PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

Bernd Schmitt

Detector Development at the Swiss Light Source

We develop detectors for applications:

- Mythen: powder diffraction
- Pilatus: protein crystallography
- Eiger: scanning small angle scattering, CDI, XPCS
  Protein crystallography

Single photon counting

We want to be prepared for the Swissfel:

- AGIPD: 2D for XFEL
- Gotthard: 1D for XFEL

Charge integrating

We do detector research:

- small pitches/pixels what are the limits for the resolution?
- other sensors: thick Si (up to 2mm), CdTe

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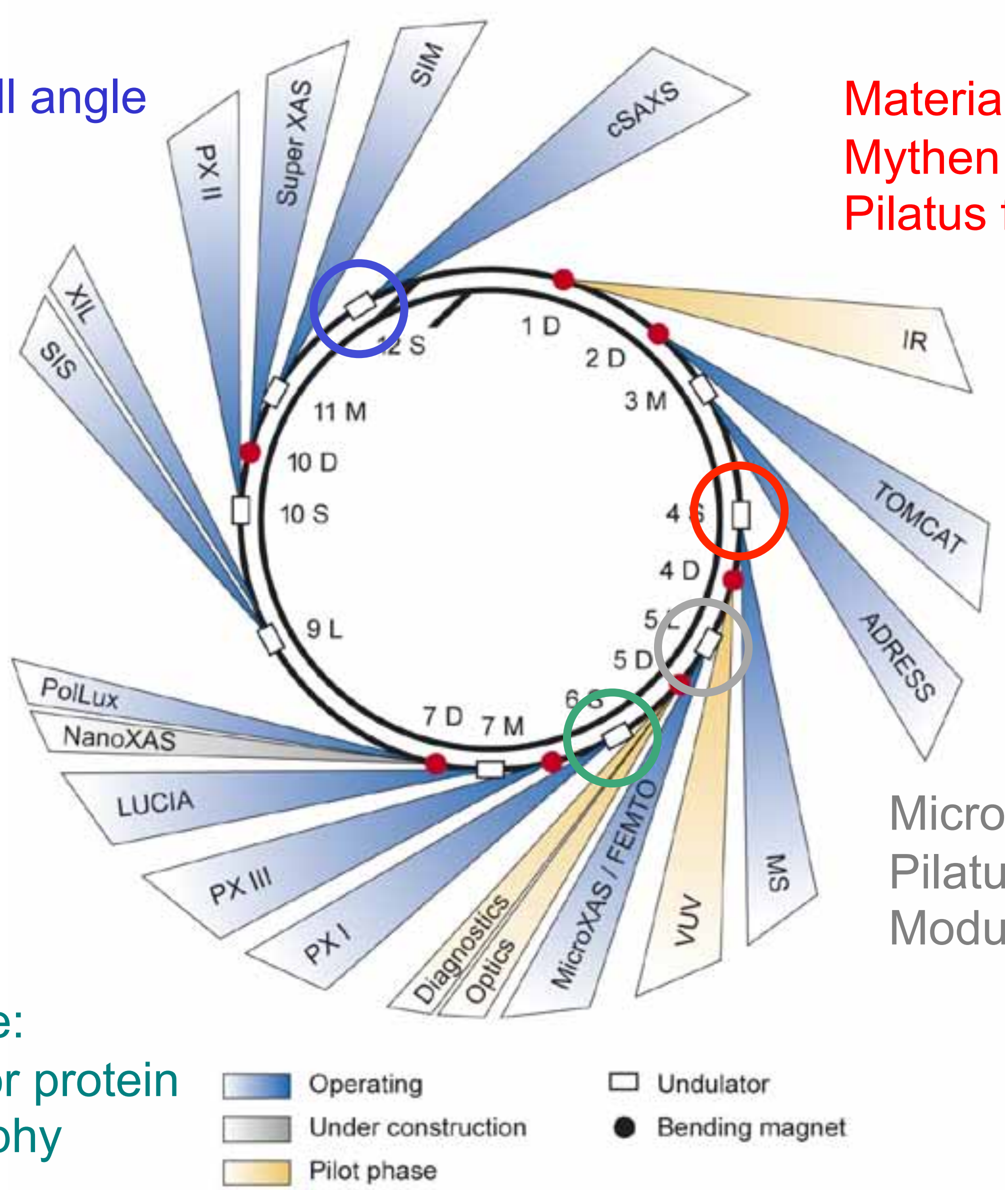
csax beamline:
Pilatus2M for small angle scattering

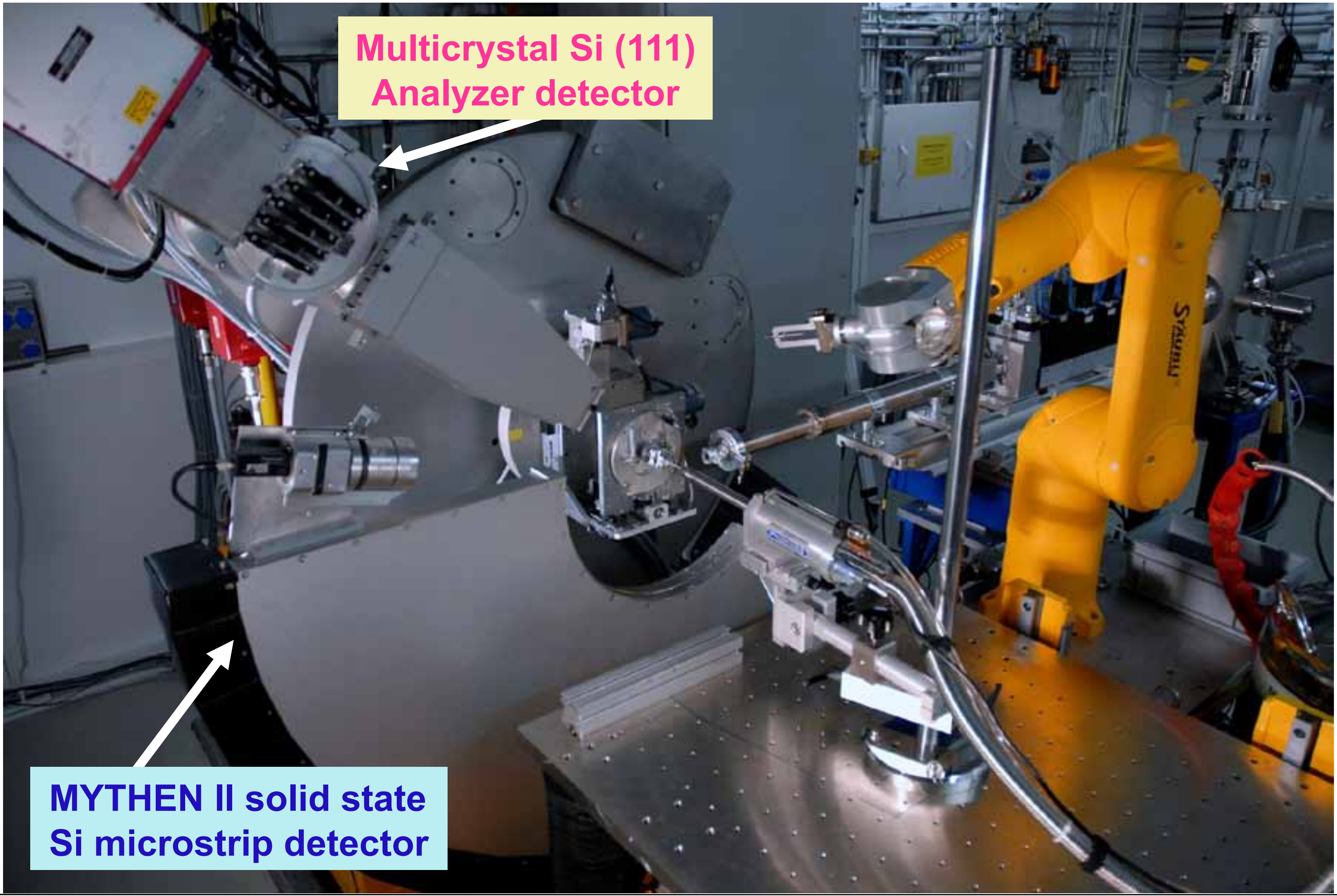
Material science beamline:
Mythen for powder diffraction
Pilatus for surface diffraction



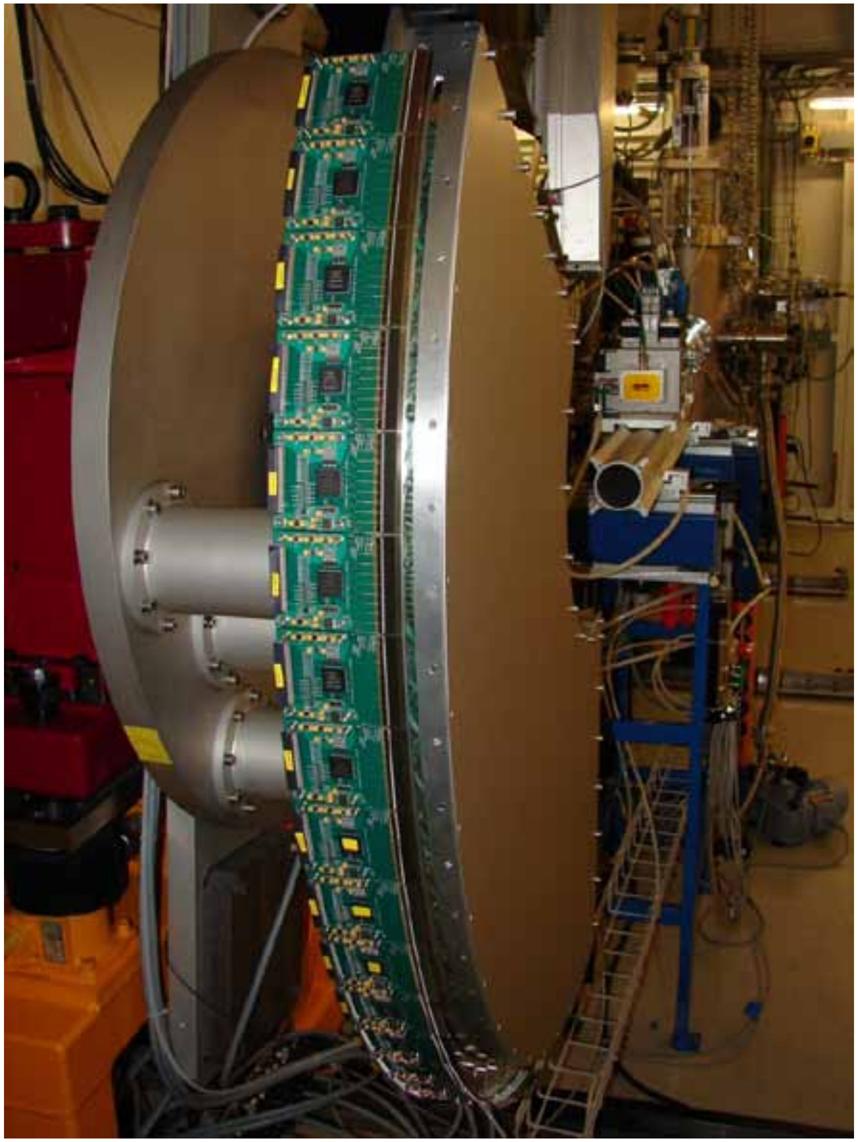
MicroXAS/Femto:
Pilatus and Mythen single Module Systems

PX beamline:
Pilatus6M for protein crystallography

MythenII detector system at PD station

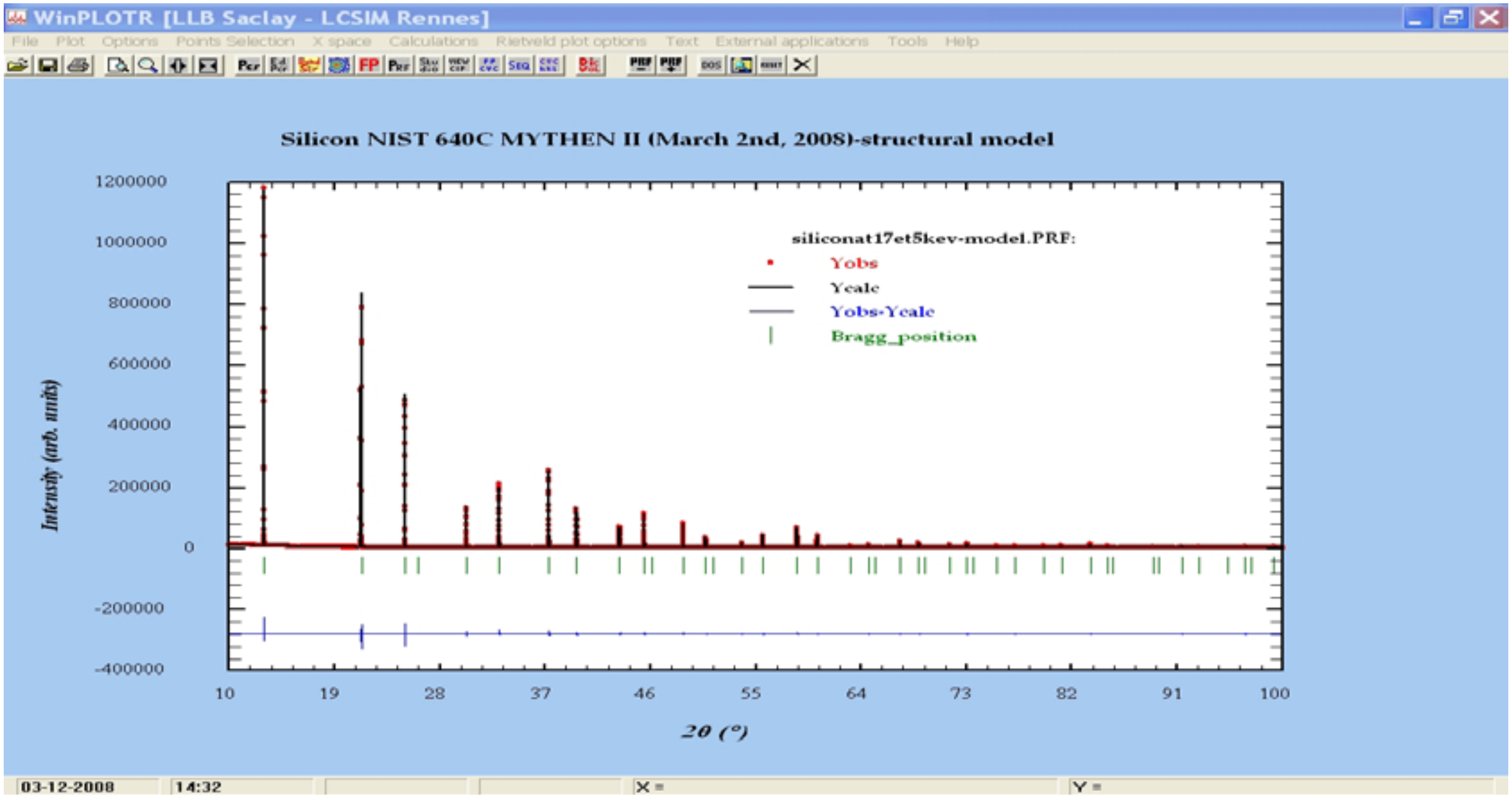


MythenII at PD



- Modular system: 1 to 24 modules,
  for PD at SLS 24 modules covering 120^o
  30k channels ⇨ gain factor of 30k
- Full 120^o PD spectrum in <1s, typically 0.1s
- Intrinsic angular resolution 0.004^o (0.01^o)
- Energy range: 5-40 keV (at SLS PD)
- Frame rate 100Hz for 1 and 5Hz for 24 modules
  ⇨ in future 1kHz (End 10)
- Main applications:
  - Time resolved, in Situ measurements
  - Temperature scans
  - Organic Materials (reduces radiation damage dramatically)

Standard powder samples (Si)

