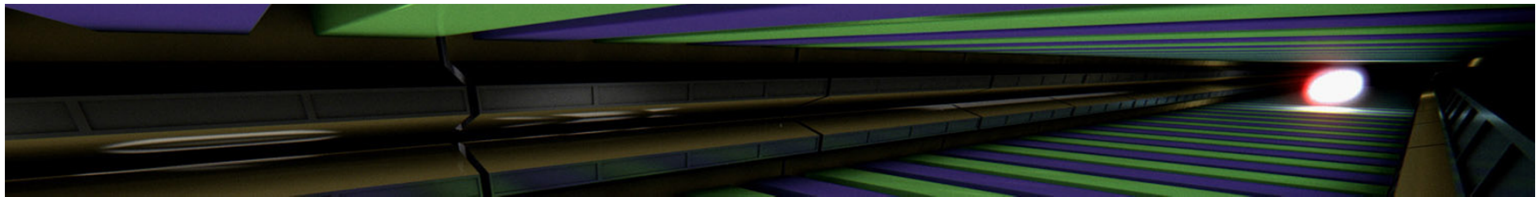
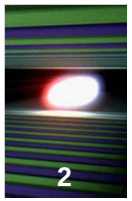


Soft X-ray detectors at European XFEL

Andreas Koch
European XFEL, WP-75, Detector Development
26.1.2012

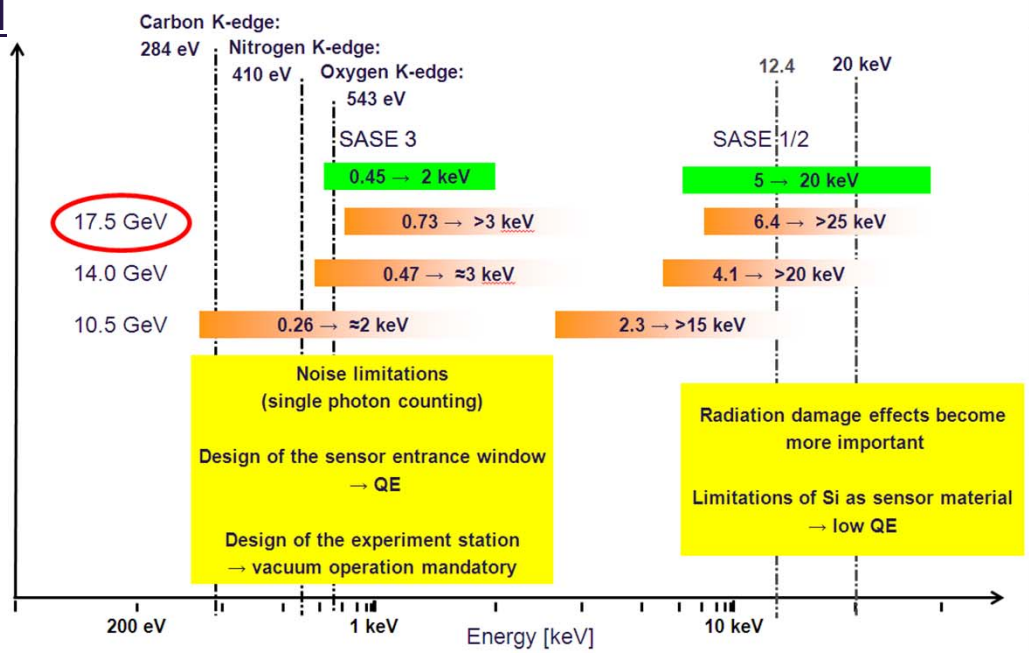
Outline



- Status of detector activities for low energy applications
- Overview on
  potential suppliers, collaborations for developments
- Most promising suppliers, labs
  examples

Requirements for low energy 2d detection at XFEL

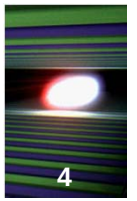
- General



Pixel size	10 ...100s μm
Detector size	1kx1k or rectangular
Tiling	central hole
Quantum eff./ sensor thickn.	> 80%
Energy range	0.25 – 3 keV
Dynamic range	10^3 … 10^4…
Noise / noise equ. signal	Single photon sensitivity
Frame rate	4.5 MHz, 2700 im., 10 bursts

- Specific RIXS requirements (dispersive imaging):
  - Dispersive axis: pixel size down to 10 μm, even smaller.
  - Axis for angular coverage of incoming radiation: more pixels or larger pixel size, i.e. rectangular pixel (aspect ratio x2 … x10).

