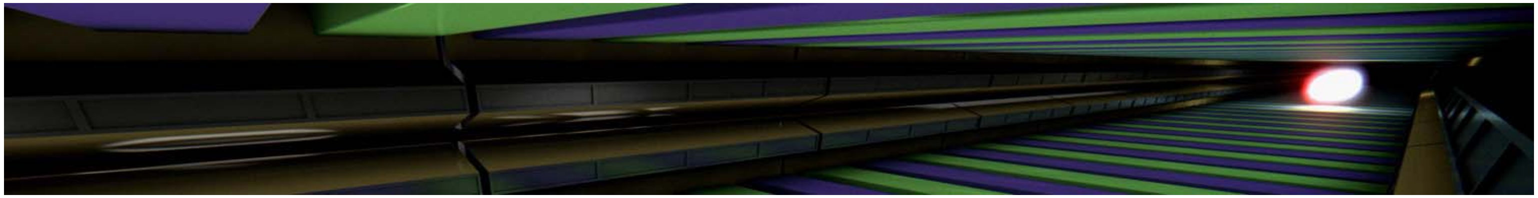


Area detector developments for CDI and XPCS experiments

MID-Workshop Oct. 2009
ESRF - Grenoble

H. Graafsma (WP75 leader; AGIPD project leader)
28-Oct-2009

- Introduction and history
- Challenges and conflicting requirements
- The LPD-project
- The DSSC-project
- The AGIPD-project
- HORUS and science simulations
- Summary and fuel for discussion

Introduction and History

- 2006: TDR including a chapter on detector needs
- X-ray Area detectors identified as main task (largest projects, longest lead times, etc.)
- Summer 2006: call for EoI to build and deliver 2D X-ray detectors
- Early 2007 XDAC selected 3 consortia ➔ full proposals
- End 2007 two accepted: LPD and AGIPD (HPAD)
- 2008 LSDD revised to DSSC and accepted
- Radiation damage and "plasma effect" as separate projects.

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

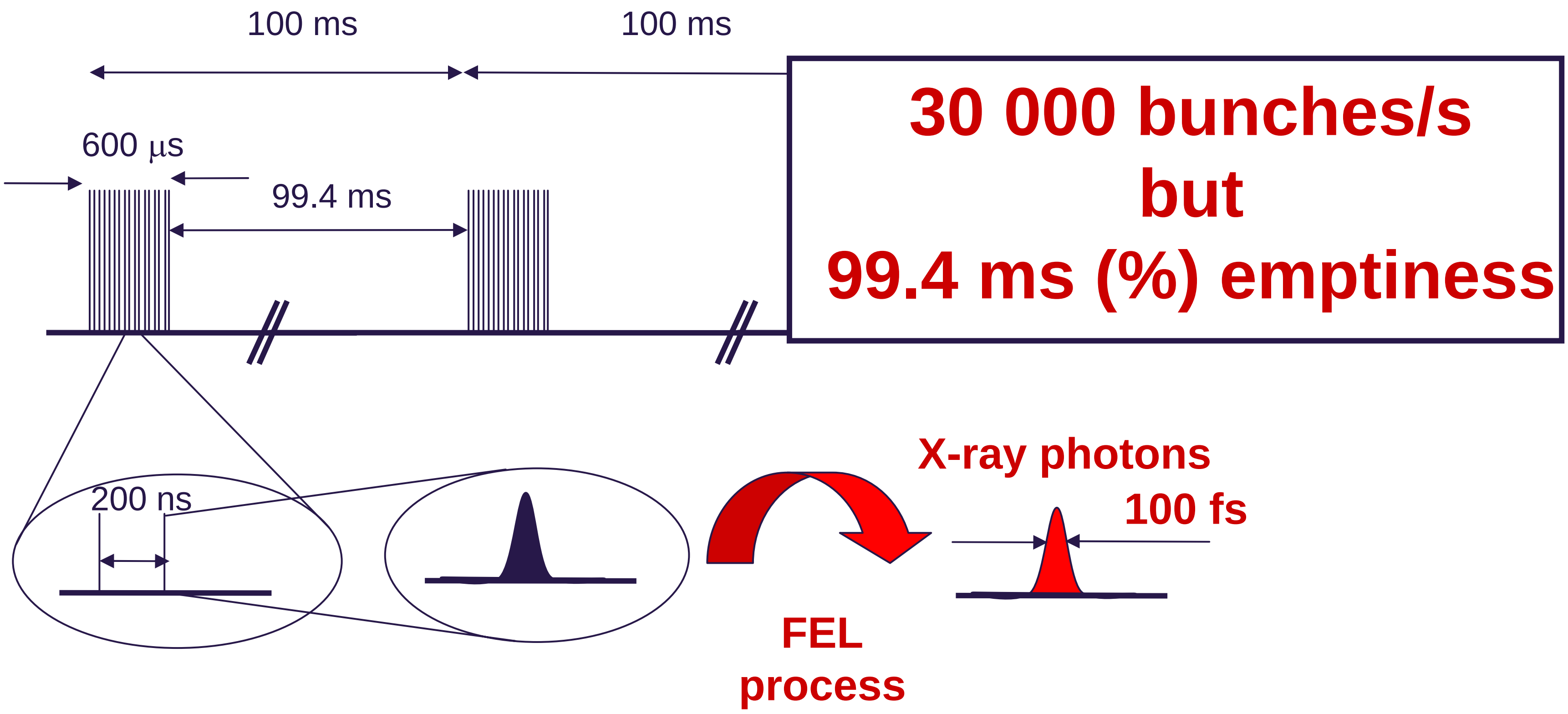
1

Requirements For CI as in the call for EoIs

	SPI	CDI	XPCS
E (keV)	12.4	0.8-12	6-15 (0.25-3.1)
ΔE/E	No	No	No
QE	>0.8	>0.8	>0.8
Rad Tol	$2\ 10^{15}$	$2\ 10^{16}$	$2\ 10^{14}$
Total Size (deg)	120	120	0.2 (1.2)
Pixel size	0.5 mrad	0.1 mrad	4 µrad
# pixels	4k x 4k	20k x 20k	1k x 1k
tiling		See text	
Local Rate (ph/pixel/pulse)	10^4	10^5	10^3
Global Rate (ph/pulse)	10^7	10^7	10^6
Timing	10 Hz	5 MHz	5 MHz
Flat Field	1%	1%	1 %
Dark Current	<1 X	<1 X	< 1 X
Readout Noise	<1 X	<1 X	< 1 X
Linearity	1%	1%	1 %
PSF	<1 pixel	<1 pixel	< 1 pixel
Lag	10^{-3}	$7\ 10^{-5}$	10^{-3}
Vacuum	Yes	Yes	No
Other			

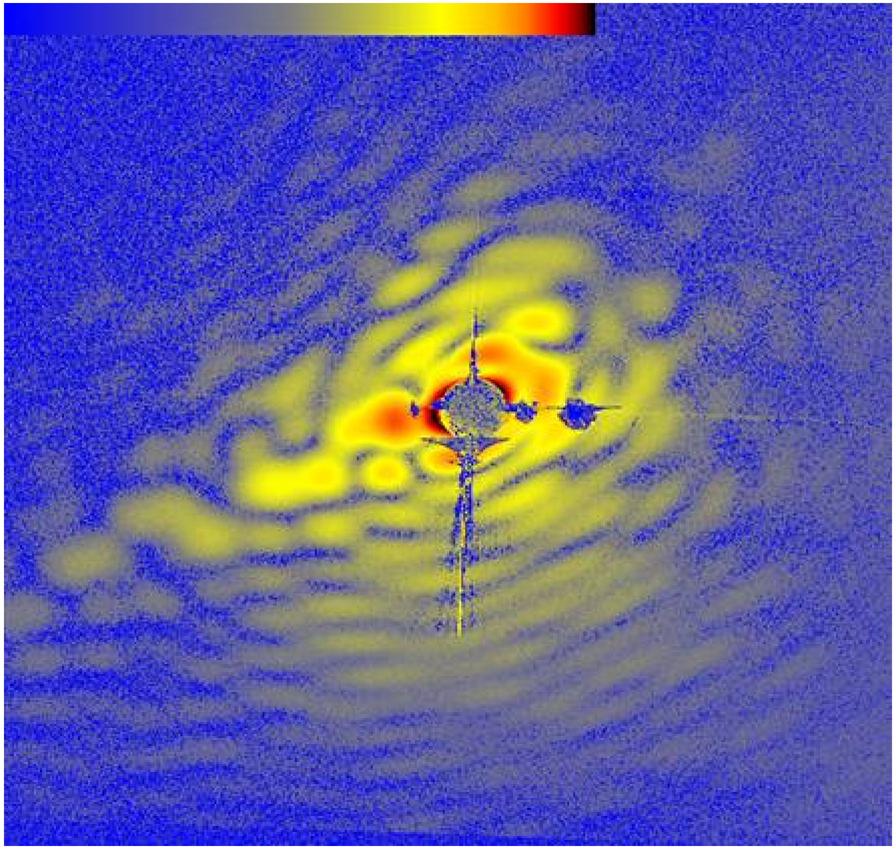
Challenge: Time structure: difference with “others”

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

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**

Three projects launched

Large Pixel Detector (LPD)

