Single photon counting hybrid pixel detectors

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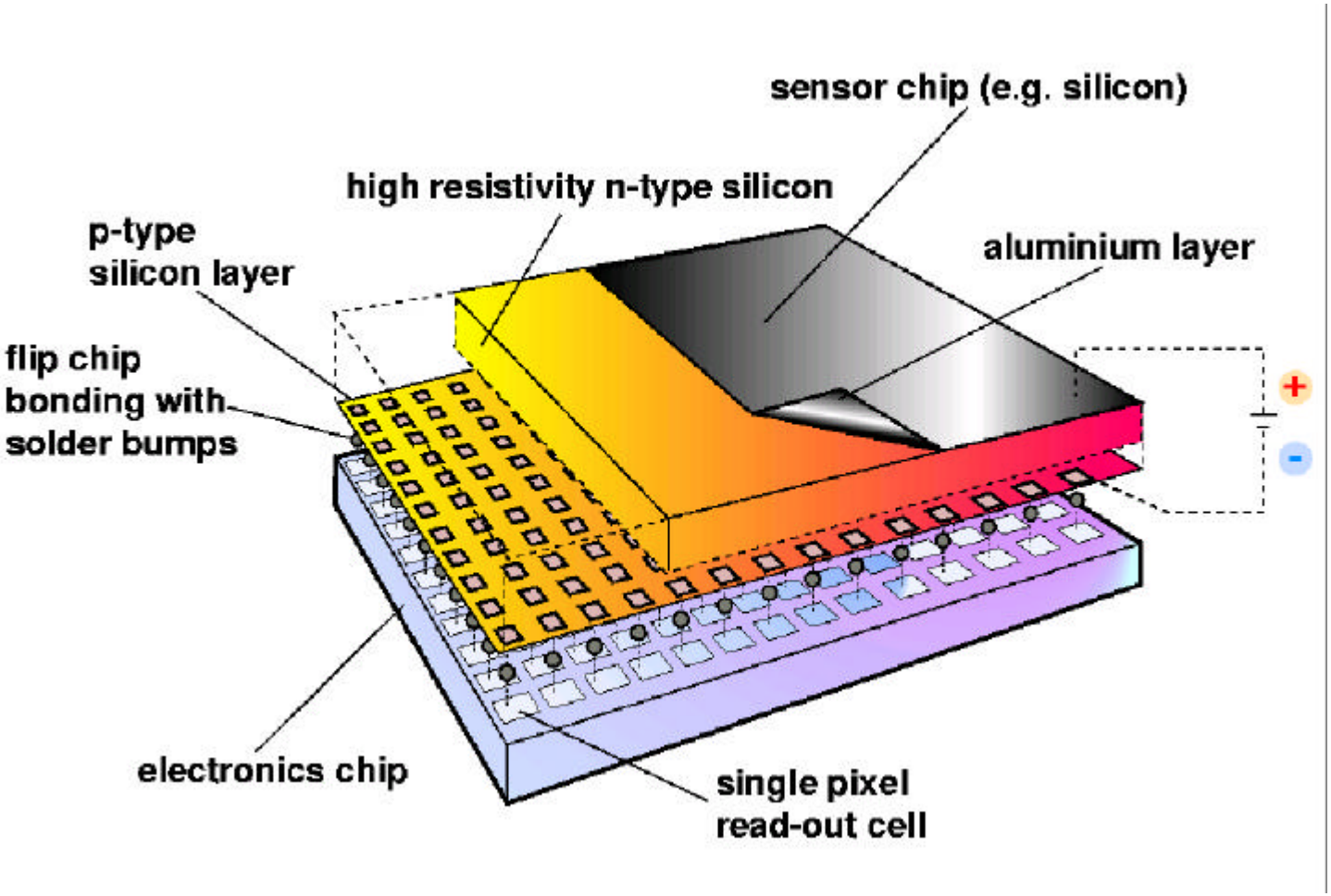
Spokesman, Medipix2 Collaboration

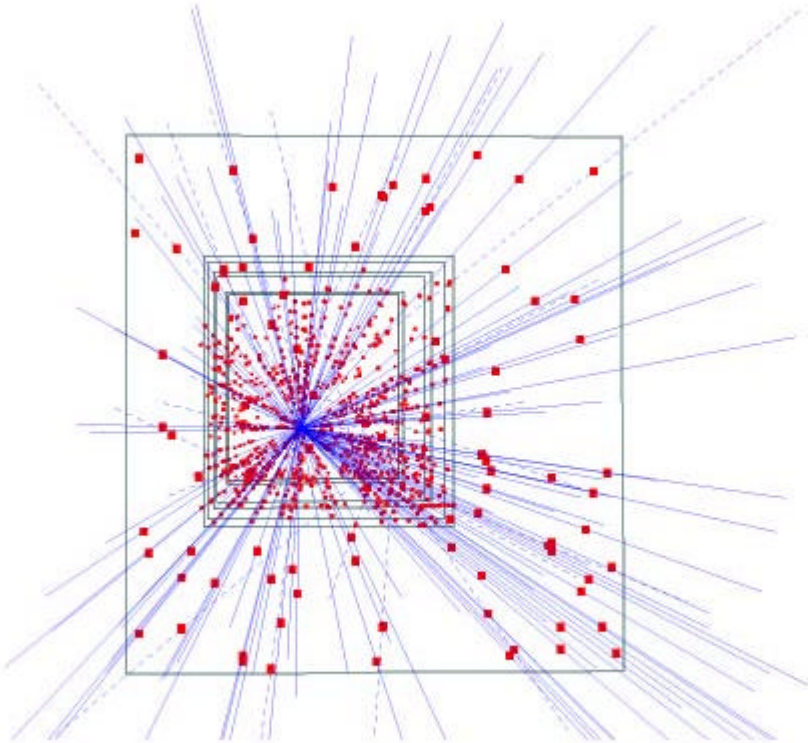
Outline

- Hybrid pixel detector basics
- High Energy Physics applications
  - Origins in heavy ion physics
  - Towards the Large Hadron Collider
  - Radiation hardness of CMOS
- From single event processing to x-ray imaging
- Medipix1 – a 4k pixel chip
- Medipix2 - a 64k pixel chip
- Future developments