Overview of detector development efforts / Motivation



- Baseline detector at XFEL
  for low energy applications is the DSSC detector (DEPFET Sensor with Signal compression)
  Full scale, full commissioned version is delayed to 2017.

- Day-1 detector
  in 2015 for SPS, SQS is needed.
  Small pixel size down to 50 µm is an additional requirement.
  Possible solutions and options are presented.

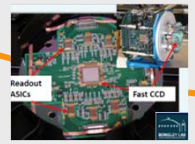
- A phase 2 detector
  with enhanced performance is under discussion.

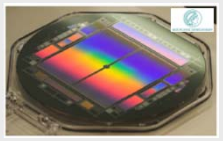
Low energy detector alternatives

Market scan July – December 2011.
18 companies and laboratories contacted.
5 contacts are closer investigated.

Labs:
Cornel Univ.
BNL
LCLS
SACLA (with e2v)
ESRF
SLAC
LBNL
CEA
Desy
RAL
MPI

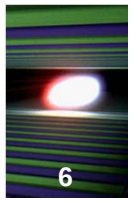
Companies:
e2v
Hamamatsu
Bruker
Photonic Science
Dalsa
Dexela
Pyxalis (ex – e2v)





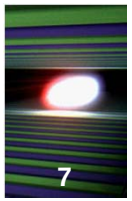
Promising replies:
LBNL (with Dalsa)
XCAM / SACLA (with e2v)
Photonic Science
Desy
MPI

Benchmarking



	Requirements low energy detector XFEL	DSSC	CS-PAD	pn CCD MPI	Commercial CCD, Cmos, < 15 keV	Commercial CCD, Cmos, > 15 keV
	For SCS, SQS	XFEL baseline	Operational at LCLS		Commercial	
Technology		DEPFET hybrid	hybrid	CCD	e.g. Roper CCD deep depleted PIXIS-XO	e.g. Dexela 2930MAM mammography
Pixel size	10 ...100s μm	204x236 mm^2, hex.	110 μm	75μm	13 μm	74.8 μm
Detector size	1kx1k or rectangular	1kx1k	1516x1516 or smaller	1kx1k central hole		29x30 cm^2
Tiling	central hole	Yes, with central hole	Yes, multiple tiles	2 tiles		4 tiles
Quantum eff./ sensor thickn.	> 80%	>80% @0.4-10 keV 60% at 0.25 eV	500 μm Si	>80% @ 0.3-12 keV	100 μm Si	70% @ 20 keV
Energy range	0.25 – 3 keV	0.5 – 4 keV	<1 –10 keV, opt. 8 keV nominal	0.05-24 keV	0.03-10 keV (Roper)	> 18 keV,
Dynamic range	10^3 … 10^4…	10^4	10^3-10^4	10^3		10^3-10^4
Noise / noise equ. signal	Single photon sensitivity	1 keV rms	1 keV rms	2 el. rms	2 el. rms	1000 el. estimated
Frame rate	4.5 MHz, 2700 im., 10 bursts	4.5 MHz, 576 images dig. on-chip	120 Hz	200 Hz	2 Hz (Roper) 5 Hz (4x4)	26 Hz
Costs					≈ 60 keuros	≈ 45 keuros
Product full spec		2017	?	2015	commercial	commercial
Risks		Calibration, Delay				
Remarks	Specific needs for dispersive	ongoing	to be rebuilt option low energy	to be rebuilt	For vacuum operation	With scintillator

