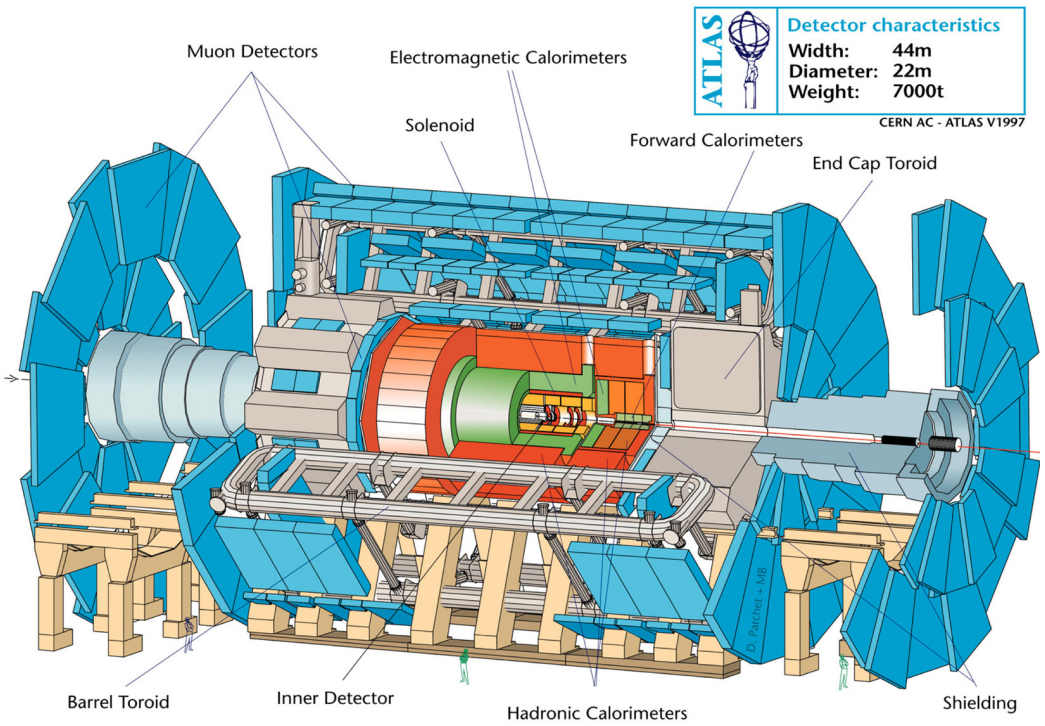
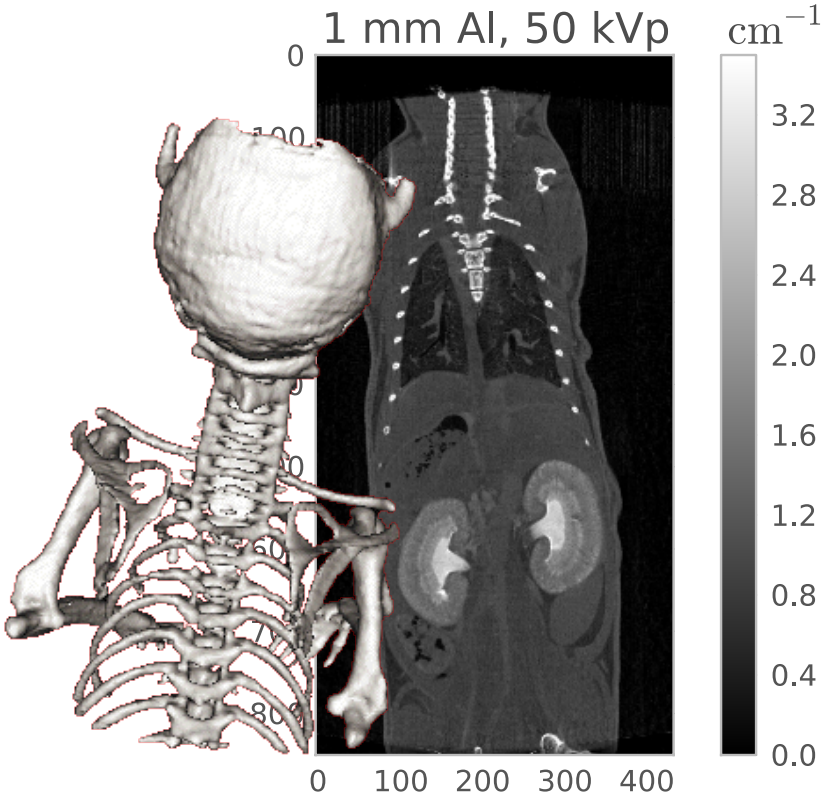
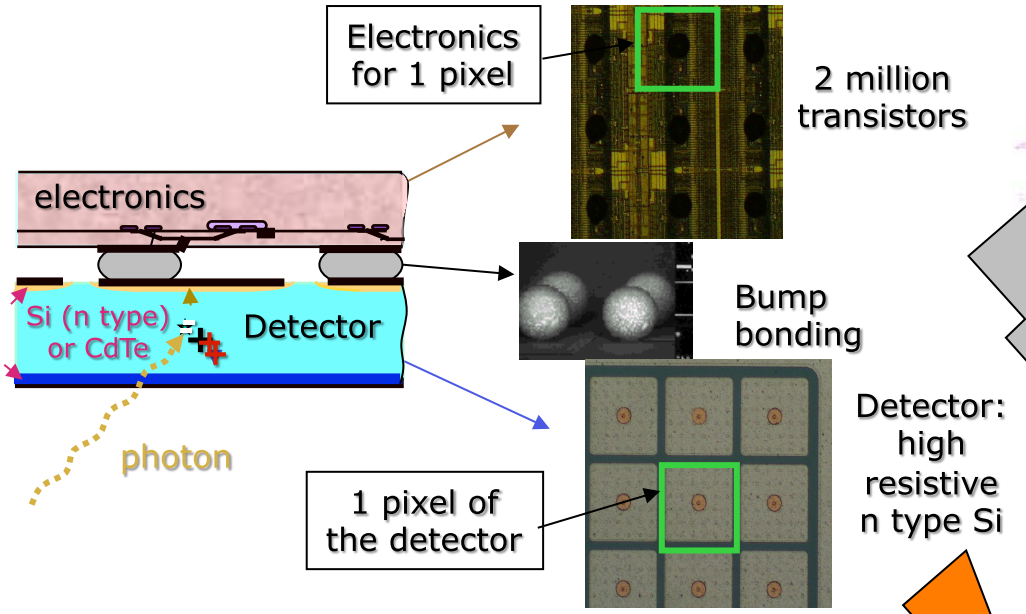
Développement de la tomographie spectrale par comptage de rayons X avec le circuit XPAD3

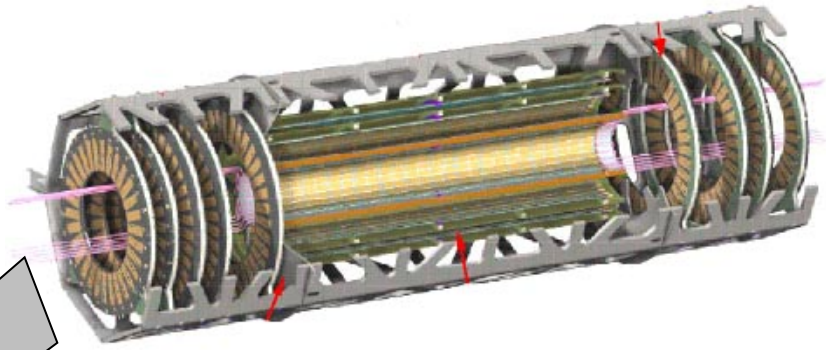




AG GDR MI2B, 4 sept 2015, Marseille

Hybrid Pixels for X-ray photon counting CT





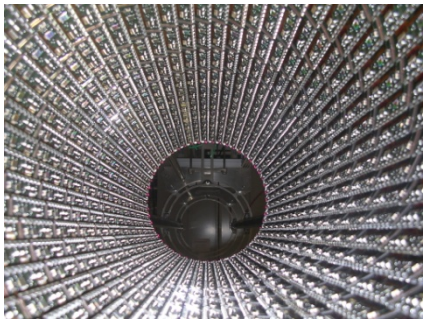
- Very fast data acquisition
- Choice of the sensor (Si, CdTE, AsGa)
- Optimized efficiency

- Noise suppression
- Energy selection
- Very high dynamics

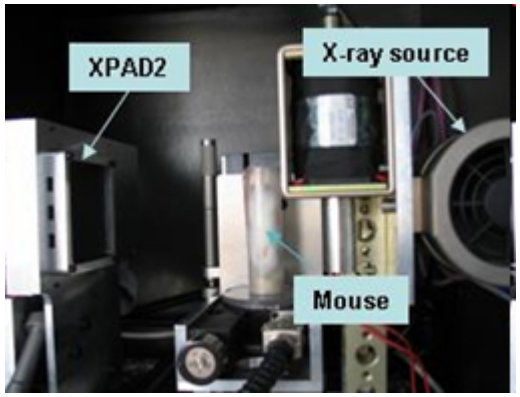
Reduce radiation dose
Improve contrast
Perform spectral analysis

Research & Development on Hybrid Pixels at CPPM

Start of the hybrid pixel project



ATLAS: 50 x 400 μm^2 pixels

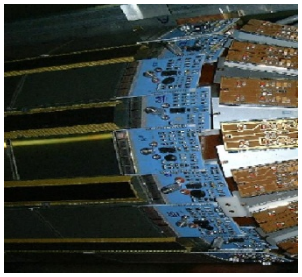


XPAD2: 330 x 330 μm² pixels

1991 — 1996 — 1998 — 1999 — 2001 — 2006

DELPHI:

World premiere

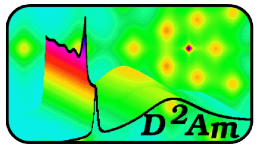


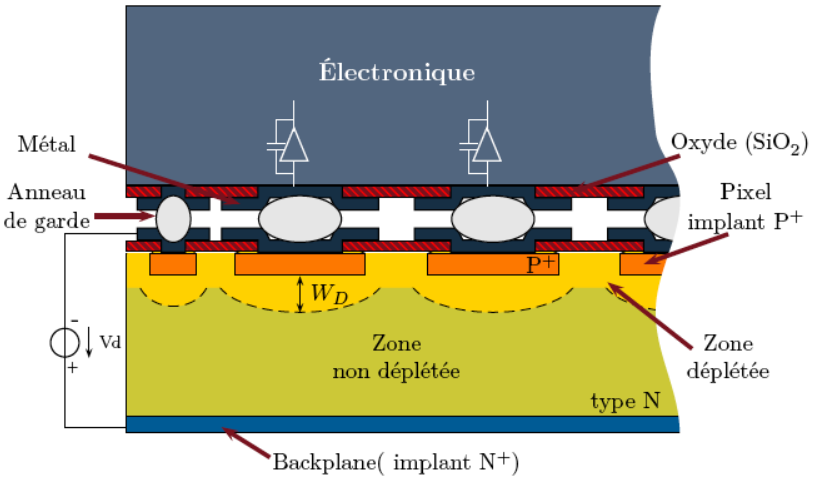
XPAD1: first hybrid pixel detector for X-ray applications

