3DX: A micromachined silicon crystallographic X-ray detector

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- Much of the electronics copied from ATLAS
- Tests conducted at APS 13BM (Mark Rivers)
- Tests conducted at ALS 10.3.1 (Al Thompson)
- Tests conducted at ESRF ID18F (John Morse)
- Tests conducted at ALS 4.2.2 (Ed Westbrook)

Protein crystallography detectors now:

Phosphor screen, with fiber-optic coupling to multi-CCD readout. ~200 x 200mm^2 square and with spatial PSF ~200μm (FWHM)

- Intense diffraction spots in image spoil the usable dynamic range (which in any case never exceeds "16 bits")

- *Sample is rapidly destroyed in the X-ray beam (>10^{13} photons/sec).* CCD systems require a few seconds to readout, while strongly diffracting crystals can saturate the CCD in 0.1sec

- Long tails associated with the wide spatial response of the phosphor screen+optics. This limits the precision of flat field correction and the measurement of signal intensities of closely grouped diffraction peaks

3DX pixel detector benefits:

Direct absorption in silicon:

- Single photon sensitivity
- (Pseudo) counting detector: dynamic range??

Quasi-continuous (64μs periodic) readout

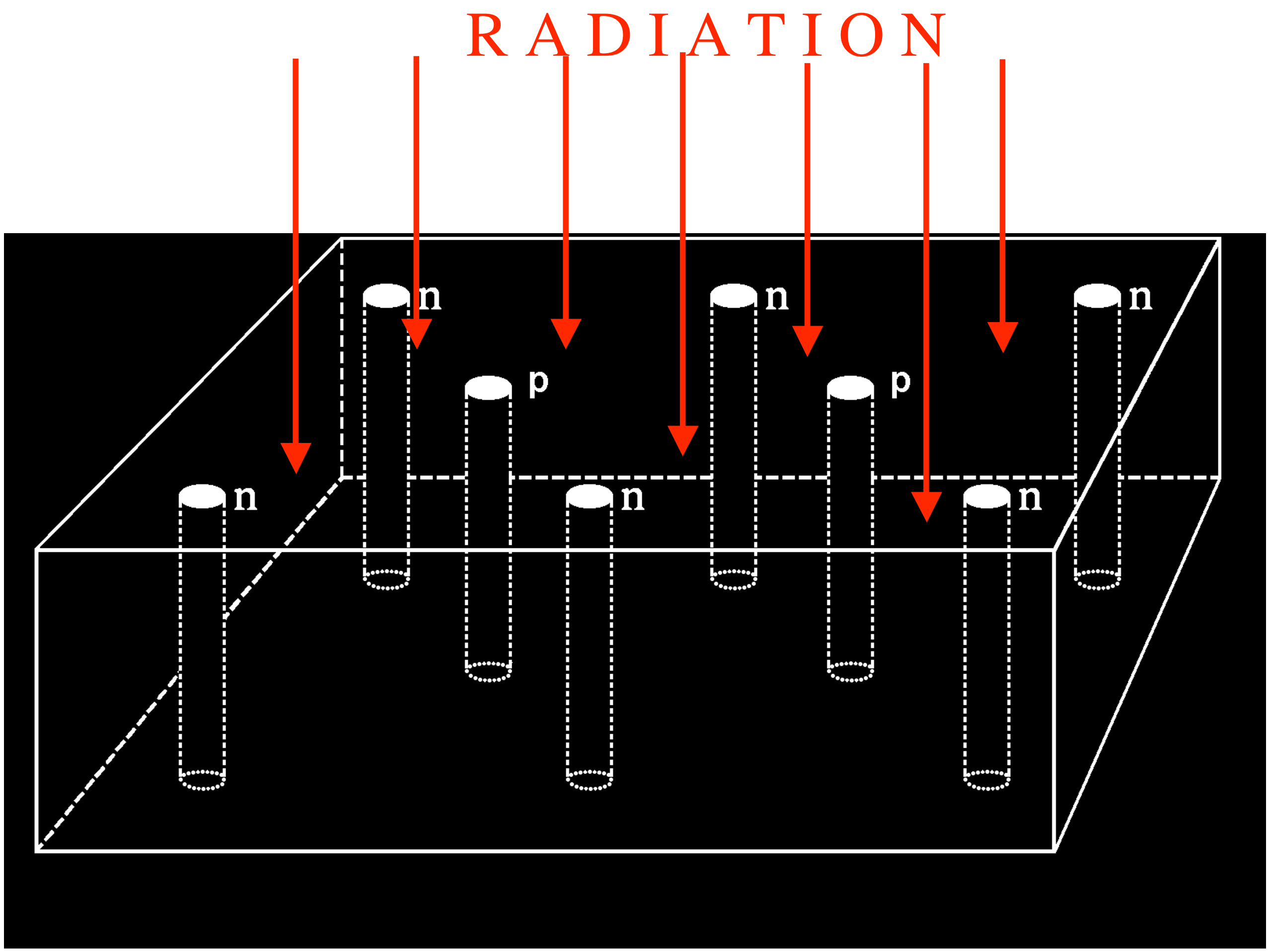
'Single pixel' point response function (150μm)

Use 3D silicon with active edges => large area can then be covered with small sensors (yield!) with no insensitive border areas

3D* detectors

Column electrodes penetrate through the semiconductor substrate. Electrode spacing choice is independent of the substrate thickness.

*S. Parker, C. Kenney, J. Segal, *Nucl. Instrum. and Meth*. **A395** (1997), 328-343.



Electrode geometry for the 3DX pixel detector

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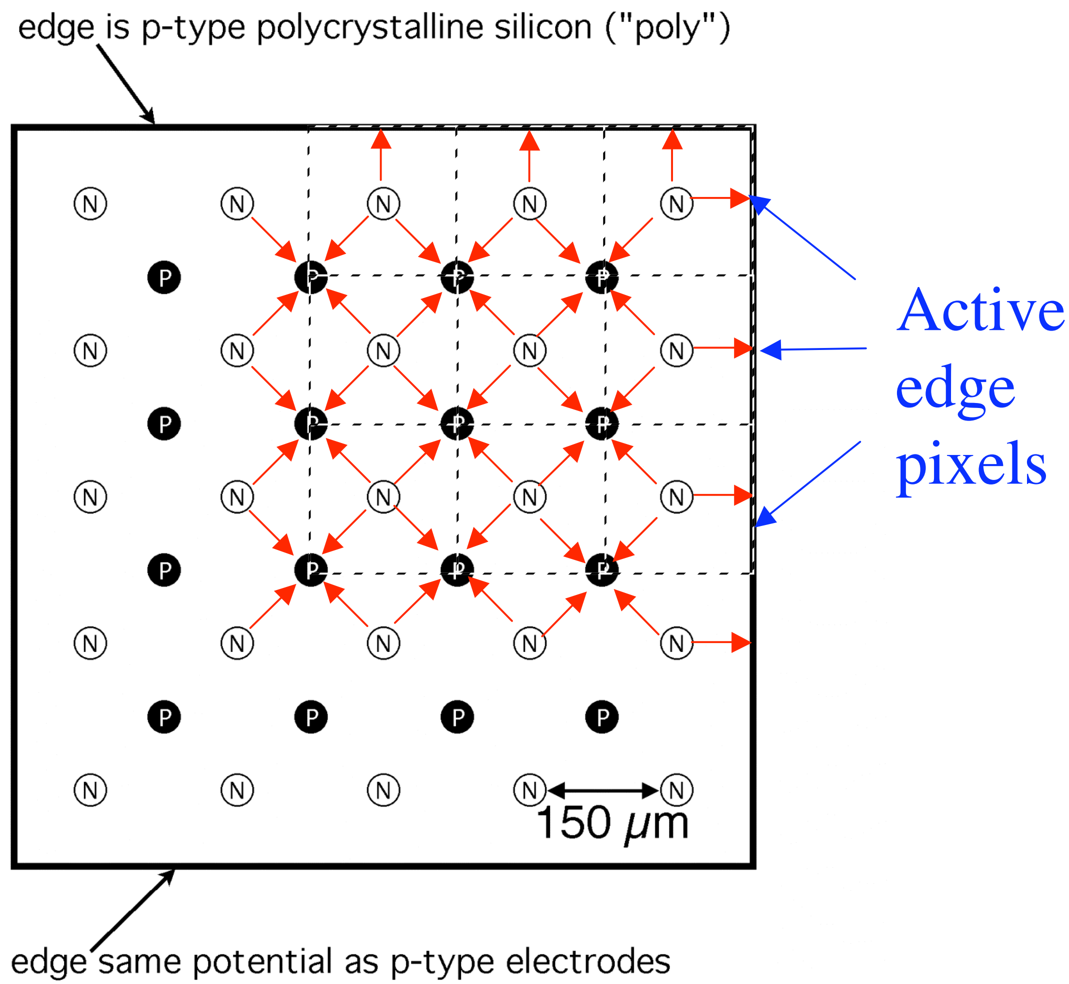
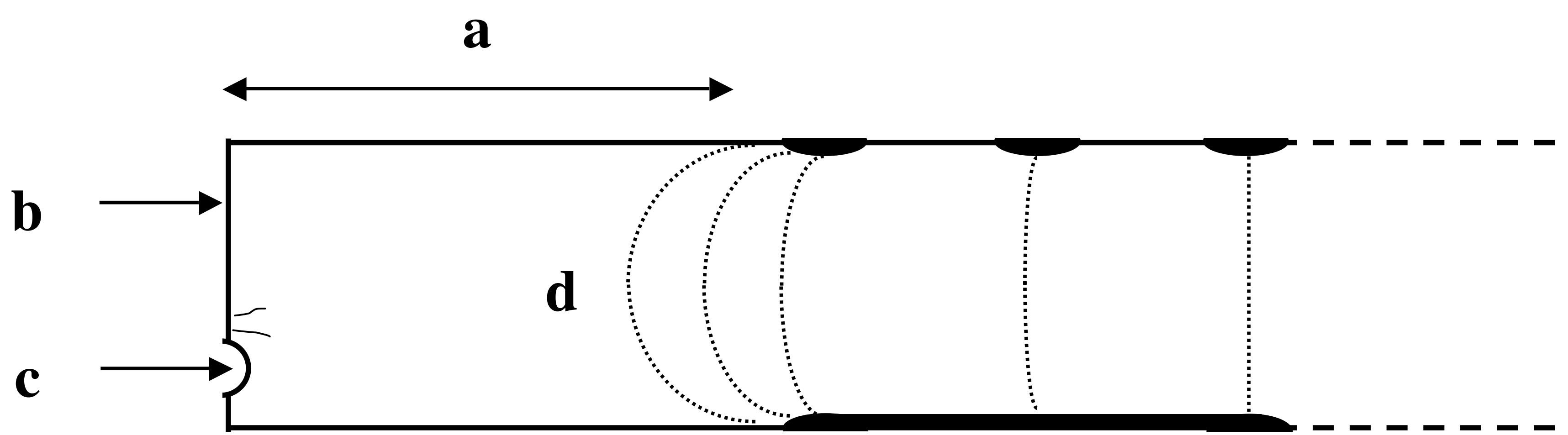
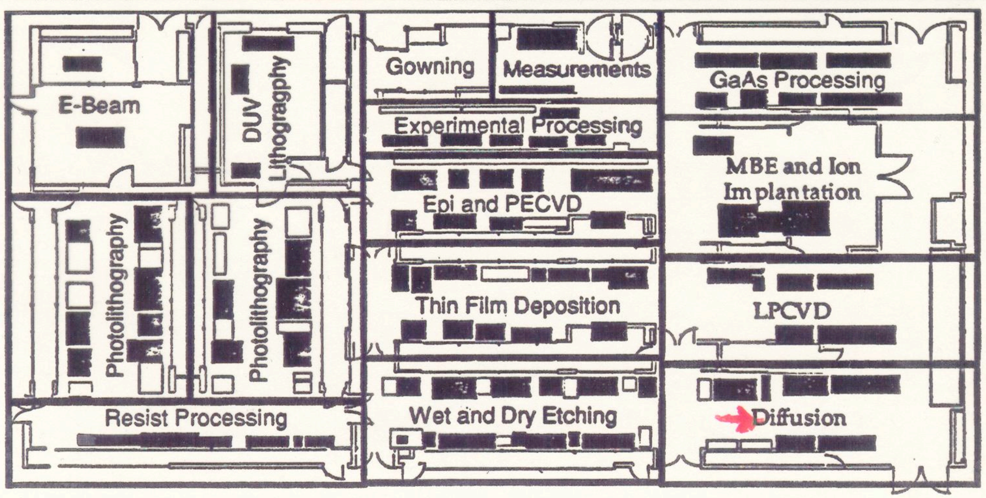

edge is p-type polycrystalline silicon ("poly")
N
P
150 μm
Active edge pixels
edge same potential as p-type electrodes

