The 2D X-ray detector development program for the European XFEL

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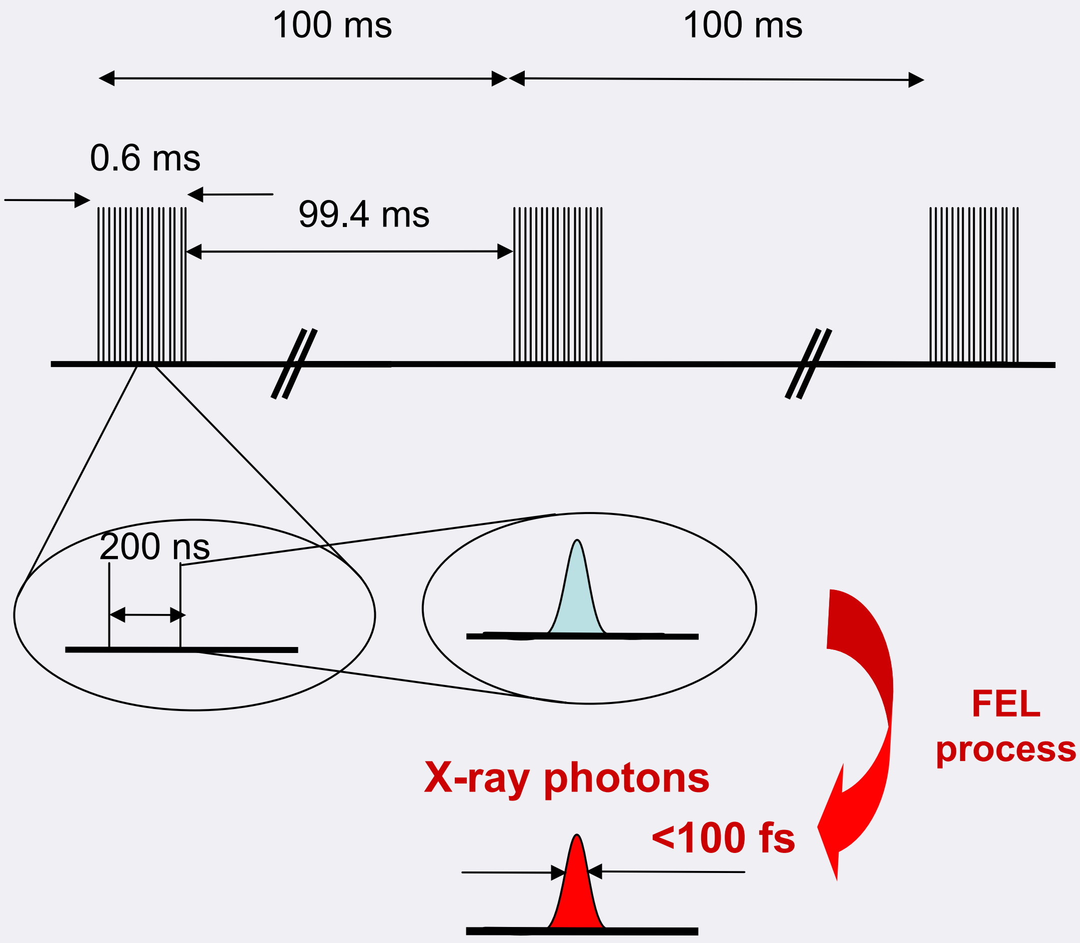
WorkPackage Detectors for XFEL

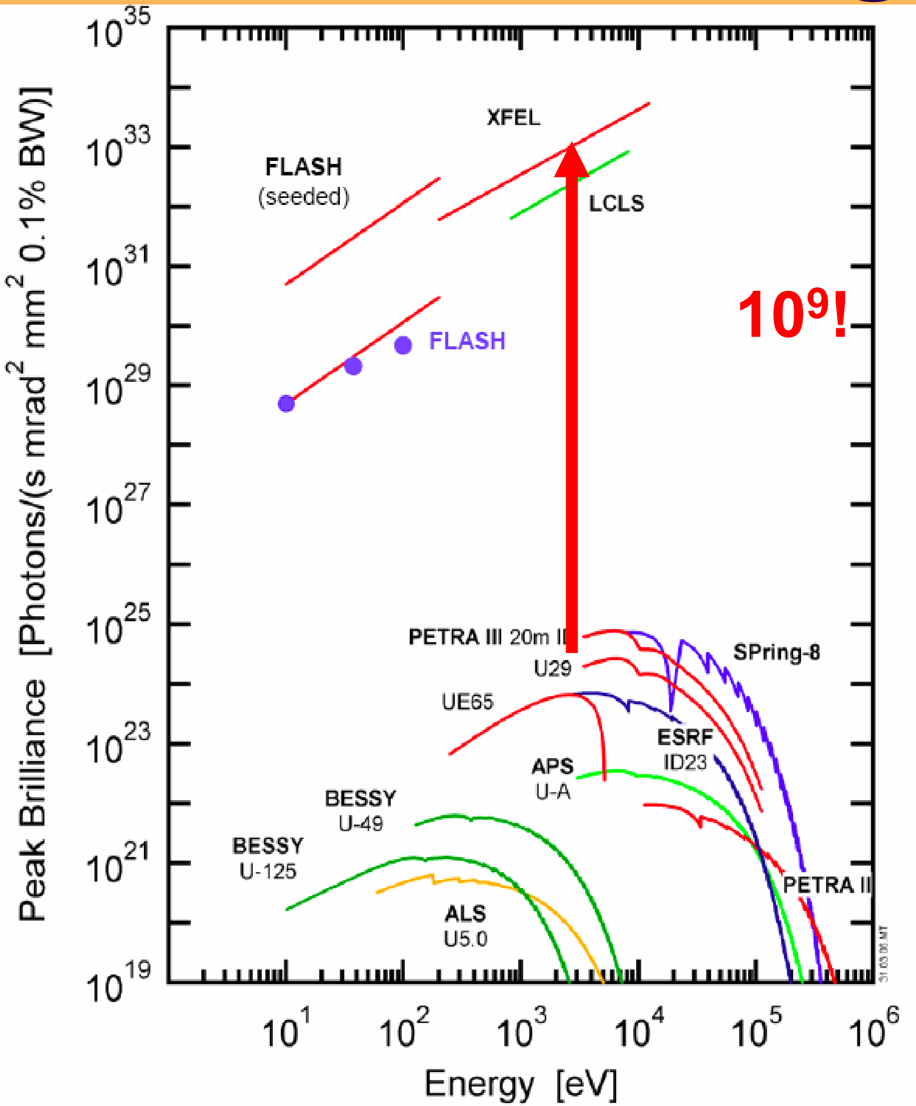
Where is the challenge?



Challenges:

- up to 30,000 bunches per second
- very high intensities (up to $10^{12}\gamma$/bunch)
- „instantaneous" energy deposition
- very high repetition rates (up to 5 MHz)
- large variability
  - pulse patterns
  - pulse to pulse variations

Thinking ahead…



- **It is difficult to think over 9 orders of magnitude.**

XFEL Detector Requirements: TDR

- Energy 0.8..15keV
- No energy resolution
- High efficiency (>0.8)
- High dose 1GGy/3a
- Low dead area <10%
- High dynamic range
- XFEL Timing compliant
- Low noise (<1 ph)
- Low crosstalk
- Vacuum compatible
- Central hole

	PPnX	PPX	CDI	SPI	XPCS
E (keV)	6–15	12	0.8-12	12.4	6 – 15
ΔE/E	No	No	No	No	No
QE	>0.8	>0.8	>0.8	>0.8	>0.8
Rad Tol	10^{16} ph	10^{16} ph	2×10^{16} ph	2×10^{15} ph	2 10^{14} ph
Size	200 deg	120 deg	120 deg	120 deg	0.2 deg
Pixel	7 mrad	100 μm	0.1 mrad	0.5 mrad	4 μrad
# pixels	500 × 500	3k × 3k	20k × 20k	4k × 4k	1k × 1k
tiling	<20%	<10%	See text		<20%
L Rate	5×10^4	3×10^6	10^5	10^4	10^3
G Rate	3 $x10^7$	10^7	10^7	10^7	10^6
Timing	10Hz	10Hz	5MHz	10Hz	5MHz
Flat F	1%	1%	1%	1%	1%
Dark C	<1 ph	<1 ph	<1 ph	<1 ph	<1 ph
R Noise	<1 ph	<1 ph	<1 ph	<1 ph	<1 ph
Linearity	1%	1%	1%	1%	1%
PSF	1 pixel	100 μm	1 pixel	1 pixel	1 pixel
Lag	10^{-3}	10^{-3}	7×10^{-5}	10^{-3}	10^{-3}
Vacuum	No	No	Yes	Yes	No
Other	Hole	Hole			Hole