Benchmarking

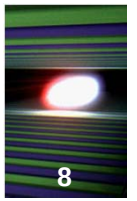


	LBNL FS-CCD	XCAM / SACLA	Desy / RAL	Photonic Science	Cornell / SLAC / ESRF	Phase 2 development ?
	Development projects other labs, companies					XFEL
Technology	Frame transfer CCD, back-illuminated	CCD open electrode, Riken design (MPCCD)	MAPS, Cmos	New Cmos design, back-illum.	sCmos Fairchild (back-illum. in preparation)	3D Cmos, bump bonded sensor, 65 nm SOI
Pixel size	30 μm	40 μm	25-30 μm	15 μm	6.5 μm	50–100 μm
Detector size	1kx1k, monol., option hole	1kx1k, 4 tiles, central hole	20x20 cm^2, hole, 4 tiles	4kx4k, monolithic	2kx2k, monolithic	1kx1k or larger, tiles
Tiling	Several mm gaps if tiled	Yes	2 side buttable	Yes, with gaps	no	4 side butta
Quantum eff. / sensor thickness	200 μm Si	20% @ 10 keV 40 μm Si	95% @ 1 keV 12 μm Si	15 μm Si	?	Si sen bd.
Energy range	0.25-8 keV	0.3-10 keV	0.25-1 keV	To be defined	?	0.2-20 keV
Dynamic range	10^3-10^4	10^3-10^4	10^6, 3 gains	10^4	10^4	10^6, 4 gains
Noise / noise equ. signal	30-40 el. rms	20 el.rms	15 el. rms 50 eV rms	4 el. rms	2.5 el. rms	200 eV rms
Frame rate	100 Hz	10 Hz	120 Hz	10 Hz	17 Hz (34 Hz for 1k)	4.5 MHz, 2700 images, digital
Costs	rel. low	rel. low				
Product, full perf.	2014	2013	2014	1.5-2 years	?	4-5 years
Risks			Noise, delay	Consortium needed		3d integration
Remarks	Ongoing, ≈15 cameras	Riken prototype, options possible	Ongoing project for Flash	Proposal	• Project idea • scintillator ?	Proposal - high-end

Waiting for more information

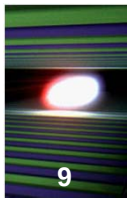
Tentative specs

Other specifications, open points



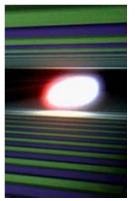
- Radiation hardness
- Medium term stability (temperature, voltages, charge effects)
- Local electron / hole plasma effects in the Si sensor
- Calibration
- Data acquisition
- a.o.

