Wow a particle track on my screen!

Particle physics is a truly exciting field that intrigues people regardless of their age. However, since it is difficult to visualize the interaction of particles with matter, the students must just accept the concepts explained by their teacher. Unfortunately, this inability to visualise the perform measurements and experiments with the different types of radiation leads to misconceptions about nuclear physics.

However, thanks to the development of new detectors at CERN and, more specifically, thanks to the Medipix2 collaboration described below, this issue is solved by adapting the detectors for educational purposes.

Minipix-Edu; a detector made for educational purposes.

Figure : Minipix-EDU connected to a laptop. Taken from: https://www.linkedin.com/pulse/fascinating-patterns-drawn-radiation-particle-physics-jan-jakubek/

Minipix-EDU can be connected with a USB to a laptop, as shown in Figure 1. Then, thanks to a specialised software (Pixet) it is possible to visualize the particle tracks from the radiation that is detected by the detector's sensor. Different types of radiation interact in different ways with the sensor of the detector causing distinct track shapes (Figure 3). Therefore, it is possible to distinguish if the particle that interacted with the detector is alpha, beta, gamma or even a muon particle. Furthermore, apart from understanding the different types of radiation, the students can analyse the data, thanks to the software, and learn how to work as a data-scientist, as it can be seen in Figure 2.

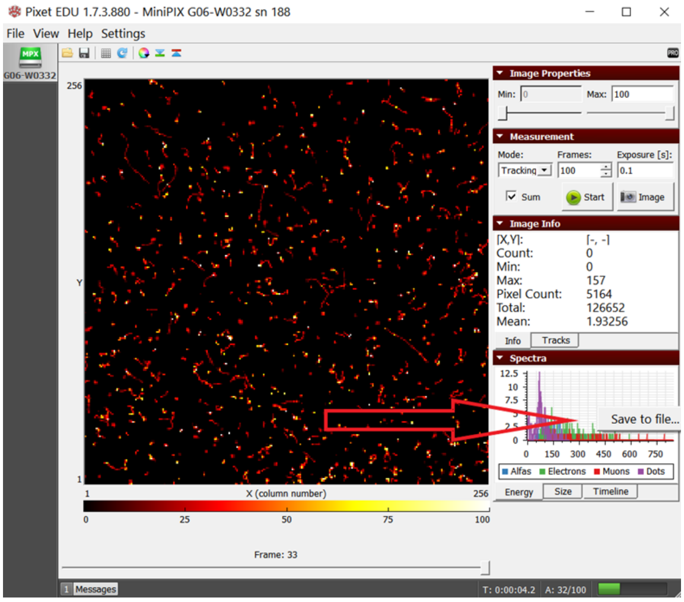

Figure : Data analysis through the Pixet software. Taken from: https://hawkeyesi.com/experiments/introduction-to-pixet-basic-software/

