



PAUL SCHERRER INSTITUT



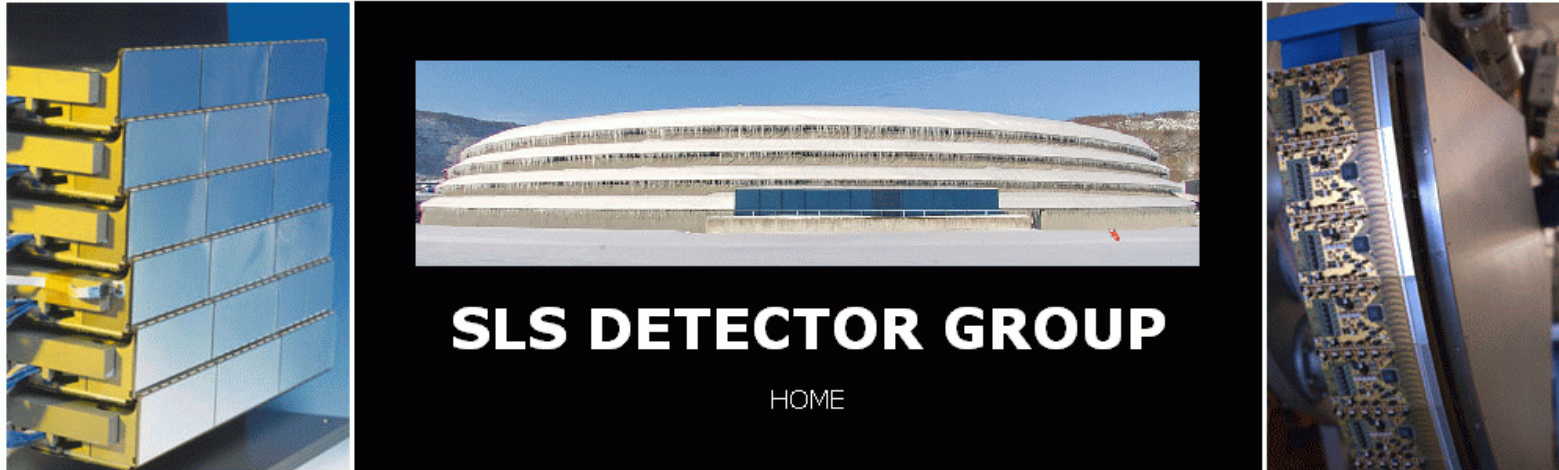
The PILATUS Detector for Protein Crystallography

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CH-5232 Villigen-PSI, Switzerland

PSI with the
Swiss Light Source
SLS



SNIC 2006, 3-6.4.06, SLAC



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

R. Horisberger, H.K. Kaestli, B. Meier*, S. Streuli*, et al...
*PSI, CMS-Pixel, Villigen-PSI, Switzerland, *IPP ETH-Zuerich*

D. Luethy, E. Schmid, G. Theidel, et al...
PSI, Electronics Departement, Switzerland

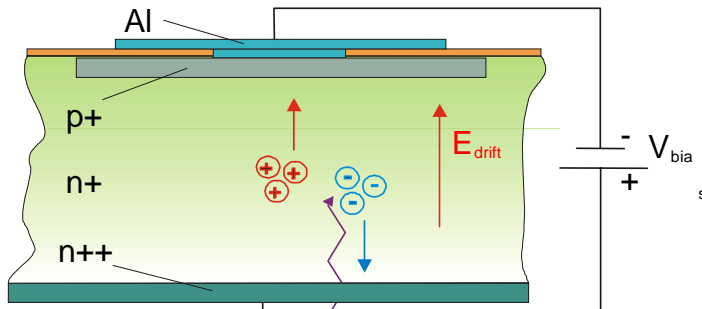
F. Glaus, J. Lehmann, et al...
PSI, LMN, Villigen-PSI, Switzerland

