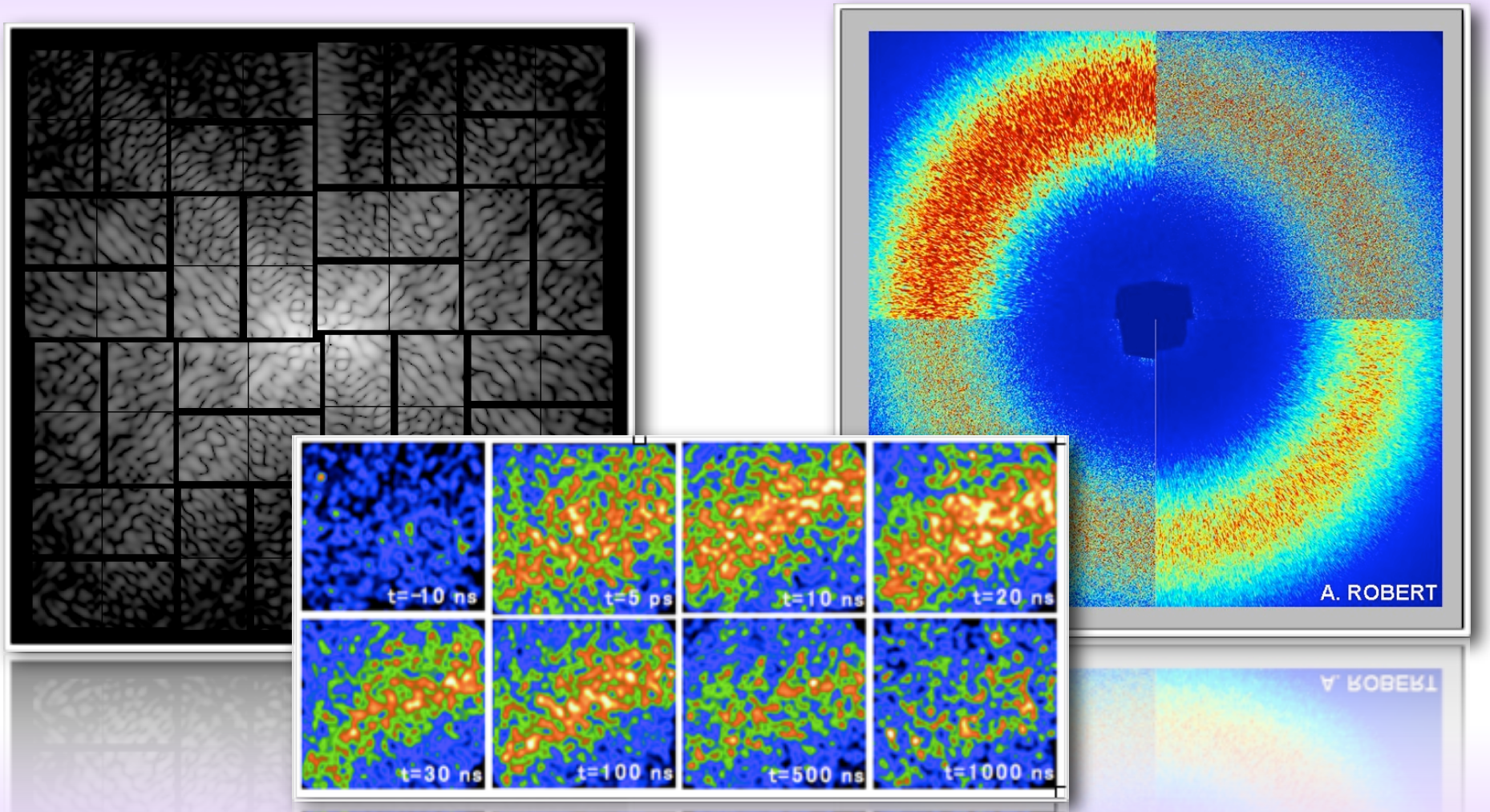
2D Detectors



Niels van Bakel
nielsvb@slac.stanford.edu

Outline

- Detector program
- XPP detector
  - Requirements, Technical, Schedule, Status & Budget
- XCS detector
  - Requirements, Technical, Schedule, Status & Budget
- CXI detector
  - Requirements, Status
- DAQ
- Summary & Outlook

Niels van Bakel
nielsvb@slac.stanford.edu

Specifications

- Intense (10^{12} ph) and short (100 fs) pulses at 120 Hz need integrating detectors with fast readout (< 8 ms)
- Detector specs, what will be available for LUSI

	CXI	XPP	XCS
Readout noise	< 0.3 ph	<1 ph	<<1 ph
Full well capacity	1-10^3 ph	1-10^4 ph	1-100 ph
Pixel size	110 µm	90 µm	≤ 35 µm
Number of pixels	760^2 (1500^2)	1024^2 .	1024^2 .

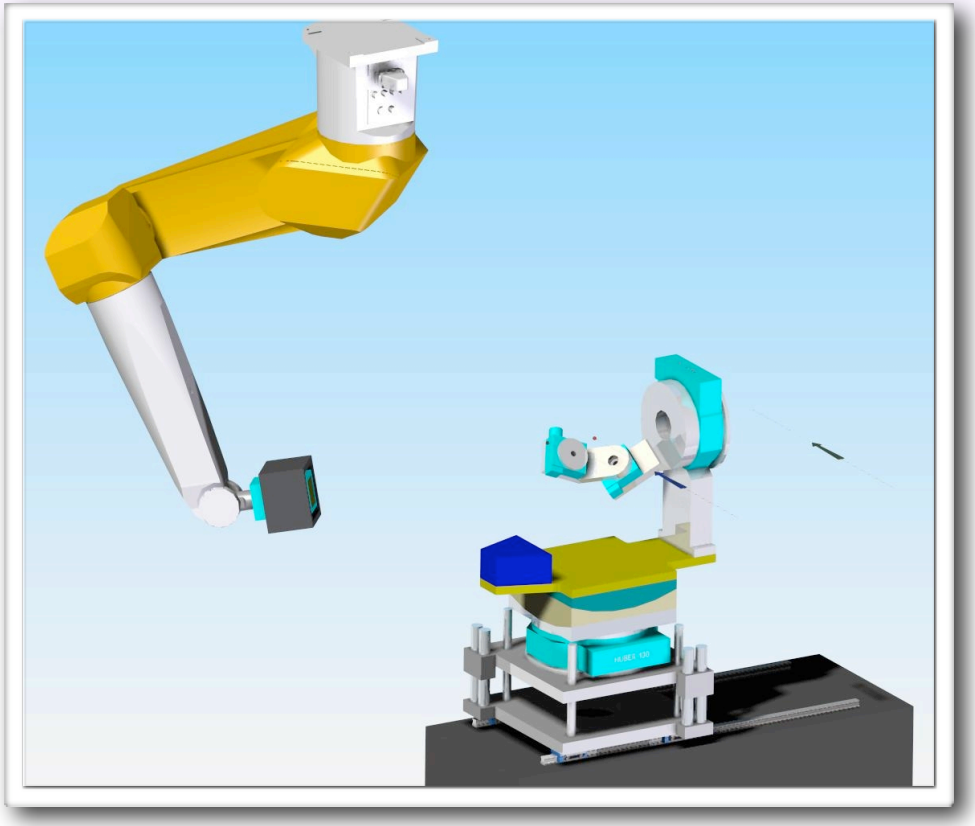
Niels van Bakel
nielsvb@slac.stanford.edu

Commercial CCD technology

- Active thickness of commercial CCDs (1-50 μm) gives poor quantum efficiency
- Pixel sizes < 20 μm for standard CCDs
  - Small area devices or heavy tiling
  - Charge sharing works against 'photon counting'
- Best commercial CCDs have full-well of ~500,000 electrons
  - One 8 keV photon generates 2200 electron-hole pairs → about 200 photons max full well.
    - Spec. up to 10^4
- Readout of commercial devices not fast enough
  - Millisecond readout requires highly parallel readout structure

