Development of Detectors for ALS

- Photoemission

- 2 GHz pulse counting linear detector (after c/plates)
- 10 years of development!

- Diffraction / tomography / imaging / optical microscopy……..

- column parallel CCD (LDRD funded)
- 30 micron pixels, 120 frames / sec, 16 bits

- Proposals

- LCLS: CP-CCD in a SAXS / WAXS configuration

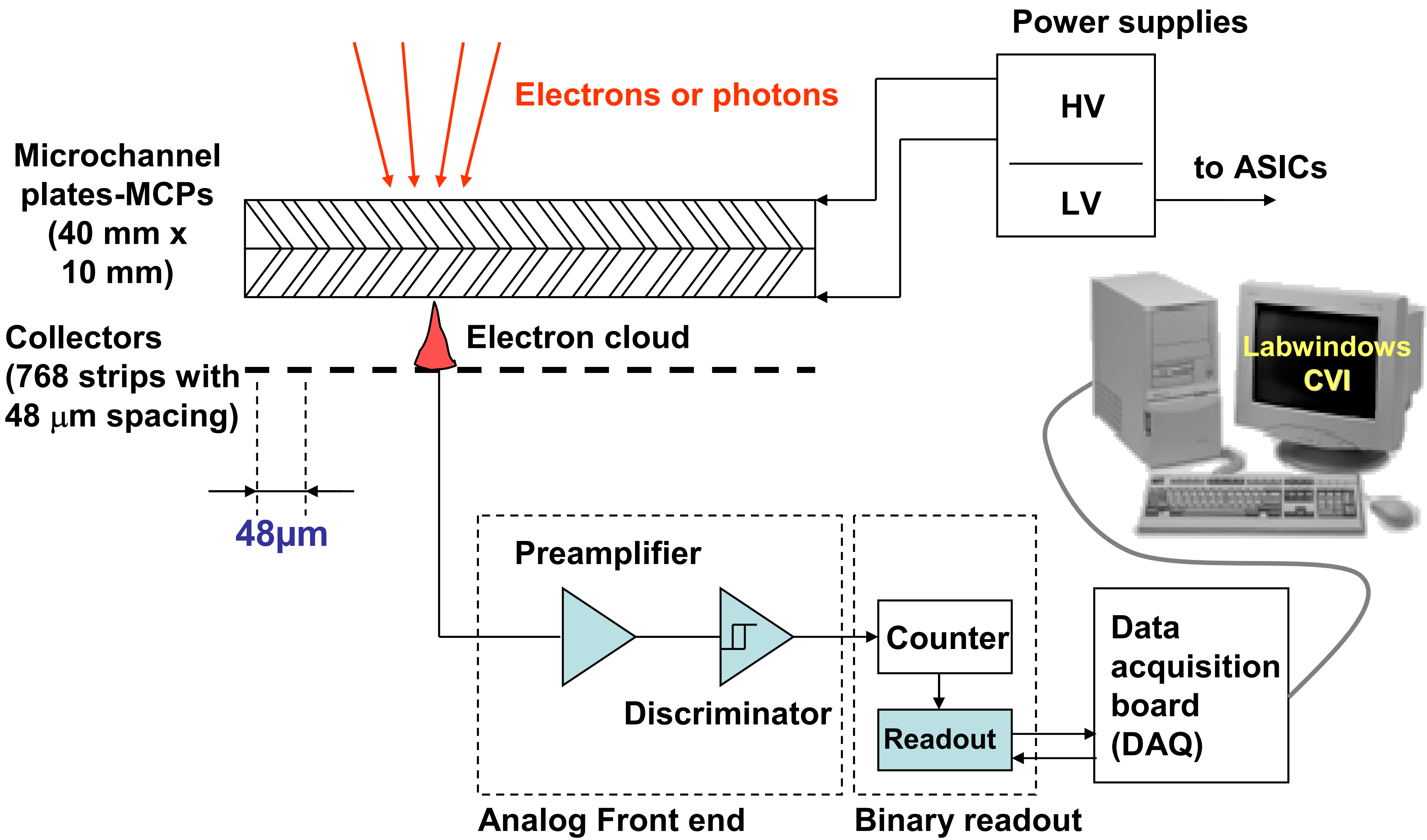
- LCLS: direct detection CP-CCD

- BES: energy / time resolving x-ray pixel detector

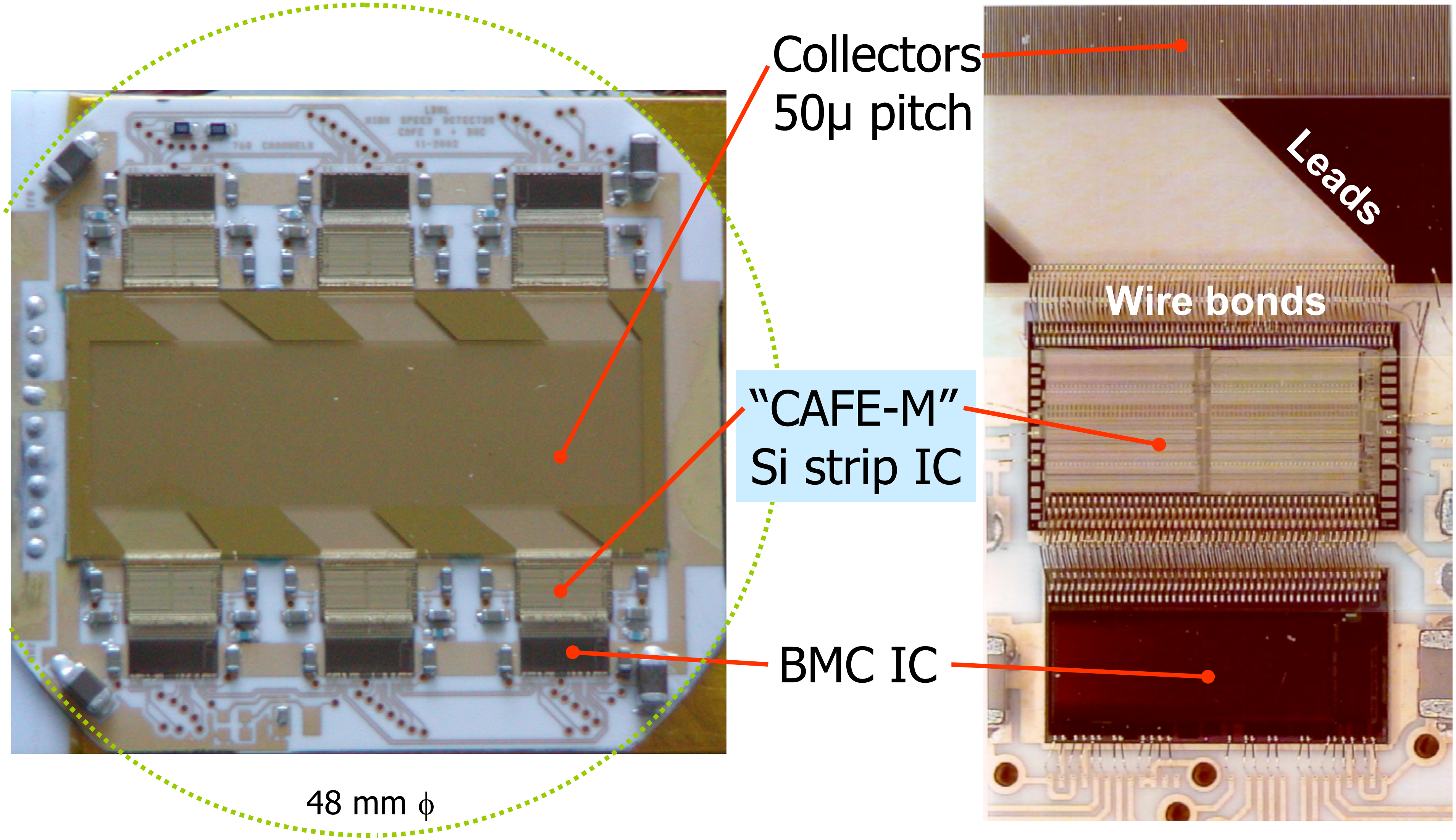
  - reviewed and stalled for present!

- …………

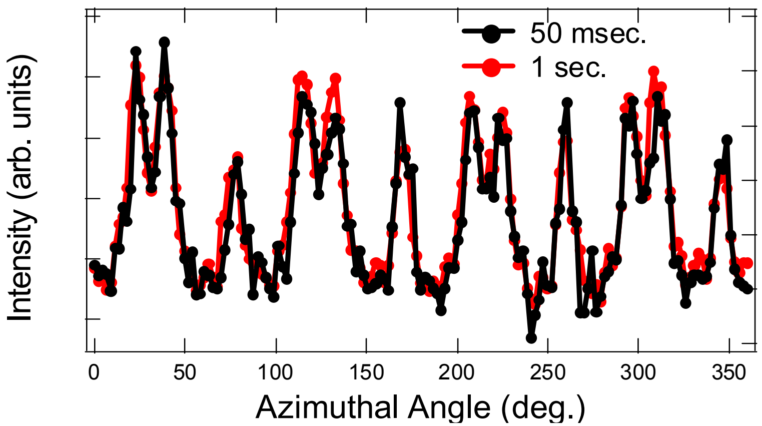
1D pulse counting detector for Photoemission

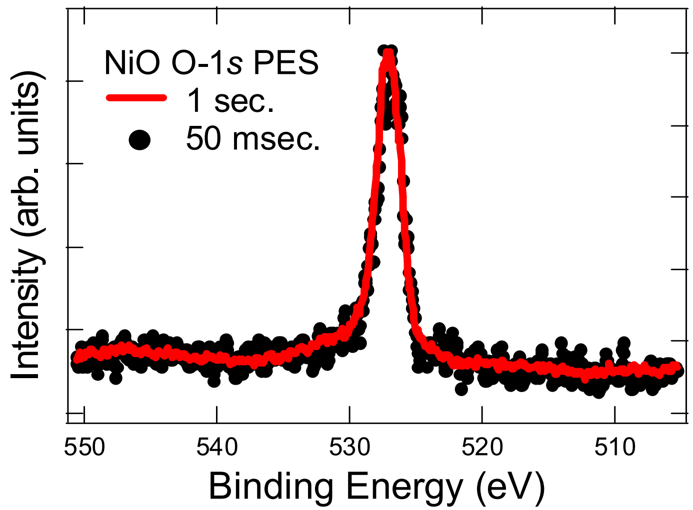


1D pulse counting detector for Photoemission



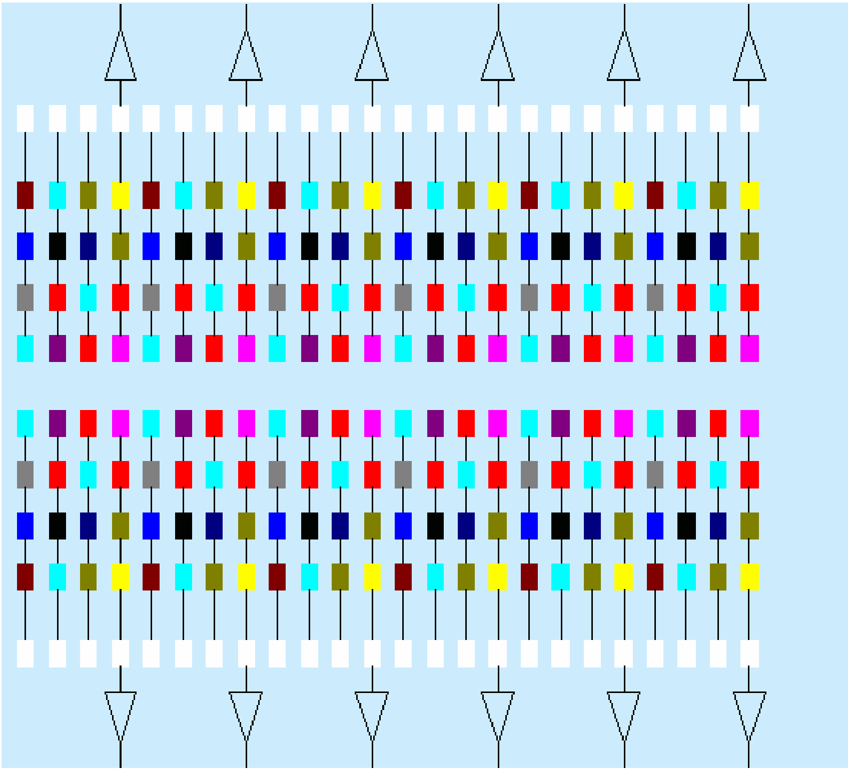
1D pulse counting detector for PES: first results





