The Photon Science Detector Group

Heinz Graafsma
DESY

Sources/Stations

- Now: DORIS; 2nd generation SR; 37 stations
- Now: FLASH; shortest λ FEL; 5 stations
- Now: part of ESRF
- +3 years: PETRA-3; high brilliance SR
- +3 years: access to LCLS
- +6 years: European XFEL next door

Goals @ DESY:

- Develop a strong PS Detector-group
- Give support to Storage Rings
- Take a major role in the XFEL photon detector developments
- Utilize all competences and resources available at DESY
- Strive for synergy Photon Science - HEP

PETRA-III Roadmap

BL1	Inelastic X-ray Scattering	***12 (18) cell SDD, pnsensor***	d ≈ 3cm	1x1	
	Pico Second Science	***Streak camera C5680, HAMAMATSU***			
BL2	High Resolution Diffraction	***Cyberstar NaI, Oxford danfysik***		1x1	
		Cyberstar YAP, Oxford danfysik		1x1	
		APD complete system, Oxford danfysik		1x1	
		single cell SDD, pnsensor	d ≈ 6mm	1x1	
		detecting scattered radiation from a foil	8x8mm^2		
		CCD: PI-SCX 4096, Roper Scientific (4x4 binning)	60x60µm^2	1*k*x1*k*	1 *s*
BL3	µSAXS / WAXS	***CCD: PI-SCX 4096, Roper Scientific (2.5:1 taper)***	38x38µm^2	4*k*x4*k*	4.5 *s*
		pnCCD	51x51µm^2	*256x256*	1 *ms*
BL5					
BL6	µX-Ray Fluorescence	***Si(Li), e2v scientific instruments***	80mm^2	1x1	
	X-ray Absorption Spectroscopy	***Si, radiant***	50mm^2	1x1	
	EXAFS	***HPGe, e2v scientific instruments***	30mm^2	1x1	
	µdiffraction	***CCD: PI-SCX 4096, Roper Scientific (4x4 binning)***	114x114µm^2	1*k*x1*k*	1 *s*
	µTomography	***FReLoN-camera 2k14, ESRF***	0.5x0.5µm^2	1*k*x1*k*	8fps
BL7					
BL8	Resonance Scattering	***single cell SDD, pnsensor***	d ≈ 6mm	1x1	
		pnCCD with scintillator	75x75µm^2	1kx1k	1 s
BL10	X-ray Photon Correlation Spectroscopy	***single cell SDD, pnsensor***	d ≈ 6mm	1x1	10µs
		MCAT gaseous detector	<300x300µm	1*k*x1*k*	<10 *ms*

PETRA-III + FLASH Roadmap

- New Roper Scientific CCD camera ordered and waiting delivery.
- PILATUS 100K modules received and tested
- Collaboration on MYTHEN strip detector (6-10 MYTHEN, plus new integrating chip; Q1 2007)
- Joined Medipix-3 collaboration
- Test of pnCCD in early 2007 at FLASH, if successful consider also for PETRA-III
- APD-array and Diamonds still in start-up phase

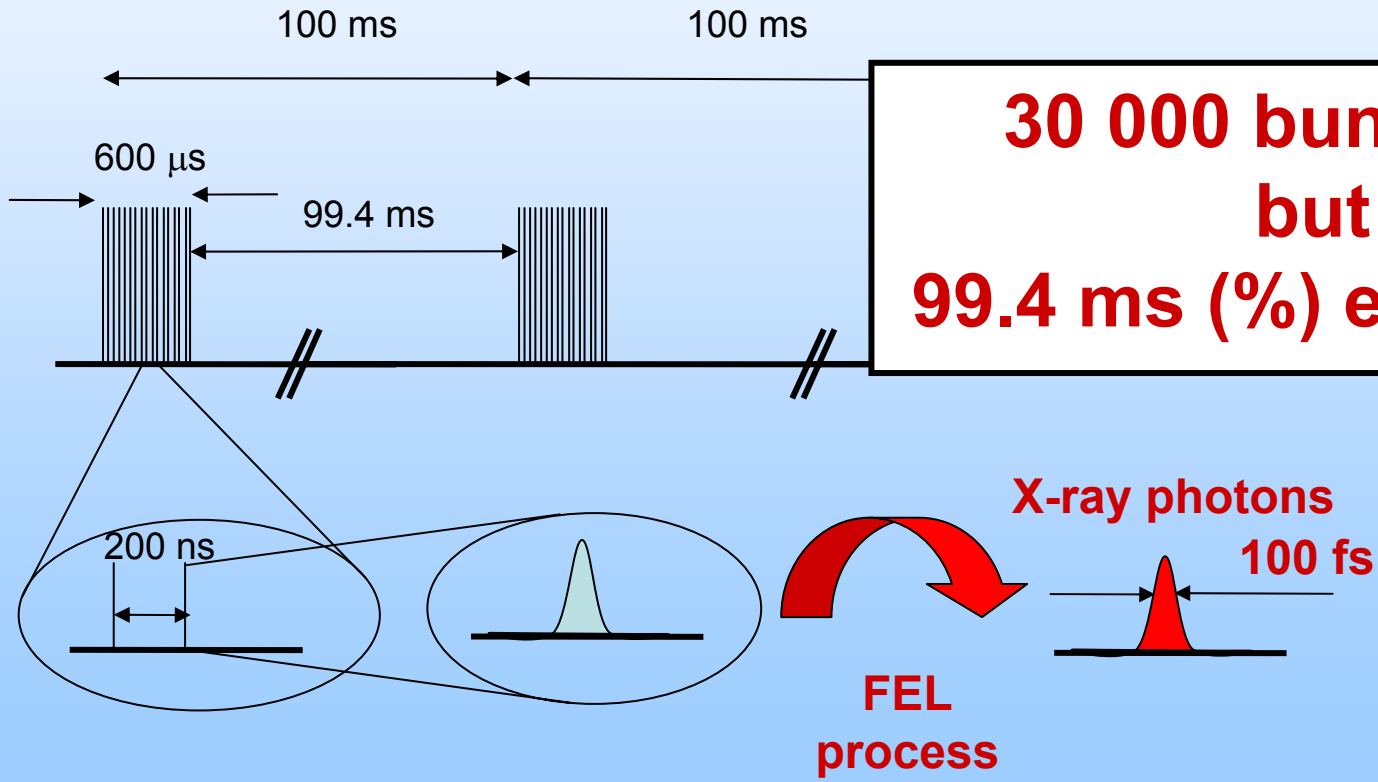
Developments
driven by
XFEL project

spin-off to
other sources

What are the challenges for Detectors?

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

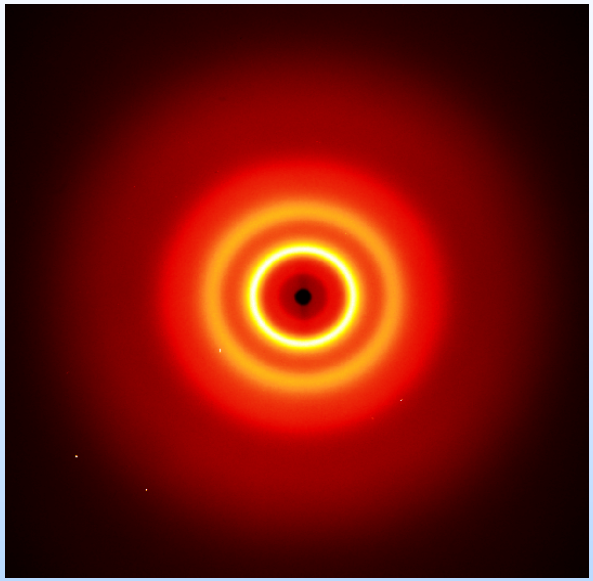
- Either: < 10Hz or > 1.5 kHz; best 5 MHz
- All photons arrive in 100 fsec ➔ integrating detectors.
- Experiments should profit from high luminosity (30 000 shots/sec).
- Every shot is a new experiment (jitter, sample destruction,..)

What are the different needs?

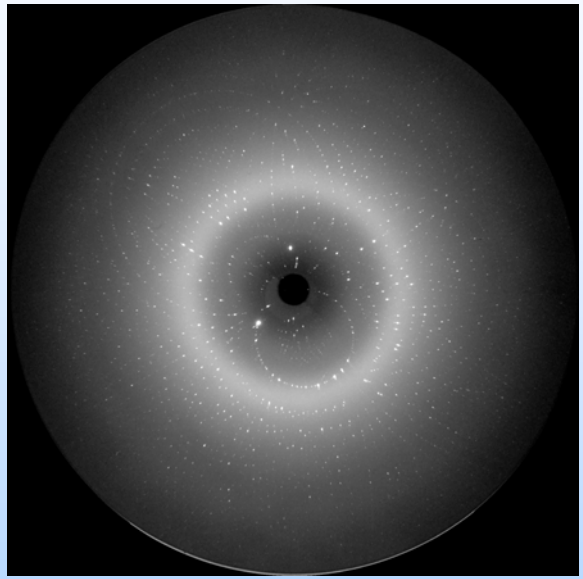
Different detectors are needed and are foreseen:

- X-ray Streak Cameras: **Coming out today!**
- Particle detectors
- 0D/1D detectors
- **2D X-ray detectors:**
  - **Single Particle Imaging**
  - **Coherent Diffraction Imaging**
  - **X-ray Photon Correlation Spectroscopy**
  - **Pump-Probe non-crystalline diffraction**
  - **Pump Probe crystalline diffraction**

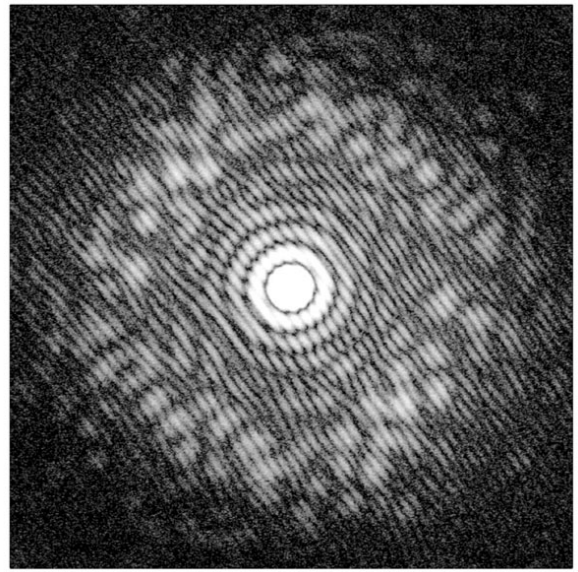
Some images



Liquids



Crystals



Particles

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

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Replies to the Call for Expression of Interest

EoI No.	Submitted by	Subject
XFEL Detectors EoI-01	Advanced Study Group of MPG, DESY, University of Siegen	The fully depleted, back-illuminated high speed, large format X-ray pnCCD
XFEL Detectors EoI-02	Advanced Study Group of the Max-Planck Gesellschaft, DESY, the IHP (FFO), the University of Mannheim, the University of Siegen, the Politecnico di Milano/INFN and PNSensor	Large Format X-ray Imager with Mega-Frame Readout Capability based on a Linear Silicon Drift Detector (LSDD)
XFEL Detectors EoI-03	[redacted]	GaAs and Si detectors with CMOS readout for the XFEL
XFEL Detectors EoI-04	CCLRC	CCLRC Large Pixel Detector
XFEL Detectors EoI-05	The DESY/PSI/UniBonn/UniHamburg consortium	The Analogue Pipe-Line Hybrid Pixel Array Detector
XFEL Detectors EoI-06	[redacted]	Large Area Pixellated X-ray Detectors, Single Particles and Biomolecules (SPB)

Analogue Pipeline HPAD

Diode Detection Layer

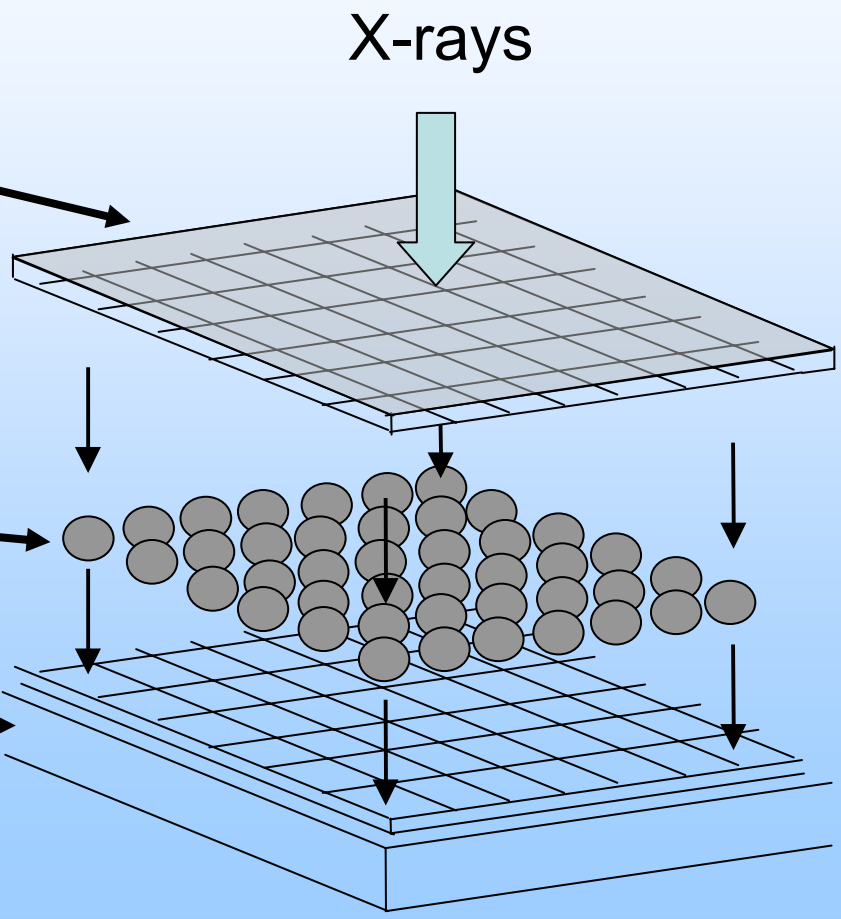
- Fully depleted, high resistivity
- Direct x-ray conversion
- Silicon, GaAs, CdTe, etc.

