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Detectors for Current and Future Synchrotron Light Sources

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IWORID 7, 4.-7.7.05, ESRF













Detectors for Current and Future Synchrotron Light Sources

- 1. Introduction
- Existing Detector Systems Rapid Mythen Pilatus
- Future Detector Systems
 Pilatus XFS
 APAD
 Analog Hybrid Pixels for FEL Apps
- 4. Conclusions



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Synchrotrons Worldwide



New Projects in Europe:

- Soleil, Fr (2006)
- Diamond, UK (2006)
- Petra upgrade, Ge (2009)
- Alba, Esp, (2010)
- Tesla FEL (2010)

- High demand for detectors in Europe
- Current and future science more limited by the detectors than the sources
- ->optimized detector systems for SR





Detector development was systematically under-funded

Huge mismatch btw properties of the source and capabilities of the detectors:

Count rate limitations

Long readout times

Solid angle coverage

Detection efficiency

SR experiments are very diverse

We must deal more efficiently with the radiation delivered by the synchrotrons



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The Source - Detector Mismatch in the SR community

Examples:

Count rate limitations

Pilatus I: 10 kHz/pixel/s -> 2.5*107 /cm²/s

SLS X06SA PX I BL: Beam Intensity attenuated to 3%

Al-Filters in the beam to avoid saturation or damage of detector is a common situation

Long readout times

Mar165 CCD at BL X06SA: t_{exp} =1s, t_d =3s

$$duty \ cycle = \frac{t_{exp}}{t_{exp} + t_d} = 25\%$$

Radiation Hardness

3 years of operation: > 3 Mrad

Direct beam (SLS X04SA Wiggler BI): 250krad/s/pixel

Solid angle coverage

Analyzer crystals for Powder diffraction

Point detectors on diffractometers

Detection efficiency

 $E_{ph} > 20 \text{ keV}$







Requirements for SR Detectors



•High local and global count rate capability

- •Short read-out time
- •High spatial resolution
- •High dynamic range
- •High detection efficiency
- •Large solid angle coverage
- •Very good signal to noise ratio
- Precise calibration
- •Radiation hardness
- ●(Software Integration ⇔ User operation)

Single Photon Counting Detectors (?)

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Single Photon Counting vs Integrating Detectors for SR

Property	Single Photon Counting	Integrating				
Detection	Charge of Photon is amplified, counting above predefined threshold	Charge is integrated in Pixel				
Count-Rate	Limited, dead time corrections for high rates, 1 MHz/pixel	Unlimited				
Read-out	Digital highly parallel data transmission, Noisefree, 1 ms	Analog data transmission, ADC conversion, noise of few X-rays added, >100ms				
Spatial resolution	> 55 x 55 um ² , PSF 1 pixel,	$> 10 \text{ x} 10 \text{ um}^2$, PSF type depending				
Dynamic Range	10 ⁶	104				
Detection efficiency	74% at 12 keV, low above 20keV	Depending on scintillator				
Solid angle coverage	Modular detectors	$CCD > 30 \text{ x } 30 \text{ cm}^2$				
Signal to noise ratio	Fluorescent background suppression	Limited by dark current and readout noise				
Calibration	Energy calibration with X-rays Rate calibrations	Established corrections procedures				
Radiation Hardness	Several Mrad required	Several Mrad required				





Single Photon Counting: Fluorescent background suppression



Diffraction pattern from GaAs/AIAs sample at the 18 keV X-ray beam







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The Rapid2 SAXS/WAXS micro-gap detectors





Wire MicroGap Detector



- Small Anode to Cathode gap (0.5 mm) gives good local count rate.
- Intrinsically 2D
- Difficult to maintain anode/cathode gap.

Careful control of wire tension and PCB flatness



Charge Distribution





Presenters: Paul Buksh, Nick Clague, William Helsby

RAPID 2 as 2D Data Acquisition System





Presenters: Paul Buksh, Nick Clague, William Helsby

Collagen Collected at Spring-8 with 2D RAPID 2 2





Presenters: Paul Buksh, Nick Clague, William Helsby

Rapid detector system



- High parallel readout system for Multi Wire proportional counters.
- Can readout 1D and 2D detectors
- Uses ADC per channel to provide interpolation.
 - Gives spatial resolution of typically 512 to 4096 pixels from 128 channels
- Count rate performance
 - 1D Up to 40x10⁶ Events/s
 - 2D Up to 15x10⁶ Events/s
 - Maximum Frame rate > 1KHz