Examples

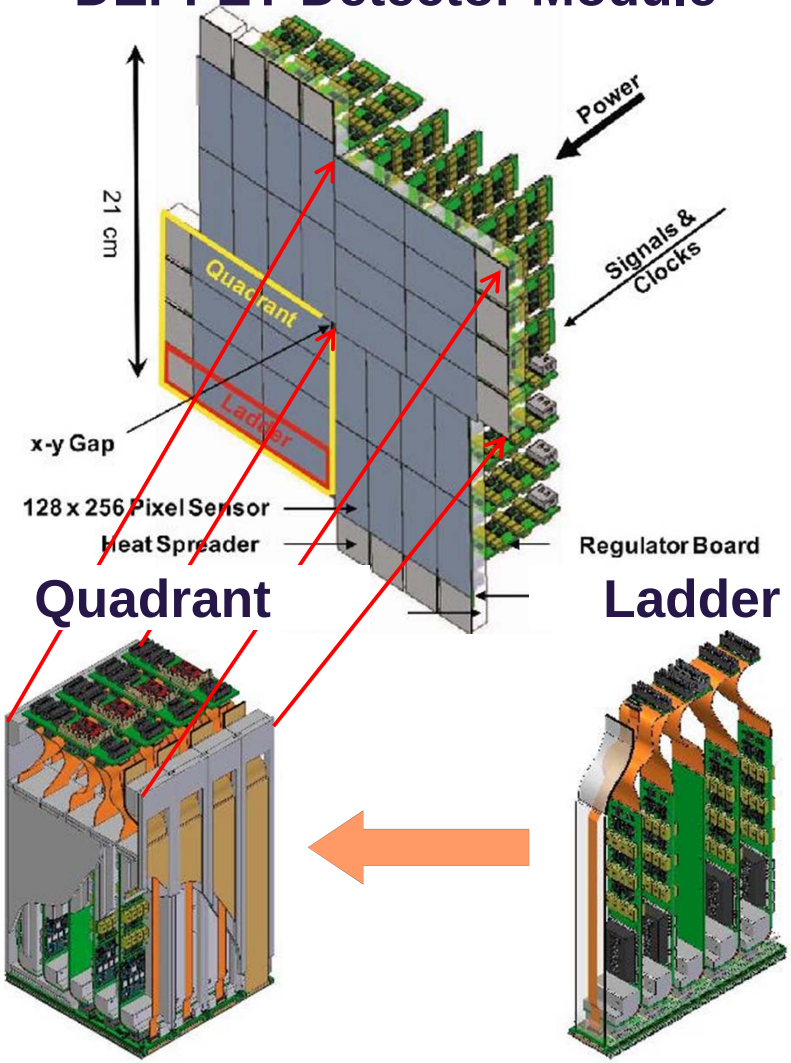


European XFEL

DSSC 1 MPixel Detector Module



DEPFET Detector Module



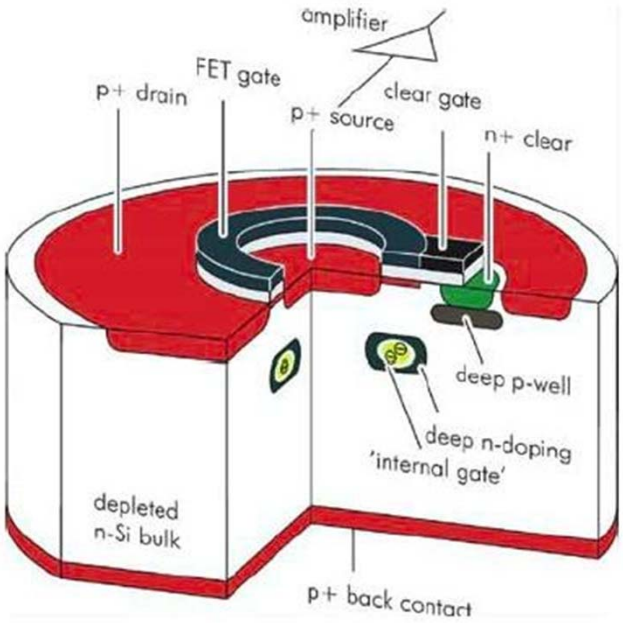
Key Detector Parameters

- Goal: Single photon sensitivity
  5 σ @1 keV and 4.5 MHz
- Energy range
  0.5 – 6 (25) keV
- Dynamic range
  > 6000 photons/pixel/pulse @1 keV
- Single photon sensitivity
  5 σ @ 1 keV (5 MHz)
  5 σ @ 0.5 keV (≤ 2.5 MHz)
- Number of storage cells 576
- Smallest detector unit “ladder
  128 x 512 pixels
- 4 ladders built on quadrant
- 4 quadrants = 1k x 1k detector

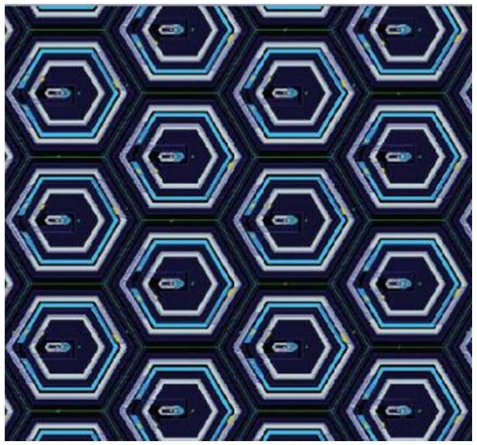
DSSC - DEPFET Sensor with Signal Compression

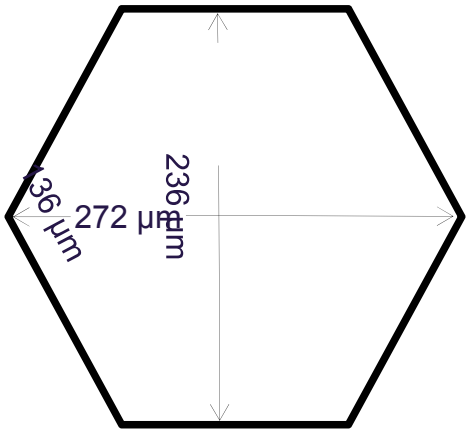
Pixel Cell

- DEPFET combined with Silicon drift detector
- → scalable pixel size
- Low noise
- → Good energy response down to 500 eV