Hybrid Pixel Detector



The origins in Heavy Ion Physics



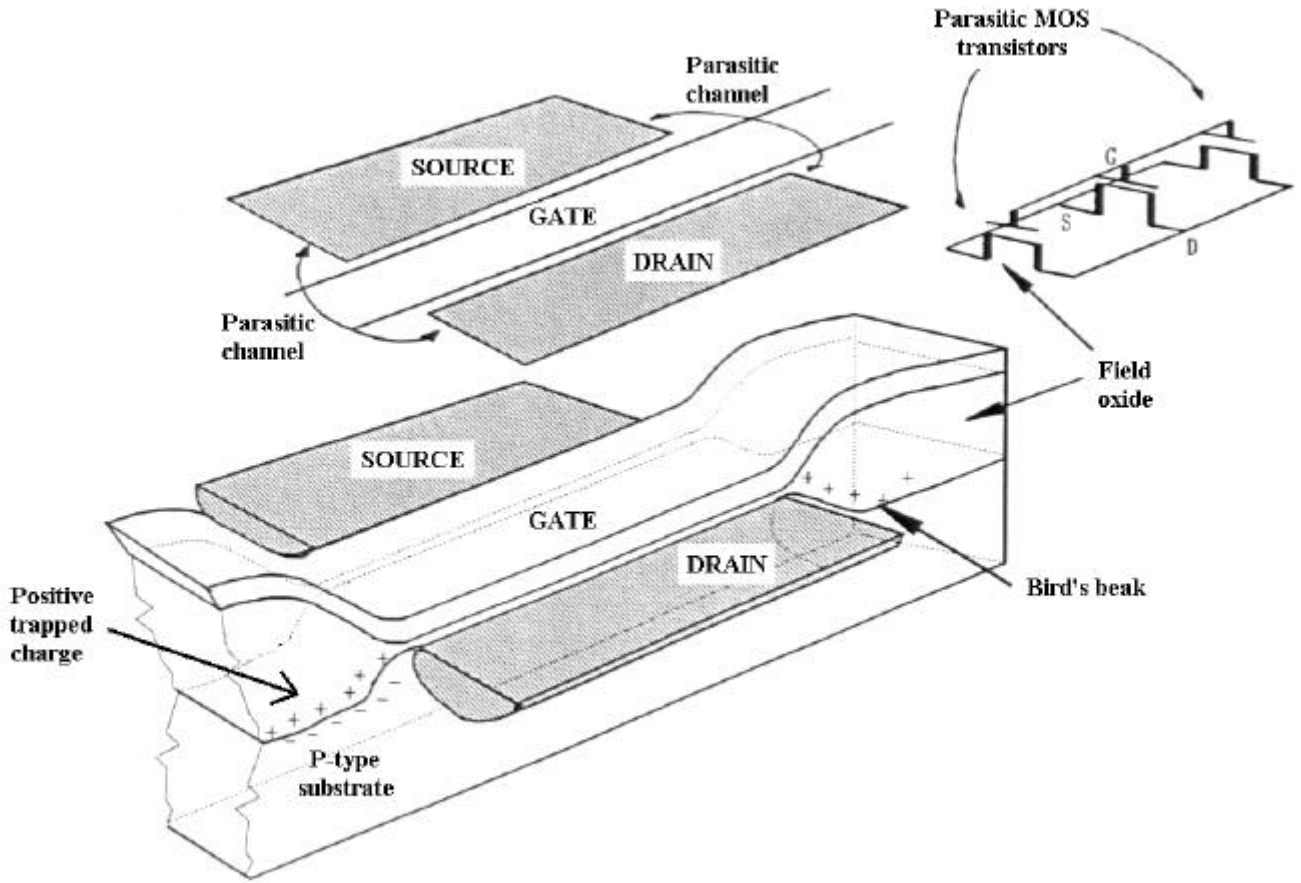
CERN Experiment WA97 (1995)

5 x 5 cm² area
7 detector planes
Pixel dimensions 75 x 500 ? m²
Trigger precision 1 ? sec
1 kHz trigger rate

The Large Hadron Collider Challenge

- 40 million bunch crossings per second, each producing...
- About 1 000 tracks
- All tracks should be recorded but only a tiny subset read out
- The position information should be precise to about 10?m
- Some experiments >10MRad total dose
- Pixel systems must operate for years without access
- Pixel systems must be transparent to particles
- Pixel systems should consume minimal power

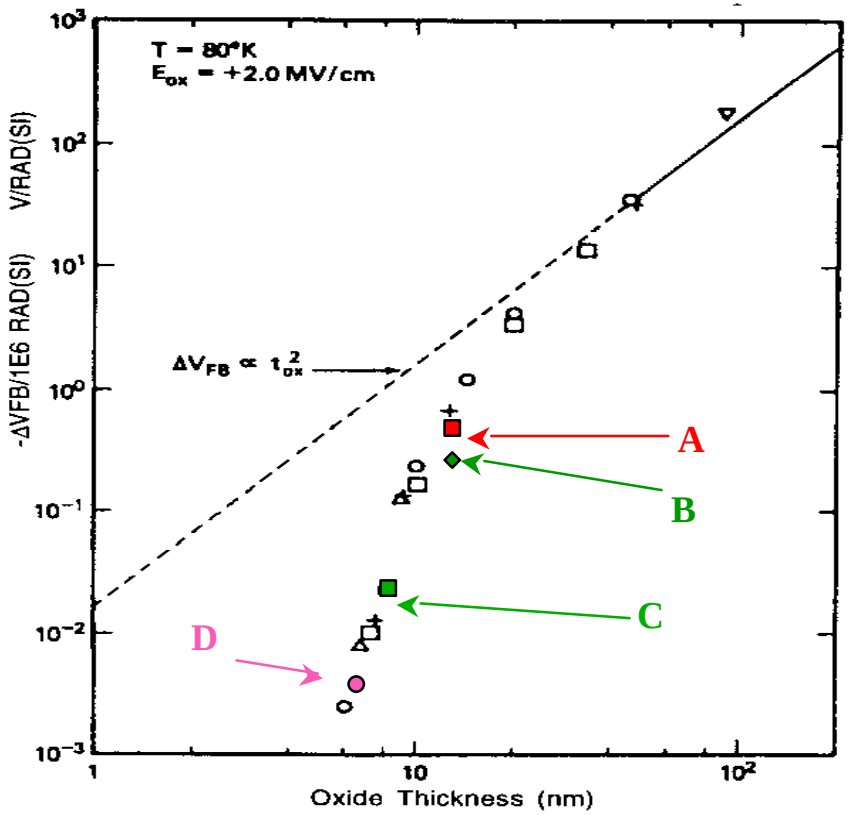
Effect of ionizing radiation on CMOS transistors - total dose



R. Gaillard,J.-L.Leray, O.Musseau, "Techniques de durcissement des composants, circuits et systemes electroniques,"Notes of the short course of the 3rd European Conference on Radiation and its Effects on Components and Systems, Arcachon (France), Sept. 1995.

MOS Flatband voltage shift versus gate oxide thickness after 1MRad(Si) @ 80°K

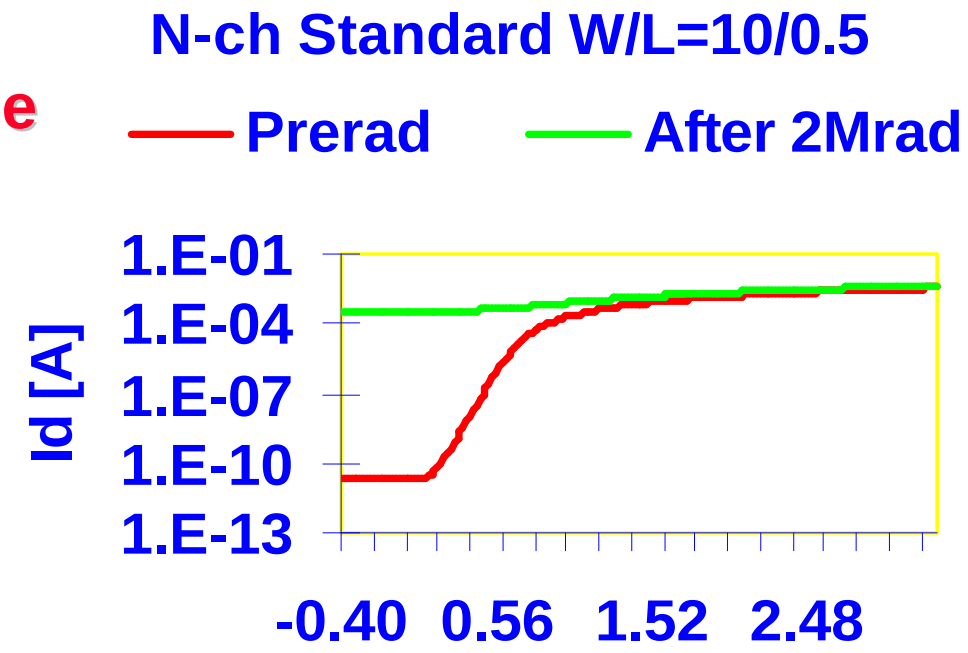
- Tunneling of trapped charge in thin oxides
- ? VT ~ $1/tox^2$ for tox > 10nm
- ? VT ~ $1/tox^3$ for tox < 10 nm



