Particle Physics Experiments for High School Using Medipix/Timepix

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Used equipment: The Medipix chip and Jablotron MX-10 edukit setup

Figure 1. **The MX-10 Edukit**

The Medipix/Timepix chip developed by CERN is usually being used in medical imaging, material analysis, optics or even in space programs. However, in a setup named Jablotron MX-10 (figure 1) it is ready for in-classroom use and its use can improve students' understanding of radioactivity and nuclear physics.

The MX-10 set consists of the pixel detector mounted by Medipix chip (pixelated 300 µm Si, 256 × 256 pixels, 55 µm pitch), school alpha source, sliding bench, a few weak, safe and common radiation sources like uranium glass, a set of shields and powerful software called Pixelman.

Unlike traditional detectors like Geiger tubes, the pixel detector accompanied by software offers a real-time display, recognizes different particle types, is able to show particle tracks and acts as a spectrometer: measures deposited energy for each particle.

Uranium glass: Types and tracks of particles

Uranium glass contains a number of radionuclides belonging to uranium decay chain, all of them in low concentrations. It is a safe source of weak nuclear radiation of all three basic types and it is perfect for demonstrating the different tracks of different radiation types (figure 2).

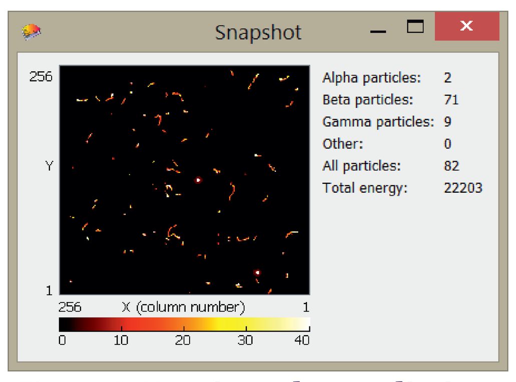


Figure 2. **Uranium glass radiation, 10 s exposure**

Figures 3a – 3c depict these tracks as they appear in the Pixelman Simple Preview software. Alpha particles (figure 3a) are usually large blobs covering 30 or more pixels. The center of the blob is white which means highest energy deposited in the detector, border pixels are red because of lowest energy deposited. Beta particle tracks (figure 3b) are thinner, snake-like looking and usually carrying less energy than alpha. Finally, gamma are usually one-pixel sized hits. Their energies differ greatly and due to chip properties (probability of gamma photon interaction with thin silicon layer decreases rapidly with photon energy) only low-energy gamma radiation can be detected reliably.

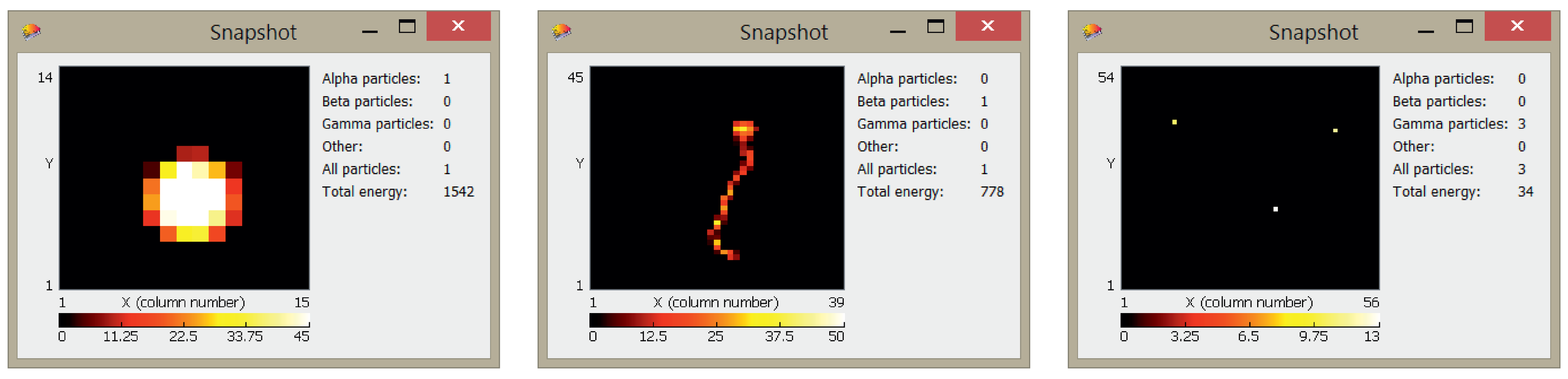


Figure 3a – 3c. **The tracks of three basic types of nuclear radiation**

Unexpected radiation sources

Besides traditional and uncommon radioactive materials like uranium, plutonium or americium it is possible to observe radioactivity emitted from much more common materials. Their radioactivity is of course very weak, however measurable.