Collaboration with SPring 8, M. Suzuki, H. Toyokawa
JASRI, Spring 8, Japan

Solid State Pixel Detectors

Spin off from HEP

Sensor: Si pn-junction



3.6 eV to create 1 eh-pair

Sensor 0.32mm Silicon

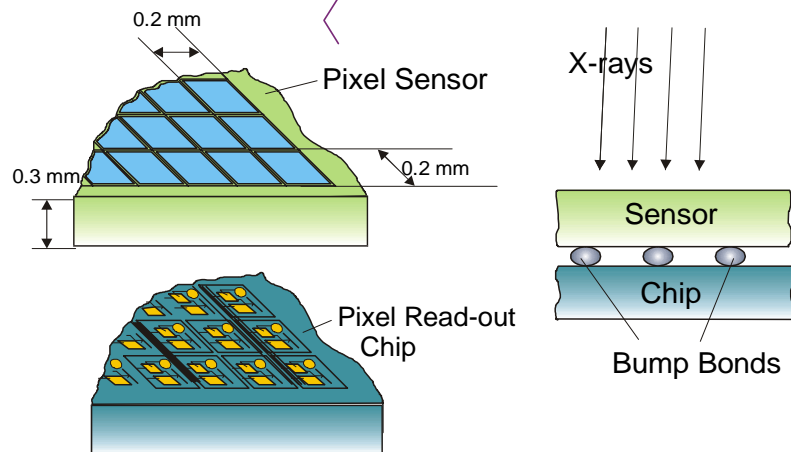
very good Q.E from 5 to 15 keV

- High quality p+ in n diode array

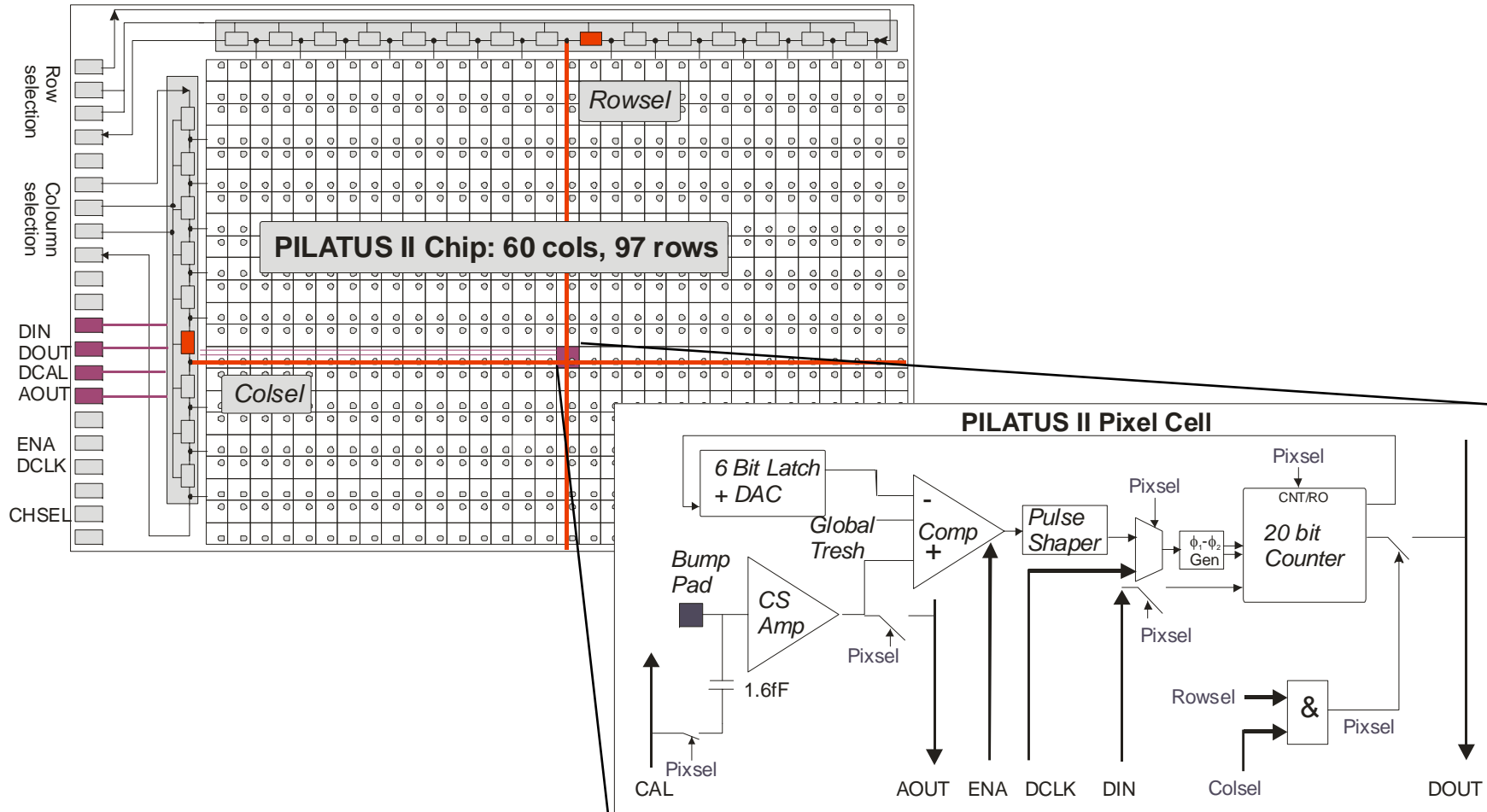
directly coupled to

- High quality input transistors on modern CMOS VLSI chip

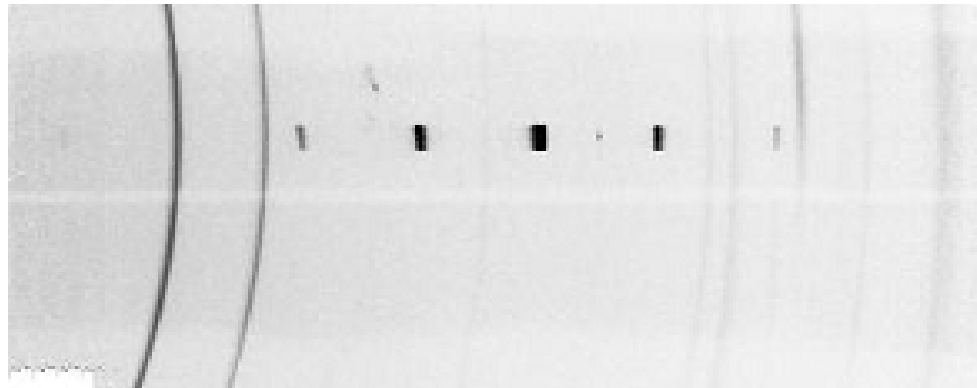
Pixel Detector (2D)



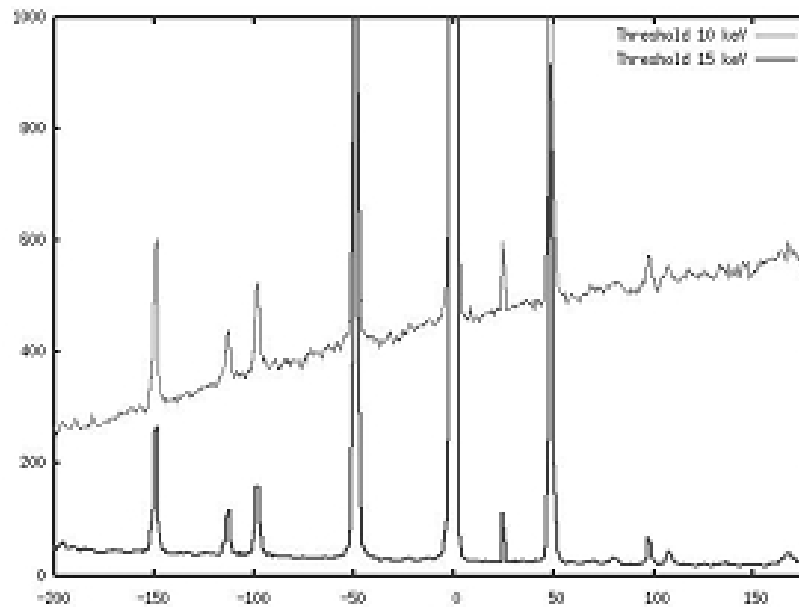
PILATUS chip architecture: Single photon counting electronics



Single Photon Counting: Fluorescent background suppression

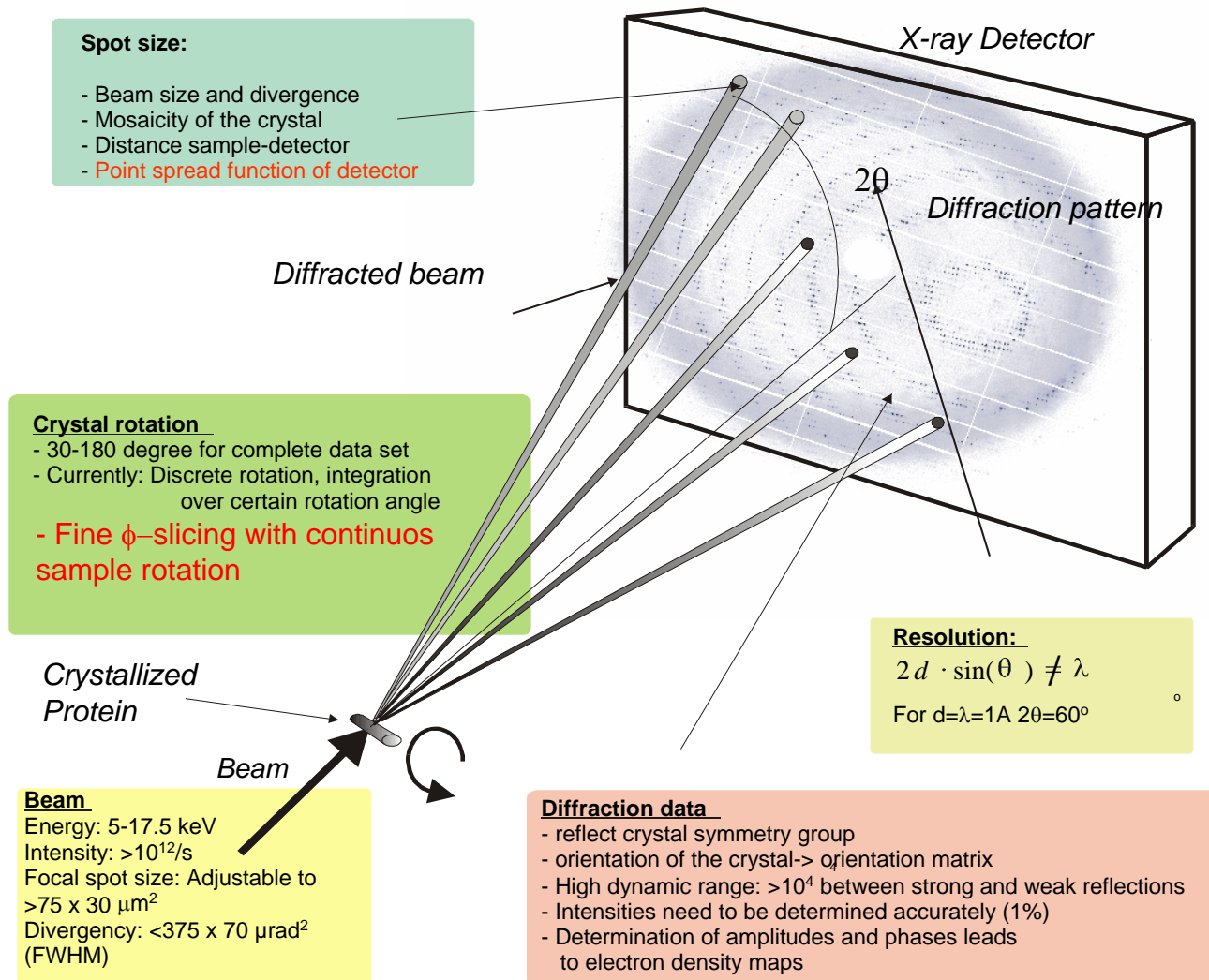


Diffraction pattern from GaAs/AlAs sample at an 18 keV X-ray beam



Results for 2 different threshold settings

Pixel Detectors for Protein Crystallography



Bump-Bonded Multi-Chip-Module (PILATUS I)

- Pixel size $0.217 \times 0.217 \text{ mm}^2$
- Chip has 44×78 pixels
- 16 chips bump-bonded to 1 Silicon Sensor
- Module has 366×157 pixels
- Active Area is $79.4 \times 34.1 \text{ mm}^2$

