Adaptive Gain Integrating Pixel Detector

"AGIPD, a high dynamic range fast detector for the European XFEL"

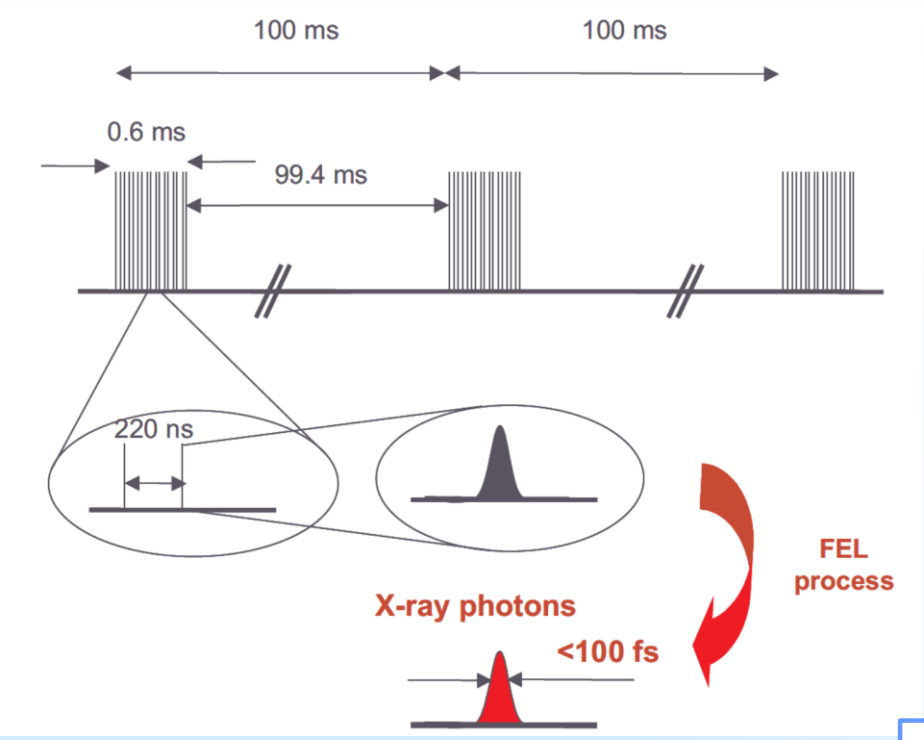
Alexander Klyuev for the AGIPD collaboration

10th International Conference on Position Sensitive Detectors

Outline

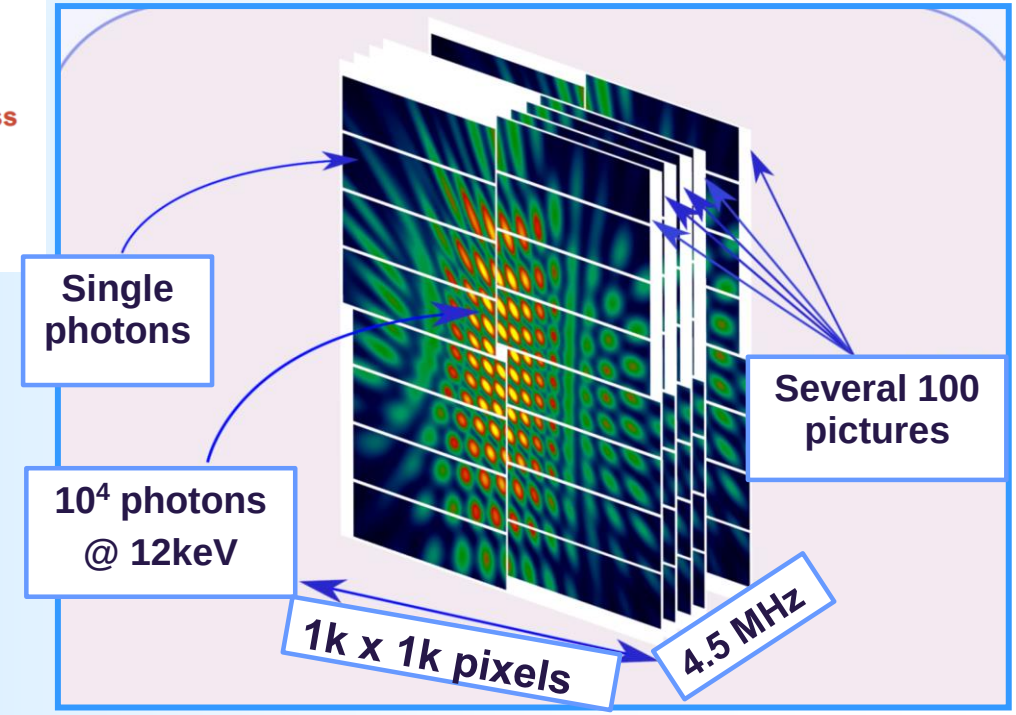
- Intro – detector challenges
- AGIPD concepts
- ASIC
- Experiments
- Summary

Detector challenges



Constraints and challenges for the detector:

- Sufficient radiation hardness (>10 MGy)
- Low noise (<500 e)
- High dynamic range (up to 10^4 12 keV photons)
- XFEL timing compliant
- Lowest possible dead area
- Vacuum compatible
- Central hole



Key features of the European XFEL

- Very high peak brilliance and intensity (>10^{32} pht/pulse)
- Highly coherent fast pulses (< 100 fs)
- 4.5 MHz pulse repetion rate
- 2700 images per train

Detector structure

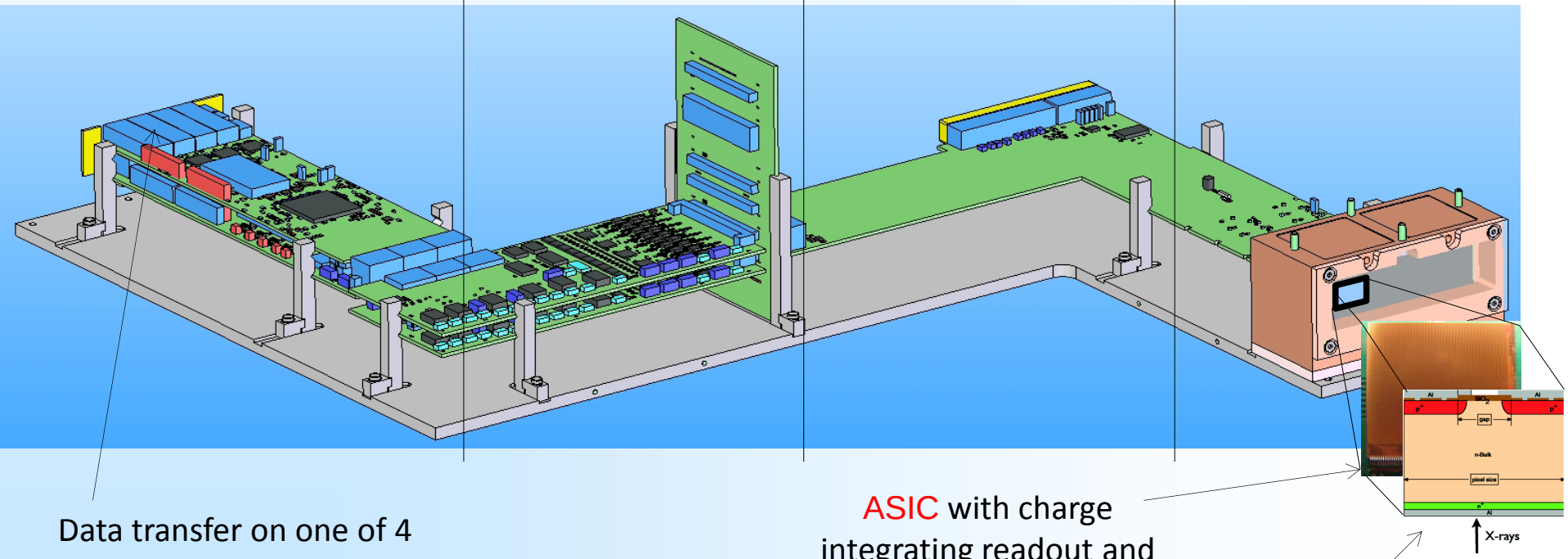
AGIPD 1M consists of 16 detector modules:

Digital part:
FPGA daughter board
on carrier board

Analogue part:
64 ADC
channels on a two
board system

Vacuum board
with a flexible
connection

Detector head:
512x128 pixel sensor
bump bonded to
8x2 ASICs

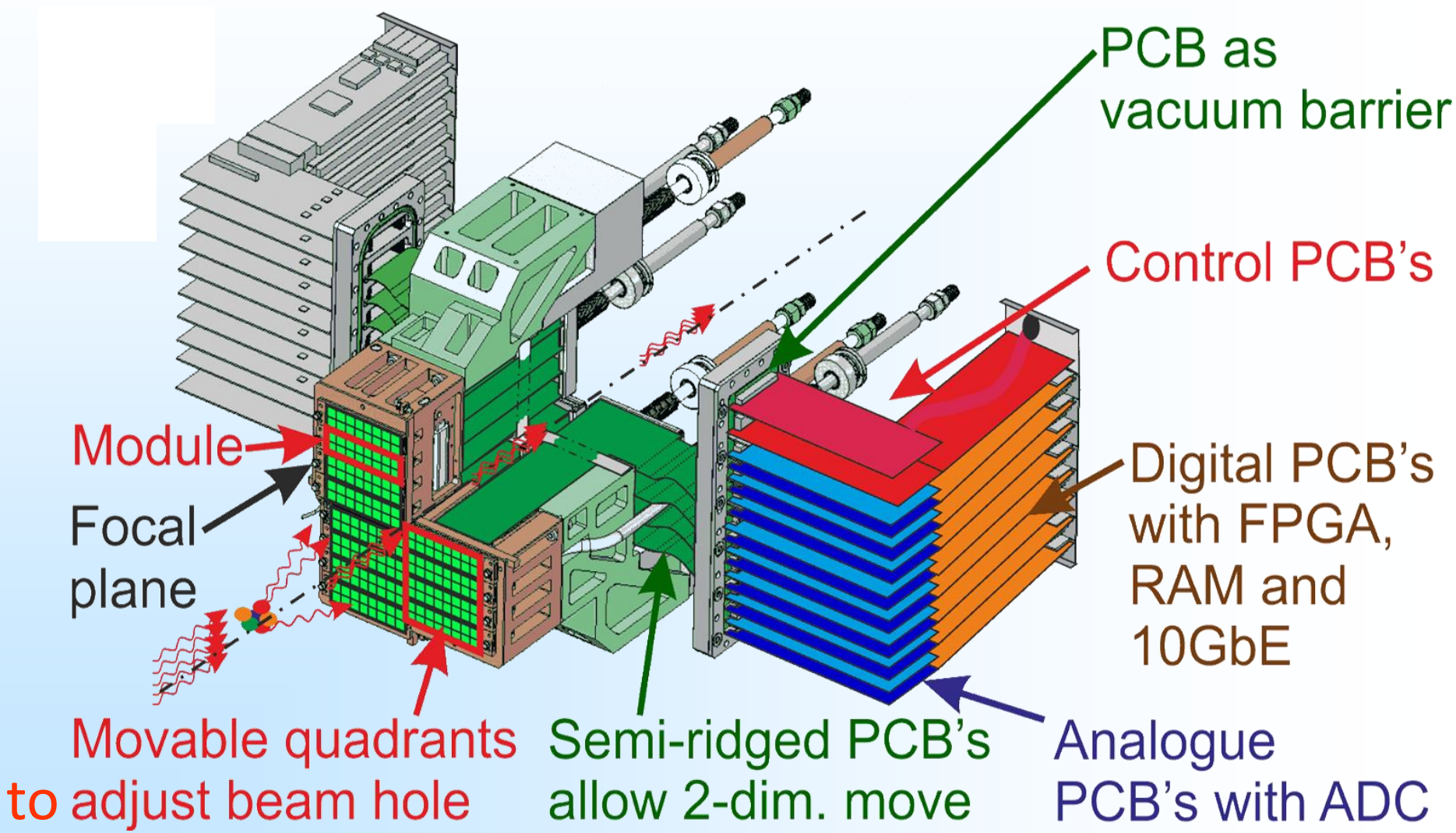


Data transfer on one of 4
10G compatible standard
ethernet links via
TCP/UDP

ASIC with charge
integrating readout and
analogue frame storage
behind each pixel

