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From analog readout to ML-processed Silicon Device signal-sharing and LGADs at BNL

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Resistive Silicon Devices (RSDs), such as AC-coupled Low Gain Avalanche Diodes, achieve a fine spatial resolution while maintaining excellent timing resolution when they have internal gain, achieving time and space (4D) tracking measurements for collider experiments in High Energy Physics (HEP) at the Large Hadron Col- lider (LHC), Electron-Ion Collider (EIC), and Lepton Collider experiments. The typical pad arrangement imposed by readout electronics imposes geometrical disposition constraints of the pads in matrix arrays of equidistant pixels. For RSDs and, more specifically, AC-LGADs, the shape disposition of the readout pads can be modi- fied to arbitrary geometries. However, when ionizing radiation hits these devices, the collected charge spreads well beyond the two adjacent pixels. This complex charge collection challenges the devices readout due to the increased signal sharing and the noise in readout electronics. Current readout methods restrict themselves to either using only one high-level quantity or imposing (spatial) restrictions on the number of readout channels used due to the complexity. Given the complexity of correlated degrees of freedom involved in the charge collection, applying Machine Learning (ML) techniques becomes advantageous. Although previous studies performed in this direction showed little performance gains, they used the above-mentioned restrictions. By benefiting from all the correlations among all the readout quantities of the device, such as amplitude, rise time, pulse width, and amount of signal shared across electrodes, among others, the information loss will be minimized. Preliminary studies showed that on pixel sensors, ML techniques could potentially exploit the complexity of the signal-sharing in two dimensions due to AC-coupling of the signal across pixels. In a full system design, this information must be transmitted from the sensor to off-detector electronics, allowing ML algorithms to be exploited. Additionally, ML algorithms eliminate the need to solve the analytical laws governing complex geometry-induced behaviors. This motivates the optimization of these additional degrees of freedom, which can be fine-tuned when targeting a specific application. In turn, non-standard arrangements of readout pads, such as squares, triangles, hexagons, or different shapes, can be optimized for optimal spatial resolution. This project aims to pair compression algo- rithms in digitizing the analog signal of RSDs that exploit the correlated degrees of freedom for improved spatial resolution with the sensor design. This unique approach is expected to significantly reduce the data throughput while optimizing the sensor geometry with arbitrary pad arrangments to maximize the spatial resolution.

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