7th Workshop on Medical Applications of Spectroscopic X-ray Detectors

15–18 Apr 2024
CERN
Europe/Zurich timezone

Workshop Summary

Anthony Butler
Radiologist and Physicist

CERN

UNIVERSITY of OTAGO

mars
Medipix All Resolution System

Disclaimer

My job is as a clinician; My hobbies are physics and engineering

My apologies about terrible pronunciation of names

Listening, understanding, and writing simultaneously is hard

Since 2005 I’ve been associated with CERN and Medipix

I am a founder of MARS Bioimaging Ltd

Overview

- What is SpecXray about?
- The workshop
- Review of talks
- Conclusions

CERN

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What is SpecXray about?

"Spectral X-ray in medicine"

… majority of content is "Spectral Photon Counting CT"

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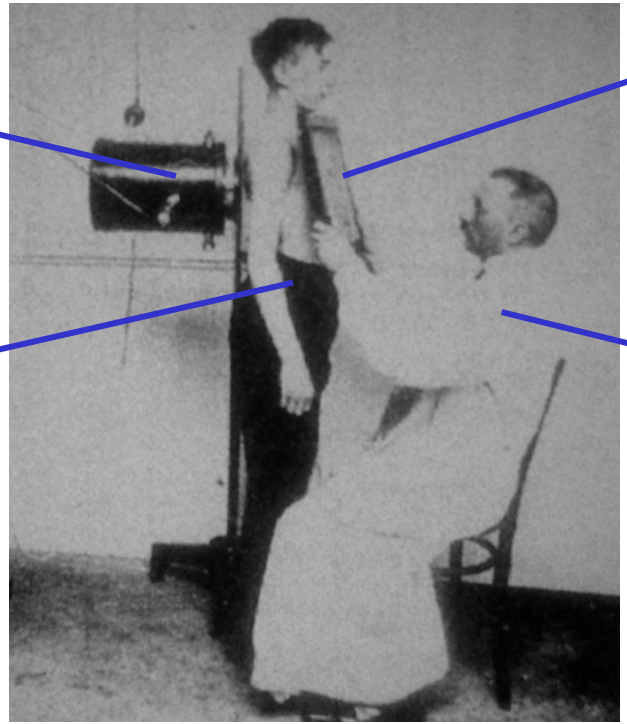
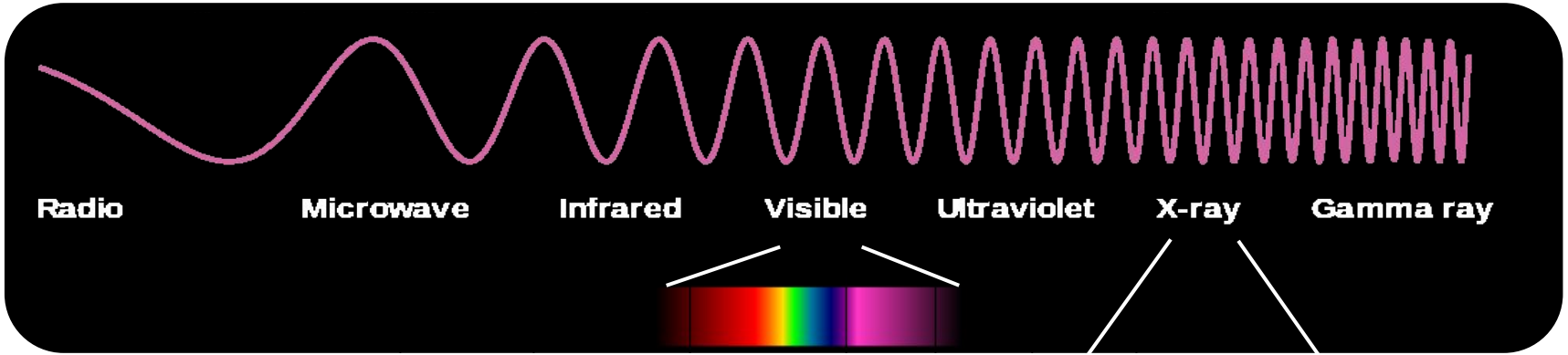
X-rays