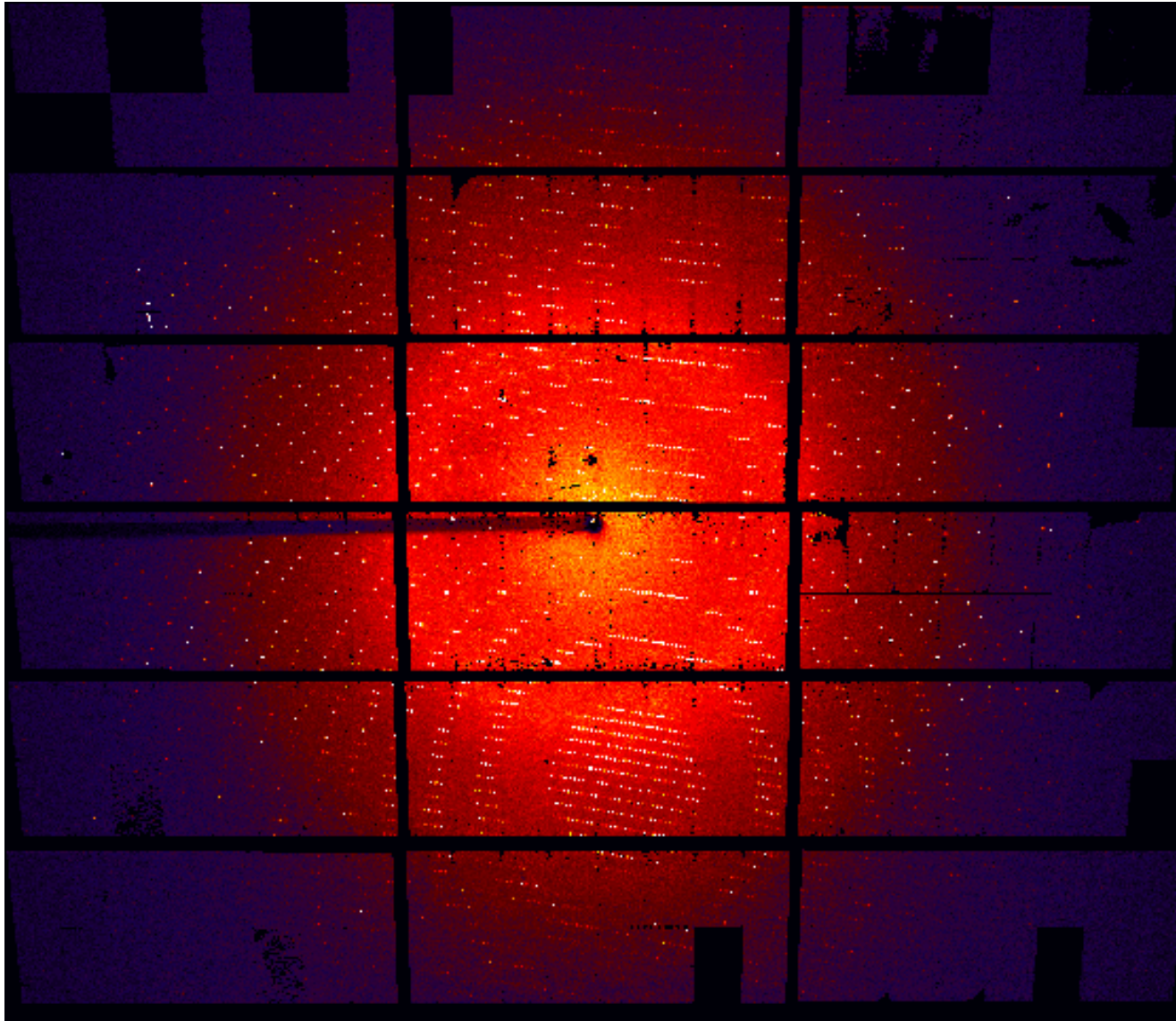


The PILATUS 1M Detector for Protein Crystallography

- Finished in Fall 2003
- First large area pixel detector for Protein Crystallography (Prototype)
- 6 banks a 3 modules, 1120 x 967 pixels
- Area: 21 x 24 cm²
- Readout time: 6.7ms
- 2 frames/ s
- Fine- ϕ slicing with continuous sample rotation
- Active area: 85%
- Moderate count rates (<10kHz/pixel)
- PX Data processing difficult due to limitations of PILATUS I chip
- Extremely important for further development of pixel detectors for PX



*Brönnimann et al., J. Synchrotron Rad., 13, 2005,120-130.
The Pilatus 1M Detector.*



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

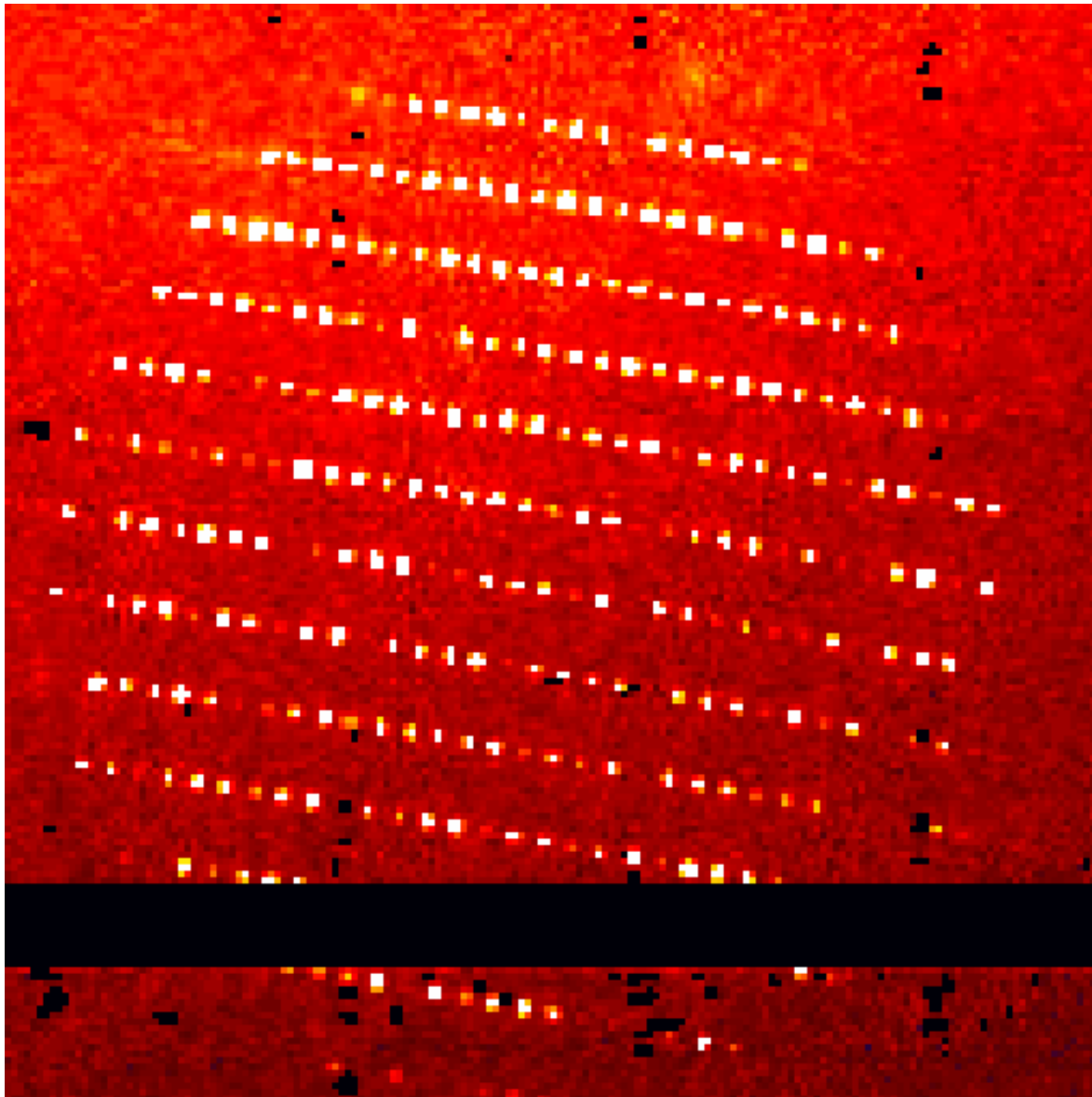
Analysis:

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

Merging of 3 datasets at 3 positions

Processing with XDS

Refinement with SHELXL

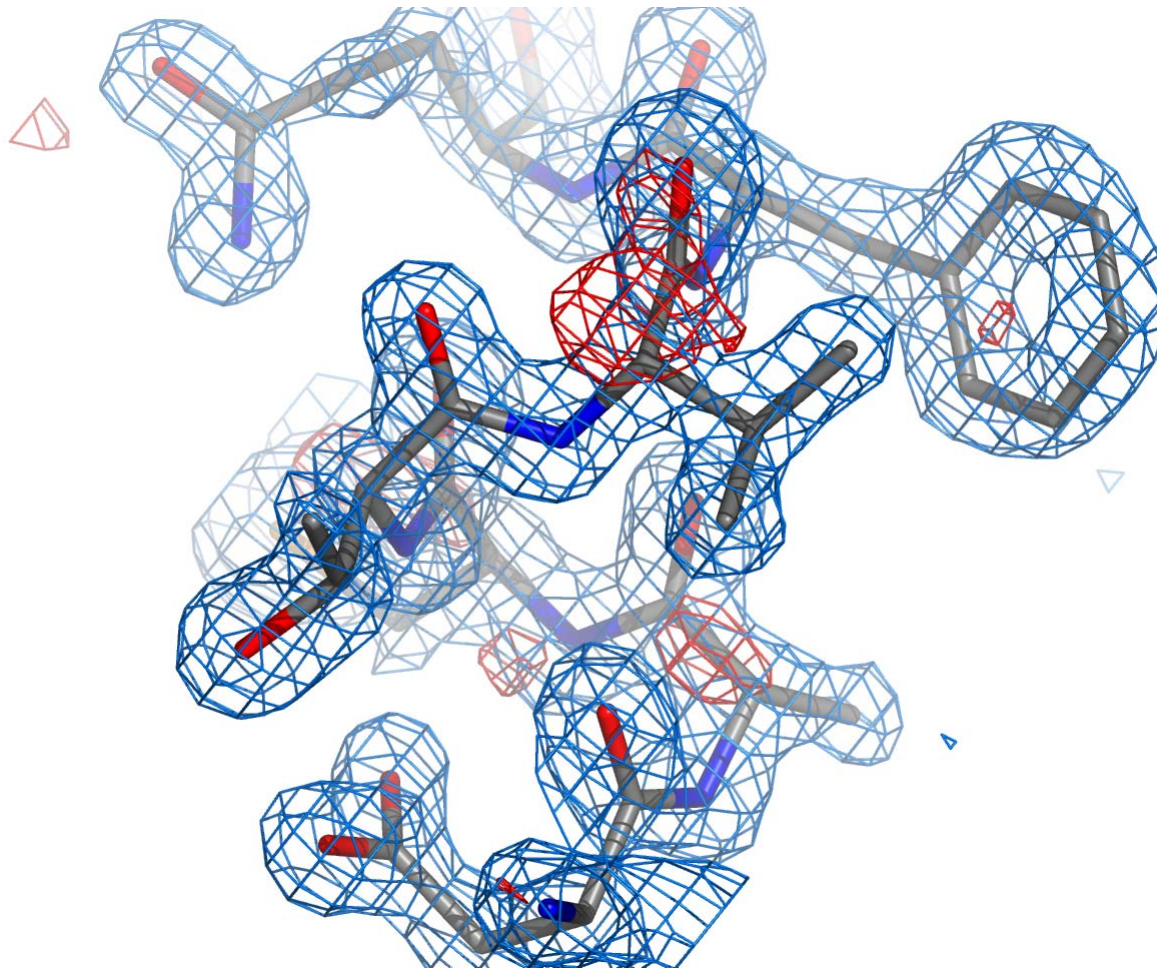
Completeness: 90.3%

R_{sym} 8.4%

Resolution: 1.4 Å

Refinement:
R-Factor 28%

blue contours: $2 \cdot \text{Fo} - \text{Fc}$ (2sigma)
red contours: $\text{Fo} - \text{Fc}$ (2sigma)



•Hülsen *et al.*, *Nuc. Instr. and Meth. A*, **548**, 2005, 540-554.

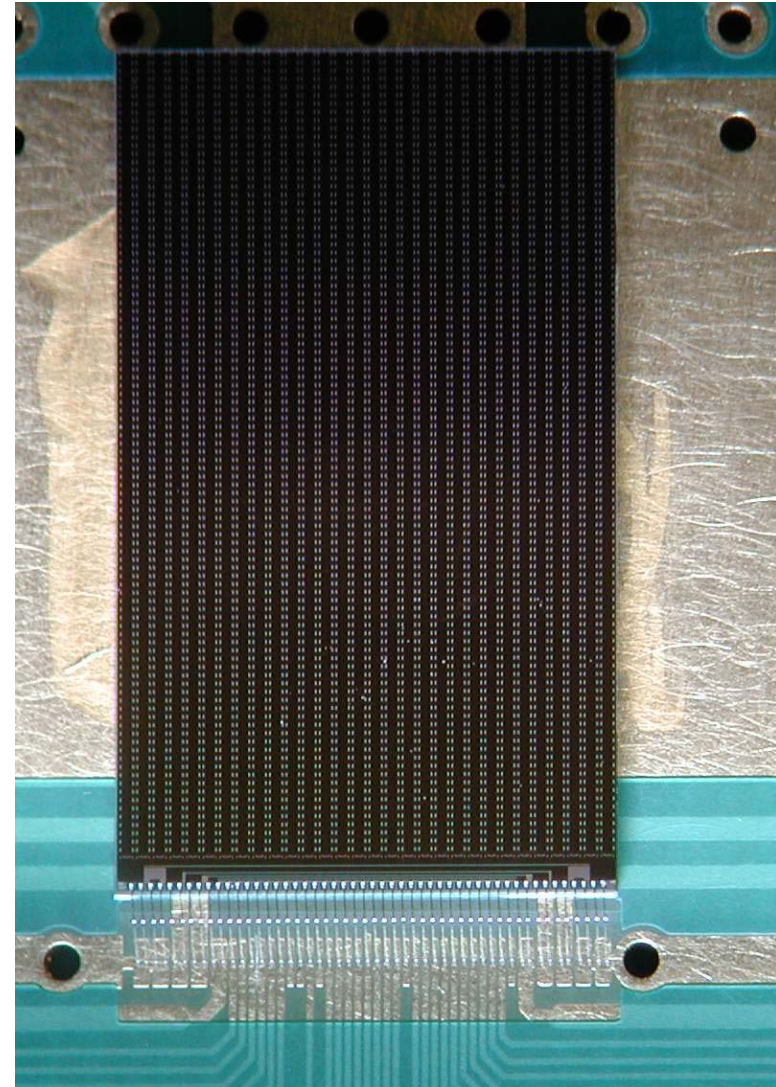
Distortion Calibration of the Pilatus 1M Detector.

•Hülsen *et al.*, *J. Appl. Cryst.*, 2006, accepted

Protein Crystallography with a Novel Large Area Pixel Detector

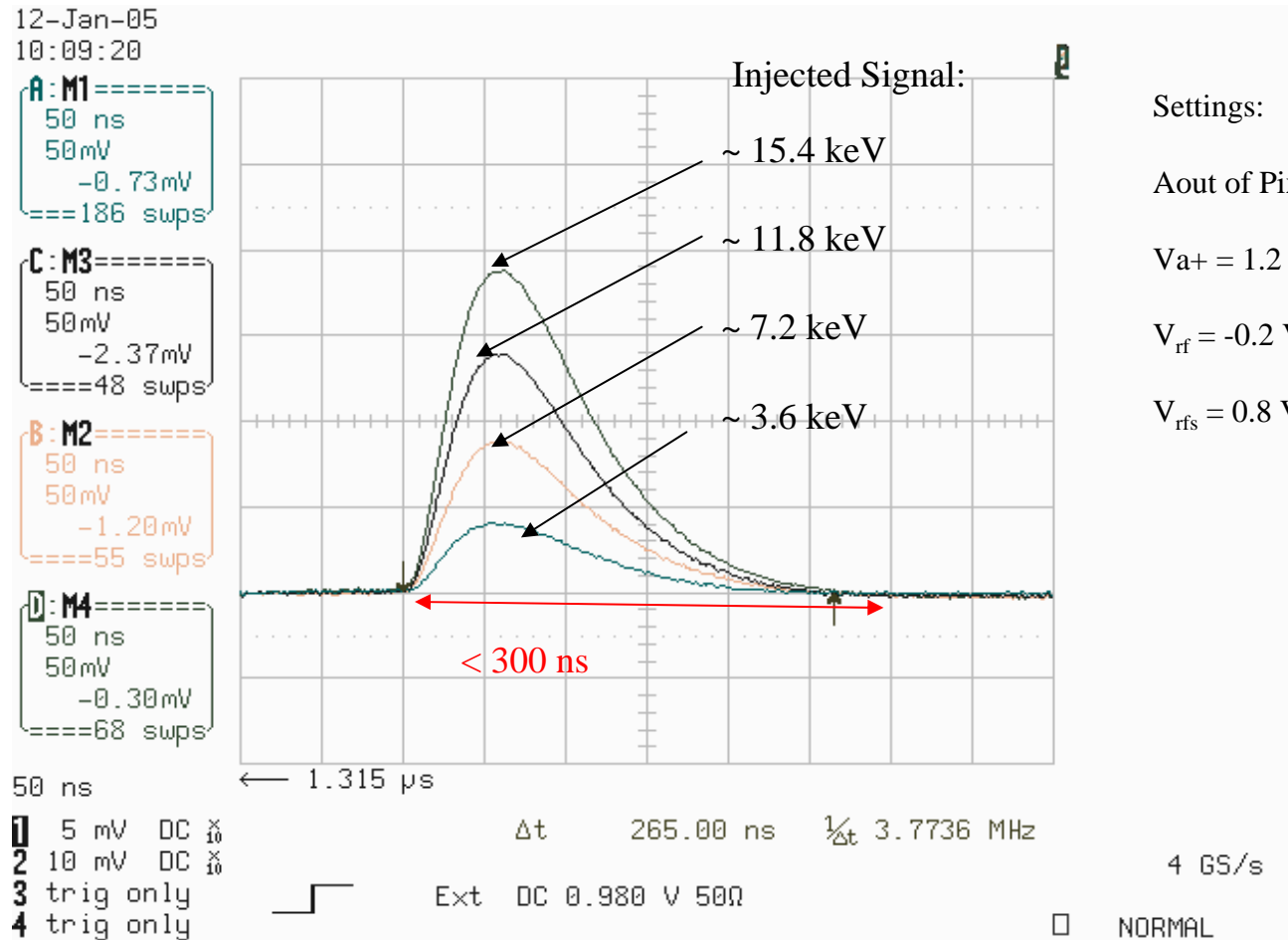
PILATUS II Chip

- Improvement of the PILATUS I Chip
- Radiation hard design
- 60 x 97 pixels = 5820 pixels
- Pixel size 172 x 172 μm^2
- 17.540 x 10.450 mm^2
- Count rate: 1MHz/pixel
- 20 bit counter/pixel (1'048'575 X-rays)
- 6 bit DAC for threshold adjustment
- $T_{\text{ro}} = 5 \text{ ms}$
- Submitted 29.09.04
- Received 1.12.04