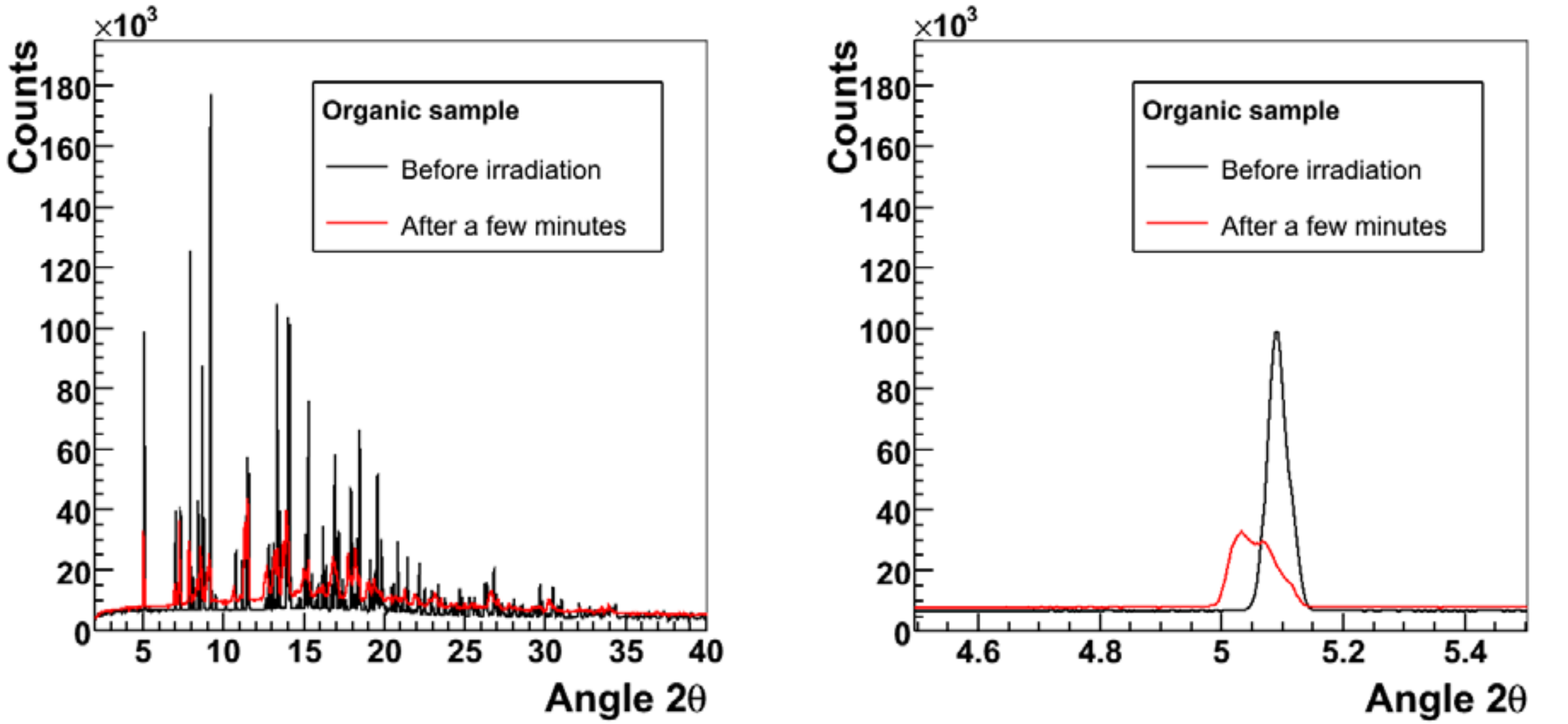


➡ Structures can be determined from microstrip data

Courtesy of Fabia Gozzo, PSI

Organic powder samples

Example of an organic sample from an industrial user before and after irradiation



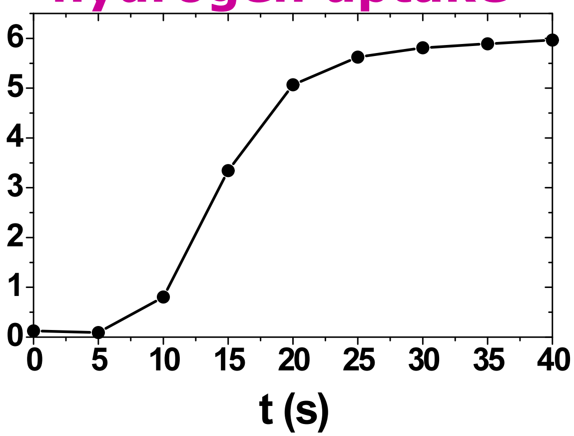
Measurement is so fast that no radiation damage is visible!

In-situ dynamic study of the LaNi5 hydrogen absorption process

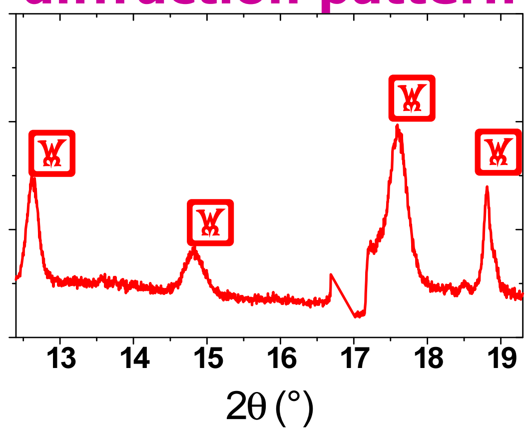
- In-situ hydrogen absorption at 15 bar
- In-situ desorption by connecting the cell to a vacuum pump
- Continuous measurements while the reaction takes place

Joubert et al. Acta Materialia, 54 (2006), 713-719

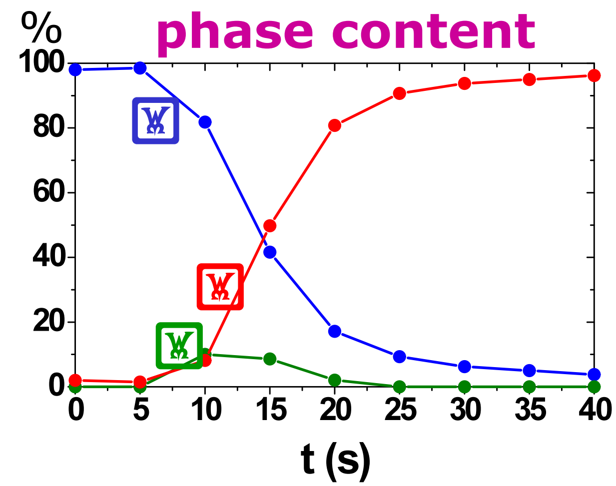
hydrogen uptake



diffraction pattern



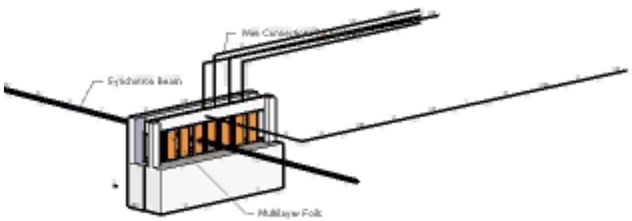
phase content



R. Cerny (Uni Geneva)

t = 40 s

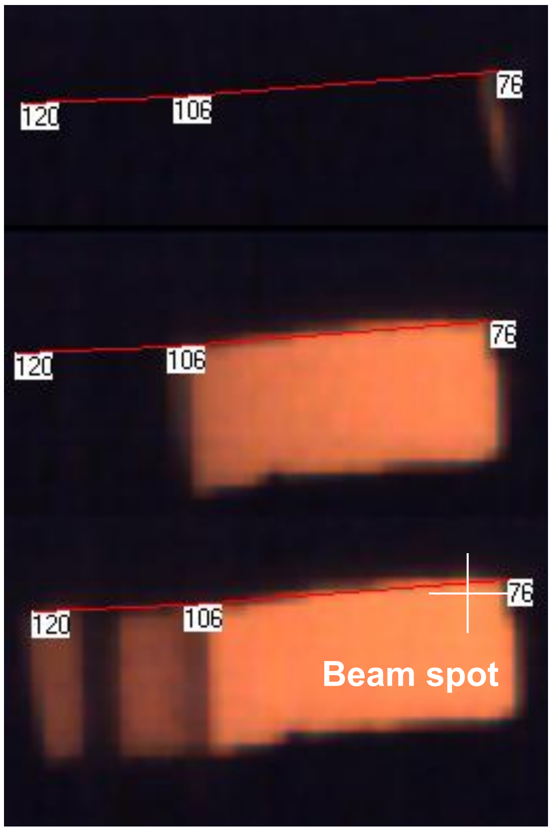
Self propagating exothermic reaction



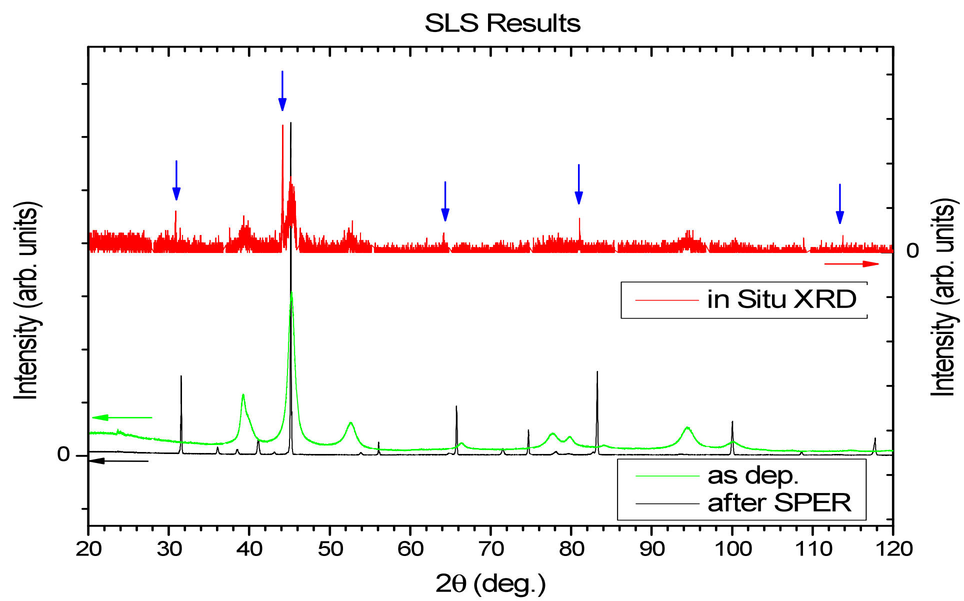
- Samples: Sputtered NiAl multilayer foils
- Beam size 500x500 μm^2
- Frame recording time 125 μs (16 frames)
- Diffraction patterns, high speed camera images and infrared camera images are recorded

Courtesy of K. Fadenberger, University of Cyprus

Experimental proof of intermediate structure



HS-frame 76;106 and 120, markers showing flame front location



- **Without Mythen only structure before and after the reaction were measureable !**

Courtesy of K. Fadenberger, University of Cyprus

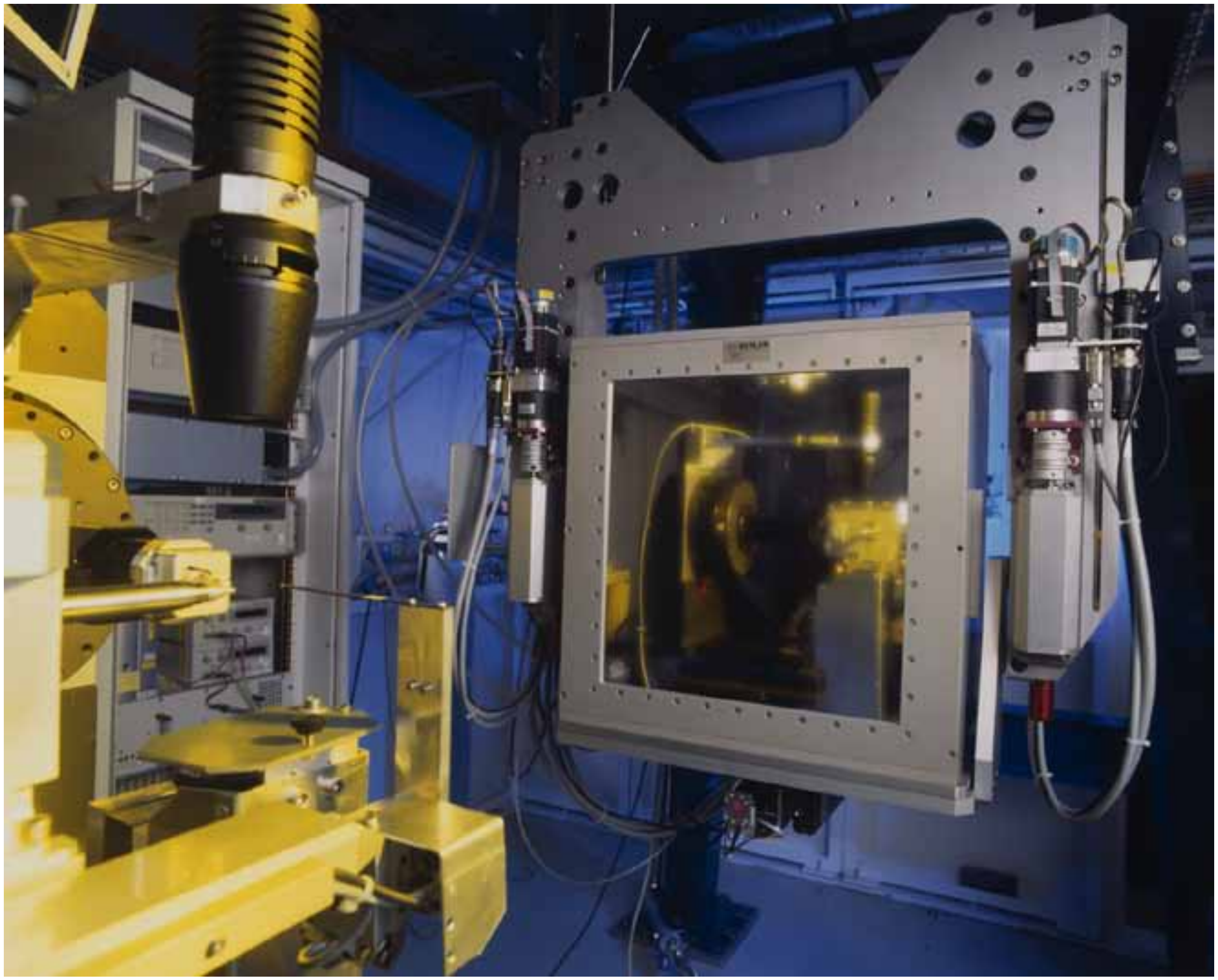
Status MythenII

- calibration at a level which allows Rietfeld refinement and structure determination, resolution high enough for most experiments
- unique tool for time resolved PD

Future Developments:

- higher frame rate (1kHz for full PD)
- thick Si sensor (up to 2mm), high-Z sensor material
- longer term: MythenIII new readout chip and system

PilatusII 6M at Protein crystallography



Main features:
- 172 mm pitch
- 12.5 Hz frame rate
- dead time: 4 ms
- 20 bit counter

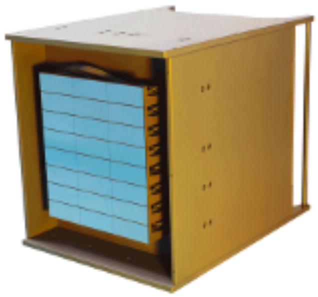
Advantages:
- point spread function
- noise free readout
- larger dynamic range
- small dead time
  - fine phi slicing
- better data
- factor 4 faster measurement

PilatusII 2M at cSAX

The two most important applications for cSAXS are:

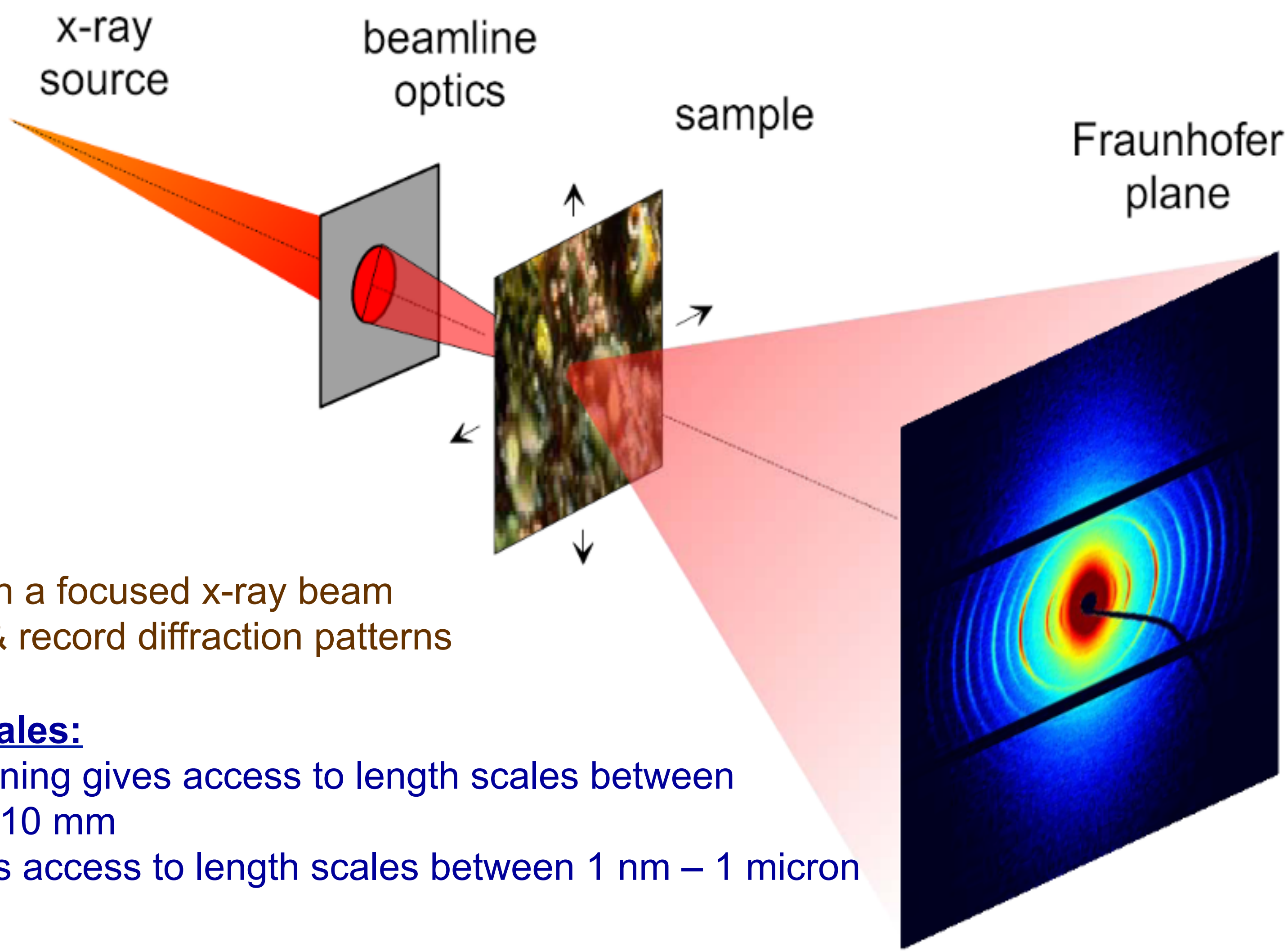
• SAXS mapping
• high resolution Coherent Scanning Microscopy

Possible due to PilatusII 2M



•X-ray Photon Correlation Spectroscopy (XPCS) seems to attract fewer people in the user community (since PilatusII is too slow)

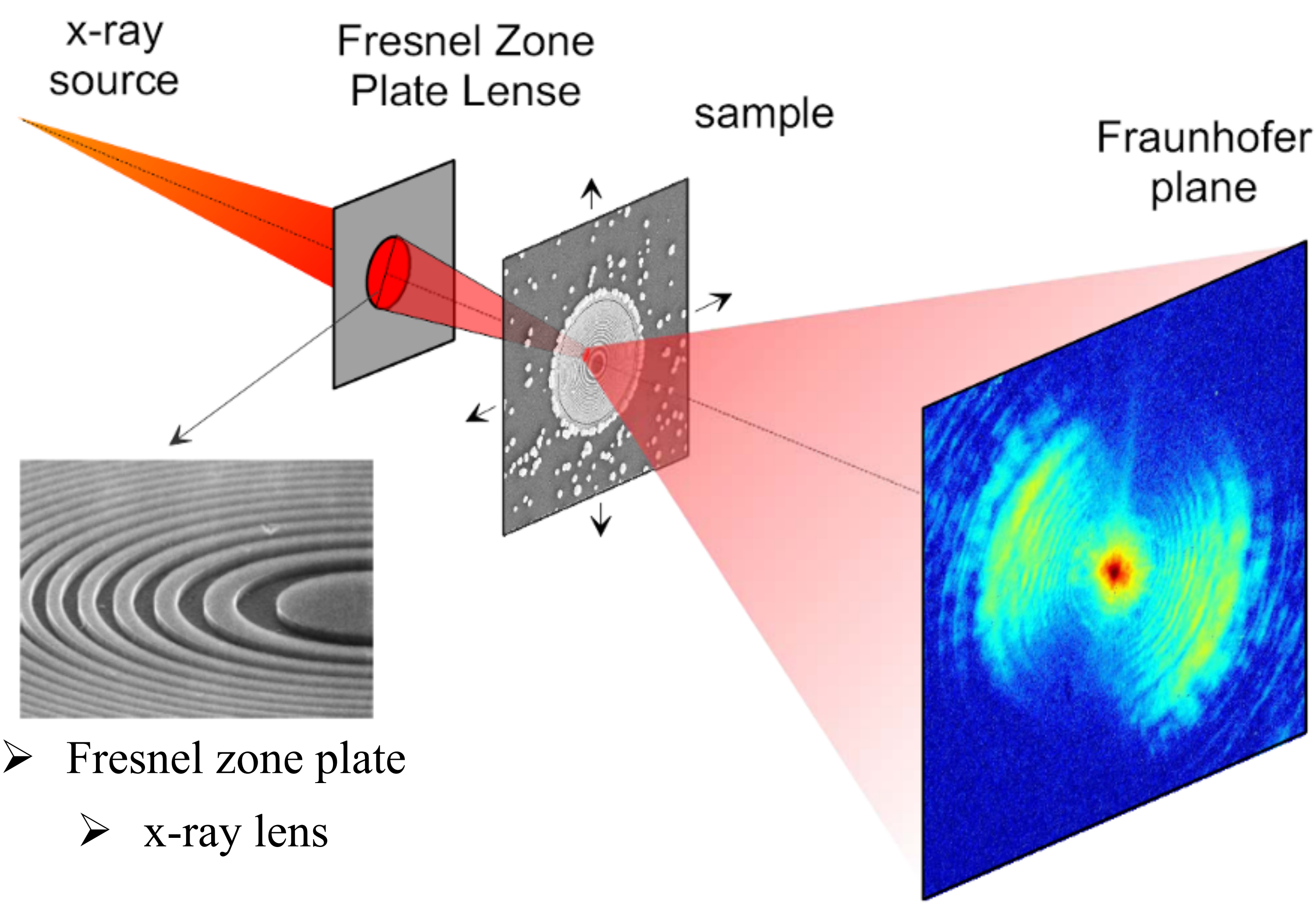
Small angle scattering combined with Scanning Microscopy



Principle:
Raster scan a focused x-ray beam
& record diffraction patterns

Length Scales:
raster scanning gives access to length scales between
1 micron – 10 mm
SAXS gives access to length scales between 1 nm – 1 micron

High resolution Scanning X-ray Diffraction Microscopy



- Fresnel zone plate
  - x-ray lens

Requirements at cSAX

Both SAXS mapping & high resolution Coherent Scanning Microscopy need large (> 2 Mpixels), very fast and noise-less 2D detectors with a large dynamic range

⇨ single photon counting

Scanning now usually done with a dead time of 50%

⇨ high frame rate and small dead time

Smaller pixels will allow larger aperture and better statistical sampling of coherent diffraction patterns (172 micron pixel are 'at the edge')

⇨ smaller pixels

There is enough flux to go 10 to 100 times faster (depending on sample)

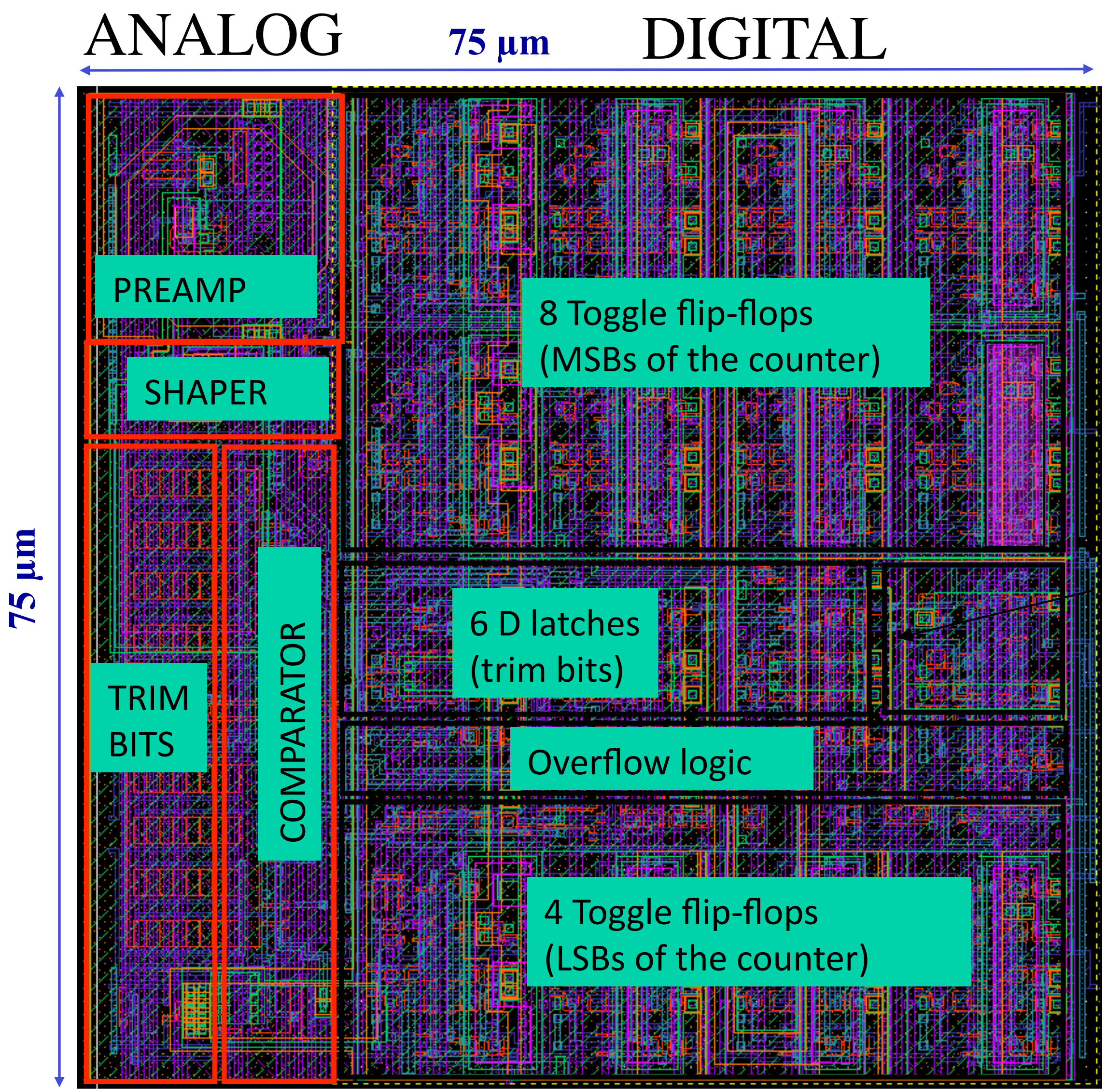
⇨ Eiger (75 mm, 10kHz frame rate, 1 ms dead time)

EIGER main features

Technological process	UMC 0.25 µm
Radiation tolerance	Full radiation tolerant design (>4Mrad)
Chip size	19.3 x 20.1 mm^2 (active 19.2x19.2mm^2) > 2 x
Pixel size	75 x 75 $µm^2$ = / 5.3
Pixel array	256 x 256 = 65536 = 11.3 x
Counter	12 bits, binary, configurable (4,8,12 bit mode), double buffered
Count rate	3.4 x 10^9 x-rays/mm^2/s = 5.3 x
Continuous readout	Yes, 1 ms dead time
Detector readout speed	~12 KHz @ 8 bit mode (Detector size doesn't matter) = up to ~2000 x (Clock=100 MHz DDR)
Threshold adjustment	6 bit DAC

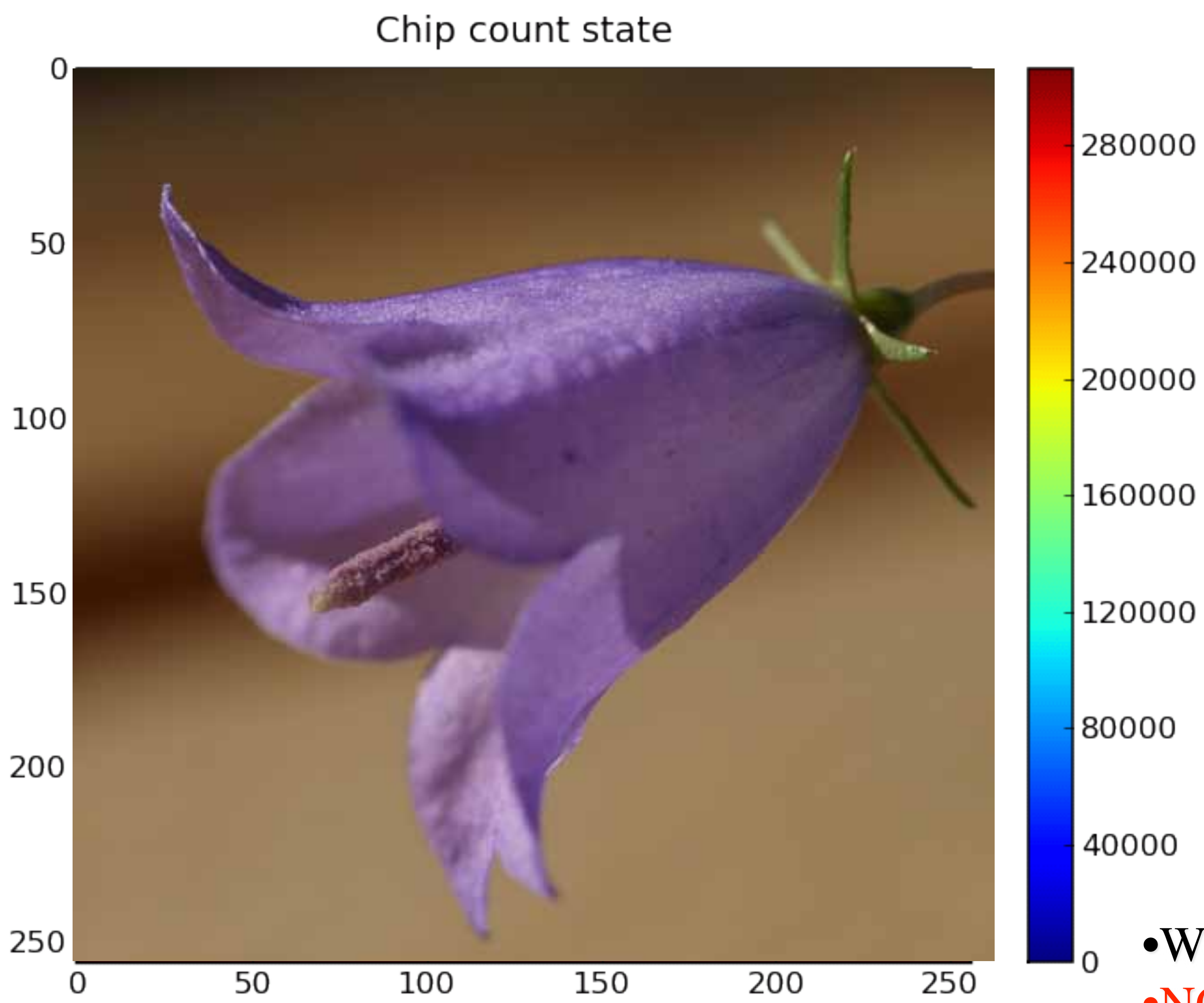
In red: Improvement factor with respect to PILATUS