Wilhelm Röntgen, 1895

Spectral X-rays

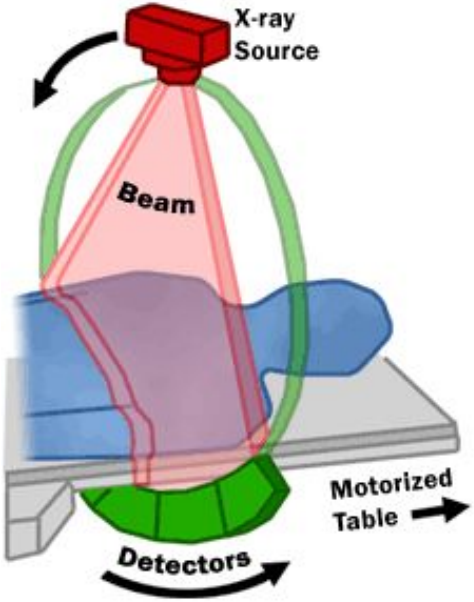


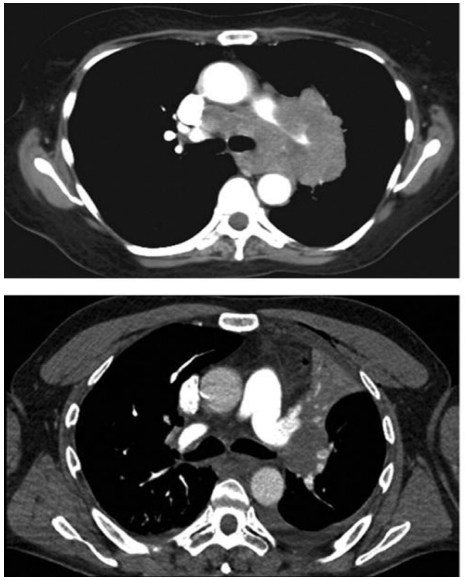
Energy 1.6 - 3.3 eV 20 - 120 keV

Synonyms: Colour, spectral, energy, wavelength, frequency, etc

Computed Tomography

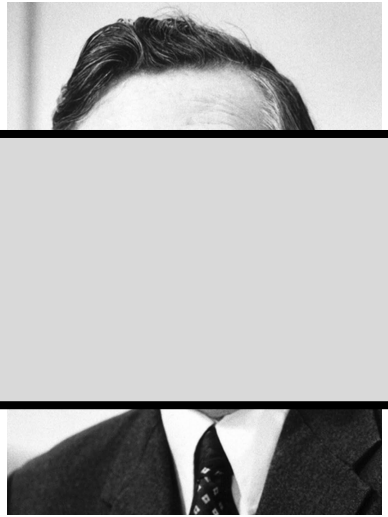
Hounsfield,
Nobel Prize 1979



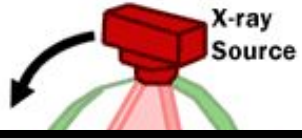


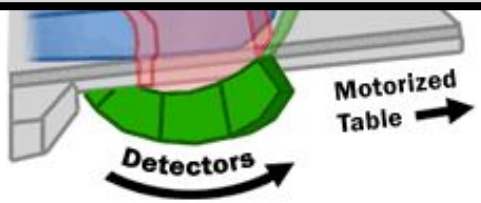
Computed Tomography is 3D X-rays

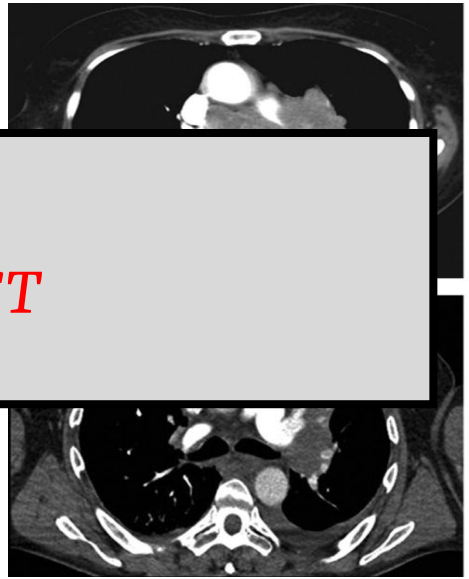
Computed Tomography



Hounsfield, Nobel Prize 1979



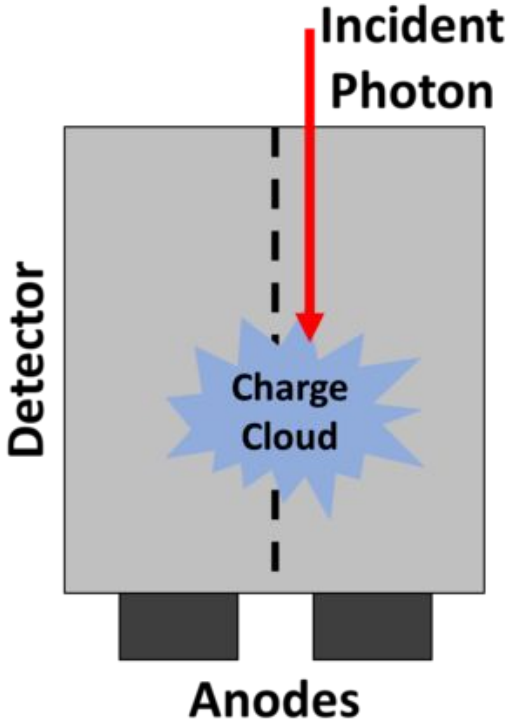




300,000,000 people per year get a CT

Computed Tomography is 3D X-rays

Photon Counting



- *Measure an x-ray beam one photon at a time*
- *Use solid semiconductors to convert directly to electrical charge*
- *Analyse the charge cloud to get time, location, and energy*

Photon Counting *The beginning…*

Erik Heijne, Robert Klanner, Gehard Lutz

2017 High Energy and Particle Physics Prize of EPS

"for their pioneering contributions to the development of silicon microstrip detectors that revolutionised high-precision tracking and vertexing in high energy physics experiments"

Photon Counting *The beginning…*

It is photon processing

Erik Heijne, Robert Klanner, Gehard Lutz

2017 High Energy and Particle Physics Prize of EPS

"for their pioneering contributions to the development of silicon microstrip detectors that revolutionised high-precision tracking and vertexing in high energy physics experiments"

Photon Counting *Before SpecXray*

Early ’80s, direct Si detectors

– Erik Heijne, Robert Klanner, Gehard Lutz

Their role is recognized by the 2017 High Energy and Particle Physics Prize of EPS

Mid ’90s, Medipix – Michael Campbell

“Various applications like Medical Imaging should profit”

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Scientific committee

Michael Campbell, CERN

Anthony Butler, Univ. of Otago & MARS Bioimaging

Steffen Kappler, Siemens Healthcare

Yoad Yagil, Philips Research Laboratories

Katsuyuki (Ken) Taguchi, Johns Hopkins University

Richard Thompson, Canon Medical Research

Brian Yanoff, GE Healthcare

Initiation only for several reasons

... with lots of assistance from **Patricia Mage-Granados**

Participants

106 registrants

2022 => 113

2019 => 119

2017 => 130

2015 => 112

2013 => 102

2011 => 76

Context

SpecXray 2011

Outside our community
there was a lot of skepticism

- ***It can not be done***

- ***It is not worth doing***

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Context

SpecXray 2011

Outside our community
there was a lot of skepticism

- ***It can not be done*** ← *I don't know how to do it*

- ***It is not worth doing*** ← *Uses are beyond my imagination*

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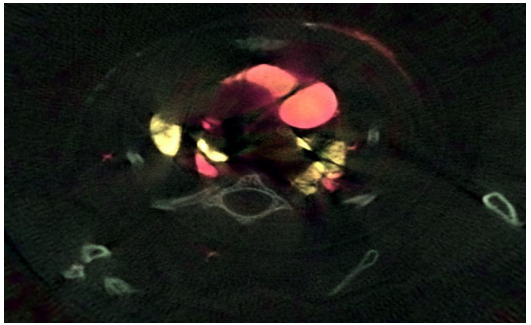
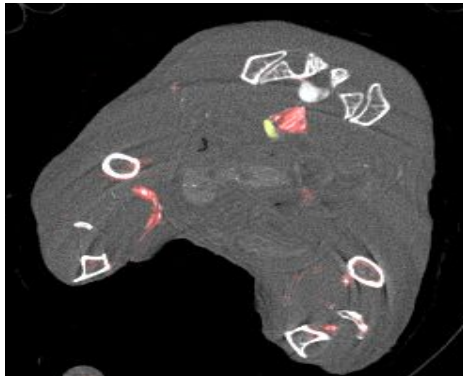
Context

SpecXray 2011



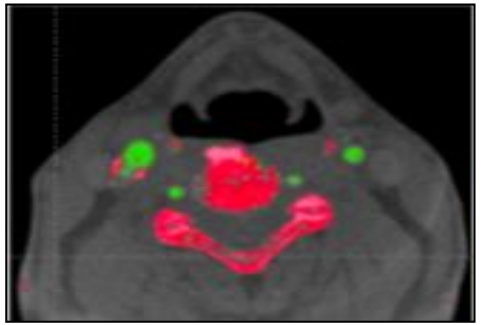
Mouse, 2 contrast agents

Anthony Butler



Mouse, functional agents

Ewald Roessel



First Human Photon counting CT,

Jerry Arenson

MARS, Philips, and GE Healthcare

Context

SpecXray 2011

Outside our community there was a lot of skepticism

- ***It can not be done***
- ***It is not worth doing***

"This may even be real"

Jerry Arenson

- Clinician want more information
- The technology is almost there
- Many people see widespread benefit

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Context

SpecXray has evolved

Community of people who have become friends

Context

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Community of people who have become friends

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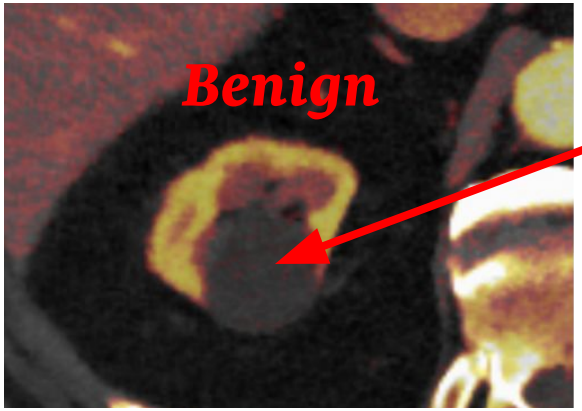
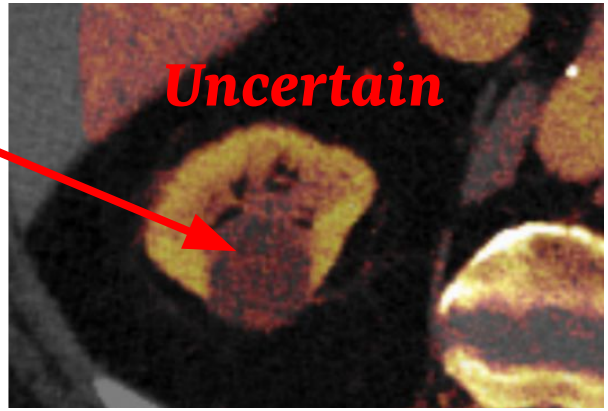
Invited talk

Benefits of photon counting, from dual energy

- Intrinsic spectral sensitivity
- Equal energy contribution
- Smaller detector pixels
- Elimination of electronic noise



Photon Counting Iodine Map
- Lower noise
- 25% lower dose



Traditional Iodine Map
Dual Source/Energy CT

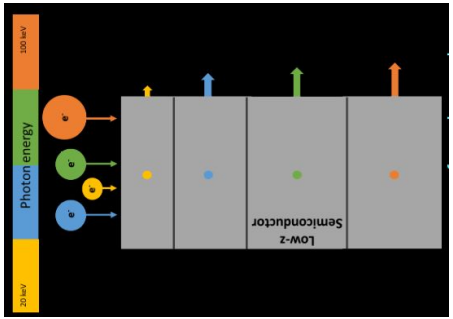
Very large number of clinical uses of multi-energy imaging

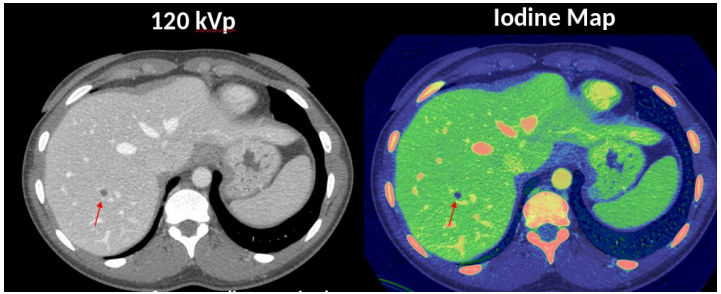
Aaron Sodickson (Harvard)

