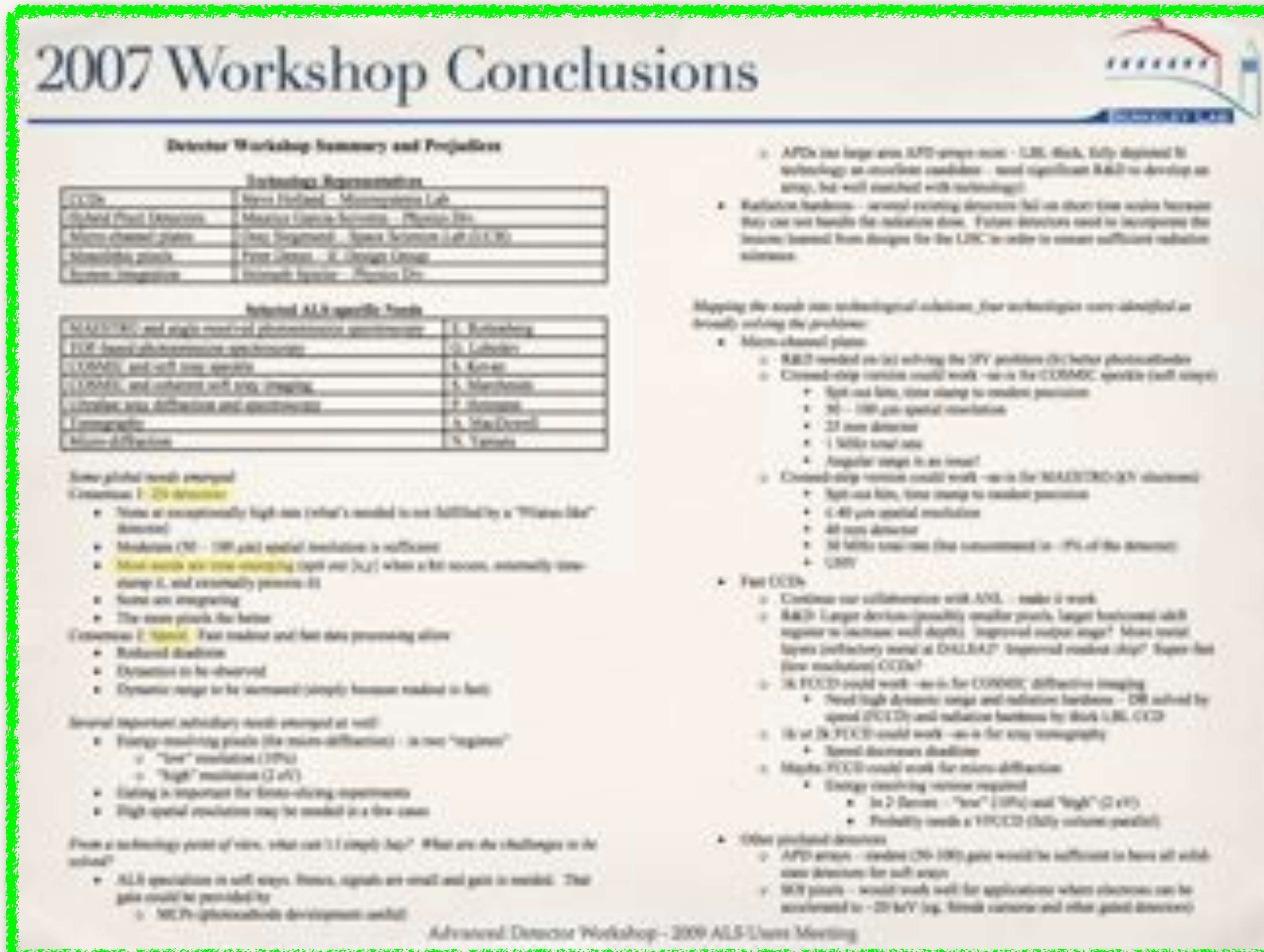
ALS

Detector Development - Update to SAC

- Last detailed report to SAC in 2007
- Since then
  - LDRD-developed fast, direct-detection CCD prototypes deployed at ALS and APS
  - ARRA funds received for construction of multiple FCCD cameras
    - Map needs at 2009 ALS User's Meeting
  - BES Detector and Accelerator R&D funded

Detector development driven by ALS needs

- Can't do everything
- Focus on soft xrays
- Collaborations for hard xrays
- Needs from users
  - 2007 workshop
  - 2009 workshop



2007 Workshop Conclusions

Detector Workshop Summary and Prejudices

Technology Representatives

Selected ALS-specific Needs

Advanced Detector Workshop - 2009 ALS Users Meeting

→ **Fast, 2D, Pixillated (Time-stamping) Detectors**

2009 User's Meeting Workshop

Workshop on Advanced Detectors

October 16, 2009

This year's workshop was structured similarly to the 2007 workshop: a 1st half discussing detector technologies and capabilities, and a 2nd half surveying needs at the ALS.

Funded by Strategic LDRD, a very fast pseudo column parallel CCD has been developed for a number of synchrotron research areas. This was based on CCD technology developed for SNAP, and modified so that 10 columns are read out into individual ASIC channels. This massively parallel architecture speeds readout compared to typical scientific CCDs up to a factor of 100. It also has the advantage of being based on thick Silicon, offering therefore sensitivity from the IR to the hard x-ray regions. In a collaboration with the APS, this chip has been built into a camera, and tested on several experiments at ALS and APS. At the ALS, the prototype has been tested on 12.3.2 for hard x-ray microdiffraction and 9.0.1 for soft x-ray ptychography.

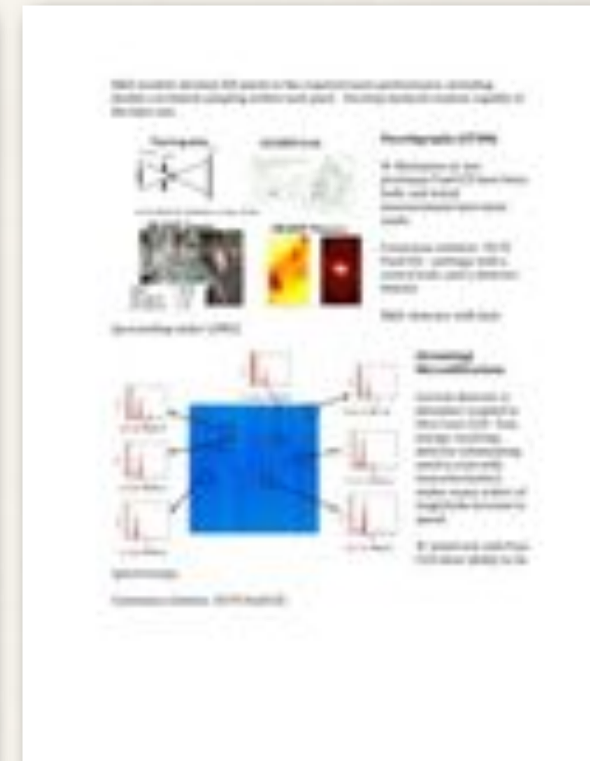
ARRA funds to deliver FastCCD systems to ALS beamlines were received in 2009, and a new BES Detector R&D program was also funded. For this workshop, the goals were to review the needs for FastCCD systems as well as performance specifications and to see what are the needs for the future which R&D can address.

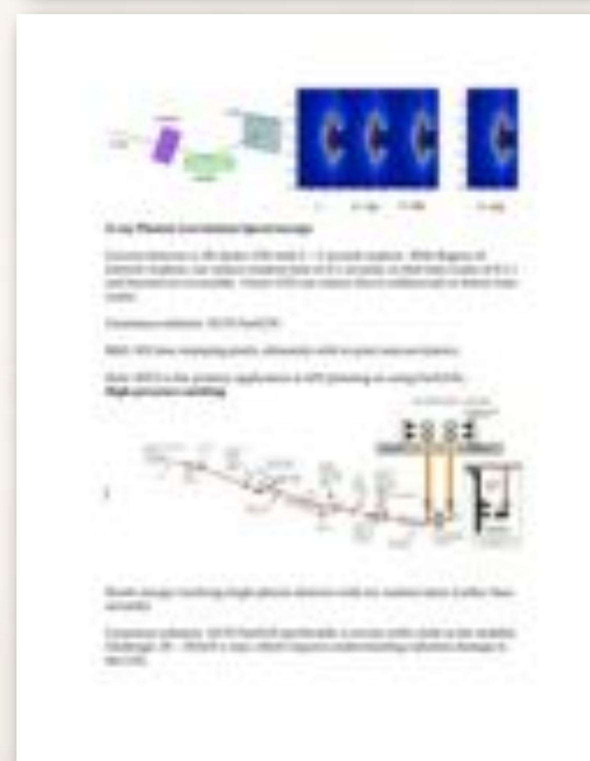
Technologies:

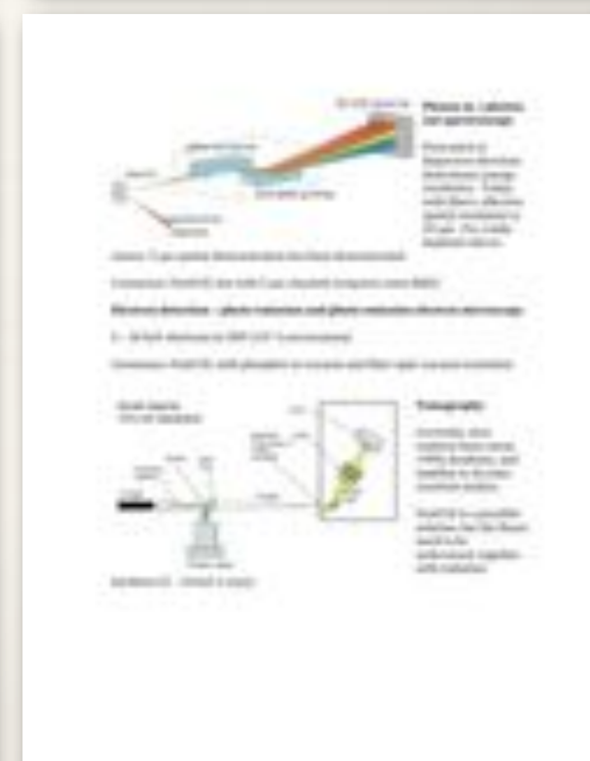
FastCCD experience at ALS	D. Doering
FastCCD experience at ALS	J. Weizeorick
Silicon-on-Insulator	D. Contarato
Thin window, fully depleted detectors	C. Tindall

Needs at the ALS:

T. Tyliszczak	STXM
M. Marcus	micro-XAS
P. Heimann	ultrafast
S. Marchesini	CXDI
N. Tamura	micro-diffraction
A. MacDowell	tomography
A. Scholl	PEEM
Y-D Chuang	x-ray fluorescence and scattering
A. Bostwick	photoemission
S. Clark	high pressure
S. Roy	Coherent scattering

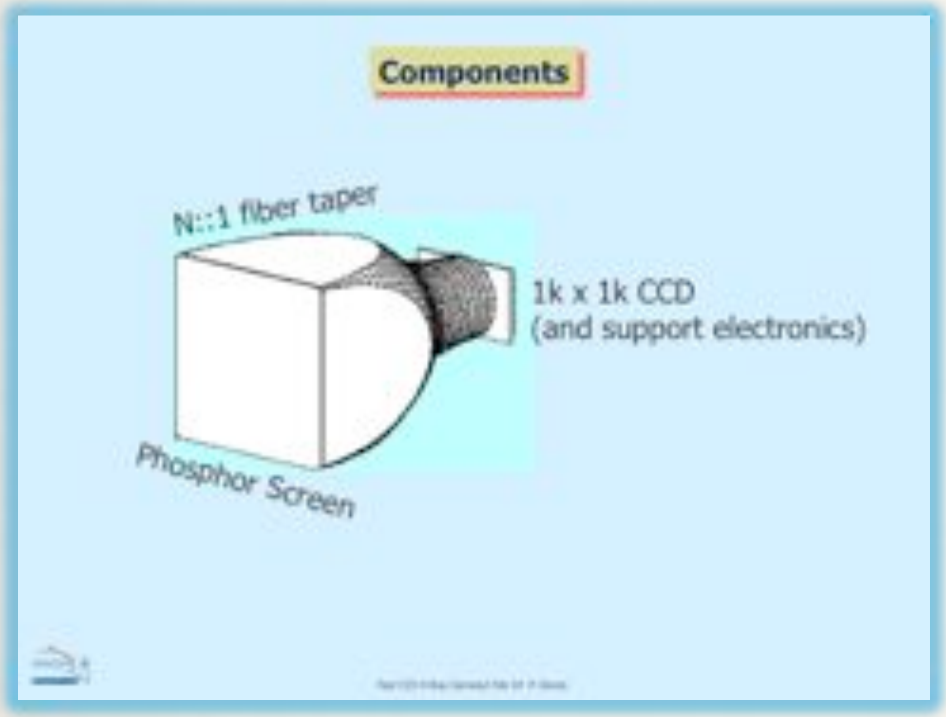


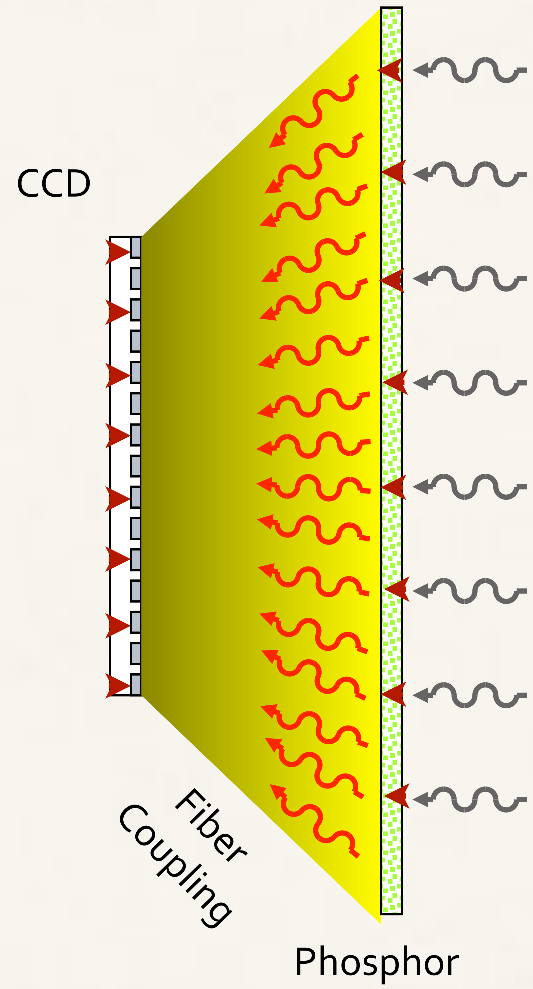




FastCCD - Maximize impact, direct (or indirect) detection

Concept - late 2003



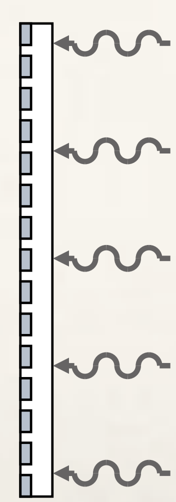


Canonical x-ray detector

- X-ray photoconverts in phosphor
- Photoelectron ionizes → scintillation photons
- Photons bounce around in phosphor and get distorted in fiber
- Photons photoconvert in CCD
- Collect the photoelectrons

Original specs:

- ≥ 100 frames / s
- 15 bit dynamic range
- 8 bit resolution
- sparse scan

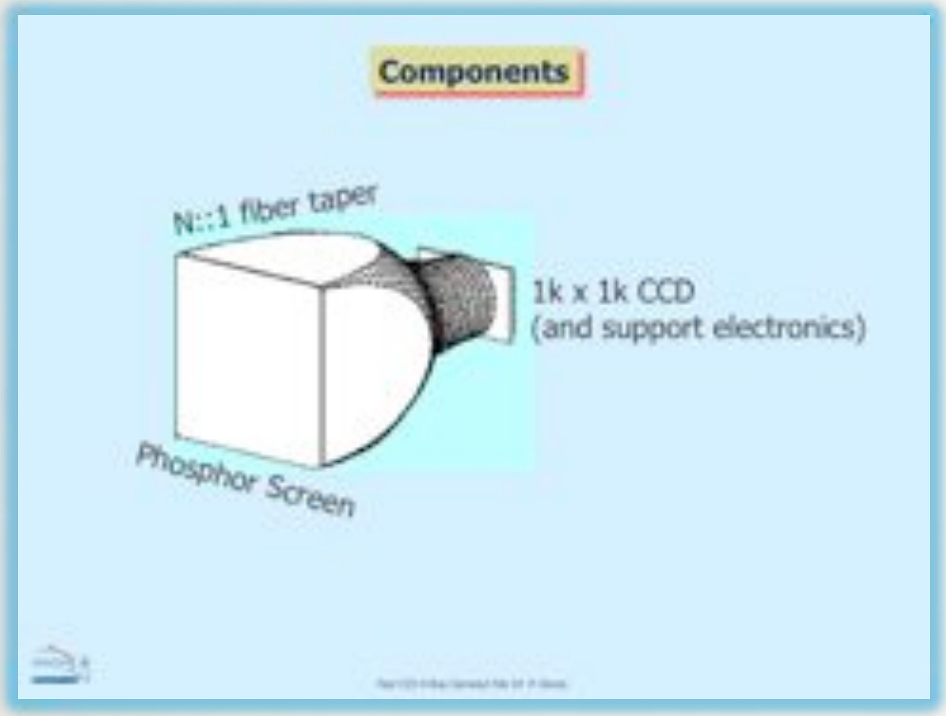


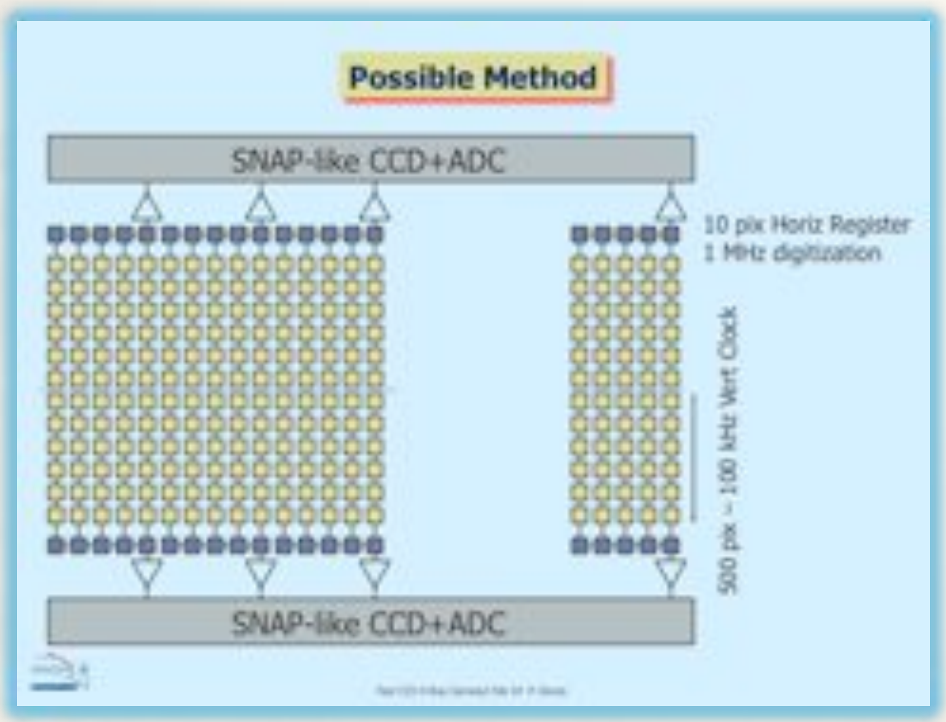
Direct x-ray detector

- X-ray photoconverts in silicon
- Collect the photoelectrons
- (Much more signal)

