AGIPD

PERCIVAL

Radiation Detector developments for low- and medium-energy photons

Alessandro Marras

on behalf of the DESY FS-DS group
and collaboration partners

DESY PSI bonn UHH DESY elettra

In a glance

A.G.I.P.D.

(Adaptive Gain Integrating Pixel Detector)

- European X-FEL, Petra P01/10
- ~12keV photons
- single photon upto $\sim 10^4$ photons/pixel/frame
- 300e noise
- 1Mpixel, 200um pitch
- 4.5 Mframe/s (burst)
- hybrid Si-Si detector

P.E.R.C.I.V.A.L.

(Pixellated Energy Resolving Cmos Imager, Versatile And Large)

- Petra P04, Flash, low-En synch/FELs
- 250e V ~1keV photons
- target: single photon upto $10^4 \sim 10^5$ photons/pixel/frame
- target: <15e noise
- 10~16Mpixel, 25~27um pixel pitch
- 10-120 frame/s
- back-illuminated MAPS

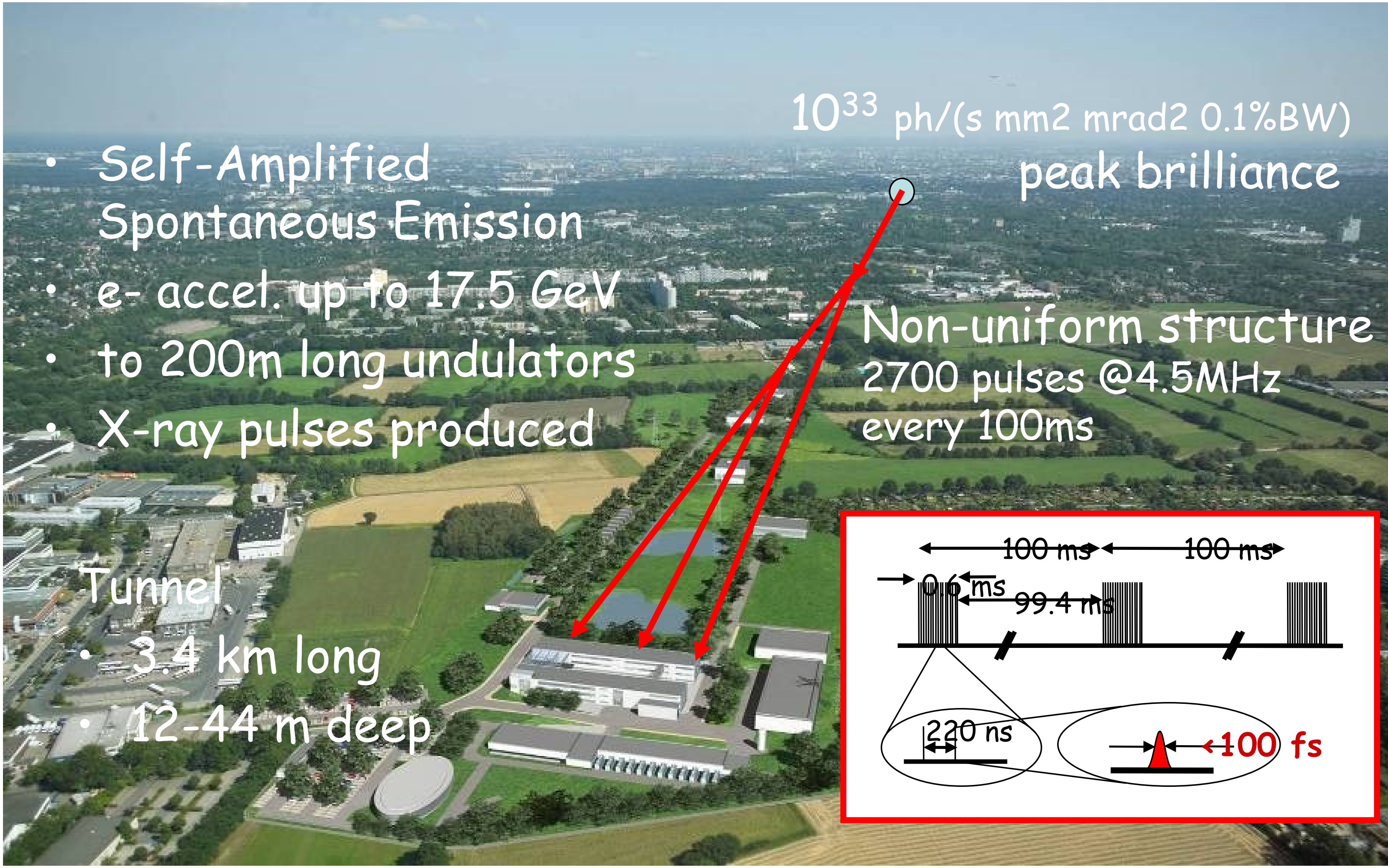
European X-FEL

- Self-Amplified Spontaneous Emission
- e- accel. up to 17.5 GeV
- to 200m long undulators
- X-ray pulses produced

10^{33} ph/(s mm2 mrad2 0.1%BW) peak brilliance

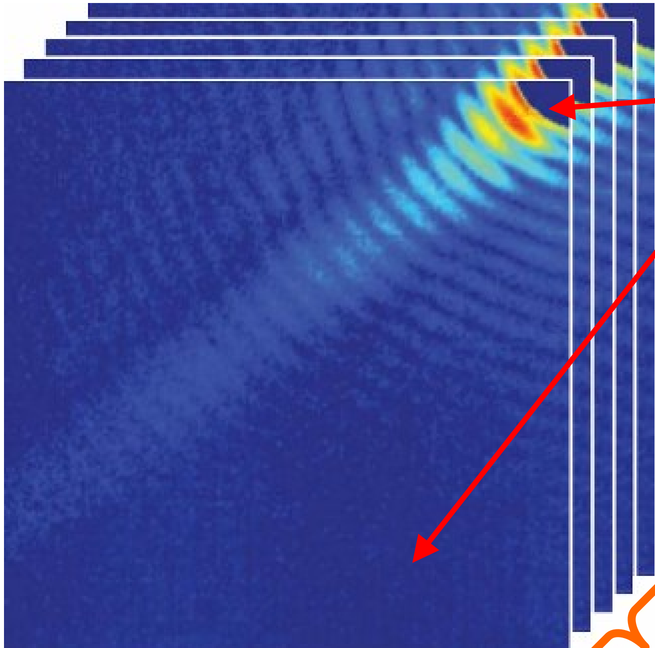
Non-uniform structure
2700 pulses @4.5MHz
every 100ms

Tunnel
- 3.4 km long
- 12-44 m deep



Constraints

AGIPD



in the same image:
- up to ~ 10^4 photons
- down to 0~1

4.5MHz x 2700 images

radiation tolerant!

1-photon resolution!
(or better than poissonian)

single-image experiments!
as many as possible!

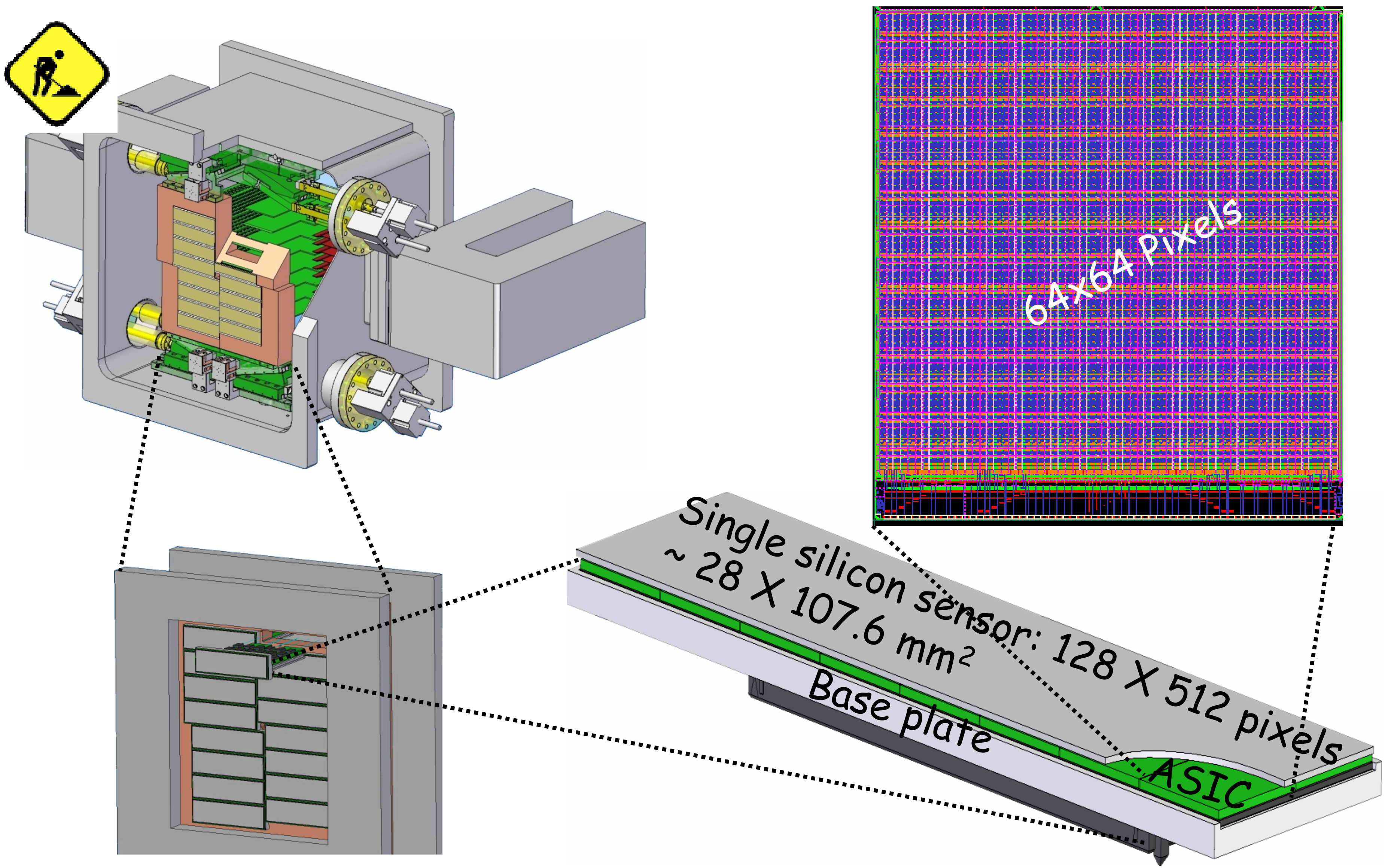
many pixels!
small pixels!

- Charge integration
- Adaptable Gain O(2)
- noise ~ 0.1 photon
- 1Mpixel, 200 μm pitch
- in-pixel Memory (352)

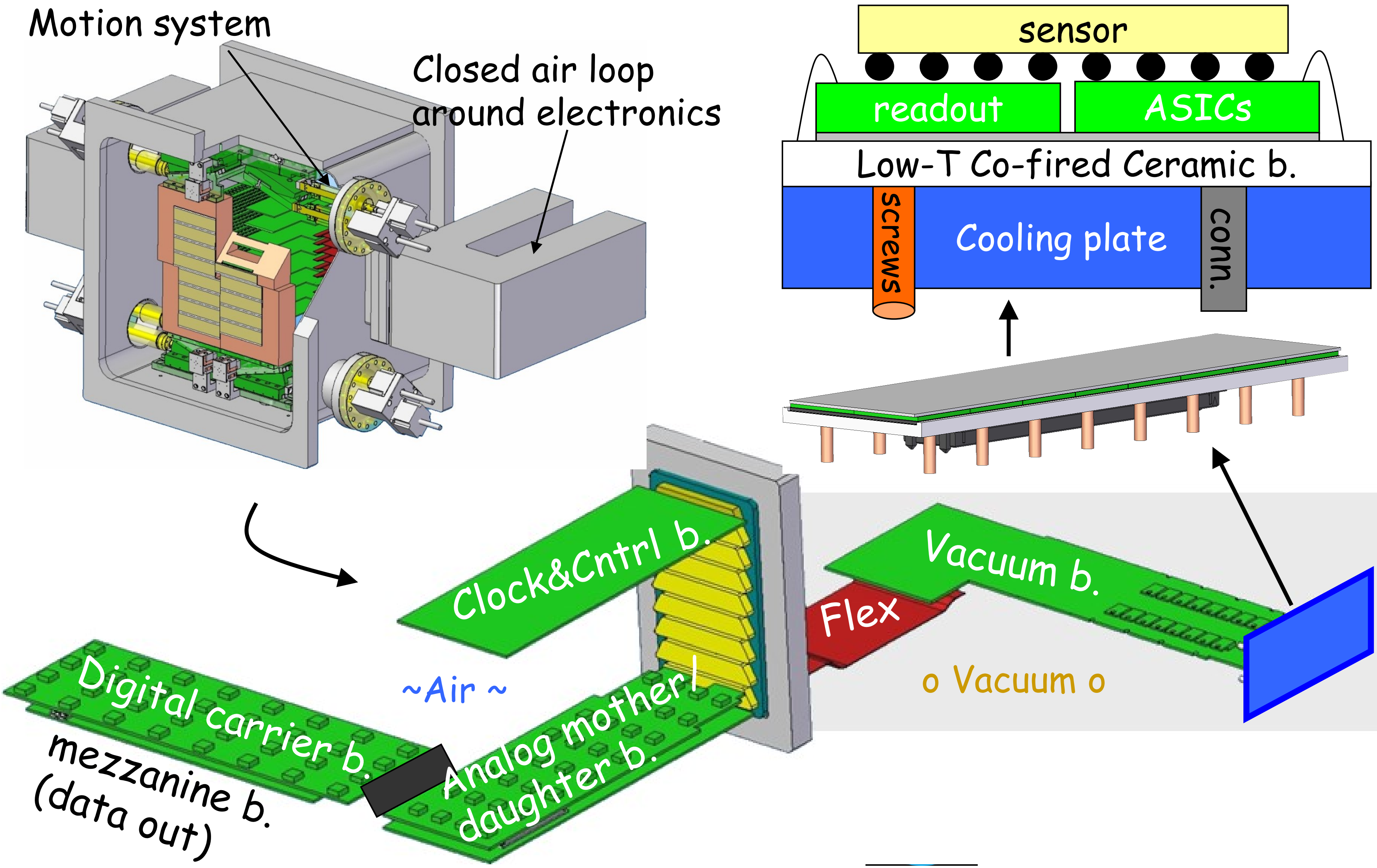
- veto schema
- leakage minimization
- rad hard design

DESY PSI bonn UHH

The A.G.I.P.D. (1assembly)

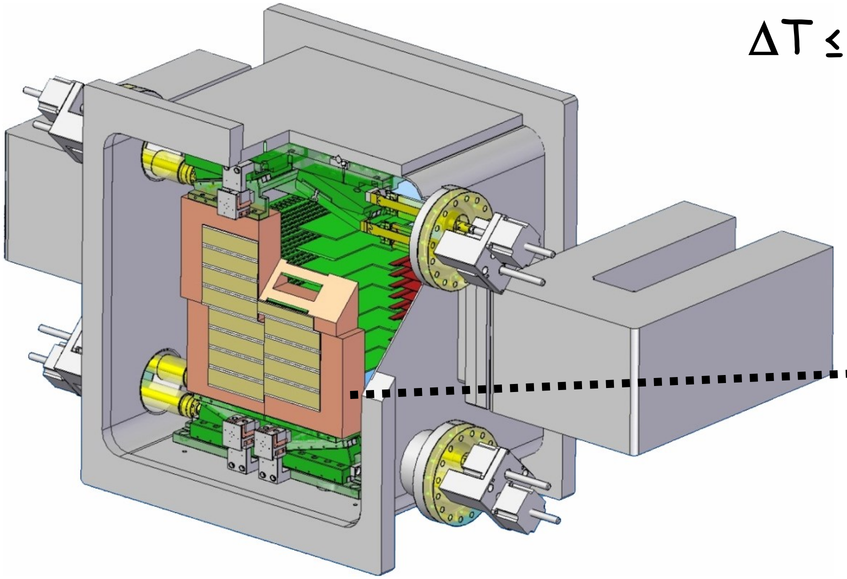


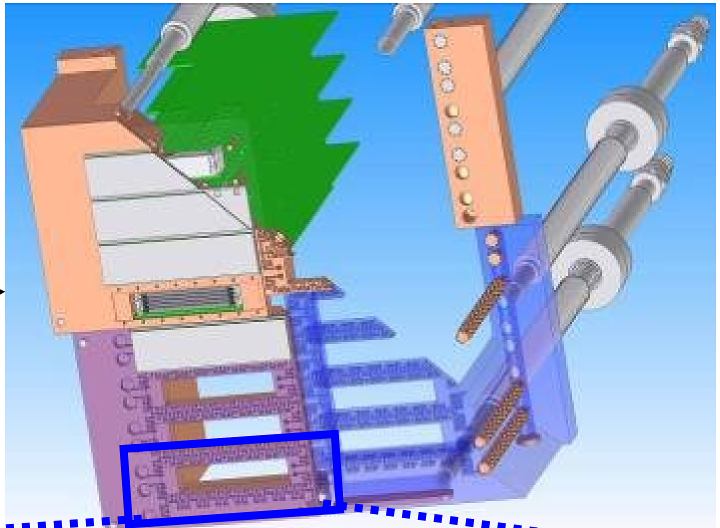
The A.G.I.P.D. (1boards)

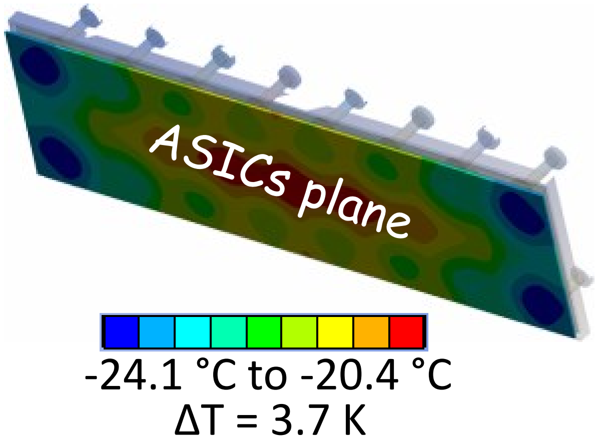


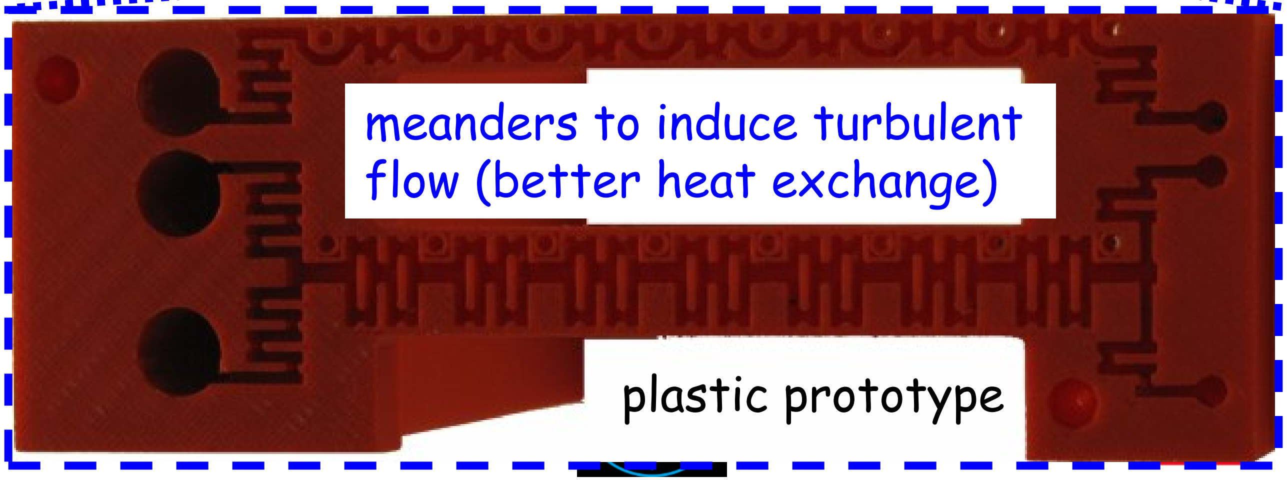
The A.G.I.P.D. (1 Cooling)

ASIC : T ≤ -20°C (less droop post irradiation)
ΔT ≤ 5 K (less spread parameters)





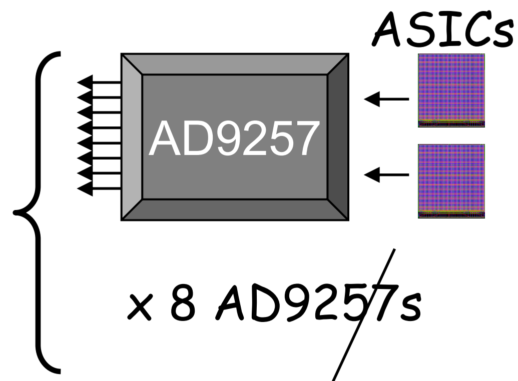




The A.G.I.P.D. (1data out)

