Percival soft X-ray imager

Pixellated Energy Resolving CMOS Imager, Versatile and Large

Cornelia Wunderer
DESY – Photon Science Detectors
iWoRiD 2018, Sundsvall

CFEL SCIENCE

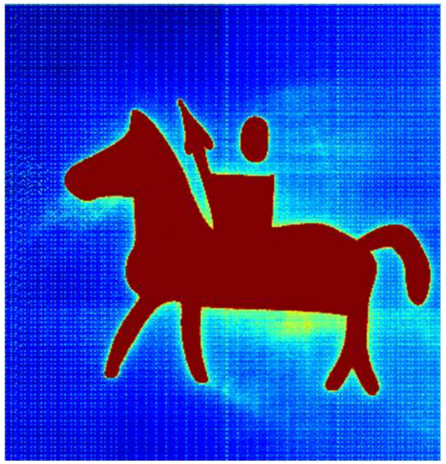
PAL

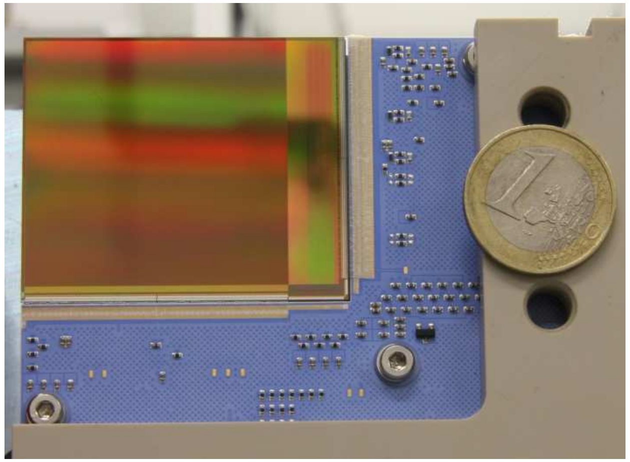
DESY.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Percival

In a nutshell





Unprecedented combination:

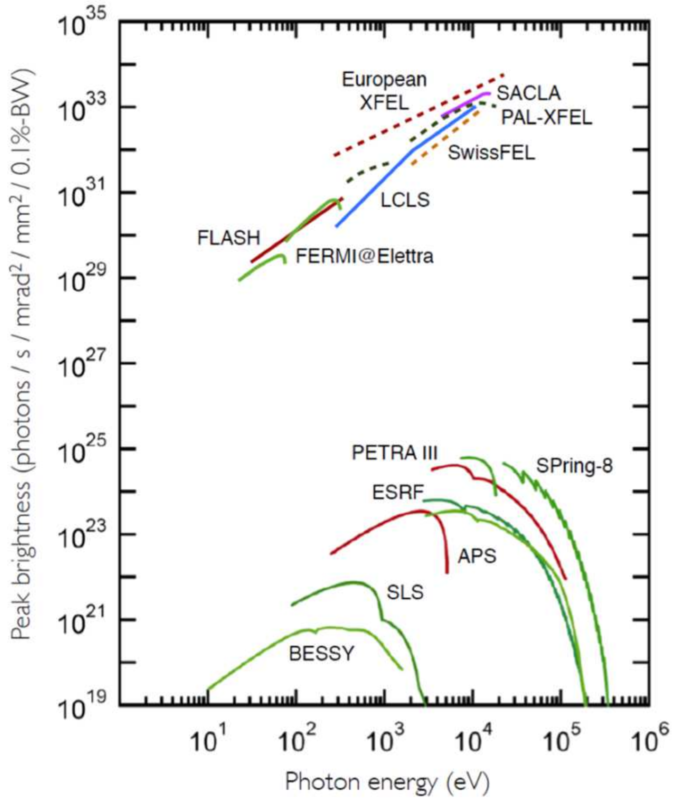
- 1408 × 1484 pixels
- 300 Hz frame rate
- below 15 e^- noise
- sensitive to single photons
- handle $5 \cdot 10^4$ ph/pix/frame

… BSI processed for good soft X-ray performance

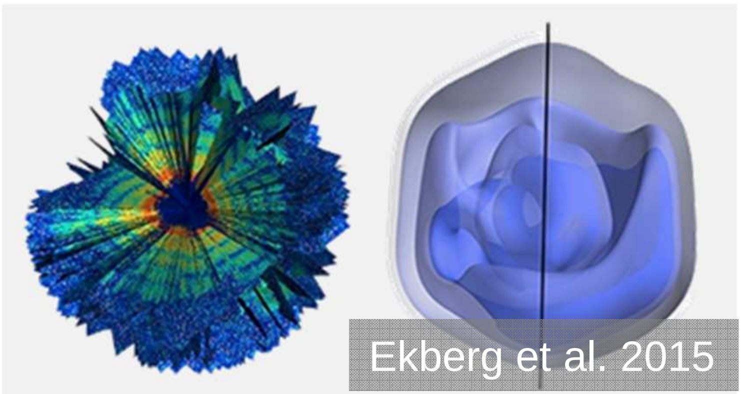
Science Motivation

Watching biomolecules in action … and more

- Making optimal use of the brilliance of today's photon sources requires
  - Single-shot imagers with suitable frame rates
  - Very large dynamic range
    - single-photon discrimination to
    - 10^4 photons/pixel/frame and more
  - Millions of pixels with little/no dead area



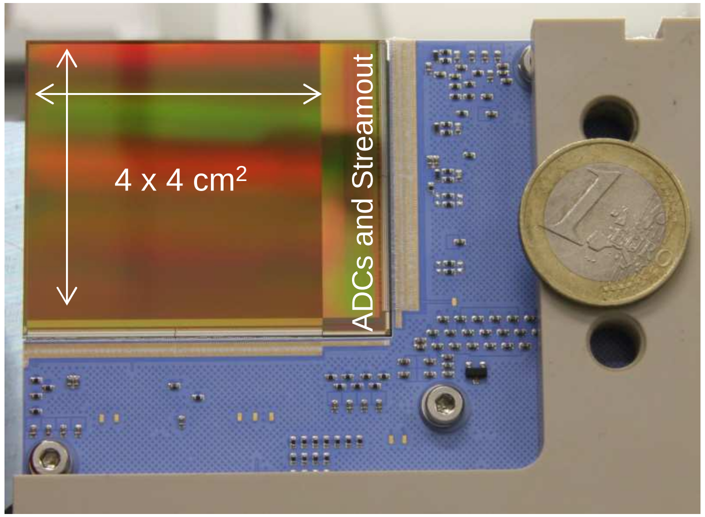
- In the soft X-ray regime
  - Scientific interest e.g. biosystems, weakly scattering samples
  - Particular challenge: small signal requires very low noise
  - Particular challenge: sensor surface



P2M Sensor

Designed by partner Rutherford Appleton Lab / STFC

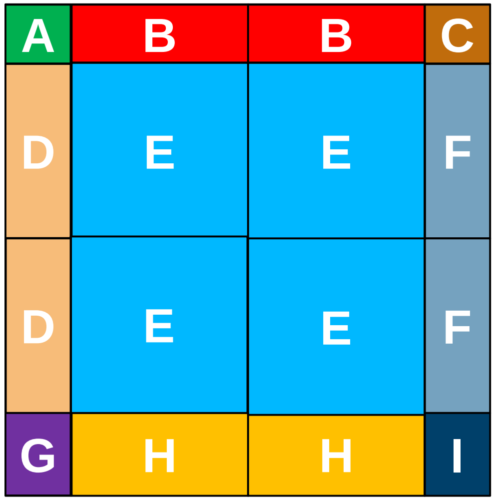
- CMOS imager (180nm technology)
- On-chip digitization (11520 ADCs)
- 3 auto-adjusting gain levels (per pixel, per frame, overflow)
- 1408 × 1484 pixels, 27µm × 27µm
- 4 × 4 cm^2 continuous imaging area (stitched sensor)
- Data rate at 300Hz frame rate is 20 Gbit/s, streamed out over 45 LVDS lines (240 MHz, double data rate)