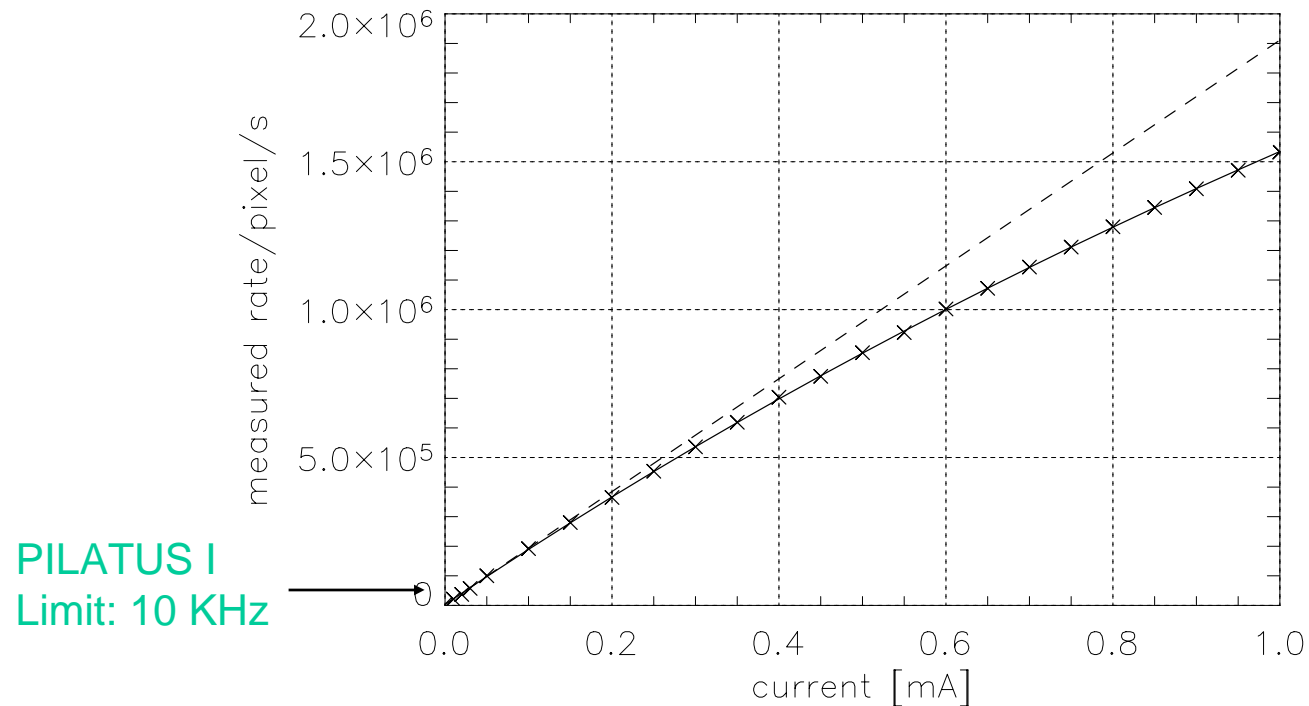
Philipp Kraft, Characterization of the Readout Chip for the PILATUS 6M Detector, ETHZ-IPP Internal Report 2005-03 (March 2003)
Available on-line

PILATUS II: Analog Frontend Amplifier



PILATUS II Rate Tests

8keV X-rays, avg rate of 20 pixels



Paralyzable counter:

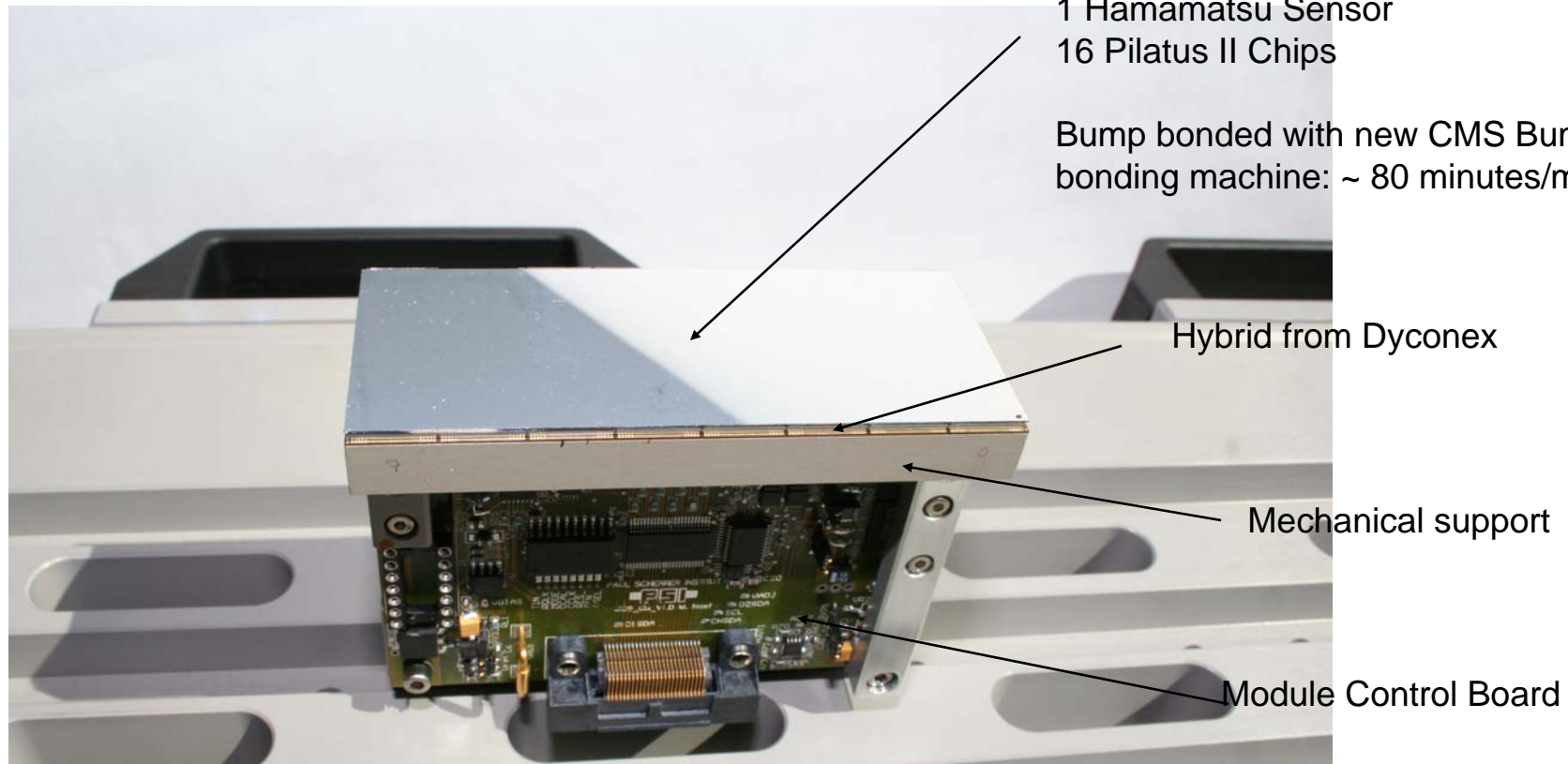
$$R' = a \cdot x \cdot e^{(-a\tau x)}$$

$$\tau = 113 \text{ ns}$$

Count Rate capability:

$$\sim 3 \cdot 10^6 \text{ X-rays/s/pixel} = \sim 10^{10} \text{ X-rays/s/cm}^2$$

PILATUS II Module



Module Parameters:

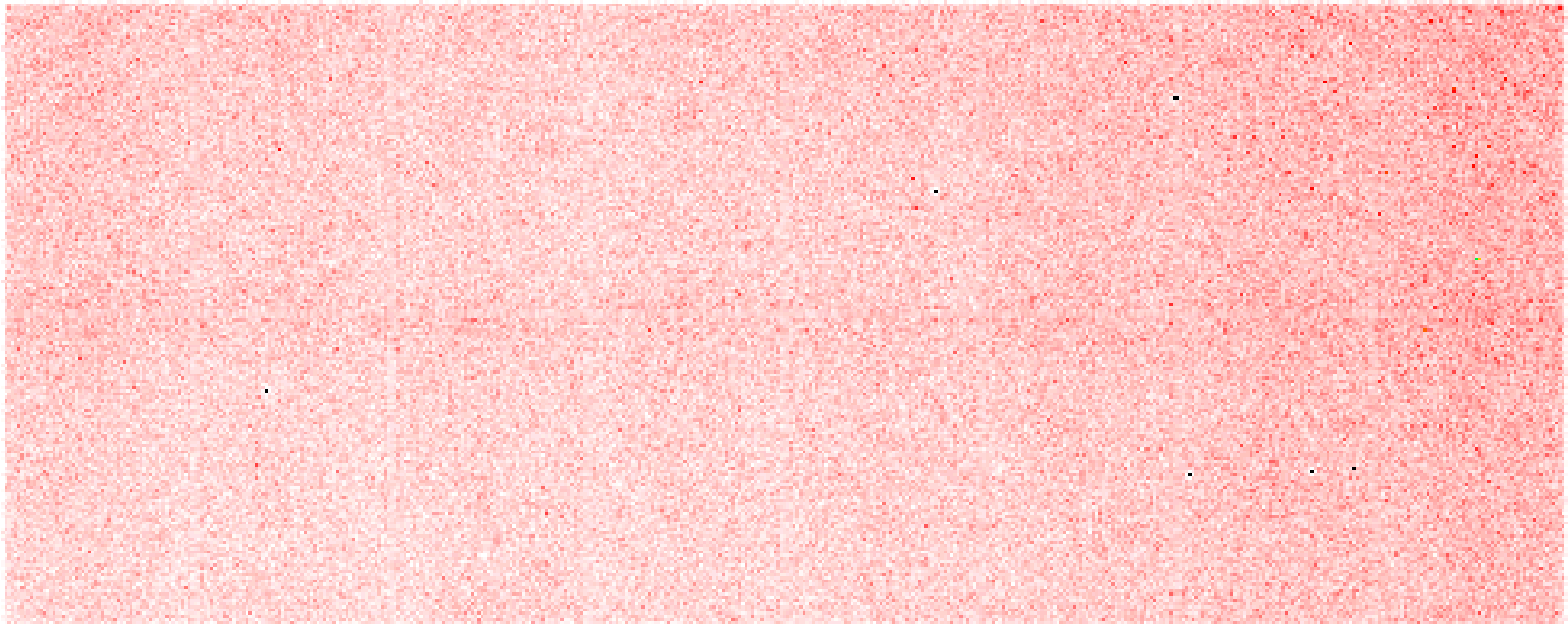
$487 \times 195 = 94'965$ pixel

$T_{ro} = 5$ ms

Maximum Frame Rate with Gigastar PCI Card: 150 Hz

Bump bonding quality

Module 58: Flatfield illumination with 6.4 keV X-rays, 7 dead pixels



Bump bonding quality

Pilatus 1M: 5% defect Pixels/module

Pilatus II Module: 100'000 pixels

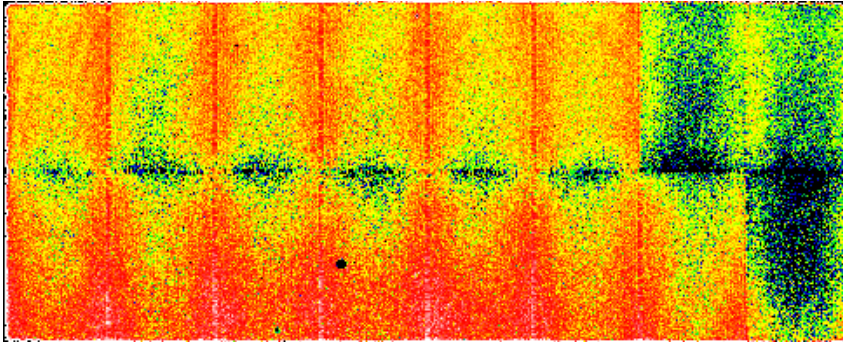
Goal: < 0.1% pixels, (<100 pixels)

Mod Nr	Date	Total defect pixels
39	2006-01-31	0.004 [%]
55	2006-03-20	0.005 [%]
40	2006-02-01	0.015 [%]
56	2006-03-23	0.028 [%]
36	2006-01-30	0.031 [%]
43	2006-02-03	0.035 [%]
35	2006-01-23	0.043 [%]
41	2006-02-02	0.043 [%]

Pilatus II module database, top 8 modules

PILATUS II Stability

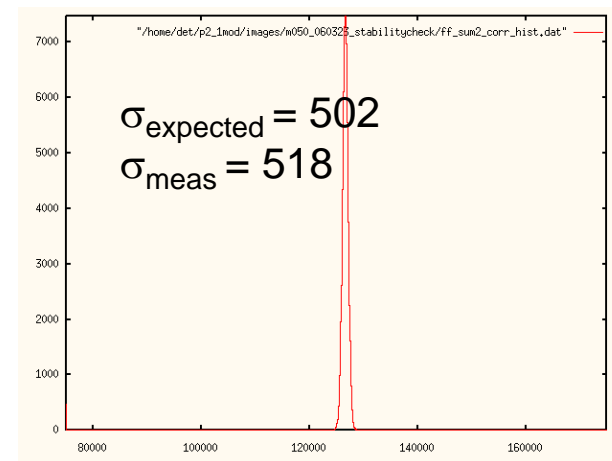
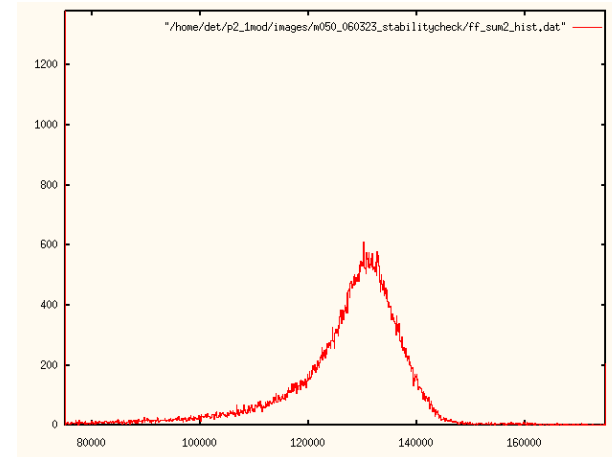
Flatfield illumination with 6.4keV X-rays,
t=10 hours, untrimmed



Flatfield correction with
2nd image (10 hours,
untrimmed)