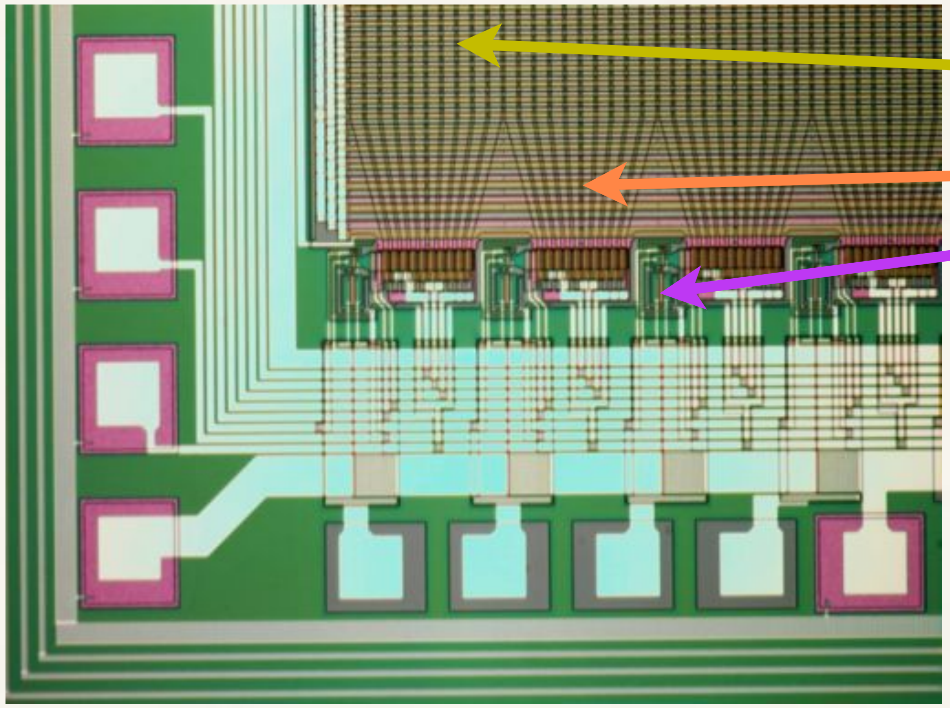
FastCCD - Maximize impact, direct (or indirect) detection

Concept - late 2003



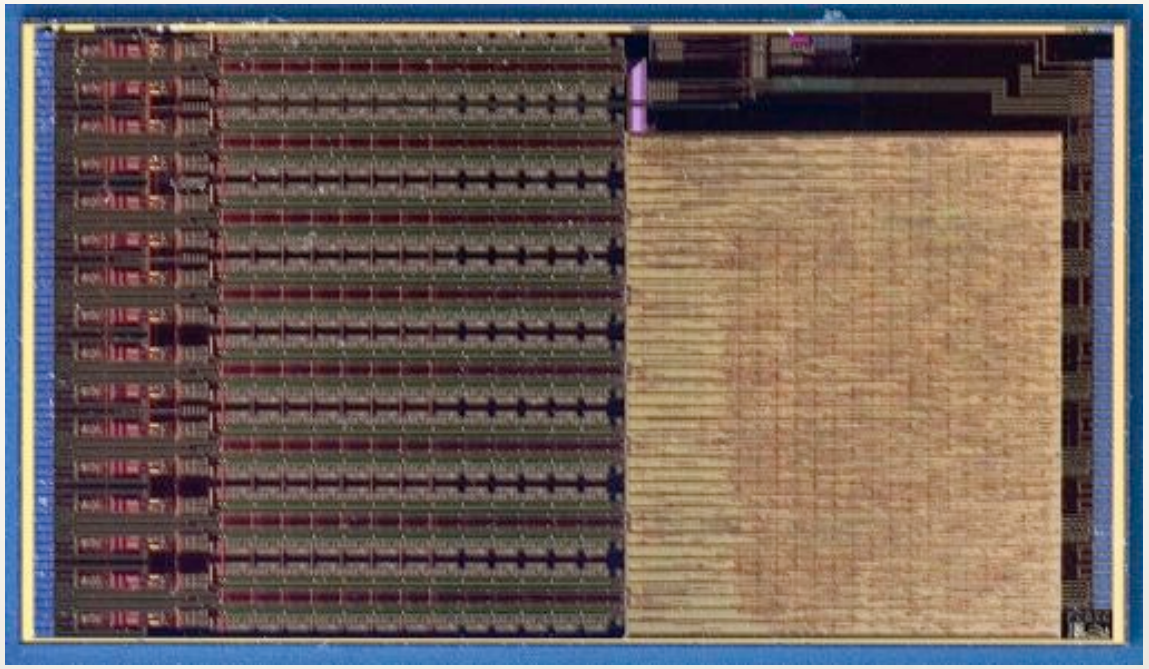


CCD - 2006/7 (LDRD)



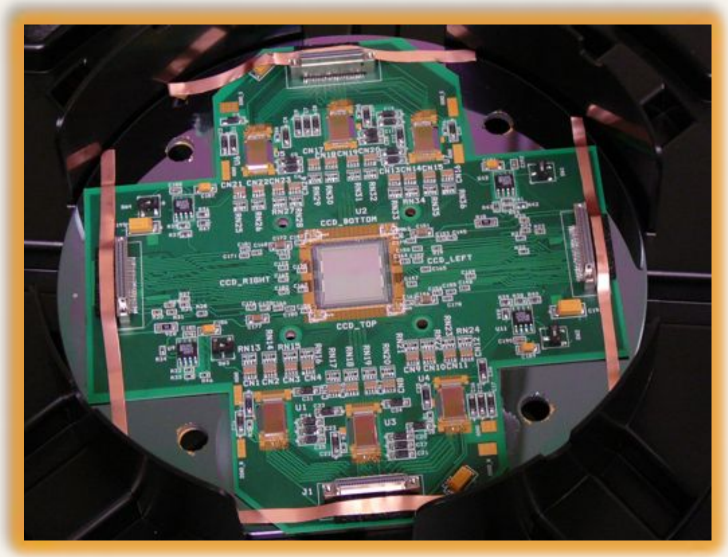
- Metal-strapped gates (first time at LBL)
- Constant-area "taper"
- Output stages on 300 μm pitch
- LDRD version: 480 x 480 30 μm pixels

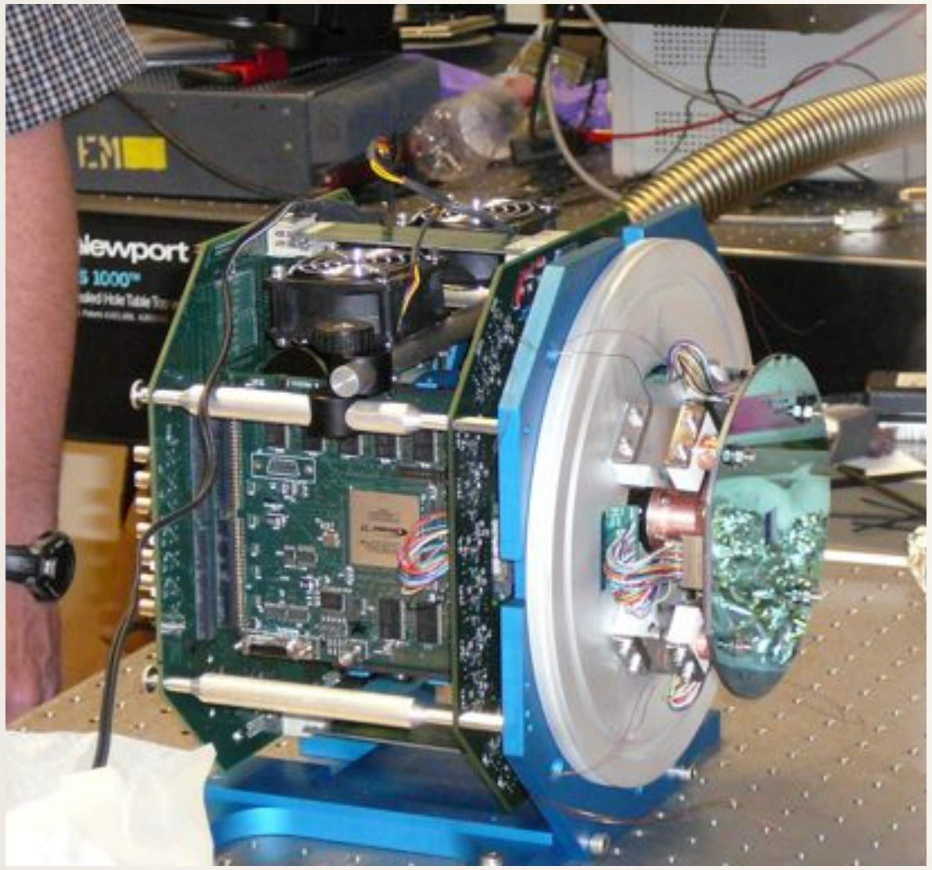
Readout ASIC - 2006 (LDRD)



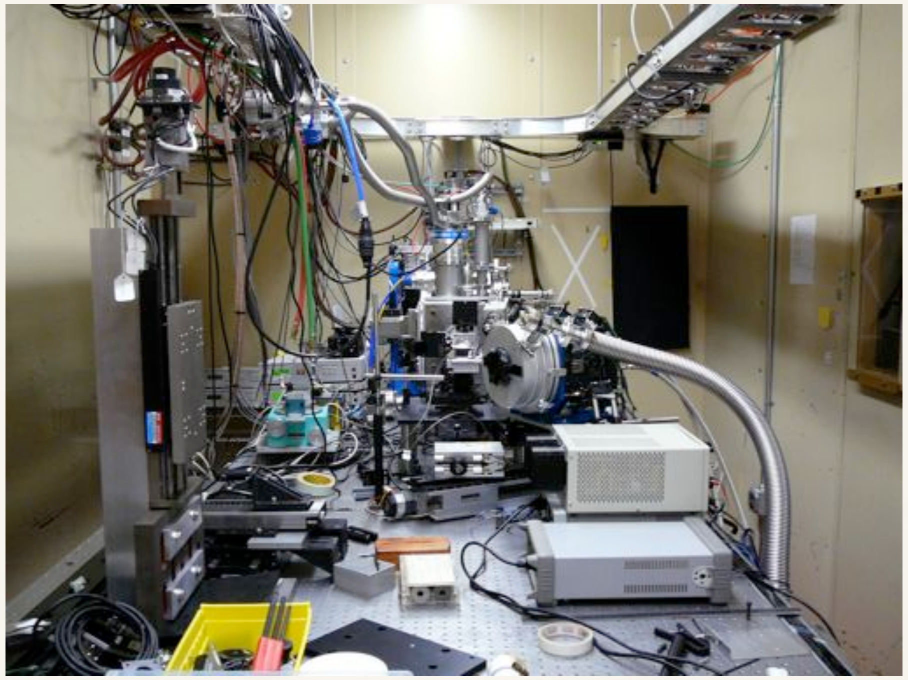
- 16 channels
- 300 μm pitch
- 15 bit dynamic range
- Correlated Double Sampling
- 1 MHz/channel
- **> 200 frame/sec**

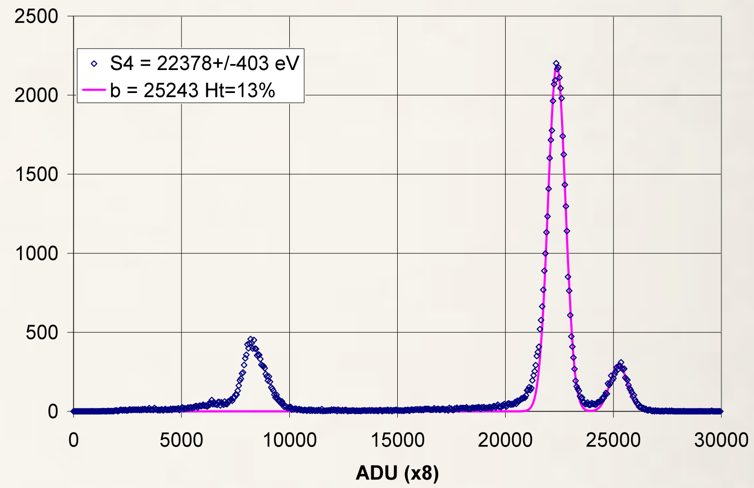
FastCCD - 2nd ½ of 2008: Integrate and Characterize





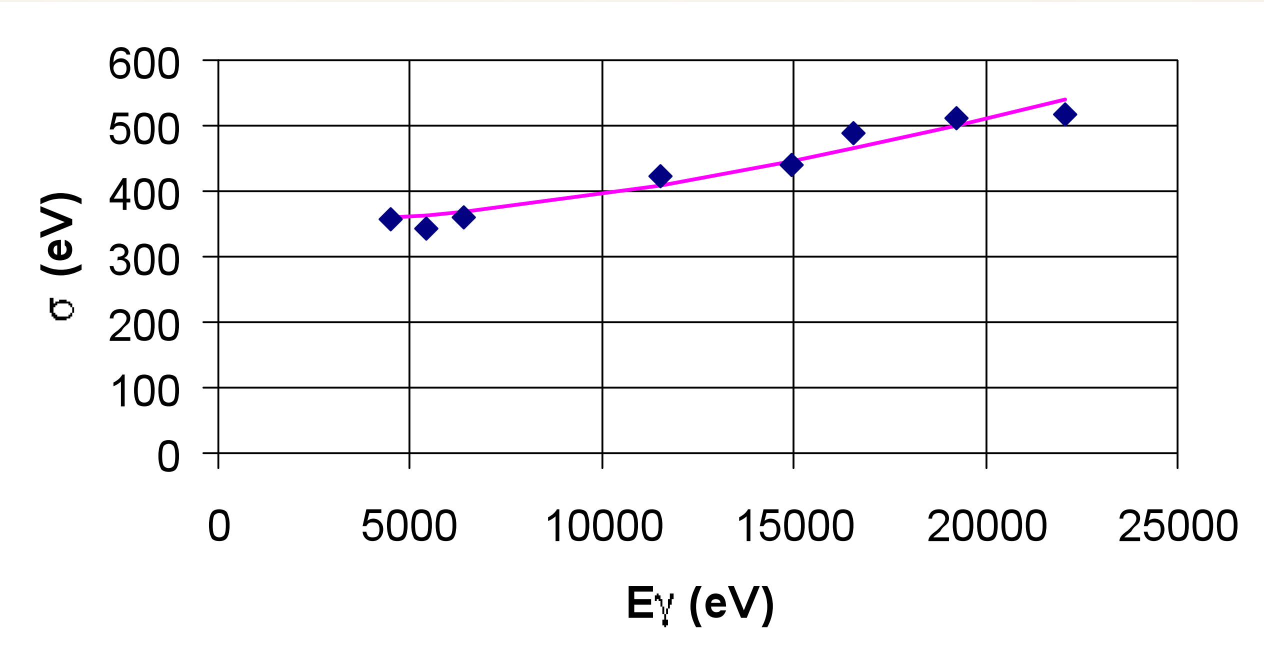
Characterize on 5.3.1



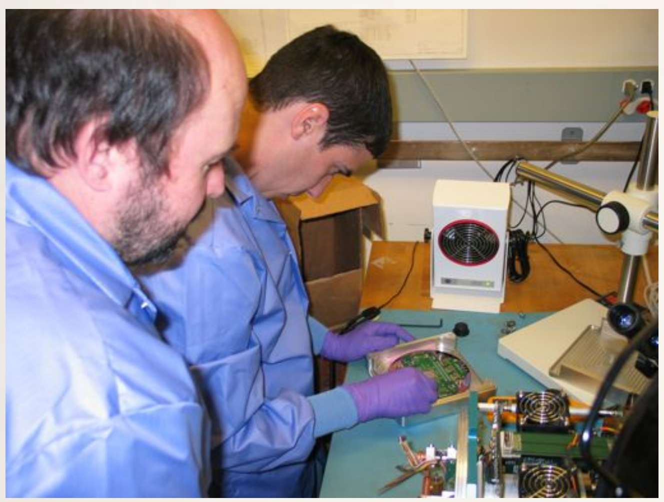


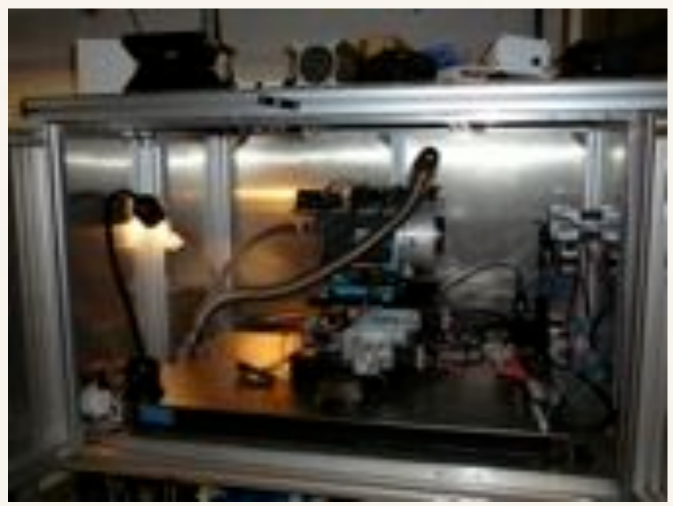
Calibrate with fluorescence photons. 200 μm thick, but E > 10 keV certainly detectable (ε < 1)