Selection of first instruments

Hard X-rays

Soft X-rays

Instrument	Brief description of the instrument
SPB	Ultrafast Coherent Diffraction Imaging of Single Particles, Clusters, and Biomolecules – **Structure determination of single particles: atomic clusters, bio-molecules, virus particles, cells.**
MID	Materials Imaging & Dynamics –**Structure determination of nano- devices and dynamics at the nanoscale.**
FDE	Femtosecond Diffraction Experiments – **Time-resolved investigations of the dynamics of solids, liquids, gases**
HED	High Energy Density Matter – **Investigation of matter under extreme conditions using hard x-rays, e.g. probing dense plasmas.**
SQS	Small Quantum Systems – **Investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena.**
SCS	Soft x-ray Coherent Scattering –**Structure and dynamics of nano-systems and of non-reproducible biological objects using soft X-rays.**

Other general challenges

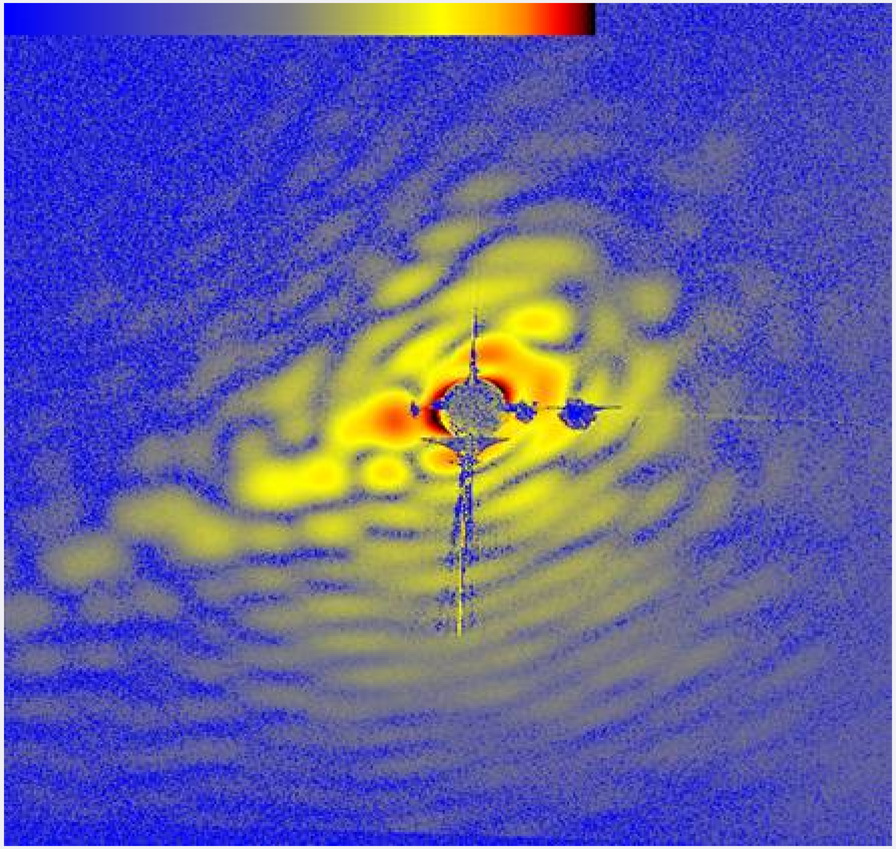
High radiation dose at small angles: 10^4 photons per pixel per shot ➔ over 3 years 1 GGy

- Radiation damage of sensor & electronics
- Program for radiation damage studies.

High radiation dose at specific pixels: 10^5 photons in 10 x 10 microns 10^5 photons of 12 keV create: $(10^5 \times 12 \times 10^3)/ 3.6 = 3 \times 10^8$ electron-hole pairs ➔ "plasma effect" gives shielding of drift field ➔ diffusion before drift ➔ peak broadening (space and time).

- Program for charge explosion

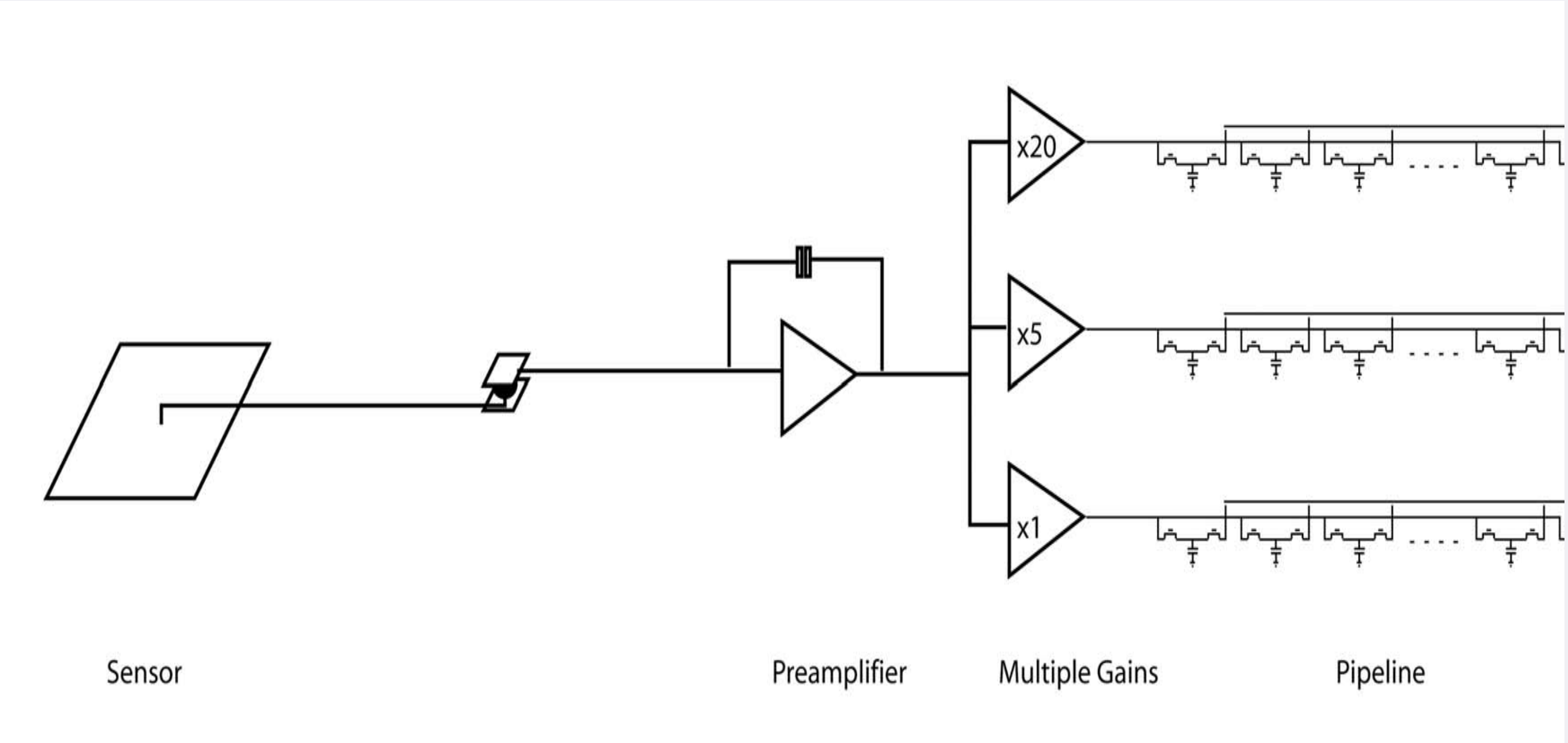
Some Requirements and Specifications



Requirements:
- 1k x 1k (4k x 4k) pixels
- "no noise"
- 10^4 ph/pixel/pulse
- Few 100 images/train
- …

