Non HEP uses of HEP instrumentation

- Instruments designed to detect high energy charged particles and photons also often work well with lower energy particles and gammas.
- HEP instrumentation from scintillating crystals (NaI, BGO) to multiwire pwc's have found applications outside HEP.
- The number of possible applications is huge.
- Today I will give examples of non-HEP use of silicon detectors.

Two examples

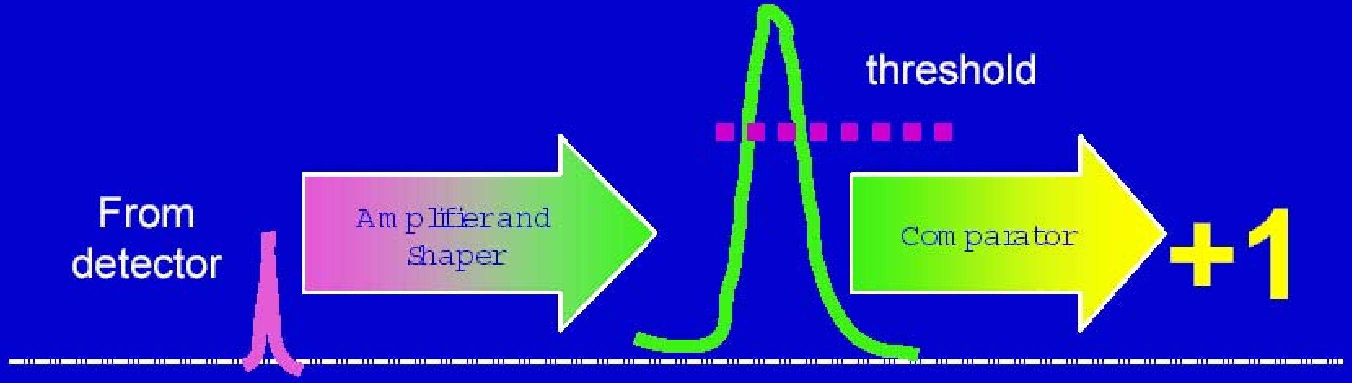
- “Edge-on” silicon strip detectors
  - Medical imaging
    - Use with synchrotron beam.
- Pixel Detectors & fast zero-suppressed readout
  - Protein crystallography

Photons in silicon detectors

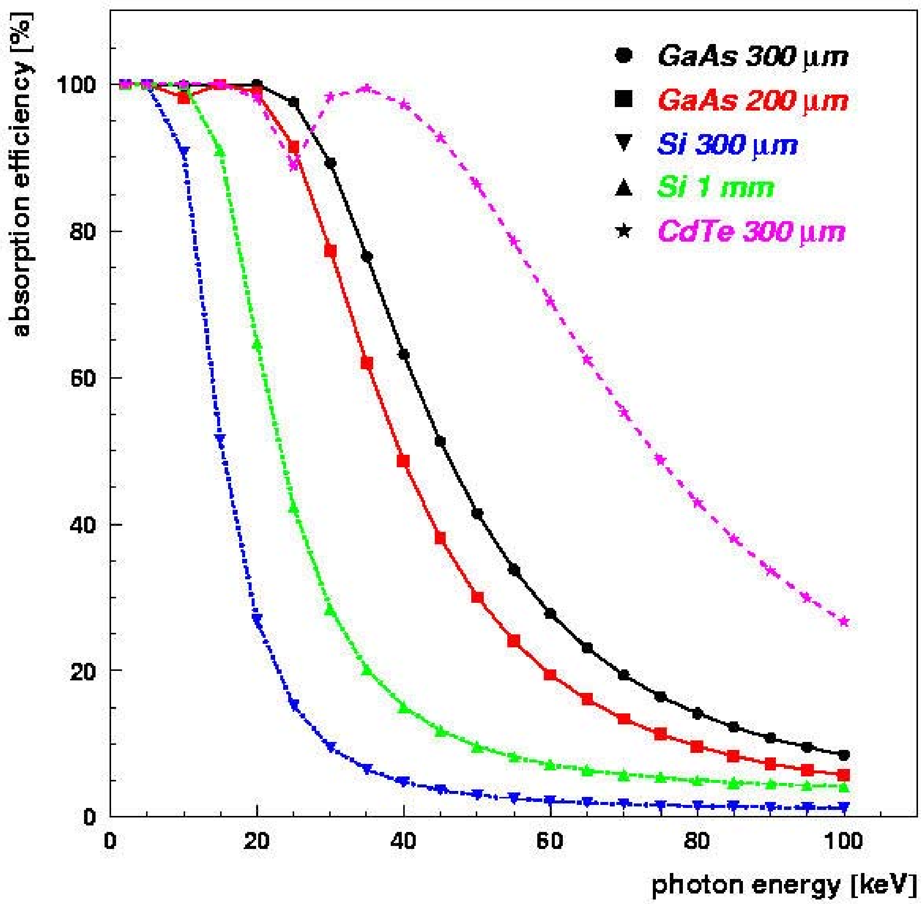
- Can detect visible light photons with energy greater than the band gap of 1.1 eV.
- On average, 1 e-h pair created in Silicon per 3.6 eV energy deposited.
- Both good energy resolution and good spatial resolution are possible.
- Single photon counting is possible for energies above 5-10 keV.

