PAUL SCHERRER INSTITUT

PSI

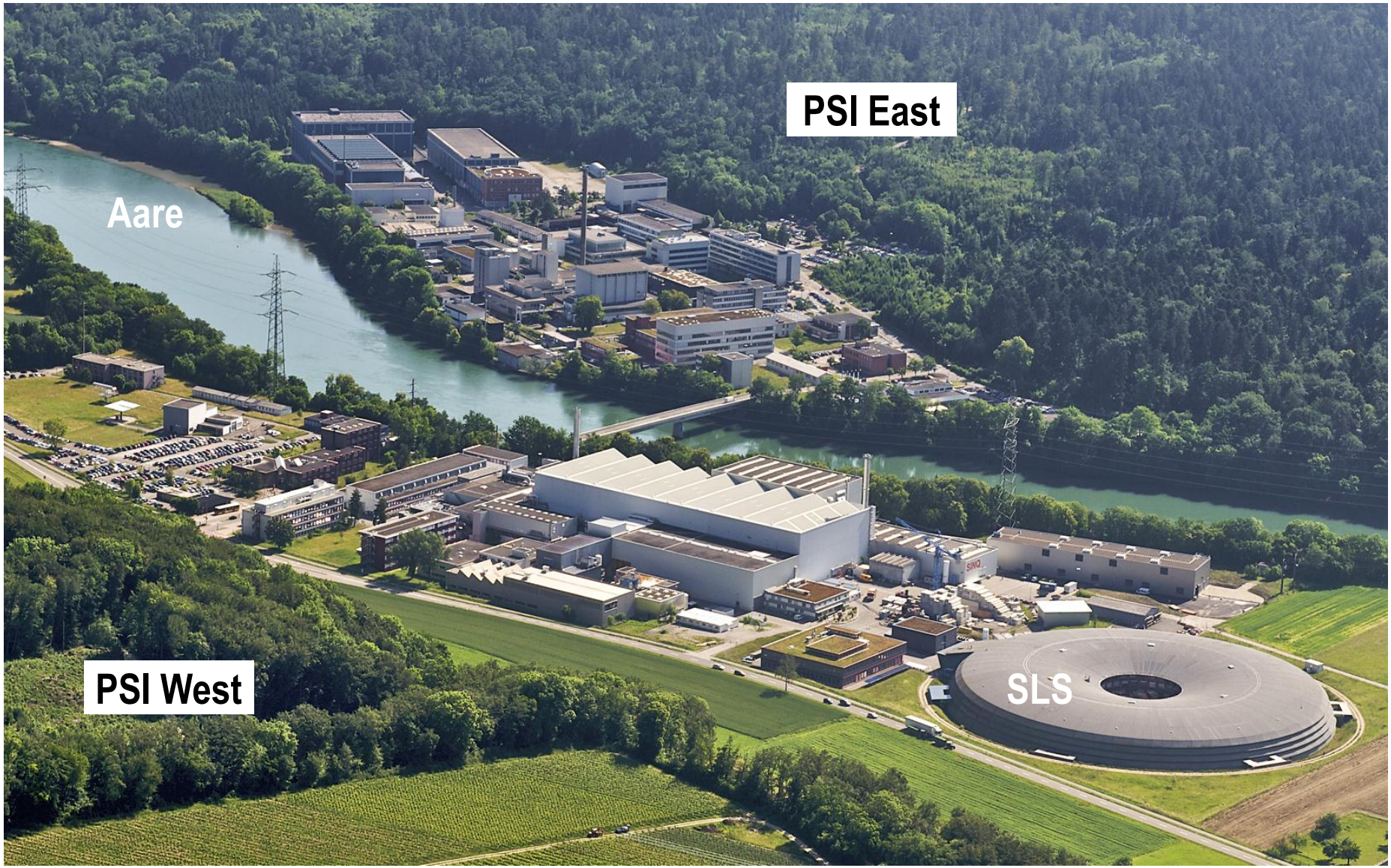
Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

Bernd Schmitt

Pixel detector Developments for Synchrotrons and XFELs

PAUL SCHERRER INSTITUTE



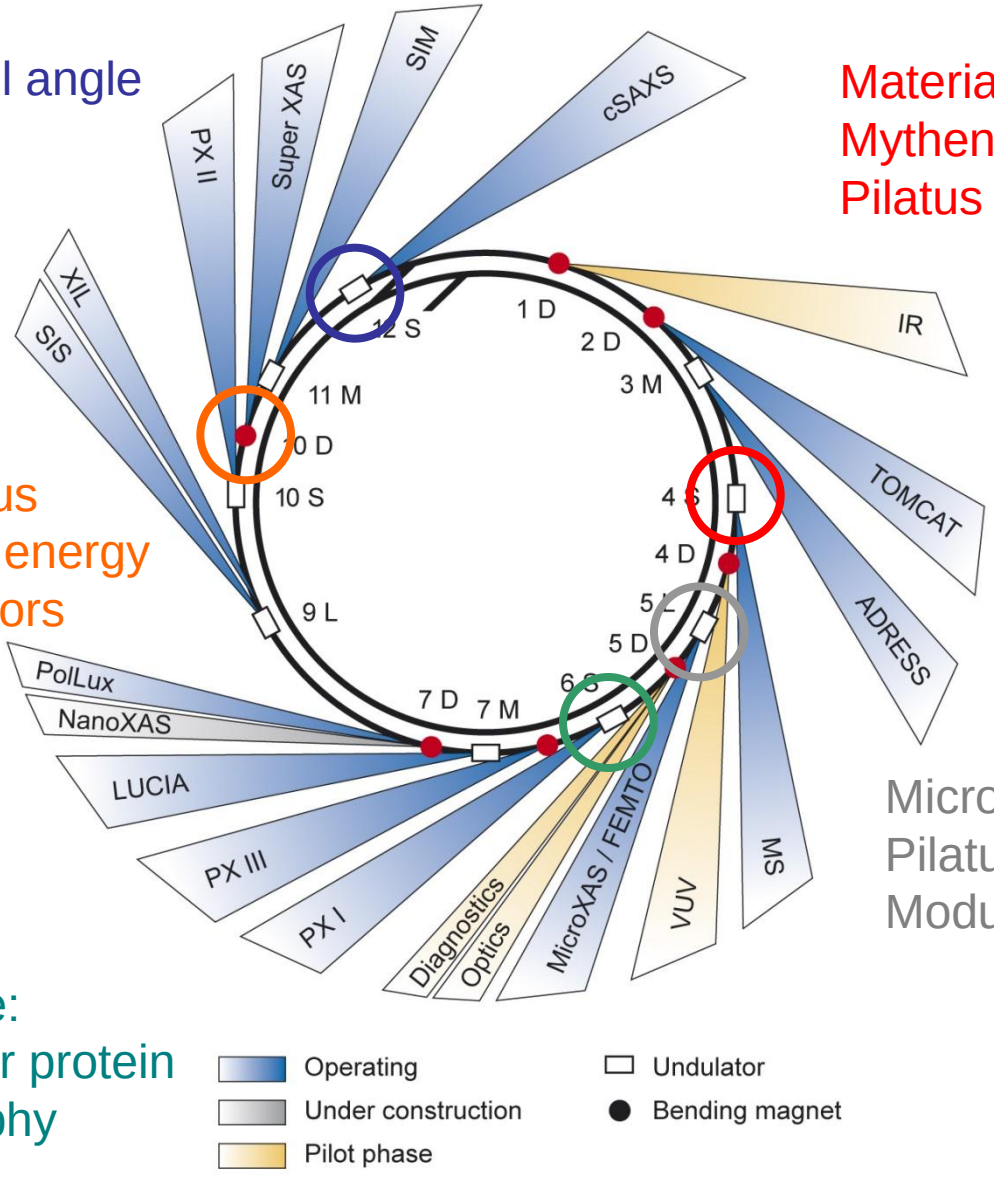
~1500 Staff employees; 30Km from Zurich, task in ETH domain: run large scale facilities

