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VIRTUAL LABORATORY – VIRTUAL EDUCATIONAL TOOLS AND HANDS-ON PRACTICUM

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Experiments have always been an integral part of the experimental sciences, and are one of the most effective ways to get first-hand knowledge about certain concepts and principles in a study field such as nuclear physics. The Virtual Lab project (VLab) has a history of several years and now project results are used in the educational process universities in 13 countries. The first stage of the project was devoted to creation of the Virtual Laboratory of Nuclear Fission. Currently the project is developing in three directions: 1. Virtual laboratory of gamma spectroscopy; 2. Laboratory of detectors and signal processing. Laboratory of data analysis in ROOT; 3. Preparation and conduction of hands-on practicums for university and high school students. In the framework of the VLab project several hands-on practices were successfully held for university and high school students from different countries. During the practices students started their work with signal generators, oscilloscopes, coincidence circuits, scintillation counters, and finished assembling a simple scintillation telescope that allowed them to register cosmic radiation particles. Then, under supervision of young scientists, students worked with gamma-, X-ray and light ion spectrometers. Attention was given to the analysis of experimental data.

Keywords: virtual laboratory, hands-on practicum, education, online courses, experimental nuclear physics

1. Introduction

Experiments have always been an integral part of the experimental sciences, such as Physics, and are one of the most effective ways to get first-hand knowledge about certain concepts and principles in a study field such as nuclear physics. It is challenging for some universities to set up an excellent practicum on nuclear physics, because they do not have enough equipment available. Moreover, it would be interesting to hold a practicum on nuclear physics for high school students specializing in physics and mathematics, but the schools do not have the appropriate equipment or teachers trained for it.

2. Virtual Laboratory of Nuclear Fission

The Virtual Lab project (VLab) has a history of several years. The result of the first phase of this project was the Virtual Laboratory of Nuclear Fission.

The aim of this project was to create a hardware-software complex for training specialists for LIS experiment (Light Ion Spectrometer), conducted at the JINR Laboratory of Nuclear Reactions to study spontaneous fission. The Virtual Laboratory of Nuclear Fission includes educational materials and virtual practicums as on the basics of working with nuclear physics equipment (oscilloscopes, detectors, data acquisition system), as on the basics of working with real experimental data obtained from LIS setup.

At the next stage of the project the Interactive Environment for Nuclear Experiment Modeling was developed. Working in this environment, students can assemble a personal experimental setup from elements of virtual nuclear physical equipment contained in the libraries of the environment. Also in the environment there is a library of radioactive sources for conducting your own experiment. For advanced students with programming skills there is the opportunity to develop their own virtual radioactive sources, detectors, blocks of electronics, etc. and integrate them into the environment [1].

On the basis of the Interactive Environment for Nuclear Experiment Modeling students of Dubna University completed 2 graduate qualification bachelor theses. In one of them, a virtual radioactive source (radium-226) was simulated, and in another, some elements for the libraries of detectors and electronics of a nuclear physical experiment were developed.

Testing the project showed the need to develop additional materials that allow the student to fill the lack of knowledge to complete a virtual laboratory work, without going beyond the scope of the project. Therefore, open courses on experimental nuclear physics were developed for students with different levels of basic training.

Now all these results are used in the educational process of universities in 16 countries.

Currently the project is developing in three directions: 1. Virtual laboratory of gamma spectroscopy; 2. Laboratory of detectors and signal processing. Laboratory of data analysis in ROOT; 3. Preparation and conduction of hands-on practicums for university and high school students.

In active collaboration with our colleagues from JINR Member States and Associate Members, a virtual practicum on gamma spectroscopy is being developed. That is why a series of virtual practicums on this topic is currently being developed. They are:

1. Scintillation gamma spectrometers;
2. Semiconductor Ge(Li) gamma spectrometer. Energy measurements of gamma-activity;
3. X-ray measurements. Moseley's law;
4. Practical task from low background laboratory;
5. Attenuation of gamma radiation (remote experiment).