3D Compared to planar PIN diodes:

- **order-of-magnitude faster signal risetime**
- **greater resistance to bulk radiation damage**
- **minimal 'charge sharing' between pixels**
- **'active edge' electrodes eliminate dead borders around the cut edges of planar processed diodes.**



Schematic cross-section view of a standard sensor edge, showing some reasons for the insensitive region there: (a) space may be needed for guard and voltage-dropping rings, (b) the saw-cut edges are conducting, and (c) often contain chips or small cracks, all of which must remain clear of (d), the bulge of the edge of the electric field in the depleted region.



The Stanford Nanofabrication Facility

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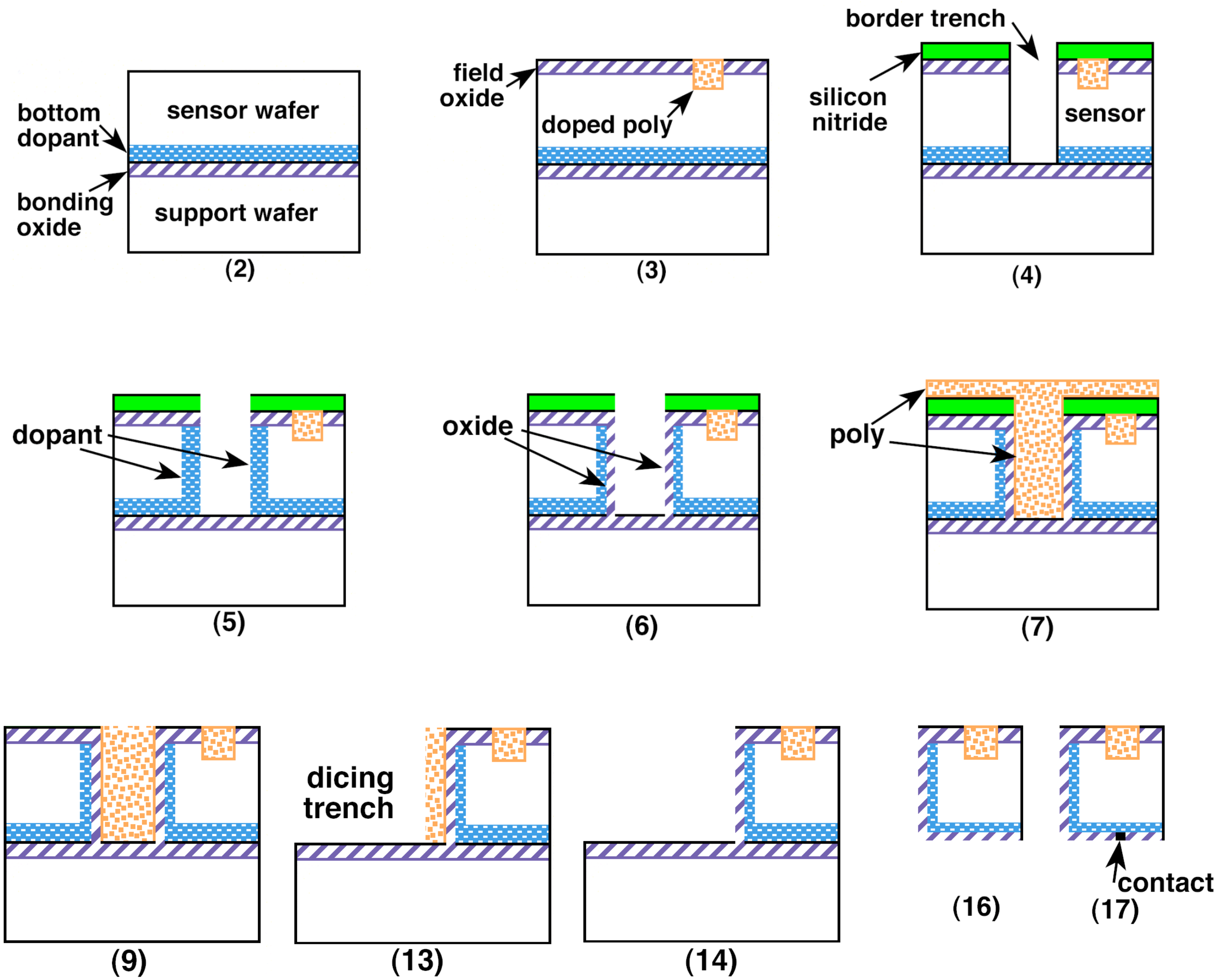
bottom dopant
bonding oxide
sensor wafer
support wafer
(2)
field oxide
doped poly
(3)
border trench
silicon nitride
sensor
(4)
dopant
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oxide
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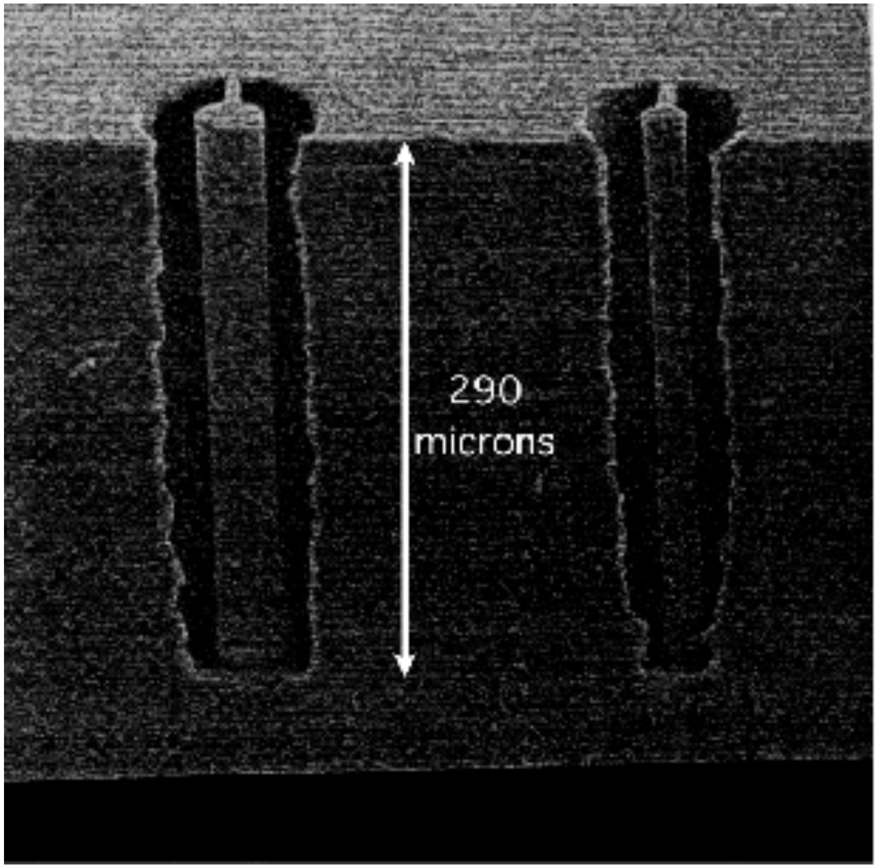
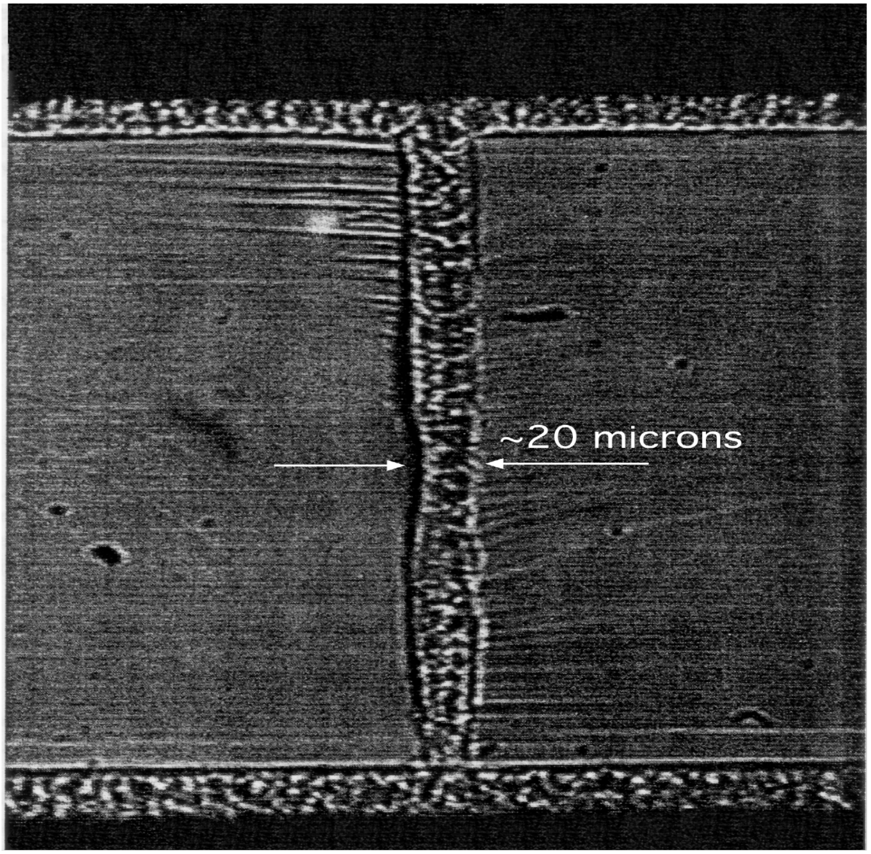
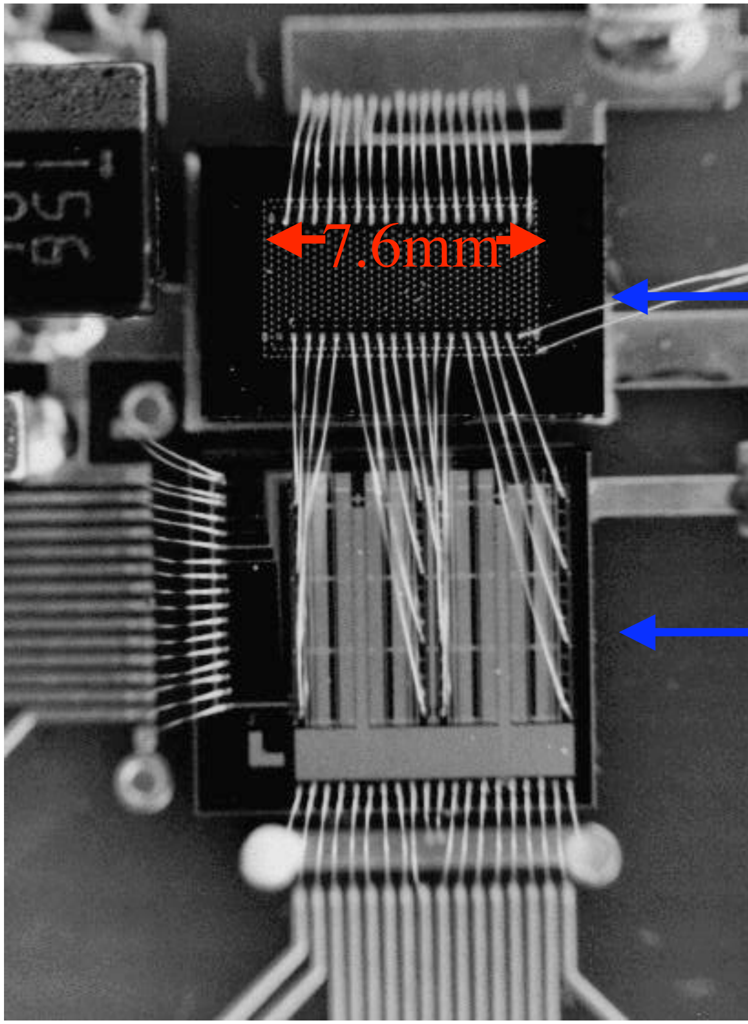
(16)
contact
(17)



