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Digital Advances in Triggering and Data Acquisition Systems for Large Scale Dark Matter Search Experiments

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Abstract

With a wealth of astrophysical evidence that confirms that the baryonic matter we understand accounts for only 5% of the matter and energy in the universe, the search is on for the mysterious dark matter, that is said to account for 25% of the universe composition. The leading candidate for dark matter is the Weakly Interacting Massive Particle (WIMP).

Large Underground Xenon (LUX), a 370 kg two-phase (liquid/gas) xenon time projection chamber operating at 4850 feet underground at the Sanford Underground Research Facility (SURF), has recently completed its operation, setting the world's best limit on the WIMP-nucleon cross section. This thesis presents the research and development of a novel, FPGA-based, triggering system. This system has operated at SURF since 2011 and through digital signal processing techniques identified events of interest in real-time. The system processes the incoming data at its filter stages with a rate of 5,100 MB/s and does so consuming a total of only 15 W. The system is based on custom-built hardware developed in close collaboration with the author. The firmware and software were entirely developed by the author. The system offers great flexibility through the reconfigurability feature of FPGAs, which was exercised often during the course of the experiment. The system allows for fully remote operation, minimizing the personnel needs deep underground. For this type of detectors, this triggering system has shown to offer the best efficiency in detecting signals as small as few liquid electrons.

LUX-Zepplin (LZ) is a next-generation dark matter detector, that is scheduled to start probing the remainder of the uncharted WIMP-nucleon cross section in 2020. It is a significantly larger successor of LUX, with a total xenon mass of 10 tonne. It will be instrumented with 745 photomultipliers, totaling 1,359 digitizing channels. The author is developing the LZ Data Acquisition and Data Sparsification system and also holds an L3 managerial position on the project. This system is going to handle a continuous input rate of over 200 GB/s and its key elements have already been shown to meet and exceed the LZ requirements.