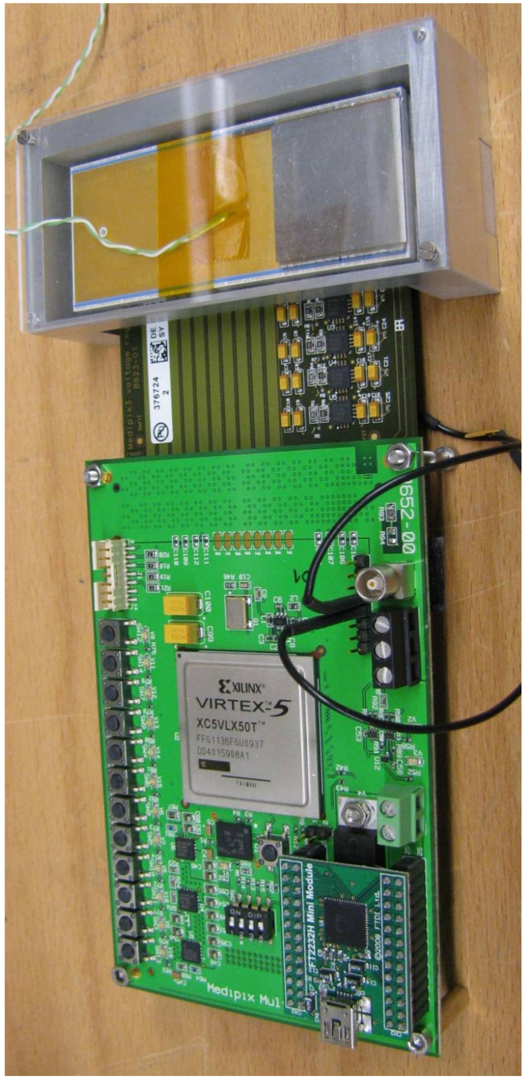
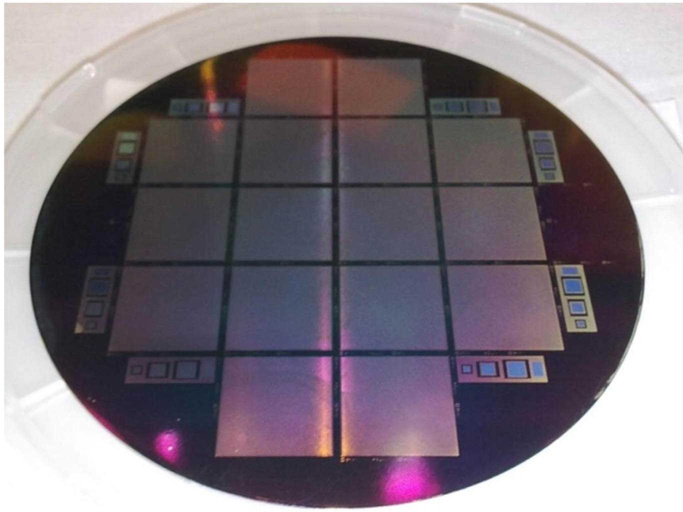
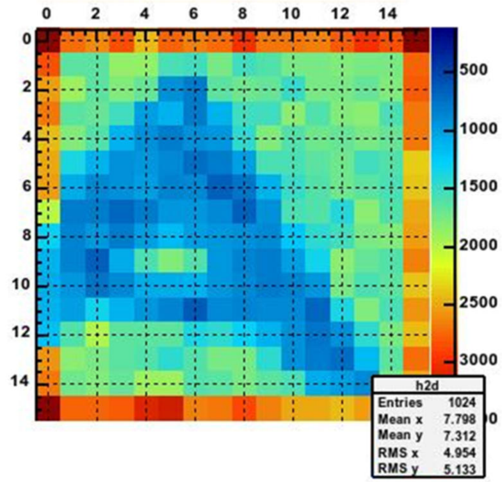
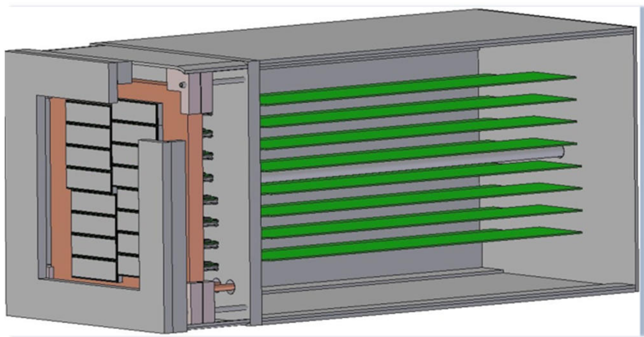
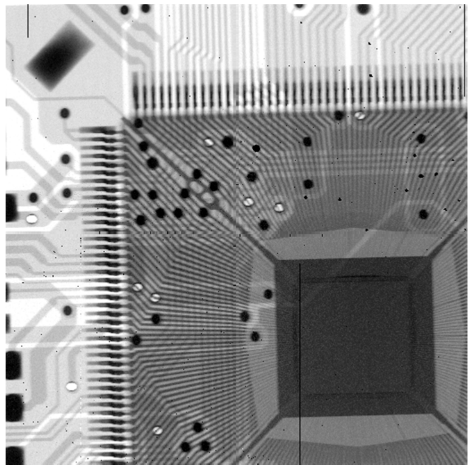
Detector development activities at DESY FS-DS











Julian Becker

Photon Science Detector Group, DESY

Overview

- Introduction to our group: DESY FS-DS
- Projects for synchrotron radiation detectors
  - LAMBDA
  - High-Z pixel detectors (hard X-ray detectors)
  - PERCIVAL
- Project for the European XFEL
  - AGIPD

Our group: DESY FS-DS

Heinz Graafsma
Group leader

Stephanie Jack
Project manager

Michael Lohmann
Detector scientist

Trixi Wunderer
Detector scientist

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David Pennicard
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Electronic engineer

Sergej Smoljanin
Electronic technician

Helmut Hirsemann
Mechanical engineer

Matthias Bayer
Mechanical engineer

Björn Nilsson
Mechanical technician

Our detector development projects (all collaborations)

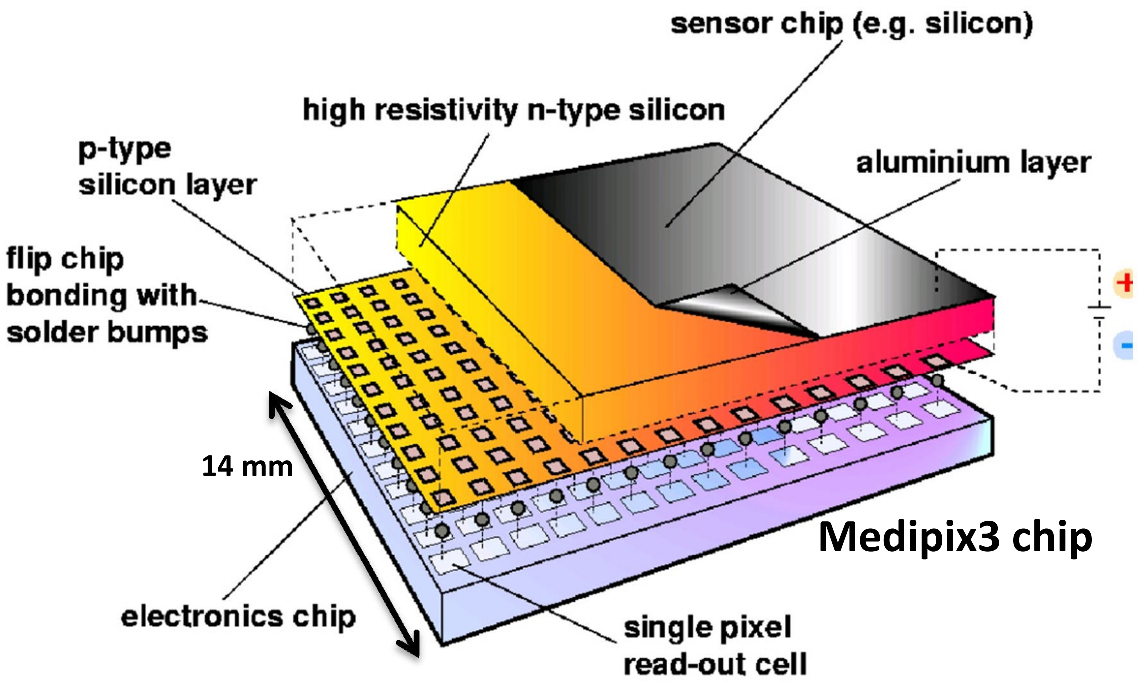
- LAMBDA (Large Area Medipix3-Based Detector Array)
  - Photon counting pixel detector module
- High-Z detectors (Ge, HiZpad collaboration, GALAPAD)
  - New semiconductor pixel detectors for hard X-rays
- PERCIVAL (Pixelated Energy Resolving CMOS Imager, Versatile And Large)
  - Low E (250 eV – 1 keV) imaging detector
- AGIPD (Adaptive Gain Integrating Pixel Detector)
  - 2D detector for XFEL, developed with PSI, Uni Hamburg, Uni Bonn
- DSSC (DEPMOS Sensor with Signal Compression)
  - XFEL detector project, led by MPI-HLL, Munich