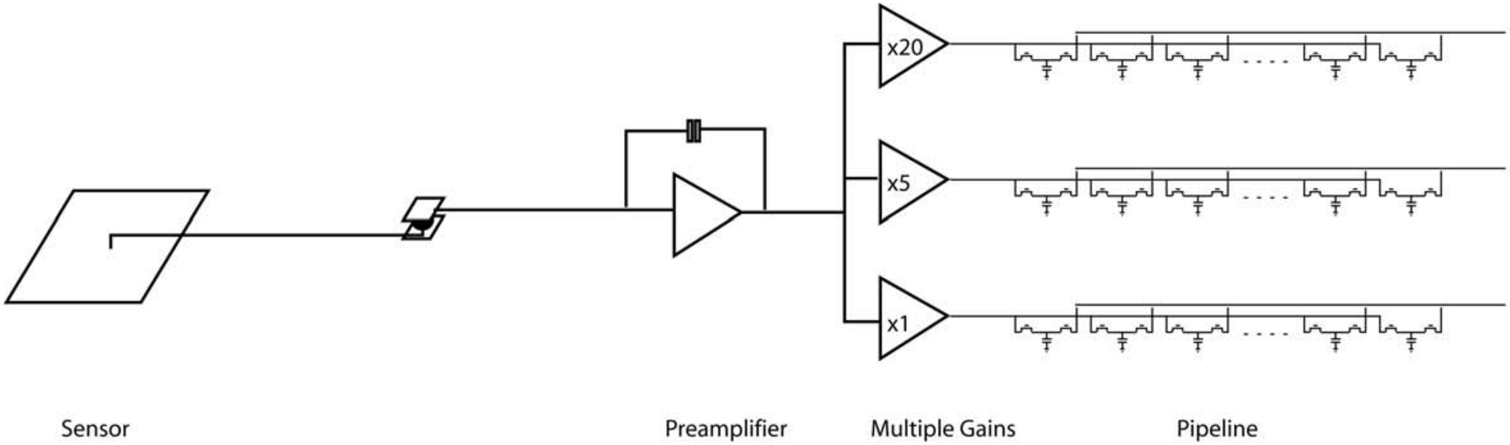
Depfet Sensor with Signal Compression (DSSC)

Adaptive Gain Integrating Pixel Detector (AGIPD)

The Large Pixel Detector (LPD) Project (STFC)

- **Multi-Gain Concept**
- Dynamic Range Compression required
- Experience with calorimetry at CERN
- Relaxes ADC requirements
- Fits with CMOS complexity

Threefold analogue pipeline
On-chip ADC

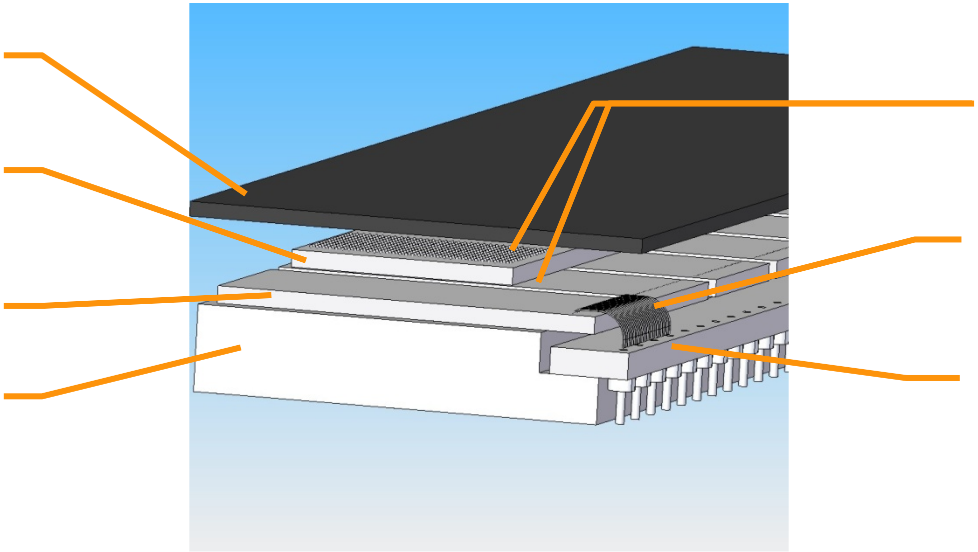


- STFC/RAL
- University of Glasgow

(M. French, STFC)

The Large Pixel Detector (LPD) Project (STFC)

- Sensor tile detail (exploded view)
  - Hidden wire bonds permit ‘edge-to-edge’ sensors
  - Sensor bias communicated via ASC and interposer



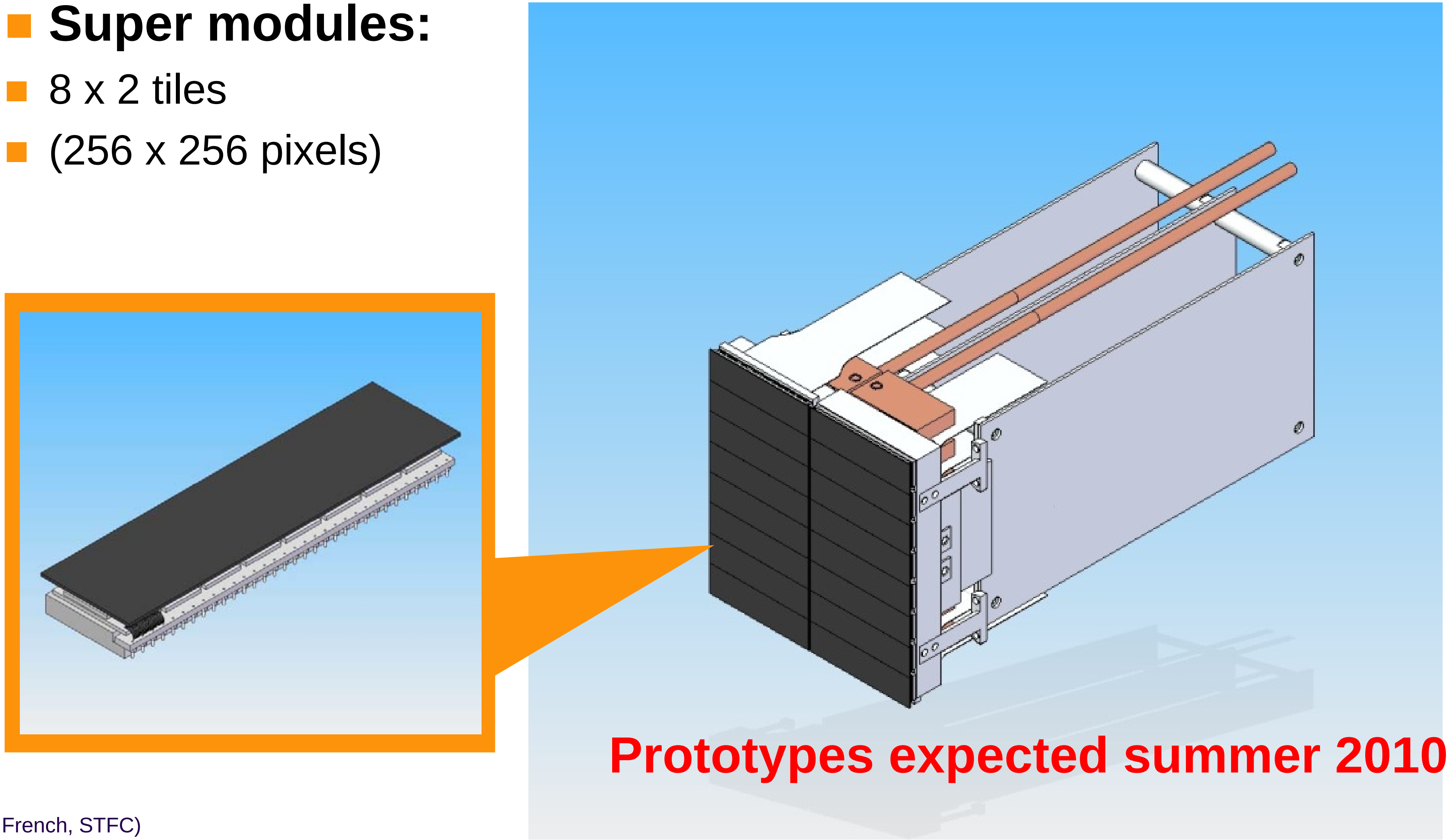
- **Sensor tile**
- **Silicon interposer**
- **ASIC Die**
- **Moly Metal Mount**
- **Area bump bonds**
- **Hidden wire bonds**
- **‘Door step’ ceramic and connector**

- 128 x 32 pixels
- of 500 x 500 μm

(M. French, STFC)

The Large Pixel Detector (LPD) Project (STFC)

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

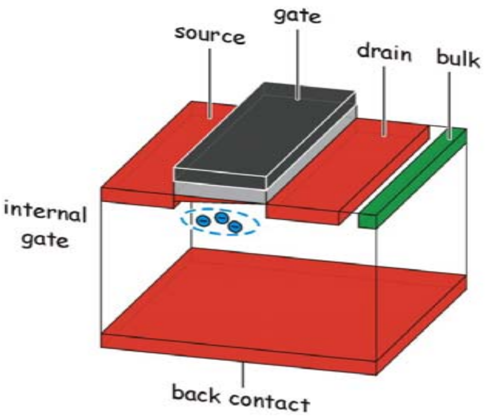


Prototypes expected summer 2010

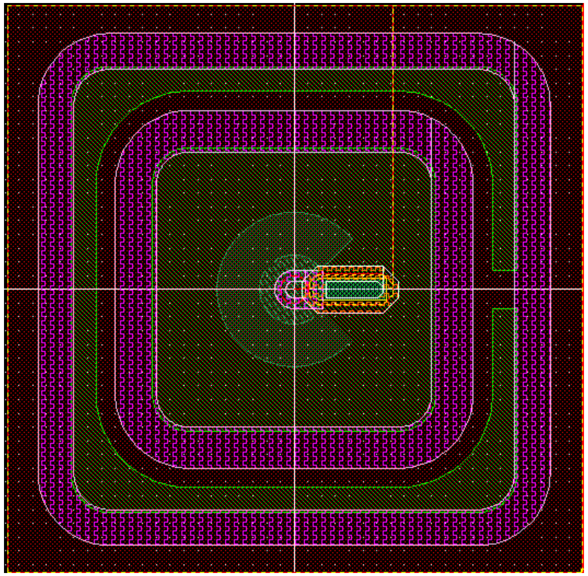
(M. French, STFC)

