# Detector R&D at Berkeley Lab

Peter Denes

BERKELEY LAB

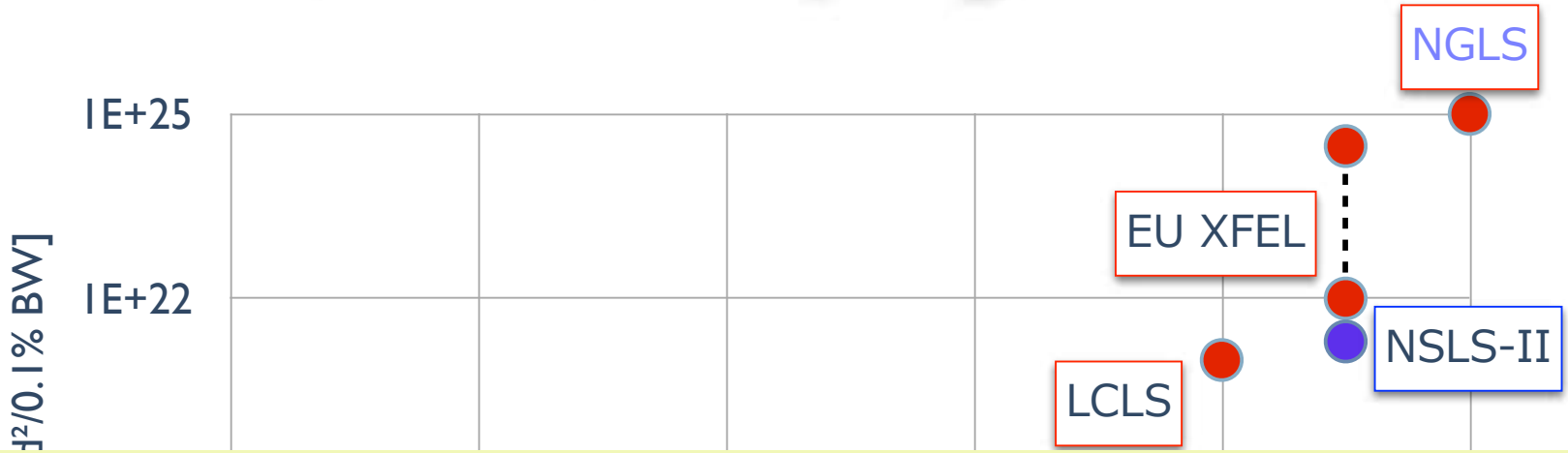
U.S. DEPARTMENT OF ENERGY
Office of Science

Accelerator and Detector Research and Development Program Principal Investigators' Meeting
August 22-23, 2011
The Westin, Annapolis, MD

Advanced Light Source
An Office of Science User Facility

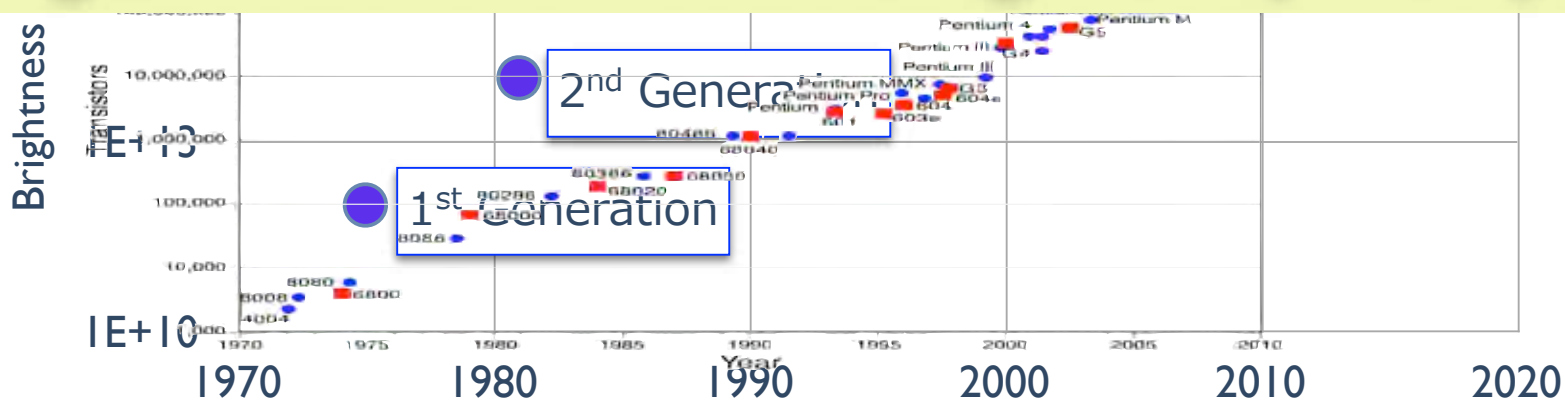
ALS ADVANCED LIGHT SOURCE

# Evolution of X-ray Light Sources




"Moore's law" - doubling every 2 years

Light sources - doubling every ~1 year



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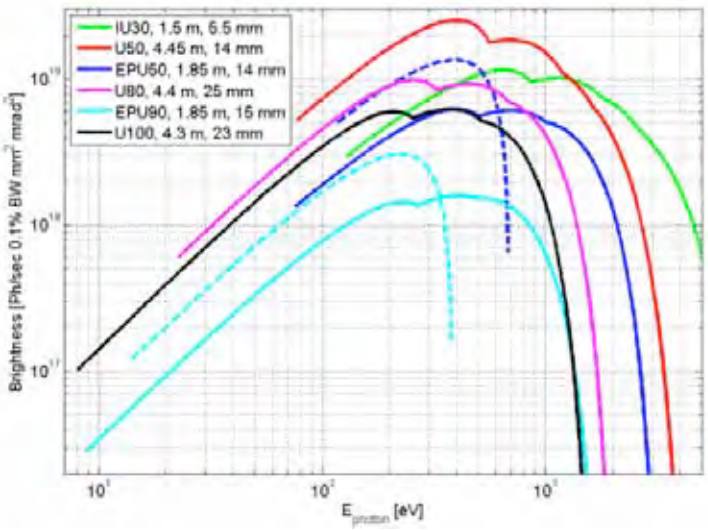
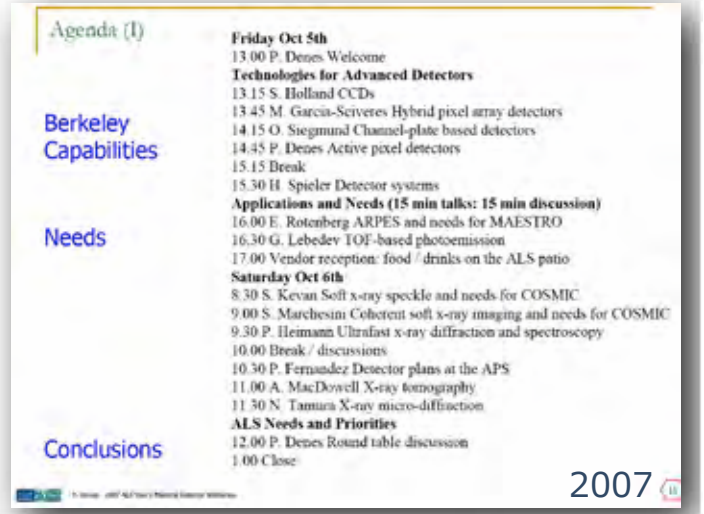
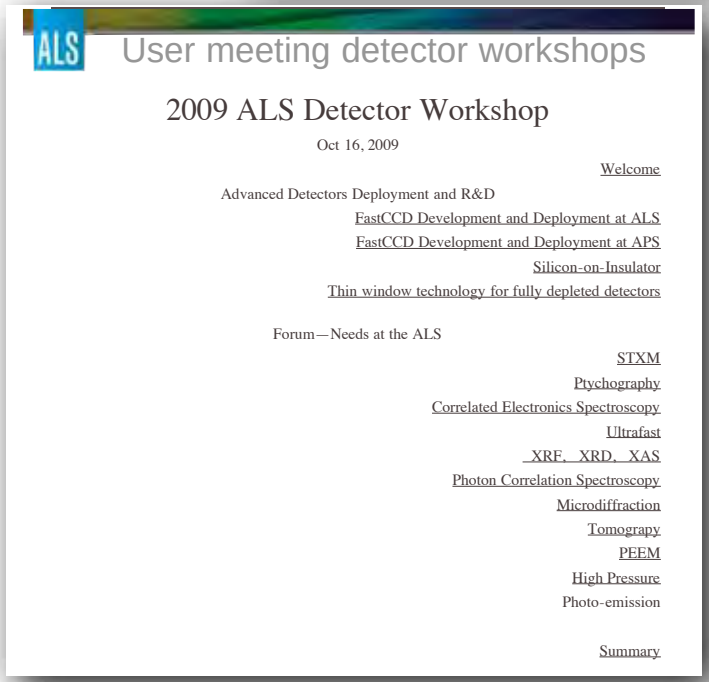
# Detector Needs at the ALS




Establish needs through a series of workshops




- Primarily a soft X-ray facility



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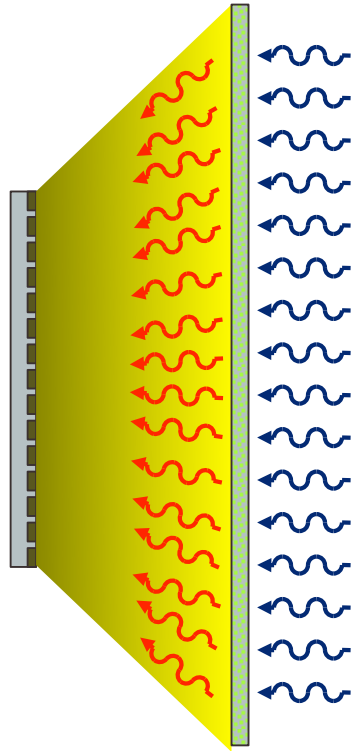
# Ancient History ~10 years ago

What *one* detector development would have the most significant impact on scientific productivity at the ALS?

