Gamma-ray Spectroscopy with HPGe and $LaBr_3$ Detectors

Gamma-ray spectroscopy is a broadly applied technique where information about an atomic nucleus is extracted from the analysis of the energy and intensity of its emitted gamma rays, as well as the correlations and coincidences between them. The applications of this nuclear physics experimental technique range from astrophysics to geology. This practice aims to provide a hands-on example of gamma-ray spectroscopy, where the student will acquaint with scintillator and semiconductor detectors, measure radioactive sources, analyze gamma-ray spectra with ROOT and compare the obtained results to Geant4 simulations.

Introduction

Gamma Emission

A gamma ray is a high-energy photon emitted by an excited atomic nucleus as a mode of de-excitation to a lower energy state. The measurement of gamma-ray emissions is an ideal tool to probe nuclear structure, it also has many practical applications, like the calibration of a detector or the identification of a radioactive nucleus.

Photon Detection

The detection of a gamma ray requires the high-energy photon to interact with an absorbent material, so it transfers part or all its energy to the latter. There are three main interaction mechanisms between radiation and matter i.e., photoelectric effect, Compton scattering and, if the photon energy is high enough, electron pair production.

In a **scintillation detector** a luminescent material constitutes the active region where radiation is absorbed, there is a wide variety of scintillating materials with an equally wide variety of properties, for this practice, a phsowich **$LaBr_3$(Ce)** /$LaCl_3$(Ce) scintillation crystal will be used. The working principle is that the ionizing radiation interacts with the material exciting a specific atomic level, so when it de-excites a light pulse of a characteristic wavelength in the visible spectrum is emitted. The amount of light emitted is proportional to the energy of the impinging gamma ray. For collecting the light pulse, the crystal is coupled to a photomultiplier (PMT) or a photodiode, where the photons are converted into an electric current. If the detector is properly set, the output current at the anode of the PMT provides information about the energy and time of the incident gamma ray, as the response is very fast.

In a **semiconductor detector** radiation interacts with an impurity-doped semiconductor material, this generates an energy-proportional number of electron-hole pairs, which become charge carriers. An inversed electric field is applied to the active region, which is free of charge. When the radiation arrives to the material and the electron-hole pairs are created, they feel the field at the borders of the depleted region, this ensures that the negative and positive carriers drift in opposite directions, producing an electric current. If this process is properly set, the induced current is proportional to the energy deposited by the incident gamma ray. For this practice, a **High Purity Germanium (HPGe)** detector will be used, which needs to be cooled down with liquid nitrogen for operating.

Electronic chain

The objective of the electronic chain is to shape the electronic signal coming from the detectors in order to be processed by the Data Acquisition system (DAQ). In this practical exercise, the electric signals will go through a standard analogical logic setup before being fed to a digitizer, a simplified logic scheme of the electronic chain used in this experiment is provided in Figure 1.

