Requirements for and developments 2D detectors for the FEL.

Heinz Graafsma; DESY and European XFEL

ZFEL workshop: “Nanoworld in action” June 2010

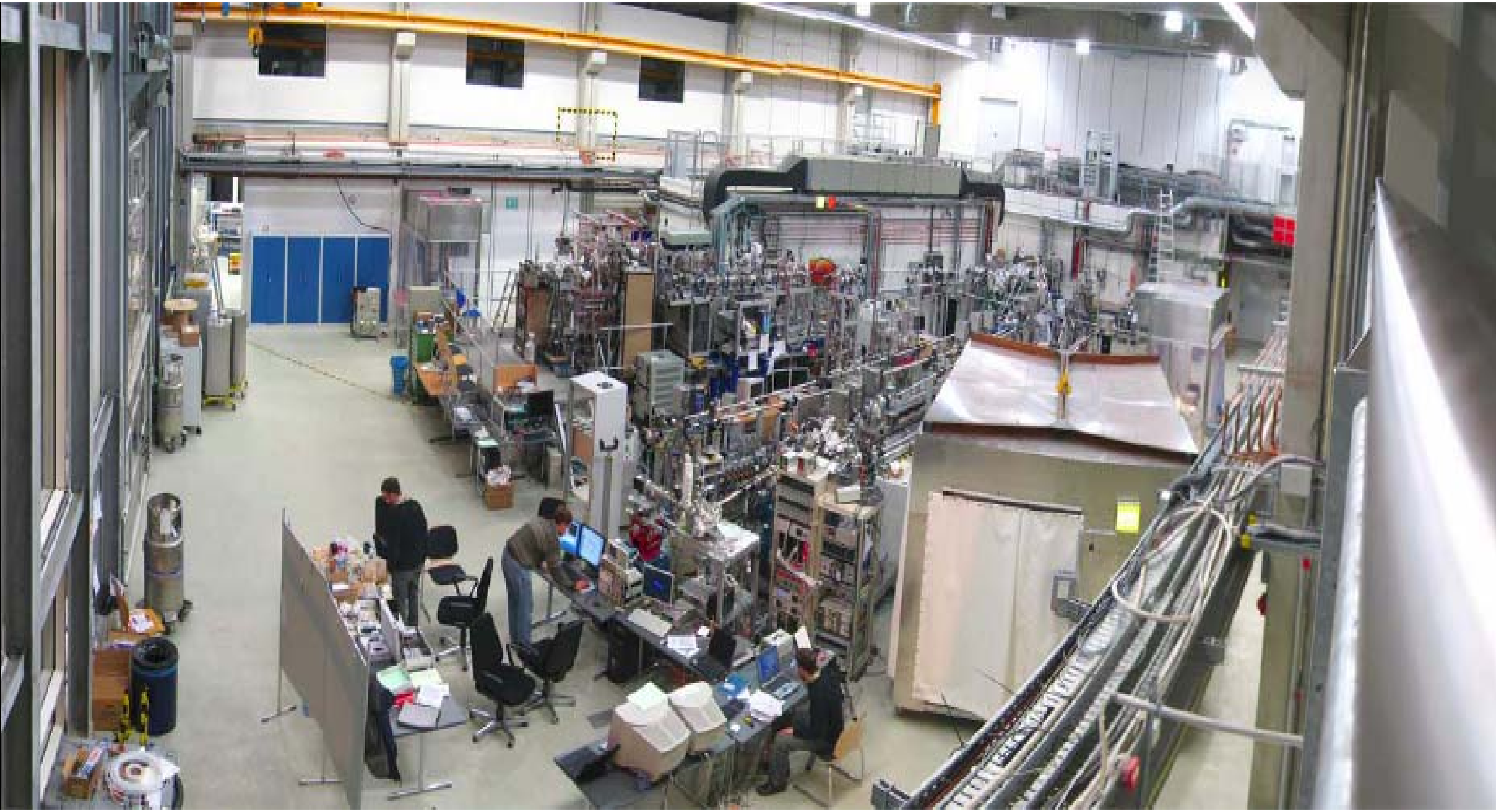
HELMHOLTZ ASSOCIATION

DESY

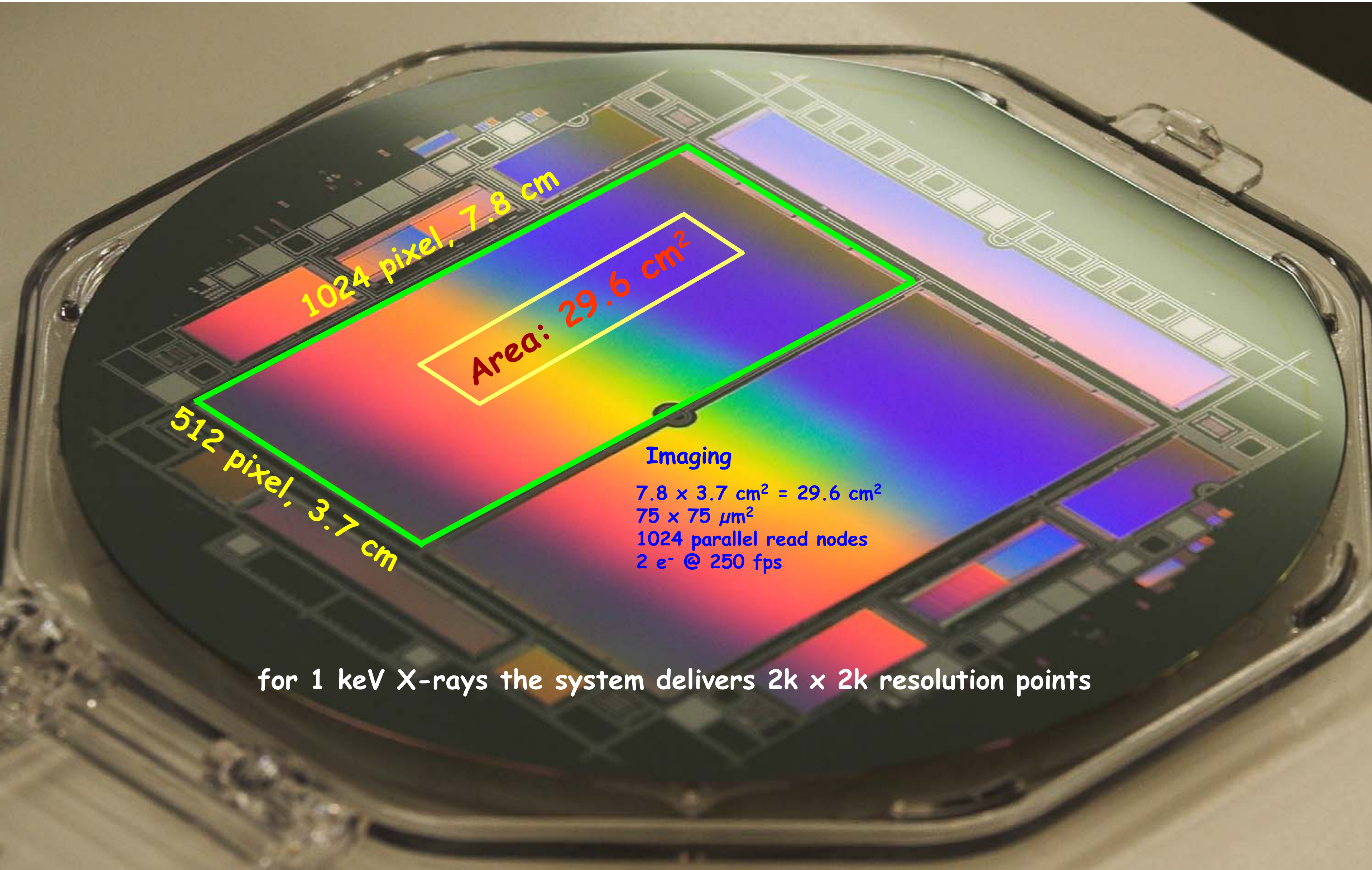
- **pnCCDs for FLASH and LCLS**
- **The European X-ray Free Electron Laser**
- **The Detector Challenge**
- **The ongoing 2D Detector Projects:**
  - **LPD**
  - **DSSC**
  - **AGIPD**
- **Simulations (HORUS)**
- **DAQ**
- **Conclusion**

