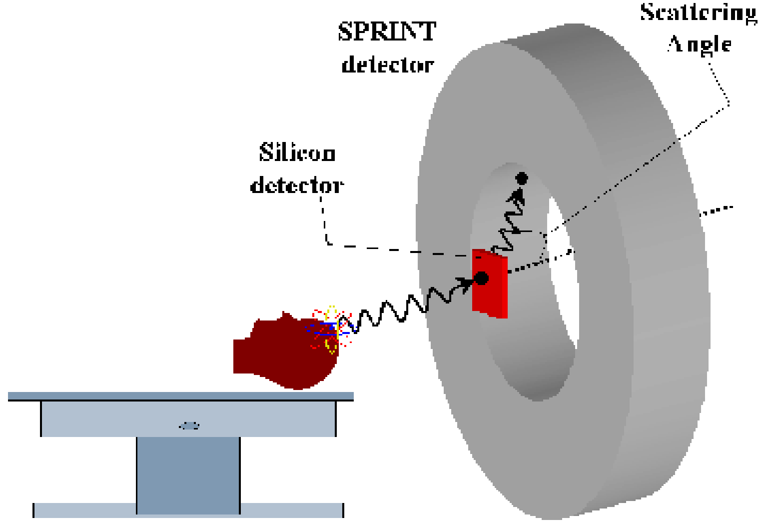
First Coincidences in a Pre-Clinical Compton Camera Prototype for Medical Imaging

Andrej Studen,
Jožef Stefan Institute
for
CIMA collaboration



Outline

• Why Compton collimated imaging for medical applications?

• Promising results of our prototype.

• Simulations proving Compton collimation based devices useful at combating cancer .

Single photon emission imaging

Radio tracers – atoms emitting γ rays.

Source	Energy [keV]	Half-life [min]
99m Tc	140.5	6 h
111 In	245	2 days
131 I	364	8 days
22 Na, 18 F, 11 C, 15 O	511	950 days, 1.8 h

Bonded to a bio-molecule (glucoses,enzymes,...)

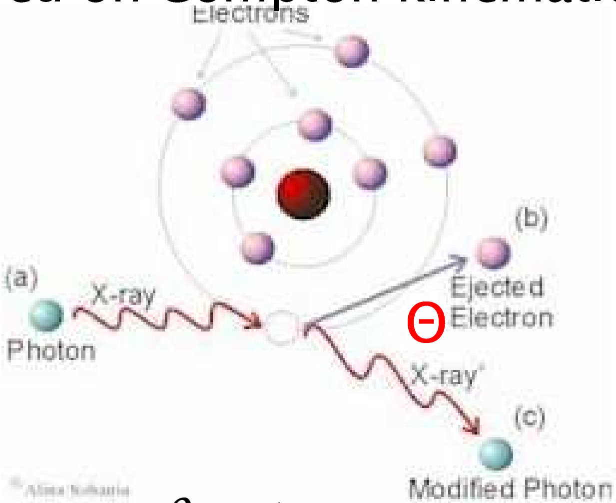
Detecting the spatial distribution of the sources is detecting the spatial distribution of the bio-molecule.

In vivo imaging of the bio-molecule metabolism in humans and animals.

Compton collimated medical imaging

AIM: To detect the spatial distribution of the radio tracers

Reconstruction of the scattering angle based on Compton kinematics.



$$\sin^2\frac{\theta}{2} = \frac{1}{\mu}\frac{\epsilon}{1-\epsilon}$$

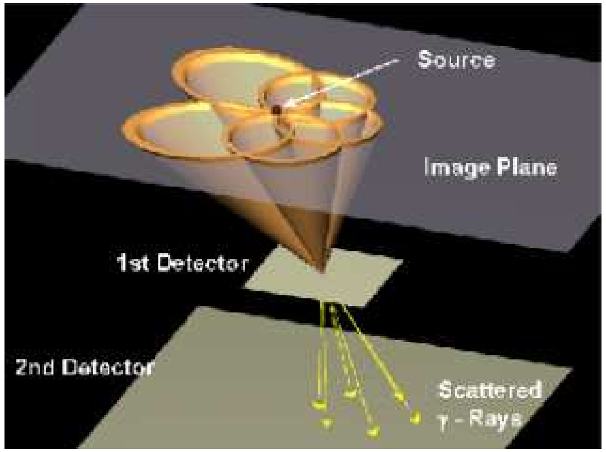
Θ – scattering angle

ϵ – fraction of the initial photon energy transferred to the electron

μ – energy of the initial photon in units of the electron rest mass

Two detectors:

a scatterer(1st) and an absorber(2nd).



→ Measure: ϵ, two interaction points → The cone with opening angle θ

Intersections of the cones reconstruct the 3D spatial distribution of the sources.

Requirements - -resolution

Resolution of the reconstruction:

- scattered photon track (spatial resolution of both detectors)
- scattering angle (most challenging):
  - energy resolution in scatterer
  - Doppler broadening

Energy resolution Δε

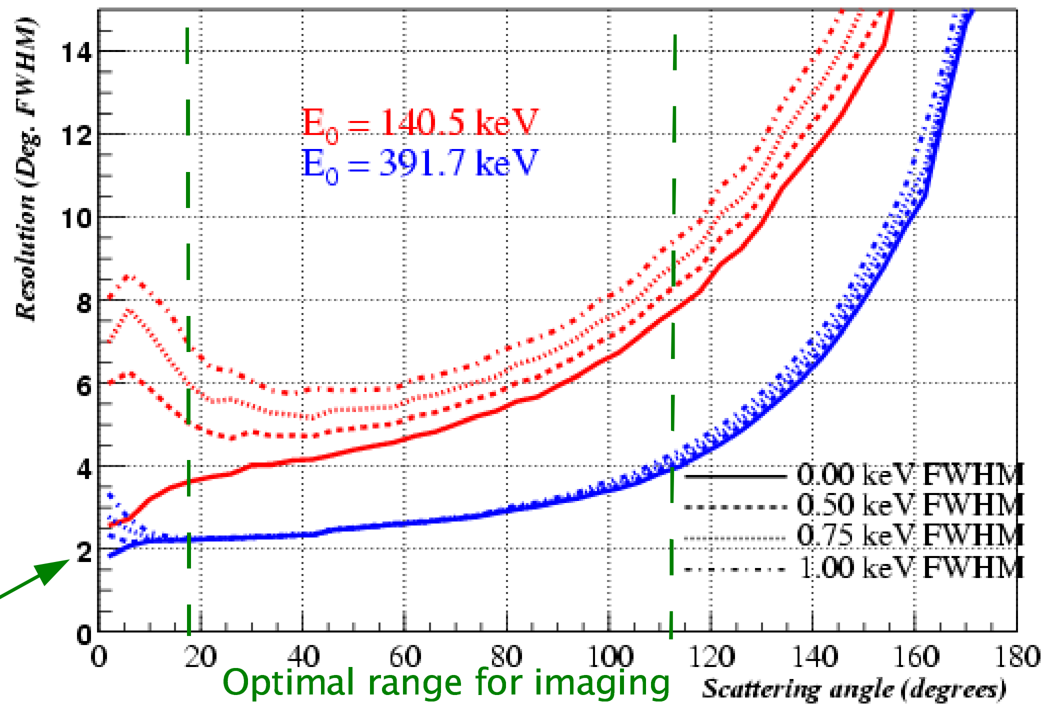
$$\sin^2\frac{\theta}{2}=\frac{1}{\mu}\frac{\epsilon}{1-\epsilon} \longrightarrow \Delta\theta=\frac{1}{\sin\theta}\frac{\Delta\epsilon}{\mu(1-\epsilon)^2}$$

Doppler broadening

Bound electron has a non-negligible kinetic energy.

1 mm res.
3 cm from detector

Angular resolution combined (Si)

