Past / Future in Scintillation

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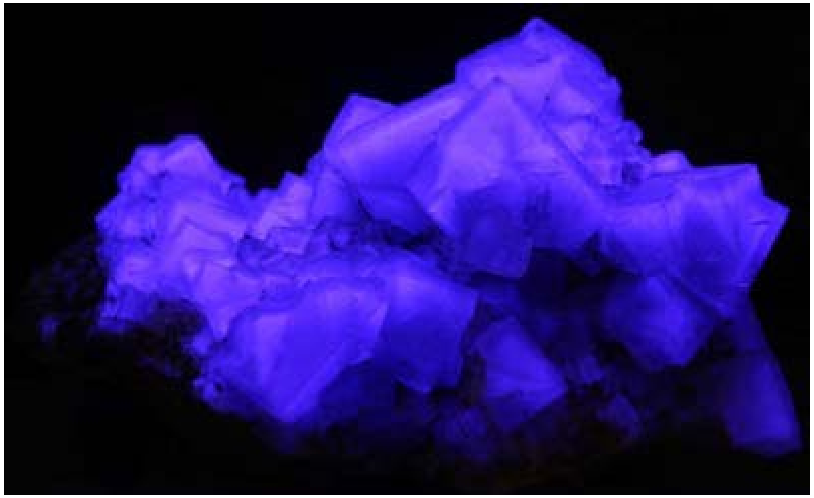
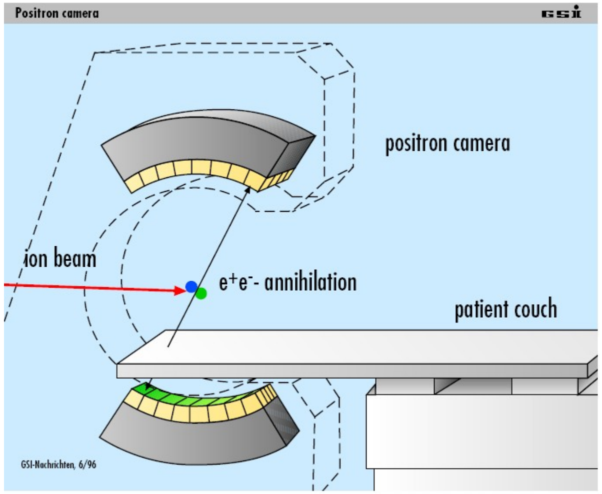
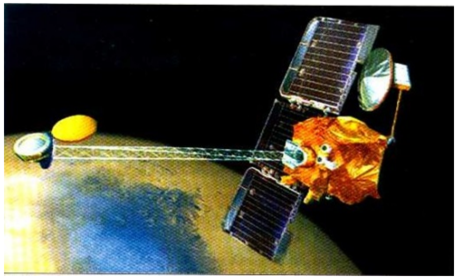




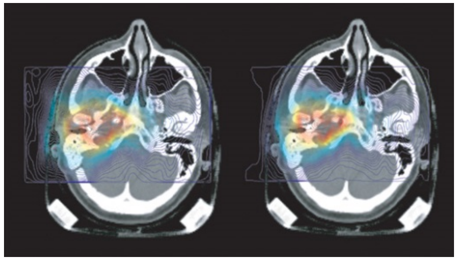
Past / Future in Scintillation



- **High energy astrophysics**

Correlate the detected photon to source object as known from more precise observations in other wavelength

- **Biomedical research**

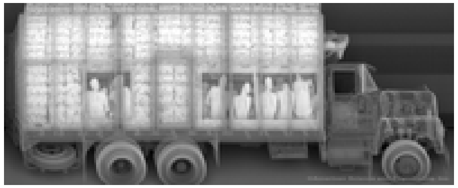


Precise localization of radioactive tracers in the body
Cancer diagnosis
Molecular targeted radiation therapy
Monitor changes in the tracer distribution → dynamic studies

- **National security**

Nuclear non-proliferation / nuclear counter terrorism
Contraband detection
Stockpile stewardship
Nuclear waste monitoring and management

- **Industrial non-destructive assessments**

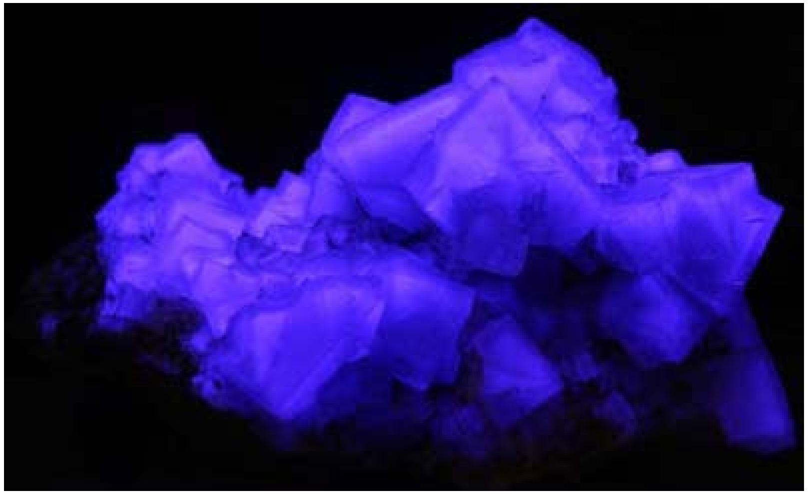


Determination of the material density distribution between the source and detector

Past / Future in Scintillation

Afterglow = *phosphorescence*

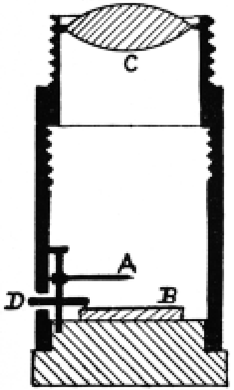
Phosphorescence is a property of many crystals and organic materials

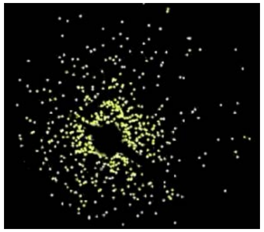


Light is produced by deexcitation of molecules

Zinc Sulfide ZnS(Ag) Scintillation Material

- 1866 – Theodore Sidot reported the phosphorescence of ZnS.
- 1903 – William Crookes invented a device called a spinthariscope with a ZnS screen to see scintillations from α-particles.



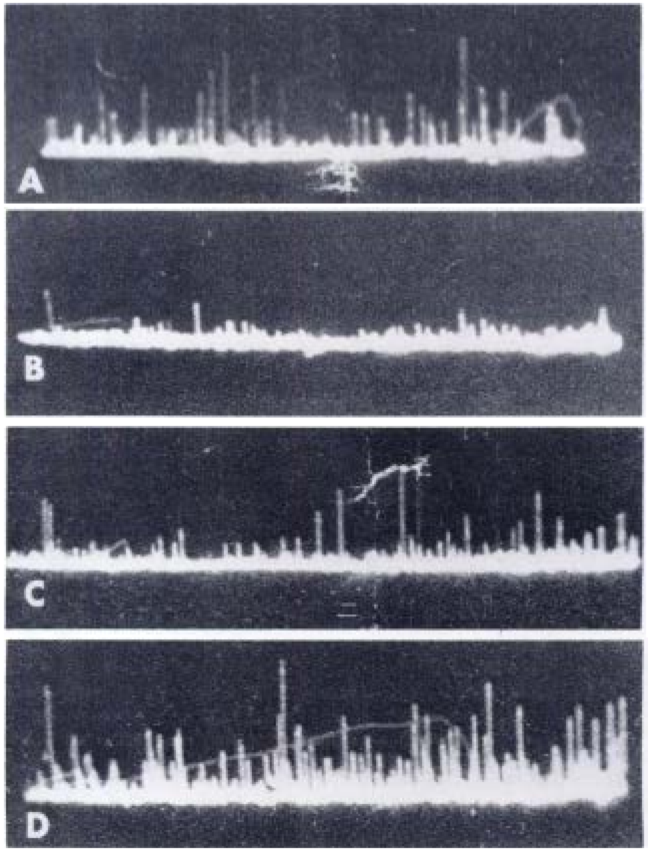


In 1903 W. Crookes demonstrated in England his “spinthariscope” for the visual observation of individual scintillations caused by α-particles impinging upon a ZnS screen. In contrast to the analogue methods of radiation measurements in that time the spinthariscope was a single particle counter, being the precursor of scintillation counters since. In the same period F. Giesel, J. Elster and H. Geitel in Germany also found that scintillations from ZnS represent single particle events. This paper summarizes the historical events relevant to the advent of scintillation counting.

A spinthariscope from 1904. Height about 5 cm, Ra-source (A), ZnS screen (B), magnifying glass

Zinc Sulfide ZnS(Ag) Scintillation Material

- 1944 – photomultiplier tube was invented



α-particles

background pulses
of naphtalene -20^0

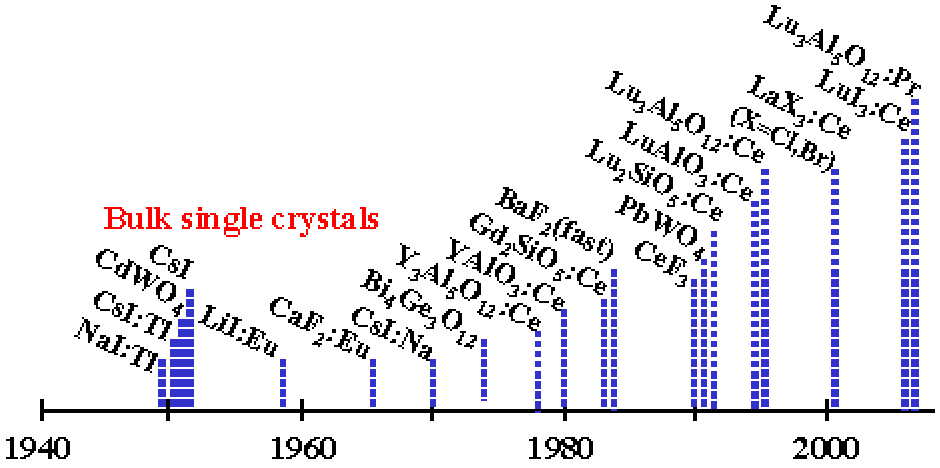
β-particles

γ-rays

- 1948 – H. Kallmann

History of Scintillators

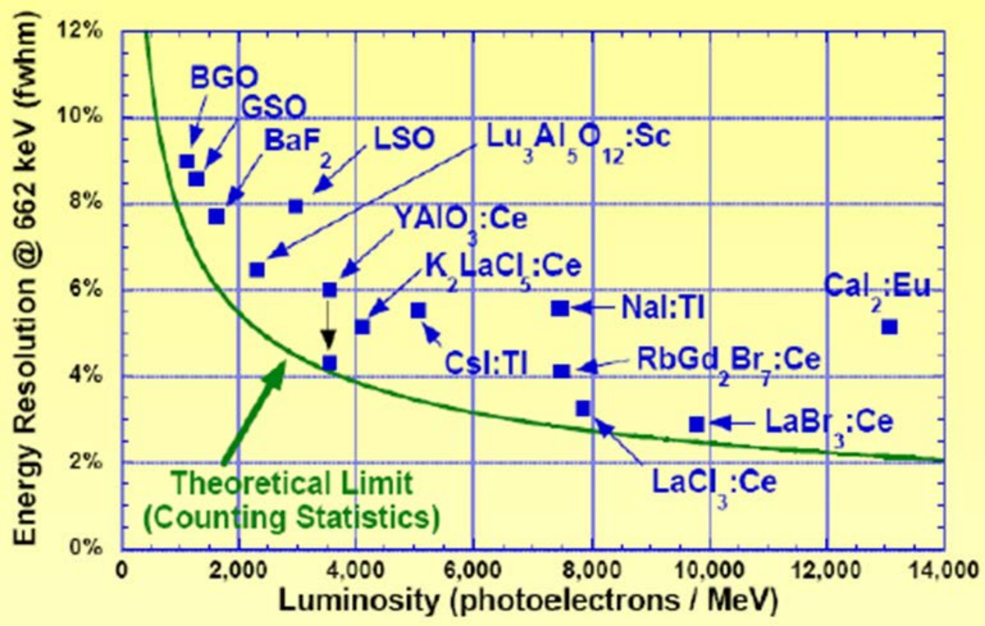
- History of scintillators starts short after the discovery of X-rays at the end of 19^{th} century

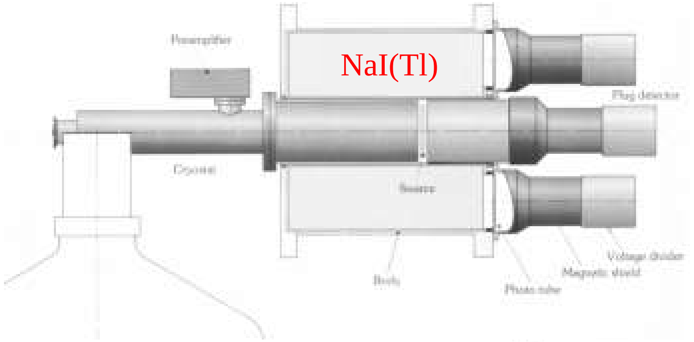


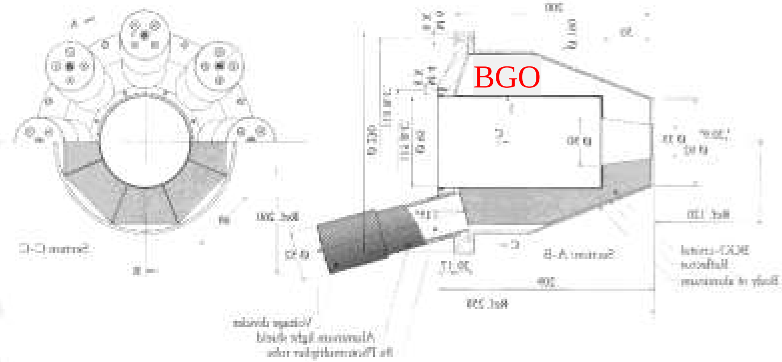
year of introduction of a scintillation material

