Application of Nuclear Physics

Frontier of gamma-ray spectroscopy

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<tr>
<th>IR</th>
<th>visible light</th>
<th>UV</th>
<th>soft X-ray</th>
<th>X-ray</th>
<th>hard X-ray</th>
<th>gamma-ray</th>
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<tbody>
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<td>0.1</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1e3</td>
<td>1e4</td>
<td>1e5</td>
</tr>
</tbody>
</table>

Photoelectric effect

Compton scattering

Germanium semi-conductor detectors

energy [eV]
Why imaging gamma-rays?

➢ **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
Application of Nuclear Physics

- First X-ray image by Wilhelm Conrad Roentgen (1895)

Standard X-ray imaging

Absorption of X-rays by bones and transmission through soft tissue produces image

- What if we want a 3D image?
- What if we want detailed information on organs, bones and muscles etc?

Nobel Prize 1901
Tomographic Imaging

PET

SPEC

CT

OPTICAL

MRI

The Electromagnetic Spectrum
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
Positron emission tomography
Most commonly used tracer in SPECT is $^{99}\text{Tc}^m$, 140 keV a pure single photon emitter $T_{1/2} = 6.02\text{ h}$.

Utilizes a gamma-ray camera rotated in small $\sim 3^0$ 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 \( \Delta x = 2 \) mm
- Large field of view (FOV) = 8x9 cm²

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

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

www.siemens.de

Gem-imaging.com
Gamma Camera: Individual multi-anode readout

16 wires in X axis and 16 wires in Y axis

![ANODE PATTERN (TOP VIEW)](image1)

LYSO scintillator

d = 76 mm
t = 3 mm
ρ = 7.4 g/cm³

Hamamatsu R2486 PSPMT

Photocathode = 56.25 mm

Which $\gamma$-ray camera to be used?

**Requirements:**
- Excellent resolution $\Delta x = 2$ mm
- Large field of view (FOV) = 8x9 cm$^2$

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Scintillator

Position

Sensitive

PMT

Gem-imaging.com
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![Diagram of gamma-ray camera components: Scintillator, Position Sensitive PMT, and Gamma-ray source](Gem-imaging.com)
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![Diagram of $\gamma$-ray camera components](Gem-imaging.com)
HPGe detector – working principle
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\[ \vec{E} = -\vec{V} \text{ V} \]

+ HV = 4000 Volts
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \ V \]

\[ + \text{HV} = 4000 \text{ Volts} \]
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \text{ V} \]

$\gamma$-ray

electrons, holes

Electric signal

+ HV = 4000 Volts
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \text{ V} \]

+ HV = 4000 Volts

\[ \gamma \text{-ray} \]

electrons, holes

Electric signal

Oscilloscope
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \text{ V} \]

+ HV = 4000 Volts

\( \gamma \)-ray

electrons, holes

Electric signal

Oscilloscope
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \text{ V} \]

+ HV = 4000 Volts

gamma-ray

gamma-ray 2

electrons

holes

Electric signal
HPGe detector – working principle

\[ \vec{E} = -\vec{V} \text{ V} \]

+ HV = 4000 Volts

γ-ray

Electrons, holes

Electric signal

\[ \gamma \text{-ray} \]
Characterization of planar HPGe detector

Front view

Planar Ge

\( d = 4 \, \text{cm} \)

\( t = 2 \, \text{cm} \)

\( ^{22}\text{Na} \)

Side view

Position sensitive detector
Planar HPGe detector scan

Intensity distribution for photopeak events

(a)

(b)
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

$Y$ (orthogonal direction)

Ge(i)

$X_1$  $X$  $X_2$

20 $\mu$m

280 $\mu$m

No PSA

With PSA

Shadow of 12 mm diameter collimator

Position resolution of <0.5 mm 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)

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

- **Si(Li)**
  - 2x32 strip DSSD Si(Li) detector with 2 mm pitch and 10 mm 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.