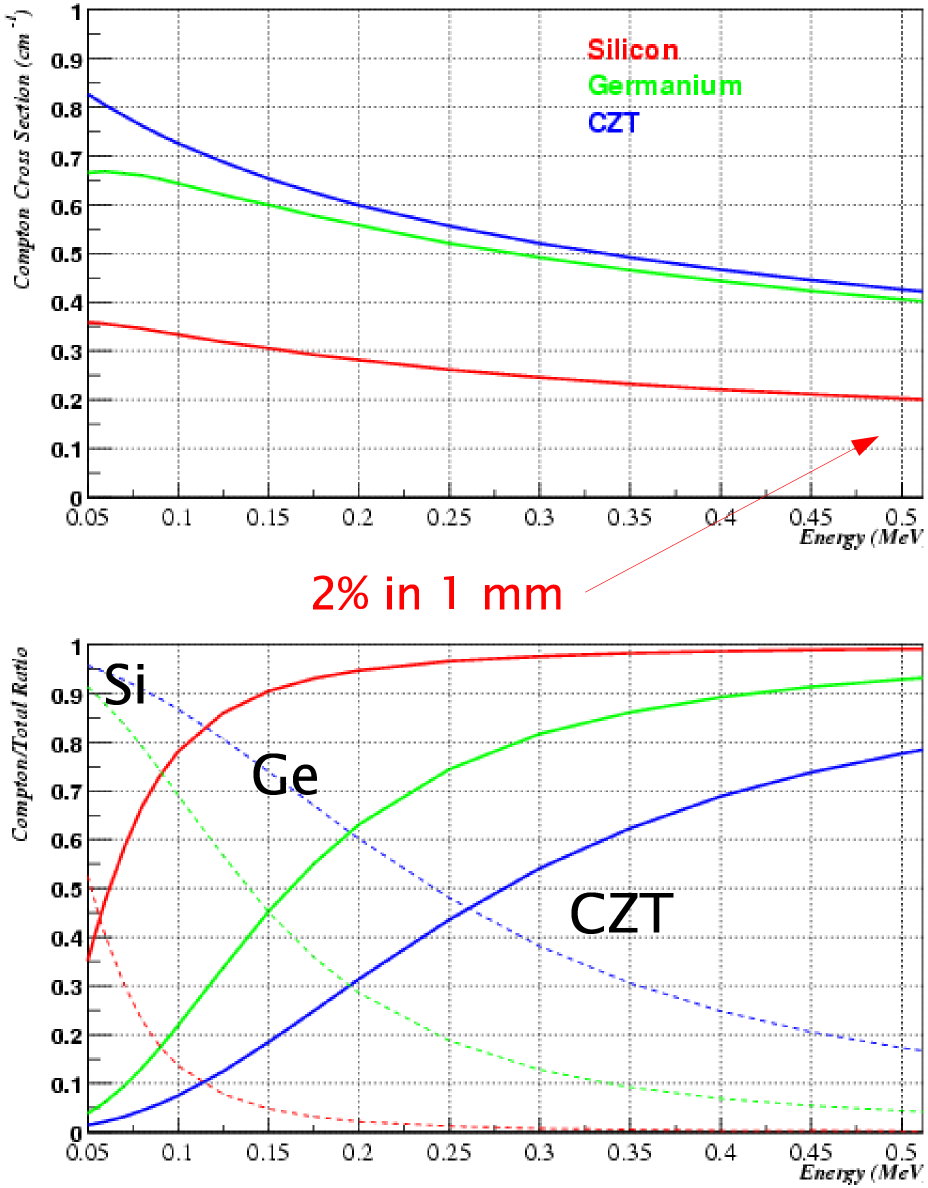


Resolution on electron energy in the scatterer should not be worse than 1 keV FWHM for resolution on a mm scale.

Requirements – Si as a scatter detector

- Good energy and position resolution.
- Mature processing and wide-spread use.
- Simple operating conditions (hospitals!).
- Robustness.
- High Compton to photo-interaction ratio (but low interaction probability).
- Reasonable price.

Silicon seems a good candidate!

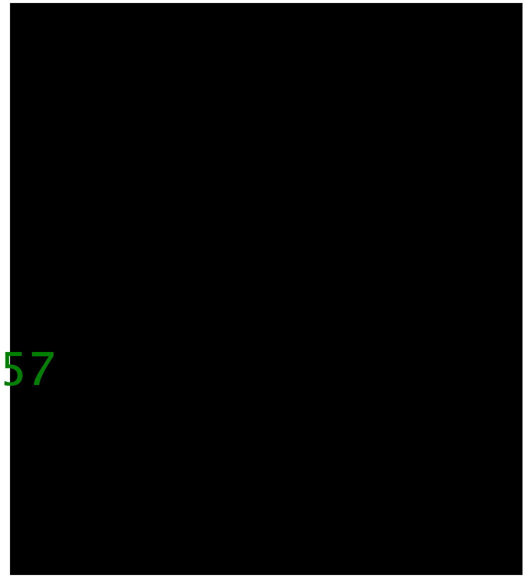


Requirements – Absorber: NaI coupled to PM tubes

- Good efficiency for photo-absorption.
- Good spatial resolution.
- Energy resolution not crucial.
- Simple and ready to use, on the market for 50 years.
- Wide-spread use in medical imaging.

Scintillator-PM modules should do the job.

Comparison with present imagers



Hal Anger, 1957

Siemens, 2000

- Mechanical collimation: trade-off of efficiency vs. spatial resolution.
- "Electronic" collimation in Compton camera (no mechanical collimation needed, no trade-off) increases efficiency for a few orders of magnitude at 5 times better spatial resolution.

BUT:

- Technically demanding.
- Demanding image reconstruction.

SETUP – Outline

Scatter detectors:

sensors, electronics, trigger.

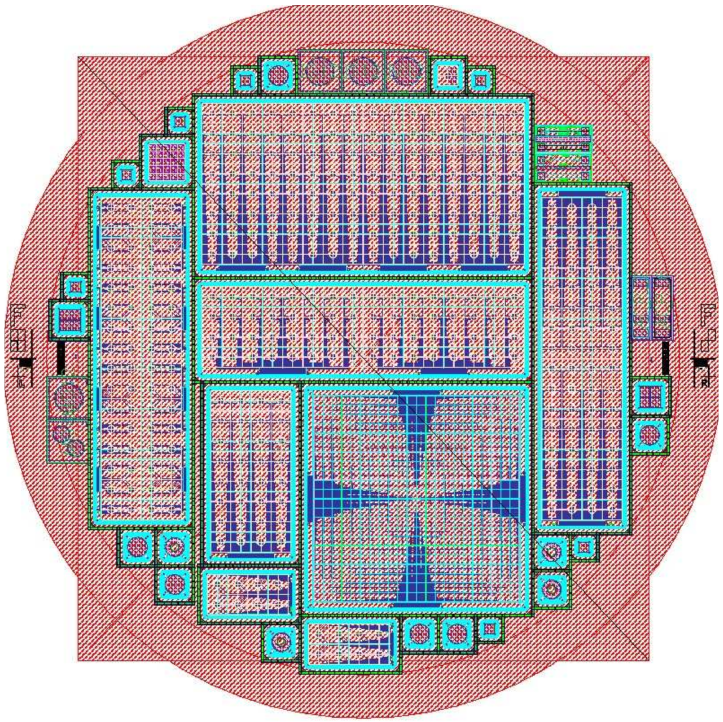
Absorber:

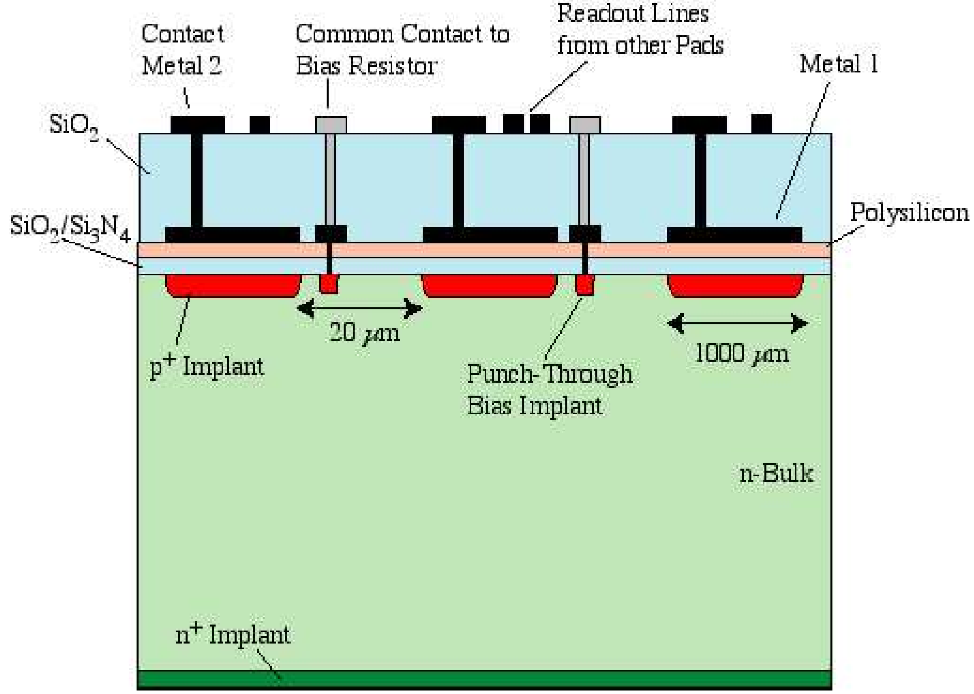
crystal, electronics, trigger.

Coincident setup:

readout, timing properties, reconstruction.