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

…

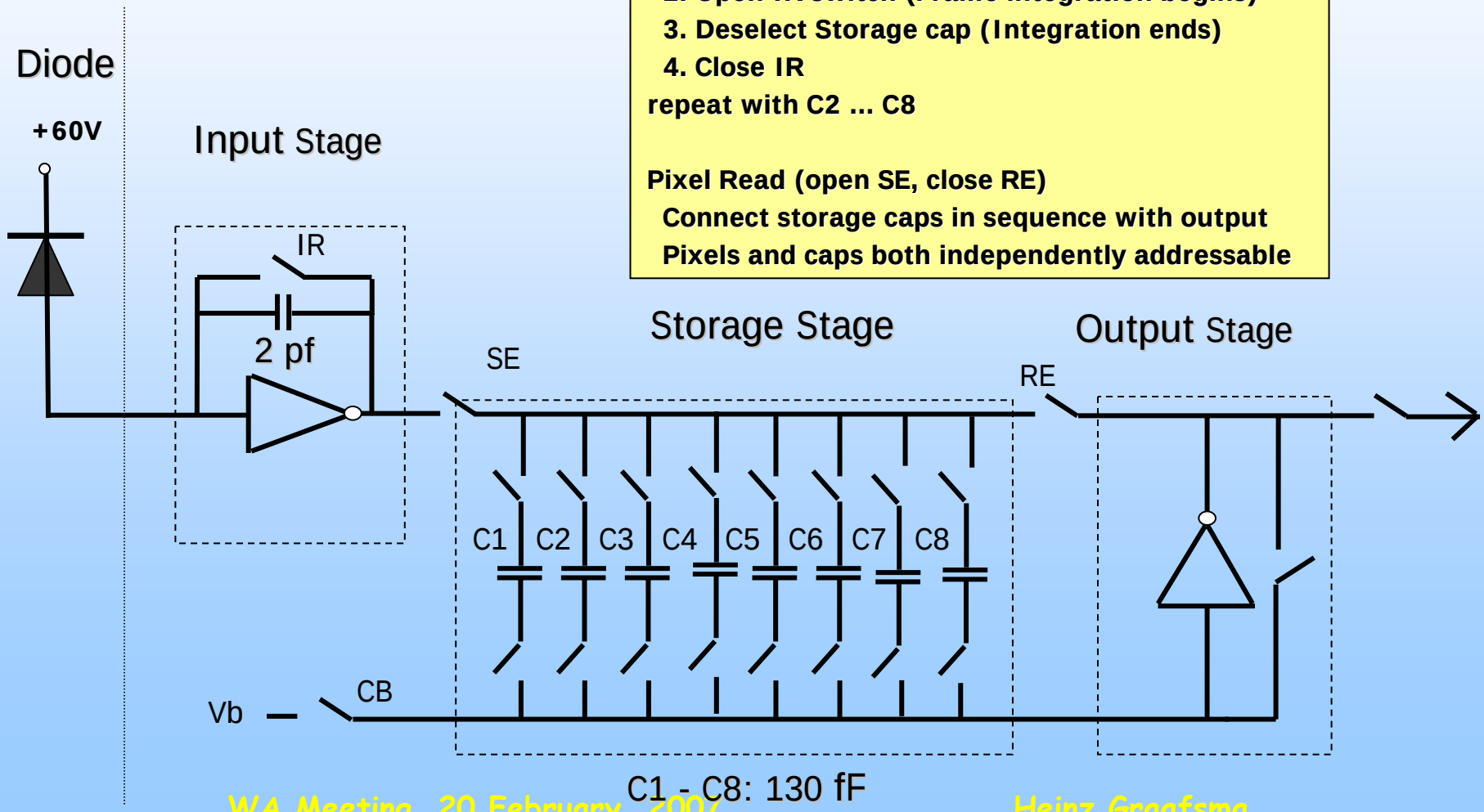
Cornell Analog PAD

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

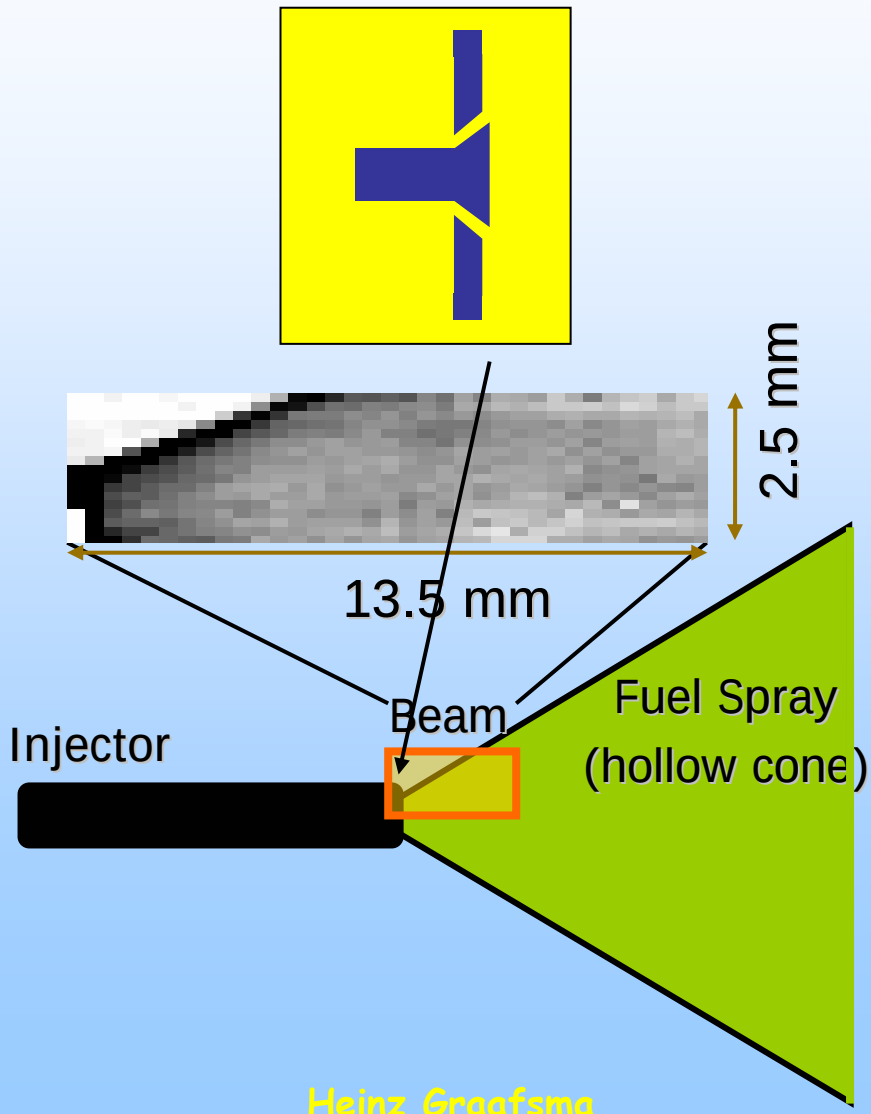
X-ray beam

- 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)

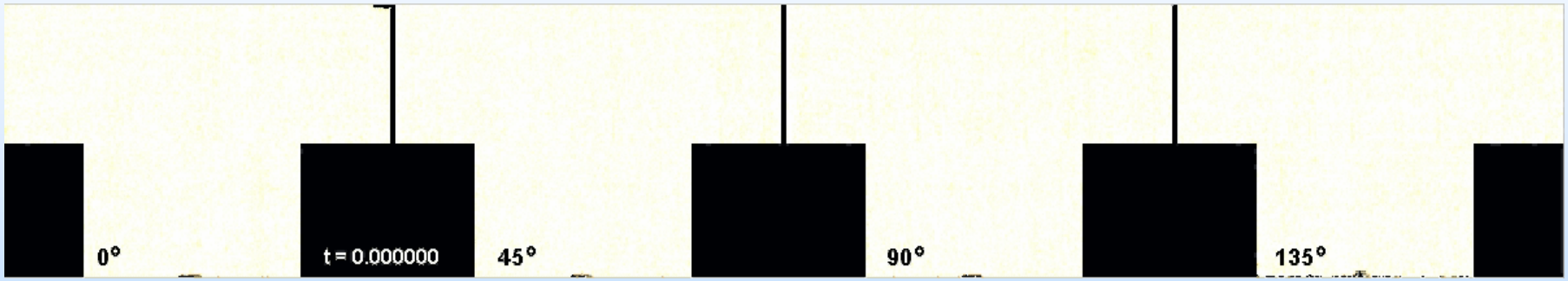


See: Cai, Powell, Yue, Narayanan, Wang, Tate, Renzi, Ercan, Fontes & Gruner

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

Gasoline fuel injector spray

Courtesy Sol Gruner

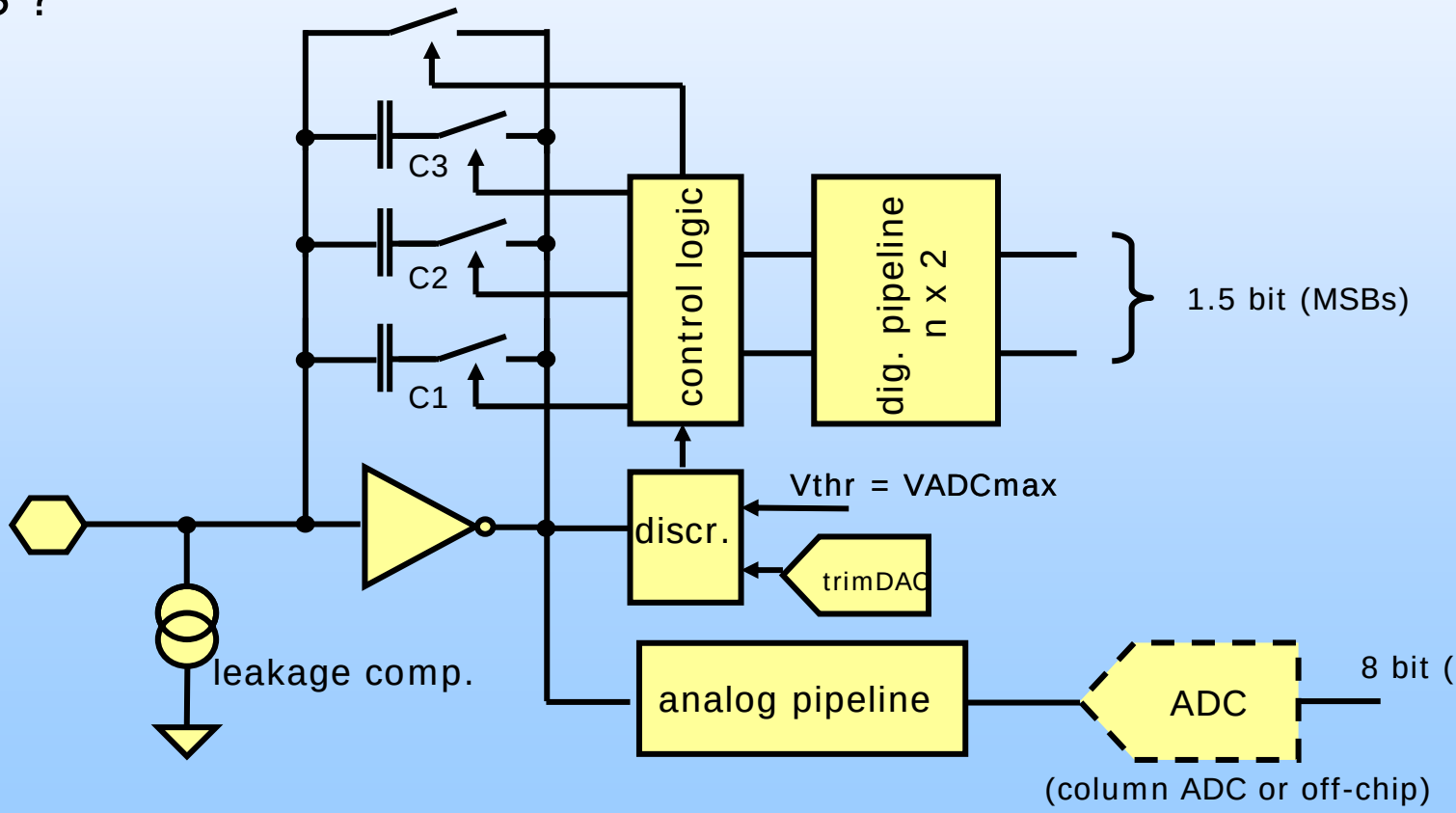


- 1.8 ms time sequence (composite). 10^5 images
- 5.13 μs exposure time. (15.4 μs between frames)
- 88 frames (11 groups of 8 frames), Avg. 20x for noise.
- 1000 x-rays/pixel/μs
- Data taken with 4 projections.