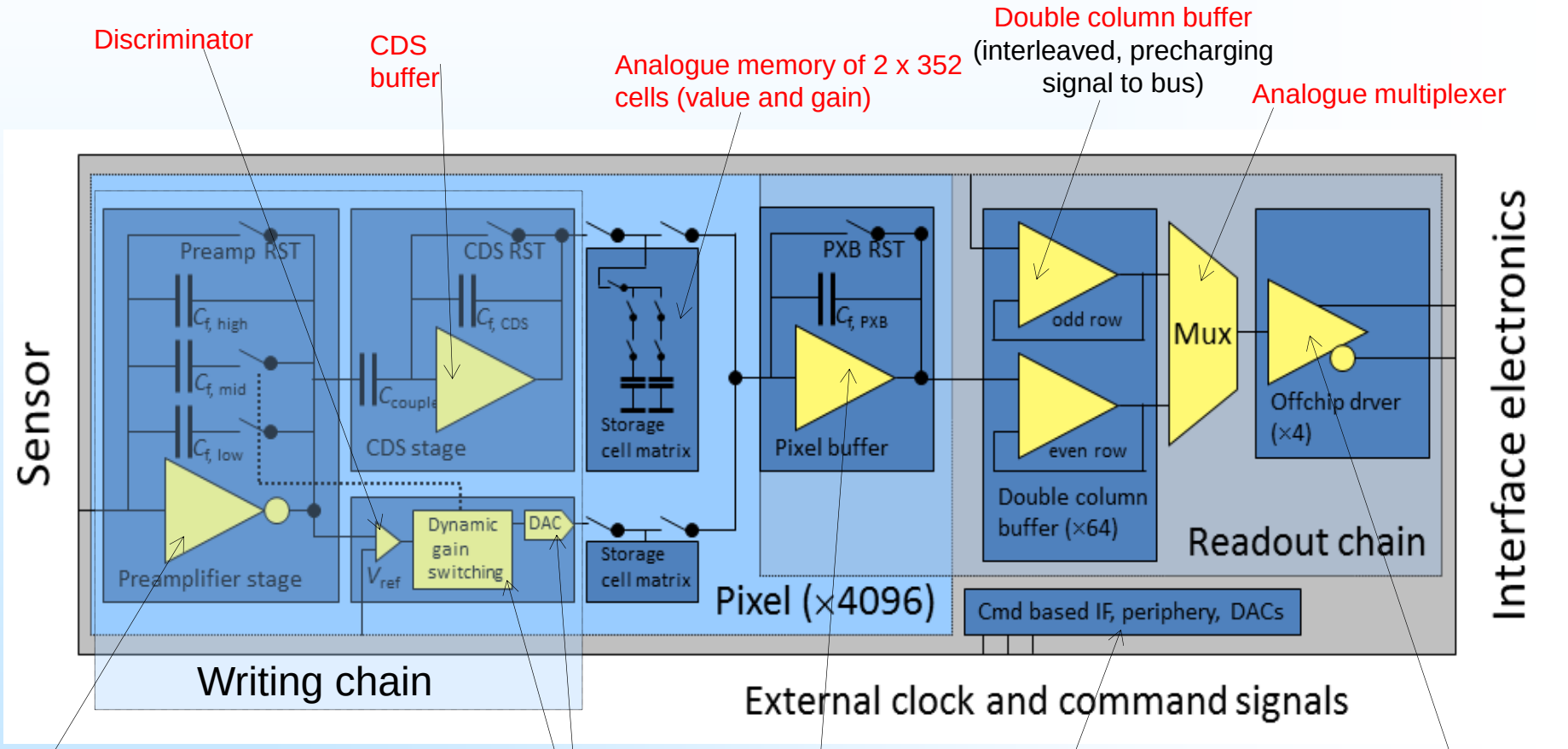
Si-Sensor with
$(200\mu m)^2$ pixels

Mechanical concept

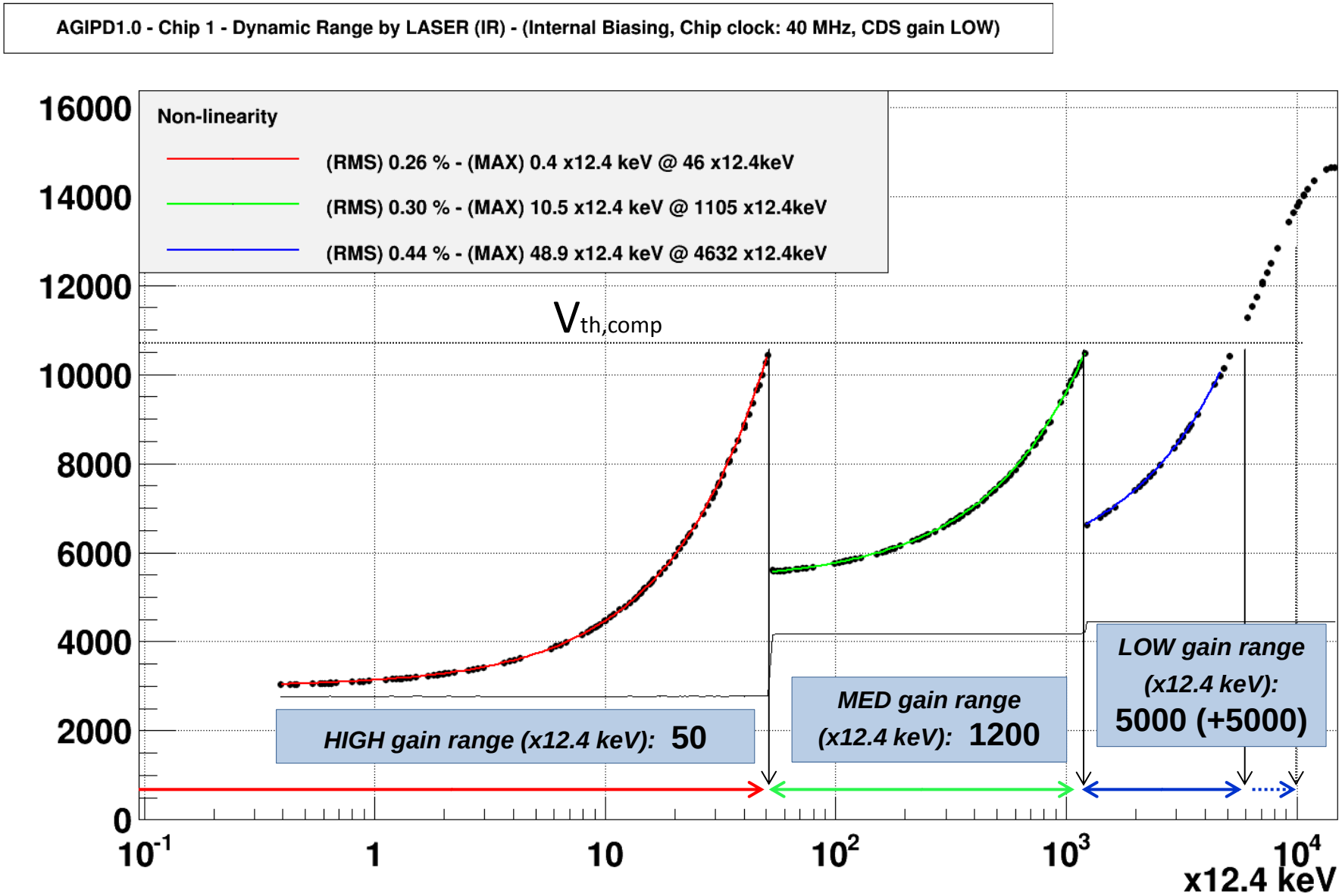


ASIC: structure

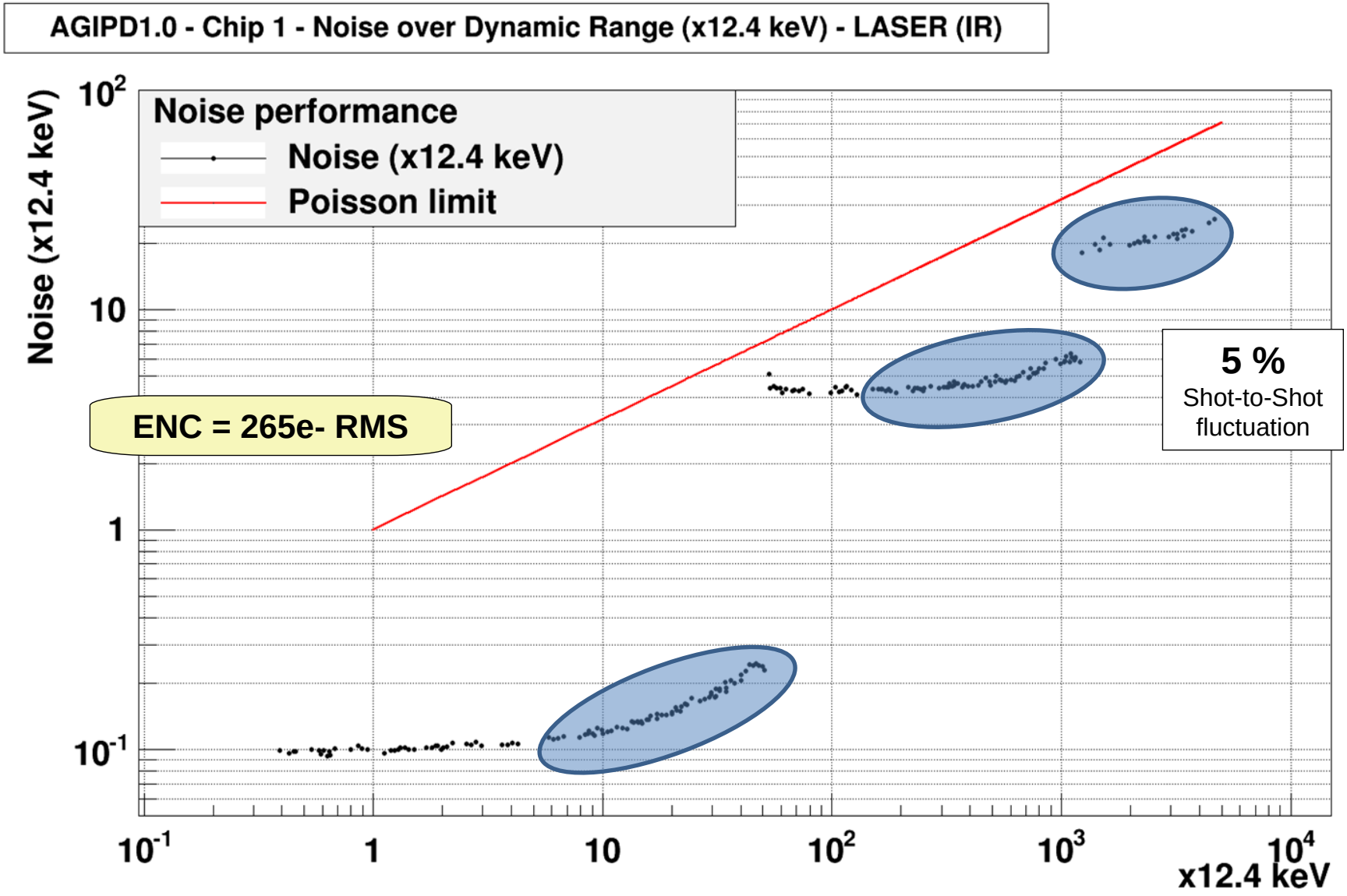
Each readout chip contains a square matrix of 64 x 64 pixels, read out on four ports