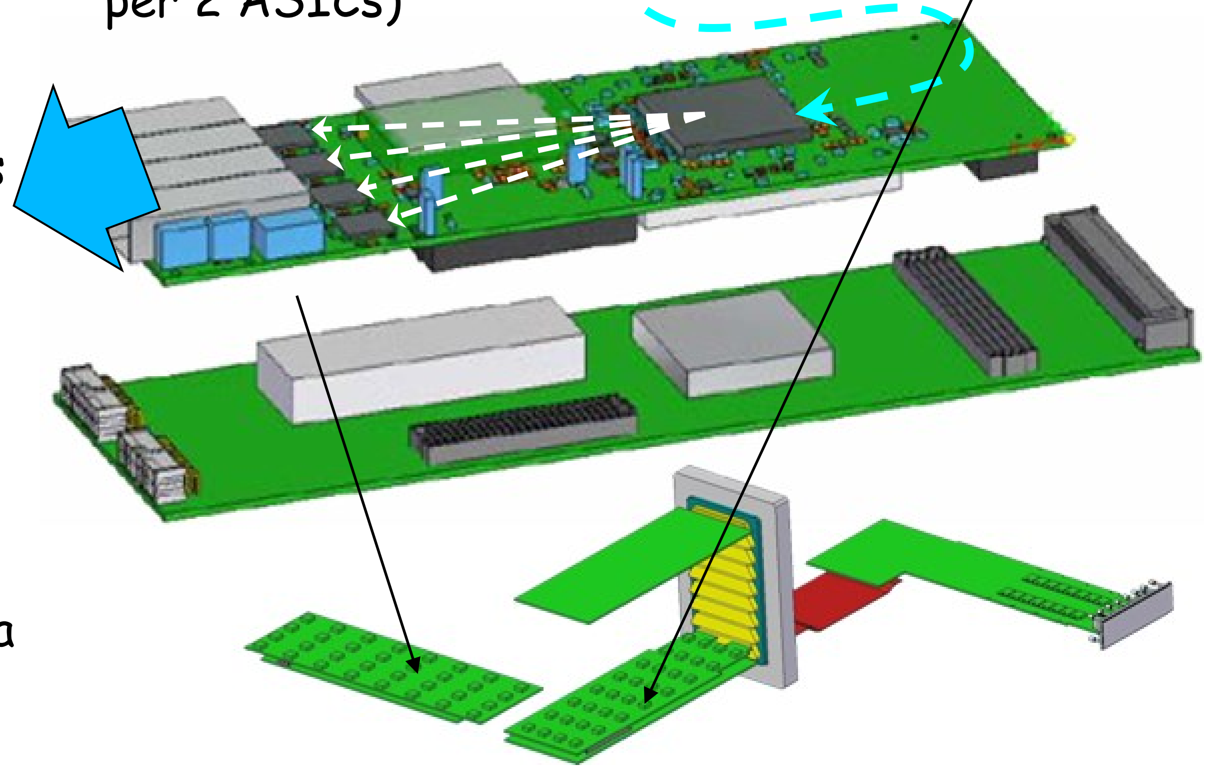
pixels	1M
mem cell/pixel	x 352
analog & gain	x2
bits/sample	x 14
in 100ms	x10
	------------
avg data rate	~96.5Gb/s

analog PCB: line reception, pickup noise filtering and digitization (@ 33MHz) 14 bits (8-channels AD9257, 1 per 2 ASICs)

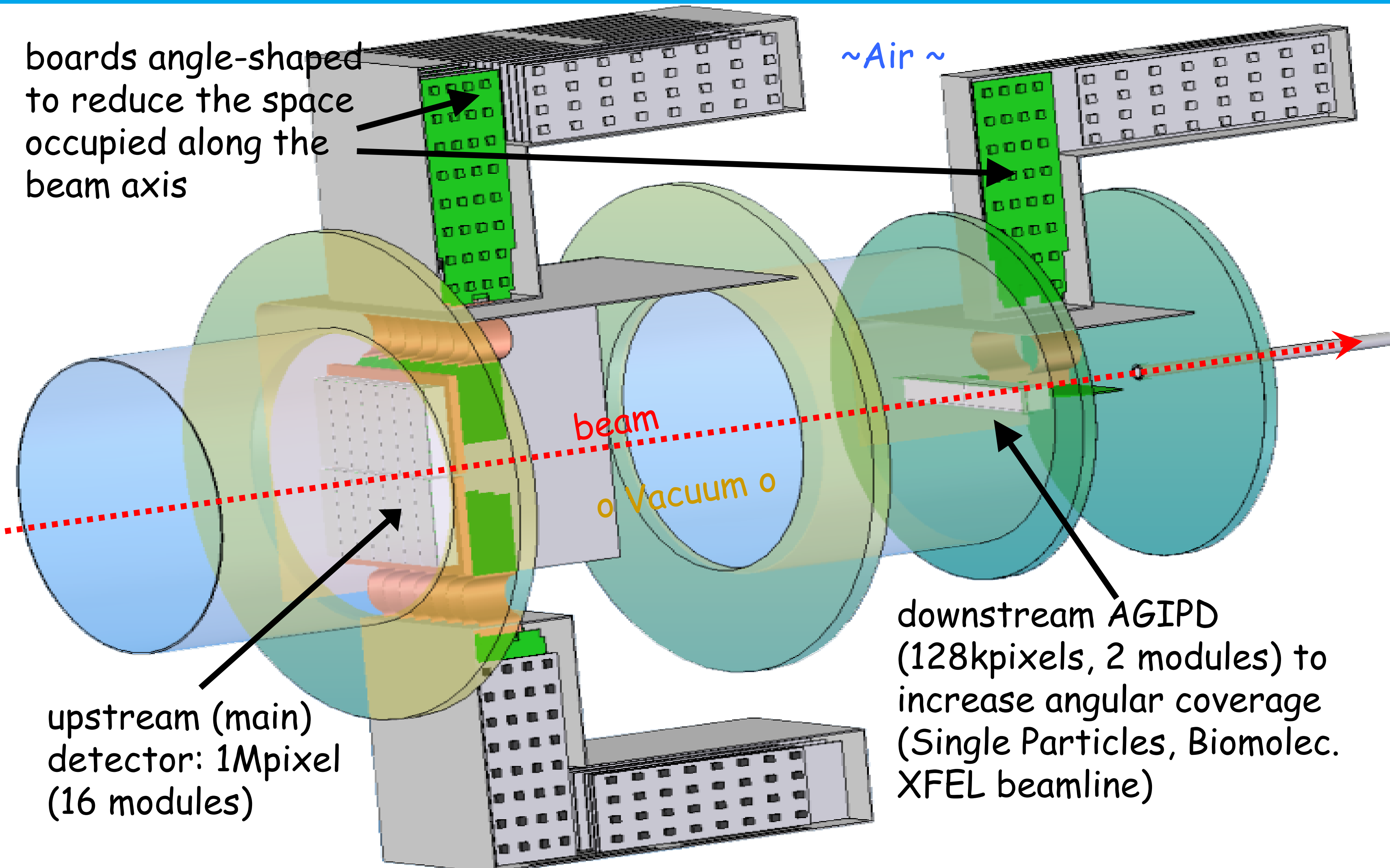


each of the 16 module has its own "mezzanine" fast out board VIRTEX-5 FPGA: limited data sorting, pass data to 4x10 GbE outputs

data collected by data acquisition train builder card (receive, sort and reject data from the 1Mpixel camera)



The A.G.I.P.D. (1even 2 planes)

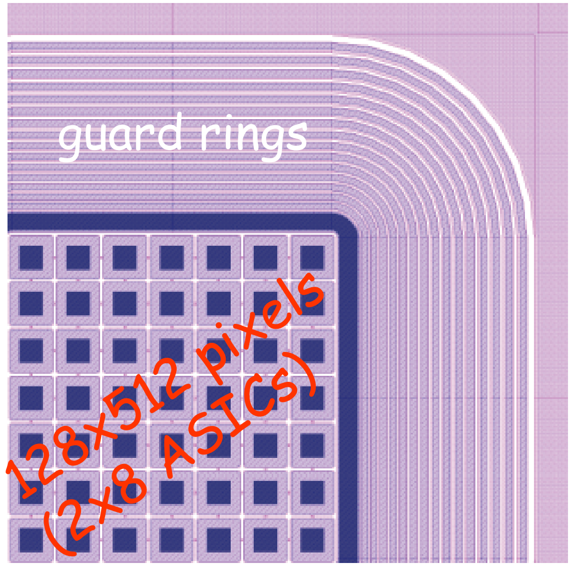


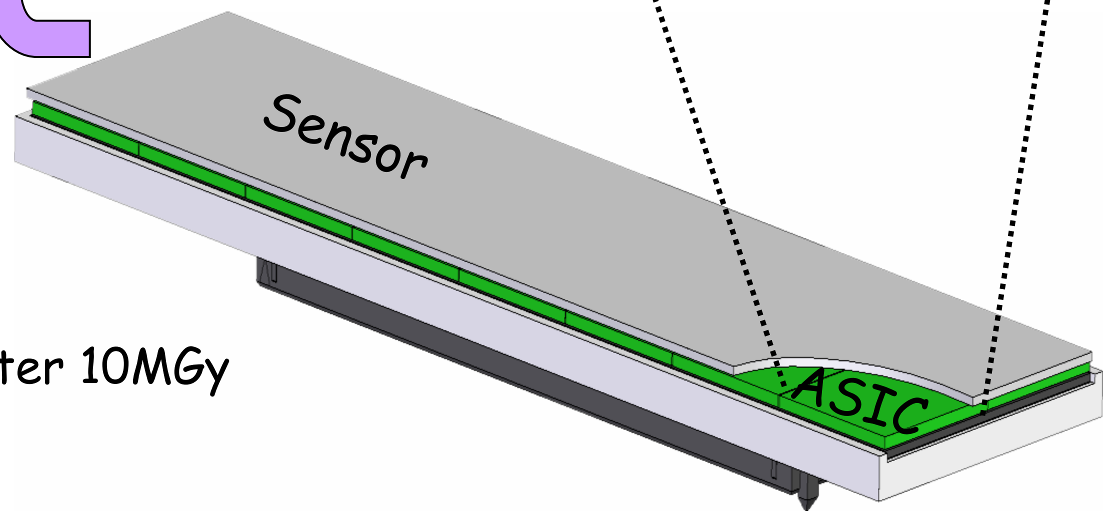
The A.G.I.P.D. (1front sensor)

- Si sensor p+ over n (hole collection)
- 107.6x28 mm (large monolithic sensors reduce the overall dead area)
- 500um thick

→ (>90%QE @12.4keV)

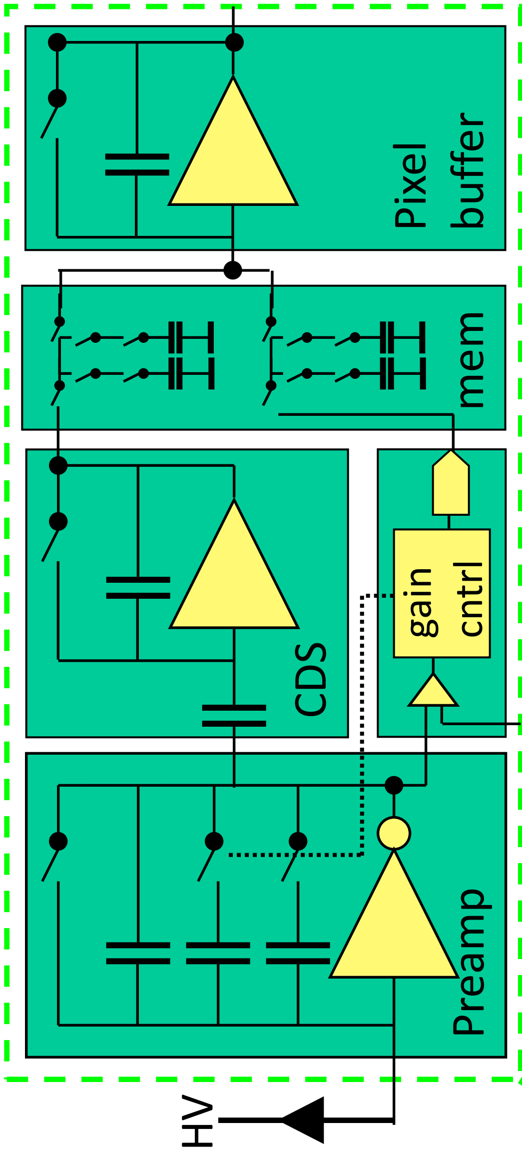
- effective entry window <2.5um (reasonable QE at lower energies)
- bias voltage > 500V (minimizes impact plasma effects)
- SINTEF tech
- UniHH design

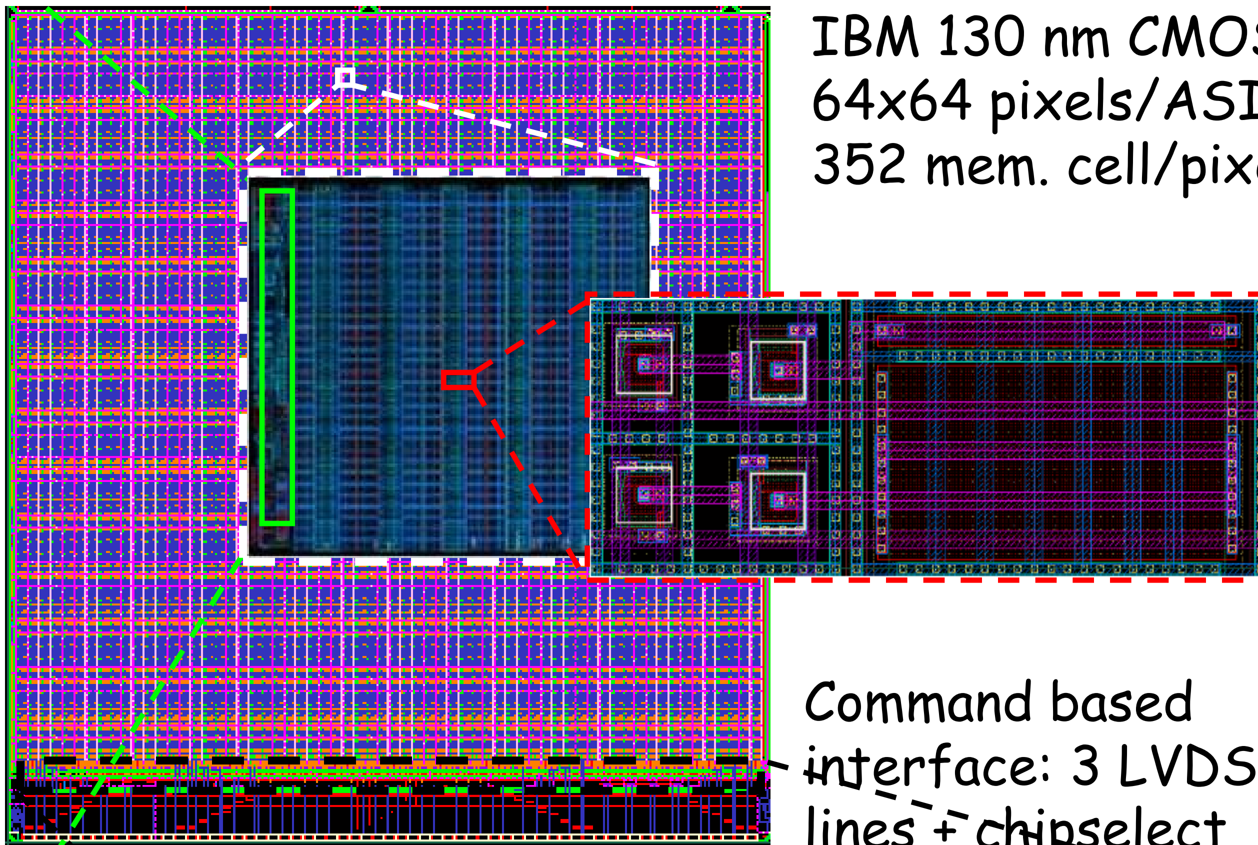




rad-aware design: Bd > 900V after 10MGy

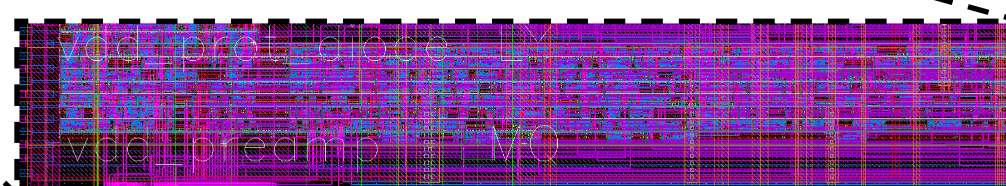
The A.G.I.P.D. (2)



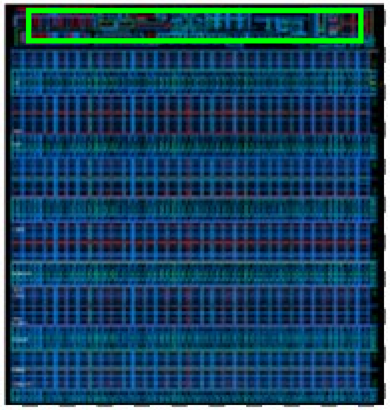


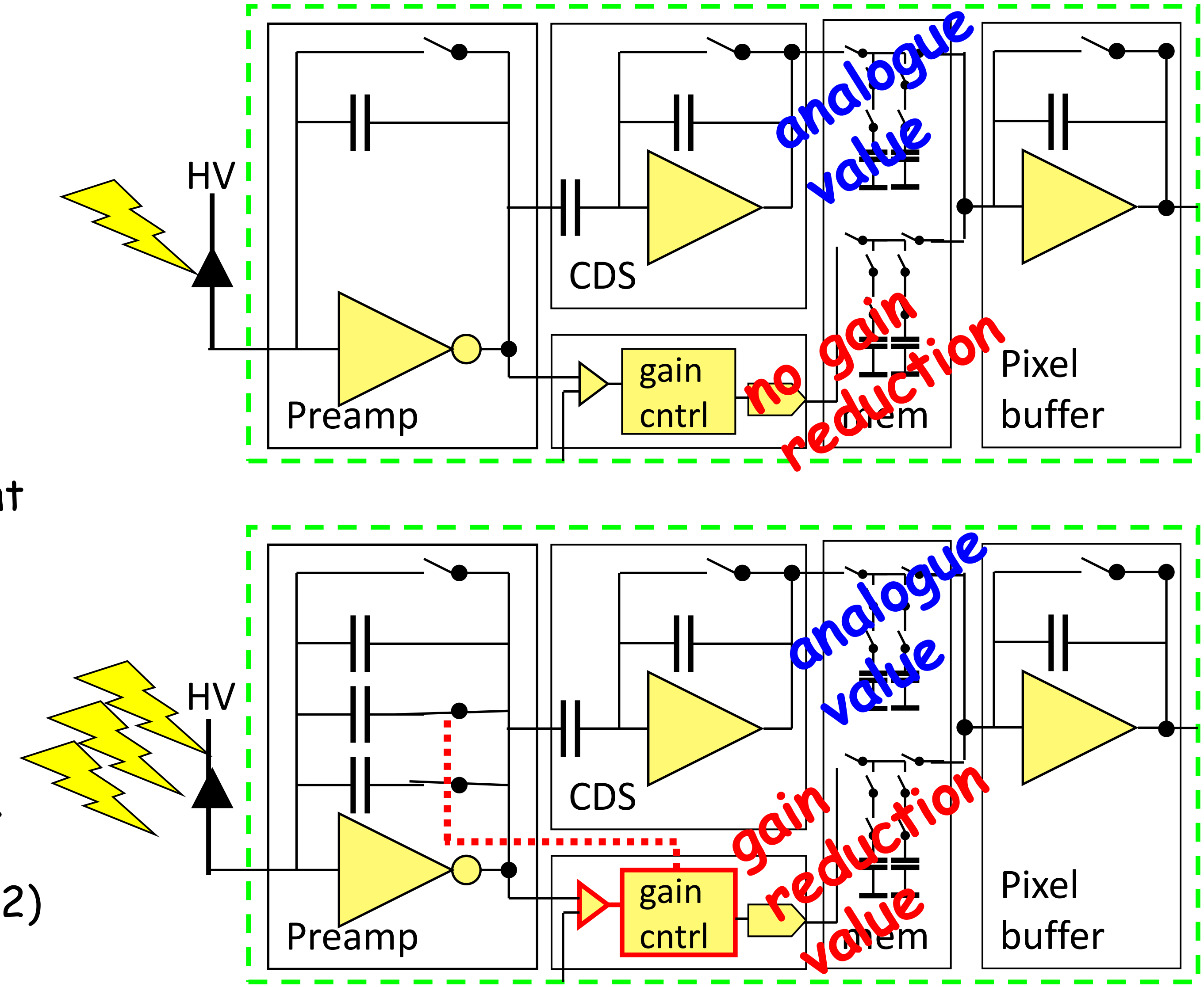
IBM 130 nm CMOS
64x64 pixels/ASIC
352 mem. cell/pixel

