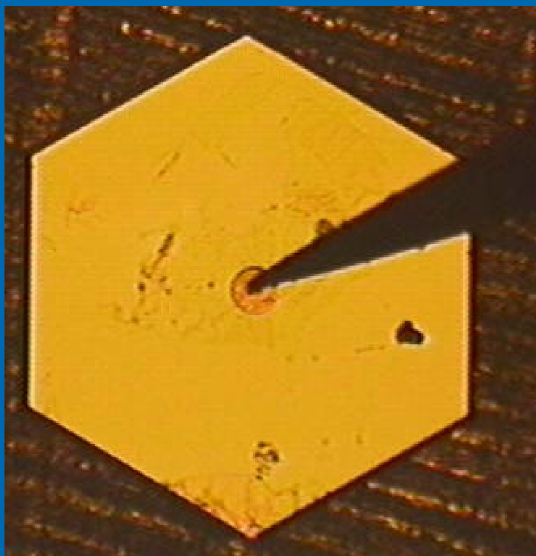
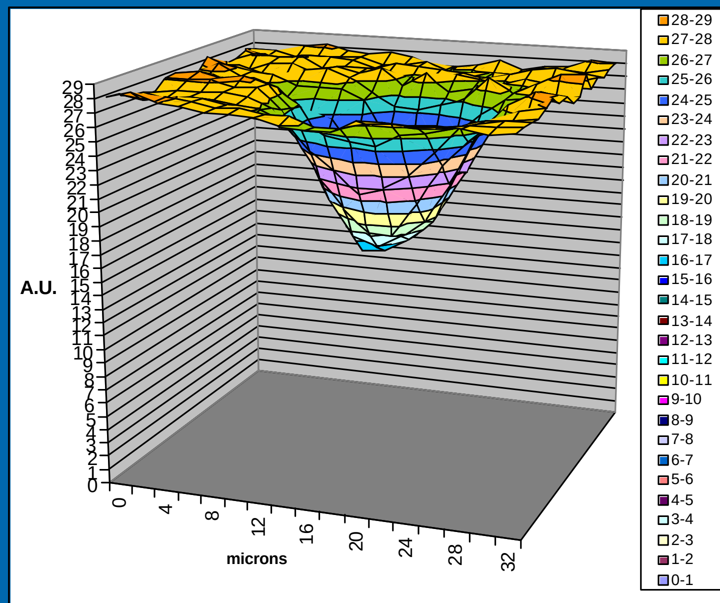
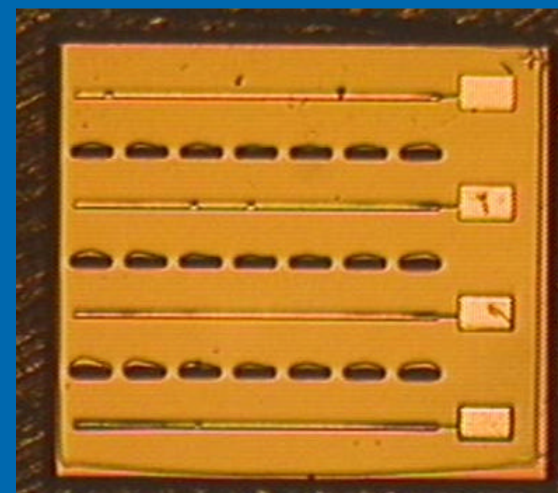
Active Edge and 3D Sensors



Chris Kenney





International Symposium on Detector Development

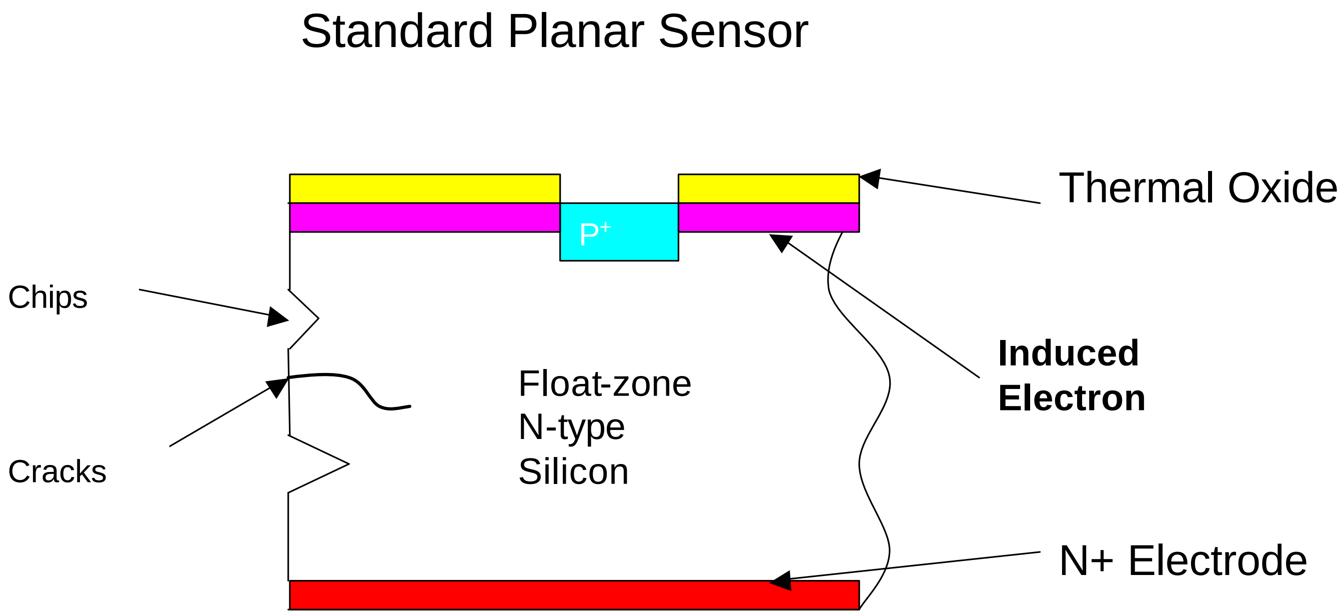
SLAC, April 5, 2006

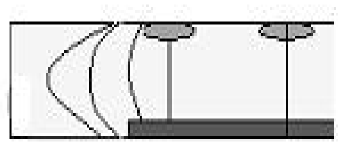
kenney@slac.stanford.edu

Project Members

- **Molecular Biology Consortium** - C. Kenney, E. Westbrook, A. Thompson, E. Perozziello
- **Brunel University** - J. Hasi, A. Kok, C. da Via, S. Watts
- **University of Hawaii** - S. Parker
- **Lawrence Berkeley Laboratory** - D. Gnani, E. Mandelli, G. Meddeler
- **CERN – M. Deile, G. Anelli**
- **European Synchrotron Research Facility** - J. Morse

Standard Planar

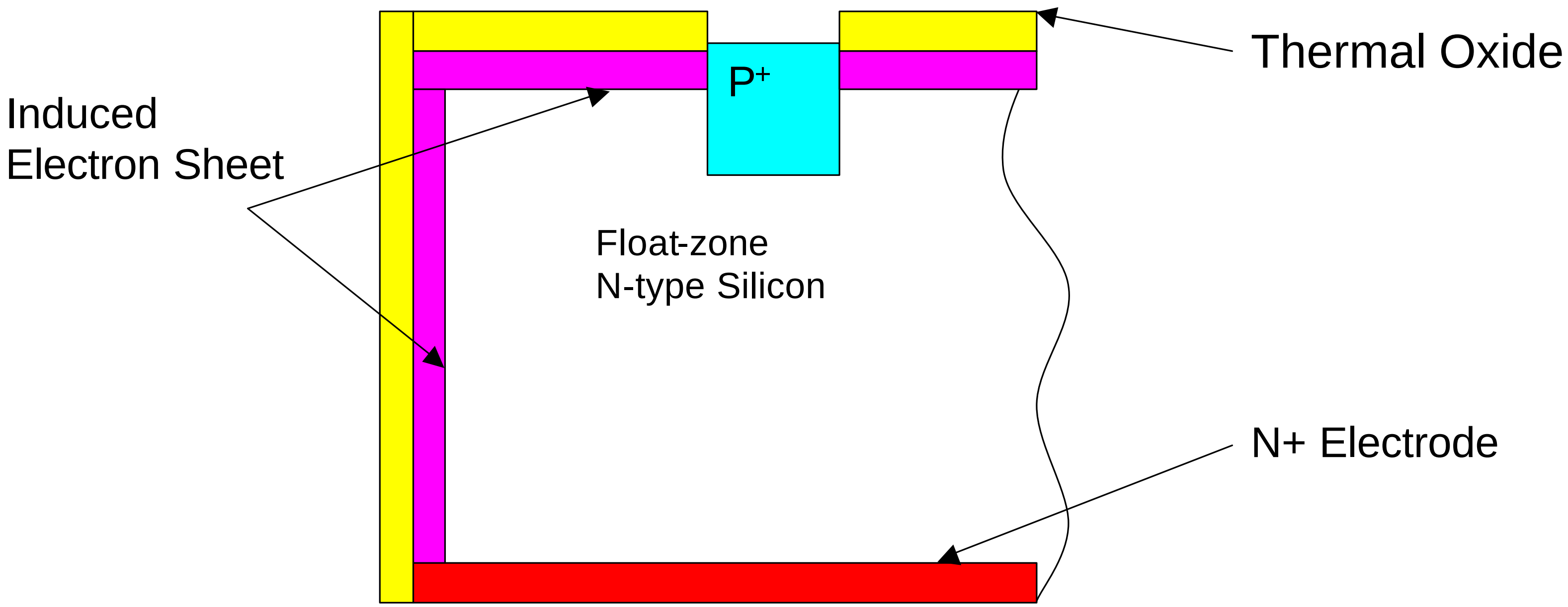




- Sawed Edge
- Edge is Undefined
- Many Dangling Bonds
- Effective Short Between Surfaces