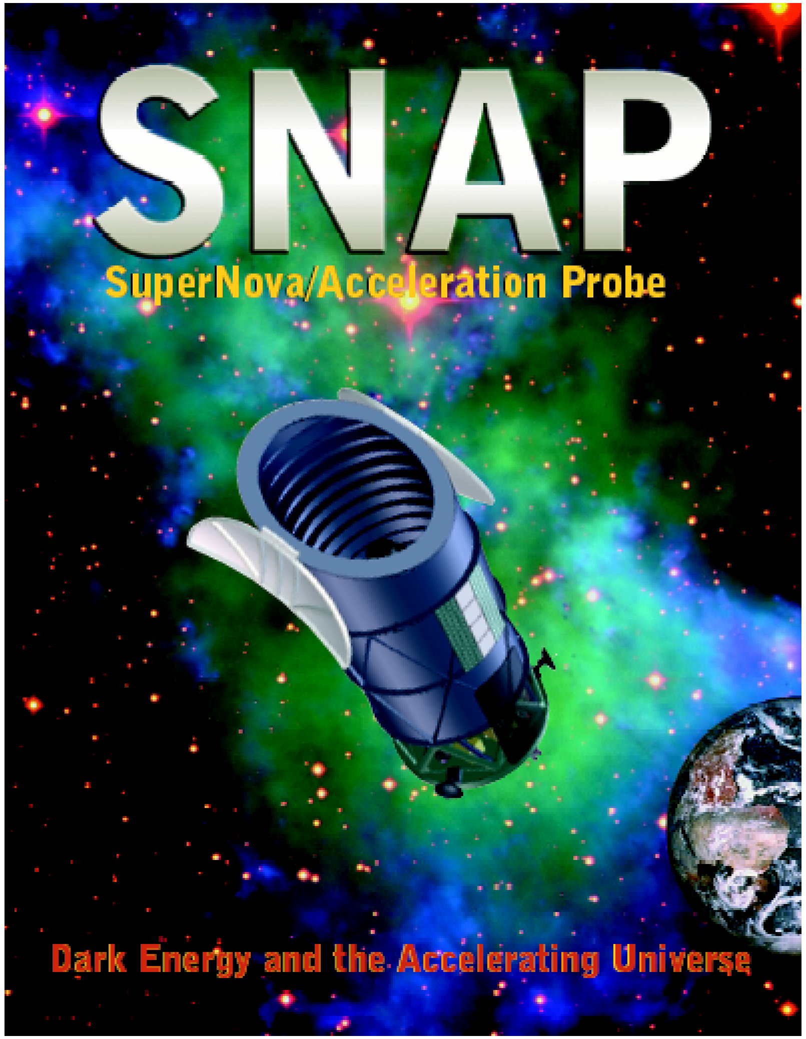
A. Nambu, J.-M. Bussat, B.C. Sell, M. Watanabe, A.W. Kay, N. Mannella, B.A. Ludewigt, M. Press, B. Turko, M. West, G. Meddeler, G. Zizka, H. Spieler, T.Ohta, Z. Hussain, C.S. Fadley, Journal of Electron Spectroscopy and Related Phenomena, 137-140, 691 (2004).

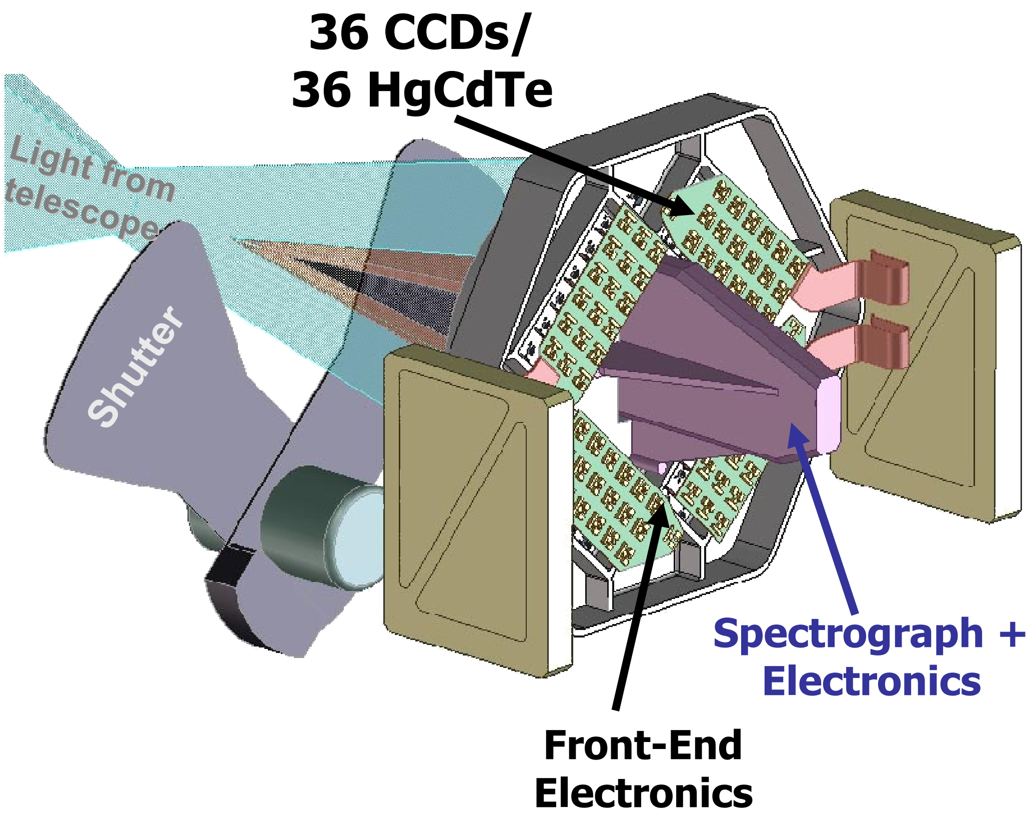
Column Parallel CCDs



- Speed increased by N_{PORTS}
- N_H *large* enough to minimize the number of ADCs needed
- N_H *small* enough to ensure 120 Hz readout
- Only possible with high integration → Integrated Circuits
- Applications in x-ray, optical and electron detectors

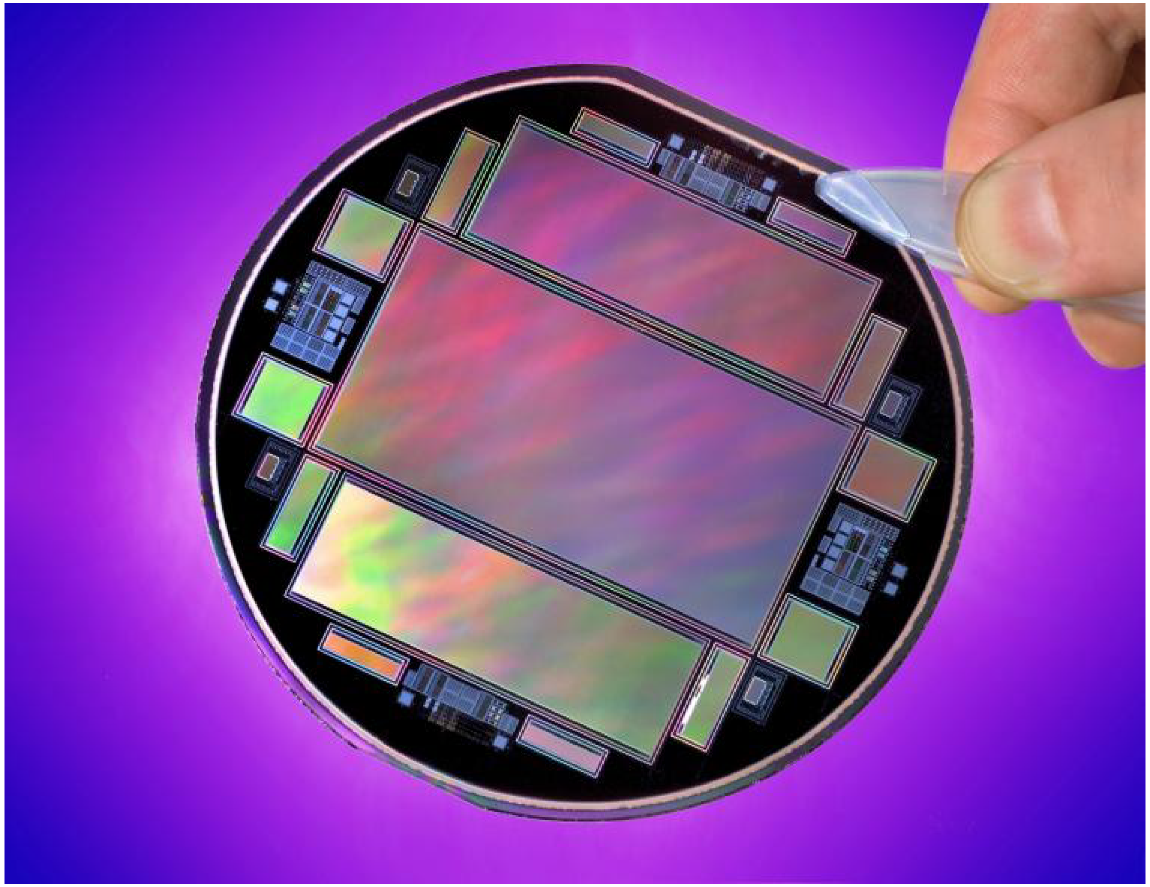
Thick, deeply depleted, back illuminated CCDs and CMOS CCD readout used in SNAP