Photon Counting Read Out

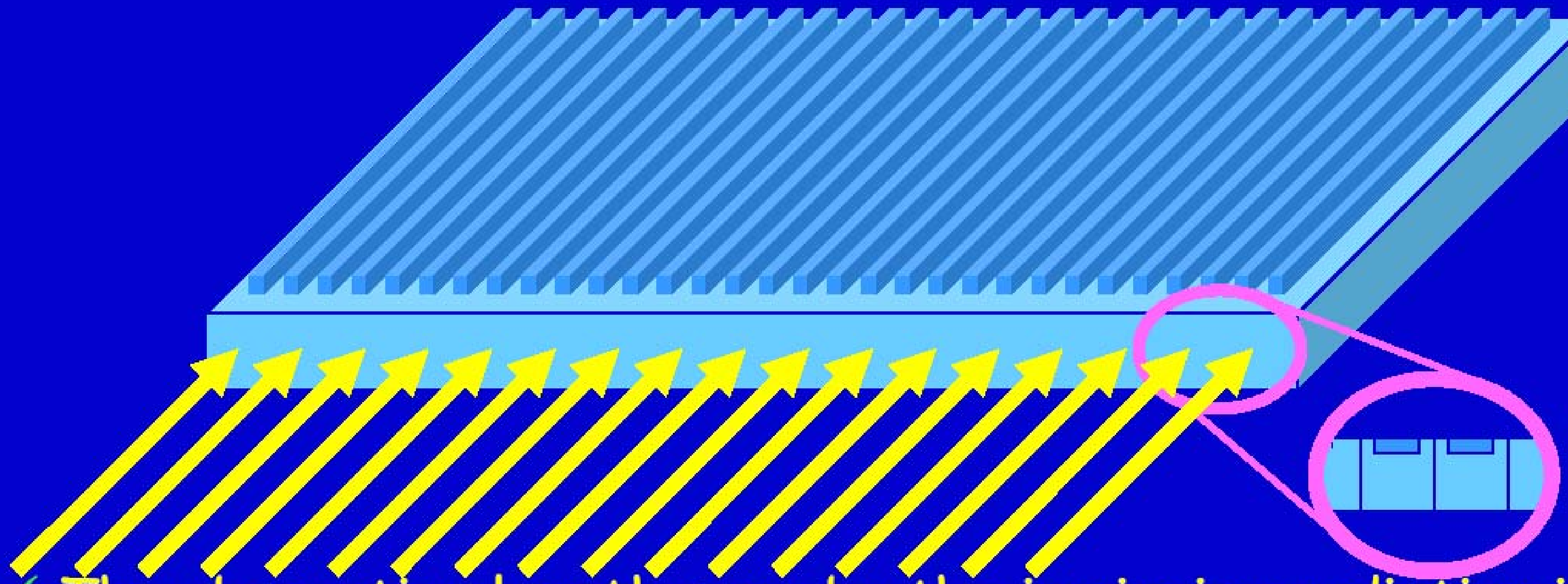
- ✓ Maximum information from each single photon
  - Almost complete noise suppression
  - Maximum SNR
  - Perfect linearity
  - High dinamic range
  - Energy discrimination (scattering rejection, dual energy radiography, K-edge subtraction…)



“sweet spot” for 300 μm thick silicon is ~5-15 keV



Edge on detectors



✓ The absorption length seen by the impinging radiation is given by the strip length

➢100% absorption probability in 1 cm of silicon for 20 keV photons

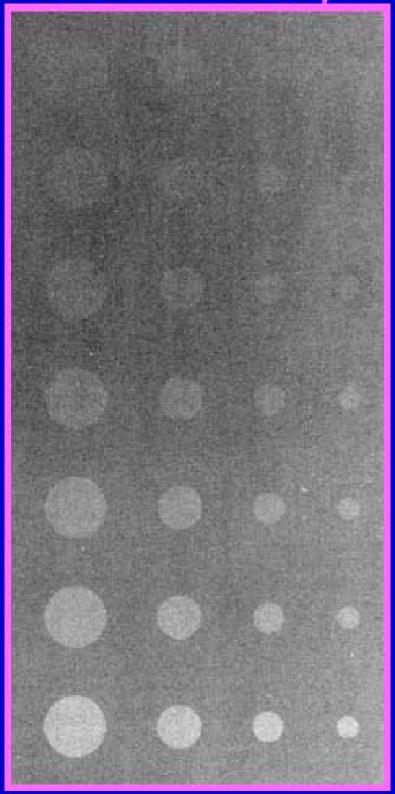
✓The pixels of size is determined by the strip pitch times the detector thickness

