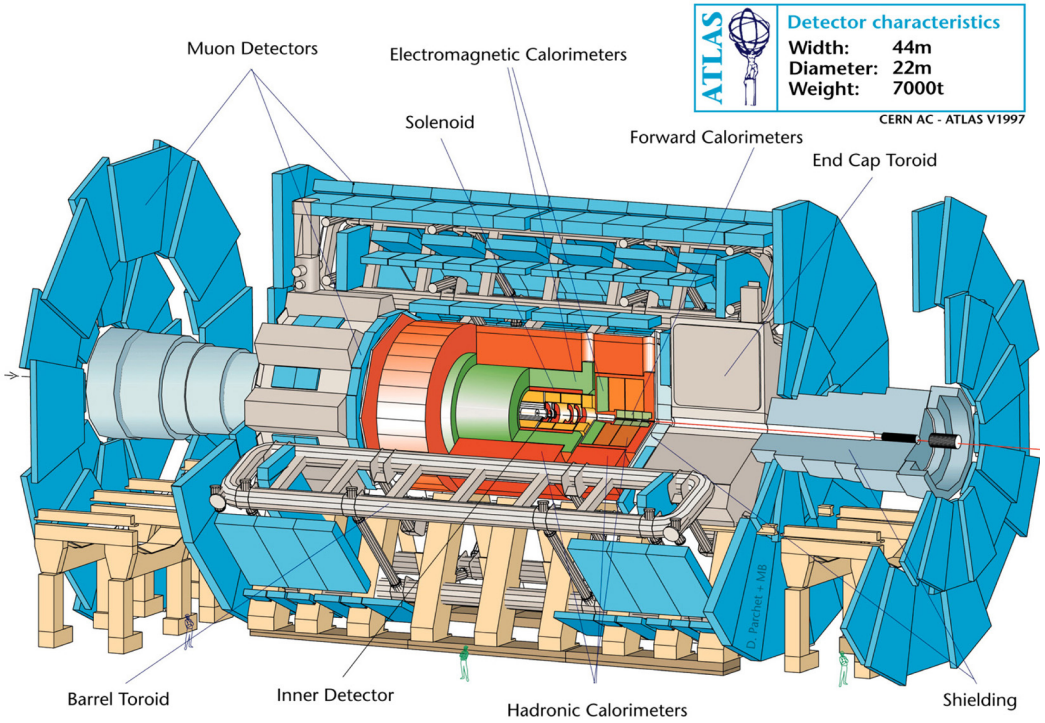
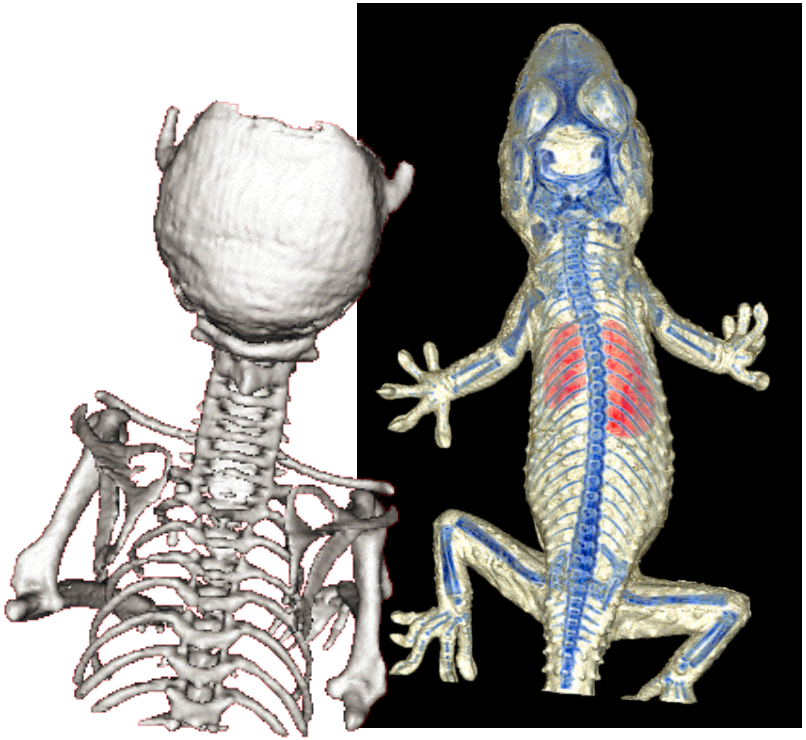
Development of X-ray spectral CT using photon counting Hybrid Pixel detectors





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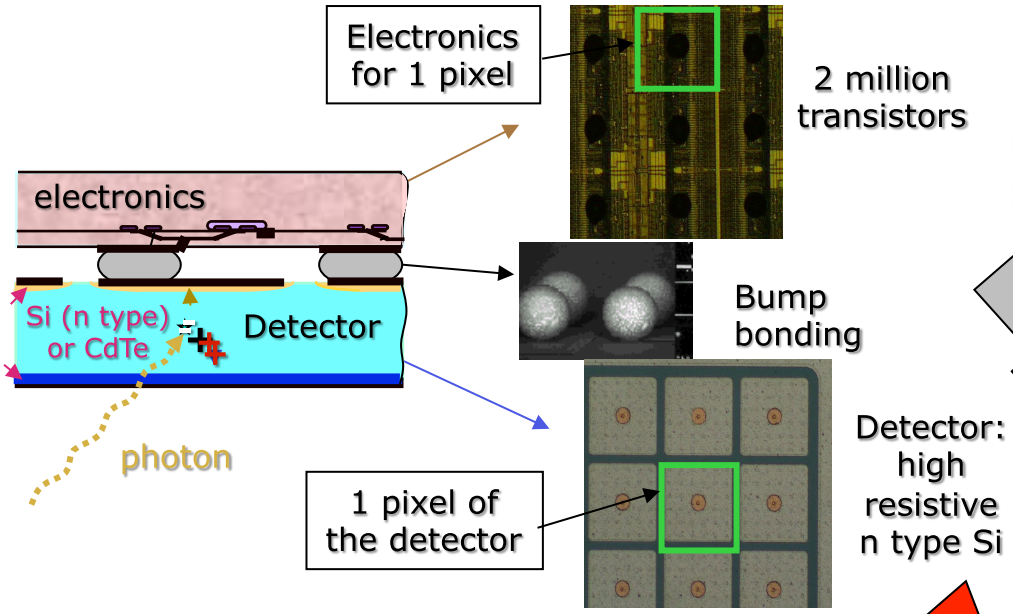
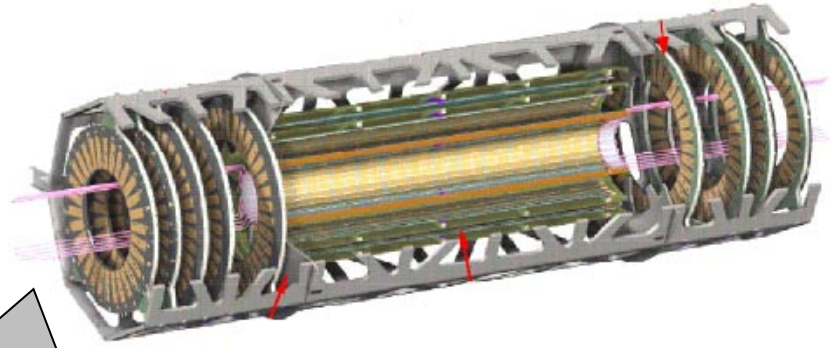
Hybrid Pixels for X-ray cone beam CT (CBCT)