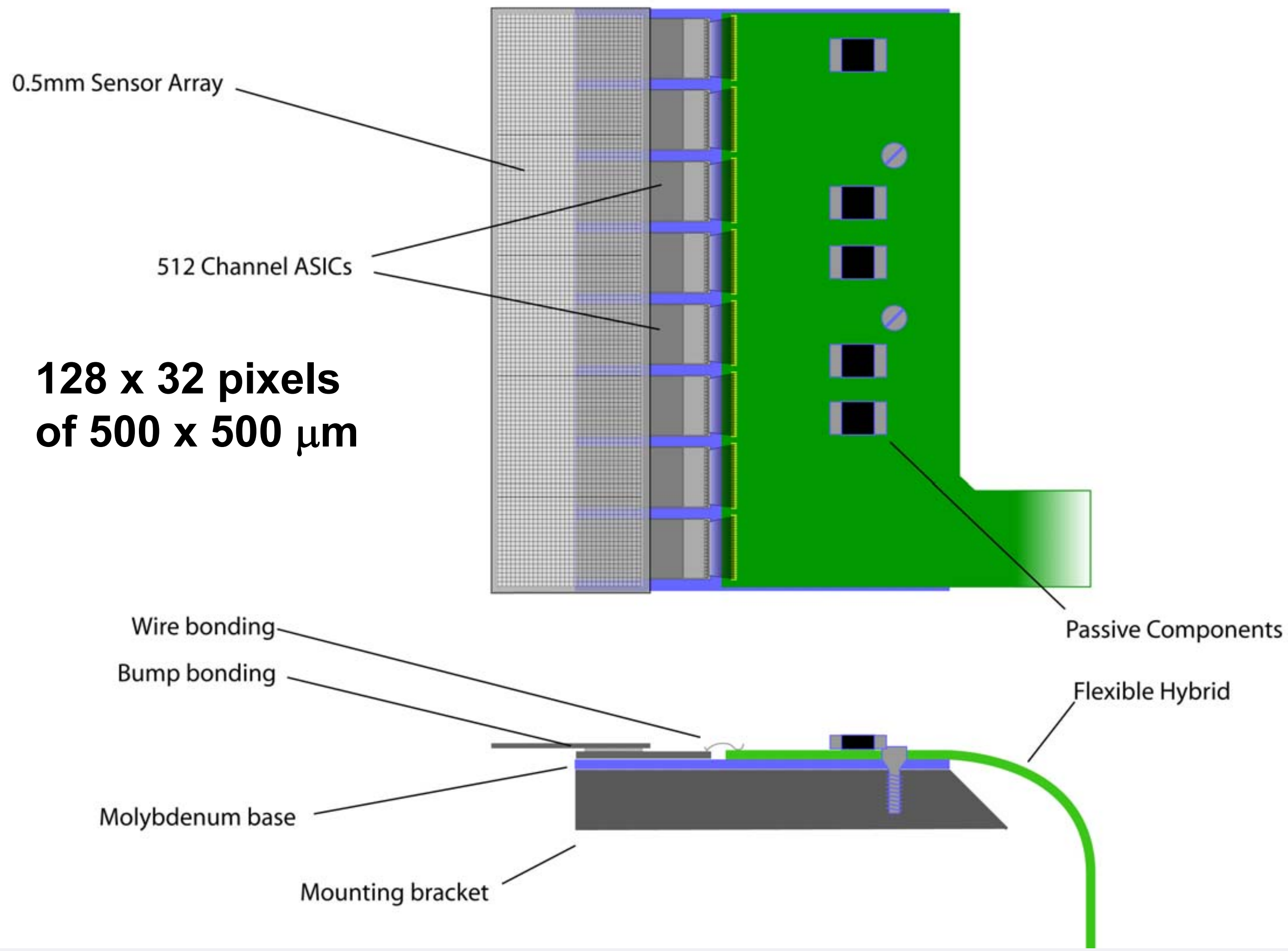
Consequences:
- Integration detectors
- Low noise
- In-pixel frame storage
- Multiple gains or
- Non-linear gain

(a) Large Pixel Detector – LPD (M. French)

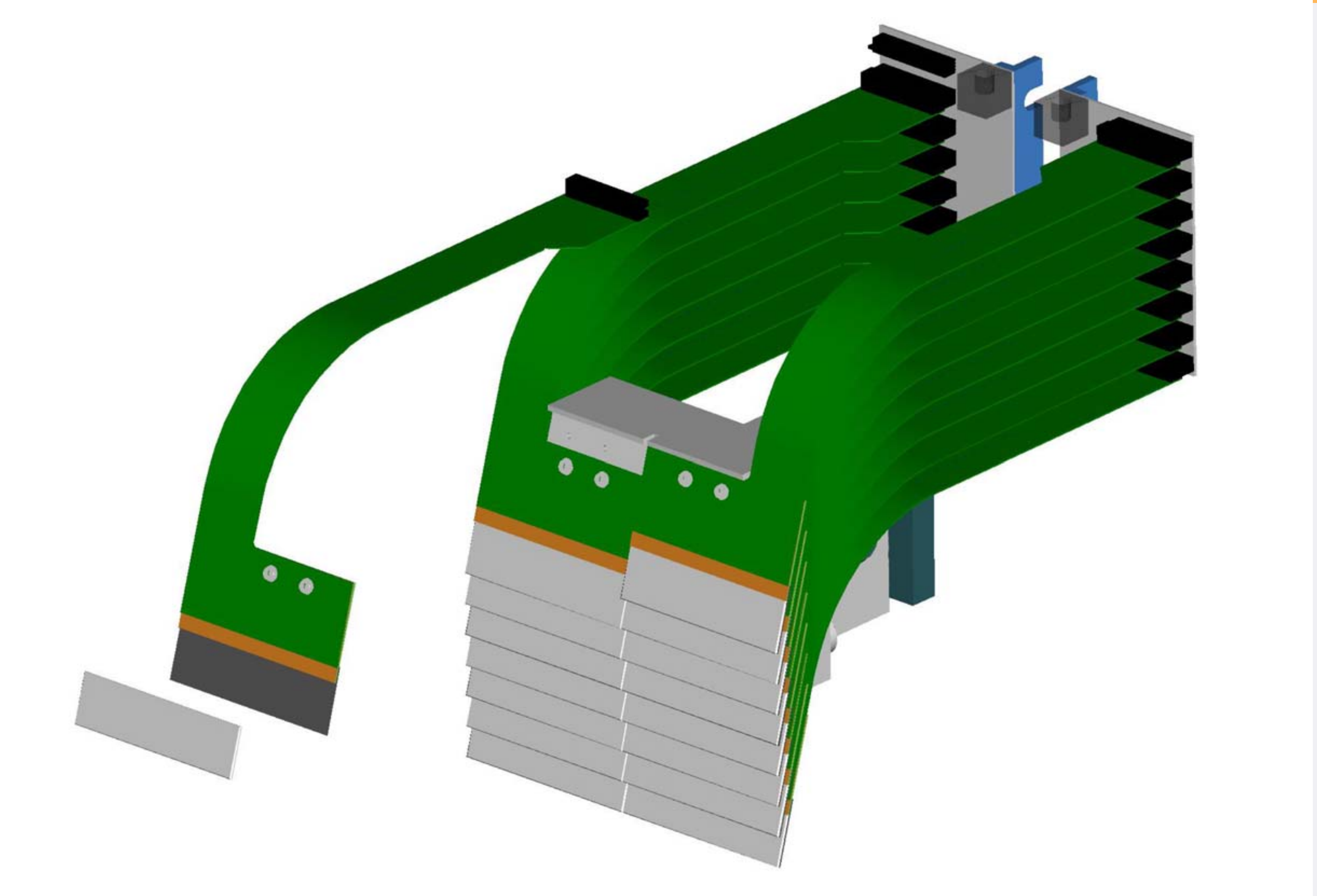


Principle: tiled hybrid with 500 μm pixels

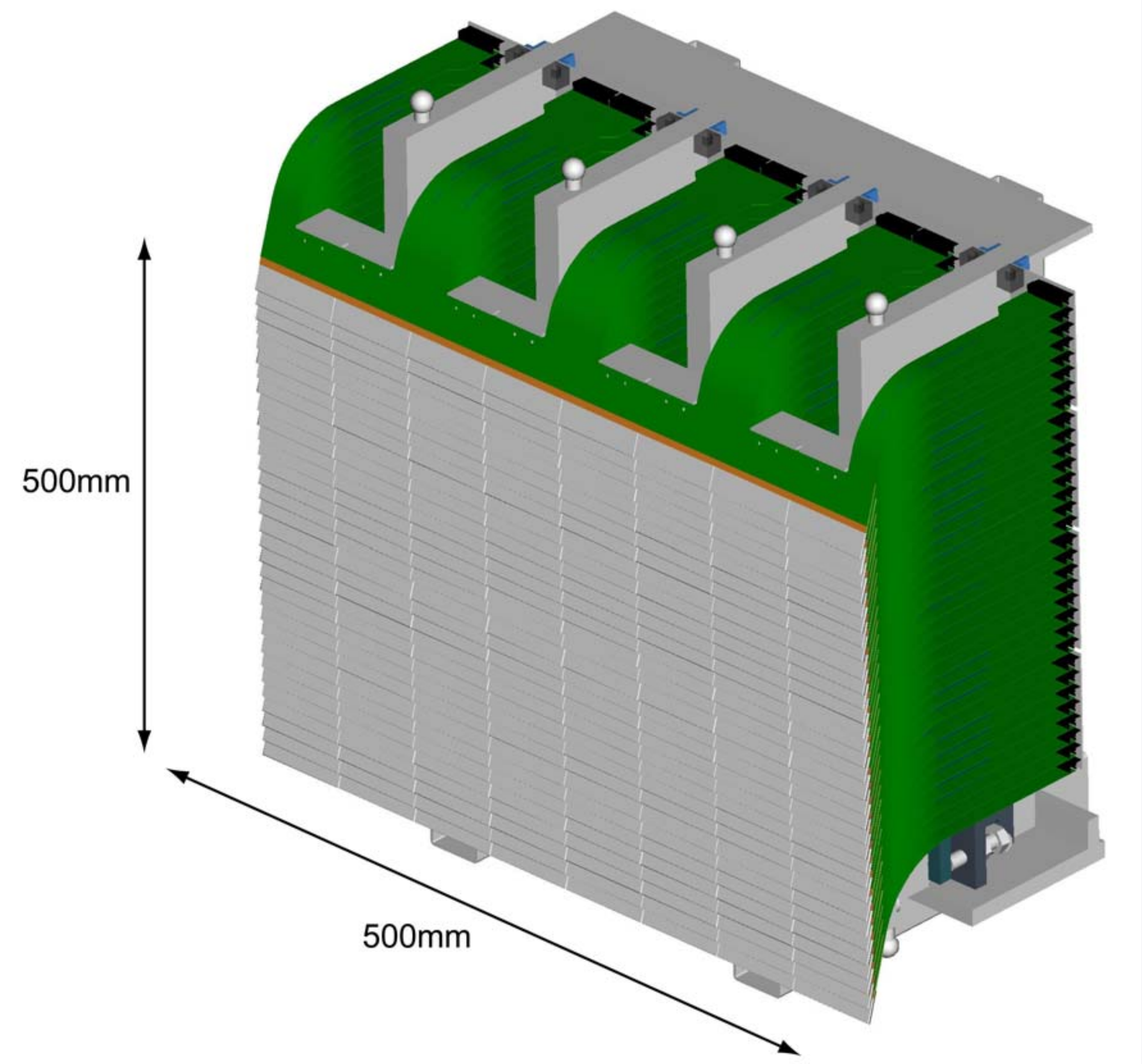
128 x 32 pixels of 500 x 500 μm



Super modules: 8 x 2 tiles (256 x 256 pixels)



