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Applications of the Timepix-based devices in research, teaching, practice of radiation safety and nuclear physics

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Abstract

The Timepix readout chip is a highly accurate and versatile device with many applications in radiation detection and measurement. One such application is Minipix Edu, a set of nuclear and radiation experimental tools designed for educational purposes. It includes a Minipix detector, USB interface, and software package that allows students to perform experiments related to radiation measurement, nuclear physics, and radiation safety. The kit covers a wide range of topics, including radiation sources, radon measurement, radiation shielding, nuclear decay, and nuclear reactions... In this study, we will review the specific applications that have been implemented worldwide as well as the potential applications of Timepix detector for research and training in radiation safety and nuclear physics

Keywords: Timepix; Hybrid pixel detector; Radiation detection and measurement; Minipix Edu

1. Introduction

Radiation detection has always been an important field of research as it has many applications in nuclear physics, medical imaging, and environmental monitoring. One of the most widely used radiation detectors is the Timepix readout chip. It is a small, versatile, and powerful device capable of measuring the energy and type of radiation particles with high accuracy. The chip is based on the Timepix technology developed by the Medipix Collaboration at CERN, and it has been used in various scientific fields such as particle physics, astrophysics, medical physics, space exploration and biology [1-5]. In this article, we will discuss the Timepix readout chip and its application in Minipix Edu, a set of experimental tools used in radiation measurement, teaching radiation safety, and nuclear physics. The Minipix Edu was equipped at the Training Center - Da Lat Nuclear Research Institute to serve as a model for specialized internships in nuclear physics and radiation safety. This will provide students with practical experience in using radiation measurement equipment and performing experiments related to radiation detection and measurement.

2. The Timepix Readout Chip

The Timepix readout chip is a small, low-power, and high-resolution device designed for radiation detection. It is based on the Timepix technology developed by the Medipix Collaboration at CERN, which is a hybrid pixel detector that combines silicon sensors with CMOS readout electronics. The chip consists of an array of pixels, each of which is capable of measuring the energy and type of radiation particles. The pixels are interconnected using a digital bus, which allows for simultaneous readout of all pixels [1].

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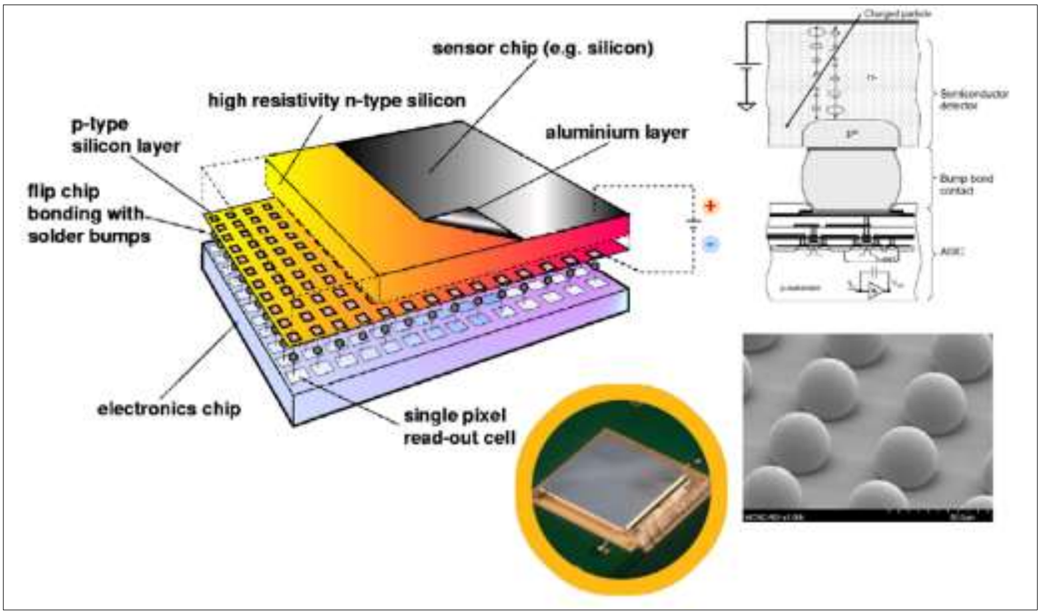

