Cluster Trigger System for the KOTO Experiment at JPARC

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The paper presents the Cluster Trigger upgrade for the KOTO experiment at J-PARC, Japan. The physics demand of KOTO needs sophisticated triggering from data throughout the whole detector. The sophistication translates to various factors including intensive I/O and correlational calculations. We have implemented a new Cluster Trigger which generates Cluster Bits from the CsI detector data and runs in parallel with the Total Energy (Et) based Level-1 Trigger. At every Level-1 Triger pulse, a number of successive samples from each channel of the CsI ADCs are analyzed, and a bit is set High when the peak sample from that set is above a specified threshold. The process takes place in real time inside all of the 176 CsI-ADC modules, and one Cluster Bit per channel is generated. These bits are then collected for a full crate into a Clock Distribution and Trigger (CDT) module within 400 ns of a trigger pulse. The CDT module also acts as a crate fan-out and jitter cleaner, distributing the clock and Level-1 triggers to the ADCs. An Optical Fiber Center (OFC), which is a 6U VME module with 18 SFP transceivers and one Intel Arria V FPGA, communicates directly with all CDTs, and gathers all Cluster Bits for the corresponding Level-1 trigger with minimal dead time and latency. A map of the entire CsI detector is created for each energy based event inside the OFC Module. By utilizing an algorithm based on topology, the numbers of isolated clusters in the CsI calorimeter are calculated. This Cluster Map provides information for triggering on the desired decay modes. The trigger decision can be made based on the physics of interest. The new KOTO Cluster Trigger system expands the capability of doing complex trigger logic and improves monitoring and debugging of the full DAQ.

KOTO Cluster Trigger and Veto – Architecture

Figure 1 and Figure 2 present simplified trigger block diagrams of the CsI ADC Modules and Crates. Each crate includes 16 ADC Modules, which require a clock and two trigger pulses: Level 1 Accept Trigger (L1A) and LIVE. The Clock Distribution and Triger Module (CDT) receives these signals and distributes them to the ADC Modules. The whole system includes 11 crates receiving signals from the CsI Detector and 7 crates connected to the Veto Detector.

