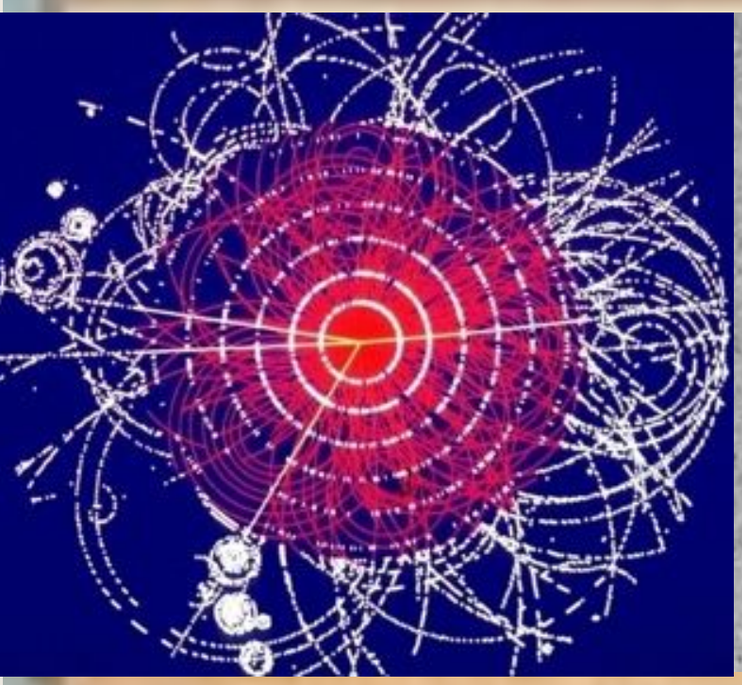
X-ray Detector Development at LBNL

$r_e = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{mc^2}$ ~10^{-15} m

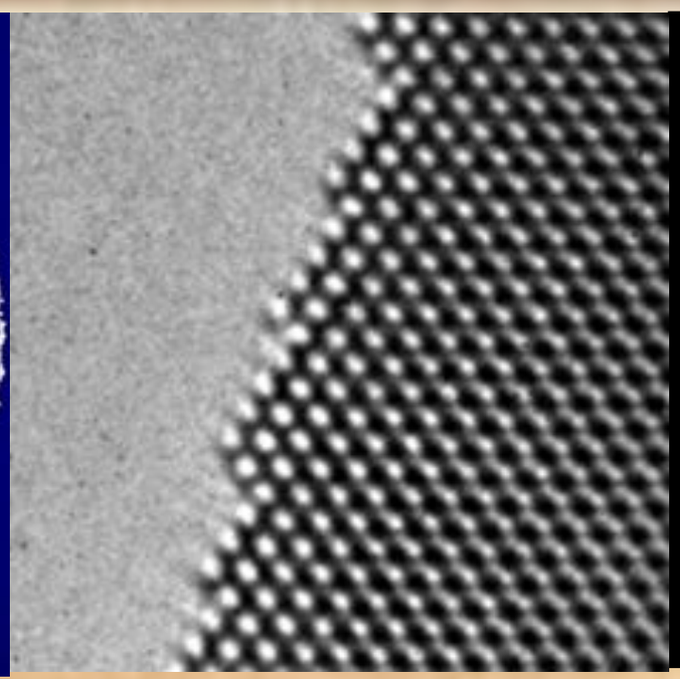
~10^{-10} m

~10^{-8} m

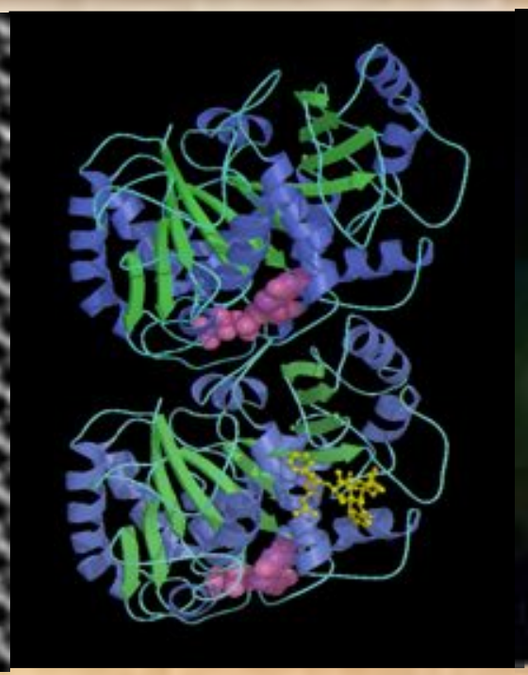
$R_E = \frac{c}{\sqrt{4\pi G\rho}}$ ~10^{26} m



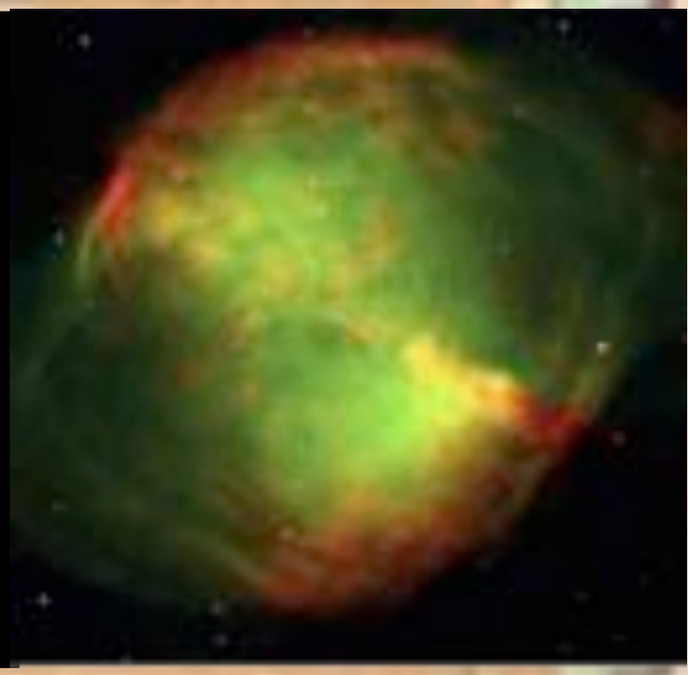
Elementary particles



Atoms



Proteins, Molecules



Universe

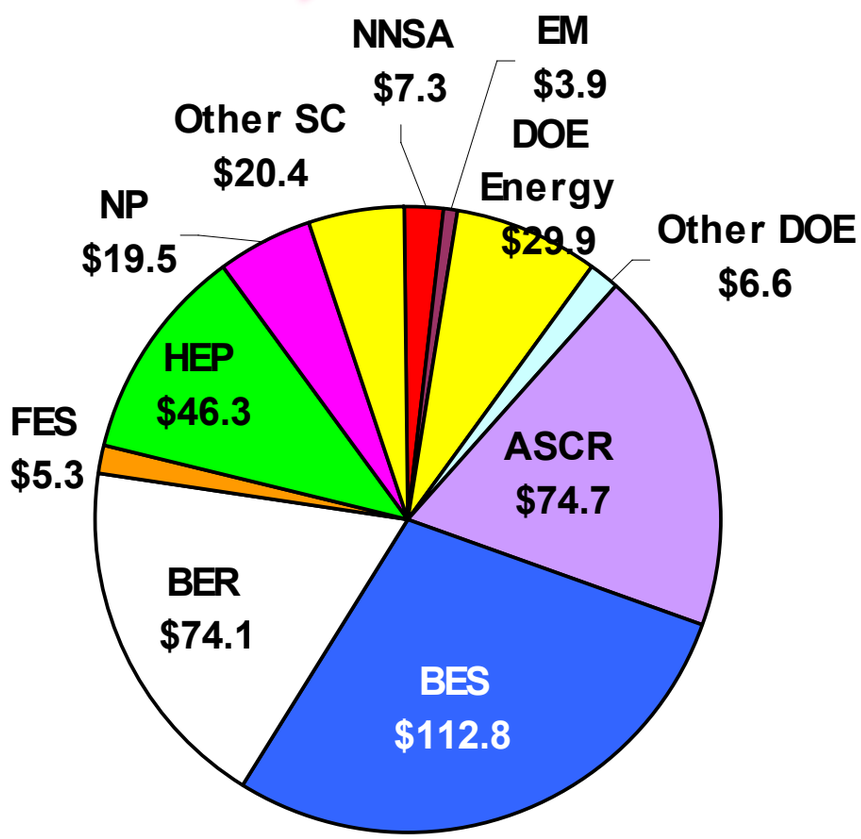
P. Denes

Acting Director Engineering Division

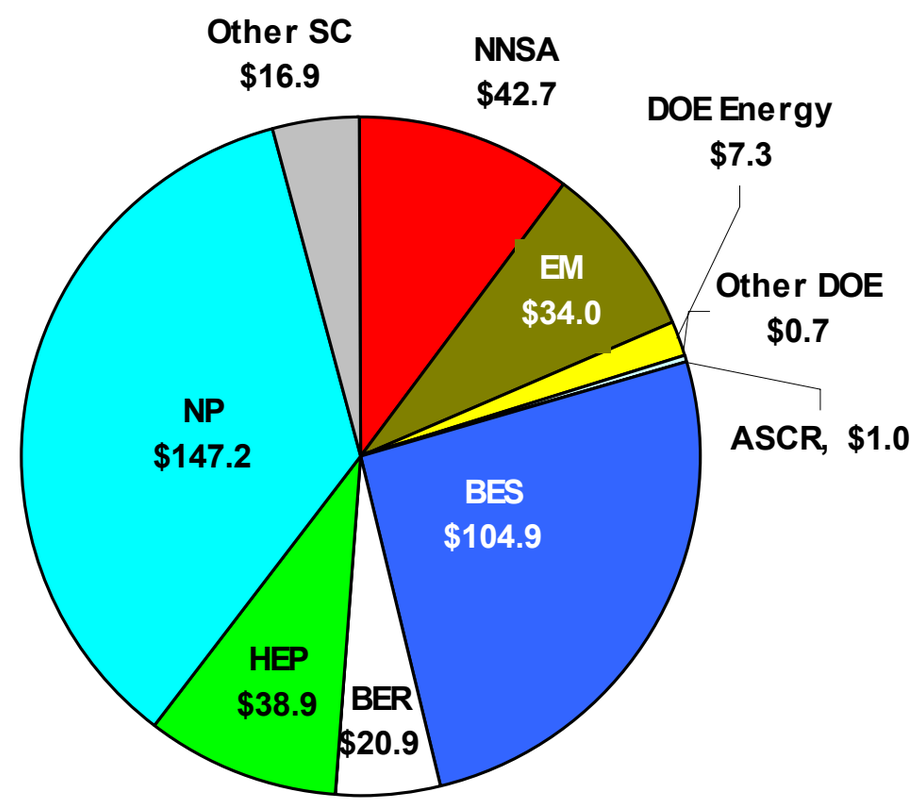
Deputy Director for Engineering, Advanced Light Source

0.25 μm ATLAS pixel chip

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY



FY 2006 Non-DOE Funding: $111M
FY 2006 Dept. Homeland Security: $6.4M



FY 2006 Non-DOE Funding: $55.3M
FY 2006 Dept. Of Homeland Security: $2.6M

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

detectors@lbl.gov

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY • UNIVERSITY OF CALIFORNIA

INTERNAL AUDIT
T.L. HAMILTON

TECHNOLOGY TRANSFER
C.A. FRAGIADAKIS
Department Head

LABORATORY DIRECTOR
A.P. ALIVISATOS

DEPUTY DIRECTOR
J.D. KEASLING, Acting

CHIEF OPERATING OFFICER
J.T. KRUPNICK

Office of the Director

- **CHIEF FINANCIAL OFFICER** — *J.A. FERNANDEZ*
- **LABORATORY COUNSEL** — *G.R. WOODS*
- **CHIEF INFORMATION OFFICER** — *R. ALVAREZ*
- **RESEARCH AND INSTITUTIONAL INTEGRITY OFFICE** — *M. MONTGOMERY*
- **INSTITUTIONAL ASSURANCE** — *H. HATAYAMA*
- **CHIEF OF STAFF** — *C.L. YETTER, Acting*

OPERATIONS
J.T. KRUPNICK
Associate Laboratory Director and C.O.O.
A.P. GURSAHANI
Deputy C.O.O.

- **FACILITIES** — *J.S. RIDGEWAY*, *Division Director*
- **INFORMATION TECHNOLOGY** — *R. ALVAREZ*, *Division Director*
- **PUBLIC AFFAIRS** — *J.W. MILLER*, *Department Head*
- **ENVIRONMENT, HEALTH AND SAFETY** — *D.M. FLEMING*, *Division Director*
- **OFFICE OF THE CHIEF FINANCIAL OFFICER** — *J.A. FERNANDEZ*, *CFO*
- **HUMAN RESOURCES AND WORKFORCE DIVERSITY** — *V. POTAPENKO*, *Chief Human Resources Officer*

LIFE SCIENCES
J.W. GRAY
Associate Laboratory Director

- **EARTH SCIENCES** — *D.J. DEPAOLO*, *Division Director*
- **GENOMICS** — *E.M. RUBIN*, *Division Director*
- **LIFE SCIENCES** — *J.W. GRAY*, *Division Director*

ENERGY & ENVIRONMENTAL SCIENCES
Vacant
Associate Laboratory Director

- **CHEMICAL SCIENCES** — *D.M. NEUMARK*, *Division Director*
- **ENVIRONMENTAL ENERGY TECHNOLOGIES** — *A.J. GADGIL*, *Division Director, Acting*
- **MATERIALS SCIENCES** — *M.B. SALMERON*, *Division Director*
- **PHYSICAL BIOSCIENCES** — *P.D. ADAMS*, *Division Director, Acting*

COMPUTING SCIENCES
H.D. SIMON
Associate Laboratory Director

- **COMPUTATIONAL RESEARCH** — *H.D. SIMON*, *Division Director*
- **NATIONAL ENERGY RESEARCH SCIENTIFIC COMPUTING CENTER** — *K.A. YELICK*, *Division Director*

GENERAL SCIENCES
J.L. SIEGRIST
Associate Laboratory Director

- **ACCELERATOR & FUSION RESEARCH** — *S. GOURLAY*, *Division Director*
- **ENGINEERING** — *P. DENES*, *Division Director, Acting*
- **NUCLEAR SCIENCE** — *T.J. SYMONS*, *Division Director*
- **PHYSICS** — *J.L. SIEGRIST*, *Division Director*

PHOTON SCIENCES
R.W. FALCONE
Associate Laboratory Director

- **ADVANCED LIGHT SOURCE** — *R.W. FALCONE*, *Division Director*

300 staff
60% Mechanical
40% EE/CS

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Evolution

Spectroscopic Detetctors

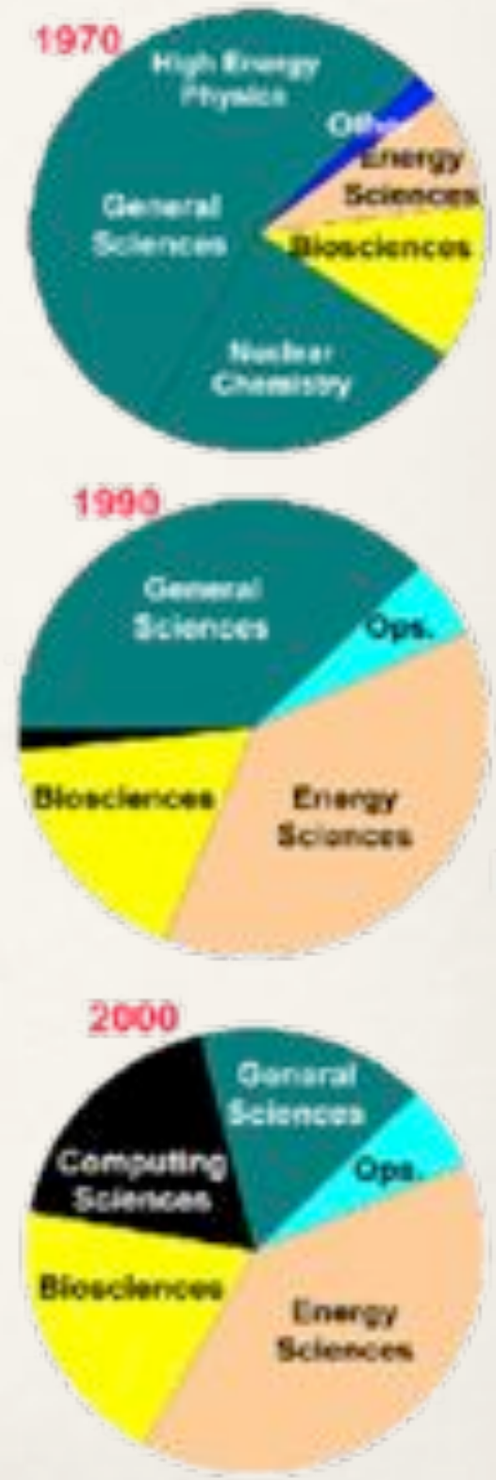
- High-purity Ge
- Nuclear medicine
- Gas detectors

Tracking detectors

- Si Strips
- Si pixels
  - CCD (astro)
  - hybrid (particles)

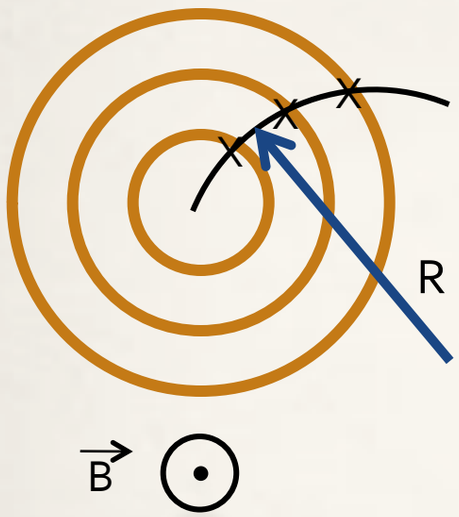
Digital Medicine

- Spectroscopic pixels
- Monolithic pixels



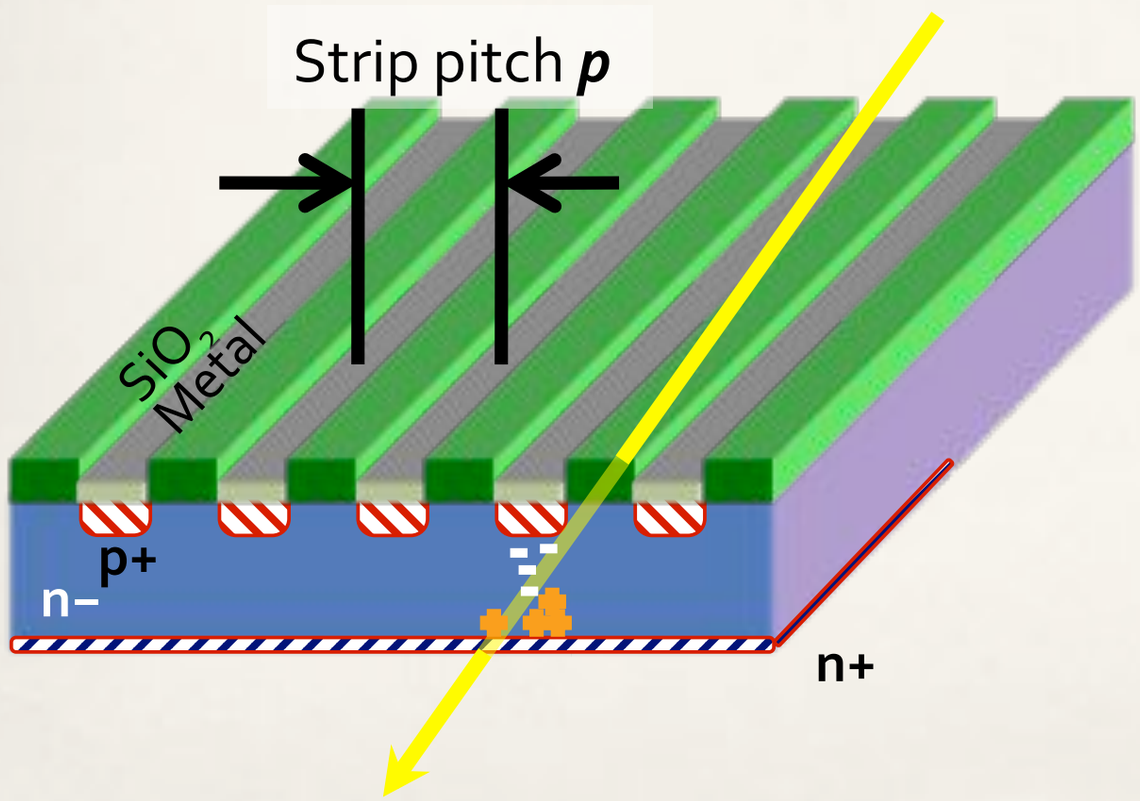
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

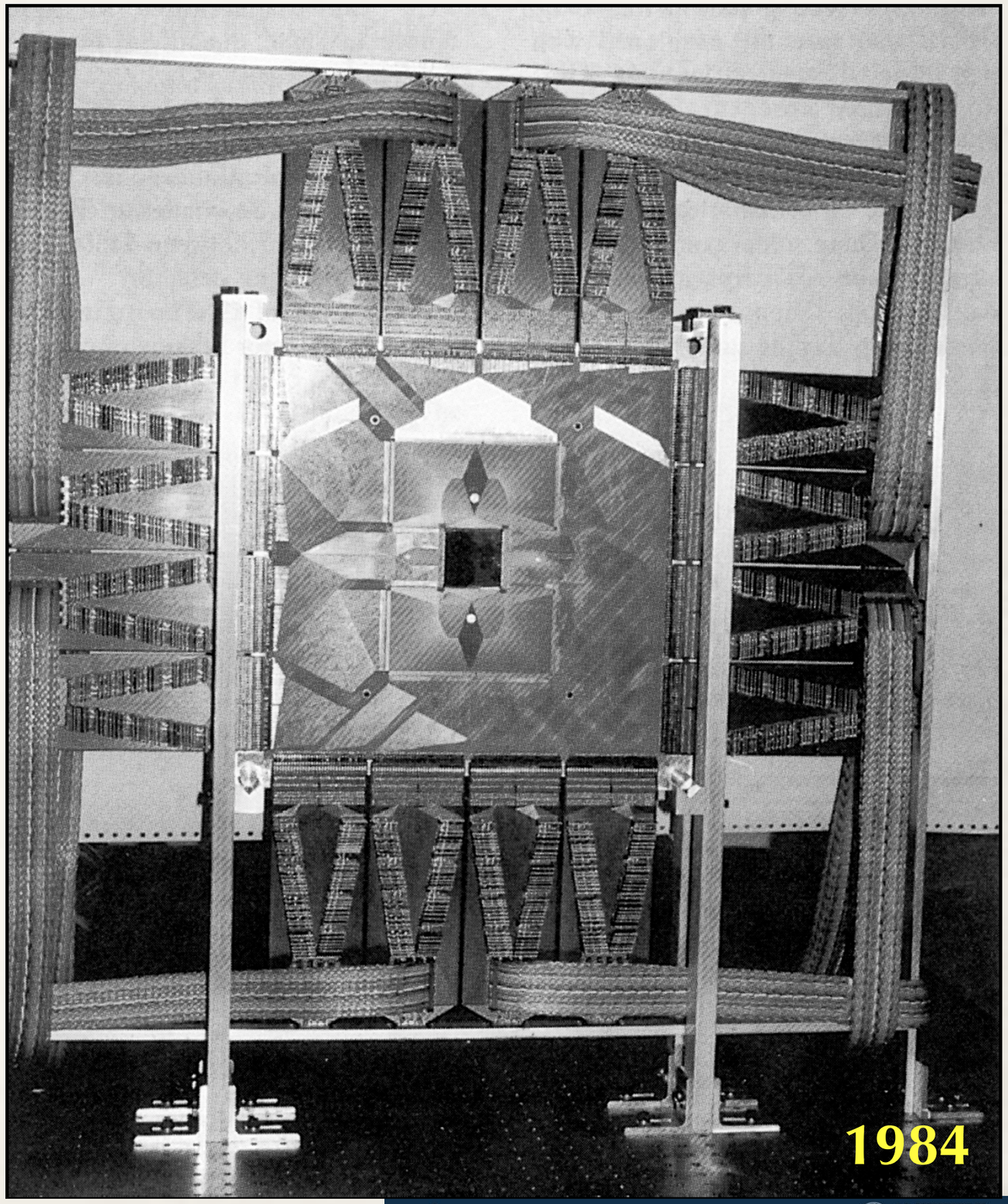
How did we get into this?



Charged particle tracking:
Measure positions
$R = p / qB$ $\delta p/p \sim \delta R/R$

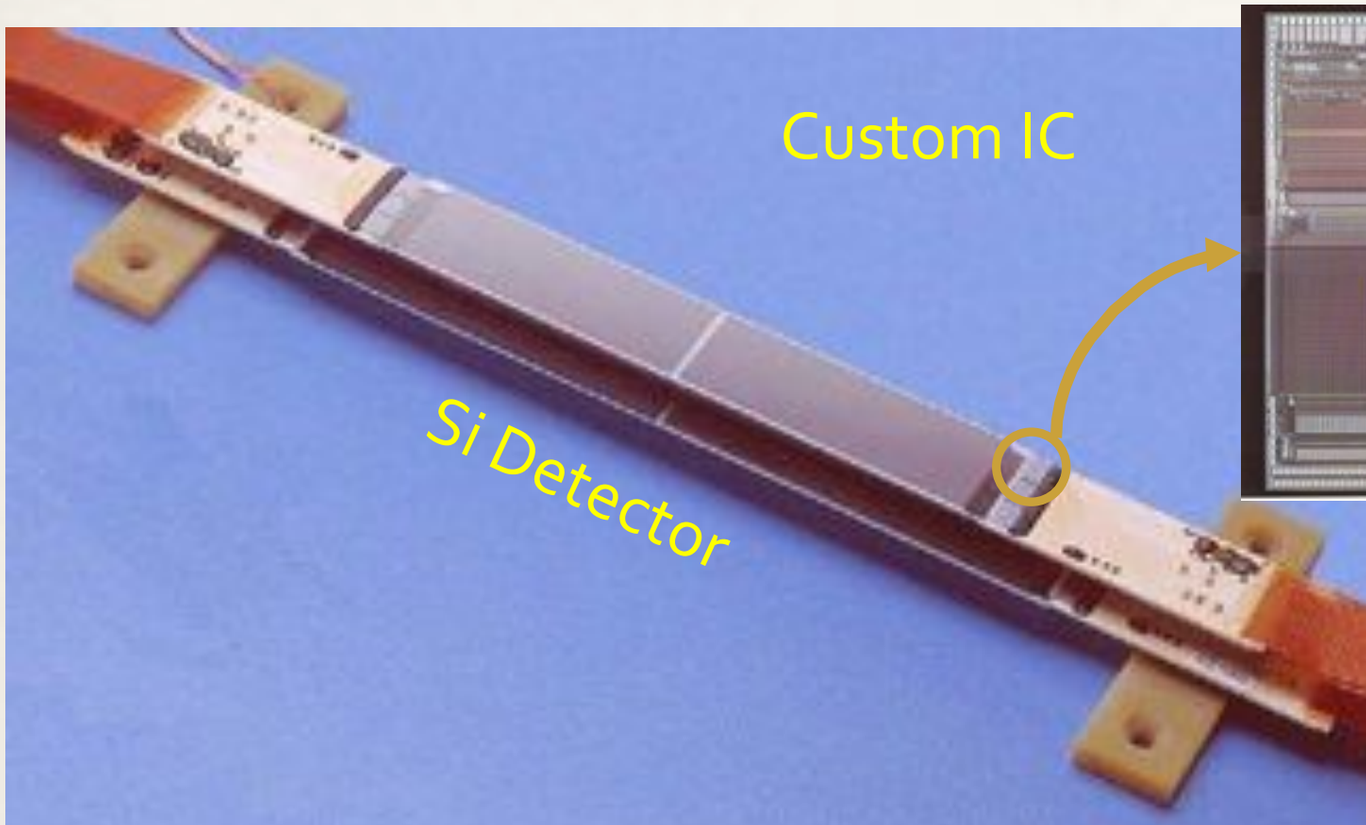
Silicon strip detector

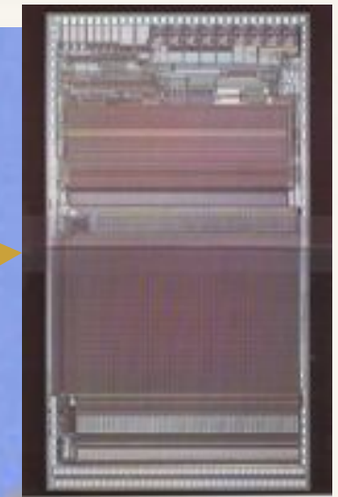




BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

CDF / DØ / BaBar ATLAS

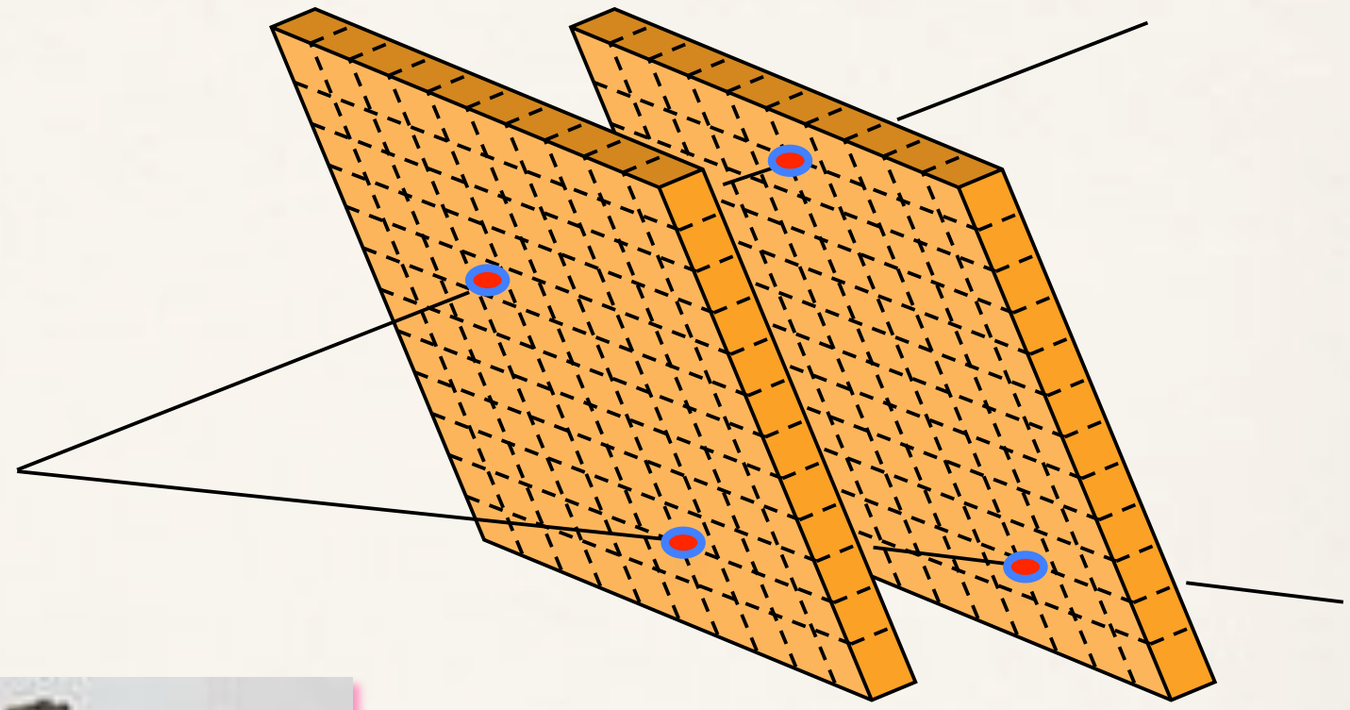




BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Pixel Detectors for Particle Physics

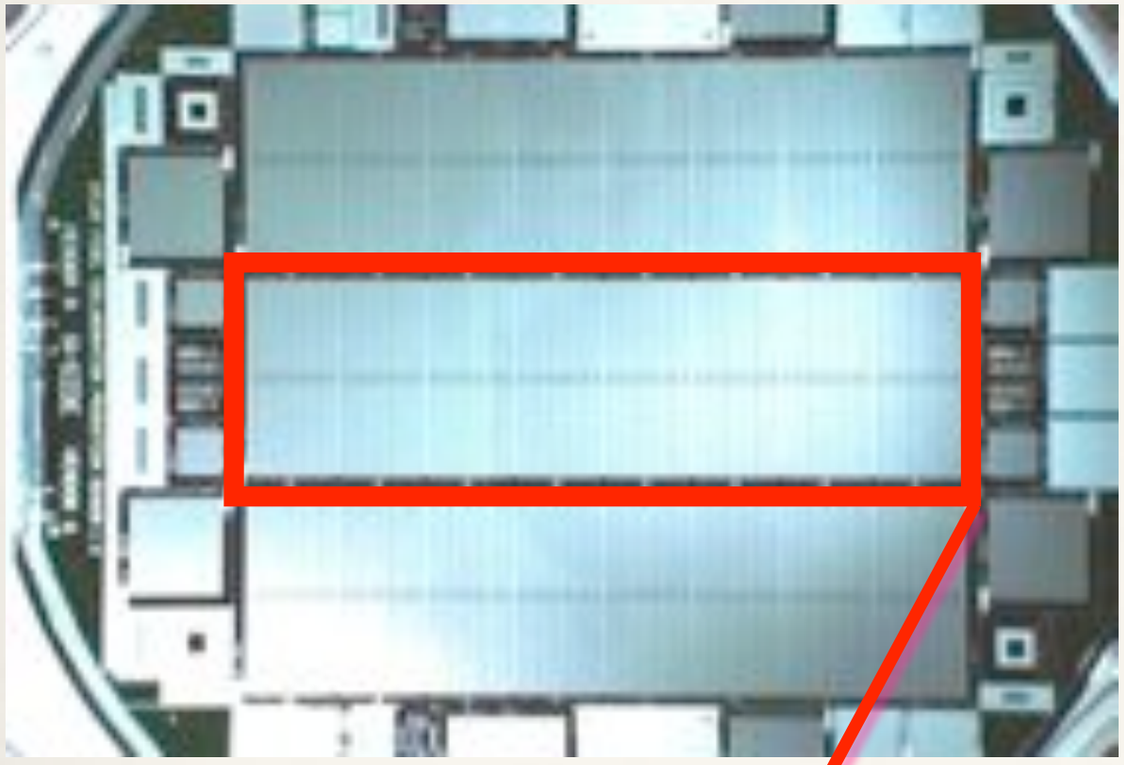
Originally CCDs
Then hybrid pixels

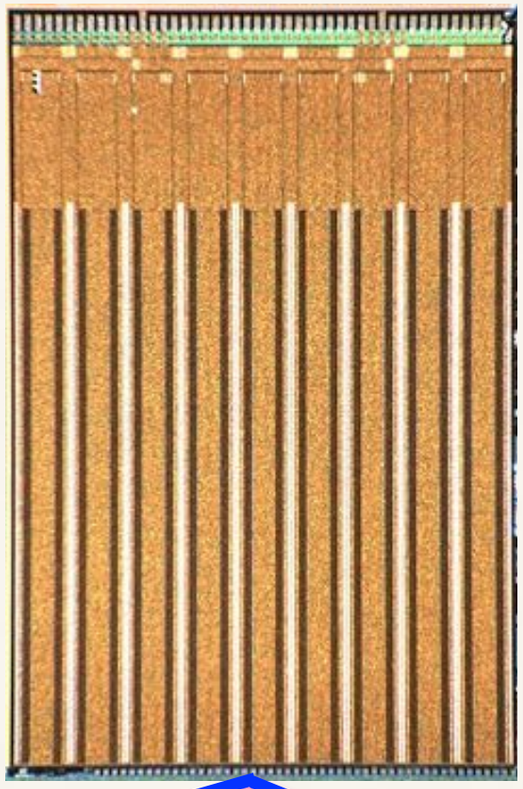


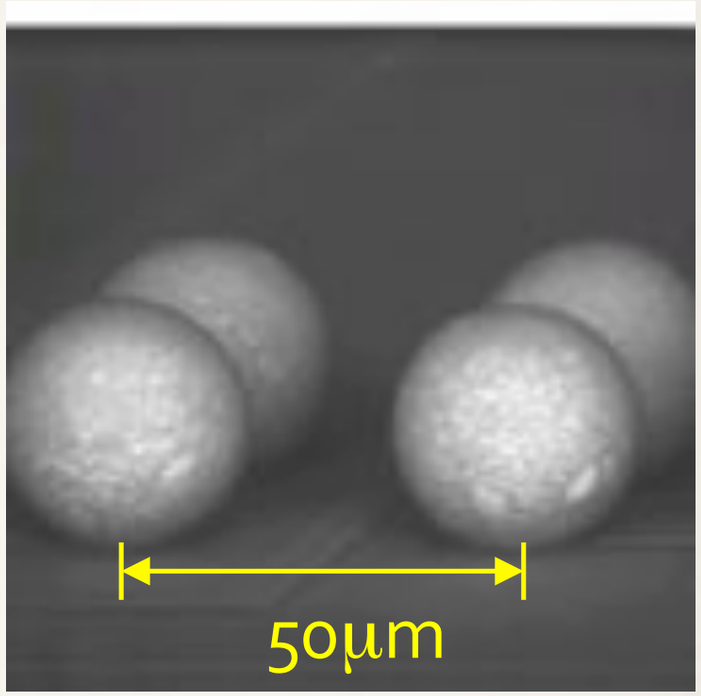
- 1996 - SLD Vertex Detector
- 3×10^8 pixels
- 96 3.2 MPix 20 μm CCD
- 120 Hz collision rate
- <1 Hz readout rate