After N.S. Saks, M.G. Ancona, and J.A. Modolo, IEEE Trans.Nucl.Sci., Vol. NS-31 (1984) 1249

Total ionizing irradiation dose problem in commercial CMOS

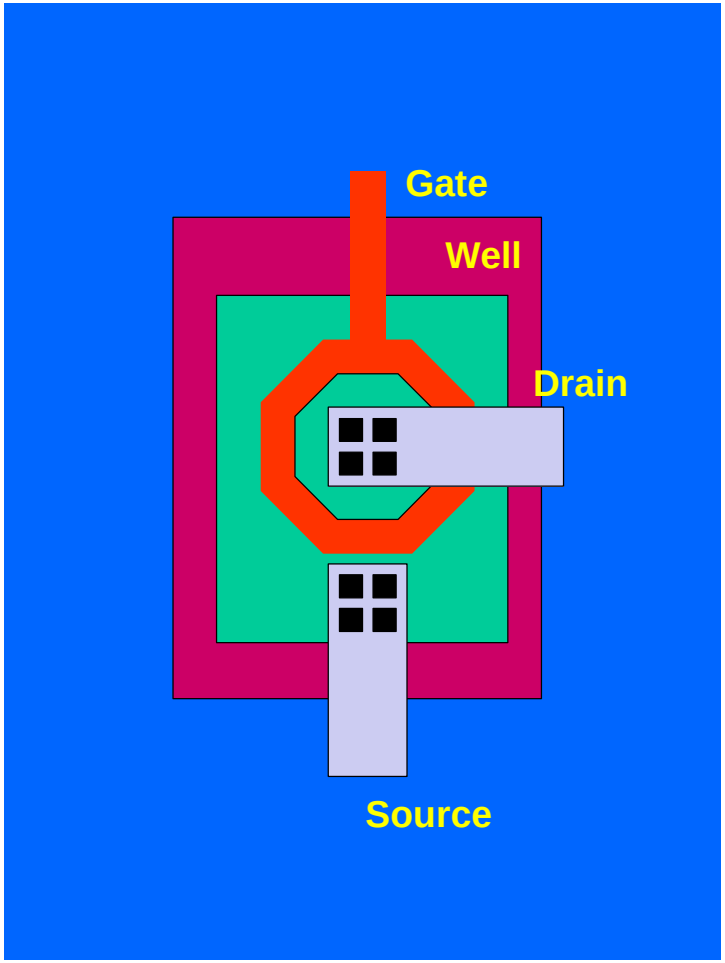
- Radiation induces positive fixed oxide charge and interface states
- Vt - shift
- weak inversion slope change
- mobility change
- LEAKAGE in NMOS transistors

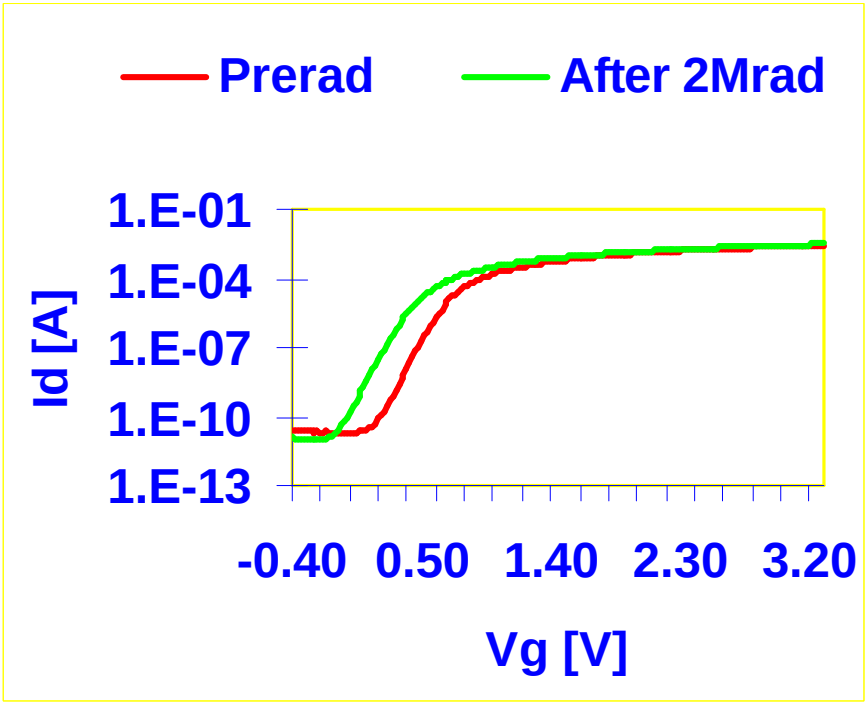


Example from 0.5 ?m technology (tox ~ 10 nm)