Niels van Bakel
nielsvb@slac.stanford.edu

XPP Detector



- Pixel sensor
- Readout ASIC
- DAQ
- Mechanical design

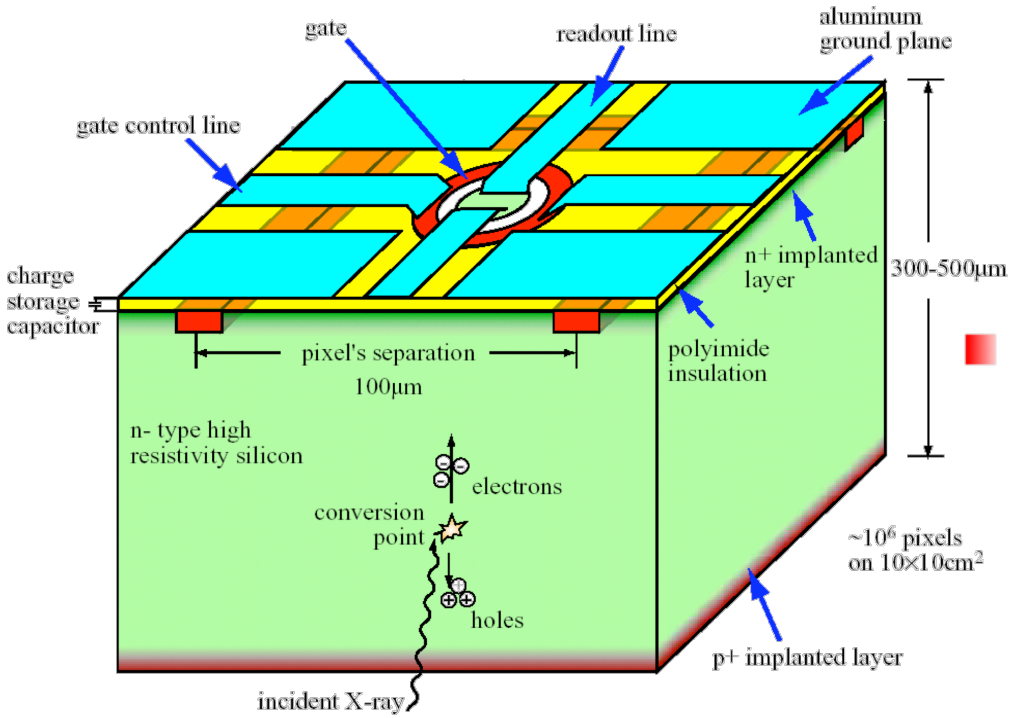
Niels van Bakel
nielsvb@slac.stanford.edu

XPP Requirements

- A sample is 'pumped' to an excited state by a pump pulse (e.g. laser) and analyzed after Δt with an LCLS pulse. Image the scattering intensity that is slowly varying with scattering angle (in steps) or a number of Bragg peaks.
  - High QE to achieve enough counting statistical accuracy to capture the relative intensities that resolve the induced structural changes.
  - Total angular coverage of $2\theta = 180°$ to measure changes down to Ångstrom length scales
  - Angular resolution or pixel size: Bragg peaks on the detector mainly defined by beam size on the sample. For a beam size ≤ 200 μm (FWHM), a pixel size of 90 μm and variable sample to detector distance one can resolve the Bragg peaks.
  - Number of pixels 1024 x 1024 to resolve up to a few 100 diffraction peaks over the detector area.
  - Read-out noise < 1 equivalent 8.2 keV photon to allow single photon sensitivity

Niels van Bakel
nielsvb@slac.stanford.edu

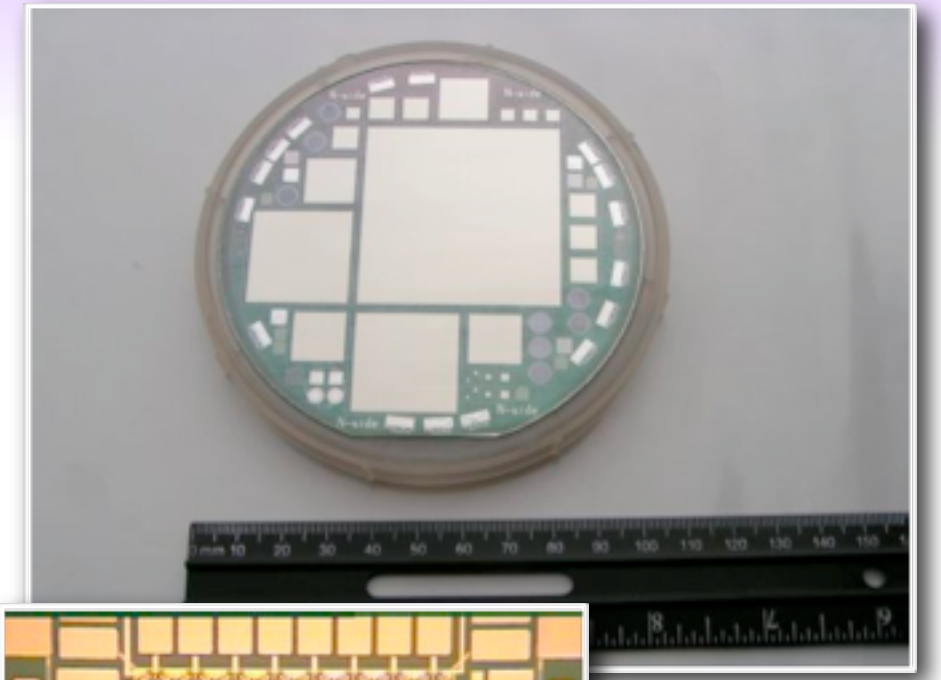
X-ray Active Matrix Pixel Sensor



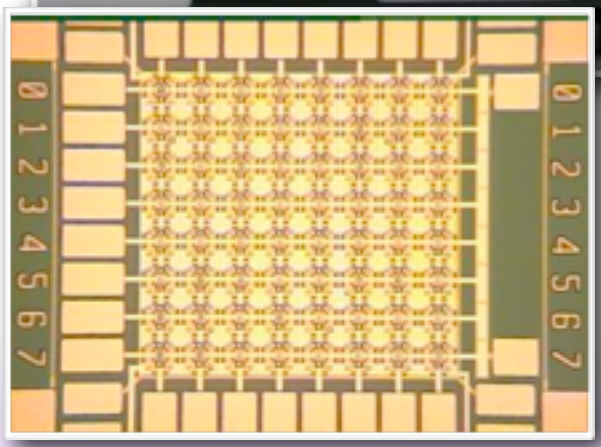
- Switch-matrix structure for XPP experiments
- During data accumulation each row of pixels is switched on and the pixel charge is readout
  - Extremely challenging spec: >10^4 S/N, single-shot, fast readout
- XAMPS
  - Monolithic devices built on silicon provide simplest structure
  - Need to develop technology to form transistors directly on high-resistivity Silicon substrate
  - No bump-bonding and no on-pixel amplifier allows for smaller pixel size

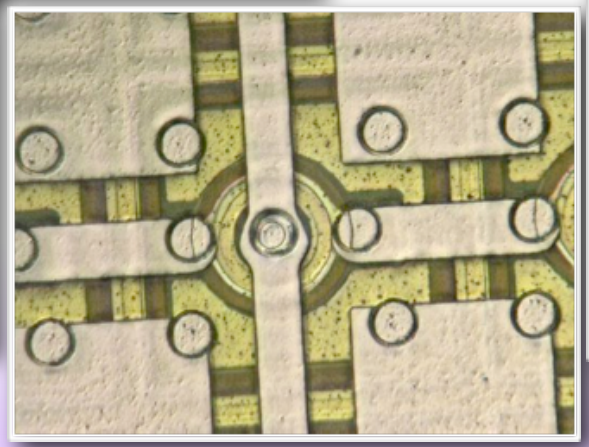
Niels van Bakel
nielsvb@slac.stanford.edu

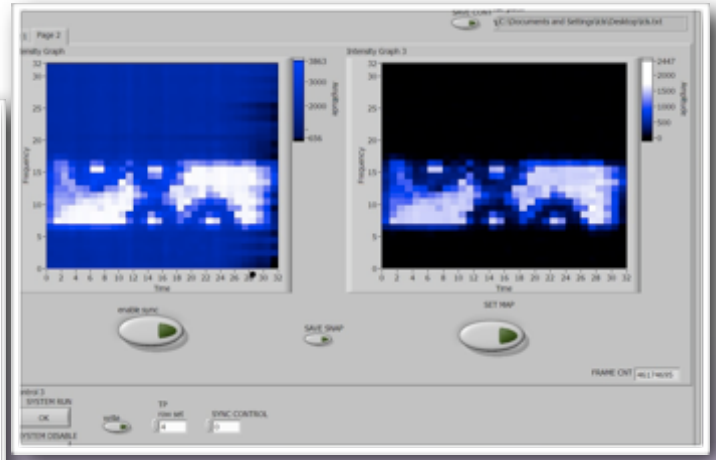
BNL XAMPS



- 512 x 512 module
  - 100 mm n-type wafer
  - 400 μm thick
- BNL in-house process
  - Vias and inter-metal layers
  - Metalization step for 150 mm
- X-rays with 32x32 module