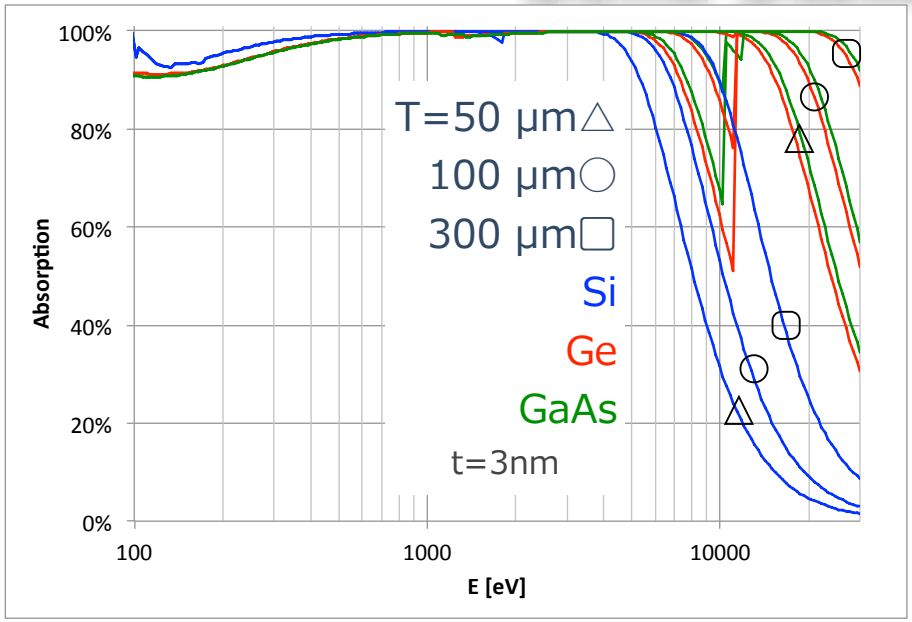


**Canonical x-ray detector**

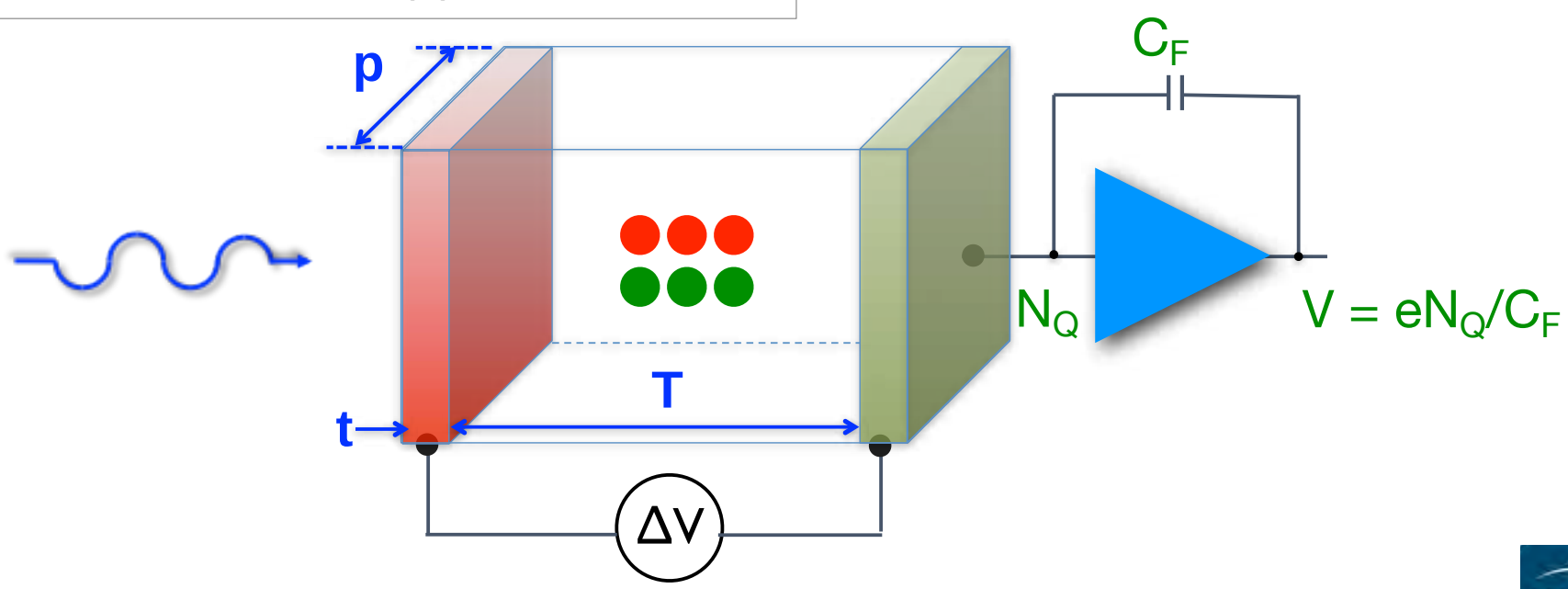
- X-ray photoconverts in phosphor
- Photoelectron ionizes → scintillation photons
- Photons bounce around in phosphor and get distorted in fiber
- Photons photoconvert in CCD
- Collect the photoelectrons

Improve this

# Solid State Detector




- $N_Q = E_\gamma / \varepsilon$
  - $\varepsilon = 3.6$ eV in Silicon
- $\sigma^2(N_Q) = F \cdot E_\gamma / \varepsilon$



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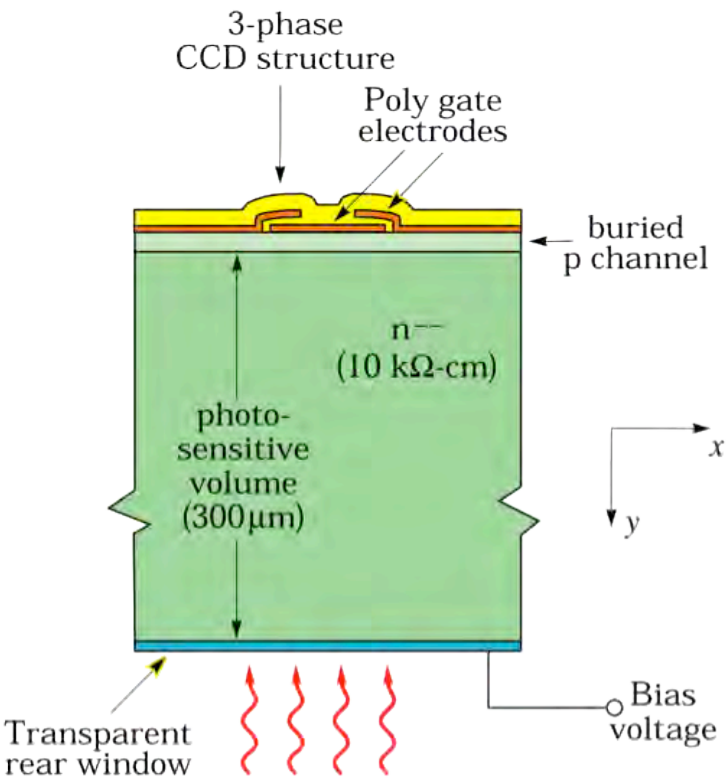
# Thick, Fully Depleted CCD

*Developed at LBNL MicroSystems Lab*



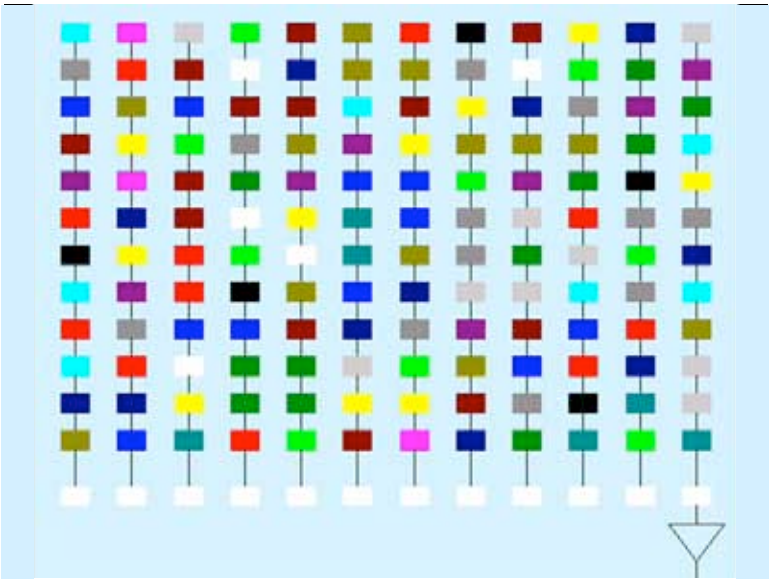
- <4 μm PSF
- ≥9.5 μm pixels
- 2 $e^-$ noise at 100 kHz / pixel