New concepts

Courtesy Hans Krueger

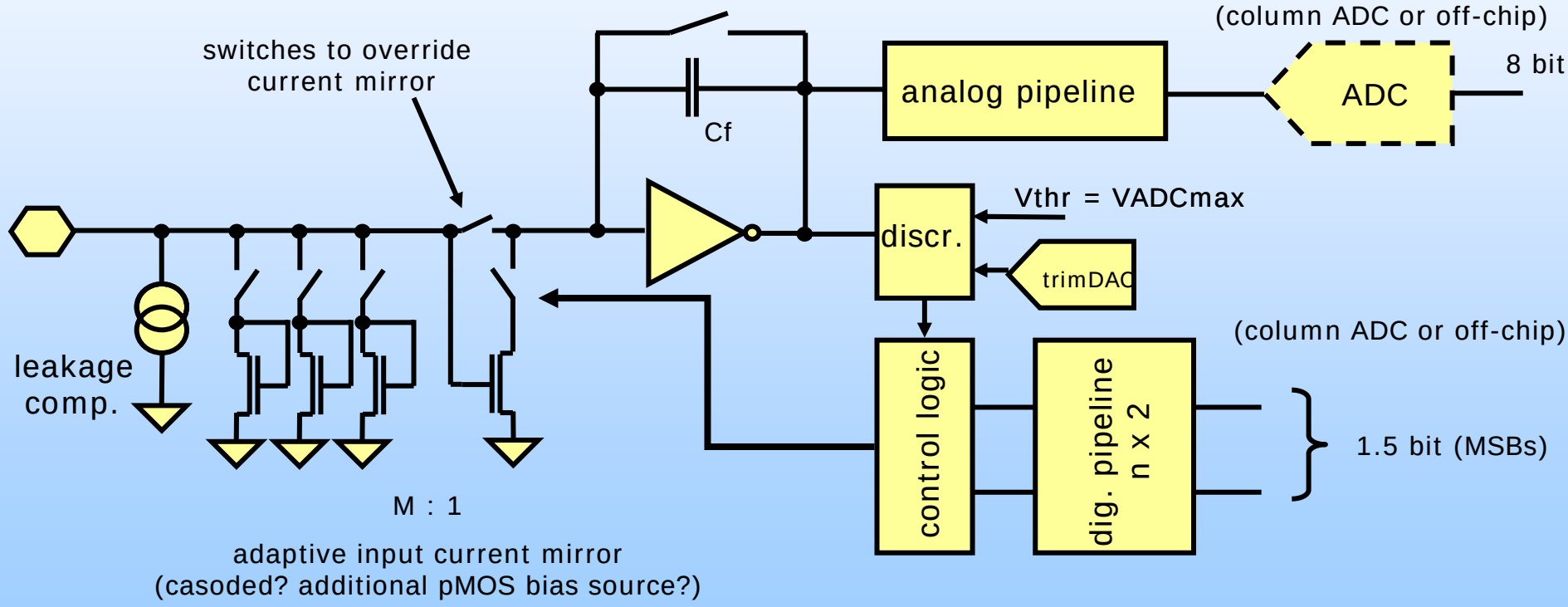
- wide dynamic input range
- multiple (3) scaled feedback capacitors
- reduced ADC resolution (8 bit instead of 10 bit)
- analog + digital (2 bit) pipeline
- in-pixel CDS ?



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

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:

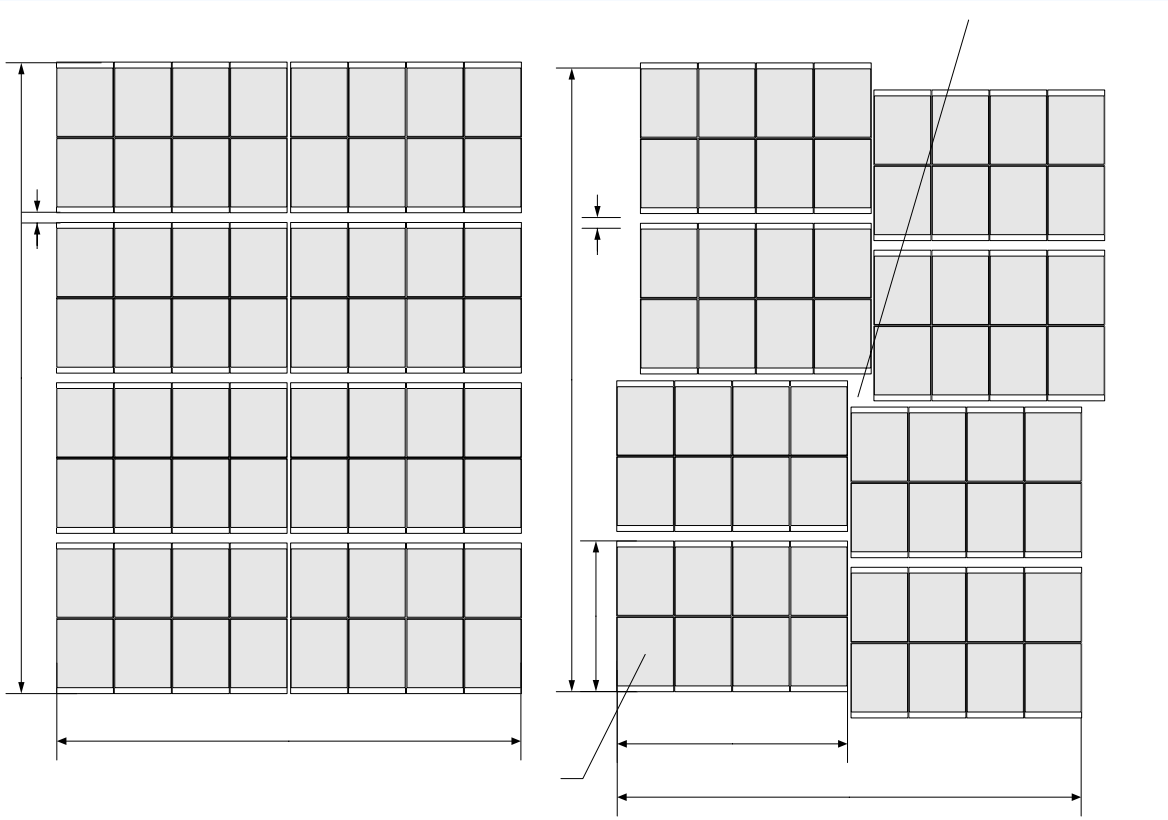
Programmable and flexible pipeline control (Off Chip):

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

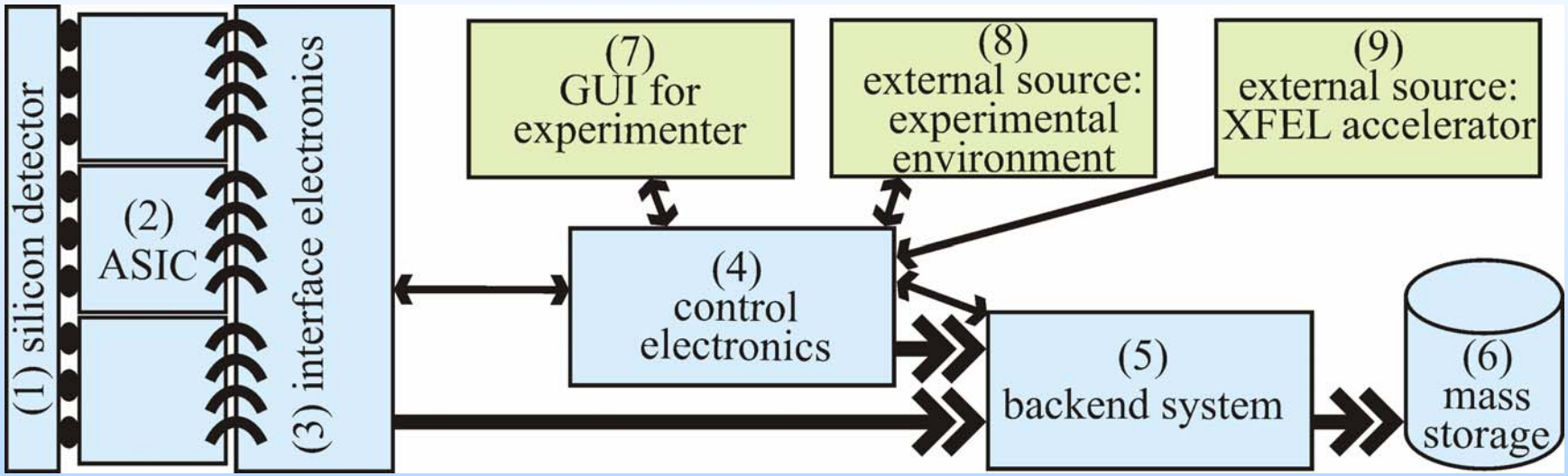
Adding of X-ray pulses (2 together, every 3rd pulse, …)

Hybrid Pixel Detector (HPD) - Layout

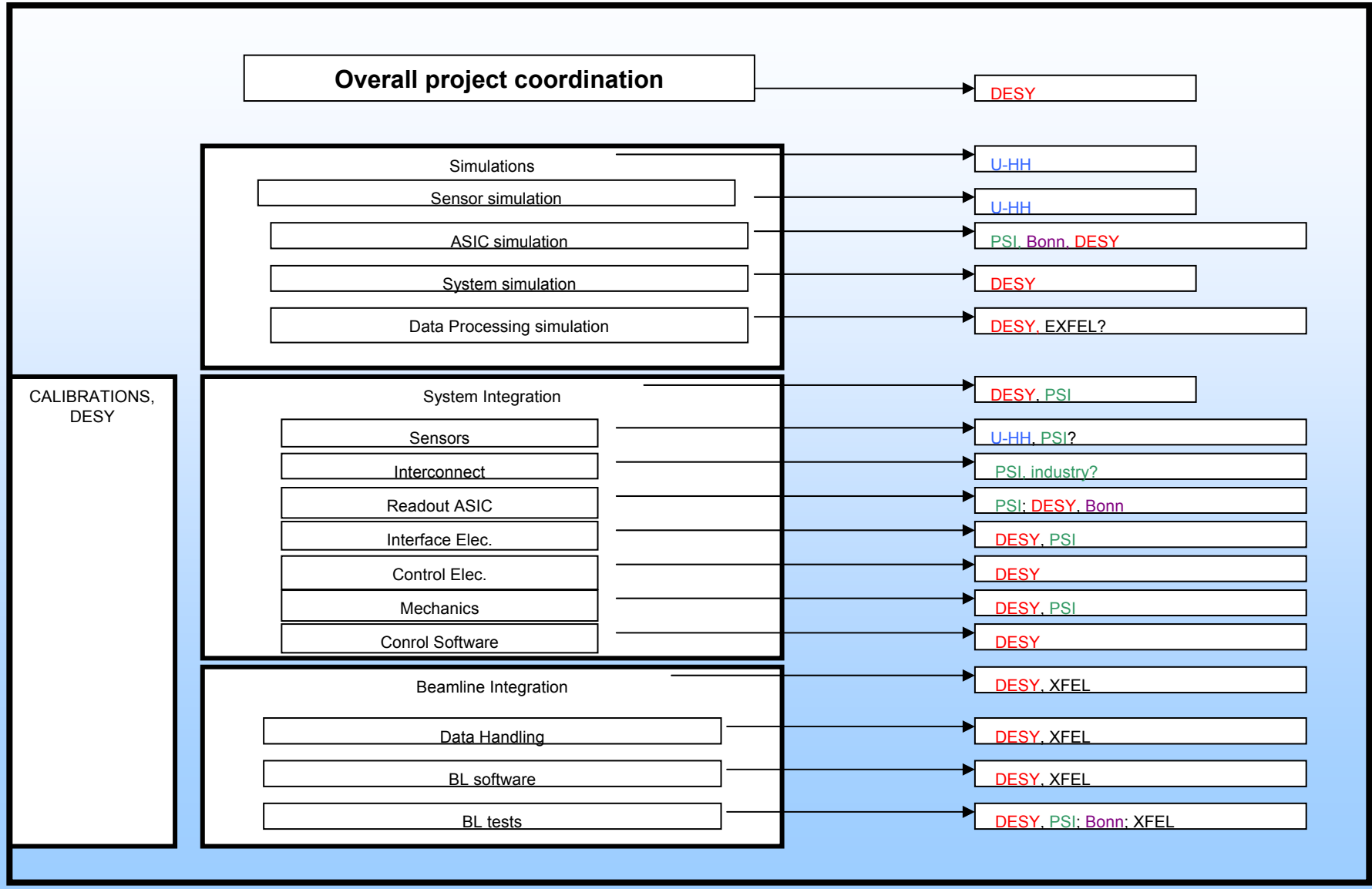
- Basic parameters:
- 100 micron pixels
- 5 MHz framing
- 400 frames storage
- 10^4 dynamic range
- 256 x 512 blocks
- 1k x 1k system
- Based on proven concepts



