Nuclear waste monitoring and hazard detection software for Timepix3 detector network

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Increased decommissioning of nuclear power plants brought new challenges regarding the storage and monitoring of radioactive waste. Complex networks of hybrid pixel detectors have shown promising results in long-term monitoring and characterization of large particle fluxes inside the caverns of ATLAS and MoEDAL experiments at CERN [1].

As members of the Horizon 2020 project Measurement and Instrumentation for Cleaning and Decommissioning Operations (MICADO) [2] we proposed monitoring system based on a network of the Timepix3 detectors with various sensor types (Si with thicknesses of 100, 300 and 500 µm, and CdTe with a thickness of 1 mm; Si detectors are equipped with neutron convertors).

The radiation field in nuclear waste sites is predominantly constituted of γ-rays and neutrons. Timepix3 with its precise time and energy resolution (1.56 ns and 2 keV for 300 µm Si at 60 keV [3]) and continuous operational (data-driven) mode offers great capabilities in waste radiation field characterization. With improved Katherine readouts [4] a novel long-term measurement detector network was developed.

A newly developed MM Track Lab control and acquisition software with specifically designed plugins for the presented network, permits not only to control and acquire measurement data from all detectors simultaneously, but also displays current particle fluxes in real time. With such capabilities, the system can offer a near instant nuclear waste hazard warning with detailed characteristics of the ongoing accident.

Following previous results in particle classification with Timepix3 [5,6,7], we plan to build on the developed techniques and present classification of electrons, alpha particles, γ-rays and other particles. A variety of artificial-intelligence-based classifiers (e.g. neural networks, decision trees) will be developed and tested to correctly identify the mentioned particle classes. These methods will be based on the data directly measured by Timepix3 as well as on morphological features of the clusters (e.g. skeletonization) and the classification algorithms will operate in real-time.

Training data from neutron fluxes for classifiers will be measured at the Czech Metrology Institute and for complex nuclear waste radiation field measurement, it is planned to use a phantom (testing) nuclear waste drum. A comparison of the methods used will be presented (including their accuracy).

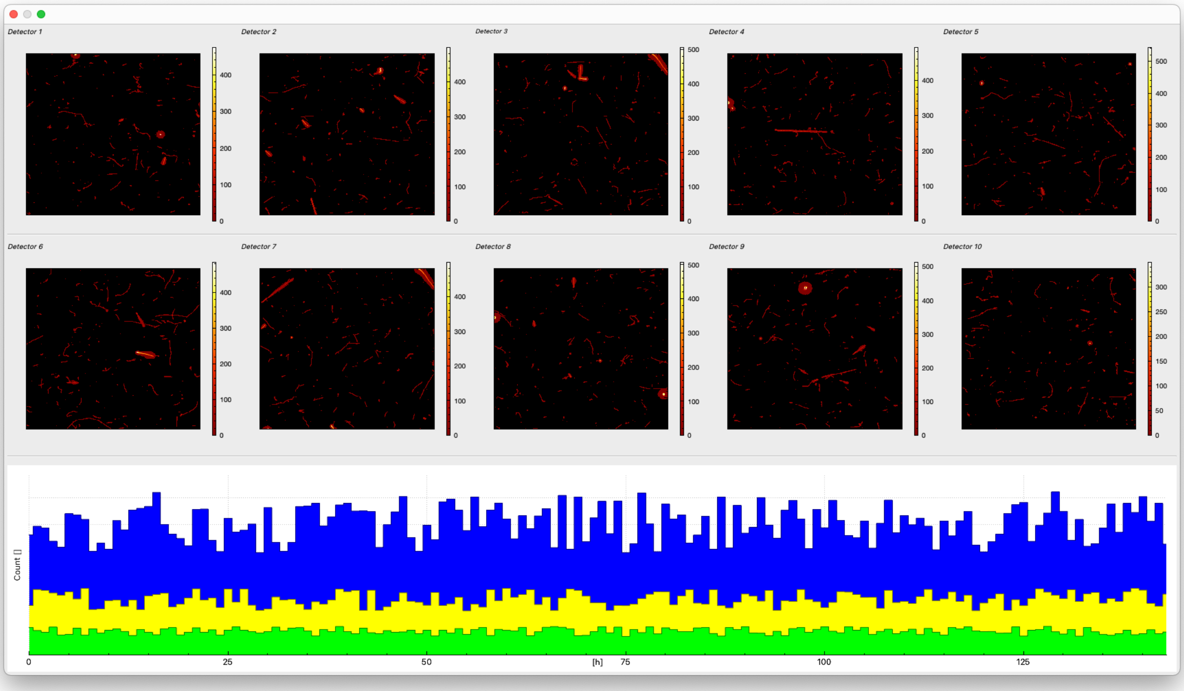

Figure. 1. User interface of the network monitoring system. Cells of top two rows represent a matrix of individual Timepix3 chips. The bottom row shows the statistics of different classes in a timeline (blue color chart represents gamma rays, green alfa particles and yellow electrons). Displayed data do not represent actual radiation field around nuclear waste.

[1] B. Bergmann, T. Billoud, C. Leroy and S. Pospisil, "Characterization of the Radiation Field in the ATLAS Experiment With Timepix Detectors," in IEEE Transactions on Nuclear Science, vol. 66, no. 7, pp. 1861-1869, July 2019, doi: 10.1109/TNS.2019.2918365.
[2] https://www.micado-project.eu
[3] Poikela, T., et al. "Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout." Journal of instrumentation 9.05 (2014): C05013.
[4] P. Burian, P. Broulím, M. Jára, V. Georgiev and B. Bergmann, "Katherine: Ethernet Embedded Readout Interface for Timepix3", Journal of Instrumentation, Volume 12, no. 11, pp. C11001--C11001, November 2017
[5] L. Meduna, B. Bergmann, P. Burian, P. Mánek, S. Pospíšil and M. Suk, "Real-time Timepix3 data clustering, visualization and classification with a new Clusterer framework", arXiv preprint arXiv: 1910.13356 (2019)
[6] P. Mánek, "Machine learning approach to ionizing particle recognition using hybrid active pixel detectors", Master Thesis, 2018.
[7] L. Meduna, "Detecting elementary particles with Timepix3 detector", Master Thesis, 2019.

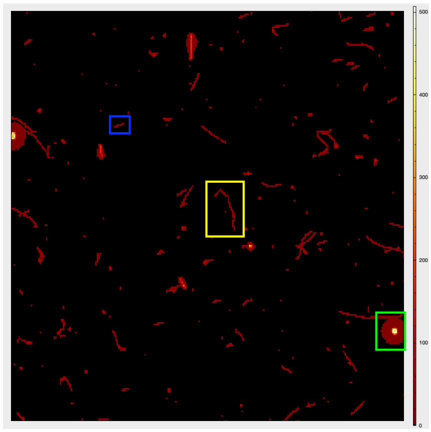

Figure. 2. Detail of one device with highlighted types of events. The electron is marked in yellow, the alpha particle (visible below the ^{6}LiF foil after a $^{6}Li(n,\alpha)^{3}H$ reaction) in green and the γ-ray in blue.