LBNL fully depleted back illuminated CCDs

- Custom CCD
- 2k x 4k 15 micron pixels
- 300 μm depletion

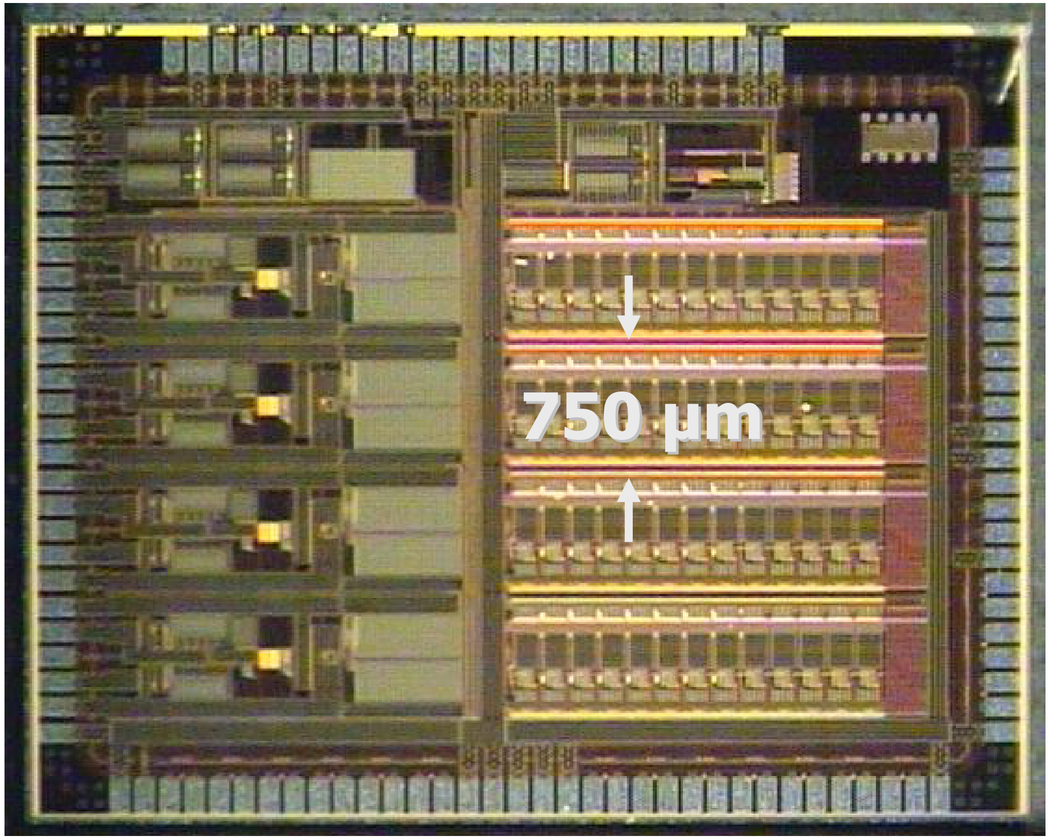


Development of Fully Depleted, Back-Illuminated Charge Coupled Devices

C.J. Bebek, D.E. Groom, S.E. Holland, A. Karcher, W.F. Kolbe, N.P. Palaio, N.A. Roe, B.T. Turko, and G. Wang

Optical and Infrared Detectors for Astronomy, edited by James D. Garnett, James W. Beletic, Proc. of SPIE Vol. 5499 (SPIE, Bellingham, WA, 2004)
0277-786X/04/$15 · doi: 10.1117/12.552295

SNAP CCD Readout Chip (CRIC)



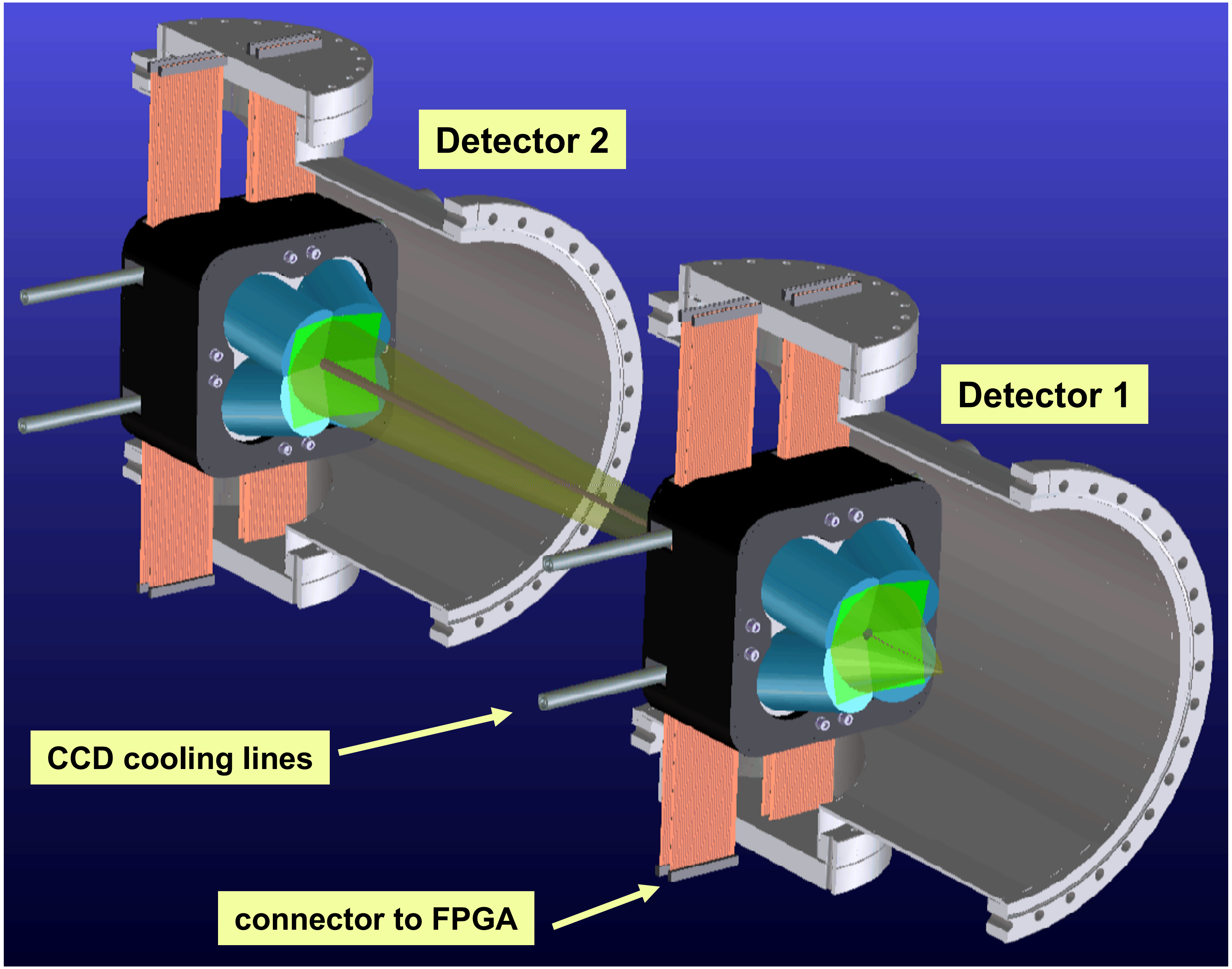
- 16-bit multi-slope front-end
  - 2 e^- noise at 100 kHz
- 13-bit pipelined ADC
  - INL < +/-1.5 LSB
  - DNL <+/-0.5 LSB
- 10 mW/channel
- Space qualified
- 4 channels/chip for SNAP
- 100s of channels for CP-CCDs

A Low Power, Wide Dynamic Range Multigain Signal Processor for the SNAP CCD

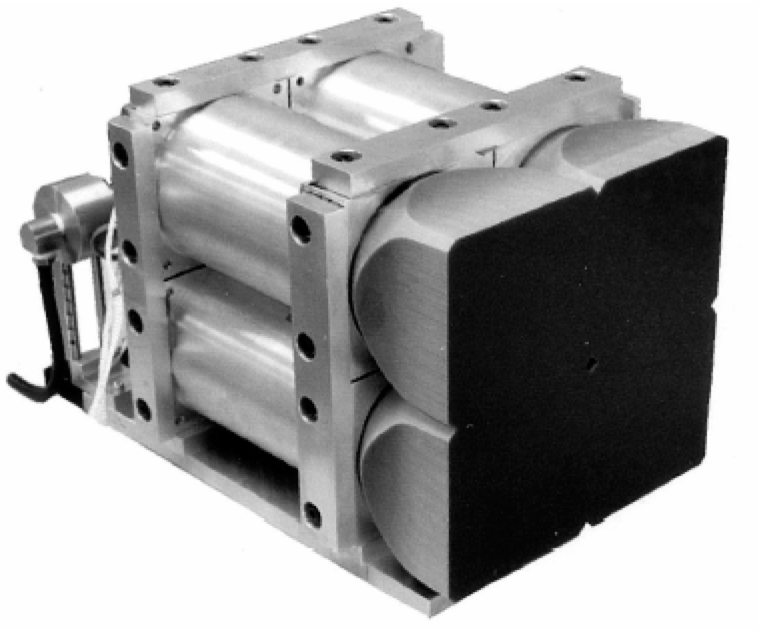
J.-P. Walder, G. Chao, J.-F. Genat, A. Karcher, B. Krieger, S. Kurz, J. Steckert, and H. von der Lippe

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 5, OCTOBER 2004

Double 2x2 array phosphor - fiber - CCD x-ray detector



Brandeis phosphor- 4:1 taper – CCD detector for PX

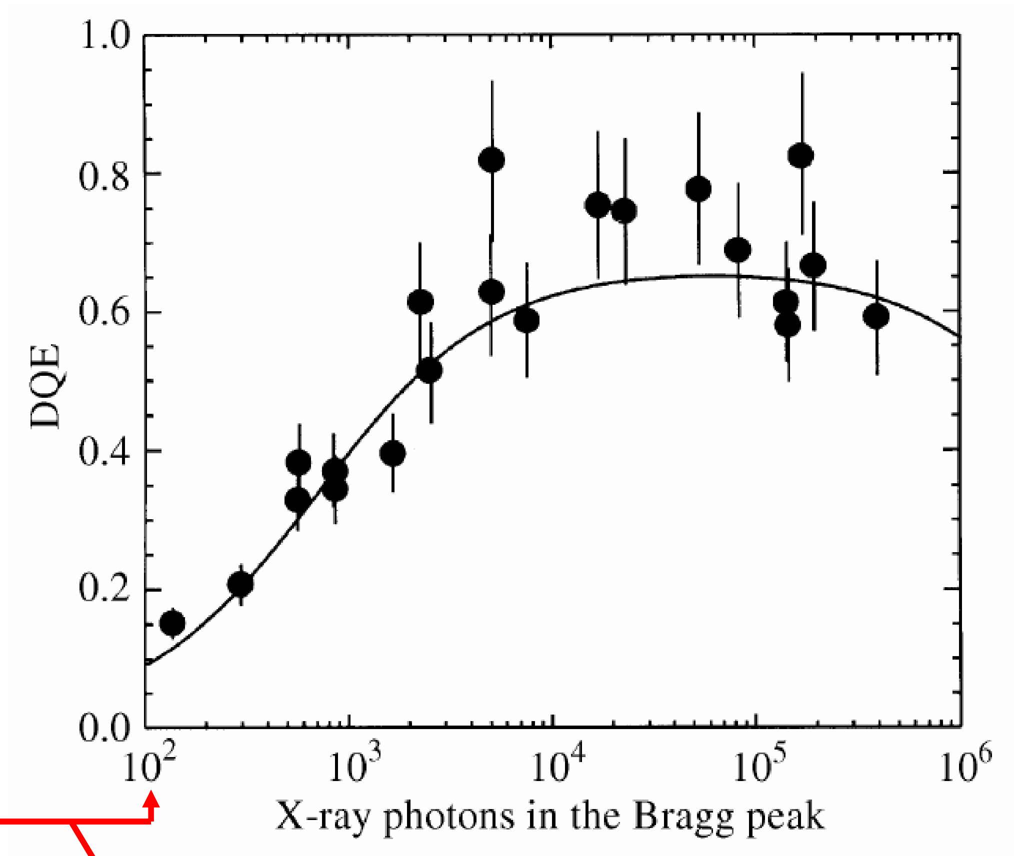


GdO_2S:Tb 13 mg/cm^2 , 4:1 taper
8 keV

FWHM = 120 microns
FW@10% = 260 microns
FW@1% = 410 microns

Phillips *et al.* *J. Appl. Cryst.* (2000). **33**, 243–251

Typical DQE as a function of intensity (4x4 binning)