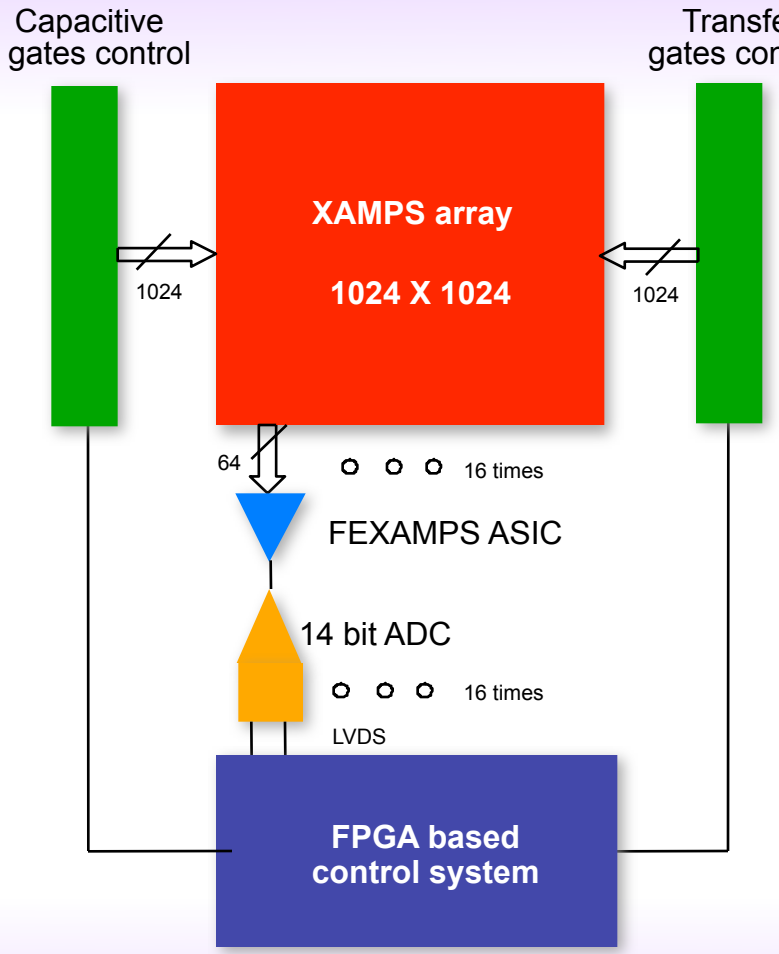


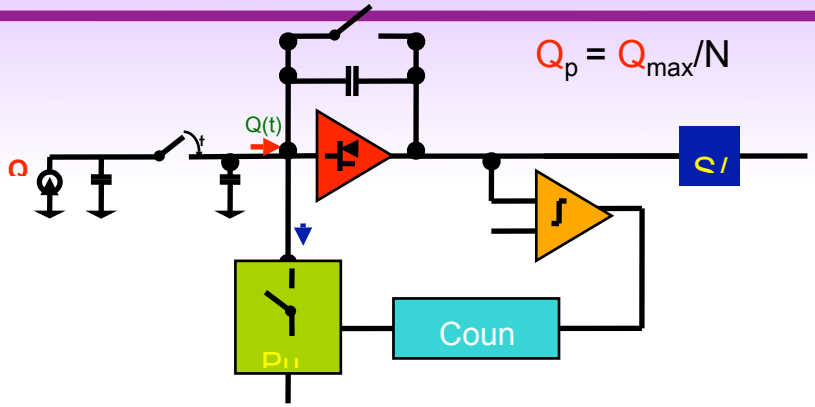


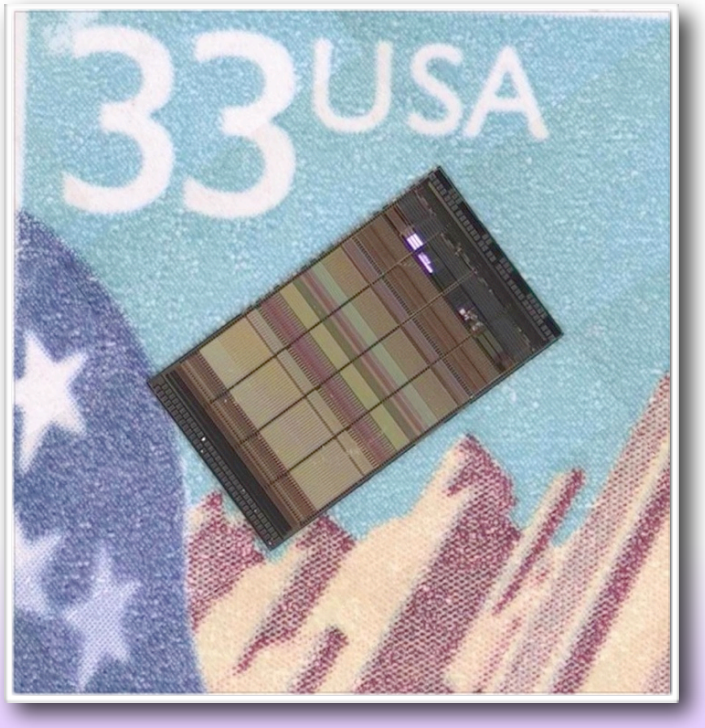


Niels van Bakel
nielsvb@slac.stanford.edu

XAMPS ASIC

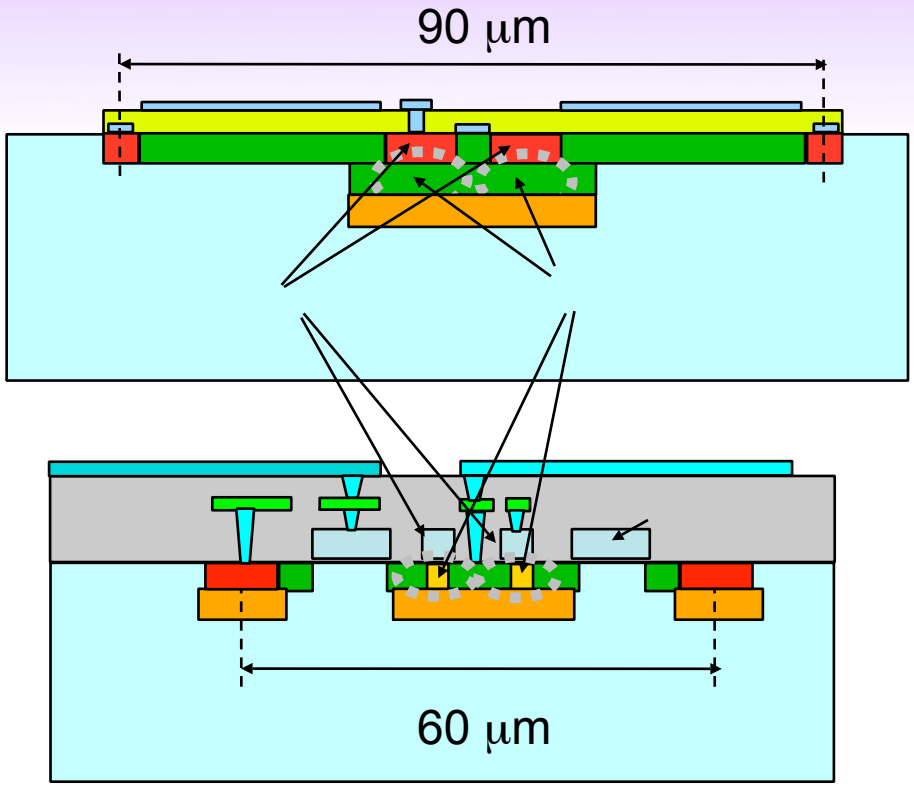






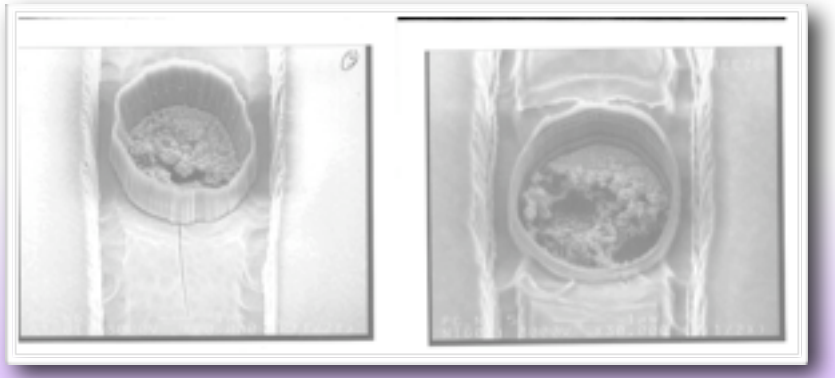
Niels van Bakel
nielsvb@slac.stanford.edu