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

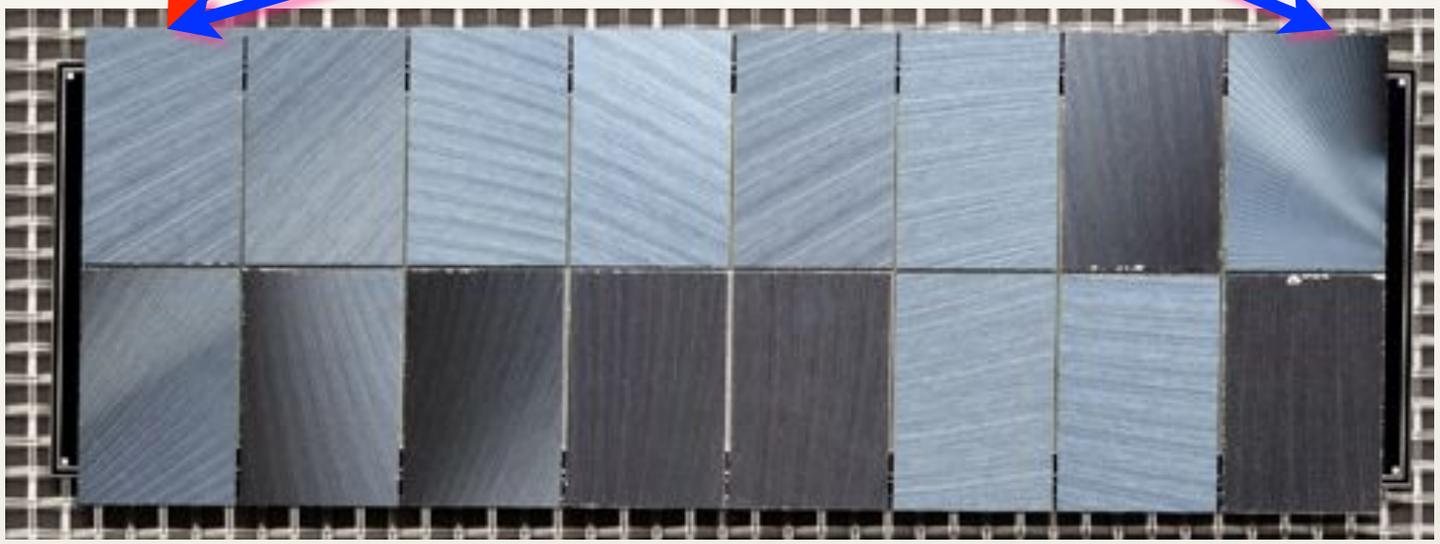
ATLAS Pixel







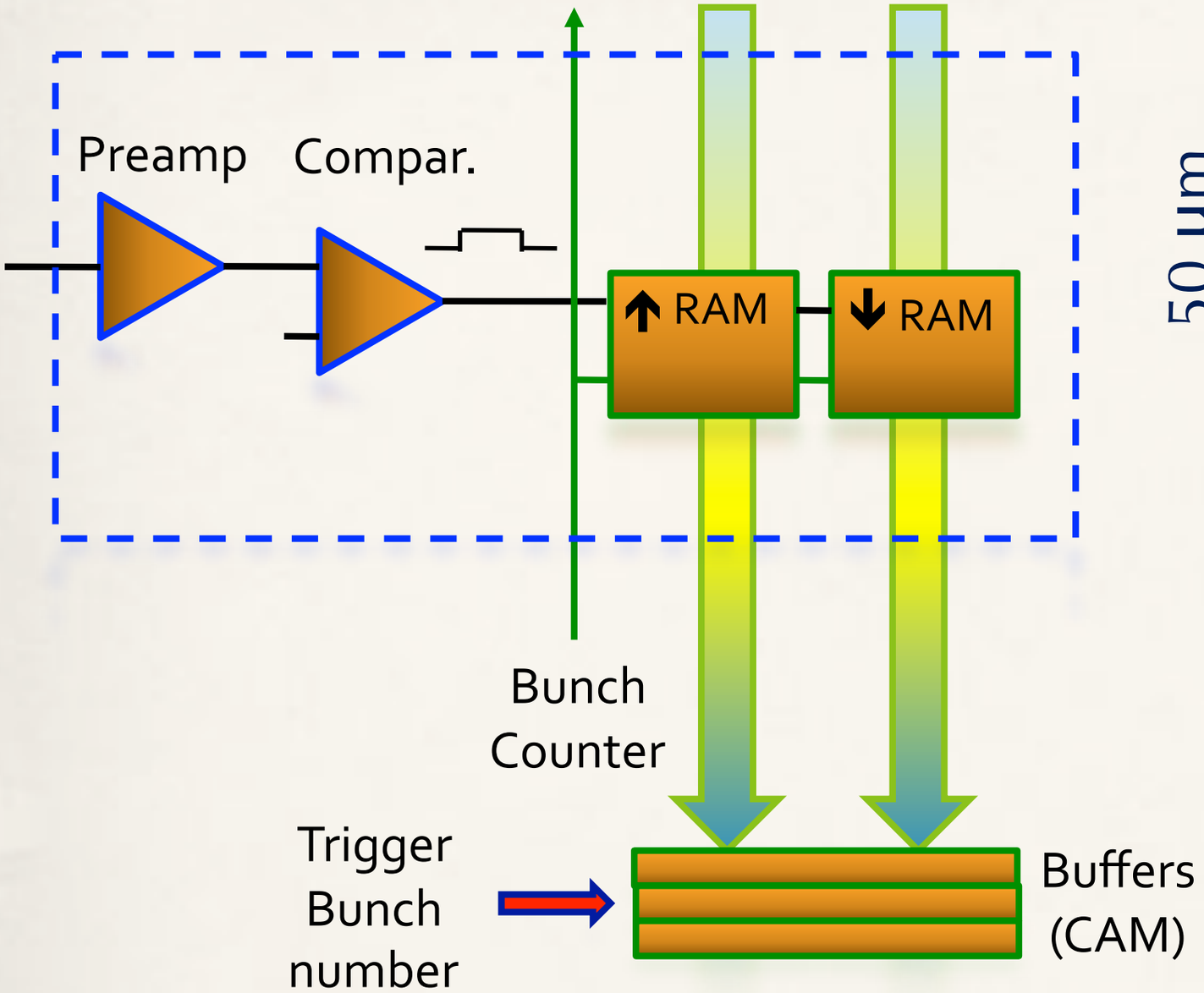
46,080 pixels
50 x 400 μm^2

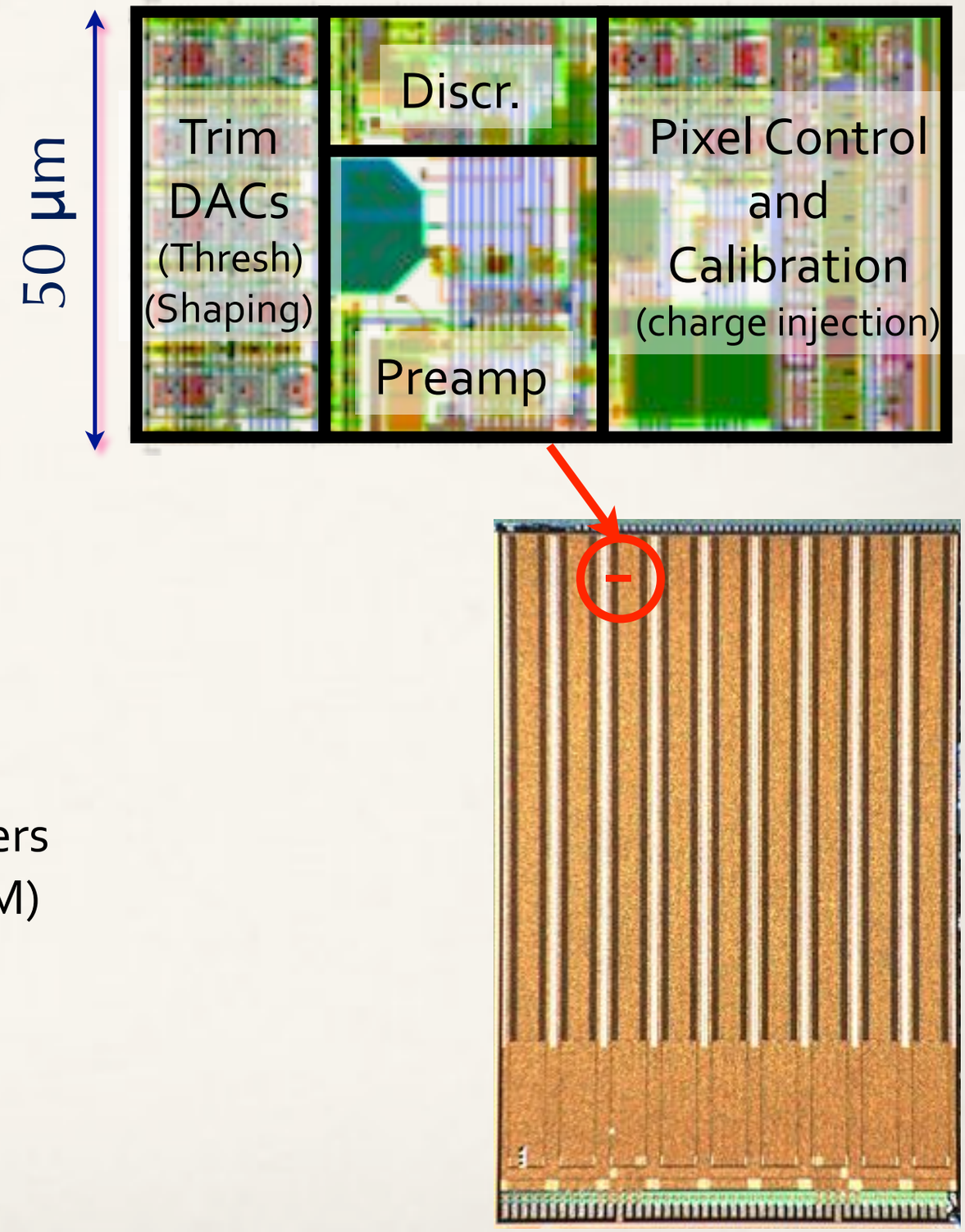


2007 ATLAS Pixel Detector

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

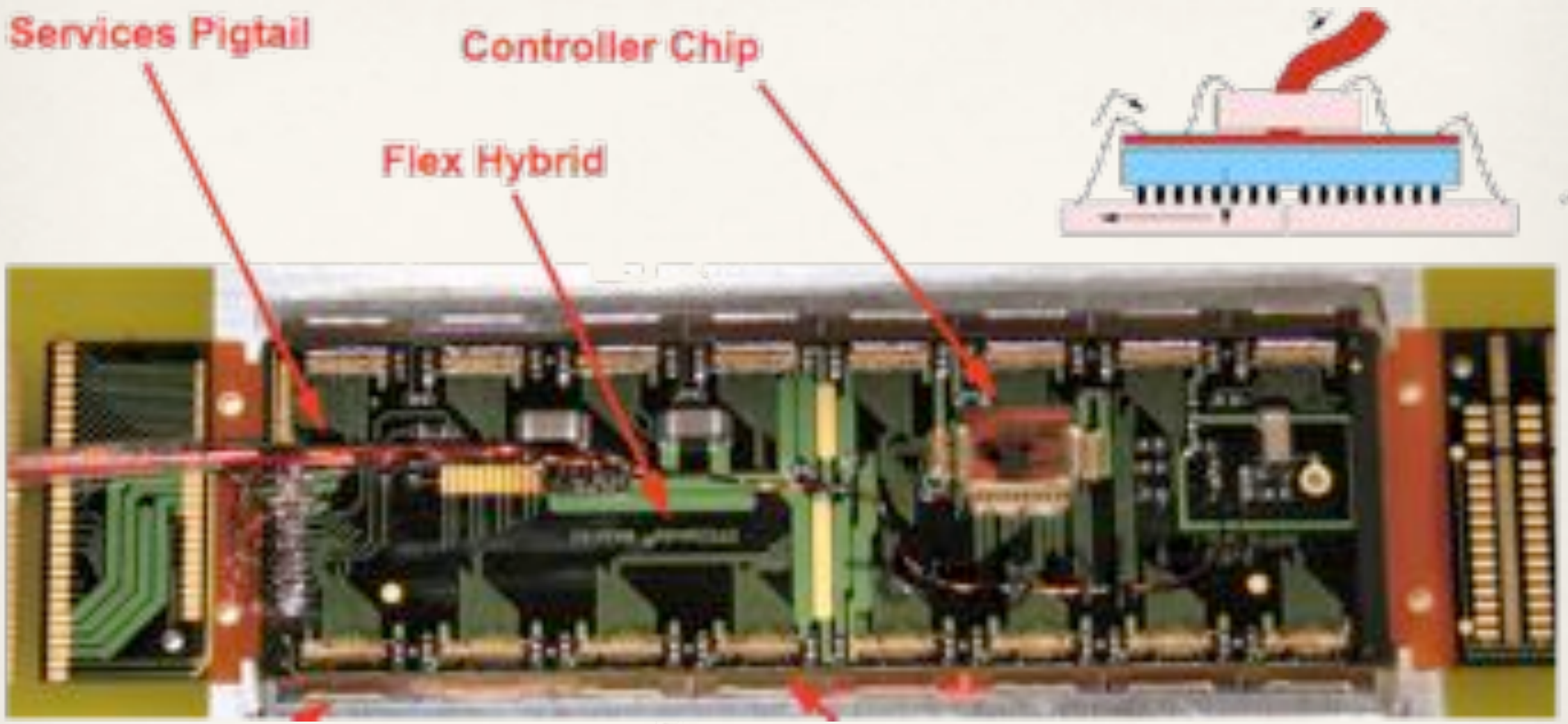
Architecture

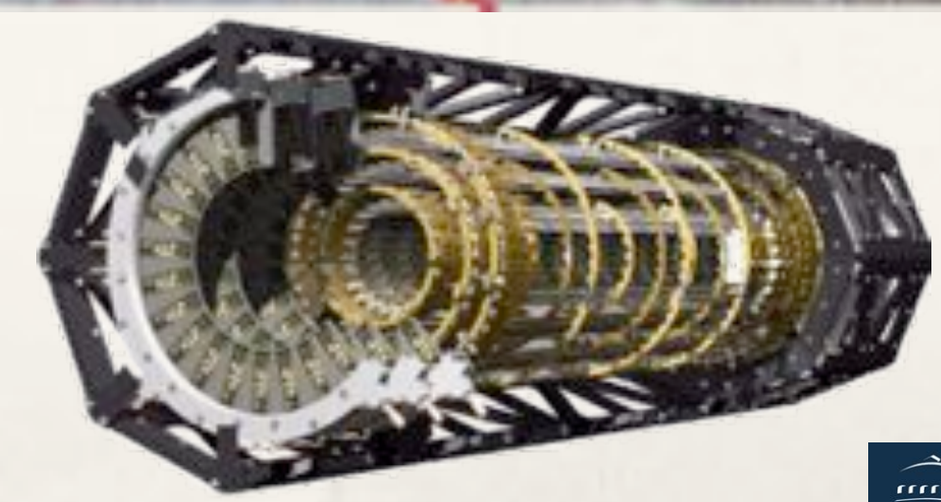




BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

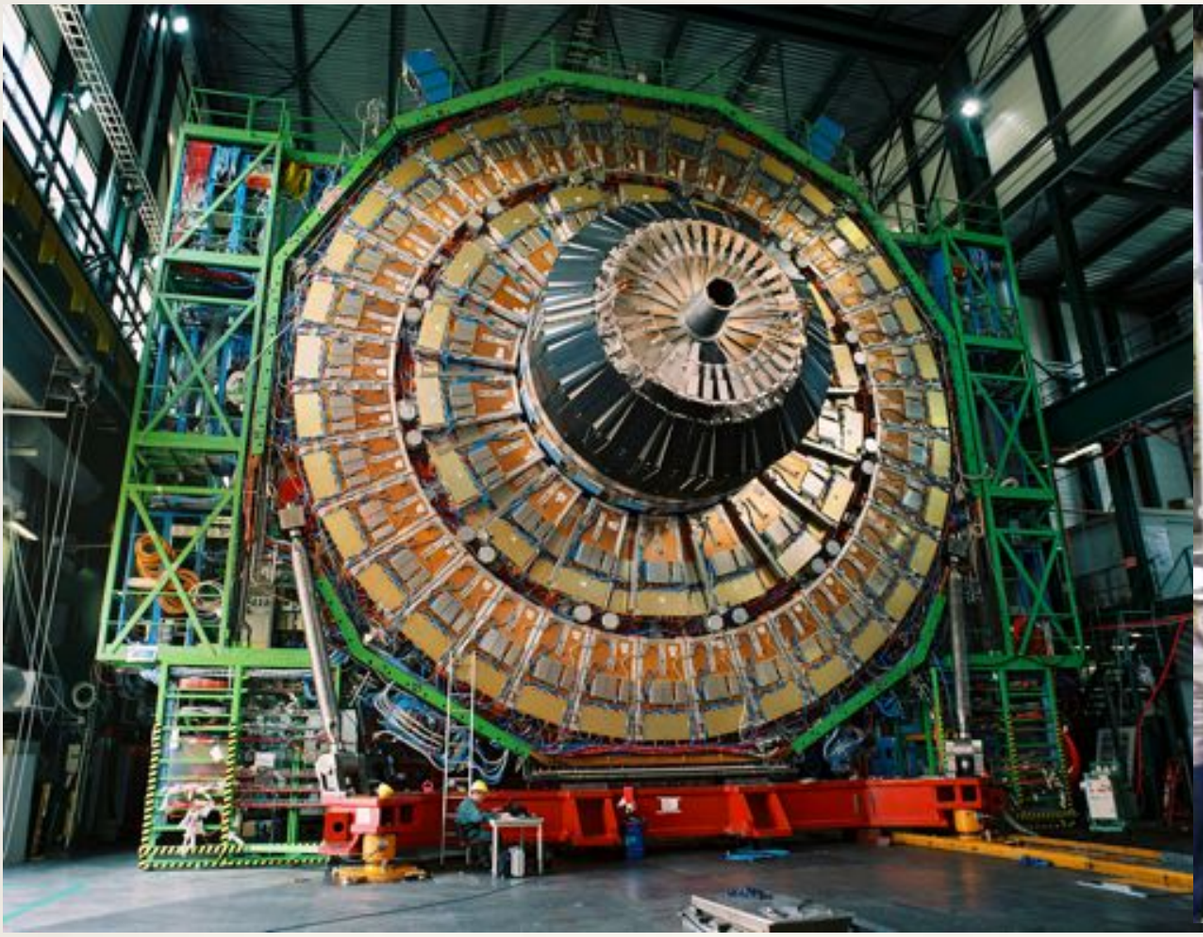
Detector



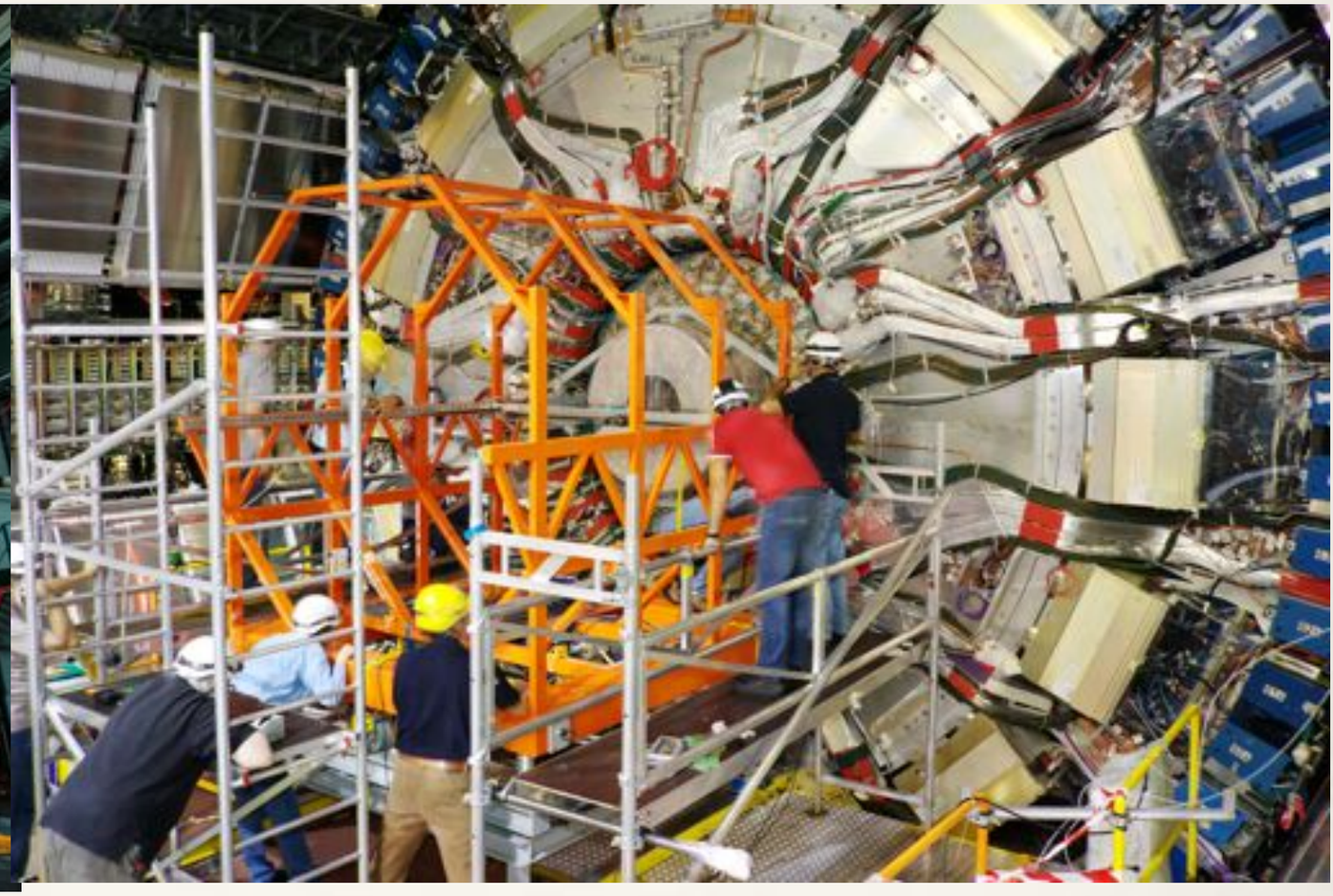


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

LHC Pixels

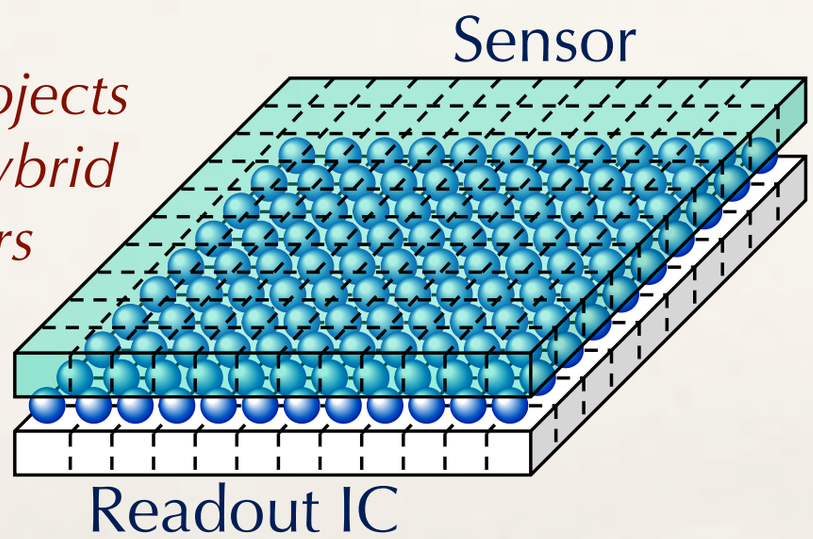


CMS



ATLAS

Two large projects to develop hybrid pixel detectors



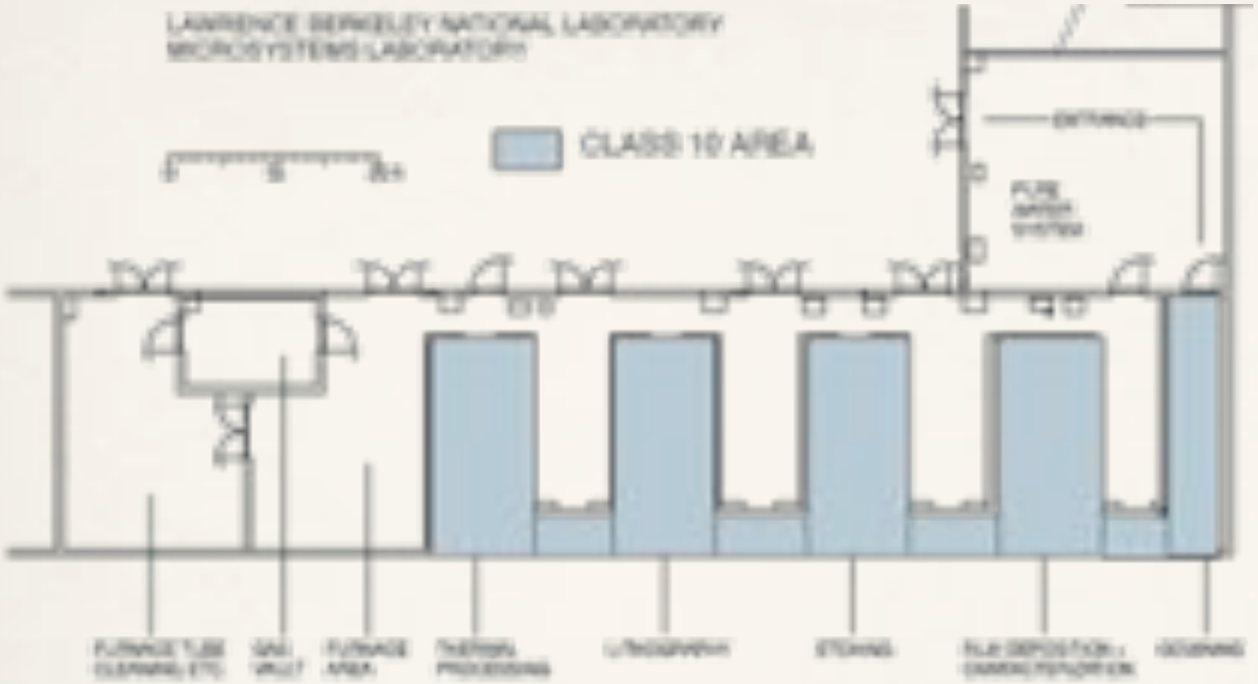
Synchrotron Spinoffs

CMS → PSI → Pilatus

ATLAS → LBNL →

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

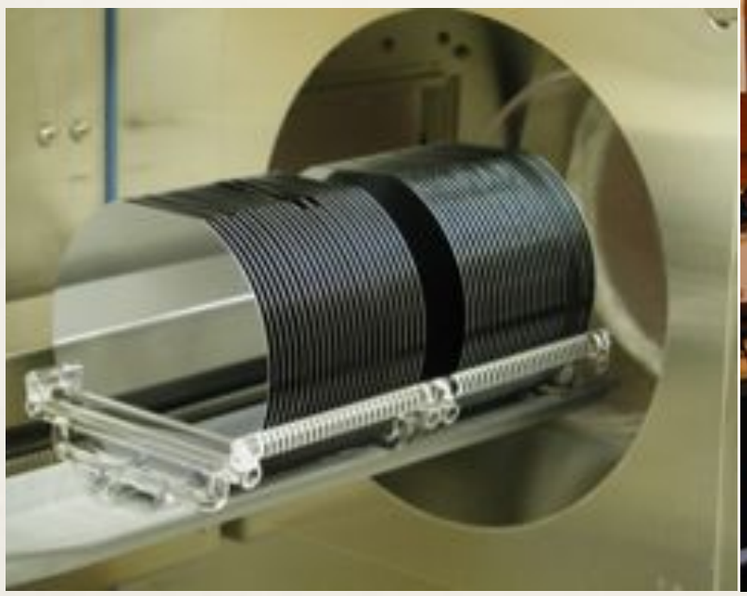
MicroSystems Lab



Bring silicon valley expertise to silicon strips

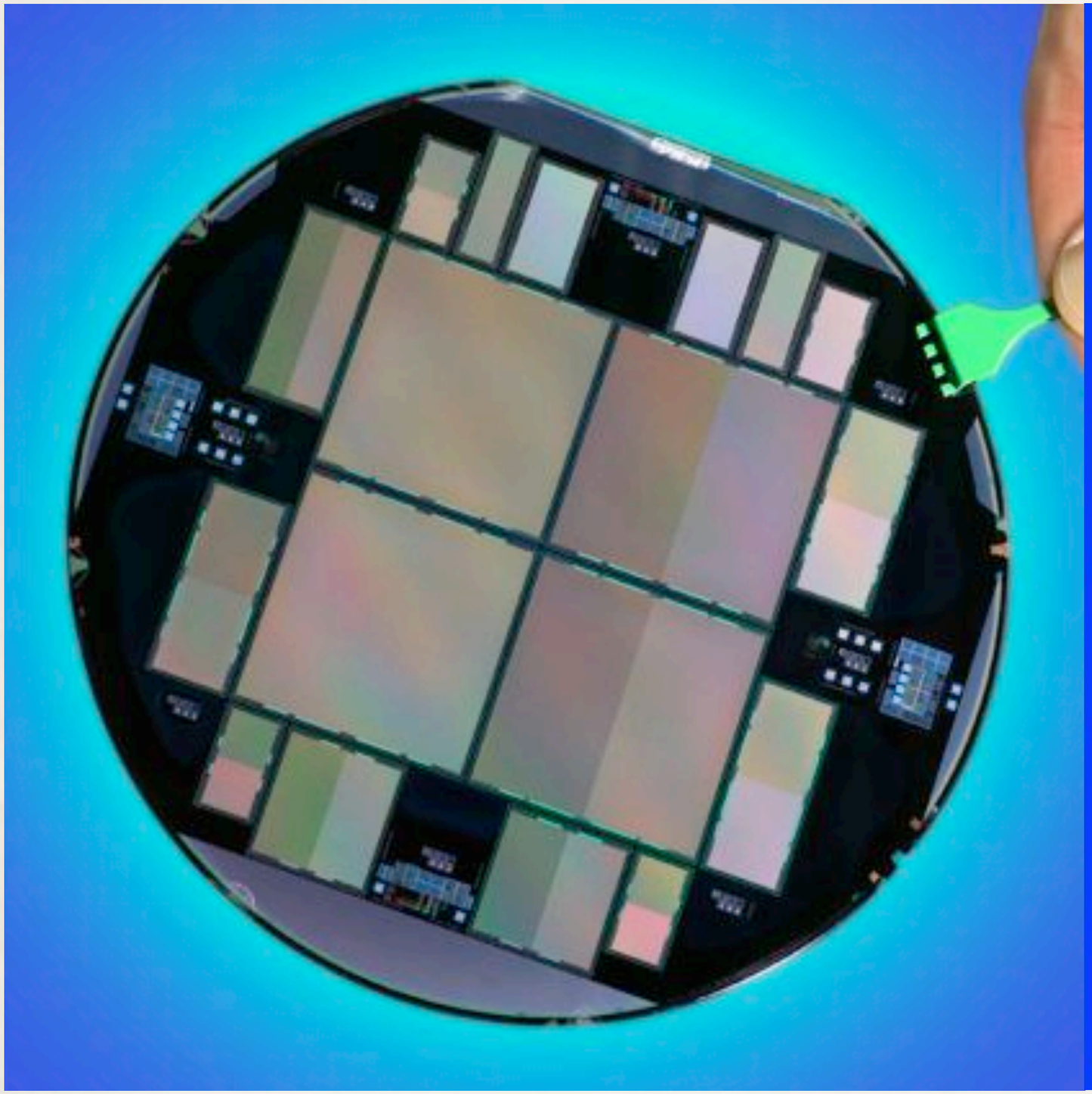
Class 10 cleanroom

- completed 1989



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

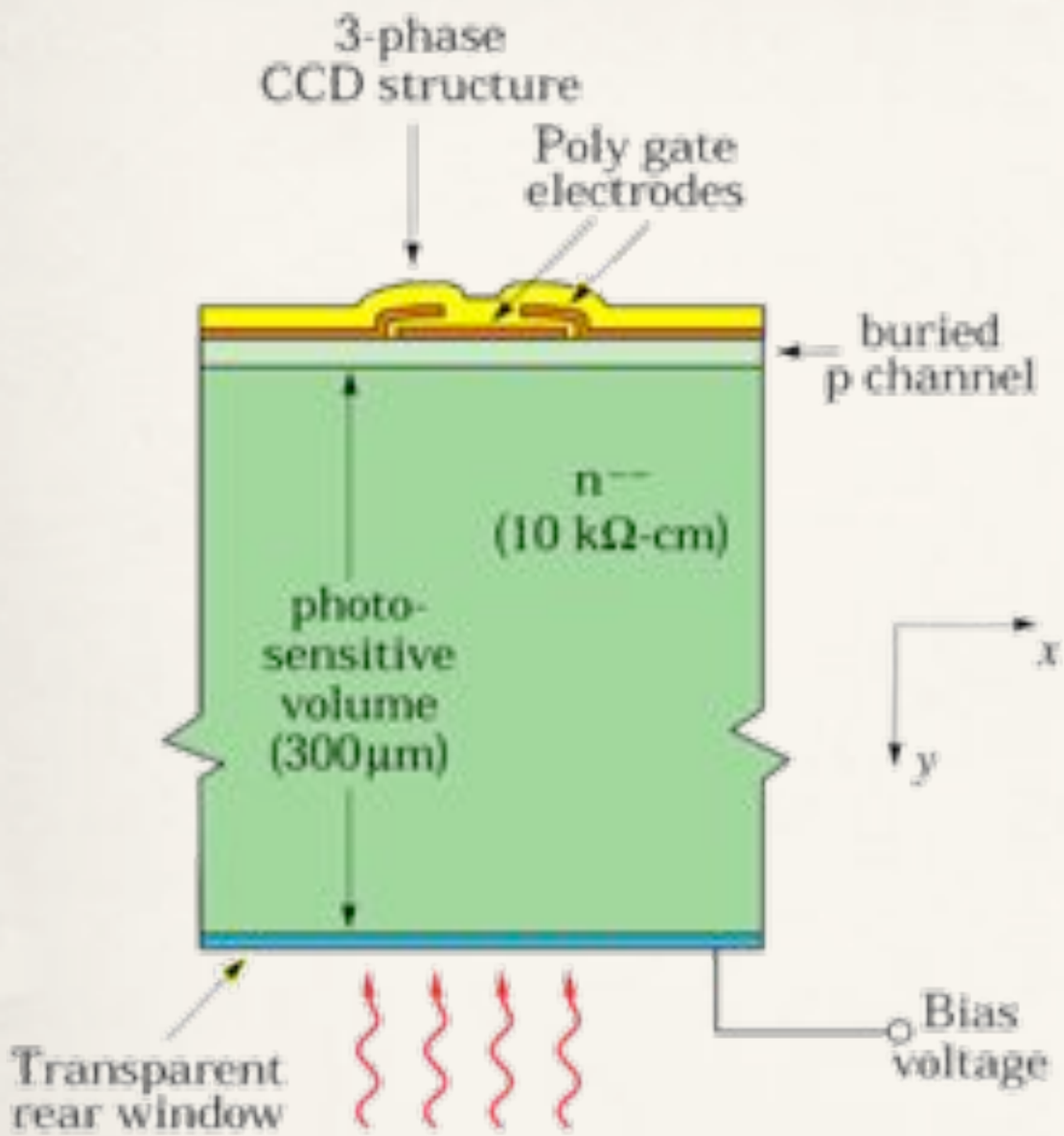
LBNL CCD

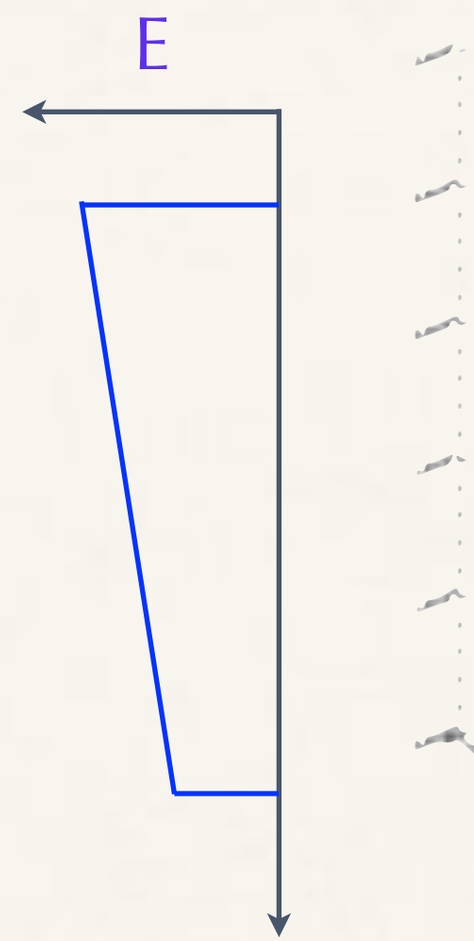


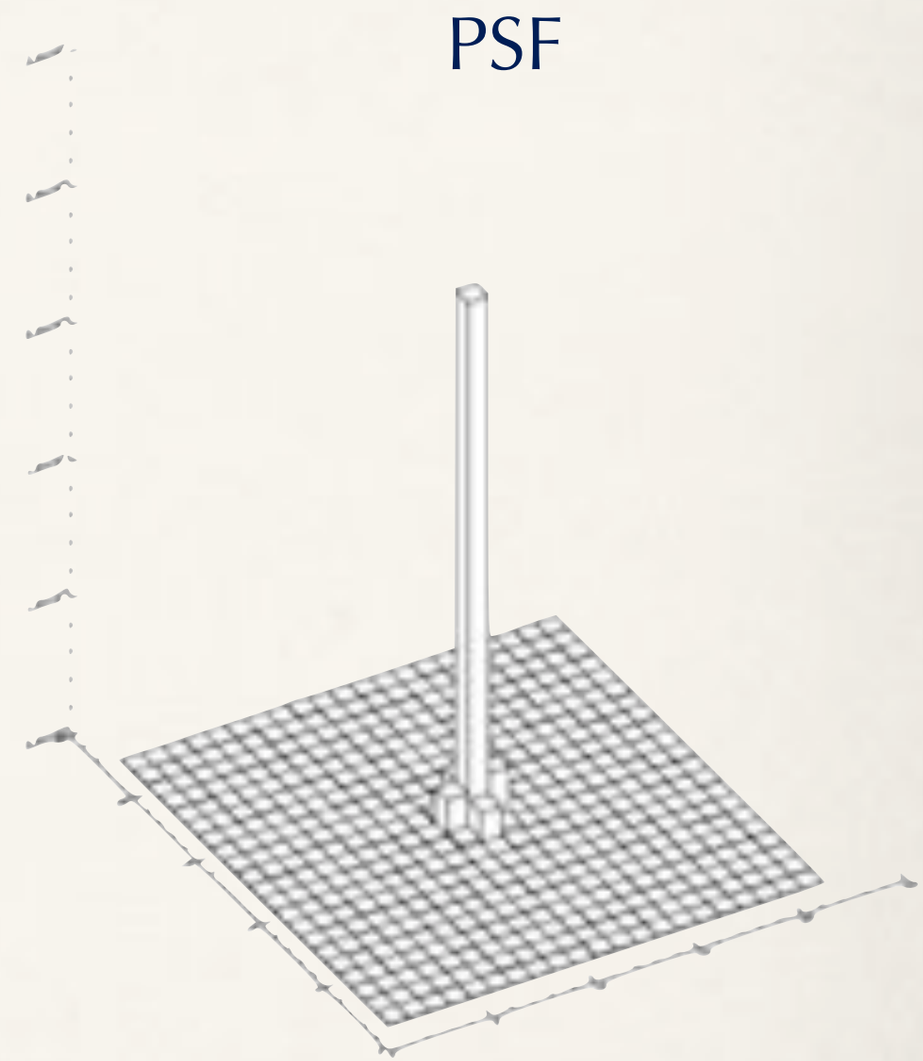
LBNL 2k x 4k CCD:
Blue: H- at 656 nm Green: SIII at 955 nm Red: 1.02 μm

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Thick, Fully Depleted CCD





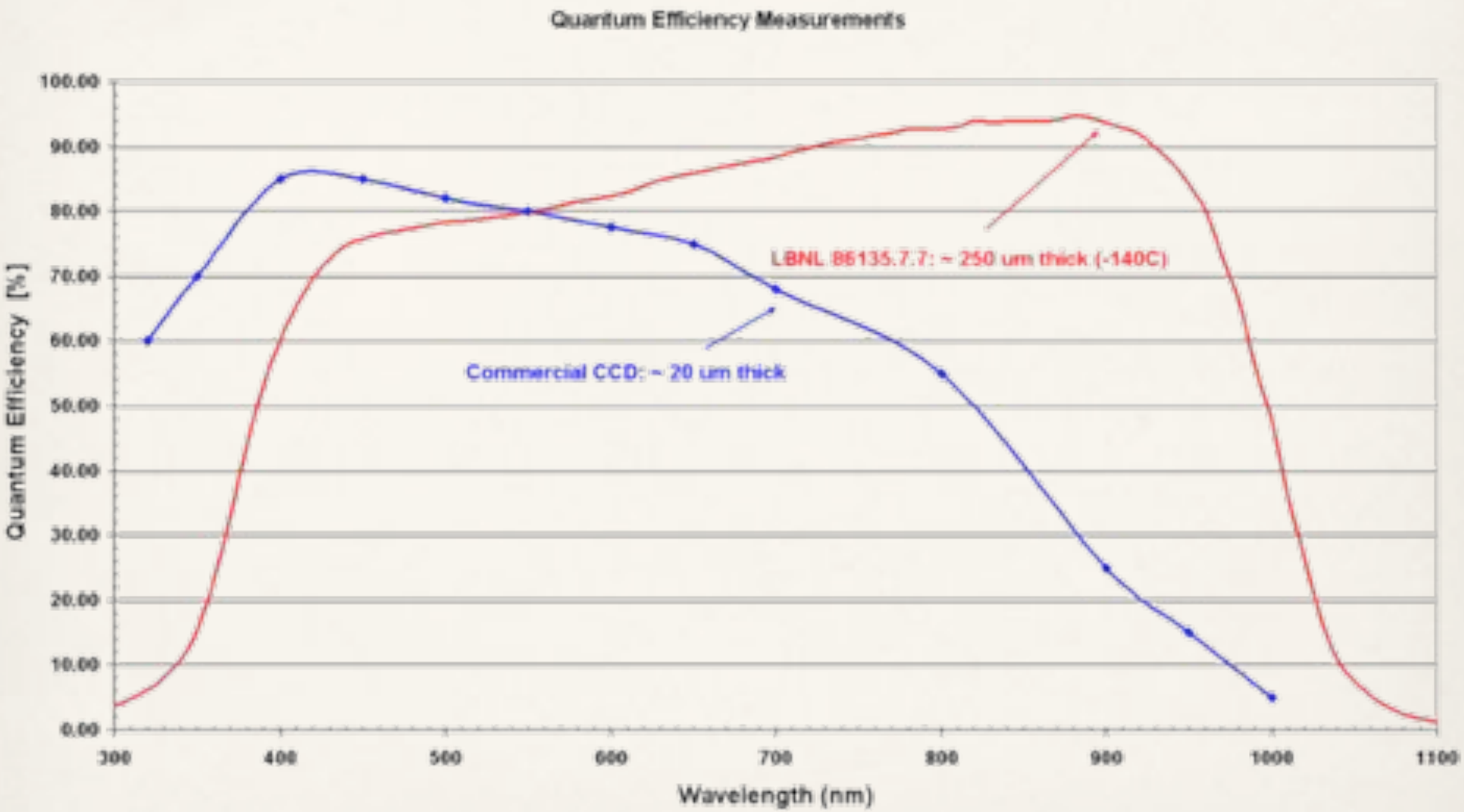


At V_{SUB} = 115 V,
$\sigma_D = 3.7 \pm 0.2$ μm

S. Holland

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Thick, Fully Depleted CCD



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Improve Blue Sensitivity

Delta doping High purity P-channel Arrays:R&D

JPL
California Institute of Technology

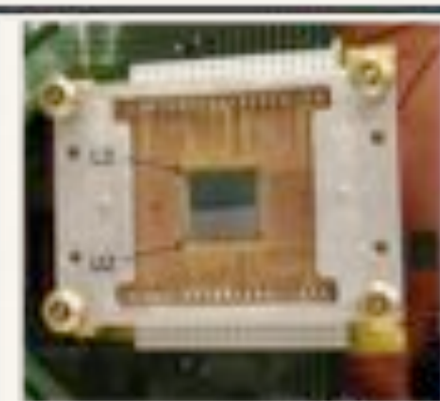
N-type delta doping process for high purity substrates was developed

