Gamma-ray Spectroscopy with HPGe and $LaBr_3$(Ce) Detectors

Gamma-ray spectroscopy is a widely used technique that enables researchers to collect information about atomic nuclei by analyzing the energy and intensity of emitted gamma rays, as well as the correlations and coincidences between them. This experimental method in nuclear physics has applications across various fields, including astrophysics and geology. Like any experimental technique, implementing it in an experiment requires an electronic chain that connects the detectors to data acquisition systems.

This hands-on practice serves two main objectives: first, it provides students with a practical example of gamma-ray spectroscopy by comparing the resolution of scintillator and semiconductor detectors; second, it introduces the students to the concept of an electronic chain, which they will test using an oscilloscope.

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. 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 interactions 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 **$LaBr_3$(Ce)** scintillator crystal will be used. The inner workings of this detector won´t be explained here since it is the focus of the **$LaBr_3$(Ce)** exercise.

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 at 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) [LB-GEM-SH]** detector will be used, which needs to be cooled down with liquid nitrogen for operation.

Electronic chain

When conducting a physics experiment, the electronic chain refers to a collection of electronic components that transmit the detector signals to a computer known as the DAQ (Data Acquisition System). The complexity of these chains can range from just two modules to hundreds.

In simple terms, the flow of information through the electronic chain is conveyed by two types of signals. First, energy signals are Gaussian (or nearly Gaussian) pulses, the height of which is directly proportional to the signal measured by the detector. This signal contains physical information about what we are measuring. However, detectors often capture irrelevant background processes, and there may be instances where we only want to record data when two detectors are activated simultaneously. Therefore, *it is essential not only to know what we are measuring but also when to record it,* time signals are used for this purpose. Unlike energy signals, time signals are sharper (less Gaussian-like) and travel faster through the electronic chain. This characteristic allows them to be employed in logical operations that determine when and for how long the DAQ should record data. Additionally, in some advanced techniques, time signals can also hold physical information.

In this exercise, we will use a very simple electronic chain to conduct a basic gamma spectroscopy experiment.

Objective

In this exercise we will compare the resolution of two types of gamma detector, a semiconductor and a scintillator using a set of gamma sources. This will require to first check the that basic electronic chain is sending the signals correctly from the detector to the computer (we will use an oscilloscope for this), then calibrate the detector using a known source, and finally compare the resolutions of the detectors In addition, the student has to identify an unknown source based on its gamma spectrum and compare their results with the Geant4 exercise.

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

1. **Preamplifier**: Amplifies the weak signals coming from the detector, normally mounted as close as possible to the detector to minimize energy losses of these weak signals in the cable.
2. **Amplifier:** Amplifies the signal provided by the preamplifier and shapes it in a way convenient for further processing, this is crucial to avoid pile-up shaping at the end of the signal.
3. **Gate Generator:** Provides a logical signal of a determined duration and frequency with which to generate the acquisition trigger.
4. **Fan In/Fan Out:** The Fan In mode combines several input signals into a sum signal, and the Fan Out mode multiplies the single input signal into several identical output signals of the same height and shape.
5. **Analog to Digital Converter (ADC):** Converts the information of an analogic signal into an equivalent digital number.
6. **MVLC:** Transmits digitalized information to the computer.