The EIGER pixel on silicon



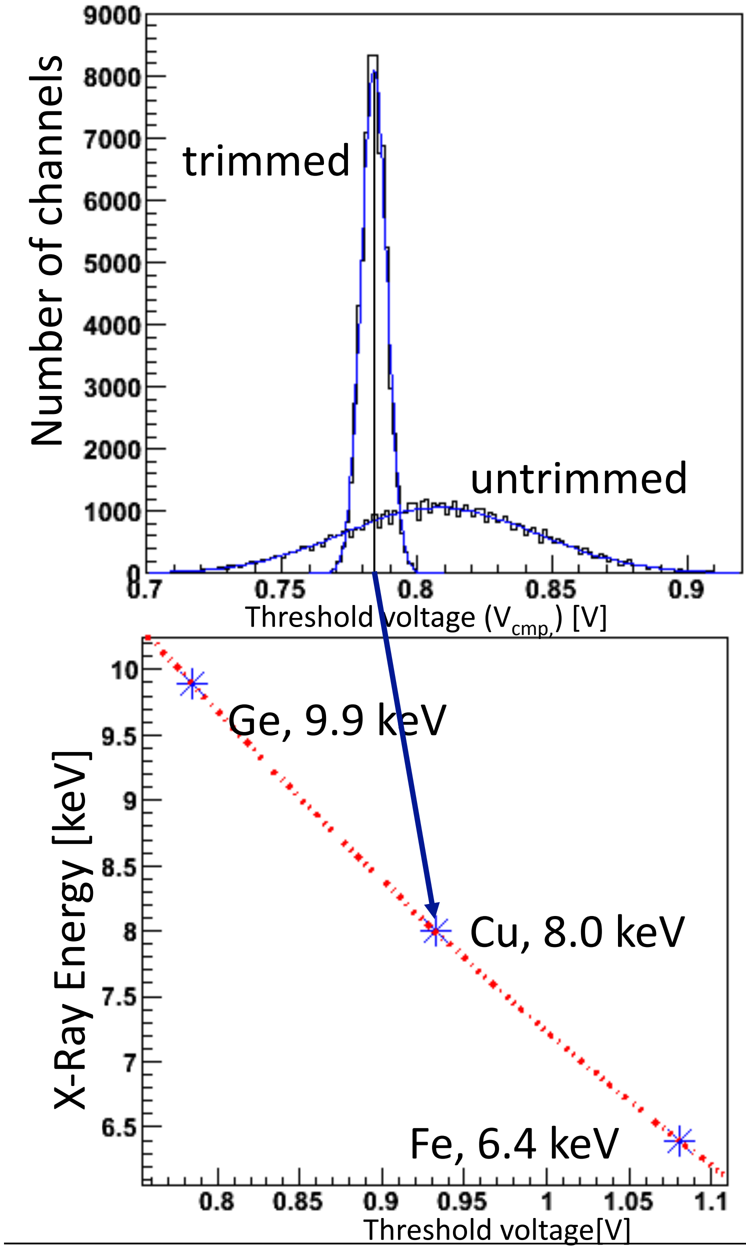
UMC 0.25 mm Technology, full radiation tolerant layout

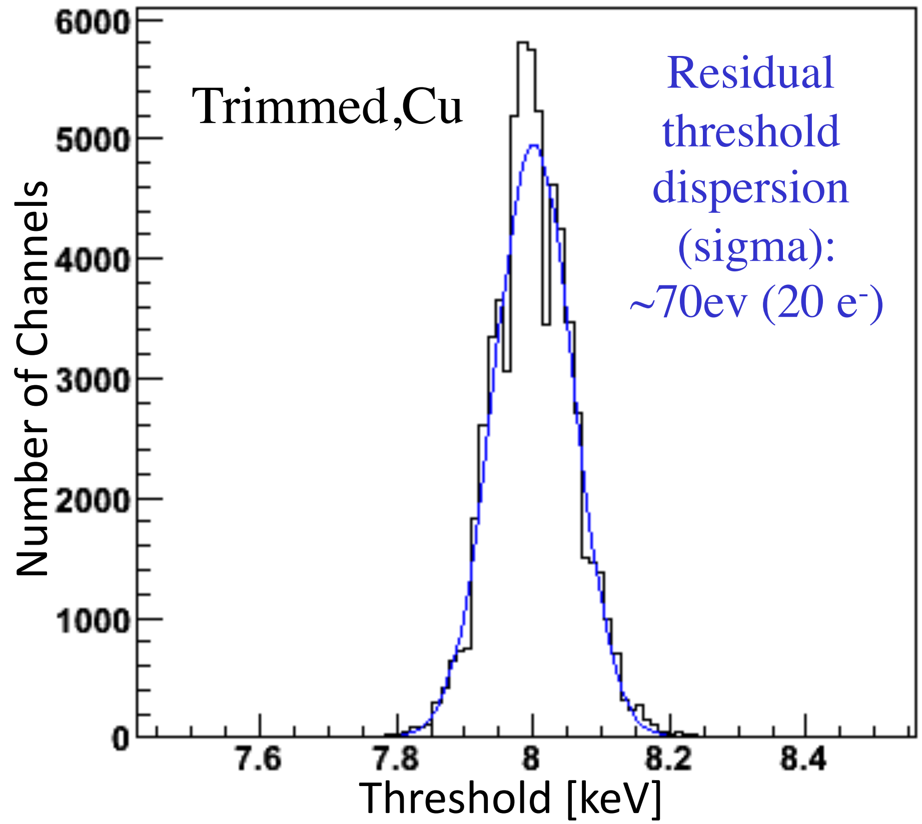
EIGER absorption images



- With flat field
- NO trimming

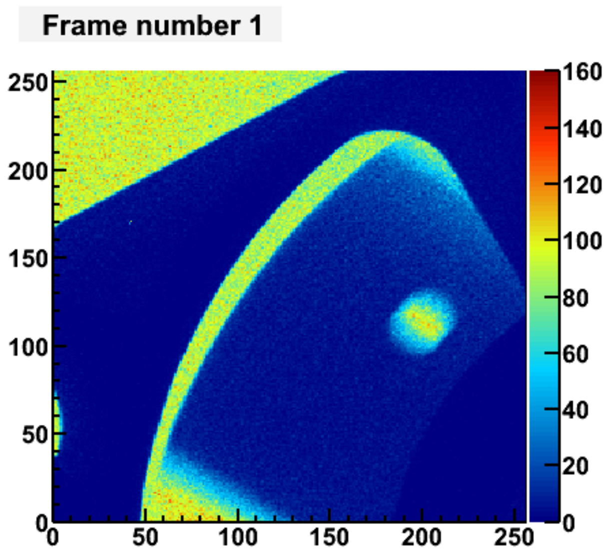
Trimming and energy calibration

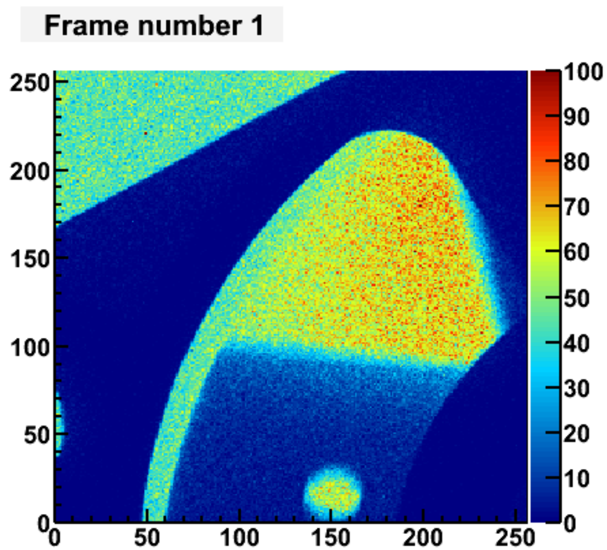


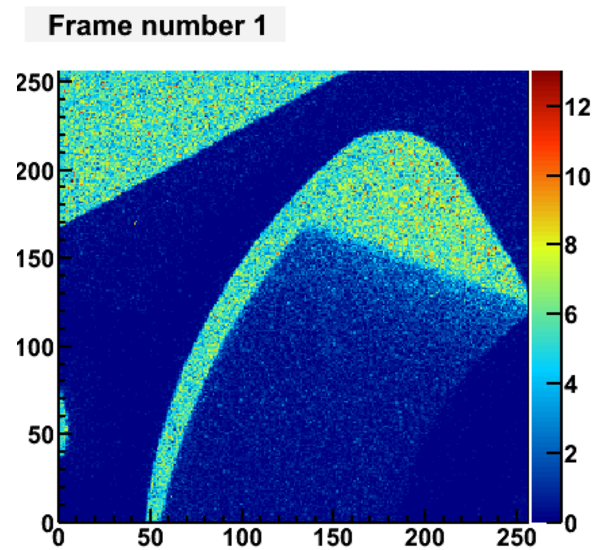


- Noise (sigma) ~650 eV (=180 e^-)
- Minimum threshold ~4.5 keV (=1250 e^-)
- Threshold dispersion (sigma) ~70 eV

EIGER high frame rate Demo







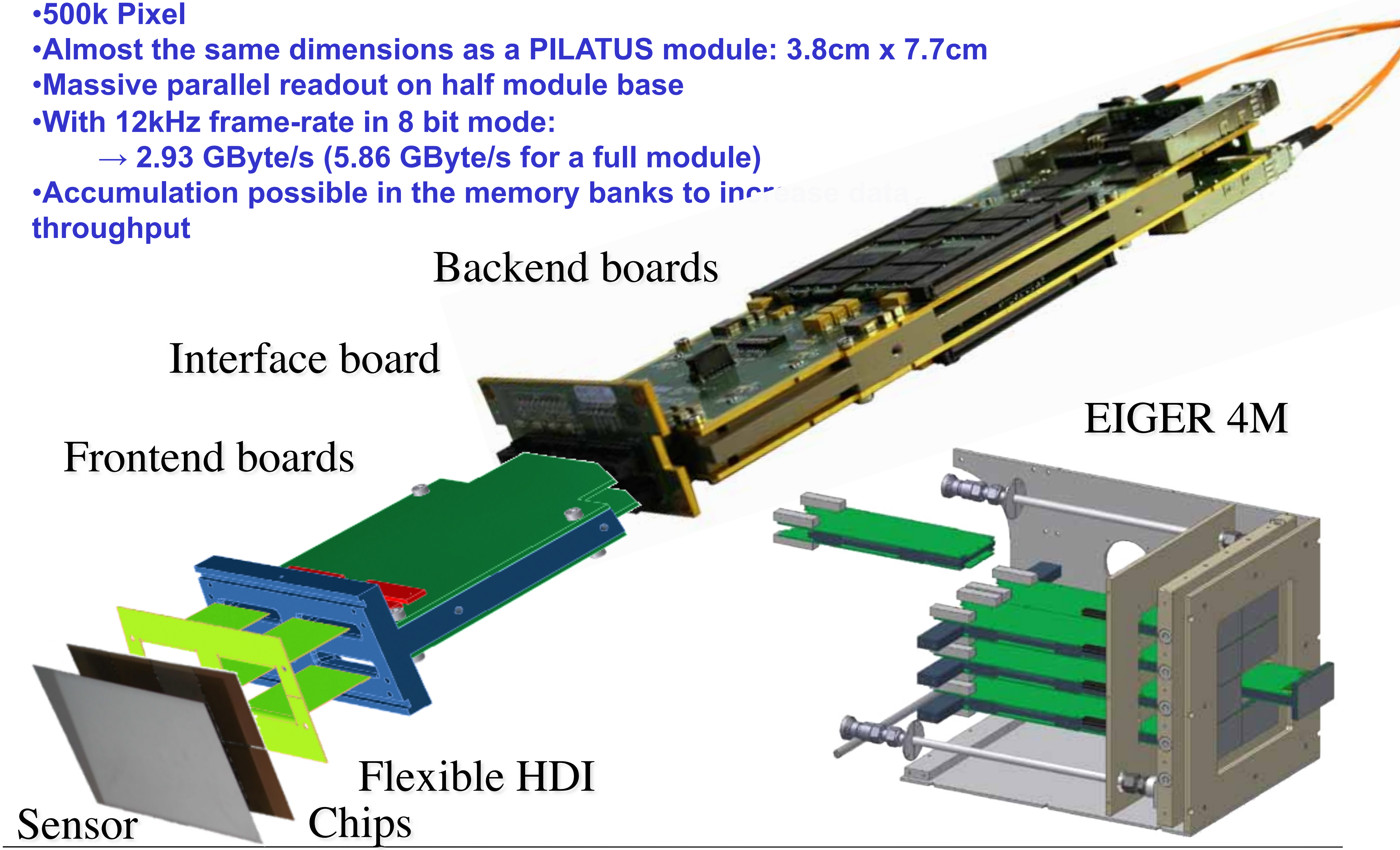
Chip in 12 bit Mode
Exposure time 125µs
Dead time 3µs
Frame rate 7.8 kHz

Chip in 8 bit Mode
Exposure time 85µs
Dead time 3µs
Frame rate 11.4 kHz

Chip in 4 bit Mode
Exposure time 45µs
Dead time 3µs
Frame rate 20.8 kHz

From chip to module to system

- 500k Pixel
- Almost the same dimensions as a PILATUS module: 3.8cm x 7.7cm
- Massive parallel readout on half module base
- With 12kHz frame-rate in 8 bit mode:
  → 2.93 GByte/s (5.86 GByte/s for a full module)
- Accumulation possible in the memory banks to increase data throughput



Present status

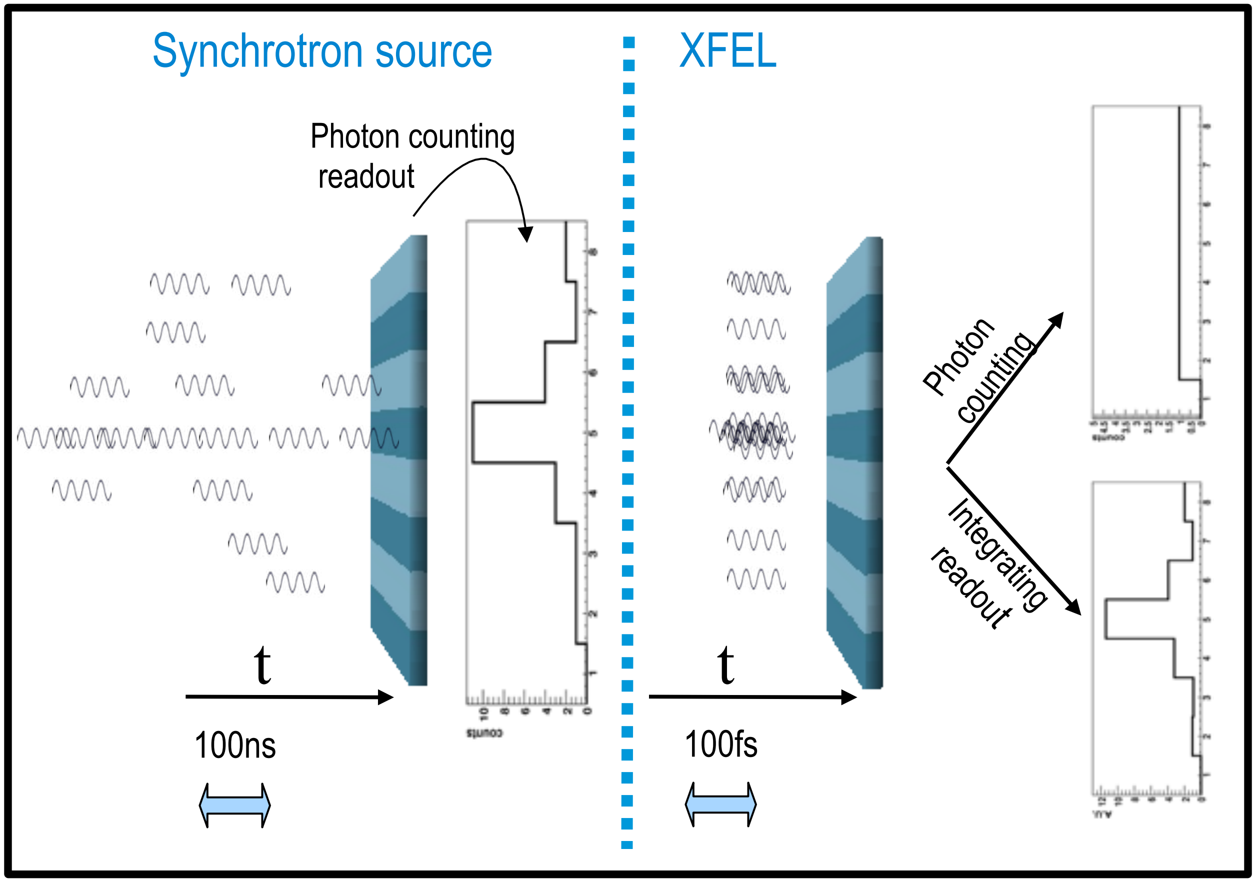
Chip and Sensor •
Produced and tested
Bump bonding •

