



# Front end electronics for European XFEL sensor: the AGIPD project



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Michael Karagounis, Hans Krueger,

Robert Klanner, Joern Schwandt, Jiaguo Zhang



# Outline



- European XFEL
  - constraints for our detector
- The Detector
- ASIC Prototypes : Handling the constraints
  - Adaptive Gain
  - Embedded Memory
  - On-board Logic
  - Rad-hardness
- Summary & Perspectives

# European XFEL



- SASE (Self-Amplified Spontaneous Emission)
- e- bunches accelerated up to 17.5 GeV (linear superconducting accelerator)
- conveyed to undulators (up to 200 m long )
- X-ray pulses produced

DESY

Switch Building  
(Osdorfer Born)

Tunnel

- 3.4 km long
- 12-44 m deep

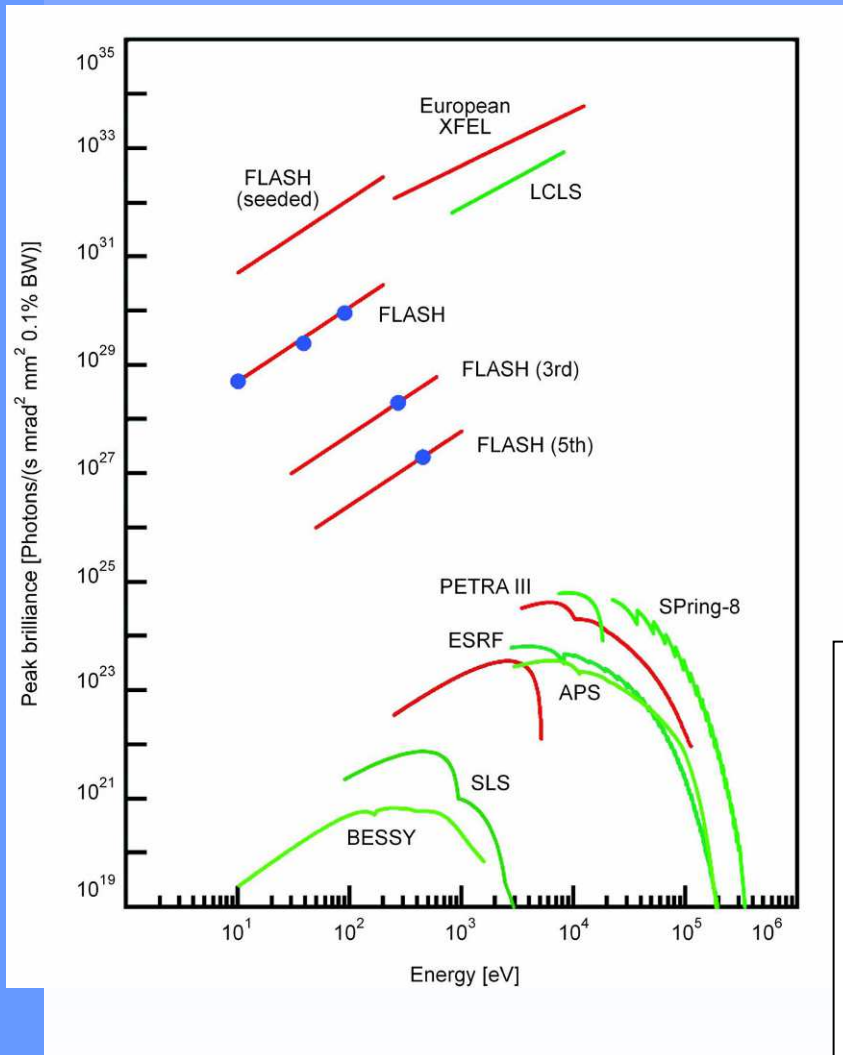
Experimental Hall  
(Schenefeld)

# Requirements at the XFEL experiments

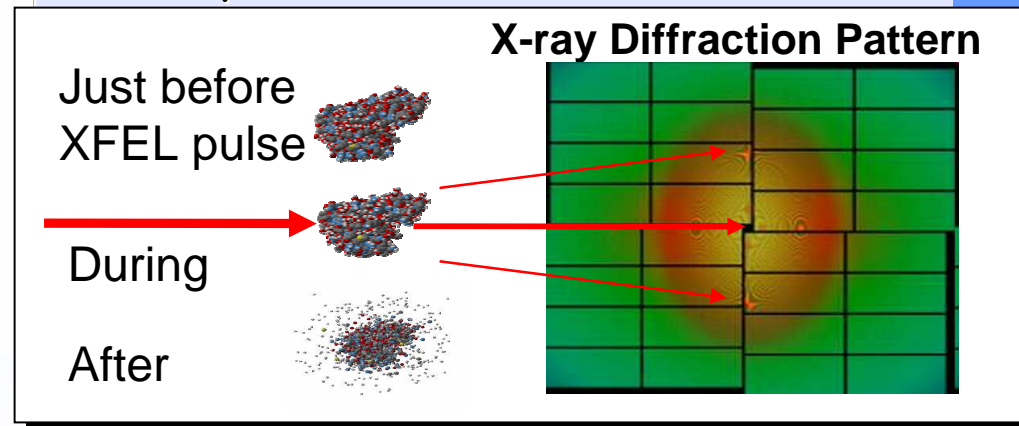


	Experiments	Energy	ph/pulse
SASE1	Femtosecond X-ray Experiments (FXE), <u>Single Particles, Cluster &amp; Biomolecules (SPB)</u>	3-25keV <u>(12.4keV)</u>	$10^{12}$ - $10^{13}$ <u><math>\sim 10^{12}</math></u>
SASE2	<u>Material Imaging &amp; Dynamics (MID)</u> , High Energy Density Matter Experiment (HED)	3-25keV <u>(12.4keV)</u>	$10^{12}$ - $10^{13}$ <u><math>\sim 10^{12}</math></u>
SASE3	Small Quantum Systems (SQS) Spectroscopy & Coherent Scattering (SCS)	0.26-3keV	$10^{13}$ - $10^{14}$

# E-XFEL constraints



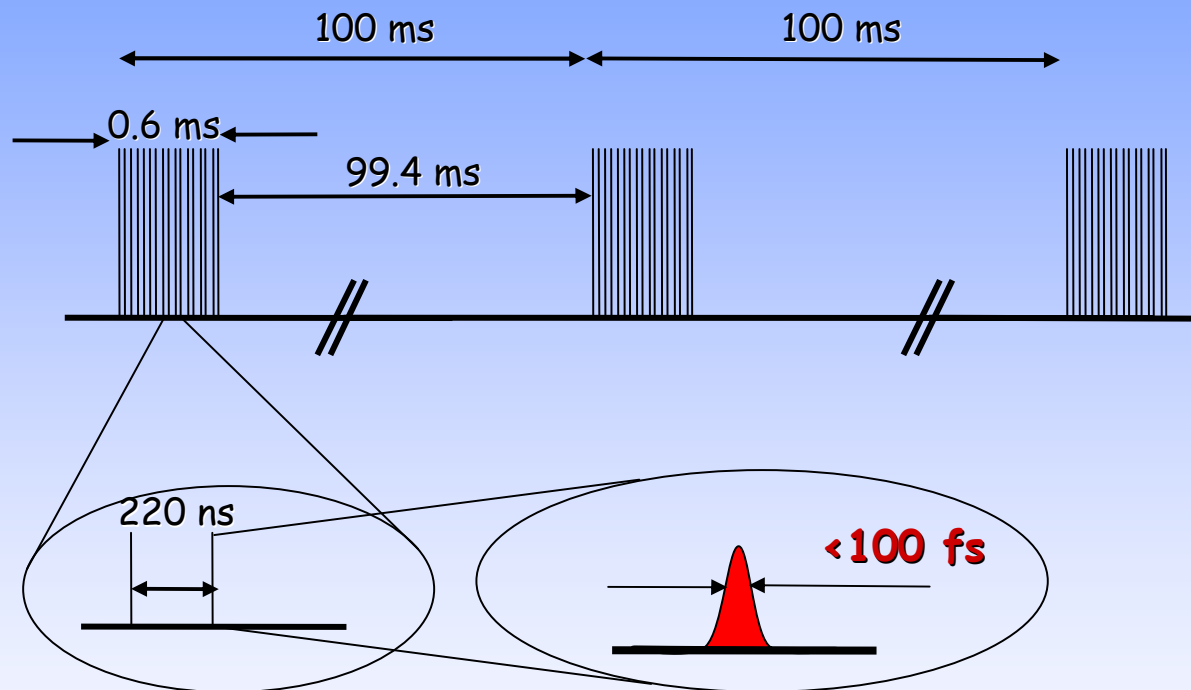
- 10<sup>33</sup> ph/(s mm<sup>2</sup> mrad<sup>2</sup> 0.1%BW) peak brilliance
  - 10<sup>9</sup> more than 3rd gen. synchrotrons
- ~ 10<sup>15</sup> photons over 3 years
  - ASIC exposed ~ 10MGy
- From 1 up to 10<sup>4</sup> 12.4keV photons per pulse on a pixel
- Single photon (or  $\sqrt{n_{ph}}$ ) sensitivity required



# E-XFEL constraints

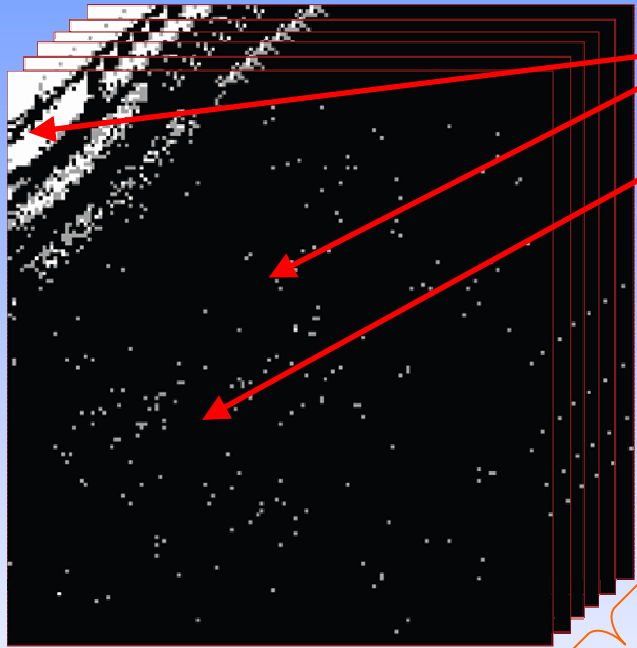


- Non-uniform time structure



- 2700 pulses @4.5MHz every 100ms
- "instantaneous" energy deposition

# Constraint Summary



in the same image:

- up to  $\sim 10^4$  photons
- down to 0~1

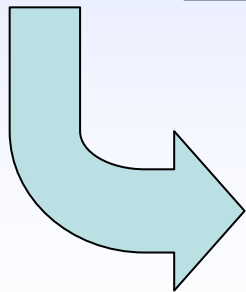
radiation tolerant!

1-photon resolution!  
(or better than poissonian)

single-image experiments!  
as many as possible!