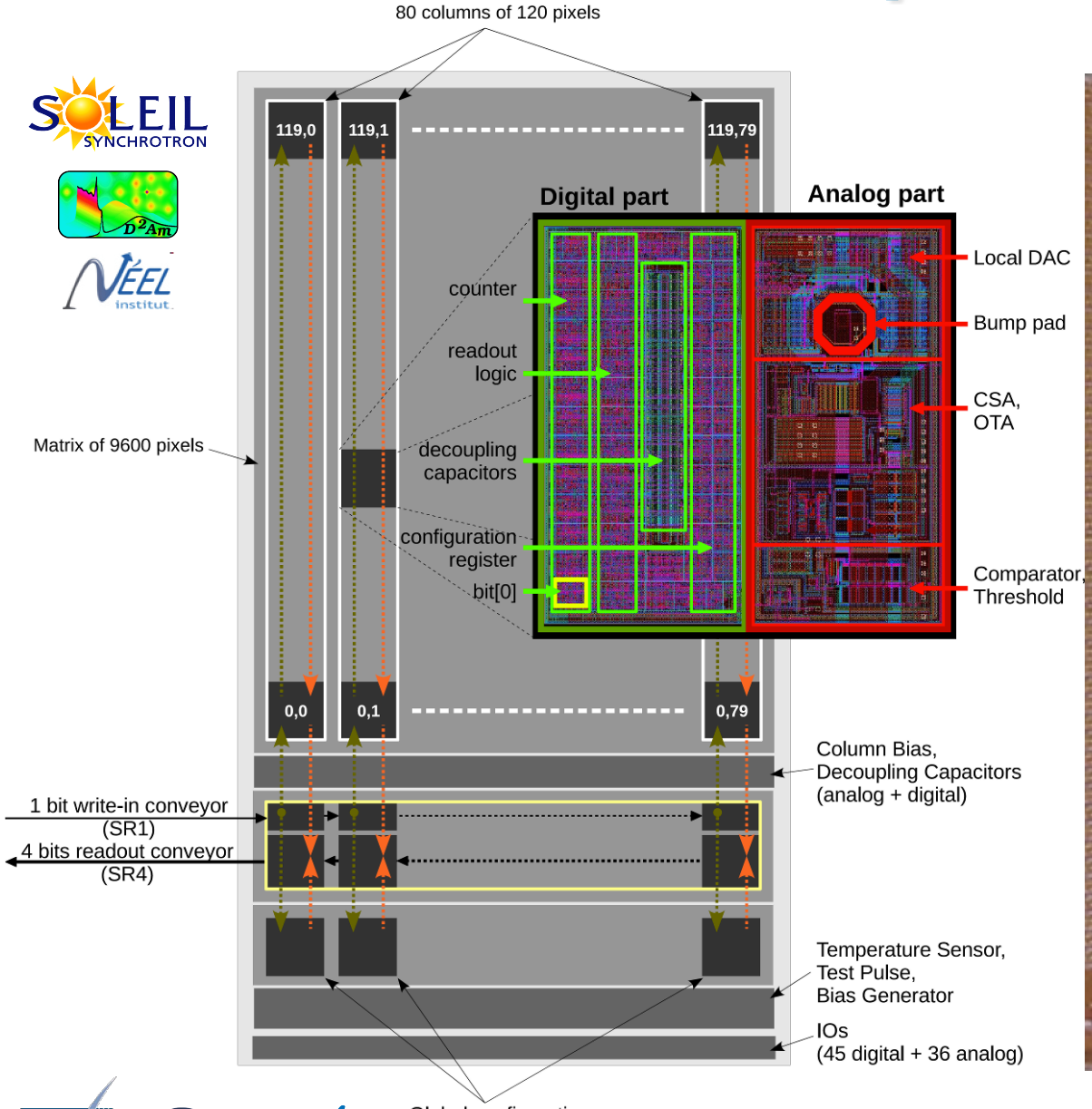
- Noise suppression
- Energy selection
- Very high dynamics

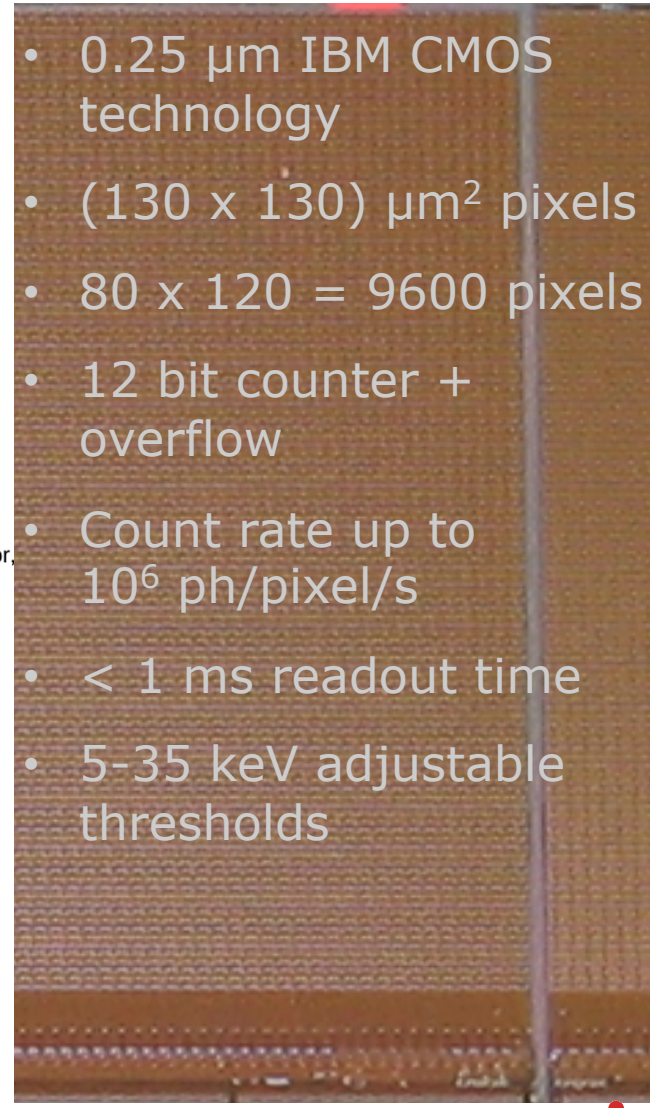
- Very fast data acquisition
- Choice of the sensor (Si, CdTE, AsGa)
- Optimized efficiency

¿ Improvement of contrast ?

¿ Reduction of radiation dose ?

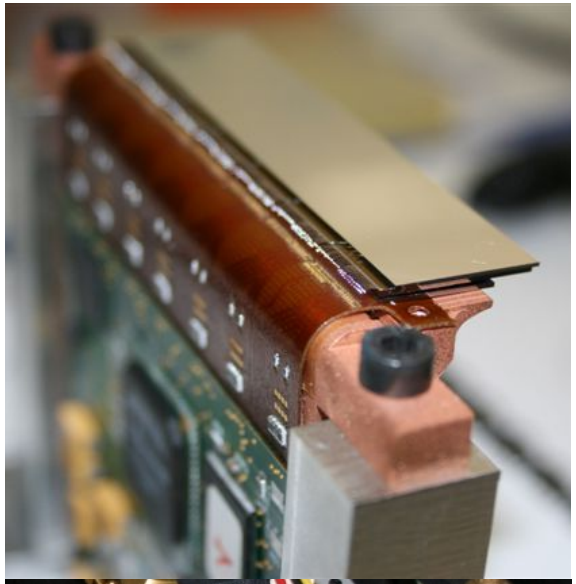
XPAD3: Si and CdTe Hybrid Pixels for X-ray

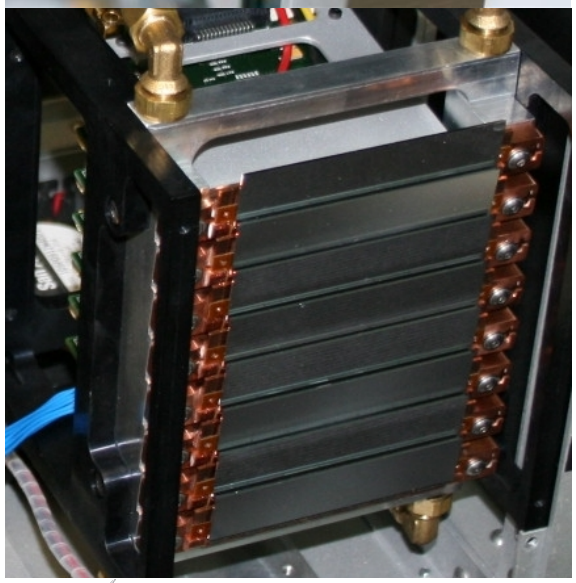




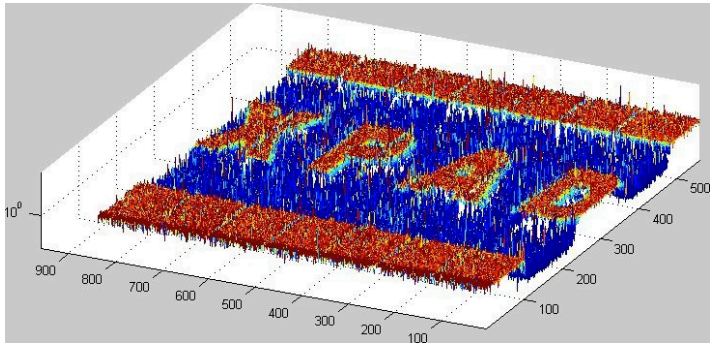
- 0.25 µm IBM CMOS technology
- (130 x 130) µm^2 pixels
- 80 x 120 = 9600 pixels
- 12 bit counter + overflow
- Count rate up to 10^6 ph/pixel/s
- < 1 ms readout time
- 5-35 keV adjustable thresholds

