DECTRIS

Challenging the limits of detection technology

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Contributors and acknowledgements

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DECTRIS team in May 2023

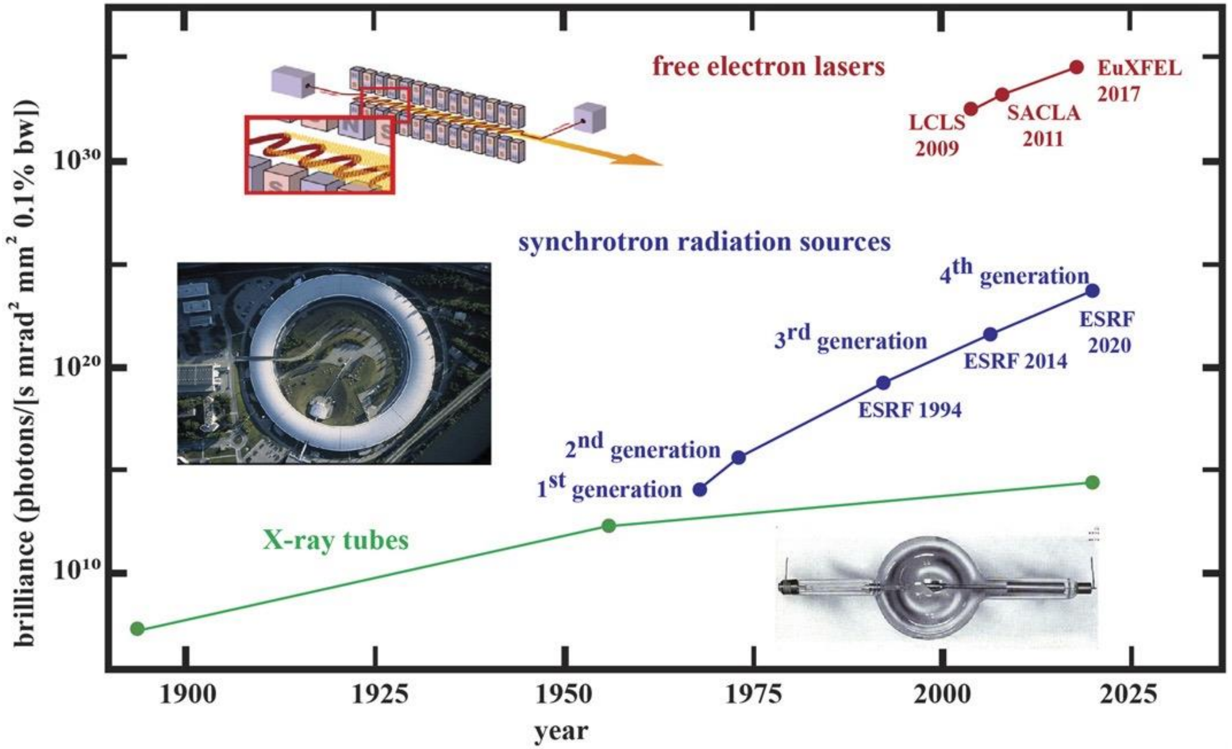
The Challenge

Henry Chapman, IUCrJ (2023) 10, 246

Thirty years ago*, the performance of beamlines was often* ***limited by*** *the speed of* ***detectors****.*
XFELs were such a startling jump of a billion times in peak brightness that large investments were necessary in high-speed ***integrating detectors****.*
These are now a ***great match*** *for the* ***upgraded synchrotrons****.*

Counting hybrid pixel detectors are a **great match** for **synchrotrons** and **electron microscopy!**

9 orders of magnitude in 35 years !



