Compton Camera

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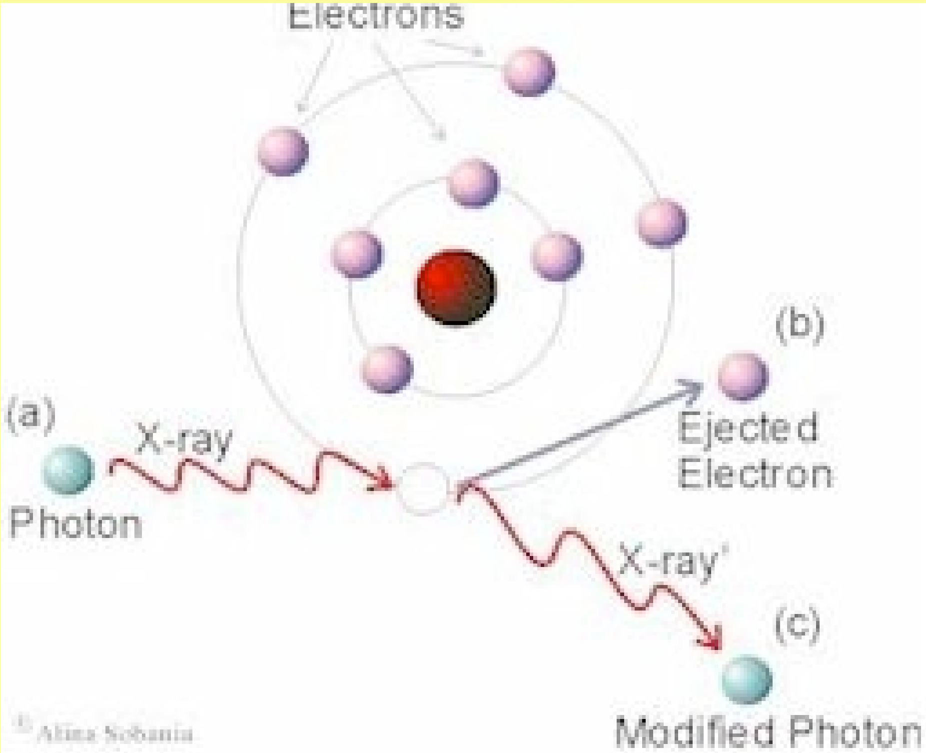
Overview

- What is the Compton effect?
- How is it used in imaging?
- Why use silicon detectors?
- Implementation of the ideas
- Comparison with conventional methods

The Compton effect

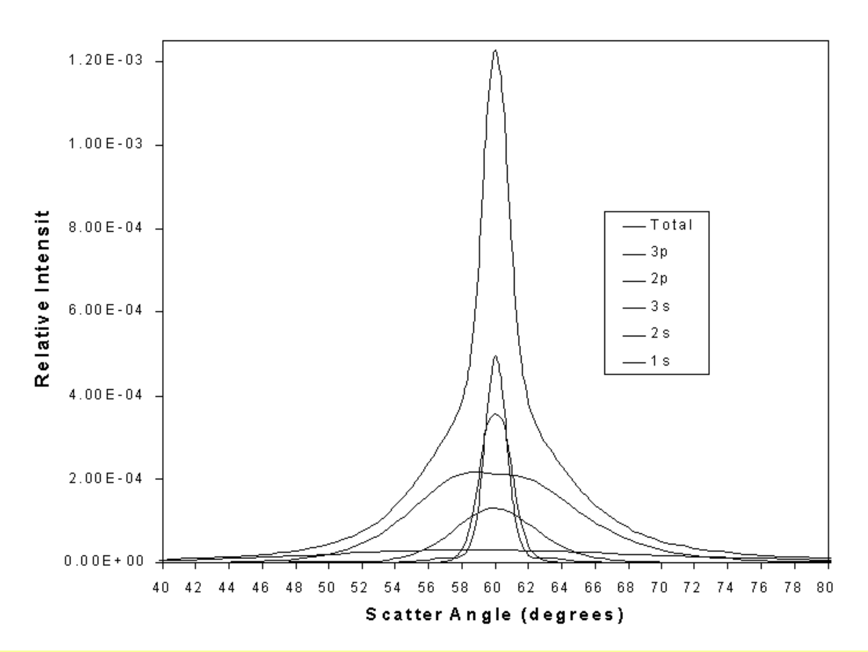
- Incoming photon has its energy and direction changed by scattering
  - Usually a nuisance

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1 - \cos\theta)}$$

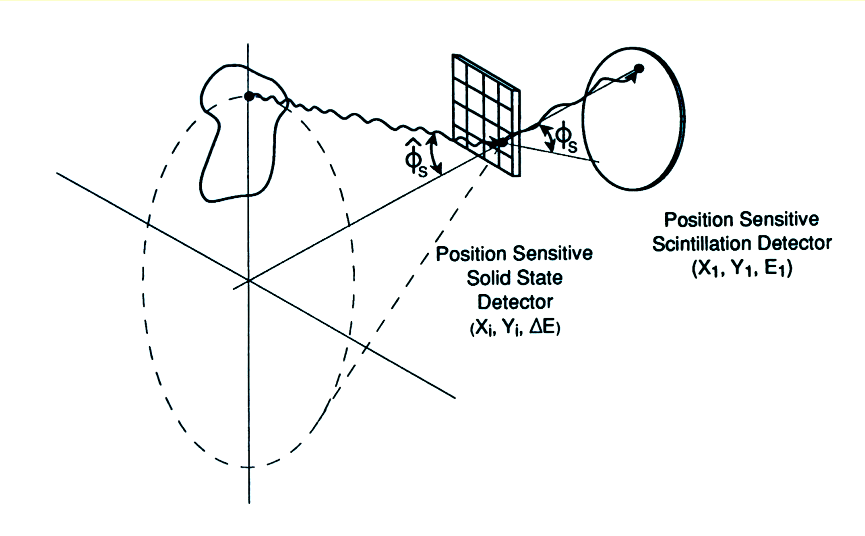


Doppler broadened compton effect

- Classic (student) example assumes the electron is at rest. In practice the electron has momentum which spreads the distribution of angles and energies
  - Can be used as an investigative tool