Compton Suppression Shields NaI(Tl) versus BGO

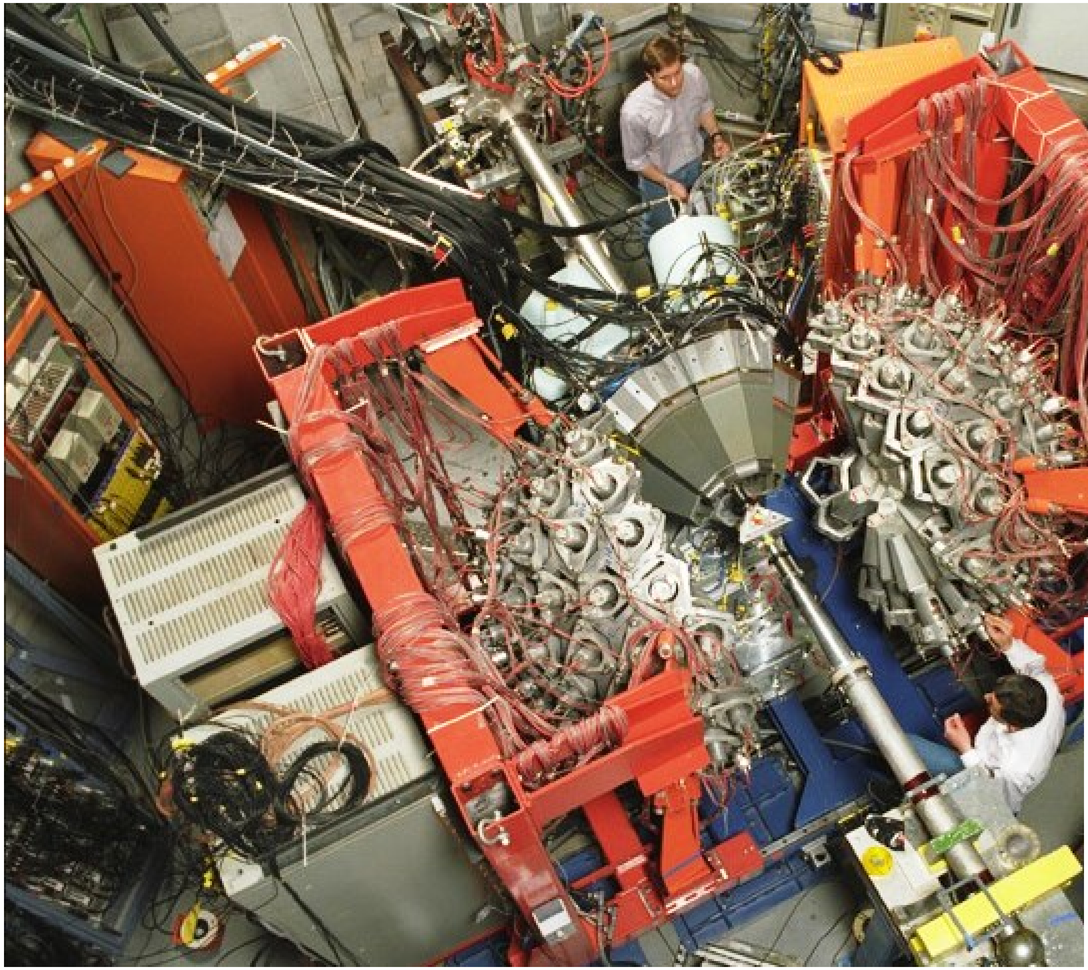
material	NaI(Tl)	BGO
density (g/cm^3)	3,67	**7.13**
50% attenuation for 662 keV in cm	2.5	**1.0**
Index of refraction n	1.85	2.15
Emission (photons/keV)	**38**	8
Decay time (ns)	250	300
Maximum size grown (mm)	700	75
Radioactive contamination	^{40}K	^{207}Bi



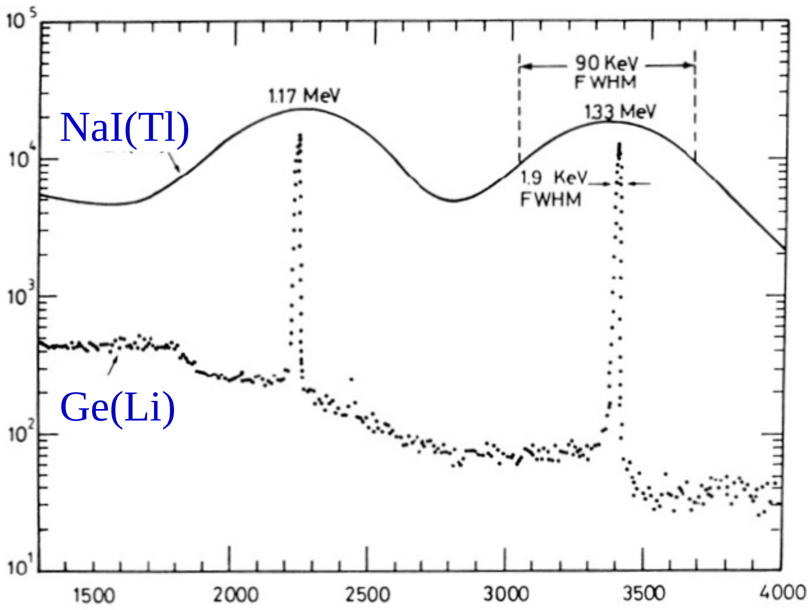




Heidelberg – GSI Crystal Ball

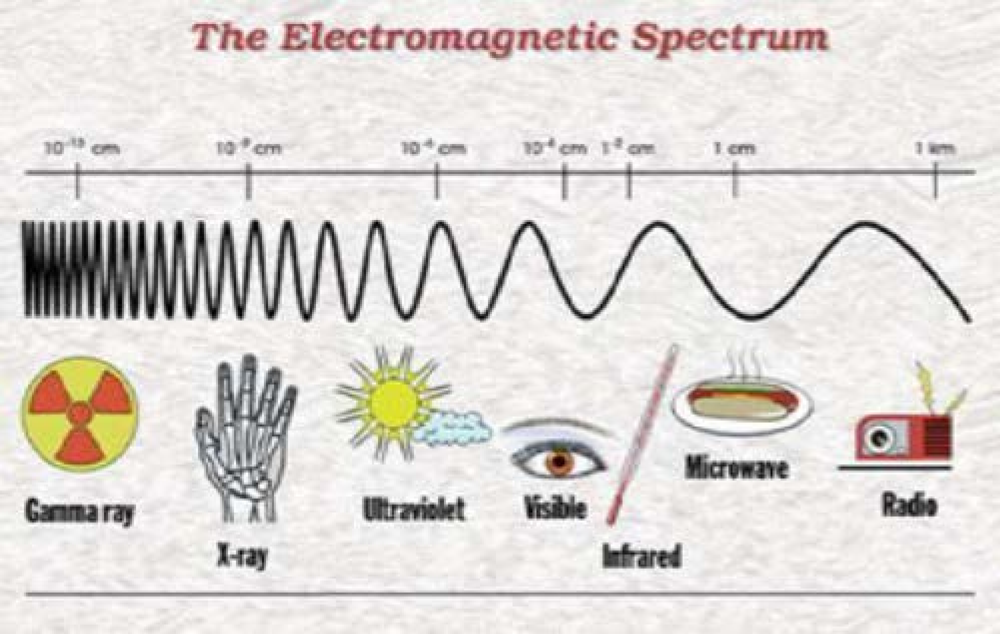


~160 NaI(Tl) and 5 EUROBALL detectors



Tomographic Imaging

PET



SPEC

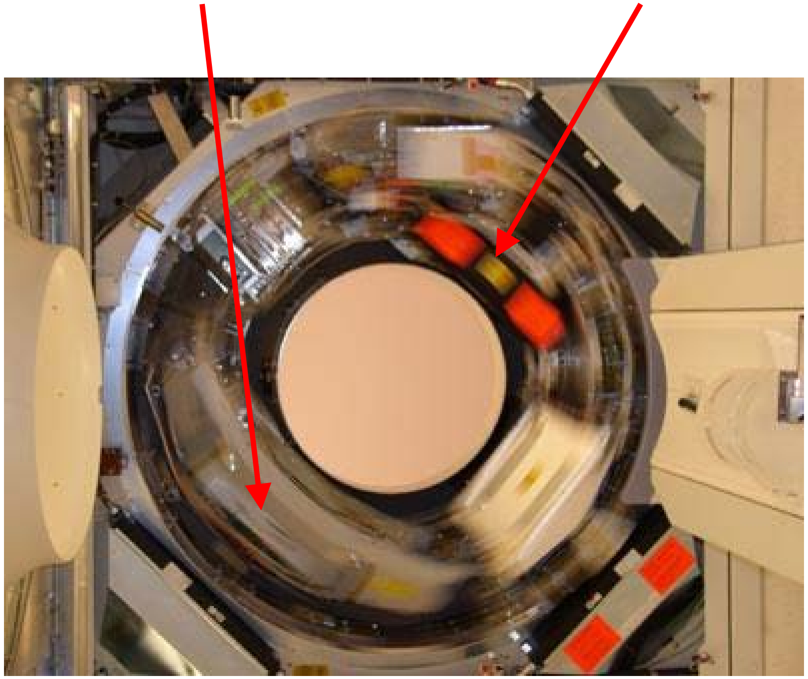
CT

OPTICAL

MRI

Computed Tomography

- CT scanning (originally known as CAT)
- X-rays taken at a range of angles around the patient
- Generation of 3D images