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**

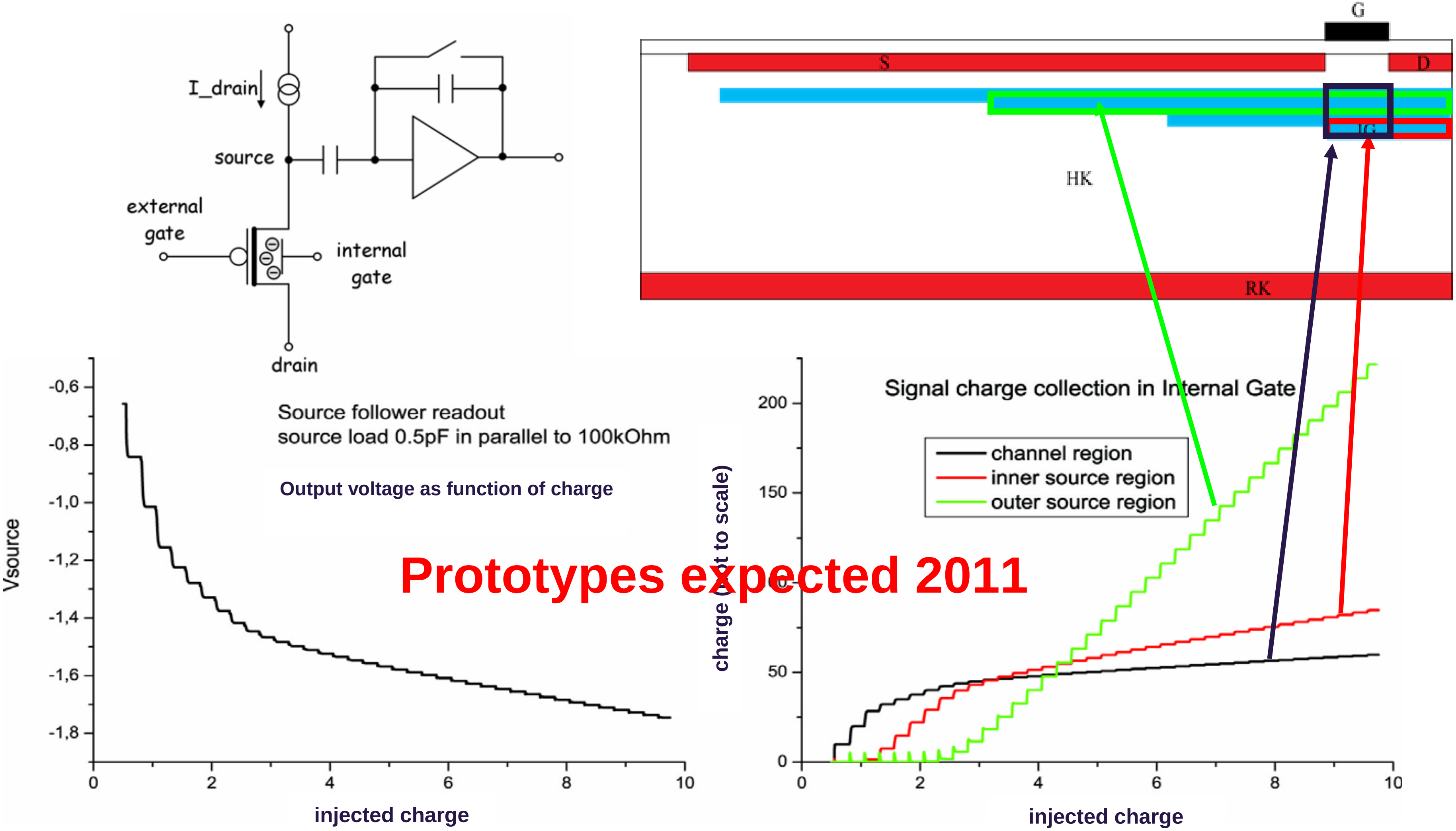


- combines DEPFET
- with small area drift detector (scaleable)

(L. Strüder, MPI-HLL)

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

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



Prototypes expected 2011

(L. Strüder, MPI-HLL)

AGIPD - Adaptive Gain Integrating Pixel Detector (DESY)

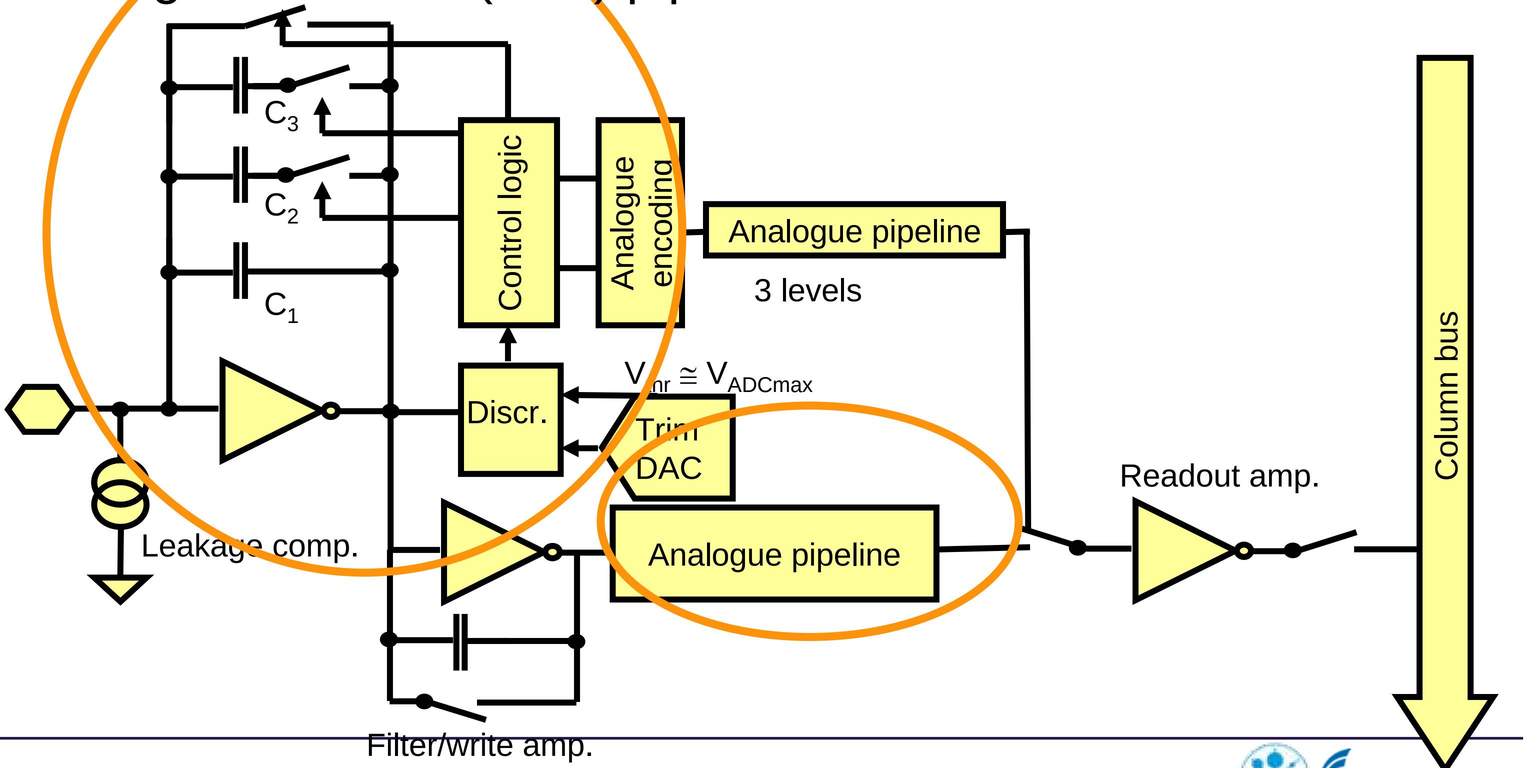
- **Basic parameters**
- 200 µm x 200 µm pixels
- 5 MHz framing speed
- Single photon sensitivity at 12keV
- 2 x 10^4 dynamic range, using 3 switched gains
- 200-400 images storage depth
- 128 x 256 monolithic tiles
- Flat detector

The AGIPD consortium:

