University of Glasgow

CERN

Hybrid Pixel Detectors

Trends for novel imaging techniques

Overview

Where we've come from

Diagnostic CT

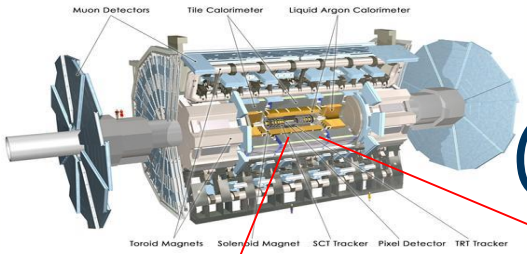
Medipix

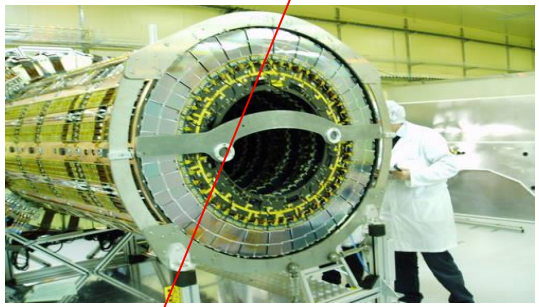
New Tricks

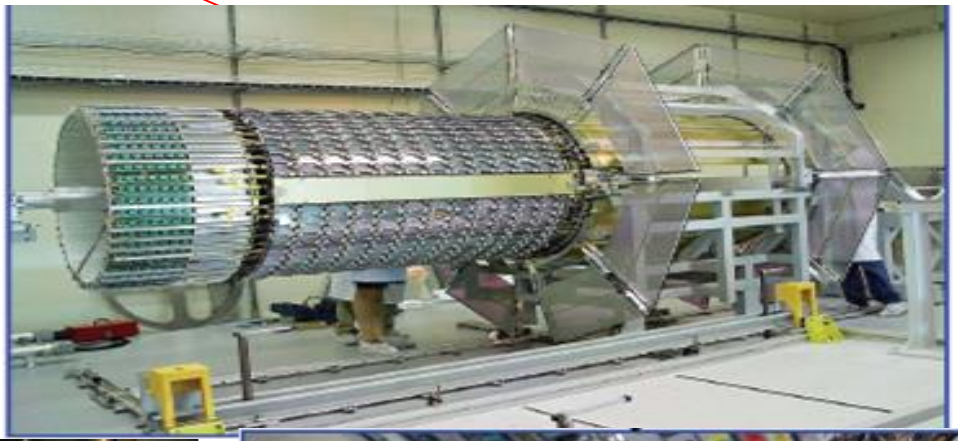
Where they're going (medicine)

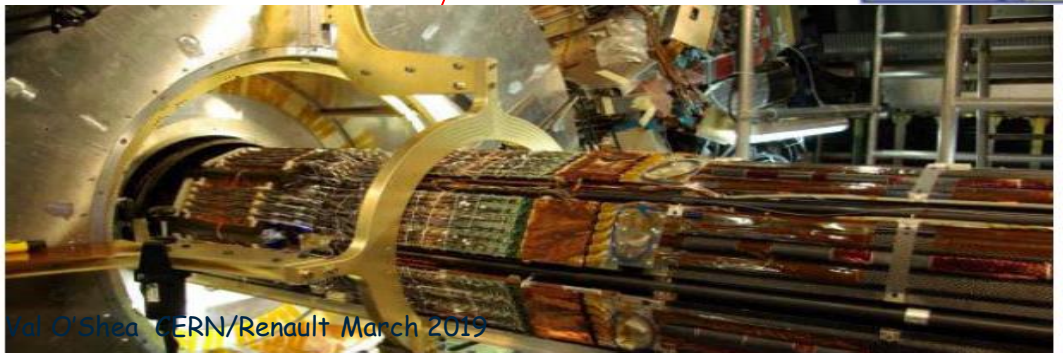
Where we're going (technology)

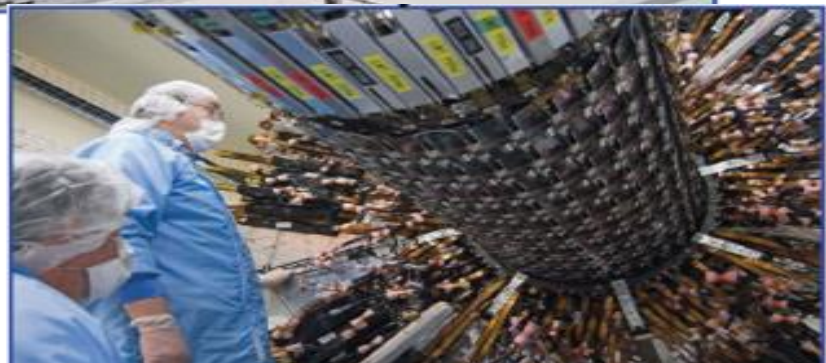
ATLAS SCT
(61m^2 of silicon sensors)