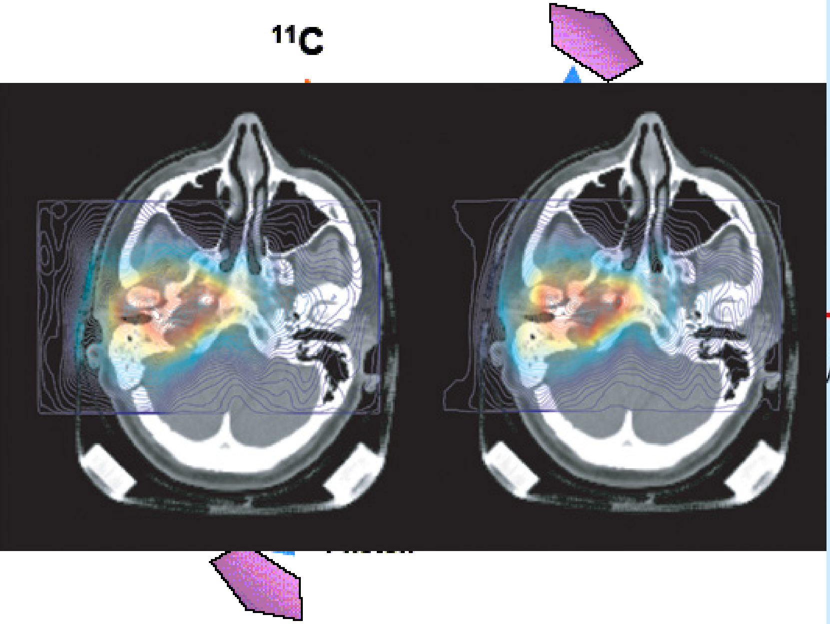


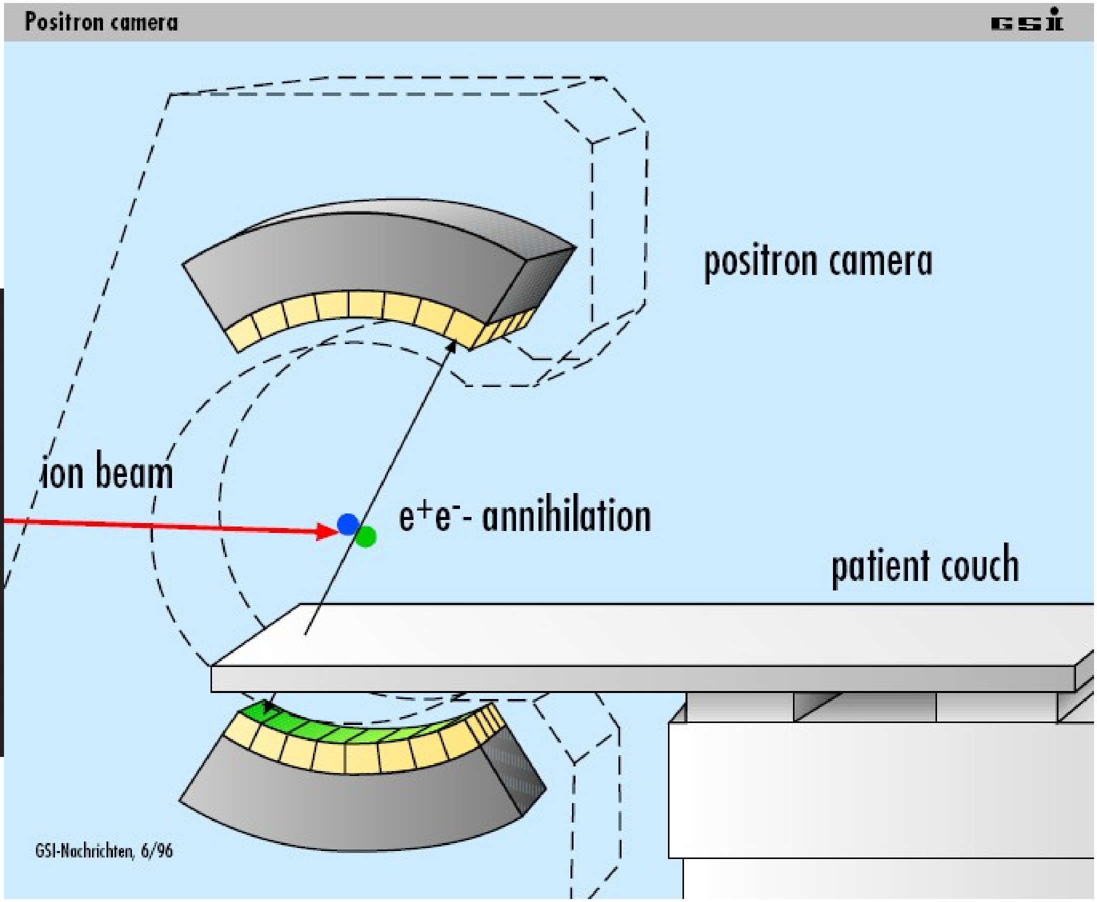
Radiation detector

X-ray source

Standard CT-system

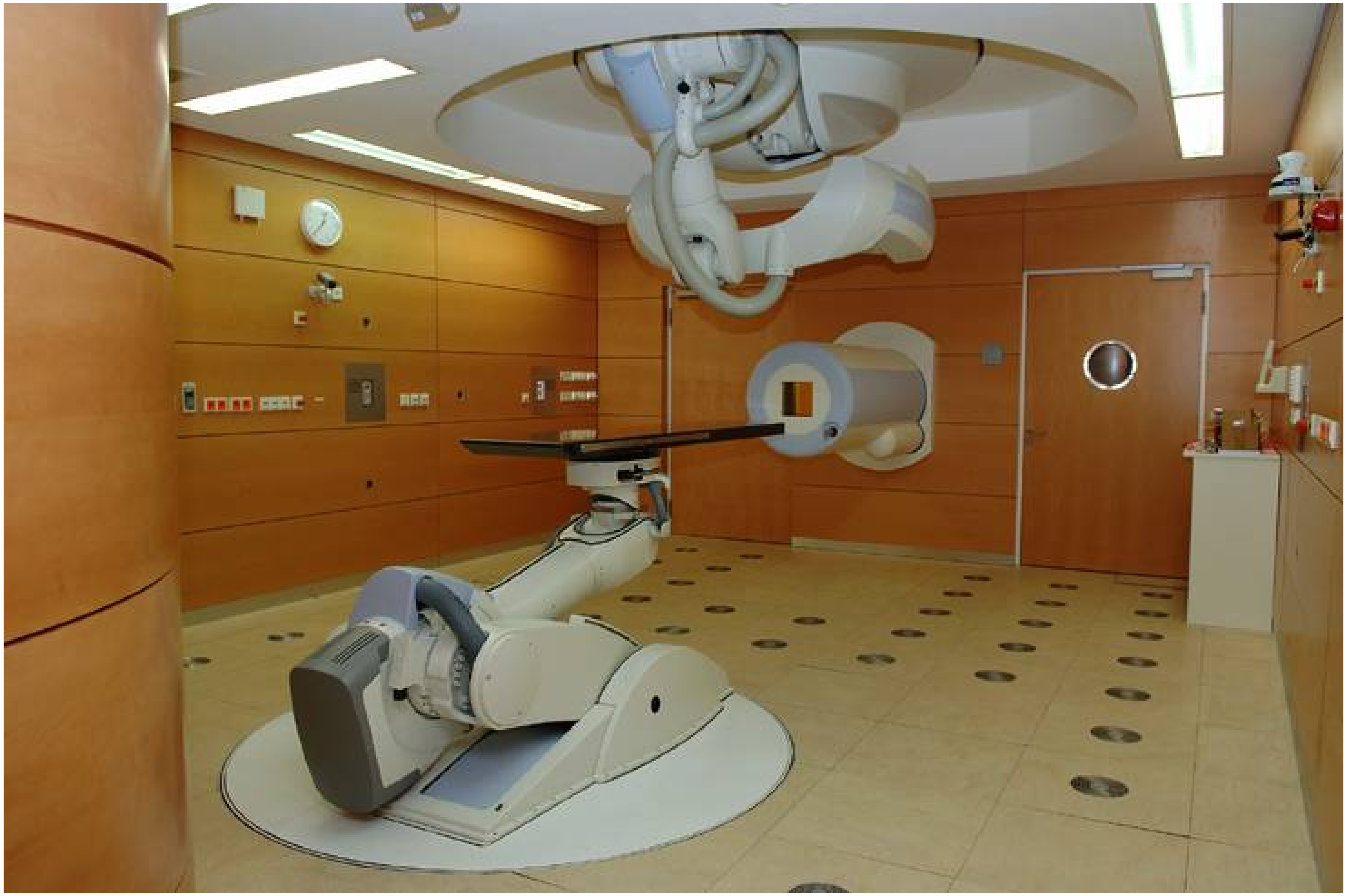
Positron Emission Tomography



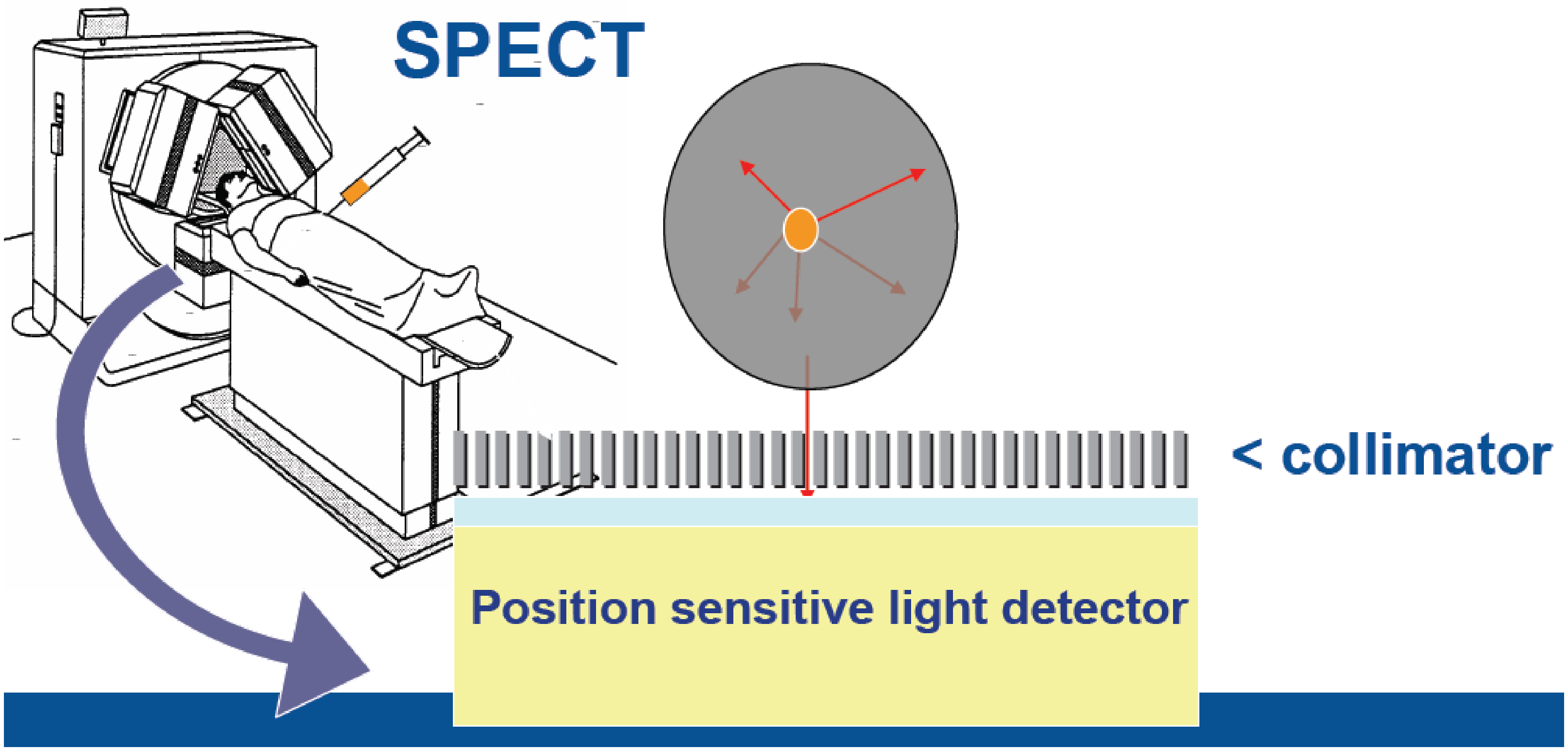


GSI-Nachrichten, 6/96

Positron emission tomography



Single Photon Emission Computed Tomography



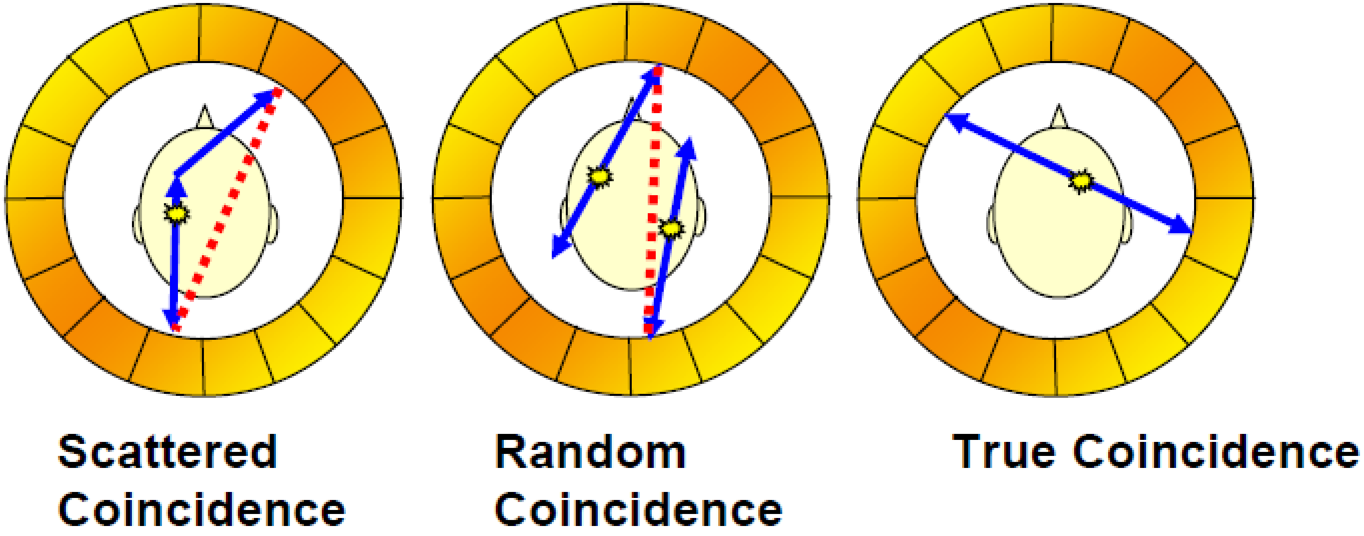
SPECT

< collimator

Position sensitive light detector

- Most commonly used tracer in SPECT is $^{99}Tc^{m}$, 140 keV a pure single photon emitter $T_{1/2}$ = 6.02 h.
- Utilizes a gamma-ray camera rotated in small ~3^0 steps around the patient.

The motivation behind the project



- Existing technology relies on BGO scintillator technology

  - Limited position resolution
  - High patient dose requirement.
  - Poor energy resolution only accept photopeak events.
  - Will not function in large magnetic field

- SPECT applications utilizing Compton Camera techniques.

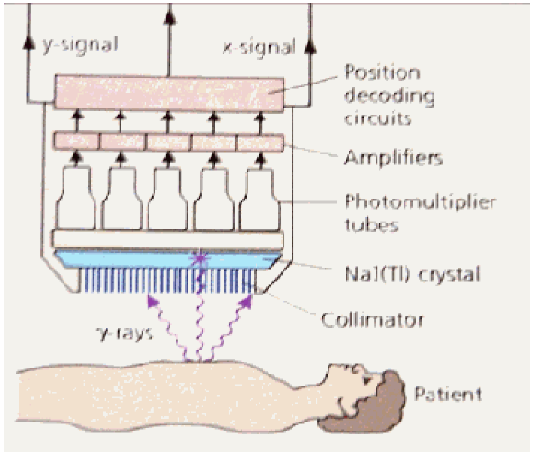
Which γ-ray camera to be used?

Requirements:

- Excellent resolution Δx = 2 mm
- Large field of view (**FOV**) = 8x9 cm^2

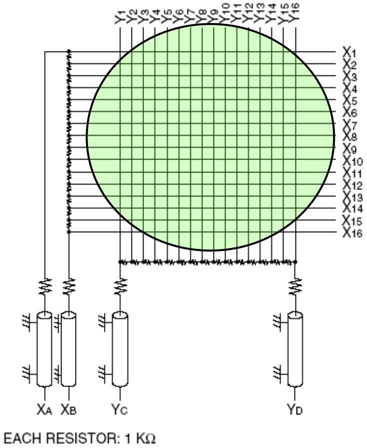
- Large FOV of ~20 cm diam.
- Low spatial resolution 0.5-1 cm

www.siemens.de



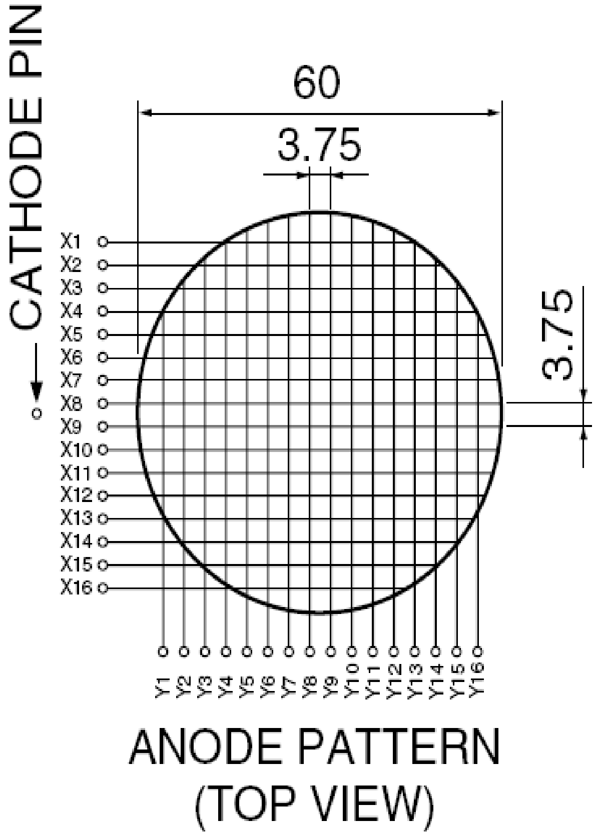
- Small FOV of 3-4 cm diam.
- High spatial resolution 2-3 mm

Gem-imaging.com



Gamma Camera: Individual multi-anode readout

16 wires in X axis and 16 wires in Y axis



C.Domingo Pardo, N. Goel, et.al., IEEE, Vol.28, Dec. 2009

LYSO

scintillator

d = 76 mm

t = 3 mm

$\rho = 7.4\ \text{g/cm}^3$

Hamamatsu R2486 PSPMT

Photocathode = 56.25 mm

Which γ-ray camera to be used?

