Detectors for FELs, Storage Rings, and other advanced light sources

PSD-12 Conference

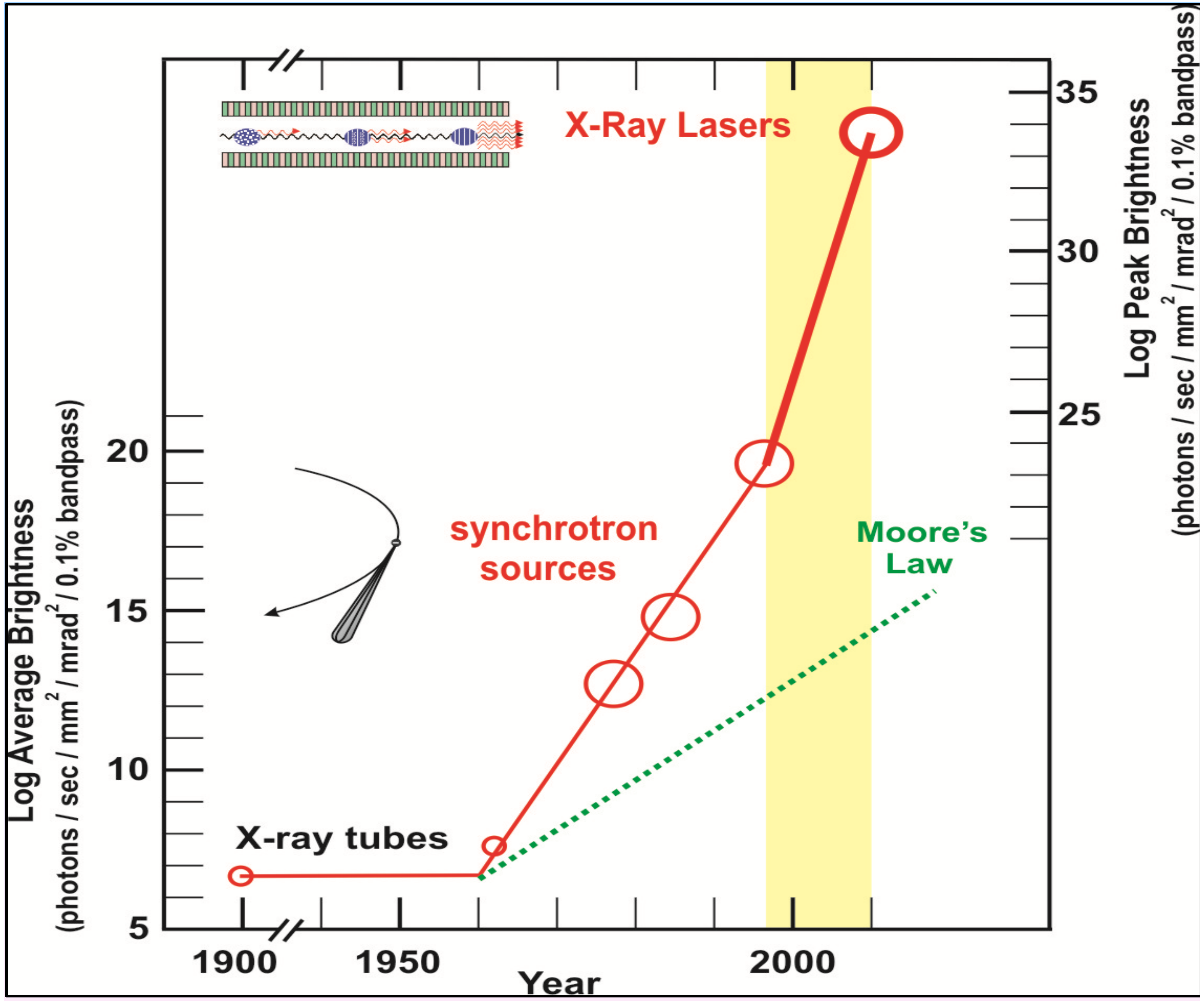
Heinz Graafsma; Photon Science - Detector Group (FS-DS); DESY-Hamburg
September 2021

Layout

- Current and Future photon-sources
- League of European Accelerator based Photon Sources : LEAPS
- Developments at DESY-Hamburg
- The Data Challenge

Current and Future Photon-Sources

The Photon-Source Evolution:



New Generation of Photon Sources

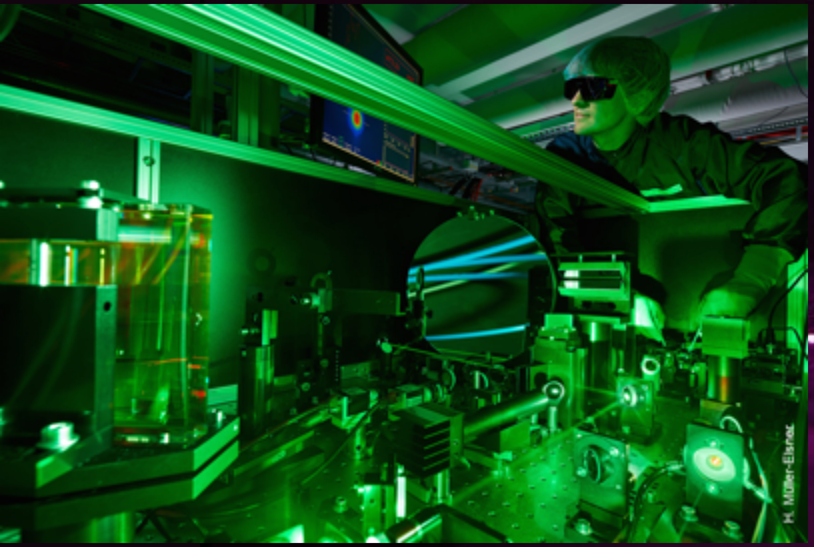
MBA upgrades SR

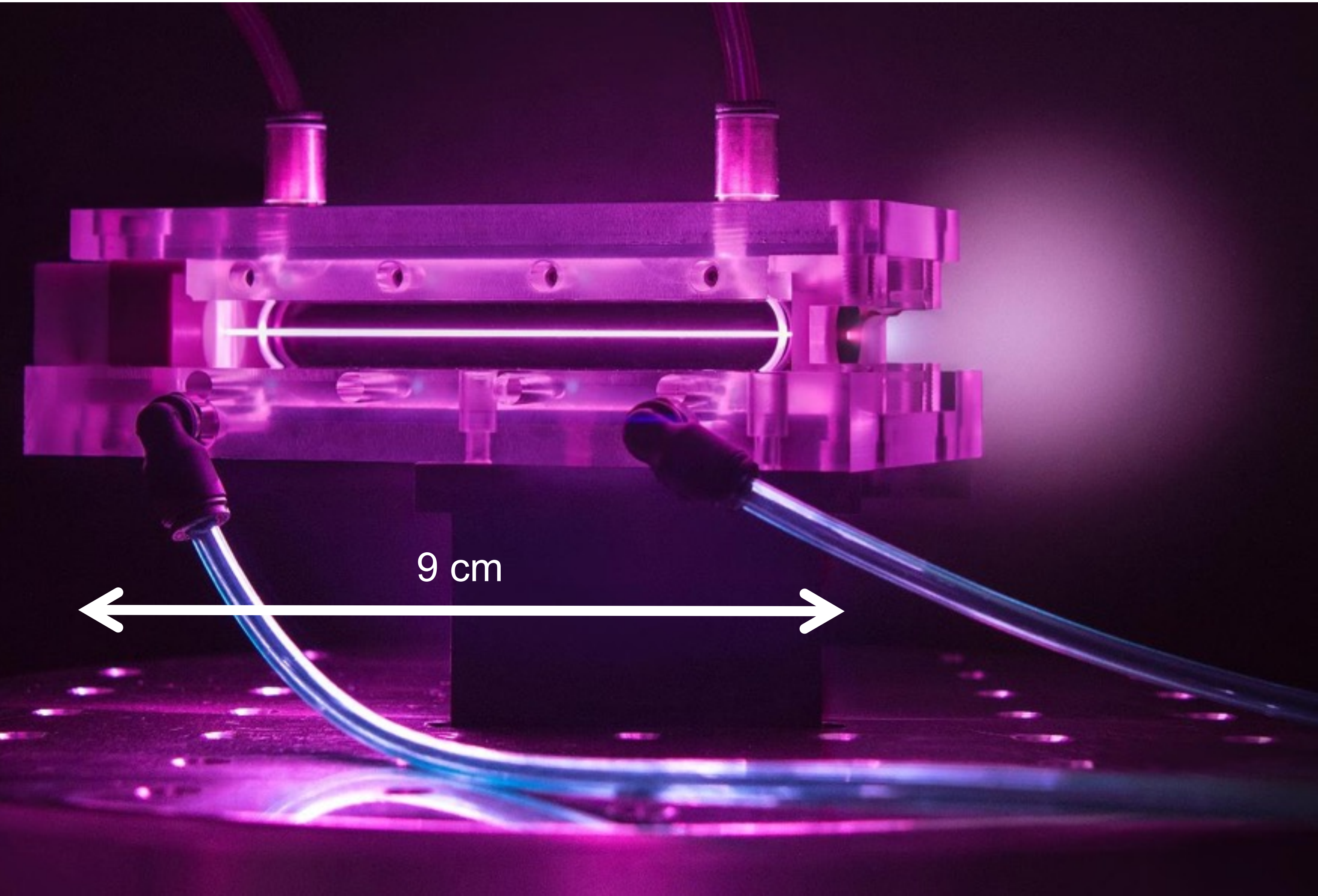
High rep-rate CW upgrades FEL

DESY plasma accelerator R&D is aiming at compact photon sources

With our novel accelerator technology, accelerators could soon fit in a lab room!

