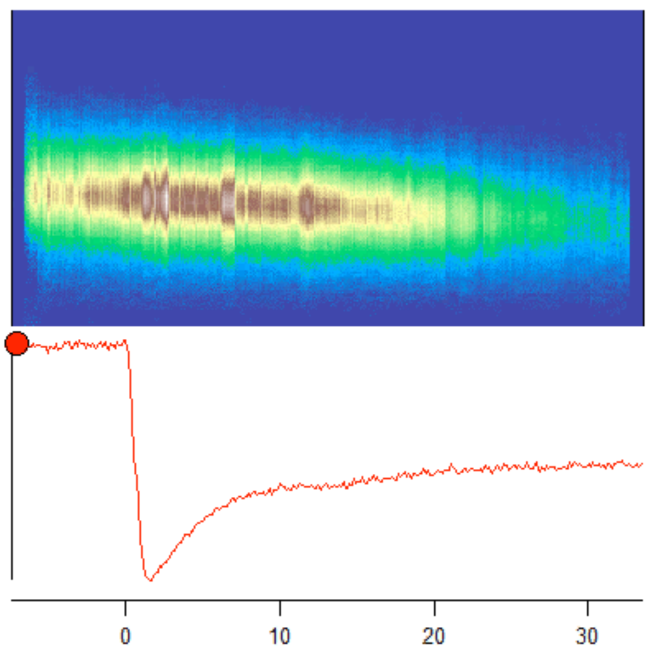
Photon (and Electron) Detector Development

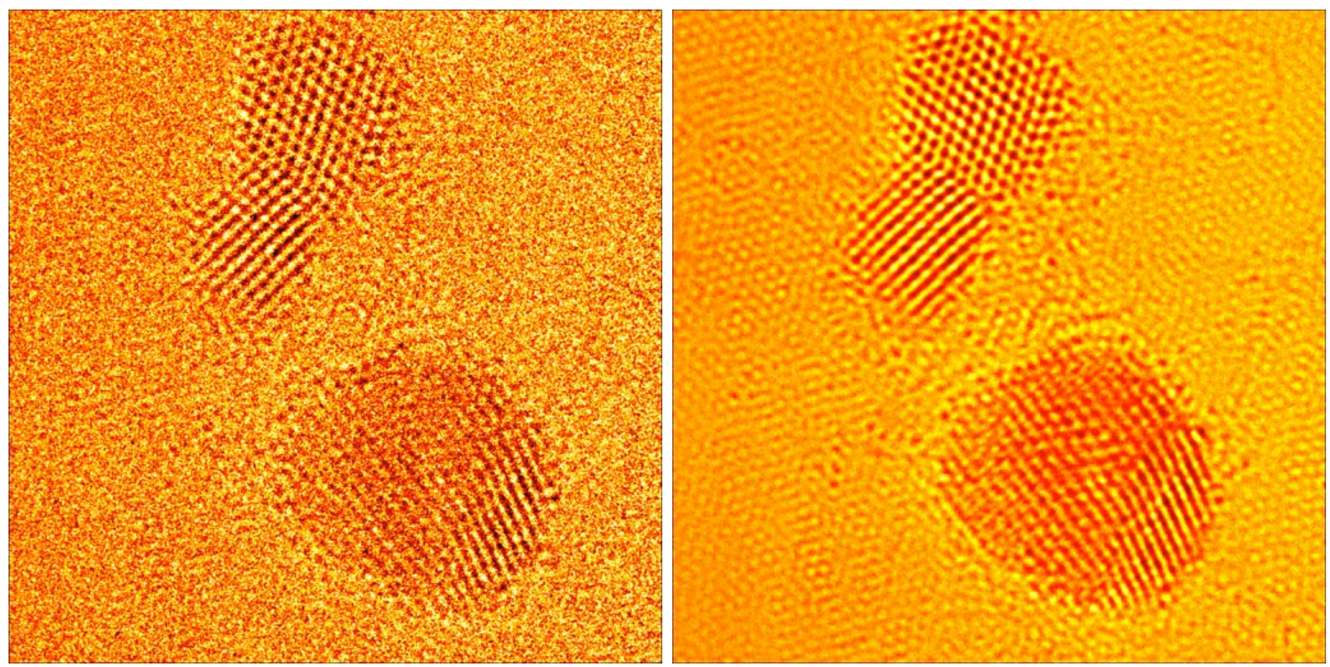
Latest news - not a general overview

Solid State Pixel Detectors (so, not TOF, ...)

800 eV γ at LCLS



Au and FeO nanoparticles on Graphene at TEAM



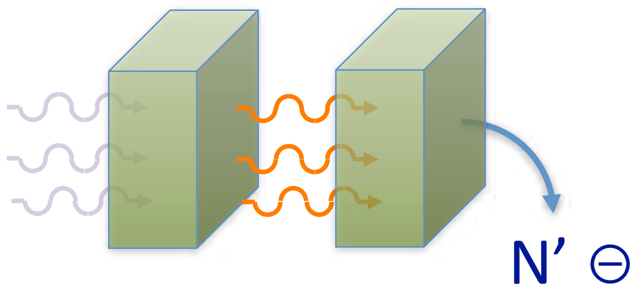
Yi-Di Chuang et al.

P. Ercius, C. Ophuls et al.

Detector Types

Old - Simple to make

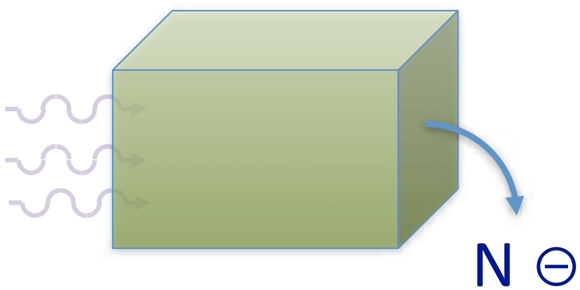
Indirect



Incident radiation converted into some other form of radiation, which in turn is converted into N’ charges inside “Sensor”

New - High QE

Direct

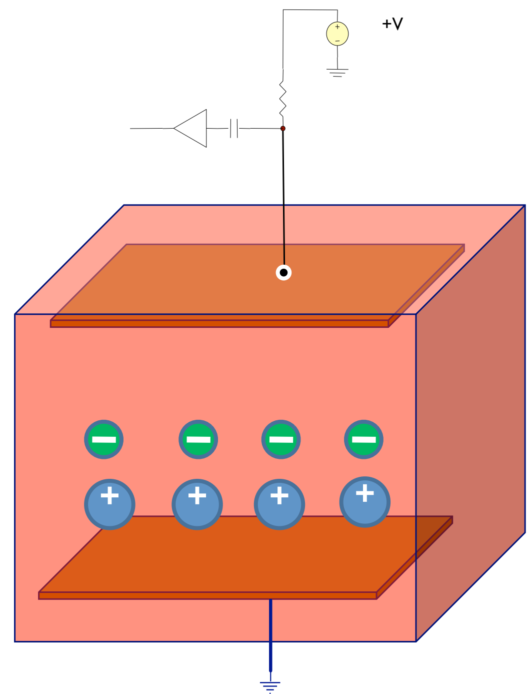


Incident radiation converted into N charges inside “Sensor”

Historical terms
Semi-meaningless

Direct Detection: Statistics - Fano Factor

"Sensor"	η = E required per secondary quanta	Mechanism
Gas	30 eV	e⁻/ion pairs
Scintillator	10 – 1000 eV	optical excitation
Semiconductor	**1 – 5 eV**	**e⁻/hole pairs**
Superconductor	~meV	breakup of Cooper pairs
Superconducting calorimeters	~meV	phonons

