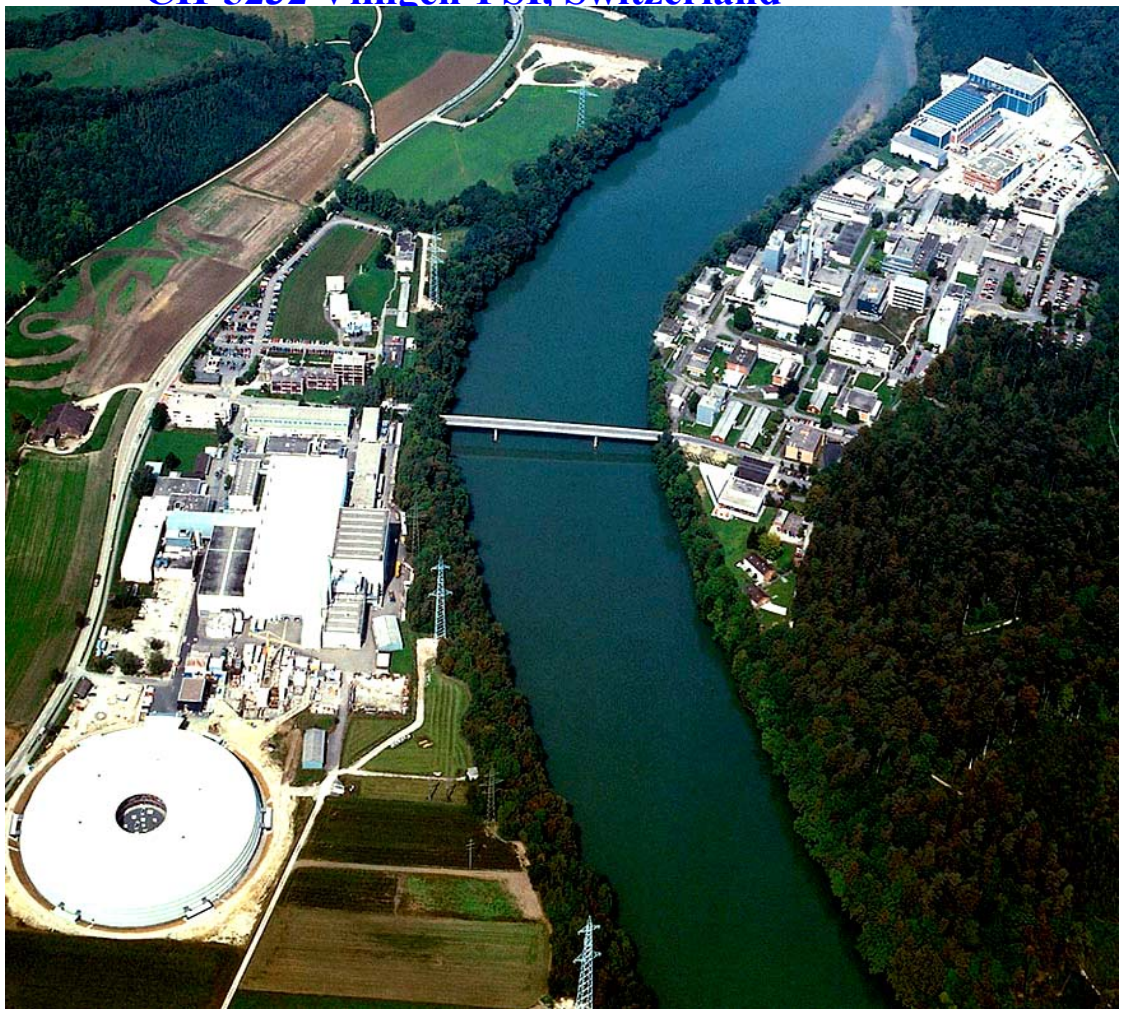
Solid State Detector Development at the Swiss Light Source

Christian Brönnimann
Group Leader SLS Detector Group
Paul Scherrer Institut
CH-5232 Villigen-PSI, Switzerland

PSI with the
Swiss Light Source
SLS



Solid State Detector Development at the Swiss Light Source

Goal: Show that solid state single photon counting detectors are excellent devices

1) Introduction

2) Mythen Detector for Powder diffraction

3) Pilatus Project
   - Surface diffraction / SAX
   - Protein crystallography
   - Pilatus 6M

4) Ideas for the future

The Swiss Light Source

Detector projects:

X04SA: MS Beamline, PD Station, E=8-30keV:

- MYTHEN detector, large microstrip detector:

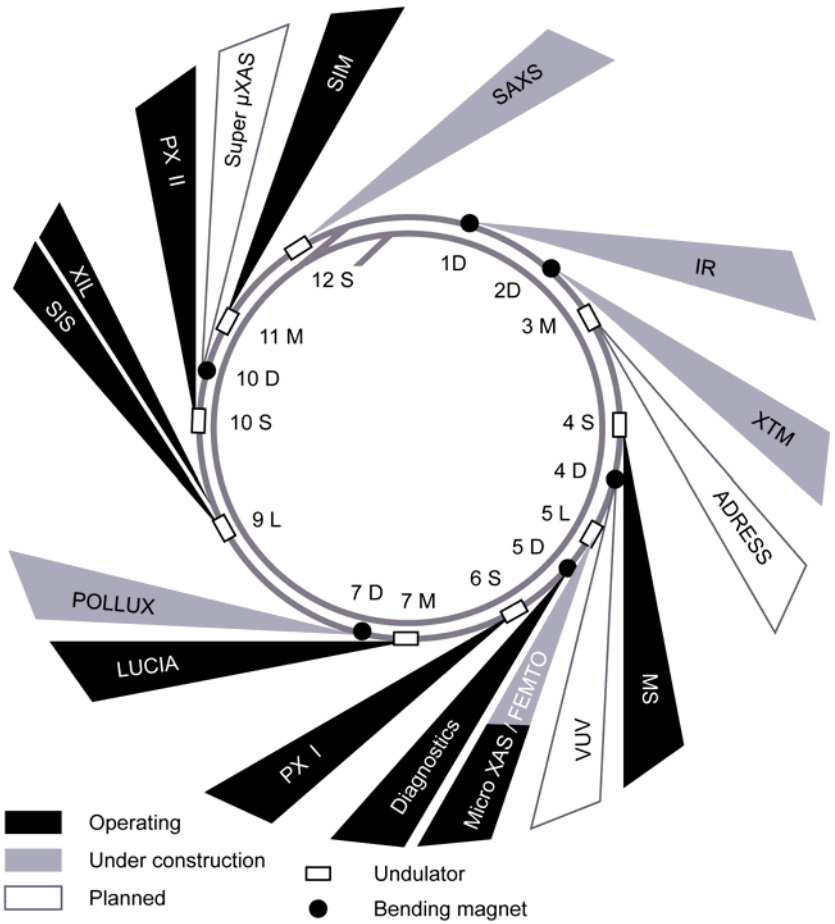
X06SA: PX I Beamline, E=5-20keV

- PILATUS detector, large area pixel detector

X04SA: MS Beamline, SD Station, E=8-30keV:

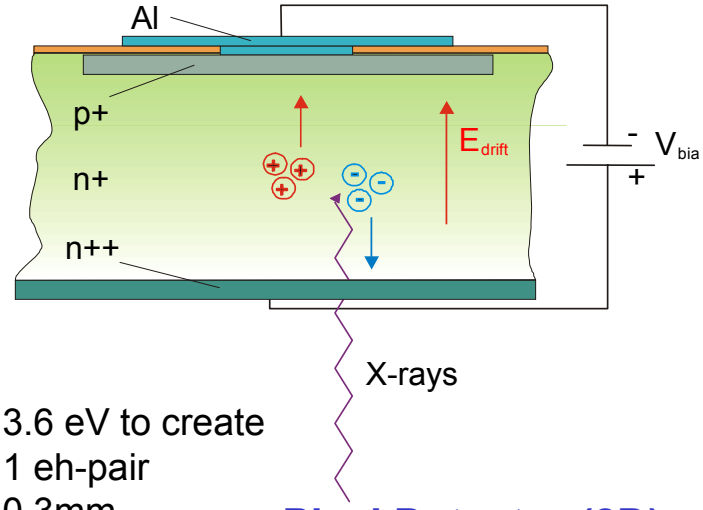
Single PILATUS Module

Energy range very well suited for Si-Detectors



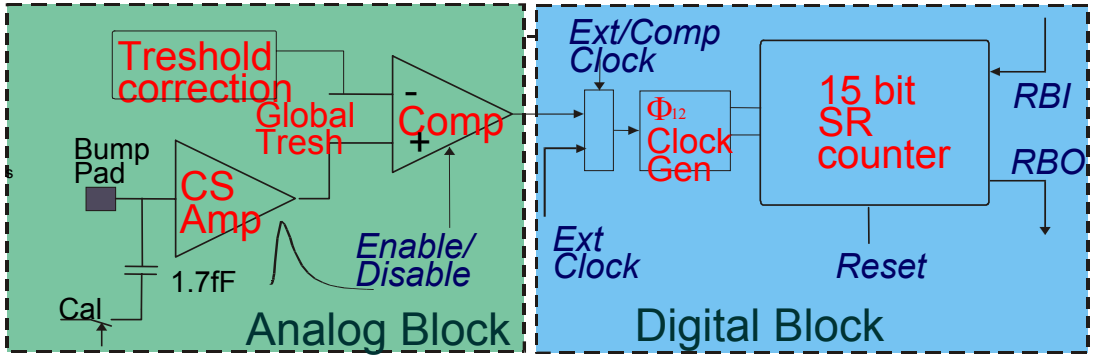
Solid State Pixel and Microstrip Detectors

Sensor: Si pn-junction

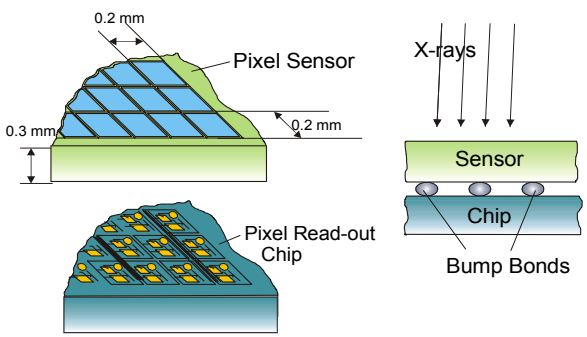


3.6 eV to create
1 eh-pair
0.3mm,

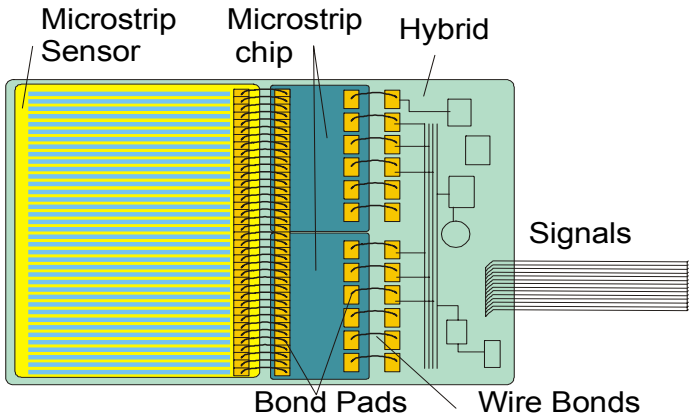
Readout Chips: Single Photon Counting Electronics



Pixel Detector (2D)



Microstrip Detector (1D)

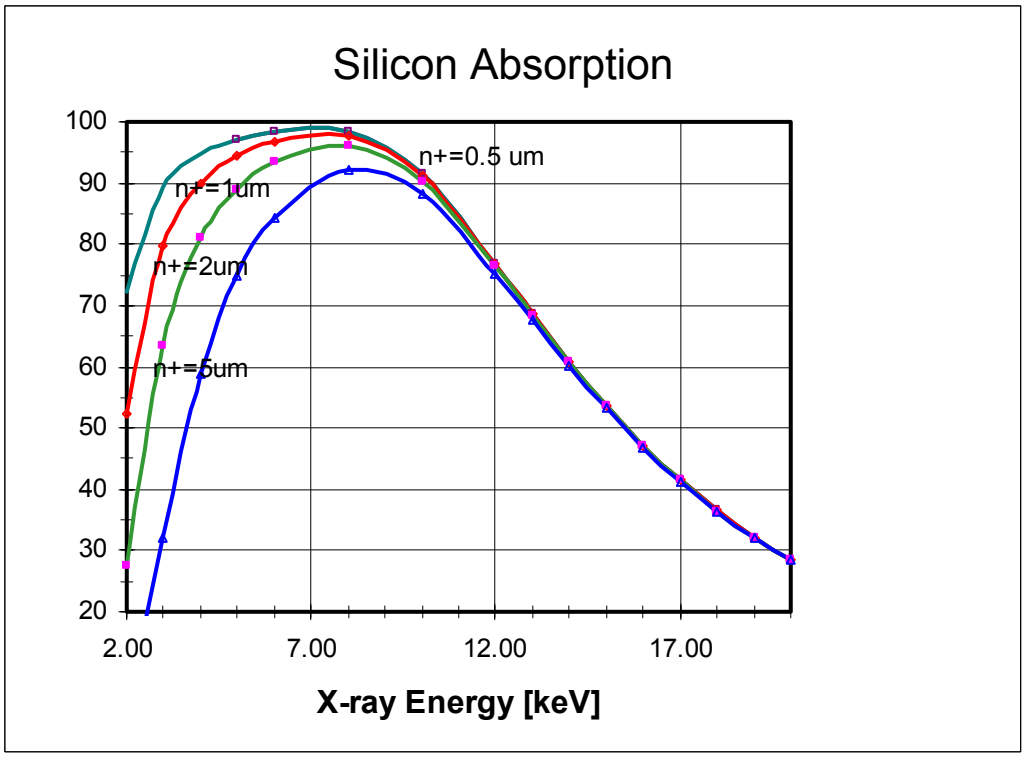


Single photon counting hybrid pixel/strip detectors

Properties:
Energy range 4 – 30 keV
No dark current
No readout noise
Excellent point spread function
Short readout times: ms
Suppression of fluorescent background
Very good signal/noise ratio