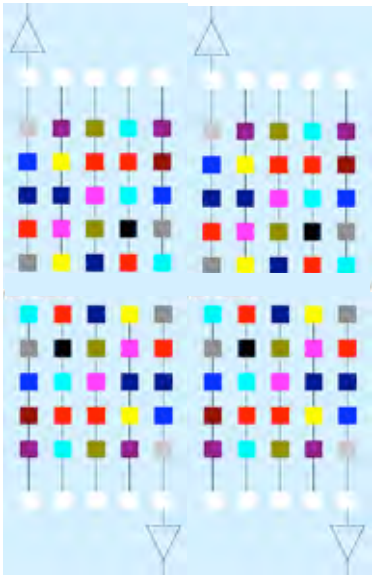
# Speed: Parallel Readout

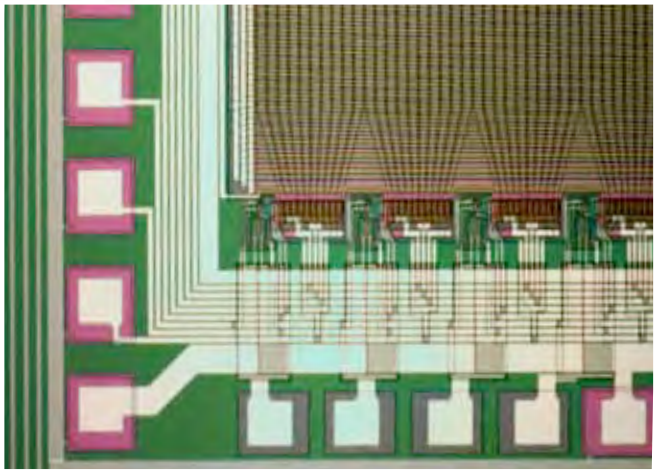
*CCDs are wonderful, but they are slow*

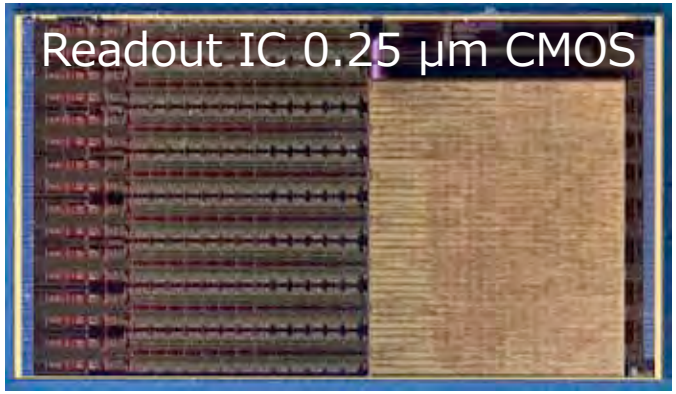
Physics - MMIX

Award-winning imagers



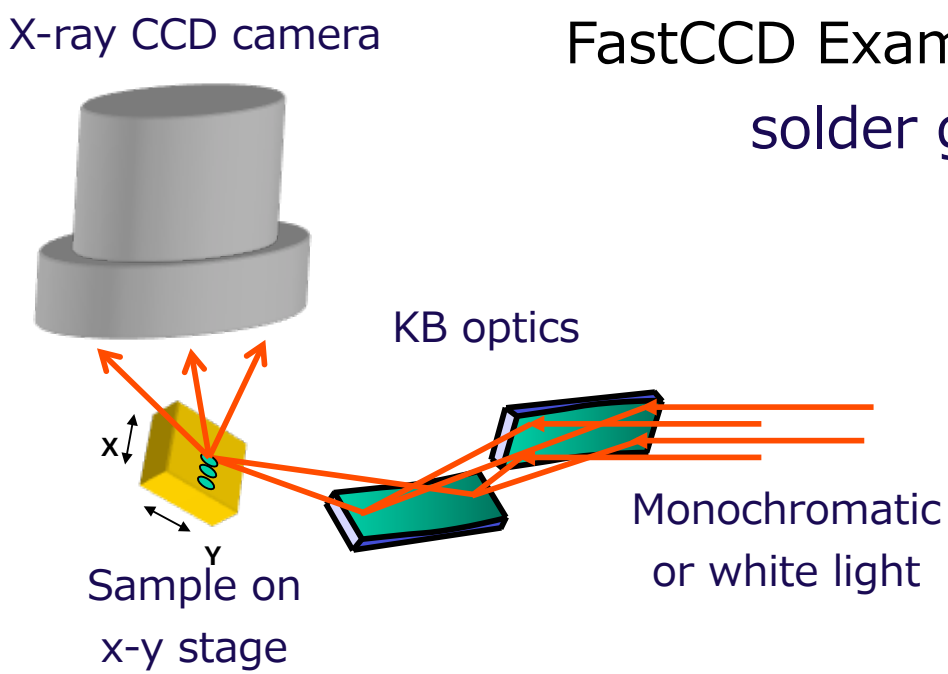




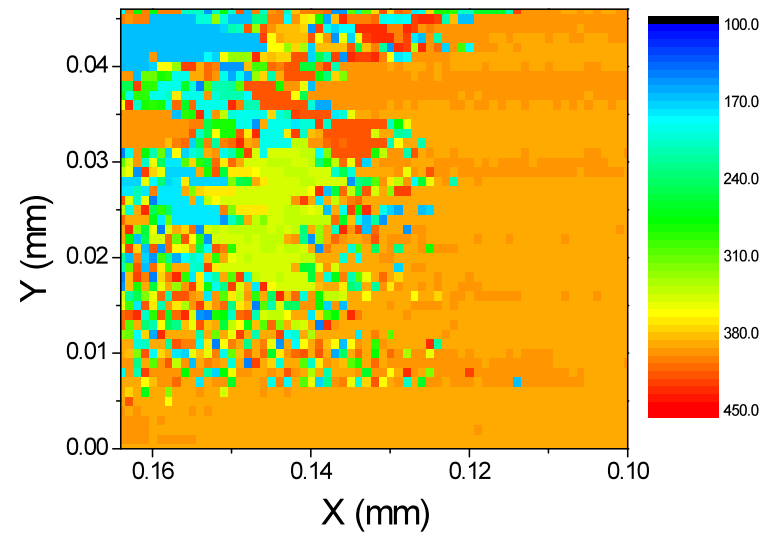



- Add many readout ports
- Add lots of electronics to read each port
- Custom (almost) Column-Parallel CCD (30 µm pixels)
- Custom 16-channel ASIC, Readout Collaboration with APS

# Example 1: Microdiffraction - ALS BL 12.3.2

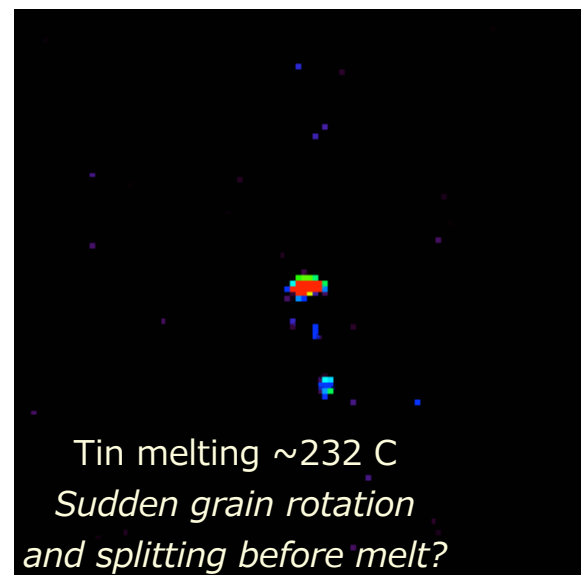



FastCCD Example:
solder grain




**6.2 hrs.** with conventional phosphor/CCD detector

3 orders of magnitude increase in speed at 200 fps




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



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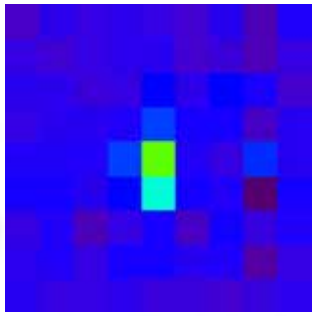
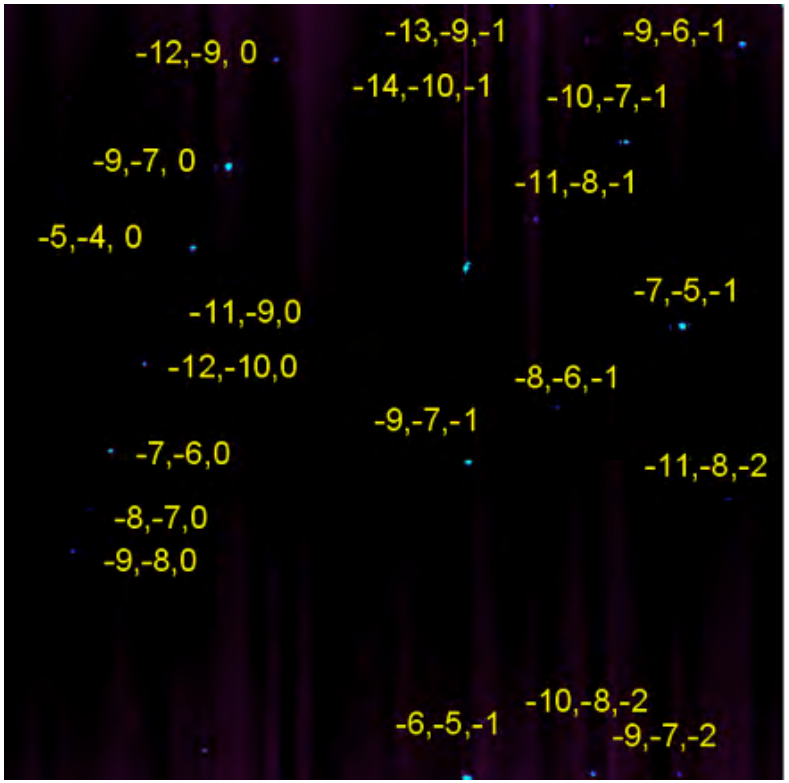
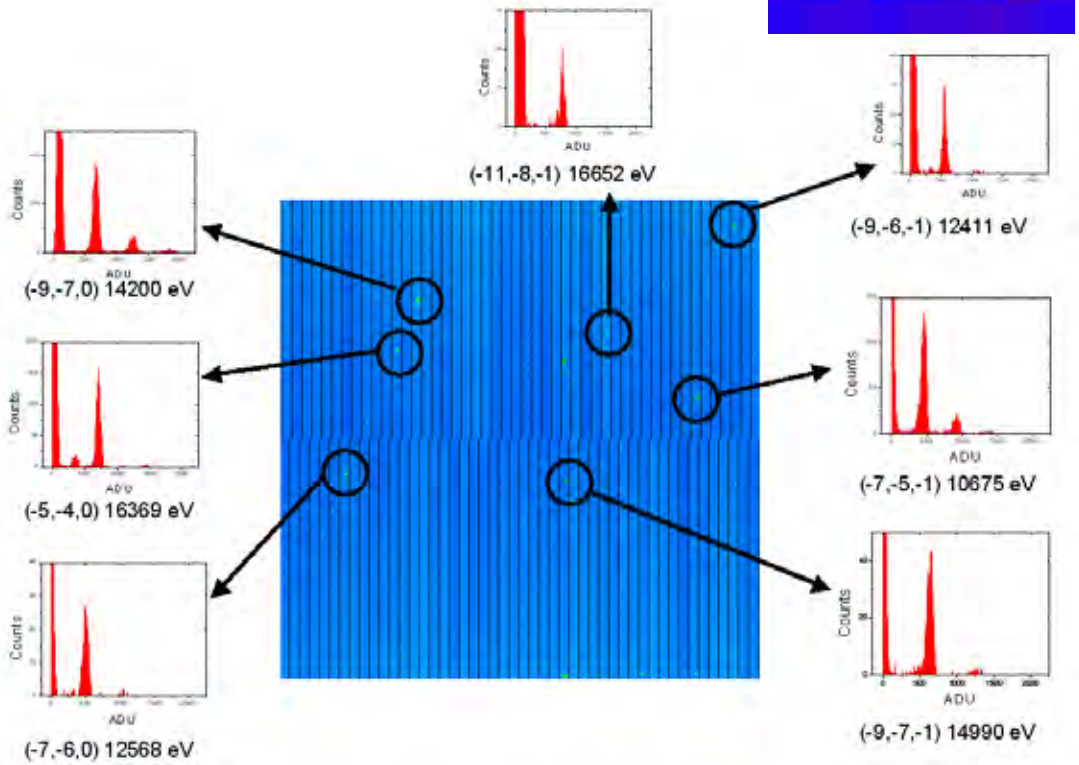
# Fast Energy-resolved Laue Diffraction