Pixel Geometry





Porro et al. NIM A (2010) vol. 624 pp. 509

- Hexagonal pixels

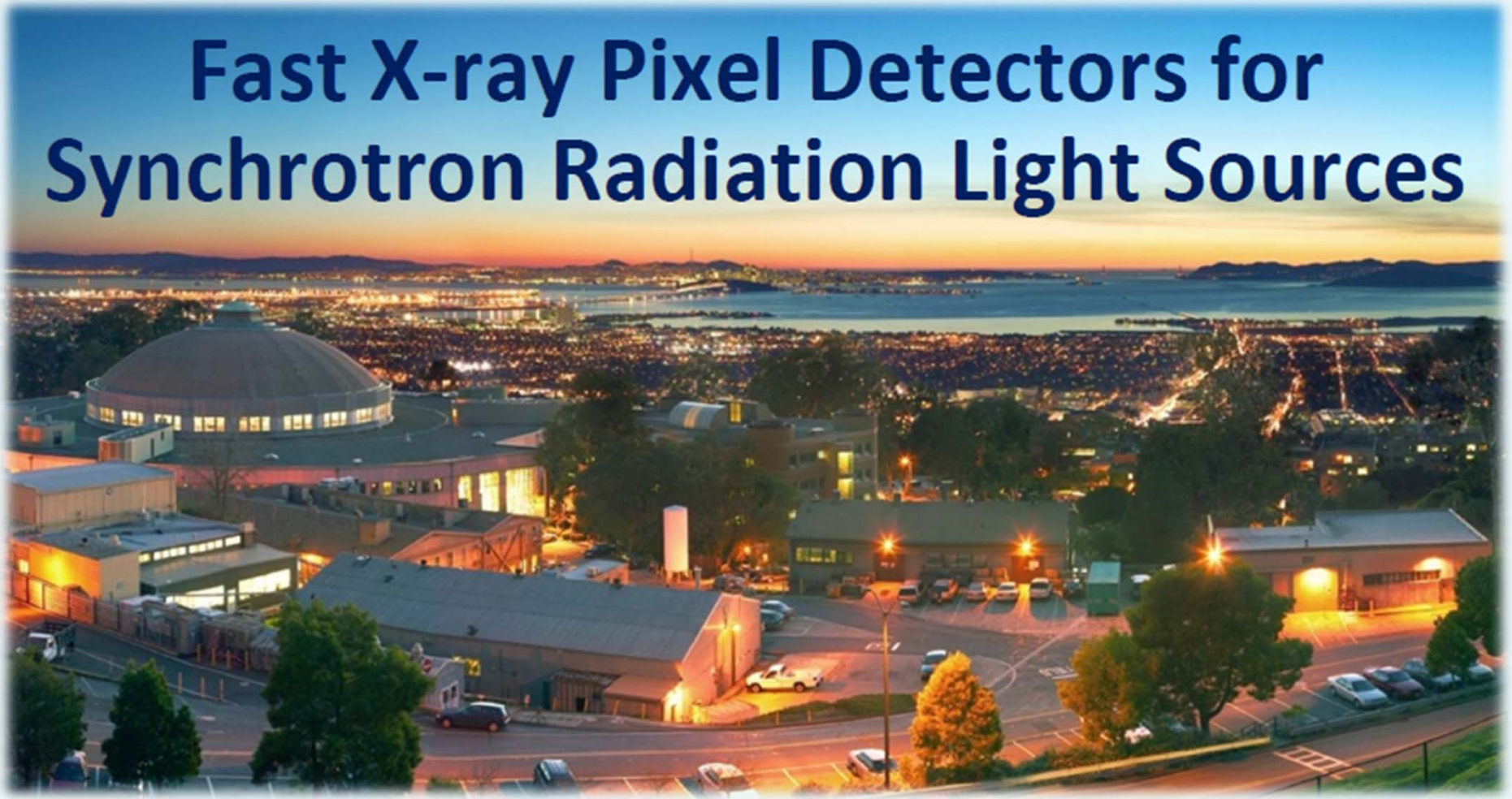
→ more homogeneous drift field

→ minimize charge collection time

→ less charge sharing (split events)

- Per pixel ADC/digital storage pipeline
- → no charge leakage
- 576 - 9 bit SRAM storage cells per pixel