Figure 1 The Timepix readout chip [1]

The Timepix chip has several advantages over other radiation detectors, such as its ability to discriminate between different types of radiation particles, its high spatial and energy resolution, and its low power consumption. It is capable of measuring the time of arrival of each particle with a precision of a few nanoseconds. This feature allows for the reconstruction of particle trajectories and the determination of the particle's origin. The chip can also be used in time-of-flight measurements, which can be used to measure the velocity of the particles. This information is useful in a wide range of scientific applications, including particle physics, astrophysics, and biology [2-3].

The Timepix chip is also capable of operating in different modes, including photon counting mode, time-over-threshold mode, and time-of-flight mode. Photon counting mode is used to measure the energy of each individual photon, while time-over-threshold mode is used to measure the energy of a continuous stream of photons. Time-of-flight mode is used to measure the velocity of the particles by measuring the time of arrival of the particle at two different points [4-5].

3. Applications of Timepix-based devices

The Timepix readout chip has many applications in different scientific fields. In particle physics, the chip has been used in the study of cosmic rays, which are high-energy particles that originate from outside the solar system. The chip has also been used in the study of the Higgs boson, which is a fundamental particle in the Standard Model of particle physics. The chip has been used to detect the decay products of the Higgs boson, which has helped to confirm the existence of this particle. In astrophysics, the Timepix chip has been used in the study of gamma-ray bursts, which are the most powerful explosions in the universe. The chip has been used to detect the gamma rays emitted by these explosions and to determine their energy and direction of arrival. The chip has also been used in the study of cosmic rays and in the search for dark matter, which is a hypothetical form of matter that is thought to make up a large part of the universe [5].

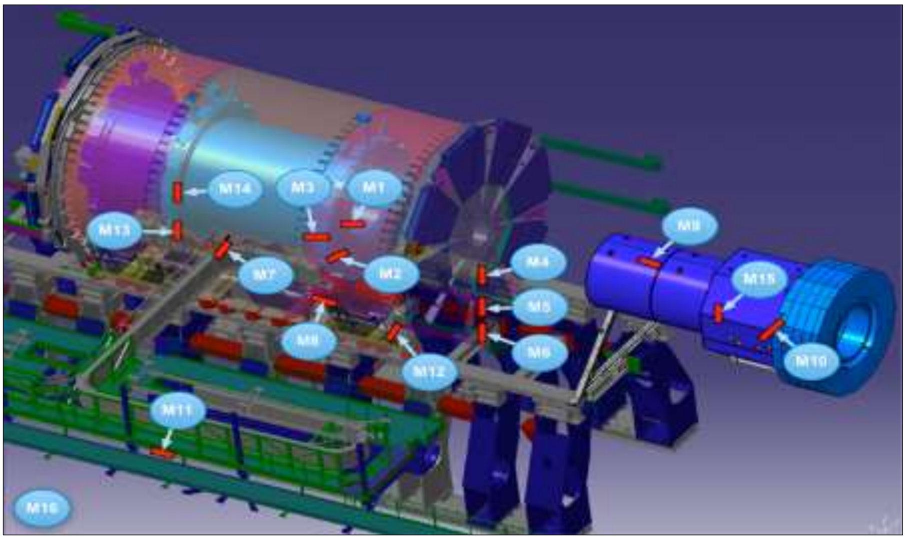

Figure 2 16 Timepix-based detectors around the ATLAS module at LHC [5]

In biology, the Timepix chip has been used in the study of radiation-induced DNA damage, which is a major concern in radiation therapy and space travel. The chip has been used to measure the energy and type of radiation particles that cause DNA damage (quantum dosimetry), which can lead to cancer and other diseases. The chip has also been used in the study of cellular response to radiation and in the development of new radiation therapies [6].