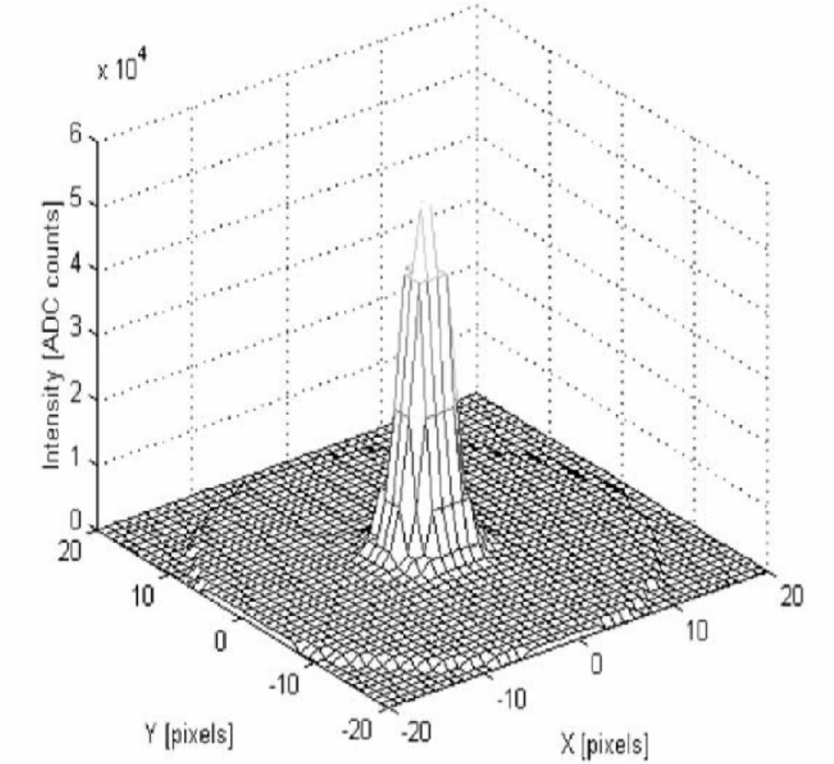
$$DQE = \frac{(s/n)^2_{out}}{(s/n)^2_{in}}$$

$$DQE = \frac{S^2 \left|MTF(f)\right|^2}{NPS(f,Q)} \frac{1}{Q}$$

Where you normally are for high resolution structure determination at the edge of the detector

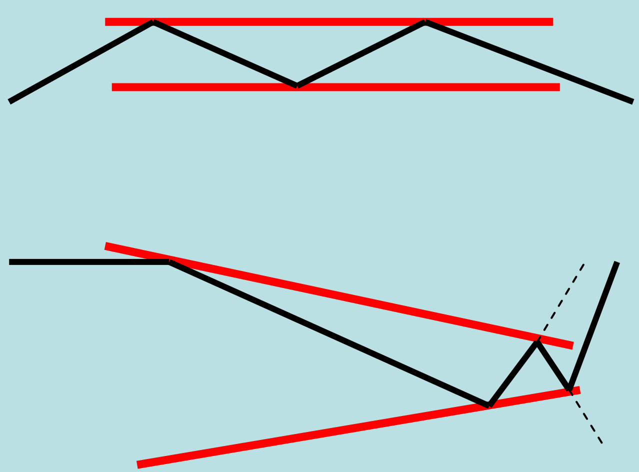
J. Appl. Cryst. (2000). 33, 243–251

Improving resolution and DQE using 1:1 fiber coupling



GdO_2S:Tb 10 mg/cm^2 4 micron grains
8 keV

FWHM = 38 microns
FW@1% = 147 microns



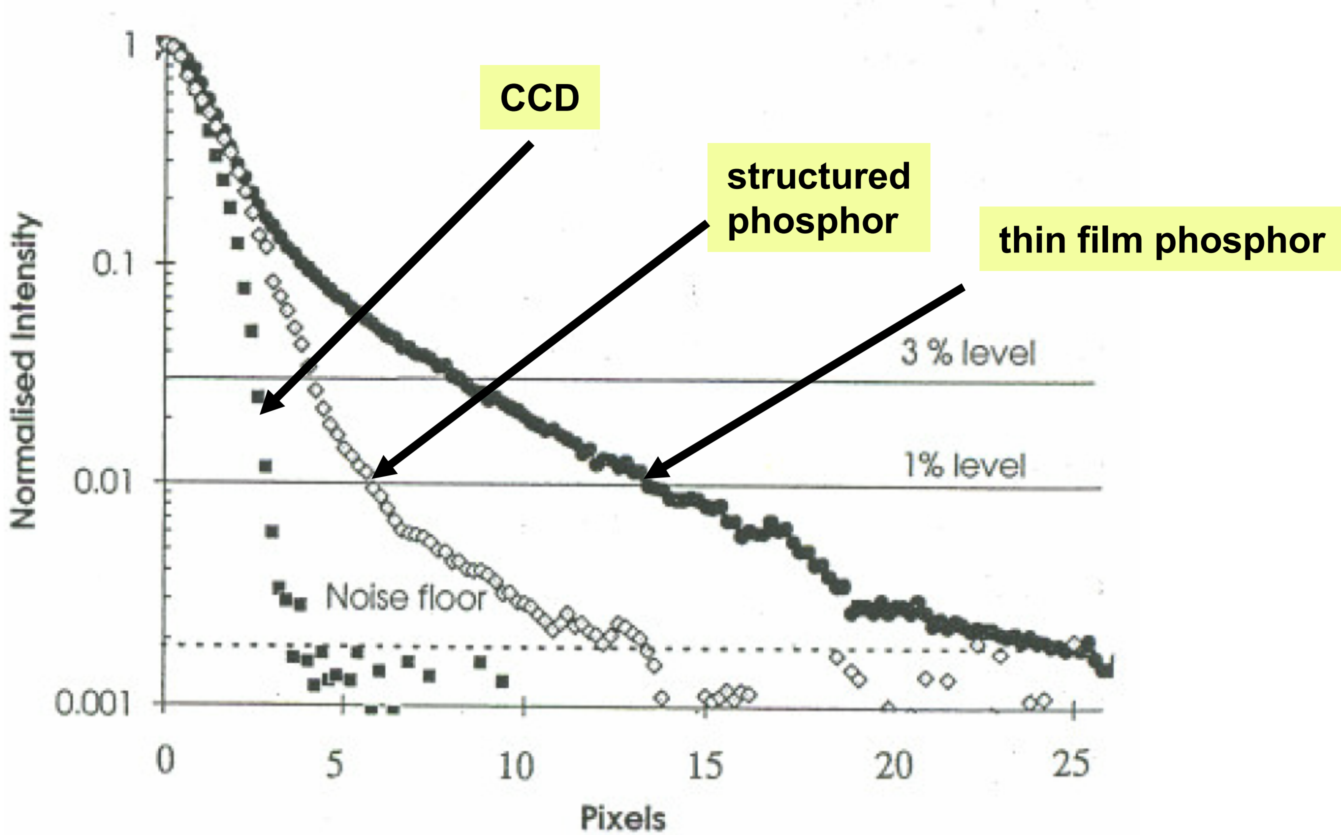
taper fiber

-increasing 'beam' angle with distance

- light progressively is lost through EMA

M. Pokrić, N.M. Allinson / Nuclear Instruments and Methods in Physics Research A 477 (2002) 353–359

Structured phosphors reduce the psf tails

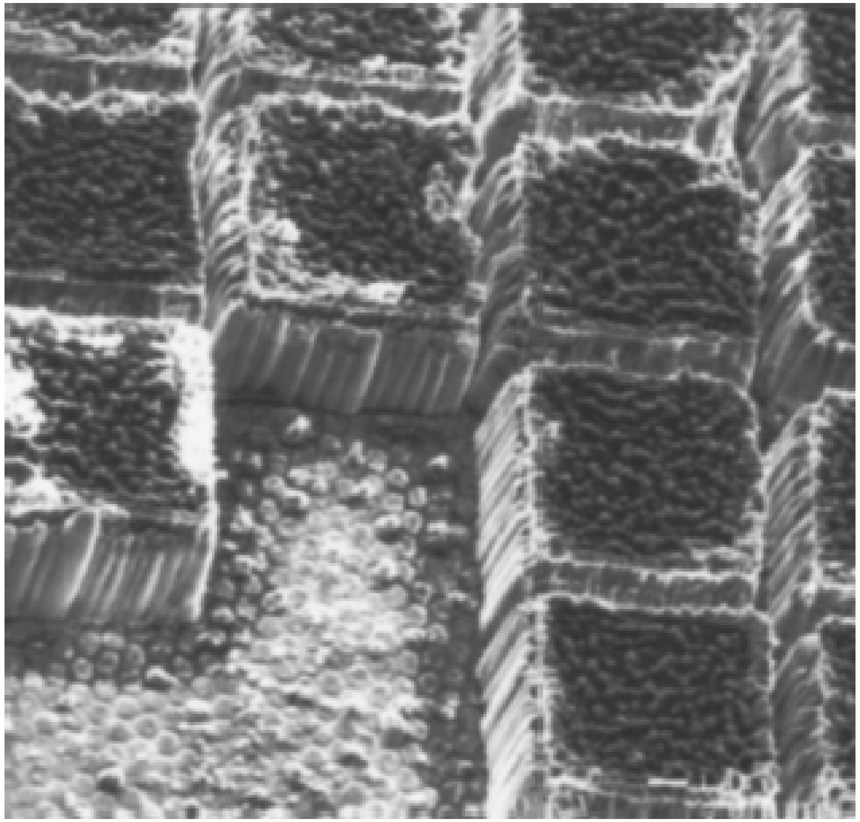


CsI:Tl, 37 microns thick (very thick for 8 keV)
8 keV

FWHM = 40 microns
FW@1% = 105 microns

C.M. Castelli et al. / Nucl. Instr. and Meth. in Phys. Res. A 348 (1994) 649–653

Improve resolution using structured phosphors

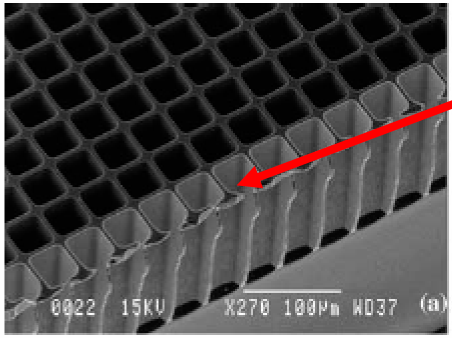


JOURNAL OF APPLIED PHYSICS VOLUME 96, NUMBER 9 1 NOVEMBER 2004

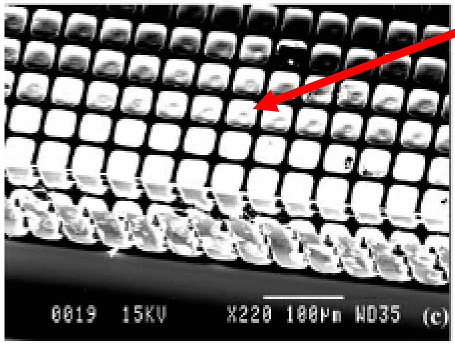
Physical mechanisms for anisotropic plasma etching of cesium iodide