Command based interface: 3 LVDS lines + chipselect



Adaptive Gain Concept

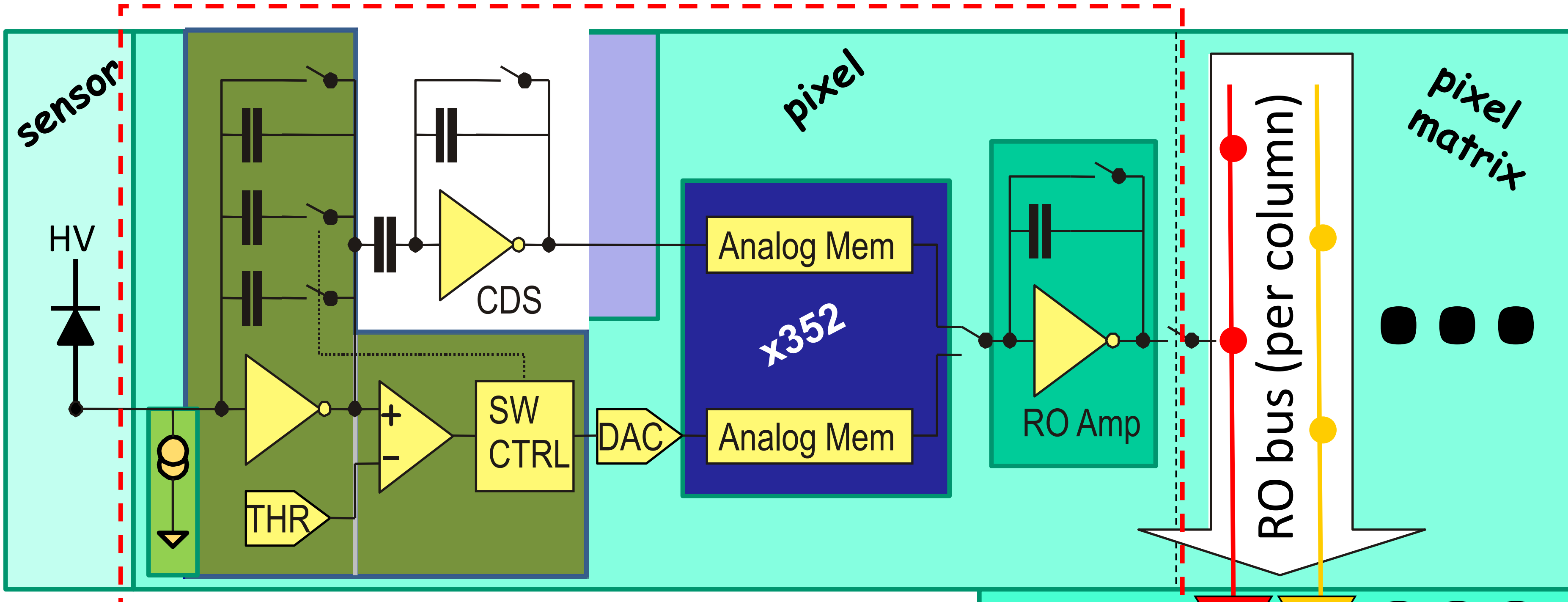


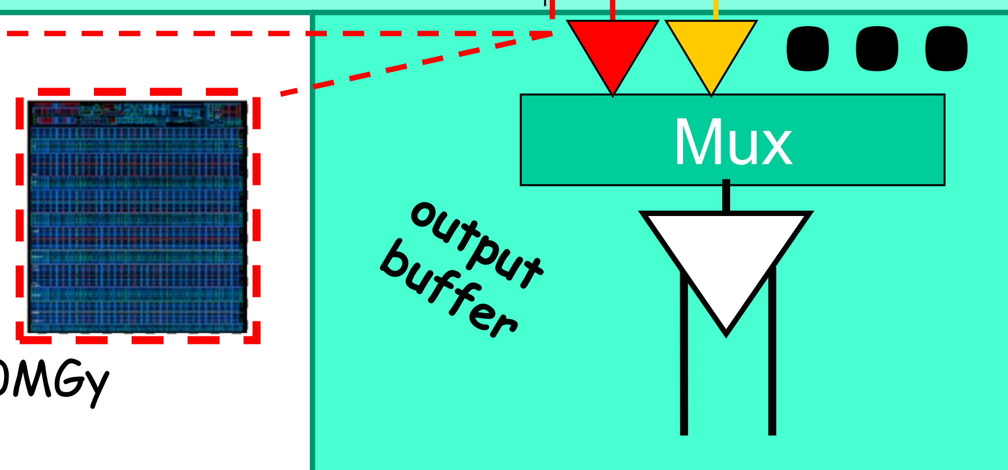


real-time adjustment of the feedback capacitance depending on the photon flux

60fF/3fF/10fF dyn. switching
=> adaptable gain O(2)

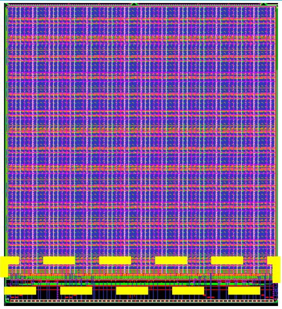
The A.G.I.P.D. (3)

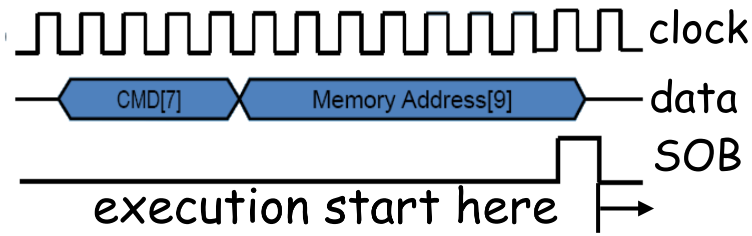




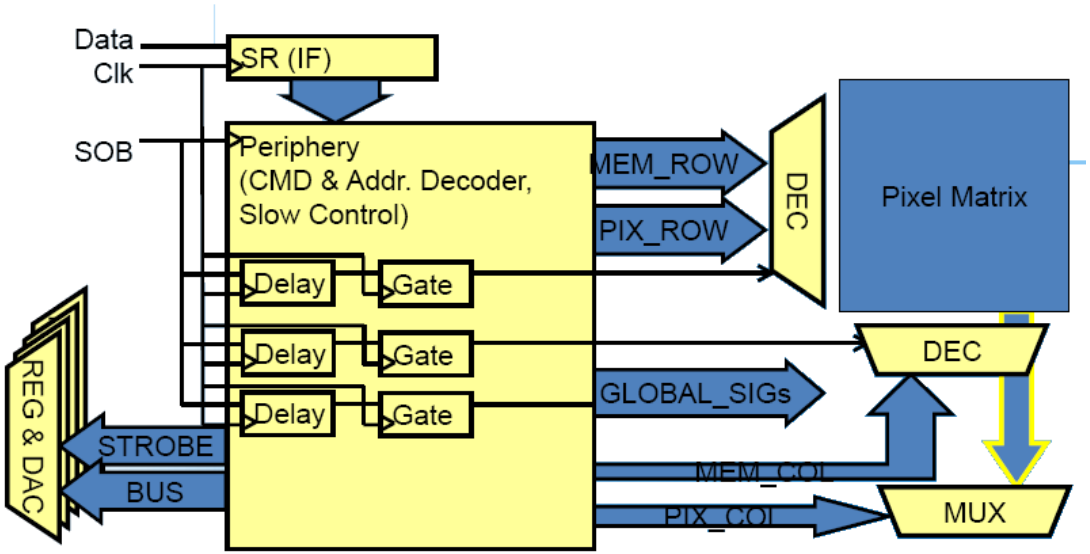
adaptable gain O(2)
Mem. 352-deep, RAM-addressable
acquisition < 200ns (tested 192ns)
noise tested 300e (<0.1 ph 12.4keV)
ELT, rad-aware design: tested 10-100MGy

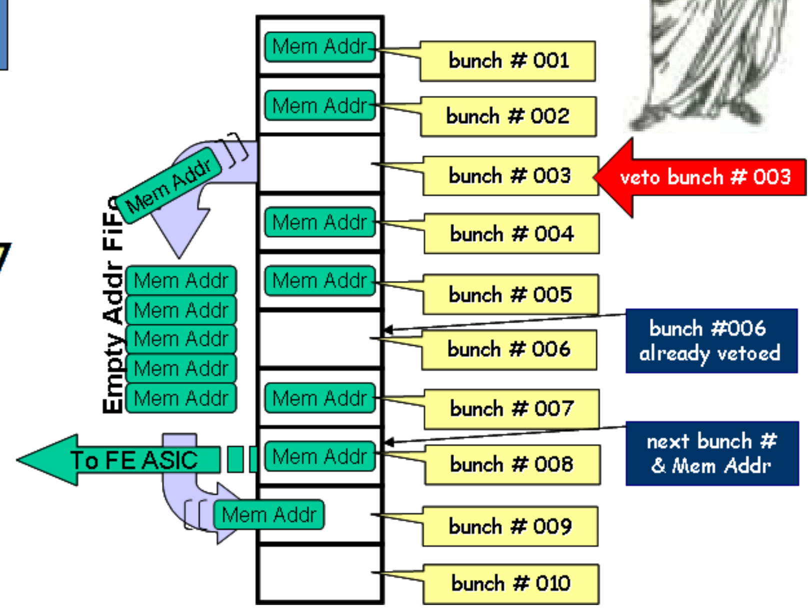
Command Serial IF





Memory space addressable RAM-like from the (external) interface electronics allows for Veto schema (overwriting of meaningless data)



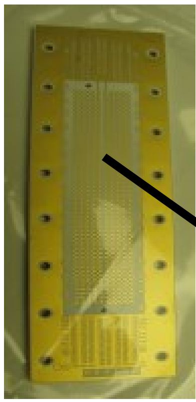


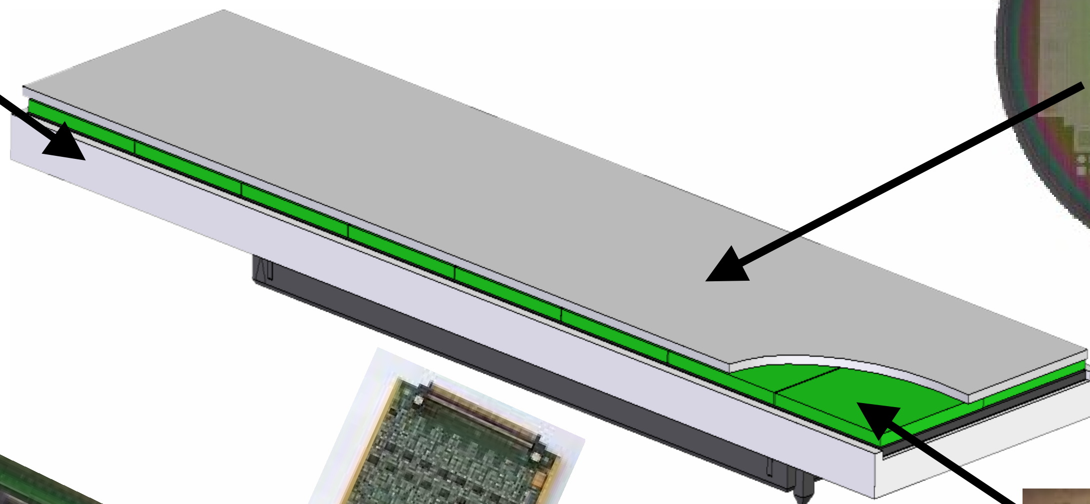
ARM cmrf8sf RVT SC Library
Command Serial Interface
3+1 LVDS Signals
prototype working after 10MGy

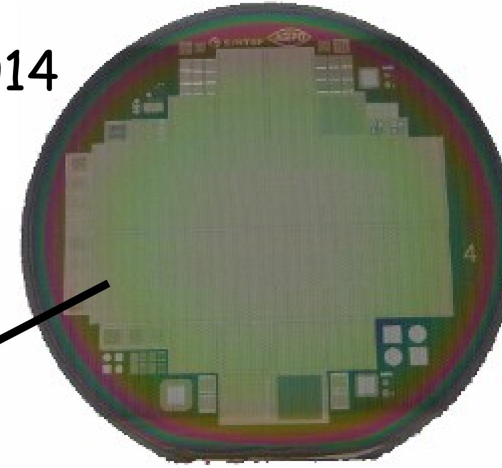
AGIPD 1.0 status

- Single chip assemblies: in a few weeks
- First modules (8x2 chips): beginning 2014
- First 1M system: beginning 2015

Low-T Co-fired Ceramic board

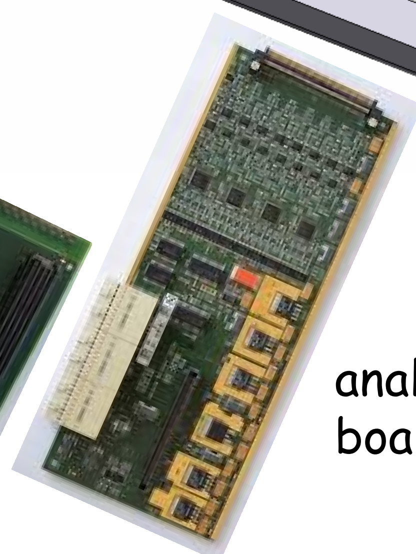






sensor

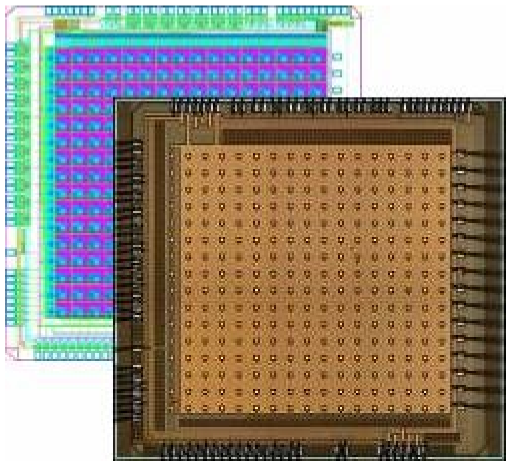
“mezzanine” fast readout board



analogue mother board (prot.)

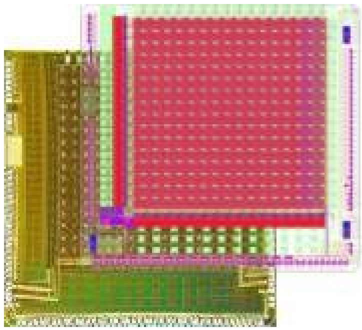
readout ASIC

former prototypes

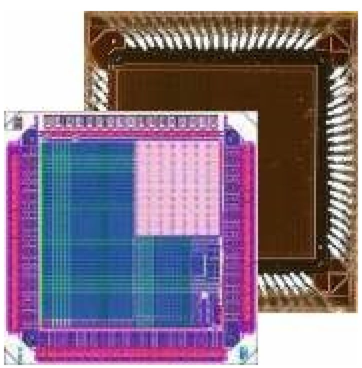


agipd04

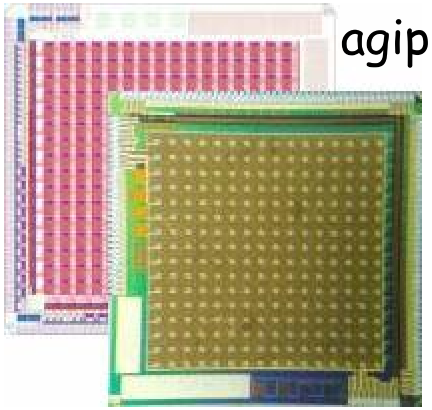
16x16 pixels
sub-opt. sensor



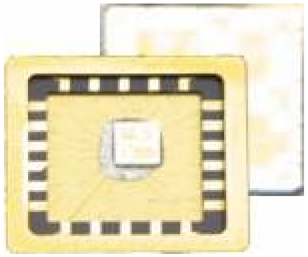
agipd03



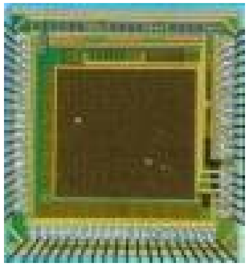
hpad1



agipd02



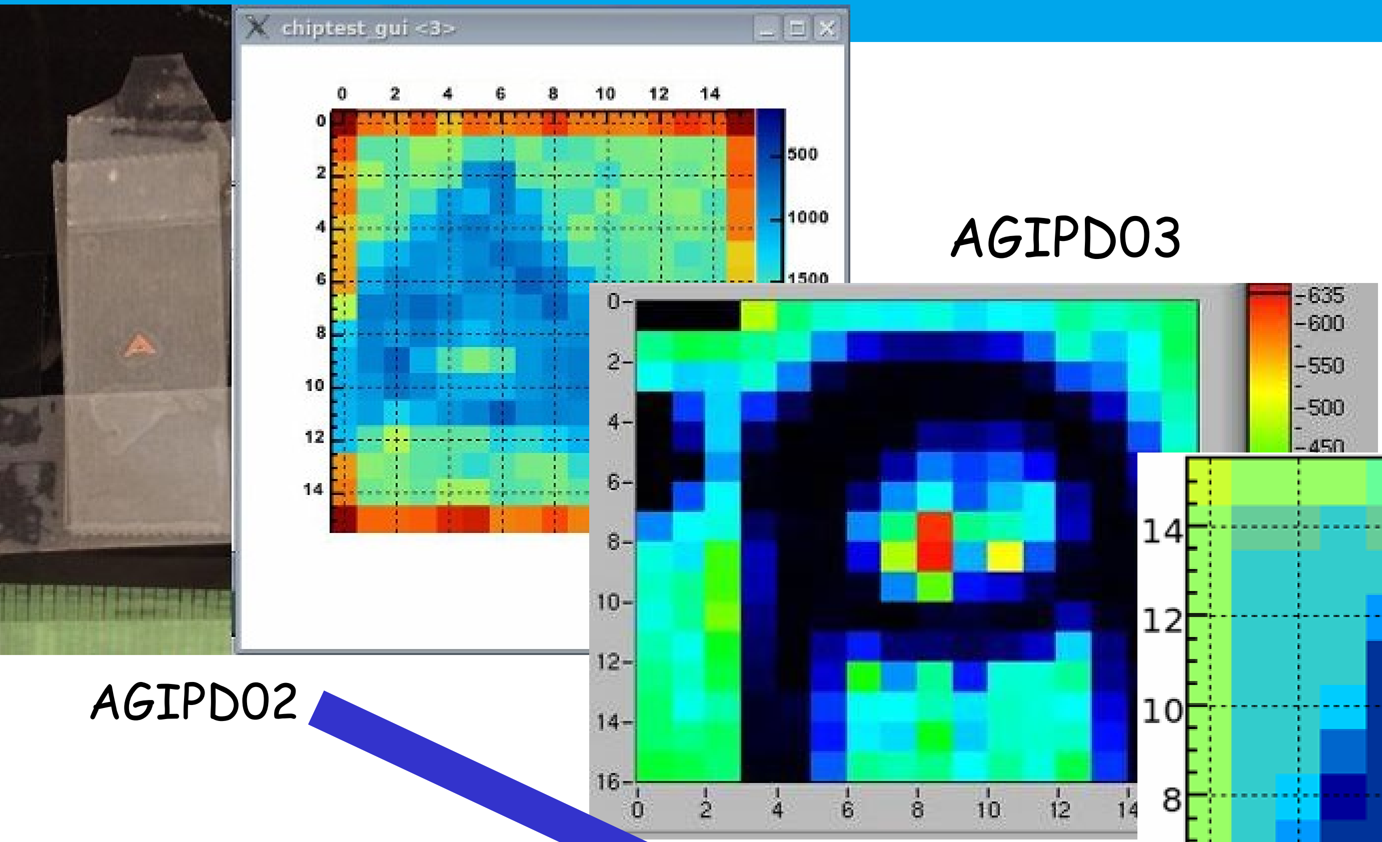
hpad2



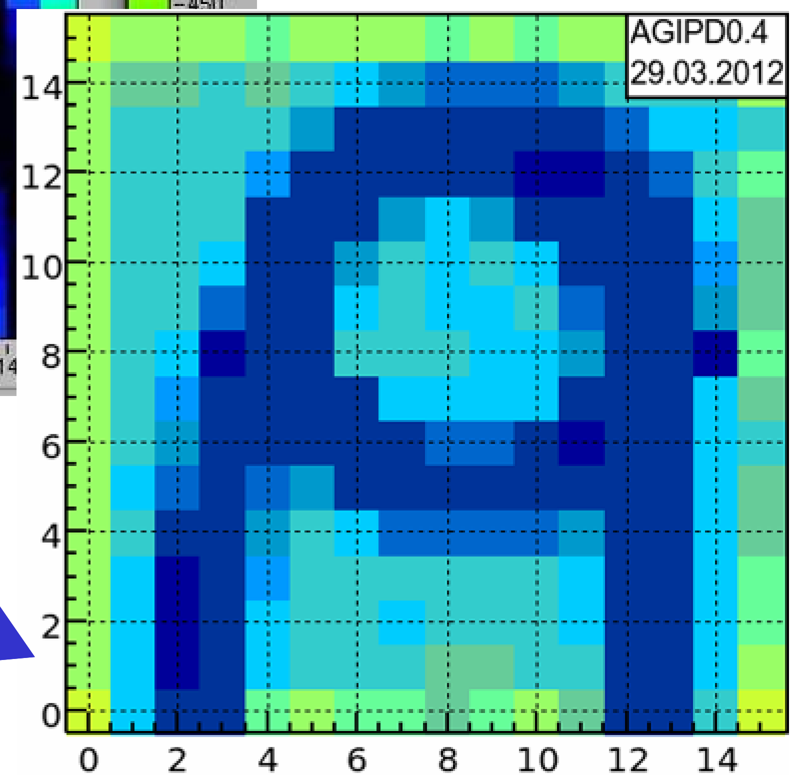
agipd01

imaging with prototypes

AGIPD03



AGIPD04



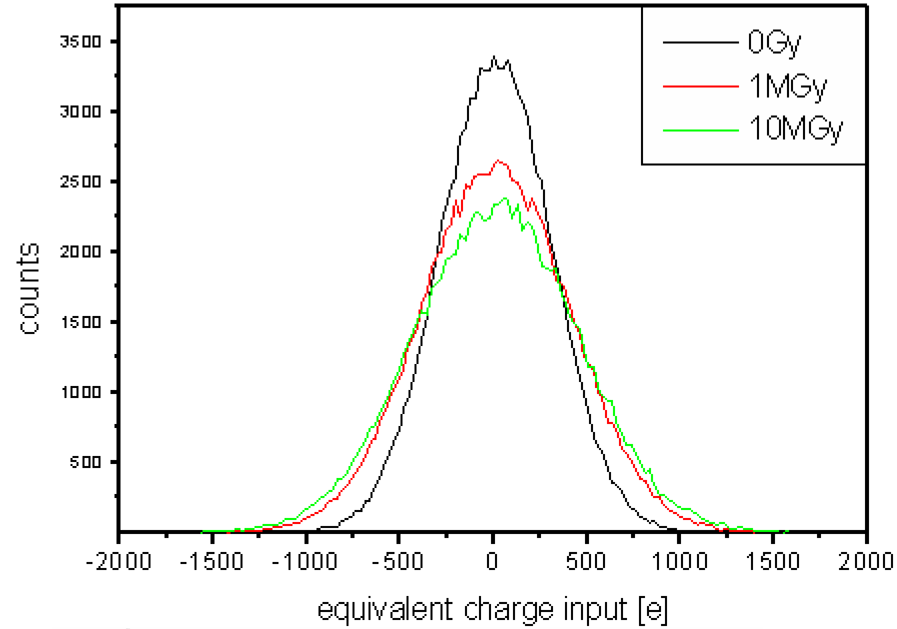
AGIPD02

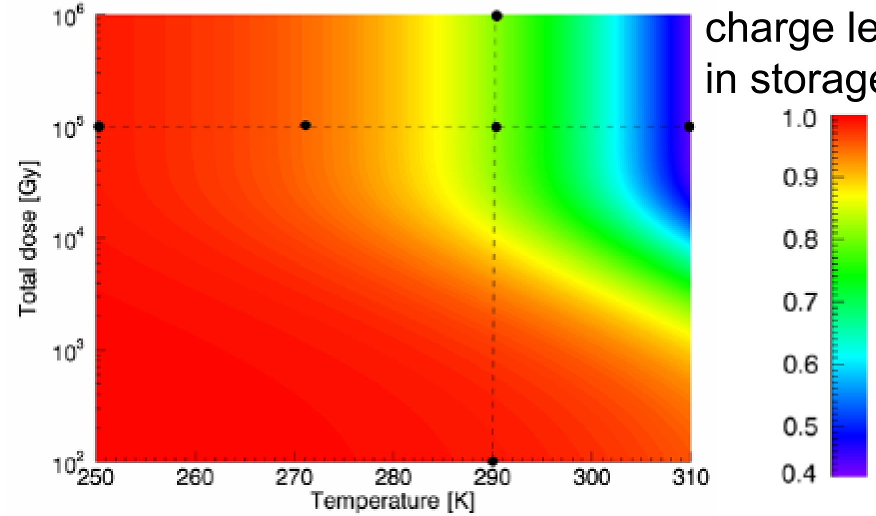
meas. done by
Dominic Greiffenberg (PSI)
Ulrich Trunk (Desy)

irradiating ASIC prot.