Fast X-ray Pixel Detectors for Synchrotron Radiation Light Sources



BERKELEY LAB
Lawrence Berkeley National Laboratory

Devis Contarato

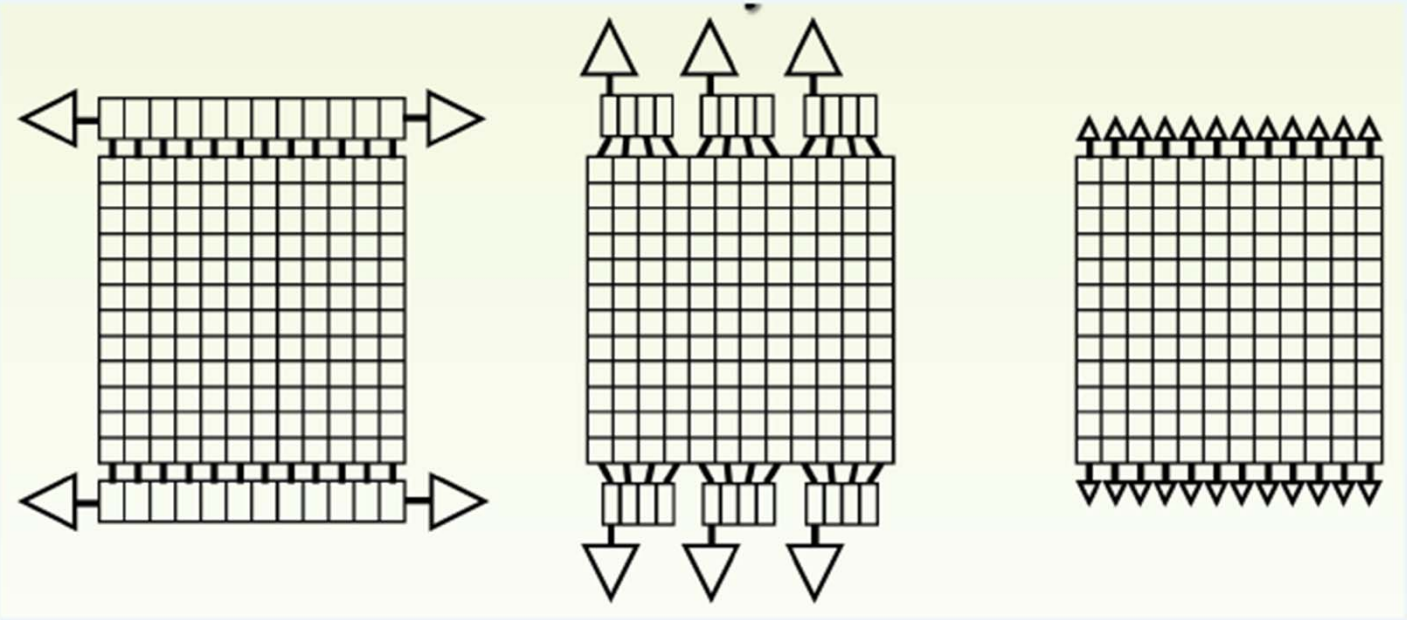
on behalf of the EG/ALS Detector Engineering Group:

P. Denes (P.I.), N. Andresen, D. Doering, C. Grace, J. Joseph, P. McVittie, J.P. Walder, C. Tindall, B. Zheng ...

... and many more contributors

PSI
13th International Workshop on
Radiation Imaging Detectors
13th IWoRiD
3th – 7th July 2011
Zurich and Villigen PSI
Switzerland