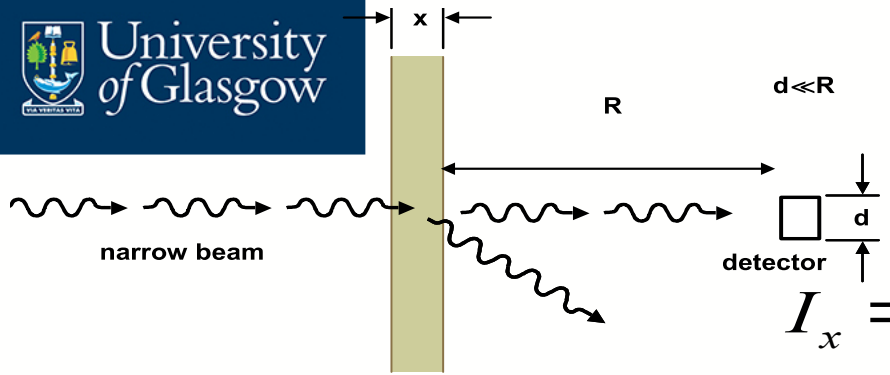






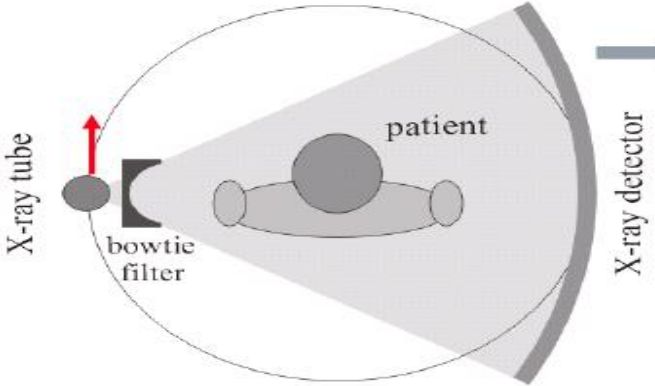


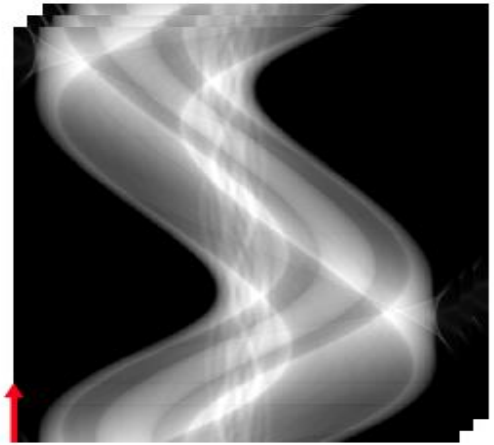
Diagnostic CT



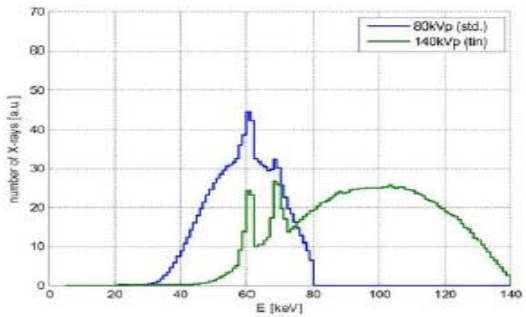
$$I_x = I_0 e^{-\mu x}$$

$$\mu = t + s + k$$





Dual-Source

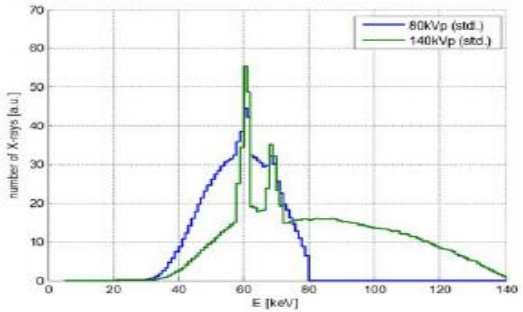


Well separated spectra due to filtration

Careful dose regulation needed

Geometrical registration is an issue

Fast kV-switching

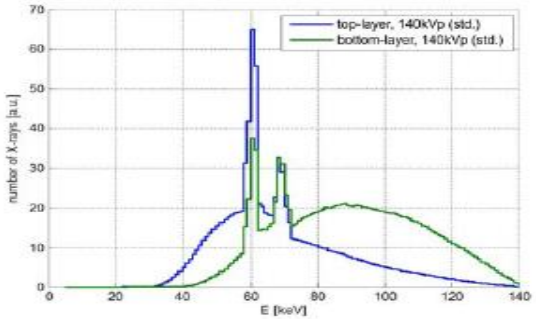


Single source device

Dose regulation is an issue

No filtration – spectral overlap
Sampling gaps

Dual-Layer



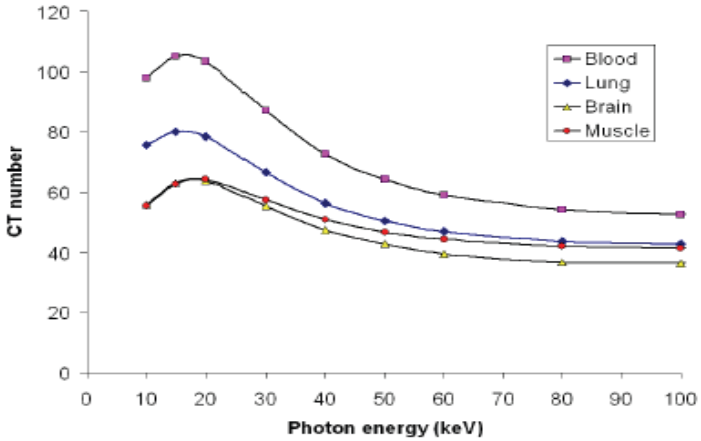
Single source device

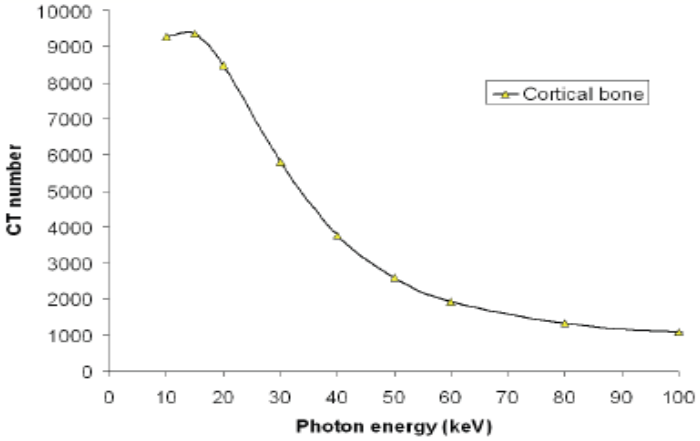
Data sets perfectly matched

Complex detector design

Poor spectral separation

Variation with Energy





$$CT_{number} = \frac{\mu_{material} - \mu_{water}}{\mu_{water}} x1000$$

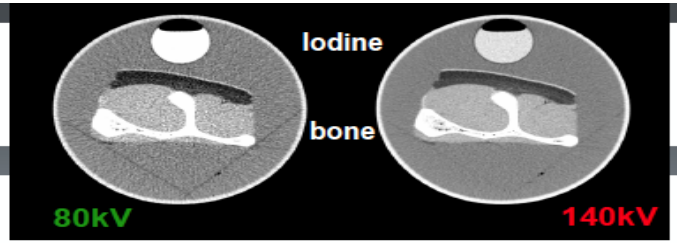
$$I_x = I_0 e^{-m(E)x}$$

$$m_{photo} \approx \frac{Z^{4-5}}{E^3}$$

Ideally, when comparing the ratio density of tumour tissue, bone density for implants etc., an accuracy of better than ± 0.5 HU is desirable.

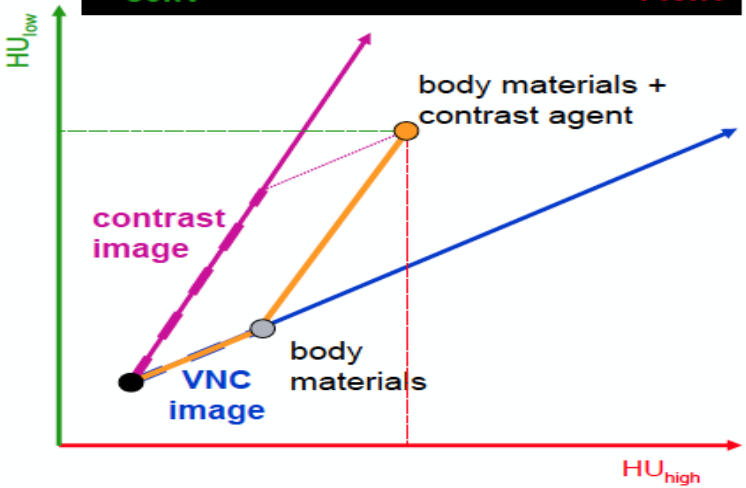
Dual Energy CT

Dual-Energy



Dual-Energy Principle

- 2 scans with 2 different spectra
  → 2-dimensional HU space:
  HU_{low} vs. HU_{high} - -
- Coordinate transformations allow to change bases:
  Photoelectric vs. Compton
  Iodine vs. bone
  Contrast vs. VNC - -
- External constraints needed for higher order material classification

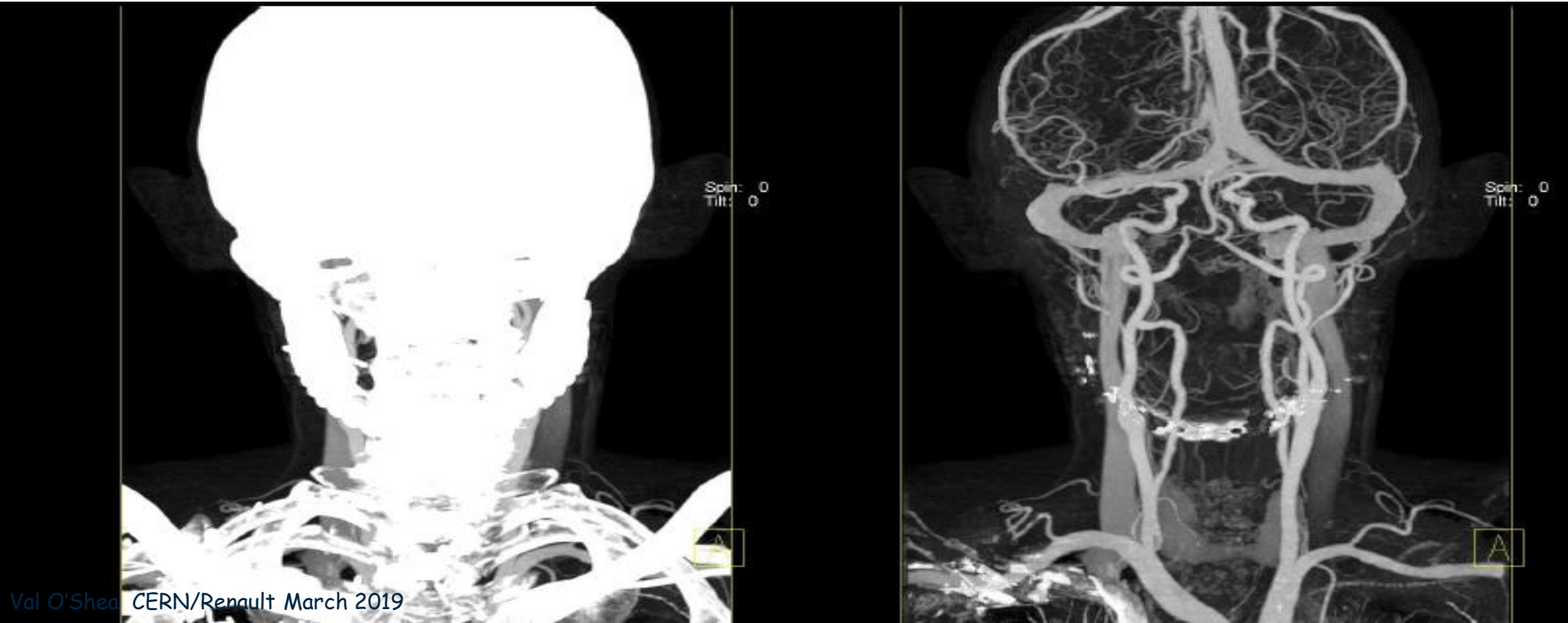


Clinical Applications

Bone removal, Iodine quantification, virtual non-contrast image (VNC), kidney-stone and gout characterization, pseudo-monoenergetic images, ...

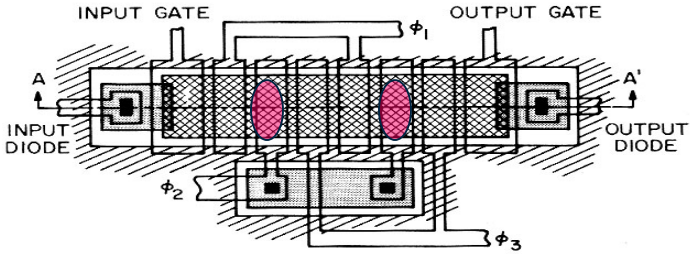
Why Dual Energy??