Materials

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

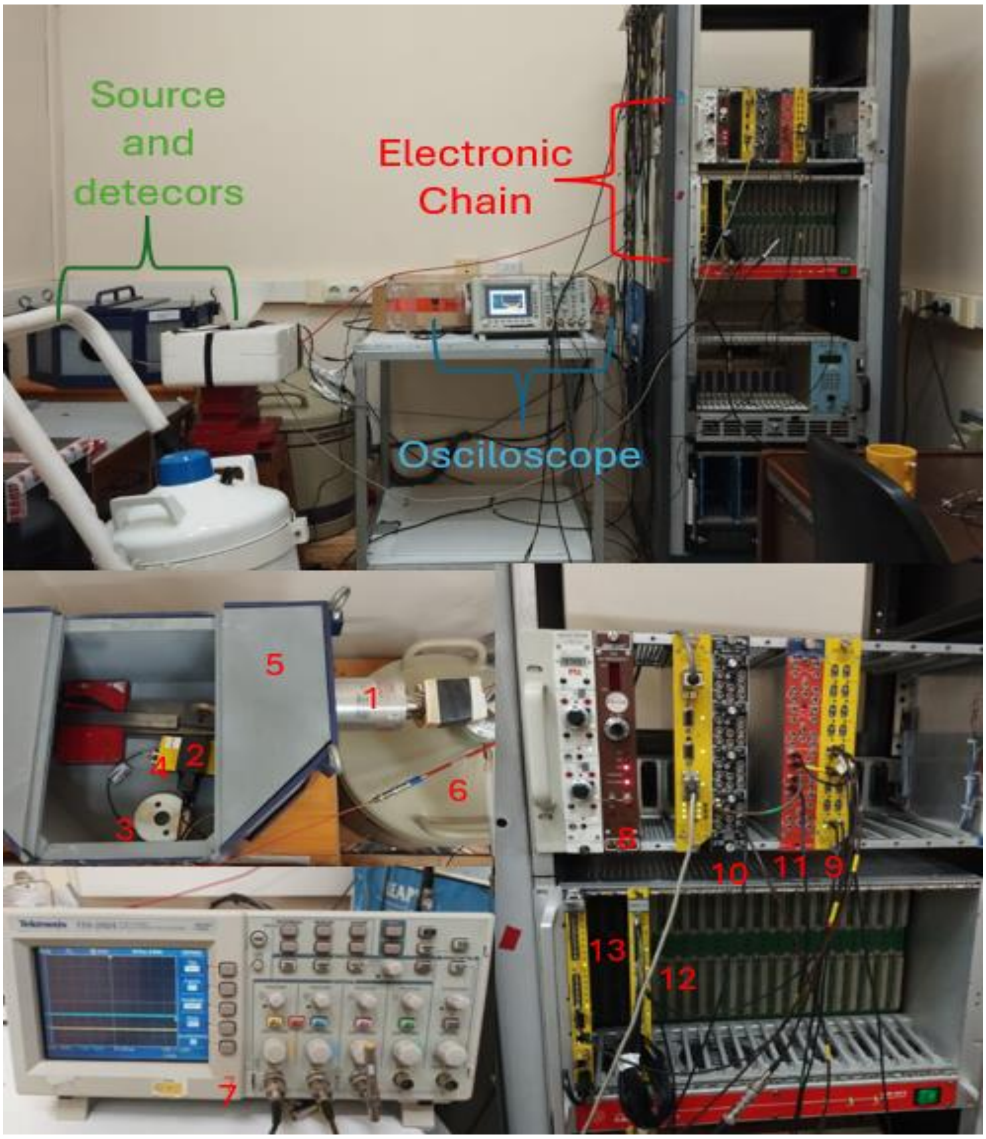

Figure 1: At the top, a photograph of the experimental setup with various subsections indicated. Below, a zoom into the subsections with the components numbered.

Laboratory Procedure

1. Observe the output signals from the HPGe and LaBr detectors.
2. Get familiar with the DAQ, the oscilloscope to obtain 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 20 min each.
6. Identify an unknown radioactive source throughout its gamma-ray spectrum. This measurement will require around 10-15 min.

To include in the laboratory report

I. Explain and compare the main characteristics of the HPGe and $LaBr_3$(Ce) detectors.
II. Draw 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 with the MVME software.
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. Identify an unknown radioactive source applying gamma-ray spectroscopy.
VII. Via the analyzed spectrums, obtain the energy resolution of the detectors and comment on any possible differences between them.
VIII. 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

For questions you can contact: daniel.fernandez@csic.es and jaime.acosta@iem.cfmac.csic.es

References

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