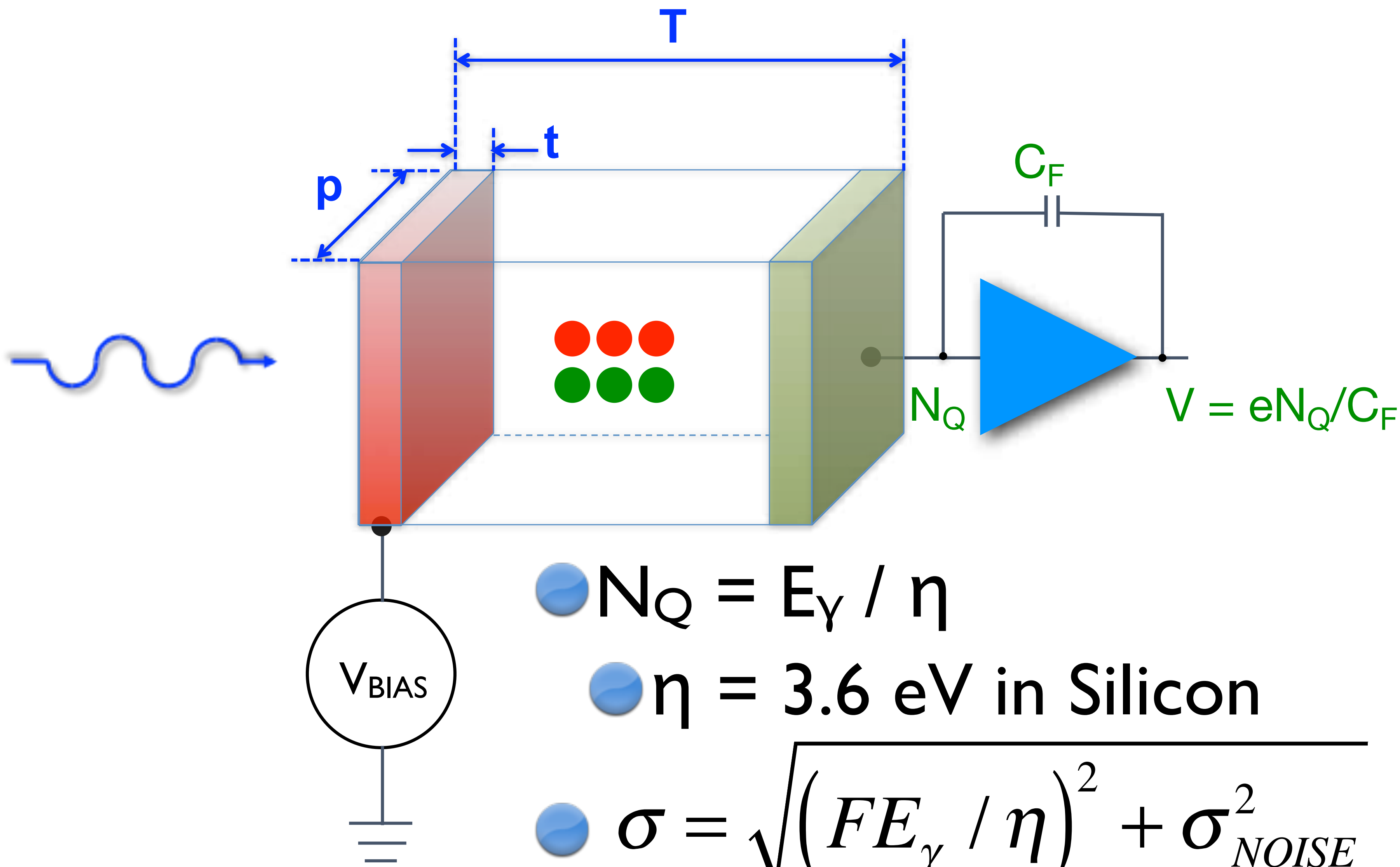


$$N_{\pm} = \frac{E}{\eta}$$

$$\sigma_N = \sqrt{FN}$$

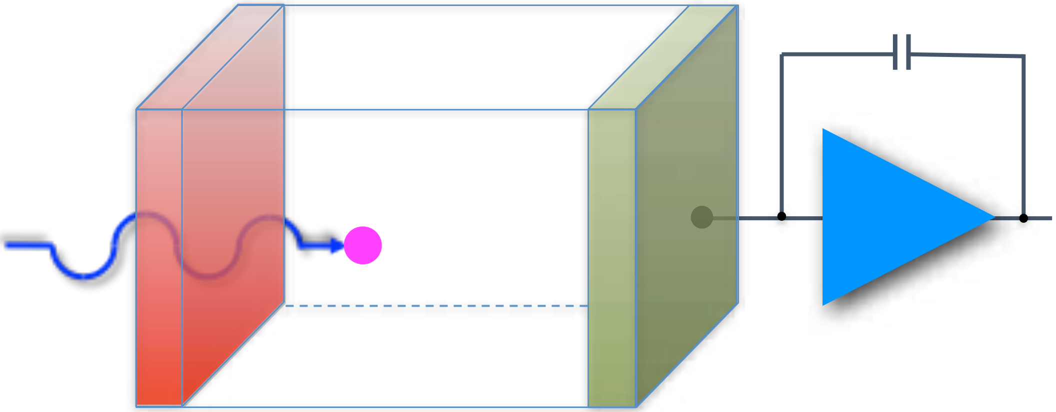
- *Intrinsic* resolution is *Fano-limited*
- σ_N/N ↓ as η ↓
  - Hence interest in superconducting calorimeters
- There are additional ways to have fluctuations on N

Solid State Detectors

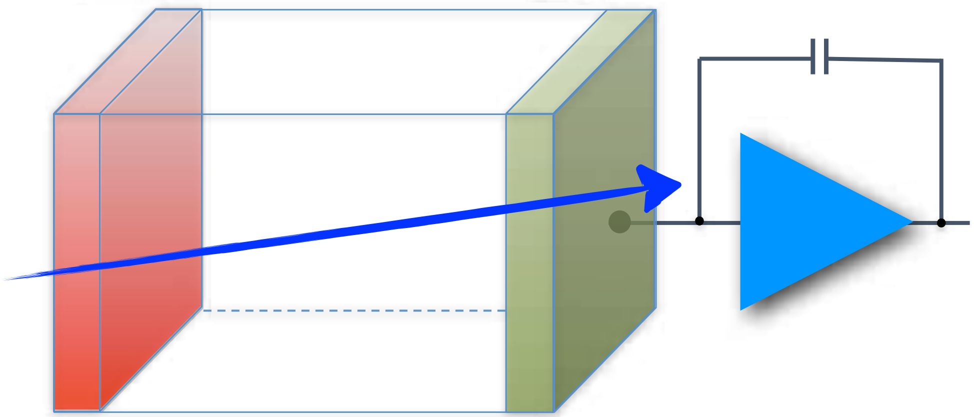


- $N_Q = E_\gamma / \eta$
  - η = 3.6 eV in Silicon
- $\sigma = \sqrt{\left(FE_\gamma / \eta\right)^2 + \sigma_{NOISE}^2}$

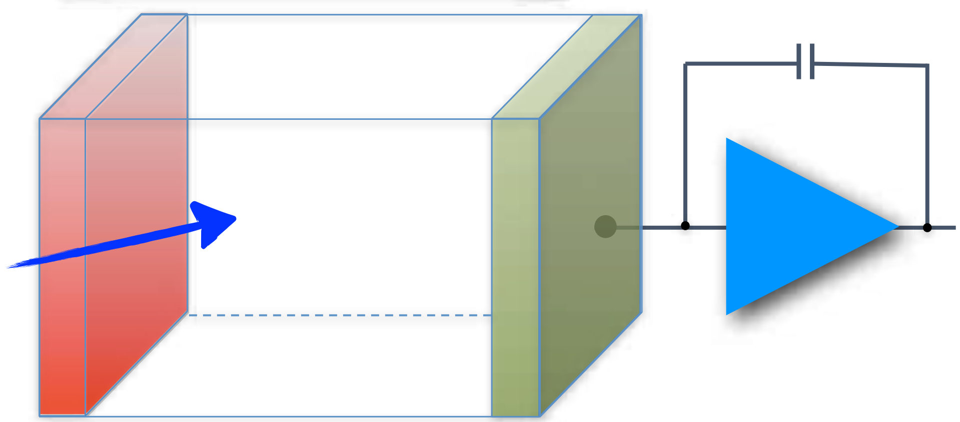
Solid State Detectors



- Moderate energy X-ray:
- Photoconversion at depth d
- $N_Q = E_\gamma / \eta$



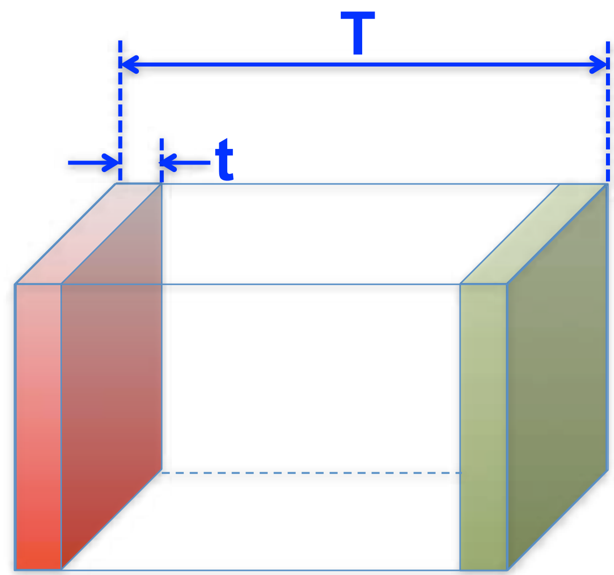
- High energy electron
- Passes through detector of thickness D
- $N_Q = D\ [dE/dx] / \eta$

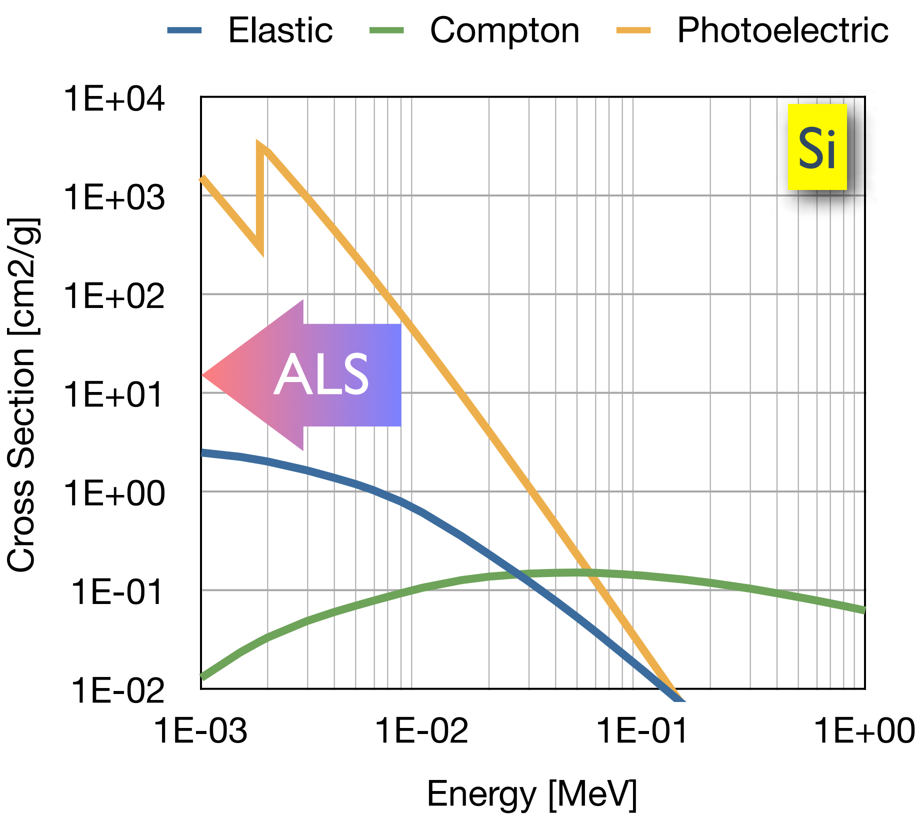


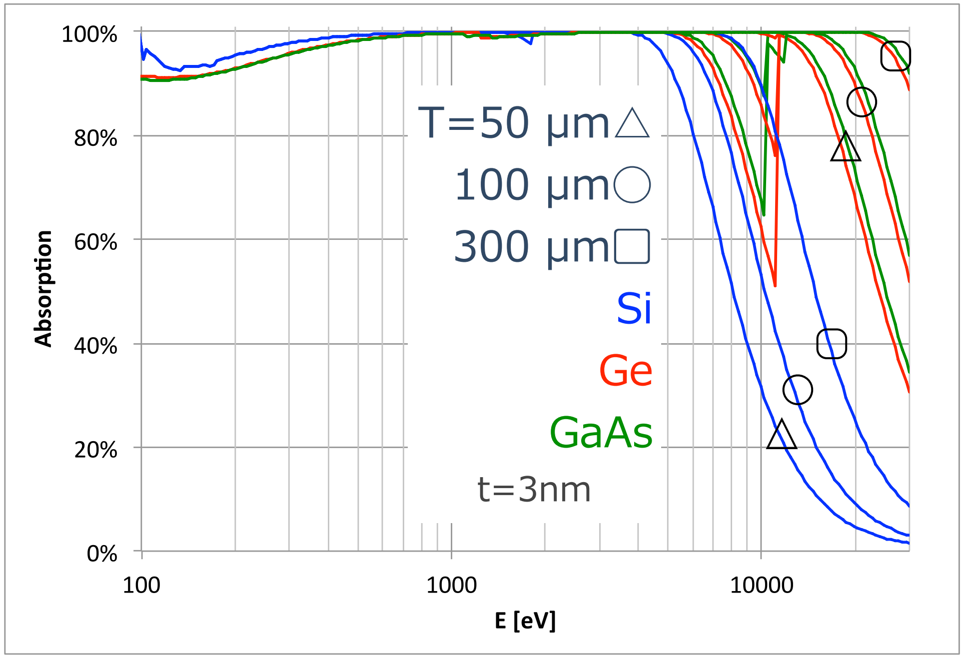
- Low energy electron
- All energy deposited in detector
- $N_Q = E_e / \eta$