Silicon sensors



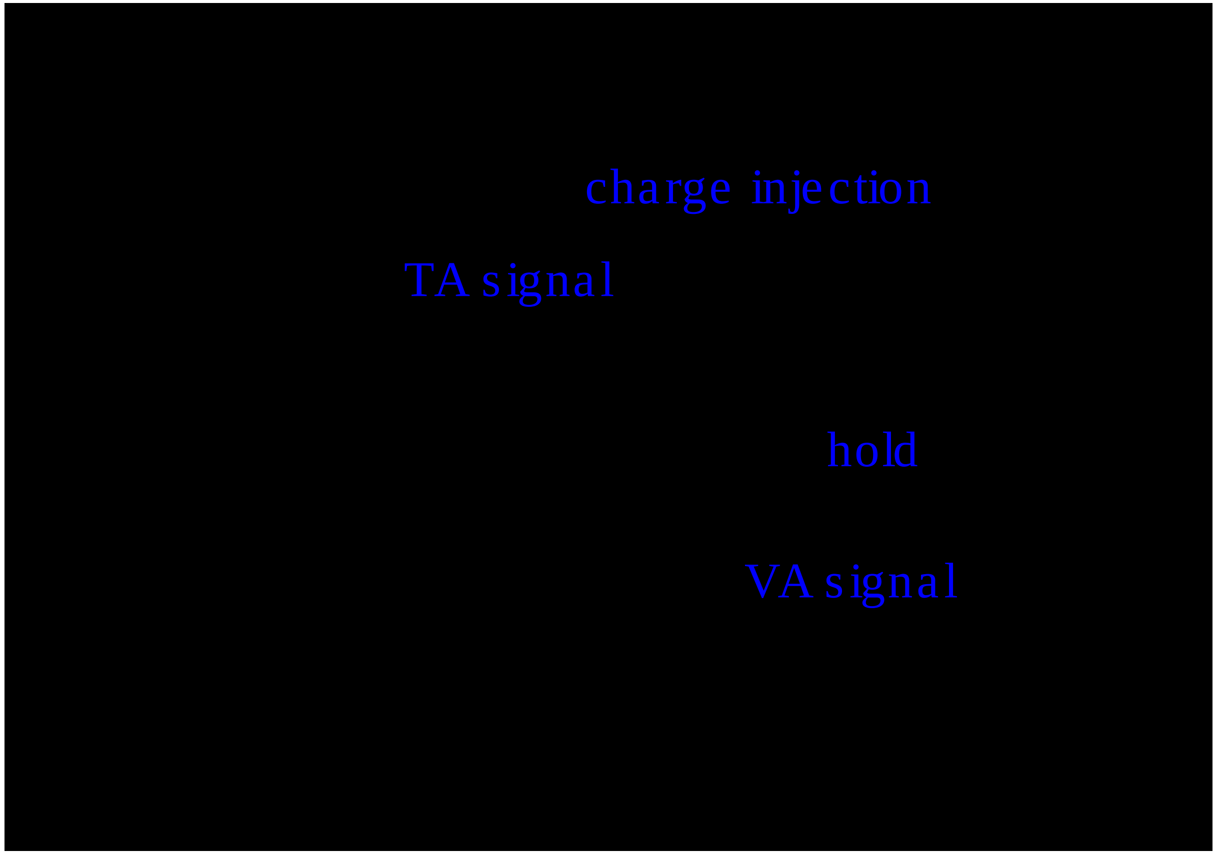


- SINTEF, 0.5 mm & 1 mm thick
- 1.4 x 1.4 mm^2 pads, double metal
- Currents less than 100 pA/pad measured
- DC coupled

Front-end electronics - VATAGP3

VATAGP3(IDEAS, Norway):

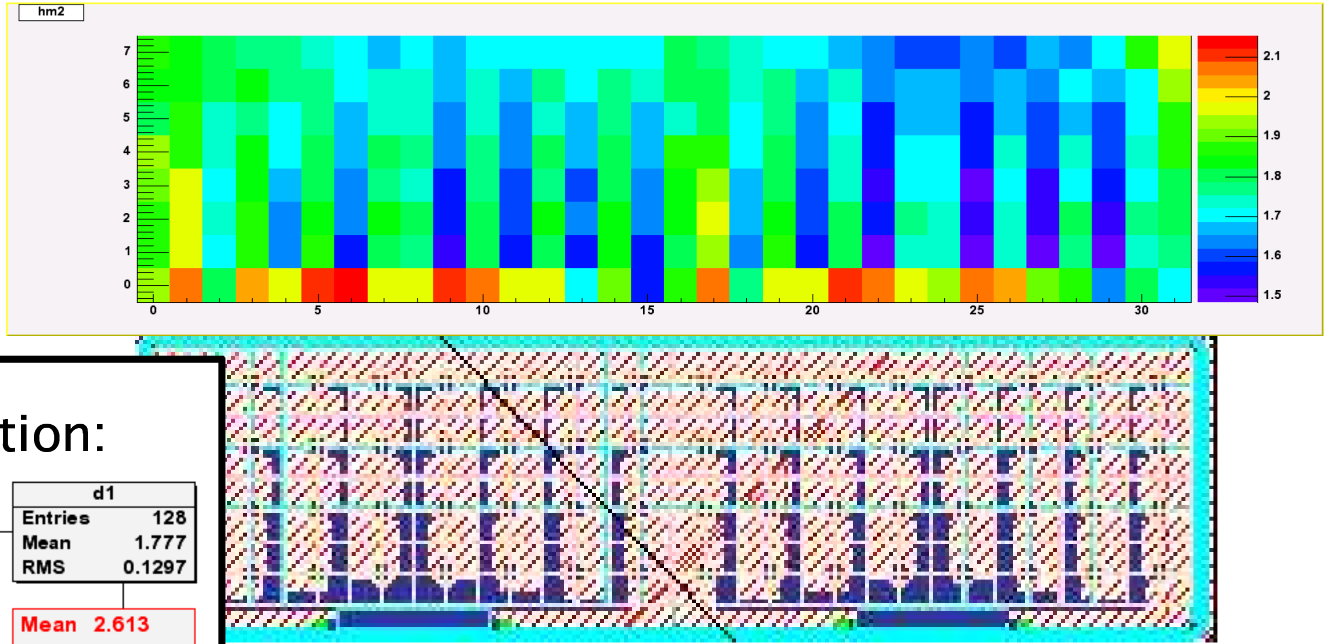
- 128 channels, amplifiers and shapers.
- Low-noise, self-triggering
- Shaping time of 150 ns for trigger.
- Shaping time of 0.5-5 μs for analog output.
- Sample & Hold.



VA part

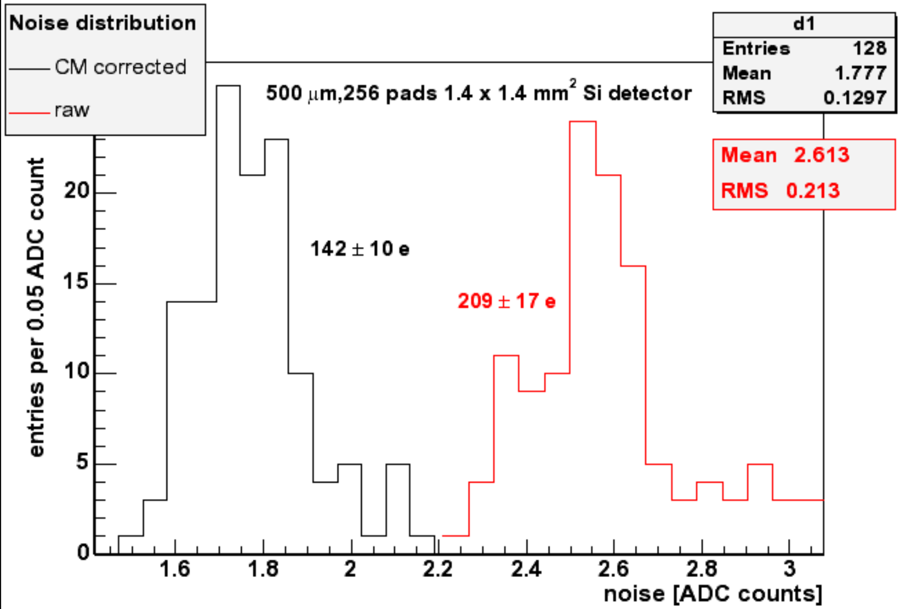
CR-RC shaping, shaping time of 4 μs selected

Measured noise, mapped to detector:



Noise correlated to 2nd metal layer capacitance

Measured noise distribution:



Current contribution less than 100pA
@ 4 μs : less than 45 e ENC -> small

σ_{total}=142 e ENC ->1.2 keV FWHM -> quite good!

TA part – the trigger

CR-RC shaping, 150 ns shaping time.

Noise: 500 e ENC.

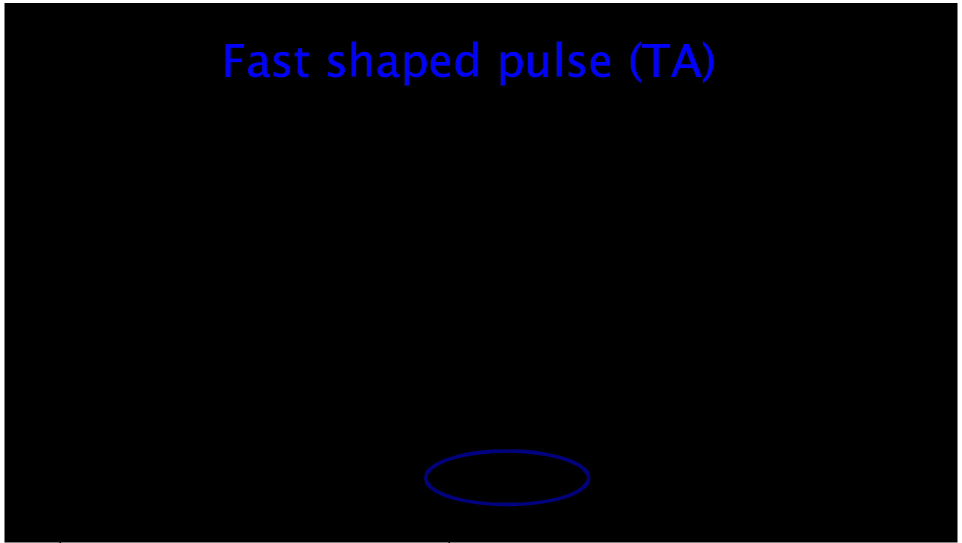
Time-walk and jitter spread the timing of the pulse.

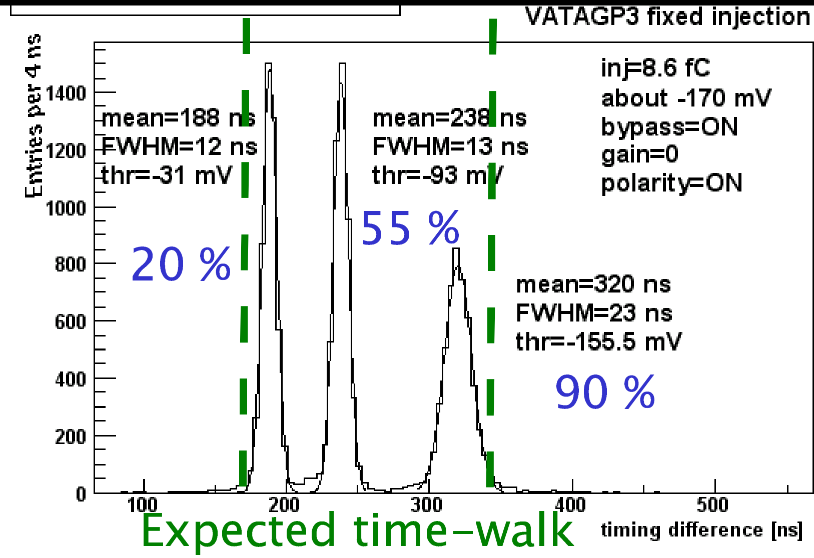
No on-chip time-walk compenstaion.