Initial single γ energy resolution

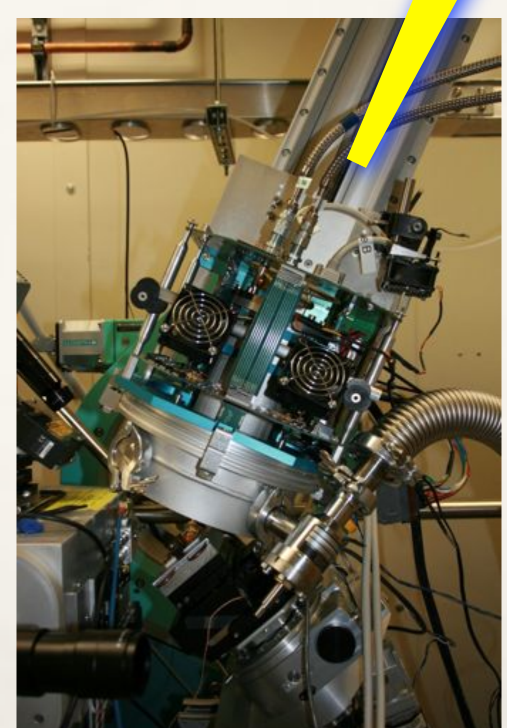


FastCCD - 1st ½ of 2009: First tests at APS and ALS



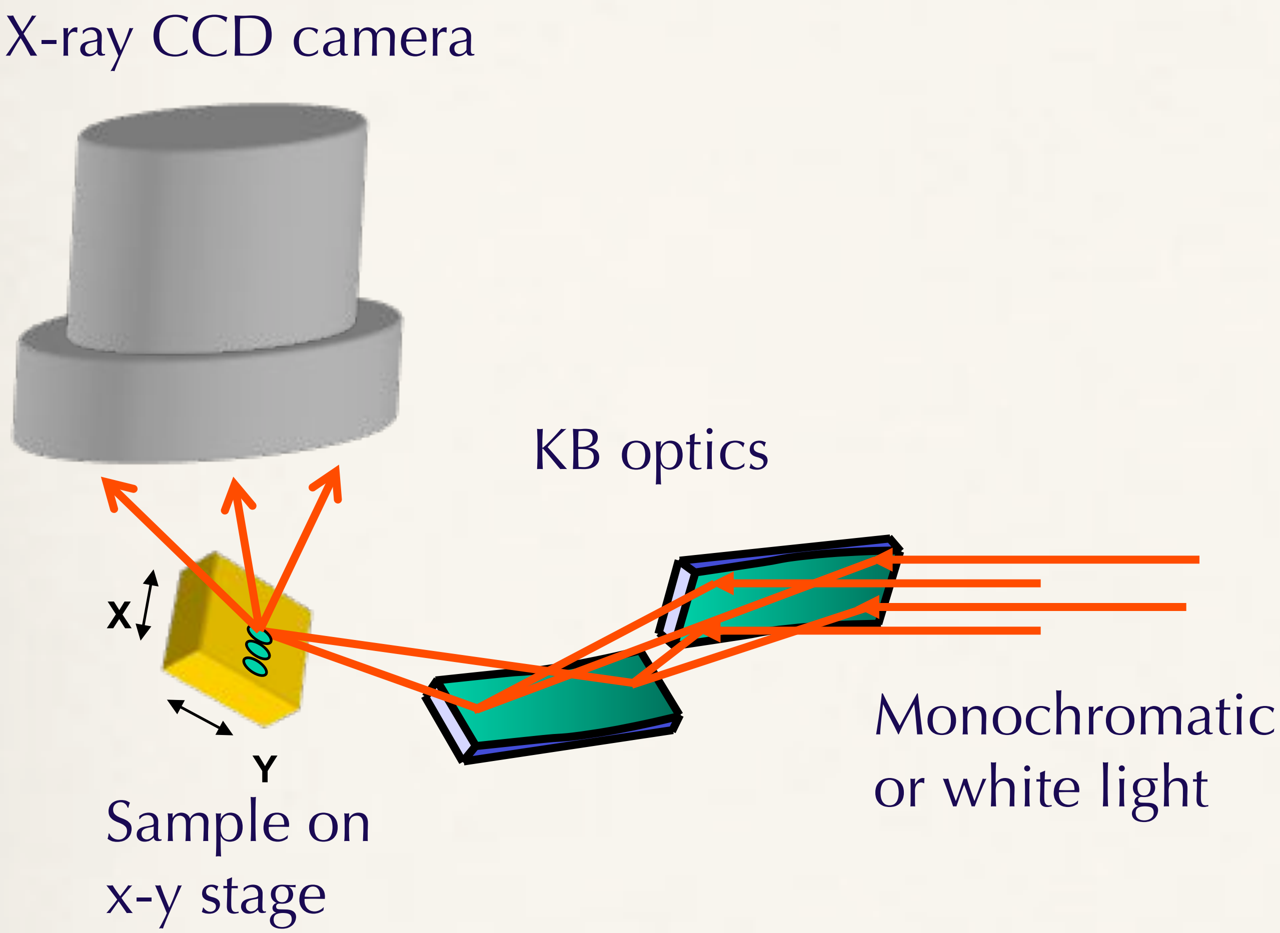


- Jan '09 x-ray tube (lab) tests at ANL
- Jul '09 1st beam at 8-ID
- Nov '09 2nd beam at 8-ID

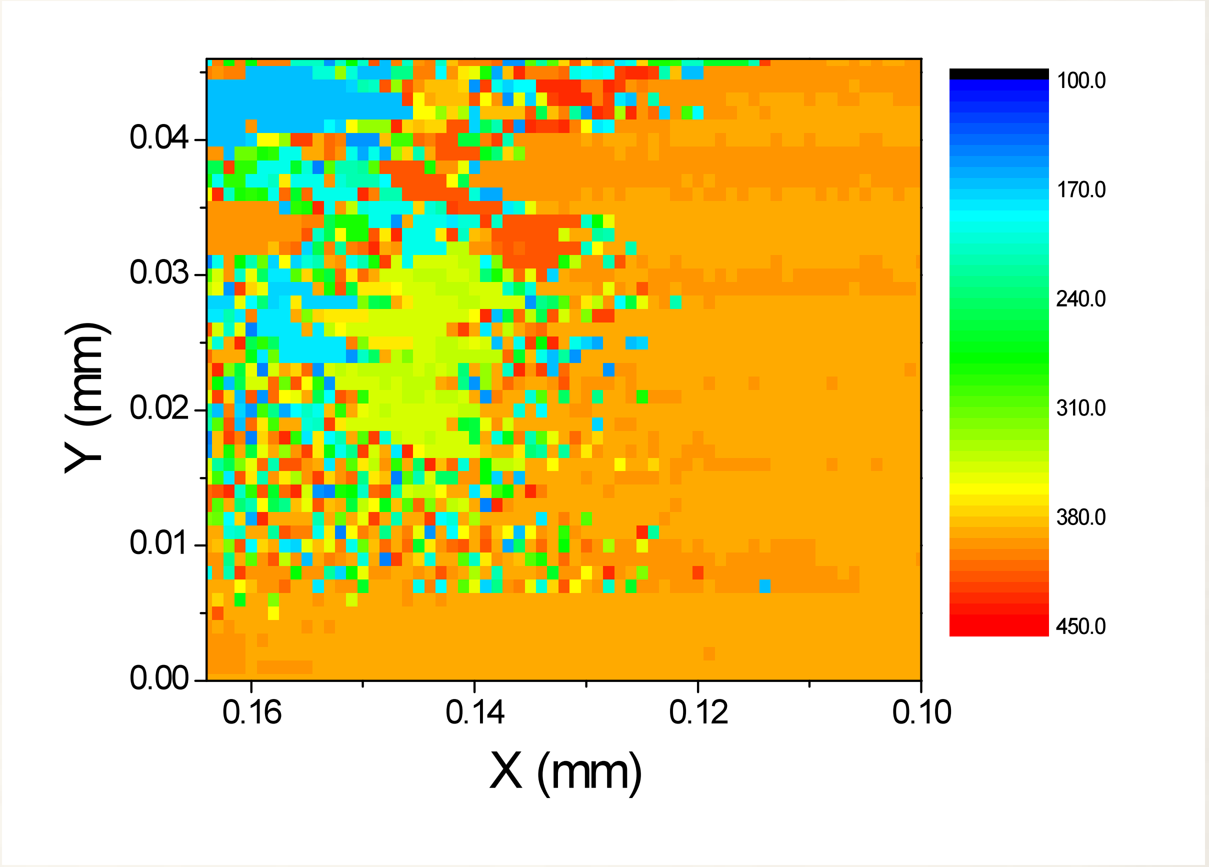


- FastCCD on micro-diffraction BL 12.3.2

Microdiffraction - today and tomorrow



Example: solder grain



3 orders of magnitude increase in speed at 200 fps

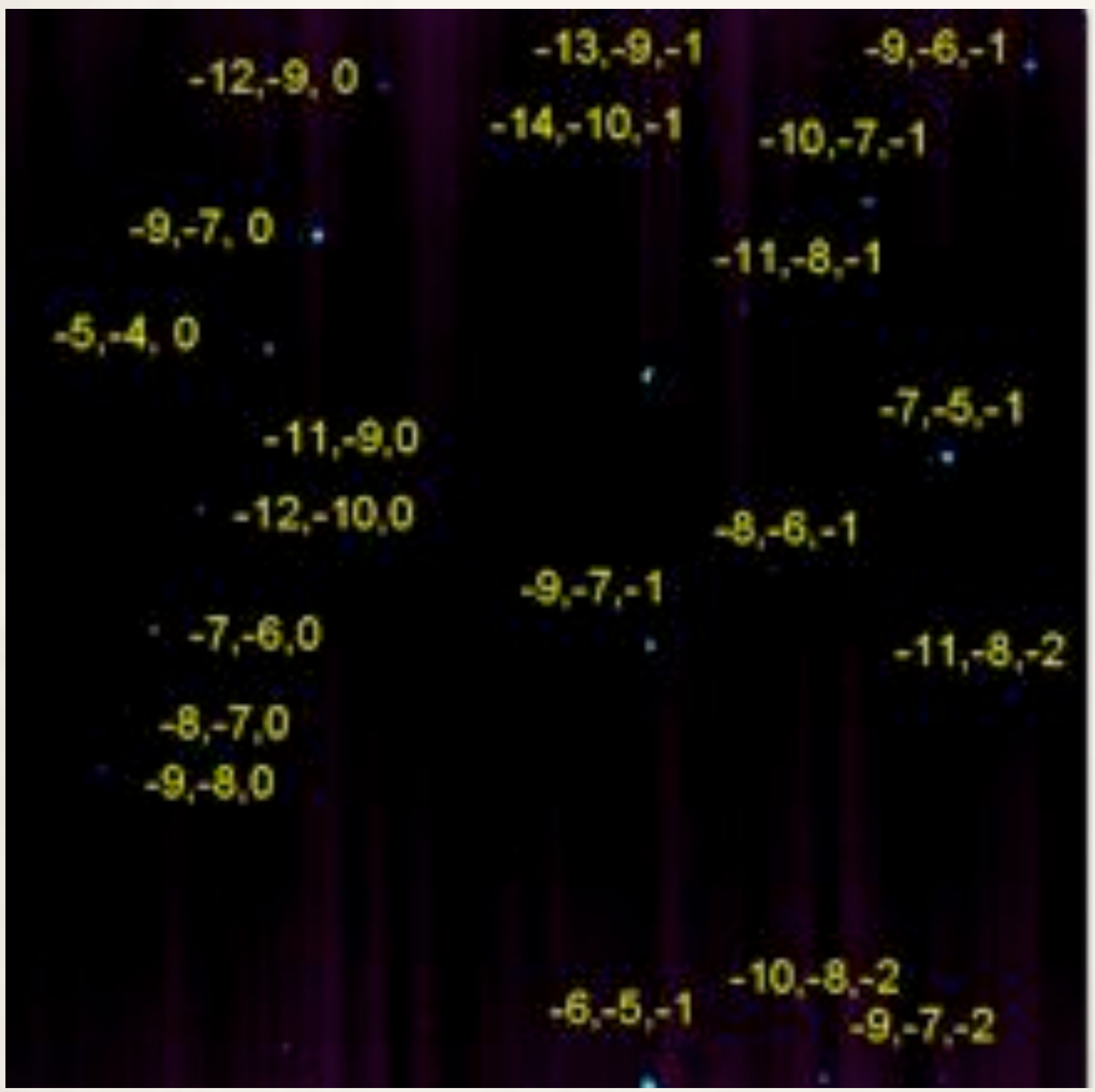
2.7 min. with FastCCD (at 20 Hz - disk write limited for this test)

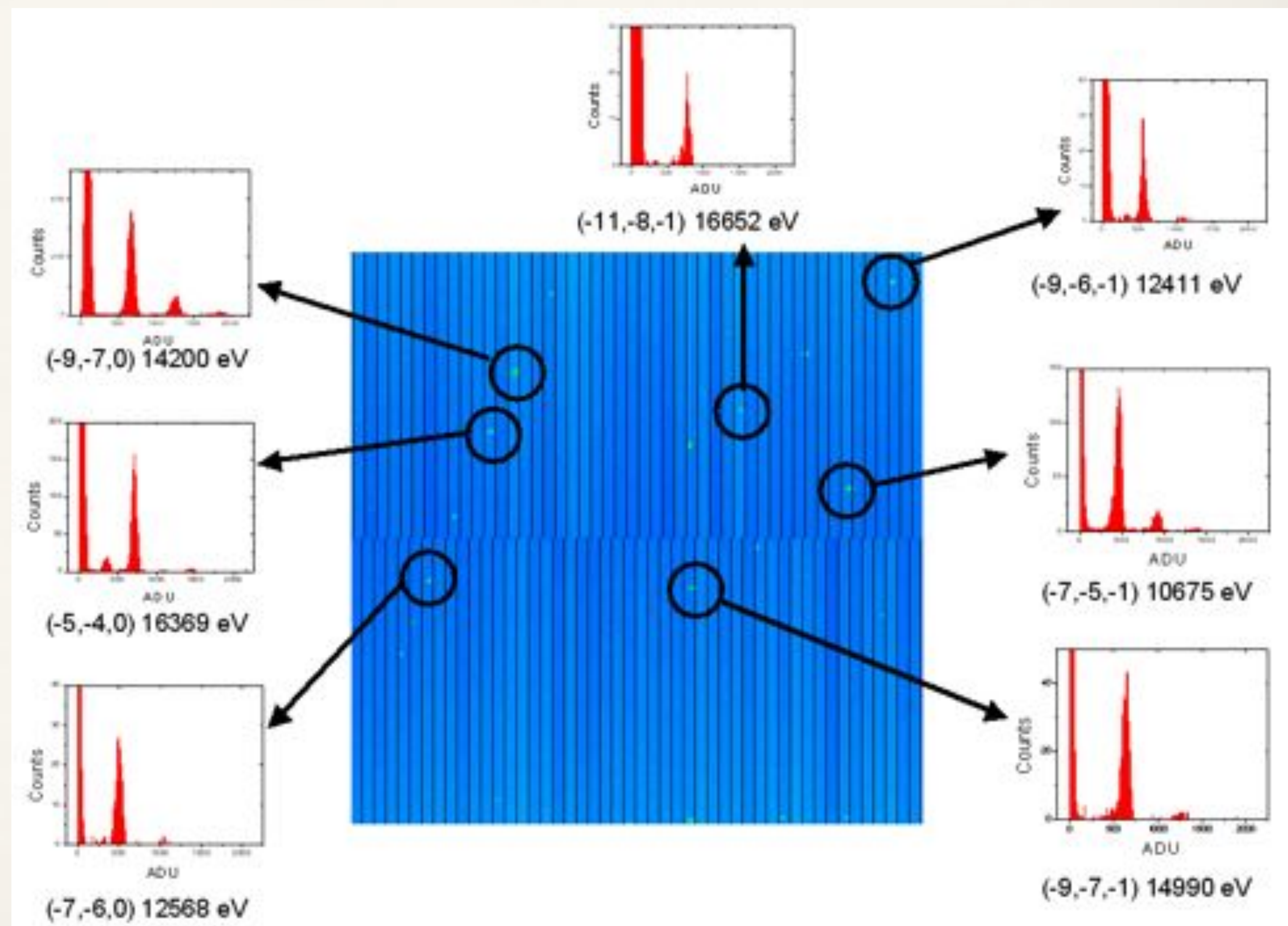
6.2 hrs. with *MAR133*

Nobumichi Tamura, Martin Kunz, Kai Chen, Rich S. Celestre, Dionisio Doering, Tae Sung Kim, Peter Denes, Patric Gruber, Andy Minor, Daniel Kiener

Fast energy-resolved Laue diffraction

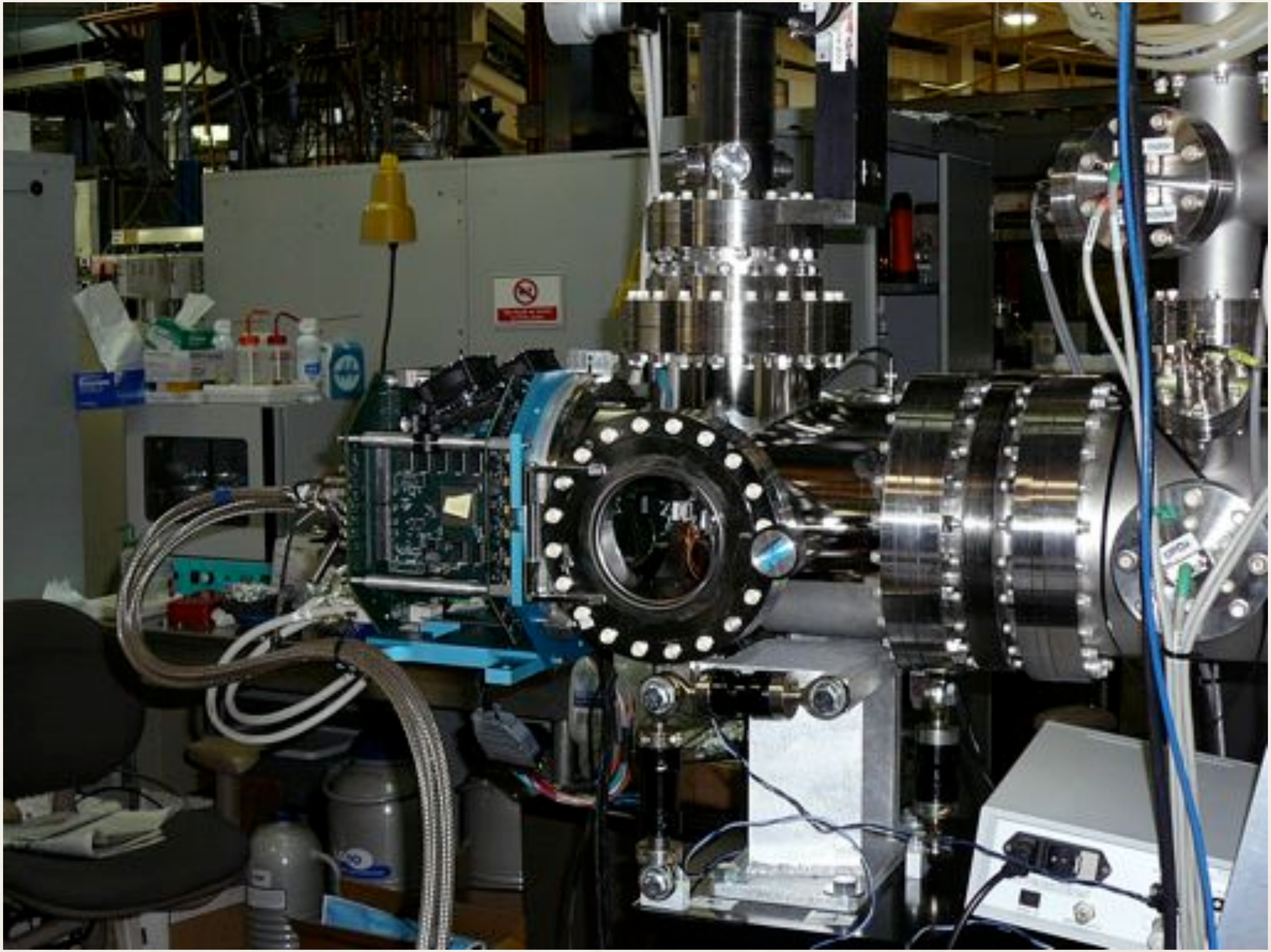
- FastCCD at high readout rate → single photon counting (spectroscopy)
- Fast alternative to monochromator energy scan
- Promising - larger detector area needed