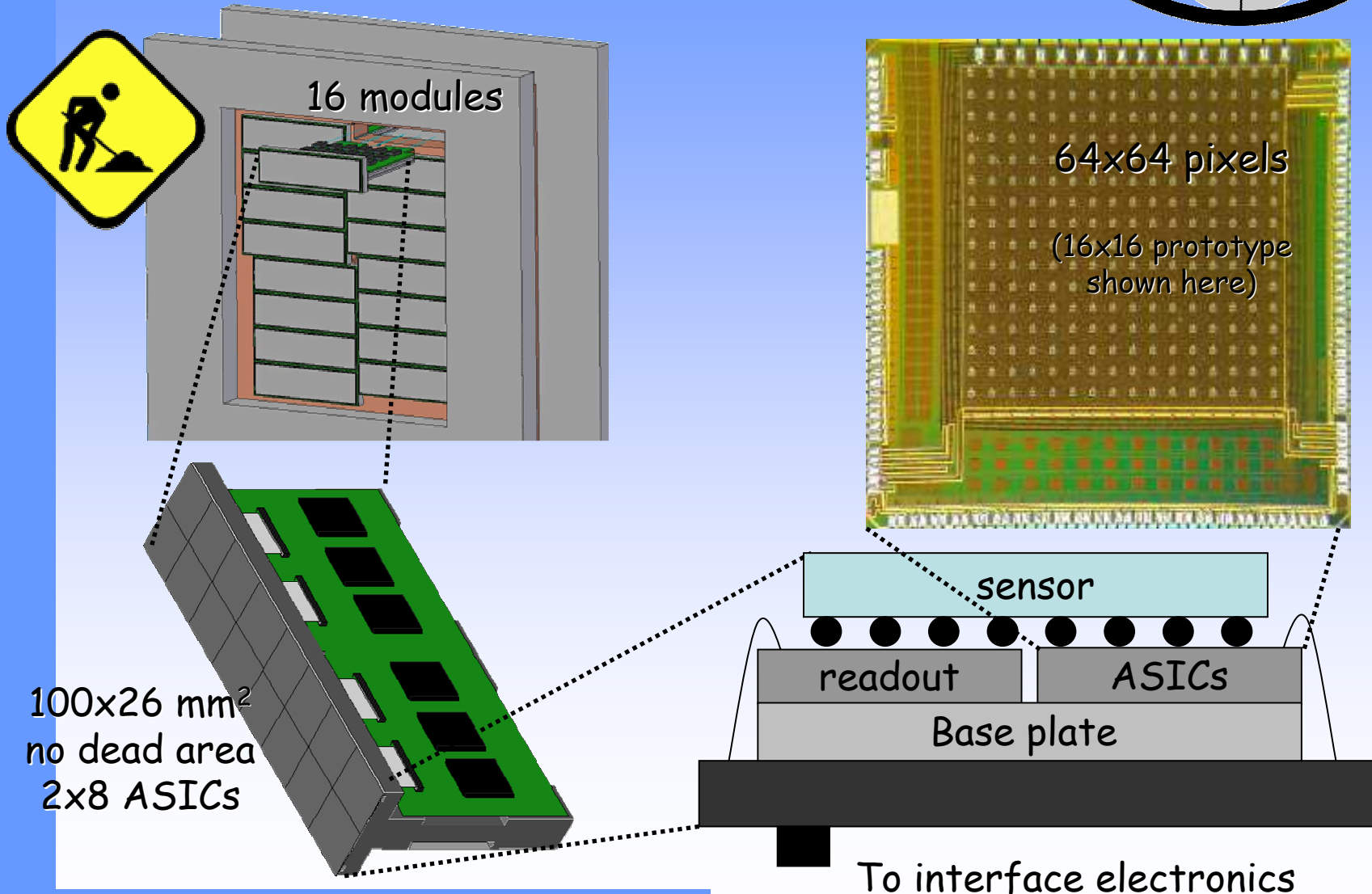
many pixels!  
small pixels!

4.5MHz x  
2700 images



- Charge integration
- Adaptable Gain  $O(2)$
- noise  $\sim 0.1$  photon
- 1Mpixel, 200  $\mu\text{m}$  pitch
- in-pixel Memory  $\sim 350$  frames
- veto schema
- leakage minimization
- rad hard design

# AGIPD Detector

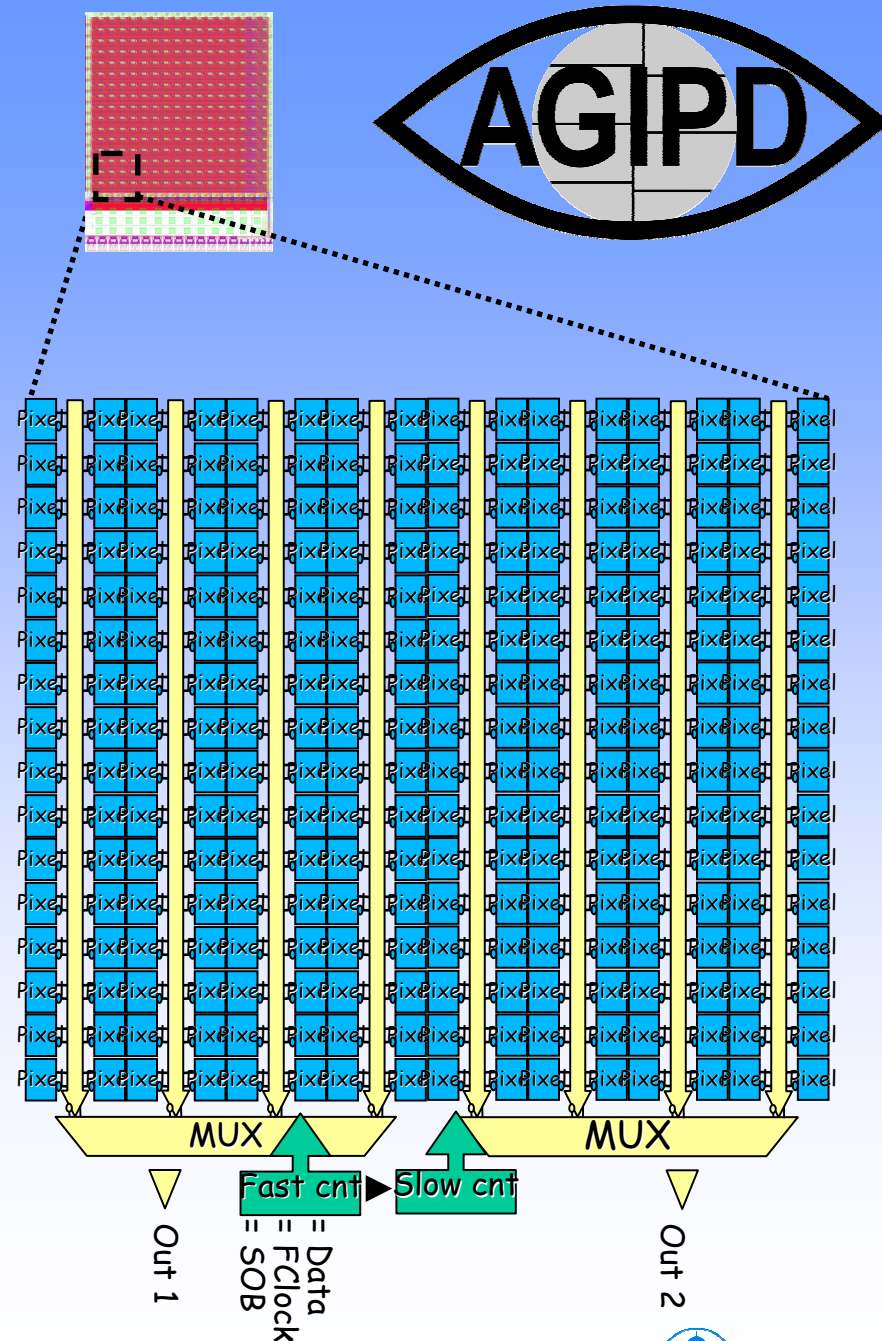


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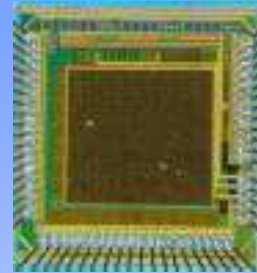


# ASIC

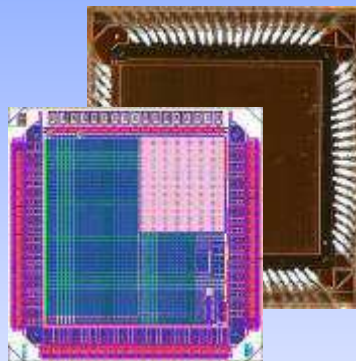
- IBM 130 nm CMOS tech
- 64x64 pixels
  - 4 readout ports
  - 16 col/output
- est. Pow = ~2W/chip



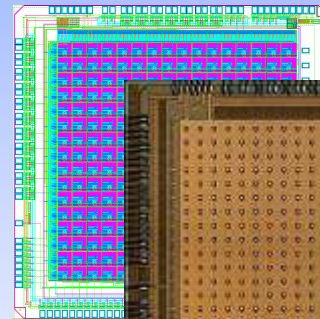
# Several Test Runs



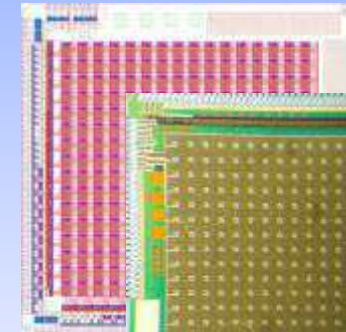
AGIPD01



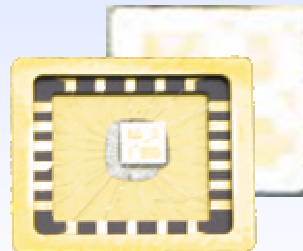
HPAD1



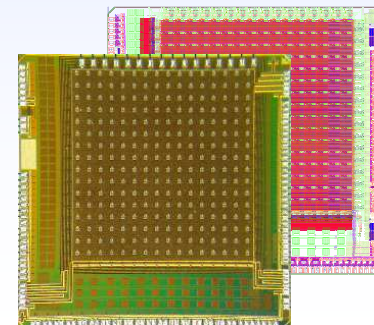
AGIPD04



AGIPD02

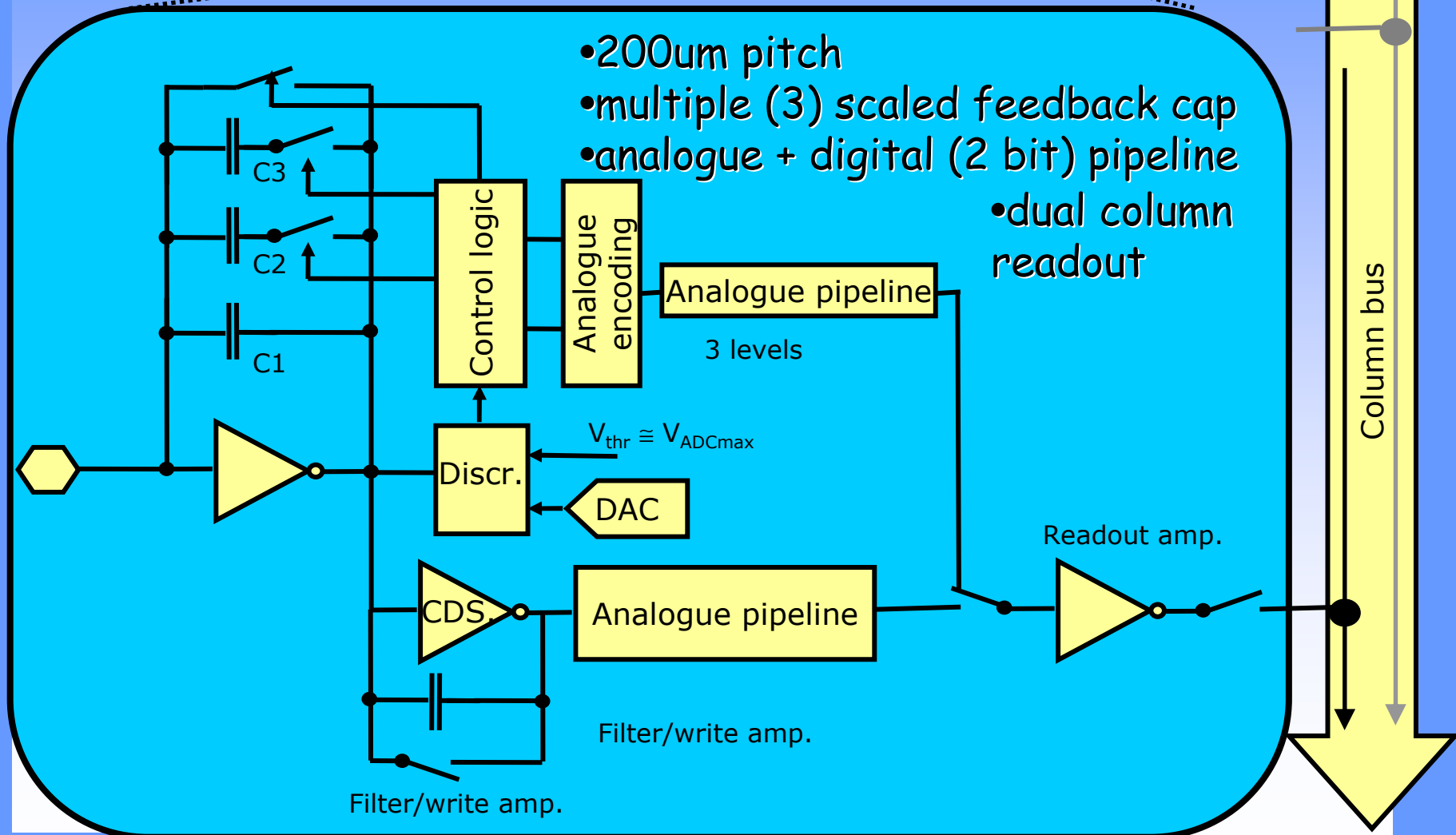
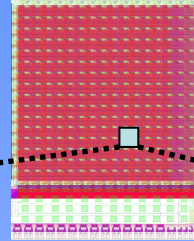