Requirements:

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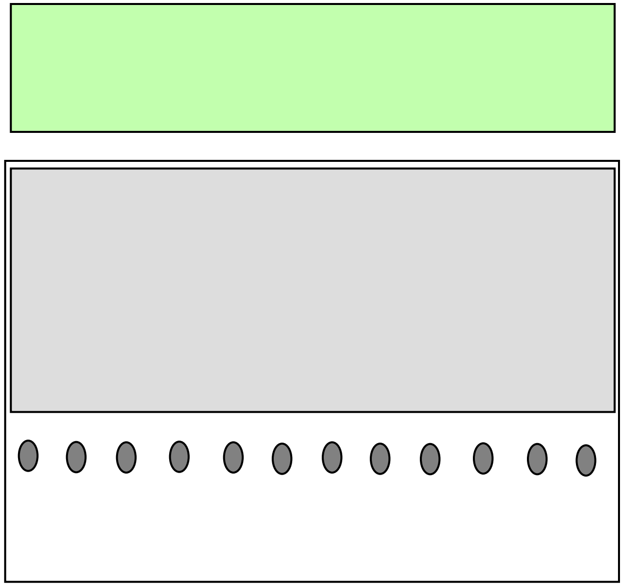
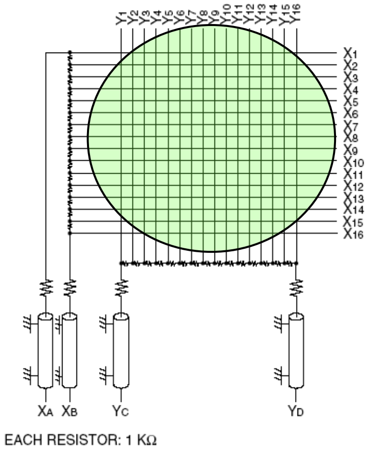


Scintillator

Position Sensitive PMT

- Small FOV of 3-4 cm diam.
- High spatial resolution 2-3 mm



Gem-imaging.com

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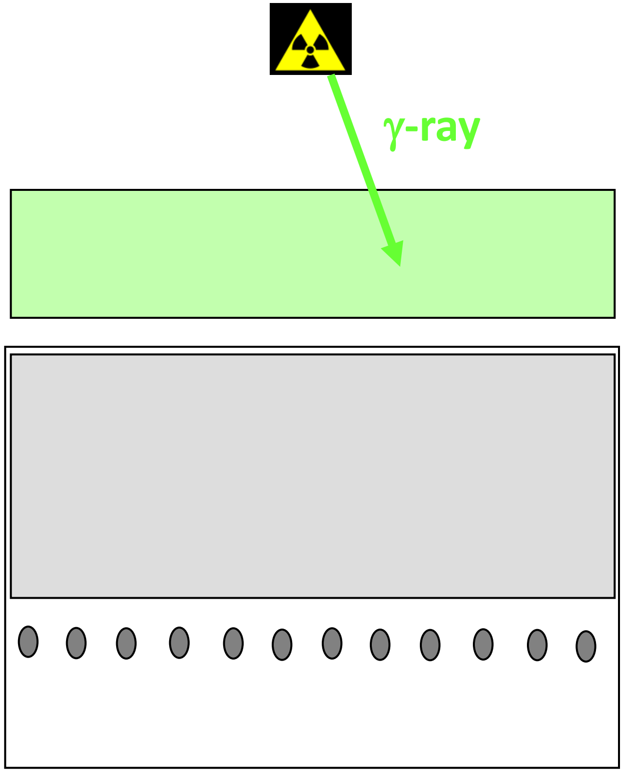

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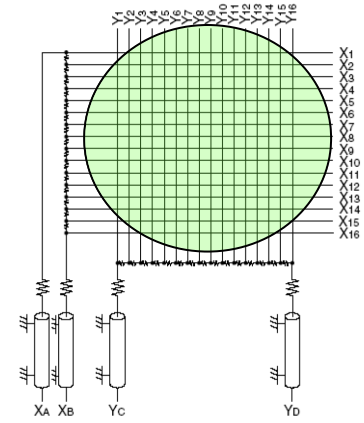

EACH RESISTOR: 1 KΩ

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Which γ-ray camera to be used?

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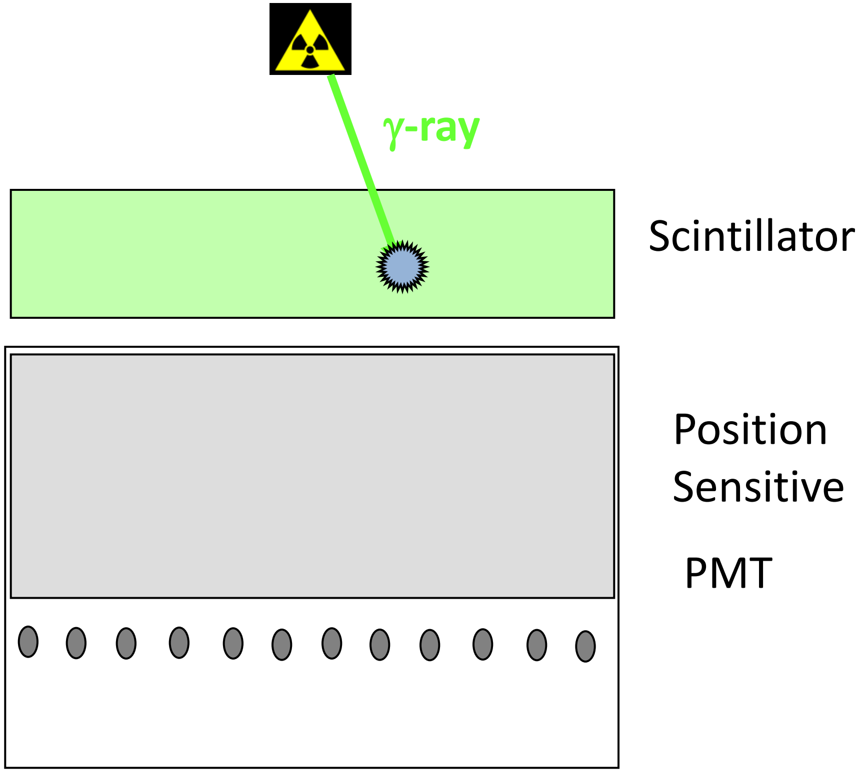

γ-ray

Scintillator

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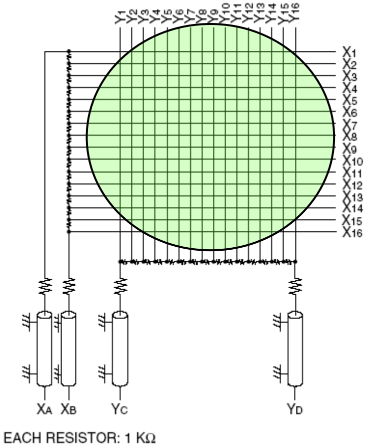

Gem-imaging.com

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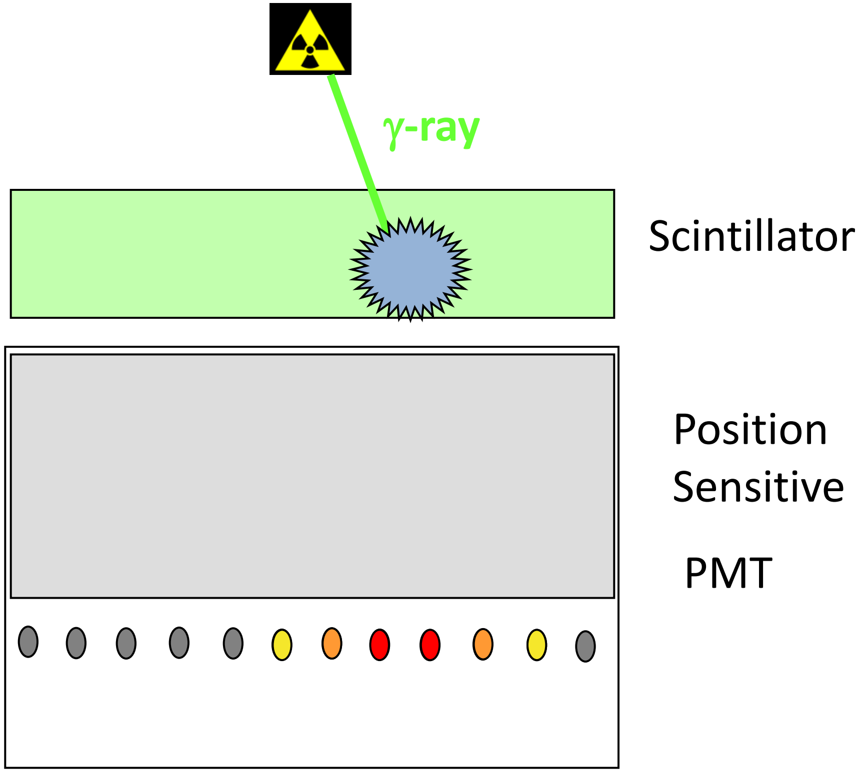

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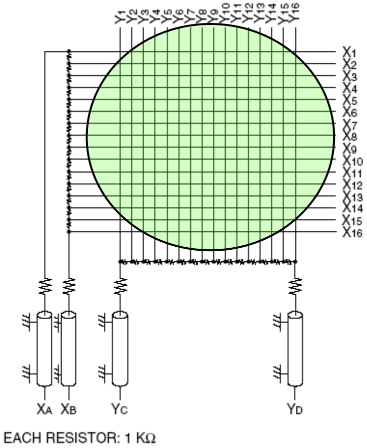

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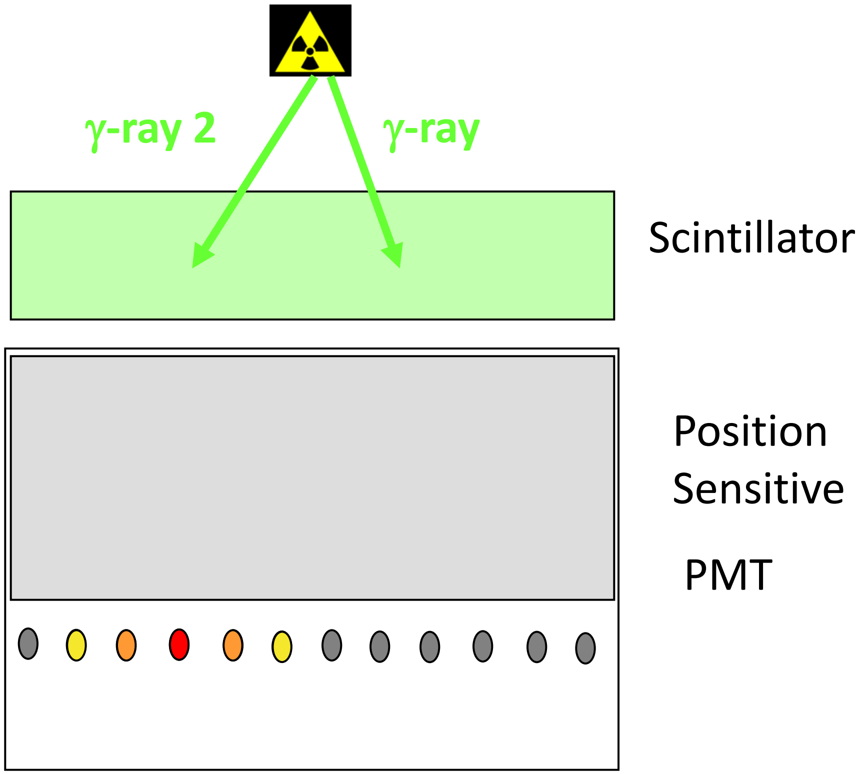

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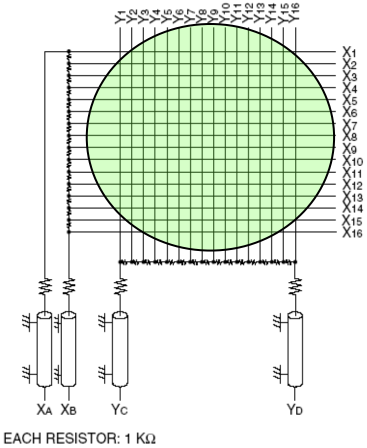

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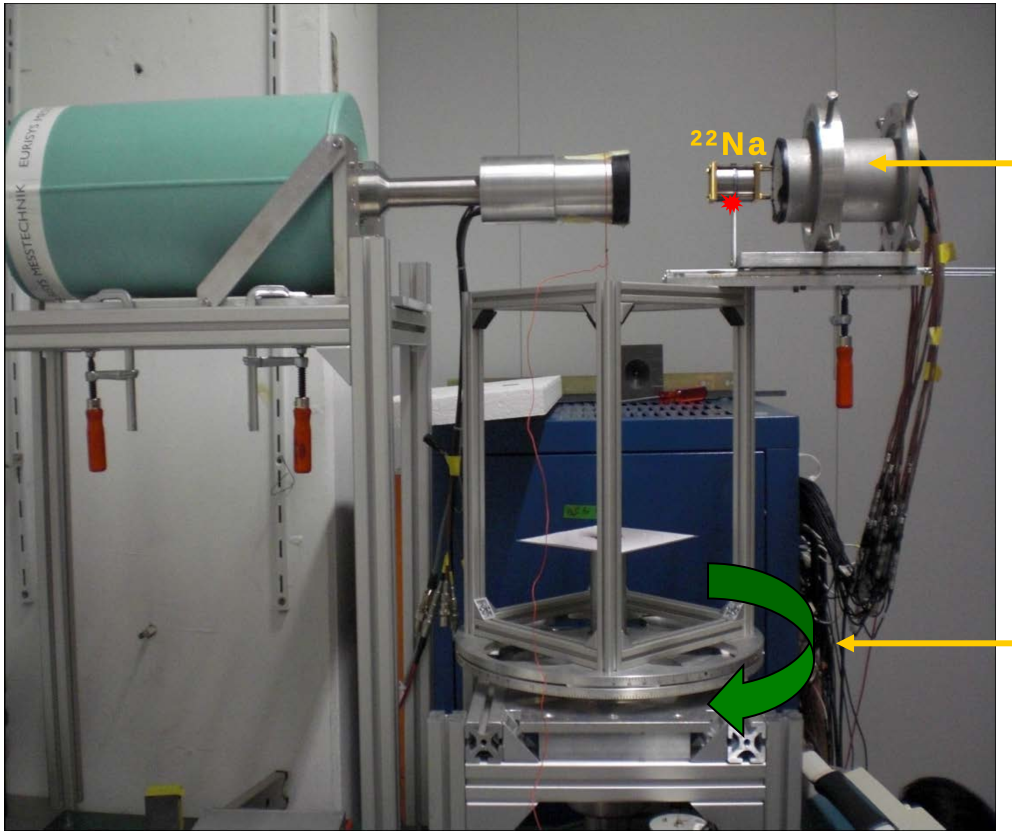
Scanner at GSI