Applications:
Protein Crystallography
Powder Diffraction
Surface Diffraction
Small Angle Scattering

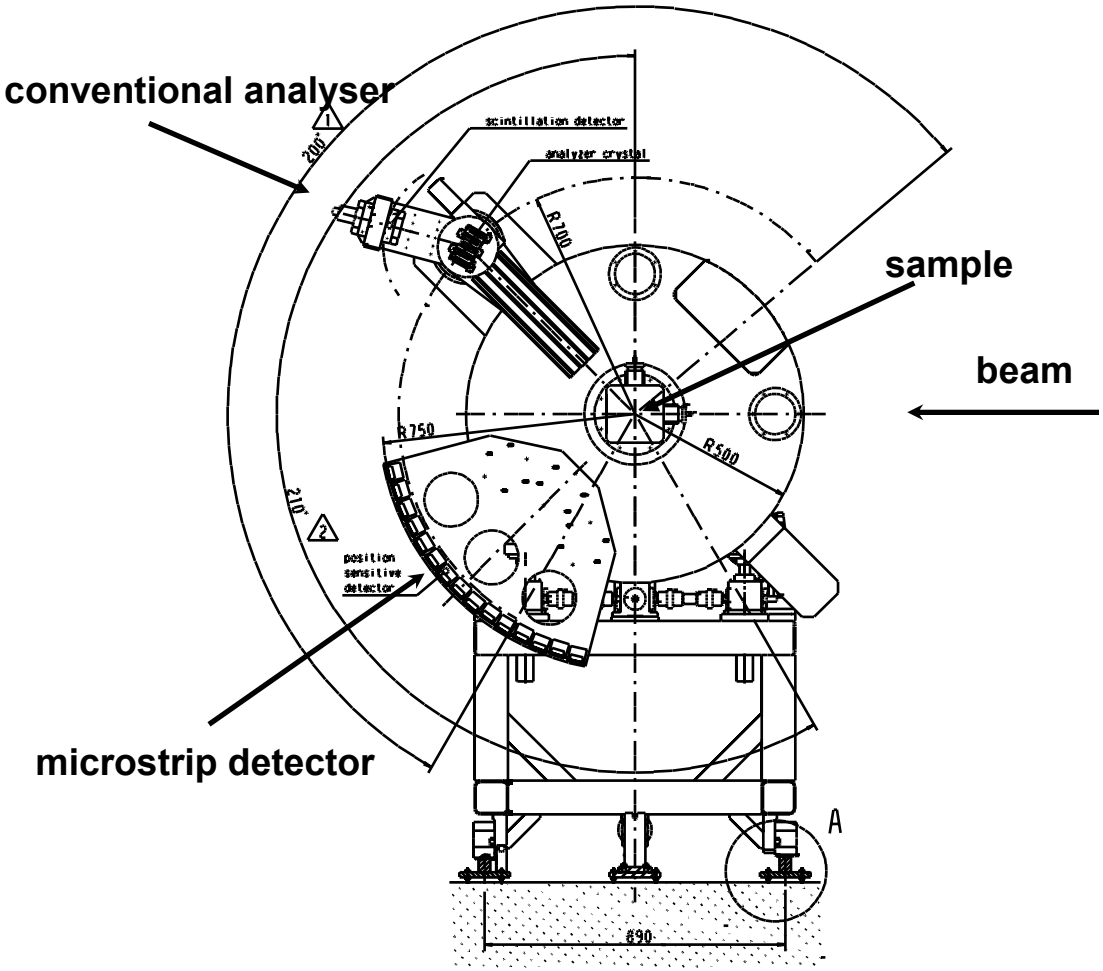
Challenges:
Quality
Stability
Calibrations, i.e. the precision of the data



Silicon is the optimal choice for SLS-Detectors

The Mythen Detector System

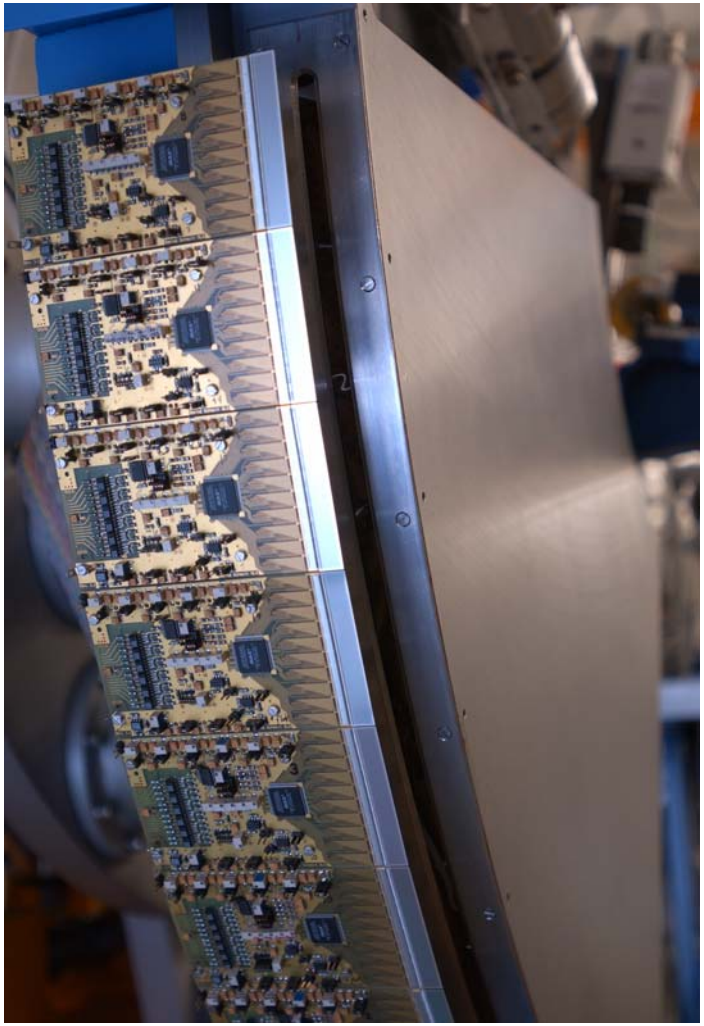
(B. Schmitt)



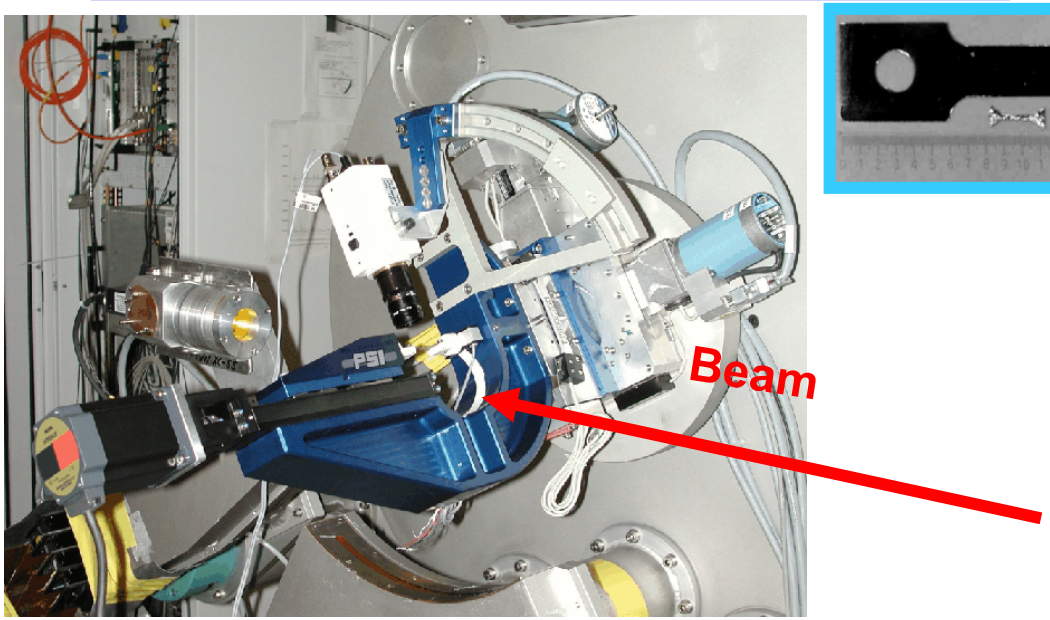
Angular coverage: 60°
No of channels: 15000
Angular resolution : 0.004°
Read-out time: 250 µs

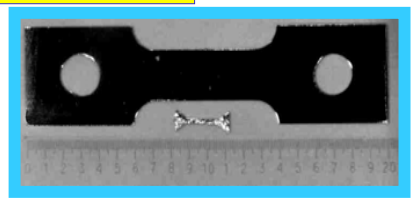
time resolved powder diffraction

The Mythen Detector System



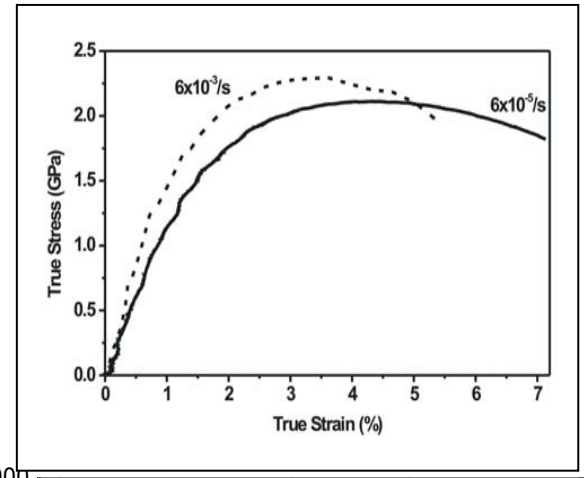
In-situ peak profile analysis at SLS

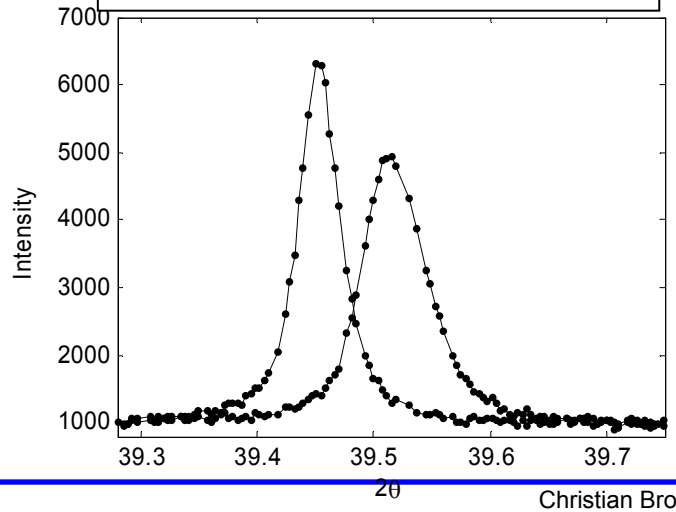




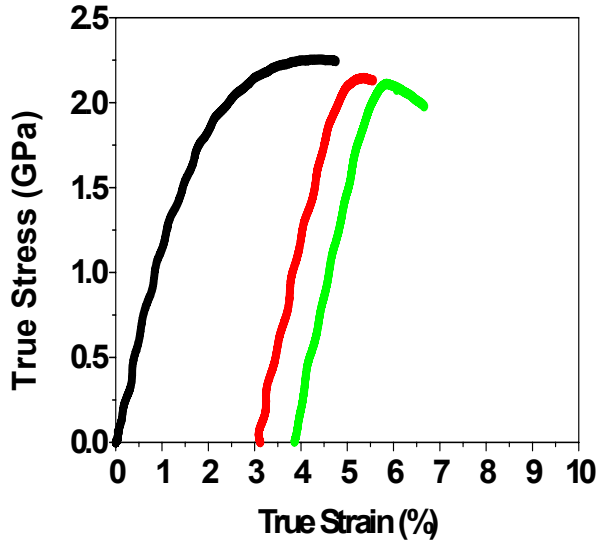
Microstrip-detector

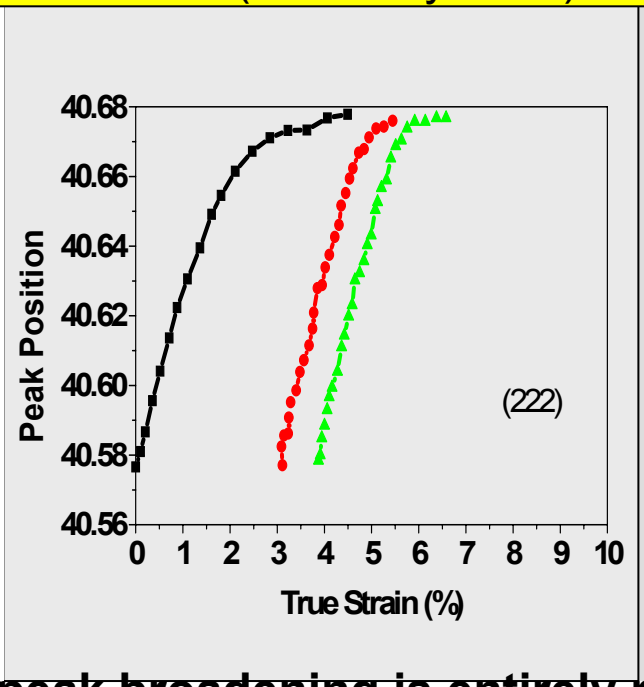
In-Situ X-ray diffraction measurements of deformation mechanisms

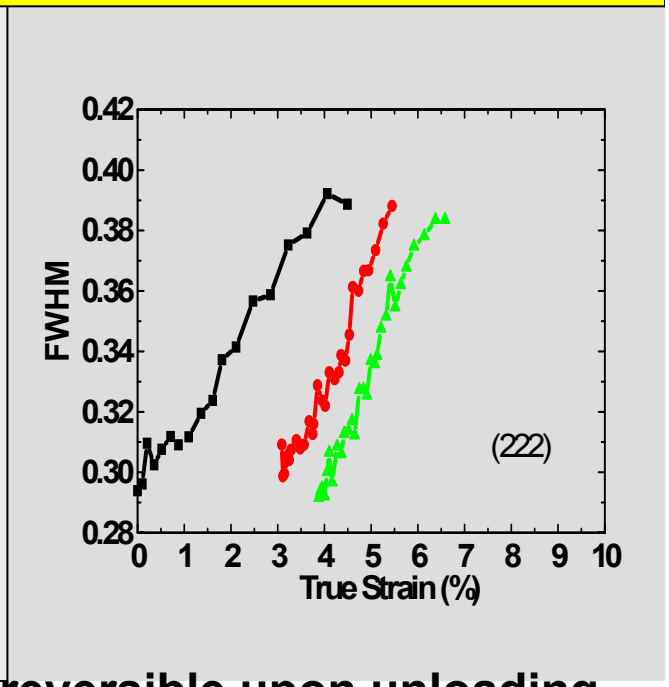




ED-Ni (26 nm by XRD)