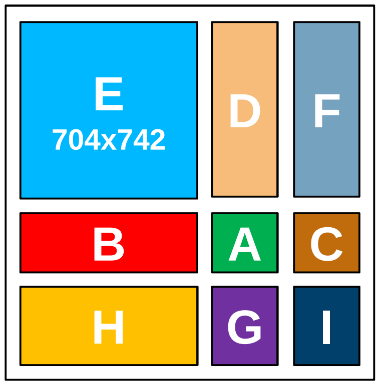
P2M – a stitched sensor

Designed by partner Rutherford Appleton Lab / STFC

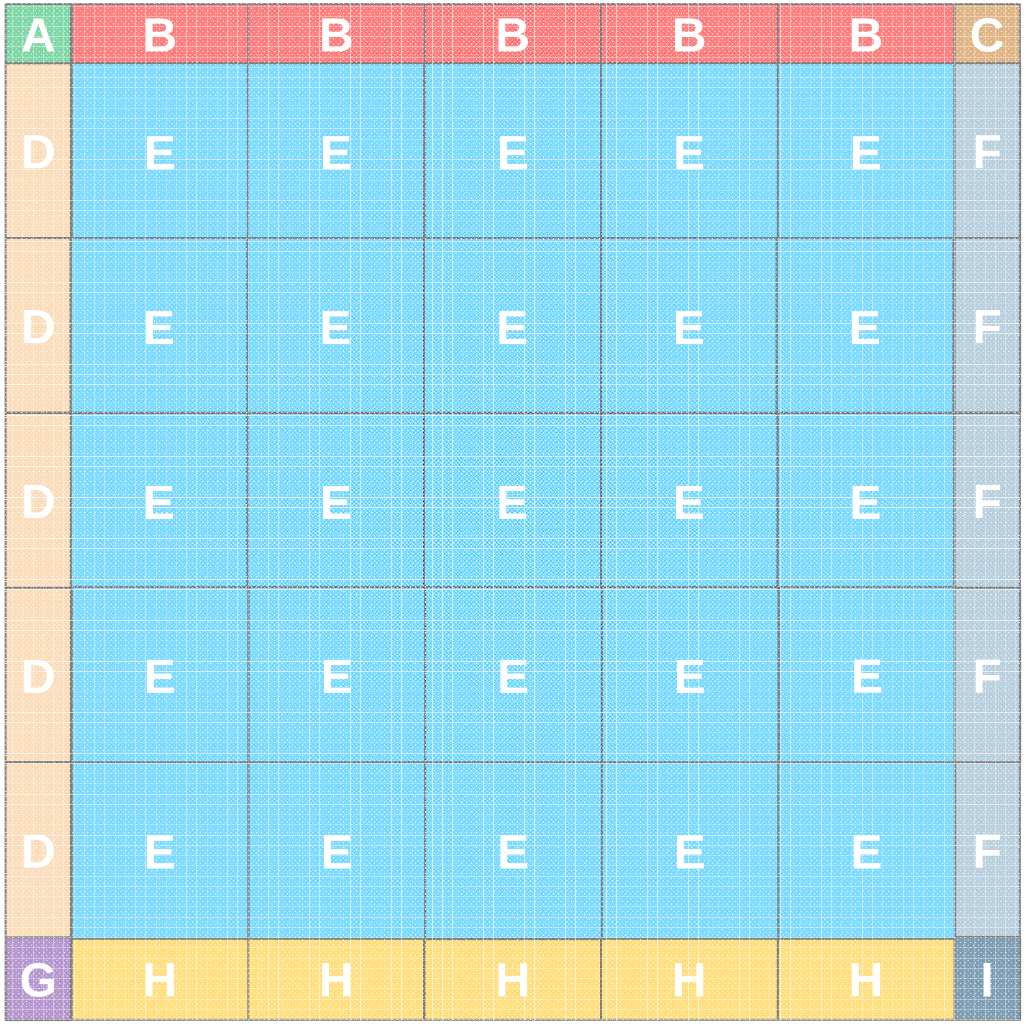
1408 x 1484 pixel P2M



stitching blocks



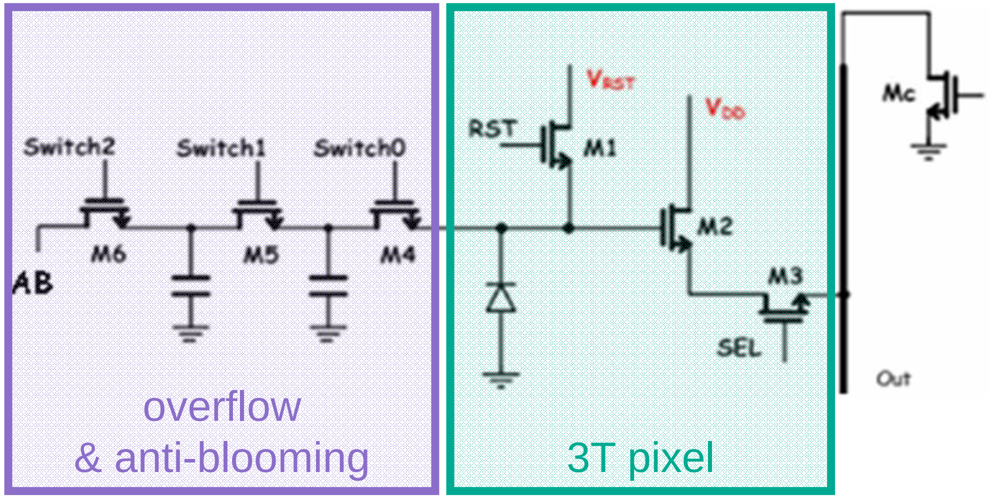
3520 x 3710 pixel variant, P13M ~ $10x10cm^2$

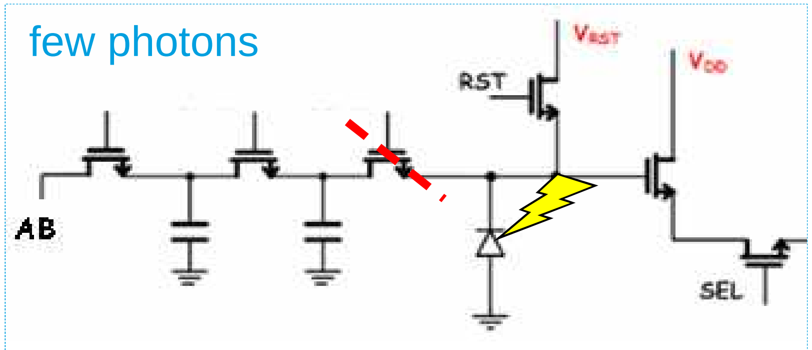


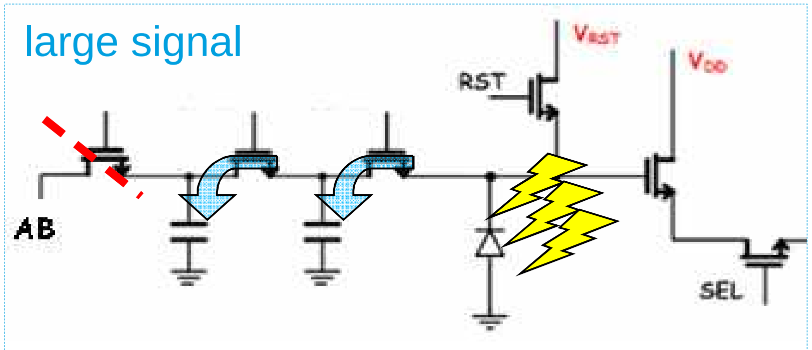
P2M Sensor – Multiple Gains

Designed by partner Rutherford Appleton Lab / STFC

- 3 auto-adjusting gain levels (per pixel, per frame, overflow)
- Readout sequentially tests all three overflow configurations for each pixel against threshold
- Only best candidate digitized & sent to DAQ