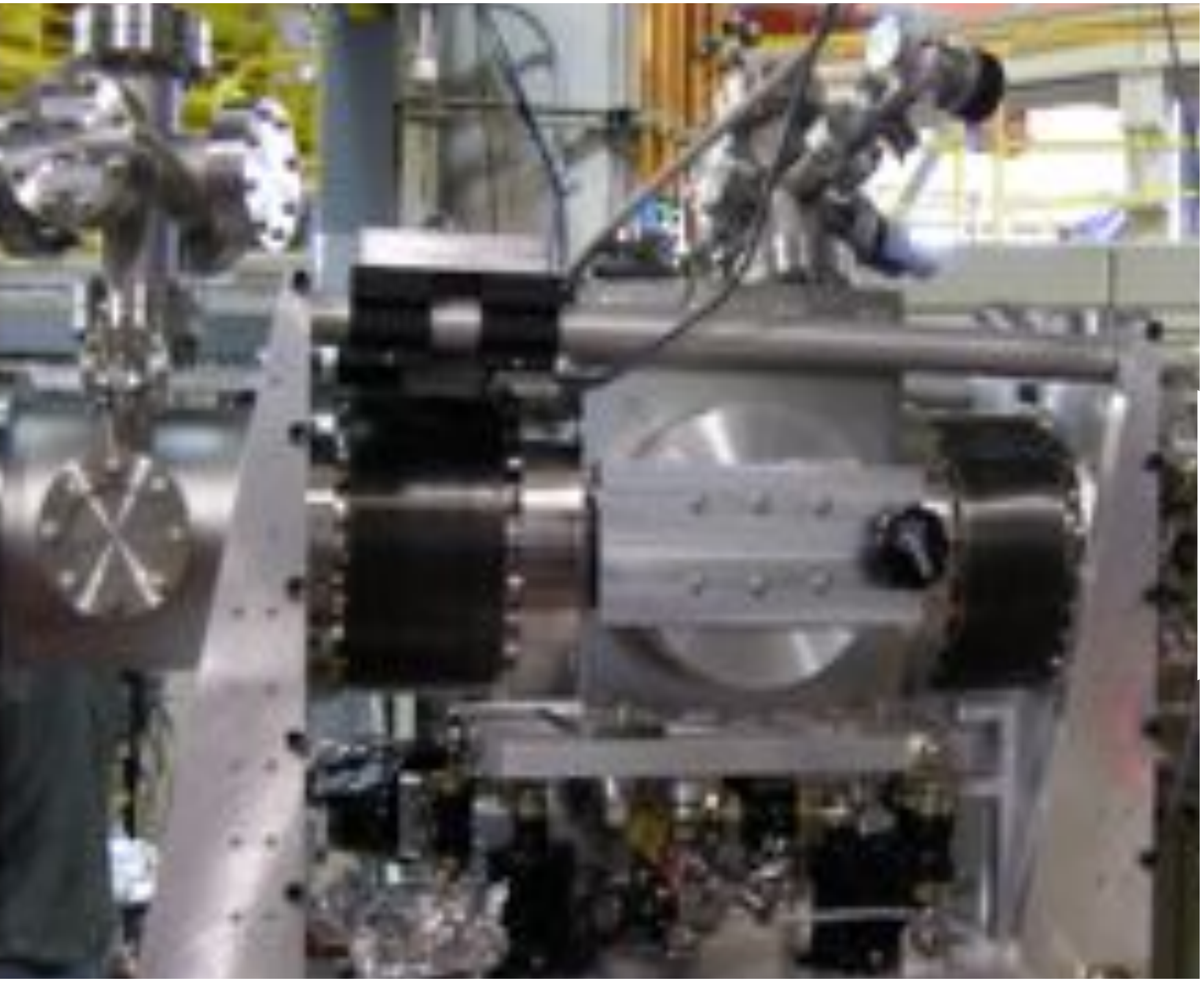
Potassium Titanyl Phosphate $KTiOPO_4$ (or KTP)

Diffractive imaging, holography and ptychography on BL 9.0.1

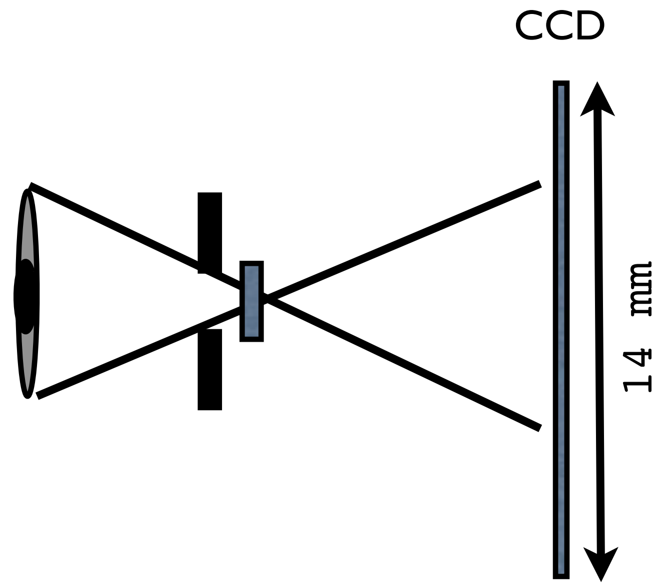


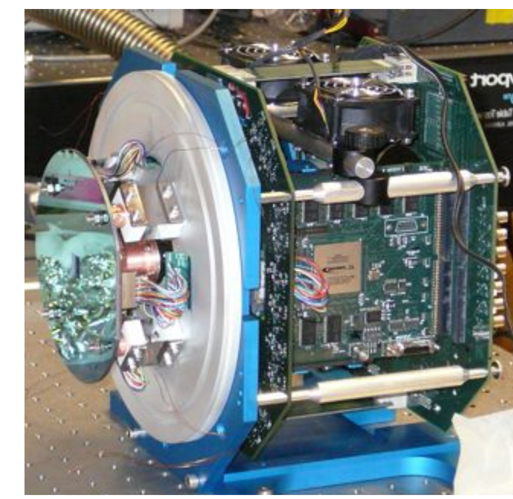
Stefano Marchesini and a cast of thousands

Scanning Diffractive imaging



Plan



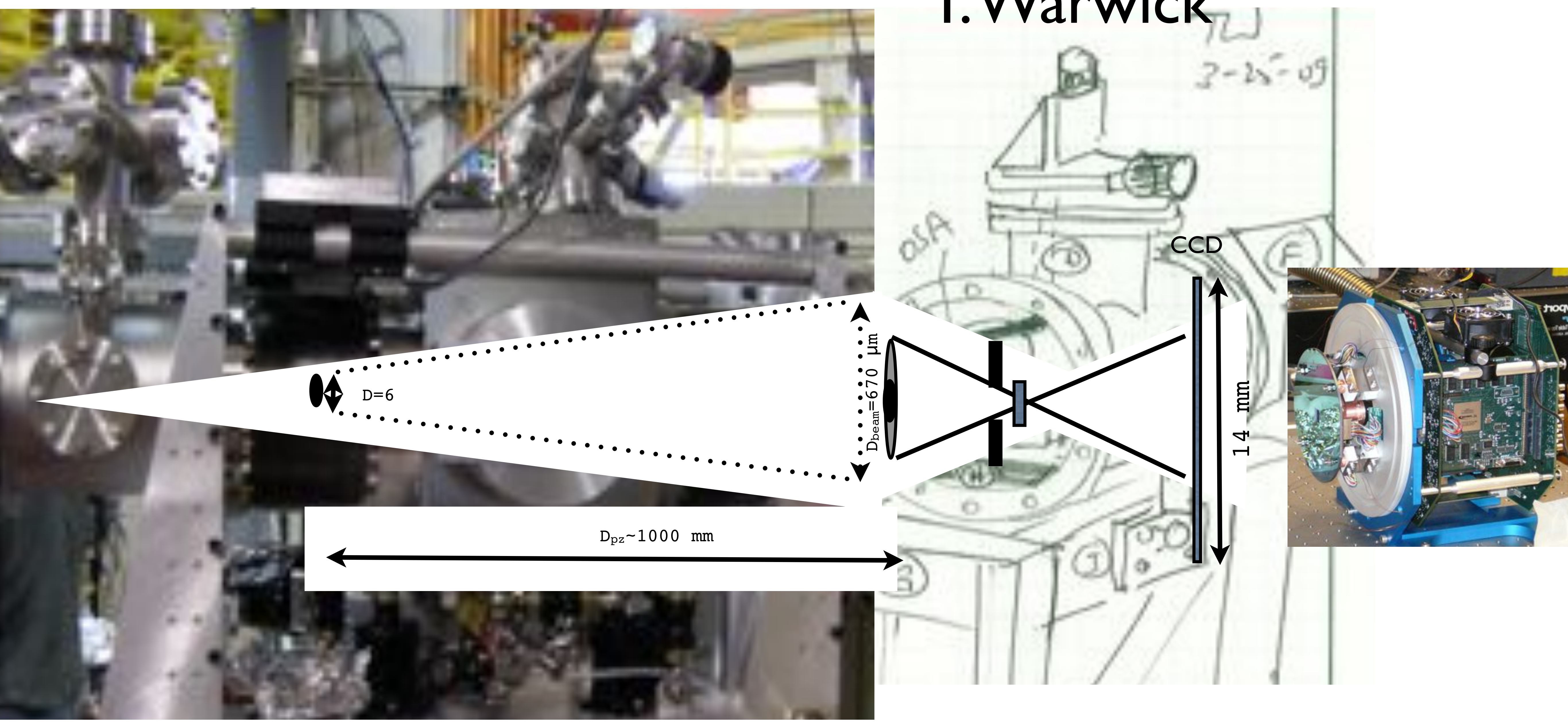


Beam
Energy: 750 eV
λ=1.65 nm
E/ΔE=500;

Pinhole: D=6 μm wide, 2 μm thick Au
Distance Pinhole-ZP D_{pz}: ~1 m
Beam size (to first min): 670 μm

Scanning Diffractive imaging

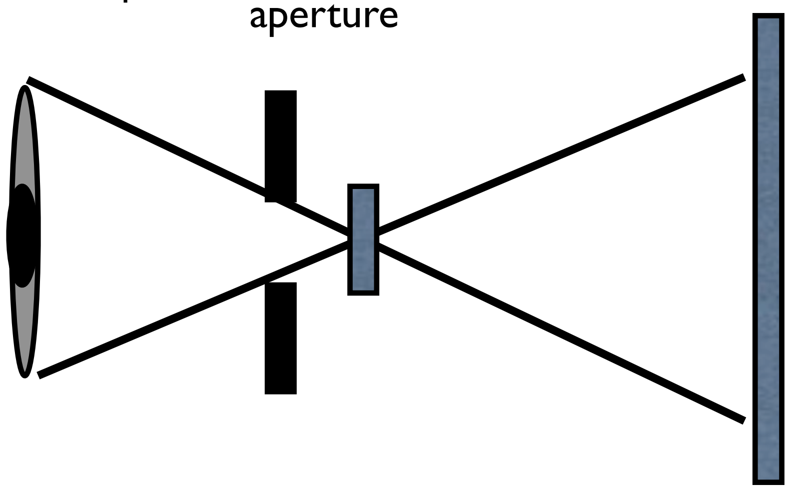
T. Warwick



Beam
Energy: 750 eV
λ=1.65 nm
E/ΔE=500;

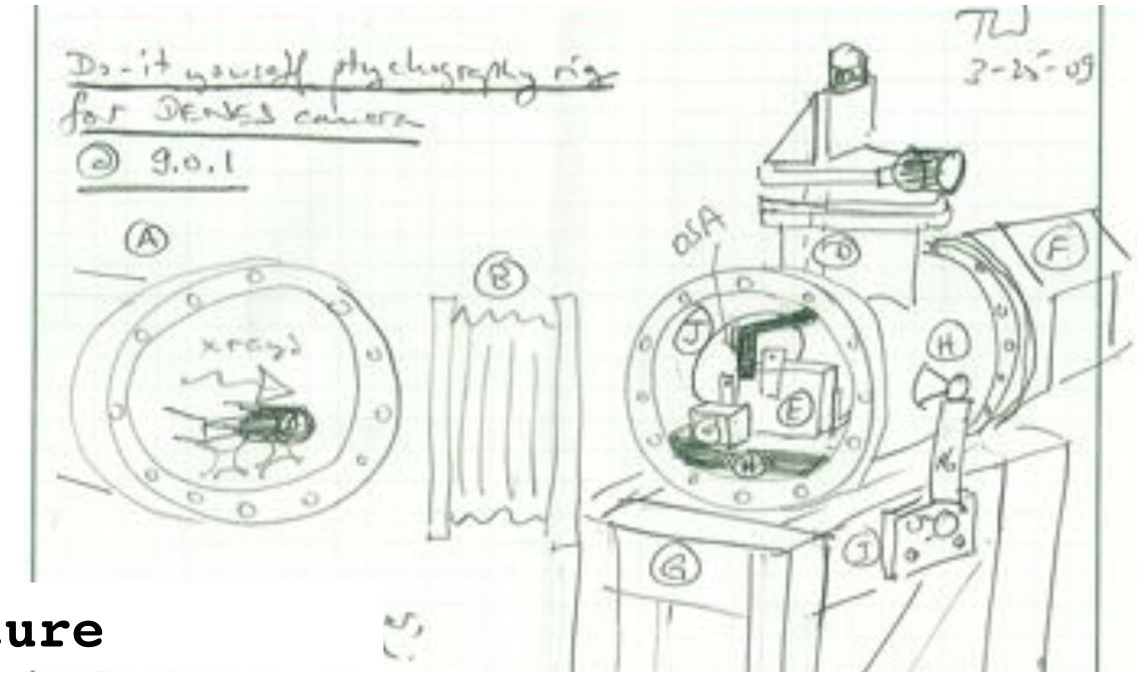
Pinhole: D=6 μm wide, 2 μm thick Au
Distance Pinhole-ZP D_{pz}: ~1 m
Beam size (to first min): 670 μm

Ptychography

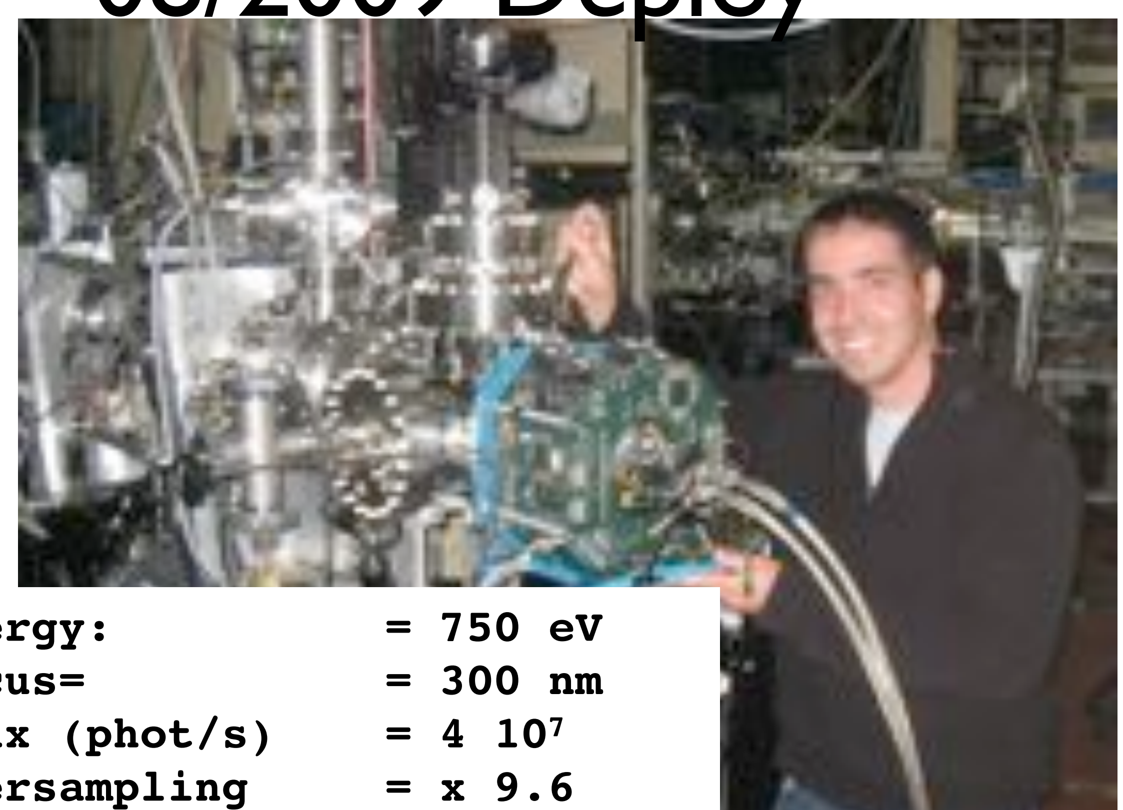


10 nm should be possible in near future

03/2009 Draft

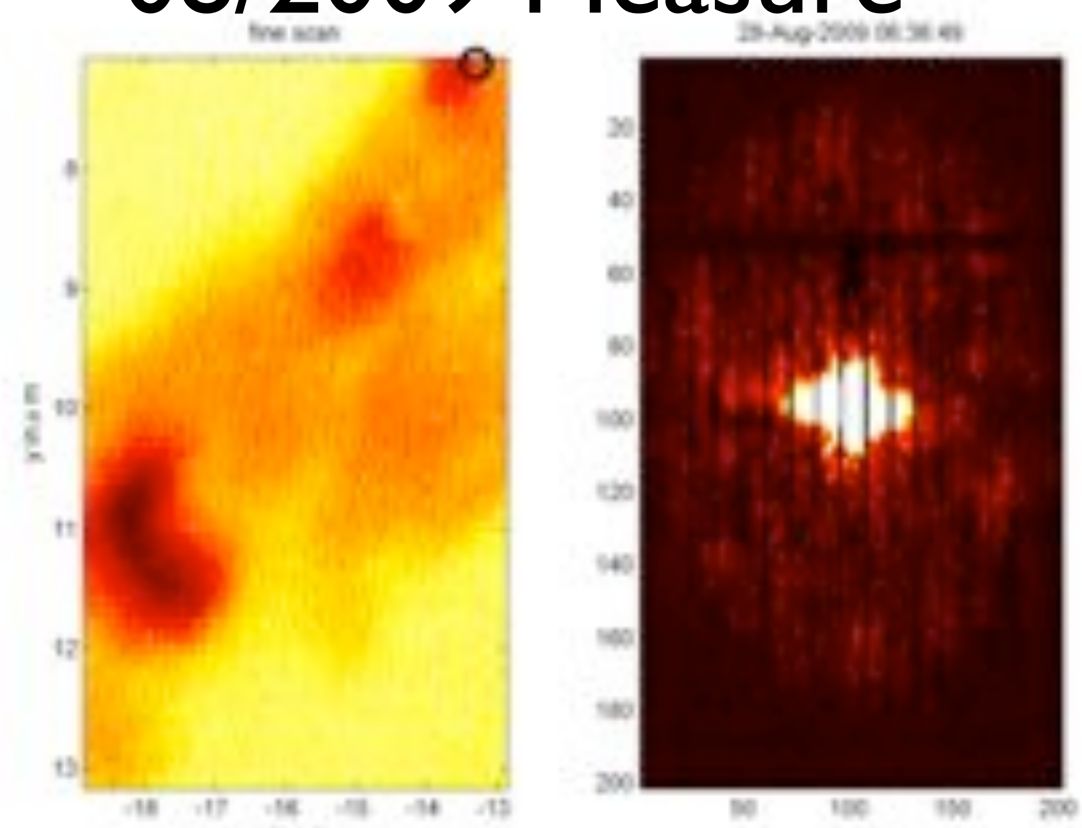


08/2009 Deploy



```
Energy:              = 750 eV
Focus=               = 300 nm
Flux (phot/s)        = 4 10^7
Oversampling         = x 9.6
max resolution       = 9 nm
```

08/2009 Measure



Prototype FCCD at APS

Argonne NATIONAL LABORATORY

Advanced Photon Source

A U.S. Department of Energy, Office of Science,
Office of Basic Energy Sciences national synchrotron x-ray research facility