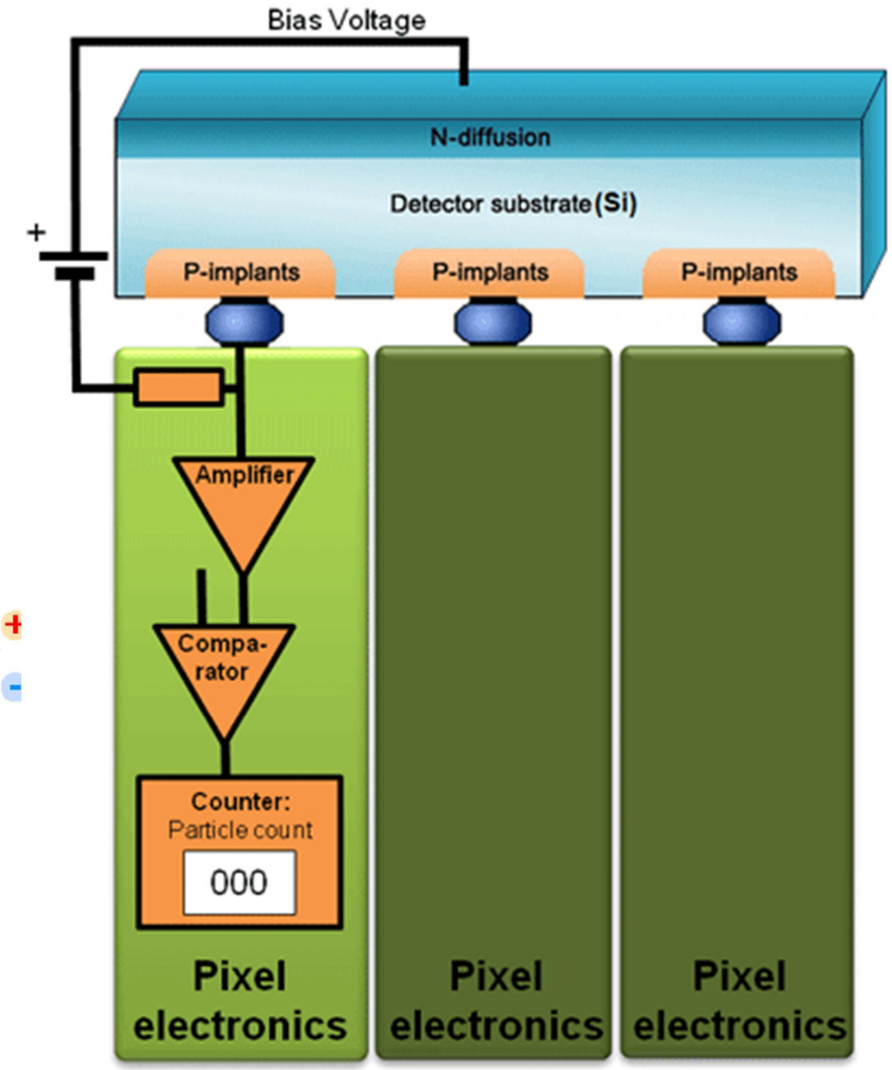
Other involvements

- CAMP (CFEL-ASG Multi-Purpose) Chamber
  - Already in use at LCLS
- Detector and science simulation (HORUS)
- XNAP (2D array of avalanche photodiodes)
  - Collaboration with ESRF, U. Heidelberg, SPring-8, Exelitas
- Diamond beam position monitors with RF readout
  - Collaboration with ESRF
- Detector loan pool
  - Pool of a variety of detectors (Pilatus, Maxipix, CCDs, imaging plates, etc.) and associated equipment to support user operation at photon sources.

Hybrid pixel detectors (counting)

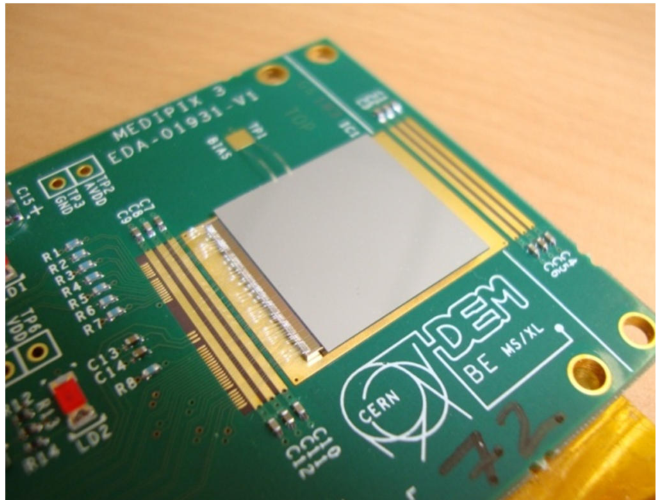
- Pixellated photodiode sensor
- Readout chip with 1 readout channel per pixel



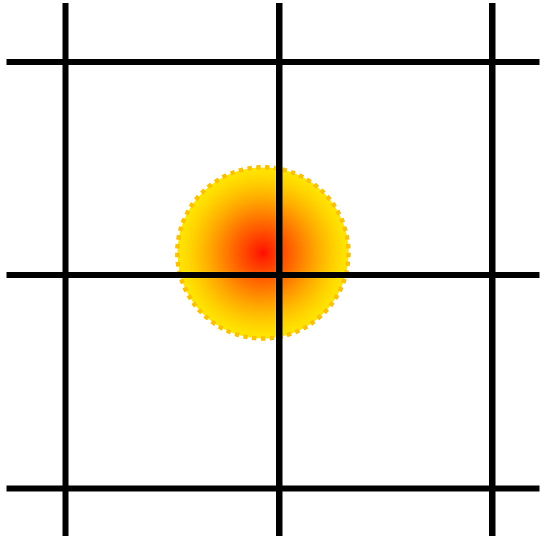


Medipix3 readout chip

- 21 groups in collaboration
  - Chip design at CERN
- Successor to Medipix2 (Maxipix)
- 256 * 256 pixels, 55µm
- 2 counters per pixel for deadtime-free readout
  - Up to 2000 fps with 12 bit counter depth
- “Charge summing” circuitry to compensate charge sharing effects
  - More reliable hit detection
  - Better energy discrimination



Charge shared between pixels



Hybrid pixels and X-ray detection

- First generation of X-ray hybrid pixels in use
  - Pilatus (Dectris, PSI; 172 µm pixels)
  - Maxipix (ESRF, Medipix2; 55µm pixels)
- Advantages
  - Single photon counting (“noise free”)
  - Fast readout
  - Large dynamic range
  - Energy discrimination

- Disadvantages
  - Pixel-to-pixel variation in electronics (must be calibrated)
  - Poor efficiency at high energies
  - Problems at high flux rates

Detector developments at DESY

> ***LAMBDA (Large Area Medipix-Based Detector Array)***

- Large detector modules using new Medipix3 chip
- 55µm pixel size, fast readout, greater functionality

> ***"High-Z" semiconductors (Ge, HiZpad, GALAPAD)***

- Si has poor absorption efficiency > 20 keV
- Heavier semiconductors (Ge, CdTe, GaAs) allow hard X-ray detection

> ***PERCIVAL (Pixelated Energy Resolving CMOS Imager, Versatile And Large)***

- Low E (250 eV – 1 keV) CMOS detector with 25 µm pixel size
- Designed by STFC, readout by DESY

> ***AGIPD (Adaptive Gain Integrating Pixel Detector)***

- Integrating detector with dynamic gain switching
- In-pixel storage for ultra fast (4.5 MHz) imaging at XFEL

LAMBDA detector head

> Large sensor area
  - 2-by-6-chip layout
  - 1536*512 pixel, 84 mm * 28 mm
  - Set by typical silicon and high-Z wafer sizes (6”, 3”)

> Suitable for high-speed readout

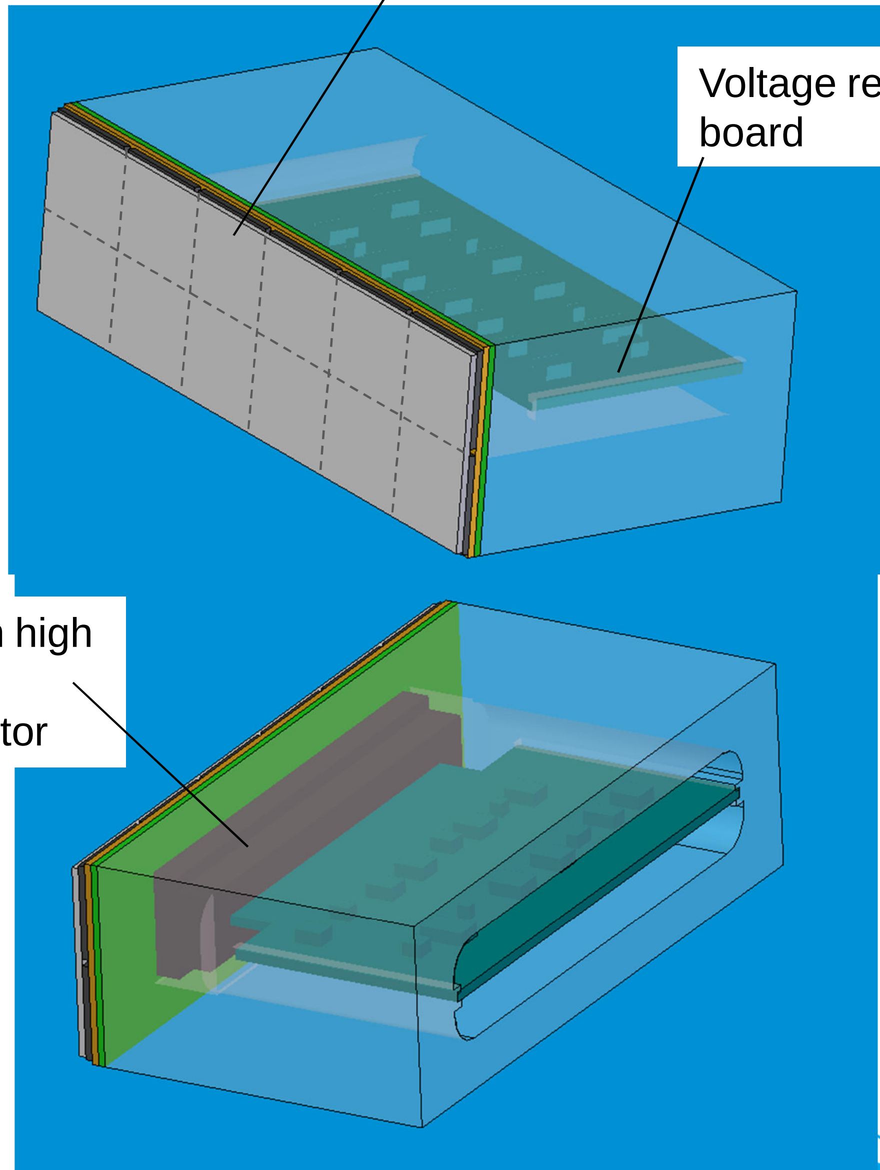
> Low-temp operation possible

> Modular design
  - Multiple readout chips build a single module
  - Multiple modules tiled in large system