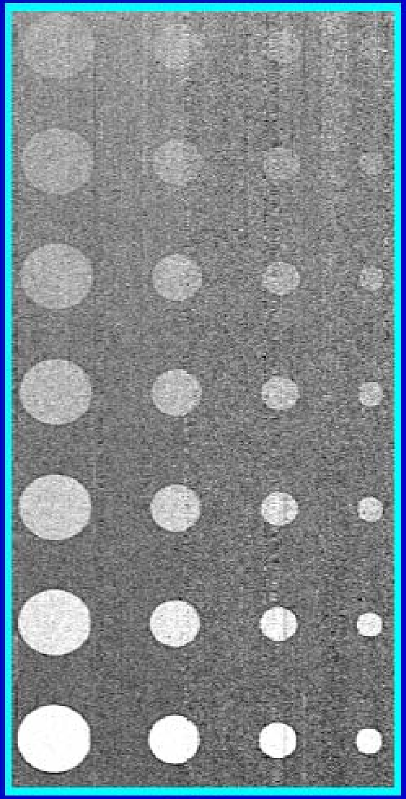
✓Almost complete scattering rejection

Arfelli et al., Physica Medica Vol IX, pp. 229-233, 1993

Detector performance evaluation

Conventional mammographic image (@26 kVp) MGD 1.8 mGy

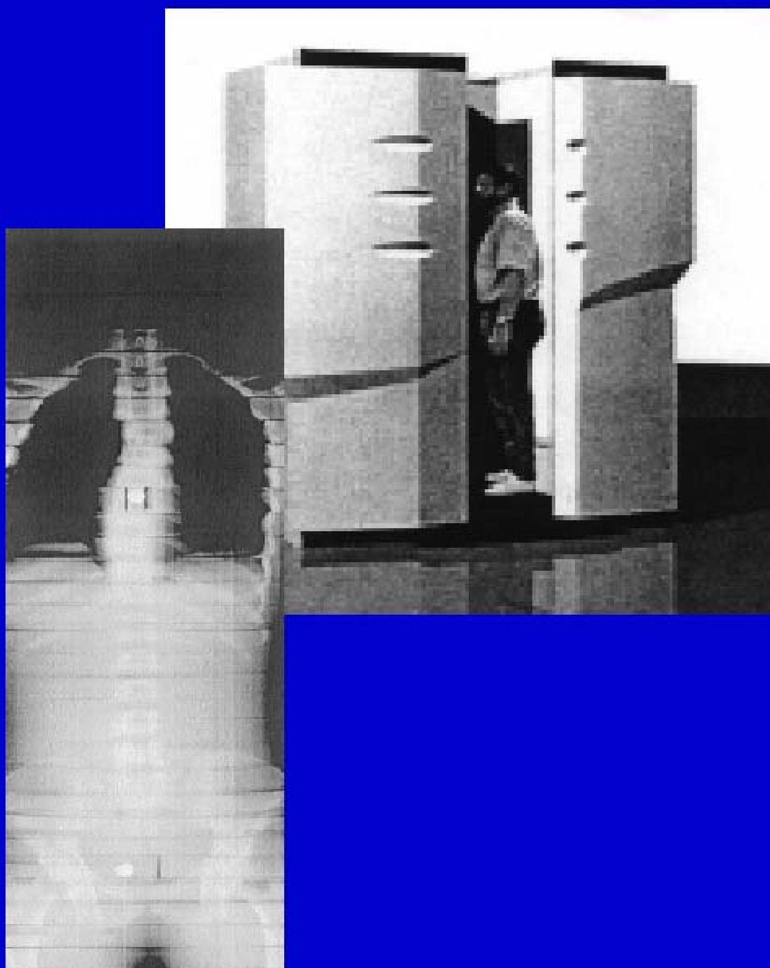




SYRMEP image (with Synchrotron Radiation@20 keV) MGD 1.4 mGy

The contrast resolution is highly enhanced due to the single photon counting capability and the dose is low thanks to the high efficiency of the detector at to the monochromaticity of the X-ray beam.