Invited talk

Clinical realisation for photon counting

Vendor	Siemens	Samsung	AB-CT	MARS	GE	Philips	Canon
Clinical availability	FDA 510(k) CE Mark	FDA 510(k)	CE Mark	Pre-clinical	Advanced Research prototype	Advanced Research prototype	Advanced Research prototype



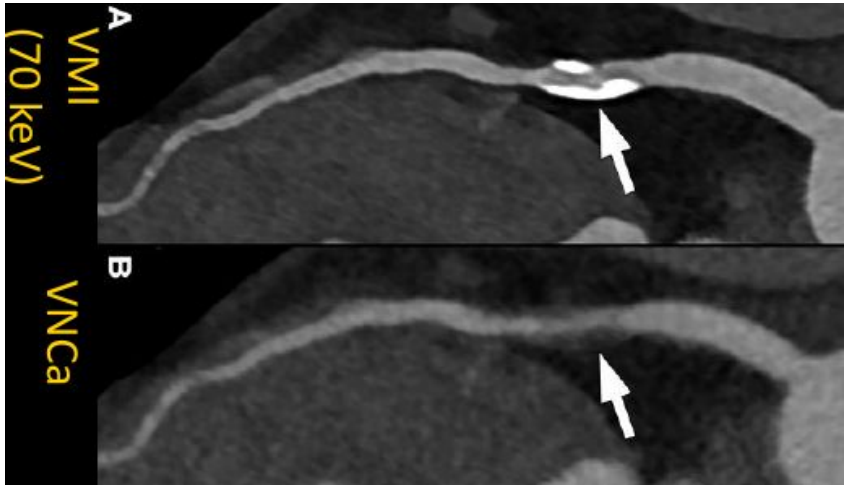


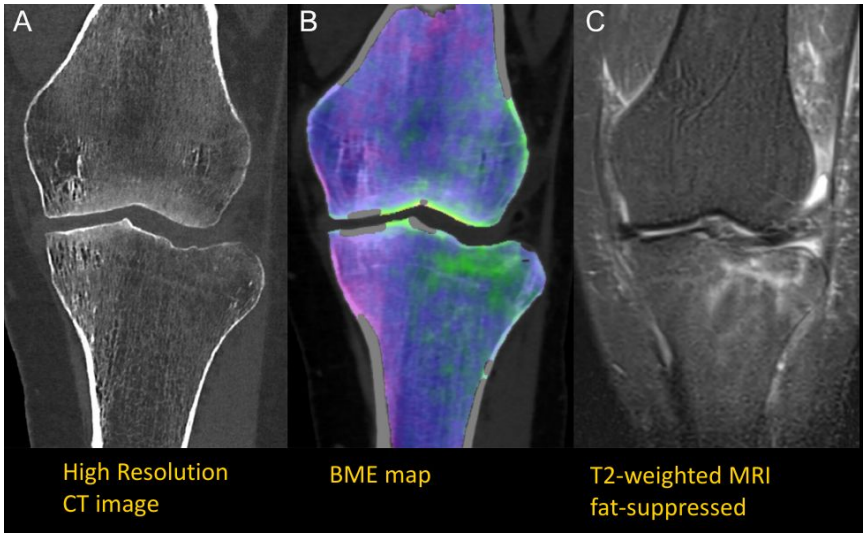
Review of scanners technologies as clinical use emerges

Fides Schwartz (Harvard)

Siemens Naeotom

FDA & CE approved spectral photon counting CT



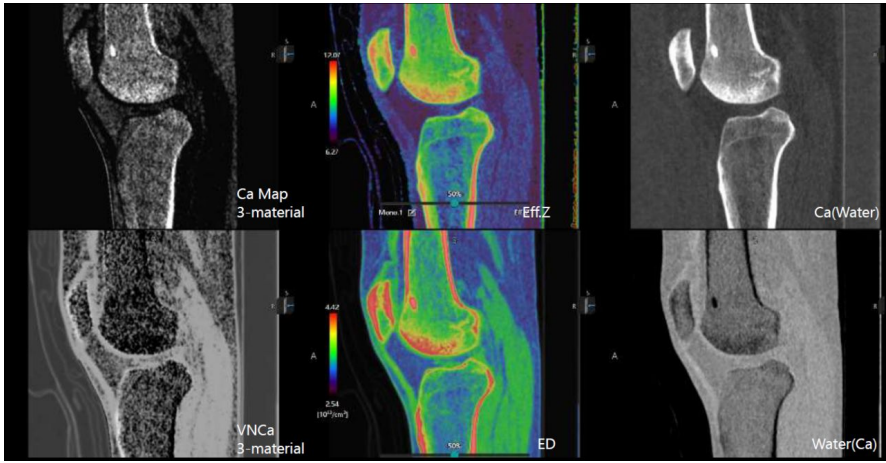


Spectral coronary artery & Musculoskeletal

Martin Petersilka (Siemens)

Canon scanner

PCCT is in their commercial roadmap

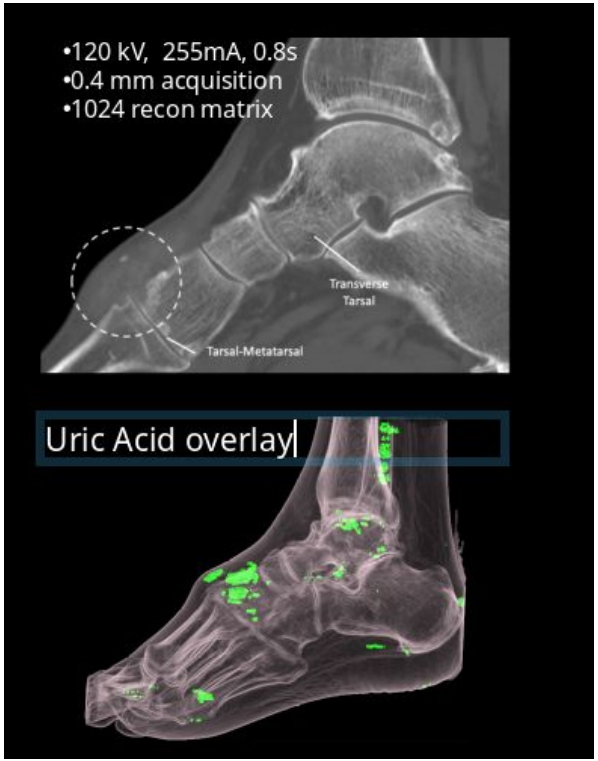


Benefits in resolution, spectral, low dose, and low noise

Richard Thompson (Canon)

GE scanner

Deep silicon detector

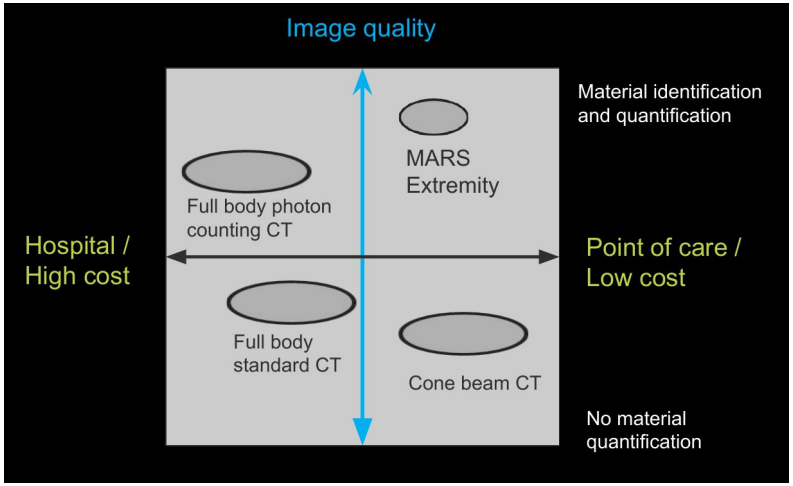


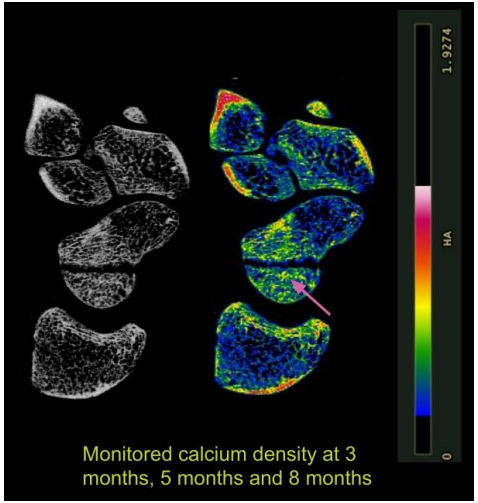
Want high spatial and spectral resolution