HPAD2



AGIPD03

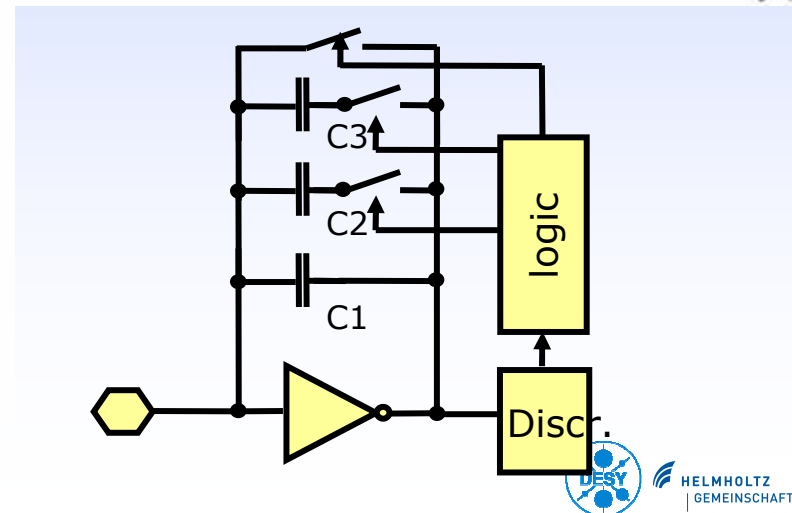
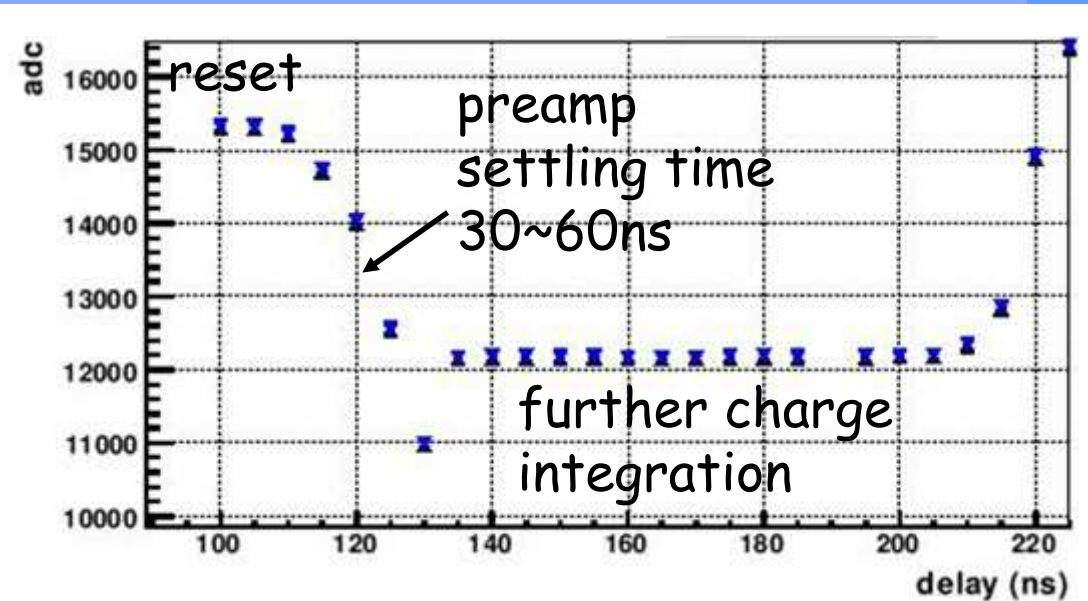
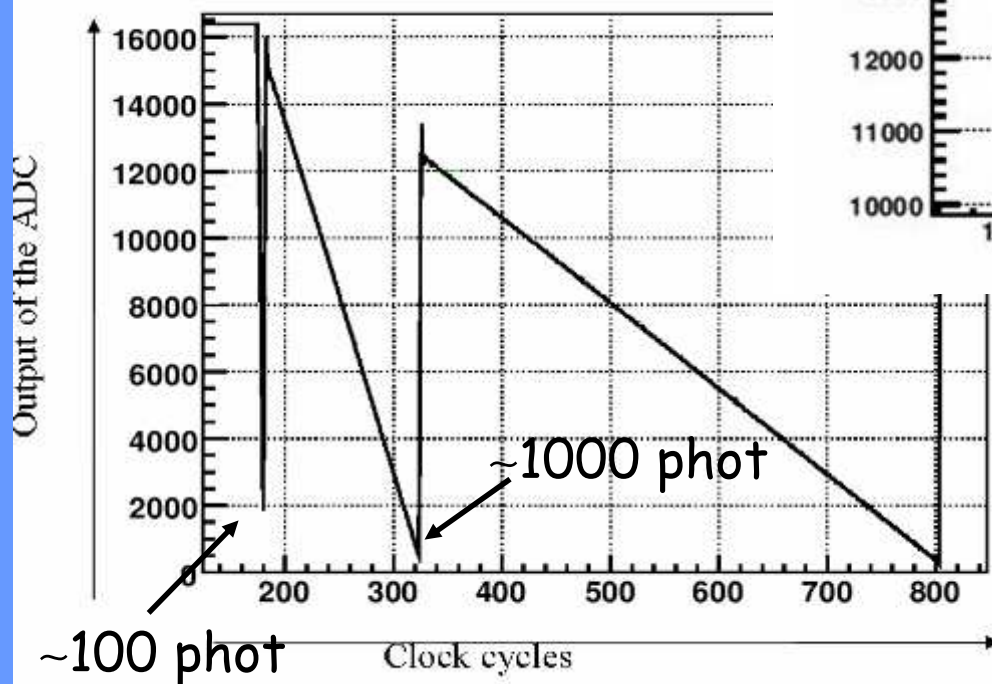
# ASIC Pixel



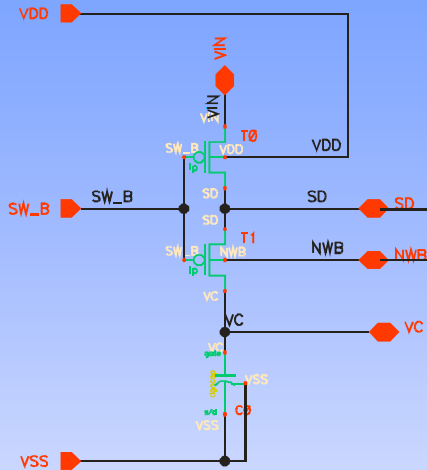
# Adaptive Gain



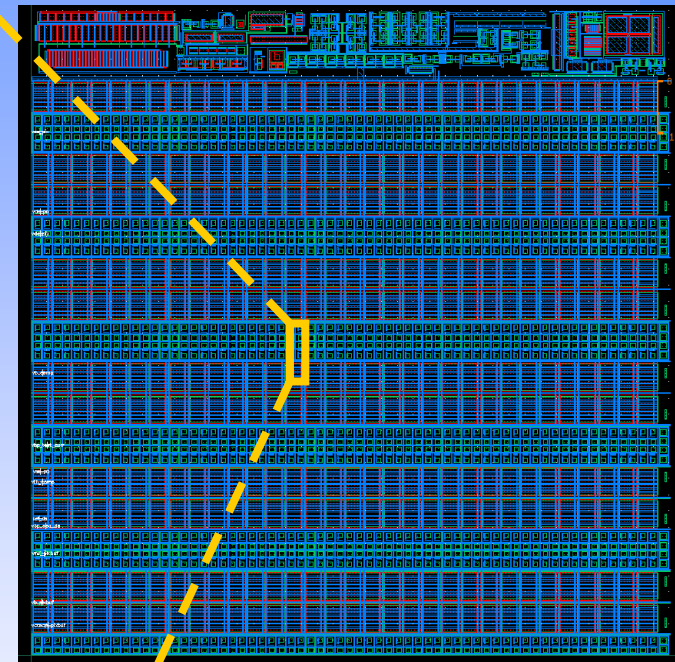
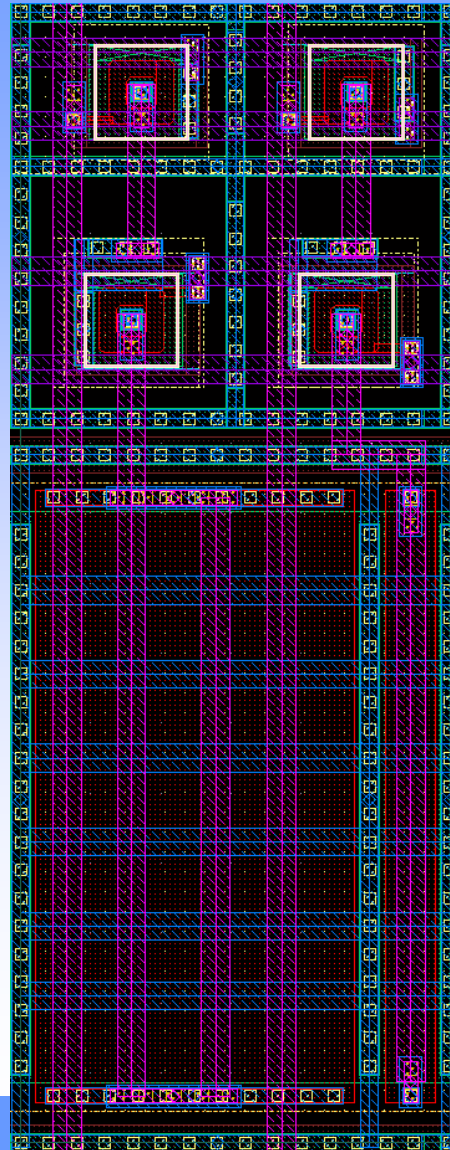
- multiple (3) scaled feedback cap (60fF/3pF/10pF)
- 1:35:4 gain reduction(s)



# Embedded memory



- info to be stored in-pixel for 50~100ms
- both amplitude signal and gain info
- $\leq 0.1\%$  signal loss
- easy to address !