Position sensitive detector

Rotating table

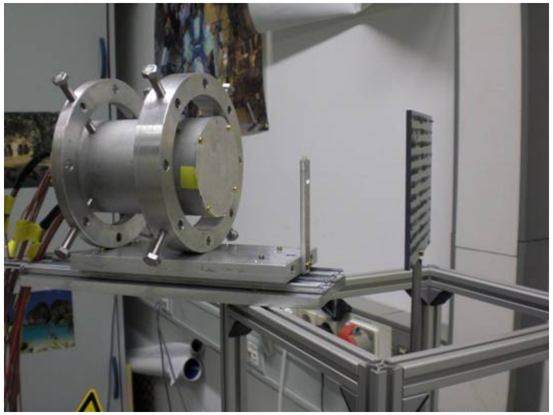
Characteristics:
- Faster
- Precision: 1-2 mm
- Imaging capability

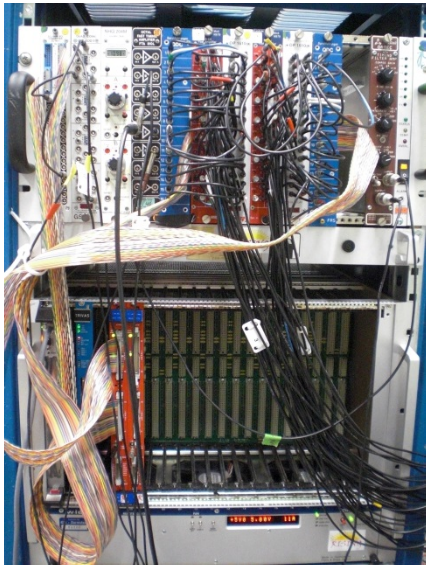
Requirements:
1. Position sensitive detector
   - Excellent Δx/x
   - Large field of view
2. Method to compare the pulses

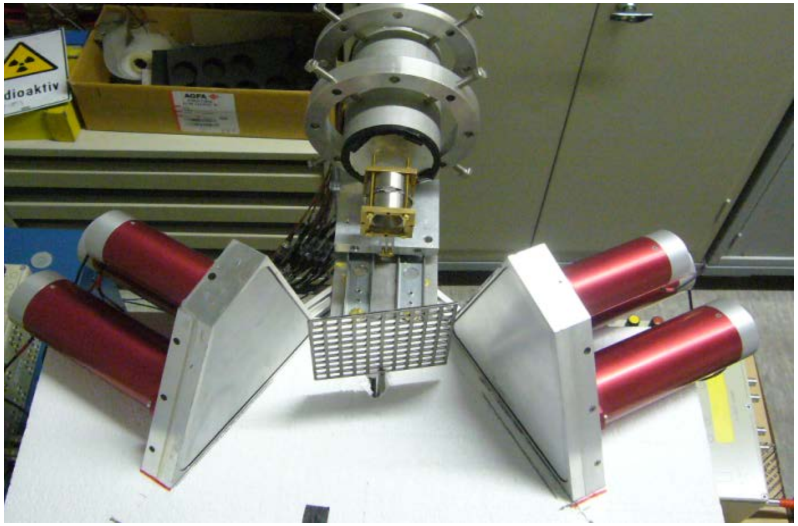
Position calibration

- Determine: $X_r(x_m,y_m)$, $Y_r(x_m,y_m)$

Gamma-ray scattering technique

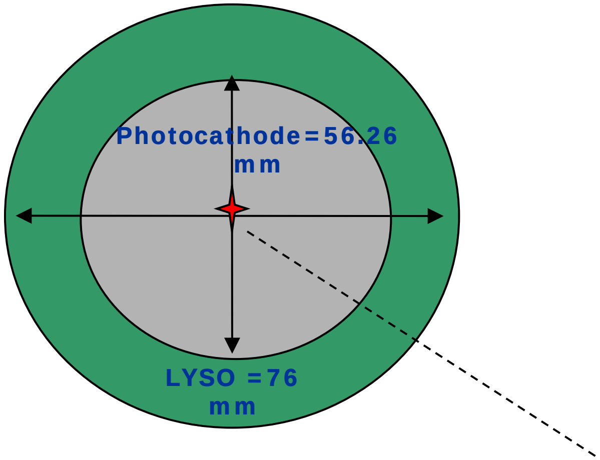


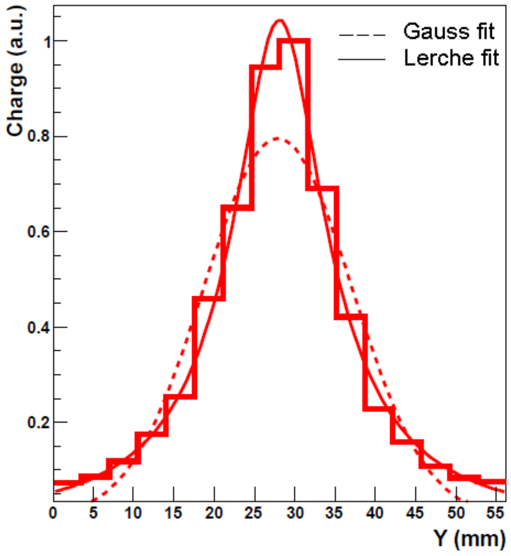




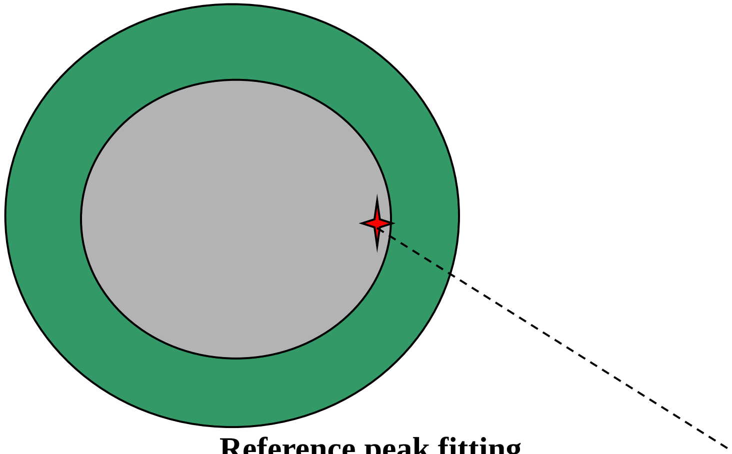
Position reconstruction

Central Interaction

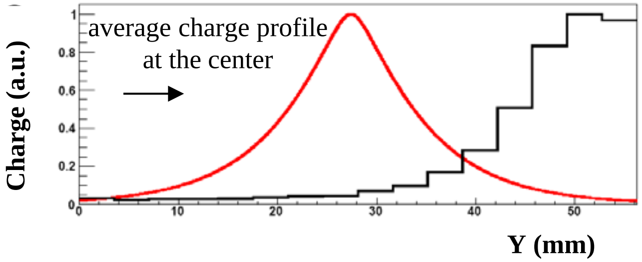


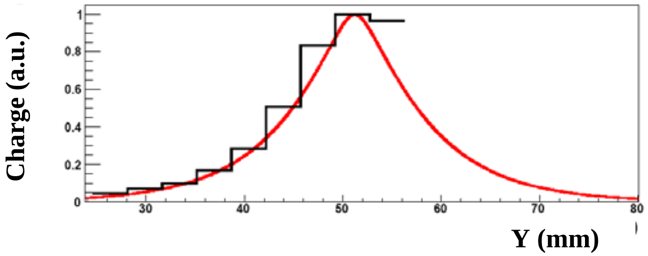


Peripheral Interaction



Reference peak fitting



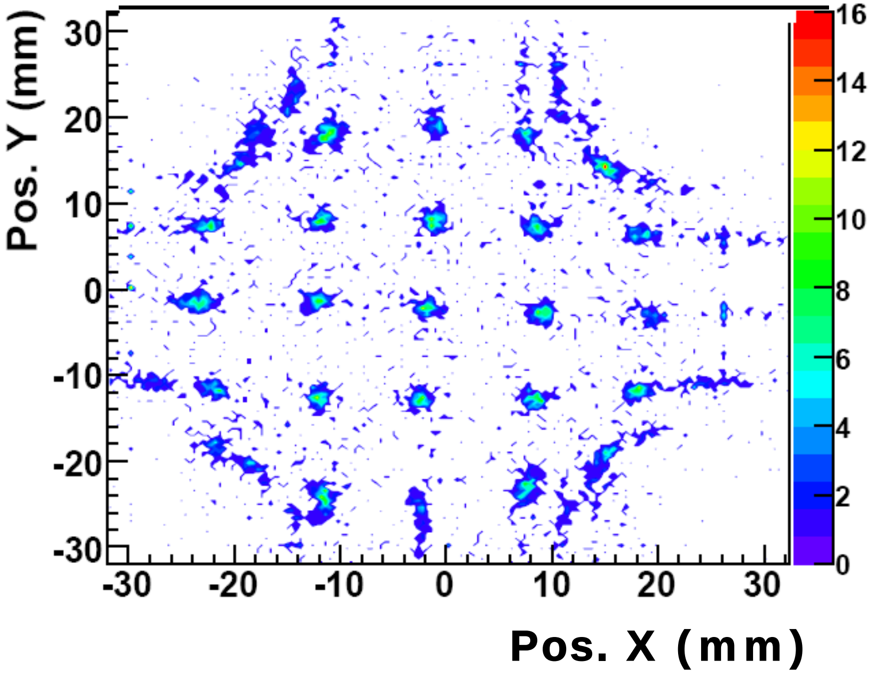


C. Domingo Pardo, N.Goel, et.al., IEEE, Dec. 2009 Volume: 28 Issue 12

C.W.Lerche, et.al., NIM A, Vol 537, pp. 326-330, Jan. 2005

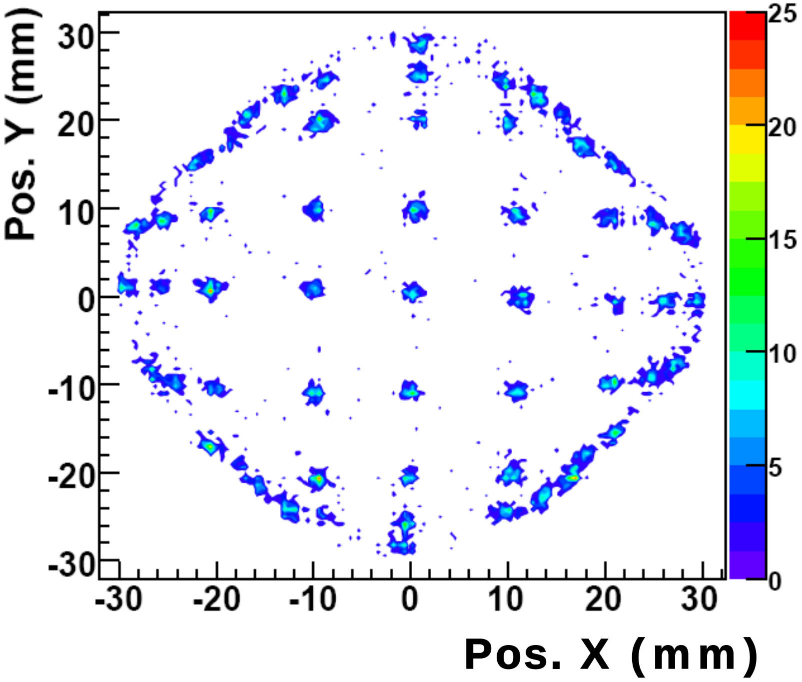
Position reconstruction

Gaussian fitting



Gaussian fitting works relatively well in the central region

Reference peak fitting

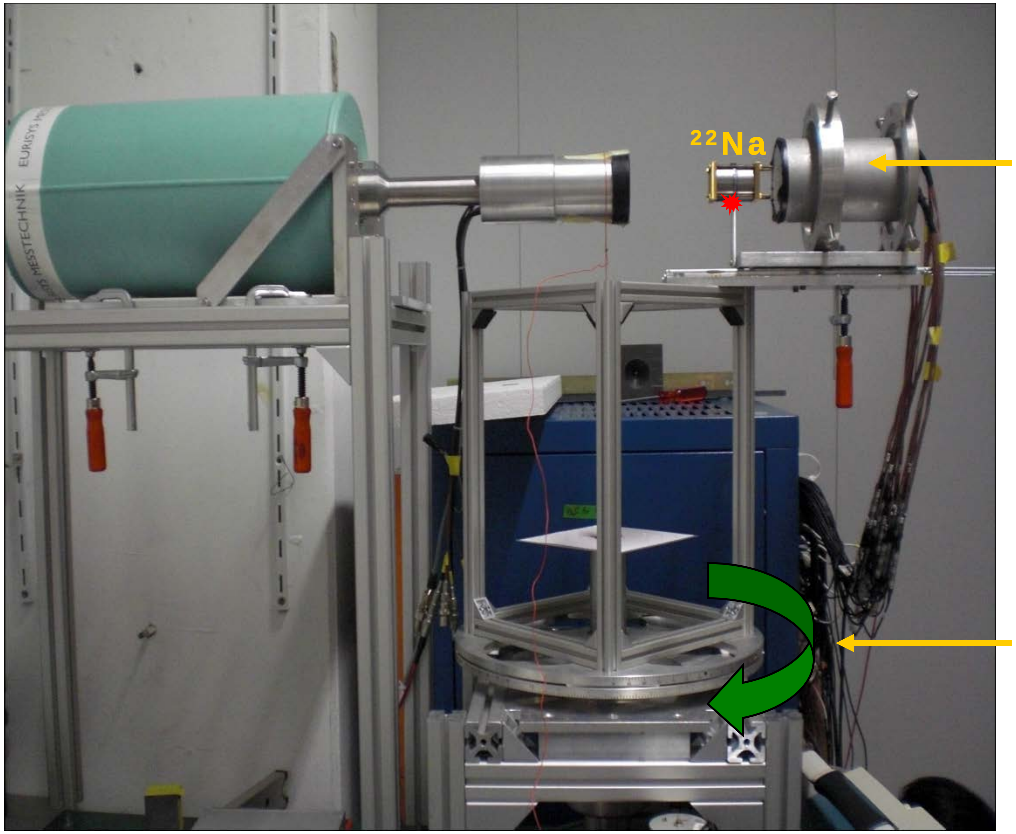


Linear for 50 mm

Field of view = 28 cm^2

Average spatial resolution in X and Y ~ 1mm

Scanner at GSI



Position sensitive detector

Characteristics:

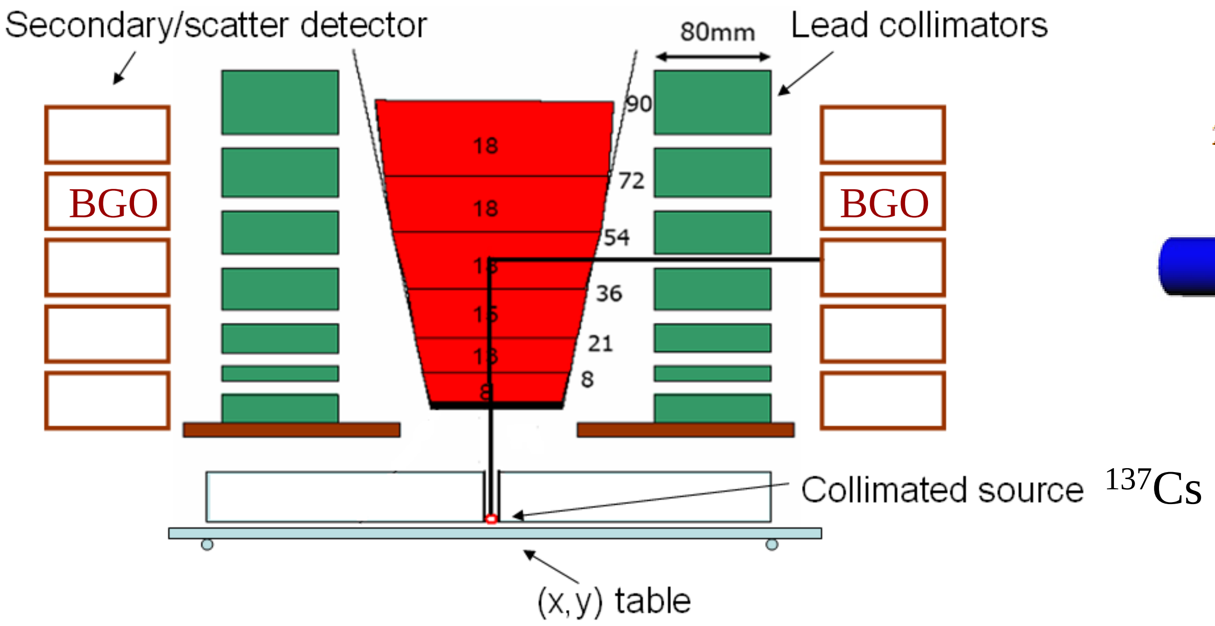
- Faster
- Precision: 1-2 mm
- Imaging capability

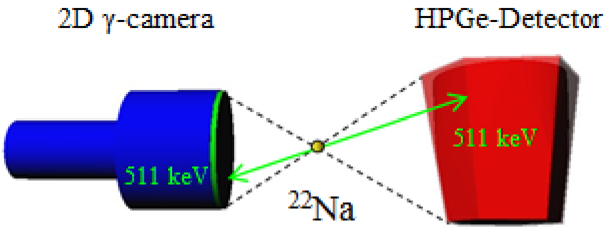
Rotating table

Requirements:
1. Position sensitive detector
    - Excellent $\Delta x/x$
    - Large field of view
2. Method to compare the pulses

Superiority over conventional scanner

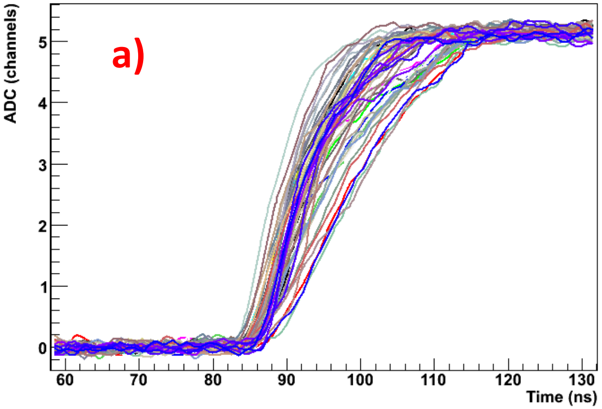
coincidence between the Germanium and BGO detectors for
90 degree Compton scattered events for depth determination

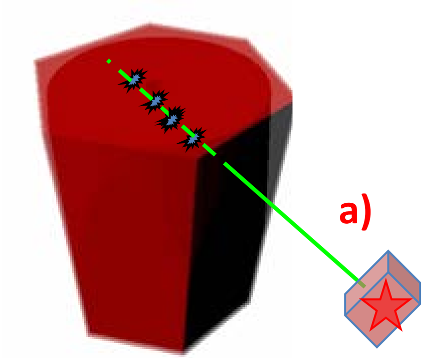




Advantage over conventional scanner: Full detector can be scanned in one measurement
10 times faster than a conventional scanner
Accuracy of simulations can be checked for complex regions of electric field

Scanner based on pulse shape comparison scan





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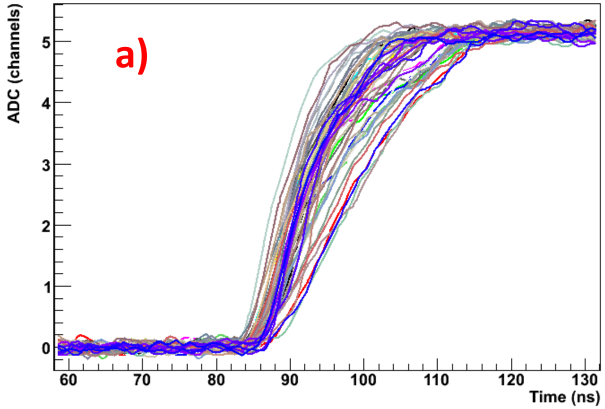
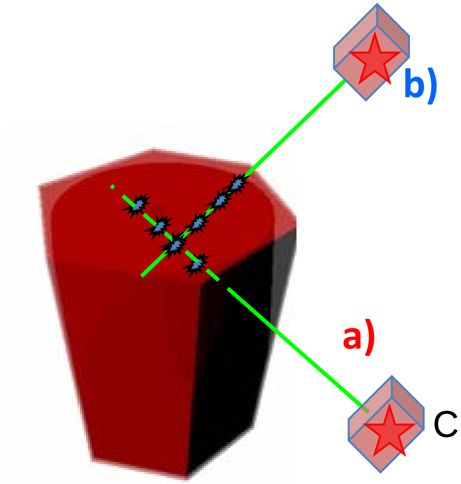
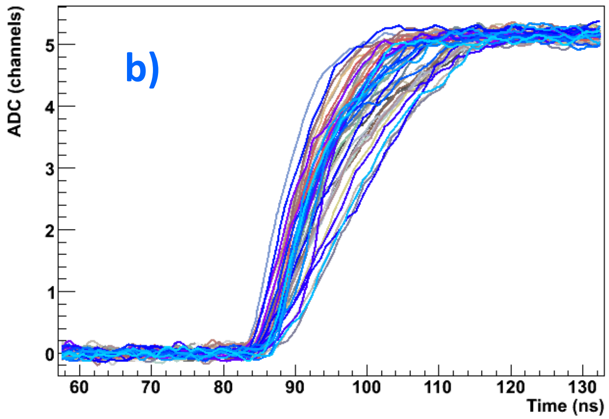


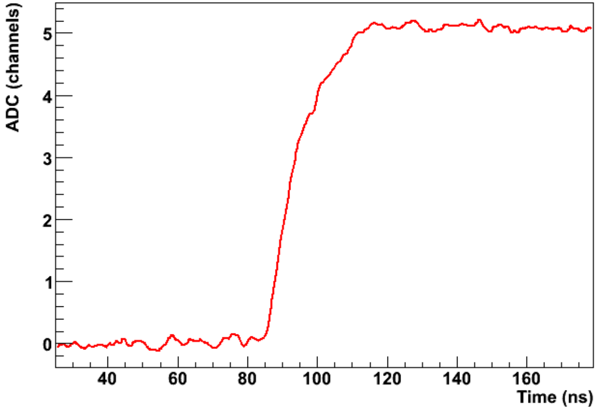


Collimated source

Geometric crossing point: **x,y,z**

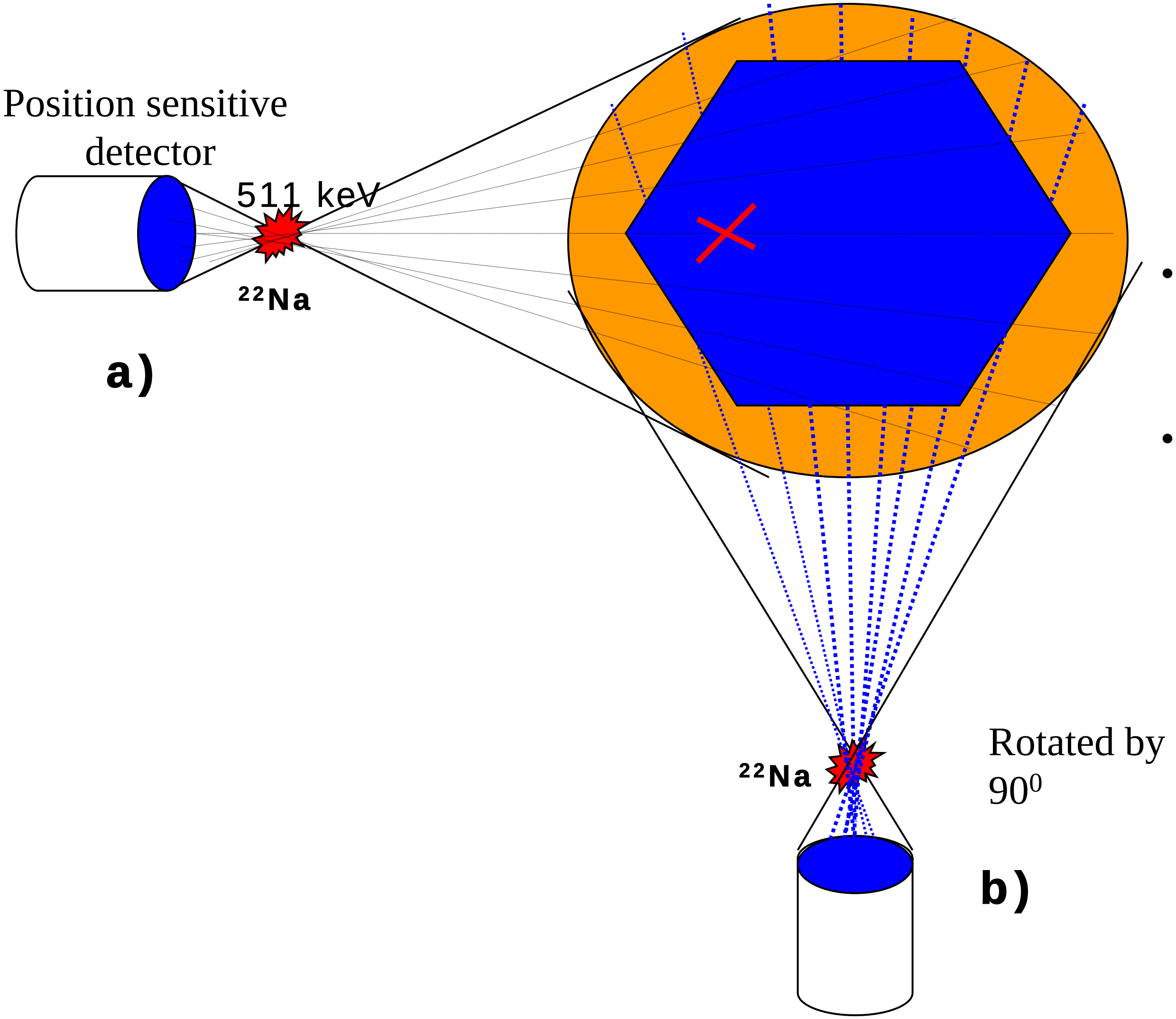


Common pulse out of data sets (a) & (b



F.C.L. Crespi, et al. NIM A 593 (2008), 440

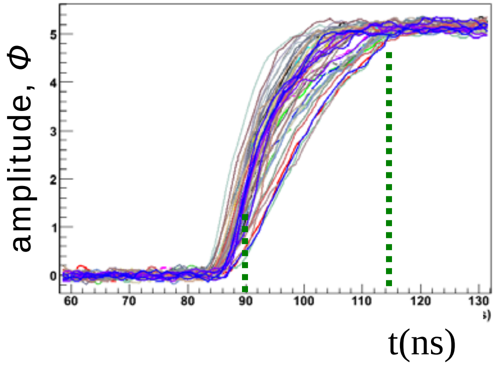
Pulse shape comparison scan method based on a position sensitive detector



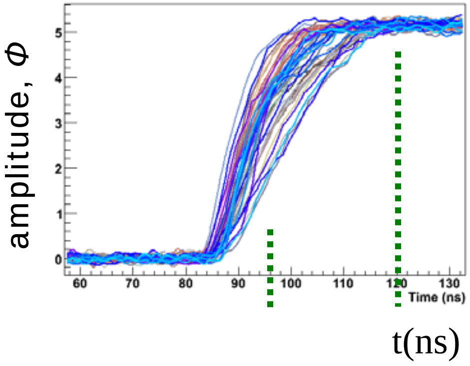
- Recording pulse shapes for positions (a) and (b)
- Identical signals at the crossing point.