Predicted time-walk of 150 ns.

Measured jitter from 12 to 23 ns FWHM.

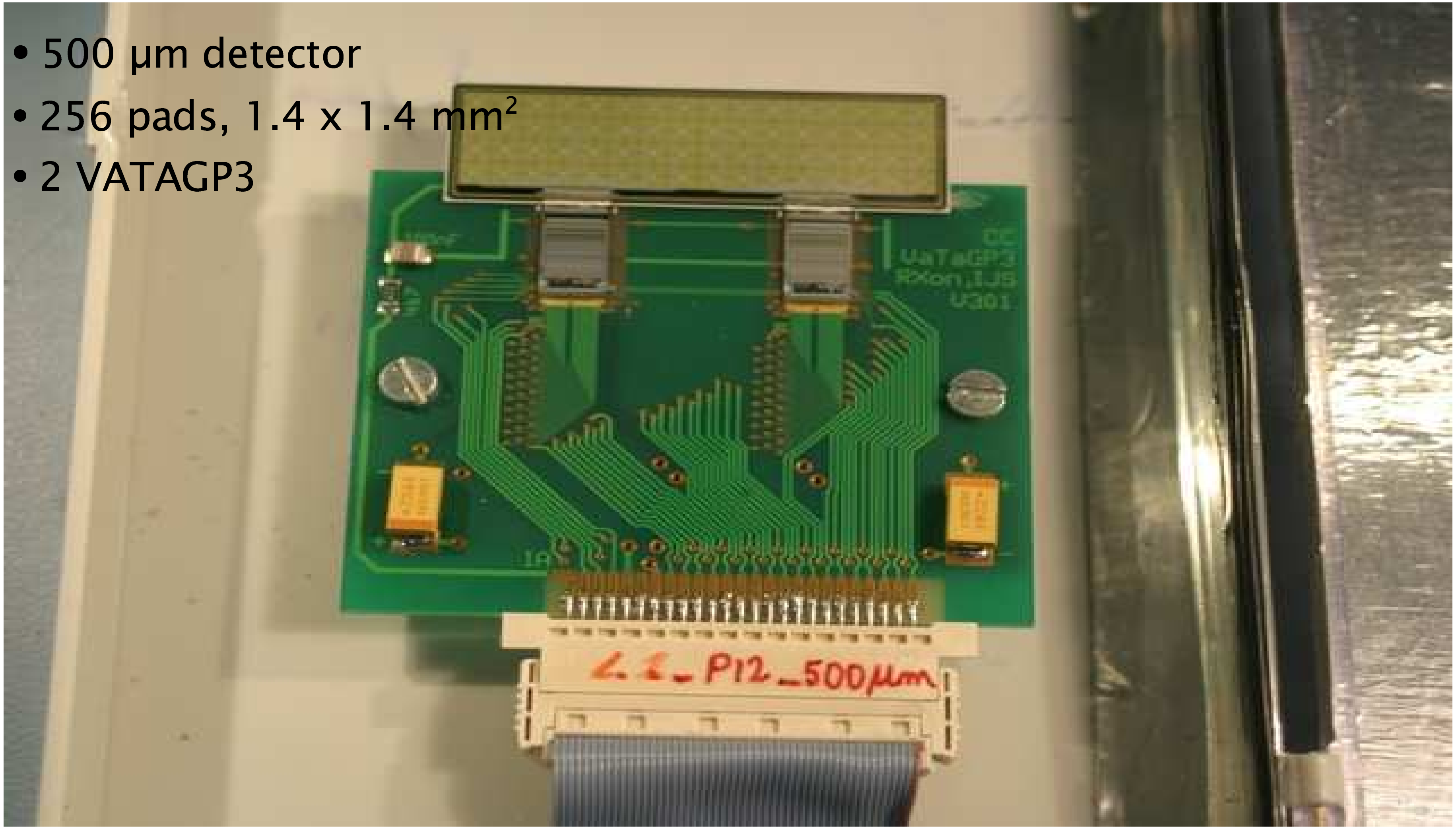
Essential for coincidence time-window!





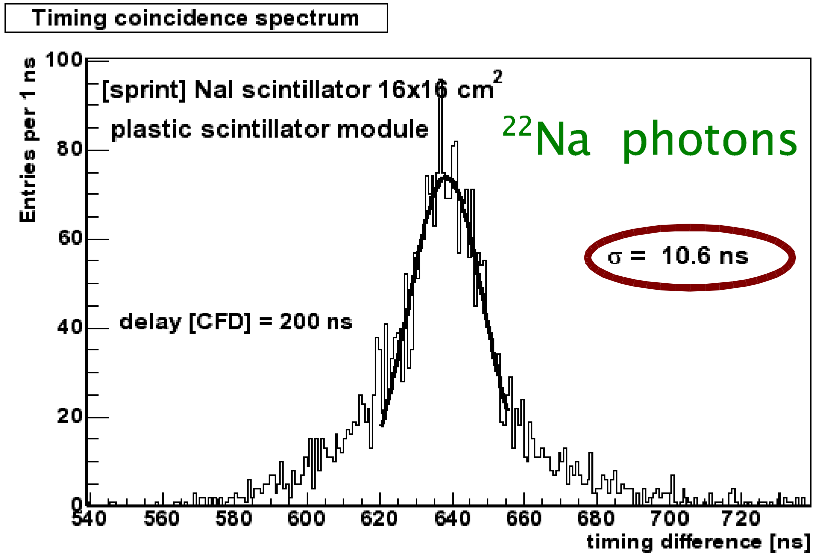
Scatter detector module

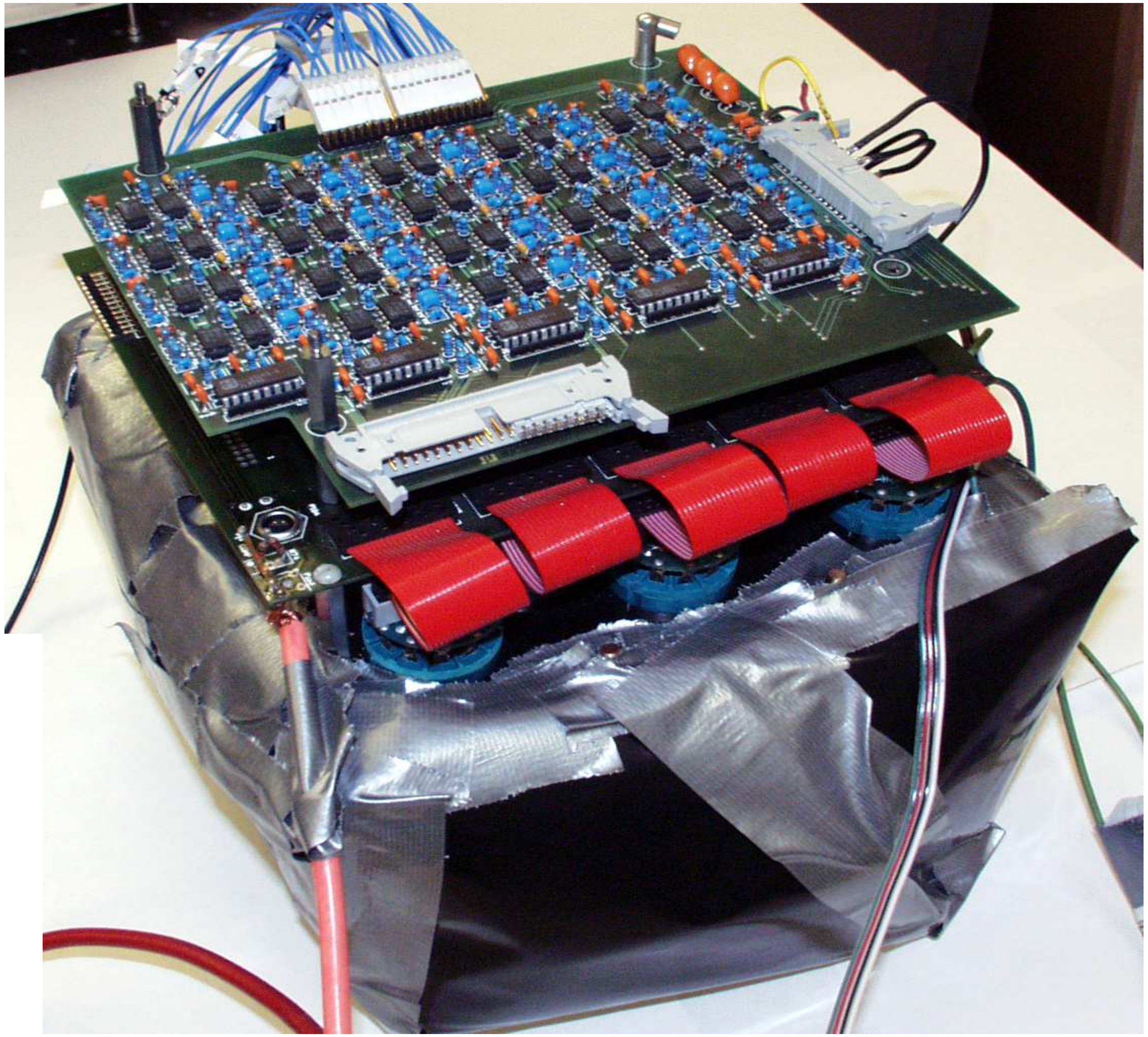
- 500 μm detector
- 256 pads, 1.4 x 1.4 mm^2
- 2 VATAGP3



Absorber module

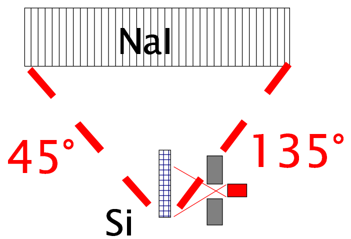
- 16 x 16 x 1 cm^3 block of NaI
- 20 PM tubes with 500 ns shaped output
- Summing amplifiers
- Trigger on CFD on 500 ns shaped hardware energy sum -> timing!