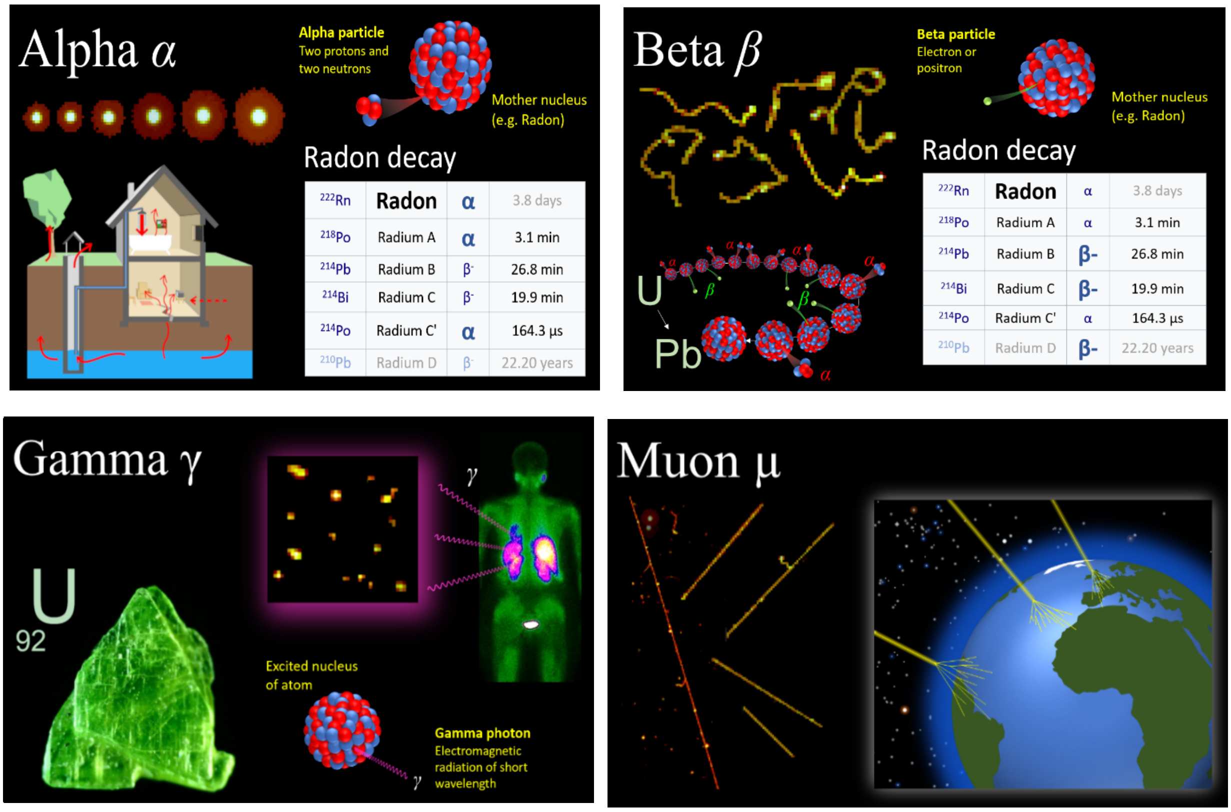

Figure : Different types of radiation and how they look like in the Pixet Software. Alpha particles look like a blob of pixel clusters, beta particles look like a wiggly line, gamma particles look like dots and muons appear in straight lines. Pictures taken from: https://www.linkedin.com/pulse/fascinating-patterns-drawn-radiation-particle-physics-jan-jakubek/

But what is different from the conventional semiconductor detector?

Minipix-EDU belongs to the family of hybrid pixelated detectors. This means that the sensor is segmented to pixels and each pixel is connected through bump bonding to the electronics. More specifically, Minipix-EDU consists of 256x256 pixels each with 55um pitch. The chip is able to measure the time of arrival of the particles and their deposited charge for each individual pixel of the matrix. This means that it is possible to reconstruct the track and energy of individual particles that interacted with the sensor. This is why it is called a photon counting detector. Furthermore, by setting proper threshold values it is possible to measure without the influence of noise. In Figure 4, a cross section view of the Minipix-Edu can be seen. With orange is the sensor material, with green the bump-bond and with blue is the electronic chip.

How does it work?

To measure ionizing radiation, a sensor made from suitable semiconductor material is necessary. When ionizing radiation interacts with the semiconductor material, it produces charged carriers (electrons, holes). Usually, the sensor material is Silicon. Then, a proper bias has to be applied on the sensor material in order to navigate the produced charged carriers to the electrodes and avoid recombination effects. The charge produced by the movement of the charge carriers is transformed into a pulse voltage that can be afterwards analyzed by the electronic chain of the detector chip.

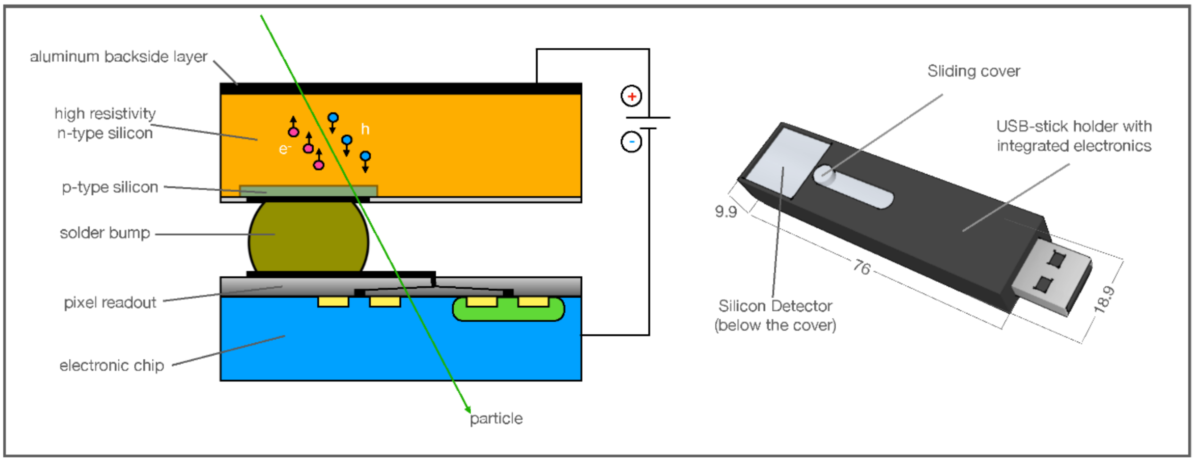

Figure : Cross section view of the Minipix Edu chip. Taken from: Rizzo, A.; Cardellini, F.; Poggi, C.; Borra, E.; Ciciani, L.; Narici, L.; Sperandio, L.; Vilardi, I. Novel Algorithm for Radon Real-Time Measurements with a Pixelated Detector. Sensors 2022, 22, 516. https://doi.org/10.3390/s22020516

Applications

It is really an exciting idea that students can take measurements with a detector developed at CERN, one of the world's largest and most respected centres for scientific research. Even more exciting is the idea that the detectors technology has been used in many fascinating fields, such as space exploration, Spectroscopic X-ray imaging for medicine and even art (material reconstruction). Some of the applications are briefly described below.