χ^2 minimization method

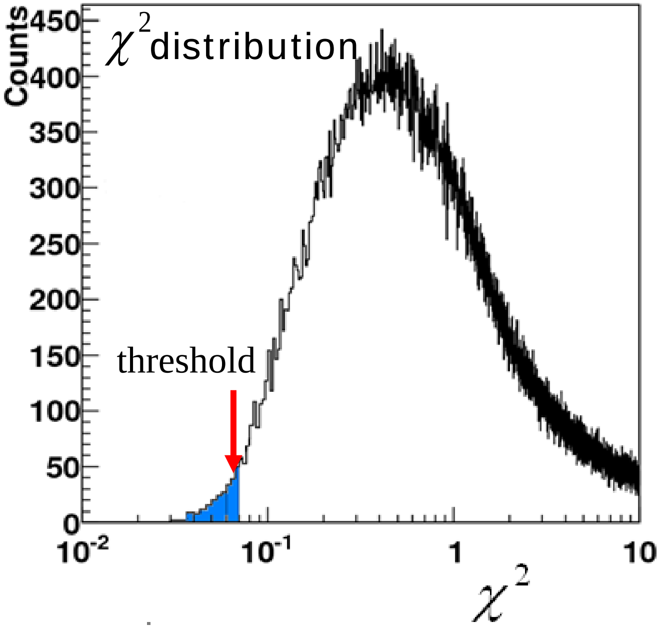
0° measurement



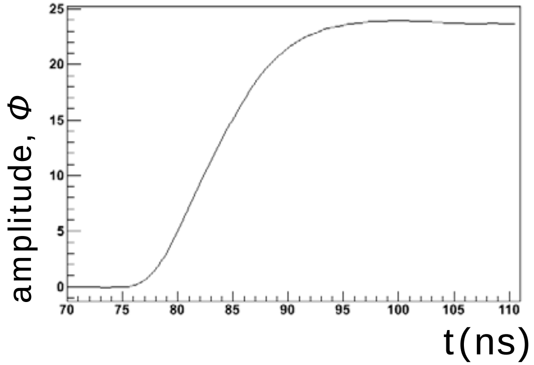
90° measurement



$$\chi^2 = \sum_t (\phi_t^{0°} - \phi_t^{90°})^2$$

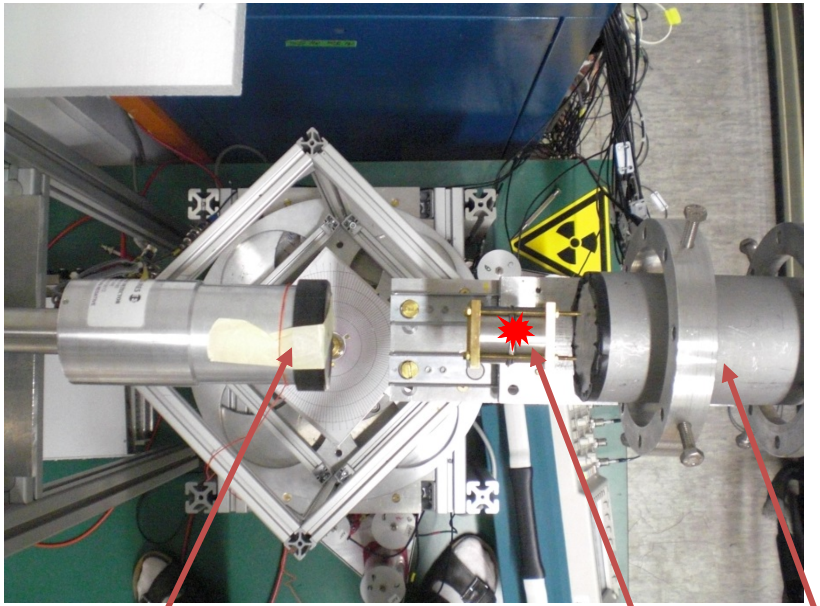


Average pulse

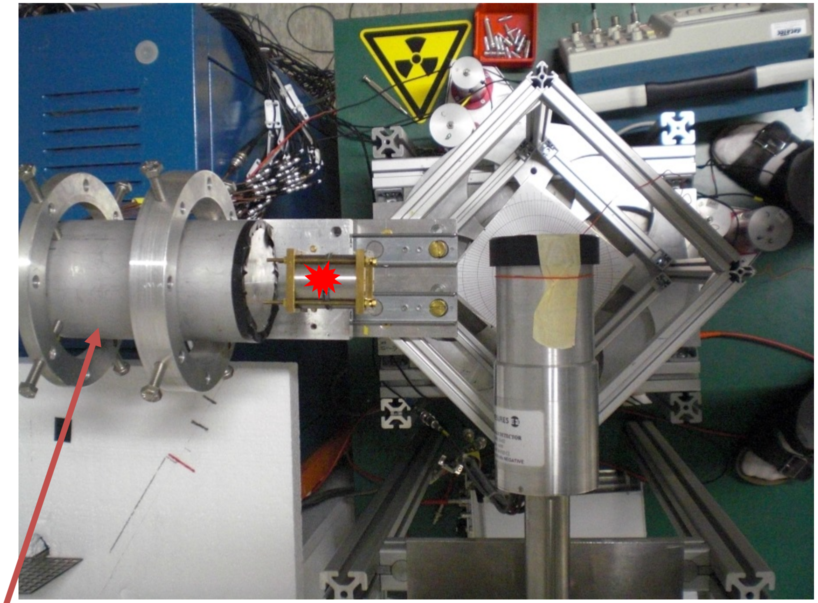


Characterization of planar HPGe detector

Front view



Side view



Planar Ge

d = 4 cm

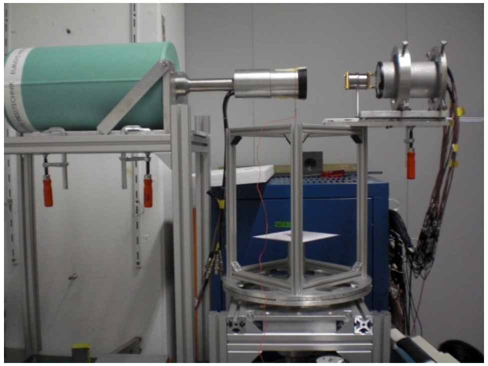
t = 2 cm

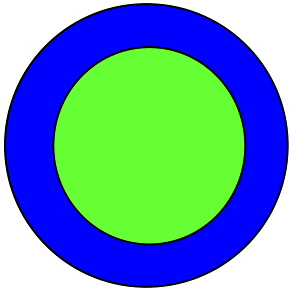
^{22}Na

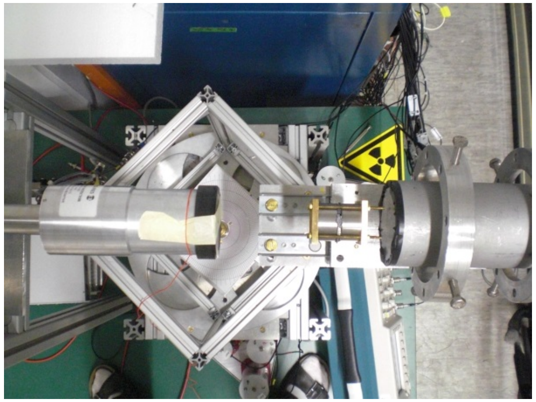
Position sensitive detector

Detector scan

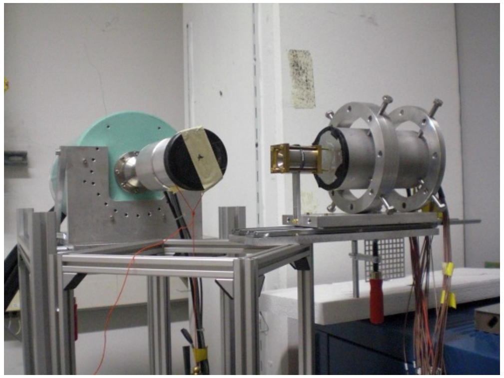
Front view (0 deg):

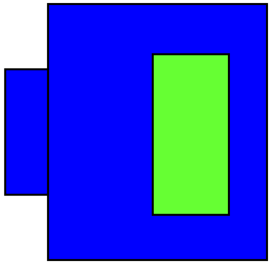


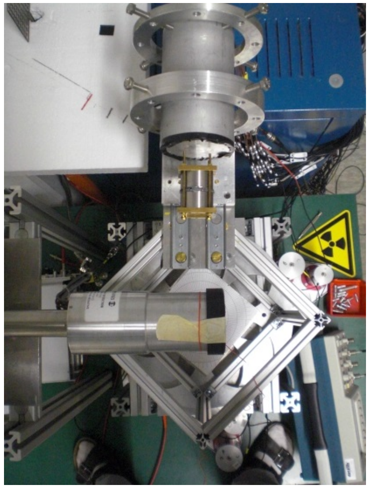




Side view (90 deg):

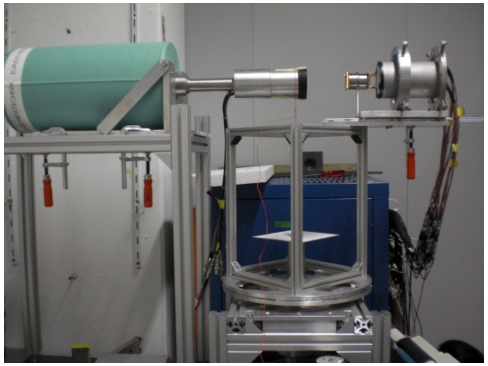


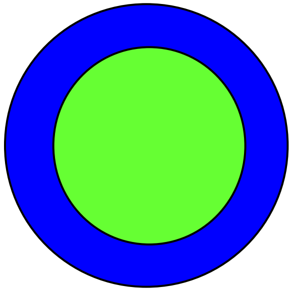


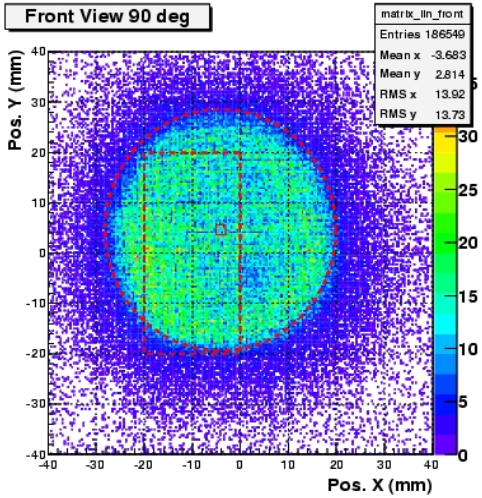


Detector scan

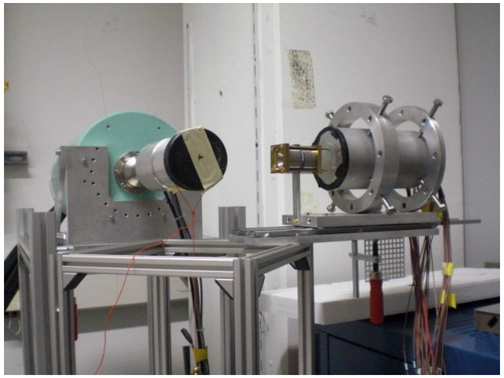
Front view (0 deg):

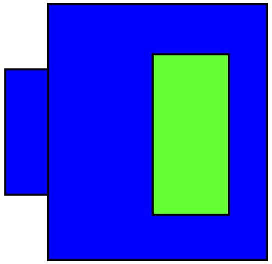


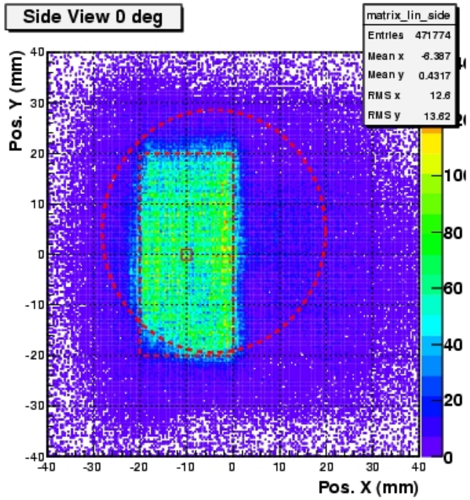




Side view (90 deg):