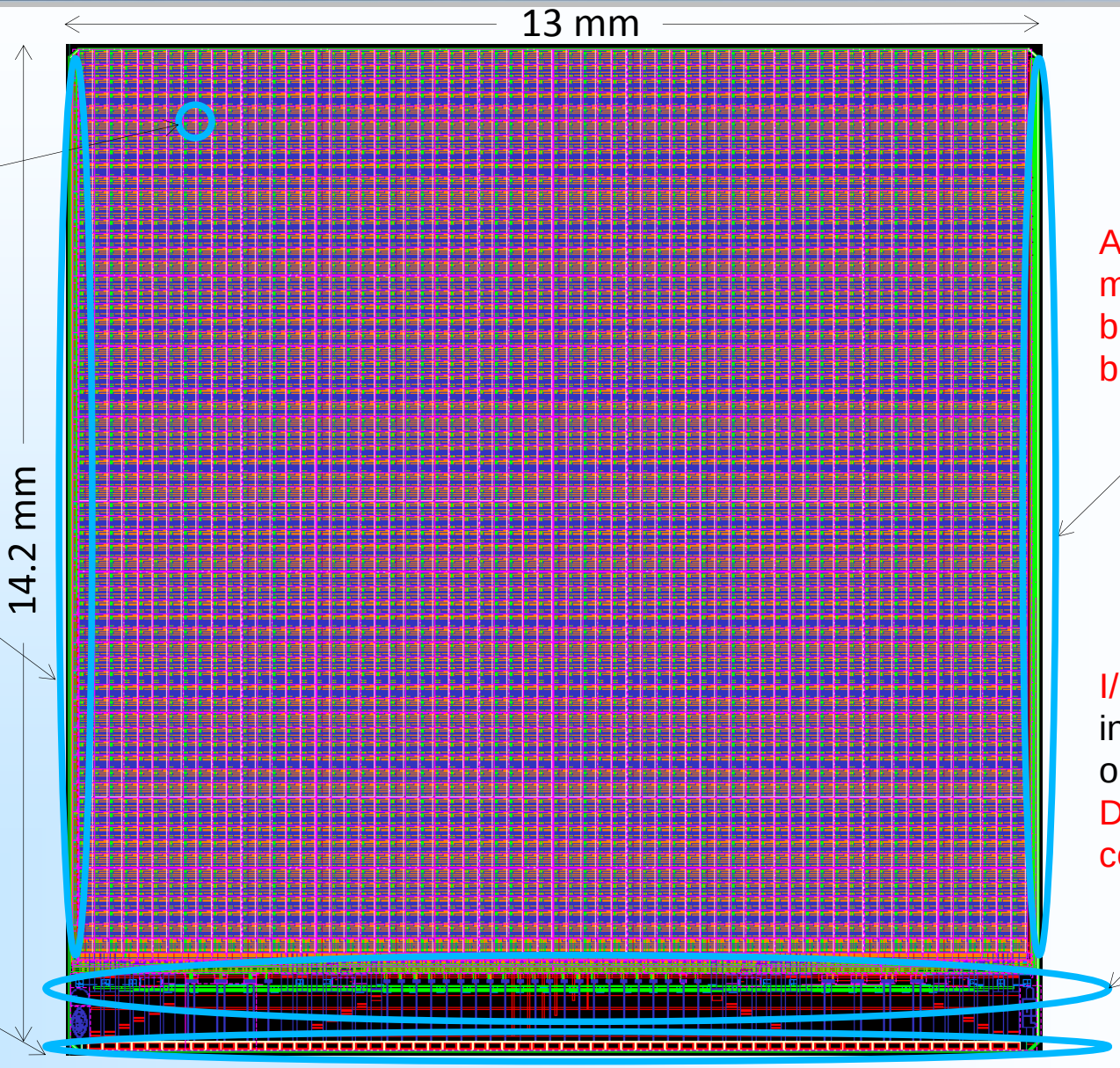
ASIC: characterization



ASIC: characterization



ASIC: AGIPD 1.0 layout



Single pixel of $(200\mu m)^2$ with bump bonds

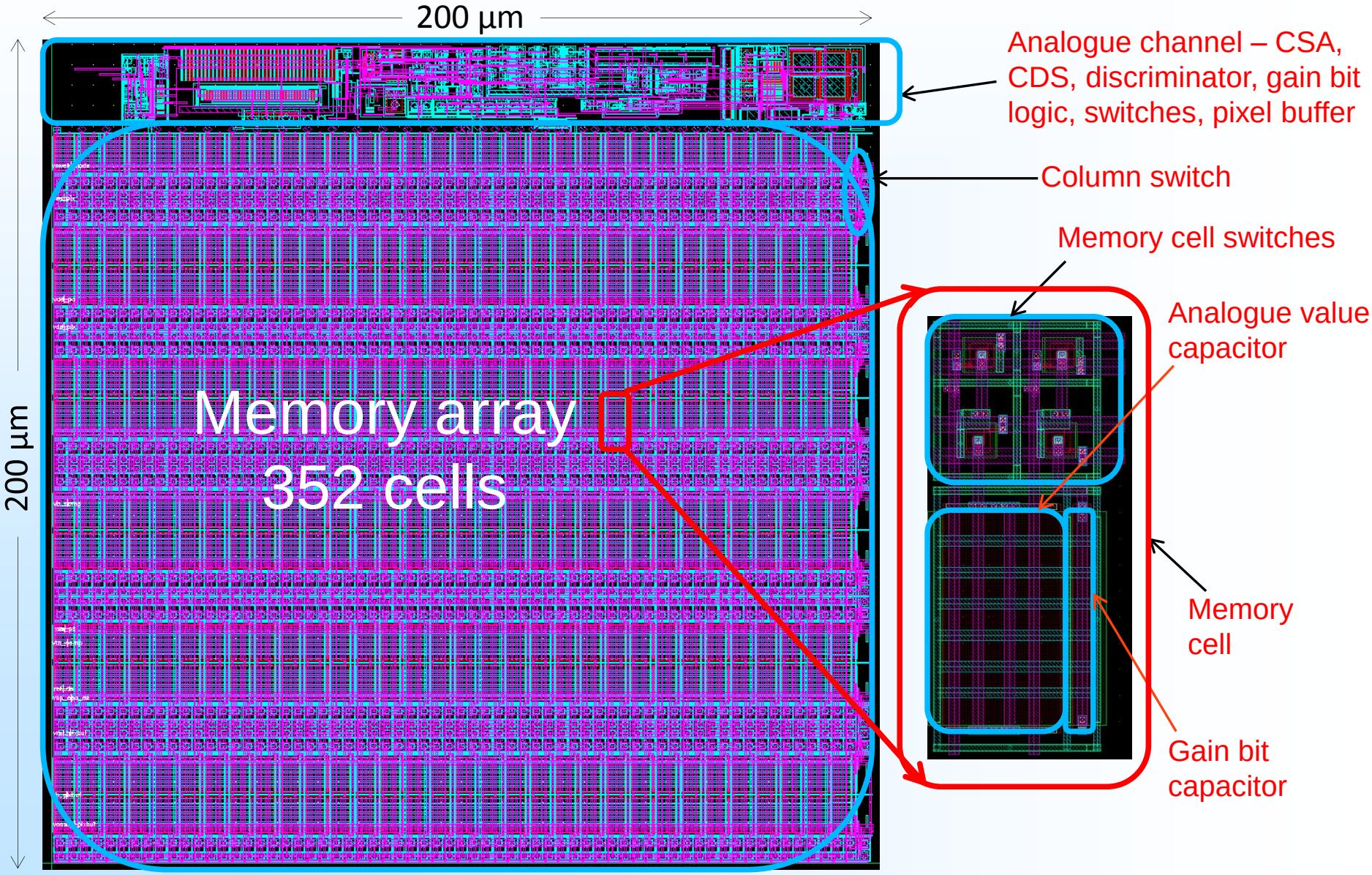
Digital buffers, power buses

Interface pads 200x80 µm rectangle – convenient wirebonding

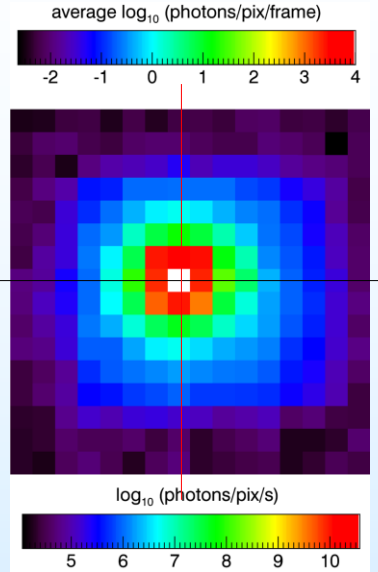
Analogue multiplexer and buffers, power buses

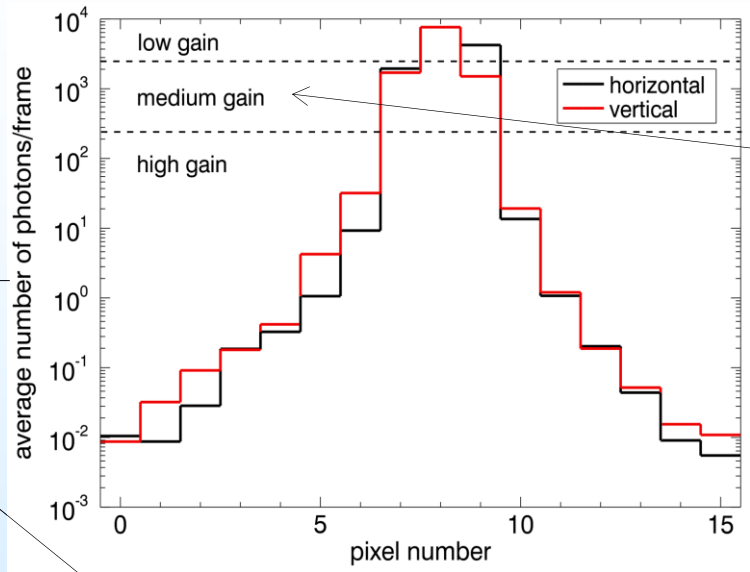
I/O ports - LVDS input, differential output, bias DACs, digital control circuit

