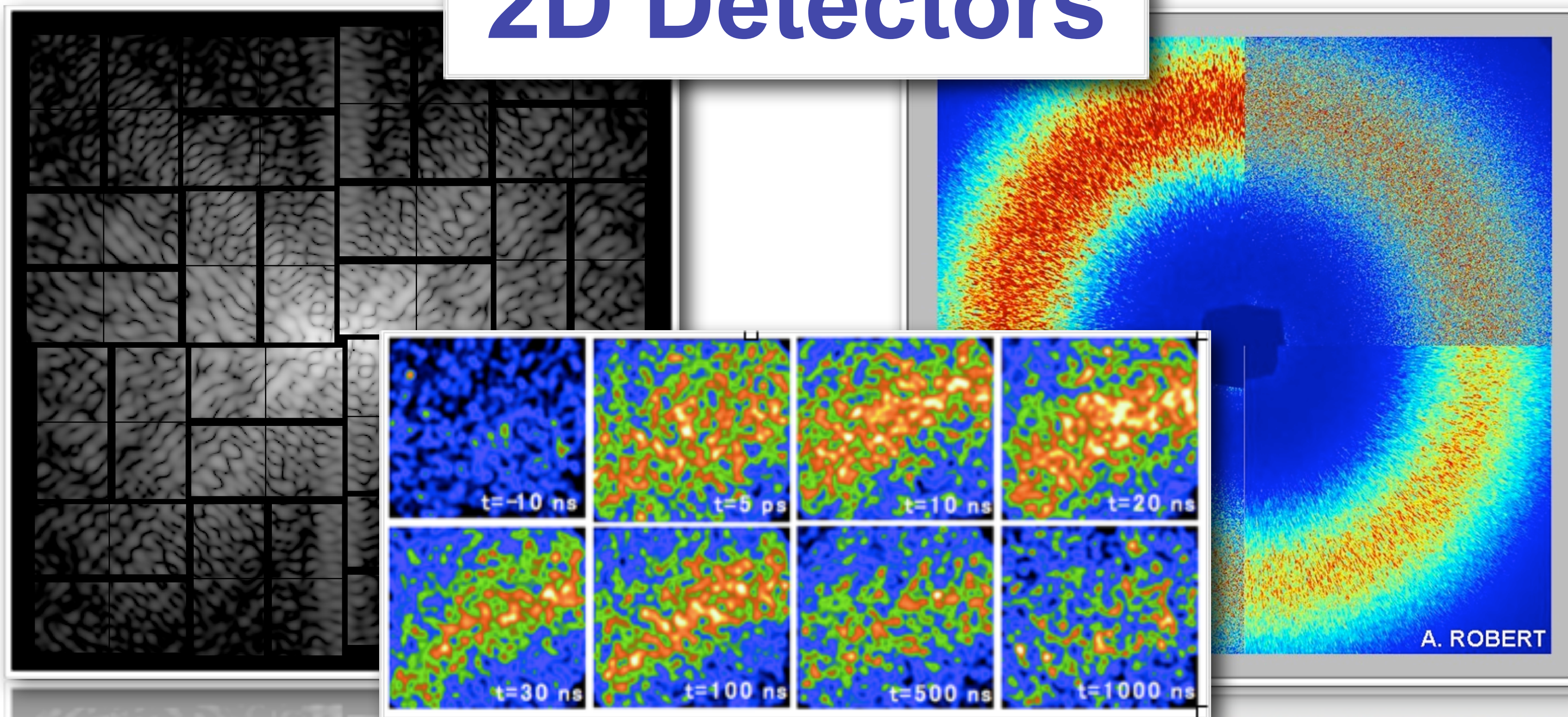
2D Detectors



Niels van Bakel – Detector Physicist

April 21, 2009

Outline

- Detector program
- XPP detector
  - Requirements & Technical progress
- XCS detector
  - Requirements & Technical progress
- CXI detector
  - Requirements & Technical progress
- Interfaces; mechanical & DAQ
- Summary & Outlook

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BNL Team

- Detector Development Group to bring advanced detectors to NSLS users for several years
  - Primary expertise is x-ray science, embedded computing and system integration
    - Peter Siddons; project leader
    - Kate Feng, Tony Kuczewski, Rich Michta, Joe Mead; DAQ and user interface
    - Gabriella Carini; detector elements
- Relies heavily on Instrumentation Division
  - Under the leadership of Veljko Radeka it has a long history of developing detector elements for ionizing radiation (historically for HEP) and readout electronics
  - Has good technical resources (total staff ~45) including semiconductor foundry for detector elements, ASIC design, detector-readout bonding, custom PCB fabrication, standard board assembly and testing etc.
    - Pavel Rehak, Zheng Li, Wei Chen, Rolf Beuttenmuller; detector elements
    - Paul O'Connor, Angelo Dragone (SLAC), Gianluigi De Geronimo; ASIC design

LDAC

- LCLS Detector Advisory Committee:
  - Gareth Derbyshire (chair): Rutherford Appleton Laboratory, UK
  - Erik Heijne (interim chair): CERN, Switzerland
  - Eric Eikenberry: PSI, Switzerland
  - Heinz Graafsma: DESY / XFEL, Germany
  - Ronnie Shepherd: LLNL, USA
  - Lothar Struder: MPI / Semiconductor Laboratory, Germany
  - Albert Walenta: University of Siegen, Germany
  - Yoshiyuki Amemiya: University of Tokyo, Japan
- Track technical progress, check if detector specs meet the original requirements and involved in technology choices
- Other topics e.g. DAQ and system integration
- LDAC report

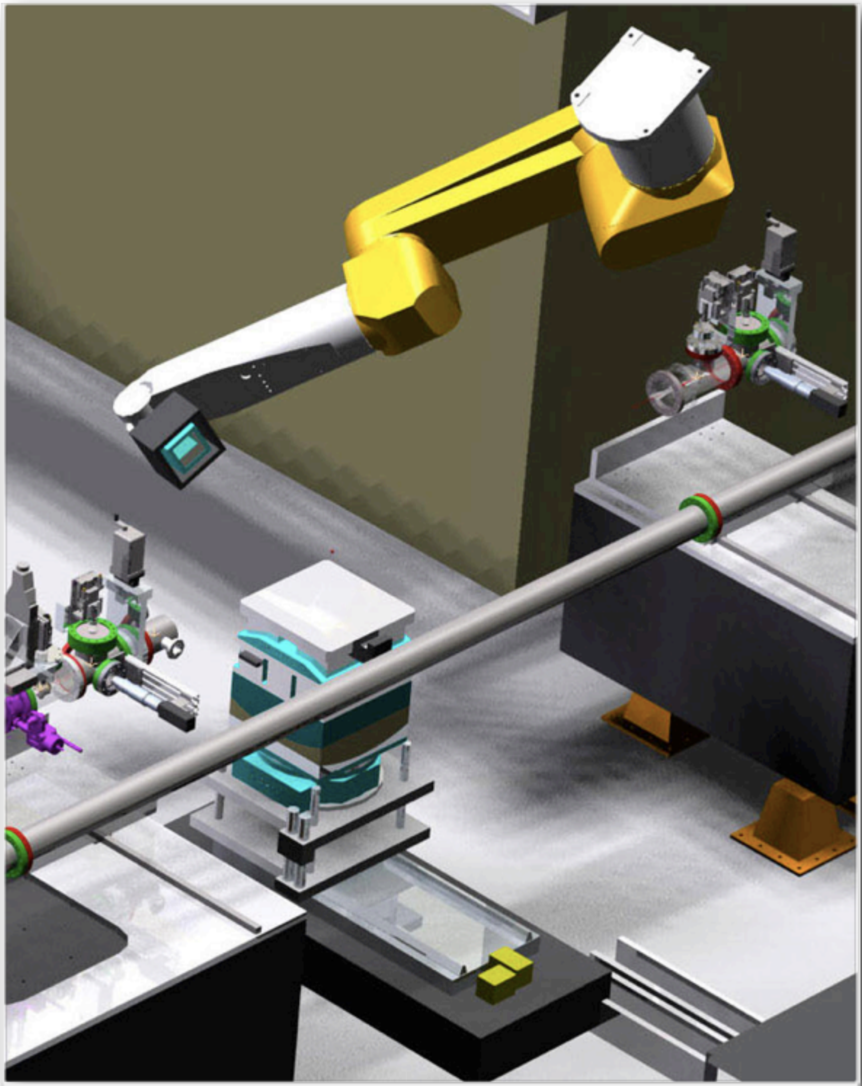
Specifications

- Intense (10^{12} ph) and short (100 fs) pulses at 120 Hz need integrating detectors with fast readout (< 8 ms)
- Commercial detectors not available

	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	≤ 50 µm
Number of pixels	760^2 (1500^2)	1024^2 .	1024^2 .

- XPP: Multi-purpose detector to image the scattering intensity that is slowly varying with scattering angle (in steps) or a number of Bragg peaks on a low intensity background.
- XCS: Image the temporal changes in a speckle patterns that are related to the sample's dynamics; the pixel size should be ≤ speckle size.

XPP Detector



- Diffractometer & robot arm
  - Sample - detector distance 10 - 100 cm
  - Quadrant of sphere
- Detector development:
  - Pixel sensor
  - Readout ASIC
  - DAQ
- Integration into XPP
  - Packaging
  - Mechanical interface
  - LCLS DAQ interface

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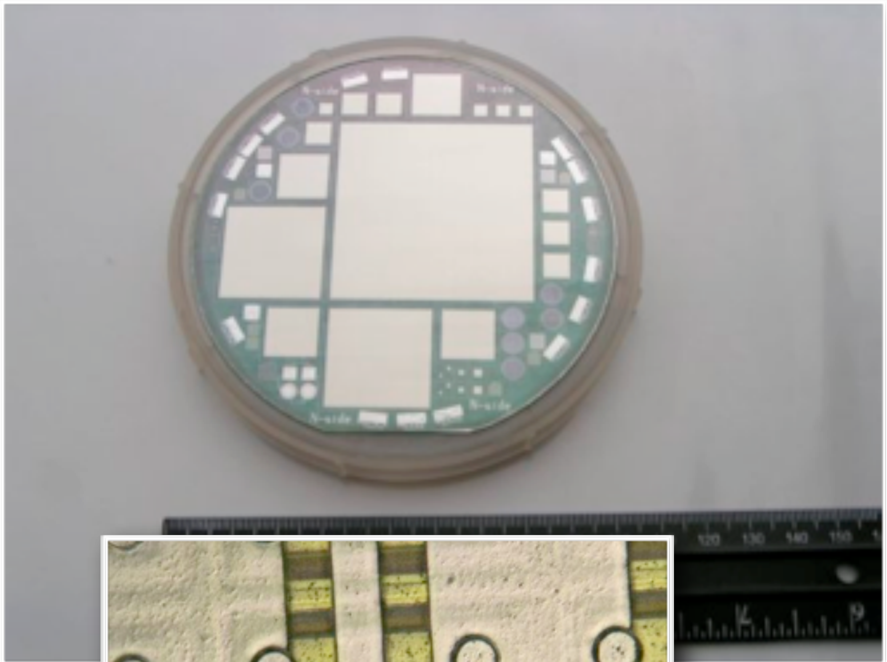
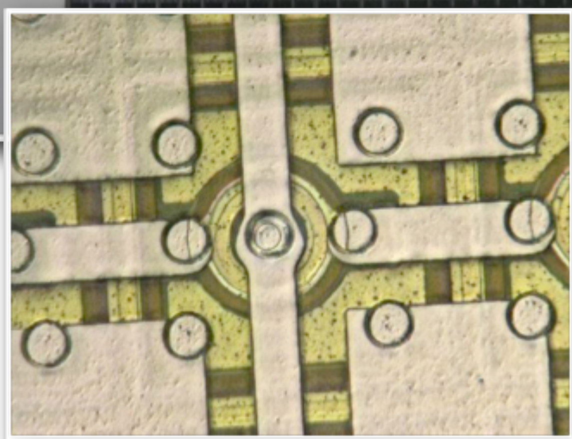
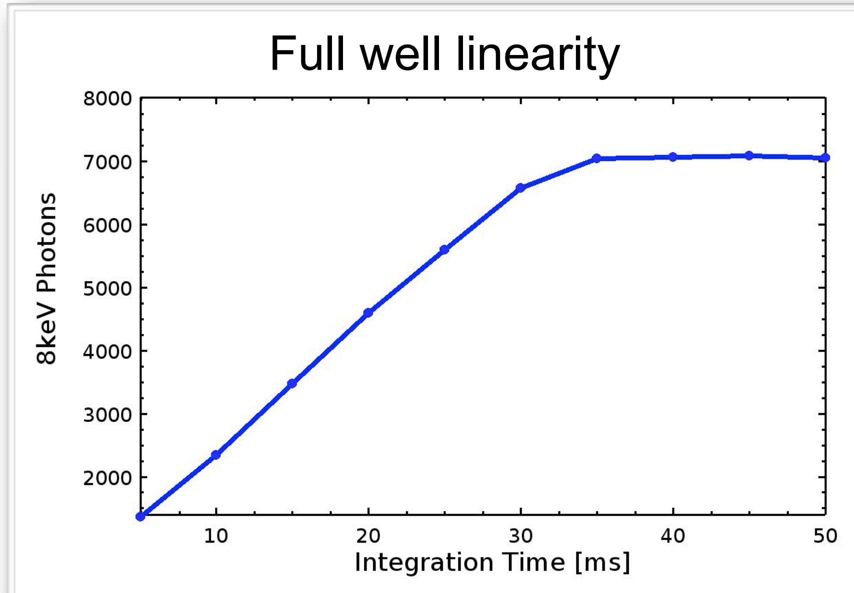
BNL XAMPS

