Science and Technology Facilities Council

Technology

Matt Wilson

UKRI – STFC – Rutherford Appleton Laboratory

On behalf of the Detectors & Electronics Division

COST ACTION CA24131

European Network for radiation-detection based Research and Innovation addressing increasing societal CHallenges (ENRICH)

ENRICH

High-Z Sensor Materials & Detection Systems for Photon Science

ENRICH COST Annual Meeting, 15th of July 2026, Krakow

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

Content

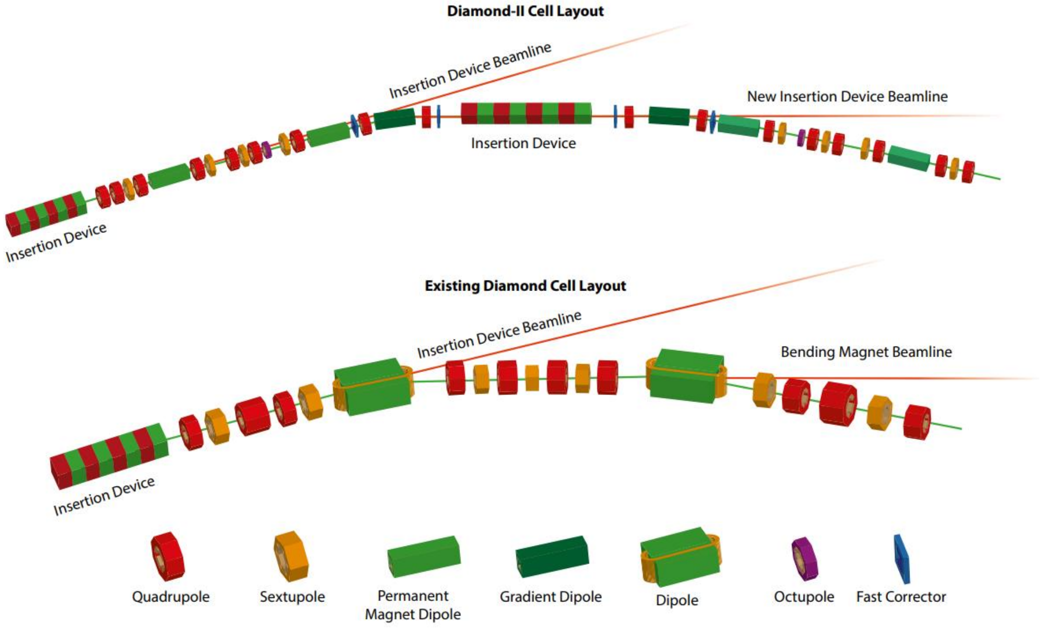
- 4^{th} Generation Synchrotrons
- Detector Requirements
- High-Z Sensors
  - Si, GaAs, CdTe, CdZnTe, Perovskites
- Detector Systems
  - Jungfrau, Cordia, MMPad, XIDyn
- Summary

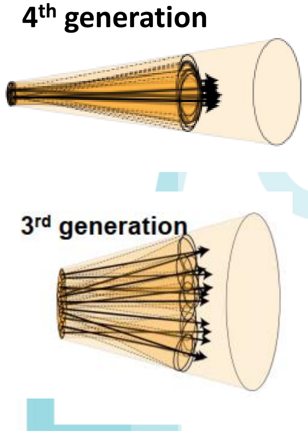
Diamond II

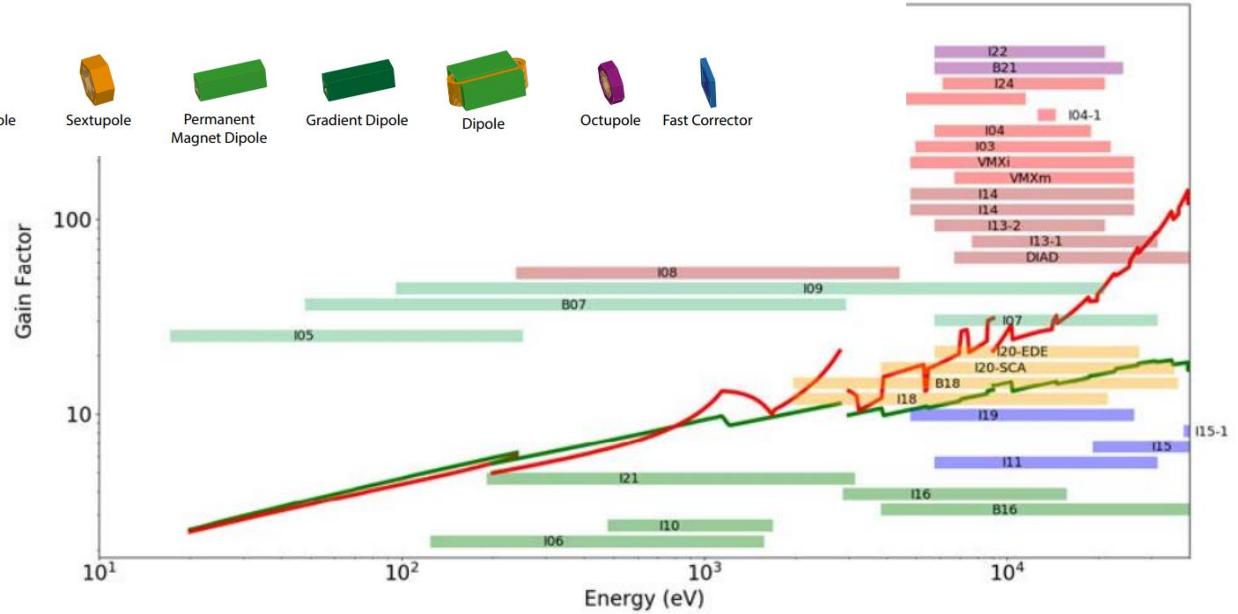
- 6-bend achromat to reduce e- emittance
- High photon flux
- Higher energy
- Scheduled build 27-28

Diamond Light Source

My office in STFC





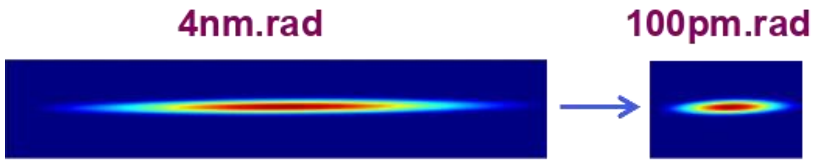


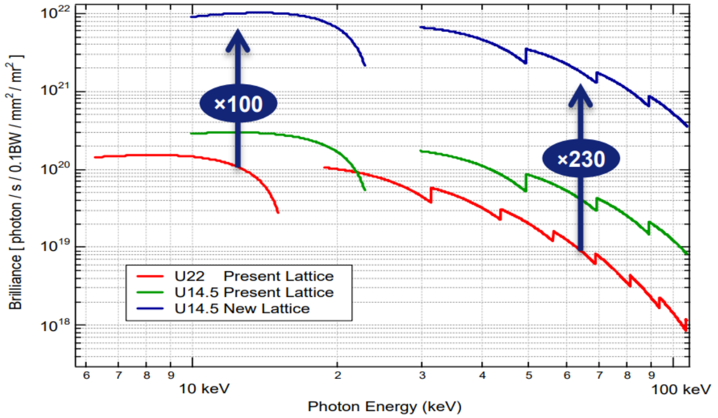
4th Generation Synchrotrons

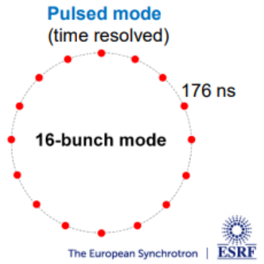
A. Ropert, J.M. Filhol, P. Elleaume, L. Farvacque, L. Hardy, J. Jacob, U. Weinrich, "**Towards the Ultimate Storage Ring-Based Light Source**", Proc. EPAC 2000, Vienna.

