Joint Institute for Nuclear Research

Flerov Laboratory of Nuclear Reactions

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LABORATORY WORK

TOF measurement of the charged particles using the MCP detector

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Introduction

Experiments on the beams of the radioactive isotopes is the direction of nuclear physics, which is currently intensively developed. The use of such beams for the researching modern nuclear physics is accompanied by some tasks, such as obtaining the required intensity of beams, accelerating them to the required energy and registering the products of the nuclear reactions. Recording and further studying the obtained results, due to the complexity of experiments of a similar level (a large variety of reaction channels, the presence of neutron and gamma background, etc.), places a special demands on the characteristics of the data acquisition equipment. Under these conditions, one of the most accurate methods for determining the energy of a particle is the time-of-flight method, in which the energy is determined by measuring the time of flight of a particle at a given distance:

$$E_K = \frac{E_0 \cdot \beta^2}{\left(1+\sqrt{1-\beta^2}-\beta^2\right)}$$

where $E_0 = m_0c^2$ is the ion rest energy $V = L/t$ is the, ion velocity, and $\beta = V/c$ is the relative ion velocity $\beta = V/c$

An important element of the time-of-flight technique is the start detector, which must have a high temporal resolution, minimal stopping losses when registering heavy reaction products, low sensitivity to the background of light particles and resistance to radiation damage.

Objective of the work

The main objective of this practice is to acquaint students with the work of electronic equipment, which is used in nuclear physics experiments in the modern facilities, as well, as to explain how to handle devices of this level, introduce the method of determining the energy of particles by their time of flight and to consolidate the skills in the studying of the obtained measurement results.

The purpose of this laboratory work is to study the time of flight of the alpha particle in a vacuum chamber. The vacuum chamber used in this work has to the following parameters: the chamber diameter is 22 cm, the length is 40 cm (Fig. 1). Also for the study needed: foreline pump, turbomolecular pump. The latter was chosen because of the use of an MCP detector as a start detector, which requires a vacuum pressure on the order of 10^{-6} tor. The results of such studies are of practical importance for modern nuclear physics measurements. In particular, it is possible to use the electronic equipment described in the work as part of the data collection system of a nuclear physical installation. Figure 1.2 shows a vacuum chamber and a data acquisition system.

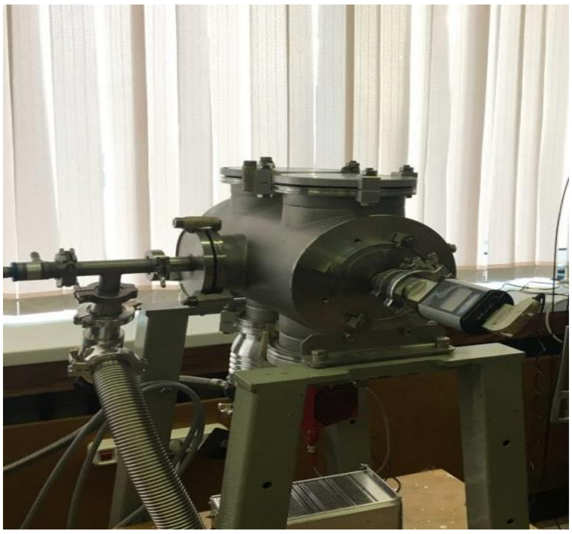

Fig.1.Vacuum chamber

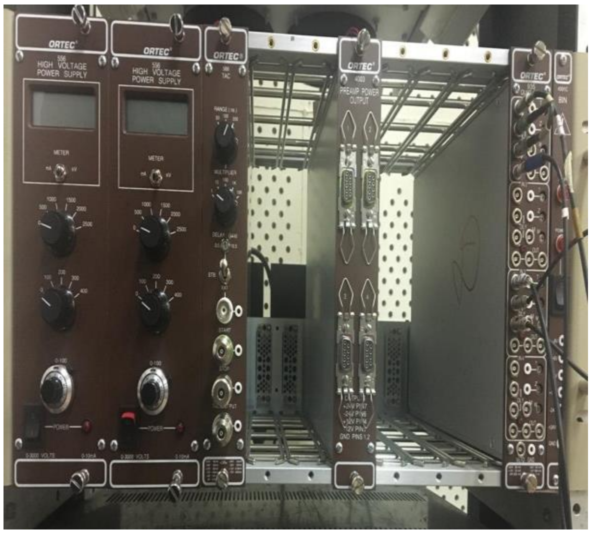

Fig.2. Data acquisition system

The method of studying the time of flight is the main one in the study of reactions with light ^{4}He ions. The radiation source is ^{226}Ra. To determine the velocity of the alpha particle, two detectors were used in the work, consisting of an MCP. The objective of this work is to measure the time of flight of a particle from the start detector to the stop detector. The distance between the two detectors is 25 cm.