In nanocrystalline Ni the peak broadening is entirely reversible upon unloading,

↓

deformation mechanism does not built up a residual dislocation network !
as was predicted by large atomistic simulations

H. Van Swygenhoven, Derlet, Budrovic, Van Petegem, Schmitt
NUM/ASQ/SLS

Science, 304 (2004)
Nat. Mat., June (2004)

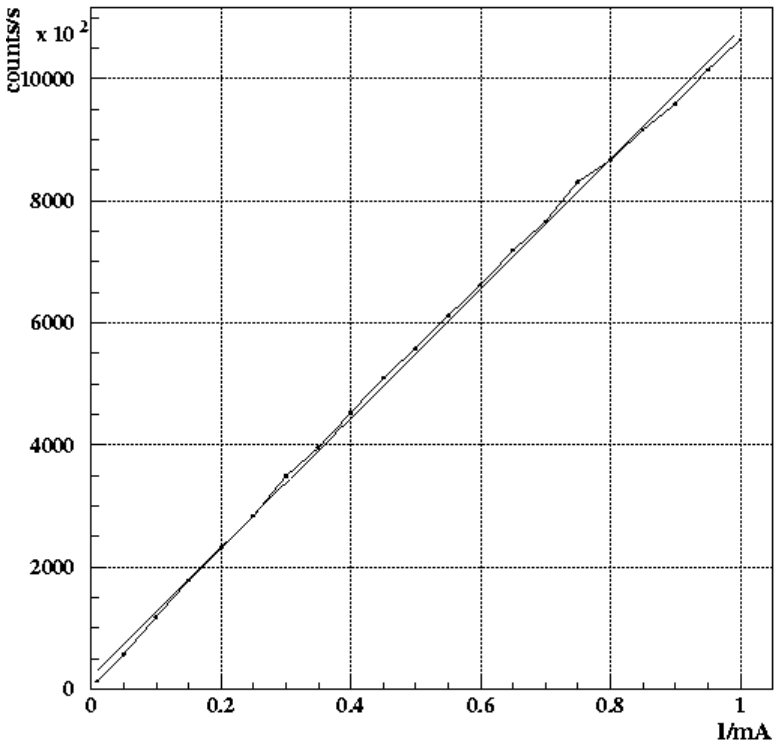
Mythen V2 (B. Schmitt)

New 0.25 µm readout chip designed

Features:
- 128 channels
- Low noise <240 ENC
- 6 bits for threshold fine-tuning
- High count rate: linear to >1MHz (measured with X-rays)
- 24 bit counter with variable length readout, readout time from 32 µs (4bit) to 64 µs (24bit) for entire chip/detector

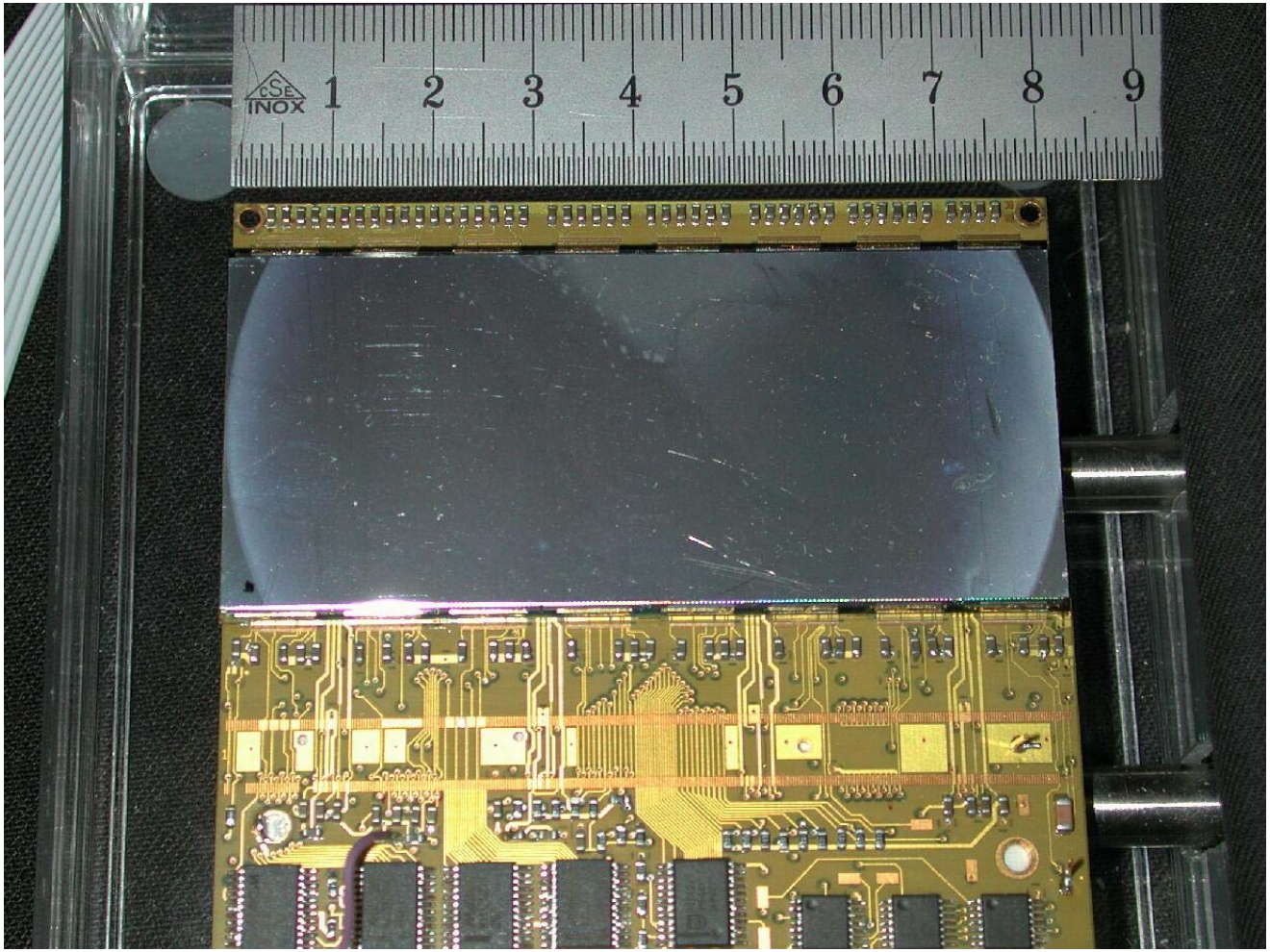
→

- Frame rates of 10kHz are planned



Current detector will be replaced by V2
Summer this year

The PILATUS Project
PILATUS Module Typ I (Aug 2001)



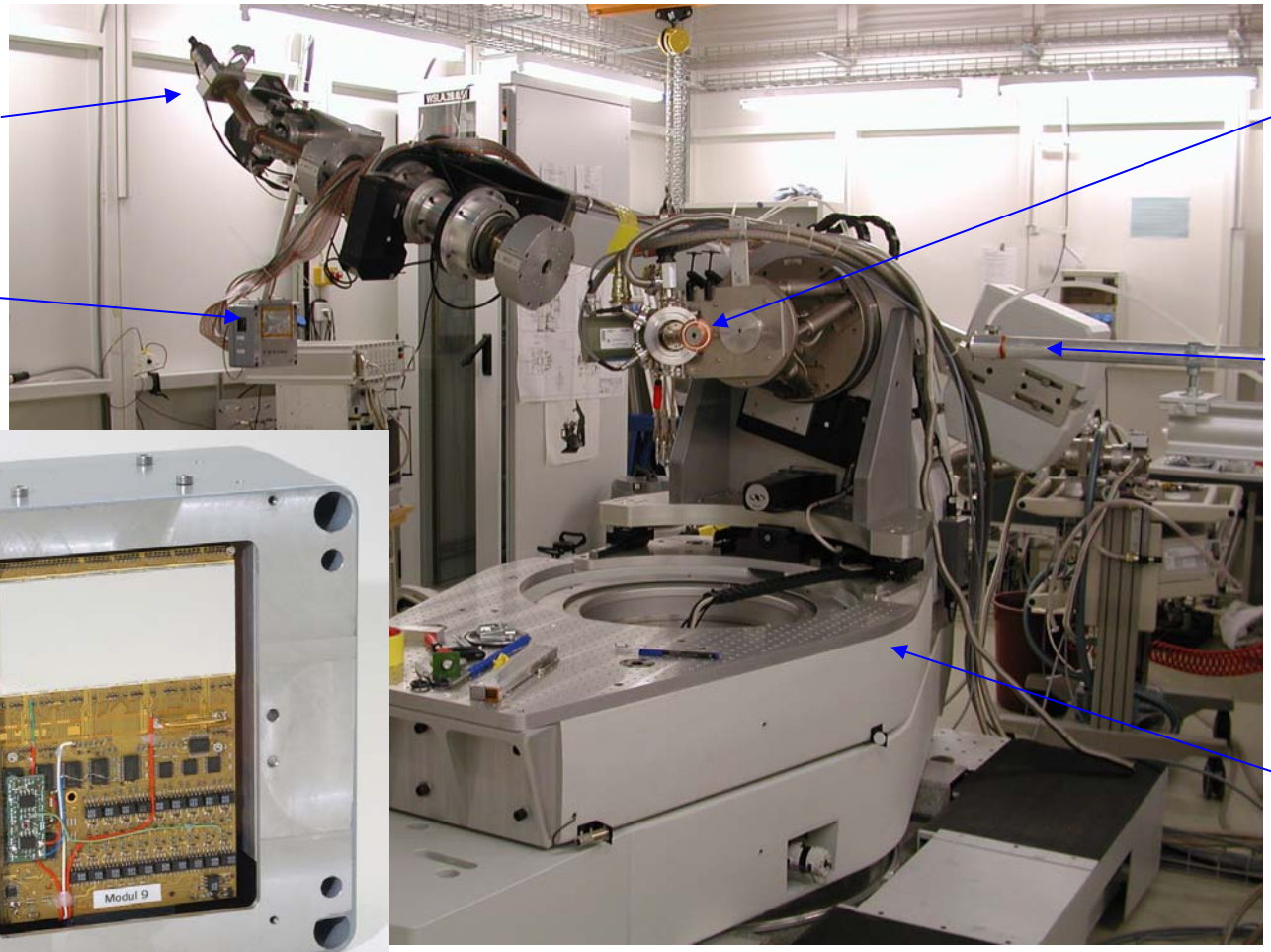
Module Data

- Active Area: 79.6 x 35.3 mm^2 (continuously sensitive)
- 157 x 366 = 57462 pixels
- 16 chips (radiation hard)
- Pixel size 0.217x0.217 mm^2
- Readout-time: 6.7 ms
- Energy Range: $E\gamma$ >4.5 keV
- Minimum Threshold: 3 keV
- Threshold adjust per pixel
- Rate: ~10 kHz/pixel
- 15-bit counter/pixel
- single photon counting, no readout noise

The Surface Diffraction Station at X04SA

Point Detector

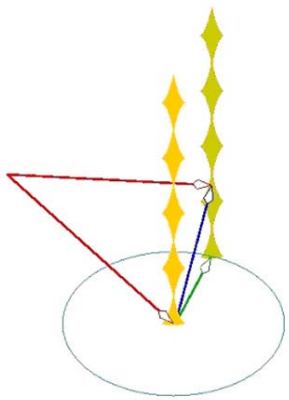
Single Module Pixel Detector Frame rate 30 Hz