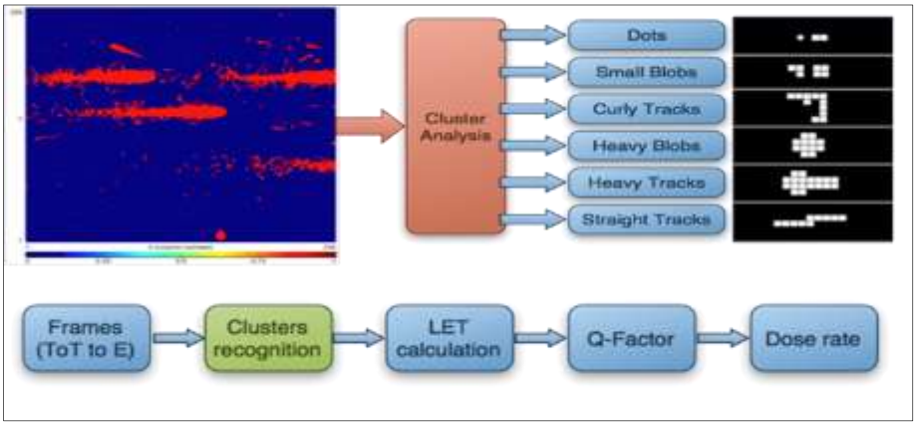

Figure 3 Quantum dosimetry using Timepix-based detector [7]

Timepix-based devices have proven to be valuable tools in medical physics, particularly in proton beam therapy, EasyPET, and microCT. Proton beam therapy is a form of radiation therapy that uses protons to target cancer cells in the body. Compared to traditional radiation therapy, proton beam therapy delivers a more targeted dose of radiation, minimizing damage to healthy tissue surrounding the tumor. Timepix-based devices have been used in proton beam therapy to verify the position and shape of the proton beam, ensuring that it is accurately targeting the cancerous cells [8].

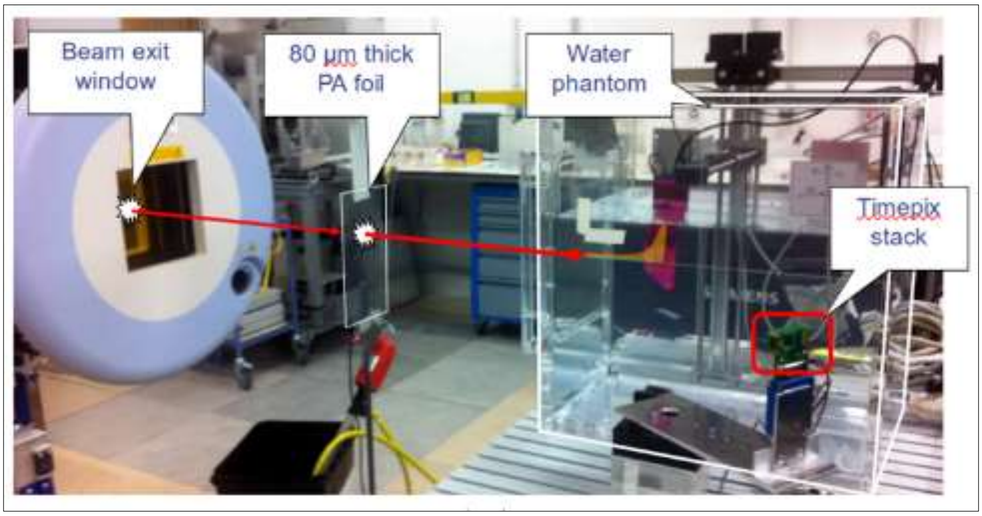

Figure 4 Measurement of the dose distribution in proton therapy using Timepix-based detectors [9]

