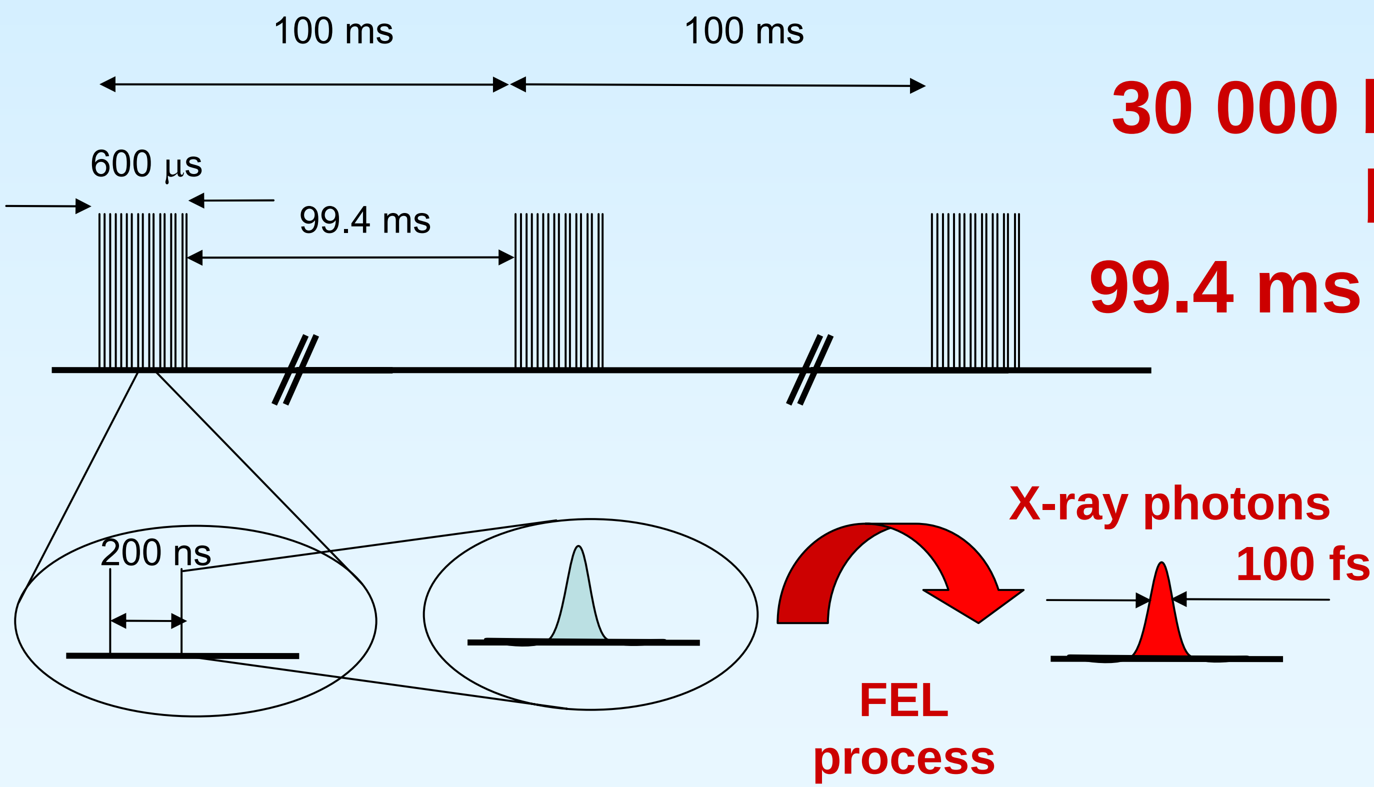
X-ray Detectors at DESY

Heinz Graafsma
DESY

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,..)

