Edge-AI enhanced radiation sensors with sub-pixel spatial & time resolution for future 4D tracking

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The radiation sensors (LGAD, LAPPD) that enable 4D tracking (measurements of the spatial and temporal coordinates) have become optimal choices for the next generation of detector upgrades to reach the physics goals. In this context, significant R&D has been ongoing at BNL to develop sensors that can at the same time achieve fine segmentation of devices down to a pitch size of tens of microns while maintaining tens of pico-second-level timing performance. For the front-end-electronics (FEEs), Application-specific Integrated circuits (ASICs) are designed to have a small enough contribution to the timing resolution and to handle the finer granularity of the sensor design. Current reconstruction algorithms suffer from the complexity of correlated signals from pixelated sensors, Landau fluctuations of energy deposition by radiations, loss of information during analog-to-digital conversion, and noise from FEEs. The application of Machine Learning (AI/ML) techniques becomes essential to achieve sub-pixel (less than pitch/$\sqrt{12}$) spatial and temporal resolution as well as noise reduction. Due to the availability of analog test beam data from FANL and a full readout chain (including sensor + FEE + aggregator/readout out), the BNL-developed AC-LGAD will be an ideal choice for the demonstrator implementation of this project. We will use the existing data on the full analog waveform from the sensor and emulate the response of the ASIC called EICROCx to train and test an AI/ML network. We will validate the output of the AI/ML network using cosmic data and the charge injection method using the output from a Xilinx ZC706 prototype readout board.

The project will deliver an AI/ML network that is capable of providing optimized sub-pixel spatial and time resolution that can be implemented in future experiments including a light source, rare process, NP, HEP, and space mission experiments. Our approach will be generic but can easily be customized for other sensors. This project will be limited to one year and pave the path toward the development of a prototype of the AL/ML processing unit using the HLS4ML algorithm on Xilinx FPGA toolkit boards such as FELIX. Such processing units can be added in a hierarchical structure in a streaming-based readout architecture to make trigger decisions to identify physics processes & reduce the data throughput. Our project will be a stepping stone for future edge-AI-based readout architecture in NP experiments at LHC and EIC. The developed technology can be commercialized to make compact AI-enhanced 4D sensors.