Irradiation of HPAD 0.1/0.2
AGIPD03/04 chips
up to 10-20-100MGy
@ DORIS F4
5.4kGy/s
highly accelerated irradiation rate → pessimistic estimation

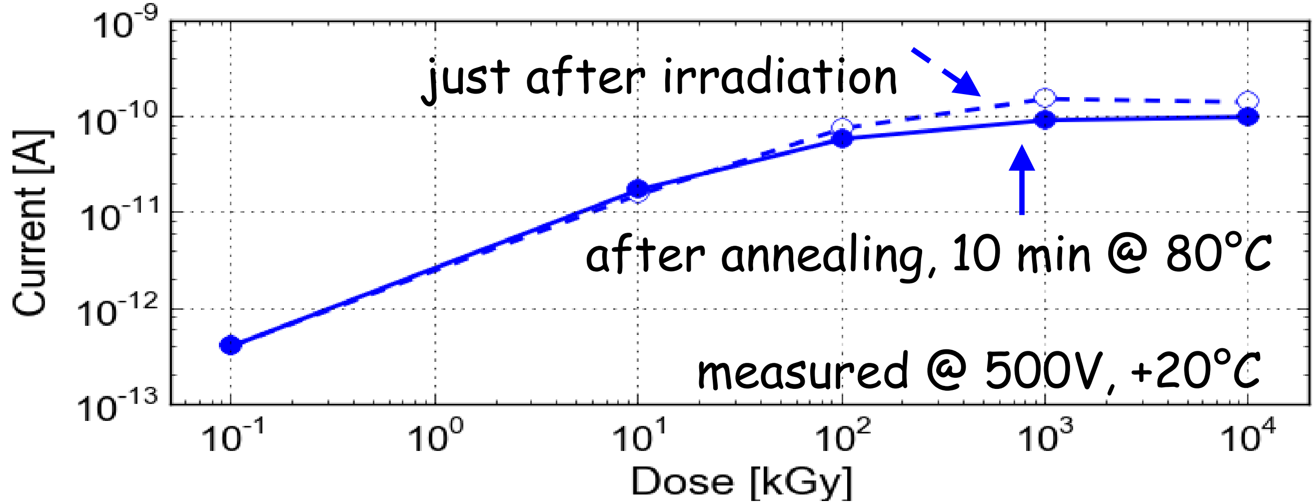
- upto 10MGy: comparable behaviour, 30~40% noise increase
- 100MGy: functionality recover after annealing
- storage cell leakage (100ms): <1% at -20°C





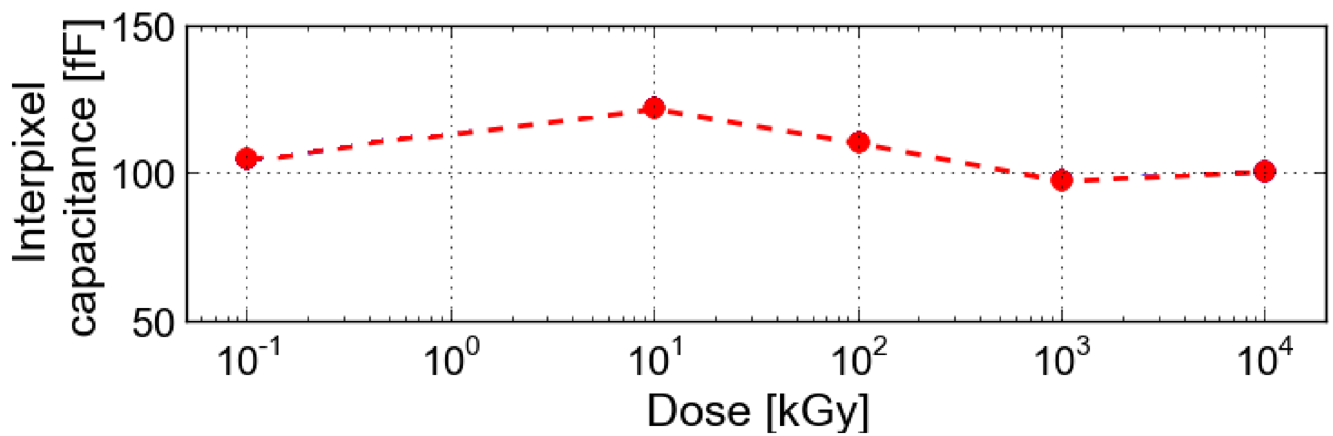
irradiating sensor

Irradiation AGIPD sensor
up to 10MGy
@ Petra P11
12keV
7.1kGy/s
J. Zhang et. al.



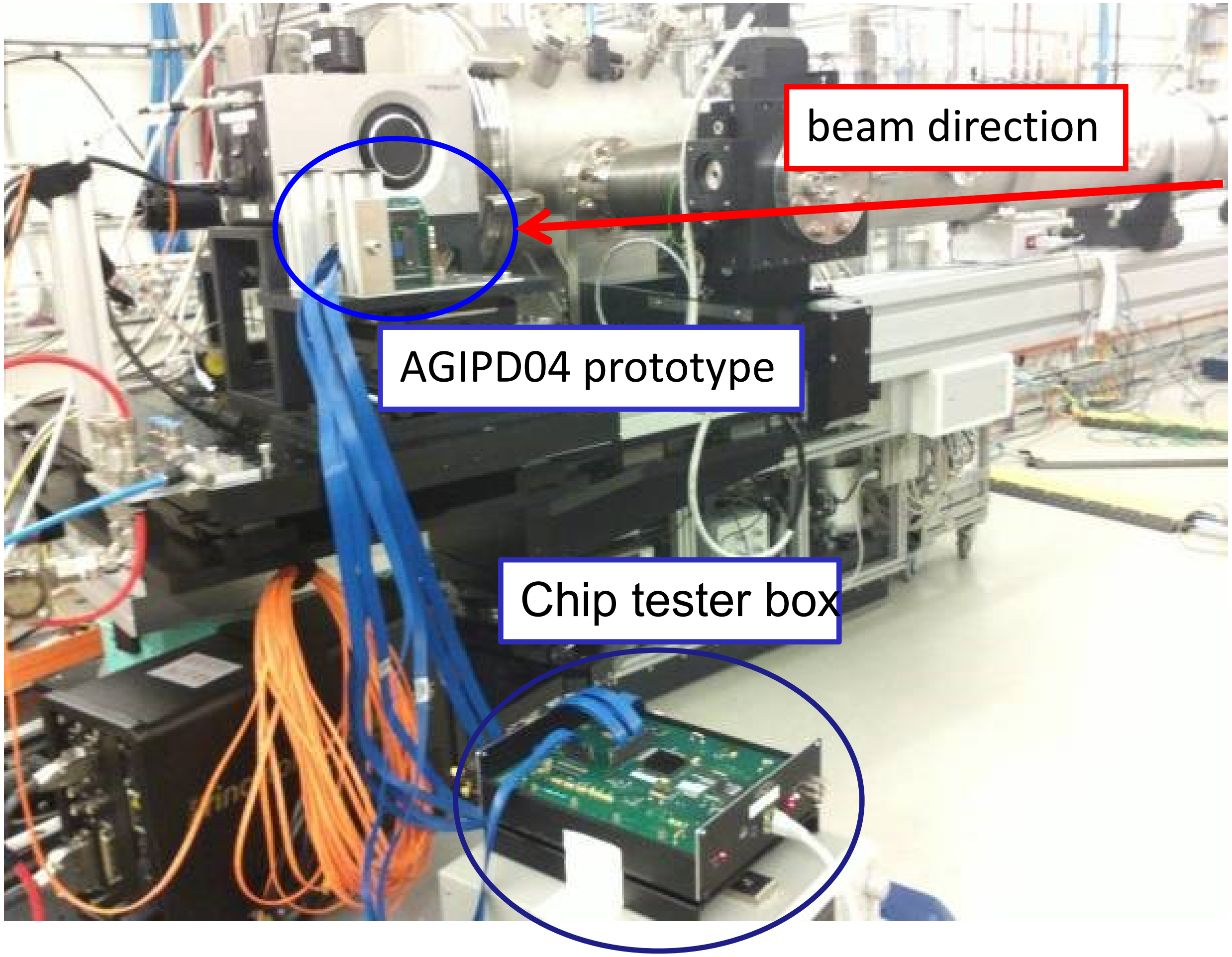
pixel current (< 0.2 nA) saturates for doses above 1 MGy

No breakdown up to 900 V after 10 MGy (and expected for even higher doses)



C_{int} (<150fF) weakly dependent on dose

AGIPD at Petra P01/10



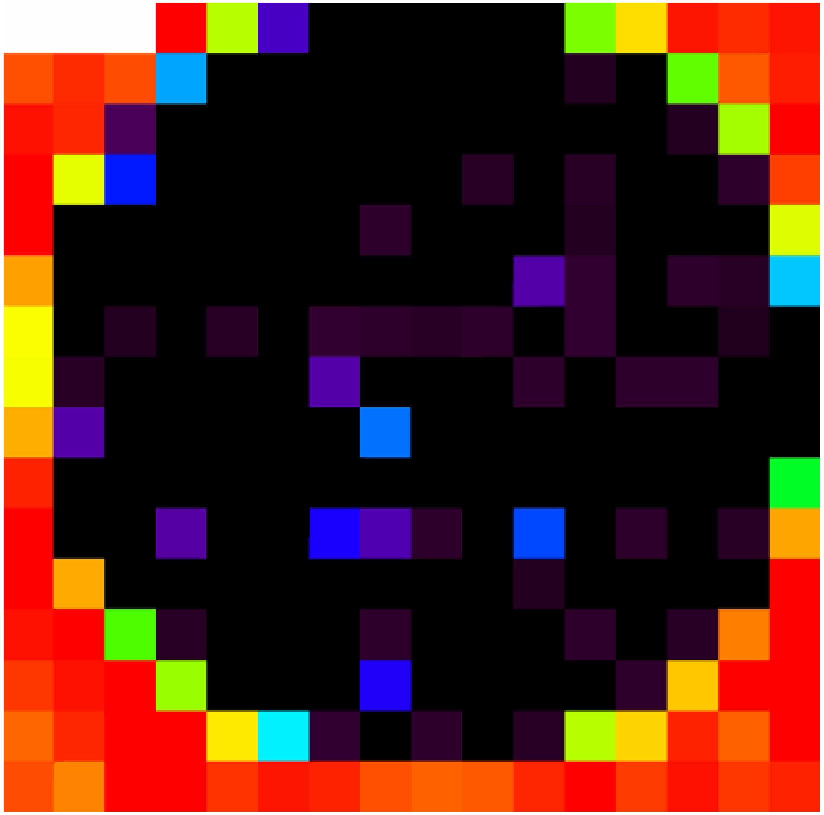
beamline P01
- Energy 14.4125 keV (high res. monochrom.)
- 192 ns/bunch
- triggered acquisition
- no sample

beamline P10
- Energy 7.05 keV
- ~1.7×10^{11} photons/sec,
- 60 bunch mode (128 ns)
- auto acquisition
- 200ns &192 ns integr.
- 2 samples: SiO2 particles in liquid (100 & 250 nm radius)

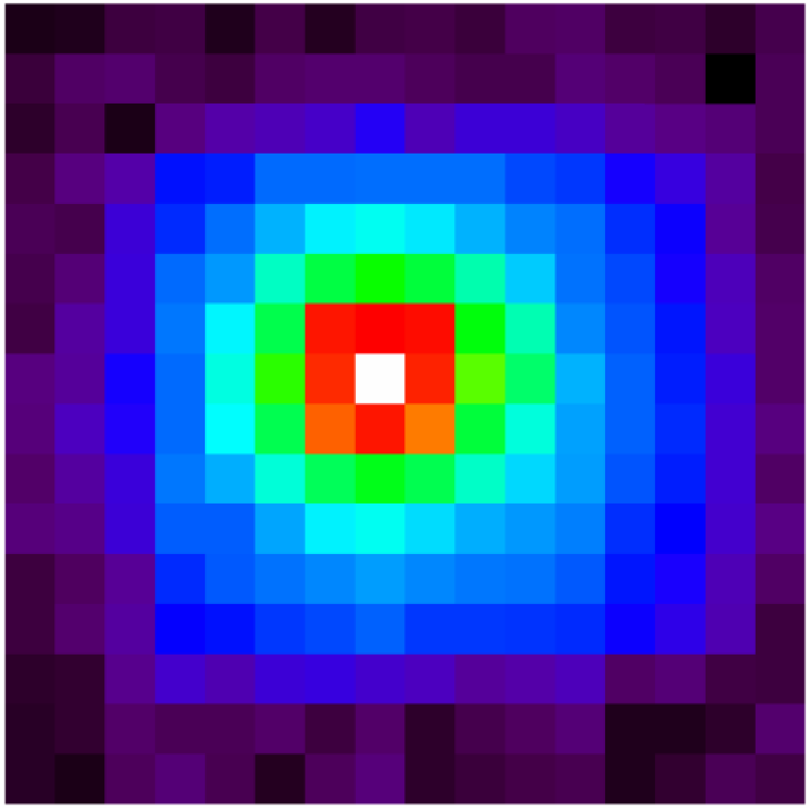
Not in the picture: Sample, control PC, me pushing buttons, …