Each of these topics includes a series of laboratory works, in the development of which not only JINR experts, but also our colleagues from universities of JINR Member States and Associate Members expressed their desire to participate. For example, now, together with specialists from Flerov Laboratory of Nuclear Reactions, a series of virtual laboratory works has been developed for the topic "X-ray measurements. Moseley's law" [fig. 1]:

- X-ray Spectrometer Structure
- Preliminary Energy Calibration with ^{60}Co
- Precise Energy Calibration with ^{152}Eu

- Moseley's Law
- Application of Moseley's Law
- Work with unknown X-ray source

Figure 1. Virtual practicum "X-ray Spectrometer. Moseley's law"

The virtual laboratory works on gamma spectroscopy are of particular interest from the point of view of their practical use in the educational process of universities of JINR Member States and Associate Members.

3. Laboratory of detectors and data processing. Laboratory of data analysis in ROOT

When working with real data, various problems and challenges arise. Before getting physical results, when working with real data, researchers need, on the one hand, to perform a series of calibrations, to separate the useful signal from the background, etc., and on the other hand, to take into account the specific features of an experimental setup. The Laboratory of detectors and data processing and the Laboratory of data analysis in ROOT are aimed at forming of these skills.

For the section "Laboratory of detectors and data processing" [fig. 2] training materials are being developed devoted to the structure and physical principles of work of the detectors for various nuclear physics experiments. The skills of working with signals from these detectors are of great importance for the training of an experimental physicist. Therefore, for each detector, a series of practical works is being developed on the processing of signals obtained in real physical experiments.

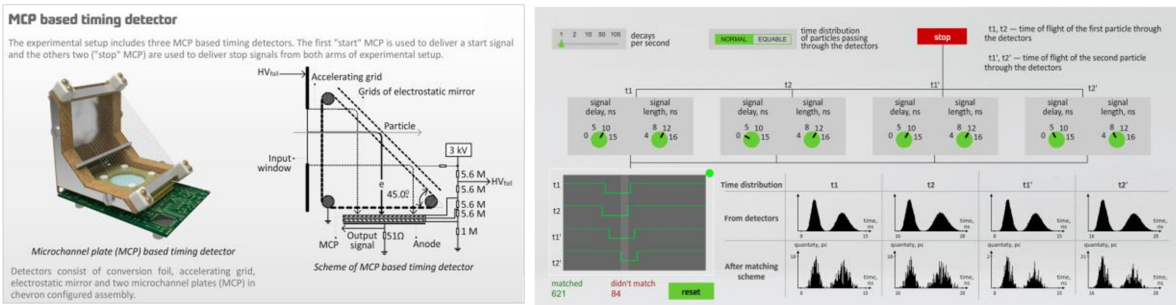

Figure 2. Fragments of Virtual Laboratory of Detectors and Data Processing

The skills necessary for the analysis of experimental data include knowledge of statistical analysis principles, the ability to use appropriate software and visualization tools, an understanding of the features of the experimental setup and methods of signal processing. The ROOT platform is widely used among experimental physicists all around the world as one of the most suitable tools for solving such problems. Section "Laboratory of data analysis in ROOT" [fig. 3] includes the course "Introduction to data analysis using ROOT" and the practicum on the analysis of real experimental data from various nuclear physics facilities. If in the section "Laboratory of detectors and signal processing" students work with processing of signals from detectors, then in this section they analyze experimental data in order to obtain a physical result.

