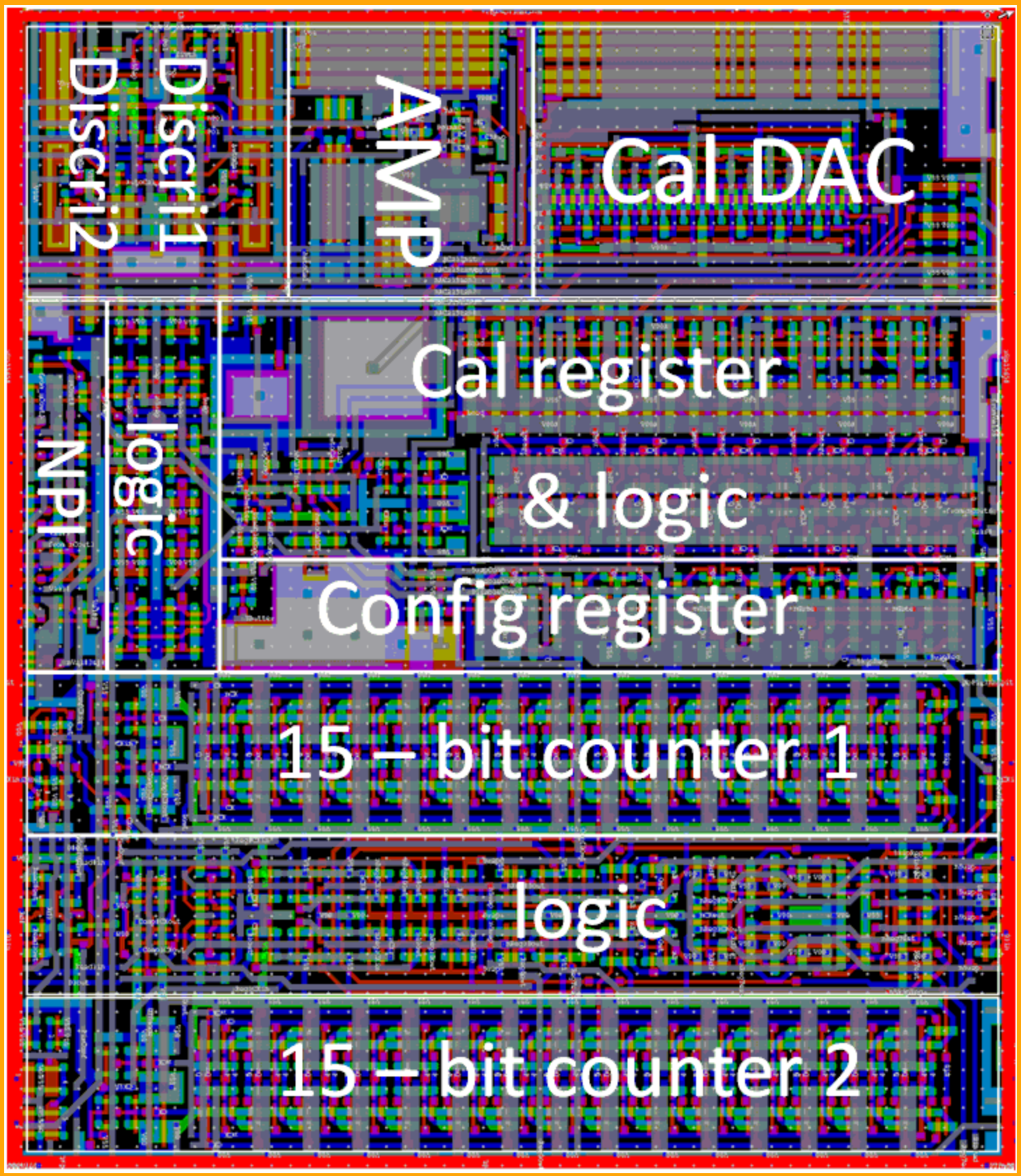
**Ronaldo Bellazzini**
INFN Pisa

15 maggio 2012 - INFN Laboratori Nazionali di Frascati

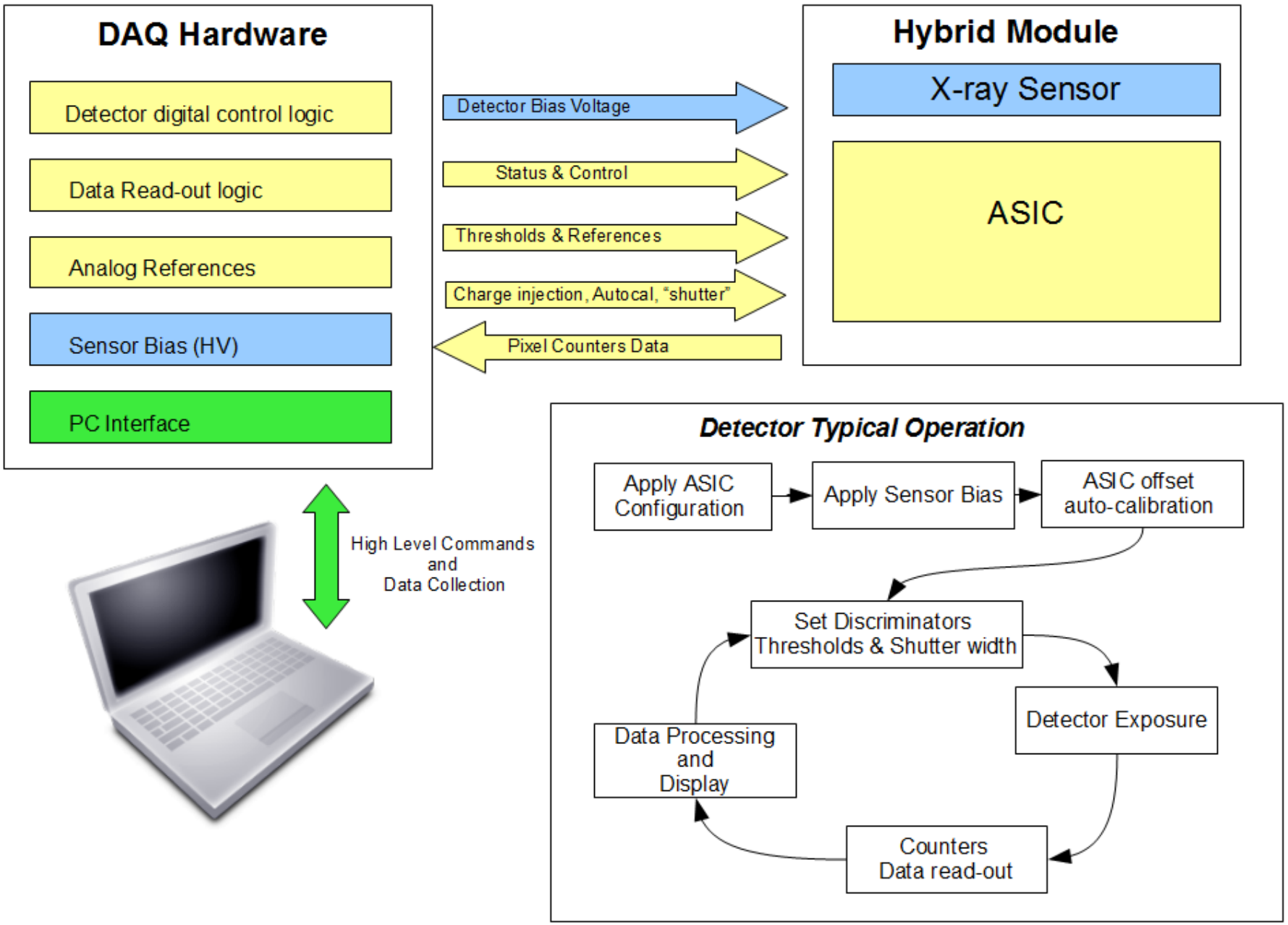

X-Ray tube
Pixel sensor
Sensor HV supply
Interconnection bumps
Pixel ASIC
50÷100 µm
ASIC LV supply
In-Pixel Electronics
External Data Acquisition Electronics
Image Processing and Display
PiXirad
Chromatic Photon Counting

## *Semiconductor Detector Material Properties*

| Material | $Cd_{0.9}Zn_{0.1}Te$ | CdTe | Ge | Si | GaAs | $HgI_2$ | $PbI_2$ | a-Si | a-Se |
|---|---|---|---|---|---|---|---|---|---|
| Atomic numbers | 48, 30, 52 | 48, 52 | 32 | 14 | 31, 33 | 80, 53 | 82, 53 | 14 | 34 |
| Average atomic number | 49.1 | 50 | 32 | 14 | 32 | 62 | 62.7 | 14 | 34 |
| Density $\rho$ ($g/cm^3$) | 5.78 | 5.85 | 5.33 | 2.33 | 5.32 | 6.4 | 6.2 | 2.3 | 4.3 |
| Band gap $E_g$ (eV) | 1.572 | 1.5 | 0.67 | 1.12 | 1.43 | 2.13 | 2.32 | 1.8 | 2.2 |
| Dielectric Constant | 10.9 | 11 | 16 | 11.7 | 12.8 | 8.8 | | 11.7 | 6.6 |