Spinal Radiography- GRPHE (Cedex) team

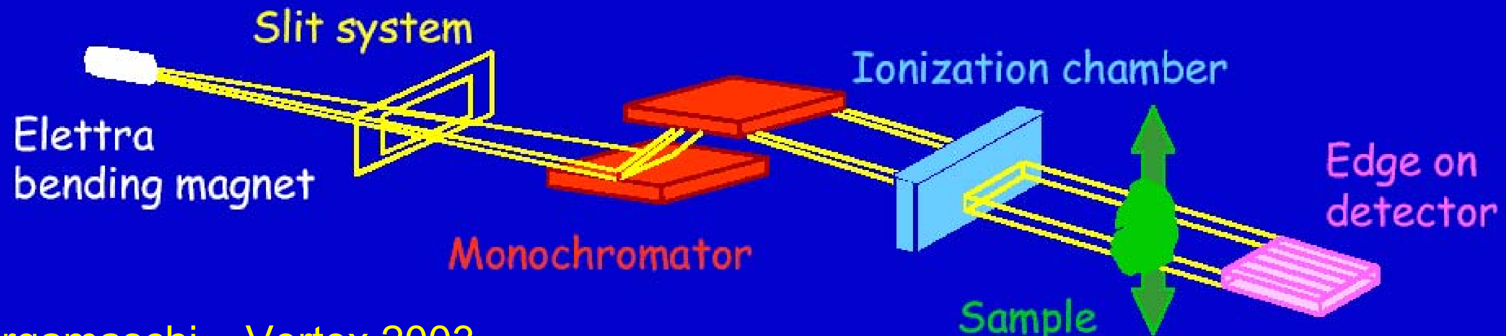


- ✓ Scanning slit with X-ray tube
  - ➢ Strip fan out to compensate for beam divergency
  - ➢ 120 cm scan
- ✓ 500 x 500 μm^2 pixel size
- ✓ 5 cm strip length
  - ➢ 90% efficiency at 50 keV
- ✓ Array of detectors covering 50 cm with a dead zone of three strips between the detectors

Hilt et al., NIM A 442, pp.38-44, 2000
Hilt et al., NIM A 442, pp.355-359,2000

SYnchrotron Radiation for MEdical Physics

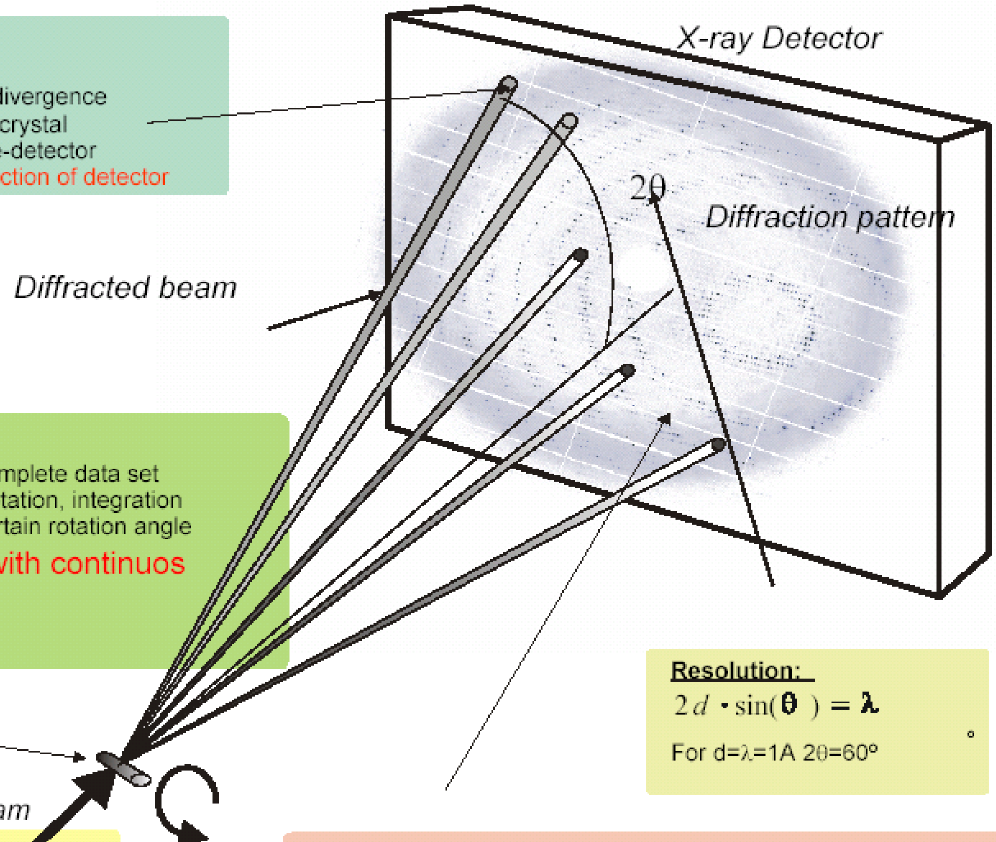
- ✓ Beam line for mammography active since 1996 at Elettra in Trieste
  - ➢ Experiments on test objects and in vitro tissues
  - ➢ Now moving toward *in vivo* examinations (2004-2005)
- ✓ Development of a digital detection system
  - ➢ Edge on silicon microstrip detector
    - High efficiency and good spatial resolution
    - Laminar active surface matches the beam
  - ➢ Single Photon Counting Read Out
    - Maximum contrast resolution