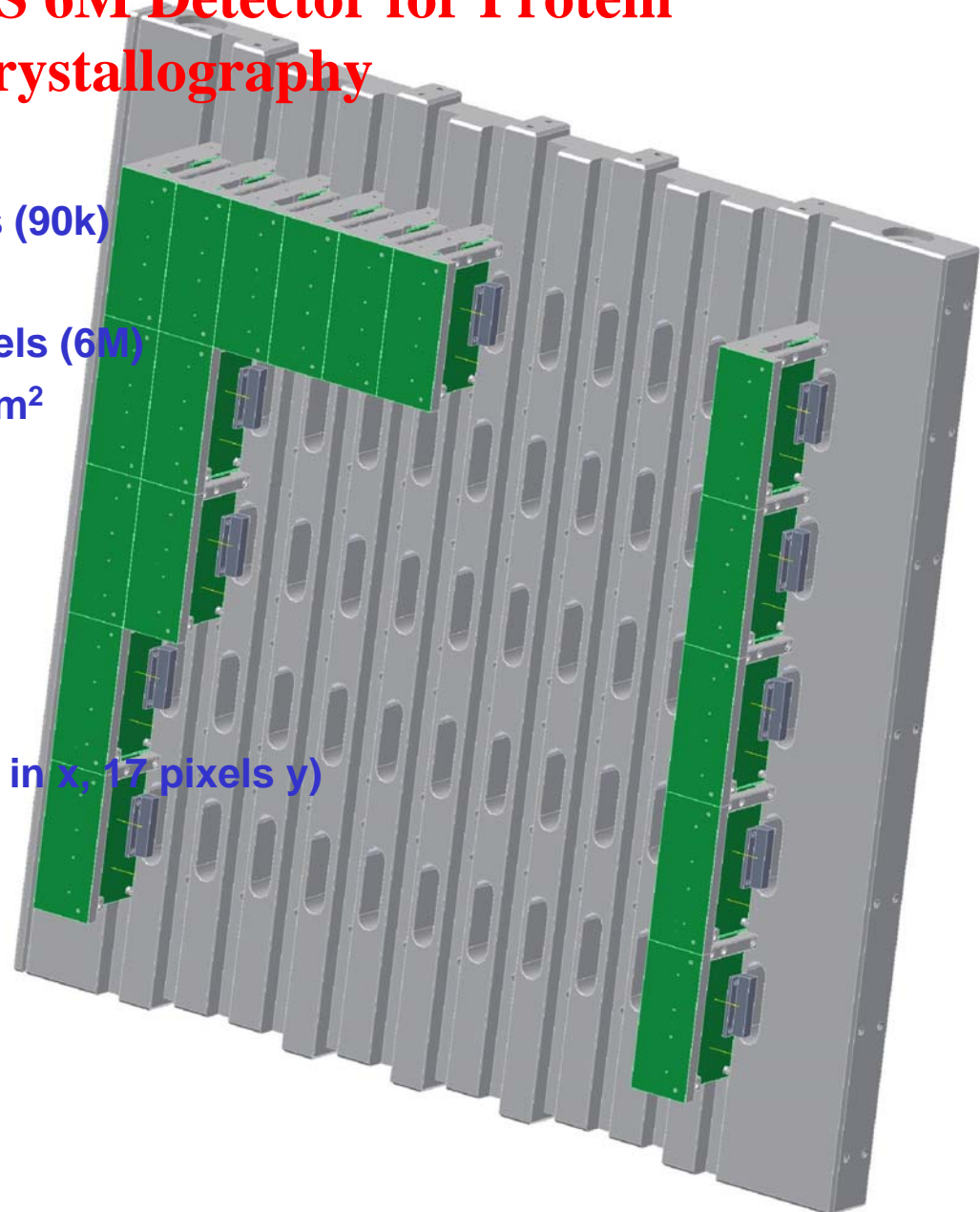
Images displayed with the same contrast



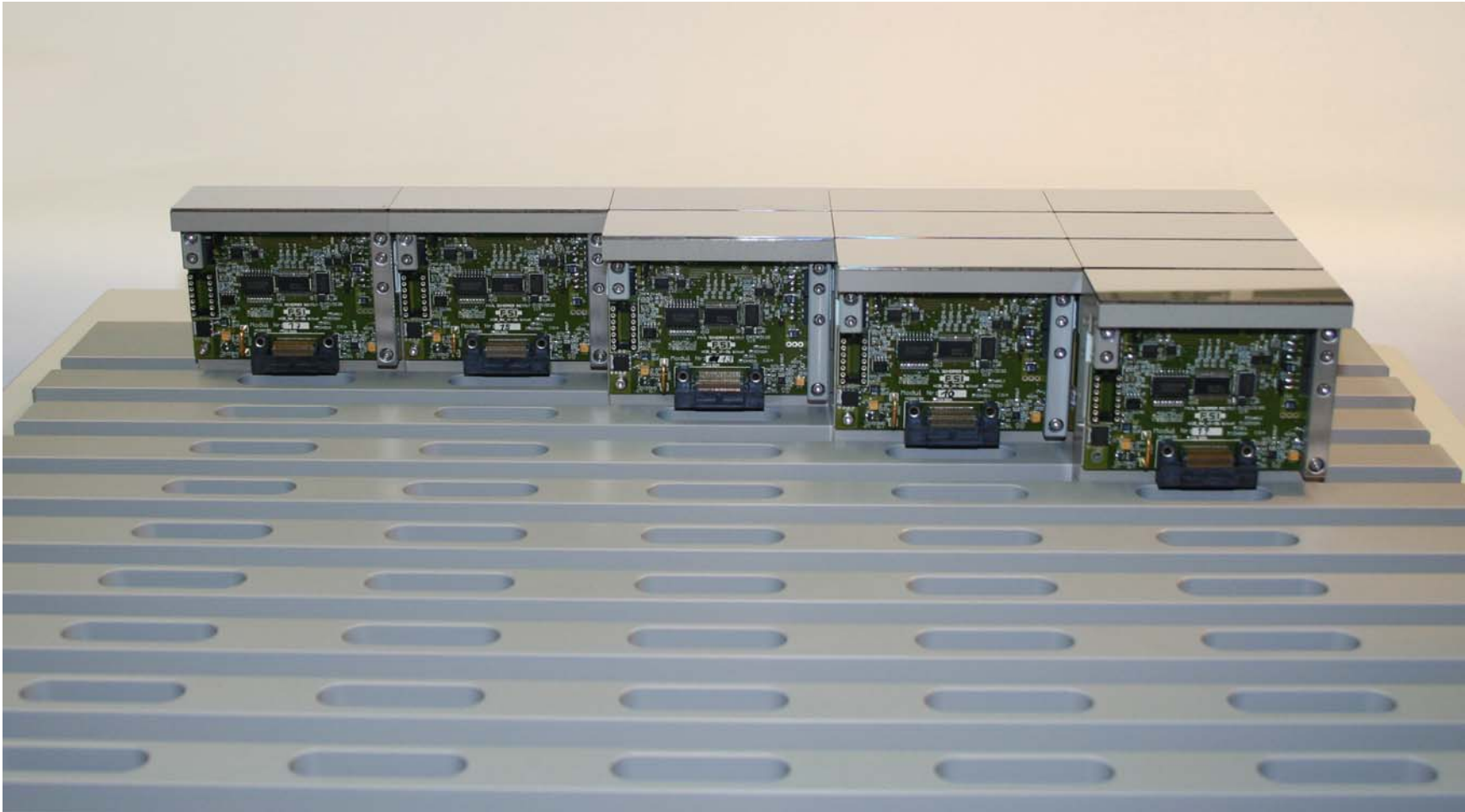
The PILATUS 6M Detector for Protein Crystallography

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: Module Production started



PILATUS 6M Detector: Construction



11 modules mounted on mechanical frame

PILATUS 6M Detector: 2 Bank Test-Setup

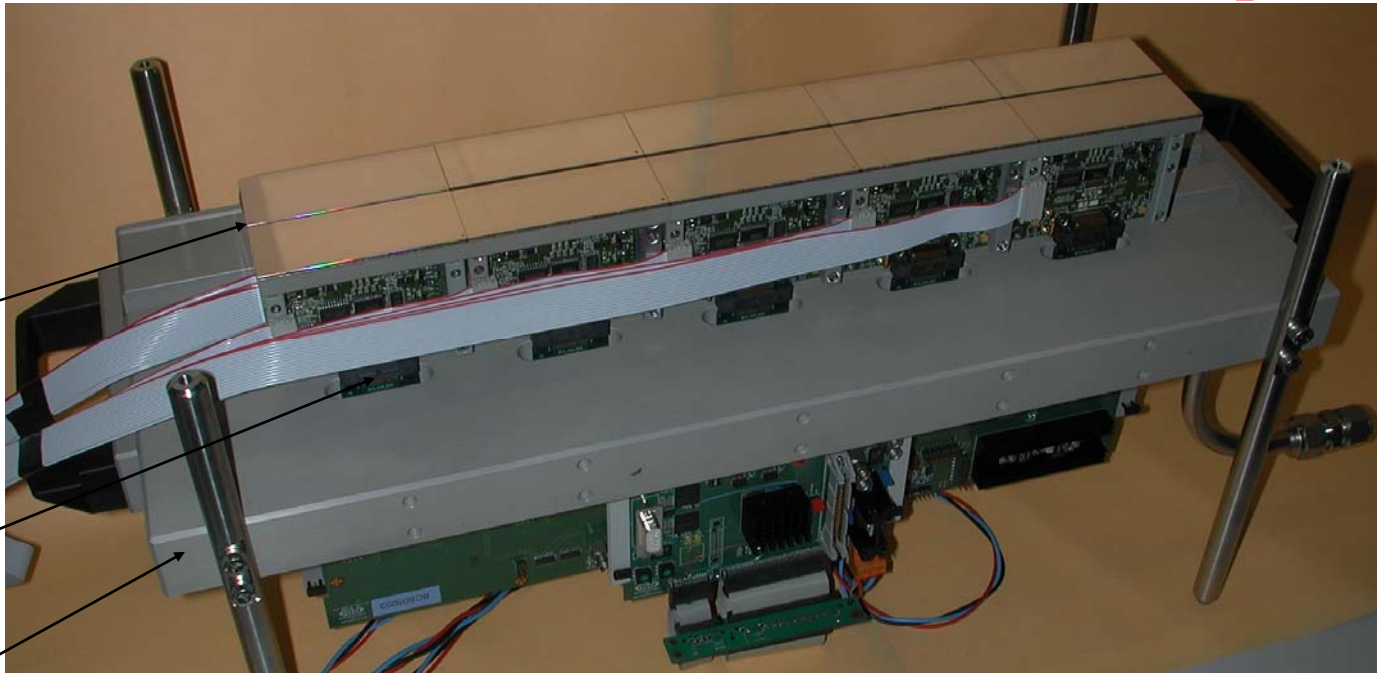
5x2 modules
(42 x 8 cm²)

Module
connector

Water cooled frame

Bank control board (BCB)
(5 Modules)

Detector Control
Board (DCB)