- Miniaturisation
- Stability
- Beam quality
- Applications

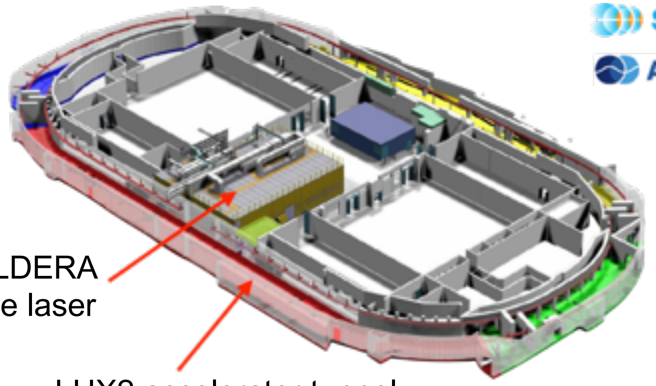




DESY pioneers the R&D on high-power plasma accelerators

From acceleration to accelerators

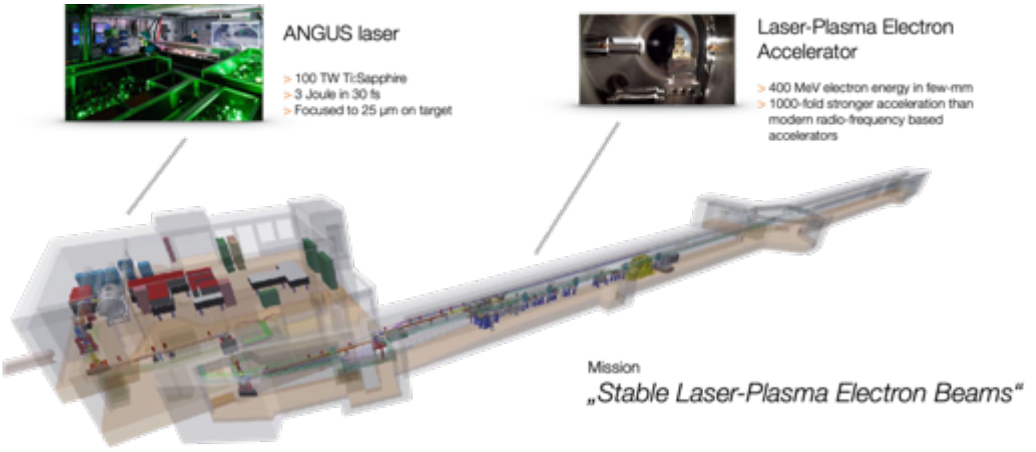
KALDERA – kW, kHz laser driver

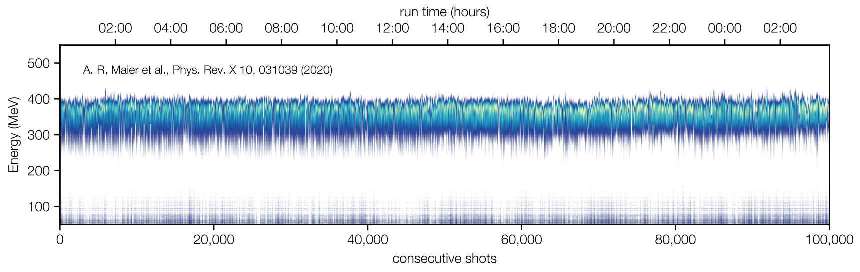


Science case

- **100 TW**-class laser @ **kHz**-level rep-rate
- **active stabilization, feedback** and **ML/AI**
- **FEL-quality** electron beams
- Currently under construction

LUX – plasma accelerator in operation



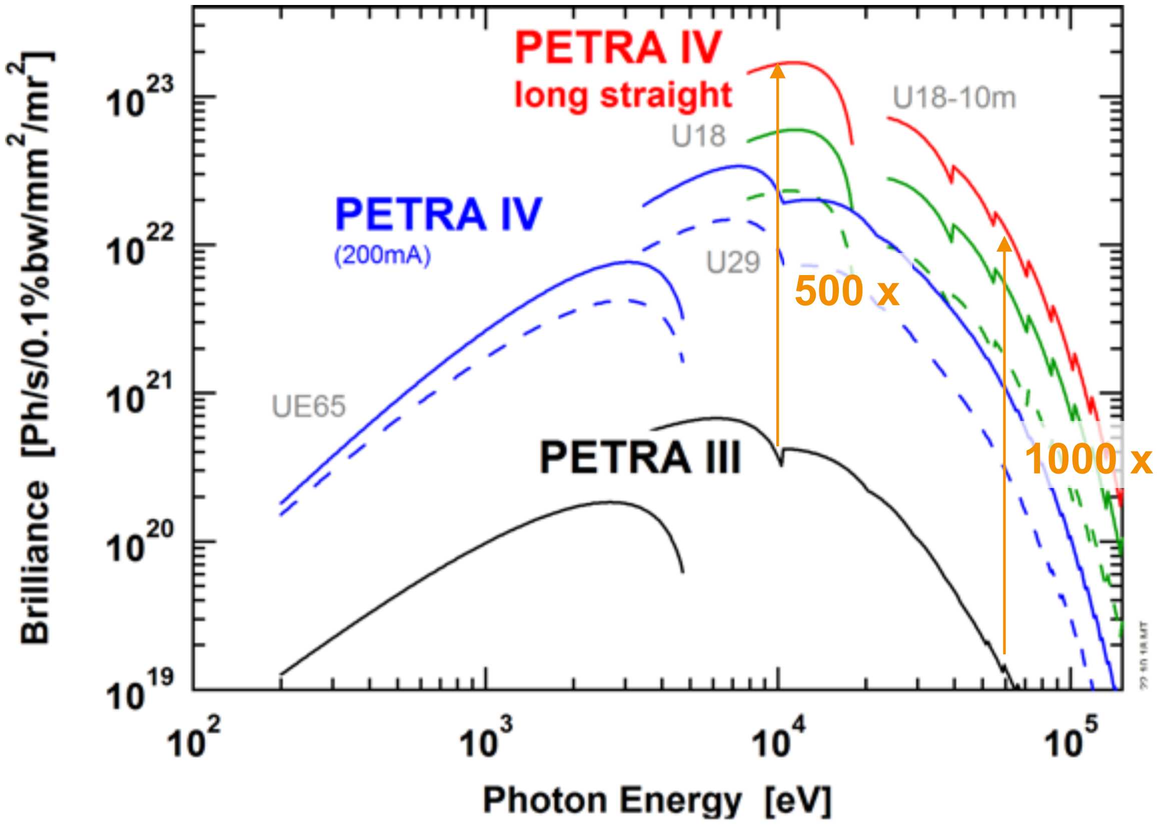


Science case

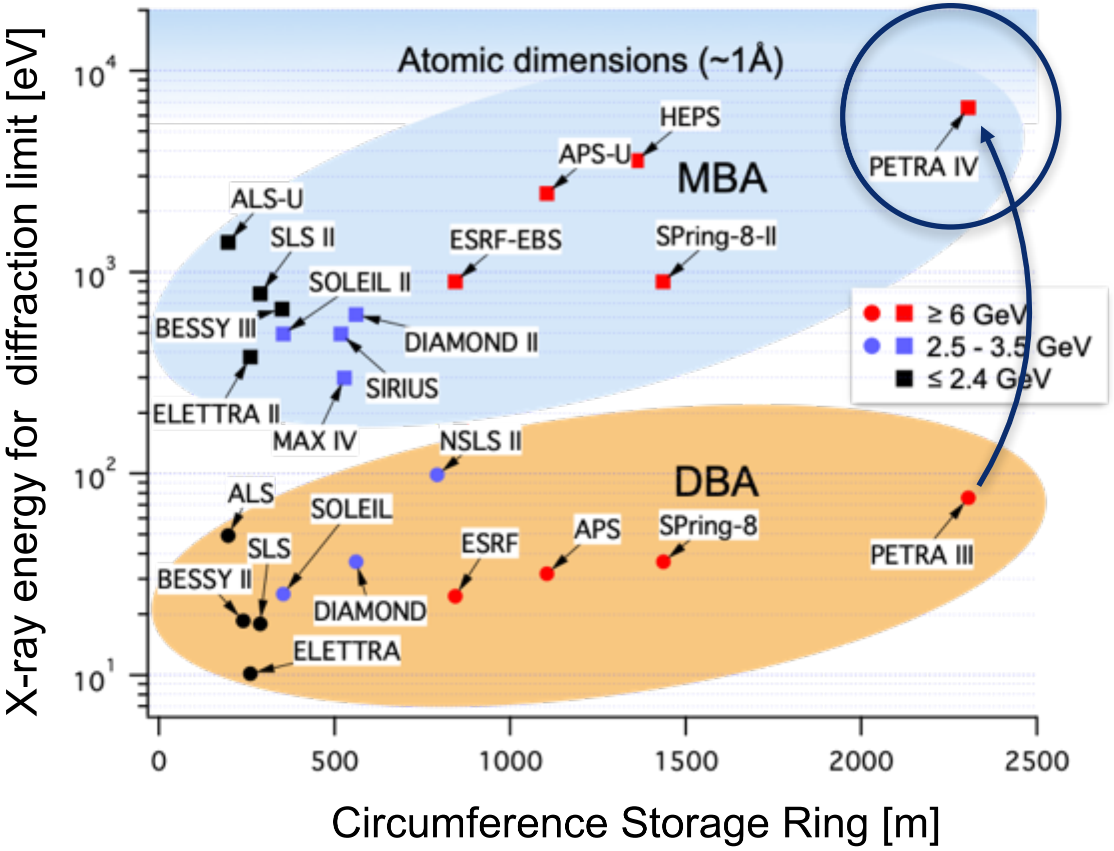
- **100 TW**-class laser @ **1 Hz**
- **Continuous 24-hour operation demonstrated**