Pixel Detectors for Protein Crystallography

Spot size:

- Beam size and divergence
- Mosaicity of the crystal
- Distance sample-detector
- Point spread function of detector



Crystal rotation
- 30-180 degree for complete data set
- Currently: Discrete rotation, integration over certain rotation angle
- Fine φ–slicing with continuos sample rotation

Resolution:

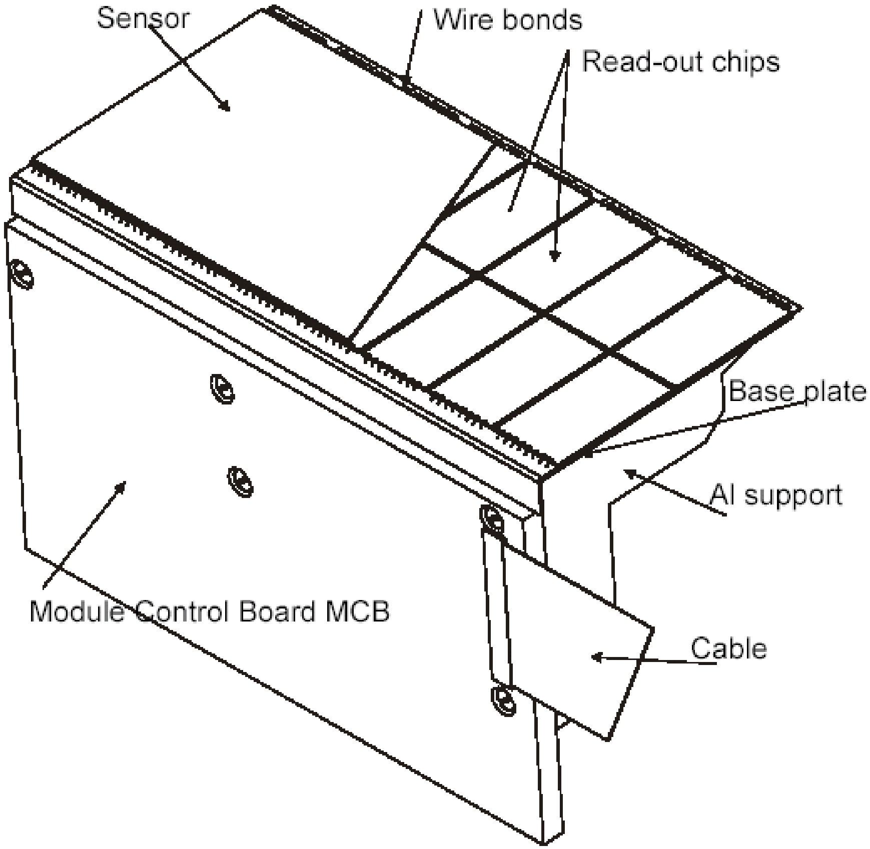
$$2d \cdot \sin(\theta) = \lambda$$

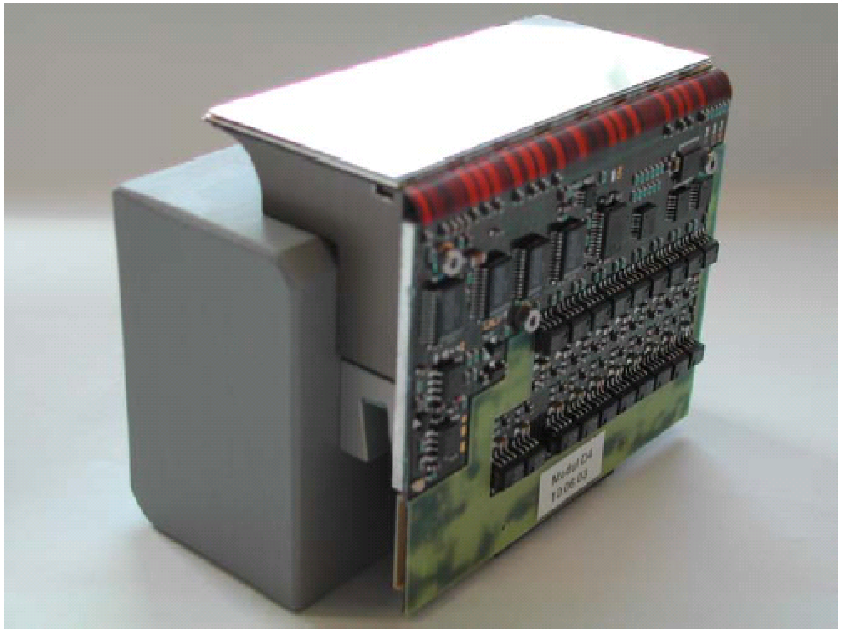
For d=λ=1A 2θ=60°

Beam
Energy: 5-17.5 keV
Intensity: $>10^{12}$/s
Focal spot size: Adjustable to $>75 \times 30\ \mu m^2$
Divergency: $<375 \times 70\ \mu rad^2$ (FWHM)

