X-ray Detectors at DESY

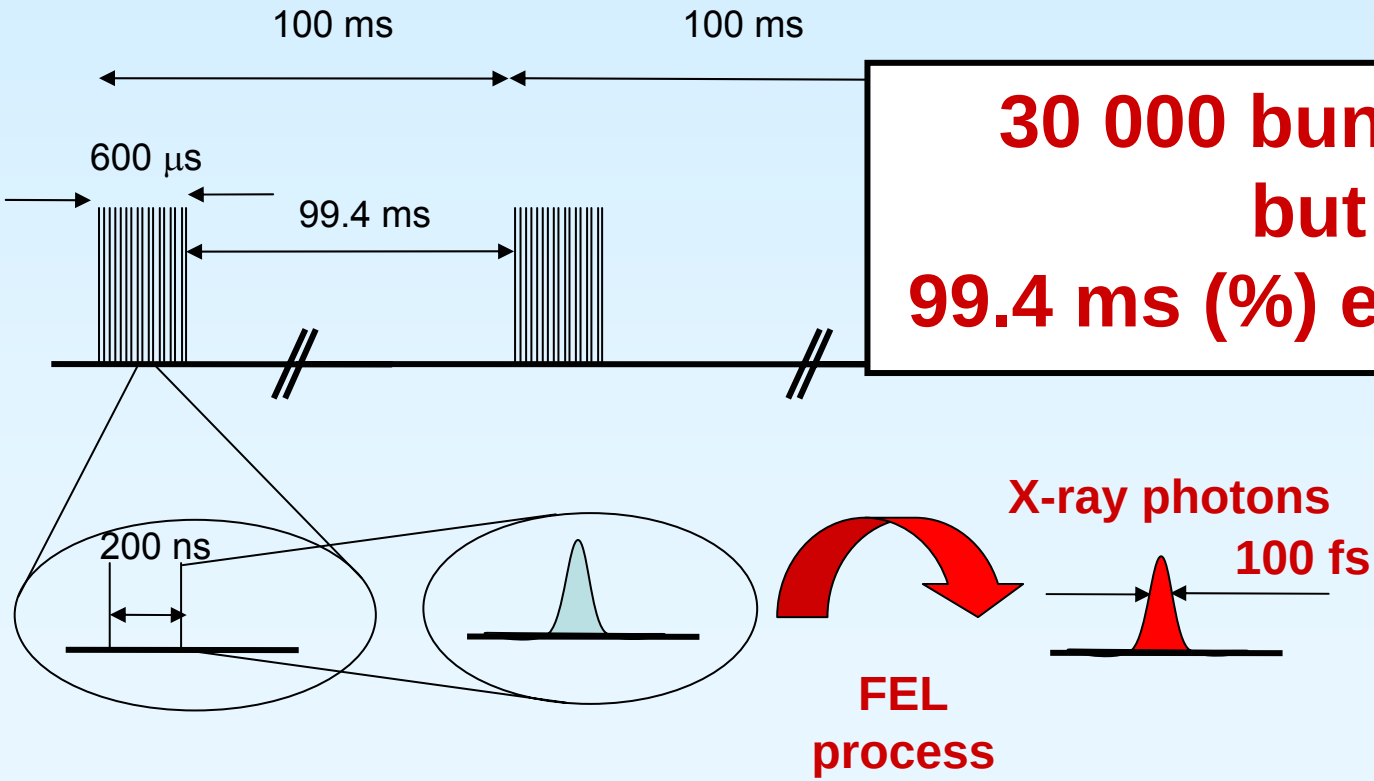
(Contribution given at the FEL2006 meeting in Berlin)

Heinz Graafsma
DESY

The European XFEL

Time structure: difference with “others”

Electron bunch trains; up to 3000 bunches in 600 μsec, repeated 10 times per second.
Producing 100 fsec X-ray pulses (up to 30 000 bunches per second).



30 000 bunches/s
but
99.4 ms (%) emptiness

Consequences of Time structure

- Either: < 10Hz or > 1.5 kHz; best 5 MHz
- All photons arrive in 100 fsec ➔ integrating detectors.
- Experiments should profit from high luminosity (30 000 shots/sec).
- Every shot is a new experiment (jitter, sample destruction,..)