XPAD3 : 130 x 130 μm² pixels

Delpierre, JINST **9** (2014) C05059

XPAD3: Si and CdTe Hybrid Pixels for X-ray detection

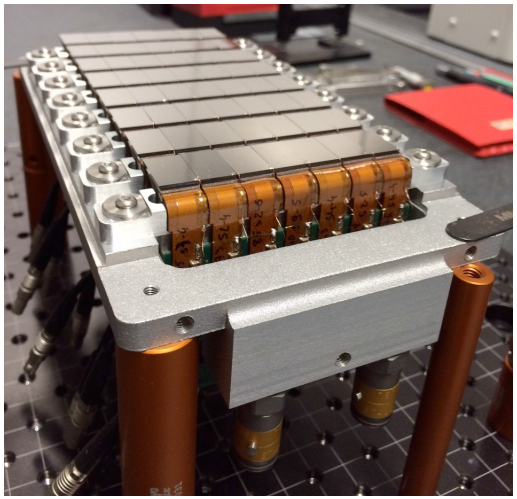




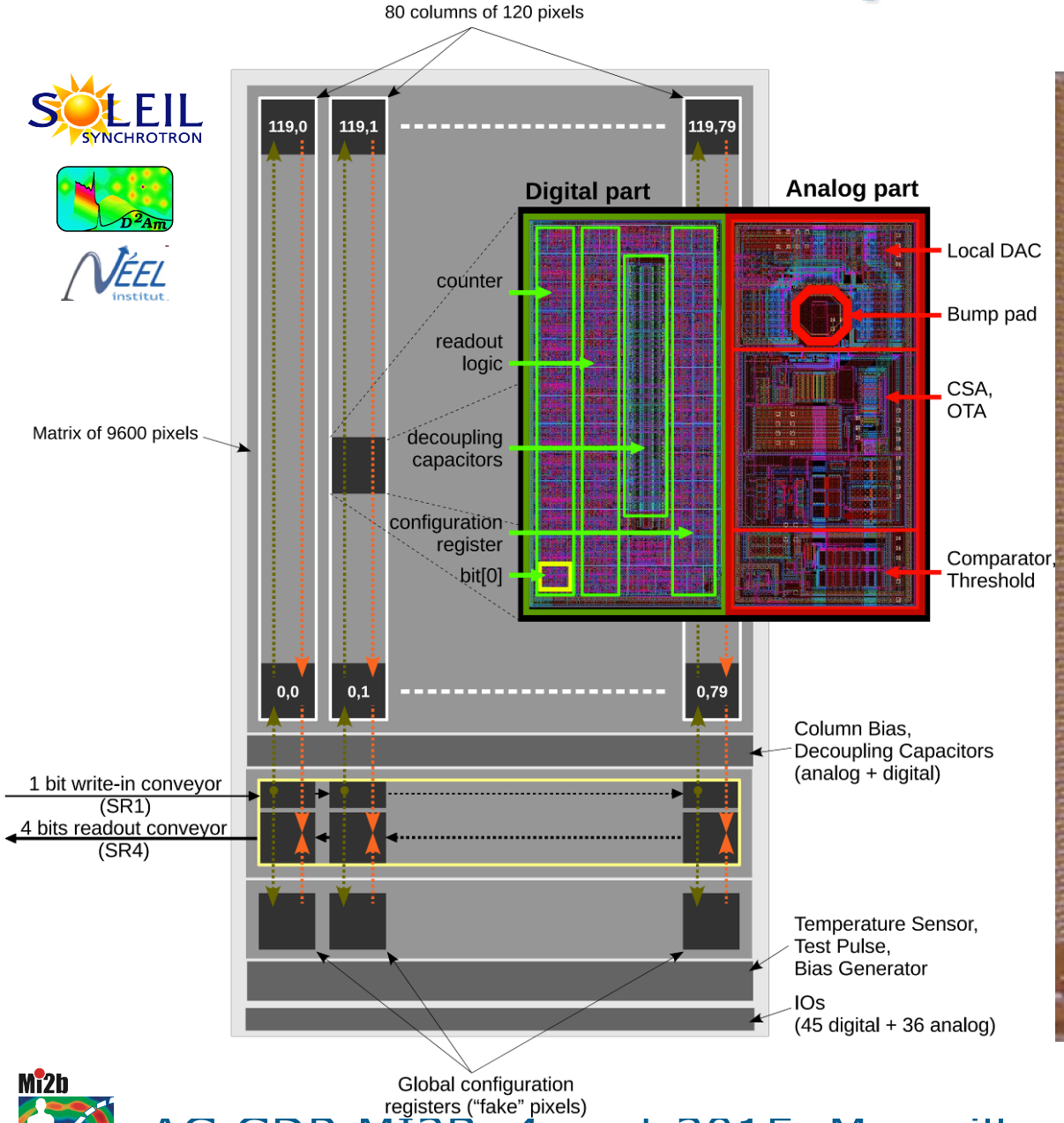
- XPIX: Development of hybrid pixel detectors XPAD.1 et XPAD3.2 with Si and CdTe sensors
  - > 0,5 Mpixels 130 x 130 µm²
  - 240 images/s
  - 2011 • 5-35 keV (XPAD3.1/Si: D1-3)
  - 2013 • 5-60 keV (XPAD3.2/Si: D4-6)

CHiPSpeCT (PhysiCancer 12)

- 2015 • Hybrids XPAD3.2/CdTe (D7)

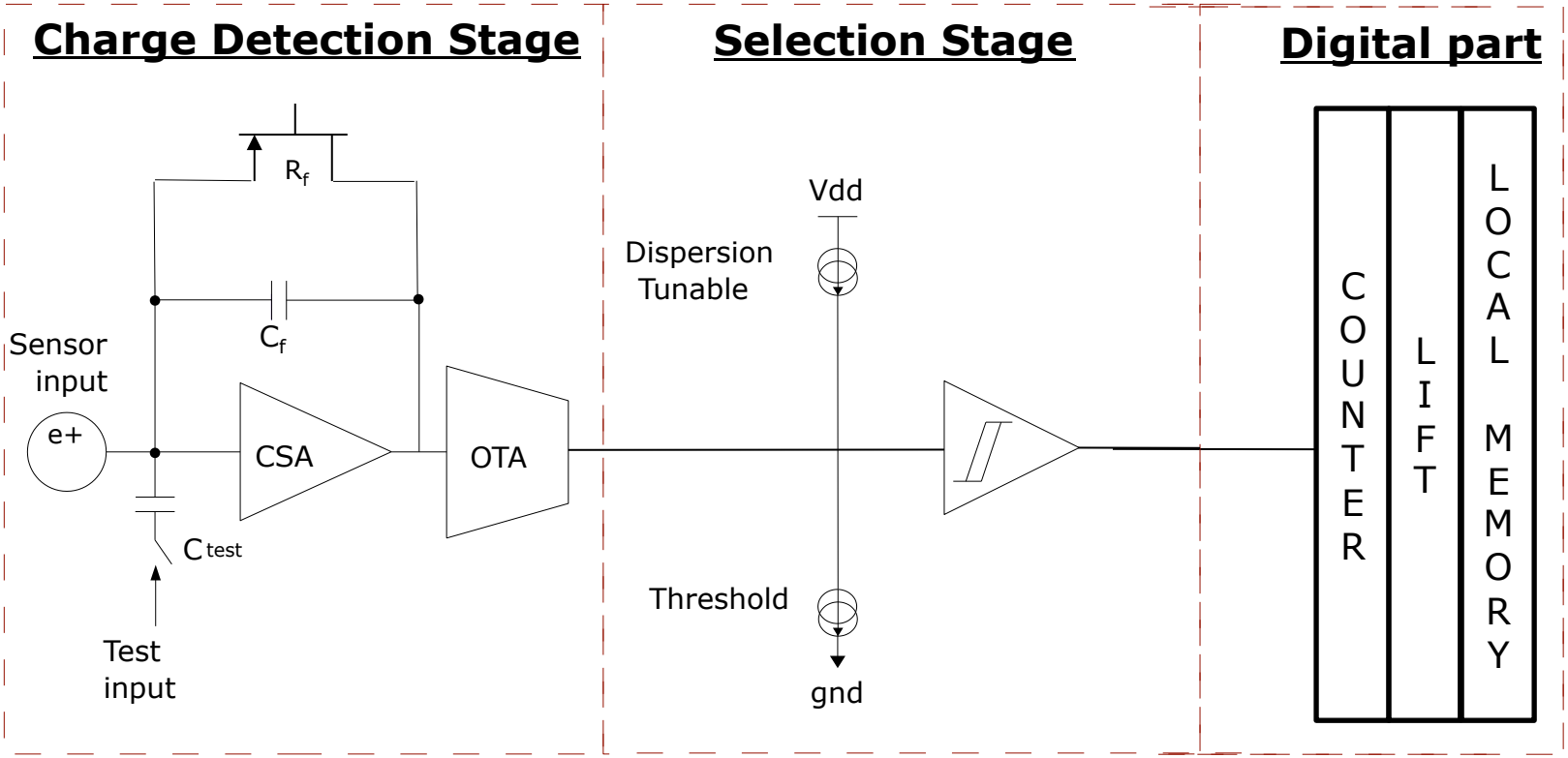


XPAD3: Si and CdTe Hybrid Pixels for X-ray



- 0.25 µm IBM CMOS technology
- (130 x 130) µm^2 pixels
- 80 x 120 = 9600 pixels
- 12 bit counter + overflow
- Count rate up to 10^6 ph/pixel/s
- < 1 ms readout time
- 5-35 keV adjustable thresholds (XPAD3.1)

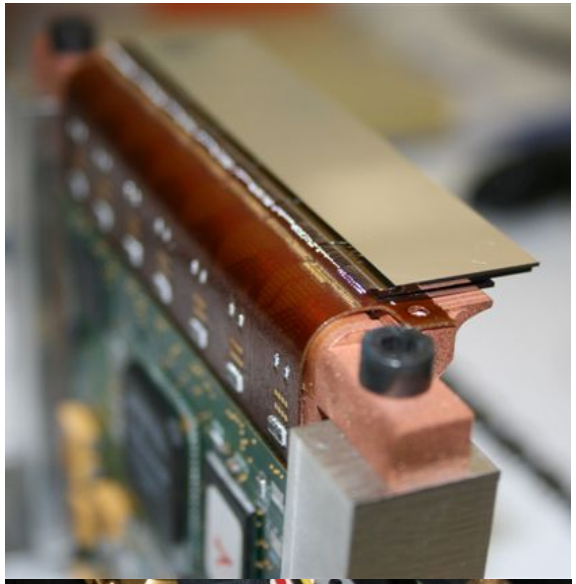
XPAD3 pixel architecture

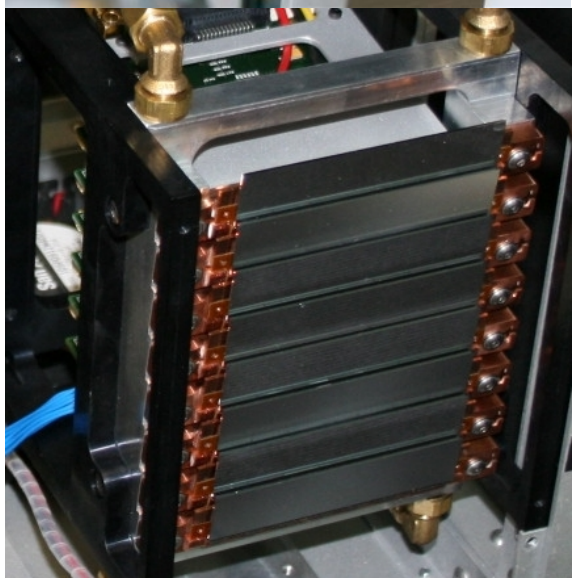


Gain : 89 nA/keV
Noise : 127 e- rms
Linearity : < 10% @ 35 keV

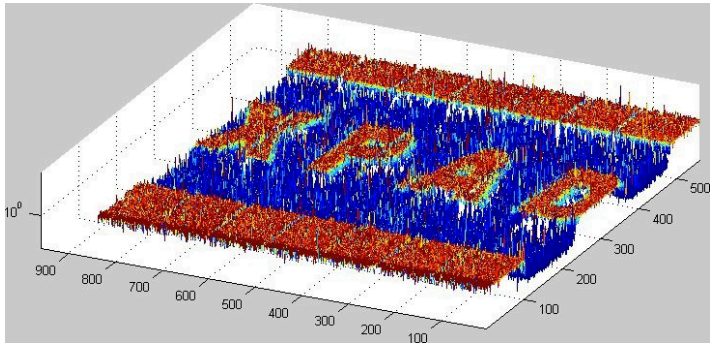
Power consumption : 40 µW/pixel
Threshold adjustment resolution : 57 e-
Minimum threshold: < 4 keV

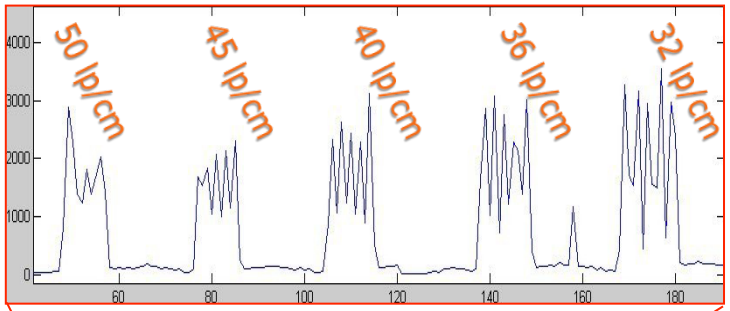
XPAD3: Si and CdTe Hybrid Pixels for X-ray detection