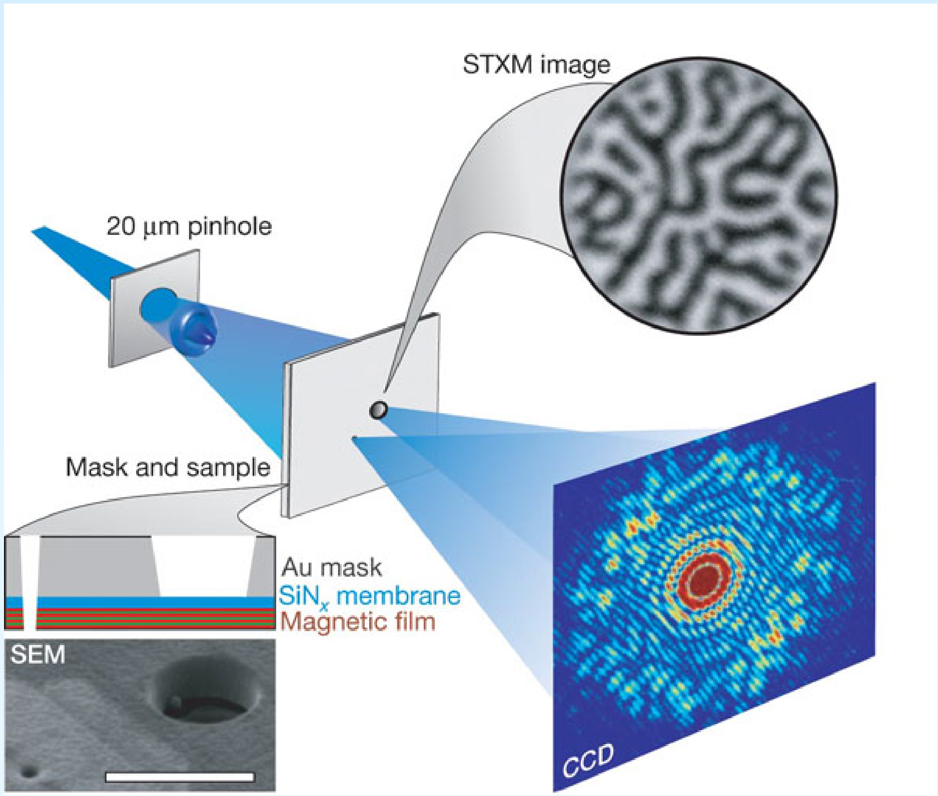
The Experiments

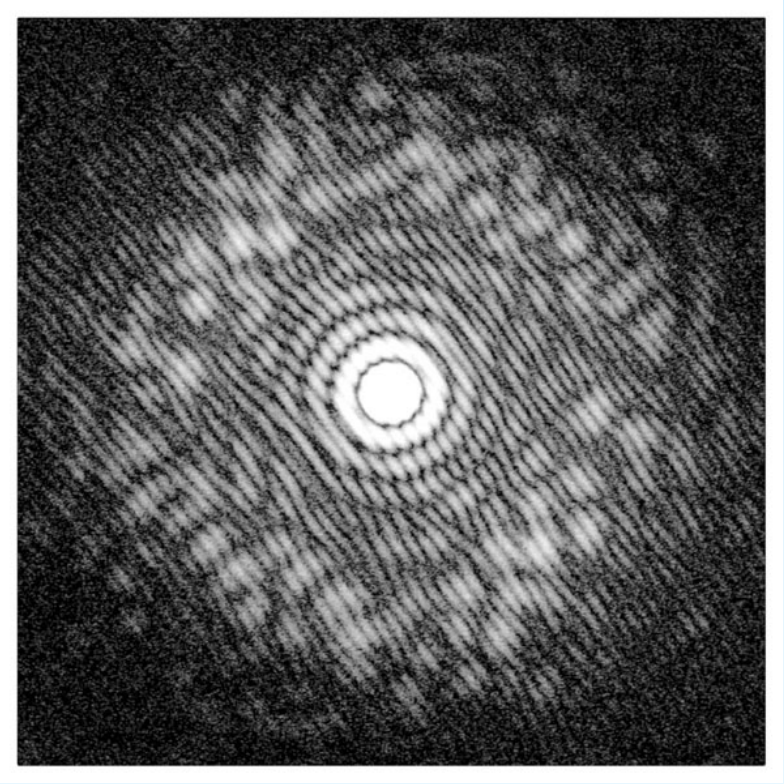
- TDR has 8 different application areas
- 5 areas need 2D X-ray detectors:
  - Pump-Probe non-crystalline diffraction
  - Pump Probe crystalline diffraction
  - Coherent Diffraction Imaging
  - Single Particle Imaging
  - X-ray Photon Correlation Spectroscopy

Typical requirements:

Direct Holographic Inversion

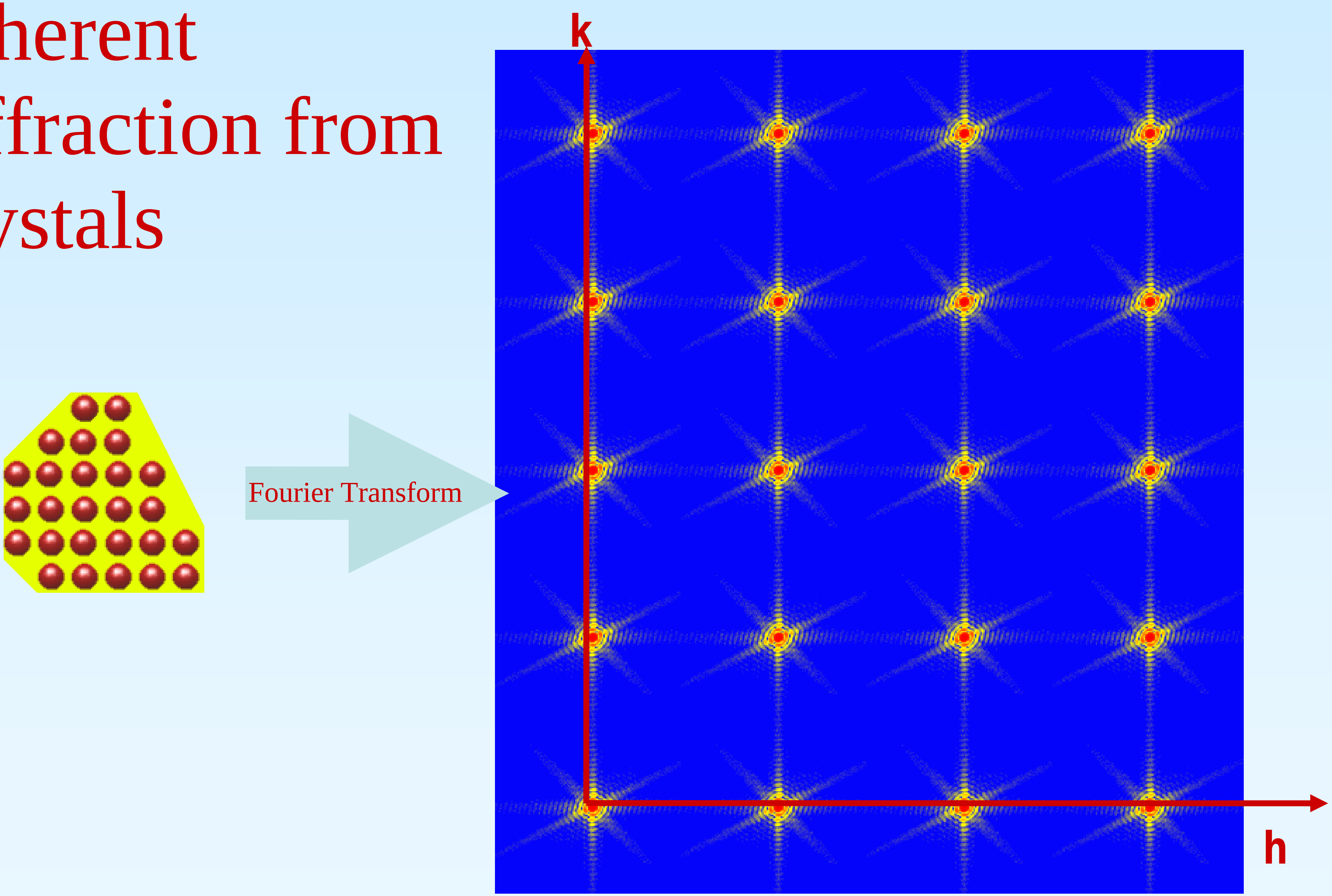
1.59nm RCP diffraction from magnetised film and pinhole
S. Eisebitt, J. Lüning, W. Schlotter, M. Lörgen, O. Hellwig, W. Eberhardt and J. Stöhr, Nature 432, 885-888 (2004)





Typical requirements:

Coherent Diffraction from Crystals



Typical requirements:

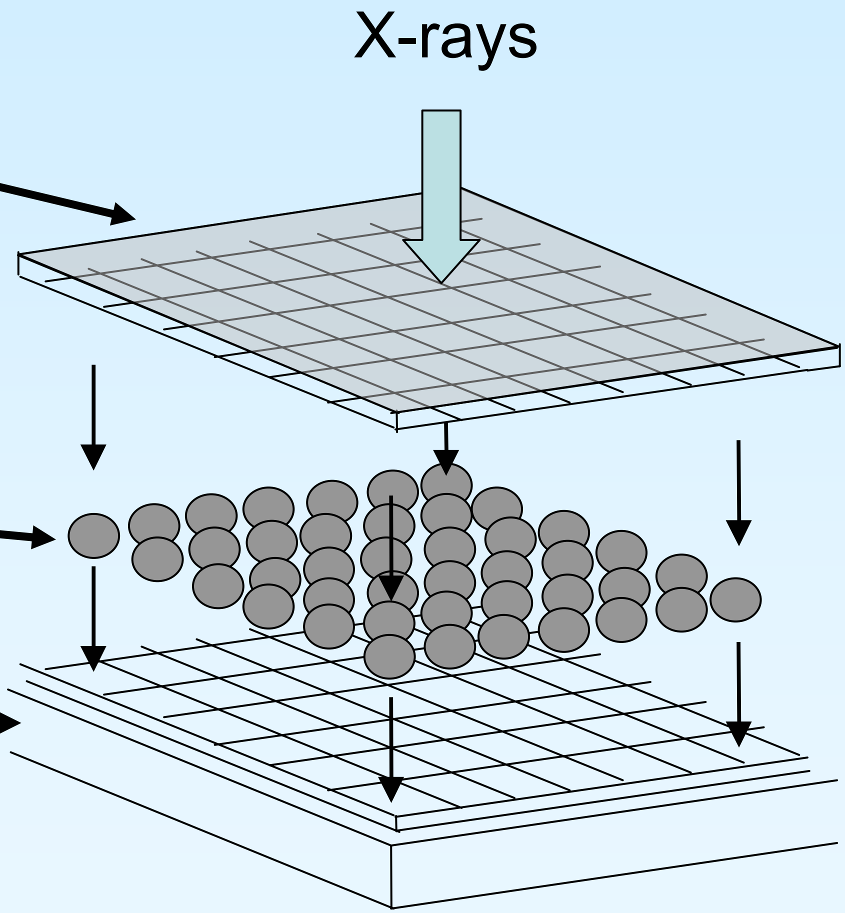
• **<u>DETECTOR CDI:</u>**	**MUST**
• Total detector angle	120 degrees
• Pixel Size	0.1 mrad
• Number of Pixels	10k x 10k
• Single photon resolution	yes (Poisson limit)
• Tiling tolerated	yes
• Signal rate/pixel/bunch	up to 10^6
• Timing	luminosity optimized
• Photon energy range [keV]	8-12
• Quantum efficiency	>0.8
• Environment	vacuum (input window ?)
• Radiation Hardness	10^{16} X-rays
• Harmonics Discrimination	no

How to solve this?

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 (Broenniman)