AGIPD at Petra P10

beam stopper

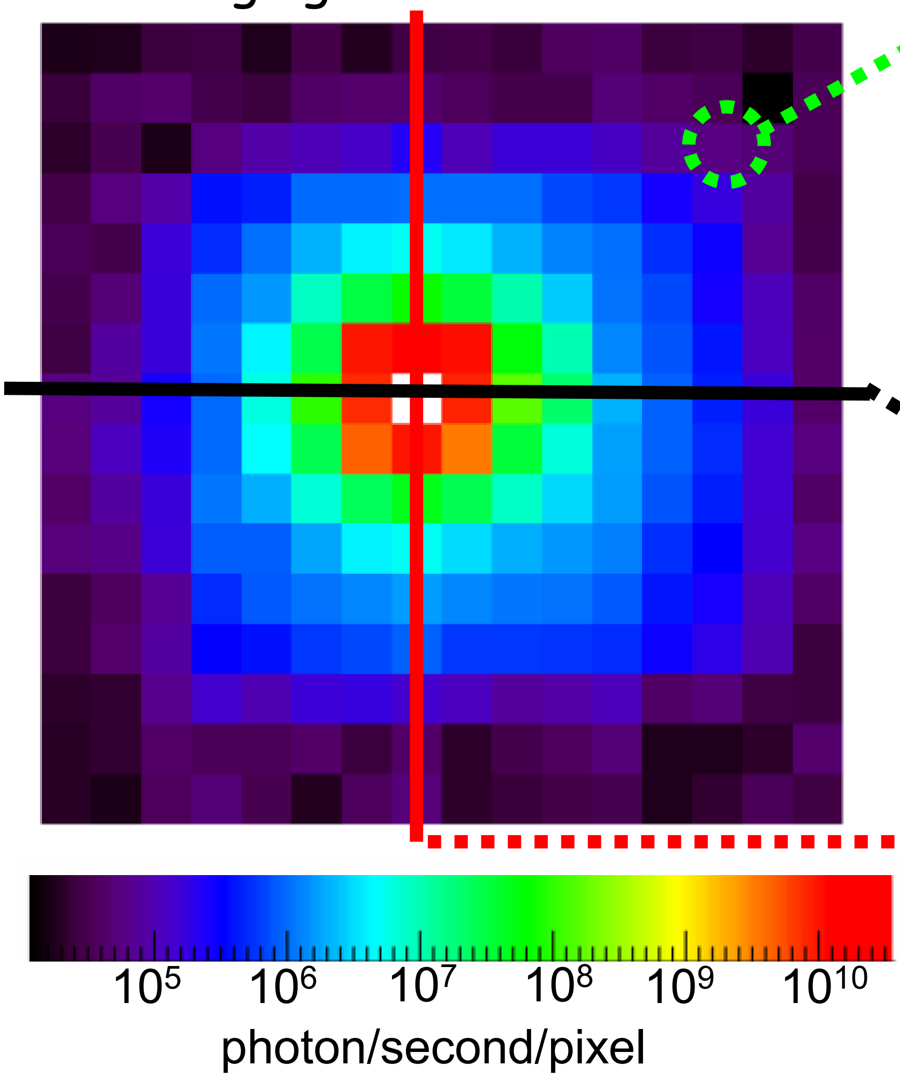


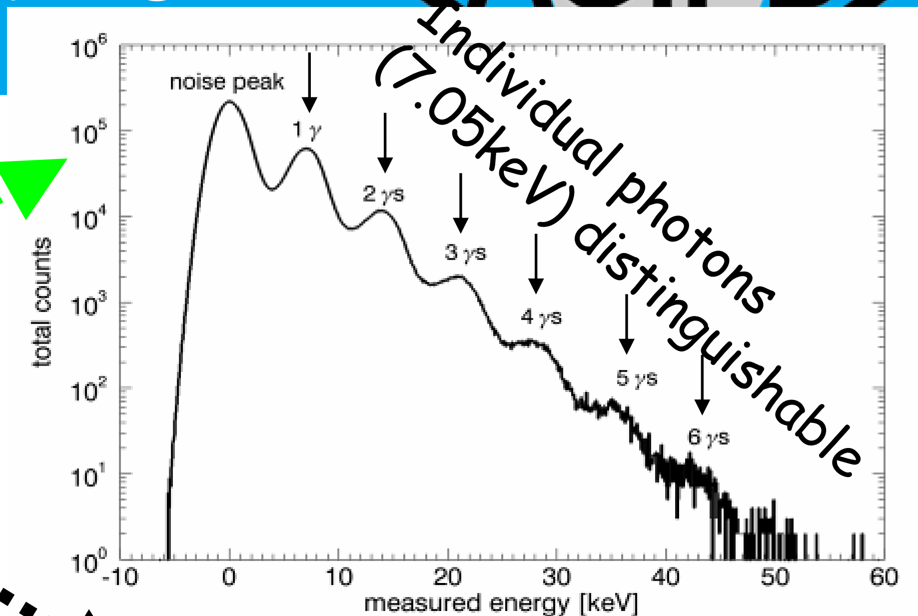
imaging the direct beam

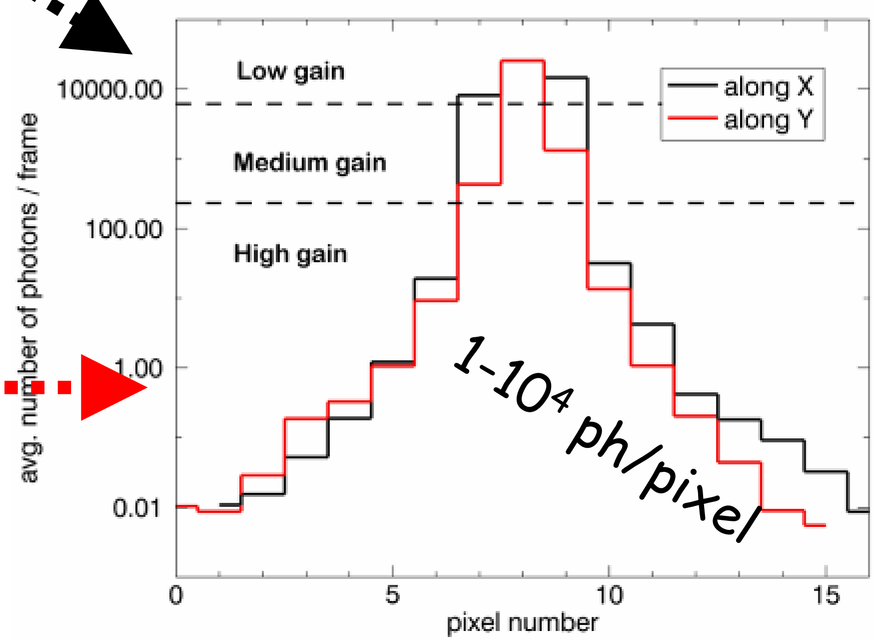


AGIPD at Petra P10

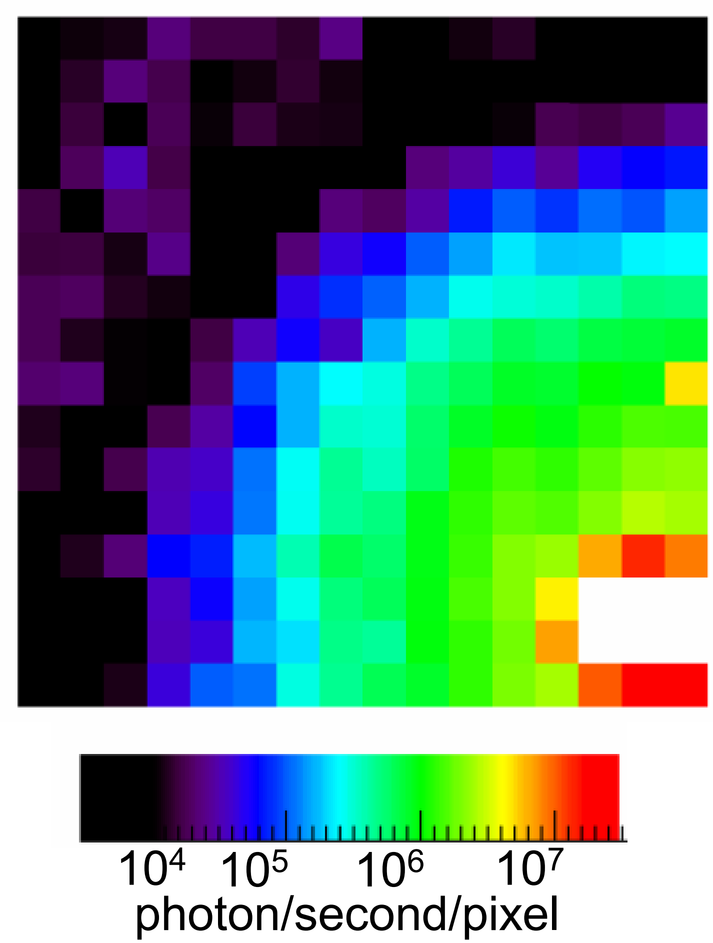
imaging the direct beam

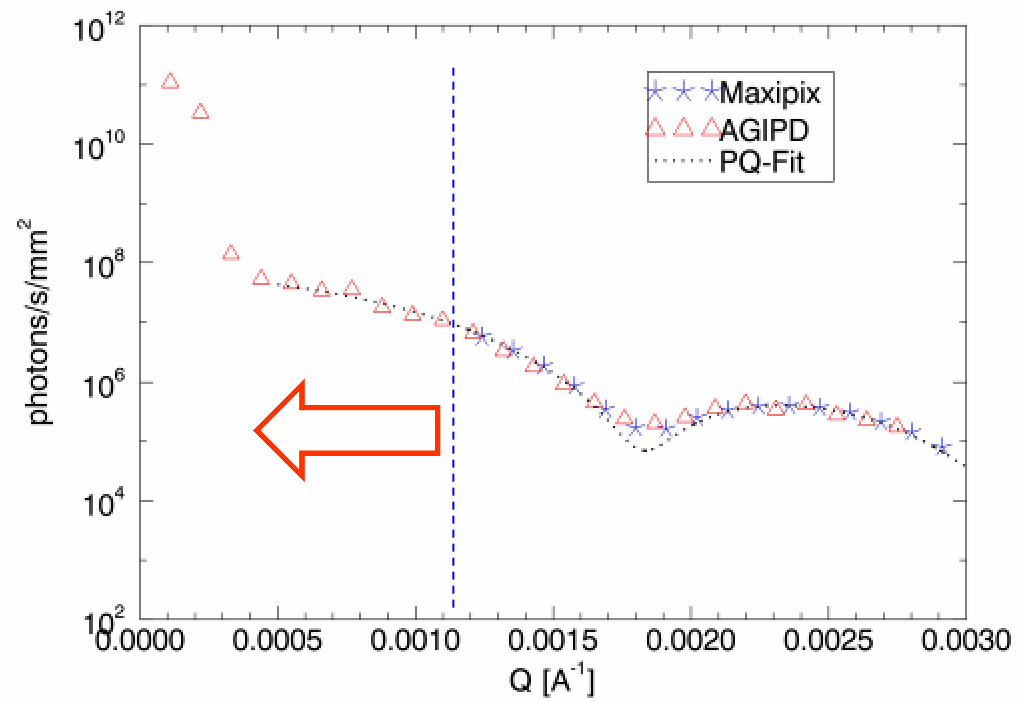






AGIPD at Petra P10





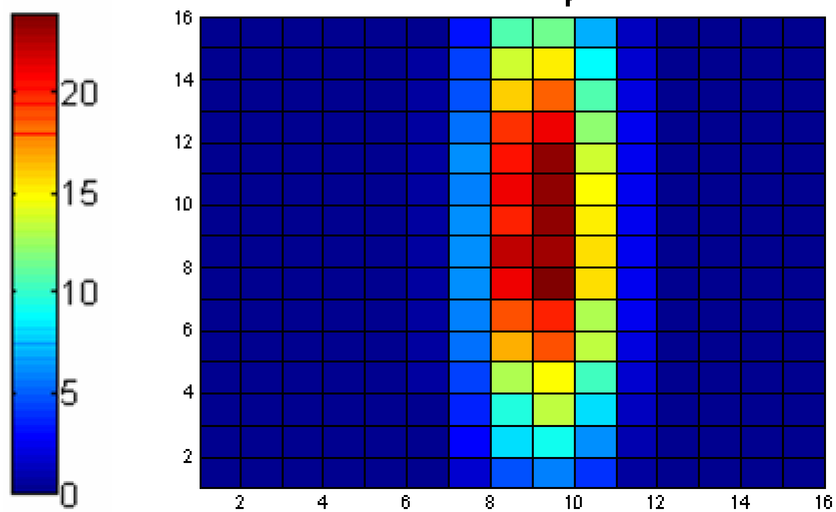
X-ray Photon Correlation Spectroscopy exp.
results comparable to estab. detectors
extending the range
(no beam stop → nearer to beam center)

AGIPD at Petra P01

imaging the direct beam (14.4keV)

photons

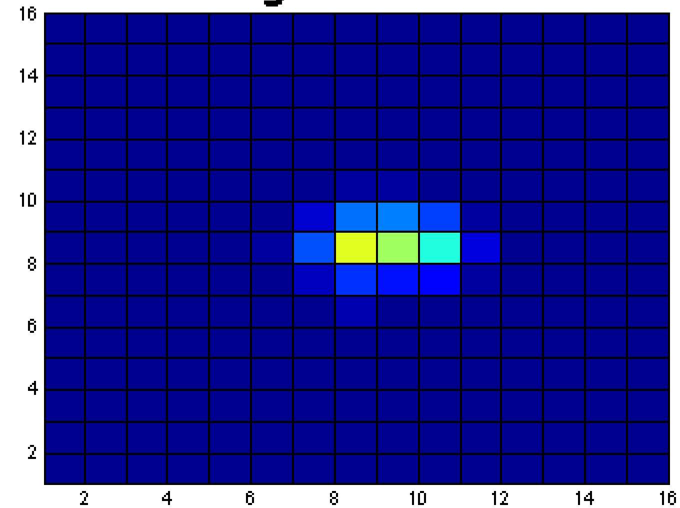
directly



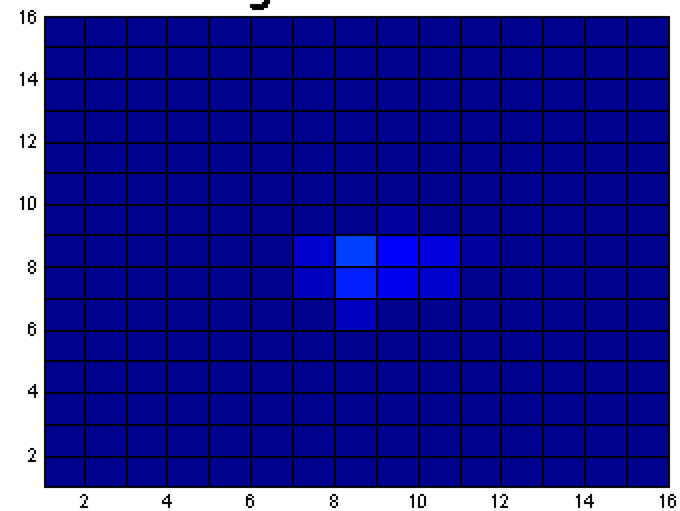
used to perform measurements of intensity correlations in the beam

High order interferometry of single storage ring pulses measured by AGIP detector
A. Singer, I. A. Vartanyants et al.
[subm for pubbl.]

through 150um slit

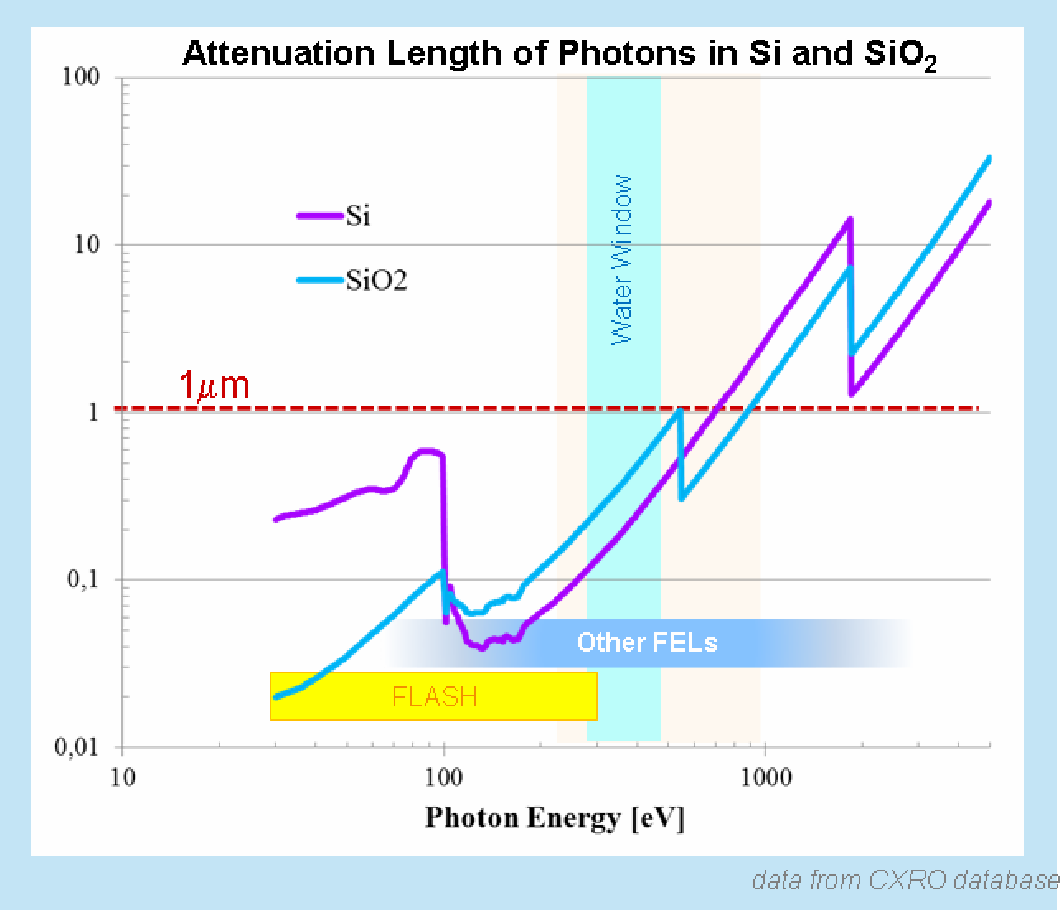


through 50um slit



What about lower energy photons?

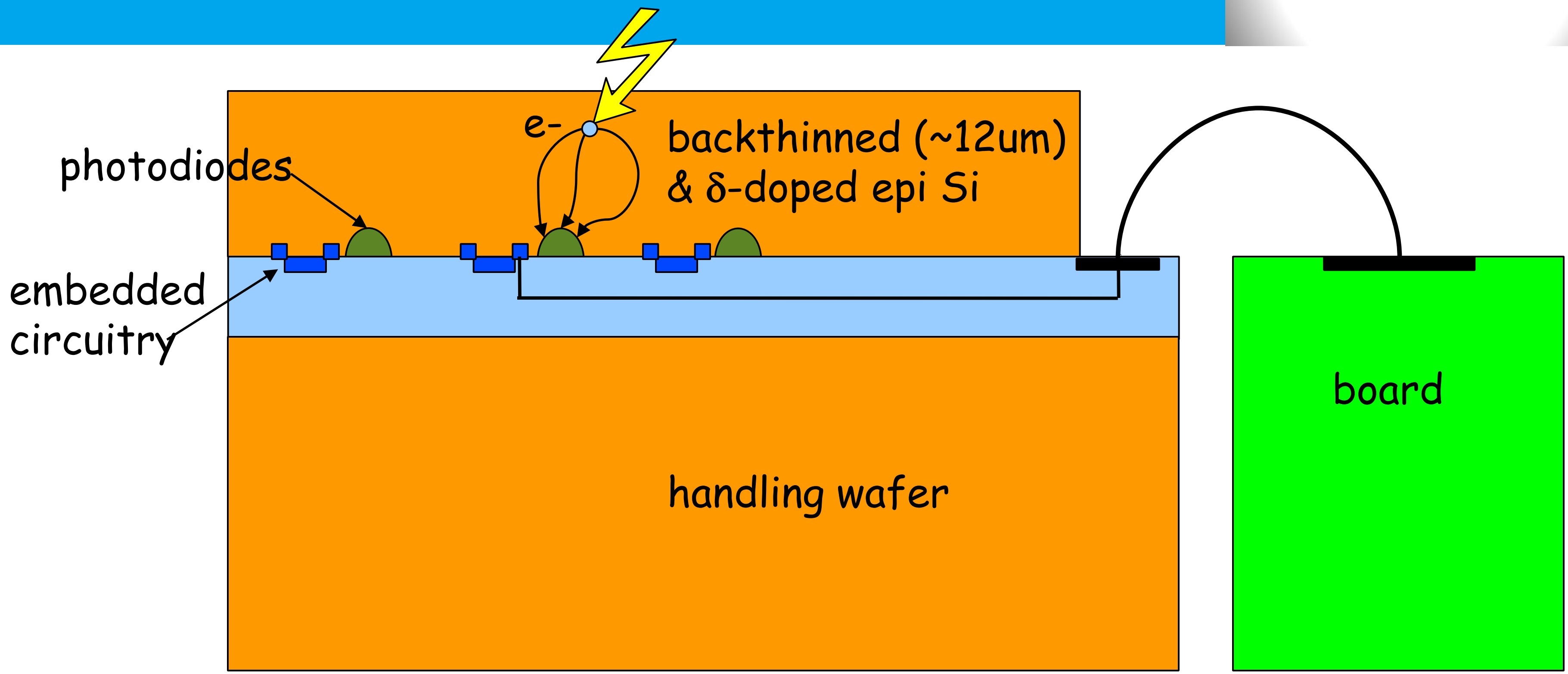
Percival: Motivation



- 1-photon resolution!
- 250 eV – 1 keV !
- high dyn range!
- 85-95% QE!
- many pixels! small pixels!
- 2-side buttable! (even more pixels)

Challenge below 1keV:
sub-um absorption lengths

MAPS



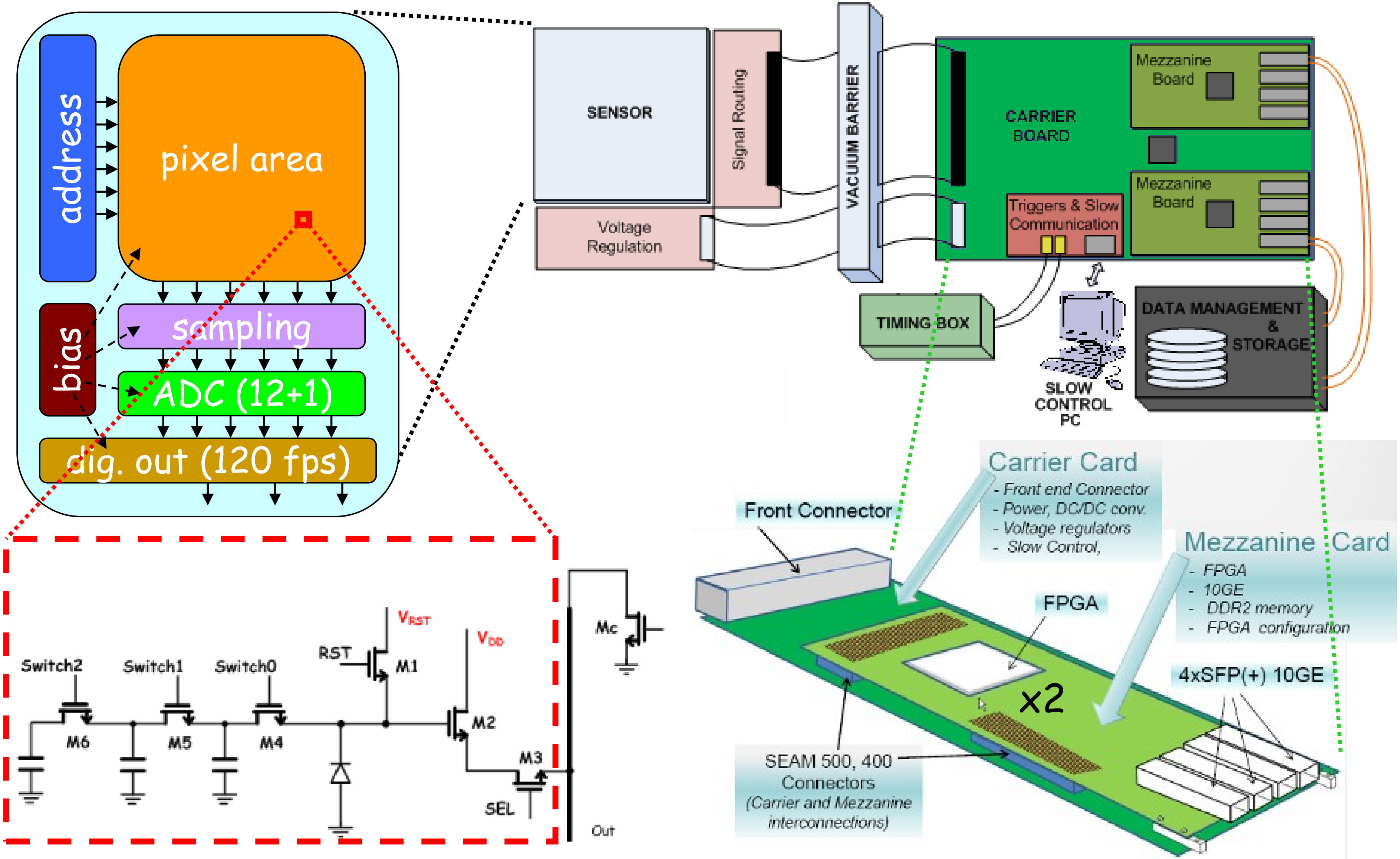
Monolithic: Collecting diodes & readout circuitry share the same substrate

Fast rise in the last ~10 yrs, today the common technology in digital cameras.