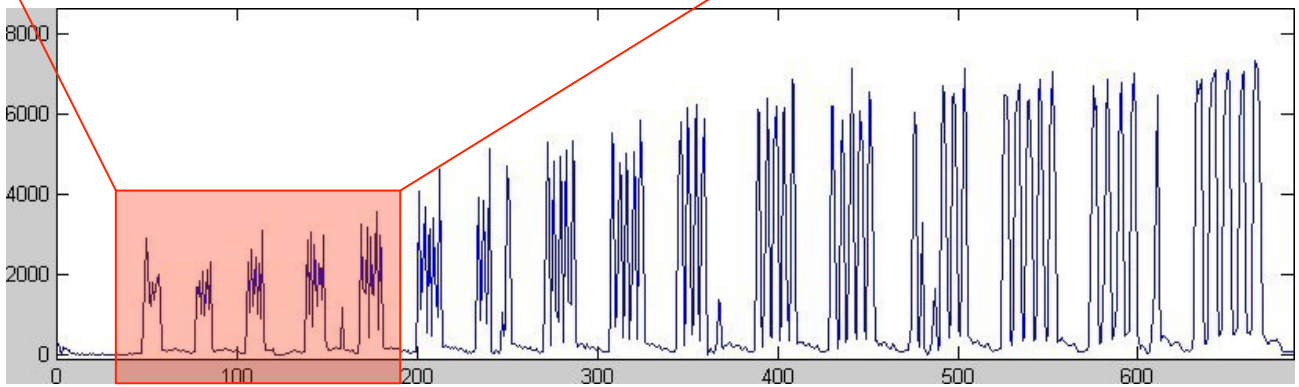




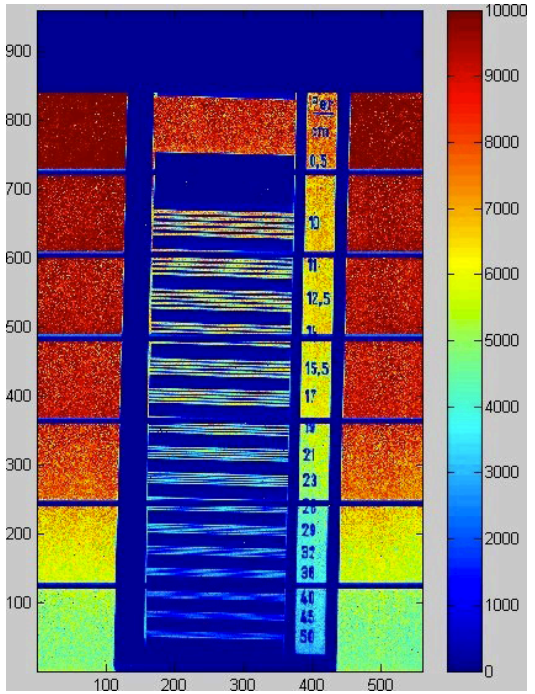
5 keV







14 keV



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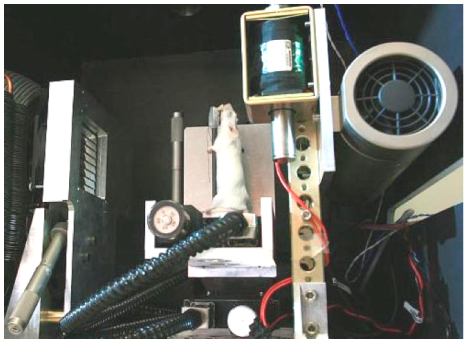
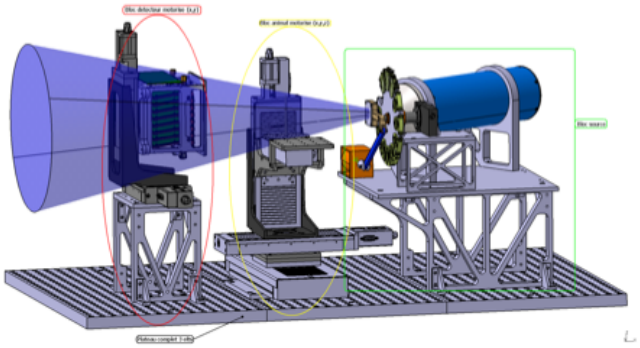
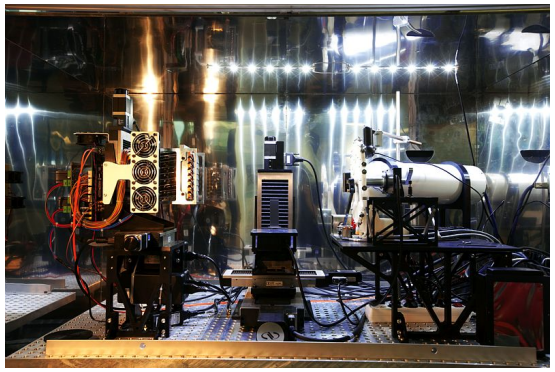
Photon counting CT with XPAD hybrid pixels

- **PIXSCAN**: micro-CT demonstrator
  - Characterization of photon counting cone-beam CT
  - Development of spectral CT



PIXSCAN I
XPAD2

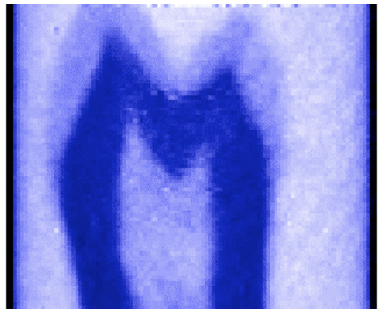




PIXSCAN II
XPAD3

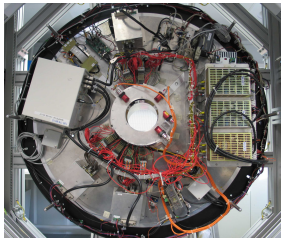
- **nPAD**: neutron tomography
  - 2010: neutron tomography of a tooth
    - Cassol *et al.* Nucl. Instrum. Meth. A **634** (2011) 85

HZB Helmholtz Zentrum Berlin



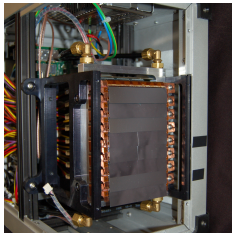
Photon counting CT with XPAD hybrid pixels

- **ClearPET/XPAD**: simultaneous hybrid PET/CT tomography



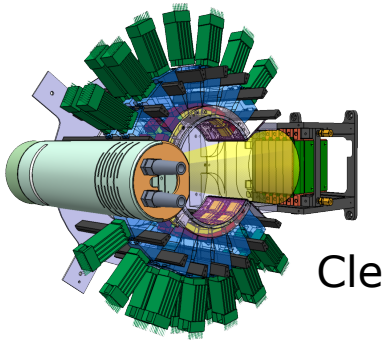
ClearPET (EPFL)

+



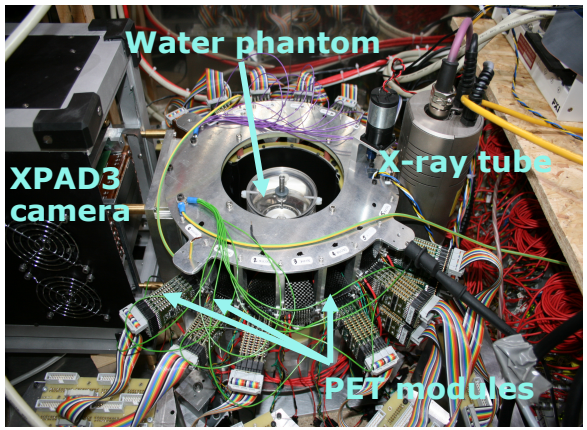
XPAD (CPPM)

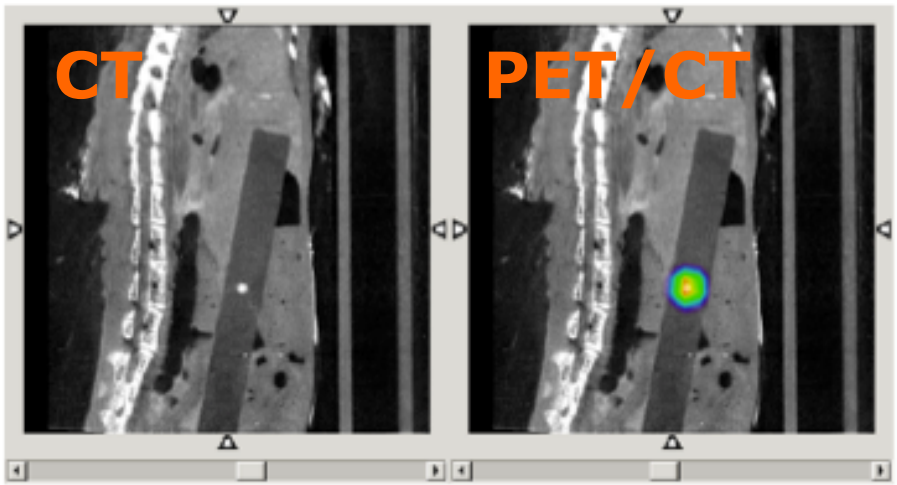
=



CleartPET/XPAD

- 2009: Proof of concept
  - Nicol *et al.* Proc. IEEE NSS/MIC 2009

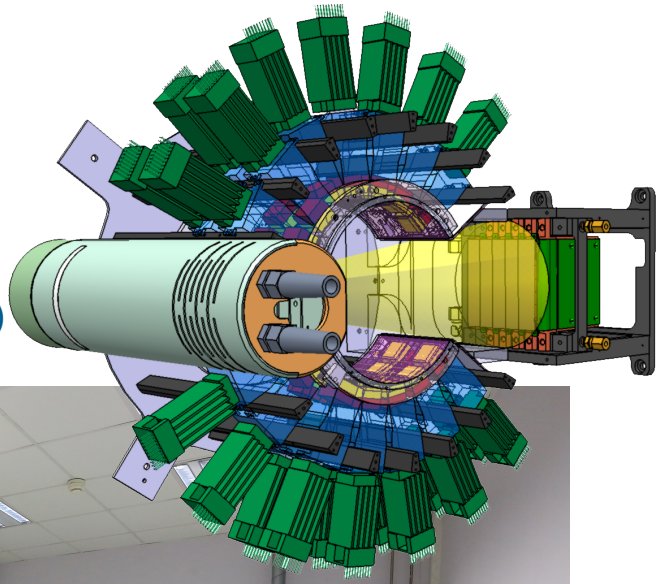


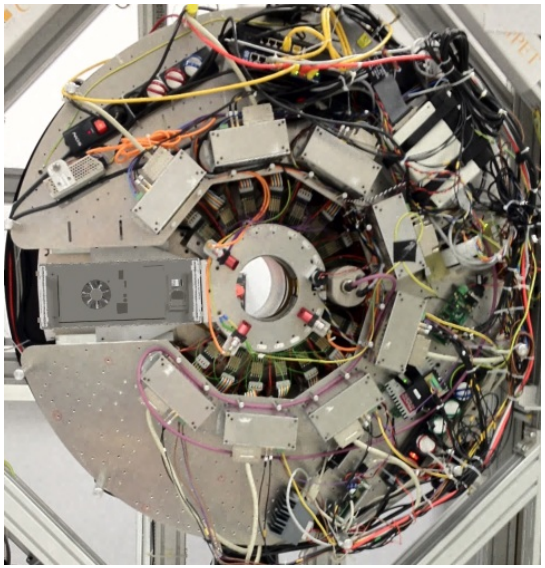


Simultaneous hybrid PET/CT tomography

CT :

- XPAD3.2 camera
- 500,000 Silicon pixels
- (130 x 130) μm^2
- 500 µm thick
- Mo anode X-ray tube (RTW)





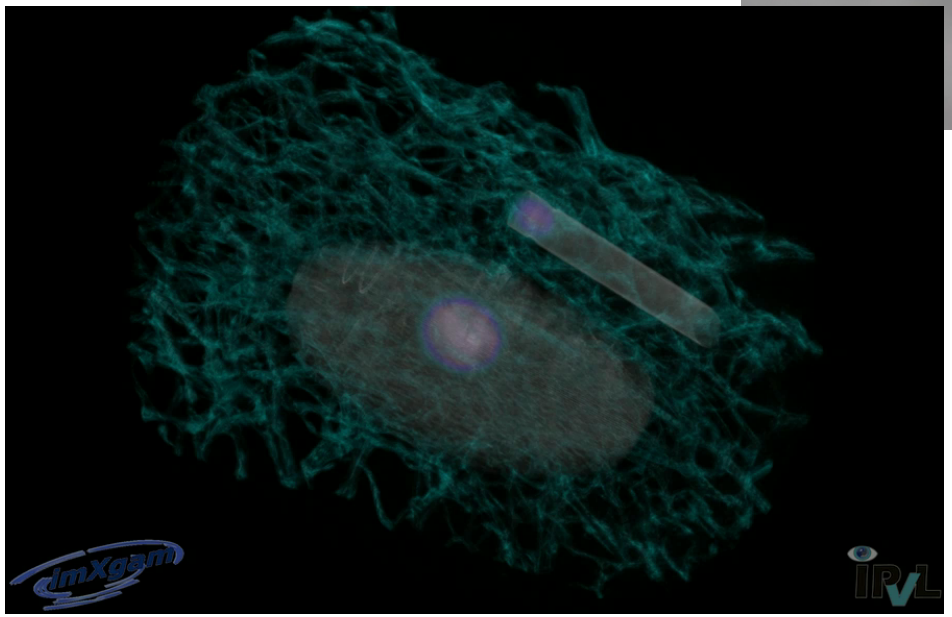
TEP :

- 21 LSO/LuYAP phoswich modules
- 64 (8 X 8) crystal arrays
- (2 x 2 x 8) mm^3
- 64 channel MaPMTs (Hamamatsu)

Simultaneous hybrid PET/CT tomography

Ad hoc phantom:

- 2 point sources inserted in a vegetal sponge named luffa covered by a metallic paint
- 79.1 KBq ^{22}Na
- 56 KBq ^{68}Ge



courtesy: L. Bidaut, U. Dundee

X-ray tube:

- 50 kV/400 µA
- Nb/Mo filtration

Acquisition :

- 0.5 rpm continuous rotation
- 250 ms pose durations
- ~ 360 projections/rotation

Simultaneous hybrid PET/CT tomography

Micro-Derenzo phantom:

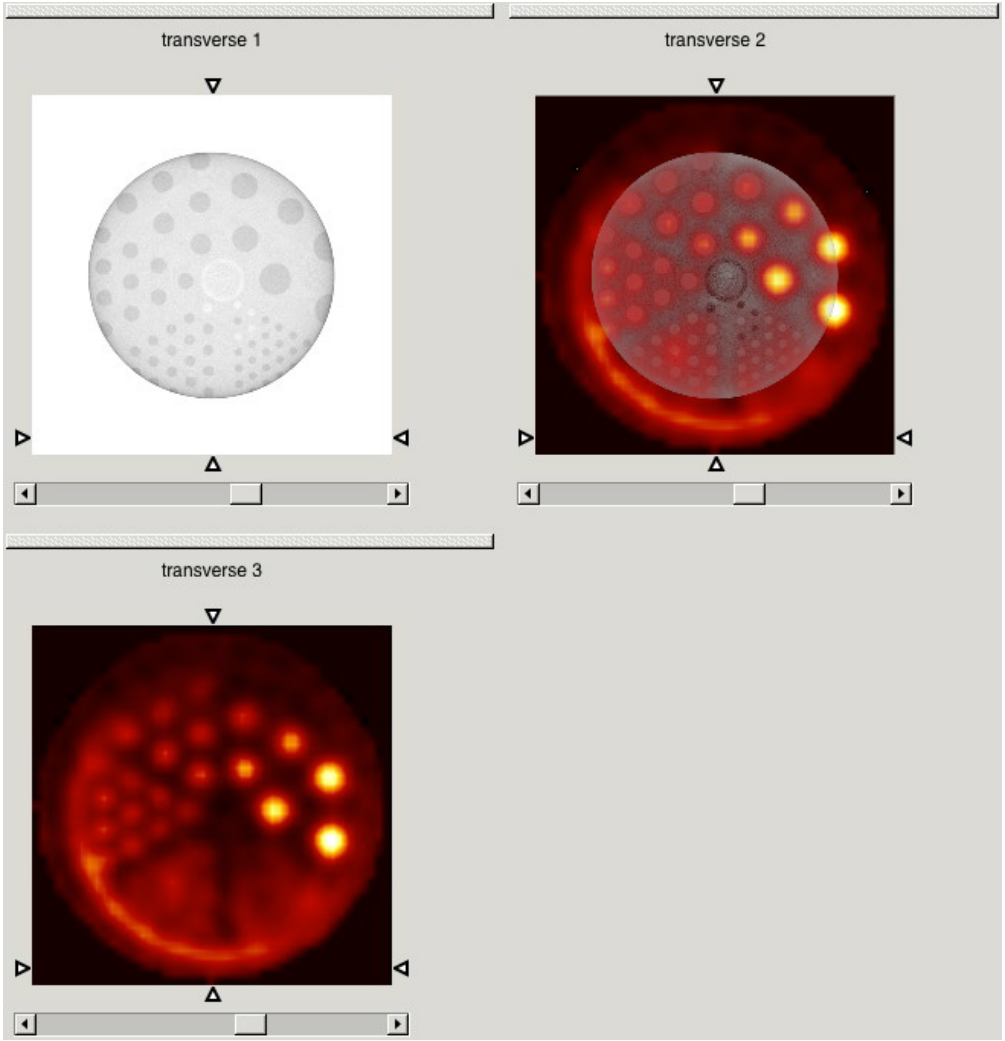
- Rod ∅ 1.2 , 1.6 , 2.4 , 3.2 , 4.0 and 4.8 mm
- Cylinder ∅ 44 mm
- 6,5 MBq [^{18}F]FDG + iodine

X-ray tube:

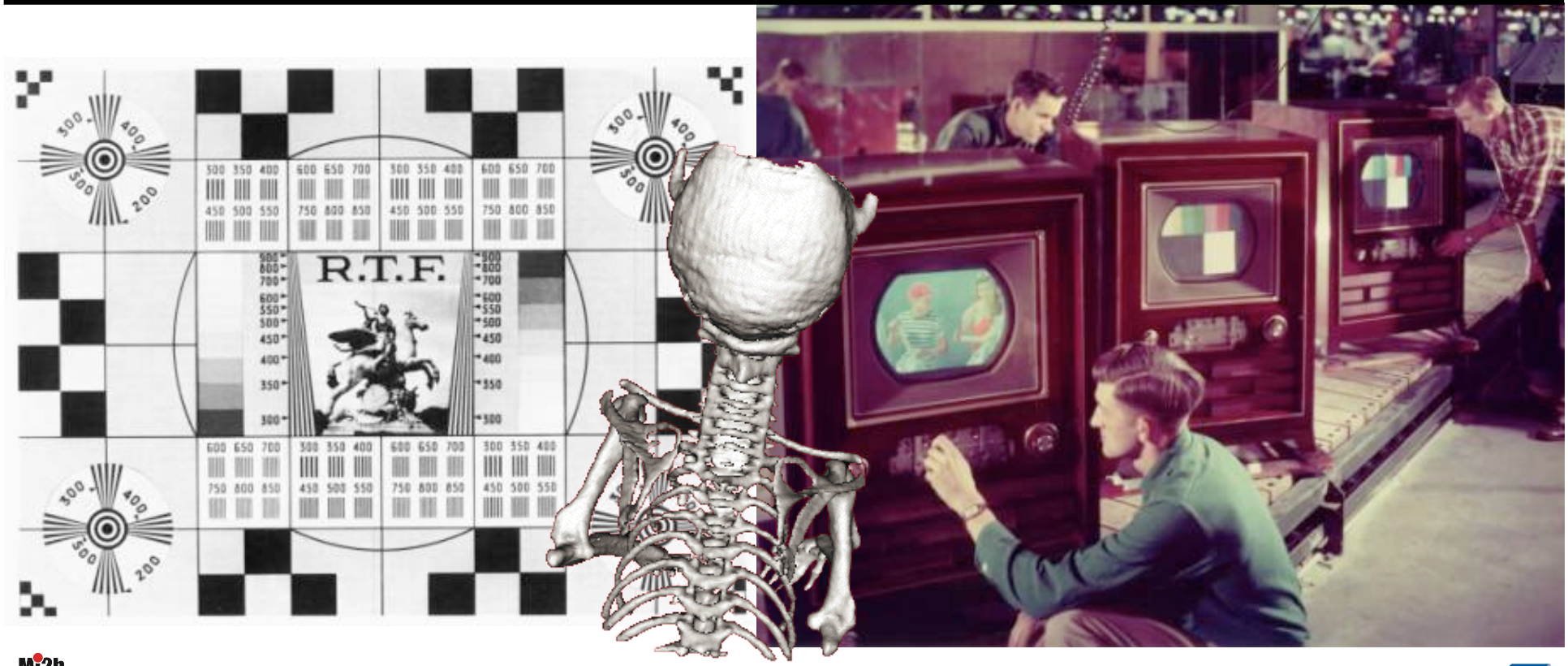
- 50 kV/600 µA
- 500 µm Al filtration

Acquisition :

- 1 h duration
- 0.5 rpm continuous rotation
- 250 ms pose durations
- ~ 360 projections/rotation

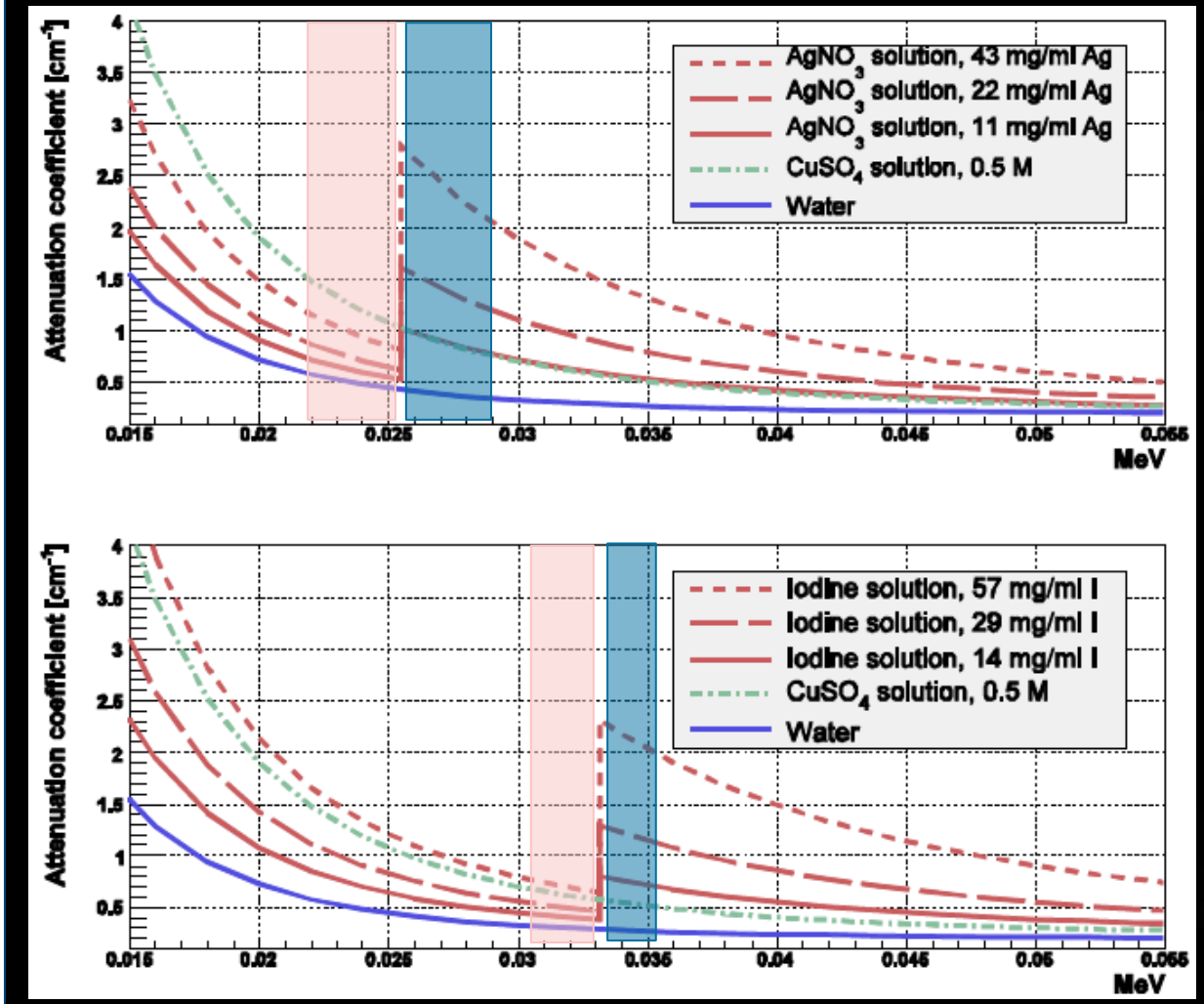


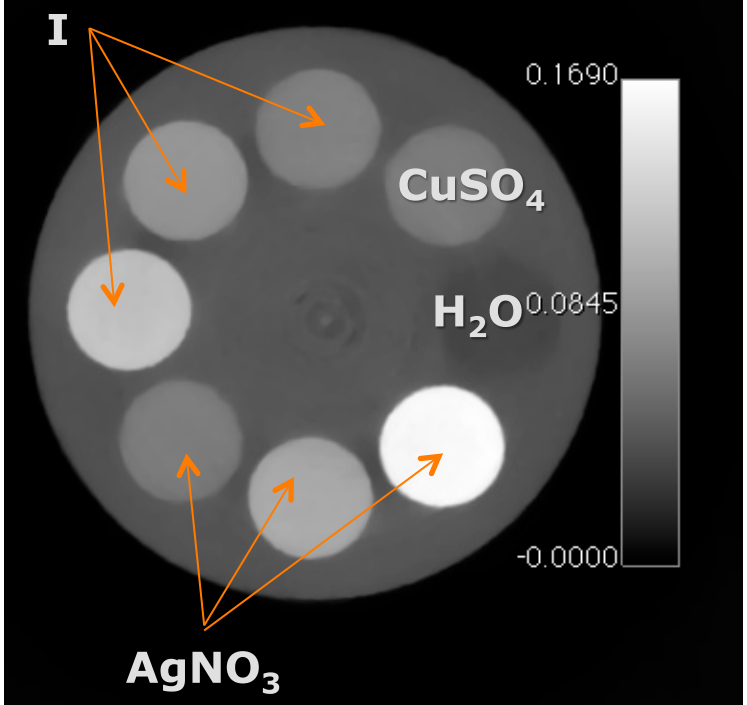
X-ray spectral CT: from black & white to colour



AG GDR MI2B, 4 sept 2015, Marseille

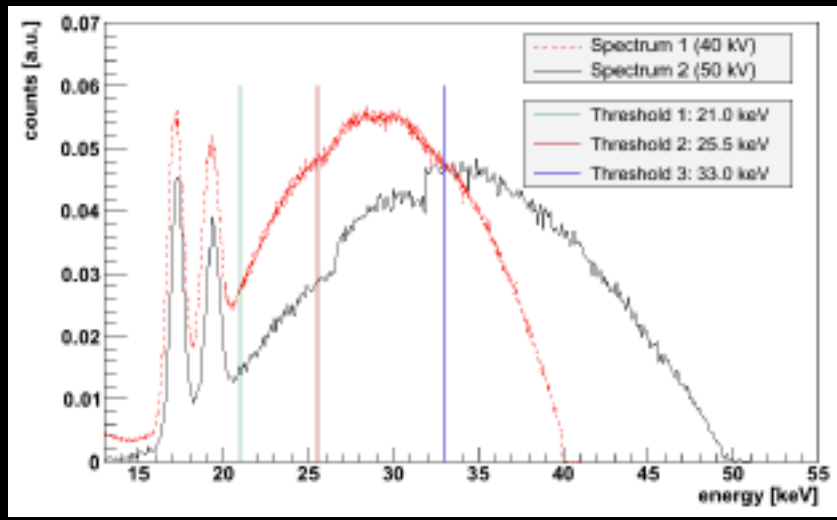
X-ray spectral CT using XPAD3





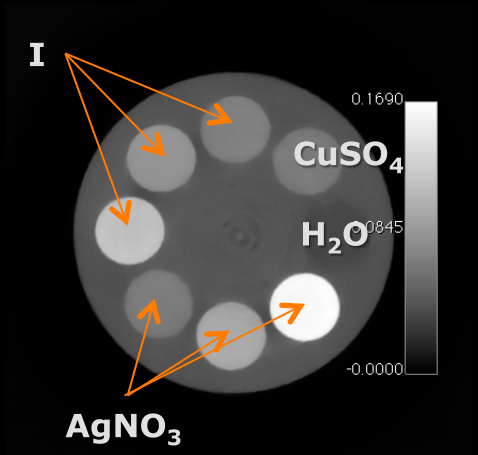
Cassol *et al.*, IEEE Trans. Nucl. Sci. **60** (2013) 103