PILATUS 100 K Detector System

Complete X-ray Camera System,
including Powersupply, PC, Software

Radiation hard design

No of pixels: $487 \times 195 = 94'965$ pixel

Pixel size: $172 \times 172 \mu\text{m}^2$

Dynamic Range/pixel: 20 bits

Read out time: $T_{ro} = 5 \text{ ms}$

Energy Range: 3 – 30 keV

Total Power Consumption: 15 W

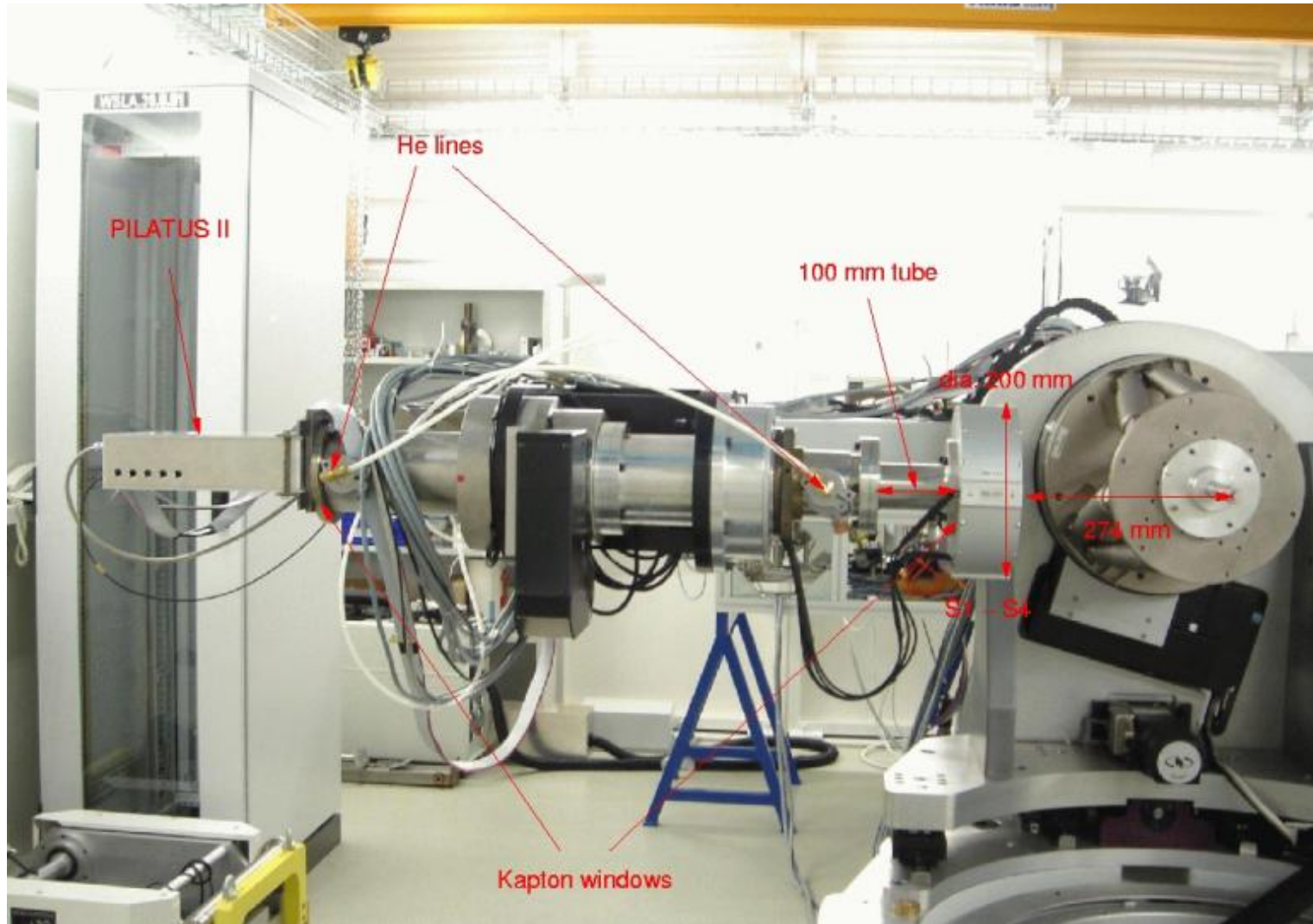
Frame Rate, PCI RO system: 100 Hz

Air cooled, very simple operation

Electronic shutter, external synchronisation



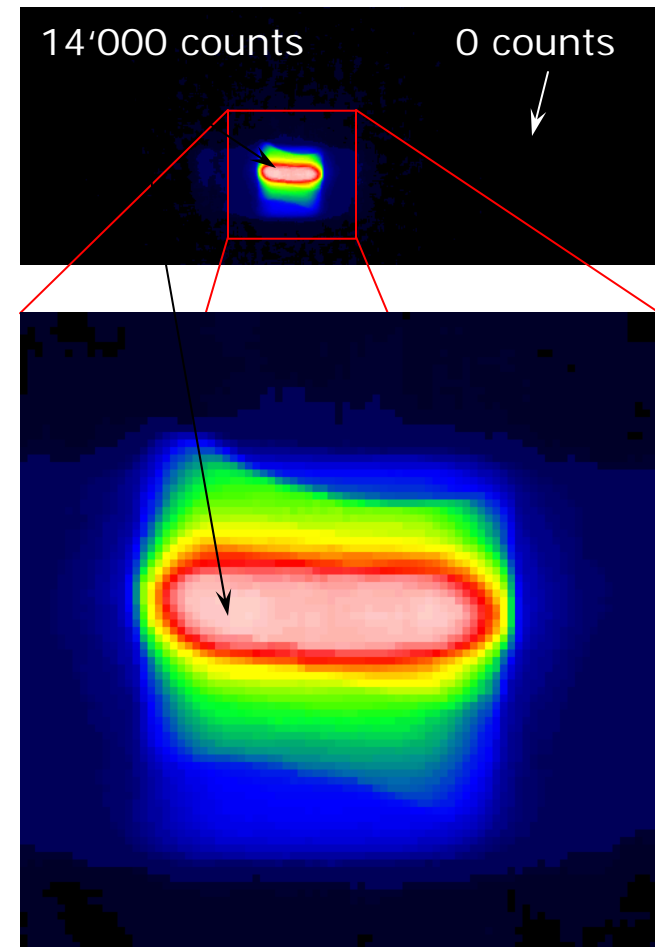
PILATUS 100K @ BL X04SA



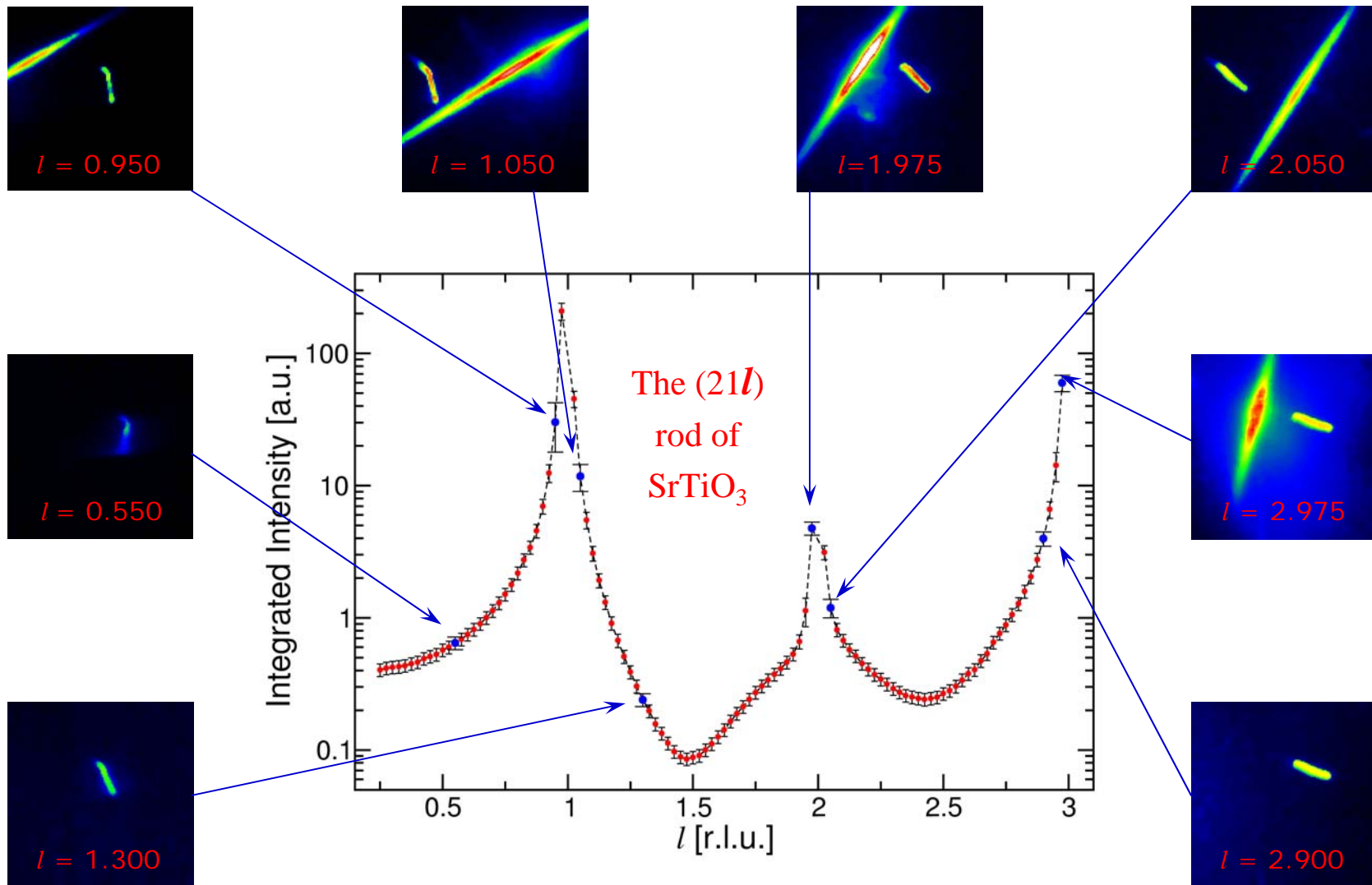
Direct beam on the detector

Example (right):

- Looking at defocussed direct beam
- Integrated signal of 9.6 Mcounts in 0.005 seconds!
- Maximum count rate = 2.7 Mcounts/s (nonlinear)



Recording CTRs with PILATUS



Summary

Single photon counting pixel detectors are becoming more and more mature
-> much higher local and global count rates, better quality and stability

Pilatus 100k is beginning to be commercially available

Main focus lies on PILATUS 2M/6M: Module fabrication with good quality, DAQ-System, Software. Large area systems should be completed in 2006

Thank you for your attention