NMOS TRANSISTOR LEAKAGE

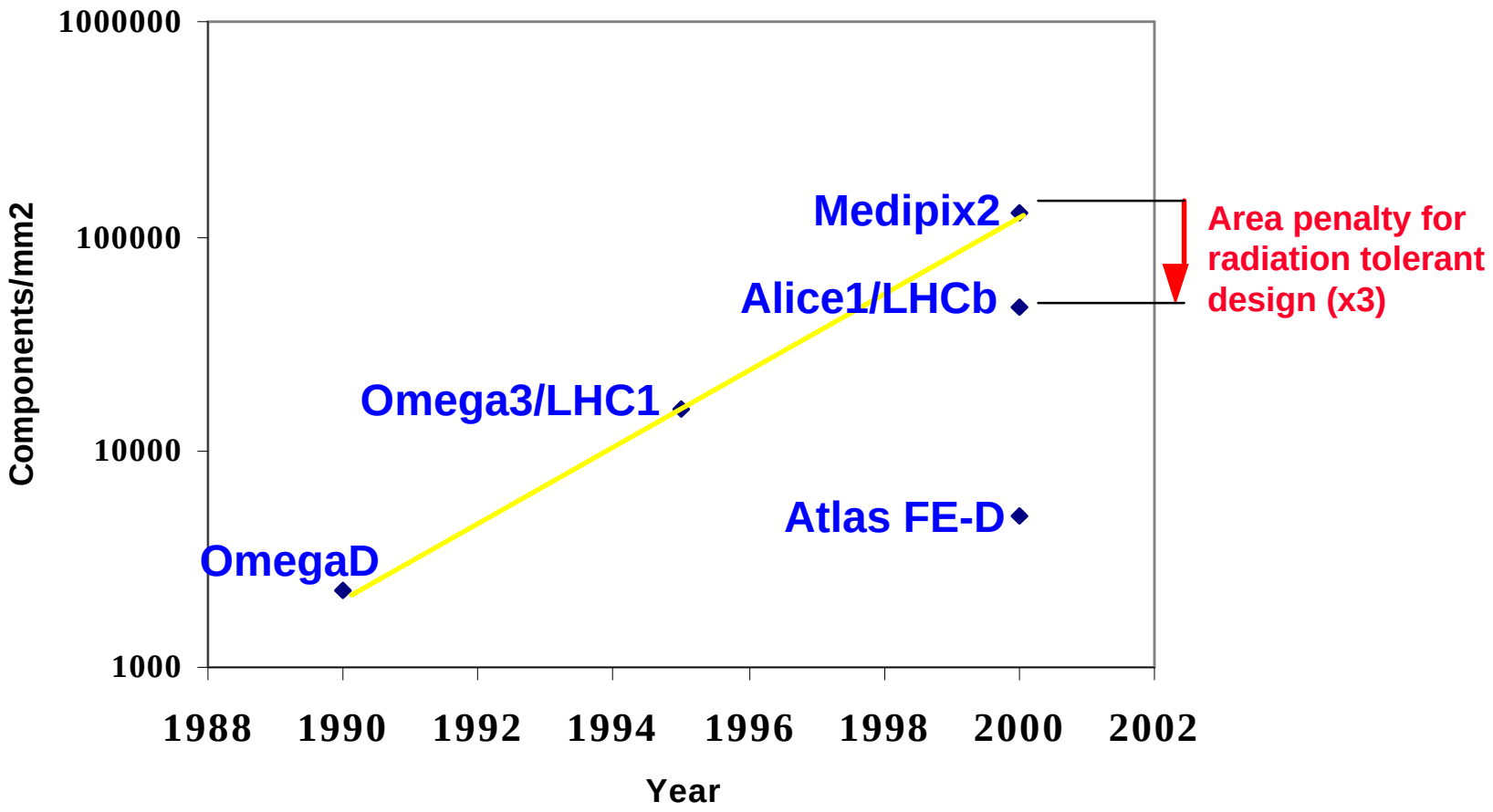
ENCLOSED TRANSISTOR LAYOUT





0.5um Technology (tox = 10nm)

Pixel readout chips- component density



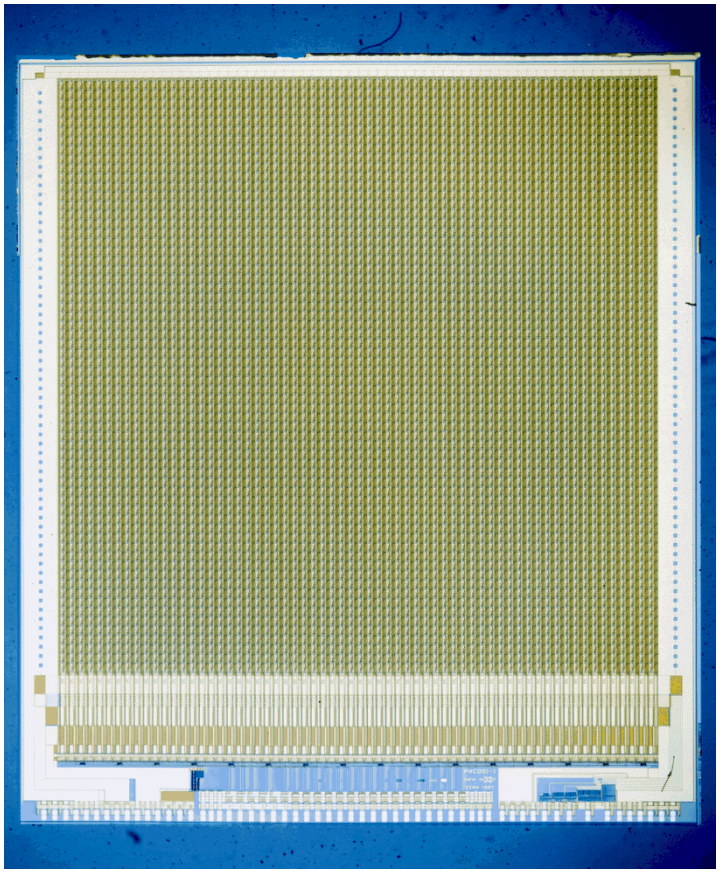
From HEP to x-ray imaging

- Pulse processing circuitry eliminates dark current noise
- But readout should be changed from HEP (event stored until trigger arrival) to single photon counting (using a shutter)
- HEP pixels are small, but the wrong shape - usually rectangular for momentum measurements in magnetic fields
- All HEP applications use high ? silicon. For imaging front-end should allow both electron and hole collection

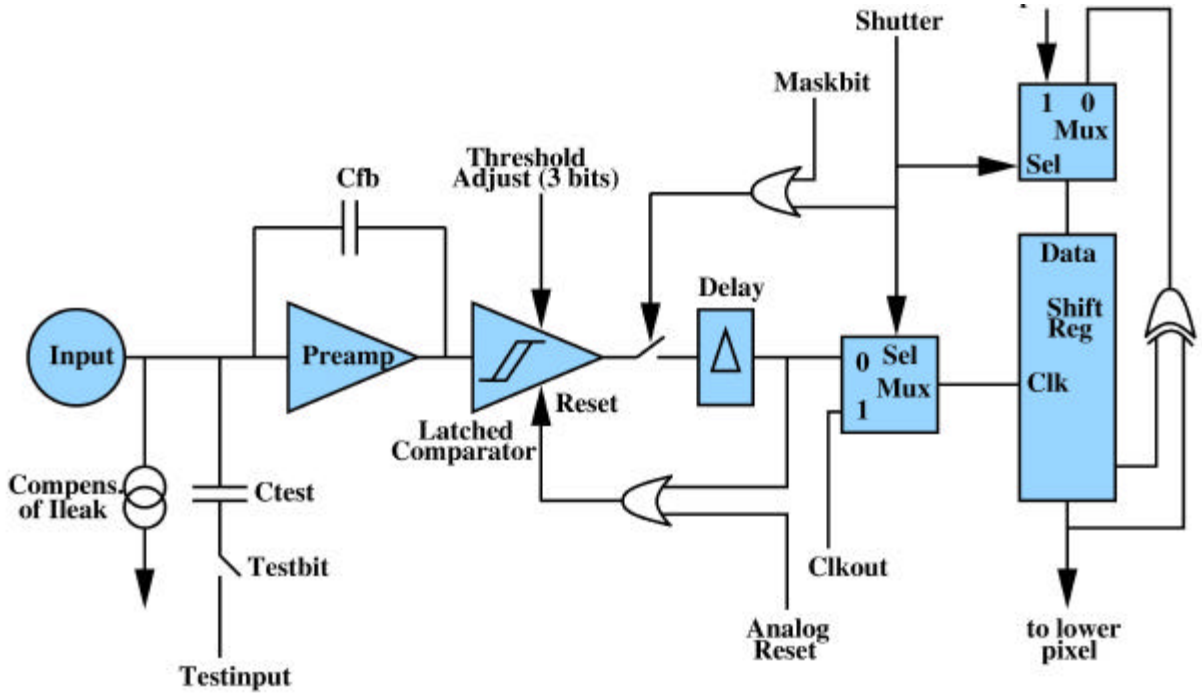
Medipix1 chip

based on ideas developed by the RD19 collaboration (CERN)

SACMOS1 FASELEC technology
Matrix of 64 x 64 pixels
Pixel size 170 ?m x 170 ?m
1.2 cm^2 sensitive area
1.7 cm^2 total area
1.6 M transistors