X-ray spectral CT using XPAD3

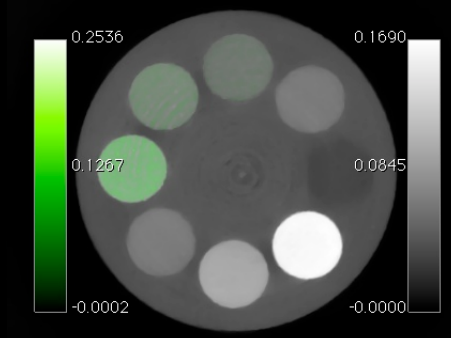


Silver	Iodine
$E_{1Ag} = 21$ keV	$E_{1I} = 25.5$ keV
$E_{2Ag} = 25.5$ keV	$E_{2I} = 33$ keV
$E_{3Ag} = 33$ keV	$E_{3I} = 40/50$ keV

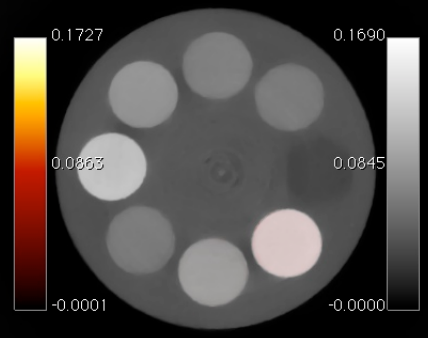
Standard CT



Iodine and Silver K-edge imaging



$(E_{2I}-E_{3I}) - (E_{1I}-E_{2I})$



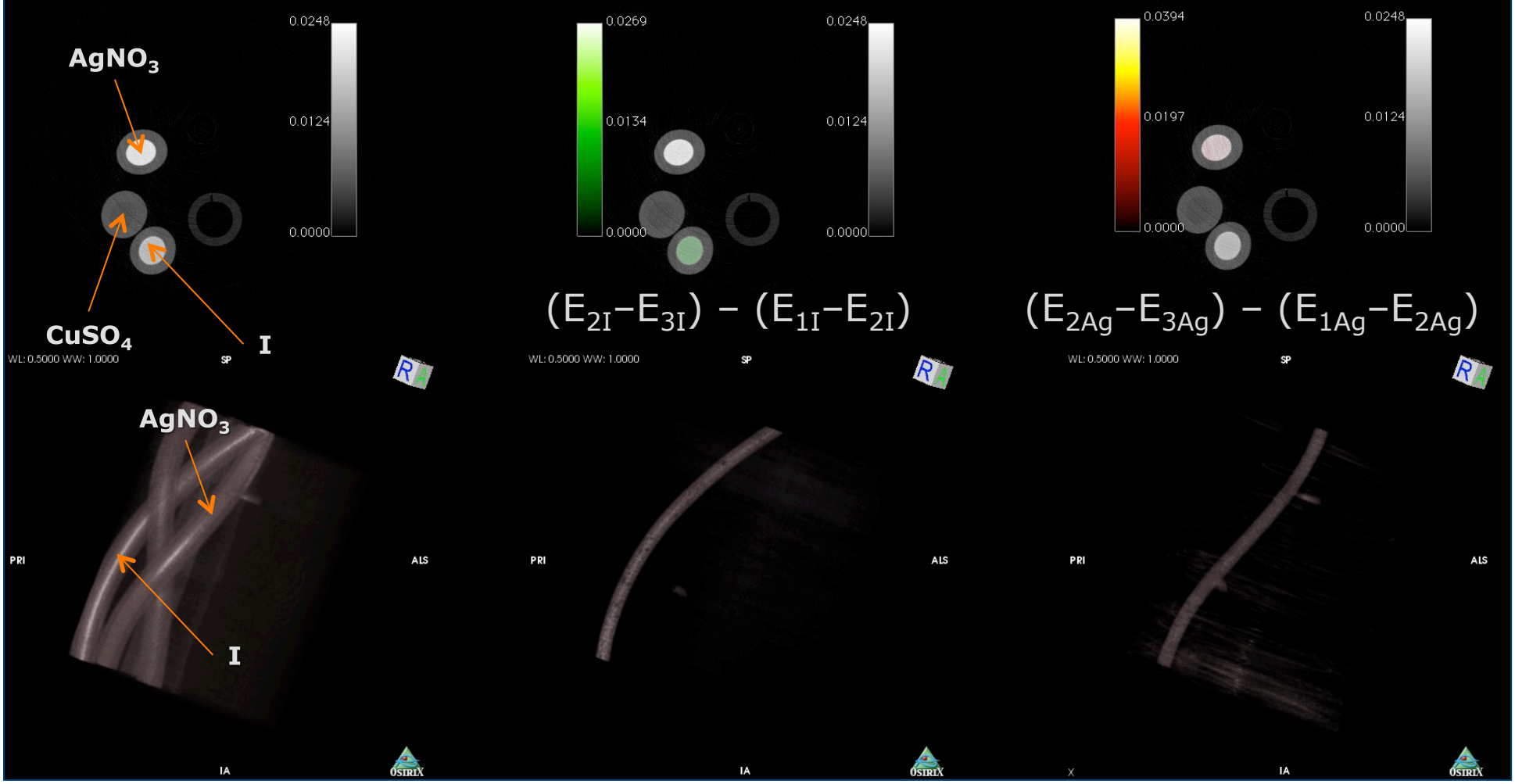
$(E_{2Ag}-E_{3Ag}) - (E_{1Ag}-E_{2Ag})$

Cassol *et al.*, IEEE Trans. Nucl. Sci. **60** (2013) 103

X-ray spectral CT using XPAD3

Standard CT

Iodine and Silver K-edge imaging

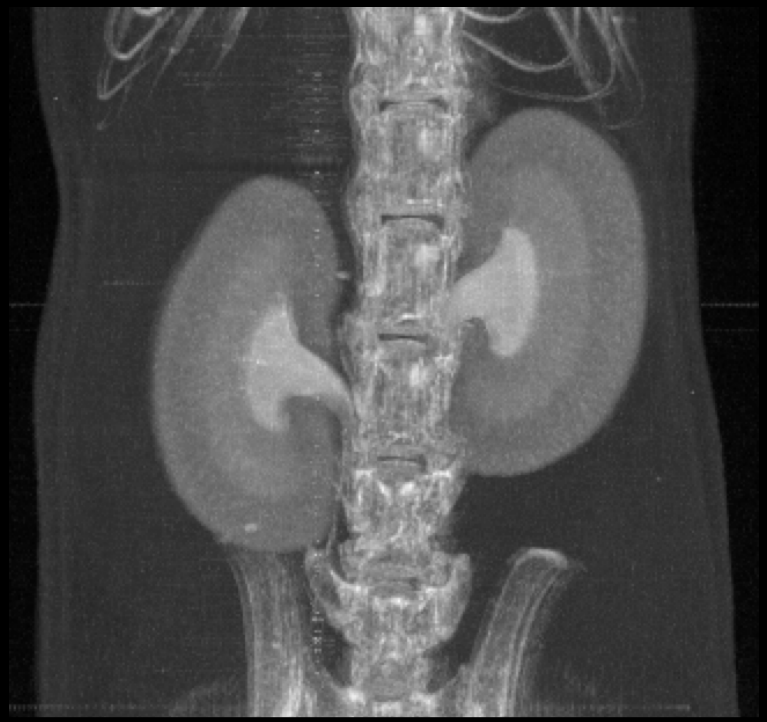


Cassol *et al.*, IEEE Trans. Nucl. Sci. **60** (2013) 103

X-ray spectral CT using XPAD3

Standard CT

Maxixmum intensity projection



- Injection of 200 µL Iomeron
- Molybden anode X-ray tube
- 50 kVp, 30 W

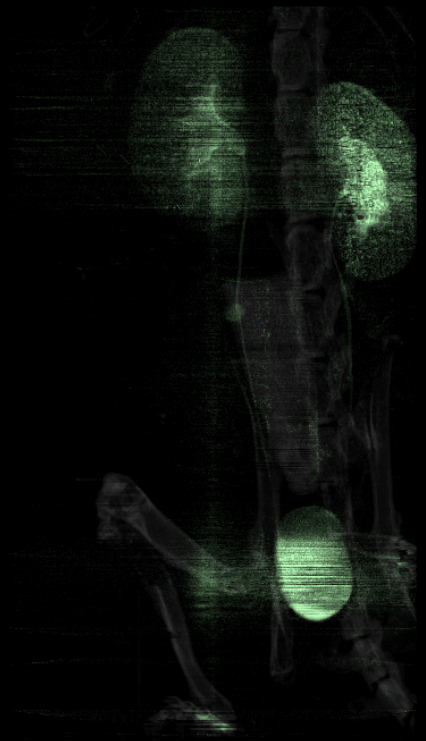
Iodine K-edge image

Maxixmum intensity projection

- 100 µm Cu filtering
- 5 s/image
- 360 projections

X-ray spectral CT using XPAD3

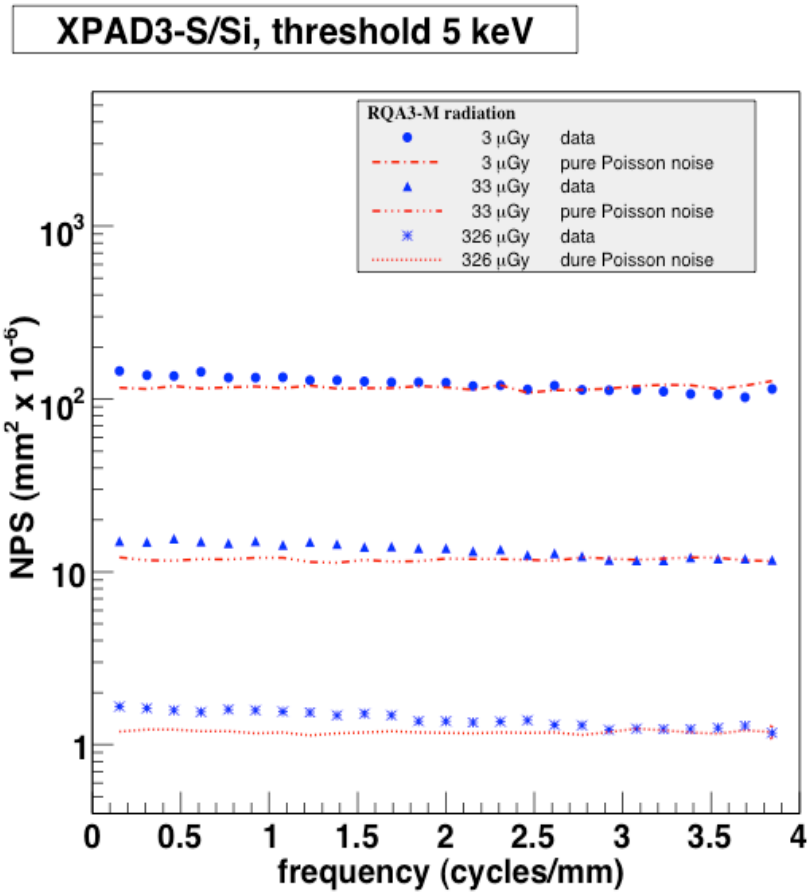
beta = 0



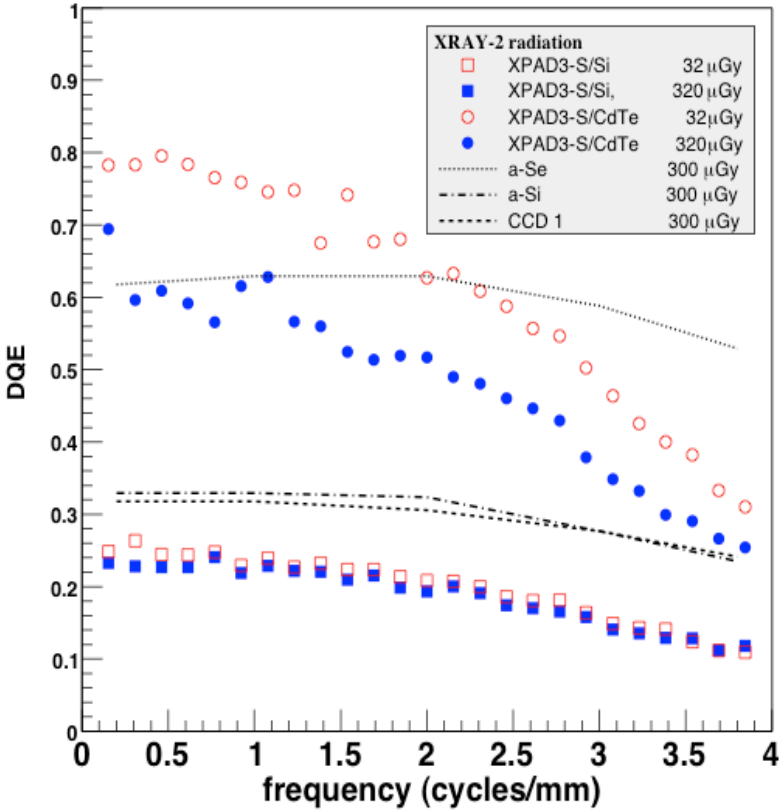
- Injection of 200 µL Iomeron
- Molybden anode X-ray tube
- 50 kVp, 30 W
- 100 µm Cu filtering
- 5 s/image
- 360 projections

Single chip XPAD3 Si et CdTe detector characterisation

Noise Power Spectrum



Detective Quantum Efficiency



Goertzen *et al.*, Phys. Med. Biol. **49** (2004) 5251
Cassol *et al.*, Phys. Med. Biol. **54** (2009) 1773