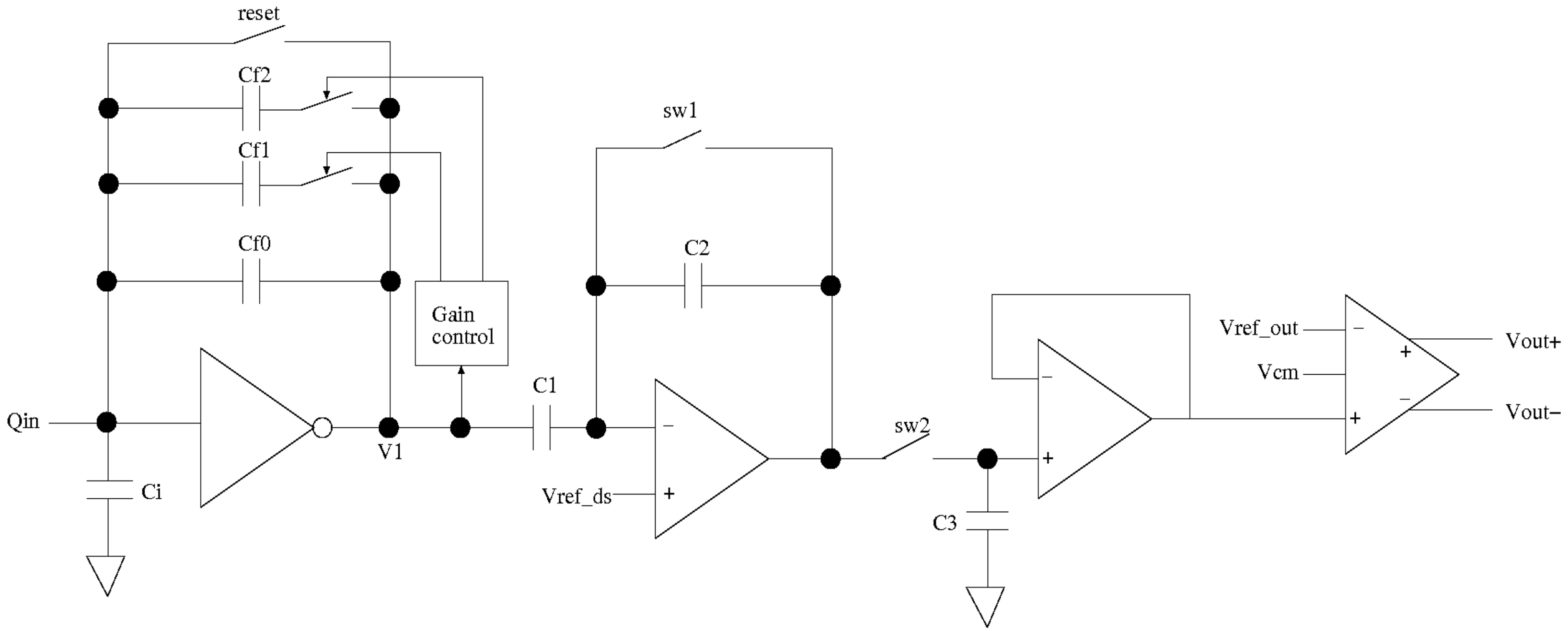
PSI/SLS -Villingen:	chip design; interconnect and module assembly
Universität Bonn:	chip design
Universität Hamburg:	radiation damage tests, “charge explosion” studies; and sensor design
DESY-Hamburg:	chip design, interface and control electronics, mechanics, cooling; overall coordination

AGIPD - Adaptive Gain Integrating Pixel Detector (DESY)

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



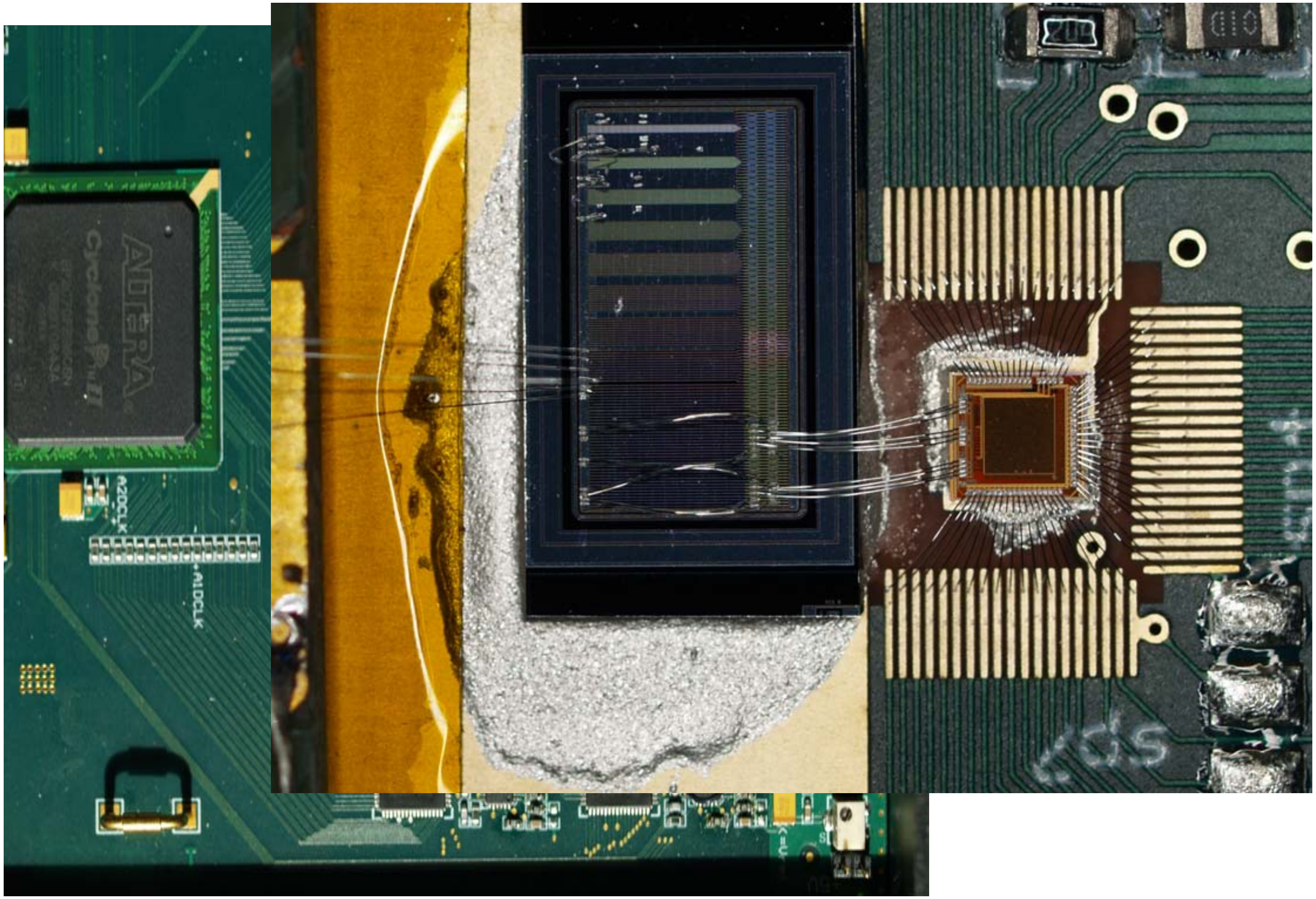
Overview of the readout amplifier



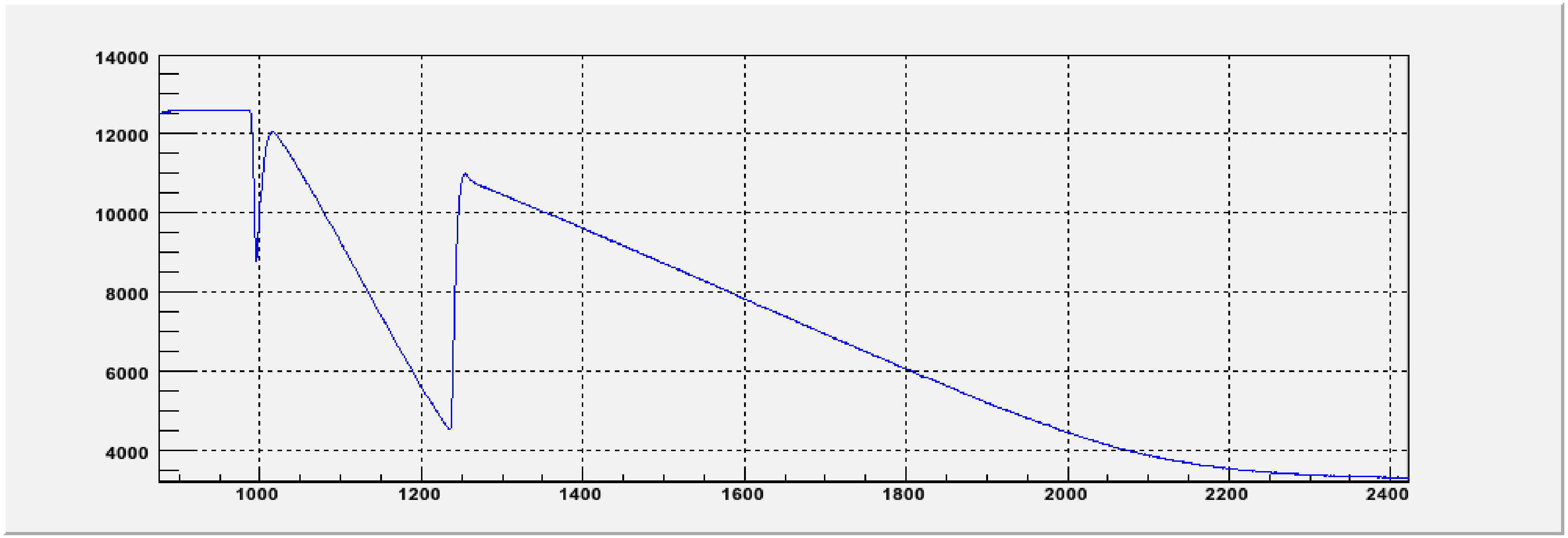
We DO filter the analogue signal!