| Pair creation energy $E_{pair}$ (eV) | 4.64 | 4.43 | 2.95 | 3.62 | 4.2 | 4.2 | 4.9 | 4 | 7 |
| Resistivity $\rho$ ($\Omega$cm) | $3x10^{10}$ | $10^{9}$ | 50 | $< 10^{4}$ | $10^{7}$ | $10^{13}$ | $10^{12}$ | $10^{12}$ | $10^{12}$ |
| Electron mobility $\mu_e$($cm^2/Vs$) | 1000 | 1100 | 3900 | 1400 | 8000 | 100 | 8 | 1 | 0.005 |
| Electron lifetime $\tau_e$ (s) | $3x10^{-6}$ | $3x10^{-6}$ | $> 10^{-3}$ | $> 10^{-3}$ | $10^{-8}$ | $10^{-6}$ | $10^{-6}$ | $6.8x10^{-9}$ | $10^{-6}$ |
| Hole mobility $\mu_h$ ($cm^2/Vs$) | 50 – 80 | 100 | 1900 | 480 | 400 | 4 | 2 | 0.005 | 0.14 |
| Hole lifetime $\tau_h$ (s) | $10^{-6}$ | $2x10^{-6}$ | $10^{-3}$ | $2x10^{-3}$ | $10^{-7}$ | $10^{-5}$ | | $4x10^{-6}$ | $10^{-6}$ |
| $(\mu\tau)_e$ ($cm^2/V$) | $(3–10)x10^{-3}$ | $3.3x10^{-3}$ | > 1 | > 1 | $8x10^{-5}$ | $10^{-4}$ | $8x10^{-6}$ | $6.8x10^{-8}$ | $5x10^{-9}$ |
| $(\mu\tau)_h$ ($cm^2/V$) | $5x10^{-5}$ | $2x10^{-4}$ | > 1 | > 1 | $4x10^{-6}$ | $4x10^{-5}$ | | $2x10^{-8}$ | $1.4x10^{-7}$ |