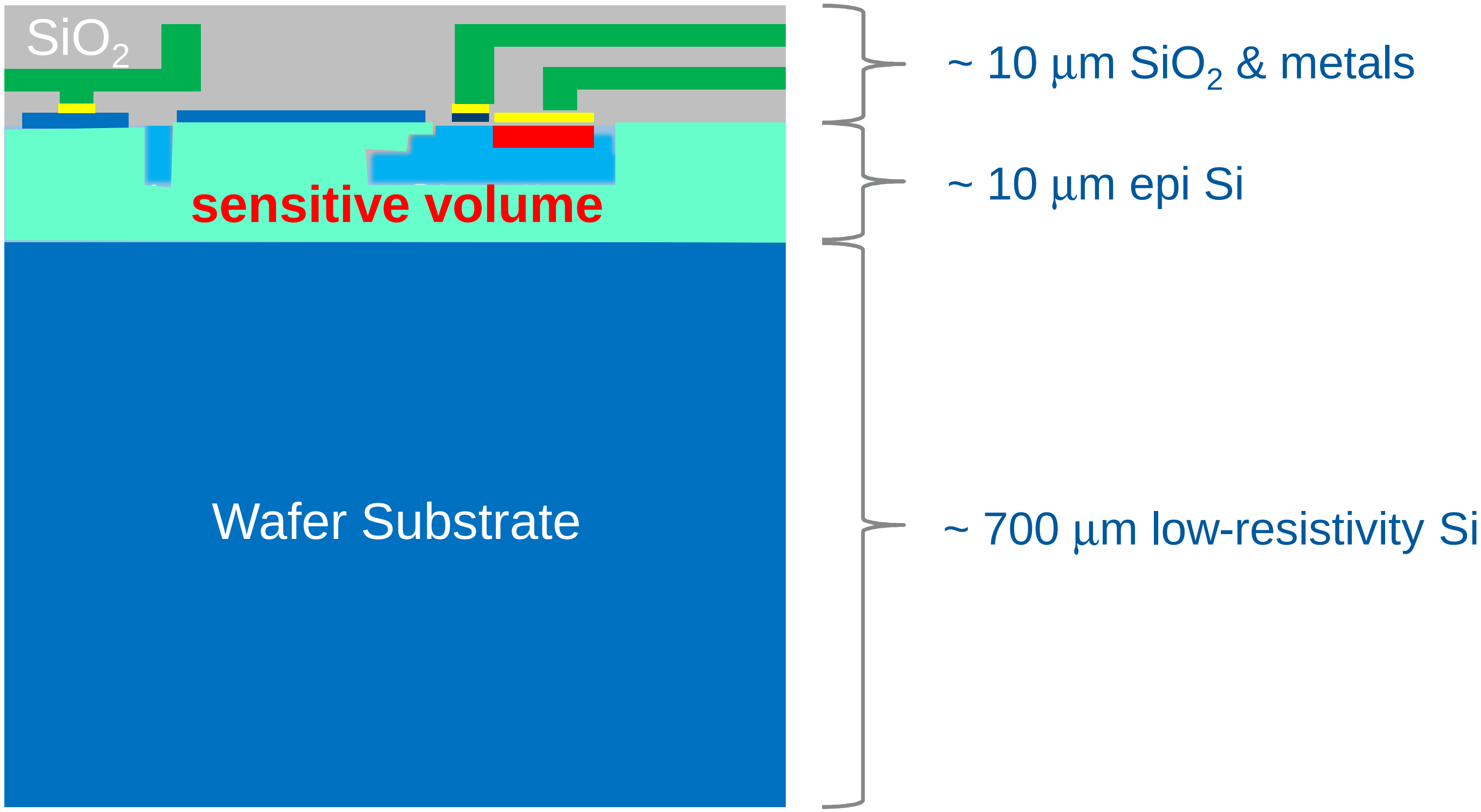




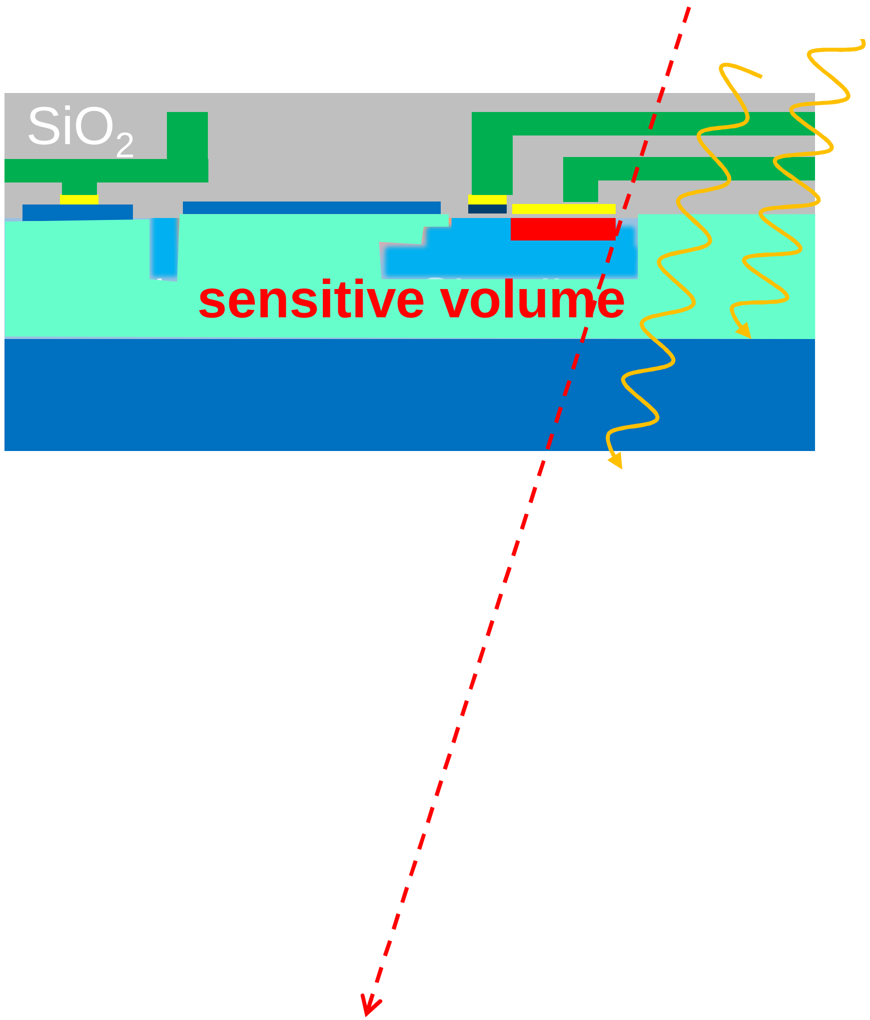


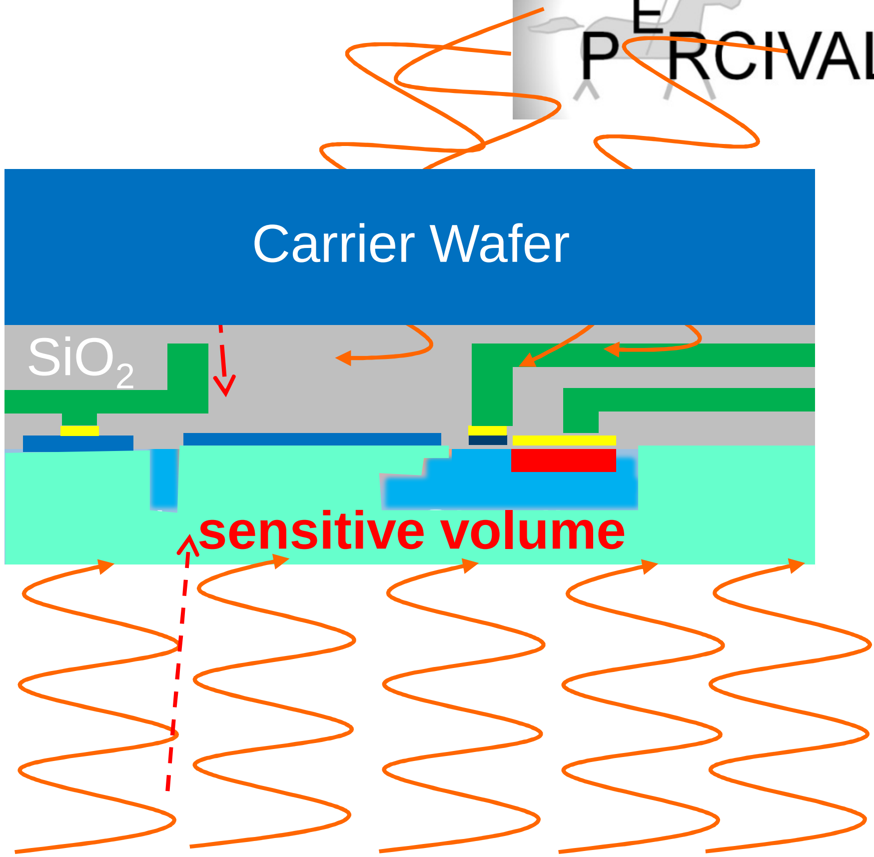
Backside Illumination

How to enable soft X-rays to interact in the sensitive volume



Backside Illumination





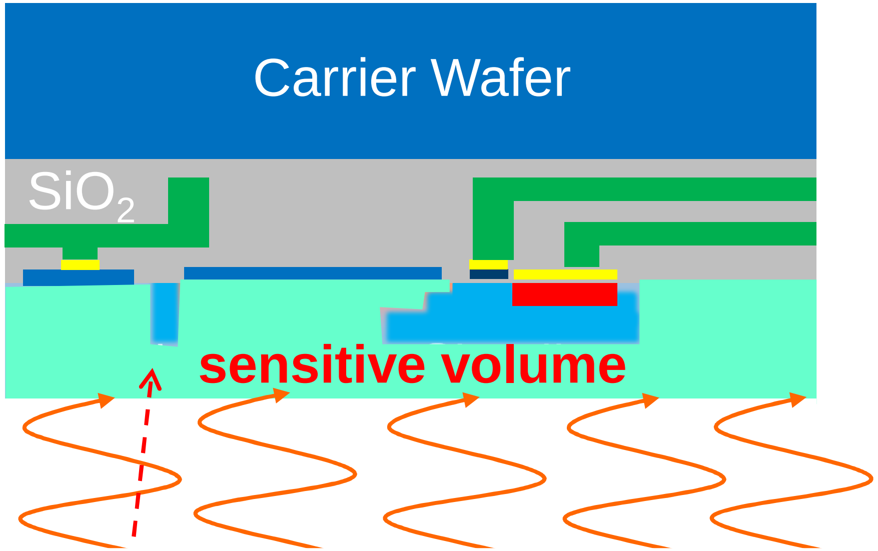
Entrance window post-processing

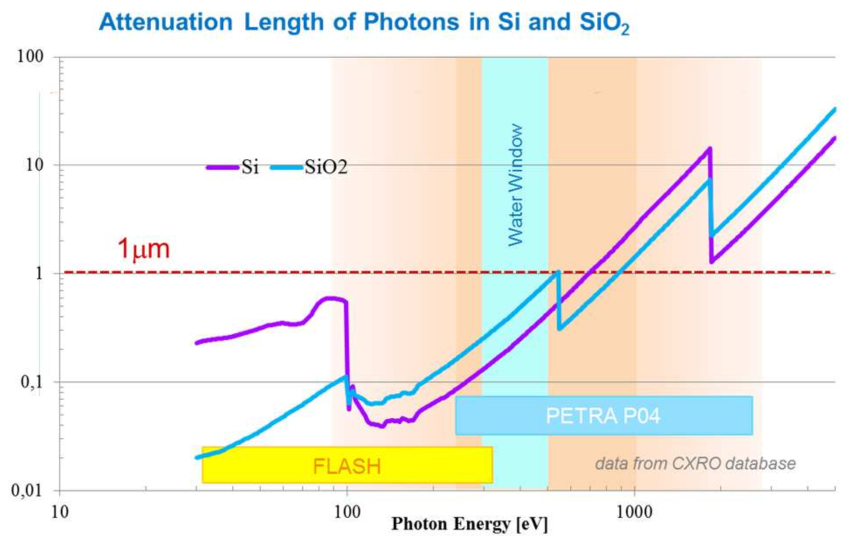
High sensitivity to low-energy radiation requires:

- Absence of passive material
- Absence of traps
- Optimized field geometry at sensor surface

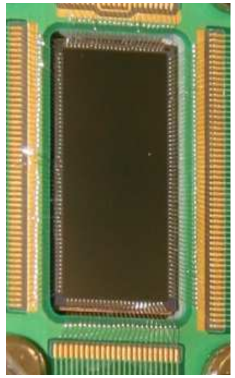
➡ **High-quality backside processing is crucial!**

e.g. 50 nm of SiO_2:
loss of 25% of 250 eV photons





Post-Processing for Percival



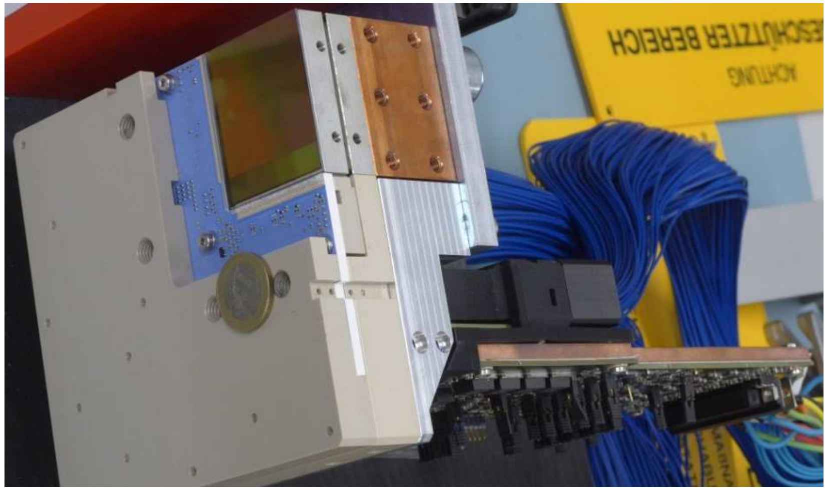
- Prototype Sensor post-processed by NASA's JPL "delta-doping"
  - Pioneered ultra-thin entrance windows (few nm)
  - Bureaucratic difficulties mainly make access difficult & time-consuming
  - TS sensors processed by JPL give nice soft X-ray performance
  - Unfortunately – due to said bureaucratic difficulties –
    e.g. not possible to BSI-process 2nd generation test devices in reasonable time

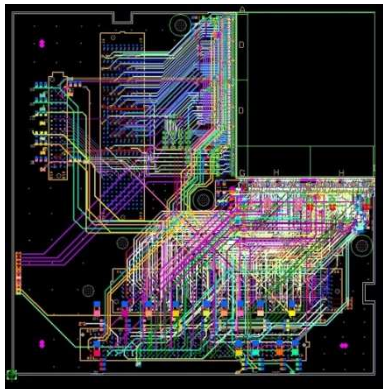
- P2M sensor post-processing
  - JPL remains a key partner and will process wafers
  - Exploring alternate routes to "good" post-processing
    (for some applications 10s of nm are acceptable)
  - EMFT currently a partner in tests (bonding, thinning, pad exposure)
  - Some routes to thicker dopant layers (10s to 100s of nm) exist, not tried yet
  - Easier-to-access MBE-based post-processing capable of processing both wafers and single (prototype) sensors direly needed