Dominic Grotty (GE Healthcare)

Point-of-care

Addressing clinical needs of MSK practices



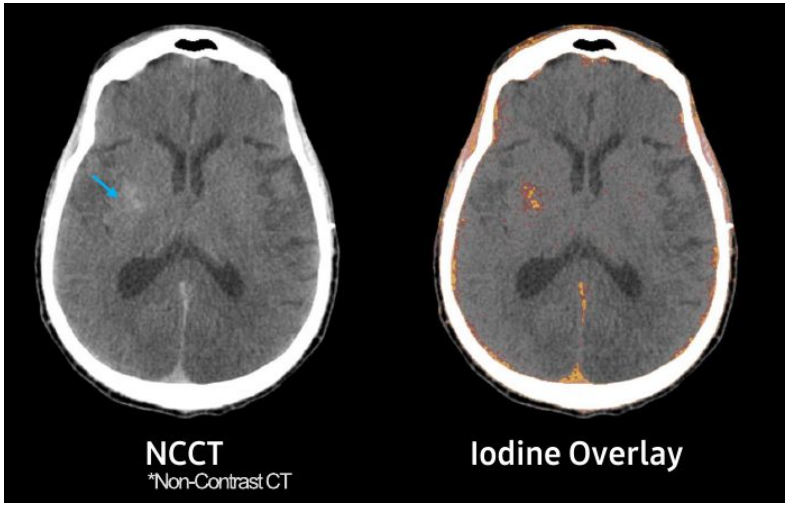


Point-of-care high spatial resolution with high spectral fidelity

Jenn Clark (MARS)

Mobile head scanner

Take spectral photon counting to the patient



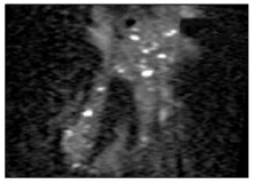
FDA cleared, with 3 scanners around the world

Junyoung Park (Samsung)

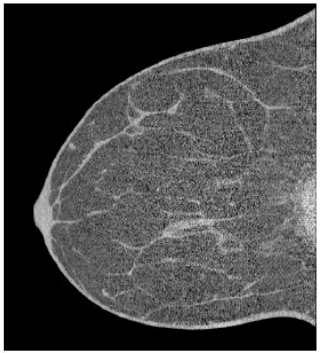
Breast CT scanner

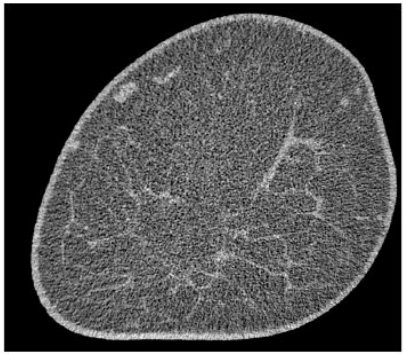
Low dose and high spatial resolution

… plus spectral data in future



Calcification cluster



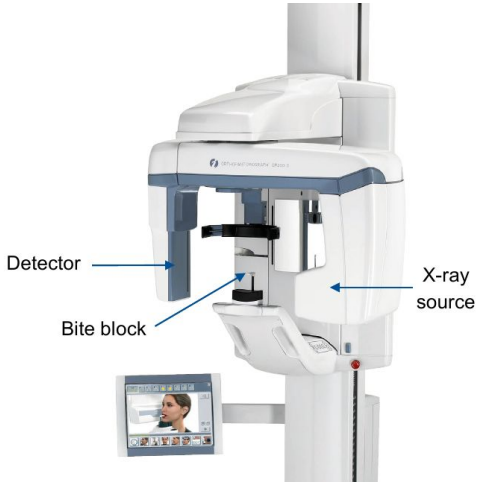


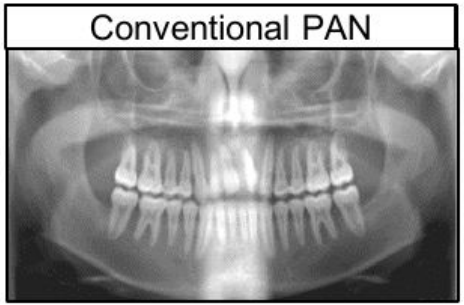
Focus on an important clinical problem

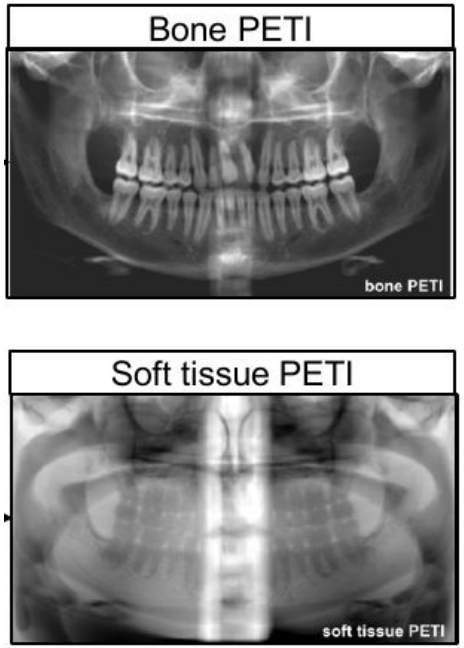
Veikko Ruth (AB-CT, Advanced Breast CT)

Dental imaging (simulation)

2D X-rays are extremely important still





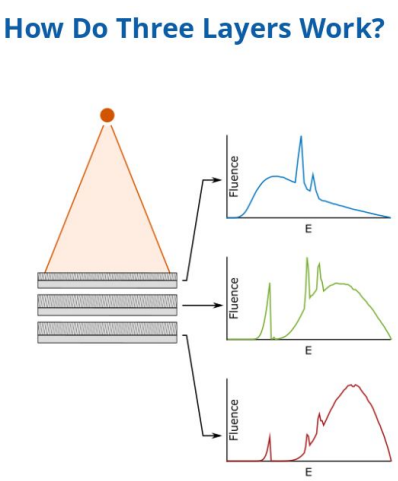


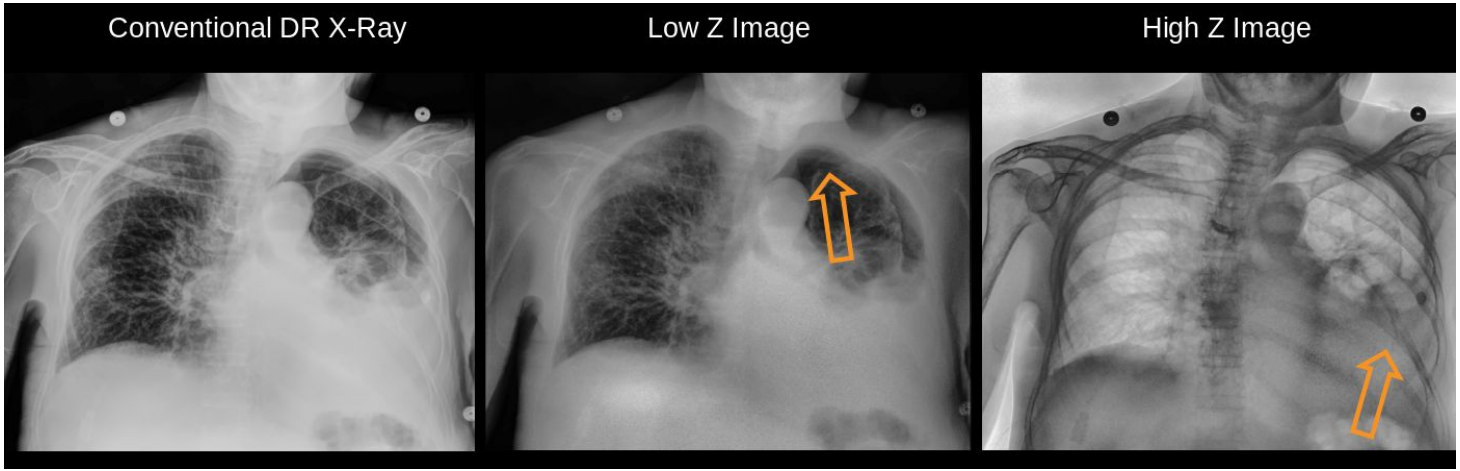
Spectral data is useful everywhere

Daniel Berthe (Technical University of Munich)