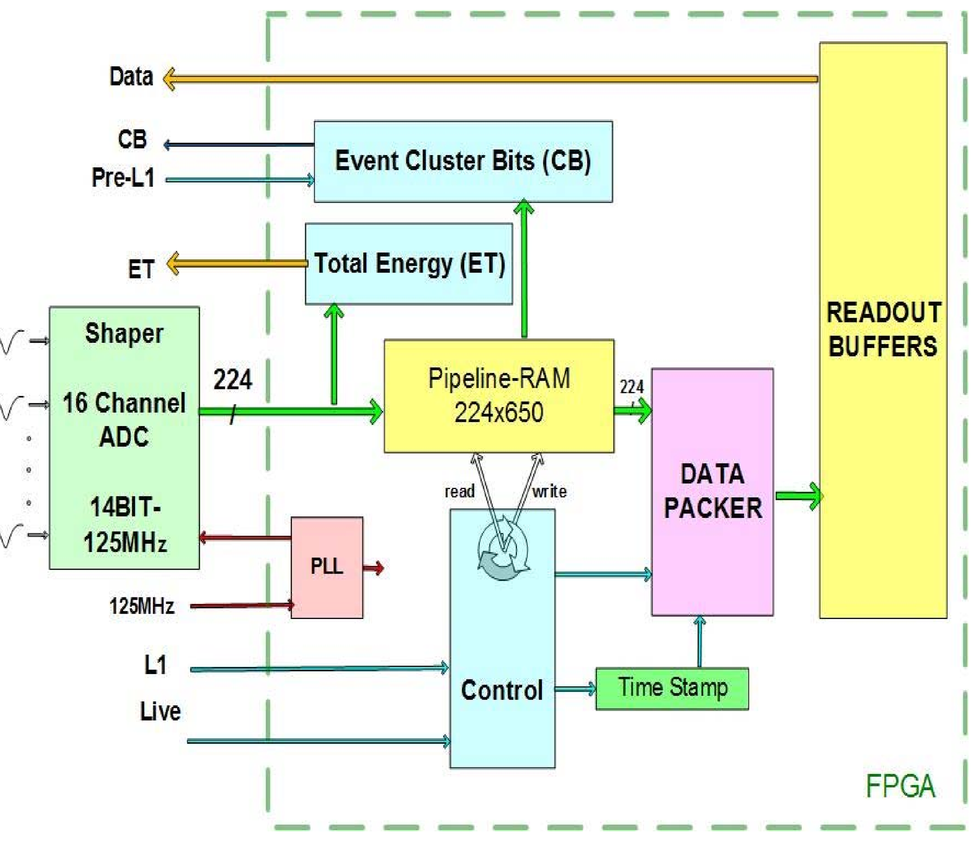


Figure1. Block Diagram - ADC Module