Welding electrode

Some types of tungsten welding electrodes contain a low concentration of thorium oxide (this additive greatly improves arc initiation). The MX-10 edukit contains one such electrode.

If we observe the radiation emitted by the electrode, we can see radioactivity of all three basic types as shown in figure 4. This happens because the electrode contains not only thorium but all elements from its decay series.

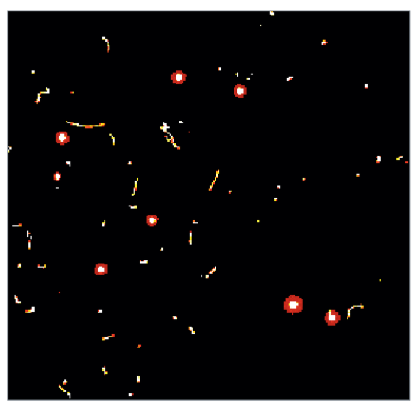


Figure 4. **Welding electrode**

E_0 [keV]	$3.73 \cdot 10^6$	Alpha			
T [keV]	7387	6472	8575	7474	8611
v/c	0.063	0.059	0.068	0.063	0.068

E_0 [keV]	511	Beta			
T [keV]	780	515	607	791	632
v/c	0.92	0.87	0.89	0.92	0.89

Tables 1a–1b. **Kinetic energies and calculated relative velocities (with respect to c) of particles emitted by thorium electrode.**

An analysis of detected particle energies brings an interesting comparison. Tables 1a and 1b contain typical measured energies of alpha and beta particles and their velocities calculated from these energies. We can see that while the alpha are quite slow, beta have highly relativistic velocities. The fact that something emitted by a simple metal rod is about 2000 times faster (in case of alpha) than any device constructed by a man, is quite surprising for students.

Flower fertilizer

Many common flower fertilizers are in fact mostly composed from a chemical substance called potassium sulfate. Besides stable isotopes ^{39}K and ^{41}K this substance also contains radioactive isotope ^{40}K that decays through β-decay into stable calcium ^{40}Ca and through K-capture into stable ^{40}Ar with a byproduct of gamma radiation. Both these types of radiation can be detected using the MX-10 set (figure 5).

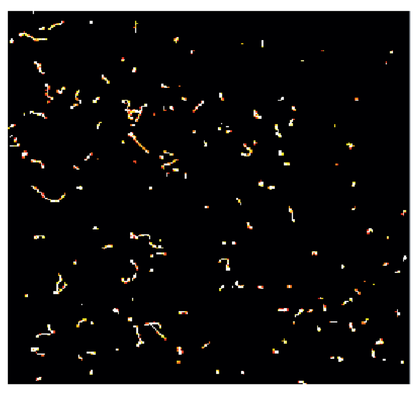
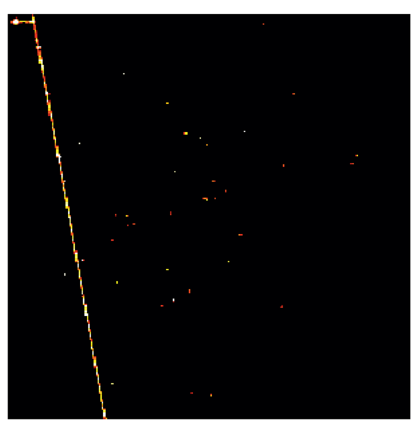


Figure 5. **Flower fertilizer**

Muon: A rare but not unexpected visitor



Besides the tracks of common particles that we have shown before, it is sometimes possible to observe a different track — thin, straight, long (often across entire detector), quite energetic (deposited energy of the order of units of MeV), like the one captured at figure 6.

Such track belongs to a muon that comes as a part of cosmic radiation. (Muons have high rest mass, 106 MeV/c^2, compared to decay energy of radiactivity, therefore they are never a product of radioactive decay. Besides cosmic rays they can be produced also at accelerator experiments.)

Figure 6. **Track of a muon**

Radioactive decay as a random process

The activity of a radioactive source is a quantity whose value decreases exponentially in time according to the law of radioactive decay. However, for an isotope having long decay half-life this decrease is immeasurable and activity appears to be constant in time.