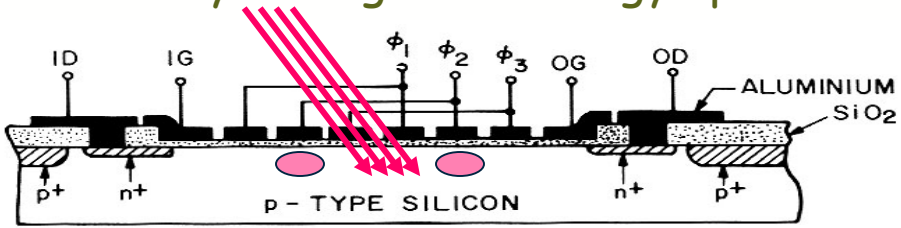
Bone Iodine separation - 'Bone removal'



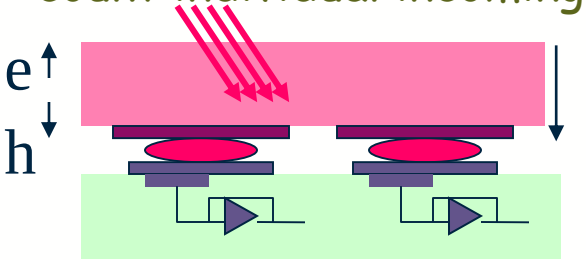
integration vs photon counting

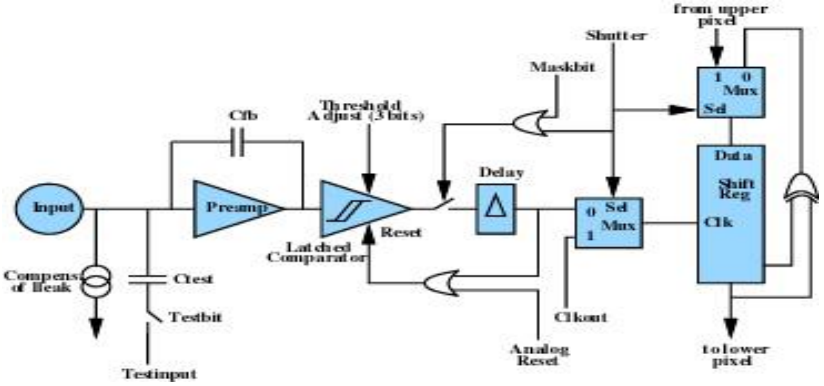
CCD system: charge integration, affected by leakage and energy spread



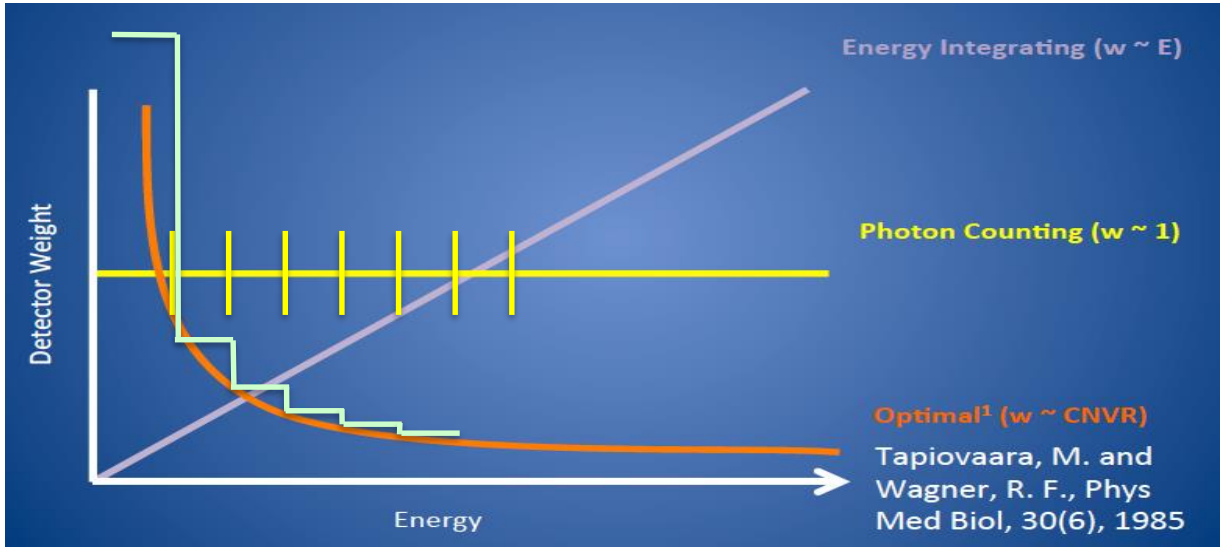


count individual incoming photons, no leakage effects





Spectral CT – Energy Weighting

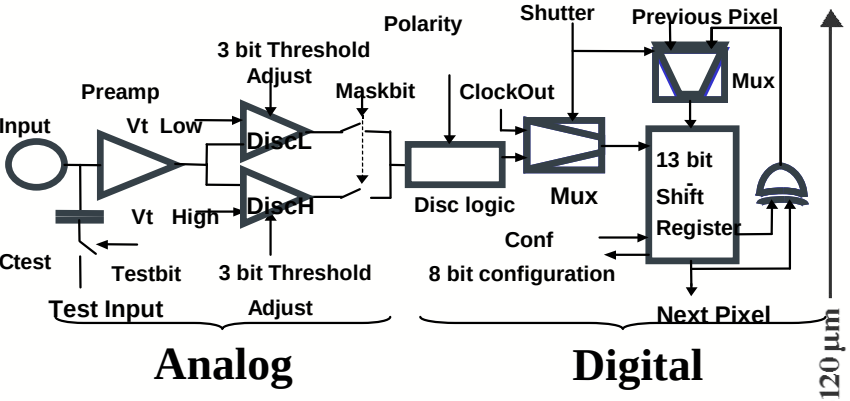


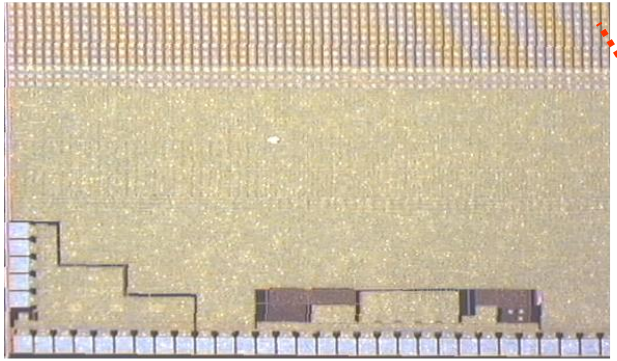
$$I_x = I_0 e^{-\mu(E)x}$$

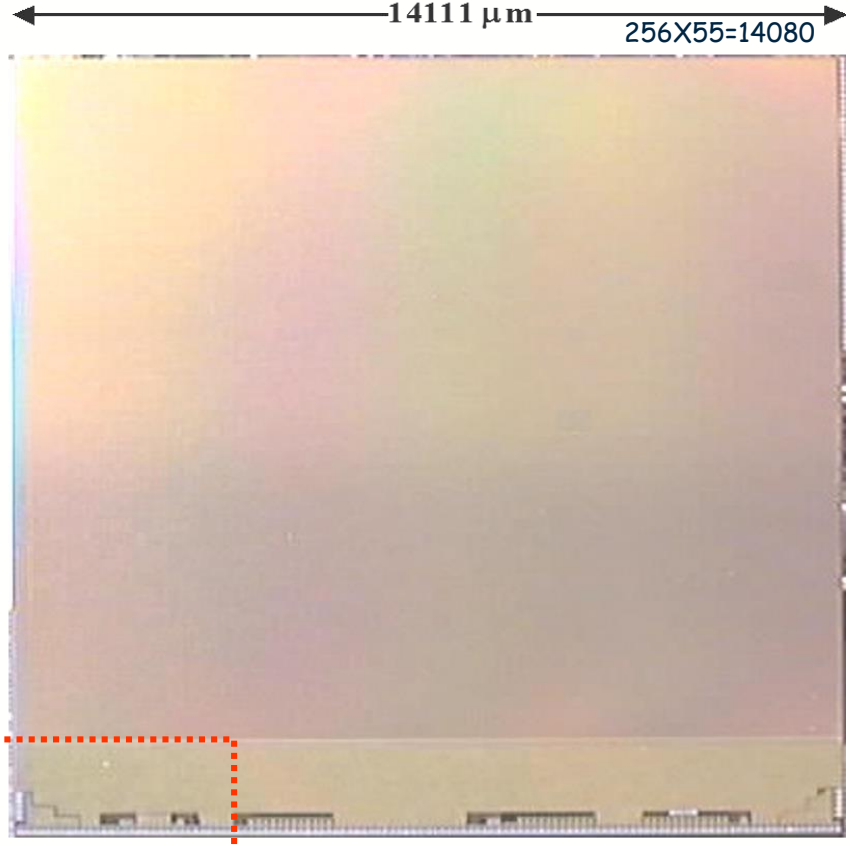
$$\mu_{photo} \gg \frac{Z^{4-5}}{E^3}$$

Simulations show that ~ 35% reduction in dose for equivalent image quality can be achieved