2D radiographs

Able to get spectral radiographs



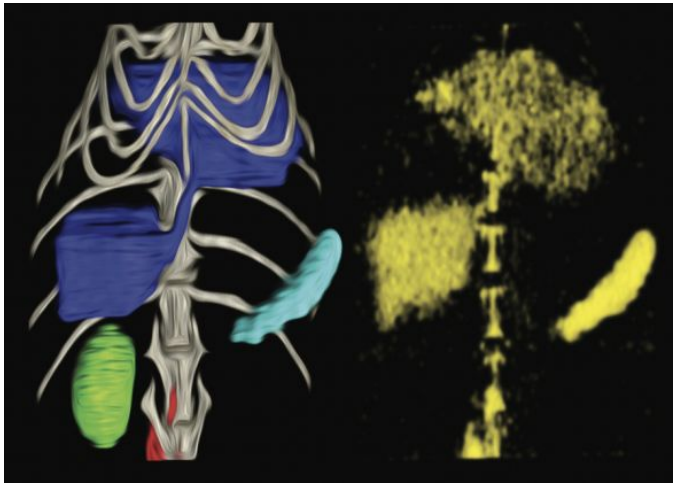


Cheap accessible technology encourages broad adoptions

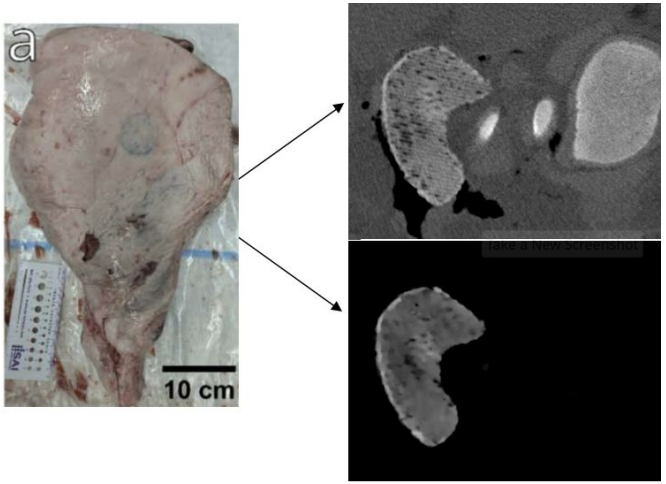
Karim S. Karim (KA Imaging)

Colour Hype or Hope?

Examples of cell tracking, tissue engineering, and multicontrast



Macrophage tracking



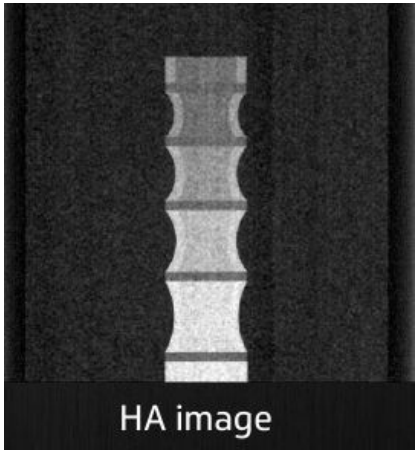
Tissue scaffold

Spectral data allows us to do functional imaging

Salim A. Si-Mohamed (University of Lyon)

2D whole body spectral

Replacing single energy with multi-energy photon counting



Phantom image

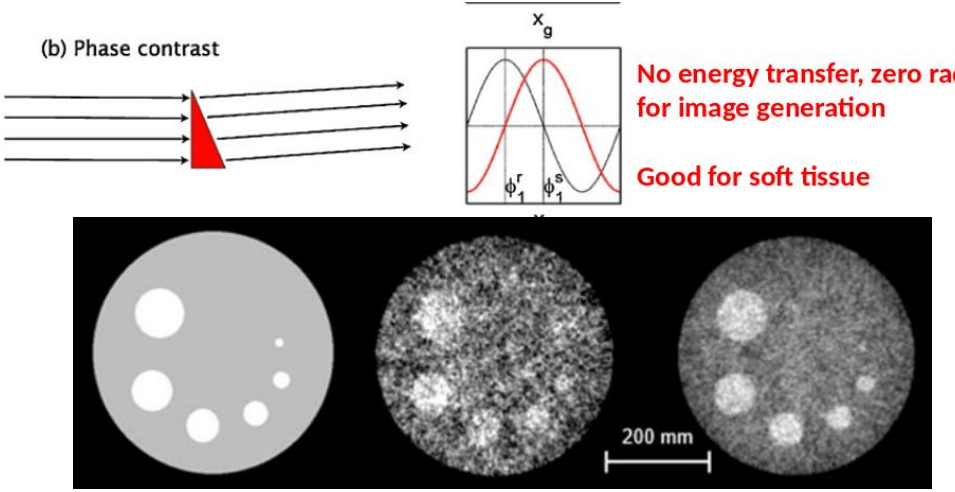
Calcium maps of spines

In future most x-ray systems will be spectral

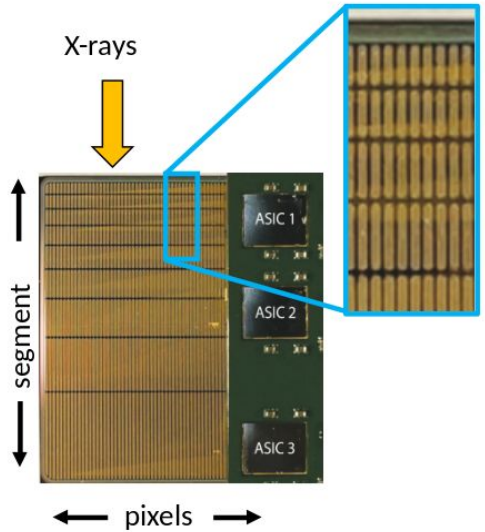
Jerome Beucher (EOS imaging)

1um phase contrast

Phase contrast imaging based on variant of deep silicon detectors



Simulation results

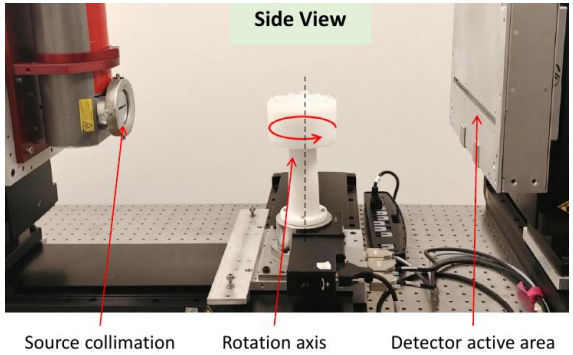


Phase contrast is a developing application of photon counting

Mats Danielsson (KTH Royal Institute of Technology)

Improved spectral models

Detector models for accurate iodine quantification

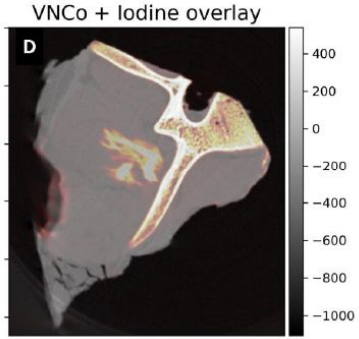


B: Exhaustive model

Sidky, 2005, Schmidt 2017

$$\bar{c}_b(l^W; l^I) = \sum_{E=1}^{kVp} S_{bE} e^{-\mu_E^W l^W - \mu_E^I l^I}$$

-> Incident spectrum with energies from 20 to 120 keV
= 100 free parameters per bin
-> Initialized with the simulated spectrum