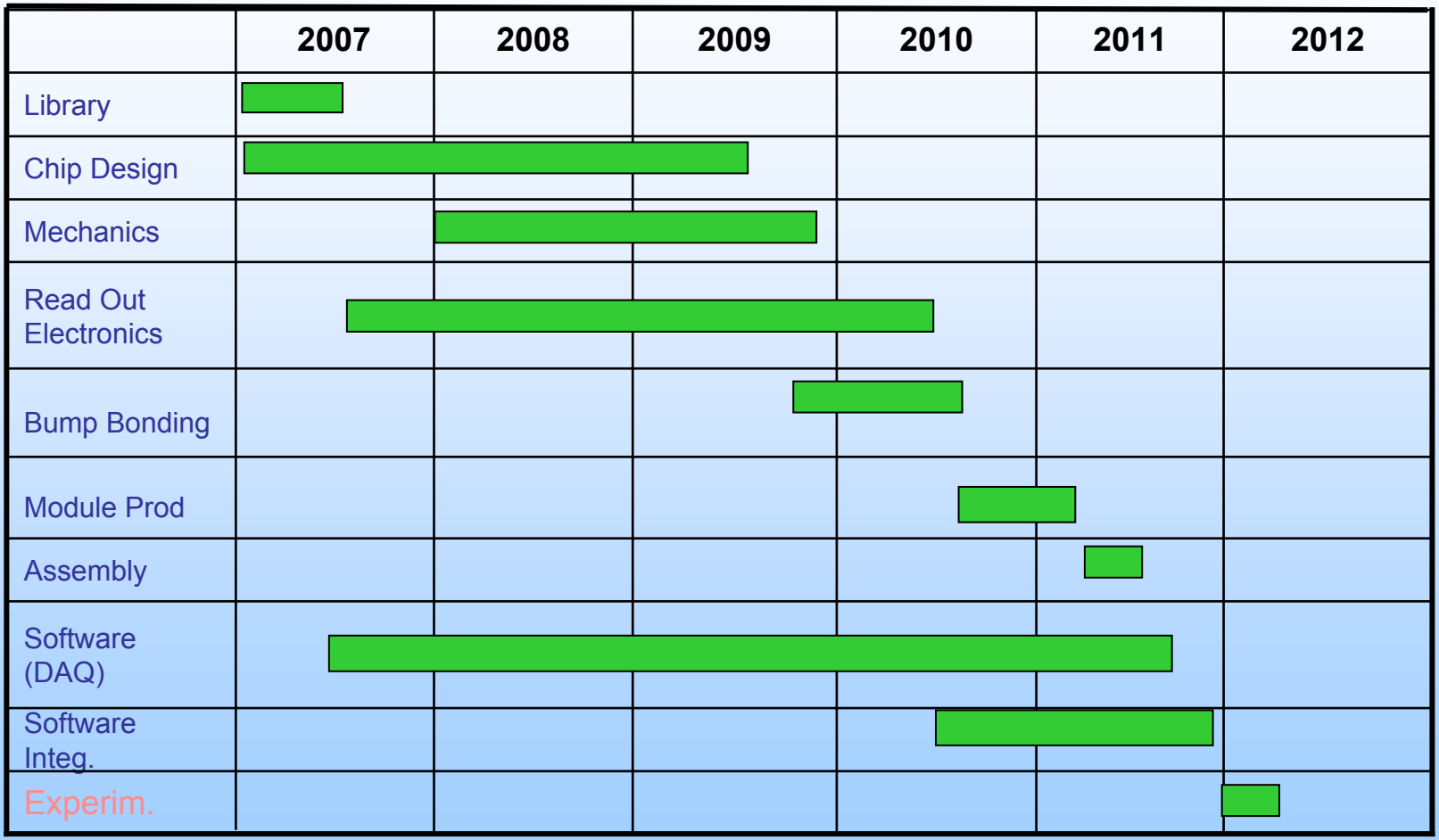
Analog Pipeline Pixel: System Architecture



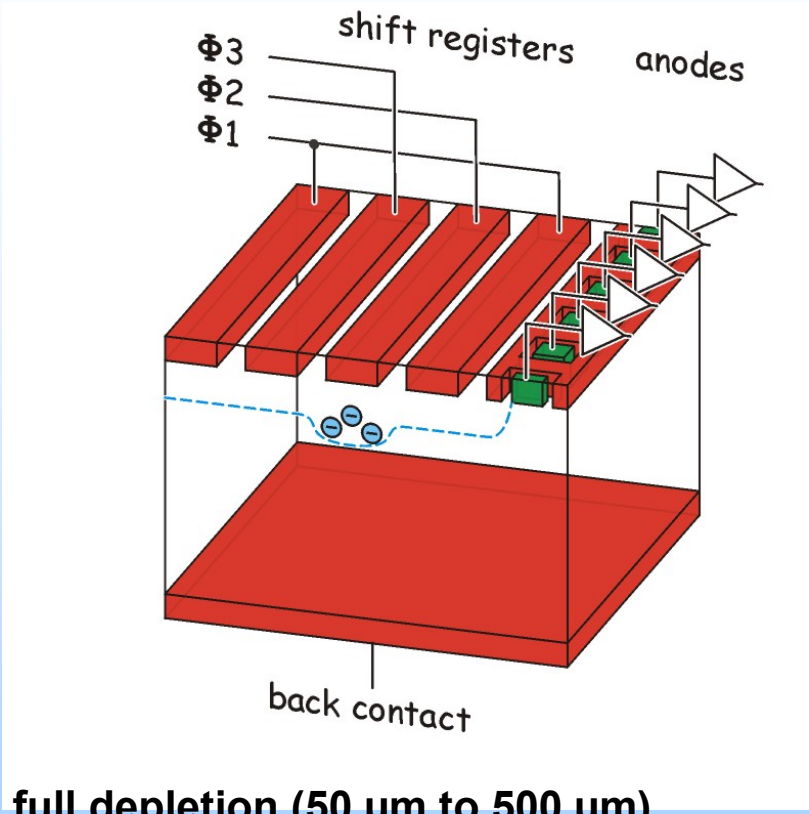
Analog Pipeline Pixel: Project Layout

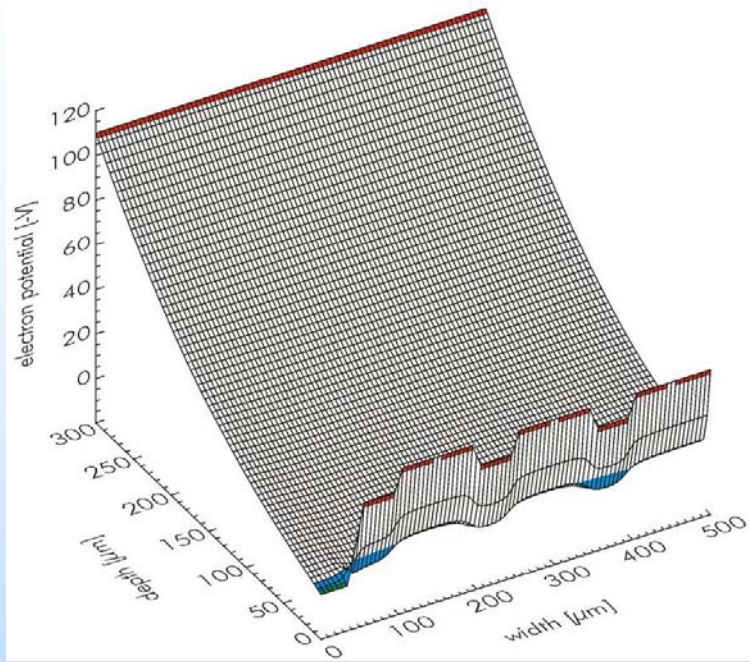


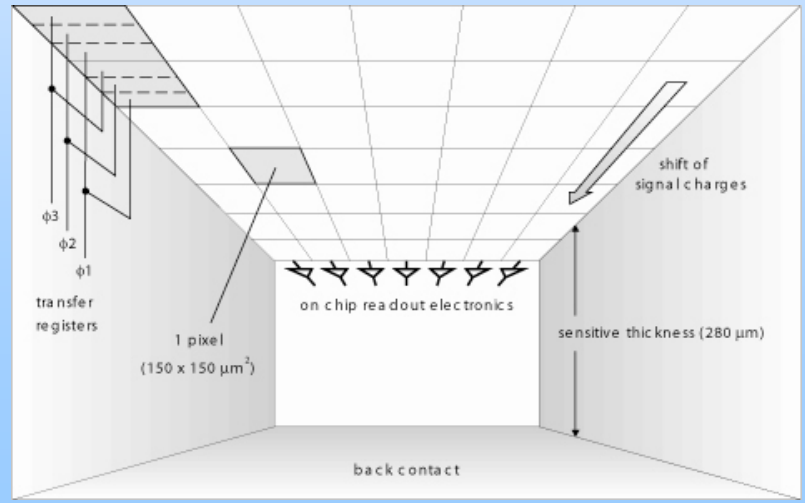
Analog Pipeline Pixel: Project Timeline



2nd project (MPI/HLL): pnCCD (basics)

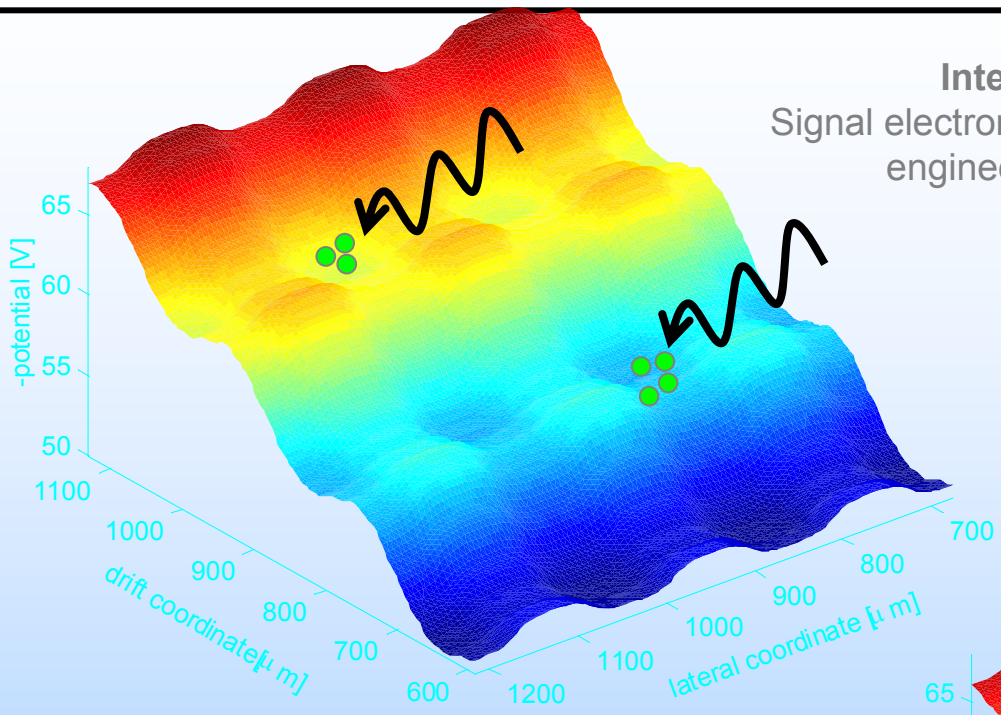






- **full depletion (50 µm to 500 µm)**
- **back side illumination**
- **radiation hardness**
- **high readout speed**
- **pixel sizes from 30 µm to 1 mm**
- **charge handling: more than 10^6 e^-/pixel**
- **high quantum efficiency**

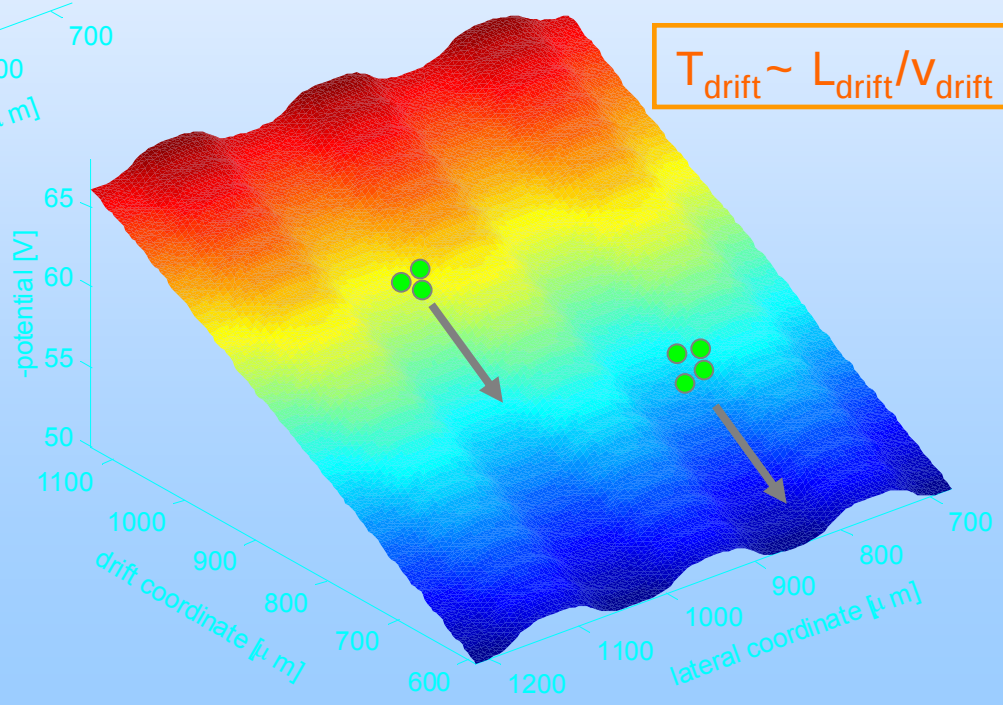
2nd Project (MPI/HLL): pnCCD



Integration phase:
Signal electrons are collected in suitably engineered potential wells

Readout phase:
A uniform drift field transports the electrons to the readout anodes in few μs.