This is also the case of the isotope ^{241}Am that has a decay half-life of 420 years. On figure 7 (a screenshot of the Pixelman Simple Preview software) we can see two graphs generated during one measurement of the ^{241}Am school source activity (100 expositions, each taking 0.05 s). The top one shows actual number of alpha particles detected in each frame, bottom one is a histogram of alpha particle rate. From the graphs we can conclude that while the alpha particle flux is quite constant over long times, the actual number of events in one frame is unpredictable. The radioactive decay is a random process.

If we increase the number of exposures, the histogram of alpha particle rate appears to be "smoother", as in figure 8. (3000 expositions, each taking 0.05 s) The higher is the exposition count, the better the histogram corresponds to Poisson's distribution.

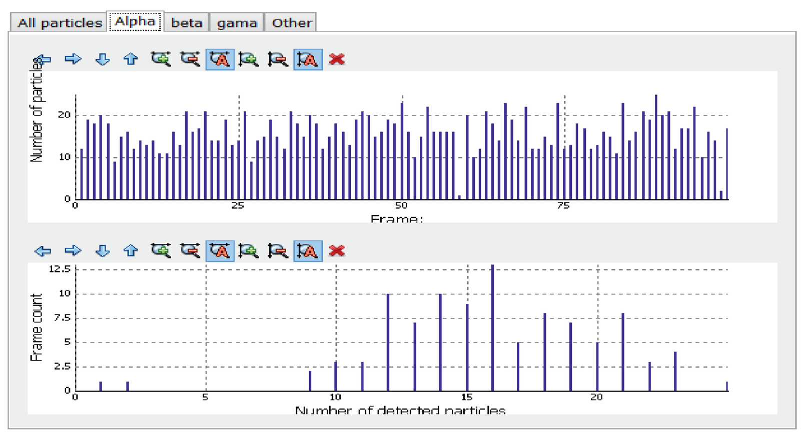


Figure 7. **Histogram of rate at 100 exposures**

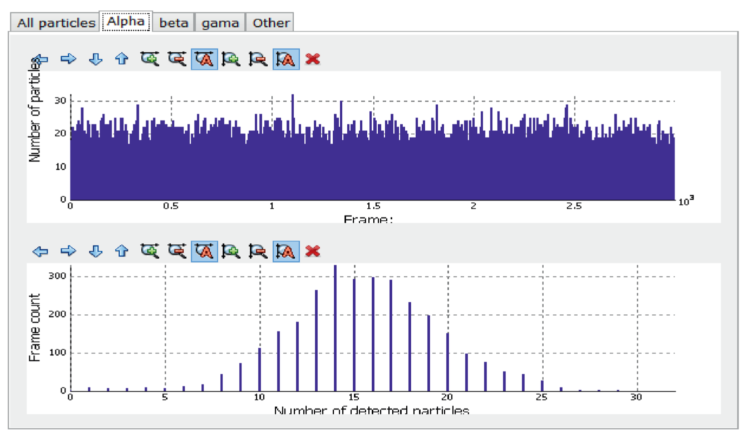


Figure 8. **Histogram of rate at 3000 exposures**

Absorption of alpha radiation in air

Alpha particles have high ionizing effects and quickly lose energy even when traveling through the air. The mean range of alpha particles emitted from americium is about 4 cm in the air.

Figures 9a – 9d show the decrease of particles detected by the camera when the radiation source is moved away from it. We can see that while the measured energies for lowest reachable distance (ca. 8 mm) are about 2 MeV, for larger distances detected energy falls even to the order of tens of eV. At about 4 cm it is not possible to detect any alpha particles at all.

The mean range is a variable which depends on the energy of the emitted particle and has been introduced for alpha particles. Mean range of alpha particles emitted from various radionuclides ranges somewhere between 2 cm and 10 cm.