- FastCCD at high readout rate → single photon counting (spectroscopy)
  - Heterogeneous samples
- Fast alternative to monochromator energy scan

*Single Photon*






Potassium Titanyl Phosphate $KTiOPO_4$ (or KTP)



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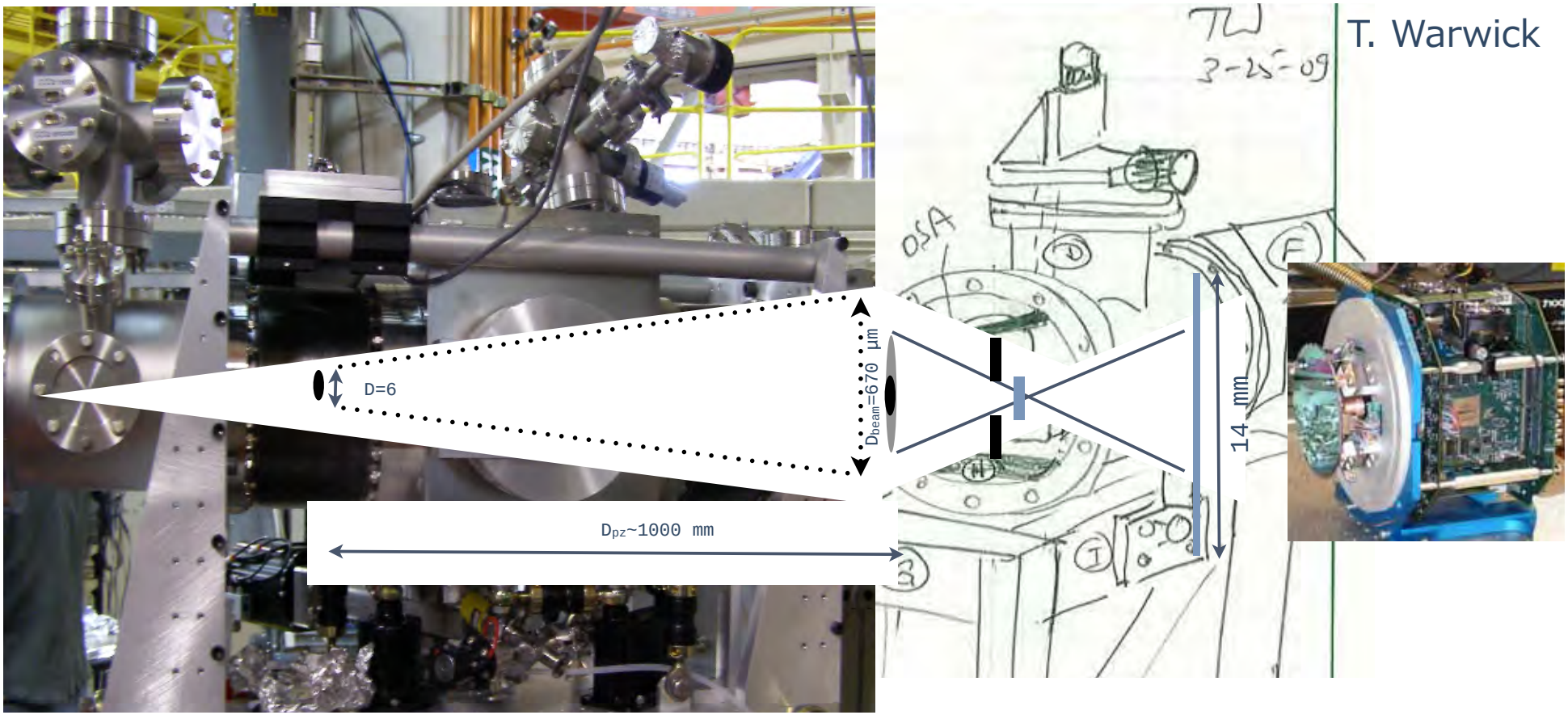
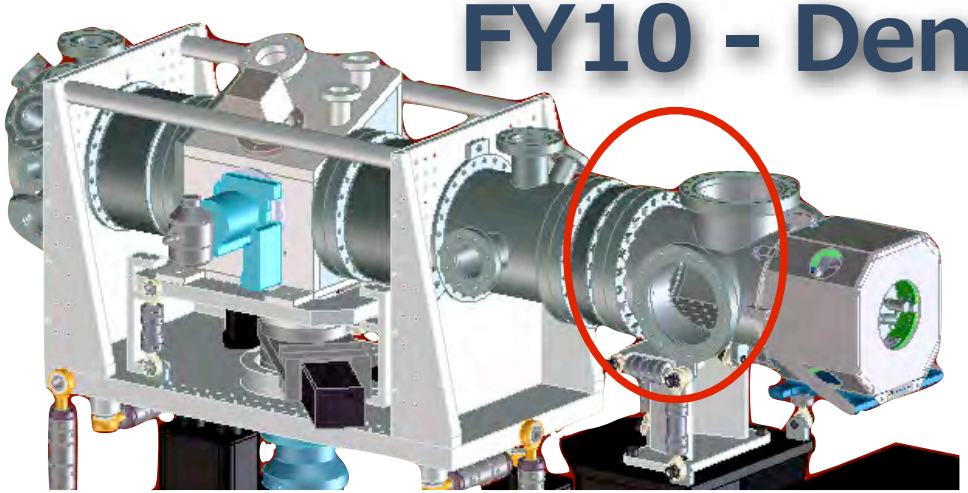
# Example 2: Soft X-ray Ptychography



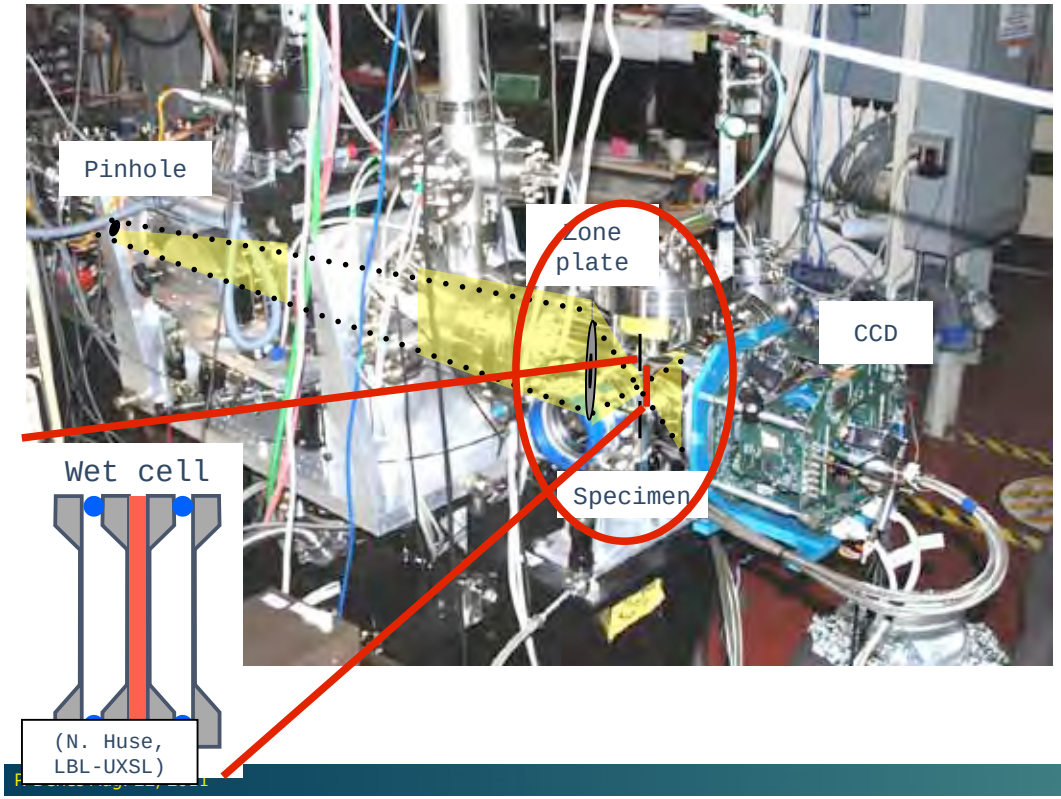

**Beam**
Energy: 750 eV
λ=1.65 nm
E/ΔE=500;

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

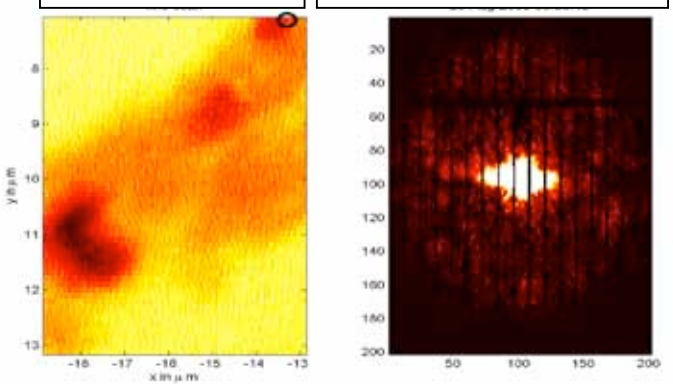
# FY10 - Demonstration



- Implemented ptychography **at 750 eV**
- wet cell
- $2 \times 10^3$ photons/(10 nm)$^3$/second
- 50 MB/second 4 TB/day