1 large Si sensor
84 mm * 28 mm

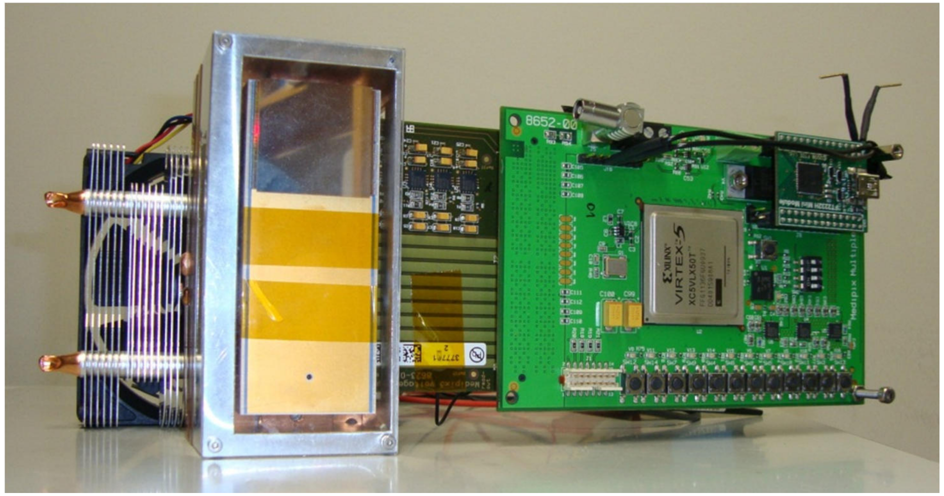
or

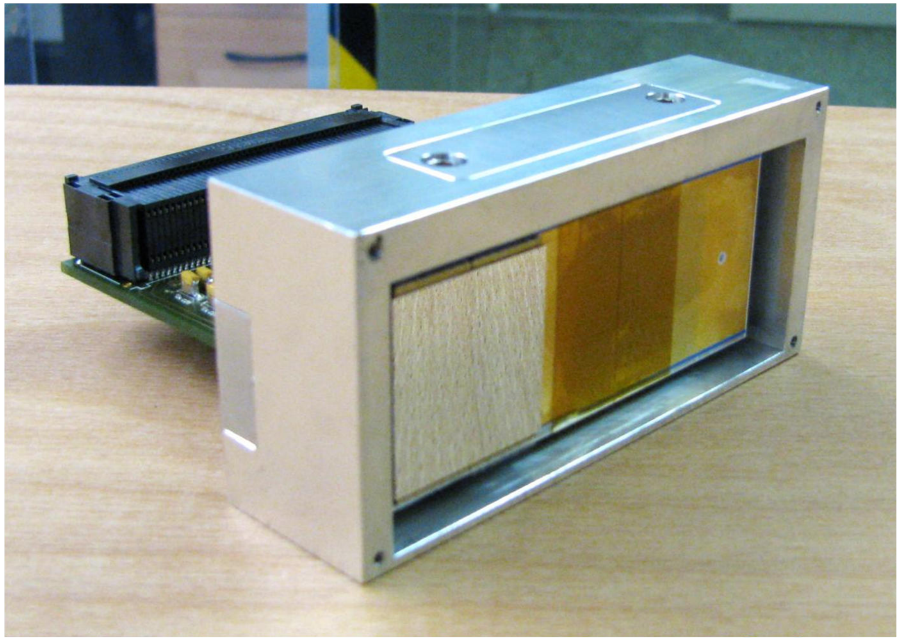
2 “hexa” high-Z sensors
Each 42 mm * 28 mm



First prototype systems

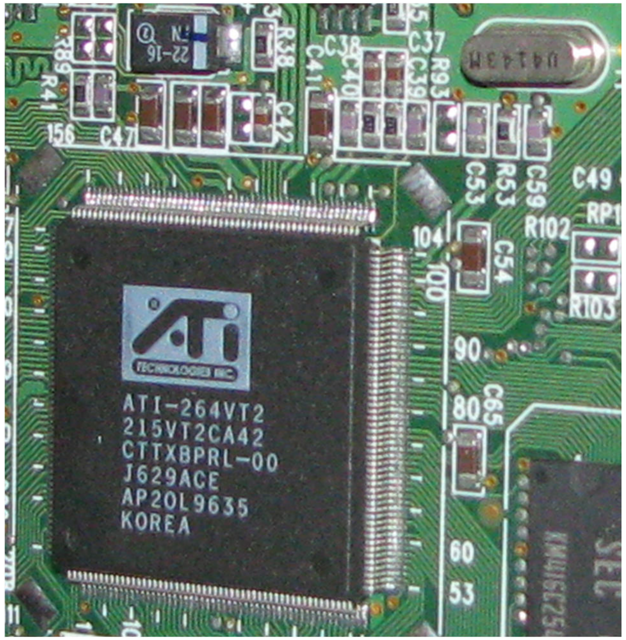
- 4 modules built with “quad” sensors (2*2 chip, 512*512 pixels)
- Mechanics with Peltier cooling
- Electronics to one side of sensor (but right-angle connector now available)
- Prototype readout board (completed)
  - USB2 communication with control PC (10 frames per second with large-area sensor should be possible)
- High-speed readout
  - Common readout mezzanine board being developed for LAMBDA, PERCIVAL and AGIPD
  - Multiple 10 Gigabit Ethernet links for full-speed readout

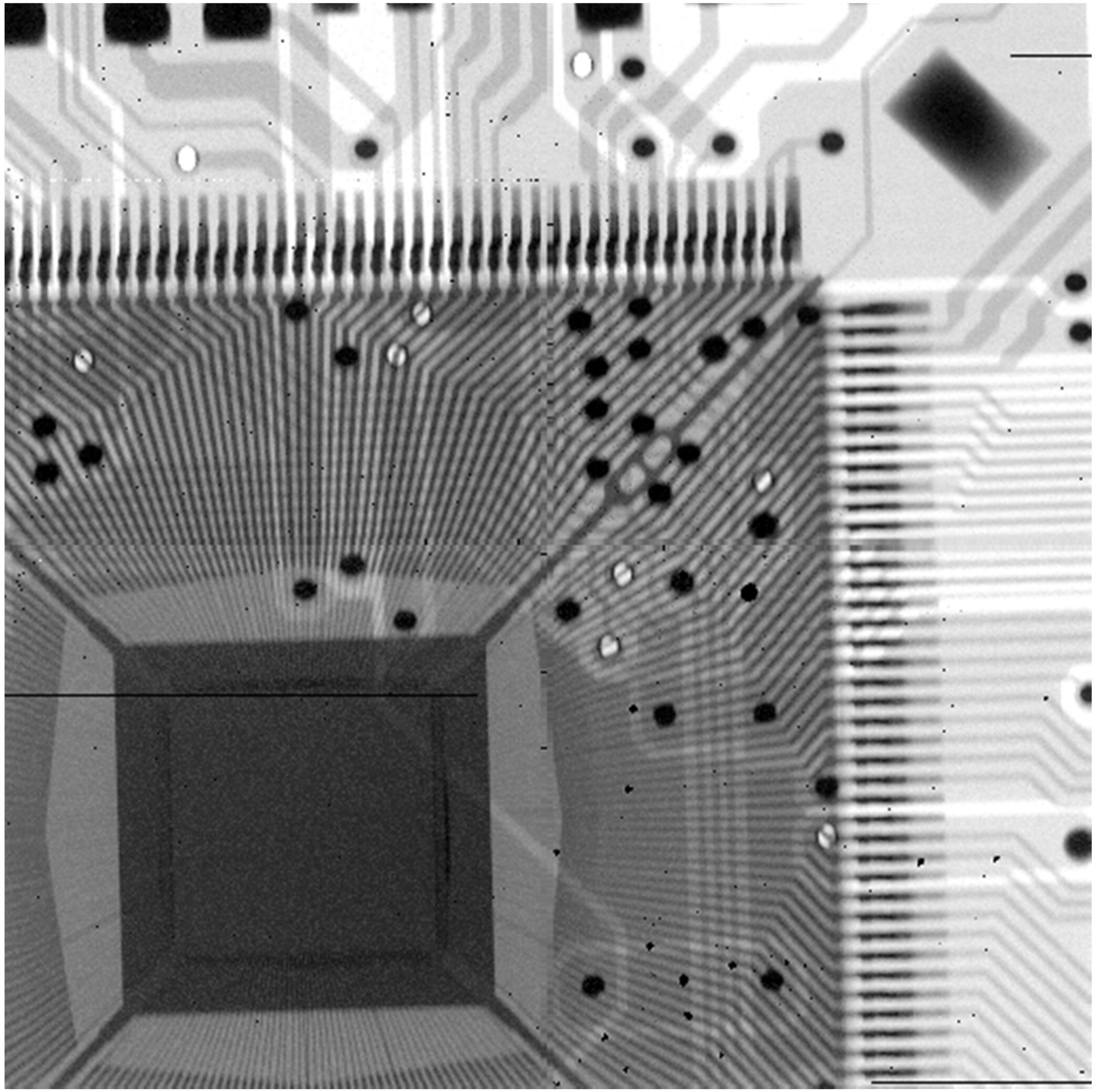




Test results so far

- Quad detectors are functional
- Full-size sensor currently being bump-bonded at IZM
- Working on high-speed readout