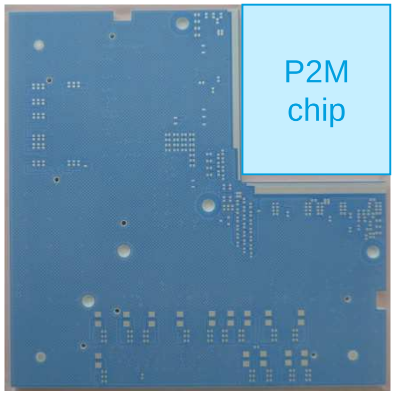
P2M System

Currently undergoing benchtop tests in front-illuminated configuration

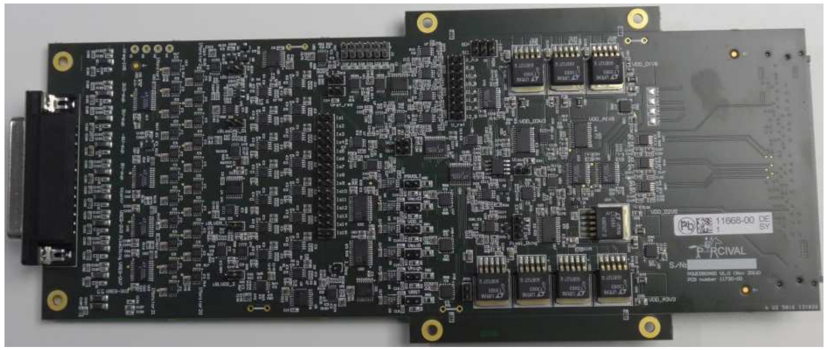
- In-vacuum detector head
    - sensor
    - Includes sensor biasing board
    - Several hundred LVDS control & data lines, are (re)distributed here
    - Sensor will be cooled to ~ -30°C
    - 2-side buttable
    - movable







LTCC routing & actual board

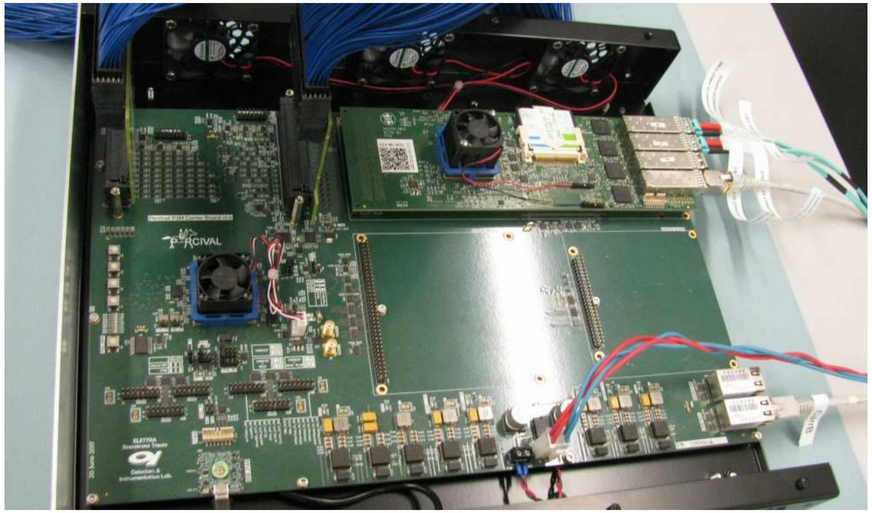


PowerBoard for sensor supply & biasing

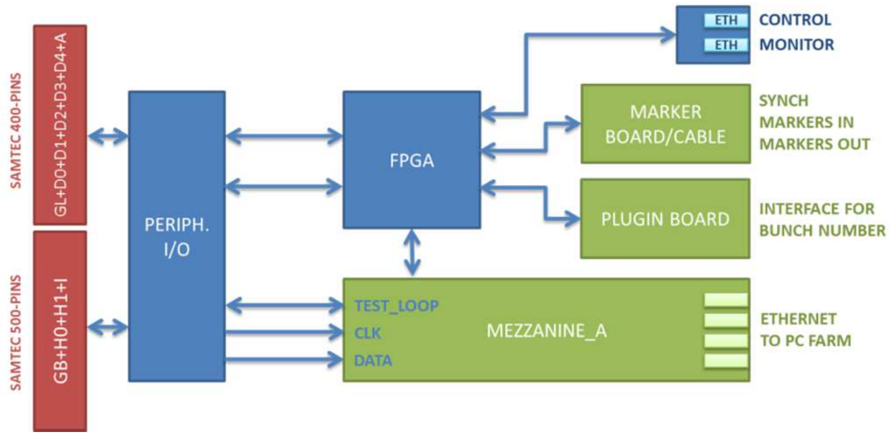
P2M System

Currently undergoing benchtop tests in front-illuminated configuration

- Carrier board hosts
  - FPGA running finite state machine
  - Mezzanine board (also AGIPD, Lambda) reordering data for easier processing streaming out 20 Gbit/s data
  - Interface to slow control, facility information, trigger



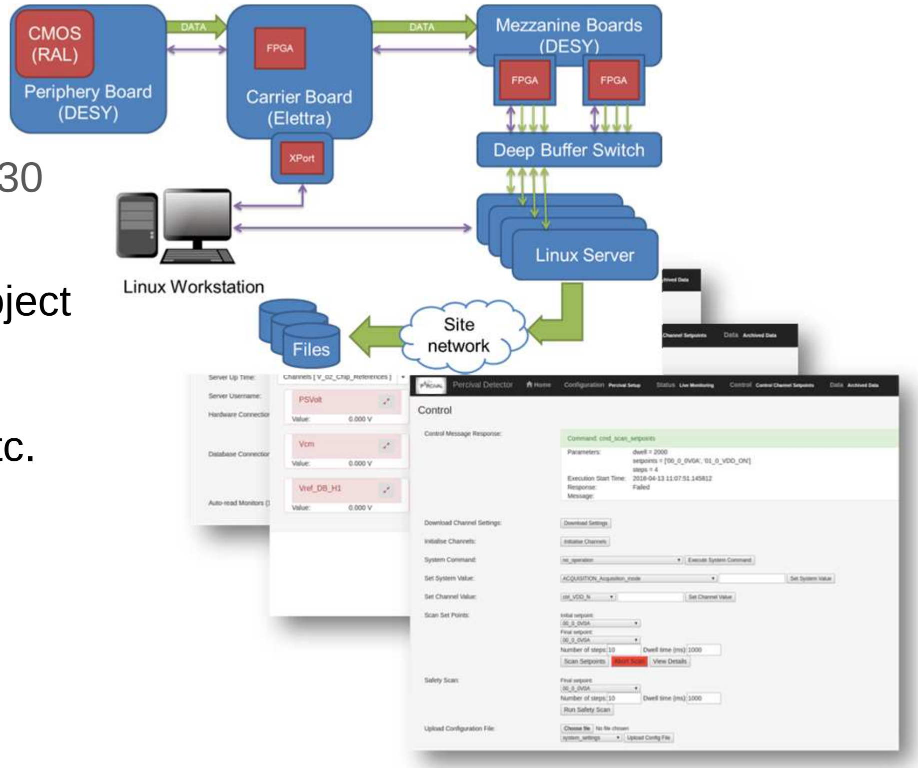
Mezzanine for data streamout
shared by AGIPD, LAMBDA, and Percival



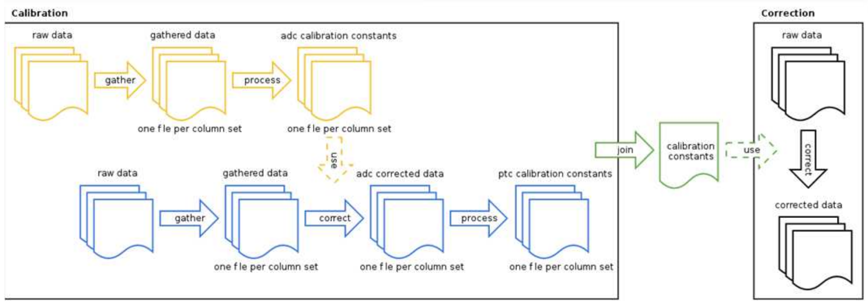
P2M System

Currently undergoing benchtop tests in front-illuminated configuration

- Control & DAQ
  - 20 Gbit/s from one sensor
    (reading full images: 300 Hz, 2M pixels, 30 bit/pixel incl. CDS)
  - Virtual hdf5 developed in part for this project
  - Python interface & Odin GUI interface
  - API for link to Tango, DOOCs, EPICS, etc.