Beamlines and Detectors at the Swiss Light Source

CSAX beamline:
Pilatus2M for small angle scattering

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

Super XAS:
Mythen and Pilatus
with Si-crystal as energy
Dispersive detectors



MicroXAS/Femto:
Pilatus and Mythen single Module Systems

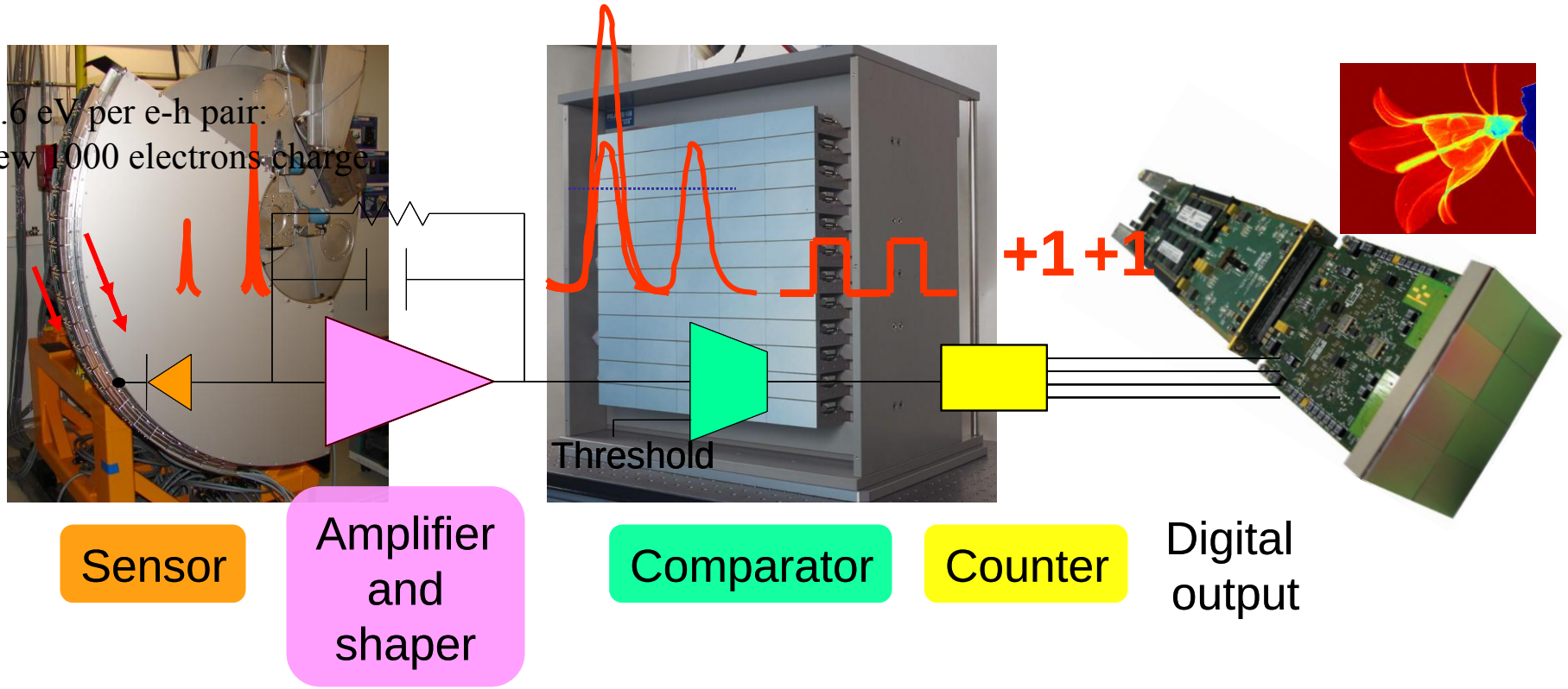
PX beamline:
Pilatus6M for protein crystallography

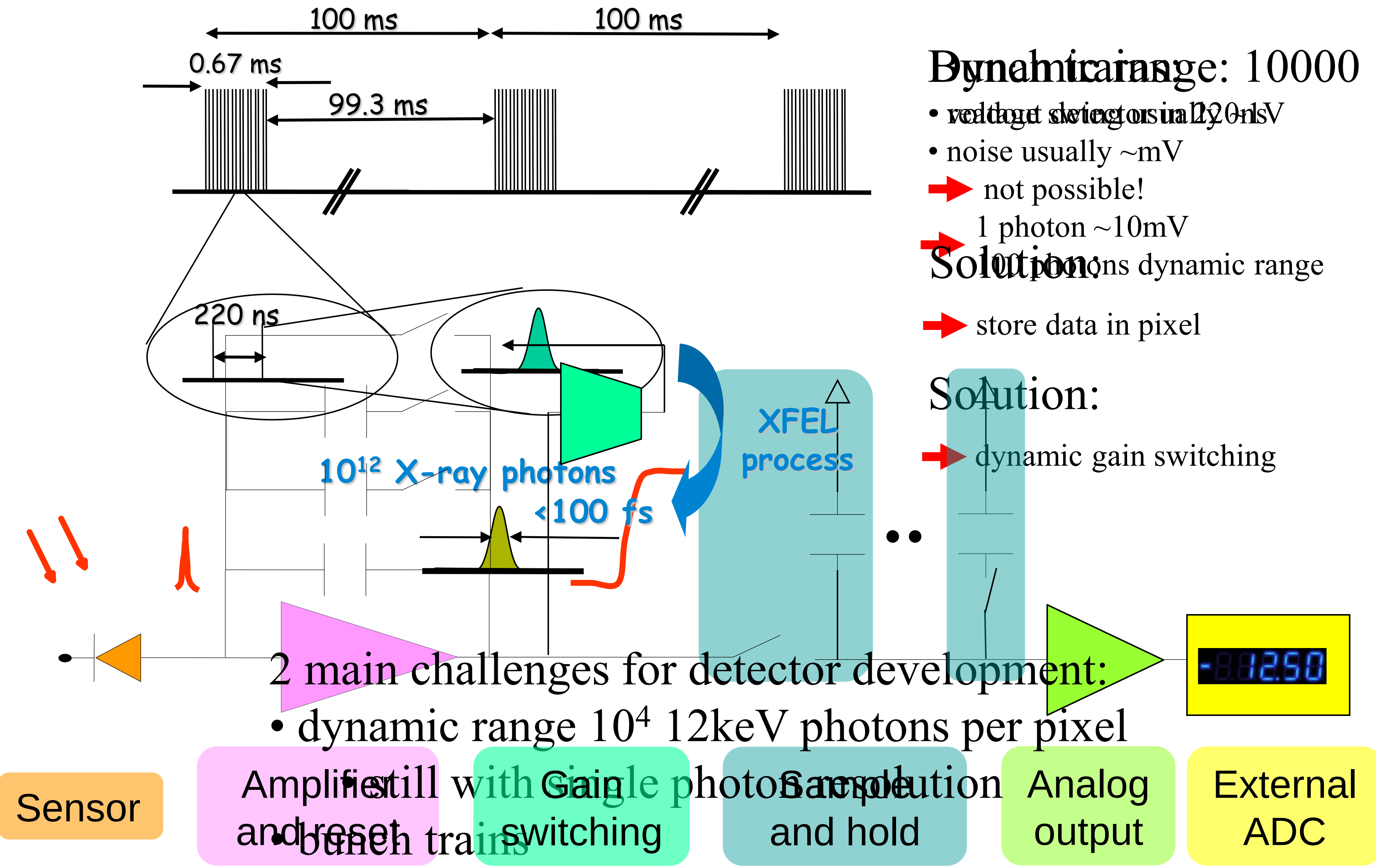
From single photon counting hybrid detectors for synchrotrons…

MYTHEN
1k to 30k 50µm strips for powder diffraction, small angle scattering, medical imaging…

PILATUS
100k to 6M 172µm pixels for protein crystallography, small angle scattering, imaging …

EIGER
500k to 9M 75µm pixels, for small angle scattering, CDI, XPCS, protein crystallography, imaging ....





Bunch trains

Dynamic range: 10000

- readout detector in 220 ns
- voltage swing usually ~1V
- noise usually ~mV

➔ not possible!

1 photon ~10mV

➔ 100 photons dynamic range

Solution:

➔ store data in pixel

Solution:

➔ dynamic gain switching

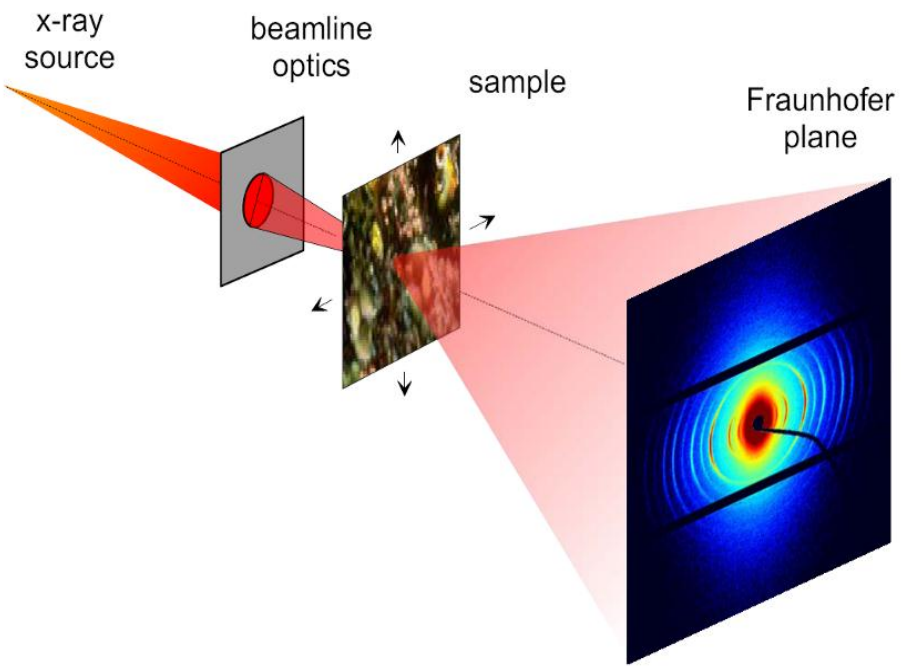
2 main challenges for detector development:

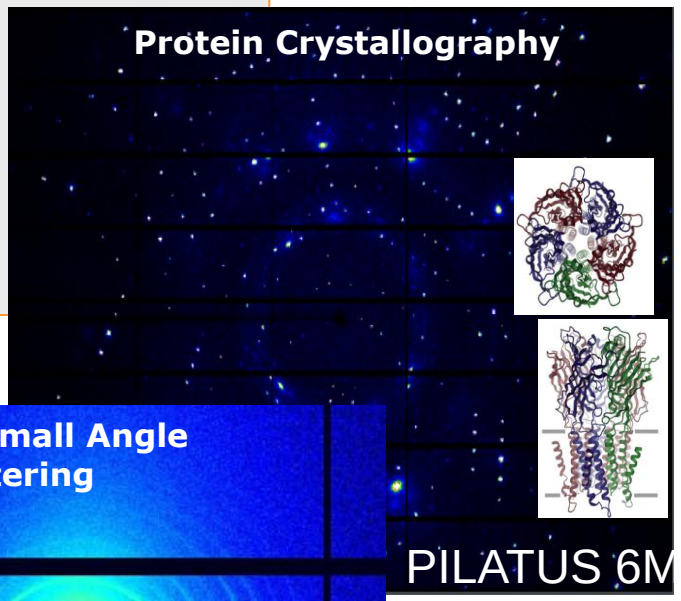
- dynamic range 10^4 12keV photons per pixel
- still with single photon resolution
- bunch trains