Process extended to devices and optimized on 1k x 1k p-channel CCDs

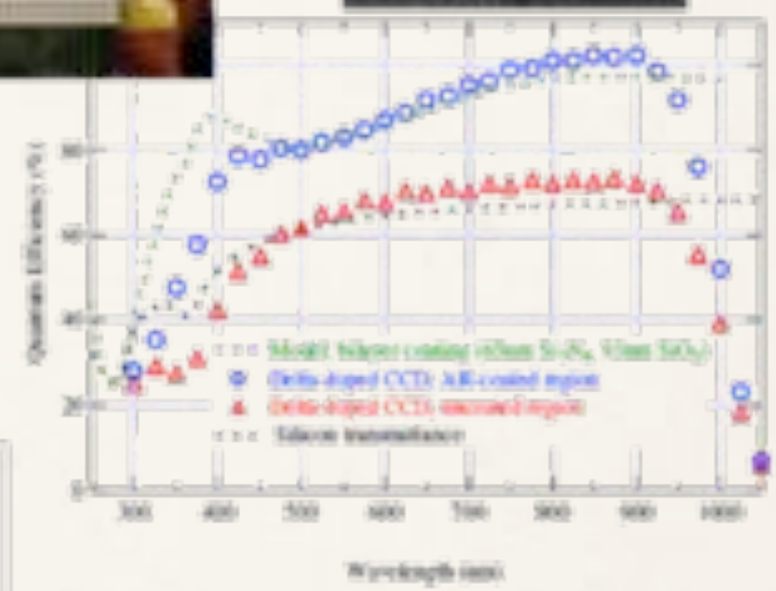
Delta doped large format p-channel CCDs

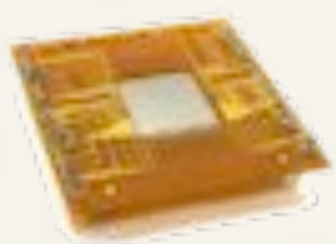
AR coating developed in house

Excellent QE, dark current, CTE, and uniformity observed

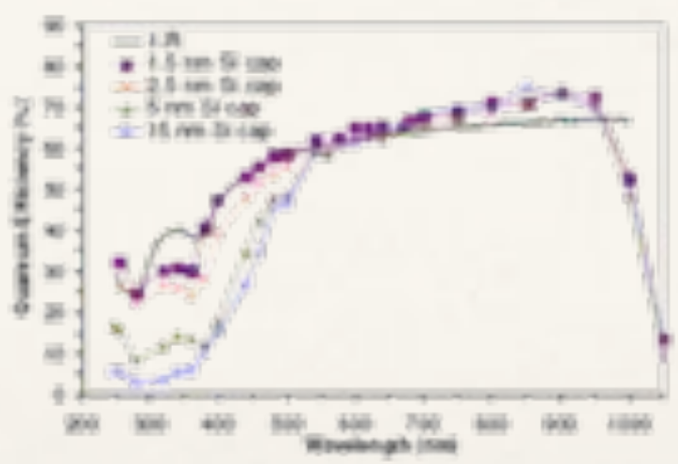


In house AR coating





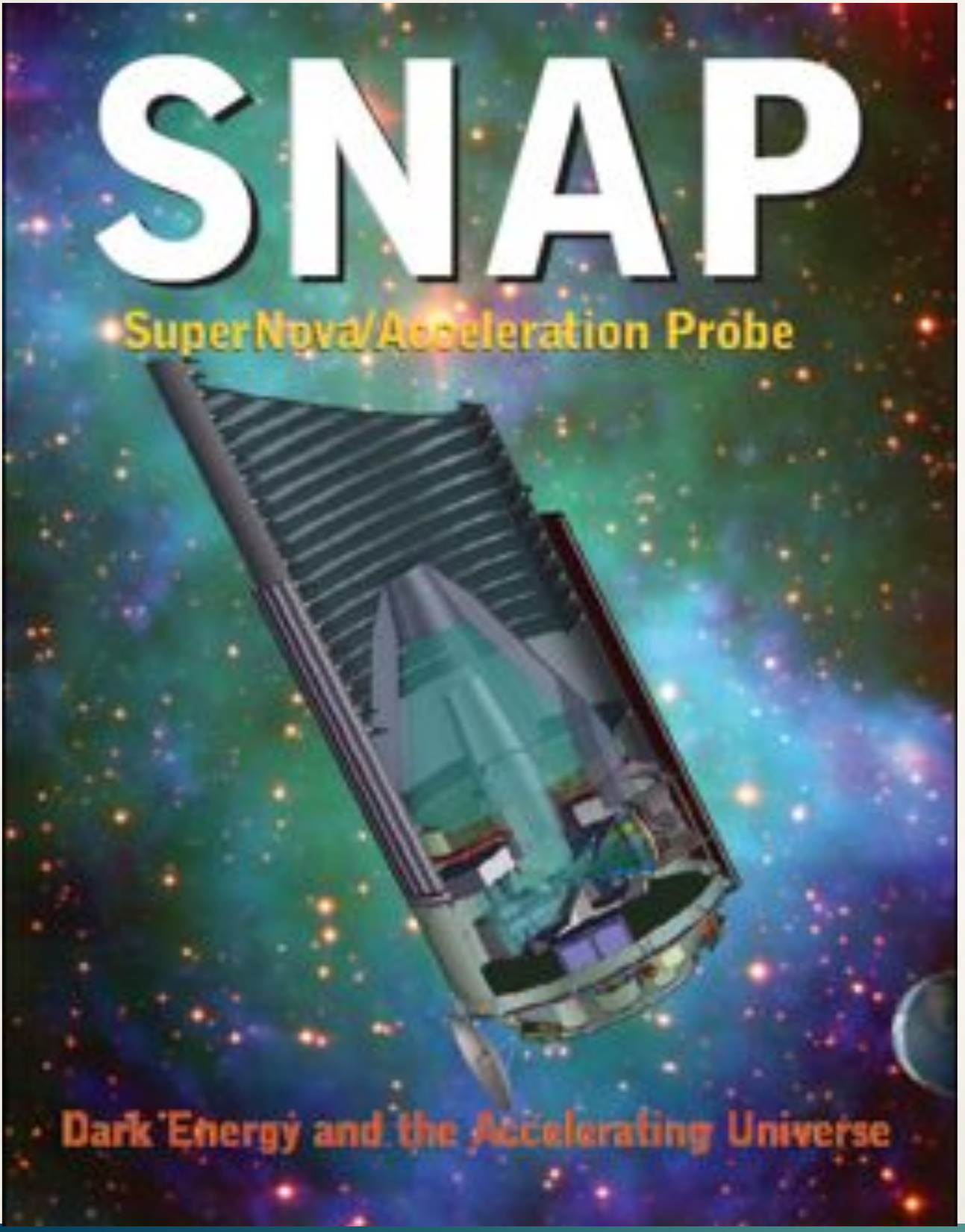
Delta-doped p-channel CCD, LBNL 1k x 1k

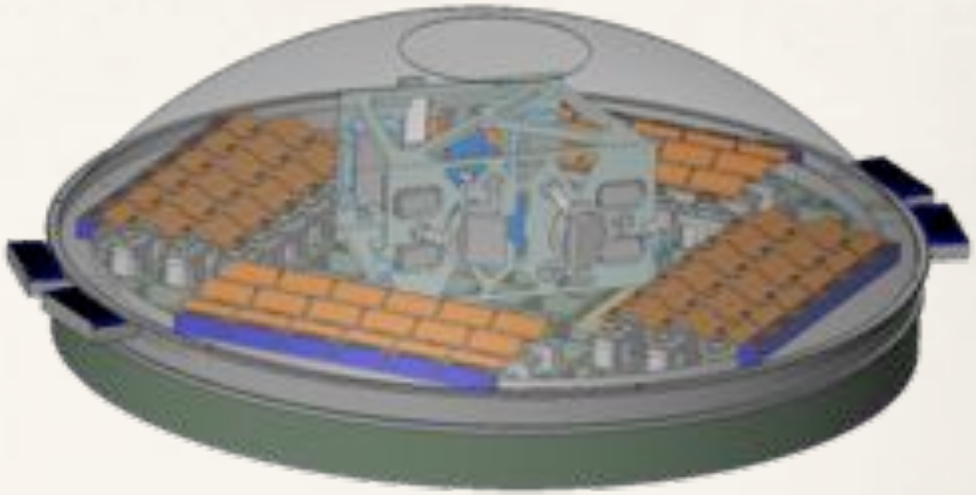


2K x 4K Array in the MBE

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

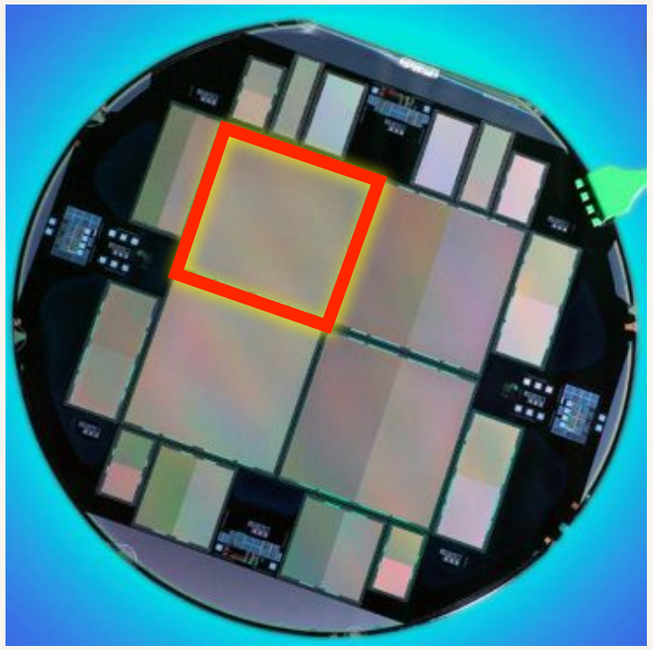
The West is Red

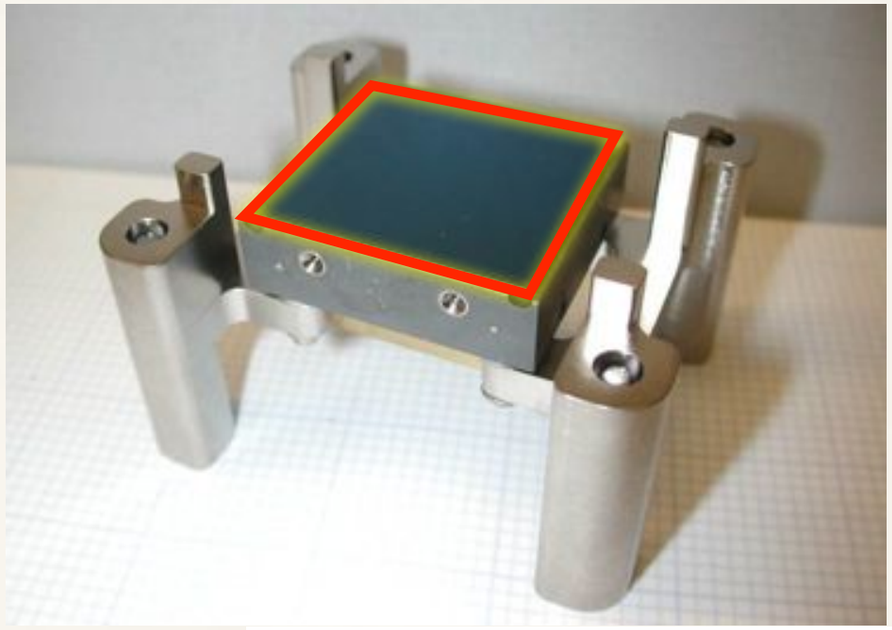




BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

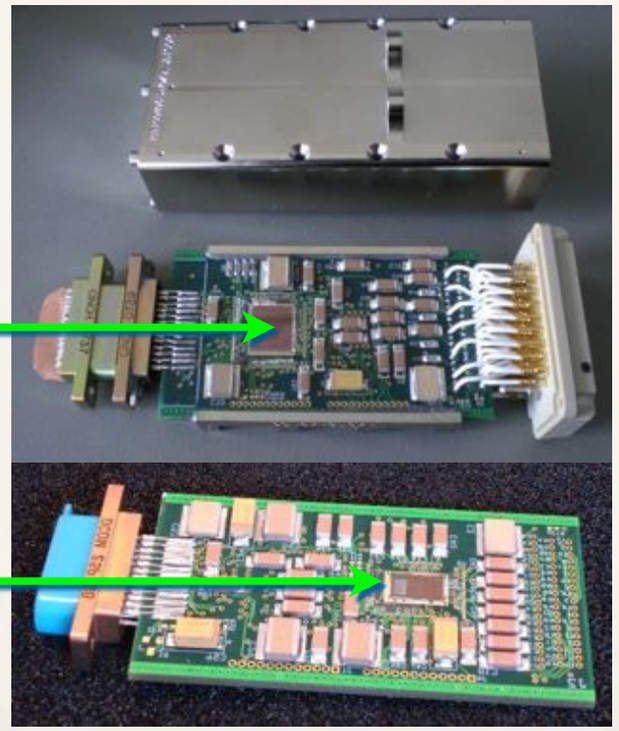
SNAP

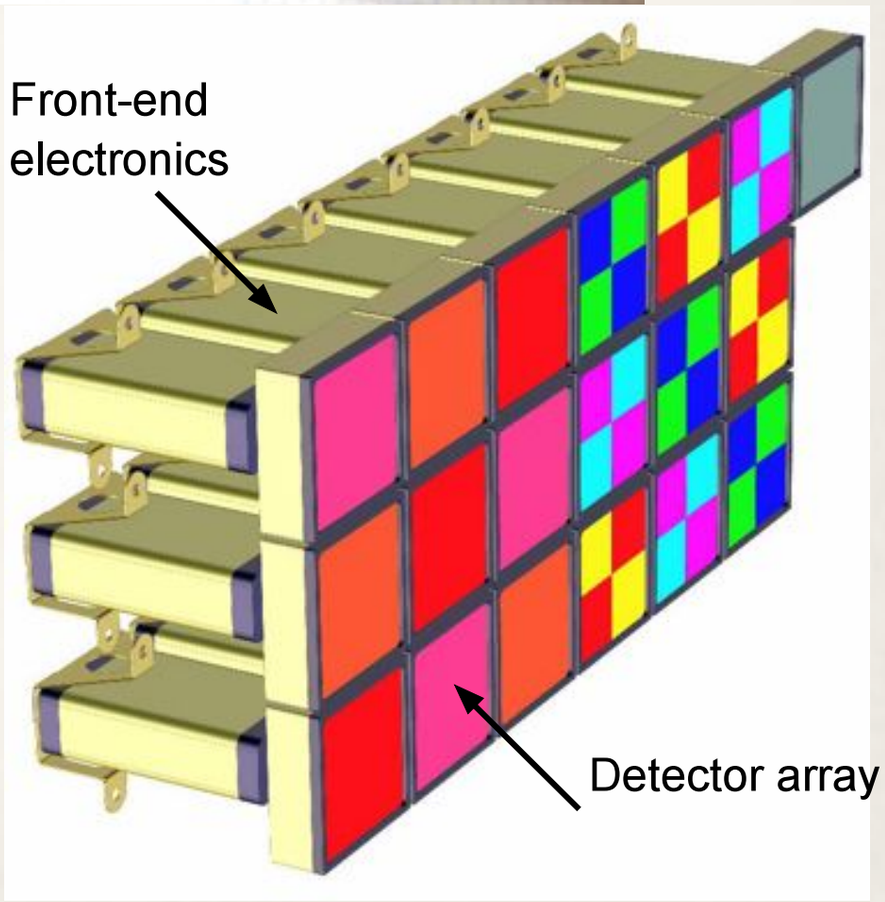




CLIC

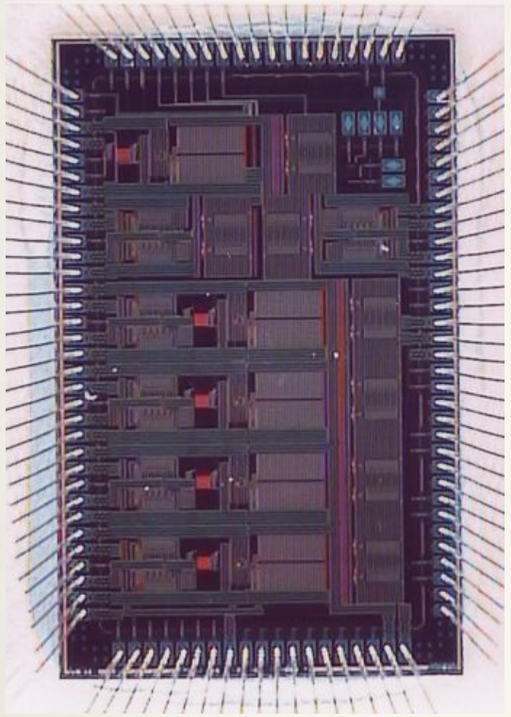
CRIC



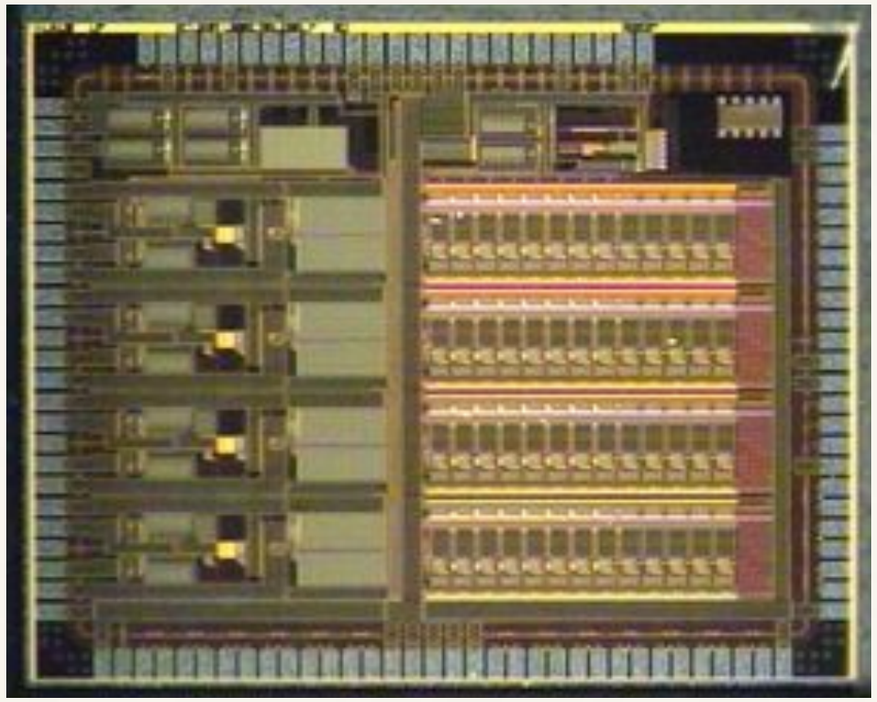


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

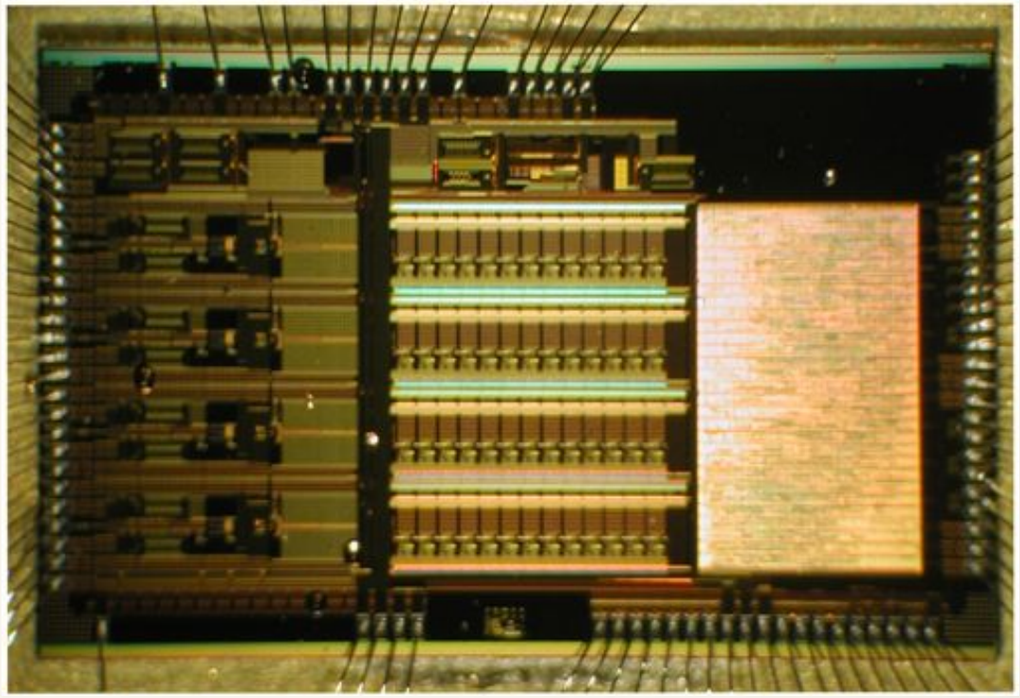
SNAP Readout



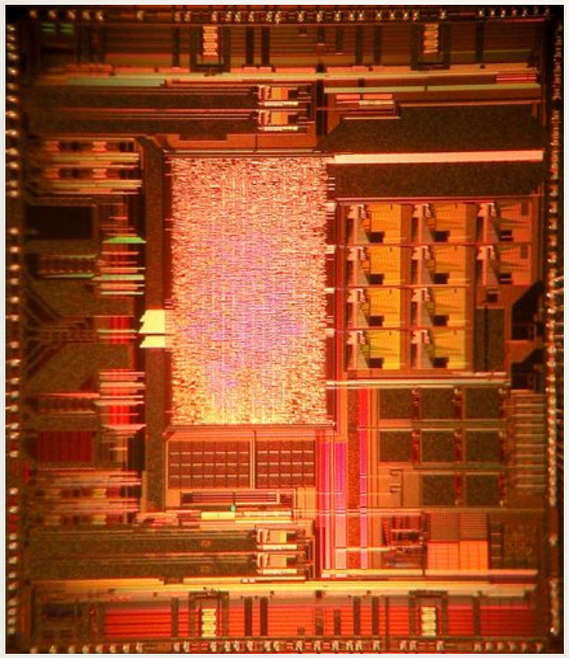
CRIC 1
Floating-point FE



CRIC 2
⊕ Pipelined ADC



CRIC 3
⊕ Digital Calibration / Control



CLIC
HV DI CMOS
Programmable voltages
Programmable clock patterns

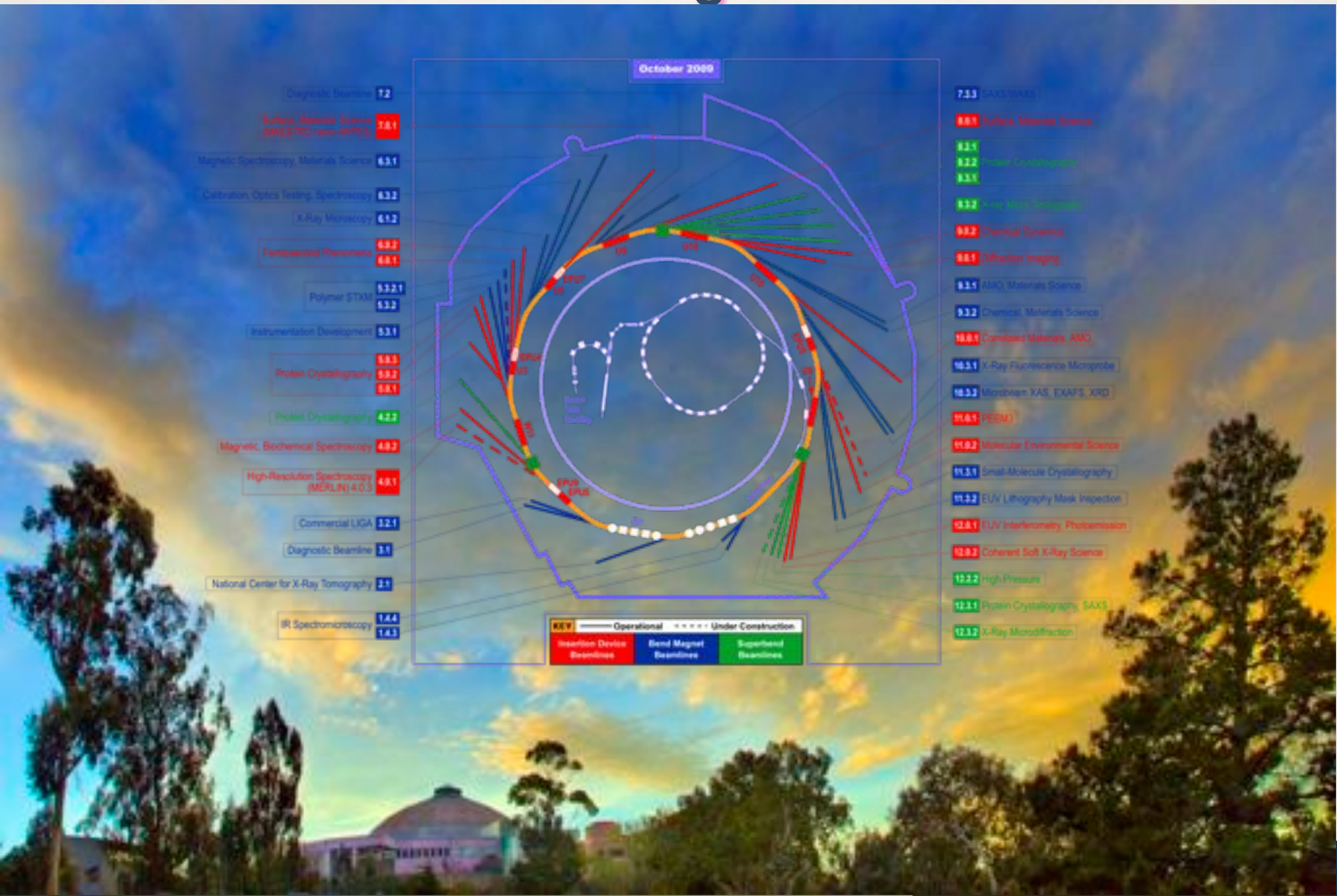
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

"Detectors" at Berkeley Lab

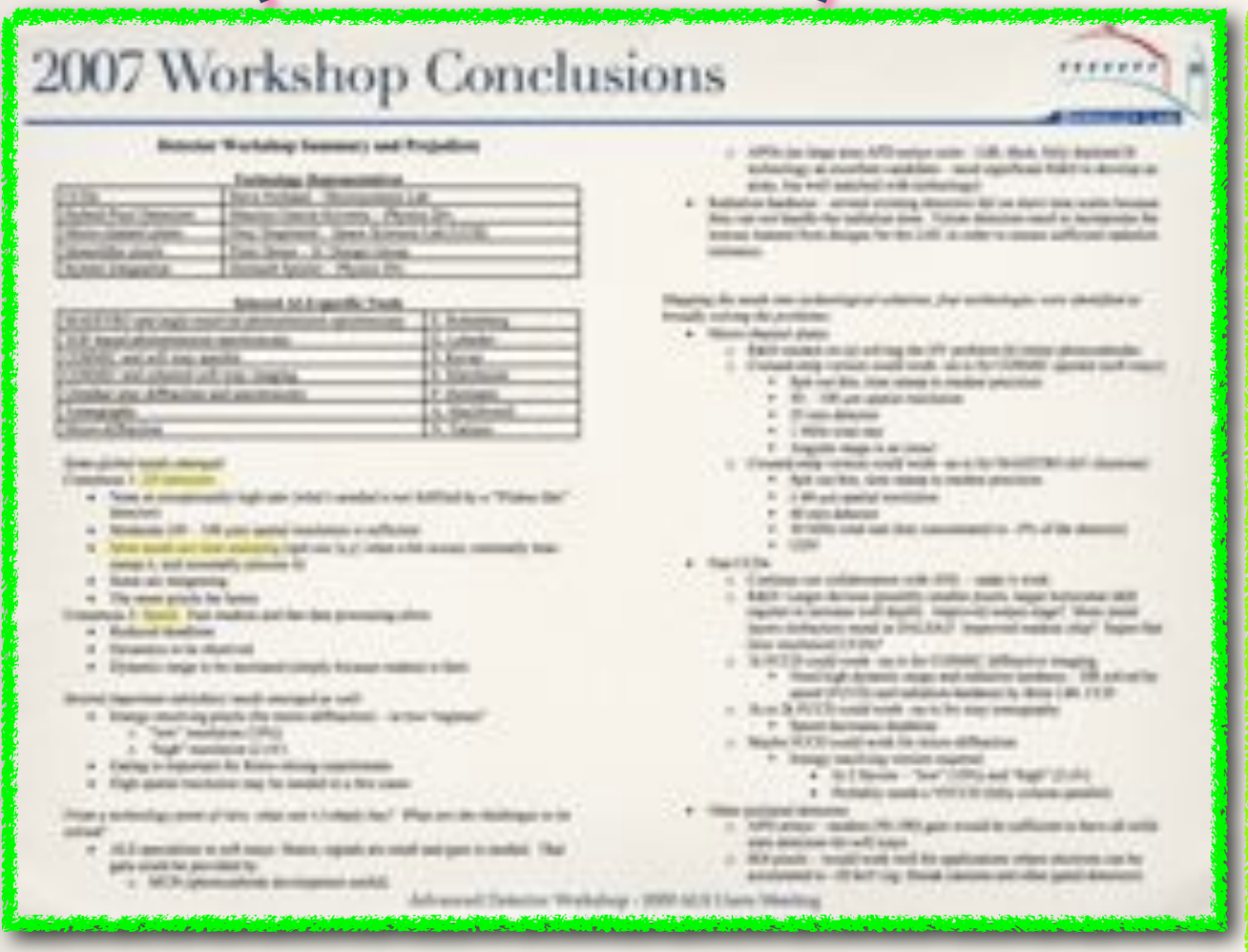
Enabled by	Microelectronics	Materials	Systems
Examples	CCDs Strip detectors Pixel detectors	Scintillators Other semiconductors (Ge, CZT, ...)	TPCs Large Č detectors Optical detectors
Development Facilities	MicroSystems Lab IC group	Int. Systems Lab Ctr. for Func. Imaging	Elec. Sys. Group Machine Shop
Initial Uses	HEP (tracking) Various (astro)	NP (γ spectroscopy) BER/NIH (PET)	HEP, NP, BES (accel. diag.)
Emerging Uses	BES (x-ray, e-) Biology "DHS"	Other medical "DHS"	"DHS"

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Advanced Light Source



(Un-fulfilled) Detector Needs at the ALS



Consensus:

- fast, 2D detectors
- moderate size/number of pixels in most cases
- Majority soft x-ray
  - some hard x-ray
  - some low energy electrons

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

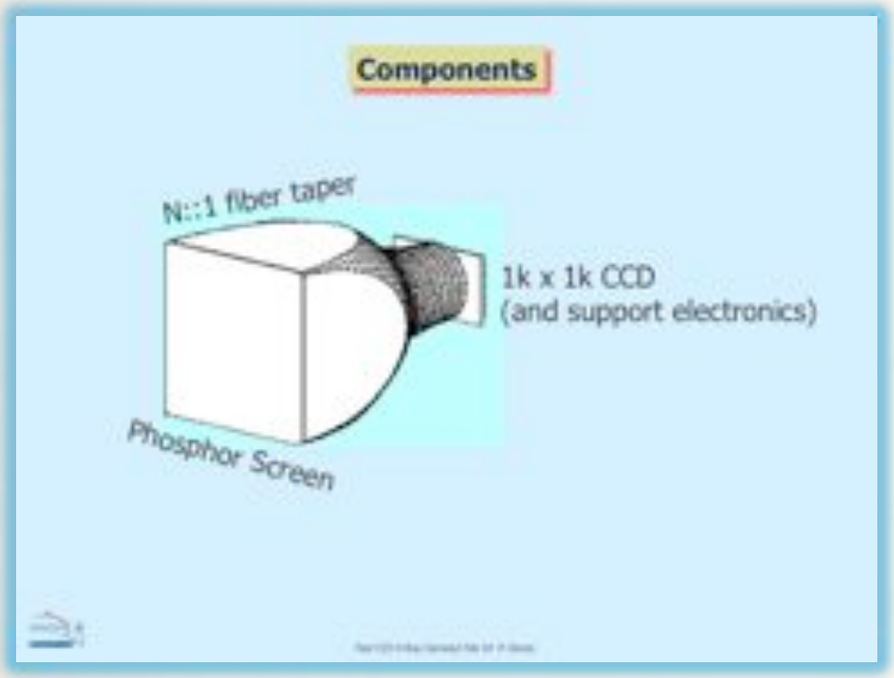
Needs at the ALS:

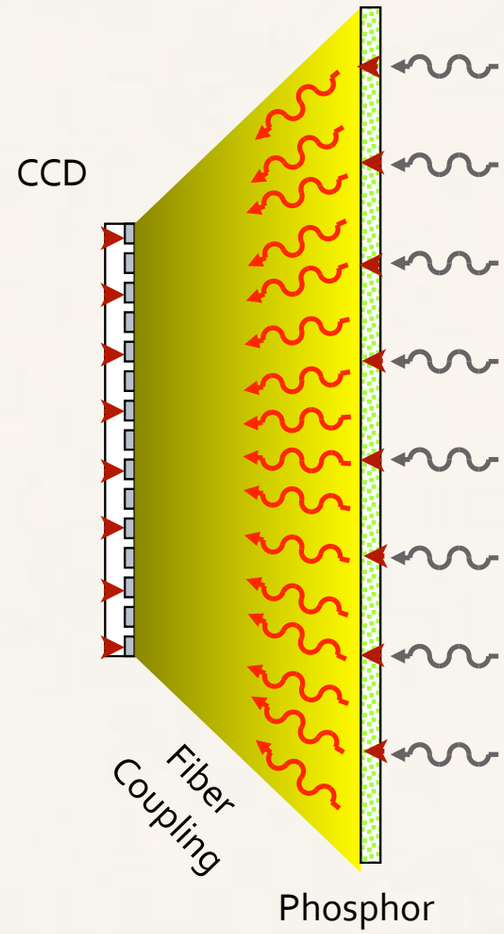
T. Tyliszczak	STXM
M. Marcus	micro-XAS
P. Heimann	ultrafast
S. Marchesini	CXDI
N. Tamura	micro-diffraction
A. MacDowell	tomography
A. Scholl	PEEM
Y-D Chuang	x-ray fluorescence and scattering
A. Bostwick	photoemission
S. Clark	high pressure
S. Roy	Coherent scattering

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

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

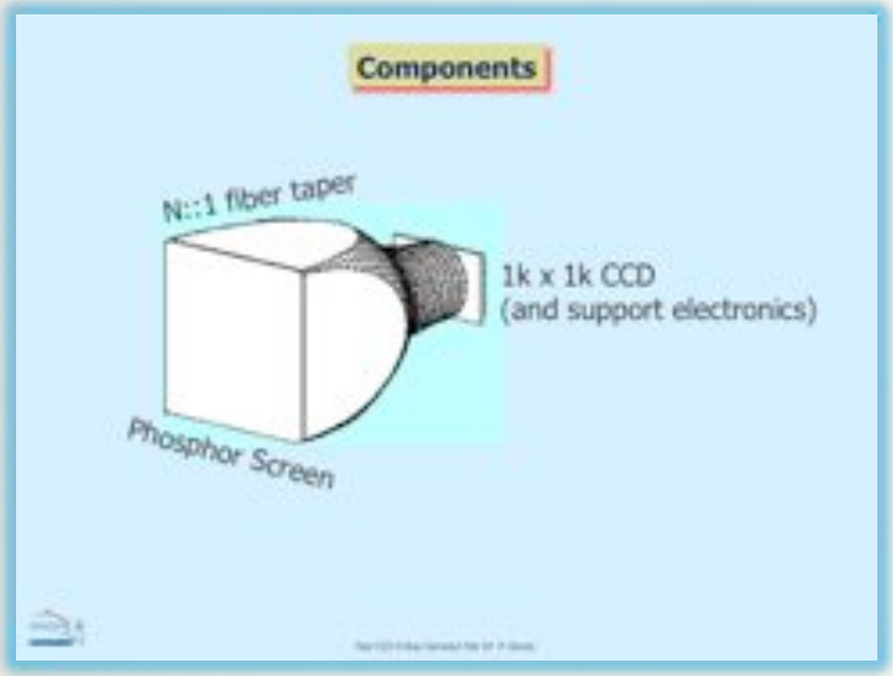
Direct x-ray detector

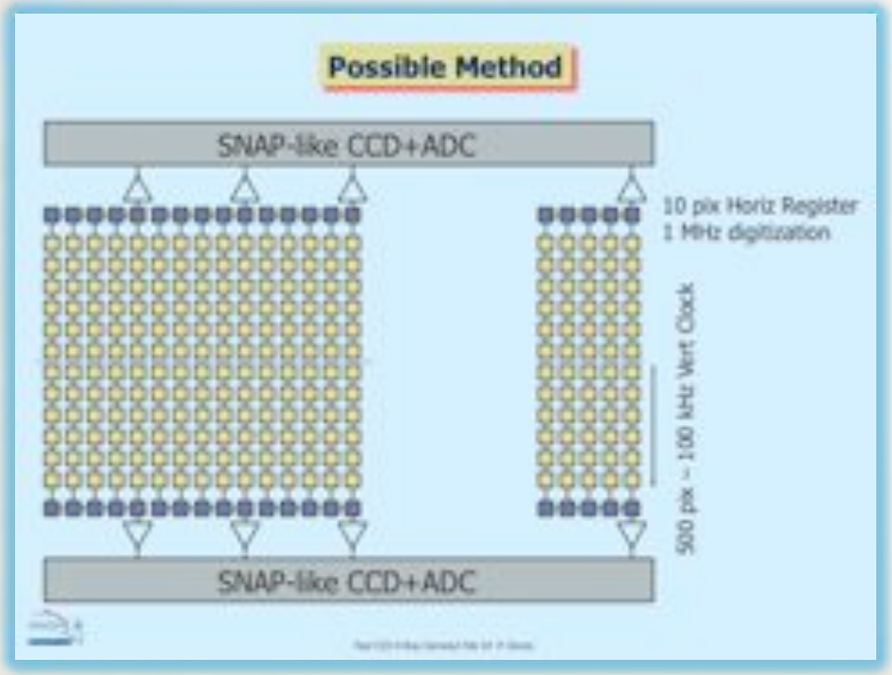
- X-ray photoconverts in silicon
- Collect the photoelectrons
- (Much more signal)

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

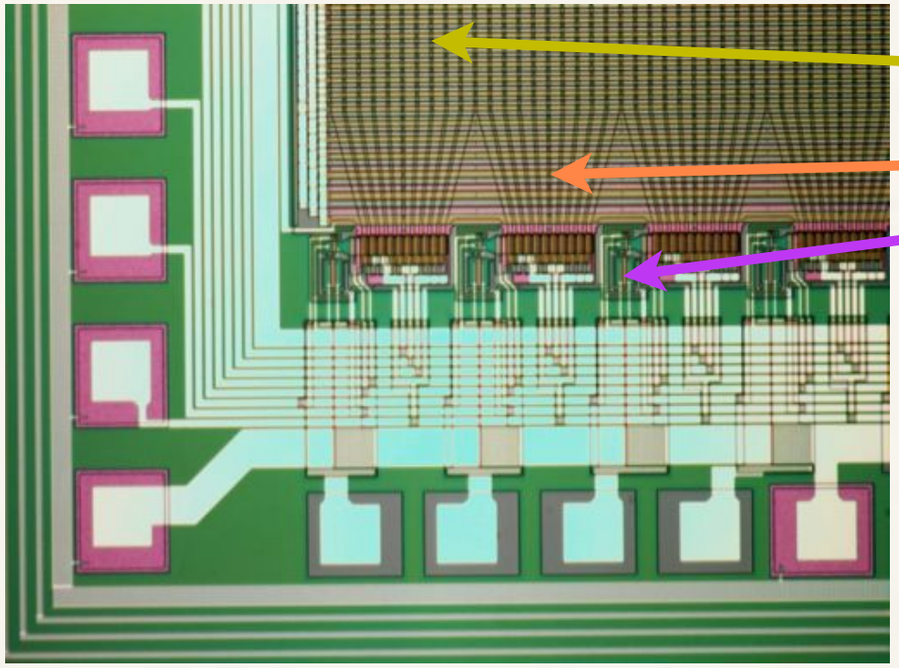
FastCCD - maximize impact, direct (or indirect) detection