‘C’ hole structures in silicon, fabricated at Stanford Nano-Fabrication Facility using Bosch process (inductively coupled SF_6 plasma etching)



'Cracked' 3D detector, revealing doped polycrystalline silicon column electrode 20μm diameter



3DX chip

8 channel charge preamp and shaper

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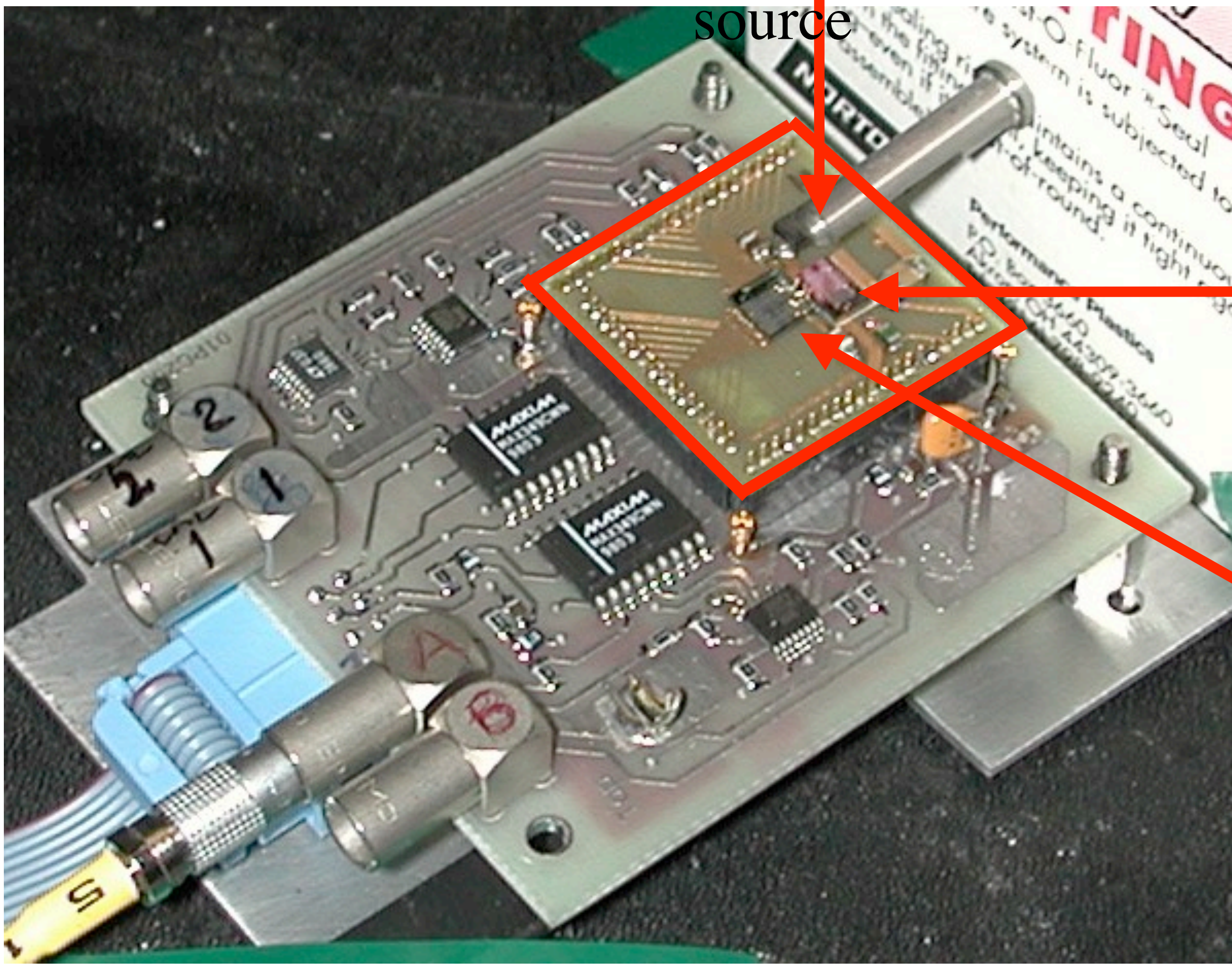
Fe^{55}
source



3DX
chip

ASIC
preamp

3DX chip + 8 channel charge preamplifier test board

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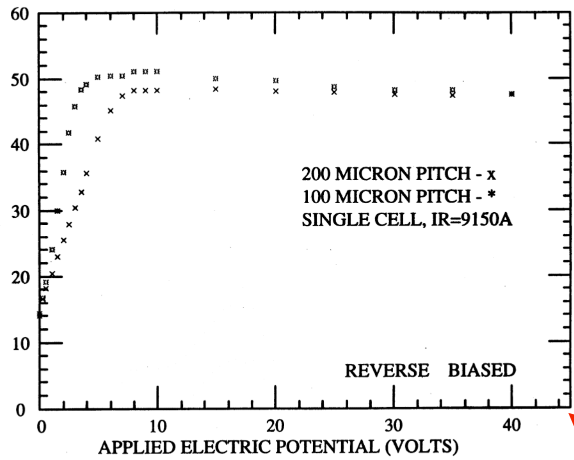
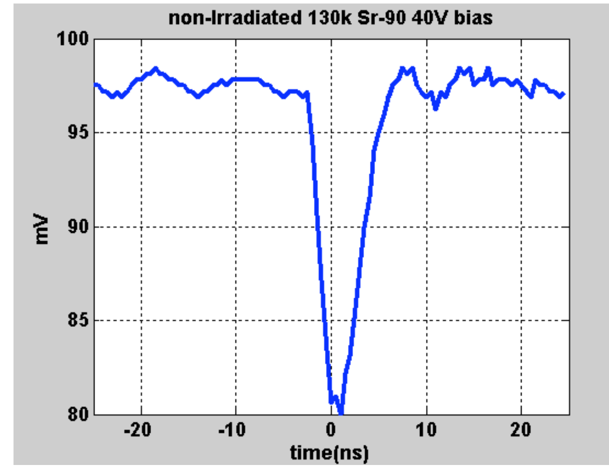
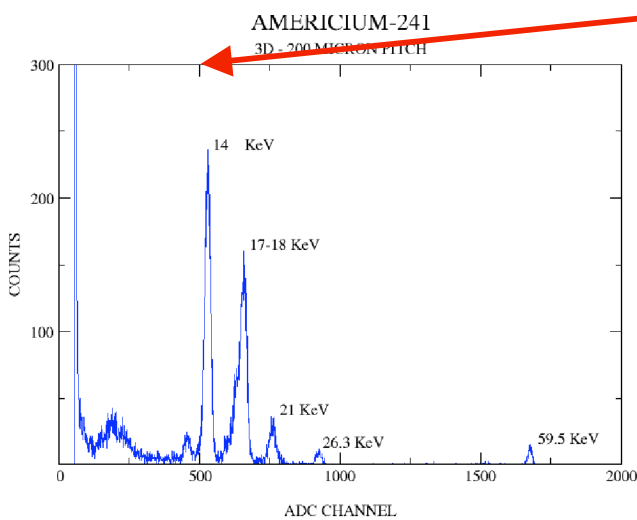
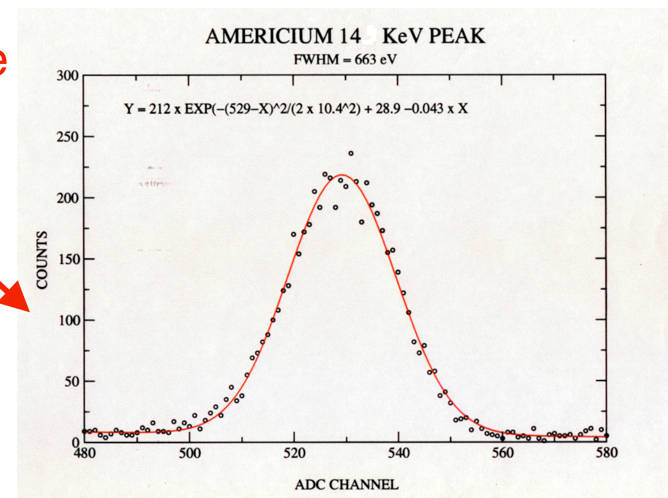