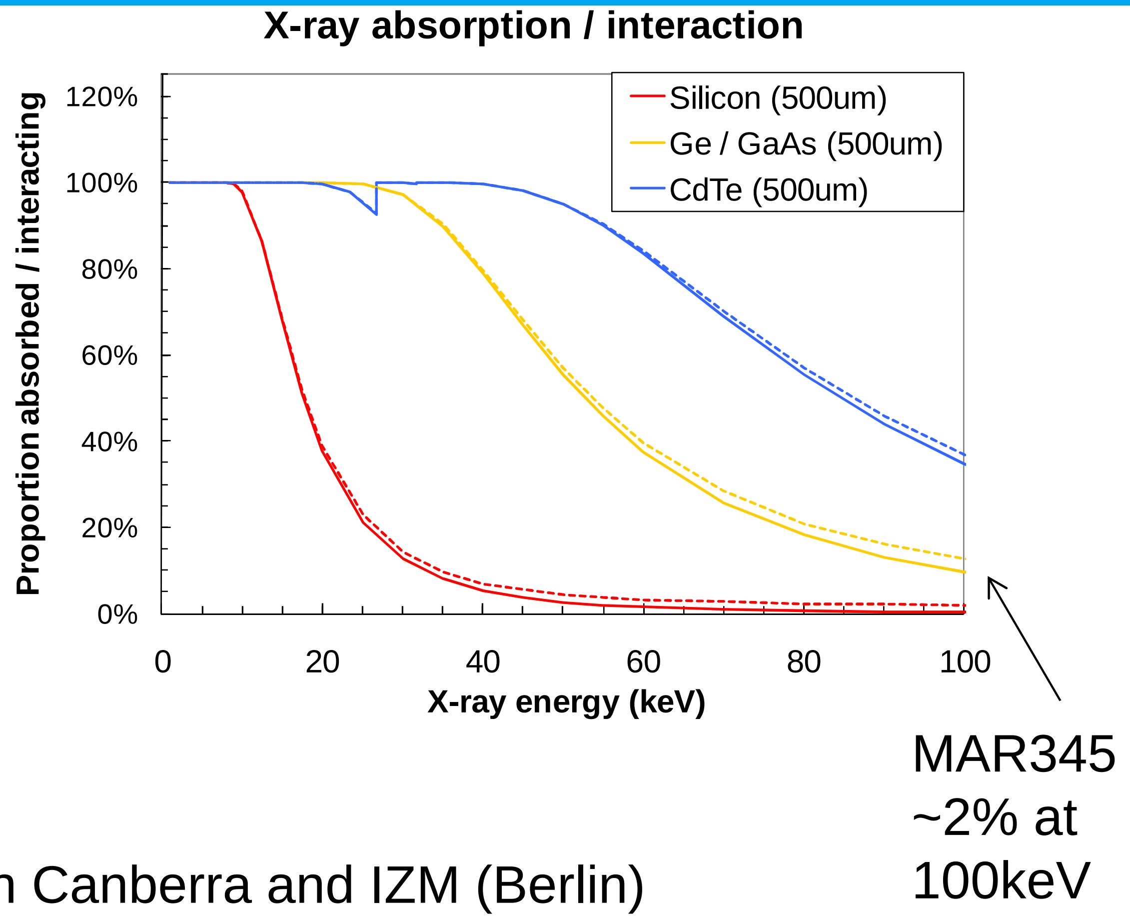




High-Z materials – X-ray absorption efficiency

- Replacing Si with high-Z material could combine hybrid pixel advantages with high efficiency with hard X-rays

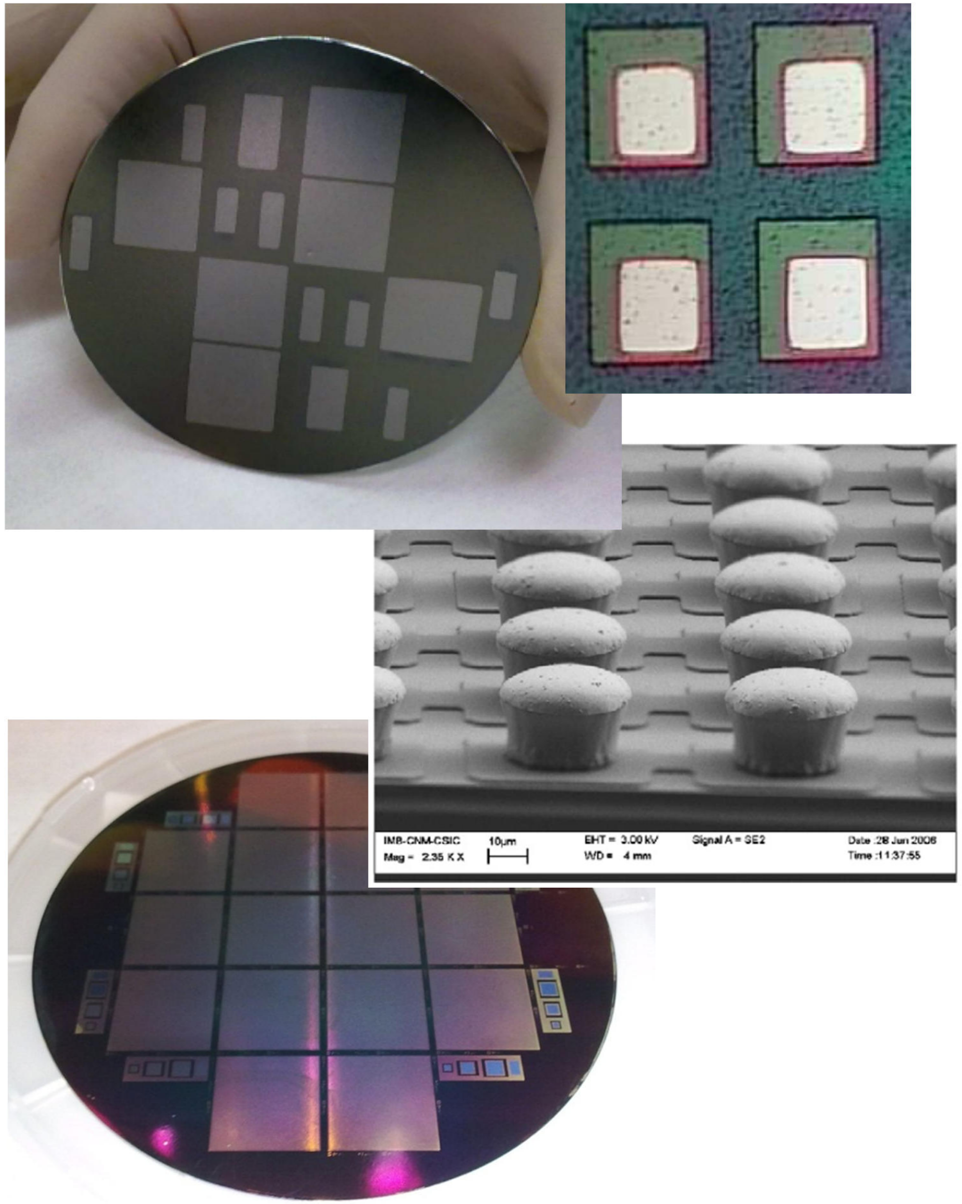
- However, each high-Z material has its downsides!