The Multi-Bend Achromat upgrades for Storage Rings

PETRA III to PETRA IV Upgrade



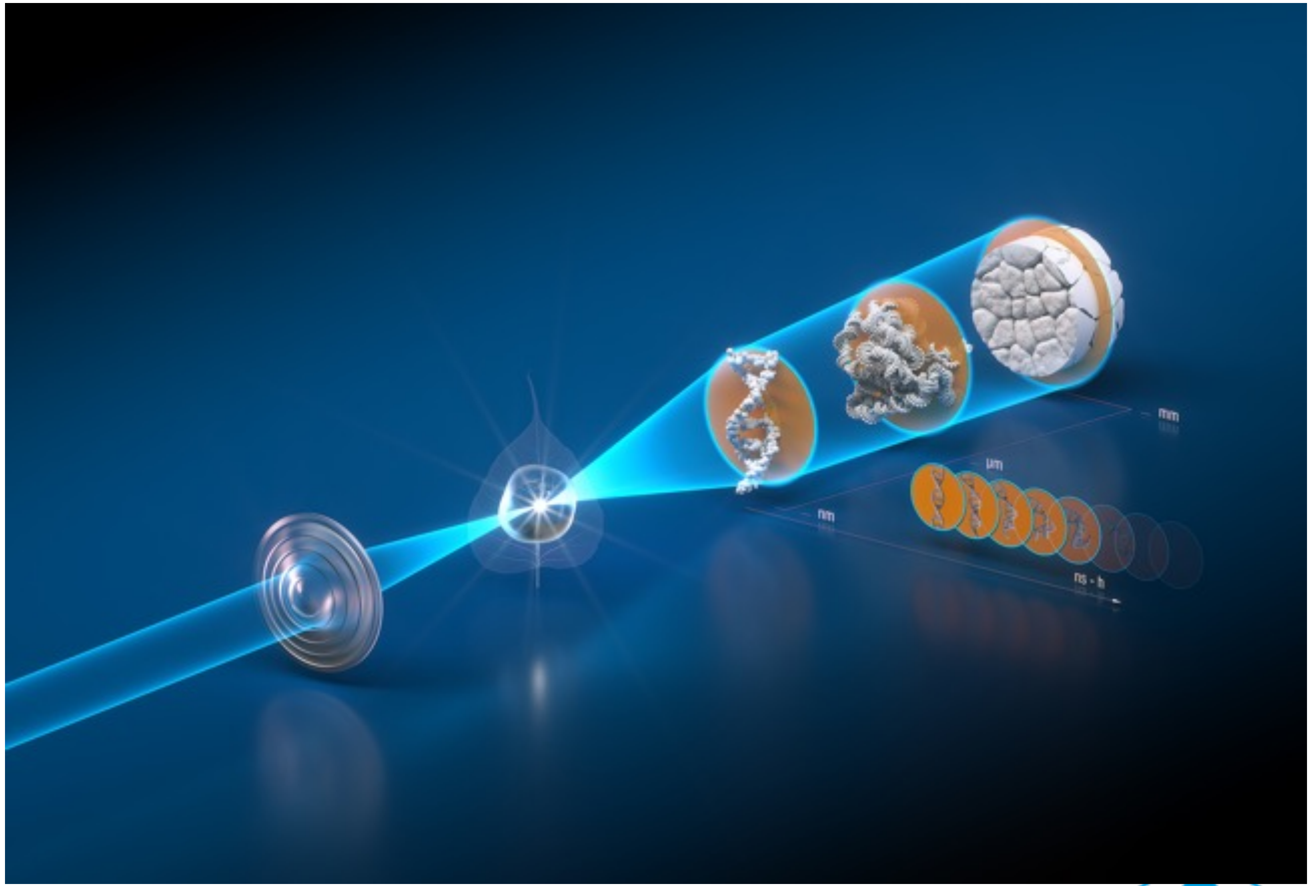
International landscape Storage Ring Upgrades



(Details: see PETRA IV CDR,
DOI: 10.3204/PUBDB-2019-03613)

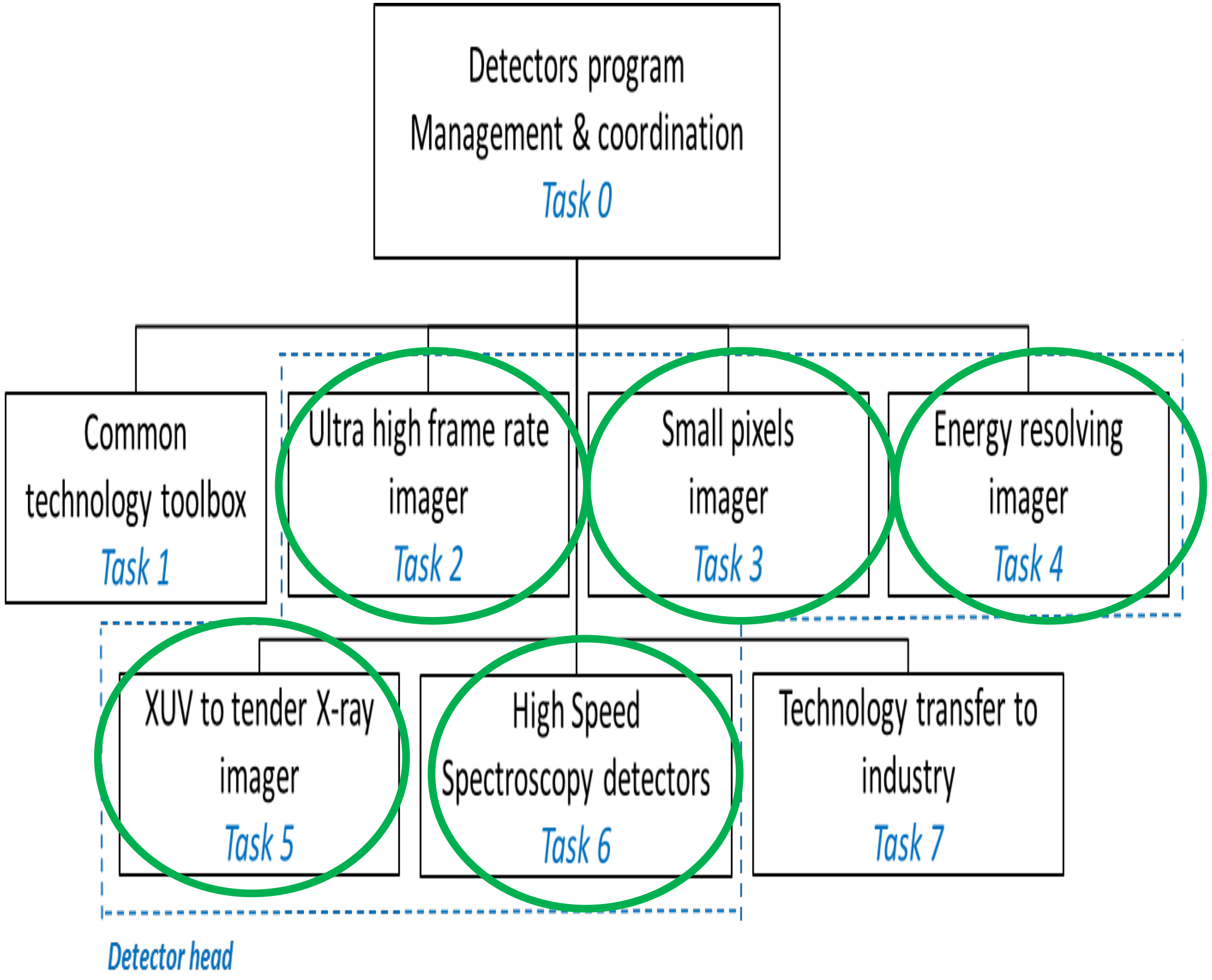
Cross-scale view of structure and function of complex systems in nature and technology:

- Zoom: structural details on all relevant length scales (from Å to mm)
- Chemical, structural, electronic and magnetic properties of individual nano objects in a macroscopic context
- Follow processes under working conditions: in-situ / operando
- Dynamics down to the nanosecond scale



LEAPS:
League of European Accelerator based Photon-Sources

• LEAPS – WP1.1: Detectors Roadmap



- Different facilities have started to work on different tasks
- Increasing collaboration between sources
- Increasing involvement of Universities and Research Facilities
- Increasing willingness of management to invest in detector **developments**
- See i.e. IFDEPS & IWORID-2021 programs

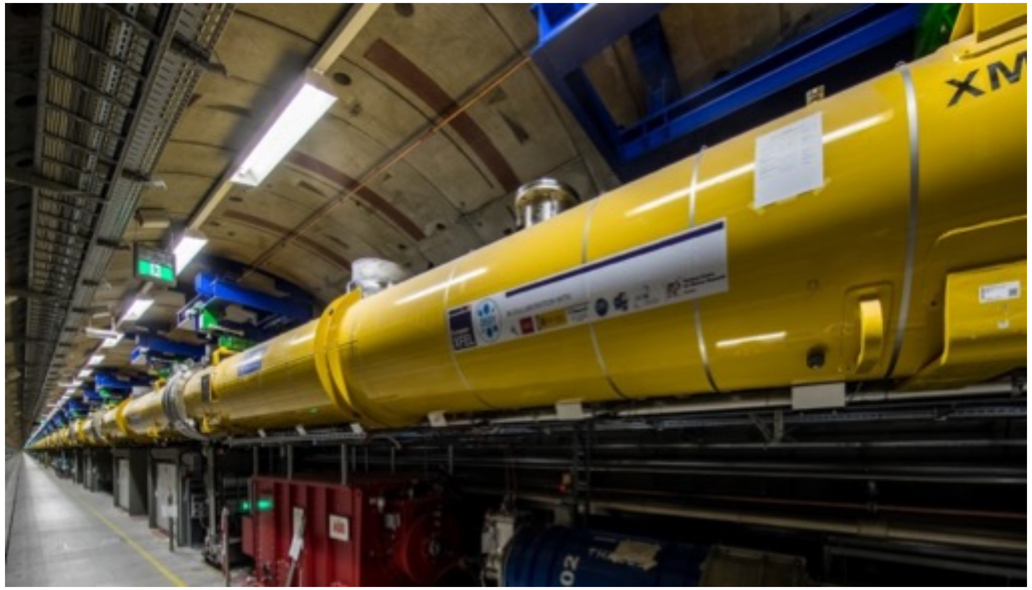
Developments at DESY

Requirements for future sources at DESY

PETRA-IV

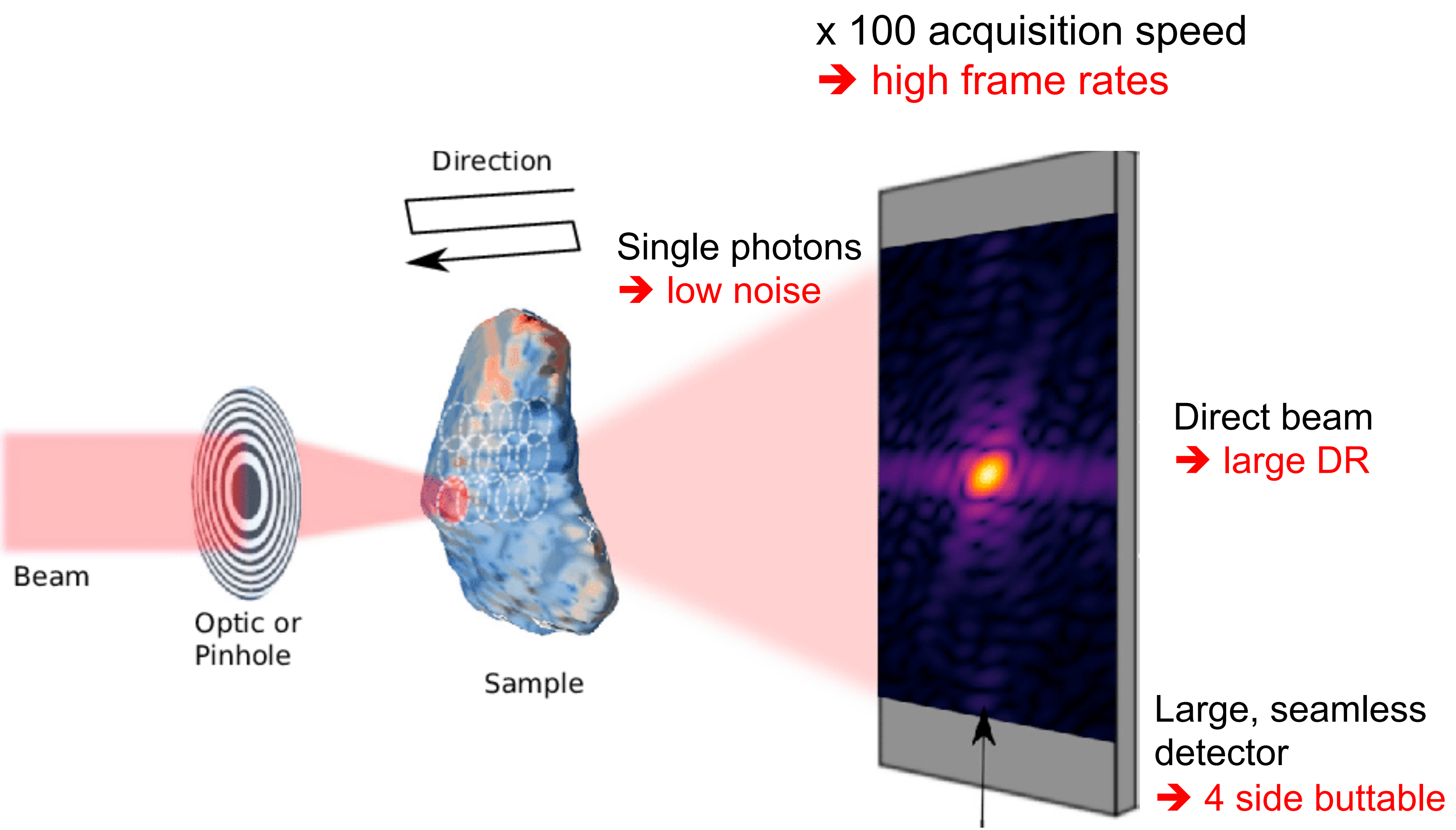
- Diffraction-Limited Storage Ring
- Approx continuous X-ray beams
- >100 increase in X-ray brilliance
- Measurements from atomic to macroscopic scale, 10µs resolution

CW-FLASH & CW-XFEL



- Free electron laser
- Extremely intense X-ray pulses
- 100 kHz to 1MHz continuous bunch rate
- “Flash photography” on atomic scales

Example – coherence-based imaging (e.g. ptychography)



Development of CoRDIA: a detector for diffraction-limited SRs and CW FELs

A. Marras[1,2], A. Klyuev[1,2], T. Laurus[1,2], D. Pennicard[1,2], U. Trunk[1,2], C.B. Wunderer[1,2], T. Hemperek[3], T. Kamilaris[3], H. Krueger[3], T. Wang[3] and H. Graafsma[1,2,4]

1) Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany
2) Center for Free Electron Laser Science (CFEL), Hamburg, Germany
3) University of Bonn, Bonn, Germany
4) Mid Sweden University, Sundsvall, Sweden