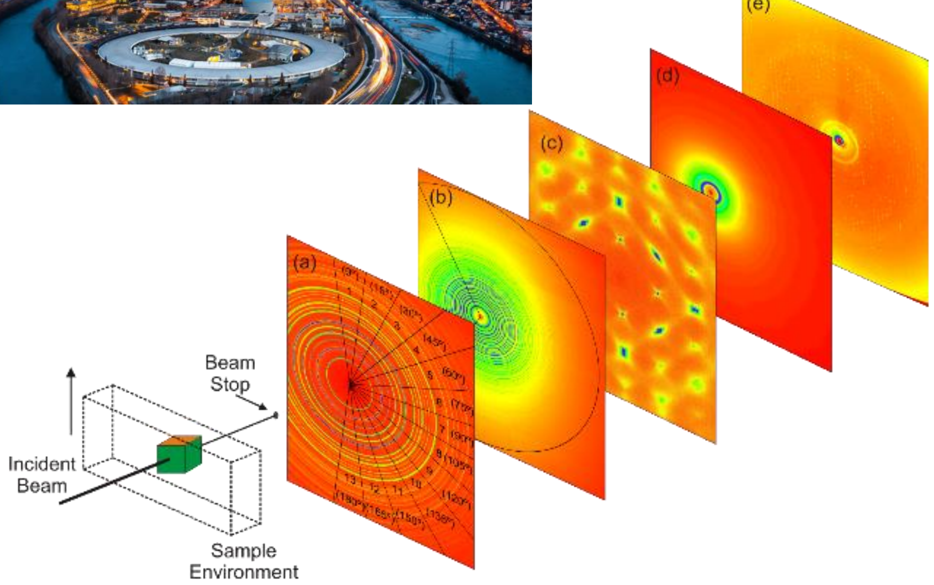
ESRF-EBS

- Operation now

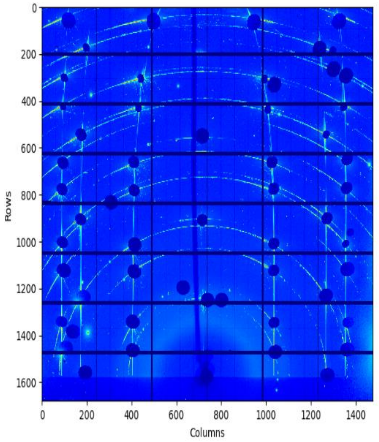






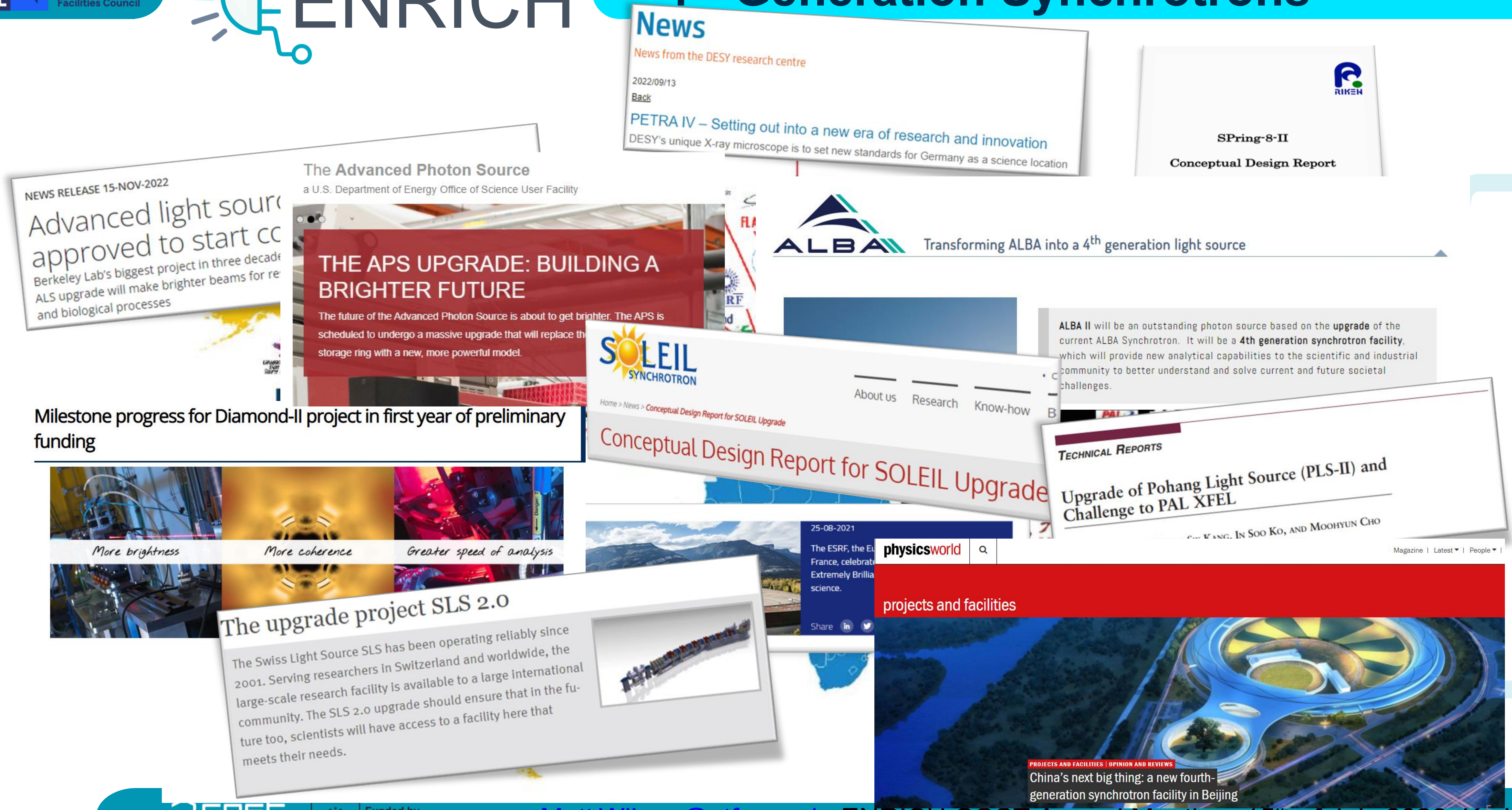


Credit: V. Honkimäki ESRF

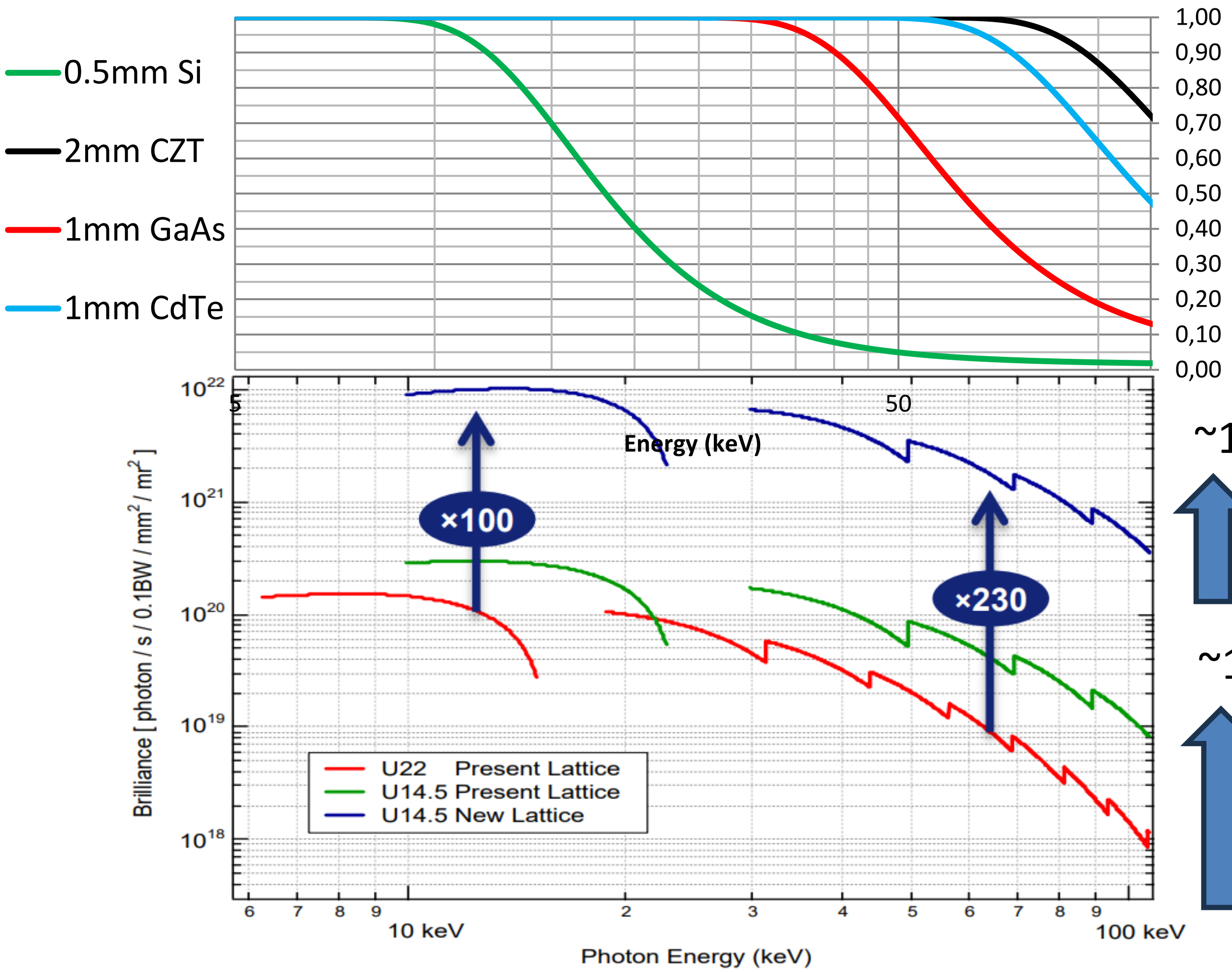


Detectors have to have beam stops over the Bragg peaks to cope with the flux

4th Generation Synchrotrons



Detector Requirements



~10^{10} ph/pix/s

Integrating

~10^{8} ph/pix/s

Photon Counting

Hard X-ray Detector Material

Integrating Detector and High Frame Rates

…and ~100µm pixels… and Mpixel scale with minimal dead space

Science and Technology Facilities Council

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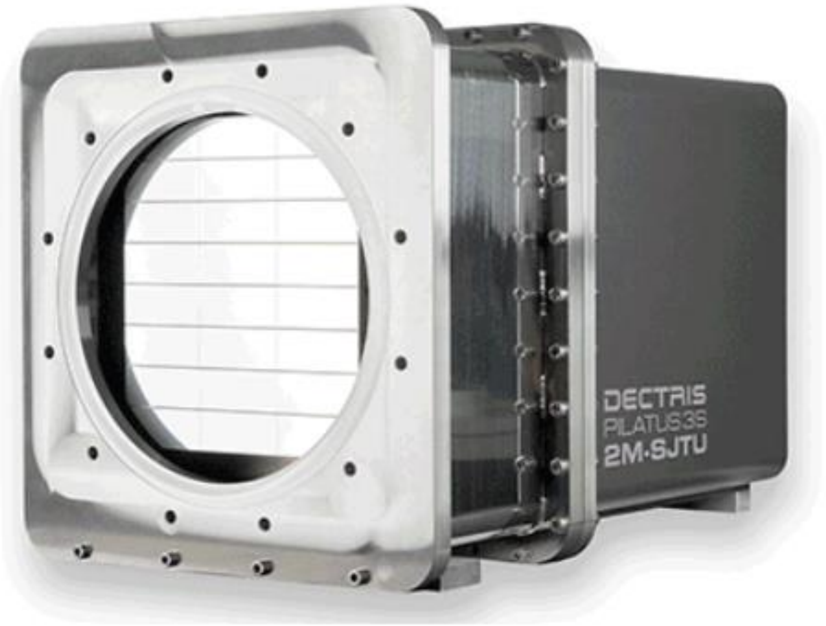
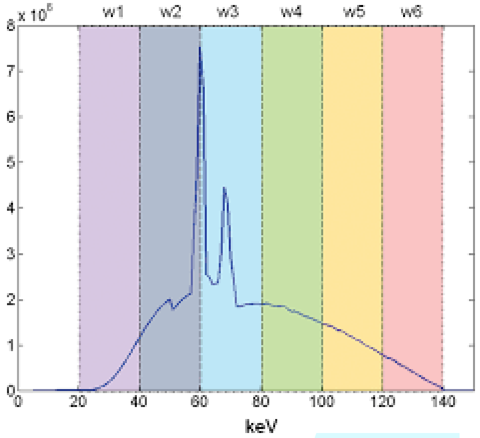
High-Z Detectors - Silicon



- ✓ Charge Transport
- ✓ Supply Availability
- ✓ Wafer Size
- ✓ Cost
- × Stopping Power

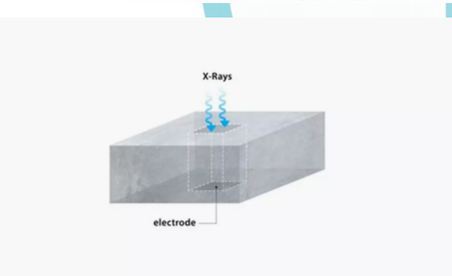


Could Silicon still be used for higher energies?