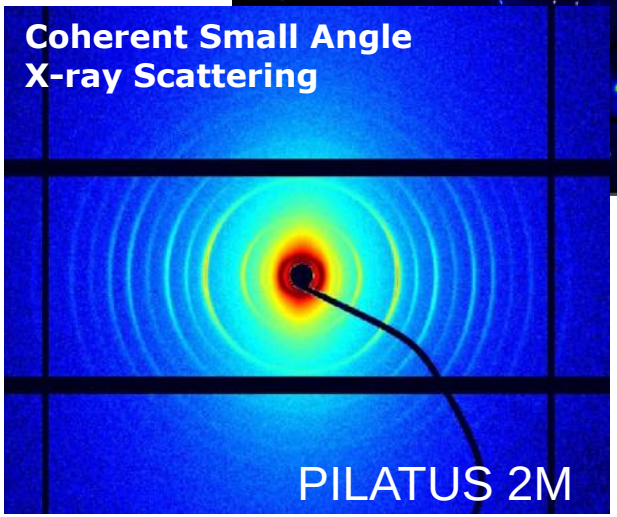
Applications of single photon counting detectors at the SLS

Single photon counting hybrid pixel detectors for synchrotron applications are aimed towards diffraction experiments

- Applications at CSAXs:
  - Scanning Coherent Small Angle X-ray Scattering
  - Coherent Diffractive Imaging
  - X-ray Photon Correlation Spectroscopy
- Protein Crystallography







Current Problems for hybrid pixel detectors

Energy Range
- low energies (<1.5keV) limited by noise and cross-talk
- high energies by sensor efficiency (Si) (used up to 40 keV)

Pixel Size:
- Pilatus 172 μm
- ImXpad 130 μm
- Medipix 55 μm (no big systems available yet)
- Eiger 75 μm (soon)

Frame rate:
- for small systems few 100Hz to 1kHz
  (but not for systems of a few Mpixels: few 10Hz)

Limited count rate capability:
- currently a few MHz per pixel

Ideal detector: energy range: 200eV to 150keV
pixel size: 50-75 micron
frame rate: 20-30 kHz
count rate: 20 MHz per pixel

Some applications (low energy XRS) micron resolution
- see presentation by Matthew Soman

New Detector Developments for Synchrotrons

New Developments for soft X-rays:

- Parceval (Desy, STFC, Trieste)
- CCDs + MAPS: P. Denes (LBNL)
- CCDs: L. Strueder (MPI HLL)

New Developments single photon counting:

- Excalibur (Diamond)
- Lambda (Desy)
- Pilatus3 (Dectris)
- SPring8
- Eiger (PSI)

New Developments for XFELS

- LPD (STFC)
- DSSC (HLL MPI, Uni Heidelberg)
- Agipd (DESY, PSI, Uni Hamburg, Bonn)
- Gotthard and Jungfrau (PSI)
- Sophias (Riken, Sacla)
- CSPAD (LCLS, Cornell)

Improvements

New Developments for soft X-rays:

- Parceval (Desy, STFC, Trieste) — low energies monolithic MAPS
- CCDs + MAPS: P. Denes (LBNL)
- CCDs: L. Strueder (MPI HLL)

New Developments single photon counting:

- Excalibur (Diamond) — small pixel
- Lambda (Desy) — small pixel, high energies
- Pilatus3 (Dectris) — high count rate
- SPring8 — high energies
- Eiger (PSI) — small pixels, high frame rate

New Developments for XFELS

- LPD (STFC)
- DSSC (HLL MPI, Uni Heidelberg)
- Agipd (DESY, PSI, Uni Hamburg, Bonn) — single bunches
- Gotthard and Jungfrau (PSI) — small pixels, high intensity
- Sophias (Riken, Sacla) — monolithic SOI process
- CSPAD (LCLS, Cornell)

Outline

New Developments for soft X-rays:

- Parceval (Desy, STFC, Trieste)
- CCDs + MAPS: P.Denes (LBNL), — see presentation Peter Denes
- CCDs: L. Strueder (MPI HLL)

New Developments single photon counting:

- Excalibur (Diamond)
- Lambda (Desy)
- Pilatus3 (Dectris) — see presentation Clemens
- SPring8 — see presentation Toko
- Eiger (PSI) — see presentation Roberto

New Developments for XFELS

- LPD (STFC)
- DSSC (HLL MPI, Uni Heidelberg)
- Agipd (DESY, PSI, Uni Hamburg, Bonn) — see presentation Alessandro
- Gotthard and Jungfrau (PSI)
- Sophias (Riken, Sacla) — see presentations Takaki Hatsui and Makoto Motoyoshi
- CSPAD (LCLS, Cornell)

Soft X-ray pixel detector

PERCIVAL (Pixelated Energy Resolving CMOS Imager, Versatile and Large)

X-ray Imaging MAPS for (X)FELs and Synchrotrons

- Ongoing development project between DESY, RAL / STFC, and Elettra
- Aim: develop X-ray imager for FLASH & FERMI, soft X-ray beams at PETRA III, ELETTRA, and for the use of CFEL scientists at other facilities
- Sensor developed at RAL, Readout developed by DESY and Elettra
- Project timeline
  - First test circuits expected soon
  - First small backthinned test sensors in hand ~spring 2013
  - First full backthinned system ~ first half 2014

Cornelia Wunderer Desy

Performance Aiming Points

- ~25 μm pixels, 10 cm × 10 cm monolithic active sensor ⇒ 4k × 4k pixel sensor
- 4 sensors can make up 64 Mpixel 20cm x 20cm detector with central hole

- electronic noise < 15e-, dynamic range from single photons to > 10^5 photons
- Primary energy range 250 eV – 1 keV (will work from <200 eV to few keV)
- Back-illuminated, back-thinned for high QE (need >85%, wish >95%)

- 120 Hz frame rate and lower

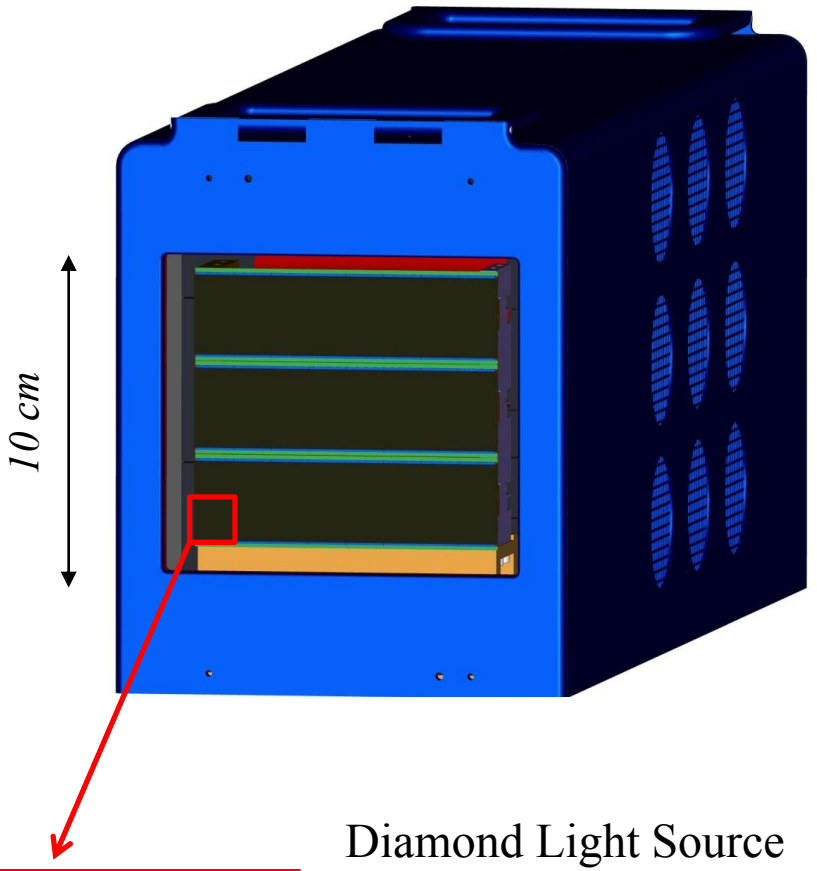
Hybrid single photon counting detectors

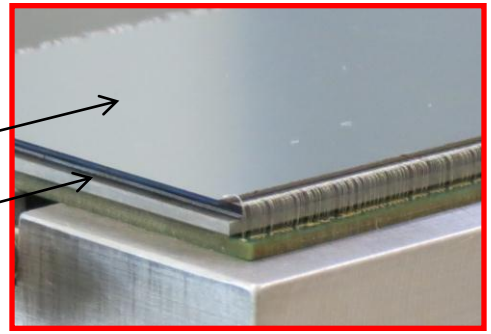
EXCALIBUR

Enhanced **X**-ray **CA**mera for **L**ive **I**maging and **BUR**st mode operation

❖ Application: **Coherent X-ray imaging** on **I13 beamline** at Diamond

Mode	Counting
Pixels	55 µm
Read-out time	500 µs
Sensor	Silicon (300 µm)
Area	11 cm x 10 cm (3M pixels)
ASIC	MEDIPIX3
Frame rate in continuous mode	100 images/s @ 12bit/pixel ~0.6 GBytes/s
Frame rate in « Burst » mode	1000 images/s @ 12bit/pixel ~ 6 GBytes/s towards RAM