V Cerantola *et al*
J. Phys.: Condens. Matter **33** (2021) 274003

DECTRIS milestones

2006 — **DECTRIS** founded

DECTRIS

2007 — **PILATUS** 7 employees

2008 — **MYTHEN** 12 employees

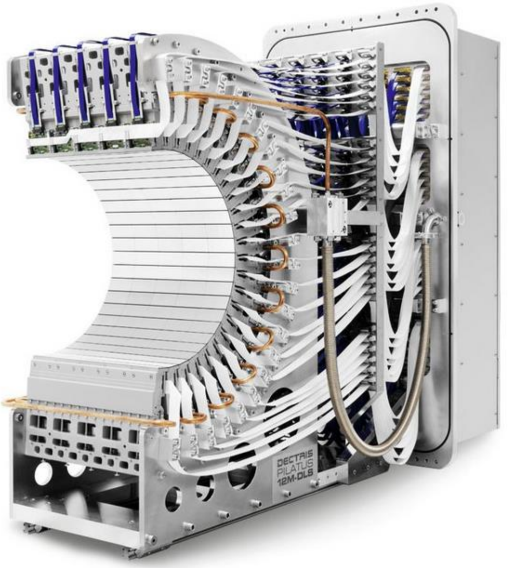
2012 — **PILATUS3** 44 employees

2015 — **EIGER, MYTHEN2** 79 employees

2018 — **DECTRIS USA, EIGER2** 100 employees

2020 — **EIGER2 CdTe, QUADRO, ELA** 130 employees

Now — **DECTRIS JAPAN** **ARINA** 160 employees



Challenging the limits of detection technology

2007 PILATUS

2012 PILATUS3

2014 PILATUS3 CdTe

2014 EIGER

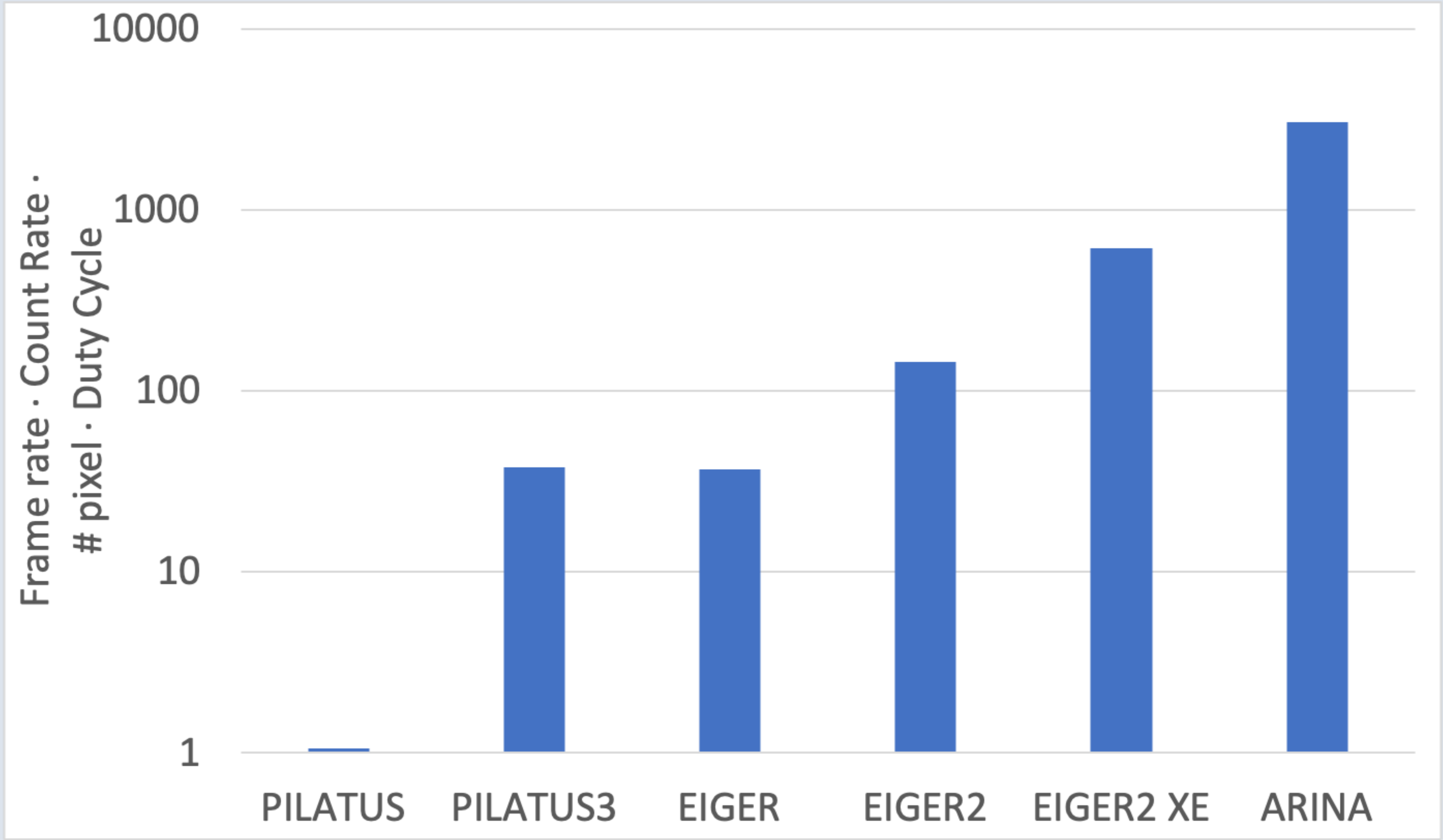
2017 EIGER2

2018 EIGER2 CdTe

2019 EIGER2 XE

2022 E2 feature upgrade

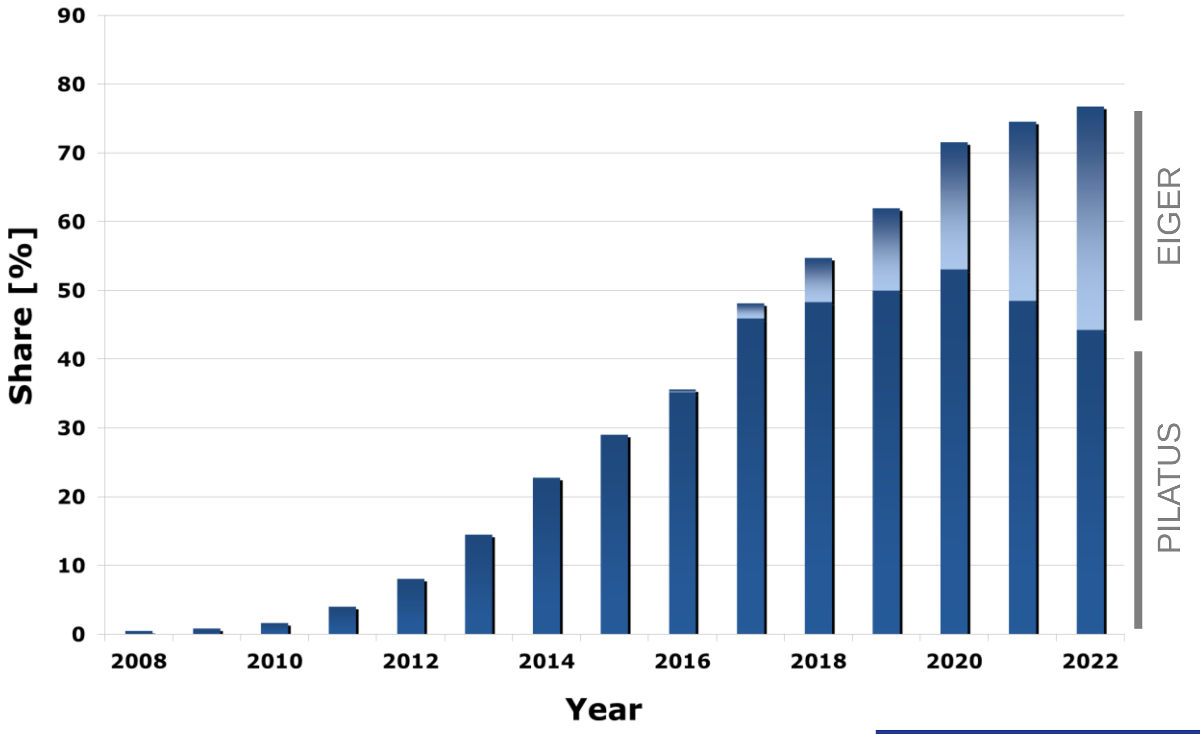
2022 ARINA



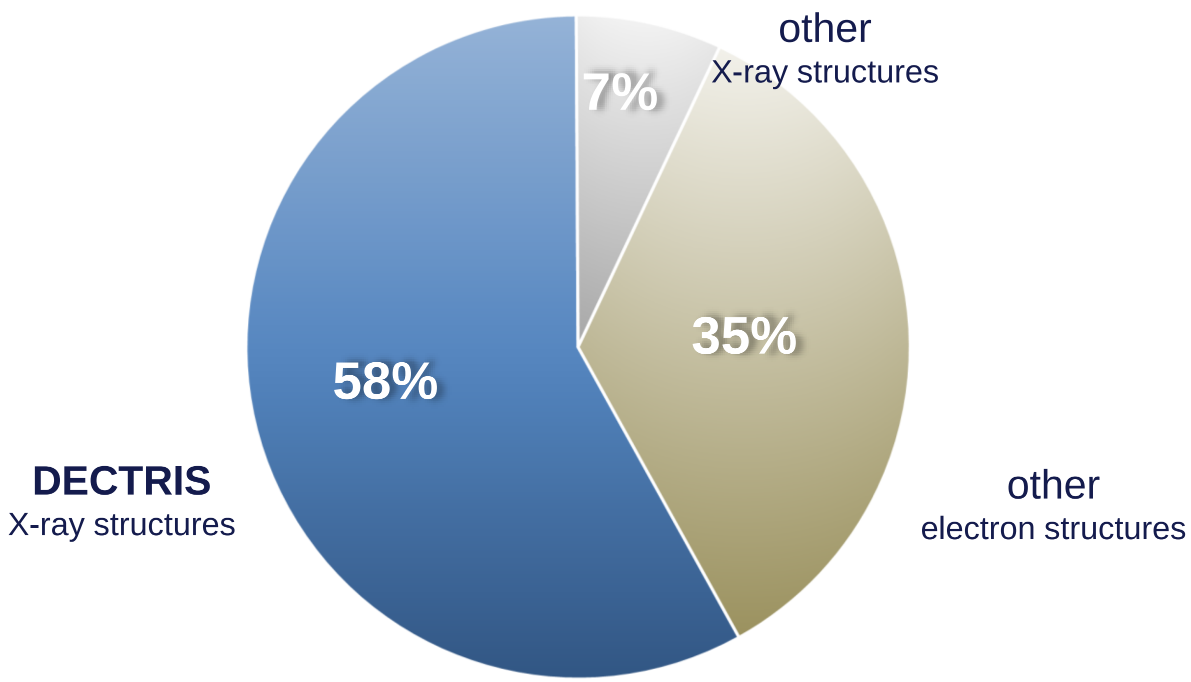
DECTRIS detectors transforming protein crystallography

DECTRIS detectors for Protein Crystallography

Protein Crystallography structures in PDB determined **with DECTRIS detectors**



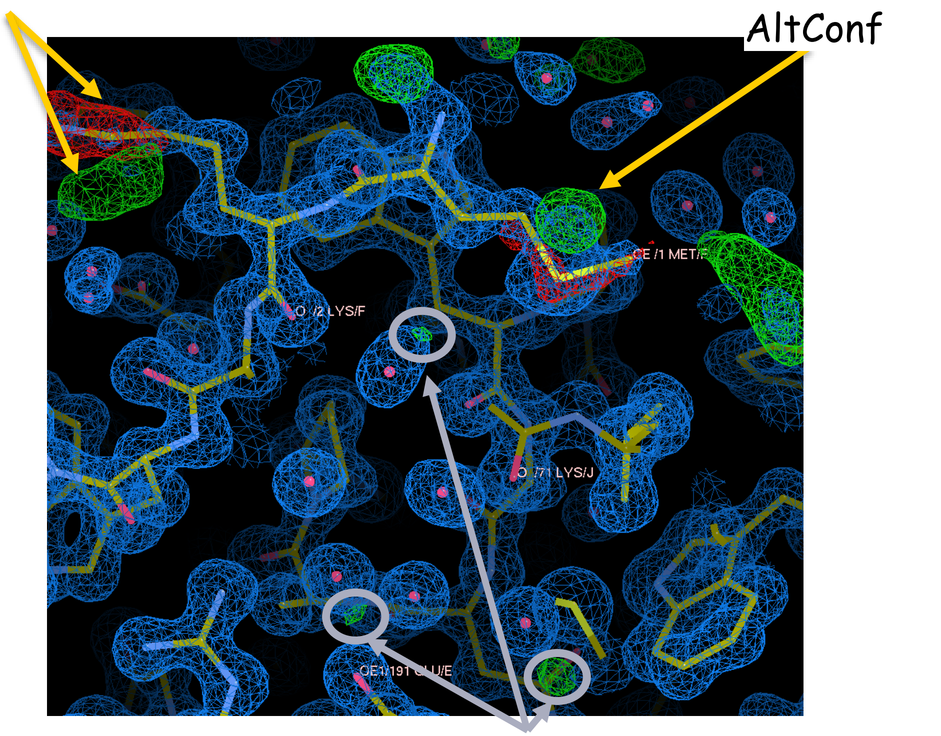
SARS-COV2 portein structures in PDB determined with **DECTRIS detectors**



DECTRIS accelerates modern drug development

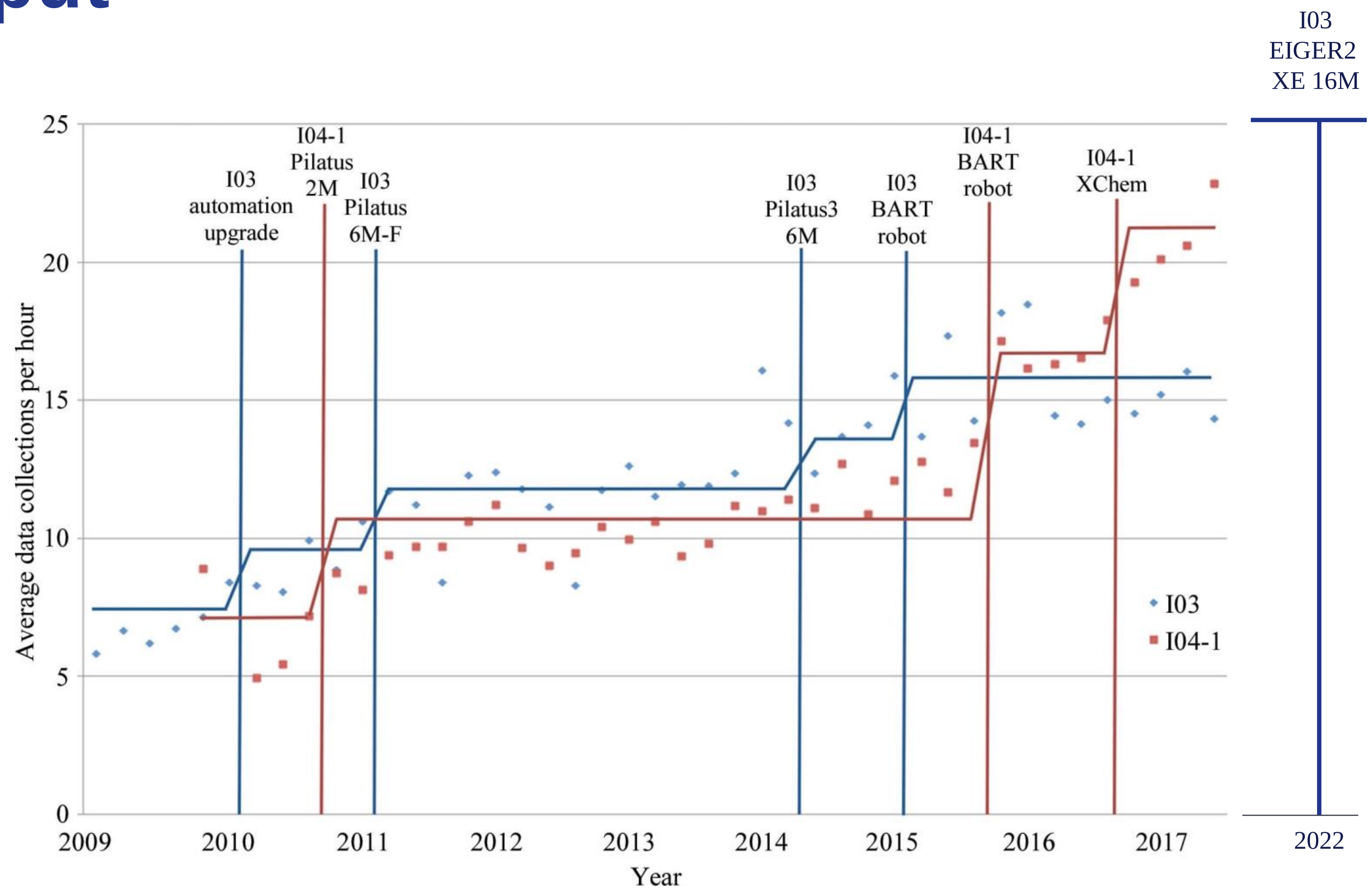
Data quality and throughput

DECTRIS Detectors for Protein Crystallography



Indications of partially occupied waters, separately validated as belonging to alternate water networks.