Timepix detectors can provide precise information about the location and energy of the protons, making it possible to monitor the treatment in real-time and adjust the beam as needed to achieve optimal results. EasyPET is a small animal positron emission tomography (PET) scanner that utilizes Timepix detectors. EasyPET has been designed to be used in preclinical research, allowing researchers to study diseases and treatments in animals before testing them in humans. Timepix detectors provide high spatial and temporal resolution imaging, which is essential for detecting small tumors and tracking the distribution of radiotracers in the body [5, 8]. The use of Timepix detectors in EasyPET has improved the quality and accuracy of PET imaging in preclinical research.

MicroCT is a 3D imaging technique that uses X-rays to generate high-resolution images of small objects. Timepix detectors have been used in microCT systems to improve the quality and resolution of the images. Timepix detectors are capable of providing energy-resolved X-ray imaging, which can be used to differentiate between different materials and tissues. This can be particularly useful in imaging small animals, where different tissues may have similar densities and be difficult to distinguish with traditional imaging techniques. These applications demonstrate the versatility and potential of Timepix detectors in advancing the field of medical imaging and radiation therapy [5-8].

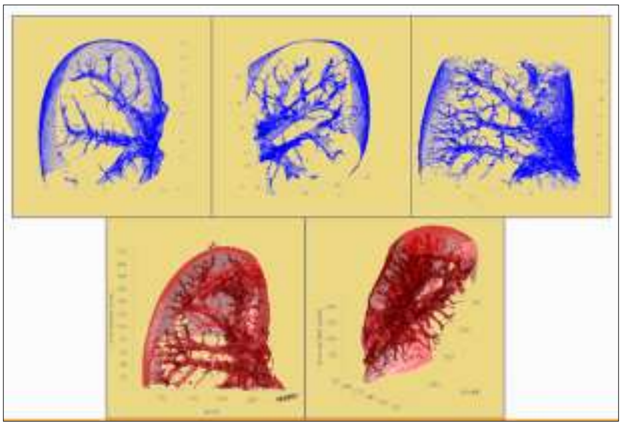

Figure 5 Mouse kidney tomography using MicroCT [5]

4. Minipix Edu toolkit

The Minipix detector is a small and portable device that is based on the Timepix readout chip. It is capable of measuring the energy and type of radiation particles with high accuracy and resolution. The detector is easy to use and can be connected to a computer via a USB interface. The software package includes a graphical user interface that allows students to control the detector and analyze the data in real-time [10]. The Minipix Edu kit is designed to provide an engaging and interactive way for students to learn about radiation sources, radiation protection, nuclear decay, and nuclear reactions. The kit includes a range of experiments that cover various aspects of radiation and nuclear physics, using the Minipix detector as the primary measurement tool.

Figure 6 MiniPix Edu toolkit

One of the experiments included in the kit is radiation mapping. This experiment allows students to use the Minipix detector to create a radiation map of their environment, identifying areas with higher levels of radiation and taking appropriate measures to reduce their exposure. This experiment provides students with an understanding of the sources of radiation in their environment and the importance of radiation safety. Another experiment in the Minipix Edu kit is radon measurement. Radon is a radioactive gas that is a major cause of lung cancer. This experiment allows students to use the Minipix detector to measure the radon levels in their homes and to learn about the risks associated with radon exposure. This experiment provides students with an understanding of the sources of radon, its health risks, and the importance of radon testing and mitigation.