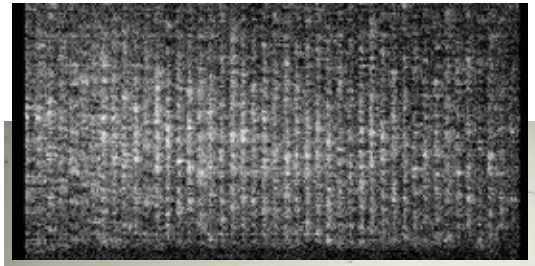


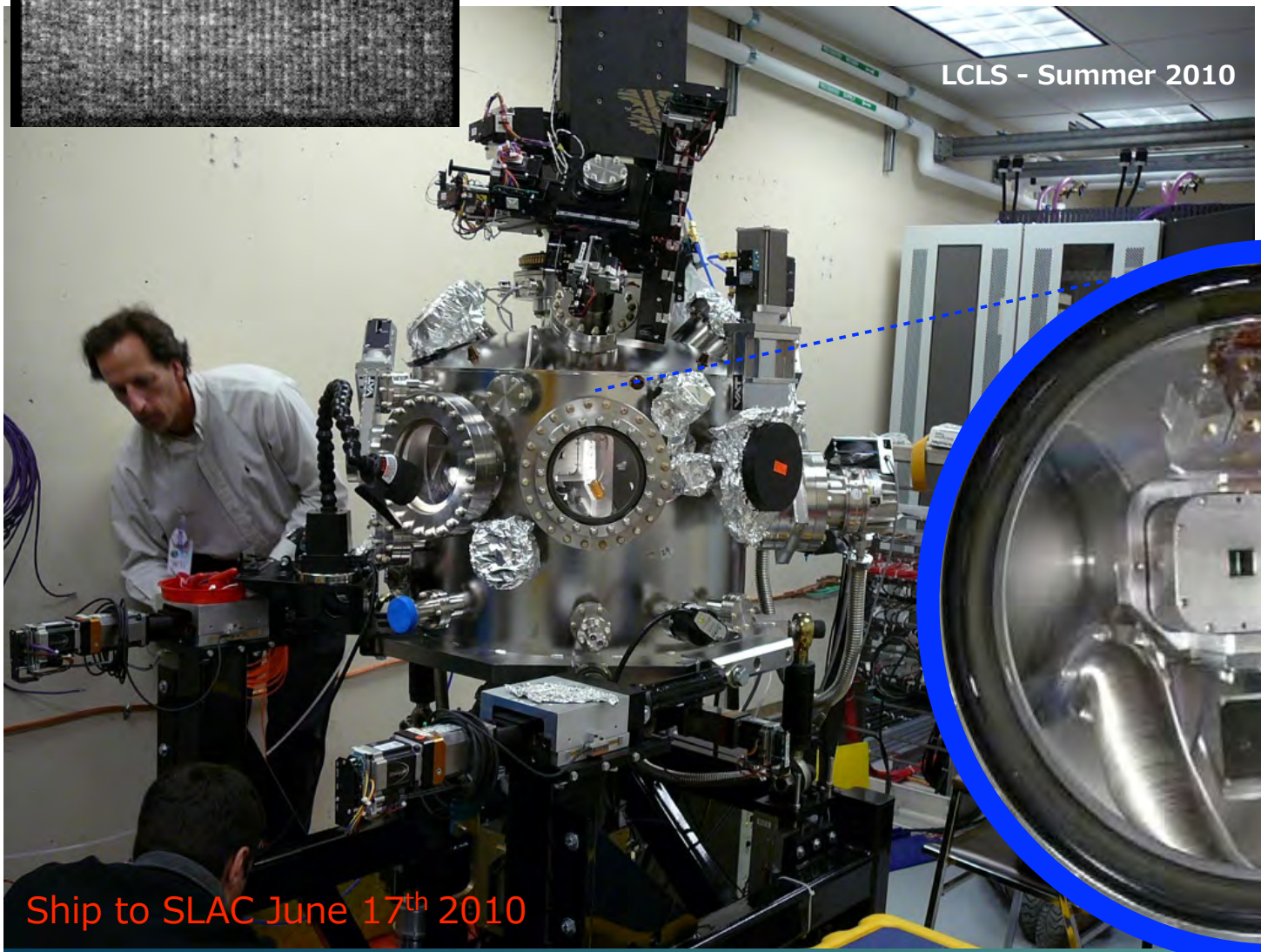

Scanning | Diffraction

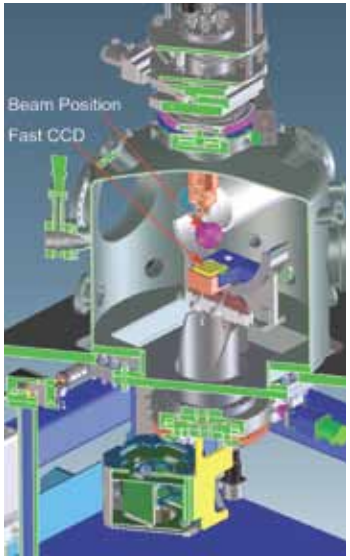


# Example 3: RSXS at LCLS

1st light - Jul. 2010








Ship to SLAC June 17th 2010



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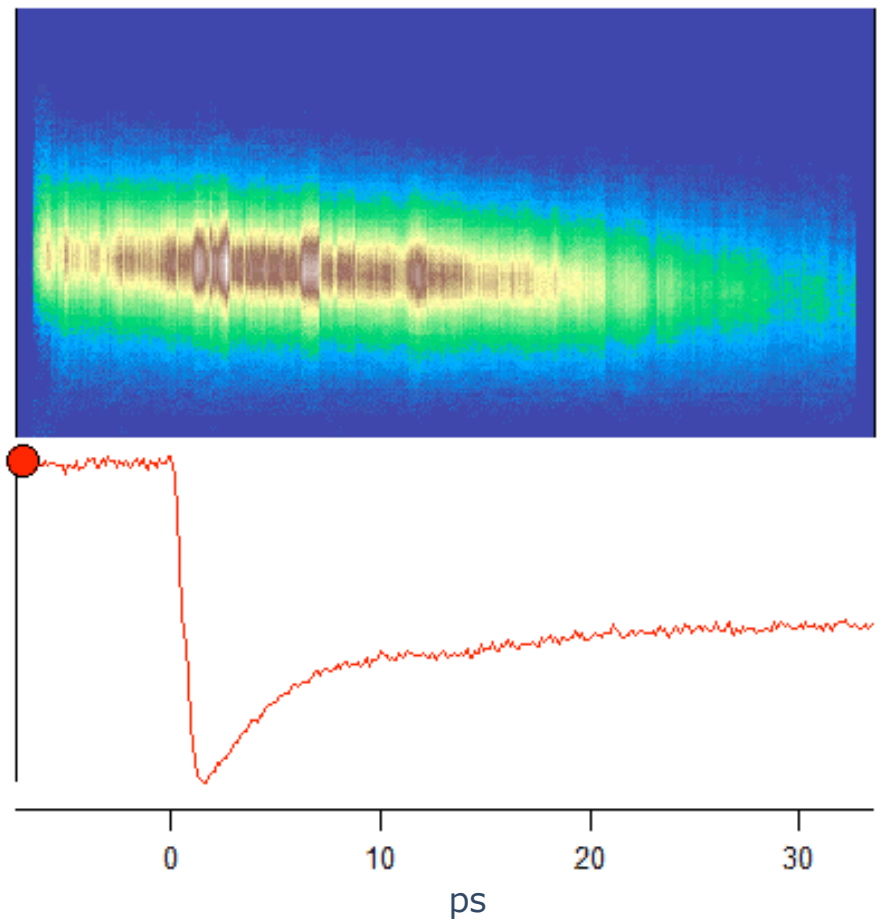
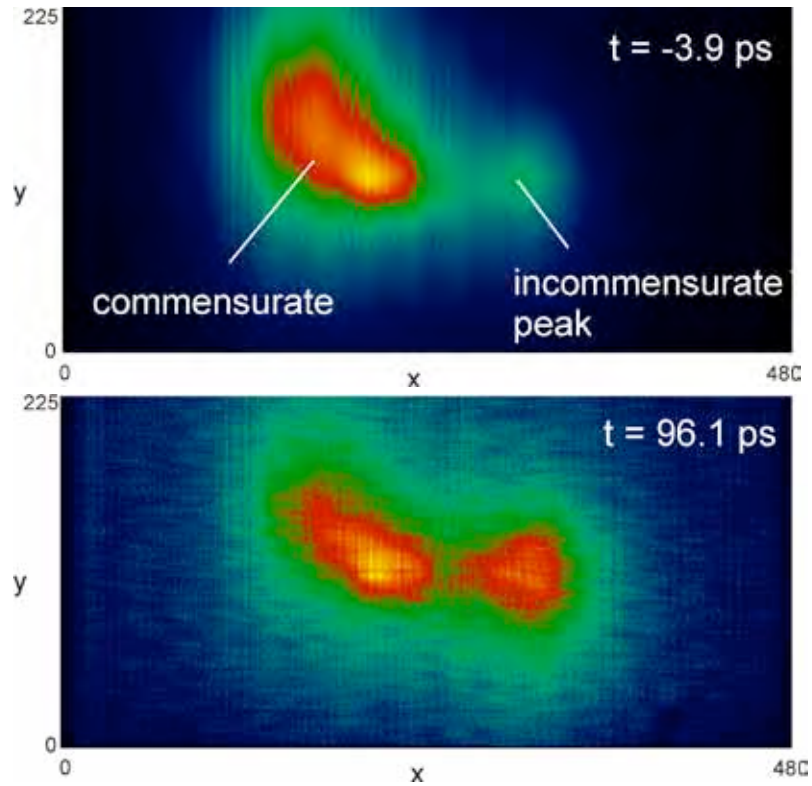
# Spin Ordering (SO) – the Movie