IBM process



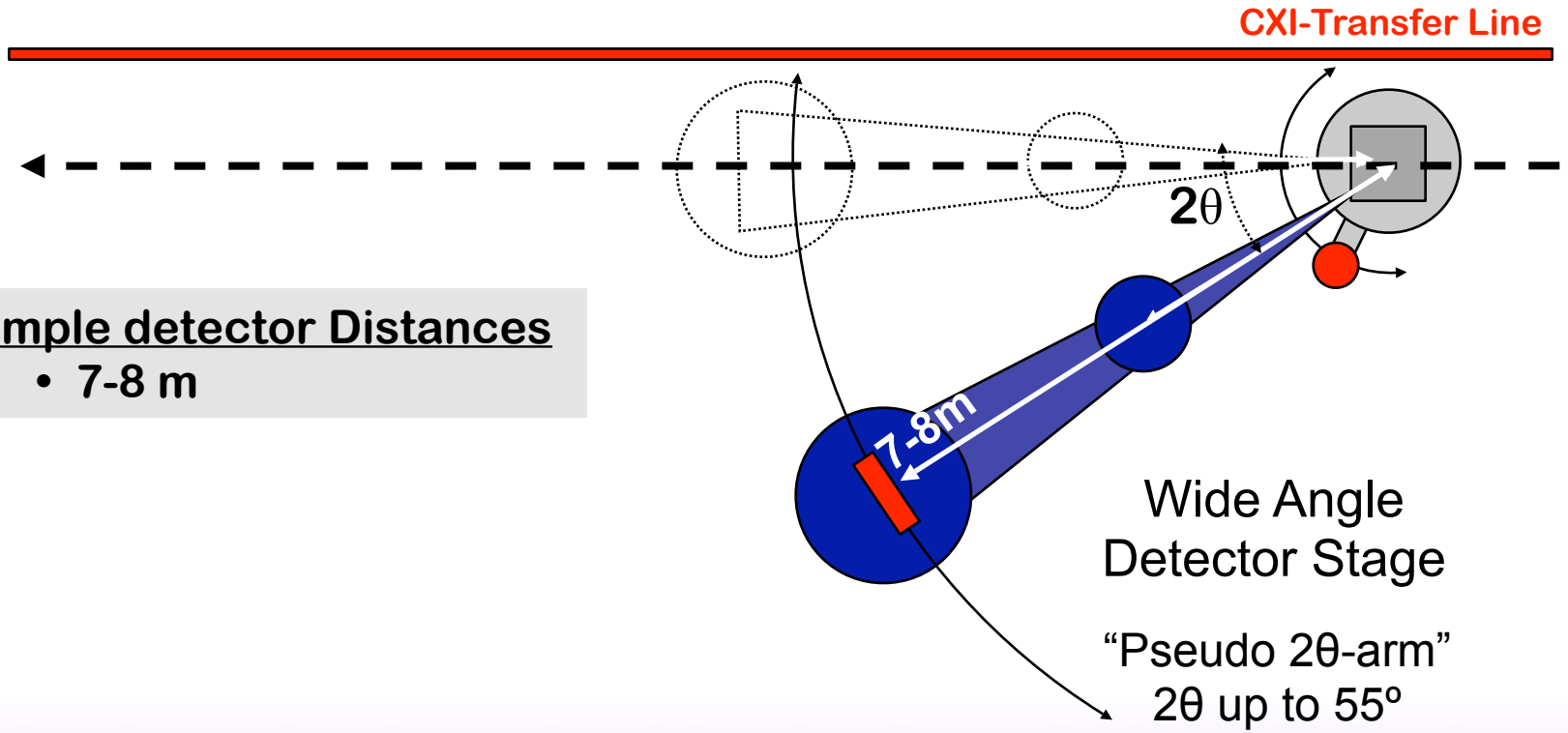
- Allows more complex circuits
- Reduce noise

- Significant alignment and processing difficulties.
  - Veils of unknown origin cannot be etched away
  - M2 deposition not possible until this is resolved
- No pixel-side test structures were functional.
- Processing stopped until this problem resolved.



Niels van Bakel
nielsvb@slac.stanford.edu

XCS Detector Stage



Sample detector Distances

- 7-8 m

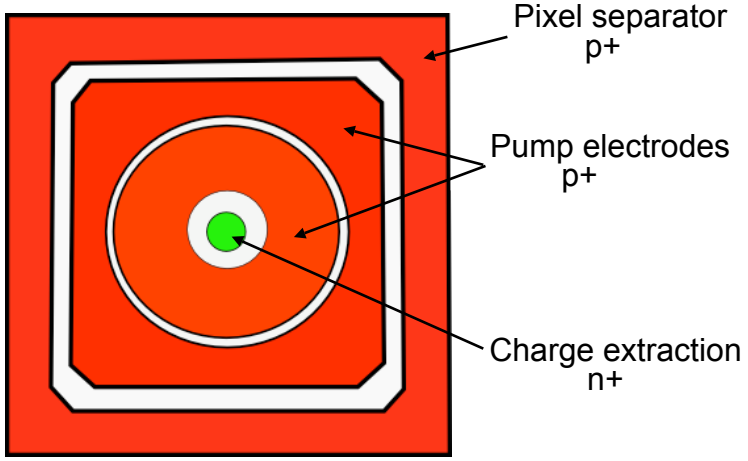
Niels van Bakel
nielsvb@slac.stanford.edu

XCS Requirements

- Image the temporal changes in a speckle patterns that are related to the sample's dynamics. The method takes advantage of the coherence properties of the beam.
  - Energy range 4 - 25 keV
  - Need a high QE (> 90%) to measure the spiky nature of the speckle pattern
  - Total angular range is $2\theta = 55°$
    - The detector size is determined by the maximum Q value achievable in the small angle regime
  - Angular resolution or pixel size: the pixel size should be ≤ speckle size
    - For L = 7 - 8 m, D_b = 10 - 100 μm the speckle size D_s = 11 - 120 μm (@ 8 keV)
  - Number of pixels calculated by the total angular coverage and angular resolution needed for SAXS @ 8m. The basic detector module has 1024 x 1024 pixels
  - Read-out noise << 1 equivalent 8.2 keV photon to allow single photon sensitivity

