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# Detection of Neutrino-Induced Air Showers by the Artificial Neural Network FPGA Trigger

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Neutrinos play a fundamental role in the understanding of the origin of ultra-high-energy cosmic rays. They interact through charged and neutral currents in the atmosphere generating extensive air showers. However, the very low rate of events potentially generated by neutrinos is a significant challenge for detection techniques and requires both sophisticated algorithms and high-resolution hardware.

A trigger based on an artificial neural network was implemented into the Cyclone V E FPGA 5CEFA9F31I7, the heart of prototype Front-End boards developed for testing new algorithms in the Pierre Auger surface detectors.
Showers for muon and tau neutrino initiating particles at various altitudes, angles and energies were simulated in CORSIKA and OffLine platforms, giving a pattern of ADC-traces in Auger water Cherenkov detectors. Several three-layer neural networks were taught in MATLAB by simulated ADC traces for various energies, angles, initialization points and types of primary particles according the Levenberg-Marquardt algorithm.

Results show that the probability of an ADC traces generation is very low due to a small neutrino cross-section.
Nevertheless, ADC traces for low-energy showers, if they occur, are relatively short and can be analyzed by a 16-point input algorithm. We optimized the coefficients from MATLAB to get a maximal range of potentially registered events, and for fixed-point FPGA processing, to minimize calculation errors.
We noticed that there is not so significant discrepancy in a detection efficiency for various networks, starting from 12-8-1 and going to much more complicated and on the other side going to much simpler. It looks like a relatively simple network could select on-line preliminary events for a future more detail off-line analysis.
Offline simulation were performed mostly for 40 MHz as a basic pattern. 120 MHz Offline version is in a development phase and these data should be treated as preliminary.

New sophisticated triggers implemented in CycloneV E FPGAs with a large amount of DSP blocks, and embedded memory running with 120 MHz sampling, may support a discovery of neutrino events in the Pierre Auger Observatory.

We investigated also the pattern recognition of DCT coefficients generated from ADC-traces in a trigger region. Unfortunately we did not observe a significant improvement which would justify much sophisticated FPGA network structure.

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