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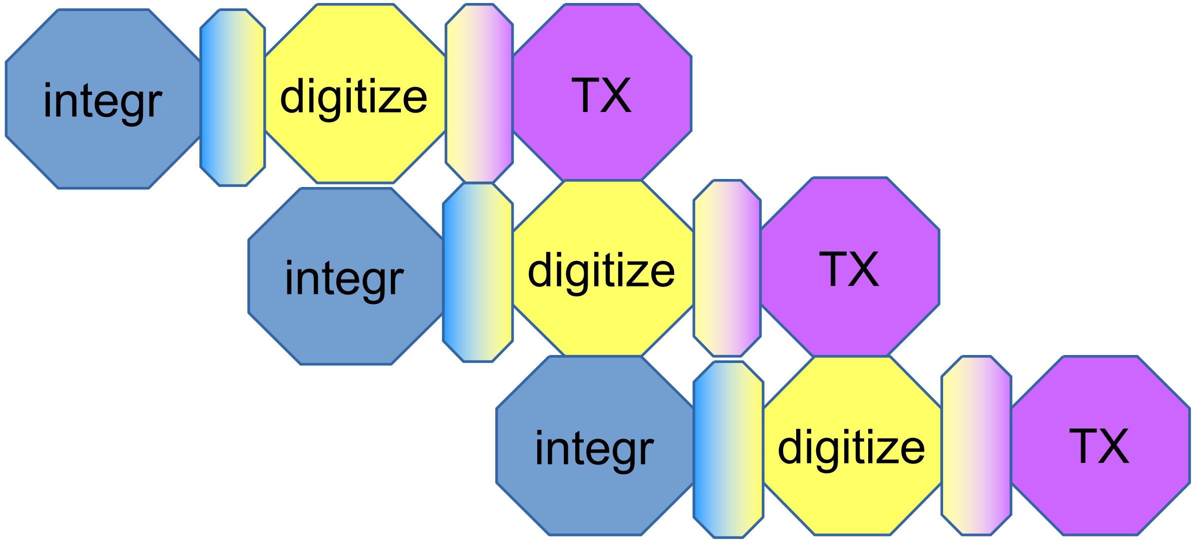
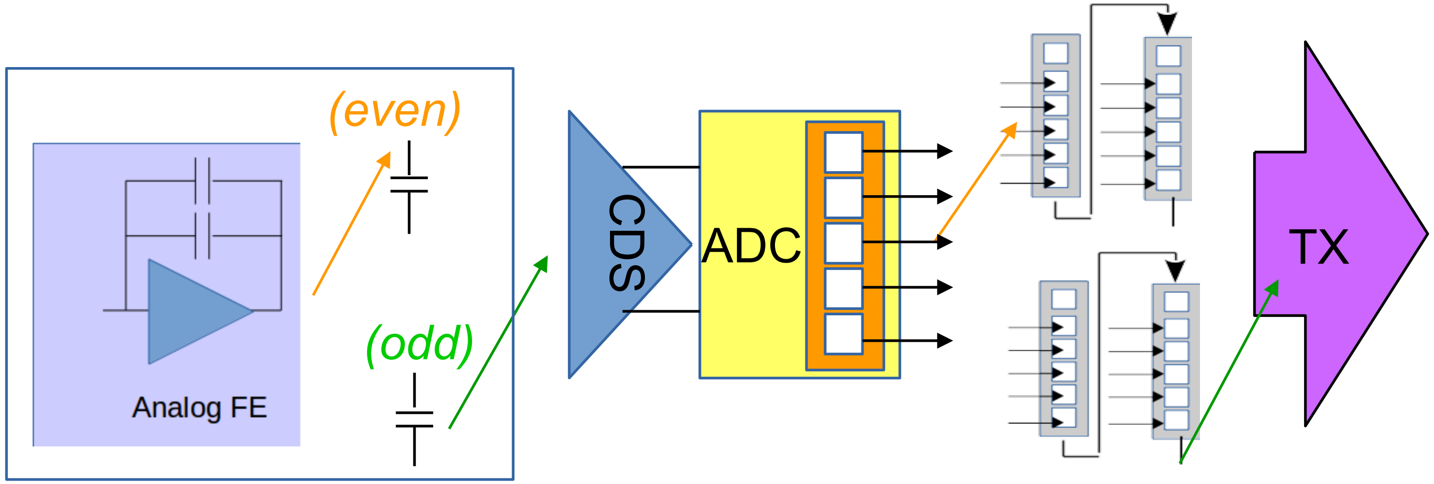
CoRDIA – target specifications

- ≥ 132 kHz continuous frame rate (PETRA revolution frequency)
- ≤ 100 µm pixel size
- Multi-megapixel (modular design)
- Minimal dead area (TSV based)
- Single photon sensitivity at 6 keV
- $\geq 10^4$ ph/pixel/image dynamic range (10^9 ph/pixel/s)
  - Noise below Poisson statistics
- Compatible with different sensors
  - Standard Si sensors
  - High-Z (e.g. CdZnTe) for hard X-ray detection
  - Amplifying sensors (LGAD) for soft X-ray detection

COntinuous Readout Digitising Imager Array



CWR scheme
using pipelined
signal-process chain



16x integrating FE
CDS/ADC

shared

GWT

AdGn FE adapt.
from AGIPD

on-chip ADC
developed by
Bonn University

adopt. Timepix4
GWT developed
by Nikhef

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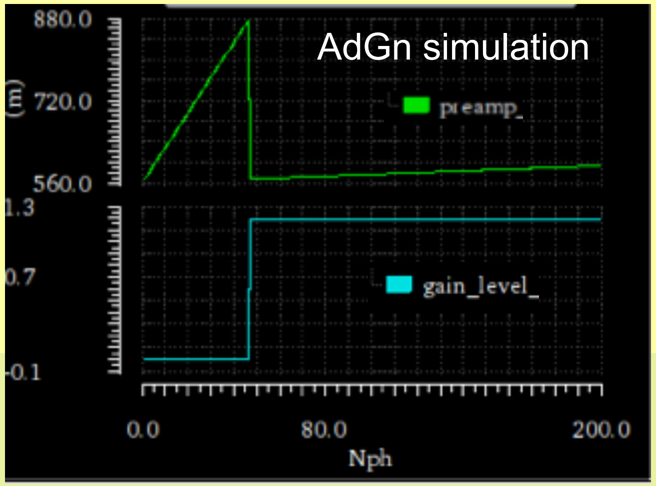
The ASIC development approach

validation of individual circuit blocks

- Analog FE & ADC: design → manufacture → test → miniasic
- digital streamout: Tpix4 corr → adapt → manufacture → test

validation of individual circuit blocks → validation of circuit chain as a pixel array → validation as a component of the overall detector system



explor. MPW (TSMC65) this year

expansion to full-scale ASIC → 1st gen ASIC

expansion to full-scale ASIC → performance improvement study

moderate performances will target pixel pitch, cont. readout >100KHz

performance improved ASIC → 2nd gen ASIC

improved performance extend dynamic range, reduce noise, minimize blind areas

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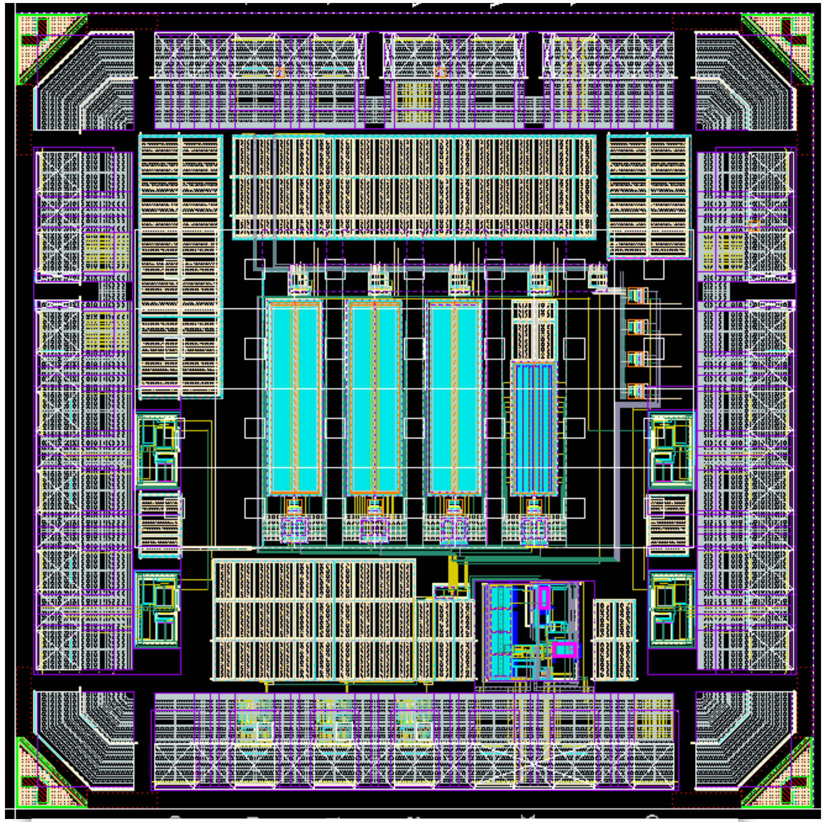
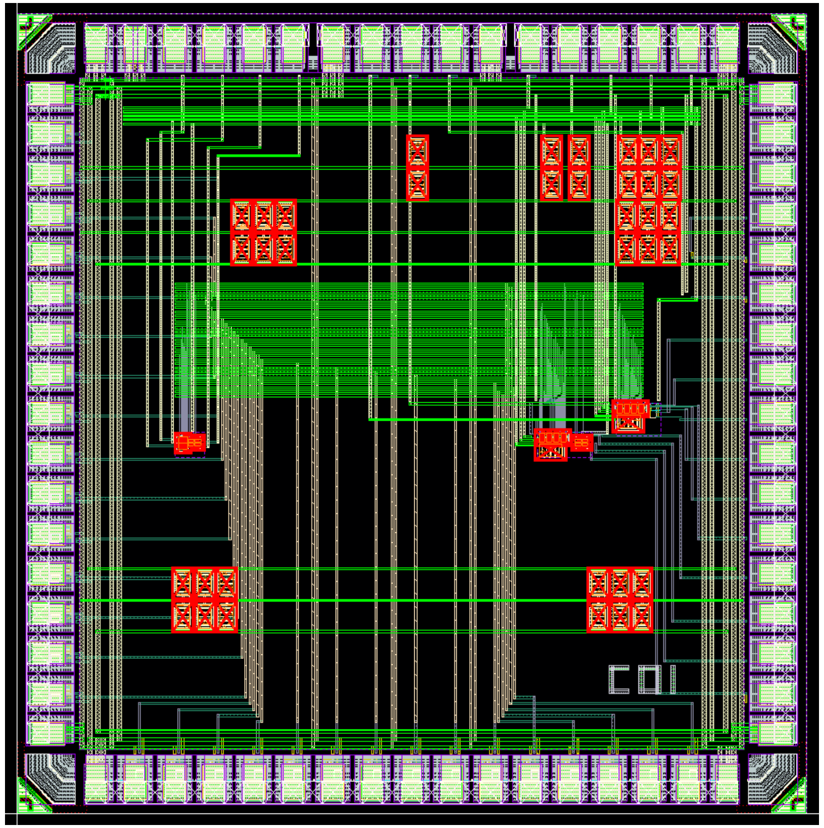
Two test chips taped out in July 2021 (TSMC 65 nm)