Xiaoji Yang and Jeffrey A. Hopwood

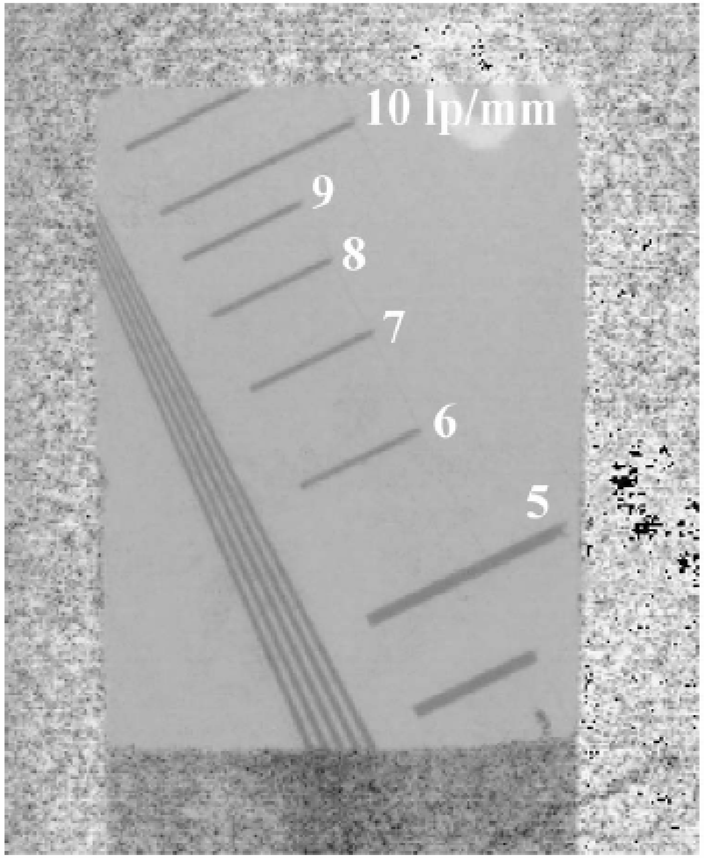
Eliminate psf tails: use a cellular phosphor



45 micron square Si cells
Oxidized / Rh coated



CsI:Tl filled cells



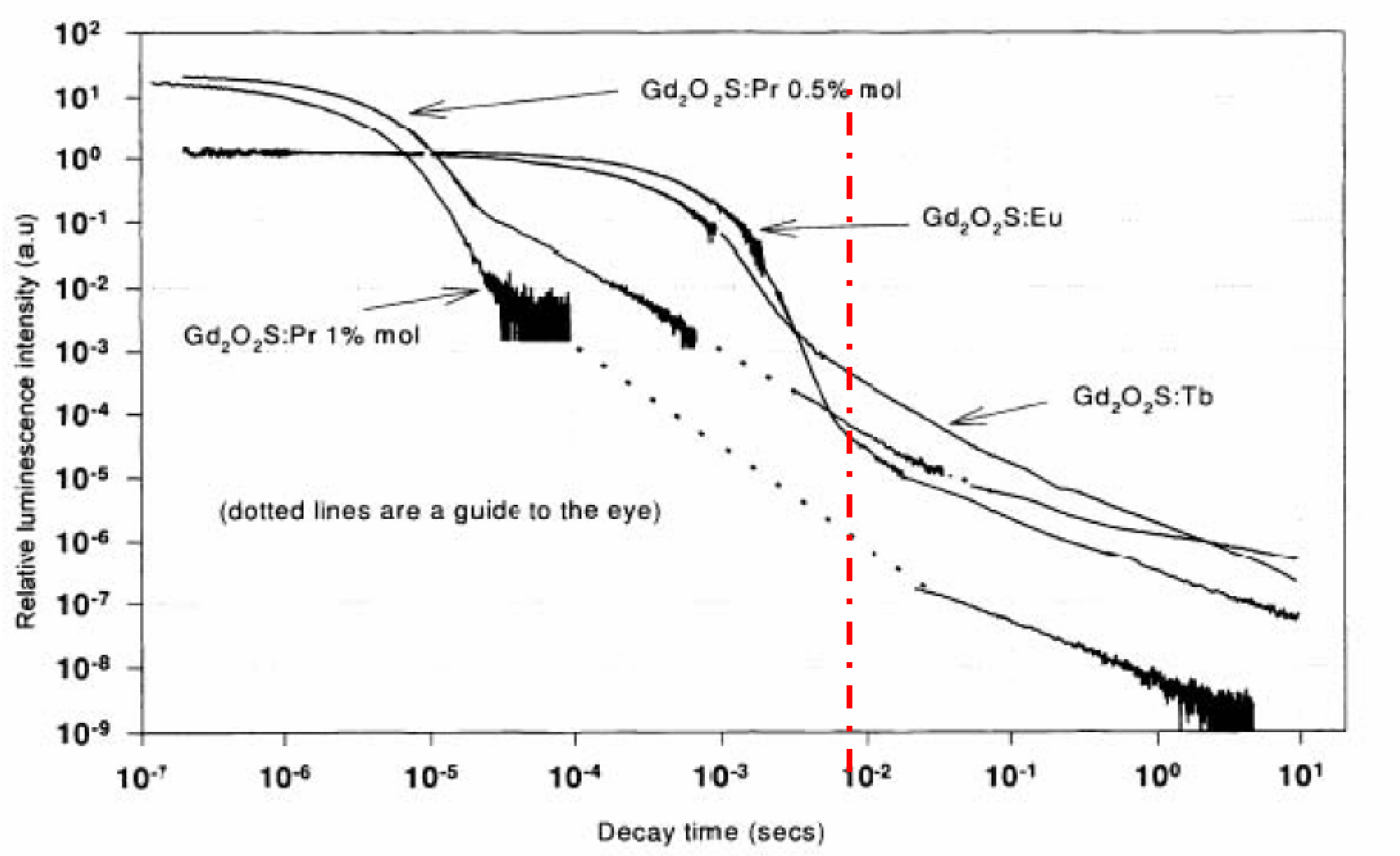
CsI:Tl, 250 microns thick
30 keV

9 LP/mm resolution

X. Badel et al. / Nuclear Instruments and Methods in Physics Research A 487 (2002) 129–135

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 3, JUNE 2004

Fast detectors need fast phosphors



- Gd_2O_2S:Pr 1%: intensity drops to 10^{-7} at LCLS rep rate

- phosphor developed by Applied Scintillator Technology, UK

J. P Creasy and G. C. Tyrrell, SPIE 3942 (2000), 114 - 121

Use of CP-CCDs in optimized geometries

- Protein crystallography
    - huge improvement in low signal / high spatial frequency DQE
    - enables many frames to be taken, eg. fine phi slicing
    - means better high resolution data and data on large unit cell (weak scattering) systems

- Tomography
    - match frame rate to acquisition rate: factor 100

- Microdiffraction
    - match frame rate to acquisition rate: factor 100

- SAXS
    - enable few msec time resolved studies

- Coherent x-ray diffractive imaging
    - allow hugely improved effective dynamic range

- Optical microscopy
    - improved dynamic range and enabling of faster dynamics studies

- Direct x-ray and electron detection at high rates, excellent spatial resolution

- …………and 101 other areas

Where are we now in detector work at ALS

This is what we are involved in now:

- CP-CCD funded by strategic LDRD
    - follow on funding from LCLS?
    - follow on funding from…?

- 1d electron detector
    - finished (almost)

This is a very short list!

- we need to expand the range of areas we are working in
    - need to identify key needs
    - need to identify funding
    - need to establish a significant ALS detector group

We need to be aware of the international competition

Swiss Light Source

- full scale x-ray pulse counting pixel detector for protein crystallography
- several linear and area pixel detectors for powder diffraction and other apps.
- advanced detectors are starting to give SLS a strategic advantage
    - gestation period for projects makes this lead very difficult to catch up

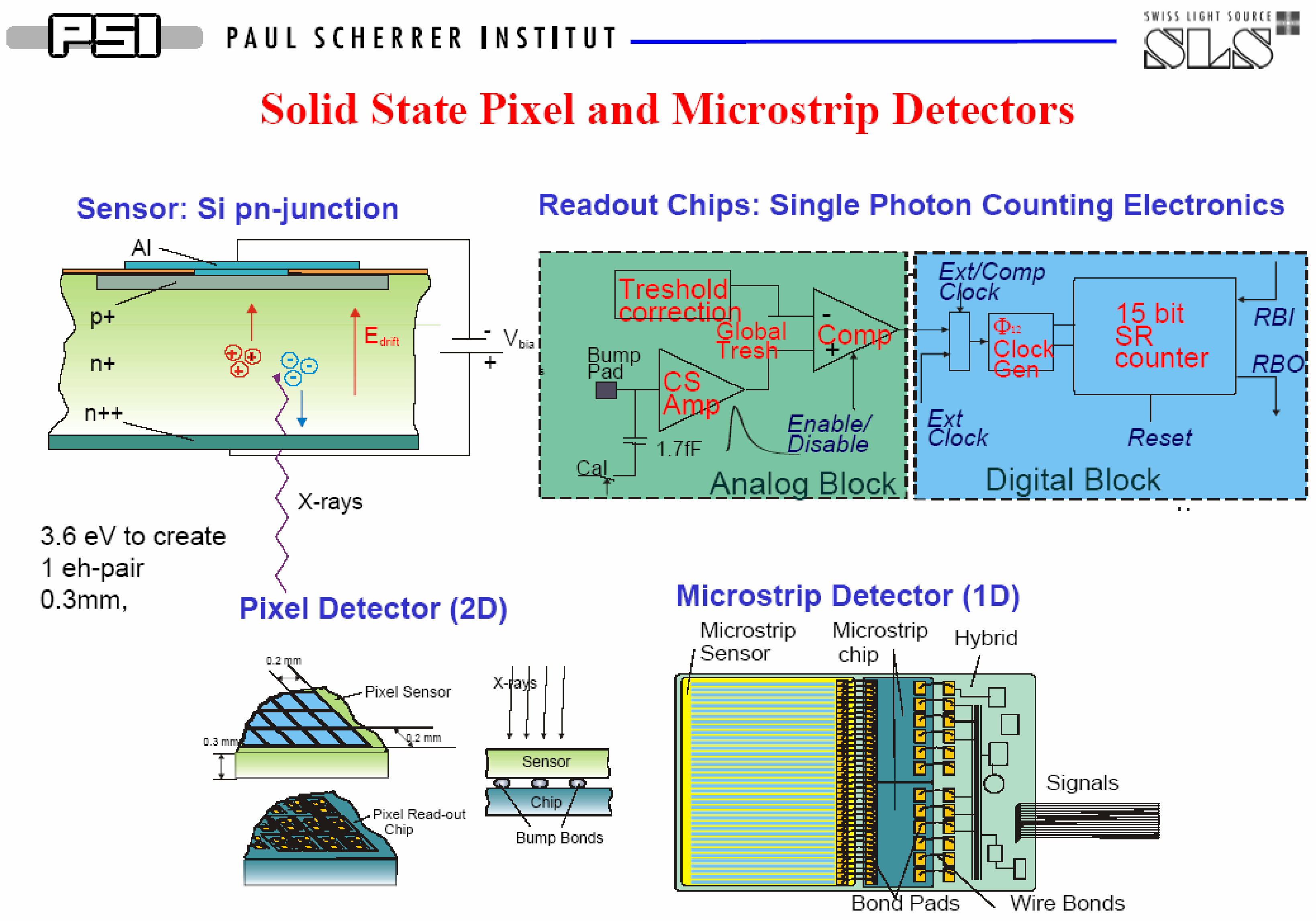
Diamond / RAL

- RAL are responsible for provision of advanced detectors for Diamond
- pixel, strip, CP-CCD etc