- Our projects:
  - Germanium – development with Canberra and IZM (Berlin)
  - Cadmium Telluride – HiZPAD consortium (led by ESRF)
  - Gallium Arsenide – Russian-German partnership with FMF, KIT, JINR (Dubna) and RID Ltd. (Tomsk)

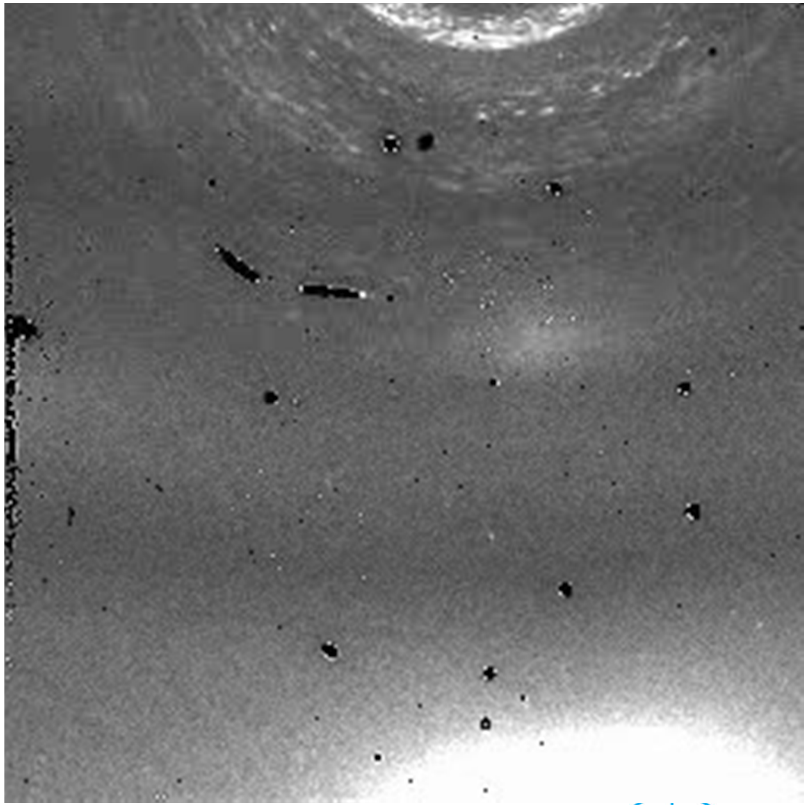
Germanium sensor production and bump bonding

- Sensor structure (Canberra)
  - Modification of existing strip detector technology
  - 55µm pixels, 700 µm thick
- Indium bump bonding (IZM)
  - Sensor and ASIC bonded at T < 100°C
  - During cooling, ductility of Indium compensates for mismatch in contraction
- 2 high purity Ge wafers plus mechanical dummies received from Canberra
  - 16 Medipix3 singles / wafer
  - IZM optimizing process using dummies
  - HP Ge bonding follows soon
- Readout and mechanics by DESY (LAMBDA framework)

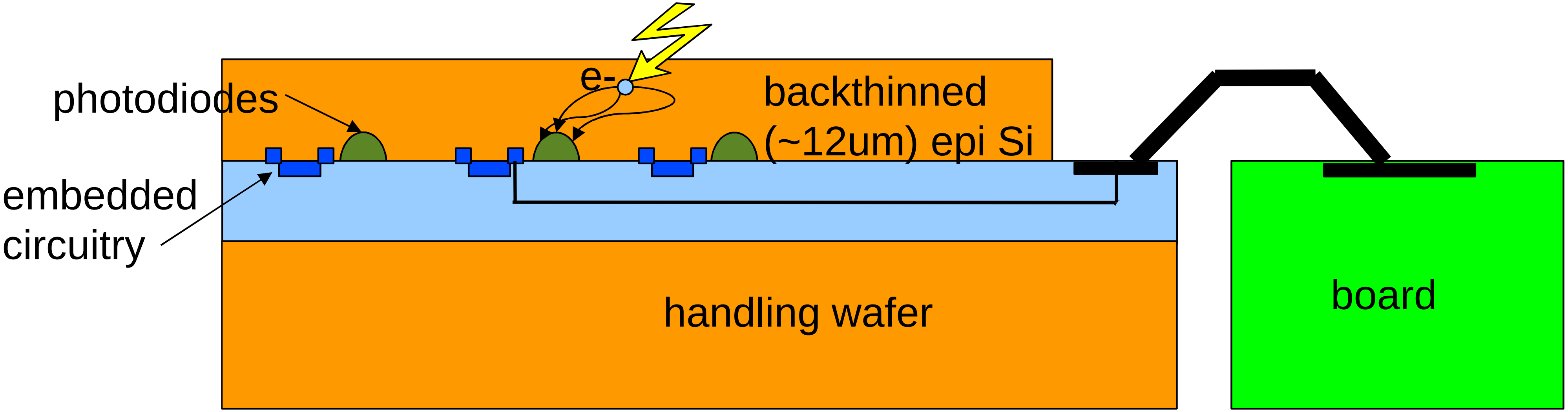


Cadmium Telluride

- HiZPAD (High-Z sensors for Pixel Array Detectors)
  - EU-funded consortium – 12 institutes (led by ESRF)
- CdTe ($Z_{Cd,Te}$ = 48, 52, Z_{Si} = 14)
  - Already used in single-element detectors / small arrays
  - Small wafers (3”), often with inhomogeneities
- Tested CdTe sensor with Medipix2 readout
  - 55µm pixel, 256 * 256 array, 1000 µm thick
  - Tests done at DORIS III - BW5 beam line (160 keV photons)



PERCIVAL project



Aspired performance parameters:

- Primary energy range 250 eV – 1 keV (will work from <200 eV to few keV)
- 12 µm Si sensitive volume with 25 µm pixels ⇒ 4k × 4k pixel sensor
- 4 sensors in cloverleaf arrangement can make up 64 Mpixel (20cm x 20cm)
- back-illuminated, back-thinned for uniform QE > 90%
- 120 Hz frame rate and lower
- 2-side buttable (space between active pixel edges on the order of 1mm)
- electronic noise < 15e-, “full well” ~ 20 Me-
- Multi-gain approach to access full dynamic range,
  all gains active all the time

Overview

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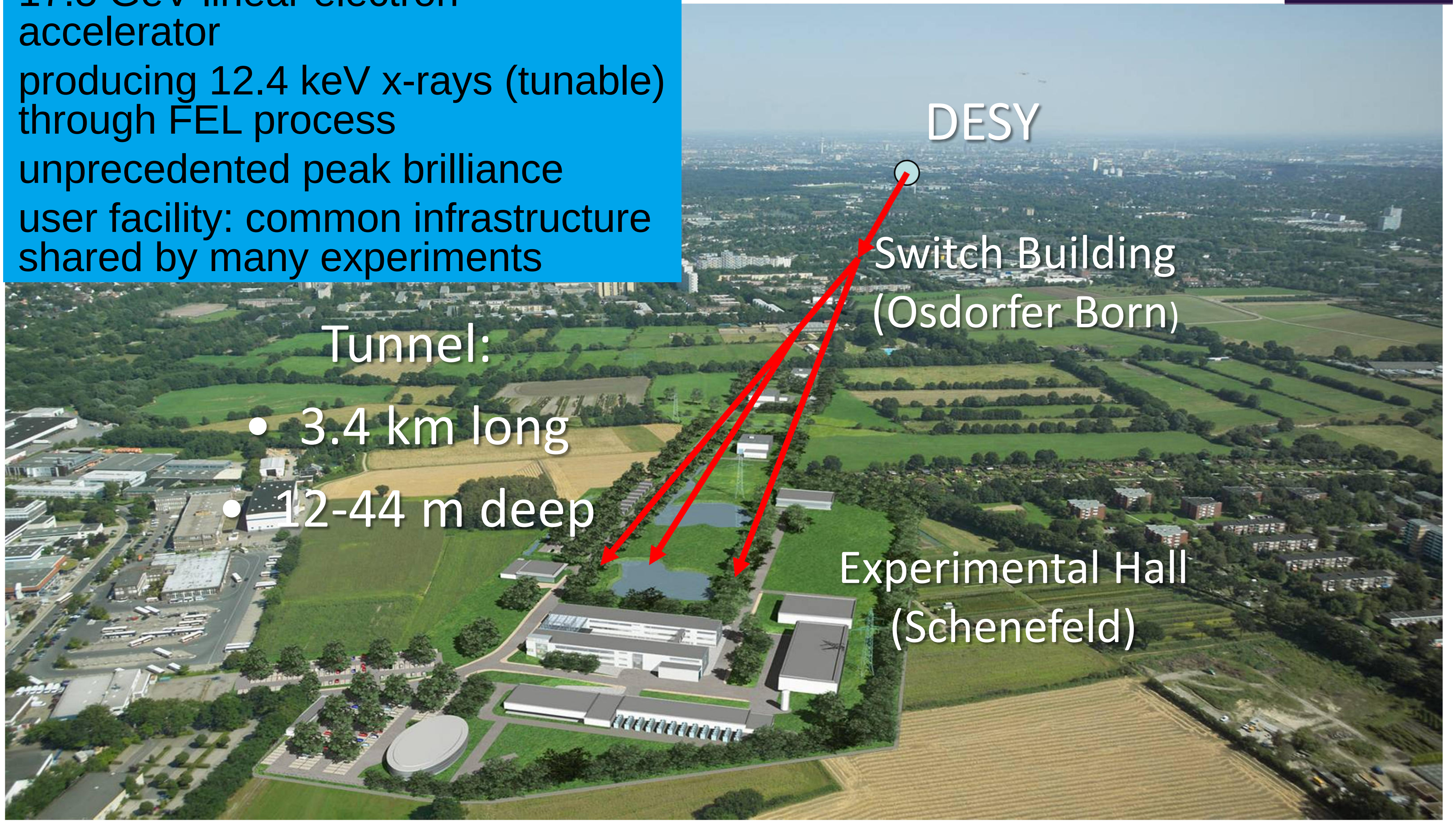
The European XFEL