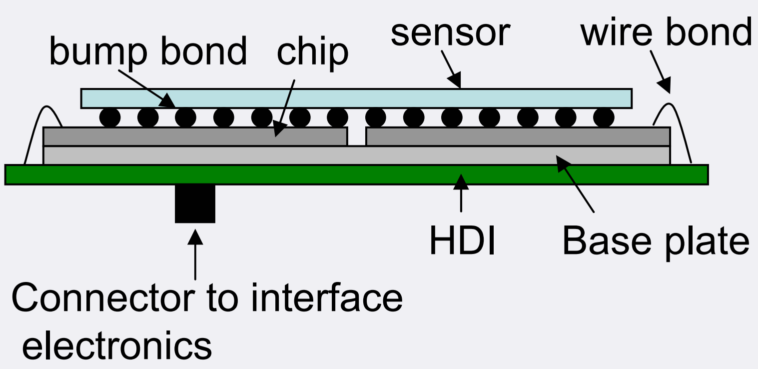
1k x 1k system with 4 x 4 super modules

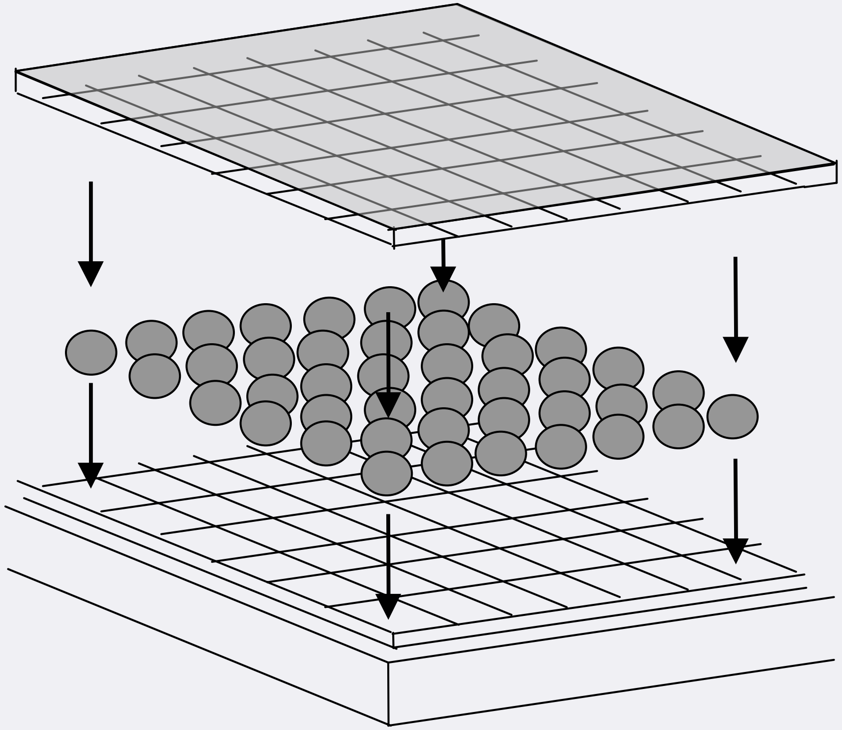


(b) Hybrid Pixel Detector – AGIPD (H. Graafsma)

Analogue Pipeline Hybrid Pixel Array Detectors

- DESY
- PSI/SLS
- University Bonn
- University Hamburg





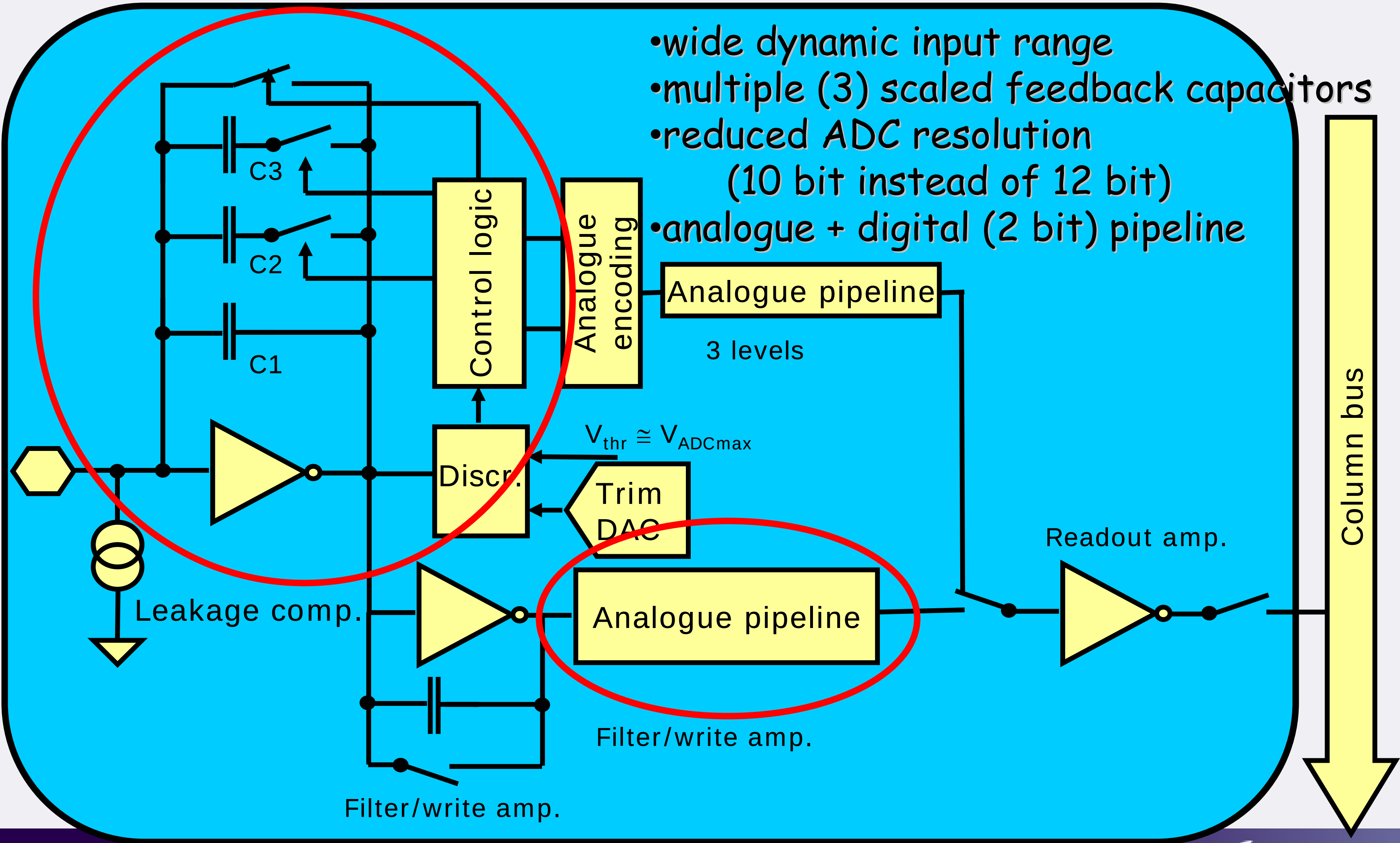
HPAD-AGIPD Target Specs

Basic parameters

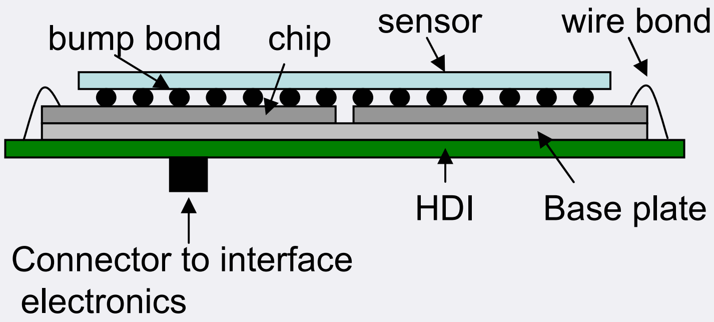
- 1 Megapixel detector (1k × 1k)
- 200 μm × 200 μm pixels
- Flat detector
- Sensor: Silicon 128 x 256 pixel tiles
- Single shot 2D-imaging
- 5MHz frame rate
- 2×10^4 photons dynamic range
- Adaptive gain switching
- Single photon sensitivity at 12keV
- Noise ≤150e (50×10^{-3} photons @ 12keV)
- Storage depth ≥200 images
- Analogue readout between bunch-trains