The $20B medical imaging market think it is worth a try…

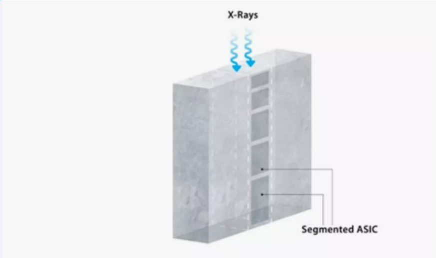
GE HealthCare

Photonova Spectra is 510(k)-pending with the U.S. FDA. Not CE Marked. Not available for sale.



Historic Challenges of Silicon as a Semi-Conductor Material

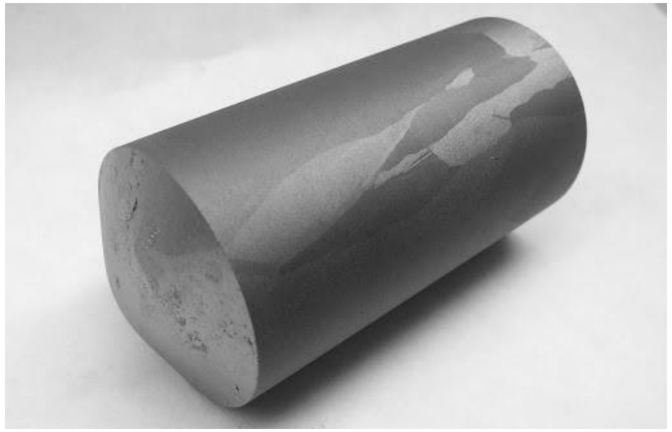
The main challenge has been that it has a relatively low atomic number such that when placed in a "face on" position, it is too thin to stop and collect a sufficient number of x-ray photons.



GE HealthCare Overcomes the Challenge with Patented Novel "Edge On" Positioning

Our approach puts silicon sensors edge on so the detector is deep enough to absorb high energy photons and fast enough to count and quantify energies of hundreds of millions of CT photons per second.

High-Z Detectors - GaAs

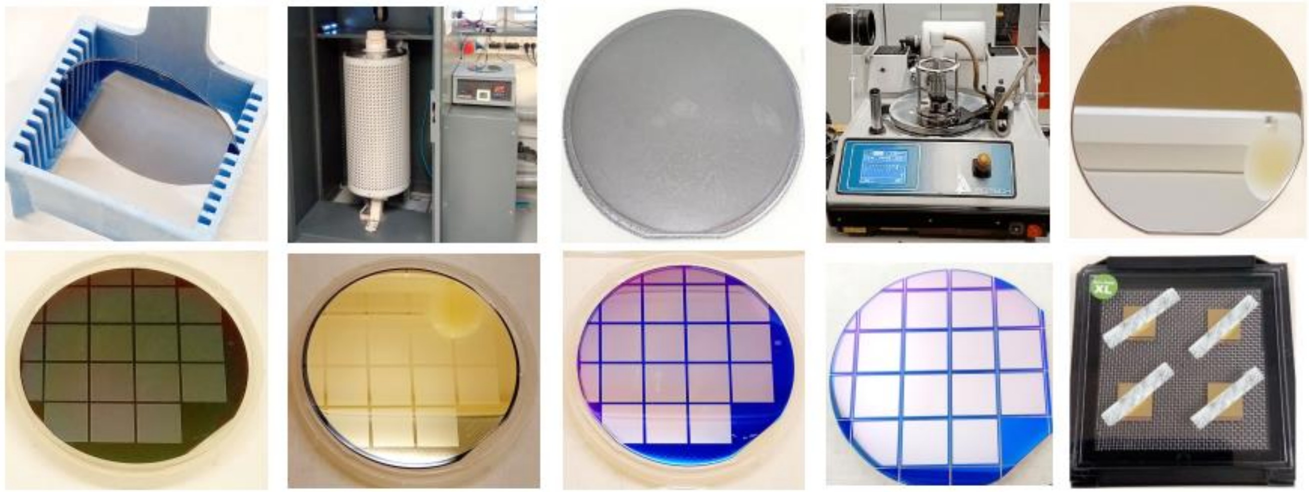


- ? Charge Transport
  - ? Cr compensation
- ? Supply Availability
  - × Tomsk Development
  - ✓ European commercial
- ? Wafer Size
  - ✓ Area
  - ? Thickness
- ✓ Cost
- ✓ Stopping Power

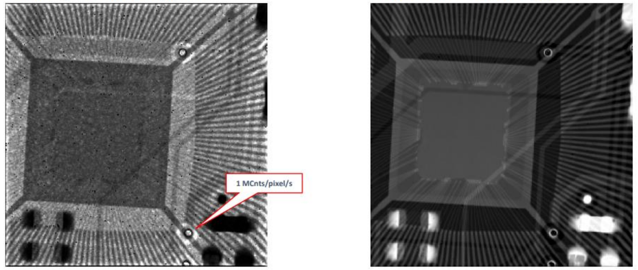
ADVAFAB Semiconductor solutions

Credit: Juha Kalliopuska, IWORID 2024

- Process flow: Cr sputtering, Annealing, Polishing, Passivation, Lithography, Contact metal, Lithography, UBM sputtering, Dicing and Flip-chip bonding



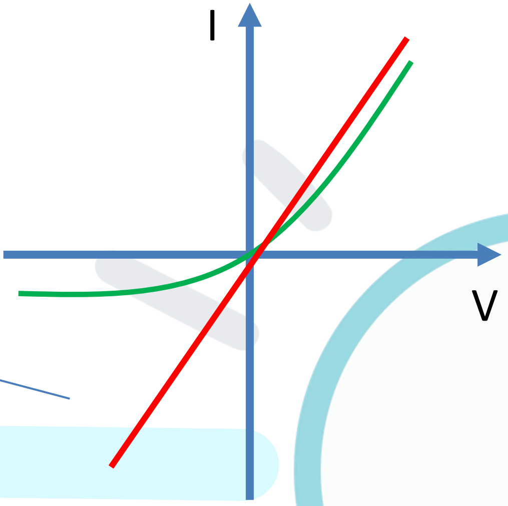
Raw image at 370 MCnts/s/mm²   BH corrected at 370 MCnts/s/mm²



Fine pitch photon counting demonstrated

High-Z Detectors - CdTe

Photon counting ASIC can be tolerant of relatively high leakage currents

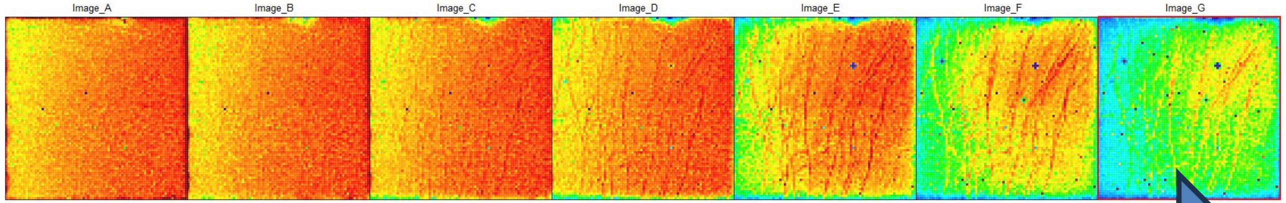


Ohmic – Pt/Au – CdTe – Pt/Au

Schottky – Pt/Au – CdTe – In/Al

? Charge Transport
    ? e- okay, h+ poor
? Supply Availability
    ✓ Acrorad – 50% Siemens
? Wafer Size
    ? Area
    ? Thickness (Ohmic vs Schottky)
✓ Cost
✓ Stopping Power