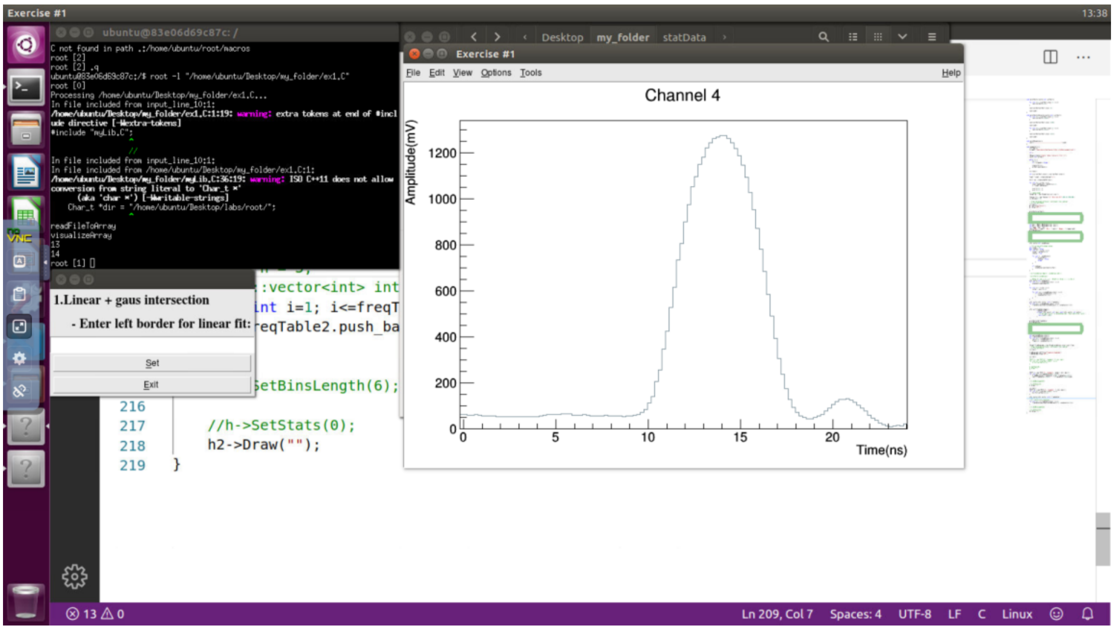

Figure 3. Virtual Laboratory of Data Analysis in ROOT

4. Hands-on practicums for university and high school students

In the framework of the VLab project several hands-on practices were successfully held for university and high school students from different countries [2]. During the practices students started their work with signal generators, oscilloscopes, coincidence circuits, scintillation counters, and finished assembling a simple scintillation telescope that allowed them to register cosmic radiation particles. Then, under supervision of young scientists, students worked with gamma-, X-ray and light ion spectrometers. Attention was given to the analysis of experimental data.

Over the past few years, the specialists of the Virtual Laboratory project have participated in organizing and conducting the following three-week practices for university students from JINR Member States and Associate Members:

- September Student Practice 2014 at JINR (III stage)
- September Student Practice 2015 at JINR (III stage)
- July Student Practice 2017 at JINR (I stage)
- September Student Practice 2017 at JINR (III stage)

The hands-on practice program has been adapted for high school students [fig. 4]. Recently, 4 hands-on practices have been organized for students from Israel (2018, 2019), the Czech Republic (2019) and Germany (2019). In these practices students participated with their physics teachers. The lectures and workshops were so successful that school teachers expressed a desire to take their new students to these practices next year.

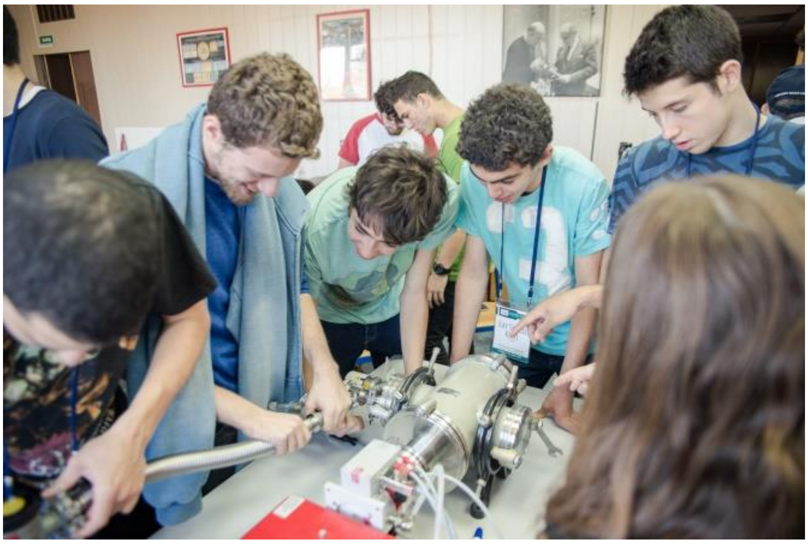

Figure 4. High school students from Israel assembling the vacuum system

For this practices methodological resources were used, which include step-by-step instructions that guide the students to achieve the results needed.

We invite all teachers and students from JINR Member States and Associate Members to the Joint Institute for Nuclear Research to take part in the hands-on practicum on Nuclear Physics in the framework of the VLab project.

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