•Interface board
Produced and tested
•Backend board

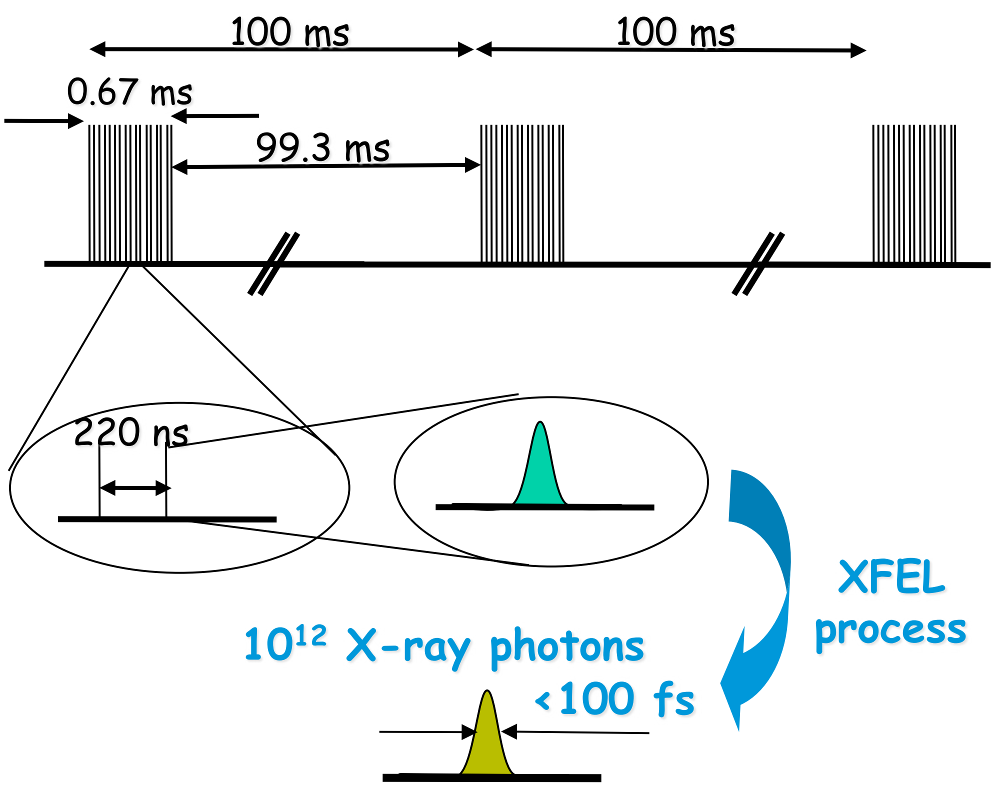
XFELs => charge integration

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

•No easy solution for bunches in a train,

only a fraction of the frames will be

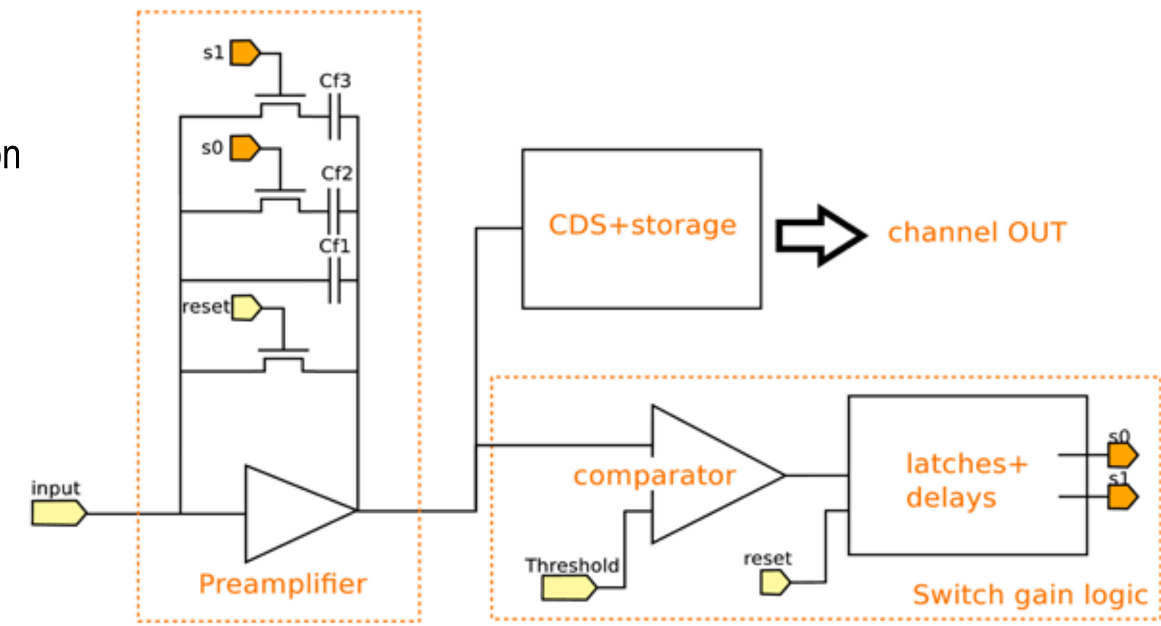
recovered

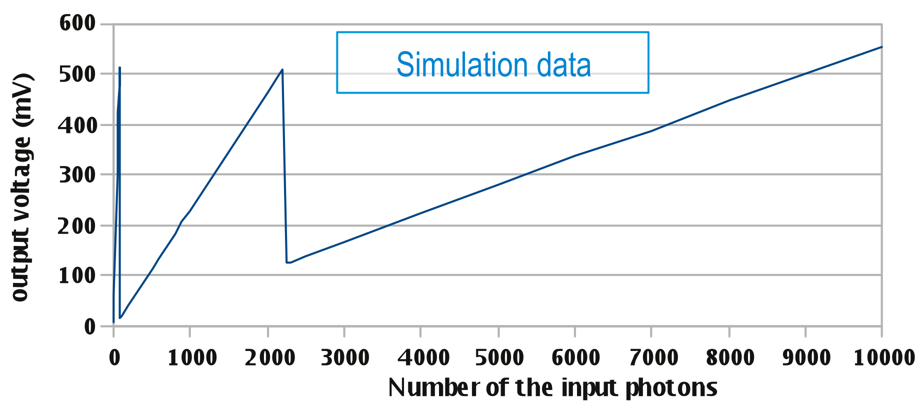
E-XFEL Detector requirements

- High dynamic range (in the $10^{4\text{-}5}$ g/ch. range)
- Single photon resolution (@12keV g 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)

Preamplifier with gain switching

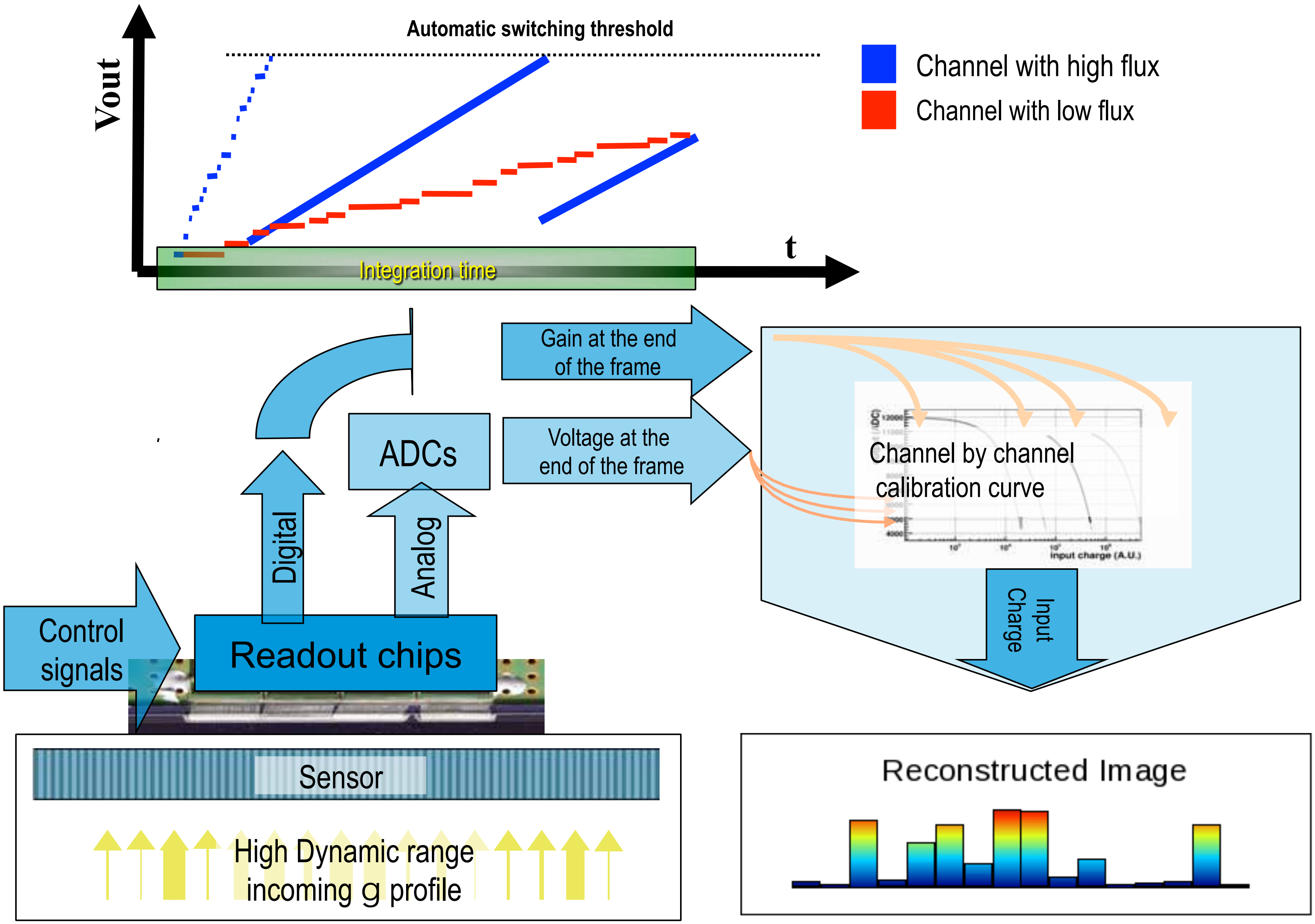
- Common for 1D and 2D
- CSA in charge integrating configuration
- 3 feedback capacitors



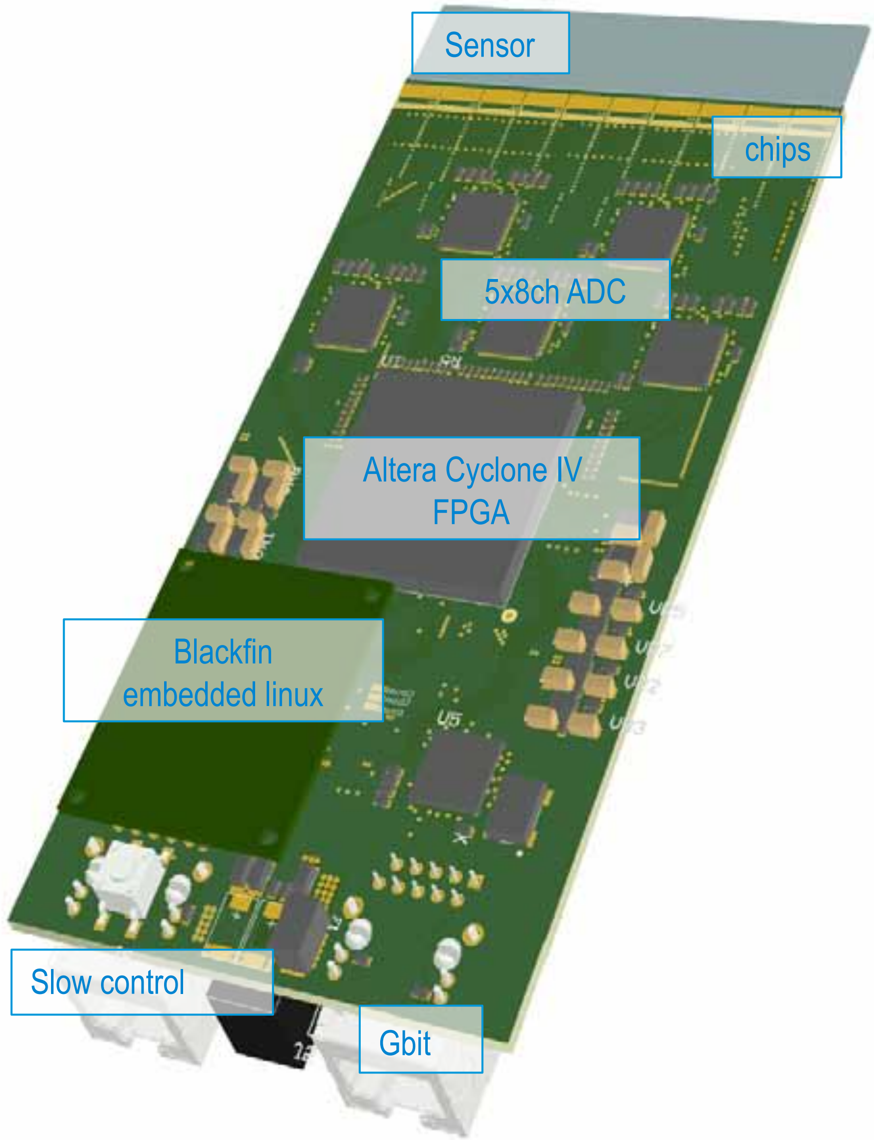


- Logic after comparator to:
  - Switch a 2nd time if 1st switch not enough
  - Avoid a 2nd switch on spikes due to the 1st one
- Switching has to be FAST (<10ns)

Automatic switching gain:theory



1d Detector design



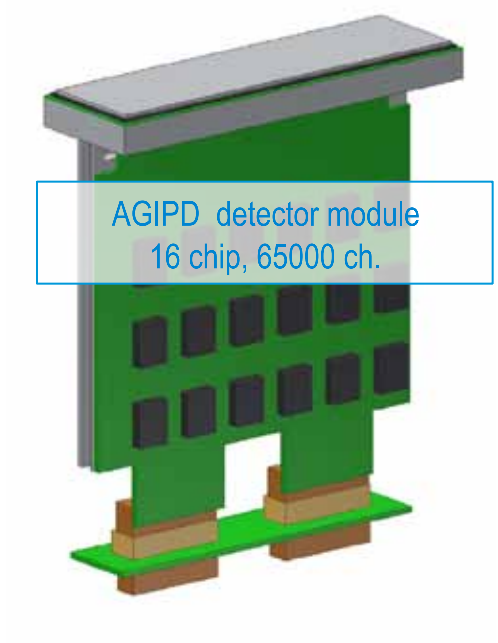
GOTTHARD:
Gain Optimizing microsTrip sysTem witH Analog ReaDout

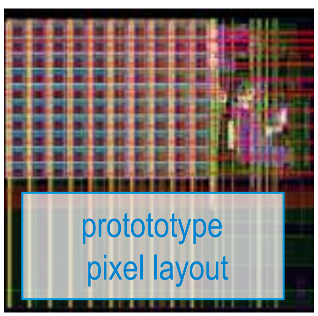
- Modular system
- 50 mm pitch, 1280ch/module
- 10 chips, 4 analog outputs per chip
- 40 ADC channels @50Mhz,14bits
- Gbit Ethernet data transfer

Solution for the bunch train problem:

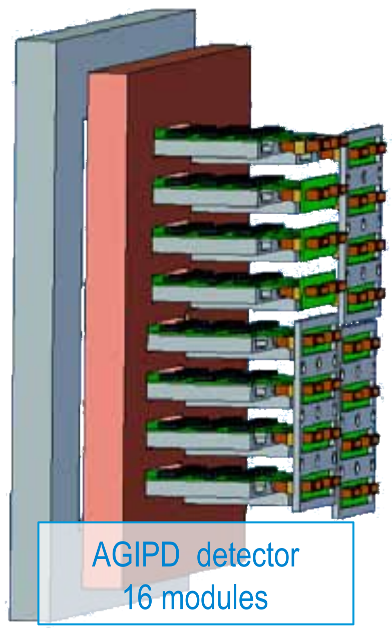
- Fast readout (>1MHz) with more than 600 bunches/train recovered