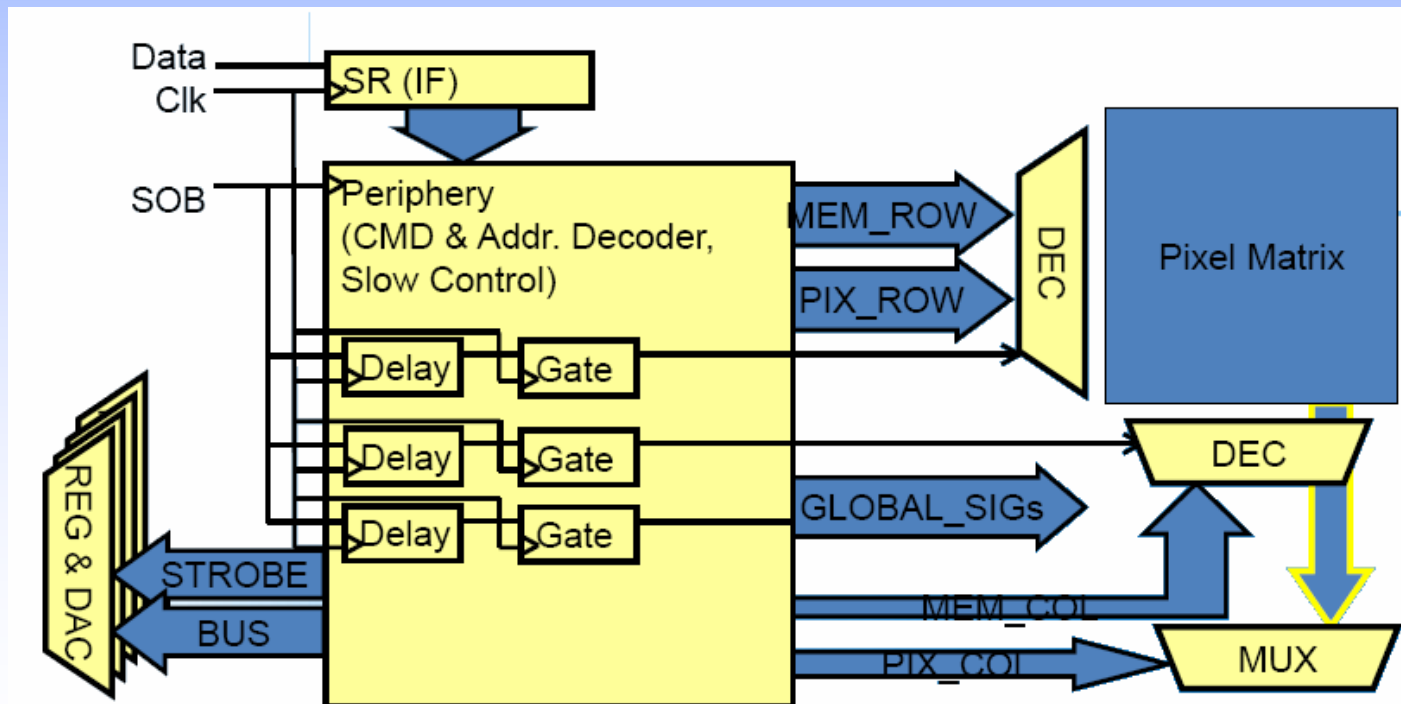
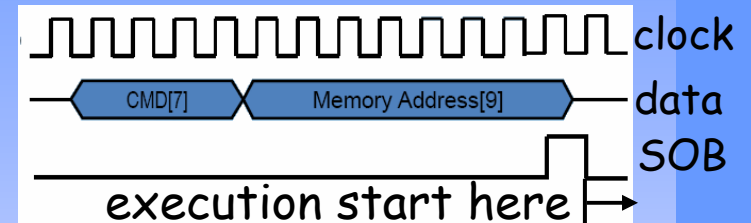


352 memory cells/pixel  
Optimized for rad-hardness (floating nwell, Vdd-biased guard rings)

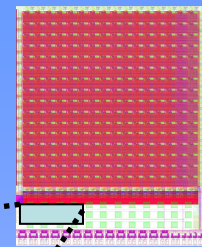
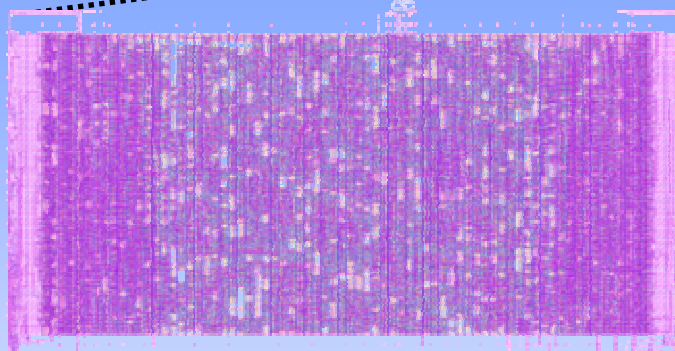
# Control Logic



- ARM cmrf8sf RVT S C Library
- Command Serial IF
  - 3+1 LVDS Signals
  - 16 bits commands, fck 80~160 MHz
- prototype working after 10MGy

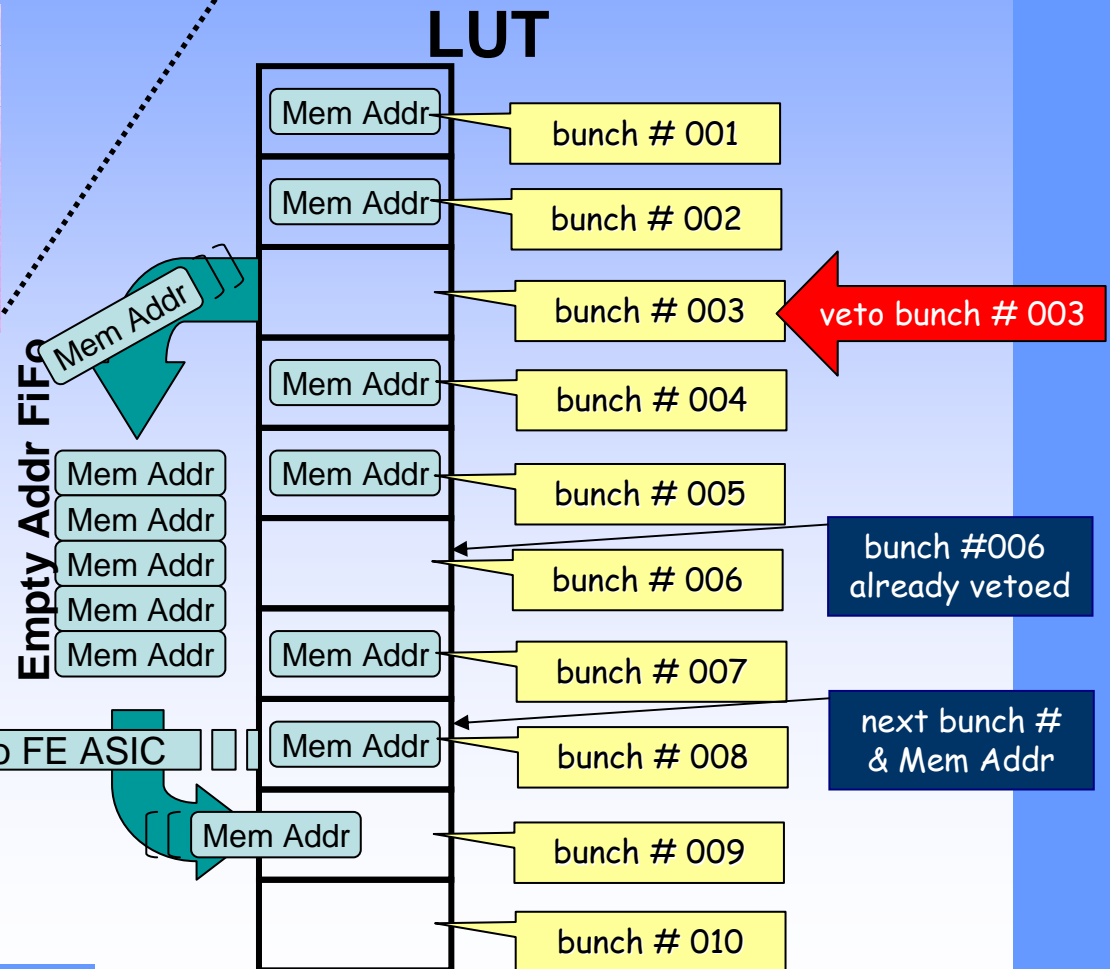


# Control Logic

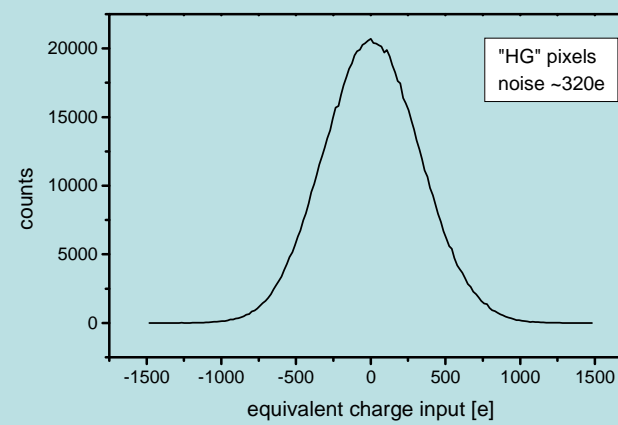
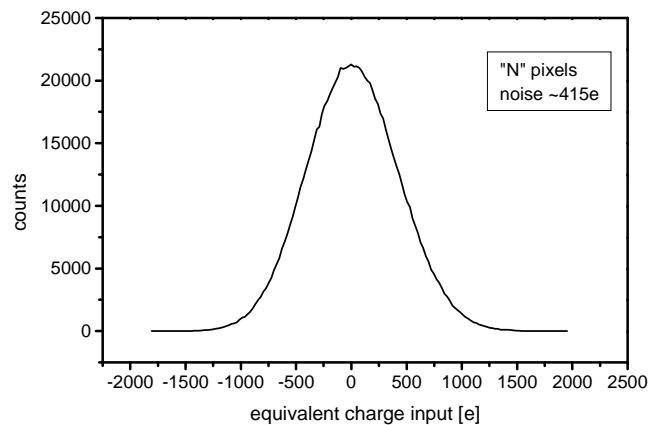
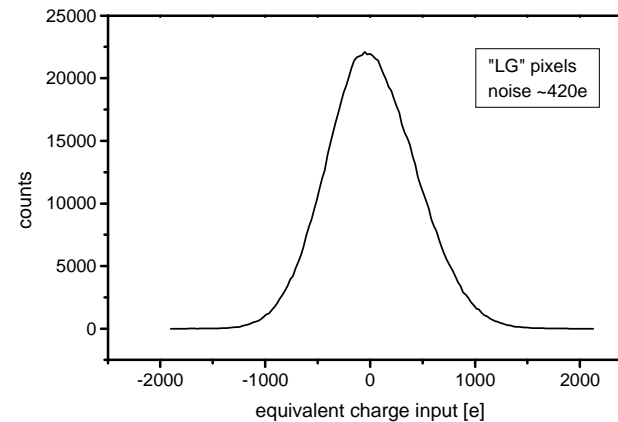
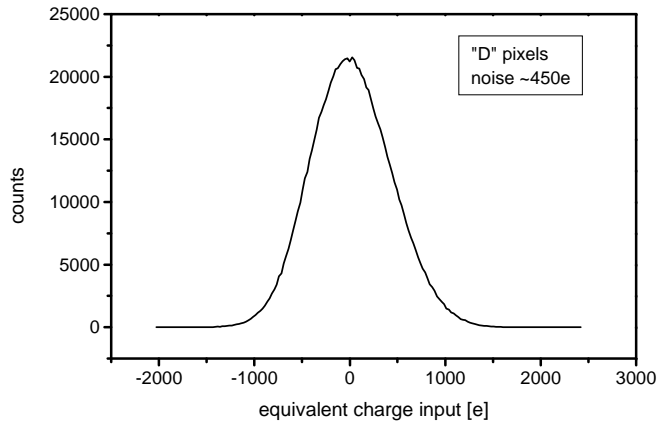


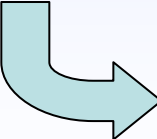
Memory space  
addressable RAM-  
like from the  
(external) interface  
electronics

- allows for Veto  
schema (overwriting  
of meaningless data)