Medipix 2 ASIC







Bump Bonding

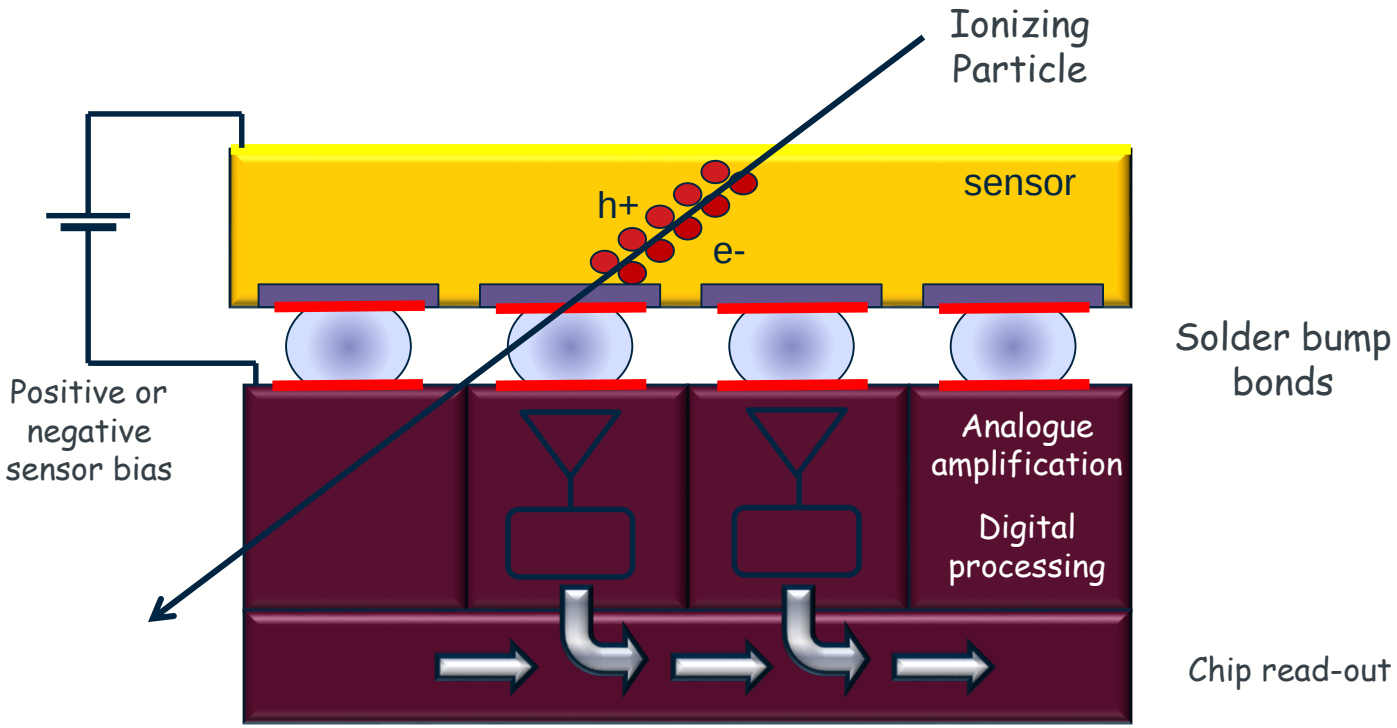
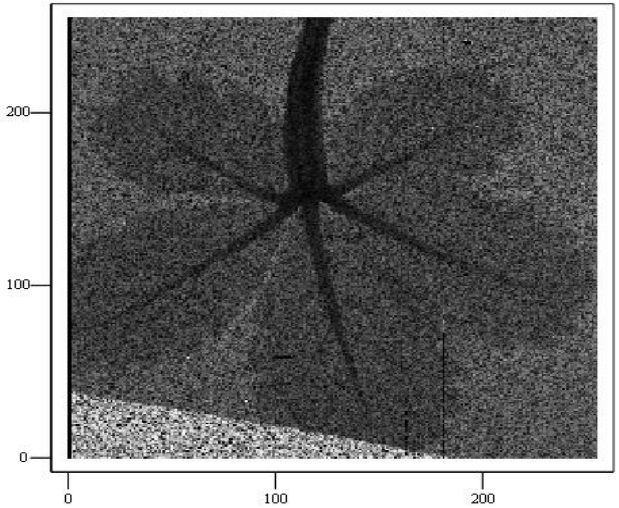
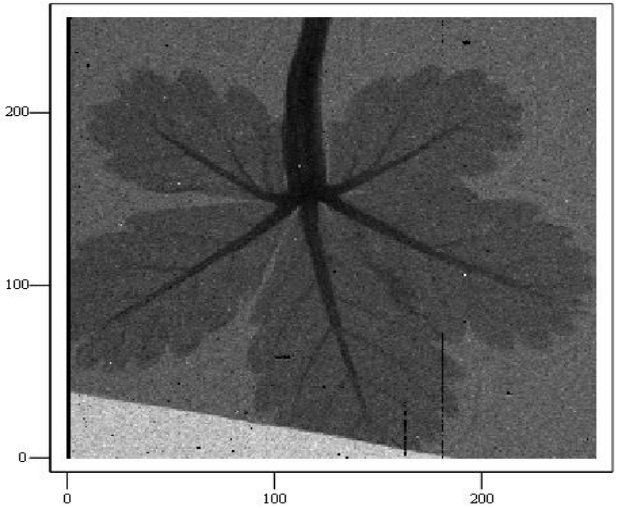


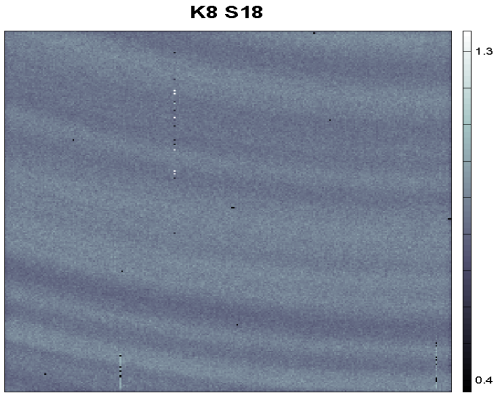
Image enhancement



Uncorrected image



Corrected image

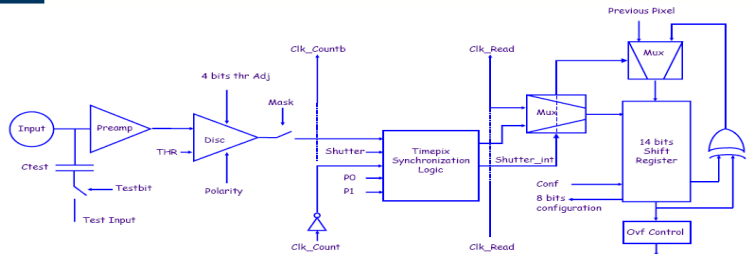


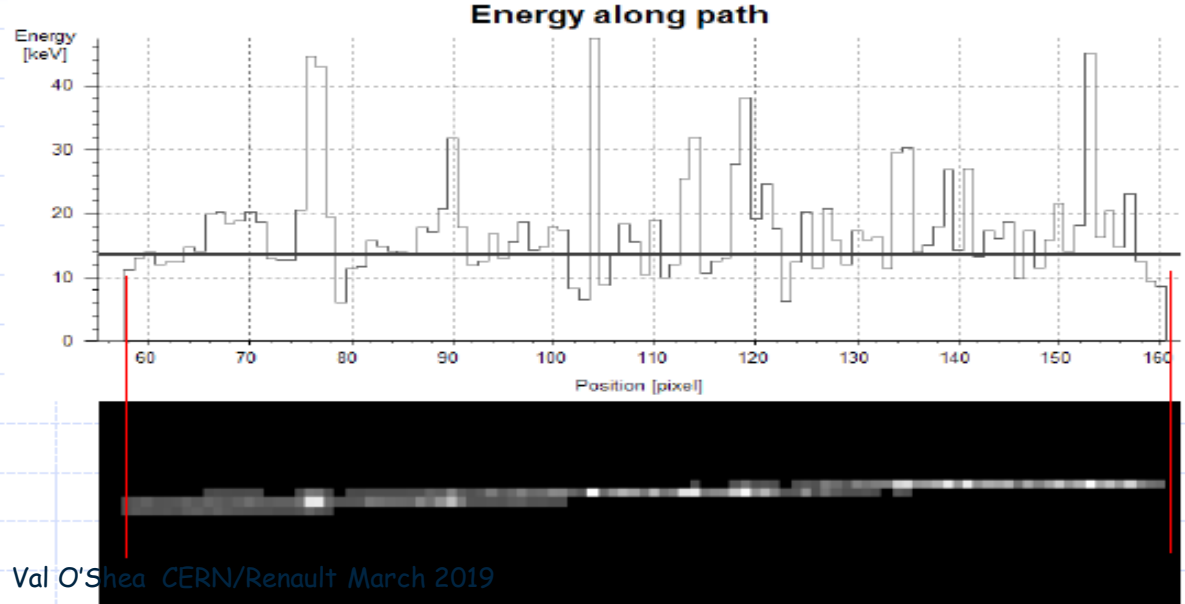
- Original image take during 10min with Fe^{55}
- 7 flood field images (2 hours each) were taken in order to find a flat field correction matrix

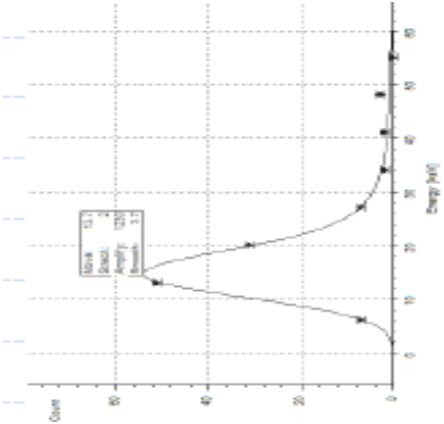
Timepix ASIC

Change discriminator to clock

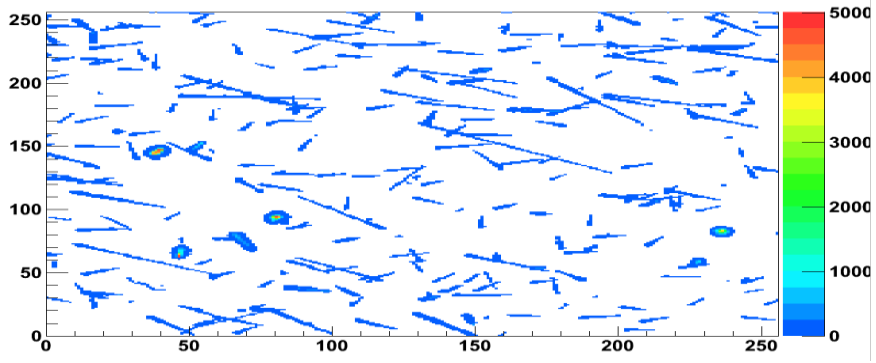
Use same config register
Can measure ToT
Can measure time to start/stop
Can photon count
Uses same ~ 500 transistors