Readout architecture options

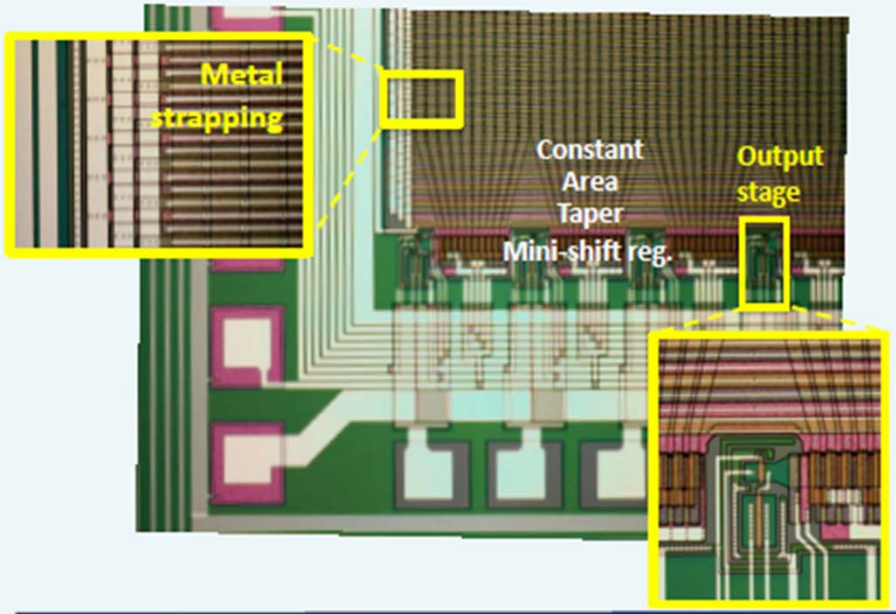


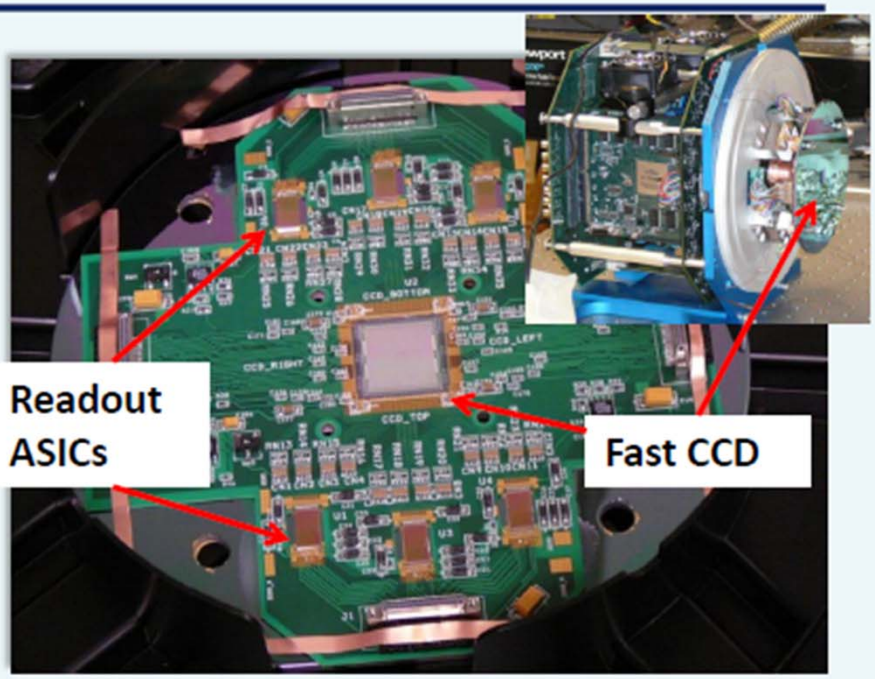
Conventional CCD	Fast CCD	Very Fast CCD
1 to few-port	(almost) Column Parallel	Column Parallel
Commercial readout	fCRIC (custom 0.25 µm CMOS readout IC)	HIPPO (custom 65 nm CMOS readout IC)
10^0 fps	10^2 fps	> $10^{3...5}$ fps

this talk

Prototype Fast CCD

- 1st generation direct soft X-ray detector developed by LBNL in collaboration with ANL:
  - multi-port
  - 200 µm thick, fully depleted
  - back-illuminated
- 480×480 pixels, 30 µm pitch
- 96 analog outs, quasi-Column Parallel readout (10 column MUX)
- 200 fps readout rate