4 ADC variants (SAR)
- Resolution: 11 bit
- Sampling rate: 2.5MS/s
- Area: 80 µm x 330 µm
- Average power ~ 20 µW
- ENOB: ~10.8b

Designers: **T. Wang**, **T. Kamilaris**



Calibration source
Adaptive Gain
CDS

Designers: **A. Marras**, **A. Klujev**

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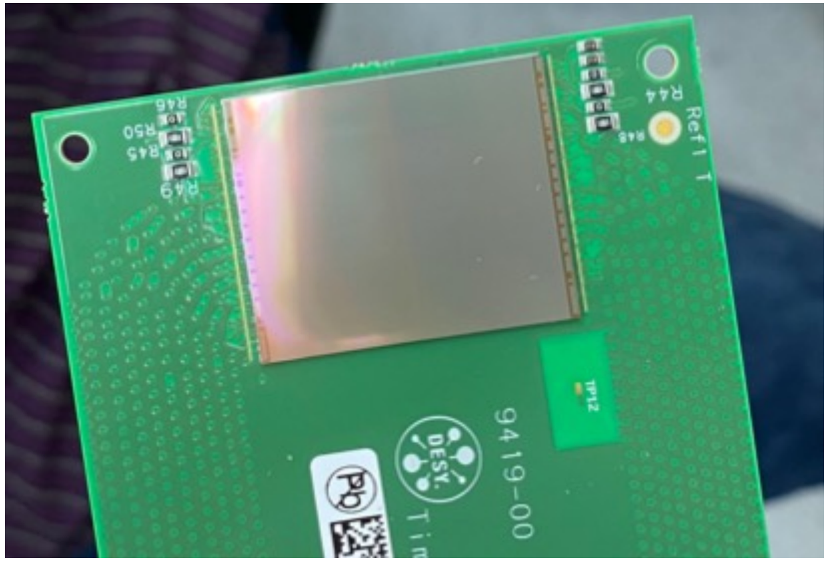
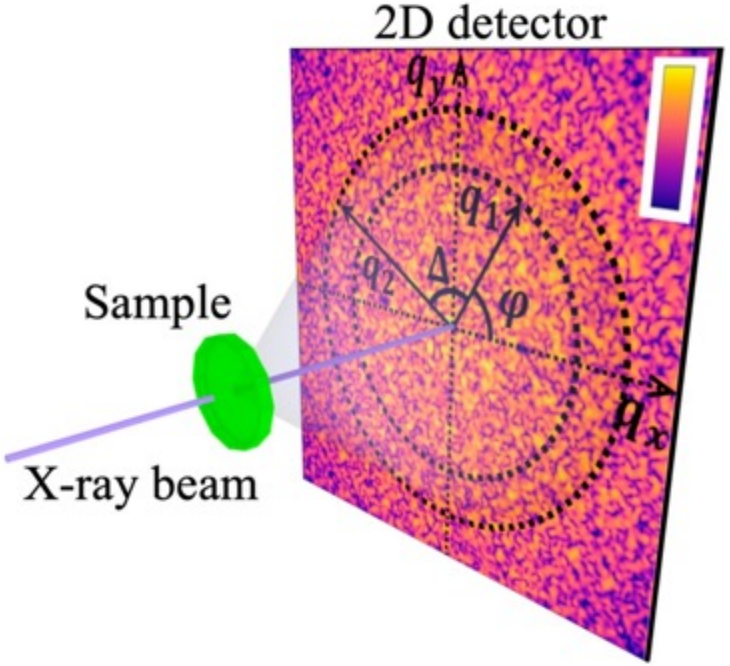
Timepix4 timestamping detector for synchrotron applications

David Pennicard, Jonathan Correa, Sergei Fridman, Sabine Lange, Sergej Smoljanin, Vahagn Vardanyan, Heinz Graafsma – DESY

Xavier Llopart, Jerome Alozy, Michael Campbell - CERN

Position Sensitive Detectors 12, Birmingham, Sept 2021

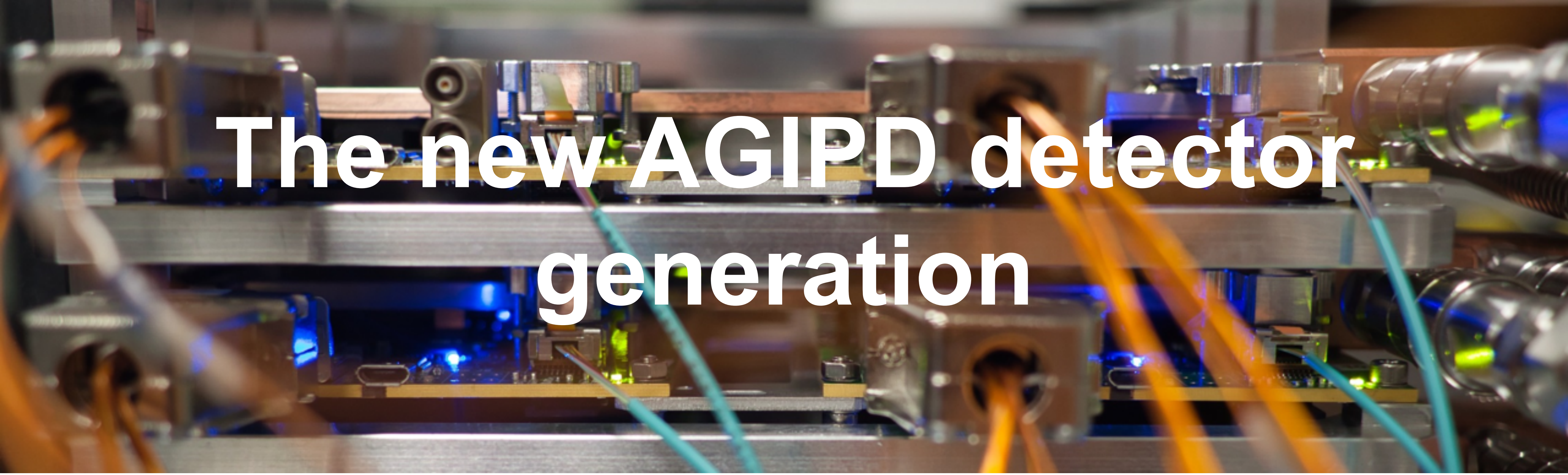




HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Upgrade Projects



The new AGIPD detector generation

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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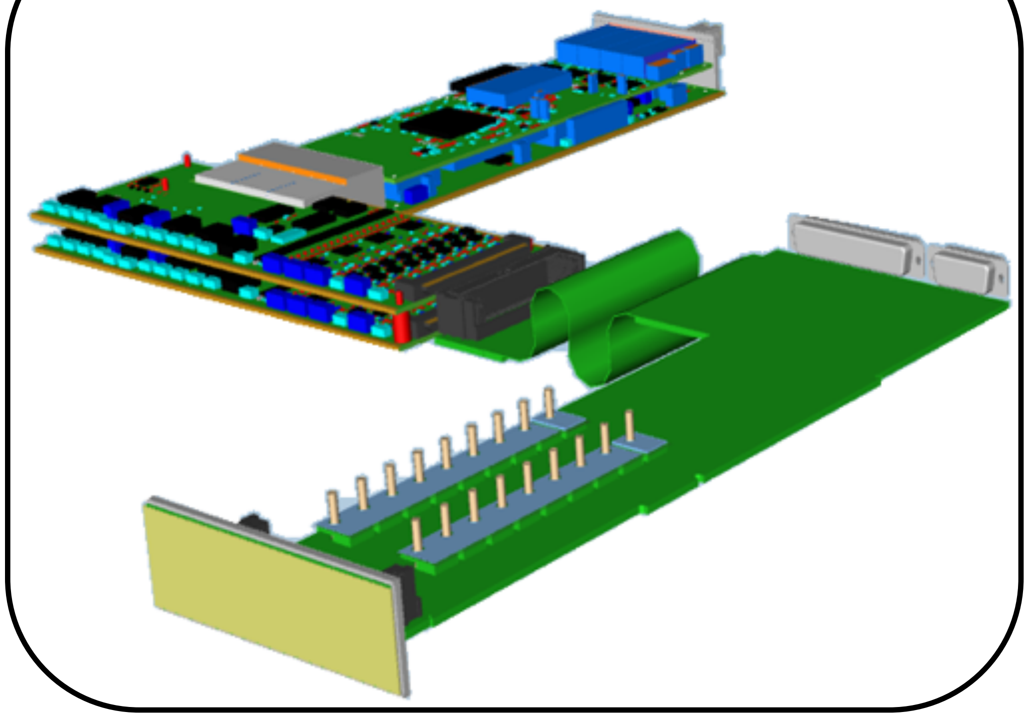
AGIPD Systems in Development