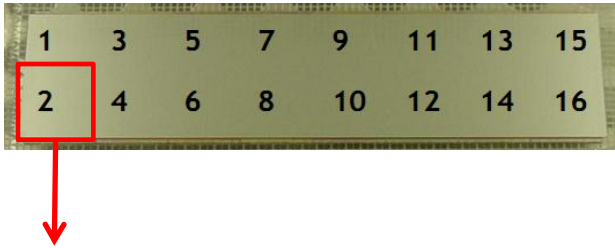


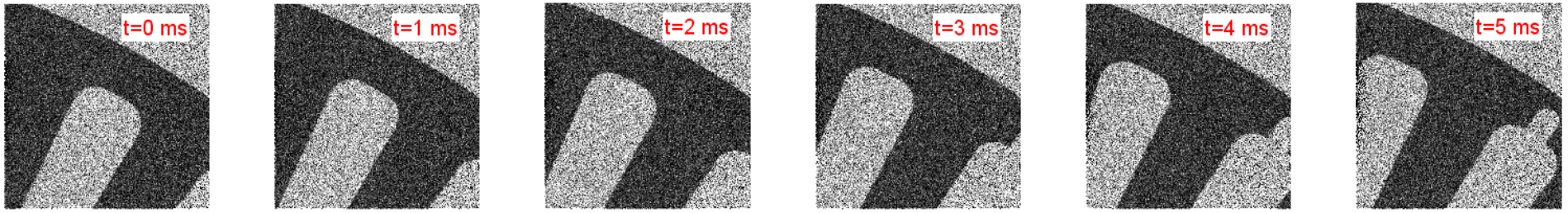
J. Marchal

Diamond Light Source
RAL-STFC project

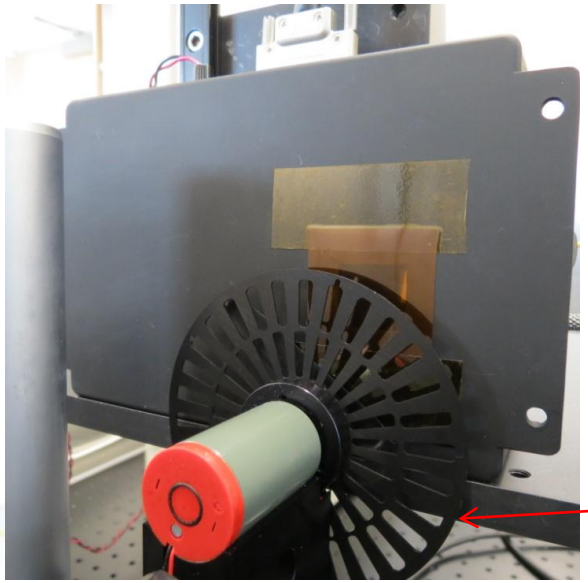
diamond

EXCALIBUR module characterisation





Exposure period: 1 ms
Exposure time: 100 µs



1 kHz frame-rate tested on 1 chip

MERLIN read-out system
Parallel read-out of 8 Data lines
(CLK freq. 120 MHz)

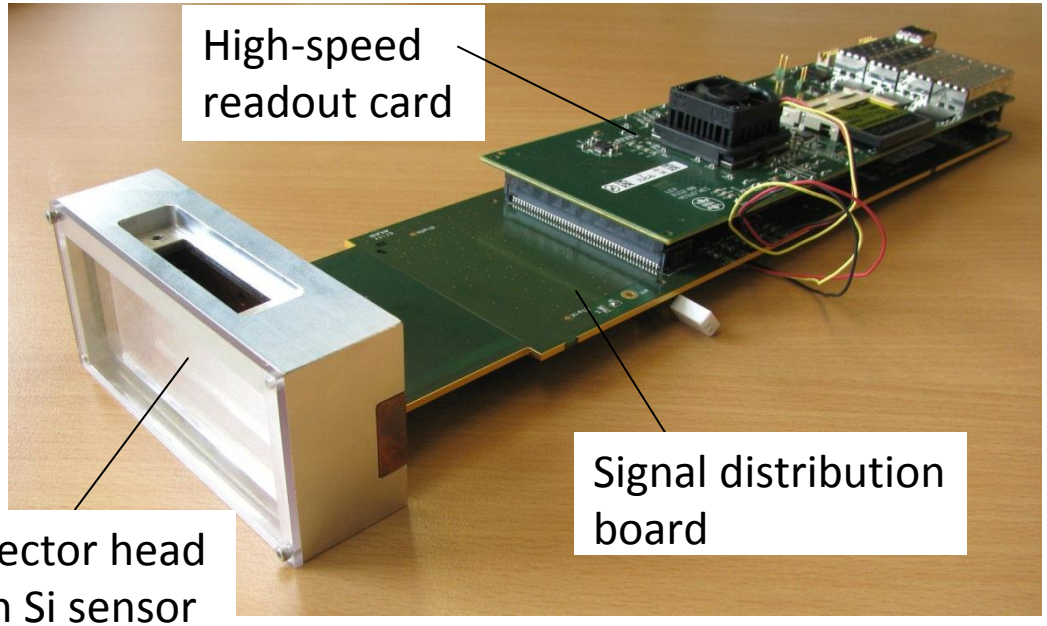
Rotating chopper

diamond

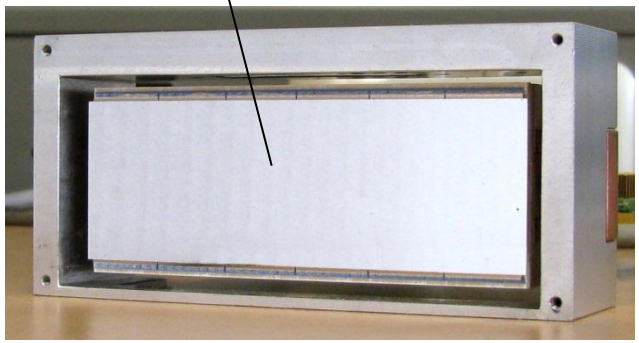
Large Area Medipix-Based Detector Array

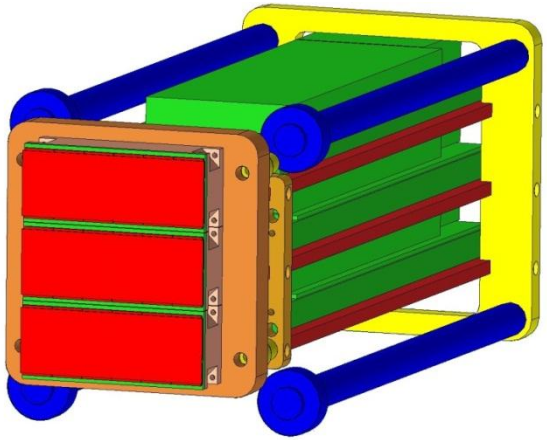
- Photon-counting detector
- Small pixel size (55µm)
- Large, tilable modules (1536 by 512 pixels)
- Fast readout (2 kHz+) in development
- High-Z compatible
  - inc. germanium sensors

D Pennicard

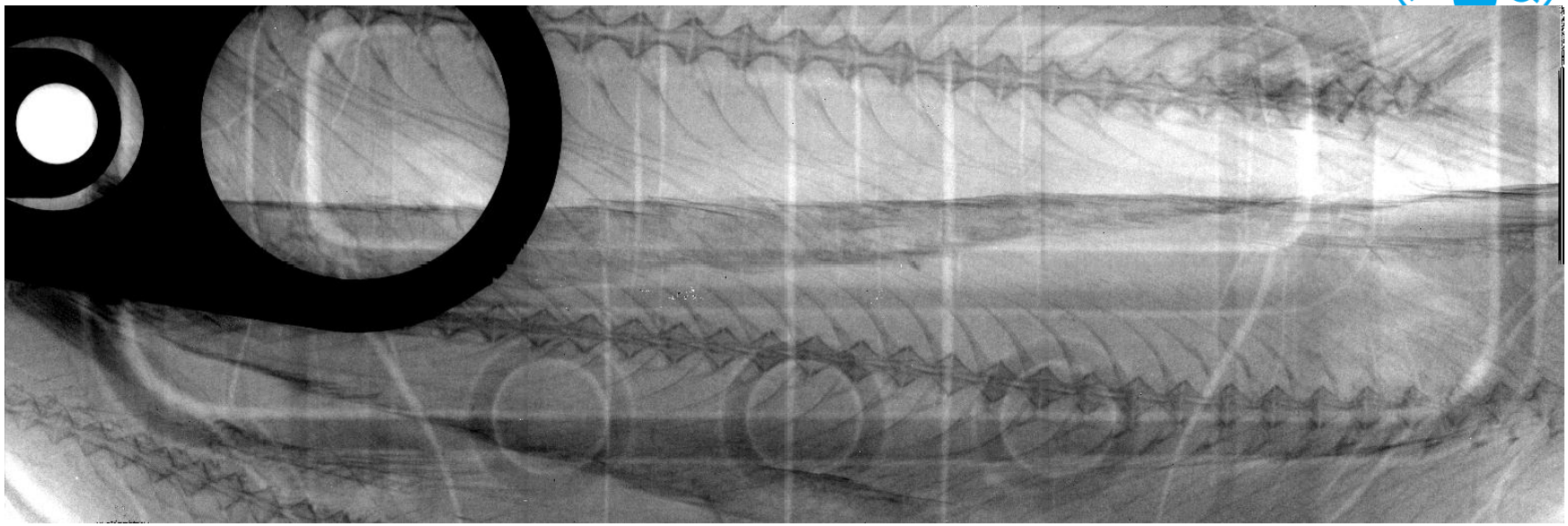


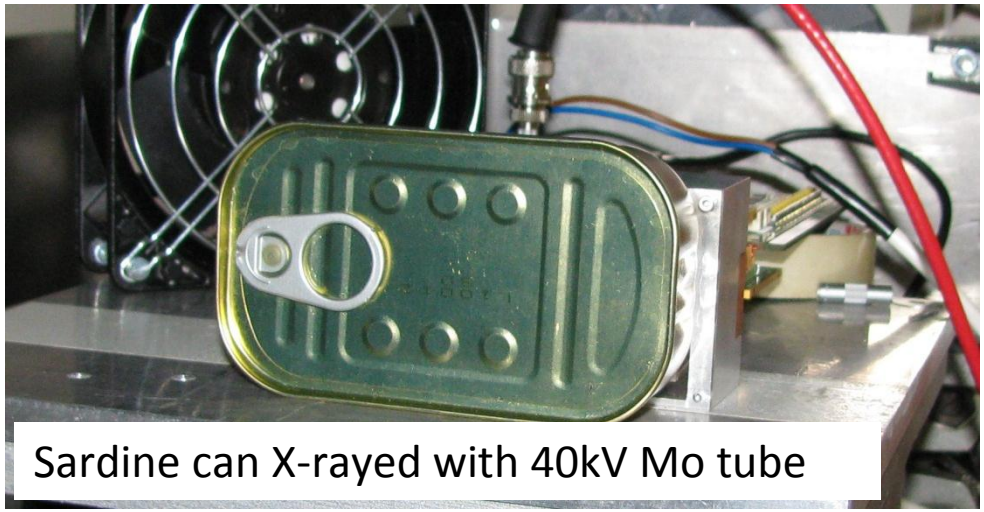
Detector head with Si sensor





Test results with Si sensor (sardine can)



