Title: Measurement of the response function of scintillation detectors to neutrons and high-energy gamma rays.

Introduction

Nuclear reactions with heavy ions are characterized by high multiplicity $M\gamma$ of γ radiation, which is associated with the processes of dissipation of the input angular momentum that occurs during the fusion of colliding nuclei. The processes of nuclear cooling and dissipation of the angular momentum of the reaction products are passing through the particle emission, emission of statistical γ-quanta and γ-ray transitions of the yrast-line, respectively.

The direct γ-decay of GDR in heavy-ion reactions is accompanied by the γ-cascade with a large value of multiplicity $M\gamma$. It leads to a «pile-up» effect (the overlapping of detection pulses) in the γ-detectors. In can leads, due to «pile-up» effect, to the situation when the sum γ-energy of «pile-up» γ-quanta will be positioned in the energy scale close to the GDR region.

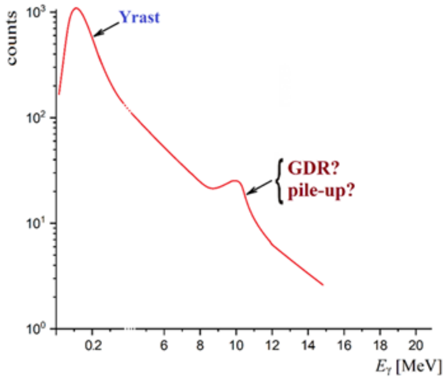

Fig.1. Illustration of the yrast-line spectrum, GDR and «pile-up» effect.

The solution to the "pile-up" problem in high-energy γ-spectroscopy is carried out using the technique of phoswich detectors.

The phoswich detector is a pair of scintillation crystals optically connected to each other and to a PhotoMultiplier Tube (PMT). The thicknesses of the scintillation crystals are chosen in accordance with the condition of preferential absorption of low-energy γ-quanta in the first scintillator, while high-energy γ-quanta pass it without interaction with a high probability and are absorbed in the second scintillator of the detector. The most efficient combinations are $CeBr_3$:Ce-NaI(Tl) and $LaBr_3$:Ce-NaI(Tl) pairs because they have similar light yields, different emission times, and provide conditions for creating large volume detectors.

Different times of scintillator illumination make it possible to sufficiently separate scintillation components with one photodetector. This made it possible to solve problems associated with the effect of pulse superposition.

MULTI setup

At the present time, to solve a number of problems related to the study of the properties of exotic radioactive nuclei in the Flerov Laboratory of Nuclear Reactions, the MULTI setup (Fig.2) is being created. This setup includes a 4π-β counter, a scintillation spectrometer of 12xCsI(Tl) detectors, assemblies of 9x$CeBr_3$-NaI(Tl) phoswich detectors, and ^{3}He neutron counters.

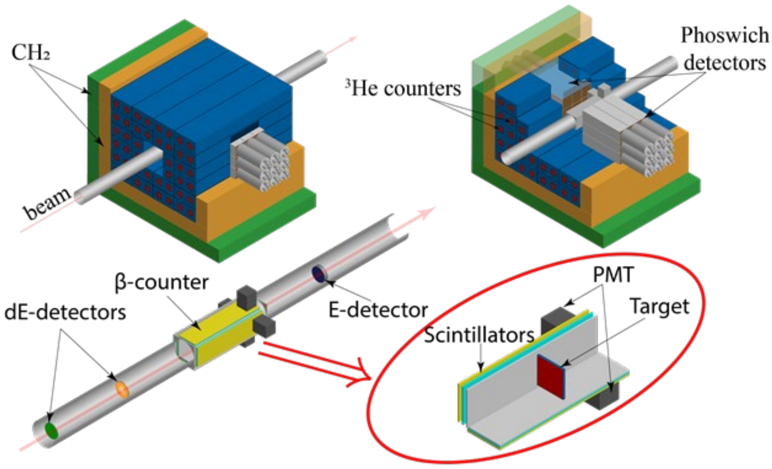

Fig. 2. The MULTI experimental setup

The phoswich detector is a pair of scintillation crystals optically connected to each other and to a PhotoMultiplier Tube (PMT). The thicknesses of the scintillation crystals are chosen in accordance with the condition of preferential absorption of low-energy γ-quanta in the first scintillator, while high-energy γ-quanta pass it without interaction with a high probability and are absorbed in the second scintillator of the detector.