Old Electronics



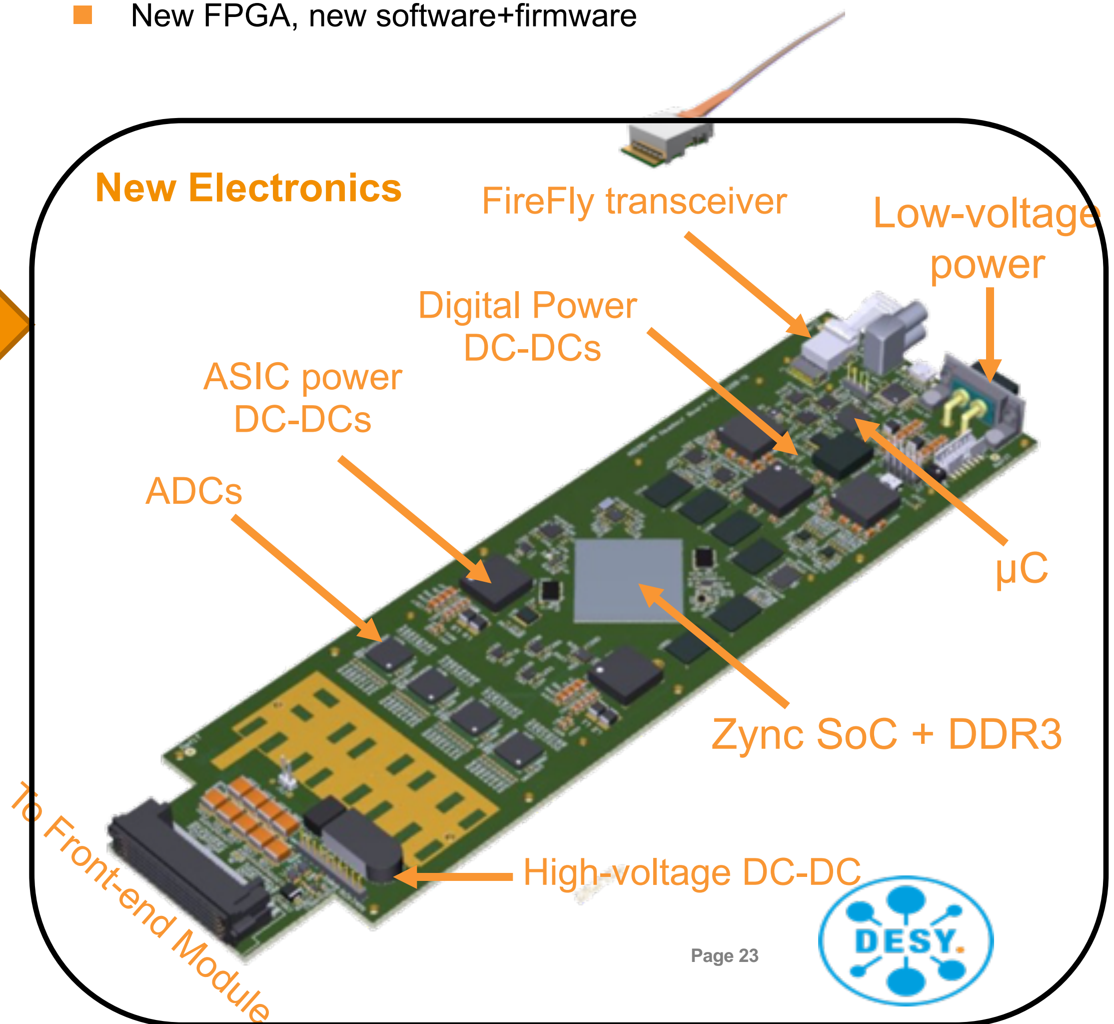
1st generation read-out electronics

- 3 boards
  - Vacuum board (high-voltage-, ASIC power distribution)
  - ADC board
  - FPGA board
- External power distribution (many external cables)
- Different, mixed (copper, fibre), separate fibre-pairs/cables for controls, data readout, timing/sync, interlocks

2nd generation read-out electronics

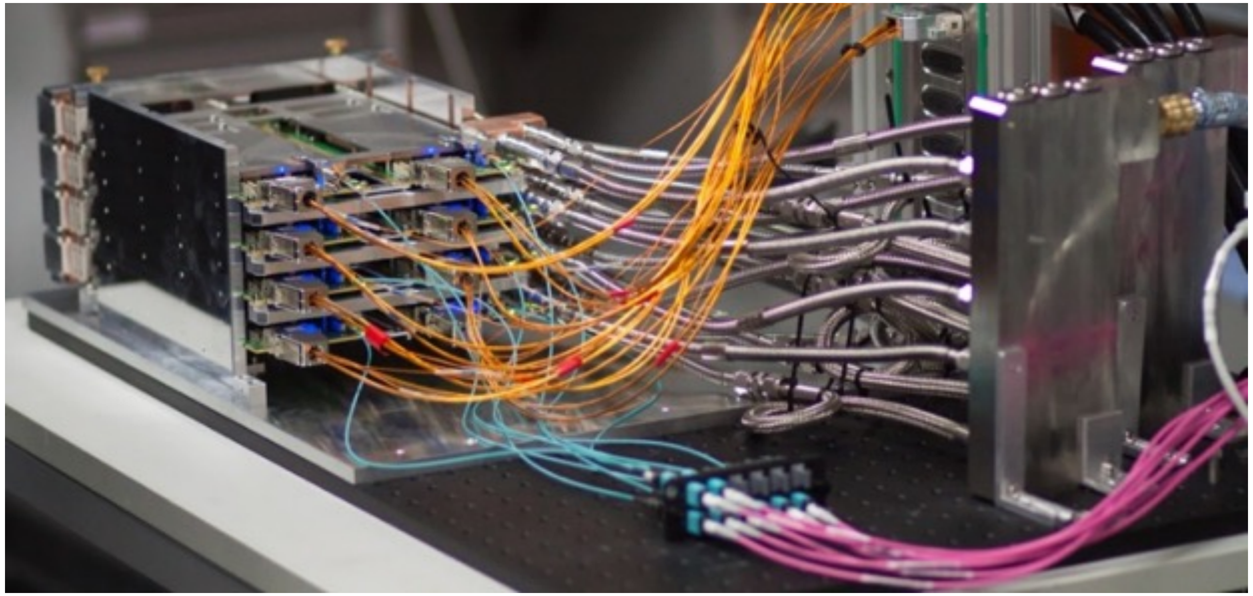
- 1 Read-out Board, all in-vacuum, small footprint, short analog pathlengths
- On-board power distribution incl. High-voltage generation
- FireFly multifibre transceiver for controls, data, timing/sync, interlock
- New FPGA, new software+firmware