European Synchrotron Radiation Facility

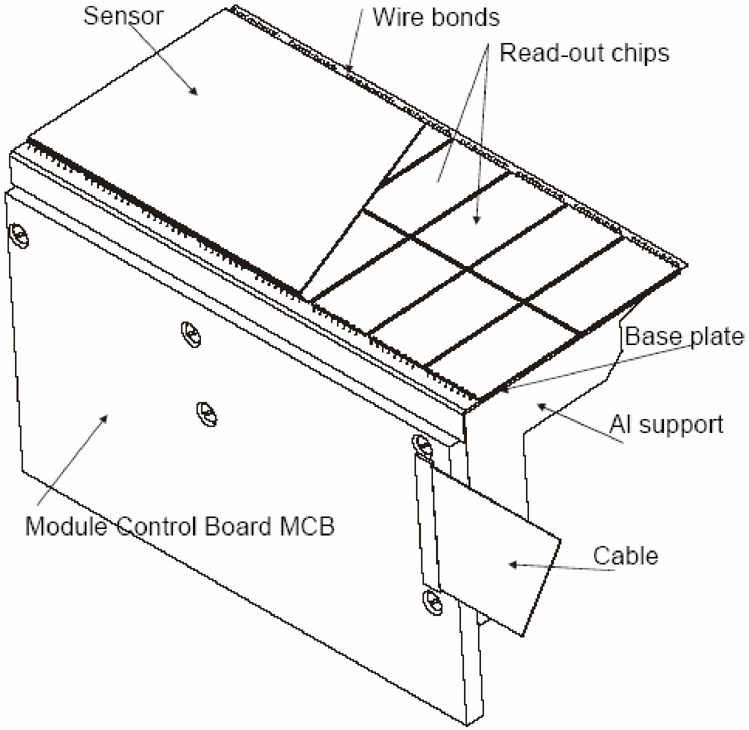
- their new medium term plan focuses on detectors as the next target area
- pixel detectors of all flavors

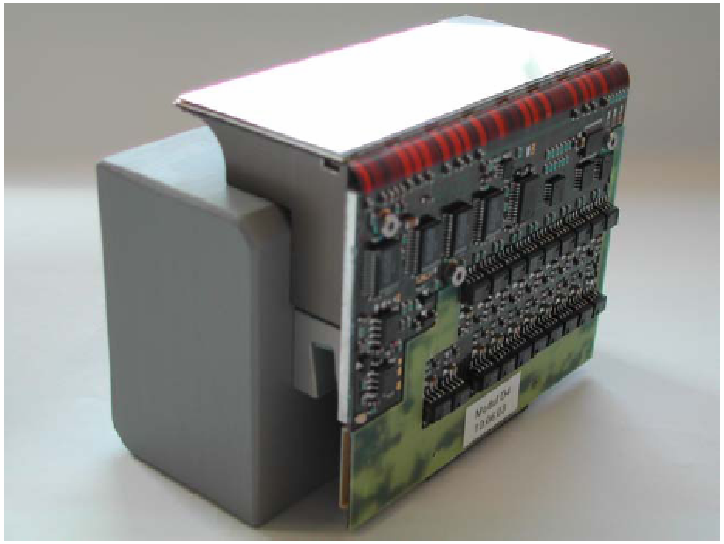
We need to be aware of the international competition



We need to be aware of the international competition

PILATUS Module Typ II (readout electronics bended)





- Flexprint 6/2 from Dyconex
- Modules can be overlapped
- 80 x 35 mm² continuous sensitive area
- 2 x 8 readout chips
- Power consumption: 7V/1.5 A -> 10.5 W
- Fabrication of 21 Modules: Mai 03- Sept 03

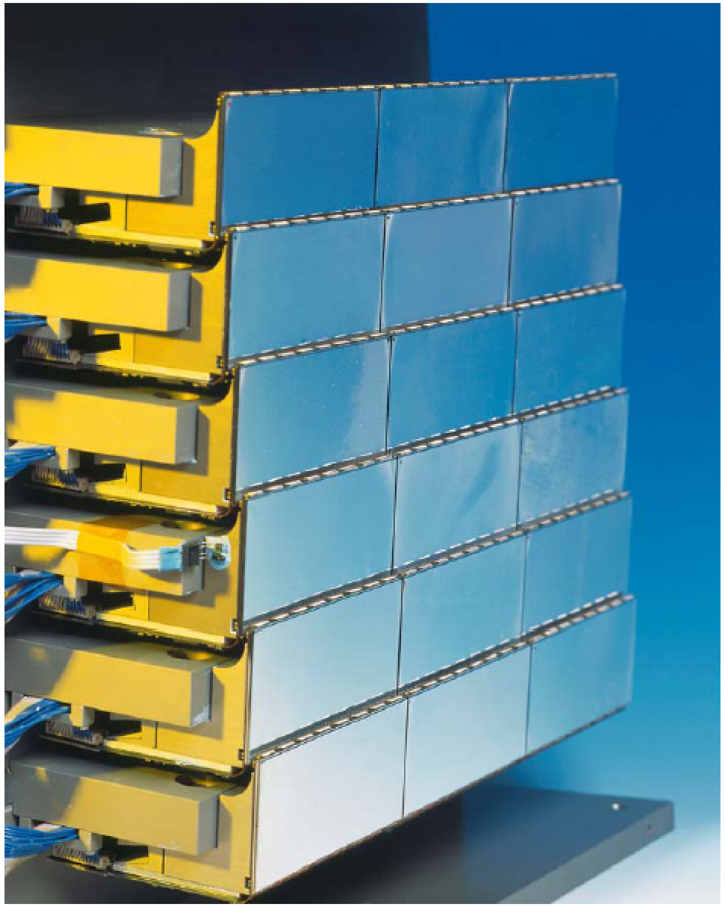
We need to be aware of the international competition

PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE SLS

The PILATUS 1M Detector

- Largest pixel detector array for SR
- 6 banks a 3 modules, 1120 x 967 pixels
- Area: 21 x 24 cm^2
- 288 chips->~300x10^6 transistors
- Readout time: 6.7ms
- Currently 2 frames/s
- 2 frames/ s
- Active area: 85%
- Moderate count rates (<10kHz/pixel)