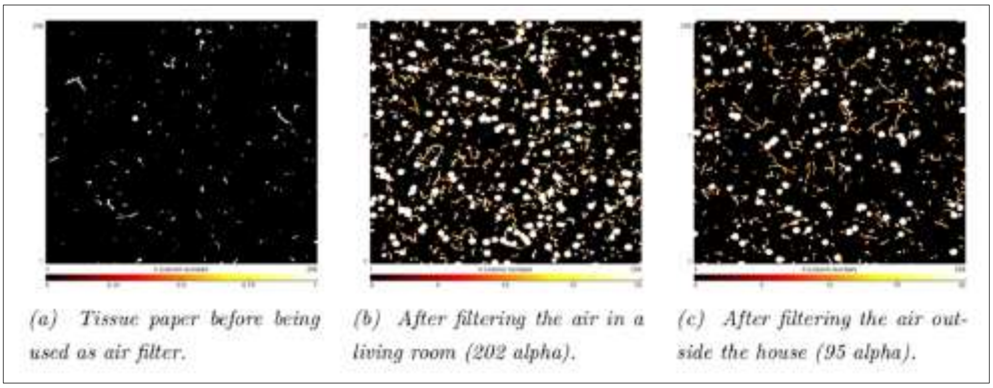

Figure 7 Measurement of radon radioactivity from tissue paper using air vacuum and MiniPix Edu [11]

The Minipix Edu kit also includes an experiment on radiation shielding. This experiment enables students to learn about the different types of materials used for radiation shielding and their effectiveness in reducing radiation exposure. Students can perform experiments to test the effectiveness of different shielding materials using the Minipix detector, providing them with an understanding of how radiation shielding works and its importance in radiation safety.

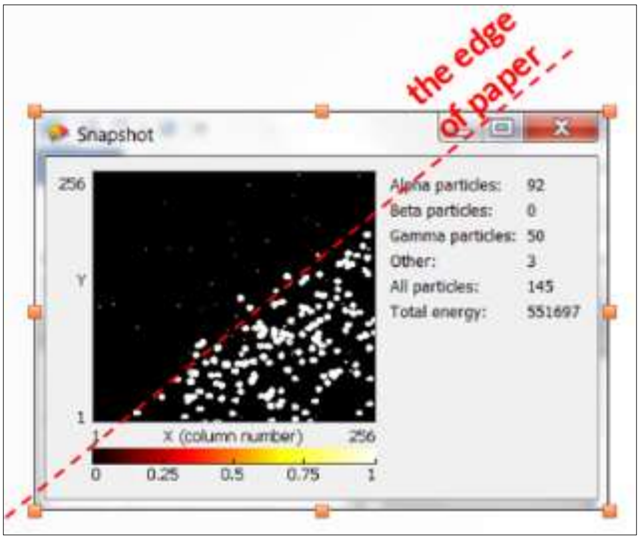

Figure 8 Alpha shielding measurement with MiniPIX EDU kit

In addition, the kit includes experiments on nuclear decay and nuclear reactions. These experiments allow students to learn about the different types of nuclear decay and their characteristics, such as decay rate and half-life, using the Minipix detector. Students can also perform experiments to measure the energy and type of particles emitted in nuclear reactions using the Minipix detector, providing them with an understanding of the applications of nuclear reactions in nuclear energy and medicine.