Discri2
Discri1
AMP
Cal DAC
NPIC
logic
Cal register
& logic
Config register
15 – bit counter 1
logic
15 – bit counter 2

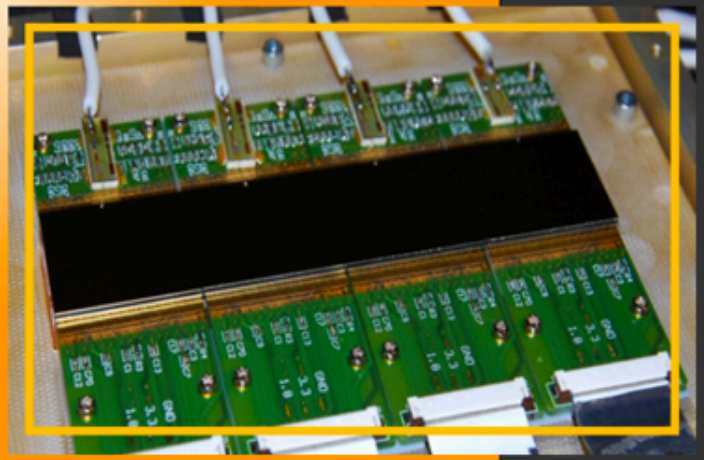
Config. register
Config. register
Config. register
Cal. register & logic
Cal. register & logic
Cal. register & logic
Cal. DAC 1
Cal. DAC 3
Cal. DAC 5
Cal circuit
AMP
discr. 1
discr. 2
discr. 3
discr. 4
discr. 5
discr. 6
Cal. DAC 2
Cal. DAC 4
Cal. DAC 6
Cal. register & logic
Cal. register & logic
Cal. register & logic
15-bit Counter 1
15-bit Counter 4
logic
logic
15-bit Counter 2
15-bit Counter 5
logic
logic
15-bit Counter 3
15-bit Counter 6


DAQ Hardware
Detector digital control logic
Data Read-out logic
Analog References
Sensor Bias (HV)
PC Interface
Detector Bias Voltage
Status & Control
Thresholds & References
Charge injection, Autocal, "shutter"
Pixel Counters Data
Hybrid Module
X-ray Sensor
ASIC
High Level Commands
and
Data Collection
Detector Typical Operation
Apply ASIC Configuration
Apply Sensor Bias
ASIC offset auto-calibration
Set Discriminators Thresholds & Shutter width
Detector Exposure
Counters Data read-out
Data Processing and Display

# Welcome to the PiXirad home page!

INFN Spin-off

- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact



PiXirad Imaging Counters s.r.l.

The Chromatic Photon Counting

**PIXIRAD Imaging Counters s.r.l.** is an INFN Spin-off introducing an innovative, high quality radiographic sensor with intrinsically and fully digital characteristics.

PIXIRAD is based on **Chromatic Photon Counting** technology and represents a radical leap forward compared to the standard methods currently on the market.

PIXIRAD is able to count individually the incident X-ray photons and to separate them according to their energy (two *color* images per exposure).

The color mode and the very high spatial resolution (50 µm) allow to obtain the maximum ratio between image quality and absorbed dose.

The energy selection of the radiographic beam occurs in real time and single exposure thus allowing to obtain a radiological chromatic imaging and to significantly increase the information content of the images.
Energy range: 2-100 keV
Count rate > 30 GHz (4 tiles)

The individual PIXIRAD block is a two-side buttable semiconductor radiation detector made of a thin pixellated CdTe crystal (the sensor) coupled to a large area VLSI CMOS pixel ASIC (512 × 476 pixels). PIXRAD is able to deliver extremely clear and highly detailed images for medical, biological, industrial and scientific applications. 1, 2, 4, 8 tile units are available.

PIXIRAD brochure (1.1 MB) PDF

Web page and content by: Gloria Spandre

# The PiXirad imaging sensor

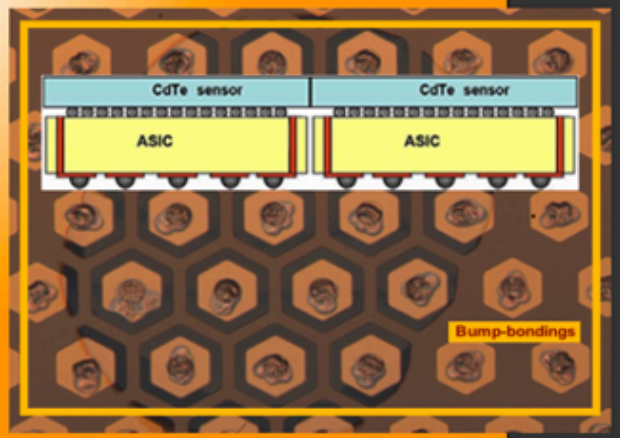

- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


The base block of the PIXIRAD radiological system is realized by coupling with the *flip-chip bonding (bump-bonding)* technique a thin layer of semi-crystalline cadmium telluride (CdTe) to a matrix of 512×476 microcircuits (ASIC CMOS) able to count the absorbed X-ray photons in each pixel of the CdTe sensor.
The system therefore has a **hybrid architecture** in which the sensor and readout electronics are manufactured and processed separately. The sensor is segmented with the same ASIC geometry.

Starting from the base block, a complete imaging system is obtained by coupling a number of blocks along one direction and then operating in **slot-scanning imaging** mode or, in near future, along both directions, and operating in **full-field imaging** mode.