Development of the DESY Campus → Also new detectors

FLASH: a 1.2 GeV FEL



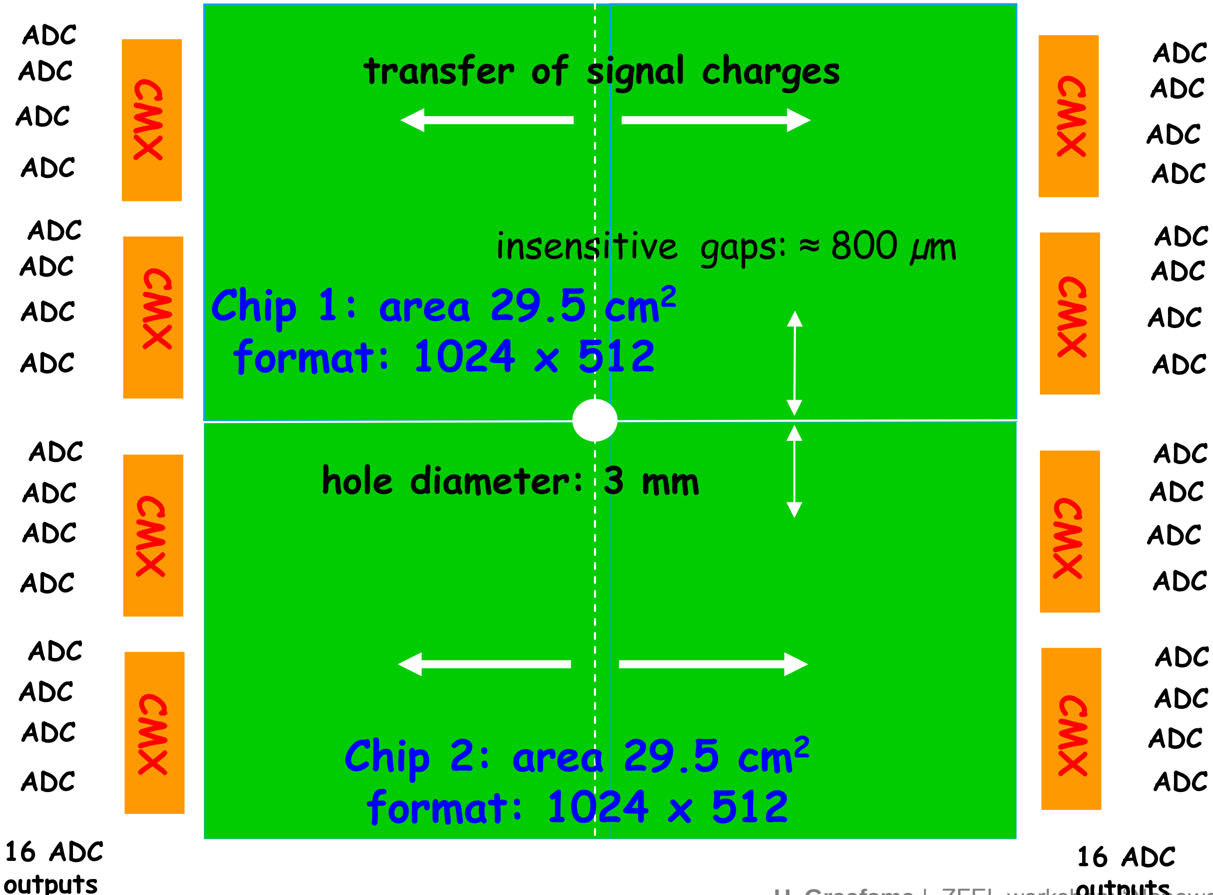
pnCCD: 1024 x 512, 30 cm^2



Detectors for FLASH+LCLS+XFEL+Petra III

device fabrication is finished now

The full sensitive area of the system is 59 cm² with 75 µm pixels, 1024 x 1024



Full Frame imaging area per chip 512 x 1024

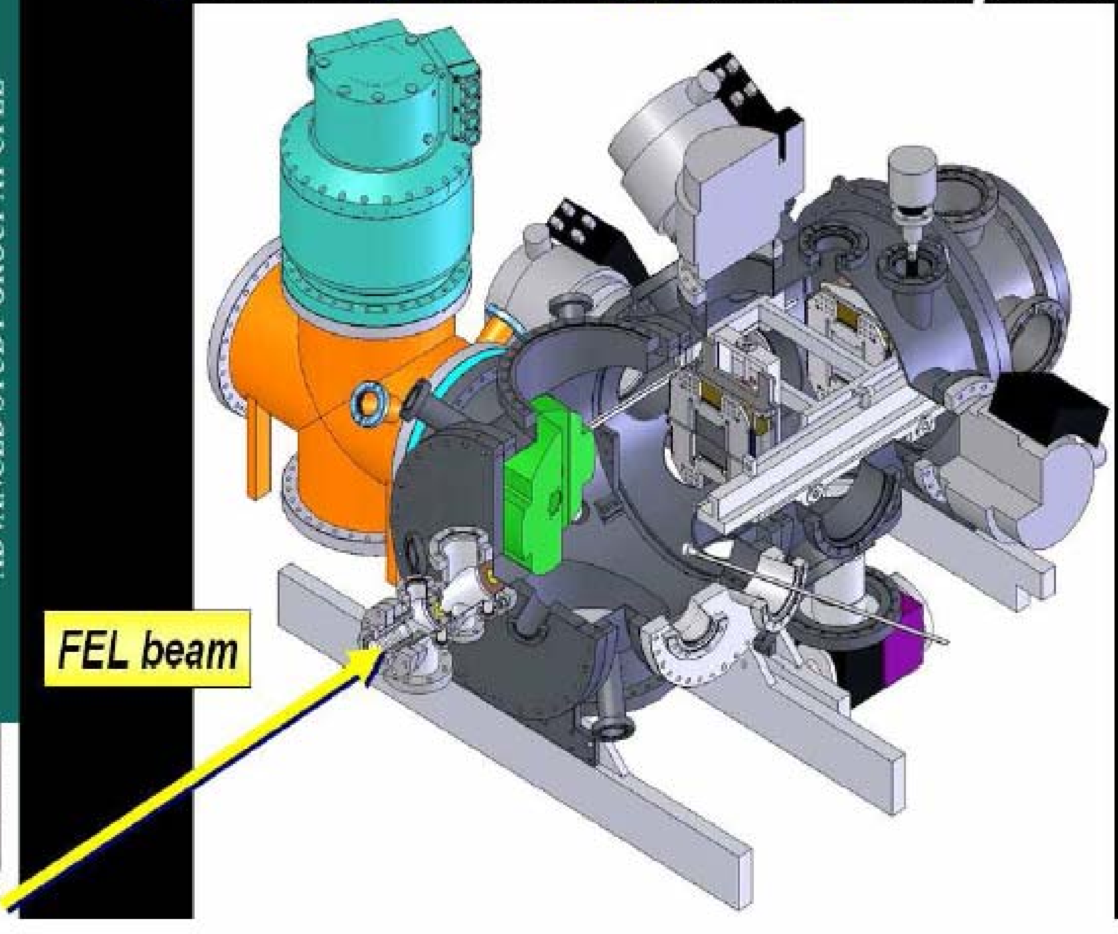
pixel size 75x75 µm²

total area per chip: 29.5 cm²

readout time per frame: 4 ms
i.e. 250 fps
can be triggered externally

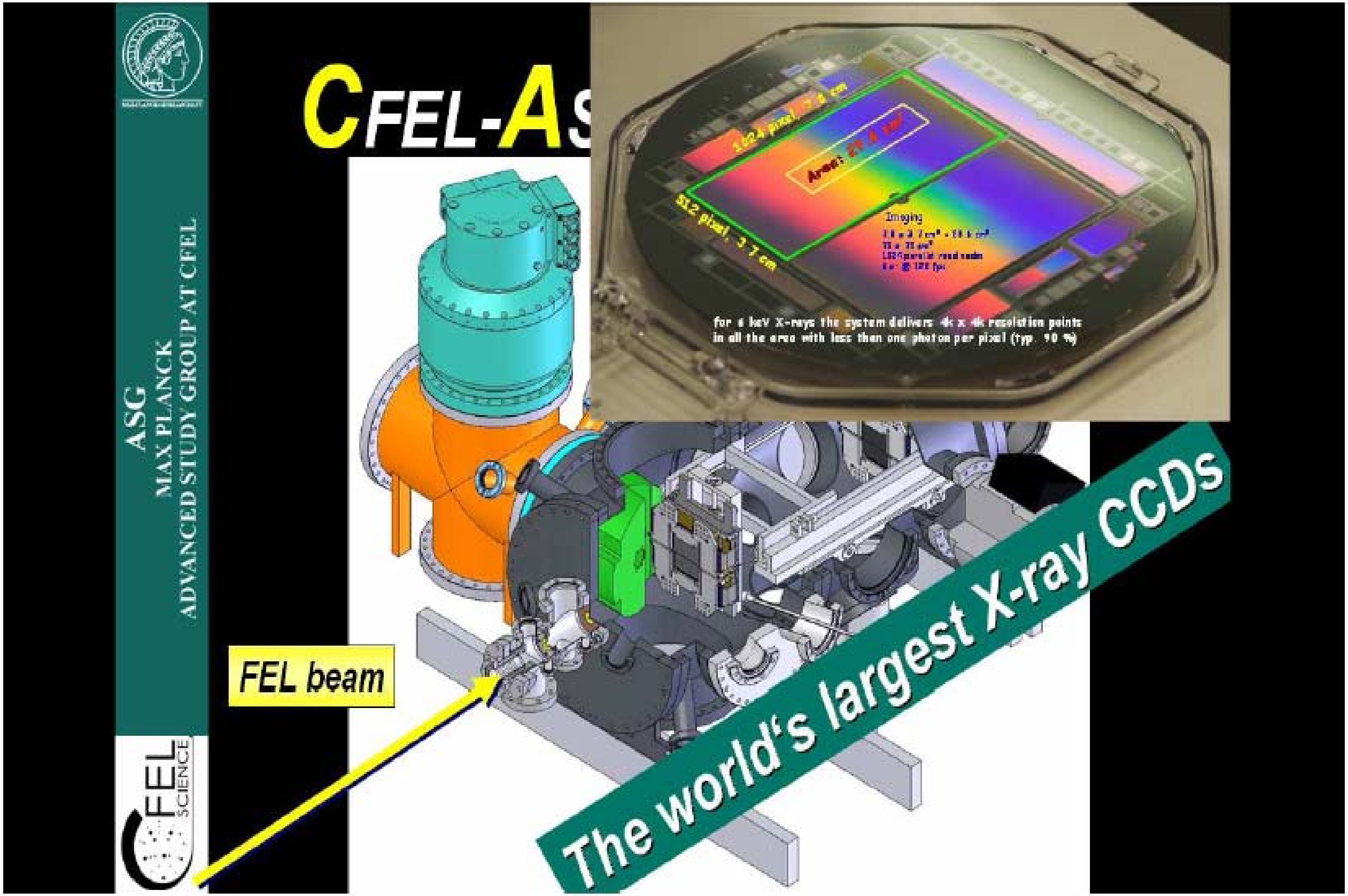
Total sensitive system area: 59 cm²

CFEL-ASG Multi Purpose



ASG
MAX PLANCK
ADVANCED STUDY GROUP AT CFEL

CFEL SCIENCE


CFEL-AS
ASG
MAX PLANCK
ADVANCED STUDY GROUP AT CFEL
512 pixel: 3.7 cm
Imaging
for 6 keV X-rays the system delivers 4k x 4k resolution points
in all the area with less than one photon per pixel (typ. 90 %)
FEL beam
The world's largest X-ray CCDs
CFEL SCIENCE

ASG
MAX PLANCK
ADVANCED STUDY GROUP AT CFEL

CAMP packed up in Hamburg:

- beginning of October 2009
- 40 containers
- 10 tons

CFEL SCIENCE

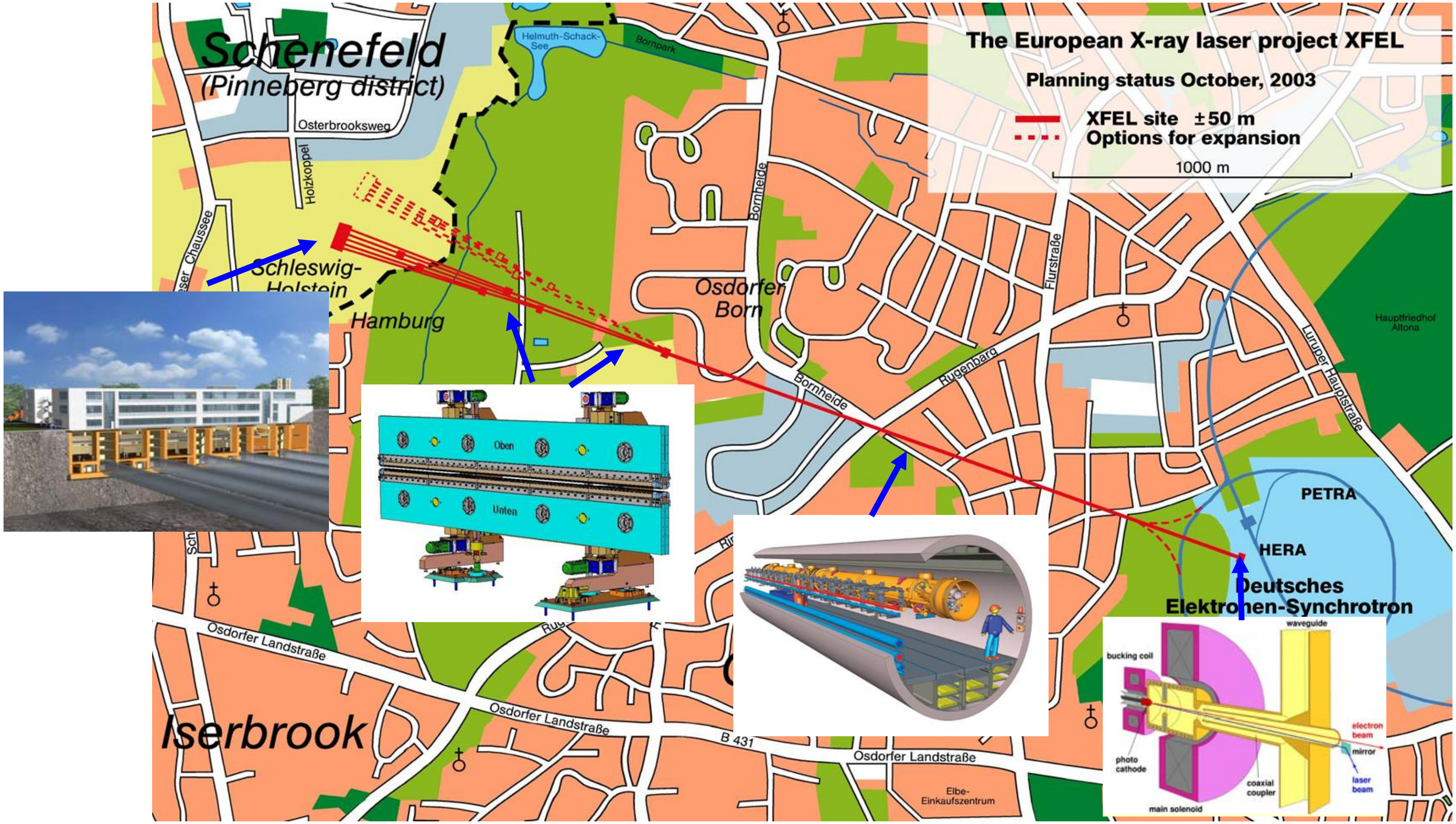
many people involved in the commissioning

The European XFEL in Hamburg

The official start of the European XFEL: 30 November 2009!