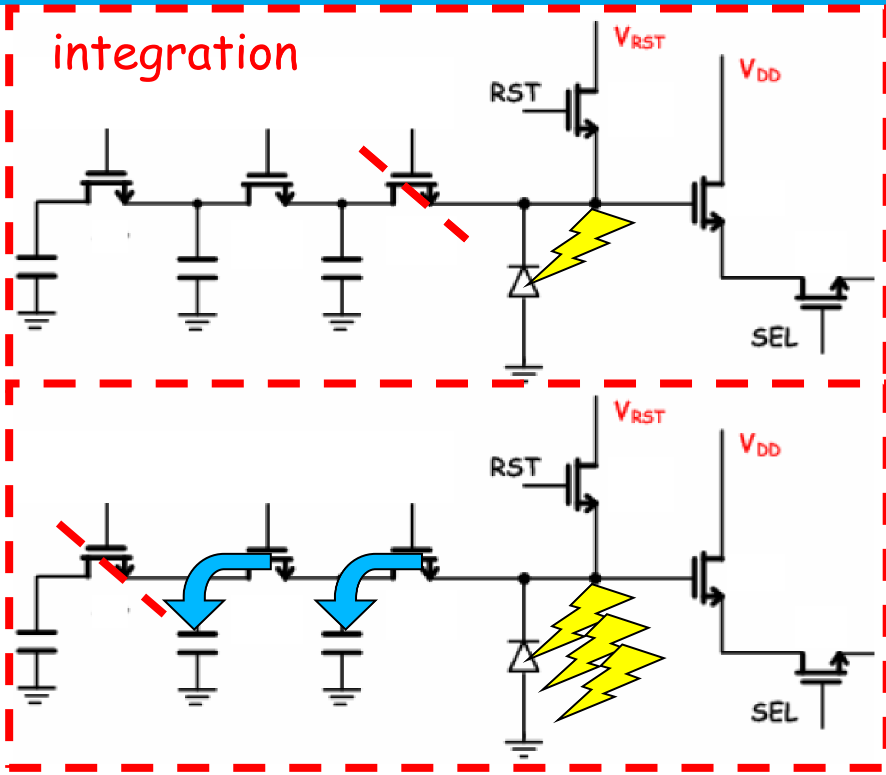
Using standard industrial CMOS processes

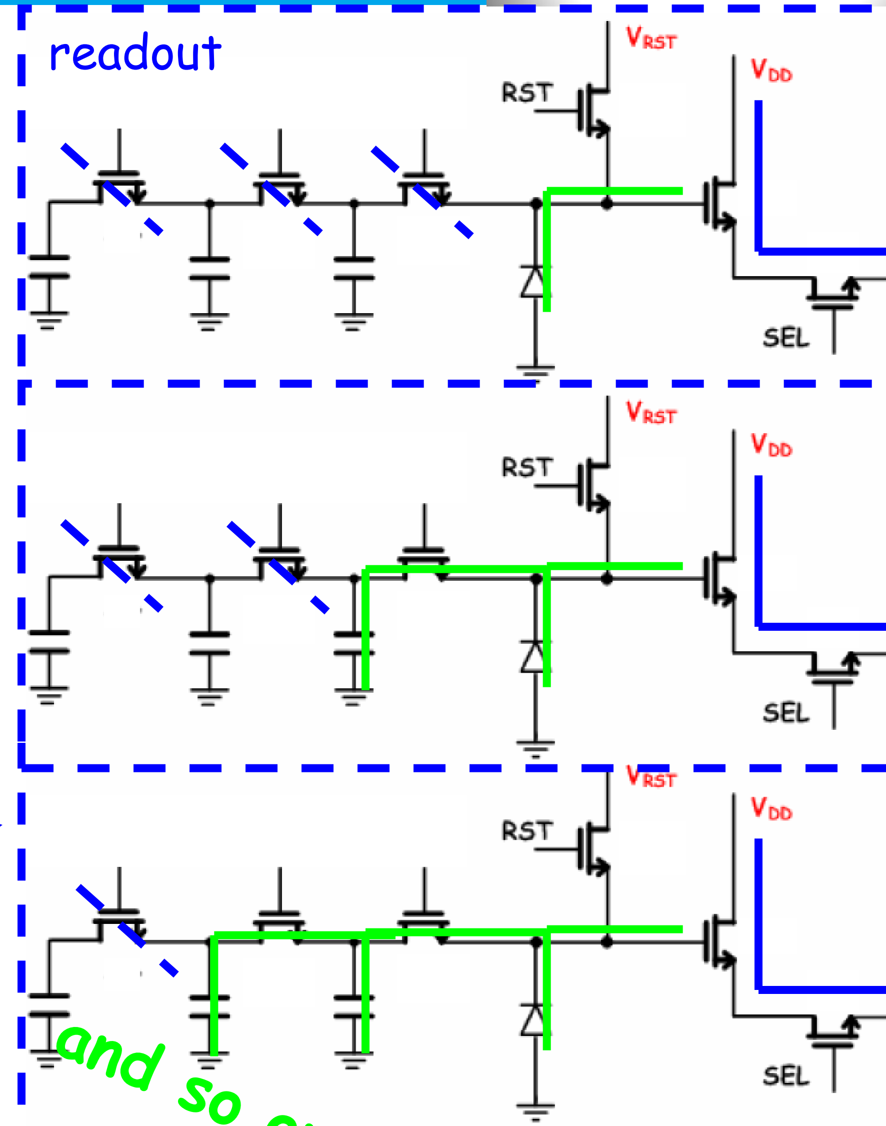
- Gain from industry developments, shrinking feature sizes, …
- Limitations imposed by commercial foundries: epilayer thickness, V constraints

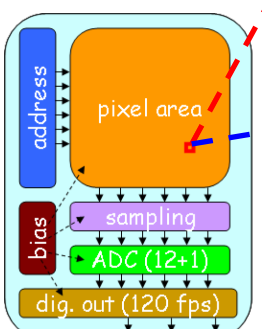
The P.E.R.C.I.V.A.L.(1)



multiple gains: a different approach



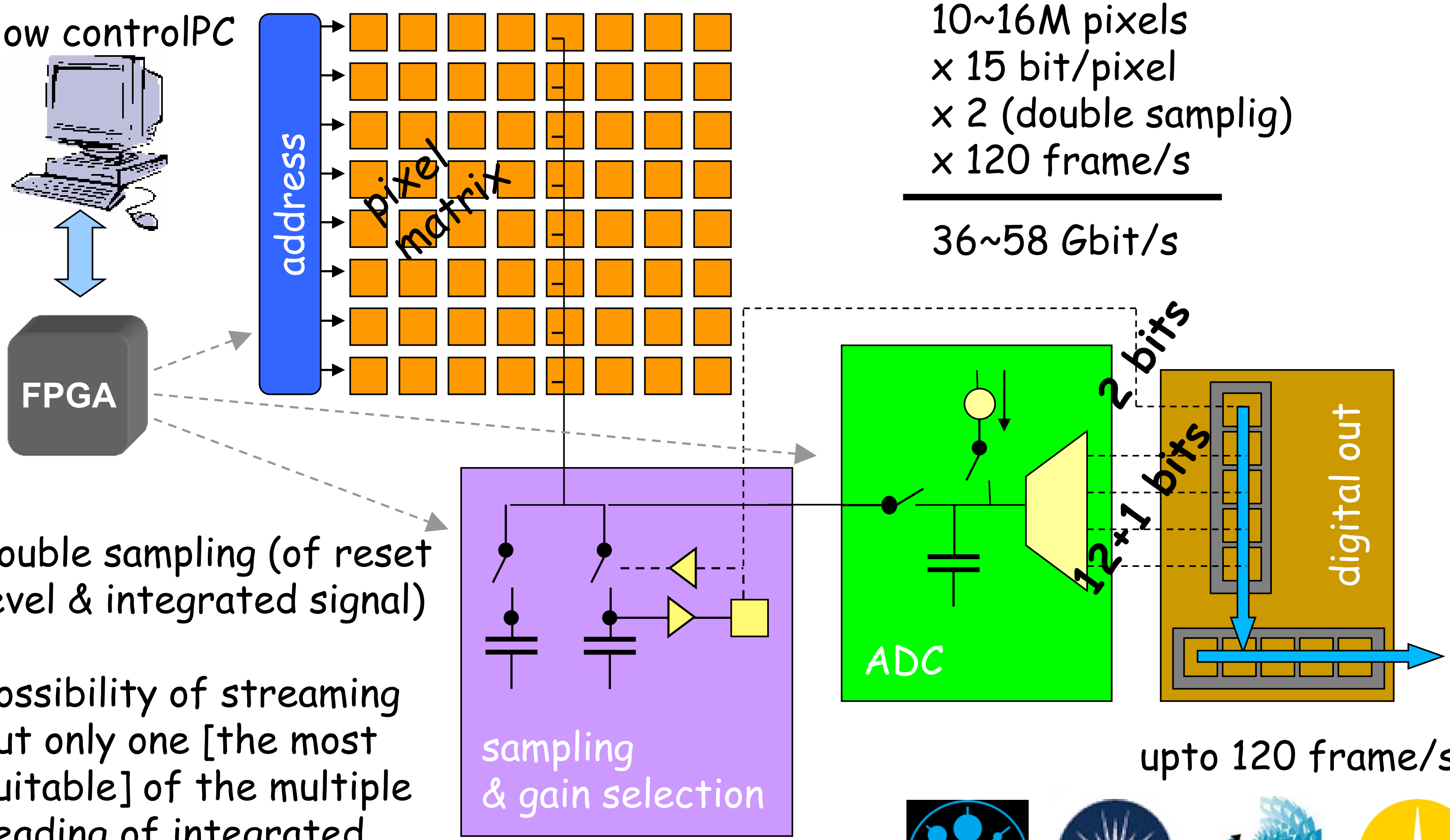




Modified 3T pixel architecture
High dynamic range achieved with multiple readings and lateral overflow

The P.E.R.C.I.V.A.L.(2)

slow controlPC



10~16M pixels
x 15 bit/pixel
x 2 (double samplig)
x 120 frame/s

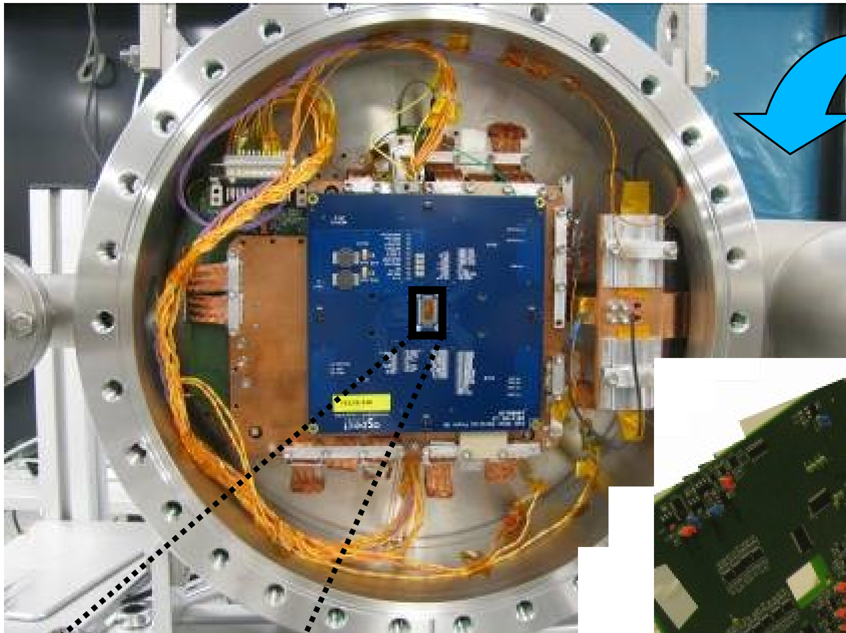
36~58 Gbit/s

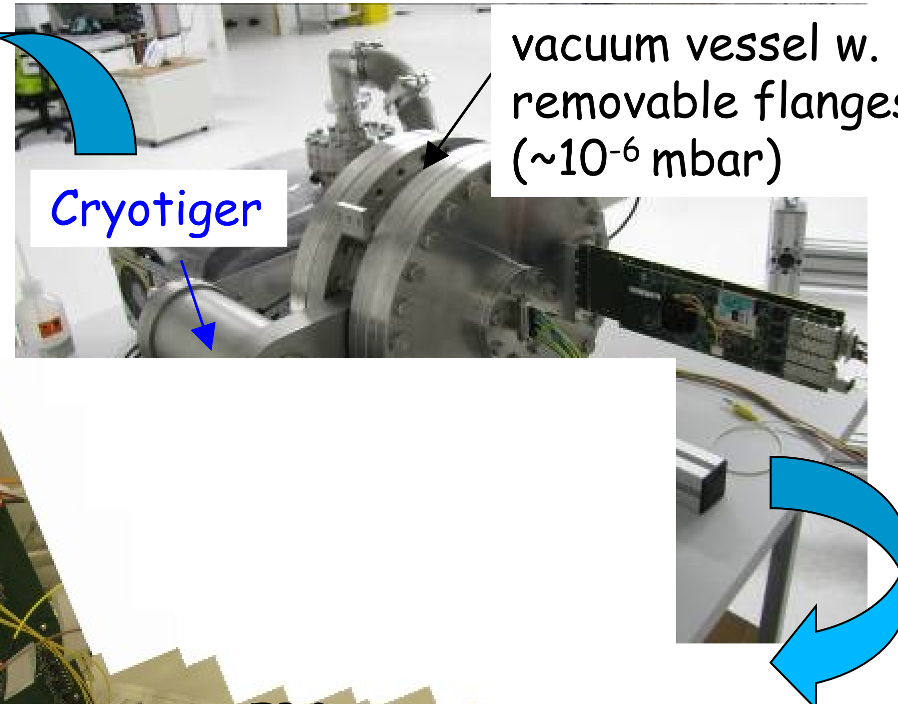
double sampling (of reset level & integrated signal)

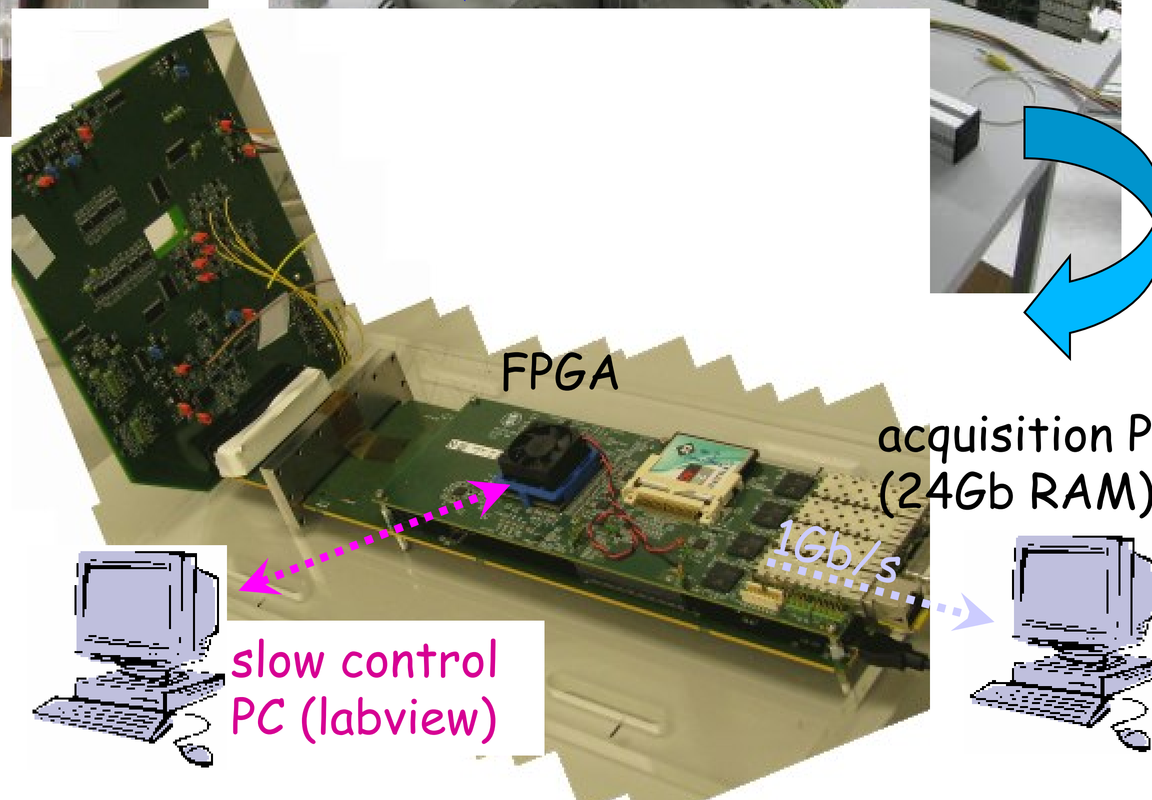
possibility of streaming out only one [the most suitable] of the multiple reading of integrated signal (+2 sel. bits)

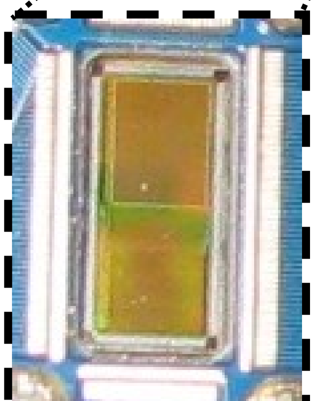
upto 120 frame/s

Percival Prototype (1)





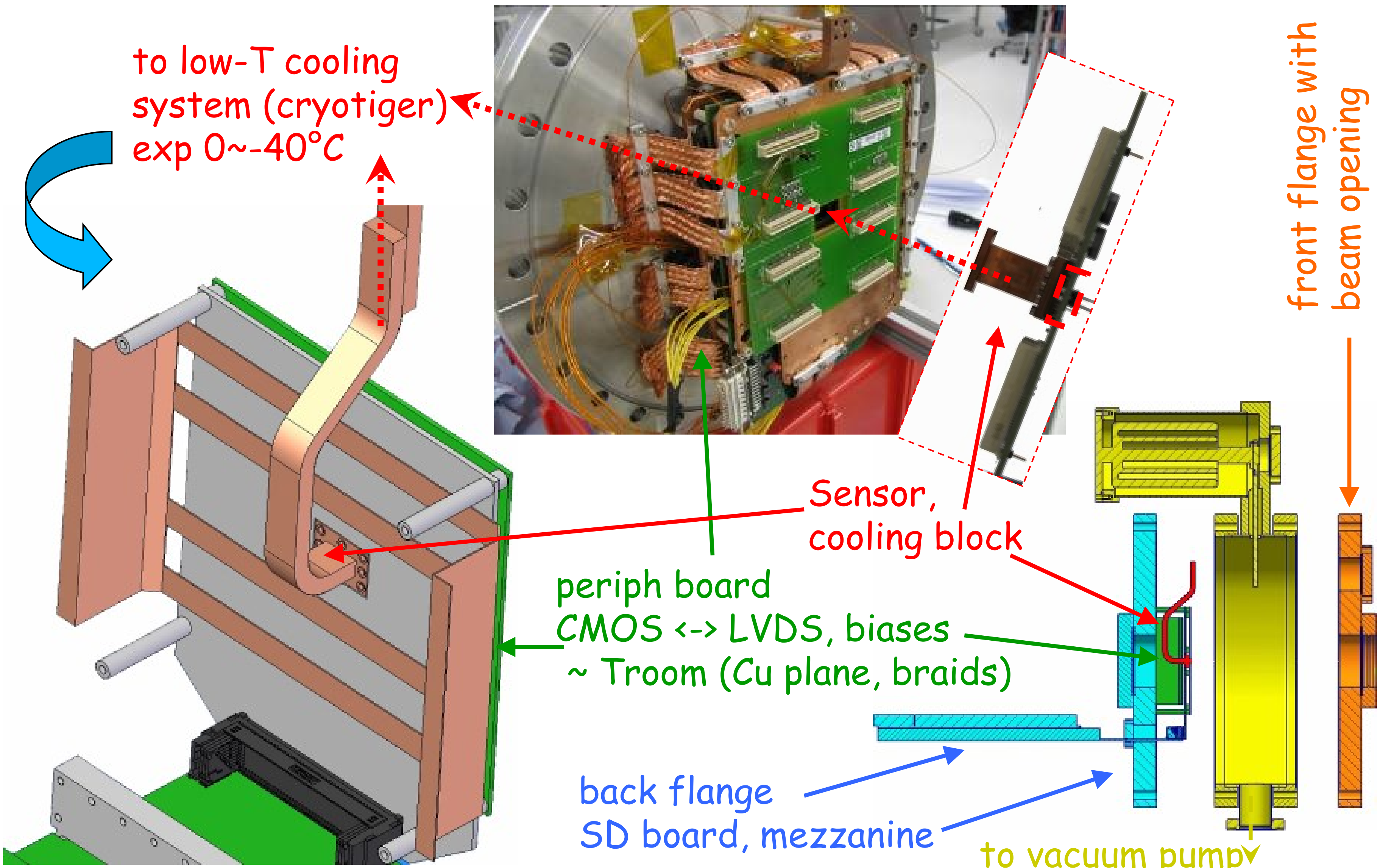




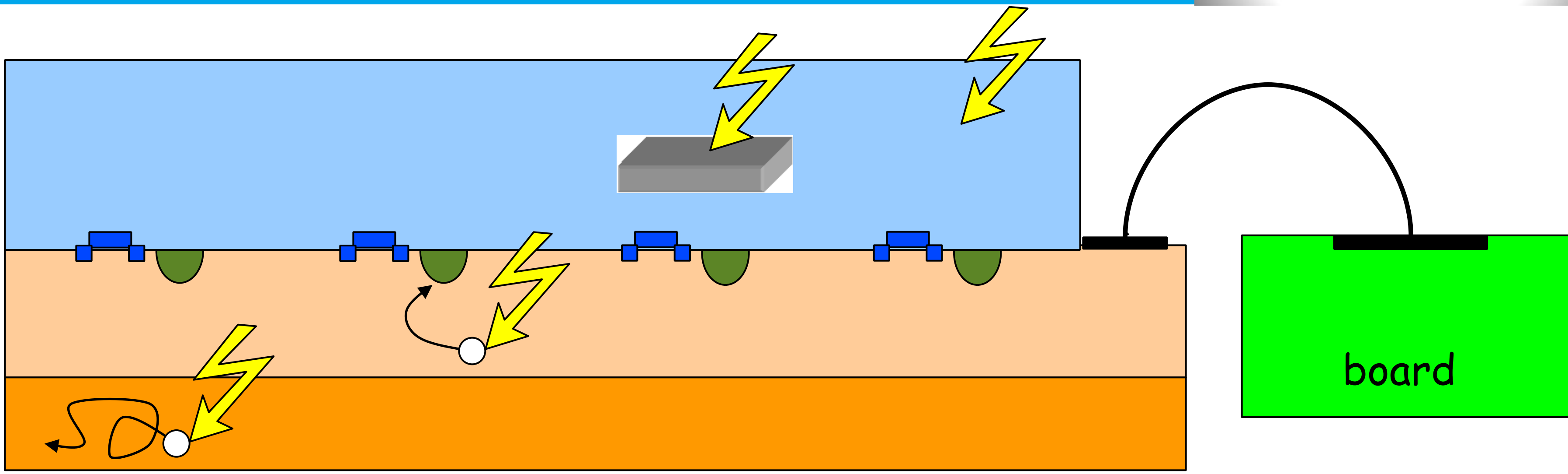
210x160
pixels
(6 flavours)
25um pitch

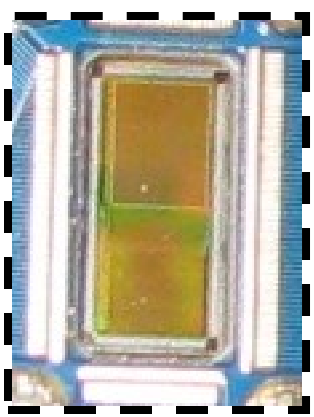
front-
illuminated

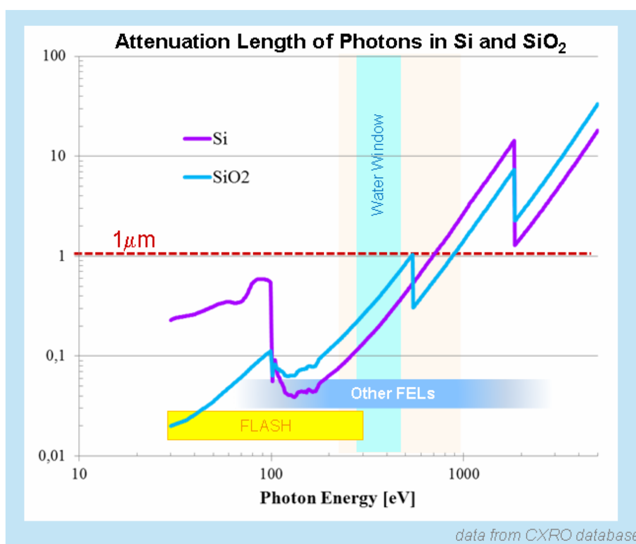
Percival Prototype (2)