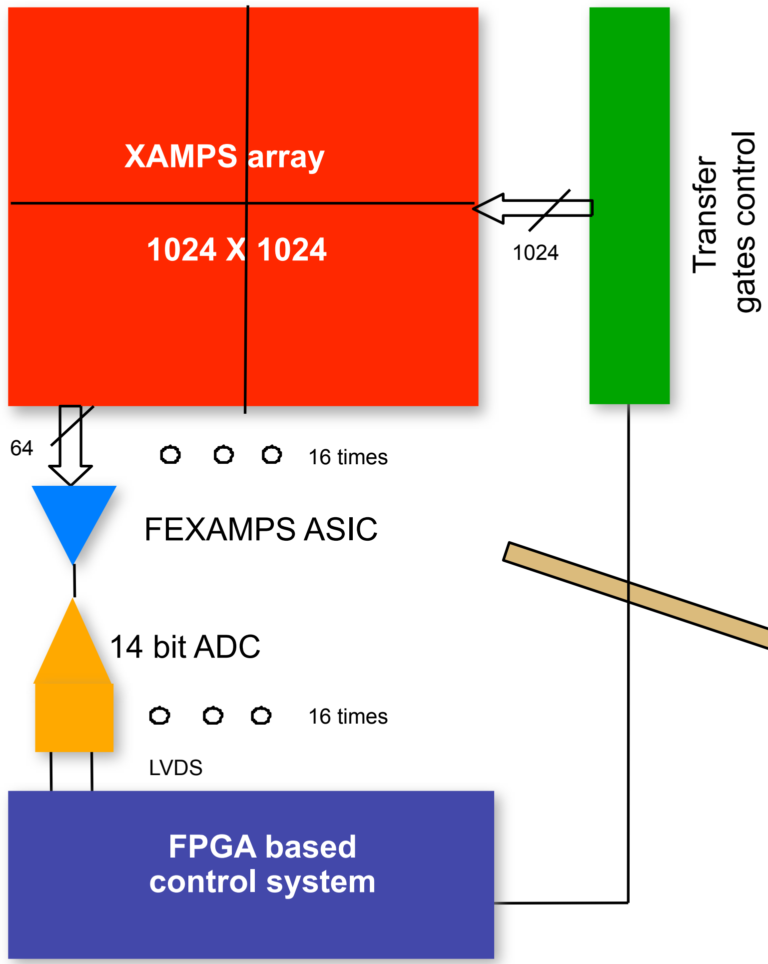




- BNL in-house process
- X-rays with 32 x 32 module
- Assembled 64 x 64 module
- 512 x 512 module
  - 100 mm n-type wafer
  - 400 μm thick
-



XAMPS Readout



- Switch-matrix structure; 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

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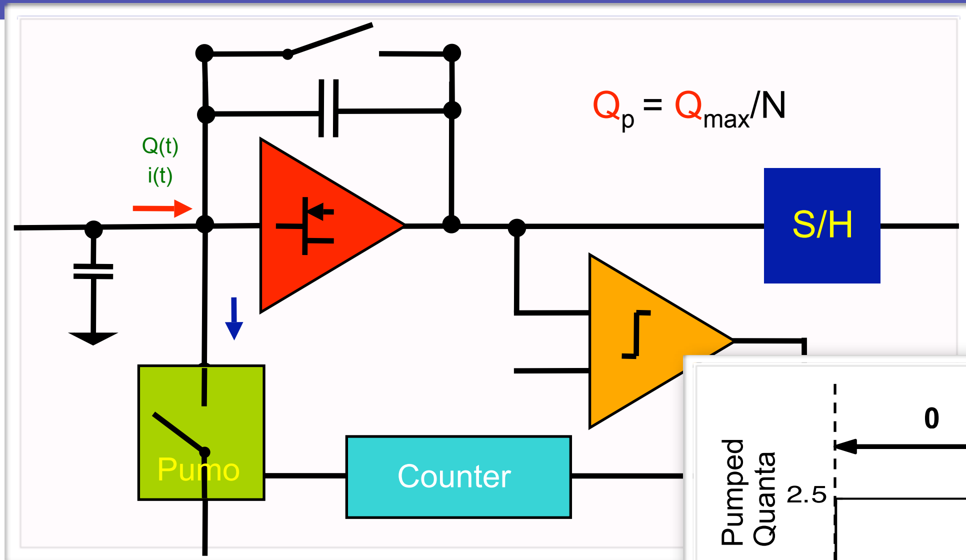
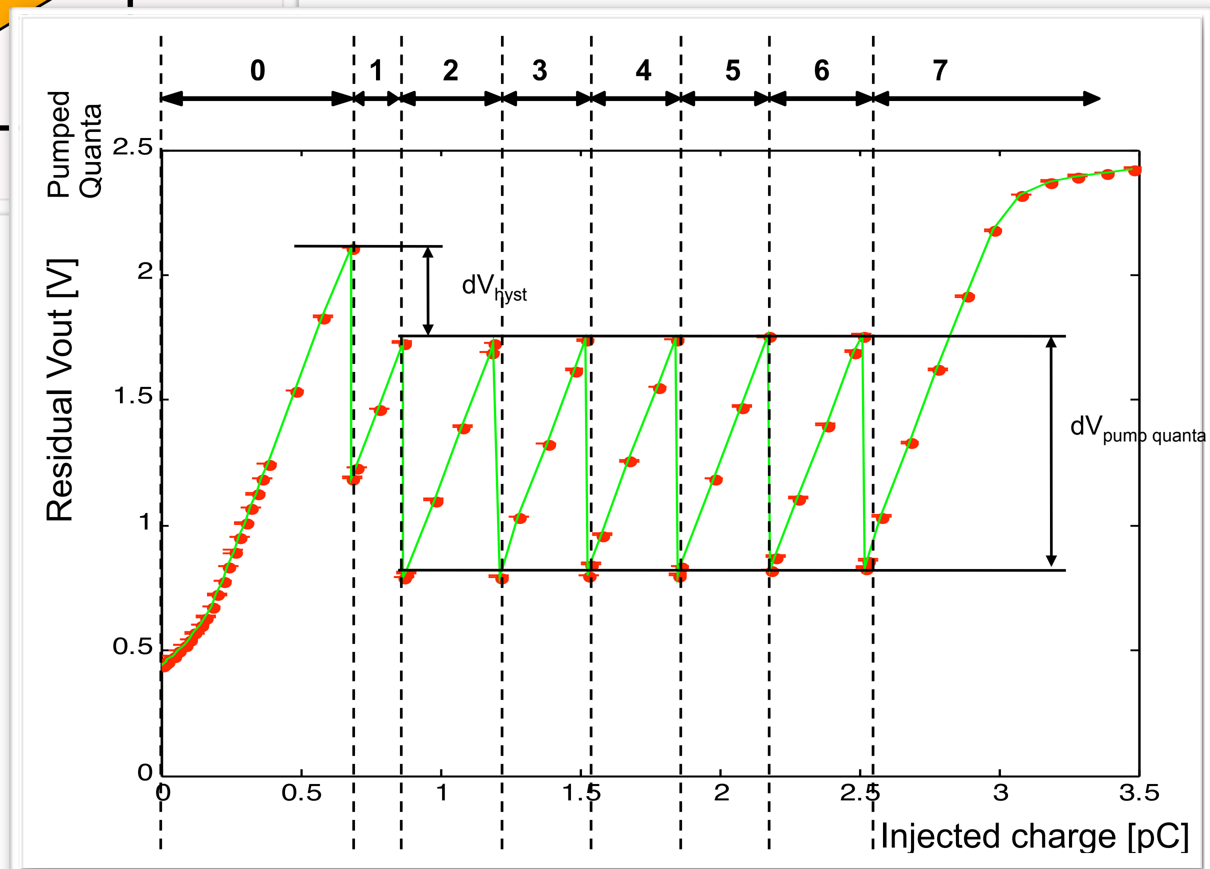
Readout ASIC





- Divide dynamic range into 8 intervals
- If $Q_{in} > Q_p$ remove (pump) a fixed amount of charge Q_p until the residual $Q_f < Q_p$
- Count number of removed quanta (3 bits)
- Sample the residual charge in C_f
- The output is converted with a 14 bit ADC (total 17 bit)

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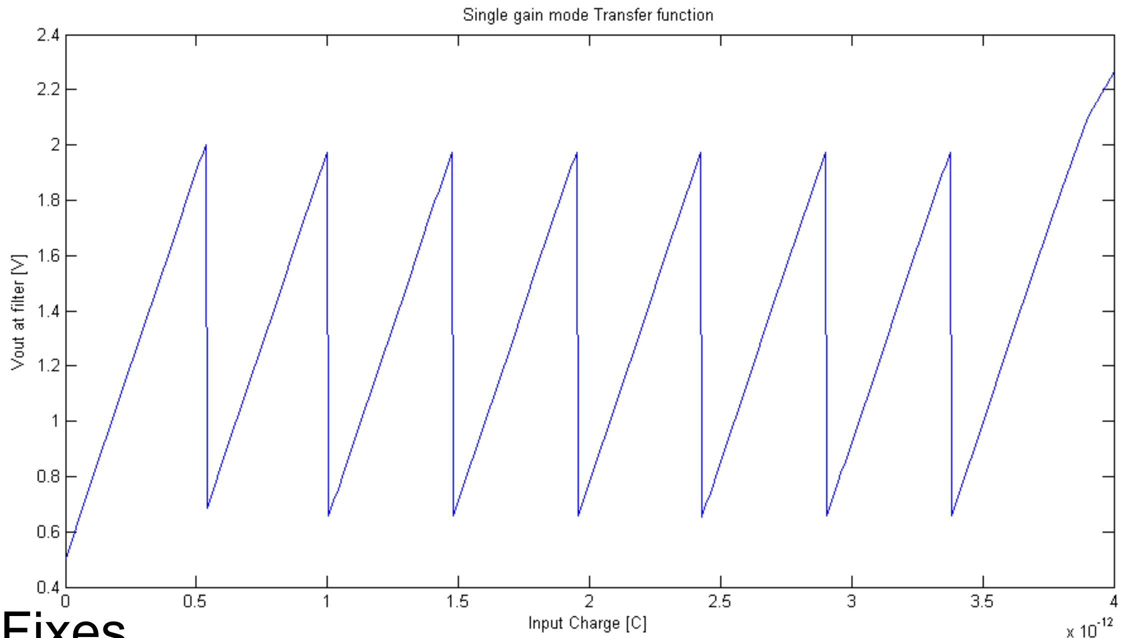
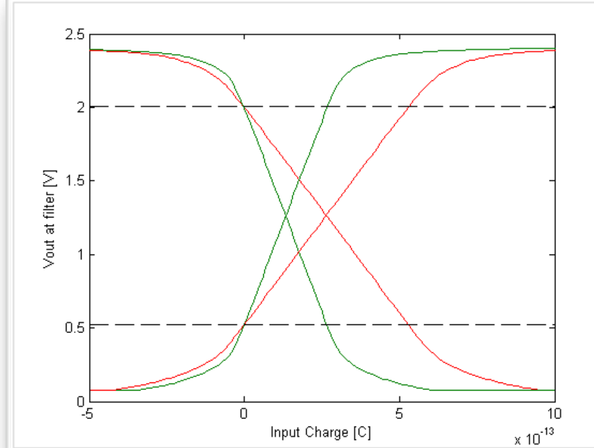
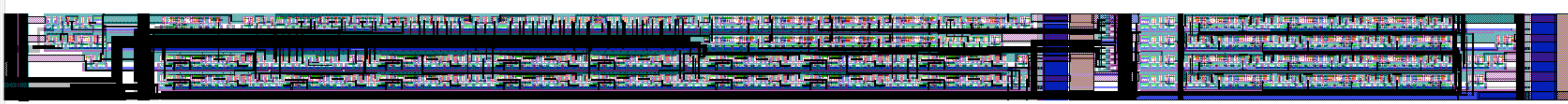
Revised FEXAMPS





- Fixes
  - Non linearity solved
  - Minimized hysteresis
  - Expanded DR to ~ 4 pC (11,400 ph)
  - Several noise sources eliminated
- Improvements
  - Dual (x2) gain preamp with improved reset
  - More robust charge pump to prevent charge glitches
  - Programmable charge pump range (8/16)