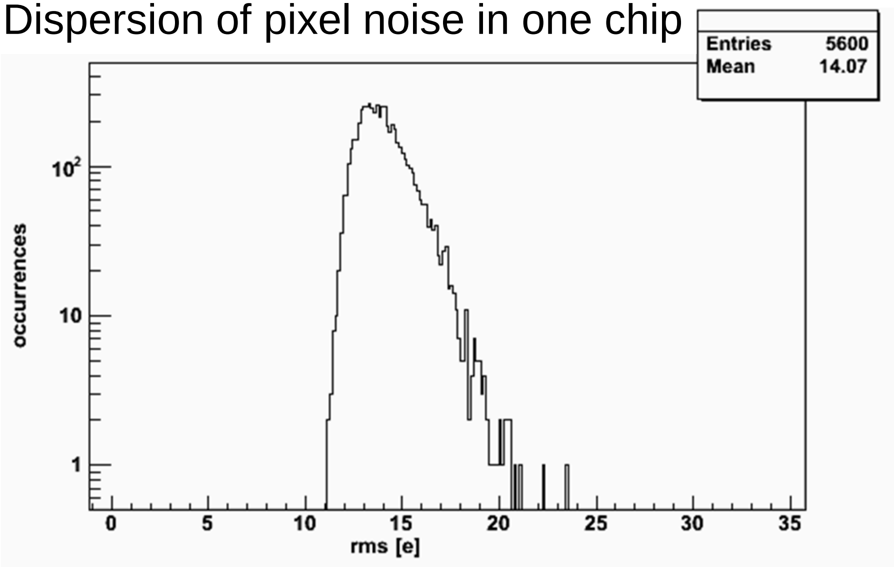
- Software Framework for Characterization
  - Data validation
  - Calibration constants
  - Sensor characterization