Specimen

Beam

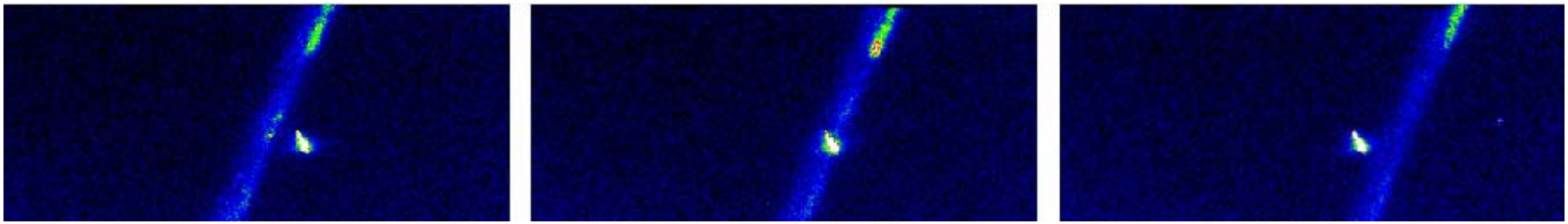
6 Circle Diffractometer



Crystal truncation rods (CTRs) at X04SA

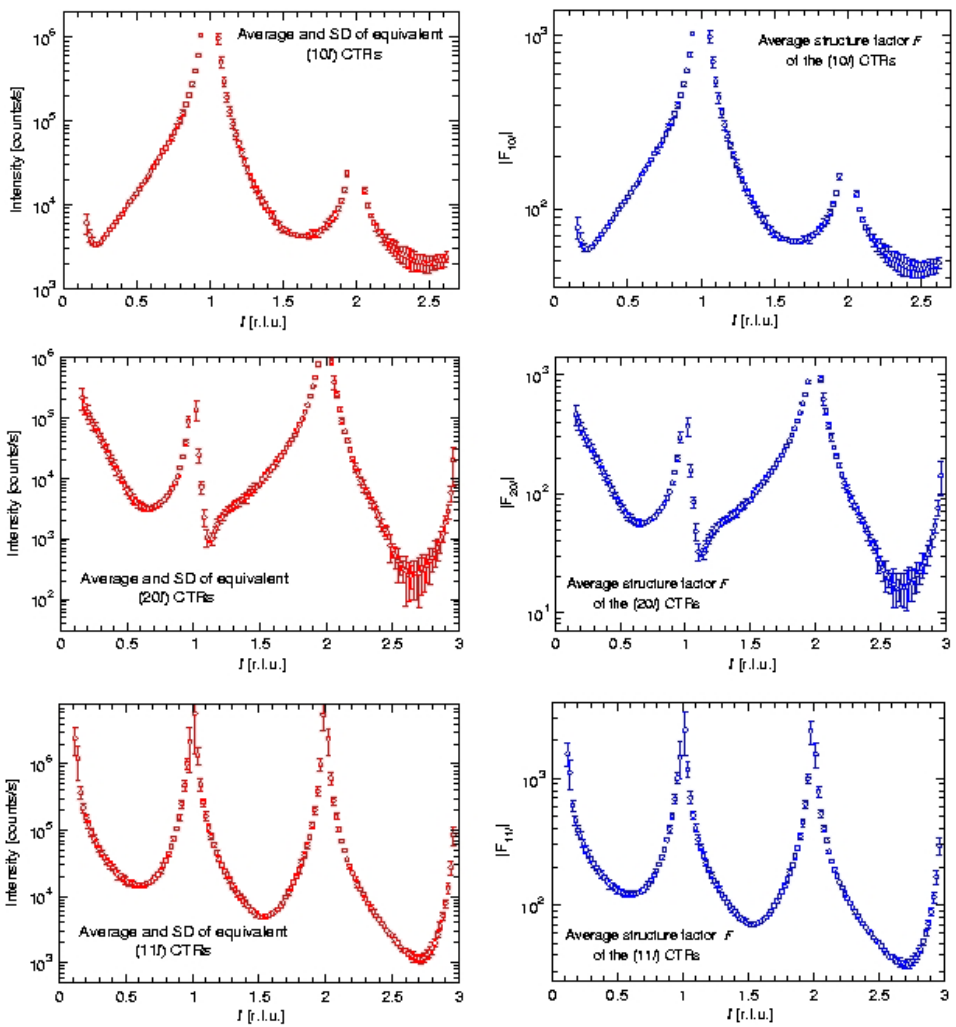
surface-sensitive structural information

Classic: Time-consuming scans with a point detector at points along the CTR
New: About 50 times faster with the pixel detector



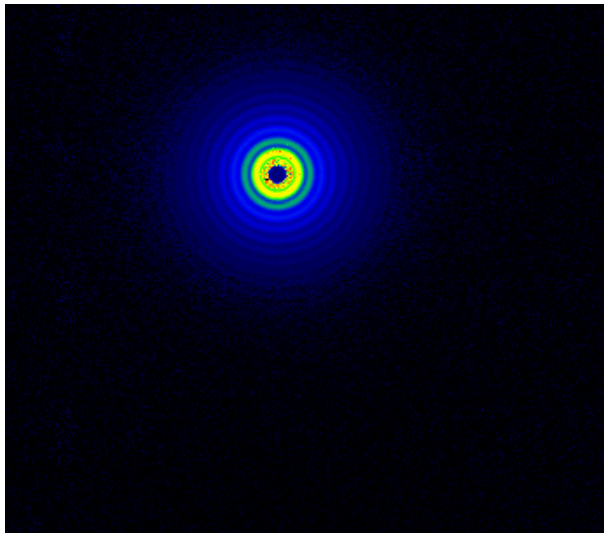
CTRs of the surface of $SrTiO_3$

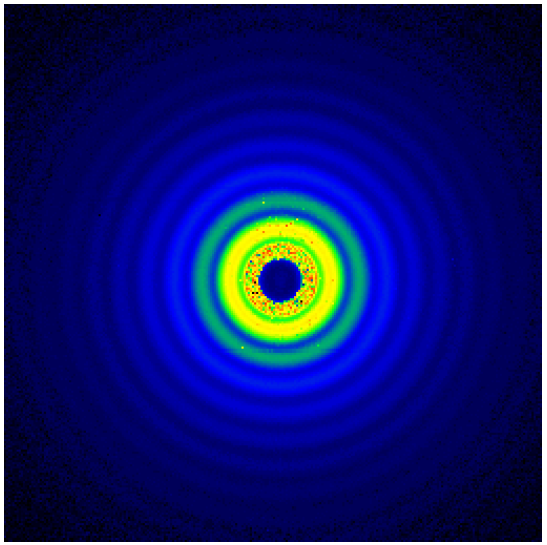
27 CTRs with 1800 data points recorded in a few hours

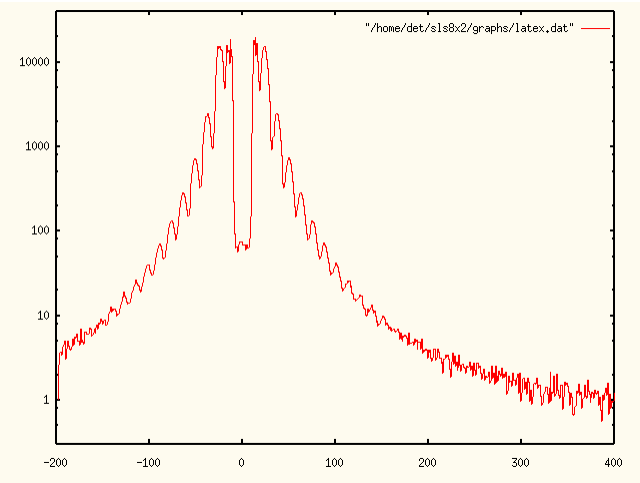


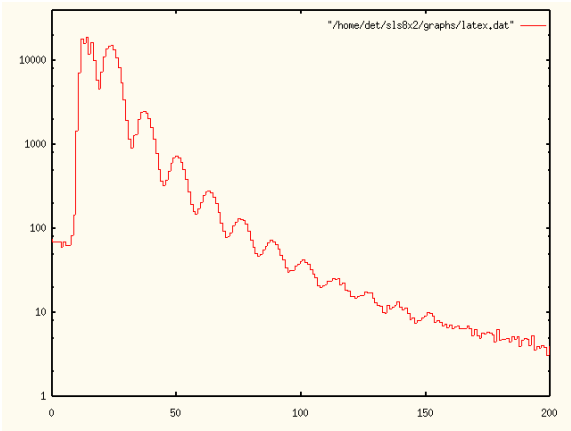
C. Schlepuetz et al, “Improved data acquisition in grazing-incidence x-ray scattering experiments using a pixel detector”, submitted to NIM A, Jan 2005

SAX Pattern of a polystyrene latex solution (H. Toyokawa, M. Suzuki SPring 8)



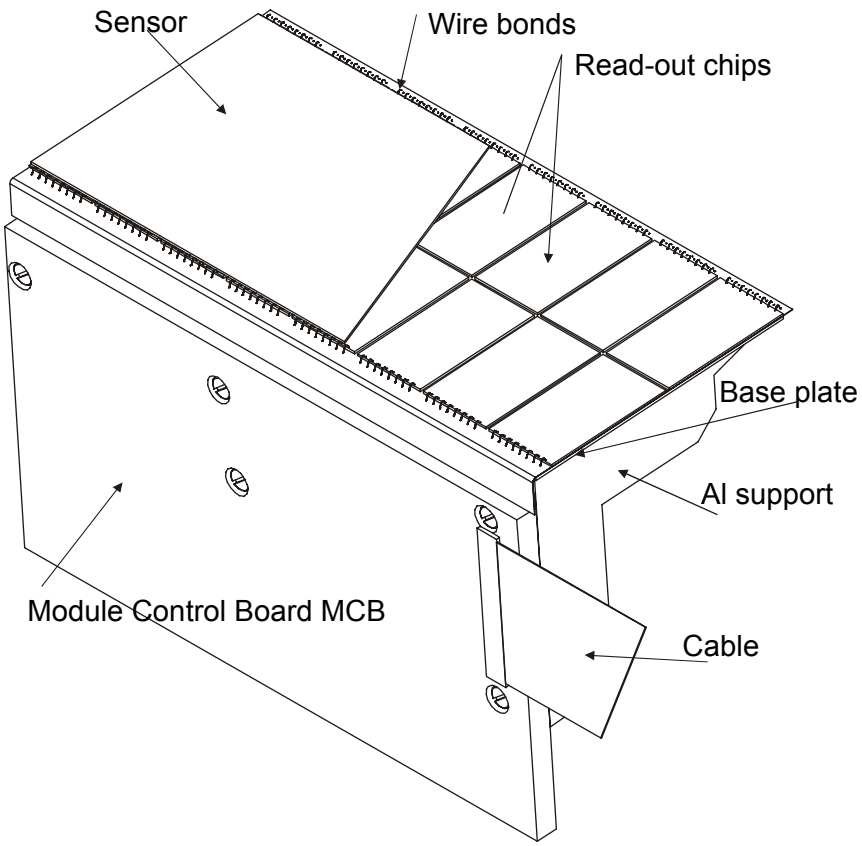


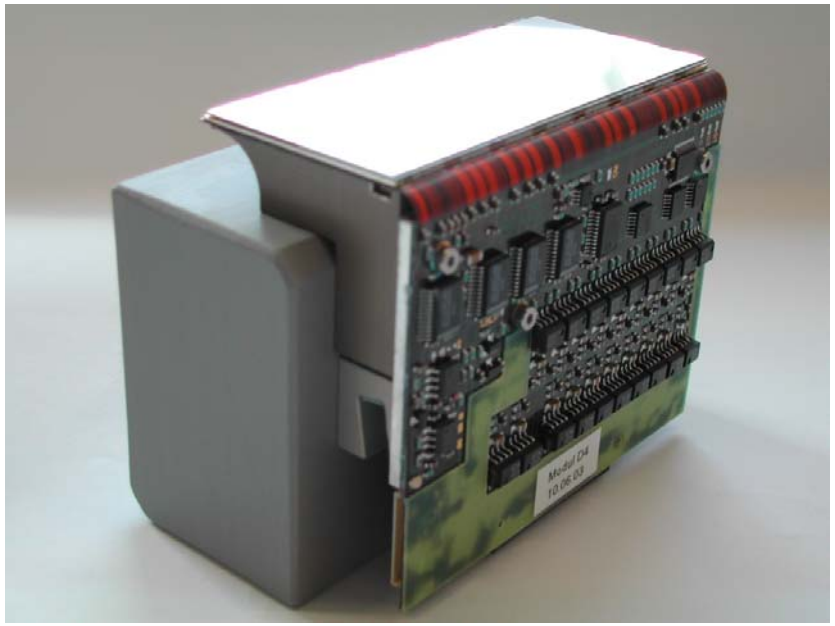




Single X-ray Resolution!

PILATUS Module Typ II (readout electronics bended)