# Noise Measurement



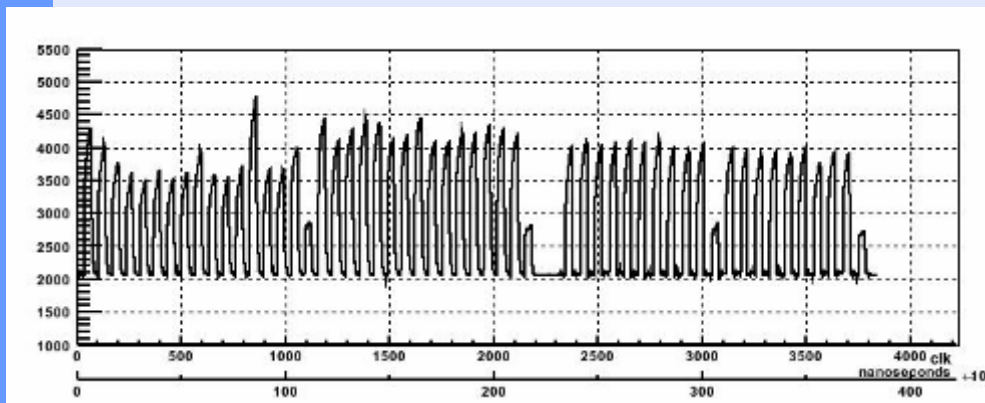
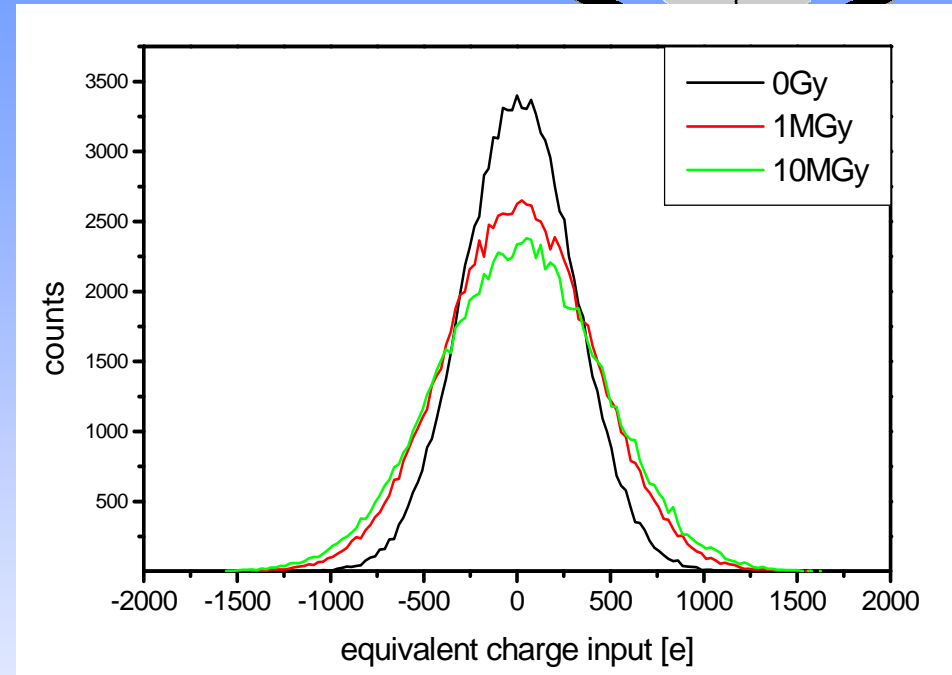
 < 0.1 photon  
@ 12.4keV



# Radiation Hardness

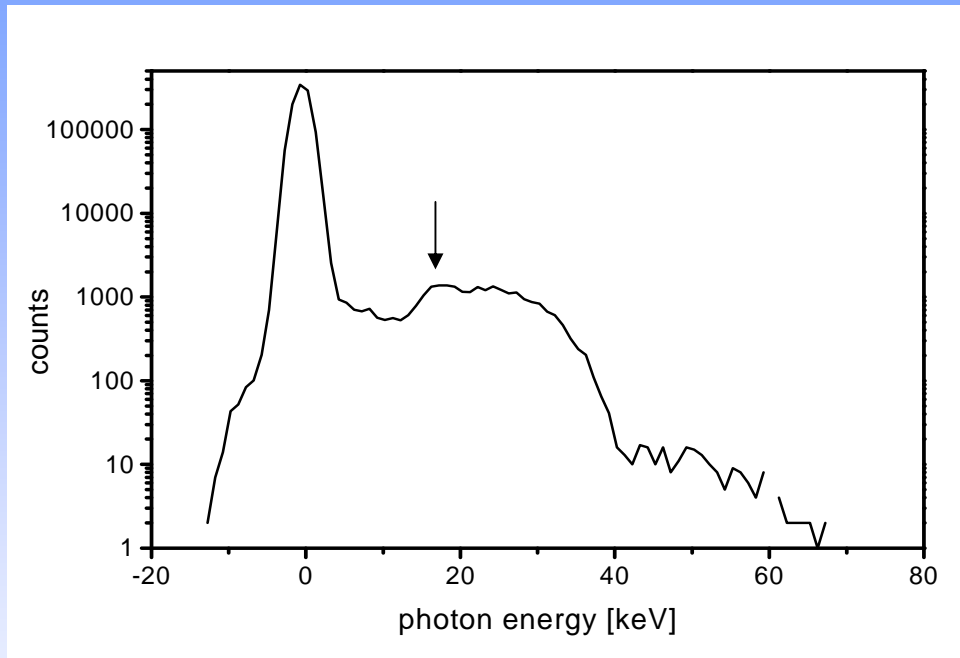


- Irradiation of HPAD 0.1/0.2 - AGIPD03/04 chips
  - up to 10-100MGy
  - @ DORIS F4
  - 5.4kGy/s

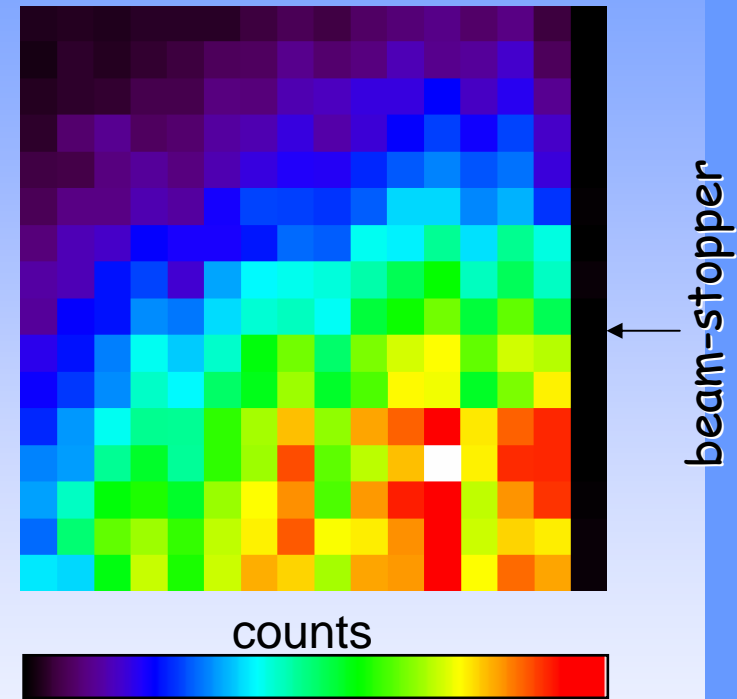


- comparable behaviour up to 10MGy
  - limited noise increase
- 100MGy: functionality recover after annealing

# X-ray detection

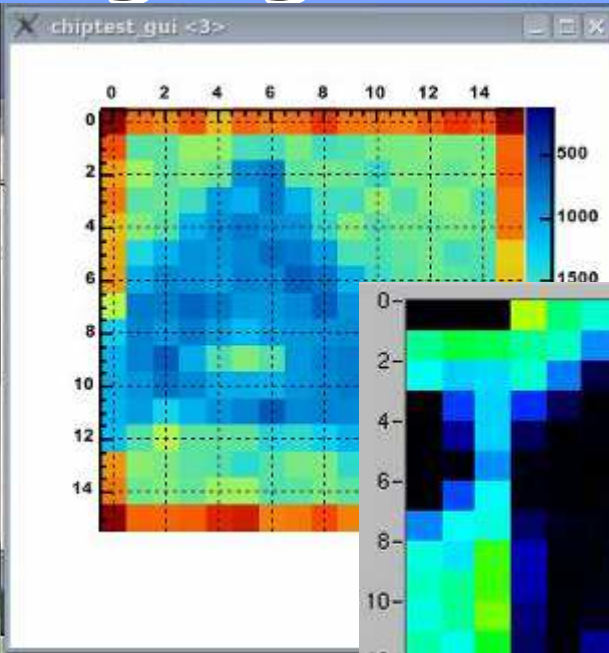


- X-ray tube, 40kV
- Mo target (17.8keV)
- 4mm Al to reduce bremsstrahlung

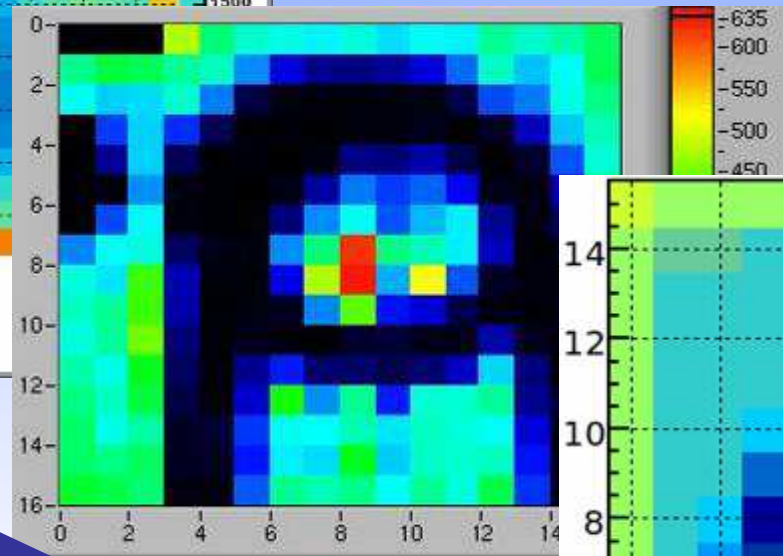


- Petra III beamline
- 7.05keV
- diffraction pattern from illumination of spherical SiO<sub>2</sub> particles in ethanol

# Imaging with prototypes



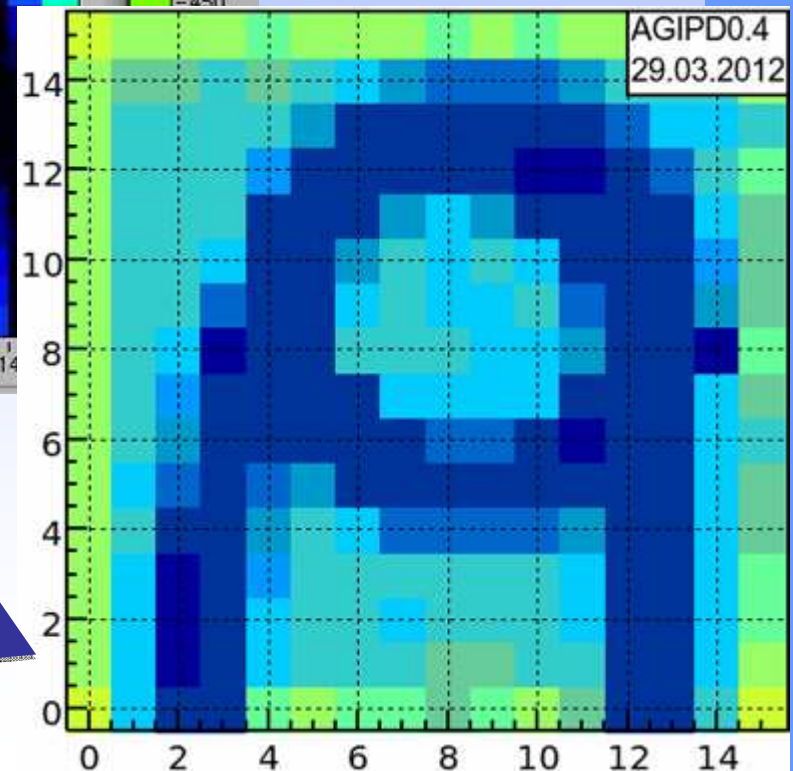
AGIPD03



AGIPD02

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

AGIPD04



# Summary



- Developing a 1Mpix sensor for the European XFEL
  - DESY, PSI, UniBonn, UniHamburg
  - several prototypes
- Adaptive gain
  - Functionality tested
- In-pixel Memory
  - ~350 frames
- ASIC for the 1Mpix system to be ready end of the year
- On-chip control logic
  - 4 LVDS lines
- Radiation Hardness
  - $\geq 10\text{MGy}$
- <http://hasylab.desy.de/instrumentation/detectors/projects/agipd>