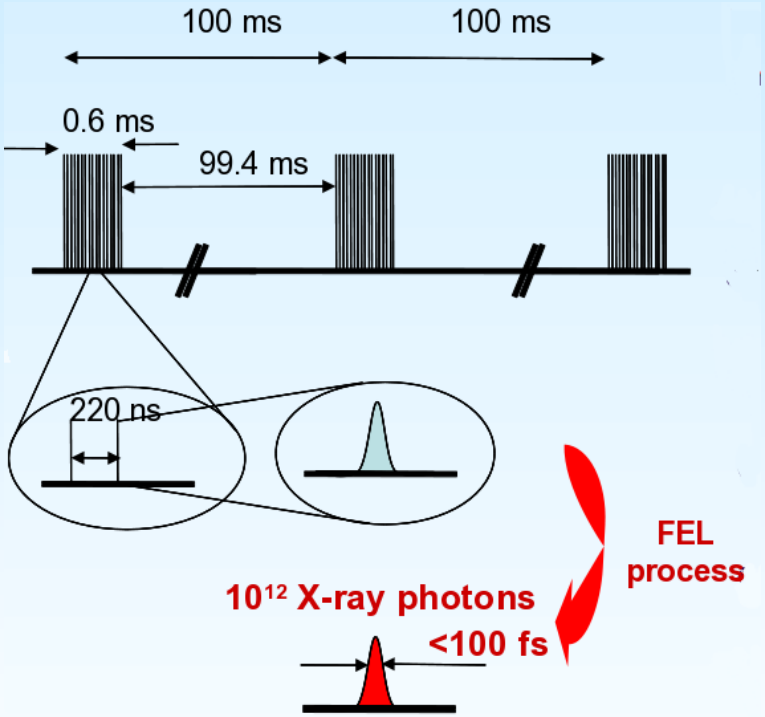


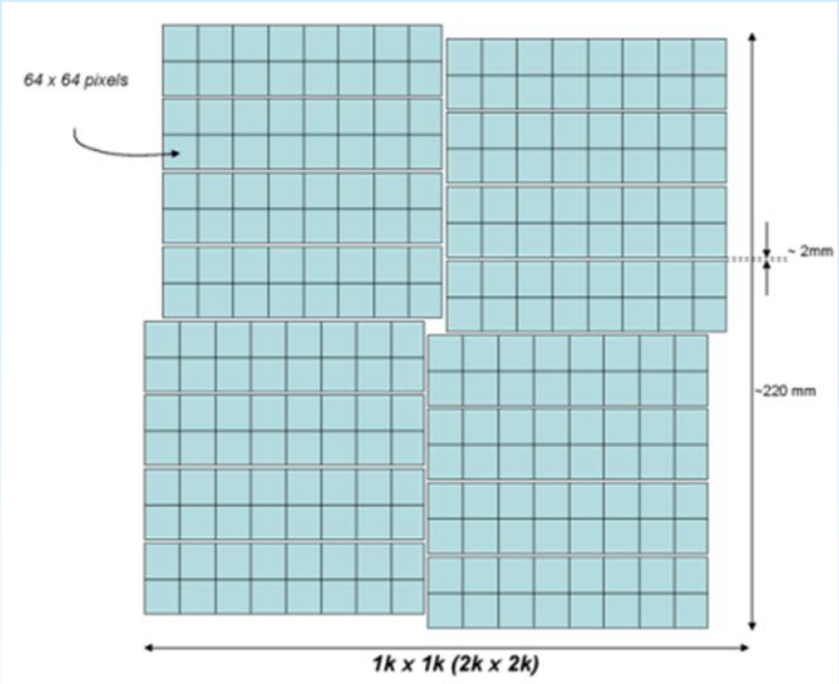
Sardine can X-rayed with 40kV Mo tube

Structure of can seen in X-ray

Detectors for XFELs

AGIPD for the EU-XFEL



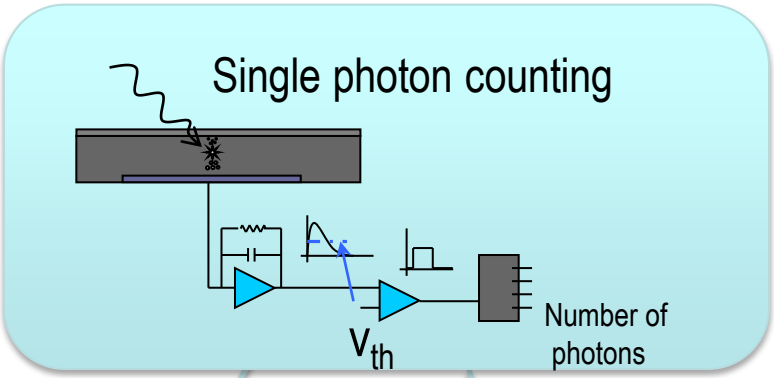


Analog storage on >350 storage cells ⇒ Capability to resolve single bunches in Synchrotrons if spacing > 150ns