ASIC: Pixel layout



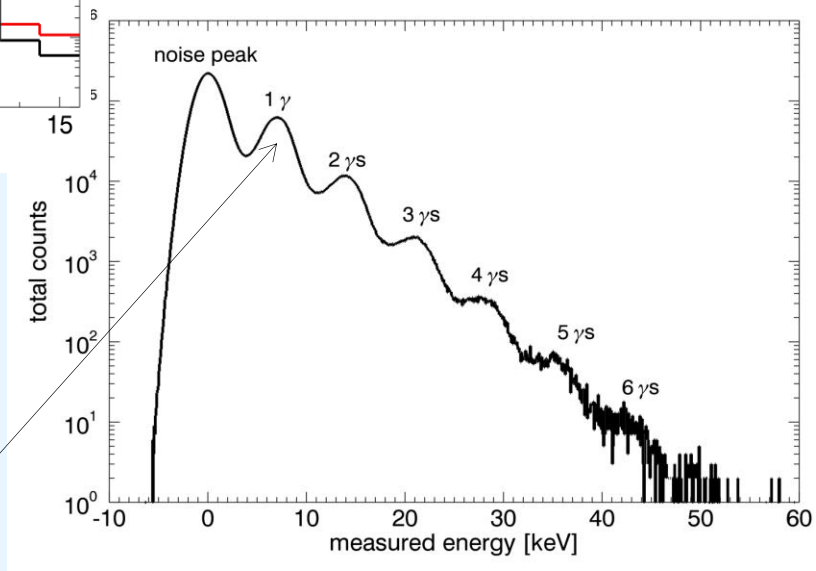
Experiments: AGIPD 0.4 @P10





Gain switching experimentally proven

Image of the direct beam

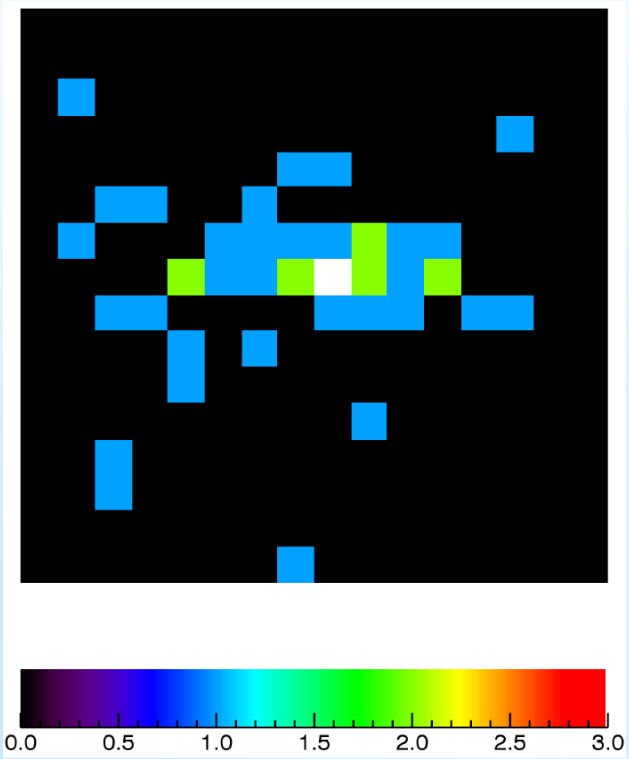


Single photon sensitivity @7.05 keV

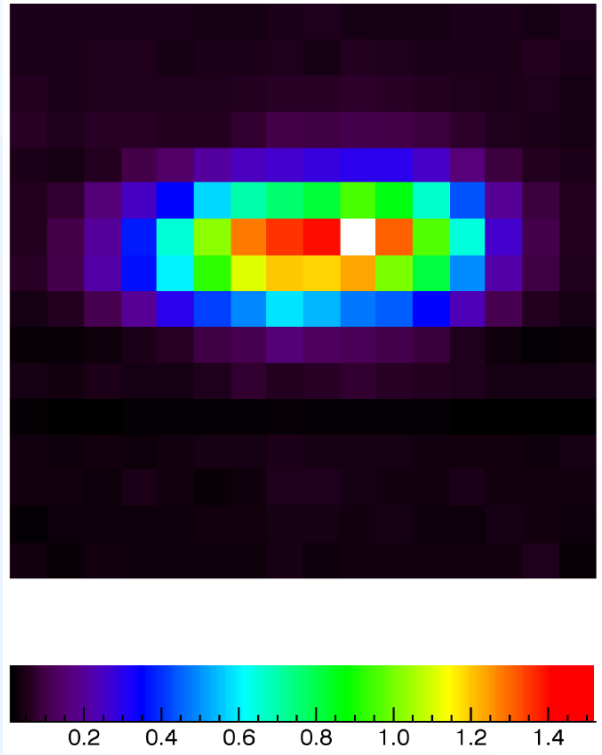
- Average intensity: 0.3 photons per 200 ns
- Count rate: 1.5 Mcps/pixel or 37.5 Mcps/mm^2
- RMS noise of this pixel: 320 electrons.

Experiments: AGIPD 0.4 @P01

- 40 bunch mode (192 ns bunch spacing)
- Photon energy: 14.4 keV
- High-resolution monochromator and KB-mirror used



Single pulse imaging

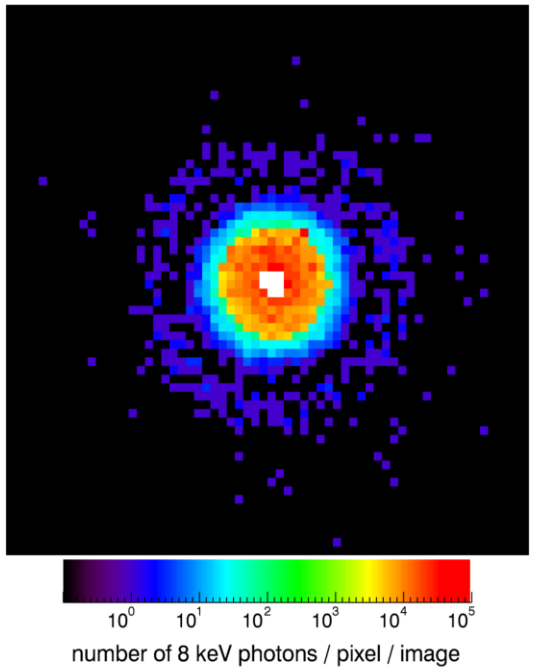


Average of 331,000 single pulses

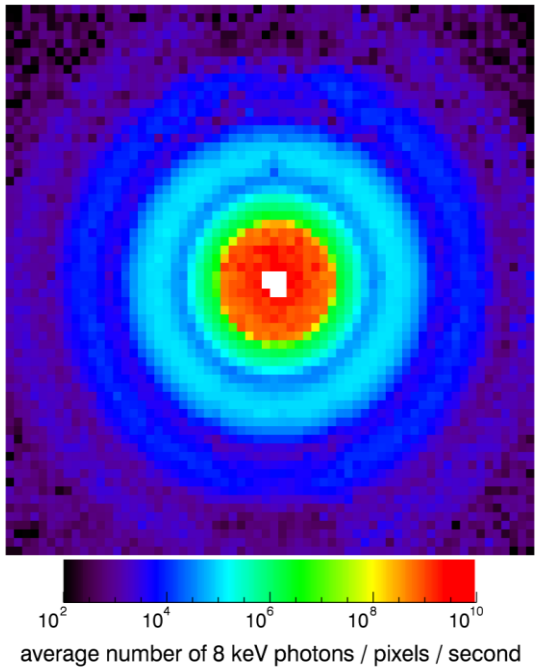
"**Intensity Interferometry of Single X-Ray Pulses from a Synchrotron Storage Ring**", **PRL 113, 064801 (2014)**,
DOI: 10.1103/PhysRevLett.113.064801, preprint: http://arxiv.org/abs/1402.3092

Experiments: AGIPD 1.0 @P10

From prototypes to the full scale ASIC



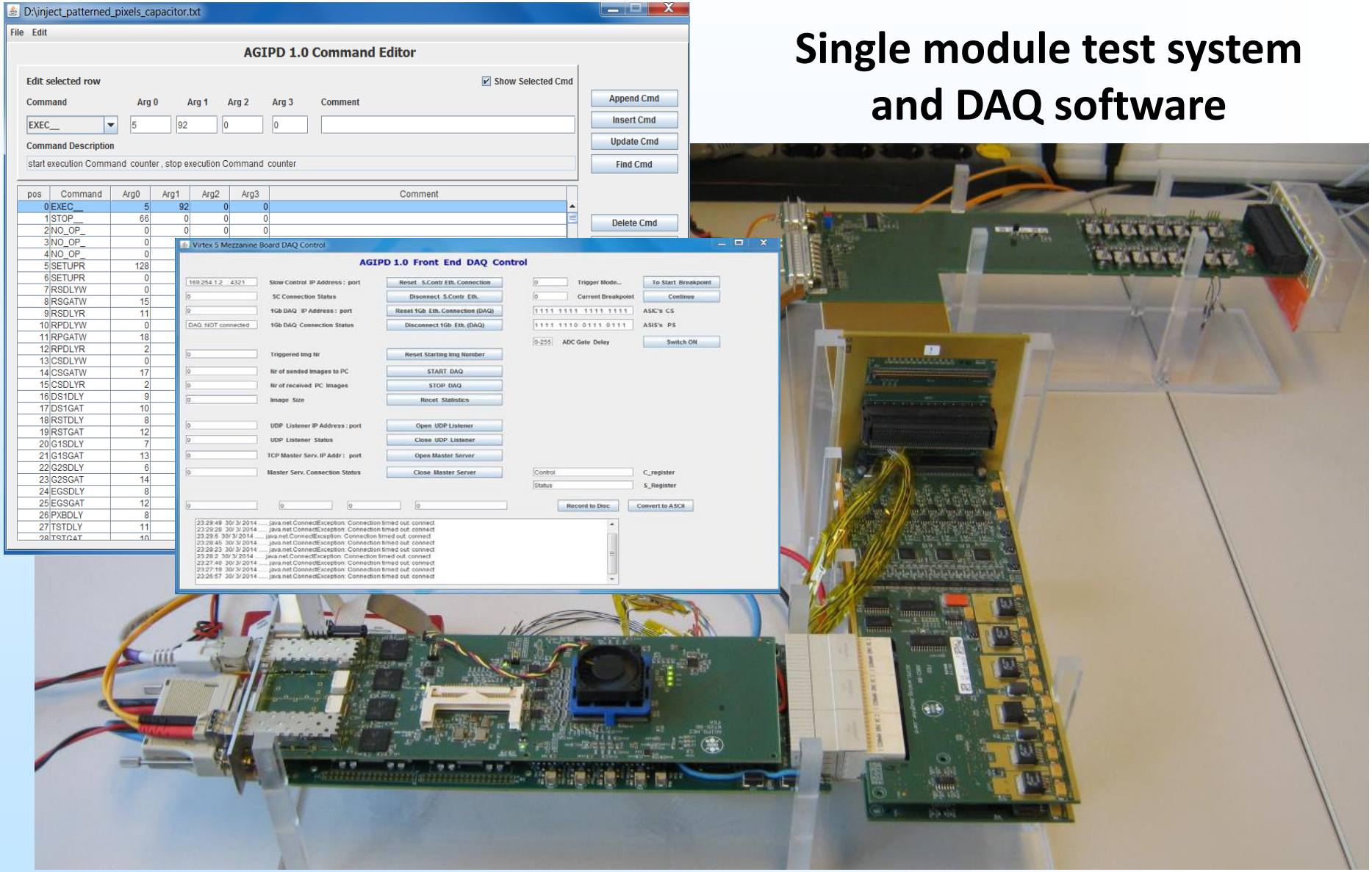
Single shot imaging synchronized to PETRA III running at 5.2 MHz