Front-illuminated limits





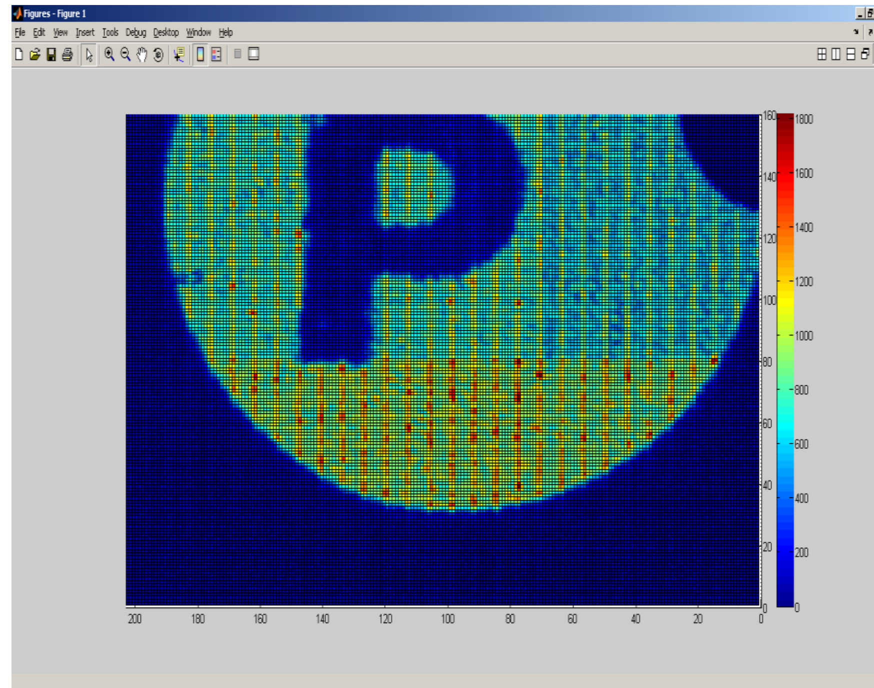


intrinsic limit: much charge will not be properly collected by photodiodes

backthinned prototypes for back-illumination to be ready ~end of the year

imaging with prototype

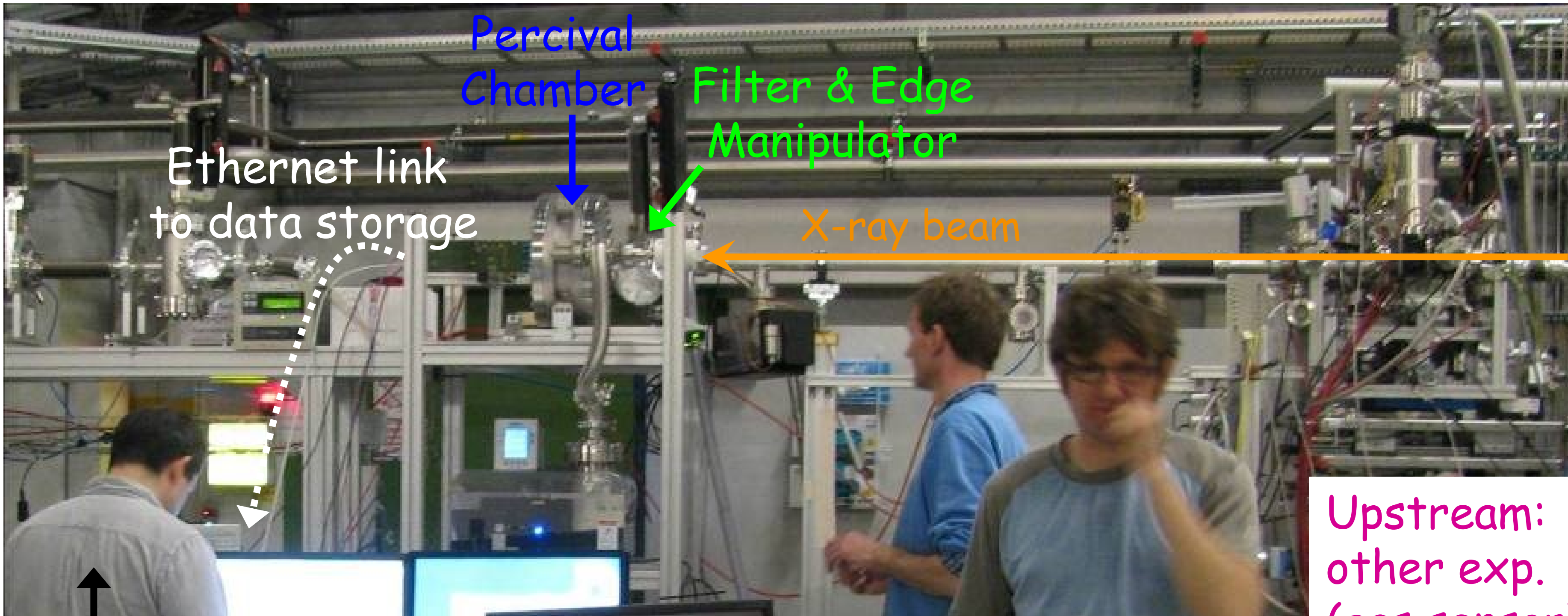
"P" laser-printed on transparent foil, mounted on circular sample holder interposed between the sensor and a white-light LED.



Vertical "stripes" due to differing metal layers modulating the incident light in front-illumination.

6 different pixel types -> different responses

Percival at Petra P04



Upstream:
other exp.
(gas sensor)

me pushing
buttons

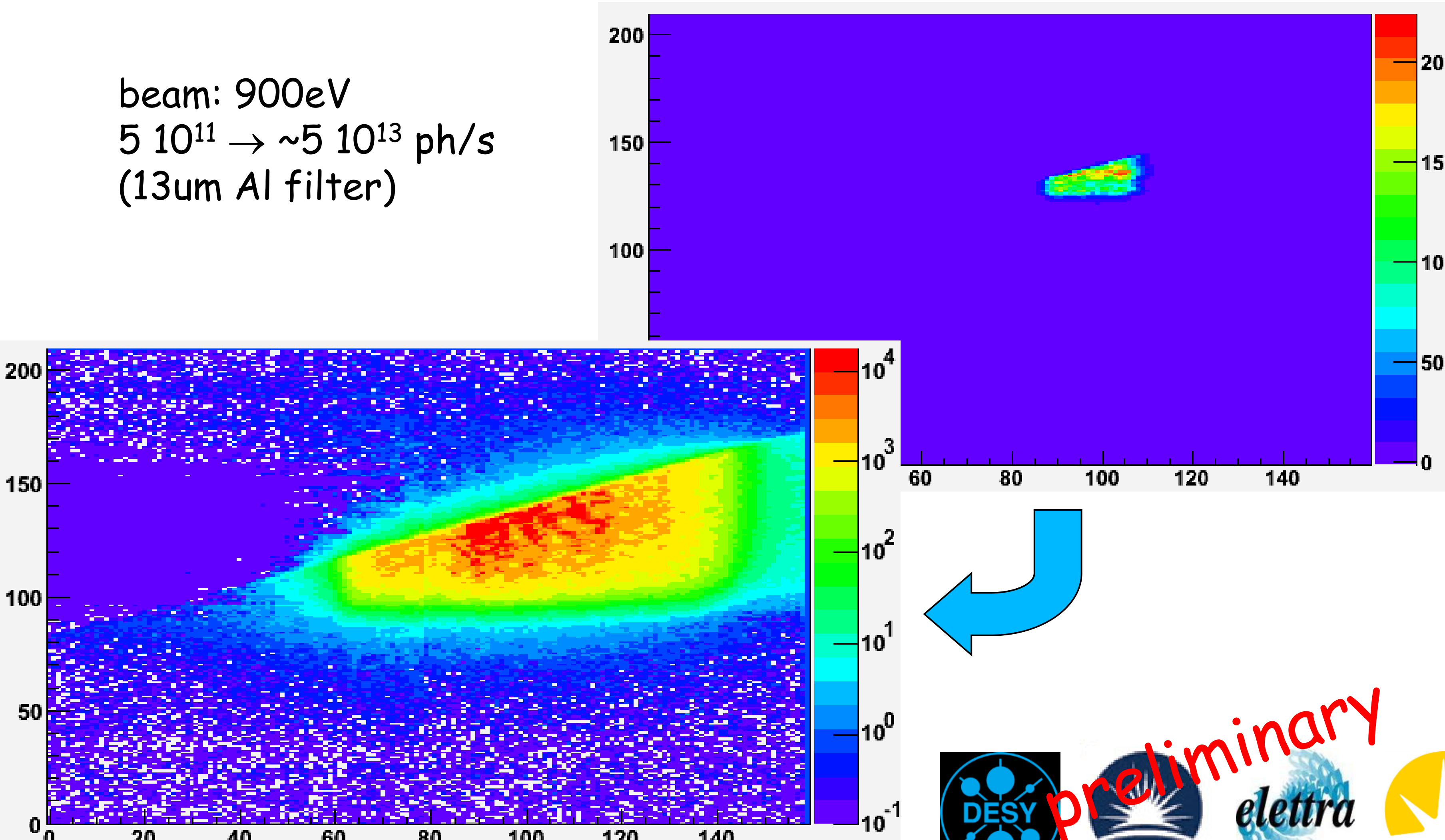
beamline 04
Energy 300eV-2keV
10^9~10^{13}photons/sec

beamline: 193ns/bunch
we: took it slow: 17 frame/s

used parasitically
(downstream gas detectors)

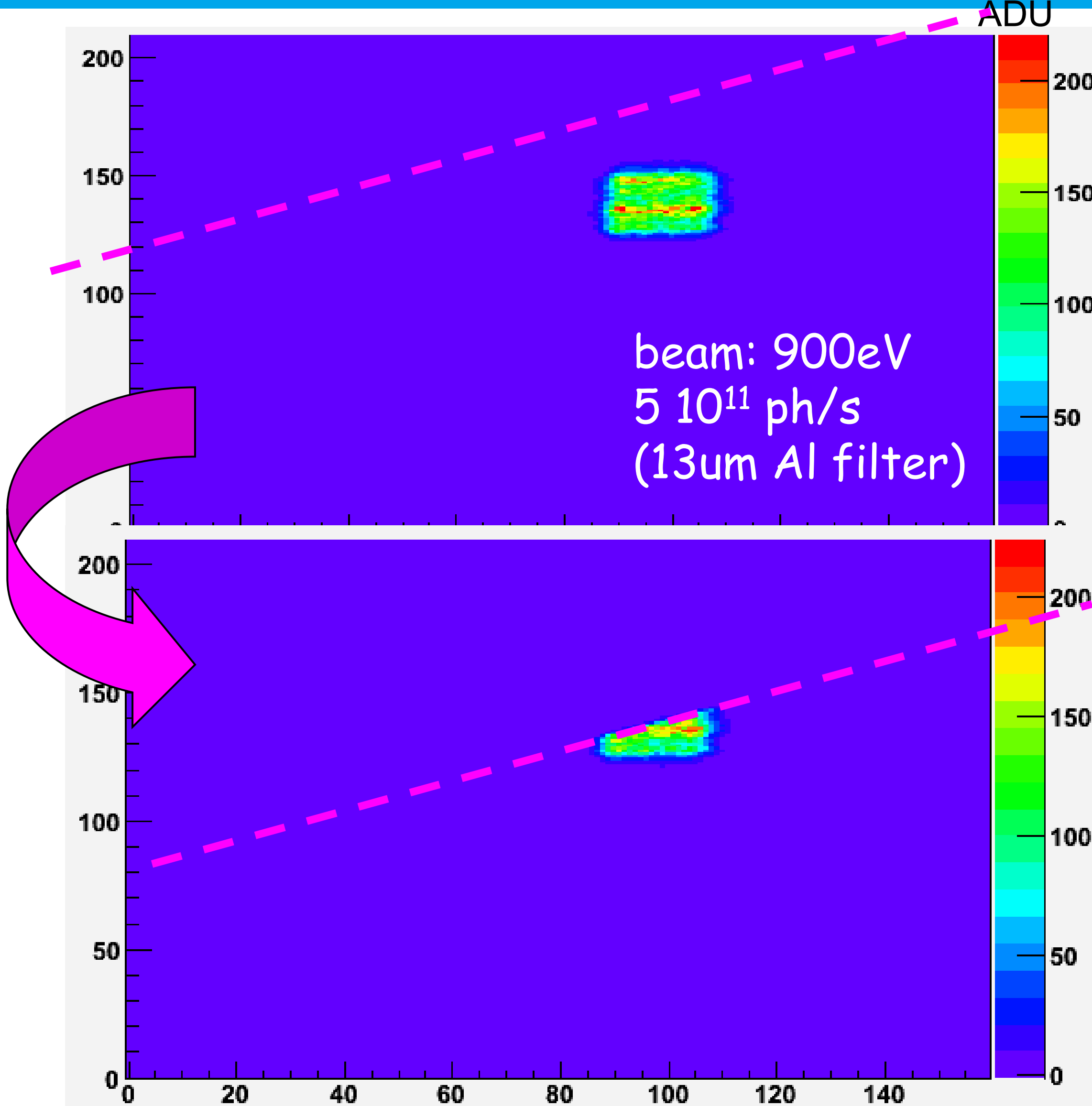
Percival at Petra P04

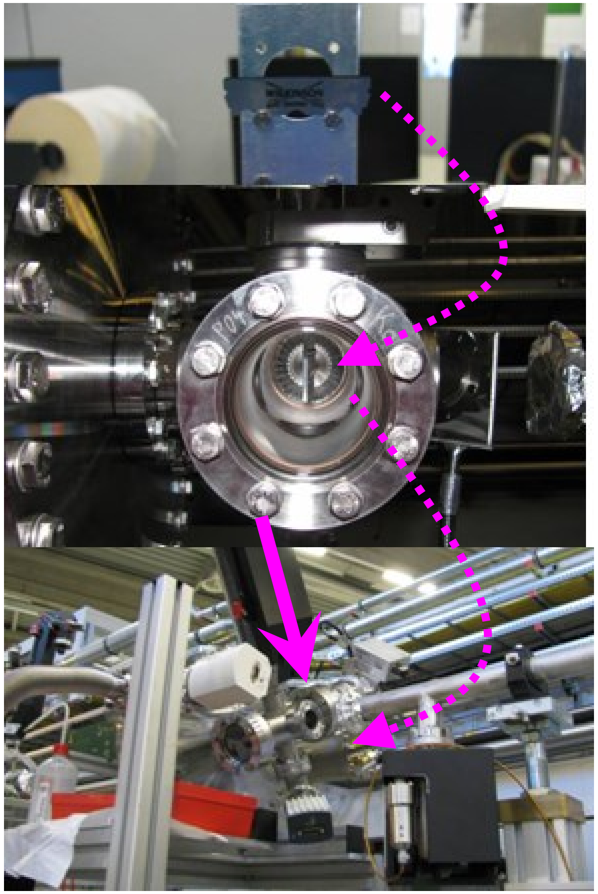
beam: 900eV
5 10^{11} → ~5 10^{13} ph/s
(13um Al filter)



preliminary

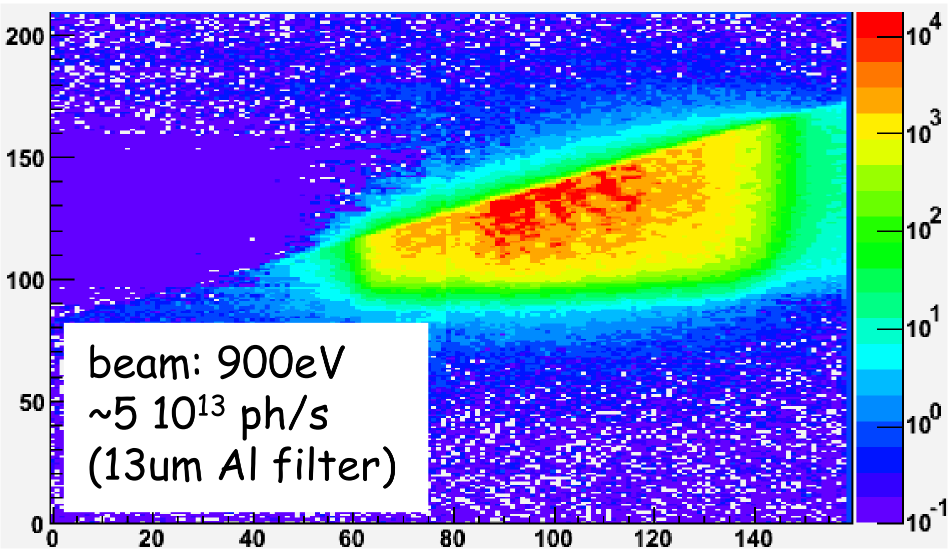
Percival at Petra P04

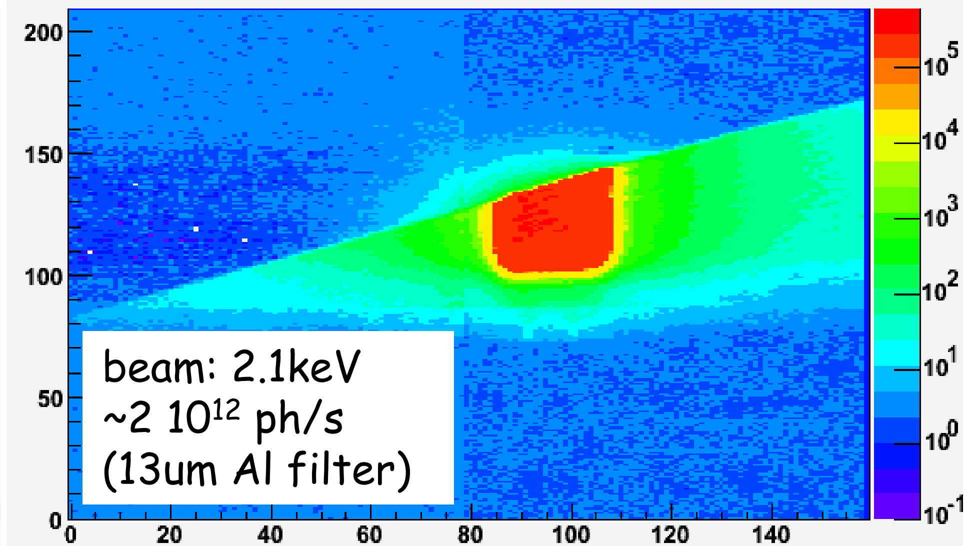


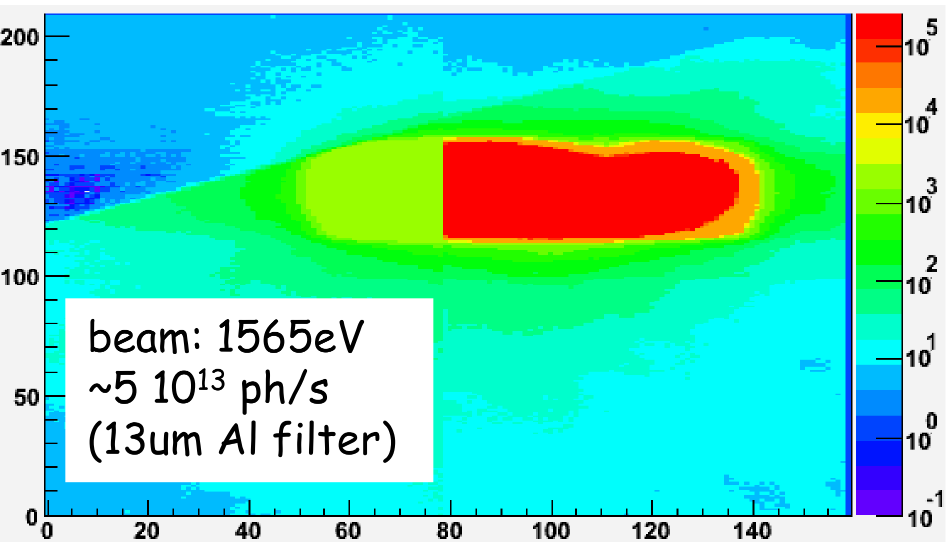


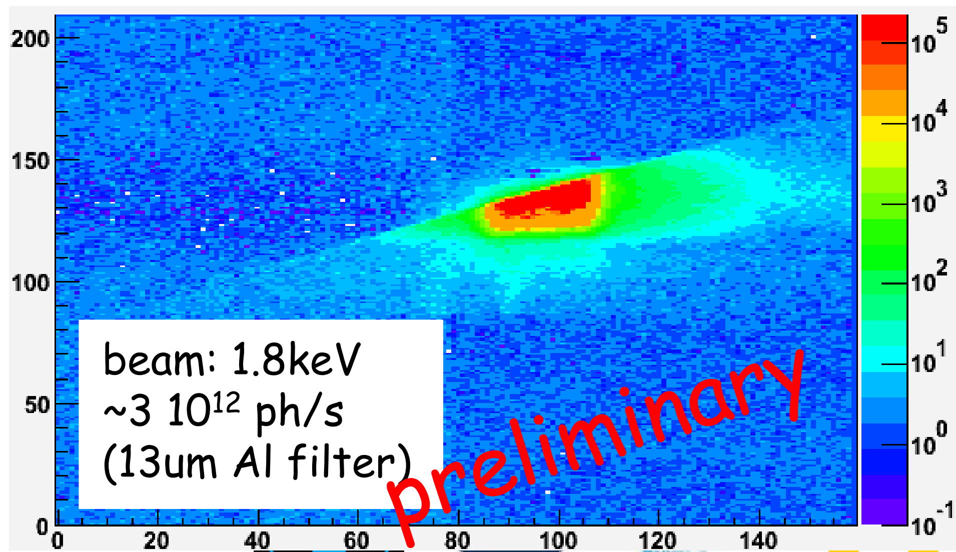
preliminary

Percival at Petra P04









AGIPD

Summary

PERCIVAL

A.G.I.P.D.