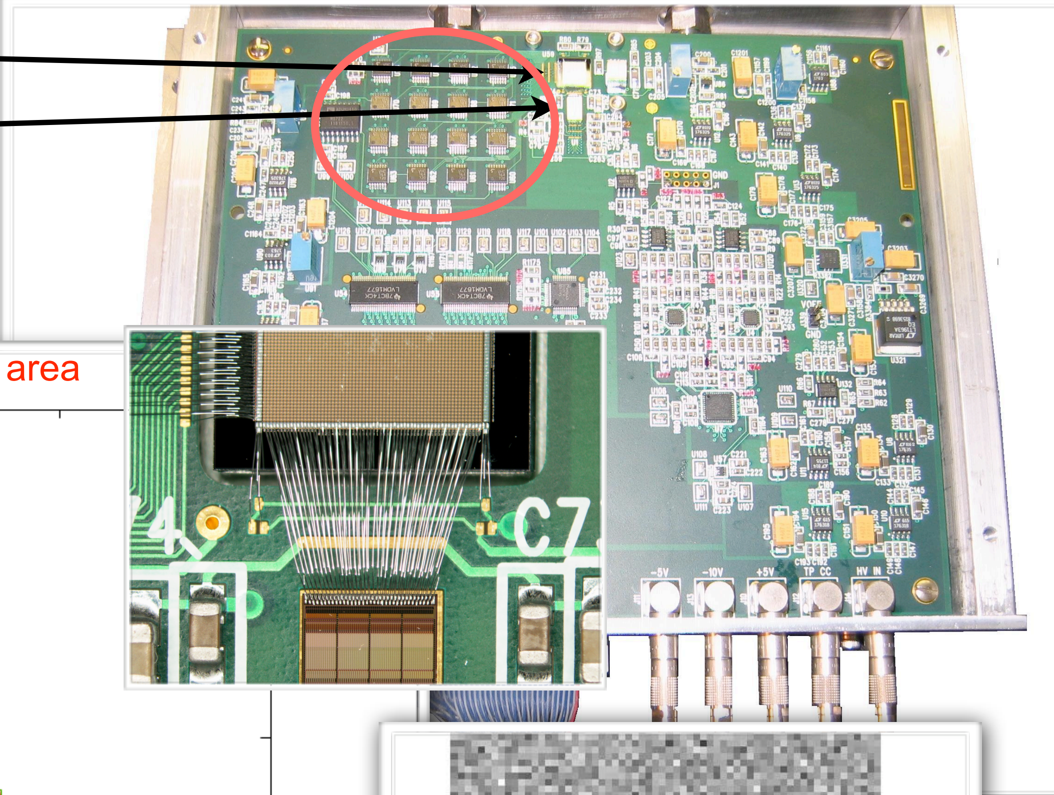
Submission imminent

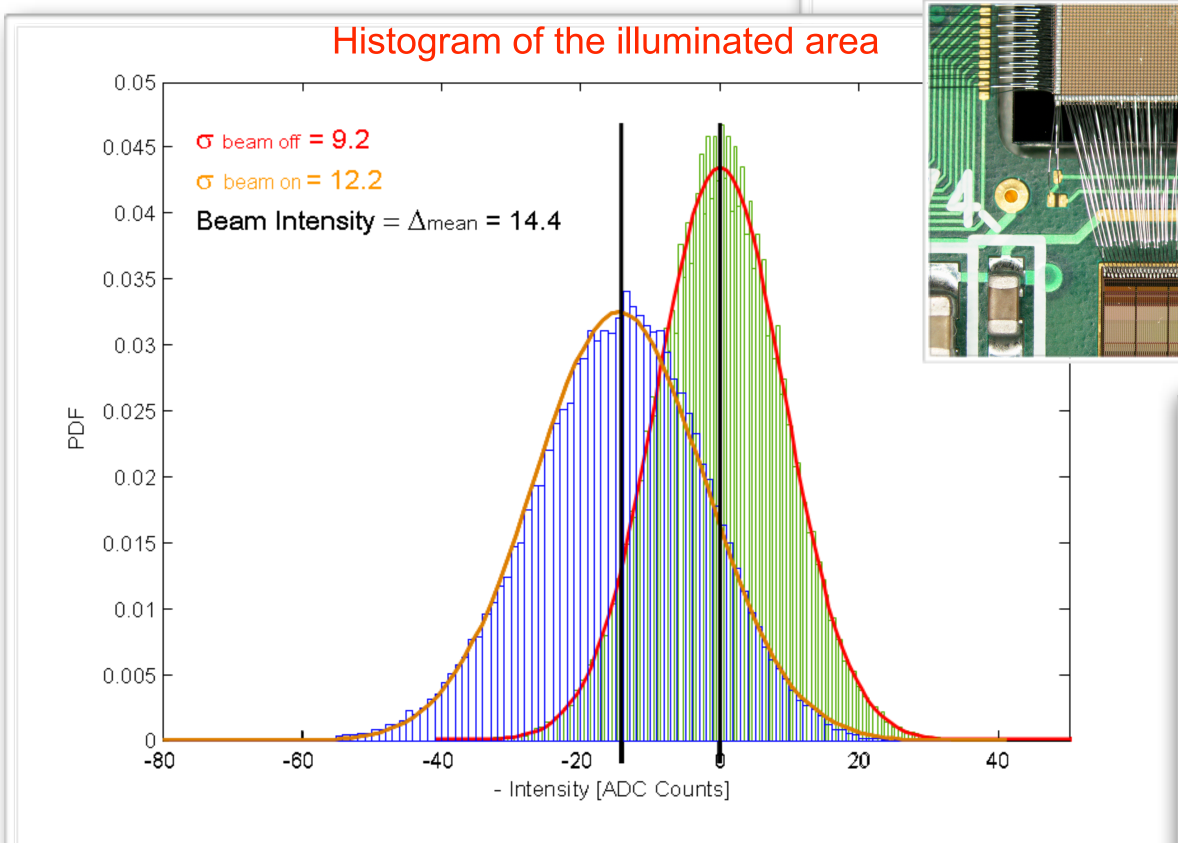
Detector tests with X-rays

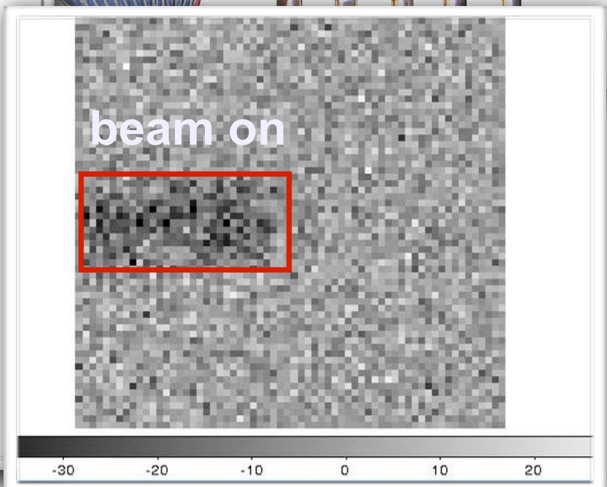
64x64 XAMPS Detector

FEXAMPS ASIC

Discrete Row Drivers







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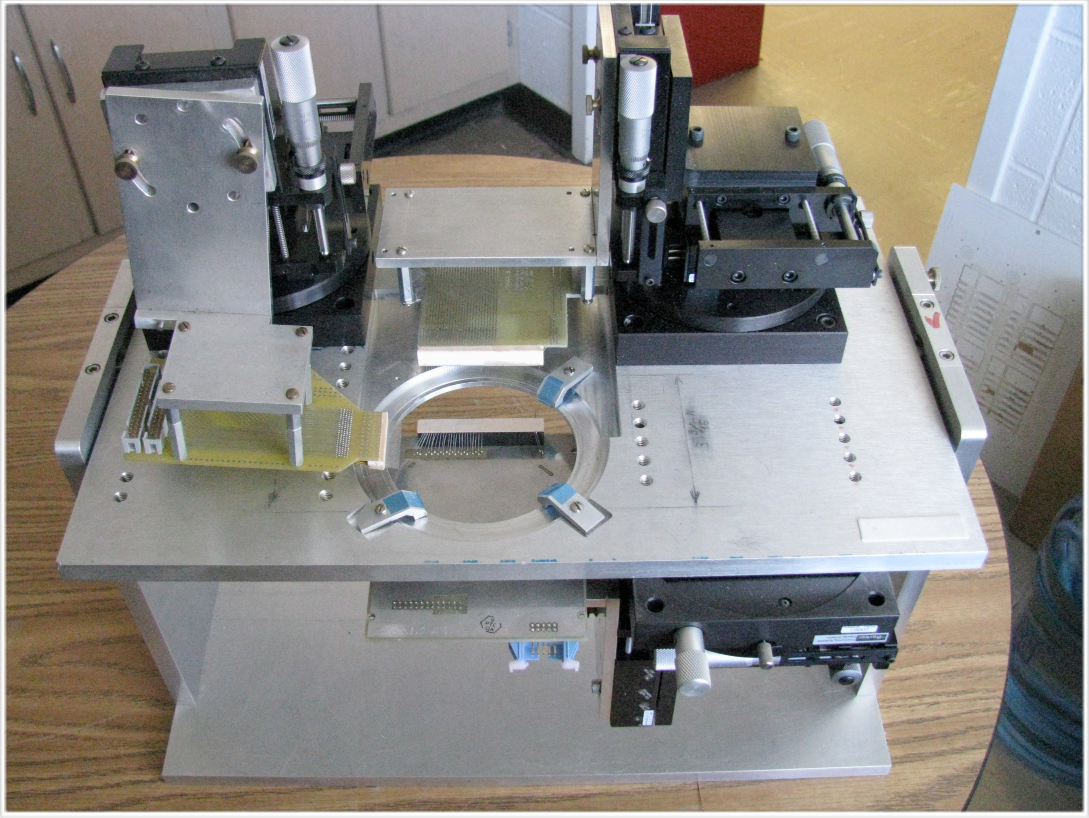
Sensor testing

- Double-sided probe station
- Three micro-manipulators for probe cards
  - 2 above, 1 below
- Handles 4” wafers



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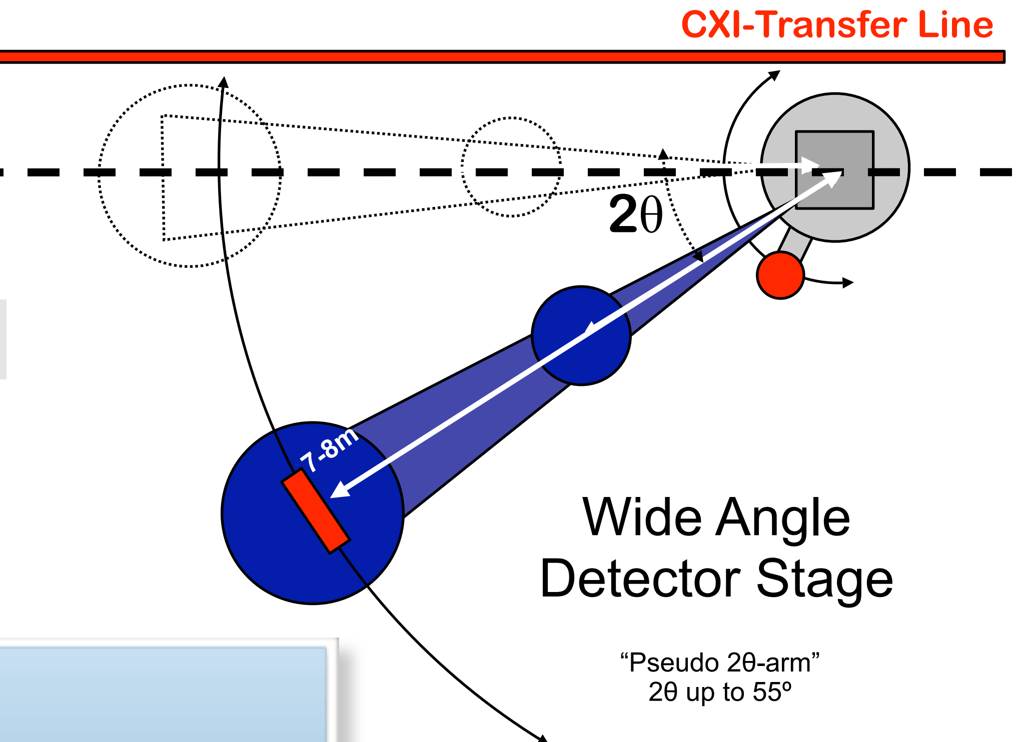
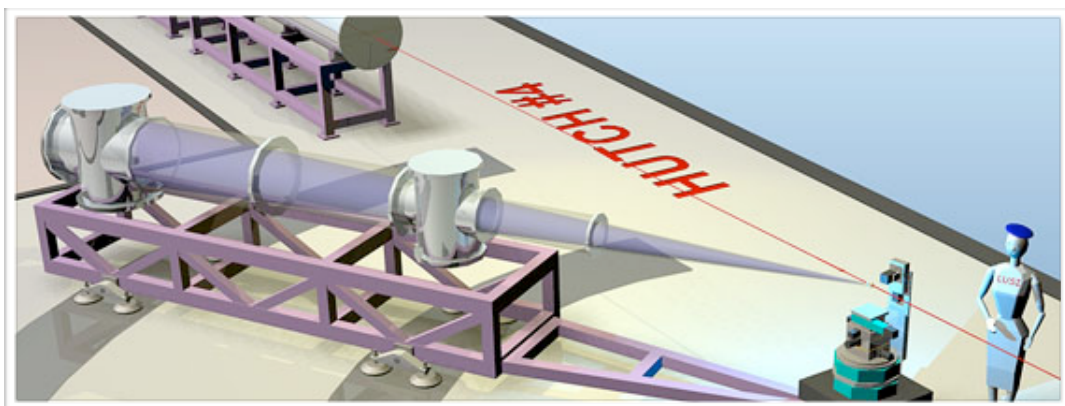
XCS Detector



Sample detector Distances

- 7-8 m



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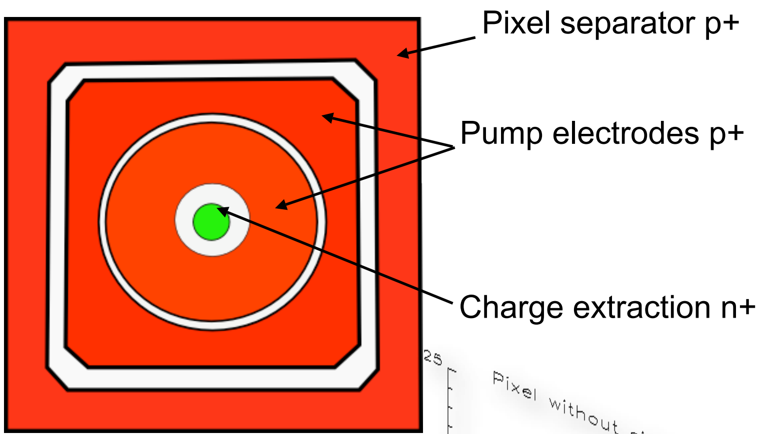
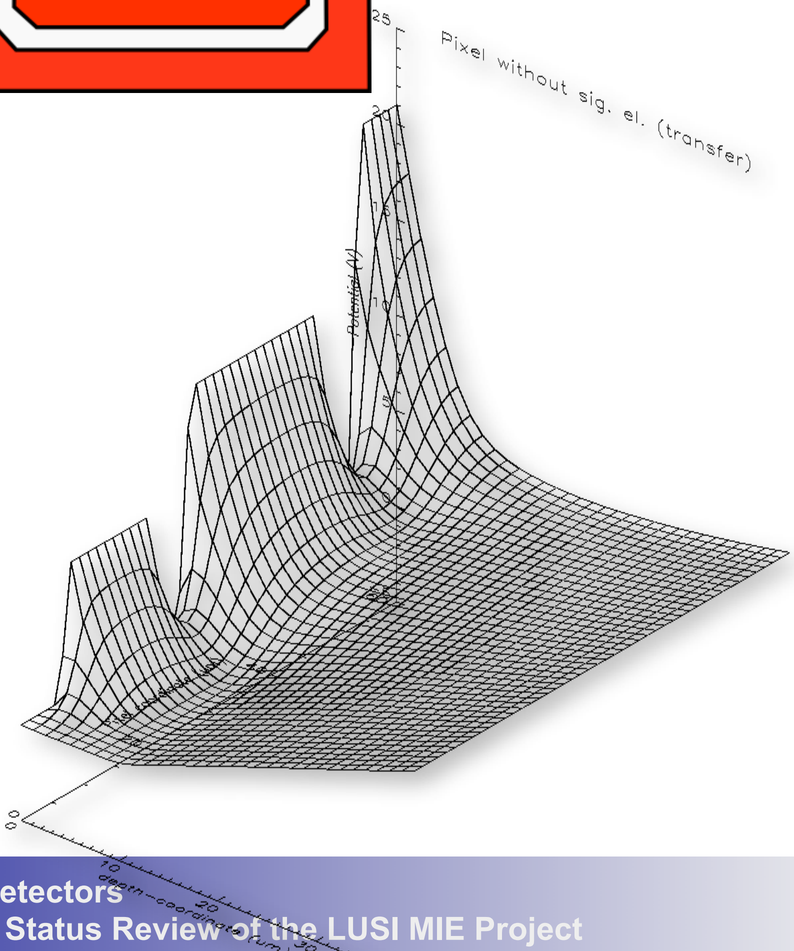
XCS Pixel





- "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 (less DR).
  - No "kTC noise"