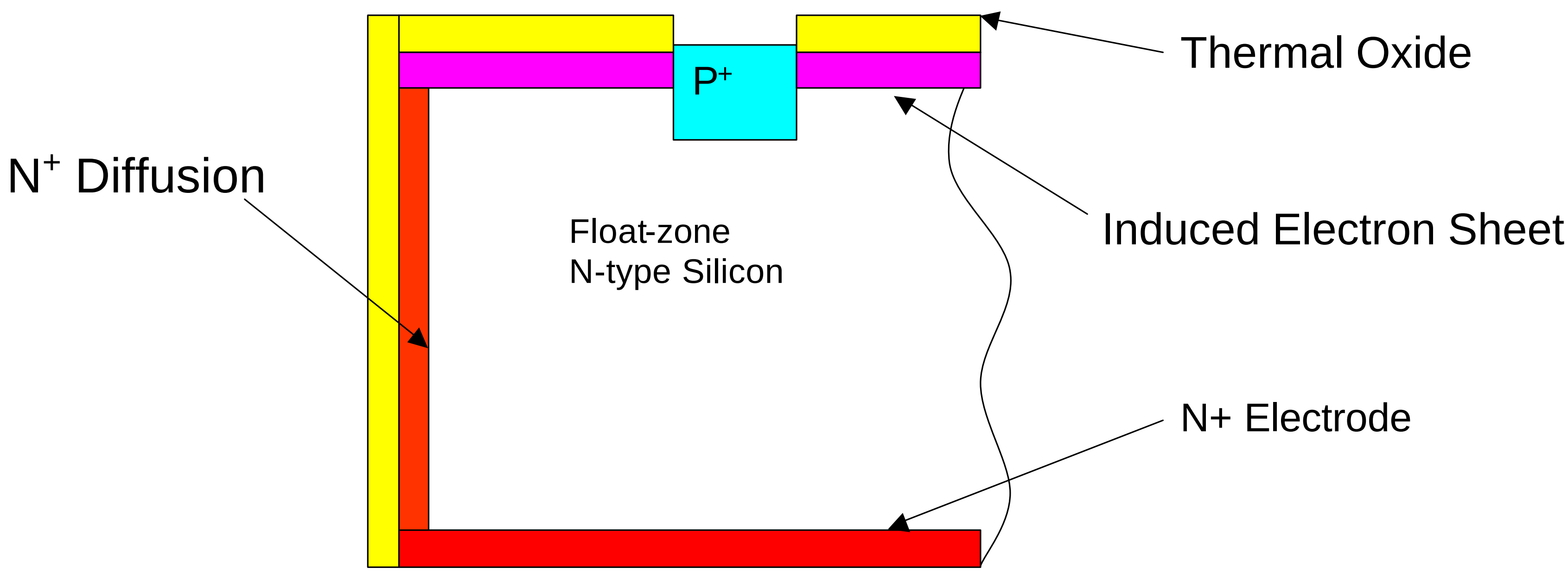
Active Edge Concept

Wrap Top Field Oxide Around Side



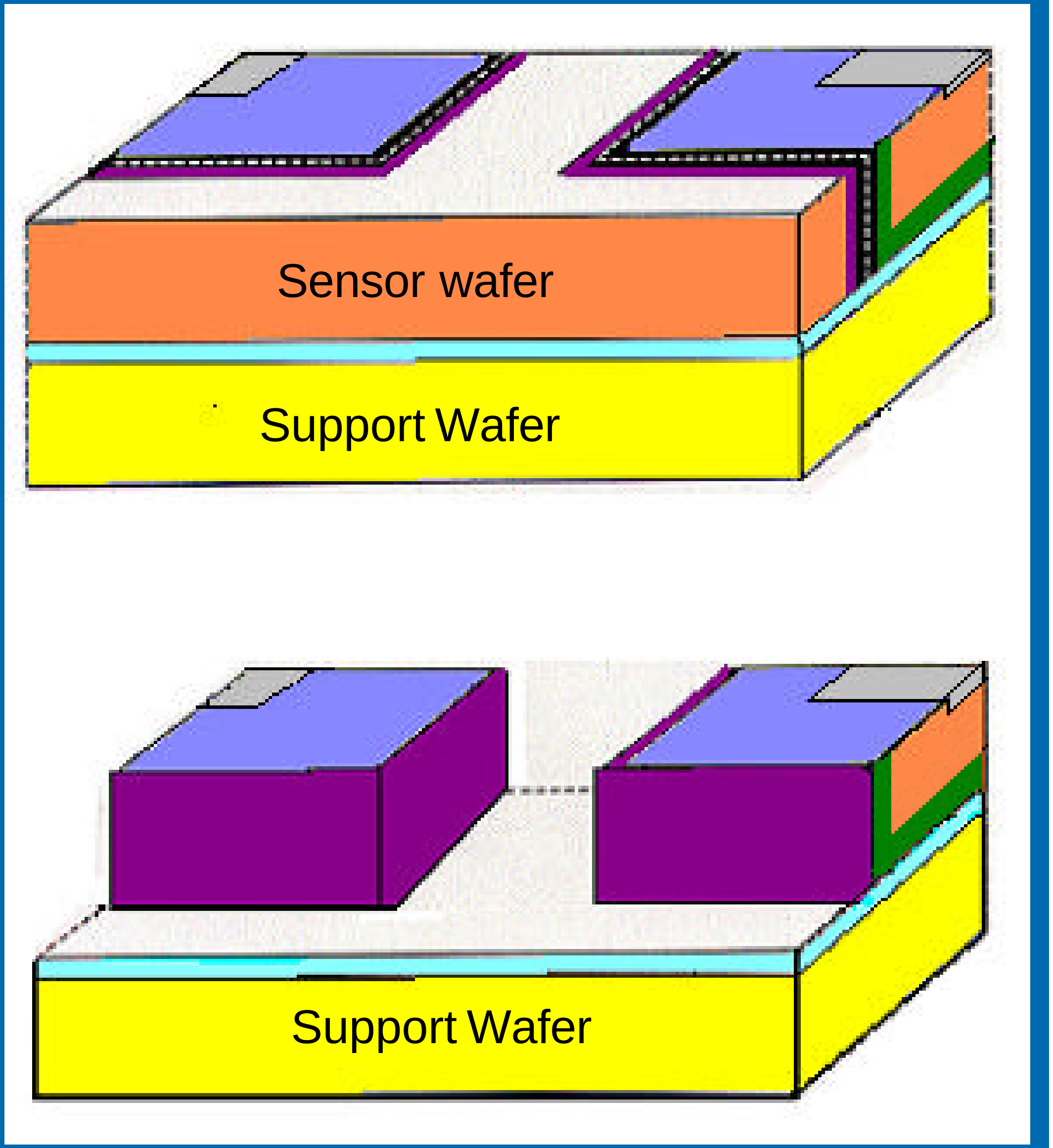
Active Edge Concept

Wrap Bottom Implant Around Side



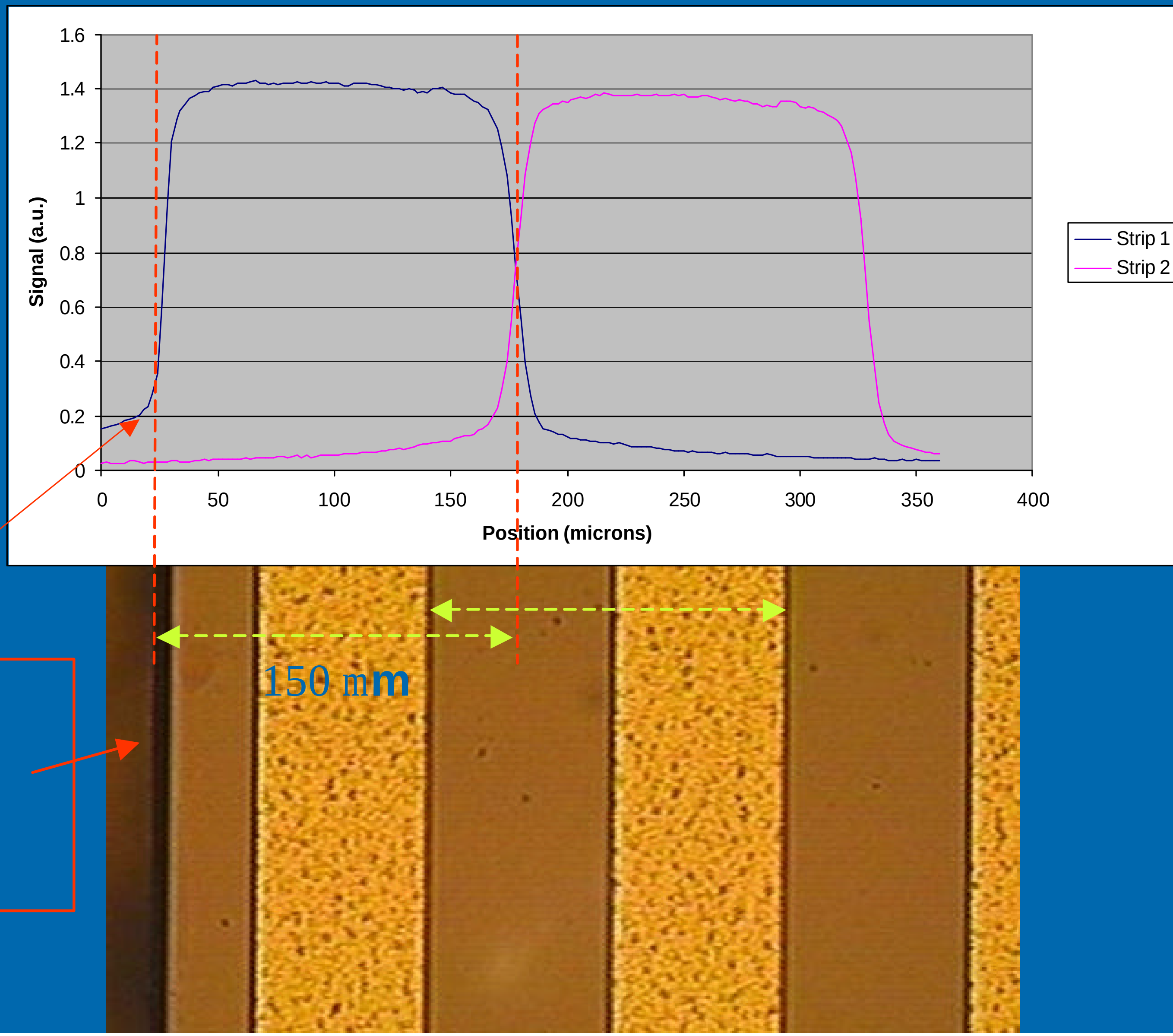
Fabrication

- ➢Use Support Wafer
- ➢No Sawing
- ➢Plasma Dice Instead
- ➢Dope and Grow Field Oxide on Edges
- ➢Otherwise same as Standard Planar



ALS X-ray microbeam signal on the IST and 2ND channels of a Active Edge planar detector

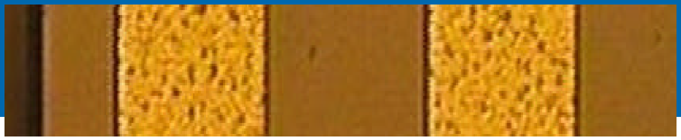
- **Current Integration Mode**
- **16 Strips**
- **150 mm Pitch**
- **100 mm thick**

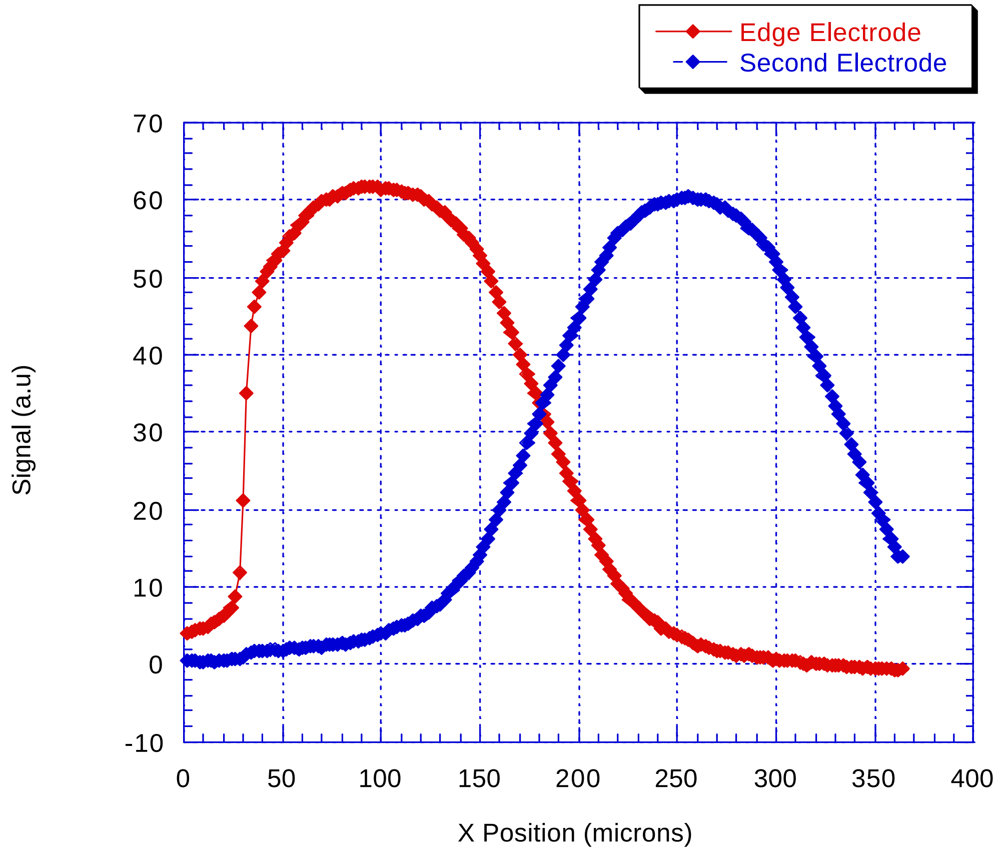


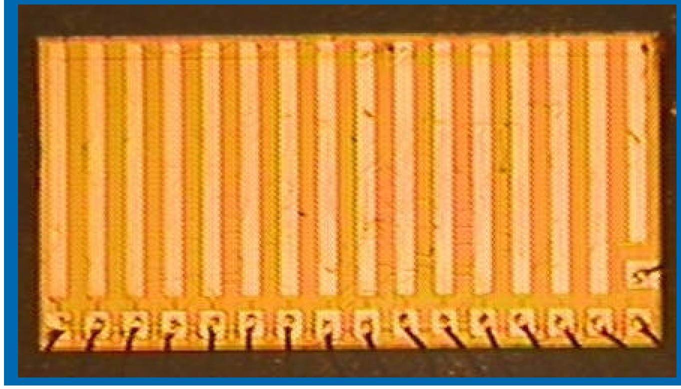
MEASURED DEAD EDGE < 5 μm

O Volts Bias

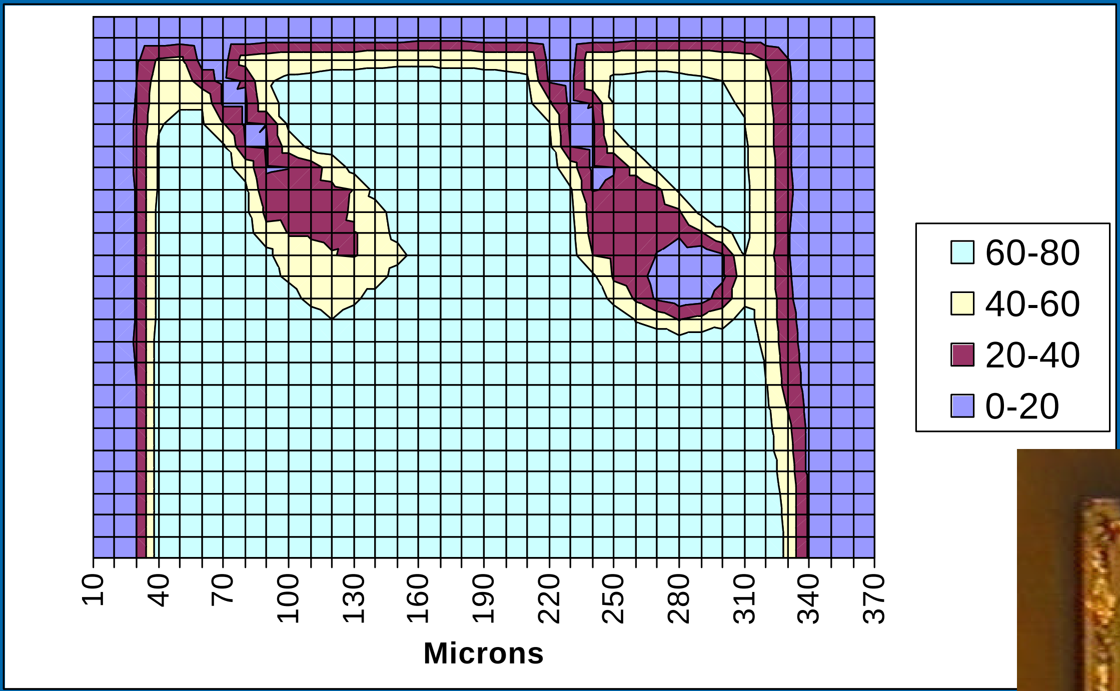
- Diffusion Paths 100 mm long
- Still 80% of Signal at Edge
- Low Trapping Probability
- Long Life times in Bulk



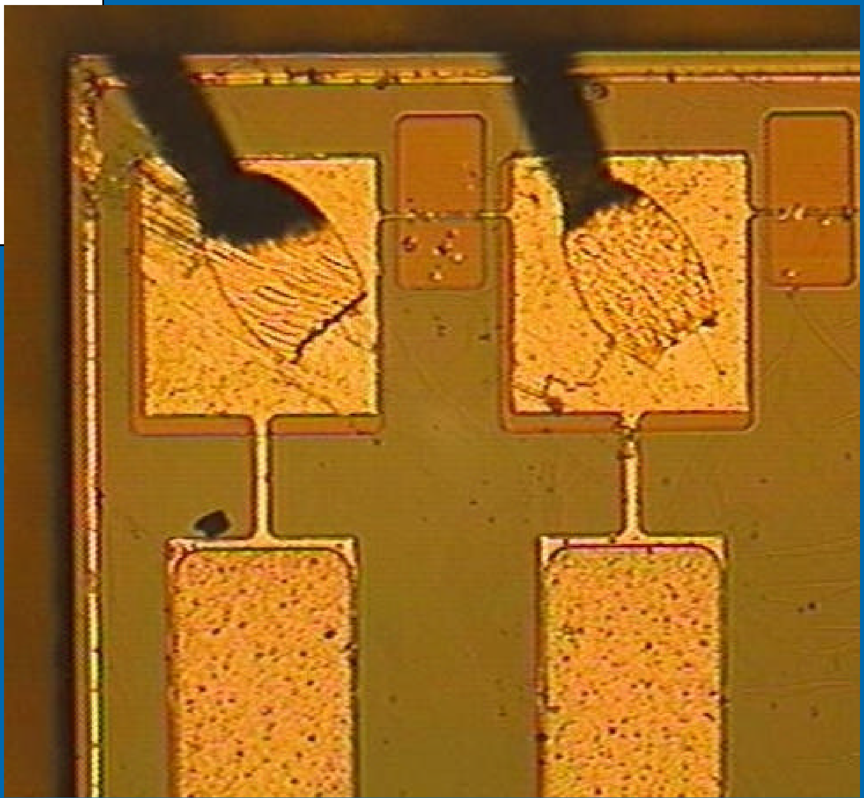




Wire Bonds



2 μm Grid



- Sensitive up to Edge
- Even With No Implant!

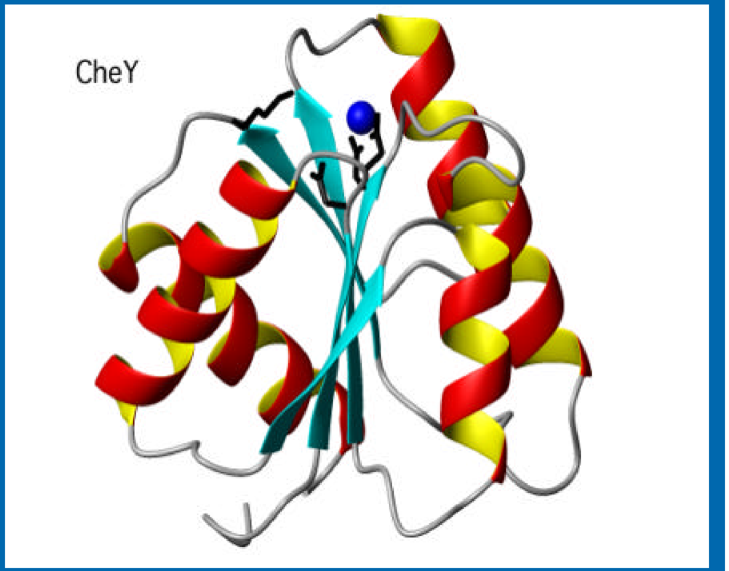
Benefits for Crystallography

Direct absorption in silicon:
Single X-photon sensitivity
(Pseudo) counting detector: dynamic range??