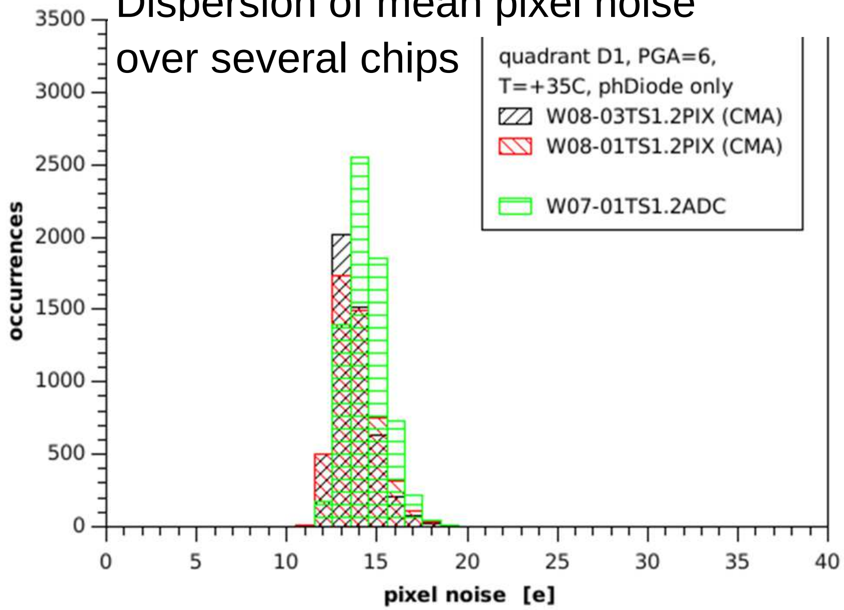
- Testing

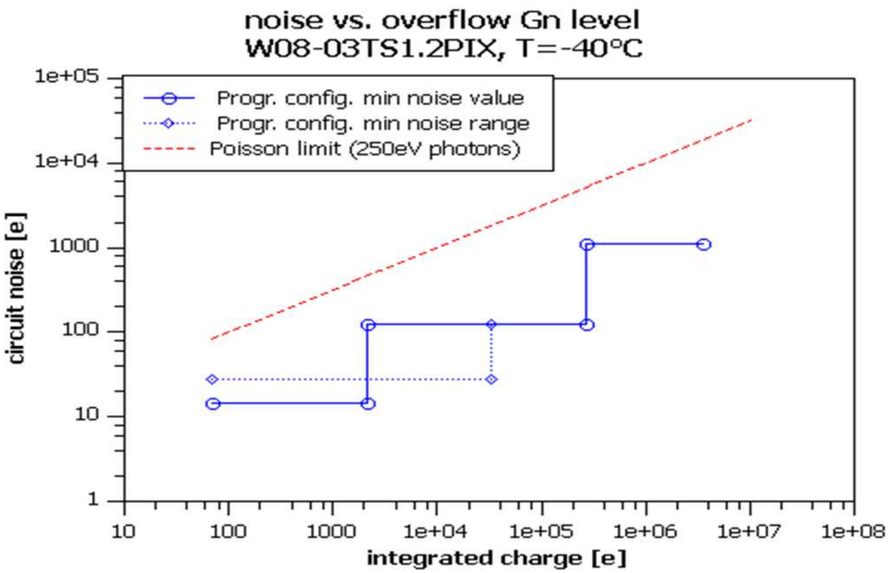
Prototype Performance – Noise

Dispersion of pixel noise in one chip



Dispersion of mean pixel noise over several chips



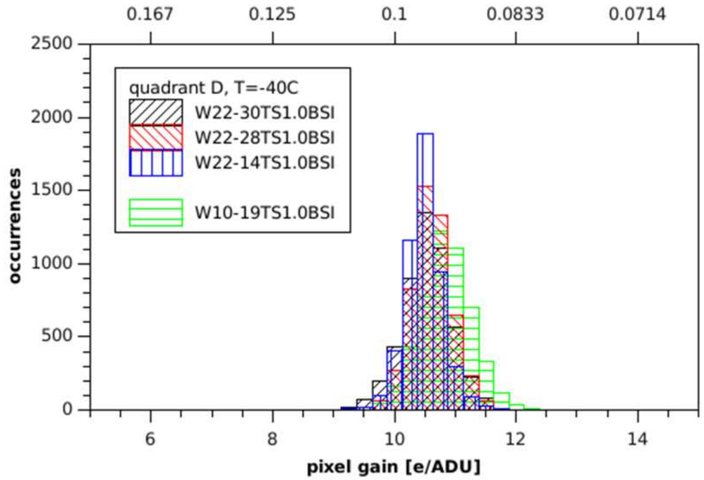


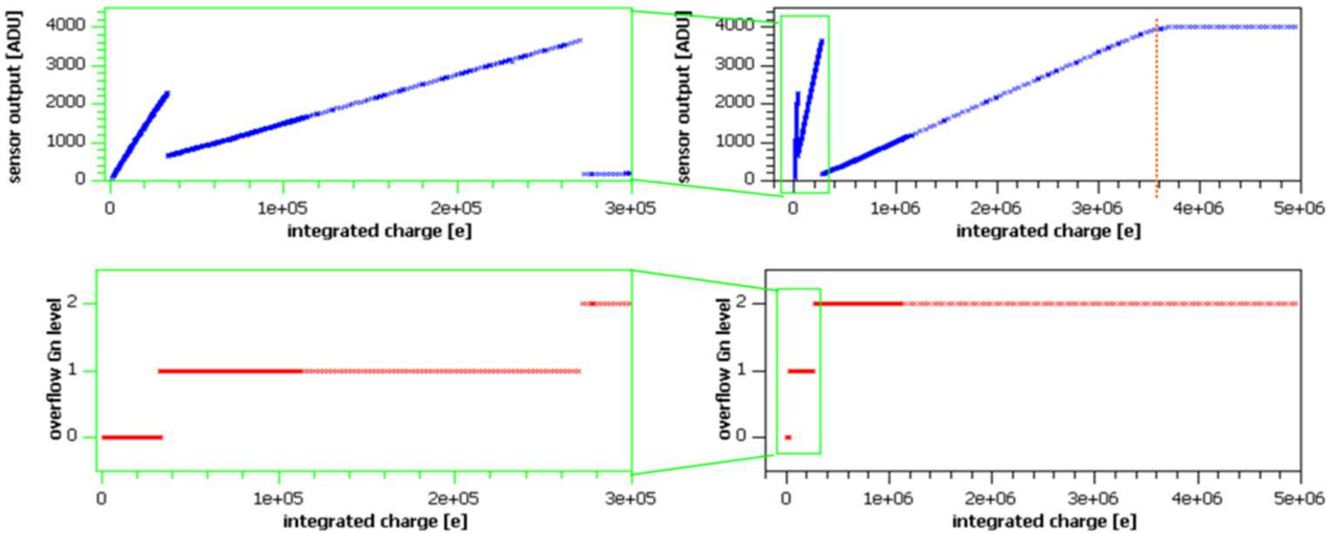
- reasonably low parameter dispersion between different samples (also from different wafers)
- Noise below Poisson limit
- preliminary tests indicate ~10e- rms reachable by multiple sampling

Prototype Performance – Gains

- Automatic gain adjustment works
- 3 gains accessible via overflow switch architecture
- Dynamic range to 3.5 Me-
  i.e. 50k photons at 250eV

Dispersion of pixel gain over several chips





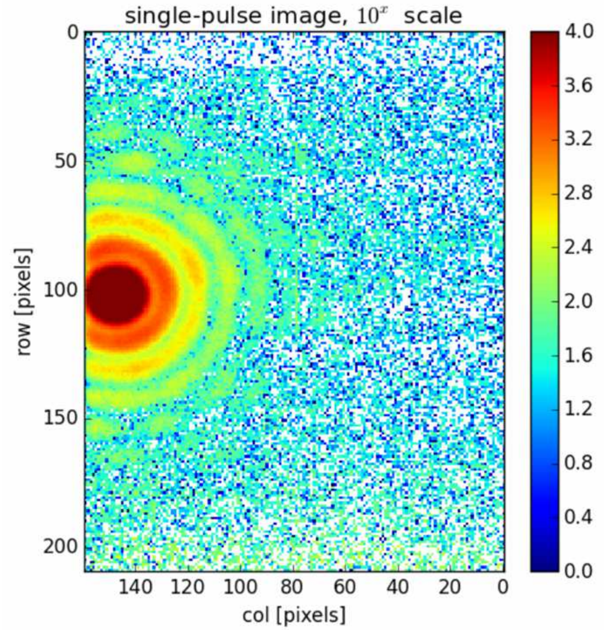
Prototype Performance – soft X-rays

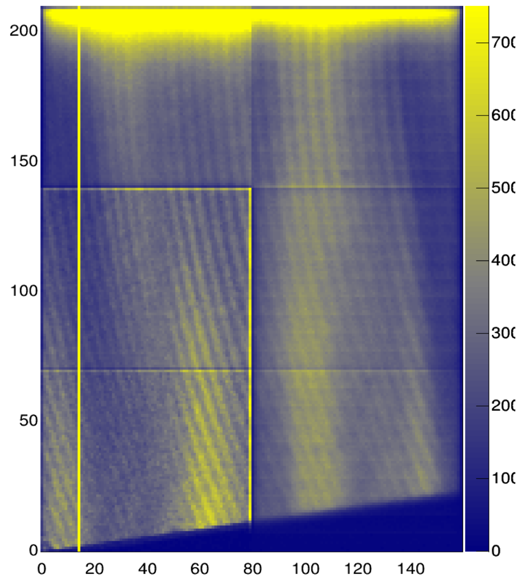
backside-illuminated (BSI)

- Imaging at 92 eV,
  single-shot at FLASH

  left: Airy ring pattern

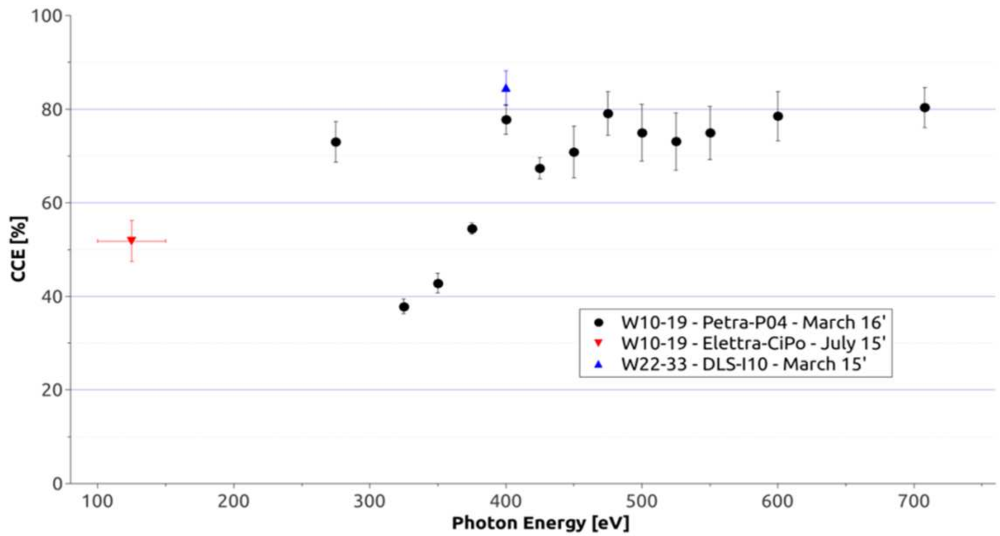
  right: fine diffraction rings
  from liquid sample



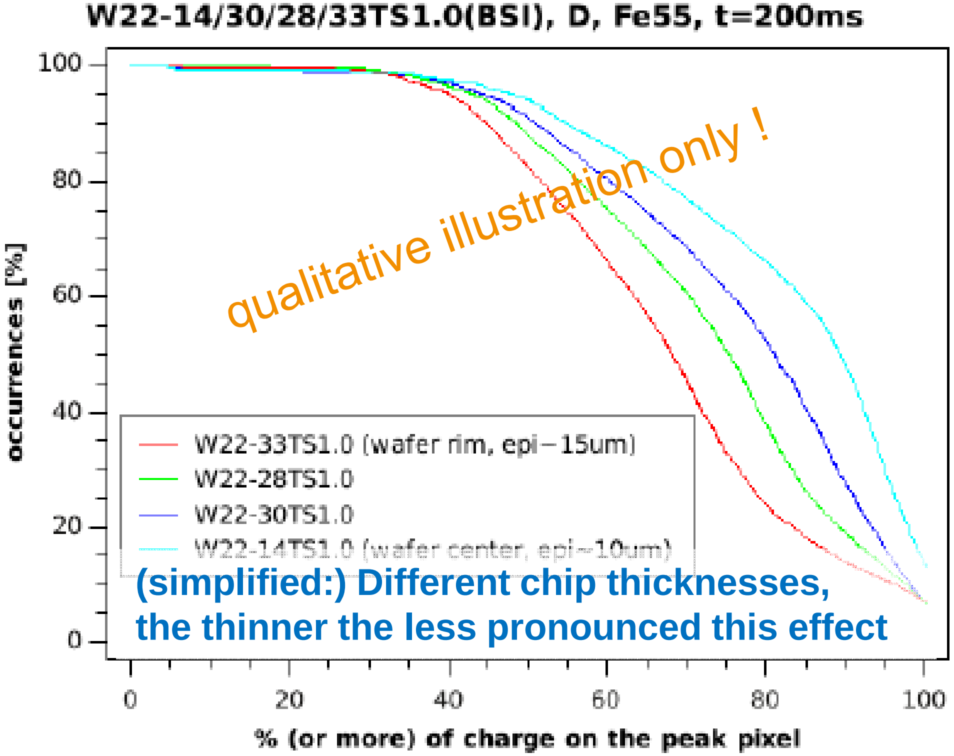


- Airy rings match expectation

- Charge Collection Efficiency (lower limit to Quantum Efficiency) measured at ~70% above 400 eV