- Small V_{FD} 5-8 V
- Speed 1.5, 3.5 ns
- Energy resolution
- Gaussian response





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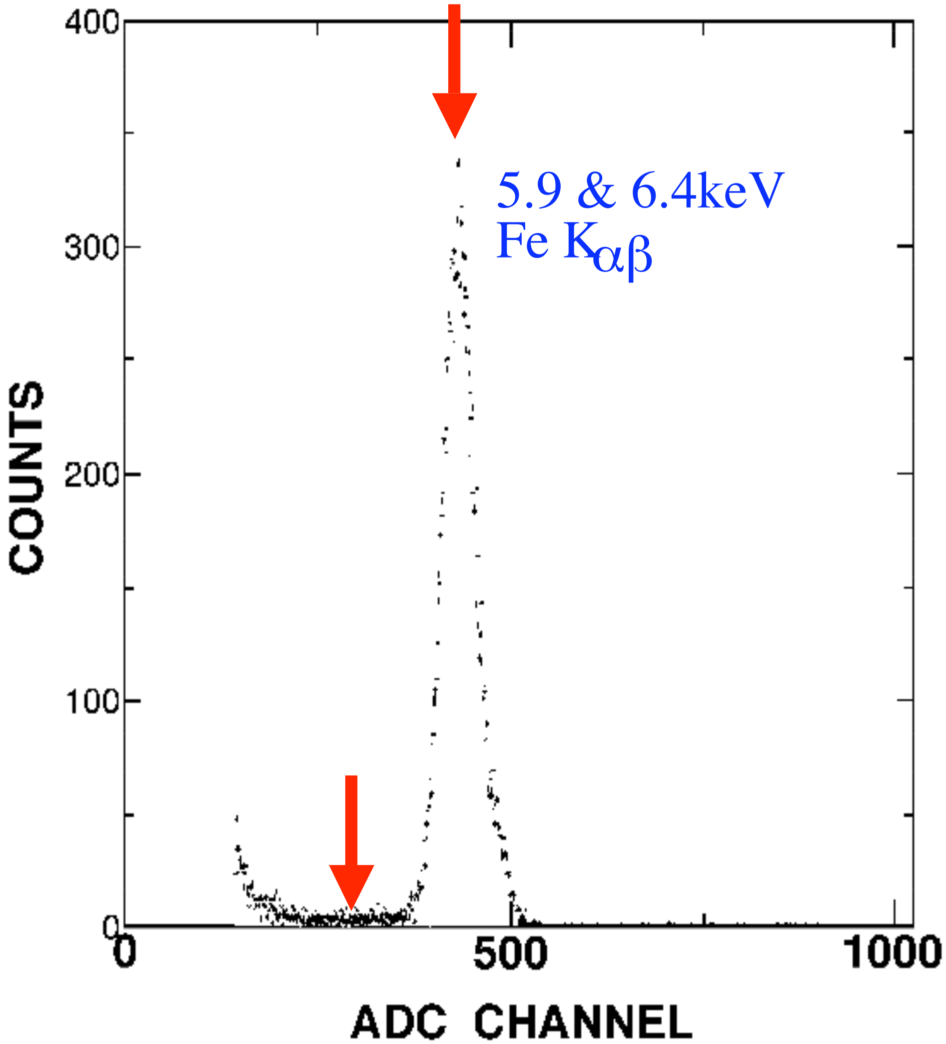
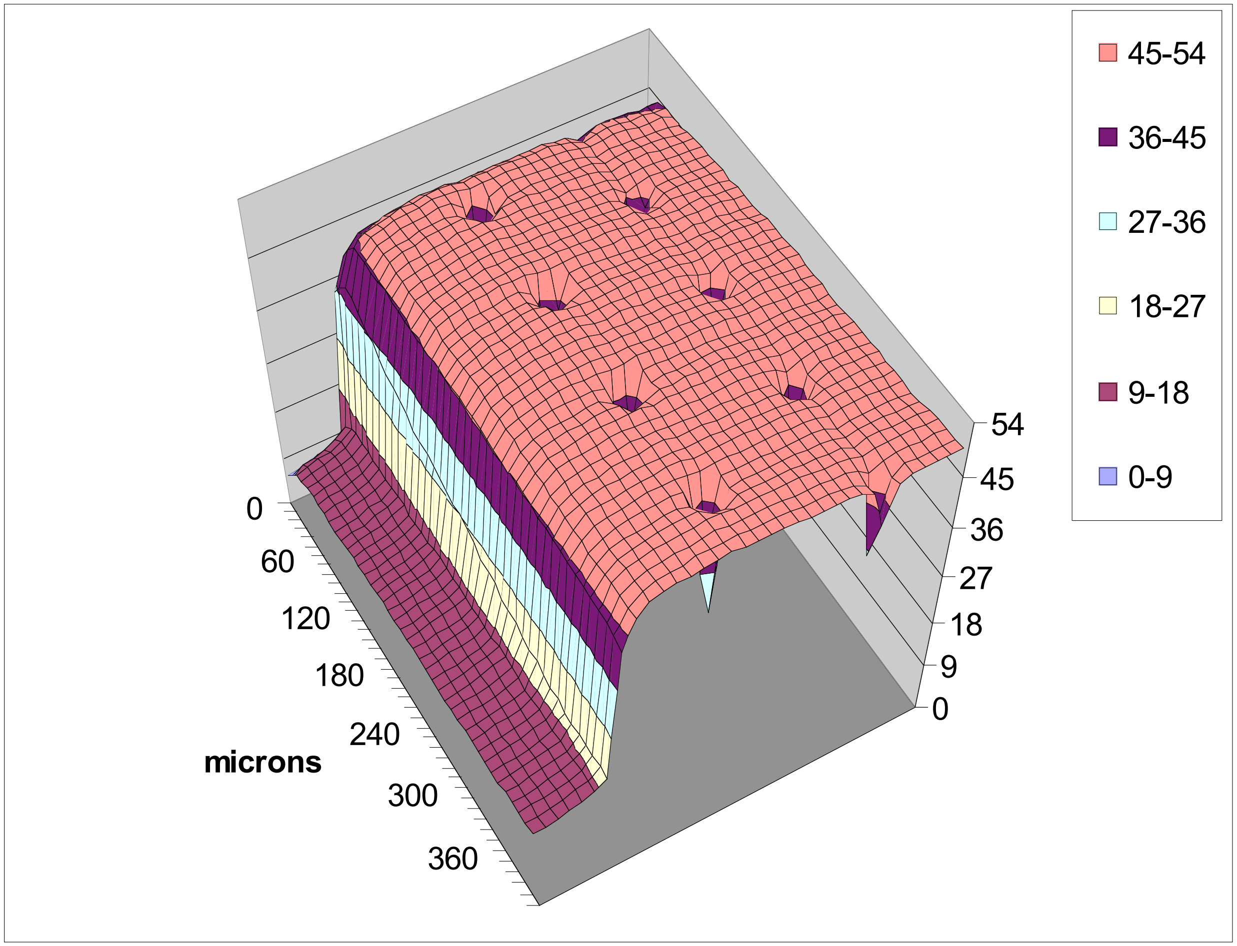