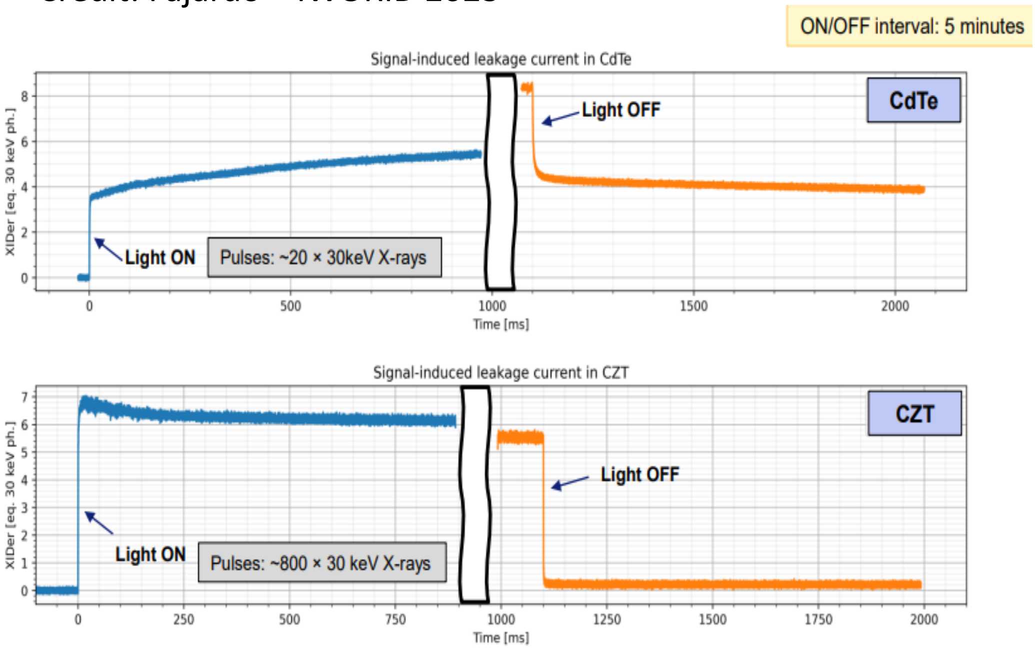
Schottky CdTe – Polarisation under bias

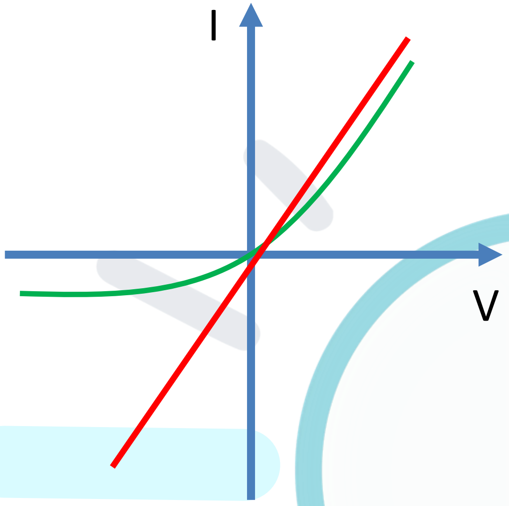


Time – Leakage current trapped by Schottky barrier and collapse of E Field

High-Z Detectors - CdTe

Credit: Fajardo – IWORID 2023



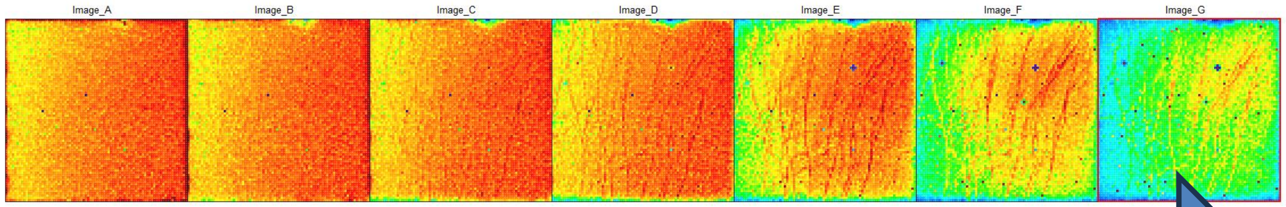


Ohmic – Pt/Au – CdTe – Pt/Au

Schottky – Pt/Au – CdTe – In/Al

Trapping and E field stability can compromise stability and time response

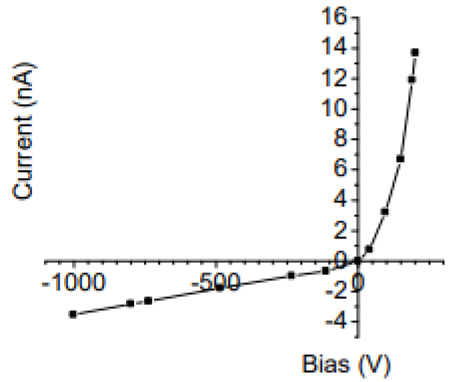
Schottky CdTe – Polarisation under bias



Time – Leakage current trapped by Schottky barrier and collapse of E Field

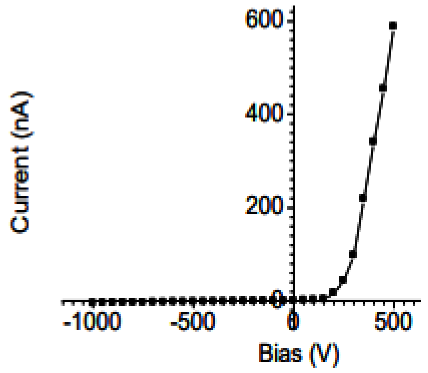
High-Z Detectors - CdZnTe

CdTe @ $10^{8\text{-}9}$ Ωcm



(a)

CZT @ $10^{9\text{-}10}$ Ωcm

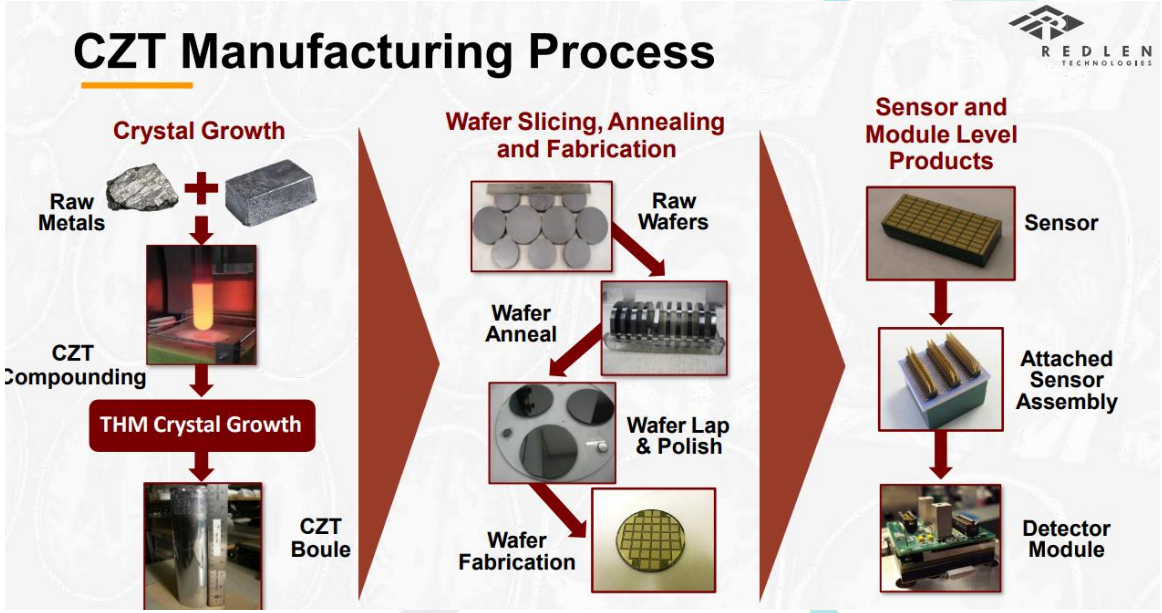


(b)

Proc. of SPIE Vol. 9213 92131L-1

Typically ~10% Zn added
Increase bandgap
Increase resistivity

- ? Charge Transport
  - ? e- okay, h+ poor
- ? Supply Availability
  - ? Redlen, Kromek…
- ? Wafer Size
  - ? Area
  - ✓ Thickness
- ✓ Stopping Power
- ✓ Cost ($$$)



Credit Redlen Technologies

High-Z Detectors - CdZnTe

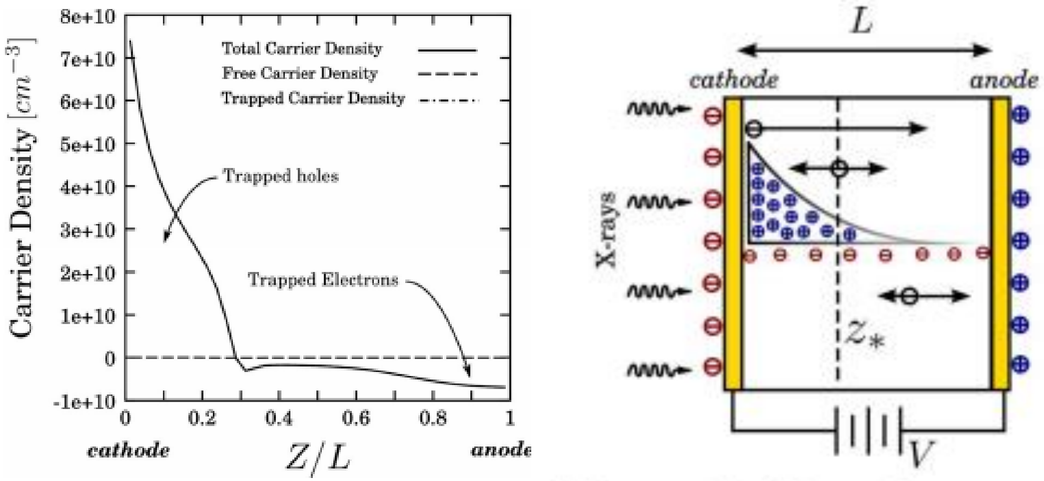
PHYSICAL REVIEW B 77, 035205 (2008)

Nature of polarization in wide-bandgap semiconductor detectors under high-flux irradiation: Application to semi-insulating $Cd_{1-x}Zn_xTe$

Derek S. Bale* and Csaba Szeles
eV PRODUCTS, Compound Semiconductor Group II-VI Inc., Saxonburg, Pennsylvania 16056, USA

(Received 7 September 2007; published 14 January 2008)

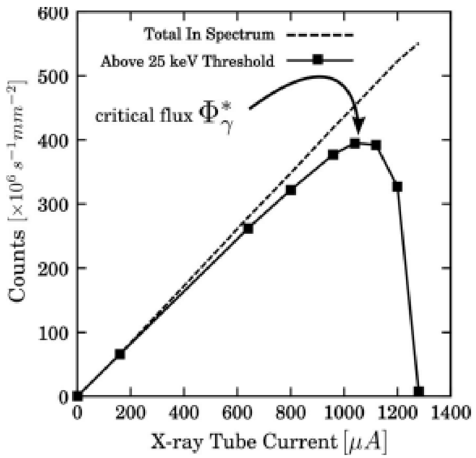
Low Hole Lifetime = Flux induced Polarisation

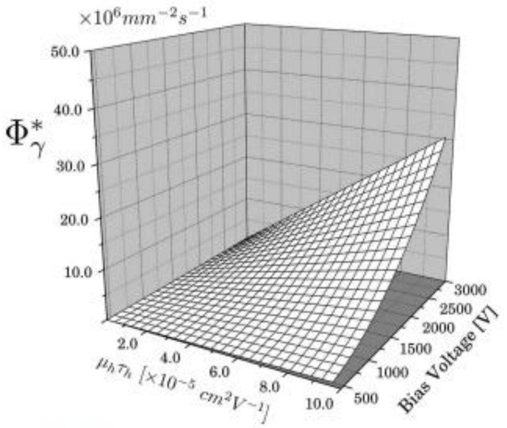


(a)Positive charge build up

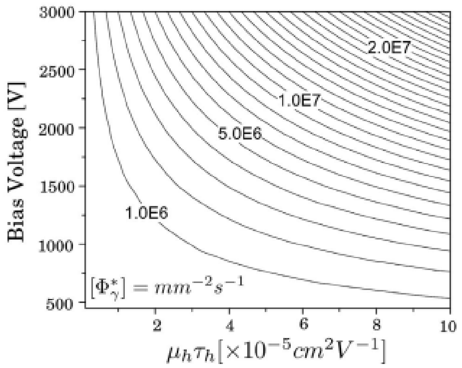
(b)Cartoon of the field strength

Maximum flux depends on drift times and lengths of holes





(a)Surface Plot



Thickness, Bias, Energy Hole mobility and lifetime is key

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High-Z Detectors - CdZnTe

	$\mu_e\tau_e$ ($\times10^{-4}$ cm^{2}V^{-1})	μ_e (cm^{2}V^{-1}s^{-1})	τ_e ($\times10^{-6}$ s)	$\mu_h\tau_h$ ($\times10^{-4}$ cm^{2}V^{-1})	μ_h (cm^{2}V^{-1}s^{-1})	τ_h ($\times10^{-6}$ s)
High Flux CdZnTe	11 ± 6	940 ± 190	1.2 ± 0.8	2.9 ± 1.4	114 ± 22	2.5 ± 1.4
Standard CdZnTe	100	1100	11	0.2	88	0.2

https://doi.org/10.1088/1748-0221/12/12/C12045

JINST

Published by IOP Publishing for Sissa Medialab

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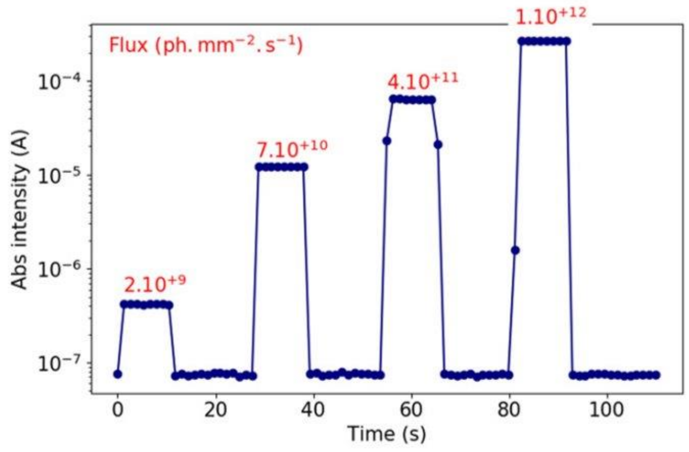
Published: September 5, 2025