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 …

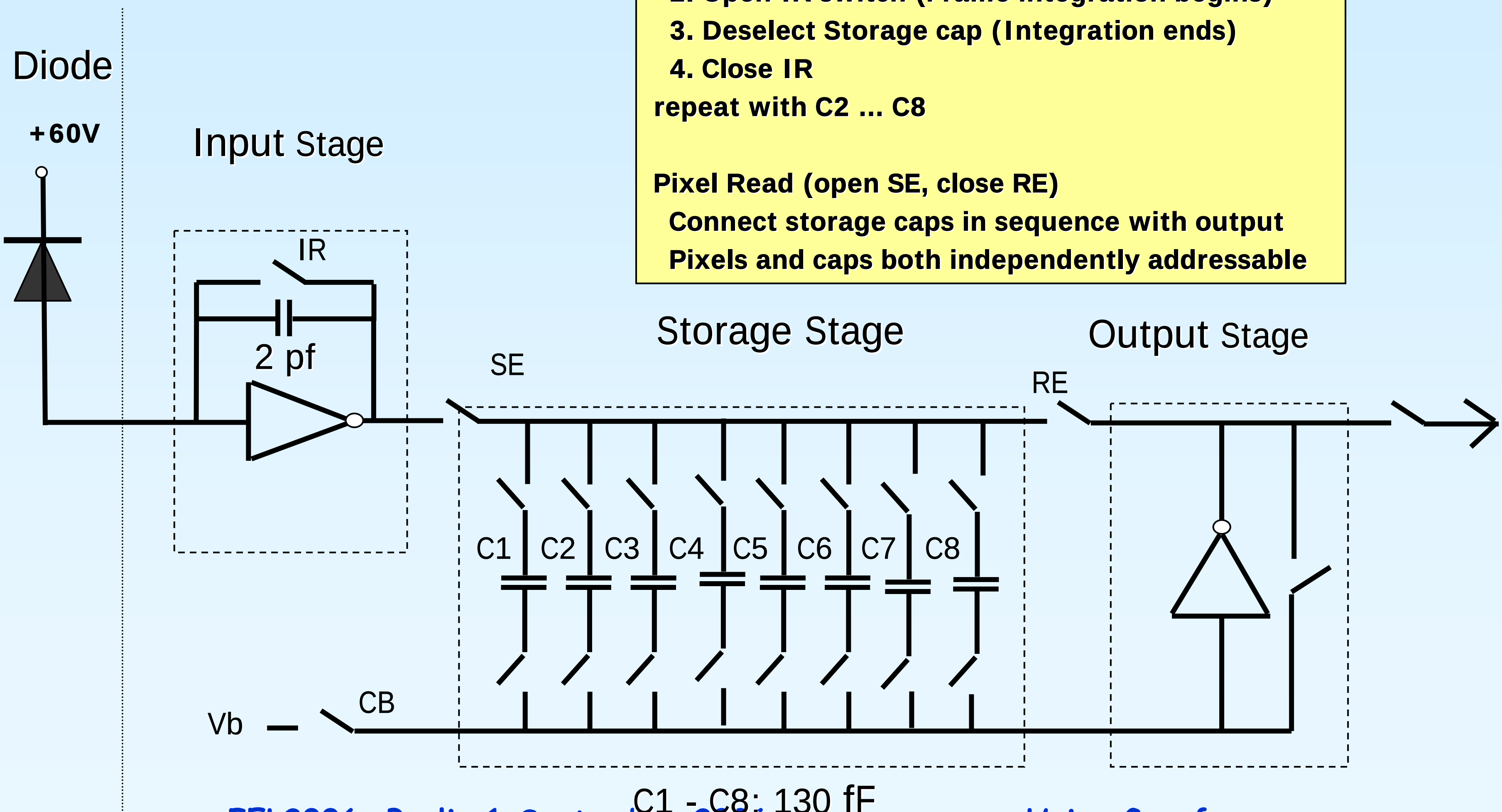
Cornell Analog PAD

Courtesy Sol Gruner

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



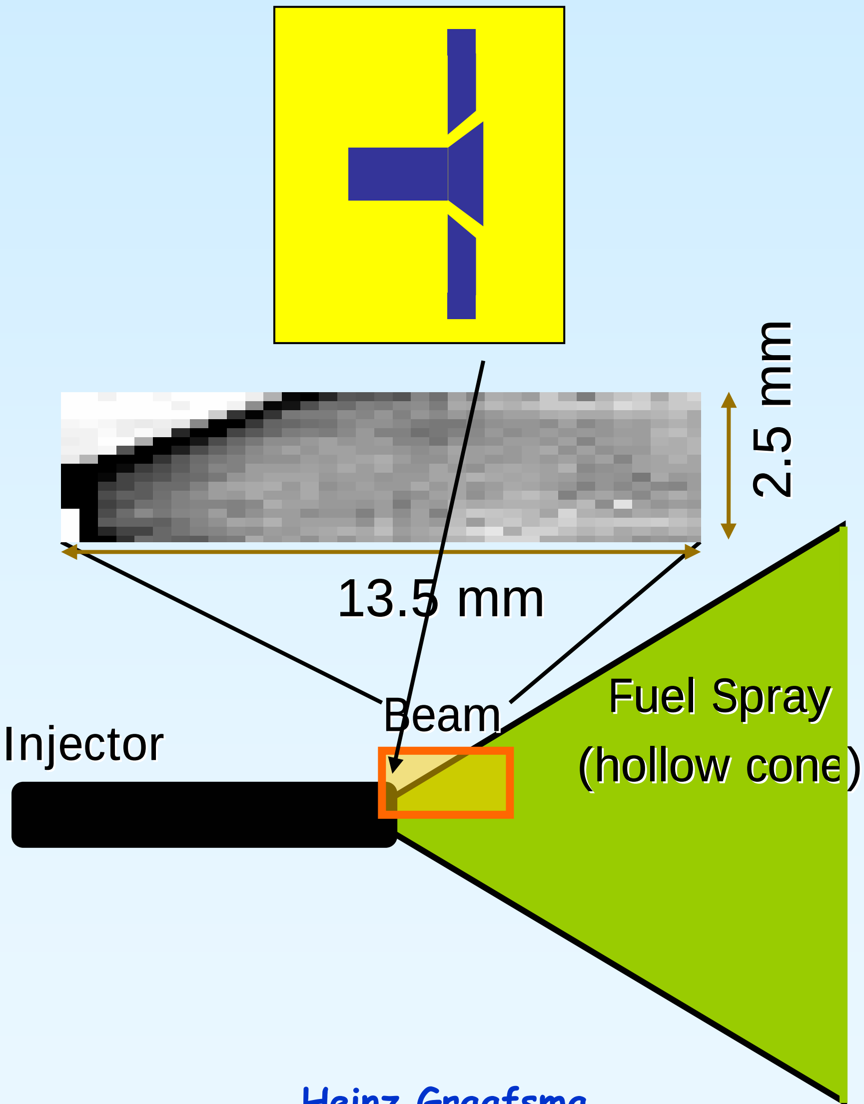
Gasoline fuel injector spray

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

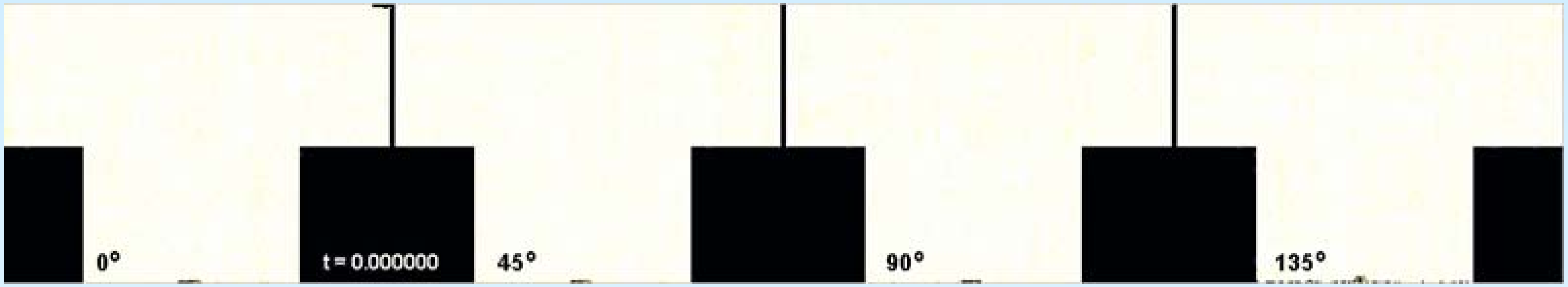
Collaboration: Jin Wang (APS) & S.M. Gruner (Cornell)



See: Cai, Powell, Yue, Narayanan, Wang, Tate, Renzi, Ercan, Fontes & Gruner
Appl. Phys. Lett. 83 (2003) 1671.