Niels van Bakel
nielsvb@slac.stanford.edu

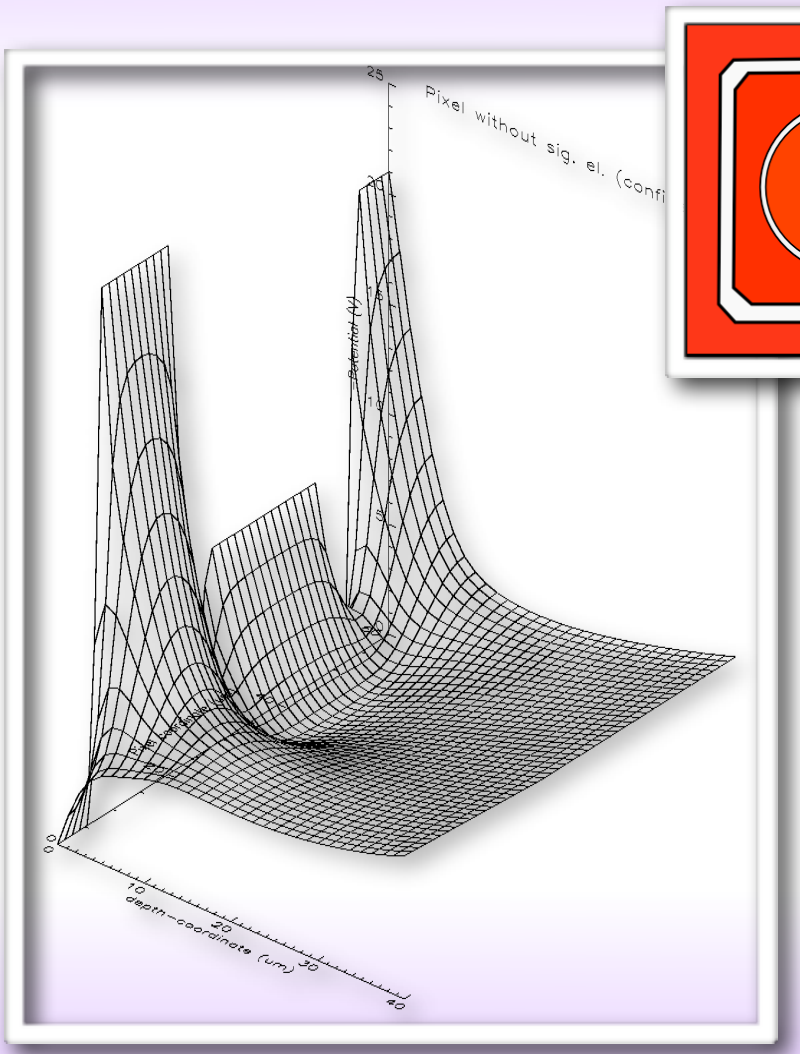
XCS Pixel

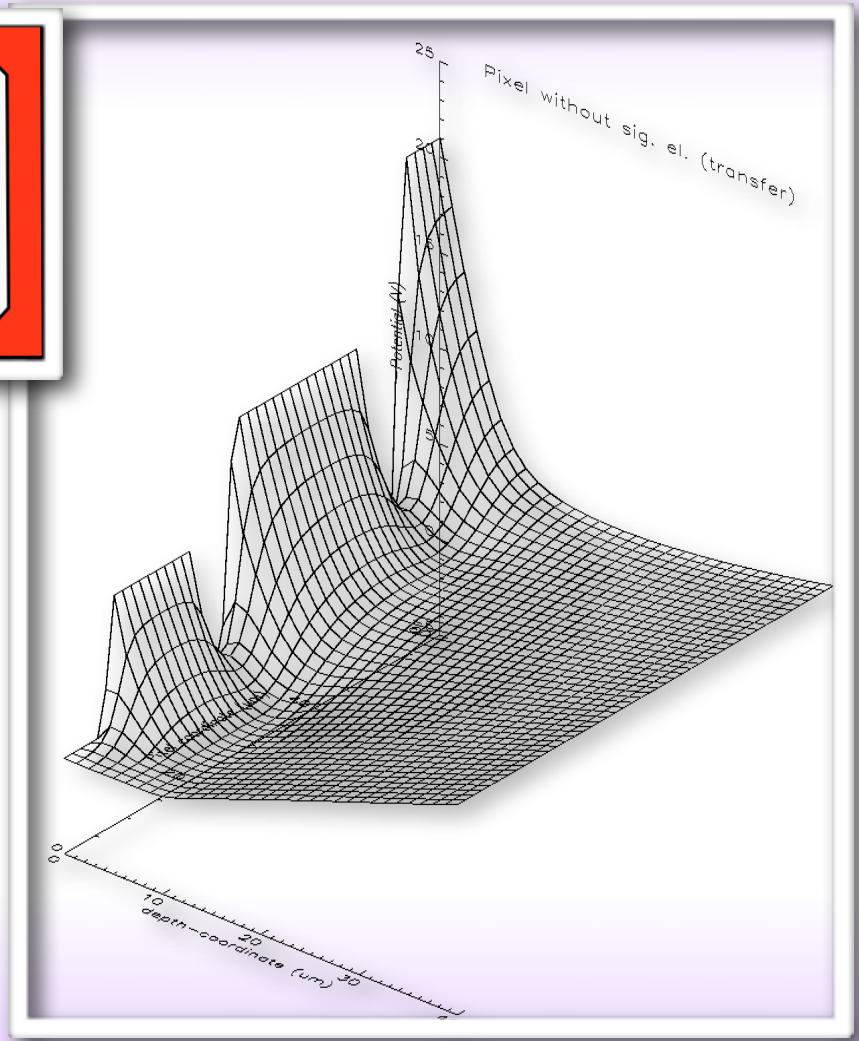


- "Charge-pump" structure for XCS experiments
  Charge is stored in a potential well and released in a controlled way similar to a drift detector
  - << 1 photon readout noise, needs different technology without transistor switch
  - Means that small pixels are possible.
  - No "kTC noise"

Niels van Bakel
nielsvb@slac.stanford.edu

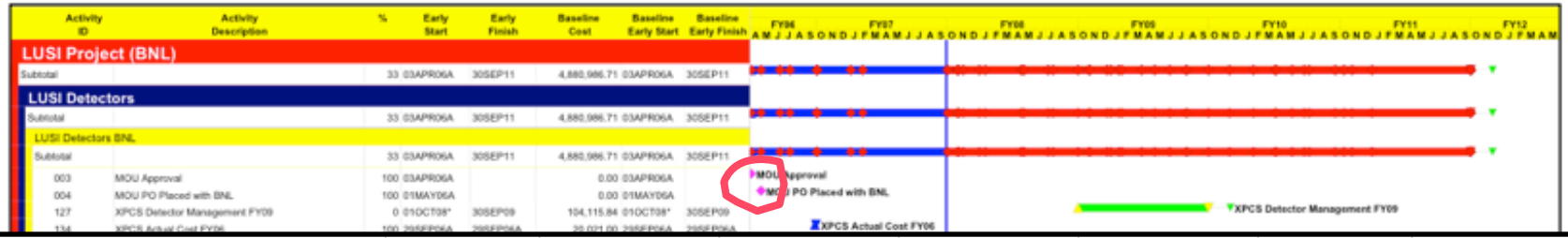
XCS Charge Pumping



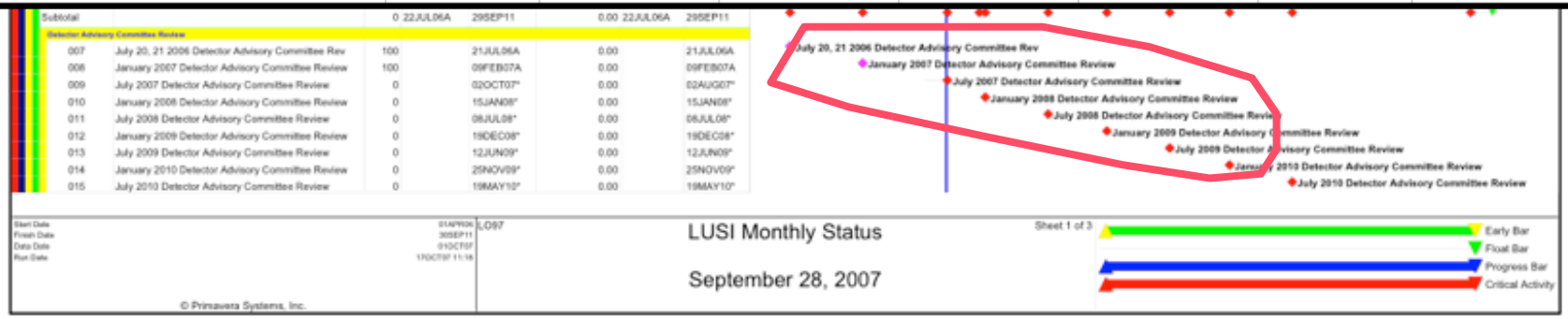


Niels van Bakel
nielsvb@slac.stanford.edu

BNL Schedule & Spending profile

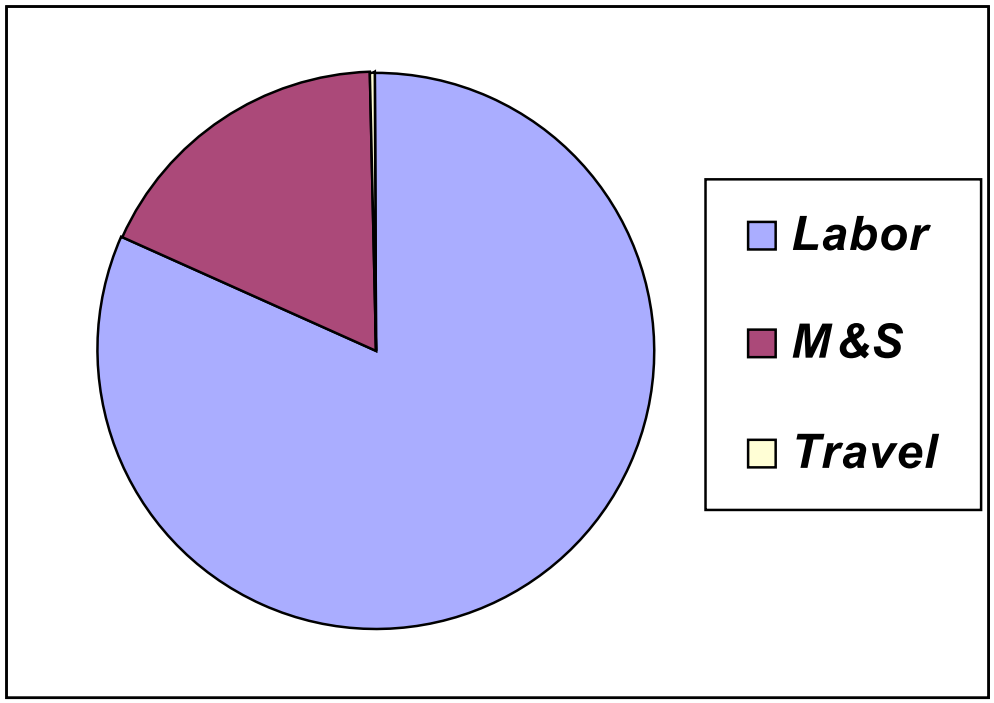


WBS	CY07	CY08	CY09	CY10	CY11	CY12	Cumulative
Niels van Bakel							
1.2.04 XPP Detector System (BNL)	$ 19,201	$ 748,307	$ 511,590	$ 9,230	$ -	$ -	$ 1,288,328
1.4.03 XCS Detector System (BNL)	$ -	$ 362,415	$ 633,474	$ 687,401	$ 204,417	$ -	$ 1,887,707
CAM Totals:	$ 19,201	$ 1,110,722	$ 1,145,063	$ 696,631	$ 204,417	$ -	$ 3,176,035



Niels van Bakel
nielsvb@slac.stanford.edu

BNL Charts



CAM - van Bakel	
Resource Type	Value
Labor	$2,593,610
M&S	$572,505
Travel	$9,920
Total BAC	$3,176,035

Including OPC: BAC = $4.8M

Niels van Bakel
nielsvb@slac.stanford.edu

BNL Schedule

- MOU May 2006
  - Technical Addendum C ends September 30 2008
- L4 Milestones achieved
  - LDAC reviews (5) and progress reports (2)
  - XPP Design and fabricate test pixels, Sept 07, $418k
  - XPP Tested Controls and DAQ interface, Nov 2007, $76k
  - XPP ASIC design computer interface, Nov 2007, $268k
  - XPP Prototype sensor test & characterization, May 07, $219k
  - XPP ASIC integration with computer system, Jan 08, $134k
  - XPP ASIC design, April 08, $147k
  - XPP pixel design finalized, May 08, $96k
  - XPP Fabricate IBM pixel, May 08, $138k
  - XPP ASIC fabrication, June 08, $40k
- Current activities: ASIC and 512 sensor testing (IBM)

