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Charge integrating Readout ASICs for X-ray detection

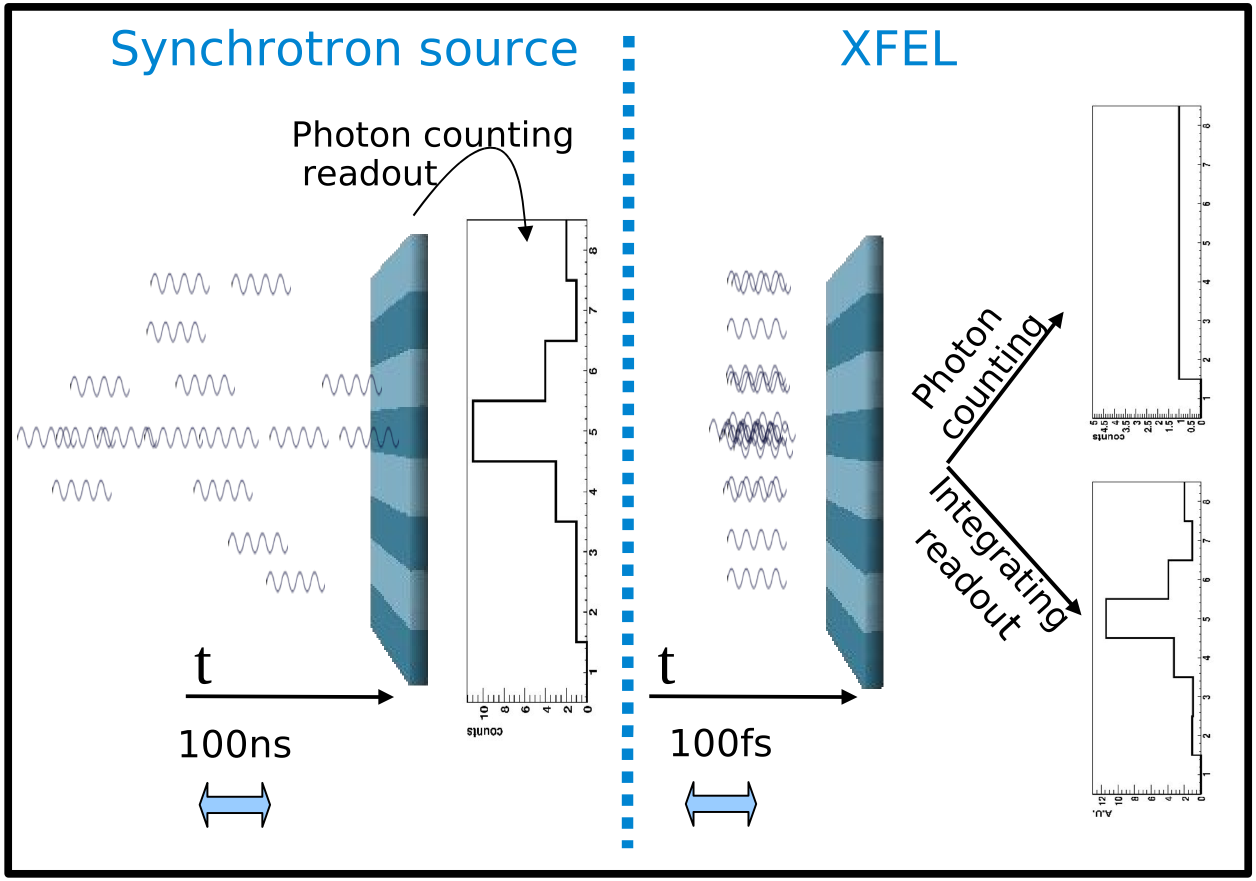
Outline

- The European XFEL: new detectors are needed
- Requirements for a XFEL detector
- Overview of the charge integrating systems under development:
  - Preamplifier with switching logic
  - Layout of 1D and 2D detectors
- Current prototypes and test results:
  - Noise performances
  - Switching gain at low and high rates
  - Speed of preamplifier and switching logic
  - Memory cell performances
- Planning for tests and full-size system
- Conclusions

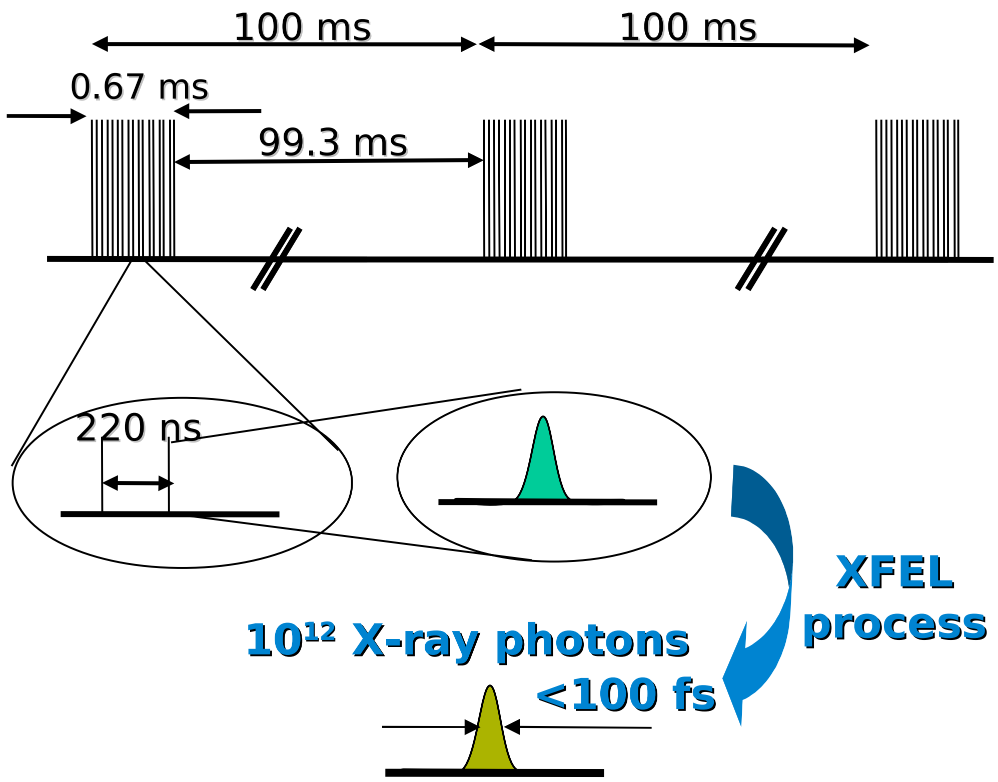
XFELs => charge integration

Synchrotron source:
- Huge number of “weak” photon bunches
- Photons impinge on the detector with a random time distribution

XFEL:
- Fewer intense bunches
- All photons inside the bunch coming at once
- Up to 10^4 particles per ch. per bunch