Gasoline fuel injector spray

Courtesy Sol Gruner

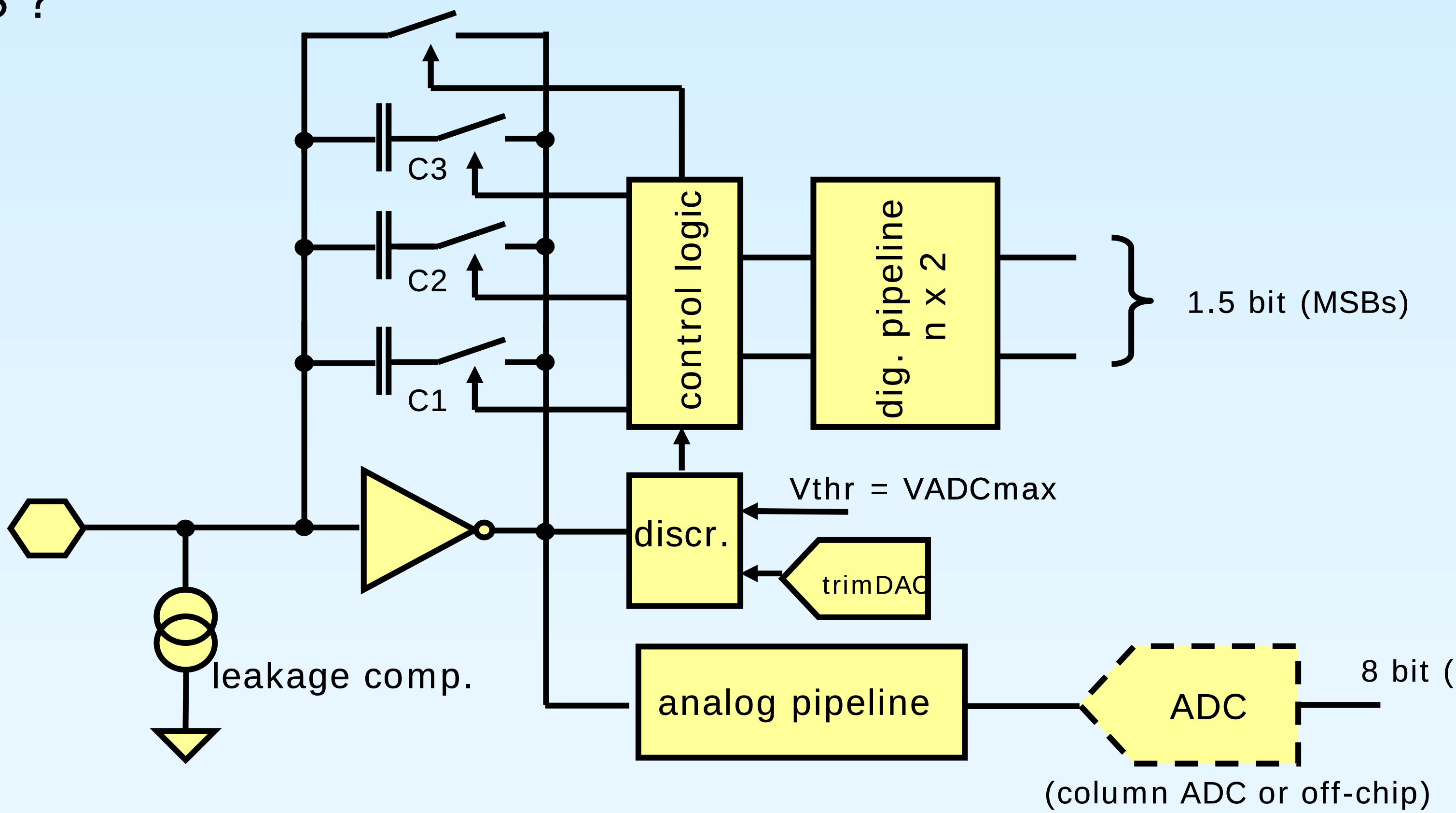


- 1.8 ms time sequence (composite). 10^5 images
- 5.13 μs exposure time. (15.4 μs between frames)
- 88 frames (11 groups of 8 frames), Avg. 20x for noise.
- 1000 x-rays/pixel/μs
- Data taken with 4 projections.

New concepts

Courtesy Hans Krueger

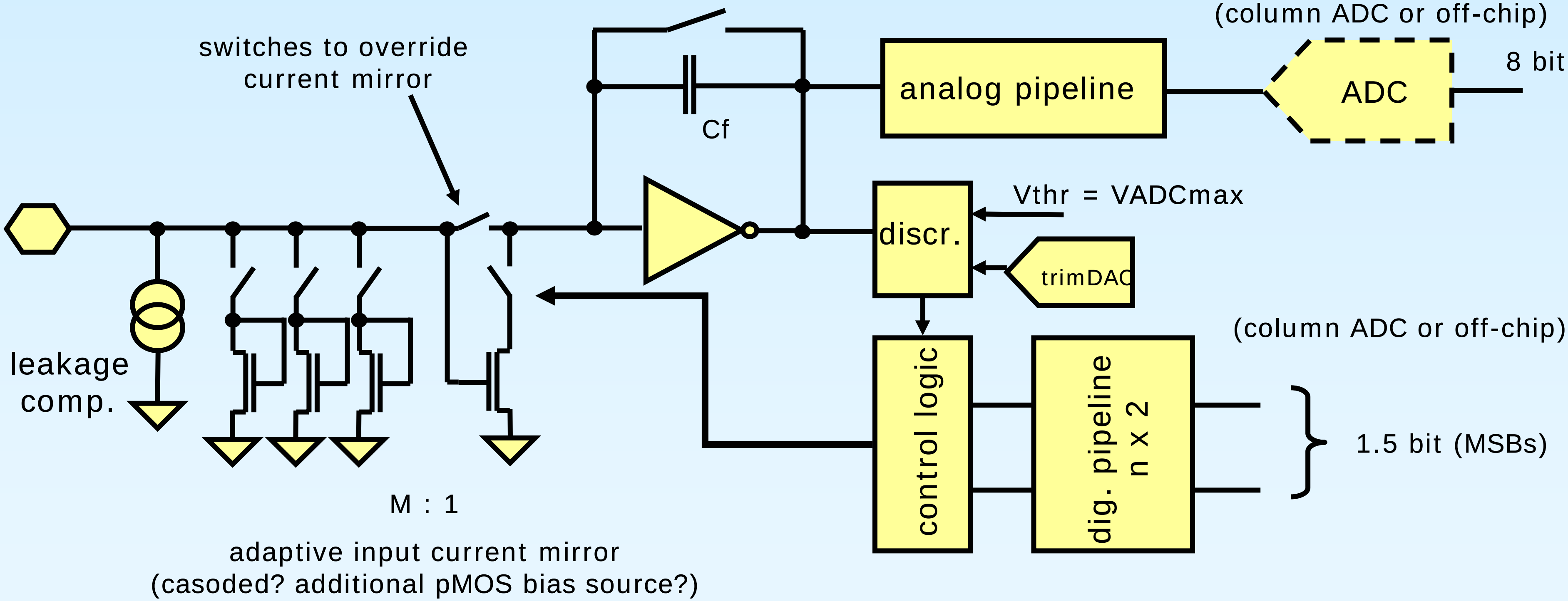
- wide dynamic input range
- multiple (3) scaled feedback capacitors
- reduced ADC resolution (8 bit instead of 10 bit)
- analog + digital (2 bit) pipeline
- in-pixel CDS ?