- low pass filter realized with limited rise time of preamp (limited by 200ns bunch spacing)
- high pass filter with double correlated sampling

Overview of the chip test board



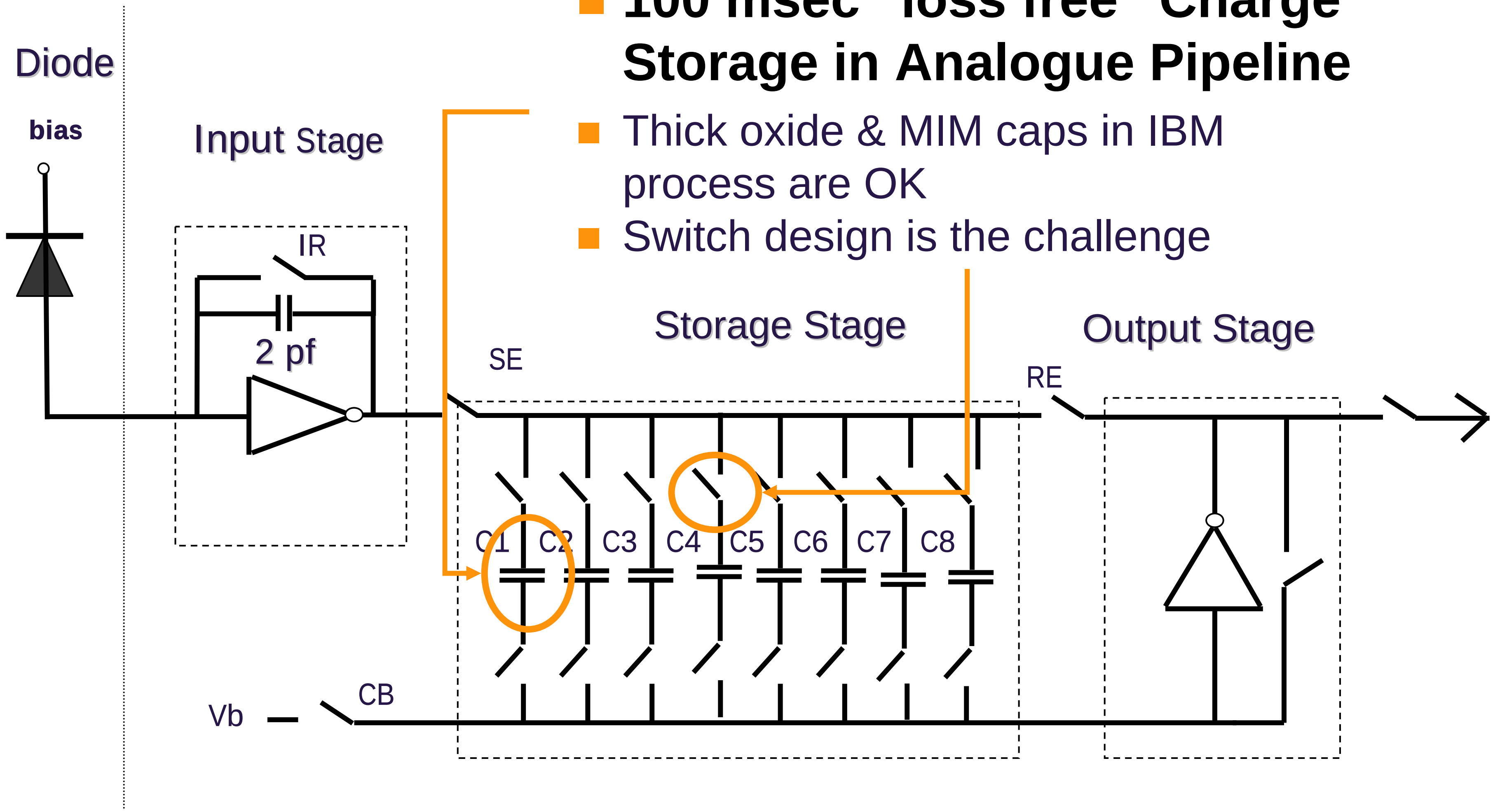
Preliminary data from the measurements



- The gain switching is tested with on chip current source.
- Linearity is good. Quantitative results are not yet available.
- Have had problems understanding the interface between the chip and the ADC (solved now).

AGIPD - Adaptive Gain Integrating Pixel Detector (DESY)

- **100 msec “loss free” Charge Storage in Analogue Pipeline**
- Thick oxide & MIM caps in IBM process are OK
- Switch design is the challenge

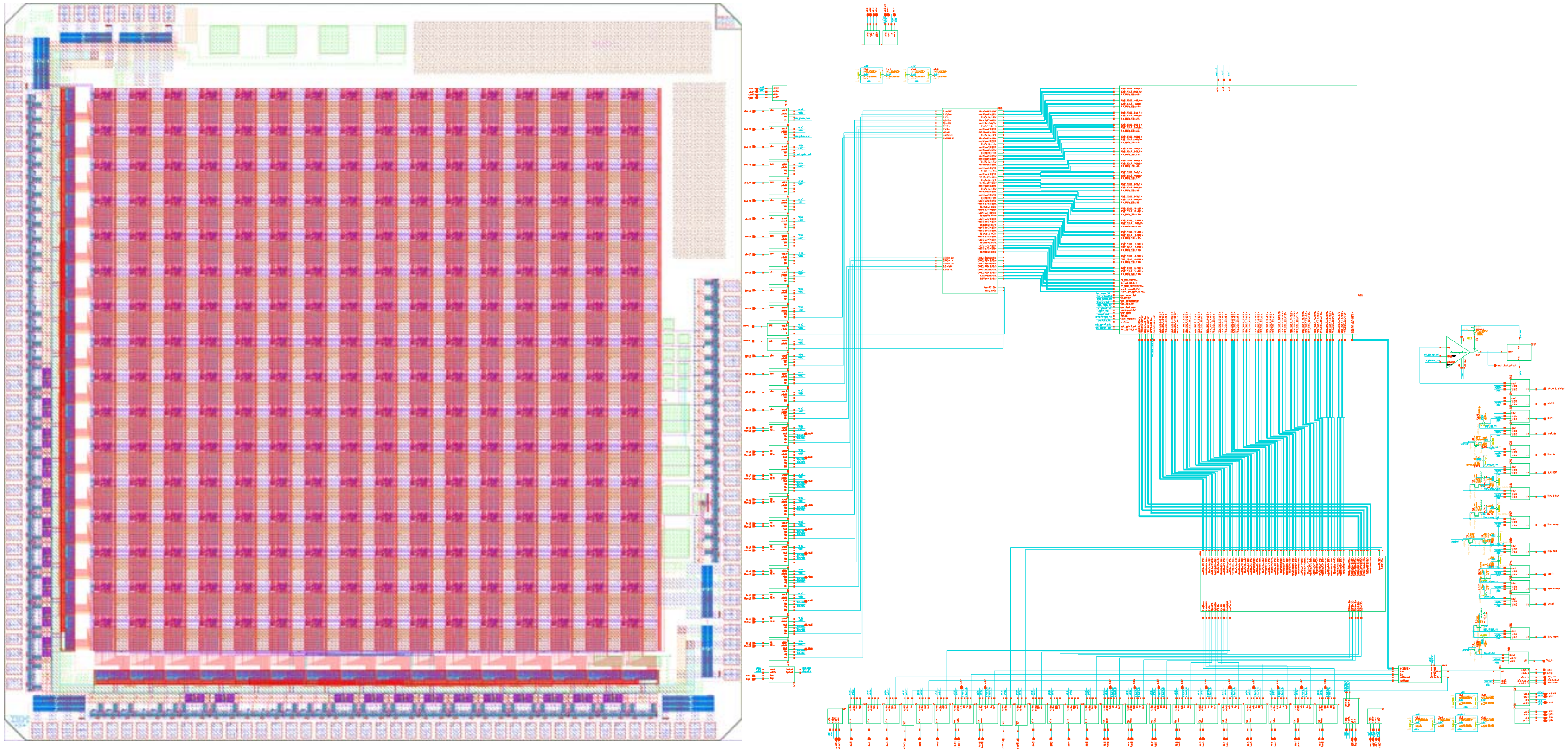


AGIPD02

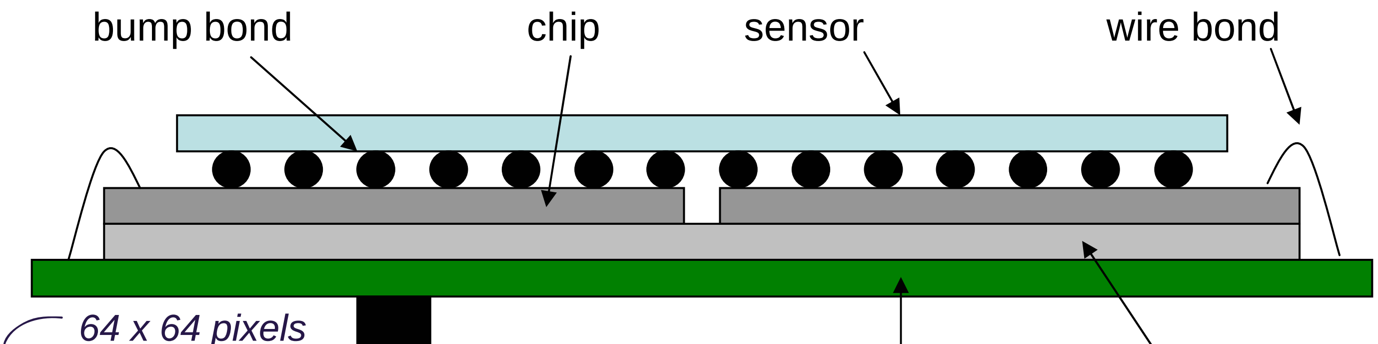
Proof-of-Principle “Small Scale Prototype”