Niels van Bakel
nielsvb@slac.stanford.edu

Detector milestones

XPP Design Finalized	Aug, 08
XPP Detector Delivered to SLAC	Jan, 10
XPP Installation at SLAC Complete	Nov, 10
CD-4a	July, 10
XCS Design Finalized	July, 11
XCS Detector Delivered to SLAC	Nov, 11
XCS Installation at SLAC Complete	Dec, 11
Closeout Review	Nov, 11
CD-4c	April, 12

Niels van Bakel
nielsvb@slac.stanford.edu

Progress

- Technical Addendum-A (4/1/06-9/30/06, $537k):
  - Complete detailed XPP detector architecture design
  - Design and begin fabrication of small prototypes of the fundamental pixel elements
  - Identify possible approaches for the XCS detector
  - First pass at computer architecture design complete
- TA-B (10/1/06-9/30/07, $1,214k):
  - First silicon of XPP pixels in hand and tested
  - Working XPP pixel prototypes fully tested and characterized
  - XPP ASIC design complete and submitted for fabrication
  - Design of XPP ASIC-DAQ interface complete
- TA-C (1/1/08-9/30/08, $779k):
  - Design XPP detector finalized and fabrication of large area array begun.
  - Integration of pixel arrays with ASIC
  - Integration of ASIC with DAQ

Niels van Bakel
nielsvb@slac.stanford.edu

LUSI WBS

1.2 XPP Instrument	
1.2.01	XPP System Integration & Design
1.2.02	XPP X-ray Optics & Support Table
1.2.03	XPP Laser System
1.2.04	Detector
1.2.05	XPP Sample Environment & Diffractometer System
1.2.06	XPP Facilities
1.2.07	XPP Vacuum System
1.2.08	XPP Installation

1.3 CXI Instrument	
1.3.01	CXI System Integration & Design
1.3.02	CXI X-ray Optics
1.3.03	CXI Lasers
1.3.04	CXI Coherent Imaging Injector
1.3.05	CXI Sample Environment
1.3.06	CXI Hutch Facilities
1.3.07	CXI Vacuum System
1.3.08	CXI Installation

1.4 XCS Instrument	
1.4.01	XCS System Integration & Design
1.4.02	XCS X-ray Optics & Support Table
1.4.03	Detector
1.4.04	XCS Sample Environment & Diffractometer System
1.4.05	XCS Hutch Facilities
1.4.06	XCS Vacuum System
1.4.07	XCS Installation

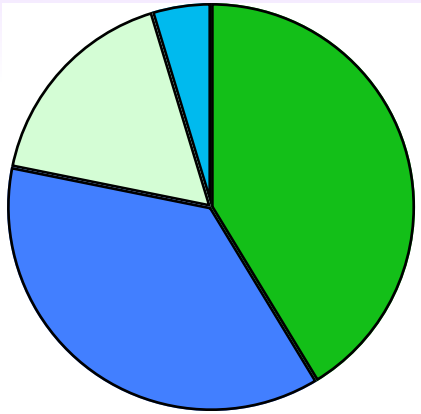
WBS	FY07	FY08	FY09	FY10	FY11	FY12	Cumulative
1.2.04 Detector	$ 0	$ 727,502	$ 698,306	$ 26,032	$ 16,053	$ 0	$ 1,467,893
1.4.03 Detector	$ 0	$ 0	$ 600,129	$ 1,064,686	$ 335,879	$ 183	$ 2,000,876

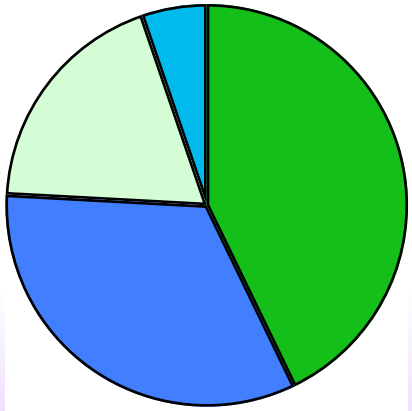
Control Account Manager	Control Accounts	Work Packages	Values
Niels van Bakel	8	9	$3,468,769

Niels van Bakel
nielsvb@slac.stanford.edu

WBS

WBS 1.2	
Resource Type	Value
Labor-SLAC	$2,454,983
Non-Labor-SLAC	$2,189,886
Labor-BNL	$1,018,849
Non-Labor-BNL	$278,767
Total BAC	$5,942,485





WBS 1.4	
Resource Type	Value
Labor-SLAC	$3,303,884
Non-Labor-SLAC	$2,548,522
Labor-BNL	$1,457,717
Non-Labor-BNL	$405,142
Total BAC	$7,715,265

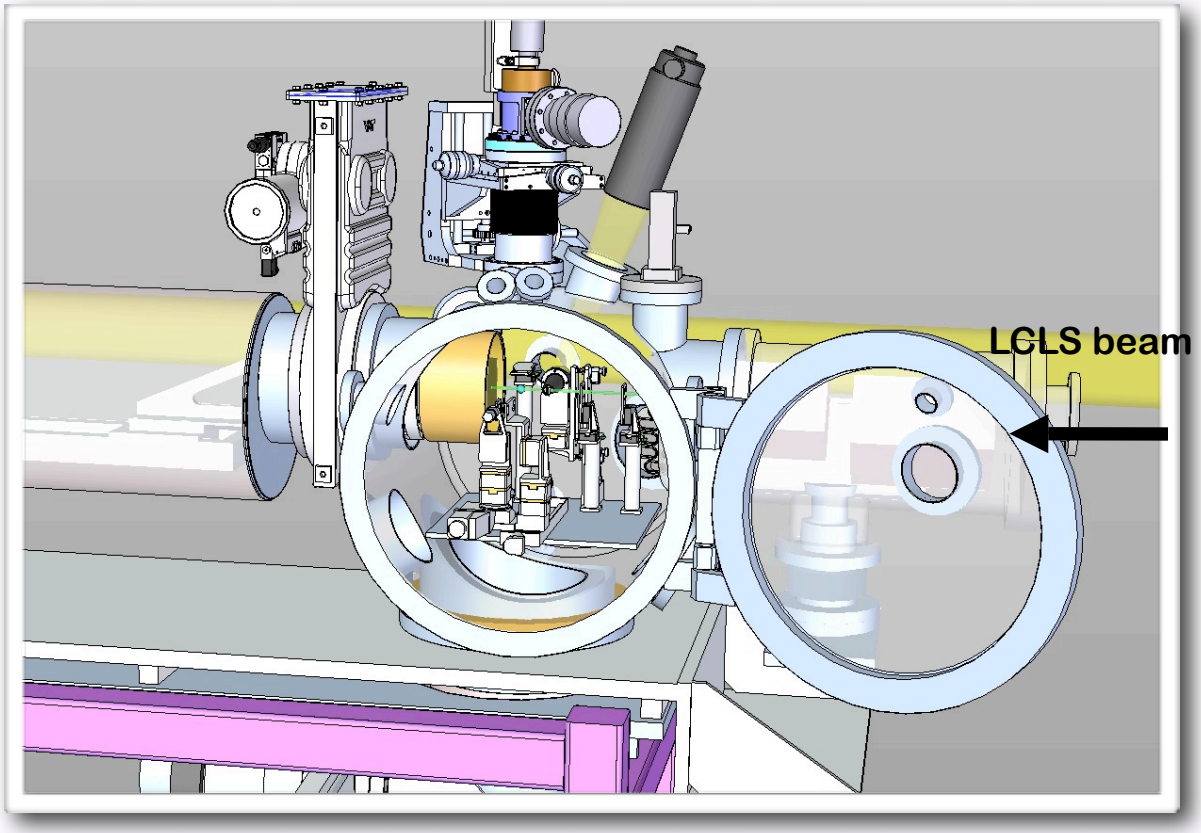
Niels van Bakel
nielsvb@slac.stanford.edu

Risk mitigation

- Three subsystems: sensor elements, FE-electronics (ASIC) & DAQ
- MOU required us to assess project risks:
  - Largest risk is associated with producing essentially full-wafer devices and the possibility of vanishingly small yield
  - Attempts to identify an additional foundry led to the IBM Thomas J. Watson Research Laboratory in Yorktown Heights, NY, long-time users of NSLS
  - Discussions with IBM engineers suggested a development path which promises more than simply risk mitigation