European XFEL bunch structure

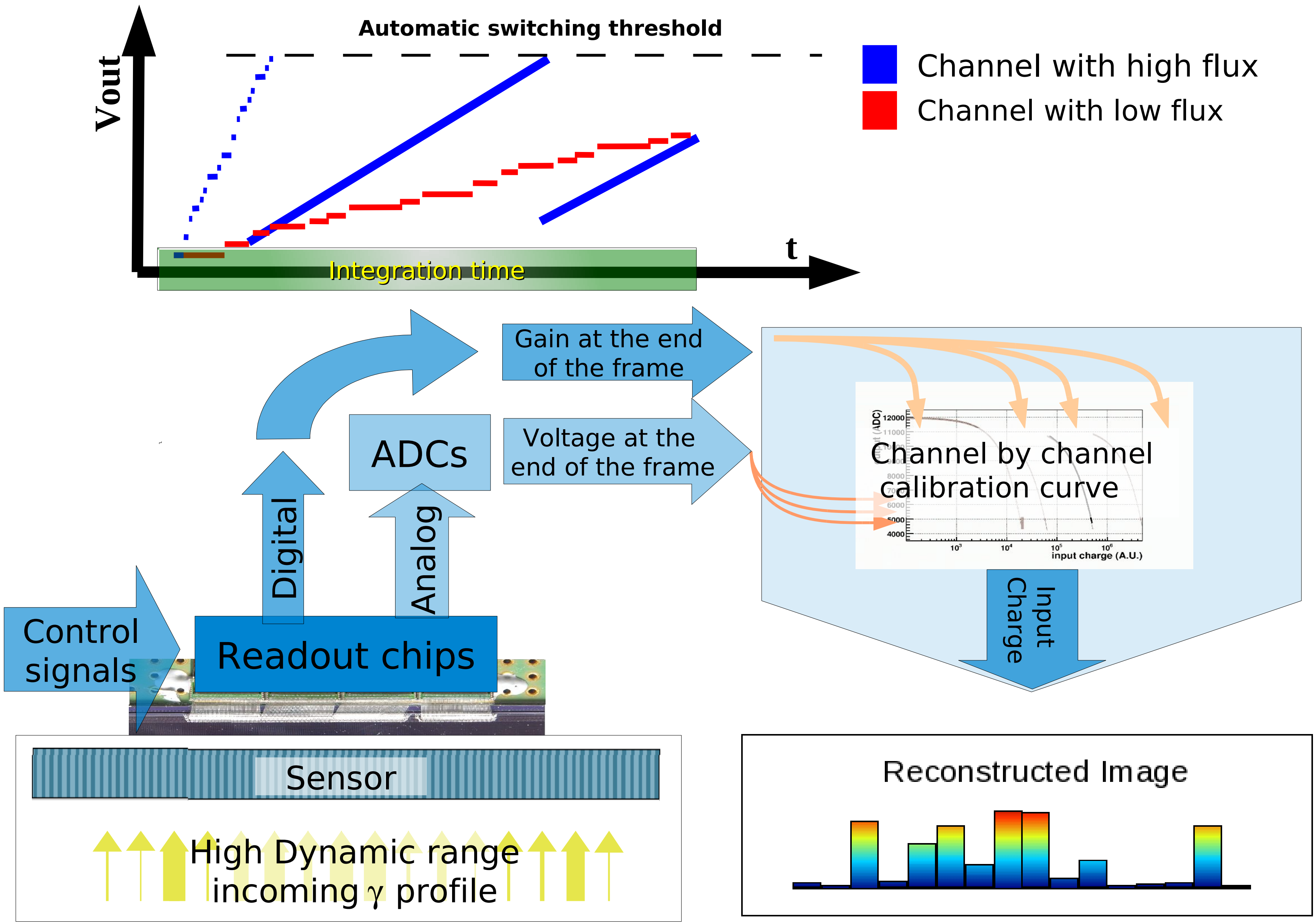


- 100 fs long X-ray pulses
- ~3000 pulses per bunch train, 10 trains per second
- Frame rate in the bunch train:4.5 MHz
- Imaging (100% occupancy)
- No easy solution, only a fraction of the frames will be recovered

E-XFEL Detector requirements

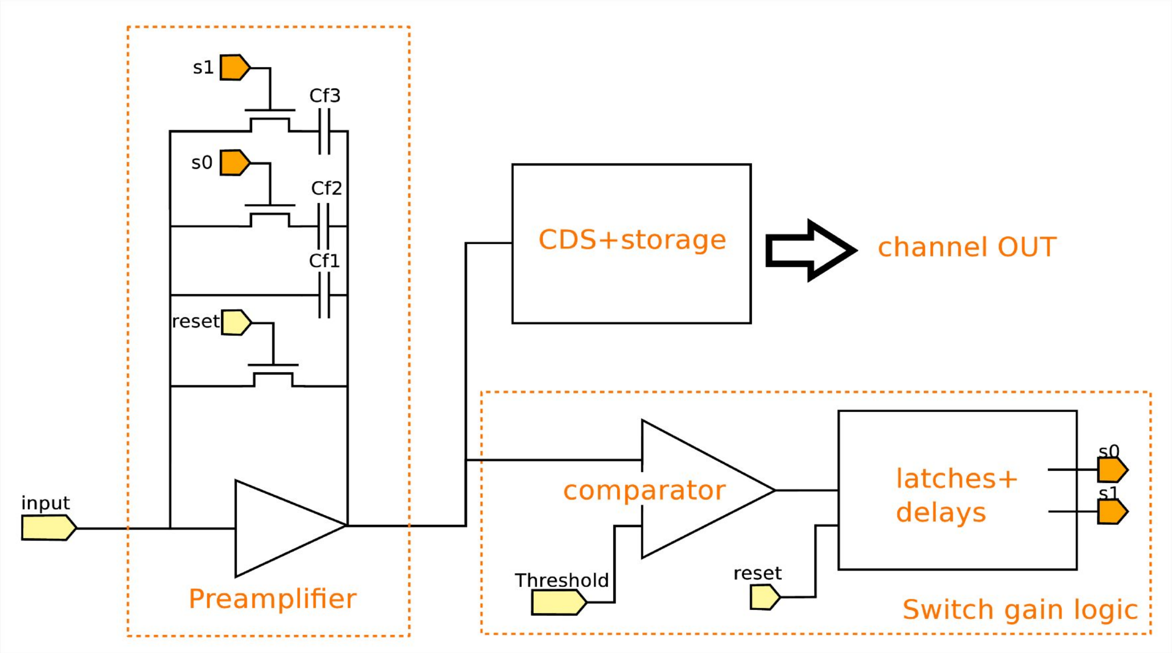
- High dynamic range (in the $10^{4\text{-}5}$ γ/ch. range)
- Single photon resolution (@12keV γ energy): same performance as a photon counting device at low rate (low signal regions)
- Electronic noise negligible with respect to Poisson fluctuations at high rate (high signal regions)
- Fast front-end: integration-store-reset cycle in <220 ns
- Ability to record as many frames per bunch train as possible
- Radiation tolerant design: expected to survive a ~GRad dose (but no bulk damage)