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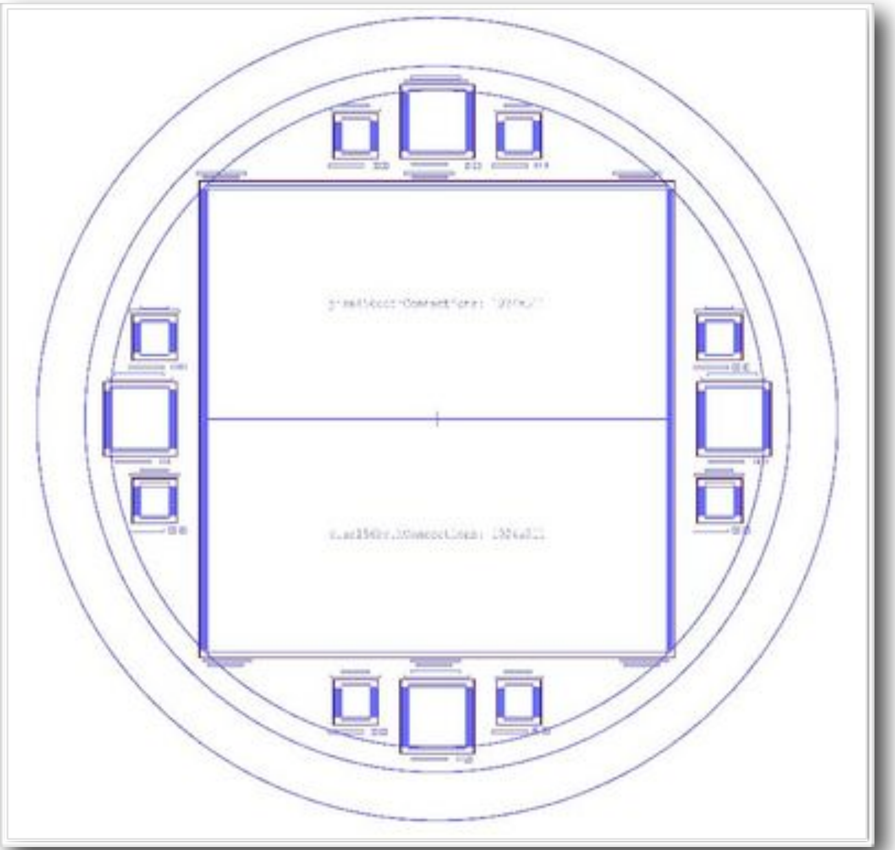
XCS Sensor

- 1k x 1k pixels
- Pixel size 56 µm
- 100 electrons noise level
- 100 8 keV photons full-well
- Split readout
- Full-wafer (4”) device



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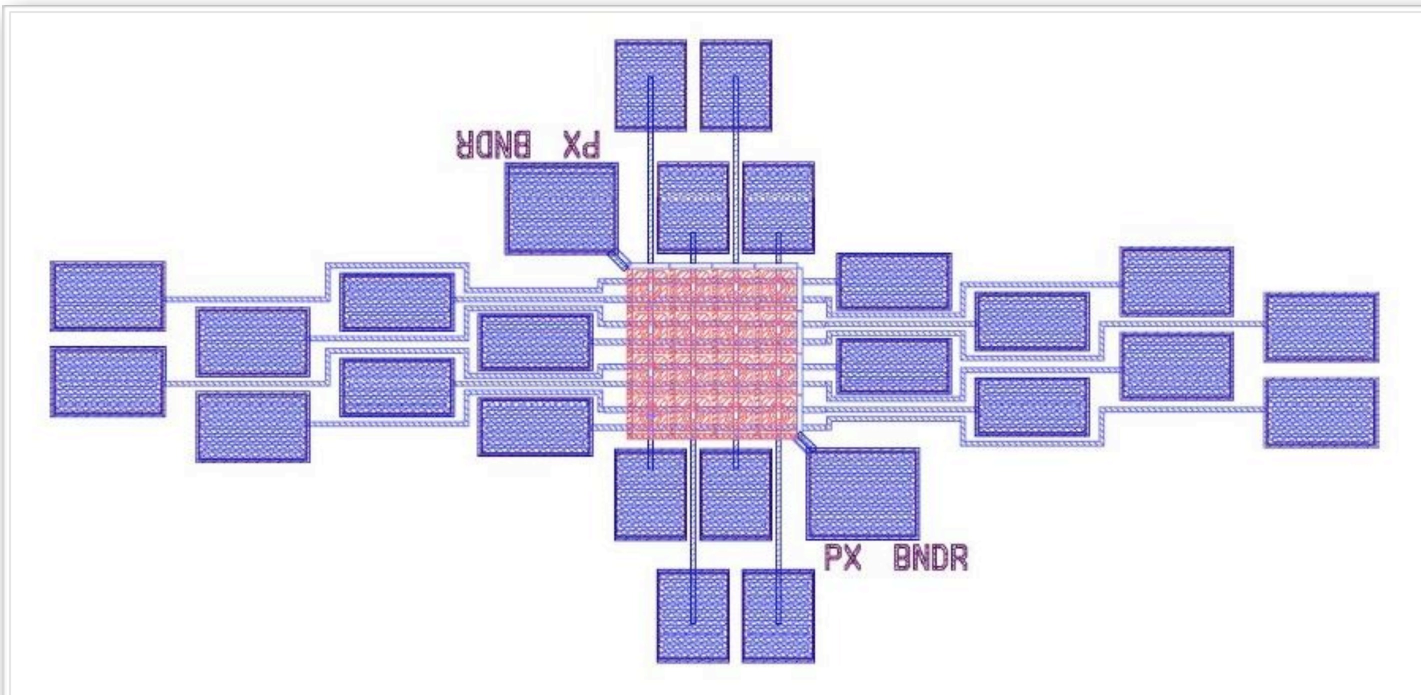
XCS 4x4 Pixel Structure

- Charge pump needs 2 drive lines per row
- 56 µm pixel size → quad bond pad layout
- Readout ASIC architecture still under discussion
  - Modify FEXAMPS or new architecture



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LDAC Recommendations

- Increase interaction with user community
  - Close interaction with Instrument Scientists
  - Team leader meetings & Instrument workshops
- BNL progress
  - Focus on evaluation of the in hand 512 x 512 sensor with x-rays
    - Try to reduce the sensor capacitance for better noise performance for single photons
    - Keep the 1024 x 1024 design in parallel: current boards & interfaces compatible with 1024
  - Need accurate planning with the deliveries of all system components
  - Find solution for clocking the detector rows: MPI ASIC
  - December 09: ‘compliments for the testing and evaluation of the readout chip, and for the first X-ray measurements with a 64x64 sensor”
- Adapt schedules to LUSI Instruments
  - Tight schedule to deliver the XPP detector in February 2010

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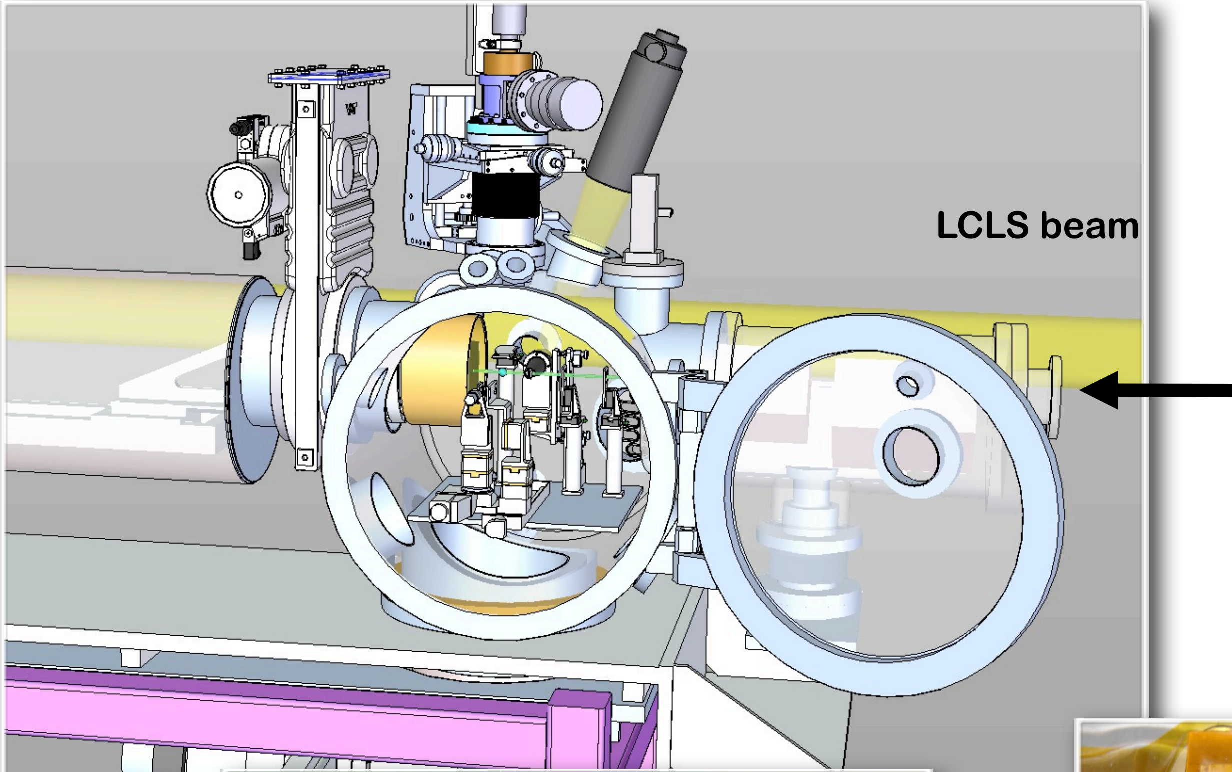
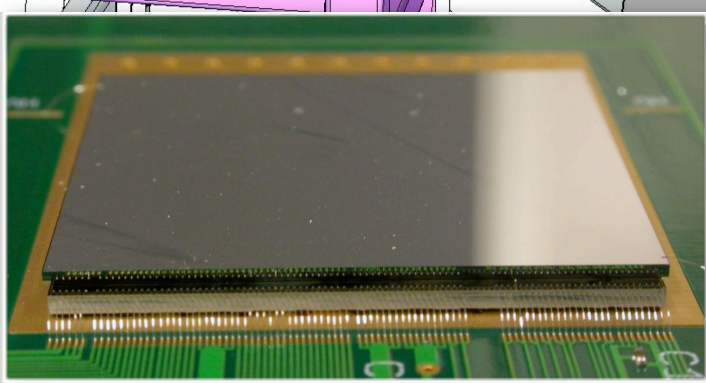
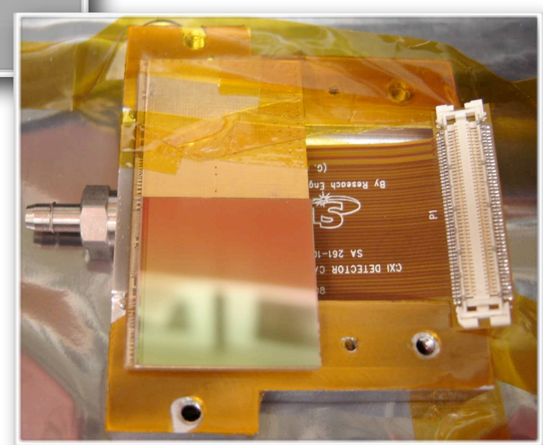
CXI Detector



- Detector in vacuum 10^{-7} Torr
- Resolution depends on the sample-detector distance
  - Requires translation stage 600 mm
  - Remote Aperture resizing 1 - 10 mm
- Cooling 10 - 25 °C





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Interfaces

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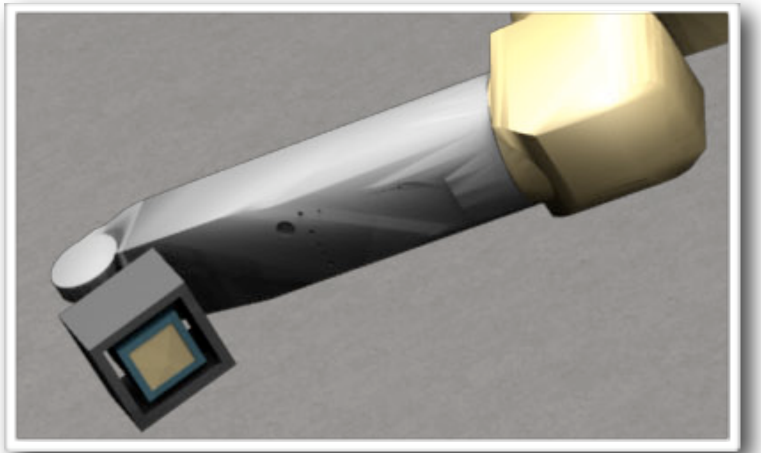
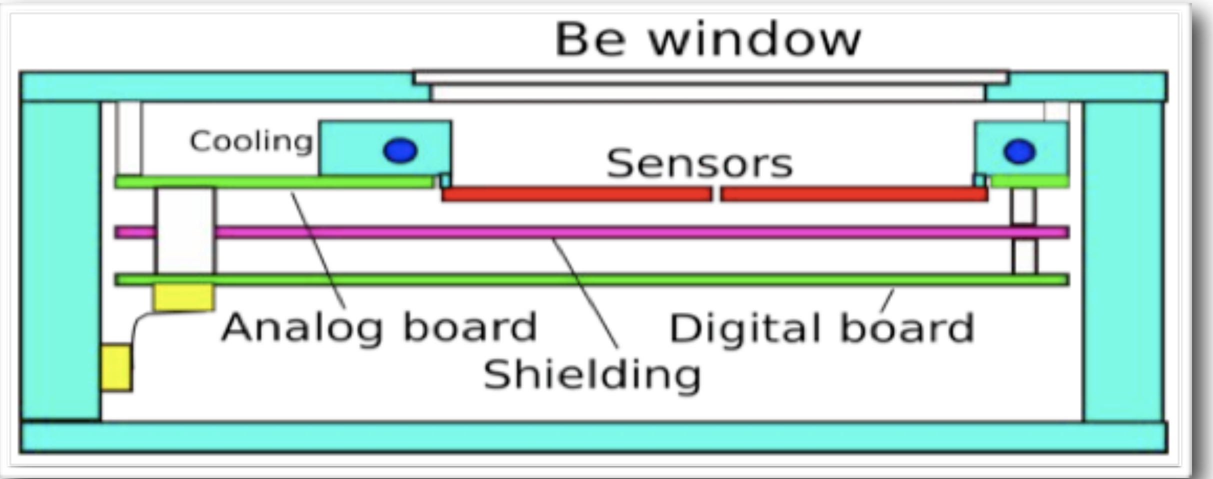
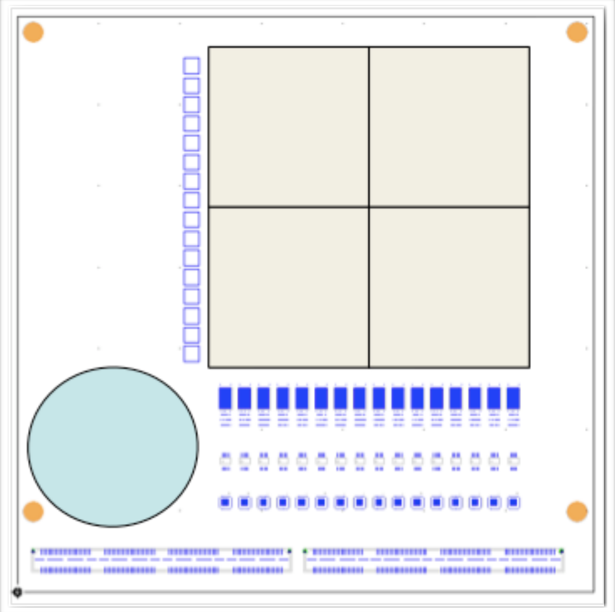
XPP Interface