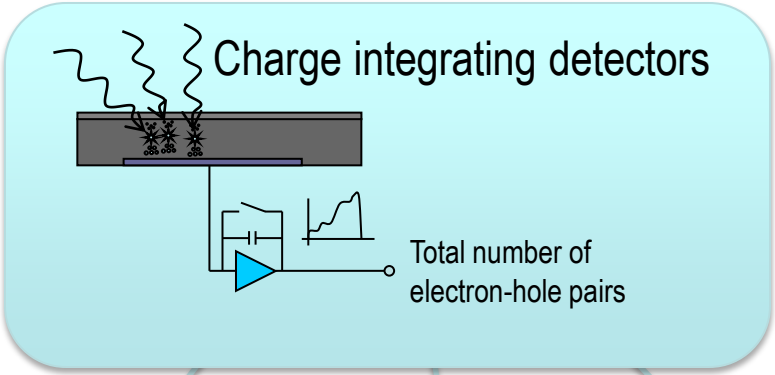
See talk by Alessandro Marras

X-ray Detector Development at SLS

Synchrotron detectors

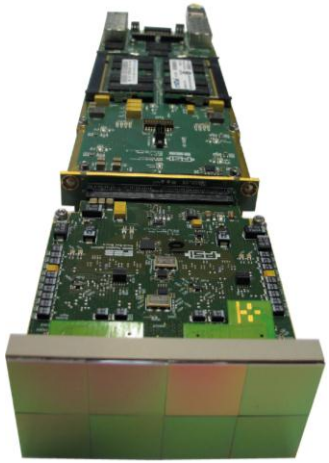


X-ray free-electron laser detectors

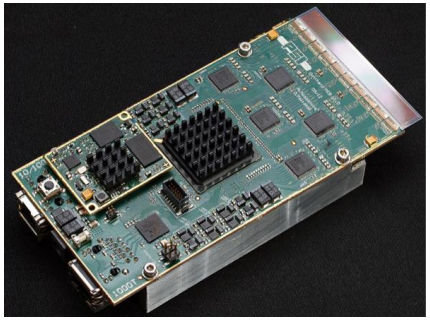


Mythen II

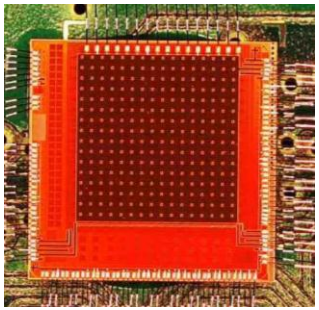
Eiger



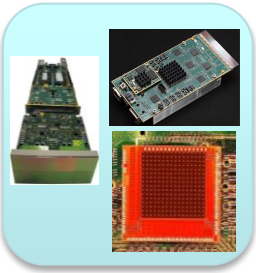
Gotthard



EU XFEL: AGIPD



SwissFEL: Jungfrau



DESY

PAUL SCHERRER INSTITUT PSI

universitätbonn

UHH

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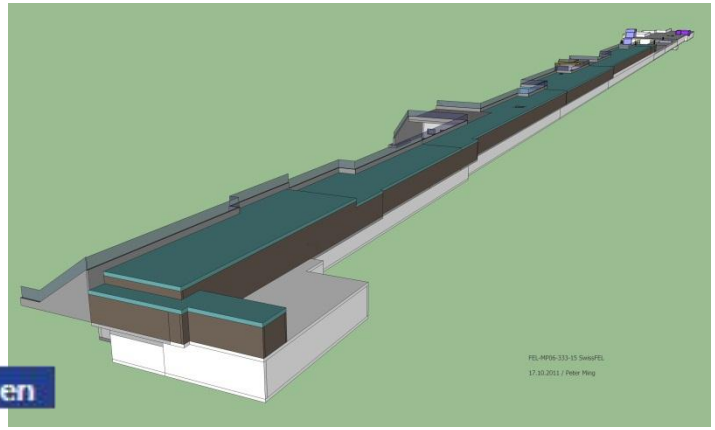
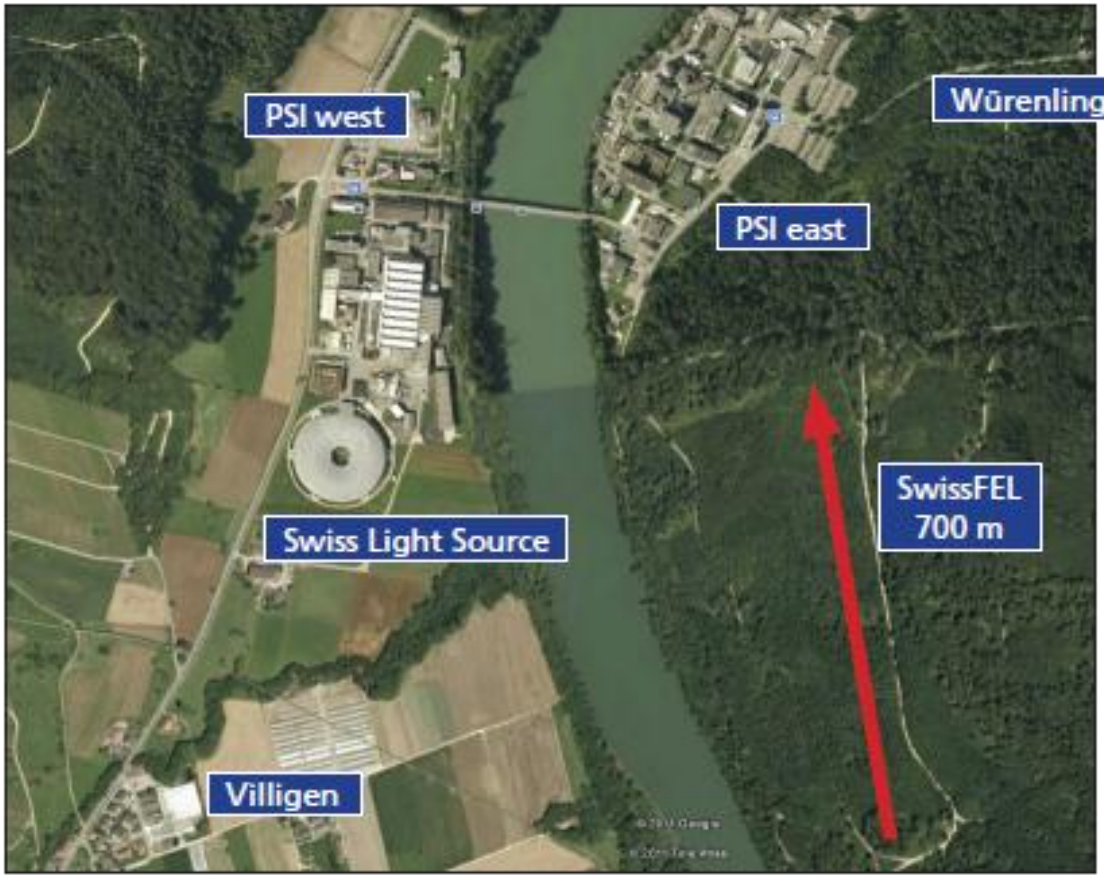
DESY

SwissFEL





Main parameters:

- 720m length
- max energy >12keV
- rep. rate 100Hz
- 3×10^{10} γ per pulse
- beam radius 20um rms
- Energy bandwidth 0.03%
- bunch length rms 30fs
- first light 2016

The Gotthard 1D detector

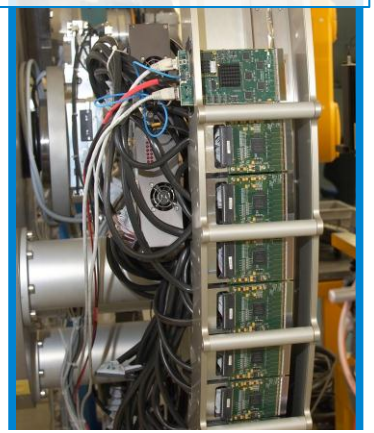
GOTTHARD:
Gain Optimizing microsTrip sysTem witH Analog ReaDout

1280 ch. 50μm pitch 1D silicon charge integrating detector

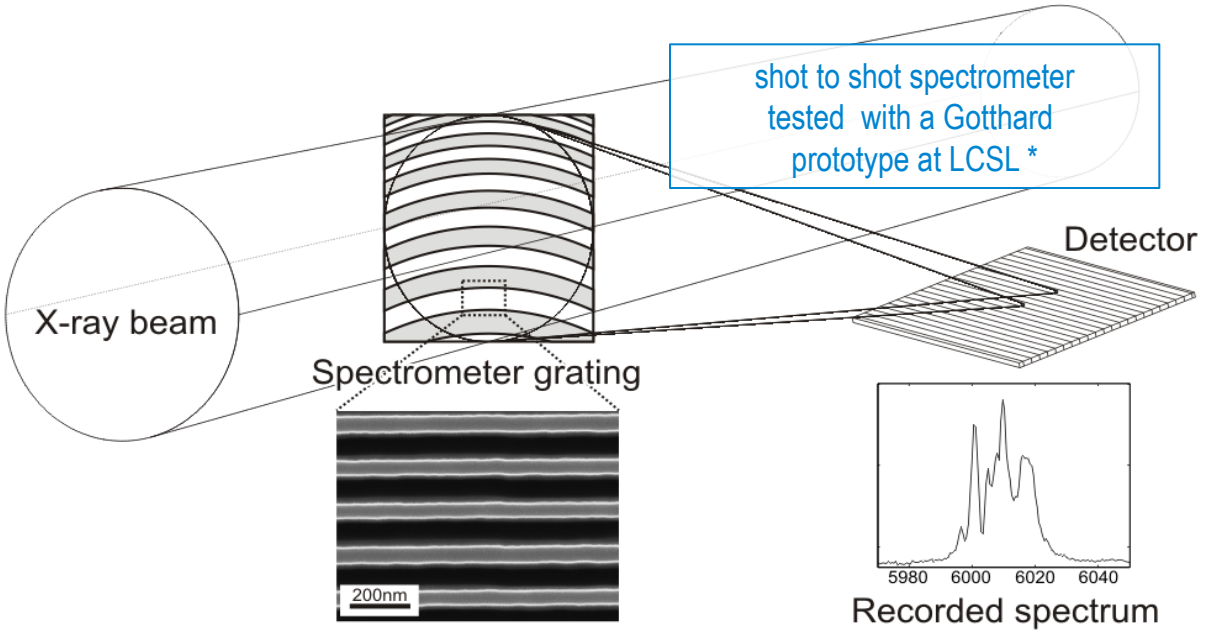
Applications @ FELs:
•powder diffraction
•XES/XAS (with energy dispersive optics)
•profile monitors, beam diagnostics

Applications @ Synchrotrons
•Diffraction experiment at very high photon rates
•pump and probe experiments in 10kHz-1MHz rep. rate
•profile monitor, beam diagnostics