X-ray Detection in Silicon

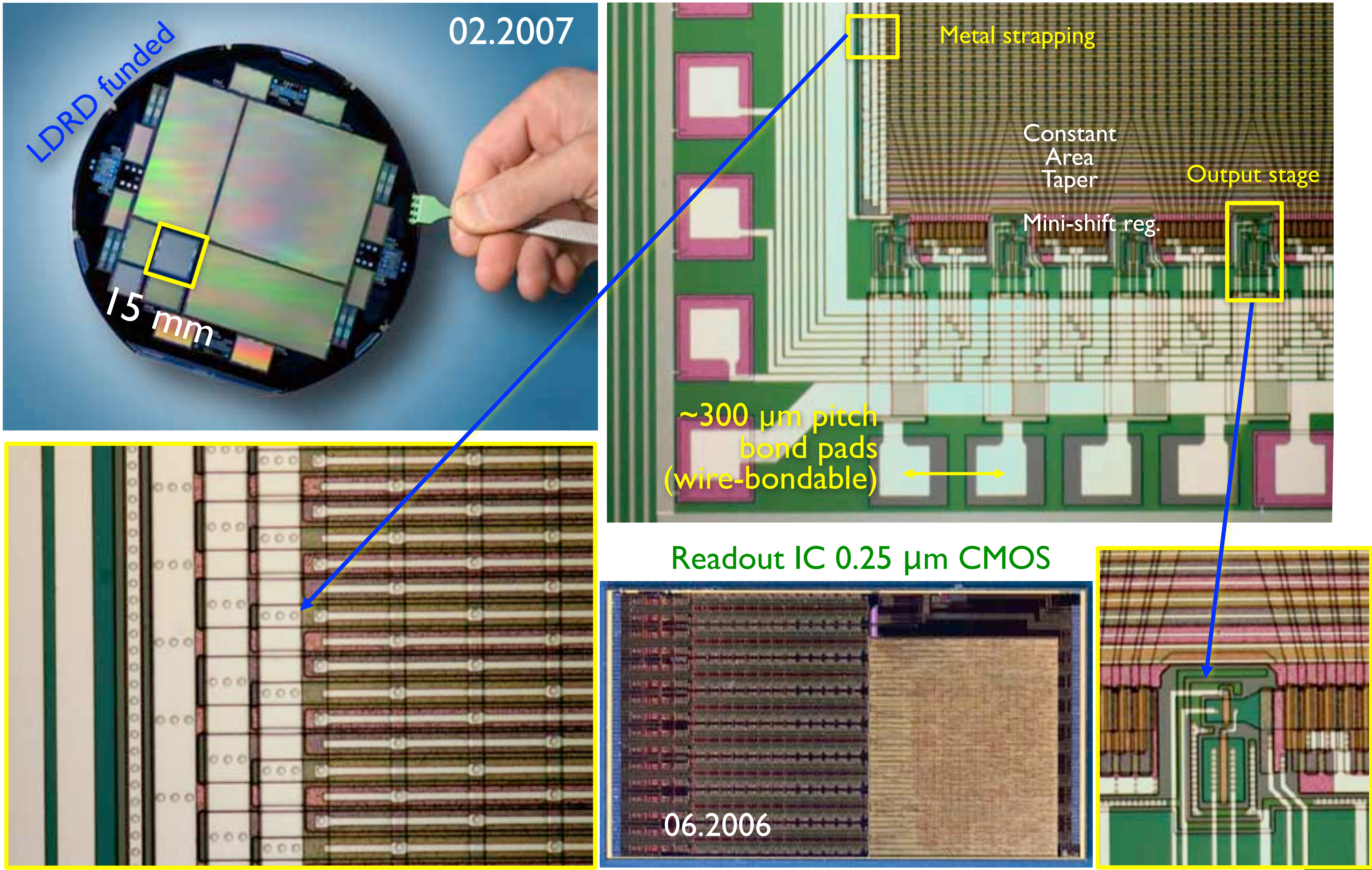
- High efficiency up to ~8 keV X-rays
- Readout noise limited for soft X-rays
- "Window"-limited for soft electrons





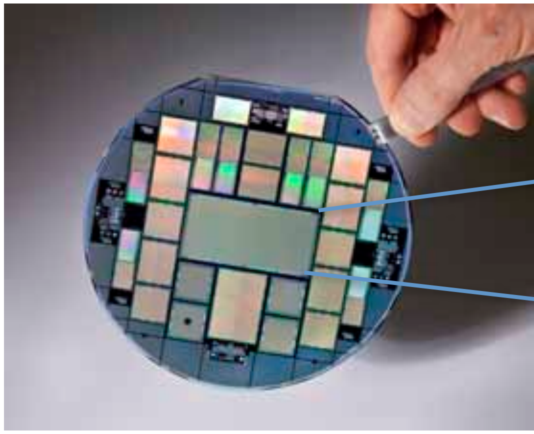


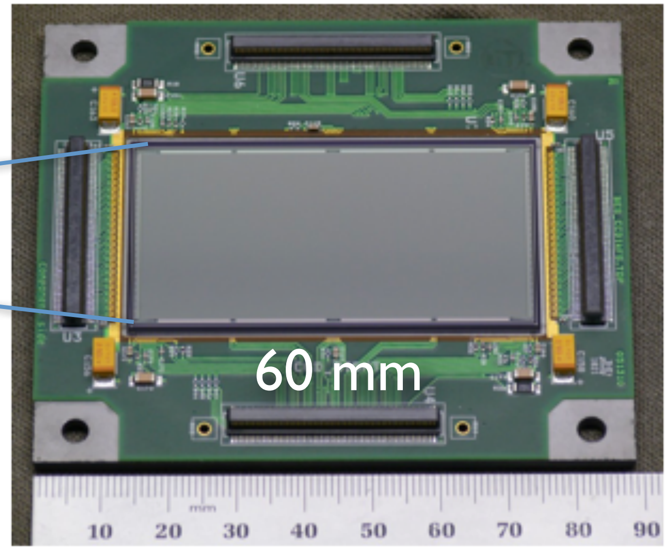
(almost) Column-Parallel CCD (200 Mpix/s)

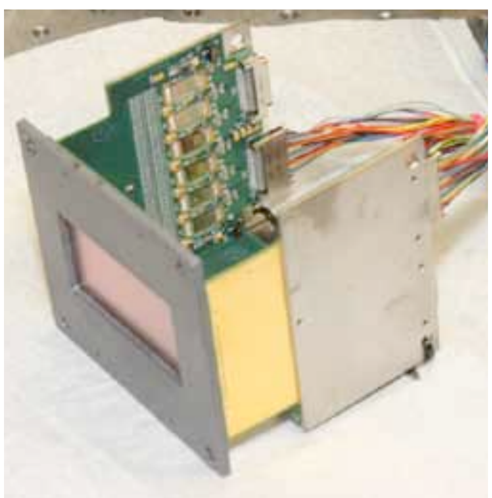


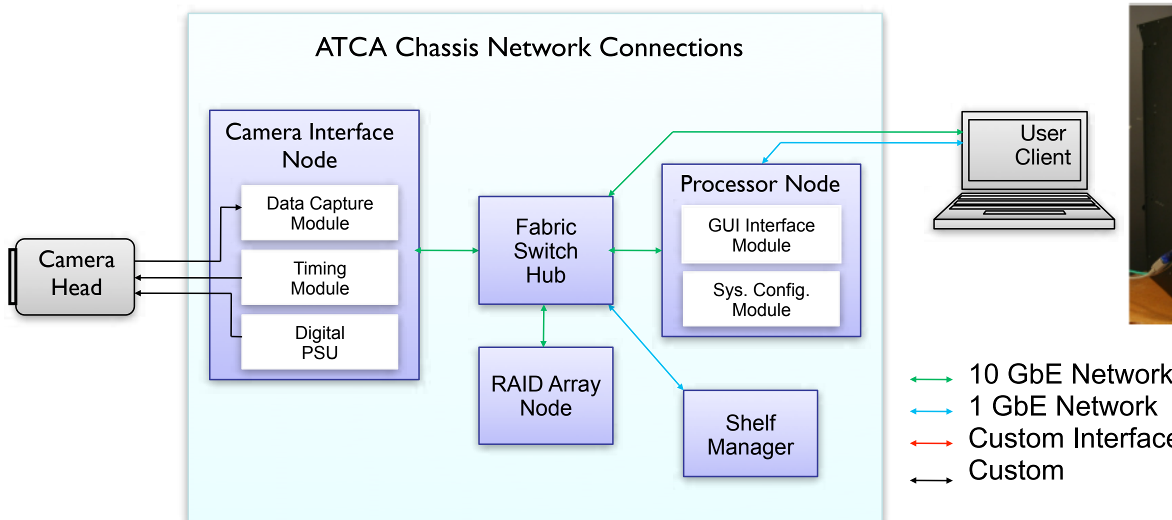
1K Frame Store FastCCD Systems

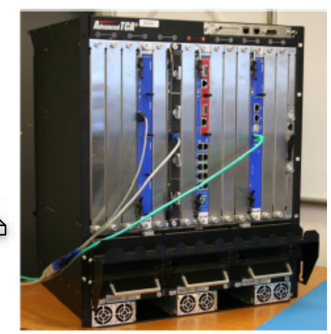
~dozen systems for ALS and APS (LCLS/SSRL and NSLS-I/II)