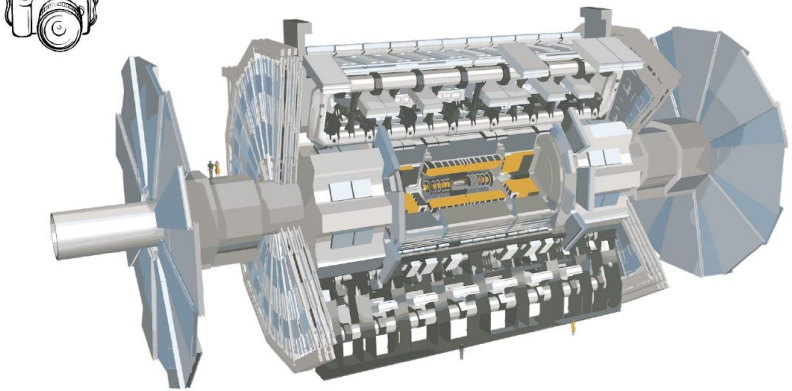


Methods for spectral analysis continue to improve

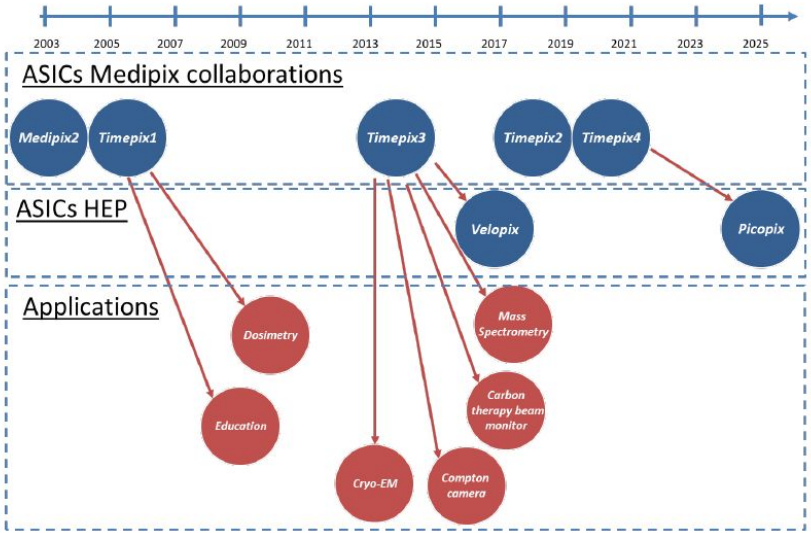
Pierre-Antoine Rodesch (University of Victoria)

Invited HEP talk

High Energy Physics gave us photon counting, whats next?



The "cameras" are large detector systems
ATLAS Detector
25m diameter, 64 m long, 7000 tonnes
100M electronic channels

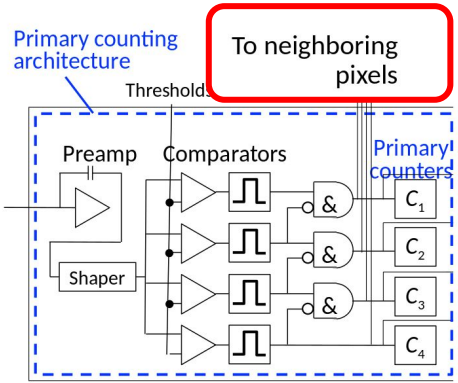


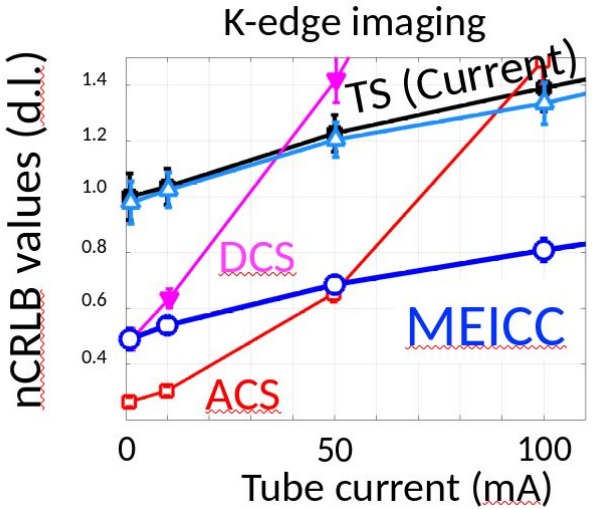
Perhaps its timing information?

Rafael Ballabriga Suñéi (CERN)

Charge sharing correction

Novel coincident correction method





MEICC (proposed): Multi-energy inter-pixel coincidence counter

ACS: Analog charge summing (e.g., Medipix3RX by CERN)

DCS: Digital count summing

No speed penalty;
N^2 extra counters required

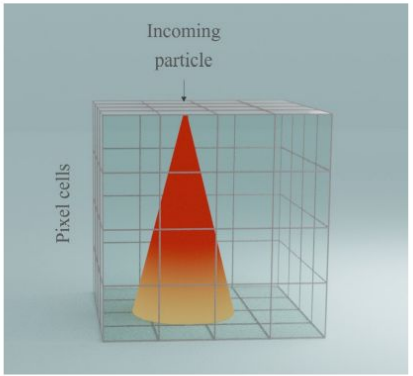
Improving spectral fidelity is important

Katsuyuki "Ken" Taguchi (Johns Hopkins University)

Super-spectral CT

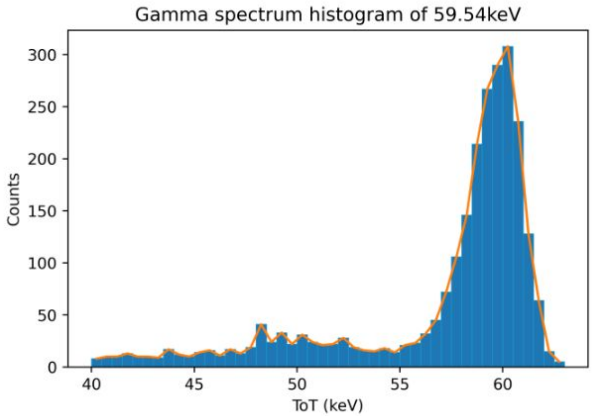
Timepix3 for off-line charge cloud analysis of charge sharing

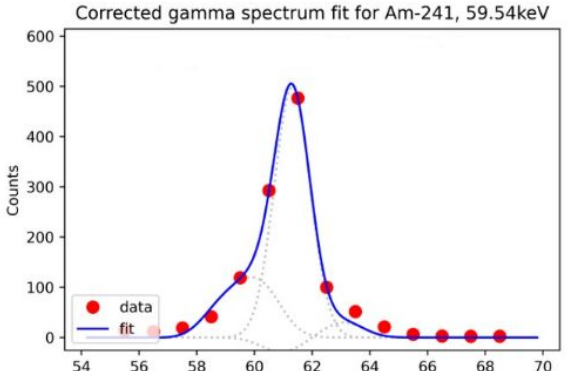
Charge sharing



Pinelopi Christodoulou et al 2024 JINST **19** C01026

Fine energy binning





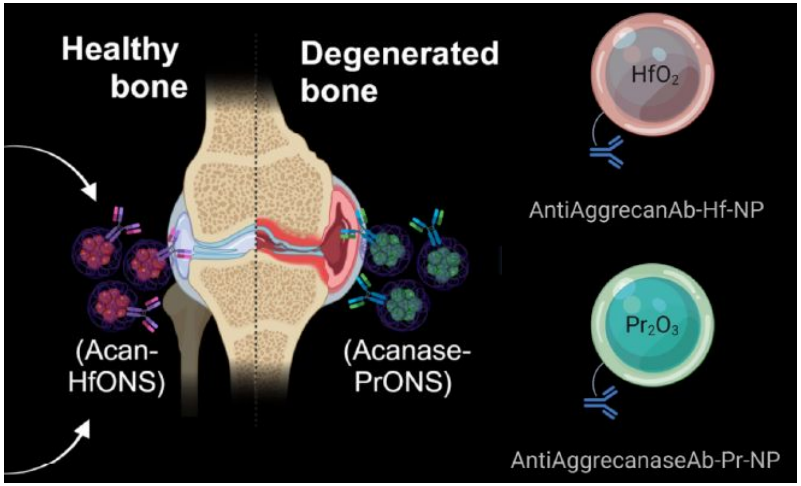
Sigma = 0.62 keV

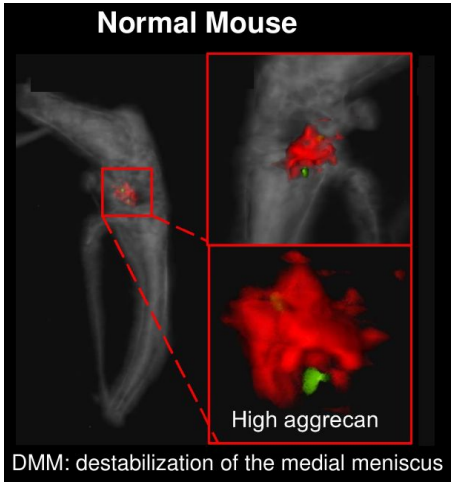
Accurate spatial and energy measure by processing photons