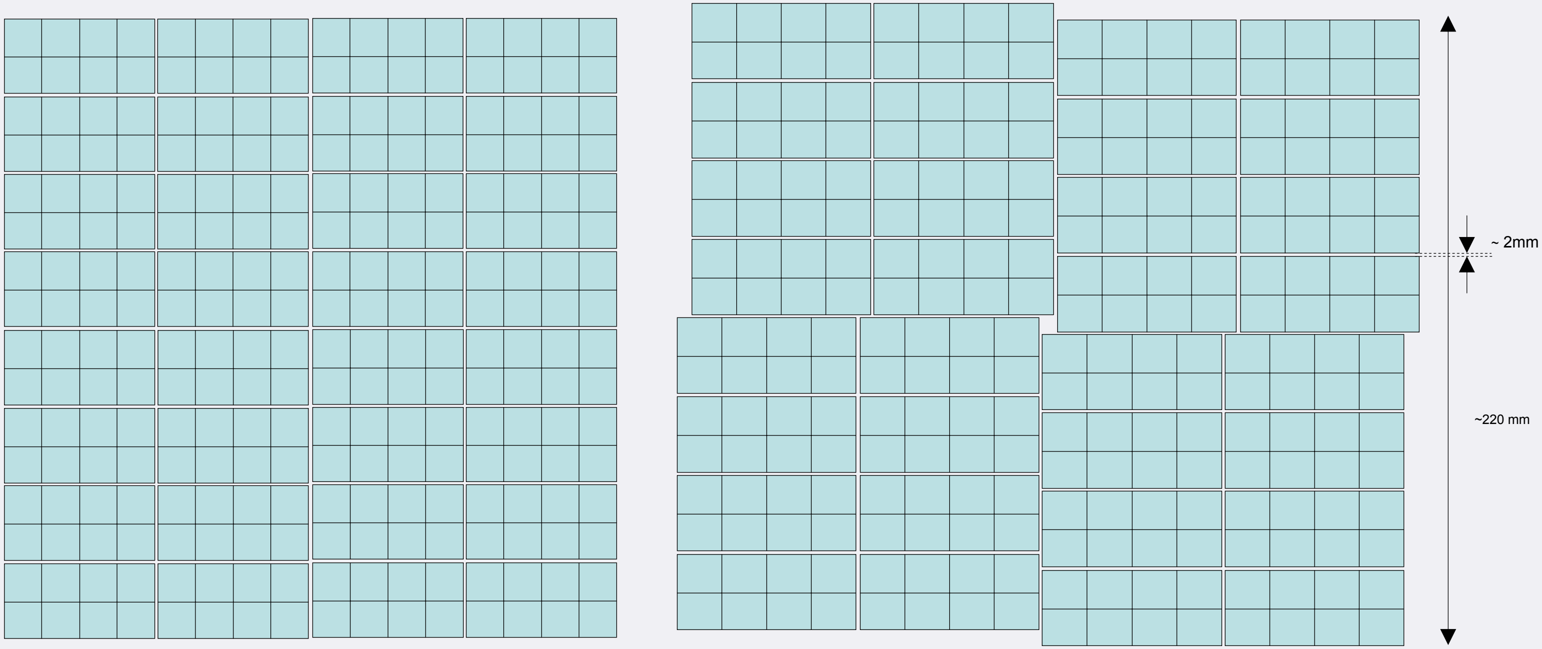
AGIPD Pixel

- wide dynamic input range
- multiple (3) scaled feedback capacitors
- reduced ADC resolution
  (10 bit instead of 12 bit)
- analogue + digital (2 bit) pipeline



HPAD layout


bump bond
chip
sensor
wire bond
HDI
Base plate
Connector to interface
electronics

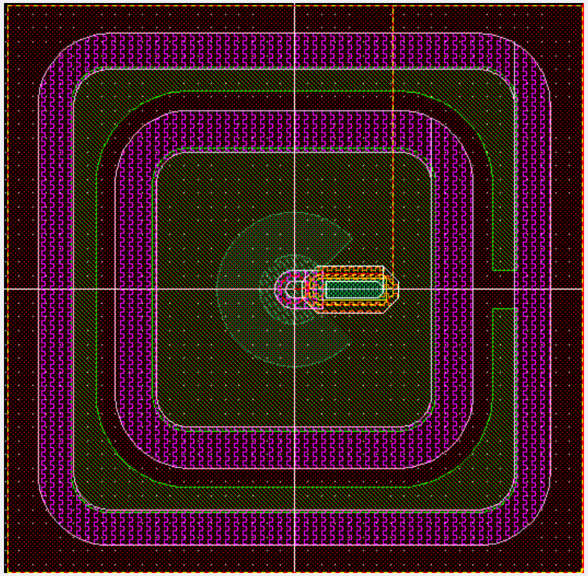

~ 2mm
~220 mm

(c) DEPFET Active Pixel Sensor (L. Strüder)

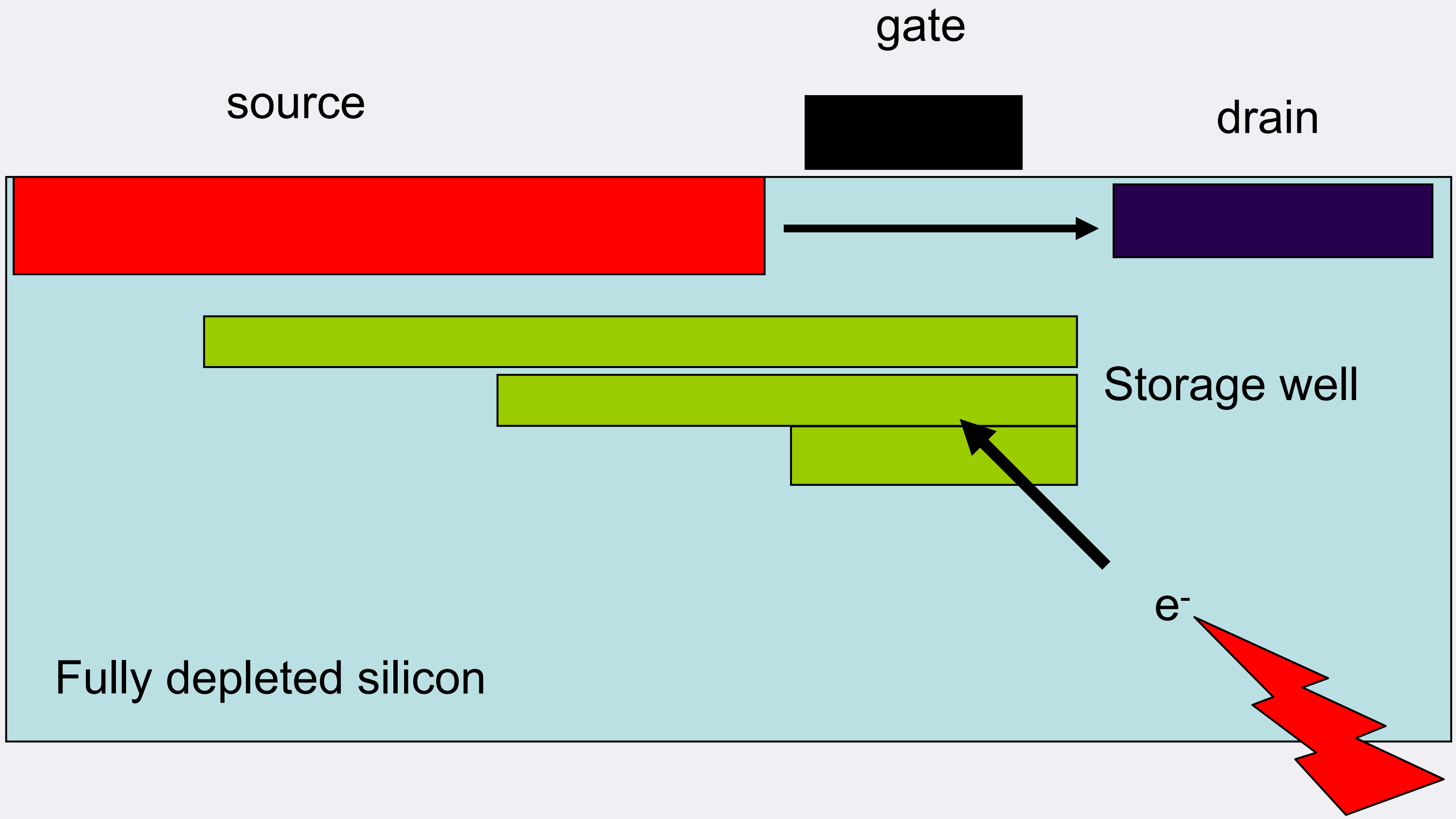
- DEPFET per pixel
- Very low noise (good for soft X-rays)
- non linear gain (good for DR)
- in pixel adc
- digital storage pipeline

- MPI-HLL, Munich
- University Bonn
- University Heidelberg
- University Siegen
- Politecnico di Milano
- University Bergamo