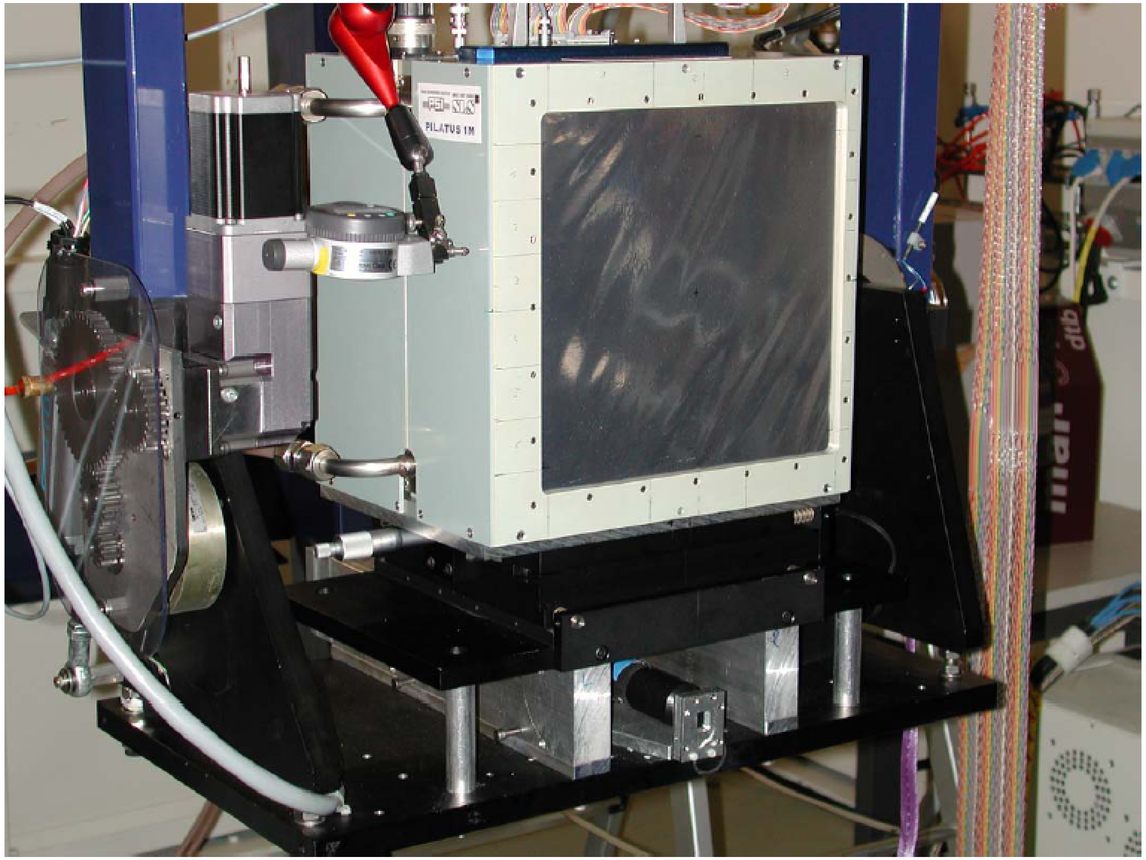


We need to be aware of the international competition

PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE SLS

PILATUS 1M Detector at X06SA

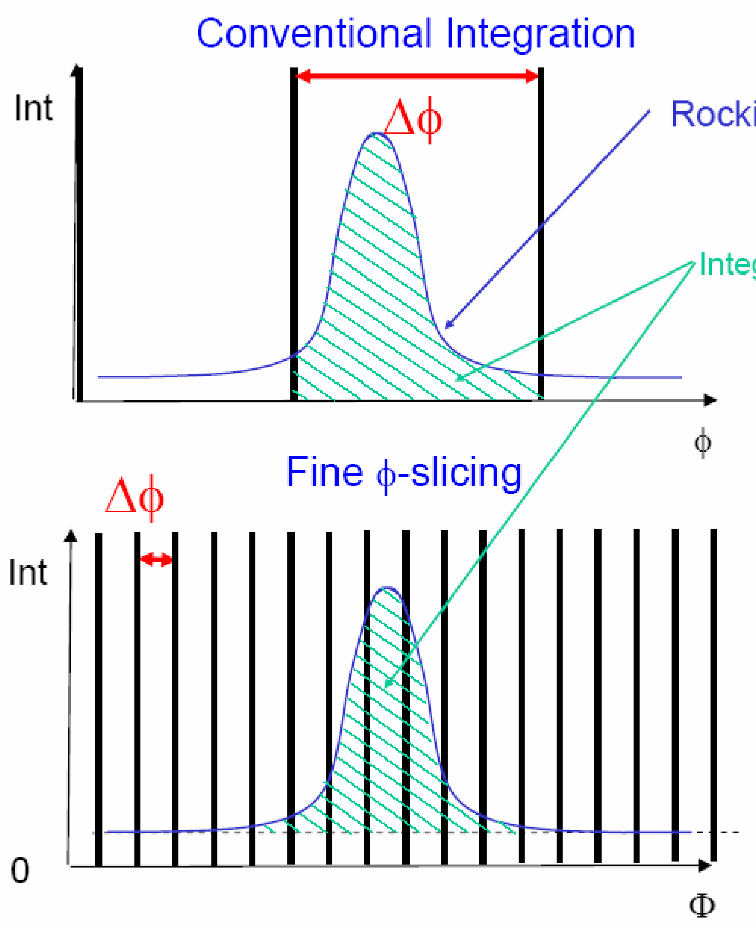


We need to be aware of the international competition

PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE SLS

Fine ϕ-slicing with the PILATUS-Detector



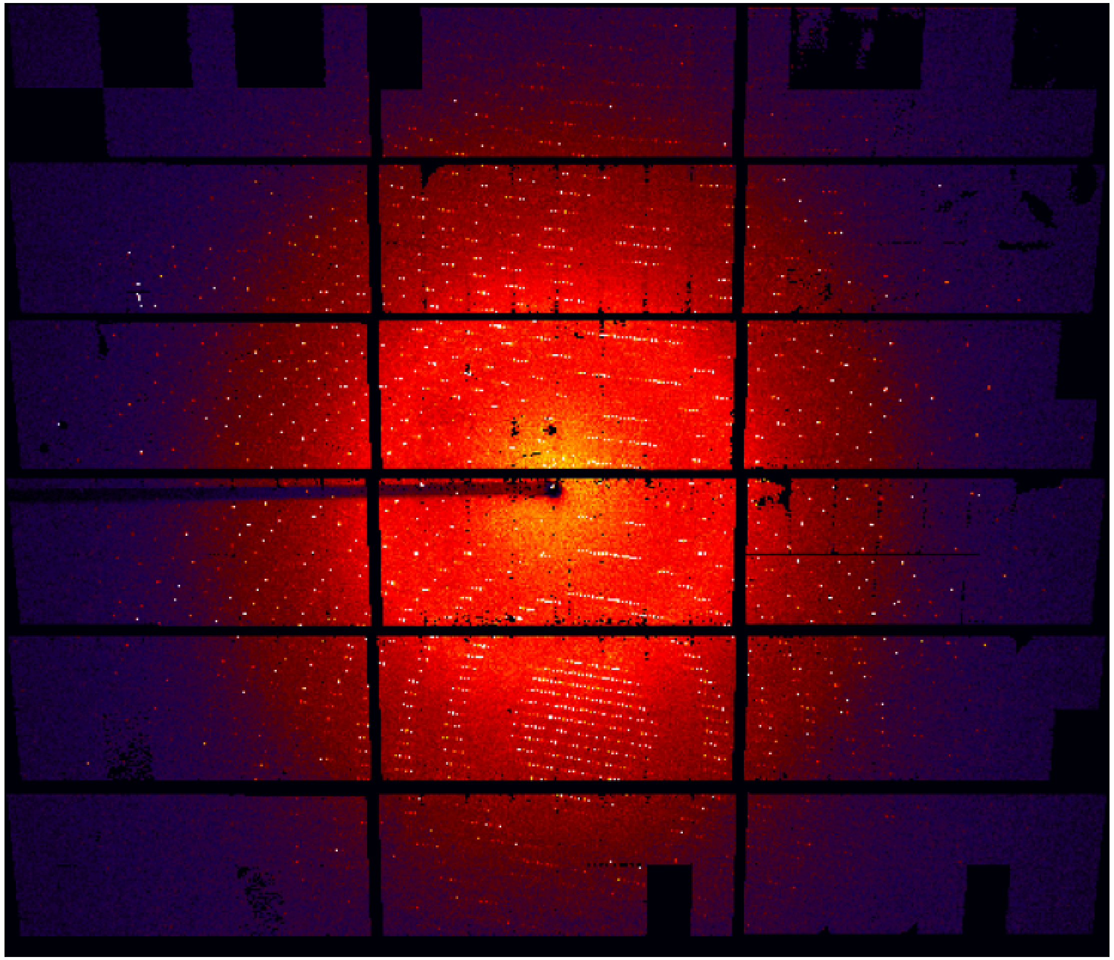
- short readout-time
- Continuous rotation -> no shutter
- no read-out noise

Angular speed ω,

Exposure time t

$\Delta\phi = t^*\omega$

We need to be aware of the international competition



Thaumatin crystal

Data Taking:

Data set: 120°
Exp Time: 4s
Integration: 1°
Beam energy: 11.9 keV
Beam intensity: 13.5%
D Sample-Det: 128 mm
Resolution: 1.4 Å

Analysis:

3 data sets merged
full geometrical correction
Processed with XDS

R_{obs}: 8.9% (overall)
Completeness: 90%
(98% up to 1.6 Å)

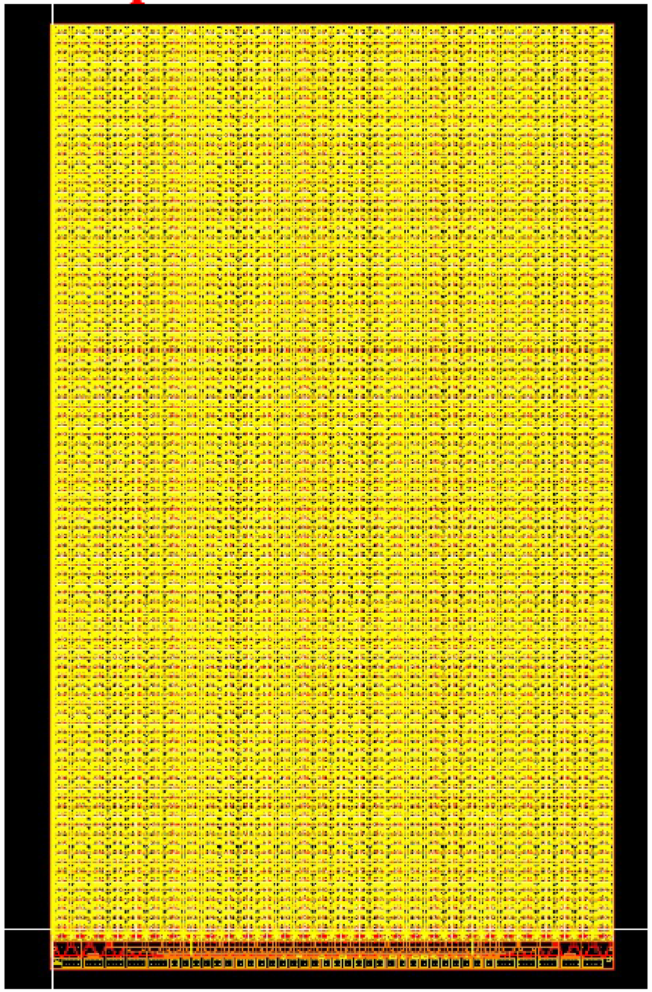
We need to be aware of the international competition

PAUL SCHERRER INSTITUT

SWISS LIGHT SOURCE SLS

PILATUS II Chip

- UMC_25_MMC process; Radiation hard design
- 60 x 97 pixels = 5820 pixels
- Pixel size 172 x 172 um^2
- 17.540 x 10.450 mm^2
- Count rate: 1MHz/pixel
- 20 bit counter
- Counting timer circuit
- 6 bit DAC for threshold adjustment
- XY-adressable
- Analog output
- 100 MHz LVDS readout (T_{ro} = 1.2 ms)
- Submitted 29.09.04
- Received 1.12.04



$4*10^6$ Transistors

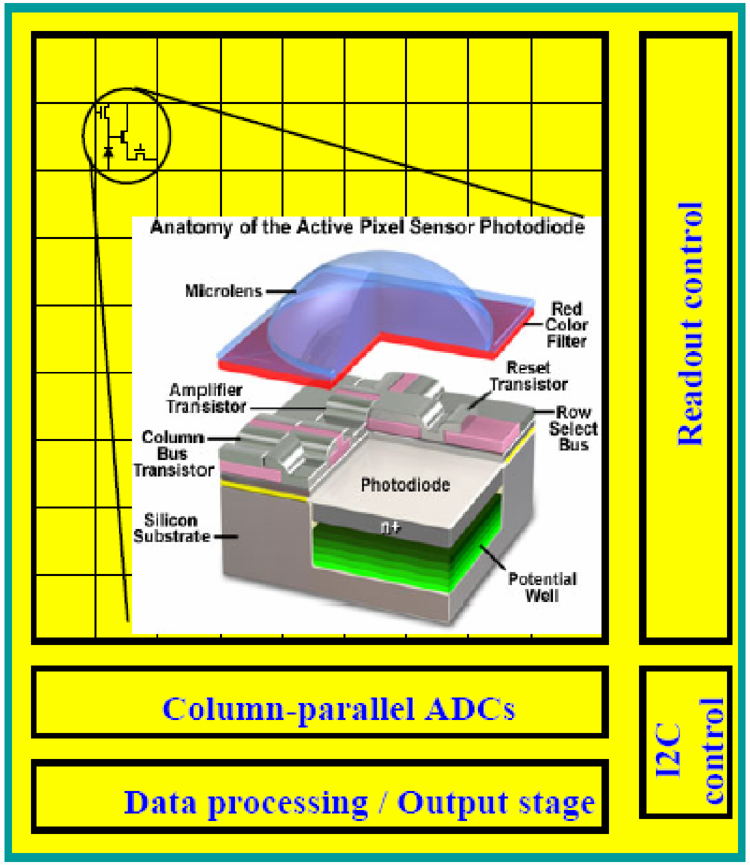
We need to be aware of the international competition

CCLRC Rutherford Appleton Laboratory

CMOS (Monolithic) Active Pixel Sensor (MAPS)

(Re)-invented at the beginning of '90s: JPL, IMEC, …

- Standard CMOS technology
- all-in-one detector-connection-readout = *Monolithic*
- small size / greater integration
- low power consumption
- radiation resistance
- system-level cost
- Increased functionality
- increased speed (column- or pixel- parallel processing)
- random access (Region-of-Interest ROI readout)



We need to be aware of the international competition

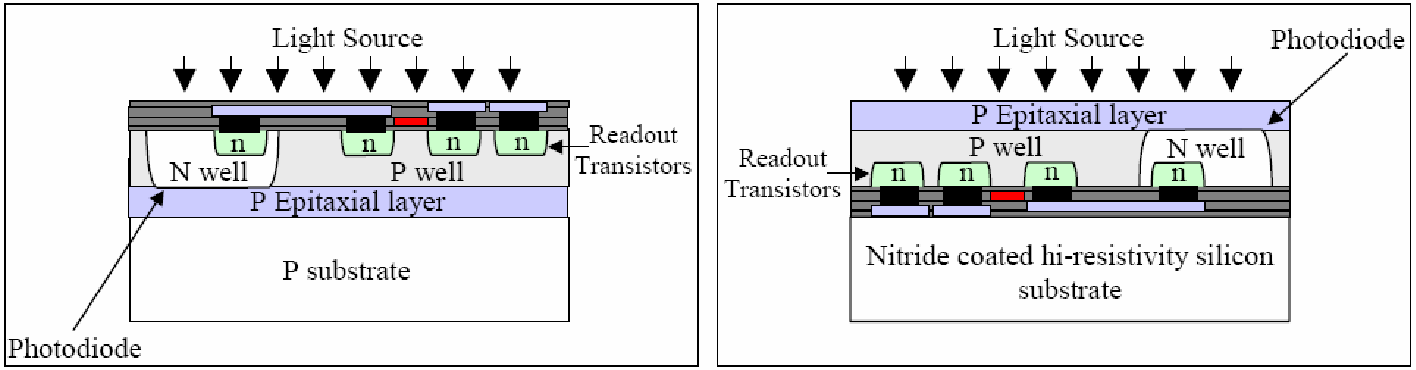


Fig. 2. (a) A typical CMOS sensor cross-section; (b) Example of a cross-section after back-thinning.