Fast melting and slow recovery of spin ordering around 50K
(shot-by-shot readout to correct time jitter and intensity fluctuation)




Aug. 2010 - 28 mJ/cm$^2$ S. Johnson, Luc Patthey et al. PSI



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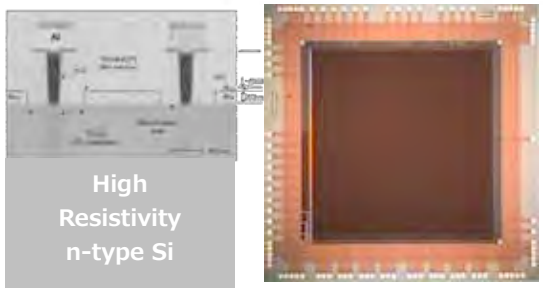
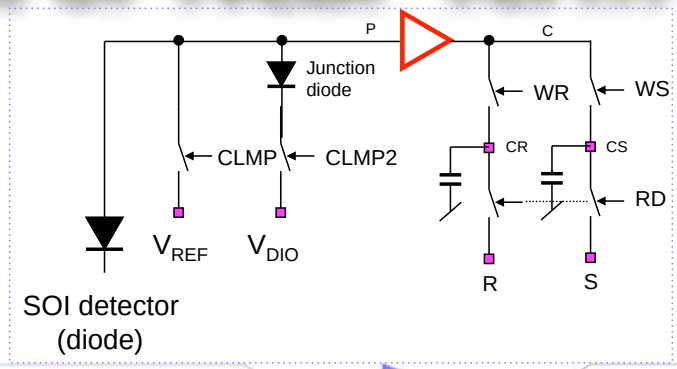
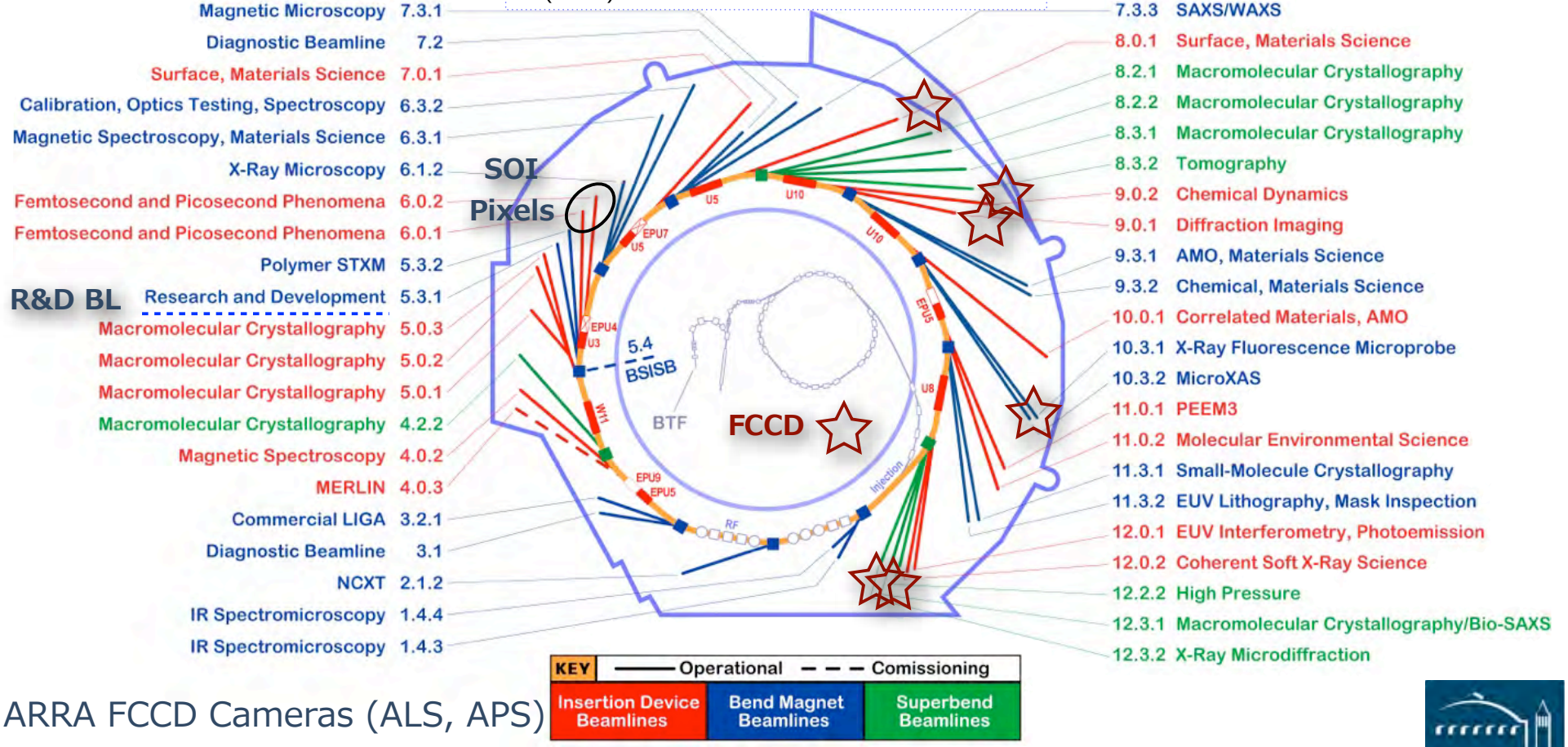
# Present or Near-Term Impact




- 4,000 frames / sec.
- 17.5 μm pixels
- in-pixel CDS
- Firmware processing




ARRA FCCD Cameras (ALS, APS)



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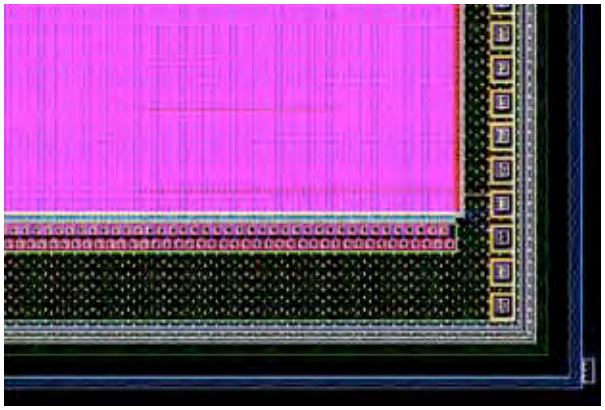
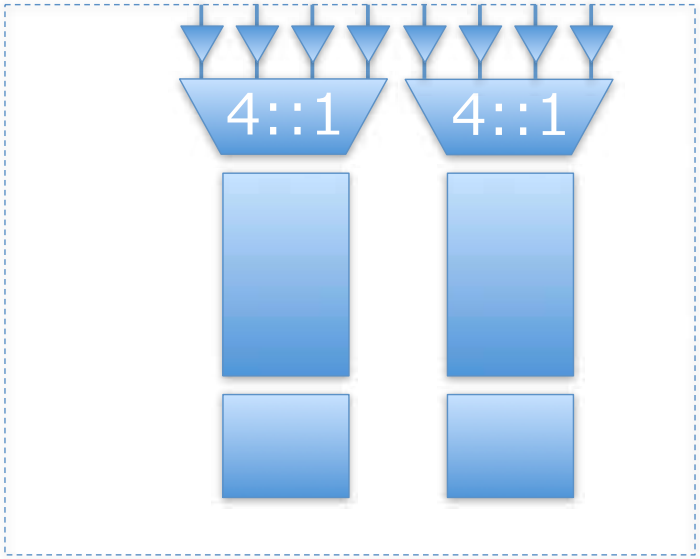
# Almost Parallel → Fully Parallel



- Still a CCD
- Limit will be $10^3$ – $10^4$ Mpix/s
  - Limited by clock rates
- 2 developments required:
- Prototype CCD – in fabrication now
- Prototype readout IC – in testing now

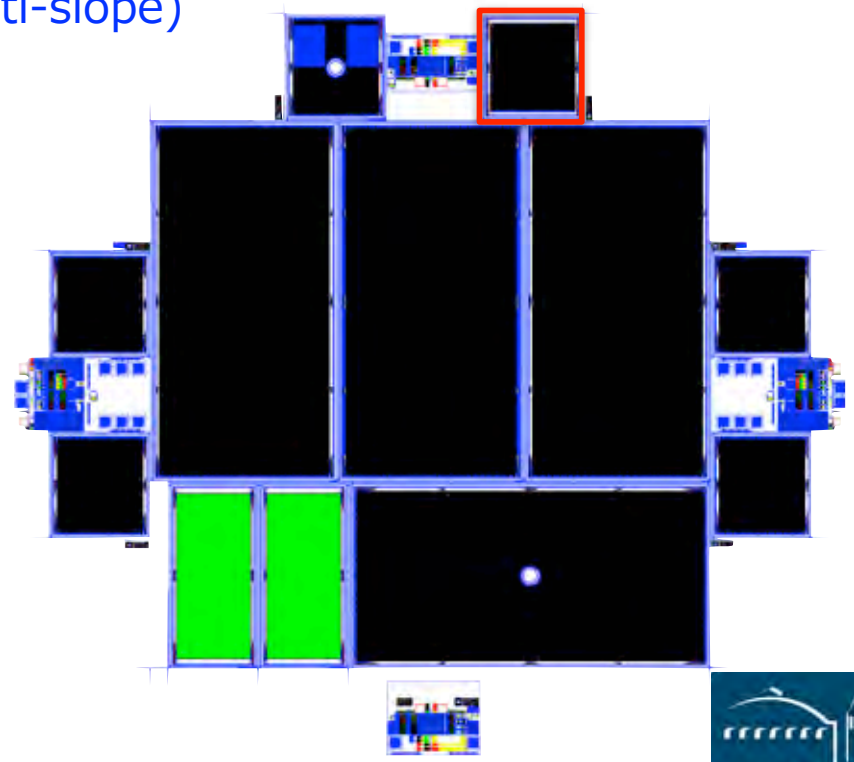



Preamp (multi-slope)