$T_{drift} \sim L_{drift}/v_{drift}$



Parameter settings

The following scenario is based on:

- **36 x 36 μm² pixel size**
- **51 x 51 μm² pixel size**
- **75 x 75 μm² pixel size up to 2k x 2k**
- **100 x 100 μm² pixel size**

Operating temperature: ≈ -10 ° C

Fabrication on high resistivity FZ silicon, 500 μm thick

Availibility of chips

1. **256 x 512 is existing (2006)**
2. **512 x 1024 actually fabricated, ready in early 2007**
3. **1024 x 2048 end of fabrication in 2009/10**

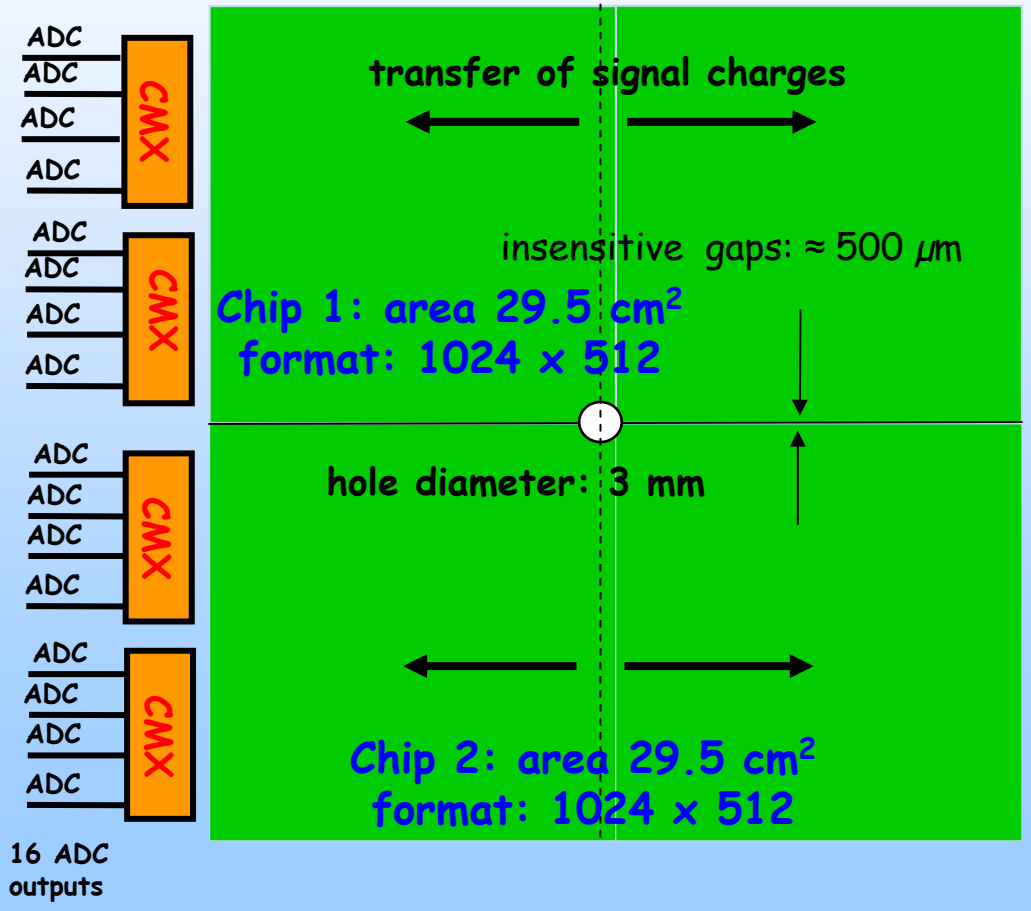
Availibility of systems

add 2 years to get from a chip to a system

Proposal for phase 1

devices are in preparation^, fabrication ready: mid. 2007

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

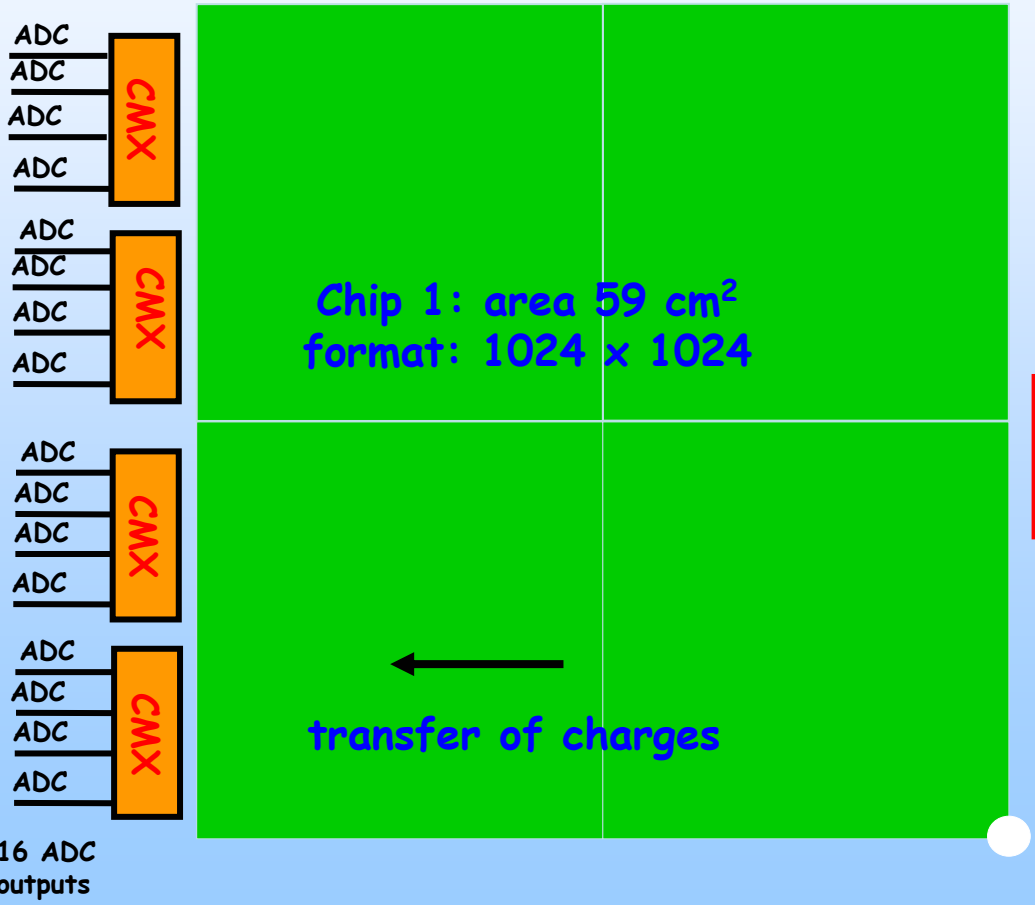
readout time per frame: 4 ms i.e. 250 fps

Total sensitive system area: 59 cm

2nd phase upgrade

devices are scheduled for fabrication in 2009
ready: mid. 2010

The full sensitive area of the system is 239 cm² with 75 µm pixels, 2048 x 2048



Full Frame imaging, format per chip 1024 x 1024

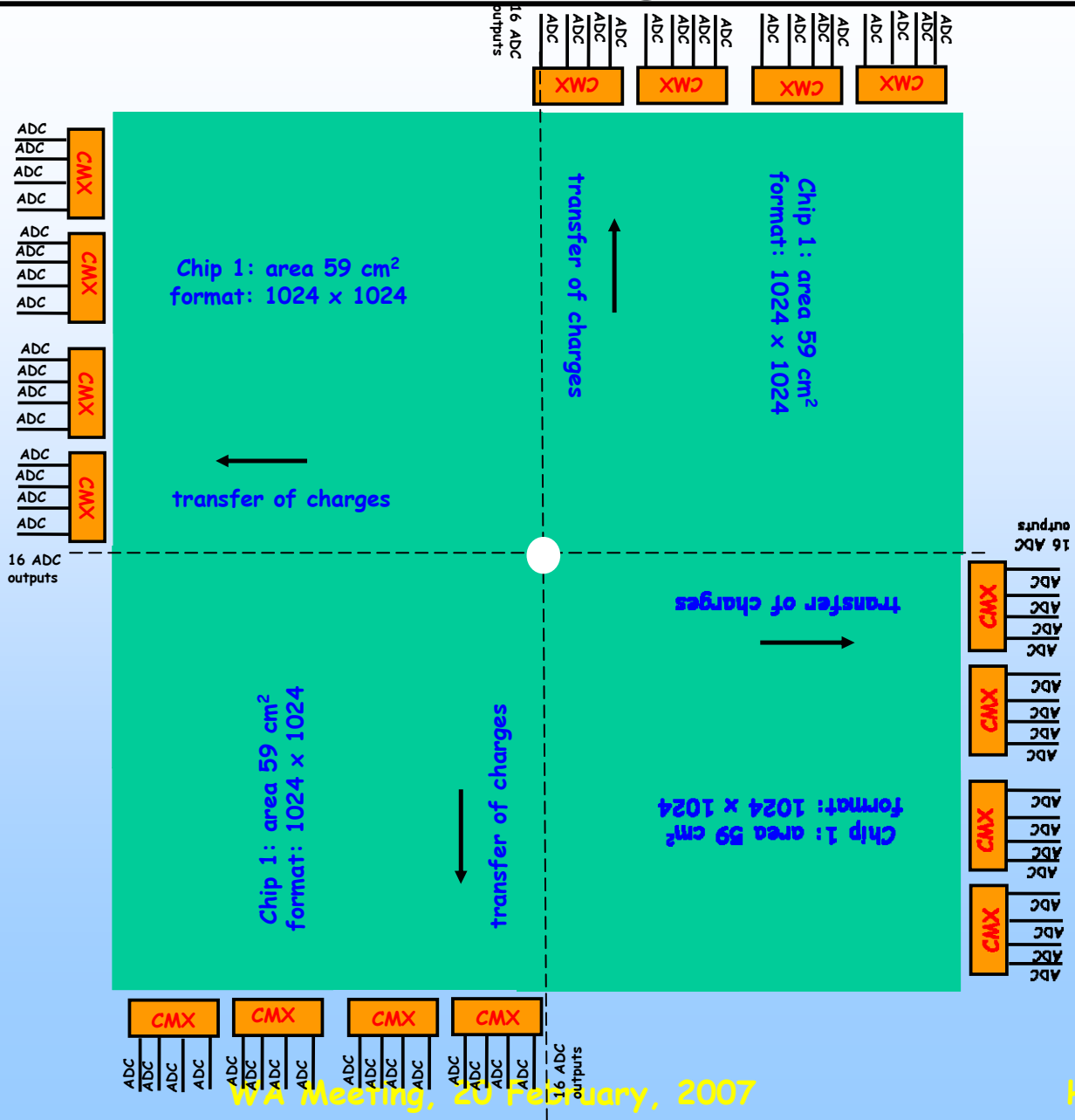
pixel size 75x75 µm²

total area per chip: 59 cm², per system: 236 cm²

readout time per frame: ≈ 8 ms
i.e.≈ 125 fps

This system is 3 – side buttable, can be extended to a 2048 x 2048 array

Detector upgrade in 2012/13



2048 x 2048 CCD array

pixel size: 75 x 75 μm^2

total area: 236 cm^2

readout time: < 8 ms

read noise < 15 electrons

Charge handling capacity:
> 1000 photons pp

Energy 0.2<E<24 keV

thickness: 500 μm

operation temperature:-10°C

Project outline pnCCD

Area detector I + II: pnCCD system (1k x 1k and 2k x 2k)