Different scintillator exposure times make it possible to sufficiently separate the scintillation components with a single photodetector. This made it possible to solve the problems associated with the effect of pulse superposition

Phoswich cluster 9 $CeBr_3$-NaI(Tl) detectors

The cluster of 9 phoswich detectors ($CeBr_3$-NaI(Tl)) was created within the framework of the PARIS international collaboration, which included participants from 10 countries, including JINR, Dubna, Russia.

This detector can work not only in the inclusive mode, but also in the clover detector mode. Our group carried out simulations (Geant4) and measurements of the operation of phoswich detectors in the Compton suppression mode. Calculations using the Geant4 code showed that, in comparison with an HPGe detector of similar size (78x72.8 mm), the central detector of the cluster (51x51 mm) of 9 phoswich detectors has a similar Compton spectrum component suppression coefficient. However, the $CeBr_3$-NaI(Tl) detector has a higher efficiency at the total absorption peak compared to the HPGe detector. Another advantage of phoswich detectors is that they do not require constant cooling.

The total detection efficiency of the spectrometer and the detection efficiency in the total absorption peak for γ-quanta $E\gamma$=1173 keV depending on the distance of the spectrometer to the source is shown in Fig.3.

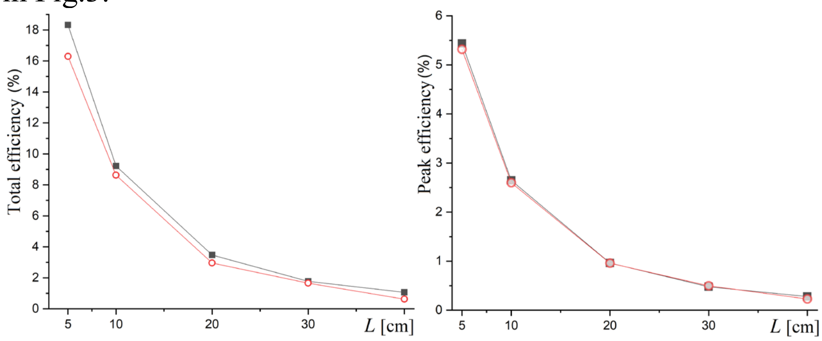

Fig. 3. Total efficiency and peak efficiency as a function of distance to –source ^{60}Co. The measurements for target -quanta with E = 1173 keV. Squares — calculated results, circles — measured results.

Our group also discovered that this assembly of detectors can register and separate neutrons and γ-quanta by time of flight with fairly good resolution.

Work plan:

The student is asked to perform a series of measurements and analyze the properties of this assembly and a number of other detectors.

Determination of the efficiency of registration of high-energy γ-quanta for CeBr3, NaI(Tl), Stilbene, CeBr3-NaI(Tl), 9xCeBr3-NaI(Tl) detectors using a 238Pu+13C source. This source emits γ-quanta with an energy of 6.13 MeV and neutrons with an energy of 4 MeV.

Determination of the efficiency of neutron detection depending on energy for detectors CeBr3, NaI(Tl), Stilbene, CeBr3-NaI(Tl), 9xCeBr3-NaI(Tl) using a 238Pu+13C source by the method of tagged γ-quanta.

The measurement is intended to be carried out using the existing data acquisition system-VME. Data analysis will be performed using an open source data analysis platform - ROOT. Also, the trainee will participate in the planned experiments and direct processing of the obtained experimental data.

Fig. 4. The experimental setup for measuring the response function to neutrons and γ-quanta.

Requirements:
Basics knowledge of C++ programming language
Basic knowledge in nuclear physics

Recommended literature:

1. Ivan Sivacek, Sergey Stukalov, Yuri Sobolev, et al., "The MULTI spectrometer for measurement of β-decay process in exotic nuclei", EPJ Web of Conferences 253, 01003 (2021), ANIMMA 2021, https://doi.org/10.1051/epjconf/202125301003;
2. Zh. Zeinulla, Yu.G. Sobolev, S.S. Stukalov, et al., "Gamma-ray spectrometer assembled from 9 CeBr3-NaI(Tl) phoswich detectors", Acta Physica Polonica B №4, pp. 755-760, (2021);

Requirements:
Basics knowledge of C++ programming language
Basic knowledge in nuclear physics

Number of students for the project: 2-3

Project supervisors:
Mr. Sergey Stukalov, Dr Yuri Sobolev, Flerov Laboratory of Nuclear Reactions