Diffraction data
- reflect crystal symmetry group
- orientation of the crystal-> orientation matrix
- High dynamic range: $>10^4$ between strong and weak reflections
- Intensities need to be determined accurately (1%)
- Determination of amplitudes and phases leads to electron density maps

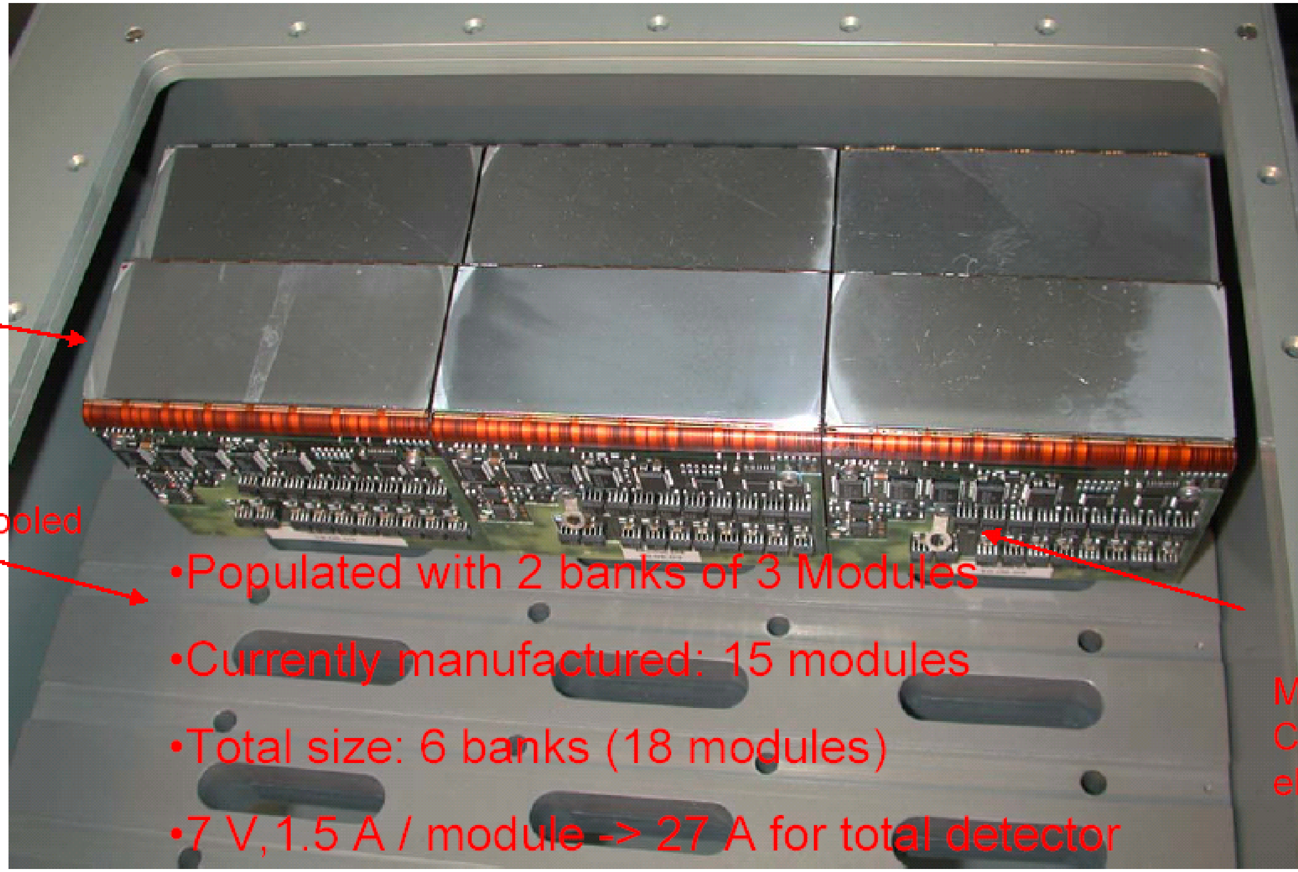
PILATUS Module Typ II (readout electronics bended)