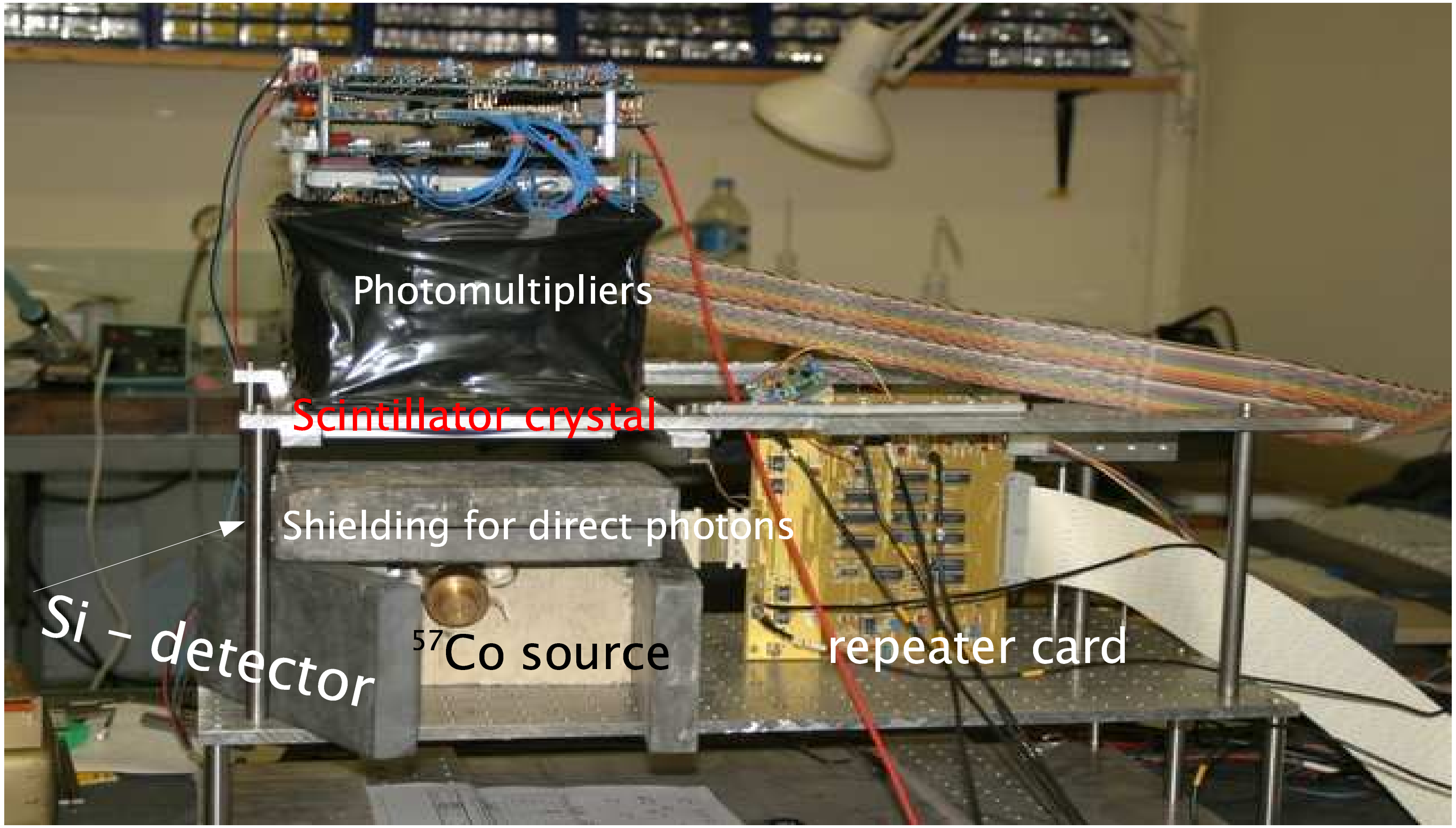




Compton camera setup

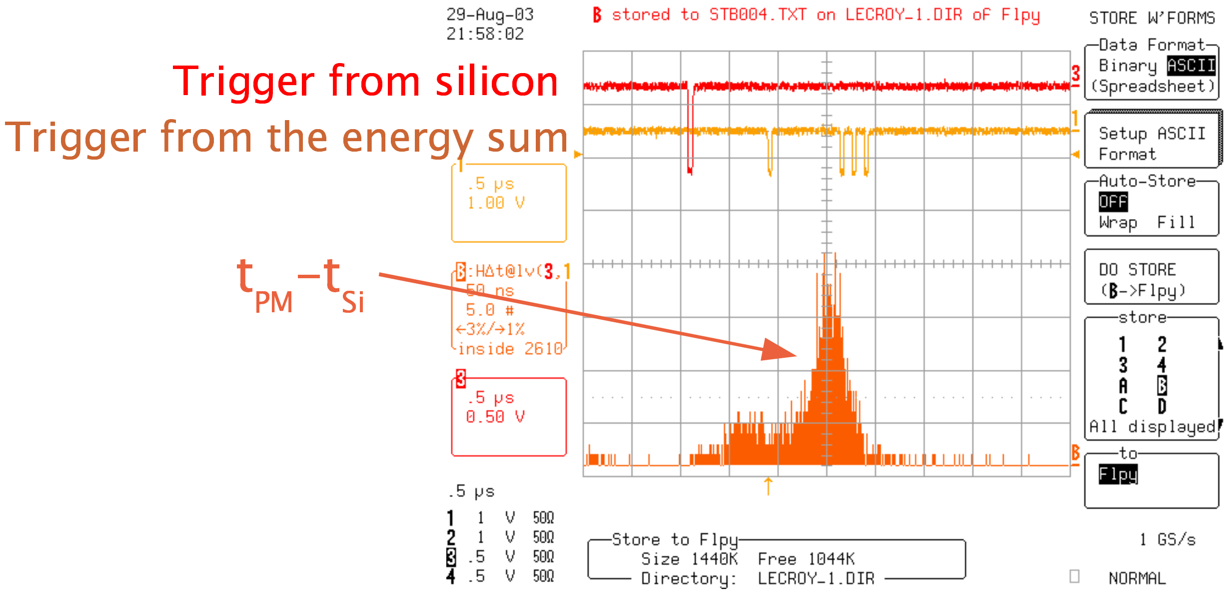
View from the side

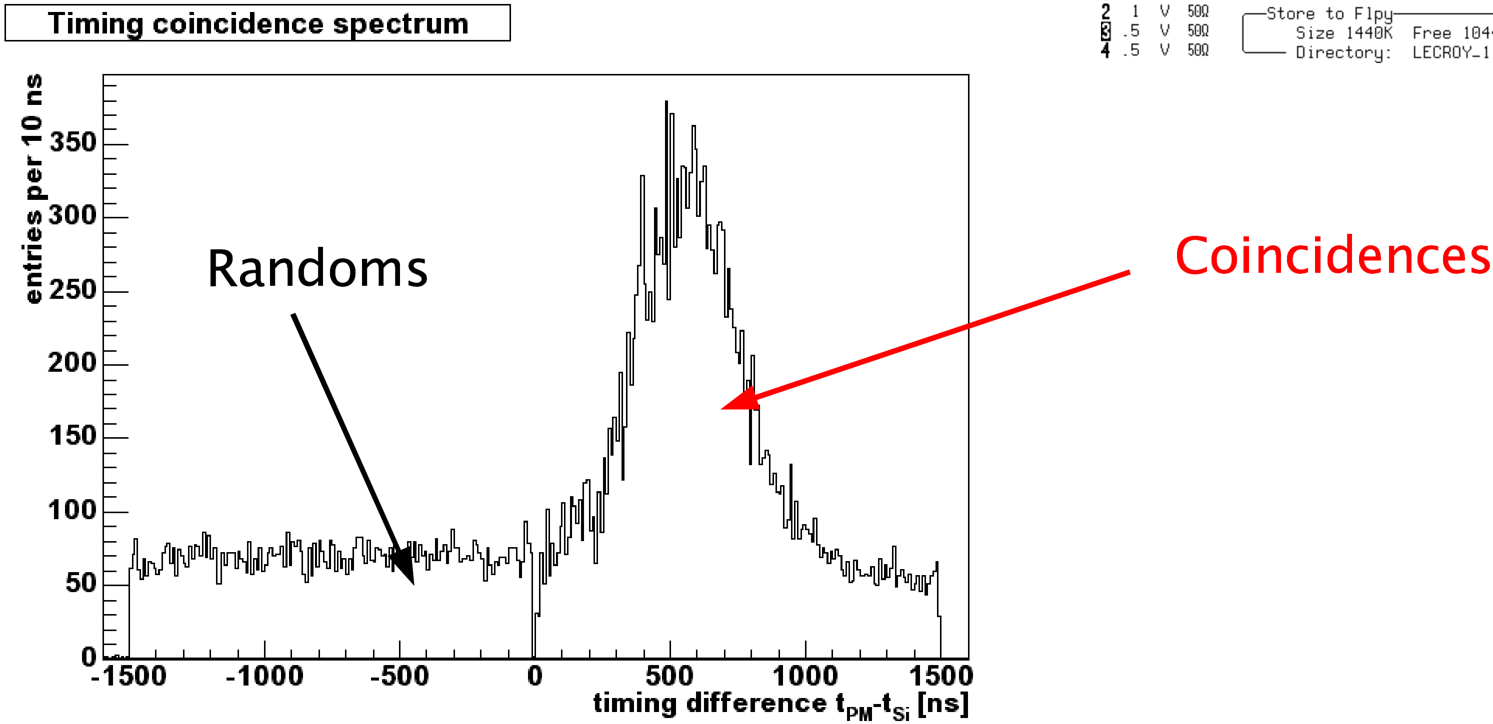




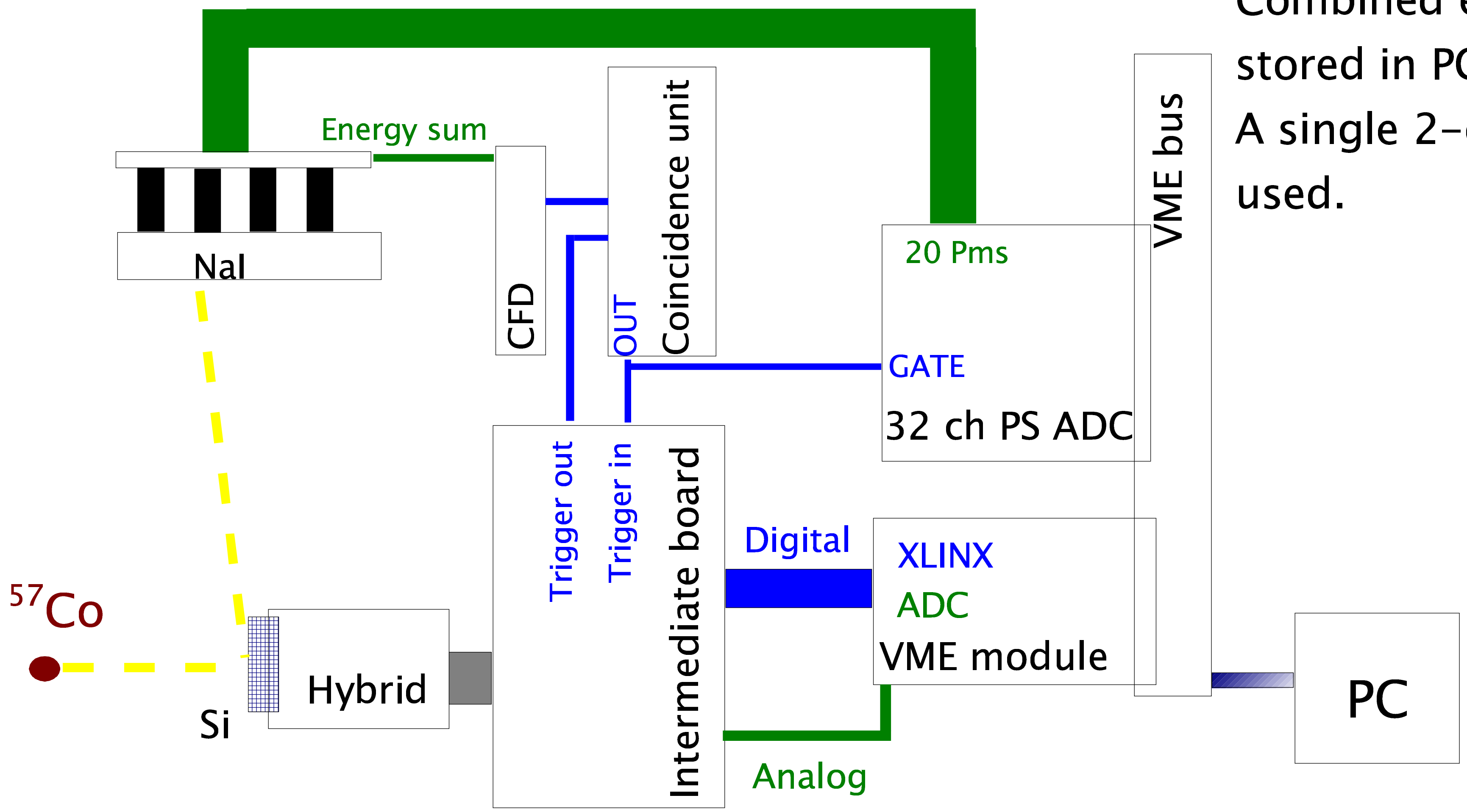