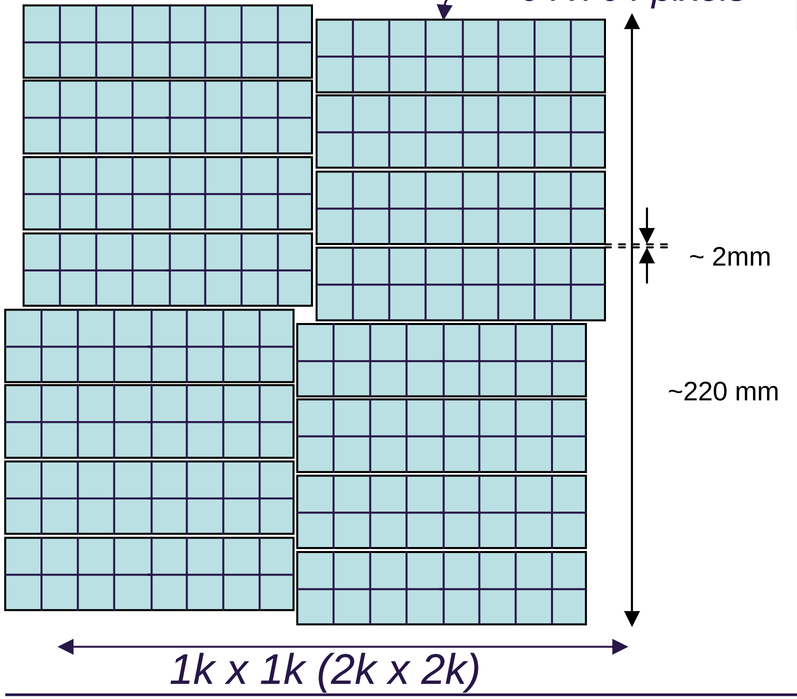
- 16 × 16 Pixels
- Adaptive Gain Switching
- Analogue Storage for 100 samples/pixel
  - ➔ Based on DGNCAPs
  - ➔ dual LPPFET (thin oxide) on hot side
  - ➔ NFET (thin oxide) at gnd plate to suppress charge injection
- Shift Register based control circuitry
  - ➔ Has to be replaced with a decoder based solution for the final chip to enhance trigger/veto capabilities

AGIPD02



AGIPD Adaptive Gain Integrating Pixel Detector (DESY)





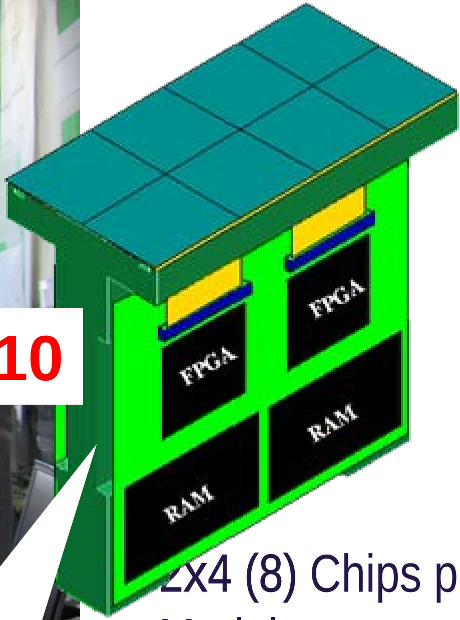
- 64×64 pixel/chip
- 2×8 chips/sensor
- 1×4 sensors/quadrant
- 4 quadrants = 1024×1024 = 1048576 pixel

AGIPD: How things will look

The PILATUS 6M of the SLS@PSI

Prototypes expected beginning 2010

Pilatus XFS Module



AGIPD mechanics will be based on the Pilatus XFS

2x4 (8) Chips per Module.

- ~78 x 39 mm^2 (XFS)
- ~50 x 27 mm^2 (AGIPD)

Why develop HORUS: a simulation tool ?

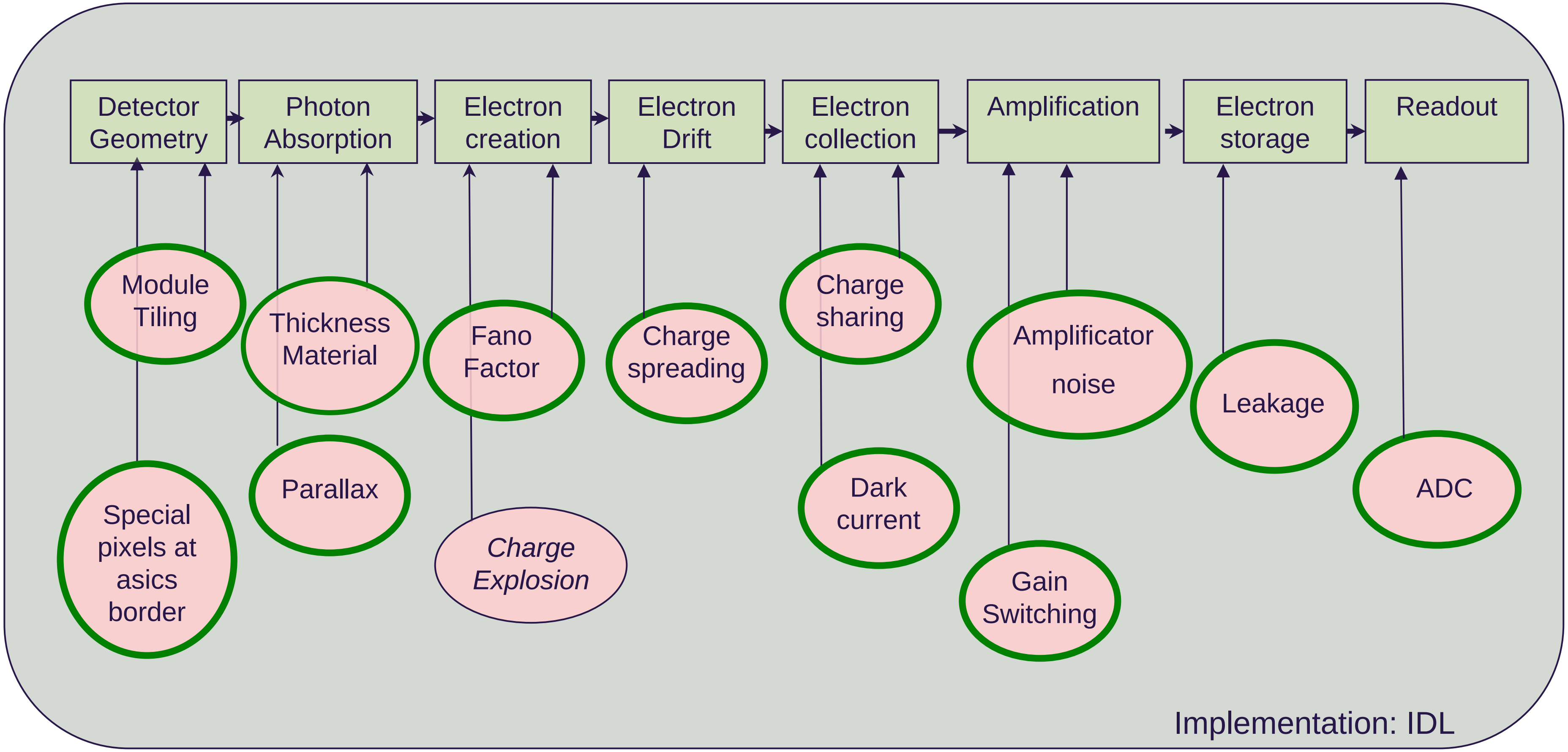
- How do we know the system performance before building the detector ?
- How can we get a good dialogue between application scientists and detector scientists ?
- How to determine the best compromises between scientific wishes and technological limitations for each application ?

HORUS: both a detector development tool and a science simulation tool.

Simulation of the detector Performances (G. Potdevin)

The code is built on a modular structure

HORUS



Implementation: IDL

Noise budget analysis:
False hits

Contributions:

- Sensor Leakage. If assuming
  - 100nA/cm^3 so **1pA per pixel**
  - **10µA per pixel** (surface current)
  - ⇒ ~ **100 electrons /pixel/picture**
- Amplifier noise
  - **150 electrons /pixel/picture**
- Analog pipeline storage
  - No number so far…
- ADC converter
  - 4.6LSB / 14bit