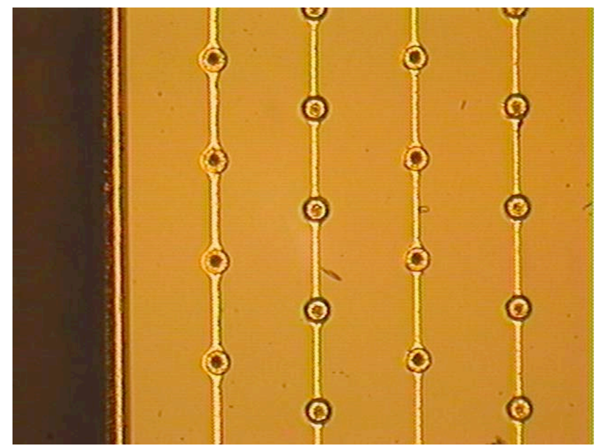
Flood exposure to ^{55}Fe iron source

Fe K α, Kβ fluorescence lines not separated due to 620eV ASIC preamplifier noise

- 12 KeV X Rays at ALS



Beamline 10.3.1
~ 1 μm focused spot



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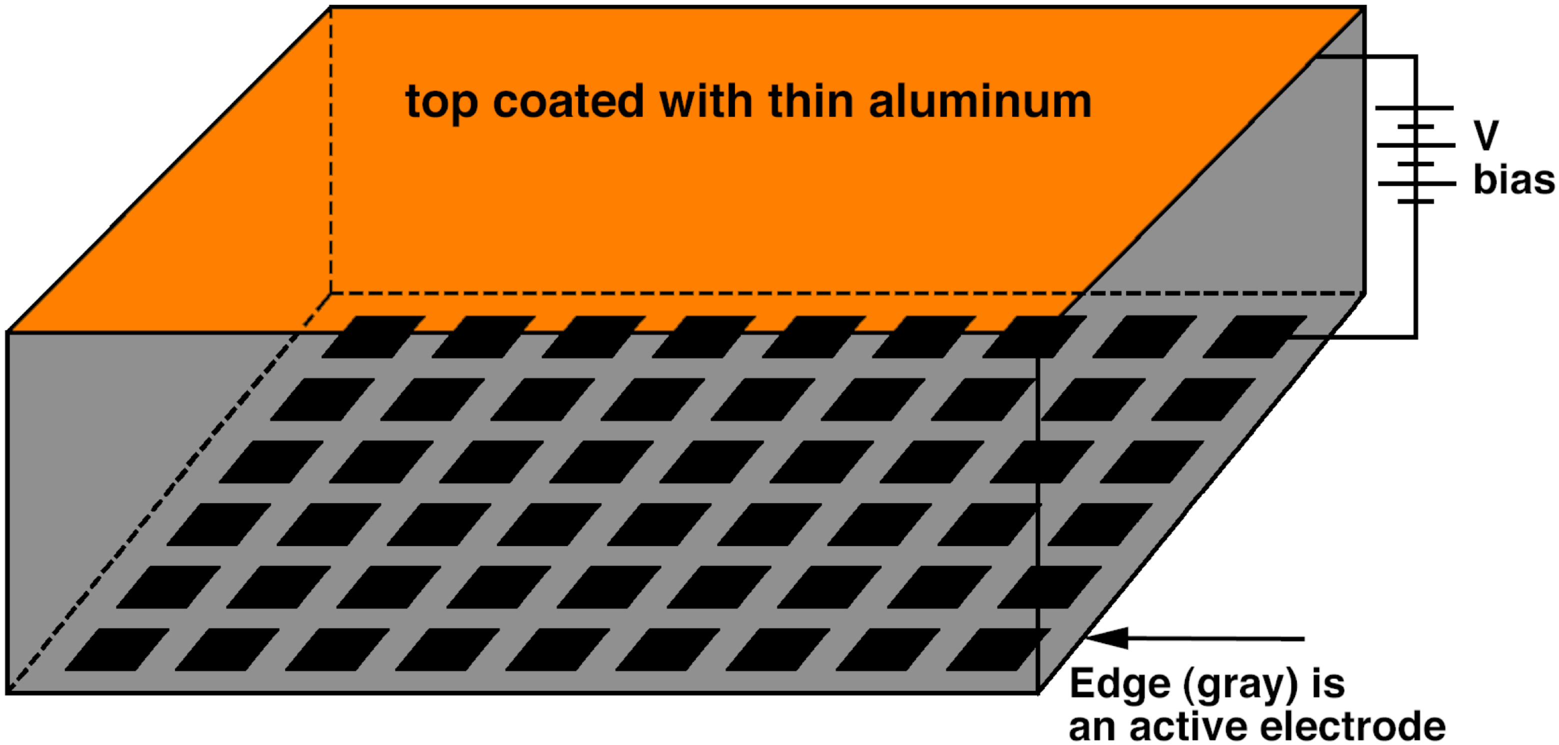
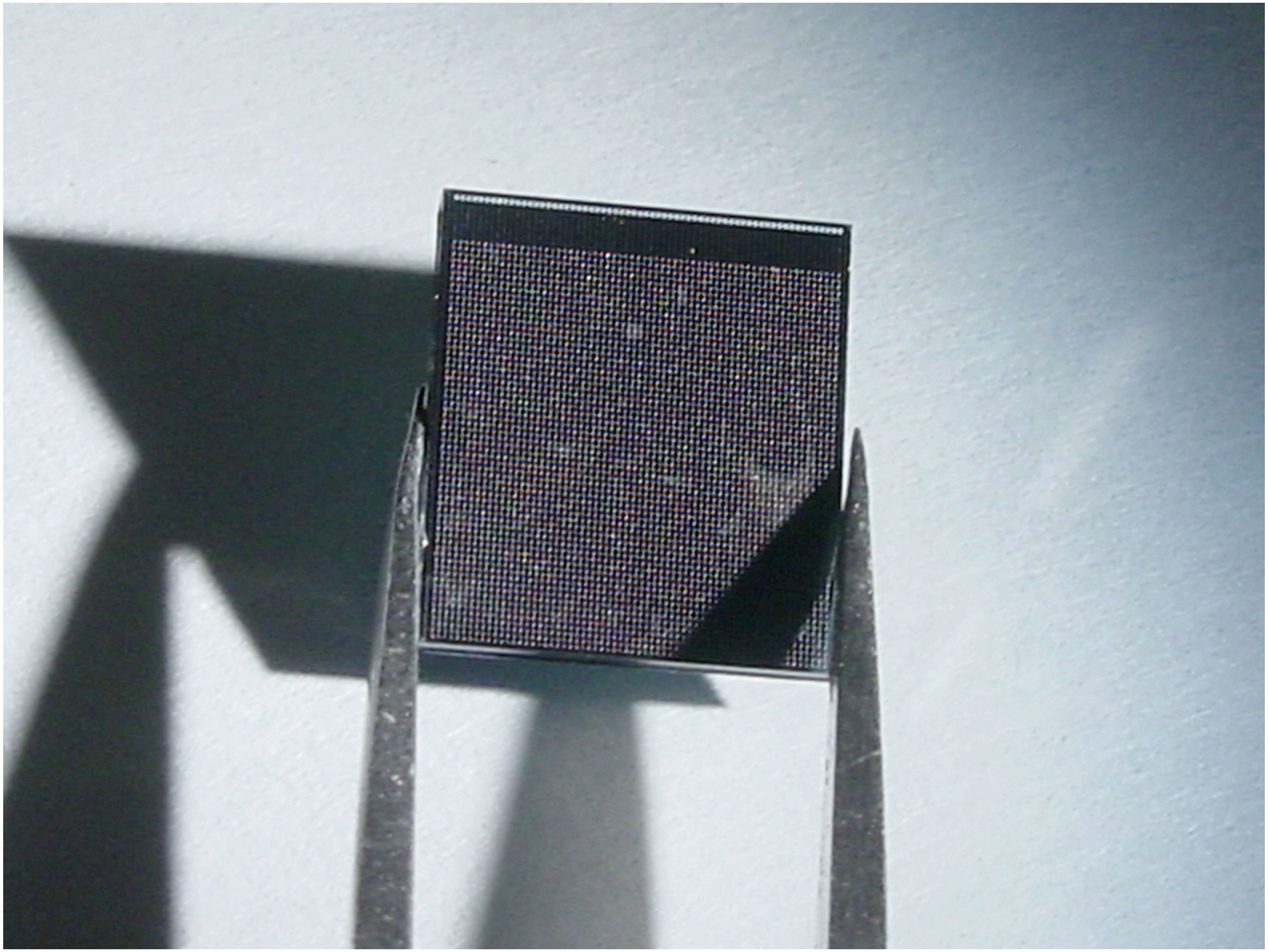
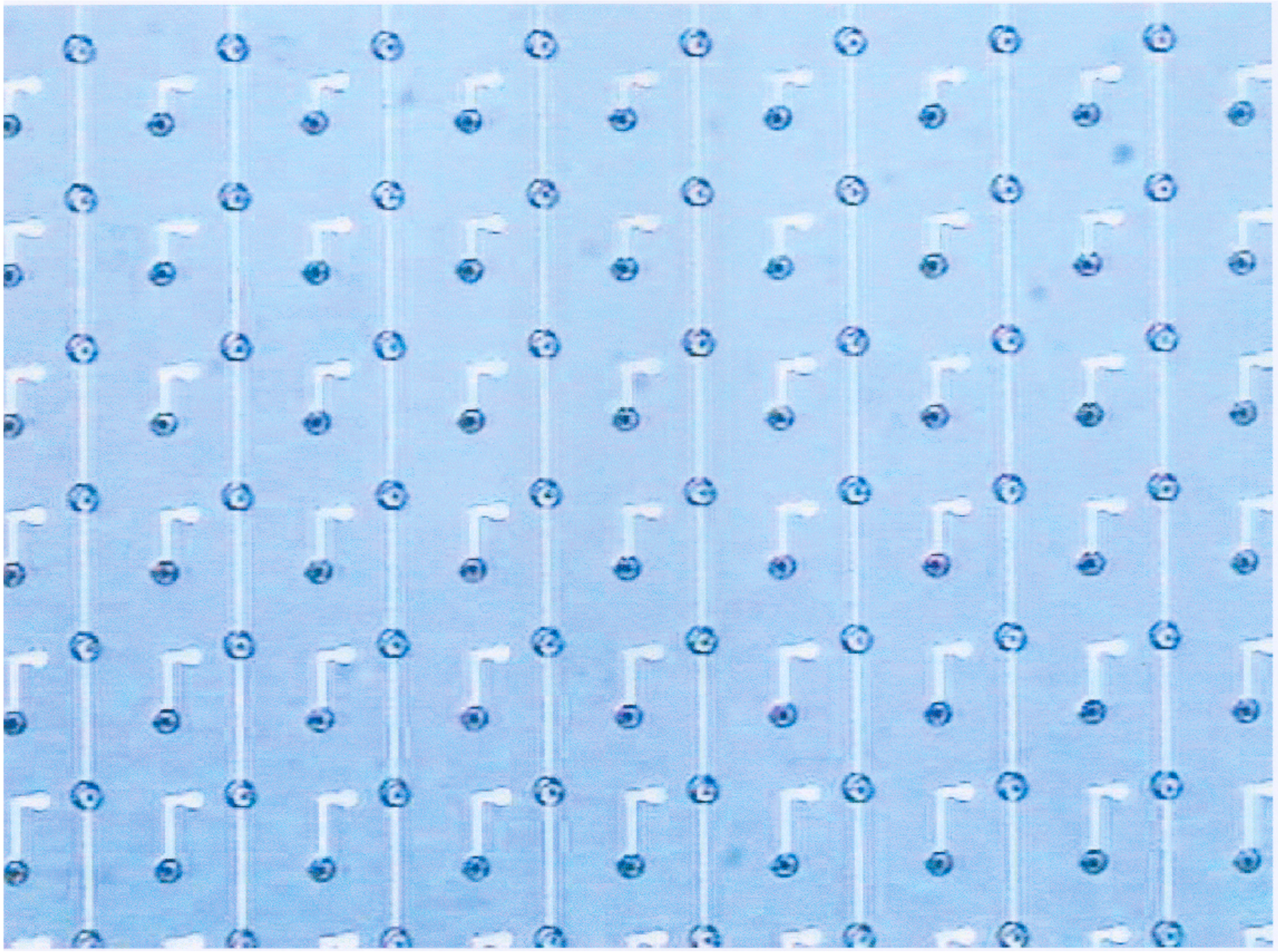


“Planar 3D” devices have active edges, but no Internal electrodes



Backside of a 64x64 planar sensor with 150μm pixels (indium bumps are applied)

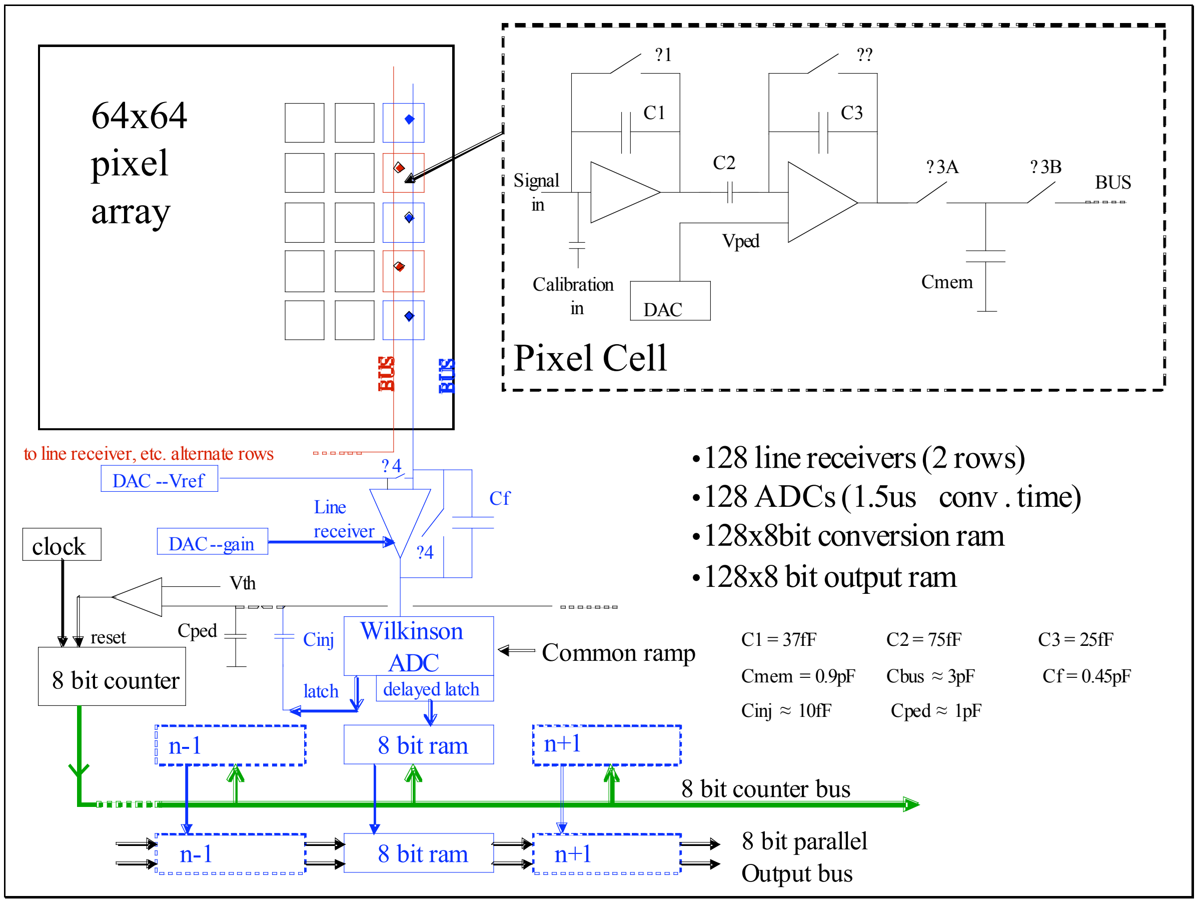


Sensor pixel raster is 150μm,

but readout raster is 144μm.