Prototype – Charge sharing



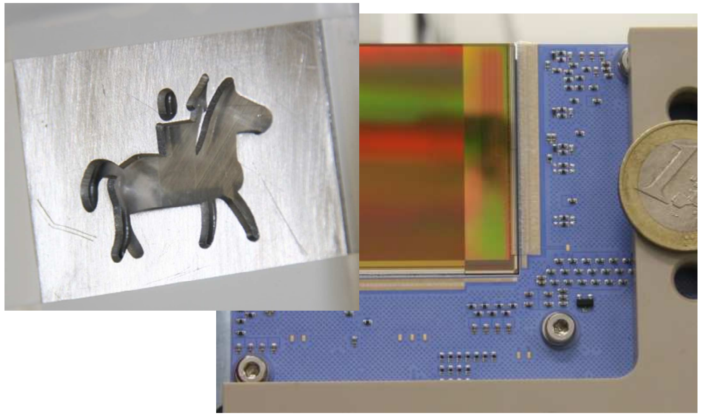
- Charge from a single photon's interaction in most cases spreads over more than one pixel
- This makes detecting the photon more difficult, and more so the lower the photon's energy
- A CCE of 80% at 400eV does NOT promise we'll be able to find 80% of single photons at 400eV

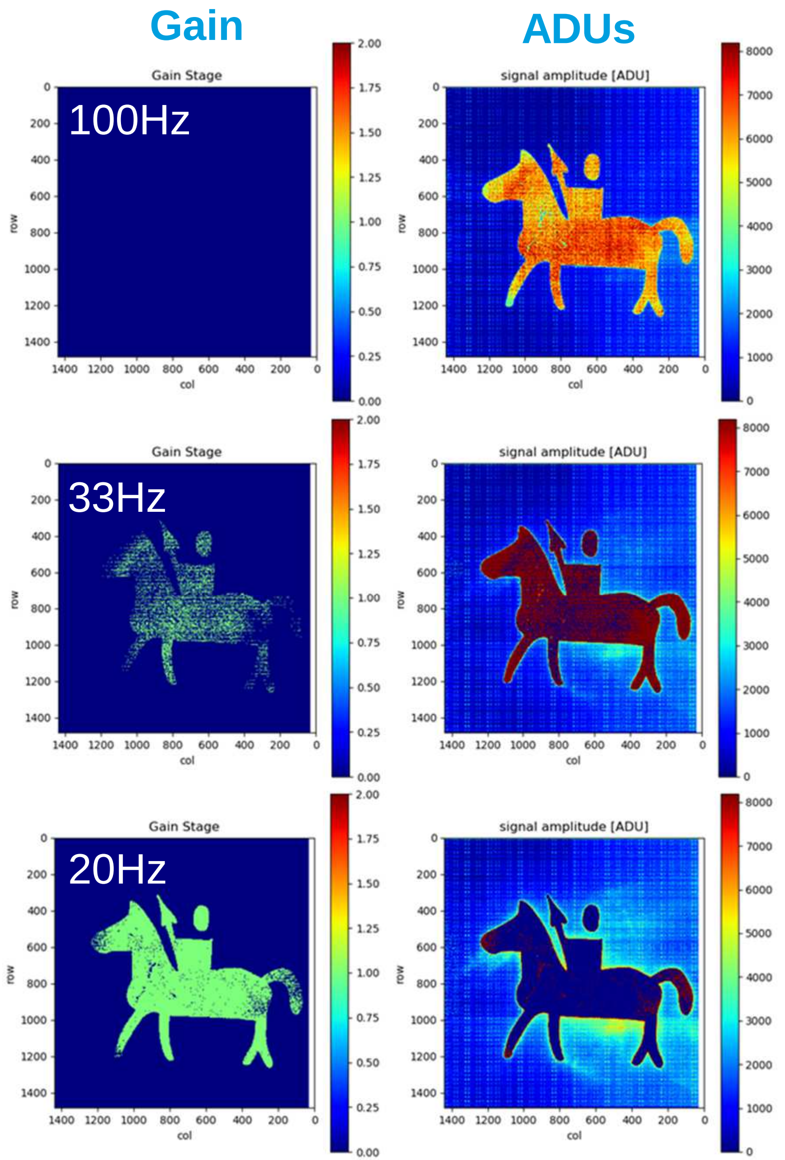
E.g. *single* 600eV photons would be easily found (brightest pixel bright enough) in ~ 2/3 - 3/4 of cases

Epilayer thickness aim 10µm to optimize soft X-ray response

P2M Operation

- First light
- Visible light, room temperature
- 100Hz frame rate
  (streamout speed of full acquisition system still ramping up)
- Automatic gain switching works



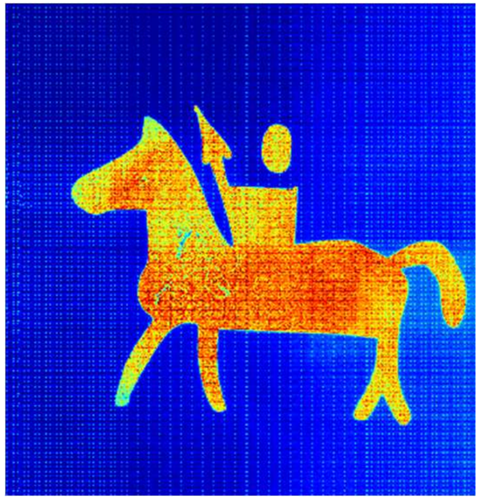


Project Status & Outlook

P2M FSI undergoing benchtop testing

- P2M system operates, saw first light
- P2M sensor demonstrates auto gain switching in response to illumination
- Detailed characterization (including bias tweaking etc.) ongoing
- Circuit functionality at 300Hz frame rate demonstrated (reading partial image), full readout & system ramping up to this

- P2M backthinned sensor in hand, awaiting wirebonding
- Expect first X-ray tests in fall 2018
- First delta-doped P2M BSI ~ Xmas 2018



Thank you for your attention!

and

Thanks to Percival collaborators:

DESY:
Alessandro Marras
Jonathan Correa
Steve Aplin
Peter Goettlicher
Frantisek Krivan
Manuela Kuhn
Sabine Lange
Magdalena Niemann
Frank Okrent
Igor Shevyakov
Sergej Smoljanin
Manfred Zimmer
Heinz Graafsma

RAL:
Iain Sedgwick
Ben Marsh
Nicola Guerrini

Elettra:
Giuseppe Cautero
Dario Giuressi
Anastasiya Khromova
Giovanni Pinaroli
Luigi Stebel
Ralf Menk

Diamond:
Alan Greer
Tim Nicholls
Ulrik Pedersen
Nicola Tartoni

PAL:
HyoJung Hyun
KyungSook Kim
Seungyu Rah

Soleil & DESY:
Benjamin Boitrelle

JPL:
April D. Jewell
Todd J. Jones
Michael E. Hoenk
Shouleh Nikzad

EMFT:
Andreas Drost
Christof Landesberger
Armin Klumpp

… plus past contributors: Matthias Bayer, Dipayan Das, Simone Farina, Przemyslav Gasiorek, Julien Marchal, Nick Rees, Salim Reza, Joshua Supra, Maximilian Tennert, Renato Turchetta, Michele Viti, Qingqing Xia, Hazem Yousef,

and beamline staff at Petra P04, Elettra TwinMic & CiPo, DLS I10, and Flash BL2 for their support

PERCIVAL

Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

Cornelia Wunderer
Photon Science Detectors
cornelia.wunderer@desy.de
+49 40 8998-6186