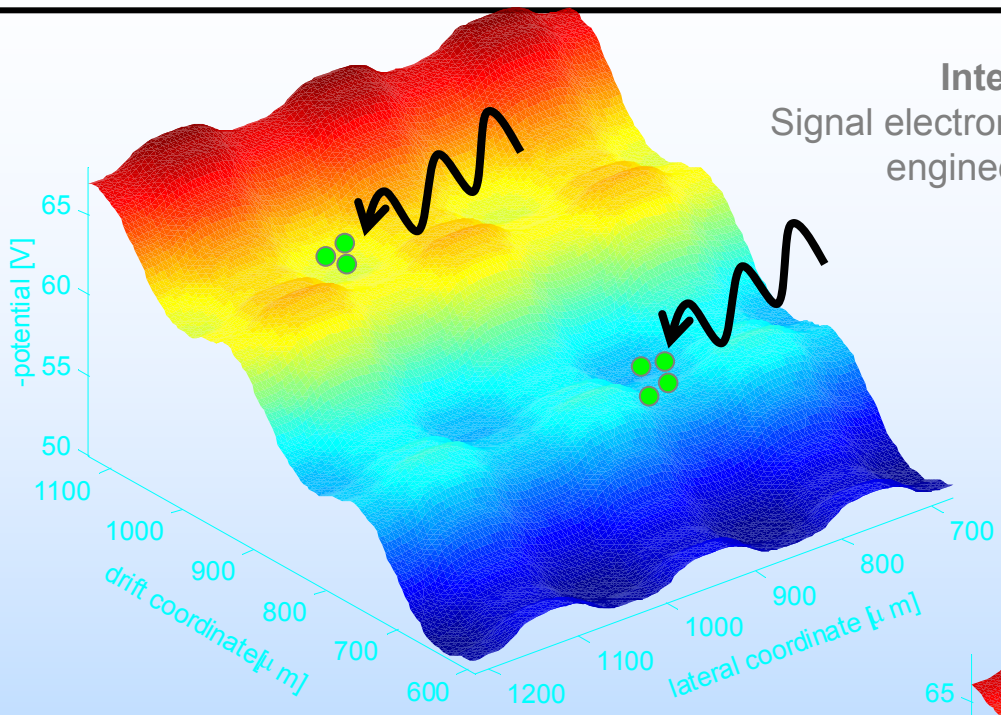
1. Detector development — MPI HLL
2. Front-end integrated analog electronics — MPI HLL
3. DAQ, slow control, mechanical and thermal integration, modelling — MPI HLL, DESY
4. Instrument and data analysis S/W, calibration — (U.Siegen) + DESY + MPI HLL

Estimated time for system I: 3 years (2009)
Estimated time for system II: 5 years (mid 2012)

pnCCD time schedule (phase I)

		2006 2. half			2007 1. half			2007 2. half			2008			2009		
1.	Project definition layout, fabrication															
2.	System concept, ASICs, PC boards, mechanical, thermal															
3.	Electrical tests, mounting, bonding,															
4.	System tests, qualification															
5.	Beamline tests @ DESY, LCLS implementation, test															

2nd Project (MPI/HLL): pnCCD



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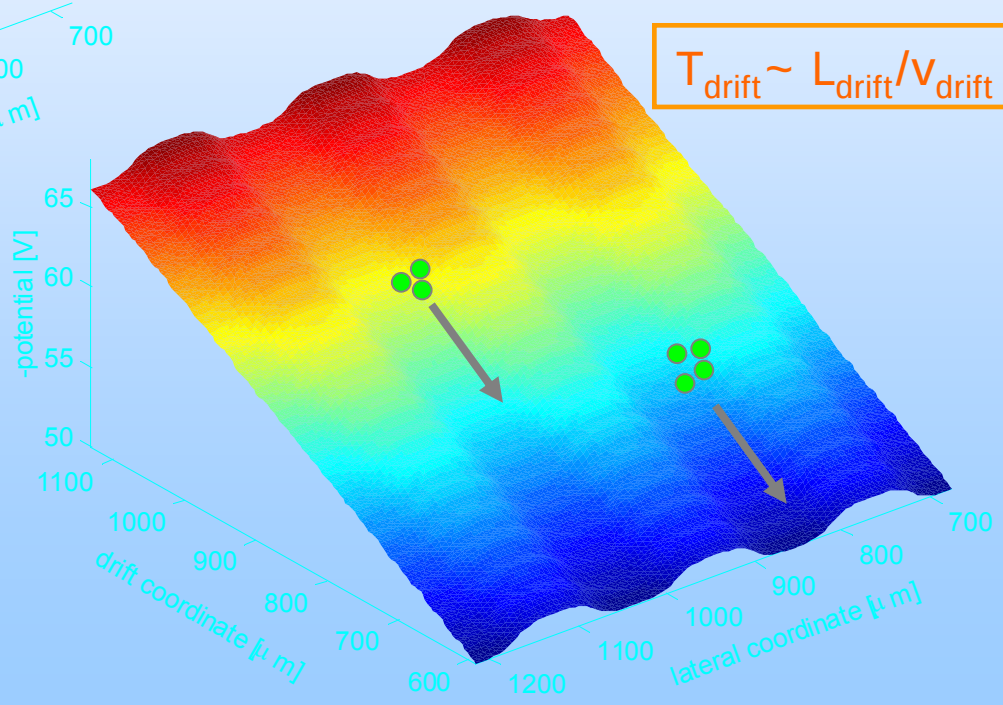
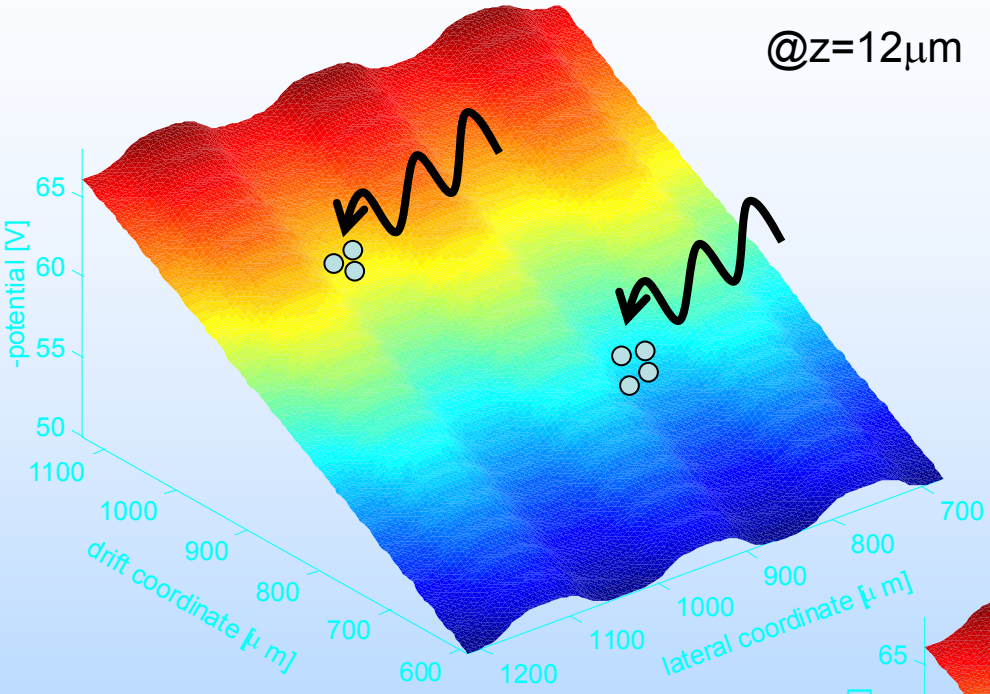
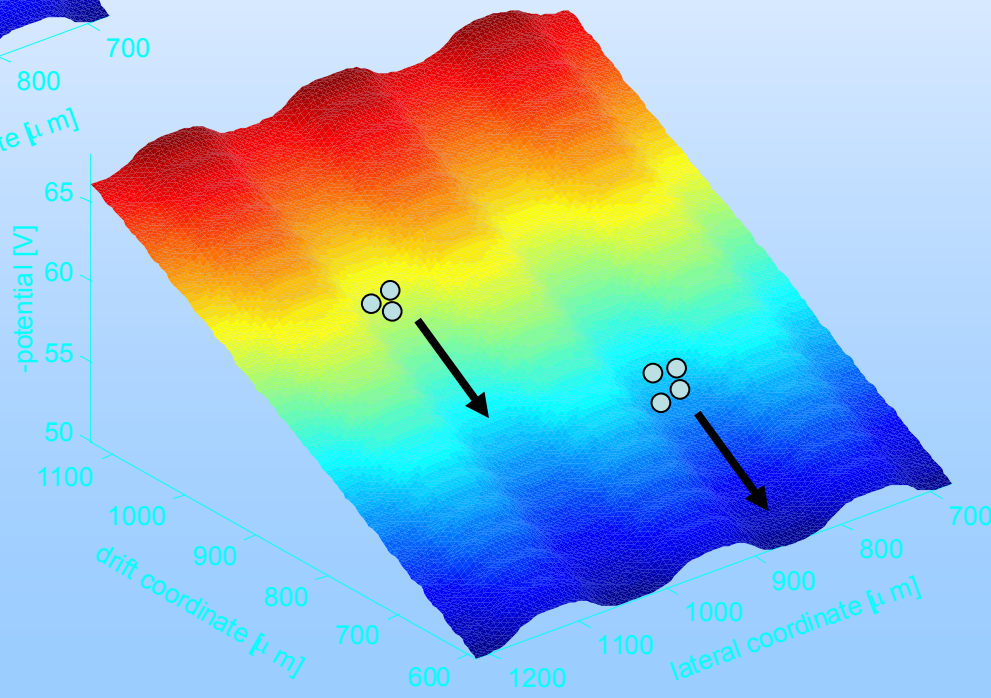


Linear – Silicon -Drift Detector - simulation



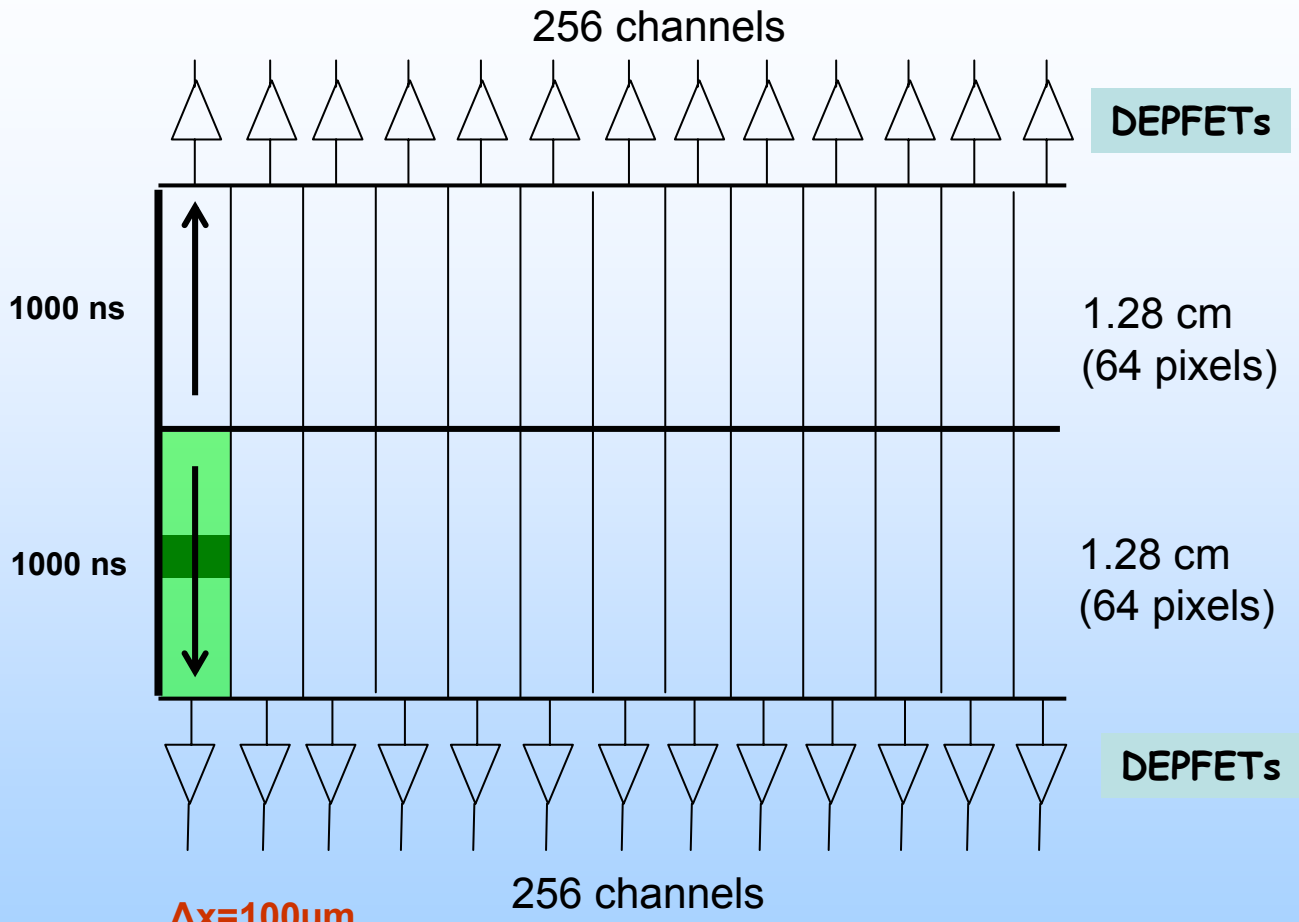


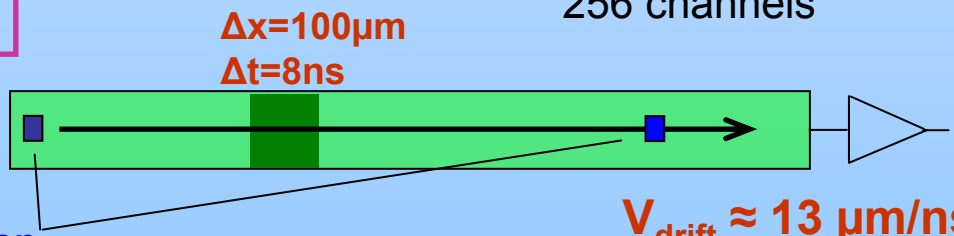
The X-ray position along the drift is obtained from the electrons' drift time