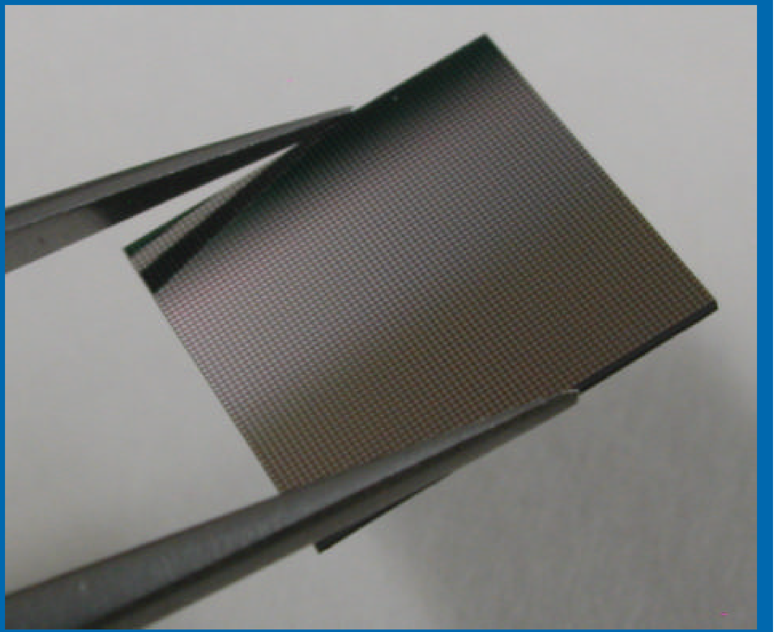
active edges => large area can be covered with small sensors (yield!) and with near zero insensitive border areas

Quasi-continuous readout with no deadtime (continuous spindle rotation?)

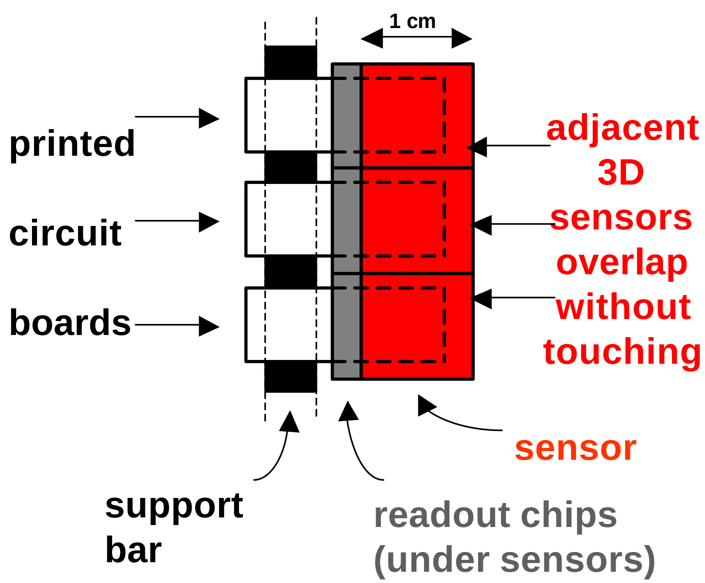
Single pixel spatial response (~100µm typical 'pixel' size)

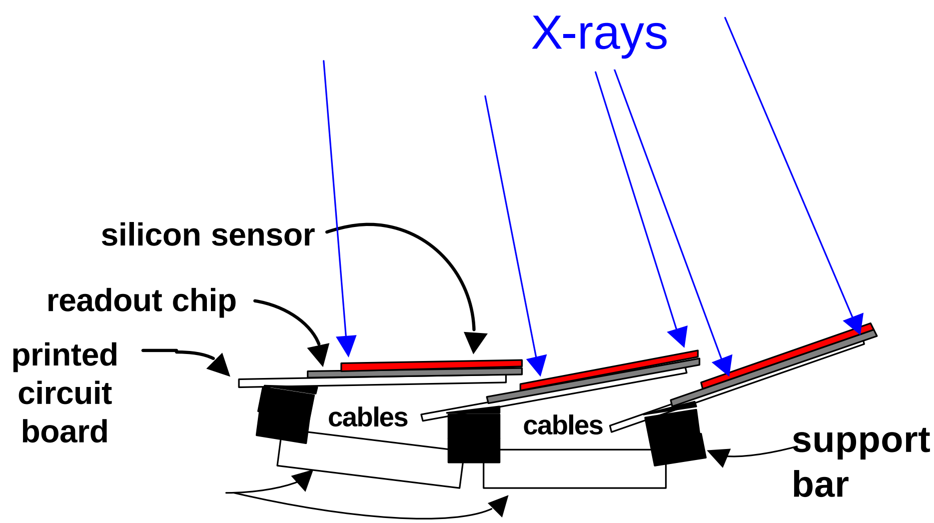


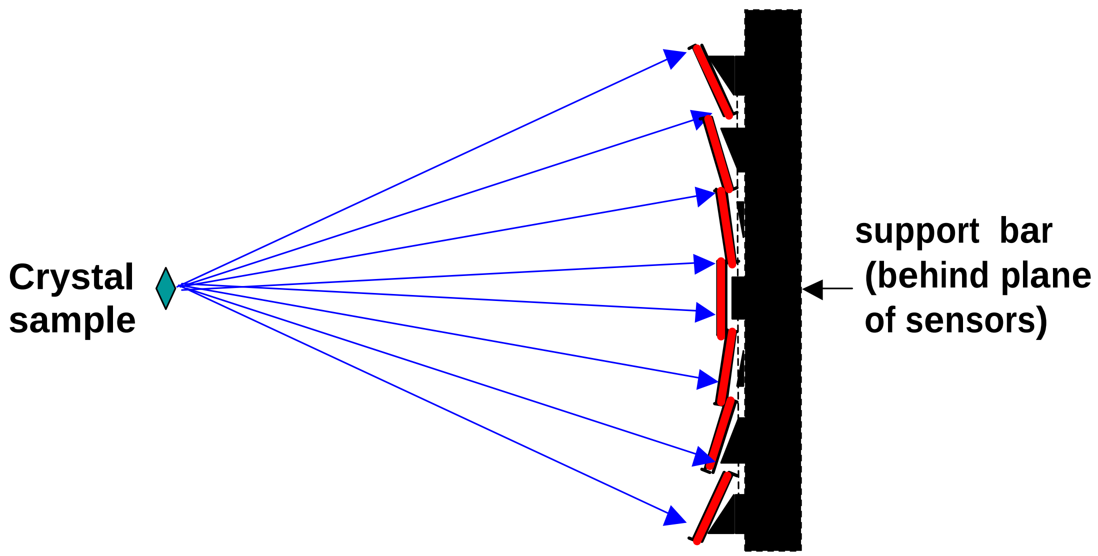
Courtesy of MBC
Phil Matsumura



System Geometry







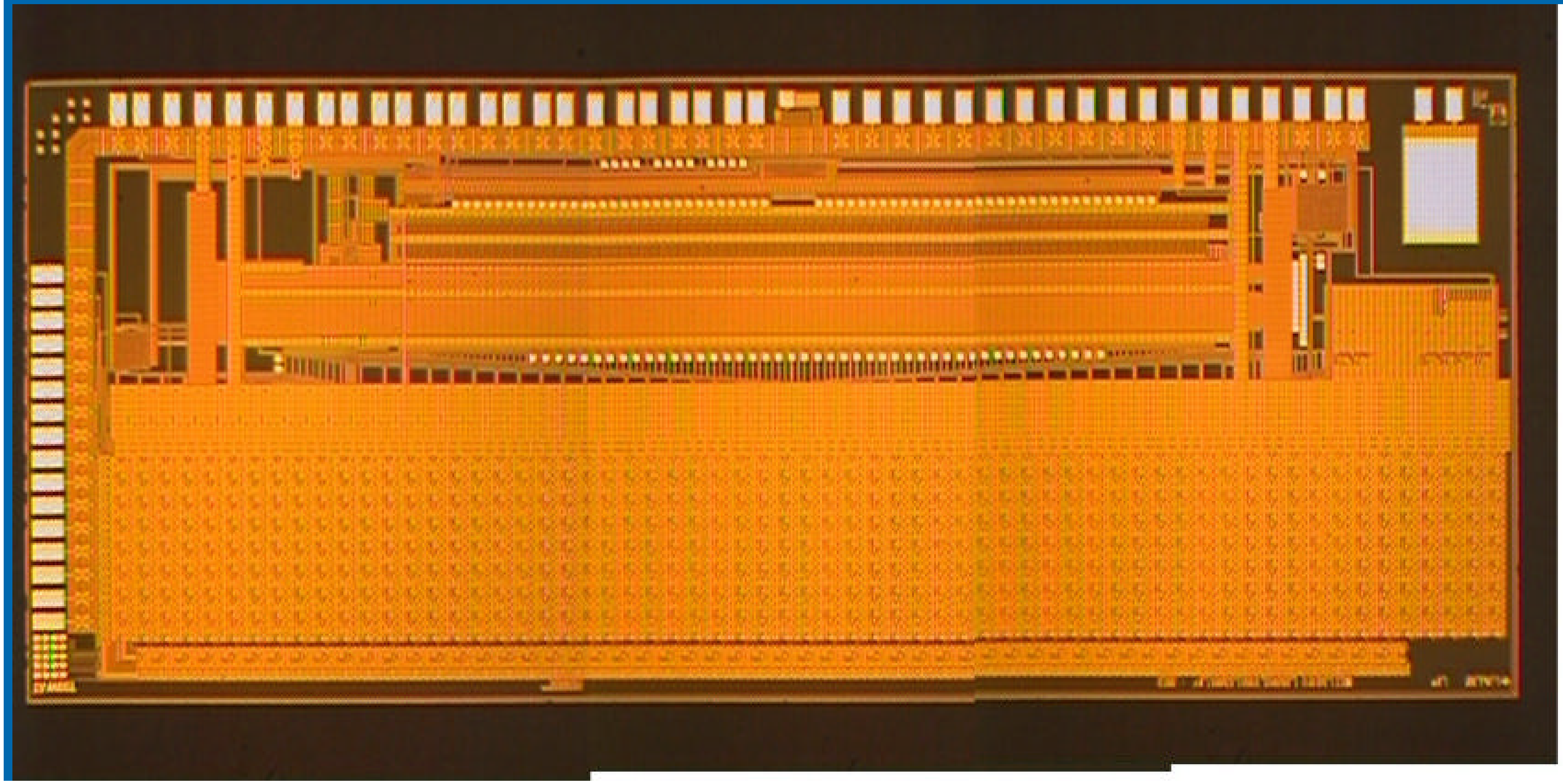
All X Rays are within 3 Degrees of Normal to the Sensors

ASIC Design

1. 64 x 64 pixels, each 150 µm x 150 µm.
2. Readout pixels are only 144 µm x 150 µm, keeping the readout chip fully under the sensor.
3. Each pixel has an integrating amplifier.
4. 2 rows are read out together, using 128 lines.
5. Integration resumes after 1 µs.
6. Pulse heights are digitized in a Wilkinson ADC.
7. Readout moves to next two rows after an additional µs.
8. Data is output to the computer from alternate buffers. The full sensor is readout every 64 µs.
9. Charge-shared signals can be recombined in the computer.
10. Small replaceable units for efficiency

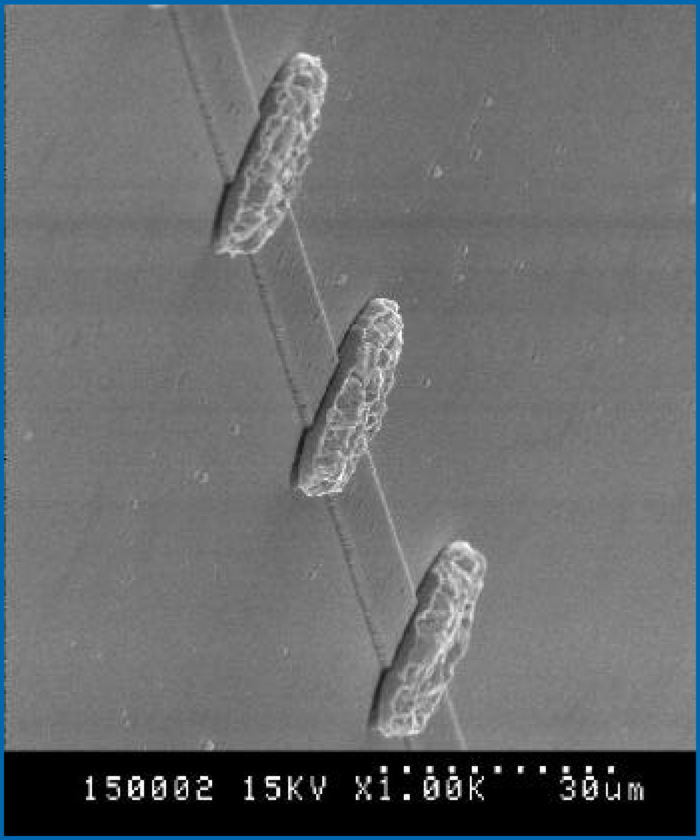
PXTAL ASIC

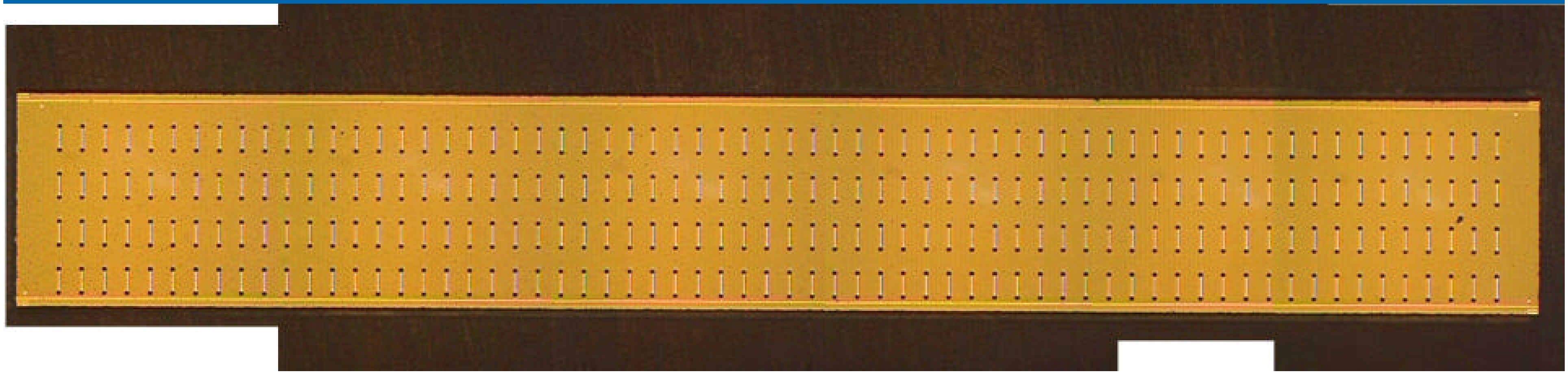
- 8 by 64 Pixel Array, plus Full-Size 9th Test Column
- 128 ADCs