- Aluminum base plate with
  - Robot mount
  - Alignment fiducials
- Detector Package
  - Analogue & Digital board
  - Cooling to stabilize T
  - Beryllium window





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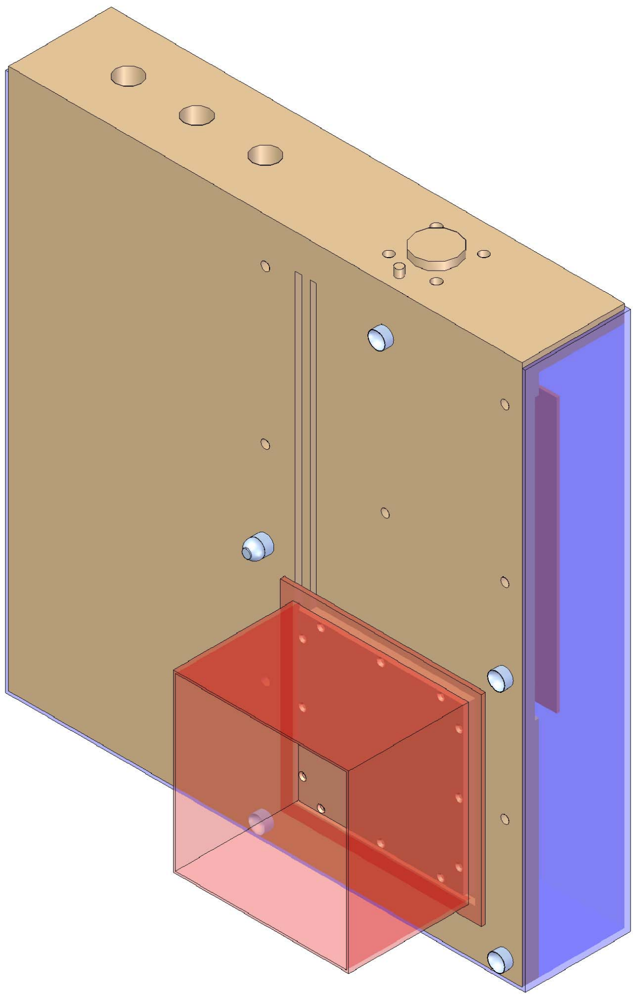
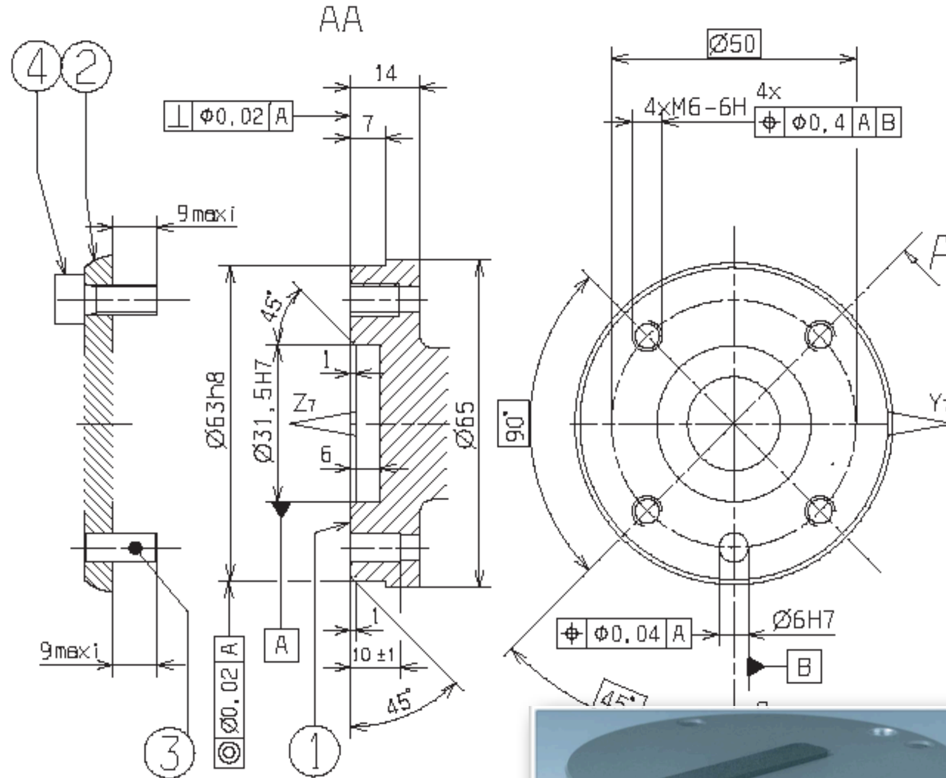
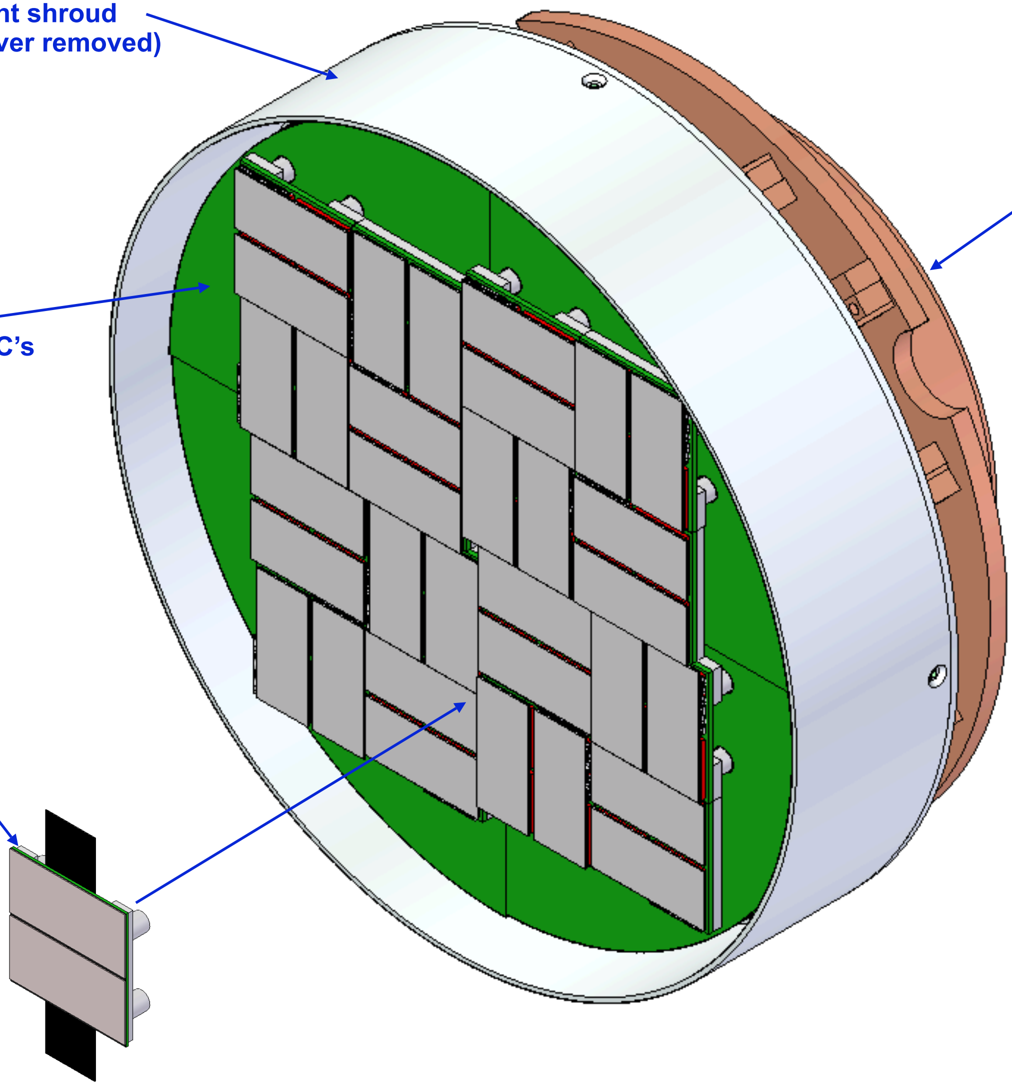
XPP Detector Housing