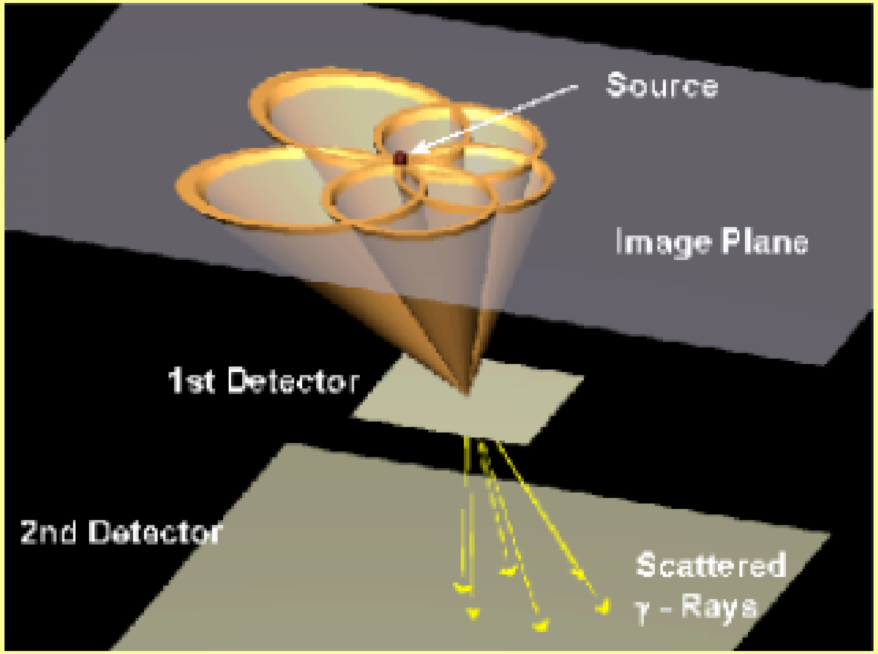


Compton for medical imaging



- Replace the conventional lead collimator (e.g. Anger camera) with an active target

Compton in medical imaging

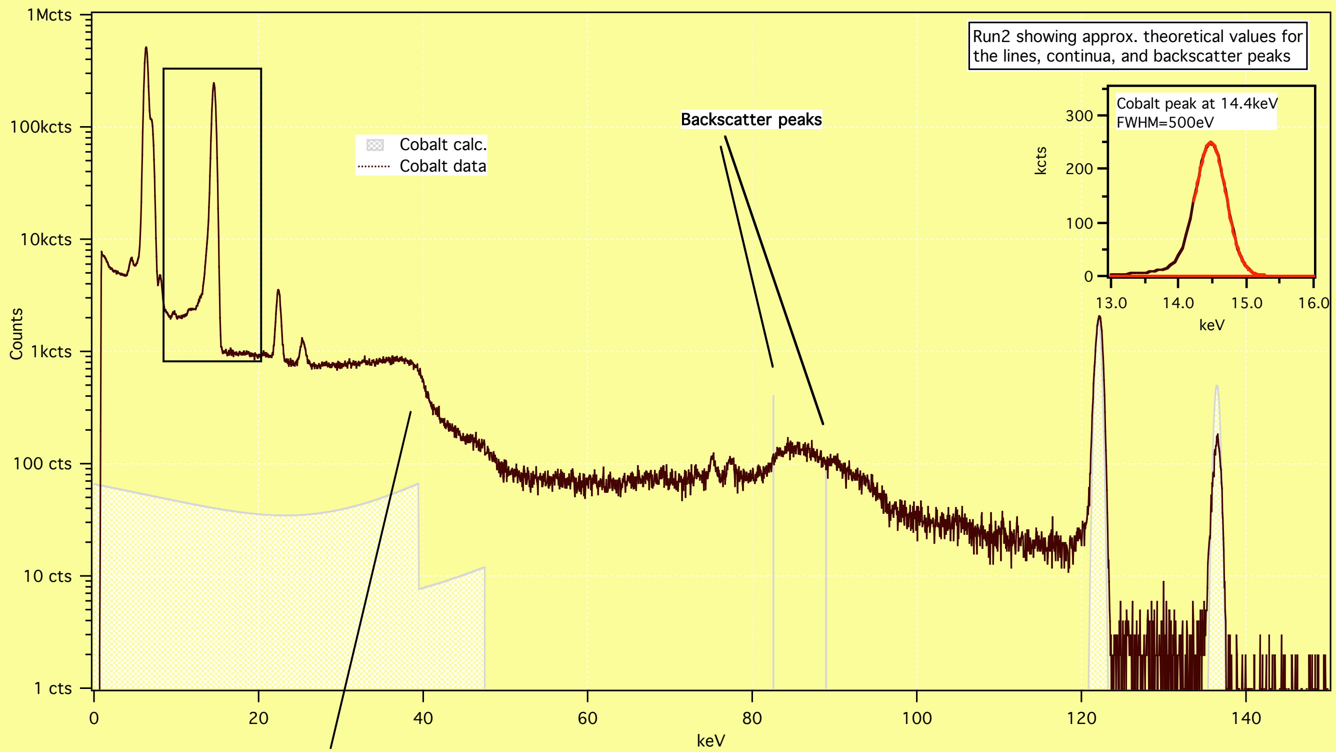


- Knowing the energy of the source and the position of the scatter, cones are reconstructed
  - Measured parameters:
    - x,y,z of first scatter
    - x,y,z of absorption
    - Energy of recoil electron in first detector
    - Energy of scattered photon in second detector

Factors affecting resolution

- Precision in the measurement of the scattering angle Θ depends strongly on the energy resolution in the measurement of the kinetic energy of the recoil electron which is stopped in the first detector
  - May be improved by using a better detector or electronics
- An intrinsic physical limitation is set by the magnitude of doppler broadening