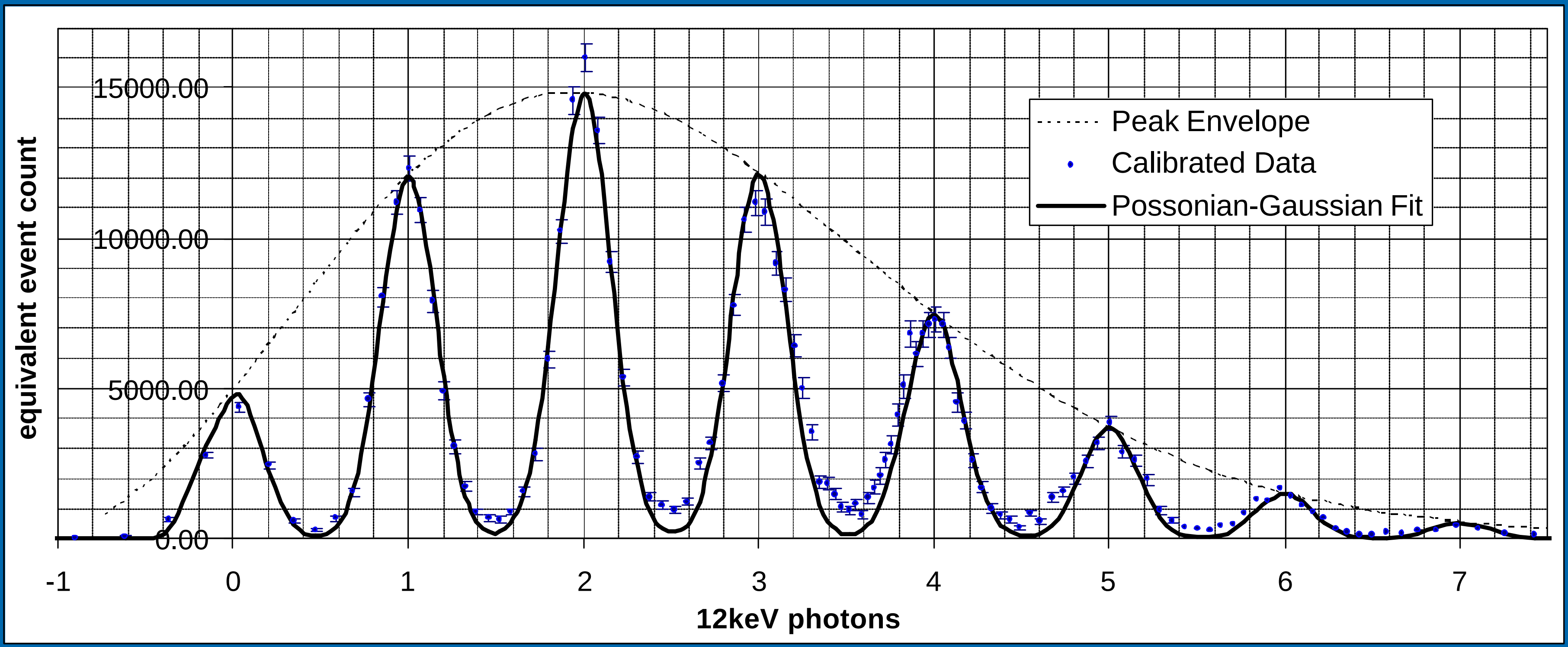
PXTAL Bumps

- Indium Bumps Deposited at Stanford
- Indium to Indium
- 4 mm Bump Height
- Flip-chip Bonding Done at Stanford



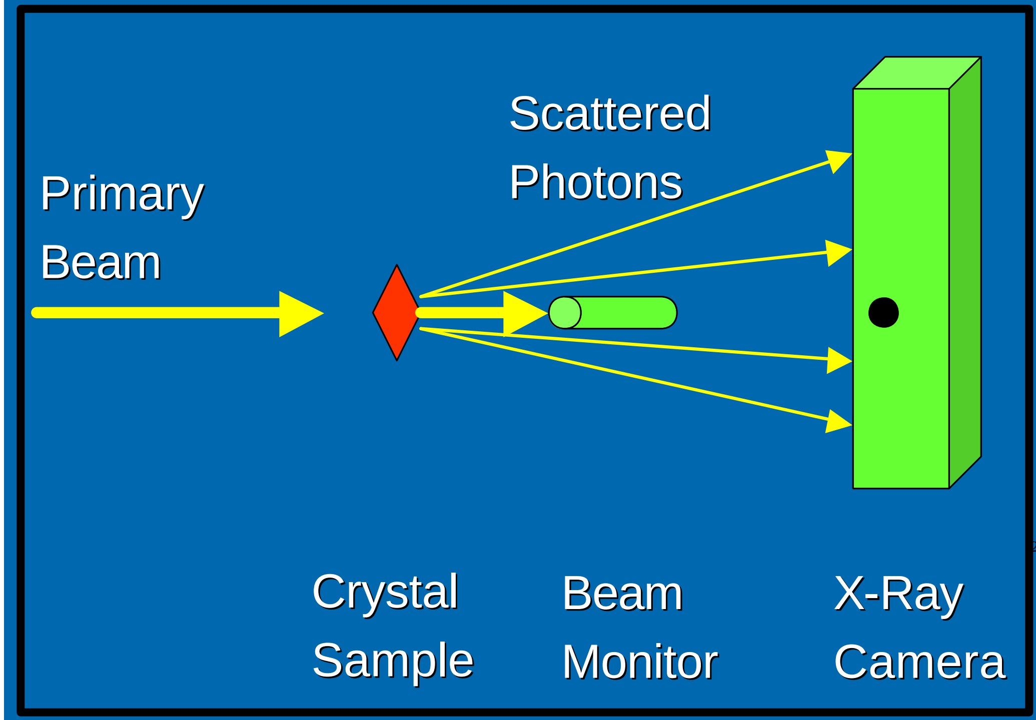


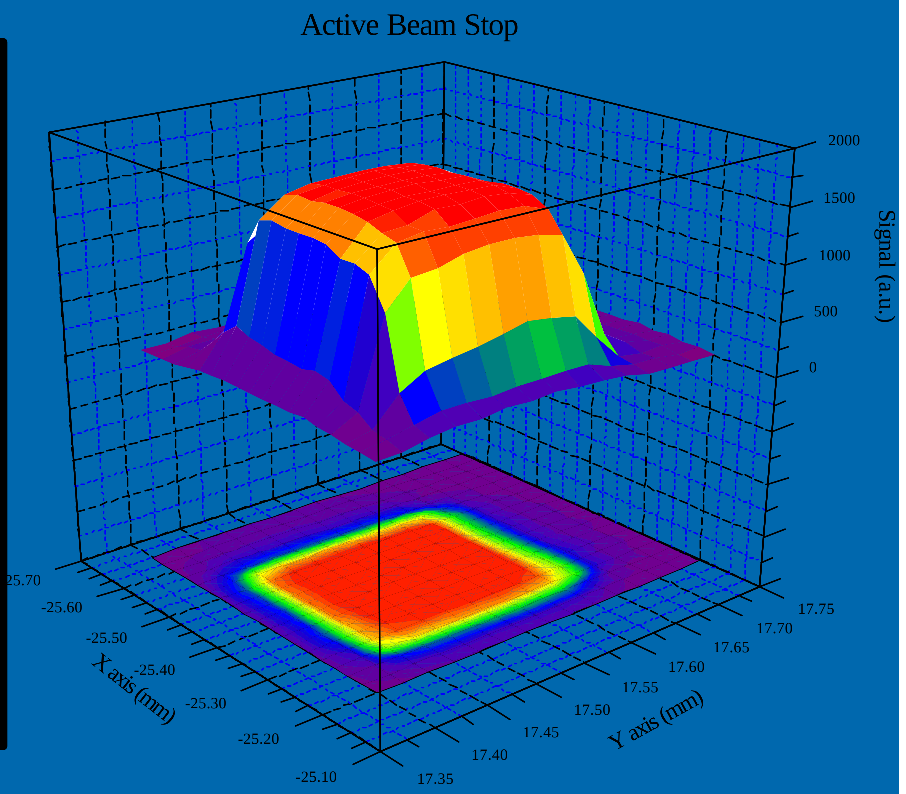
Photon Counting



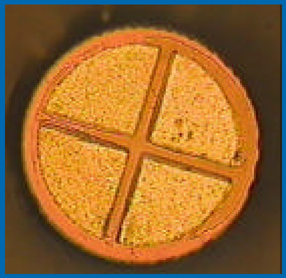
- Simultaneous Fit to All 8 Peaks
- Fit to Poisson Distribution Envelope

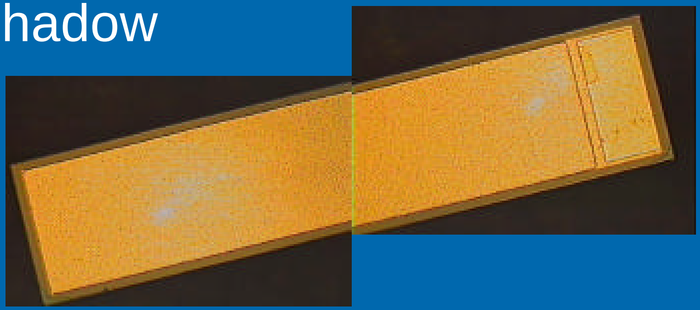
Active-Edge Beam Stops

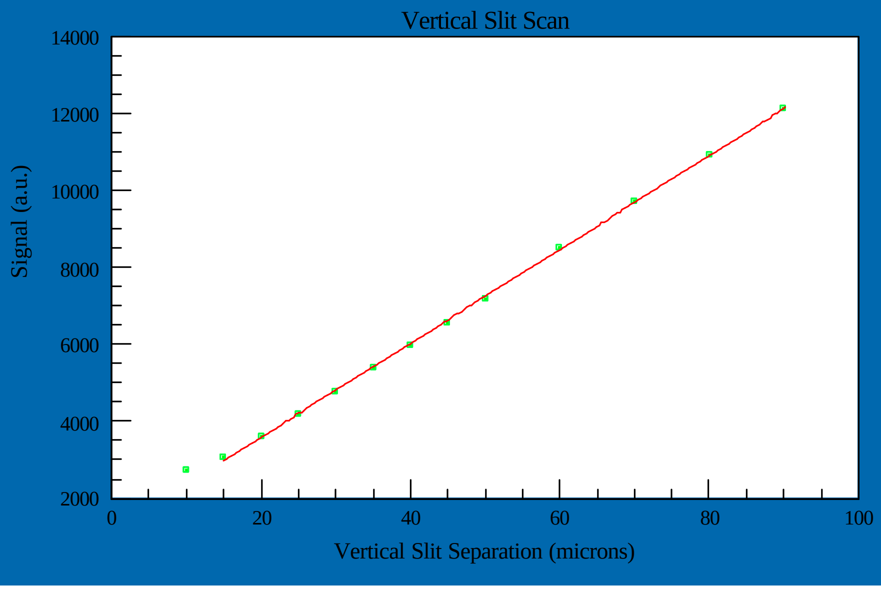




- All 6 Surfaces are Sensitive
- Square 220 μm Sides
- 3 – 10 mm Long
- Small Shadow
- Linear

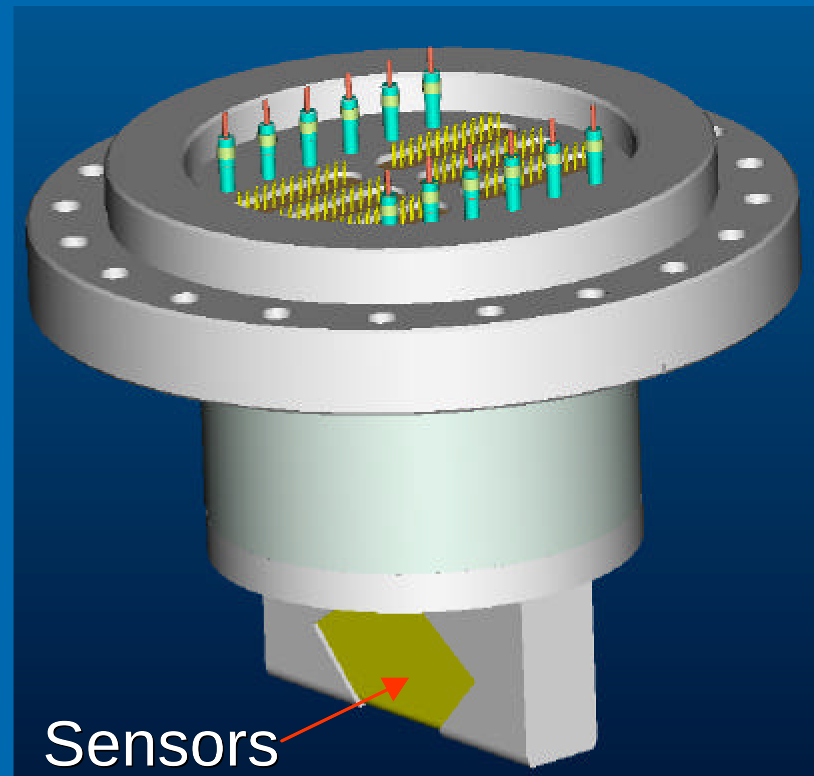


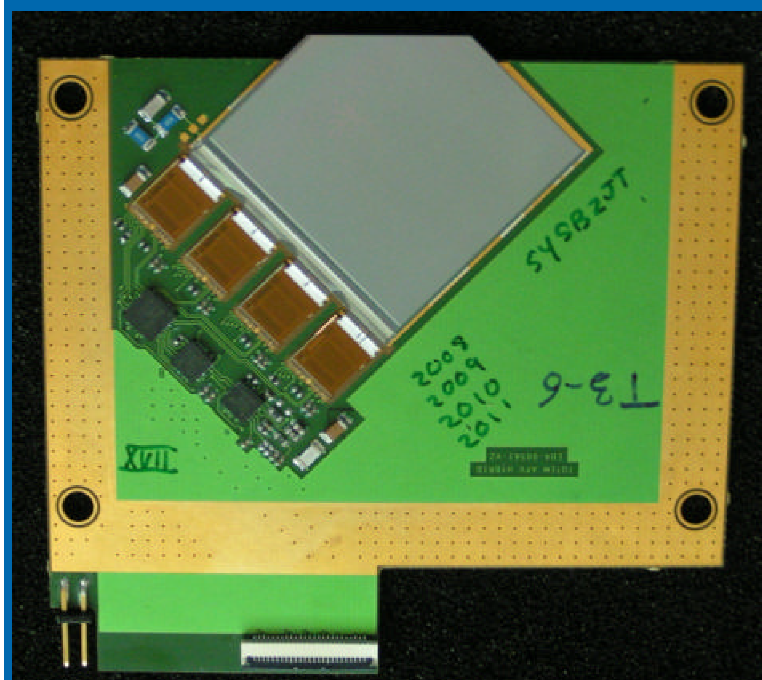




TOTEM

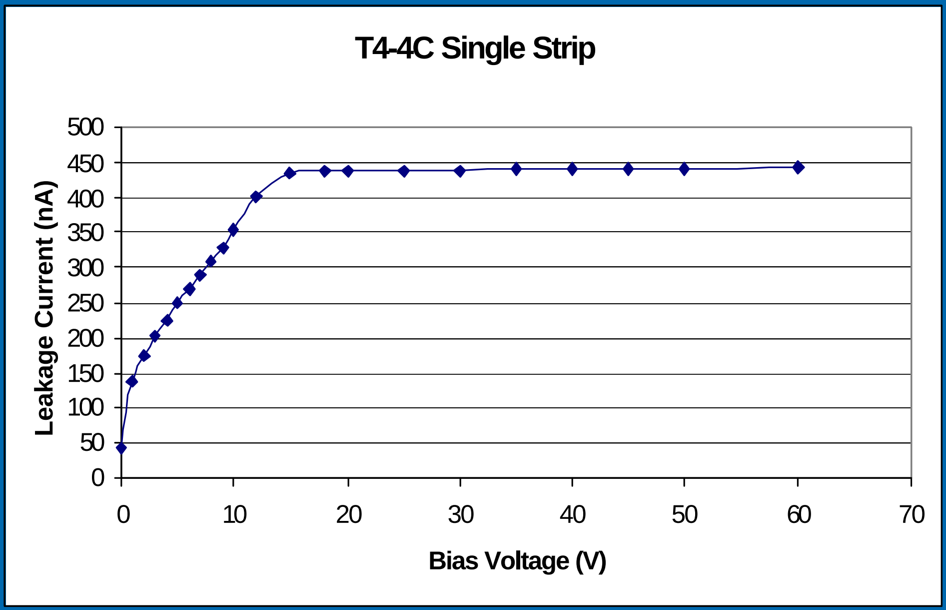
- LHC Experiment
- Roman Pots – 220 m from CMS
- Close to Beam
- Active Edge is Critical for Physics