Powder Diffraction with Mythen Detector (SLS BL X04SA)



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

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Christian Broennimann



Mythen V2 (B. Schmitt)

New 0.25 μm readout chip available

Features:

- 128 channels
- Low noise <240 e- ENC
- 6 trim bits High count rate: linear to >1MHz (measured with X-rays)
- 24 bit counter with variable length readout, readout time from 32 μ s (4bit) to 64 μ s (24bit) for entire chip/detector
- Frame rates of 10kHz are planned

Current detector will be replaced by V2 in 2005







The PILATUS 1M Detector for Protein Crystallography

- Largest pixel detector array for SR
- 6 banks a 3 modules, 1120 x 967 pixels
- Area: 21 x 24 cm²
- 288 chips->~300x10⁶ transistors
- Readout time: 6.7ms
- 2 frames/ s
- Active area: 85%
- Moderate count rates (<10kHz/pixel)
- PX Data processing difficult due to counting errors of PILATUS I chip









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

Ch. Broennimann et al, "The PILATUS 1M Detector", submitted to J. Synchrotron Rad. (2005) G. Huelsen et al., "Distortion Calibration of the PILATUS 1M Detector", accepted by NIM 2005



Fine ϕ -slicing with the PILATUS Detector



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

Angular speed ω , Exposure time t $\Delta \phi = t^* \omega$ SWISS LIGHT SOURCE



Results of Fine-phi slicing data-sets

CCD Data:

Finer slicing -> more readout noise, -> higher R-Factors

PILATUS 1M Data:

Finer slicing -> higher ϕ resolution -> somewhat lower R-Factors

New version of XDS from W. Kabsch to process the 9000 frames a 0.02°/frame



G. Huelsen et al.," Protein Crystallography with a Novel Large Area Pixel Detector", in preparation

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PILATUS II Chip

- UMC_25_MMC process; Radiation hard design
- 60 x 97 pixels = 5820 pixels
- Pixel size 172 x 172 um²
- 17.540 x 10.450 mm²
- Count rate: 1MHz/pixel
- 20 bit counter
- Counting timer circuit
- 6 bit DAC for threshold adjustment
- XY-adressable
- Analog output
- 75 MHz LVDS readout (T_{ro} = 2 ms)
- Submitted 29.09.04
- Received 1.12.04

4*10⁶ Transistors

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

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PILATUS II: CS Amplifier



10⁶ photons/s/pixel with poisson distributed time-intervals should be possible





PILATUS II Rate Tests

8keV X-rays, avg rate of 20 pixels



Count Rate capability:

- local 1.5*10⁶ X-rays/s/pixel
- global 5*10⁷ X-rays/s/mm²

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PILATUS II Vcmp calibration

V_{cmp} scans from flat-field illuminations, after trimming, averaged over all pixels

6 keV

8 keV



 $\sigma = 158 e^{-} (= 570 eV)$

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Pilatus II Counting Statistics







Radiation Hardness (preliminary)

Counting detector delivers

deposited dose directly:

$$D = \frac{N_x \cdot E_x}{m_p}, with$$

$$N_x = 10^6 / pix / s$$

$$E_x = 13.5 keV$$

$$m_p = 2 \cdot 10^{-5} g$$

$$1 rad = 6 \cdot 10^{10} keV / g$$

$$\Rightarrow D = 10 rad / s$$

- Put Pilatus II chip in direct beam
- Adjusted beam intensity to obtain ~10⁶ X-rays/pixel
- Increased beam intensity by 100
 ->~ 10⁸ X-rays/pixel
- -> central pixels saturated
- Exposed for 3600s
- Peak doses ~2 3 Mrad (20- 30 Gy)
- Flat field illumination befor and after irradiation
- -> count rate variation < 1%

Pilatus II Chip + Sensor are radiation hard



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Distribution of Dose on Chip



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PILATUS II: Single Module



Module Parameters:

487 x 195 = 94'965 pixel

 $T_{ro} = 2 \text{ ms}$

Maximum Frame Rate with Gigastar PCI Card: 150 Hz

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⁵⁵Fe Irradiation (6keV):

(Very sensitive to high resistivity bumps)

PILATUS I: 54912 pixels 5% overall defects

PILATUS II: 93120 pixels 0.27% overall defects (mainly sensor defects)











The PILATUS 6M Detector for Protein Crystallography

pixels

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 (6
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

Status: Module fabrication starts in August 05

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PILATUS XFS: (eXtrem Framing System)

(R. Horisberger, R. Dinapoli and Ch. Broennimann)