T_{drift}~1000 ns / 12.8 mm

Device proposal for the XFEL: CDD+int. frontend (phase I, prototyping)

256x256
2x256 channels
1 MHz
200μm pixel
room temp.
10^3-10^4 X-rays
QE>80%@10keV
ENC<30 el.
Expandable to:
512x512
1024x1024
(no dead area)



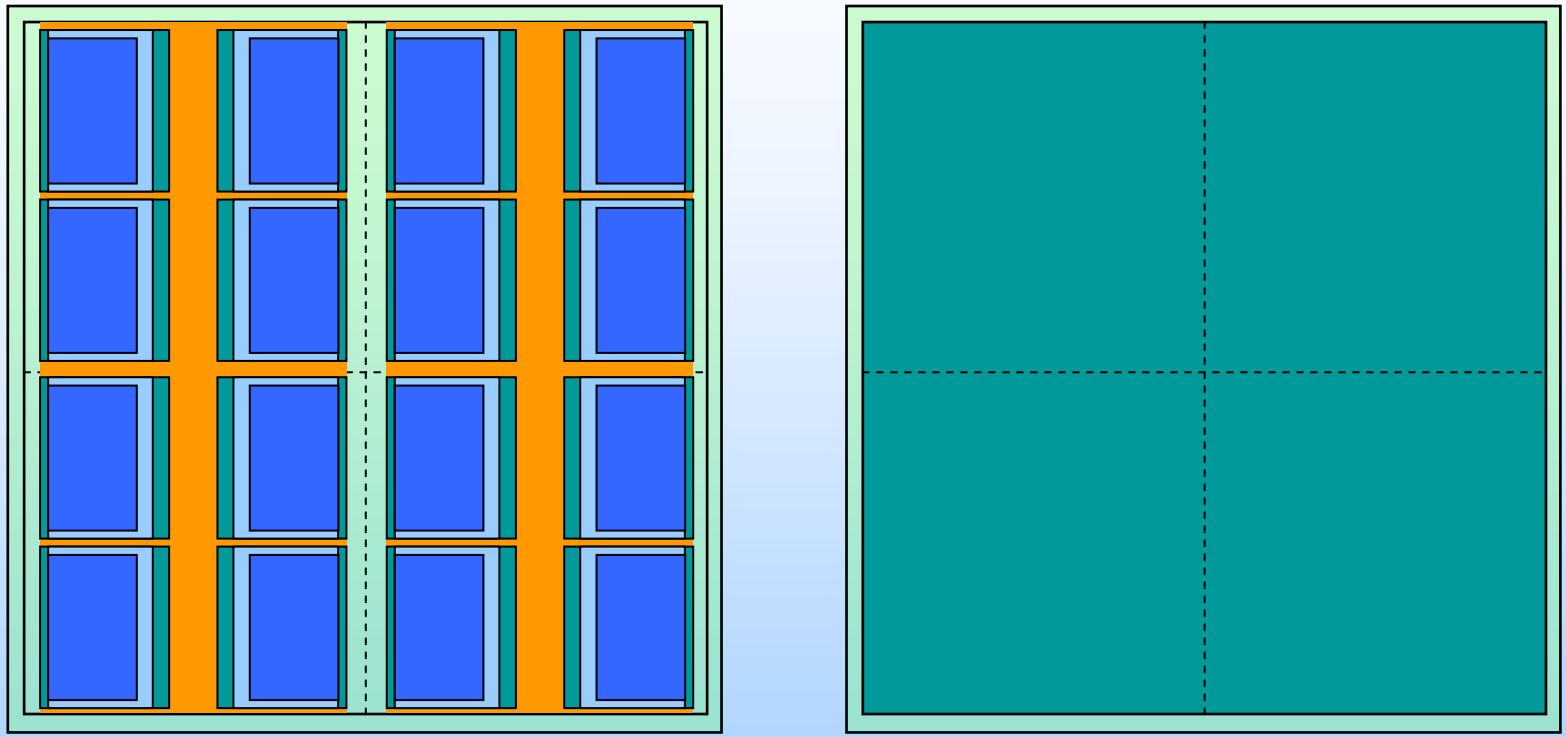


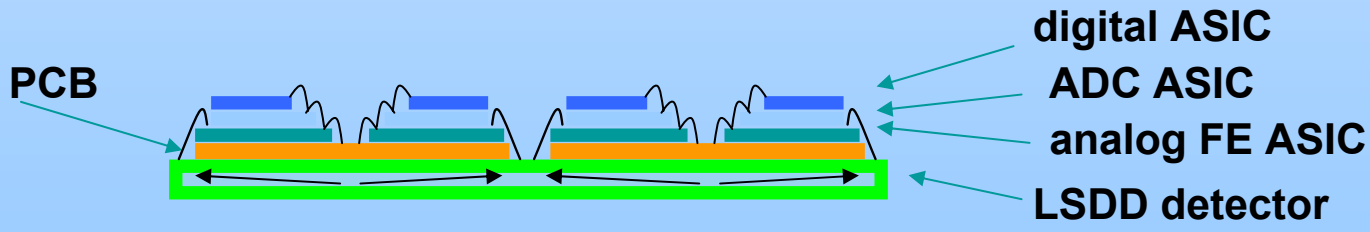
The final pixel size will be 100μm < x < 200 μm

drift velocity calibration with electron injectors

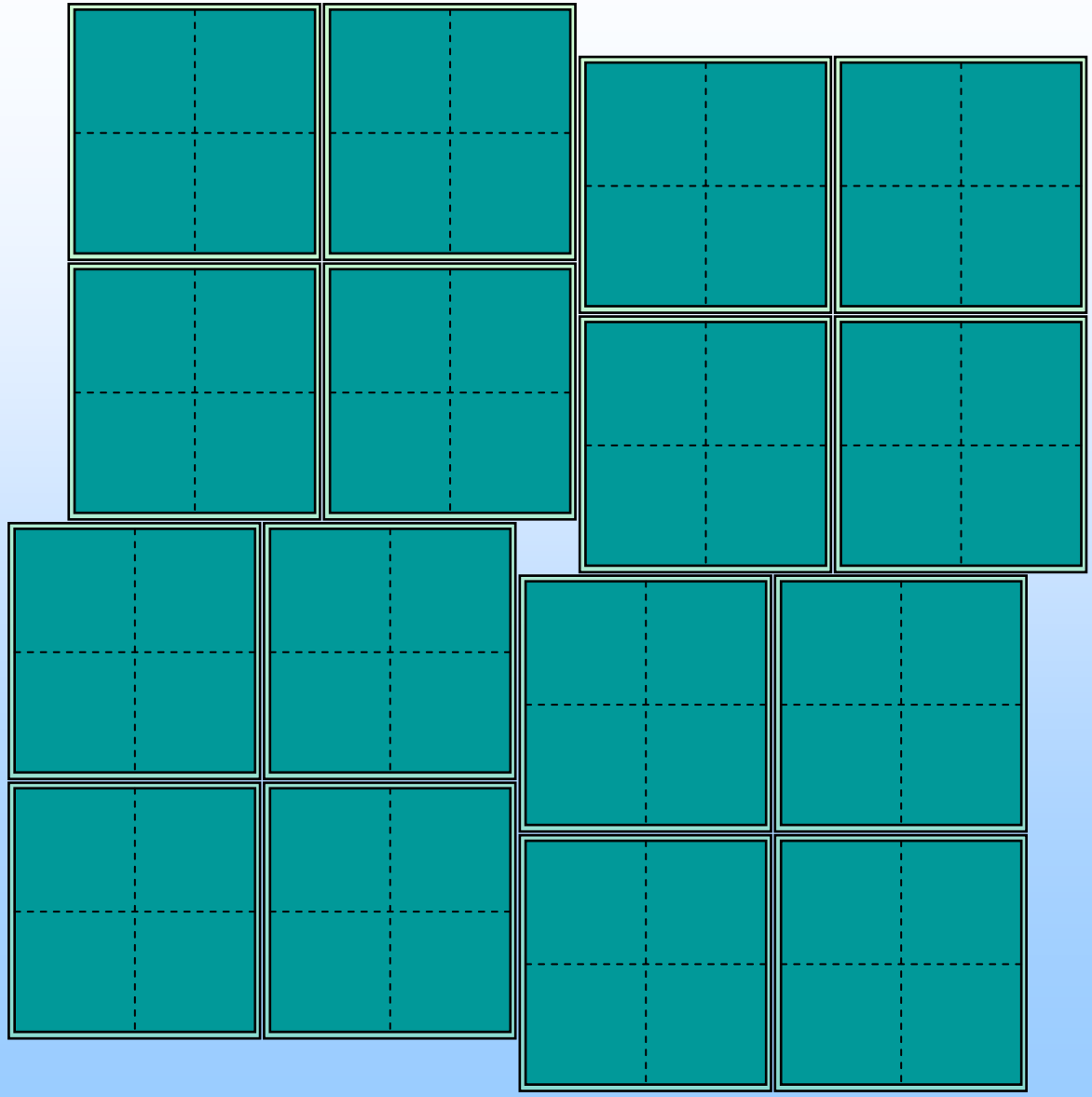
$V_{drift} \approx 13$ μm/ns (i.e. ~3.5V/30μm bias)
$T_{drift, max} = 1000$ ns

Focal Plane Module 256x256





Focal Plane arrangement 1024x1024



pixel size: 150μm – 200μm

readout time per frame: 1μs

dead area in FP: 13 %

Readout noise: < 30 electrons

max. number of photons per pixel: 10.000

Energy range: 0.5 keV – 25 keV

Q.E.: > 90 %

final format: 1024 x 1024

What is different from hybrid or CMOS pixel sensors?

An active area of 100 x 12.800 µm². (i.e. 128 pixels) is processed by one readout channel with an imaging pixel resolution of 100x100 µm².

this leads to:

- reduced problems for interconnections
- more ASIC area for signal processing
- extremely low event thresholds
- reduced power dissipation
- „flexible“ pixel size, i.e. defined by time resolution

Advantages increase if the 5 MHz „dogma“ is relaxed

Proposal (Phase I + Phase II)

- XFEL case phase I (1 Mega frames per second) (3.5 yr)

detector and electronics must be expandable from 256x256 to 1024x1024

  - sensor 256x256 with 100 μm pixel size
  - frame rate
    - » Baseline: 500 kHz
    - » Goal: 1 MHz
  - upgrade evaluation for >1 MHz operation
  - threshold 1keV, counts/pixel/bunch 10^3-10^4 (10 keV) x-rays
  - storage depth: from
    - » Baseline: 128 frames
    - » Goal: 512 frames
  - detector and front end electronics fabrication with a synchrotron beam test at the end of study (2010)

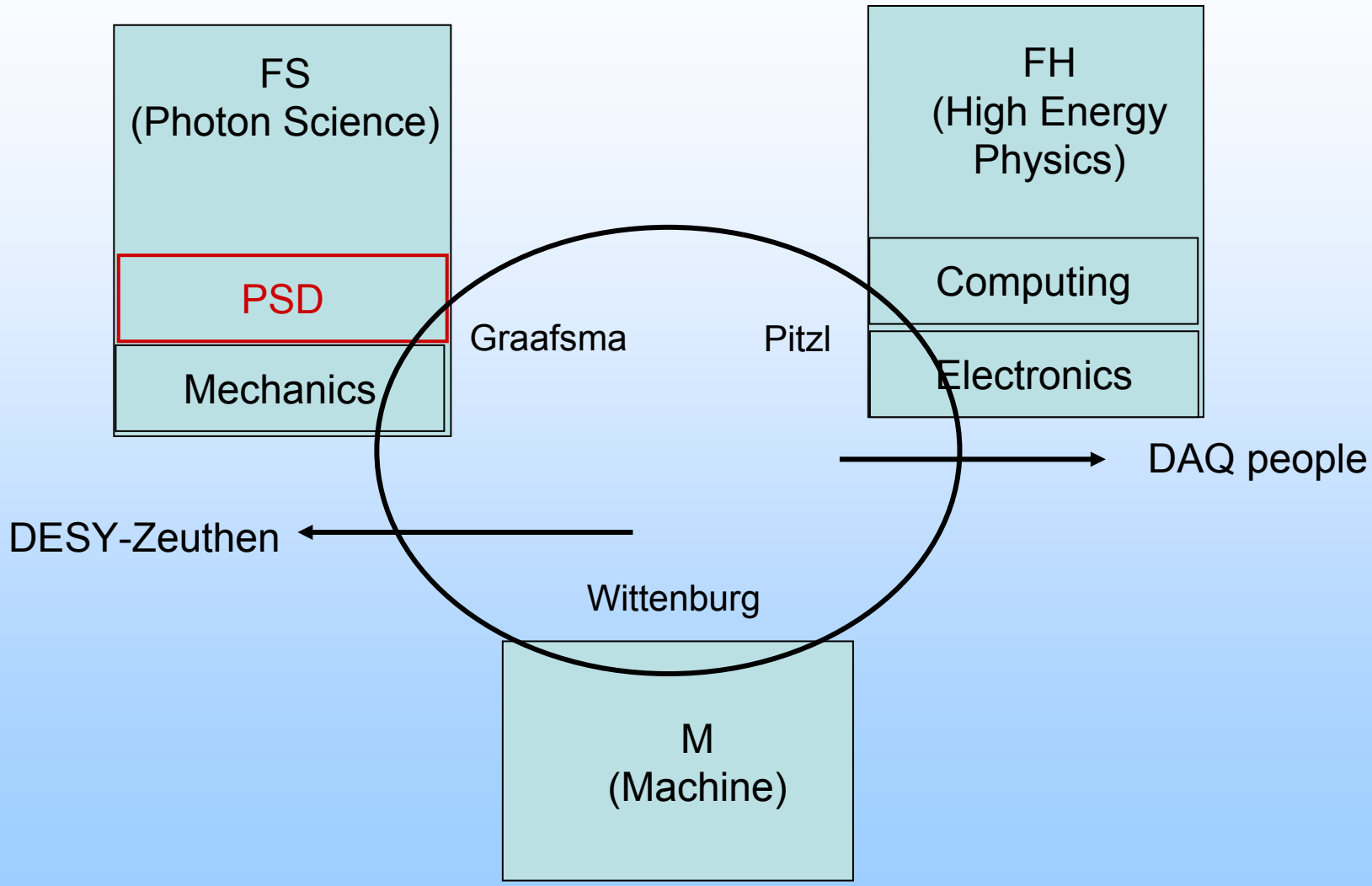
- XFEL case phase II (2 yr)

In 2011/2012 formats of 1024x1024 with 100 μm pixel operating at 1-5 MHz will be produced.