Concept - late 2003



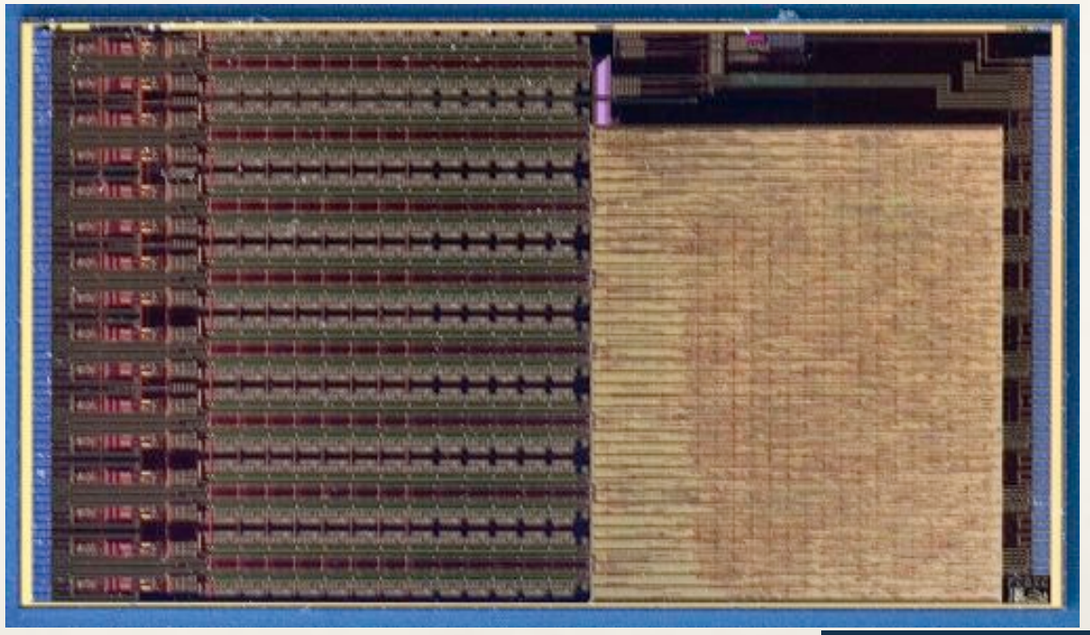


CCD - 2006/7 (LDRD)



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

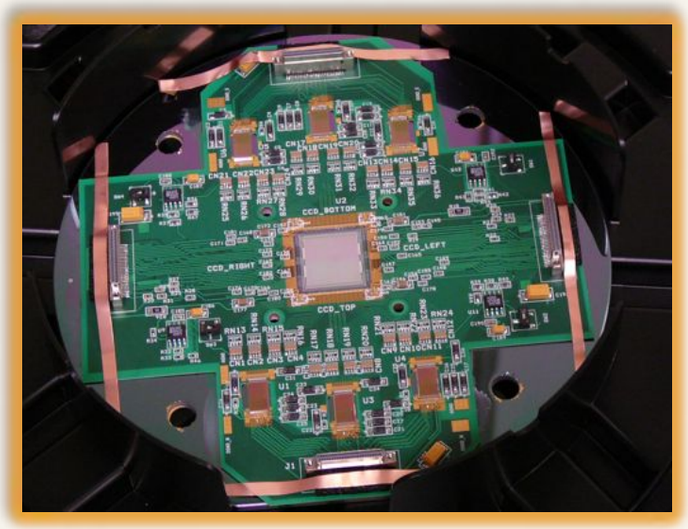
Readout ASIC - 2006 (LDRD)

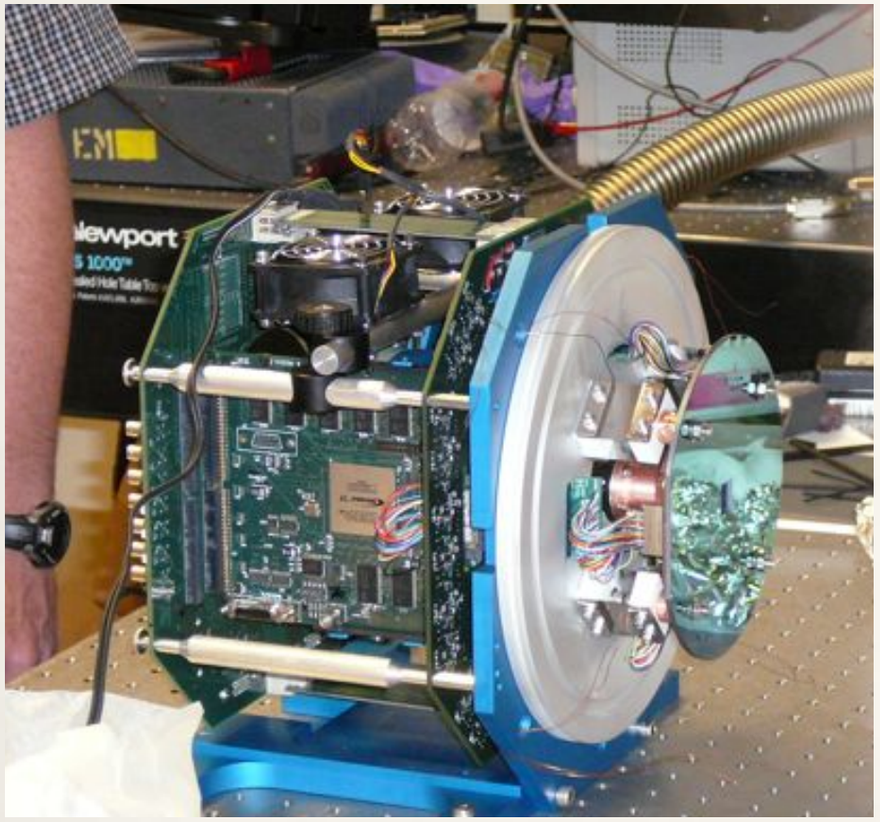


- 16 channels
- 300 μm pitch
- 15 bit dynamic range
- Correlated Double Sampling
- 1 MHz/channel
- **> 200 frame/sec**

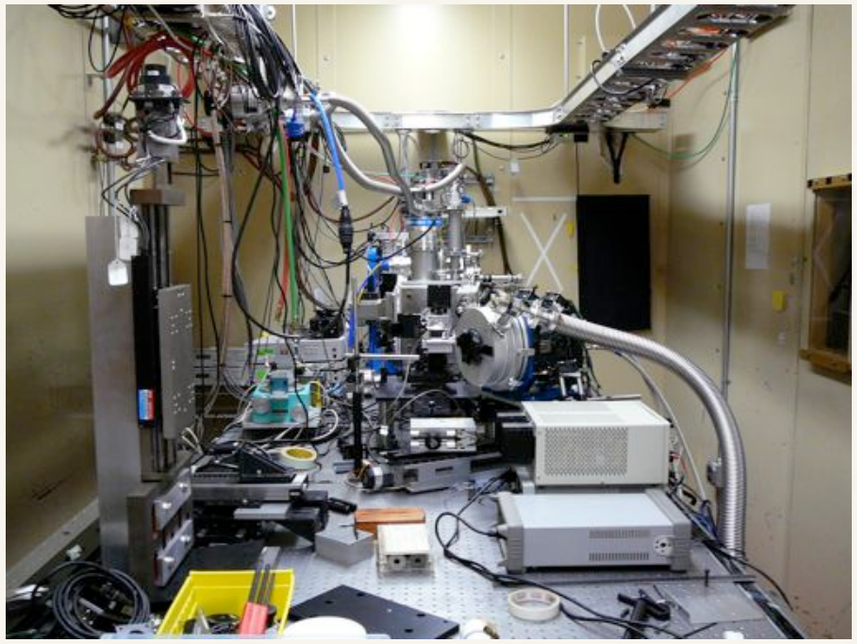
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

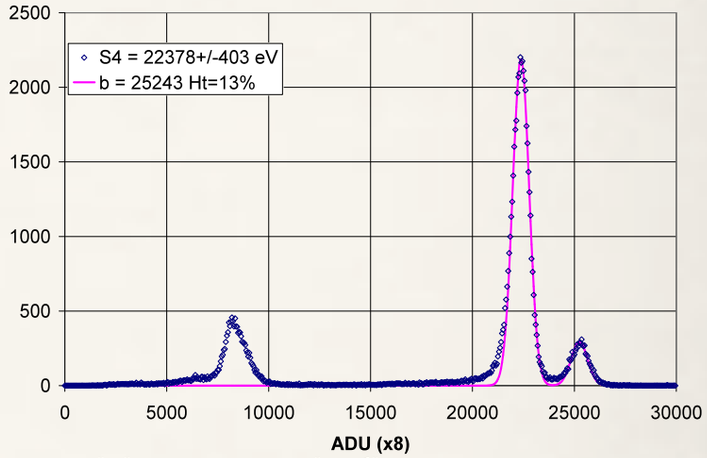
FastCCD - 2nd ½ of 2008: Integrate and Characterize





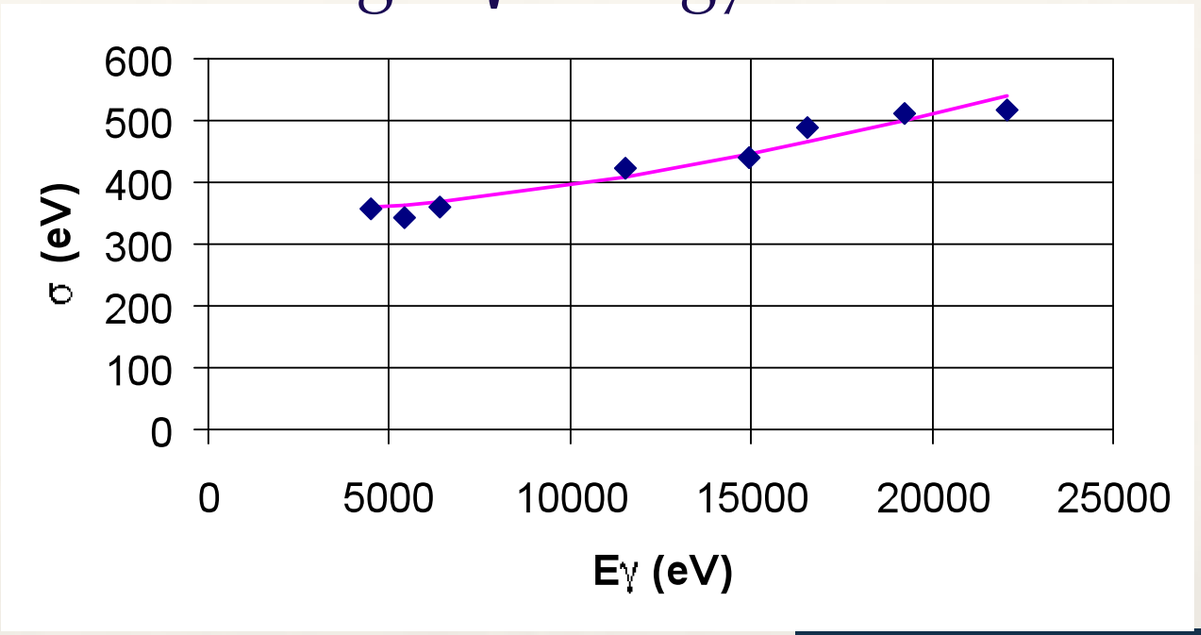
Characterize on 5.3.1





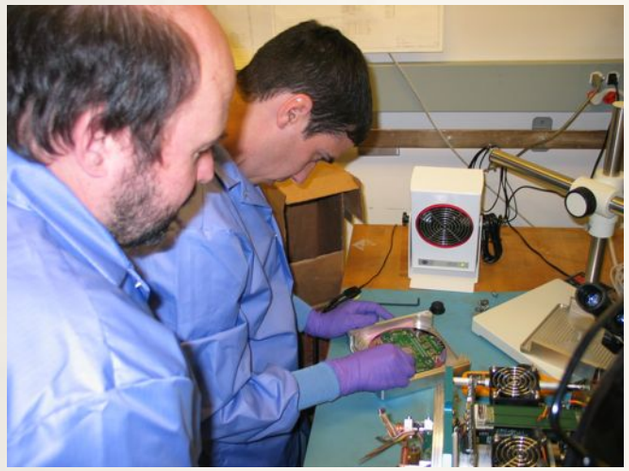
Calibrate with fluorescence photons. 200 μm thick, but E > 10 keV certainly detectable (ε < 1)

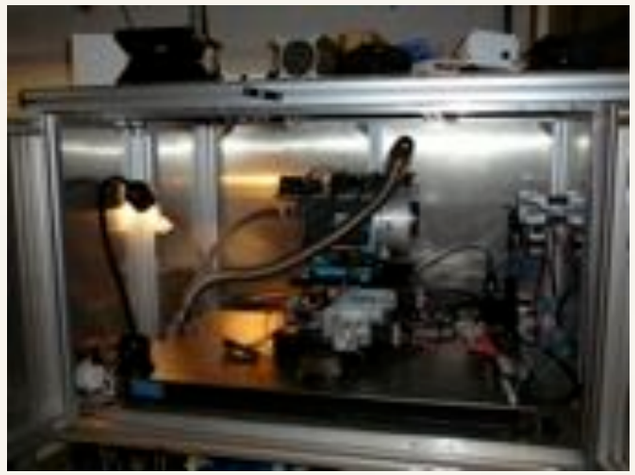
Initial single γ energy resolution

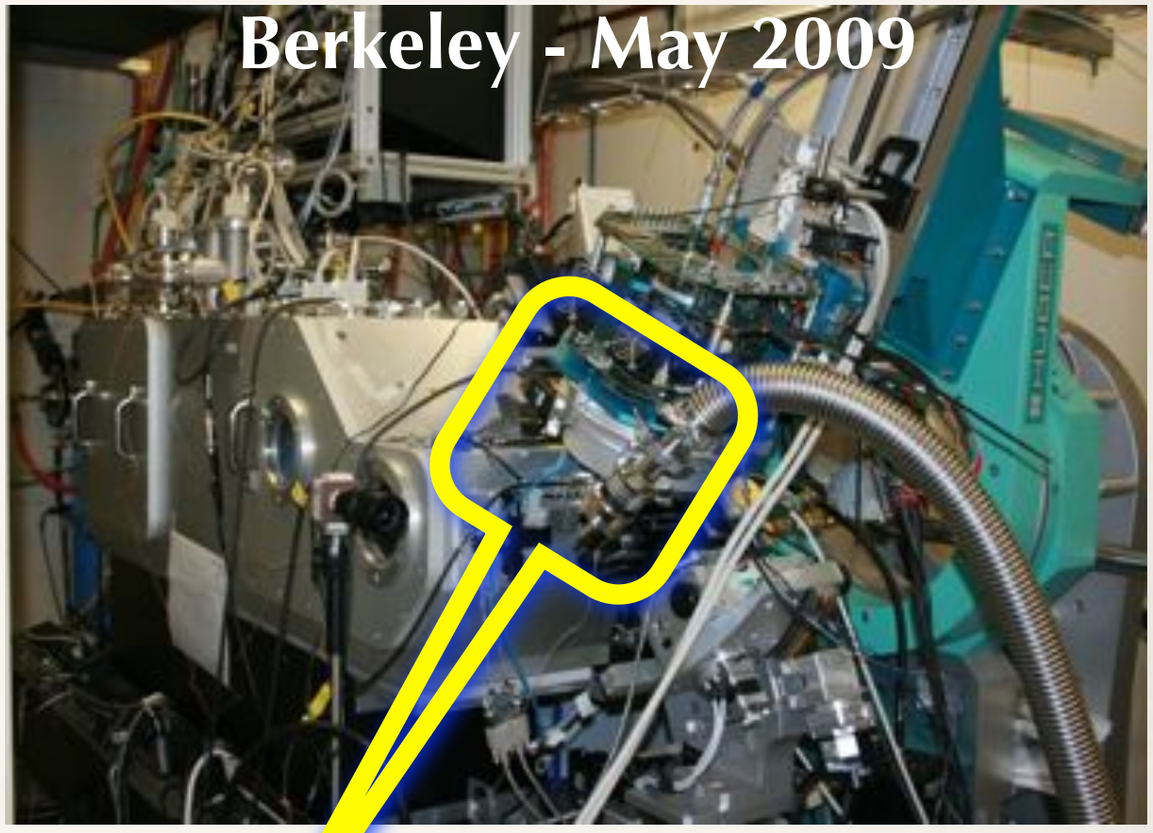


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

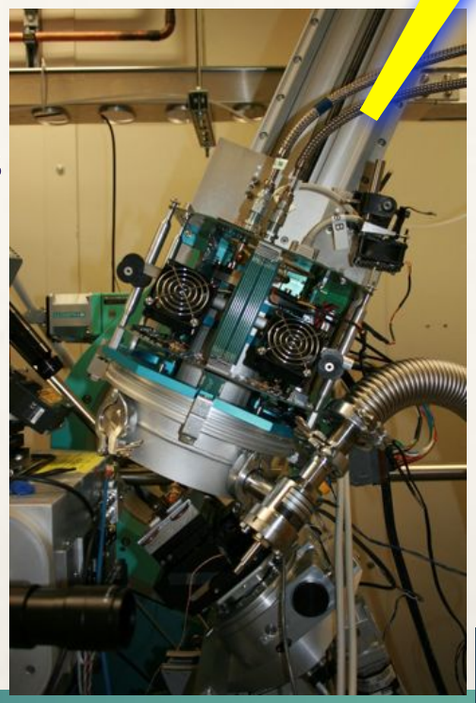
FastCCD - 1st ½ of 2009: First tests at APS and ALS







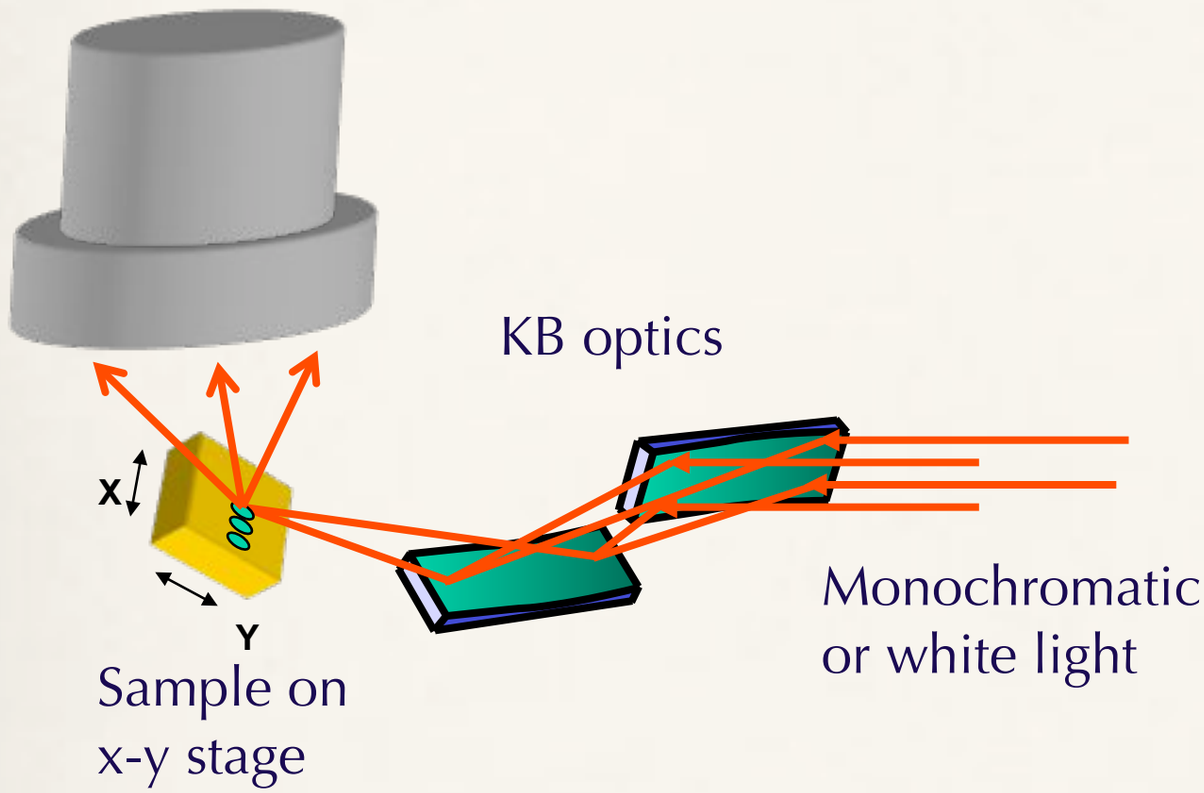
- Jan '09 x-ray tube (lab) tests at ANL
- Jul '09 1st beam at 8-ID
- Nov '09 2nd beam at 8-ID



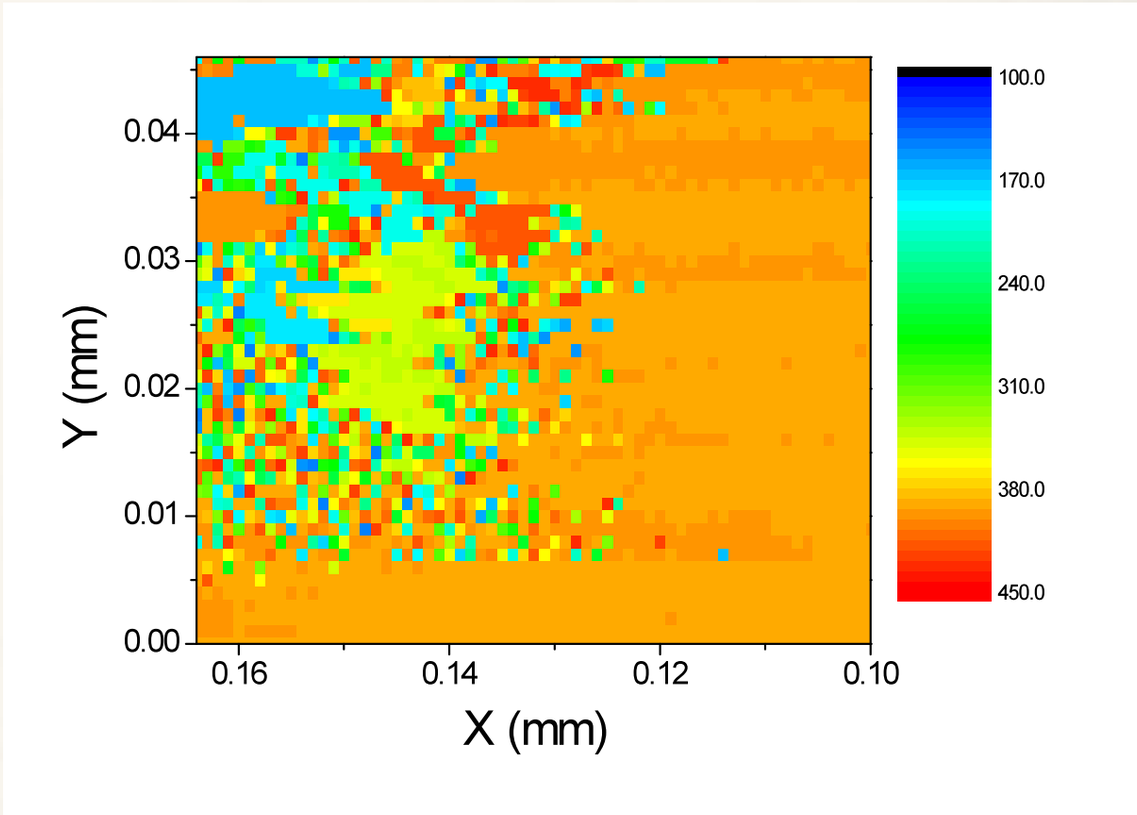
- FastCCD on micro-diffraction BL 12.3.2

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Microdiffraction - Today and Tomorrow



Example: solder grain



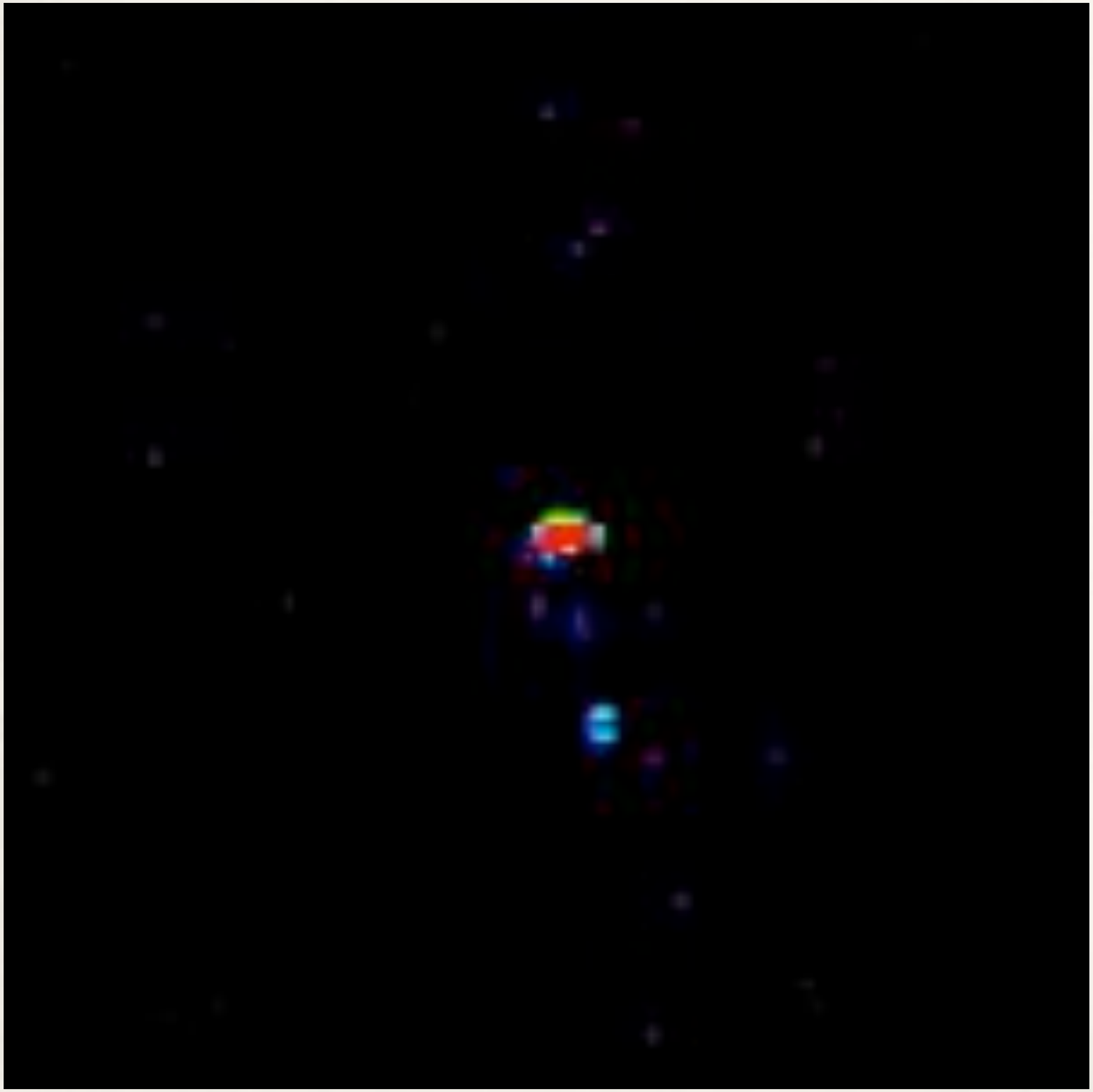
3 orders of magnitude increase in speed at 200 fps

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

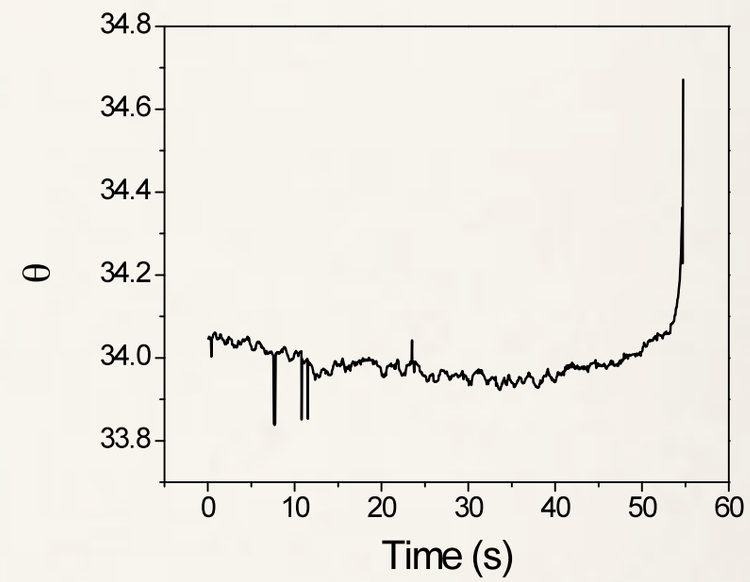
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

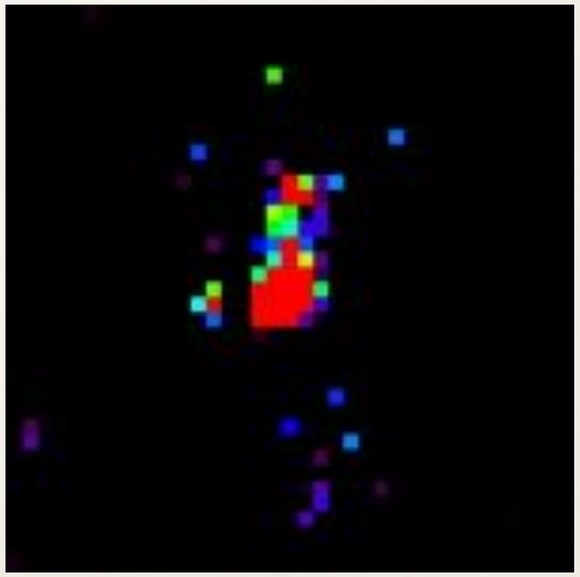
Soldering ... an example



Tin melting ~232 C

Sudden grain rotation and splitting before melt?

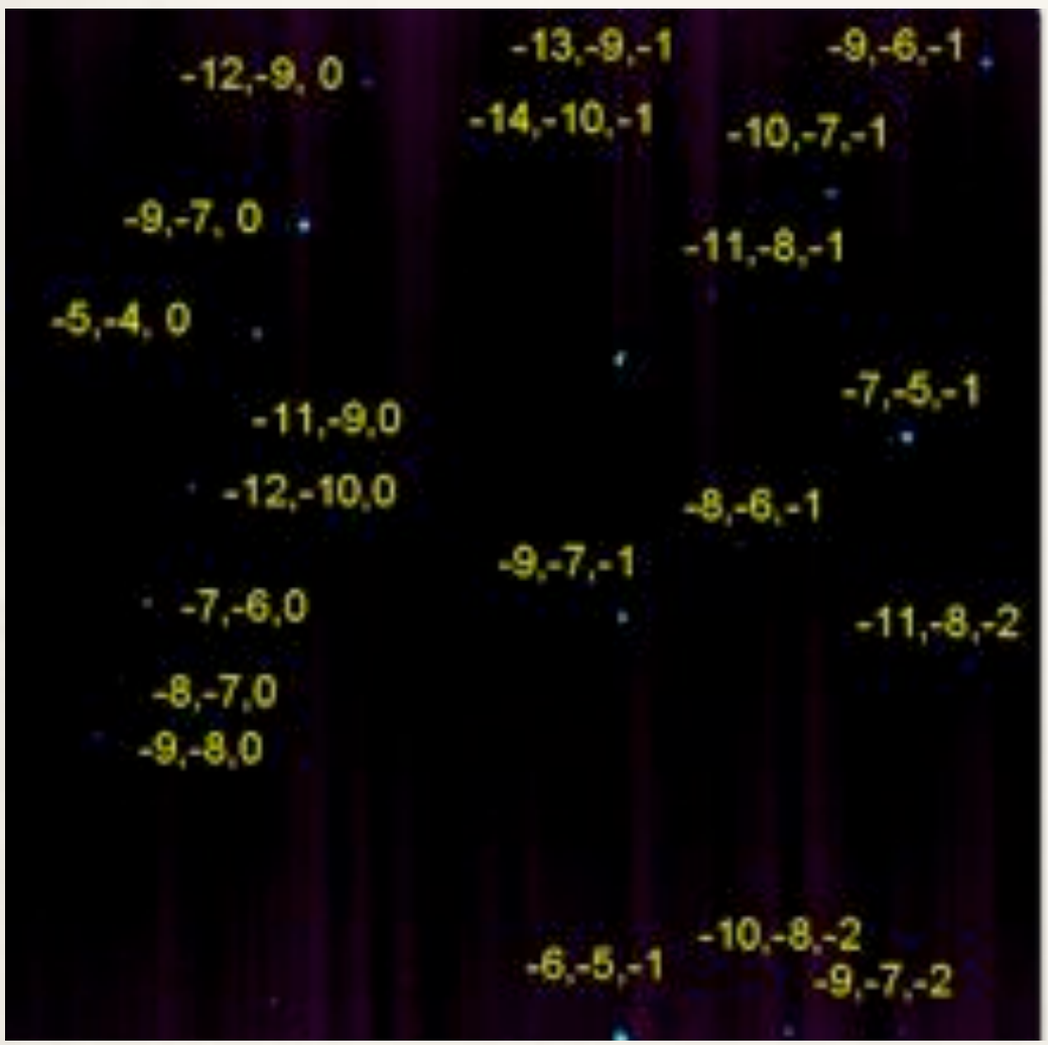


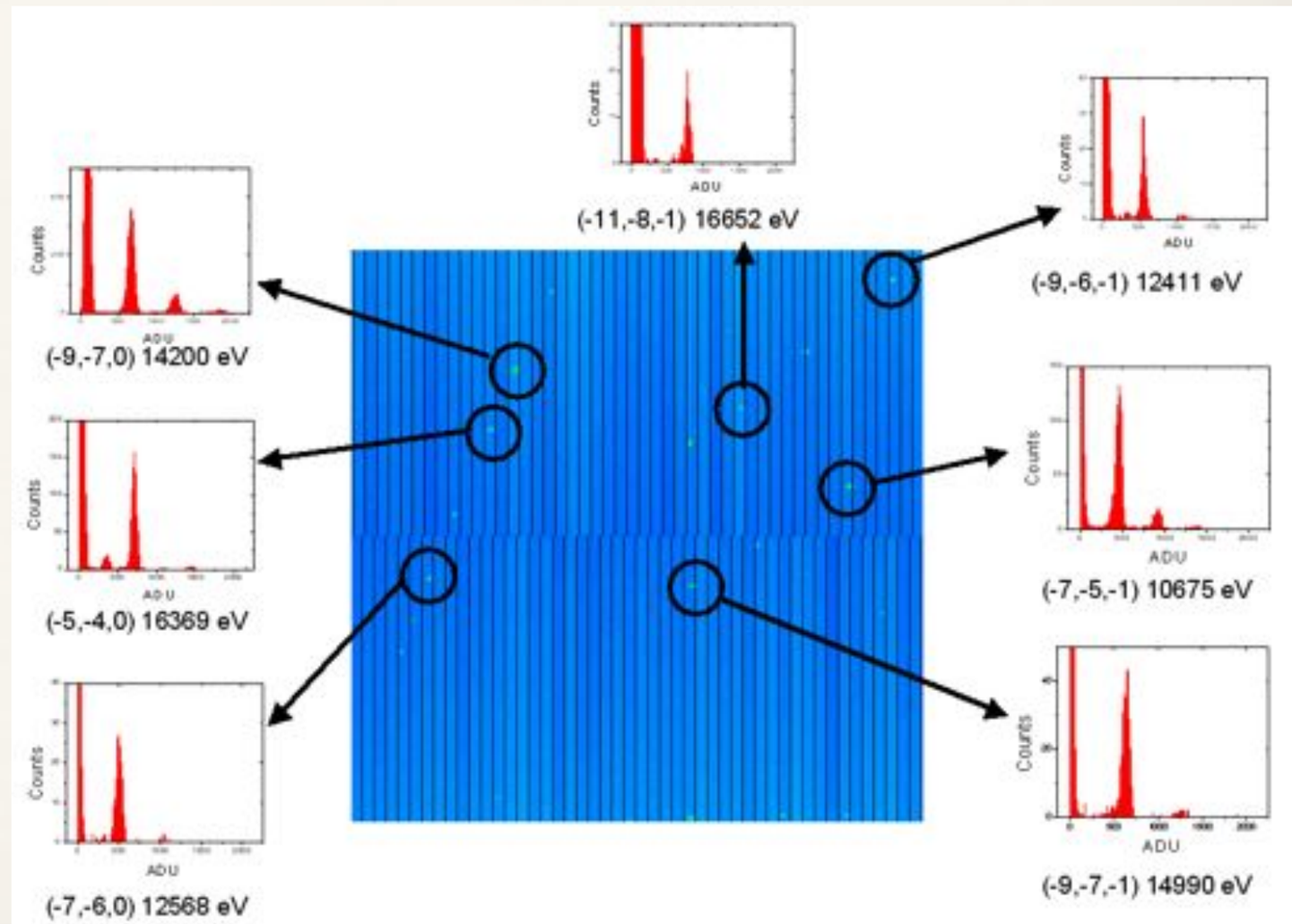


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Fast Energy-resolved Laue Diffraction

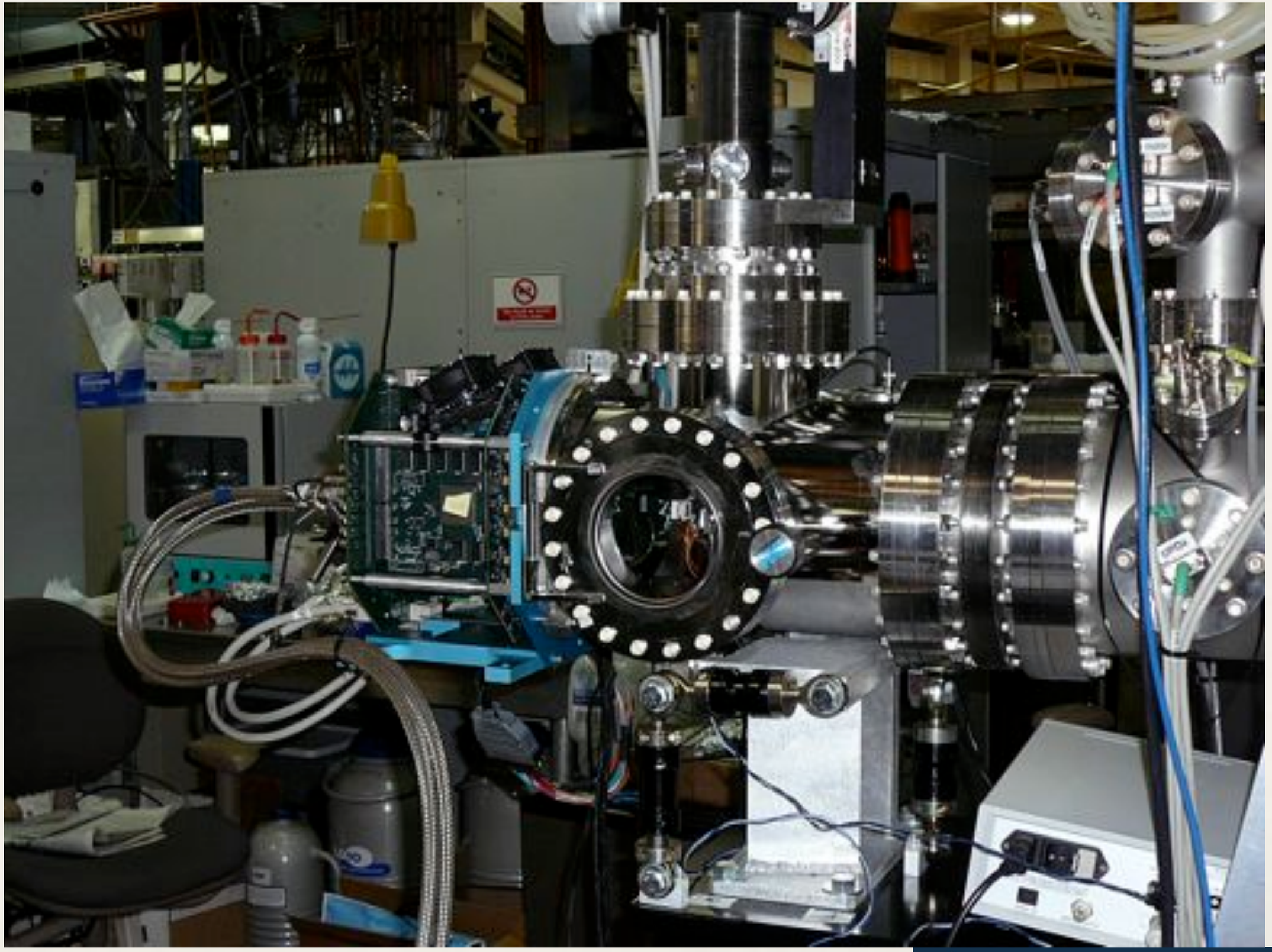
- FastCCD at high readout rate → single photon counting (spectroscopy)
- Fast alternative to monochromator energy scan
- Promising - larger detector area needed





Potassium Titanyl Phosphate $KTiOPO_4$ (or KTP)