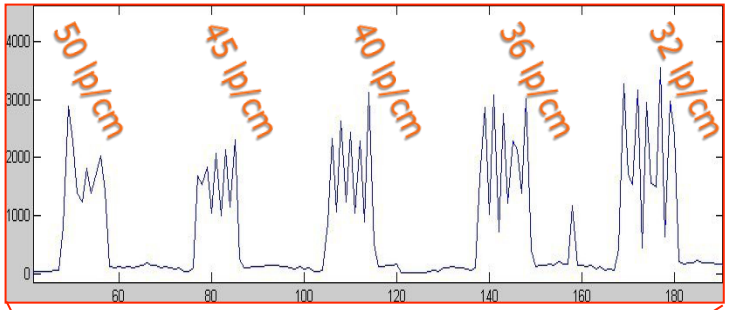
XPAD3: Si and CdTe Hybrid Pixels for X-ray detection



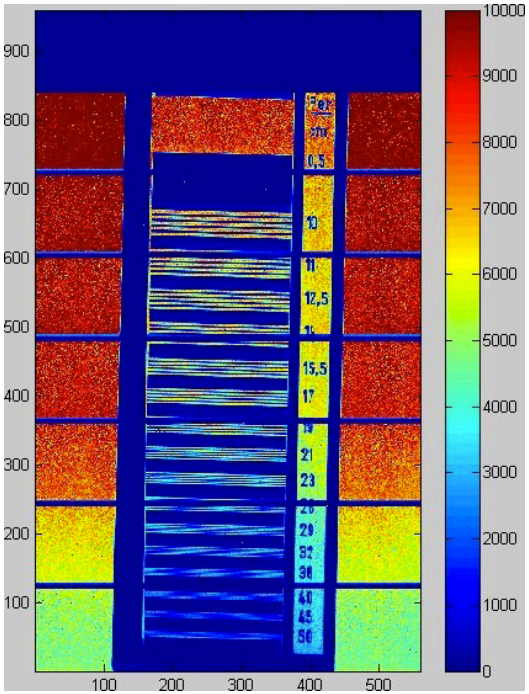


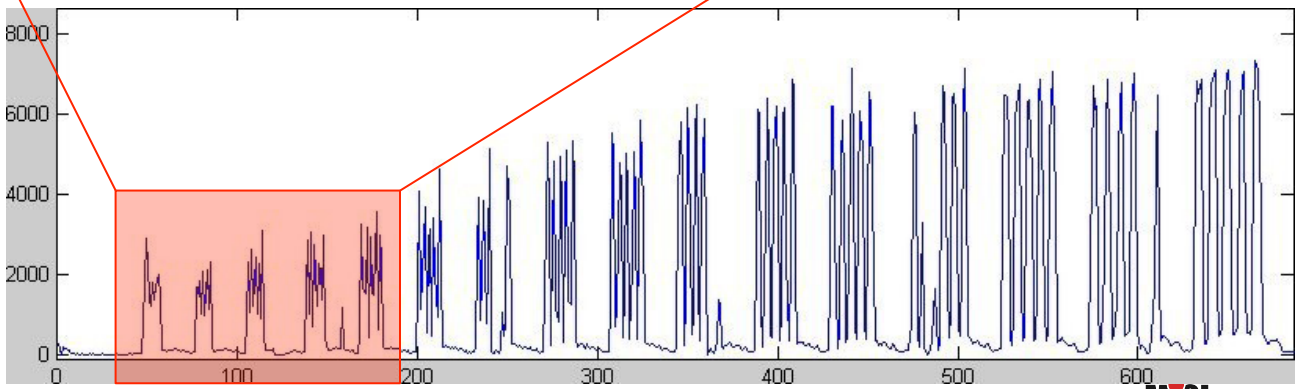
5 keV





14 keV





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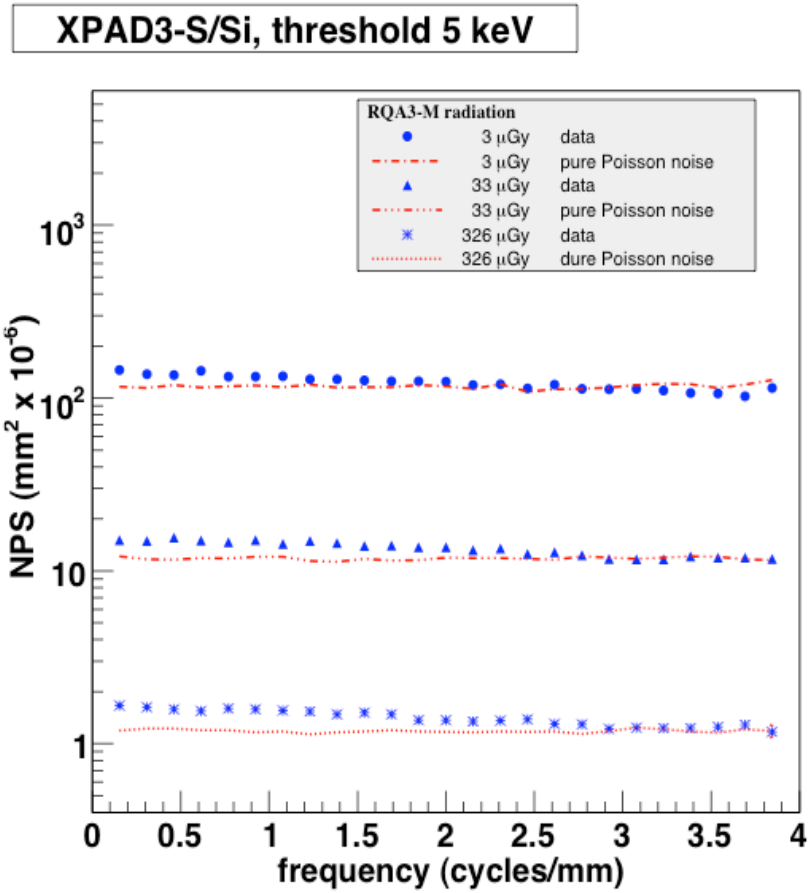
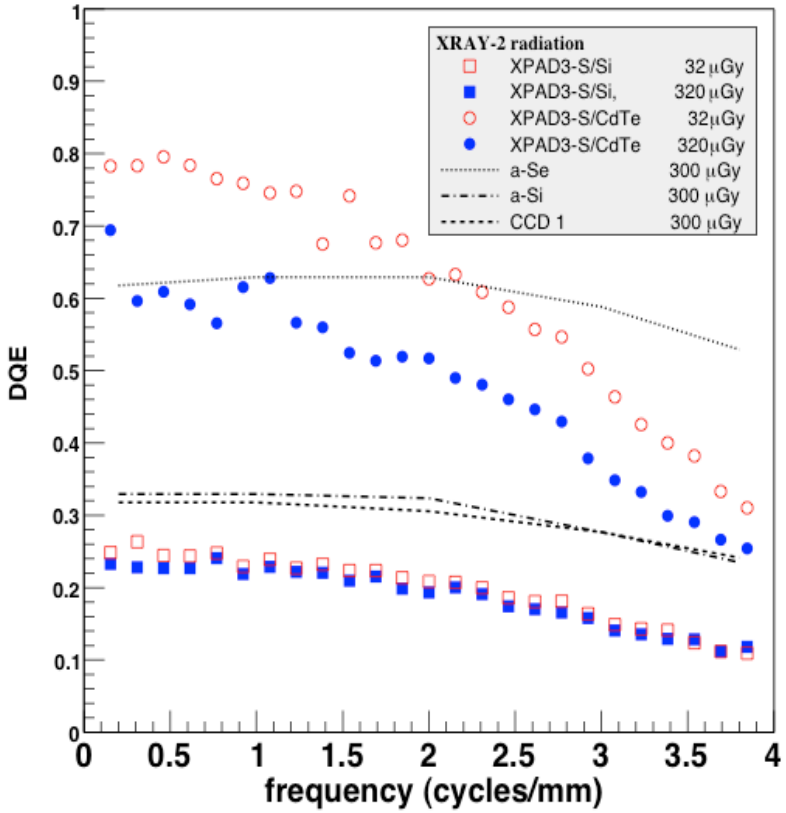
Single chip XPAD3 Si et CdTe detector characterisation