This permits ASIC border to remain behind sensor wafer

ASIC Schematic: derived from ATLAS chips: 128-fold parallel architecture, designed at LBL



In each pixel: Charge preamp, gain trim, CDS

6 - 8 bit ADC encoding

Continuous readout cycling, 64 μsec for entire chip

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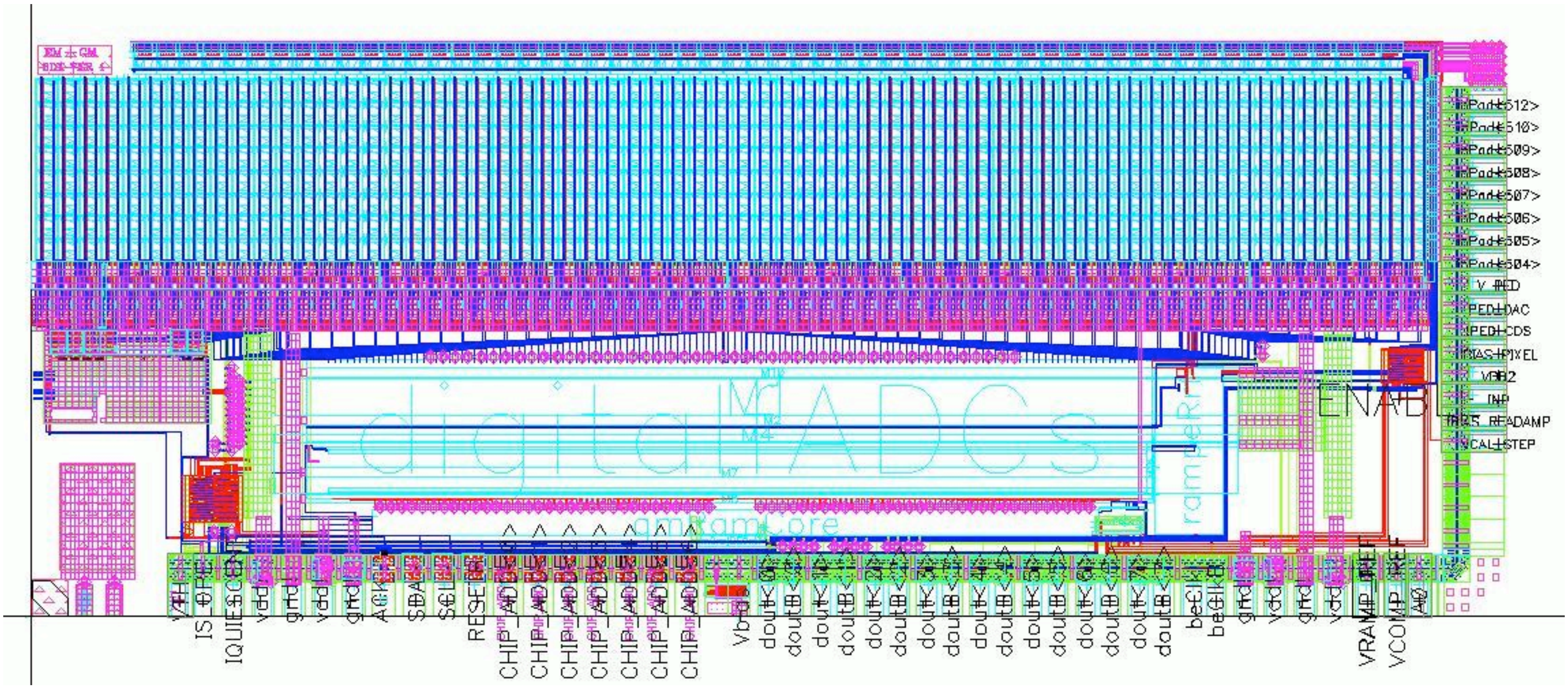
After 2 MOSIS runs, the ASIC works but has “bugs”.
We currently have ~40 working ASICS.
8 x 64 pixels in test/designASIC, to save costs
(64th column is full length, but folded to save space).



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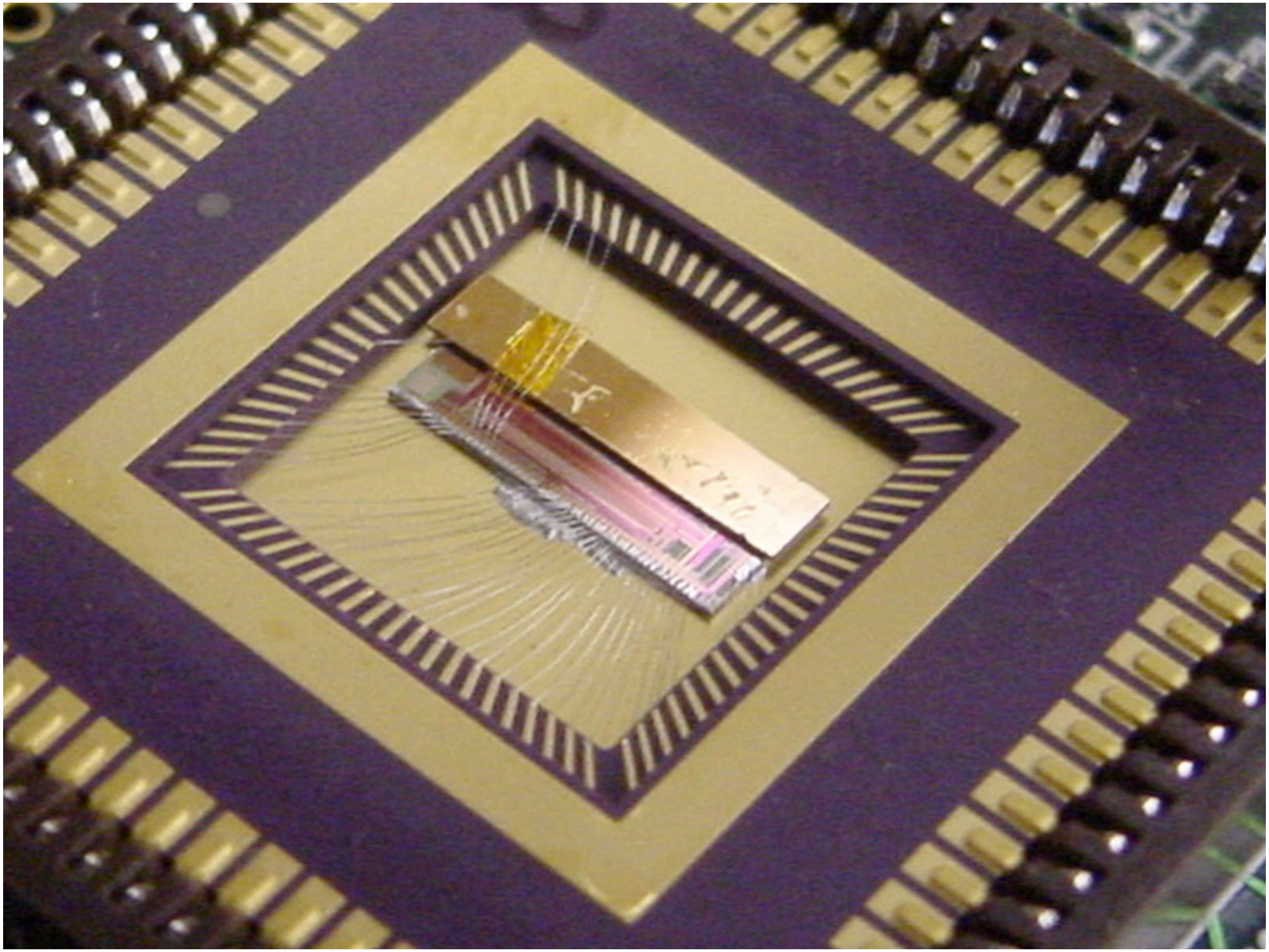

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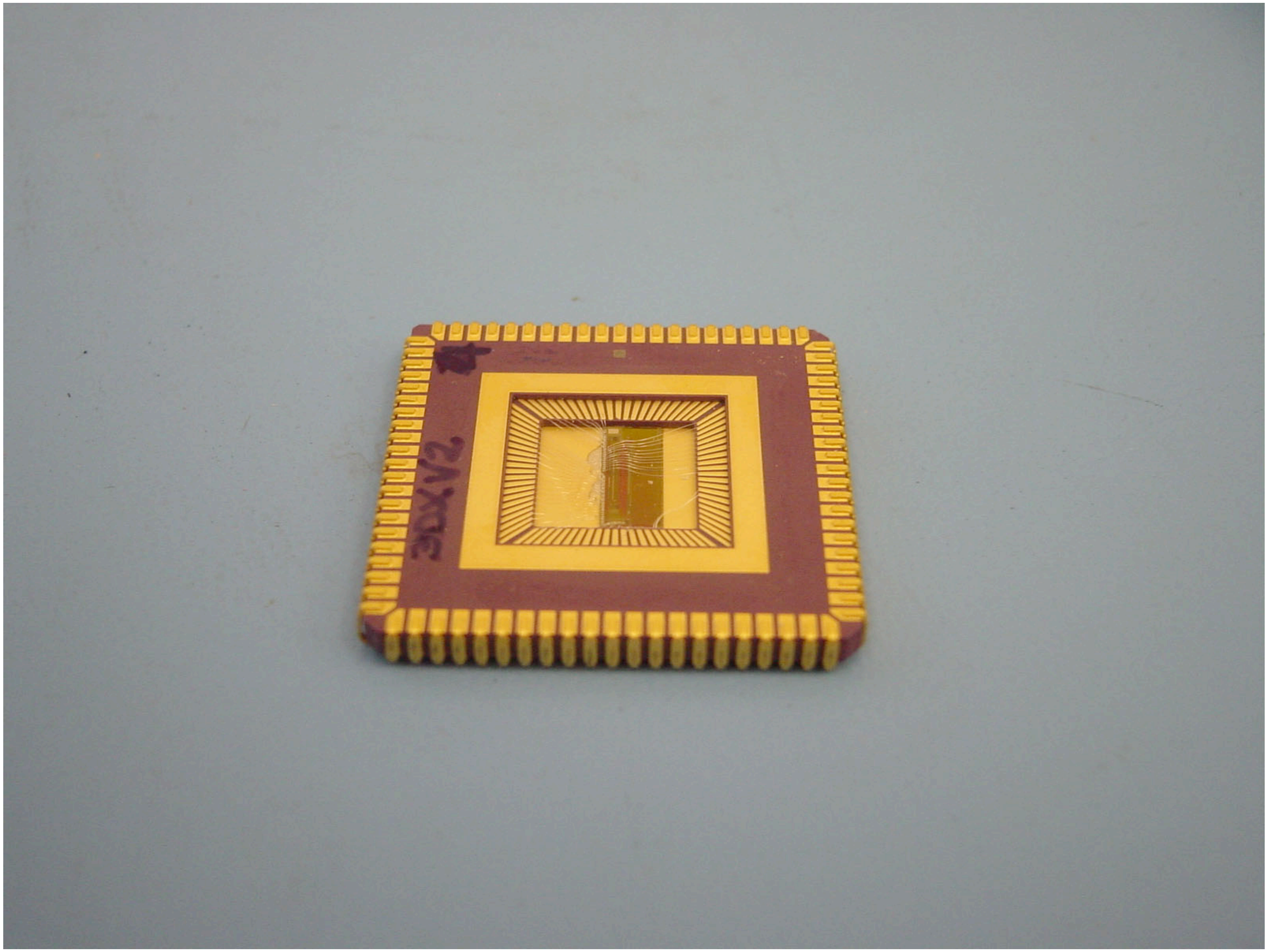