U.S. DEPARTMENT OF ENERGY

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2009
2008

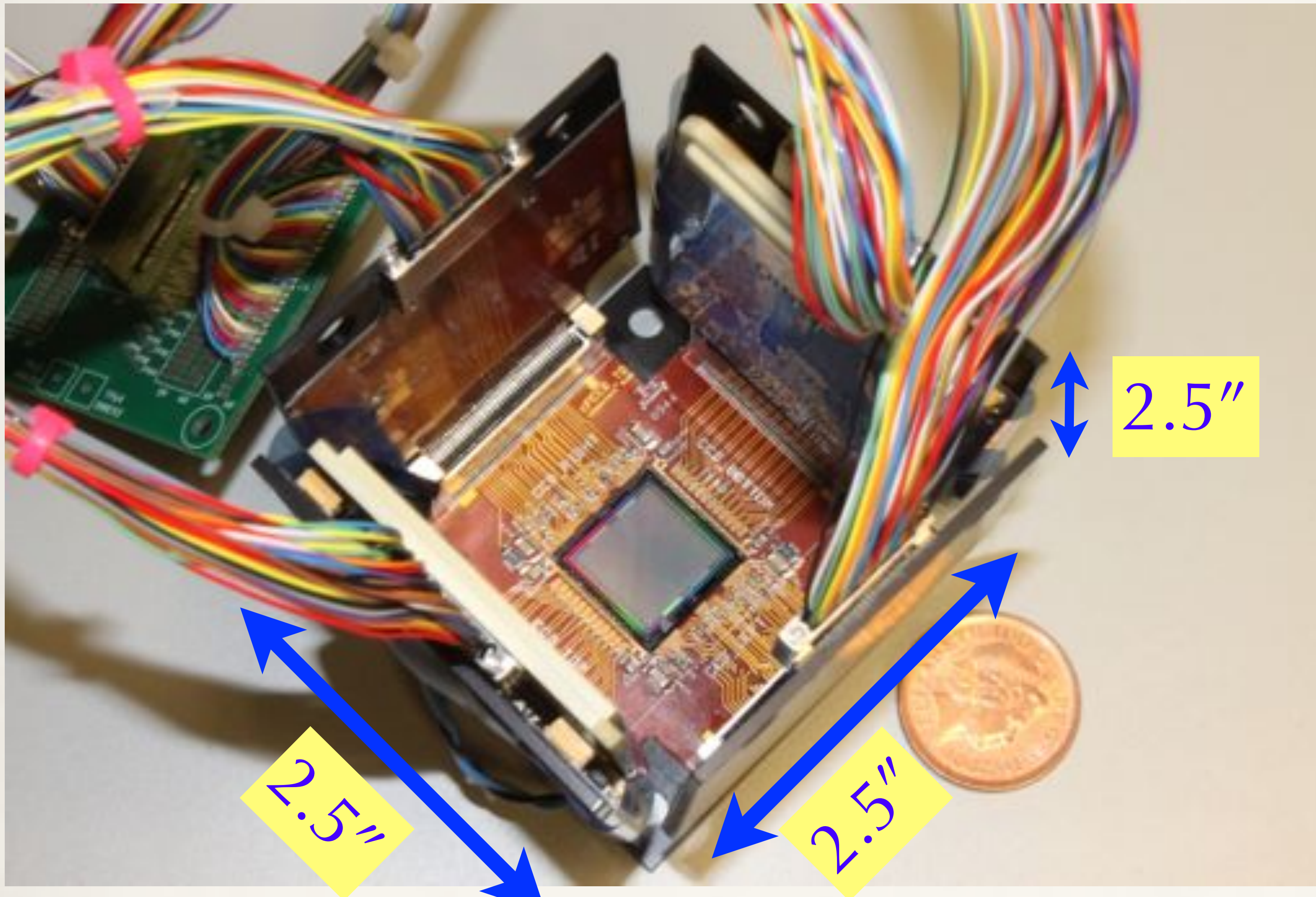
APS User News
Issue 58, November 11, 2009

The Argonne National Laboratory-Lawrence Berkeley National Laboratory (LBL) Fast CCD detector is the result of a collaboration (begun in 2005) between the Beamline Technical Support Group at the APS and the detector group at LBL. The Fast CCD detector was awarded beam time at 8-ID under a Partner User Proposal to commission and characterize the detector. The detector has a CCD chip with 480 × 480, 30 μm × 30 μm pixels, which are 200-μm thick and fully depleted. The thickness of the CCD makes the detector very efficient and is ideally suited for direct-detection operation, a key requirement for x-ray photon correlation spectroscopy (XPCS) measurements.

Detector commissioning began at station 8-ID-I in July 2009. Initial measurements focused on characterizing the detector's flat field response and efficiency, measuring static and fluctuating speckle patterns and examining performance of the control system. Results to date have demonstrated the exceptional prospects of the detector for small-angle XPCS measurements. In particular, the detector achieved a burst of images at 125 frames per second. Moreover, because of the very deep depletion layer, XPCS measurements were performed at considerably higher x-ray energies than have been used previously. This feature is especially advantageous for samples that are sensitive to radiation damage.

The detector will soon be available for use by general users in coordination with staff from the APS Detector Pool. It is anticipated that the detector will find applications in high-resolution time-resolved diffraction and coherent diffraction imaging measurements in addition to XPCS.

cFCCD (Compact FastCCD)

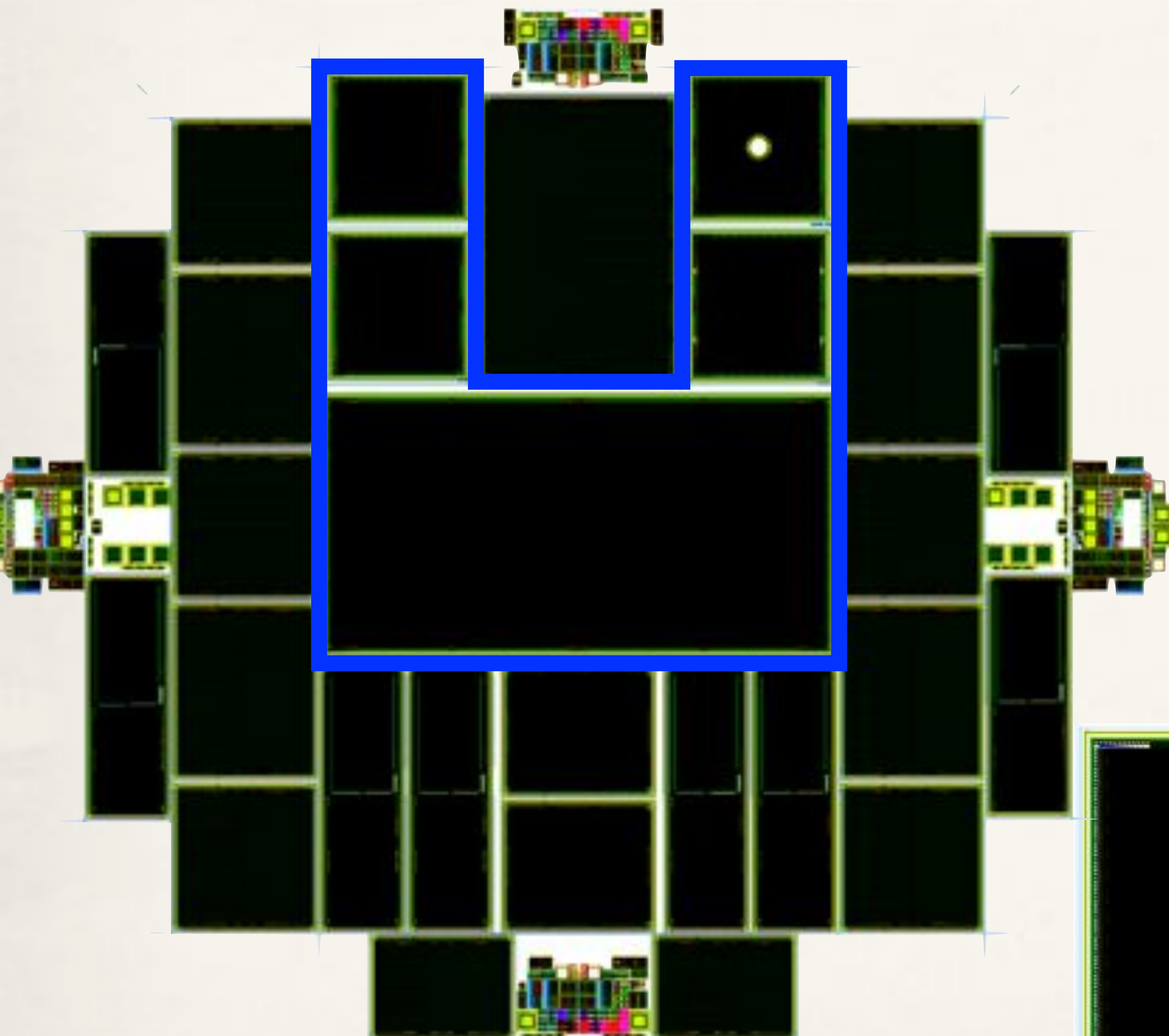


Prototype (front-illuminated)
Final mechanical / thermal verification

Highly-sophisticated test of functionality

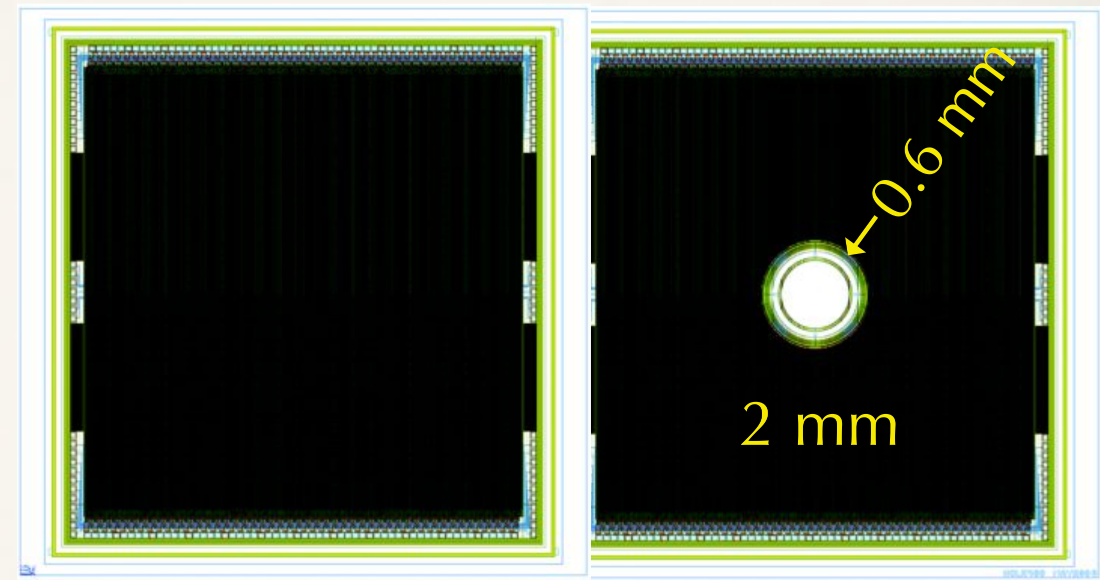
- cFCCD for LCLS Hutch 2 (delivery early 2010)
- cFCCD for BL 9.0.1
- cFCCDs with new devices

Continued (New) CCD LDRD



FY09 LDRD Wafer

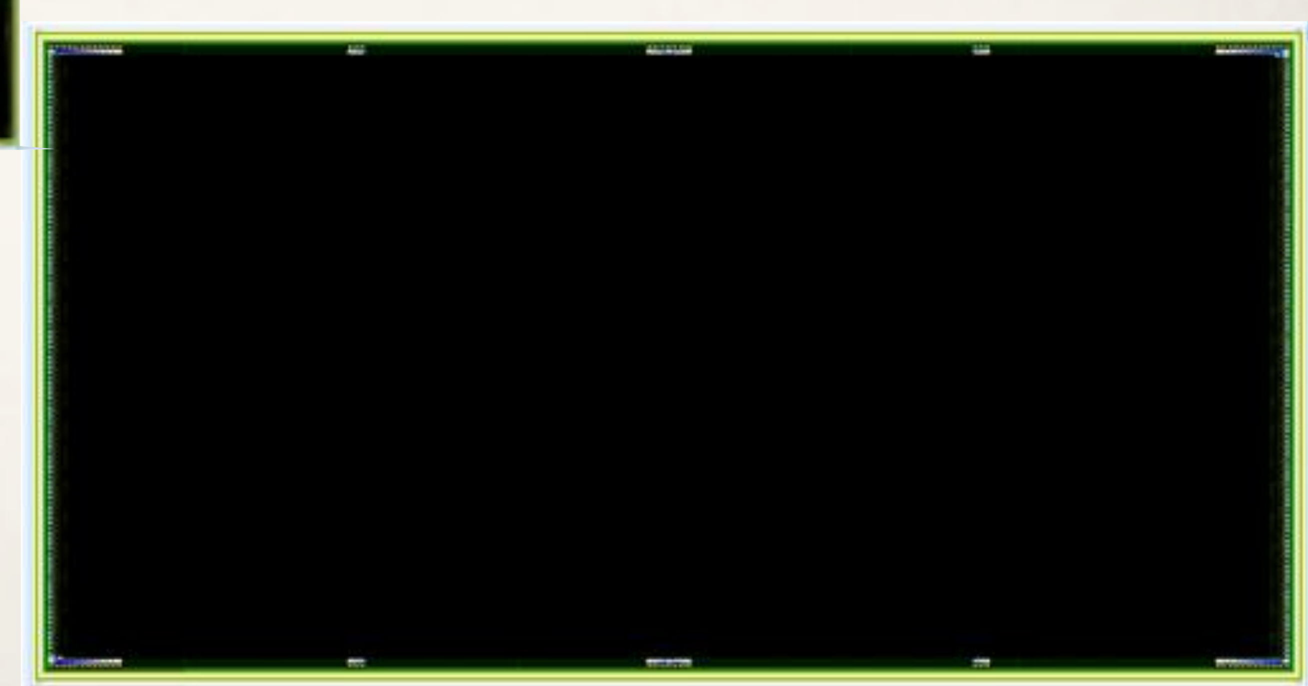
In fabrication now



New Output stages

Version with a hole

1k Frame store



ARRA-funded FastCCDs

RECOVERY.GOV

- 8 systems
- 2009 workshop:
  - 1k Frame Store
  - "hole" option
- ATCA-based DAQ
- Delivered in 2 yrs.

BERKELEY LAB

LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

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BERKELEY LAB PROJECTS

Advanced Light Source Accelerator Improvement and Equipment

Berkeley Lab's Advanced Light Source (ALS) is receiving $11.3 million to help it maintain its position as one of the world's premier soft x-ray light sources. The ALS is a national user facility serving more than 1,900 scientists annually doing research in a wide variety of fields, from biology and earth science to the study of optics and semiconductors; they use the light sources to examine structures on the atomic and molecular level.

First, the ALS will receive $5.8 million to acquire sextupole magnets to increase brightness by a factor of two to three, keeping the ALS at the cutting edge of soft x-ray science. Second, ALS will receive $2 million to construct and install an elliptically polarizing undulator to provide a new x-ray source for the femtosecond soft x-ray beamline 6.0.2, effectively doubling the capacity of this facility by enabling soft and hard x-ray branchlines to operate simultaneously. This will allow new research on complex materials, such as superconductors, nanostructures, and transition-metal oxides.

Third, ALS will receive $2 million to equip its beamlines with advanced CCD-based detectors developed at the ALS to enhance the reach and productivity of the beamlines. Lastly, ALS will receive $1.5 million to develop a unique superconducting magnet for a beamline, allowing experiments leading to novel insights into the magnetic structure of engineered magnetic nanostructures and materials not accessible by any other technique.

BES Detector and Accelerator R&D

- FY09: $700k
  - received Sep. '09
- FY10: $700k

Office of Basic Energy Sciences

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Wanda Smith, Administrative Specialist

BES Budget and Planning
Bob Astheimer, Senior Technical Advisor
Margie Davis, Financial Management
Vacant, Program Support Specialist

BES Operations
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Don Freeburn, DOE and Stakeholder Interactions
Robin Hayes, AAAS Fellow
Katie Perine, Program Analyst / BESAC
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Vacant, Technology Office Coordination

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Rocio Meneses, Program Assistant

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  - NSRCs & EBMCs** — Tof Carim, ◆ Joe Horton, ORNL, Vacant
  - Accelerator and Detector R&D — Eliane Lessner
  - Facility Coordination, Metrics, Assessment — Van Nguyen
- **Construction**
  - Linac Coherent Light Source — Tom Brown
  - NSLS II — Tom Brown
  - Spallation Neutron Source Upgrades — Tom Brown
  - Instrument MIEs (SING, LUSI, etc.) — ◆ John Tapia, LANL
  - Advanced Light Source User Support Building — Tom Brown

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Diane Marceau, Program Analyst
Michaelene Kyler-King, Program Assistant

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* Experimental Program to Stimulate Competitive Research

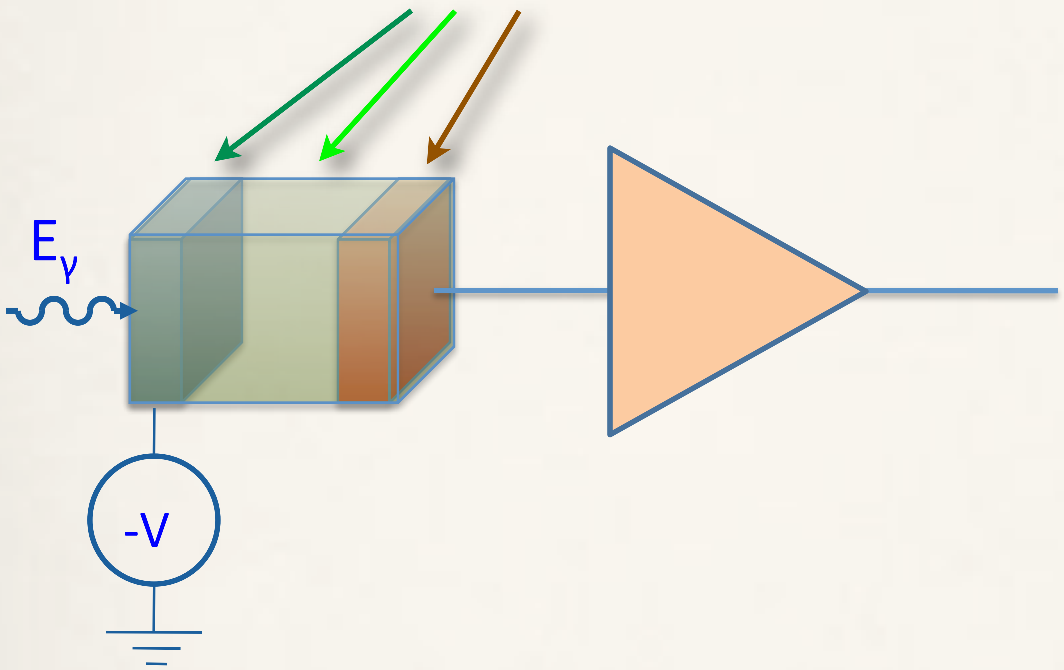
** Nanoscale Science Research Centers & Electron Beam Microcharacterization Centers

LEGEND
- ◆ Detailee (from DOE laboratories)
- ■ Detailee, ½ time
- ■ Detailee, ½ time, not at HQ
- ● Detailee, ¼ time, not at HQ
- ◆ On detail from SC-2, ½ time
- △ IPA (Interagency Personnel Act)
- ☆ On active military duty
- P.A. Program Assistant