Medipix1 – cell schematic



charge sensitive preamplifier with leakage current compensation

discriminator with globally adjustable threshold

3-bit local fine tuning of the threshold

1 test and 1 mask bit

external shutter activates the counter

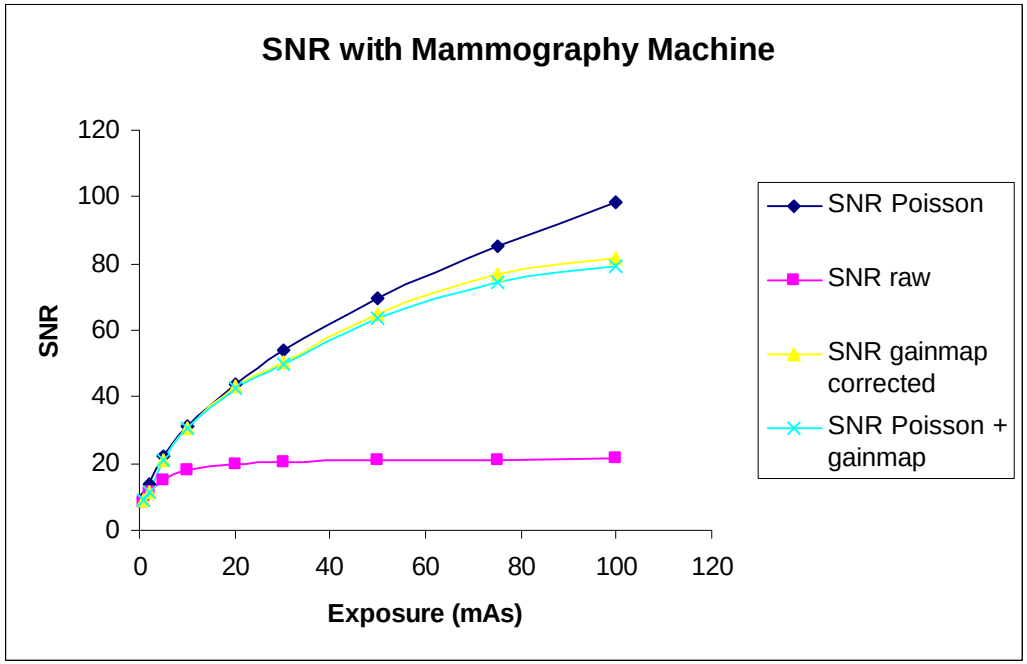
15-bit pseudo-random counter

Max count rate 1MHz (continuous)

readout frequency: max. 10 MHz

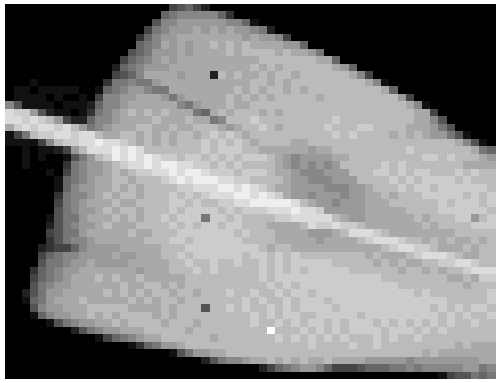
readout time: 384 ?s

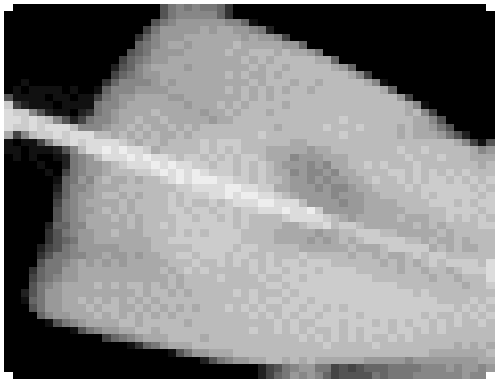
Measured SNR with Mammograph



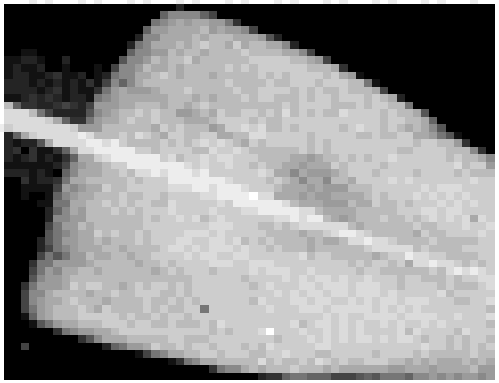
Note that exposure is at 2x normal distance

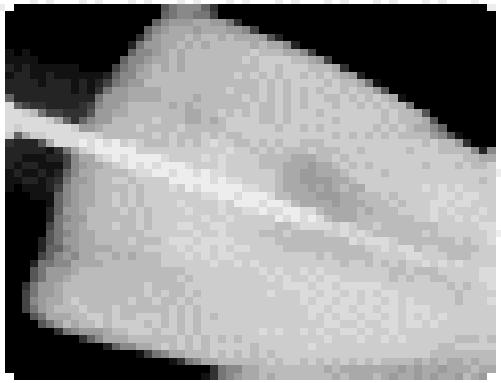
Examples of the performance of the Photon Counting Chip





Images of a tooth taken with Medipix system.
The upper images use the standard dental x-ray settings.
The lower images use a dose reduced by a factor of 30.





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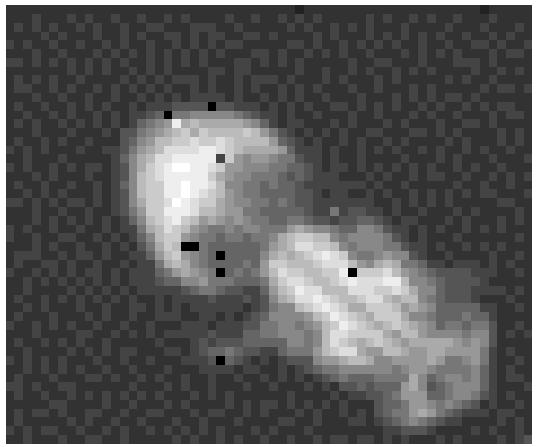
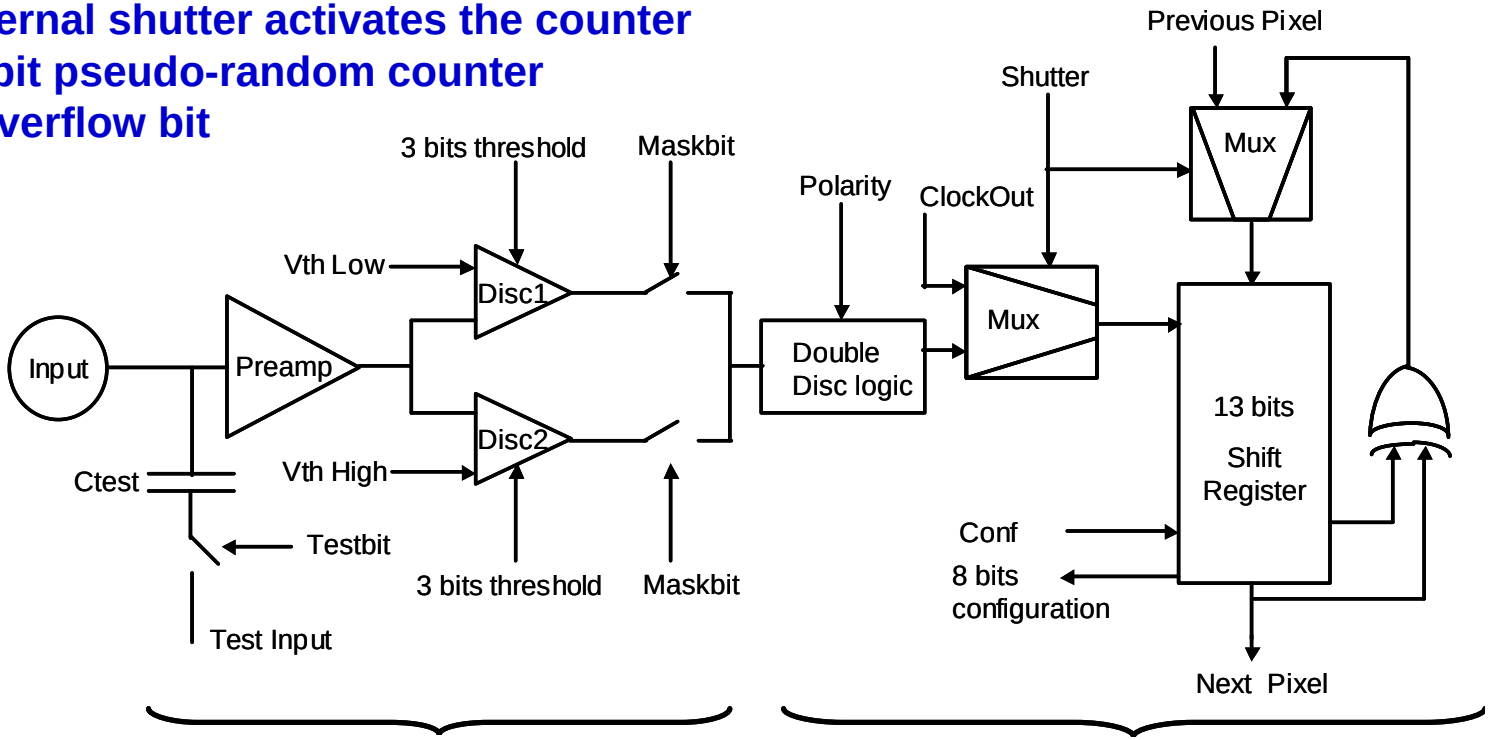