Averaged image

Experiments: AGIPD module @APS

Single module test system and DAQ software



Experiments: AGIPD module @APS

Single bunch imaging – a challenge to find processes fast enough

Experimental setup

- Drilled equidistant holes into a DVD
- DVD covered with zinc paint to increase absorption
- Mounted DVD on a fast electric motor
- Measurement of hole to hole frequency
- with diode and oscilloscope:

1.208kHz

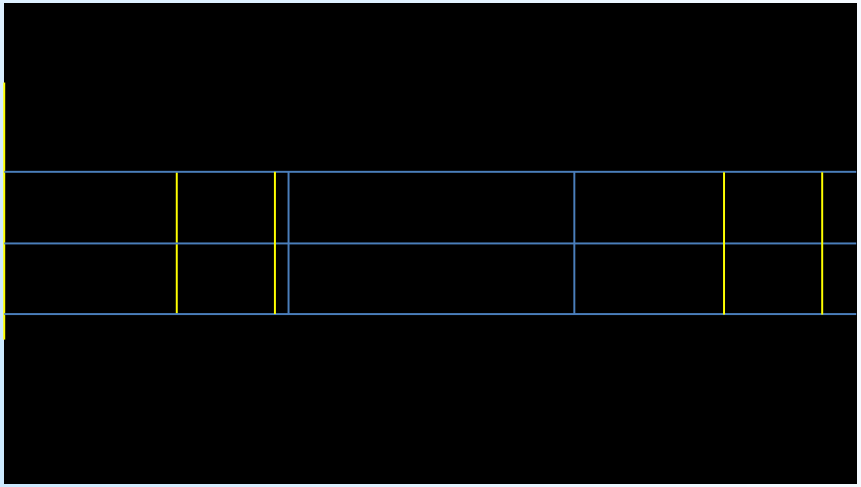
Experiments: AGIPD module @APS

Calculation for burst imaging

- APS bunch spacing: t = 154ns
- Number of pixels crossed
- during burst of 352 images: ~ 8
- Pixel size: 200µm

Result from laser measurement

Vdisc, AGIPD = 29.51m/s	**≈**	**Vdisc, Laser = 29.83m/s**



Single bunch imaging is possible even at a repetition rate of 6.5MHz!!

AGIPD systems

- First 1M, SPB beamline
- Second 1M, MID beamline
  - Carbon copy of 1st 1M system with flange adapter
- AGIPD 4M, SFX station on SPB beamline
  - Needs redesign of boards
  - New/revised mechanics needed
- 2-module downstream detector
  - Only for SPB beamline
- Single module systems
  - Mechanics can be a lot simpler (no moving parts)
- Dedicated PETRA/PSI systems?
  - Would single modules be sufficient?
- AGIPD 2.0?
  - New ASIC?
  - New sensor?

Summary

- Adaptive gain approach is tested and working
- High dynamic range allows for direct imaging of the synchrotron beam along with single photon sensitivity
- Burst imaging up to 6.5 MHz frame rate
- First single module system successfully tested at APS

Ongoing activities:

- Wafer testing
- Edgeless sensors (talk by Jiaguo Zhang) and TSVs
- Design of additional boards and mechanics for different AGIPD systems
- ASIC developments

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4 University of Bonn, Bonn, Germany
5 Mid Sweden University, Sundsvall, Sweden

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PETRA P01: A. Singer, U. Lorenz, A. Marras, K. Schlage, P. Skopintsev, O. Gorobtsov, A. Shabalin, H.-C. Wille, H. Franz, I. A. Vartanyants

APS BM-1: Robert Bradford, David M. Kline, Stanislav Stoupin

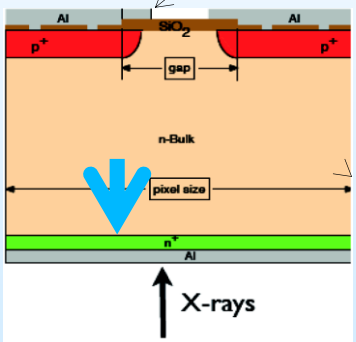
There are open positions for PostDocs and Master/PhD students!

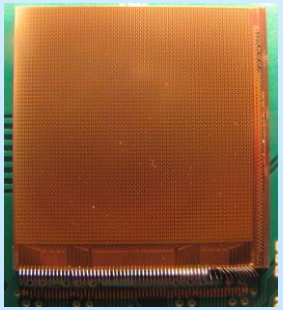
http://photon-science.desy.de/research/technical_groups/detectors/index_eng.html

Backup

Detector structure

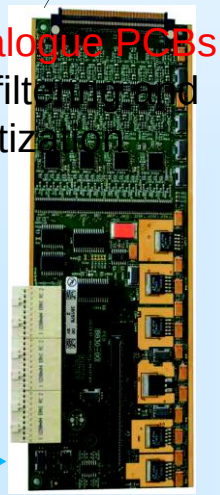
Si-Sensor with pixels 200µm squared





ASIC with electronics

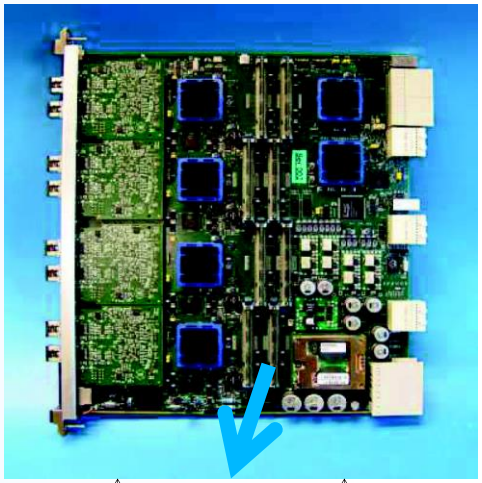
store
e



Analogue PCBs for filter and digitization

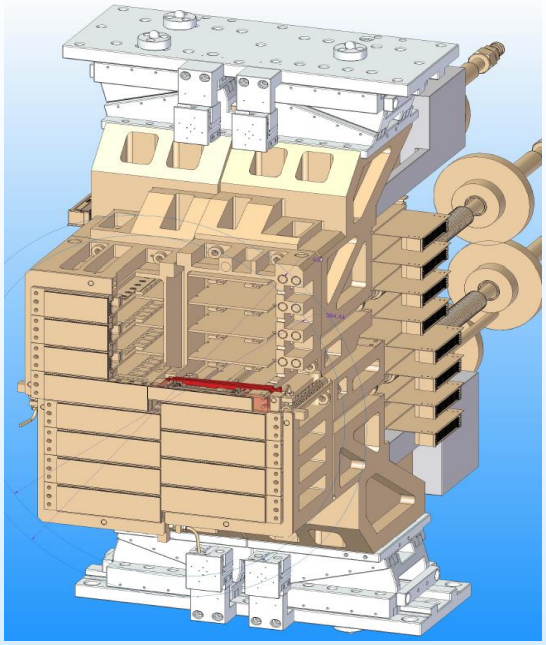
Digital PCBs for preprocessing and data transfer adapted to train cycle