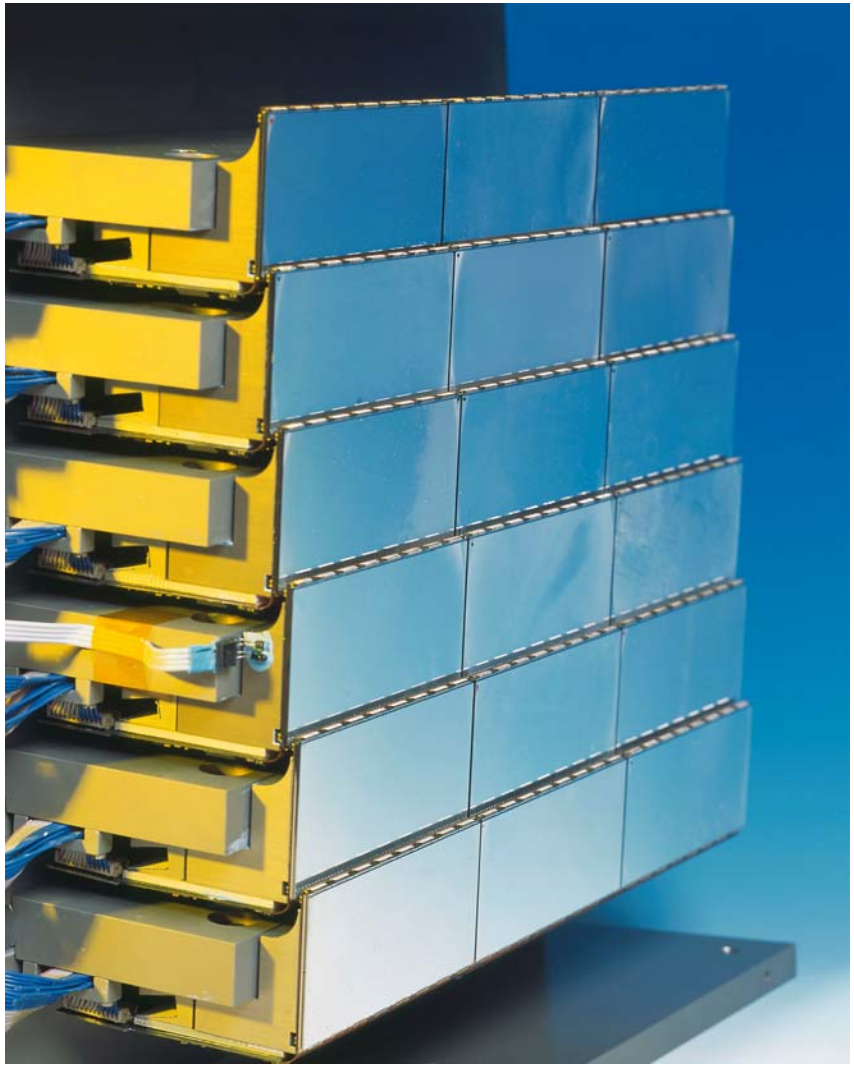




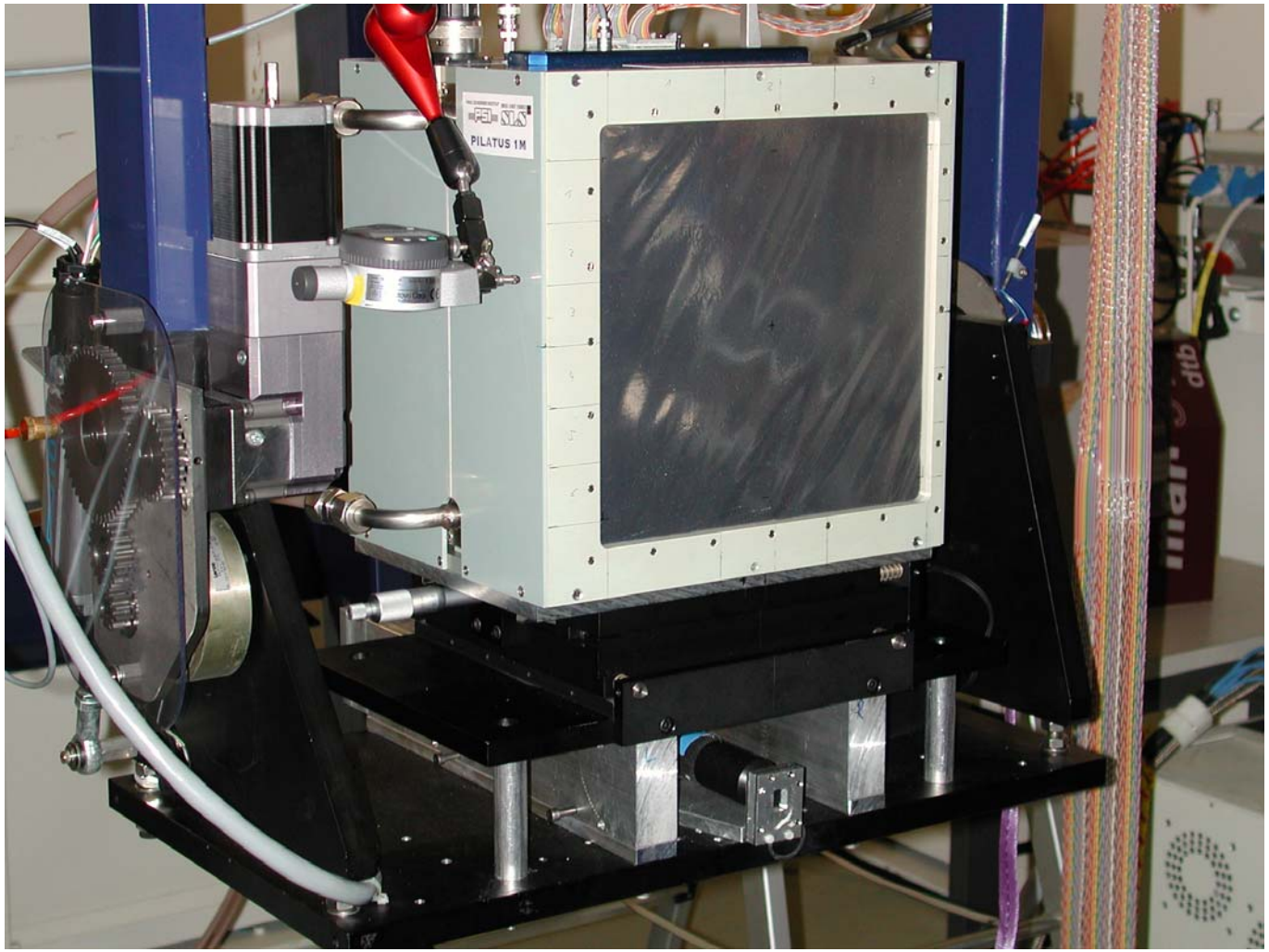
- Flexprint 6/2 from Dyconex
- Modules can be overlapped
- 80 x 35 mm^2 continuous sensitive area
- 2 x 8 readout chips
- Power consumption: 7V/1.5 A -> 10.5 W
- Fabrication of 21 Modules: Mai 03- Sept 03

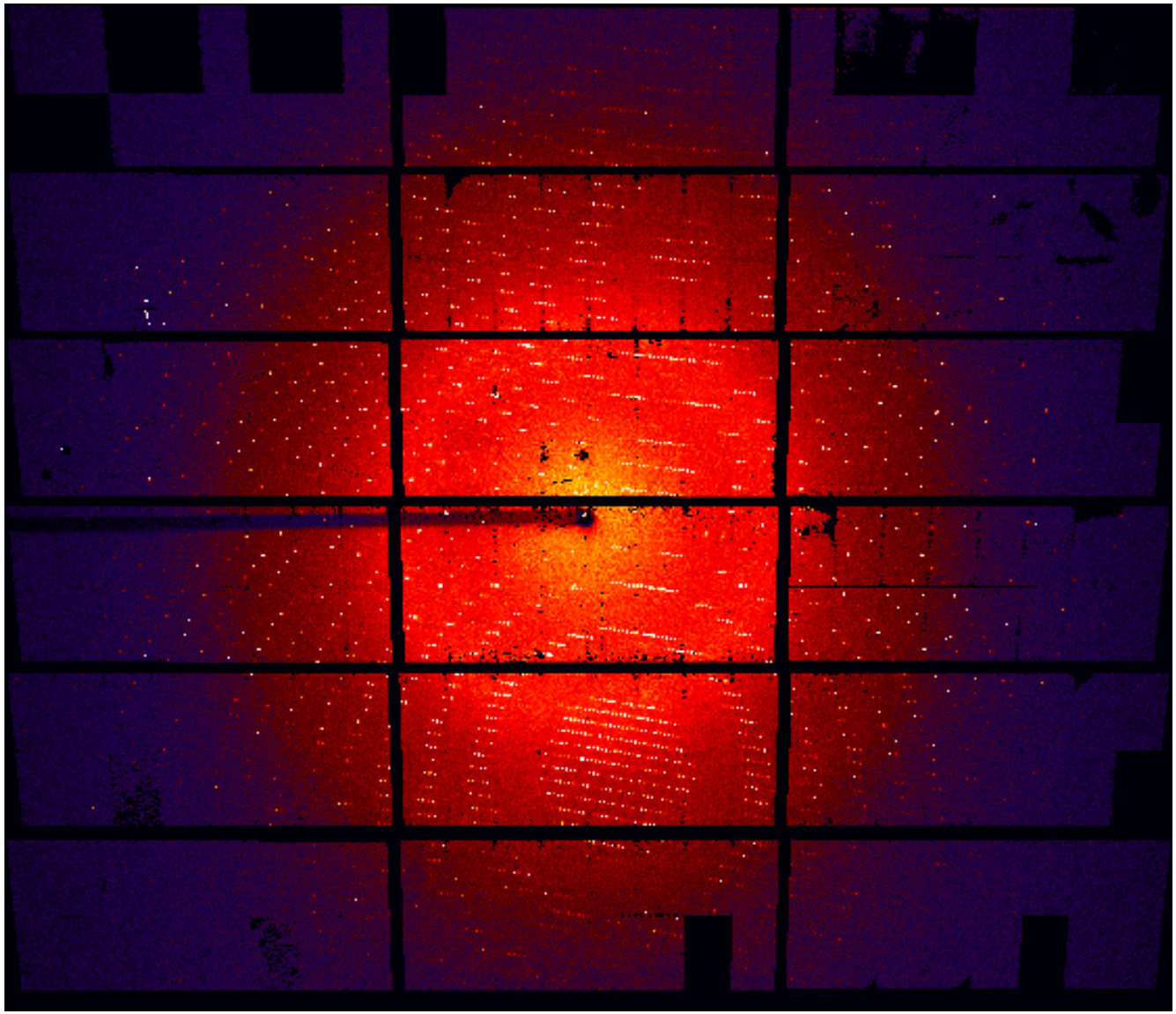
The PILATUS 1M Detector

- Largest pixel detector array for SR
- 6 banks a 3 modules, 1120 x 967 pixels
- Area: 21 x 24 cm^2
- 288 chips->~$300x10^6$ transistors
- Readout time: 6.7ms
- Currently 2 frames/s
- 2 frames/ s
- Active area: 85%
- Moderate count rates (<10kHz/pixel)



PILATUS 1M Detector at X06SA





Thaumatin crystal

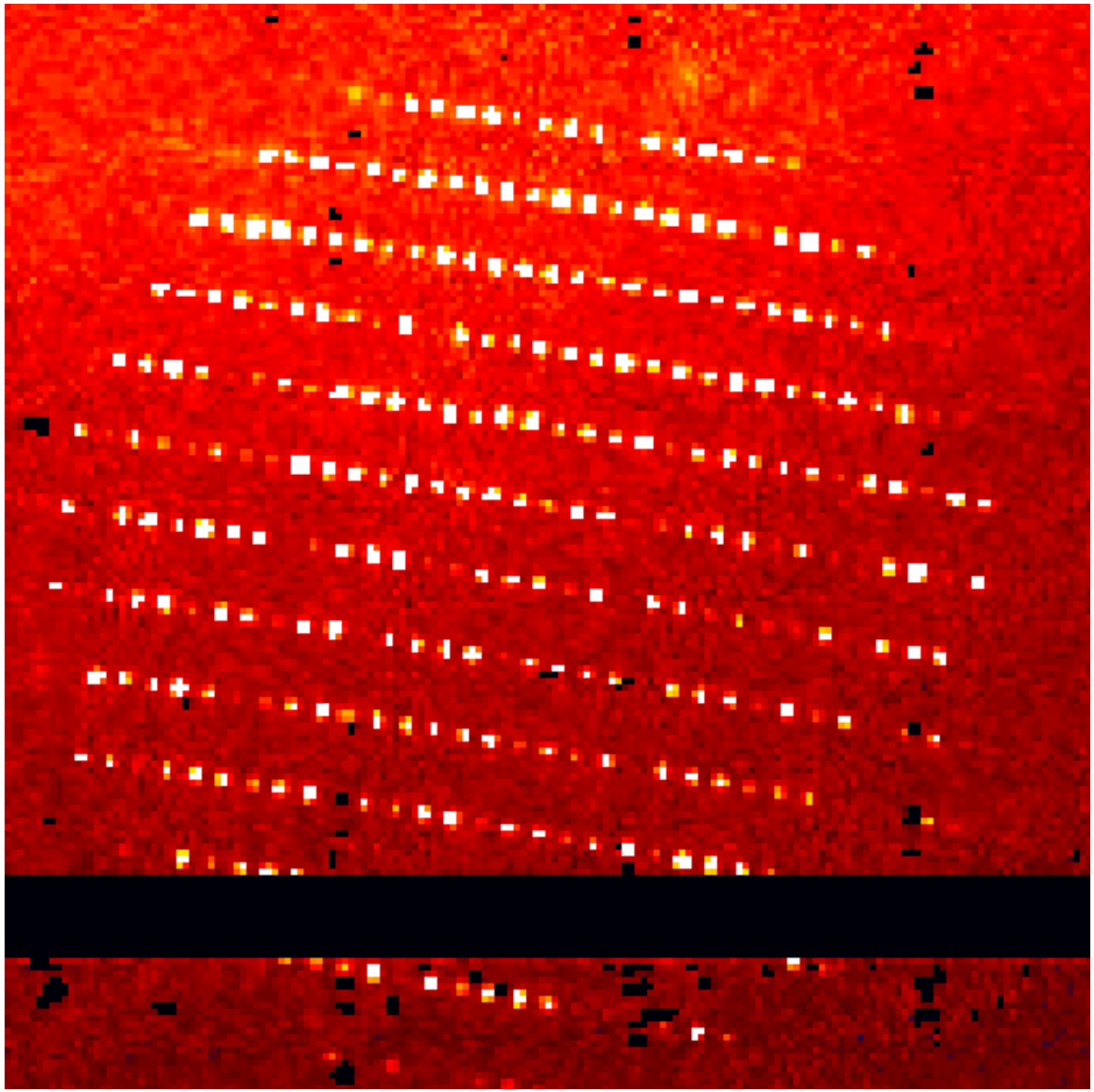
Data Taking:

Data set: 120°
Exp Time: 4s
Integration: 1°
Beam energy: 11.9 keV
Beam intensity: 13.5%
D Sample-Det: 128 mm
Resolution: 1.4 Å

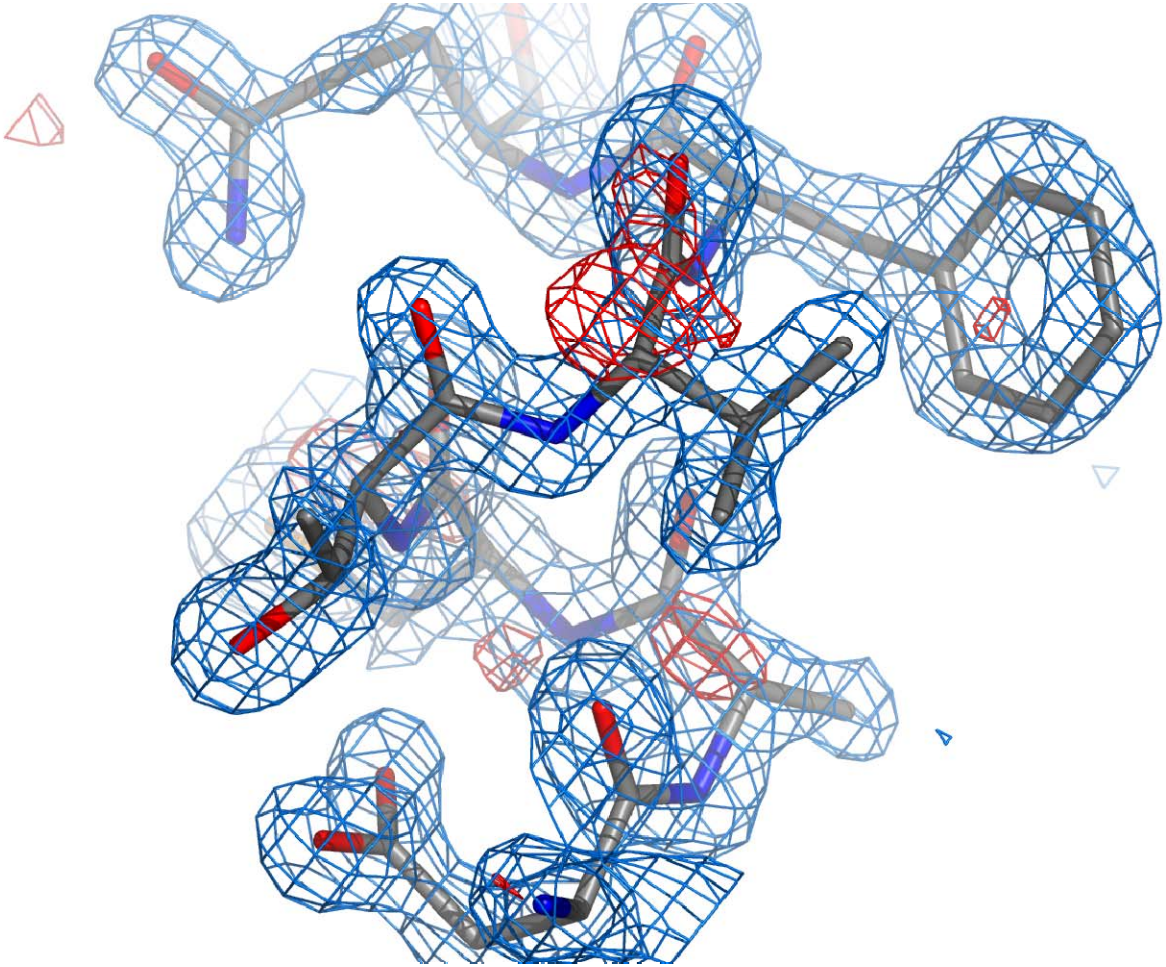
Analysis:

3 data sets merged
full geometrical correction
Processed with XDS

R_{obs}: 8.9% (overall)
Completeness: 90%
(98% up to 1.6 Å)



Zoom in



Thaumatin electron density map

Processing with XDS

Refinement with SHELXL

Completeness: 90.3%

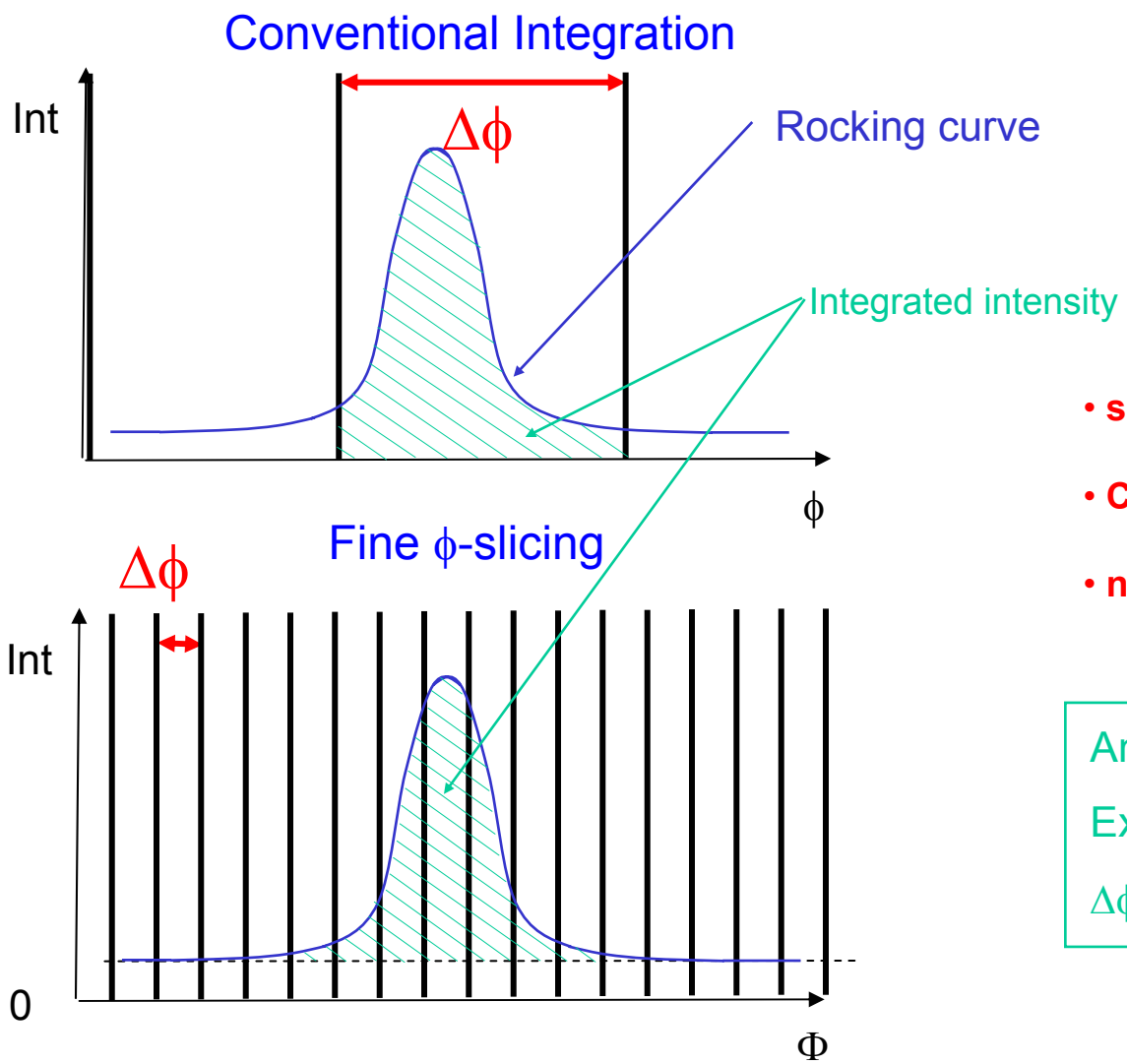
R_{sym} 8.4%

Resolution: 1.4 Å

Refinement:
R-Factor 28%

blue contours: 2*Fo-Fc (2sigma)
red contours: Fo-Fc (2sigma)

Fine ϕ-slicing with the PILATUS-Detector



- **short readout-time**
- **Continuous rotation -> no shutter**
- **no read-out noise**

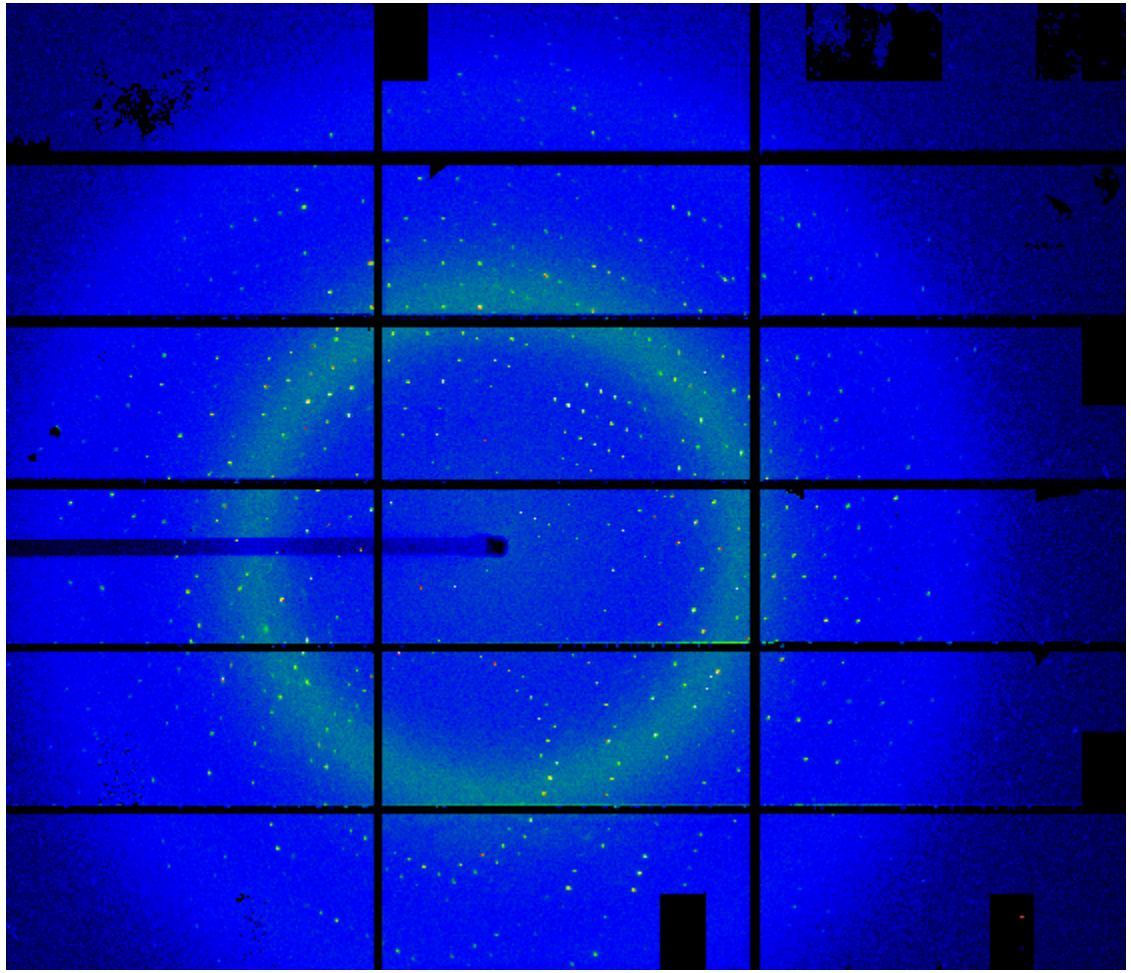
Angular speed ω,

Exposure time t

$\Delta\phi = t * \omega$

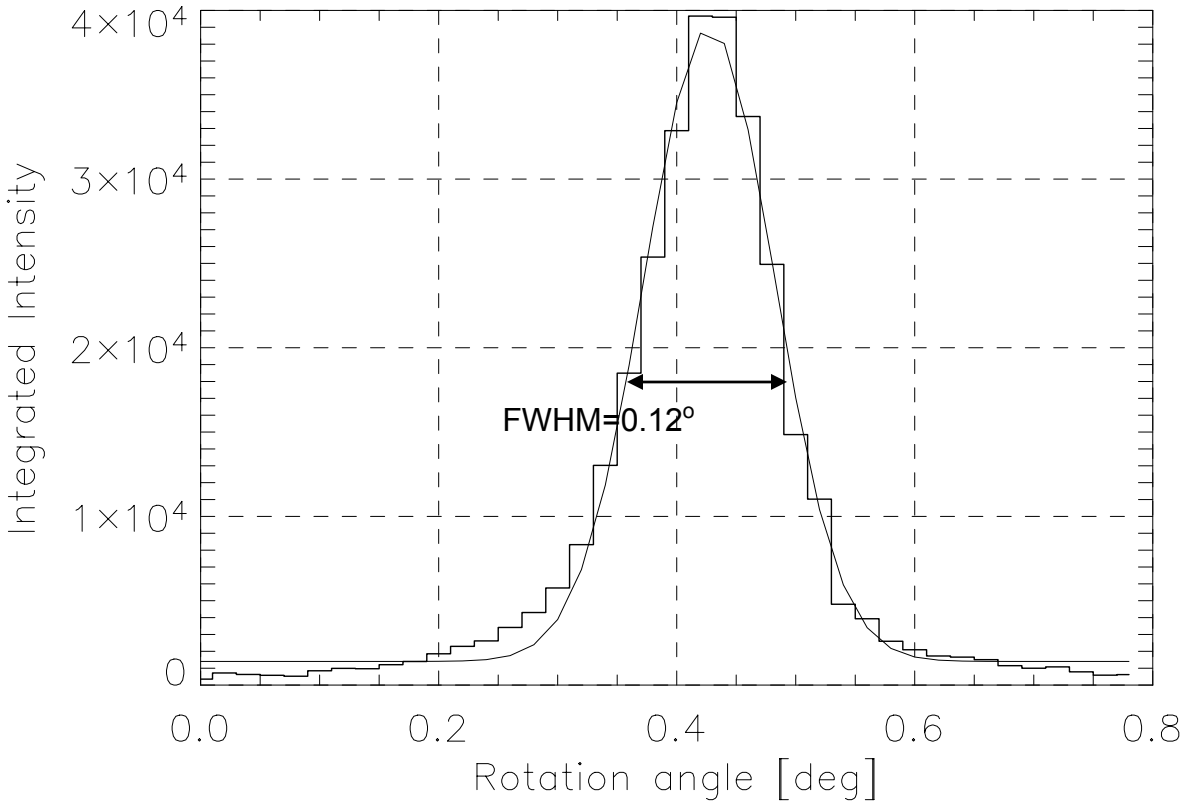
Fine-phi slicing with continuous sample rotation

(raw data)



Fine-ϕ sliced data-sets

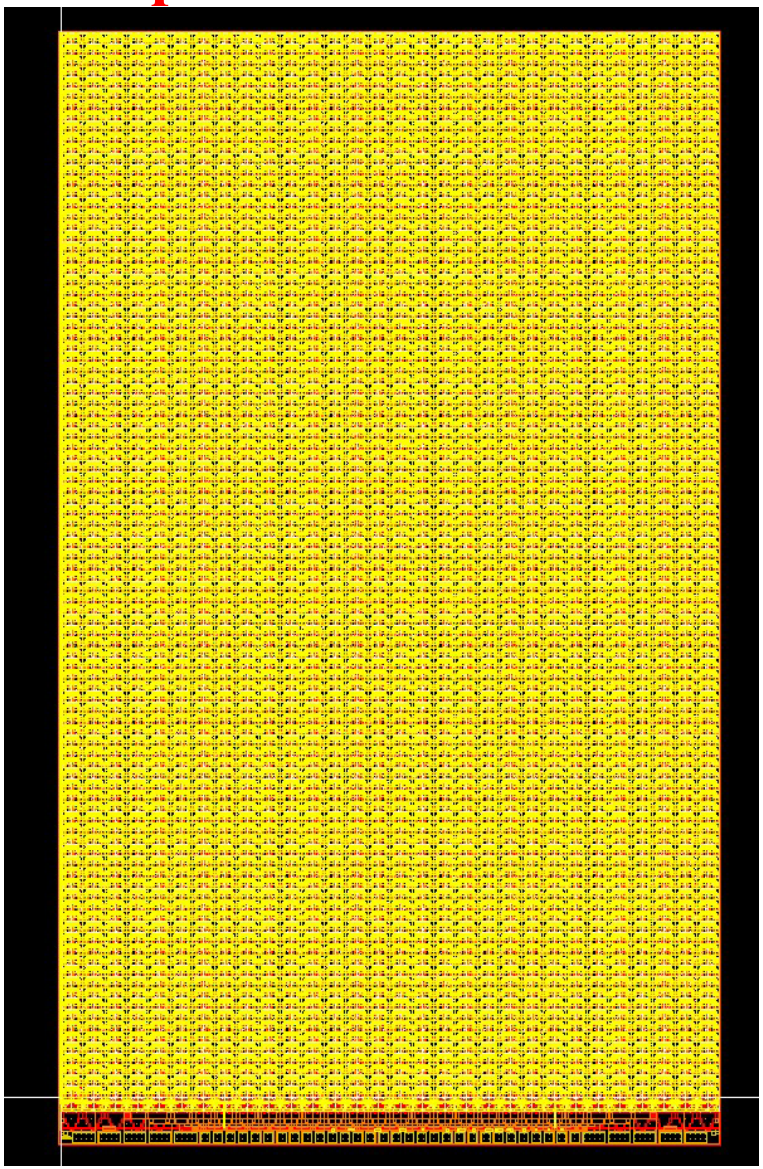
- Thaumatin crystal, 11.9keV, continuous sample rotation
- 1s exposure, 6.2ms read-out time, 180 deg
- 50 images/deg (0.02°/s)
- Complete data set ~ 9000s, 9000 frames
- data-set overexposed