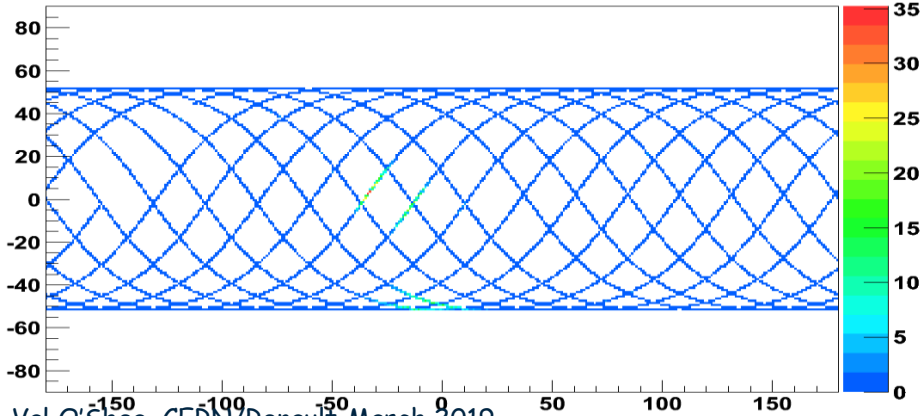


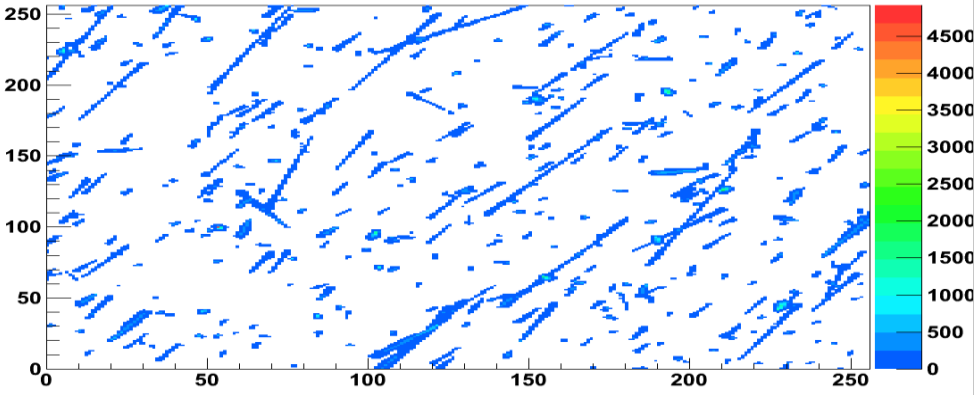




Dosimetry on ISS







Imaging capability

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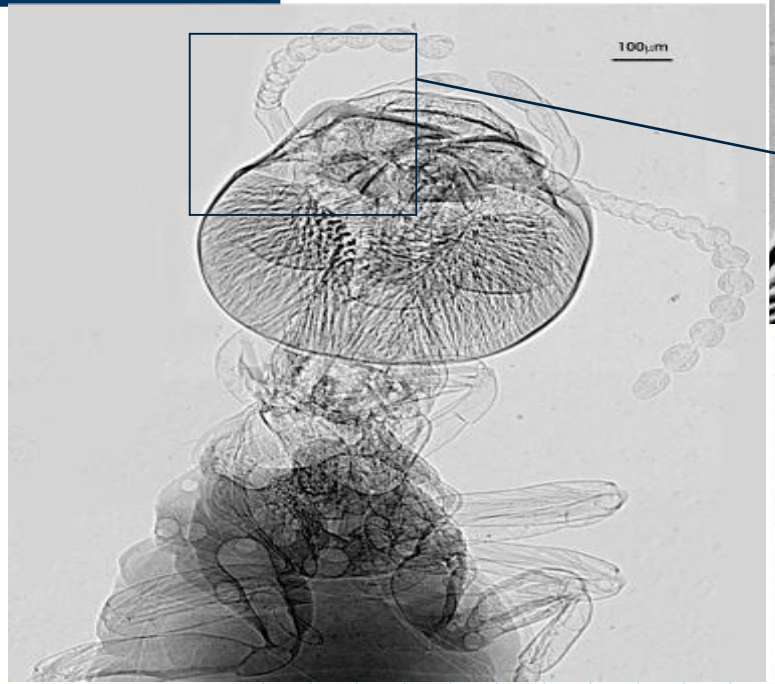