2d Detector design





AGIPD:
Adaptive Gain Integrating Pixel Detector



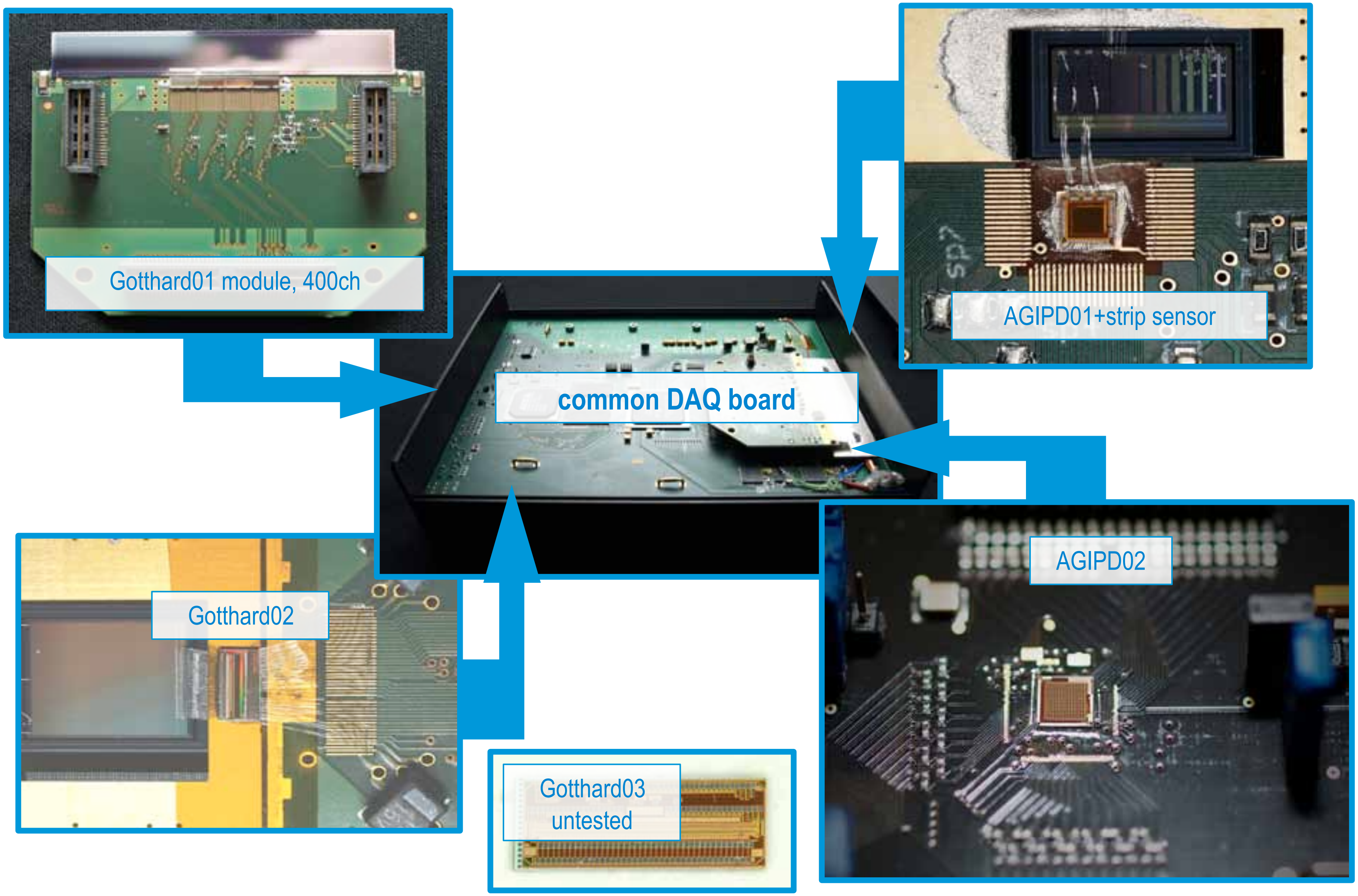
- 200x200mm^2 pixel size
- 64x64 pixels per chip
- 8 chip/module,
- 1024x1024 total pixel count

Solution for the bunch train problem:

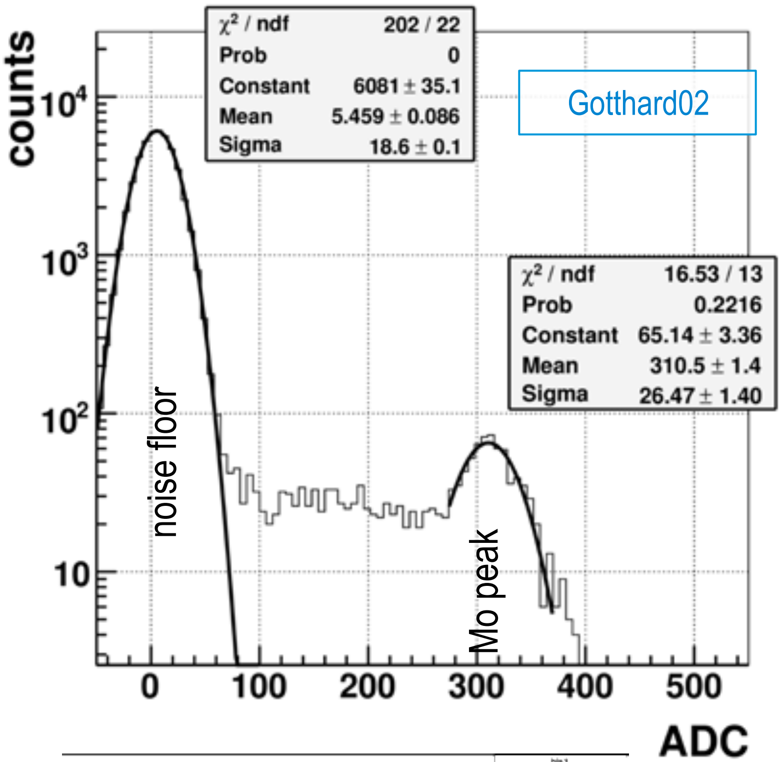
- ~200 on-pixel storage cells
- Storage cell access logic allowing to overwrite bad frames

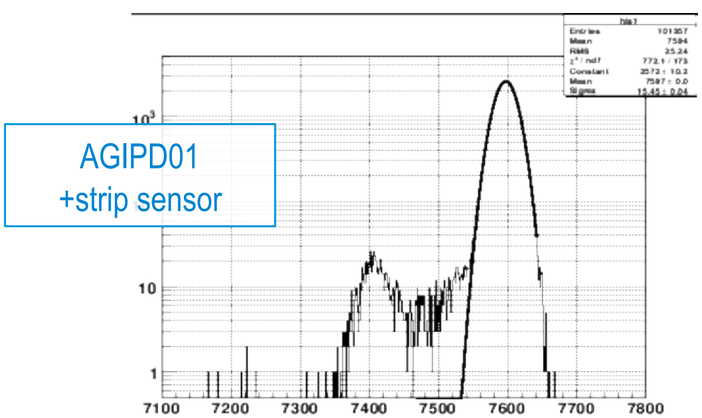
AGIPD — PAUL SCHERRER INSTITUT PSI — universitätbonn — UH Universität Hamburg — DESY

Prototypes


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

Noise measurements

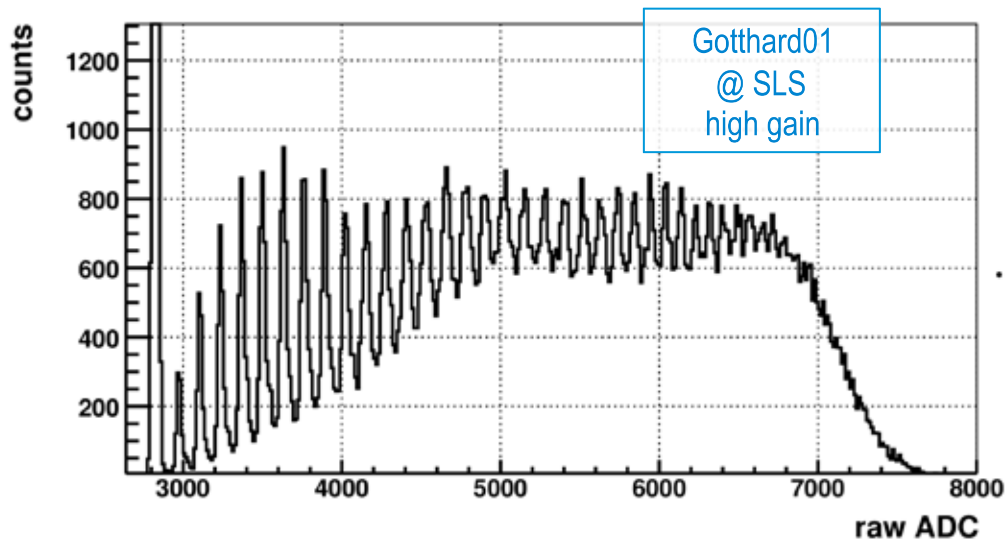


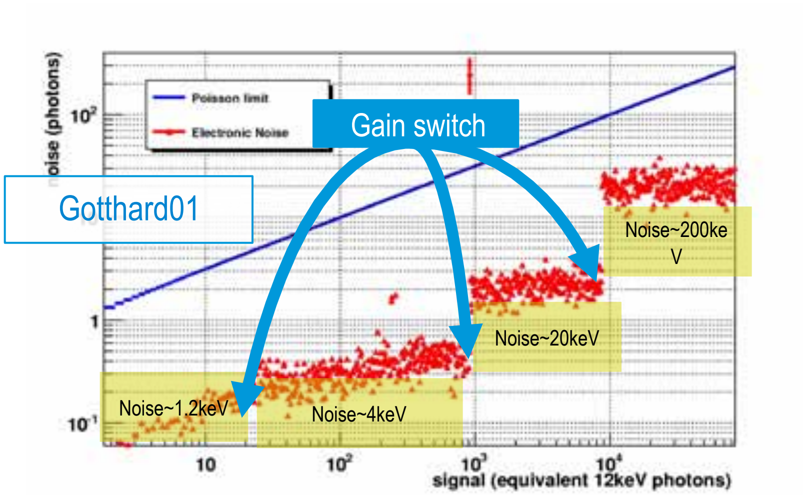


- Noise performance at the highest gain measured with X-ray (Mo fluorescence peak=17.4keV)
  - 295 e^- r.m.s. noise
  - implies single photon resolution down to a few keV
  - strip capacitance ~ 1pF
  - @ room temperature
- Similar result for AGIPD
  - ~300 e^- r.m.s. noise after correction for the capacitive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

Noise – many photons

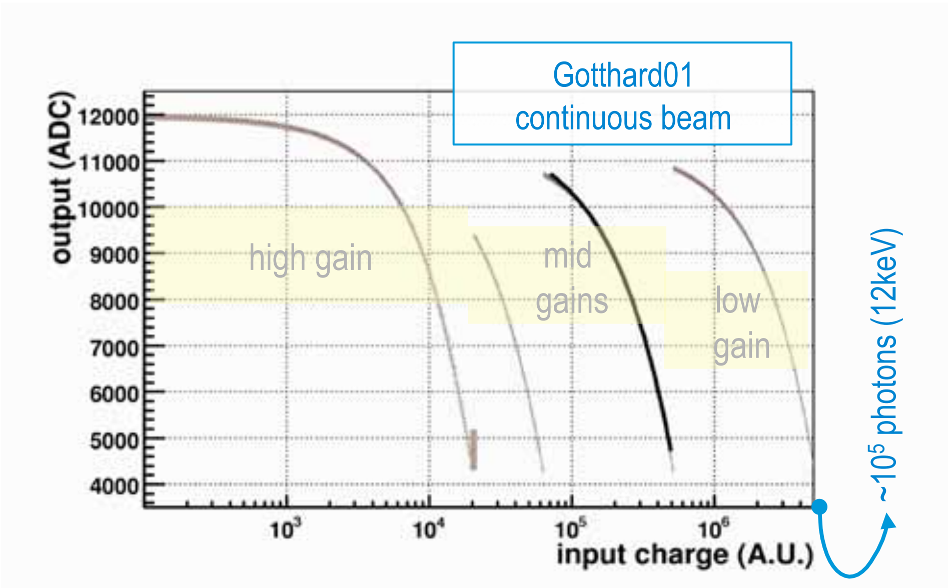
- To avoid charge sharing, a 10um beam was collimated in the center of the channel
- up to 40 photons peaks are visible (@17.5keV energy) in the P.H. distribution
- integration system can "count" photons





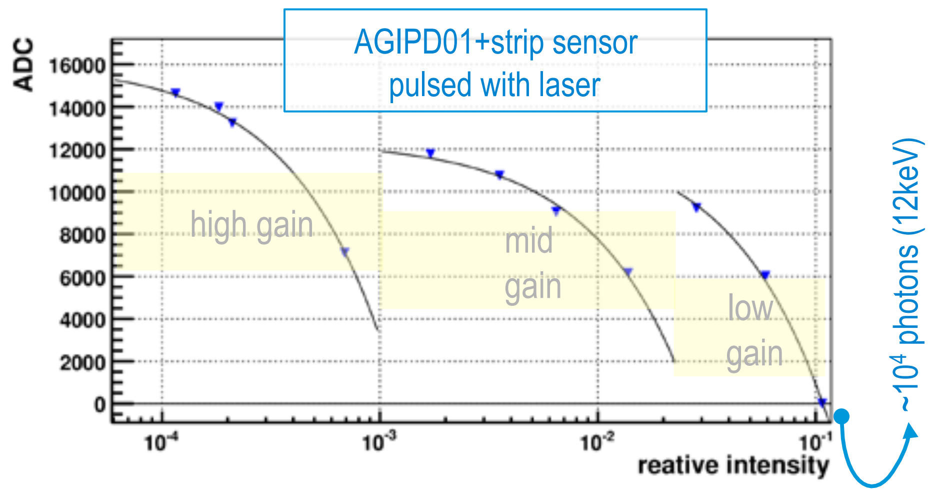
- an integration time scan at constant current was used to evaluate the noise at low gains
- at all gains the electronic noise is well below the Poisson level

Switching gain functionality



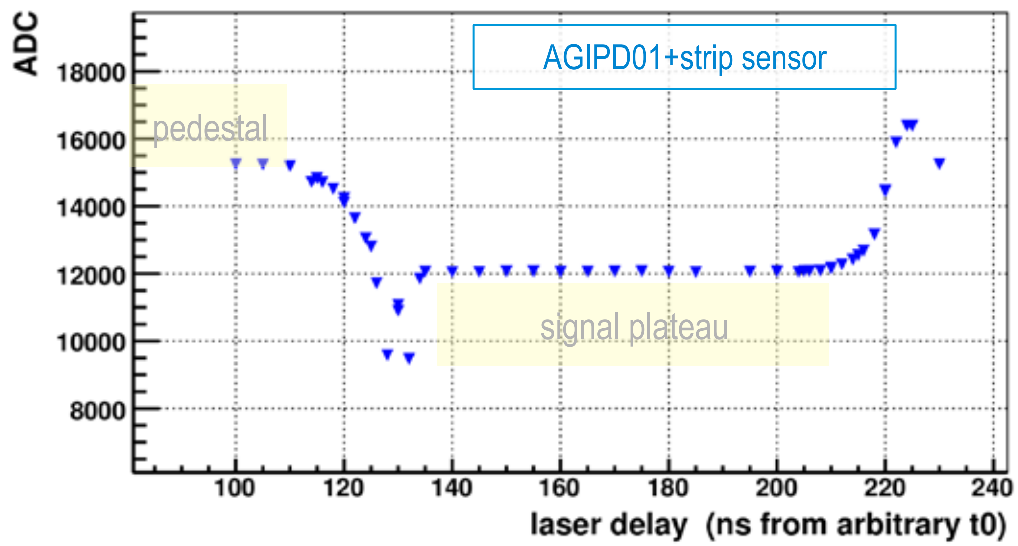
- Gotthard01 switching was tested with constant current
- non-linearity ~3% due to output buffer

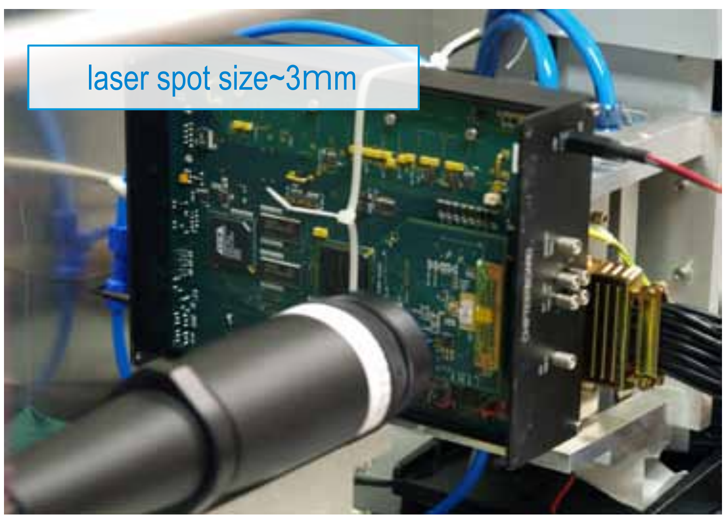
- on AGIPD01 the switching was tested with a subnanosecond laser pulse hitting the strip sensor
- Switching works at the required speed