Diffractive Imaging, Holography and Ptychography on BL 9.0.1

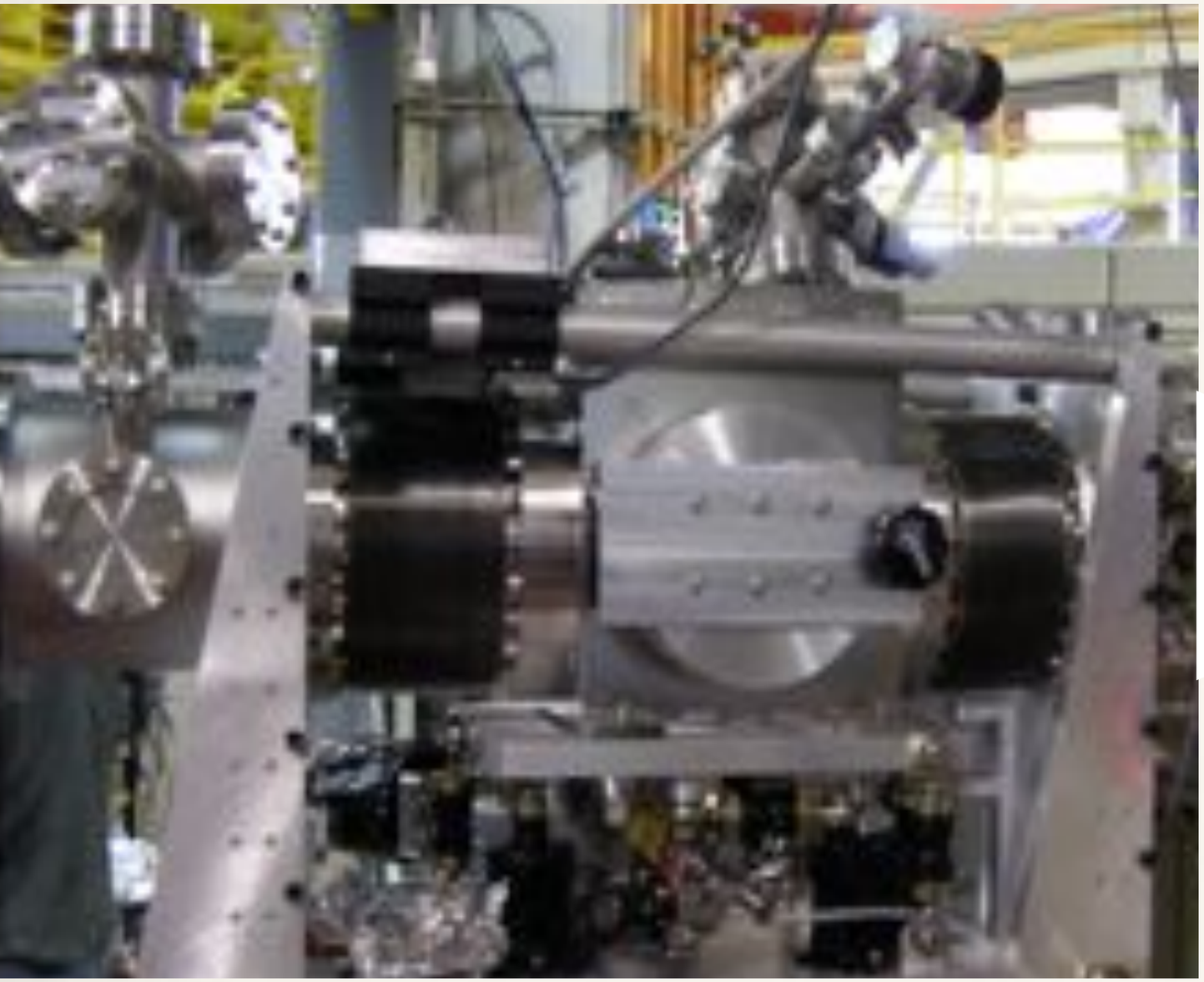


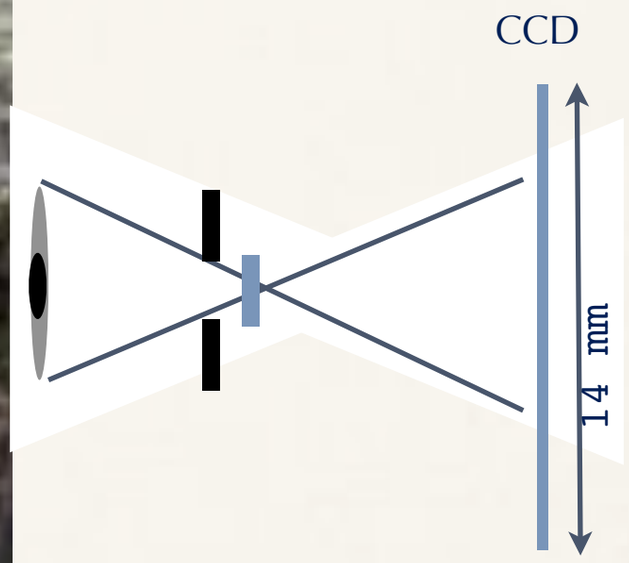
Stefano Marchesini and a cast of thousands

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Scanning Diffractive Imaging

Plan





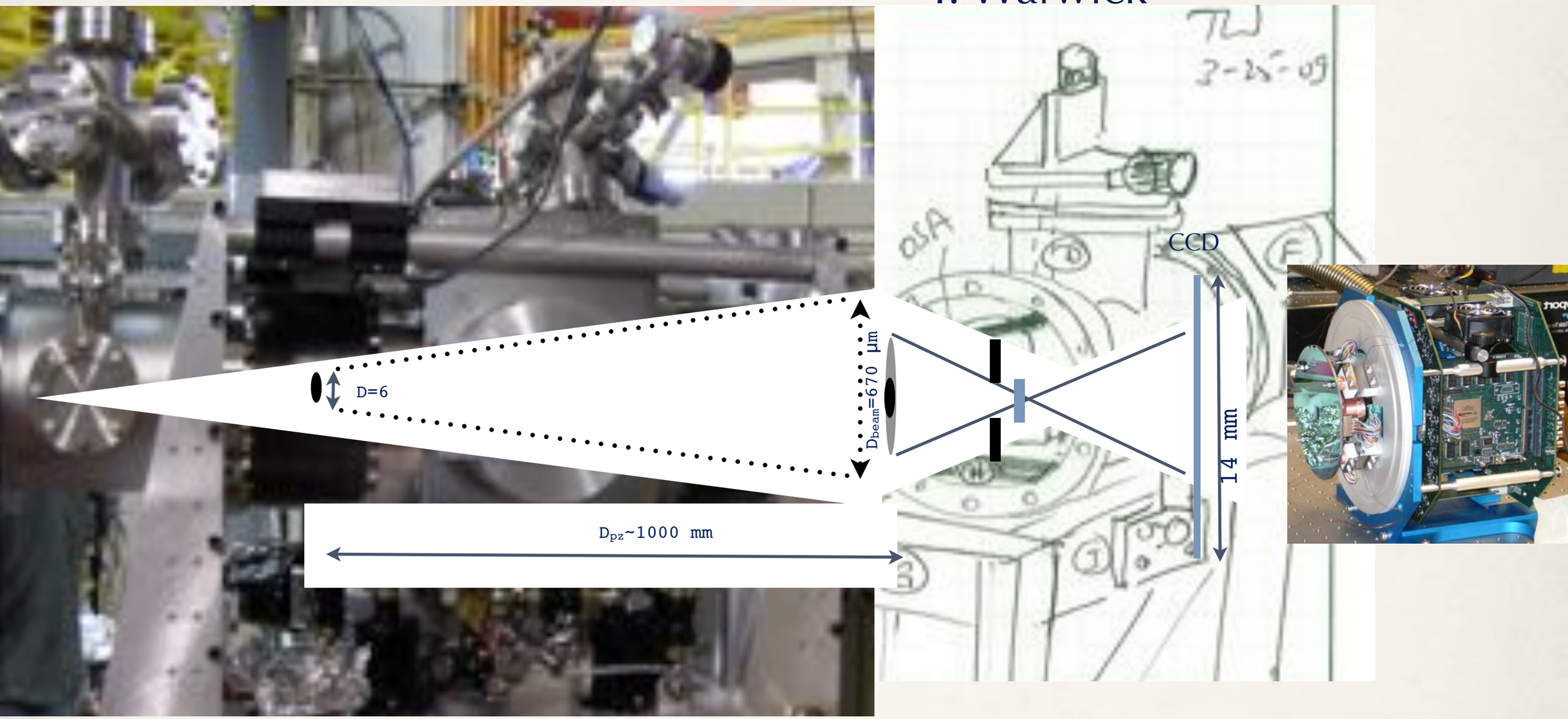
Beam
Energy: 750 eV
λ=1.65 nm
$E/\Delta E$=500;

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

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Scanning Diffractive Imaging

T. Warwick

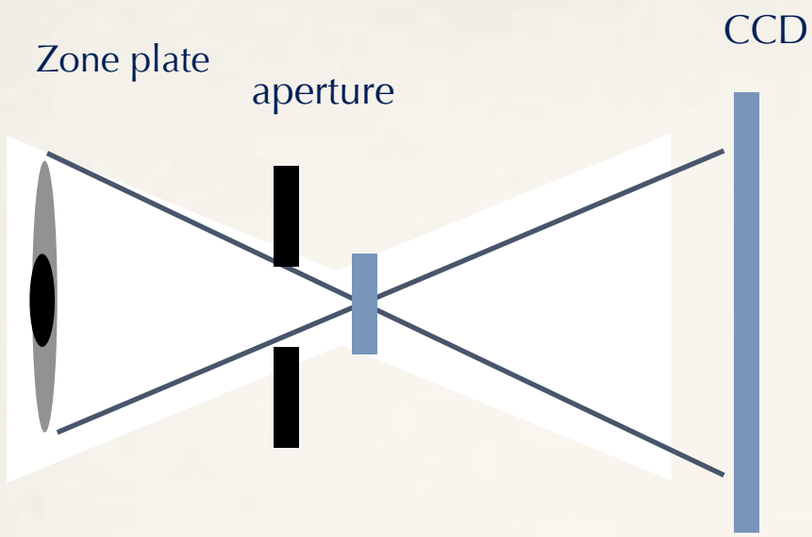


Beam
Energy: 750 eV
λ=1.65 nm
$E/\Delta E$=500;

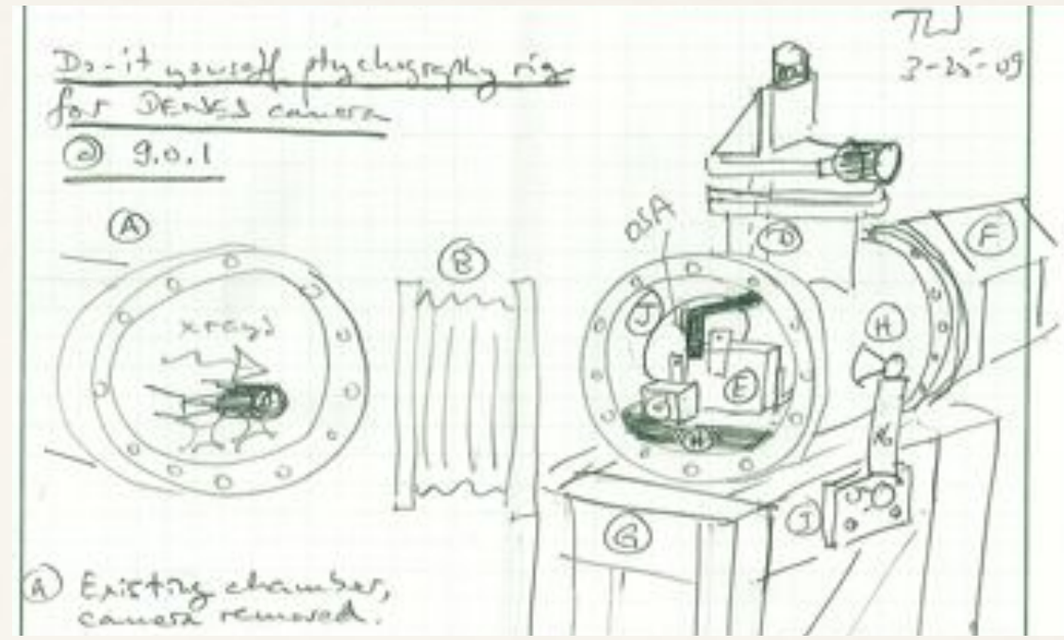
Pinhole: D=6 µm wide, 2 µm thick Au
Distance Pinhole-ZP D_{pz}: ~1 m
Beam size (to first min): 670 µm

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Ptychography

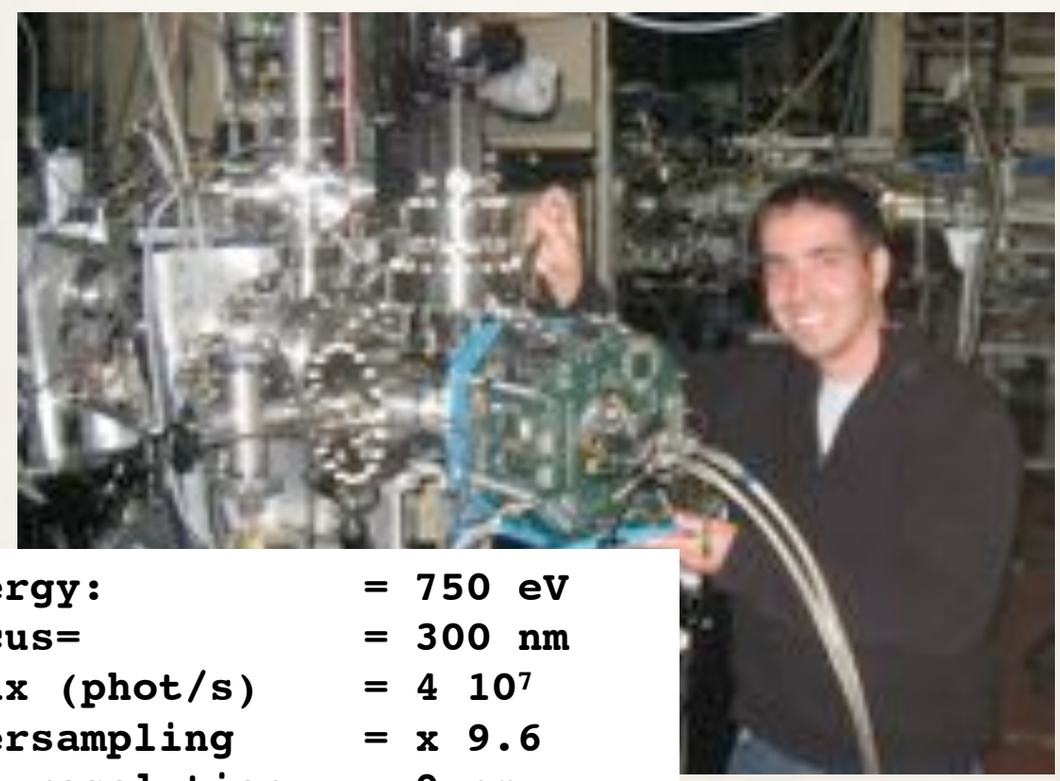


03/2009 Draft



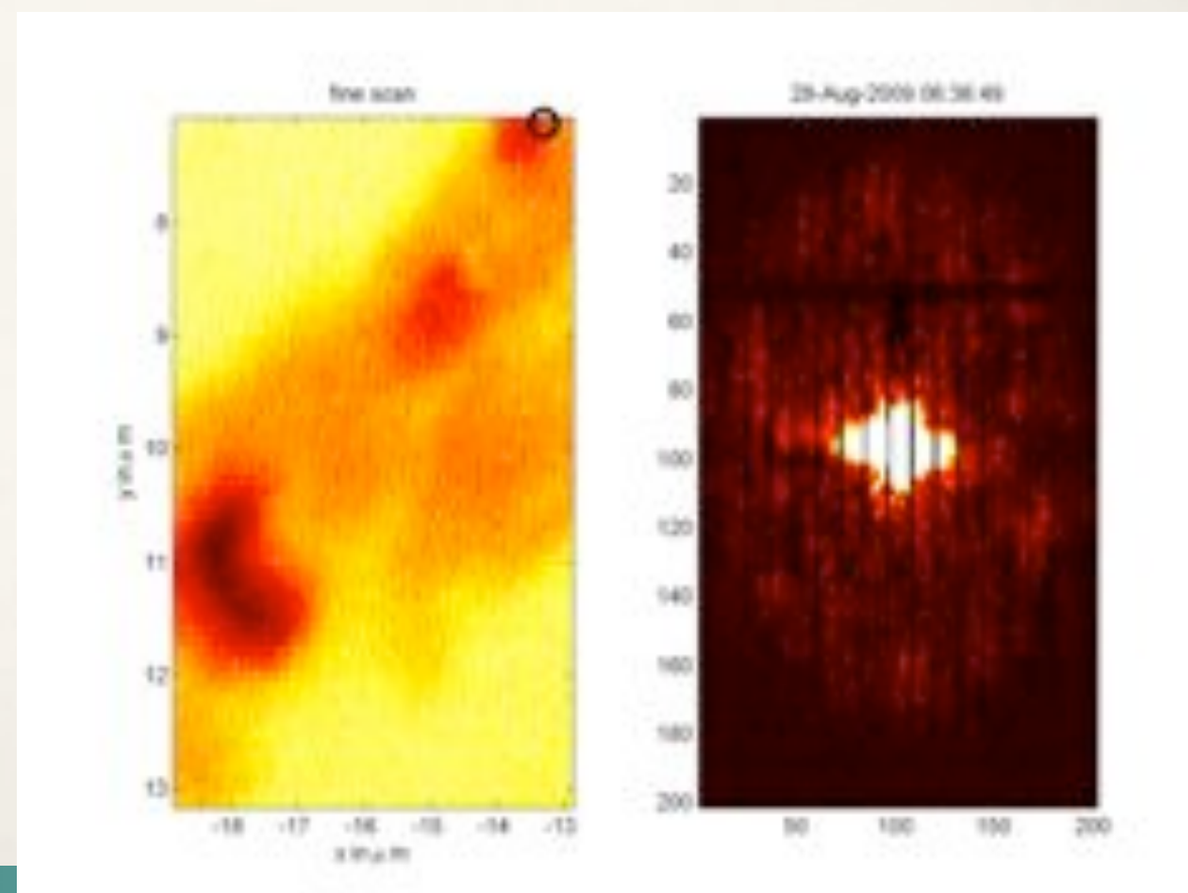
10 nm should be possible in near future

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

About | User Information | Science & Education | Media Center | Beamlines | Divisions | Search APS ...

Argonne Home › Advanced Photon Source › Users › Communications › User News › 2009 ›

2009
2008

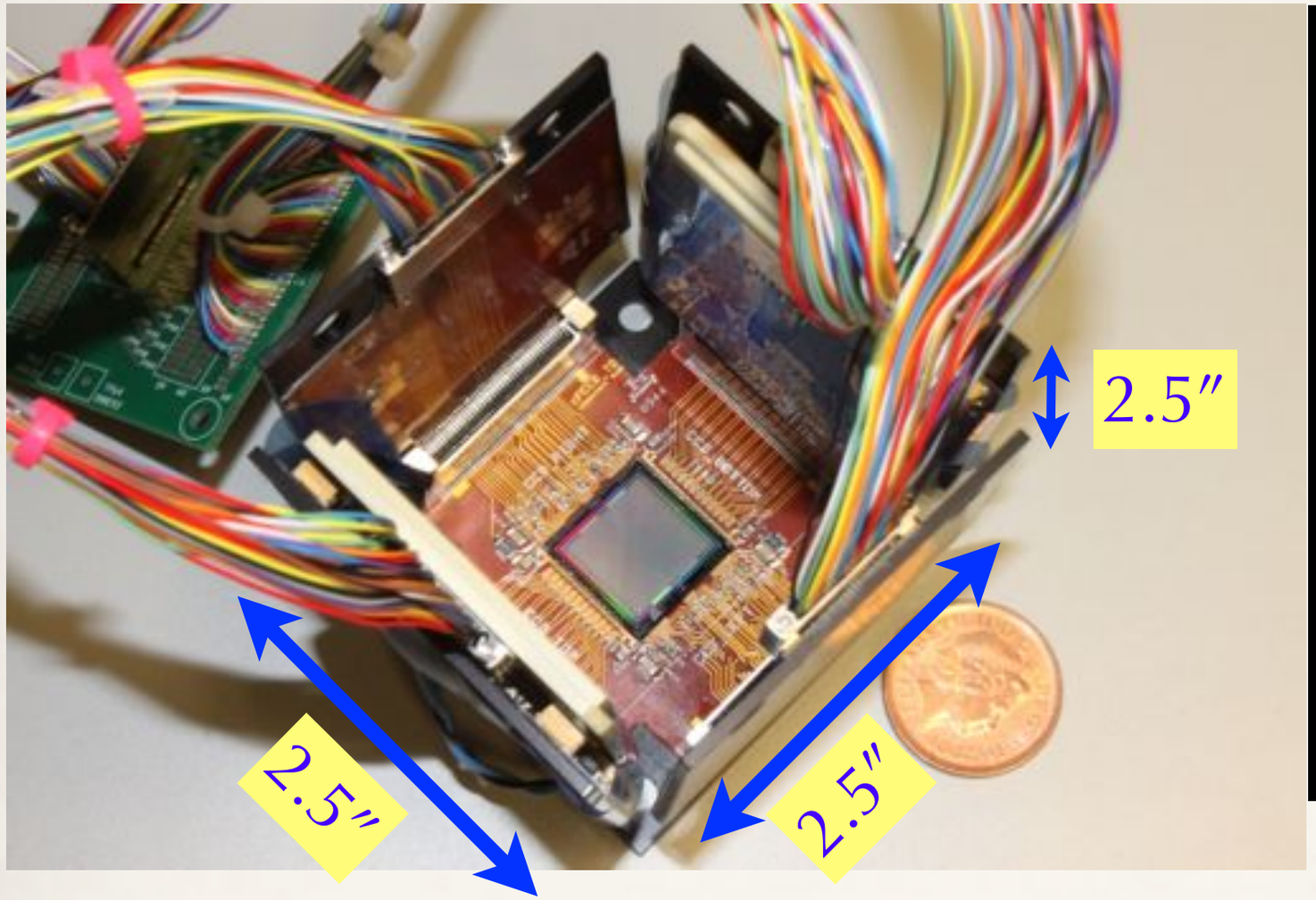
APS User News
Issue 58, November 11, 2009

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.

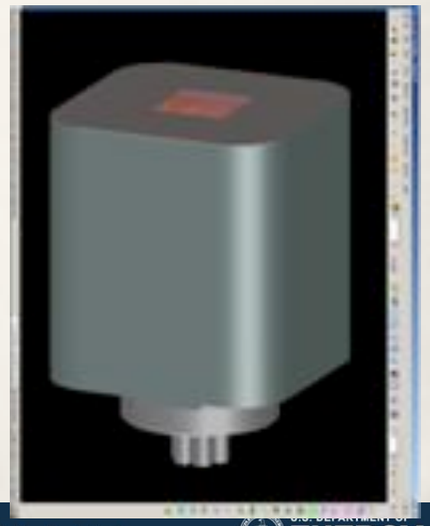
Detector commissioning began at station 8-ID-I in July 2009. Initial measurements focused on characterizing the detector's flat field response and efficiency, measuring static and fluctuating speckle patterns and examining performance of the control system. Results to date have demonstrated the exceptional 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)



Highly-sophisticated test of functionality

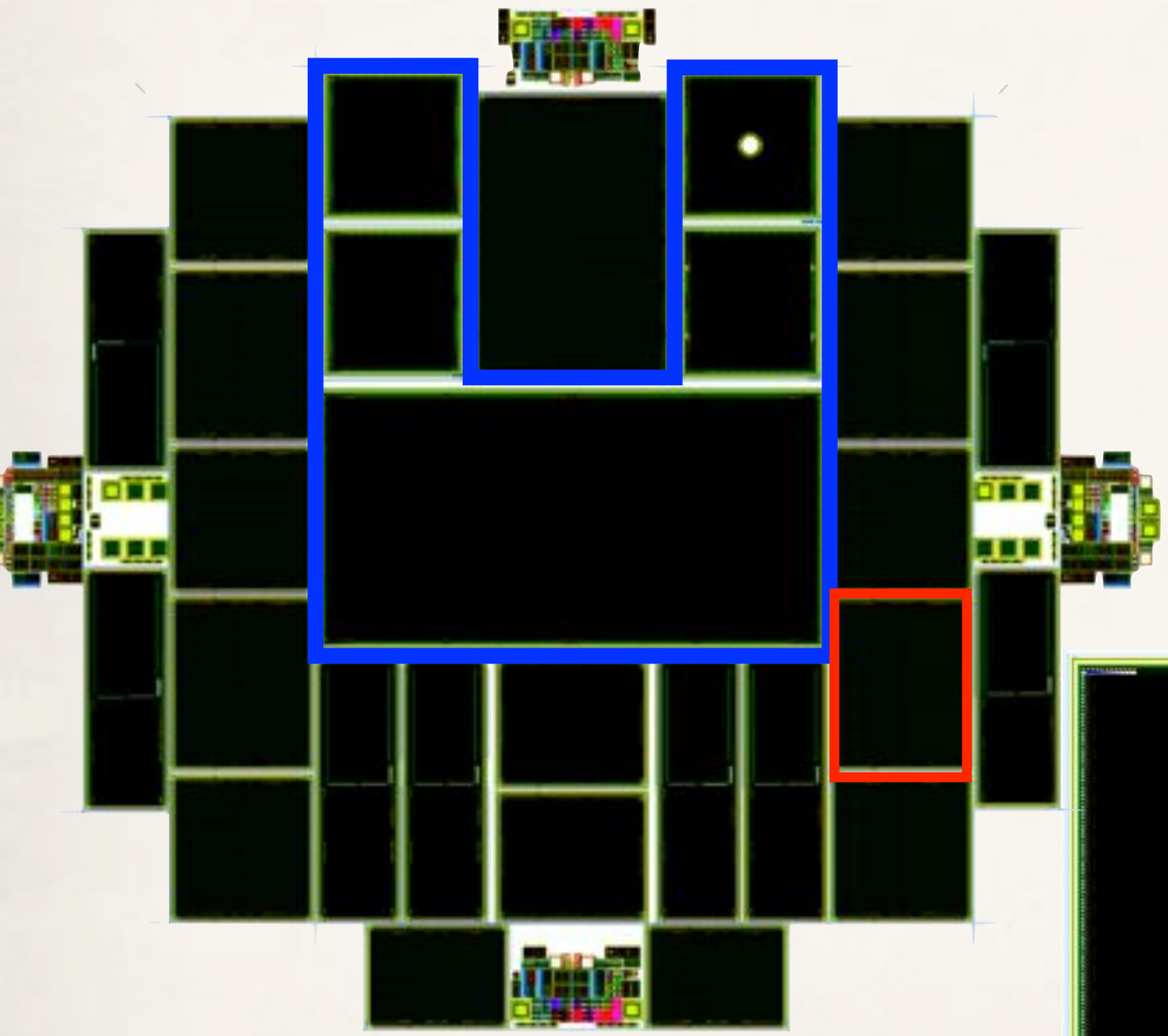


Prototype (front-illuminated)
Final mechanical / thermal verification

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

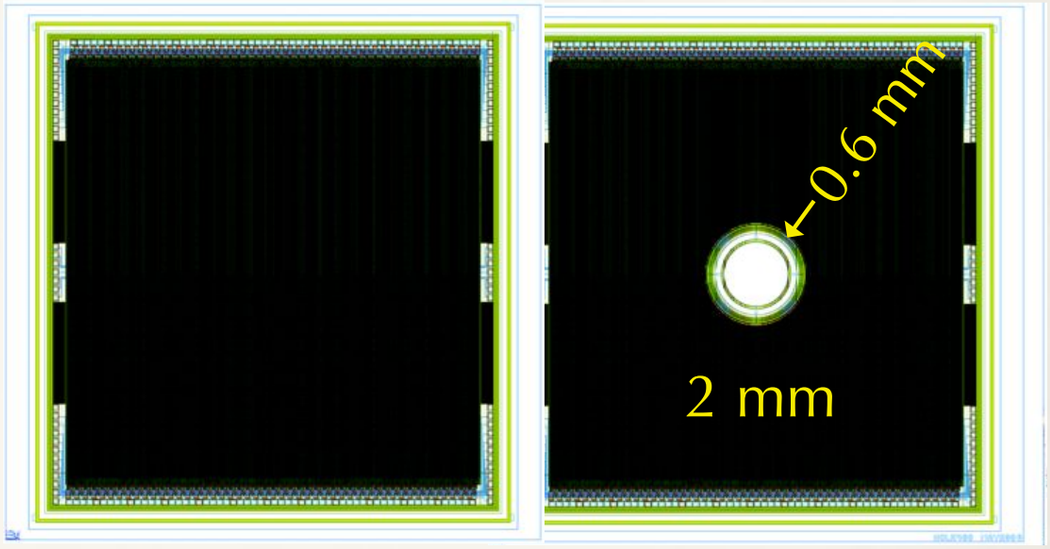
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
ENERGY

Continued (New) CCD LDRD

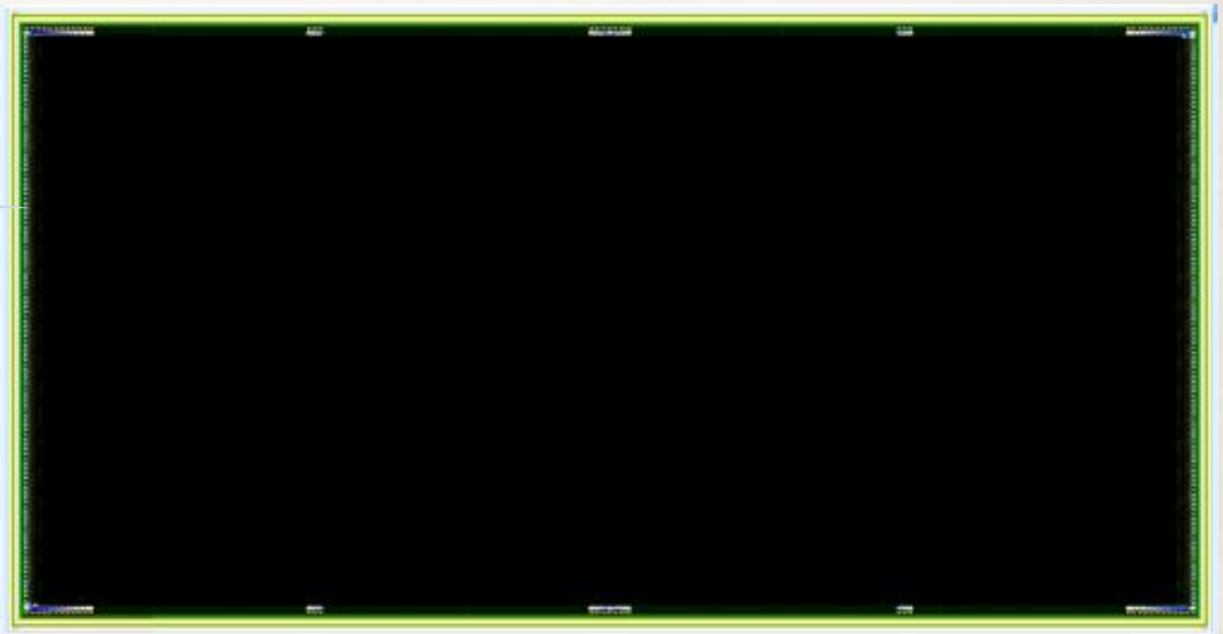


FY09 LDRD Wafer

In fabrication now

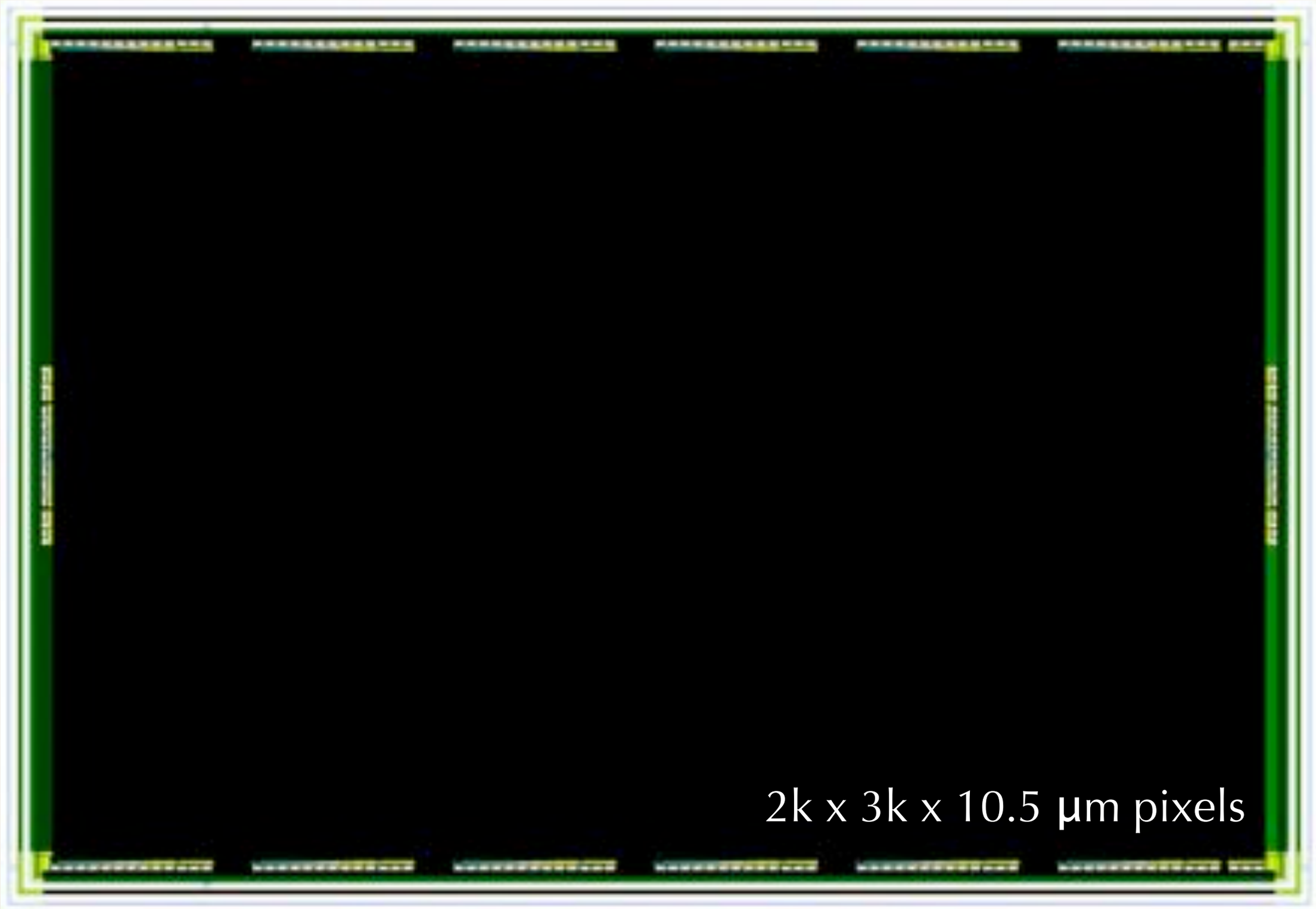


New Output stages
Version with a hole
1k Frame store



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

LSST-like Prototype



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

ARRA-funded FastCCDs

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

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
A-Z INDEX | PHONE BOOK | JOBS | SEARCH
U.S. DEPARTMENT OF ENERGY

Berkeley Lab Information Related to the American Recovery and Reinvestment Act of 2009
RECOVERY ACT ACTIVITIES

HOME | AMERICAN RECOVERY AND REINVESTMENT ACT OF 2009 | REPORTING | HOW TO APPLY | CONTACT US

BERKELEY LAB PROJECTS

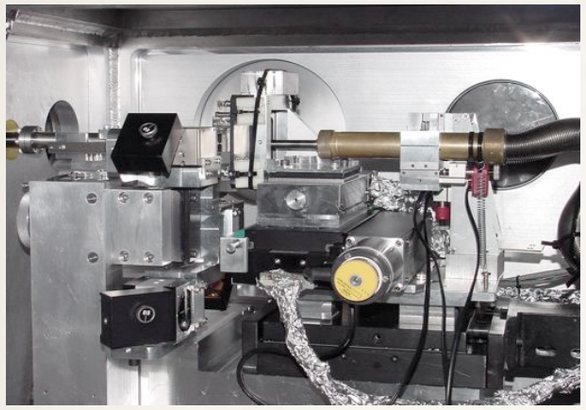
Advanced Light Source Accelerator Improvement and Equipment

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.

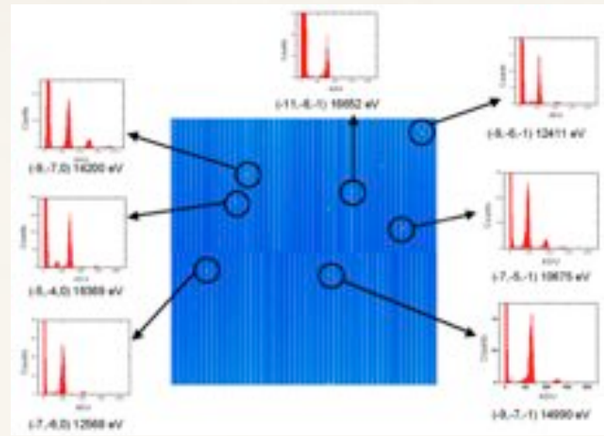
First, the ALS will receive $5.8 million to acquire sextupole magnets to increase brightness by a factor of two to three, keeping the ALS at the cutting edge of soft x-ray science. Second, ALS will receive $2 million to construct and install an elliptically polarizing undulator to provide a new x-ray 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.