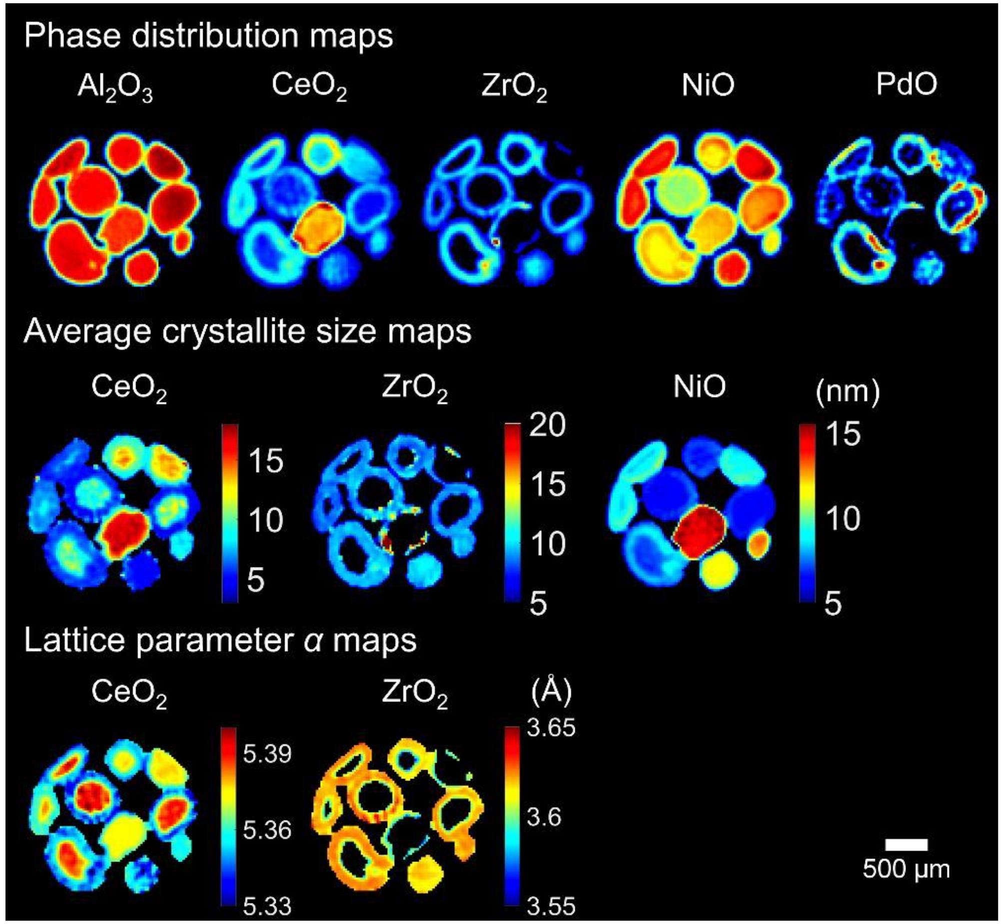
By courtesy of A. Chari, G. Bourenkow, G. Bricogne et al.



Grimes *et al.* Where is crystallography going? Acta Cryst. (2018). D74, 152–166
https://www.diamond.ac.uk/Instruments/Mx/I03/I03-Manual/Unattended-Data-Collections/Experiment-Types.html

Mastering society's most important challenges

Maps from Rietfeld analysis of XRD-CT



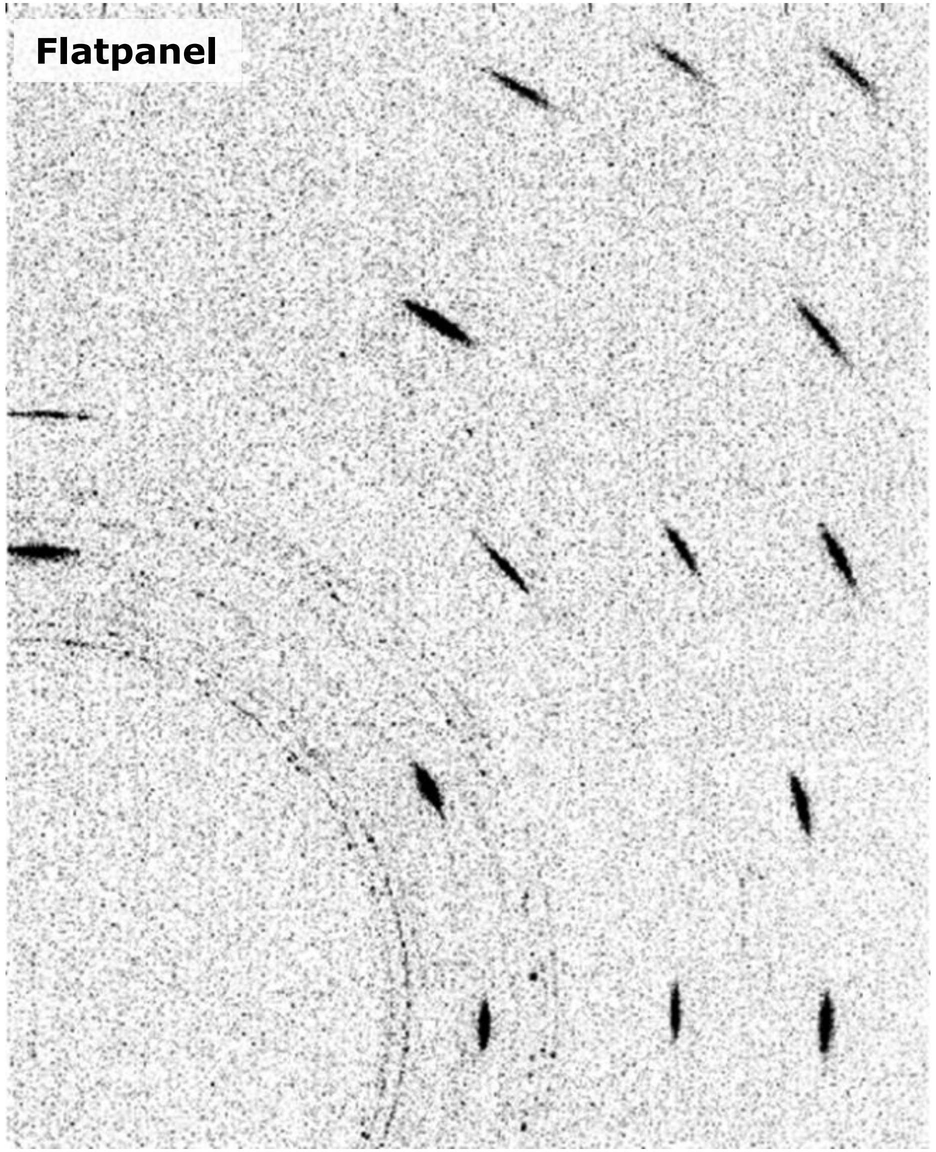
Energy: 70 keV Beamsize:25×25μm2 (H×V) Translation step: 25 μm Vertical step: 25 μm Exposure time: 10 ms, Reactor cell: 2 mm OD

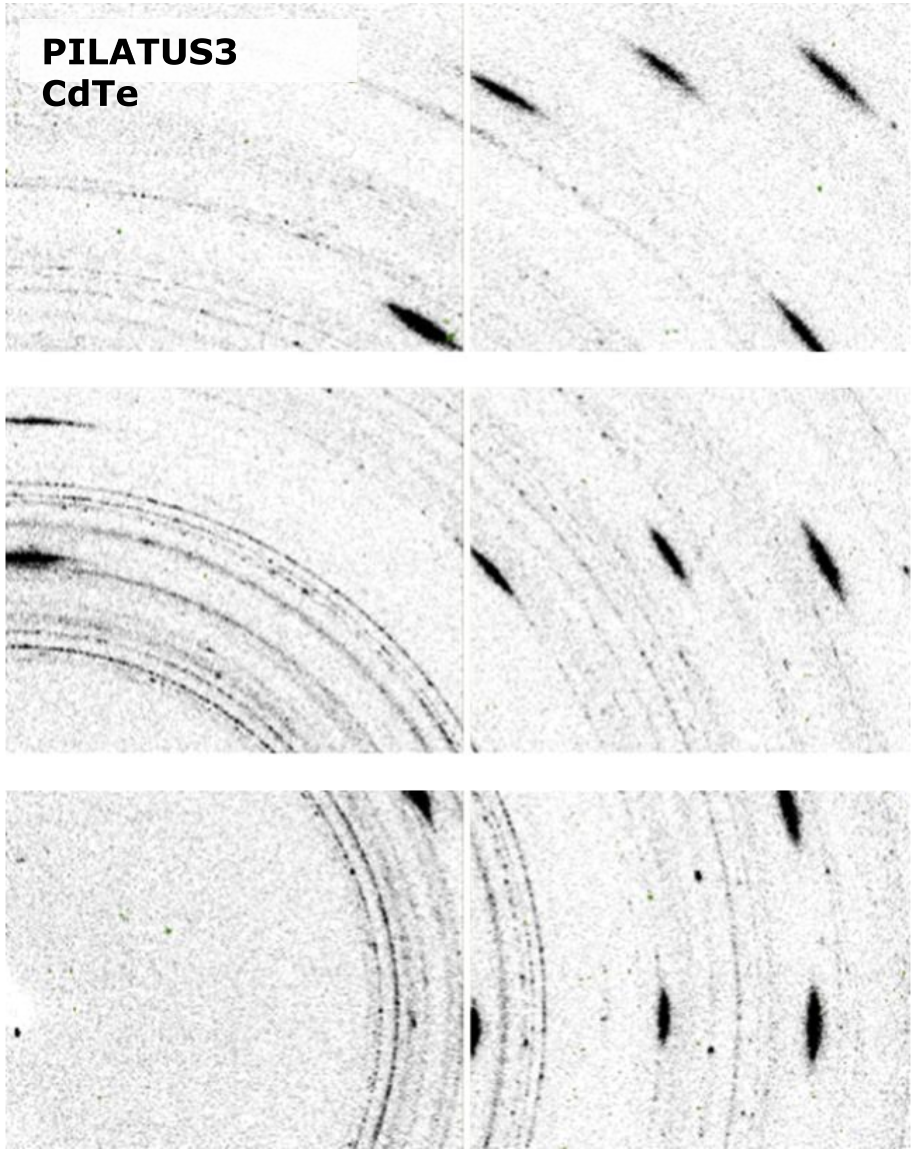
The XRD-CT Pioneers

Winner: 2023 Analytical Science Horizon Prize: Sir George Stokes Prize

Finden Ltd, a British scientific consultancy, has achieved significant advancements in X-ray diffraction computed tomography (XRD-CT) and related chemical imaging methods like pair distribution function computed tomography (PDF-CT) or multimodal-CT through collaborations with academic and industrial partners. Most recently, Finden has driven the development of XRD-CT to the point where high-quality data can be generated for a variety of **functional materials under operational conditions.**

No readout noise: X-ray Powder Diffraction





Sample:
Superconducting filament containing Nb_3Sn powder in a tungsten tube (Ø50µm).

Energy: 46.3 keV

Same static powder diffraction pattern:

- same solid angle (same flux) per pixel,
- same exposure time 100 ms.