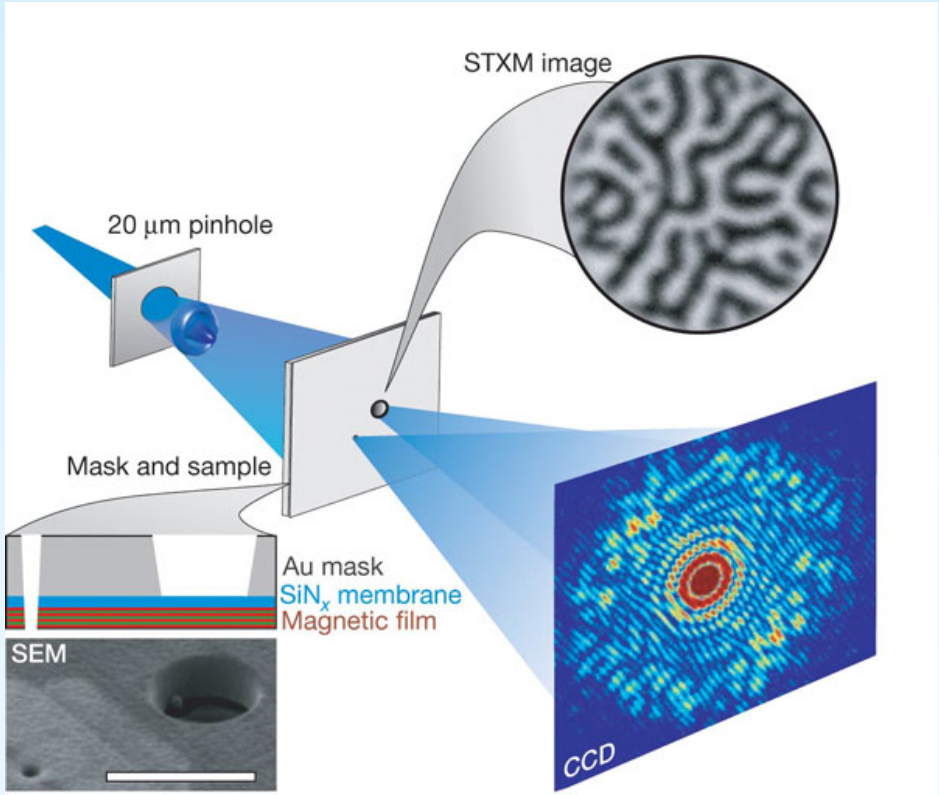
The Experiments

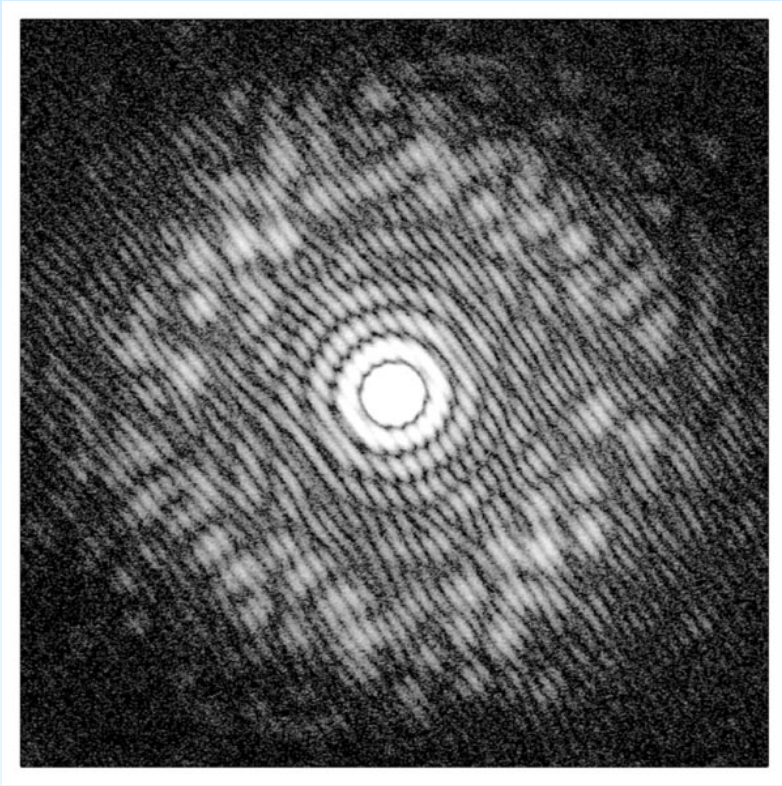
- TDR has 8 different application areas
- 5 areas need 2D X-ray detectors:
  - Pump-Probe non-crystalline diffraction
  - Pump Probe crystalline diffraction
  - Coherent Diffraction Imaging
  - Single Particle Imaging
  - X-ray Photon Correlation Spectroscopy

Typical requirements:

Direct Holographic Inversion

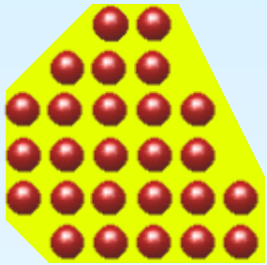
1.59nm RCP diffraction from magnetised film and pinhole
S. Eisebitt, J. Lüning, W. Schlotter, M. Lörgen, O. Hellwig,
W. Eberhardt and J. Stöhr, Nature 432, 885-888 (2004)



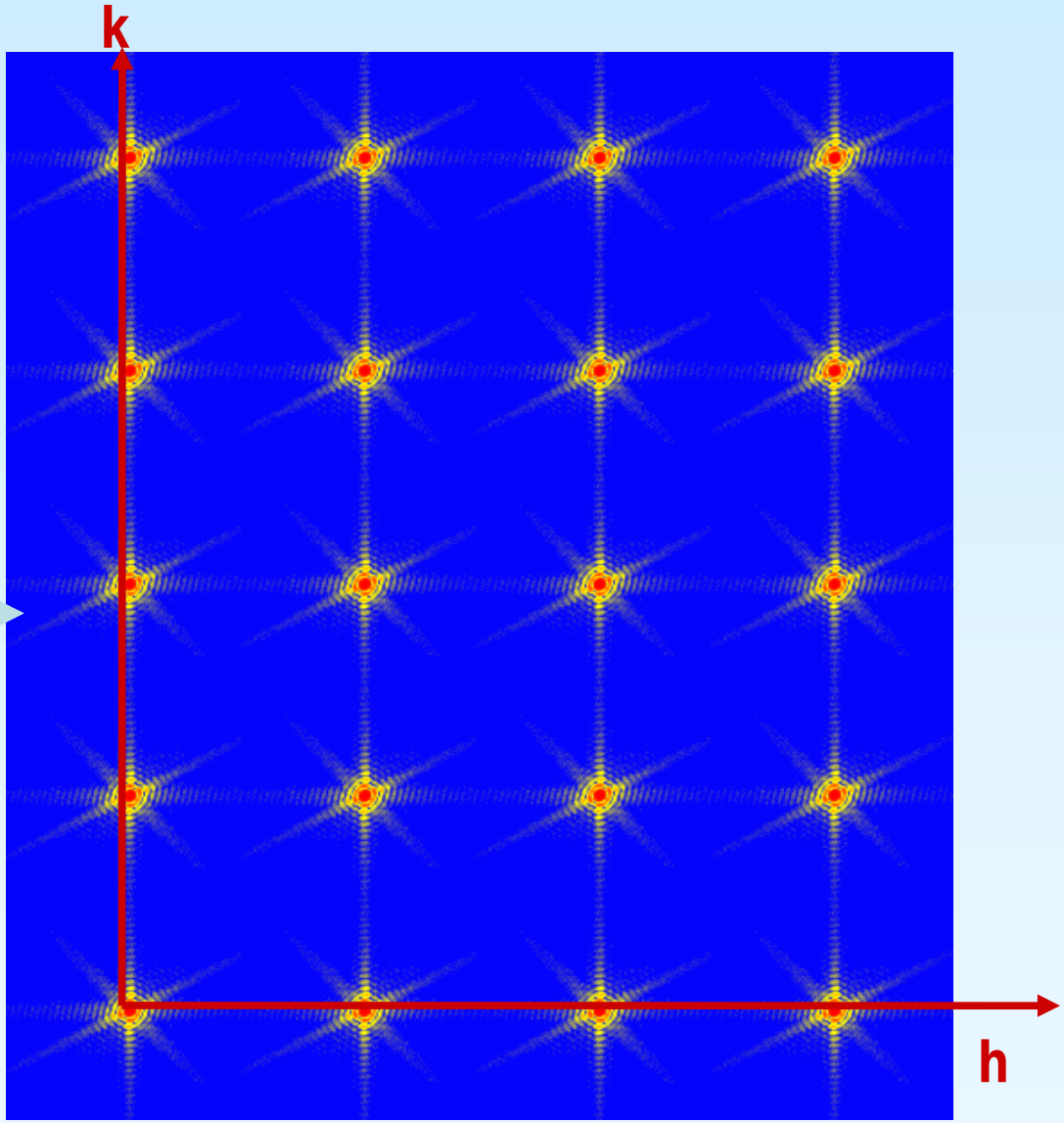


Typical requirements:

Coherent Diffraction from Crystals



Fourier Transform



Typical requirements:

• **DETECTOR CDI:**	**MUST**
• **Total detector angle**	**120 degrees**
• **Pixel Size**	**0.1 mrad**
• **Number of Pixels**	**20k x 20k**
• **Single photon resolution**	**yes (Poisson limit)**
• **Tiling tolerated**	**yes**
• **Signal rate/pixel/bunch**	**up to 10^6**
• **Timing**	**luminosity optimized**
• **Photon energy range [keV]**	**3-12**
• **Quantum efficiency**	**>0.8**
• **Environment**	**vacuum (input window ?)**
• **Radiation Hardness**	**10^{16} X-rays**
• **Harmonics Discrimination**	**no**

How to solve the challenge?