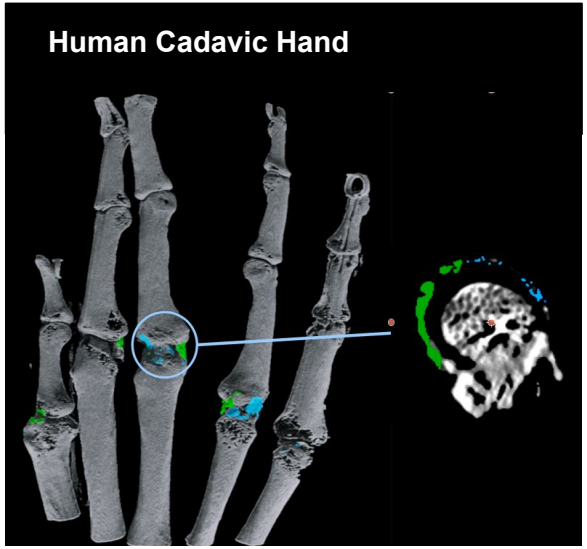
Pinelopi Christodoulou (Czech Technical University)

Molecular imaging

Multi-contrast imaging for arthritis





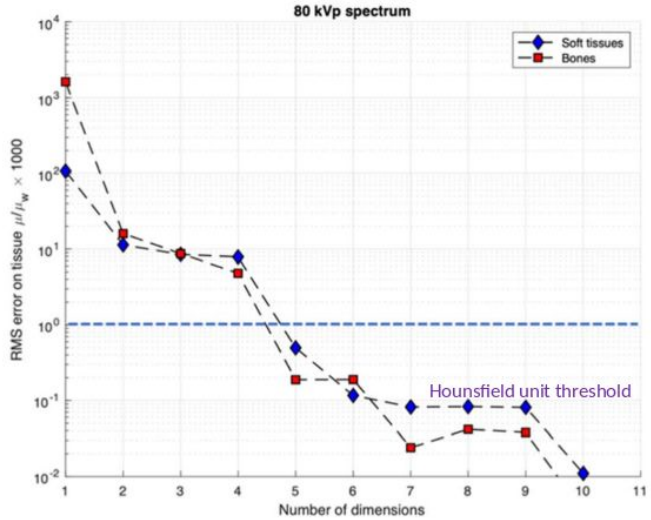


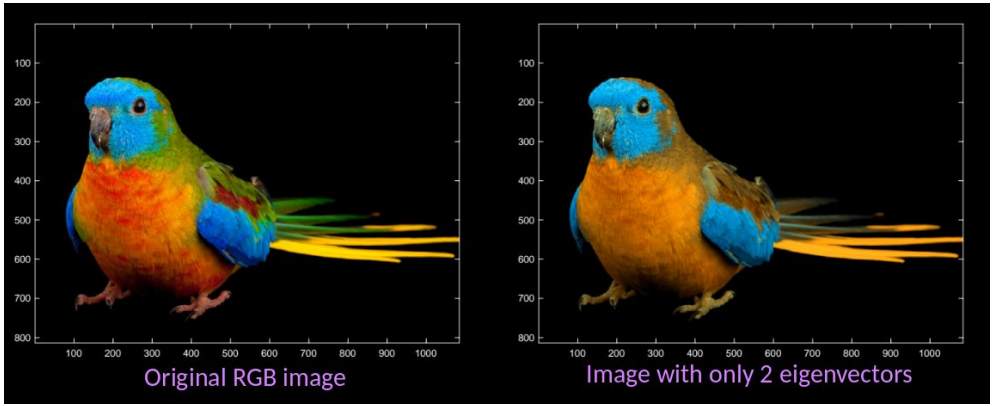
I'm looking forward to clinical trials of some of these particles

Dipanjan Pan (PennState)

Radiotherapy planning

Working out elemental composition of tissues



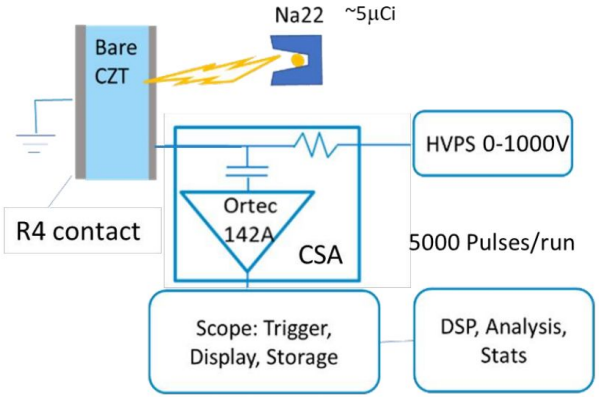


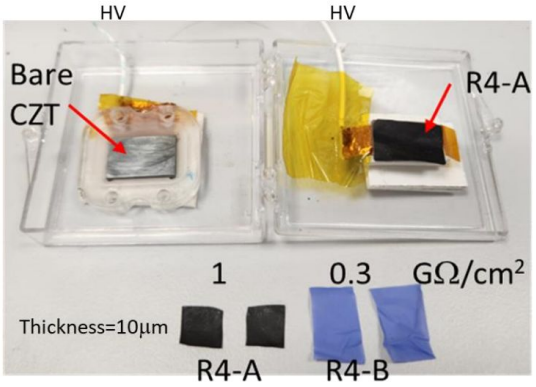
Dimensionality of tissues is at least 5, but hard to extract

Hugo Bouchard (Université de Montréal)

CZT characterisation

Removable Reusable Resistive Rubber - characterisation with fab





CZT samples used: S1, S2 …

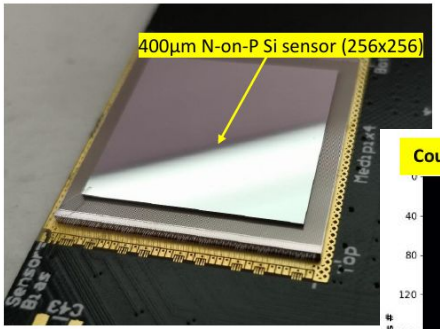
Nice to see new methods for semiconductors testing

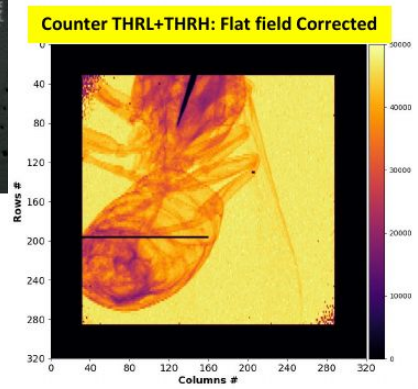
Klaus Erhard (Philips)

Medipix4

First chips is being tested

Silicon sensor + Medipix4 ASIC arrived at CERN two weeks ago:





- **5.76 cm²** sensitive area.
- **4-side buttable** architecture to cover **99.37% active area**.
- Inter-pixel architecture to correct **charge sharing** and **fluorescence photons**.
- **2 thresholds** in Fine Pitch Mode and **8** in Spectroscopic Mode using **Window Discrimination.**
- Configurable analog modes to accommodate **a large range of different applications** (from very fast to very low noise).
- **Pile-up filtering** circuit to discard tail pile-up events in the measurement.