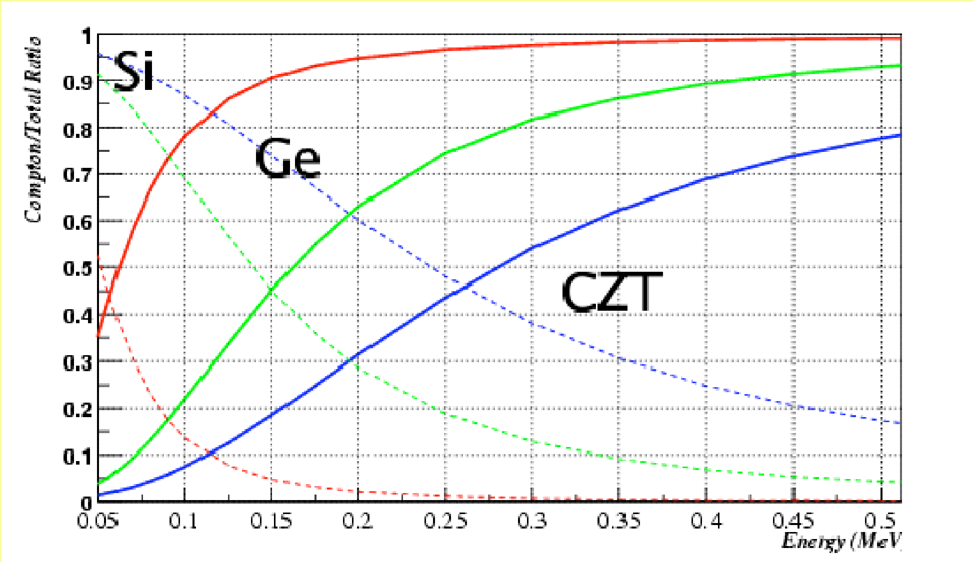
Observation of doppler broadening



Compton edges smeared by ~1keV FWHM

Why silicon?

- Requirements for first detector
  - Excellent energy and good position resolution.
  - Mature processing and wide-spread use
  - Simple operating conditions (hospitals!!!)
  - Robustness.
  - High Compton to photo-interaction ratio
  - Affordable price.



Silicon is a good choice!

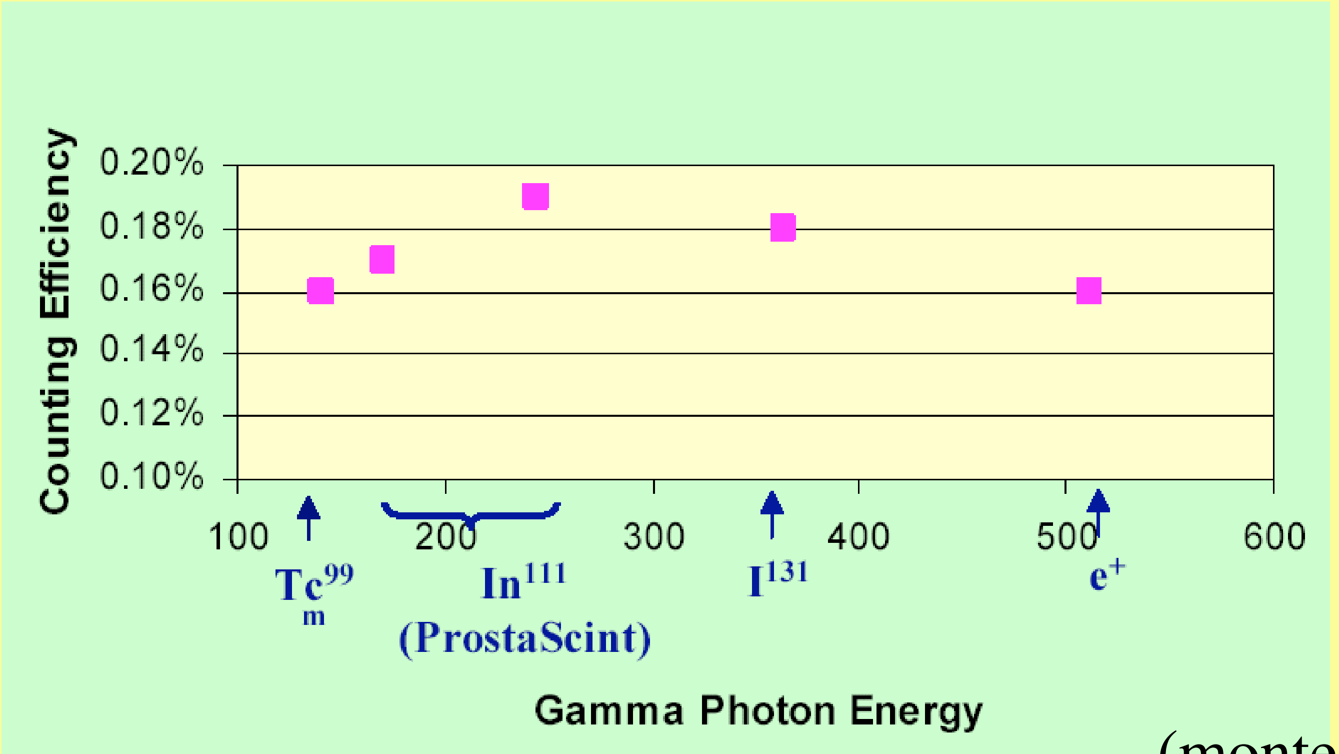
Comparison with conventional techniques

- The Compton Camera concept has great promises to bring improvements over Anger cameras:
  - Very significantly in sensitivity
  - Moderately in image resolution at ^{99m}Tc energy of 140 keV
  - Significant improvement in image resolution at higher isotope energies:~ 5 mm at 15 cm distance

Improvements over conventional methods (using In^{111})

Imaging Distance: 10cm	Efficiency	Resolution
Compton probe	1.8×10^{-3}	2.47mm
High sensitivity collimator	1.11×10^{-4}	15.9mm
High resolution collimator	4.0×10^{-5}	10.5mm