Interconnections and power board to adapt to mechanical needs and provide power

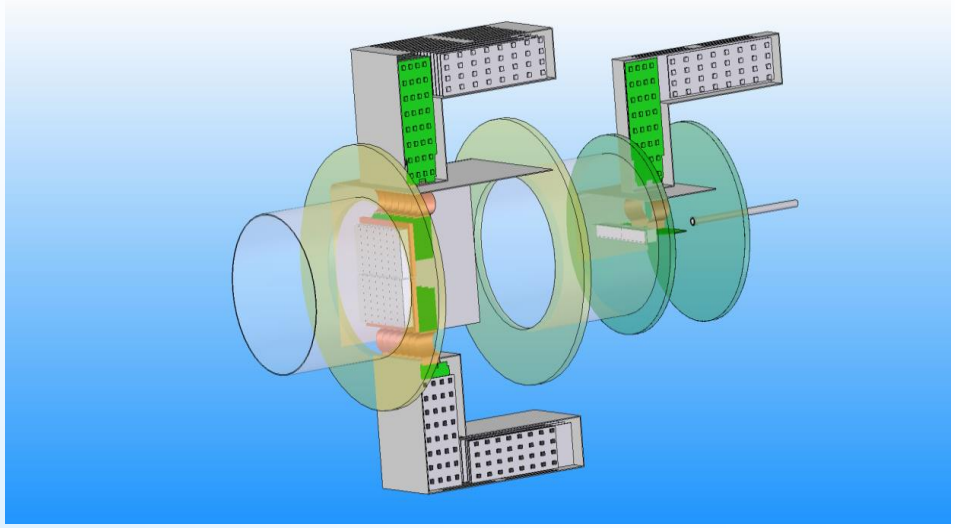


Off detector DAQ for data handling

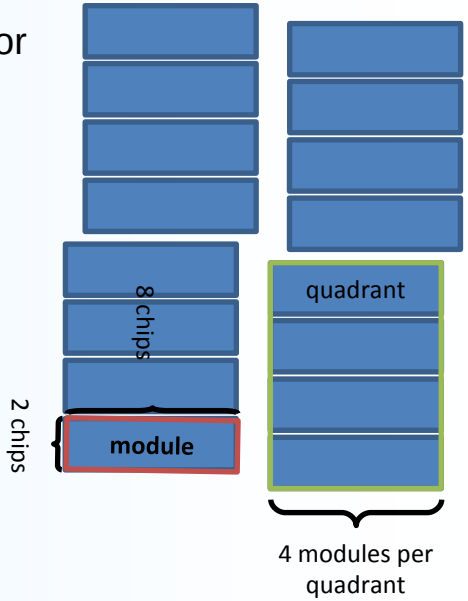
Mechanical concept



One megapixel system without vacuum tank



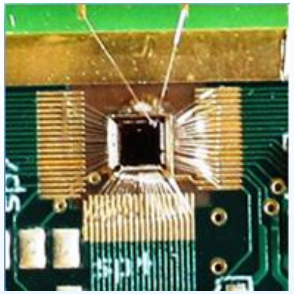
Wing layout and downstream detector



Modules and quadrants

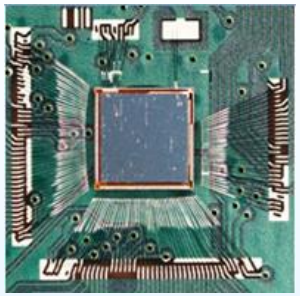
ASIC: prototype development

AGIPD 0.1 Jan. 2009



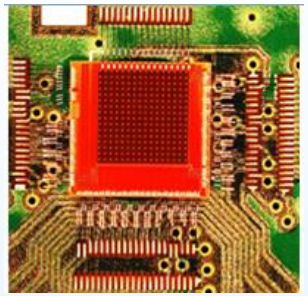
- No pixels
- 3 readout blocks consisting of:
  - Readout chain (Preamp + CDS stage)
  - 3 different kinds of leakage current compensation

AGIPD 0.2 May 2009



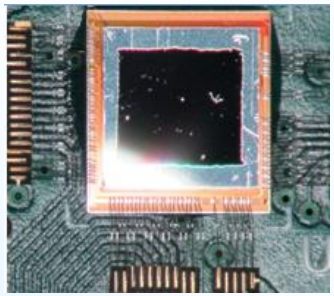
- 16 x 16 pixels
- 100 storage cells
- No leakage current compensation
- Different combinations of preamps and storage cell architectures

AGIPD 0.3 Nov. 2010



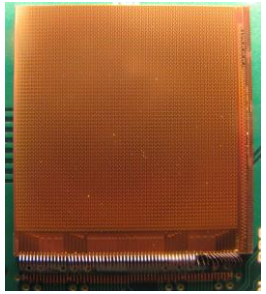
- 16 x 16 pixels
- 200 storage cells
- Radiation hard storage cell design
- High speed command based control interface
- Improved discriminator and CDS buffer

AGIPD 0.4 Nov. 2011

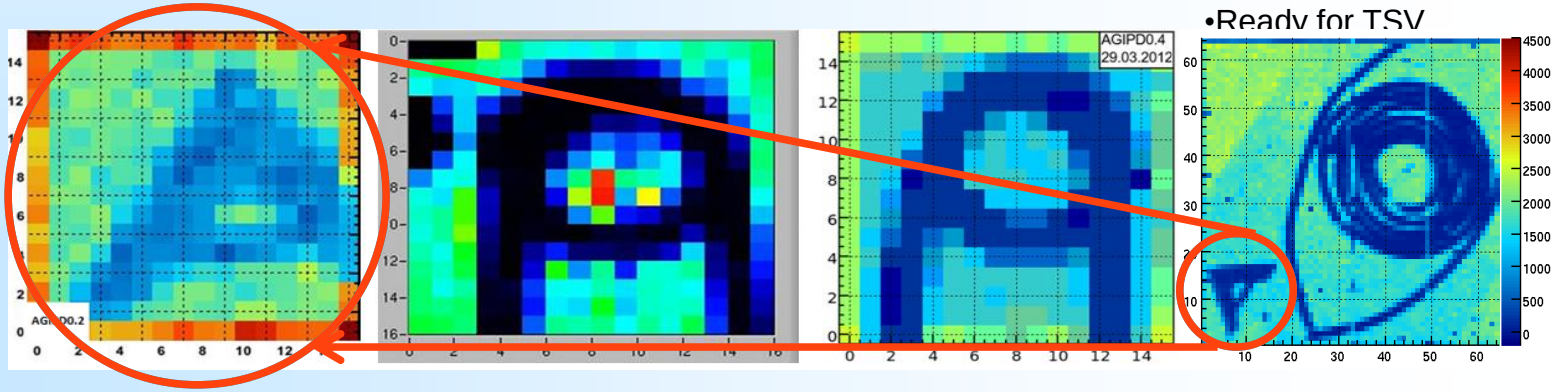


- 16 x 16 pixels
- High sensitivity preamp (Cf = 60 fF)
- 352 storage cells
- Double-column readout
- New multiplexer
- New off-chip buffer
- No command based control circuit

AGIPD 1.0 Apr. 2013



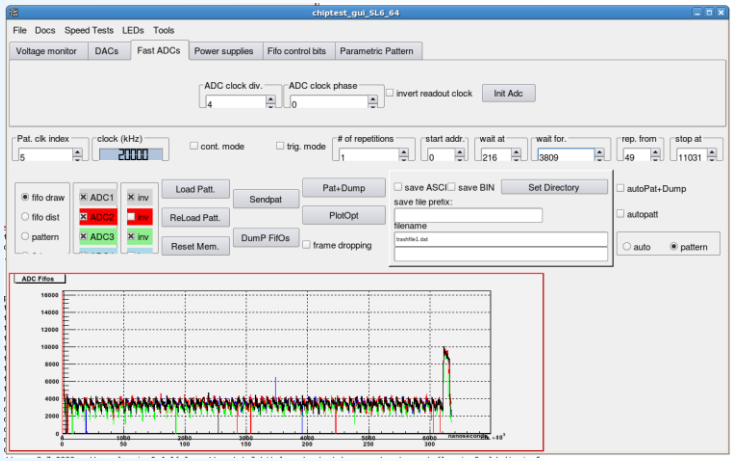
Full-scale chip:
- 64 x 64 pixels
- High sensitivity preamp (Cf = 60 fF)
- 352 storage cells
- Double-column readout
- High speed command based control interface
- Ready for TSV



First imaging tests with the AGIPD prototype chips in an X-Ray box. The 'A' was made from copper. From left to right: AGIPD0.2, AGIPD0.3, AGIPD0.4, AGIPD1.0 – AGIPD0.2 „A“ in addition to the fragment of an AGIPD logo made of Sn soldering wire.