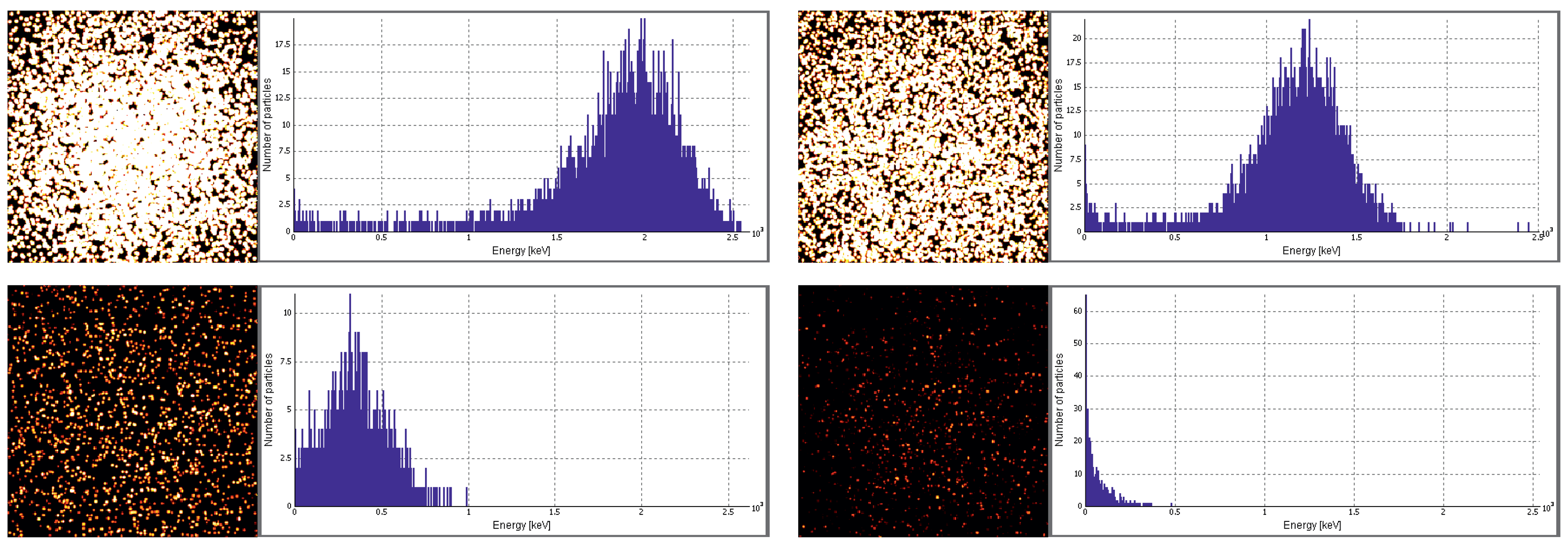


Figure 9a.–9d. **Absorption af alpha radiation in air (distance ca. 8 mm, 20 mm, 30 mm, 35 mm)**

Absorption of alpha radiation in water

Although we are used to thinking of water as of a transparent environment, which is true for visible light as well as for gamma photons, for alpha particles it behaves differently. For this experiment, the detector was covered by a thin stretch wrap foil that does not shield alpha particles and then a droplet of water was placed onto the foil. At this arrangement the detector was exposed to radiation of the school source (^{241}Am, alpha and gamma radiation).

Figure 10 shows the result — we can see that while around the droplet there are a lot of alpha particles detected, the droplet is for alpha impenetrable. A layer of water only 45 µm thick is enough to absorb all alpha particles emitted by americium. The area is not absolutely clear, though — gamma photons do not significantly interact with the thin layer of water and get through to the detector.

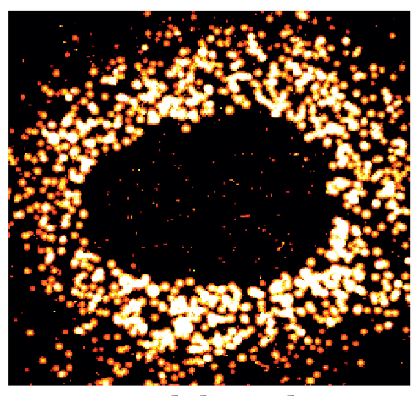


Figure 10. **Alpha and gamma radiation through water droplet**

Nondestructive examination (X-ray)

Figure 11. **Air gun pellet**

The principle of X-ray nondestructive examination lies in exposing the examined sample to X-ray (gamma) photons and detecting them behind the sample. Because there are a lot of materials that are opaque for visible light but transparent for gamma photons, it is possible to "see through things" and detect hidden structures inside that absorb more or less photons.

This method can be demonstrated using the MX-10 set. Figure 11 shows image of an air gun pellet hidden inside expanded polystyrene foam and exposed to gamma radiation. While the polystyrene does not interact with gamma photons, the pellet is made out of lead and shields almost all gamma. This experiment requires a reasonably long exposure or use of a stronger radiation source. It is also necessary measure in the so called integral mode where all events are joined in one frame.

Since real X-ray imaging depends on different absorption of photons in various materials (tissues) which produces different shades of grey in the resulting image, we are demonstrating a simplification. However, metal objects like screws or tooth fillings behave the same way in medical X-ray as did the pellet used in the demonstration.

Conclusion

We have created a set of experiments and experiment-based activities with the help of the Jablotron MX-10 Edukit and successfully used them with secondary school students. This poster presents a selection of our experiments, more can be found at http://www.particlecamera.com.

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