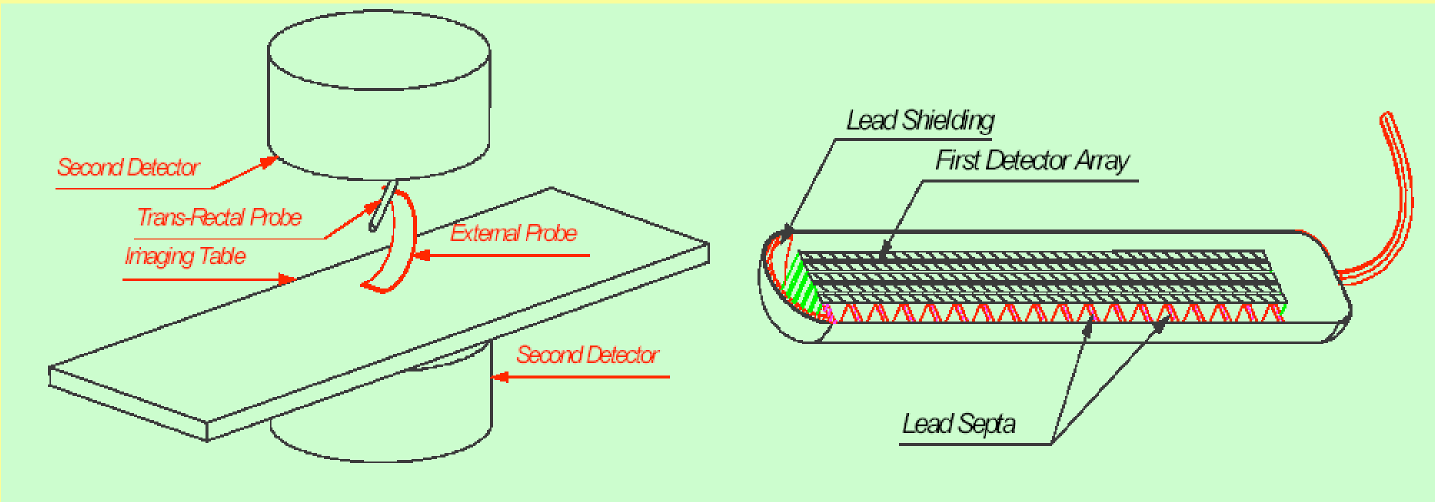
Efficiency with various probes



(monte carlo)

Specific applications

Prostate probe and scinti-mammography probes have been investigated in simulations

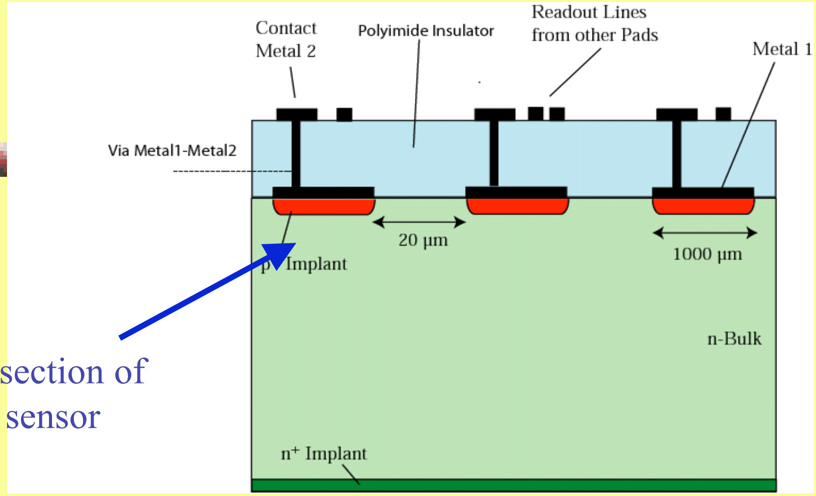


Elements of a prototype

- The primary sensor
  - Silicon pad sensor
  - 15mm stack
- Connections
  - Tab bonding (Kharkov)
- The chip
  - VATAGP(X)
  - Self triggering, analogue
- Secondary detector
  - Standard PET head

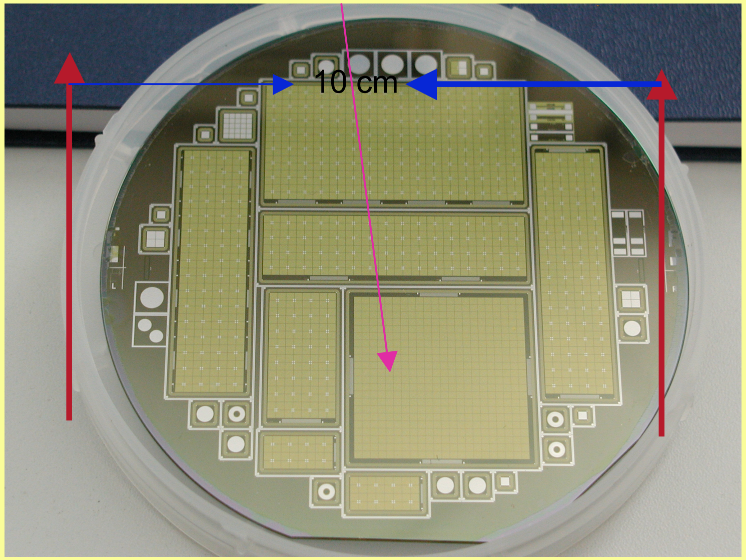
The Silicon Pad Sensors

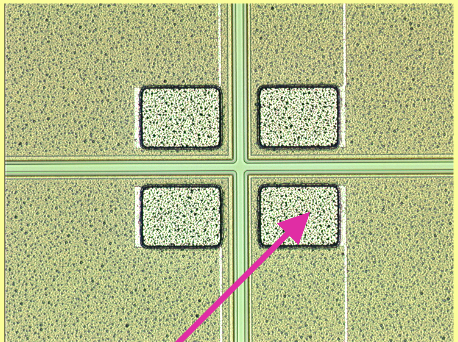
All possible solutions need to be cheap and standard technology readily available in Industry.
Modifications to a technology need to be available in the standard industrial processes