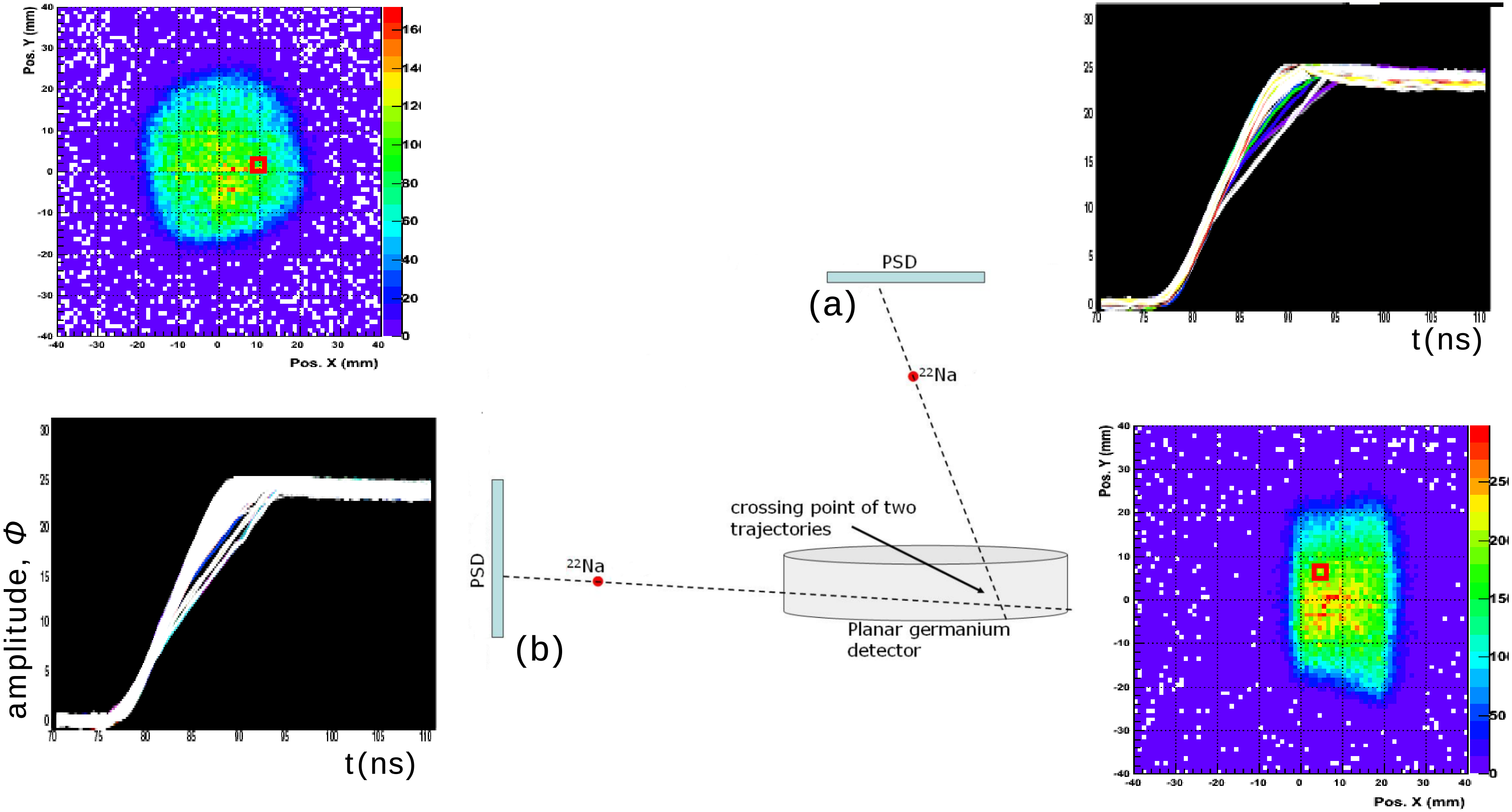




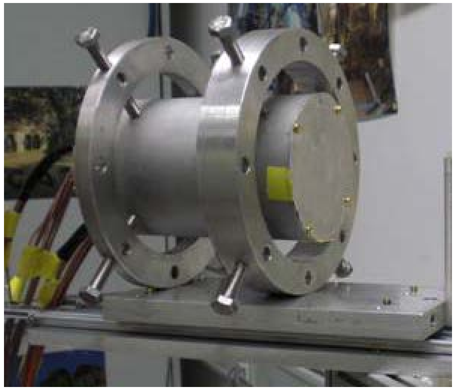


Planar HPGe detector scan

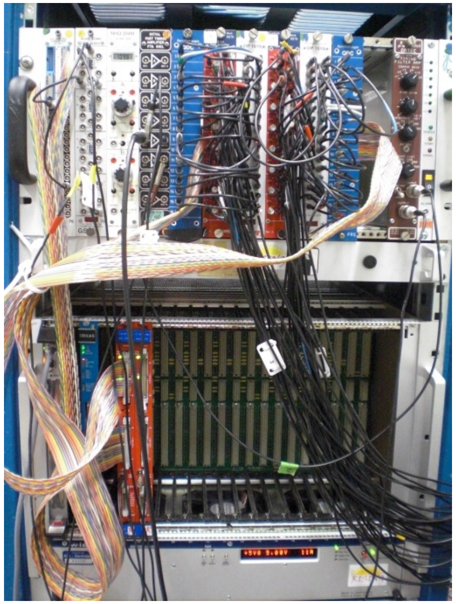
Intensity distribution for photopeak events



Outlook

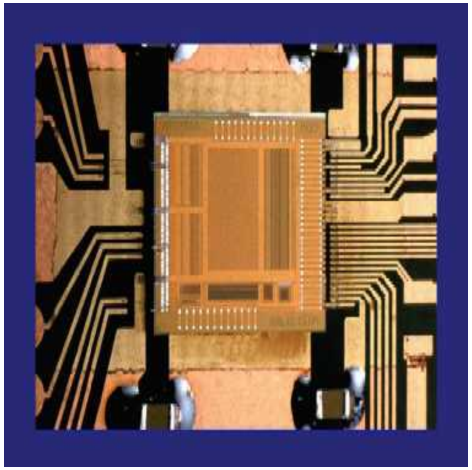


The GSI system uses conventional NIM and VME electronics, which makes it not easily portable, not easily scalable and rather expensive if one wants to build many of these devices.
However, this drawback could be overcome thanks to the increasing technology of electronics, e.g. a new acquisition system based on ASIC, FPGA, etc. technologies. This would also make the system more suitable for medical applications.



?

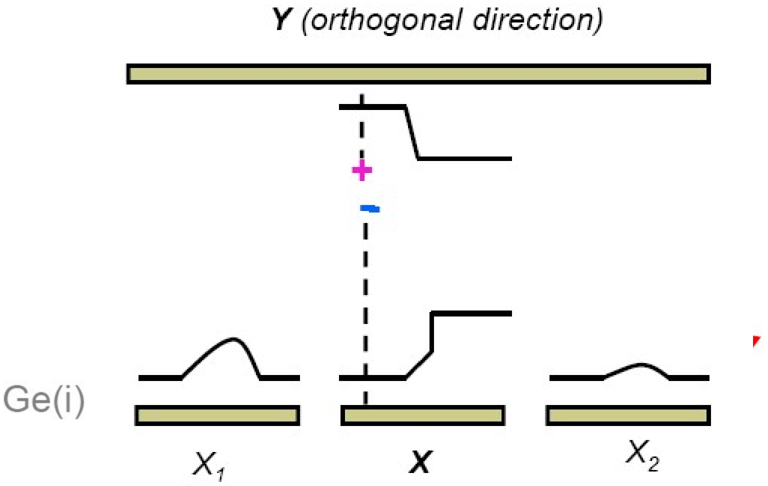
APV25 chip (from CERN CMS experiment)

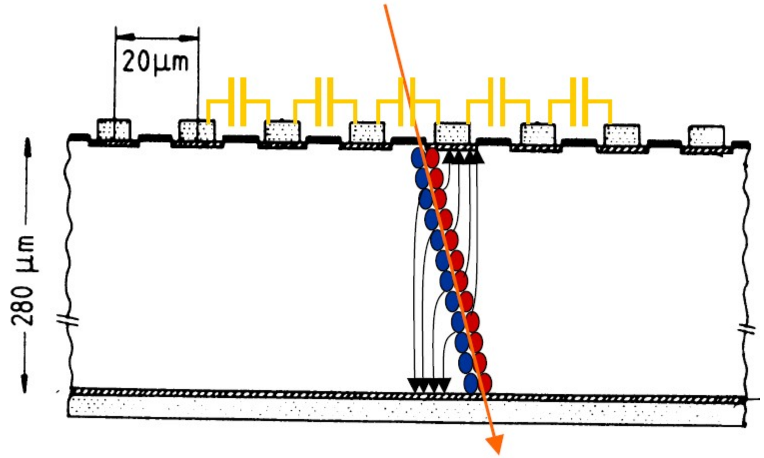


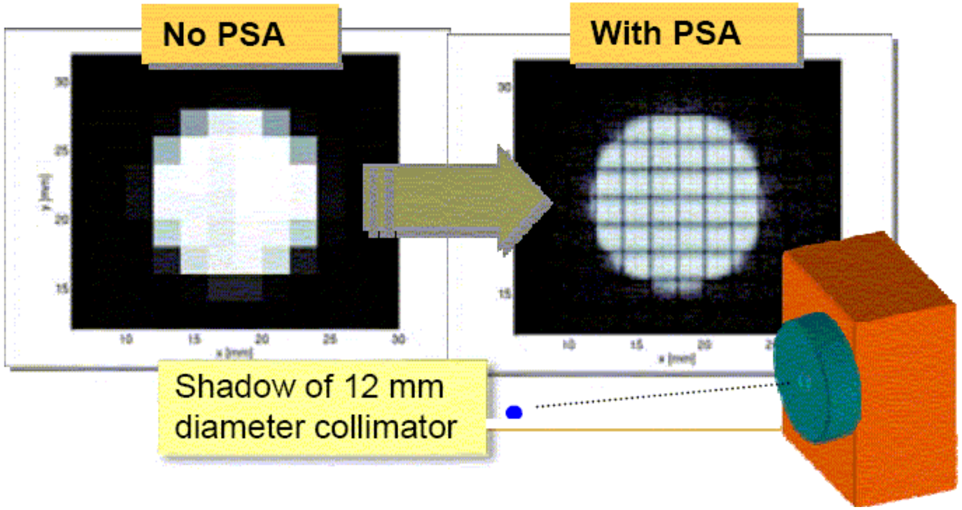
128-channel
analogue
pipeline chip

M.J. French et al., NIMA 466 (2001) 359

Position Extraction in Planar Detectors





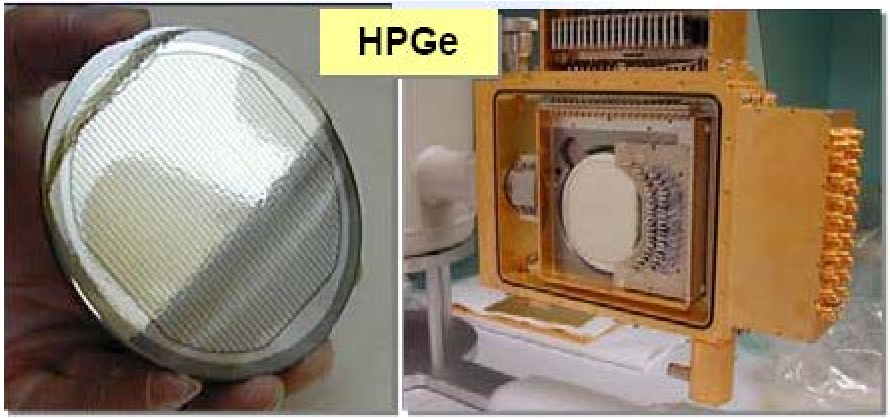


Shadow of 12 mm diameter collimator

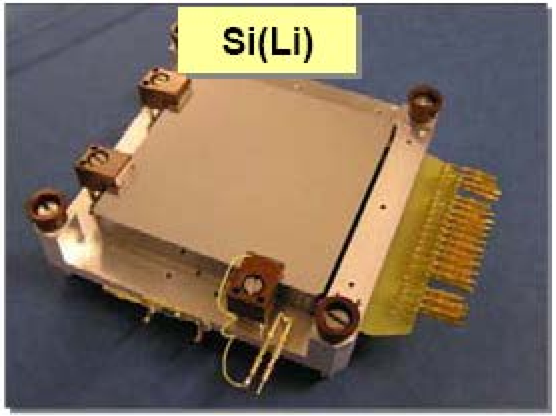
Position resolution of <0.5mm achieved at 122 keV in all three dimensions.

Position Extraction in Planar Detectors

LLNL- Double Sided Strip Detectors (DSSD) built of high-purity Ge and Li-drifted Si for gamma-ray imaging applications
(Ethan Hull, LLNL, Paul Luke, LBNL, and Davor Protic, Research Center Juelich, Germany)



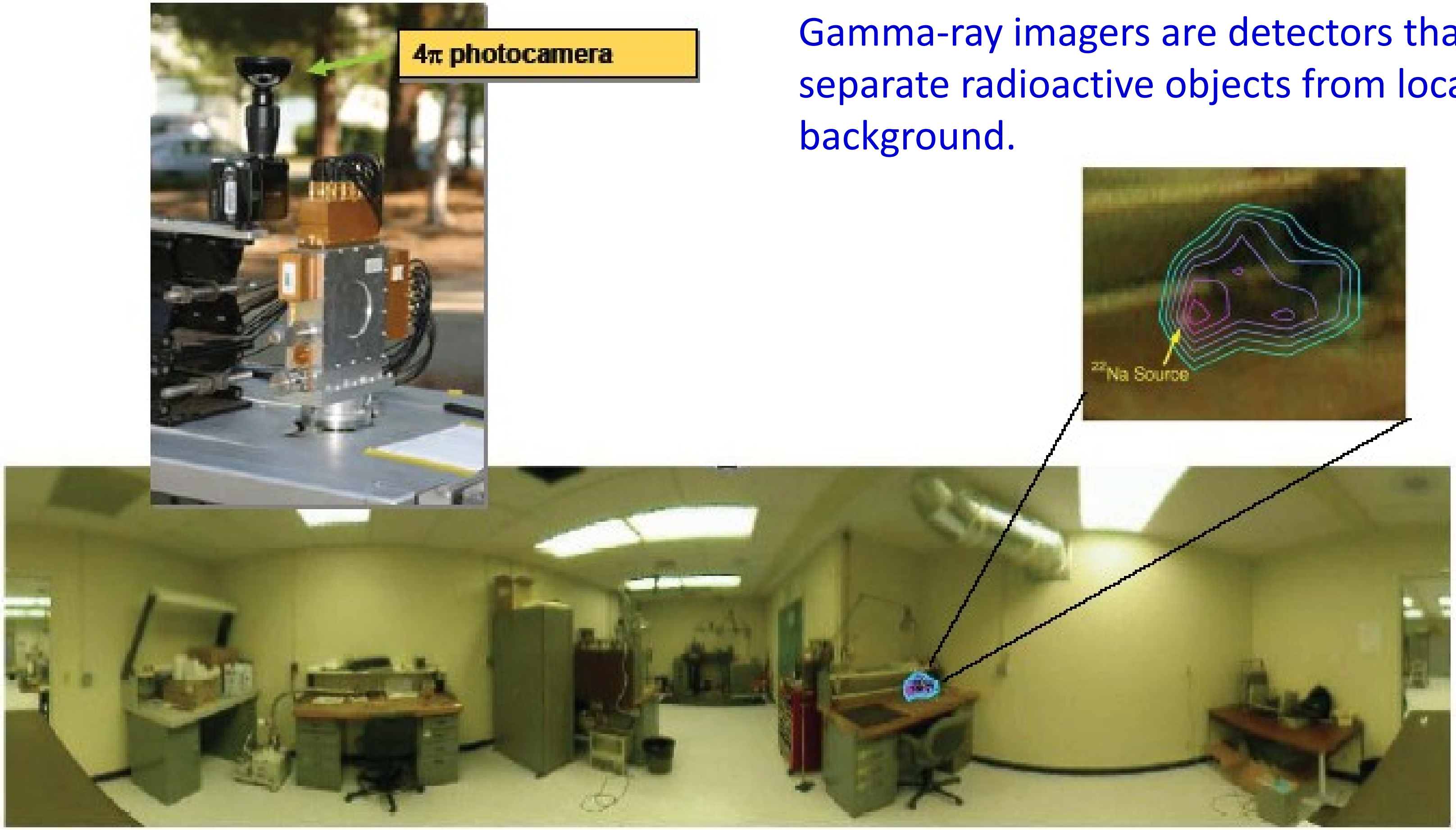
2x38 strip DSSD HPGe detector with 2 mm pitch and 11mm thickness



2x32 strip DSSD Si(Li) detector with 2 mm pitch and 10mm thickness

Gamma-Ray Imaging

Gamma-ray imagers are detectors that separate radioactive objects from local background.



Conventional detectors accept gamma-rays from all directions and can be overwhelmed by local backgrounds.