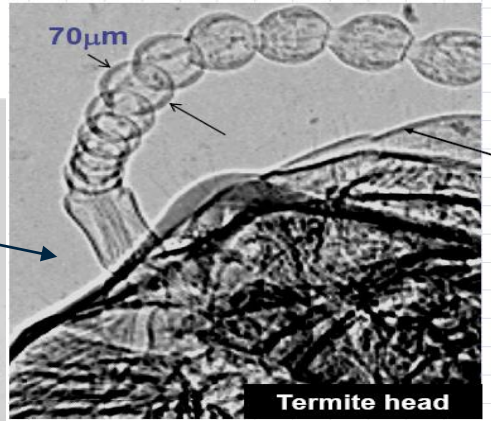

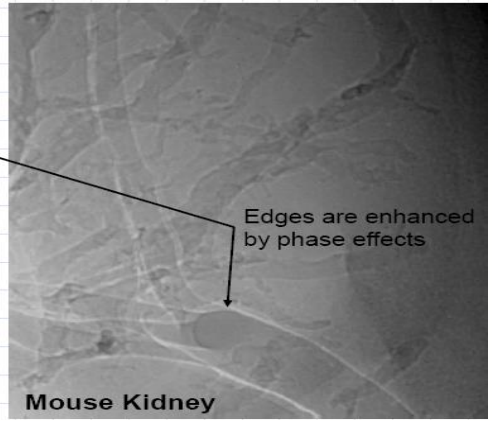

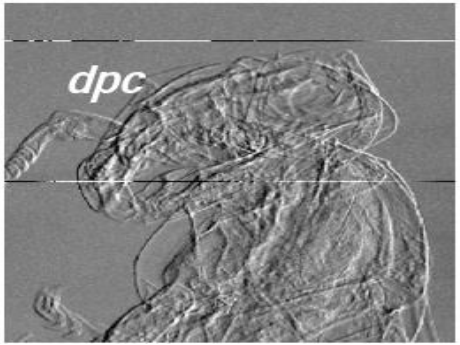

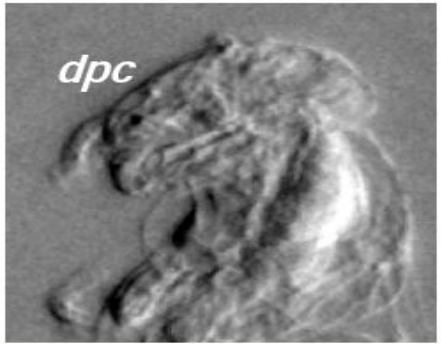

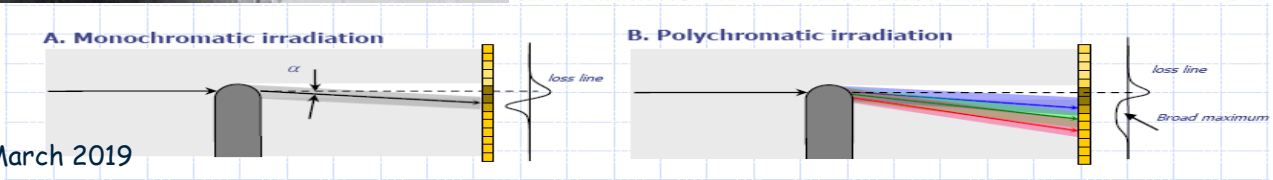

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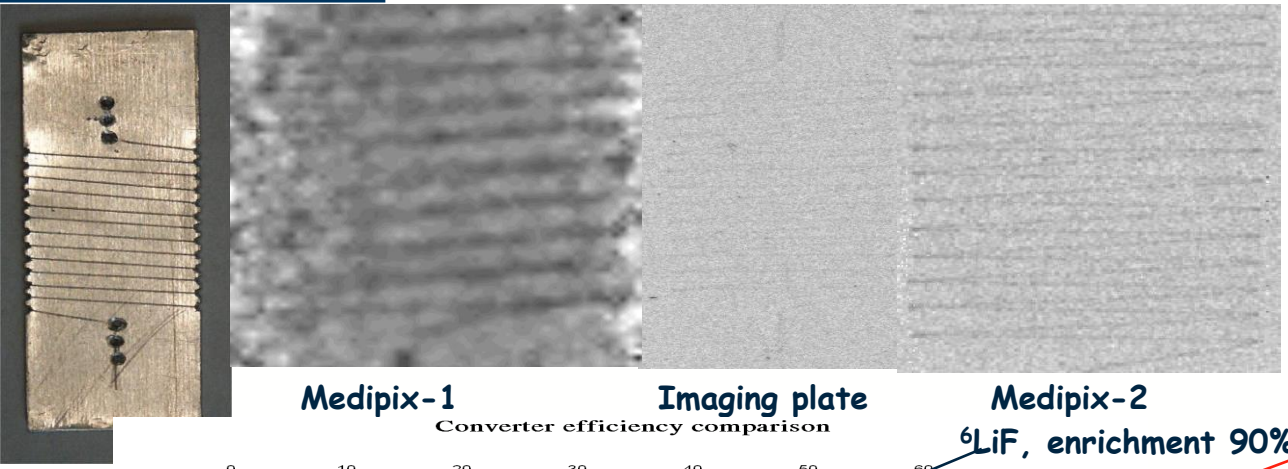
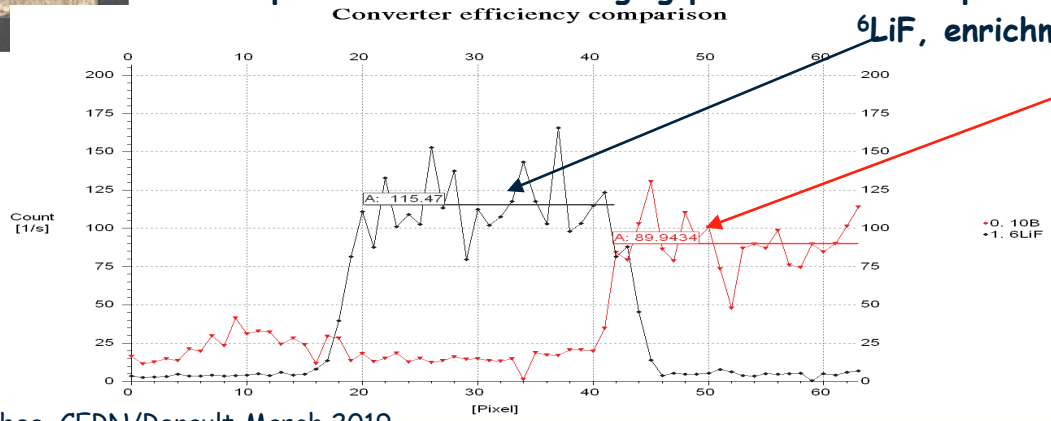
Nylon Fishing line (0.1 mm)

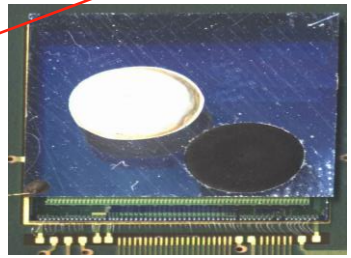


Medipix-1 Imaging plate Medipix-2

Amorphous ^{10}B, naturally occurring 80%

^{6}LiF, enrichment 90%





Ratio between ^{6}LiF efficiency and ^{10}B is 1.28

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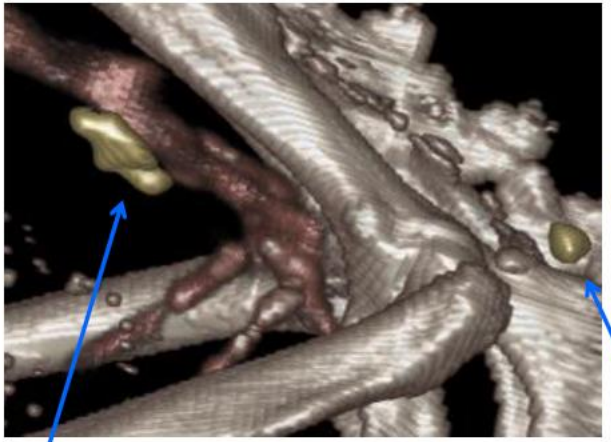
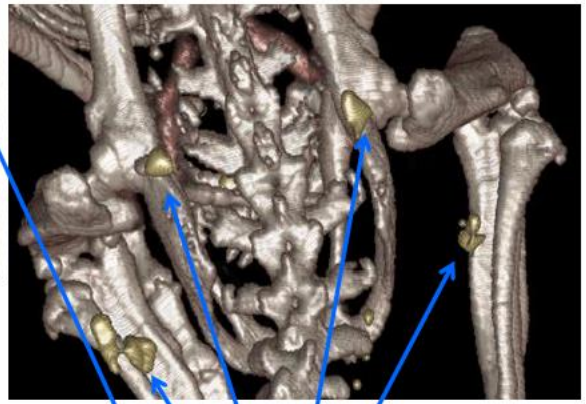
AU-HDL Macrophage-Imaging Spectral CT results



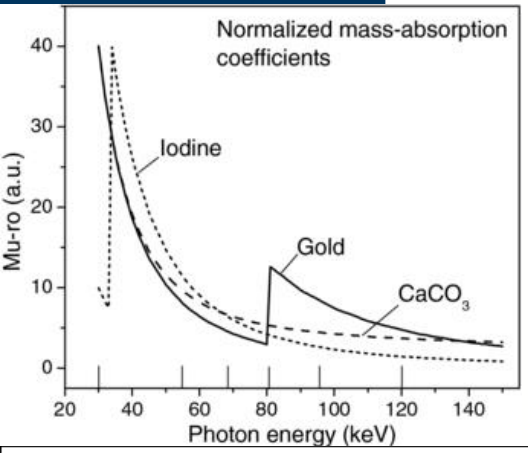


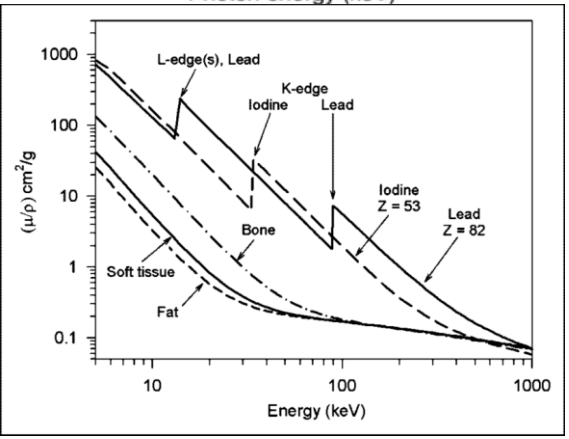
Aortic Bifurcation
"Vulnerable Plaque" detection
by Au-NP uptake of macrophages

Roessl et al. NIMA, *Nov. 2010*

Uptake in 4 lymphnodes

University of Glasgow

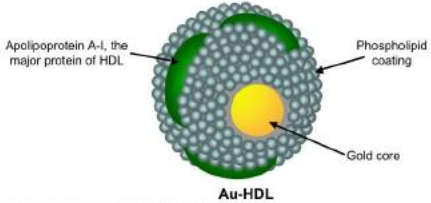


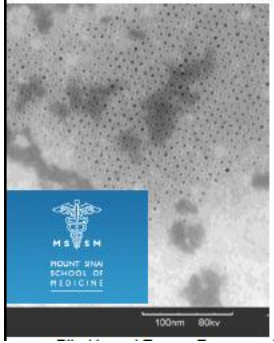


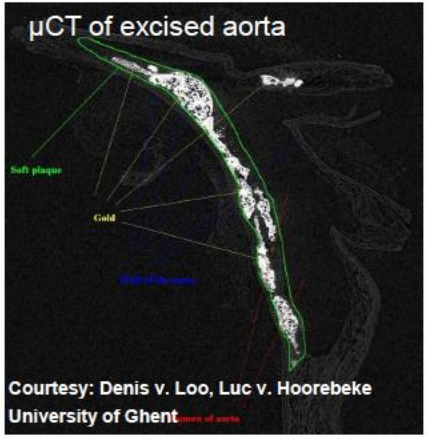
K-edge imaging of gold

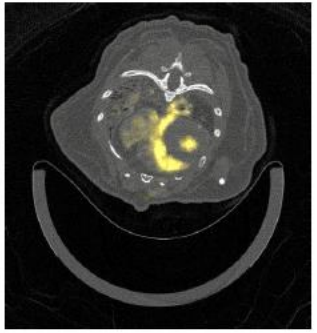
High-density lipoprotein (HDL)-coated gold nano-particles: Au-HDL

- Nano-particle being taken up by macrophages
- High risk atherosclerotic plaque has increased macrophage density
- Au-HDL is ~10 nm in diameter