Schematic cross section of double metal pad sensor

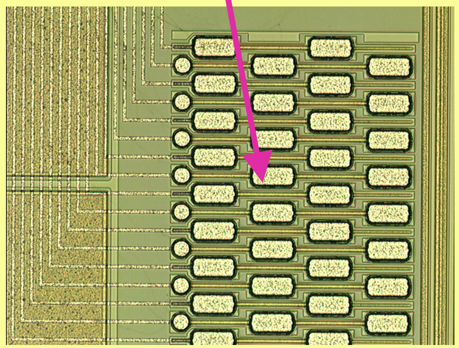
A processed wafer 1mm thick



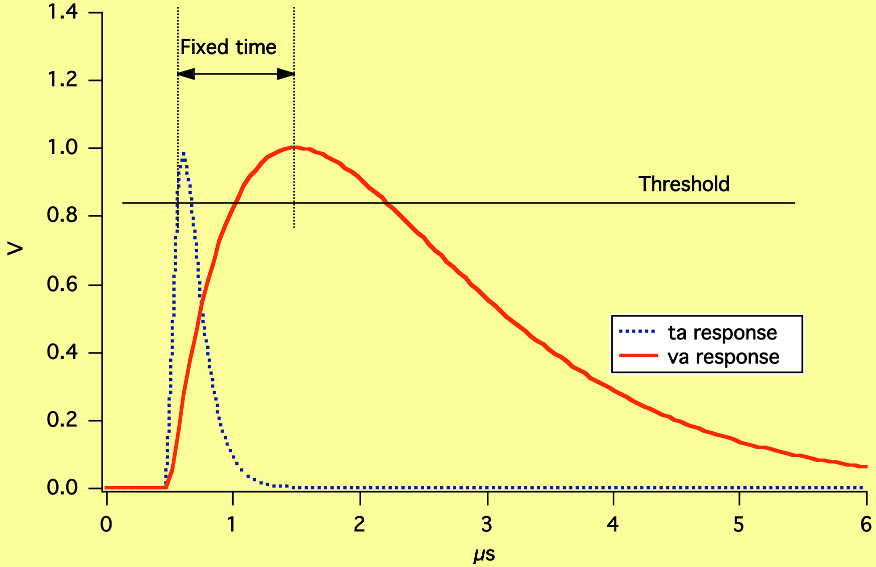


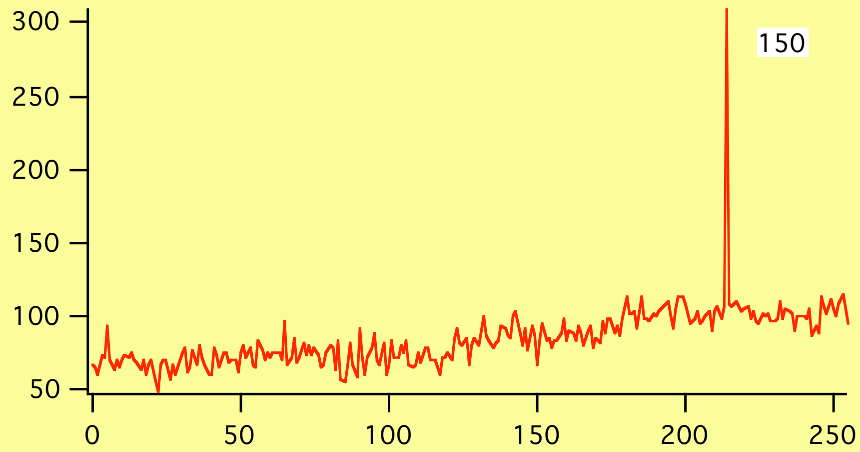
Details of routing technology on pads via double metal vias

Routing lines end at external bond pad rows for connection to readout chip



Chip functionality





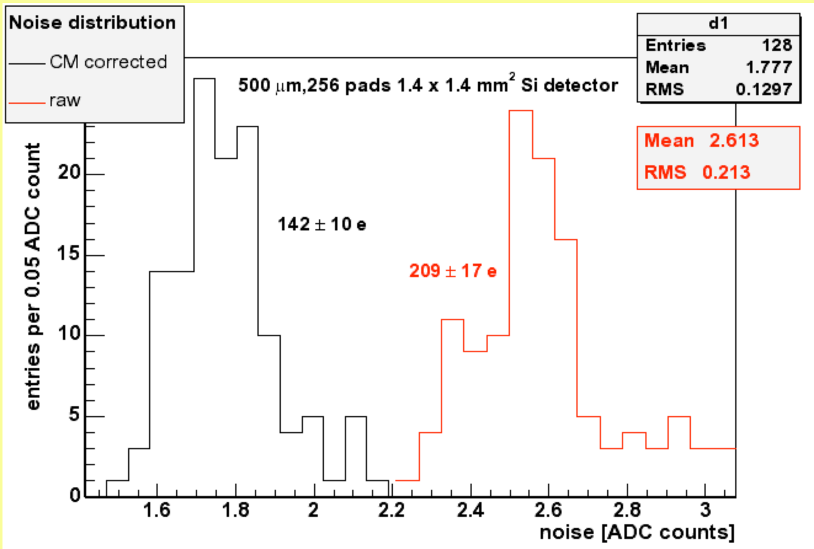
Fast shaper fires a discriminator, OR-ed on all channels.