October 2009
Posted 01OCT09

Direct detection – R&D

Reminder - p-i-n diode detector



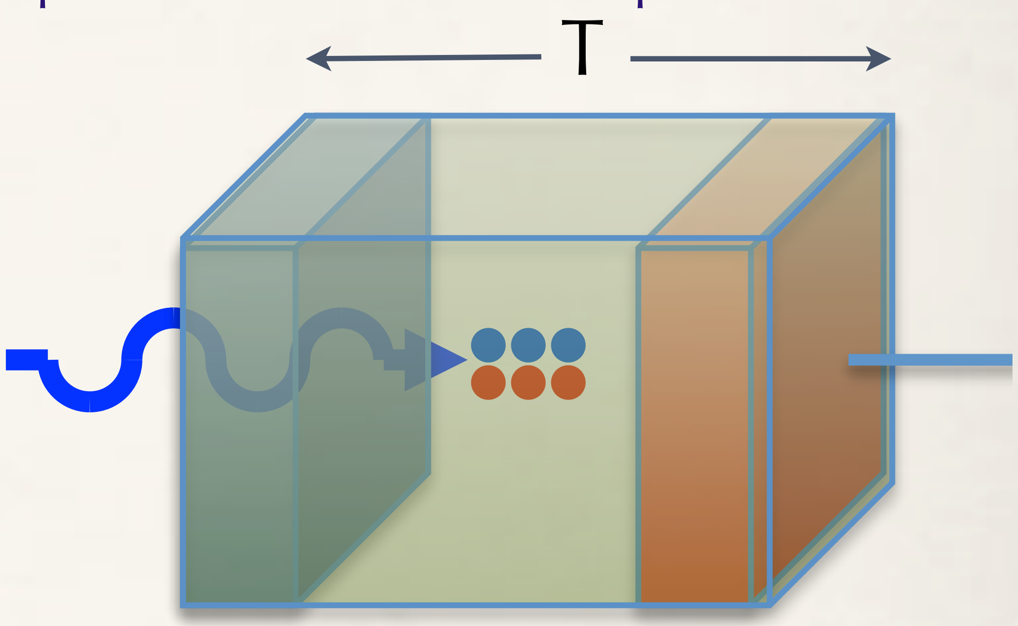
$N_Q = E_\gamma/\varepsilon$

$\sigma^2_N = F \cdot E_\gamma/\varepsilon$, F=Fano factor

Photo-conversion

⇒ photon penetrates entrance window

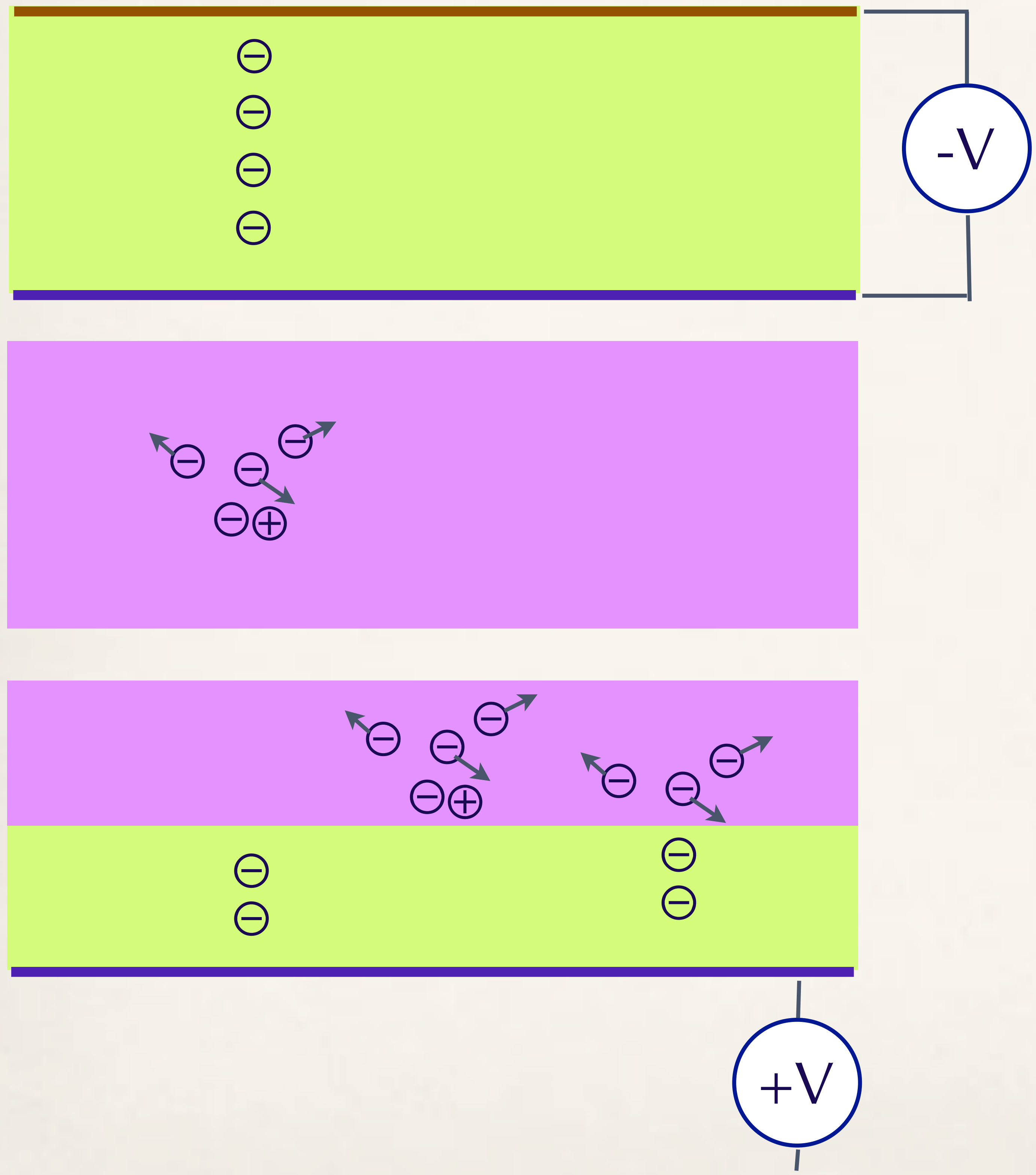
⇒ photon is absorbed in depth T



Material	Si	Ge	GaAs	Diamond
ε [eV]	3.6	3.0	4.4	13.1
F	0.12	0.13	0.10	0.08
ϱ [g/cm³]	2.3	5.3	5.3	3.5
95% @ 8 keV	200 µm	85 µm	85 µm	3 mm

Si ideal for most of ALS

Importance of Depletion



Fully depleted detector

No recombination

Charge drifts to collection electrode

PSF = 0

Undepleted detector

Diffusion + recombination

Bad PSF

Partially depleted detector

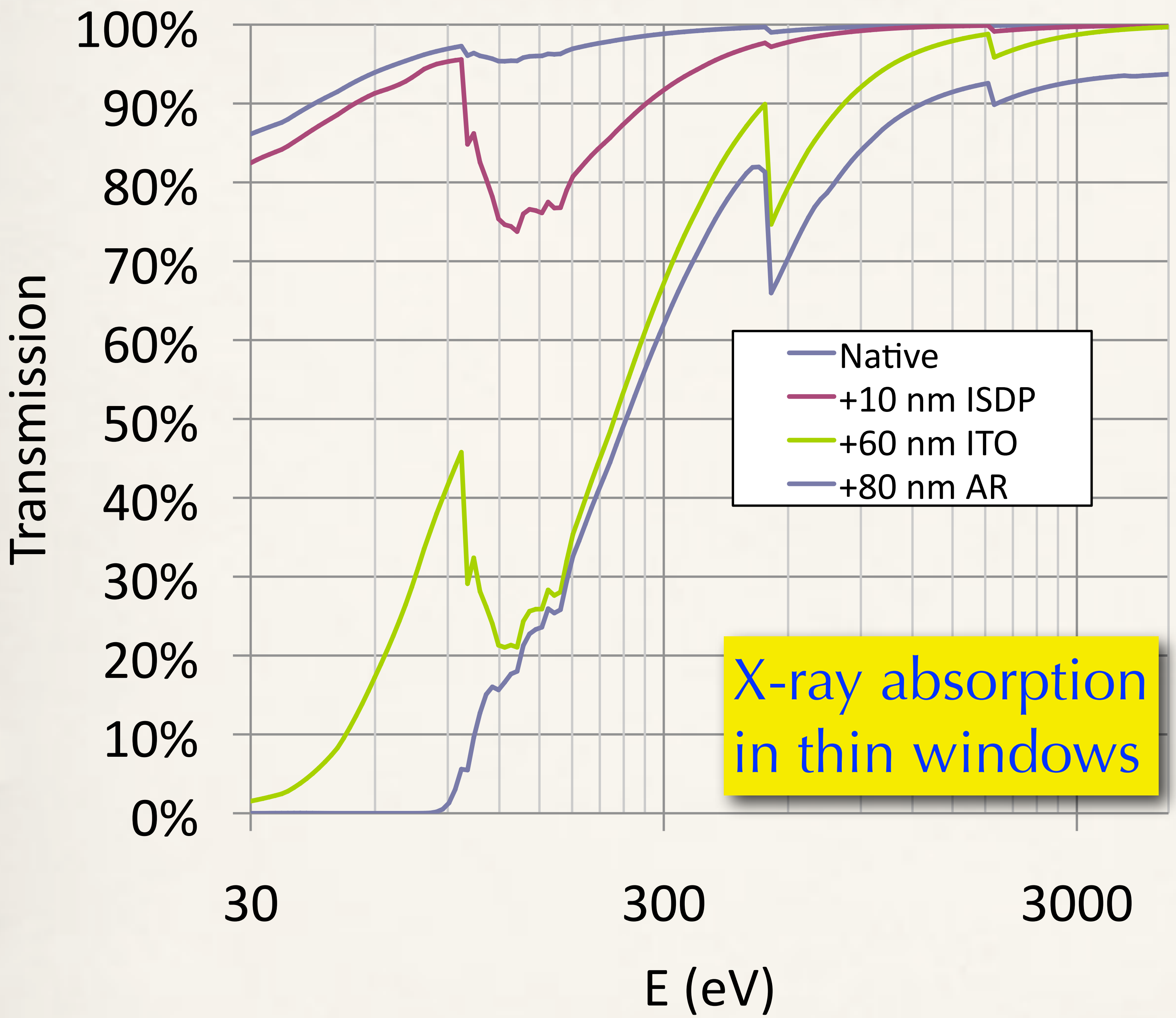
All effects

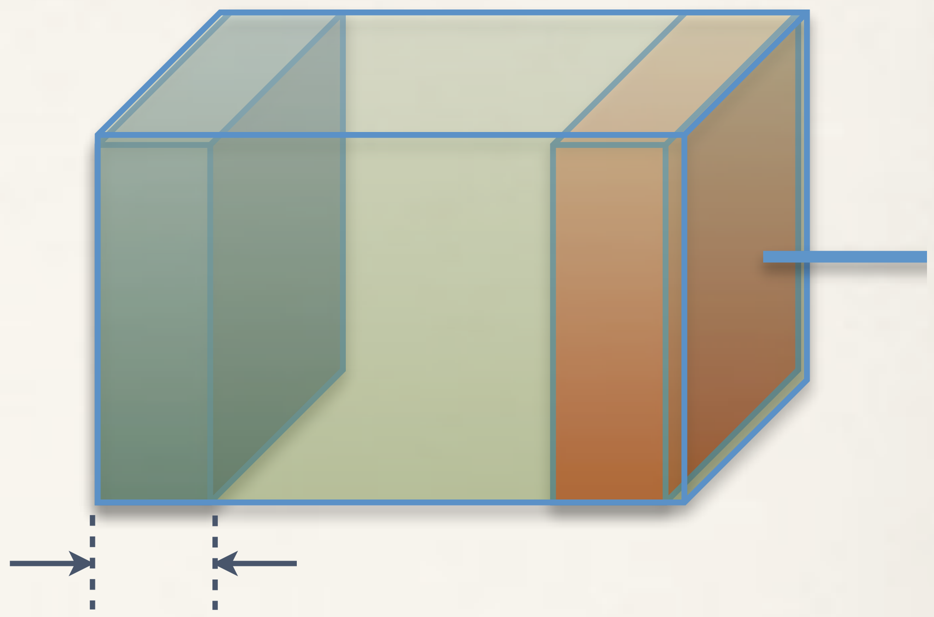
PSF and charge collection depend on site of photoconversion

Charge collection

- drift - all charge drifts directly towards anode
- diffusion - charge goes into 4π
- recombination - no charge collected

Entrance Window





Minimize this dead space for soft x-rays

SNAP (optical) CCD

Thinned, back-illuminated CCD: laser annealed, partially depleted

Thick, back-illuminated fully depleted detector: thin contact needed

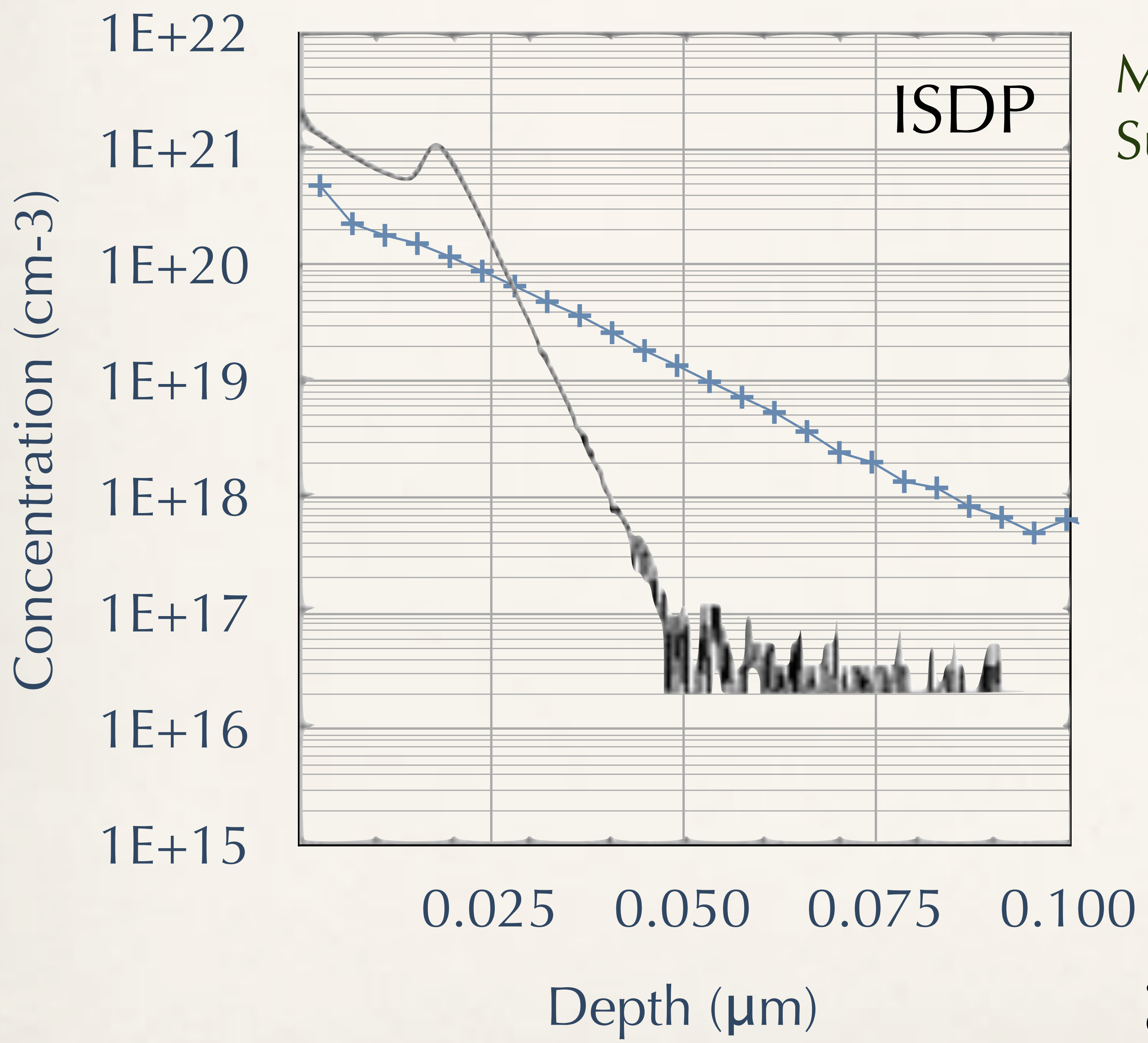
R&D Directions

- Fast, sensitive 2D detectors
  - In fully depleted silicon
  - With thin entrance windows
- FastCCD
  - Original idea: fast, wide dynamic range
  - After experience: really fast, single photon detector†
  - ➡ VeryFastCCD: column parallel [factor 10] x 10X faster readout [with lower dynamic range] > 10 kHz frame rate
  - At ~100 Hz, already have trouble writing raw data to disk
  - ➡ Processing "on-the-fly" (ATCA is prototype for architecture)
- Smarter pixels
- ➡ SOI (Silicon-on-insulator)

† "Digital" vs. "Analog" pixels - excellent discussion topic!