New concepts

Courtesy Hans Krueger

- 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 (Broennimann)

Rough dimensions:

~ 20 um^2 / cap cell ->

1000 caps (frames) ~ 140 x 140 um^2 -> Pixel size ~ 160 x 160 um^2

500 caps (frames) ~ 100 x 100 um^2 -> Pixel size ~ 120 x 120 um^2

100 caps (frames) ~ 44 x 44 um^2 -> Pixel size ~ 65 x 65 um^2

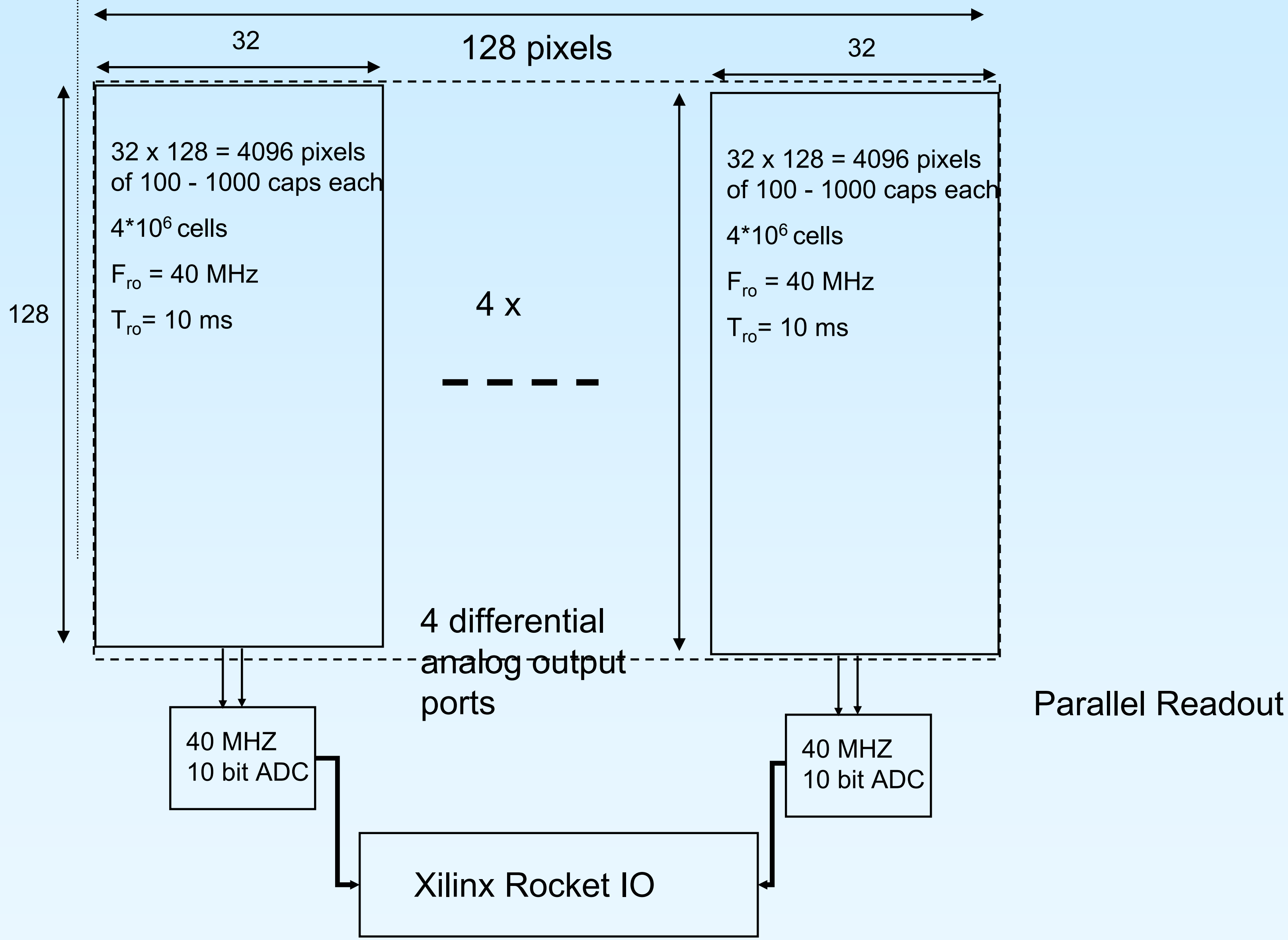
Readout system:

Programmable and flexible pipeline control (Off Chip):

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

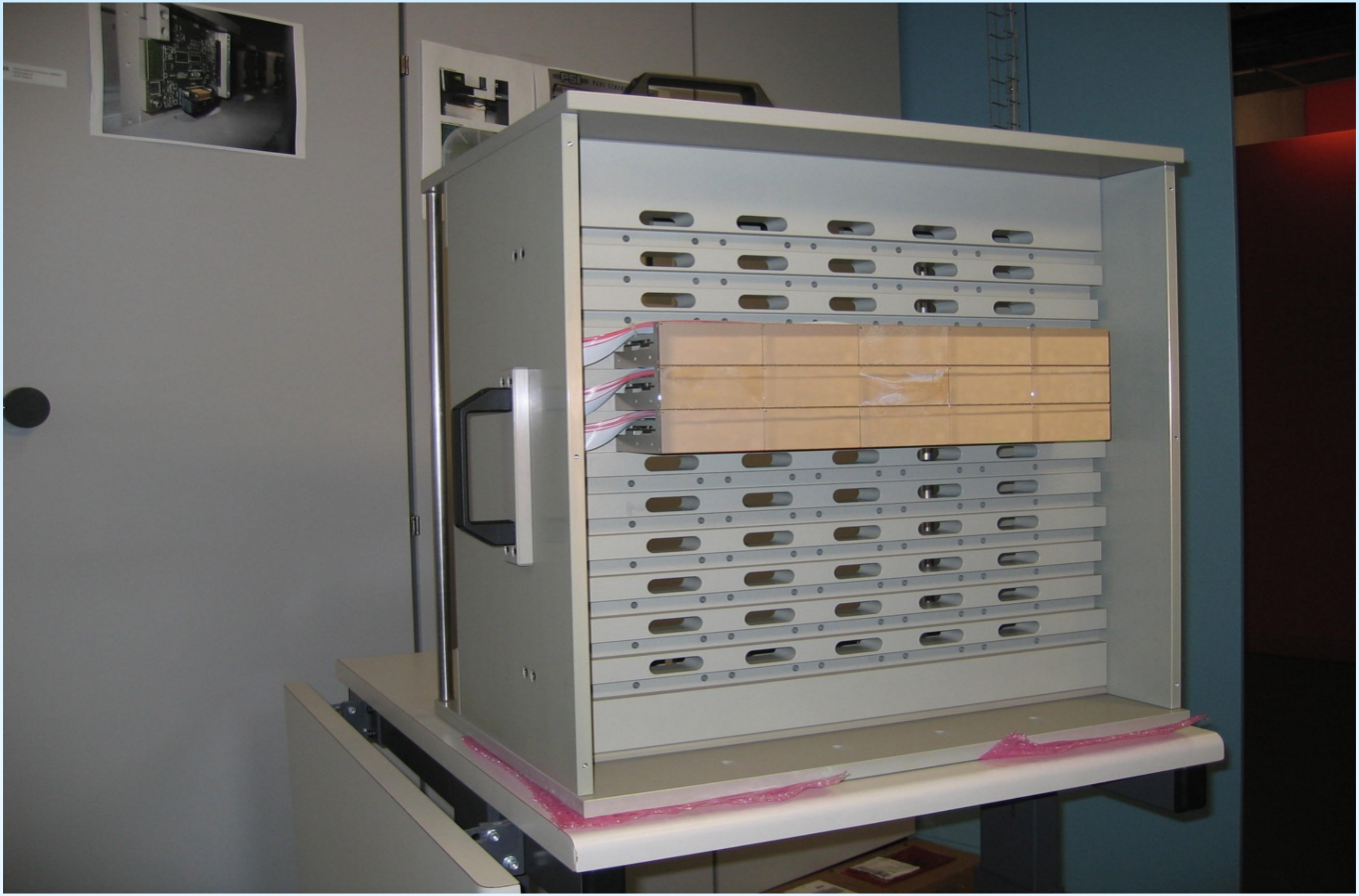
Adding of X-ray pulses (2 together, every 3^{rd} pulse, …)