The European Consortium for high speed X-ray Imaging

		2006 1. half	2006 2. half	2007	2008	2009	2010	2011	2012
1.	Project definition								
2.	Proposal phase (Phase A)								
3.	Selection phase (by XFEL GmbH)								
4.	Project study Prototyping (Phase B & C)								
5.	Imager fabrication (Phase D)								

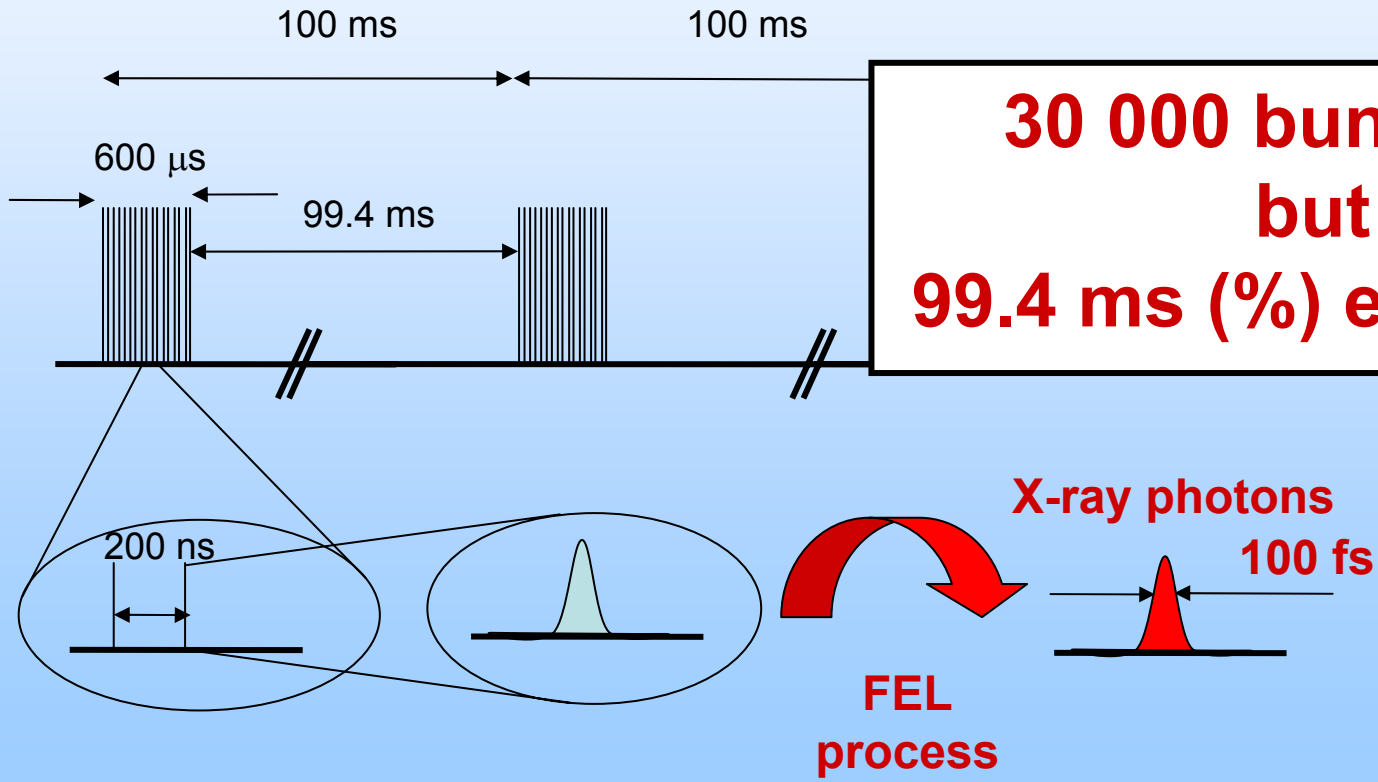
Structure @ DESY:



What are the challenges for Detectors?

Time structure: difference with “others”

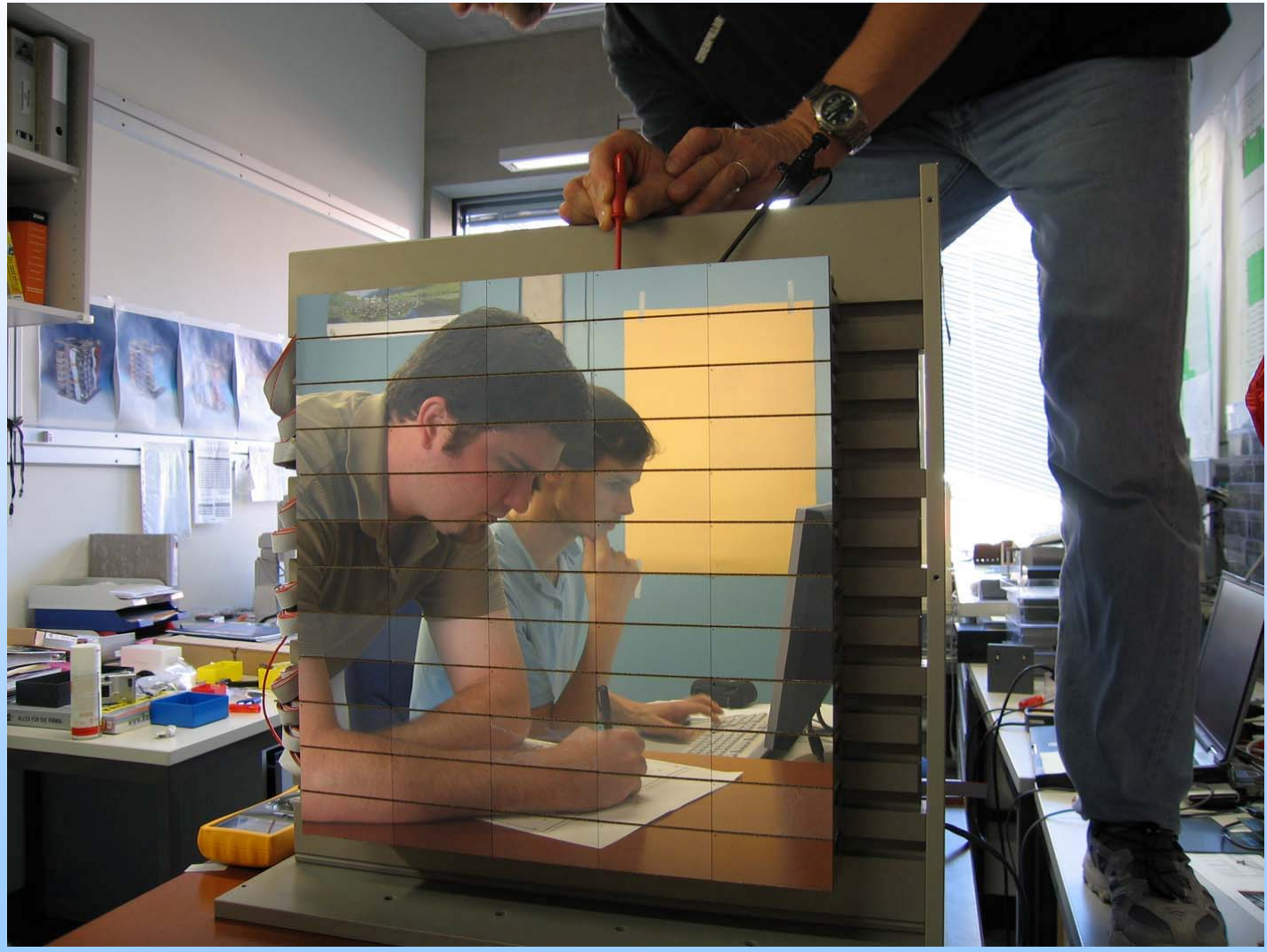
Electron bunch trains; up to 3000 bunches in 600 μsec, repeated 10 times per second.
Producing 100 fsec X-ray pulses (up to 30 000 bunches per second).



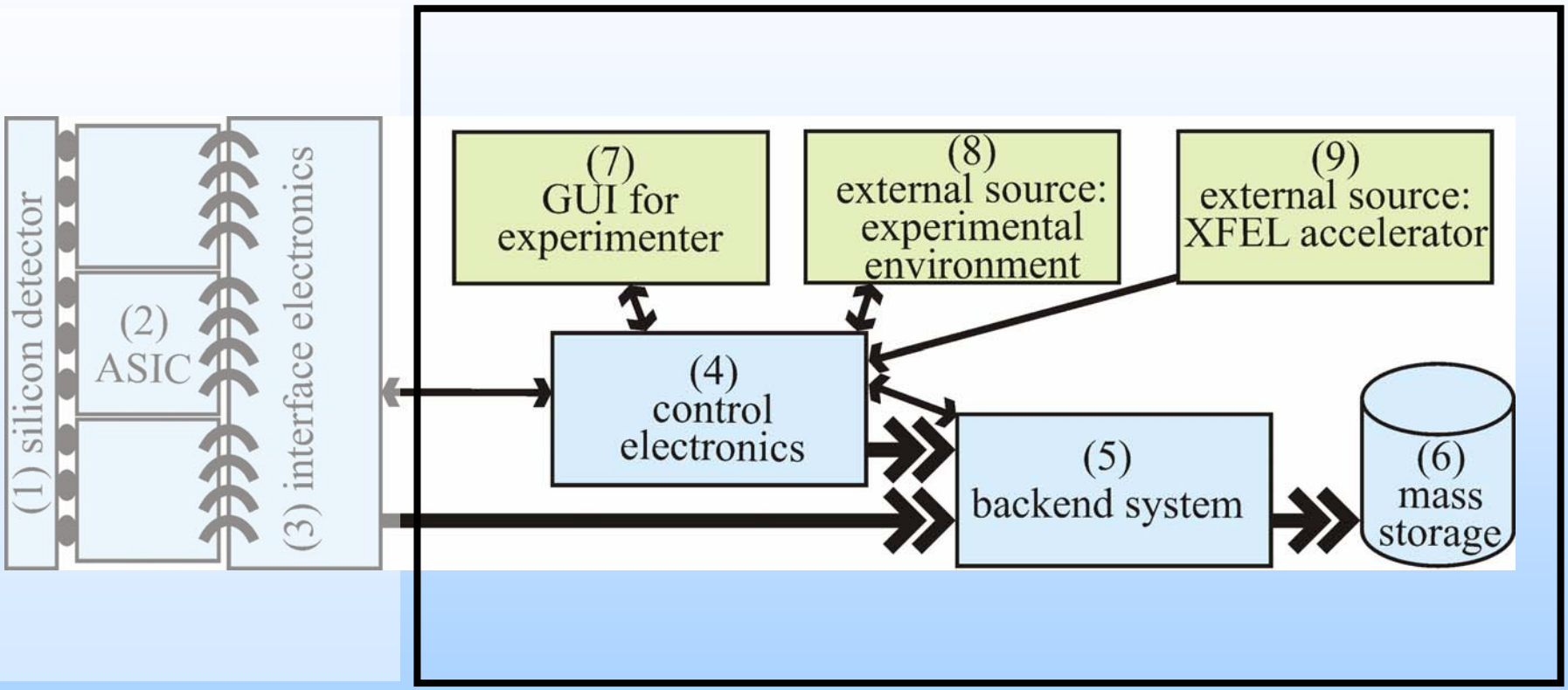
30 000 bunches/s
but
99.4 ms (%) emptiness

Hybrid Pixel Array **Detector** (HPAD)

The Pilatus 6M Courtesy Christian Broennimann



Analog Pipeline Pixel: System Architecture



DAQ

Summary:

- Petra-III roadmap advanced; detectors ordered and being tested
- XFEL 2D detectors
  - AP-HPAD: invited for proposal
  - LSDD: invited for proposal
  - pnCCD: invited for separate discussions
- Good and increasing interaction with FE
- Good and increasing interaction with DAQ
- DESY needs to strengthen ASICs competence
- Photon Science and HEP profit from synergy