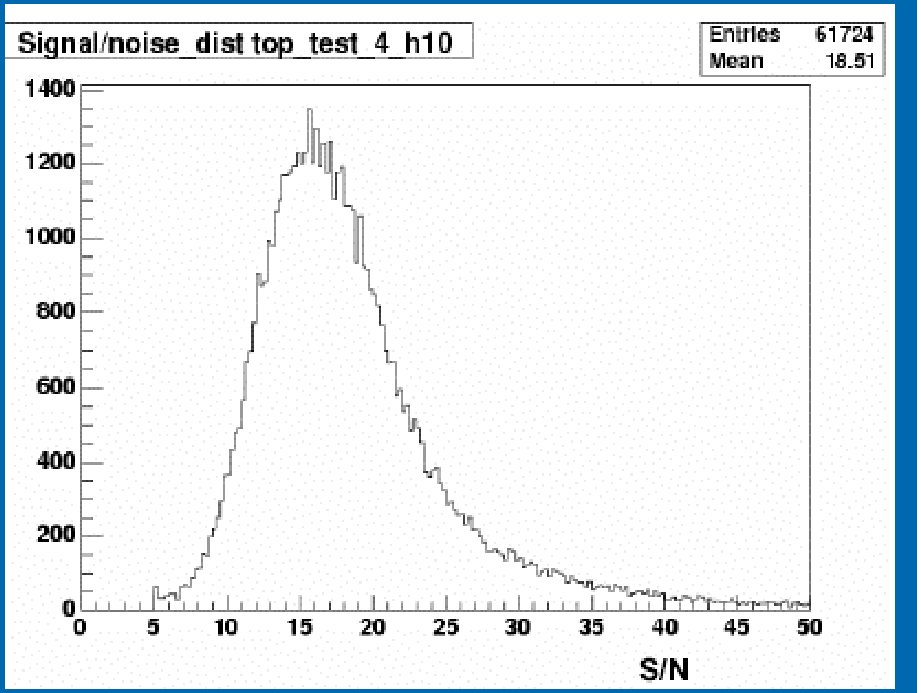


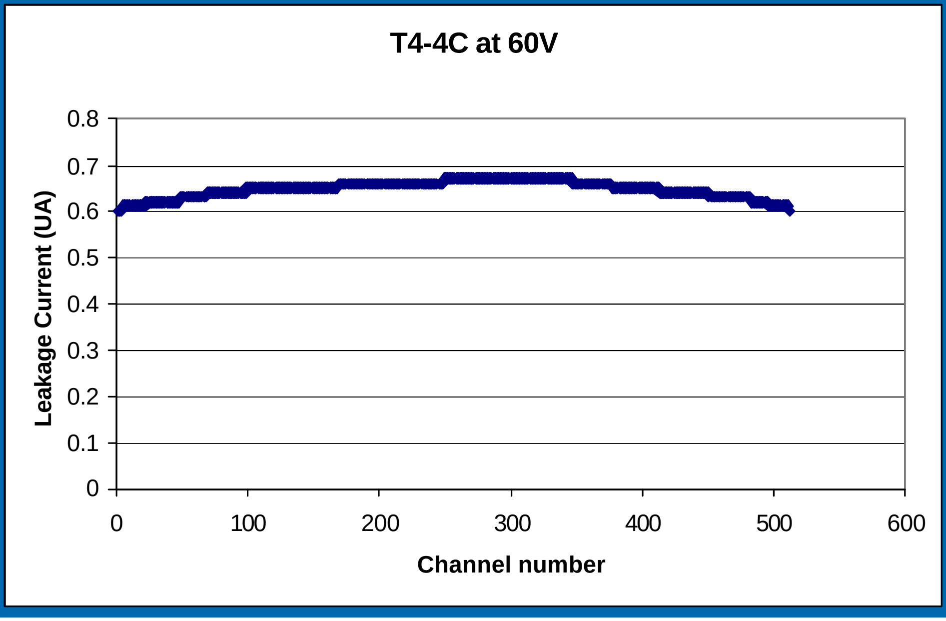


- Supplying Half of Sensors
- 10 cm^2 Sensors
- 120 Sensors

TOTEM SENSOR BEHAVIOR





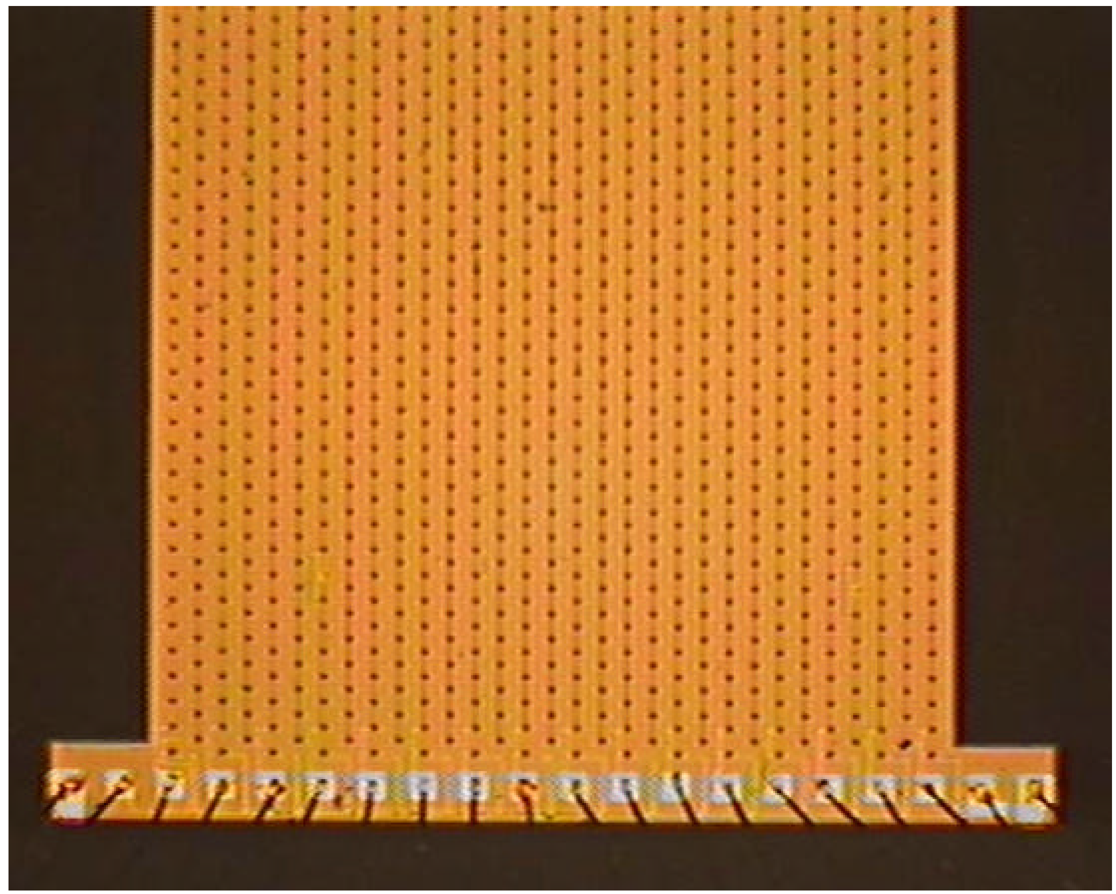


- NICE IV CURVE
- NO EXCESS EDGE CURRENT
- NORMAL LANDAU

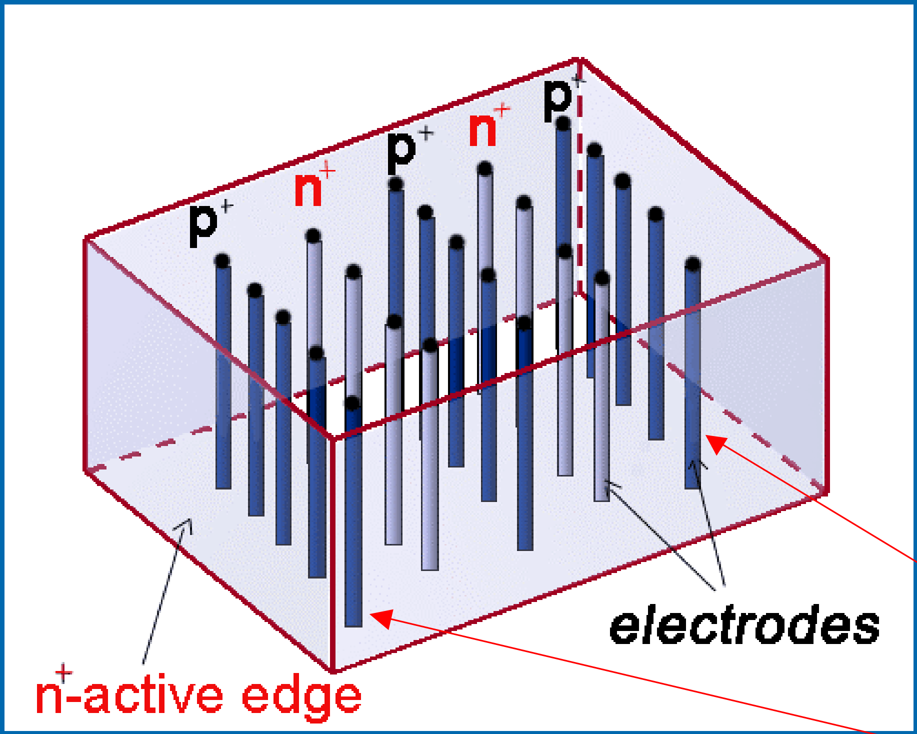
3D with Active Edges

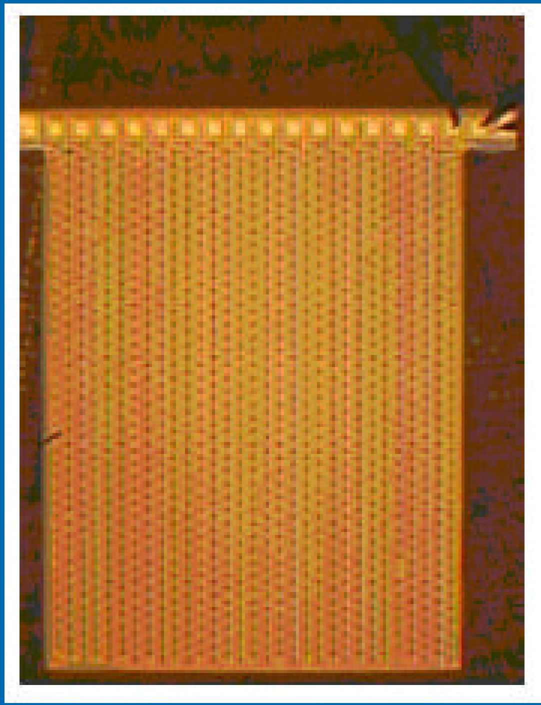
- No Guard Rings
- No Dead Area at Edges
- Allows Seamless Tiling
- Edge is an Electrode
- Efficient Wafer Use

- **200 mm pitch**
- **16 Strips**
- **180 mm thick**



3D Active Edge





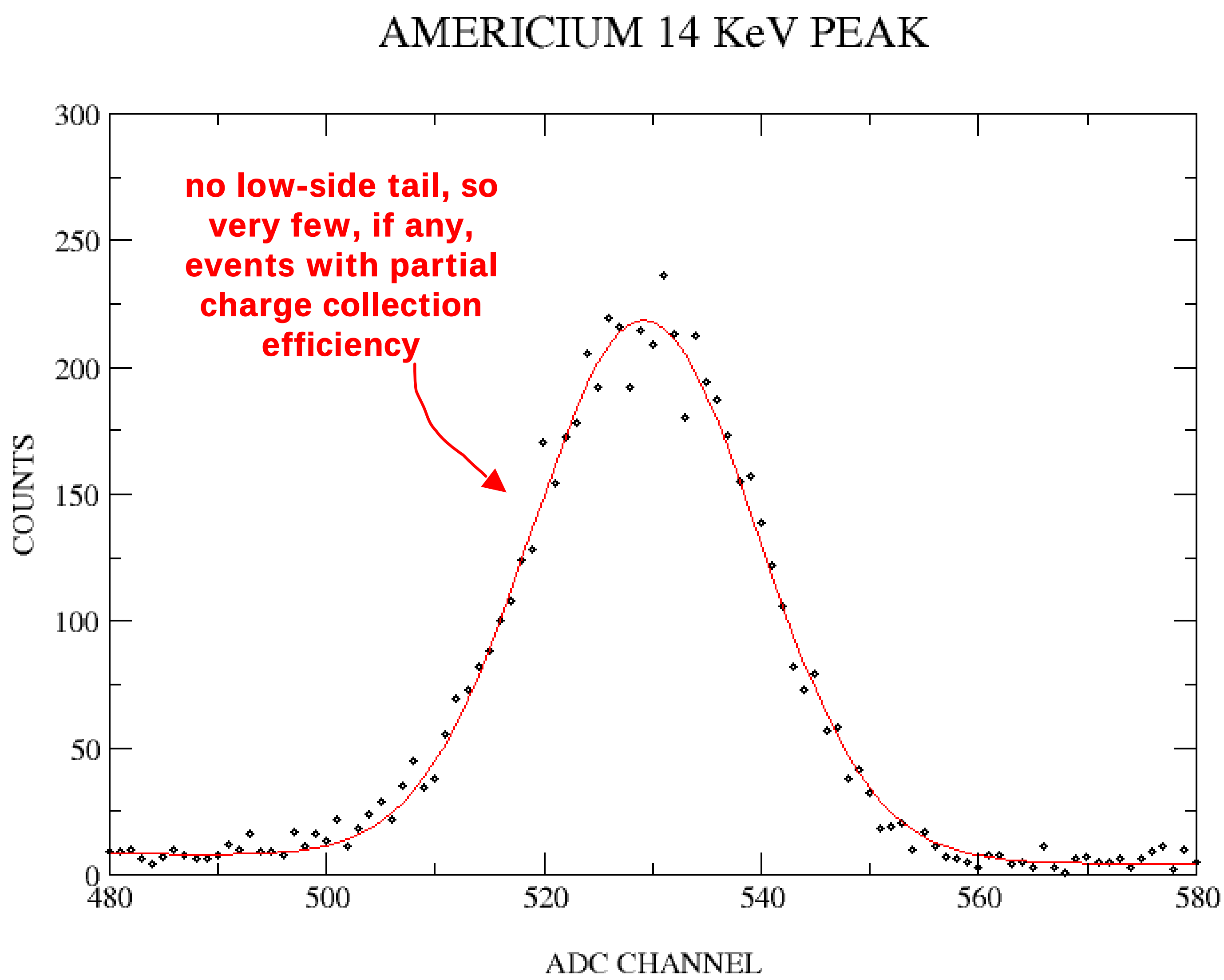
1. NIMA 395 (1997) 328
2. IEEE Trans Nucl Sci 464 (1999) 1224
3. IEEE Trans Nucl Sci 482 (2001) 189
4. IEEE Trans Nucl Sci 485 (2001) 1629
5. IEEE Trans Nucl Sci 48 6 (2001) 2405
6. CERN Courier, Vol 43, Jan 2003, pp 23-26
7. NIMA 509 (2003)86-91

3D silicon detectors were proposed in 1995 by S. Parker, and active edges in 1997 by C. Kenney.