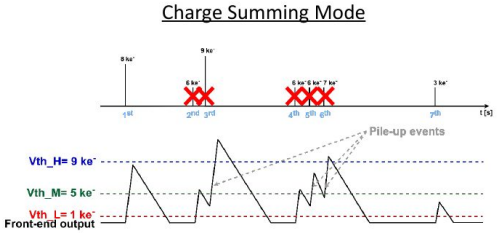
I'm looking forward to seeing the pile-up filtering

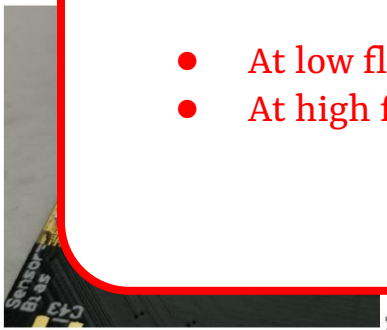
Viros Sriskaran (Medipix4 Collaboration)

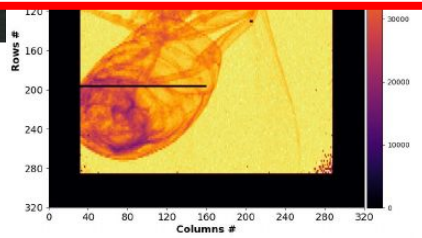
Medipix4

Processing the charge cloud in the time domain

- At low flux, all the benefits of CSM
- At high flux, don't lose "too much" information







photons.

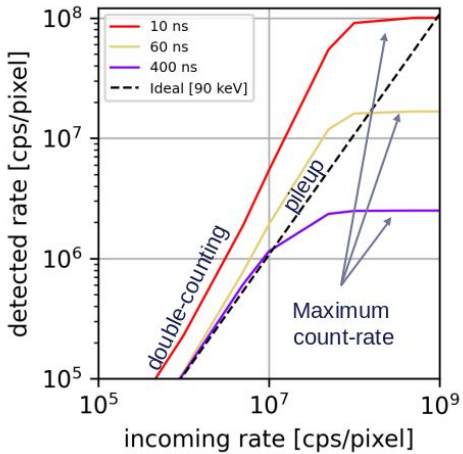
Window

- Configurable analog modes to accommodate **a large range of different applications** (from very fast to very low noise).
- **Pile-up filtering** circuit to discard tail pile-up events in the measurement.

I'm looking forward to seeing the pile-up filtering

Viros Sriskaran (Medipix4 Collaboration)

Lynx



Polychromatic re-trigger to suppress pileup

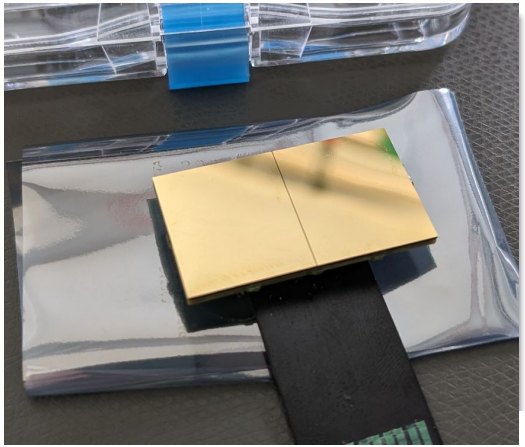
Dectris' first CT module

DECTRIS' CT ASIC platform

Ingredients

- Adapted building blocks from our proven photon-counting ASIC for Synchrotron applications
- Highly customizable:
  - Pixel pitch and pixel array
  - Overall ASIC dimensions
  - Interface
- Designed with cost-sensitivity and scalability in mind
- Compatible with Through-Silicon Vias (TSV) and Interposer

Offer a customer-specific gapless module for Computed Tomography

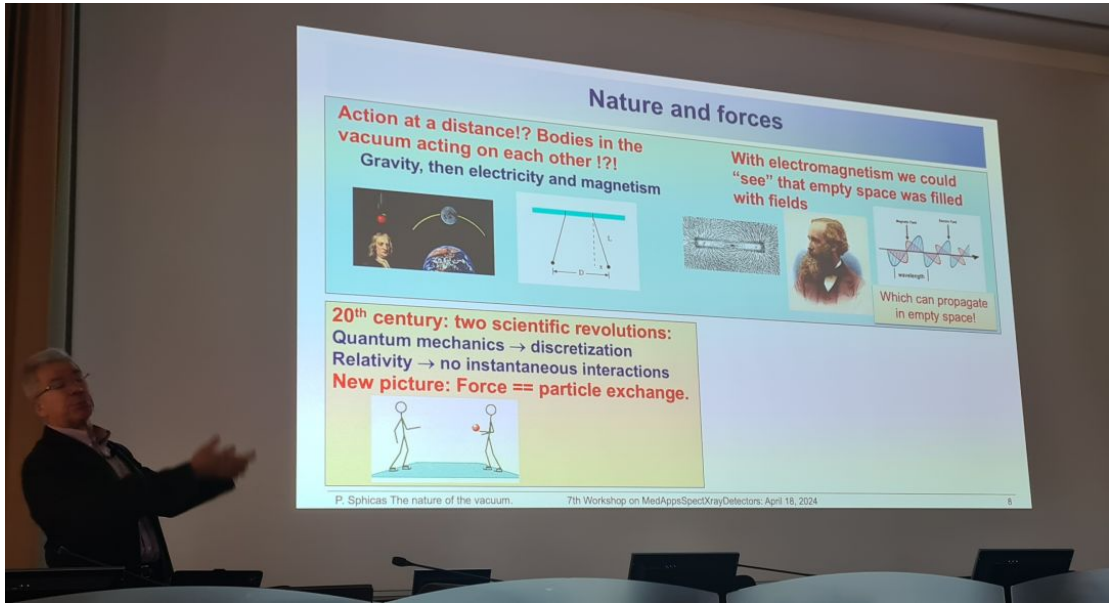


CERN

Long history of photon counting modules for synchrotrons

Christian Disch (DECTRIS Medical)

Nature of the vacuum



It wonderful to hear about advances in other fields

Paris Sphicas (CERN & University of Athens)

Overview

- What is SpecXray about?
- The workshop
- Review of talks
- Conclusions

… and my shameless uninformed opinions

Conclusion

Engineering themes

Engineering research has strong focus of improving spectral fidelity at high flux (charge sharing & pileup)

- ➔ "Charge sharing is our friend" (Stanislav Pospíšil)
- ➔ "It is photon processing" (Erik Heijne)
- ➔ Analyse the charge cloud to correct for both charge sharing and pile-up

… in a few years clinical will have both high resolution and spectral data

… and my shameless uninformed opinions

Conclusion

What is the killer app?

The talks demonstrated benefits and often early clinical use in:

- Musculoskeletal imaging
- Cardiovascular disease (stroke + heart disease)
- Respiratory disease
- Neuroimaging
- Molecular imaging

… and my shameless uninformed opinions

Conclusion

What is the killer app?

The talks demonstrated benefits and often early clinical use in:

- Musculoskeletal imaging
- Cardiovascular disease (stroke + heart disease)
- Respiratory disease
- Neuroimaging
- Molecular imaging

No killer app, but benefits everywhere

… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

Does it change management?
What level of evidence is required to change practice?
Can the patient access it in a timely manner?
What are the health economics? Is it cheaper or more efficient?
Is it dependent on other technologies? Eg. Nano-probes?

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… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

Does it change management?

- *Metal artefact in bone implants is important to surgeons planning surgery*
- *Features of fibrotic lung disease are interesting but may not immediately change manage, but enables therapy monitoring and treatment development*

… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

What level of evidence is required to change practice?

- *Breast oncologists and surgeon require long clinical studies of outcome before changing care pathways*
- *Orthopedic surgeons will change practice if the image shows stuff they couldn't see before*

… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

Can the patient access it in a timely manner?

Timing and access to imaging effects both cost and clinical utility

- *Stroke imaging must be done within minutes to be useful*
- *A excellent in-patient scanner is of limited use to an out-patient*

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… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

What are the health economics? Is it cheaper or more efficient?

Most purchasing decisions by health providers balance:

- *Clinical benefit (improved patient outcome)*
- *Cost for this benefit*

… and my shameless uninformed opinions

Conclusion

What is the killer app?

Things that drive update in different areas of medicine

Is it dependent on other technologies? Eg. Nano-probes?

Molecular imaging may be the biggest benefit from spectral CT

- *It's better than PET in terms of cost, patient access, and specificity, and resolution.*
- *Its dependent of pharma research, so timelines for adoption will be long*

… and my shameless uninformed opinions

See you again in 2 years !!

Michael Campbell, CERN

Anthony Butler, Univ. of Otago & MARS Bioimaging

Steffen Kappler, Siemens Healthcare

Yoad Yagil, Philips Research Laboratories

Katsuyuki (Ken) Taguchi, Johns Hopkins University

Richard Thompson, Canon Medical Research

Brian Yanoff, GE Healthcare