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

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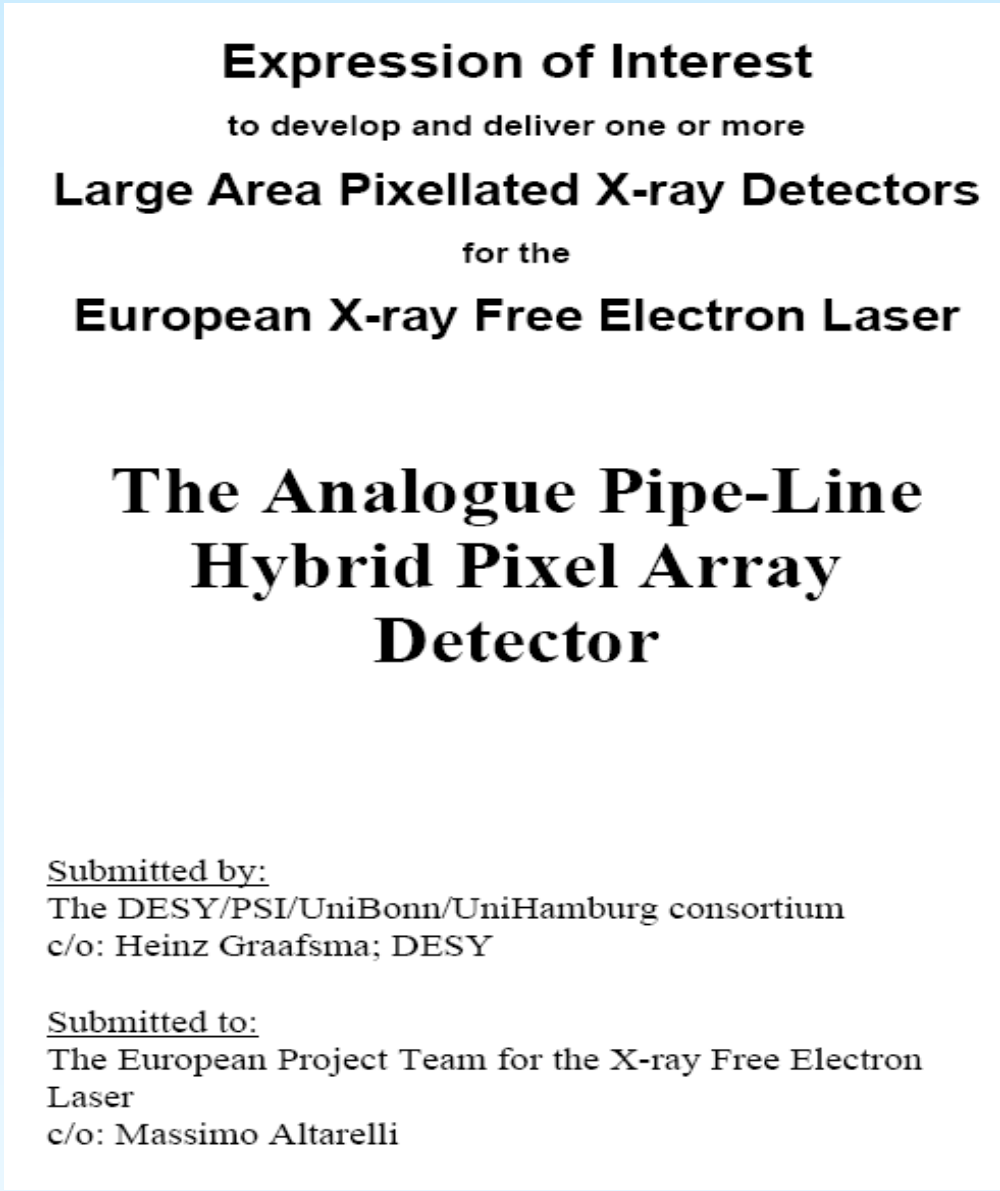
Results of Call for EoI

- 6 EoIs received:
- 1 headed by DESY (HPAD)
- 2 others with DESY as partner (SDD)
- 1 by Industry
- Detector Advisory Committee meets on October 23+24
- Decision end October (invitation for full proposals).



Expression of Interest

to develop and deliver one or more

Large Area Pixellated X-ray Detectors

for the

European X-ray Free Electron Laser

The Analogue Pipe-Line Hybrid Pixel Array Detector

Submitted by:
The DESY/PSI/UniBonn/UniHamburg consortium
c/o: Heinz Graafsma; DESY

Submitted to:
The European Project Team for the X-ray Free Electron Laser
c/o: Massimo Altarelli

Hybrid Pixel Array Detector (HPAD)

Diode Detection Layer

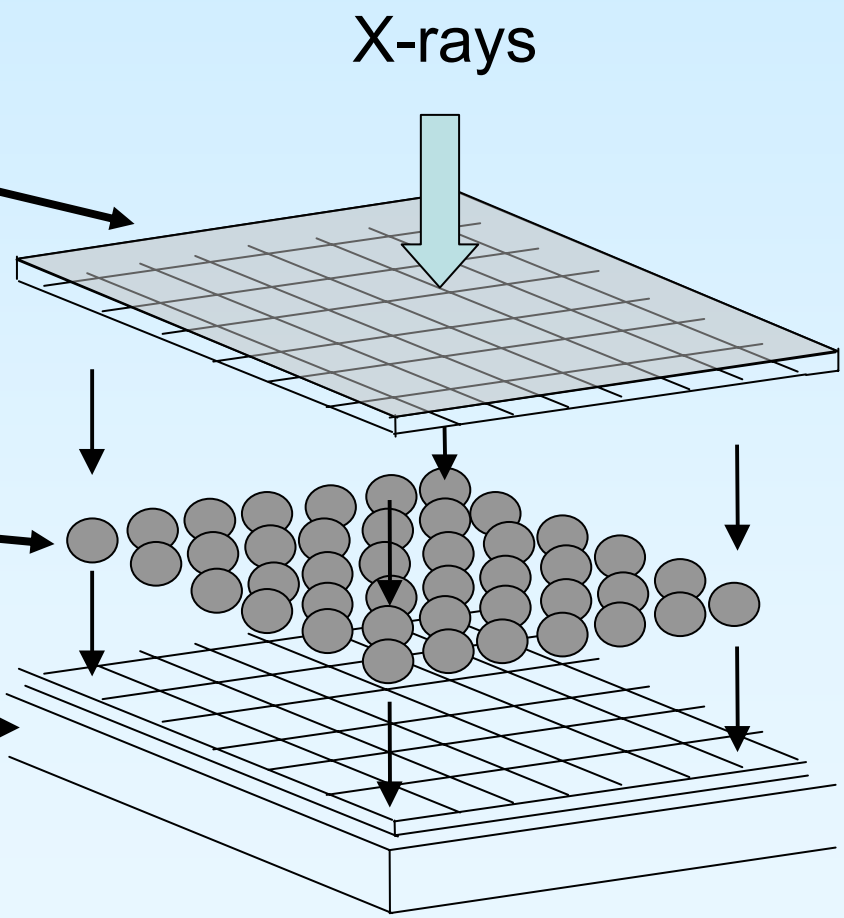
- Fully depleted, high resistivity
- Direct x-ray conversion
- Silicon, GaAs, CdTe, etc.