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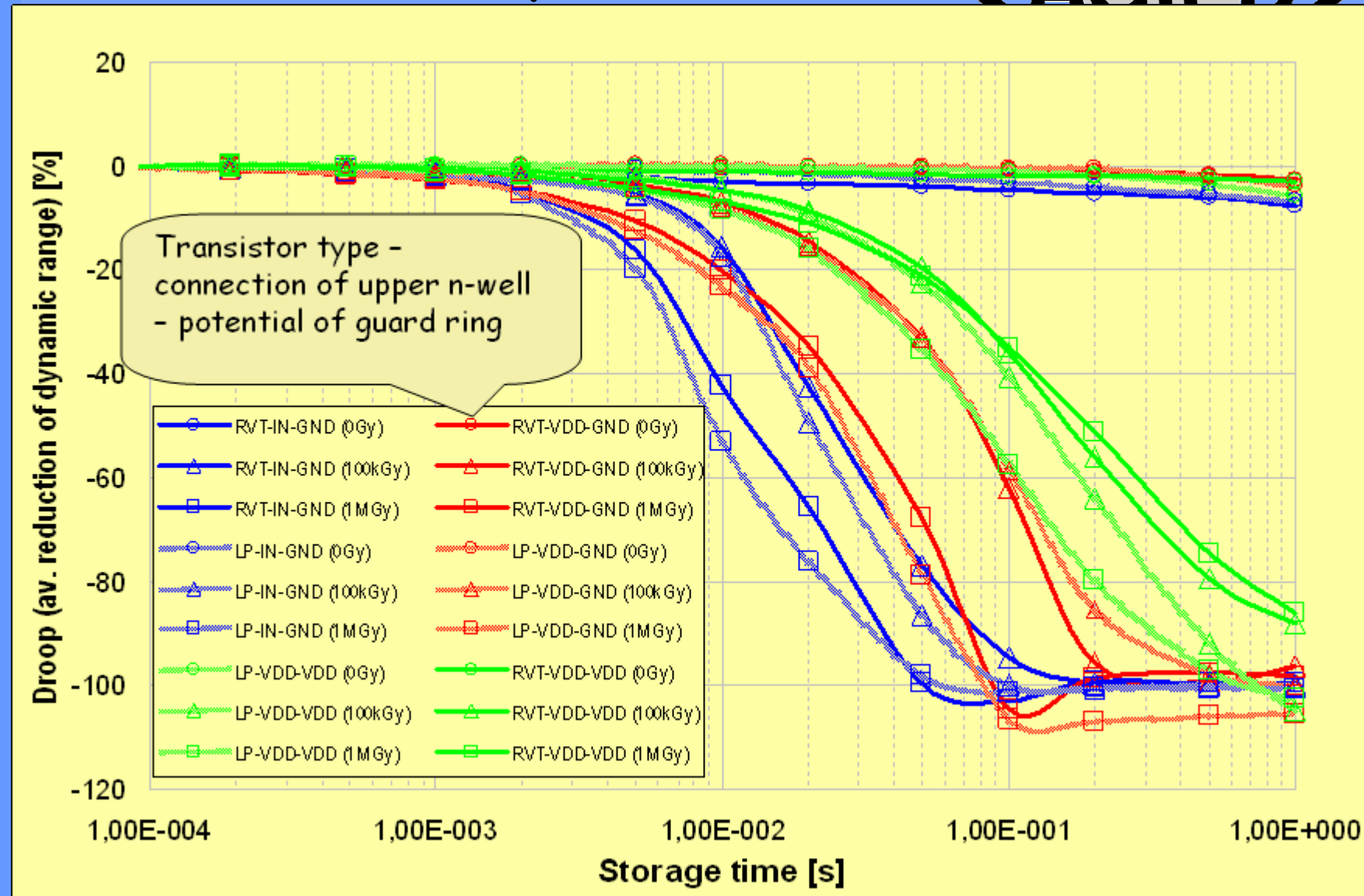


# backup slides

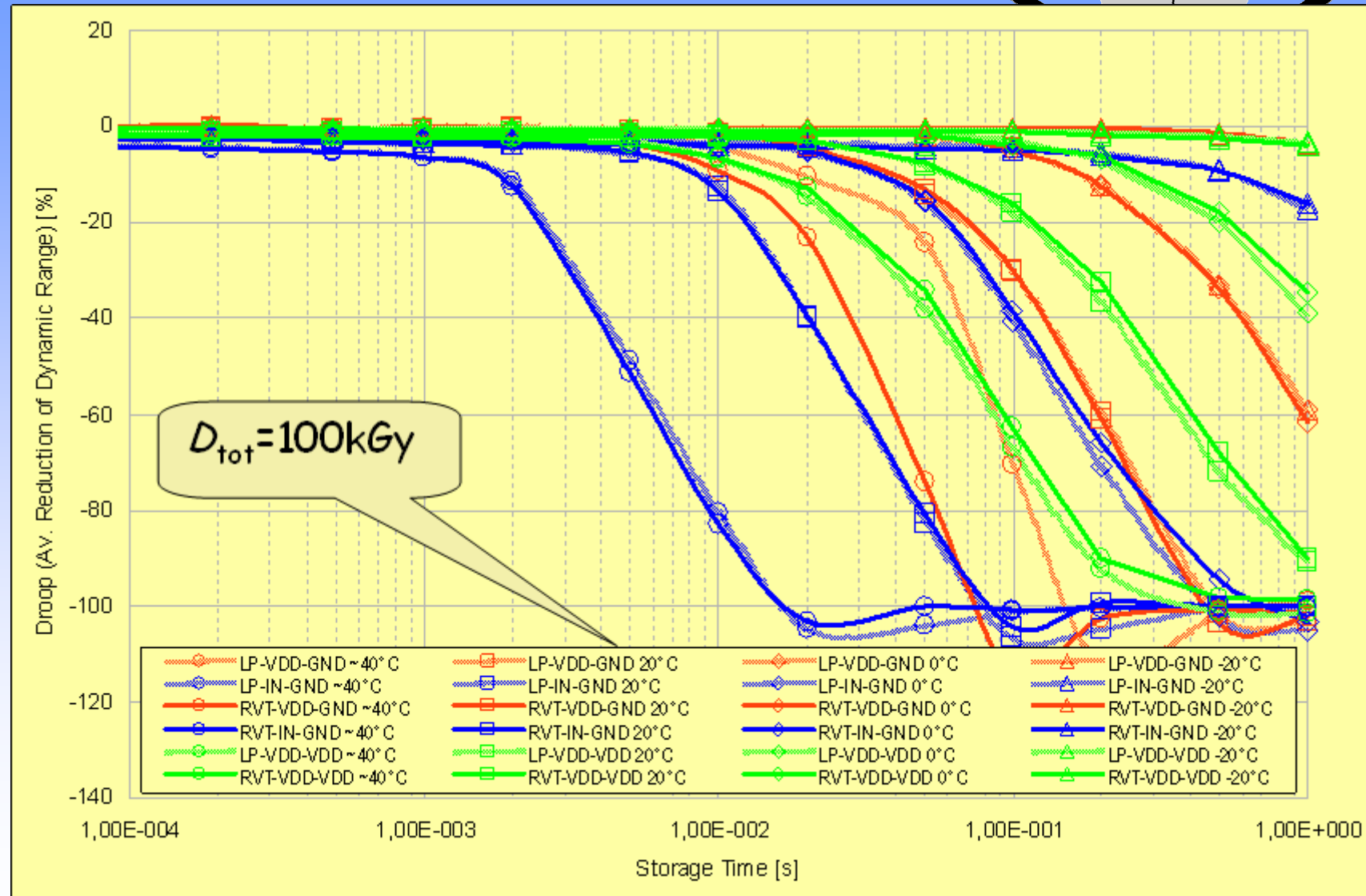
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# AGIPD03: Droop



# AGIPD03: T impact on droop

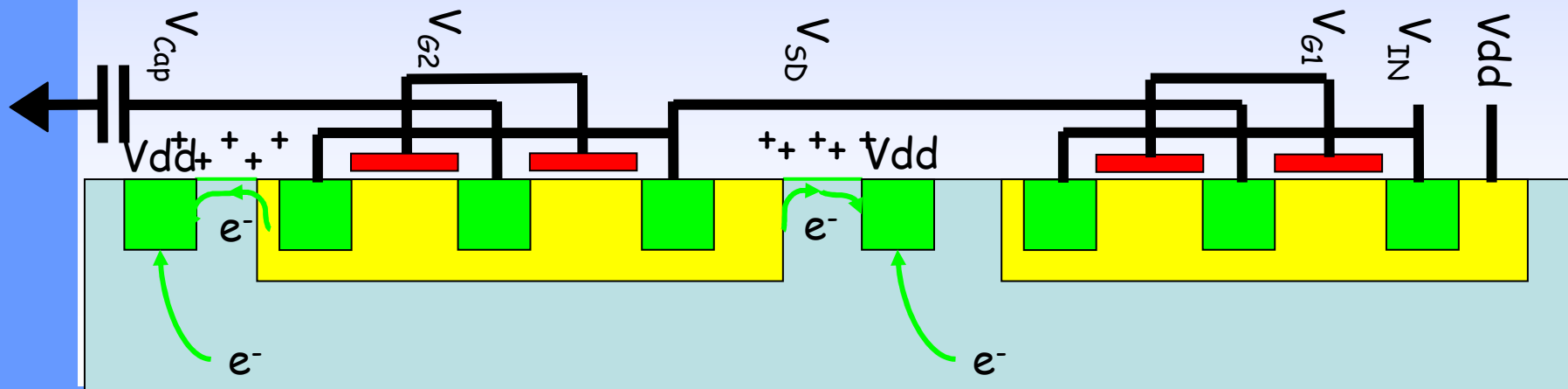




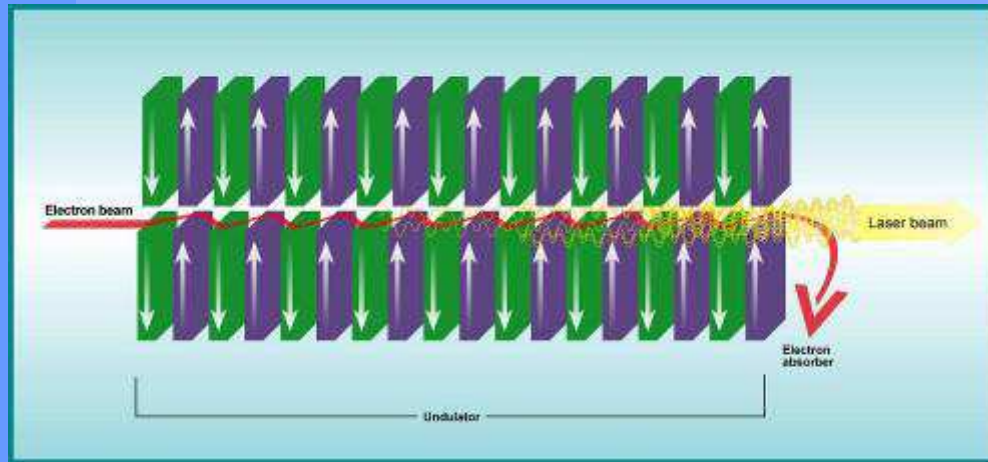
# Storage Cell Evol.