Study of charge sharing with XPAD3 Si and CdTe

Beam of E_0 = 26 keV

$n(E_{th},E_0) = (1-k)n_p(E_{th},E_0) + kn_{cs}(E_{th},E_0)$

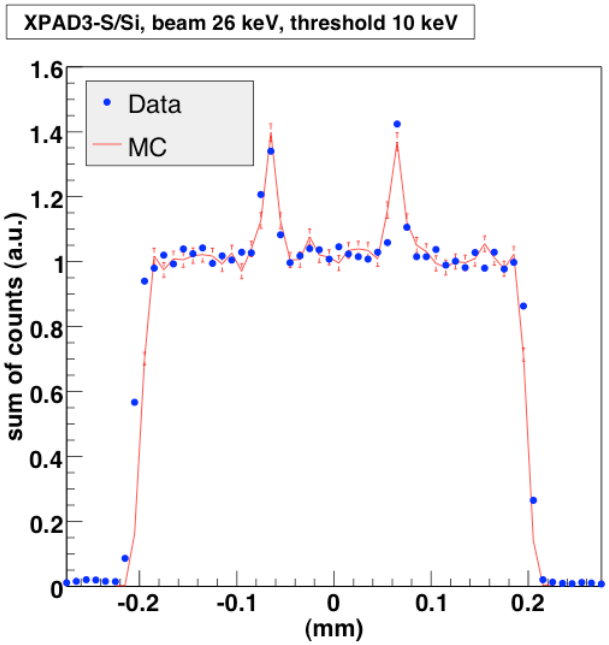
$n_p(E_{th},E_0) = N(E_0,\Delta E_0)$

$n_{cs}(E_{th},E_0) \sim 1/E_0$

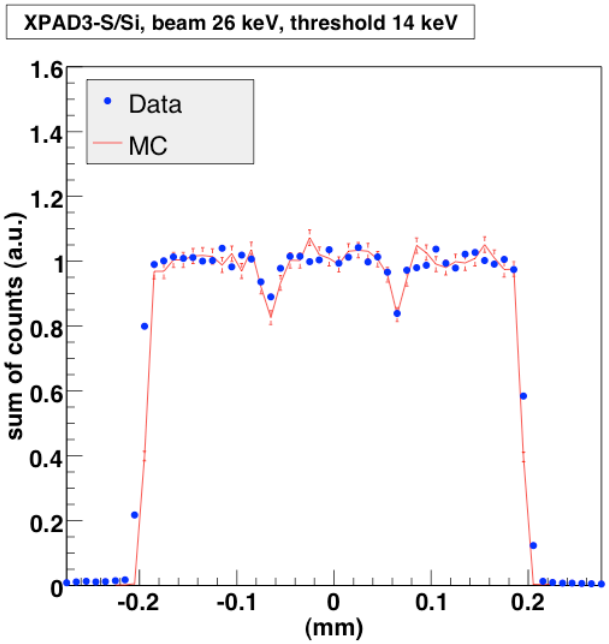
Charge sharing probability: k = 0.75 (measured), 0.76 (simulated)

$eff_p(pixel) = 1/(1\text{-}eff_{cs})$

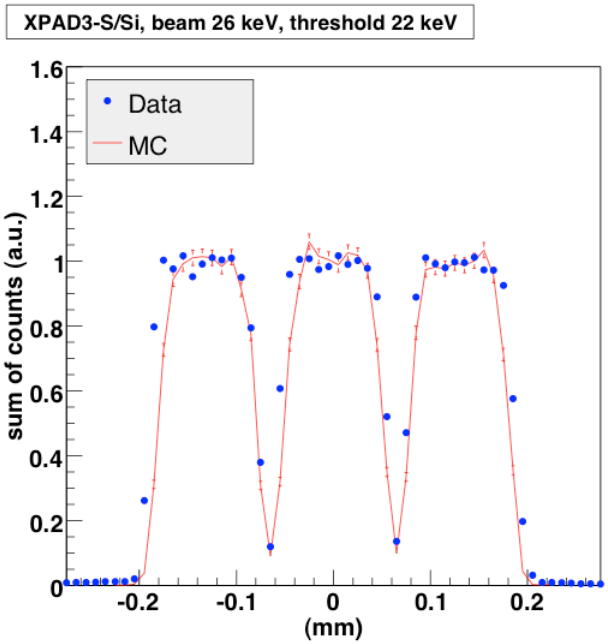
$eff_{cs} = k\,(E_0/2-E_{th})/E_0$



10 keV threshold



14 keV threshold

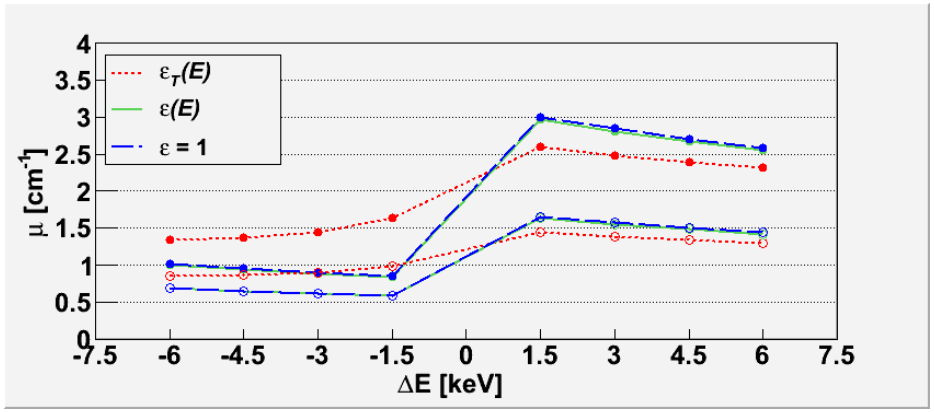


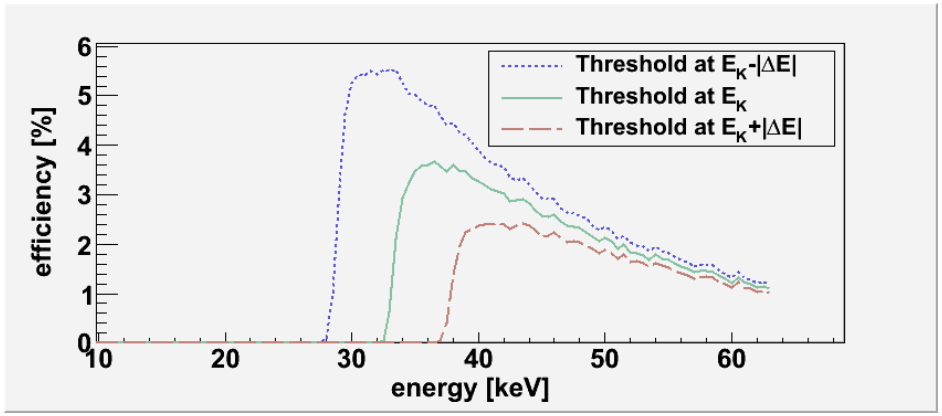
22 keV threshold

Cassol *et al.*, Nucl. Intstrum. Meth. A **633** (2011) 111

Effect of charge sharing on spectral contrast

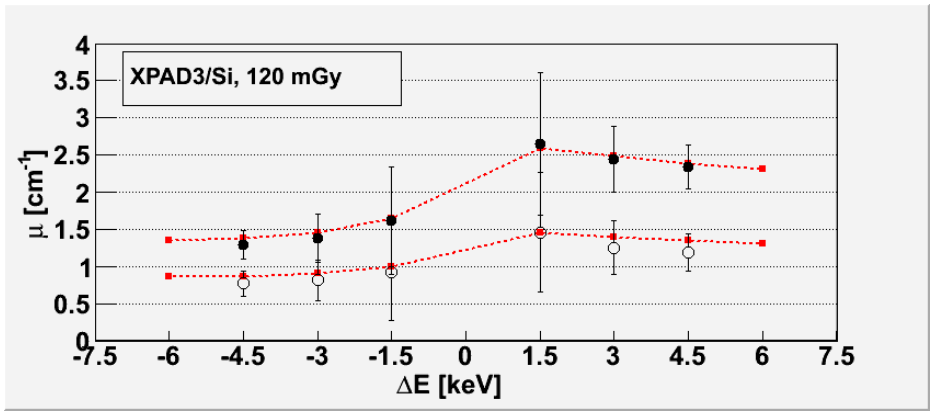
Simulation of Si sensors (full marker: 0,630 M, empty marker: 0,315 M)



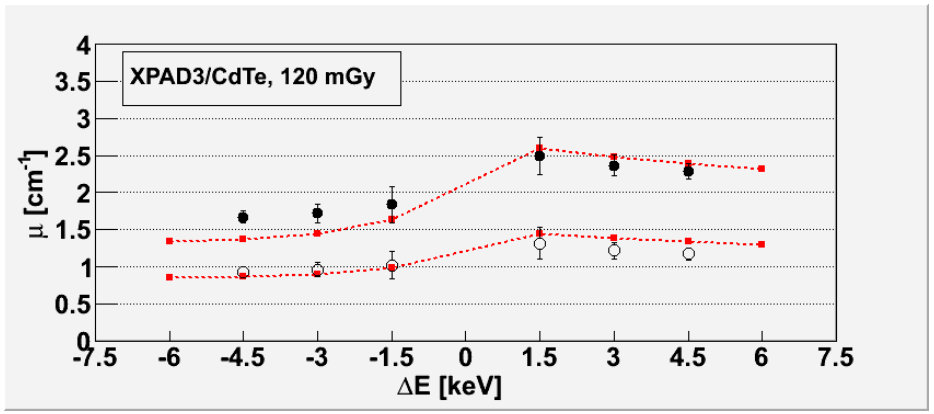


Measured data

Si



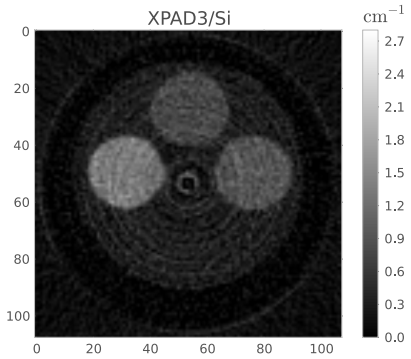
CdTe



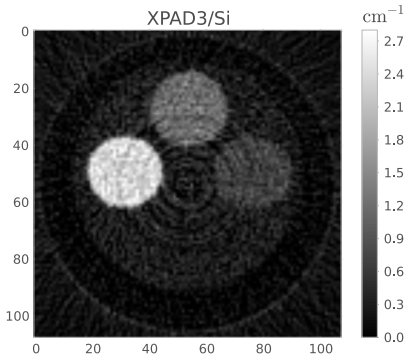
Cassol *et al.*, Phys. Med. Biol. **60** (2015) 5497