Connecting Bumps

- Solder or indium
- 1 per pixel

CMOS Layer

- Signal processing
- Signal storage & output



Gives enormous flexibility!

Analog Pipeline Pixel Chip

Basic idea:

- Integrating system
- Configurable analog frontend
- Store images of micro-bunches on caps in the pixels (5MHz switching)
- Readout the images during the 100ms gap

Predecessor Chips:

HEP: H1 strip Analog Pipeline Chip (APC), CMS & Atlas strip and others

X-ray Pixel: APAD Cornell

We do not start from scratch

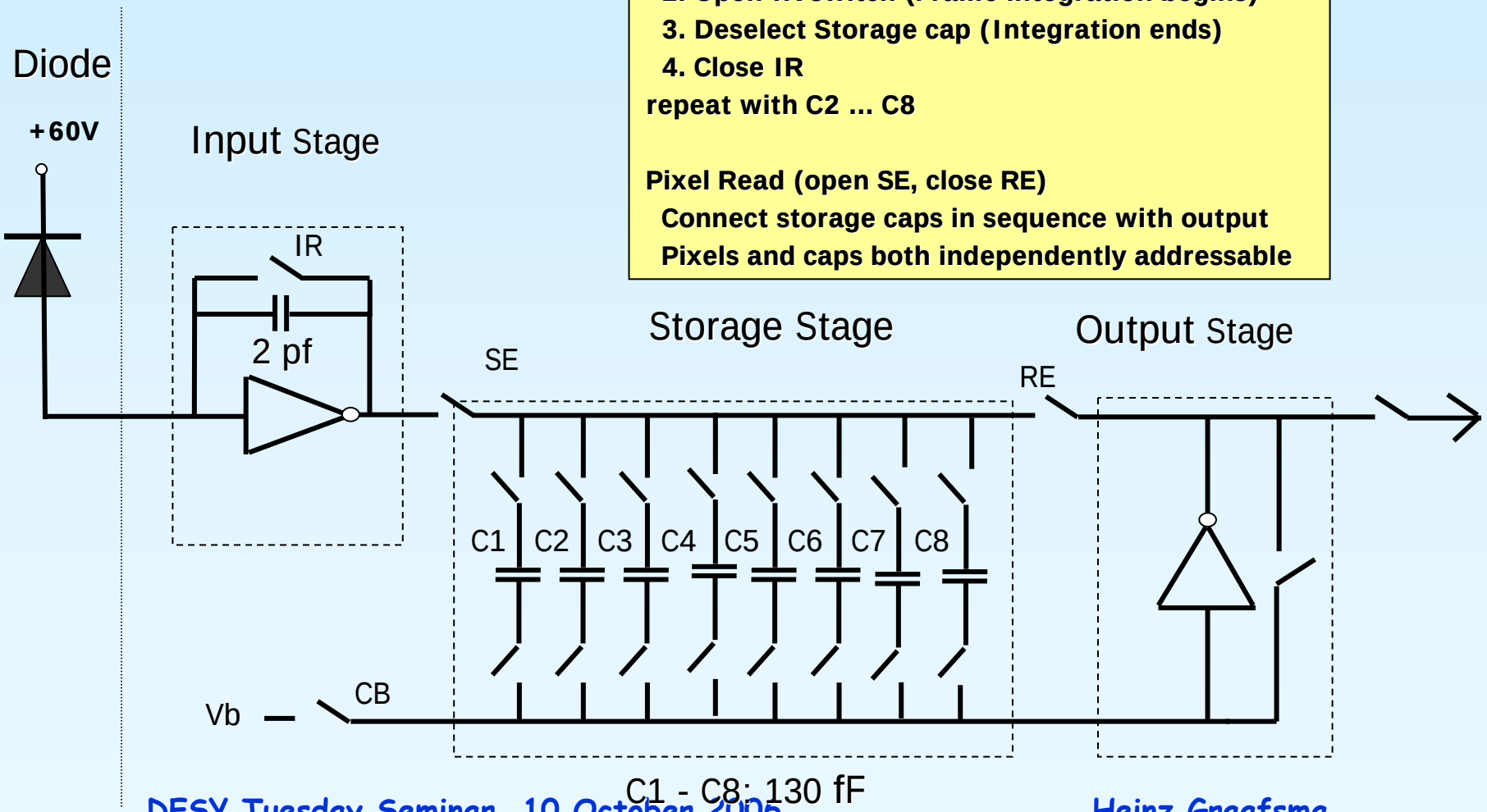
...

Cornell Analog PAD

Rapid framing (SE, IR closed)
1. select storage cap C1
2. Open IR switch (Frame integration begins)
3. Deselect Storage cap (Integration ends)
4. Close IR

repeat with C2 … C8

Pixel Read (open SE, close RE)
Connect storage caps in sequence with output
Pixels and caps both independently addressable