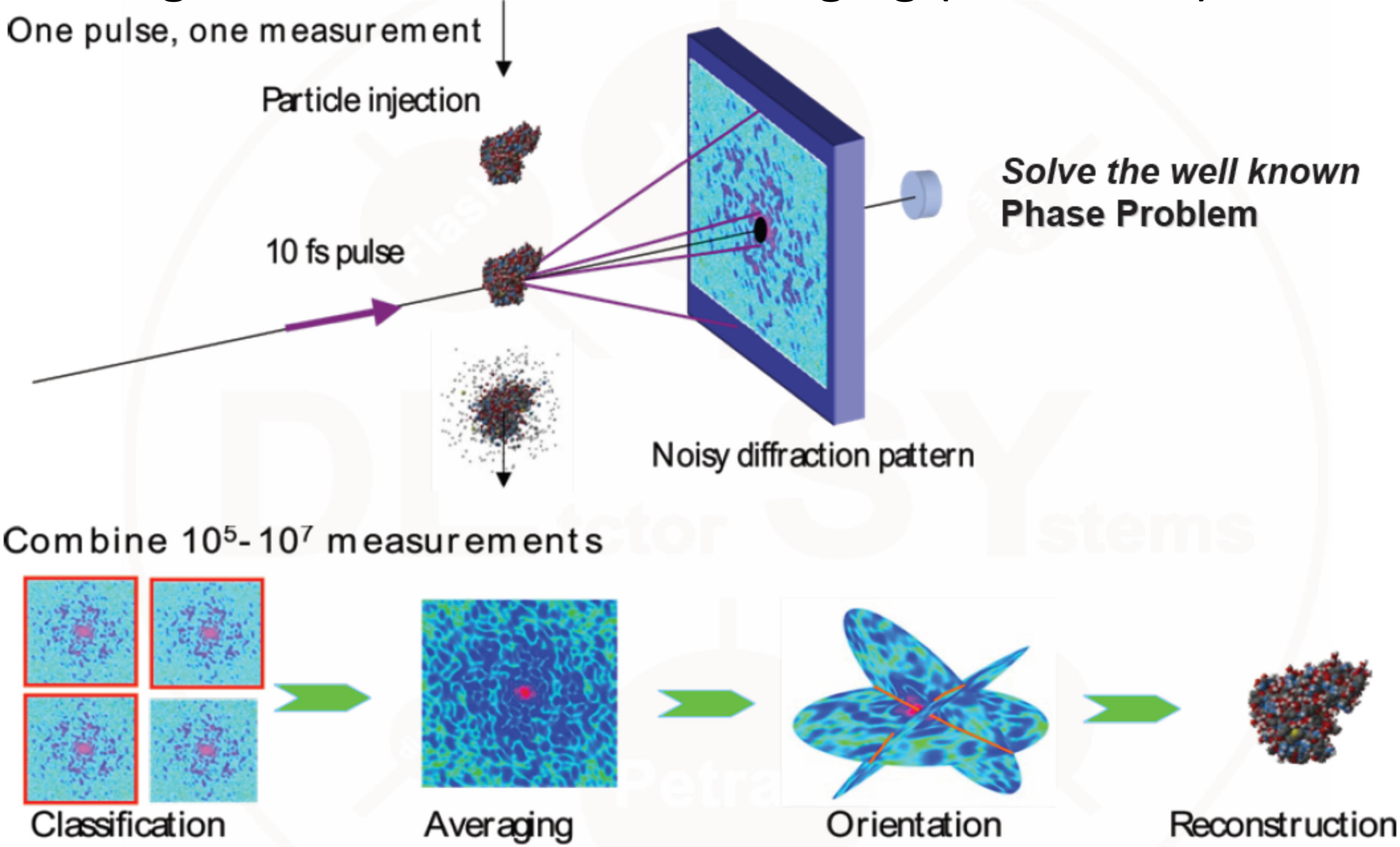
www.xfel.eu

- 17.5 GeV linear electron accelerator
- producing 12.4 keV x-rays (tunable) through FEL process
- unprecedented peak brilliance
- user facility: common infrastructure shared by many experiments



Single shot imaging…

e.g. Coherent Diffractive Imaging (CDI or CXI):



K. J. Gaffney and H. N. Chapman,
Science 8 June 2007

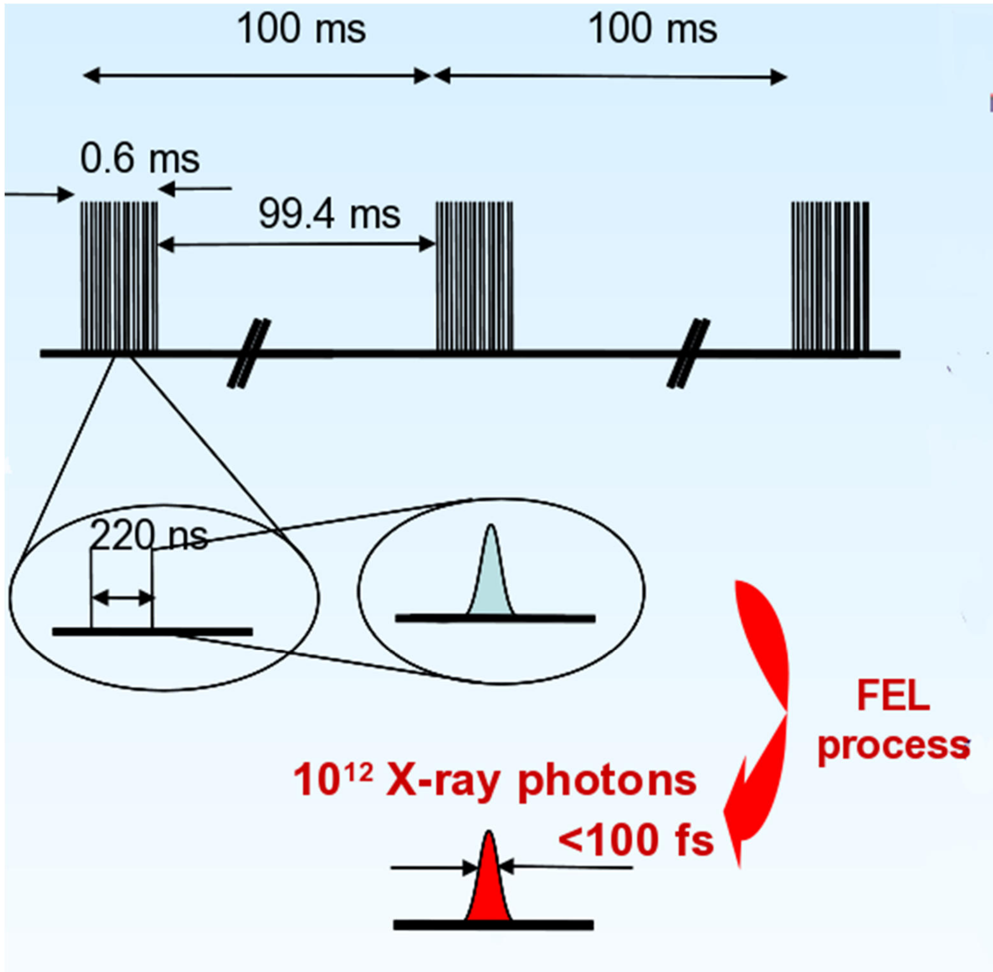
XFEL pulse trains

> Special structure of pulse trains:

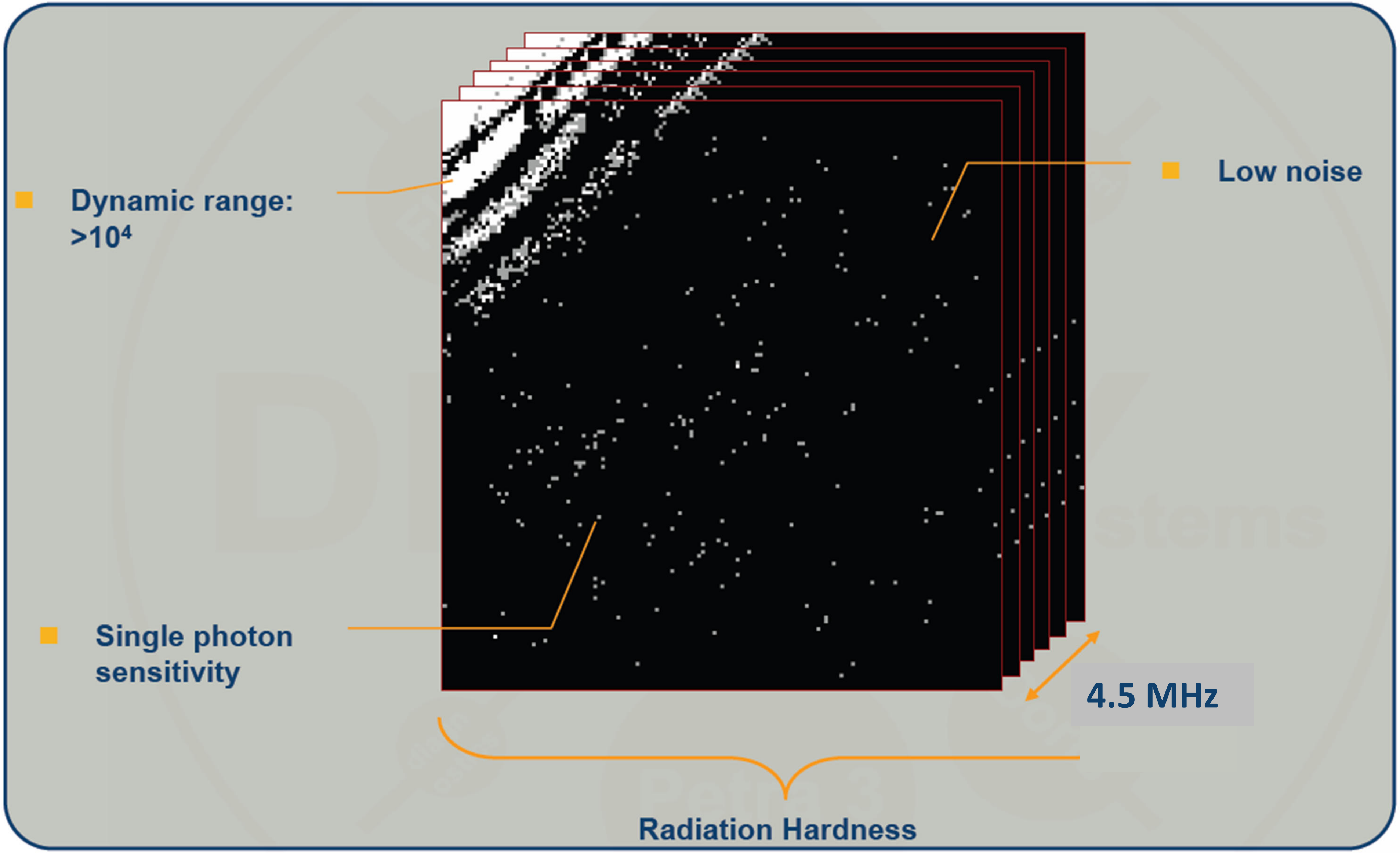
- 600 µs long pulse trains at a repetition rate of 10 Hz
- Each train consists of 2700 pulses with a separation of 220 ns
- Each (SASE) pulse consists of ≈10^{12} photons arriving <100 fs