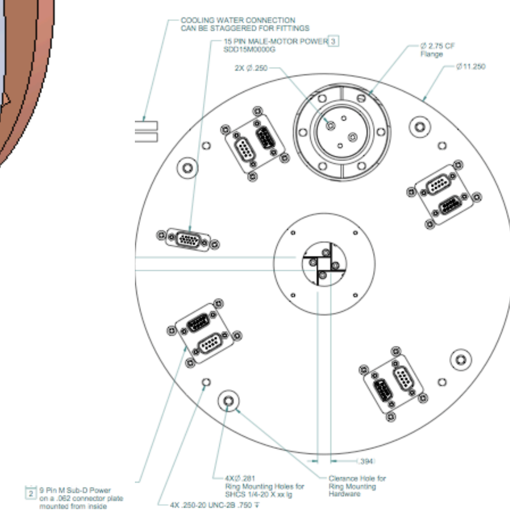




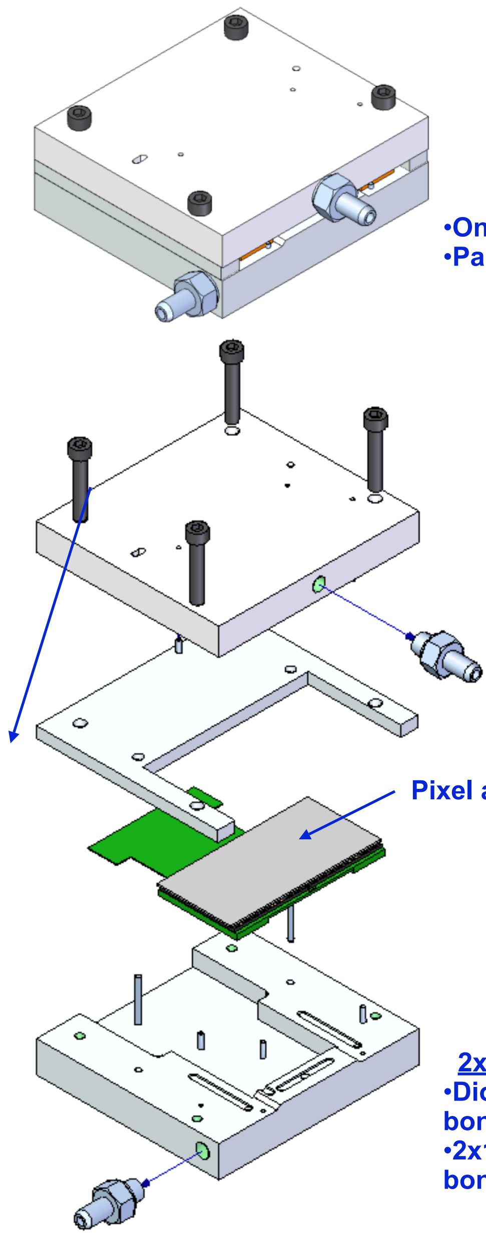
Robotic Collision Sensor

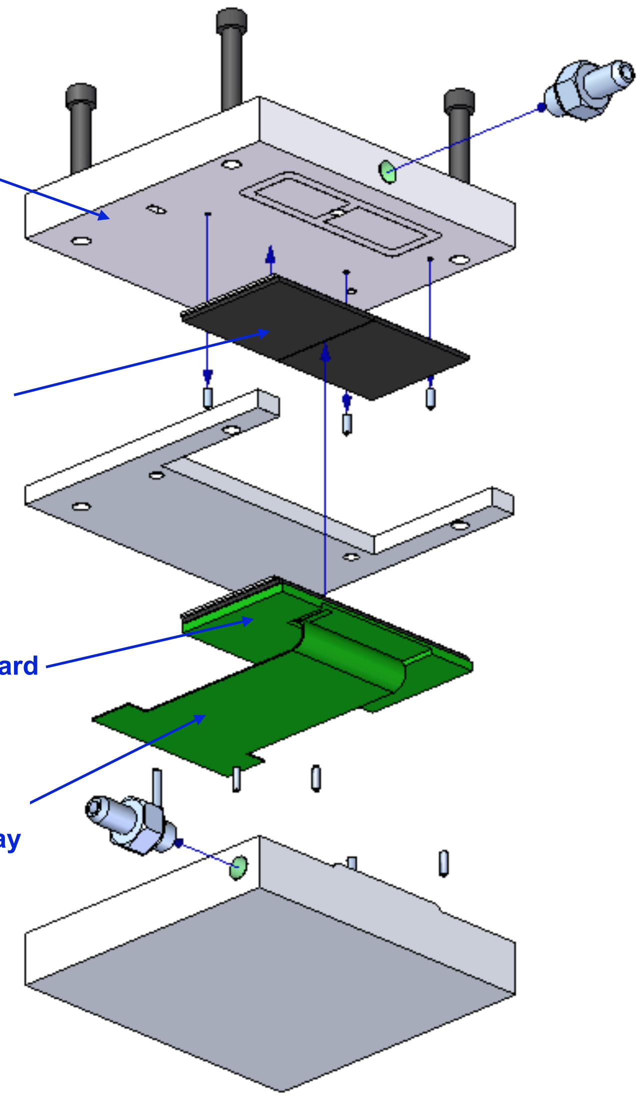
CXI Assembly





CXI 2x1 Module Packaging





Front End Board
- One board per detector
- Part of detector assembly

ASIC's on back side of detector

Carrier board

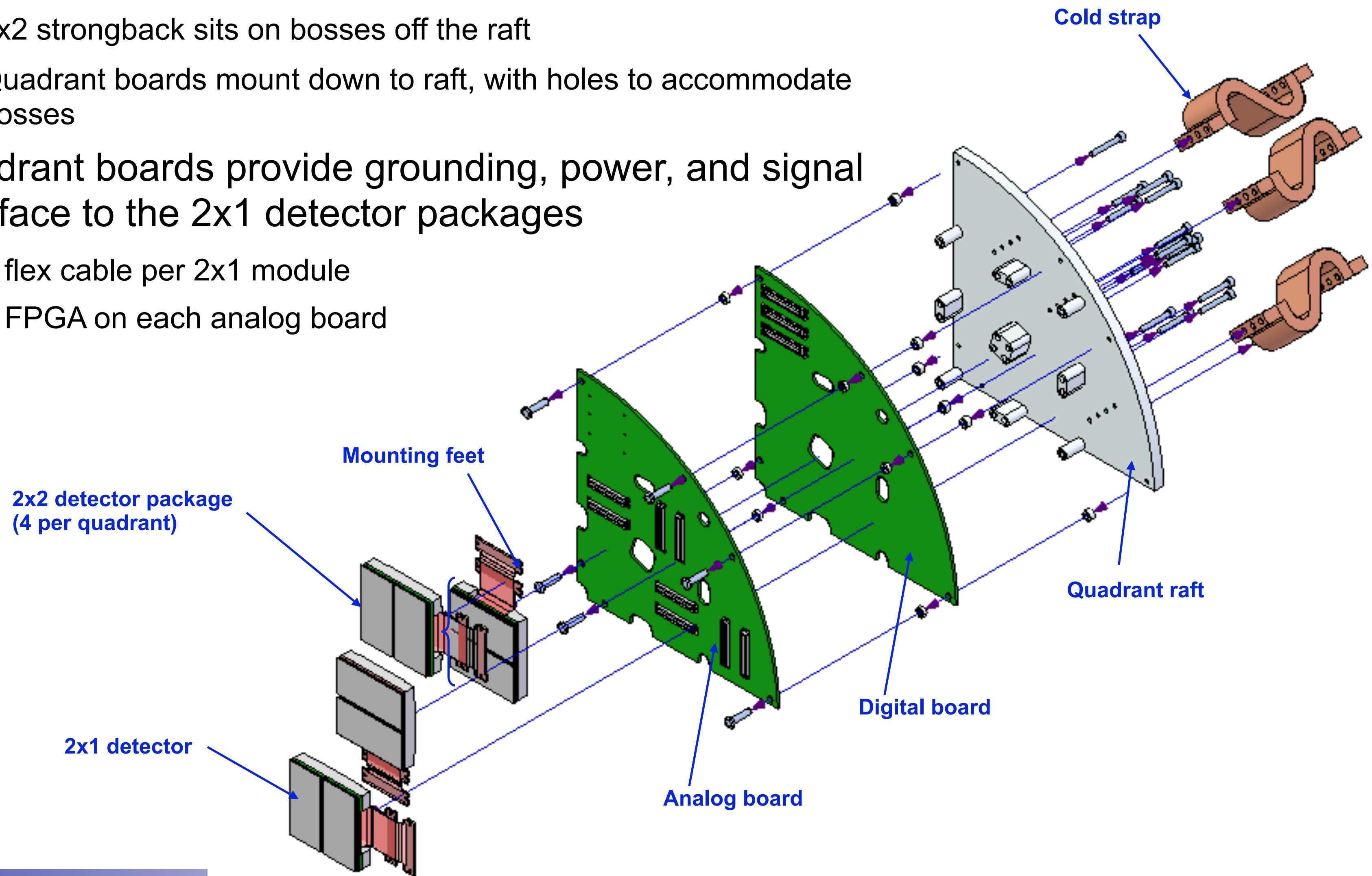
Pixel array detector

Flex cable—bent back out of the way

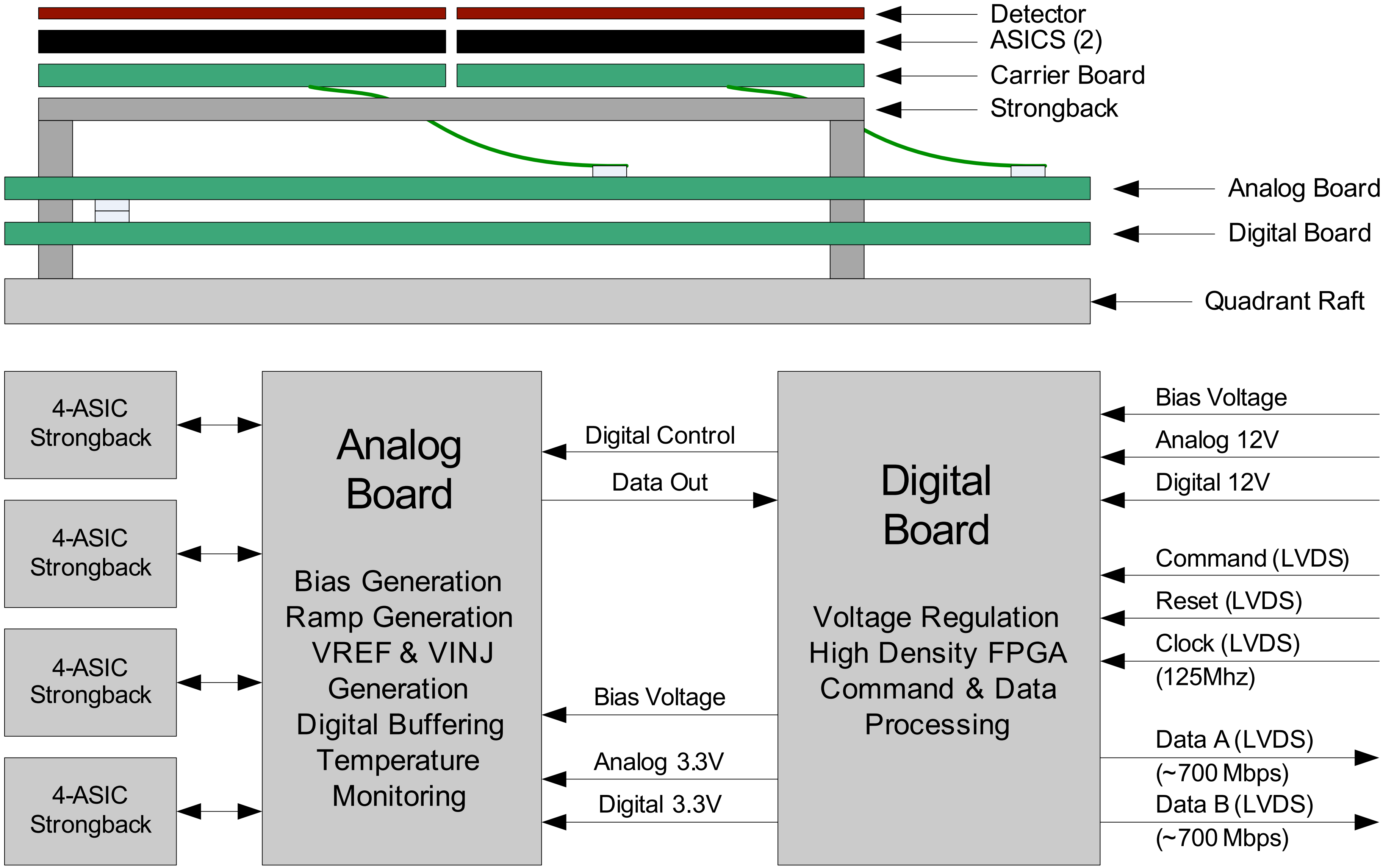
2x1 Detector Assembly Jig
- Diode-ASIC assembly bonded to carrier board
- 2x1 assembly held for wire bonding and testing

CXI Quadrant Board Interfaces

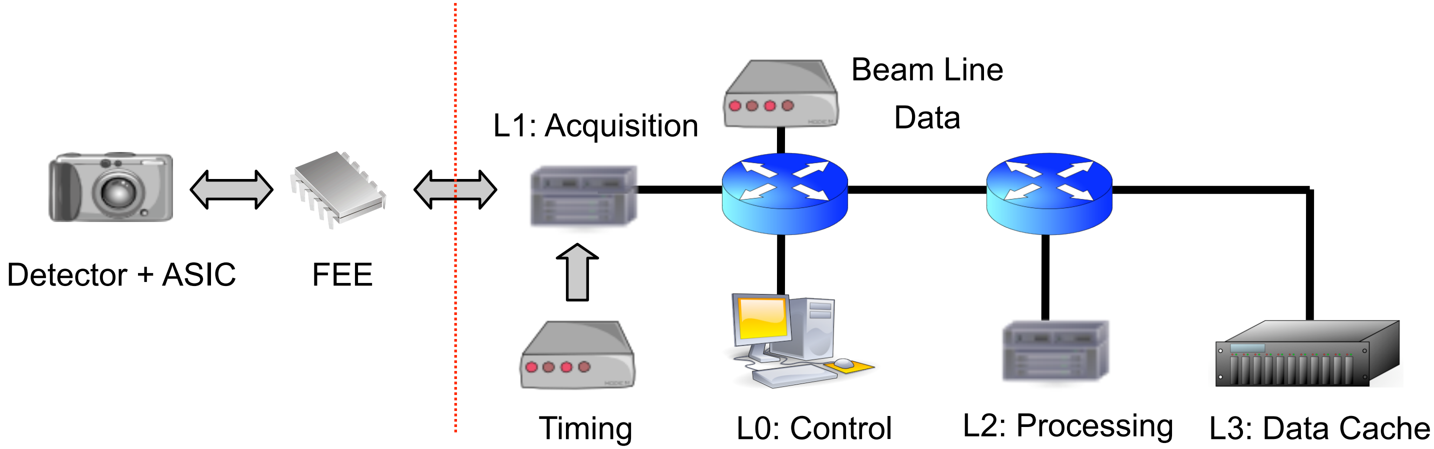
- Quadrant raft provides structural support and thermal grounding for the 2x2 detector packages
  - 2x2 strongback sits on bosses off the raft
  - Quadrant boards mount down to raft, with holes to accommodate bosses
- Quadrant boards provide grounding, power, and signal interface to the 2x1 detector packages
  - 1 flex cable per 2x1 module
  - 1 FPGA on each analog board



CXI Detector Quadrant



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

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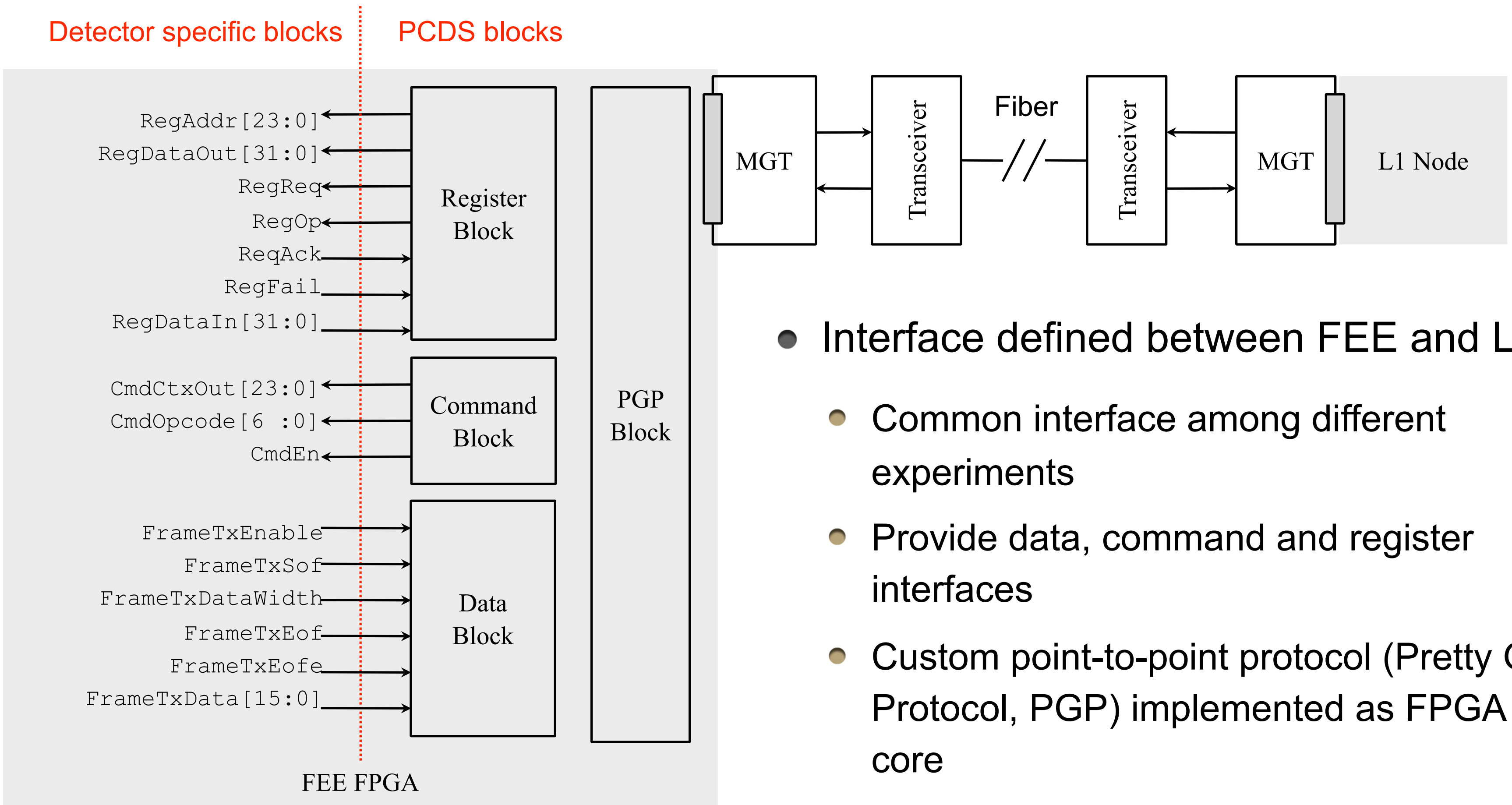
Register Command Data Interface



- 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)