DECTRIS Courtesy ESRF ID15: M. Di Michiel, G. Vaughan, R. Homs, T. Buslaps Univ. Manchester: S. Jacques

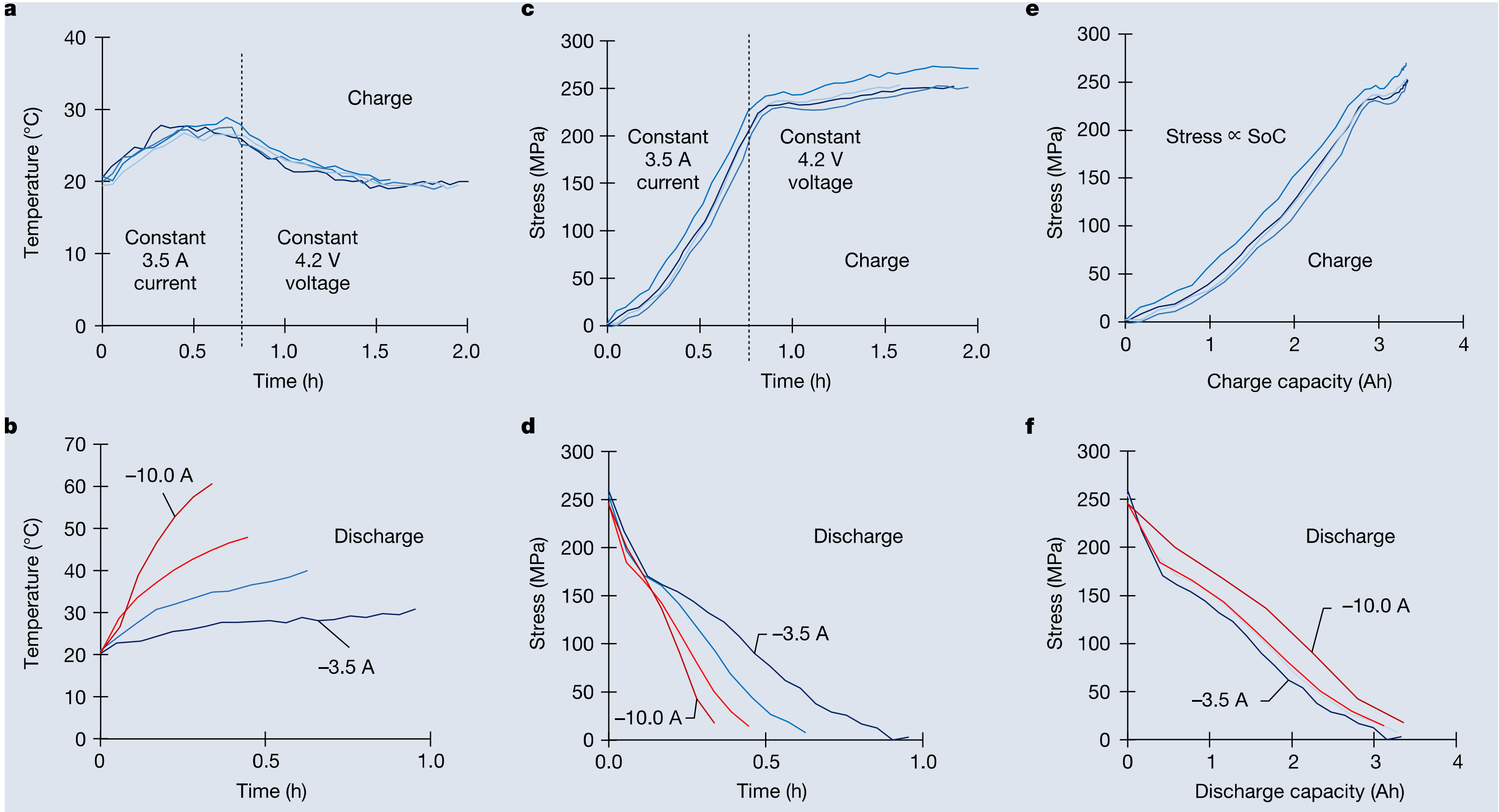
Temperature measurements in lithium ion batteries during high-rate charging and discharging

LFP and NMC cathode materials in 18650 cells

Challenge
Lattice changes due to temperature orders of magnitude smaller than due to lithiation

Solutions
3D XRD-CT data permit decoupling of thermal from mechanical contributions to electrochemical changes

Multi-channel collimator set-up allow suitable measurement precision under fast operation dynamics (internal operando studies)



T.M.M Heeman *et al.* Nature | Vol617 | 2023 | **507**

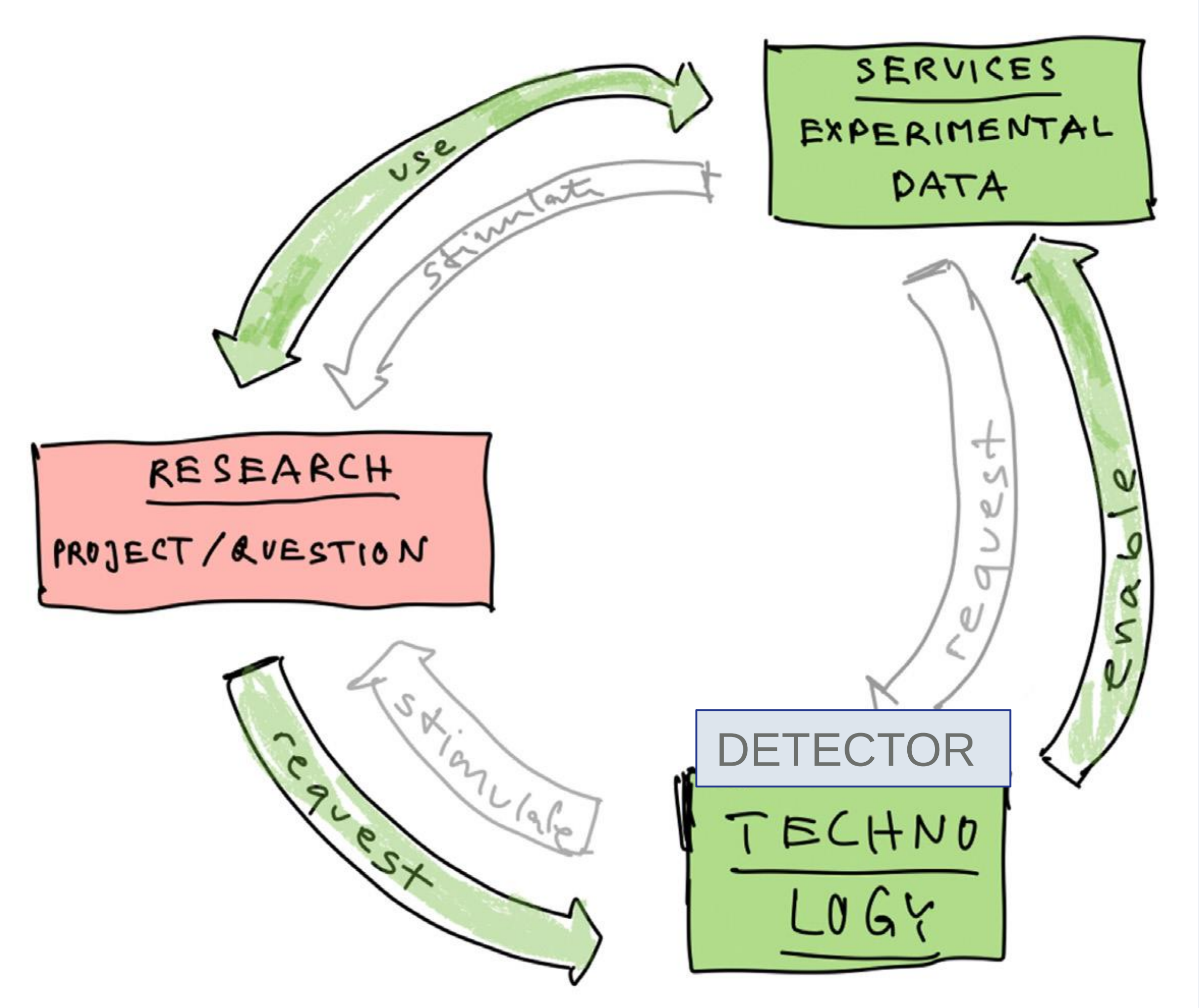
DECTRIS

DECTRIS – detecting the future

Our Vision is to be a sustainable, independent, and trusting company that anticipates the **needs of scientists and engineers around the world**.

What have we learned from the first detector generation?

1. The first detector generation was fully integrated with no EuXFEL available
   - real tests can be done only with the time structure and pulse intensity of the EuXFEL
   - it is important to test prototypes as soon as they become available
2. Last year EuXFEL provided ca 8000 hours for user beamtime
   - ease of operation is a must
   - reliability is a must, ease of intervention facilitates operation a lot
   - reliable hardware interlocks are vital
3. Data quality is the main parameters to judge detector quality
   - need for reliable calibration sources
4. Having several different technologies increases the operation burden a lot
5. The volume of the produced data is enormous and reduction strategies must be put in place



EMBL research-service-technology virtuous circle.

IBEX for electron microscopy

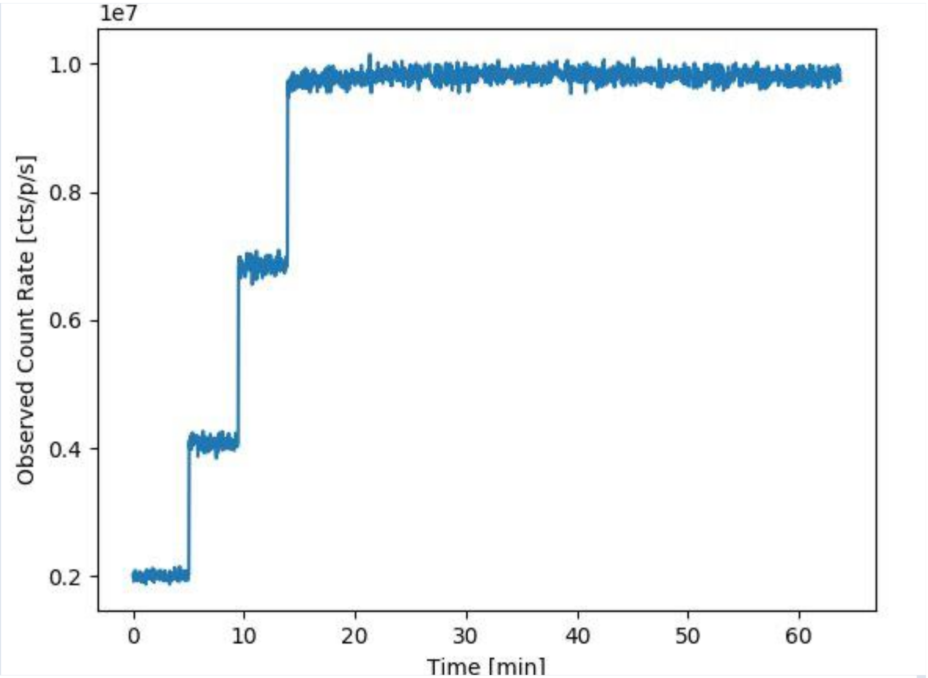
Key benefits

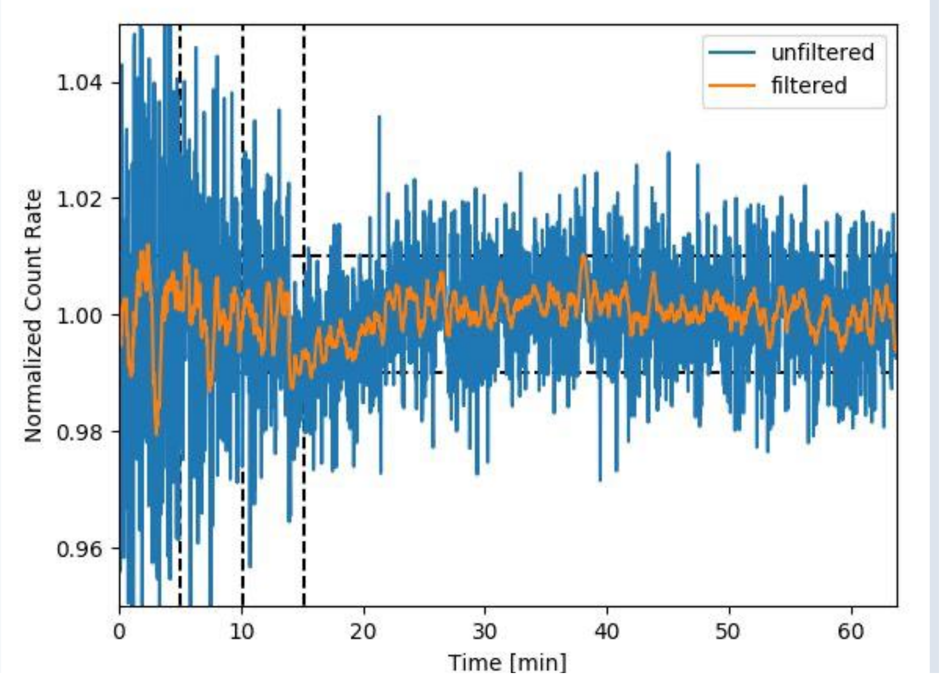
- High count-rate capability
- Noise-free counting
- High Dynamic Range
- High-frame rates

- Stability
- Radiation hardness
- Room-temperature operation

- Optimise MTF, DQE and rate capability, depending on the application needs.