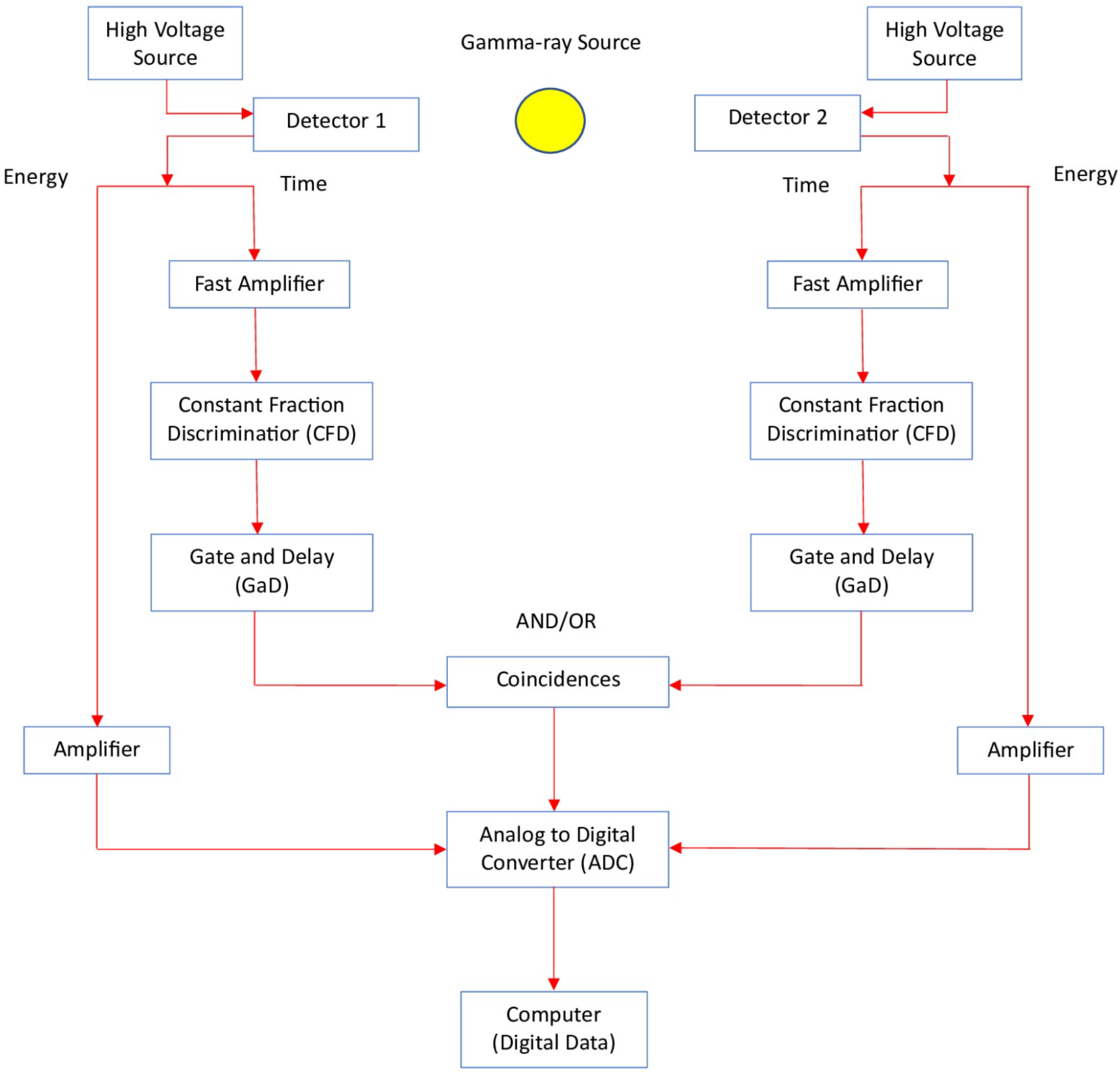


Figure 1: Scheme of the electronic chain of a standard coincidence setup.

The electronic modules that will be used in this exercise (see the **Materials** section) are:

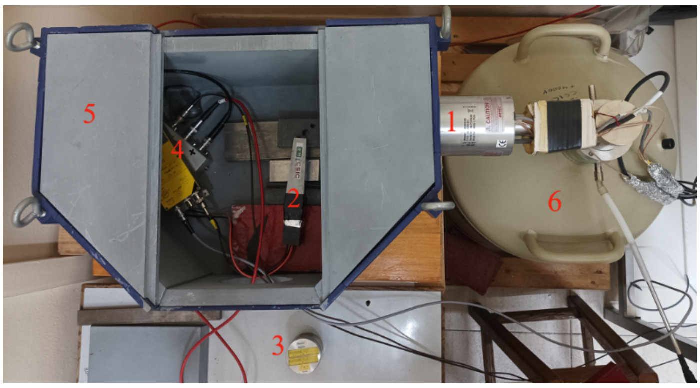
1. **Preamplifier**: Amplifies the weak signals coming from the detector, they are normally mounted as close as possible to the detector to minimize energy losses of this weak signals in the cable.
2. **Amplifier:** Amplifies the signal provided by the preamplifier and shapes it in a way convenient for further processing, The MESYTEC STM16+ includes the FA, CFD, and A of the Fig.1.
3. **Gate Generator:** Accept logic signal input**,** provides a logic signal of a determined duration that can be used as acquisition trigger.
4. **Fan In/Fan Out:** The Fan In mode allows for several logic input signals in OR, and the Fan Out mode distribute the input signal via several identical output signals. (logic signals)
5. **Analog to Digital Converter (ADC):** Converts the information of an analog signal into an equivalent digital number.
6. **MLVC:** VME controller; reads the backbone of the VME-crate; sorts, and distribute the data via USB3 to the acquisition program of the PC.