> Beam energy:

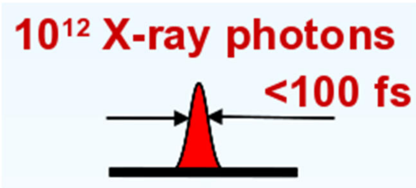
- 5 – 25 keV (depends on station)
- 12.4 keV (λ=0.1 nm) nominal design energy for AGIPD



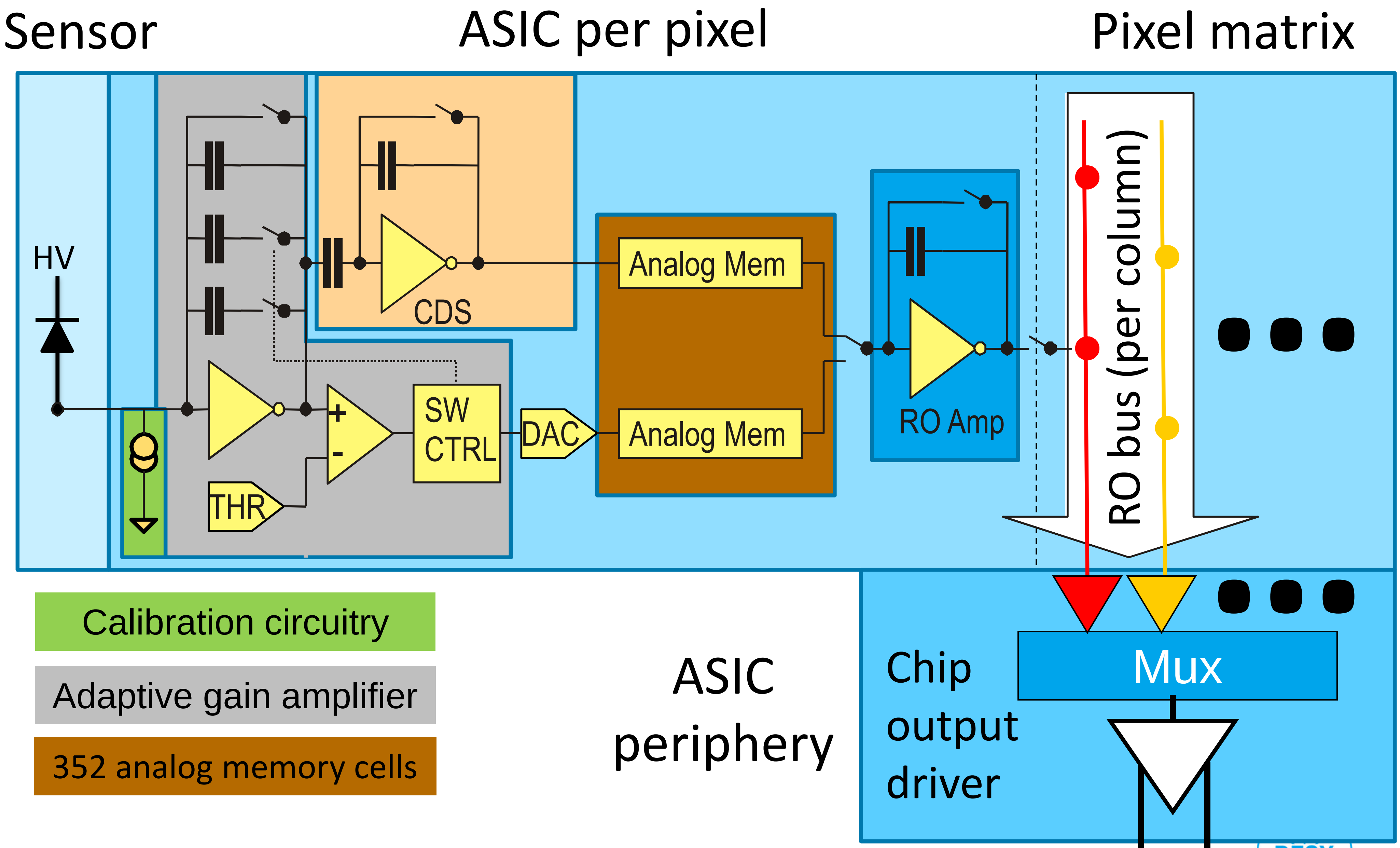
XFEL Detector requirements



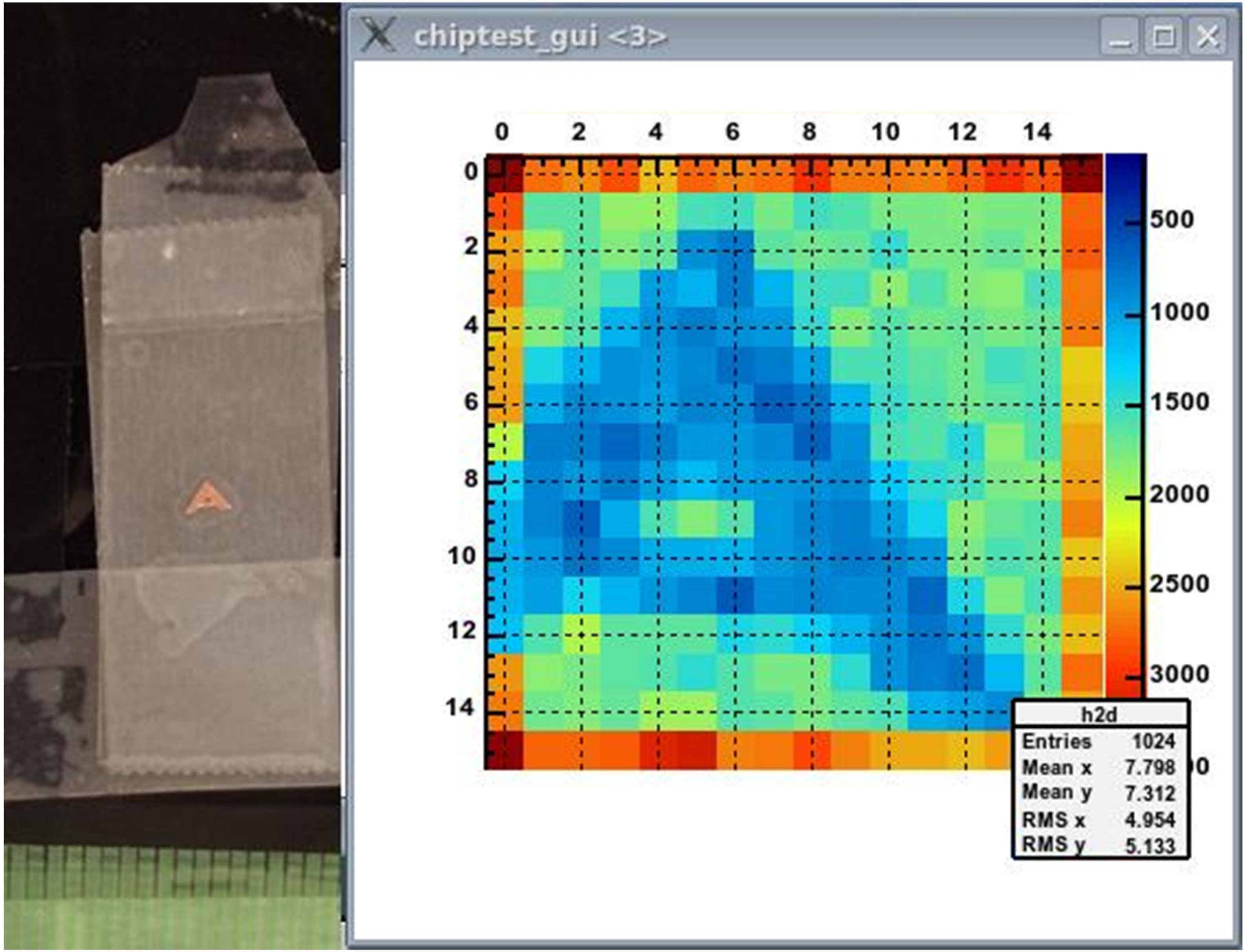
XFEL challenges

XFEL provides	*Challenges*	*Approach*
• Simultaneous deposition of all photons 	• Single photon counting not possible • Dynamic range: 10^4 photons/pixel with single photon sensitivity	• Charge integration • Dynamic gain switching → 3 gain stages → Single photon sensitivity in highest gain
• High number of bunches → 2700 bunches per train (600 µs)	• Reading out of single frames during pulse train impossible	• Analog memory in the pixel using the ≈350 storage cells per pixel