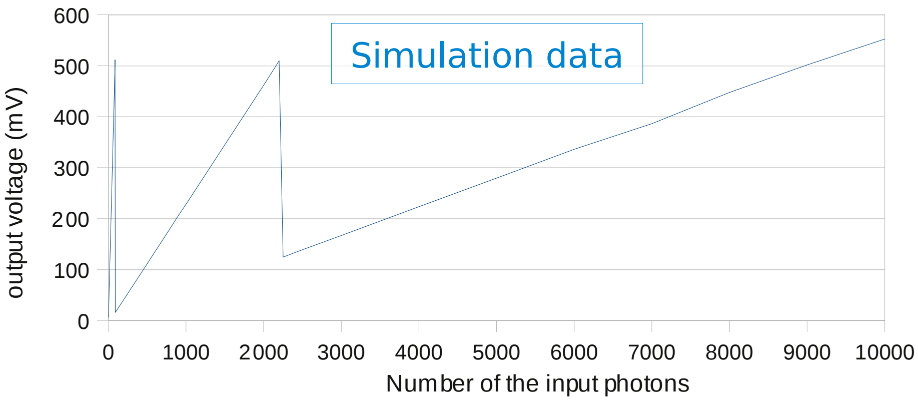
Automatic switching gain:theory



Preamplifier with gain switching

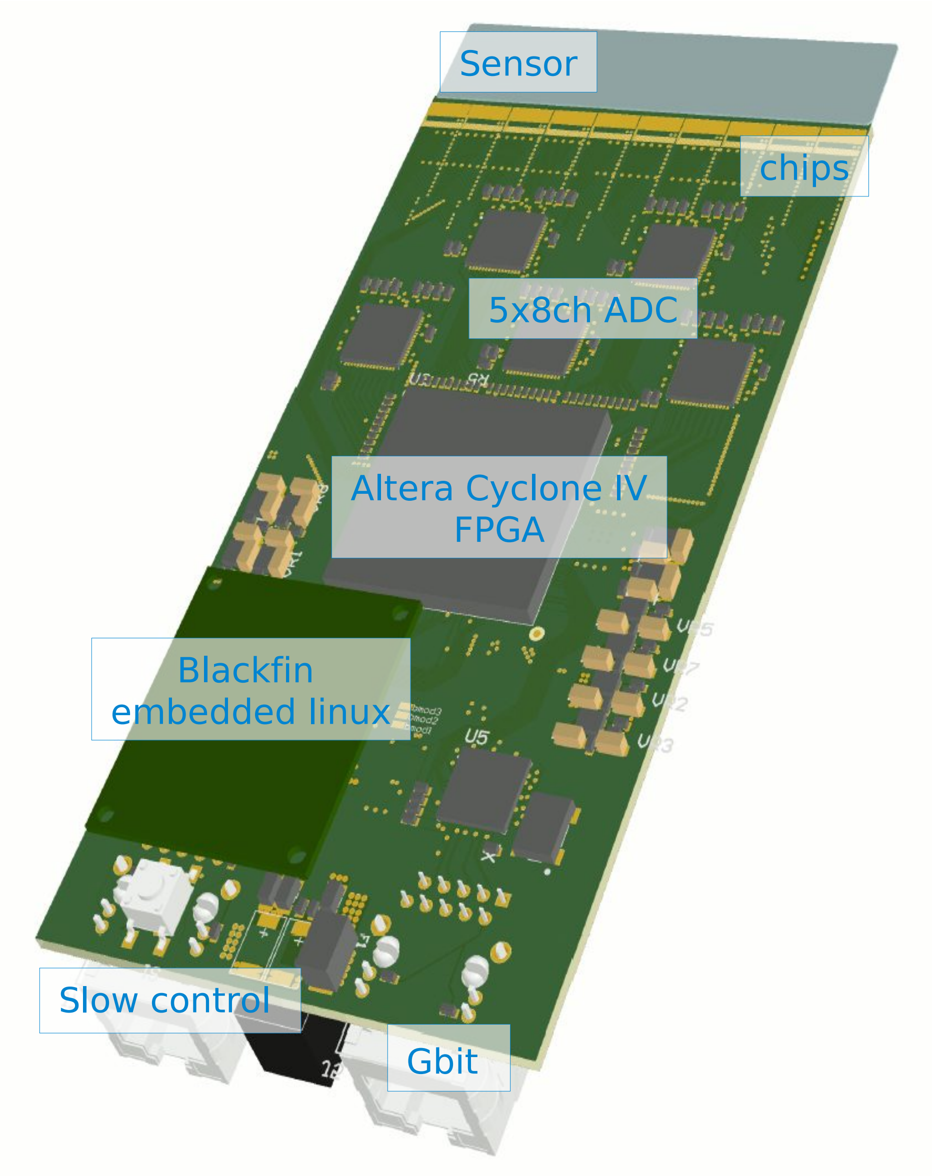
- Common for 1D and 2D
- CSA in charge integrating configuration
- 3 feedback capacitors:
  - C_{f1}=50-100fF
  - C_{f2}~20xC_{f1}
  - C_{f3}~100xC_{f1}





- Logic after comparator to:
  - Switch a 2nd time if 1st switch not enough
  - Avoid a 2nd switch on spikes due to the 1st one
- Switching has to be FAST (<10ns)

1d Detector design



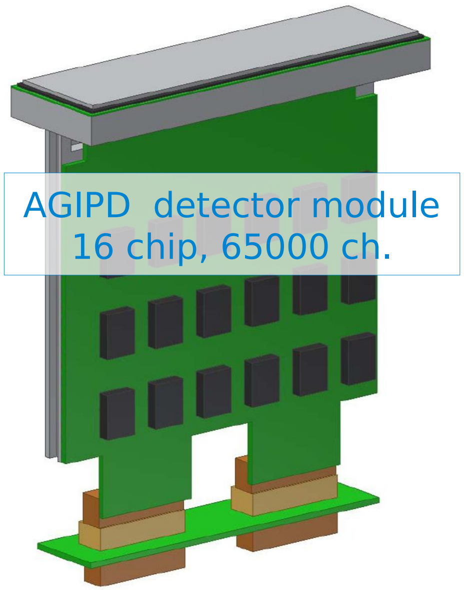
GOTTHARD:
Gain Optimizing microsTrip sysTem witH Analog ReaDout

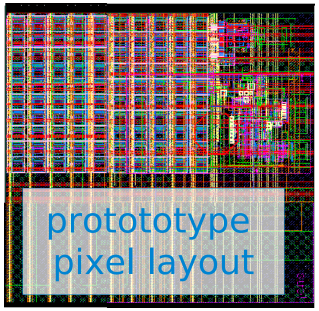
- Modular system
- 50 µm pitch, 1280ch/module
- 10 chips, 4 analog outputs per chip
- 40 ADC channels @50Mhz,14bits
- Gbit Ethernet data transfer

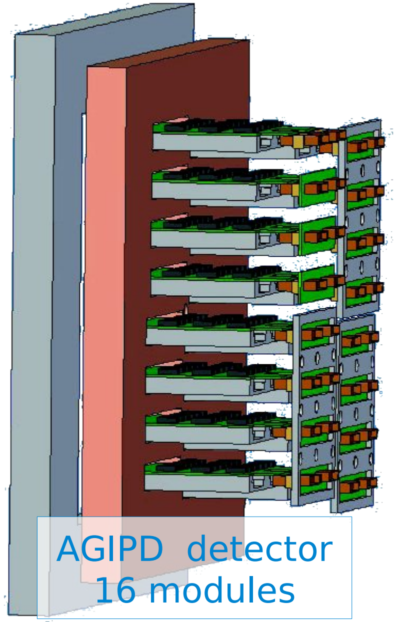
Solution for the bunch train problem:

- Fast readout (>1MHz) with more than 600 bunches/train recovered

2d Detector design







AGIPD:
Adaptive **G**ain **I**ntegrating **P**ixel **D**etector

- 200x200μm^2 pixel size
- 64x64 pixels per chip
- 8 chip/module,
- 1024x1024 total pixel count

Solution for the bunch train problem:

- ~200 on-pixel storage cells
- Storage cell access logic allowing to overwrite bad frames
- More than one (contiguous) frame on one storage cell