In the digital radiography market PIXIRAD is an **innovative, high quality system** being:

- intrinsically digital
- noise free, due to the photon counting technique
- with optimal values of contrast and spatial resolution
- with high frame rate (~100 frame/sec)
- with capability to separate the image in various color components depending on the incident radiation energy
- with capability to operate in dead-time free mode (reading one counter while taking data in the other one)




PiXirad
Imaging Counters s.r.l.

The Chromatic Photon Counting

# The CdTe sensor


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


- Pixel sensor (ACRORAD Co., Ltd.) is a Schottky type diode with electron collection on the pixels
- Large area: 30.96 × 24.98 × 0.65 mm
- Pixel pitch: 60 µm (on hexagonal matrix)
- Very low leakage current @400-500V working voltage

| CdTe semiconductor characteristics: | |
|---|---|
| Atomic numbers | 48, 52 |
| Effective atomic number | 50 |
| Density $\rho$(g/cm$^3$) | 5.85 |
| Band energy (eV) | 1.5 |
| Dielectric constant | 11 |
| Ionizing energy (eV) | 4.43 |
| Resistivity $\rho$(Ωcm) | $10^9$ |
| Electron mobility $\mu_e$ (cm$^2$/Vs) | 1100 |
| Electrons mean lifetime $\tau_e$ (s) | $3x10^{-6}$ |
| Hole mobulity $\mu_h$ (cm$^2$/Vs) | 100 |
| Holes mean lifetime $\tau_h$ (s) | $2x10^{-6}$ |
| $(\mu\tau)_e$ (cm$^2$/V) | $3.3x10^{-3}$ |
| $(\mu\tau)_h$ (cm$^2$/V) | $2x10^{-4}$ |

PiXirad
Imaging Counters s.r.l.

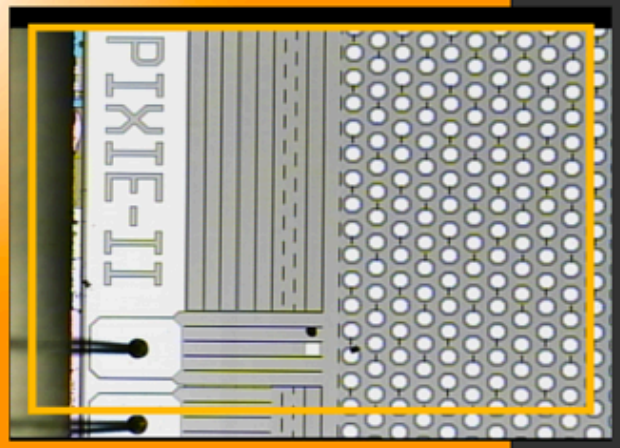
The Chromatic Photon Counting

# The CMOS ASIC

The CMOS VLSI chip has an active area of 30.7 × 24.8 mm², organized on a matrix of 512 × 476 pixels.
The chip integrates more than 350 million transistors. Each pixel incorporates a hexagonal electrode (top metal layer) connected to a charge amplifier which feeds two discriminators and two 15-bit counters.
To reduce unavoidable variations of the DC level between the pixels, a self-calibration circuit has been implemented in each pixel. In this way a global threshold per discriminator can be applied to the entire matrix.

**Matrix organization:** honeycomb arrangement with a 60 µm horizontal pitch and vertical pitch of 51.96 µm.

**Acquisition:** 2 *color* reading (2 thresholds, 2 counters) or, alternatively, counting in one counter while reading the other one (dead-time free mode).




| Pixel characteristics | |
|---|---|
| Shaped pulse duration (at the base) | 1 µs (adjustable) |
| Linear range | > 3000 electrons |
| Saturation level | > 6000 electrons |
| Equivalent noise (ENC) | 50 electrons (rms) |
| Residual offset after auto-calibration | ± 30 electrons |
| Maximum number of counts before reading | 32768 |
| Input signal | positive or negative |
| Possibility to disable, swap, by-pass pixel | user-selectable |
| **Pixel reading** | |
| Serialization of columns for best readout time | 16, 32, 64, 128 |
| Max readout clock frequency | 200 MHz |
| Readout time for 32 data outputs = 16 columns serialized (16 columns x 476 pixels x15 bits x 5 ns) | < 0.6 ms |
| Readout time for 16 data outputs = 32 columns serialized | <1.2 ms |
| Readout time for 8 data outputs = 64 columns serialized | <2.3 ms |

PiXirad
Imaging Counters s.r.l.

The Chromatic Photon Counting

# Chromatic Photon Counting


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact

Image o f a small dry animal obtained with PIXIRAD by counting the X-ray photons with low energy threshold (LOW COUNTER)

Image of the same animal obtained with PIXIRAD simultaneously with the previous one and in the same exposure but with an higher energy threshold (HIGH COUNTER)

Image of the same animal obtained by subtracting the two previous pictures, one from another. Three *'colors'* from a single exposure!

PiXirad
Imaging Counters s.r.l.