Coincidences

Timing correlation on the oscilloscope.





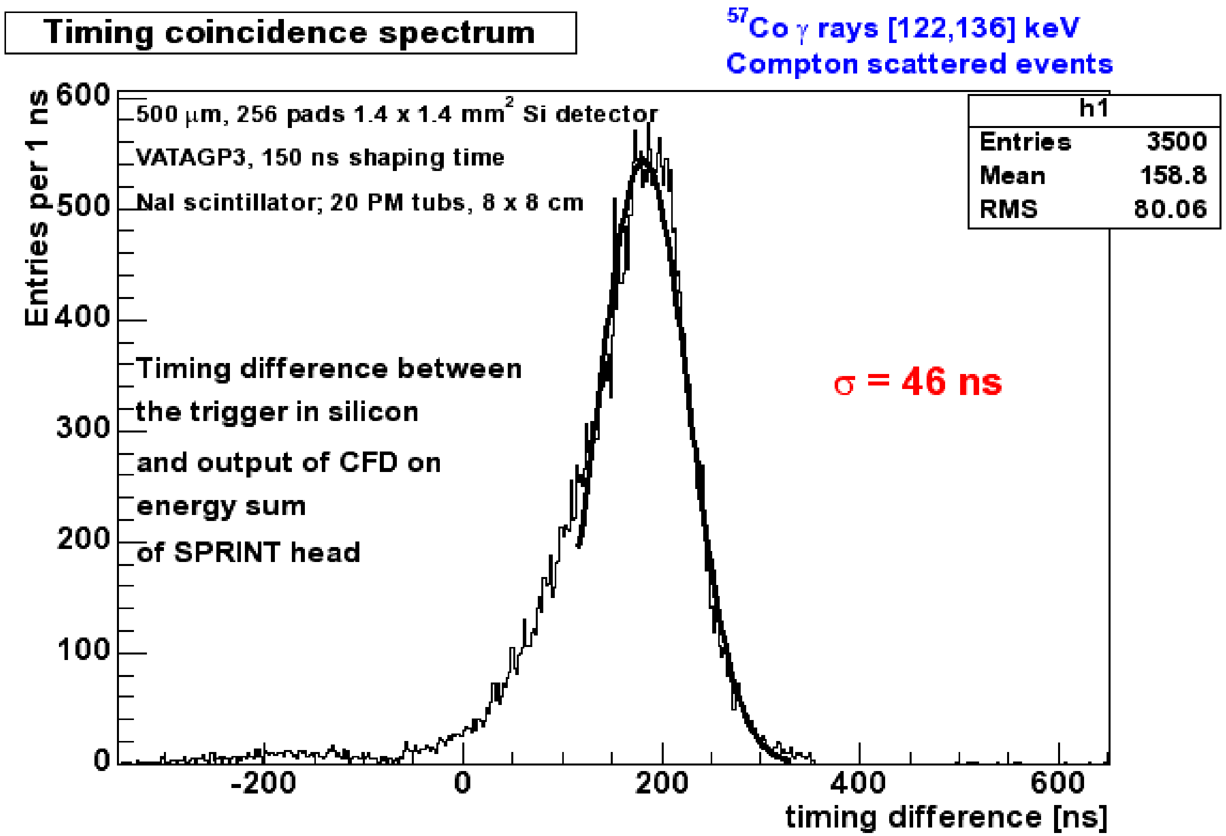
Trigger, readout and data-storage



VME based.
Combined events stored in PC.
A single 2-chip hybrid used.