Gasoline fuel injector spray

Courtesy Sol Gruner

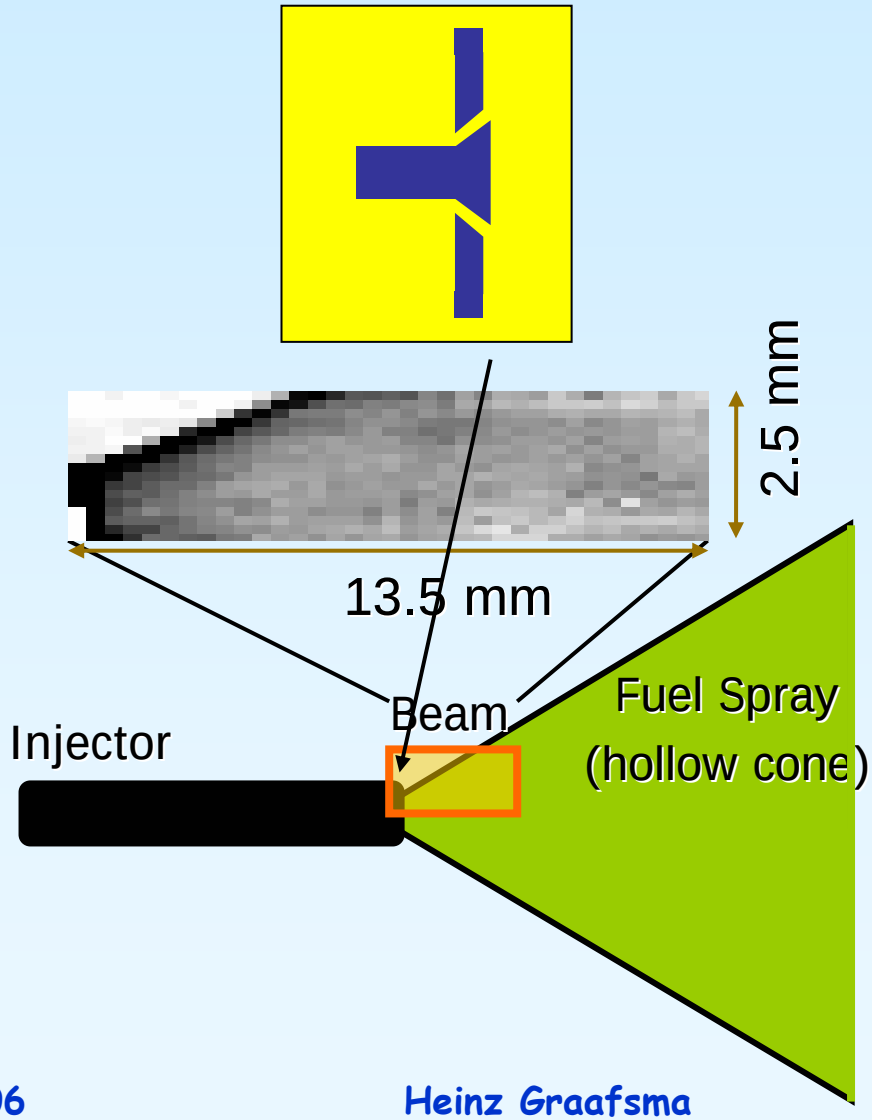
X-ray beam

- CHESS Beamline D-1
- 6 keV (1% bandpass)
- 2.5 mm x 13.5 mm
- (step sample to tile large area)
- 10^9 x-rays/pix/s
- 5.13 μs integration (2x ring period)

Fuel injection system

- Cerium added for x-ray contrast
- 1000 PSI gas driven
- 1 ms pulse
- 1 ATM Nitrogen

Collaboration: Jin Wang (APS) & S.M. Gruner (Cornell)

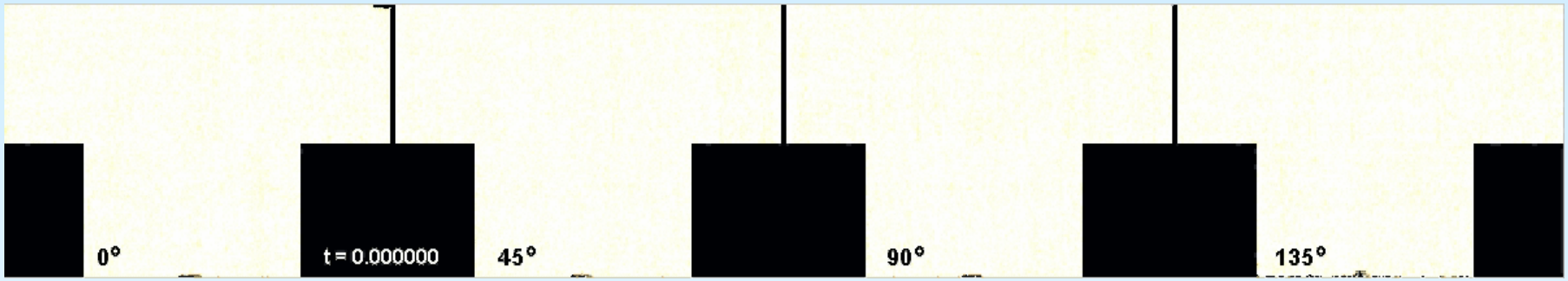


See: Cai, Powell, Yue, Narayanan, Wang, Tate, Renzi, Ercan, Fontes & Gruner

Appl. Phys. Lett. 83 (2003) 1671.