a GOTTHARD module
in the Mythen detector array
at the SLSMS beamline

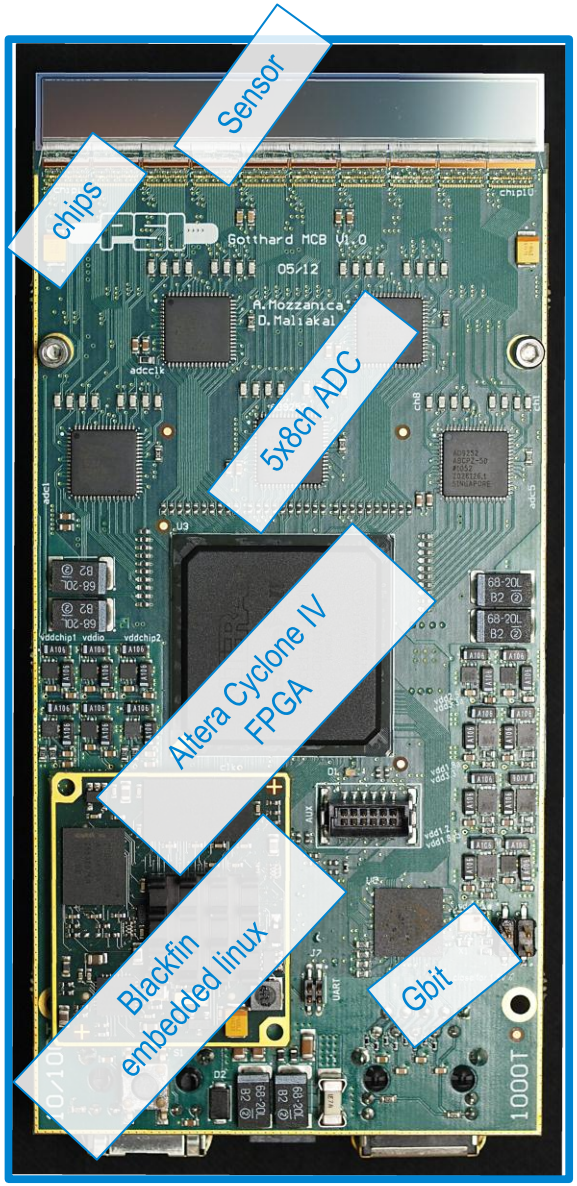


shot to shot spectrometer
tested with a Gotthard
prototype at LCSL *



* courtesy P. Karvinen

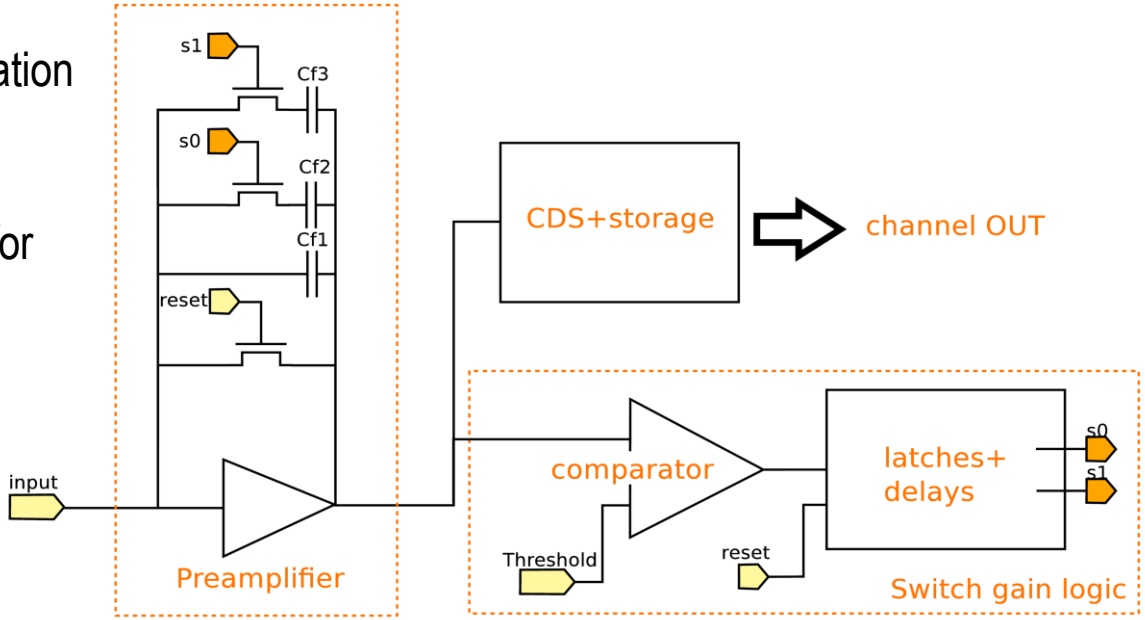
GOTTHARD module: overview

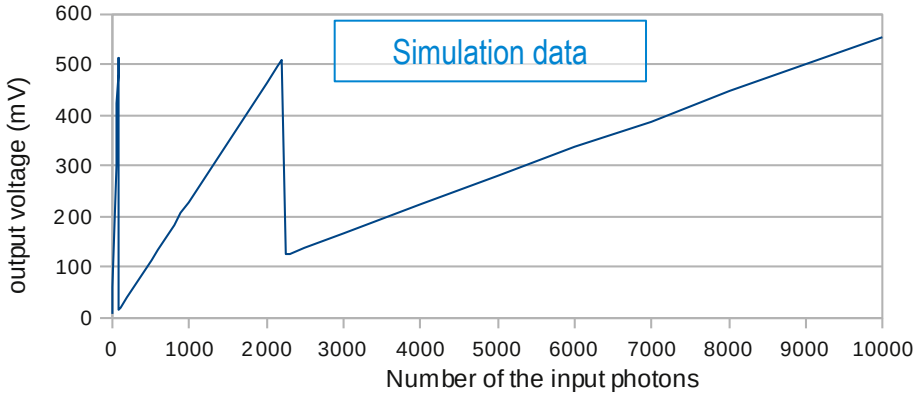


- IBM 130 nm, dynamic gain switching
- 67mm x 130mm
- 50 μm pitch, 1280ch/module (same as MYTHEN)
- GBit Ethernet data transfer for readout
- Fast readout: 1MHz (burst) 50 kHz continuous

Preamplifier with gain switching

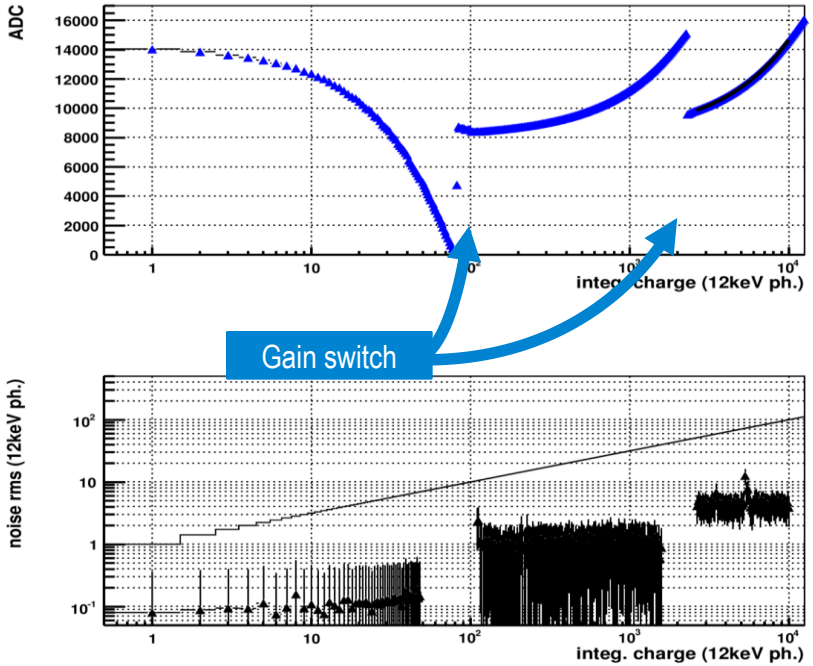
- CSA in charge integrating configuration
- 3 feedback capacitors
- Common for 1D and 2D, baseline for AGIPD, Gotthard and Swissfel





- 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)

Noise – dynamic gain switching



- at all gains the electronic noise is well below the Poisson level
- Dynamic range of 10^4 ph.

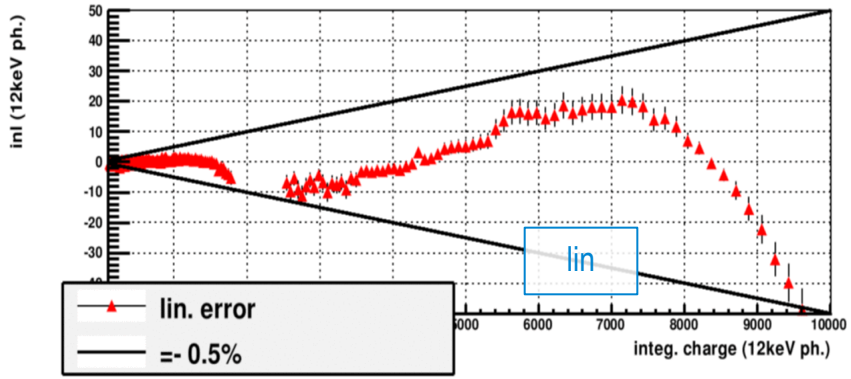
Same data quality as single photon counting

High gain mode: 160 enc:

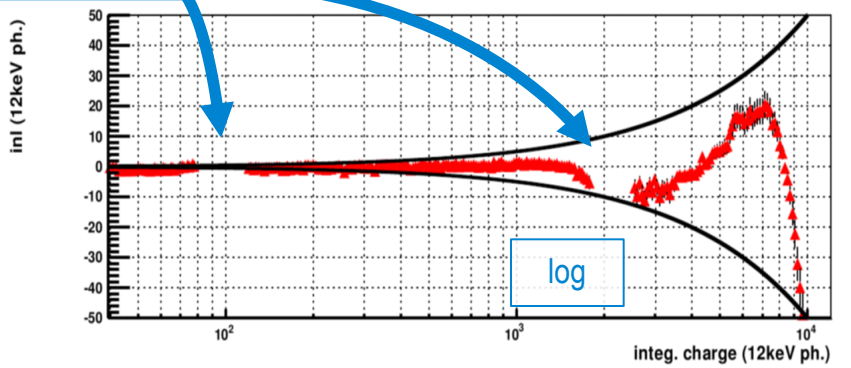
single photon resolution down to 3.5keV

Linearity

CDS disabled after switch



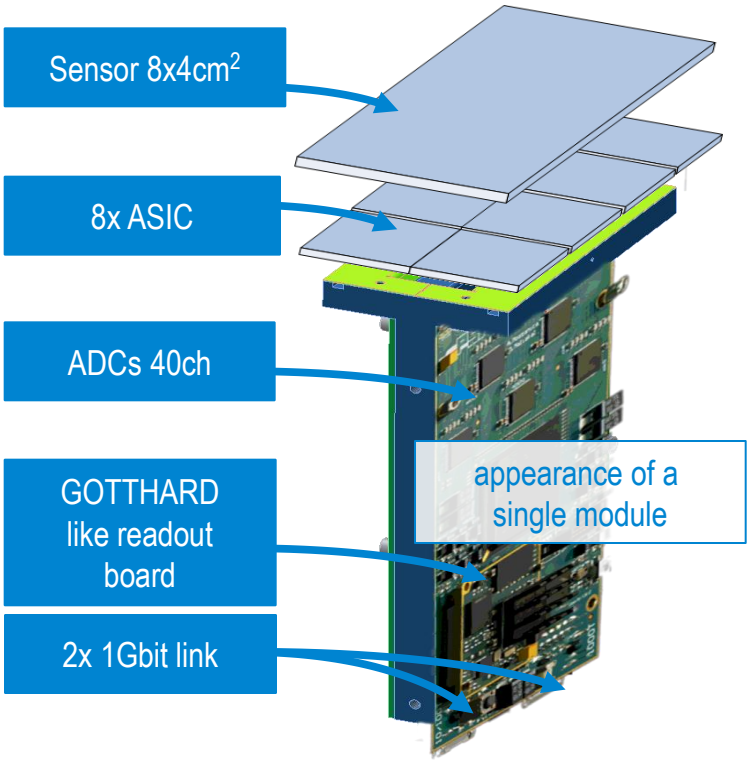
Gain switch



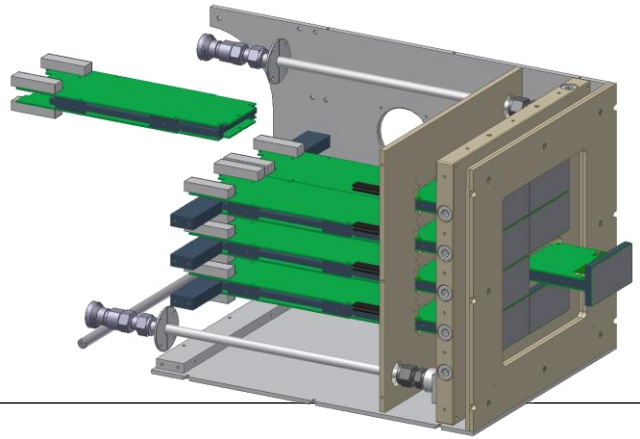
- linearity errors within +- 0.5% (source effects included) in the design input range (0-10^4 ph.)
- On smaller ranges better linearity can be achieved