Niels van Bakel
nielsvb@slac.stanford.edu

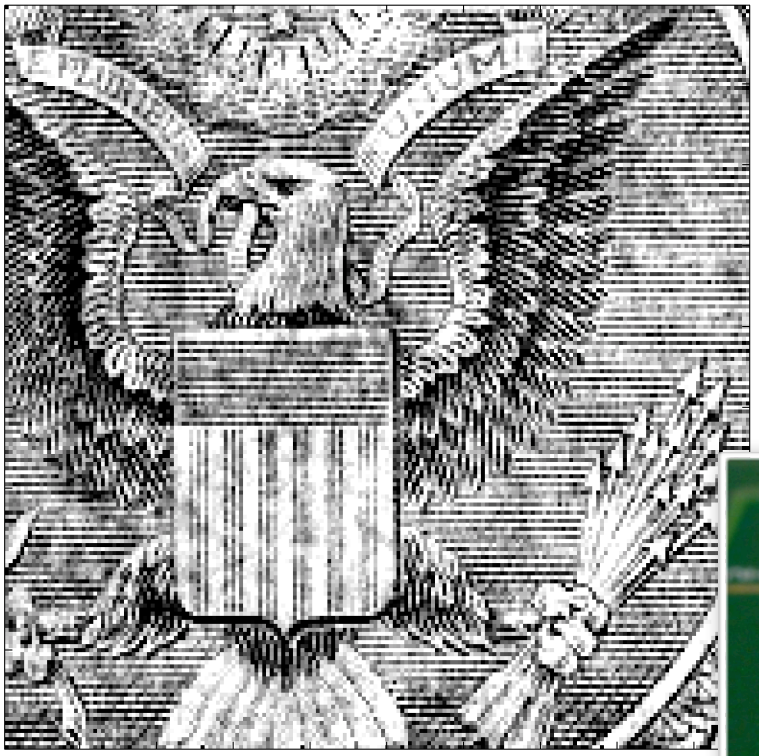
CXI Detector



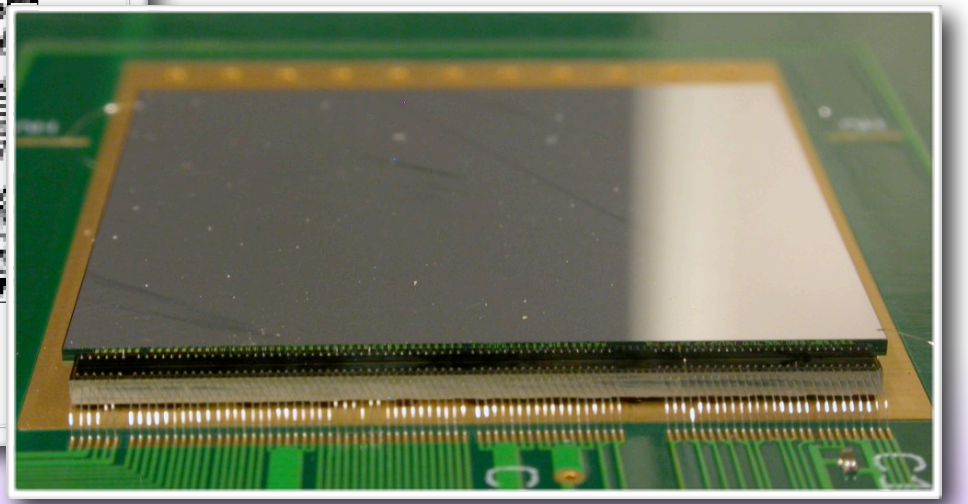
- Detector in vacuum 10^{-7} Torr
- Resolution depends on the sample-detector distance
  - Requires translation stage 700 mm
  - Remote Aperture resizing 1 - 10 mm
- Cooling 10 - 25 °C

Niels van Bakel
nielsvb@slac.stanford.edu

Cornell 2D PAD

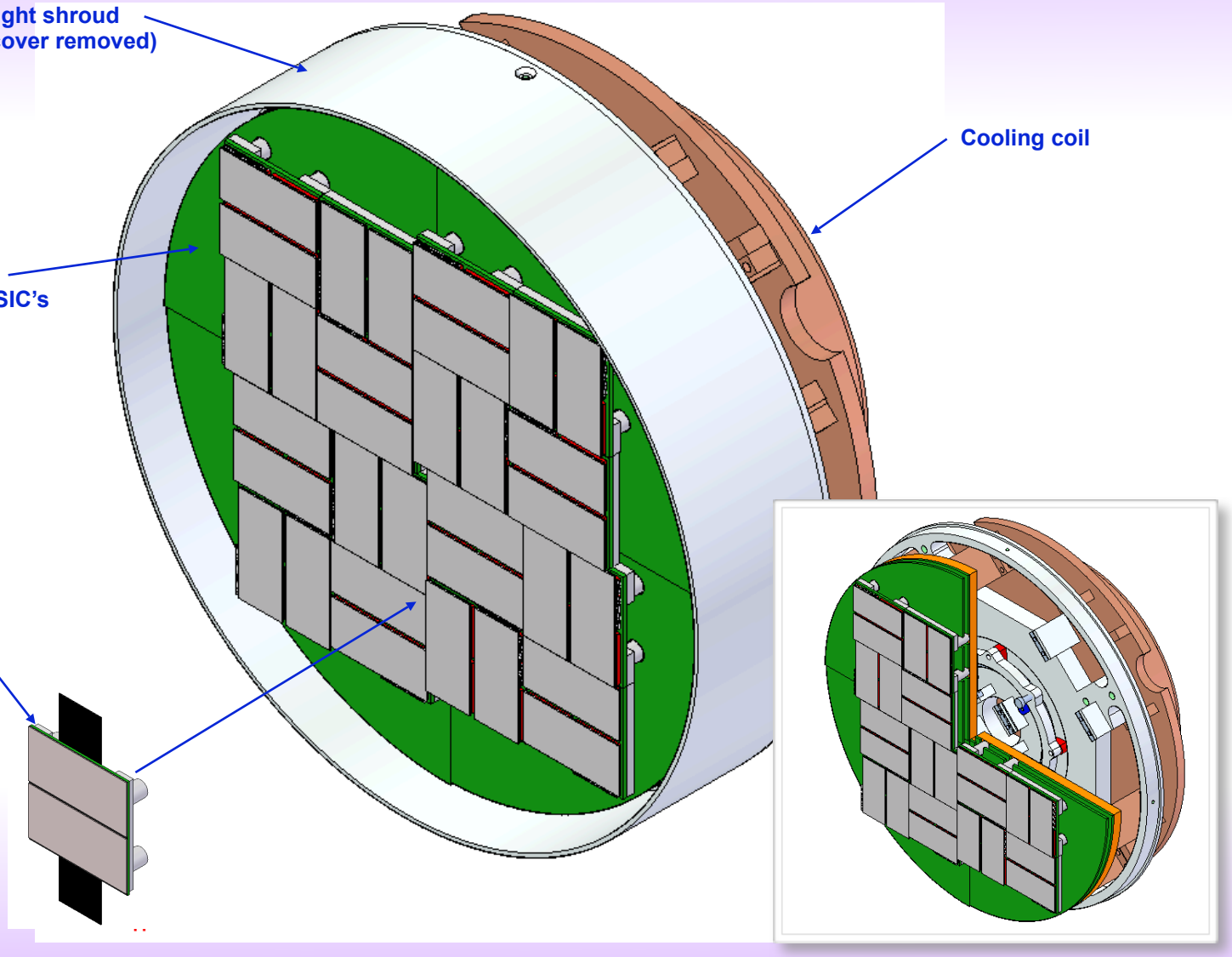


- Transmission Radiograph of a Dollar Bill taken with the LCLS Full Scale Prototype Module with Cu x-ray tube source, April 2008



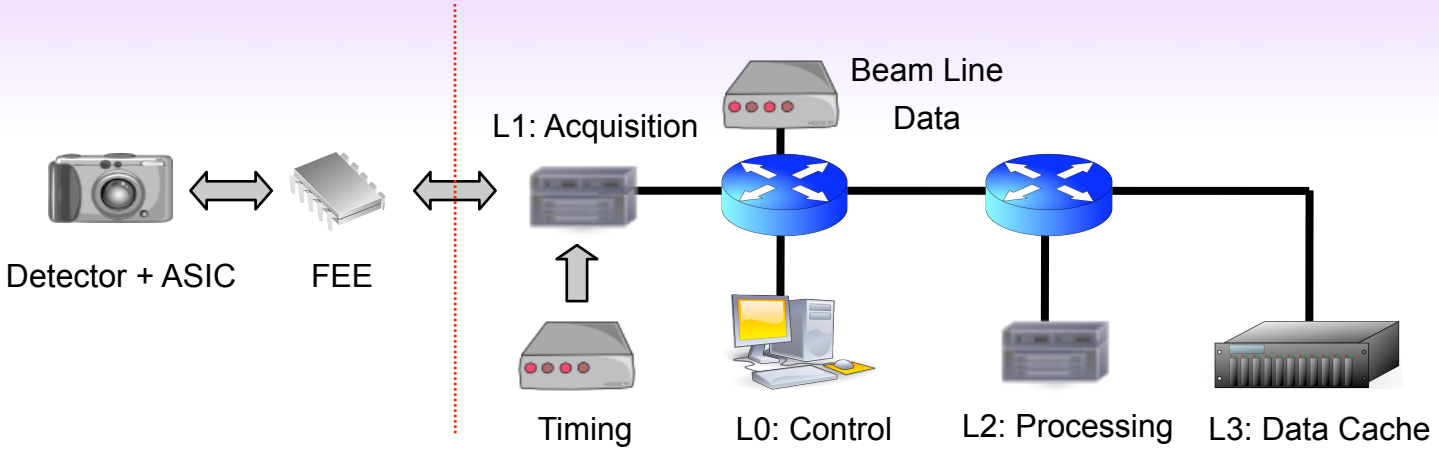
Niels van Bakel
nielsvb@slac.stanford.edu