	Pilatus XFS	Pilatus II					
Technological process	UMC 0.25 µm process	The same					
Radiation tolerance	Radiation hard design (>4Mrad)	The same					
Pixel array	$256 \ge 256 = 65536 \qquad \qquad 60 \ge 97 = 5820$						
Pixel size	$75 \times 75 \ \mu m^2 \qquad \qquad 172 \times 172 \ \mu m^2$						
Chip size	19.2 x 19.2 mm ²	17.54 x 10.45 mm ²					
Counter	12 bits, binary, configurable (4,8,12 bit mode)	20 bits, pseudo-random, not configurable					
Readout	Continuous	Separated from exposure					
Local count rate	> 10 ⁶ /pixel/s	> 10 ⁶ /pixel/s					
Overal count rate	$> 3 \times 10^8 / \text{mm}^2 / \text{s}$	> 5 x 10 ⁷ /mm2/s					
Power consumption	< 5 uW/pixel	10 uW/pixel					
Frame rate full RO	> 10 KHz	< 300 Hz					



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Pilatus XFS, the pixel architecture

•The chip is a matrix of 256 x 256 pixels of 75 x 75 μ m² each.

•It has a configurable count mode, 4, 8 and 12 bits. Moreover, it can be used in simultaneous read-write mode.

•This results in 12.5 KHz framing rate @ 8 bit, continuous readout mode.







Pilatus XFS main features

•Count rate: 1MHz/pixel (3 x 10⁸ x-rays/mm²/s)

Max. frame exposure time before overflow:

•T_{max} @ 4 bit mode = 16 μ s

•T_{max} @ 8 bit mode = 256 µs

•T_{max} @ 12 bit mode = 4 ms

- •200 MHz LVDS readout (PII:75 MHz)
 - •T_{ro} @ 4 bit mode = 40.96 µs
 - •T_{ro} @ 8 bit mode = 81.92 μs
 - •T_{ro} @ 12 bit mode = 122.9 µs

•In continuous readout mode, frame rate=1/readout time; 12.5 KHz @ 8 bit mode



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1 bit



Pilatus XFS, status

Configurable 12 bit counter with latch

Architecture defined
12 bit counter ready
Analogue section very similar to PILATUS II



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Future synchrotron sources



Peak intensities several order of magnitudes higher-> counting impossible

-> Integrating detectors



ESRF Detector Wrkshp 10 Feb 2005.

Cornell 100x92 Analog PAD

1.2 μm HP CMOS process (MOSIS) (Linearized Capacitors) 15 x 13.8 mm² active area; 100x92 pixels 150 μm square pixel 300 µm thick, high resistivity Si diode wafer (SINTEF) 120 µm solder bump bond (GEC-Marconi)

100x92 PAD developers include: Sandor Barna **Eric Eikenberry Alper Ercan** Sol Gruner Matt Renzi **Giuseppe Rossi Mark Tate**

Bob Wixted

G. Rossi, et al, J Synchrotron Rad. (1999). 6, 1095-1105.





CHESS & LASSP

Cornell





Tesla FEL



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Pixel Chip for Tesla FEL



Rough dimensions:

~ 20 um² / cap cell -> 1000 caps (frames) ~ 140 x 140 um² -> Pixel size ~ 160 x 160 um2



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Pixel Chip for Tesla FEL



Christian Broennimann





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Time scales for detector developments

	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
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Detectors for FEL																			





Summary

Single photon counting pixel detectors are becoming more and more mature -> much higher local and global count rates.

Next generation of single photon counting detectors are currently in the design phase (Medipix 3? and Pilatus XFS) Higher frame rates resp. higher spatial resolution

Next generation of SR sources will require analog integrating pixel detectors

Developments take roughly 7 years

If we want to be ready, we have to start now

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PAUL SCHERRER INSTITUT	PMD05 Workshop Paul Scherrer Institut CH-5232 Villigen P	SI Phone +41 56 310 21 11 Fax +41 56 310 21 99					
Home Scope Programme	SWISS LIGHT SOURCE						
Invited Speakers Registration	PMD05:						
Accommodation	Workshop on Pixel- an	d Microstrip-Detectors					
How to get to PSI	for Synchrotron Radiation						
SLS Home	-						
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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*

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

F. Glaus, J. Lehmann *PSI, LMN, Switzerland*

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

C. Schulze-Briese, T. Tomizaki, C. Pradervand, A. Wagner *PSI, SLS MX-group, Villigen-PSI, Switzerland*

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