MCP based start detector [4]

In this work, the MCP-detector (a detector based on microchannel plates) was chosen as the start detector.

The detector consists of a conversion foil, an accelerating grid, an electrostatic mirror, and the assembly of a microchannel plates. The principle of the operation of this type of a detector is as follows: as charged particle particle passes through a foil, it knocks the electrons out of it. The emission electrons are accelerated in the electric field between the foil and the accelerating grid to an energy of about 3 keV. In the space between the two electrostatic mirrors, the accelerated electrons are turned 90 degrees and then fall on the assembly of the MCP. Regardless of the passage of the particle through the input foil, the trajectories of electrons have the same length due to the design of the electrostatic mirror, therefore, the output time signal of the detector is position independent.

Mylar films with a thickness of 70-150 μg / cm^2 with a gold or aluminum layer thickness of 20-30 μg / cm^2 are used as the input foil, due to which the coefficient of secondary emission of electrons will significantly increase. The size of the input foil and the active area of the MCP are 20x30 and 30x40 mm. Respectively the particle passes through all the fields formed by the grids, practically without deviating from its original direction and without changing the initial velocity. Due to the use of thin films as a conversion foils, the change in the direction of a particle due to collisions with foil atoms is negligible.

Microchannel plates are fixed in glass-fiber laminate frames above the metallized anode. The output signal is taken from the anode and amplified 10 times, with the front of the time signal 1.5 ns. The voltage on the MCP, conversion foil and electrostatic mirror grids are fed through a high-voltage divider. The operation scheme of the MCP detector is shown in figure-3.