Gasoline fuel injector spray

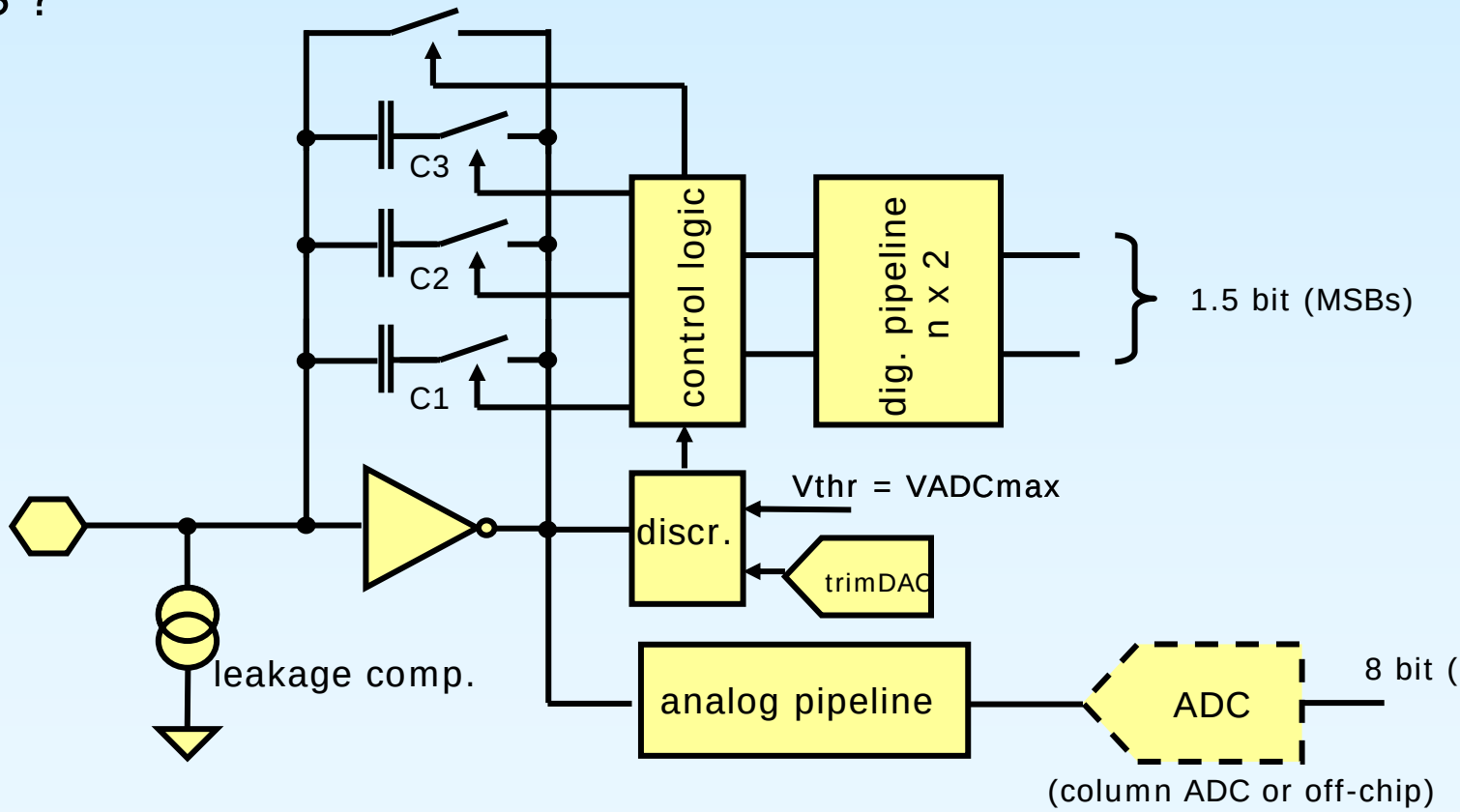
Courtesy Sol Gruner



- 1.8 ms time sequence (composite). 10^5 images
- 5.13 μs exposure time. (15.4 μs between frames)
- 88 frames (11 groups of 8 frames), Avg. 20x for noise.
- 1000 x-rays/pixel/μs
- Data taken with 4 projections.

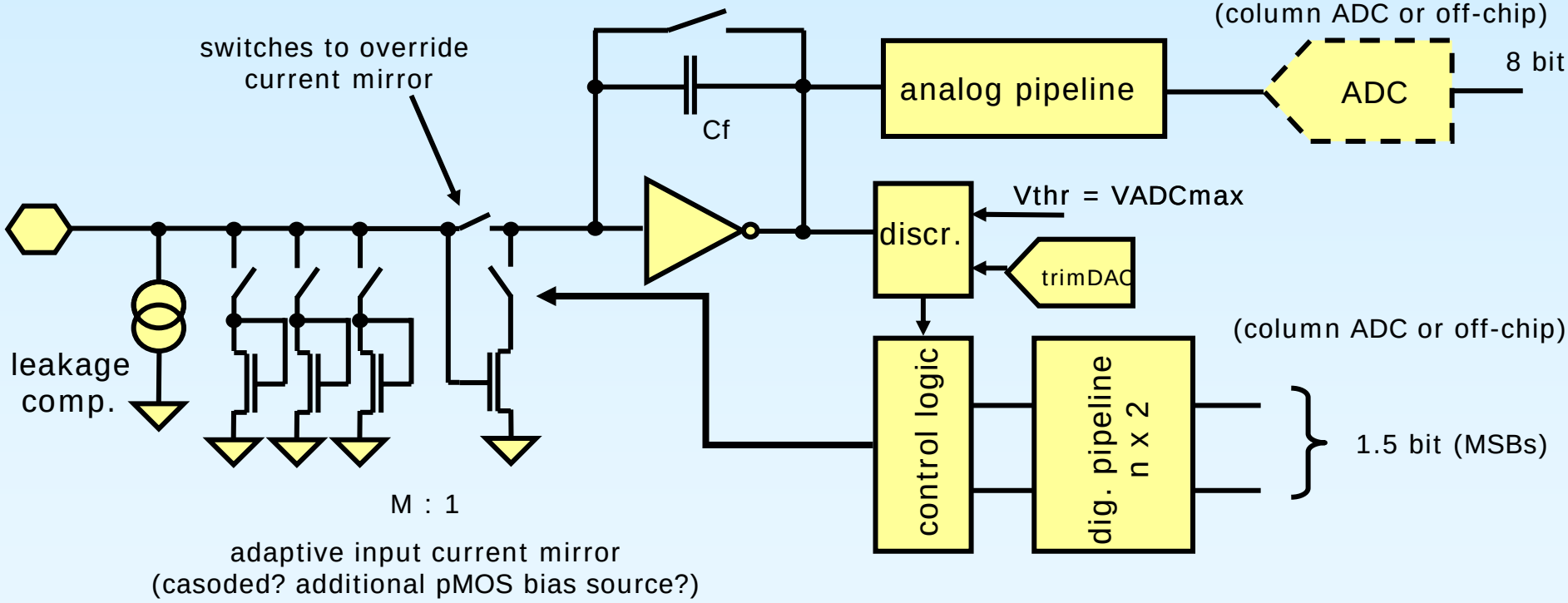
New concepts

- wide dynamic input range
- multiple (3) scaled feedback capacitors
- reduced ADC resolution (8 bit instead of 10 bit)
- analog + digital (2 bit) pipeline
- in-pixel CDS ?



New concepts

- keep C_f fixed
- scale input current with configurable current mirror: M_i = 1, 16, 64…
- increase dynamic range beyond 10^4 (i > 3)
- could be implemented in less area



Analog Pipeline Pixel

Rough dimensions:

~ 20 um² / cap cell ->

1000 caps (frames) ~ 140 x 140 um² -> Pixel size ~ 160 x 160 um²

500 caps (frames) ~ 100 x 100 um² -> Pixel size ~ 120 x 120 um²

100 caps (frames) ~ 44 x 44 um² -> Pixel size ~ 65 x 65 um²

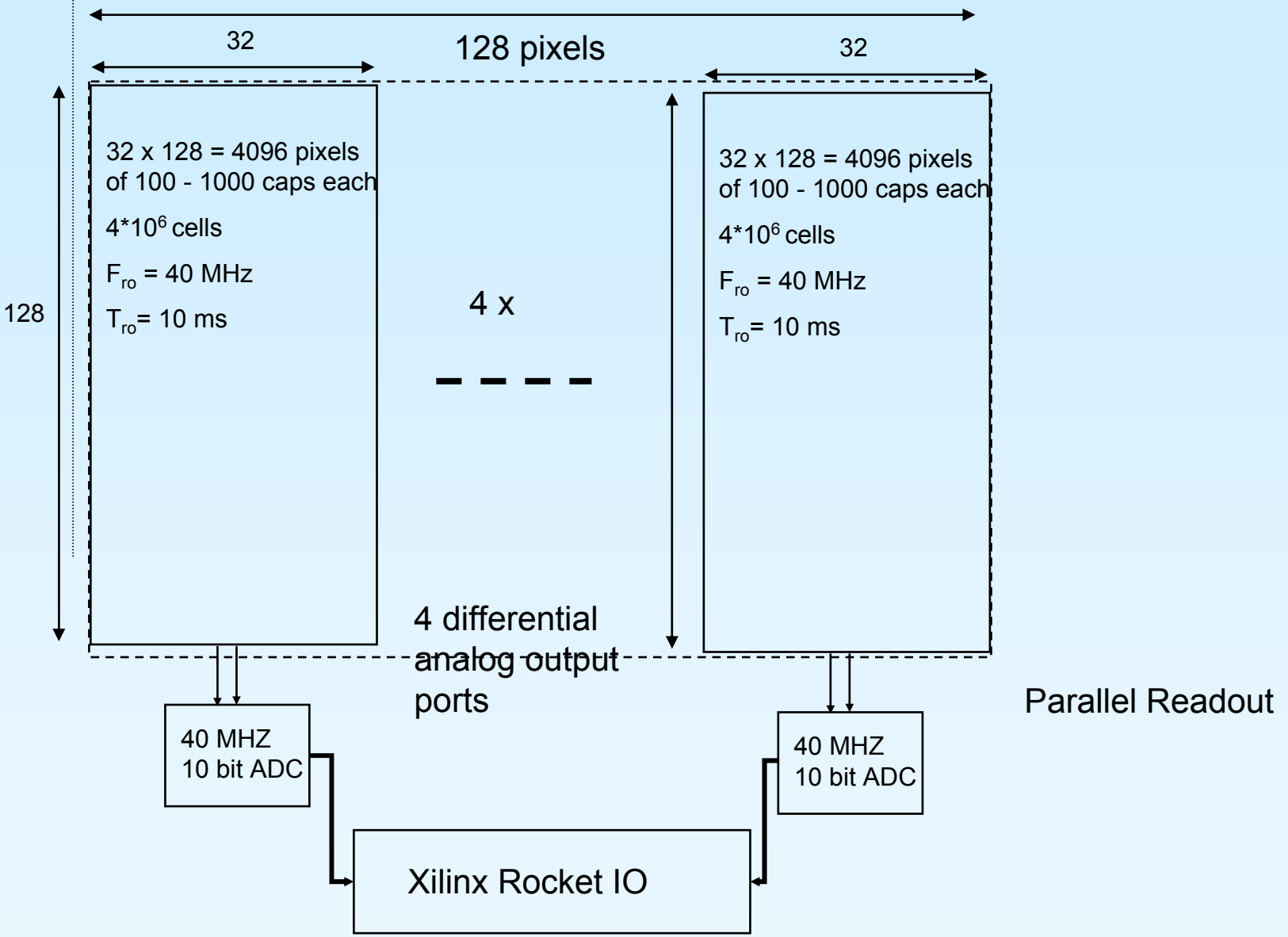
Readout system:

Programmable and flexible pipeline control (Off Chip):

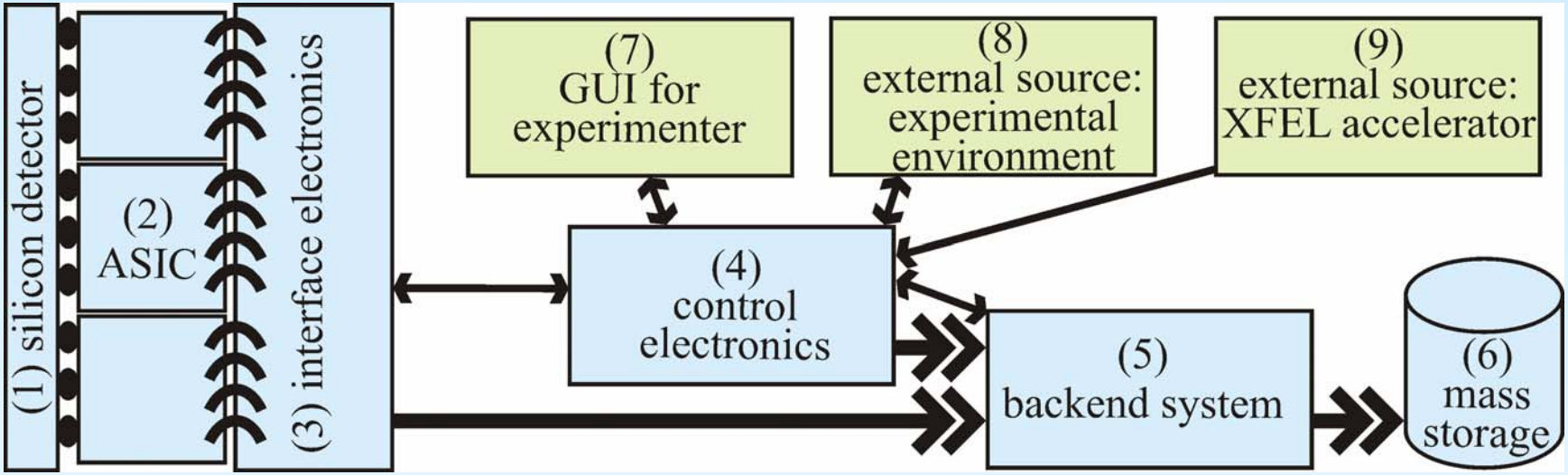
Number of X-ray pulses to be stored before readout (1, 10, or n-frames)

Adding of X-ray pulses (2 together, every 3rd pulse, …)