Overall layout of the European XFEL

3.4km



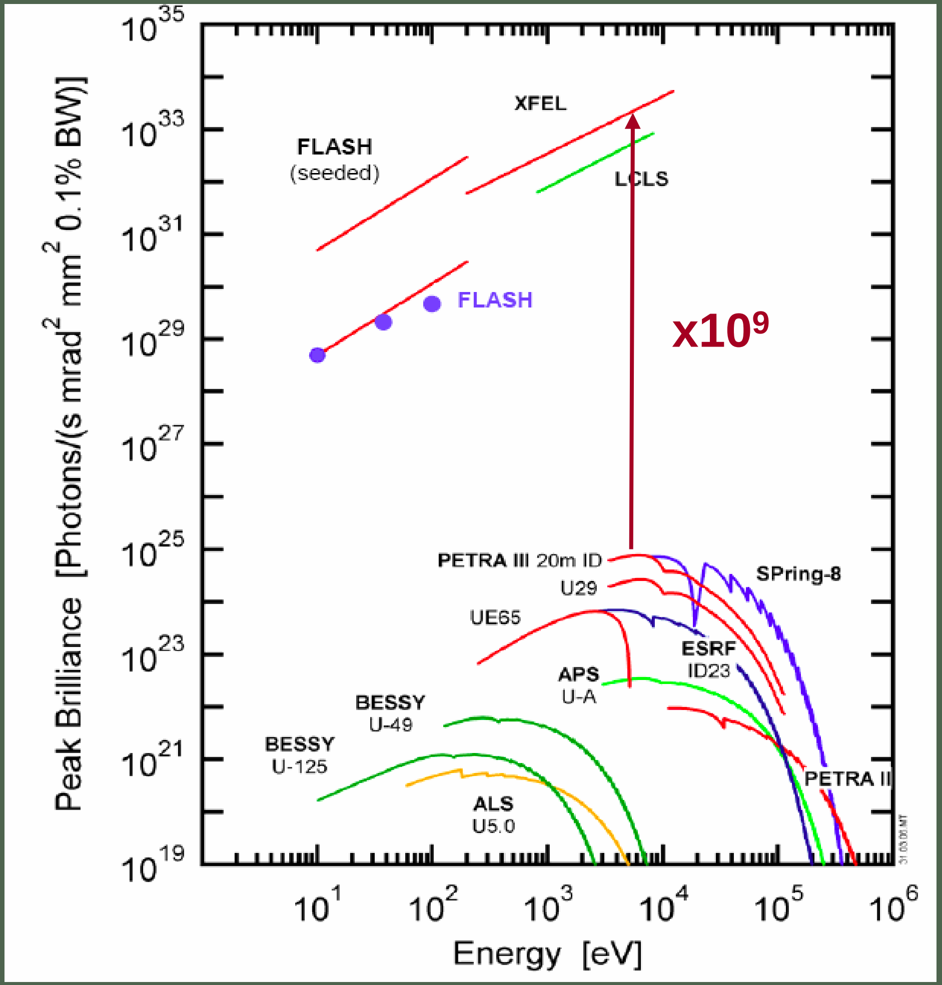
XFEL site in Hamburg/Schenefeld

… after construction *(computer simulation)*

Injector building at DESY

The end station building

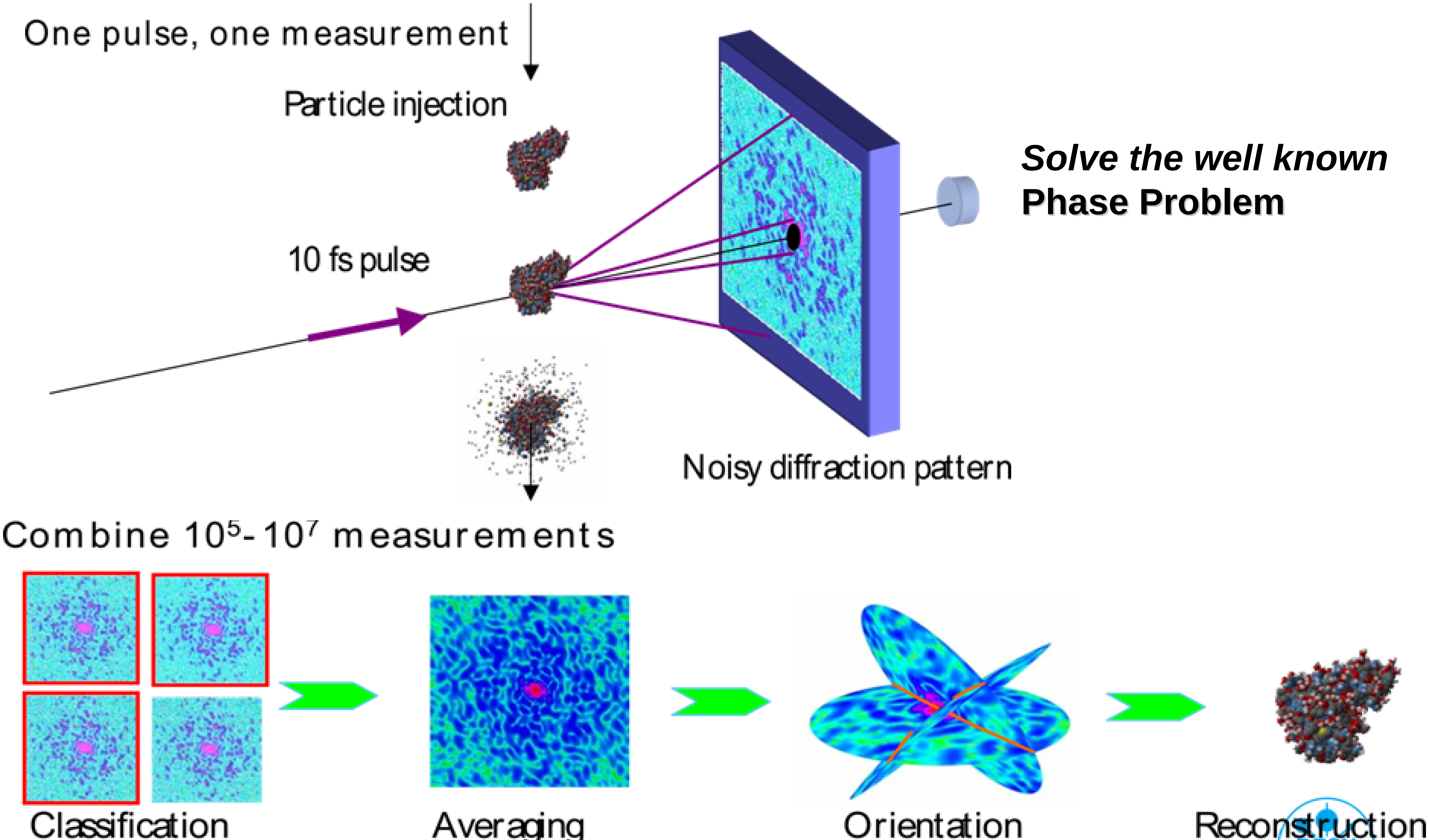
Challenge: Different Science



- Completely new science
- Fast science 100 fsec
- “Single shot” science

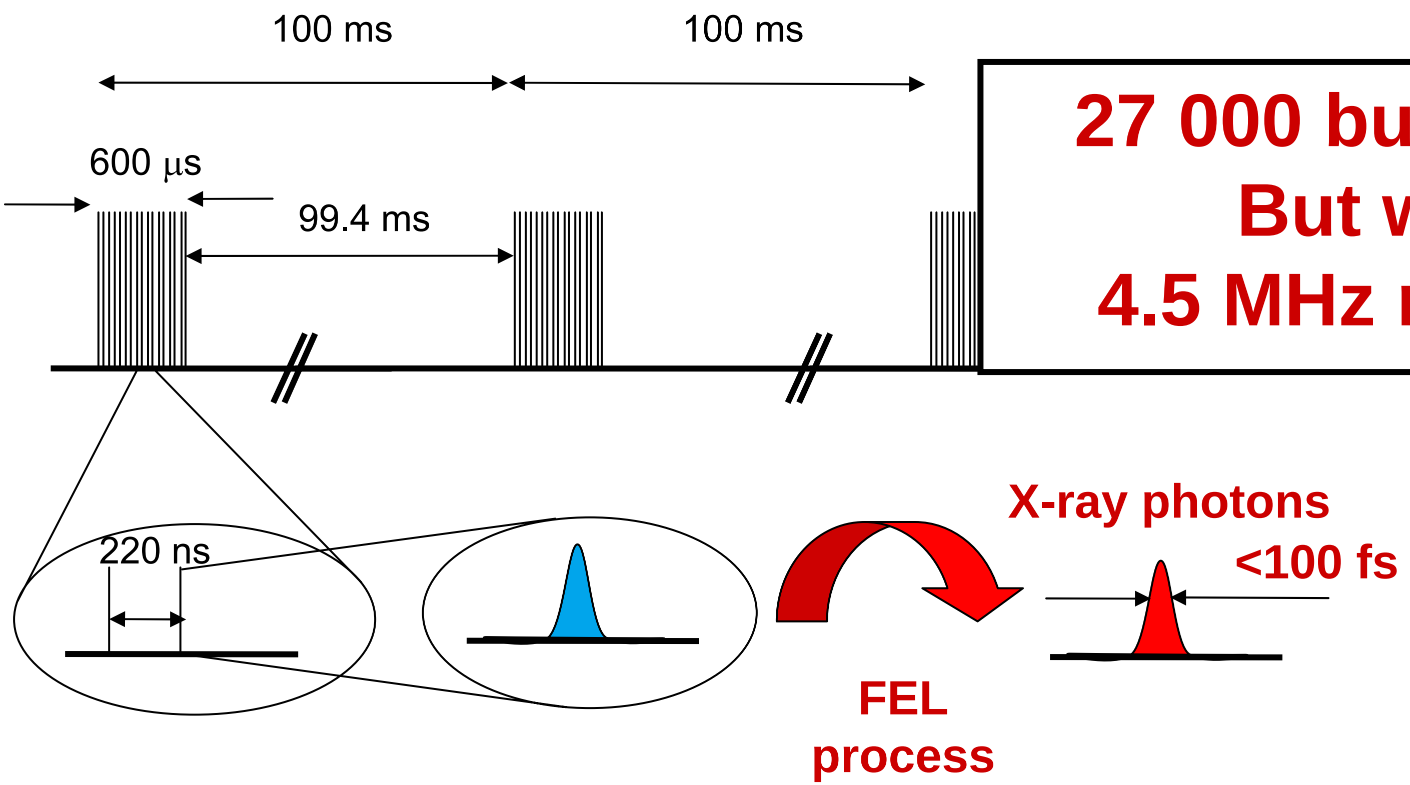
Single shot experiments

***Solve the well known* Phase Problem**



E-XFEL Challenge: Time structure = difference with “others”

Electron bunch trains; up to 2700 bunches in 600 μsec, repeated 10 times per second.
Producing 100 fsec X-ray pulses (up to 27 000 bunches per second).