Comparison of the charge transport properties of low and high flux grade redlen CdZnTe crystals

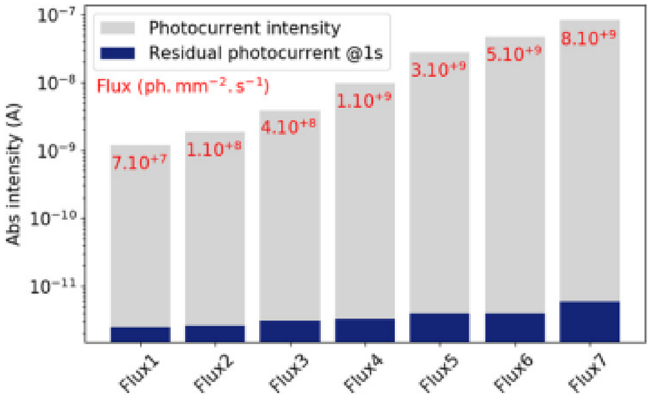
M. Bishop,[a,b,*] M.C. Veale,[b] S.L. Bugby,[a] F.K. Dejene,[a] M. Bettelli[c] and S. Zanettini[d]

Sample	Year Fabricated	$\mu_e\tau_e$ (10^{-3} cm^{2}V^{-1})	μ_e (cm^{2}V^{-1}s^{-1})	τ_e (µs)	$\mu_h\tau_h$ (10^{-4} cm^{2}V^{-1})	μ_h (cm^{2}V^{-1}s^{-1})	τ_h (µs)
A-HF	2018	5.9	990	6.0	2.4	38	6.2
B-LF	2018	12	840	14.4	0.4	-	1.1*
C-HF	2023	3.4	980	3.5	1.3	44	2.9
D-HF	2023	3.9	790	5.0	1.2	32	3.8

O. Baussens et al 2022 JINST 17 C11008

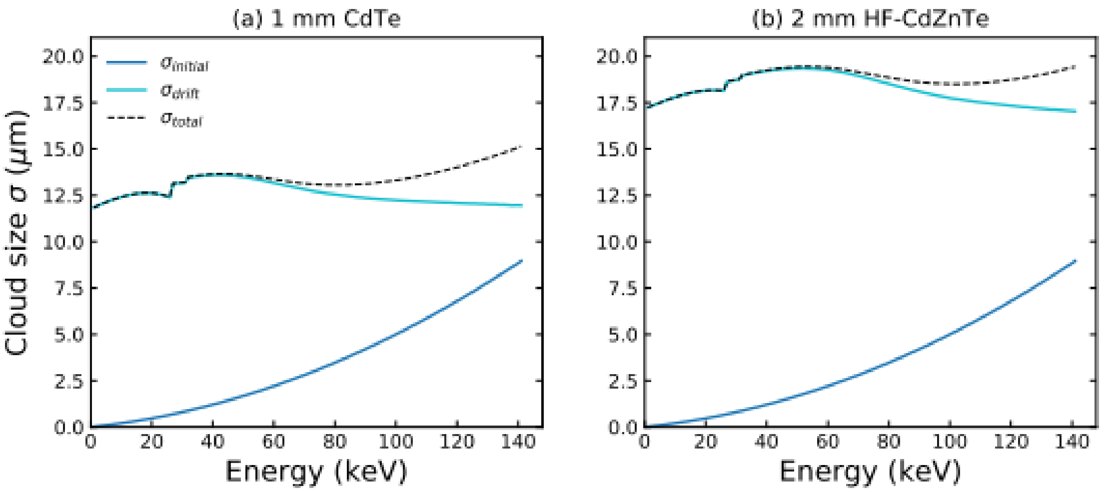


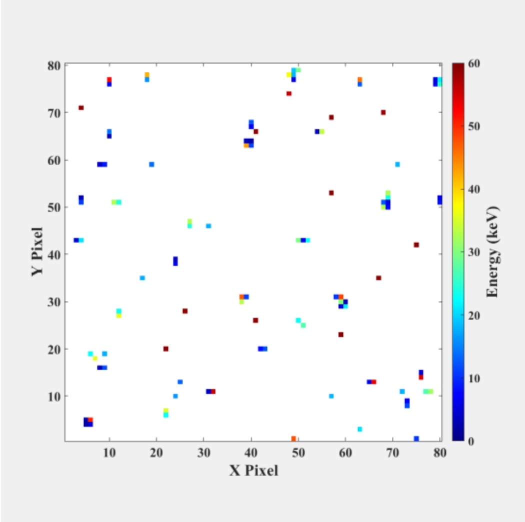
"Excess Leakage Current" and "afterglow"



High-Z Detectors - CdZnTe

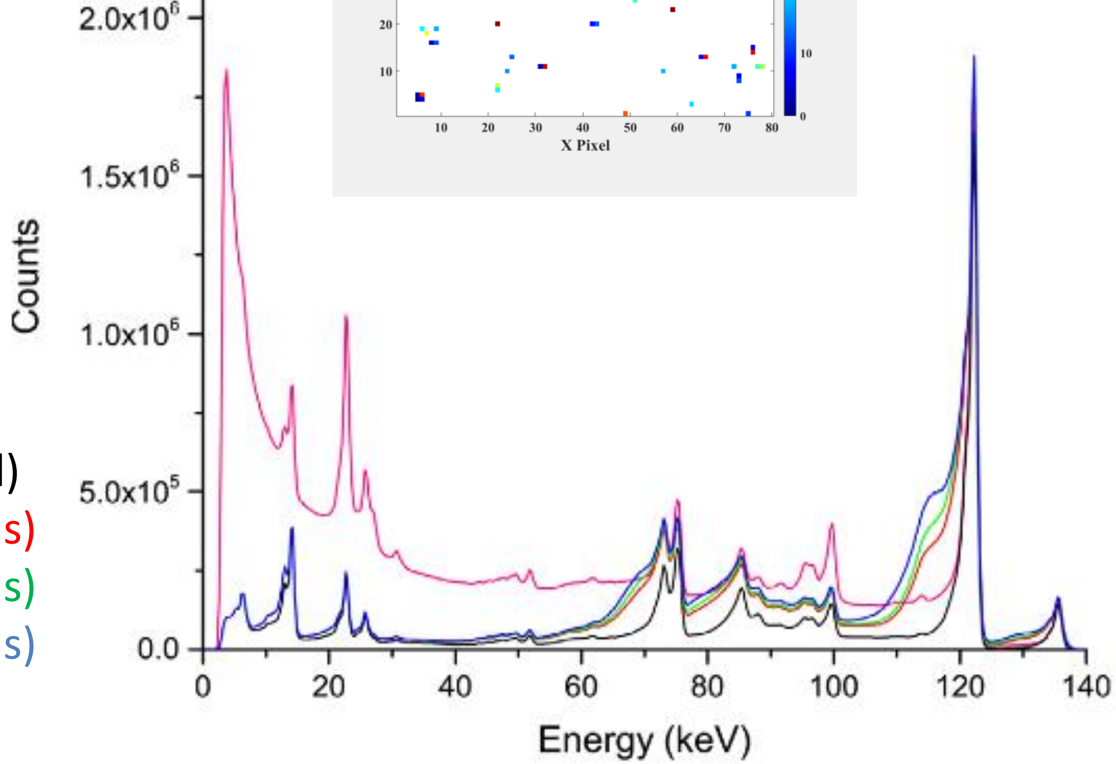
Kjell A. L. Koch-Mehrin, Leicester - Thesis





- 250μm pitch HEXITEC detectors
- 40-60% of events are spread over neighbouring pixels
- Have to reconstruct “charge sharing” for energy spectra
- Challenge for even finer pixels…

Raw
CSD (1 pixel)
CSA (2 pixels)
CSA (3 pixels)
CSA (4 pixels)



High-Z Detectors - CdZnTe

research papers

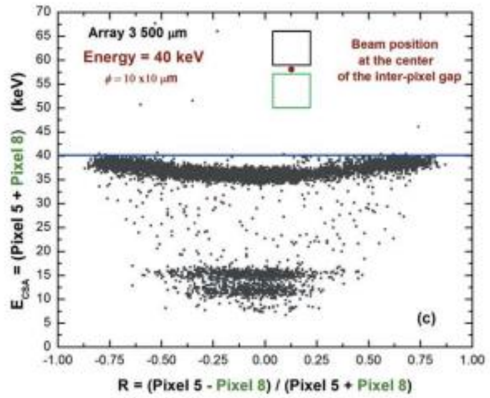
JOURNAL OF SYNCHROTRON RADIATION

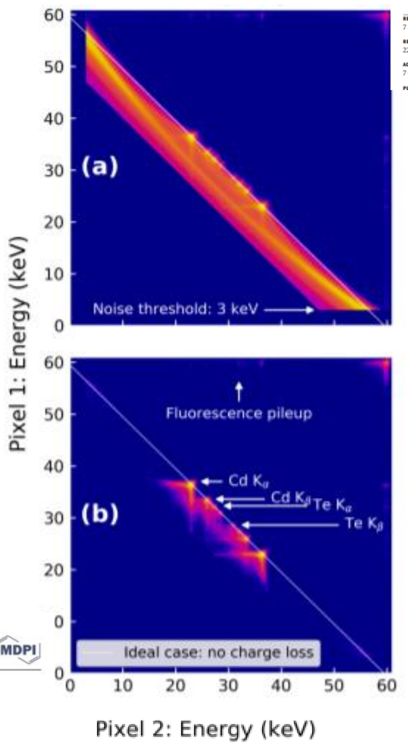
ISSN 1600-5775

Dual-polarity pulse processing and analysis for charge-loss correction in cadmium–zinc–telluride pixel detectors

Leonardo Abbene,[a*] Gaetano Gerardi,[a] Fabio Principato,[a] Manuele Bettelli,[b] Paul Seller,[c] Matthew C. Veale,[c] Oliver Fox,[d] Kawal Sawhney,[d] Nicola Zambelli,[e] Giacomo Benassi[e] and Andrea Zappettini[b]

Received 28 February 2018
Accepted 26 April 2018





- Compare shared fractions and correct for loss

sensors MDPI

Article

Charge Sharing and Charge Loss in High-Flux Capable Pixelated CdZnTe Detectors

Kjell A. L. Koch-Mehrin [1,*], Sarah L. Bugby [2], John E. Lees [1], Matthew C. Veale [3] and Matthew D. Wilson [3]