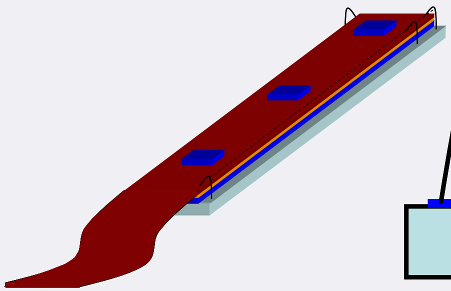
200µm x 200µm pixel combines DEPFET with small area drift detector (scaleable)

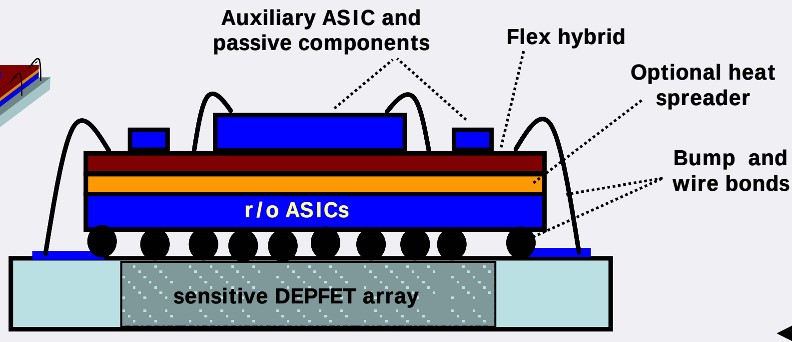


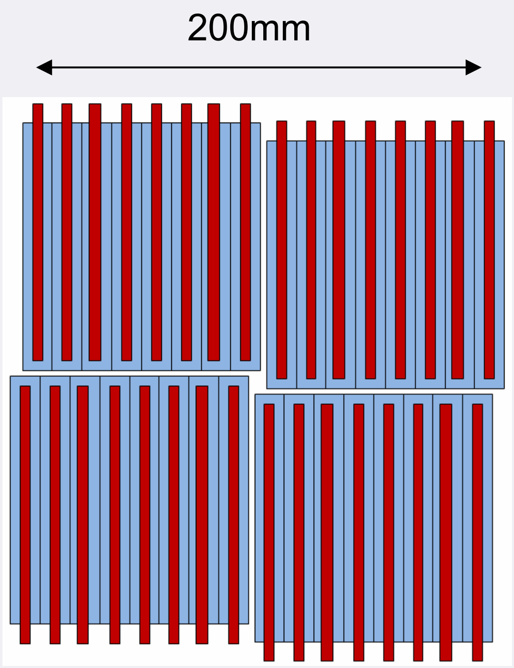
Analogue compression: non-linear gain



DEPFET Axtive Pixel Sensor Detector

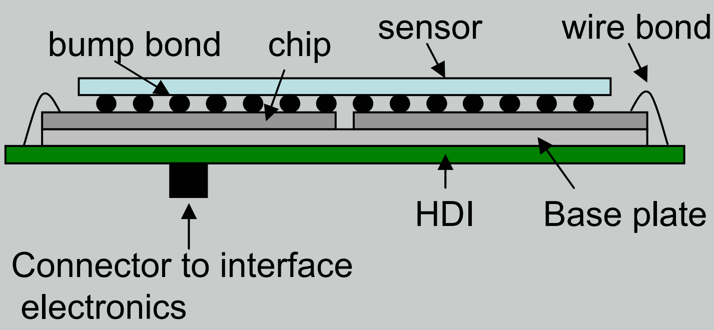


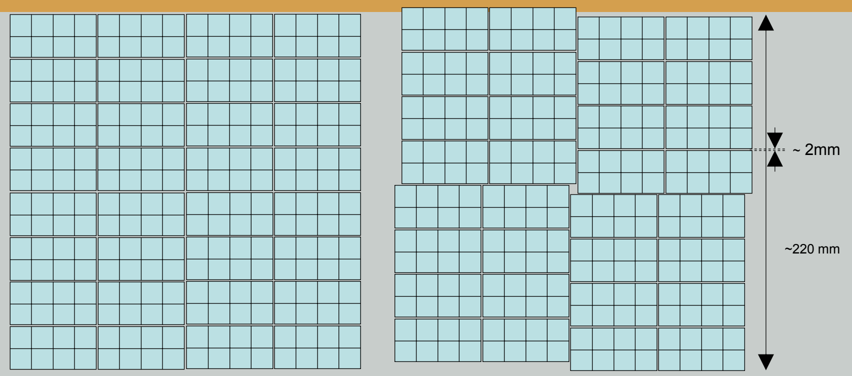


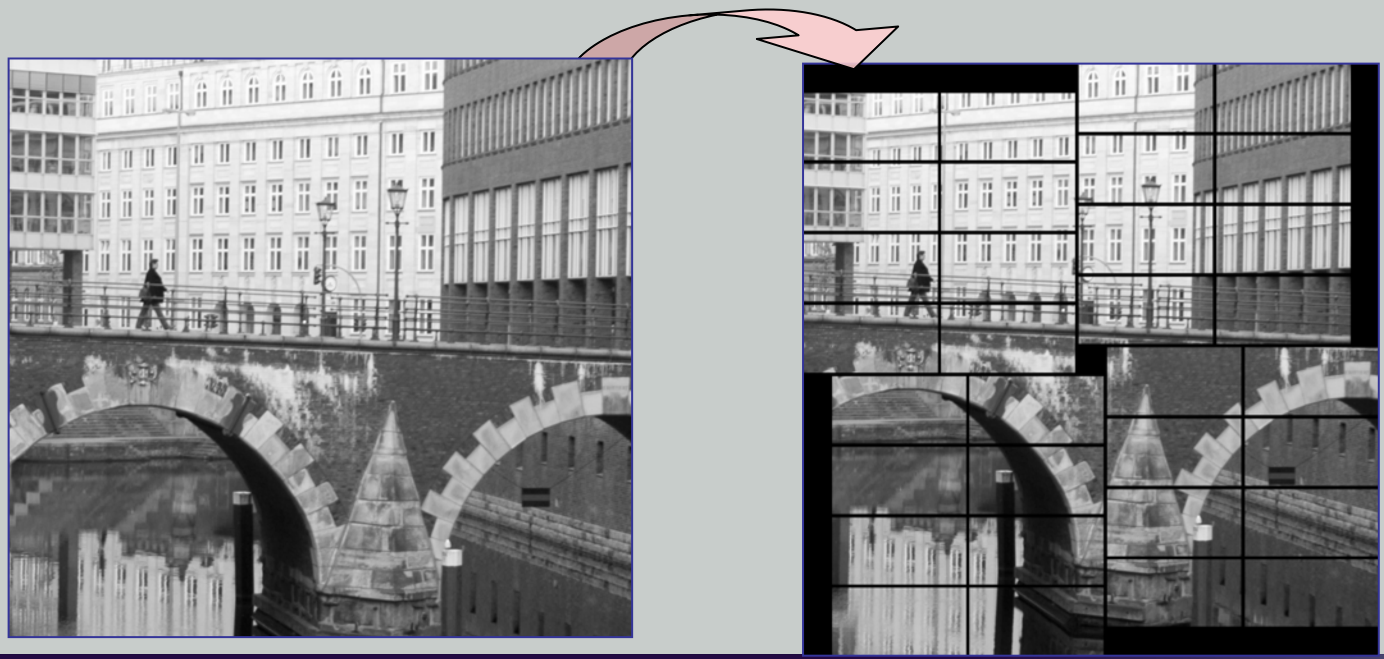


- connect detector units to ladder
- 1 ladder = 128x 512 pixels
- 8 ladders = 1 quadrant
- 4 quadrants = 1k x 1k detector

Detector response simulations (G. Potdevin)