- Vdd-Ring introduced around critical devices
- EL Transistors introduced
- waiting for tests on AGIPD03 test chip



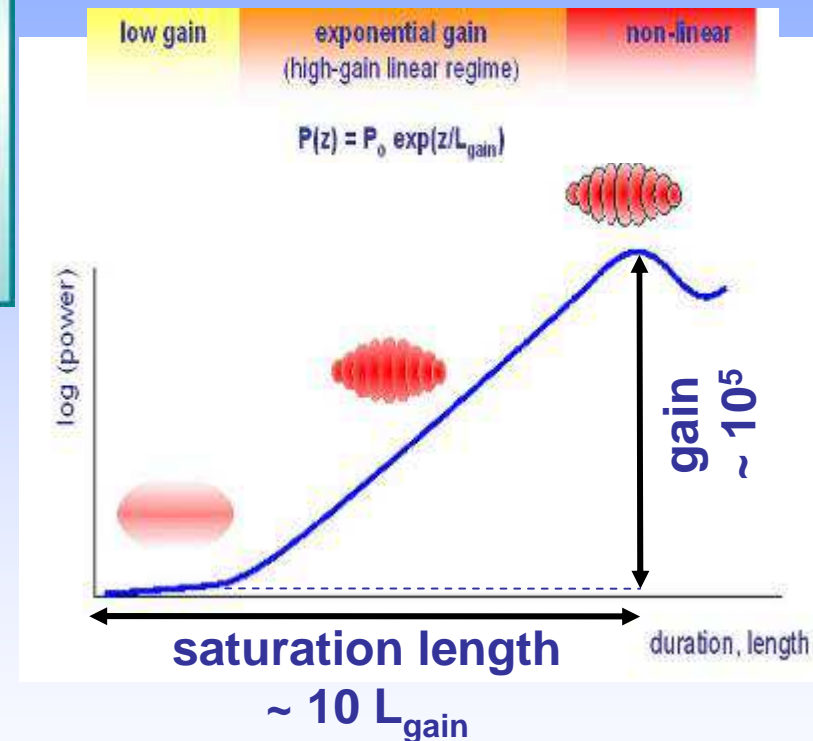
# Synchrotron Radiation in FELs



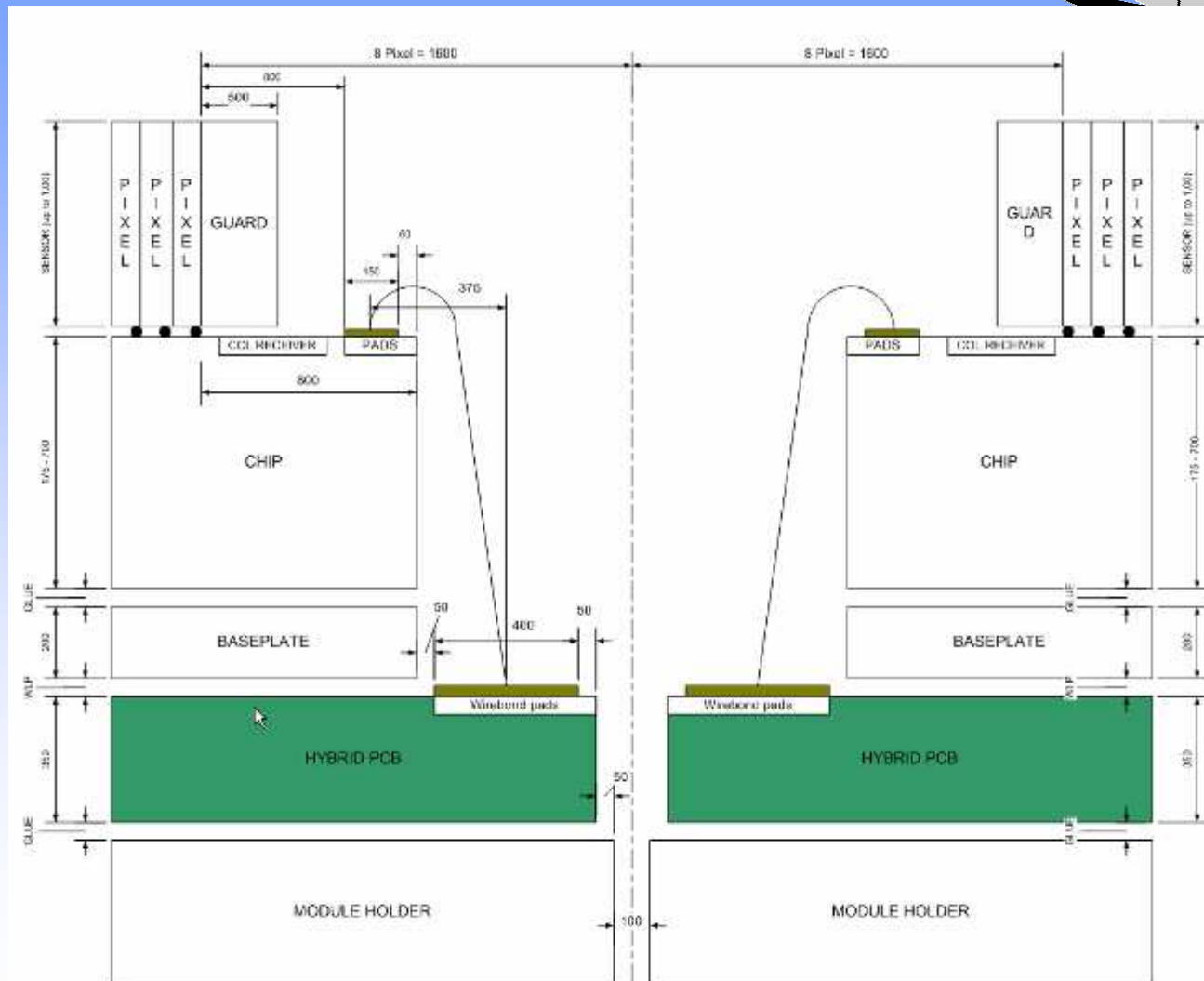
- SASE principle

- (Self-Amplified Spontaneous Emission)

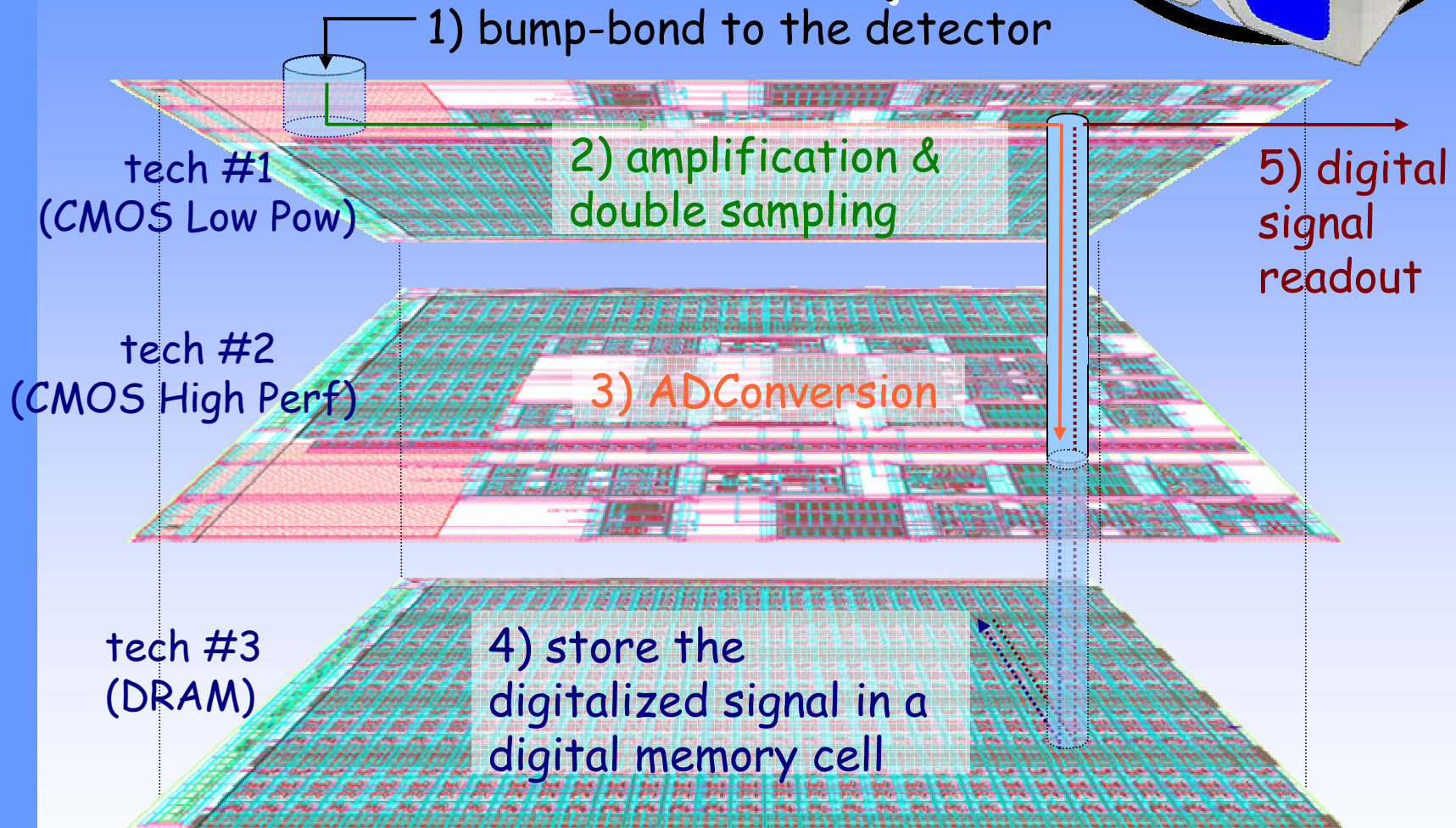
- Random seed
  - Almost 100% transverse coherence
  - Limited temporal coherence
- Tail-head phenomena
  - Microbunching
  - Exponential growth of intensity & power