⇔4.6/195*3300

⇔ **77 electrons**

So for *1750 electrons signal*

- 5 σ ie. Luxury

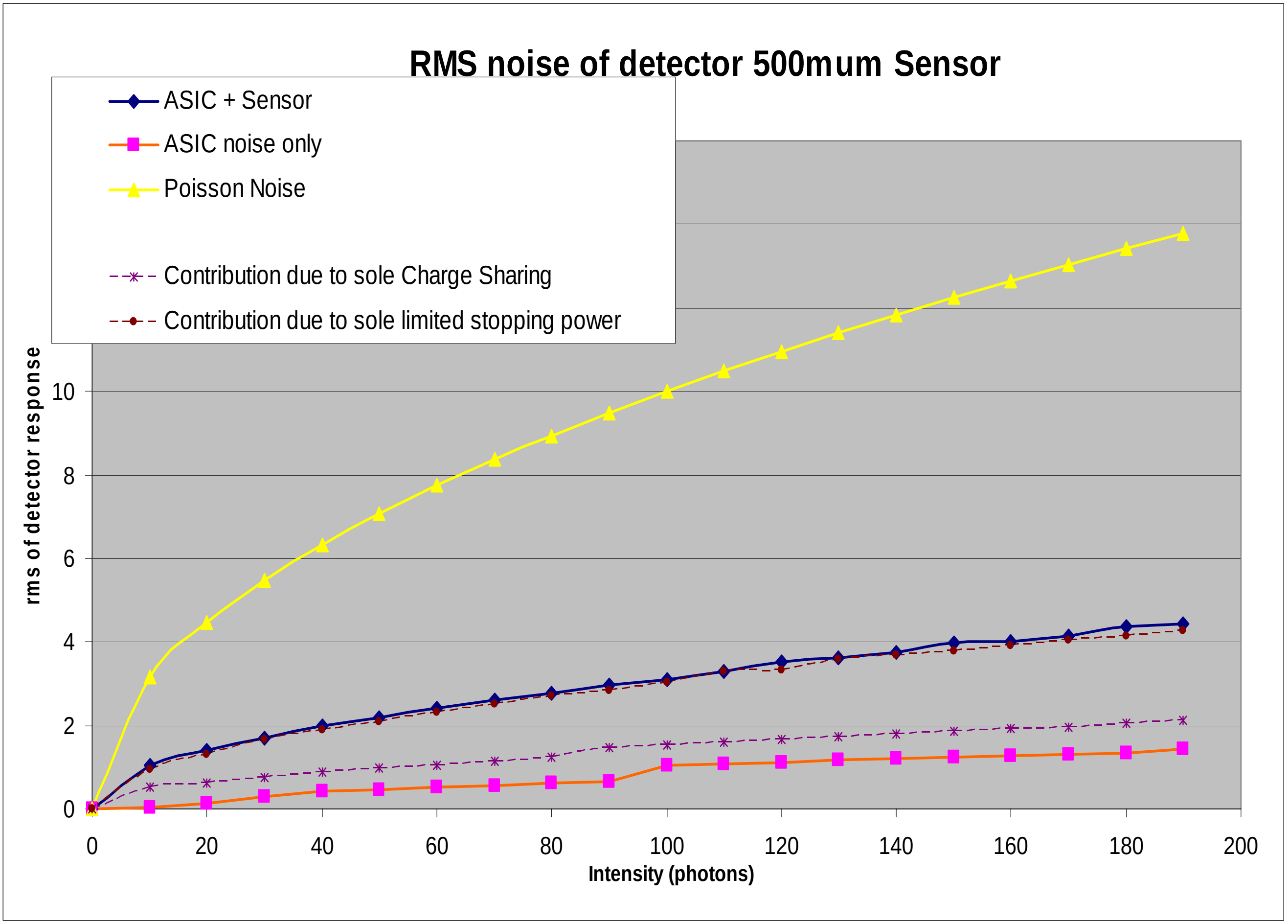
  Noise$_{Analogue\_Pipeline}$ < 300 electrons

- 3.5 σ Minimal, ⇔ ~ **1 false hit/picture**

  Noise$_{Analogue\_Pipeline}$ < 460 electrons

Noise budget analysis:
Signal fluctuations

In photons unit (for electrons @12keV, multiply by 3300)



At low Intensities, Sensor noise dominates

Noise is dominated by

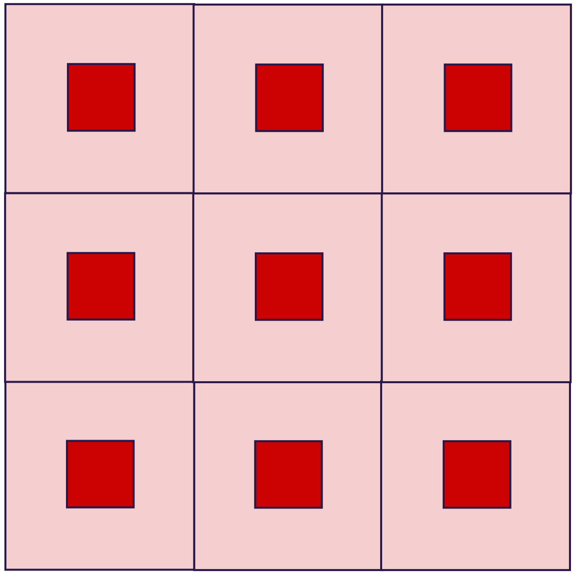
- Limited stopping power

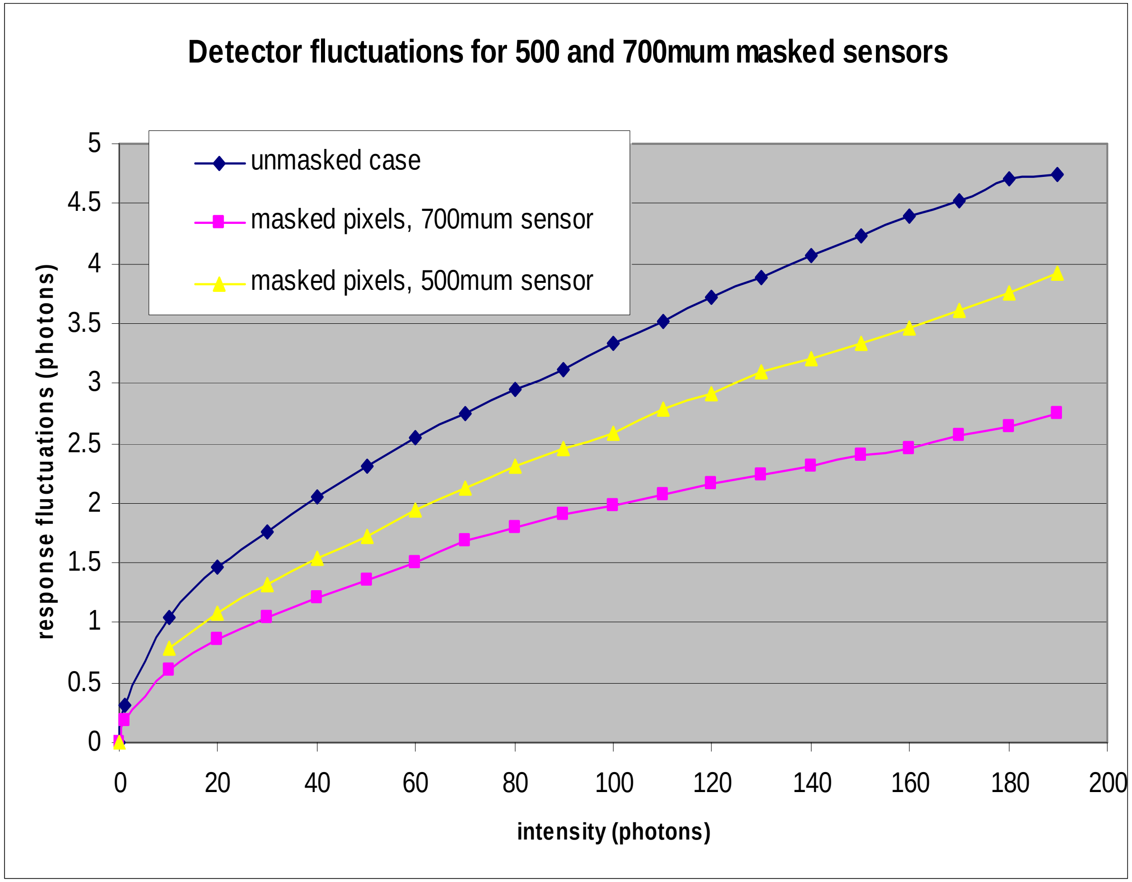
To a certain extend contribution of

- Charge sharing
- Parallax
- Electronics noise (ASIC + ADC)

XPCS requirements: Case of masked pixels

$$\beta_{eff} = \beta \times \frac{1}{1+\left({}^{p}\!/\!_{s}\right)^{2}}$$





$\text{Noise}_{\text{masked}} \sim 2/3\ \text{Noise}_{\text{normal}}$

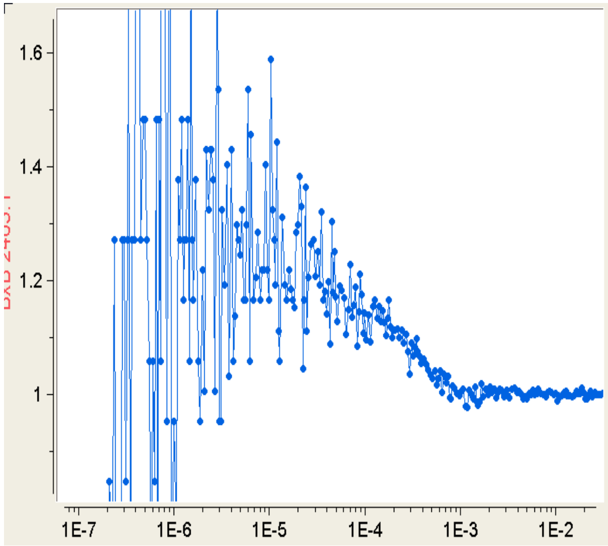
$\text{Signal}_{\text{masked}} \sim 1/4\ \text{Signal}_{\text{normal}}$

$\boxed{\text{SNR}_{\text{masked}} \sim \text{SNR}_{\text{normal}} / 3}$

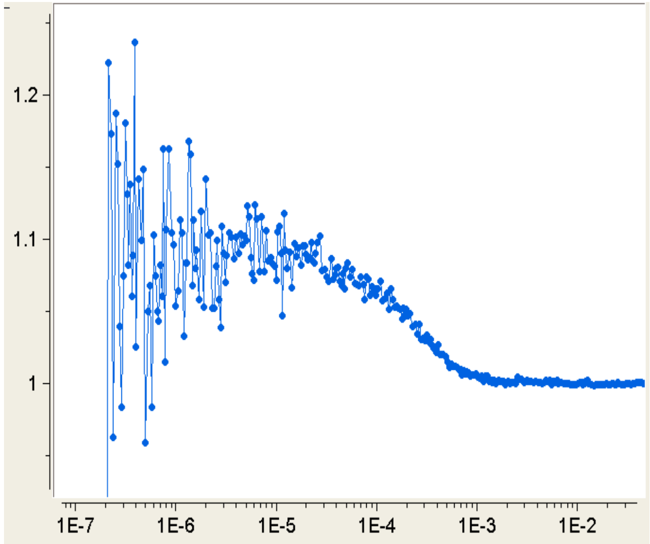
Loose the ability to get peak shape

XPCS requirements:
Case of masked pixels

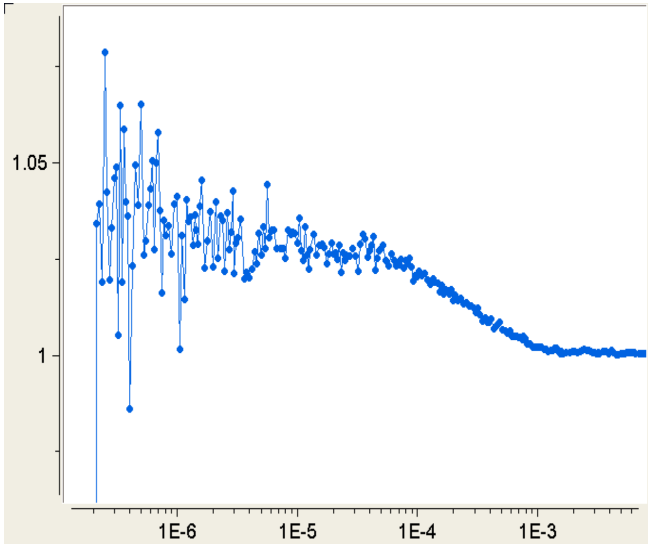
- Experimental data:
  g2 function, as function of slits opening
  Data taken on colloidal sample at ID10A (ESRF)
- Speckles: ~40µm