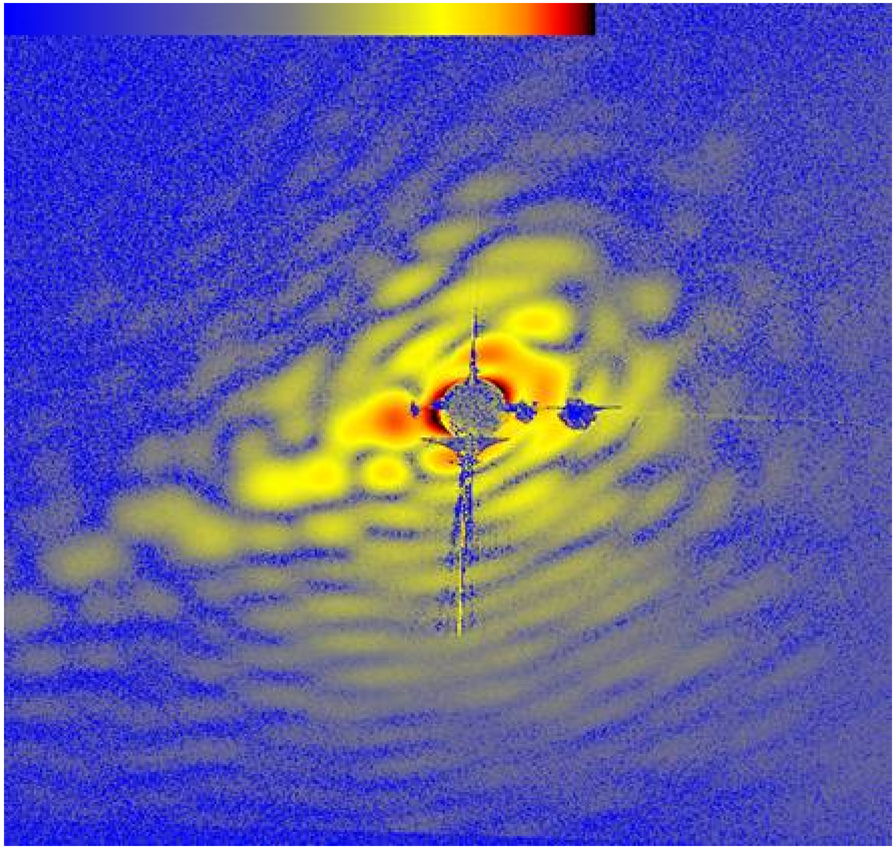
27 000 bunches/s
But with
4.5 MHz rep rate

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.**

Some Requirements and Specifications



H. Graafsma; Journal of Instrumentation (Jinst), JINST 4 P12011, (2009)

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

17th July 2006:
46 pages;
covering 5 areas

6 EoIs received; different consortia and technologies

3 EoIs selected to develop full proposal

European XFEL Project Team
c/o Deutsches Elektronen-Synchrotron DESY
in der Helmholtz-Gemeinschaft,
Notkestraße 85,
D-22607 Hamburg, Germany

XFEL
X-Ray Free-Electron Laser

Call by the:

European Project Team for the X-ray Free-Electron Laser

for:

Expressions of Interest

to:

Develop and Deliver
Large Area Pixellated X-ray Detectors.

Deadline: 30 September 2006
http://xfel.desy.de/xfelhomepage

1

The detector development projects launched

Radiation damage study

Charge cloud/explosion study

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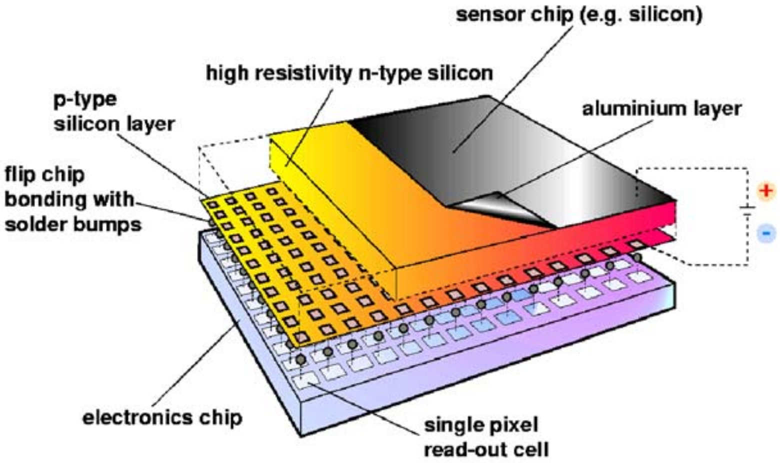
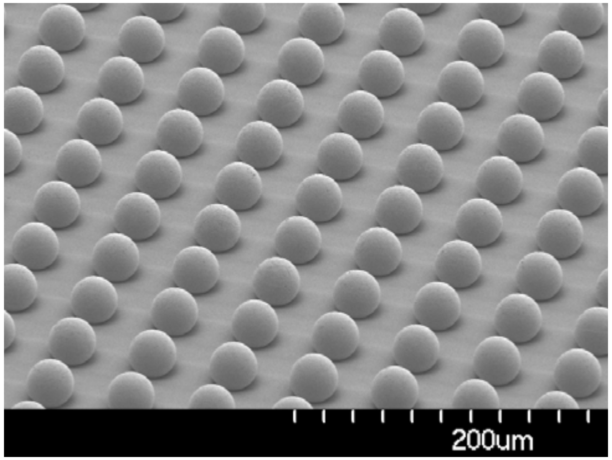
Large Pixel Detector (LPD)

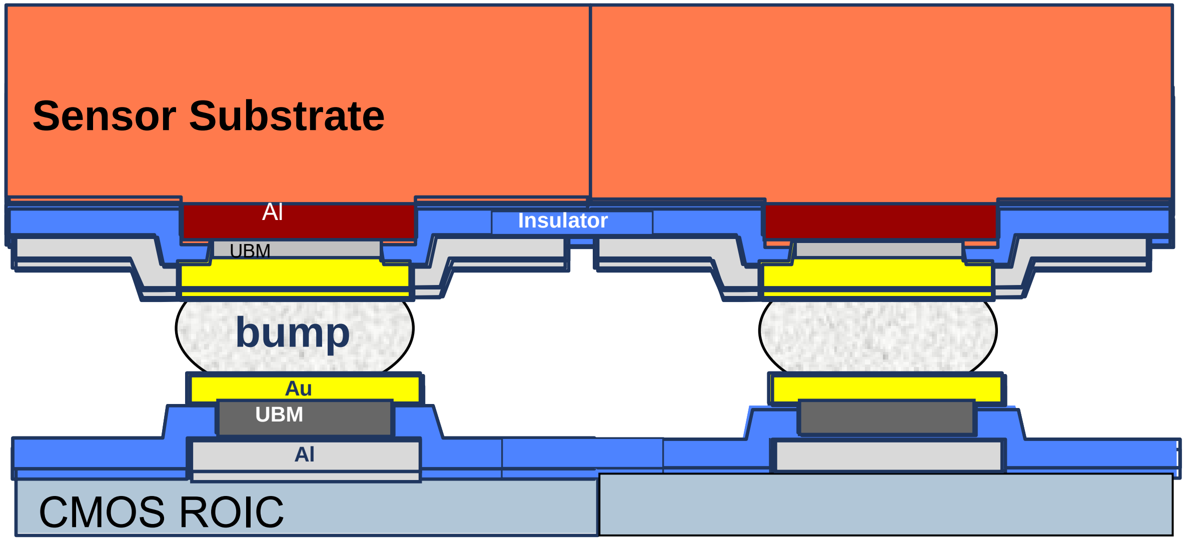
DEPFET Sensor with Signal Compression (DSSC)

Adaptive Gain Integrating Pixel Detector (AGIPD)

Hybrid Pixel Technology







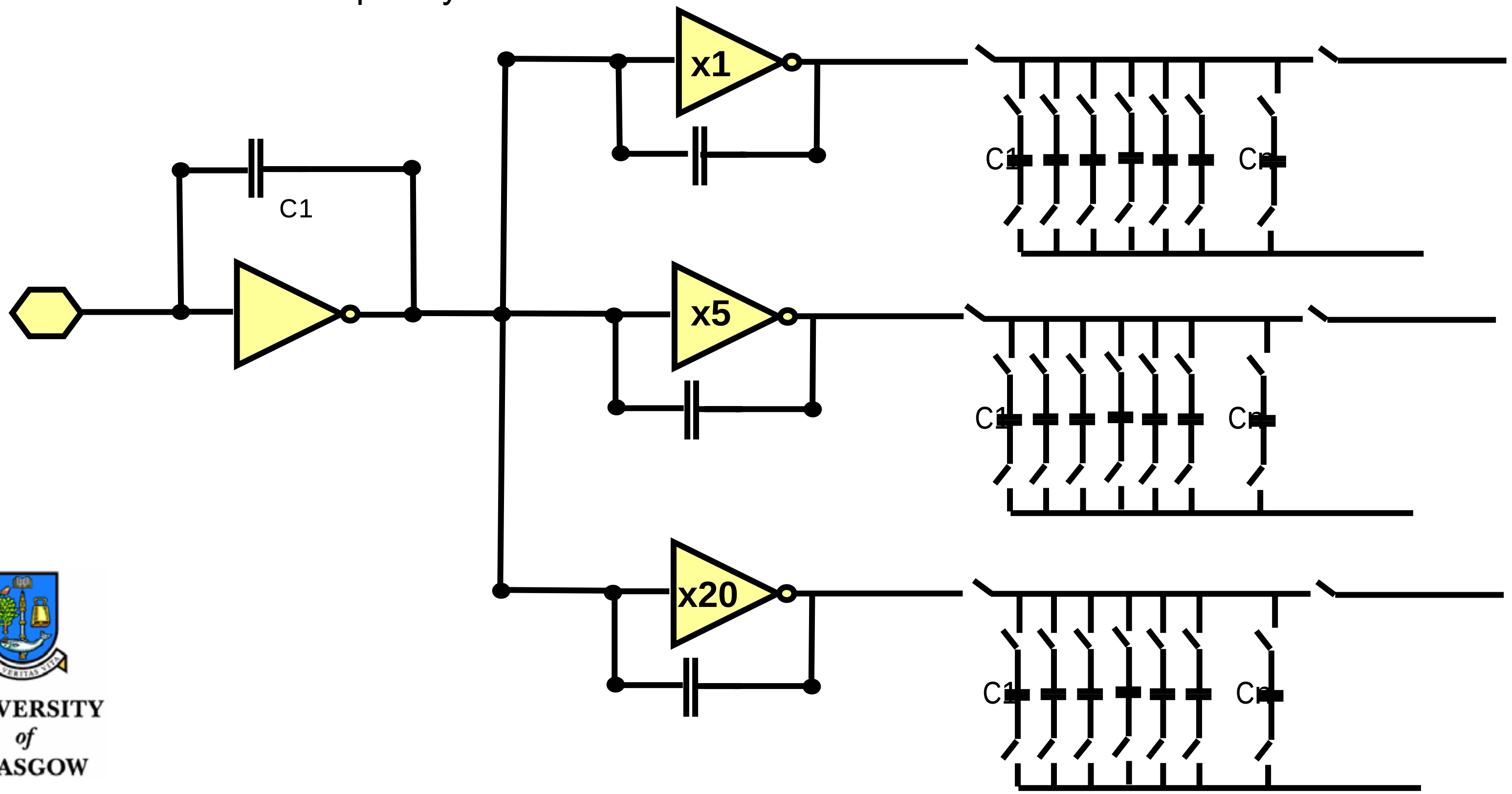
DESY

The Large Pixel Detector (LPD) project

> Multi-Gain Concept

- > Dynamic Range Compression required
- > Relaxes ADC requirements
- > Fits with CMOS complexity

Threefold analogue pipeline
On-chip ADC



UNIVERSITY of GLASGOW

Science & Technology Facilities Council
Rutherford Appleton Laboratory

(M. French, STFC)