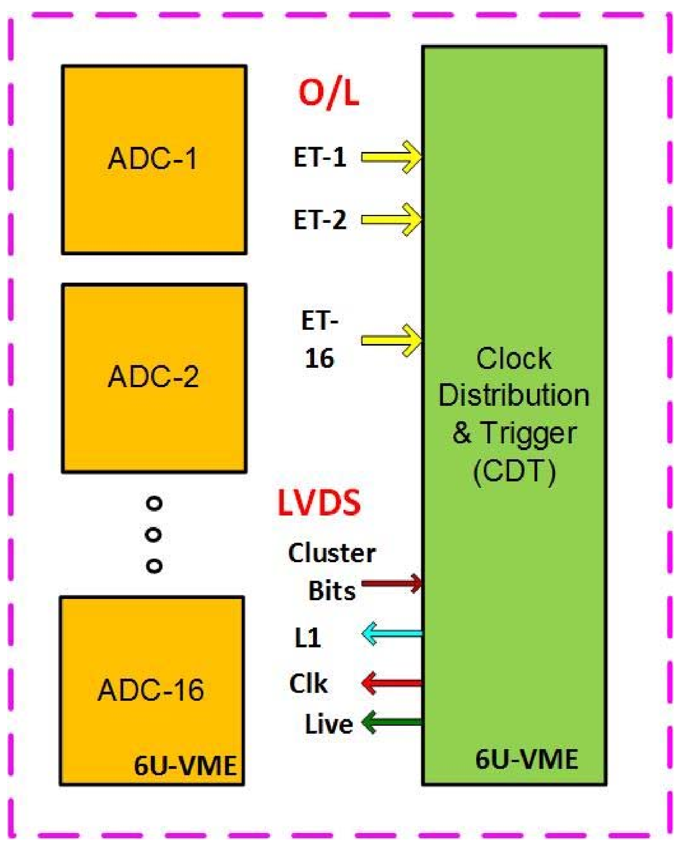
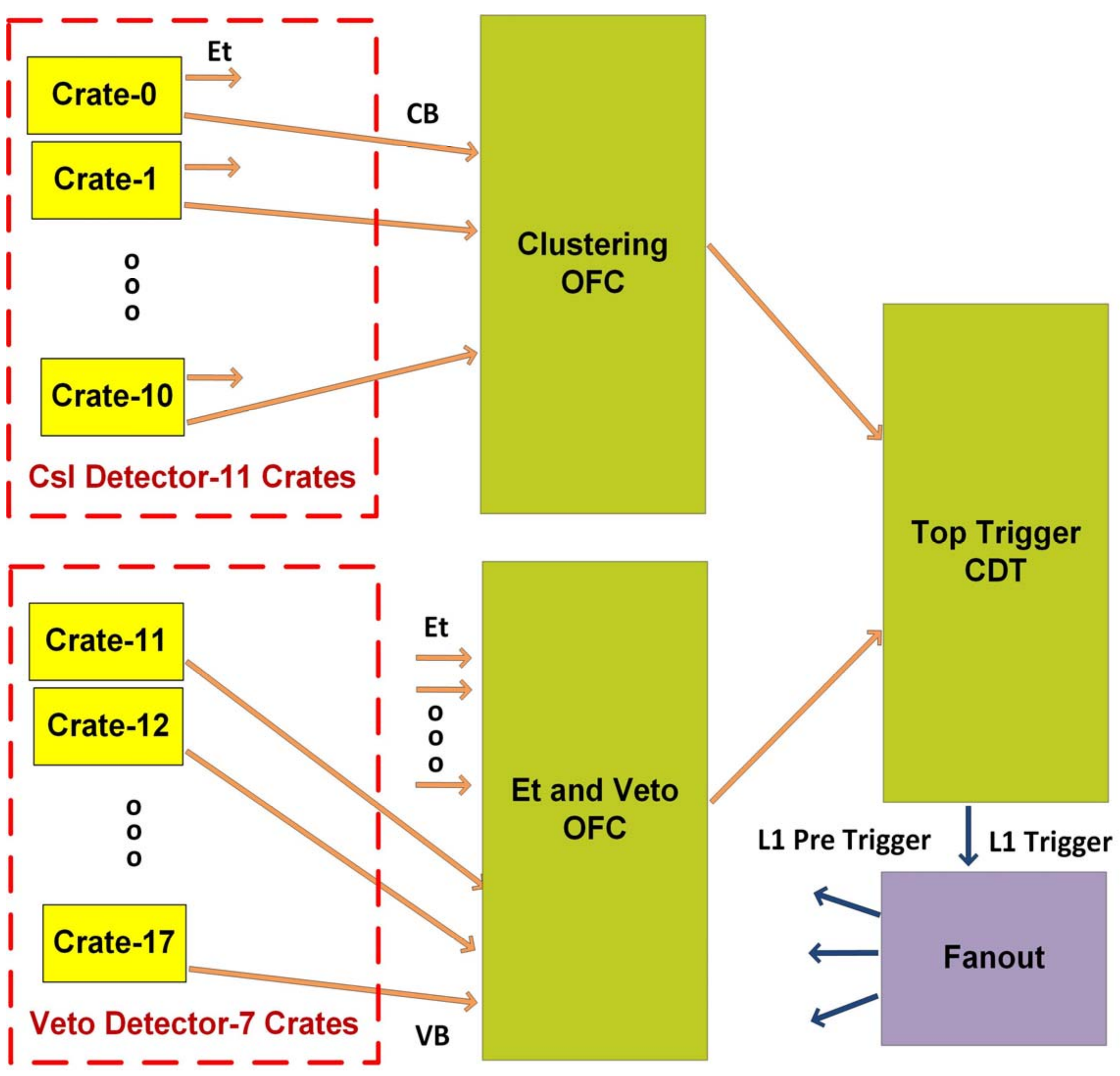