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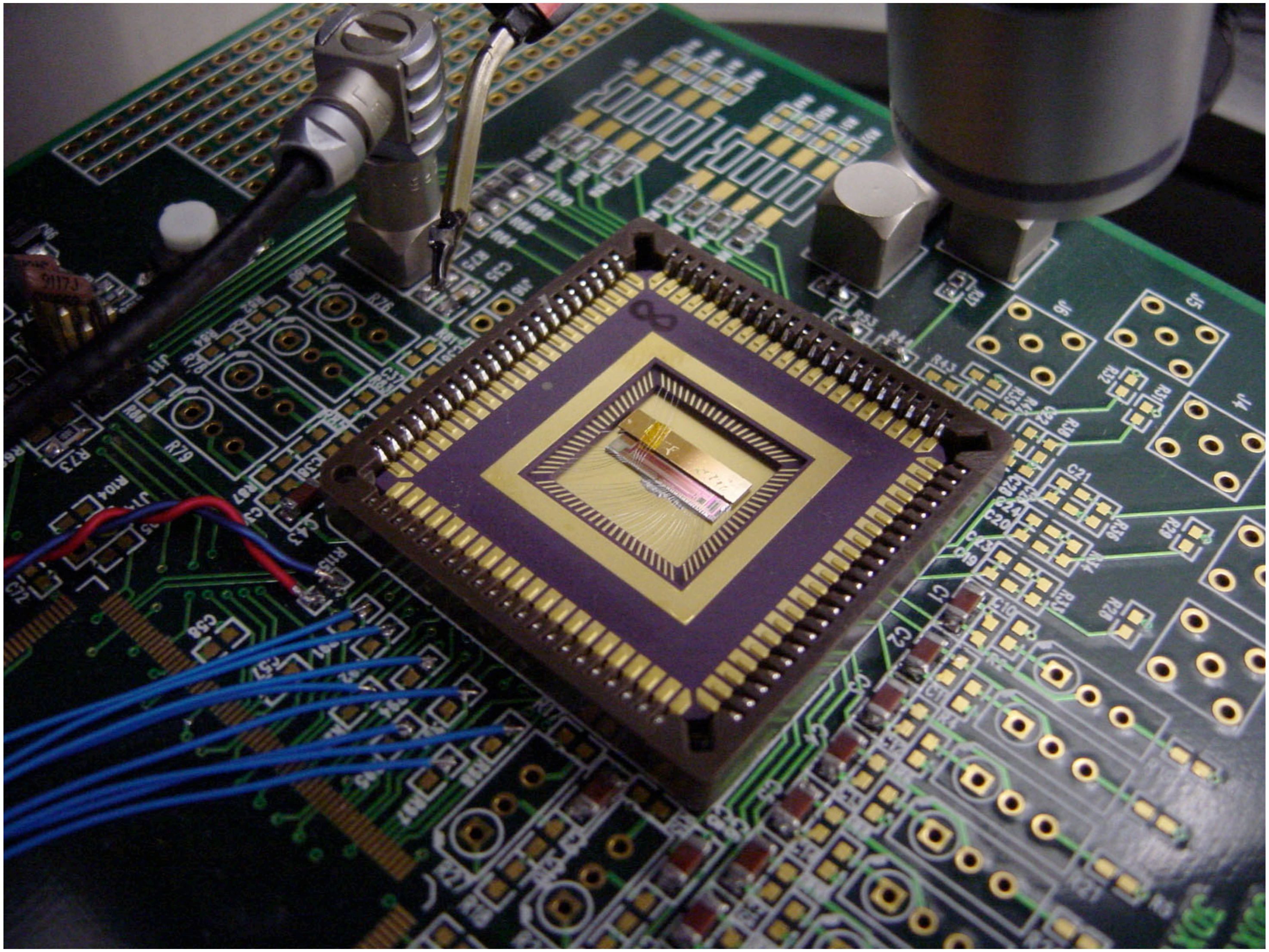

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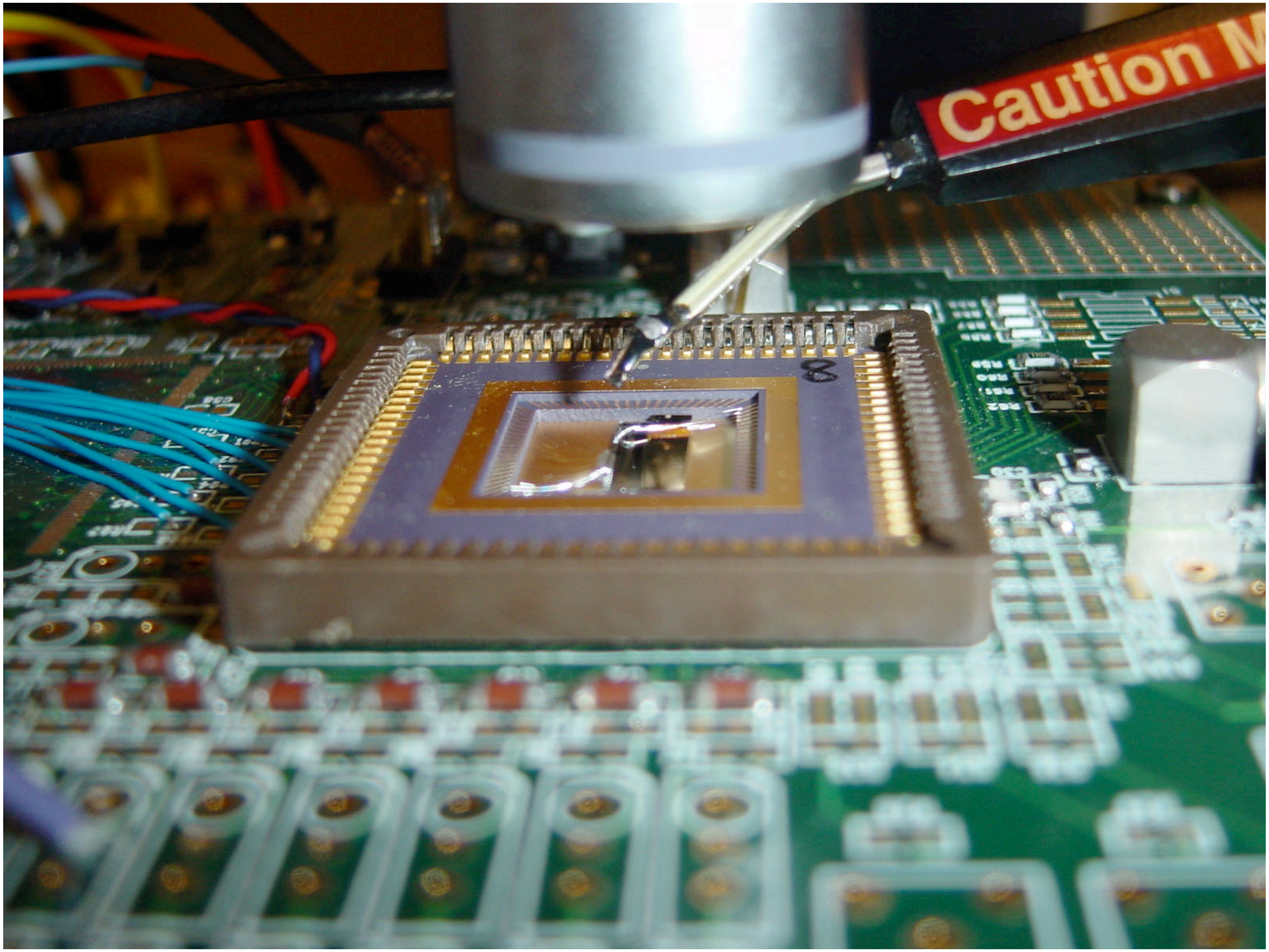

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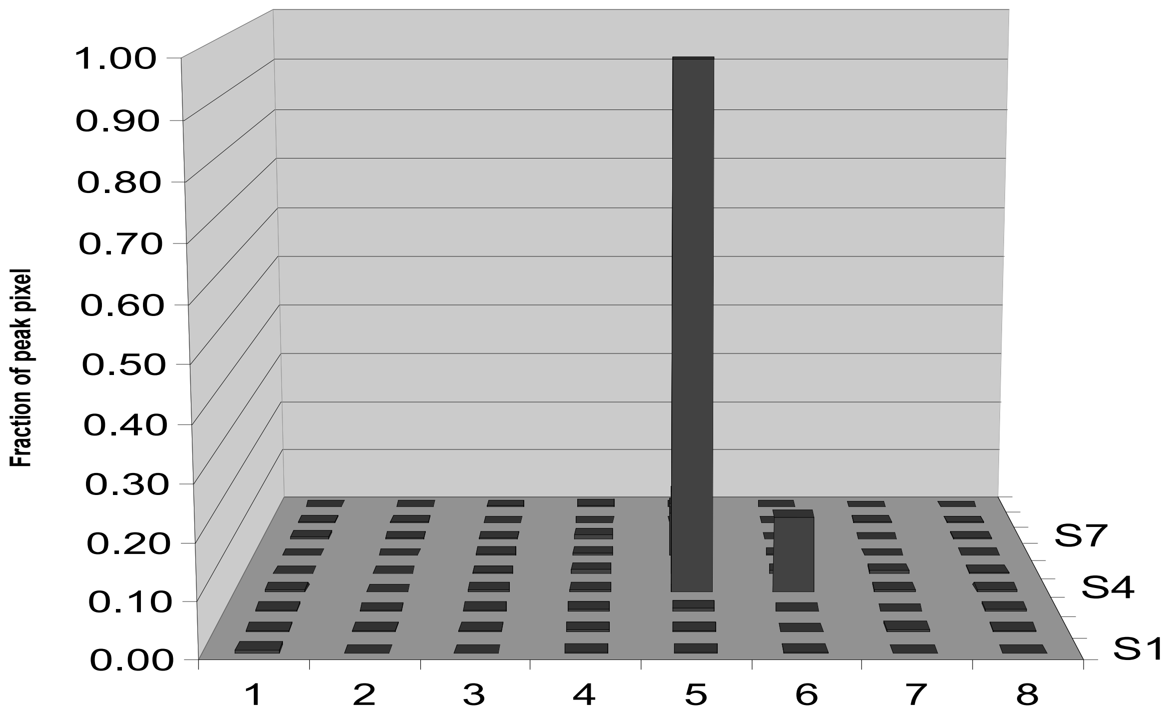
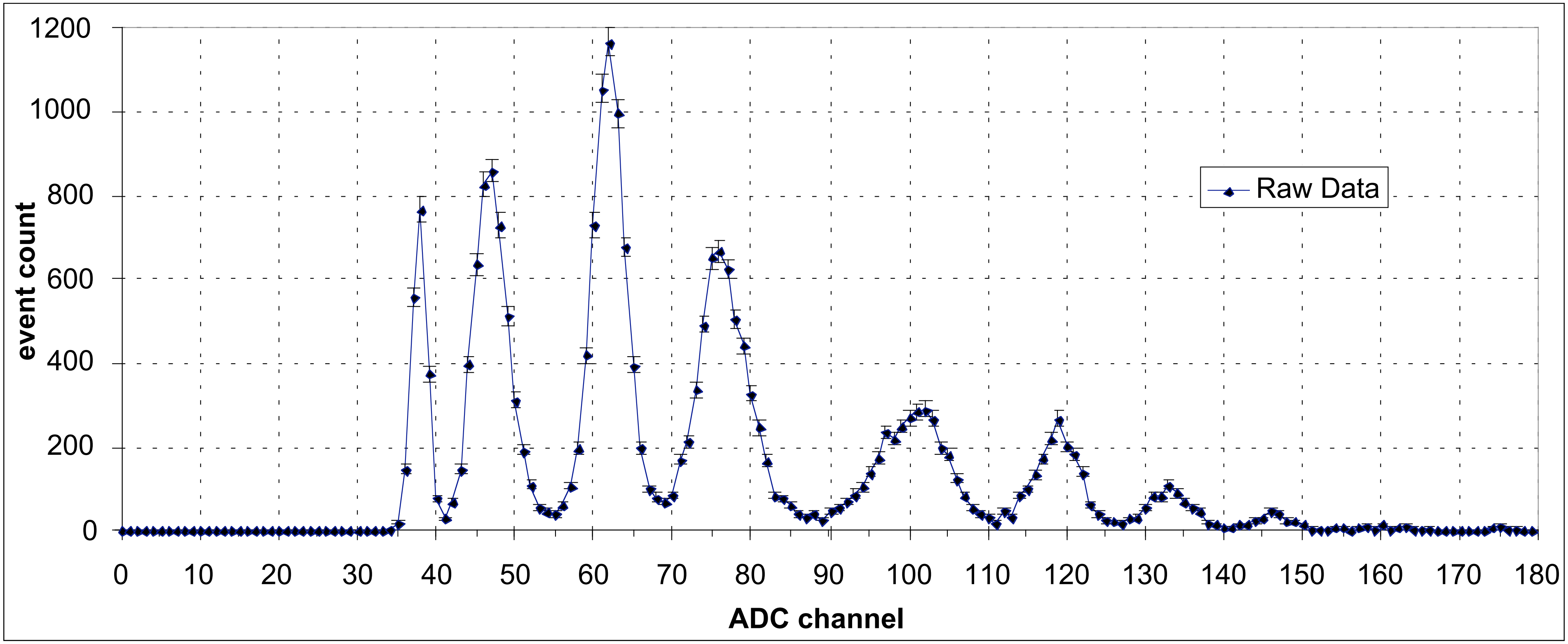
Point Response is essentially contained in a single pixel (ALS 4.2.2, ~5μm x 5μm slits)