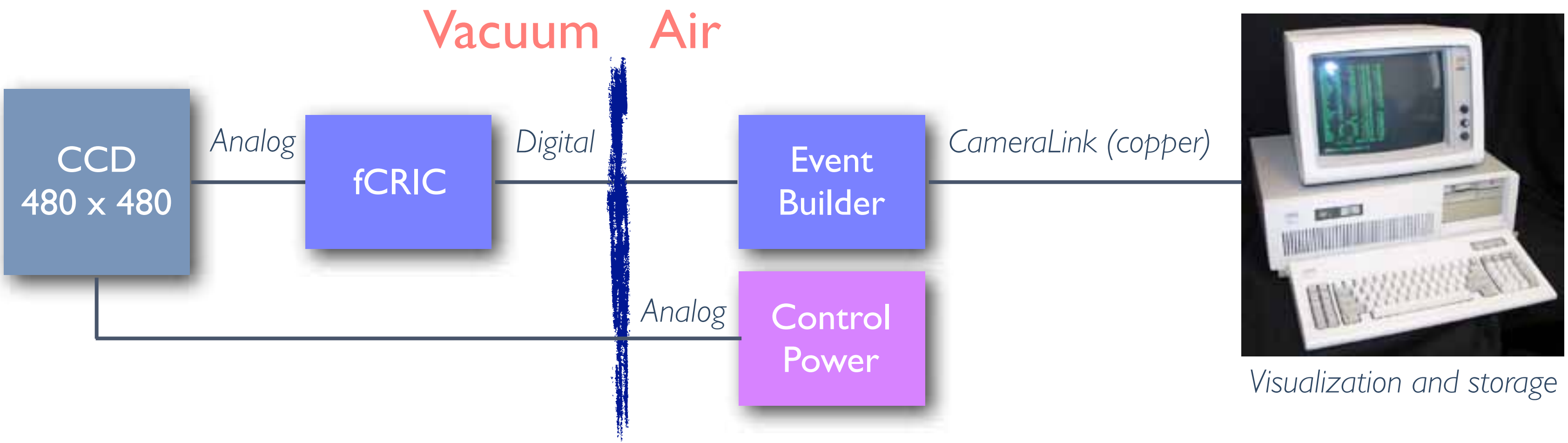


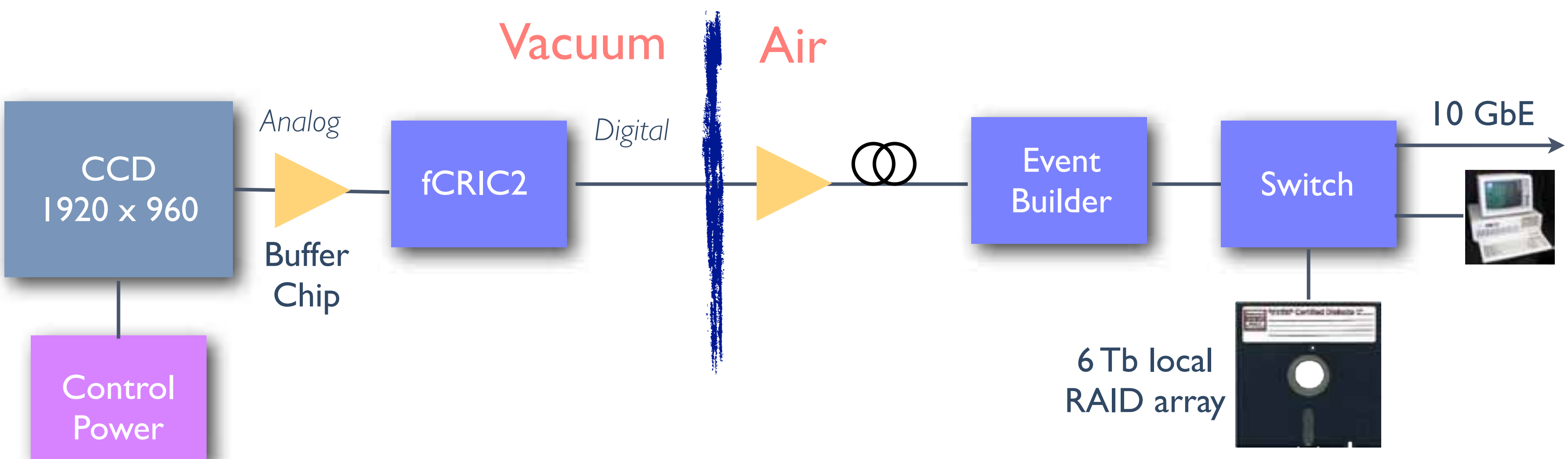


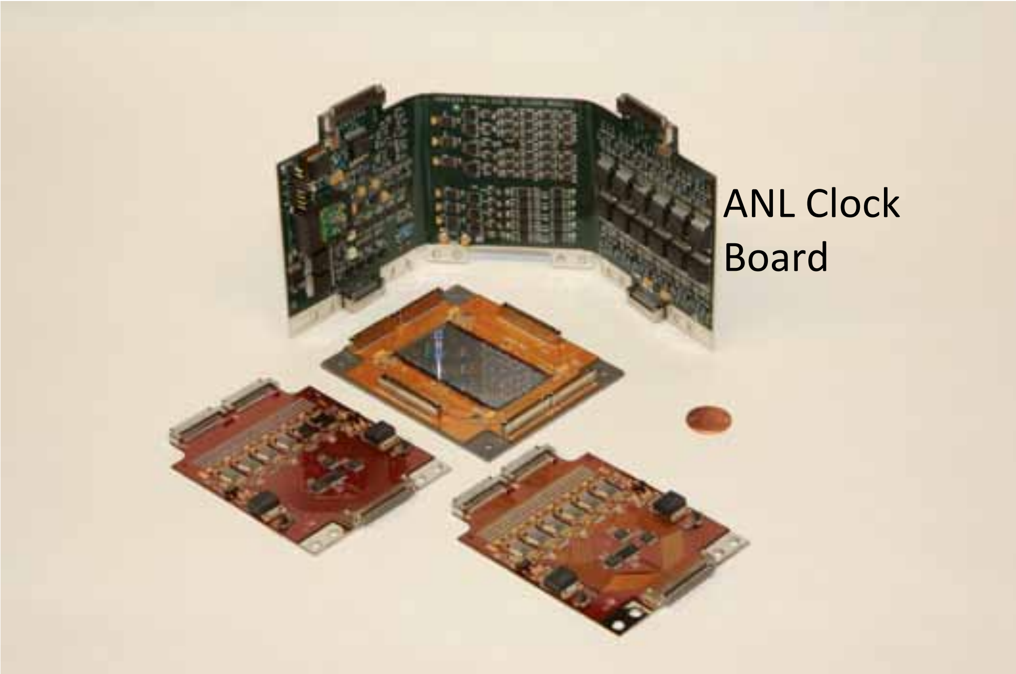


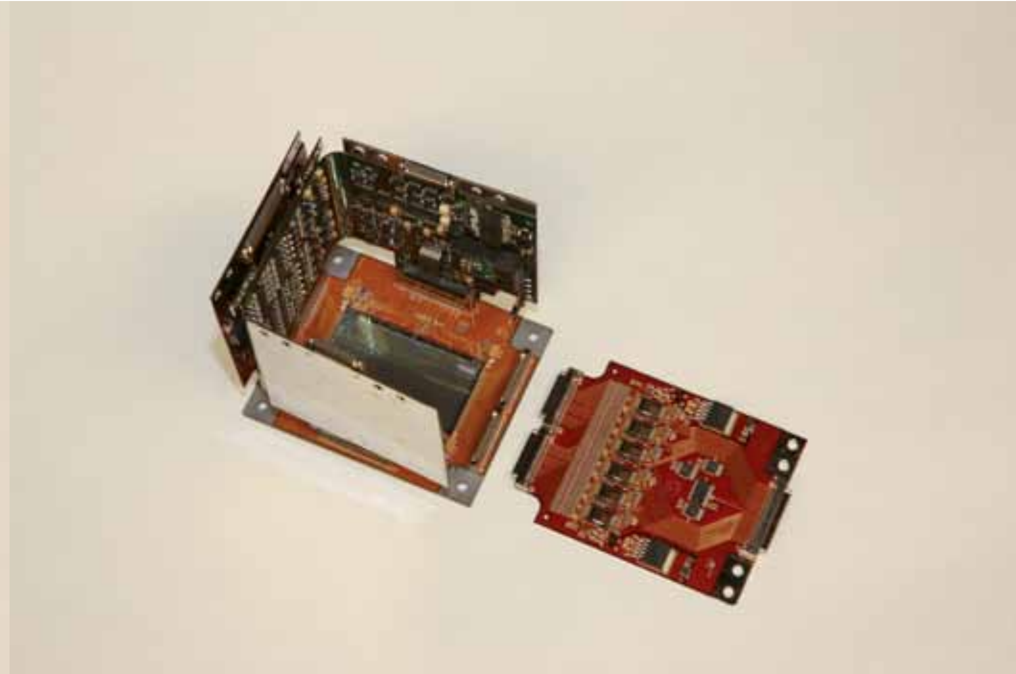


Prototype → "ARRA" System

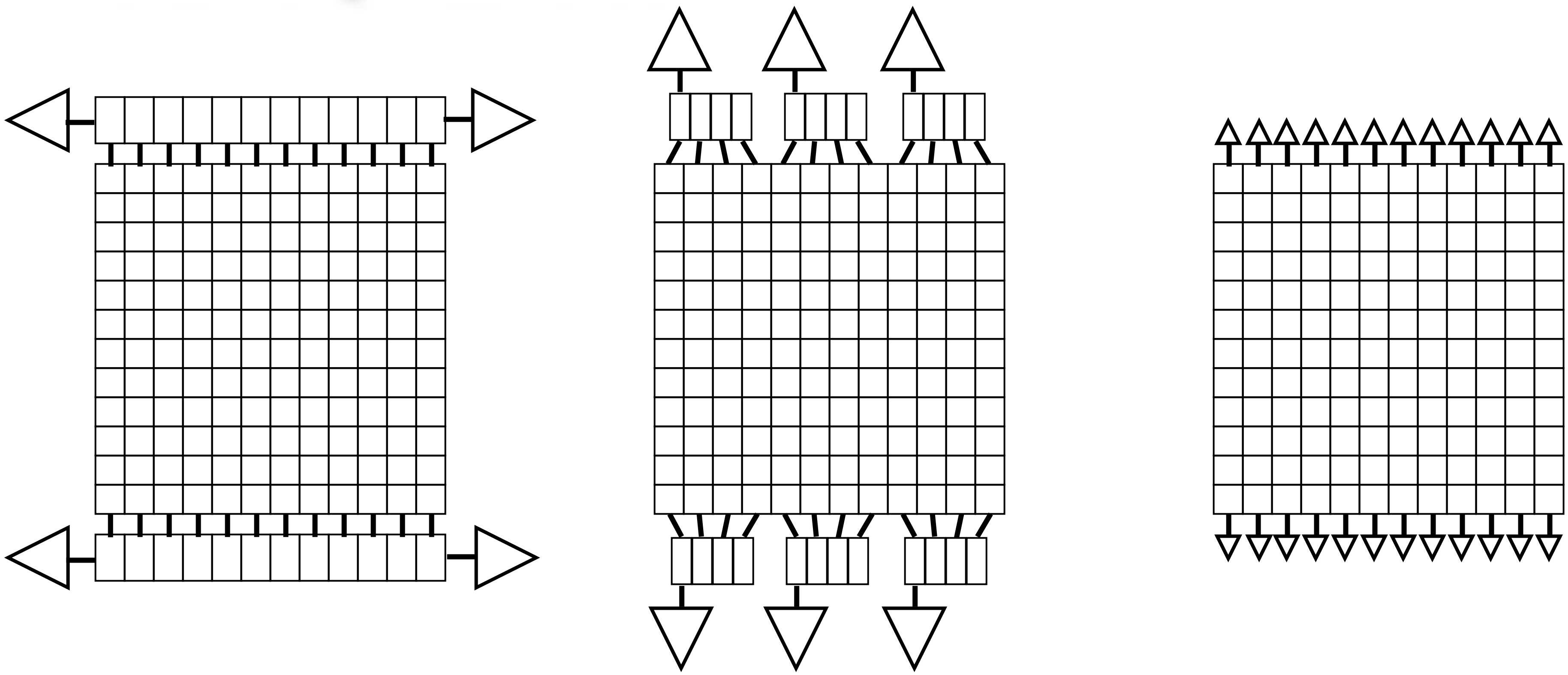





ANL Clock
Board

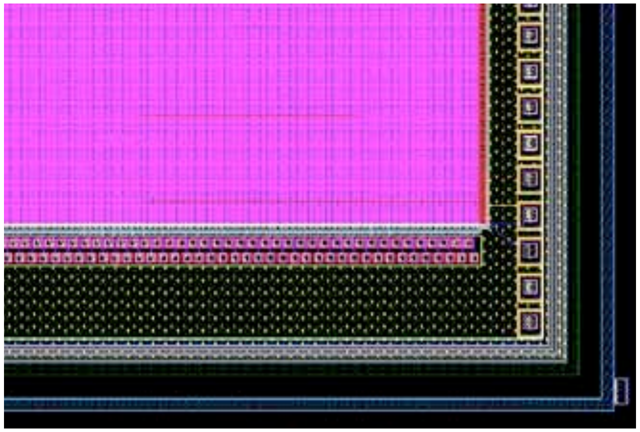


Next: Very FastCCD

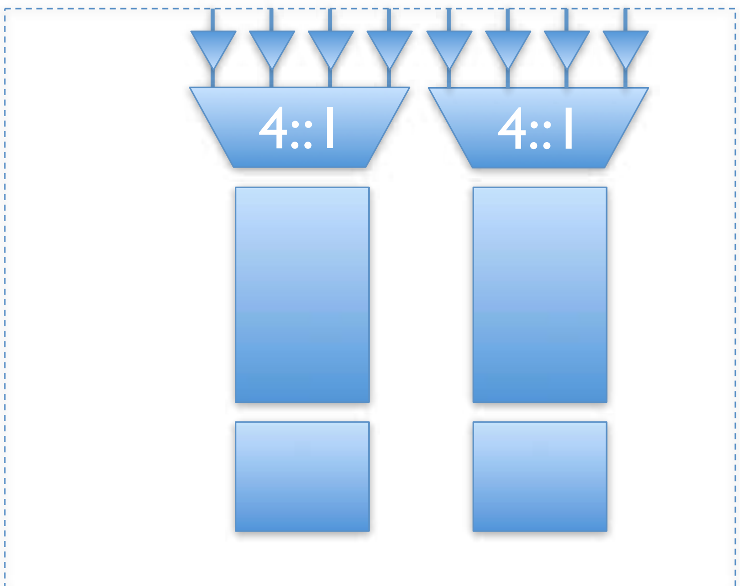


Conventional CCD	FastCCD	Very FastCCD