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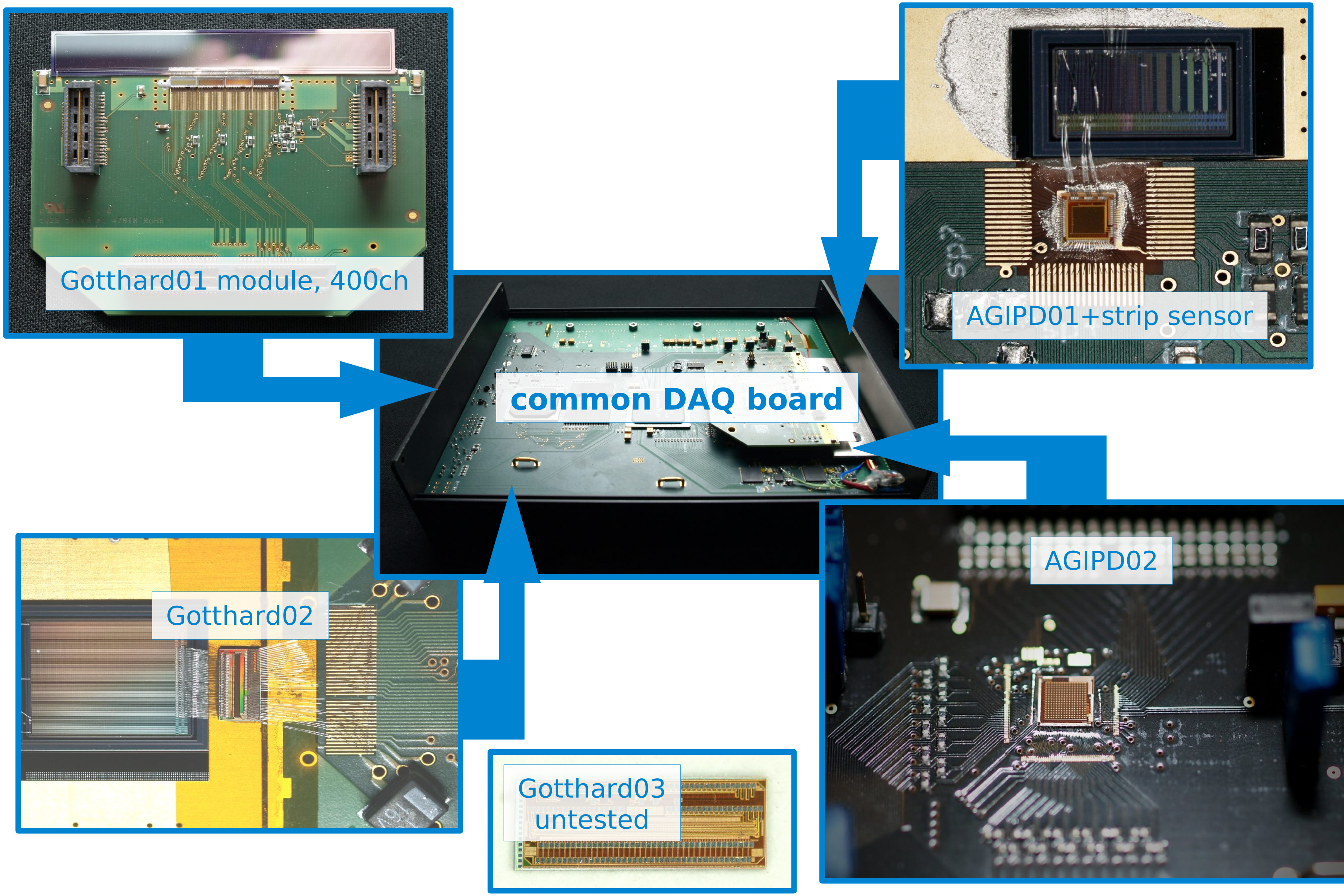
Prototypes


Gotthard01 module, 400ch
AGIPD01+strip sensor
common DAQ board
AGIPD02
Gotthard02
Gotthard03
untested

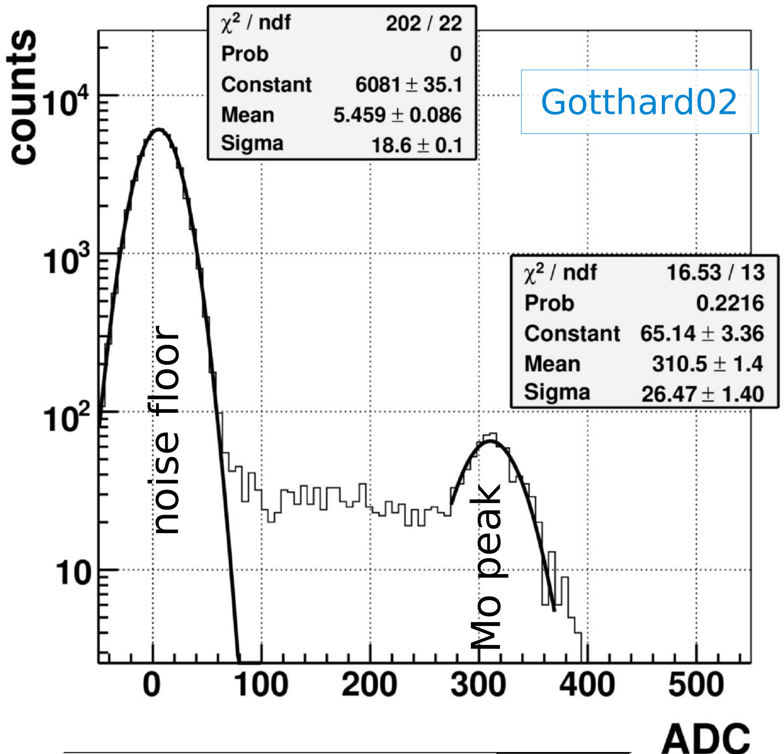
Prototypes

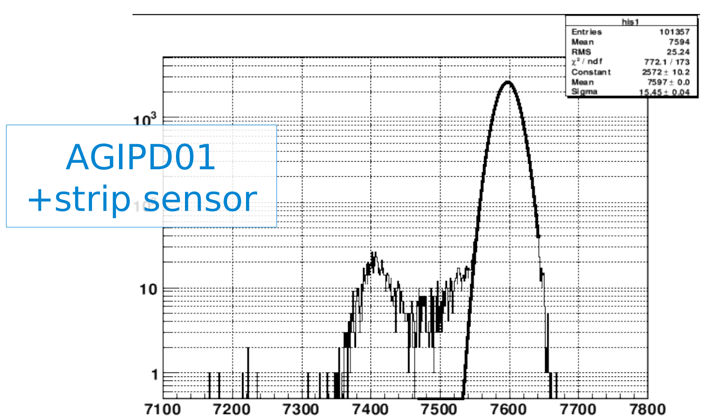
- Gotthard01 (UMC0.25) - 100ch
  - 400ch modules, different sensors
  - Extensively tested
- Gotthard02 (IBM 130nm) - 80ch
  - Preamp. noise
- Gotthard03 (IBM 130nm) – 80ch
  - gain switching, fast readout
  - not yet tested
- AGIPD01 (IBM 130nm) - 12 ch.
  - Preamp. noise
  - switching gain validation
- AGIPD02 (IBM 130nm) - 16x16ch.
  - 10x10 analog memory
  - storage cell variations
  - bump-bondable

Common DAQ system based on embedded CPU + low cost FPGA

- 4 fast ADC channel (14bit,80MHZ)
- 16 slow ADCs, 16 DAC channels
- up to 48 digital I/O
- integrated High voltage P.S.
- 100Mbit/s Ethernet link