- 1Mpixel, 200um pitch
- ~12keV photons [7~14 tested]
- single photon upto ~10^4 photons/pixel/frame
- 300e noise: tested
- 4.5 Mframe/s (burst): tested 5.2
- Single chip assemblies: in a few weeks
- First 1M system: beginning 2015

P.E.R.C.I.V.A.L.

- prototype ~33kpixel 25um
- preliminary test on front-illuminated samples 900eV~2keV
- Back-thinned test structures end of 2013 → soft X-ray testing (250eV~1keV photons)
- Full sensor [10~16Mpixel, 25~27um pixel pitch] tape-out 2014
- First full, back-thinned sensor ready for X-rays 2015

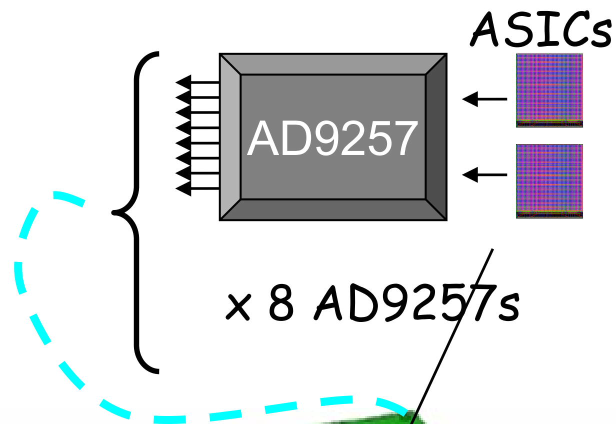
DESY PSI bonn UH DESY elettra

backup

The A.G.I.P.D. (1data out)

pixels	1M
mem cell/pixel	x 352
analog & gain	x2
bits/sample	x 14
in 100ms	x10
	------------
avg data rate	~96.5Gb/s

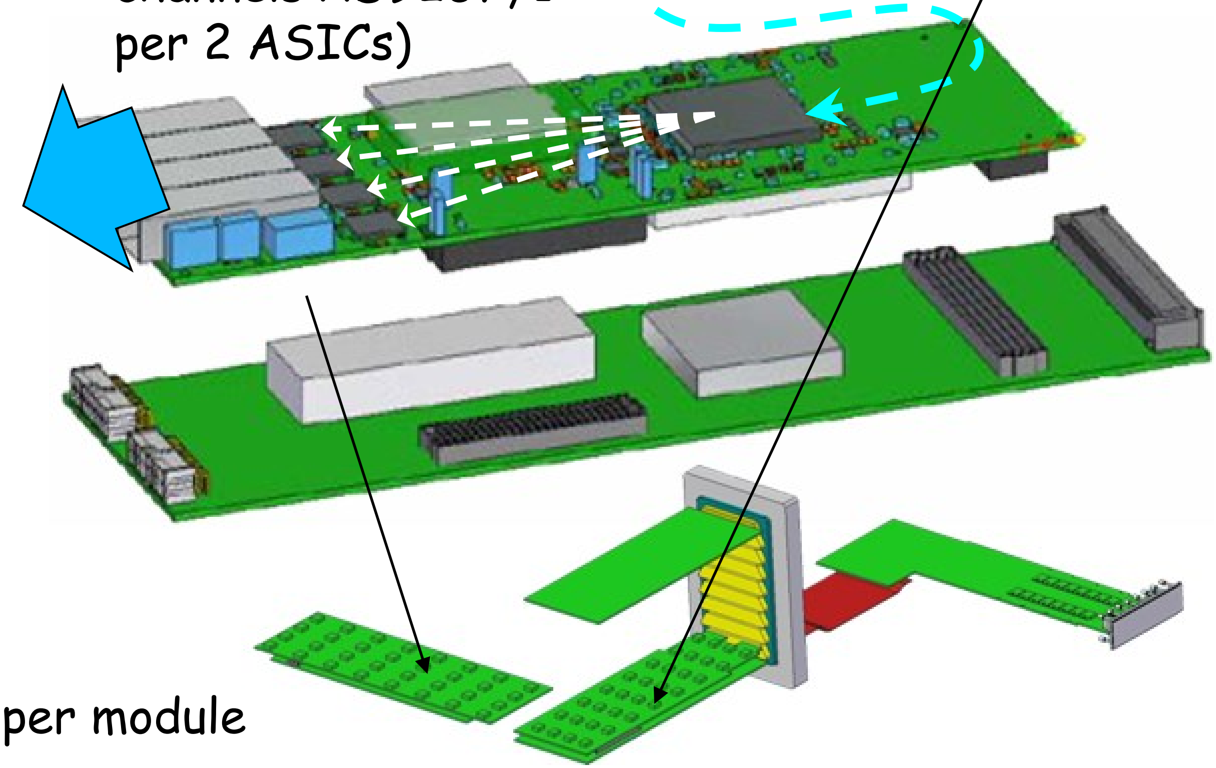
analog PCB: line reception, pickup noise filtering and digitization (@ 33MHz) 14 bits (8-channels AD9257, 1 per 2 ASICs)



then why 16 mezzanines, each with 4x10Gb/s outs?

common development with other projects

limited FPGA memory per mezzanine (resorting)



ADC out/module	8 x 8
sampled at	x 33Mhz
bits/sample	x 14
	------------
burst data rate	~29.5Gb/s per module

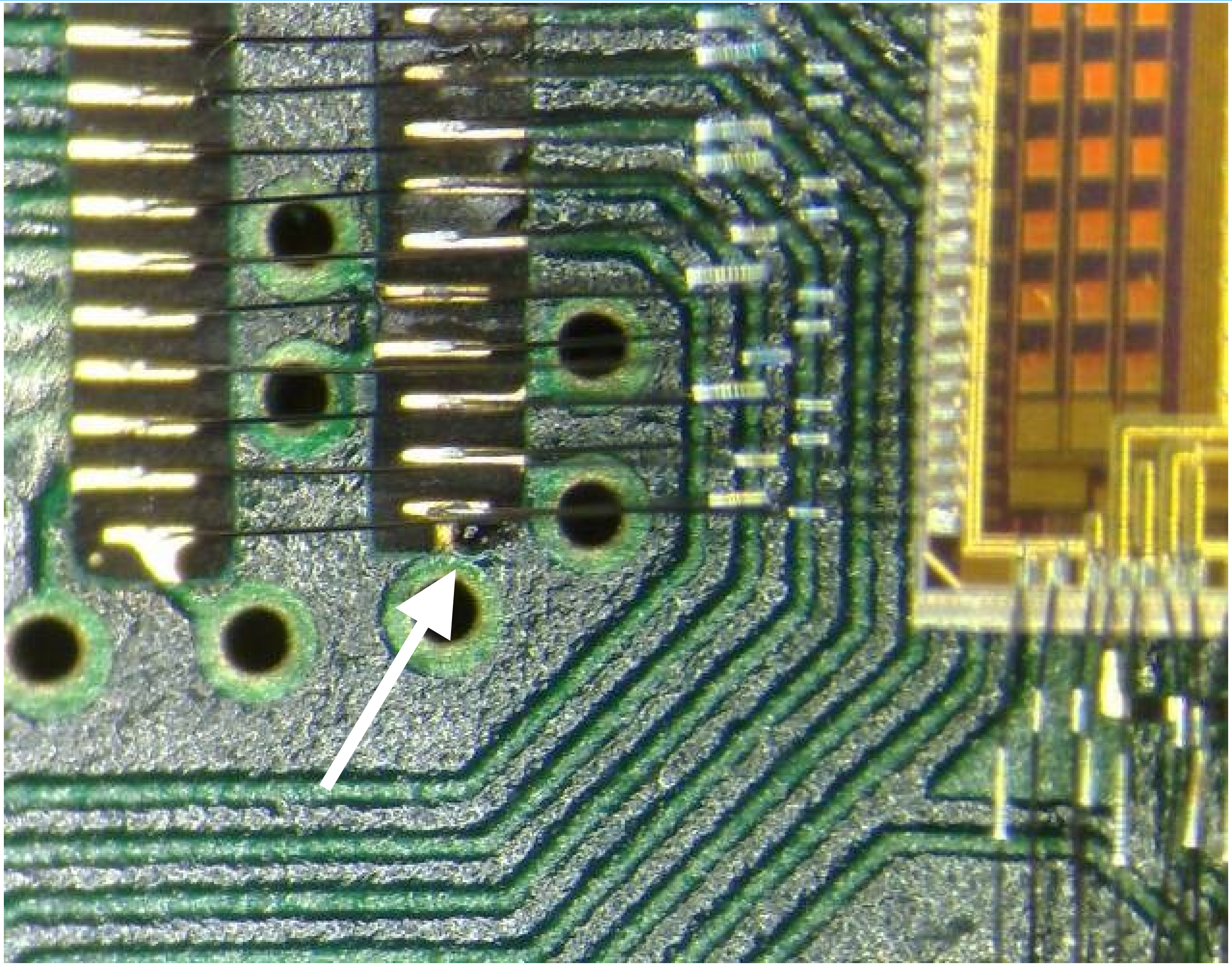
irradiating ASIC (2)

first irradiation attempts (ASIC on FR-4) gave us troubles:

12-24h after (~10MGy) chip irradiation, FR-4 begins to sprout bubble of liquid.

if one of said bubbles forms under a wire-bond pad, the wirebond (on the FR4) fails

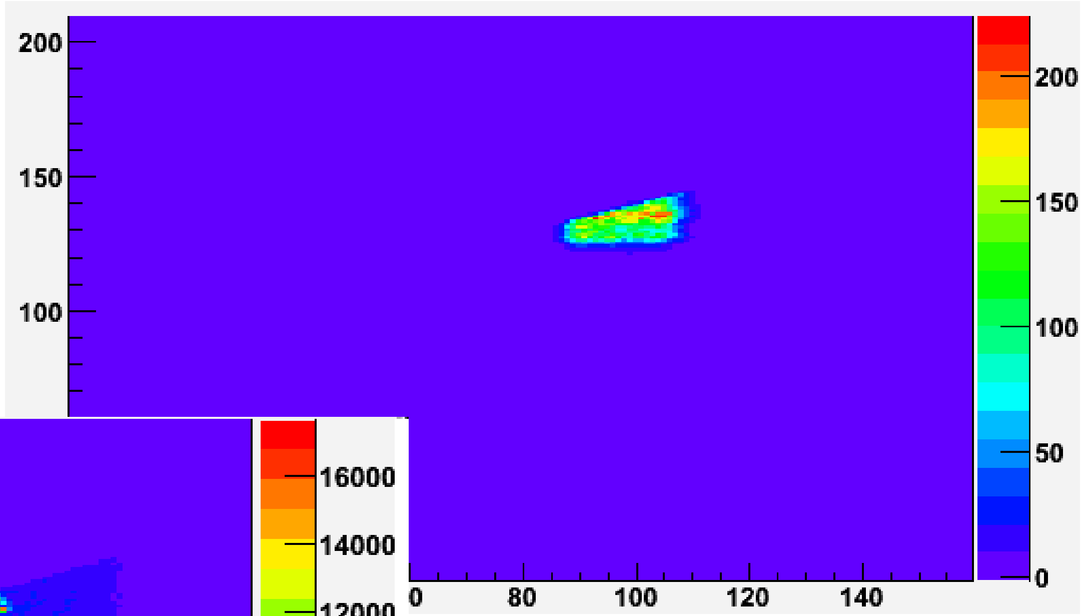
summary: use ceramics

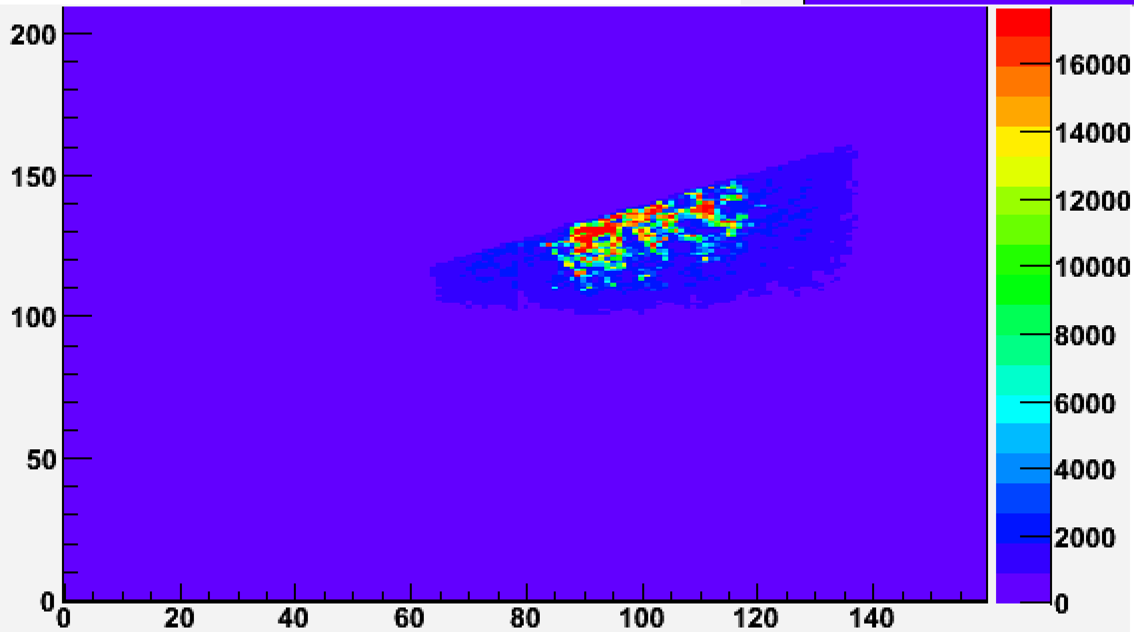


Percival at Petra P04

PERCIVAL

beam: 900eV
$5\ 10^{11} \rightarrow \sim 5\ 10^{13}$ ph/s
(13um Al filter)

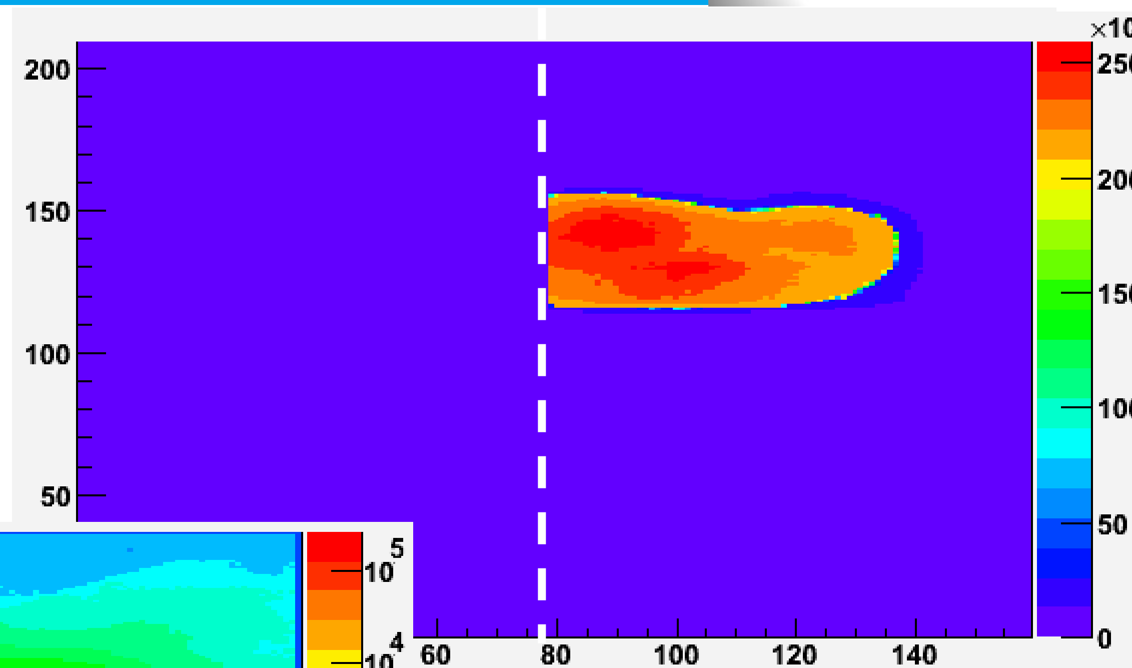


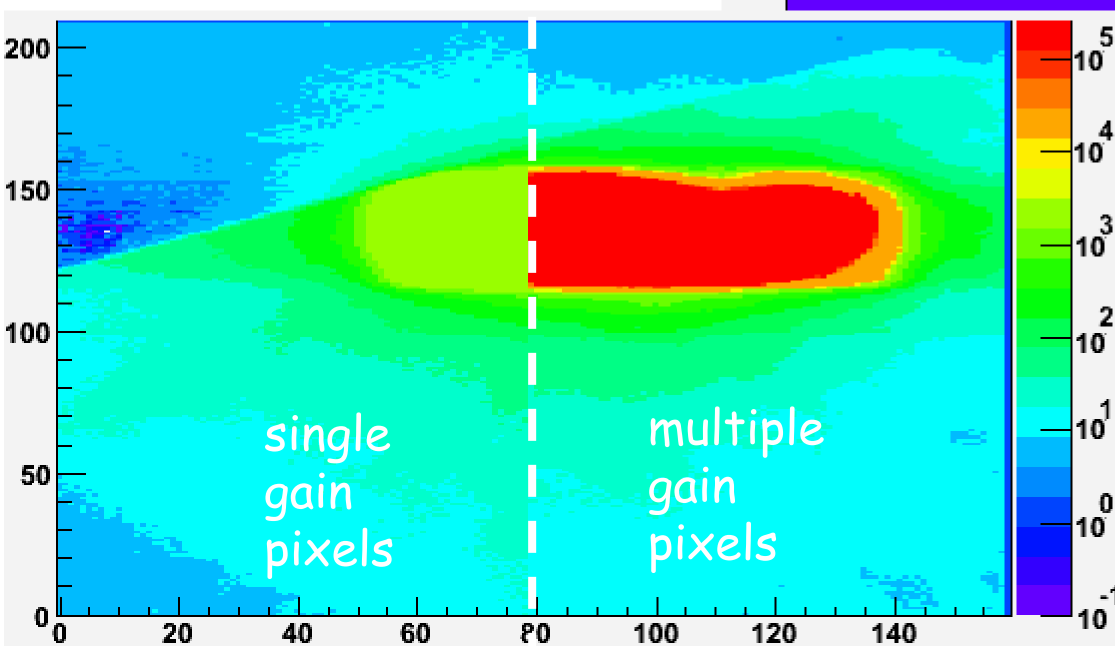


preliminary

Percival at Petra P04

beam: 1.565keV
~5 10^{13} ph/s
(13um Al filter)





preliminary

Percival at Petra P04