4-port	(almost)Column Parallel	Column Parallel
Commercial readout	*fCRIC* (custom 0.25 µm CMOS readout IC)	*HIPPO* (custom 65 nm CMOS readout IC)
10^0 fps	10^2 fps	$>10^{3.5}$ fps

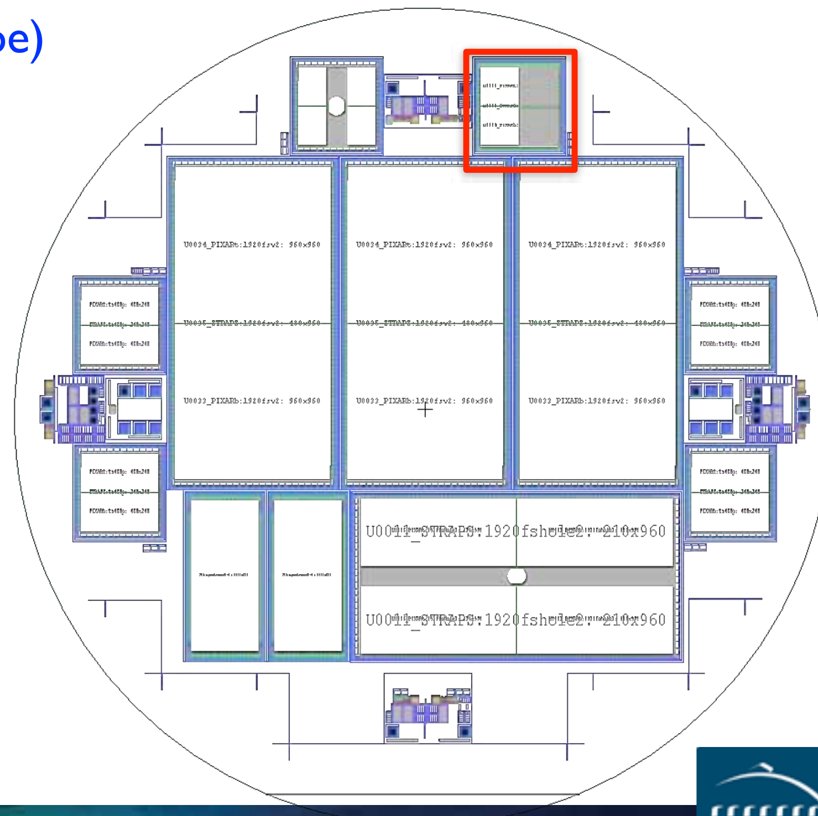
Almost Parallel → Fully Parallel



- 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 test now

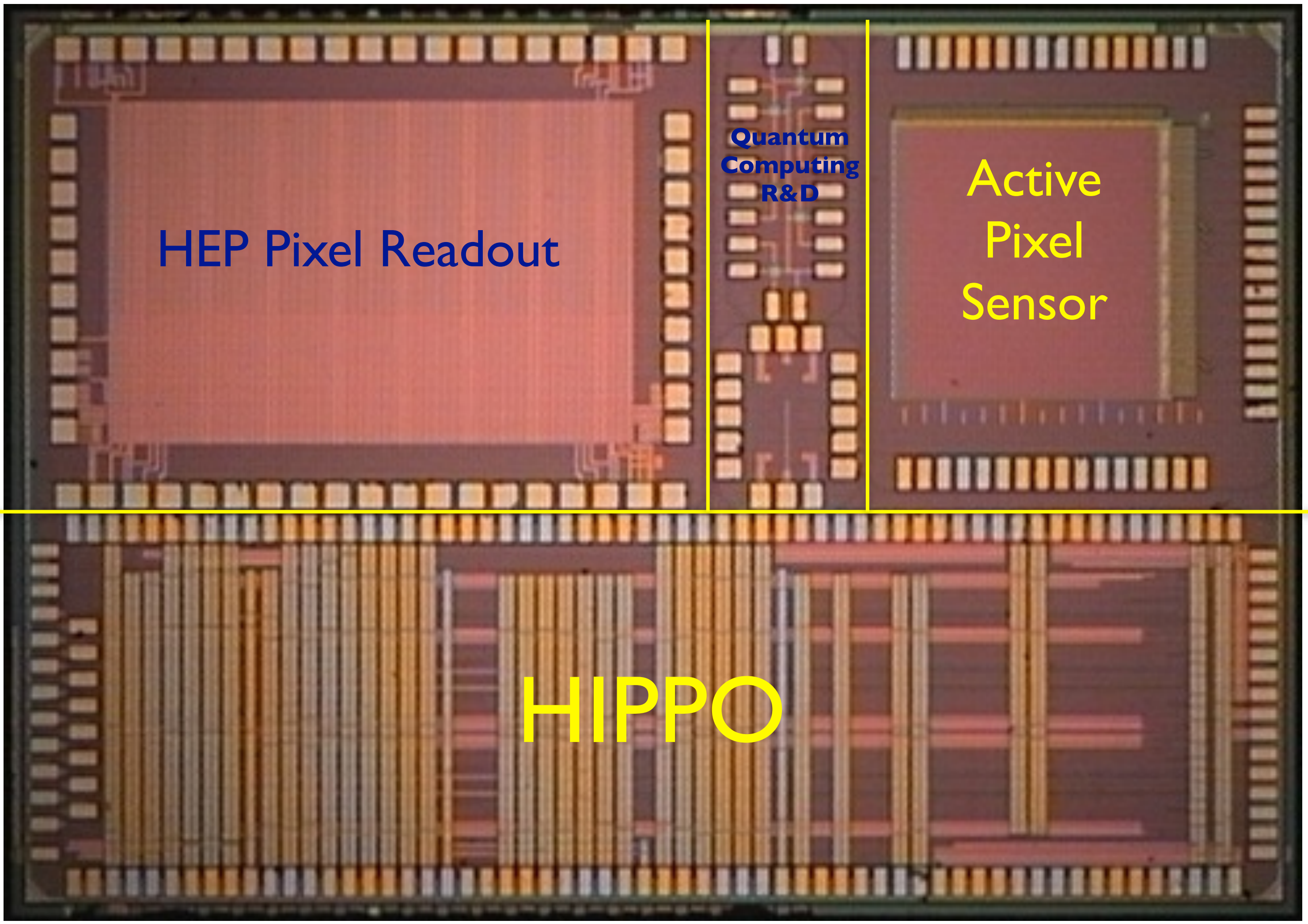


HIPPO 65 nm CMOS
High-Speed **I**mage **P**re-**P**rocessor with **O**versampling