New Electronics



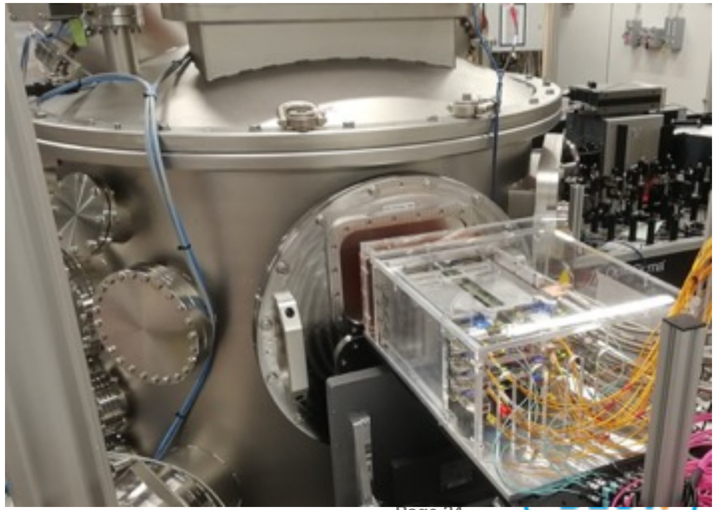
AGIPD Systems in Development

Mini-Half Prototype System

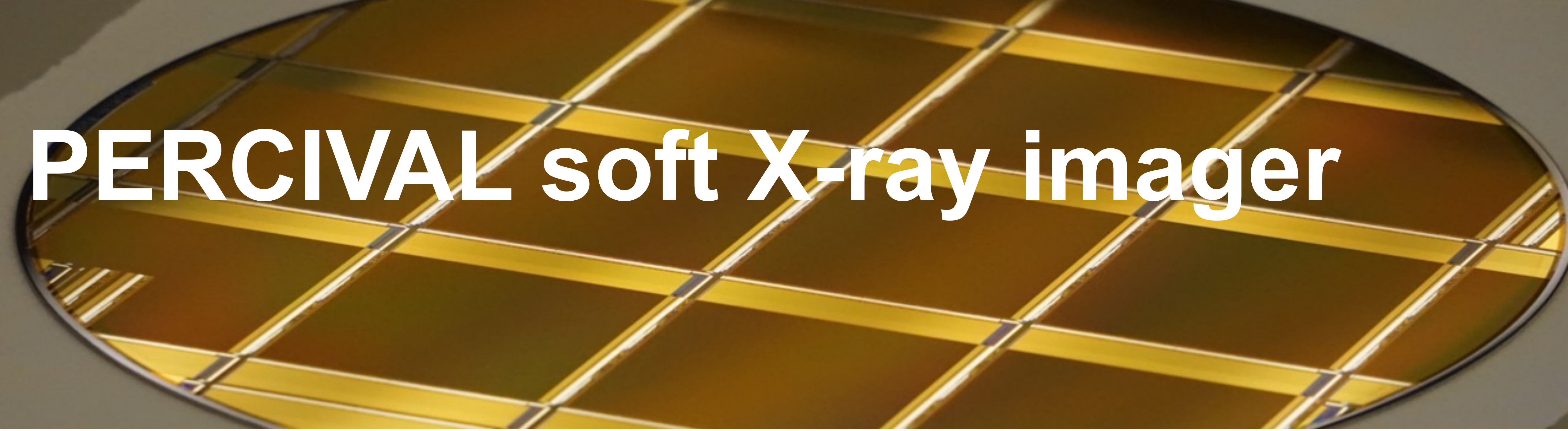


- 8 Readout Boards, 8 front-end modules = 500kpix
- 4x AGIPD1.1, 4x AGIPD 1.2 FEMs
- 1 Receiver Board – without interlock functionality, link to EuXFEL Clock&Control
- Operated in air, water cooled

- New ASIC (AGIPD1.2) to fix a gain bit encoding problem
- New ASIC (AGIPD1.3) for electron collection (High-Z and LGADs)



PERCIVAL soft X-ray imager

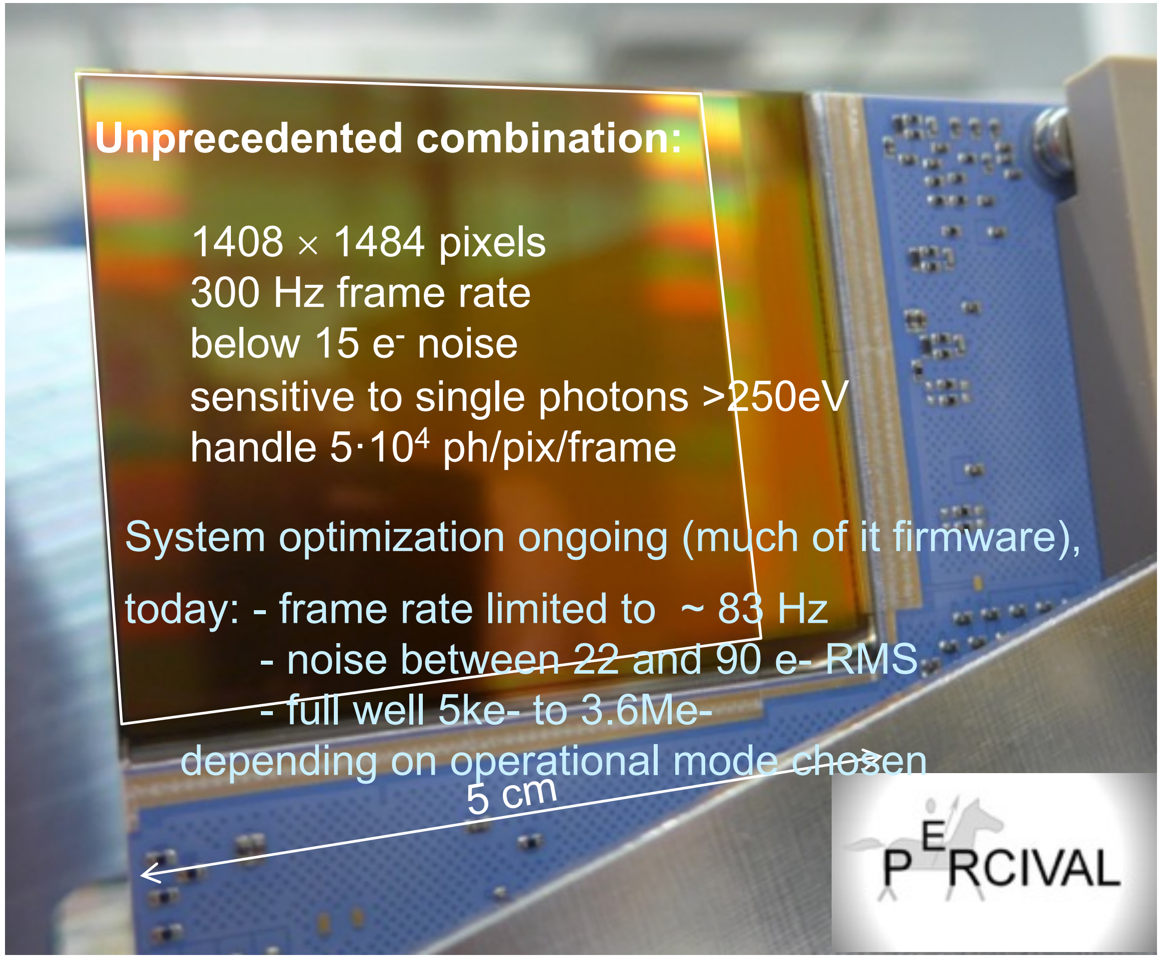


CMOS imager to meet the combination of challenges

- Novel imager meeting key FEL challenges simultaneously, in the soft X-ray regime:
  - (at least) Megapixels in a single sensor (avoid dead area)
  - fast enough for “shot by shot” science @ today’s FELs
  - dynamically adjust to single photons & large signals

- Project initiated by DESY, today 5 light sources + RAL/STFC
- 3 auto-adjusting gain levels to span 1 to $5 \cdot 10^4$ ph/pix/frame
- 4×4 cm2 continuous sensitive area (27×27 μm pixels)
- Data rate 20 Gbit/s at 300Hz frame rate

- 1st-generation demonstrator operational at beamlines
- 2nd-generation system in planning, including improved sensor design, more compact system, easier-to-use

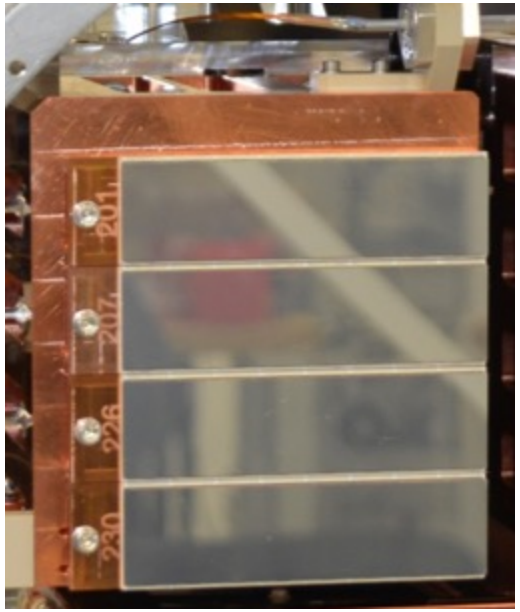


DESY | Rutherford Appleton Lab / STFC | Elettra Sinchrotrone Trieste | Diamond Light Source | Pohang Accelerator Laboratory | Soleil Synchrotron

The Data Challenge

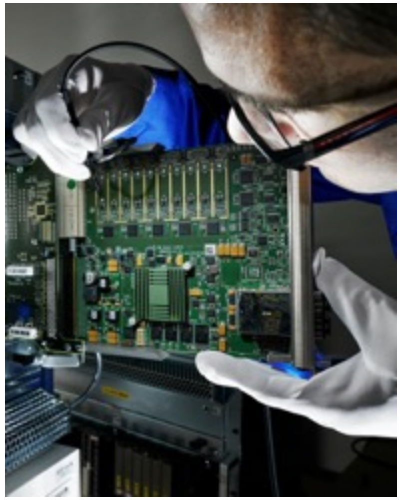
The Data rate and volume challenge

- Possible module design:
  - 1000 x 250 pixels of 100 µm (100 mm x 25 mm)
  - 14 bit depth x 132,000 fps -> 462 Gbit/s
- 4 module (1 megapixel) -> 1848 Gbit/s, i.e. 231 Gbyte/s



Real-time data processing, selection and reduction

- Plan to develop layer of hardware for image conversion and selection
- Different options will be investigated
  - MicroTCA crate with FPGA cards
  - PCs with accelerators (GPU, FPGA)
- Flexibility is an important factor (e.g. high-level synthesis of firmware)
- Work supported by collaboration projects with SLAC (Hir3x), China (CHILFEL) and within Helmholtz (Innovation Pool)


Take Home Messages:

- Photon Sources will continue to develop over the next decade(s)
- Both in quality and quantity
- Democratisation of FEL sources in the future (smaller and cheaper)

- Detector Developments for photon sources continuously rapidly increasing

- We are (continuously) looking for motivated and talented people to join in the fun

(part of the) Photon-Science Detector Group