X-rays: M. Bochenek, et al., *IEEE Trans. Nucl. Sci.* **65** (2018) 1285
Electrons: S. Fernandez-Perez *et al* (2021) *JINST* **16** P10034

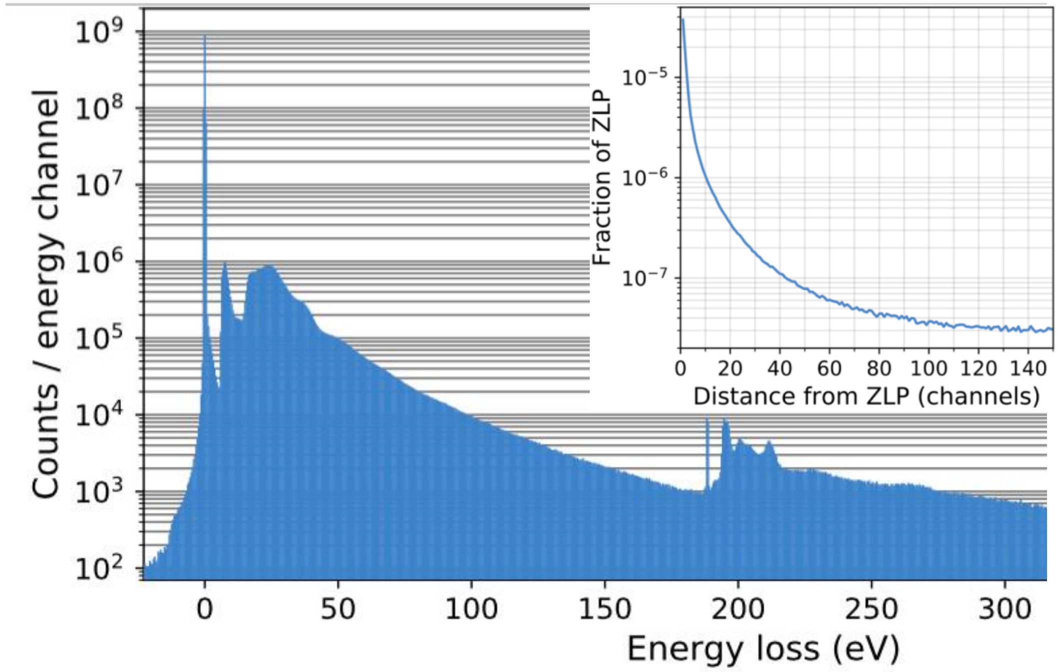




300 kV electrons, 1 ms exposure time, norm. on background

ELA for EELS

EELS = Electron Energy Loss Spectroscopy



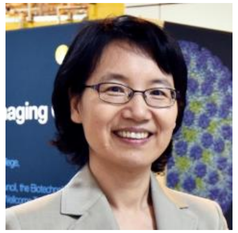
”… a spectrum showing that both the intense zero loss peak and an inner shell loss edge can be recorded in the same spectrum, under 100 pA probe current, while detecting single electrons with good DQE. That's something that no other detector with this many pixels has been able to do so far". **Dr. Ondrej Krivanek, Founder of NION**

B. Plotkin-Swing, et al.
Ultramicroscopy 217 (2020) 113067

- Detector on loan from Dectris
  - Mounted on RCaH glacios
  - Hybrid pixel detector, radiation hard, 4kHz readout