Correcting Charge Sharing Distortions in Photon Counting Detectors Utilising a Spatial-Temporal CNN

Conference paper | First Online: 04 February 2023

pp 75–90 | Cite this conference paper

IOP Publishing Phys. Med. Biol. 69 (2024) 215006 https://doi.org/10.1088/1361-6560/ad841c

Physics in Medicine & Biology

IPEM

PAPER

Exploring charge sharing compensation using inter-pixel coincidence counters for photon counting detectors by deep-learning from local information

Shengzi Zhao, Le Shen, Katsuyuki Taguchi and Yuxiang Xing

RECEIVED 7 April 2024
REVISED 22 September 2024
ACCEPTED FOR PUBLICATION 7 October 2024
PUBLISHED

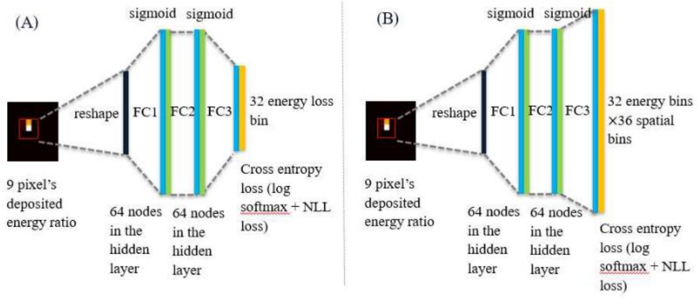
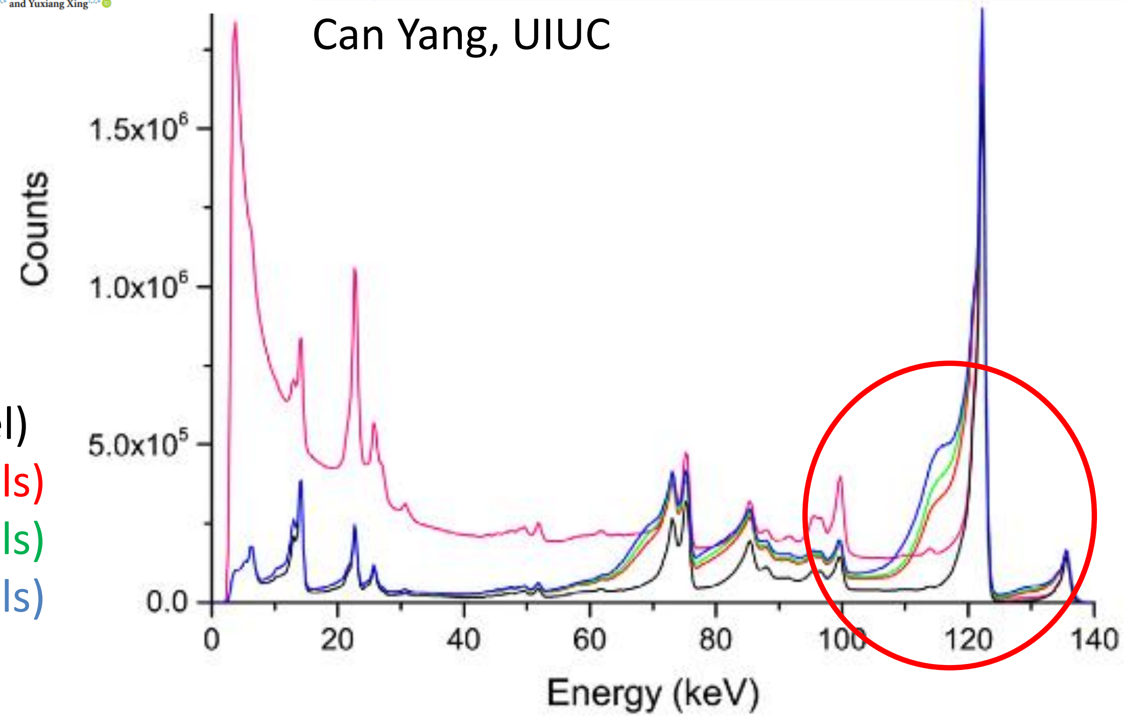


Figure 6: FCNN for energy correction, (A) energy only method, (B) combination method including the position information

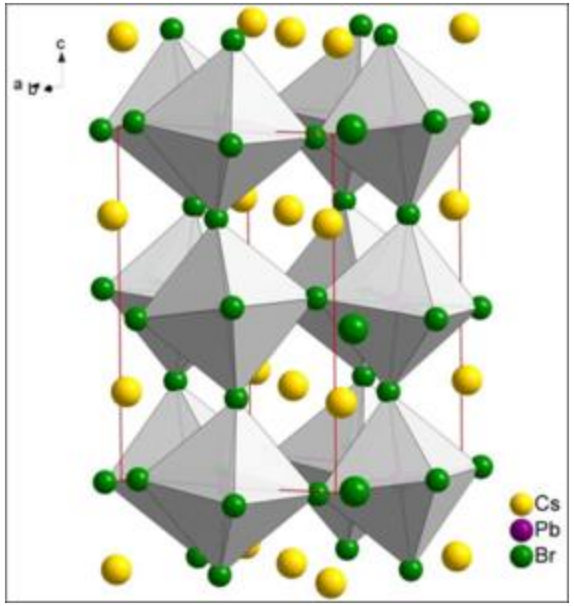
https://www.ideals.illinois.edu/items/123380

Can Yang, UIUC

Raw
CSD (1 pixel)
CSA (2 pixels)
CSA (3 pixels)
CSA (4 pixels)



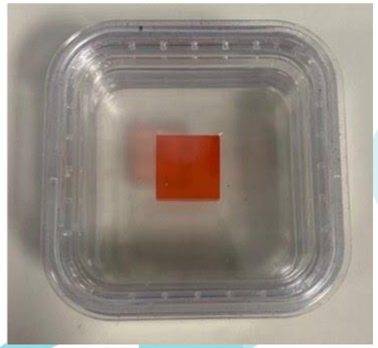
High-Z Detectors - Perovskites

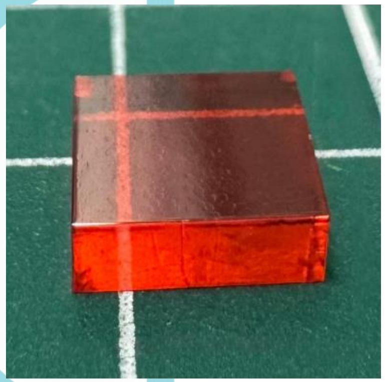


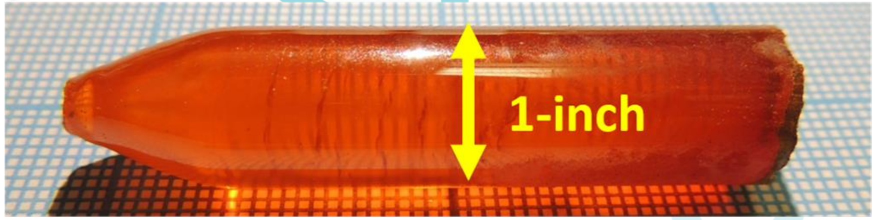
Perovskites ionic crystal structure

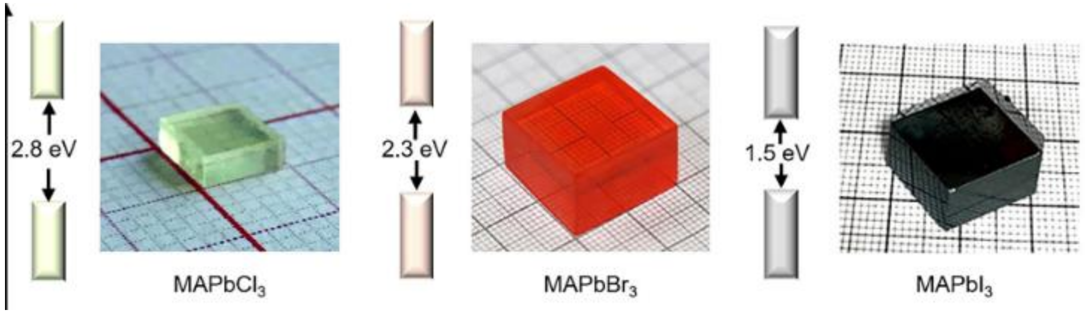
- $CsPbBr_3$
- $FAPbBr_3$
- $MAPbBr_3$
- …

Solution grown at relatively low temperature





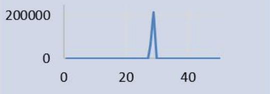
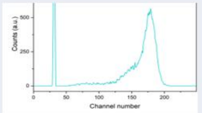
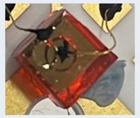
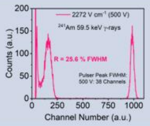
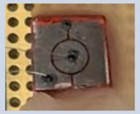
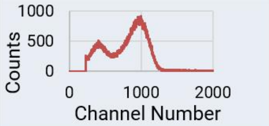
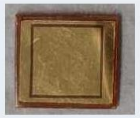


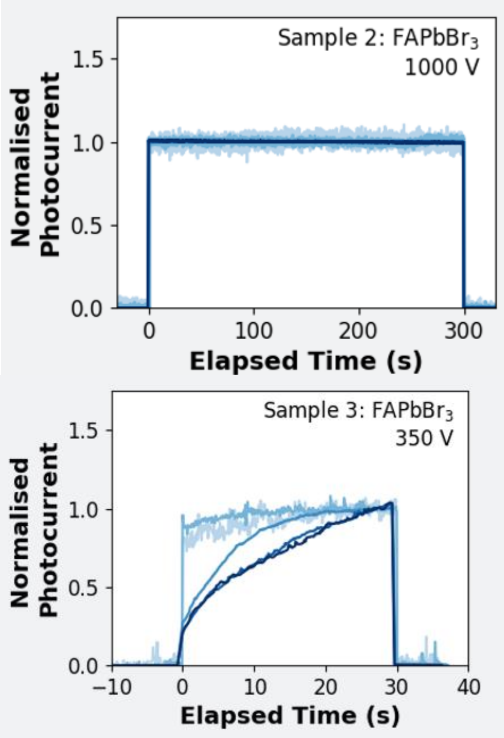


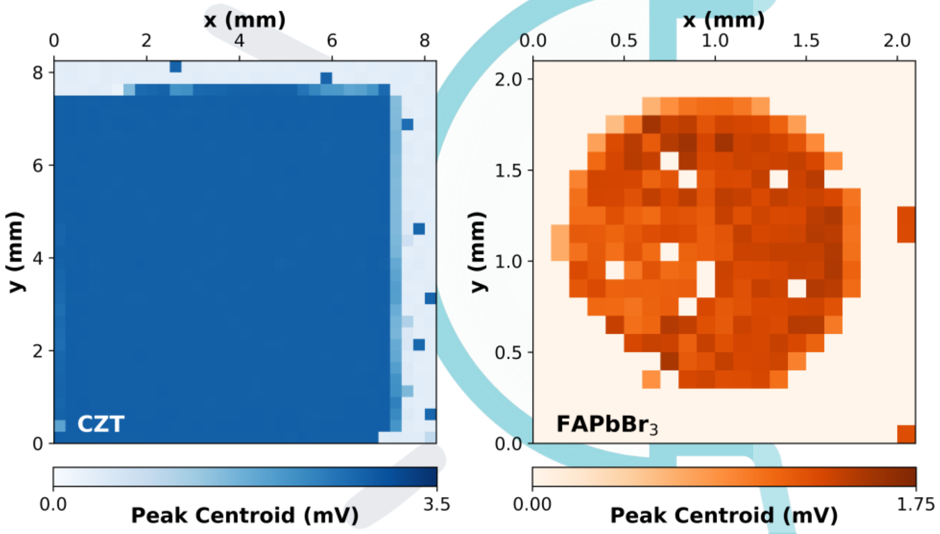
Adv. Funct. Mater. **2026**, *36*, e13676