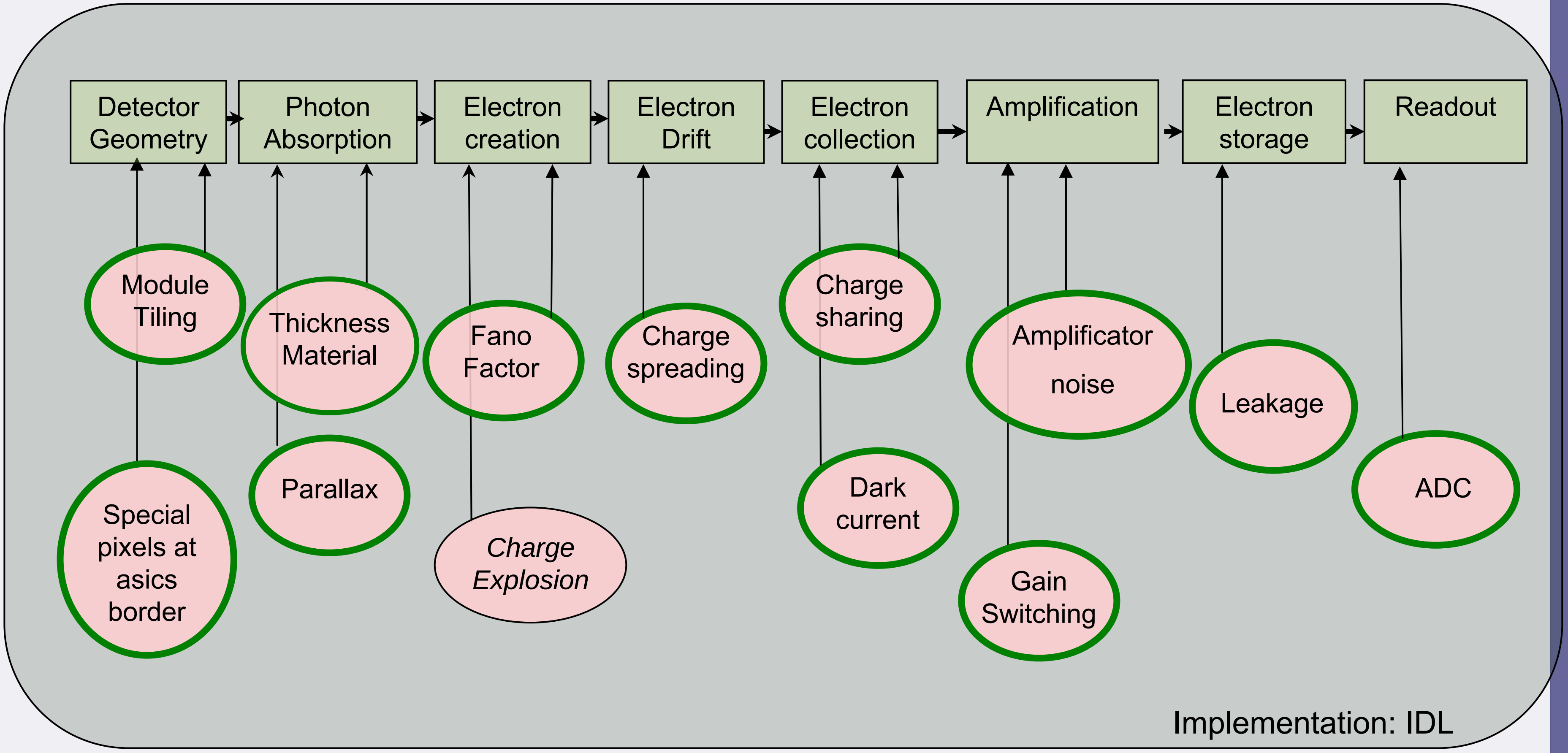
Summary of available images

Sample	Remark	Contributor
***Simulation* of Ferritin**	Single Mol, 1x1x1, 3x3x3, 5x5x5, crystal units	Pfeiffer, *et al.*
***Simulation* of Dwarf Virus**	Standalone (=single mlc) (Q: kDaltons?)	Pfeiffer, *et al.*
***Exp. data* of lithographed sample on SiN**	*Contribution from SiN* membrane to signal	Vartaniants, Schrupp, *et al.*
***Exp. data* of nanostructures**	Missing information for ADU→Photons conversion	C.Mocuta, *et al.*
Simulation of Pd nanocrystals	@100keV (irrelevant for now). No scaling in photons	Vartaniants, Blumes, *et al.*

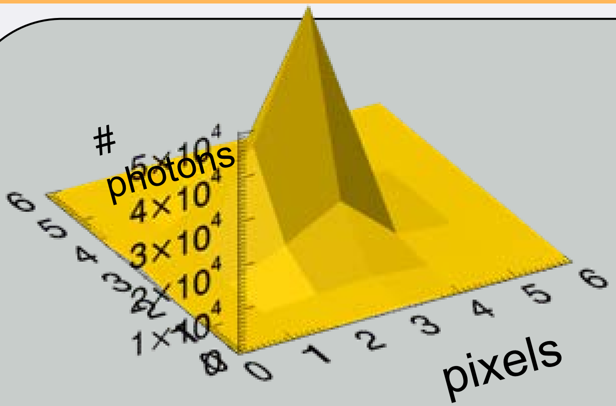
Simulation of the detector Performances (G. Potdevin)

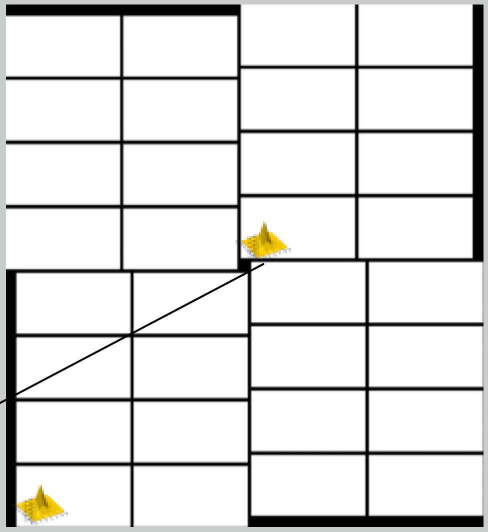
The code is built on a modular structure

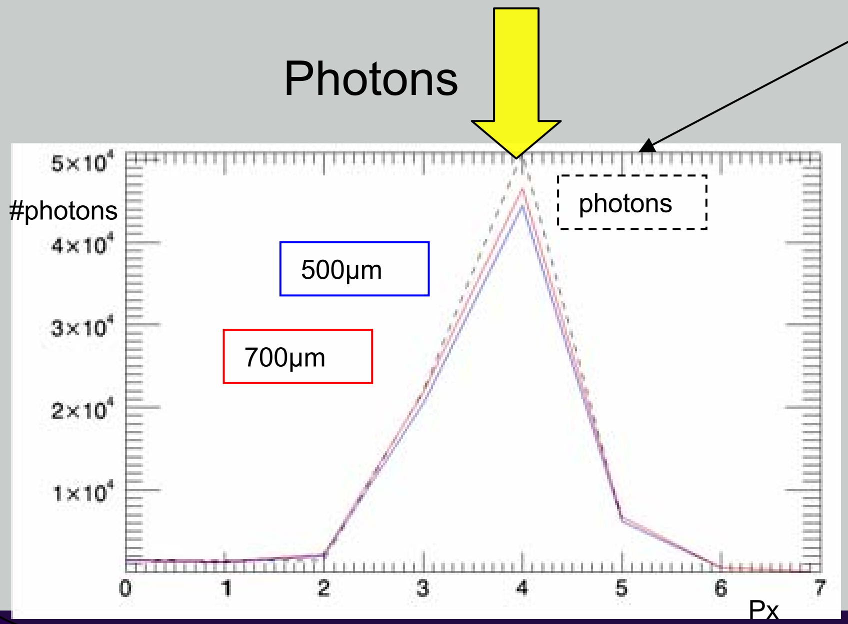
HORUS

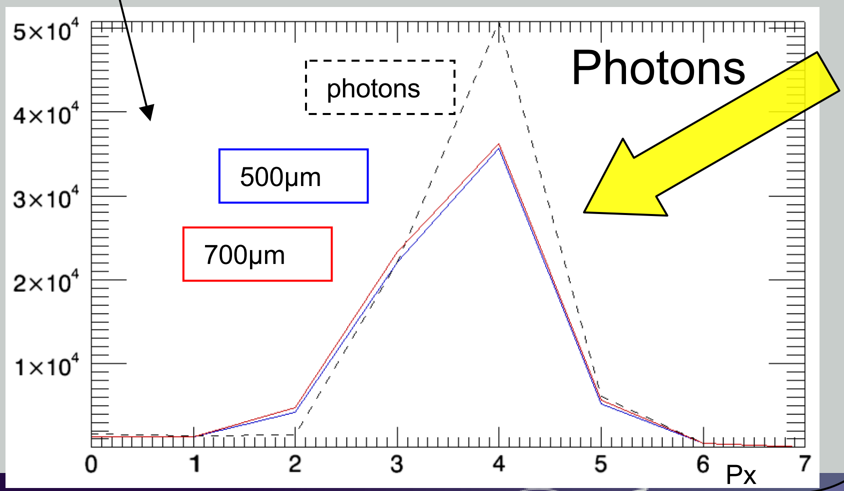


Sensor Thickness Study (G. Potdevin) 500 vs 700µm

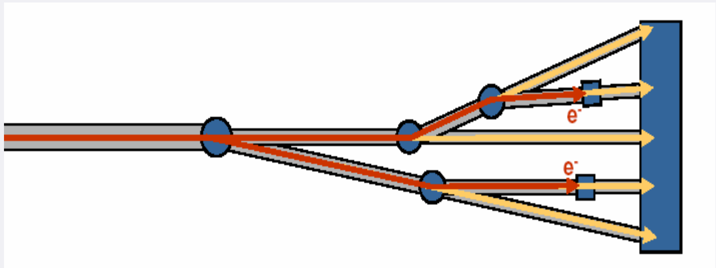








Challenges for DAQ and Control (C. Youngman)



A. Controls and Settings

- Vacuum
- Shutters and valves
- Power supplies
- Optical elements
- Cameras
- Gas flow
- Lasers
- etc.

Provide bunch to bunch correlation of accelerator and photon beam system data!