Mux

80 MHz
10-bit ADC

Serializer



*HIPPO* 65 nm CMOS
**H**igh-Speed **I**mage **P**re-**P**rocessor with **O**versampling



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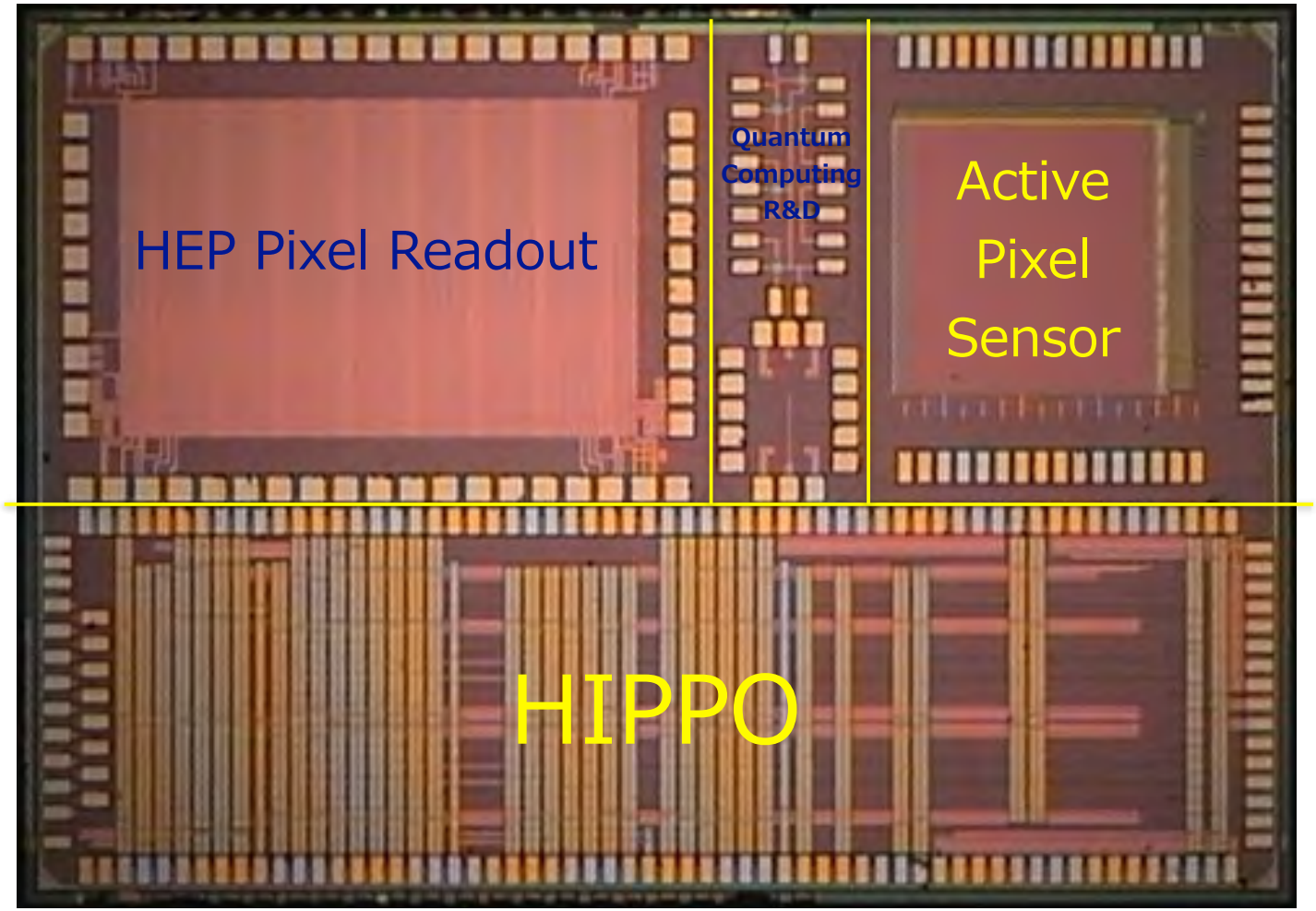
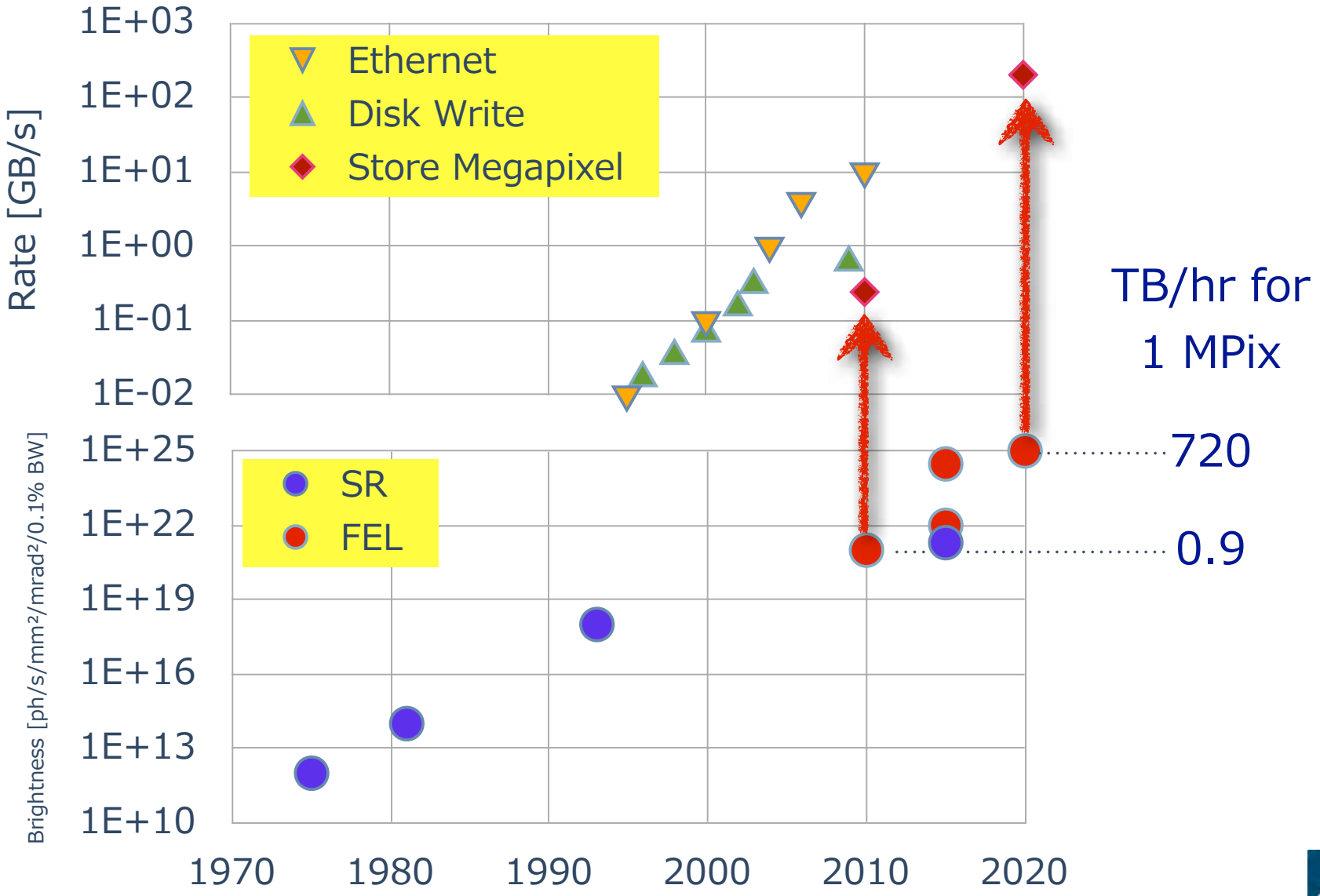
# HIPPO - June 2011

- 1st 65 nm CMOS chip in "our profession"
- Shared - BES / HEP / LDRD




HIPPO
80 MHz / 12 bit
200 μm pitch

# Data Challenge (SR and FEL)



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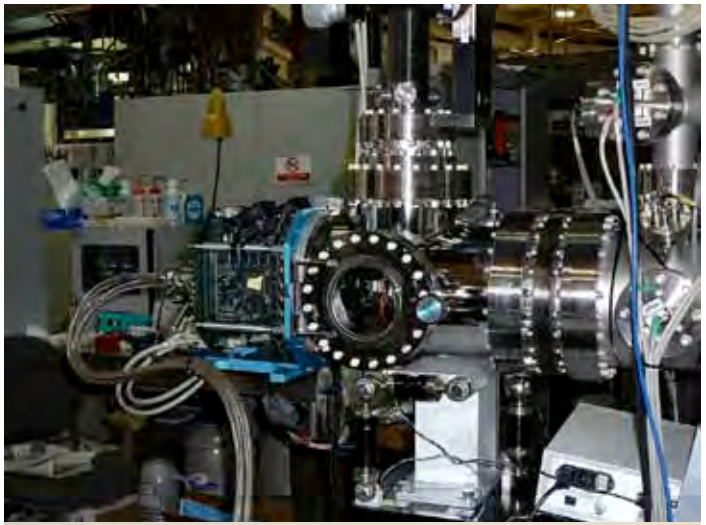
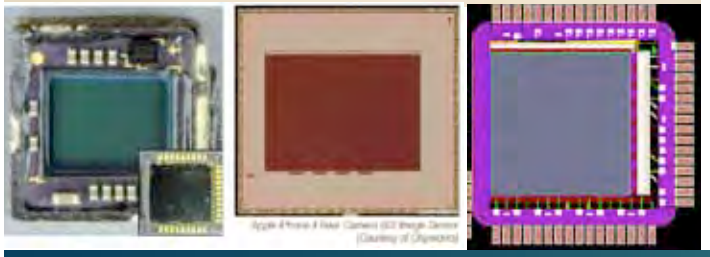
# Dealing with the Data