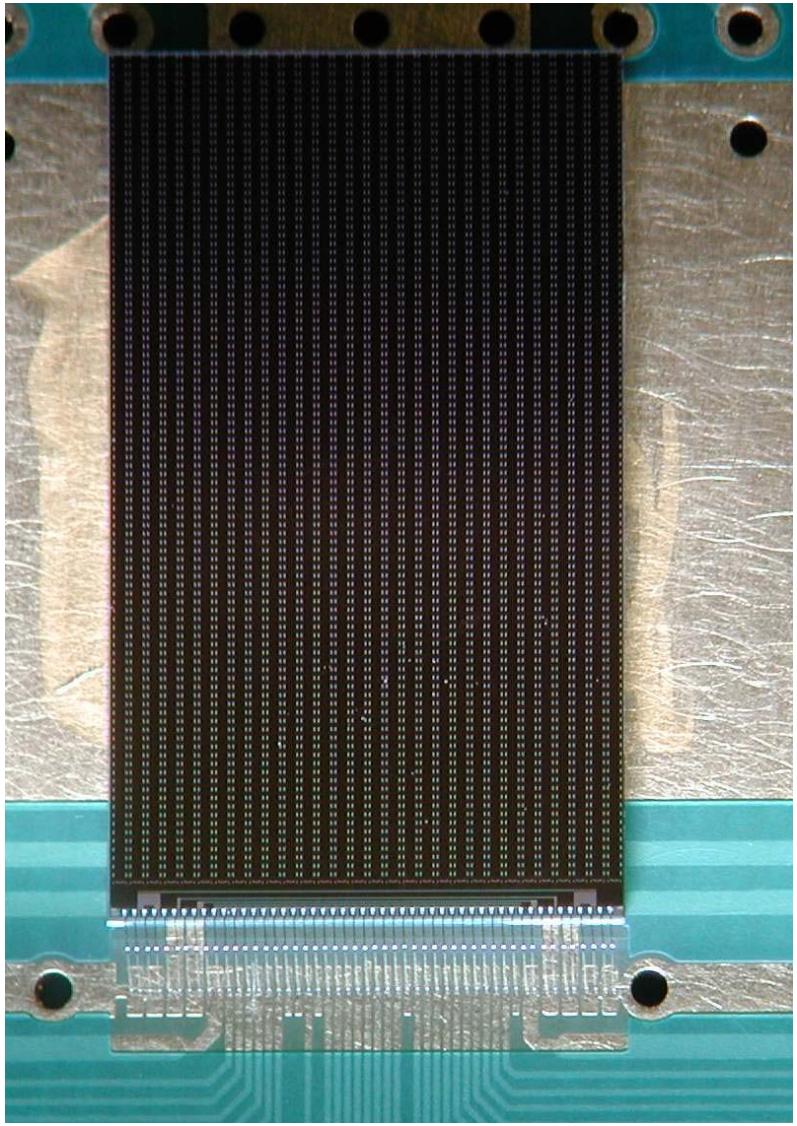
PILATUS II Chip

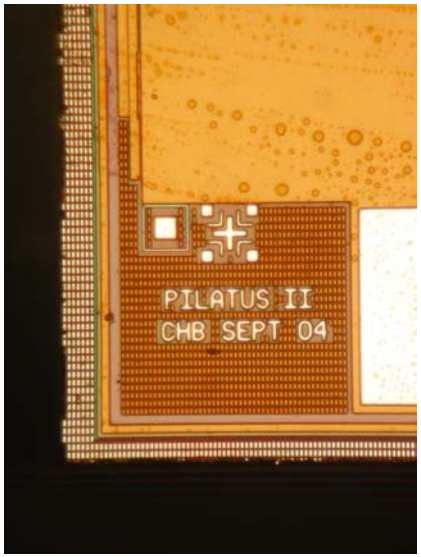
- UMC_25_MMC process; Radiation hard design
- 60 x 97 pixels = 5820 pixels
- Pixel size 172 x 172 um^2
- 17.540 x 10.450 mm^2
- Count rate: 1MHz/pixel
- 20 bit counter
- Counting timer circuit
- 6 bit DAC for threshold adjustment
- XY-adressable
- Analog output
- 100 MHz LVDS readout (T_{ro} = 1.2 ms)
- Submitted 29.09.04
- Received 1.12.04

$4*10^6$ Transistors

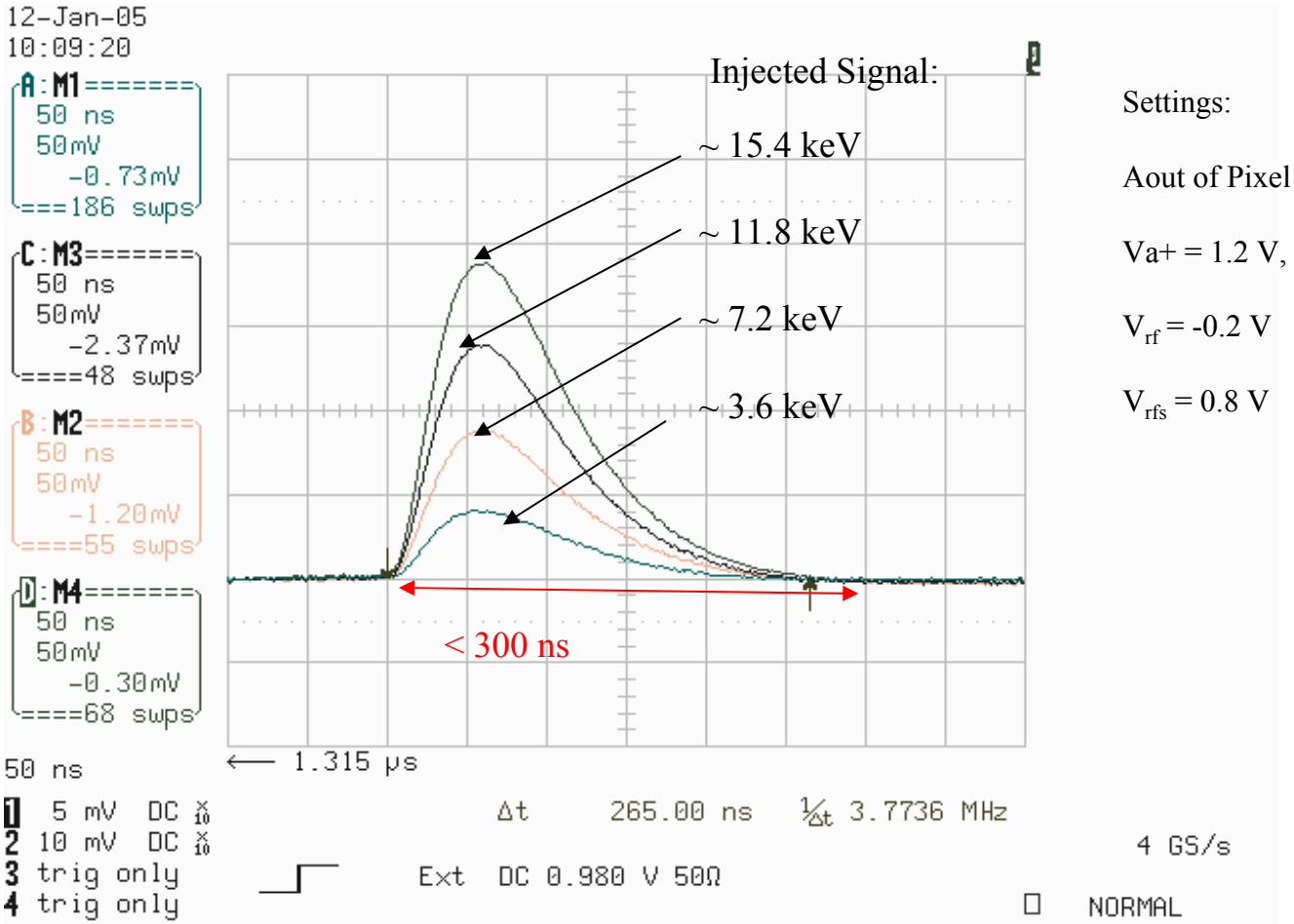


PILATUS II Pictures





PILATUS II: Analog Frontend Amplifier



Settings:

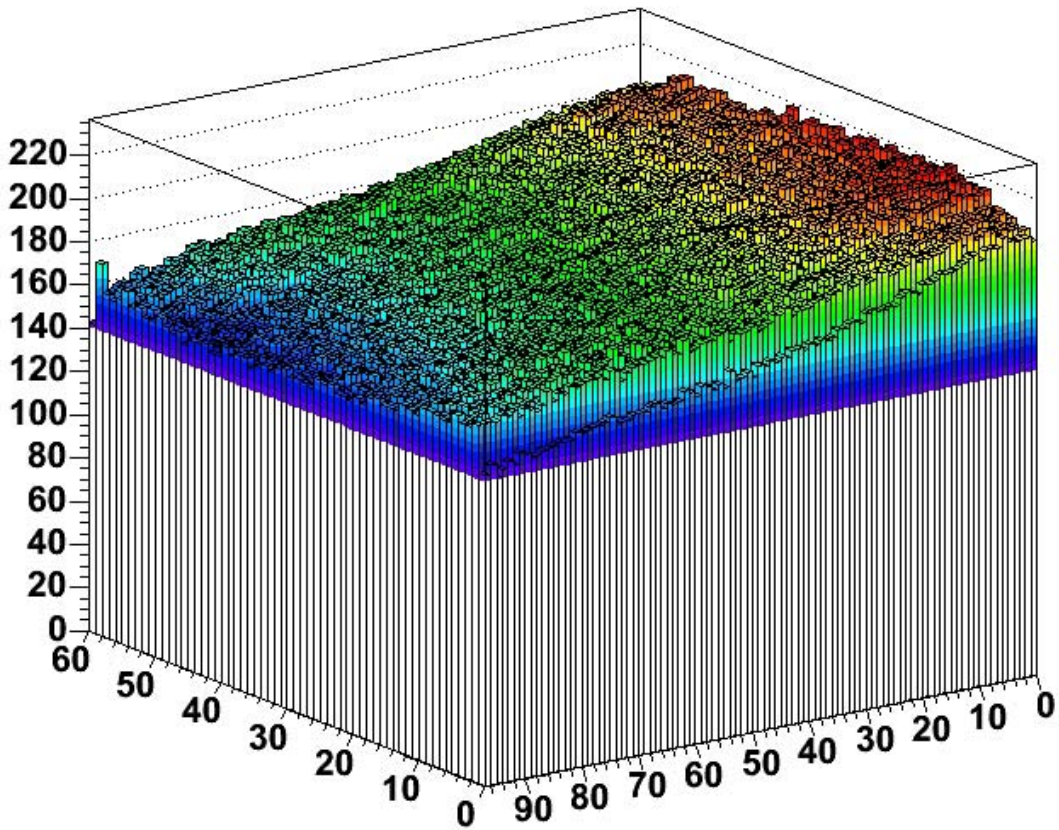
Aout of Pixel 0,0 (bottom left)

Va+ = 1.2 V, (I_{pix}= 13 µA)

V_{rf} = -0.2 V

V_{rfs} = 0.8 V

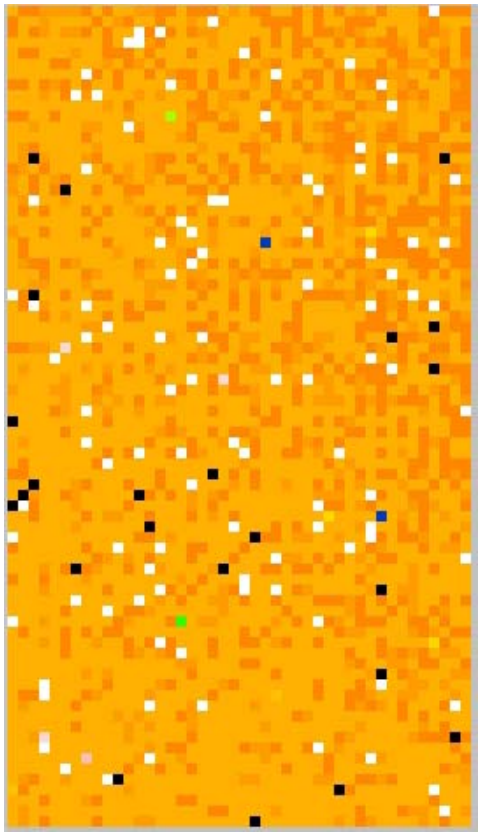
PILATUS II: Analog output of each pixel
E_{cal} = 12 keV