Timing properties

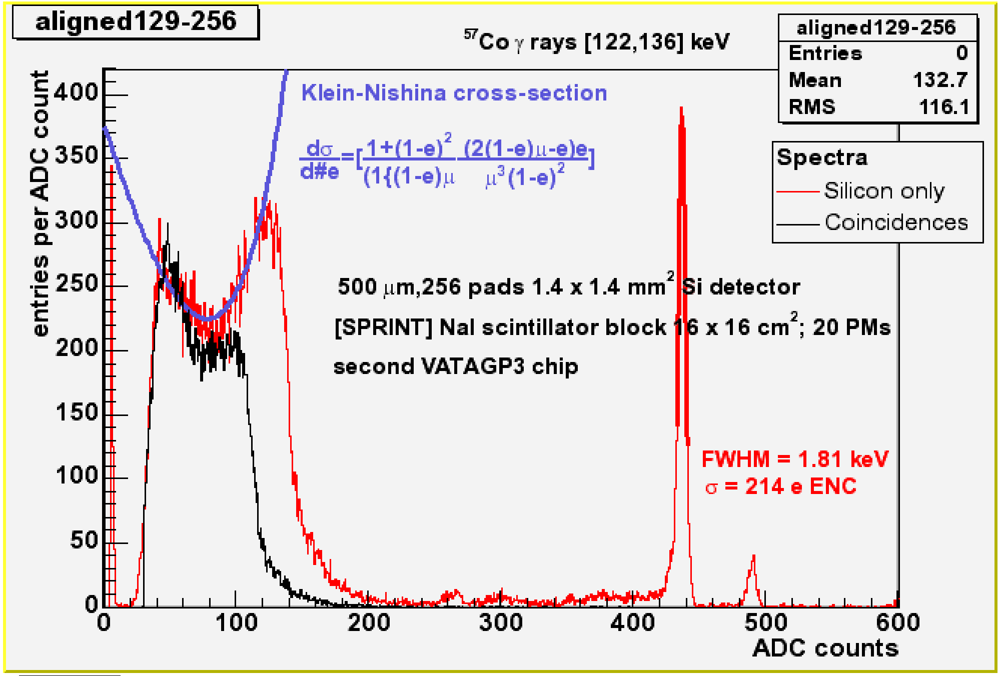
- Asymmetric
- Tail towards shorter times – lower energies in silicon
- Coincident window of 400 ns used
- Low rate of randoms

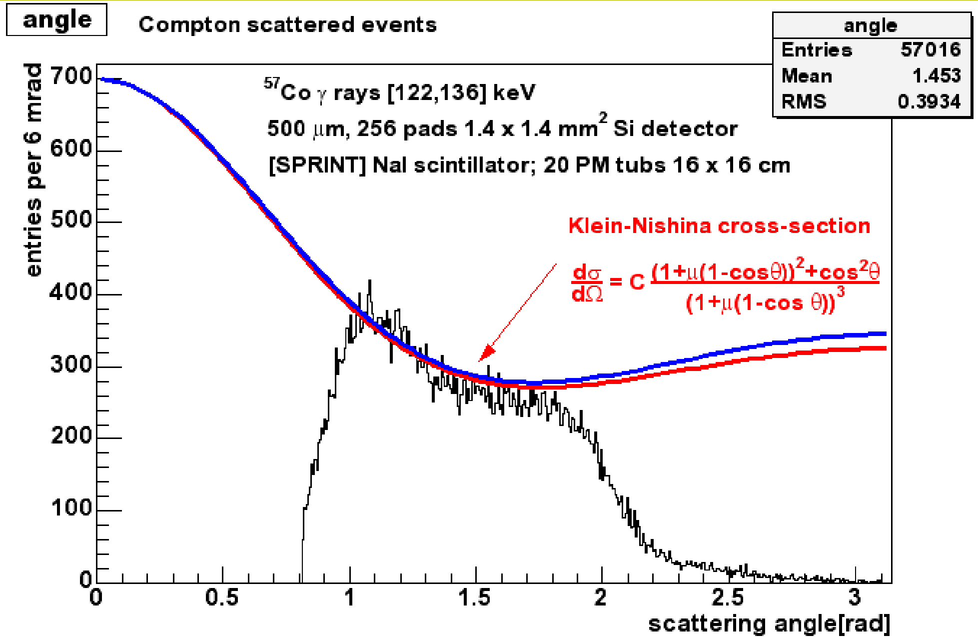


Energy spectra
Silicon detector

Si-modules in self-triggering mode vs. coincident triggers:

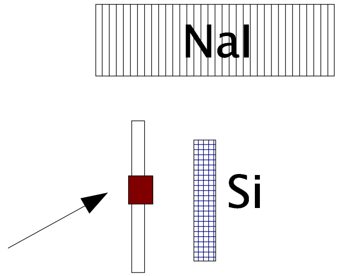
- No photo-absorption peaks present in coincident spectrum
- low random coincidence rate
- Threshold in scatterer: 8.2 keV -> 0.8 rad
- Measured angular distribution -> fits Klein-Nishina formula



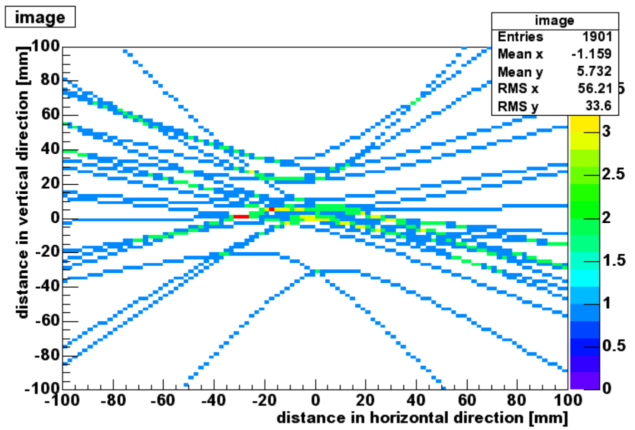


Toy reconstruction

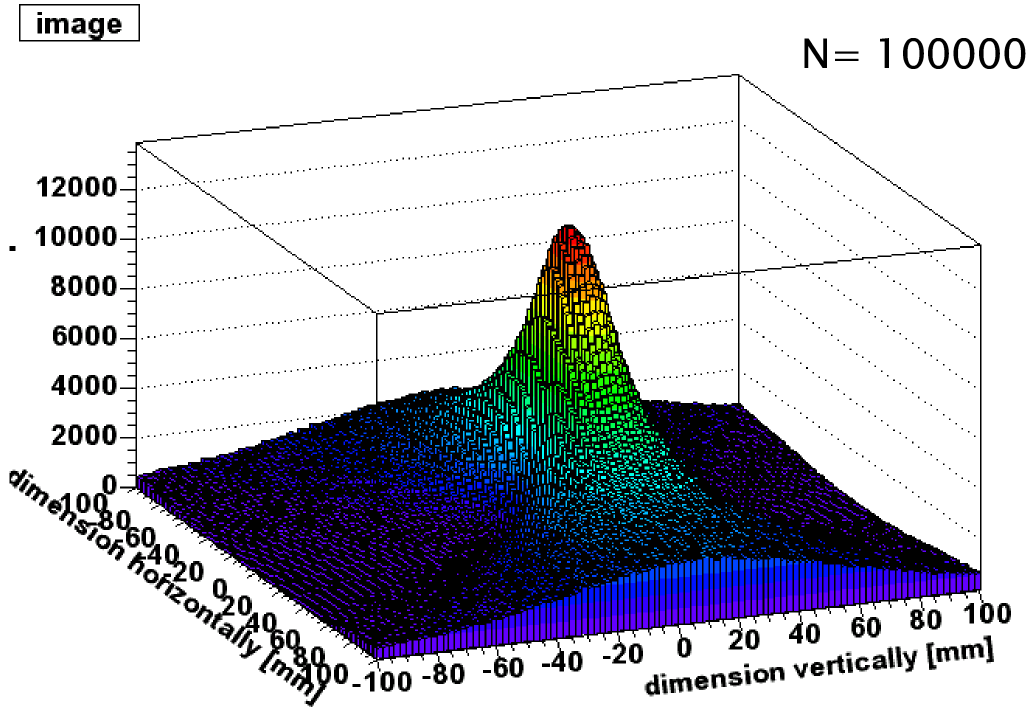
- 2D reconstruction on planes perpendicular to the scintillator plane, overlaying the cross-sections of cones with the plane in a histogram
- Low resolution:
  - poorly measured detector positions,
  - no scintillator calibration performed.



Plane containing the source



After N=10 events



N= 100000

Indication that the correct events are matched.