HIPPO - June 2011

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



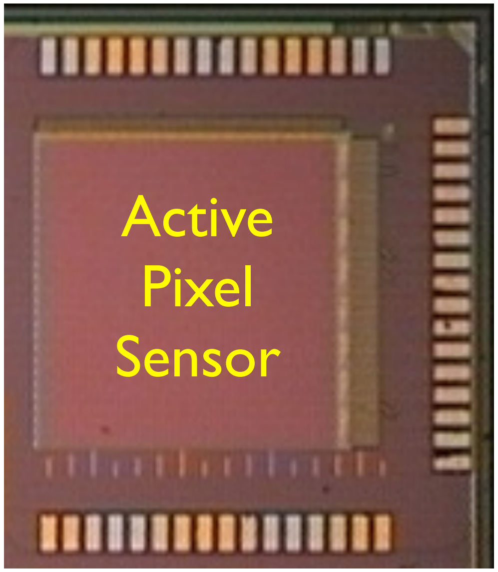
HIPPO
80 MHz / 12 bit
200 µm pitch

C. Grace et al.

Future

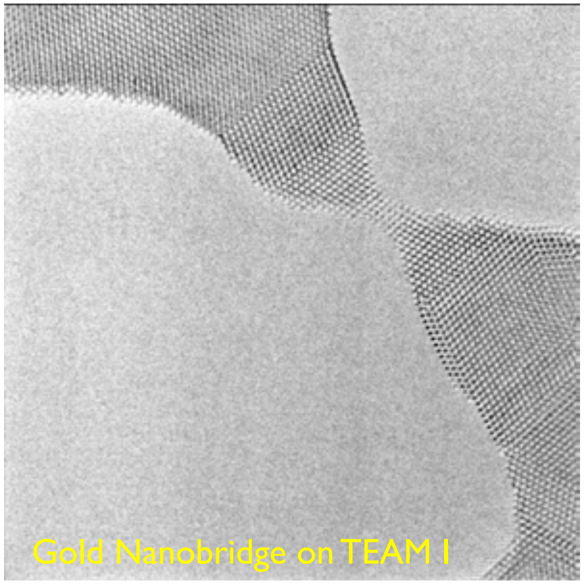
- 100,000 MPix/s soft X-ray detector
  - 65 nm APS with on-chip processing

Processing / data challenge discussed at yesterday's Computing workshop

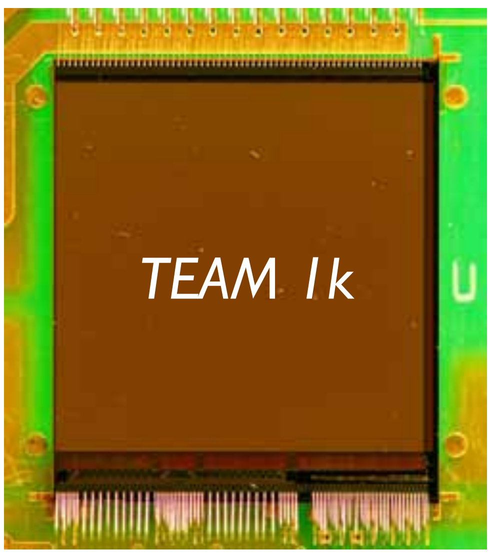


- High QE to ~1 keV
- Low energy performance will depend on entrance window
- Will work well for soft-ish electrons

Electron Detection



- ~decade of work on CMOS APS for TEM
  - Optimized for 300 keV
  - Next generation optimized for ~20 keV
- Overlaps (completely) soft X-rays