1. Make it work
2. Compare it to Ceta-D
3. Do something useful

By courtesy of David Owen,eBIC



Thermo SCIENTIFIC

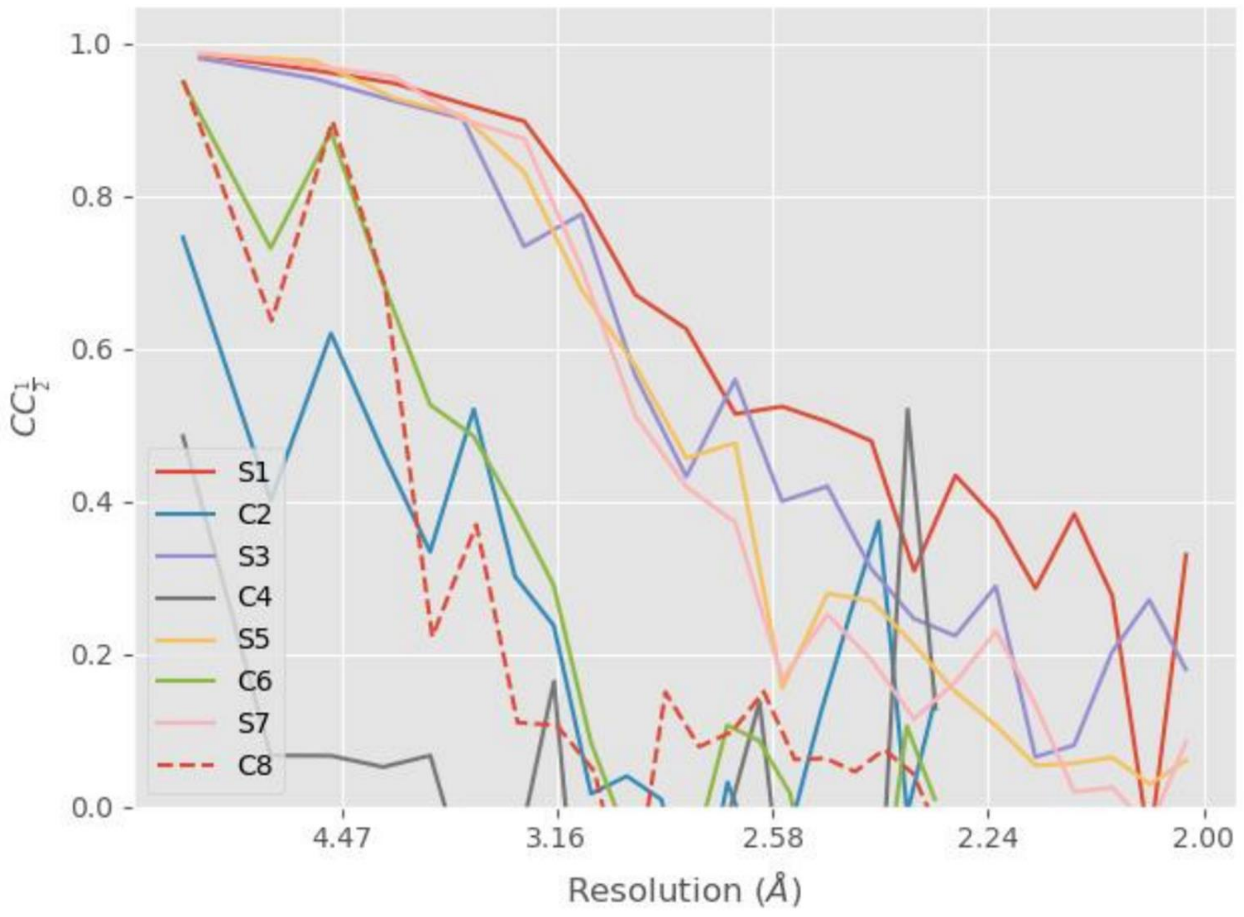
Research Complex at Harwell

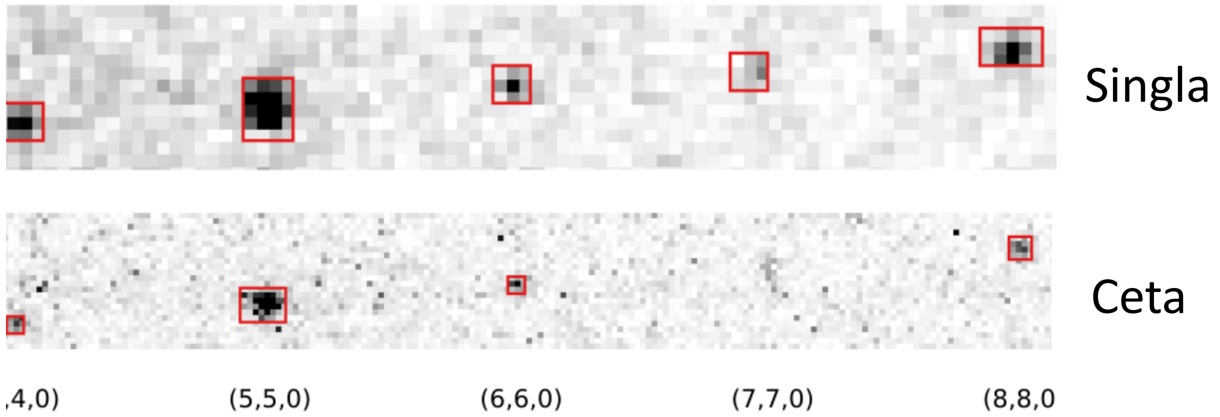
diamond

DECTRIS detecting the future

Singla → Ceta → Singla → Ceta → Singla → Ceta

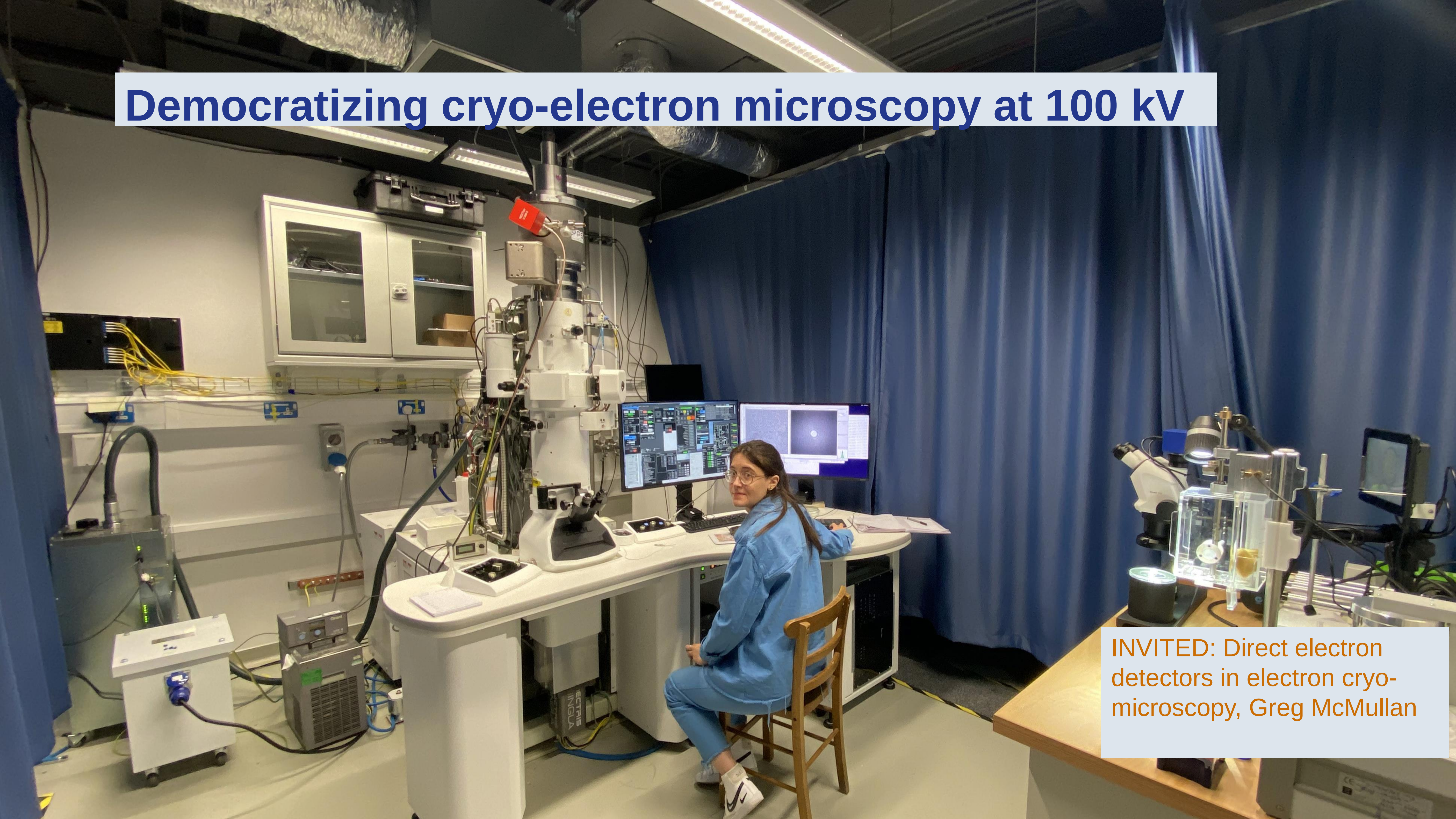
Singla	Ceta	Singla	Ceta	Singla	Ceta
(~1.1 e/Å²), 80°	(~1.1 e/Å²), 80°	(~1.1 e/Å²), 80°	(~1.1 e/Å²), 80°	(~1.1 e/Å²), 80°	(~1.1 e/Å²), 80°
Δ°=0.1-0.2	Δ°=0.5-1	Δ°=0.1-0.2	Δ°=0.5-1	Δ°=0.1-0.2	Δ°=0.5-1





By courtesy of David Owen,eBIC

Democratizing cryo-electron microscopy at 100 kV



INVITED: Direct electron detectors in electron cryo-microscopy, Greg McMullan

KITE ASIC for 4D STEM

Optimized for high frame- and count-rates

Key technical parameters of the KITE ASIC.

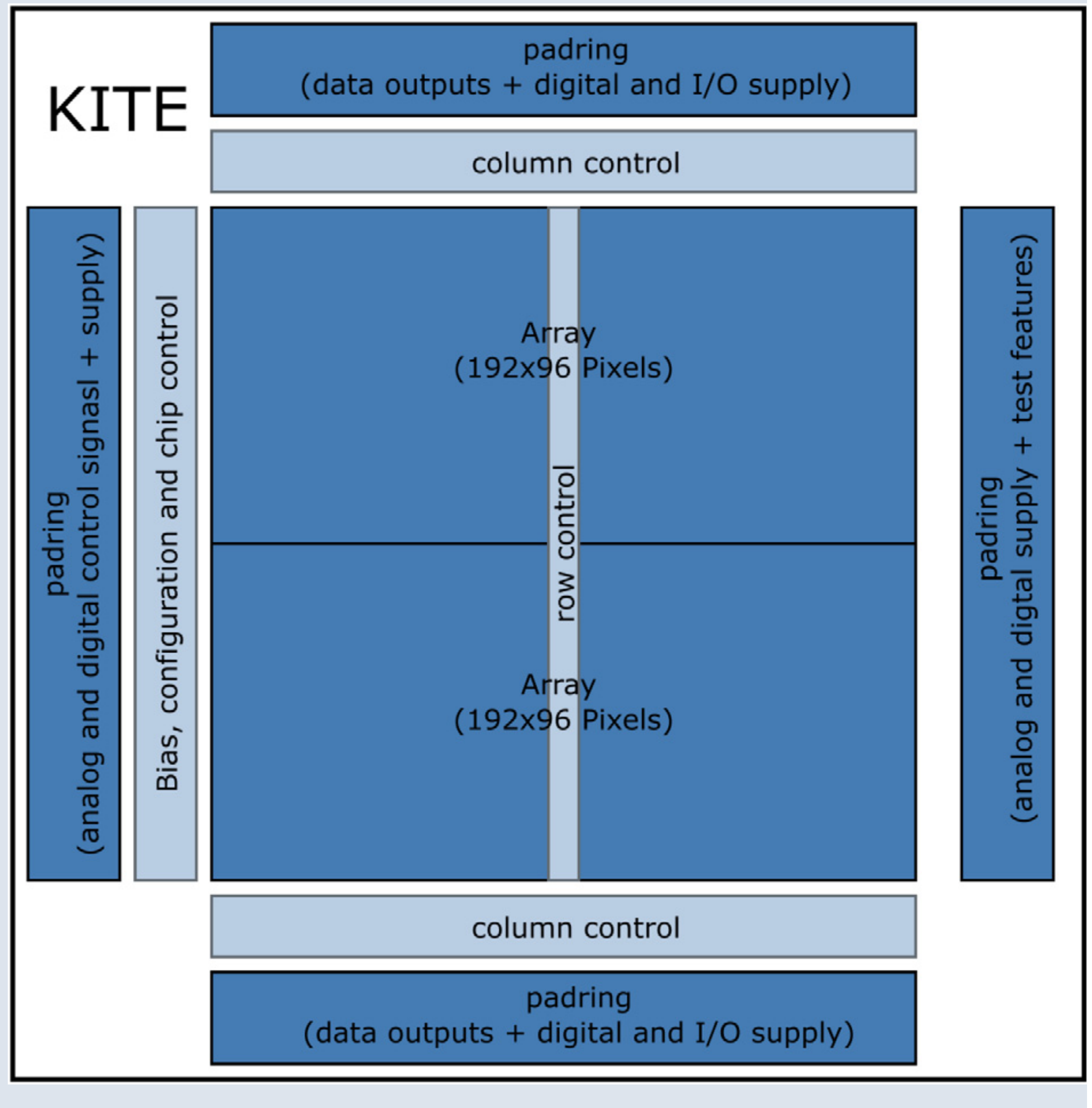
Power supply voltage	1.2 V
Pixel size	100 μm × 100 μm
Pixel array	192 × 192 pixels
Active area	19.2 mm × 19.2 mm
Die size (incl. pads)	20.5 mm × 20.5 mm
Operating mode	Particle Counting
Input polarity	Positive (Si)/Negative (High-Z)
Number of thresholds	1
Instant retrigger	Yes
Continuous readout	Yes
Readout modes	Full frame/2 × 2 pixel digital binning
Counter encoding	12-bit integer/8-bit floating-point
Operating temperature	Room temperature

Control Blocks

- all reference and bias voltage generated on-chip
- row control logic for row selection between central columns
- Column control with 12 bit shift register and 8 bit floating-point compression

I/O pad ring

- 2x 64 single-ended Serial Data-Out (SDO) lines
- Clock, digitial control signals
- Ground and power supply voltages multiplied and interleaved
- Power dissipation: 1.25 W static and < 4W dynamic



KITE ASIC for 4DSTEM, cont.

Optimized for high frame- and count-rates

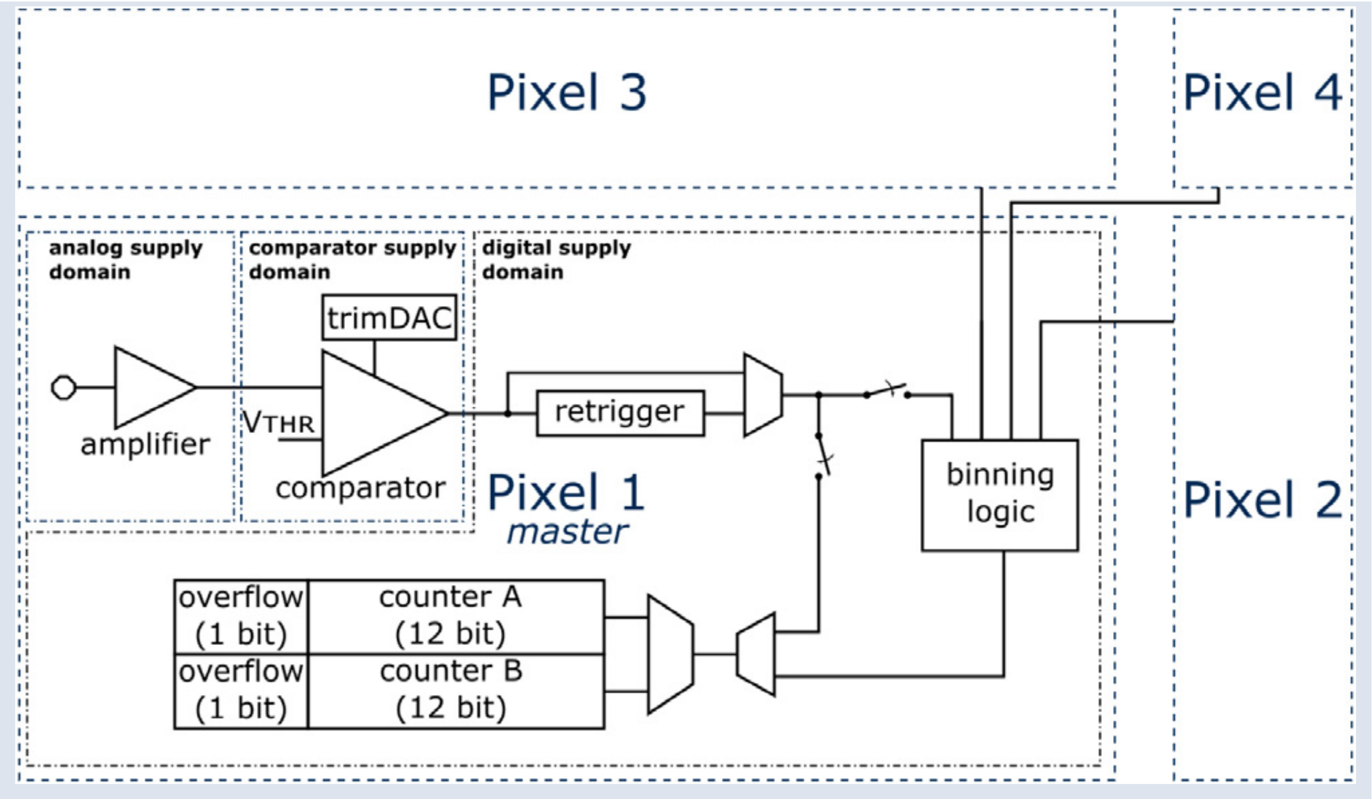
Pixel architecture

- UMC 110 nm CMOS process
- Enclosed Layout Transistors

- Independent power supply for analog, comparator and digital block to minimise digital to analog crosstalk
- CSA accepting bipolar input signals (Si and HiZ)
- Comparator with 6-bit trimming circuit
- Retrigger technology for non-paralyzable counting
- 2 x 12 bit asynchronous ripple counters (+ overflow bit)
- Digital 2x2 binning with digital *OR* logic

Maximum frame rates for the different readout modes in kfps.