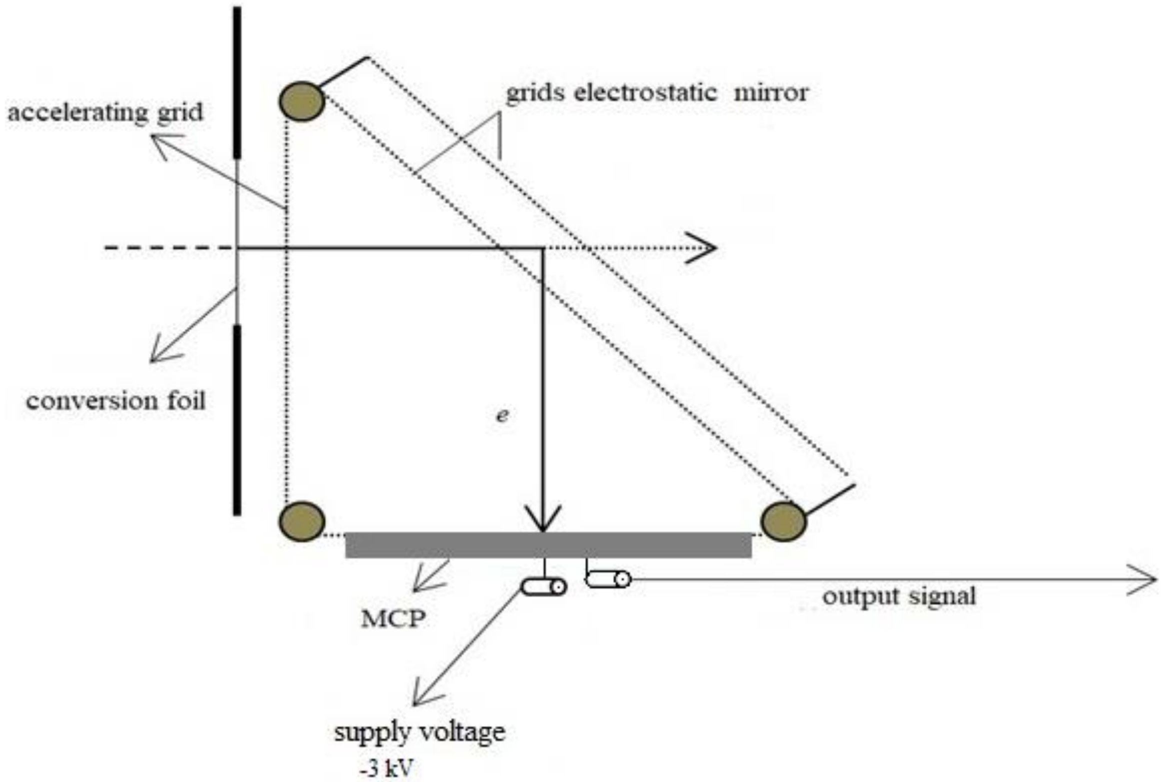

Fig.3. Scheme of the detector MCP

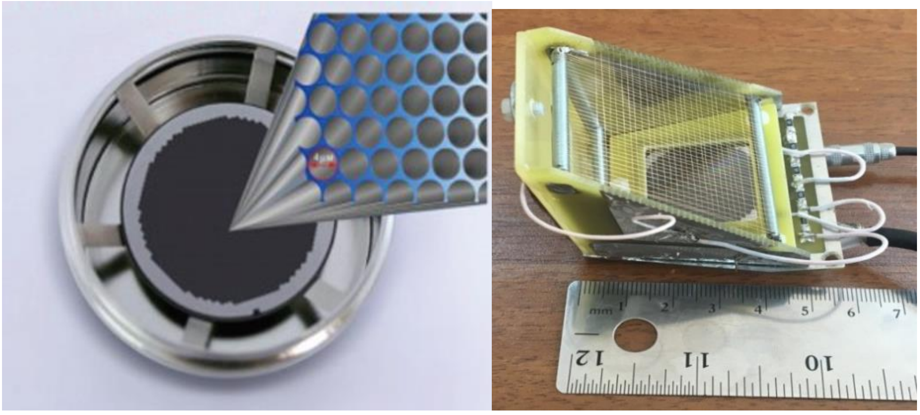

Fig.4. Configuration and structure of standard MCP

The principle of operation of the spiral backing pump and turbo-molecular pump

An integral part of any vacuum system is the vacuum pump (Fig.6). It is used to evacuate a certain volume to the low and medium vacuum ($1–10^{-4}$ tor) to create a preliminary vacuum and to maintain the pressure at the outlet of the high-vacuum pump at the required level. In high vacuum installations, the foreline pump is the used as first stage, to provide the necessary conditions for high vacuum pumps, as well as to save resources.

Fig.5. Spiral vacuum pump

Unlike spiral vacuum pumps, which are necessary at the stage of obtaining low and medium vacuums, so-called turbomolecular pumps are used to obtain high and ultrahigh vacuum. It consist mainly of rotor and stator.

The action of the turbomolecular pump is based on the to the molecules of the evacuated gas of additional speed in the direction of pumping by the rotating rotor. The rotor consists of a disk system. The rotor speed is tens of thousands of revolutions per minute. Figure - 7 shows the turbomolecular pump.

Fig.6. Turbomolecular pump (HiPace 300)

In the course of this work, an MCP is used - a detector that requires a high vacuum of the order of 10^{-6} tor. In order to obtain such a vacuum, a sequential connection of a forevacuum and a turbomolecular pump is necessary in order to obtain an average, and after that a high vacuum.

Implementation of the work

1. Turn on forevacuum and turbomolecular pumps:
   a. Turn on forevacuum pump (for pumping the working volume of the camera):
   b. Open the pump valve and keep it open until the pressure reaches 10^{-3} tor;
   c. Close the forevacuum pump valve when the required pressure is reached;
   d. Turn on turbomolecular pump;
   e. Open the turbo-molecular pump valve to obtain the required pressure of 10^{-6} tor.
2. Apply voltage of -3 kV to two MCPs - detectors through a high-voltage power supply;
3. Verification of the signals from two MCP-detectors on an oscilloscope;
4. Collect the required number of binary products via USB to CyConsole program;
5. Study of the results:

a) Build a graph of the received data;

b) Calculate the time resolution of the detector (FWHM);

c) Calculate the speed, time and energy of alpha particles.

The block scheme of the electronics for the measurement of the speed of alpha particles

To perform the task, the electronics block is used:

1) Preamplifier (ortec, model 9306);

2) High voltage power supply (ortec model 556);

3) Constant Fraction Discriminator-200 MHz; (ortec model 935);

4) Time to Amplitude Converter (ortec model 556);

5) Analog Digital Converter (ADC);

6) Data Acquisition (DAQ);

The signals from two MCP - detectors after passing the PF (preamplifier) are fed to the CFD (discriminator). The logic signals from CFD are fed to the TAC "start" and "stop" and finally the signals are fed to ADC (analog digital converter). The data are stored in the system of accumulation of information and sent via USB to the DAQ software. The PC computer connected with the KK-interface allows to record events on a disk, which allows to accumulate events with subsequent selection according to the above logic. The results obtained in the form of binary files can be used for further analysis and data processing. Figure - 8 shows an electronic block scheme.