Map of the 8 x 8 pixel area surrounding the aiming point of the x-ray beam.

Observed Spectral Response

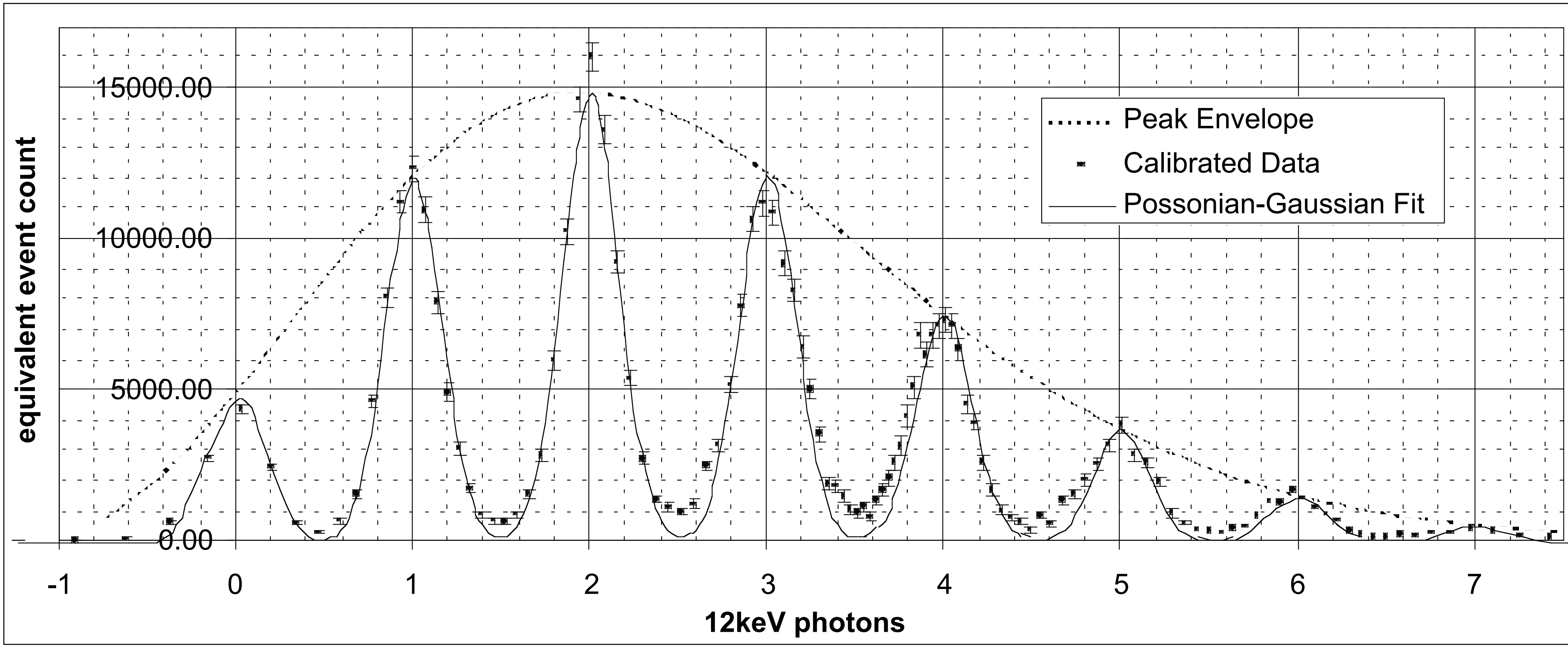
(Monochromator detuned, ~ 20,000 photons/s)



$$P(n) = \frac{e^{-<n>} < n >^n}{n!}$$

Poisson Fit to Data

<n> = 2.46



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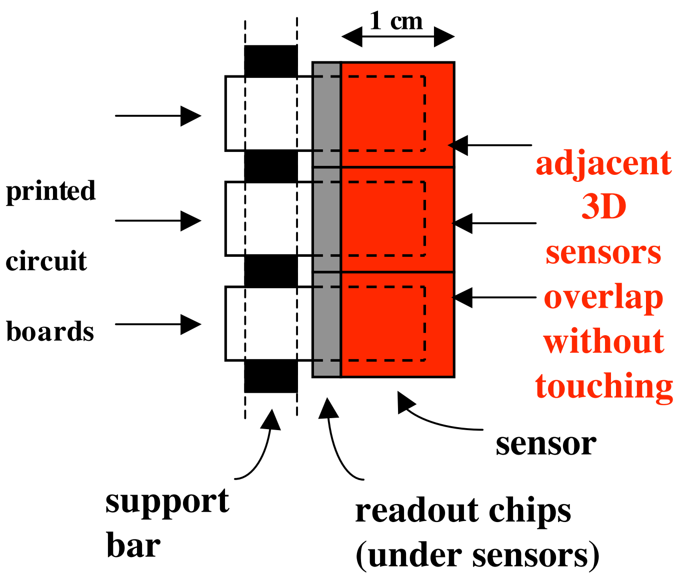

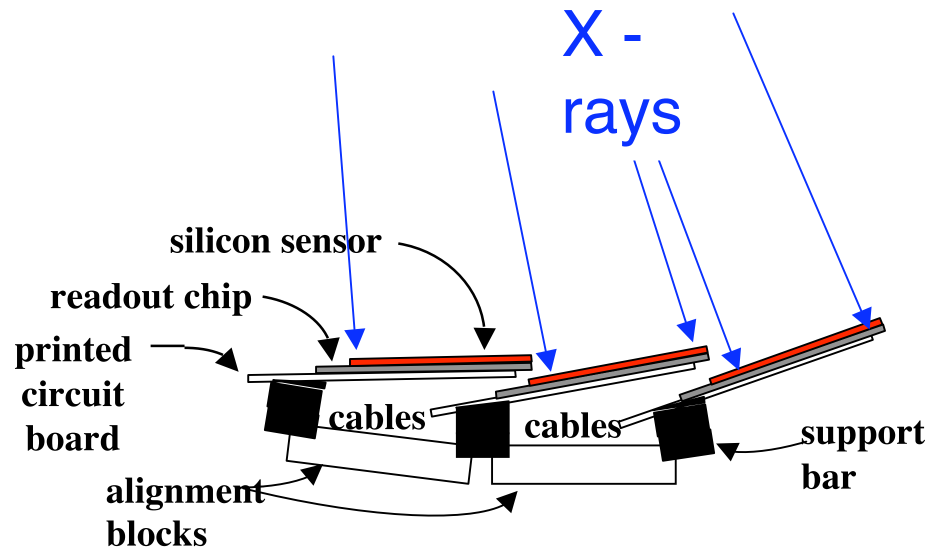

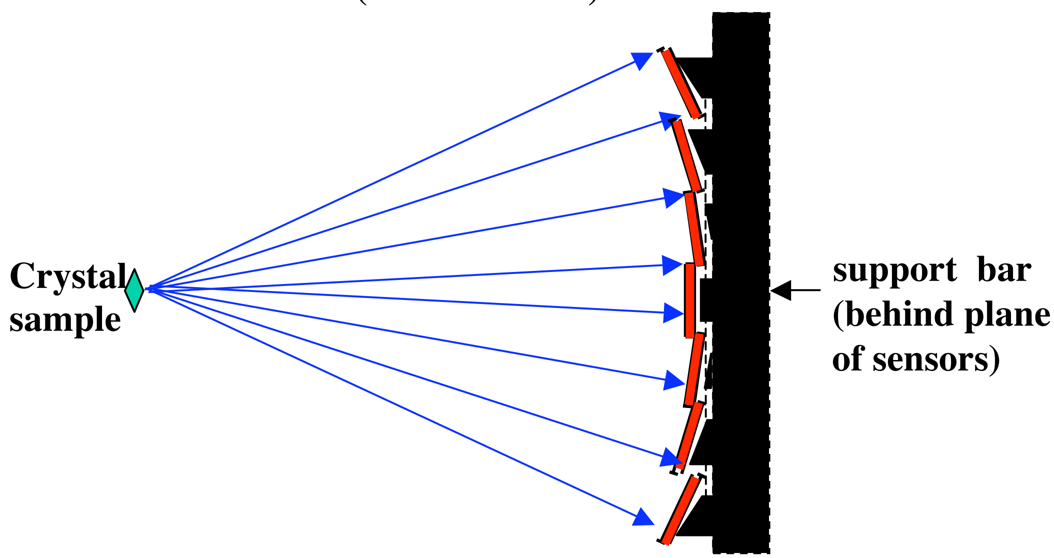

Schematic design for full scale protein crystallography detector (~300 x 300mm^2)

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