AGIPD ASIC


Sensor
ASIC per pixel
Pixel matrix
HV
CDS
Analog Mem
Analog Mem
SW
CTRL
DAC
THR
+
-
RO Amp
RO bus (per column)
Calibration circuitry
Adaptive gain amplifier
352 analog memory cells
ASIC
periphery
Chip
output
driver
Mux

Imaging with AGIPD 0.2 prototype



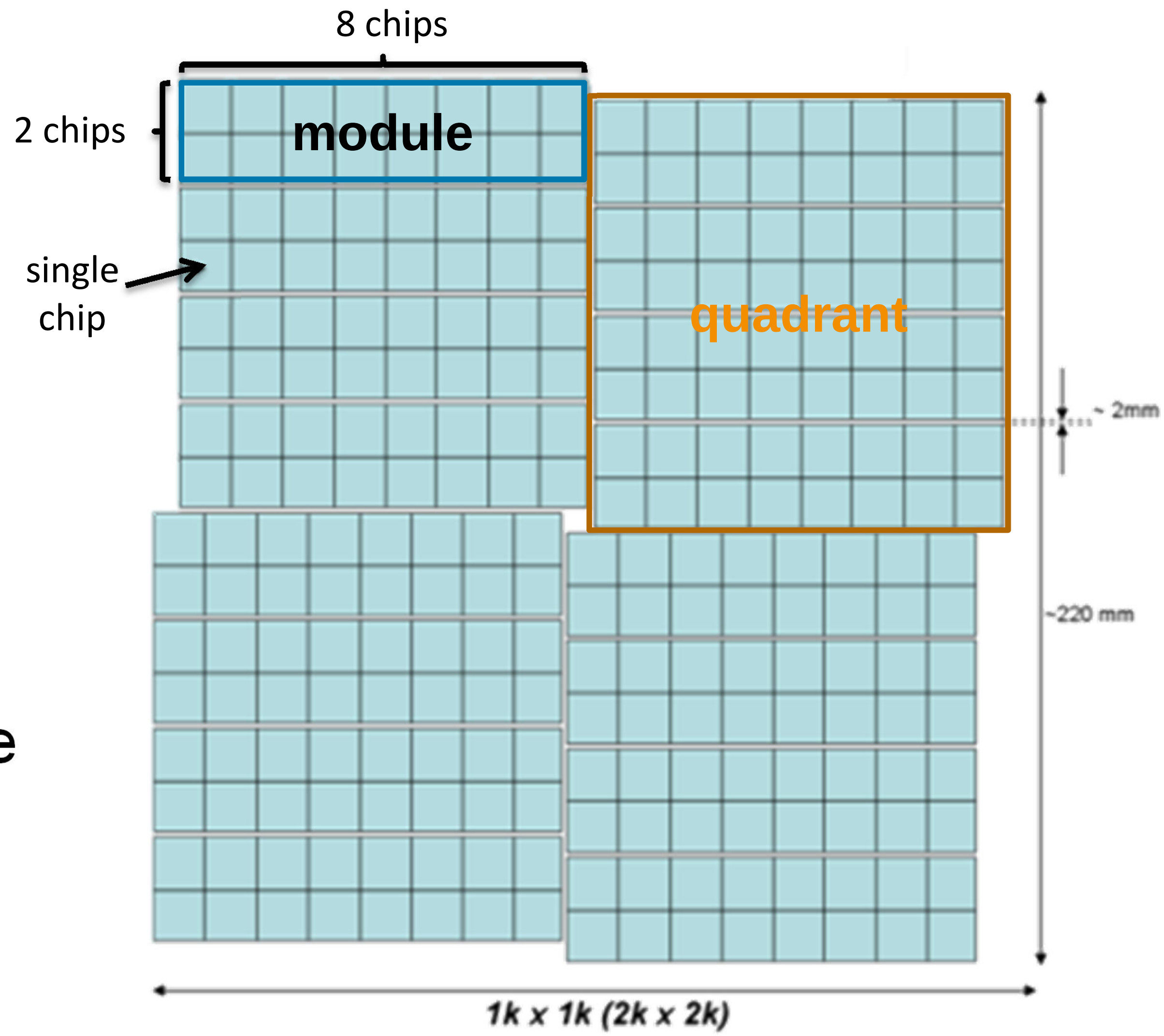
The detector layout

> ***Specifications:***

- 1 Mpixel
- 4 quadrants
- 4 modules per quadrant

- 1 module: 8 x 2 chips,
- 1 chip: 64 x 64 pixels

- 200 x 200 µm^2 pixel size
- 500 µm silicon sensor
- Hole for direct beam
- Upgradable to 4 Mpix



Summary (of detector projects)

> LAMBDA

- Large area modules (1536 * 512 pixels, 84 mm * 28 mm)
- 55 µm pixel size
- 2 kHz frame rate

> HiZ materials (Ge, GaAs, CdTe)

- Direct detection imaging at high energies
- Compatible with LAMBDA modules

> PERCIVAL

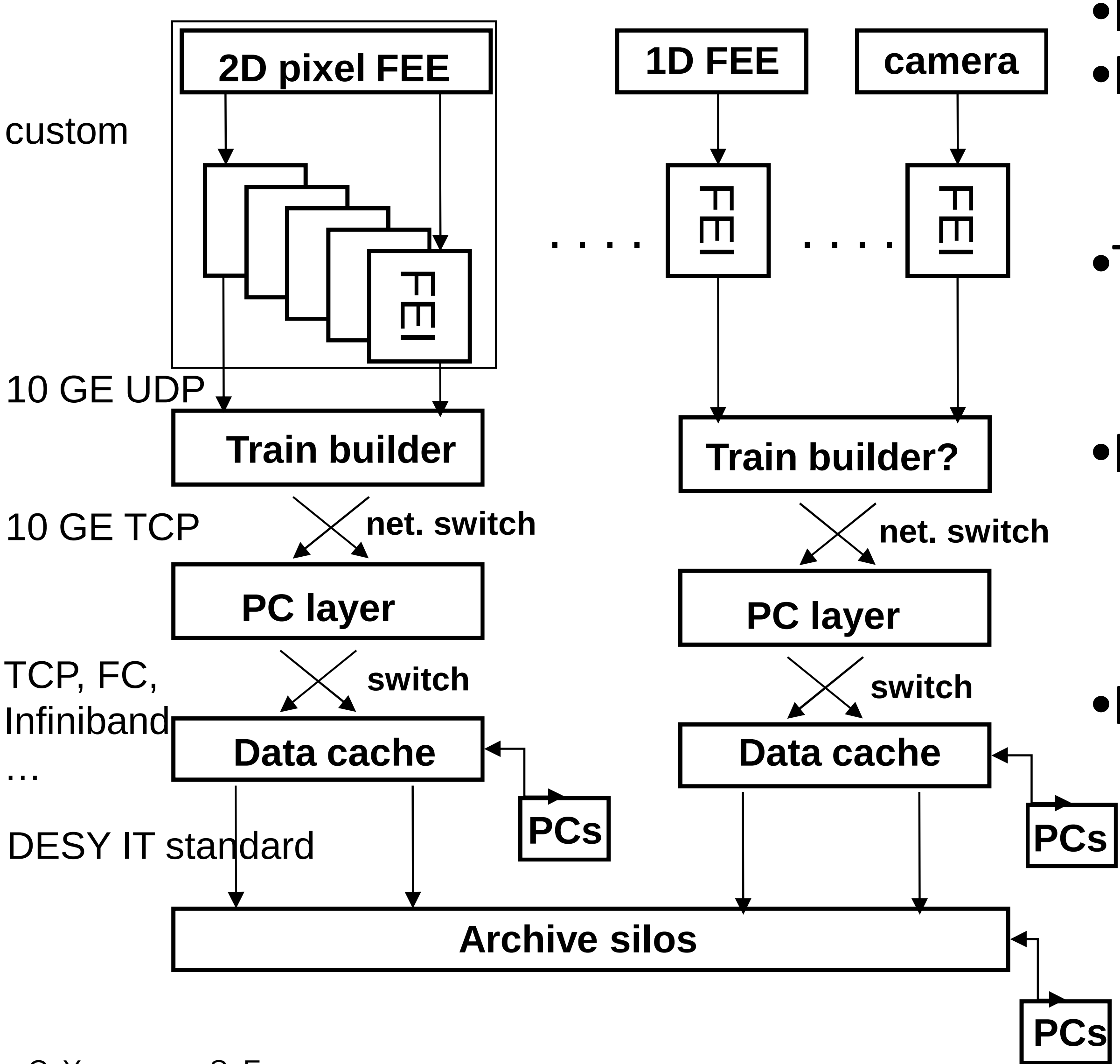
- Low energy imaging (<250 eV to >1 keV)
- 25 µm pixel size
- 120 Hz frame rate

> AGIPD

- 4.5 MHz imaging
- 10^4 12.4 keV γ dynamic range
- single photon sensitivity for E > 5 keV

Backup

DAQ architecture



- Front End Electronics (FEE)
- Front End Interface (FEI)
  - interface to Train Builder
  - integrated in 2D
- Train builder layer
  - builds trains
  - simple data processing
- PC layer
  - interface to cache
  - additional train building
  - more complex data process
- Data cache
  - hold, analyze, reduce and reject data
  - post processing
  - commit to silo

C. Youngman, S. Esanov