Comparison of K-edge imaging between Si and CdTe hybrids

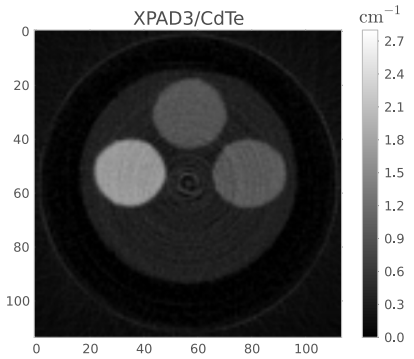
ΔE ≈ −4.5 keV



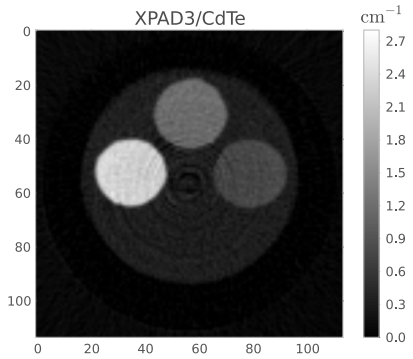
ΔE ≈ +4.5 keV

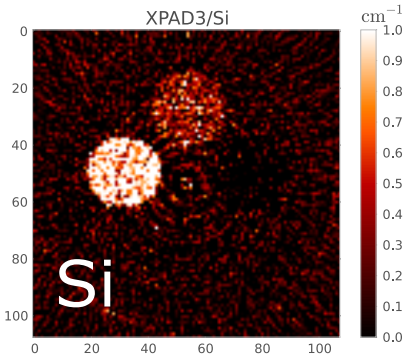


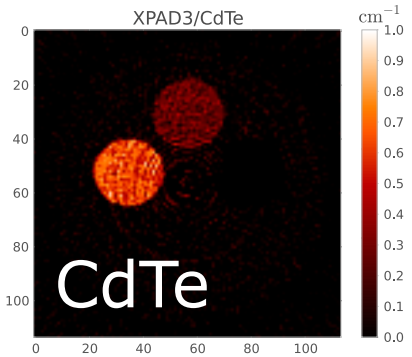
ΔE ≈ −4.5 keV

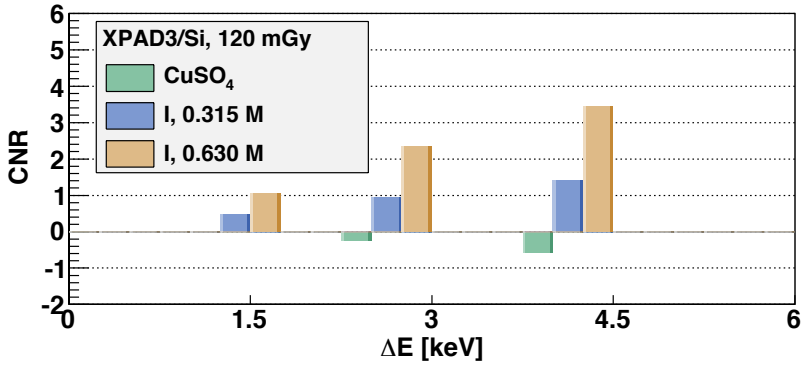


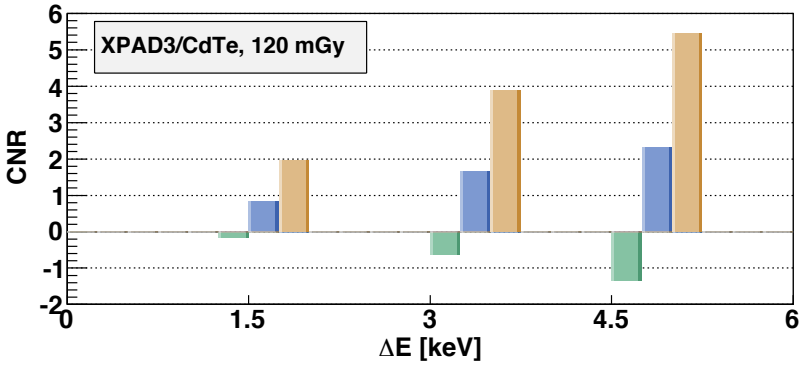
ΔE ≈ +4.5 keV









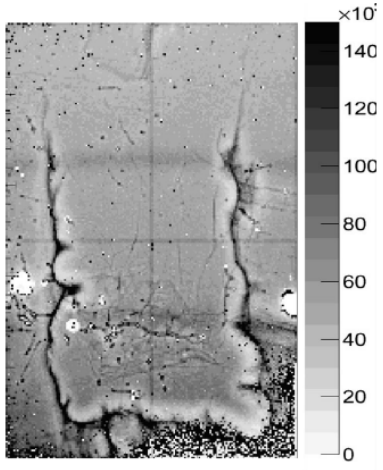


Contrast to Noise Ratio (CNR) at equivalent dose

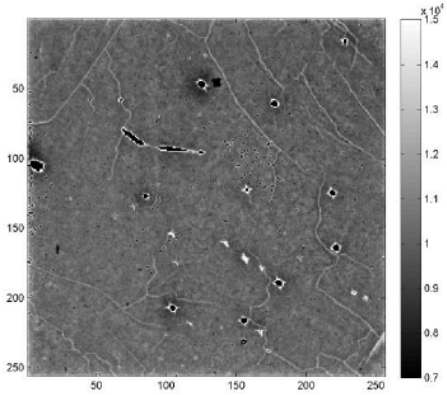
Cassol *et al.*, Phys. Med. Biol. **60** (2015) 5497

AG GDR MI2B, 4 sept 2015, Marseille

ChiPSpeCT & CALIPSO: XPAD3-2/CdTe camera

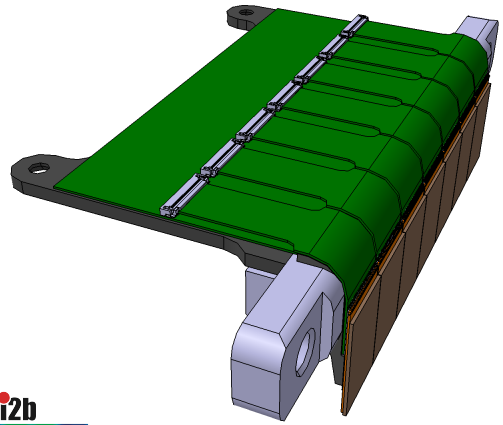


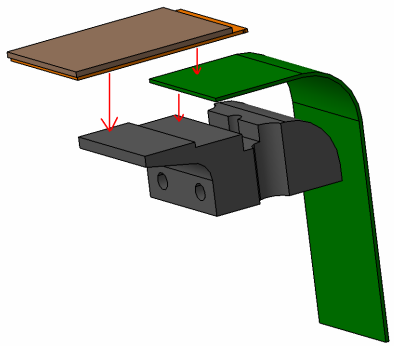
XPAD3 Quad



Medipix II Quad

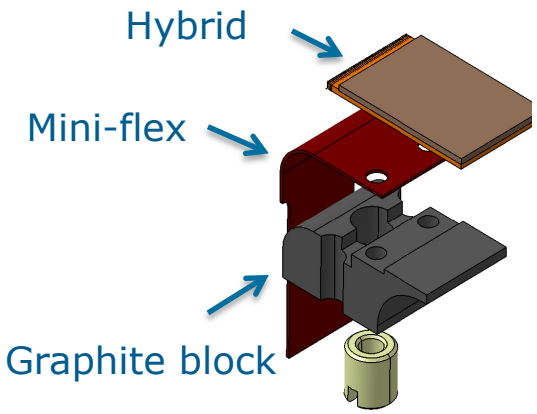
-> for **CHiPSpeCT** (Development of a CdTe Hybrid Pixel detector for X-ray Spectral CT of brain tumours) :

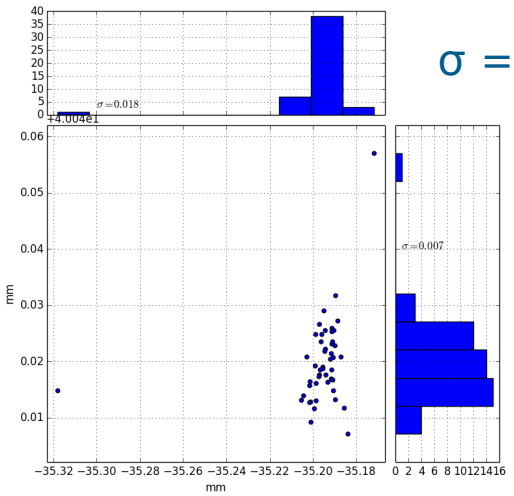




- HighZpad (FP7 ELISA)
  - « Survey » de l'état de l'art en matière de capteurs à Z élevé et des moyens de les hybrider sur des circuits pixel pour obtenir des capteurs de la plus grande dimension possible
  - 3 circuits pixel considérés (Medipix 2, Pilatus, XPAD3)
  - Un « hybrideur » : XIE, techno indium
  - Capteurs CdTe (Acrorad), ohmique → dimension pour faire un « Quad »
  - Pour tous les circuits considérés: problèmes d'hybridation ou dommages aux capteurs → taches et courant de fuite élevé

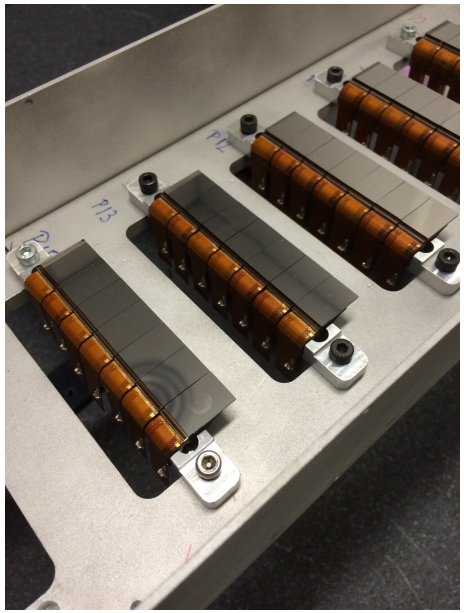
Construction of the CHiPSpeCT camera

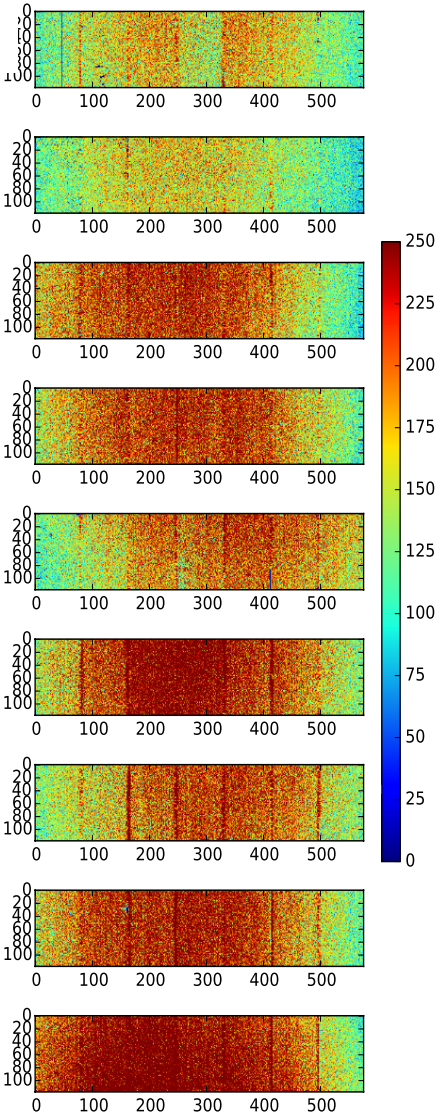




σ = 0.018 mm

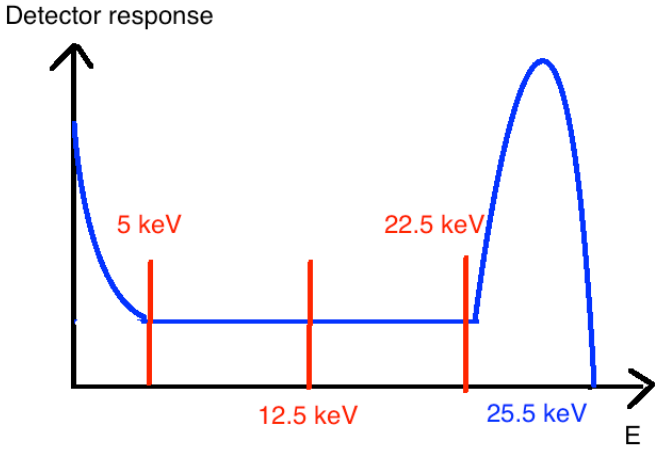
σ = 0.007 mm

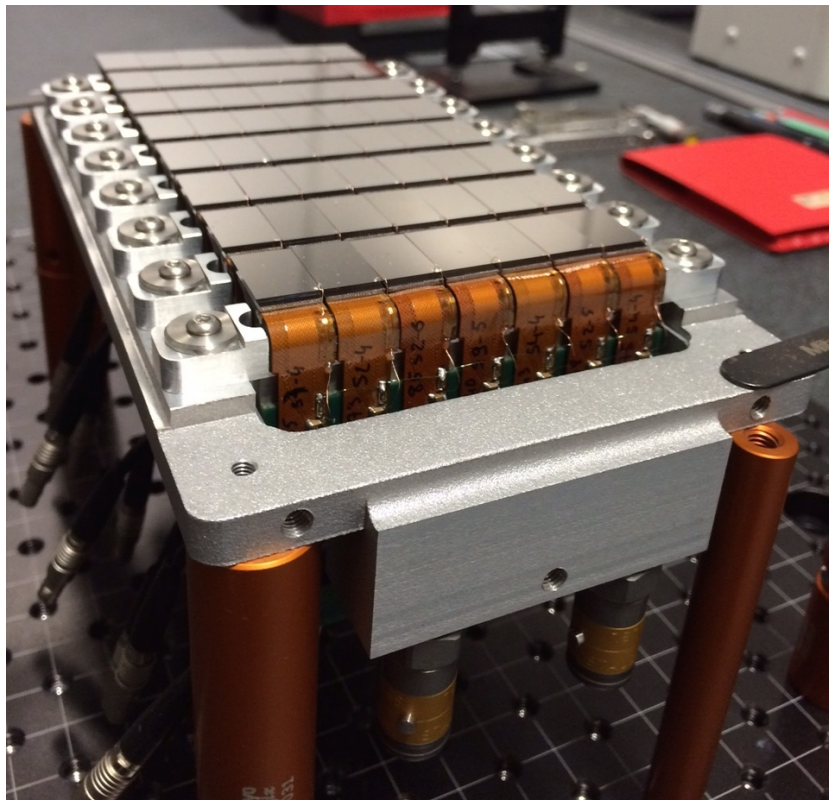


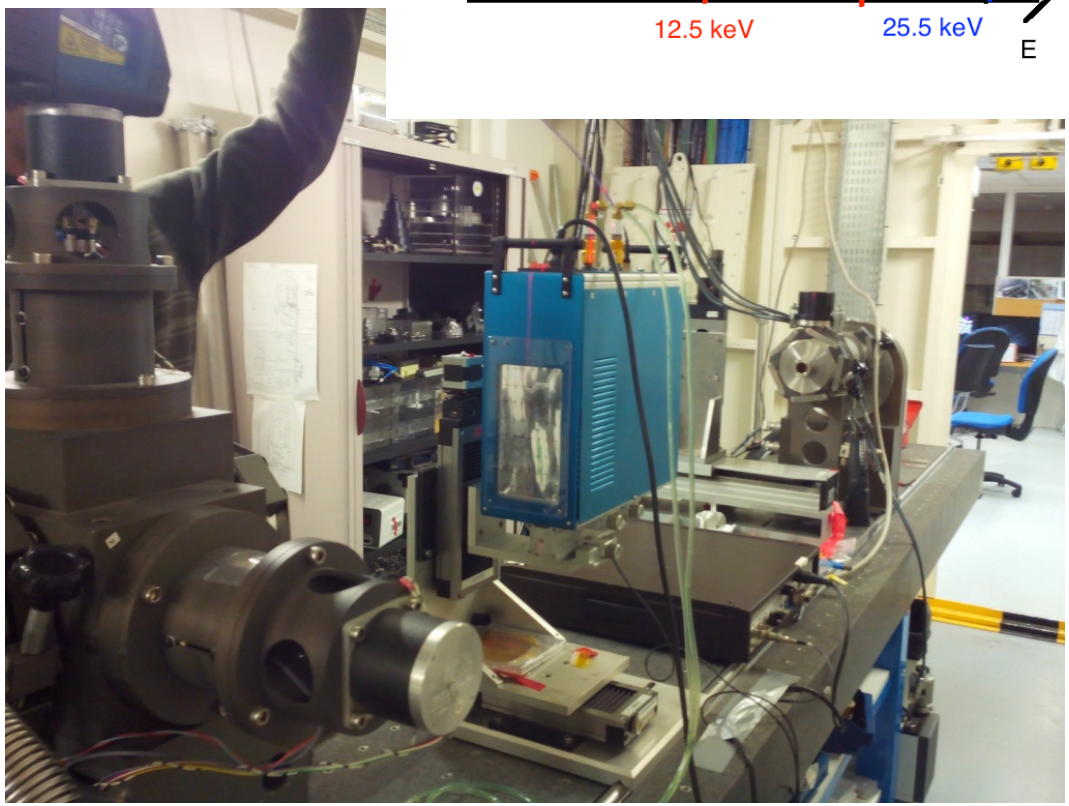


First irradiations on the D2AM beam line of ESRF at 25.5 keV

- Calibrations: 5 keV (noise), 12.5 keV and 22.5 keV
- Flat images : diffused beam
- Diffraction images : on LaB_6 and Cr_2O_3