High-Z Detectors - Perovskites

Many applications, detector types and markets → challenge of single photon resolving to high flux

Material	Growth Method	Am-241 γ-spectrum	Photo
$FAPbBr_3$	Solution grown		
$FAPbBr_3$	Solution grown		
$FAPbBr_3$	Solution grown		
$CsPbBr_3$	Melt grown		





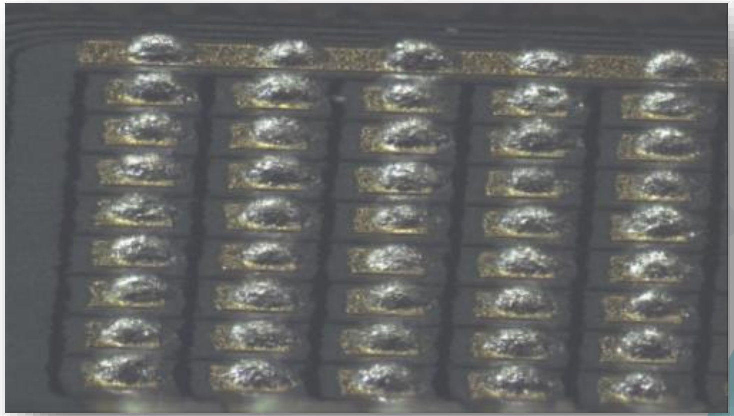
✓ Single photon resolved

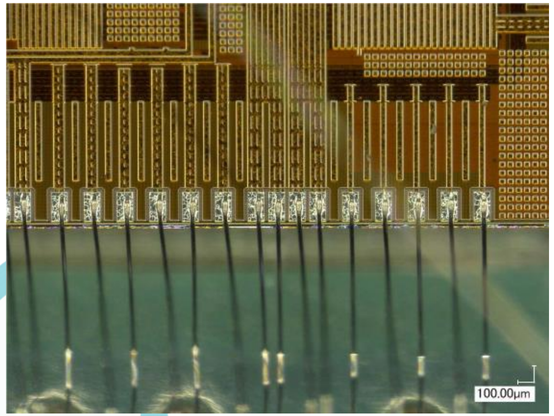
? High flux and stable

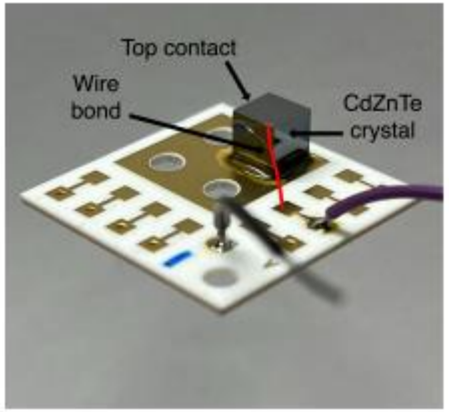
? Scale, uniformity and lifetimes

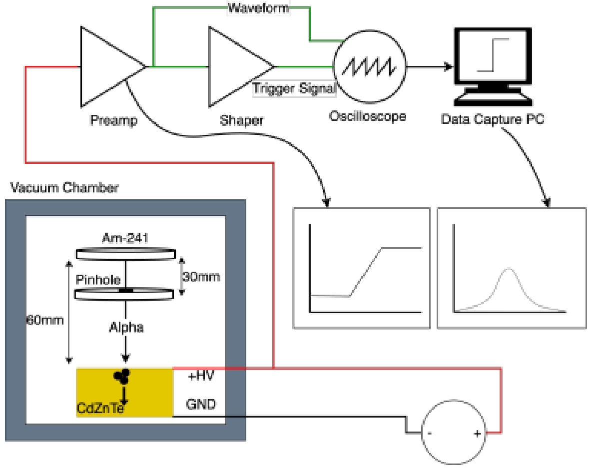
High-Z Detectors - Summary

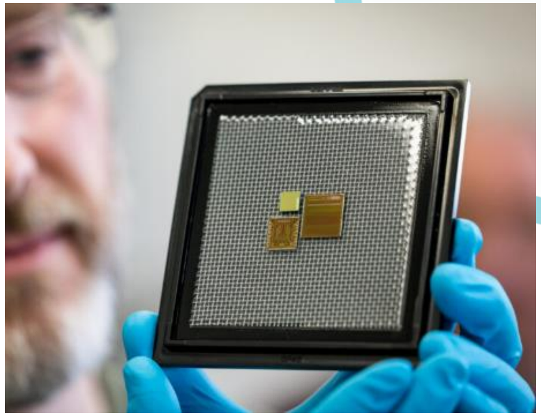
- There are a range of semiconductor detectors
- No one is perfect for the extreme case of next generation light sources
- Interested in collaborating in
  - Characterising
  - Instrumenting
  - ASIC readout
  - ...









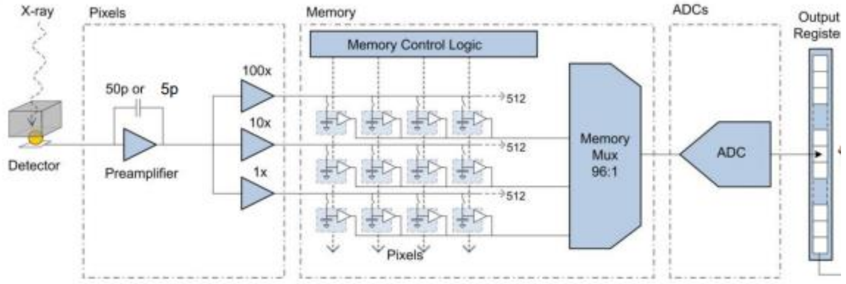


Detector Systems

- But if your flux is too high
- Or all your photons arrive instantaneously (XFEL)
- Then you have to integrate

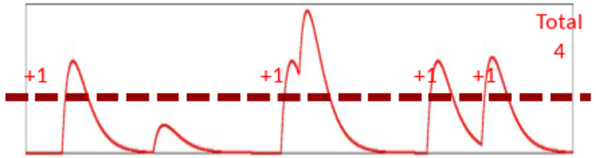
LPD at FXE @ EuXFEL

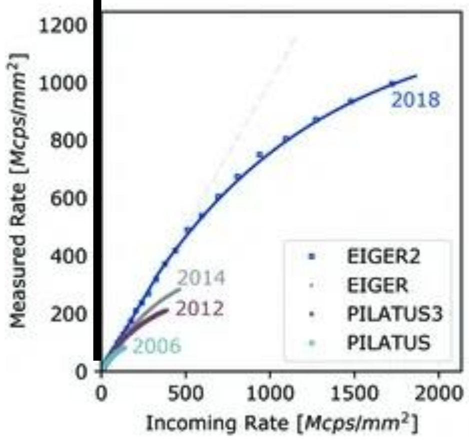
- If you can photon count… then count

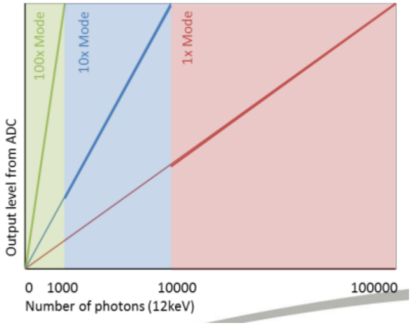


Photons

Single Photon Counter (SPC)