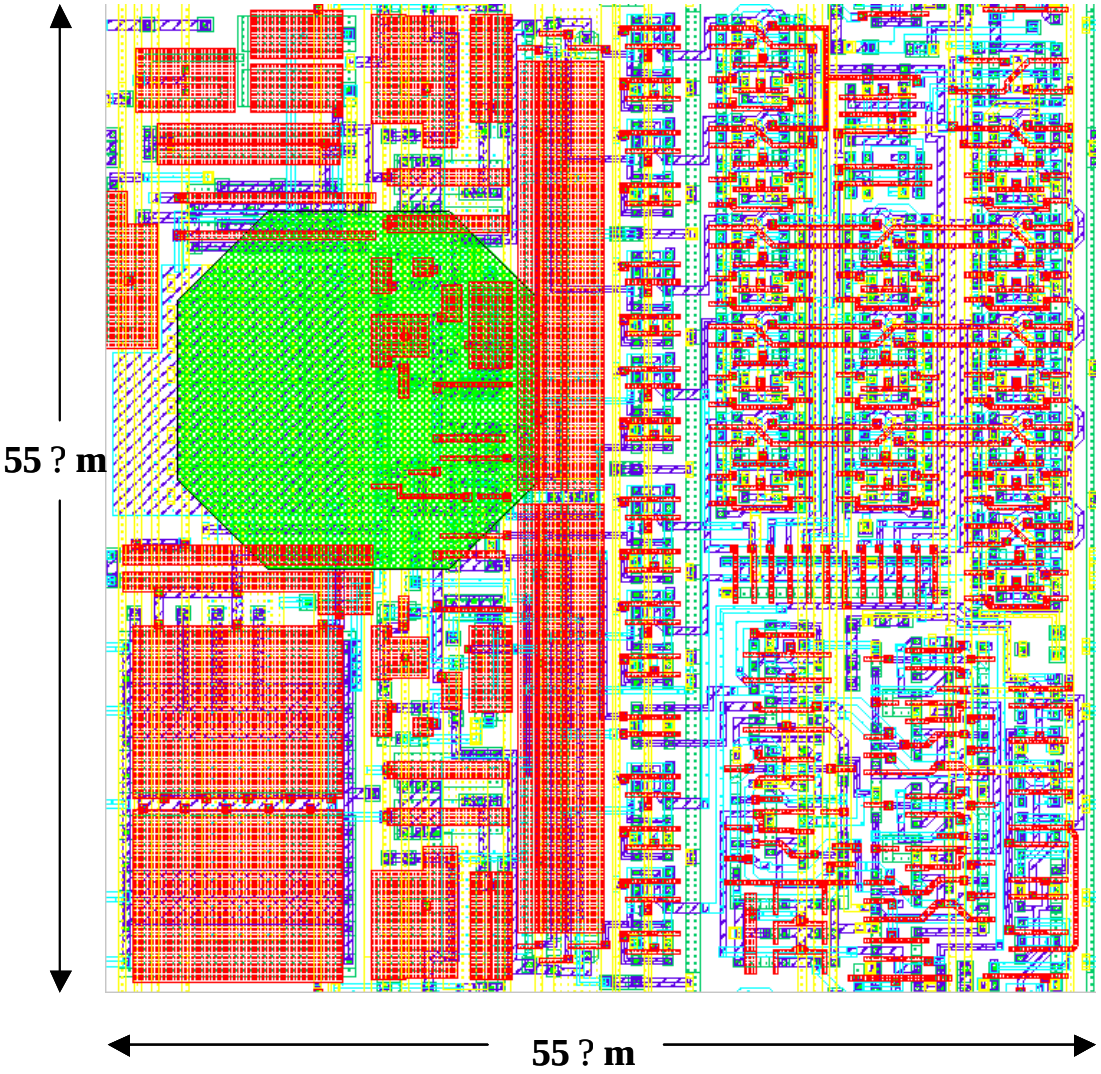
An x-ray image of a fly using an ^{55}Fe radioactive source (5.9keV).