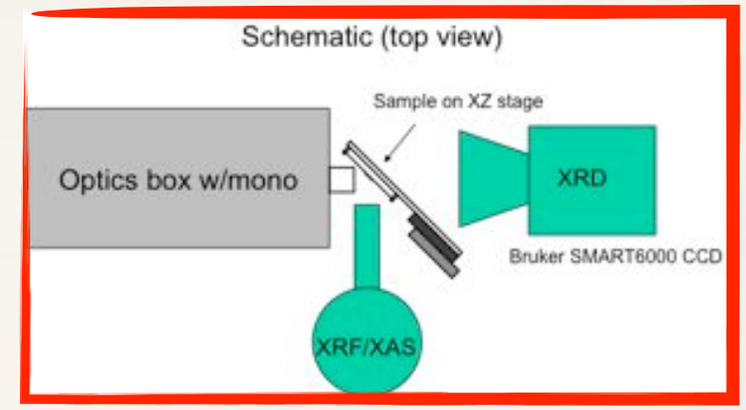
Needs Addressed with ARRA FastCCDs



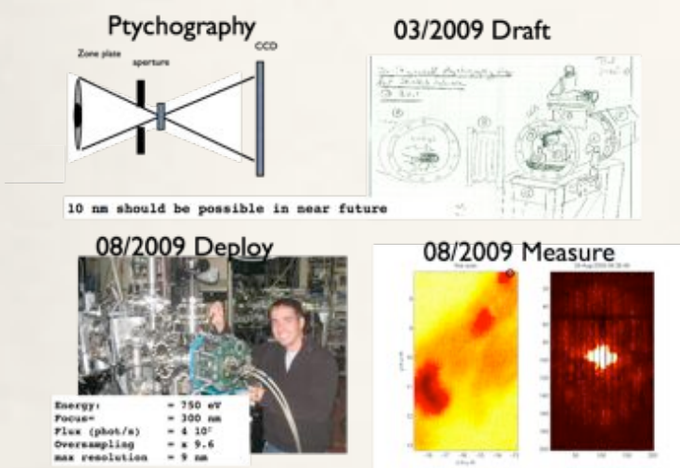
STXM



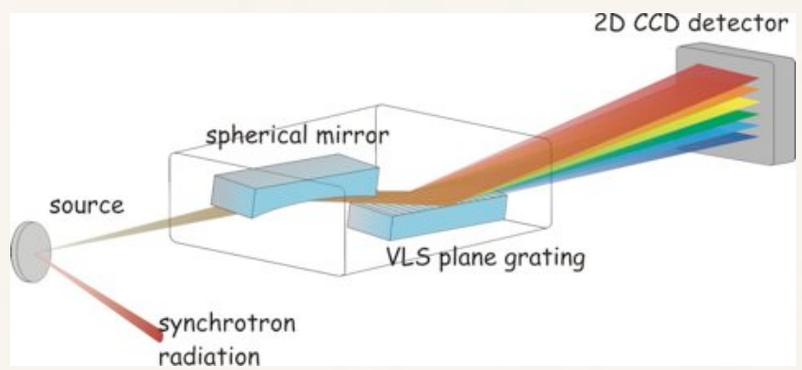
Scanning μDiffraction



μXRF,μXRD,μXAS

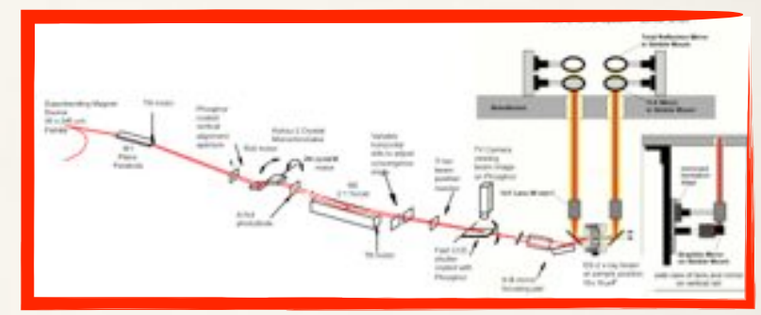


Ptychography



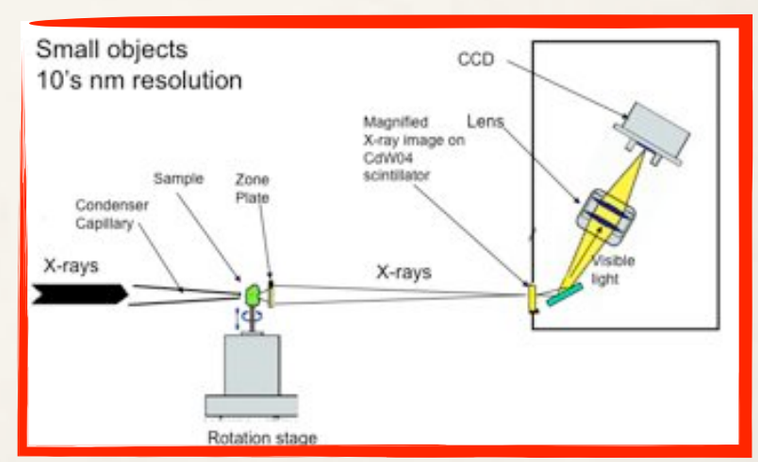
Photon in / photon out

Photoemission (phosphor)

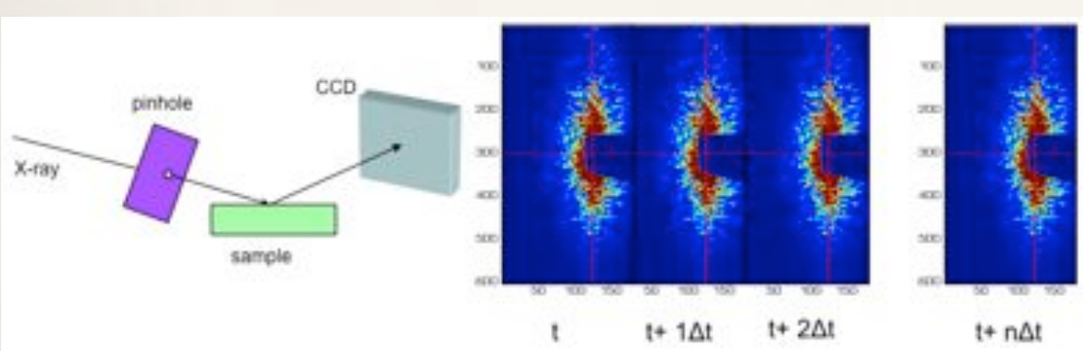


High Pressure Melting

Hard x-ray



Tomography



XPCS

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Next Steps - CCDs

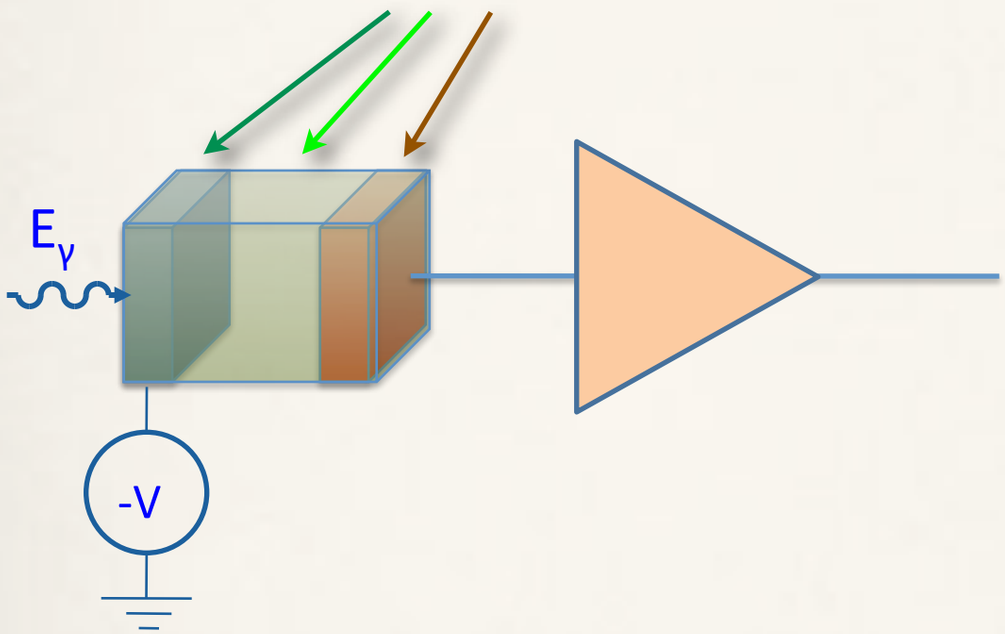
- Original idea: biggest bang/$ - improve CCD readout
  - faster readout, but with no degradation of performance
  - wide dynamic range
  - ➡FastCCD - 100 X faster (because 100 X more parallel)
- Learned in the meantime
  - **direct detection** enables spectroscopy
  - *really* want to detect single photons
  - lower dynamic range (but good SNR) higher speed
- FastCCD = (a)CP-CCD
- VeryFastCCD =
  - CP-CCD (metal strapped, so 25 - 30 μm pitch)
  - Faster ADC

- Go from 100 fps to 10,000 fps
  - Requires development of DAQ and firmware processing
    - In progress now

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Direct detection – R&D

Reminder - p-i-n diode detector



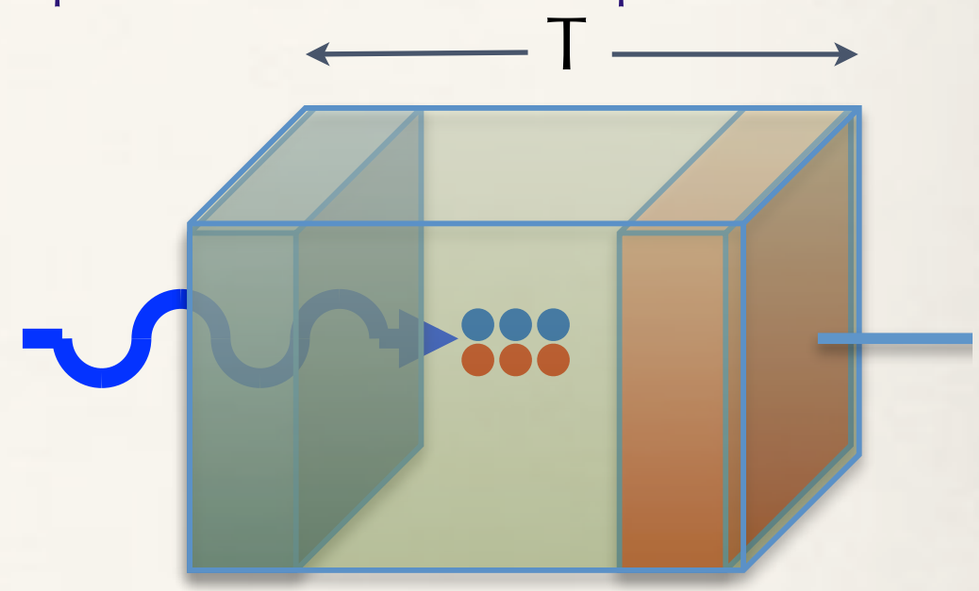
$N_Q = E_\gamma/\varepsilon$

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

Photo-conversion

⇒ photon penetrates entrance window

⇒ photon is absorbed in depth T

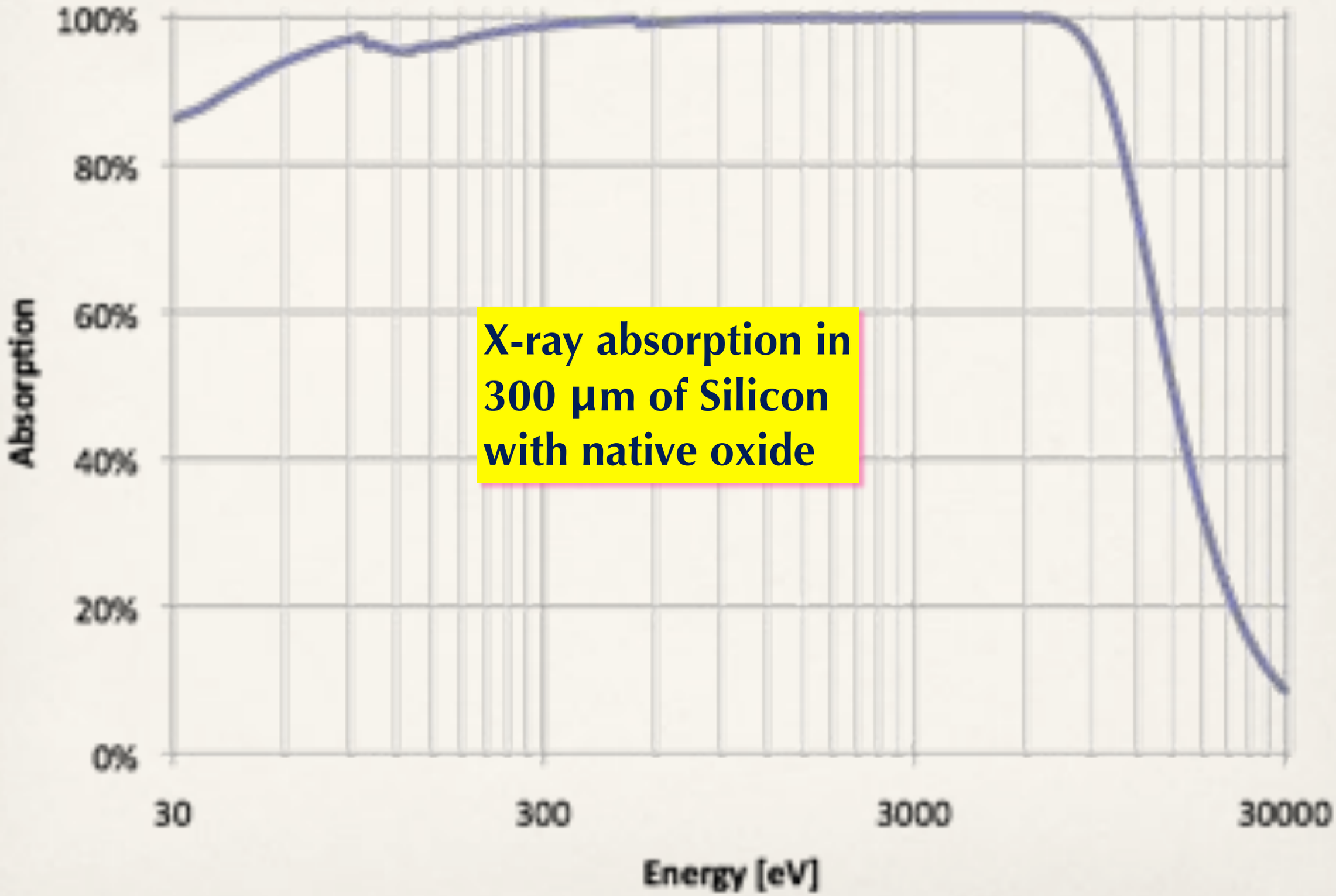


Material	Si	Ge	GaAs	Diamond
ε [eV]	3.6	3.0	4.4	13.1
F	0.12	0.13	0.10	0.08
ϱ [g/cm³]	2.3	5.3	5.3	3.5
95% @ 8 keV	200 μm	85 μm	85 μm	3 mm

Si ideal for most of ALS

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Good Stuff!



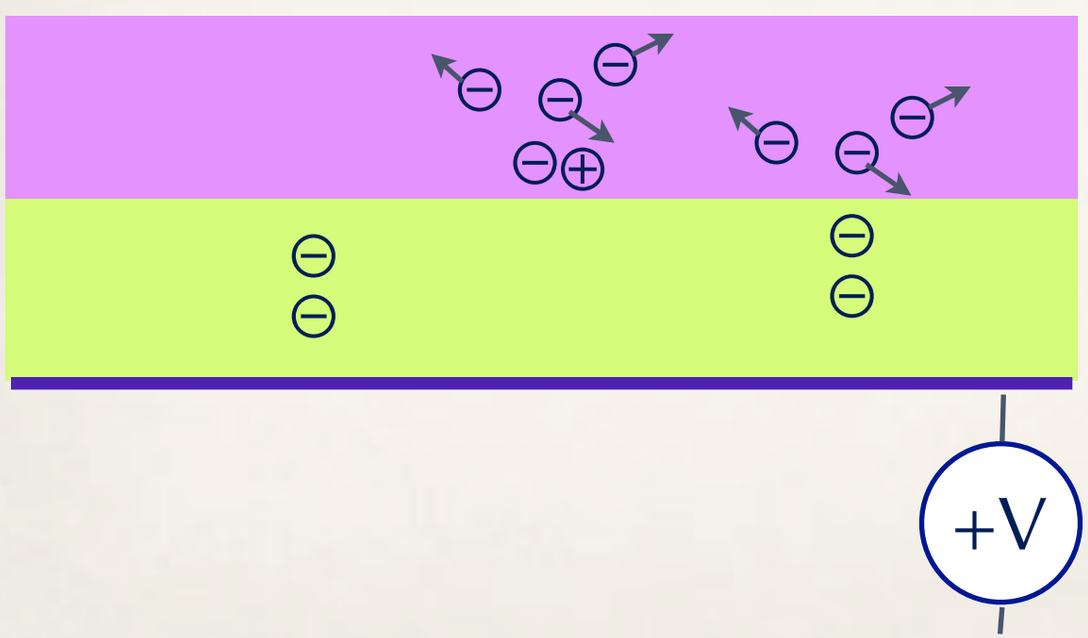
X-ray absorption in 300 µm of Silicon with native oxide

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Importance of Depletion

Fully depleted detector
No recombination
Charge drifts to collection electrode
PSF = 0

Undepleted detector
Diffusion + recombination
Bad PSF

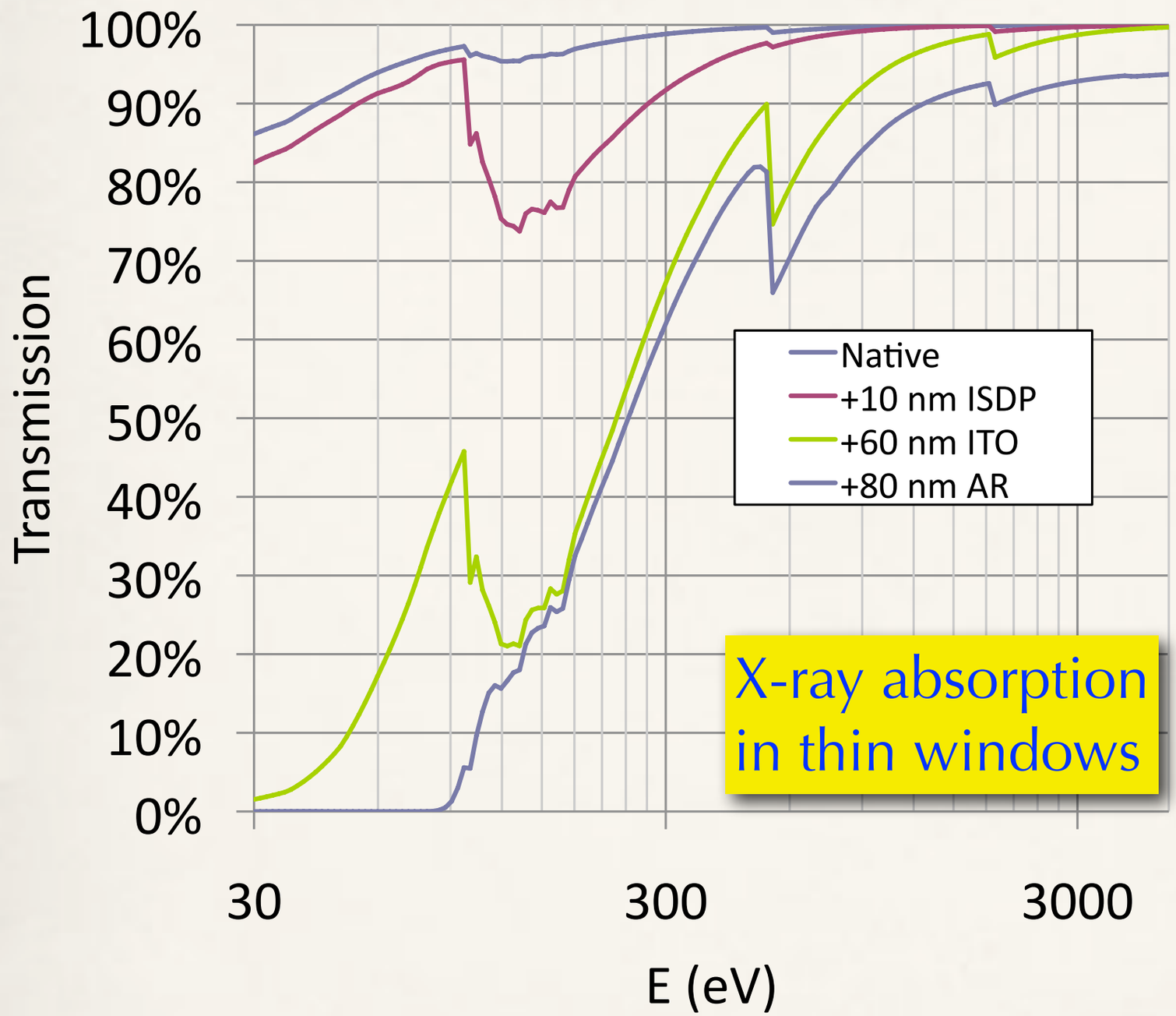


Partially depleted detector
All effects
PSF and charge collection depend on site of photoconversion

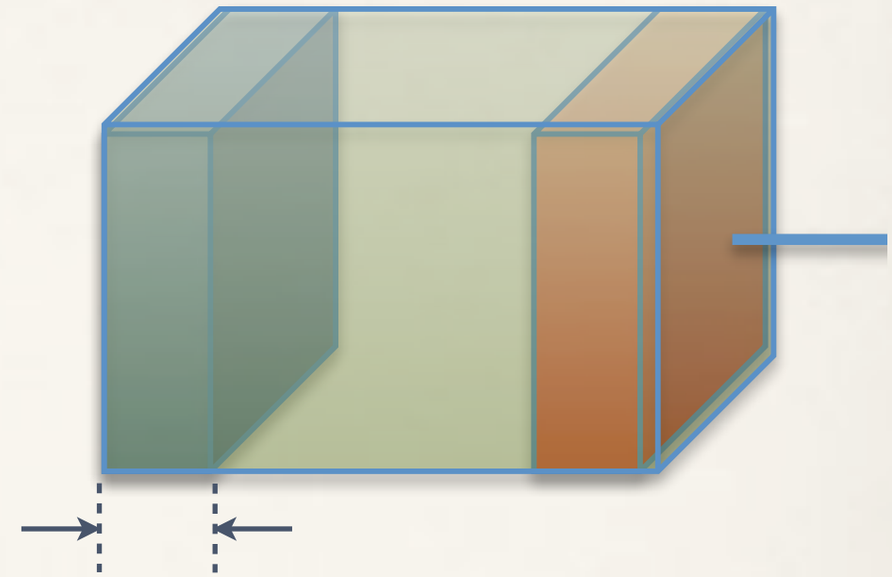
Charge collection
- drift - all charge drifts directly towards anode
- diffusion - charge goes into 4π
- recombination - no charge collected

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Entrance Window



X-ray absorption in thin windows



Minimize this dead space for soft x-rays

SNAP (optical) CCD

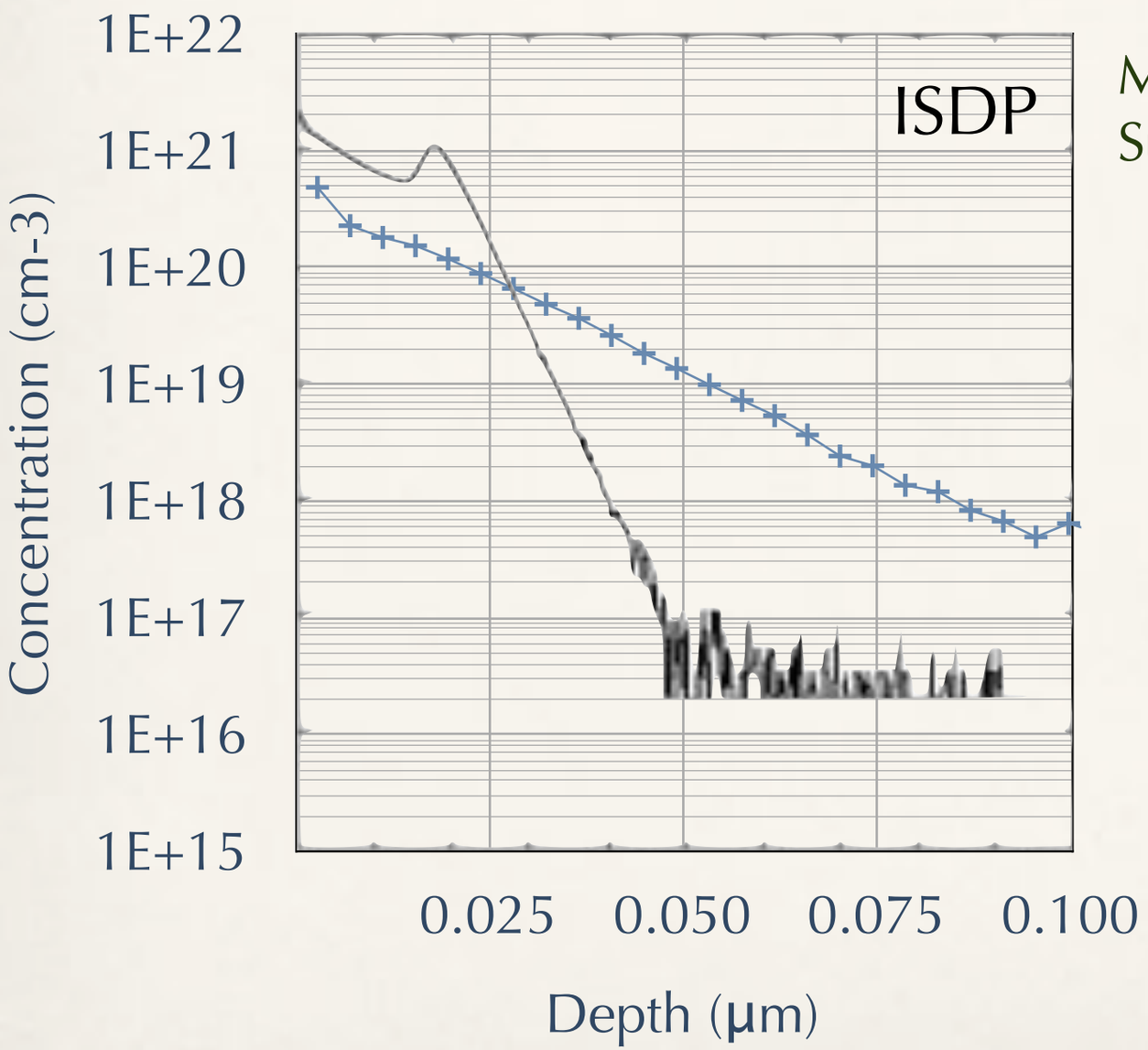
Thinned, back-illuminated CCD: laser annealed, partially depleted

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

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Low Temperature Window Process

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



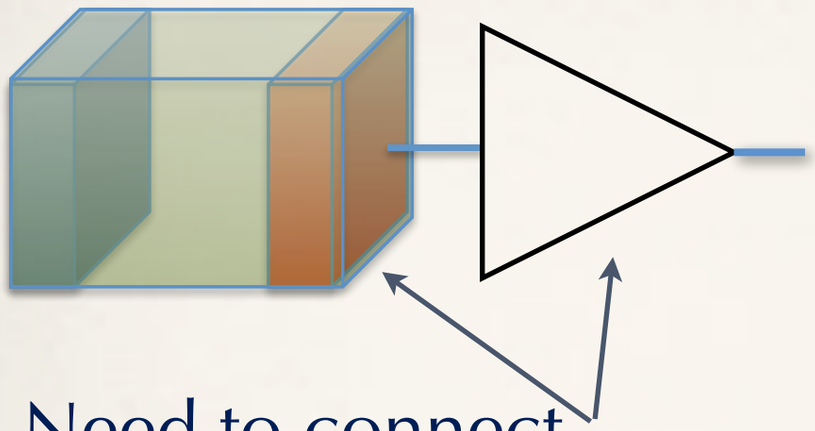
Measurements on pin diode
Successfully implanted SOI

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

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

The Problem with Pixels



Need to connect

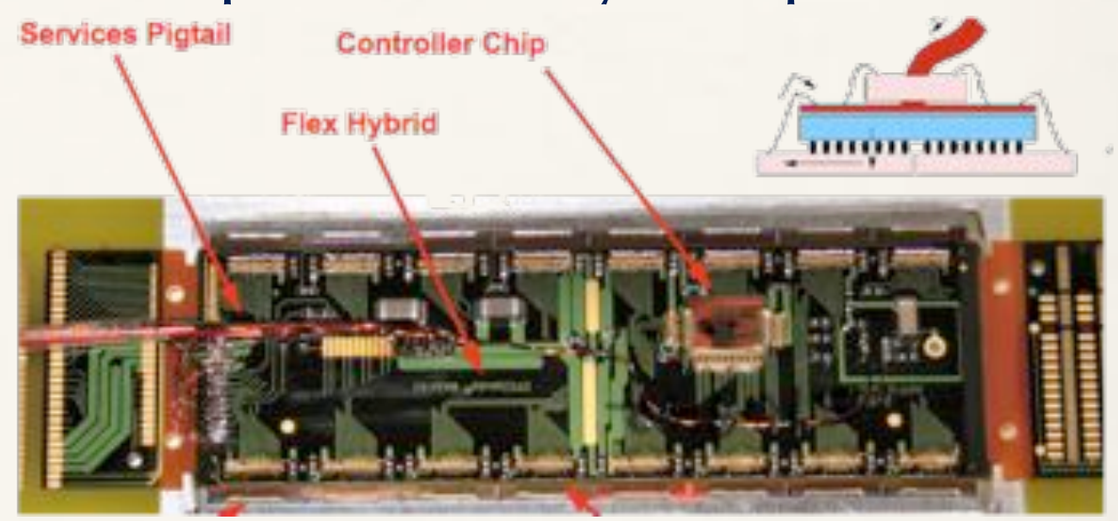
Old Fashioned Solution

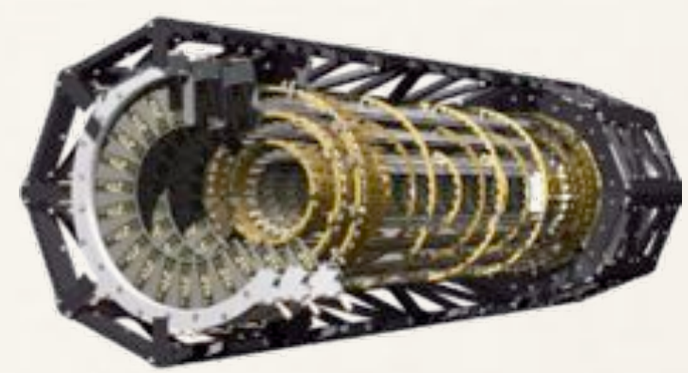
Monolithic detectors based on CMOS: CCDs

CCD Pixel IQ: 0

Current Solution

Bump-bonded hybrid pixels

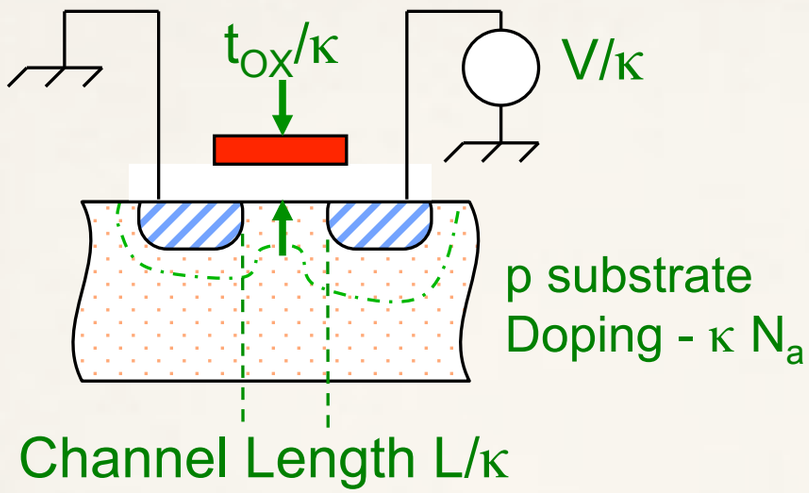


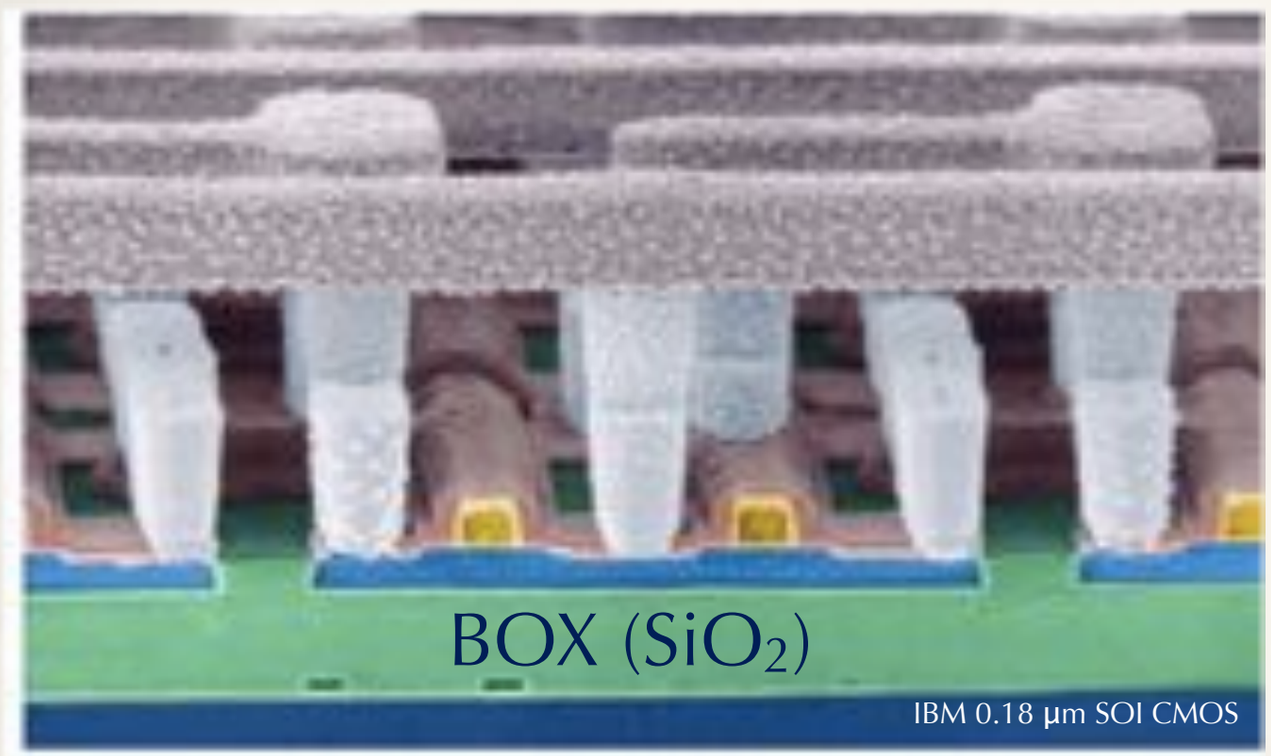


Hybrid Pixel IQ: High

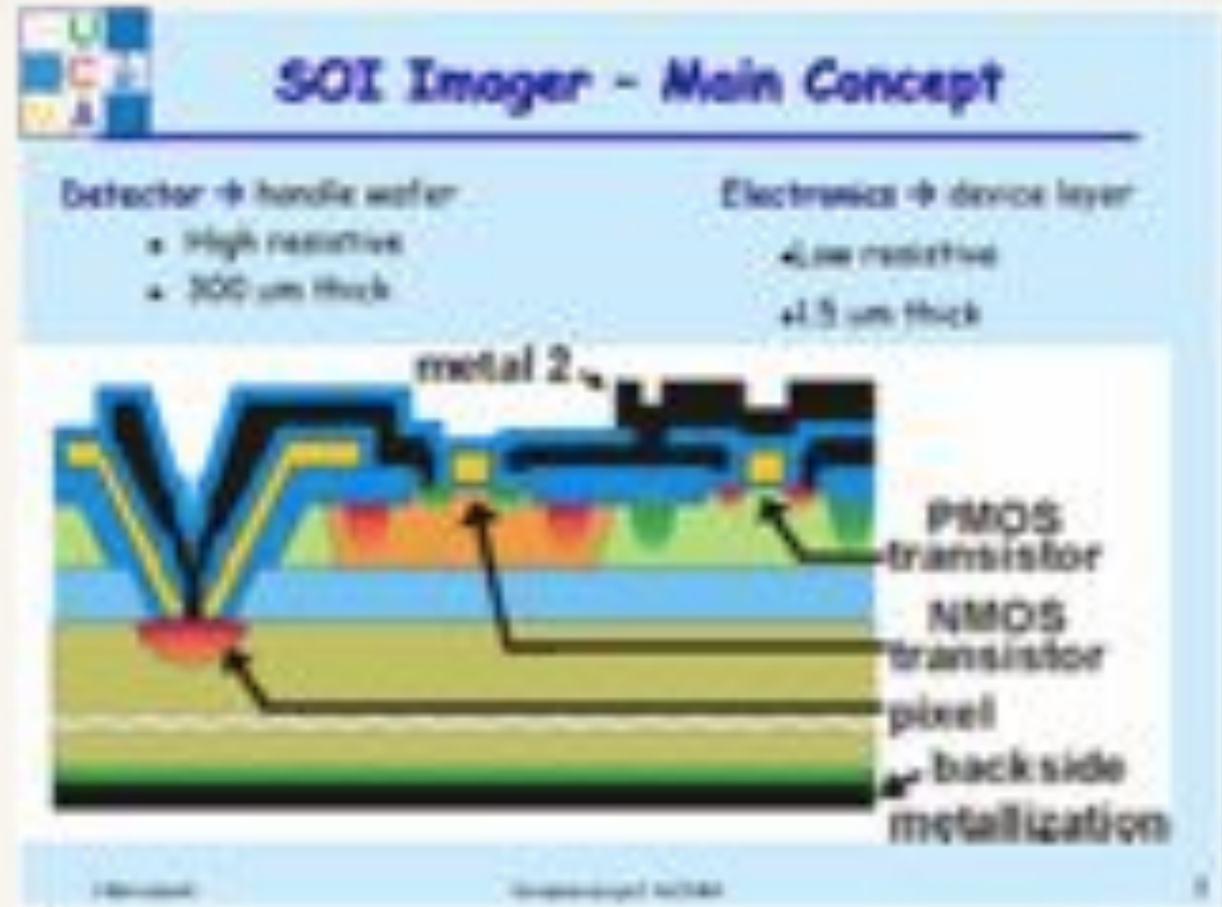
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Silicon-on-Insulator





Conventional SOI to reduce capacitance to substrate



Attempt at the "lab" level:

- High resistivity substrate
- Contact/implant through BOX

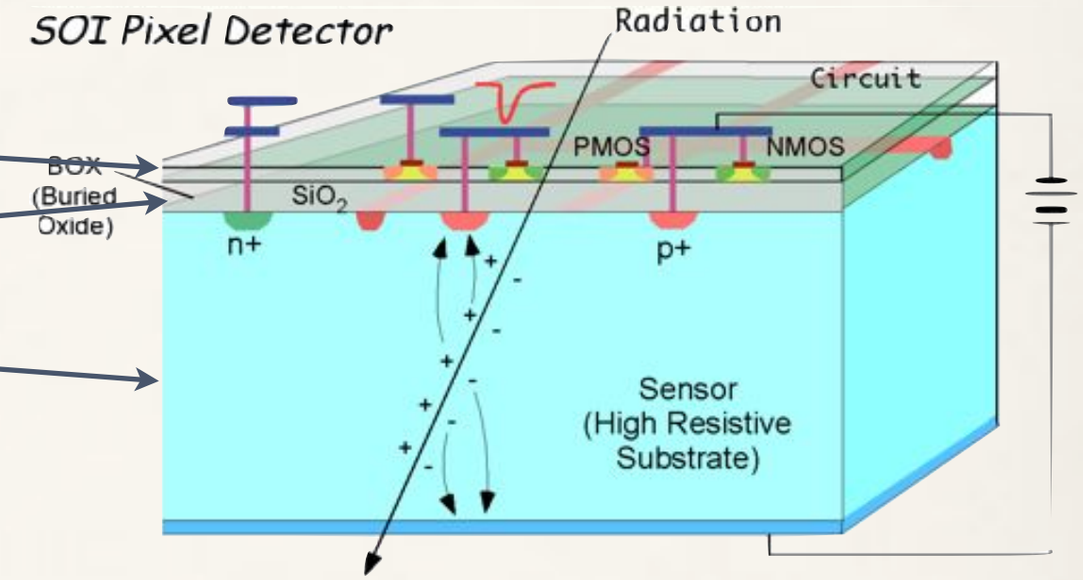
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Silicon-on-Insulator

50 nm CMOS / DI

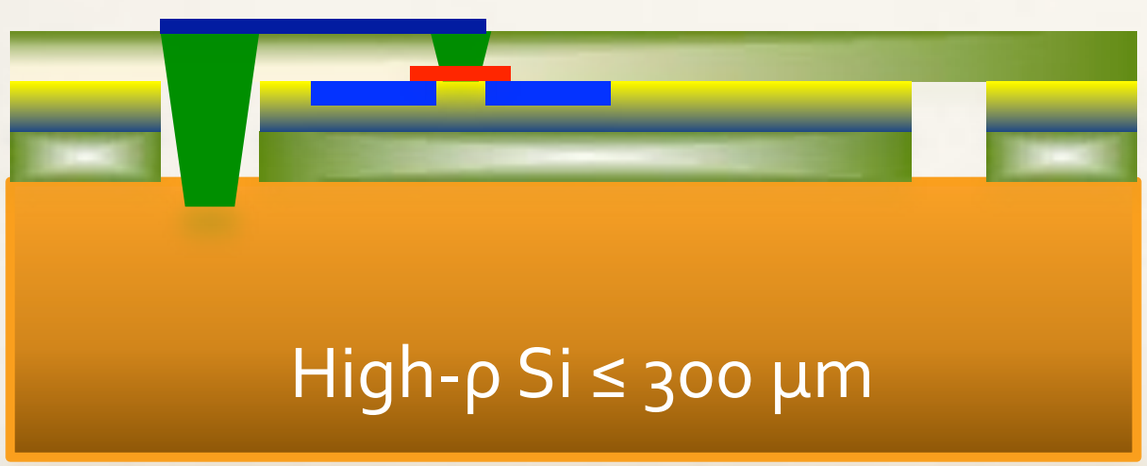
200 nm SiO_2

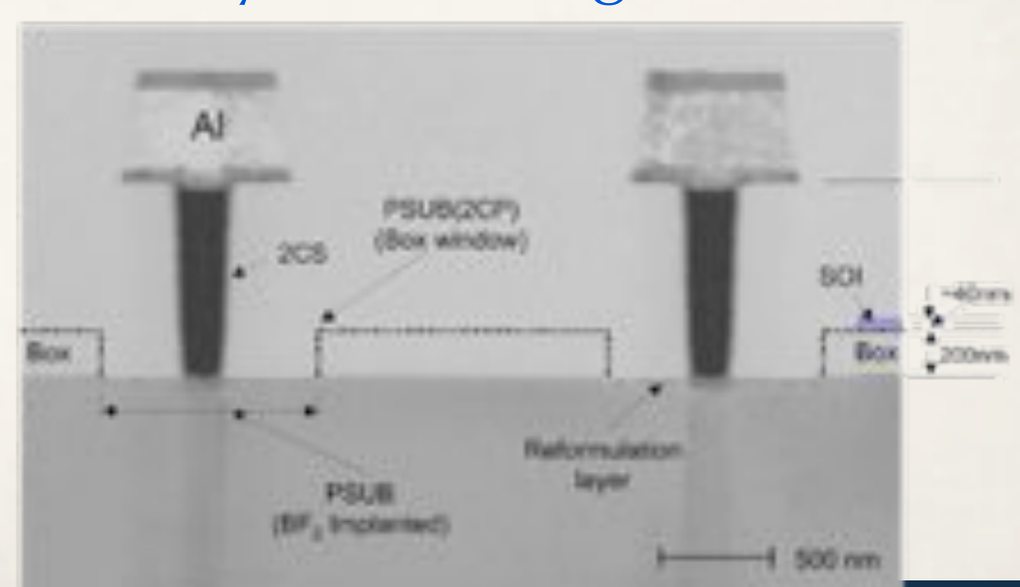
200 μm high ρ Si



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

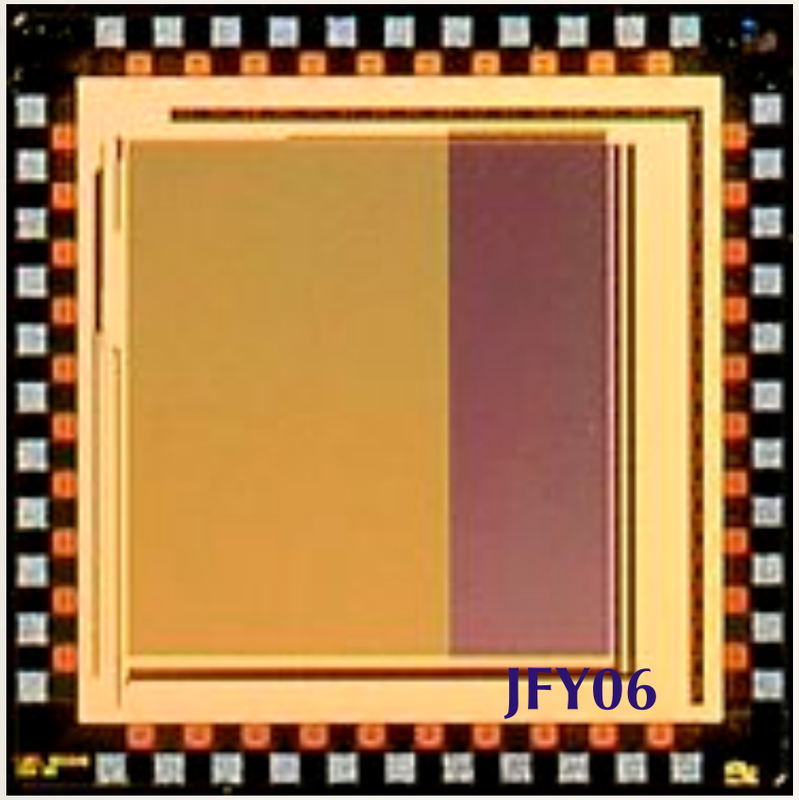
CMOS on thick, fully-depleted, high-resistivity, detector-grade silicon