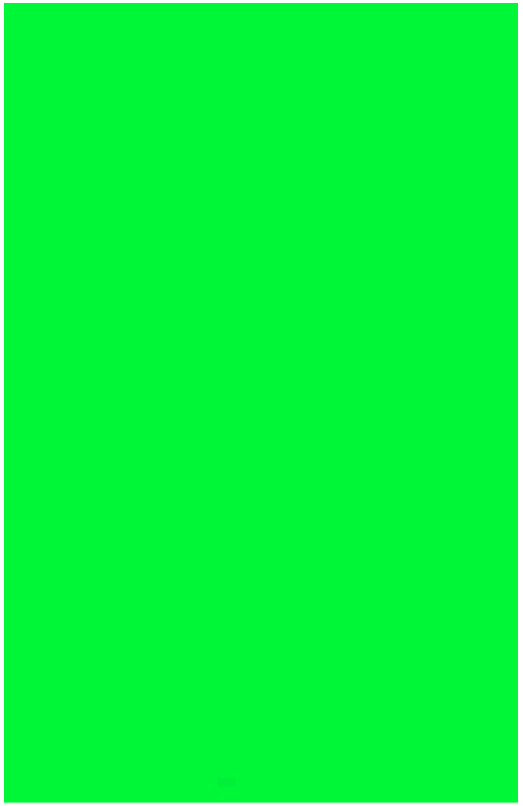
Threshold scans of SLS08-Chip (w.o. Sensor)

Comparison PILATUS I – PILATUS II Chip

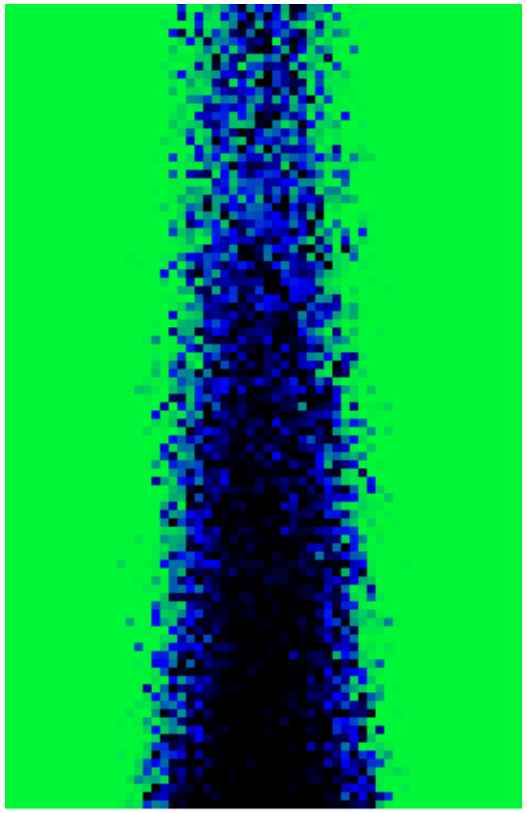
Calibrate Readback PILATUS I
(3432 pixels, 5% defects)



Calibrate Readback PILATUS II
(Vcal= 0.5V, 5820 pixels, 0 defects)



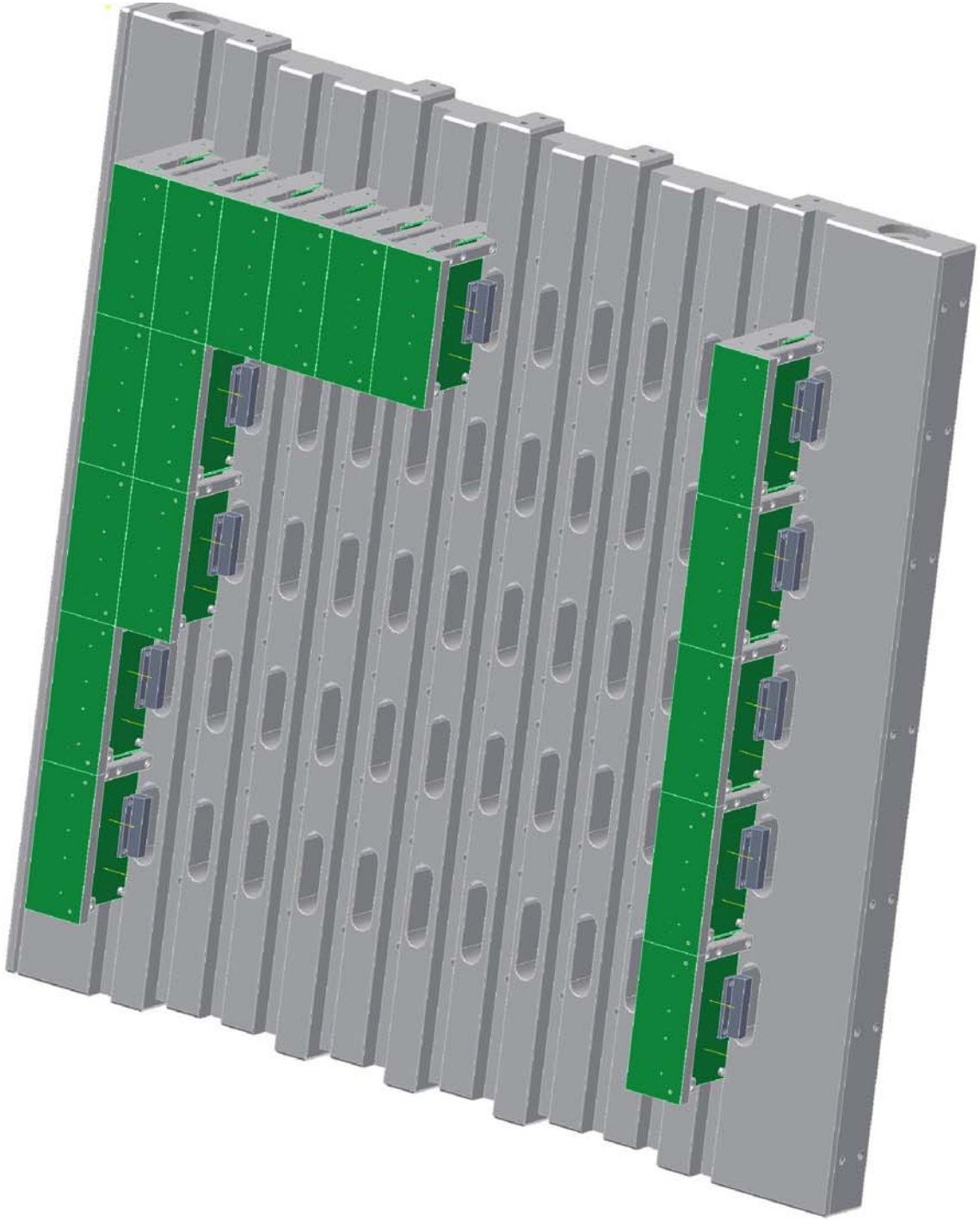
Calibrate Readback PILATUS II
(Vcal = 0.4 V)



The PILATUS 6M

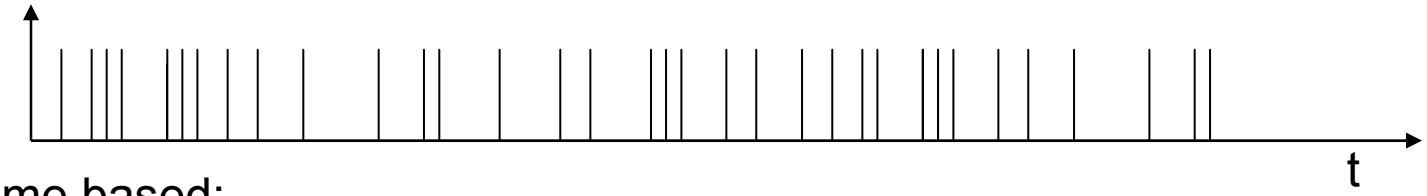
No of Modules	60
Module size	487 x 195 pixels (90k)
Detector Size	431 x 448 mm^2
No of Pixels	2527 x 2463 pixels (6M)
Spatial resolution	0.172 x 0.172 mm^2
Dynamic range:	20bits
Readout time	~2ms
Frame rate	5-10 Hz
Rate	1 MHz/pixel
Spatial distortion	Flat geometry
Dead area	~8.4 % (7 pixels in x, 17 pixels y)

Status: Currently under design

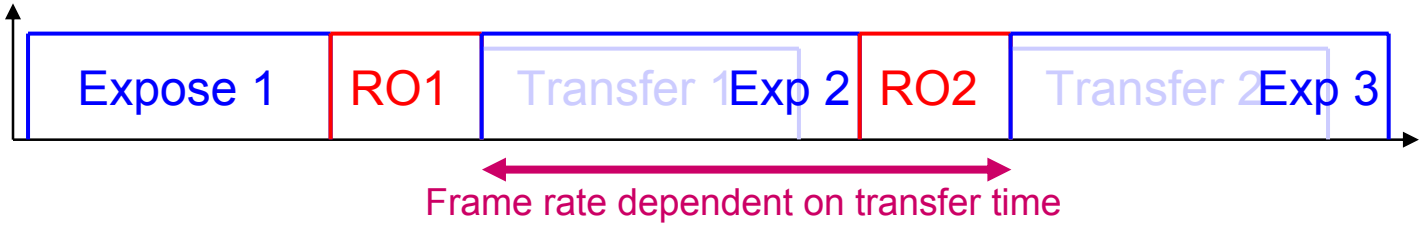


Ideas for the future

X-rays on detector:



Frame based:



Pilatus II Module: 100k pixel --> 200kBytes / frame

With fast PCI-DAQ cards: 100MBytes/s

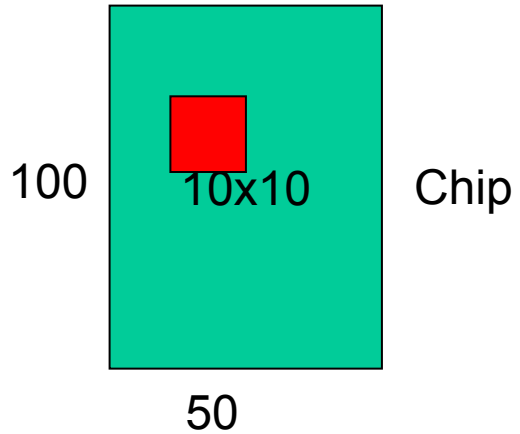
No of Modules	**Frame Rate**
2 Modules	-> 125 Hz
10 Modules (1M Pixels)	-> 30 Hz
60 Modules (6M)	-> 5 Hz

Region of Interest Readout (ROI)

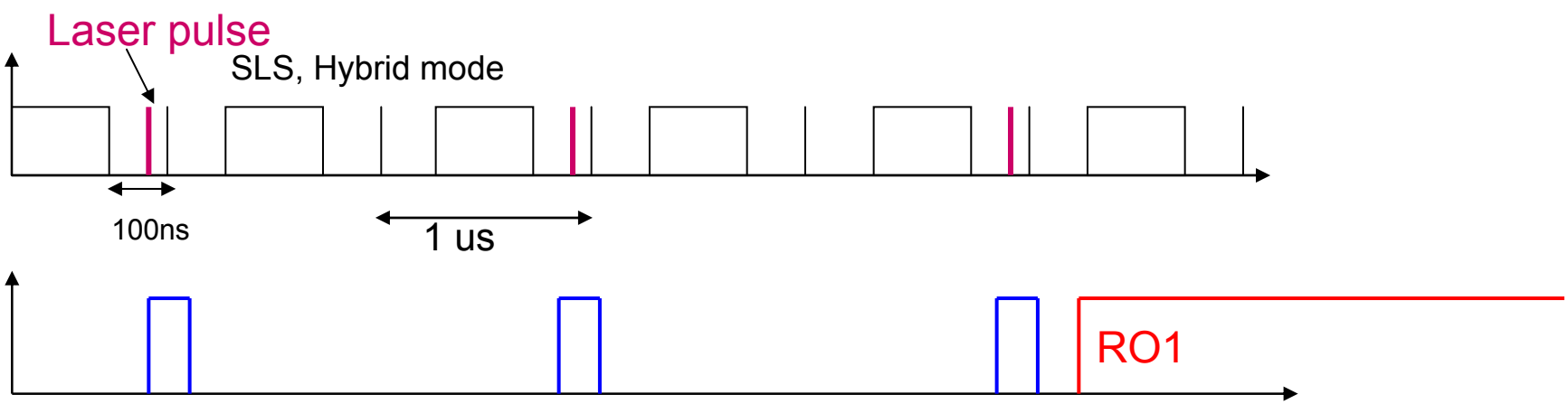
Implemented on chip level

RO: 10x10 pixels -> 20 us
Transfer: -> 100 us
Exposure = 100 us -> 100 X-rays/peak, BG=?

Frame rate -> 8000 Hz



Frame based, gated operation



Possible with Pilatus 6M Modules

Higher frame rates -> data reduction!

Image compression: e.g. difference btw neighbouring pixels in image, read out only necessary bits

Usual compression algorithms -> data reduction by a factor of 2.5

For short exposures, suppress zeros maybe factor of 10

Problem: BG extremely sample and position dependent

Fast framing pixel detector for the coherent SAXS BL

- Good quantum efficiency from 3 – 15 keV
- Rad-hard readout chip
- Single photon counting
- Pixel size: 40 x 40 to 60 x 60 μm^2
- Count rate: 1 MHz/pixel -> 3 x 10^8 x-rays/mm^2/s
- Array size: > 1000 x 1000 Pixels
- Frame rates:

  100 Hz for full readout

  >1 kHz, with data compression read-out

Currently under evaluation

Conclusion

Single Photon Counting Solid state detectors

- are still under development
- enable new experiments
- deliver excellent data
- can be developed application specific

Acknowledgements

R. Dinapoli, E.F. Eikenberry, B. Henrich, G. Hülsen, P. Kraft,
M. Naef, H. Rickert and B. Schmitt,
PSI, SLS Detector Group, Villigen-PSI, Switzerland

H. Toyokawa, M. Suzuki
JASRI, Spring 8, Japan

B. Patterson, C. Schulze-Briese, T. Tomizaki,
C. Pradervand, A. Wagner, P. Willmott
PSI, Villigen-PSI, Switzerland

R. Horisberger, S. Streuli, F. Glaus
PSI, Villigen-PSI, Switzerland