Low Temperature Window Process

- LBNL ISDP (S. Holland) - high temperature
- R&D - LBNL Low T. (C. Tindall) - just below Al melting
- R&D - JPL (S. Nikzad) δ-doping

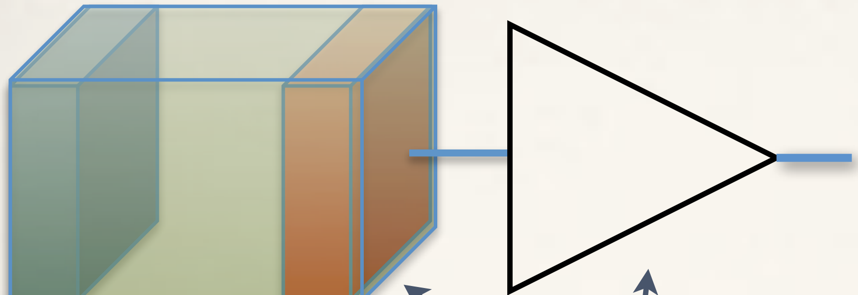


Measurements on pin diode
Successfully implanted SOI

t	**T**
δ-doping	δ-doping
ISDP	Low-T
Low-T	ISDP

- SIMS data for the implanted contact on PIN diodes after annealing @ 500°C
- Expect detection threshold of 500 eV for 0.1 μm thick contact

The problem with pixels



Need to connect

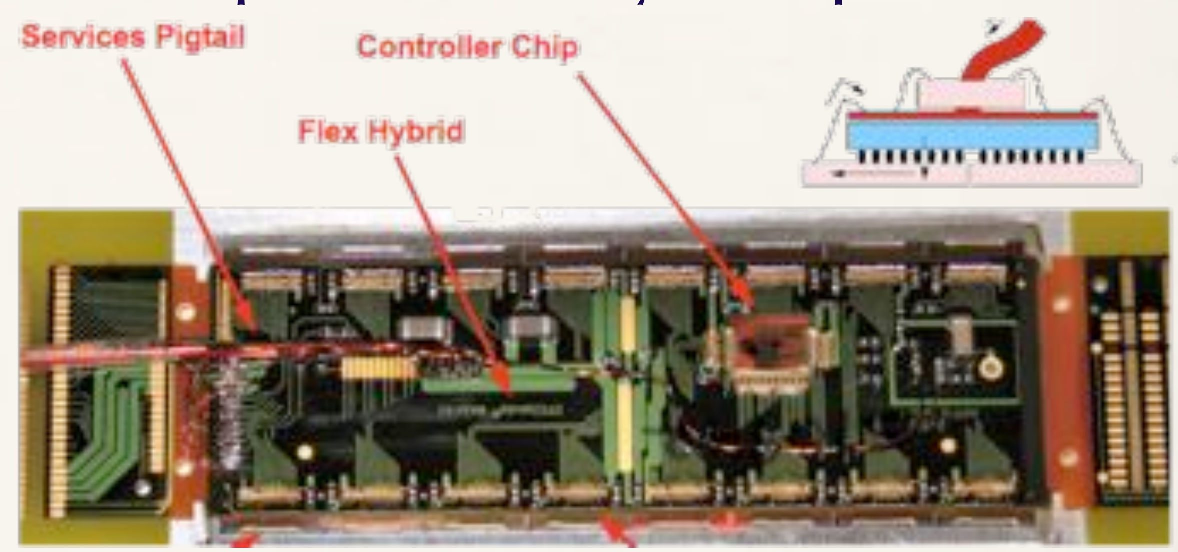
Old Fashioned Solution

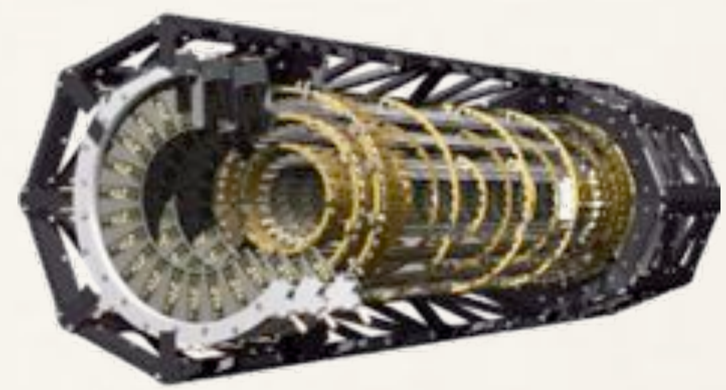
Monolithic detectors based on CMOS: CCDs

CCD Pixel IQ: 0

Current Solution

Bump-bonded hybrid pixels





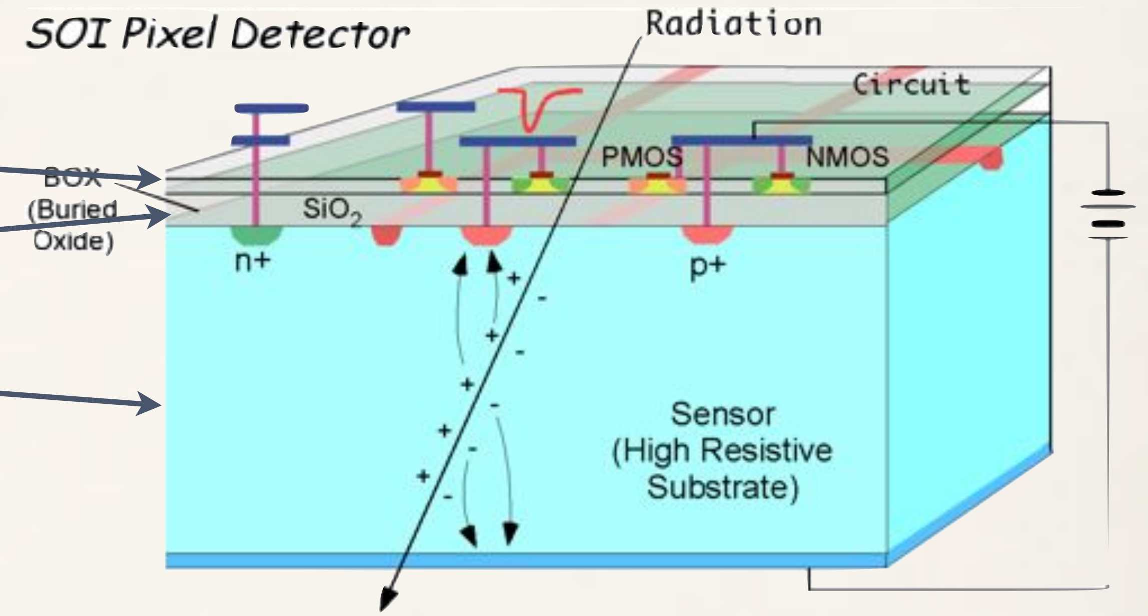
Hybrid Pixel IQ: High

Silicon-on-insulator

50 nm CMOS / DI

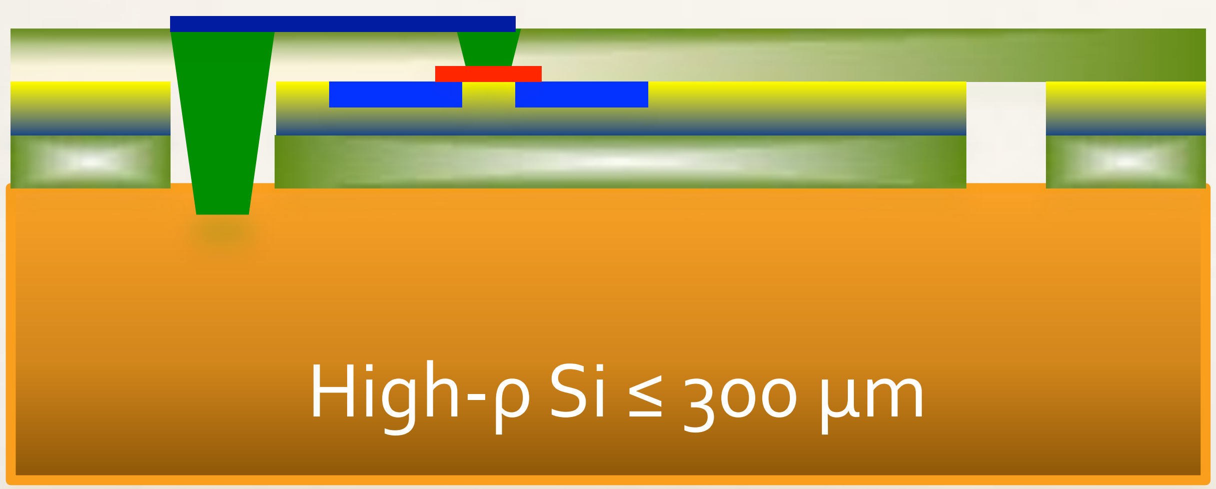
200 nm SiO_2

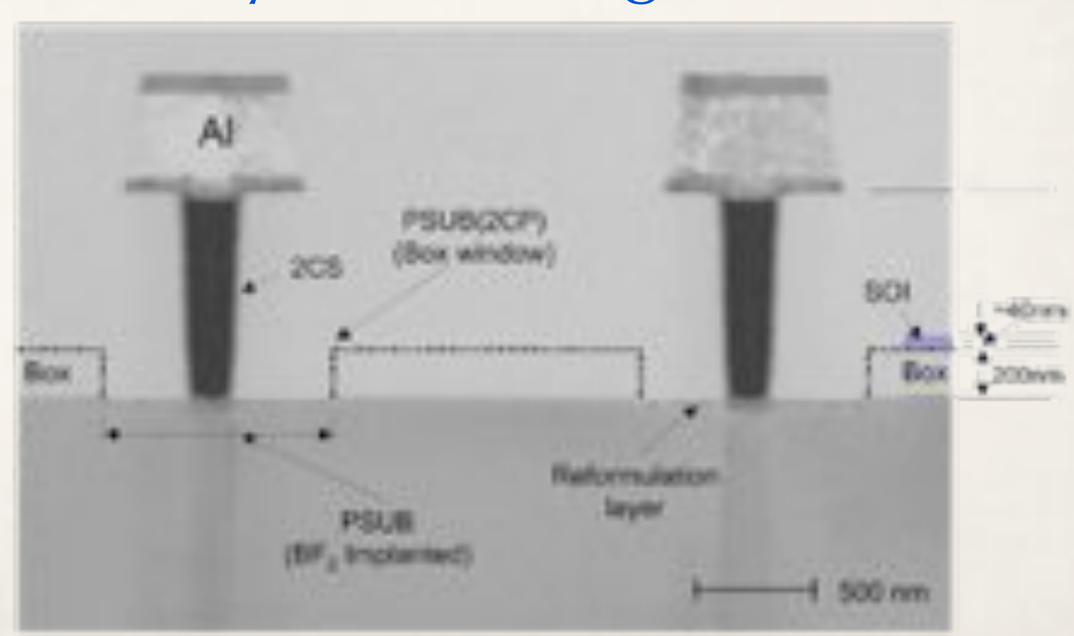
200 µm high ρ Si



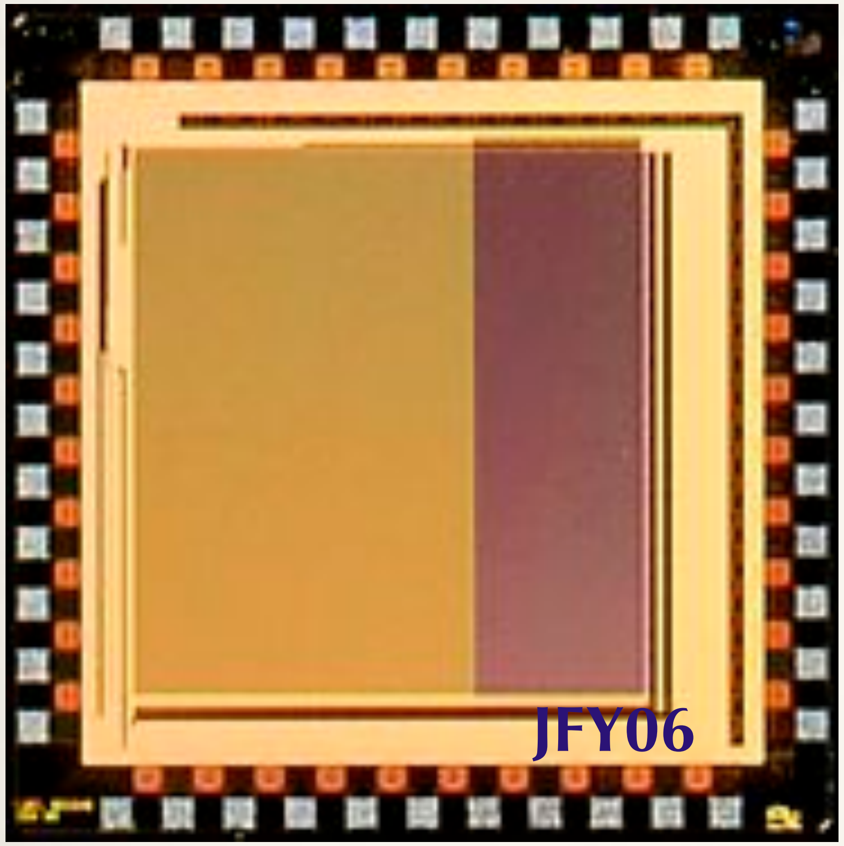
- International collaboration
  - Started in context of ILC
- Led by KEK, using Oki

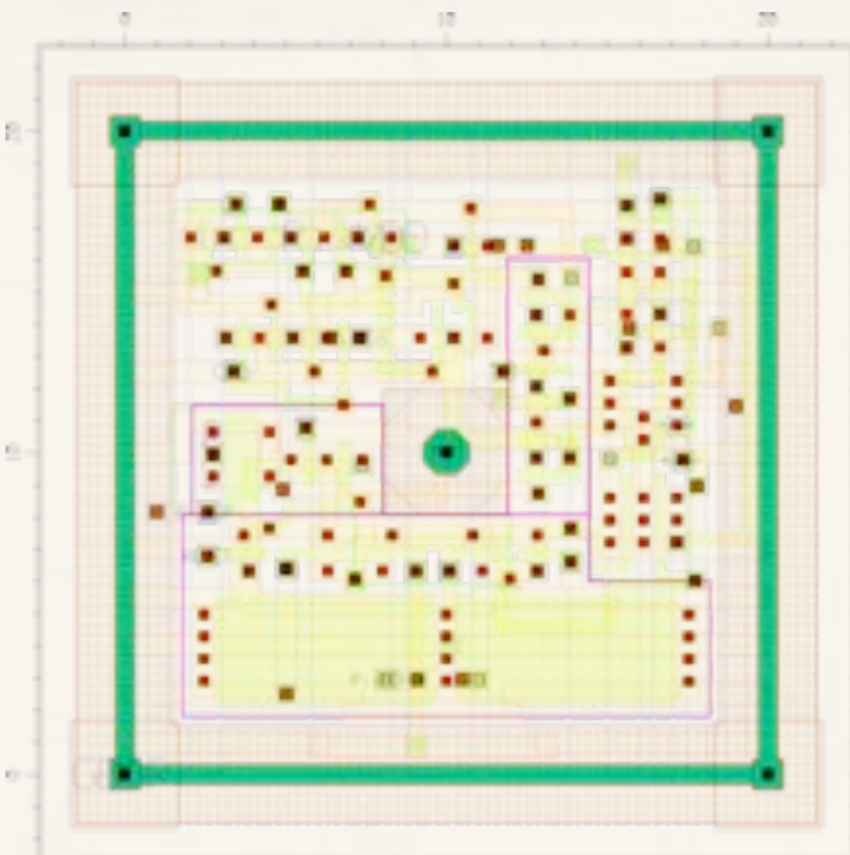
CMOS on thick, fully-depleted, high-resistivity, detector-grade silicon