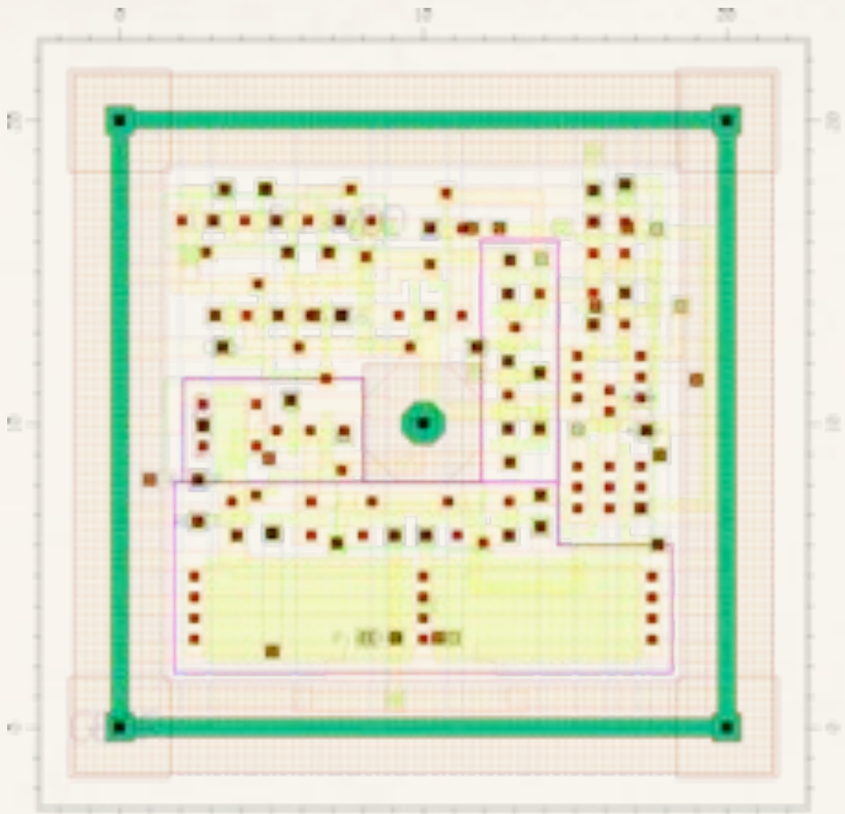


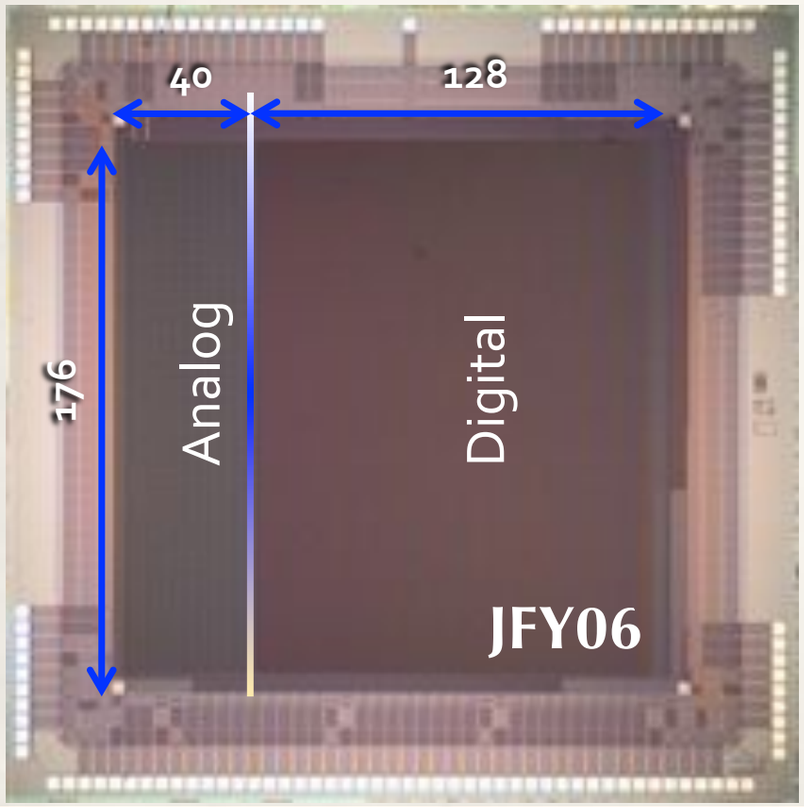


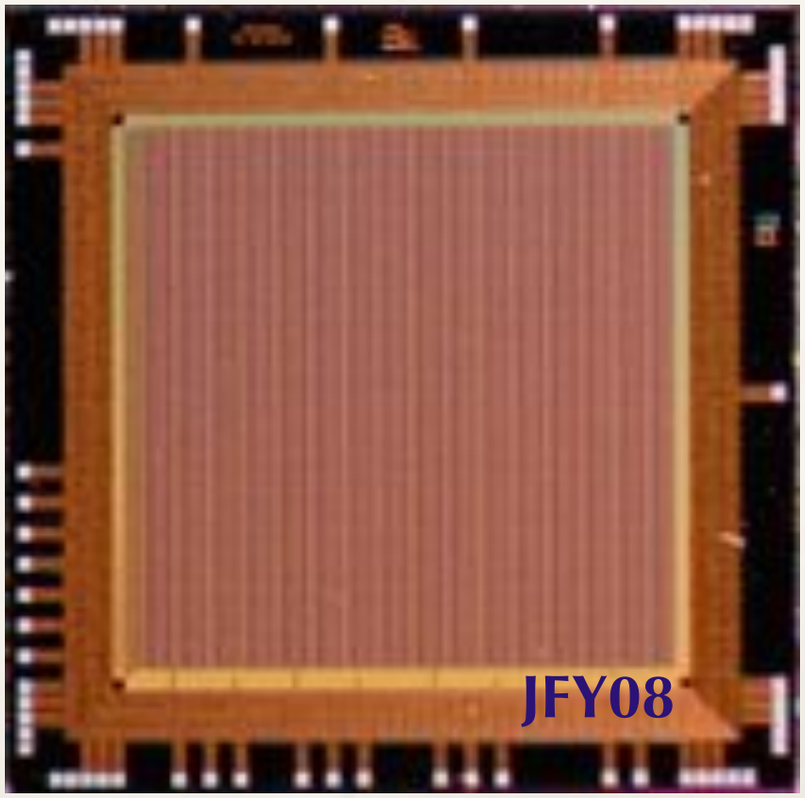
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

SOI R&D





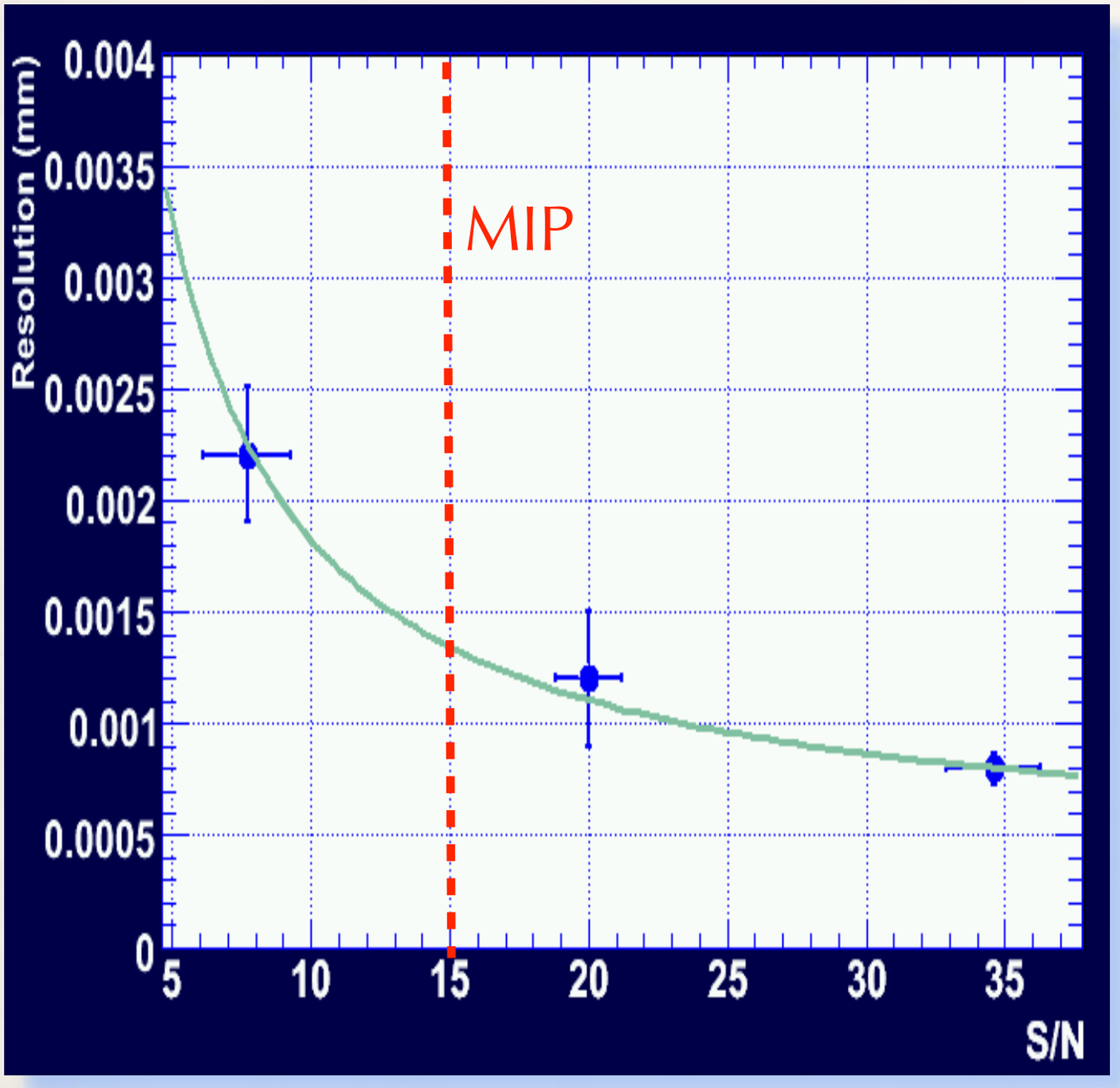


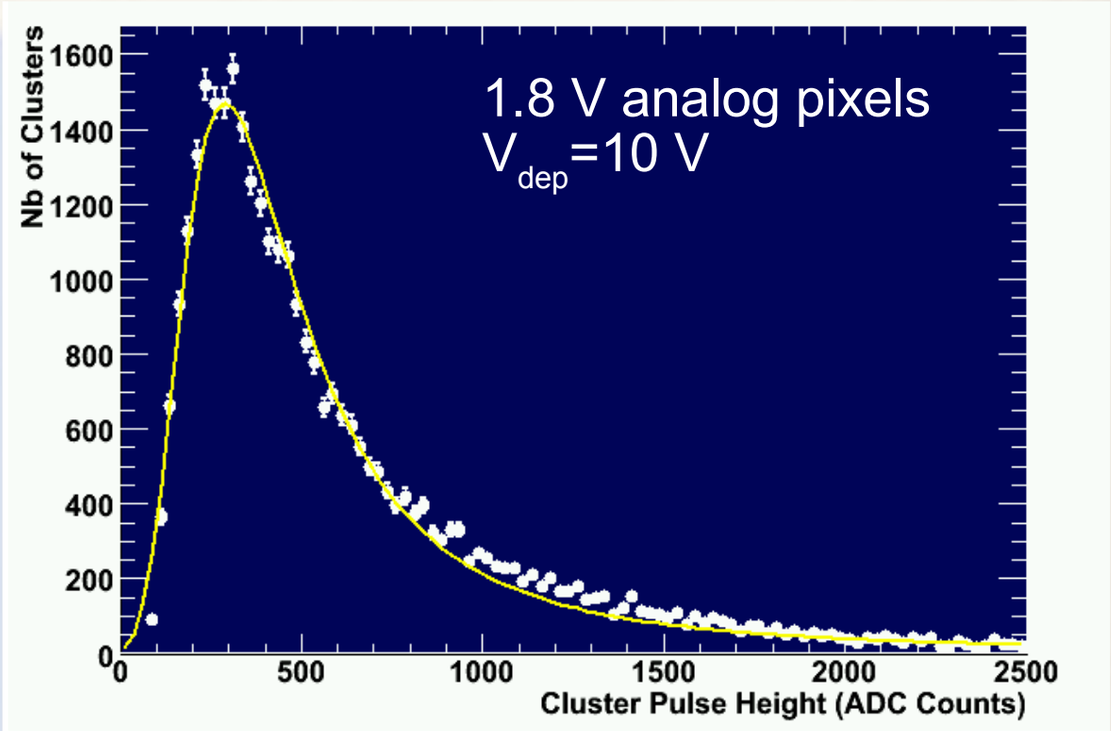


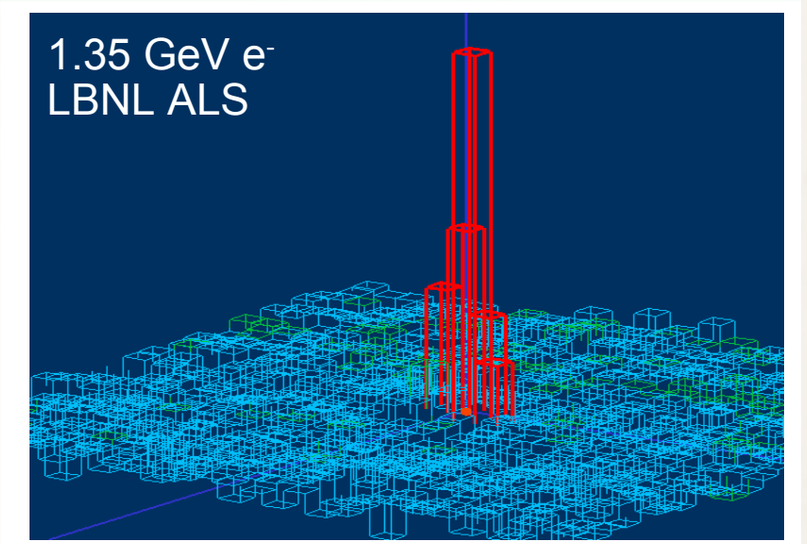
- LDRD-supported for ILC FY05-07
  - US/Japan funds
  - Analog and digital pixels
- BES detector R&D for xrays
- Start testing on 5.3.1
- femtoPix

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

SOI (in the ILC Context) Demonstrates 1 μm Resolution





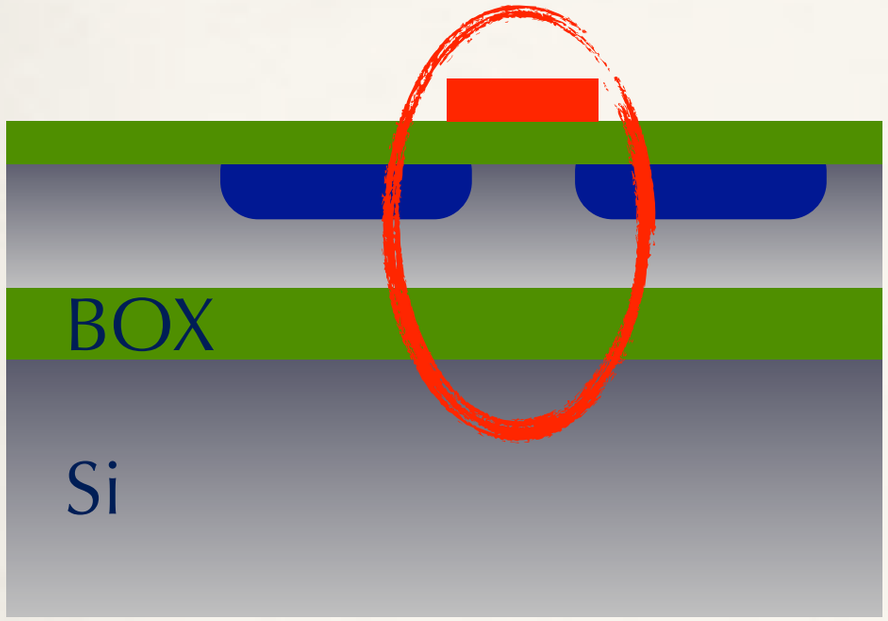


Scan with laser
vary power to simulate different S/N
cross-check with e^- beam

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

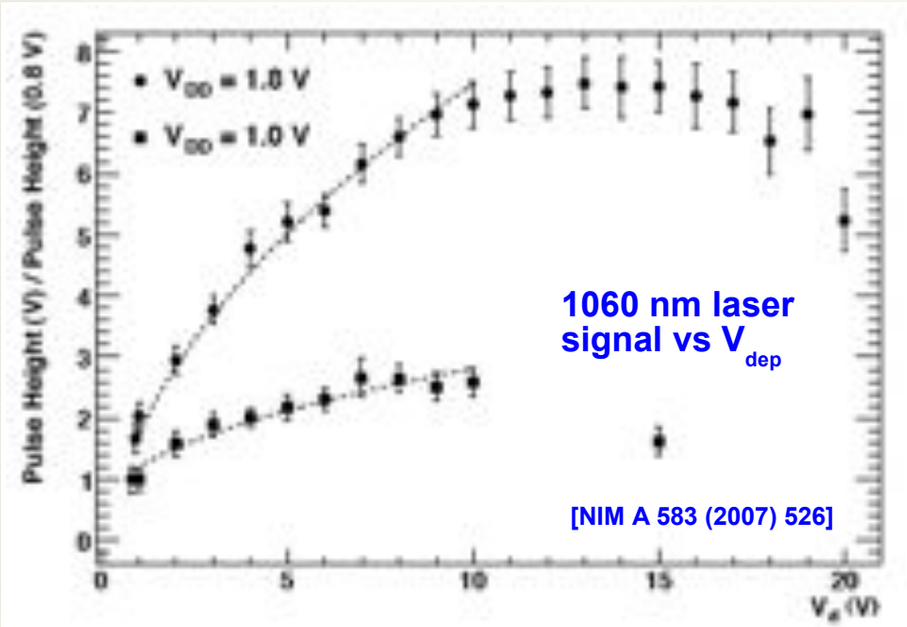
Issues

Still an "R&D" process



Back-gating:
Channel sees gate and back-gate potential

Solutions:
Design improvements
Light p-spray

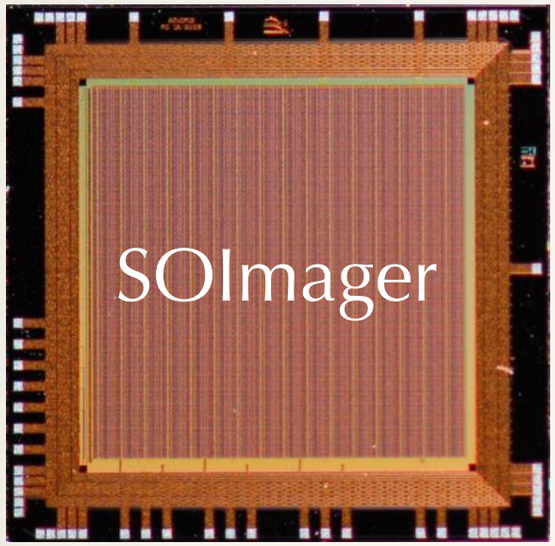


1st SOI Chip

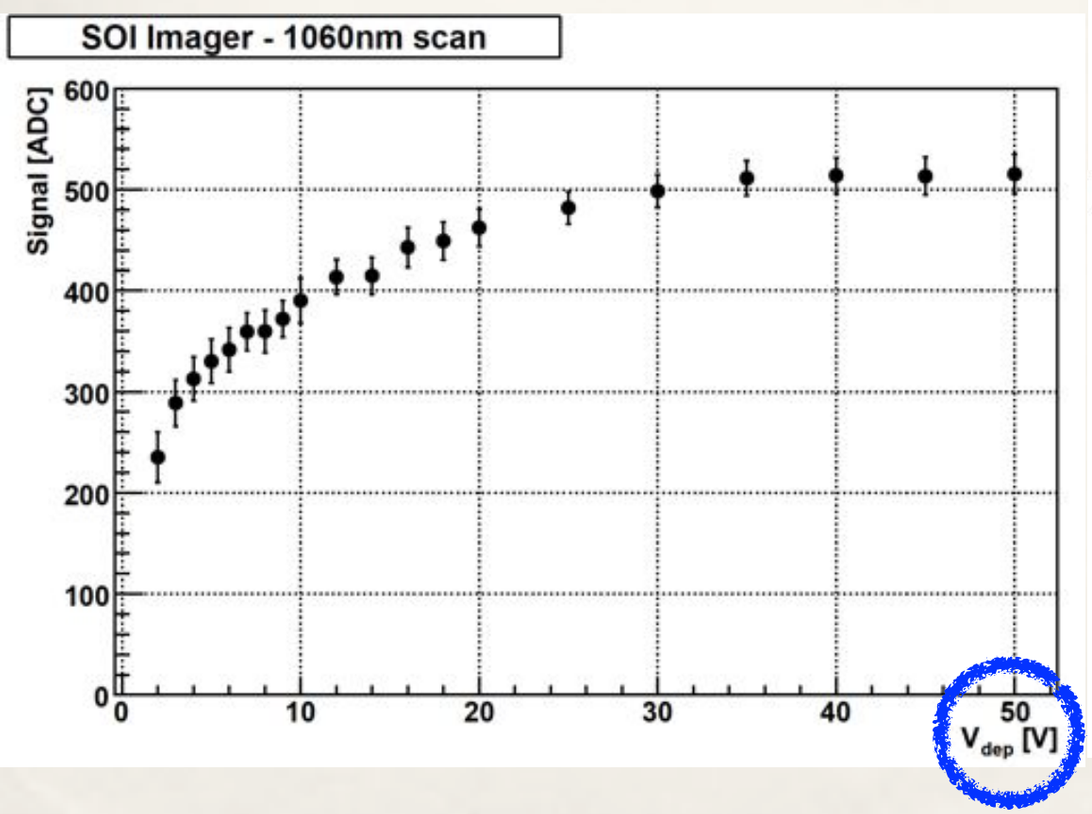
BOX poses radiation hardenss challenges

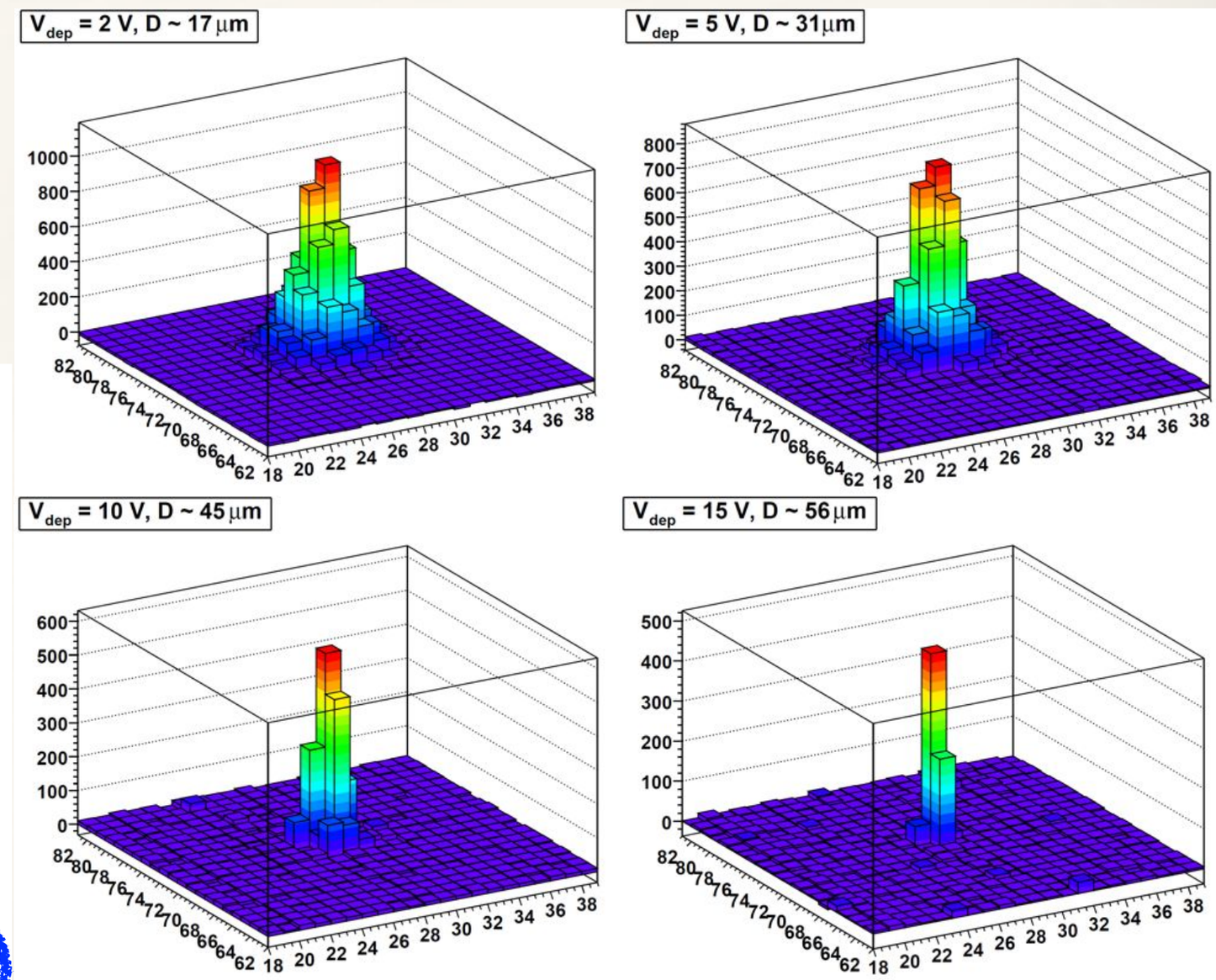
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Recent Results



- SOImager
- Thinned to 50 μm
- LBNL low-temperature implant (C. Tindall)
- δ-doping next

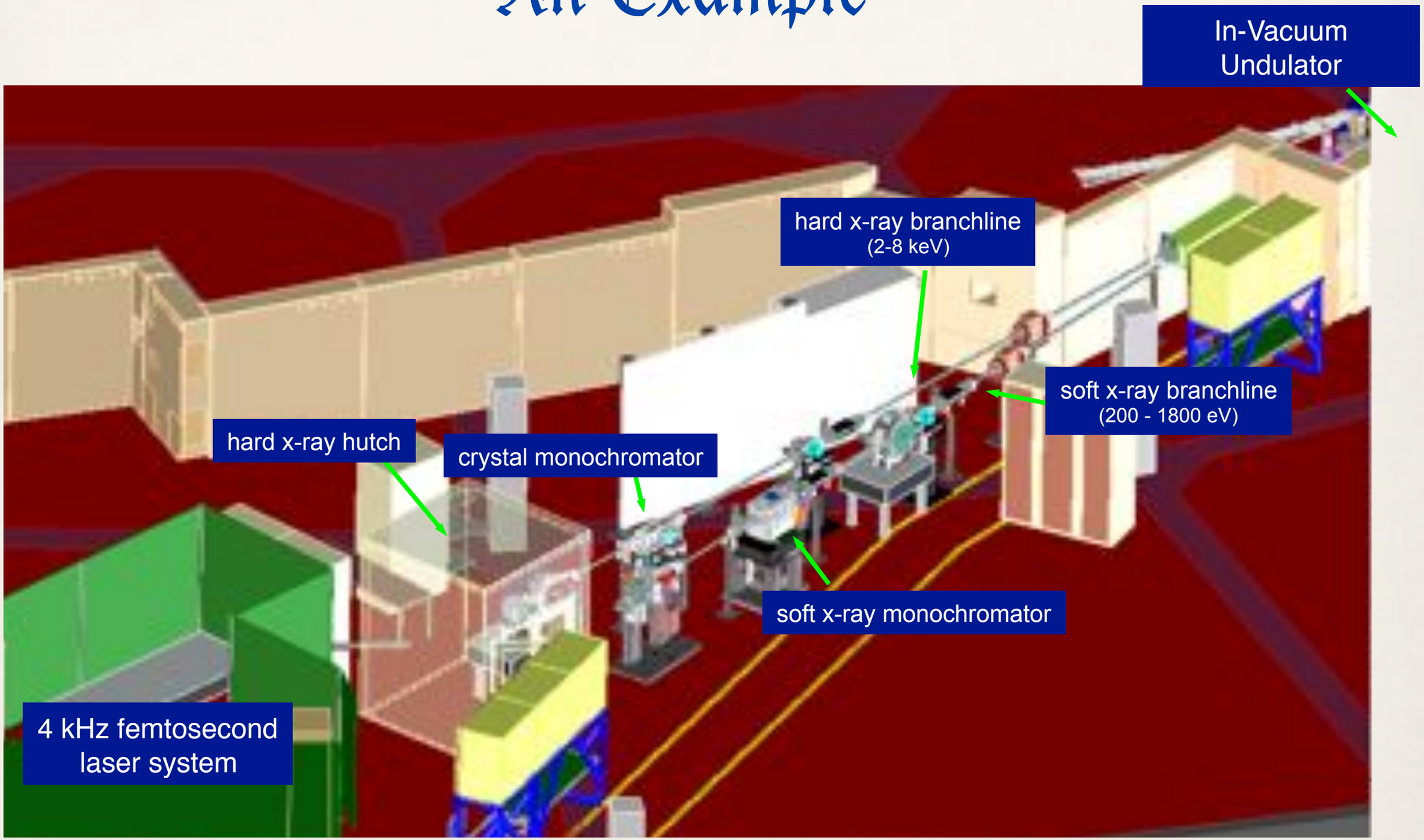




BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

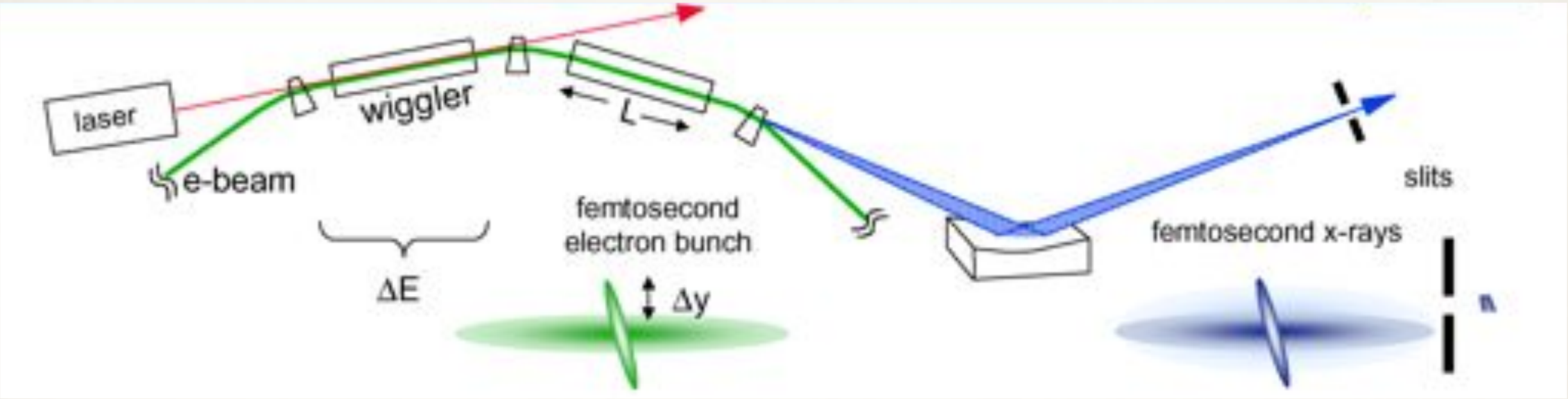
femtosecond Beamlines 6.0.1/2

An Example



BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

ALS femtoslicing BL 6.0



Zholents and Zolotorev, Physical Review Letters **76**, 916 (1996),, Schoenlein et al., Science **287**, 223 (2000)

200 fs pulses

But low flux - 10^5 γ/s/0.1% BW

Millions of dollars invested

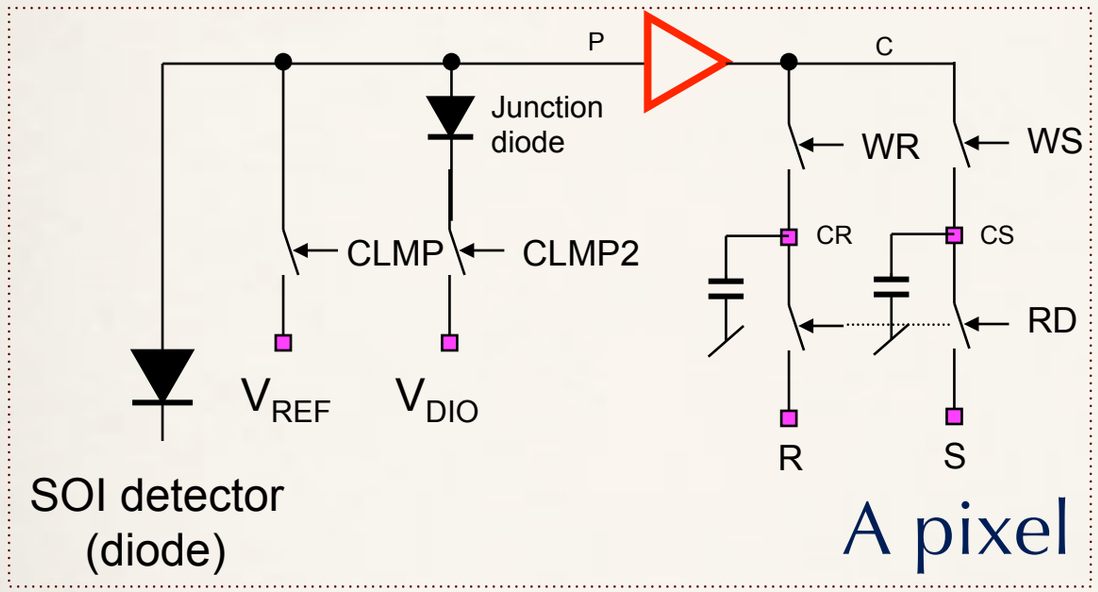
- in hardware
- in time to make this work

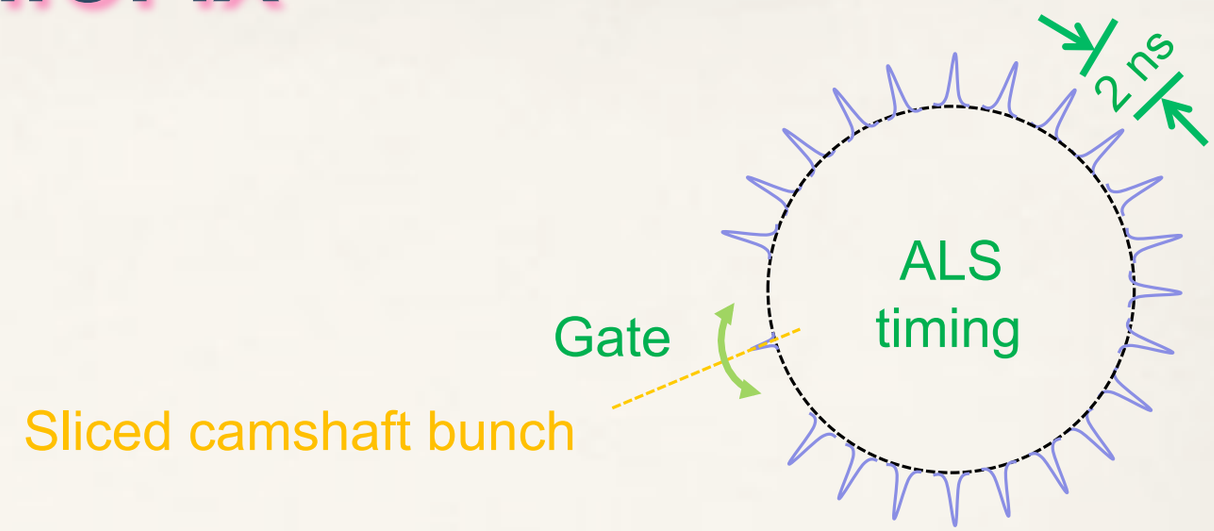
Detector used for last decade

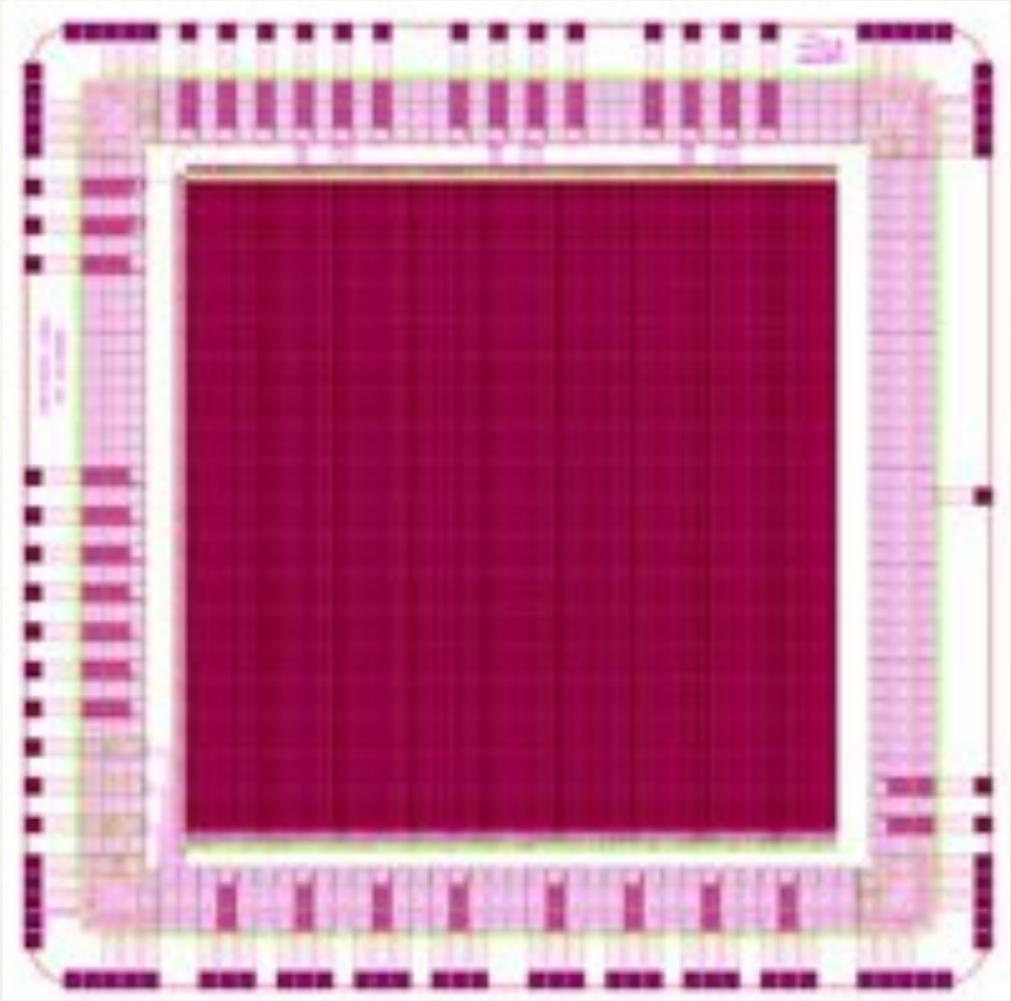
Perkin Elmer C30902: single element APD, $100