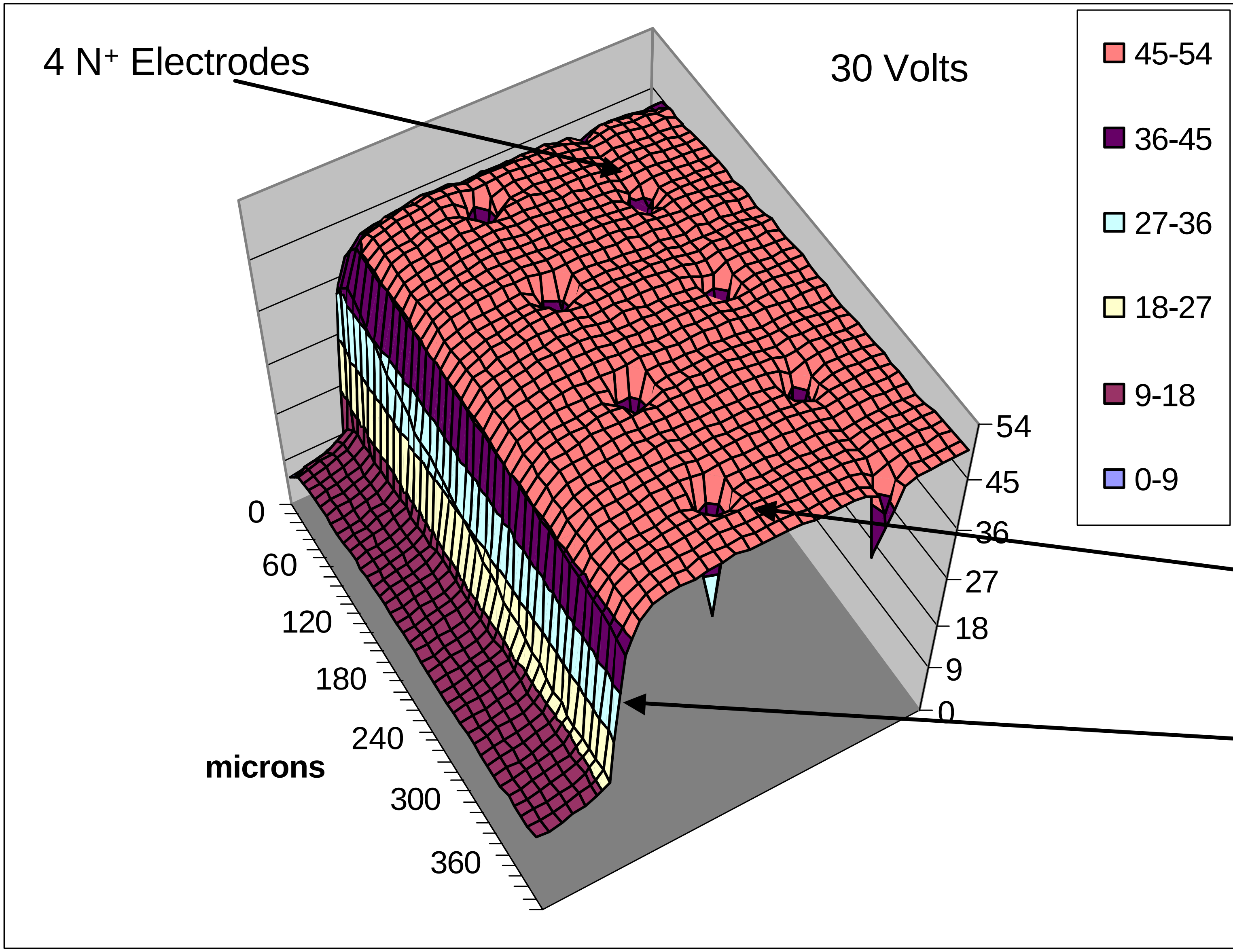
Combine traditional **VLSI** processing and **MEMS** (Micro Electro Mechanical Systems) technology.

Electrodes are processed inside the detector bulk instead of being implanted on the Wafer's surface.

The edge is an electrode! Dead volume at the Edge < 2 microns! Essential for
-Large area coverage
-Forward physics


AMERICIUM 14 KeV PEAK
no low-side tail, so very few, if any, events with partial charge collection efficiency
COUNTS
ADC CHANNEL
0
50
100
150
200
250
300
480
500
520
540
560
580

3D Active Edge Scan



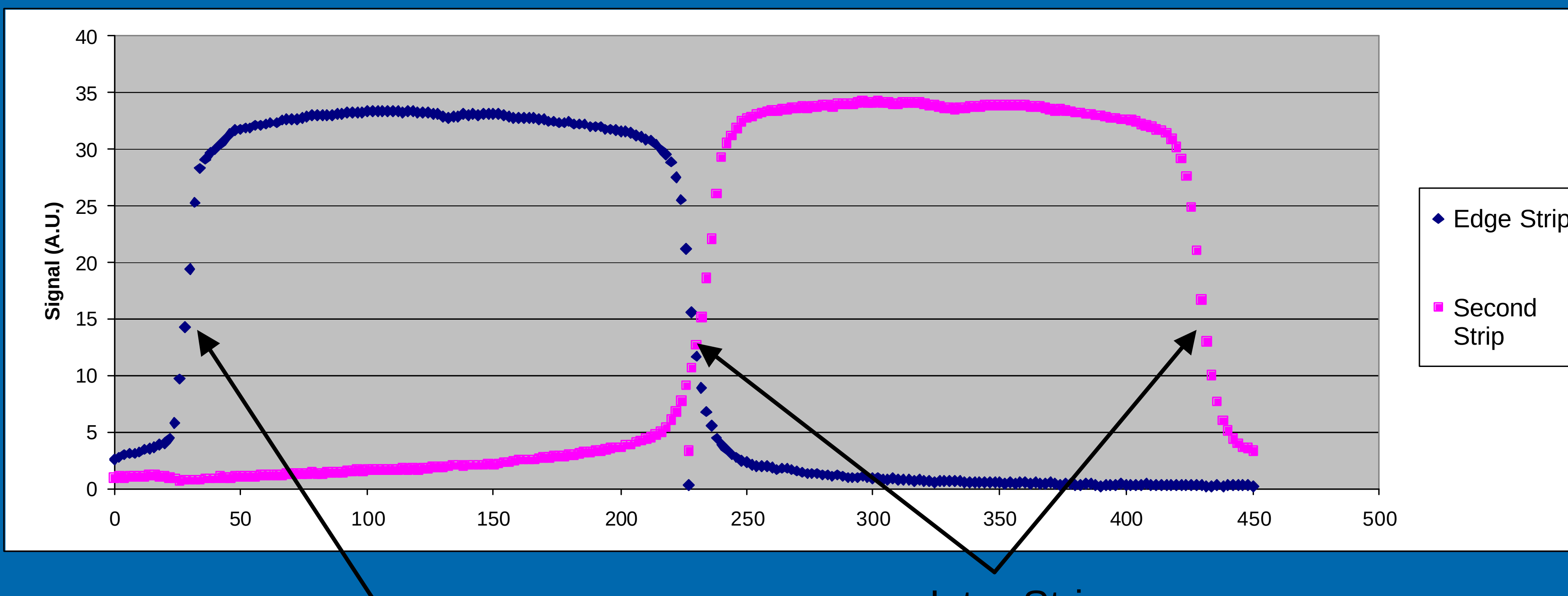
Sensitive to Within 2 mm of Edge!

Based on Full-Width at Half Maximun

Drawn Strip Pitch = 200 mm

Measured InterStrip Pitch = 199 +/- 2 mm

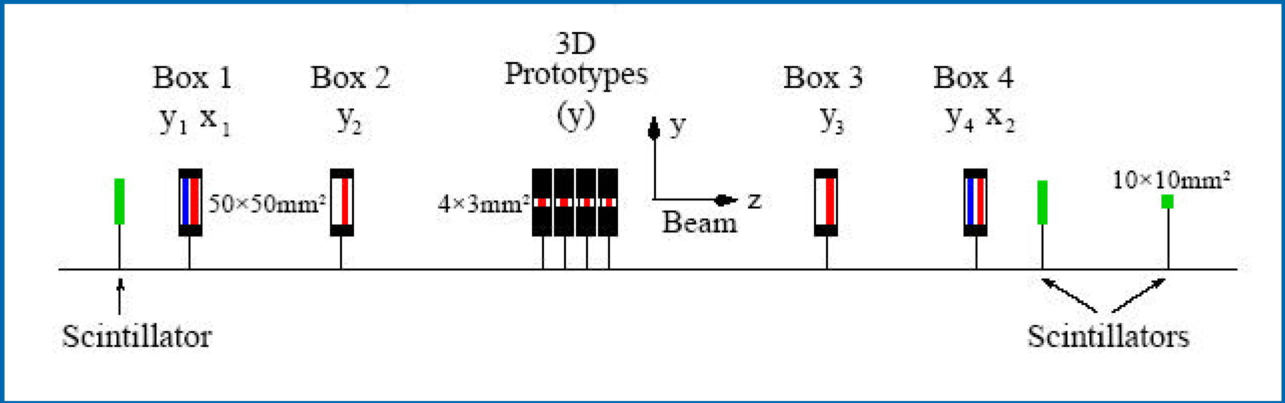
Measured Edge Strip Width = 200 +/- 2 mm



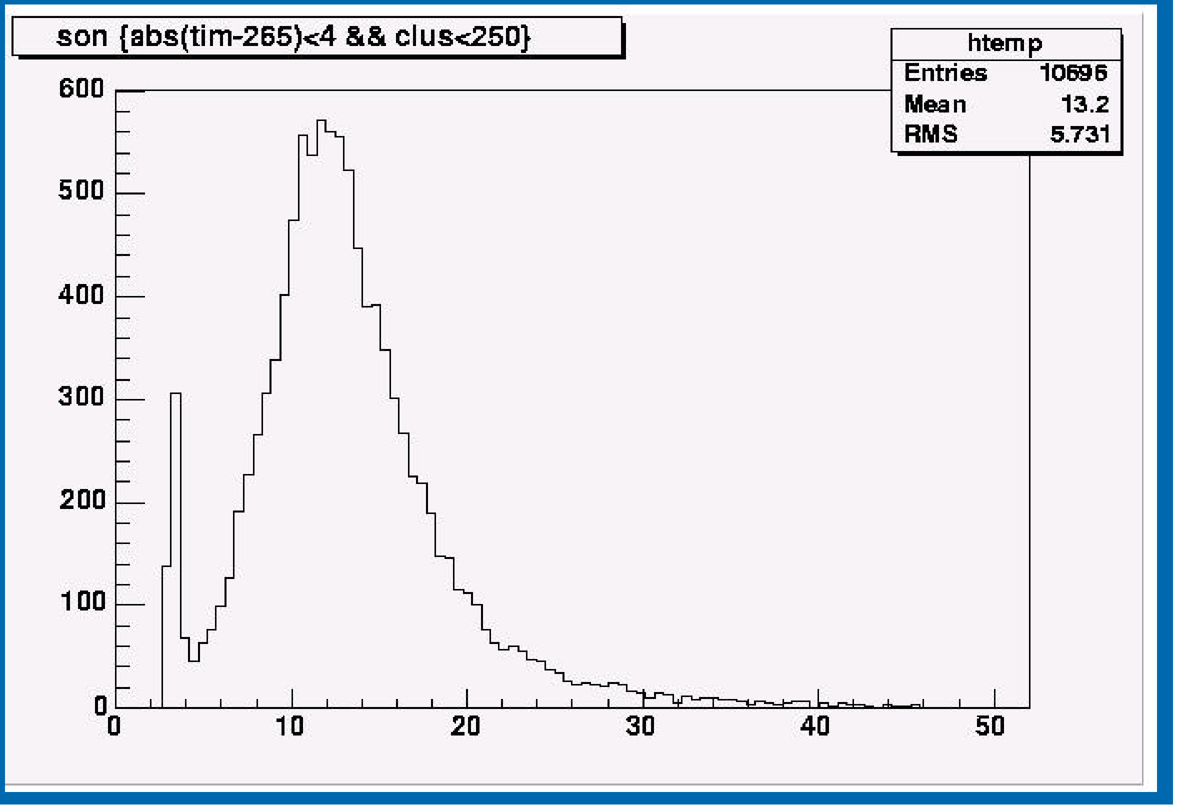
EDGE

Inter-Strip Boundary

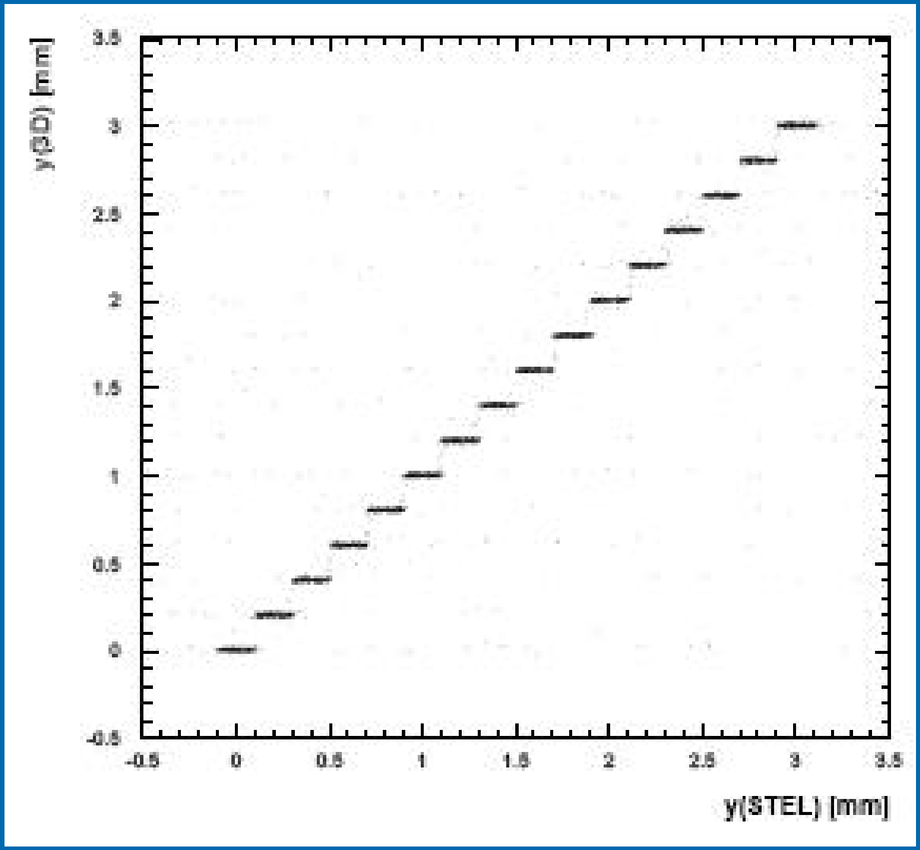
X5 test beam at CERN



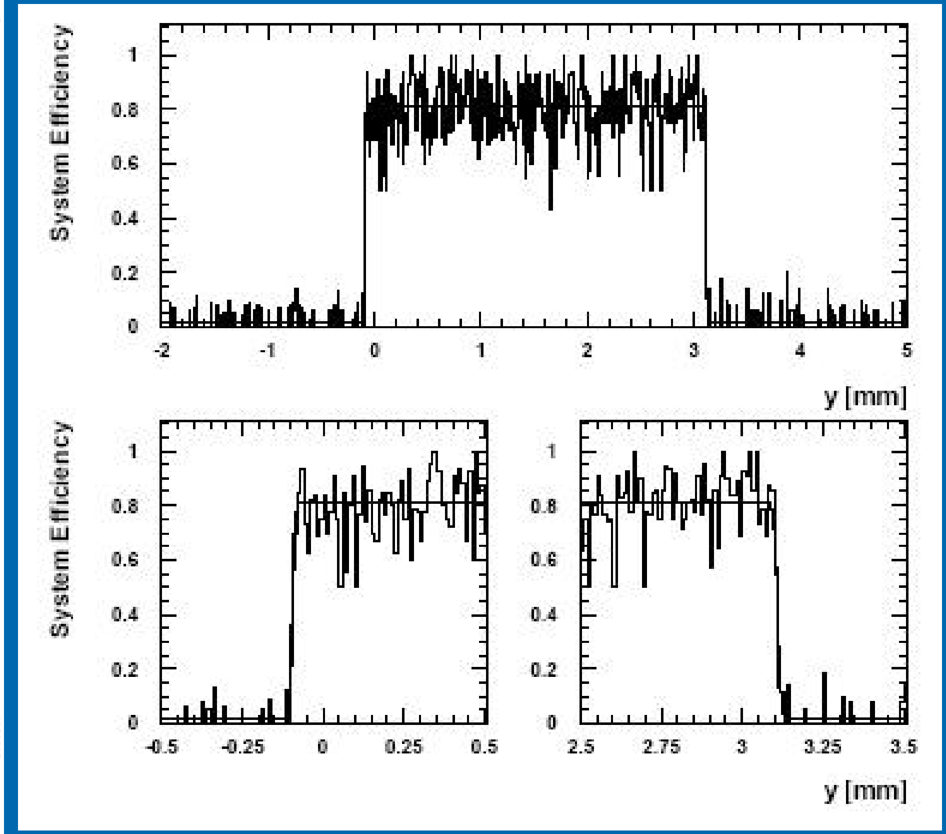
- 3D
- Active Edge
- 180 µm Thick
- 16 Strips
- 100 GeV Muons
- 5 µm Telescope