Figure2. Block Diagram – KOTO Crate



The simplified block diagram of the new KOTO Cluster Trigger System in presented in Figure 3. There are two Optical Fiber Center (OFC) Modules installed.

One OFC collects the Clustering Bits from the CsI detector.

The 2nd OFC Module connects to all KOTO crates, CsI and Veto, and collects both the Veto Bits and the Energy Values.

Figure 3. KOTO Cluster Trigger and Veto Block Diagram. All Cluster Bits (CB) are gathered into one place where the Cluster Map is generated, and Cluster Numbers are calculated. The Veto Bits (VB) are collected in the corresponding ADC crates, and passed along in a similar way for the final trigger decision.

In the KOTO experiment, the CsI Caloirmeter consists of 2240 small crystals and 476 large crystals arranged in a disc shape, as shown in Figure 4. A corresponding Map of the entire CsI Detector is created for each energy based event inside the OFC Module. By utilizing an algorithm based on topology, the numbers of isolated clusters in the CsI calorimeter are calculated in real time. This Cluster Map provides information for triggering on the desired decay modes.

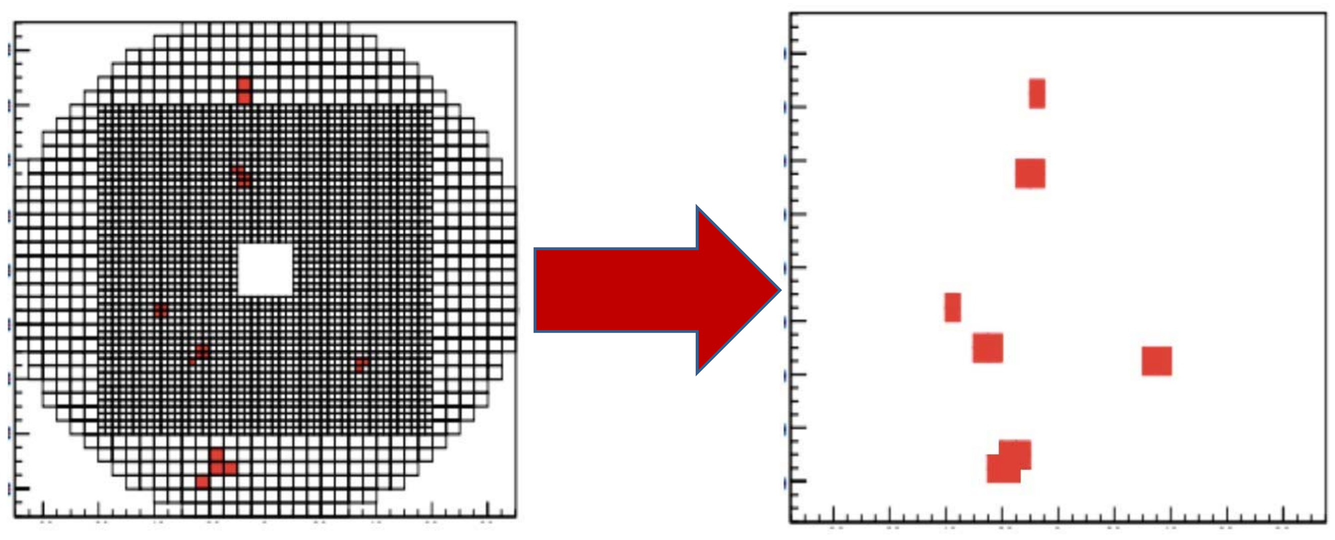


Figure 4. Layout of the original CsI grid and the corresponding Cluster Map for one Event. The trigger decision can be made based on the physics of interest.

The new custom modules used in the KOTO Cluster Bit Trigger System are shown in Figure 5 and Figure 6. Provided with powerful Intel Arria V FPGA, these Double Width 6U-VME modules can be used in many other HEP applications.