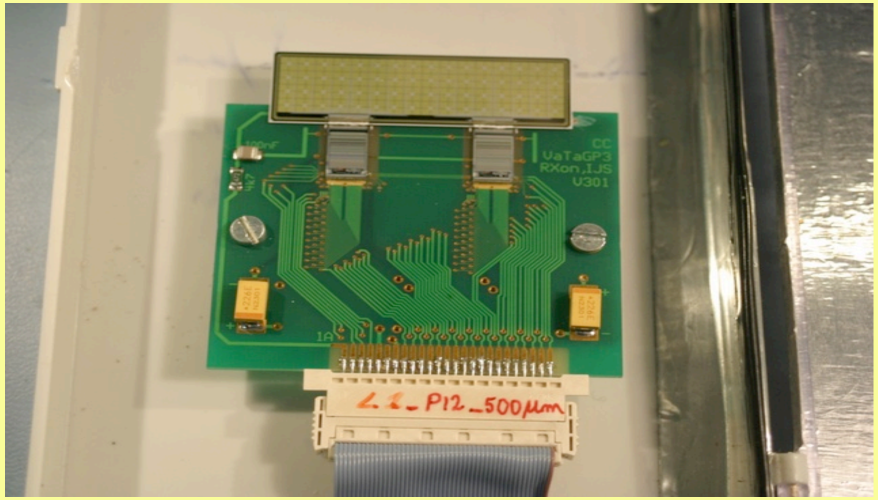
Peak of slow shaper is recorded for each channel (sparse readout is possible)

Setup:primary detector

Primary detector module exists in prototype form

Noise performance is excellent





Primary detector: noise performance

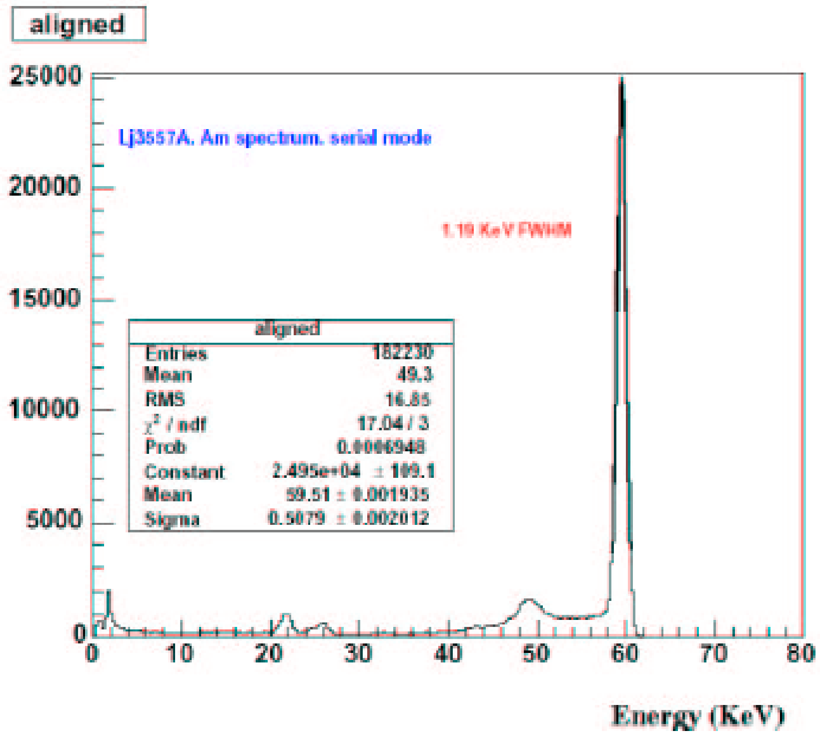
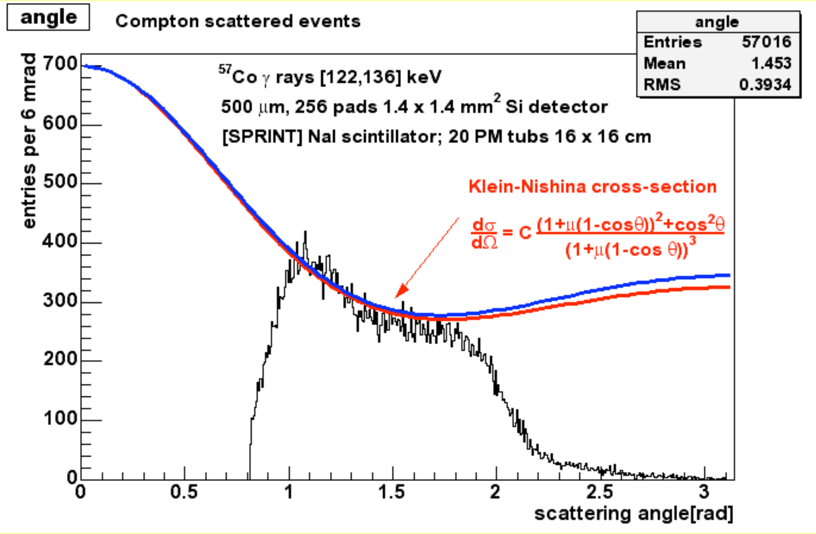
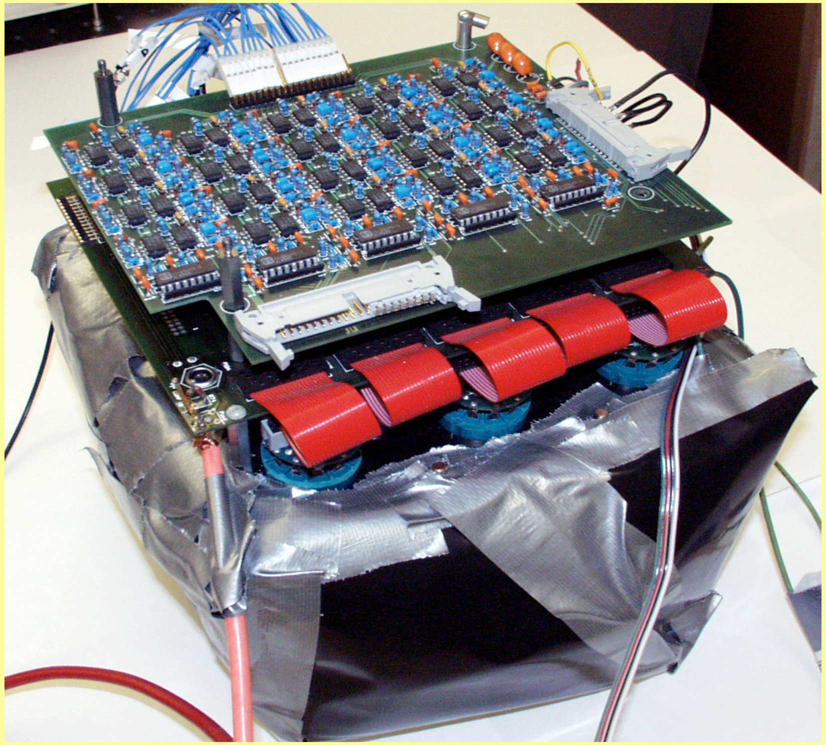


Fig. 1 Am spectrum measured with one of the detectors showing 1.2 KeV resolution.