The Chromatic Photon Counting

# Chromatic Photon Counting


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact

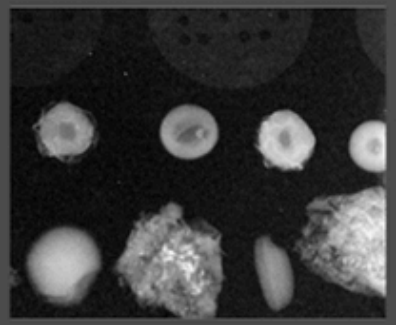



Image of the Ackermann mammographic phantom obtained with PIXIRAD by counting all the photons with a low energy threshold (LOW COUNTER)

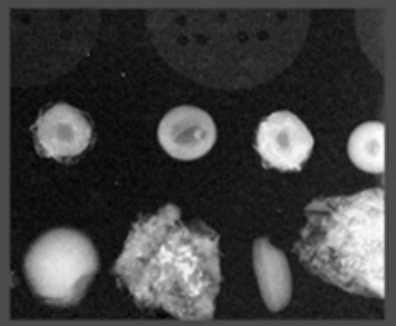


Image of the same phantom obtained by PIXIRAD simultaneously with the previous one and in the same exposure, but with a threshold of higher energy (HIGH COUNTER)

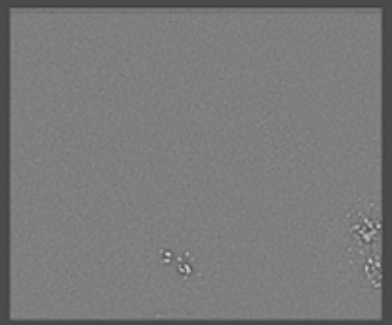


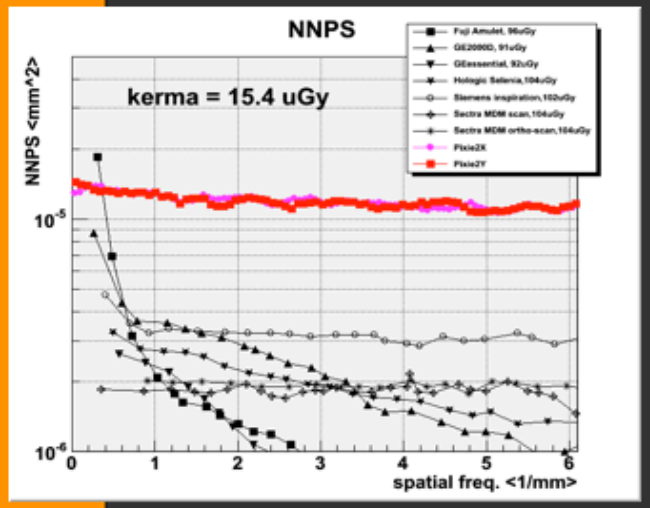
Image of the same phantom obtained by subtracting the logarithm of the two previous images.
All structures except for microcalcifications

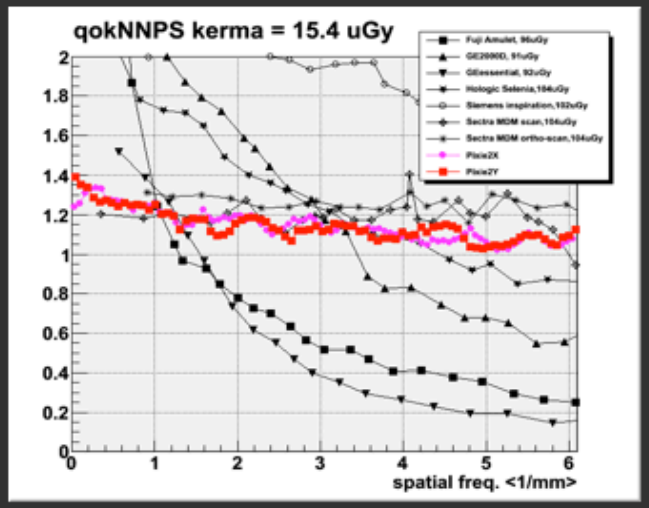
PiXirad Imaging Counters s.r.l.

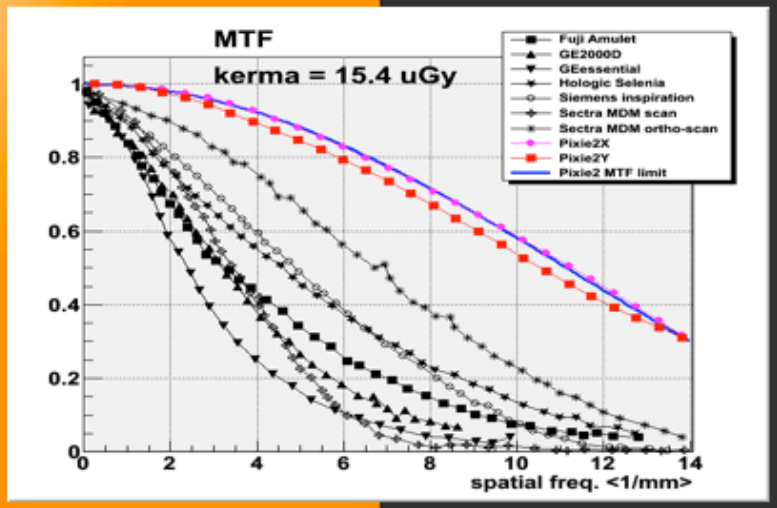
The Chromatic Photon Counting

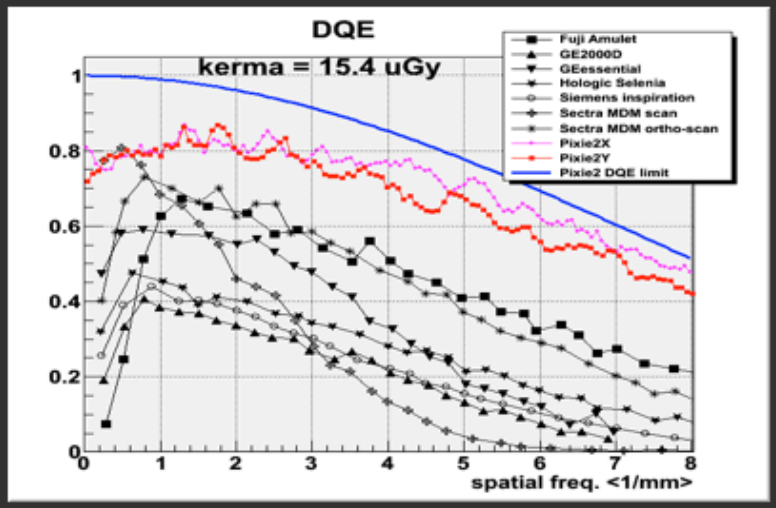
# Characteristics of the PiXirad sensor


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


PiXirad
Imaging Counters s.r.l.