Some results from the CERN X5 beam test (100 GeV muons)



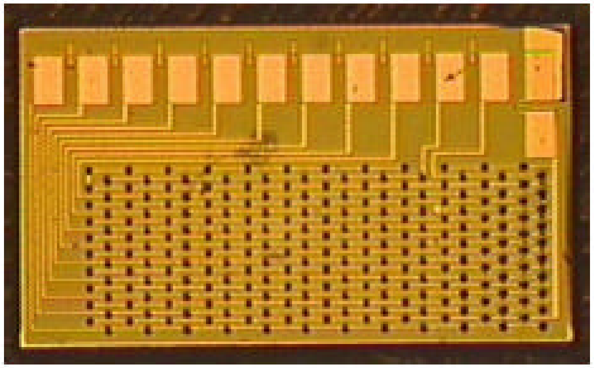
Measured hit position in 3D sensor plane #3 vs. predicted position from beam telescope.



Fitted 3D sensor width = 3,203 ±4µm. Drawn width = 3,195 µm. Sensor efficiency = 98%. System efficiency less due to DAQ, triggering electronics.

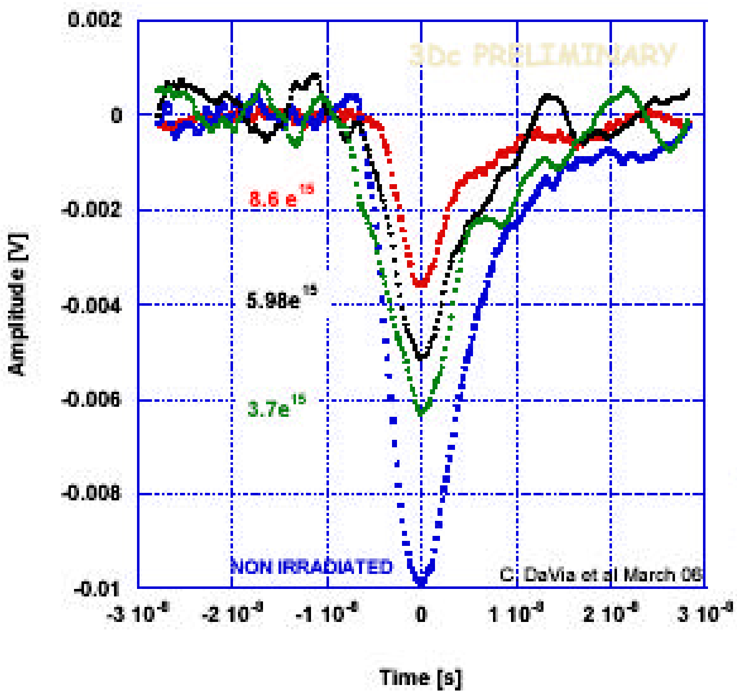
3Dc Radiation hardness tests

Volume = 1.2 x 1.33 x 0.23 mm³
Inter-electrode spacing = 71 µm
n-electrode readout
n-type before irradiation

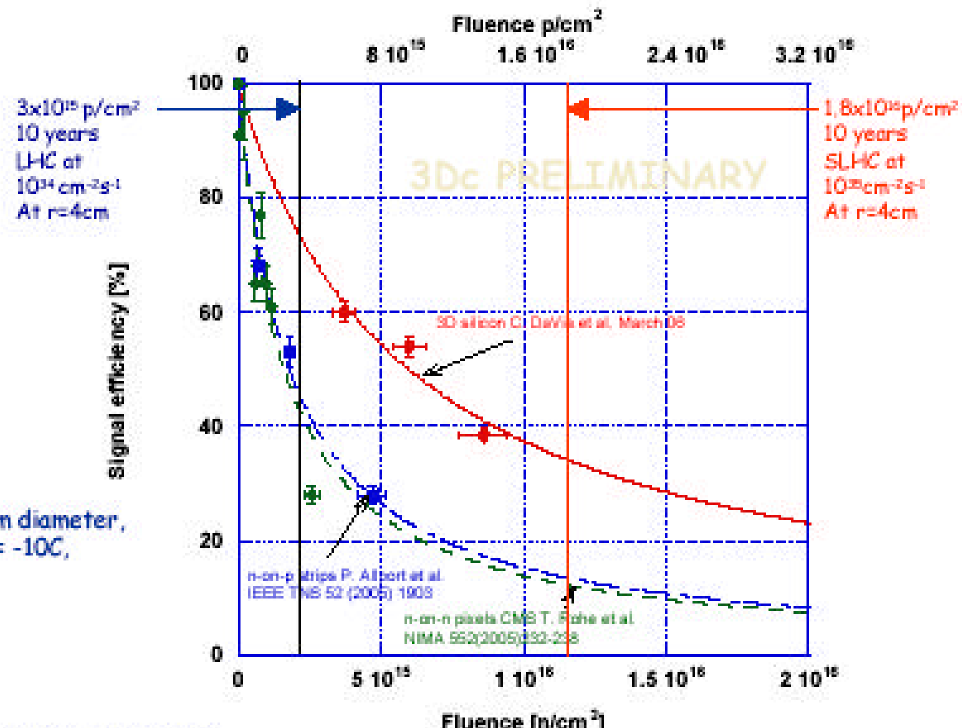


- 50 µm pitch pixels
- Different fluences Highest beyond 10^{16}p/cm²

Name	Fluence n_{1MeV}/cm^2	Fluence p/cm^2
7F	3.74e15	6.0e15
7A	5.98e15	9.6e15
7D	8.60e15	1.4e16



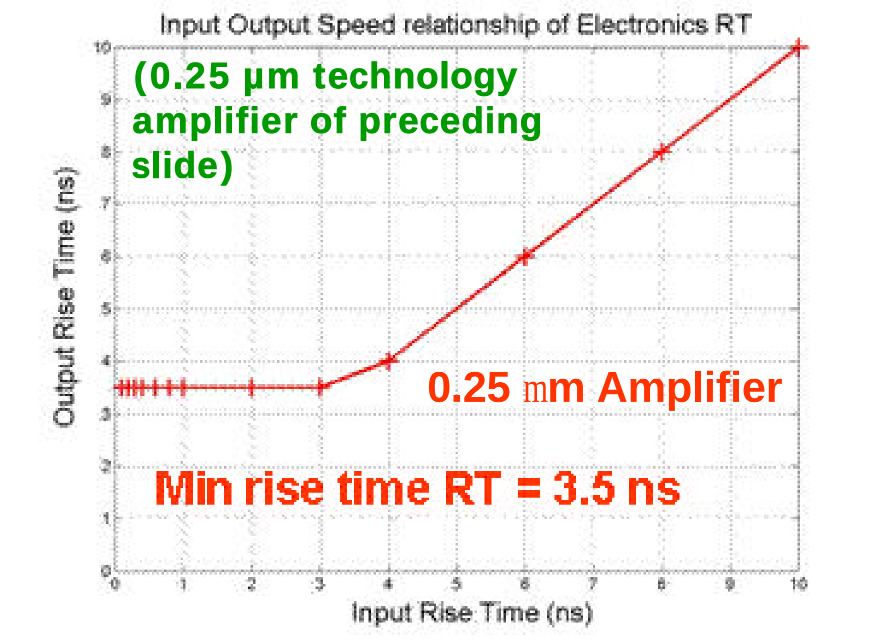
1060 laser beam
Spot size = 500 µm diameter,
1000 averages, T = -10C,
Ampli-gain=1000

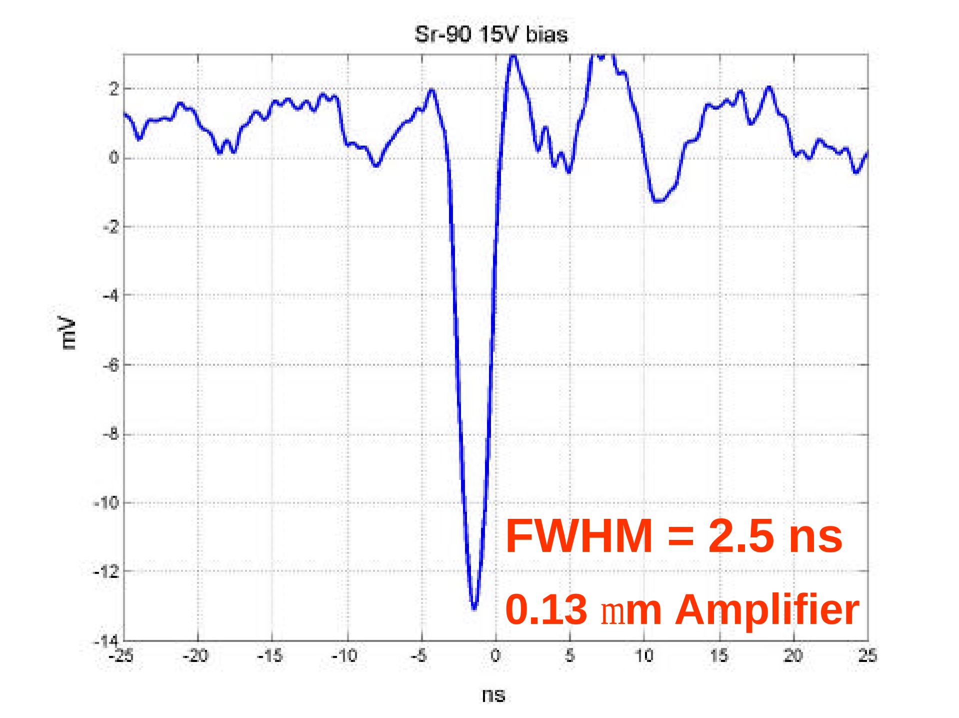


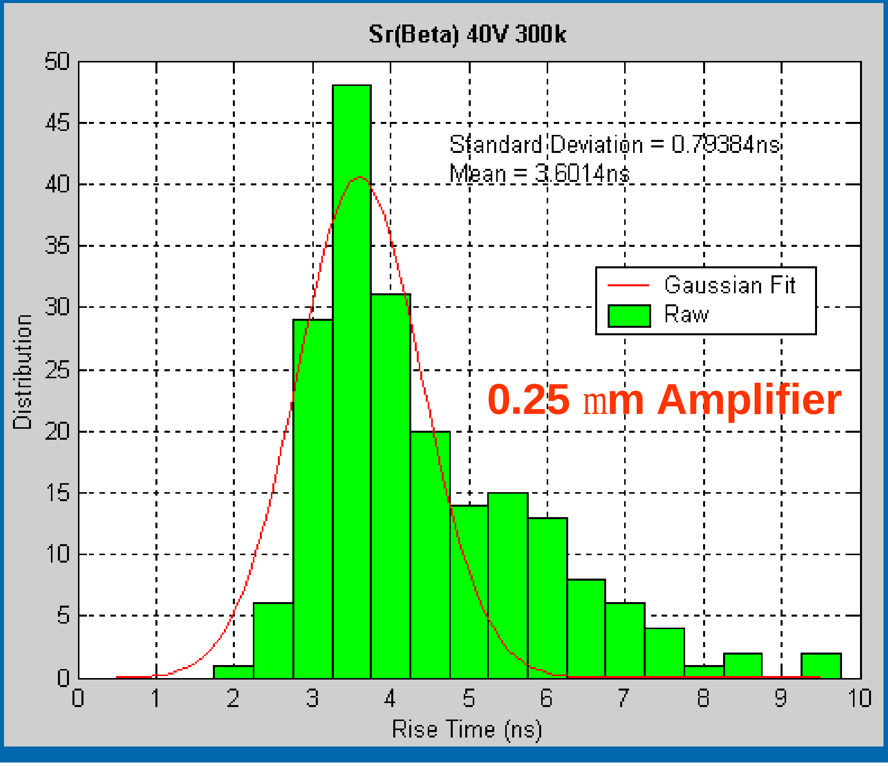
3D TIMING

- 0.25 micron amplifier and
- Response of sensor same as pulser

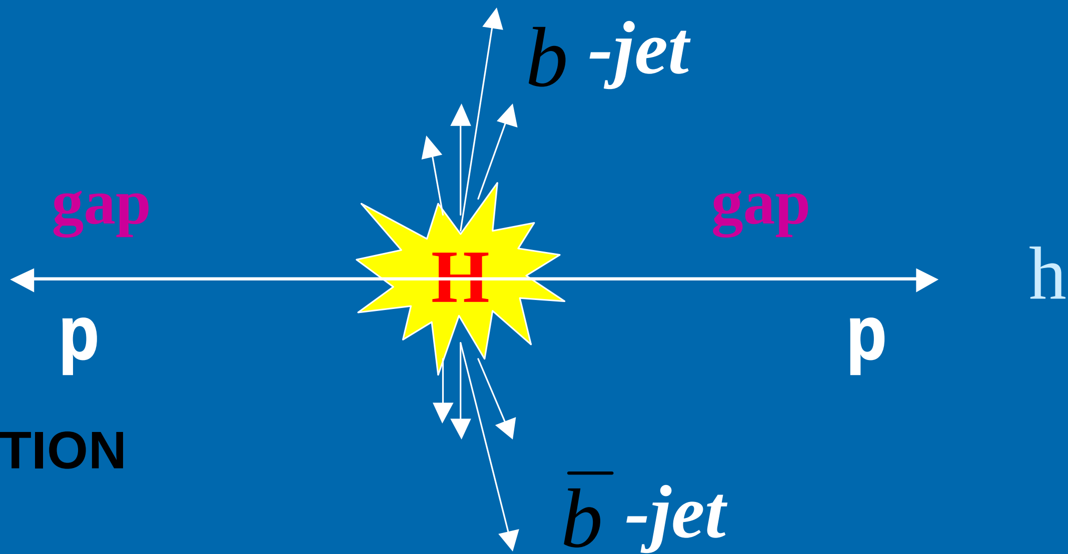
- 0.13 micron amplifier and 100 micron “diameter” hexagon/strip