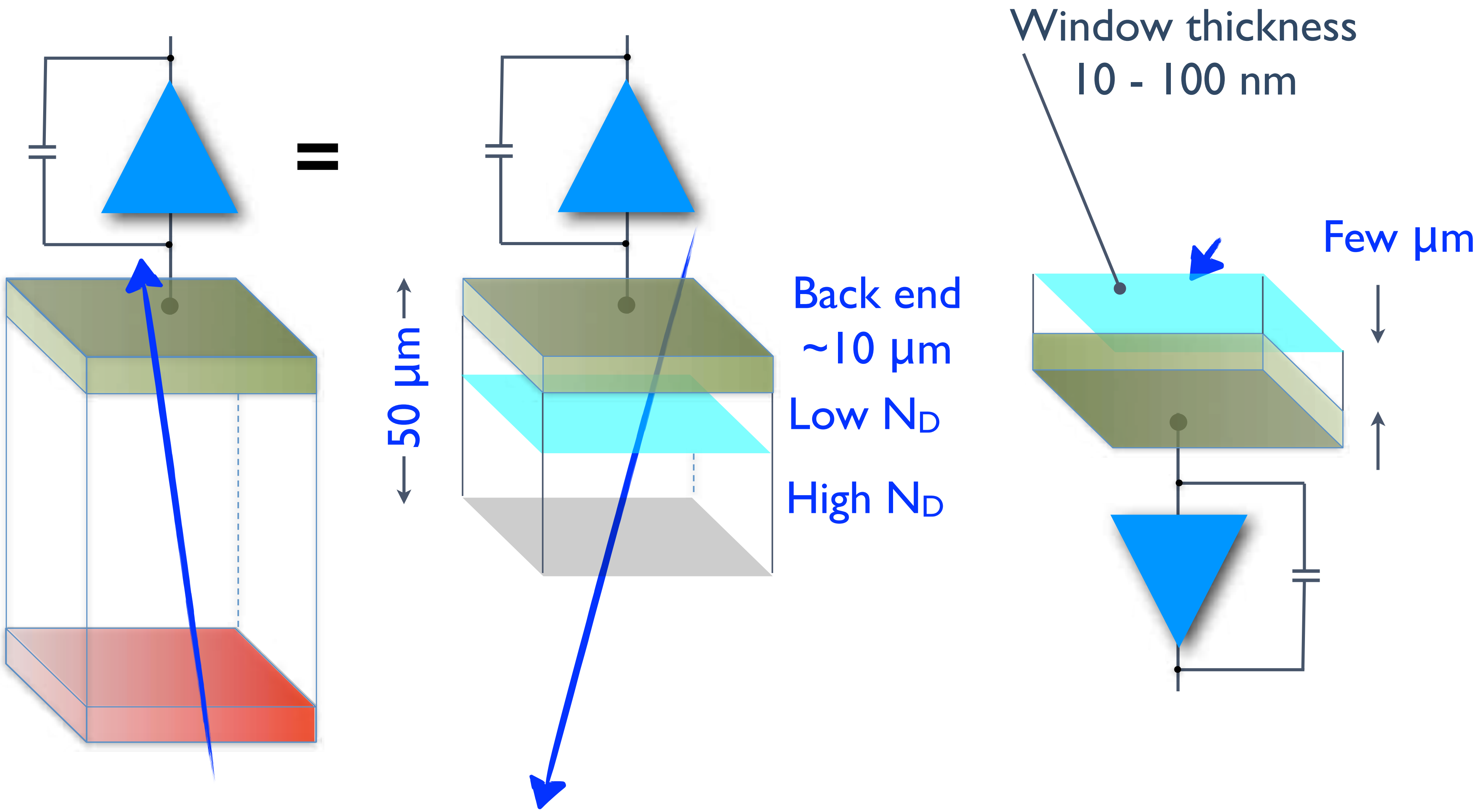


400 MPix/s

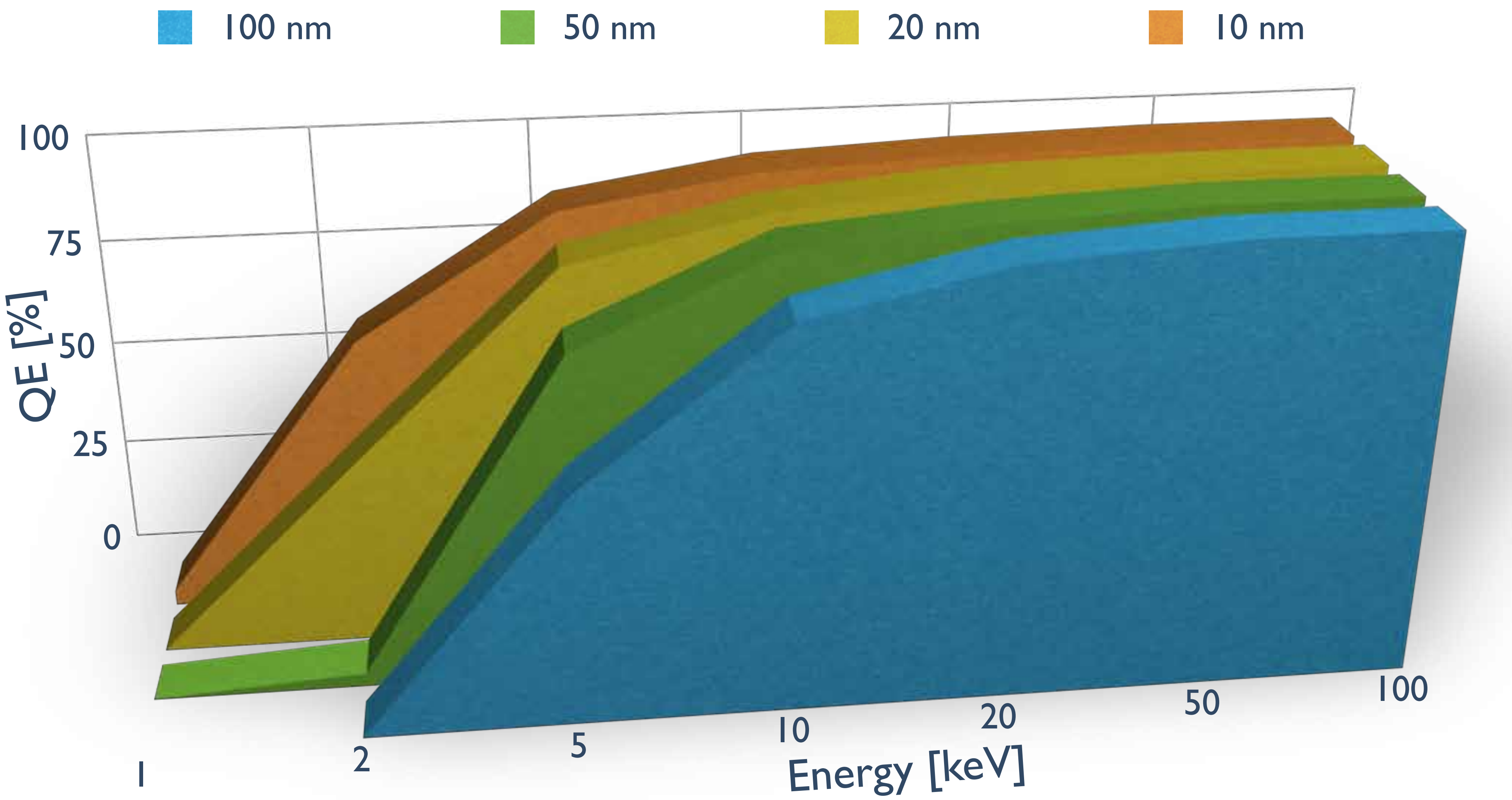
400 MPix/s

6,400 MPix/s

Thinned, Back-Illuminated CMOS APS

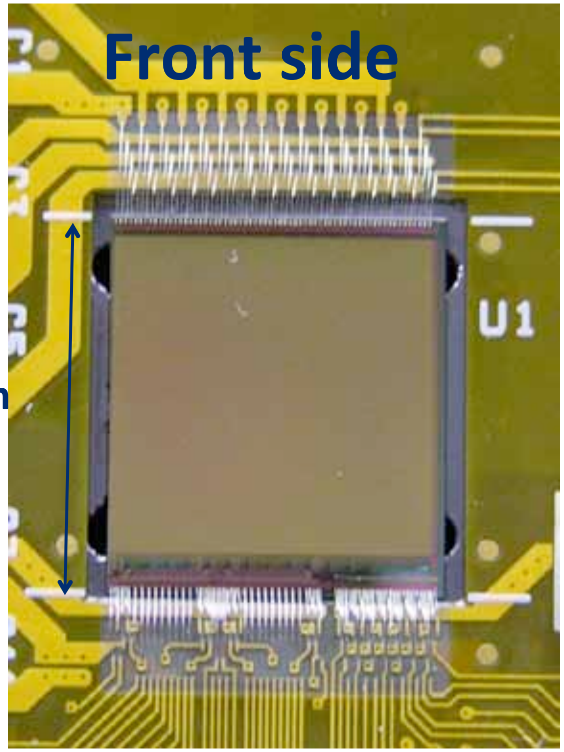


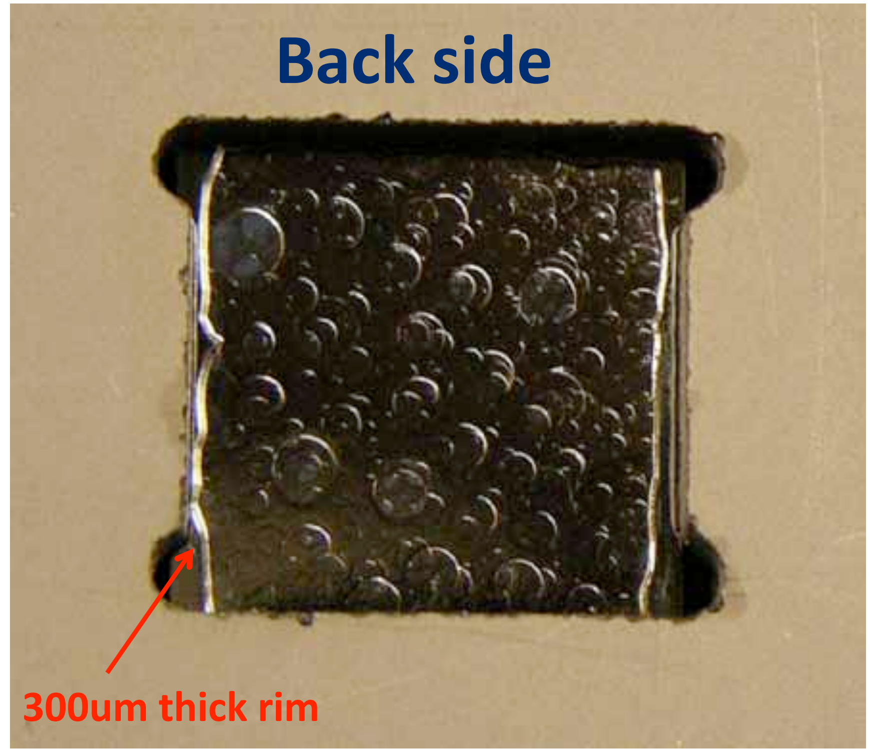
Contact Thickness and QE (electrons)



Ultra-thin, back-implanted, laser-annealed TEAM1k

11 mm

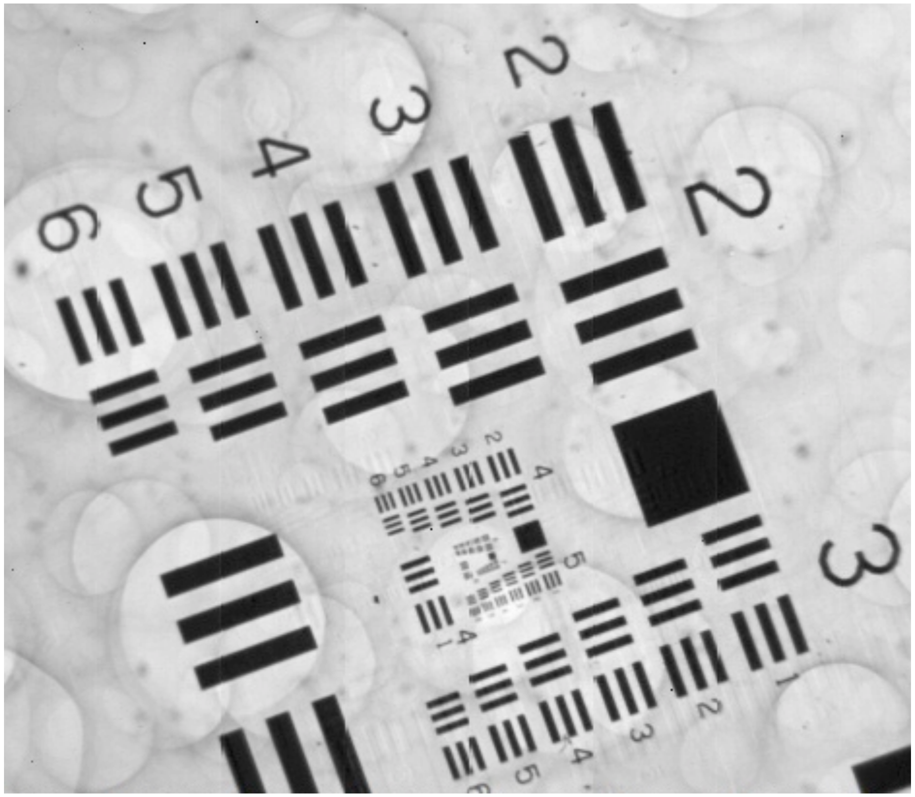




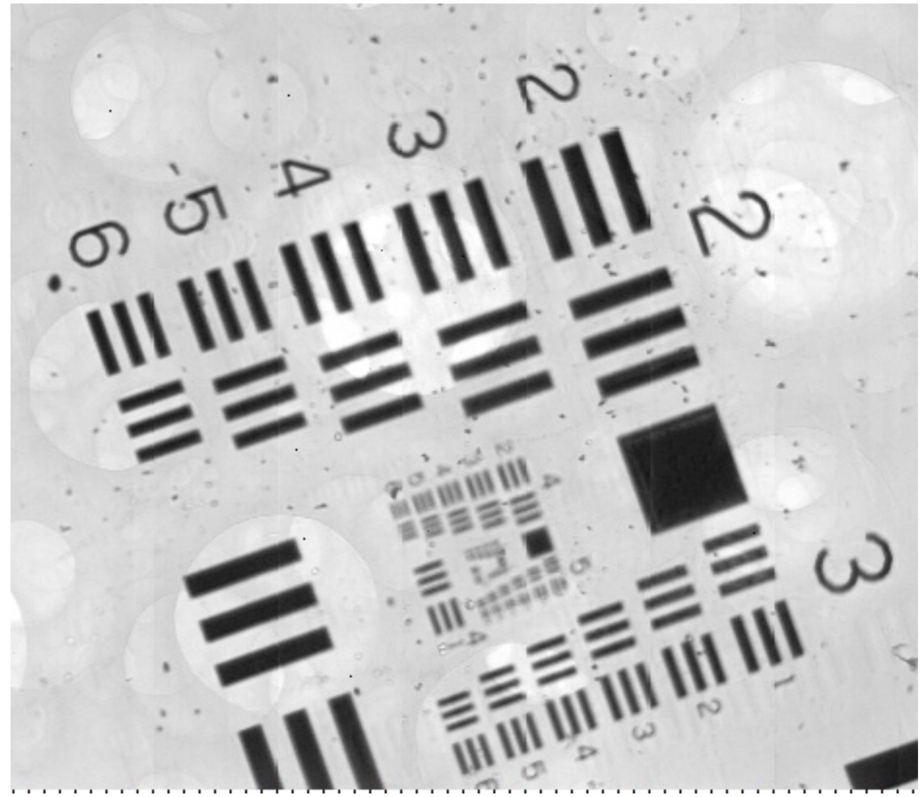
- 0.35 µm CMOS process, 1024x1024 pixels, 9.5 µm pitch
- Back-thinned to epitaxial layer by chemical etching at University of Arizona: first attempt resulted in features ("bubbles") on the chip back-side
- Backplane contact: implantation and laser annealing by commercial vendor, 70 nm thickness
- Chip functional after back-processing, tests underway

Compare front and back-illumination

Front illumination

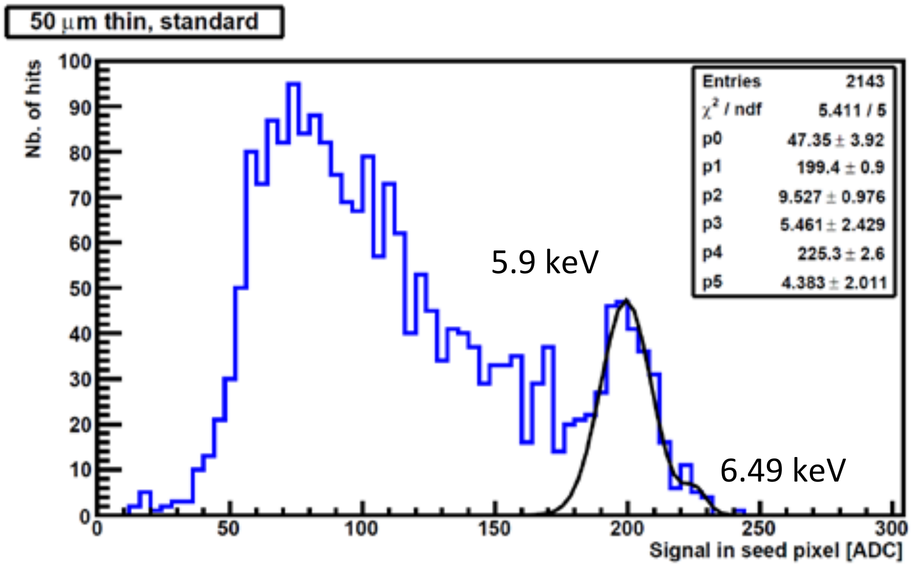


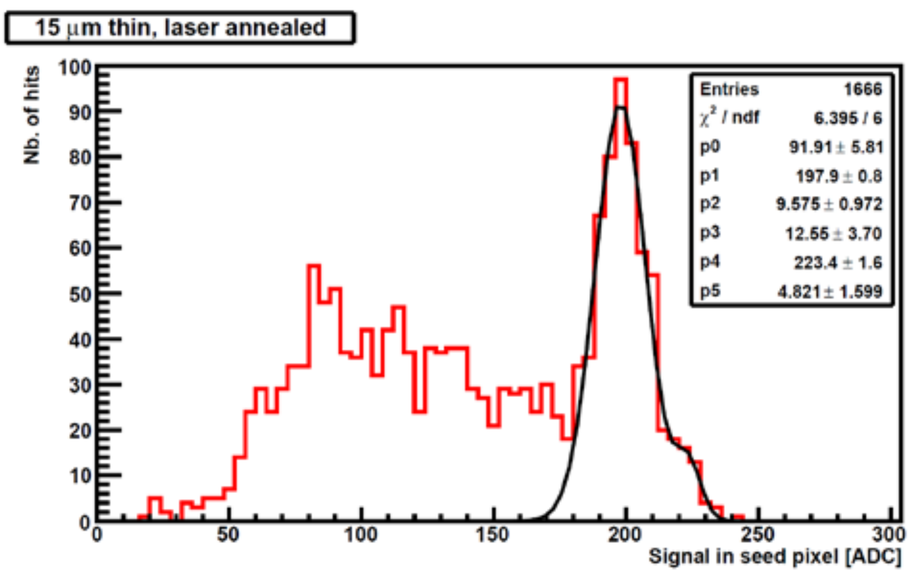
Back illumination (mirrored)