Medipix2 Cell Schematic

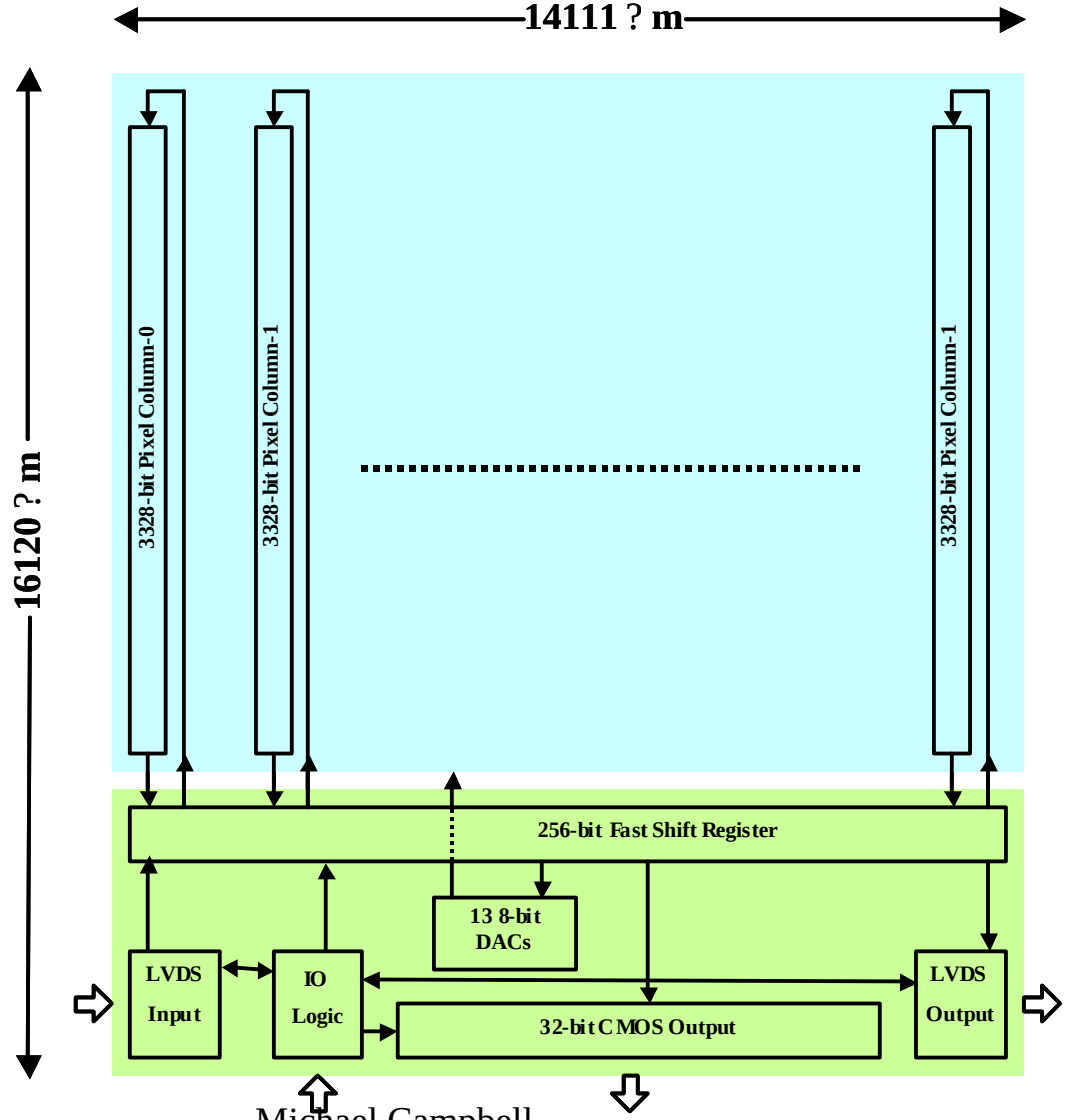
Charge sensitive preamplifier with individual leakage current compensation
2 discriminators with globally adjustable threshold
3-bit local fine tuning of the threshold per discriminator
1 test and1 mask bit
External shutter activates the counter
13-bit pseudo-random counter
1 Overflow bit



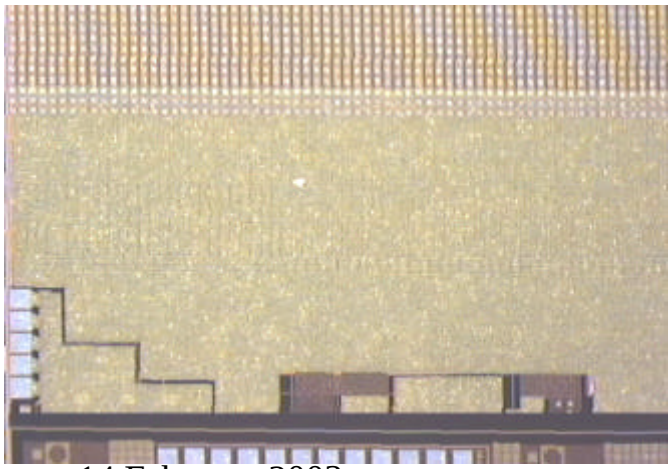
Medipix2 Cell Layout

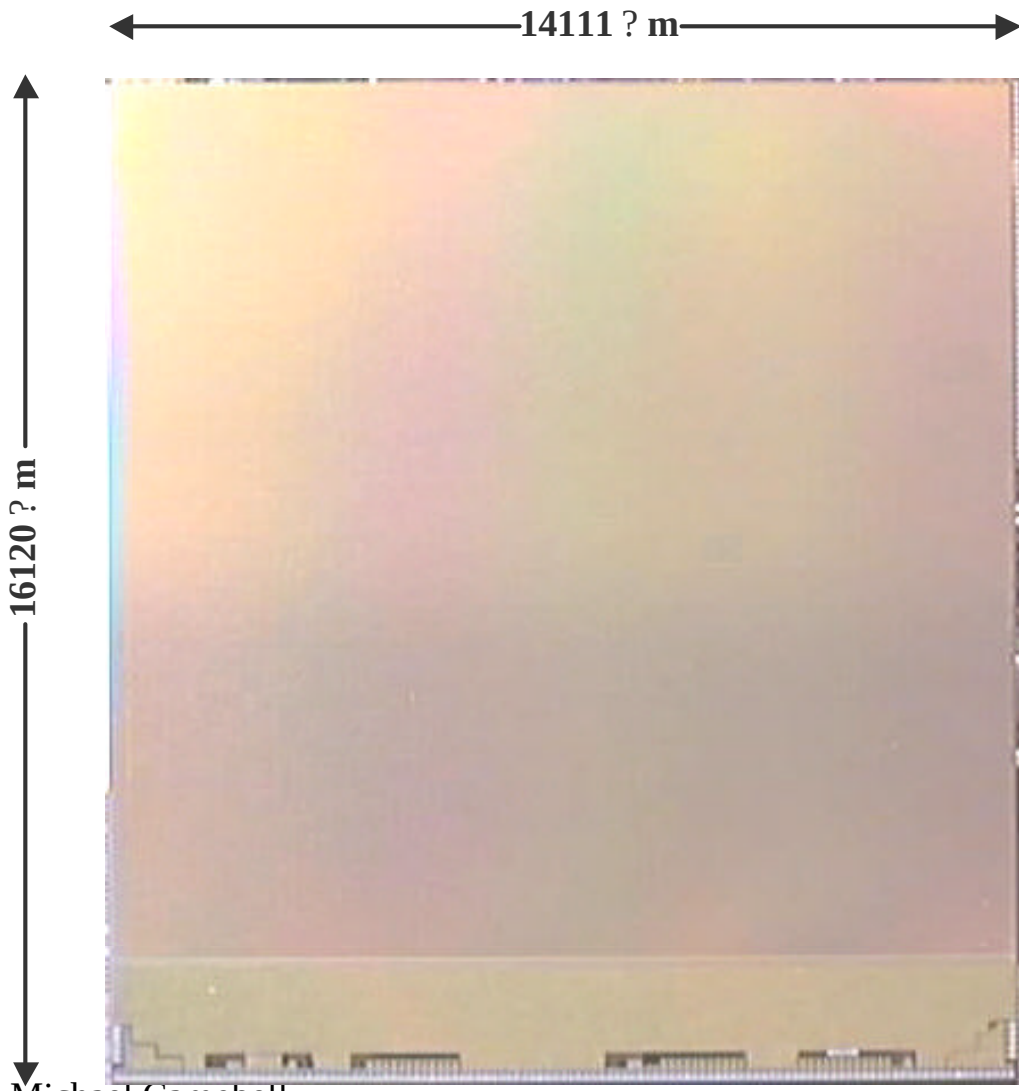


Medipix2 Chip Architecture



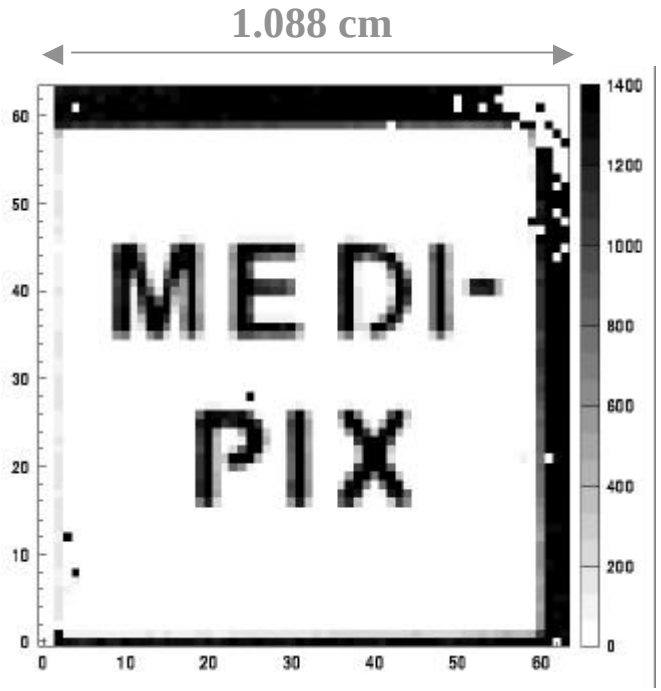
Medipix2 Chip Architecture (II)