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

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

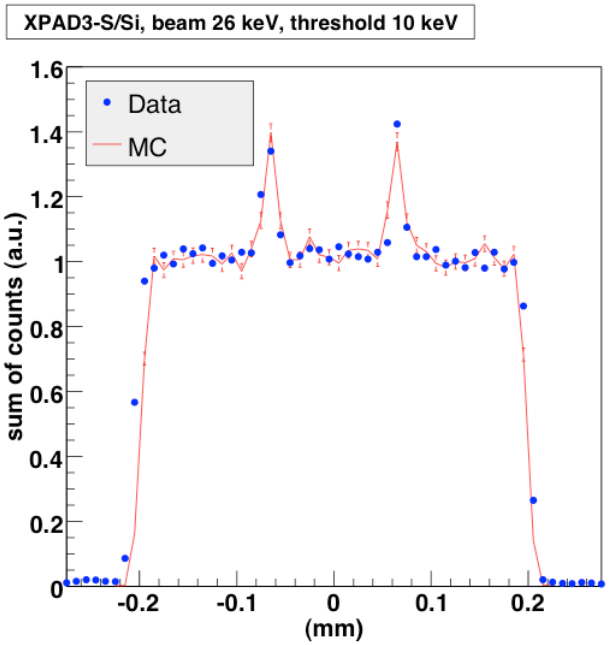
$n_p(E_{th},E_0) = N(E_0,\Delta E_0)$

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

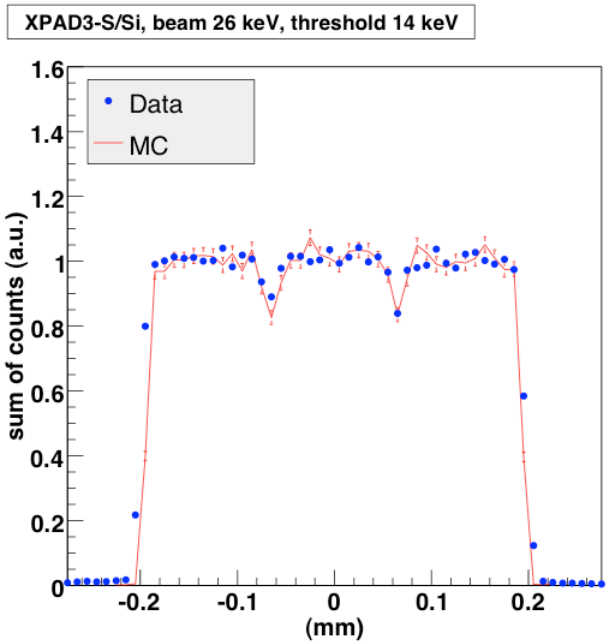
Charge sharing probability: k = 0.75 (measured), 0.76 (simulated)

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

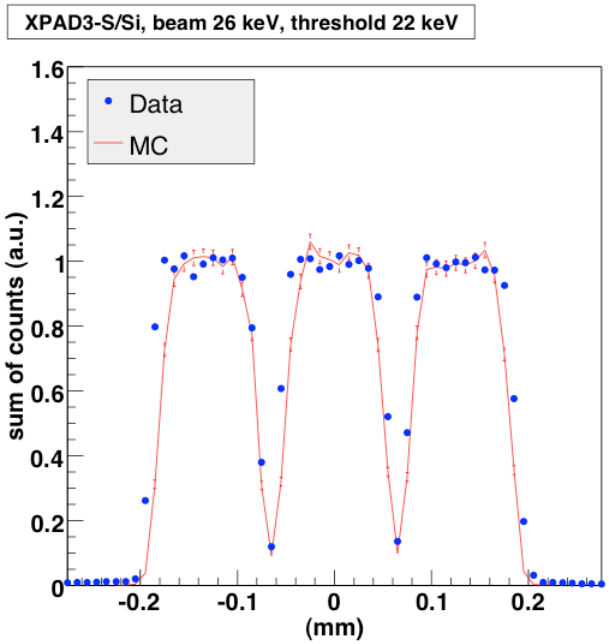
$eff_{cs} = k\,(E_0/2-E_{th})/E_0$



10 keV threshold



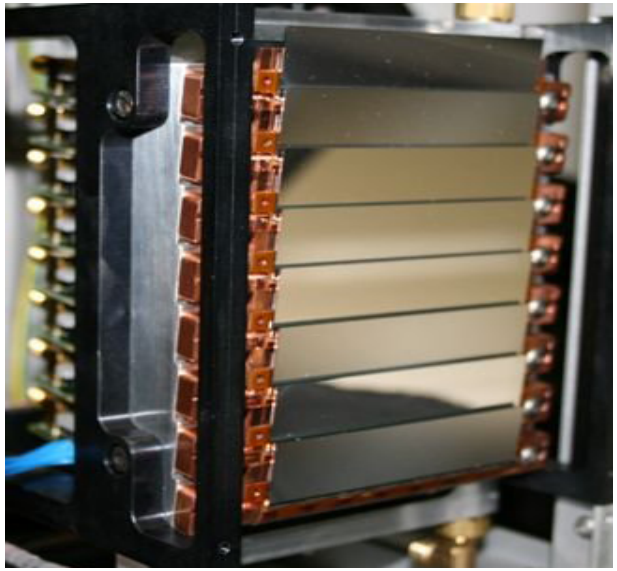
14 keV threshold



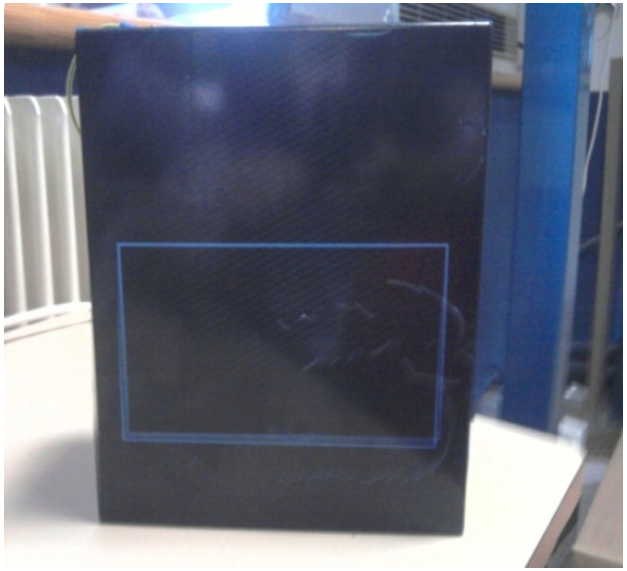
22 keV threshold

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

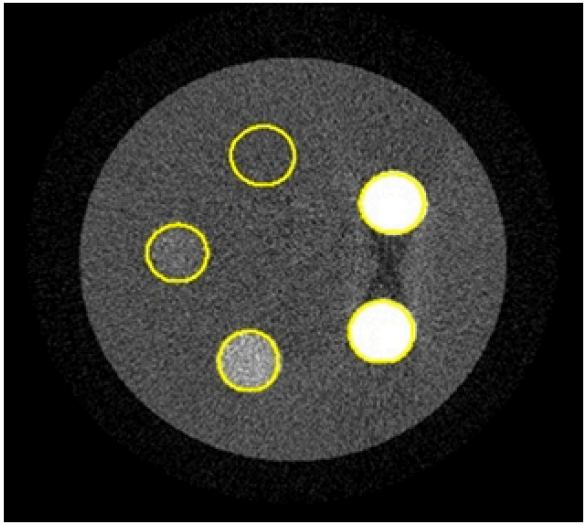
X-ray photon counting versus “charge integration” CBCT