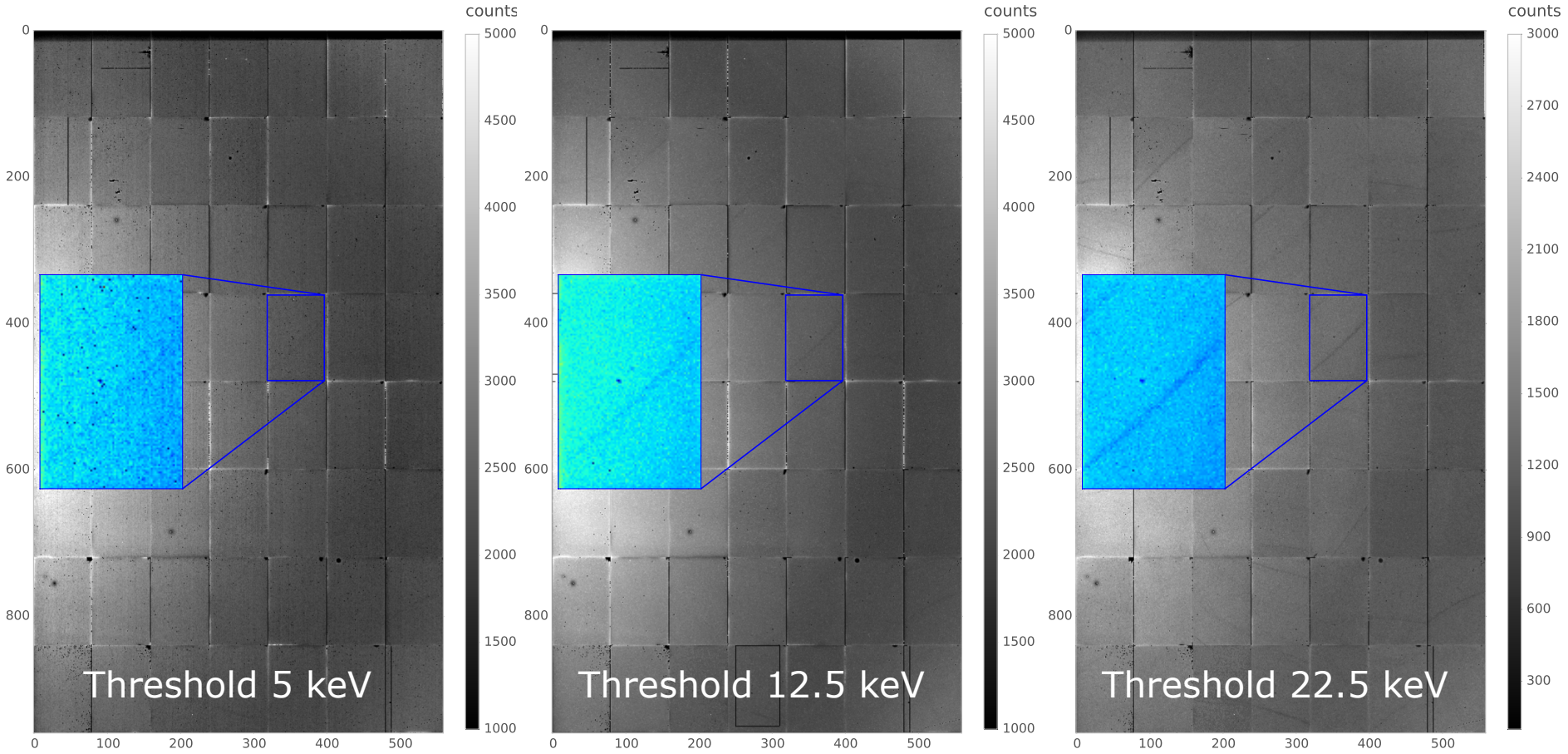






First irradiations on the D2AM beam line of ESRF at 25.5 keV

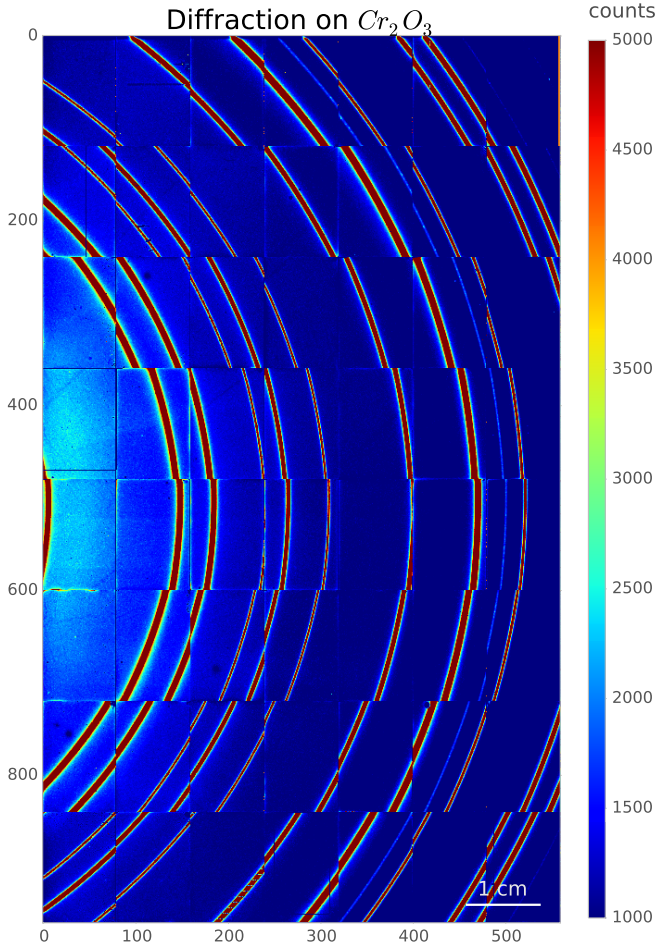
- Flat images: uniformity



- Satifactory, but some patterns remain visible for all the thresholds

Cassol *et al.*, Proc. iWoRiD 2015, DESY

Diffraction image on LaB_6 and Cr_2O_3

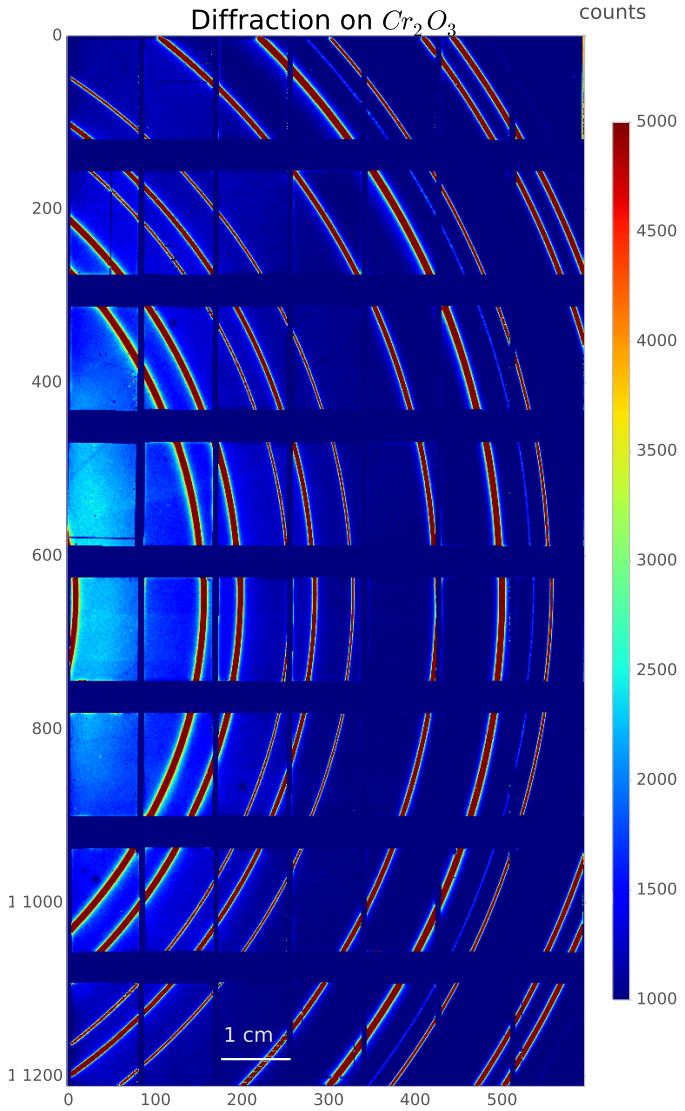


After geometry correction

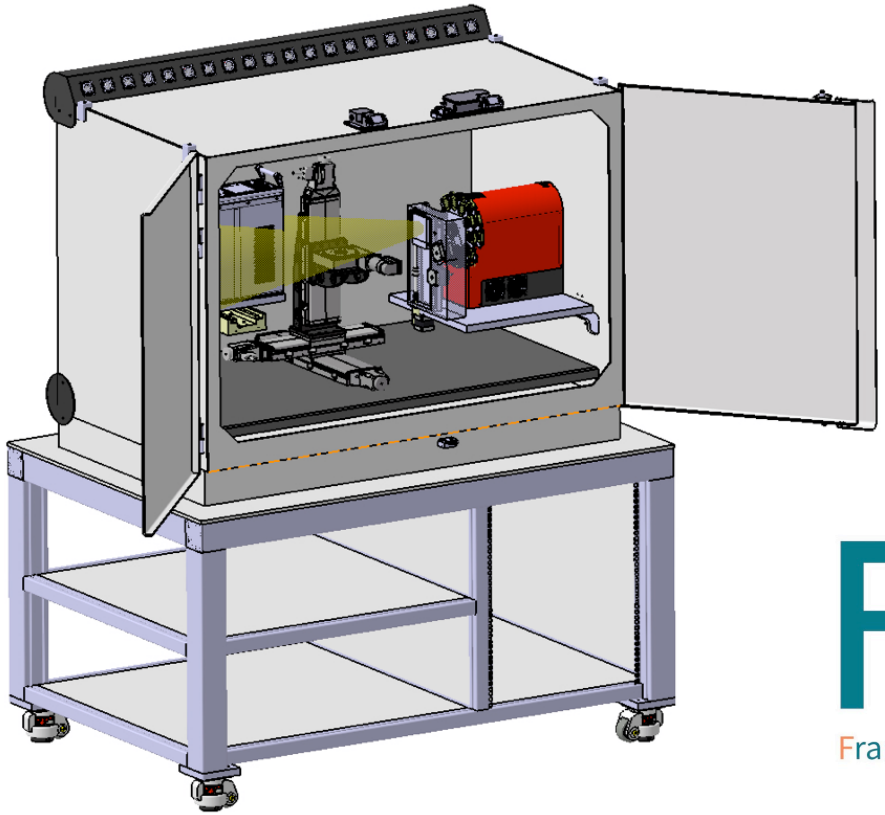
Nice reconstruction of the rings

Gaps between chips

<Δx>= 0.7 mm
<Δy>= 4.7 mm



Construction of the new spectral CT prototype PIXSCAN-FLI



France Life Imaging

Dimension (L x l x h)	1,5 x 1,1 x 1,8 m
Weight (kg)	< 1 ton
Surface	1,65 m^2
Ground load	< 400 kg/m^2
Power consumption	< 4,5 kW
Powering	230 V AC
Hamamatsu L8122-01 X-ray tube	40-150 kV, 75 W

X and gamma imaging team

Physics, instrumentation, and informatics :

- Alain Bonissent
- Yannick Boursier
- Jean-Claude Clémens
- Franca Cassol
- Pierre Delpierre (-> imXPAD)
- Mathieu Dupont (PhD 2014 -> IR AMU)
- Pierre-Yves Duval
- Thomas Fabiani
- Jonathan Graber-Bolis
- Margaux Hamonet (PhD student)
- Rana Khoury (PhD 2008)
- Carine Kronland-Martinet (PhD 2015)
- Christophe Meessen
- Christian Morel
- Hector Perez Ponce (postdoc -> imXPAD)
- Stan Nicol (PhD 2010 -> HMR Montréal)
- Hamid Ouamara (PhD 2013 -> EOS Paris)
- Loriane Portal (PhD student)

Biology :

- Franck Debarbieux

Electronics and microelectronics :

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- Patrick Breugnon
- Frédéric Bompard (-> imXPAD)
- Benoît Chantepie (PhD 2008 -> INVIA Aix)
- Arkadiusz Dawiec (PhD 2011 -> SOLEIL)
- Bernard Dinkespiler
- Stéphanie Godiot-Basolo
- Mohsine Menouni
- Patrick Pangaud
- Jérôme Royon

Mechanics :

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- Jean-Philippe Logier
- Mathieu Niclas
- Eric Vigeolas