Noise measurements

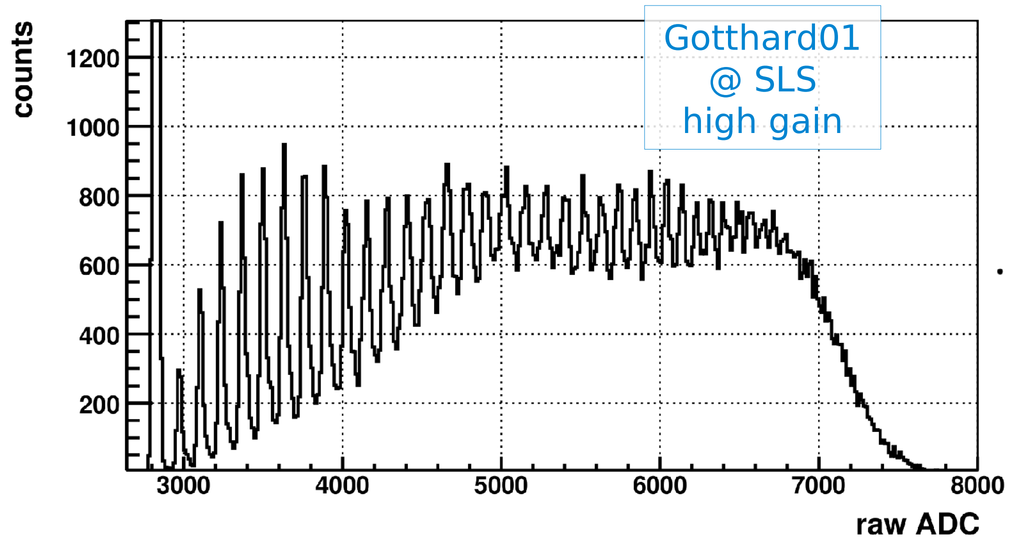


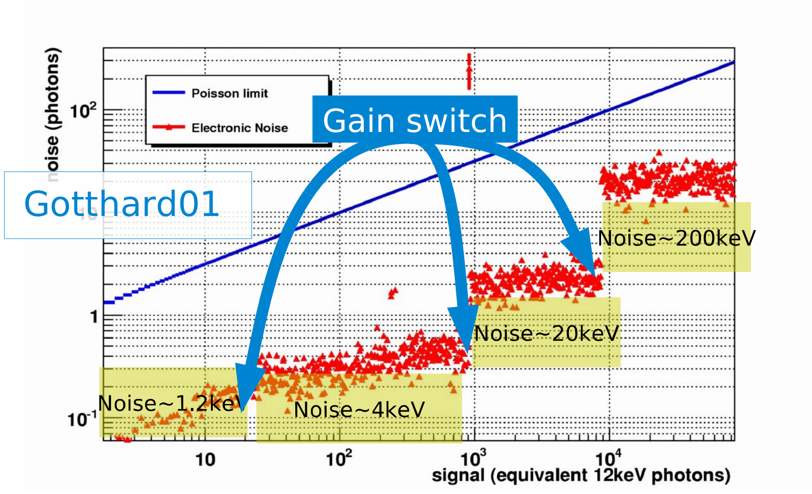


- Noise performance at the highest gain measured with X-ray (Mo florescence peak=17.4keV)
  - 295 e^- r.m.s. noise
  - implies single photon resolution down to a few keV
  - strip capacitance ~ 1pF
  - @ room temperature
- Similar result for AGIPD
  - ~300 e^- r.m.s. noise after correction for the capacitive charge loss
  - expected to be smaller with a pixel sensor (C_{det}:1pF->100fF)

Noise – many photons

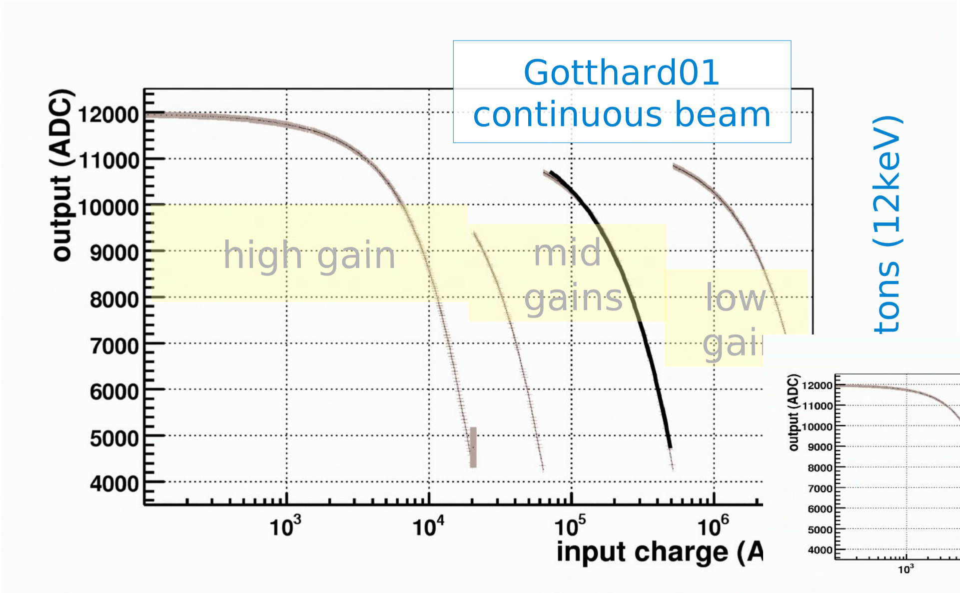
- To avoid charge sharing, a 10um beam was collimated in the center of the channel
- up to 40 photons peaks are visible (@17.5keV energy) in the P.H. distribution
- integration system can “count” photons



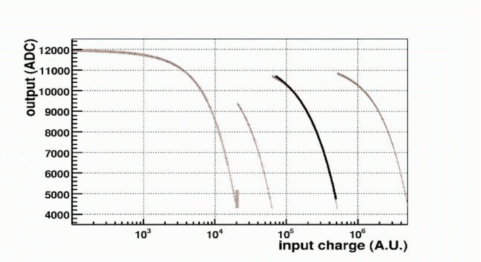


- an integration time scan at constant current was used to evaluate the noise at low gains
- at all gains the electronic noise is well below the Poisson level

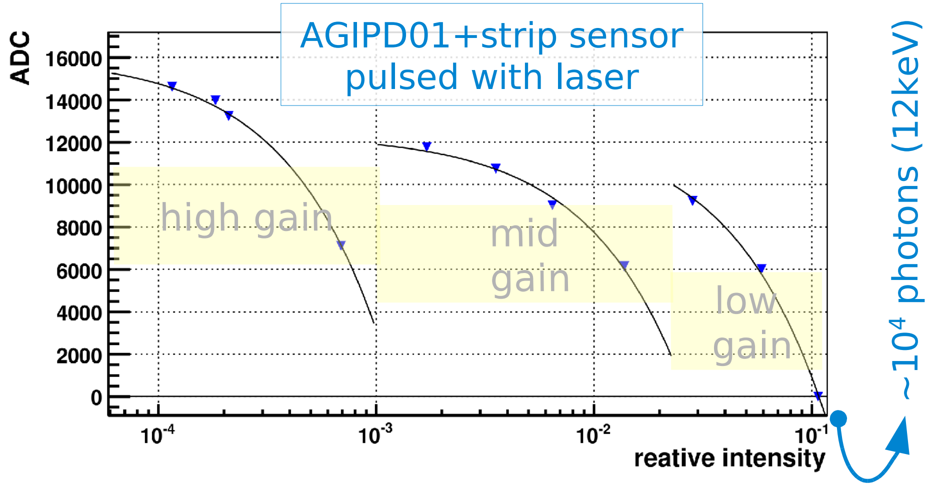
Switching gain functionality



- Gotthard01 switching was tested with constant current
- non-linearity ~3% due to output buffer