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

femtoPix





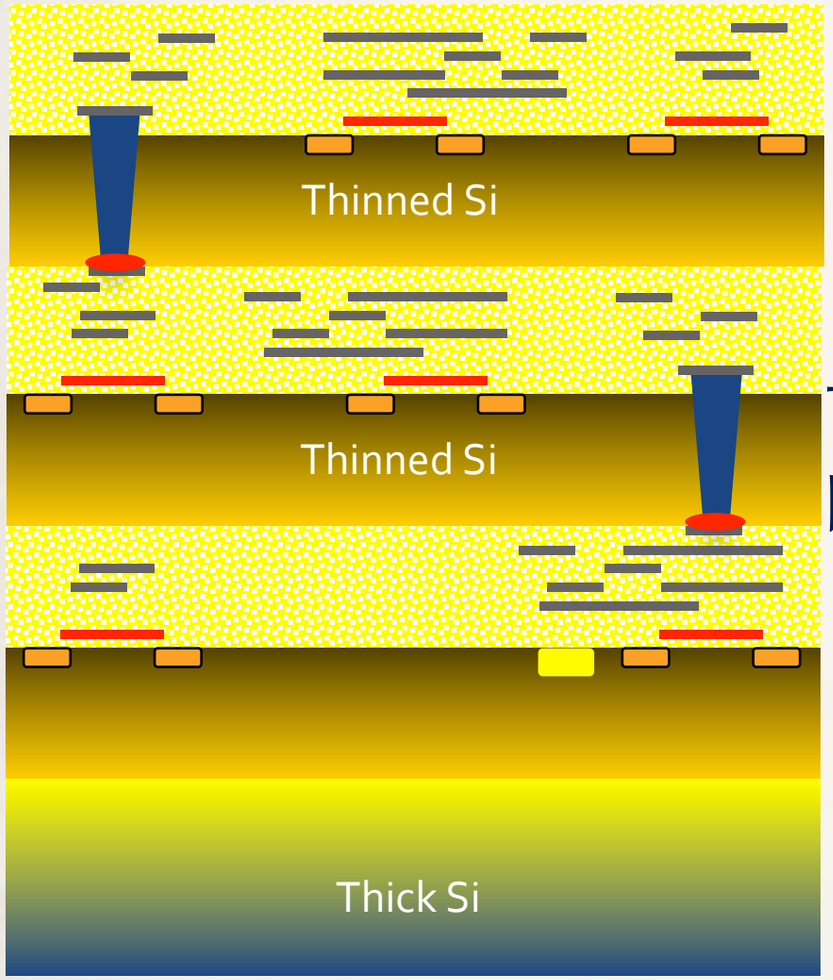


- 4,000 frames / sec.
  - 2 kHz laser on
  - 2 kHz laser off
- CDS
- Firmware processing
- Submission Jan. '10

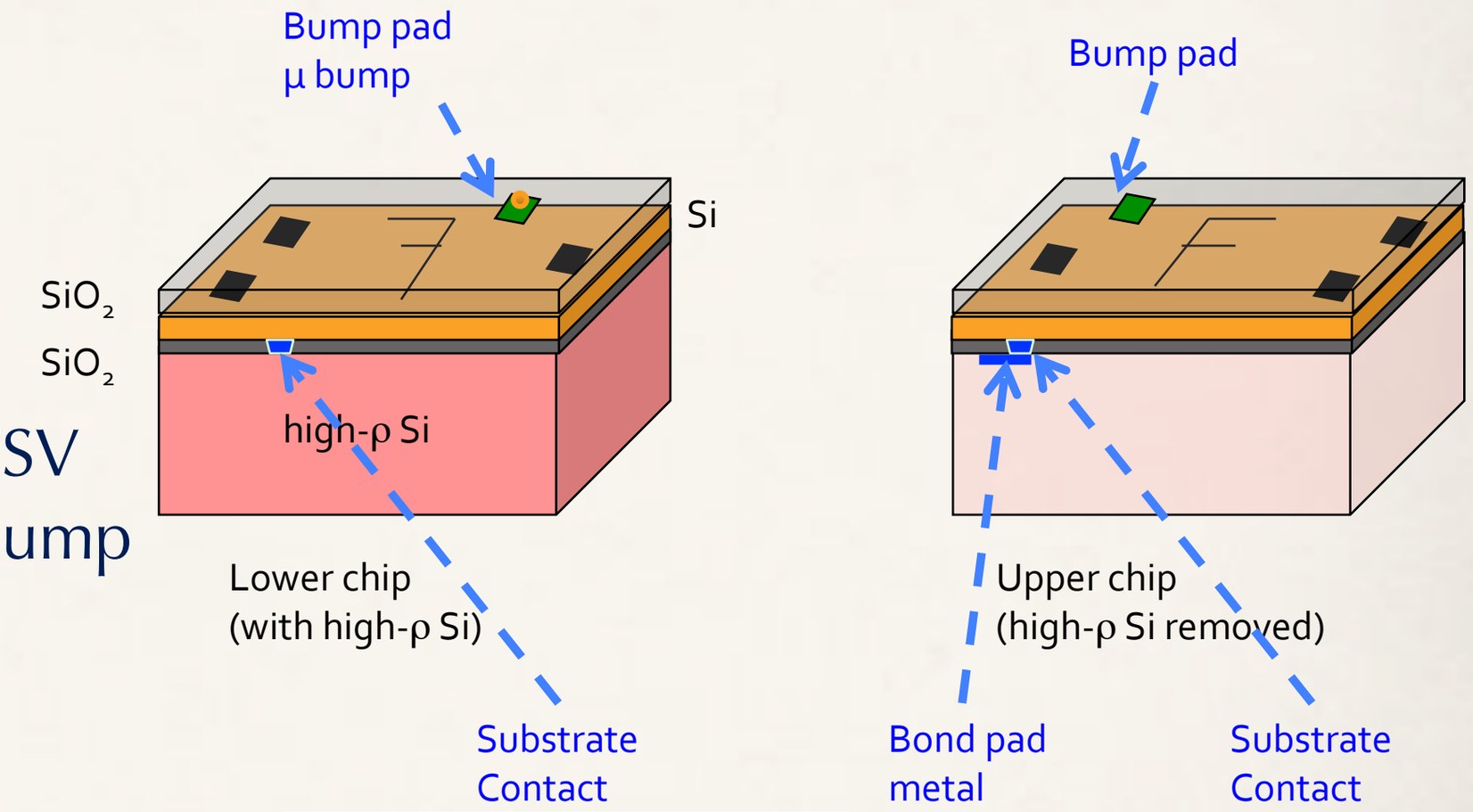
17.5 μm pixel

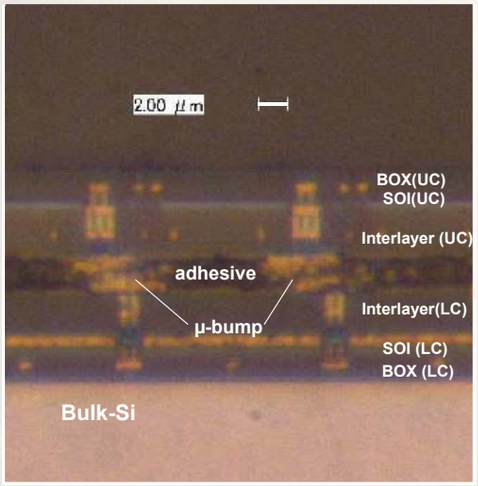
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

3D / 3D-SOI

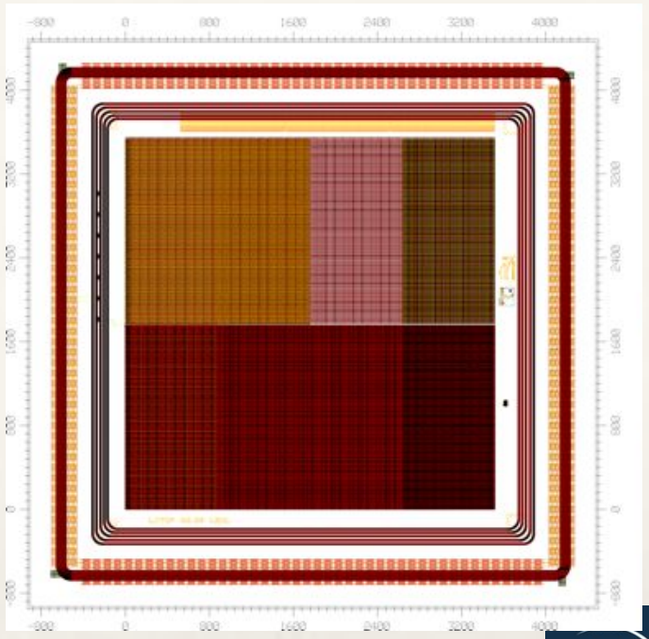


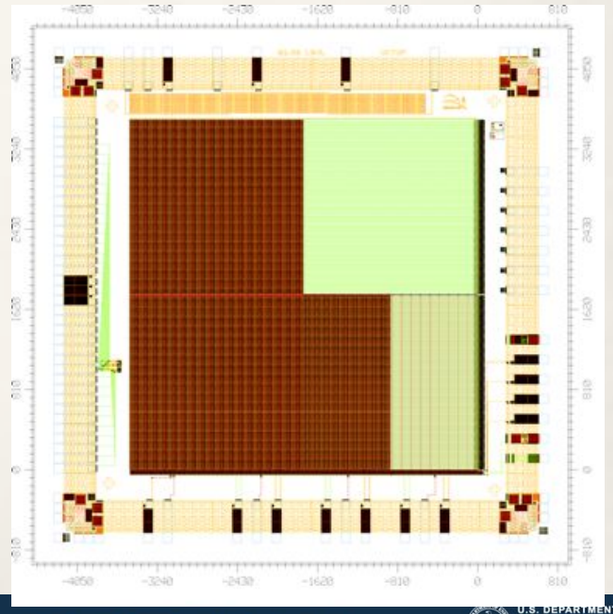
TSV
bump





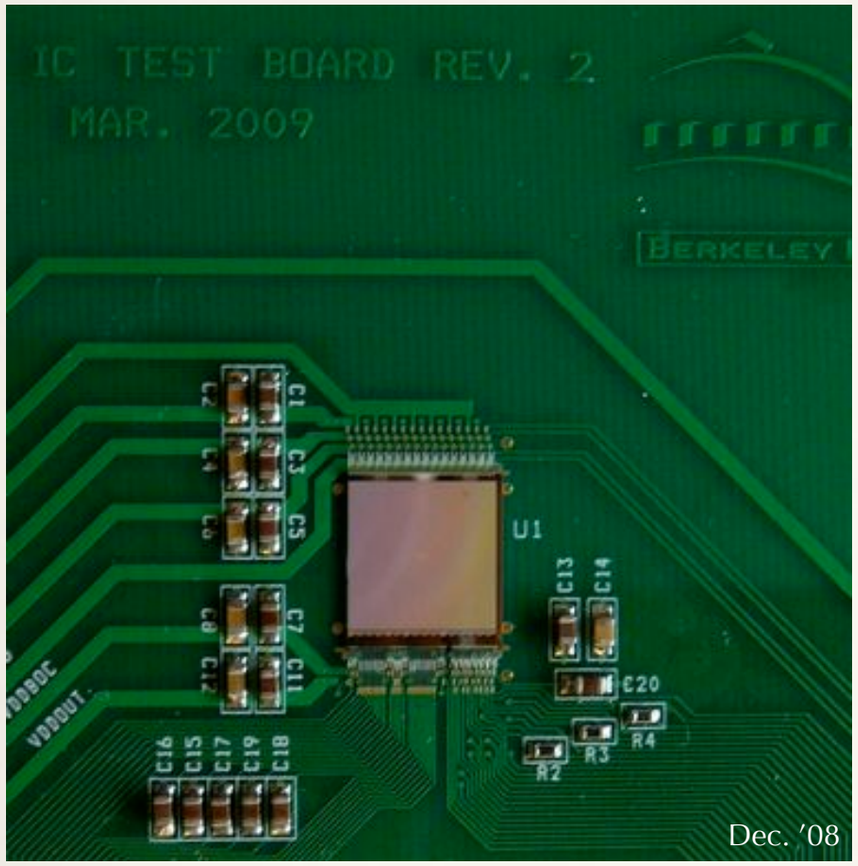
World's 1st 3D SOI
in 3D process now





BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Monolithic Detectors for Electron Microscopy

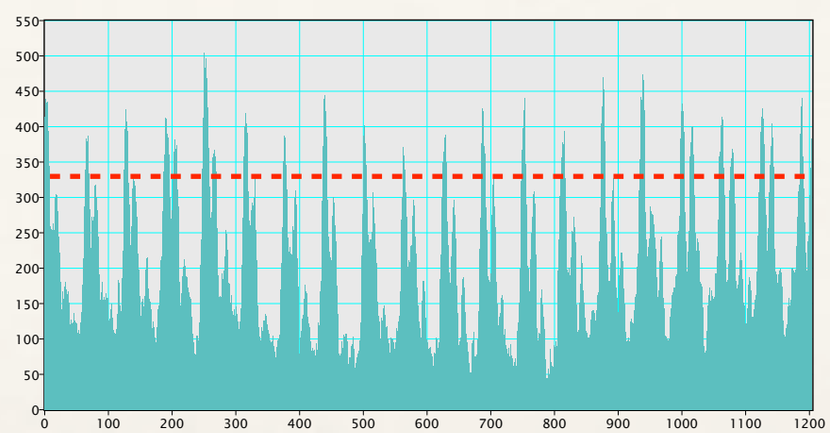


TEAM 1K

- 400 frame/s
- 9.5 μm pixels
- 0.35 μm CMOS
- **Single e⁻ S/N ~15**

Silicon dumbbells
single 2.5 ms exposure

6 e^-



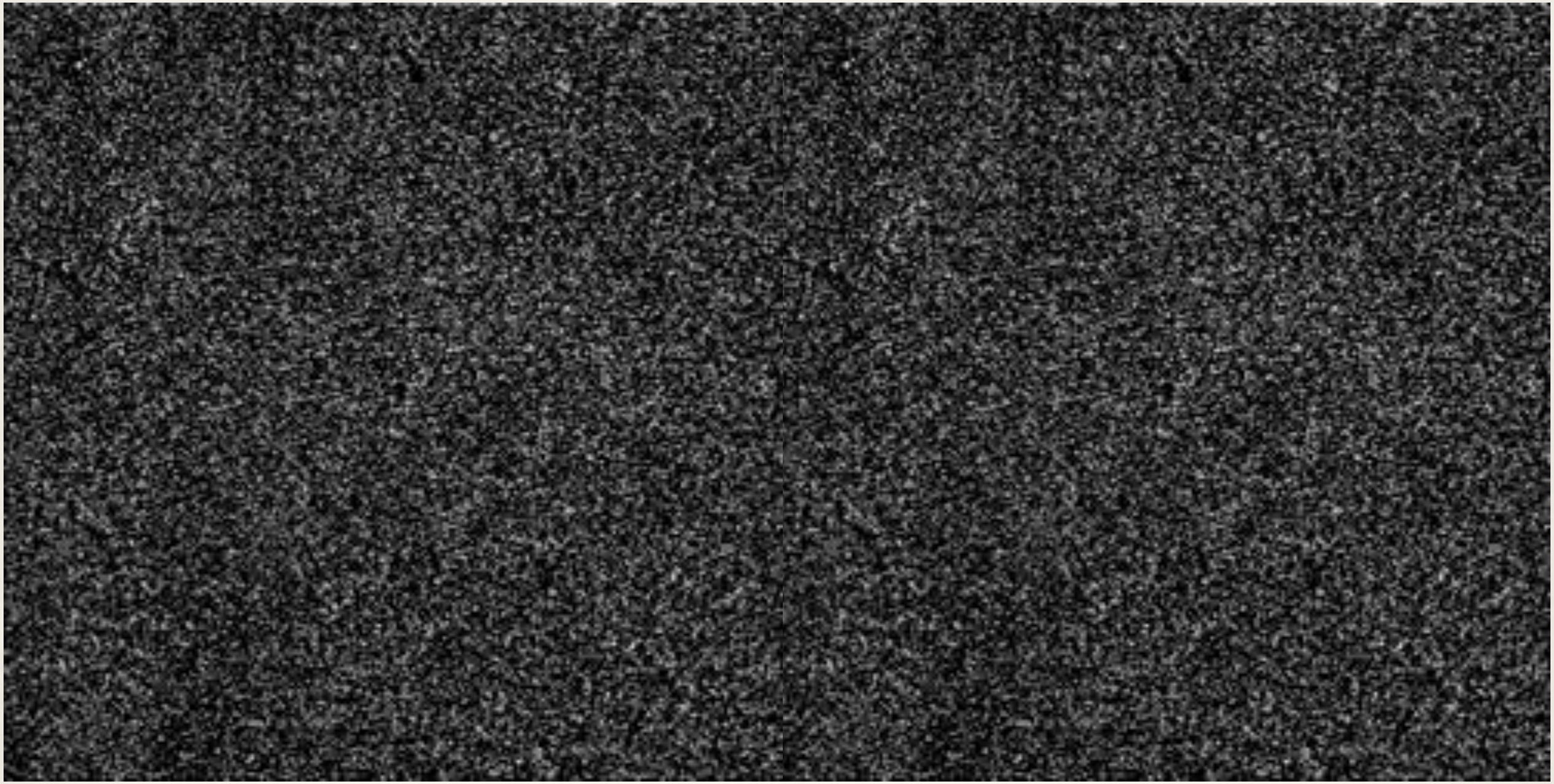
National Center for
Electron Microscopy

Advanced Light Source

The Molecular Foundry

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Boron Nitride (a la Graphene)

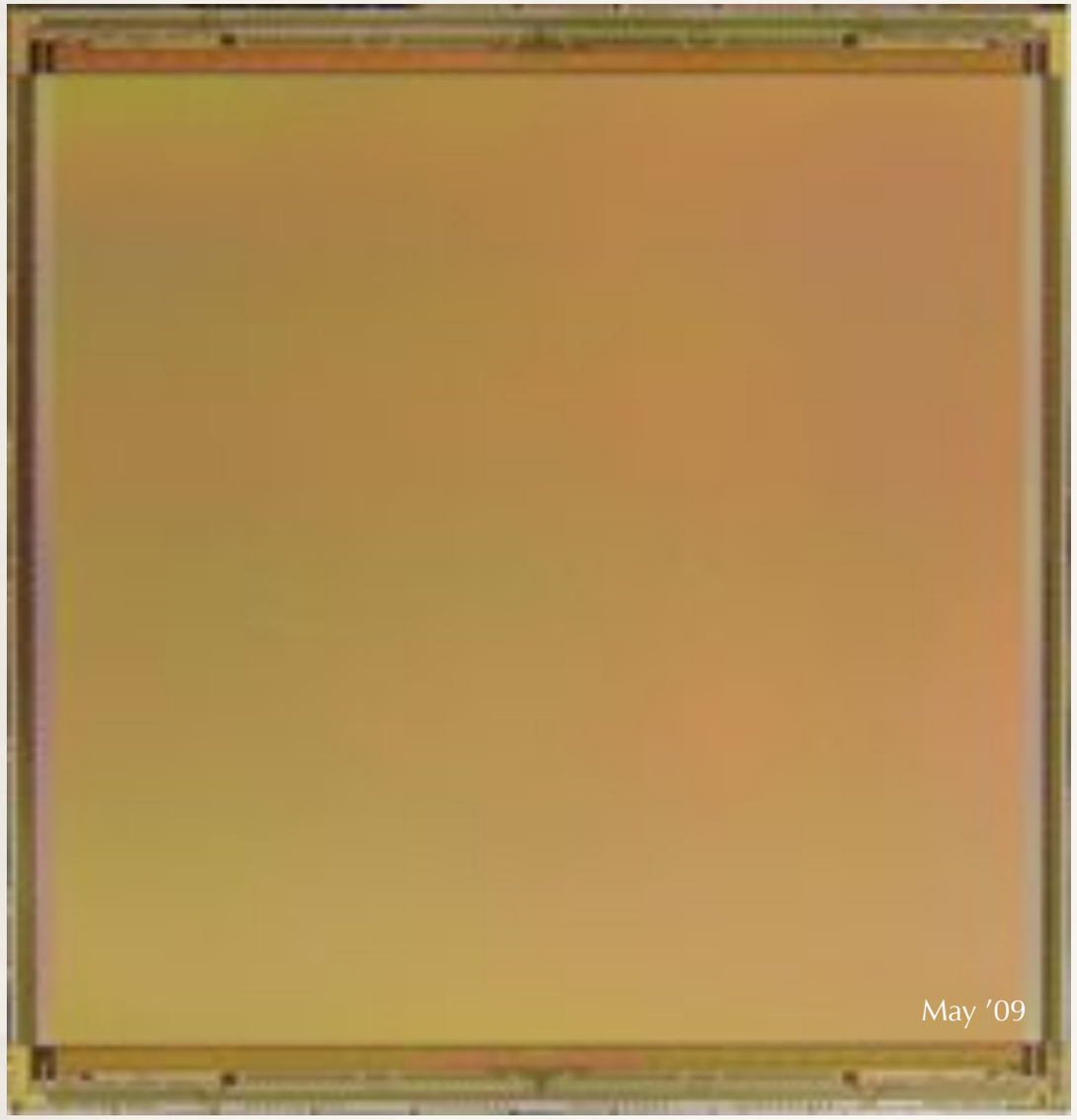


Individual 2.5 ms exposures

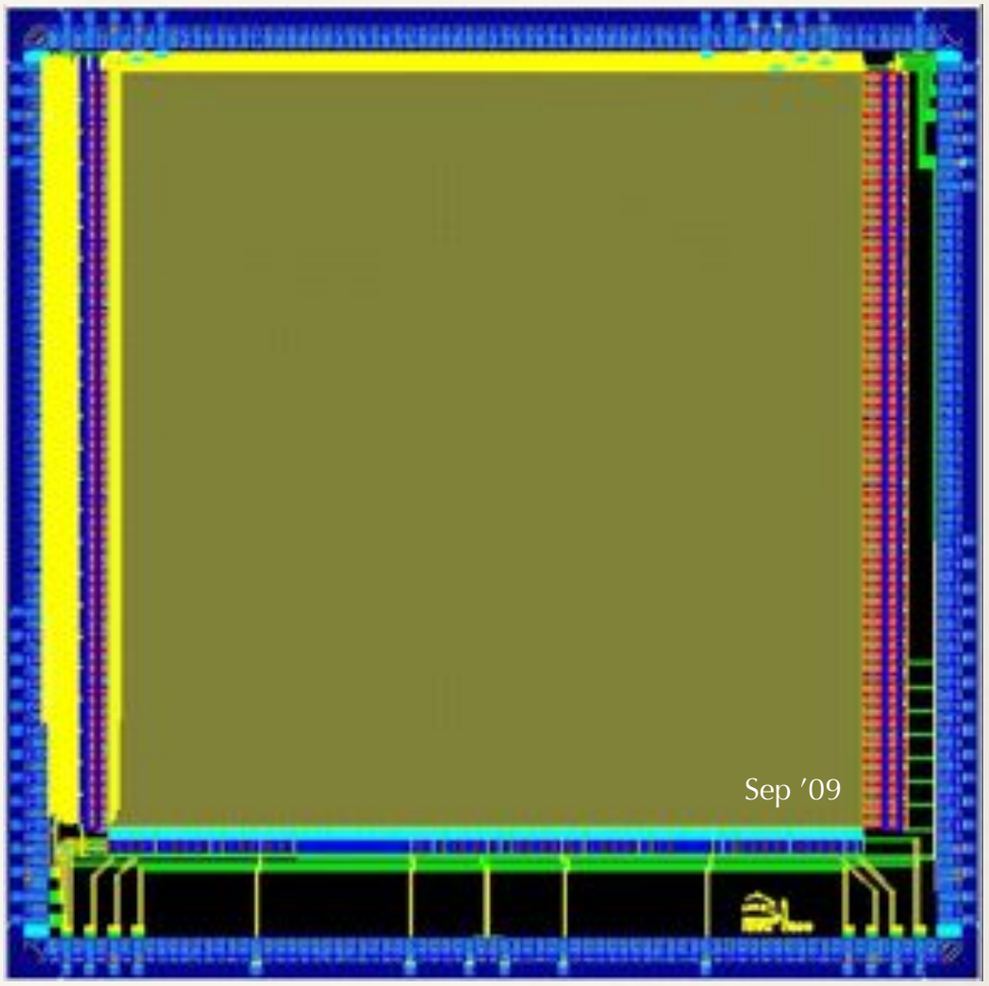
Summed

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Next Steps (e^-)



TEAM 2K
- 100/400 frame/s
- 9.5 µm pixels
- 0.35 µm CMOS
- Reticle Scale

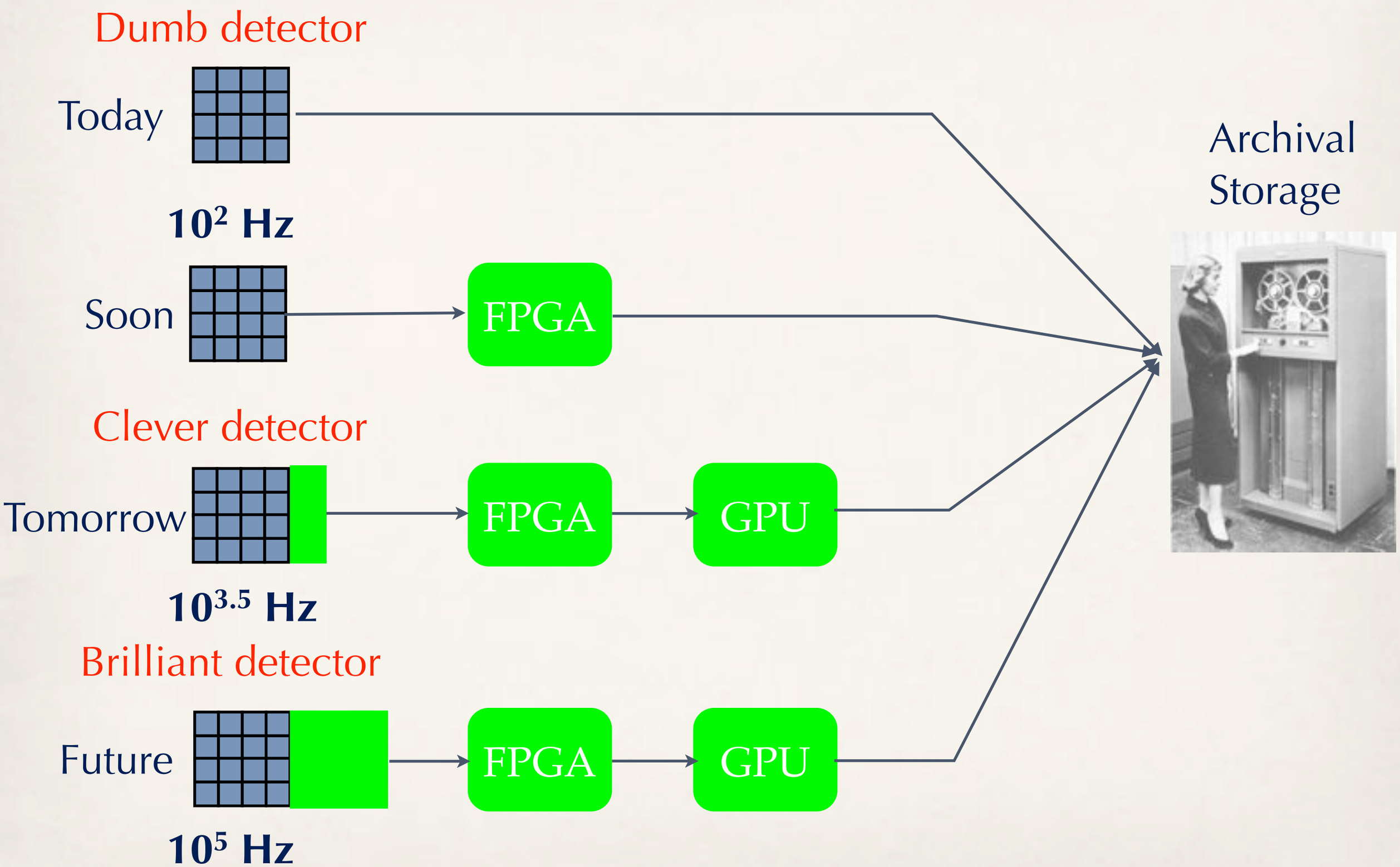


HHMI
- 5 µm pixels
- 0.18 µm CMOS

R&D - SOI for low voltage EM
(LEEM, PEEM, SPLEEM, LVTEM, ...)

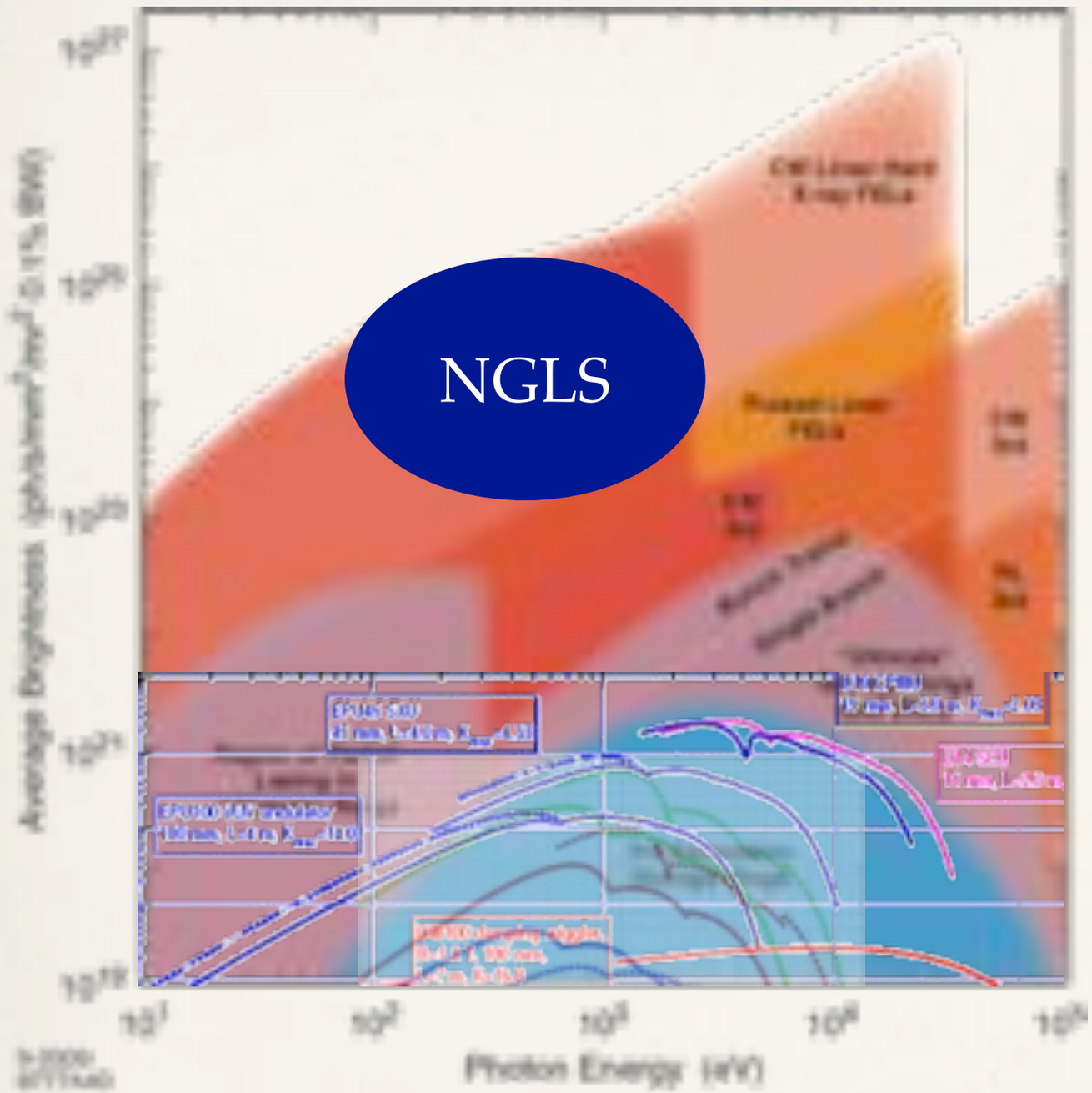
BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

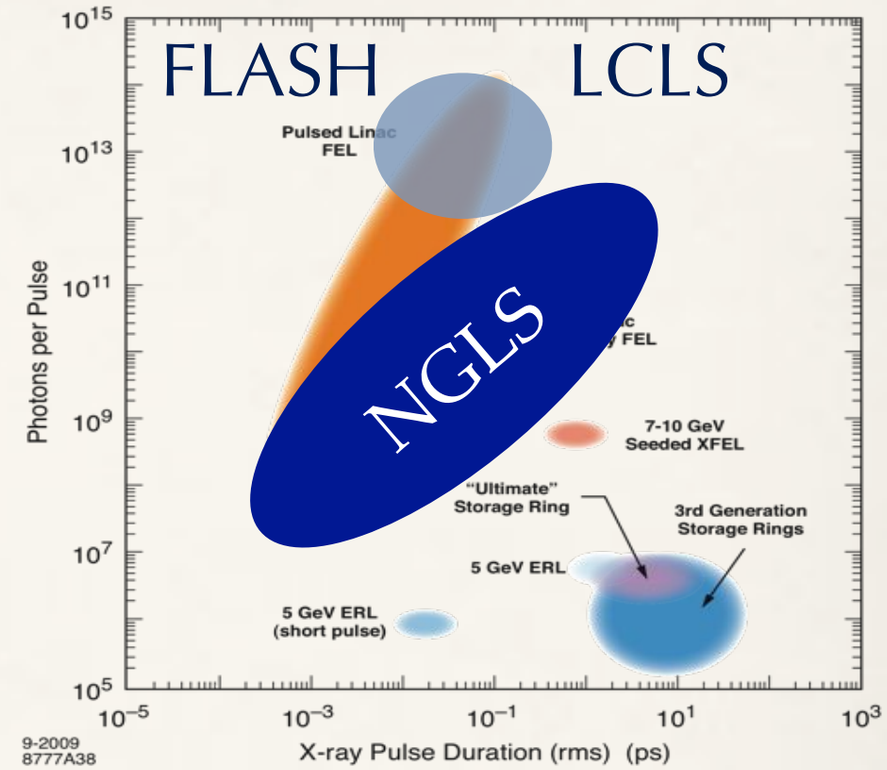
R&D Directions (1)

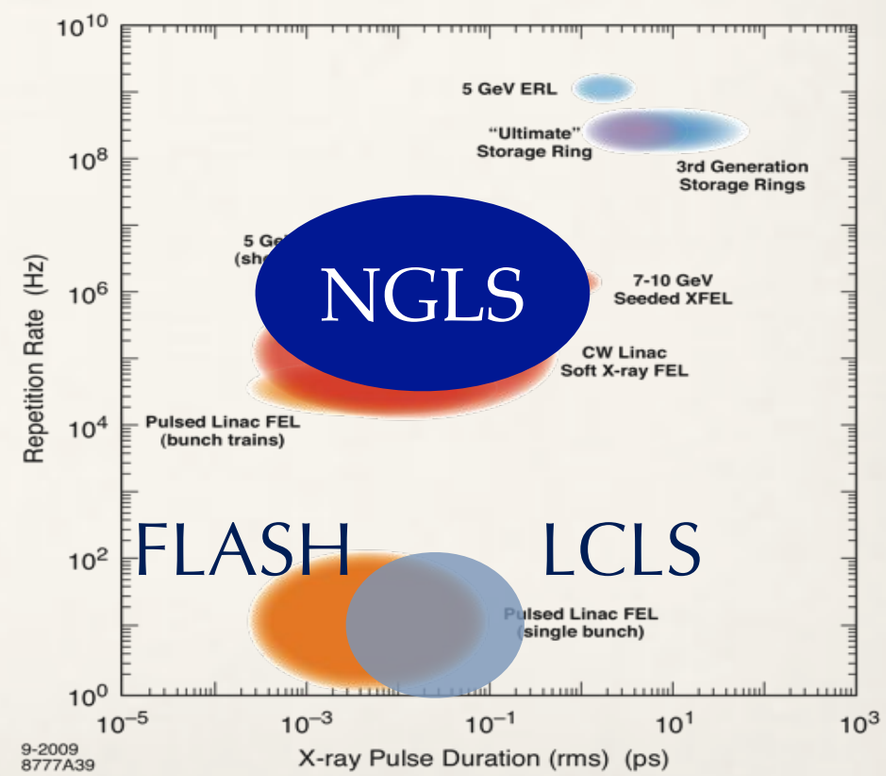


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Current and Future Light Sources



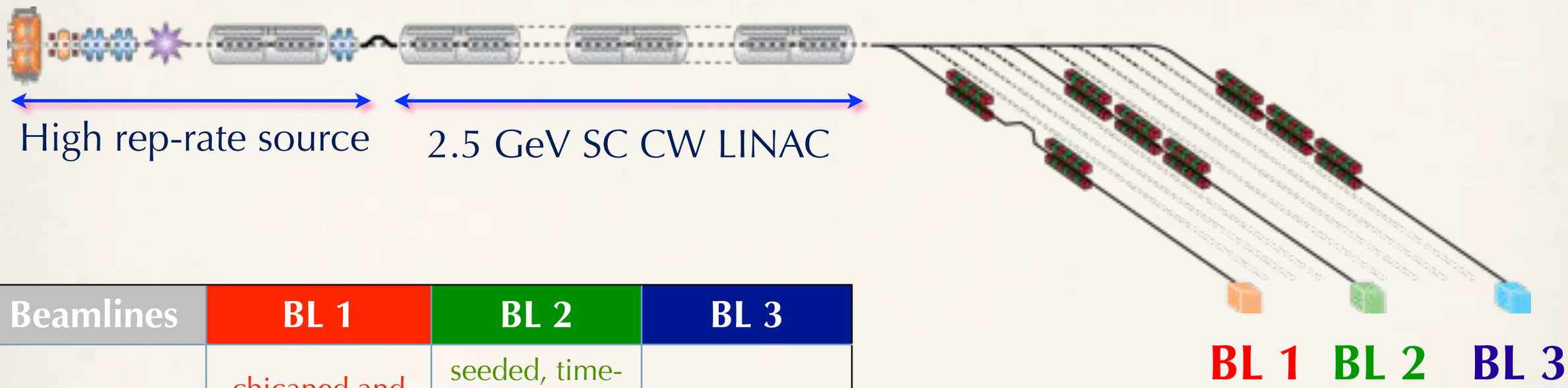




ALS Today
ALS with sextupoles
ALS "ultimate"
NSLS-II

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Next Generation Light Source



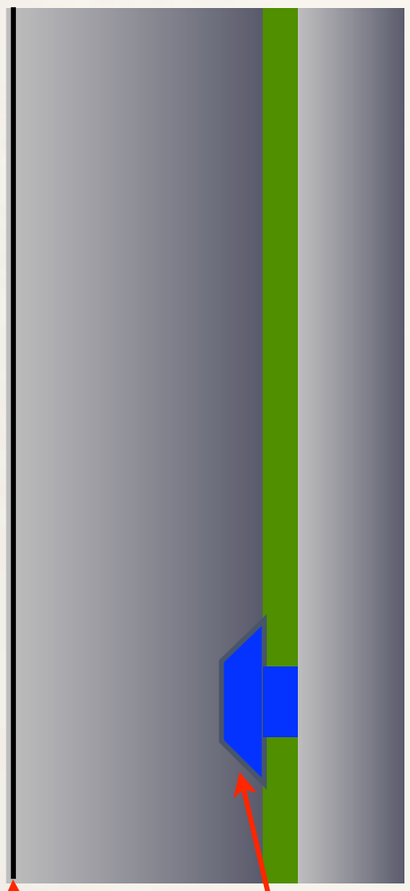
Beamlines	BL 1	BL 2	BL 3
Type	chicaned and seeded radiators	seeded, time-bandwidth limited	SASE
Feature	x-ray pump / x-ray probe with fs resolution	pump/probe with adjustable delay (THz - UV pump)	potential for seeding
Pulse Duration	250 as - 25 fs	250 as - 50 fs	1 - 50 fs
Repetition Rate	10 - 100 kHz	10 - 100 kHz	≤ 1 MHz
Peak Power	10 - 100 MW	1 GW	1 GW
R&D Options	EEHG HHG option	EEHG HGHG option	»1 MHz

Science		
BL 1	BL 2	BL 3
multidimensional spectroscopy	ultrafast dynamics	inelastic and coherent scattering
x-ray pump / x-ray probe	inelastic scattering	diffractive imaging
species-selective intramolecular dynamics		species-selective tomography

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

(My) Ideal *Soft X-ray* Detector

In 10 years, 10^5 fps



- Monolithic
- (or µ-bump) (?)
- Ever more processing
- Stitched (?)

- Radiation hardness
- Entrance window
- SNR
- Speed

- UHV

Missing (but needed)
- Z (hard x-rays)
  - Radiation hardness
- Spectroscopy
- Large area
- ...

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Questions?

Grateful acknowledgements to:
ALS Experimental Systems Group
ALS Scientific Systems Group
APS Beamline Technical Support Group
Electronic Systems Group
Integrated Circuit Design Group
MicroSystems Laboratory
National Center for Electron Microscopy
Physics Division
Engineering Division