- Flexprint 6/2 from Dyconex
- Modules can be overlapped
- 80 x 35 mm^2 continuous sensitive area
- 2 x 8 readout chips
- Power consumption: 7V/1.5 A -> 10.5 W

PILATUS 1Kx1K Detector



- Populated with 2 banks of 3 Modules
- Currently manufactured: 15 modules
- Total size: 6 banks (18 modules)
- 7 V, 1.5 A / module -> 27 A for total detector
- 288 chips->~300x10^6 Transistors
- Area: 20 x 24 cm^2

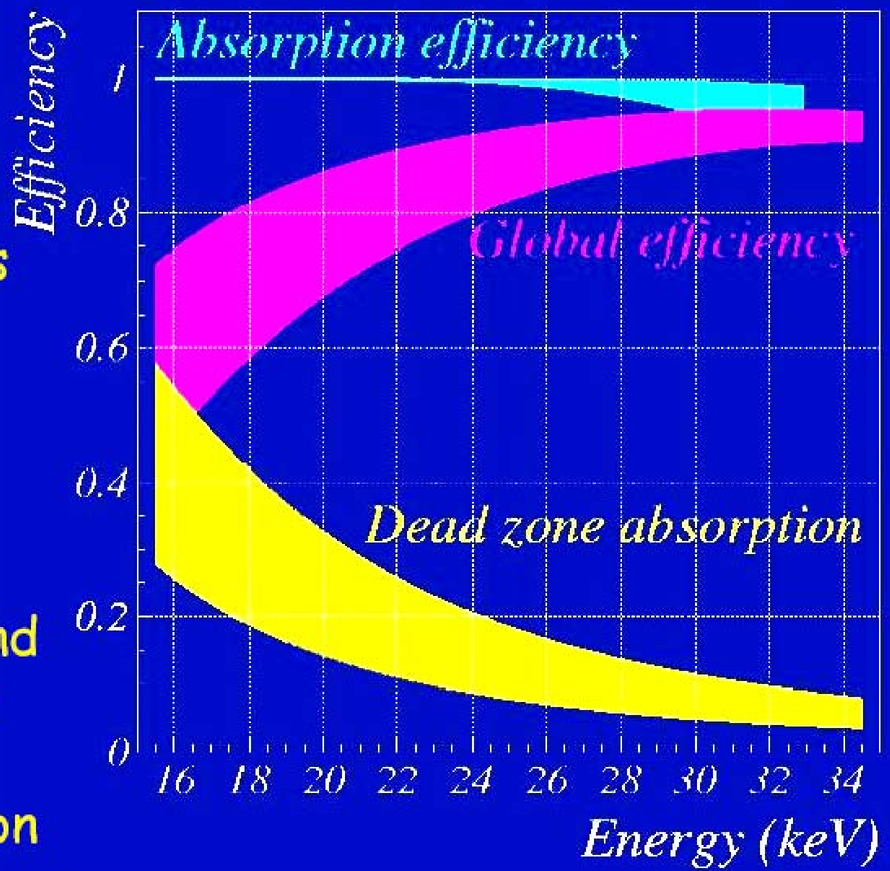
Summary

- I haven't even scratched the surface of possible applications of silicon detectors.
- HEP groups worldwide are involved in R&D aimed at adapting HEP instrumentation to non-HEP applications.
- FNAL scientists and engineers could make significant contributions.
- Benefits to FNAL would include influx of ideas from other disciplines & steadier stream of R&D projects.

Backup slides

Detector efficiency

- ✓In the entrance window of the detector there is an undepleted region
  - ➢The charge created by photons absorbed in this region is not collected leading to a loss of efficiency
  - ➢Its dimension is mainly determined by the distance between the end of the strips and the scribe line (usually 1.5 times the thickness of the detector)
  - ➢The effective undepleted region is about 100 μm thinner and can be further reduced by using higher detector bias voltage



Efficiency at energies of mammographic interest for a detector with 1-2 cm absorption length and 200-400 μm cutting distance