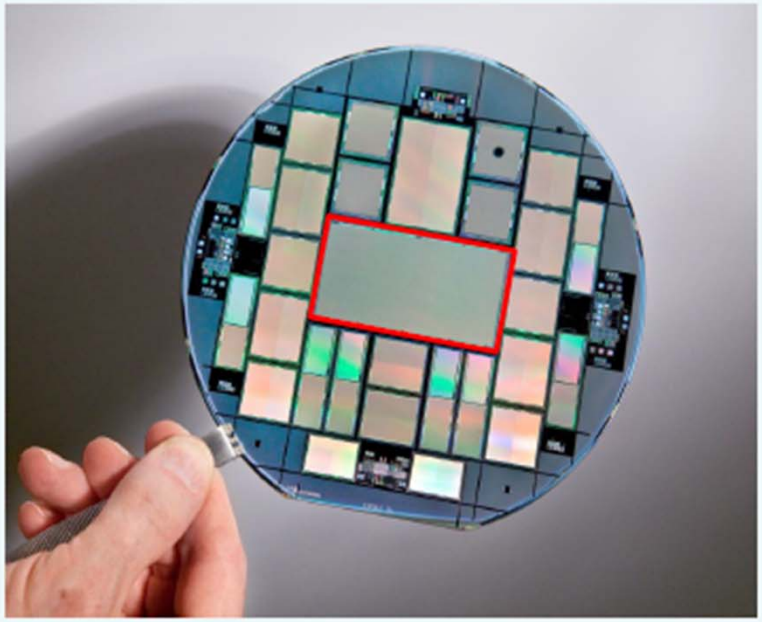


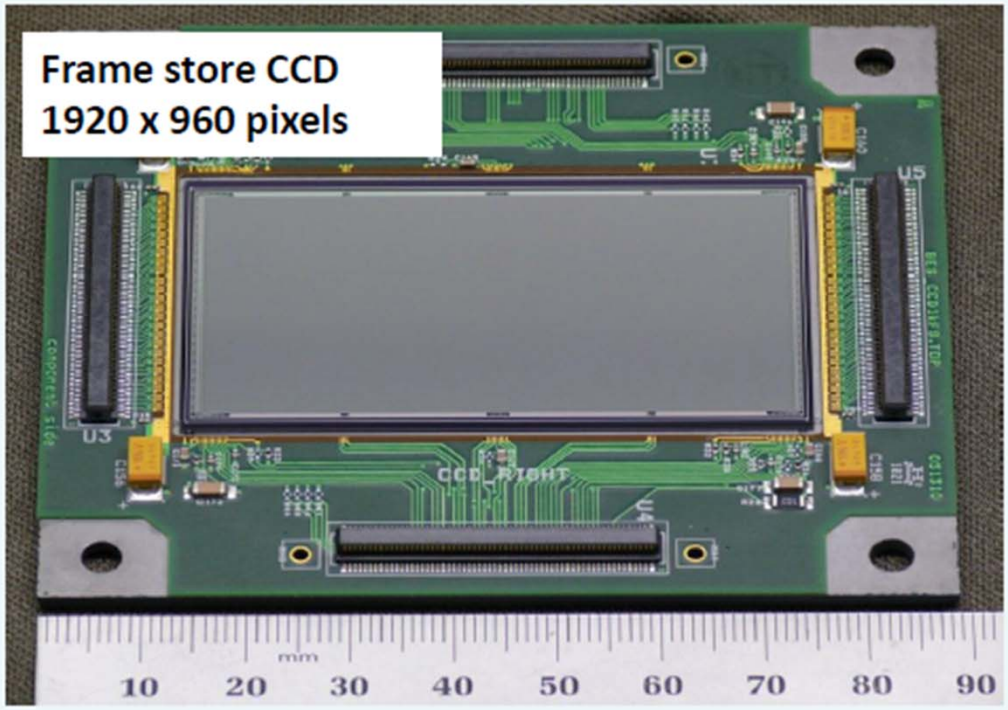


- Performance:
  - 900000 e^-/pixel full well
  - 250 eV single photon resolution
  - PSF < 1 pixel

[P. Denes et al., Rev. Sci. Instruments 80, 083302 (2009)]

1k Frame-Store CCD





- 1920×960 pixels, 30 µm pitch , sensor based on Fast CCD design and cFCCD detector head
  - 960×960 pixels X-ray sensitive area in frame transfer mode (200 fps)
  - 1920×960 pixels X-ray sensitive area in full imaging mode (100 fps)
- 192 analog outputs (quasi-CP readout), 12 custom readout ASICs, raw data bandwidth 400 MB/s
- Full detector systems being developed under Recovery Act funding, to be delivered in 2011 (8 systems @ ALS, 2 systems @ APS, interest from SSRL/LCLS and NSLS-II)

Fairchild sCMOS

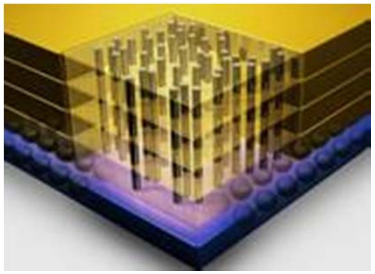
Parameter	sCMOS	Interline CCD	EMCCD
Sensor Format	5.5 megapixel	1.3 to 4 megapixel	0.25 to 1 megapixel
Pixel Size	6.5 µm	6.45 to 7.4µm	8 to 16 µm
Read Noise	< 2 e^- @ 30 frames/s	4 -10 e^-	< 1e^- (with EM gain)
Full Frame Rate (maximum)	100 frames/s @ full resolution	3 to 16 frames/s	~30 frames/s
Quantum Efficiency (QE)	60%	65%	90% 'back-illuminated' 65 % 'virtual phase'
Dynamic Range	> 16,000:1 (@ 30 frames/s)	~ 3,000:1 (@ 11 frames/s)	8500:1 (@ 30 frames/s with low EM gain)
Multiplicative Noise	None	None	1.41x with EM gain (*effectively* halves the QE)

Next steps, opportunities

- LBNL
  - Prototype testing at ALS in March.
- MPI
  - 1 Mpx sensor available at HLL Munich.
- SLAC / Cornell / ESRF

  New project ideas will be followed up:
  - Modified CS-PAD.
  - Fairchild sCMOS, back-illuminated or with scintillator.

- …. and look to future trends, a phase 2 project ?
  - Contacts and discussions foreseen.
  - Carefully understand:
    detector technology evolution & scientific requirements.
  - Identify partners, interests, costs.



Through Silicon Vias, TSVs, to link DRAM chips, by IBM