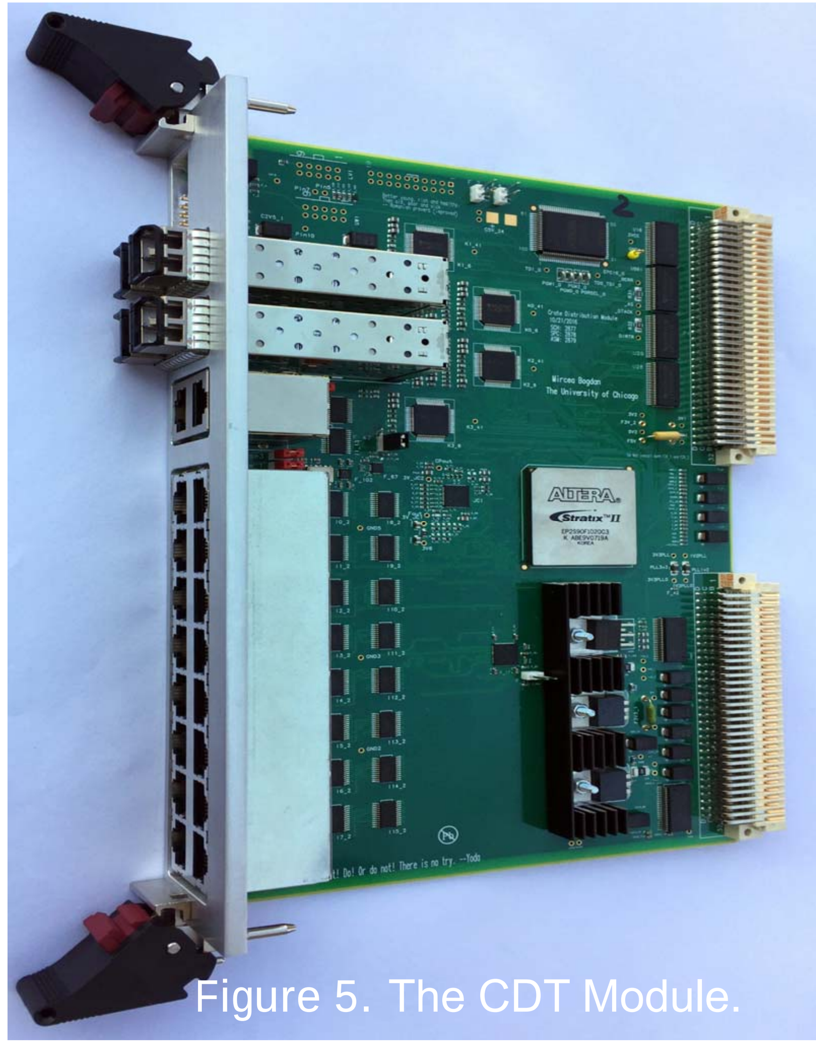


Figure 5. The CDT Module.

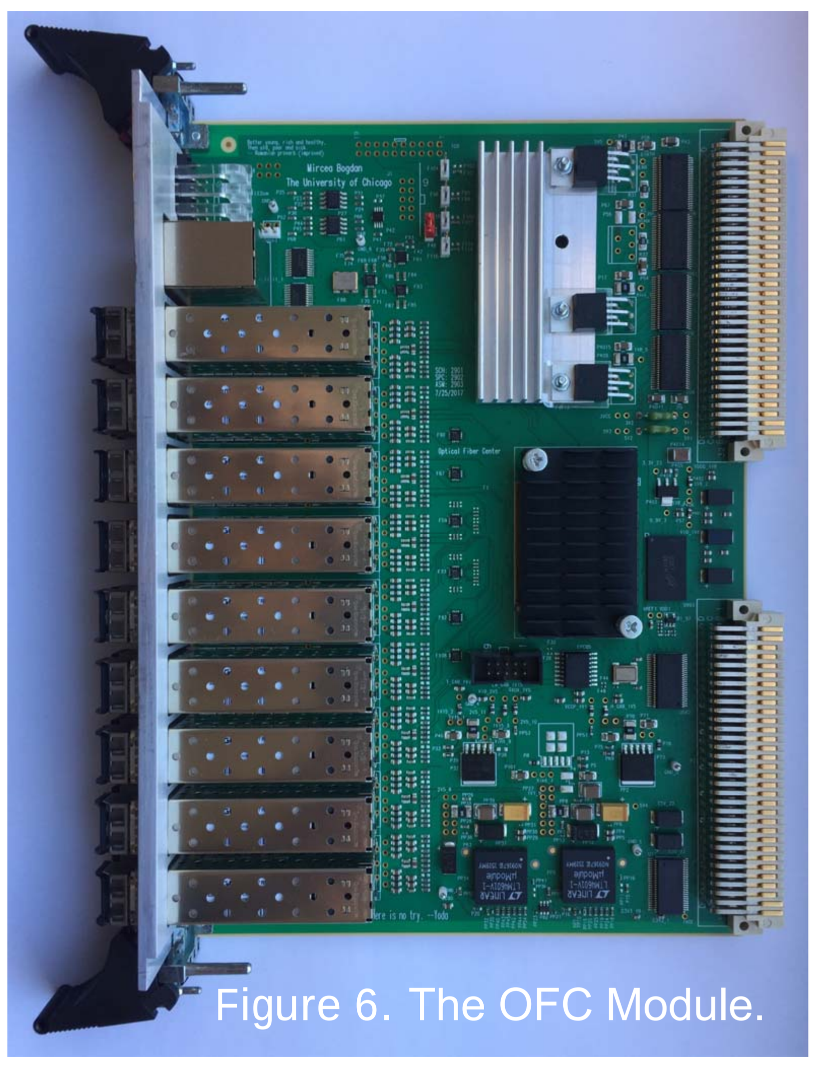


Figure 6. The OFC Module.

Conclusions

The new Cluster Trigger System was installed and is running in the KOTO Experiment since March 2017. The efficiency of taking the K_L -> π^0 ν $\bar{\nu}$ events is estimated to be 99.6% with near 100% DAQ live ratio at the current accelerator beam power of 50kW. The dead time of the cluster counting (18 clocks) is negligible compared to the wider 64-clock sampling for each event.

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