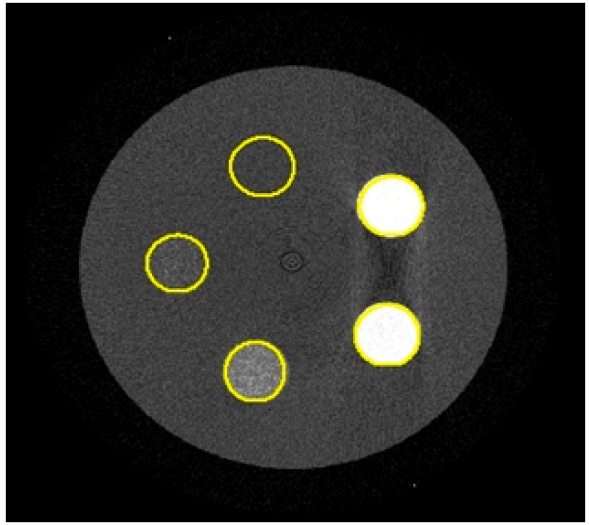


XPAD3

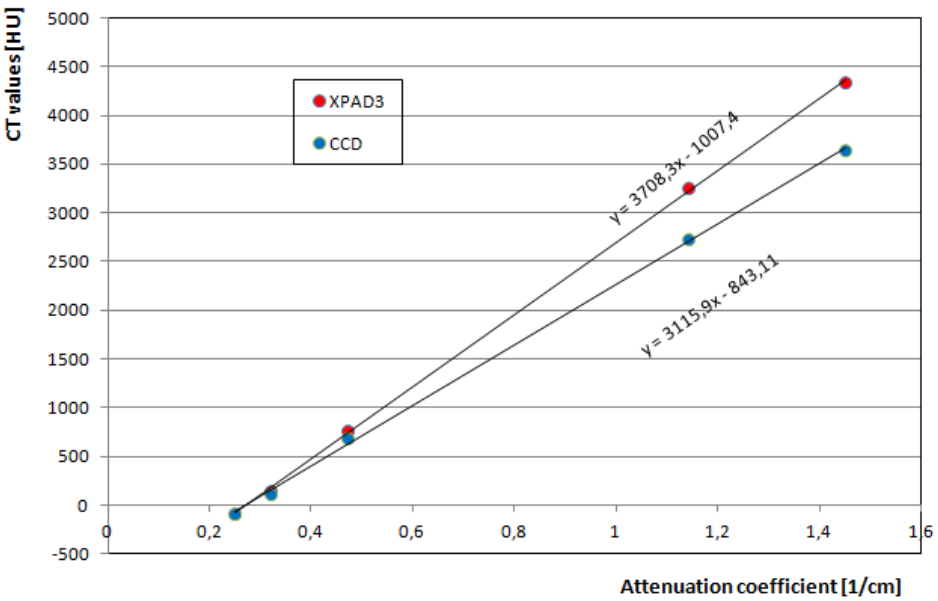


CCD

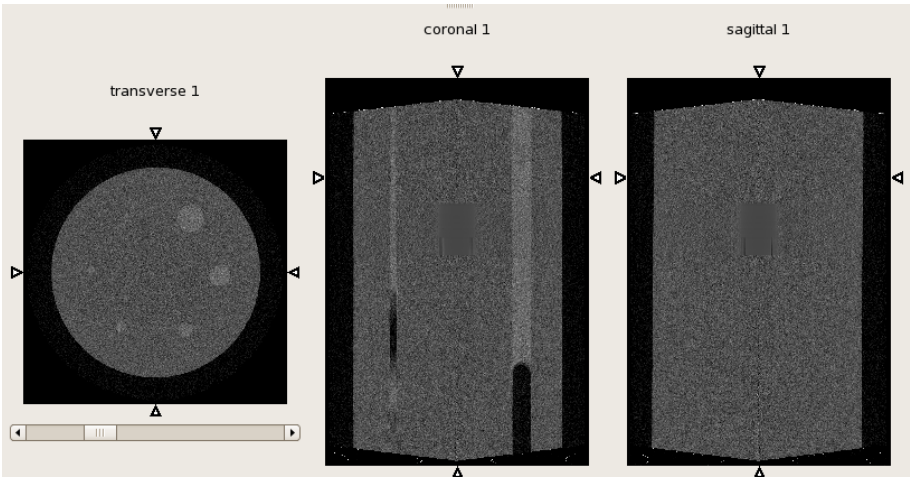


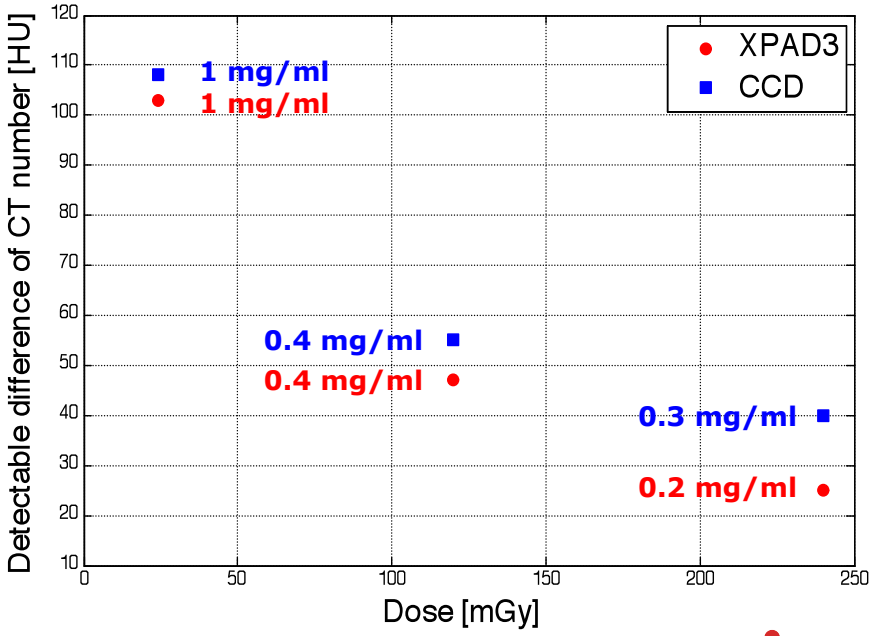


X-ray photon counting versus "charge integration" CBCT



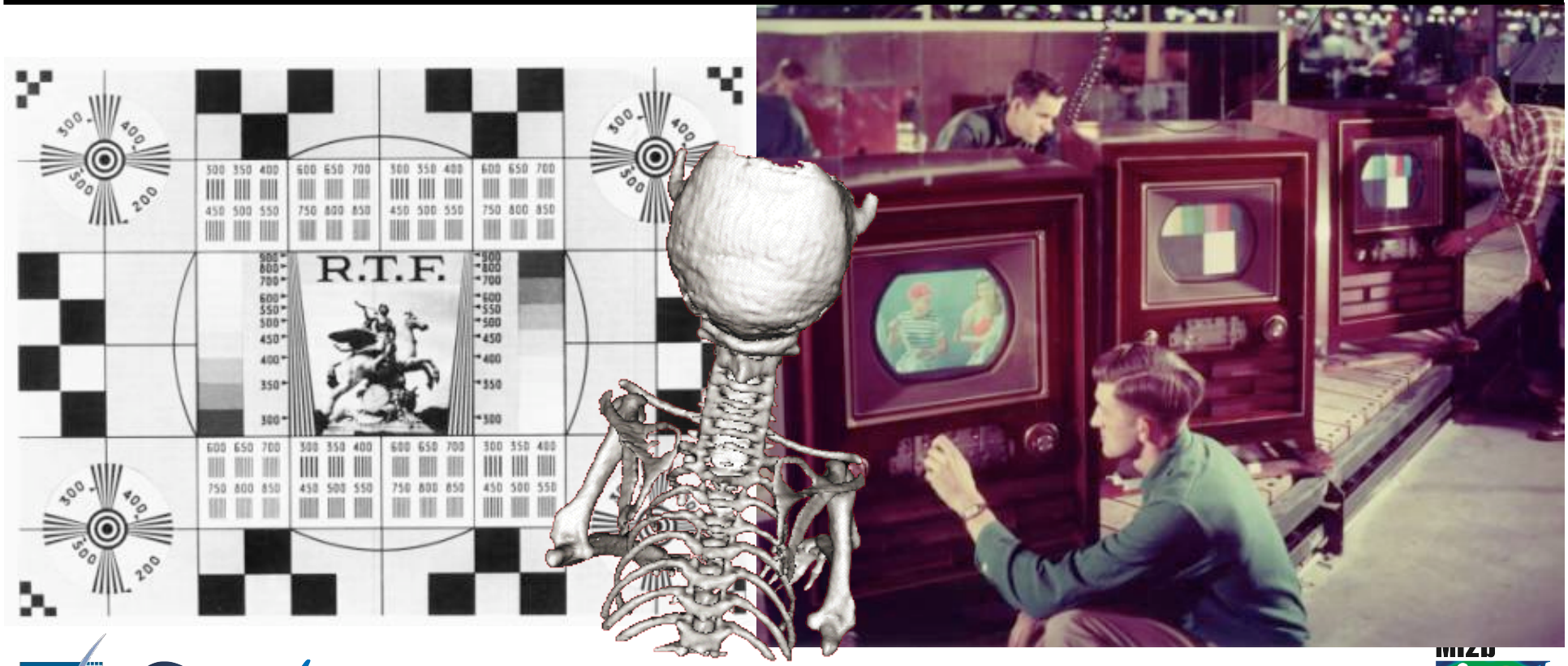
Micro-CT phantom QRM-HA