- ## Space Dosimetry

Timepix3 has been used for radiation monitoring in many missions of NASA, such as in the Orion rocket, at the International Space Station and the ARTEMIS mission. Space is an extreme environment where astronauts are exposed to radiation without the protection of Earth's atmosphere. For this reason, it is important to protect them as much as possible with proper shielding in the spaceships. The Timepix detectors are able to measure the different types of radiation providing energy and time information and, thus, enabling to measure the dose that the astronauts get from cosmic radiation. It is very inspiring for student to know that the detectors that are holding in their hands are similar to the ones that are in Space! Check the related IPPOG article on the International Space Station and CERN collaborative efforts.

Figure : Image of the astronaut Chris Cassidy working near the Timepix USB on the International Space Station (Courtesy of NASA, photo ref. no. iss036e006175)

- ## Medical Application

Tired of the conventional black and white X-ray Computed Tomography (CT) Images? Then colour X-ray imaging (or else Spectroscopic X-ray imaging) is for you!

With the Medipix3 chip, the images are no longer black and white - they have colours to indicate different energy levels of the photons. The colour X-ray imaging technique produces images with better spatial resolution which is very useful for the accurate diagnosis of diseases.

Figure : (Left) Spectroscopic X-ray imaging of a wrist using MARS setup. (Right) The MARS setup.

The future of artistic technological research is here!

Is this painting from Van Gogh or Raphael? Usually, this type of question can be answered only by art specialists and their answer can be biased or even wrong. However, with the impressive spatial and energy resolution of Timepix detectors it is possible to discover the truth behind the creation of these paintings. Timepix-like detectors offer a huge improvement from the conventional X-ray imaging techniques since they can eliminate noise and provide images with higher contrast.

This can be done by scanning the artworks with X-rays and detecting the X-rays that interacted with the artwork with Timepix detectors. By analysing the energy spectra of the X-rays, it is possible to find out the exact material used in this painting. This is called material reconstruction with high resolution X-ray spectroscopic radiography, and it can be applied for the study of cultural heritage. By scanning artworks with X-rays, it is possible to identify the materials of the painting in a non-destructive way, which is important for the painting restoration.

Figure : The huge painting (2m) was scanned for three days with Timepix detectors mounted on a robotic arm. Thanks to the information gathered by this scan it was deemed that the painting was a creation of Raphael. More information on: [CERN technology helps rediscover lost painting by Raphael | Knowledge Transfer (kt.cern)]

The story of Medipix Collaboration

In the 1990s, while researchers on the Large Hadron Collider (LHC) were putting together the detector electronics, they designed a chip able to capture particle collisions fast and without background noise.

It didn't take long to realize that this technology could be used in other imaging applications. Thus, Michael Campbell and his colleagues started the Medipix project. In collaboration with institutes all over the world, the Medipix team redesigned the chip implemented in the LHC and the Medipix chip was born.

Over the years the team has produced many different chips, such as the Medipix1 chip, the Medipix2 chip, the Medipix3 chip. Today the team is working on the latest version called (surprisingly) Medipix4. Timepix, a modified version of Medipix2 with the additional functionality of time measurements (as the name suggests), has also evolved into Timepix2, Timepix3 and more recently Timepix4.

Connection to IPPOG

Michael Campbell, who is the leader of the Medipix project, supervises the PhD work of the author of this text. He is the spokesperson of the project and has provided really nice talks on the Medipix detectors, which are available on these link: https://www.youtube.com/watch?v=SGy7zf_v7mw, https://www.youtube.com/watch?v=xklNUY8sC-Q and a short interview, which is available on this link: https://www.youtube.com/watch?v=L42EQ2w_fuk

Conclusion

In summary, Medipix and Timepix chips have a huge impact on society, with applications in a plethora of fields including medical advancements, art restoration, space exploration, education, and materials analysis.

Finally, The Medipix collaboration made it possible for students to interact with the, so far, abstract idea of radiation in a safe and fun way. All that is needed is a laptop and motivation to study the "invisible"!

Useful links

- https://medipix.web.cern.ch/home
- ADMIRA PROJECT: https://serviparticules.ub.edu/en/projects/admira-project
- Really interesting article about educational use of Timepix detectors: https://cds.cern.ch/record/2801427/files/document.pdf
- Knowledge transfer success story: https://knowledgetransfer.web.cern.ch/success-stories/medipix-chips-and-collaborations-medical-imaging-space-dosimetry
- Minipix edu from ADVACAM: https://advacam.com/camera/minipix-edu/

- SESTRA KIT and book with experiments: http://www.utef.cvut.cz/cms_files/original/cms_data/00099/SESTRA_flyer_-_2022-06-02_-_EPS_forum_Paris.docx_compressed.pdf
- Article for cultural reconstruction: CERN technology helps rediscover lost painting by Raphael | Knowledge Transfer (kt.cern)
- https://insightart.eu/gallery/x-ray-gallery/