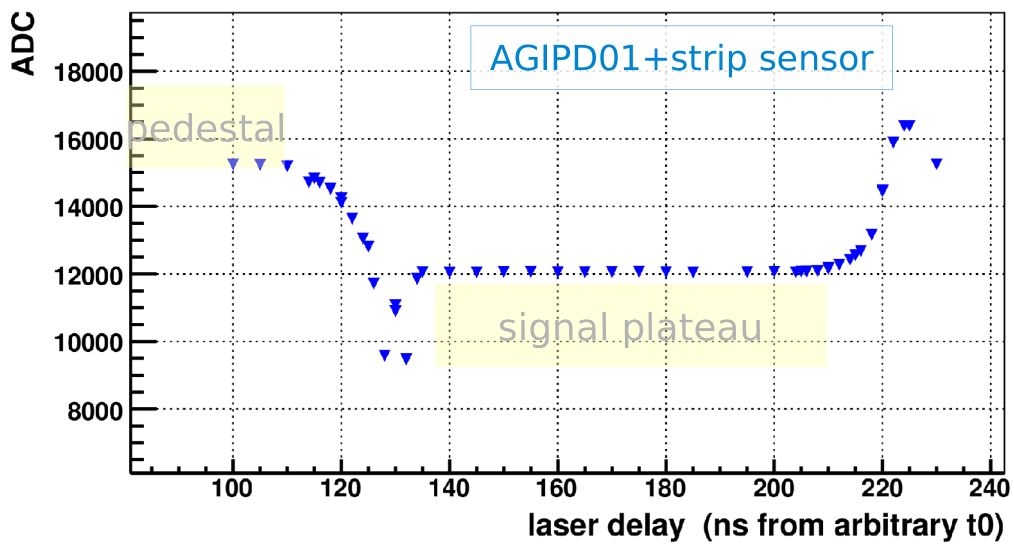


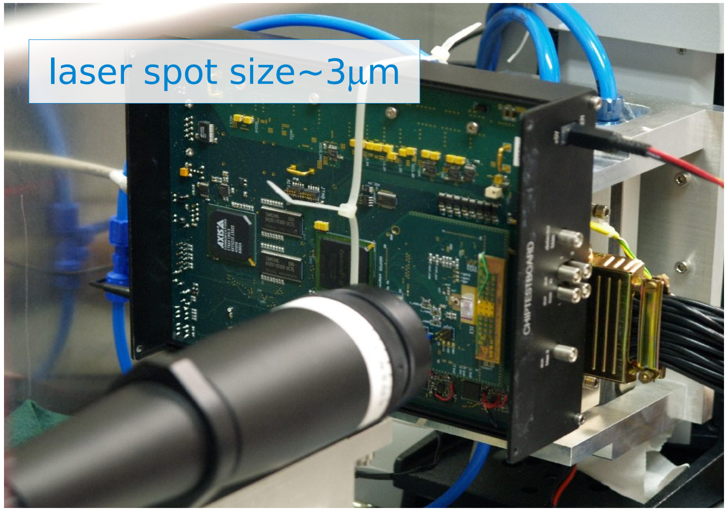
- on AGIPD01 the switching was tested with a subnanosecond laser pulse hitting the strip sensor
- Switching works at the required speed



Speed

- delay scan with a high intensity laser pulse (~500 12keV photons)
- with a 100ns integration time
- CDS output settles in <30ns
- integration times as small as 50ns can be used

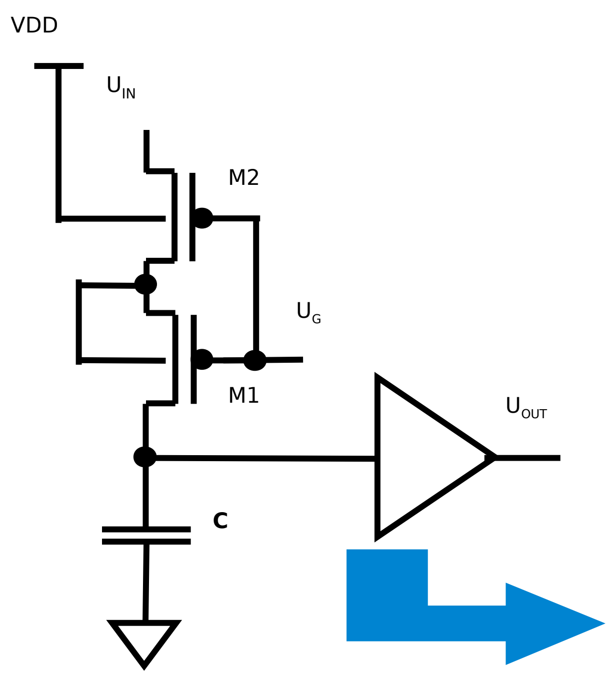




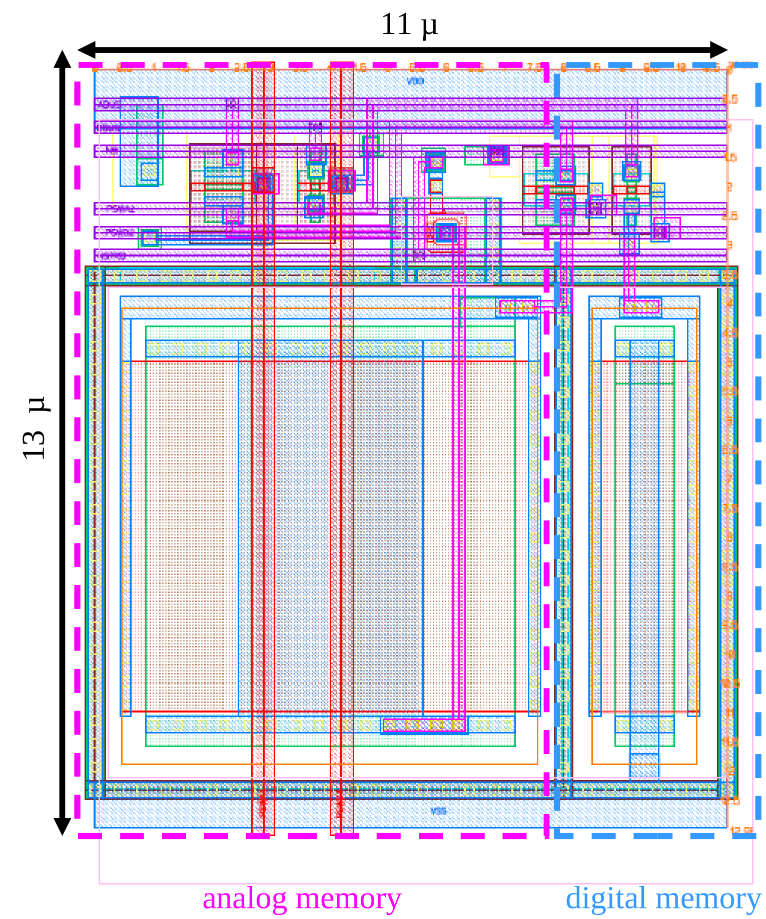
- similar result with or without automatic gain switching
- the preamplifier+switching circuitry can work at E-XFEL rates (4.5MHz)

AGIPD Memory cell

- selected out of many variations
- analog & “digital” storage element
- stacked PMOS switches
- capacitance (nominal):
  - ~200fF for analog
  - ~30 fF for digital