Ouamara *et al.*, in Proc. of IEEE NSS/MIC 2012

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



CPPM · CNRS IN2P3 Les deux infinis · Aix*Marseille université

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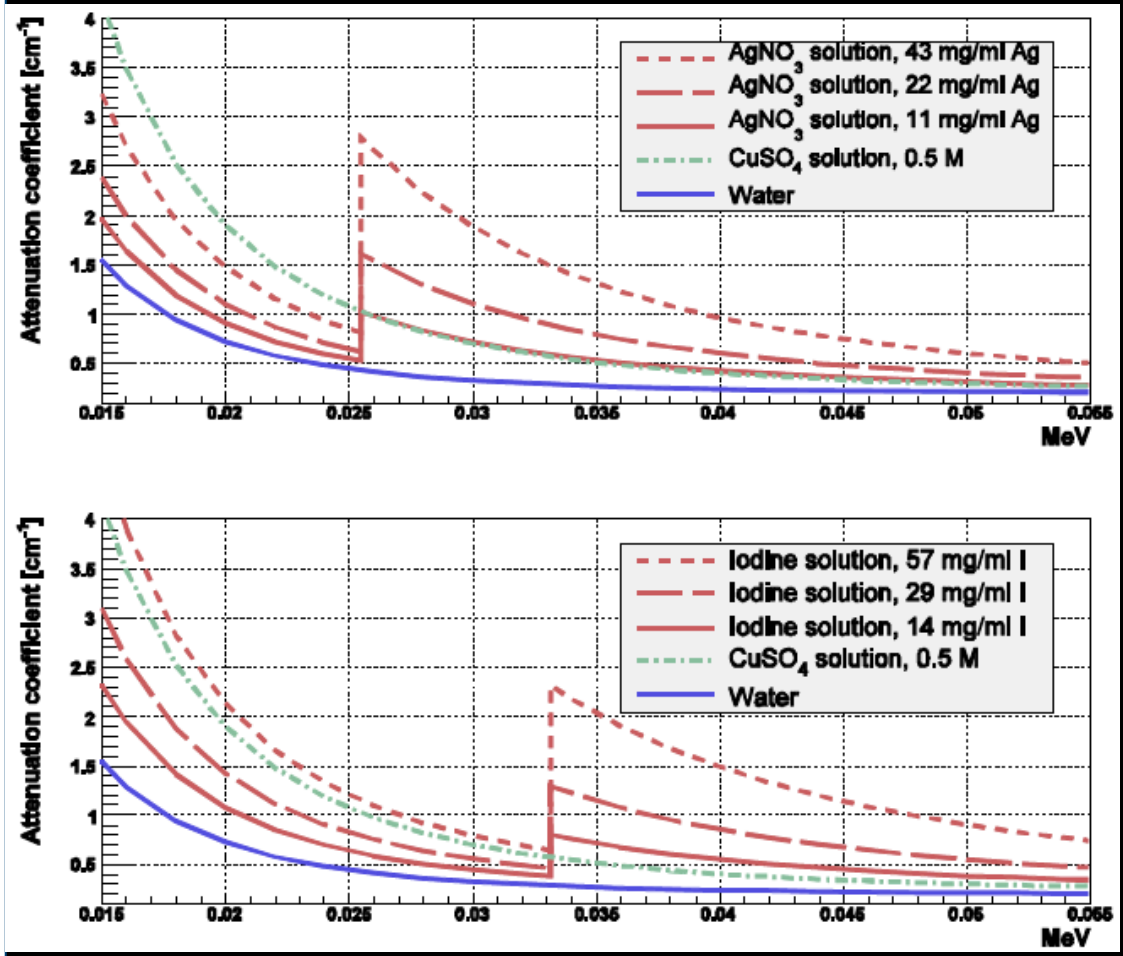
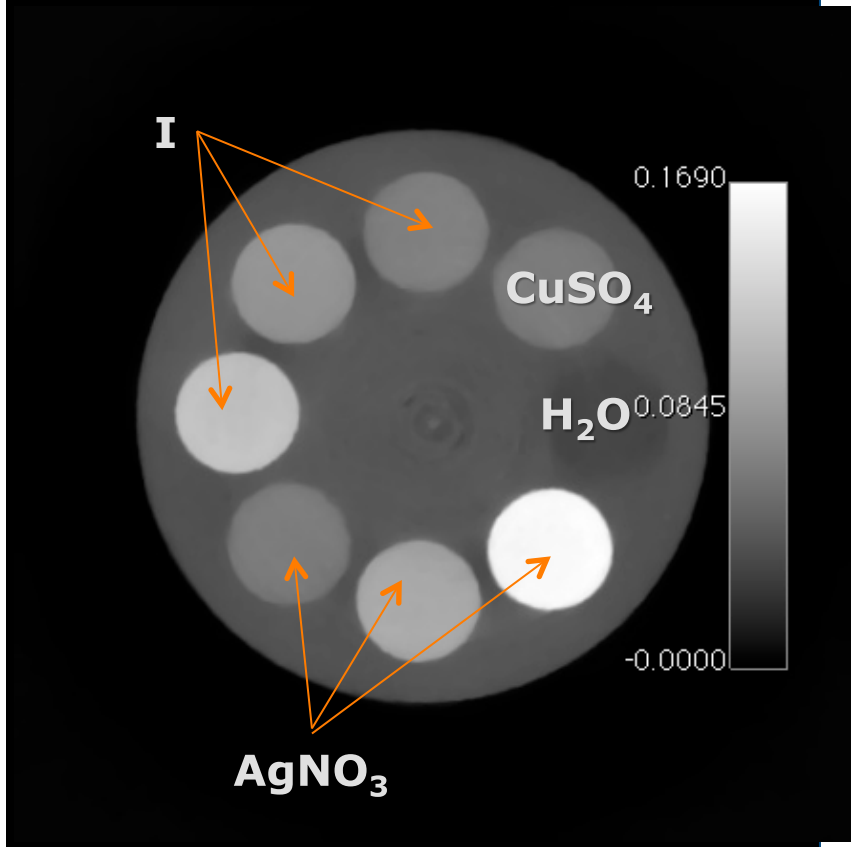
MI2B