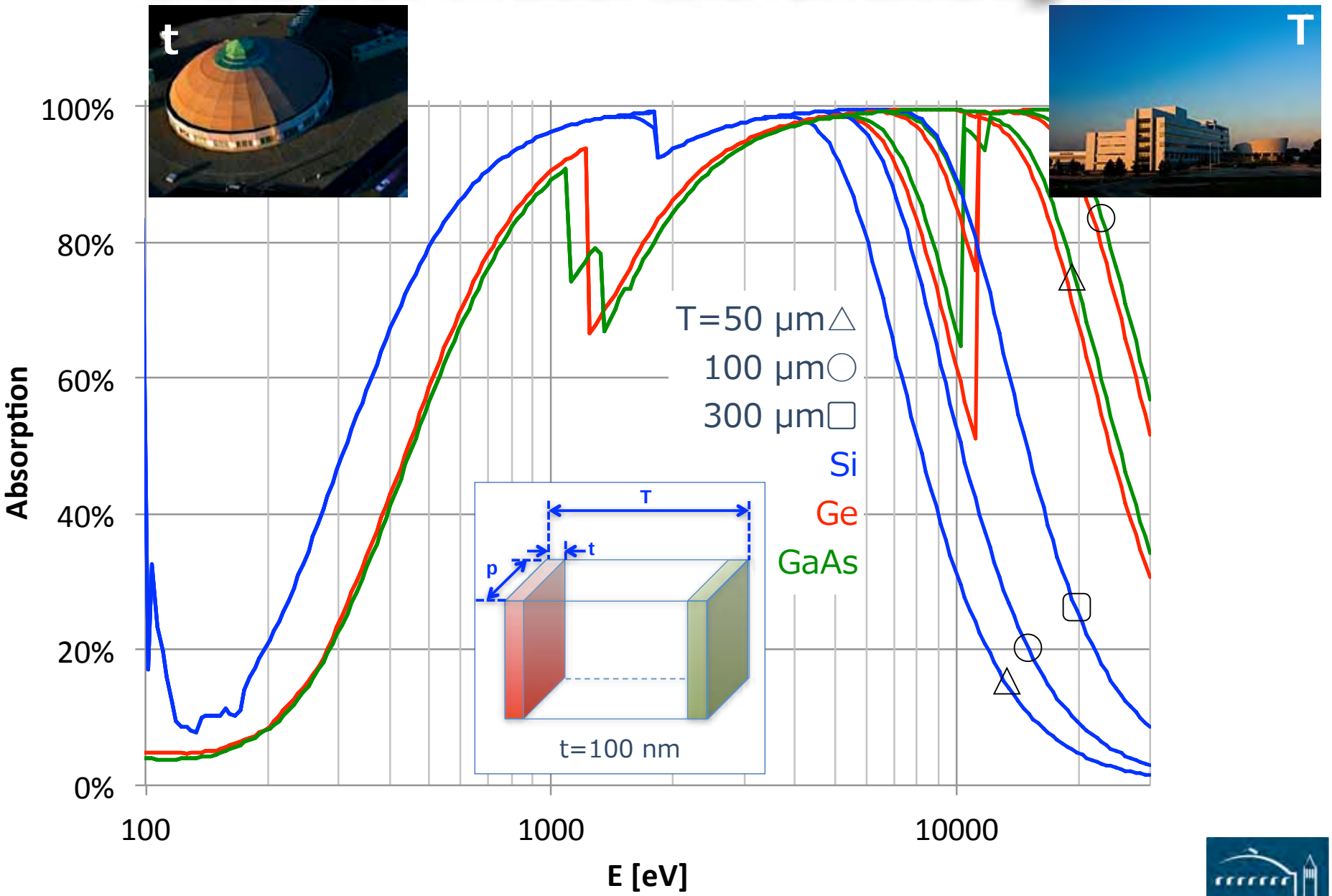


FastCCD Camera Interface Node



- Now: Fat pipe to NERSC
  - Super-computer algorithms
  - GPUs
- Soon (R&D): in-line firmware processing
  - + ATCA blade GPU
- Future (R&D): Advanced technology APS / thinned (back-illuminated) / implanted - on-chip processing
  - Soft X-rays

# Detector Materials Challenges



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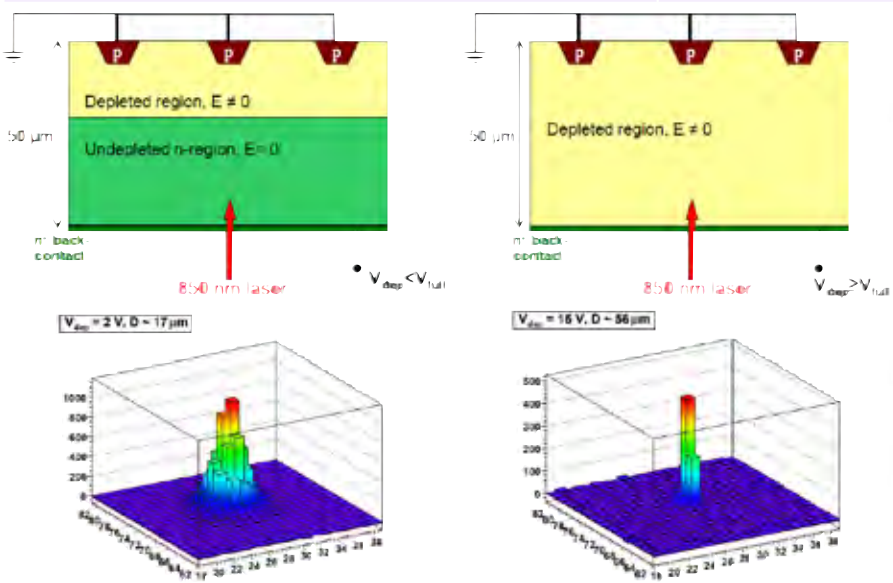
# Thin Contact Process Developments

| Process | Window thickness | Status |
|---|---|---|
| Low energy implantation + 500 C annealing | 1,000-2,000 Å | Process dependent, several SOI prototypes functional |
| Low energy implantation + laser annealing | 400-700 Å | Several SOI prototypes functional after processing |
| a-Si contact deposition by sputtering | 300 Å | Prototypes functional after processing, high leakage |
| Molecular Beam Epitaxy | 50-75 Å | Developing in-house capability |




LBNL Low Temperature Process

Back-illumination test with 850 nm laser on 50 µm thin SOI prototype



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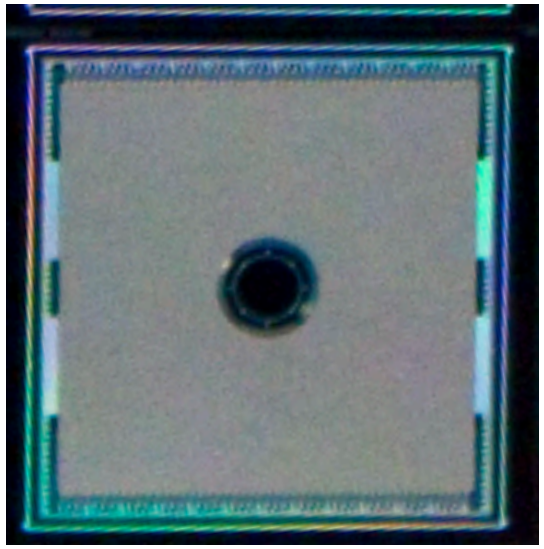
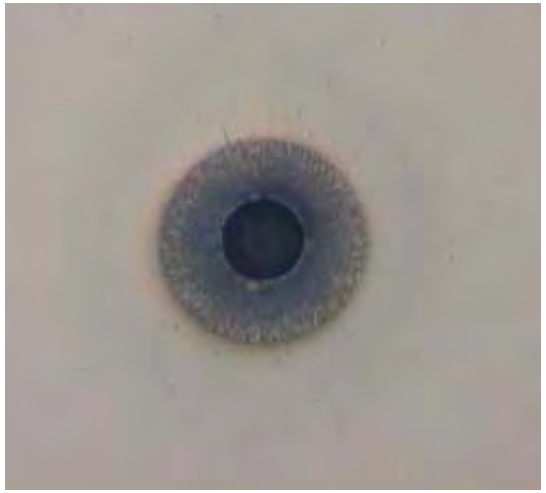
# Additional Process R&D

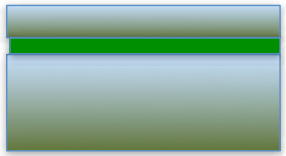
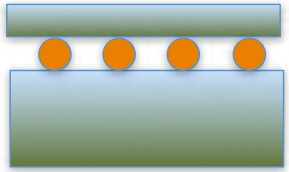
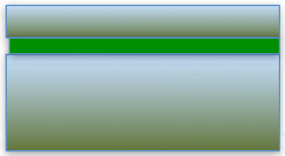
- Thinning (for ≤ 1 keV detectors)
- Laser machining
- MBE development





FastCCD with central hole

# Detector Topologies (on Thick Silicon)

| | CCD on thick, high-ρ Si | SOI on thick, high-ρ Si | Hybrid on thick, high-ρ Si | 3D on thick, high-ρ Si |
|---|---|---|---|---|
| | |  |  |  |
| Size / Area | ≤10 – <50 μm<br>$10^2$ – $10^3$ μm$^2$ | ≤10 – 20 μm<br>$10^2$ – $10^3$ μm$^2$ | 50 – 100 μm<br>$10^3$ – $10^4$ μm$^2$ | ≤10 – 20 μm<br>$10^2$ μm$^2$ |
| /pix | 0 | $10^1$ – $10^2$ | $10^2$ – $10^3$ | $10^1$ – $10^2$ |
| ENC | $10^0$ – $10^1$ e$^-$ | $10^1$ e$^-$ | $10^2$ e$^-$ | ? |

- Different experiments need different solutions
- Materials challenges (SXR, HXR)
- R&D (overcome limitations)
- Engineering (prototype ⇨ user system) – non-negligible effort
- Support / commercialization

# Questions?

This work:

N. Andresen, D. Contarato, D. Doering, D. Gnani, C. Grace, B. Krieger, J. Joseph, H. von der Lippe, P. McVittie, C. Tindall, JP Walder

Technical Staff: J. Bell, J. Eames, B. Holmes, J. Stirkkinen, R. Witharm, G. Zizka

Students: H. Bovenzi, S. Facchinetti, TS Kim, B. Niasari, S. Schindler, B. Zheng

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Physics Division

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