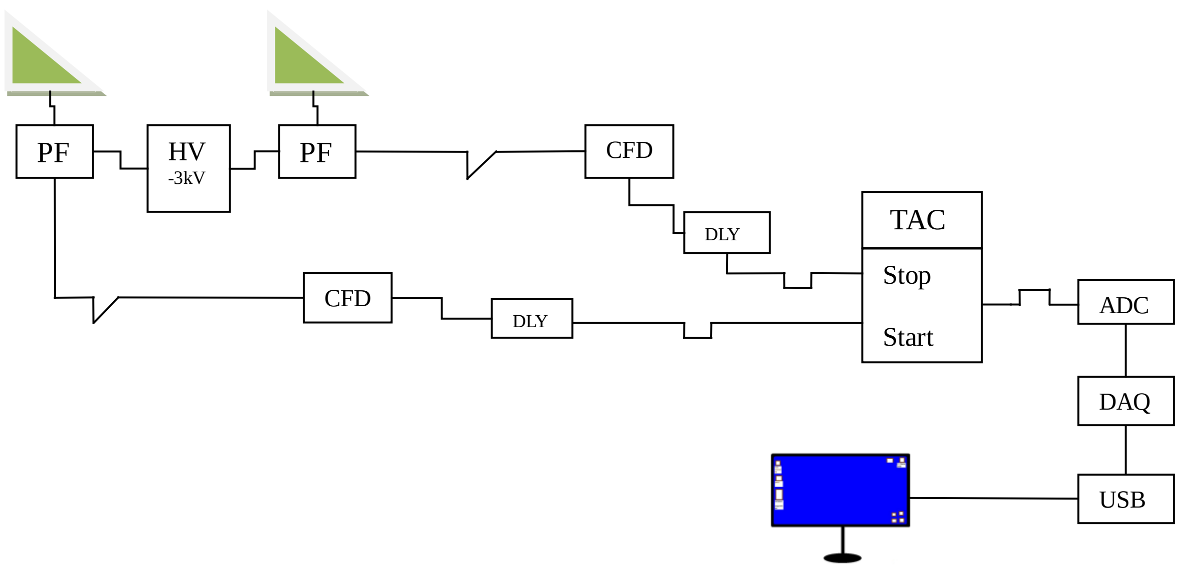

Fig.7. Block scheme of electronics

During a physical workshop, results were obtained that fully demonstrate the effective operation of our system. In Fig. 8. 4 alpha particles with different energies are presented depending on the time of flight. The temporal resolution (FWHM) was 470 ps (Fig. 8).

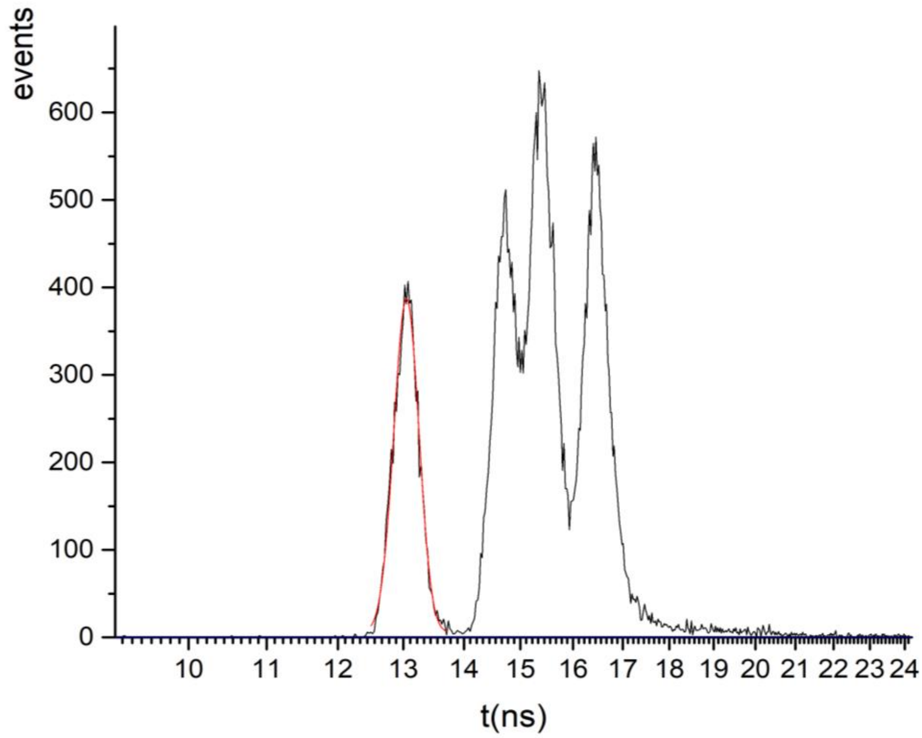

Fig. 8. One-dimensional 4He spectrum

Conclusion

In the course of this work, the use of electronic equipment used for modern nuclear physics research, the timing technique from ionizing radiation detectors was presented. The study of the time of flight of the alpha particles in a vacuum chamber was carried out, the connection, maintenance of equipment, obtaining results and their further study were shown.

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The number of participating students is limited to 4

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