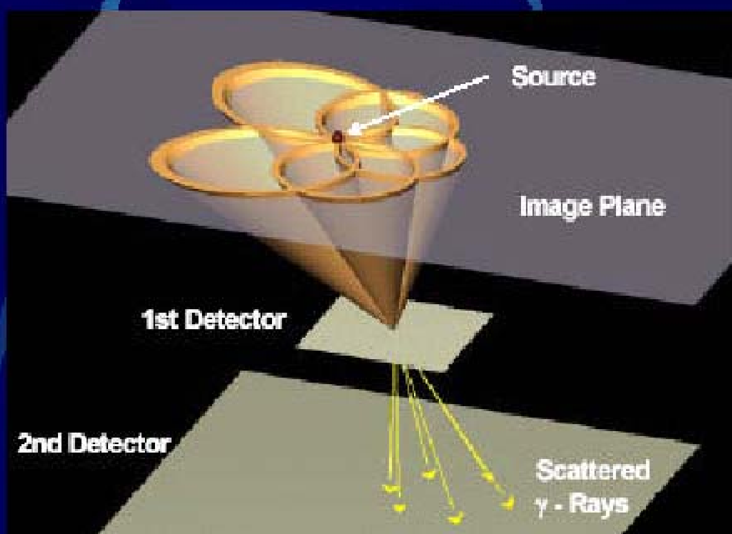
Medipix Collaboration

- Medical imaging by single photon counting – Silicon pixel detector + "Medipix" ASIC.
- Collaborating institutions:
  - IFAE, Barcelona, U. Cagliari, CEA (France), CERN, Czech Academy of Sciences, Czech Technical U.,
- Applications include dental radiography, mammography, angiography, dynamic autoradiography, tomosynthesis, synchrotron applications, electron-microscopy, gamma camera, x-ray diffraction, neutron detection, dynamic defectoscopy.
- Web link: http://medipix.web.cern.ch

1. Compton Camera

Principle of the COMPTON Camera:

The idea is to use Compton scattering of the primary γ ray in a first detector and the detection of the scattered γ ray in a second detector to measure the direction of the primary γ ray..

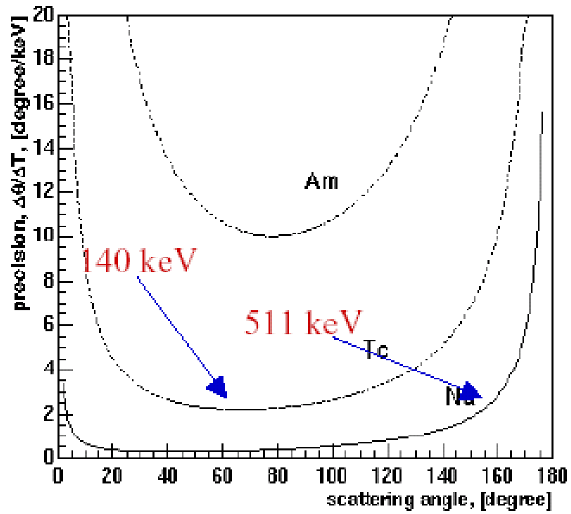


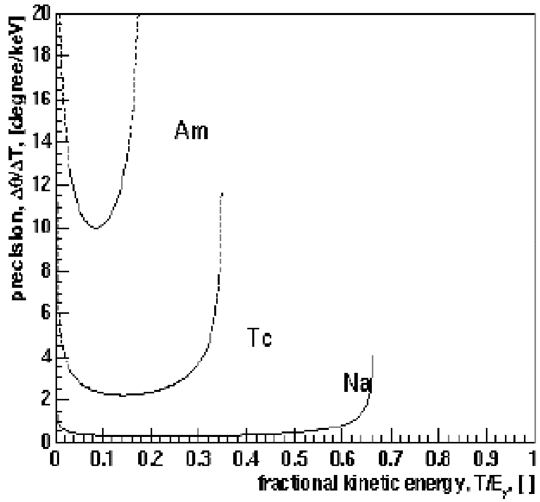
- Detection coincident events between two detectors
- Compton scatter equation relates scatter angle θ and E_o and E_{re}

$$\cos\theta = 1 + \frac{511}{E_0} - \frac{511}{E_0 - E_{re}}$$

- Photon direction is determined within conical ambiguity

Spatial Resolution as a Function of Scattering Angle θ and Energy Resolution ΔT (Compton Kinematics)





- presision of angle

$$\Delta\theta = \frac{d\theta}{dT}\Delta T \overset{\text{Eq. ??}}{=} \frac{[1+(1-\cos\theta)\gamma]^2}{\gamma E_\gamma \sin\theta}\Delta T$$

- energy precision (resolution)

$\Delta T = 1$ keV : $\Delta\theta \approx 2.3^\circ$ for ^{99m}Tc, e.g. 3 cm· tan($\Delta\theta$) ≈ 1.1 mm

➔The most important quantity is the energy resolution of the recoil electron!

Higher γ energy gives better resolution.

Peter Weilhammer – Vertex 2002

Astronomy & Astrophysics experiments with silicon detectors (an incomplete list)

- AMS http://ams.cern.ch
  - AMS-1 flew on the Space Shuttle in 1998
  - AMS-2 to fly on the International Space Station.
- Sil-Eye http://www.roma2.infn.it/research/comm5/sileye/
- NINA http://wizard.roma2.infn.it/nina/
- Pamela http://wizard.roma2.infn.it/pamela/
- AGILE http://agile.mi.iasf.cnr.it/Homepage/
- TIRGE http://tigre.ucr.edu
- GLAST http://www-glast.stanford.edu