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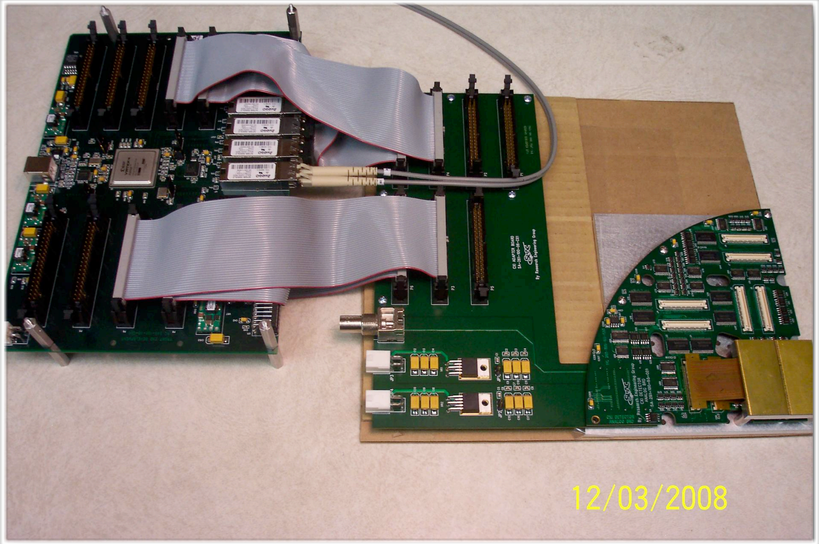
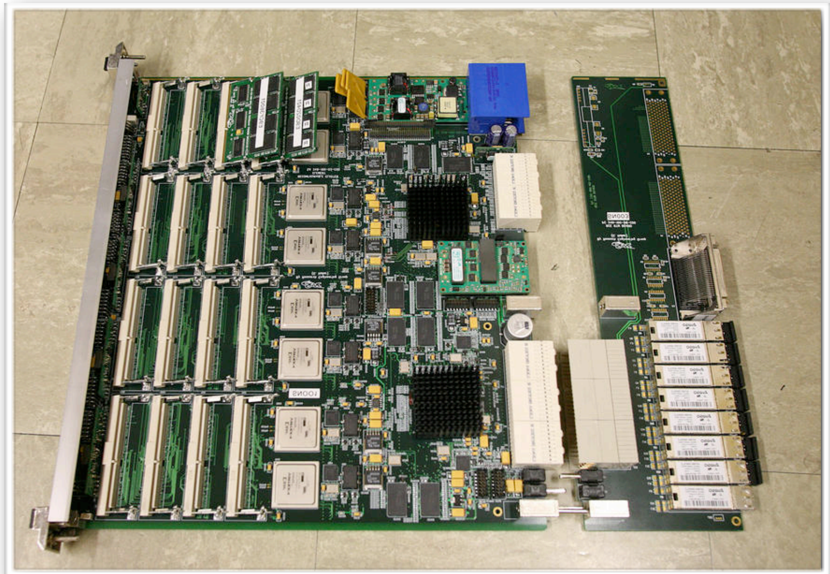
Detector Testing at SLAC



- SLAC Front End Development board, 'Digital' & Analog PCB for CXI
- Additional testing; feedback to Detector Groups
- Improves integration into LCLS & LUSI instruments

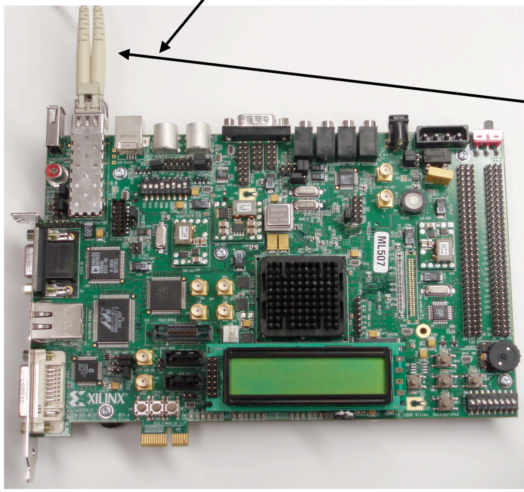
- SLAC custom made ATCA board available for detector groups
- Start testing with x-rays at SLAC
  - SSRL
  - Detector test lab; x-ray tube

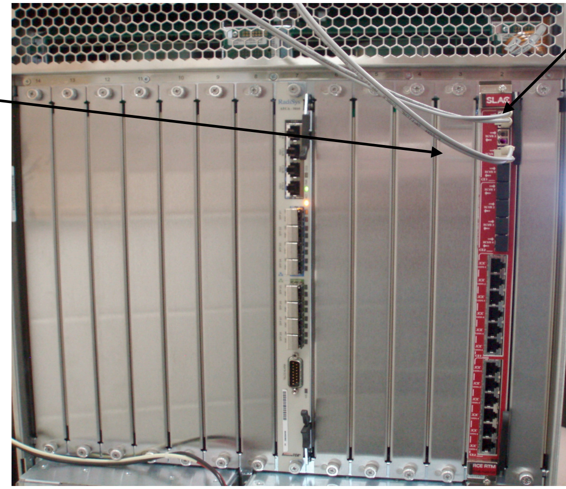


XPP Data Acquisition (BNL)

PGP link

Gigabit Ethernet





- Integration of XPP front-end with RCE module
  - RCE communicating with DHCP server via gigabit ethernet
  - ML507 Xilinx FE evaluation board to communicate with RCE (until final digital board ready)
  - Currently working on establishing communication between FE evaluation board and RCE via PGP
- PGP-Forward application loaded on RCE at SLAC
  - Forwards packets up to 2 kbytes between gigabit ethernet interface and PGP interface.
  - 1st fiber on RCE connects to XPP front end evaluation board (via PGP)
  - 2nd fiber on RCE connects to PC (via gigabit ethernet)
  - Will Need SLAC 10G switch module for final acquisition rate (120Hz x 1k*1k*2bytes = 2Gbps)

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Outlook

- BNL XAMPS detector at SLAC February 2010
  - XPP ready in July 2010
- BNL XCS detector at SLAC October 2011
  - XCS ready in December 2011
  - "Early XCS" in August 2011
    - Duplicate XPP detector needed March 2011
- Cornell 2D PAD detector at SLAC November 2009
  - CXI ready in Nov 2011
  - "Early CXI" end of 2010 or spring 2011

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

Back-up

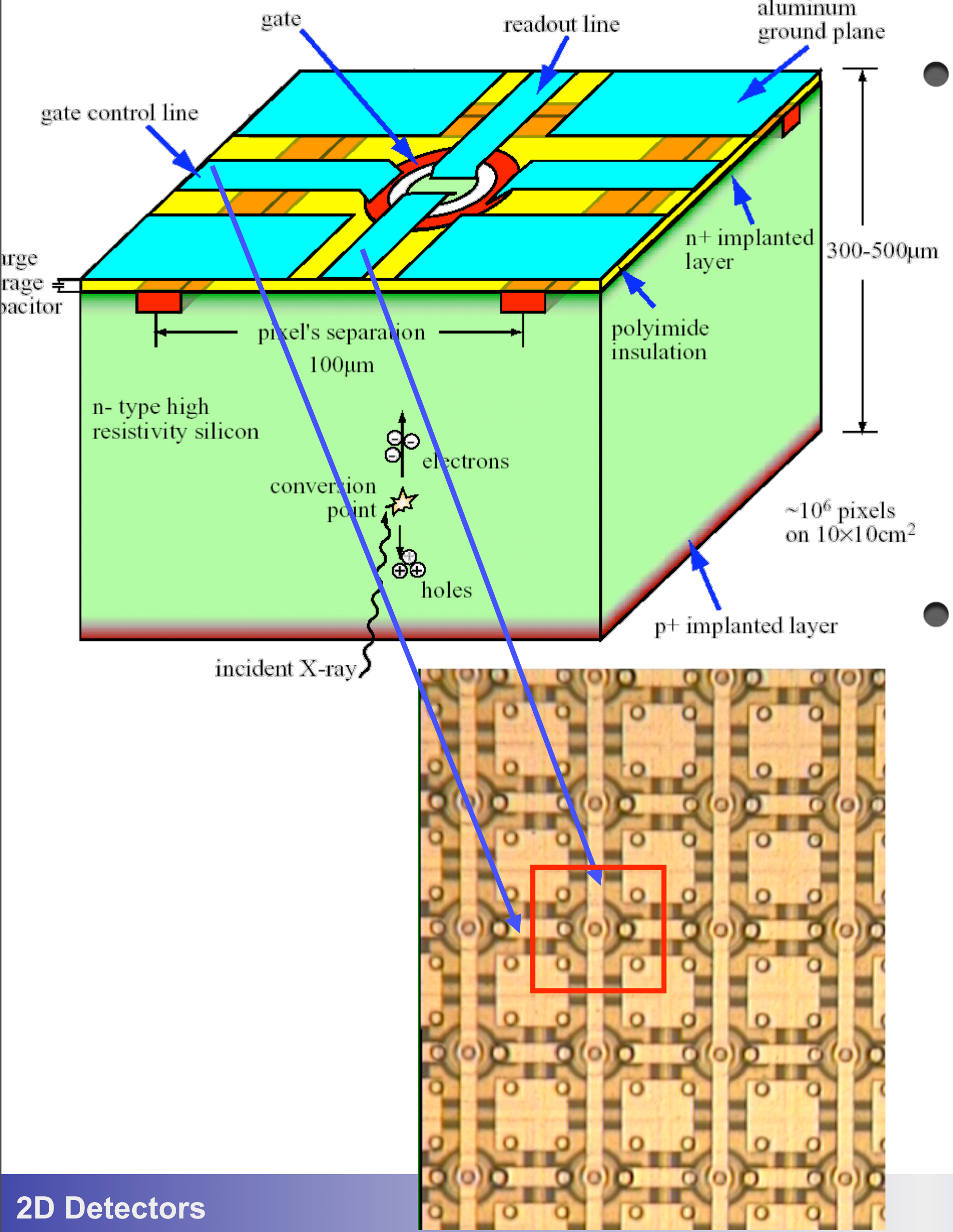
Commercial CCD technology

- 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

XPP Requirements

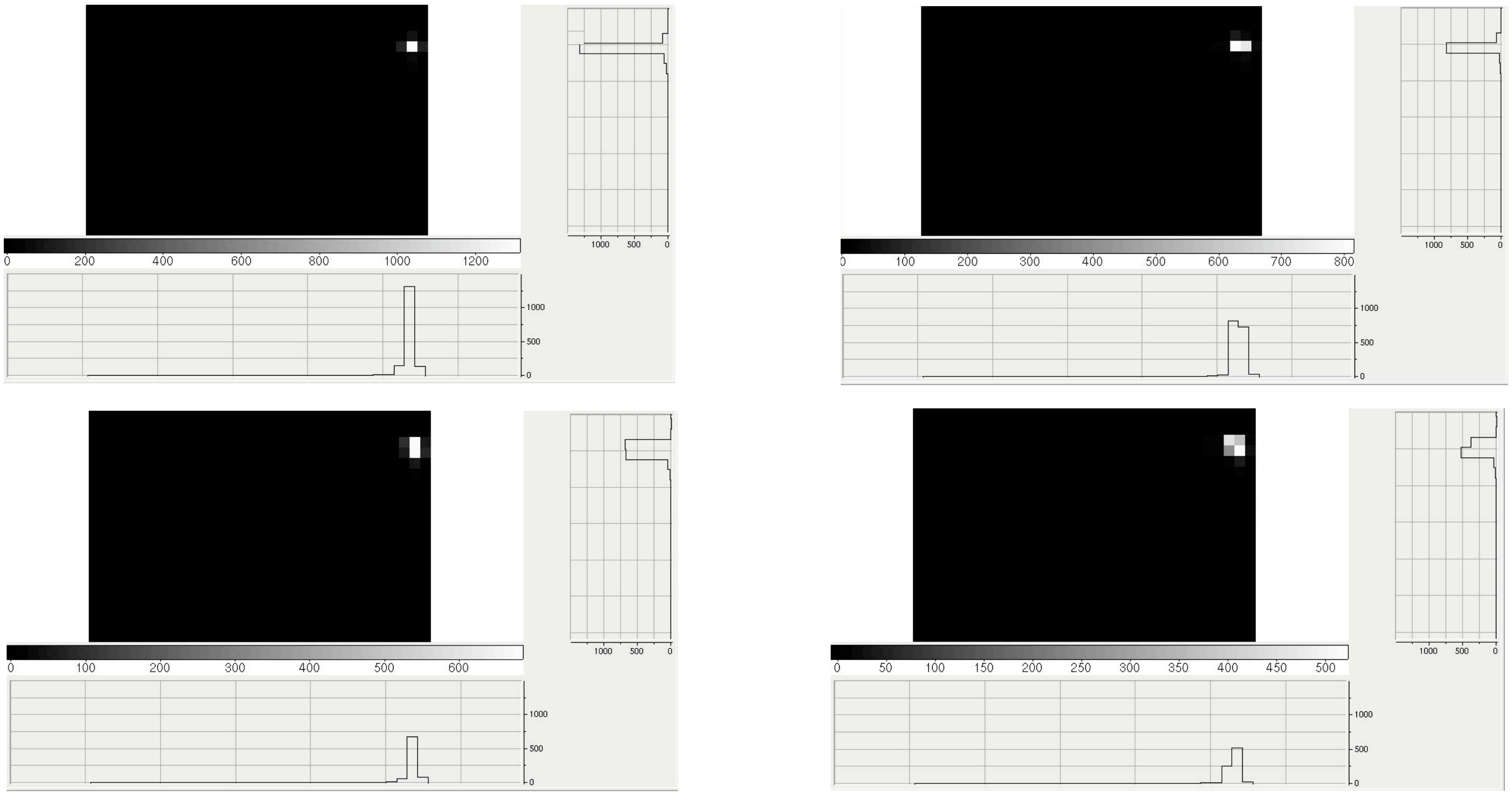
- A sample is 'pumped' to an excited state by a pump pulse (e.g. laser) and analyzed after Δt with an LCLS pulse.
- Multi-purpose detector to image the scattering intensity that is slowly varying with scattering angle (in steps) or a number of Bragg peaks on a low intensity background.
  - High QE to 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

X-ray Active Matrix Pixel Sensor



- Pixel structure
  - Fully depleted wafer (400 µm) gives good detection efficiency
  - Electrons collected in storage capacitor (switch OFF)
  - Charge is read out by turning the transistor switch ON connecting to a buss-bar
  - Readout by CSA
- 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

Point spread



Scan performed with a monochromatic beam of 8 keV, 30 x 30 μm^2 beam size and with 10 μm step.