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

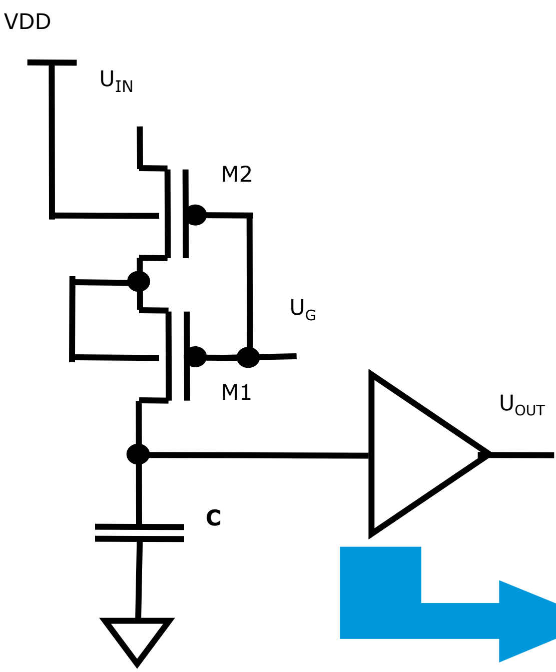




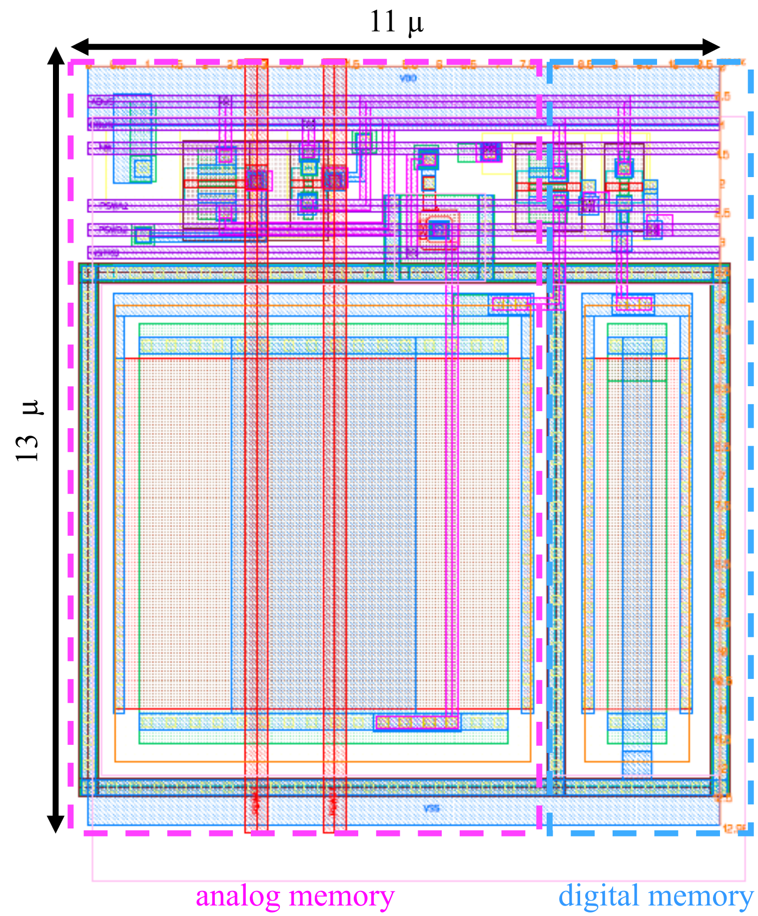
- similar result with or without automatic gain switching
- the preamplifier+switching circuitry can work at E-XFEL rates (4.5MHz)

AGIPD Memory cell

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

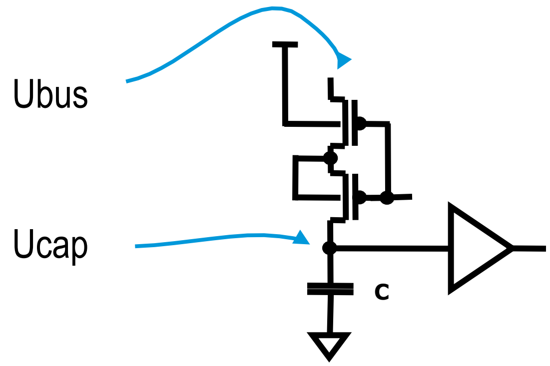


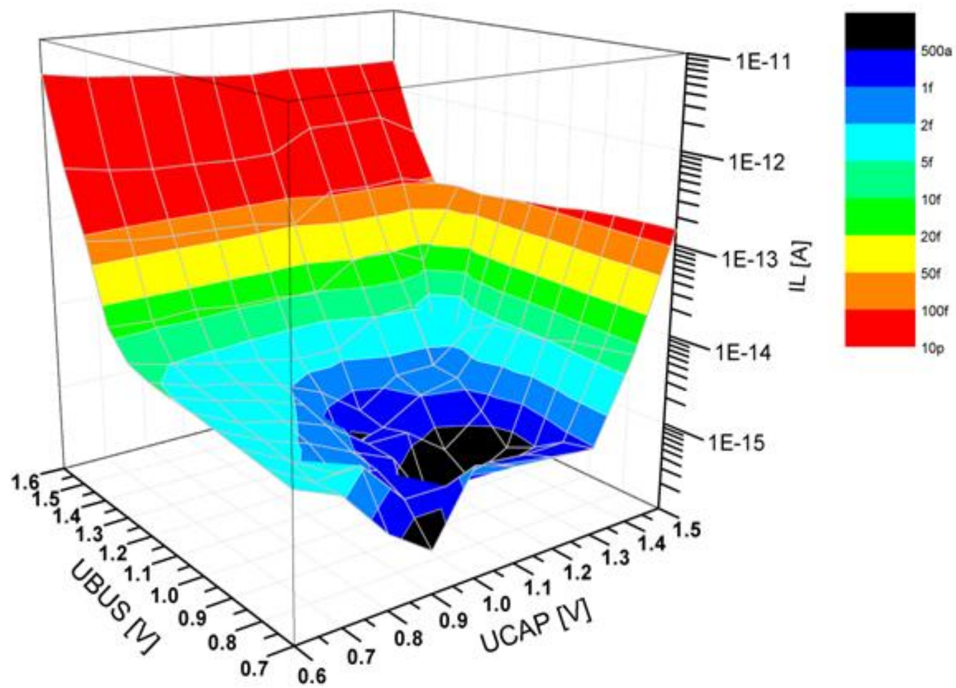
buffer for leakage meas.
not in final cell



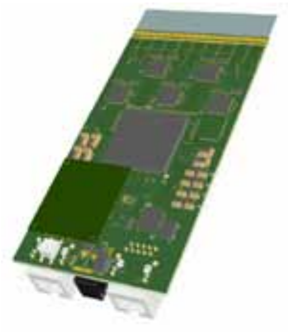
Memory cell characterization

- 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 in November 10

Conclusions I

•Mythen working well for PD, used for >90% of PD measurements

•PilatusII routinely used at PX, cSAX, faster measurement and better data quality

•EIGER well on track:

- Readout chip main features:
  - smaller pixels (75x75 μm^2)
  - frame rates up to ~ 24 kHz
  - almost dead time free readout (<3µs)
  - Noise (sigma): ~650 eV (180 e-)
  - Minimum threshold: ~4.5 keV (1250e-)
  - Threshold dispersion (sigma) : ~70 eV (20 e-)

First prototype modules by the end of this year
4M next year
16M 2012 (protein crystallography)

Conclusions II

- 1D and 2D charge integrating detectors are needed for the XFEL-based experiments
- several prototypes of 1D and 2D have been built and tested:
  - 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

- to do:
  - Testing of radiation hardness
  - Testing of reliability at >10^4 photons

future work

- decision about Swissfel end 2011
    - 75 μm integrating dynamic gain switching pixel detector
    - also smaller pixels with smaller dynamic range

SLS Detector Group

Starting soon:

- 1 technician and 1 engineer
- 1 Post-doc for AGIPD
- 1 Post-doc for Eiger

Acknowledgments

A.Mozzanica, A. Bergamaschi, R. Dinapoli, B. Henrich, Gerd Theidel, Elmar Schmitt

I. Johnson, B. Schmitt and X. Shi

Paul Scherrer Institut, 5232 Villigen, CH

J. Becker, H. Graafsma, F. Tian, U. Trunk

DESY, 22607 Hamburg, DE

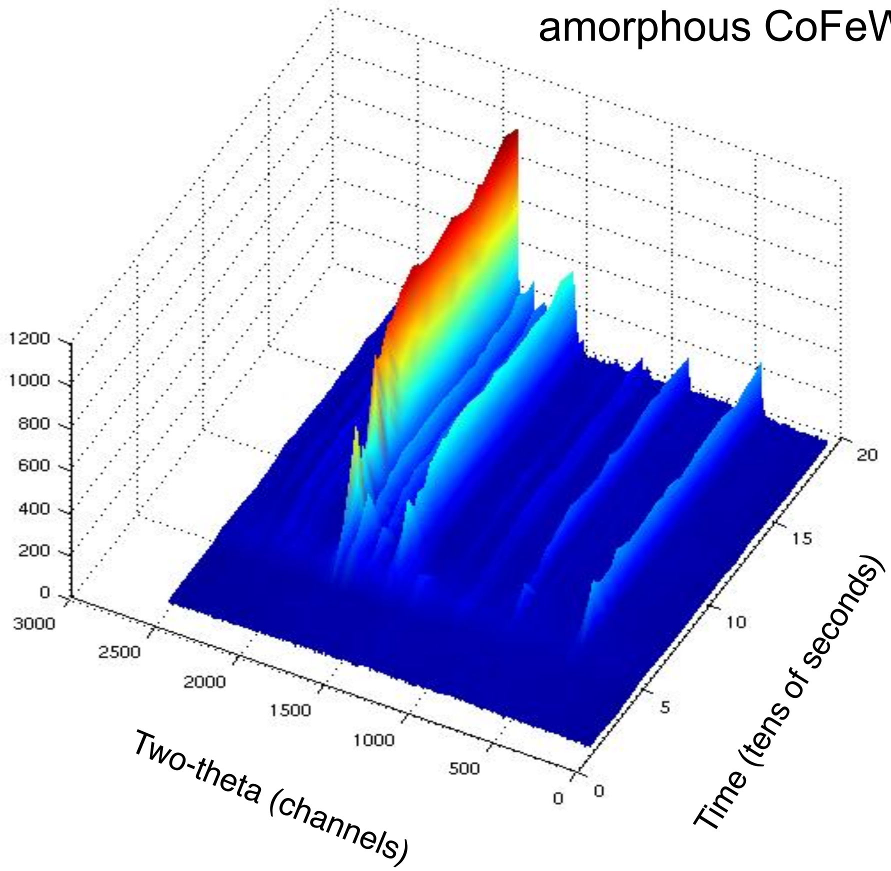
M. Gronewald, H. Krüger

University of Bonn, DE

Thank You!

Crystallization of Co-rich alloys under micro wave field

amorphous CoFeWB ⇨ Co(Fe) + $Co_{21}B_6W_2$



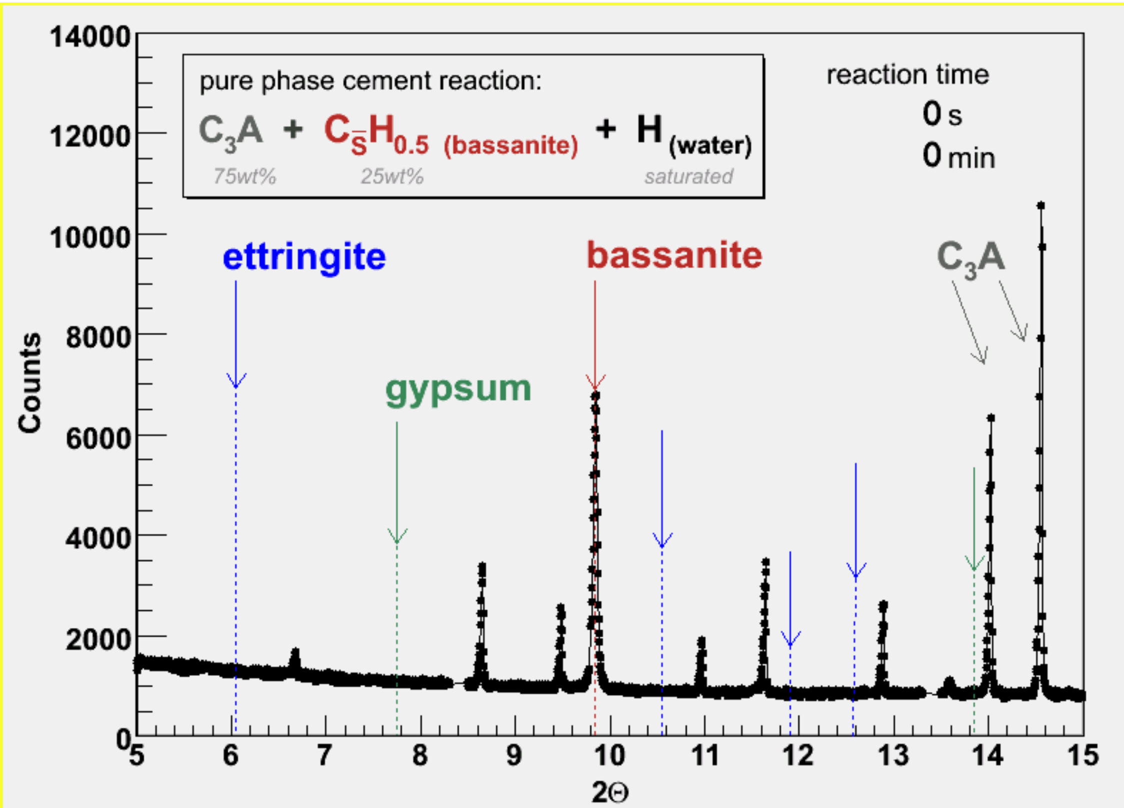
Co-rich amorphous alloys for stable high temperature use as soft-magnetic nanomaterials

Single-pulse microwave field application

One-step nanocrystallization.

Courtesy of S. Vaucher, EMPA Thun

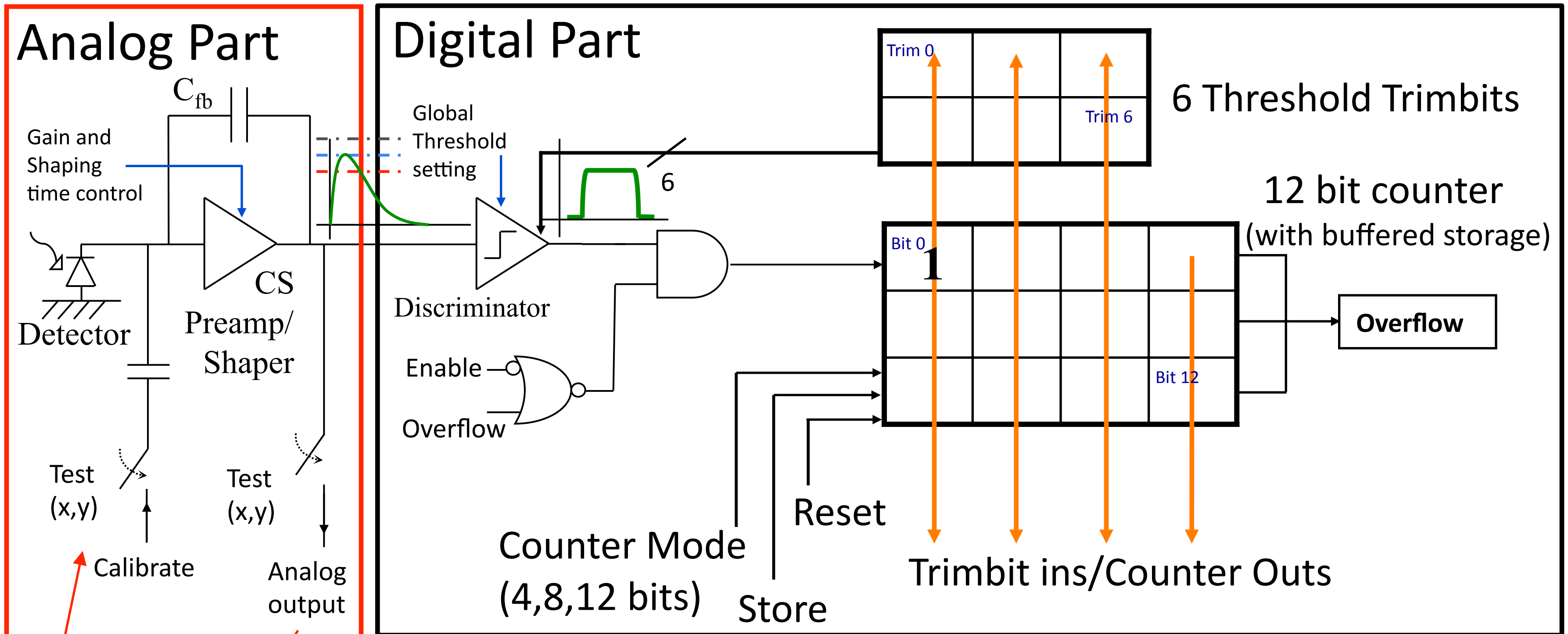
Early Hydration of cement

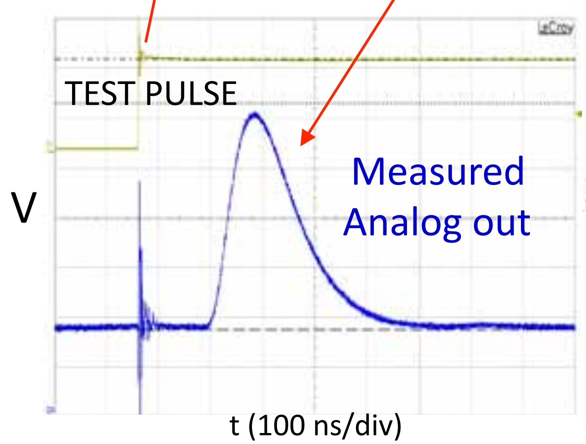


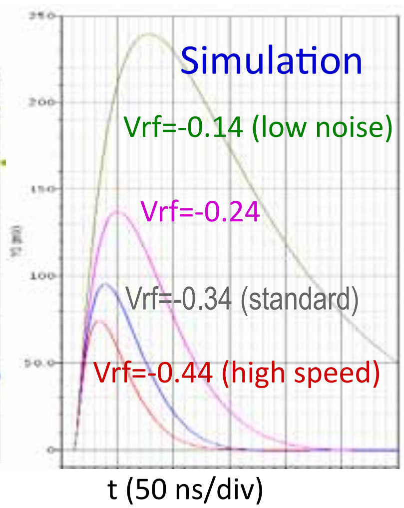
- The reaction is started injecting water using a syringe
- It should be monitored for several hours (second resolution)