# Dimensions & gaps

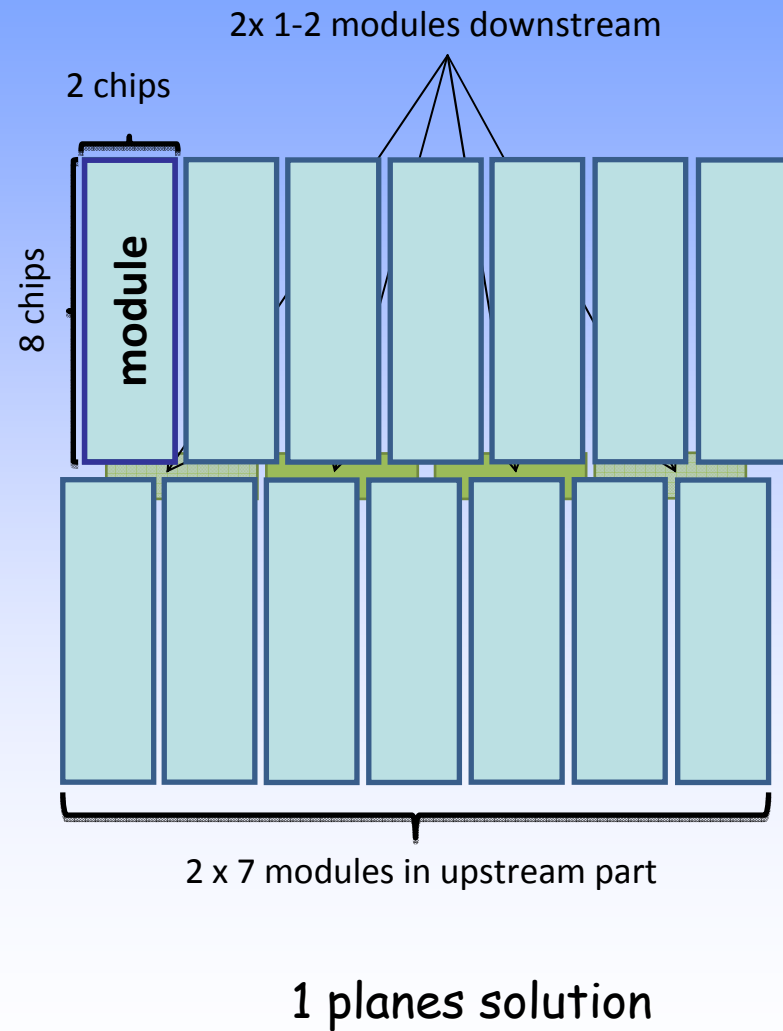
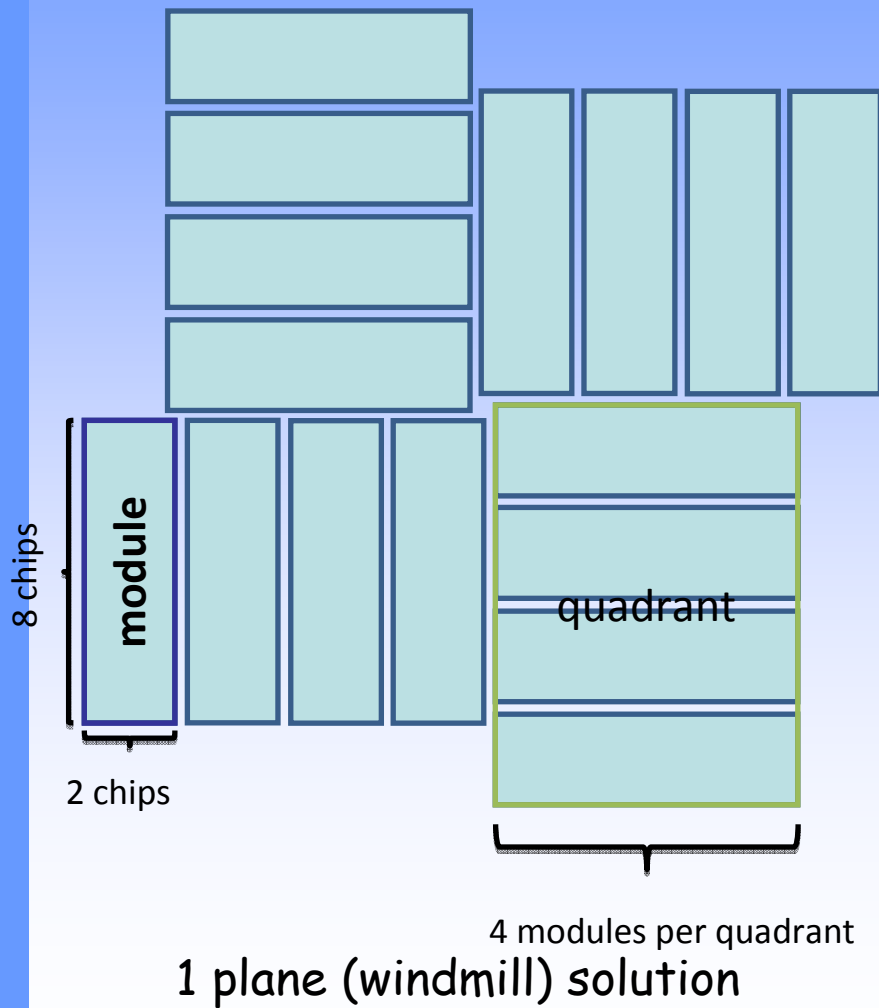


# Embedded memory



- looking to the future?

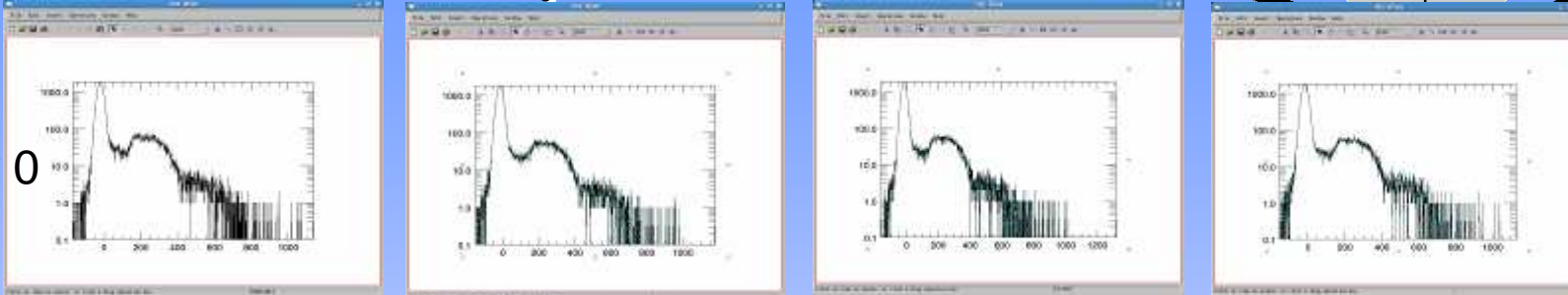
# Alternative module arrangements



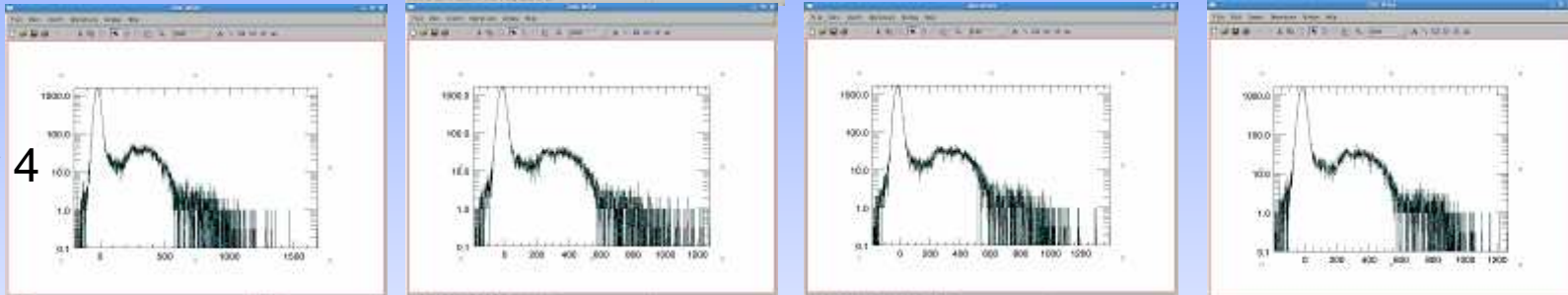
# Uniformity (preliminary)



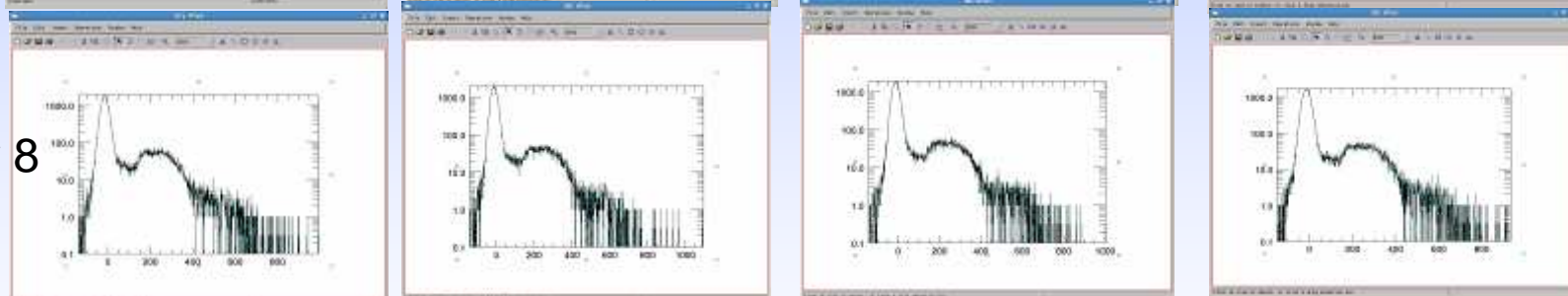
row 0



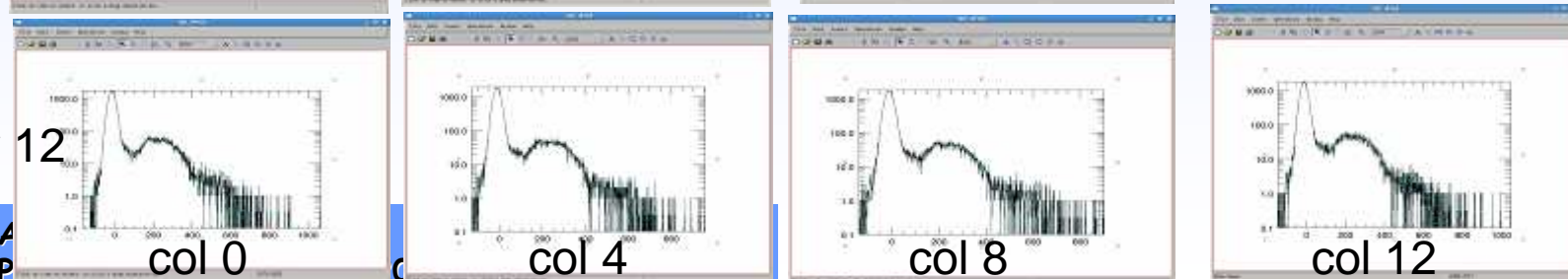
row 4



row 8



row 12



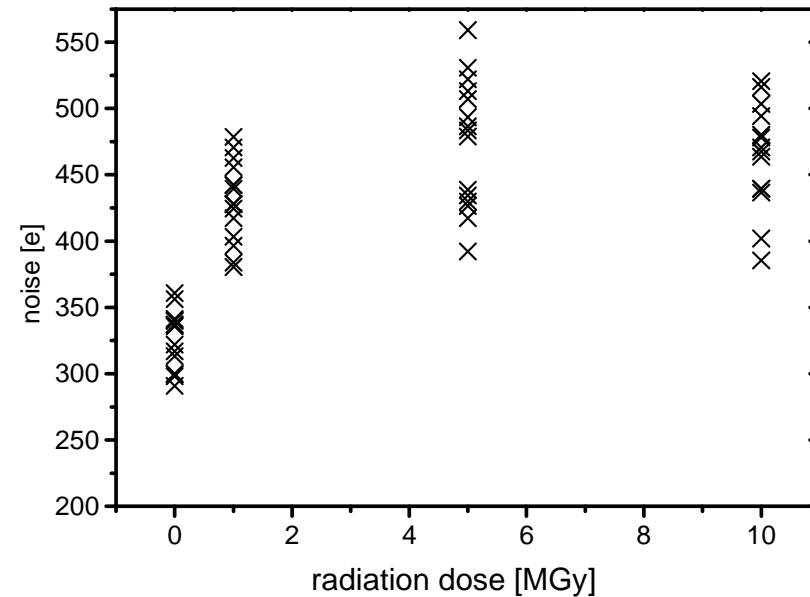
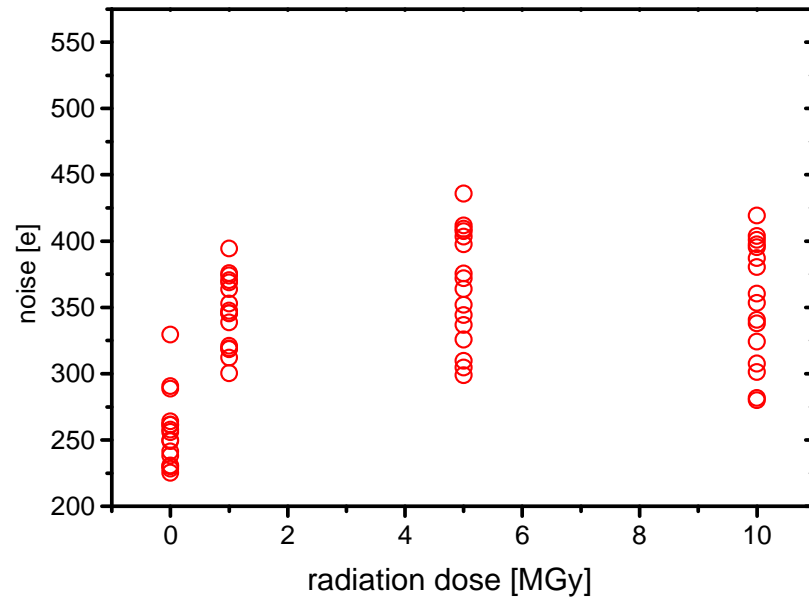
col 0

col 4

col 8

col 12

# Radiation Hardness



- 60fF feedback capacitor
  - preferred solution

- 100fF feedback capacitor