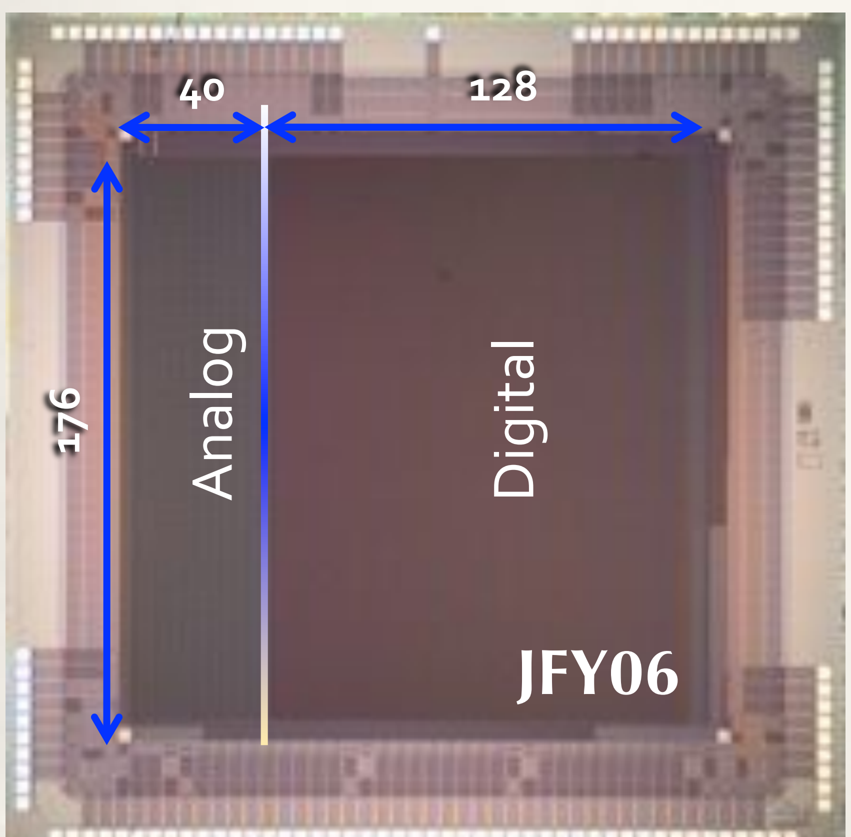


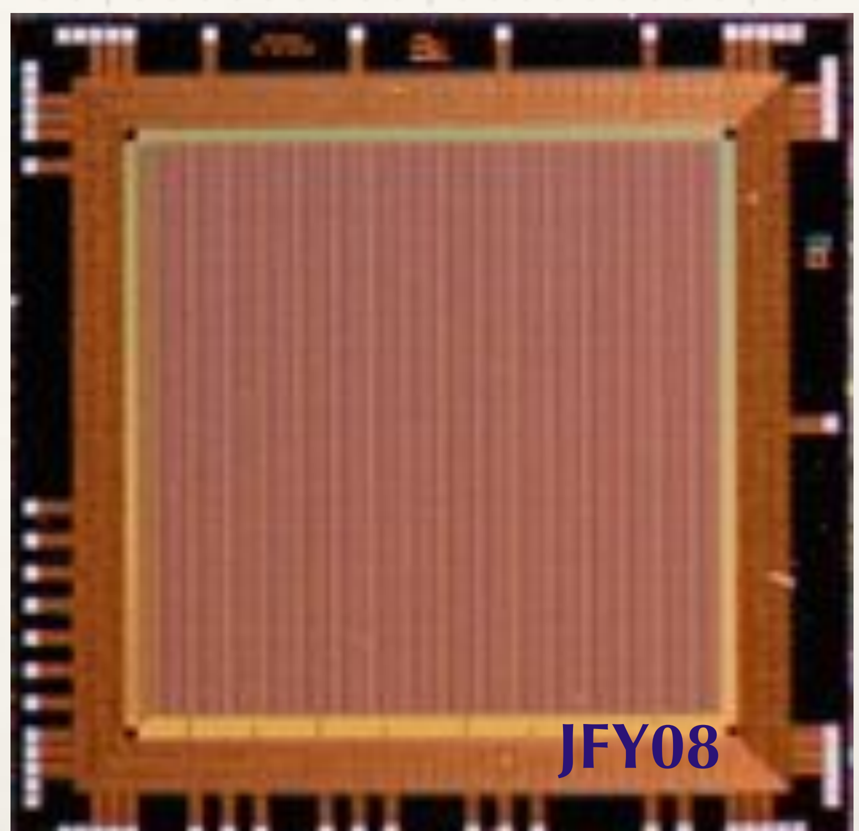


SOI R&D



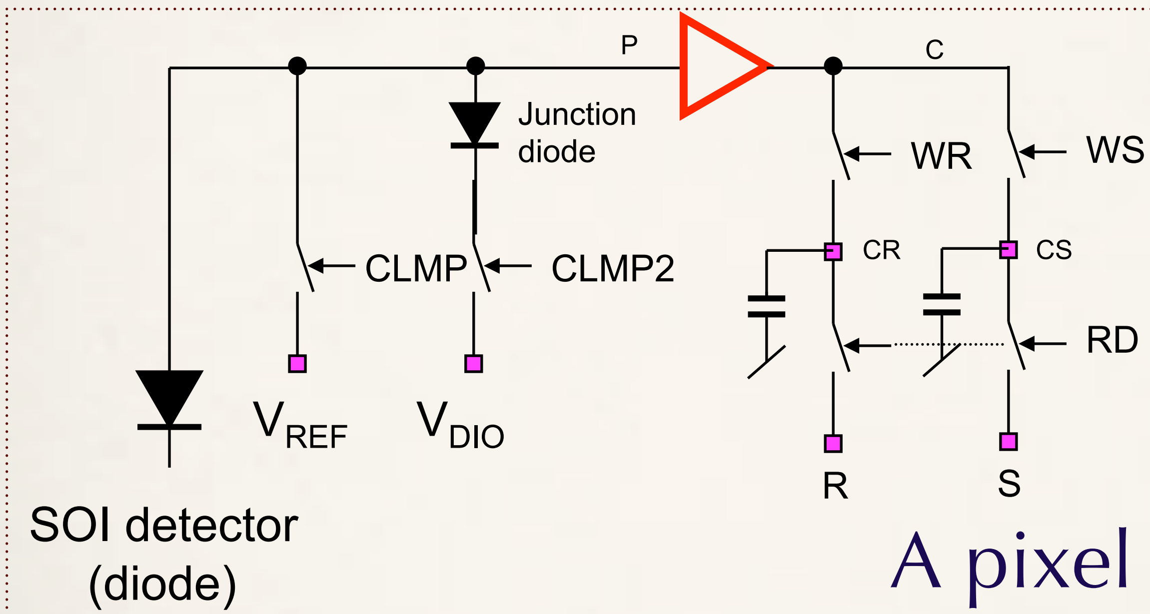


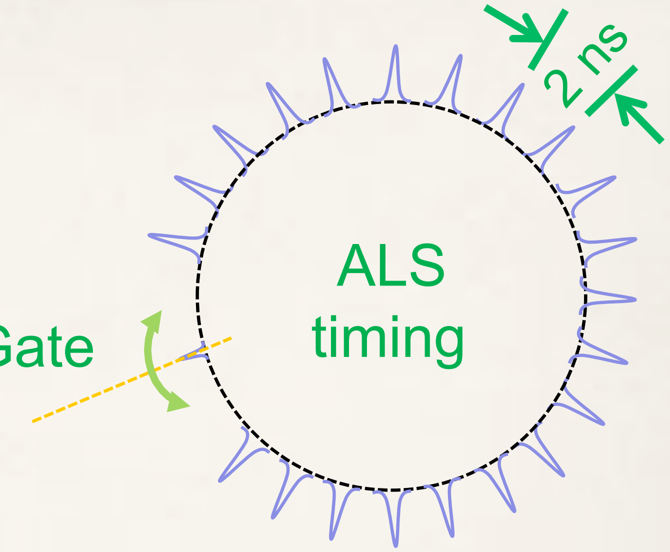




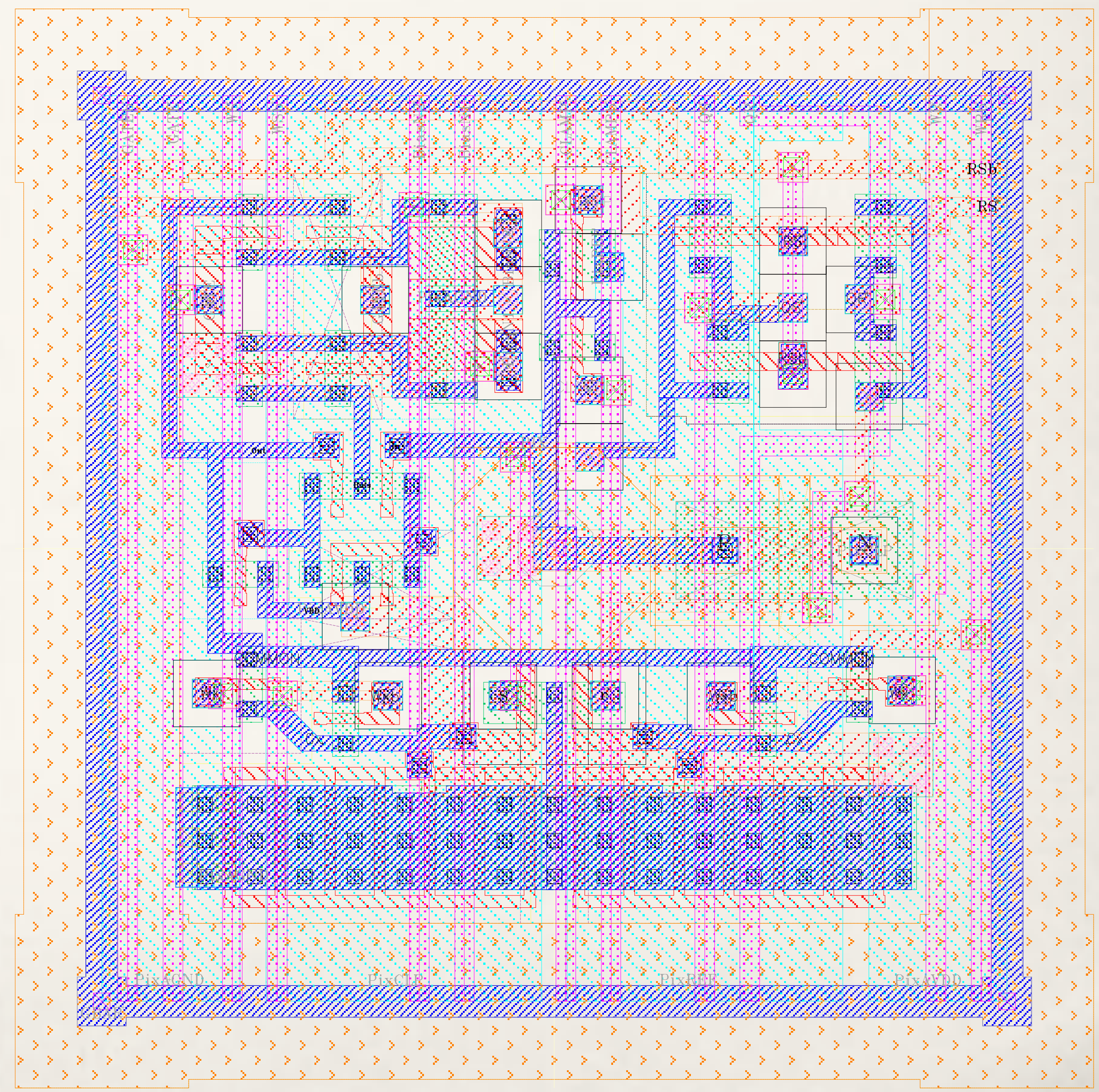
- LDRD-supported for ILC FY05-07
  - US/Japan funds
  - Analog and digital pixels
- BES detector R&D for xrays
- 1st test on 5.3.1 last week
- femtoPix

femtoPix



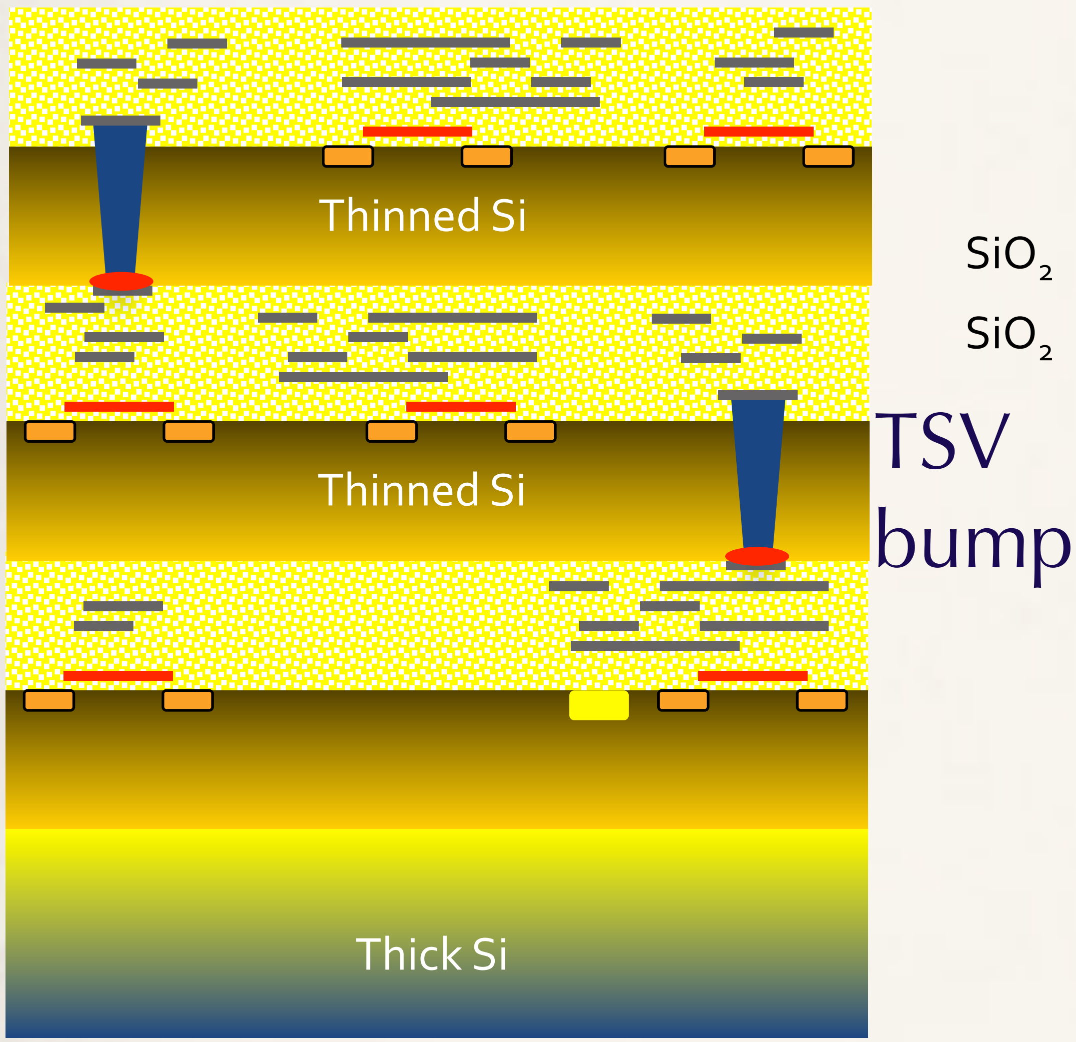


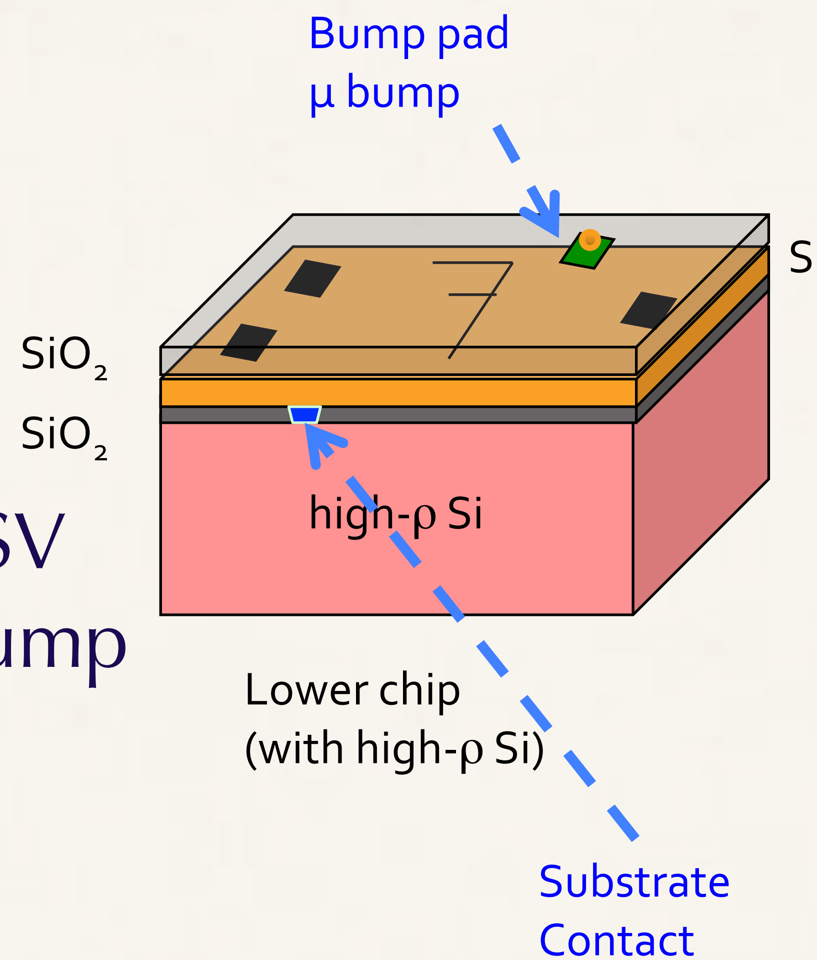
- 4,000 frames / sec.
  - 2 kHz laser on
  - 2 kHz laser off
- CDS
- Firmware processing
- Submission Jan. '10

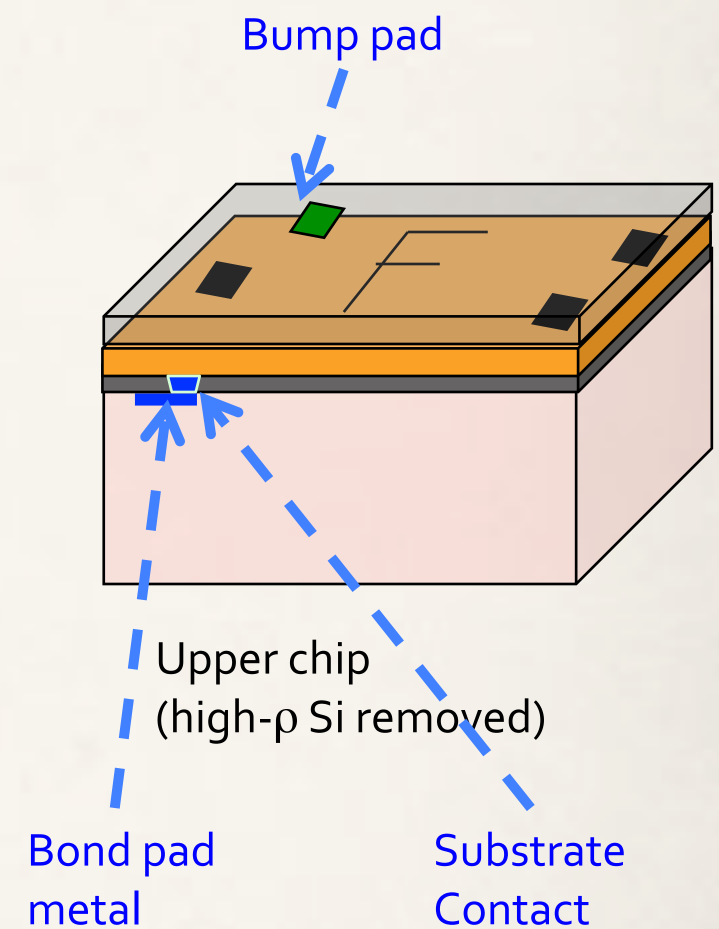


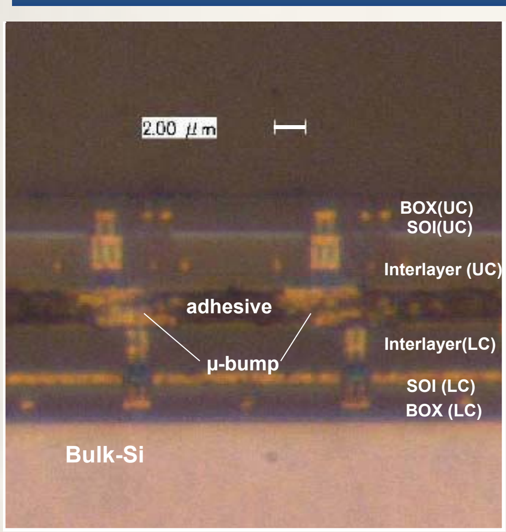
17.5 µm pixel

3D / 3D-SOI

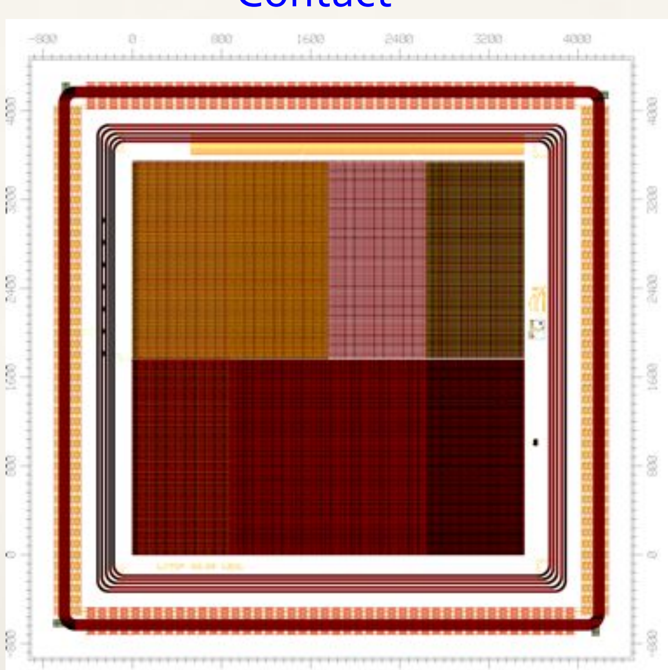


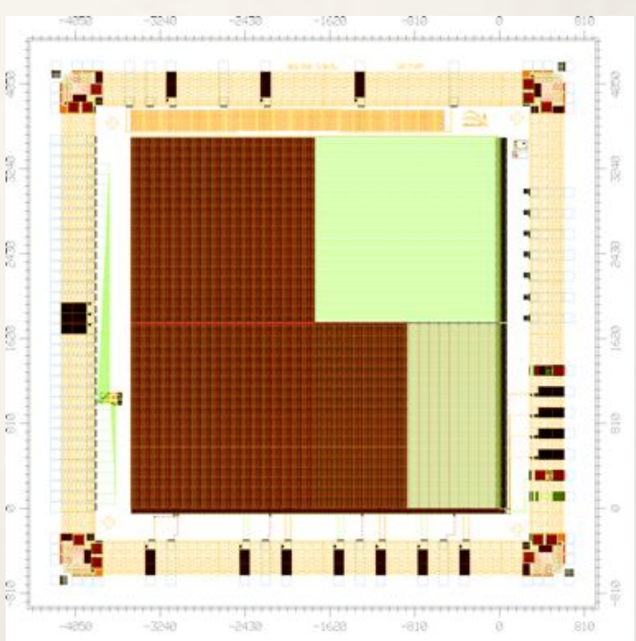






World's 1st 3D SOI in 3D process now





Pixel panoply

	CCD on thick, high-ρ silicon (LBL CCD)	SOI on thick, high-ρ silicon	Hybrid on thick, high-ρ silicon	3D on thick, high-ρ silicon

Size	10^2 - 10^3 μm^2	10^2 - 10^3 μm^2	10^4 μm^2	10^2 μm^2
/ pixel	0	10^1 - 10^2	10^2 - 10^3	10^1 - 10^2
ENC	10^1 - 10^2 e^-	10^1 - 10^2 e^-	10^2 e^-	?
	Today: FCCD R&D: VFCCD	Today: R&D Soon: femtoPix	HEP only	R&D

Conclusions

- Initial work LDRD-supported FY05 - FY08
  - ALS operation support FY09 - ∞
- FastCCD prototype → ALS, APS
  - cFastCCD → LCLS SXR, 9.0.1
- ARRA funds → 1k frame store FastCCDs to 8 ALS BLs
- R&D
  - Focus on fast, 2D silicon direct detection devices. Fully depleted, with thin windows and firmware processing
    - ➡ Faster CCDs, SOI, window implants, processing

Today 10^2 *Hz* → *Soon* 10^3 *Hz* → *Tomorrow* 10^4 *Hz* → *NGLS* 10^5 *Hz*

- Also in the pipeline
  - "Spectroscopy" CCD (~5 μm in one direction)
  - Radiation hardness testing