The Chromatic Photon Counting

Performance in digital mammography applications

# The PiXirad imaging sensors


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
  - PIXIRAD-1
  - PIXIRAD-2
  - PIXIRAD-4
  - PIXIRAD-8
- Photo gallery
- Contact


PIXIRAD Imaging Counters s.r.l. is currently developing innovative, high quality X-ray imaging sensors based on Chromatic Photon Counting technology, with intrinsic and fully digital characteristics.

PIXRAD is able to deliver extremely clear and highly detailed images for medical, biological, industrial and scientific applications.

Imaging systems with 1, 2, 4, 8 tile units are available:

- PIXIRAD-1 (3×2.5 $cm^2$)
- PIXIRAD-2 (6×2.5 $cm^2$)
- PIXIRAD-4 (12.1×2.5 $cm^2$)
- PIXIRAD-8 (24.2×2.5 $cm^2$,under test)

For more information on PIXIRAD products, contact pixirad1@gmail.com.

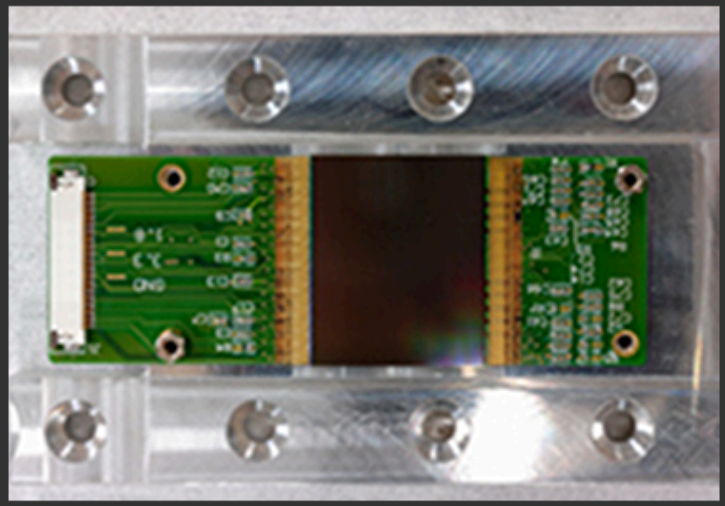
PiXirad Imaging Counters s.r.l.

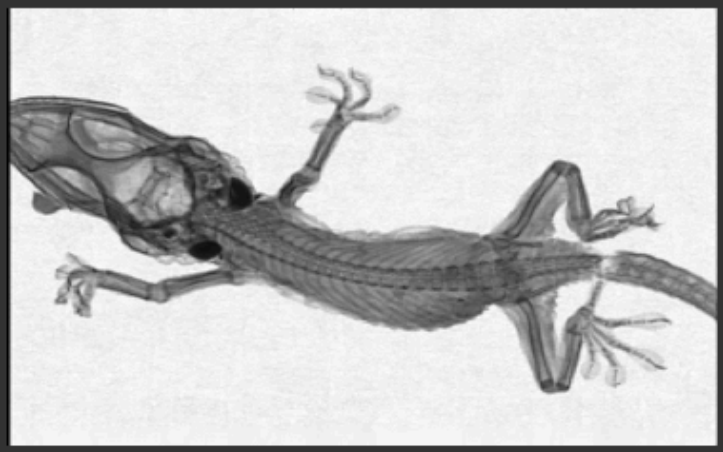
The Chromatic Photon Counting

# The PiXirad imaging sensors


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


## PIXIRAD-1: a single unit system (3×2.5 cm²)





Radiographic image of a small dry animal obtained with the single module of PIXIRAD

(Click on images to enlarge)

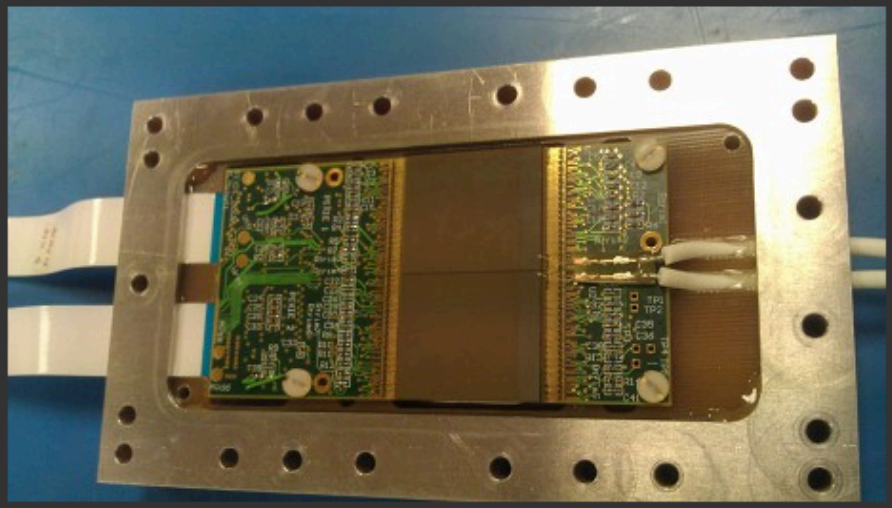
PiXirad Imaging Counters s.r.l.