- > STFC/RAL
- > University of Glasgow

DESY

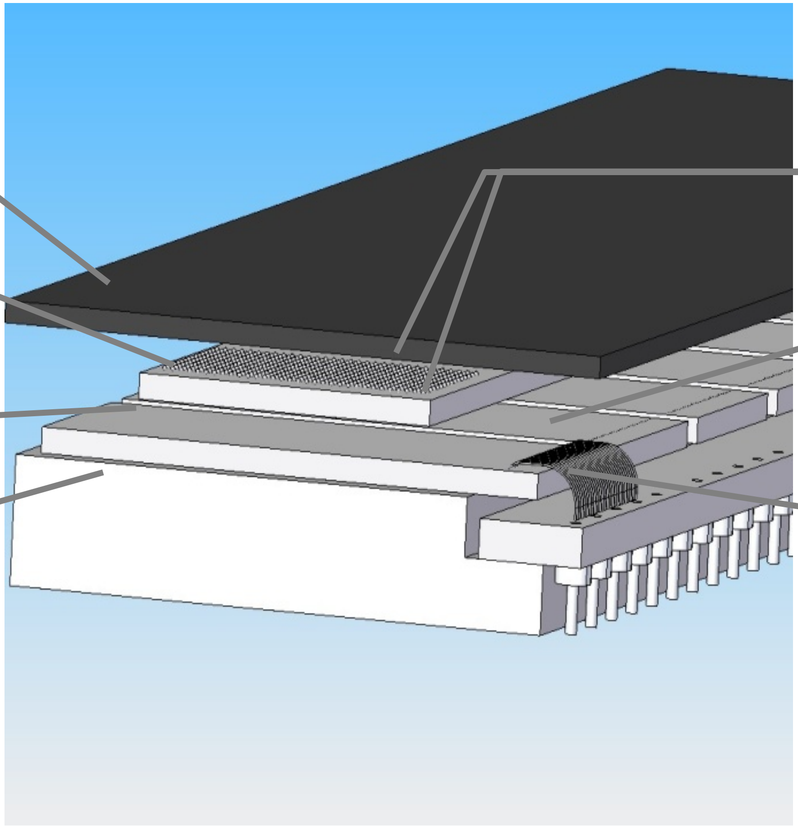
The Large Pixel Detector

> Sensor tile detail (exploded view)

- Hidden wire bonds permit ‘edge-to-edge’ sensors
- Sensor bias communicated via ASC and interposer

> 128 x 32 pixels

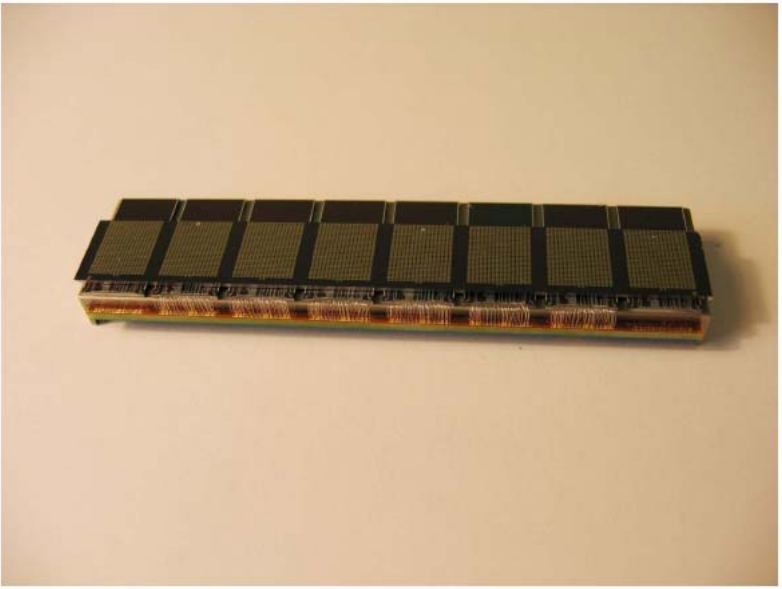
> of 500 x 500 μm

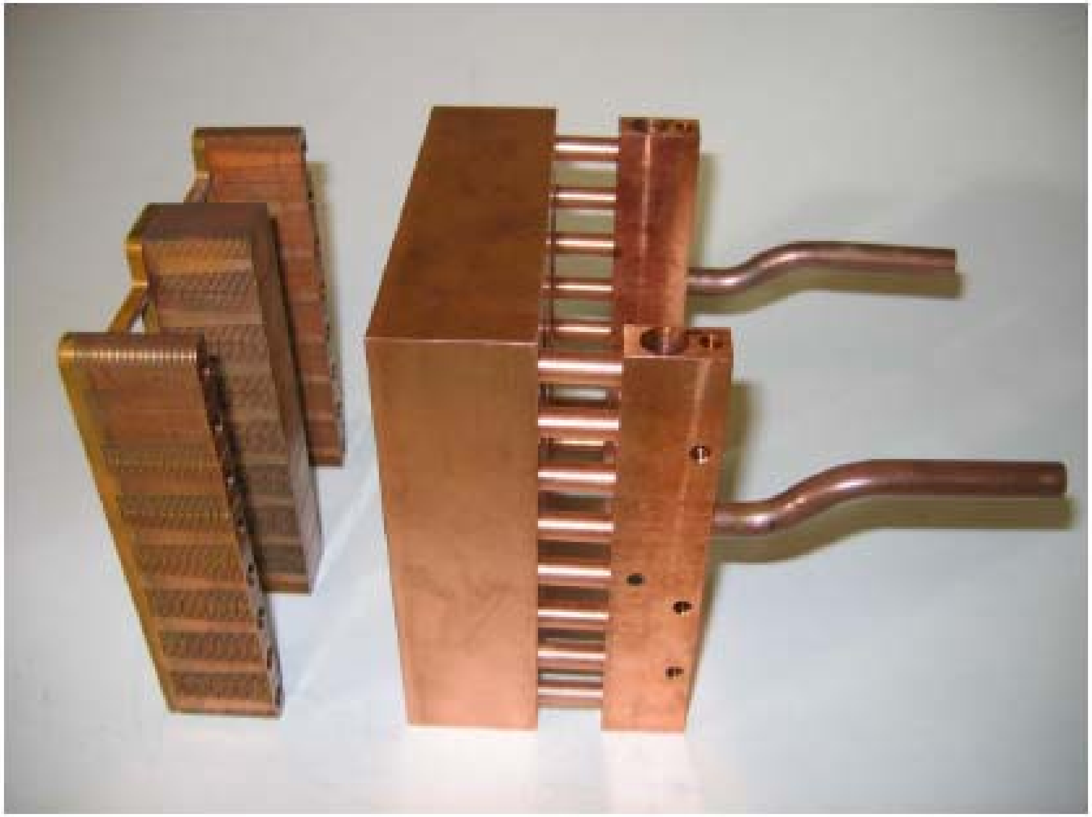


(M. French, STFC)

The Large Pixel Detector

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



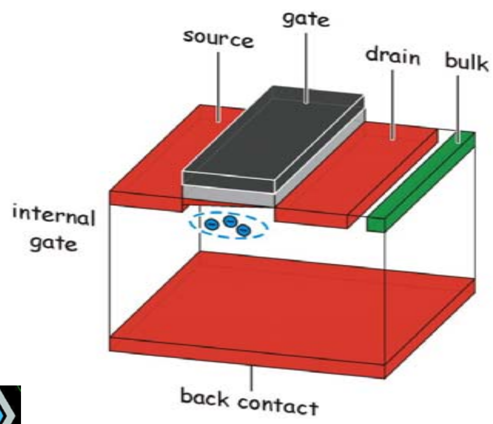


(M. French, STFC)

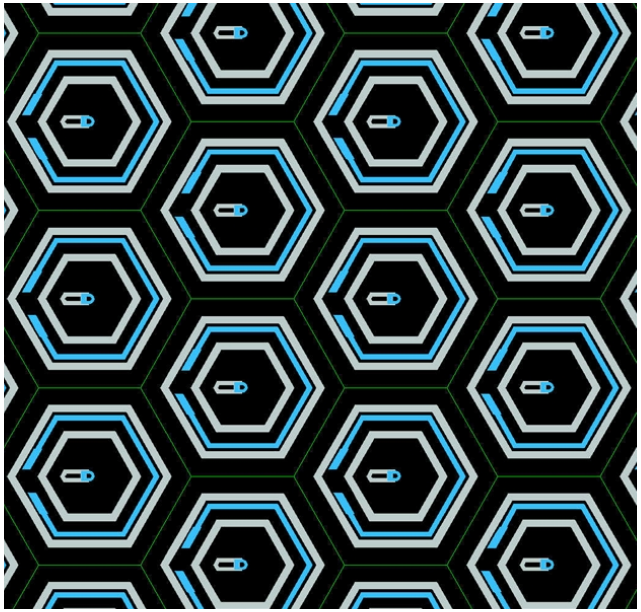
The DEPFET Sensor with Signal Compression (DSSC) project

DSSC - DEPMOS Sensor with Signal Compression (MPI-HLL)

- DEPFET per pixel
- Very low noise (good for soft X-rays)
- non linear gain (good for dynamic range)
- per pixel ADC
- digital storage pipeline



- **Hexagonal pixels ~200µm pitch**



- combines DEPFET
- with small area drift detector (scaleable)

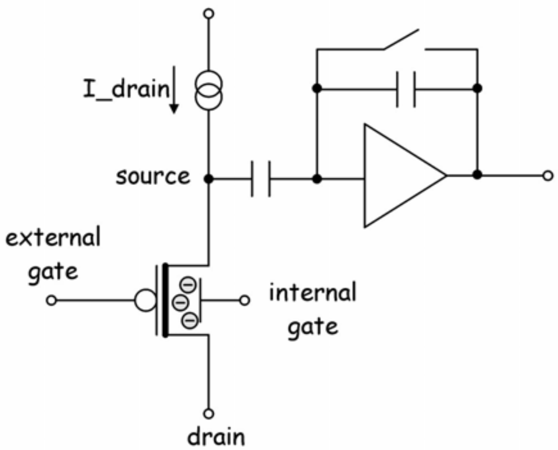
- MPI-HLL, Munich
- Universität Heidelberg
- Universität Siegen
- Politecnico di Milano
- Università di Bergamo
- DESY, Hamburg

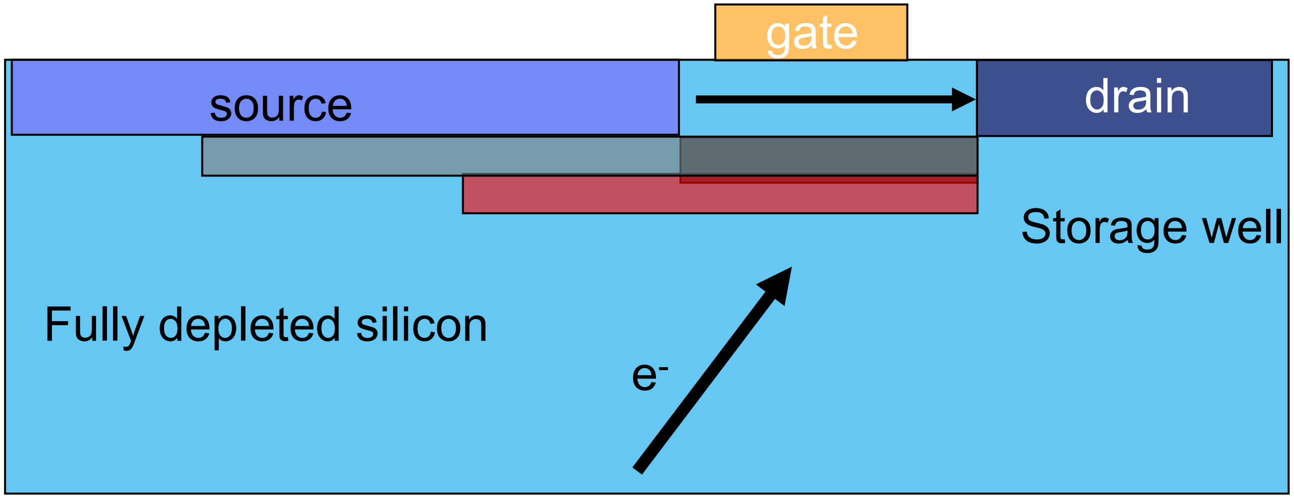
(L. Strüder, MPI-HLL)