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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

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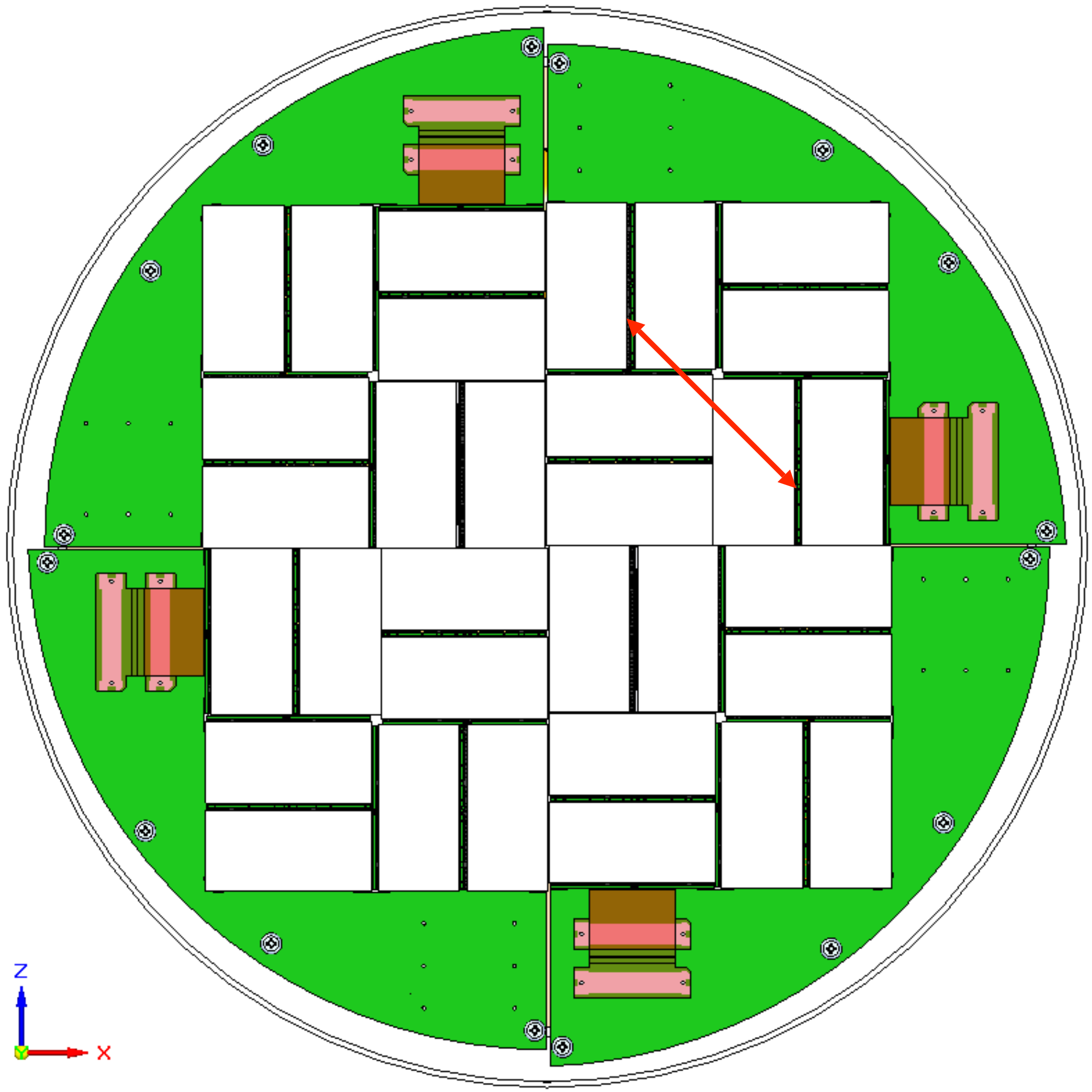
Front View—1 mm Aperture



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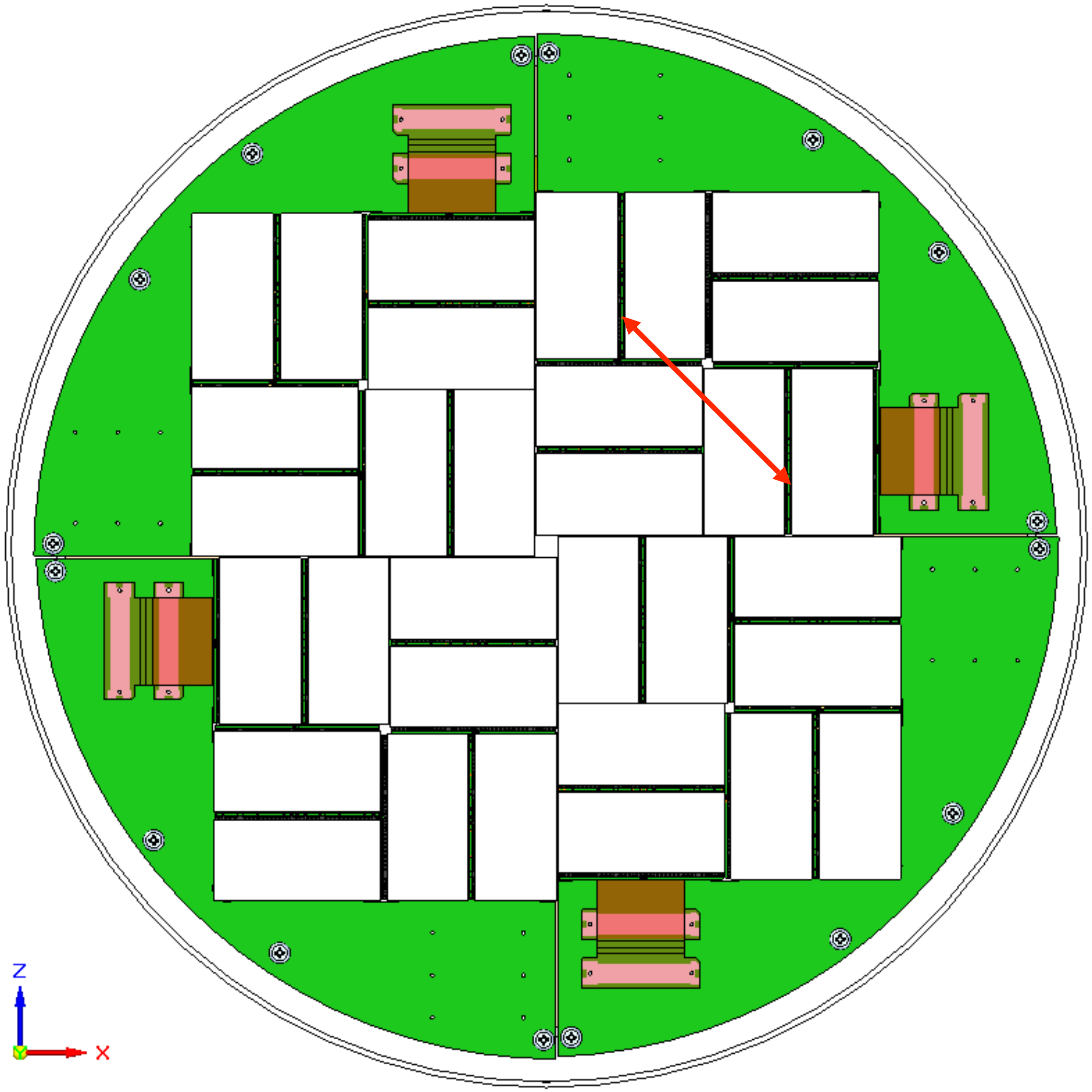
Front View—6 mm Aperture



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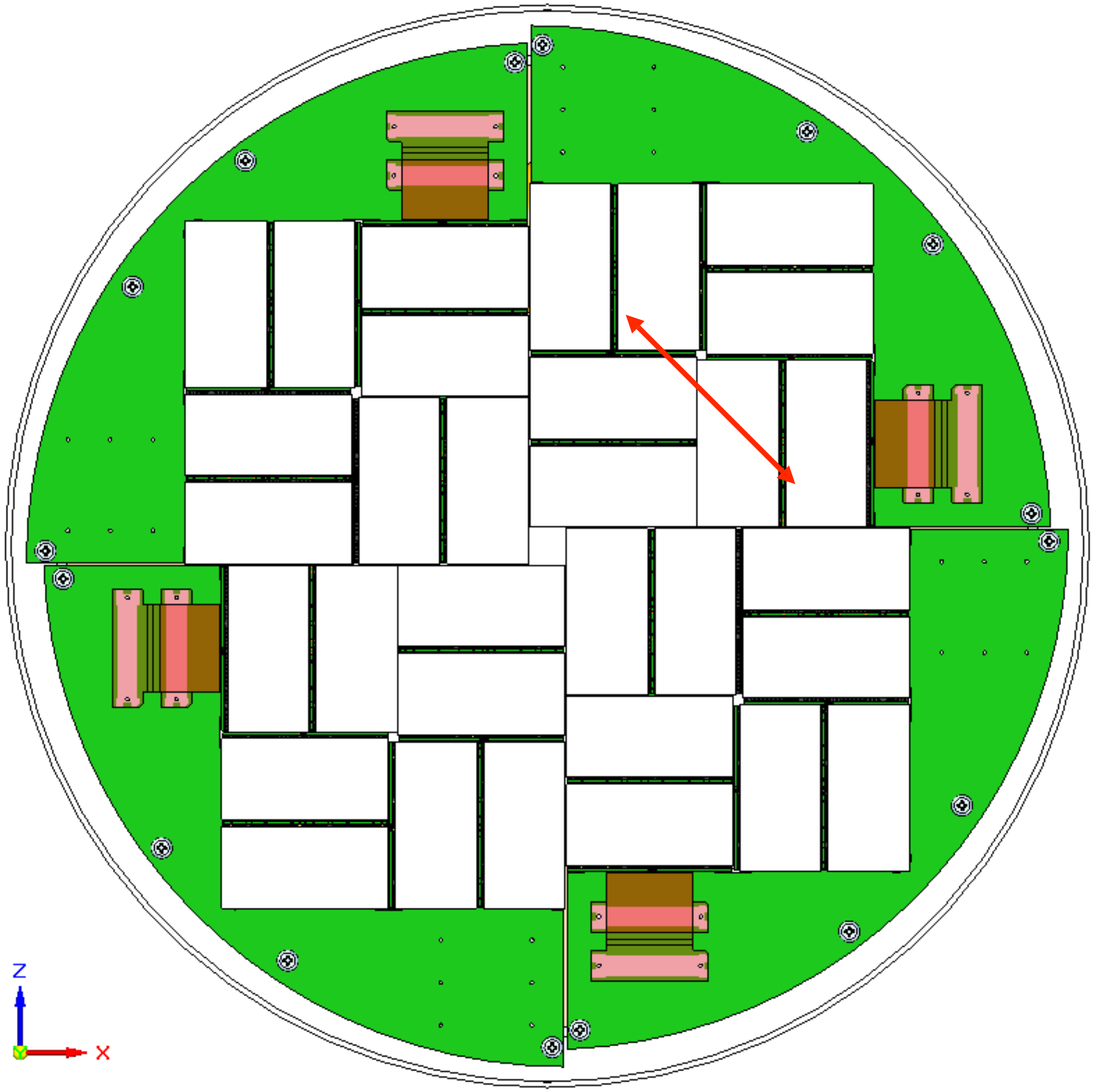
Front View—10 mm Aperture



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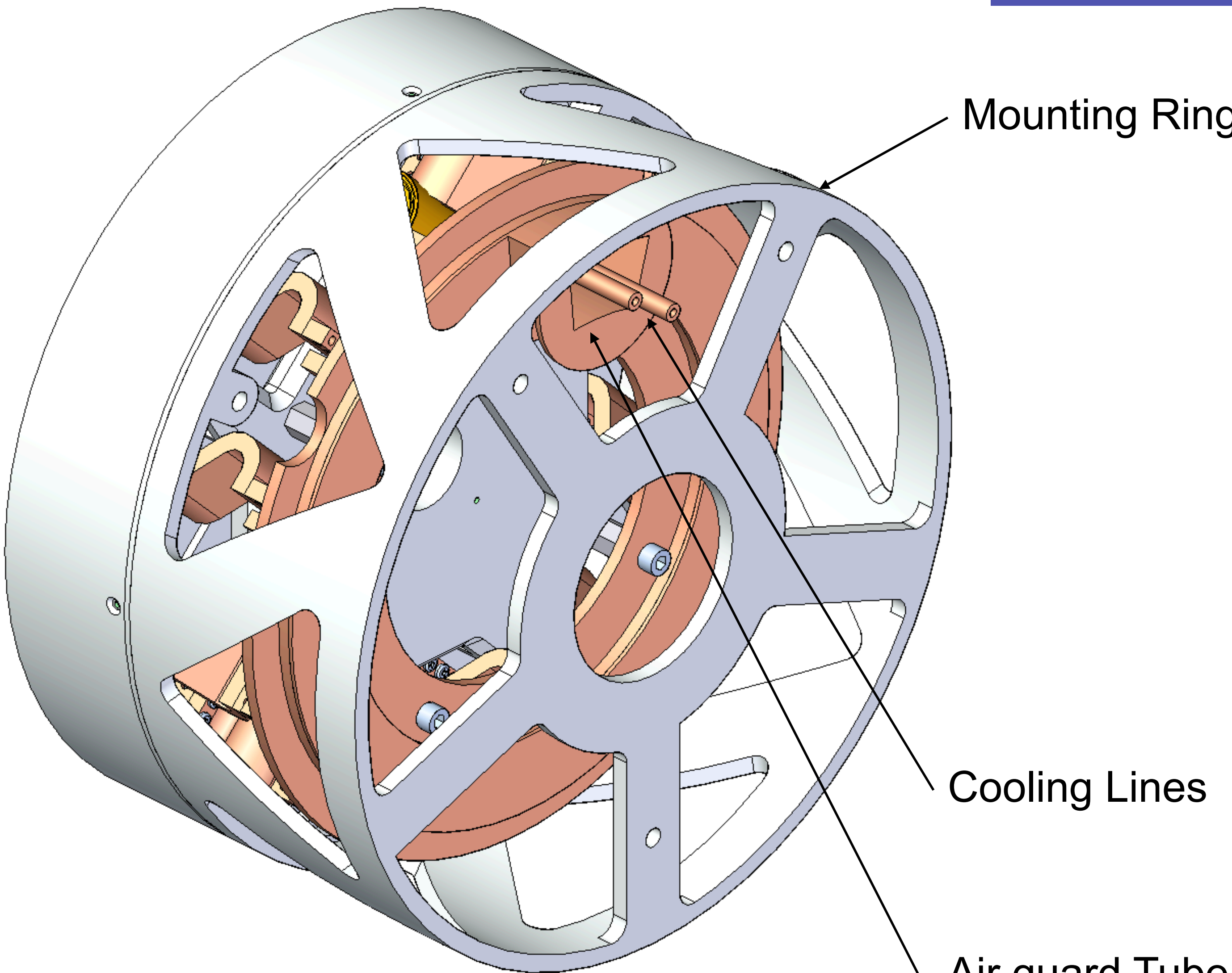

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