Jungfrau: a 2D detector for Swissfel

adJUstiNg Gain detector FoR the Aramis User station



- ASIC and readout system based on GOTTHARD:
  - 3 gains automatic switching
  - Low noise high dynamic range
- Dimensions, sensor and mechanics from EIGER:
  - 75 mm x 75 mm pixel size
  - 4 x 8 cm sensor size
- Timeline:
  - prototype now, chip 2013
  - module end 2013
  - detector end 2014 / 2015



Jungfrau pixel architecture

110 μm UMC

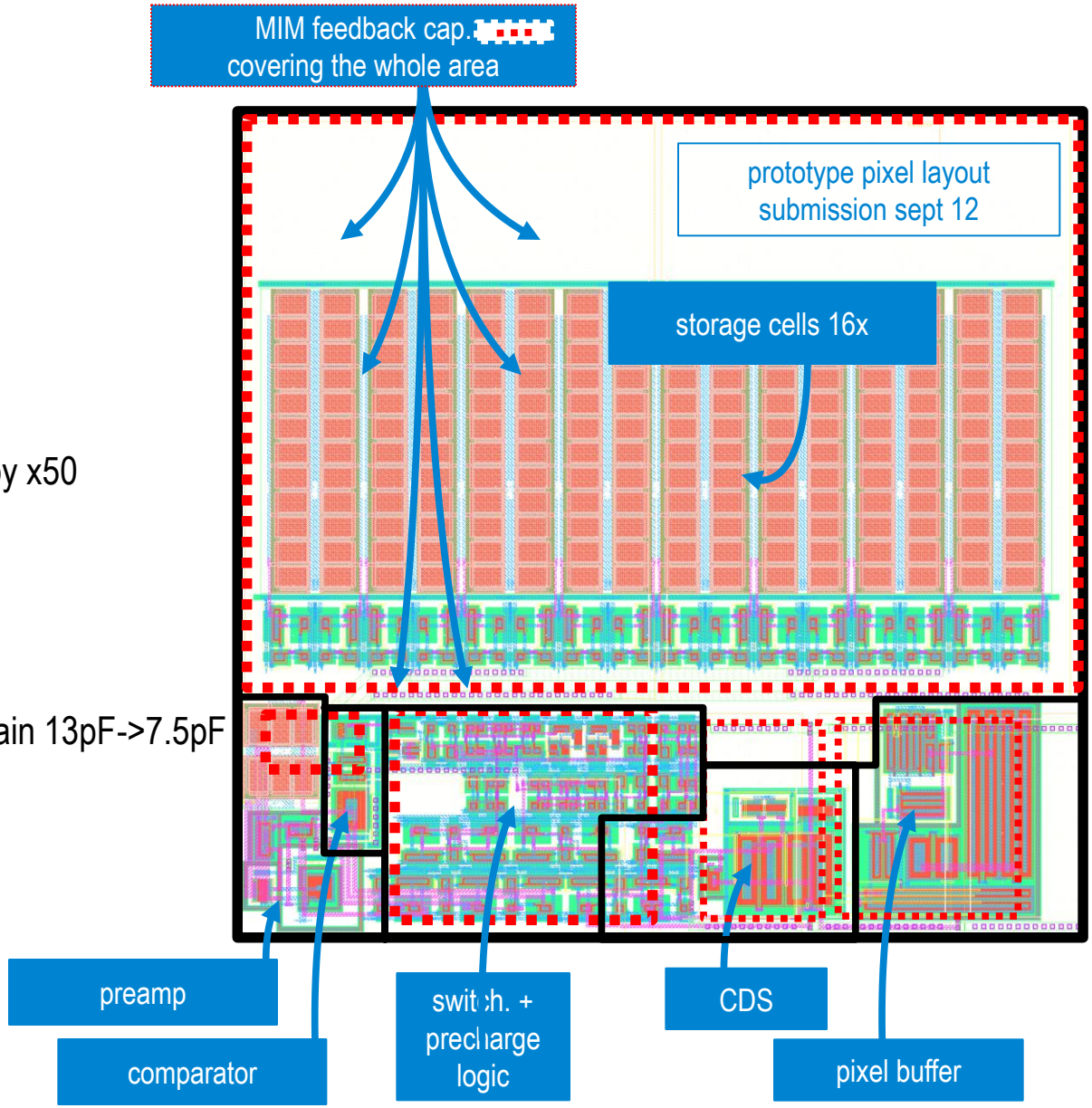
2D version of Gotthard challenges:

- Size reduced by a factor 5

- Power consumption per channel reduced by x50
  - low power preamp and CDS
  - power cycled off-pixel buffer

- Space for feedback capacitor limited, low gain 13pF->7.5pF
  - amplifier range optimization
  - precharge of feedback capacitors

- Enclosed gate layout



Pixel parameters and sim. response

Parameters:

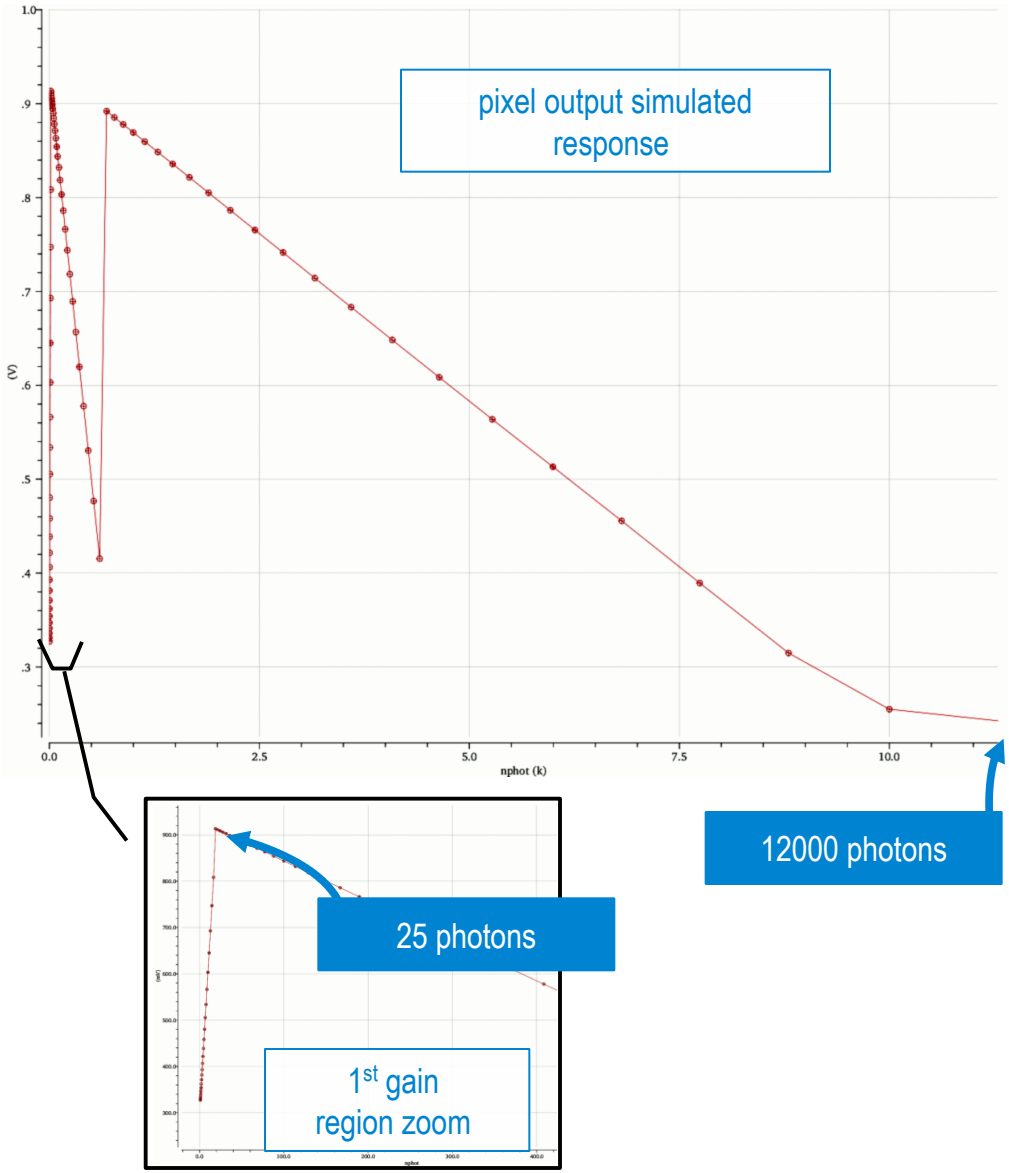
- preamp: 1.2V 8uA
- CDS+comp: 1.4V 14uA
- settling time ~100ns
- Tot. power 30uW/ch, 2A/chip
- 1st gain switch at 25 ph. , 2nd at 600
- Linear up to >9500 12keV ph.
- Linearity err. <<1%
- pix. to pix. X-talk <1%

Full chip:

256x256 pixels/chip

75 μm pixel size

Chip size 2cm x 2cm



Conclusions

- a lot of detector development is currently going on!
- parceval will be an interesting low energy detector, where currently mainly CCDs can be used
- Medipix3 finally used for full modules and larger systems
- XFEL detectors offer new possibilities also for synchrotrons
  - Single bunch resolution (in multi bunch operation): AGIPD
- Eiger offers 75 μm pixel size and 24 kHz frame rates
- Jungfrau: small pixel and kHz frame rate
  - Linear count rate capability ~20 MHz → seems ideal for PX
- Gotthard works at 1MHz frame rate in burst and 50kHz continous
  - Well suited for diagnostics of XFELs and energy dispersive detectors
  - Currently one of the fastest detectors

Thank you!

Wir schaffen Wissen – heute für morgen

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