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The Data Acquisition System of the KOTO Experiment and RPT Upgrade

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The KOTO experiment is a particle physics experiment located in J-PARC, Japan, aiming to measure the branching ratio for the $K_L \to \pi^0\nu\bar{\nu}$ decay and to explore new physics. This decay has not yet been observed and it has a branching ratio predicted by the Standard Model to be $(2.43 \pm 0.39) \times 10^{-11}$. The current upper limit of 2.6×10^{-8} was measured directly by E391a at KEK. The KOTO experiment achieved similar sensitivity to the E391a result with 24 kW proton beam in 2013. The present DAQ system, commissioned in 2015 runs with 42 kW beam power, is designed to reach the limit on the branching fraction coming from existing theoretical models of 1.5×10^{-9}.

The KOTO DAQ system consists of ADC frontend modules, two hardware triggers (L1, L2), and one software trigger (L3). Two types of ADC modules with sampling rate of 125 MHz and 500 MHz are used to digitize detector waveform signals. The L1 trigger calculates the sum over of 3000 channels of calorimetric energy and checks 1000 channels of detector veto every 8 ns. The current L1 trigger rate during physics data taking is 18.5 kHz. The L2 trigger receives up to 0.5 MB of data per trigger and makes a decision based on the center of energy of the calorimeter. The average L2 trigger accept rate is 33% and the maximum data output rate is 17 Gbps. The L3 computing farm receives events from the L2 trigger via UDP and manages event building, data compression, and data storage. The 2013 DAQ system used a commercial Ethernet switch between the L2 and L3 trigger to build events. In 2015, we implemented online lossless data compression inside the ADC modules and enhanced the L3 computing farm with a 10 Gbps Infiniband network and 288 TB of local storage for more efficient event building. The improved system is able to concurrently perform data transfer to permanent storage (3 Gbps) with DAQ data taking.

To accommodate future increases in proton beam intensity, we are developing an upgrade for the L2 hardware trigger using the RCE (Reconfigurable Clustering Element) Platform Technology (RPT) developed by SLAC with replicated mesh ATCA shelf. The RPT supports Rx/Tx link with higher input/output rate up to 120 Gbps per RCE. With full backplane connectivity and the new Zynq-7000 series FPGA computing power, event building and cluster finding processes can be done by the L2 trigger. We expect the fully optimized upgraded L2 trigger to support trigger rate 7 times greater than the current value. The RPT is used by experiments such as ATLAS CSC, LBNE, LCLS, and LSST. We will modify the RPT to support the KOTO experiment and aim to commission the upgraded L2 trigger system in 2017 run.

Author: Ms SU, Stephanie (University of Michigan)

Co-authors: RYMPH, Christopher (University of Michigan); SCHAMIS, Hanna (University of Michigan); BEECHER, Jacqueline (University of Michigan); MICALLEF, Jessica (University of Michigan); XU, Jia (University of Michigan); HUFF, Maggie (Kenyon College); TECCHIO, Monica (University of Michigan); CAMPBELL, Myron (High Energy Physics); WHALLON, Nikola (University of Washington); TAJIMA, Yasuhisa (Yamagata University); SUGIYAMA, Yasuyuki (Osaka University); WAH, Yau (University of Chicago)

Presenter: Ms SU, Stephanie (University of Michigan)

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