40µm x 40µm



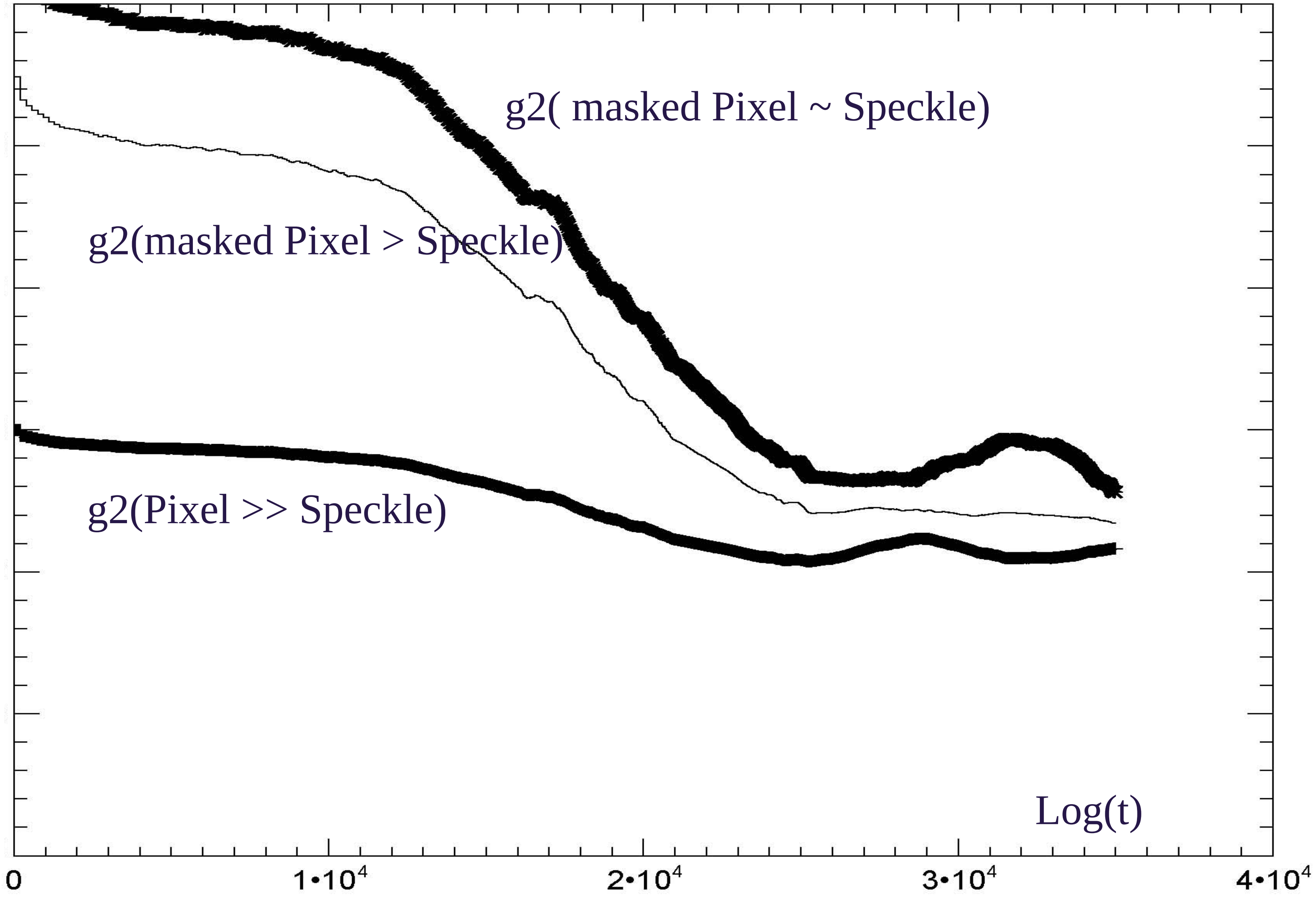
100µm x 100µm



200µm x 200µm

Bigger pixels improve the statistics, but diminish the contrast

Simulation of masking



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:

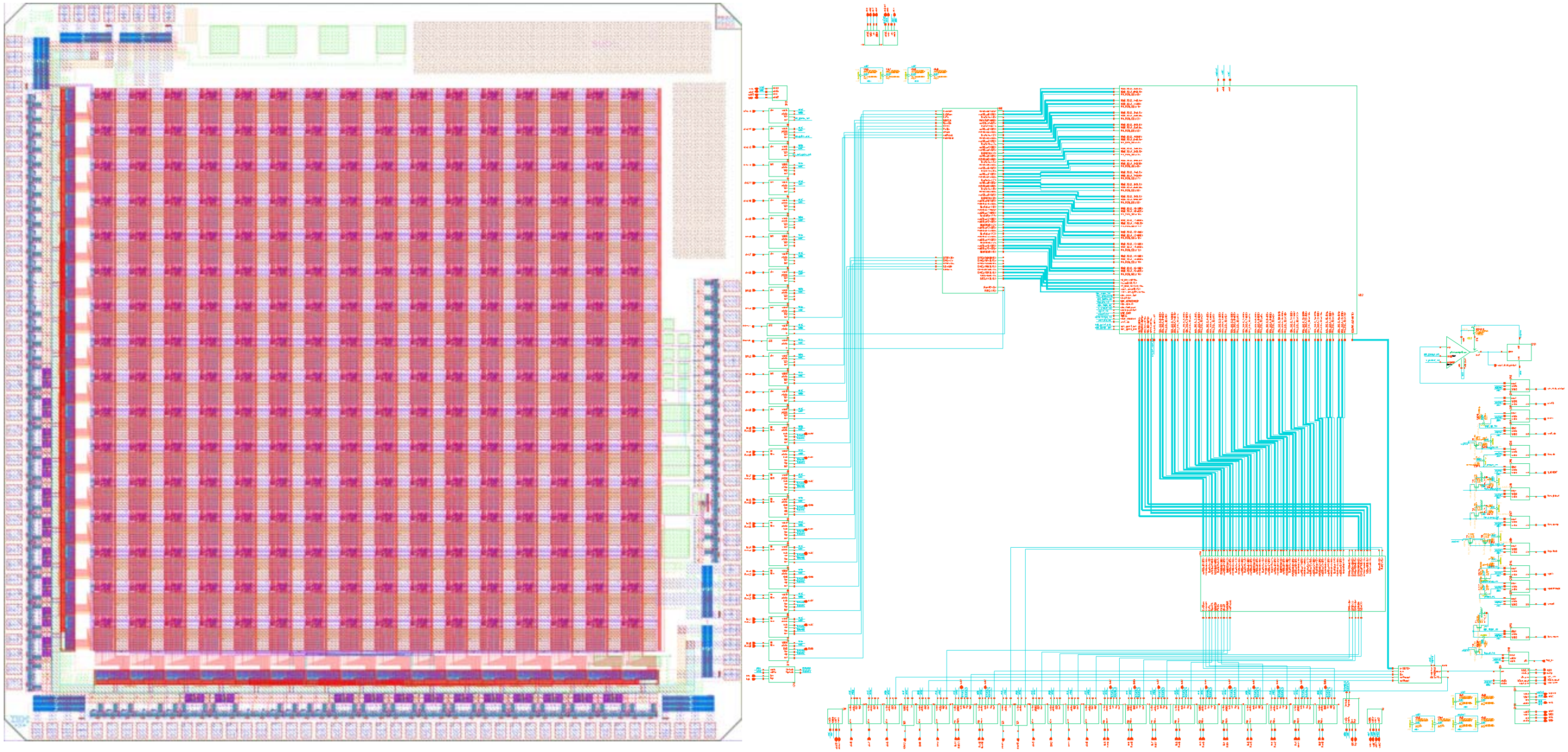
- Where do you want to sit ?
- Likely two different spots for CDI and XPCS !
- How far are they apart ?
- Dedicated version for each ?

Where do we go ?

- CDI seems to be ok with 200 micron pixels (0.1 mrad = 200 micron at 2000 mm)
- CDI needs dynamic range
- CDI wants as many frames as possible
- XPCS wants 4 microrad =160 micron at 40 m; 200 micron at 40 m = 5 microrad. Is this acceptable ?
- Is 160 micron pixels at a pitch of 200 micron acceptable (=masking)?
- XPCS needs limited dynamic range (single gain)
- XPCS needs limited number of frames
- Is a separate AGIPD with smaller pixels an option (a question of €)?

AGIPD02

Prototype testing early 2010



But let’s discuss tomorrow