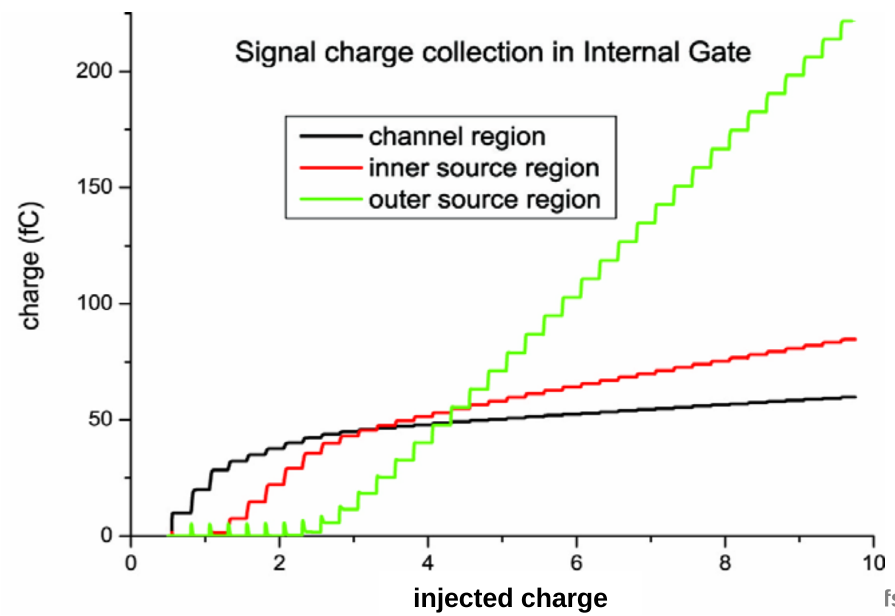
DEPMOS Sensor with Signal Compression

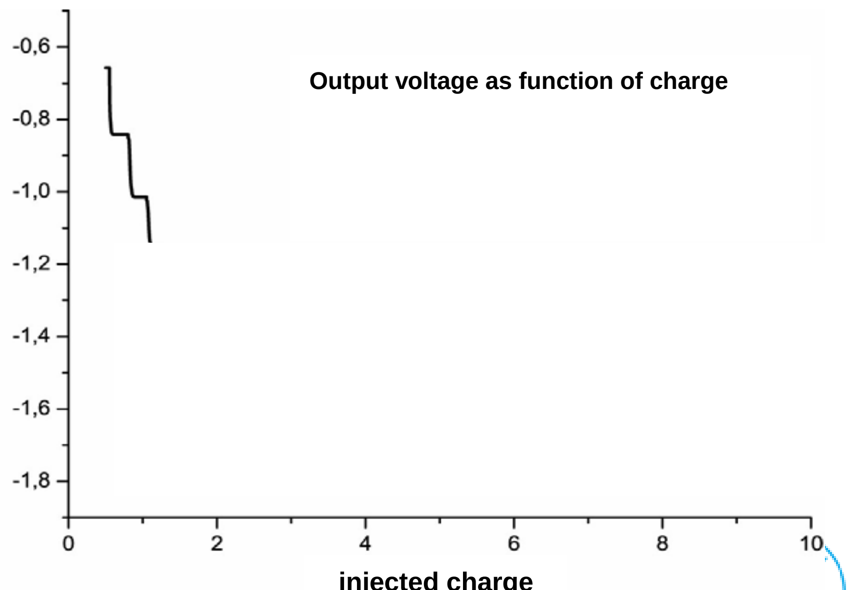
DEPFET: Electrons are collected in a storage well

⇒Trigger current from source to drain

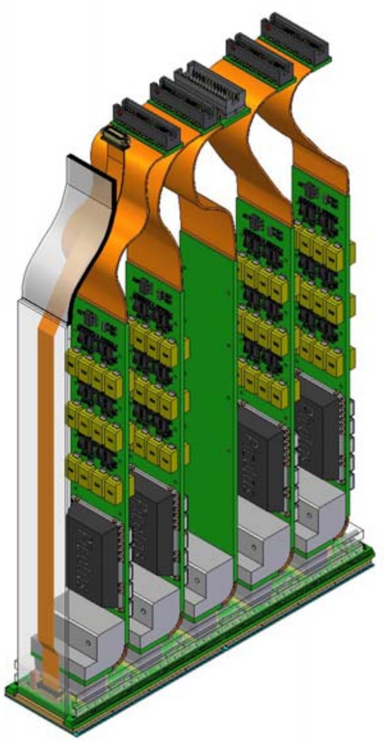


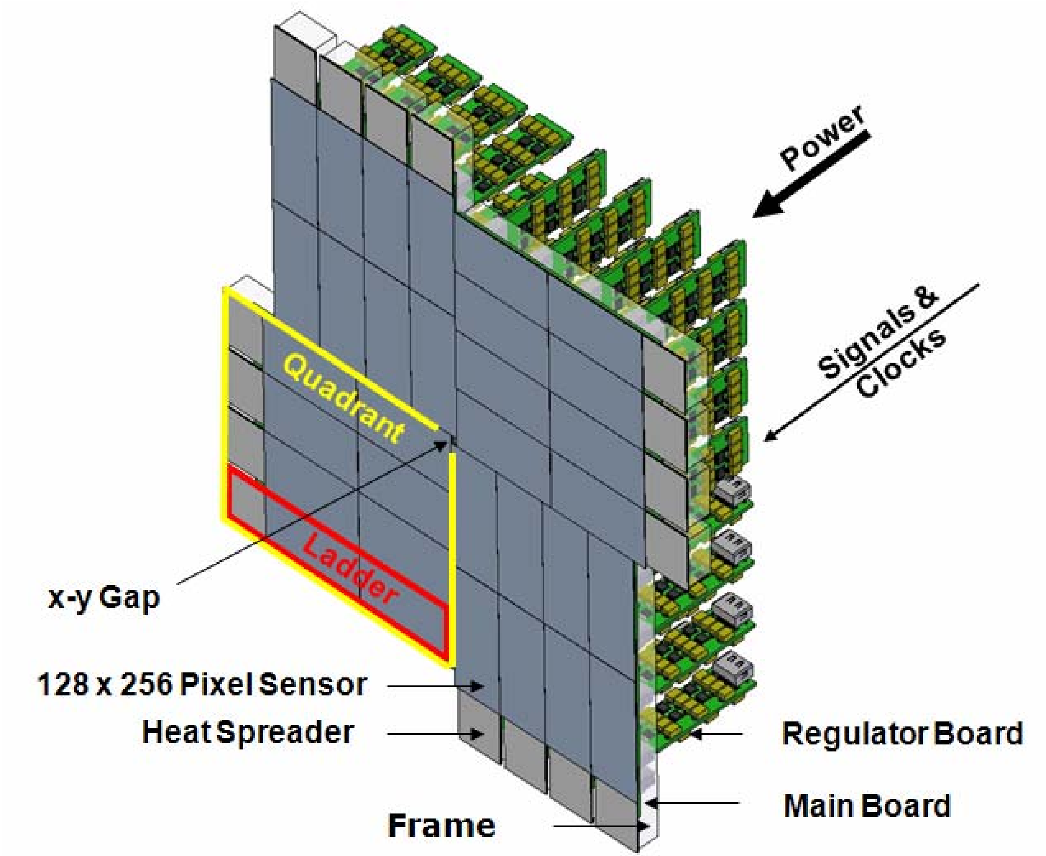






DEPFET Active Pixel Sensor Detector





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

The Adaptive Gain Integrating Pixel Detector (AGIPD) project

The Adaptive Gain Integrating Pixel Detector

> The AGIPD consortium:

PSI/SLS -Villingen: **chip design; interconnect and module assembly**

Universität Bonn: **chip design**

Universität Hamburg: **radiation damage tests, “charge explosion” studies; and sensor design**

DESY: **chip design, interface and control electronics, mechanics, cooling; overall coordination**

Some Facts

5 years development

~ 20 people

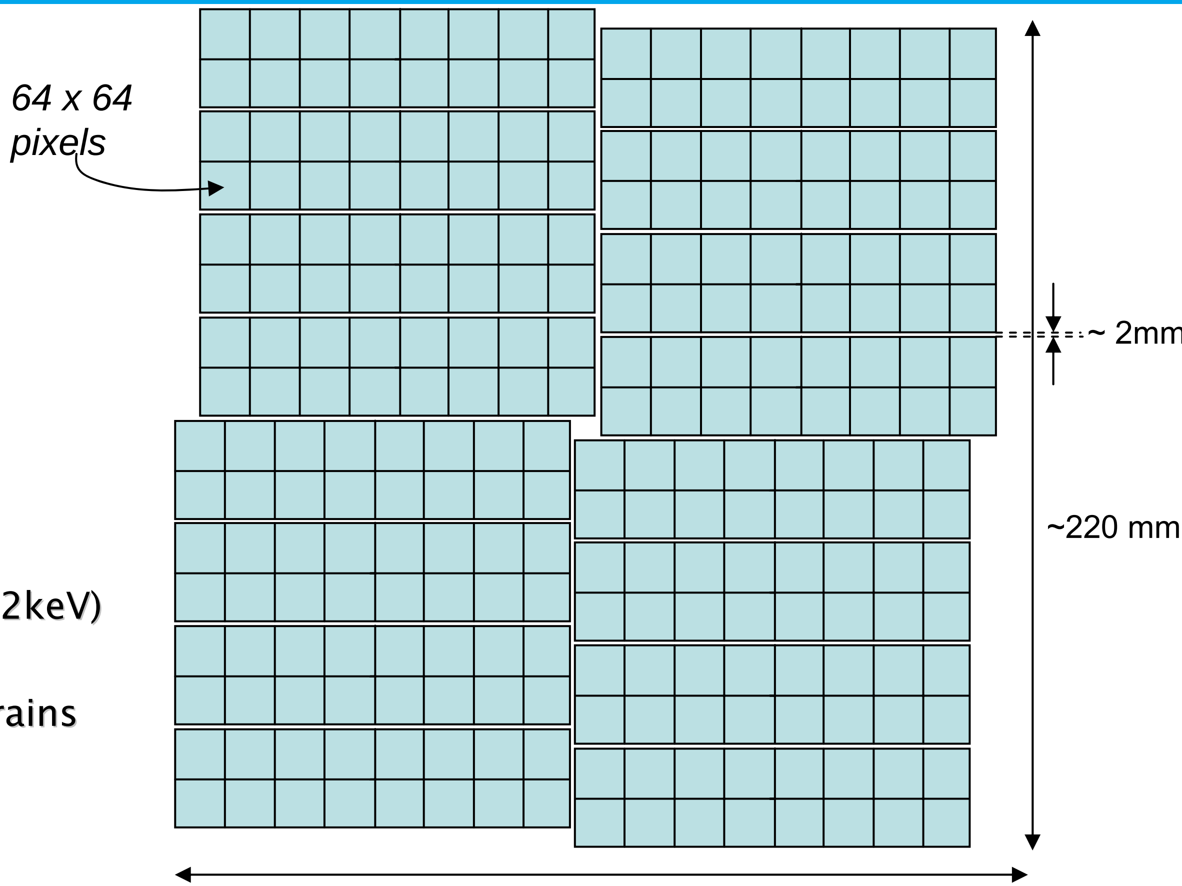
Some Milestones

First 16x16 pixels prototype	End 2009
Definition of final design	End 2010
Production, assembly and test	>2013

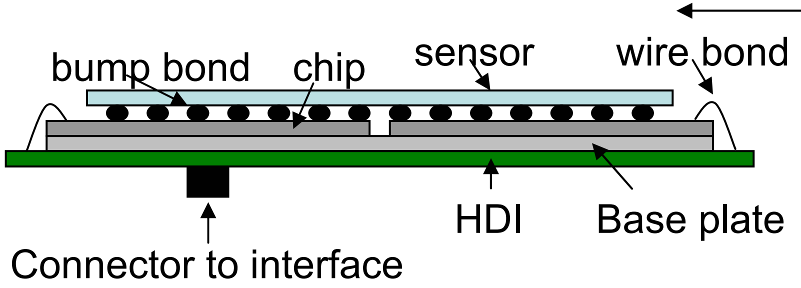
The Adaptive Gain Integrating Pixel Detector

<u>Basic parameters</u>

- 1 Megapixel detector (1k × 1k)
- 200μm × 200μm pixels
- Flat detector
- Sensor: Silicon 128 x 512 pixel tiles
- Single shot 2D-imaging
- 5MHz frame rate
- 2 × 10^4 photons dynamic range
- Adaptive gain switching
- Single photon sensitivity at 12keV
- Noise ≤200e (50 × 10^{-3} photons @ 12keV)
- Storage depth ≥200 images
- Analogue readout between bunch-trains