Analog Pipeline Pixel: Chip Architecture



Hybrid Pixel Array **Detector** (HPAD)

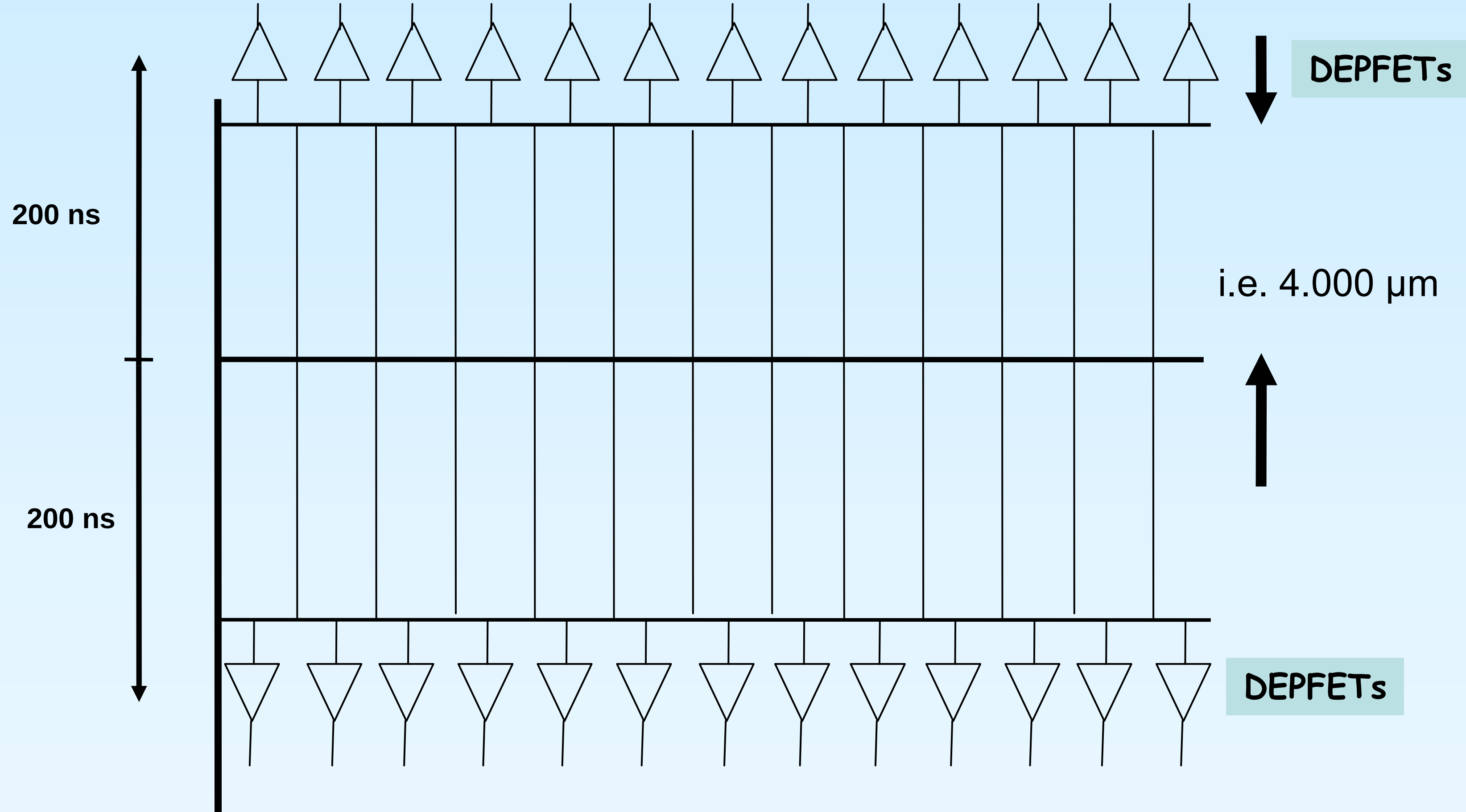
Courtesy Christian Broennimann



How to solve this?