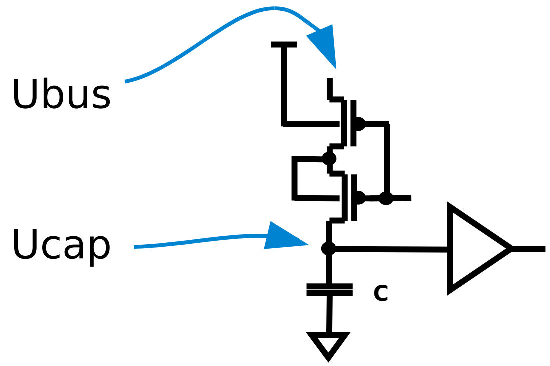


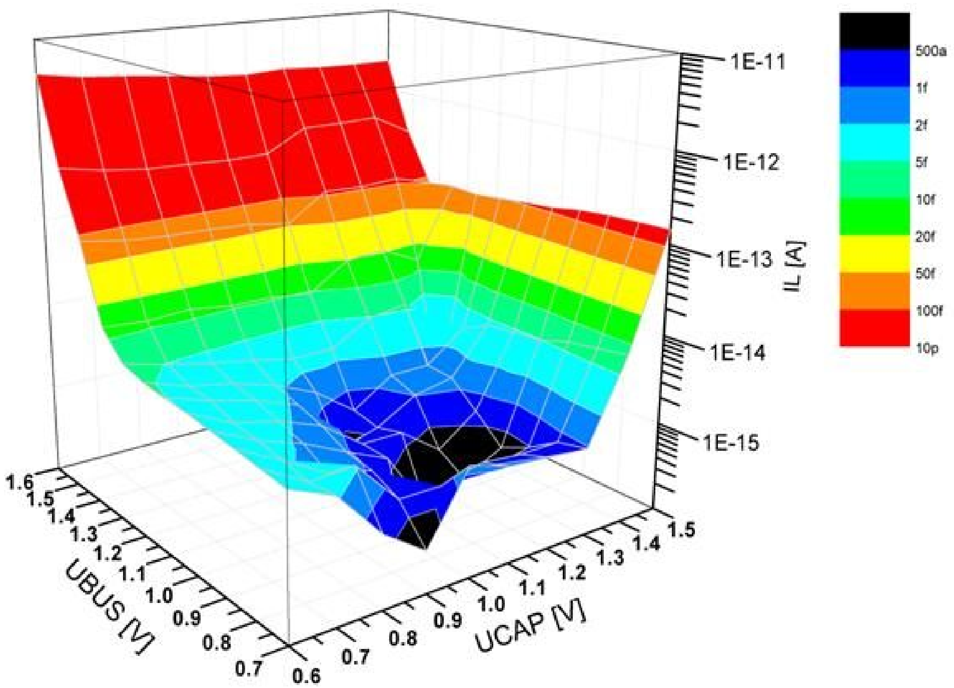
buffer for leakage meas.
not in final cell



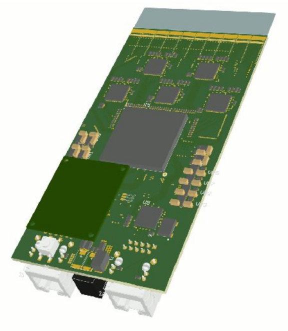
Memory cell characterization

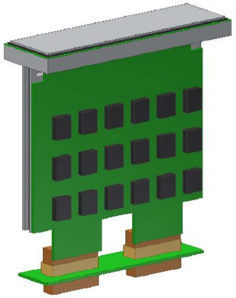
- leakage current measured as a function of stored value and bus voltage
- the cell can be operated in a region with I_{leak}<2FA
- Expected leakage-induced error:
  - C=~200fF
  - t_{store}=100ms (worst case)
  - DU ~ 1mV
- corresponding to less than 0.2% of dynamic range or 1/5 of photon at the highest gain
- functionality after irradiation still to be verified





Towards the final systems





- Tests of Gotthard03, starting next week, will verify:
  - high speed analog readout and ADC conversion
  - noise, linearity and dynamic range of the full chain
- Submission of the full featured final chip planned for Feb. 2011 (on MPW)
- Design of the module PCB is ongoing
- Gotthard module integration in summer 2011

- Test of Hybridized AGIPD02:
  - overall noise and linearity
  - cross talk
  - storage and retrieval of real image data
  - leakage current contributions
- Test of memory cell after irradiation
- Reliability at high intensity

- Next submission: 16x16 pixel matrix in final configuration

Conclusions

- 1D and 2D charge integrating detectors are needed for the XFEL-based experiments
- several prototypes of 1D and 2D have been built and tested
- the testing of the automatic switching gain preamplifier showed:
  - single photon resolution at high gain
  - low noise and high linearity on the full dynamic range
  - speed of preamp. and switching is fast enough for an XFEL beam
- a suitable storage cell has been identified and tested (but not for rad-hardness)
- the construction of full size systems has started

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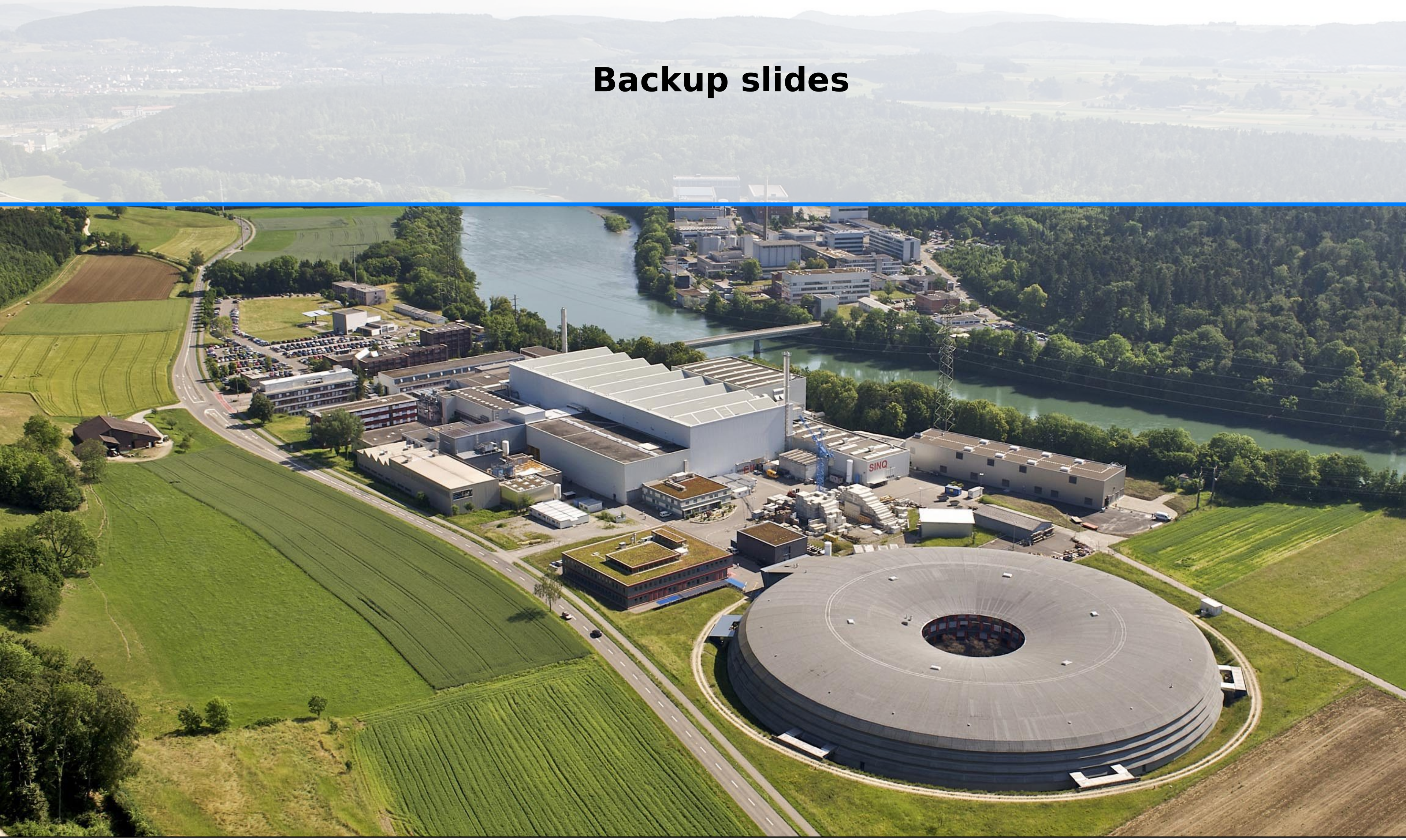
Backup slides