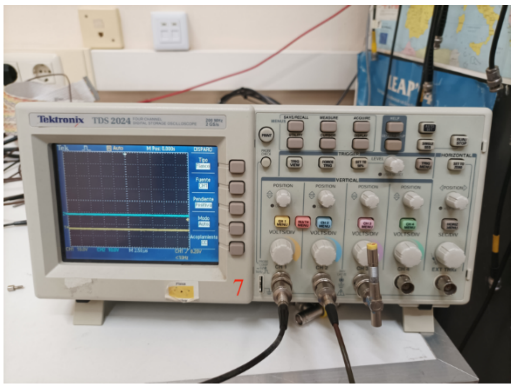
Objective

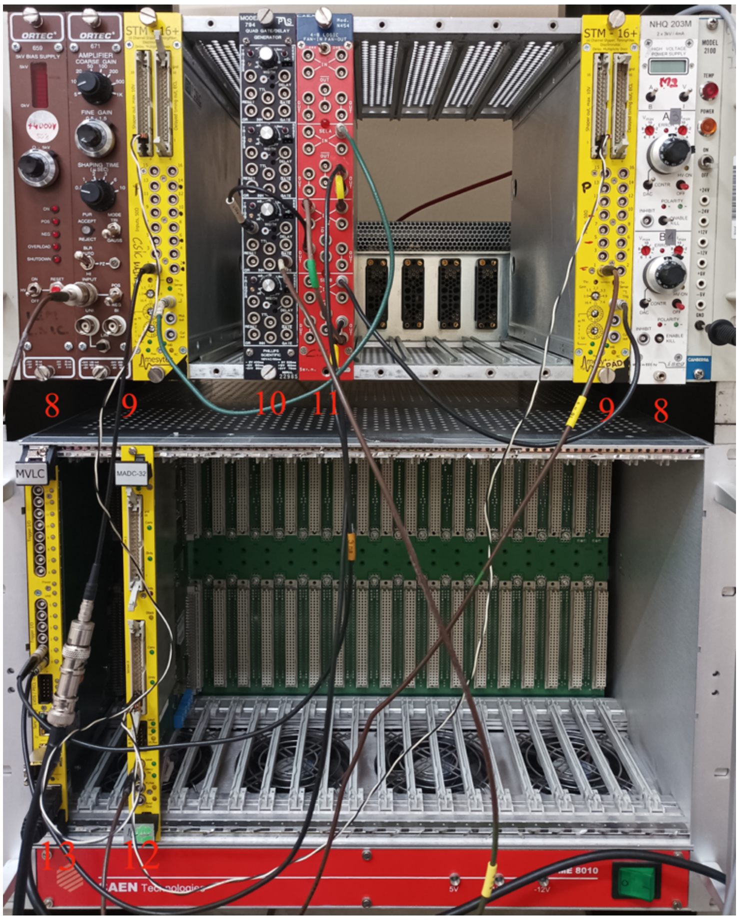
To introduce the student to the main concepts of gamma-ray spectroscopy such as processing analogical signals coming from detectors, detector energy and efficiency calibrations, fundamental aspects of gamma-ray spectra analysis through the program ROOT and to compare experimental results with Geant4 simulations.

Materials

1. HPGe Detector.
2. LaBr Detector.
3. Radioactive sources.
4. Preamplifier.
5. Lead chamber.
6. Liquid nitrogen dewar.
7. Oscilloscope.
8. High Voltage Supply (x2).
9. Amplifier (x2).
10. Gate & Delay generator.
11. Fan In/Fan Out unit.
12. ADC.
13. MLVC.







Laboratory Procedure

1. Observe the output signals of the HPGe and LaBr detectors.
2. Test the DAQ of the experiment, use the oscilloscope to show the signal in each step of the electronic chain and discuss the signal characteristics.
3. Obtain the energy spectrum of a ^{60}Co source for each detector.
4. Adjust the gain and threshold parameters of the amplifiers to obtain a suitable dynamic range and energy resolution. Then characterize the ^{60}Co source once again and justify the election of the new parameters.
5. Employ the ^{60}Co and ^{152}Eu sources to calibrate the detectors. These measurements will require about 30 min each.
6. Identify an unknown radioactive source throughout its gamma-ray spectrum. This measurement will require around 10-15 min.

Laboratory Report

The report of this practice must include the following:

I. Explain the main characteristics of the HPGe and LaBr detectors and compare them to each other.
II. Present a diagram of the experimental setup in which the function of each element of the DAQ is described.
III. Discuss the choice of gain and threshold parameters and show how they affect the energy dynamic range and resolution of the detectors.
IV. Calibrate both detectors with the ^{152}Eu source, you will use the ROOT calibration program provided from the lecture "LAB1-ROOT".
V. Identify the characteristic γ-peaks from the ^{60}Co and ^{152}Eu spectra, explain any extra peaks or additional phenomena you may observe. Do you observe any coincidences in the ^{60}Co spectra?
VI. Subtract the background from both detectors using ROOT, then repeat the previous step.
VII. Identify an unknown radioactive source applying gamma-ray spectroscopy.
VIII. Via the analyzed spectrums, obtain the energy resolution of the detectors and comment on any possible differences between them.
IX. Compute the efficiency of the HPGe detector and compare it with the one obtained from a Geant4 simulation. This will require the use of the programs from the lecture "Monte Carlo Simulation of Detectors".

Reports

All reports must be sent to: master.nuclear@iem.cfmac.csic.es
For questions you can contact: daniel.fernandez@csic.es and carlos.ferrera@csic.es

References

1. K.S. Krane "Introductory nuclear physics".
2. F. Knoll: "Radiation detection and measurement".