B. Acquisition of Data

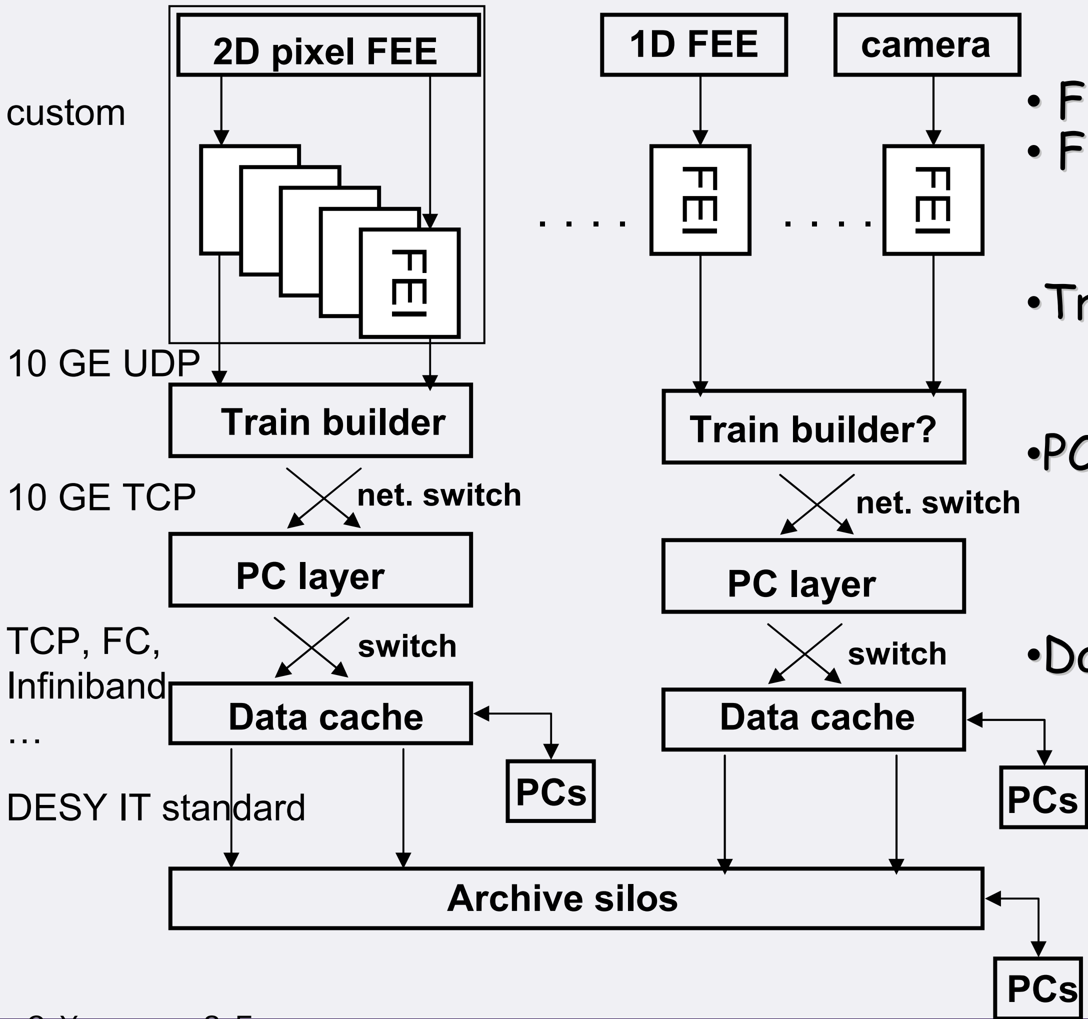
– Slow control data (Hz → KHz)
  - Status of accelerator and PBS components
  - Settings of controls and detectors
  - Machine protection system
  - Personal protection system

– Scientific Data (up to MHz)
  - e^- and photon bunch diagnostics
  - Detectors
    – Streak cameras
    – 2D Silicon Detectors
    – Spectrometer data
    – ToF
    – etc.

C. Data Management and Processing

- Online data transfer
- Processing of online data (ordering, filtering?)
- Archiving of data

DAQ architecture (C. Youngman-WP76)



- 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

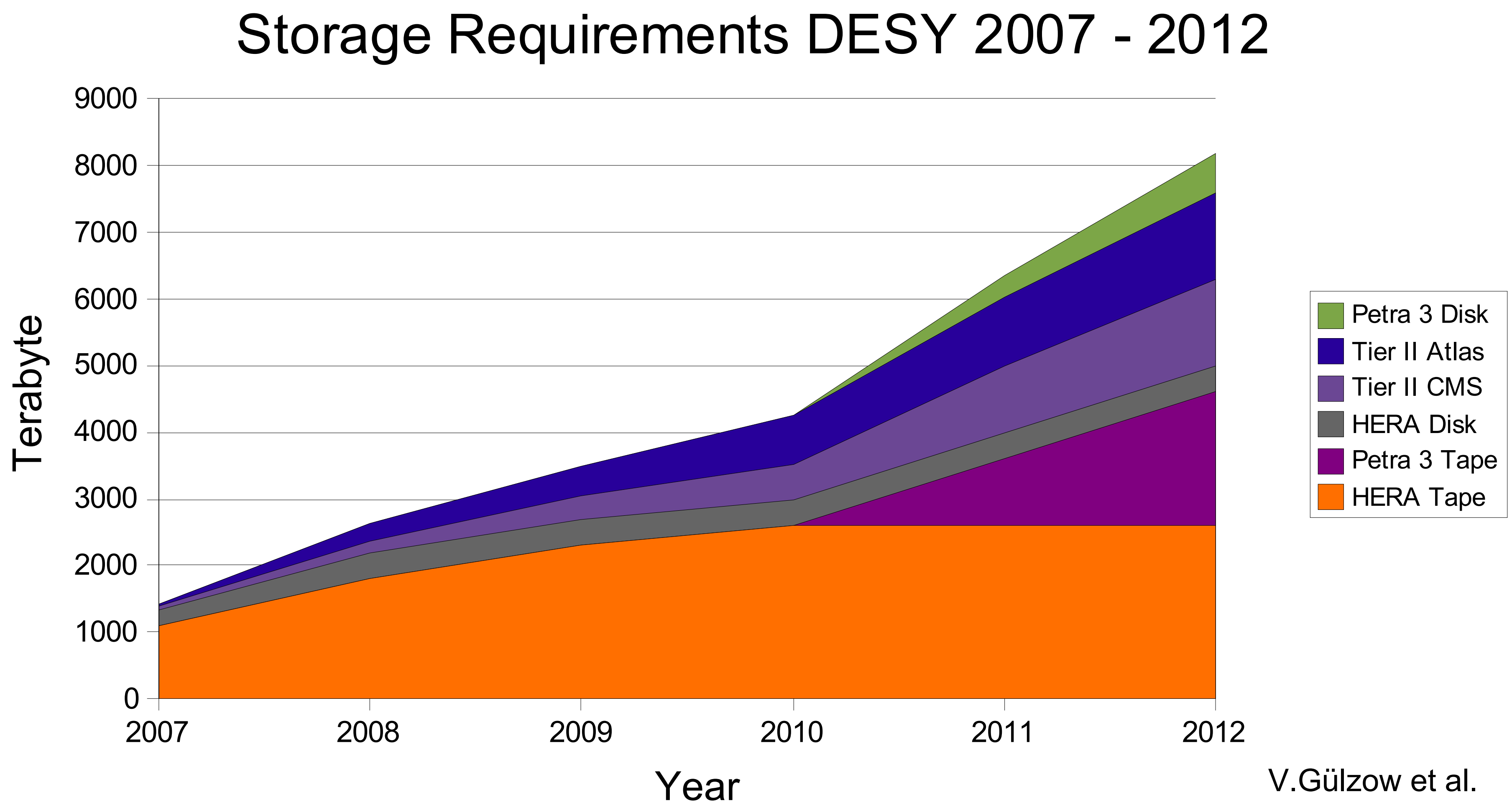
Data Storage Issues (C. Youngman-WP76)

Assume:

- 3 x 1 Megapixel 2D Detector Systems
- 2 Byte/pixel
- 500 frames per train are read taken and read out
- 10 trains per second
- Running year: 200 days = 4800 hours
- Running efficiency: 10%
- Good-frame efficiency/compression: 25% (is this realistic?)

→ ~13 Pbyte/year (1 Petabyte = 10^6 Gigabyte =10^{15} Byte)

DESY Storage Capacity Planning w/o XFEL



V.Gülzow et al.

Technology Forecast – Storage at DESY

Year	Rate Capability [Gbyte/sec]	Storage Space [Petabyte]
2009	1	3
2012	5	26
2016	40	200

- not a technology problem
- money and manpower issues
- to be determined:
  - user behaviour
  - compression and accept/reject algorithms

- potentially critical: access to data!

Summary:

- The XFELs require new generation of X-ray detectors
- 3 dedicated developments financed and under way at the European XFEL
- 2 (3) dedicated developments advanced stage in the USA (LCLS)
- Special program on Radiation Damage studies
- Special program on Charge Explosion studies
- Full detector simulation tool developed (including “real images”)
- DAQ and data storage/management structure being laid-out
- First European XFEL Prototype detectors expected 2011

A sunny future in Hamburg