charge integration for Syncrotrons

Photon counting system (PILATUS,MYTHEN, EIGER) are the state of the art for Syncrothron source instrumentation.
There are, nevertheless, a few weaknesses:

- Count rate, currently limited to ~1MHz per channel

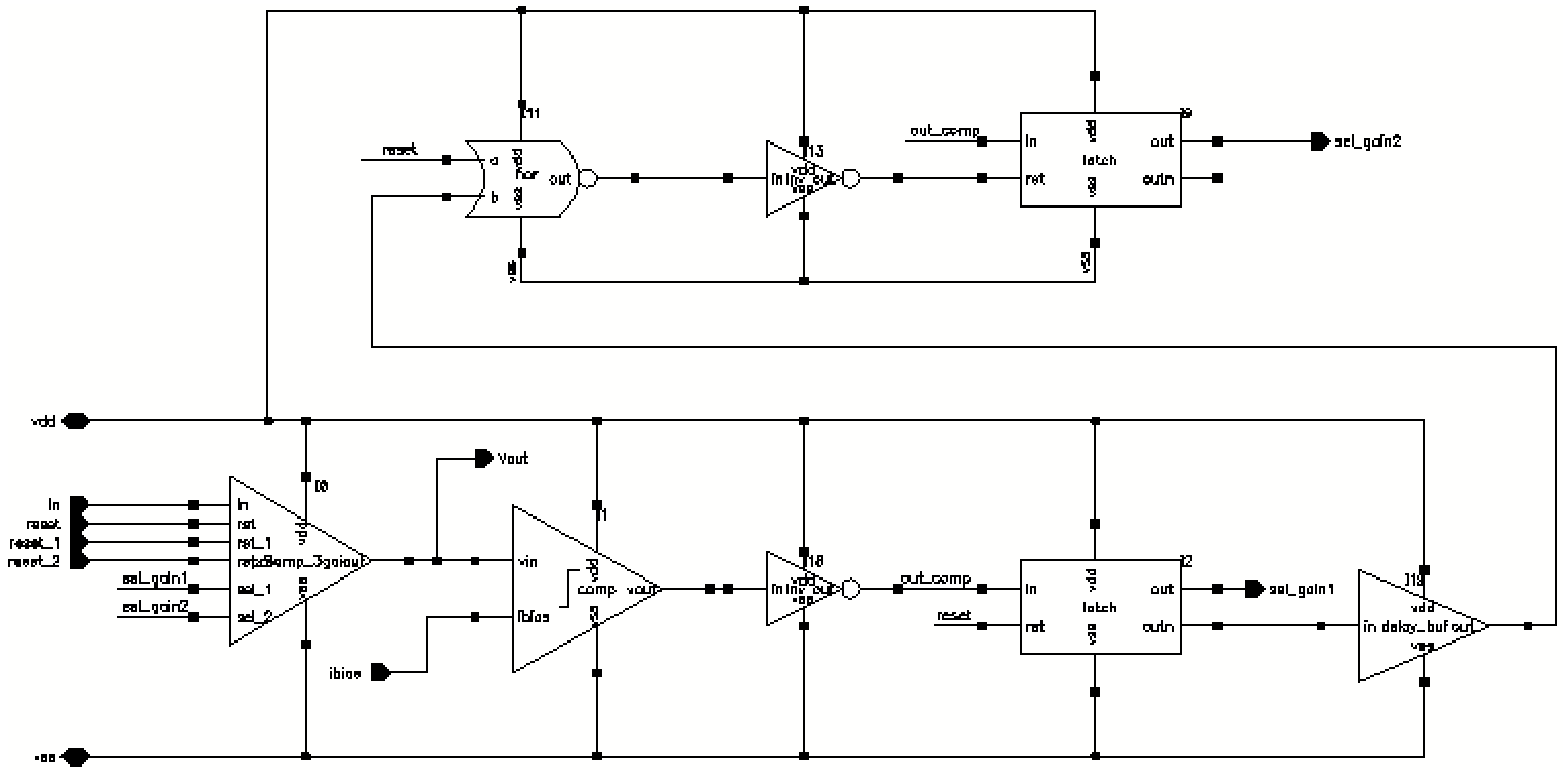
Small room for improvements

- Minimum Pixel size, that is limited by charge sharing in the sensor and by the space for electronics

- Low energy sensitivity, which is constrained by electronic noise and cross-talk

Fundamental limits

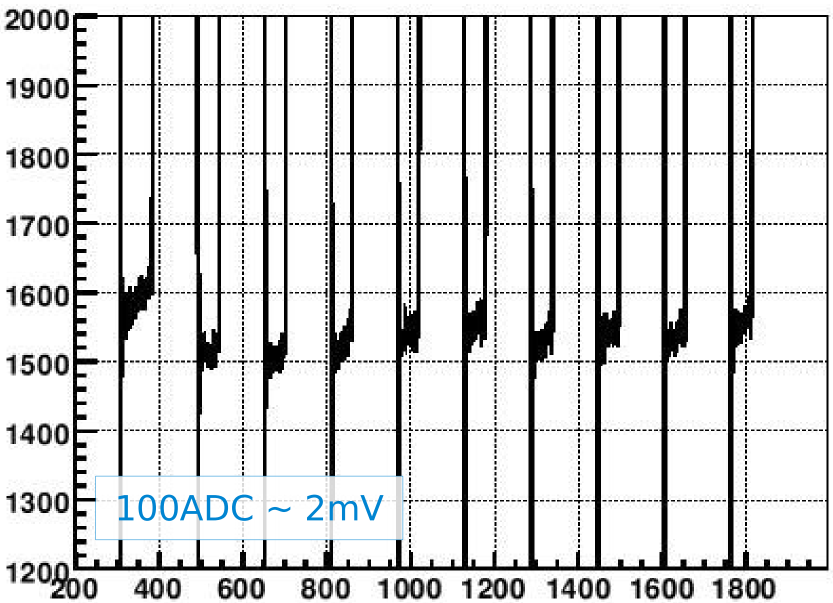
gain switching logic



AGIPD02 memory cell results

The reading out the memory signals after 100 ms delay shows almost no leakage. The leakage is visible as soon as the memory cells are connected to the pixel bus.

The memory row read out immediately after the signals are stored.



The memory row read out after100 ms delay since the signals are stored.