- So far, no attempt at depleting the epitaxial layer
- Assuming identical focus conditions, stronger effect of diffusion on PSF in back-illumination is apparent

^{55}Fe calibration, compare with standard device

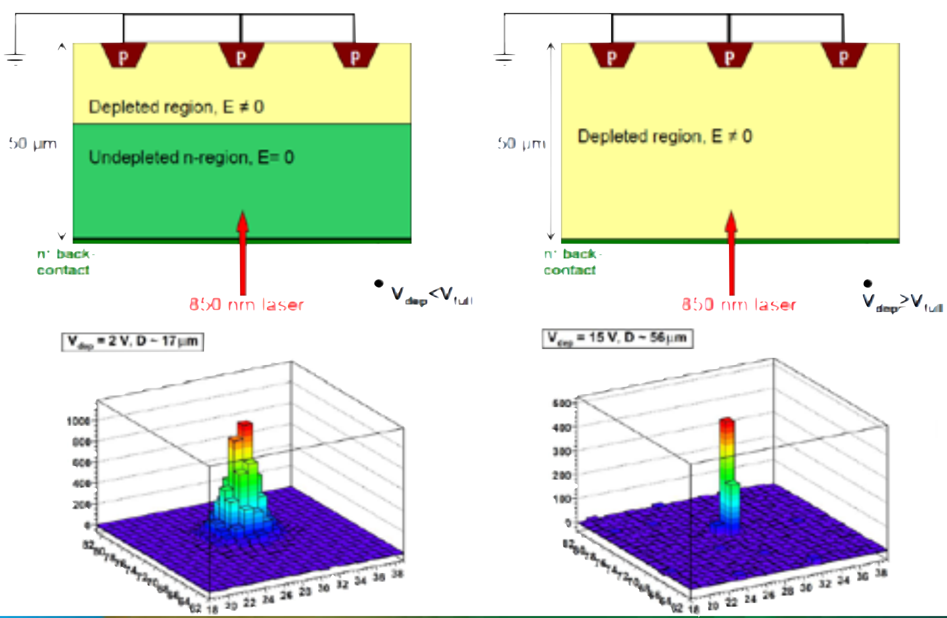




- Measurements at room T, same exposure conditions (integration time, # of frames)
- No significant difference in charge-to-voltage conversion gain (10 µV/e^-)
- In ultrathin device, observe lower total hit count and larger fraction of single pixel 5.9 keV events. Thoughts:
  - is the difference due to the loss of hits from deep in the epitaxial layer or from the low resistivity substrate?
  - how does the back-side implantation change (locally) the resistivity of the epilayer?

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

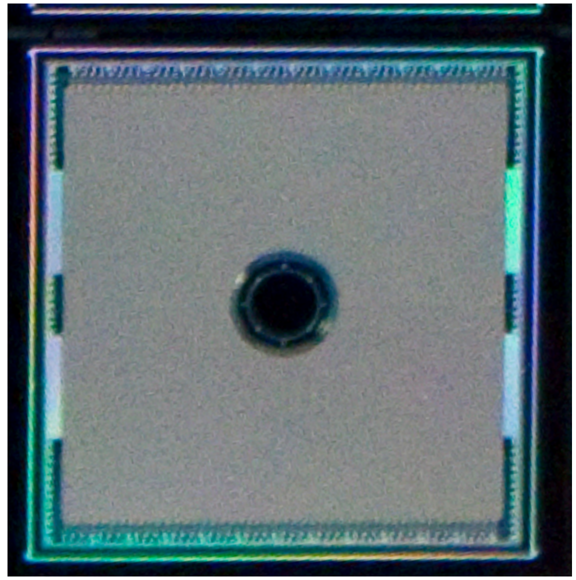
Back-illumination test with 850 nm laser on 50 µm thin SOI prototype

C.Tindall

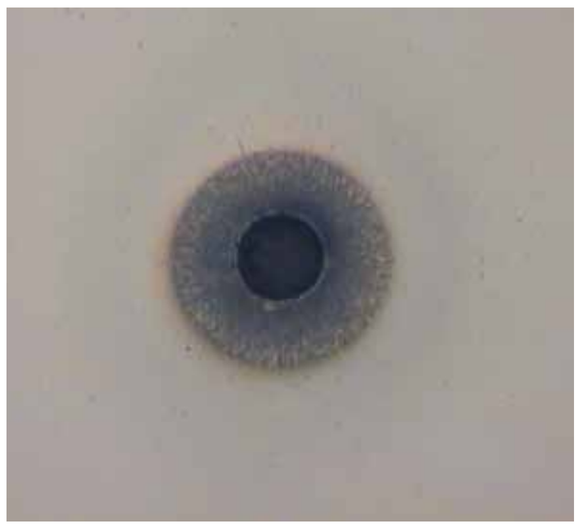
Additional Process R&D

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

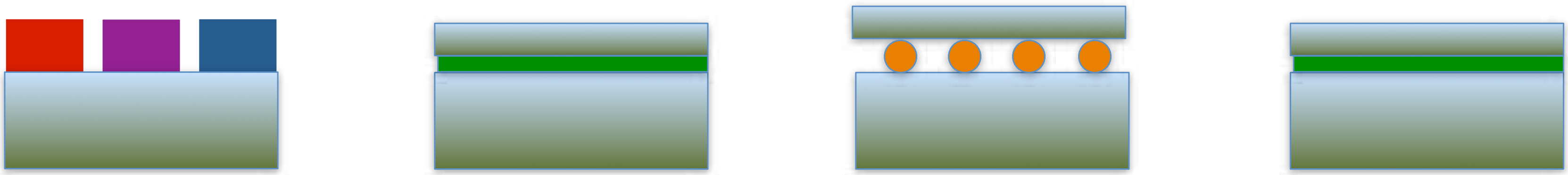
- MBE development
  - Seeded by BES ADRD
  - Completed by LBNL GPE



FastCCD with central hole (prototype shown, also “ARRA” version)



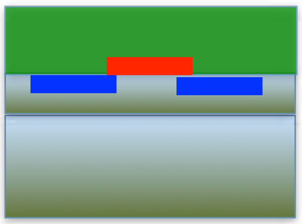
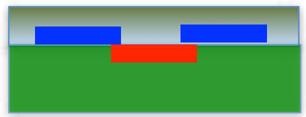
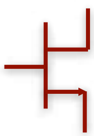
Detector Topologies (on Thick Silicon)



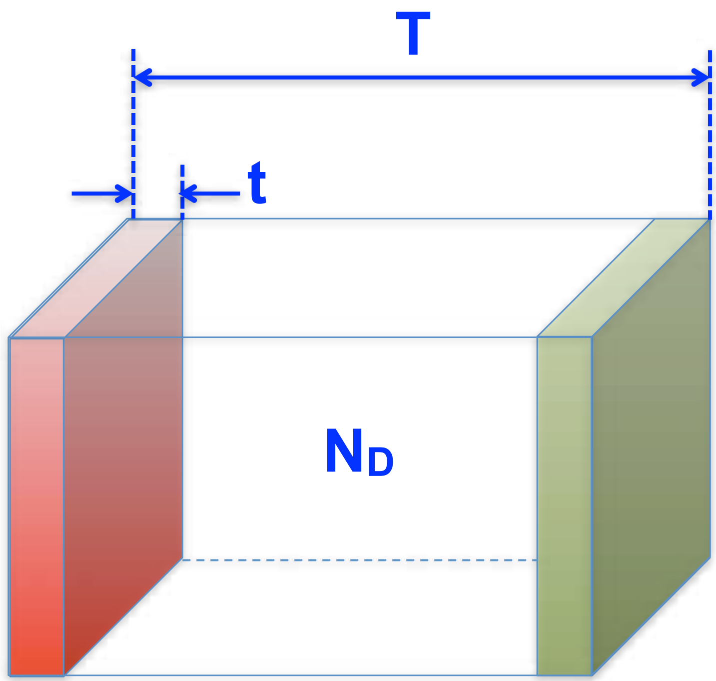
	CCD on thick, high-ρ Si	SOI on thick, high-ρ Si	Hybrid on thick, high-ρ Si	3D on thick, high-ρ Si
Size / Area	≤ 10 – <50 μm 10^2 – 10^3 μm^2	≤ 10 – 20 μm 10^2 – 10^3 μm^2	50 – 100 μm 10^3 – 10^4 μm^2	≤ 10 – 20 μm 10^2 μm^2
 /pix	0	10^1 – 10^2	10^2 – 10^3	10^1 – 10^2
ENC	10^0 – 10^1 e^-	10^1 e^-	10^2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

← ***All about interconnect*** →

Detector Topologies (on Thin Silicon)

	APS on thinned, bulk Si	APS on thinned, back-illuminated Si
		
Size / Area	$\leq 5 - < 10$ μm 10^2 μm^2	$\leq 5 - < 10$ μm 10^2 μm^2
 /pix	10^1	$10^1 - 10^2$
ENC	10^1 e$^-$	10^1 e$^-$
	TEAM / K2	HipPix, Various
	10^5 eV e$^-$	$10^{3.5}$ eV e$^-$ $10^{2\text{-}3}$ eV γ

Summary



Very simple:

- X-rays: E$\uparrow$ $\rightarrow$ T$\uparrow$
- e^-: E$\uparrow$ $\rightarrow$ T$\downarrow$
- X-rays: E$\downarrow$ $\rightarrow$ t$\downarrow$
- e^-: E$\downarrow$ $\rightarrow$ t$\downarrow$

- T $\uparrow$ $\rightarrow$ $N_D$$\downarrow$

- Readout speed:
  - dynamics
  - single γ / e^-

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

With the assistance of:

ALS Experimental Systems Group
ALS Scientific Support Group
APS Beamline Technical Support Group
LCLS DAQ Group
National Center for Electron Microscopy

Engineering Division
- Electronic Systems Group
- Integrated Circuit Design Group
- Microsystems Laboratory

Physics Division