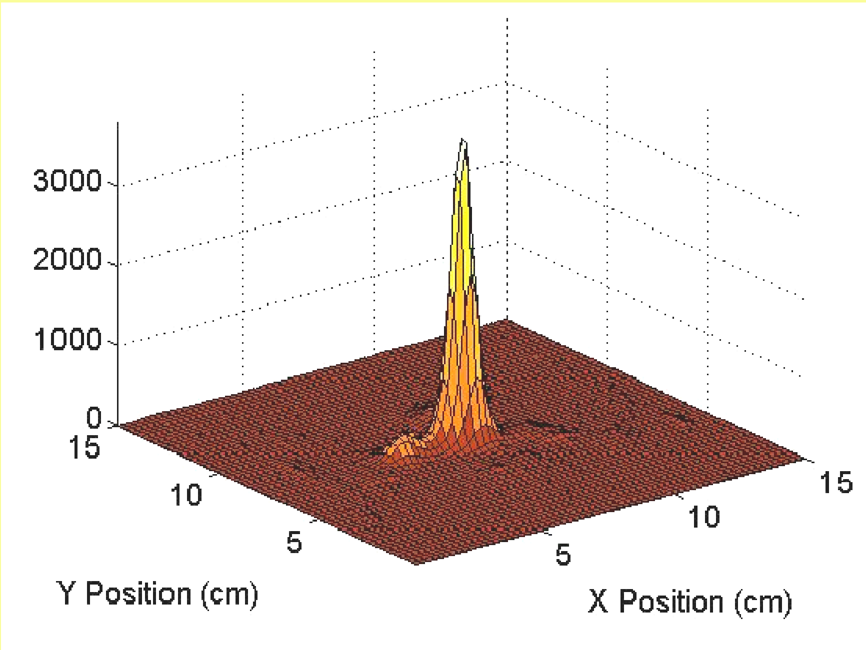
Setup:secondary detector

- Standard PET head
  - Array of scintillator/PM tubes





Results!



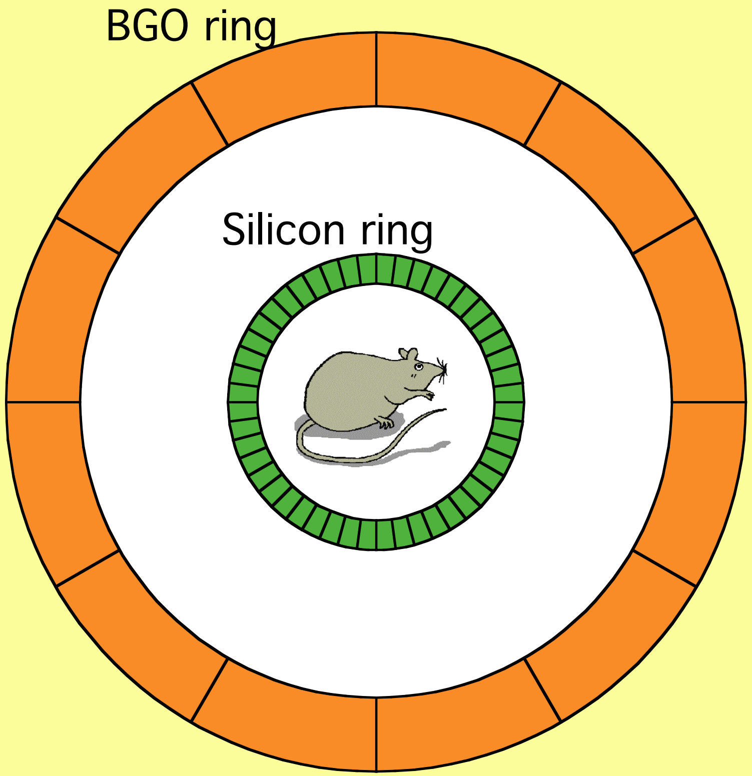
- Real resolution results 3 yrs old, from ^{99m}Tc
  - Non ideal sensors
  - Resolution 8.2mm @ 11cm
  - =>could get 4mm today