The Chromatic Photon Counting

# The PiXirad imaging sensors


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


## PIXIRAD-2: a 2 unit system (6×2.5 cm²)



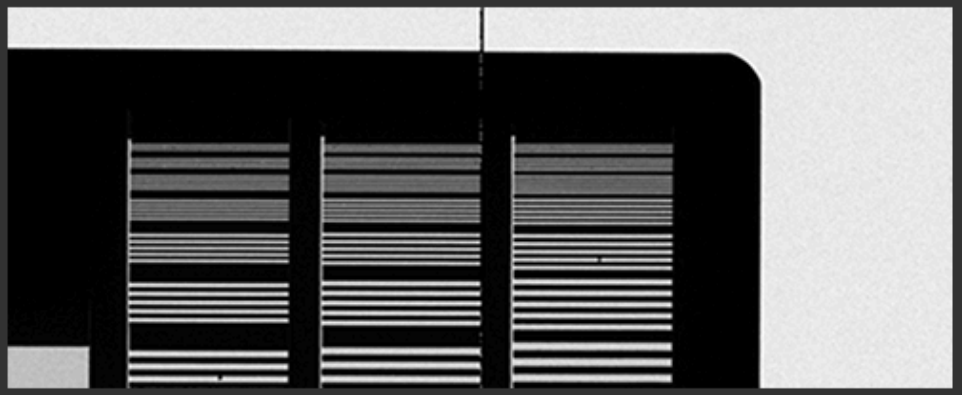


Image of a Hüttner mask to measure the resolving power

(Click on images to enlarge)

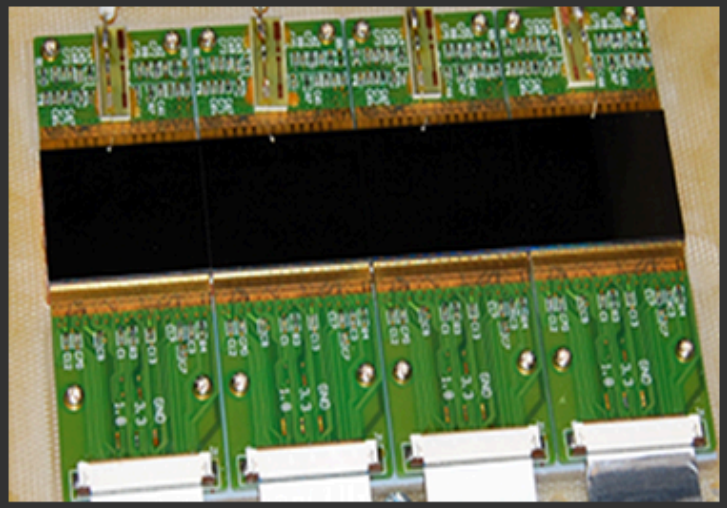
PiXirad Imaging Counters s.r.l.

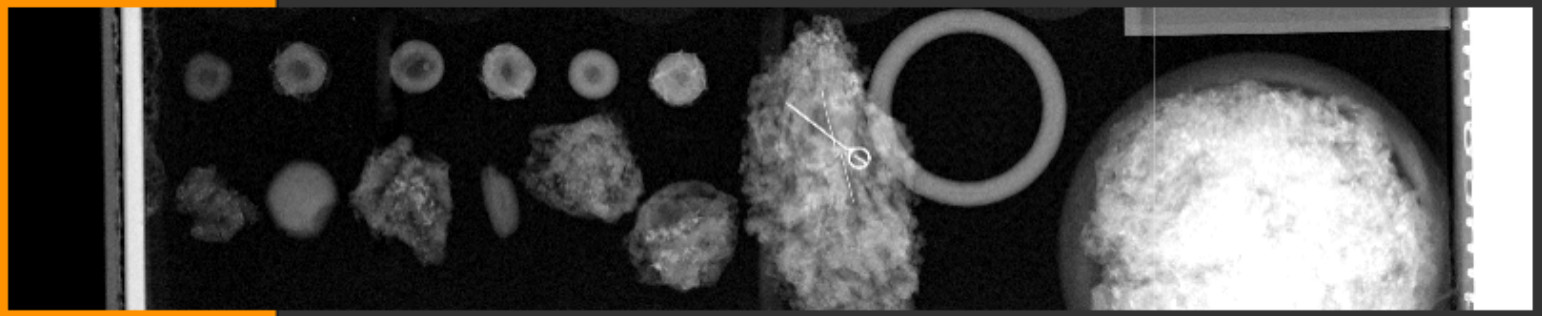
The Chromatic Photon Counting

# The PiXirad imaging sensors


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


## PIXIRAD-4: a 4 unit system (12.1×2.5 cm²)





Ackermann mammographic phantom image

(Click on images to enlarge)

PiXirad Imaging Counters s.r.l.