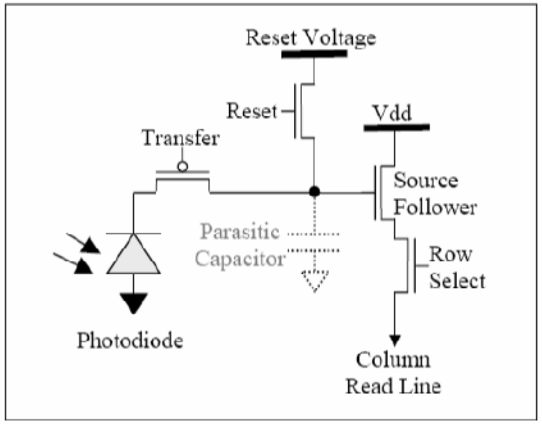


Fig. 8. Four transistor pixel schematic.

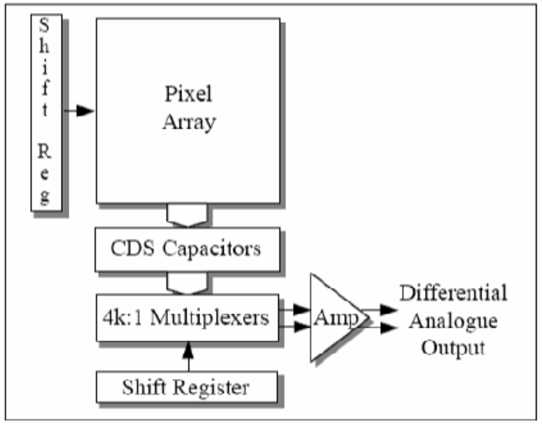


Fig. 9. Block Diagram of 4k x 3k Sensor.

Fig. 10. (a) Image taken with 4k x 3k CMOS sensor;

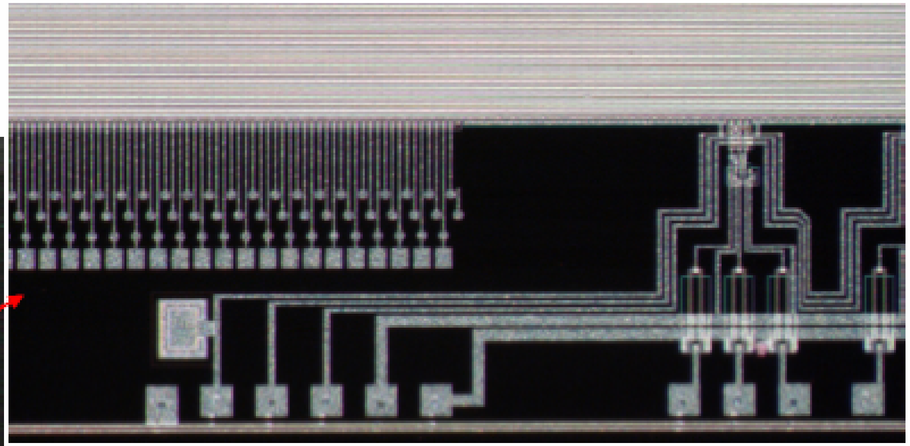
A Large Area CMOS Monolithic Active Pixel Sensor for Extreme Ultra Violet Spectroscopy and Imaging

Mark Prydderch*[a], Nick Waltham[a], Quentin Morrissey[a], Marcus French[a], Renato Turchetta[a], Peter Pool[b]
[a]Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, UK, OX11 0QX;
[b]e2v Technologies, 106 Waterhouse Lane, Chelmsford, Essex, UK CM1 2QU.

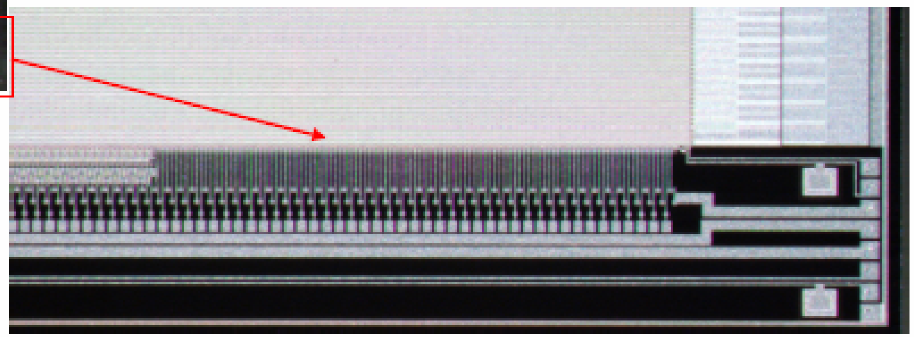
We need to be aware of the international competition

Our first CPCCD – CPC1

Manufactured by e2V (UK)



Direct connections and 2-stage source followers



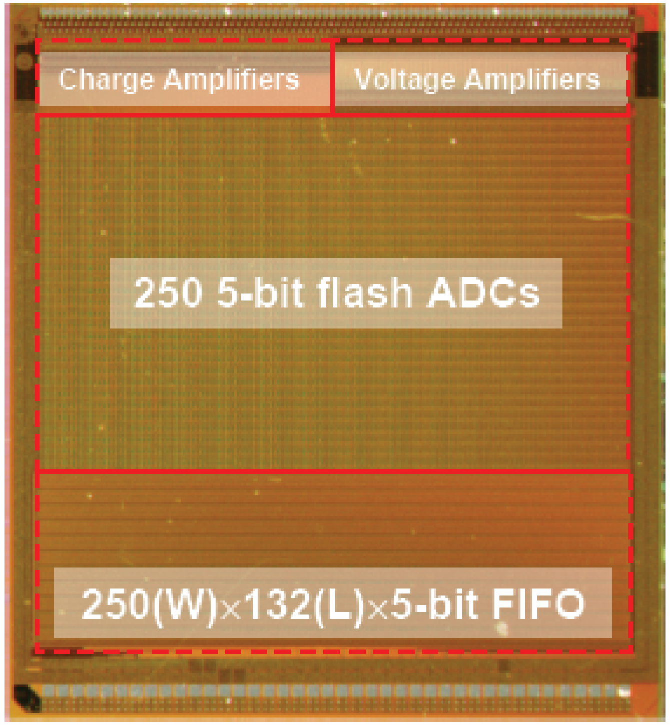
1-stage source followers and direct connections on 20 µm pitch

- Two phase, pixel size 20 µm × 20 µm;
- 400 (V) × 750 (H) pixels;
- Two charge transport regions;
- Wire/bump bond connections to readout chip and external electronics.

We need to be aware of the international competition

Readout chip CPR1

Wire/bump bond pads



Wire/bump bond pads

Manufactured by IBM

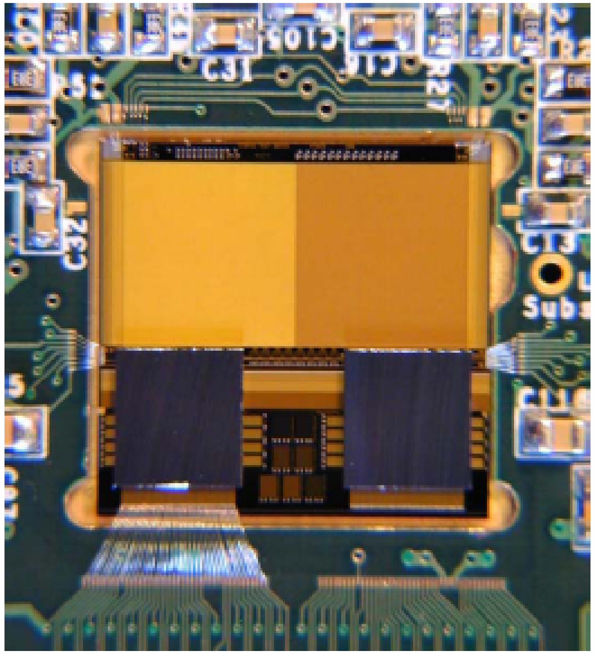
ASIC for CPC1 readout

- Designed by the Microelectronics Group at RAL
- Size : 6 mm × 6.5 mm
- Voltage amplifiers for the 1-stage SF outputs
- Charge amplifiers for the direct outputs;
- 250 5-bit flash ADCs
- Everything on 20 μm pitch, 0.25 μm CMOS process
- Fully bump-bondable and partially wire-bondable
- Scalable and designed to work at 50 MHz
- Extensively tested for 1 year

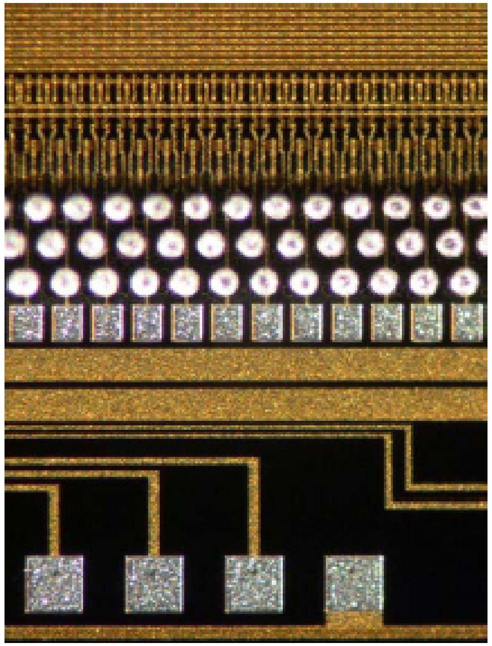
We need to be aware of the international competition

CPC1 bump-bonded to CPR1

- Bump-bonding done at VTT (solder bumps)
- High quality bumps, but with yield problems
- First time e2V CCDs have been bump-bonded



Bump-bonded CPC-1/CPR-1 in a test PCB



Bump bonds on CPC-1 under microscope

What areas of electronic detector research are important to ALS

Photoemission
- CP-CCD (evolution from present 2d system)
- 2d pixel detector (after c/plate; lots of signal!)

X-ray diffraction (Protein crystallography, small mol chem. crystallography…)
- CP-CCD (phosphor / taper); work on phosphors needed
- CP-CCD (direct detection: best point spread function; limited dynamic range)
- 2d hybrid pixel detector (direct detection, largest complexity)
    - time stamping and energy resolution crucial new features (for some expts)

Hard x-ray imaging
- tomography (single crystal [structured] scintillator / microscope objective); CP-CCD

Soft x-ray imaging
- cellular imaging (CP-CCD)

Electron imaging
- CP-CCD
- MAPS (also suitable for ARPES, without c/plate; electrons accelerated to 10 keV, detected in Si)

What technologies / skills do we need for this

Microelectronics
- CCD readout, MAPS, ASICs….

Detector elements
- phosphors, structured arrays, fiber couplers
- photodiode arrays, eg. Si, GaAs…
- direct charge injection, eg. a-Se, HARP…

Fully depleted thick CCDs

Backend processing
- FPGA, DSP….

System integration
- engineering of complete systems including data processing

Detector testing
- testing in the lab and on the beamline
- absolute quantification of detector performance

R&D
- we need to work on exploratory technologies as well as defined projects

Finding funding
- very time consuming, significant opportunities

Thanks to……

Provision of info / ppts:

Protein crystallography
- Paul Adams, James Holton, Corie Ralston, Paul Adams, Alastair MacDowell

ALS Accelerator
- David Robin

History of SR
- Herman Winnick

Photoemission
Eli Rotenberg

Detectors
Peter Denes, Chris Bebek, Hendrik von der Lippe, Chuck Fadley, ….

Soft x-ray tomography
Carolyn Larabell, Mark LeGros

and especially to Peter Denes for helping to get an ALS detector program off the ground