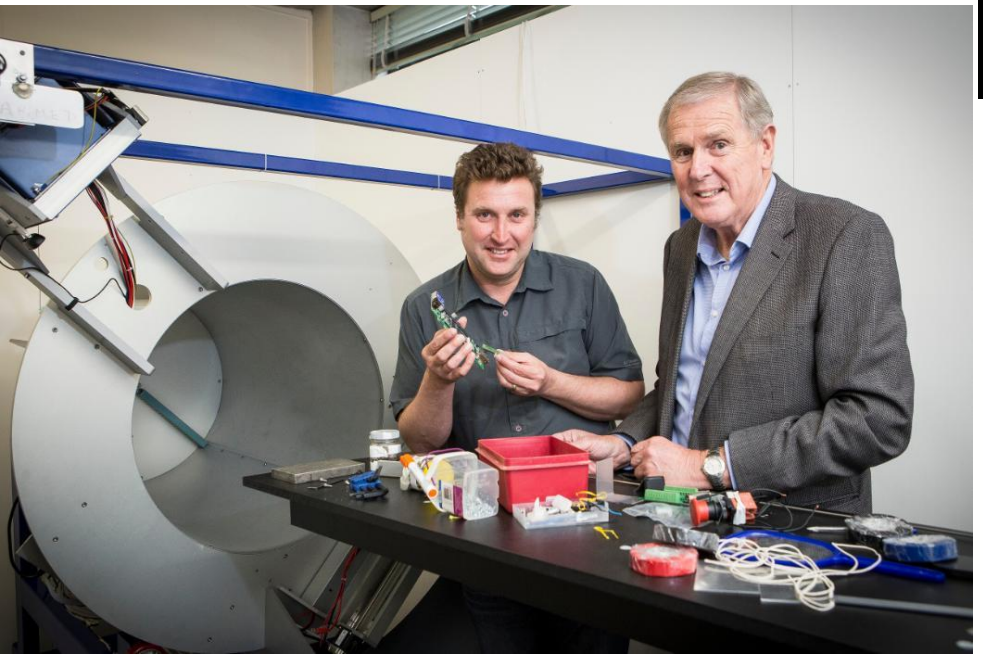


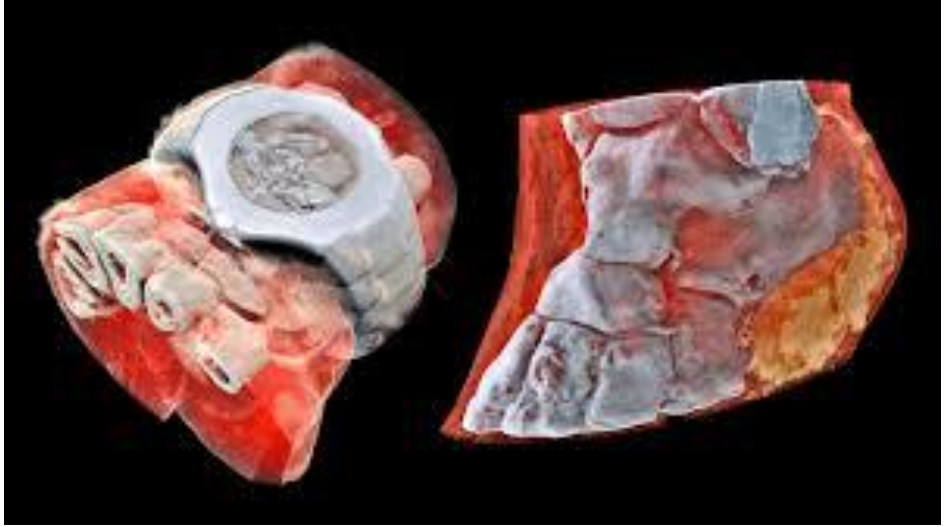


Lowest bin (25-34 keV) with Au-overlay

In collaboration with David Cormode, Willem Mulder and Zahi Fayad, Mount Sinai Medical School NY

University of Glasgow

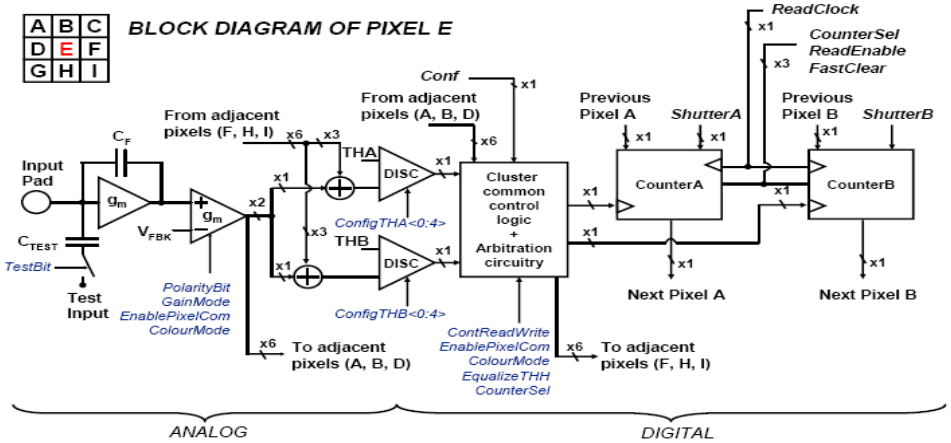




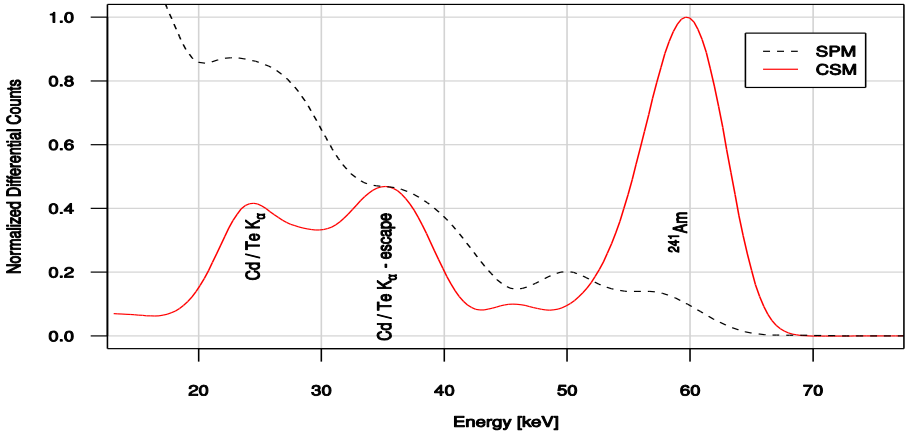
Mars Bioimaging small animal spectral CT scanner used to image live human tissue in trial – 2018. Scanner uses Medipix tehnology.

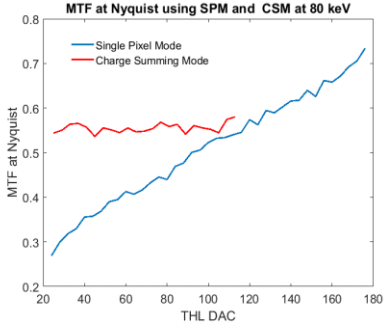
Medipix 3

- ~1400 transistors per pixel
- Simultaneous read/write
- Charge summing mode
- Colour mode



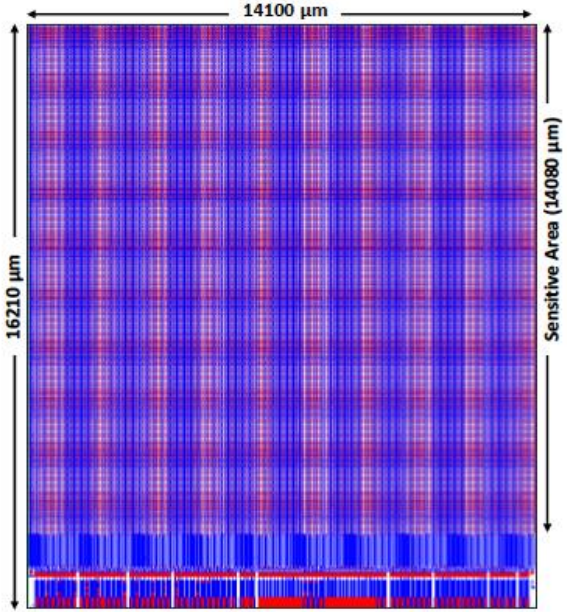
Charge sharing eliminated for 55 um pixels
TSVs for seamless tiling of large surfaces
Integration into small animal CT scanners



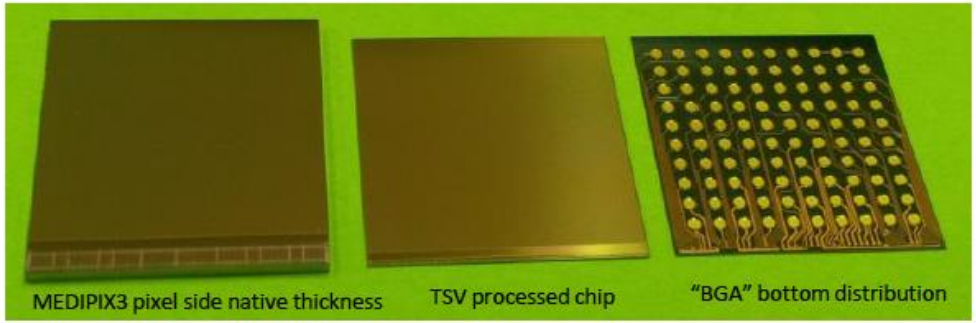


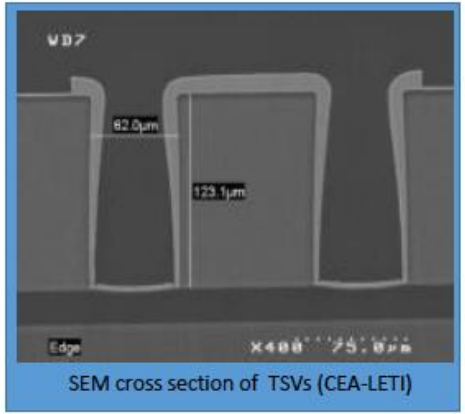
Timepix3 (2013)

Application	General Purpose particle tracking
Technology	IBM 130nm DM 4-1
Pixel size	55 x 55 μm^2
Pixel arrangement	256 x 256 (2x4 superpixels)
Acquisition modes	1) Time (TOA) AND Charge (TOT) 2) Time (TOA) 3) PC & integral charge (iTOT)
Readout Type	1) Data driven (Shutter-less) 2) Frame-based (Shutter)
Thresholds	1
Minimum threshold	> 500 e-
Time resolution (TOA)	1.562 ns
Energy Resolution (TOT)	~2 keV_{FWHM}
Power consumption	<1.5W @1.5 V
Floorplan	3 sides buttable and minimum periphery
TSVs possibility	YES. With 1.2mm periphery
Count Rate	Data-Driven: ~0.43 x 10^6 hits/mm^2/s Frame-based: 826 x 10^6 hits/mm^2/s
Output bandwidth	1 to 8 SLVS DDR @640Mbps each