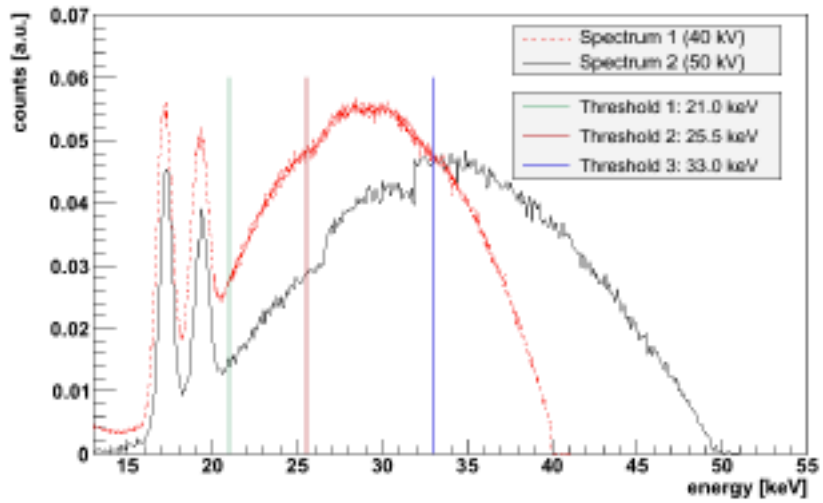
X-ray spectral CT using XPAD3





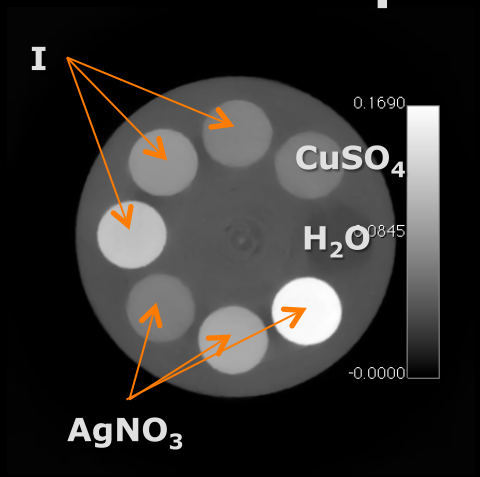
F. Cassol et al. Proc. IEEE NSS/MIC 2011

X-ray spectral CT using XPAD3

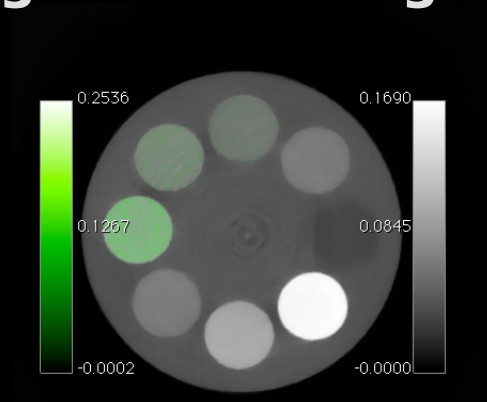


Silver	Iodine
$E_{1Ag} = 21$ keV	$E_{1I} = 25.5$ keV
$E_{2Ag} = 25.5$ keV	$E_{2I} = 33$ keV
$E_{3Ag} = 33$ keV	$E_{3I} = 40/50$ keV

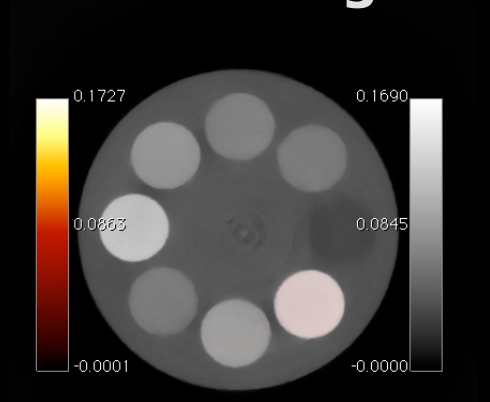
TDM classique



Imagerie au K-edge de l'iode et de l'argent



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

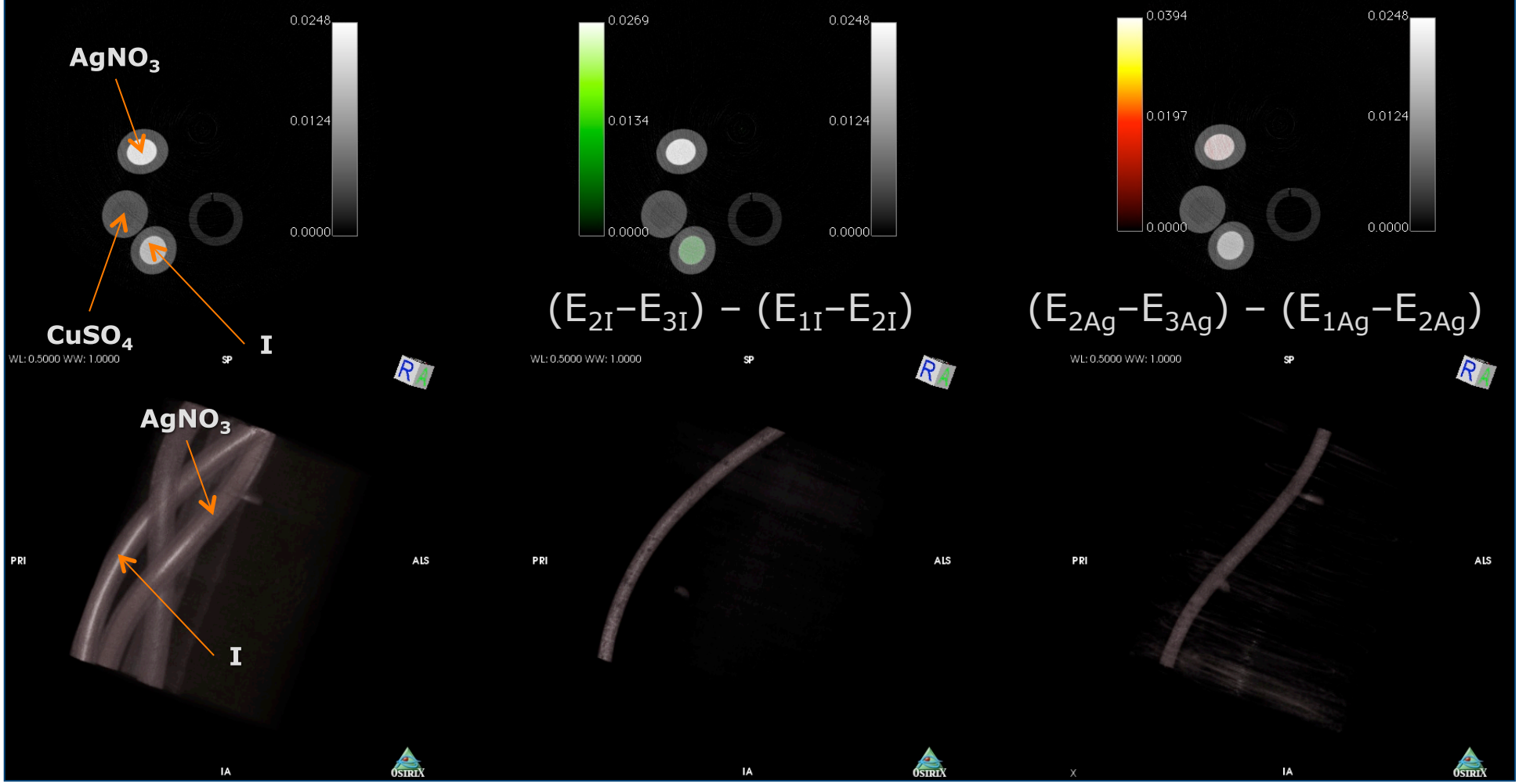


$(E_{2Ag}-E_{3Ag}) - (E_{1Ag}-E_{2Ag})$

X-ray spectral CT using XPAD3

TDM classique

Imagerie au K-edge de l'iode et de l'argent



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

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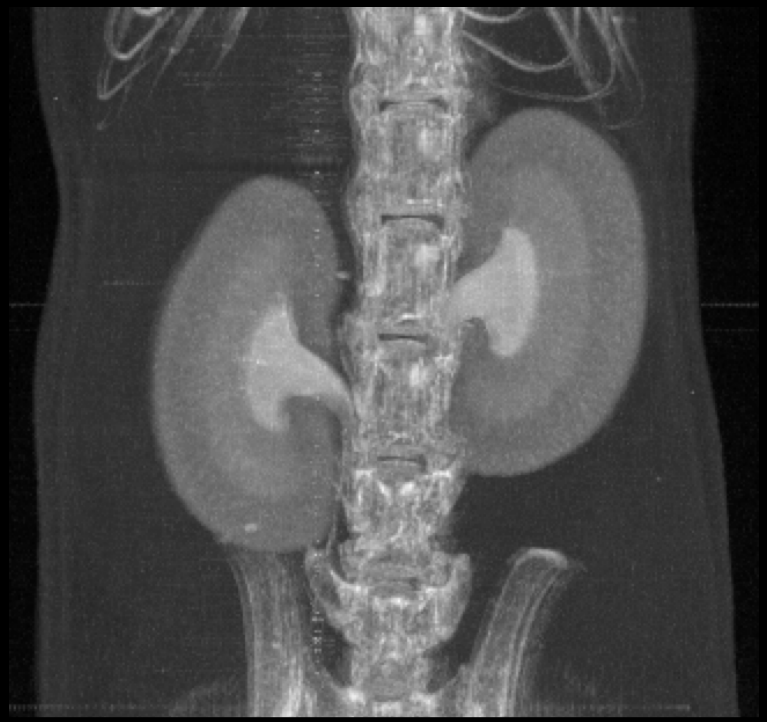
X-ray spectral CT using XPAD3