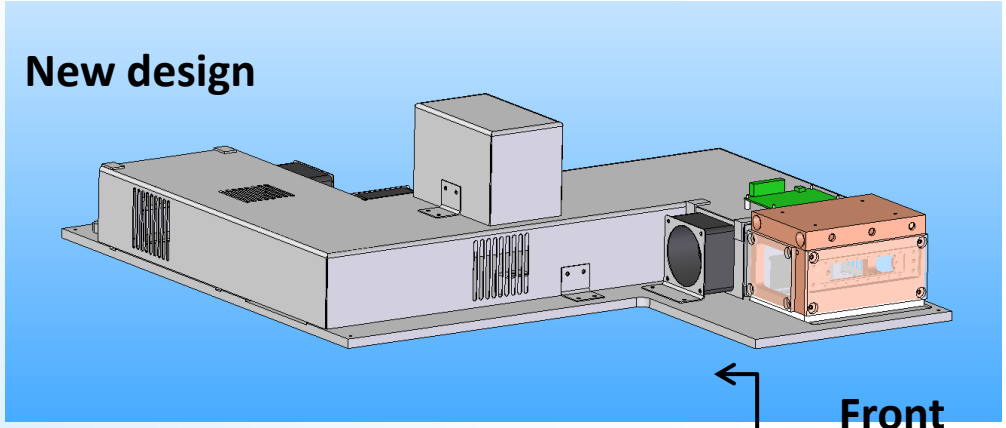
ASIC: characterization

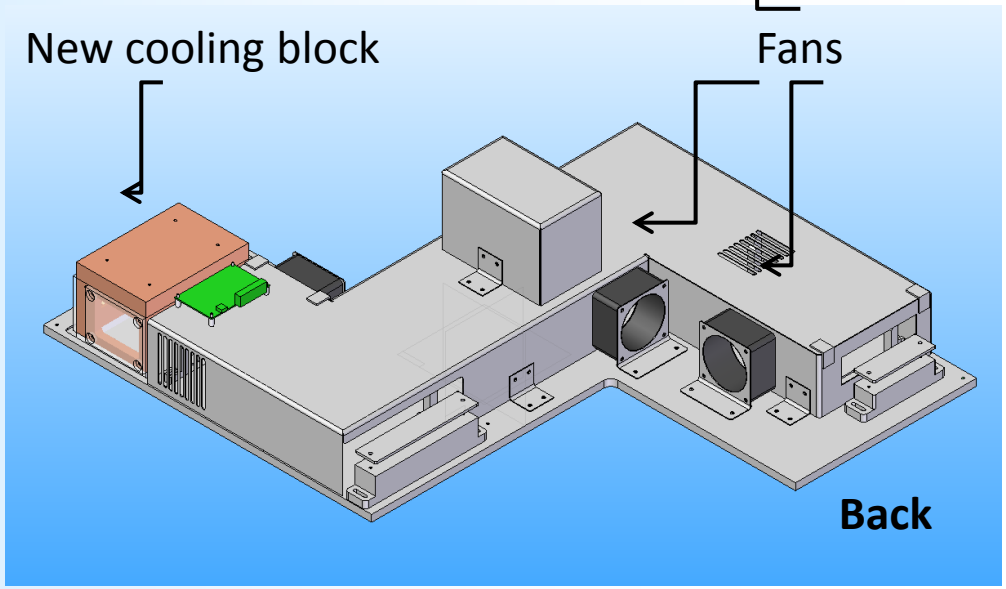
Values measured with chiptester box



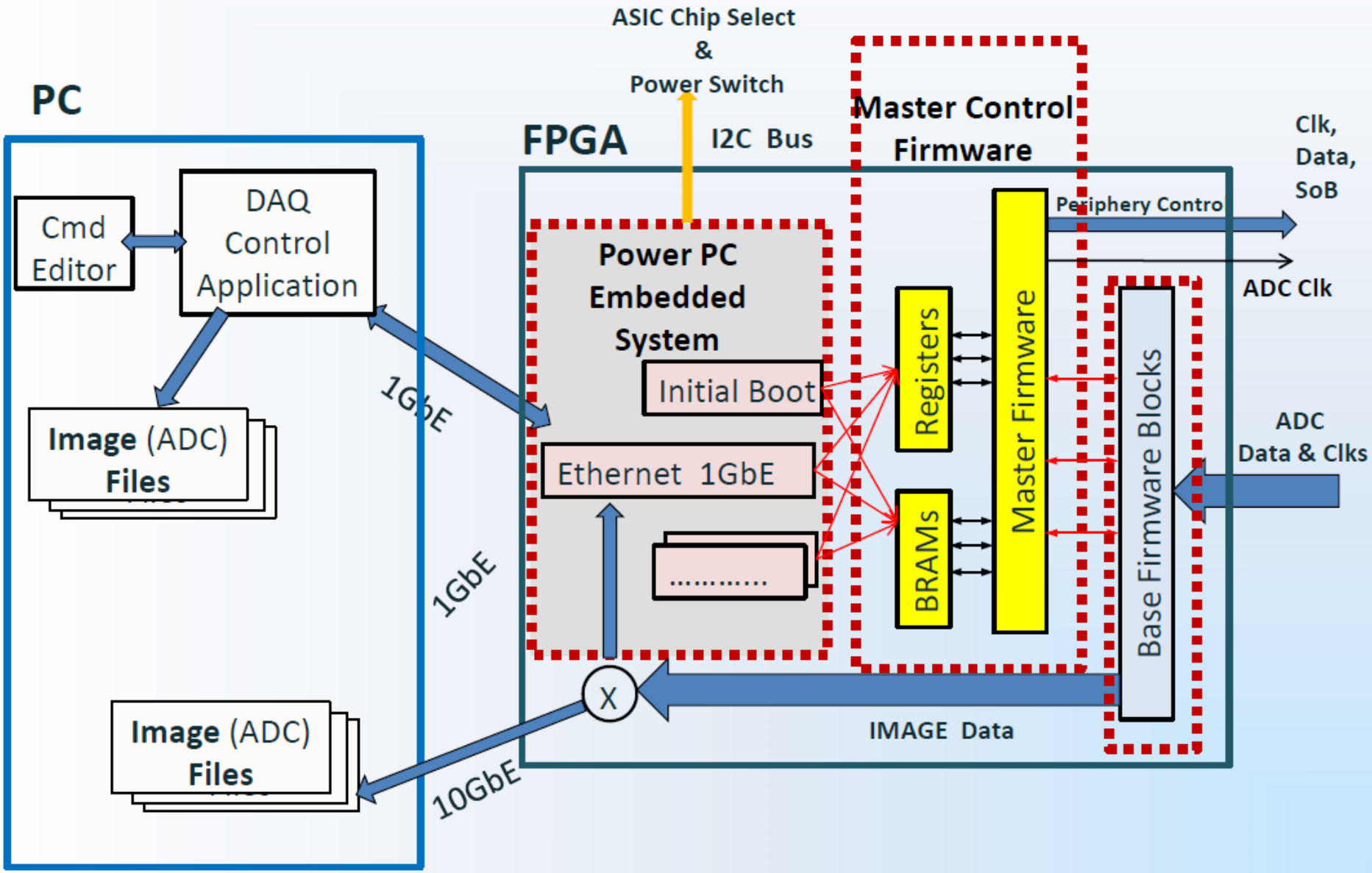
Single module test system

Single module system in the lab with housing – existing and new design



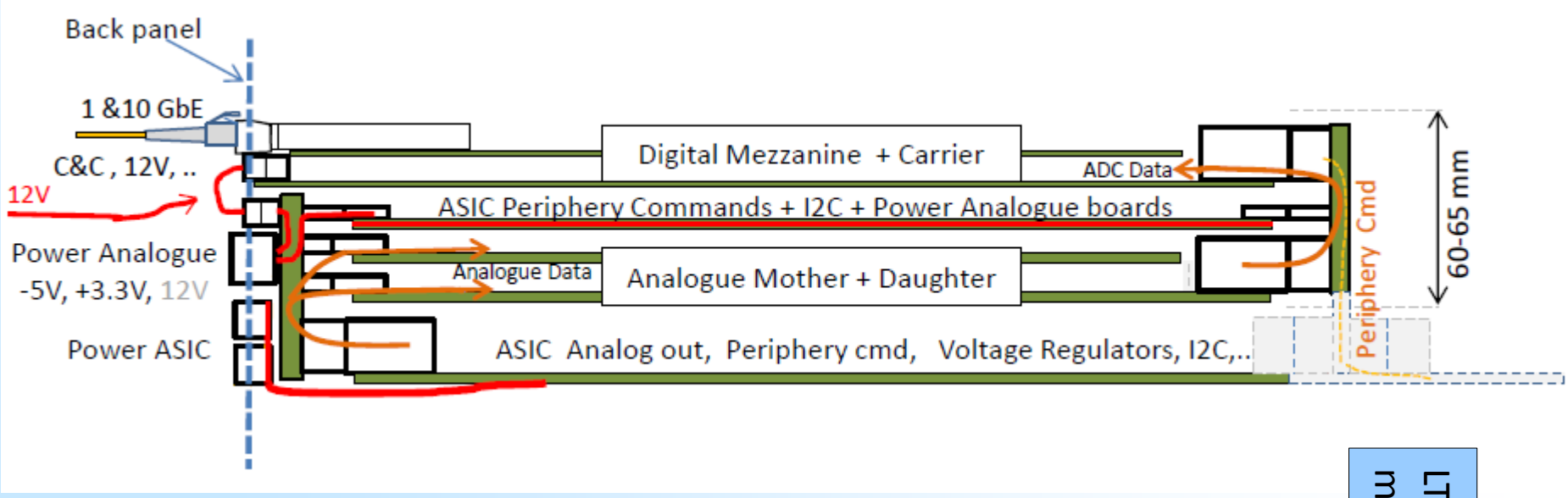


DAQ system: concept



Other AGIPD systems

AGIPD single module compact design



LTCC module