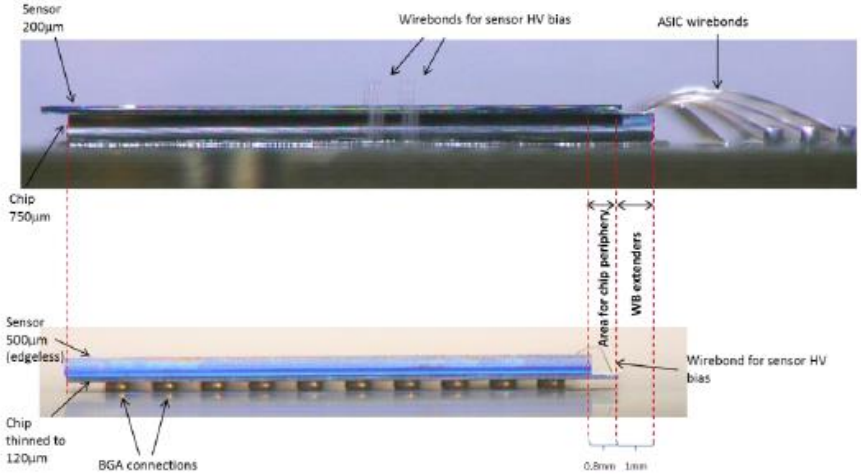


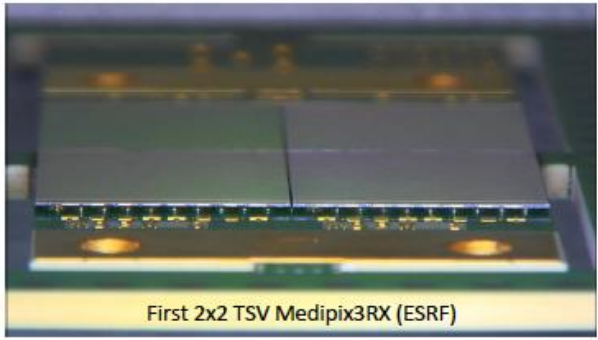
TSV Process



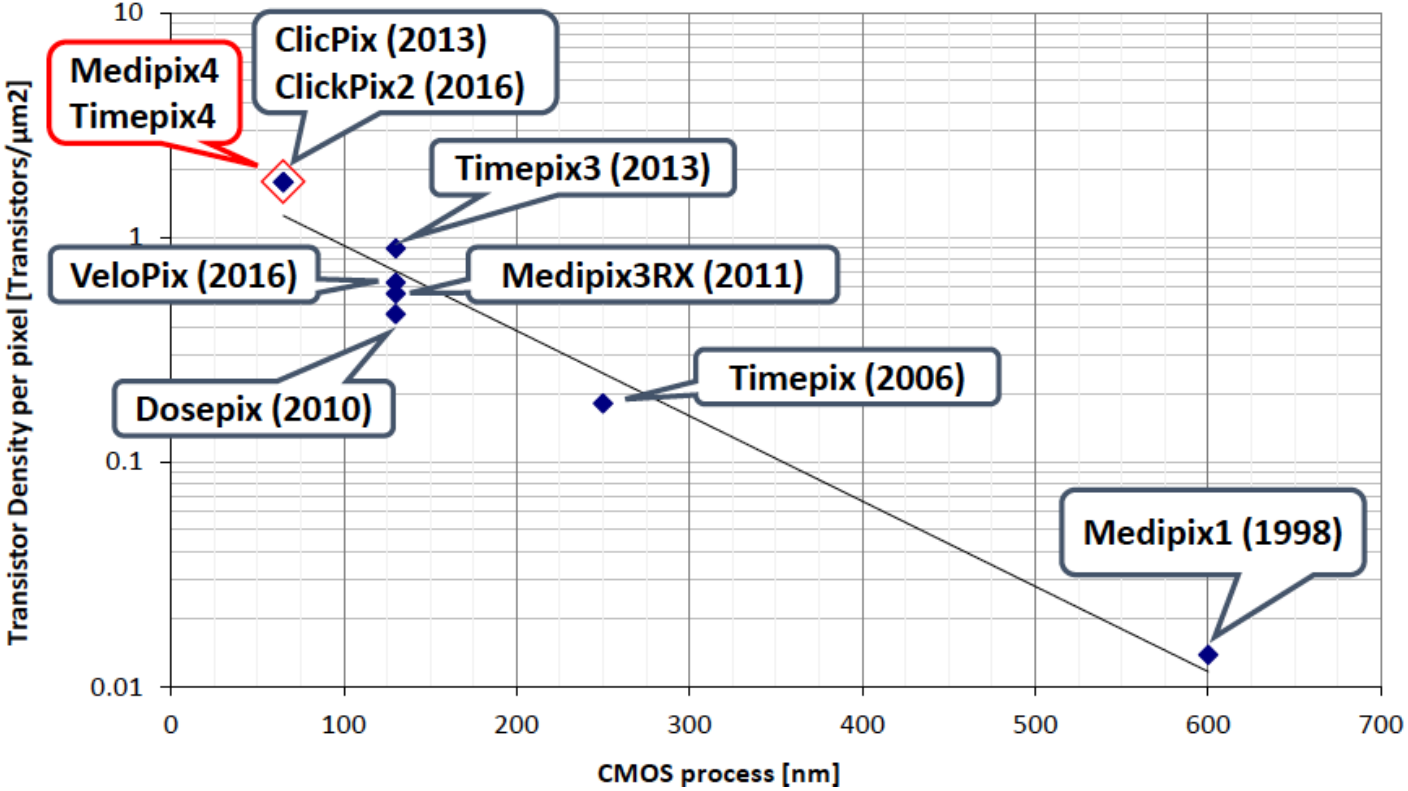


SEM cross section of TSVs (CEA-LETI)




First 2x2 TSV Medipix3RX (ESRF)

Pixel detectors ASICs developed @CERN



Timepix3 → Timepix4

Timepix4: A 4-side tillable large single threshold particle detector chip with improved energy and time resolution and with high-rate imaging capabilities

			Timepix3 (2013)	Timepix4 (2018/19)
Technology			CMOS 130nm – 8 metal	CMOS 65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448 **3.5x**
Sensitive area			1.98 cm^2	6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit **33%**
		Max rate	< 43 Mhits/cm^2/s	178.8 Mhits/cm^2/s **4x**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr) CRW (8-bit / 16-bit) Up to 44 KHz frame @8b
		Max count rate	82 Ghits/cm^2/s	~800 Ghits/cm^2/s **10x**
TOT energy resolution			< 2KeV	**< 1Kev** **2x**
Time resolution			1.56ns	**~200ps** **8x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	≤81.92 Gbps (16x @5.12 Gbps)
Target global minimum threshold			<500 e^-	<500 e^-

Swiss technology comparison

Timepix (2006)

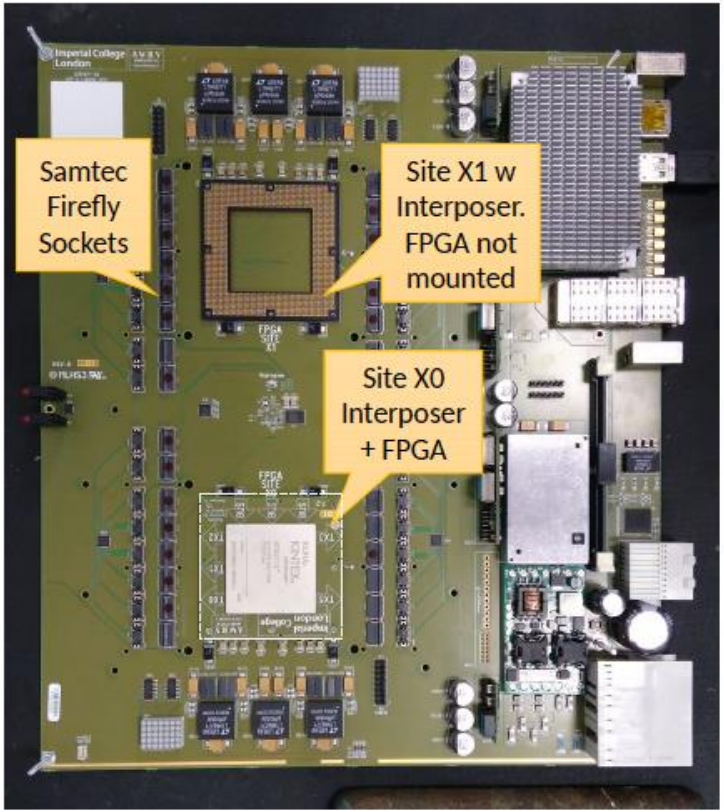
Timepix3 (2013)

Serenity

So much data – we need one of these…

- **Generic development card**
  - Different FPGAs – KU115, KU15P, VU9P
  - Multiple SerDes routing topologies
- **Samtec Interposer Connector Array**
  - Dual 72 Rx/Tx Chan Optical Site
    - Plus 64 inter-interposer pairs
  - Dual 96 Rx/Tx Chan Optical Site
    - Plus 16 inter-interposer pairs
  - QSFP for DAQ
- **Slow Control / SOC**
  - COM-Express Type 10
    - Quad-core Atom, up to 2.2 GHz, 8 GB RAM
  - IPBus over PCIe/AXI

Bristol University, Imperial College, Ioannina, INFN, KIT, RAL, SACLAY, TIFR



University of Glasgow

Thank You…… Questions?

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