TDM classique

Maxixmum intensity projection



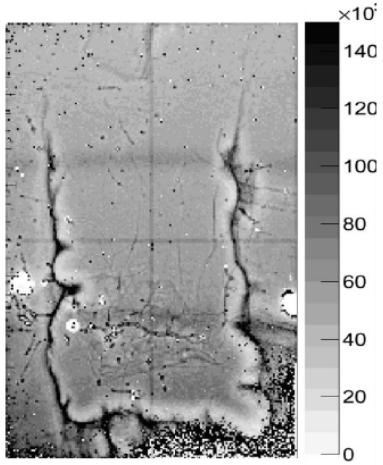
- Injection de 200 µL d'ioméron
- Tube à anode de molybdène
- 50 kVp, 30 W

Imagerie au K-edge de l'iode

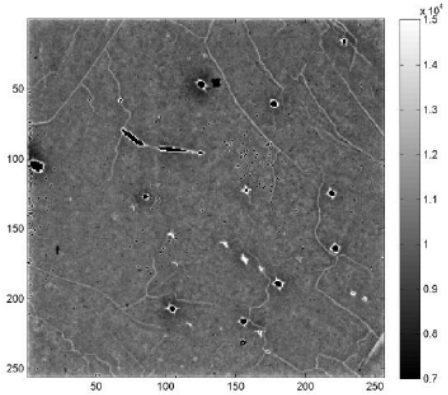
Maxixmum intensity projection

- Filtre 100 µm Cu
- Temps d'exposition 5 s/images
- 360 projections

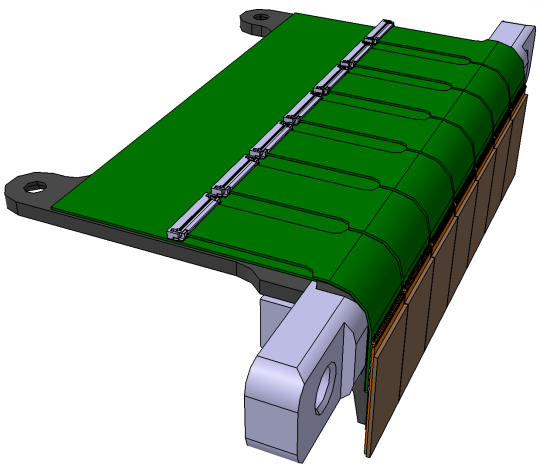
ChiPSpeCT & CALIPSO: XPAD3-2/CdTe camera

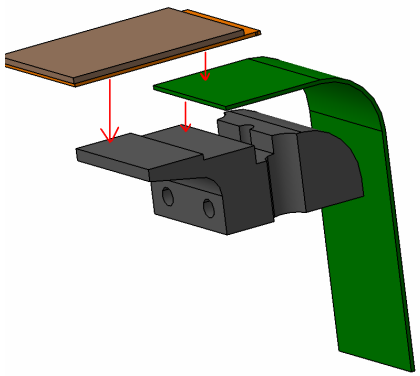


XPAD3 Quad



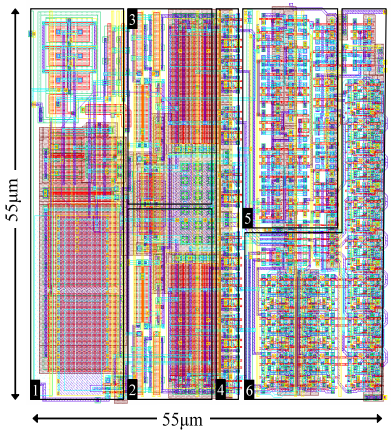
Medipix II Quad



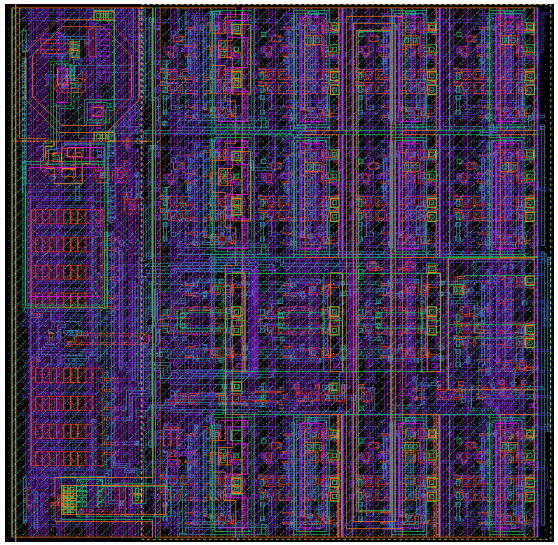


- HighZpad (FP7 ELISA)
  - « Survey » de l'état de l'art en matière de capteurs à Z élevé et des moyens de les hybrider sur des circuits pixel pour obtenir des capteurs de la plus grande dimension possible
  - 3 circuits pixel considérés (Medipix 2, Pilatus, XPAD3)
  - Un « hybrideur » : XIE, techno 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

Concurrent Hybrid Pixel designs



- MEDIPIX @ CERN
- PILATUS and EIGER @ PSI (Switzerland)
- XPAD3 @ CPPM/IN2P3 (France)



	Num. of pixels	Pixel size $[\mu m^2]$	Count rate $[ph/px/s]$	Counter depth	Readout time	Energy range $[keV]$	CMOS techn. $[\mu m]$
PILATUS II	60×97 $5'820$	172×172	2×10^6	20 bits	2.85 ms	3-30	0.25
EIGER	256×256 $65'536$	75×75	16×10^6	12 bits (4, 8, 12 mode)	85 μs 8-bit mode	-	0.25
MEDIPIX2	256×256 $65'536$	55×55	10^6	13 bits	8.5 ms in serial 266 μs in parallel	5-300	0.25
XPAD3	80×120 $9'600$	130×130	10^6	12 bits + OVF	1 ms	5-35	0.25

MEDIPIX2 Collaboration

- U INFN Cagliari
- CEA-LIST Saclay
- CERN Genève
- U Erlangen
- ESRF Grenoble
- U Freiburg
- U Glasgow
- IFAE Barcelona
- Mitthoegskolan
- MRC-LMB Cambridge
- U INFN Napoli
- NIKHEF Amsterdam
- U INFN Pisa
- FZU CAS Prague
- IEAP CTU in Prague
- SSL Berkeley

http://medipix.web.cern.ch/MEDIPIX/

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Spin-off activity on Hybrid Pixels

2003 — DxRay — www.dxray.com

2006 — DECTRIS® — www.dectris.com

2010 — imXPAD — www.imxpad.com

2011 — PiXirad (Chromatic Photon Counting) — pixirad.pi.infn.it

2006 — XRAY IMATEK (Pixelated X-Ray Detectors) — www.xray-imatek.com

2011 — AMSTERDAM SCIENTIFIC INSTRUMENTS — www.amscins.com

FUNCTIONS / APPLICATIONS	Crystallography Laboratories	Crystallography Synchrotron	Preclinical Scanner	Clinical Angiography	Clinical Scanner	Waste Sorting	Homeland security
Noise suppression	X	XX	X	X	X	X	X
Energy selection	X		XX	XX	XX	XX	XX
Dose reduction			XX	XXX	XXX		X
Large dynamic range	XX	XXX	X	X	X		X
No readout dead time	X	X					
On the fly readout		X		X		XX	
Frame rate = 1 kHz		X	X	X	X		X
Accurate time window		XX					

2003 — kromek (detect image identify) — www.kromek.com

2007 — mars (Medipix All Resolution System) — www.marsbioimaging.com

2012 — ADVACAM (IMAGING THE UNSEEN) — www.advacam.com

2011 — XIE (X-RAY IMAGING EUROPE) — www.xi-europe.com

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Mi2b