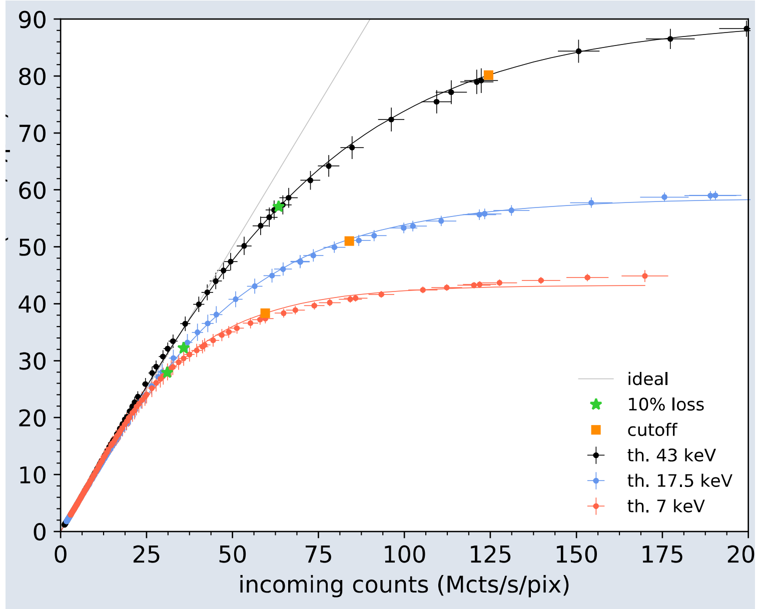
Read-out mode	Achieved in this work	Theoretical limit
12INT	20	100
8FP	30	146
2 × 2B	80	354
8FP + 2 × 2B	120	496



P. Zambon, S. Bottinelli, R. Schnyder et al.
Nuclear Inst. and Methods in Physics Research, A 1048 (2023) 167888

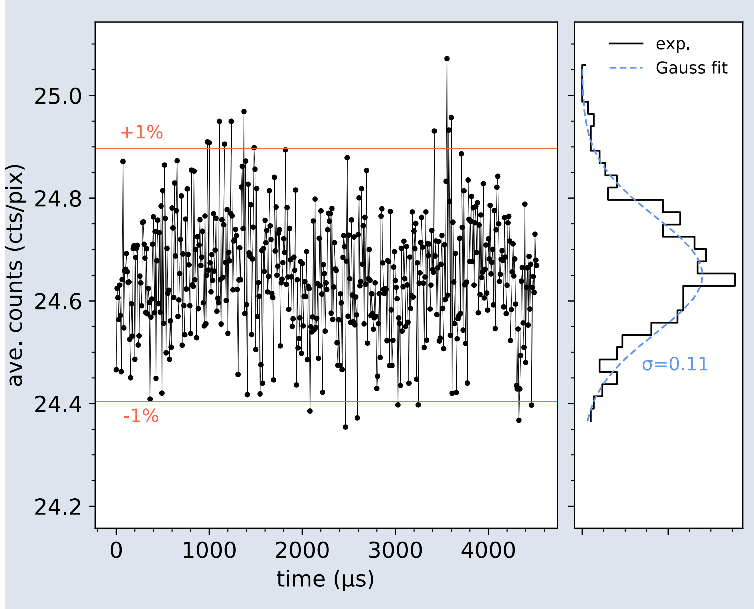
KITE performence

Up to 1.25·10⁸ cts/s/pix – 14.1 pA



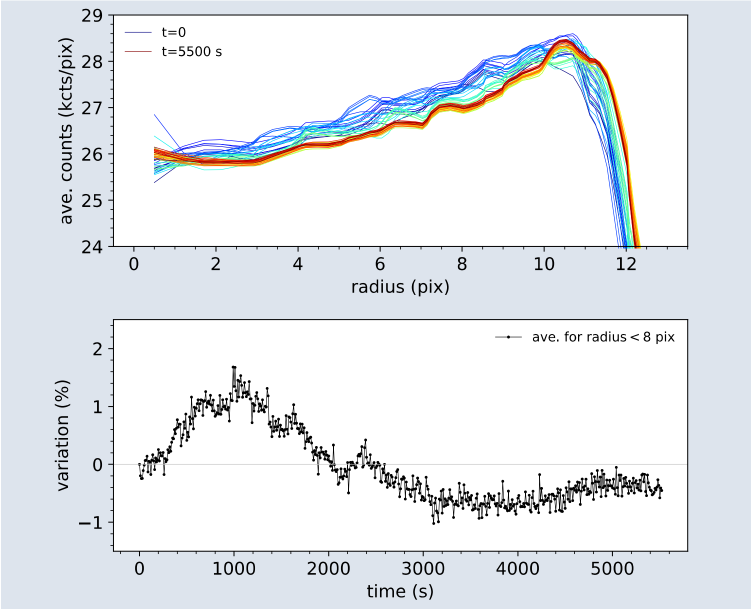
10% loss at 200 kV and 7 keV threshold: 13.2·10⁶ e⁻/s/pix – 2.1 pA/pix

Temporal stability at high frame-rates



110 kfps, 200 kV, 17.5 kV threshold

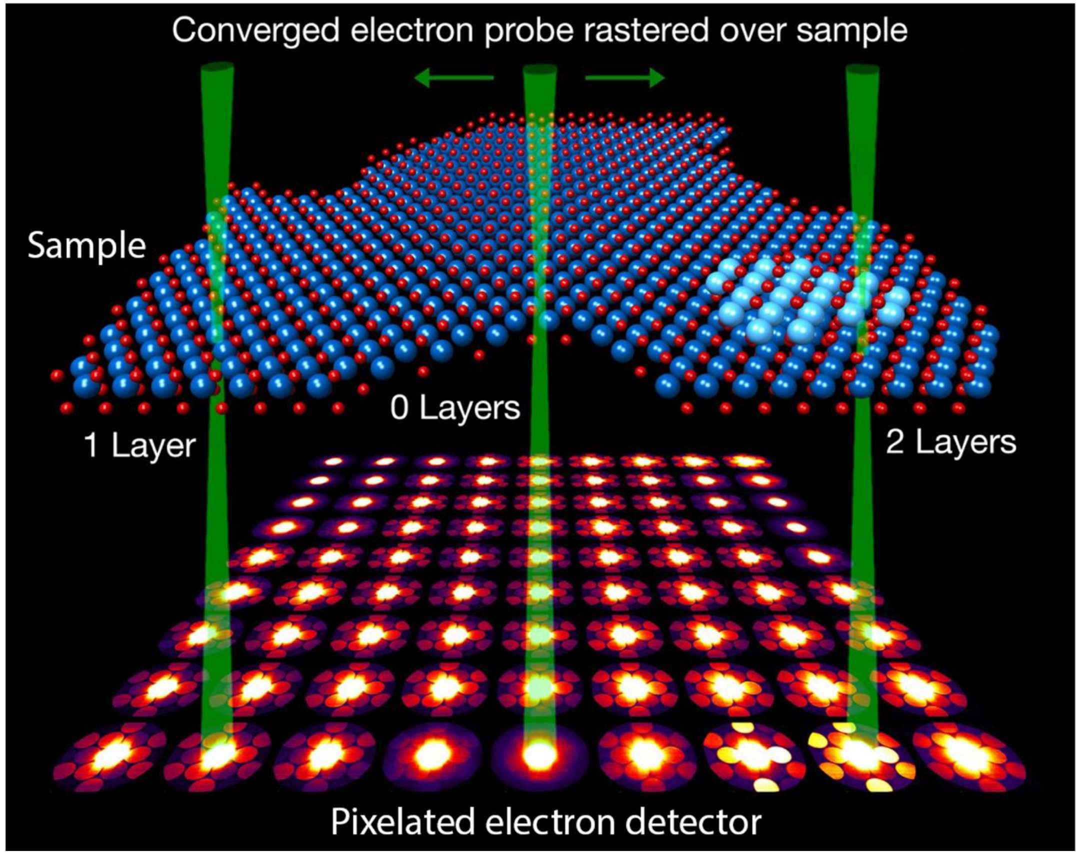
Count-rate stability CdZnTe



300 kV, 17.5 kV threshold, 37·10⁶ e⁻/s/pix – 5.9 pA/pix

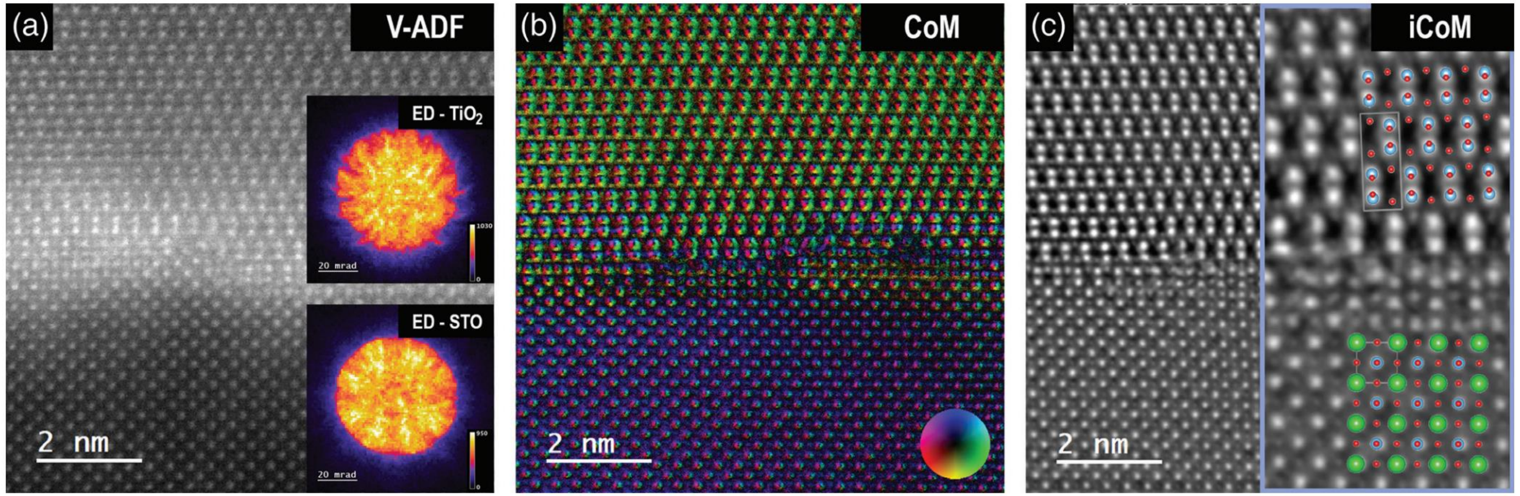
P. Zambon, S. Bottinelli, R. Schnyder et al.
Nuclear Inst. and Methods in Physics Research, A 1048 (2023) 167888