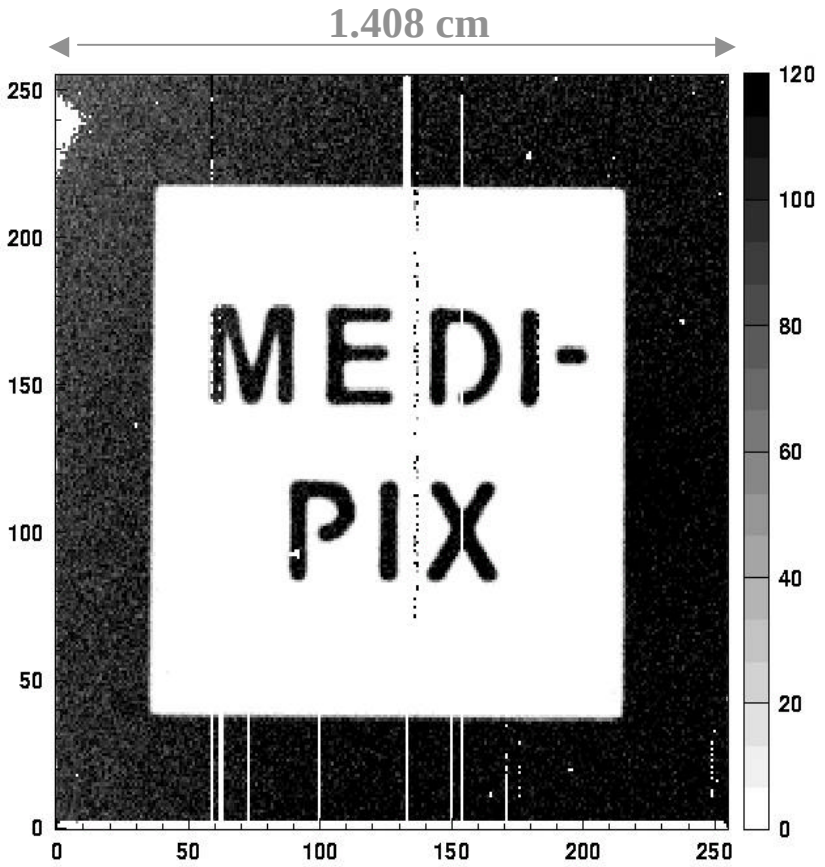


^{109}Cd Source comparison

Medipix1



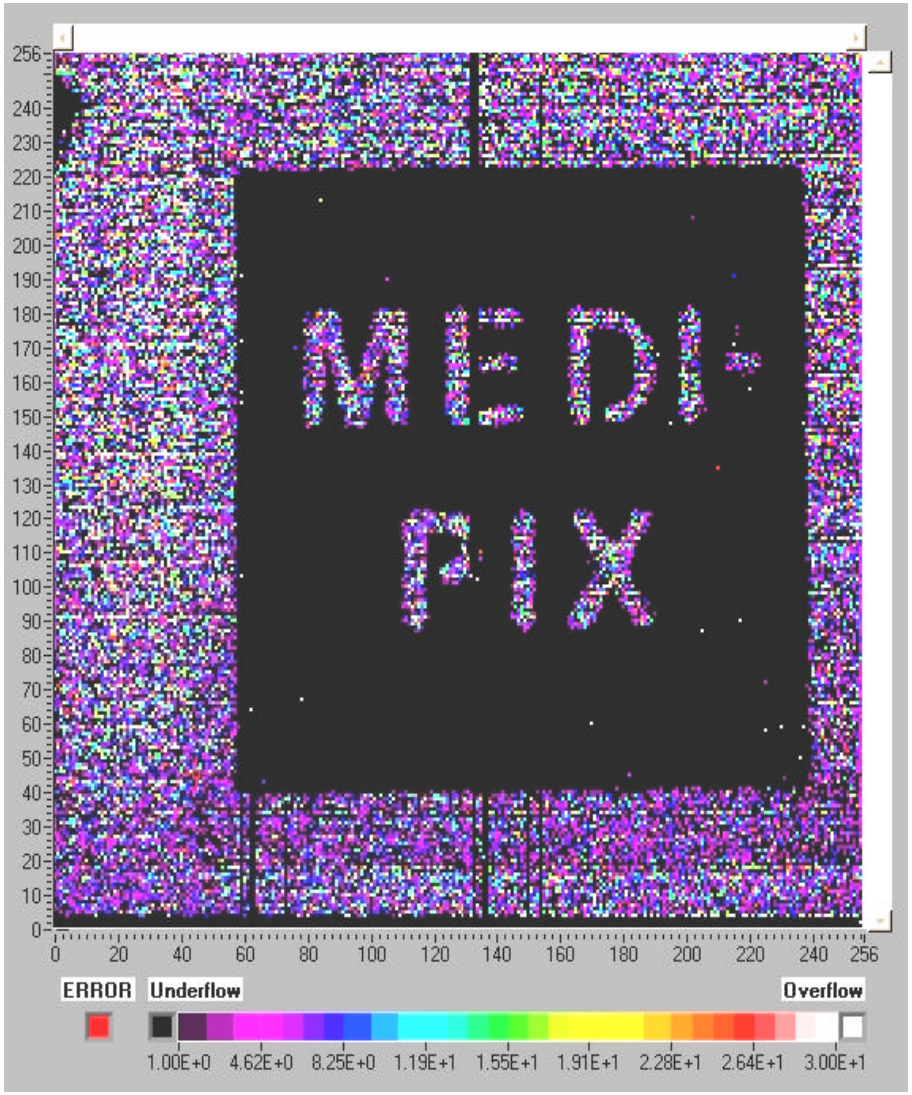
Medipix2



1hour acquisition
Threshold set to ~11KeV

^{55}Fe Acquisition

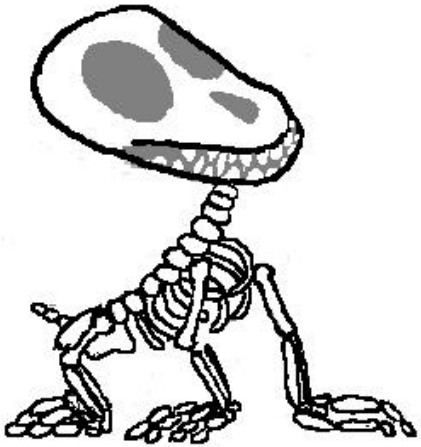
10min acquisition
Threshold set to ~4 KeV



Future Challenges

- Spectroscopic pixels
  - Implies local charge summing
- Very fast counting (1MHz randomly arriving)
- millisec frame readout
- Dead time free readout
- Large area tiling
- Uniform high-Z materials

“Idephix” IP proposal for FP6



CERN, ESRF, PSI …..