I. Mueller (Uni Muenster)

The EIGER pixel

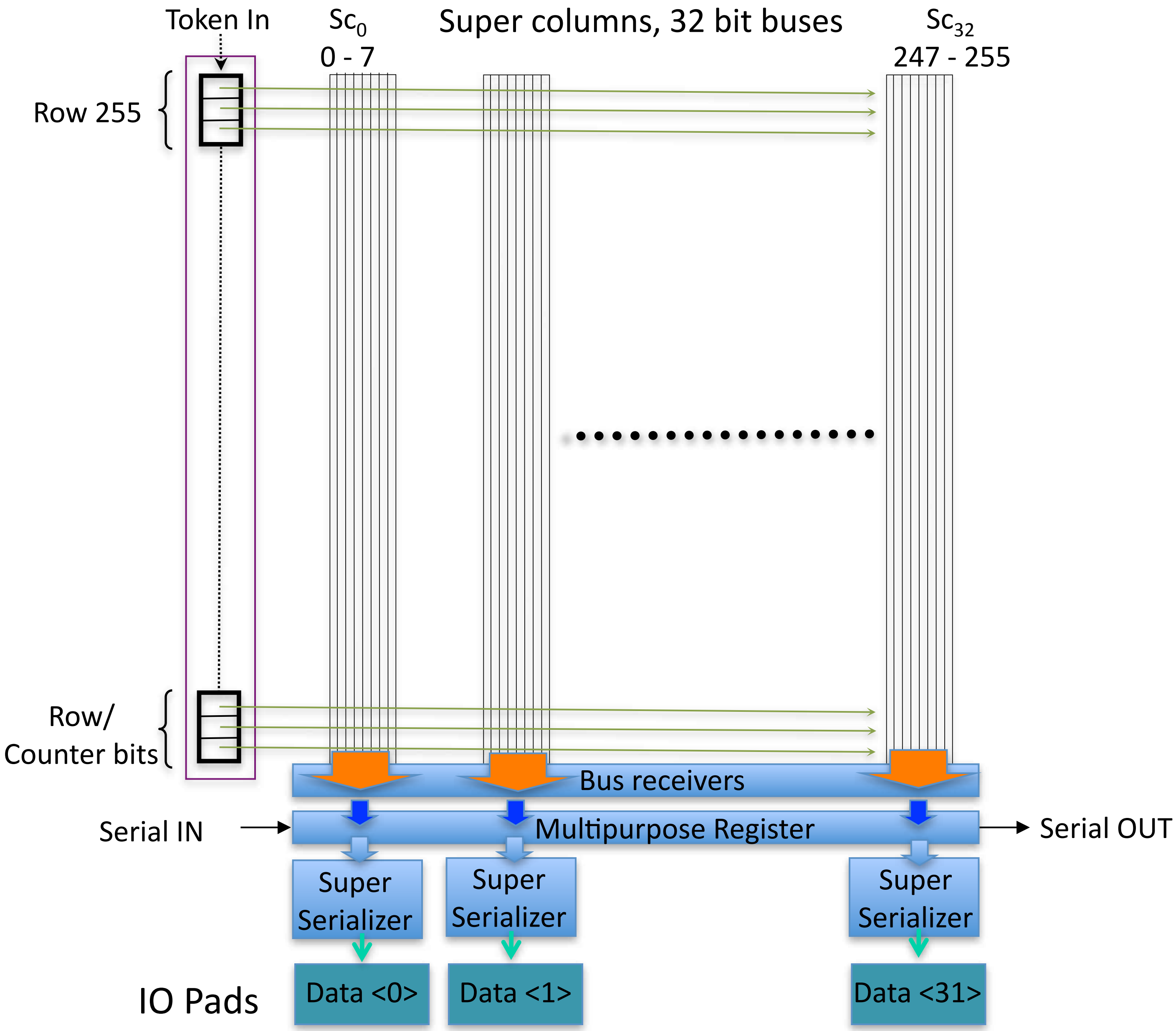






Gain	**44.6 µV/e-**
Timing	**151 ns (Ret.to 0 @ 1%)**
Noise (simul.)	**135 e-rms**
Static power	**8.8 µW/pixel (~0.6W/chip)**
Pixel counter	**12 bits, binary, double buffered (cont. readout), configurable (4,8,12 bit mode)**
Threshold adj.	**6 bit DAC/pixel**

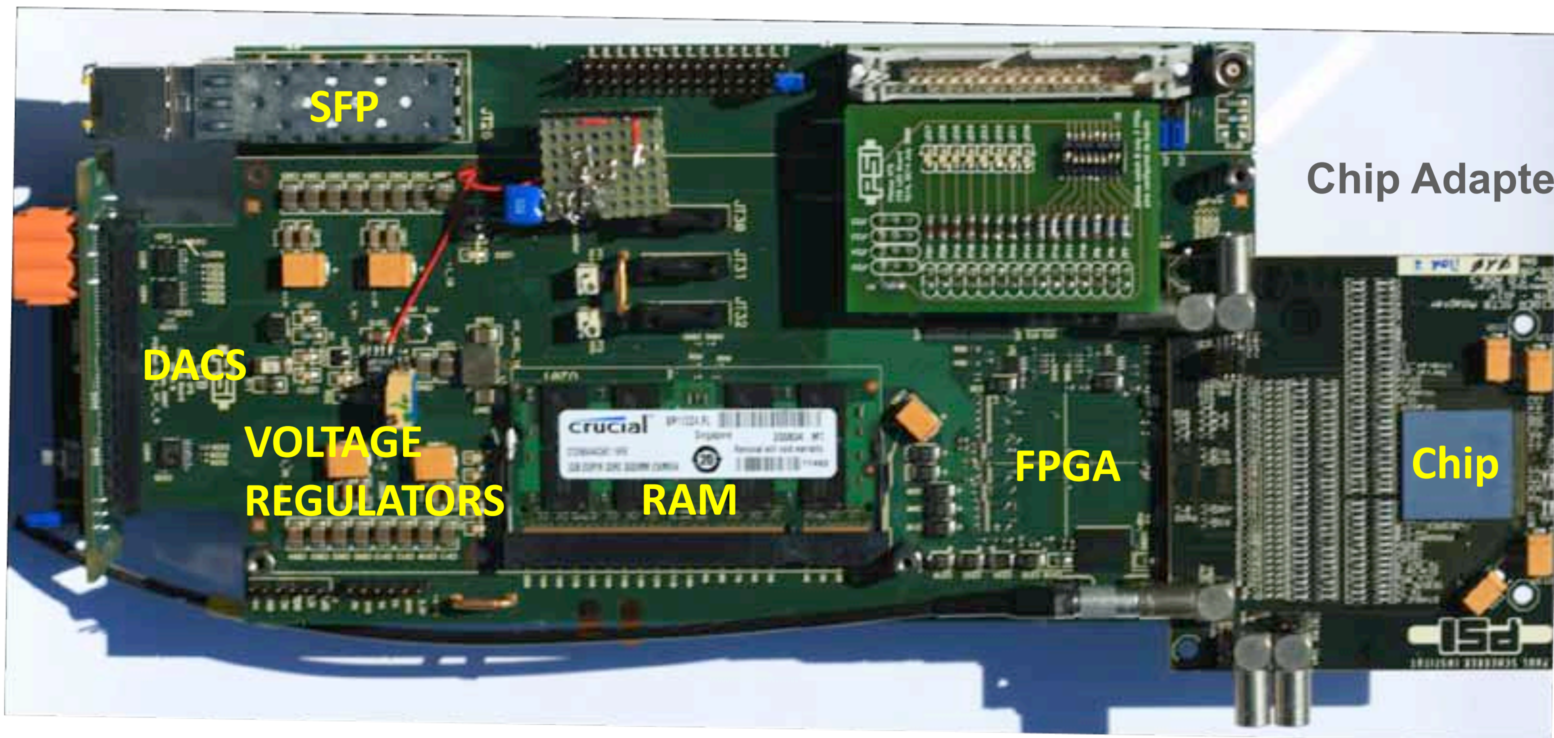
EIGER readout architecture



Single chip test setup

Pattern generator
Python scripts
Full Detector control GUI

1Gb Ethernet Data Link



Chip Adapter Board

2GBytes DDR RAM

EIGER Single Chip Detector

The SLS detector group

SLS Detectors

Bernd Schmitt

Mythen

Bernd Schmitt
Anna Bergamaschi

Operate, Maintain and improve

Pilatus

Beat Henrich,

Operate and Maintain.
New Sensor Materials

Eiger

Beat Henrich,
Roberto Dinapoli,
Ian Johnson,
Christian Ruder,
PSI Electronics Group

AGIPD

Bernd Schmitt,
Beat Henrich,
Xintian Shi,
Roberto Dinapoli

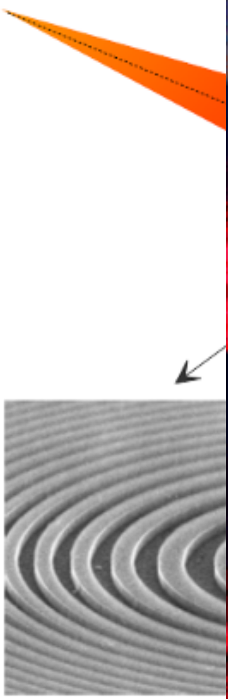
Collaboration

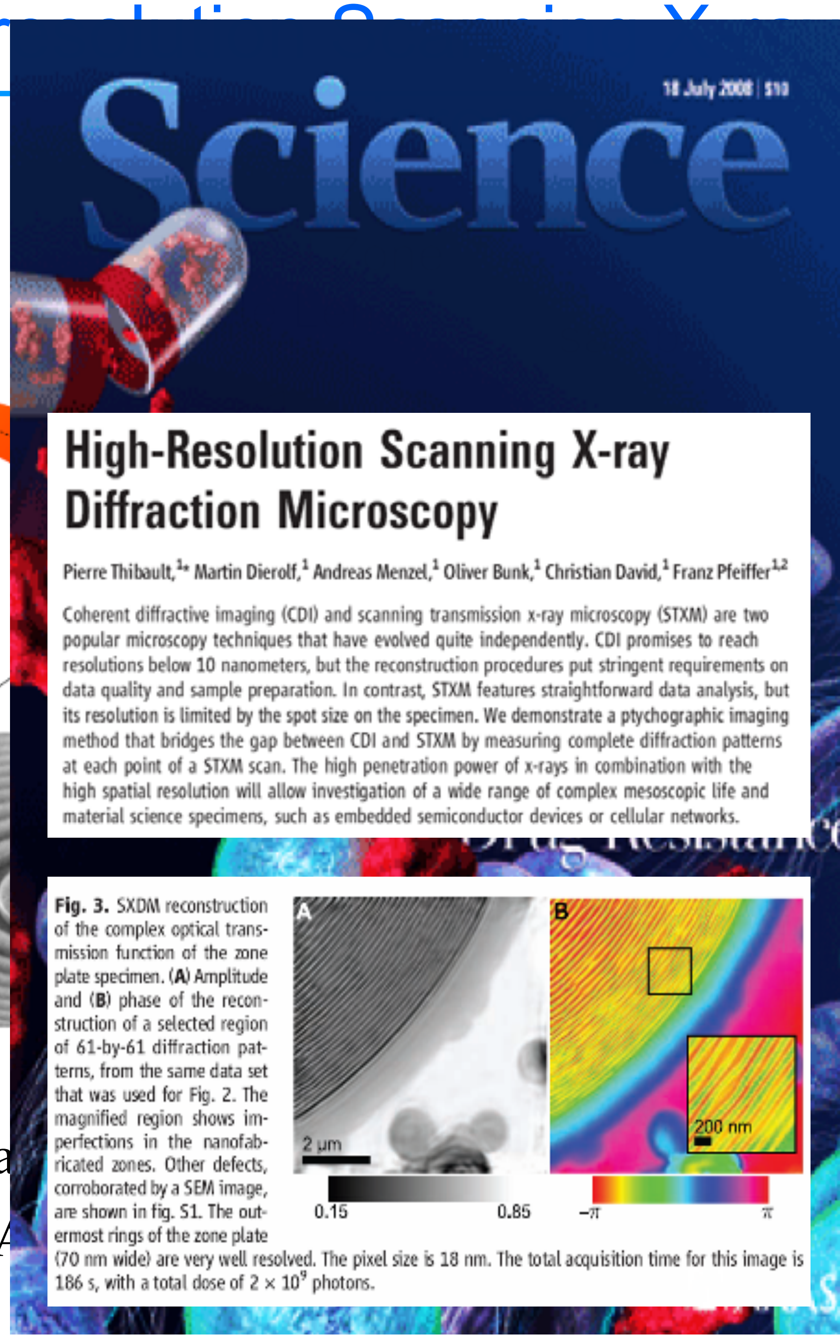
GOTTHARD

Bernd Schmitt,
Aldo Mozzanica,
Anna Bergamaschi

Analog Detector Design

High r … diffraction





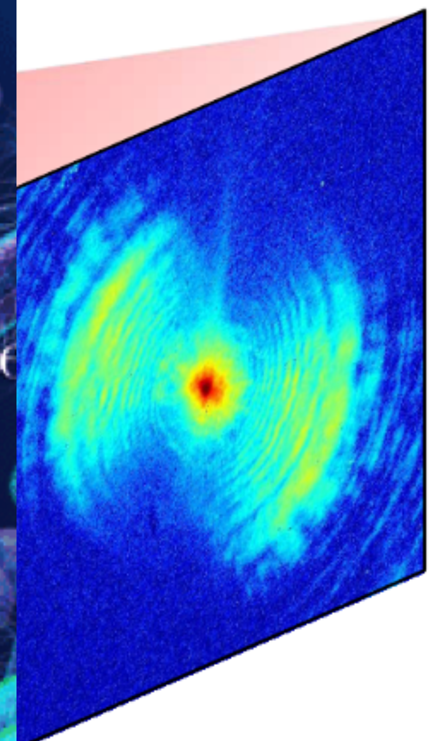
Science
18 July 2008 | $10

High-Resolution Scanning X-ray Diffraction Microscopy

Pierre Thibault,[1*] Martin Dierolf,[1] Andreas Menzel,[1] Oliver Bunk,[1] Christian David,[1] Franz Pfeiffer[1,2]

Coherent diffractive imaging (CDI) and scanning transmission x-ray microscopy (STXM) are two popular microscopy techniques that have evolved quite independently. CDI promises to reach resolutions below 10 nanometers, but the reconstruction procedures put stringent requirements on data quality and sample preparation. In contrast, STXM features straightforward data analysis, but its resolution is limited by the spot size on the specimen. We demonstrate a ptychographic imaging method that bridges the gap between CDI and STXM by measuring complete diffraction patterns at each point of a STXM scan. The high penetration power of x-rays in combination with the high spatial resolution will allow investigation of a wide range of complex mesoscopic life and material science specimens, such as embedded semiconductor devices or cellular networks.

Fig. 3. SXDM reconstruction of the complex optical transmission function of the zone plate specimen. (**A**) Amplitude and (**B**) phase of the reconstruction of a selected region of 61-by-61 diffraction patterns, from the same data set that was used for Fig. 2. The magnified region shows imperfections in the nanofabricated zones. Other defects, corroborated by a SEM image, are shown in fig. S1. The outermost rings of the zone plate (70 nm wide) are very well resolved. The pixel size is 18 nm. The total acquisition time for this image is 186 s, with a total dose of 2×10^9 photons.



- Fresnel
  - x-ra
- Experiment at cSA
  energy 6.8 keV

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

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