Forthcoming…

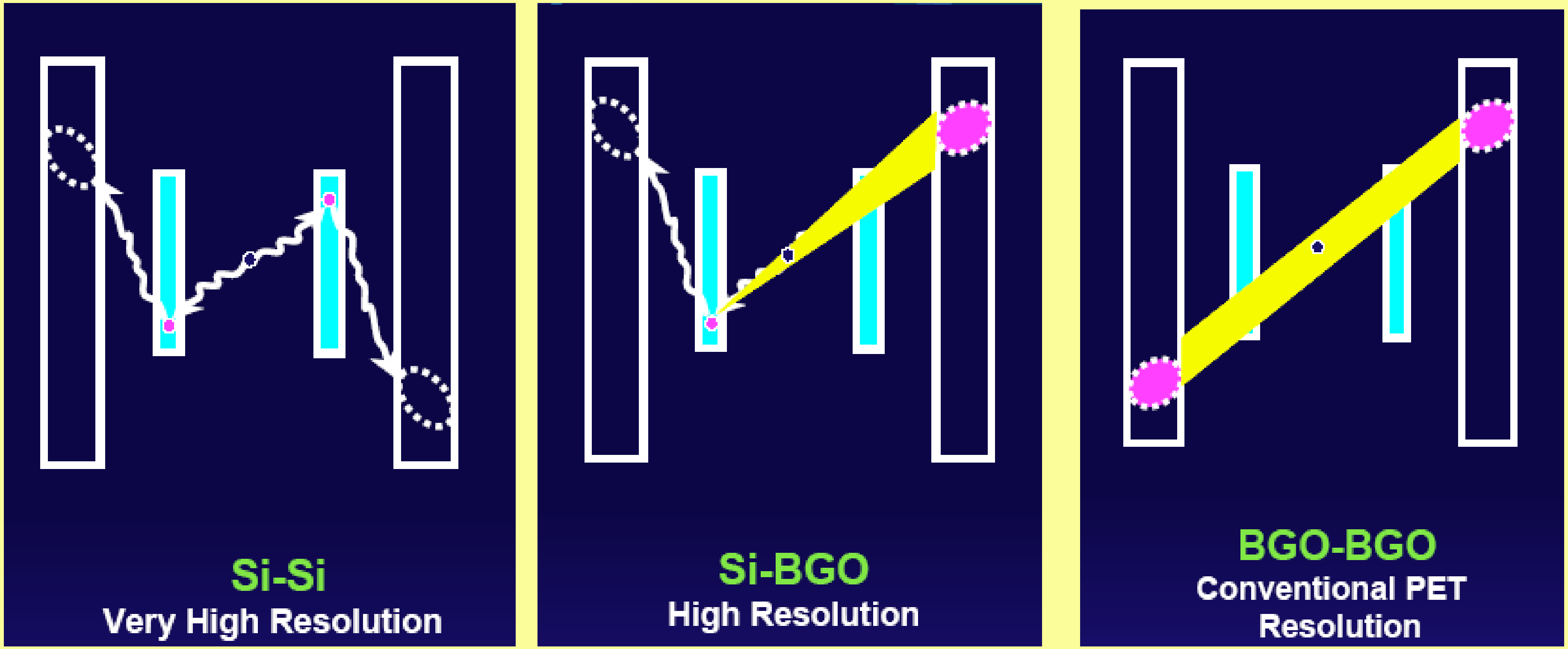
- Tests with new, 'perfect' 1 mm thick silicon pad detectors, with better performance than the specifications and almost final front-end chips have been started at CERN recently. The first results suggest that the simulated performance for the prostate probe can be reached.

Small animal PET

- Possibility to enhance conventional PET using active collimation
  - Greater resolution
  - Reasonable efficiency



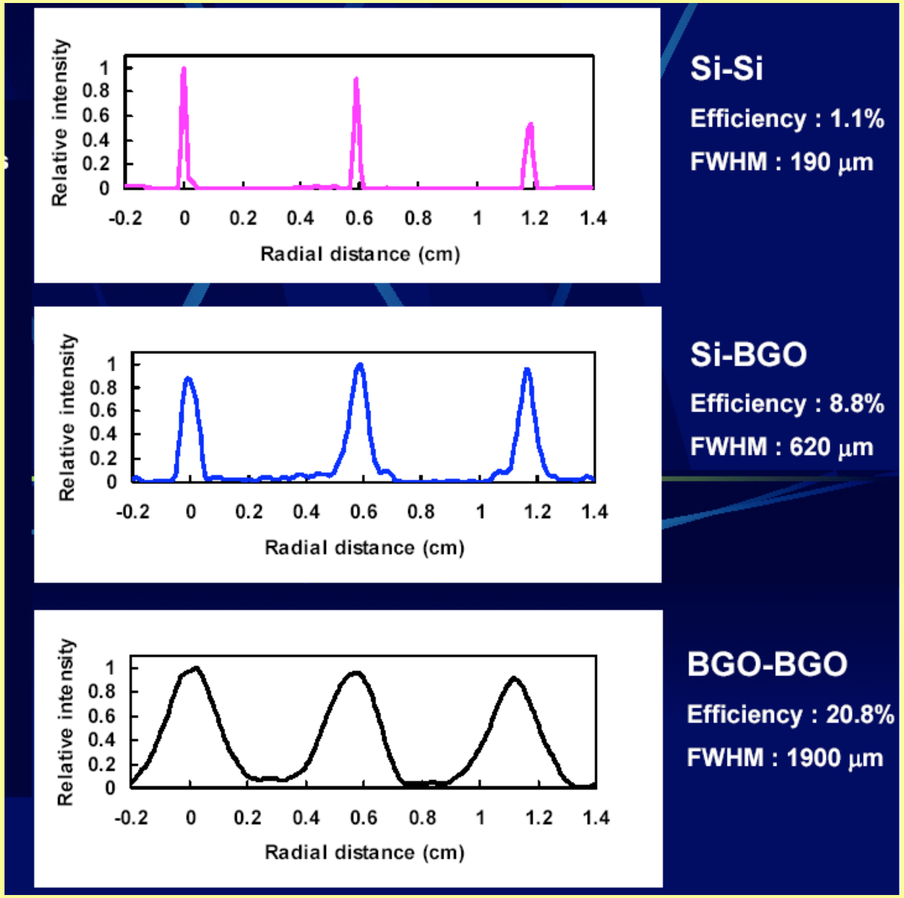
Events considered

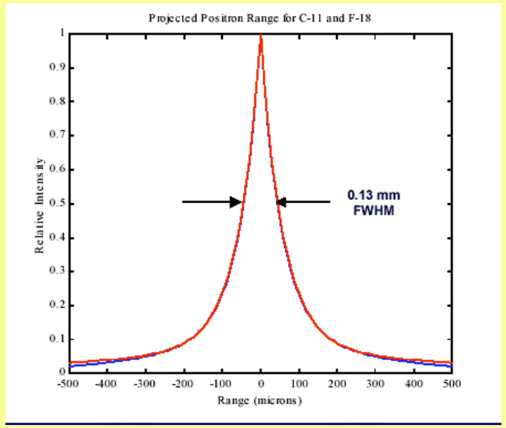


Efficiencies

	Detection Efficiency (%)		
Radial Posn. (mm)	Single – Single	Single – BGO	BGO - BGO
0	1.05	8.83	20.84
6	0.96	8.96	20.69
12	1.04	8.94	19.70
18	1.19	9.06	18.17

Resolutions





(not including Positron range)

Small animal pet

First 'real' compton imager?

Conclusions

Compton-PET appears promising for small animal imaging

- Outstanding resolution potential
- Can have high efficiency
- Still a long way to go
- Many channels of electronics –pad detectors may not be best choice
- Packaging and cooling silicon detector and electronics an issue
- Coincidence timing and ambiguity resolution needs investigation