Analog Pipeline Pixel: Chip Architecture



Analog Pipeline Pixel: System Architecture



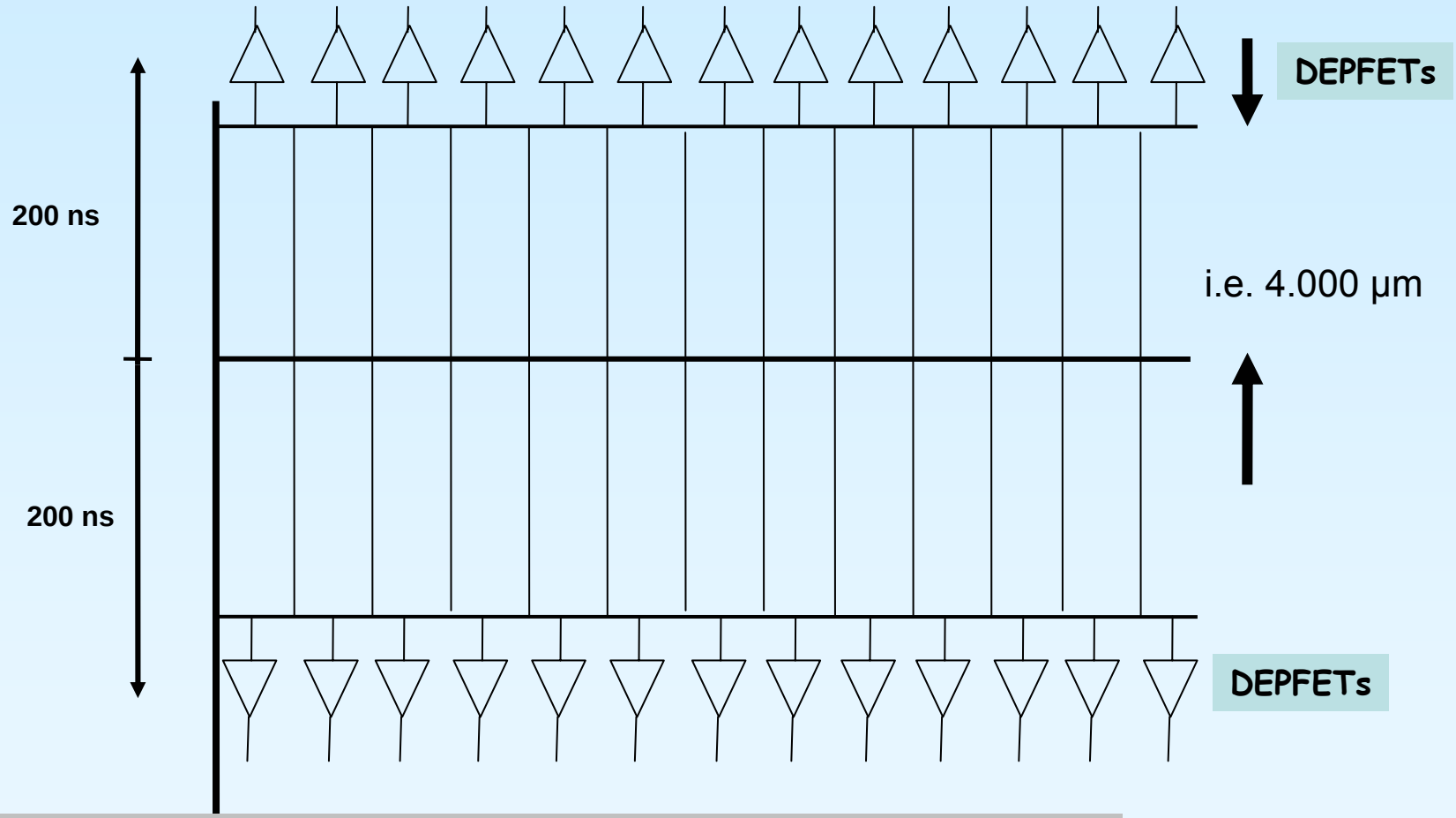
Hybrid Pixel Array **Detector** (HPAD)

Courtesy Christian Broennimann

The SDD project

Courtesy Lothar Strueder

- Silicon Drift Detectors (with DEPFET's)

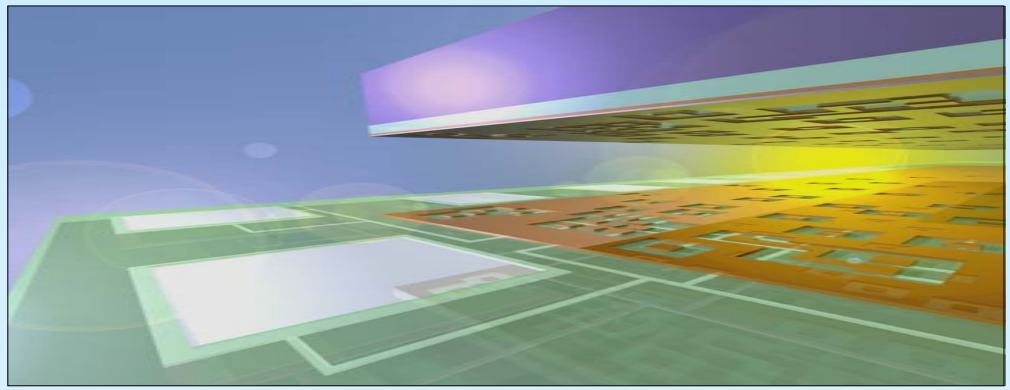


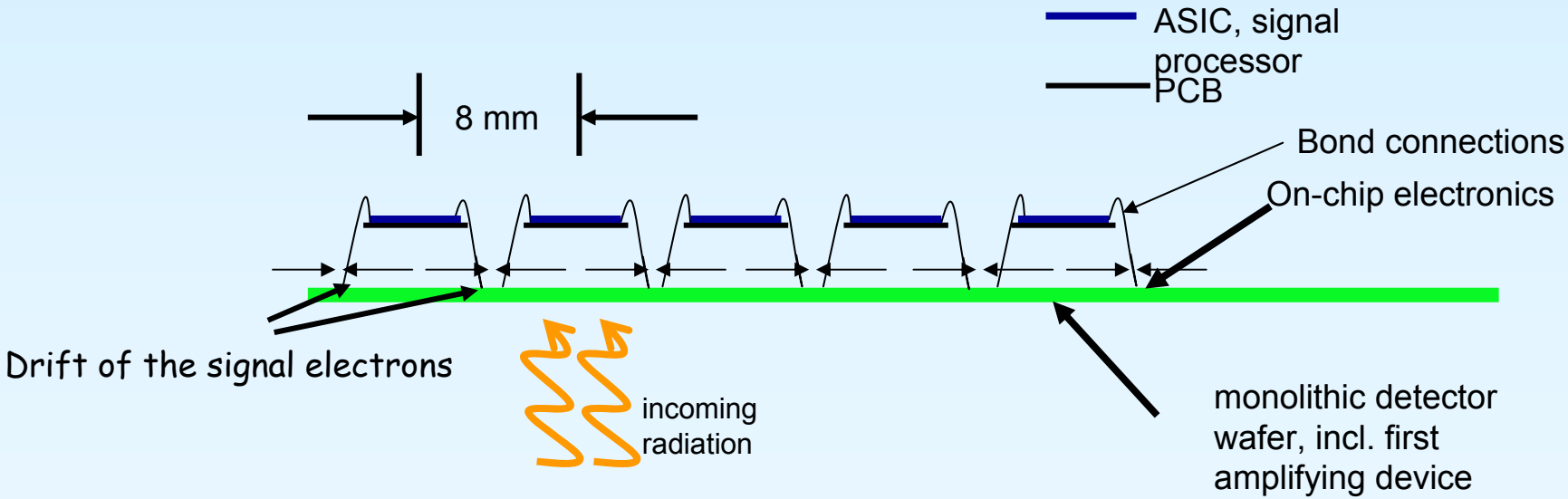
$V_{max} \approx$ 100 µm / ns, $V_{exp} \approx$ 20 µm / ns
total $area_{max}$: 80 x n•8 mm^2,

That means: Δt= 3 ns, Δx = 60 µm
CHC: unlimited (almost)

SDD (with DEPFET's)

Courtesy Lothar Strueder





Some of the challenges

- Large dynamic range with low noise (gain switching may be needed)
- Radiation hardness (in 3 years up to 10^{16} photons per pixel)
- High instantaneous flux (10^4 X-rays in 100 fsec in a few micron of Si)
- Storing 3000 images inside pixel, while keeping pixel small (100 micron)
- Very high overall data rate
- ….

Summary

- We know how to do it, it is difficult and challenging, but doable and interesting

- Now we wait for the review by the DAC and the decision by the European Project Team for the XFEL