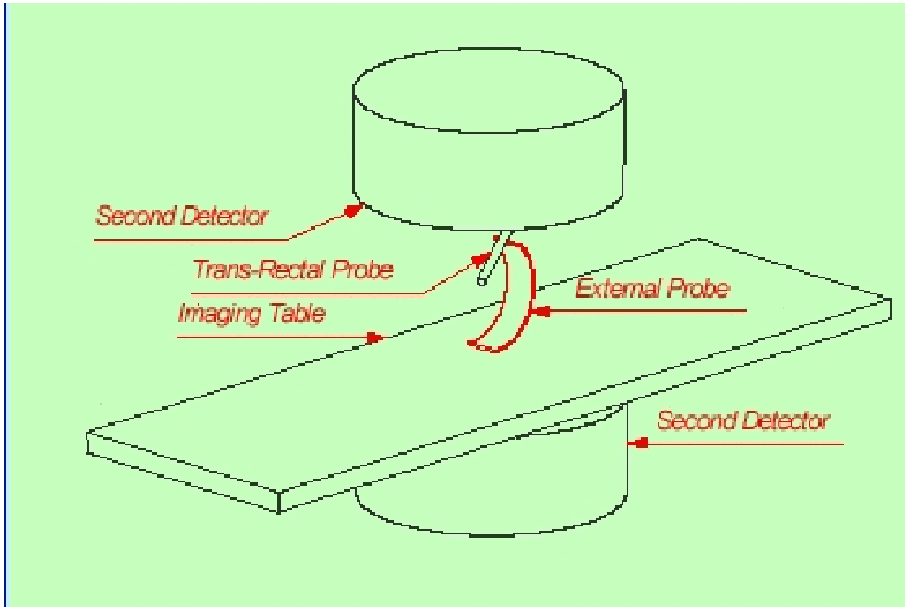
Application: Prostate probe

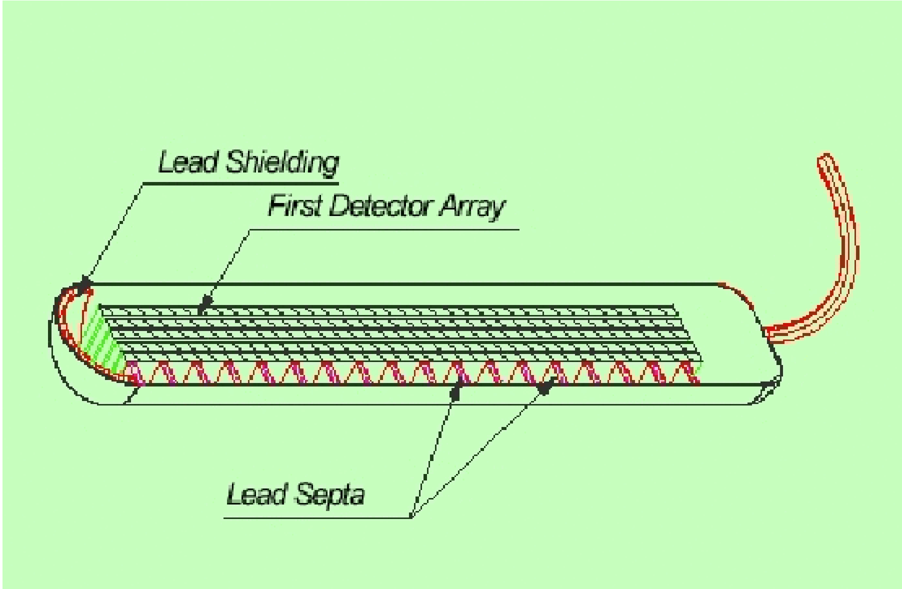
Motivation: Prostate cancer.

- 2nd most common cancer in men.
- ¼ of all cancers in men.
- 1/5 of men develop it.

AIM: To develop a non-invasive method for screening.

Status: Simulations.





Comparison of Compton probe vs. conventional imagers

Simulation results:

- 4 x 4 x 4 mm^3 voxel man phantom
- EGS4 physics simulation code.
- Compton probe (16 mm thick Si) inserted intrarectally
- external absorber ring surrounds the patient.

131 In (245 keV)	Efficiency [‰]	Resolution [mm]
Compton Probe	1.80	2.5
High-Sensitivity Collimator	0.11	15.9
High-Resolution Collimator	0.04	10.5

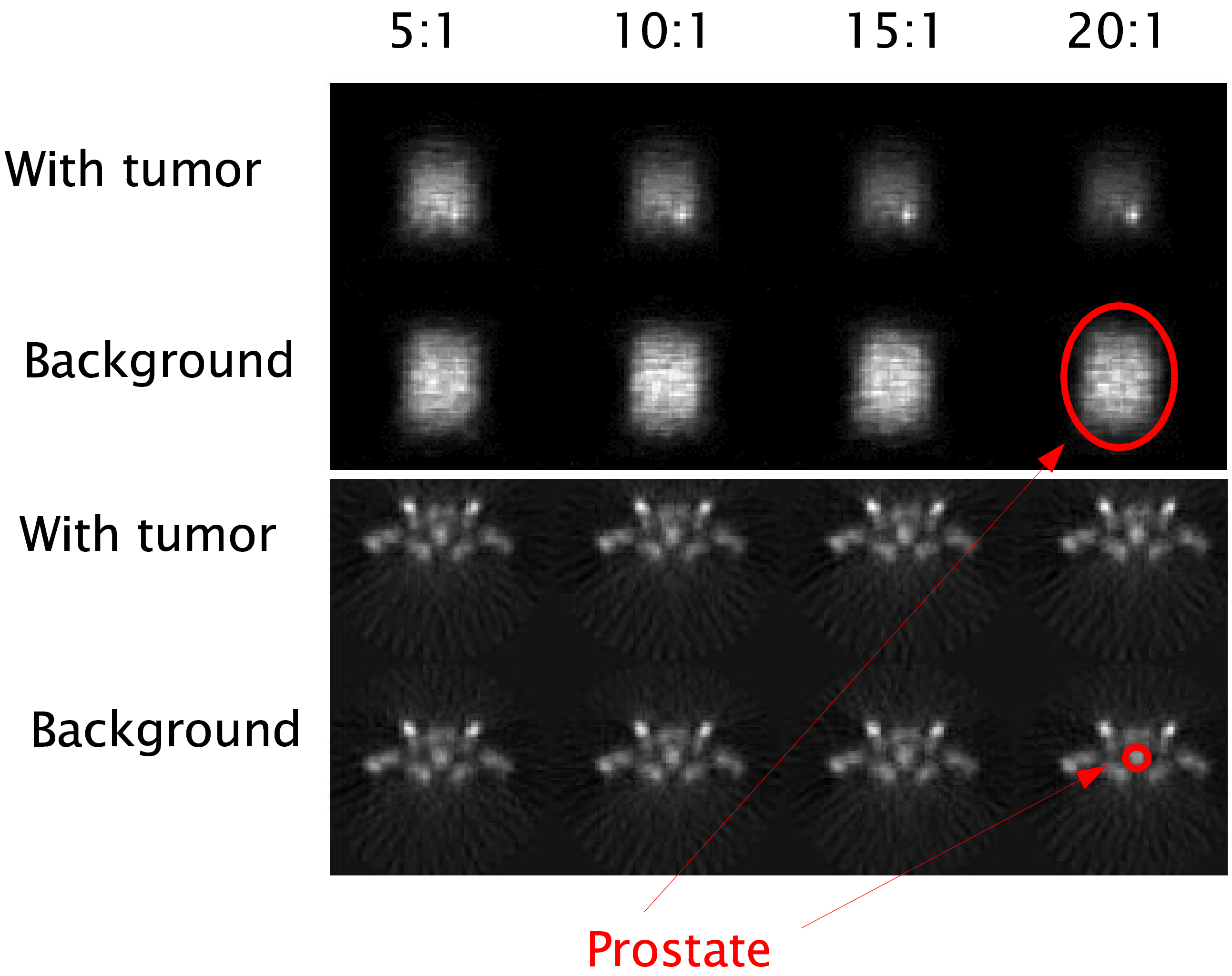
Simulated tumors

Compton probe

- Large field of view
- Proximity
- Higher resolution / efficiency

Classic Anger camera

- Image of the full body cross-section
- Small field of view
- Far away (10 cm)
- Lower resolution / efficiency



Conclusions

First coincidences have confirmed the Compton camera principle.

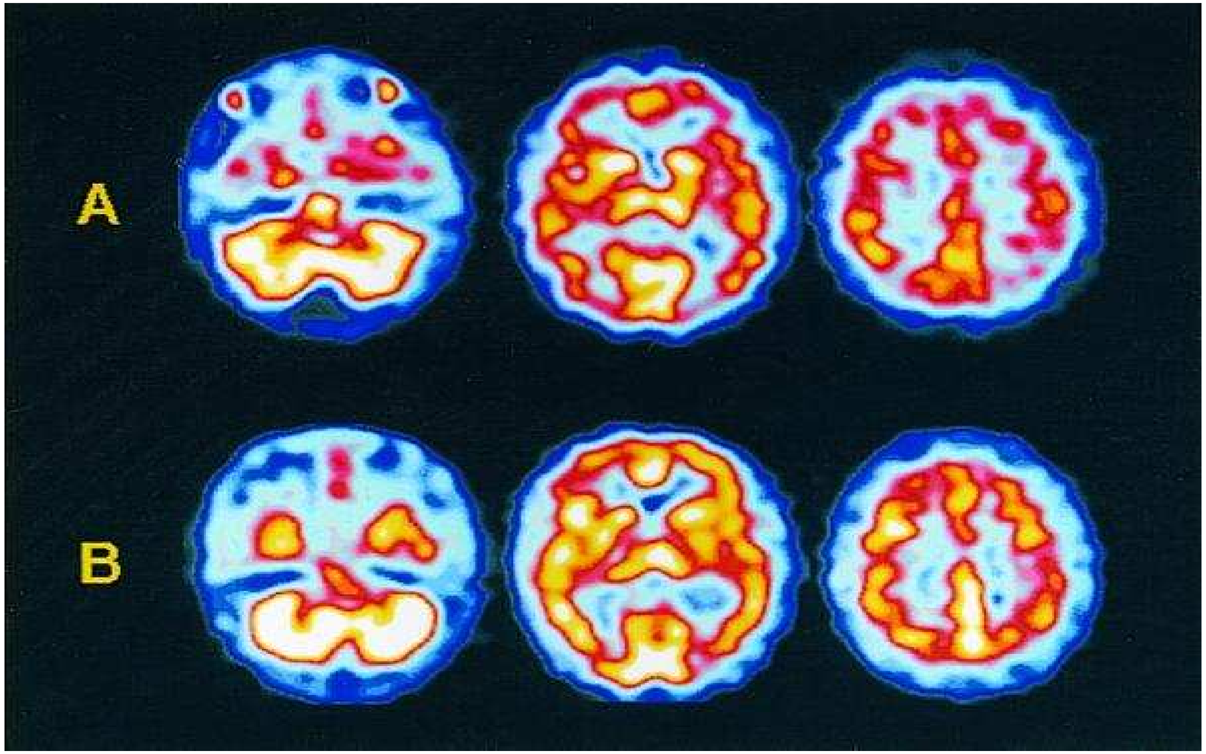
Still a lot of work to be done to integrate several layers of silicon with a full scintillator ring

Prostate probe is an interesting application:

- High efficiency and resolution
- Aimed at screening
- Promising simulation results.

Aim for pre-clinical external probe prototype in early 2004.

Example of emission tomography for detecting Creutzfeld-Jasobs disease -> brain scan



BMJ 316(7137):593-4