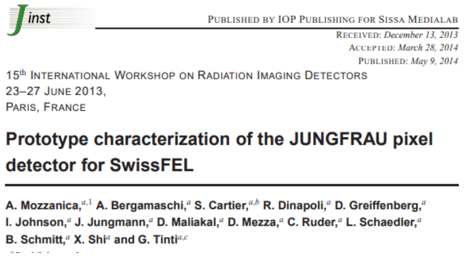






Parallel Circuits with ranges of gain – high dynamic range but takes up space

Integrating Detectors – Adaptive Gain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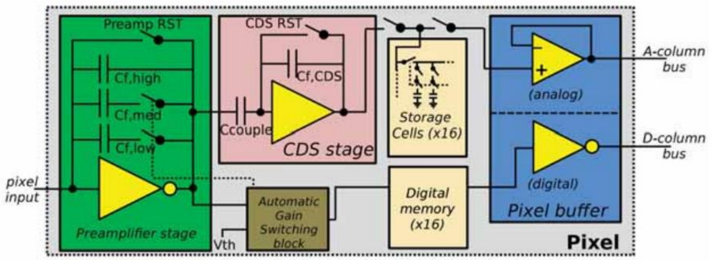
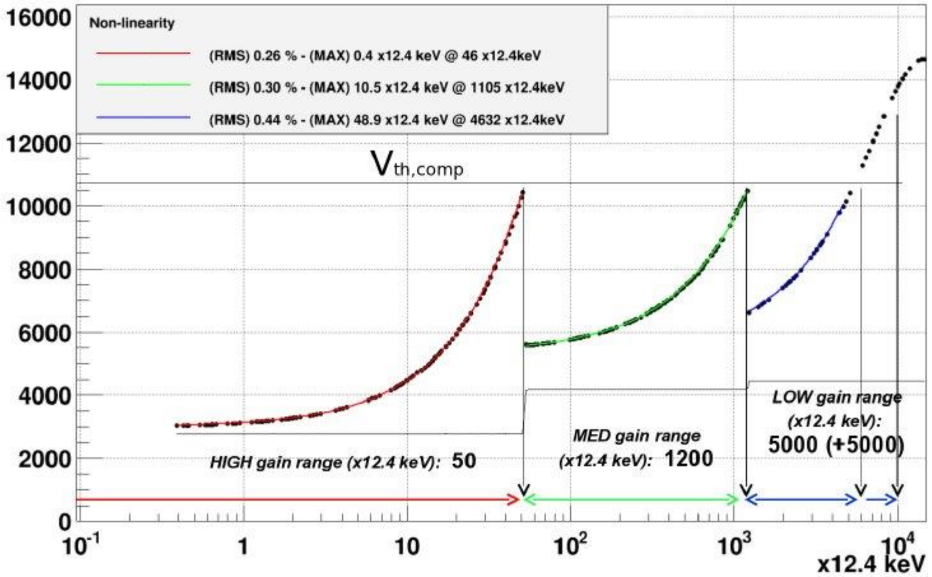
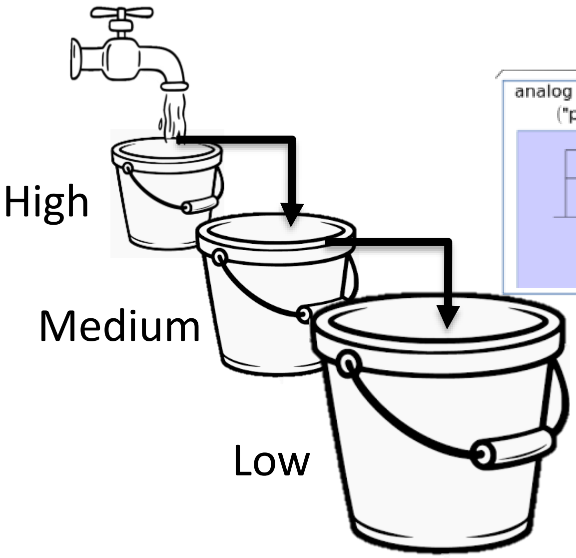
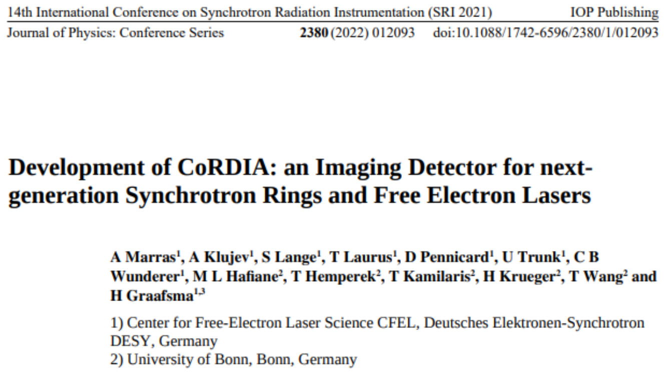
Prototype characterization of the JUNGFRAU pixel detector for SwissFEL

A. Mozzanica,[a,1] A. Bergamaschi,[a] S. Cartier,[a,b] R. Dinapoli,[a] D. Greiffenberg,[a] I. Johnson,[a] J. Jungmann,[a] D. Maliakal,[a] D. Mezza,[a] C. Ruder,[a] L. Schaedler,[a] B. Schmitt,[a] X. Shi[a] and G. Tinti[a,c]








14th International Conference on Synchrotron Radiation Instrumentation (SRI 2021) IOP Publishing
Journal of Physics: Conference Series 2380 (2022) 012093 doi:10.1088/1742-6596/2380/1/012093

Development of CoRDIA: an Imaging Detector for next-generation Synchrotron Rings and Free Electron Lasers

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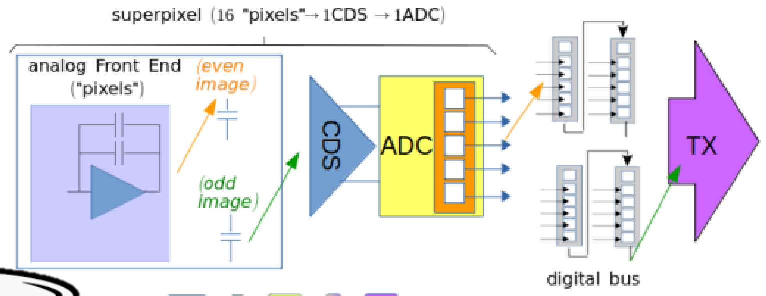
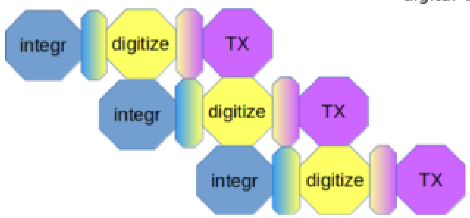
1) Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Germany
2) University of Bonn, Bonn, Germany

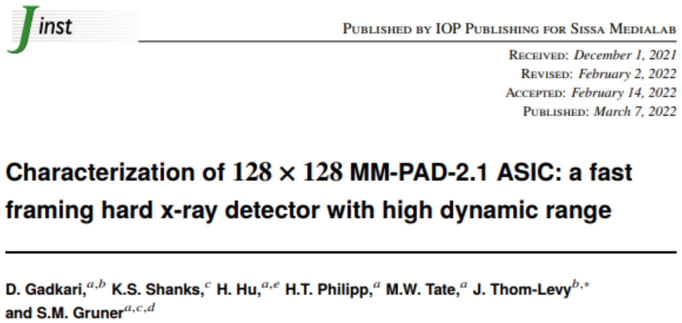




10^4 ph/pixel/pulse * ~kHz → 10^{7-8} ph/pixel/pulse
Great for pulsed sources but not sustained rates

10^4 ph/pixel/pulse * ~100kHz → 10^{9-10} ph/pixel/pulse
Addition of embedded ADC and high speed outputs

Integrating Detectors – Charge Cancellation



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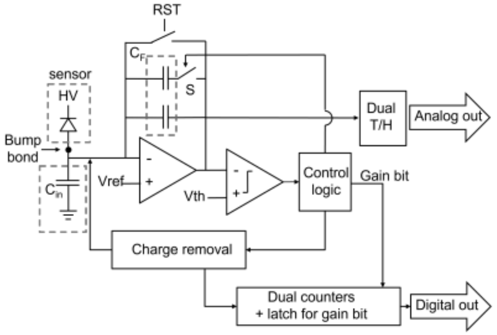
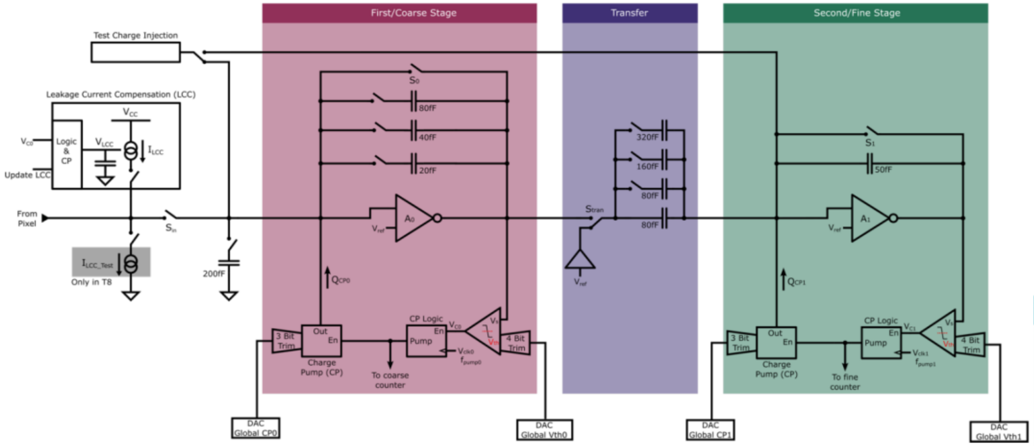
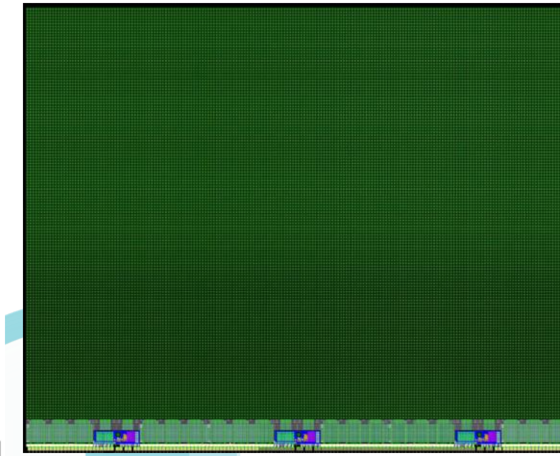
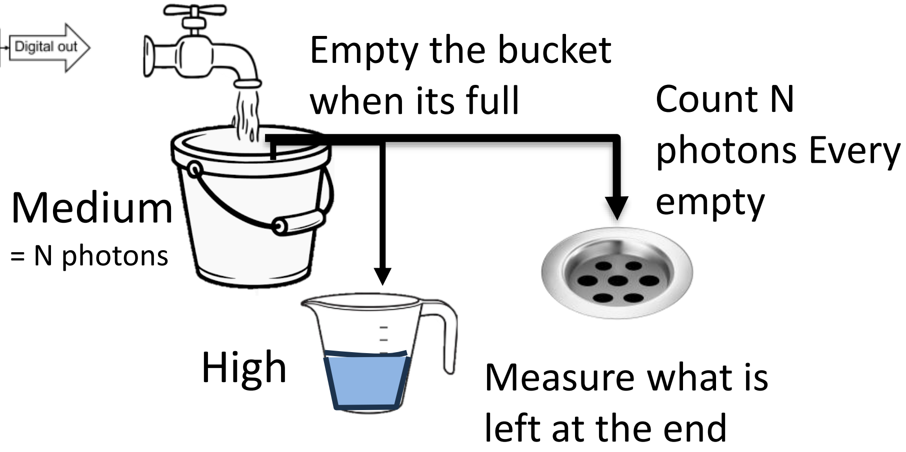
Characterization of 128 × 128 MM-PAD-2.1 ASIC: a fast framing hard x-ray detector with high dynamic range

D. Gadkari,[a,b] K.S. Shanks,[c] H. Hu,[a,e] H.T. Philipp,[a] M.W. Tate,[a] J. Thom-Levy[b,*] and S.M. Gruner[a,c,d]









XIDyn

- 192x144 Pixel with 2-stage charge cancellation - 110µm
- 16bit value per pixel
- ~133kHz frame rate using 6*14.1Gbps CML transceivers
- ~6x10^9 ph/pix/s (energy and LSB)
- In pixel RAM for high rate burst mode
- Test ASICs demonstrated and full scale about to be submitted

Summary

- 4^{th} Generation Synchrotrons are pushing the boundaries of detectors materials, readout ASICs and data rates
- High-Z Sensors are a key requirement
  - Limited suppliers, performance issues
  - Workable but not perfect
  - Developments ongoing
- Directly transferable to medical, NDT and security applications
- Interested in characterising and instrumenting detector materials and collaborators to help test detector materials

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www.cost.eu

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