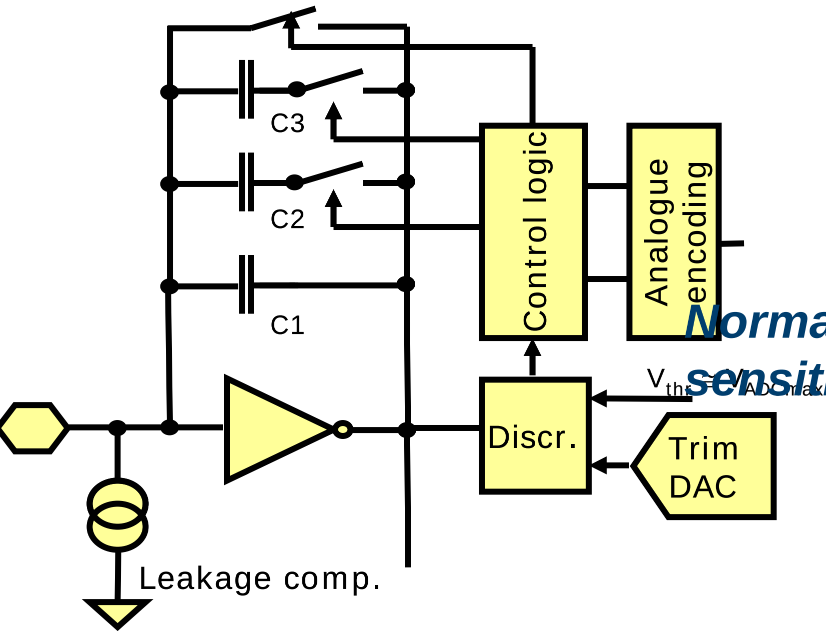
1k x 1k (2k x 2k)



The Adaptive Gain Integrating Pixel Detector

High dynamic range:

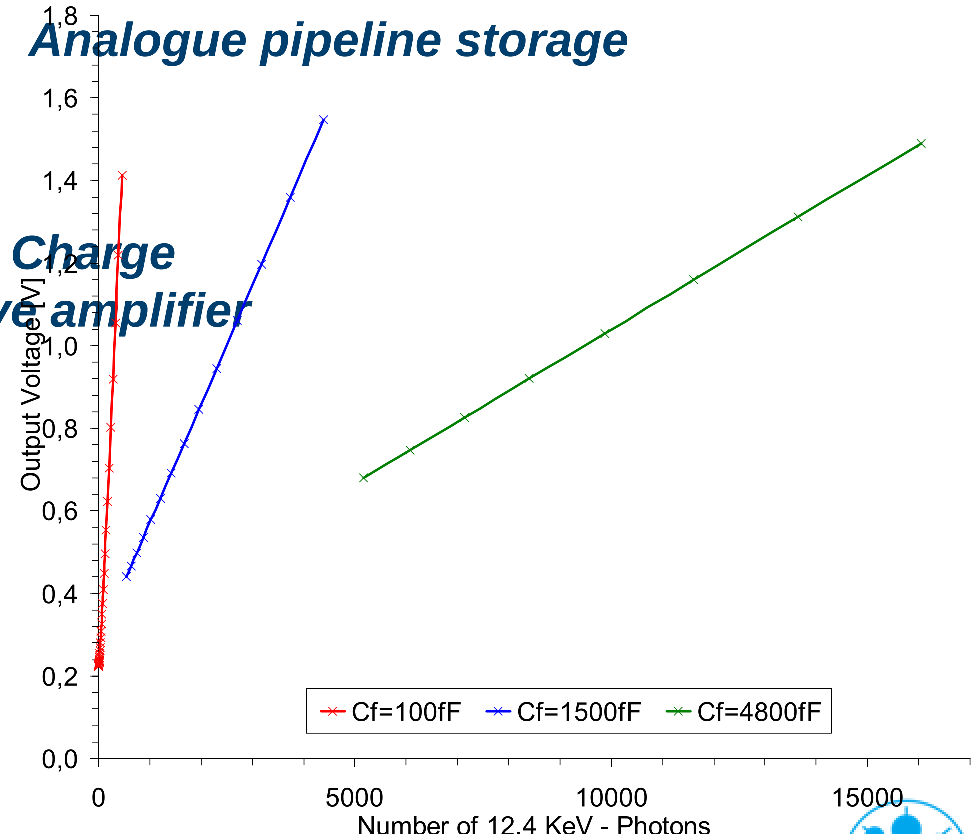
Dynamically gain switching system



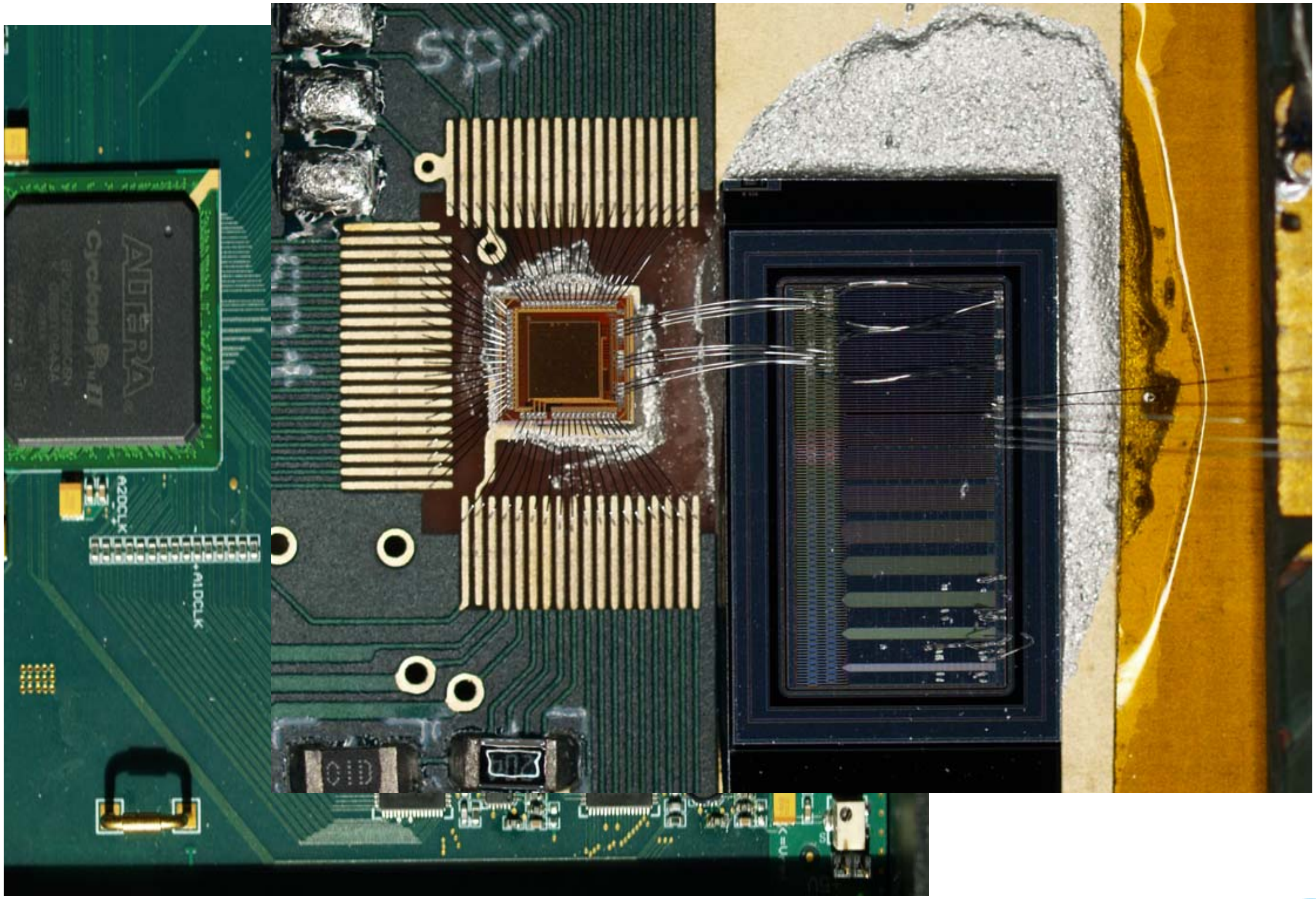
Extremely fast readout (200ns):

Analogue pipeline storage

Normal Charge sensitive amplifier



Overview of the chip test board



The Adaptive Gain Integrating Pixel Detector

High dynamic range:

Dynamically gain switching system

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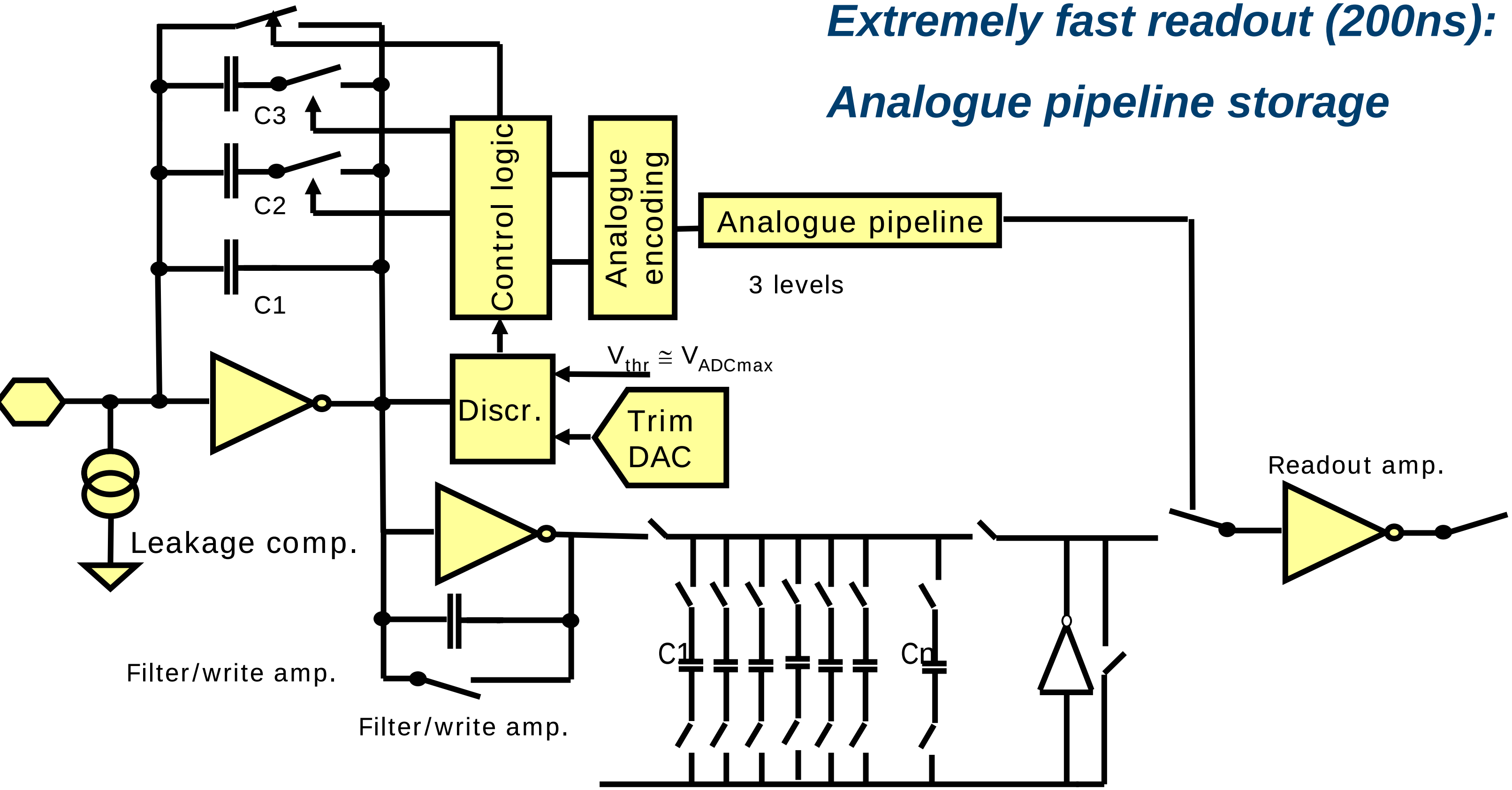
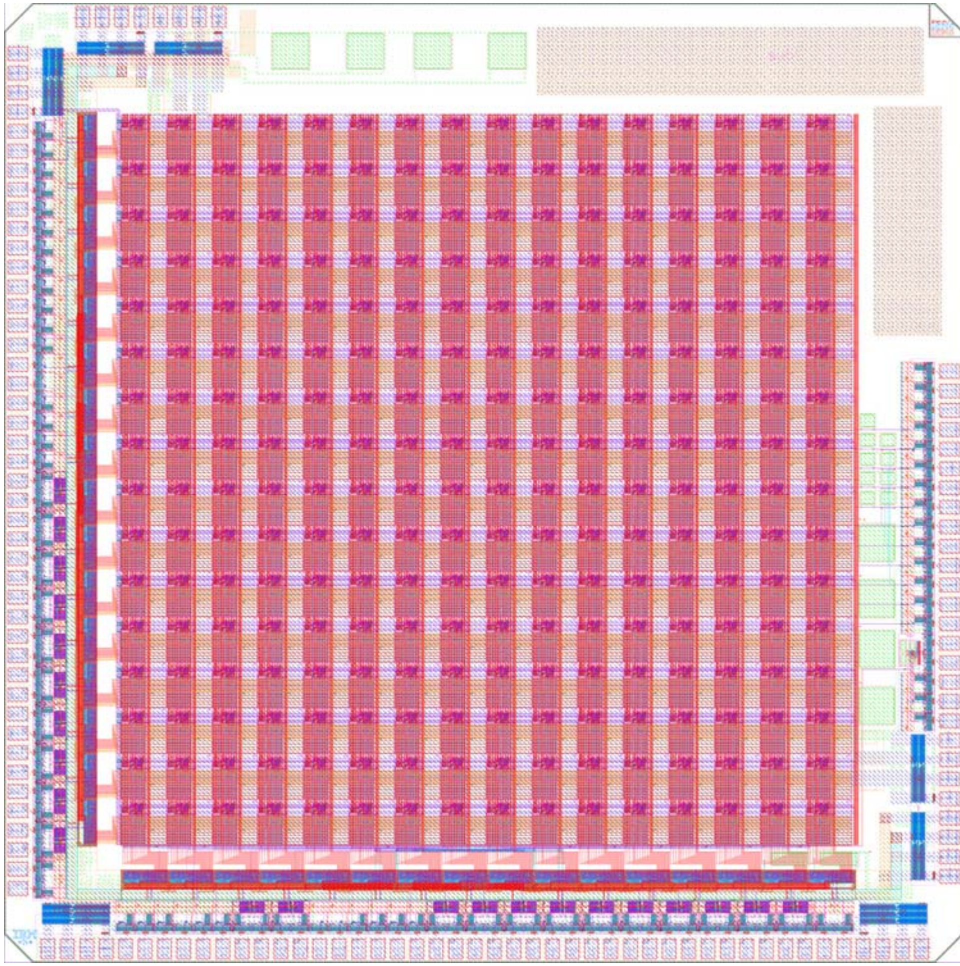
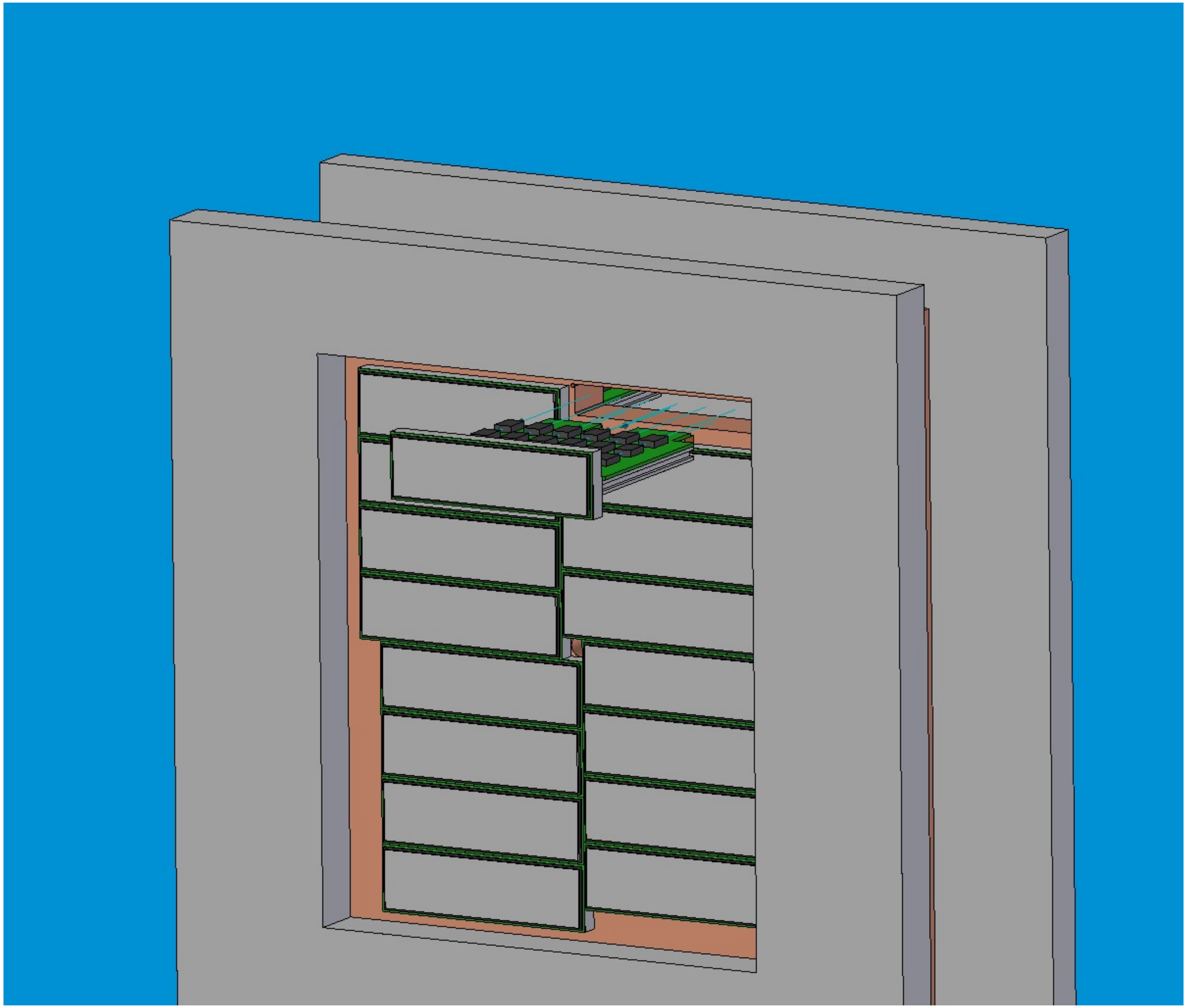


AGIPD02

- 16 x 16 pixel prototype
- Adaptive gain
- Different flavors of storage
- 100 frames per pixel



The 1k x 1k detector



How to find the best compromises ?

Many conflicting parameters:

> Pixel size versus number of frames

> Pixel size versus dynamic range

> Pixel size versus radiation hardness

> Speed versus noise

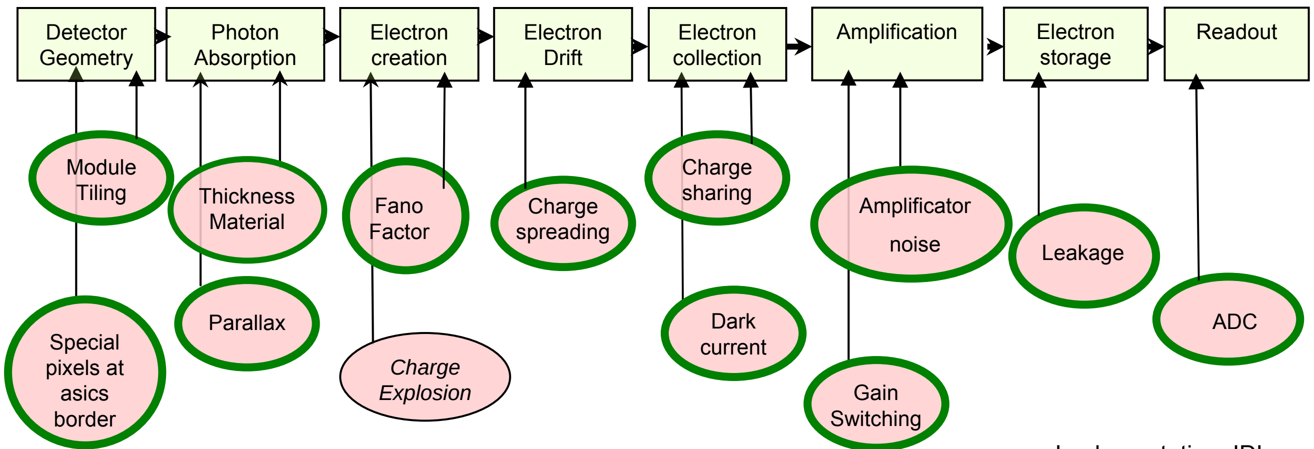
This is a surface in multi-dimensional space:

> How does this surface look like ?

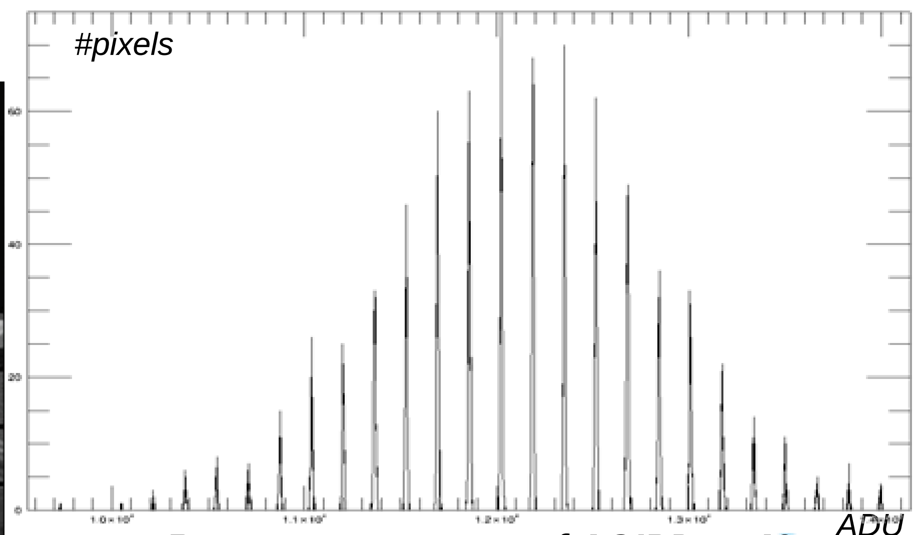
> Where do you want to sit ?

Detector simulation program

HORUS: a simulation program for HPADs



Implementation: IDL



Response spectrum of AGIPD to 40 photons intensities

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)

Problem: No easy Veto system

→ Each experiment is specific

→ Need to keep the data to refine analysis

Concluding remarks

- Radiation damage and charge explosion studies well advanced (general interest)
- 3 large 2D Detector development projects ongoing:
  - LPD: 3 parallel gains; analogue storage
  - DSSC: non-linear gain; digital storage
  - AGIPD: 3 switched gains; analogue storage
- HORUS available for detector and science simulation
- Low energy detector exist (ex: pnCCD)
- DAQ and Computing in start-up phase (HEP like structures)
- Detector development is expensive!
- Detector developments go across many disciplines (HEP, SR, FEL, Astro, Medical, Military, Security,….)
- Joint effort is the winning combination