CXI Assembly



Niels van Bakel
nielsvb@slac.stanford.edu

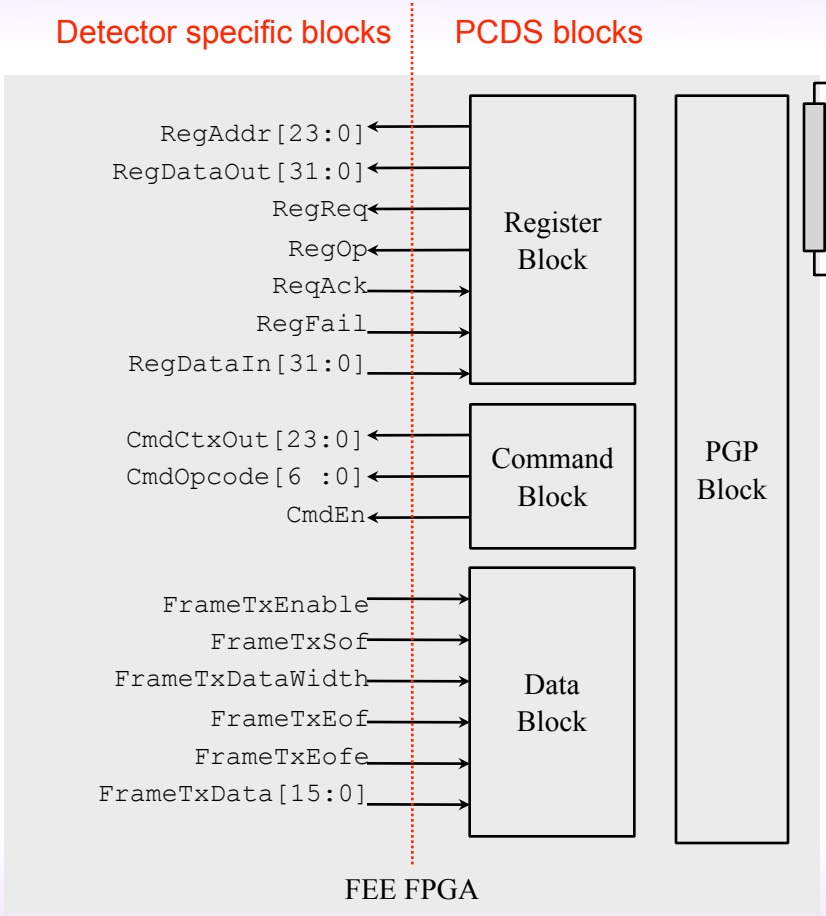
Detector - DAQ Interface

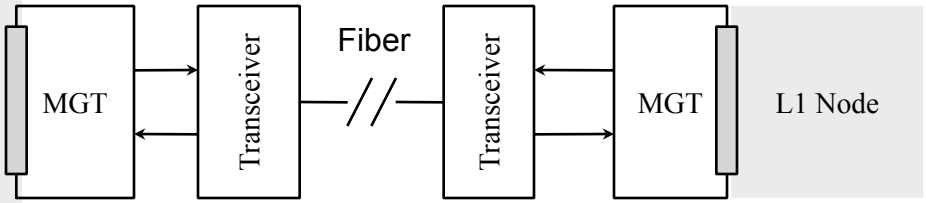


- Detector - Experiment Specific
- Front-End Electronics - Local configuration registers and state machines, FPGA used to transmit to DAQ system
- Timing info from the accelerator timing system, distributed to the detectors and L1 boards
- L0: DAQ operator consoles, control a run & configure the detector, telemetry monitoring
- L1: Acquire FEE data, detector calibration, event building, image processing, 10 Gb/s ethernet

Niels van Bakel
nielsvb@slac.stanford.edu

Register Command Data Interface

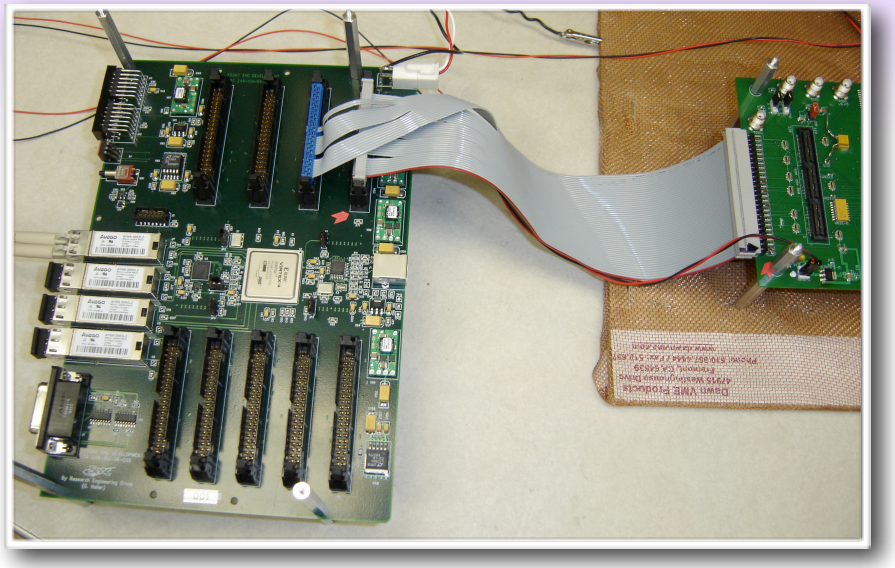




- **Interface defined between FEE and L1**
  - **Common interface among different experiments**
  - **Provide data, command and register interfaces**
  - **Custom point-to-point protocol (Pretty Good Protocol, PGP) implemented as FPGA IP core**
  - **FEE FPGA assumed to be Xilinx family with Multi Gigabit Transceivers (MGT)**

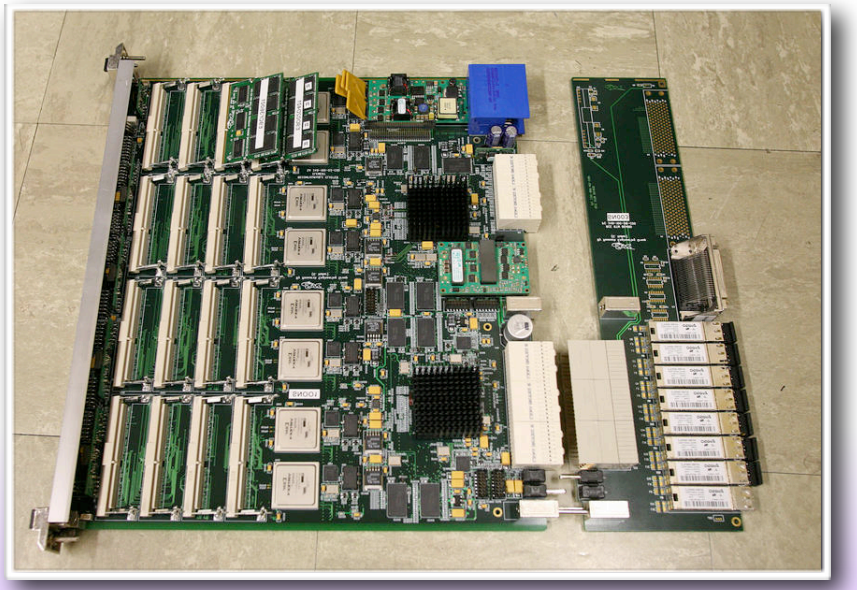
Niels van Bakel
nielsvb@slac.stanford.edu

Detector Testing at SLAC



- SLAC Front End Development board
- Additional testing; feedback to Cornell
- Improves integration in LCLS & LUSI instruments

- SLAC custom made ATCA board
- Based on System On Chip (SOC) Technology: Xilinx Virtex 4 (6)
- System Memory Subsystem: 512 MB of RAM, 8 GB/s throughput
- Configuration Flash Memory Subsystem: 128 MB for storing software code and configuration parameters (up to 16 images)



Niels van Bakel
nielsvb@slac.stanford.edu

Summary

- Cornell 2D PAD detector ready in July 2009 => CXI ready in July 2011
- BNL XAMPS detector at SLAC October 2009 => XPP ready in July 2010
- BNL 2nd detector at SLAC October 2011 => XCS ready in April 2012

Niels van Bakel
nielsvb@slac.stanford.edu

Acknowledgments

- LCLS & LUSI Scientists
- BNL: Peter Siddons, Pavel Rehak, Zheng Li, Wei Chen, Gabriella Carini, Paul O'Connor, Gianluigi De Geronimo, Angelo Dragone,
- SLAC DAQ: Gunther Haller, Amedeo Perazzo, Mark Freytag, Mike Huffer, Chris O'Grady, Leonid Sapozhnikov, Eric Siskind, Dave Tarkington, Matt Weaver
- SLAC Mechanics: Martin Nordby, David Nelson, Matthew Swift
- SLAC Testing: Ryan Herbst, Dieter Freytag
- Cornell: Sol Gruner, Hugh Philipp, Mark Tate, Marianne Hromalik, Lucas Koerner

Niels van Bakel
nielsvb@slac.stanford.edu