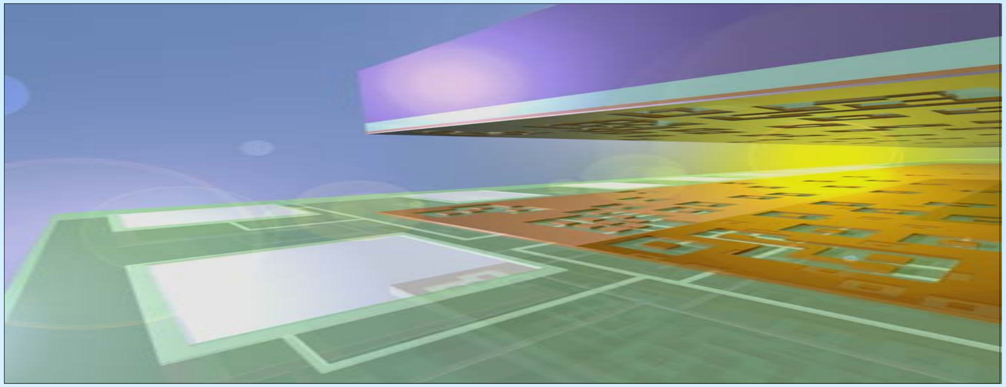
Courtesy Lothar Strueder

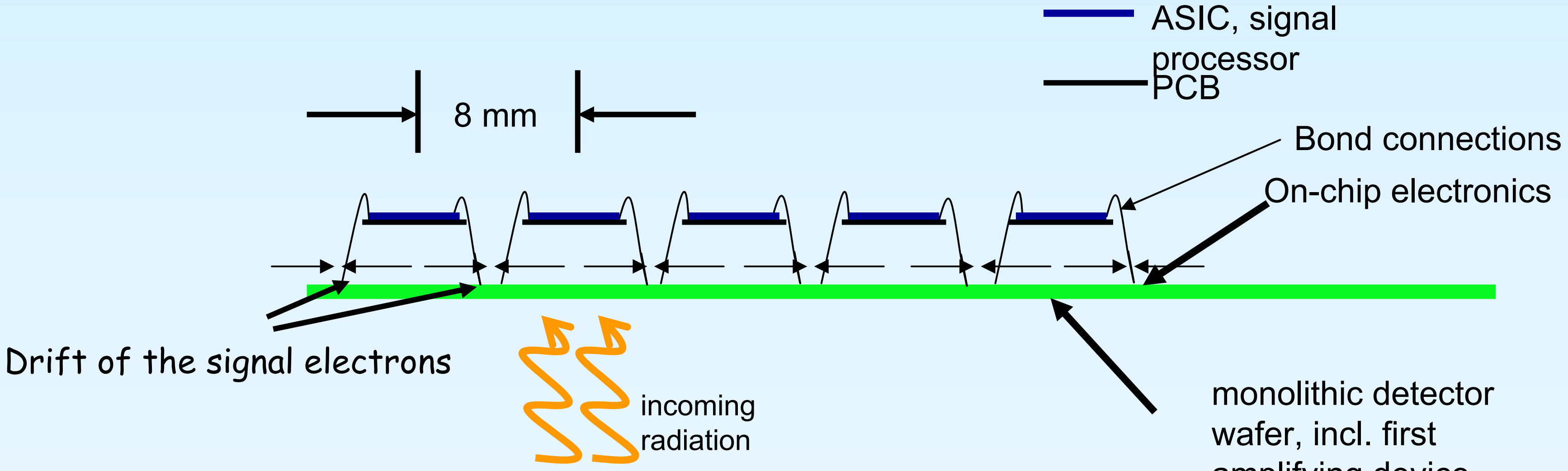
- Silicon Drift Detectors (with DEPFET's)



$V_{max} \approx$ 100 µm / ns, V_{exp} ≈ 20 µm / ns   That means: Δt= 3 ns, Δx = 60 µm
total $area_{max}$: 80 x n•8 mm^2, CHC: unlimited (almost)

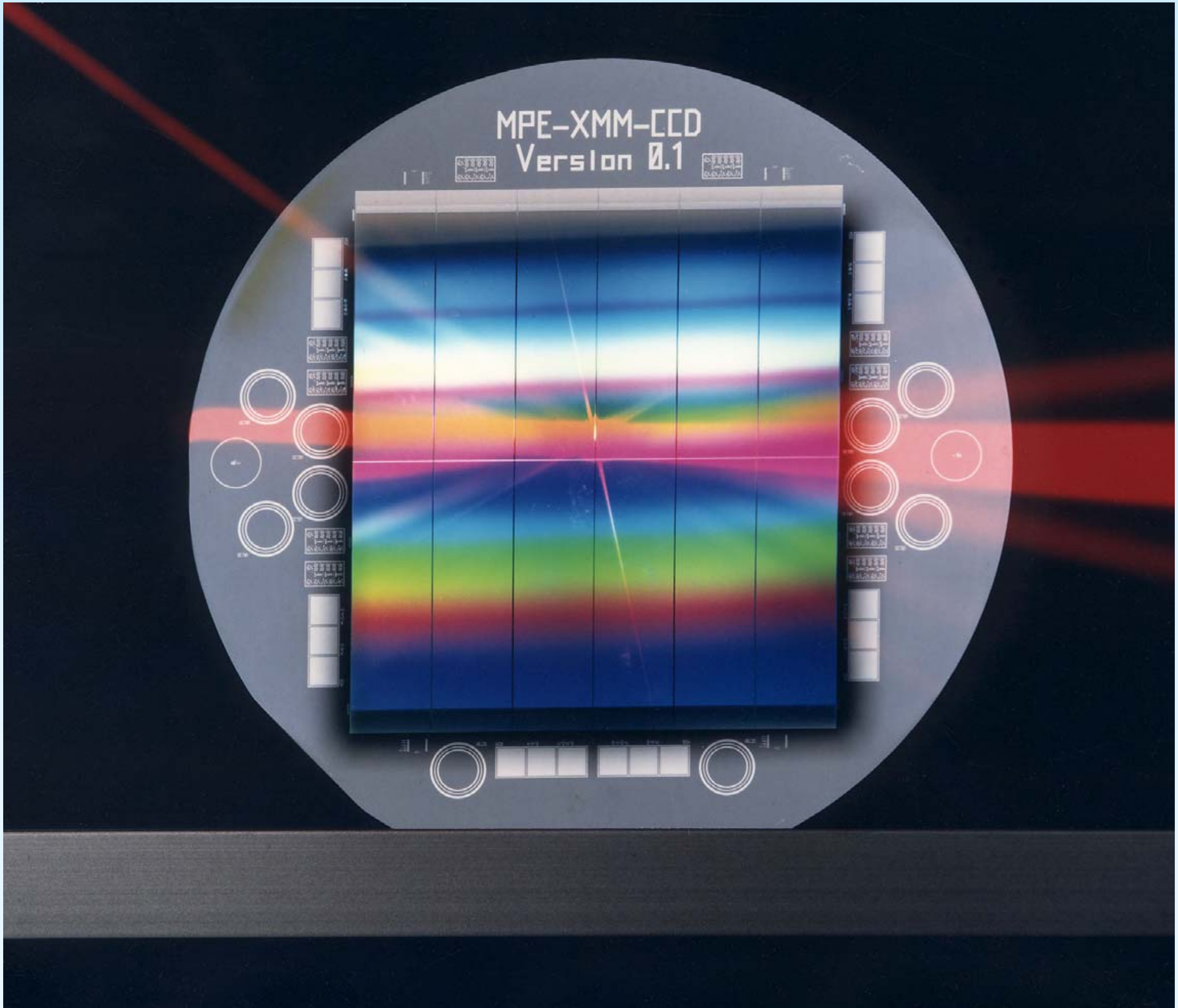
SDD (with DEPFET's)





The XMM chip

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
- ….

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