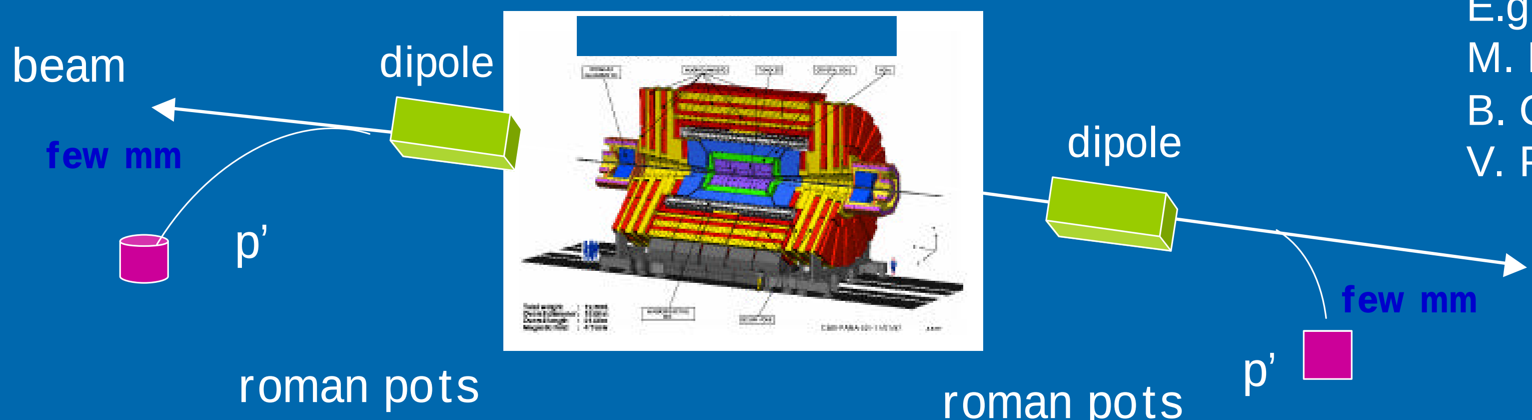


FP420 – Forward Physics at 420 meters

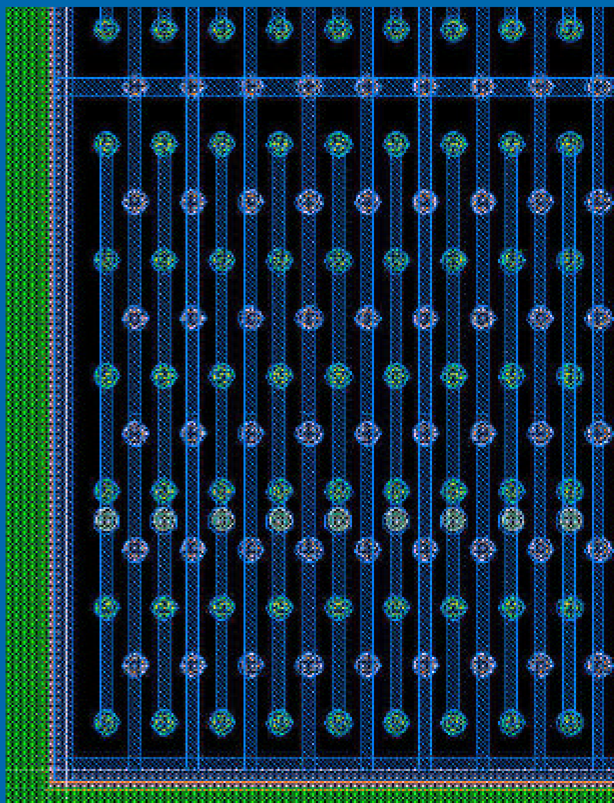


- **DIFFRACTIVE PHYSICS**
- **GOOD MASS RECONSTRUCTION**
- **AUGMENT CMS & ATLAS**
- **UP/DOWNSTREAM of ATLAS & CMS**
- **INSTALLED IN ROMAN POTS**

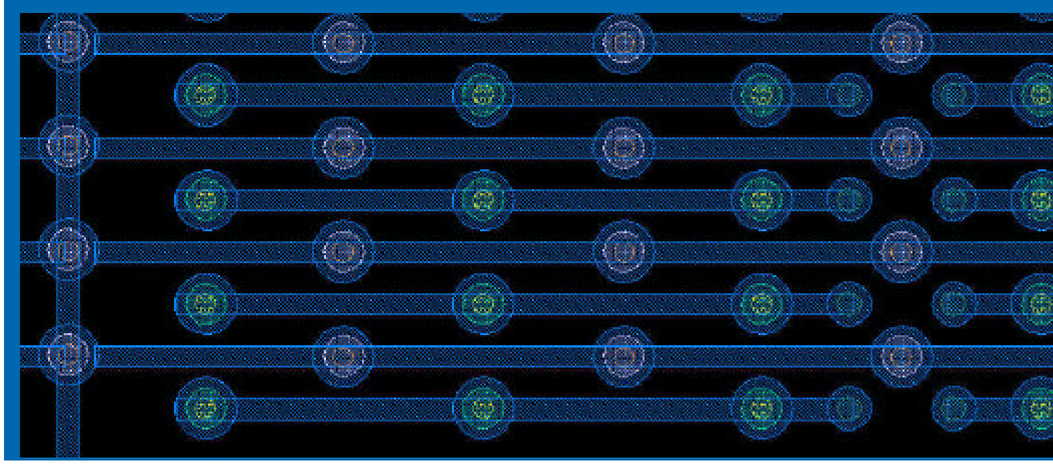
Albert De Roeck
Mike Albrow
PHYSICS:
E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al.
V. Petrov et al…



SENSORS



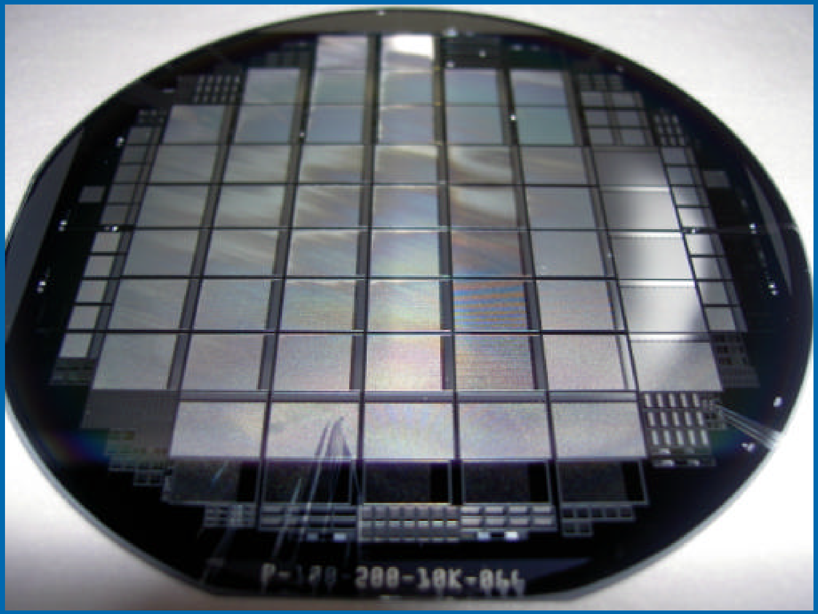
- **ACTIVE EDGES for PHYSICS ACCEPTANCE**
- **3D for RADIATION DAMAGE**
- **PIXELS for MOMENTA RECONSTRUCTION**
- **PIXELS for OCCUPANCY**
- **200 μm THICK**
- **50 μm by 400 μm PIXELS**
- **ROTATE SENSORS for X & Y**
- **OFFSET PLANES σ < 10 μm**

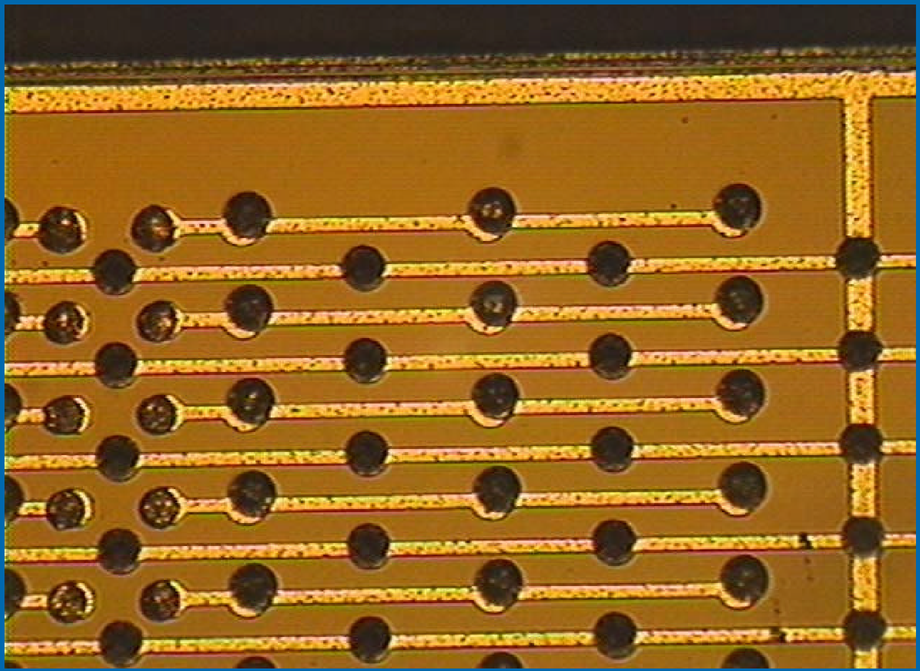


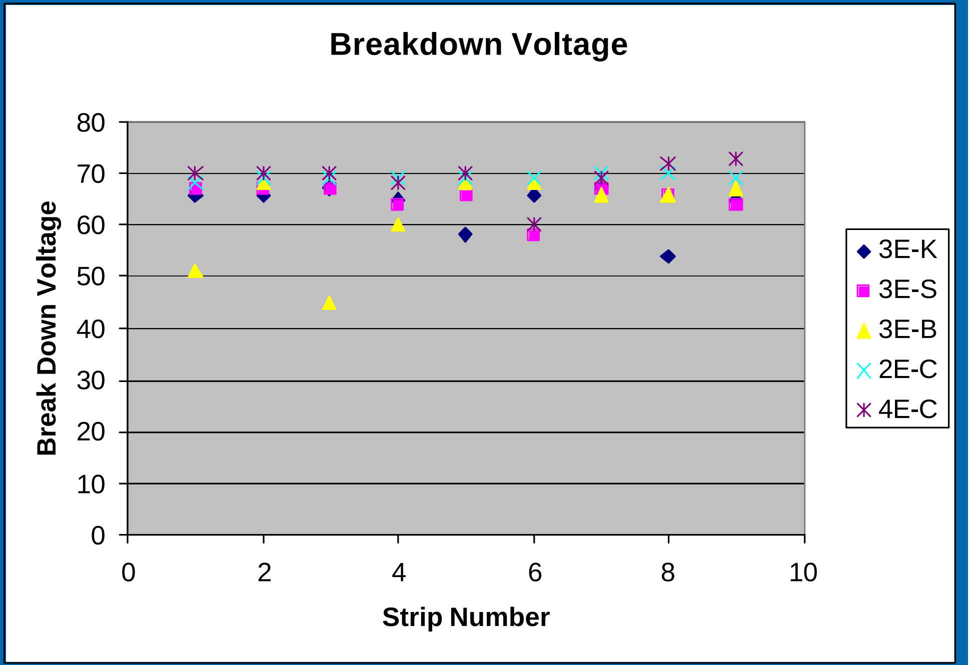
	2E	3E	4E
Electrode Area (%)	4	6	8
Depletion Distance (microns)	100	70	50

Cell Design

- Single Sensor Yield > 50 %
- Breakdown Independent of Electrode Spacing
- Active Edges Robust against Breakdown

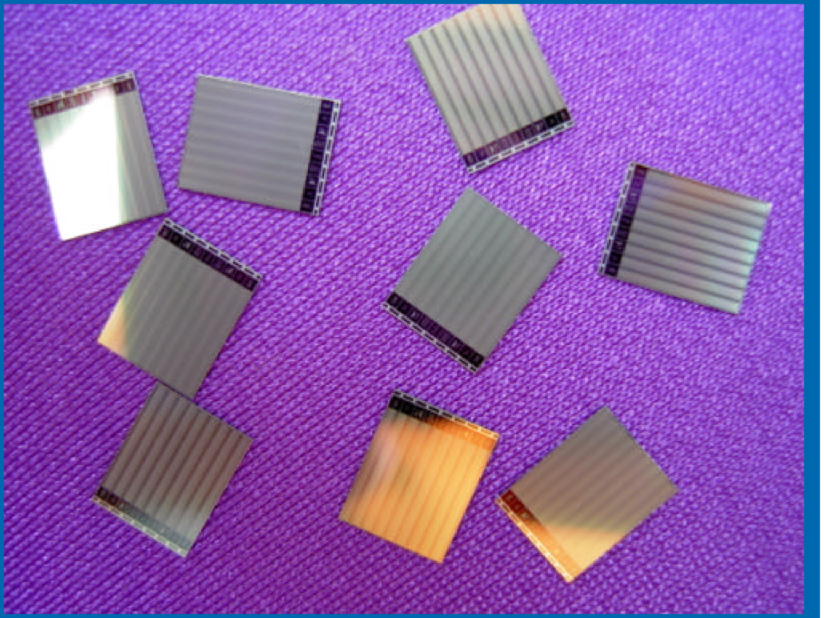


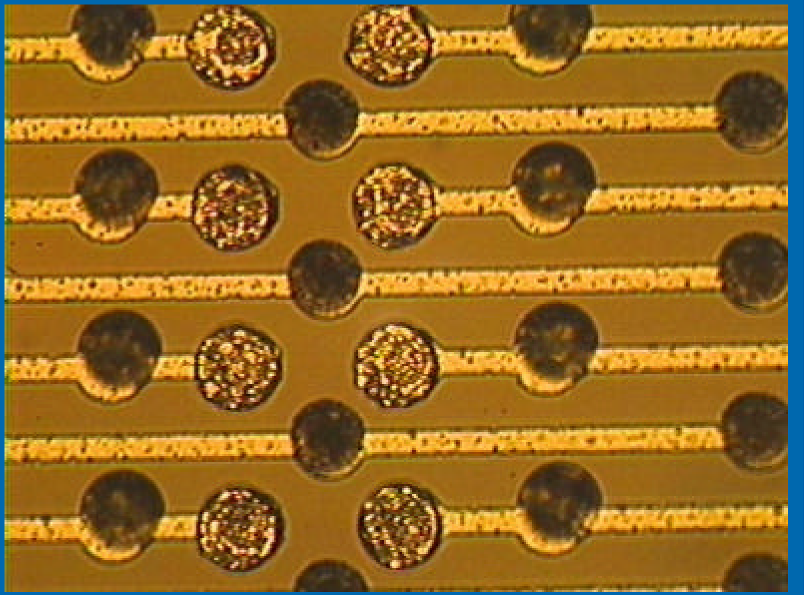




ATLAS UPGRADE

- **ATLAS ASIC for FP420**
- **SENSORS FULLY COMPATIBLE with ATLAS ELECTRONICS**
- **3D IS RAD HARD ENOUGH for B-LAYER**
- **BUMP 3D SENSORS and ATLAS ASICs**
- **CERN BEAM TEST in FALL 2006**





Tiling the Plane

PXTAL Movie

- 12 keV Photons
- Detector Stage Scanned