The Chromatic Photon Counting

Back

# PIXIRAD - IMAGE GALLERY

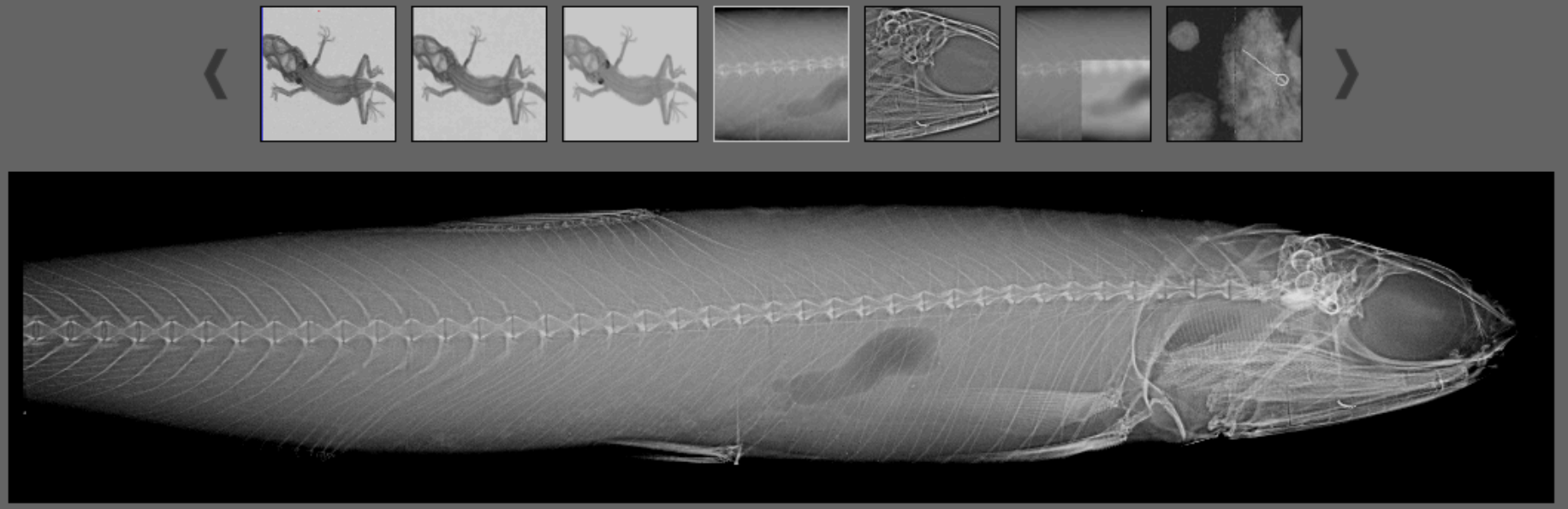
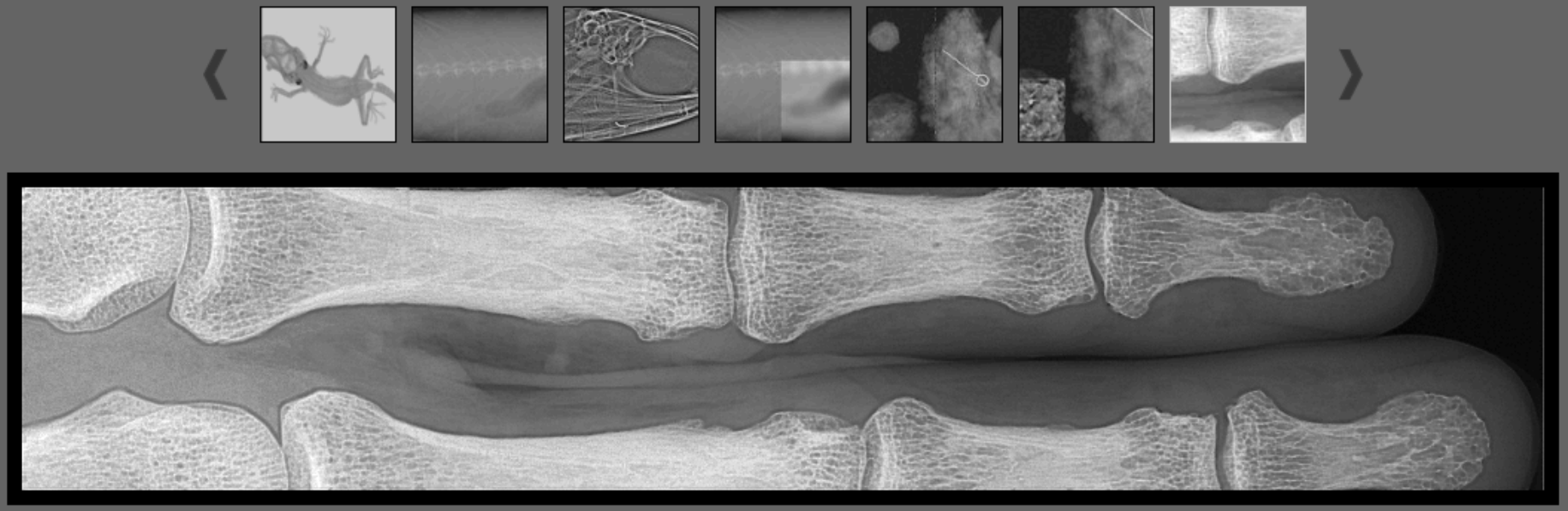


Image of a biological sample obtained with the PIXIRAD prototype

Back

PIXIRAD - IMAGE GALLERY



Detail of human hand bones

# PiXirad contact


- Home
- Imaging sensor
- CdTe
- ASIC
- Characteristics
- Products
- Photo gallery
- Contact


PIXIRAD Imaging Counters s.r.l. is a Spin-off of INFN researchers and technologists who have developed, as part of their research, in-depth knowledge of radiation detection techniques.
The company operates in the INFN-Pisa laboratories.


Web: http://pixirad.pi.infn.it
Email: pixirad1@gmail.com
Tel.: +39 050 2214 367
Address:
PIXIRAD Imaging Counters s.r.l. c/o
Istituto Nazionale di Fisica Nucleare, sez. di Pisa
Edificio C - Polo Fibonacci
Largo B. Pontecorvo, 3 56127 Pisa (Italy)


PiXirad Imaging Counters s.r.l.

The Chromatic Photon Counting