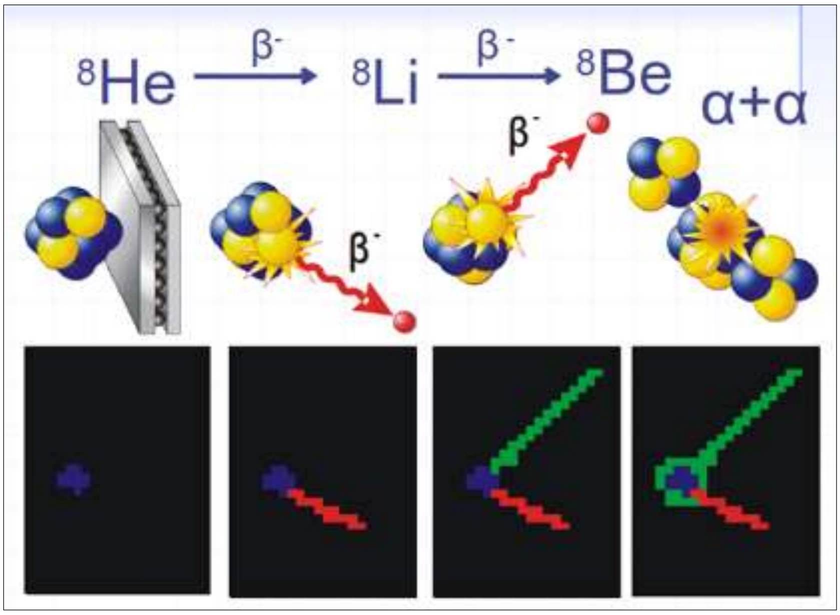

Figure 9 Subsequent decays of ^8He by emission of one beta and two alpha particles follows as ion ^8He hits the Minipix Edu detector [11]

As above mentioned the Timepix radiation detector has undergone extensive research and implementation in developed countries over 20 years. In Vietnam, numerous courses focusing on physics, radiation safety, and nuclear medicine have introduced Timepix-based devices like Minipix Edu and EasyPET by scientists from the the European Organization for Nuclear Research (CERN). However, to date, there has been no research conducted in Vietnam to explore the wide-ranging applications of Timepix detector.

Da Lat Nuclear Research Institute is a research center with a long tradition in training generations of students, postgraduates, researchers in the field of nuclear physics as well as one of the prestigious institutions in radiation safety training. With the available laboratory equipment, one of the main tasks of the Training Center, Nuclear Research

Institute is to support the training of human resources specialized in nuclear physics. Many generations of students and postgraduates majoring in nuclear physics across the country who have participated in internship courses at the Training Center are still reputable researchers and university lecturers in the field of atomic energy.

However, since its establishment in 1996, the laboratory equipments at the Training Center mostly donated by India Atomic Energy Commission, Japan Atomic Energy Agency and IAEA have largely broken down while new equipments have not been invested. Consequently, specialized practices have become monotonous and repetitive, failing to create excitement among students. Futhermore the Training Center is currently planning to develop a new radiation safety training framework for radiation safety managers (Radiation Safety Officer) and First Responders to Radiological Emergency. The new radiation safety training frameworks will feature more radiation measurement and monitoring exercises, thus placing a need for additional laboratory equipment, building new practices to enrich the training program. Timepix-based detectors such as the Minipix Edu are a very intuitive tool for hands-on teaching in nuclear physics and radiation safety at reasonable prices. The Minipix Edu radiation measuring experiment set will soon be installed at the Training Center of the Da Lat Nuclear Research Institute, we will develop specialized practices in nuclear physics and radiation safety based on the applicability of the Timepix detector. Due to its compact design and user-friendly nature, this device can be utilized for research purposes at any center within the Nuclear Research Institute or local radiation facilities. Despite the many advantages mentioned above, Minipix Edu also has limitations as its name suggests that it is only suitable for educational purposes. In order to be able to use in complex experiments with high precision, it is necessary to equip specialized Timepix-based devices with higher cost. However these initial results will serve as the basis for further studies to expand the applicability of Timepix detector in the field of radiation dosimetry, radiography, fluorescence imaging and X-ray diffraction.

5. Conclusion

The Timepix readout chip is a powerful and versatile device that has many applications in different scientific fields. Its high accuracy and resolution make it an ideal tool for radiation detection and measurement. Minipix Edu is a set of experimental tools that is based on the Timepix readout chip and is designed for educational purposes. Its compact size, high accuracy, and versatility make it an ideal tool for use in educational settings, from high schools to universities. The kit provides a safe and interactive learning environment that allows students to learn about radiation safety, nuclear physics, and radiation detection and measurement in a hands-on way. The Training Center at the Da Lat Nuclear Research Institute was equipped with the Minipix Edu radiation measuring experiment set as a model for specialized internships in nuclear physics and radiation safety. The use of Minipix Edu can help to raise awareness about the risks associated with radiation exposure and to inspire the students to pursue careers in radiation and nuclear physics research.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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