ARINA – optimized for 4D STEM



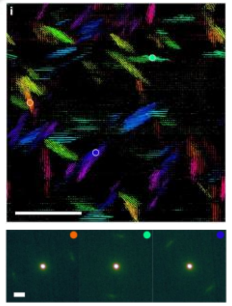
4D STEM concept - Image courtesy: Colin Ophus
Combining real space and diffraction space

Light elements visualisation

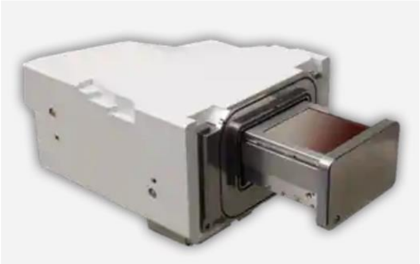


TiO_2 / $SrTiO_3$ interface revealing the atomic structure and highlighting O atoms not visible in dark field imaging

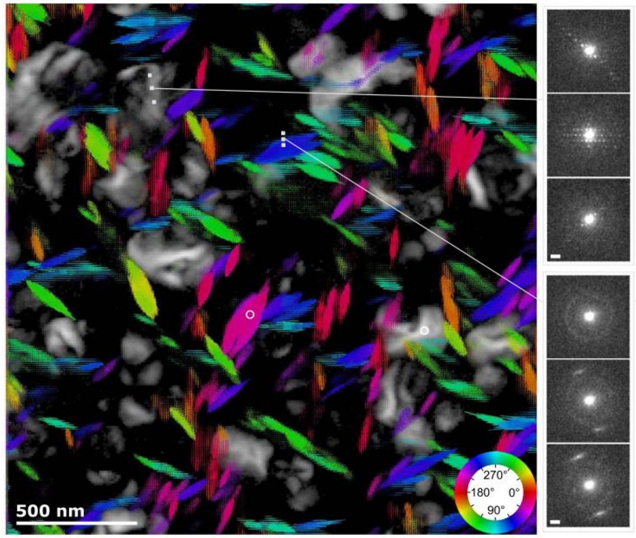
4D-STEM now and then…



2018
80x80 map
~5 min



Ceta camera: **~25 fps**



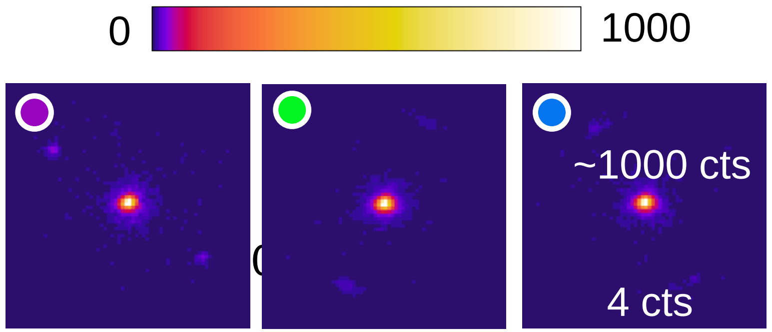
2021: 200x200 map ~ **2 min**

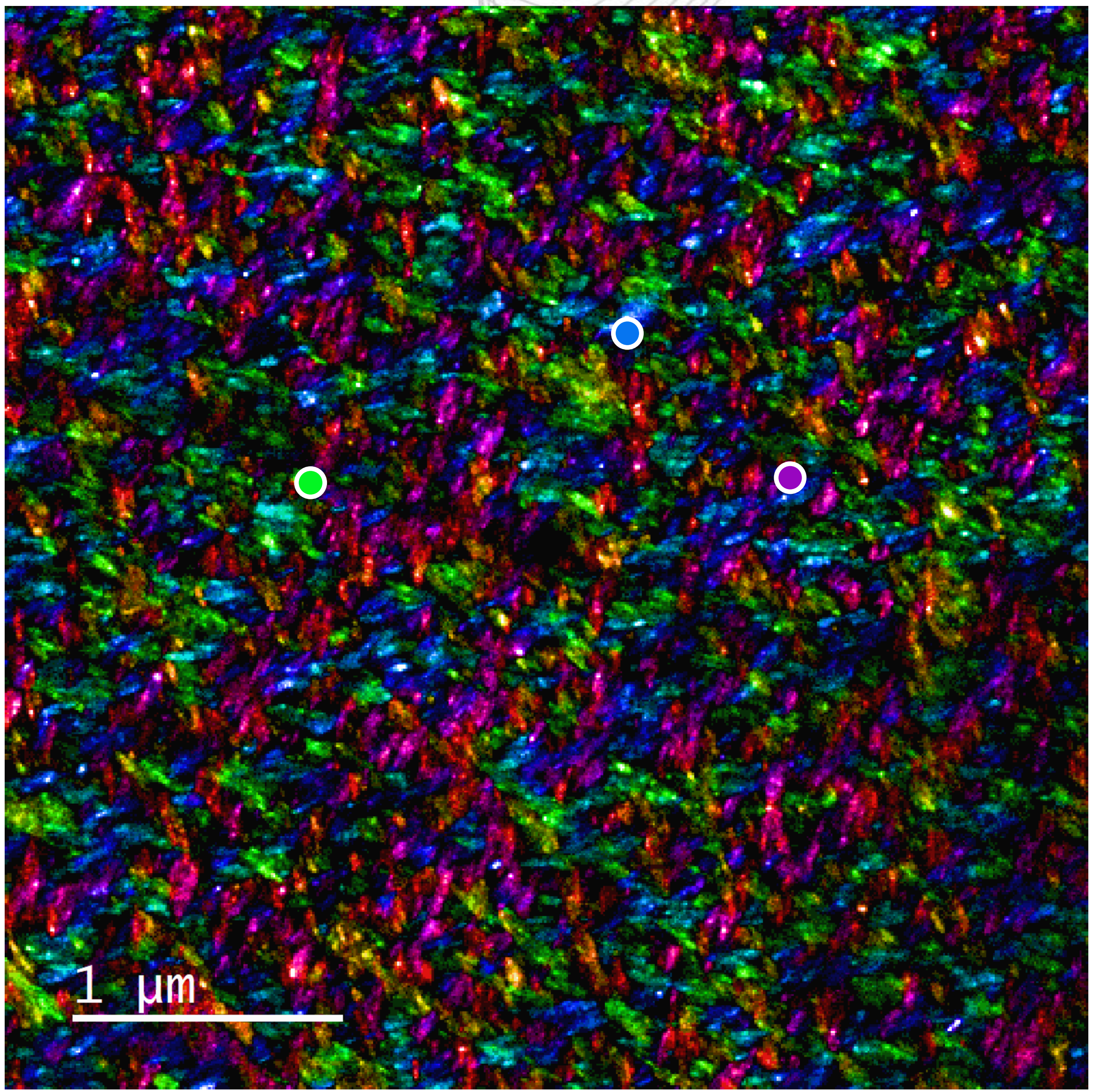
Ceta with speed upgrade: **~280 fps**

Wu *et. al.*, Nat. Commun. 13 (2022) 2911

Dectris ARINA **~100 000 fps**

2022: 1000x1000 map ~ **12 s**





The Legend Continues …
PILATUS4

Official launch at IUCr 2023 Congress

PILATUS4 will be the PILATUS3 successor

- 150 µm pixel size
- Software interface like EIGER2 (easy to integrate)

Key benefits

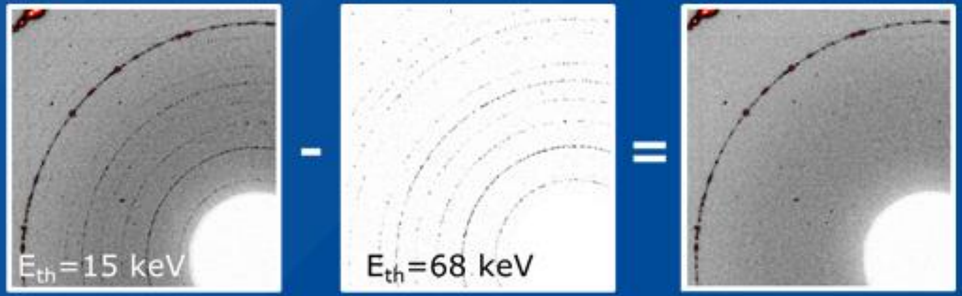
- High frame rate for large active area
- CdTe sensor ideal for high-energy beamlines
- Continuous readout (no readout time as PILATUS3)
- up to 4 thresholds

Take me home

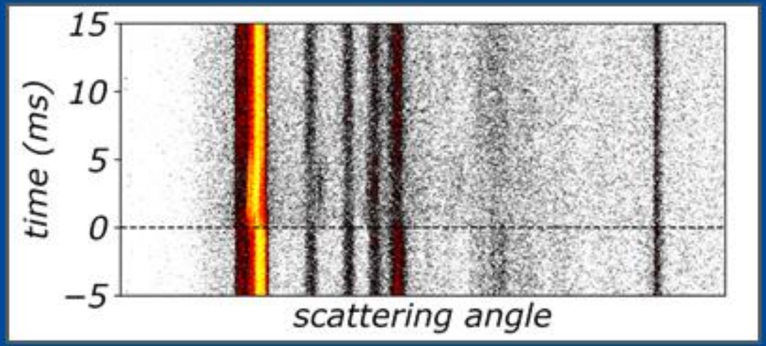
1. *DECTRIS managed transition from start-up to SME and successfully entered EM market*
2. *HPC detectors have transformed Synchrotron Science*
3. *HPC principle will allow to unlock significantly higher performance*
4. *Hybrid counting detectors can play enabling role in Material Science EM*
5. *High performance detectors can contribute to mastering society's most challenging problems*

EIGER2 can do more ...

STREAM2:
Higher Harmonic Suppression



Lines-ROI:
Reduced Readout at up to 100 kHz



... and more!

DECTRIS
EIGER2
FEATURE UPGRADE

Novel Features Overview

APPLICATION BENEFITS

8-Bit Mode	Double frame rate over full active area
Lines-ROI Mode	X-ray powder diffraction with up to 100 kHz
STREAM2	Multiple thresholds at full bandwidth
Double-Gating Mode	Optimal pump-probe picosecond experiments