Upgrades to the K0TO Experiment's Data Acquisition System

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There exists a great imbalance between the amount of observed matter and antimatter in the universe. Since there is no meaningful bias between the two states, this asymmetry is a mystery on the forefront of physics today. Leading theories as to how an asymmetry could arise from an initially symmetric state require charge parity (CP) violation. Experiments have confirmed that CP violations do occur, but the Standard Model of particle physics does not account for the magnitude of CP violations necessary to explain the asymmetry.

The K0TO experiment seeks to further understanding of CP violation by examining the CP violating decay $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$. This decay is a CP violating process, and so a more precise measurement of its branching ratio will provide new insight into CP violation. The decay starts with the K_L^0 meson which contains a strange quark and an anti-down quark. The decay results in a neutrino, an antineutrino, and a neutral pion (consisting of a down and anti-down quark). The neutral pion has a mean lifetime much shorter than that of the K_L^0, and decays to two photons in over 98% of decays. Therefore, for the purposes of K0TO's measurement the two photons are treated as originating from the location of the signal decay.

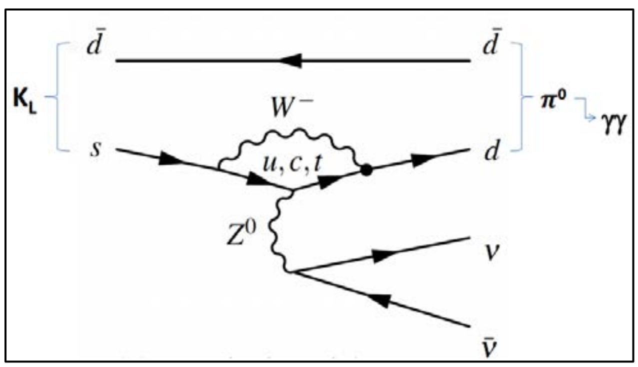

Fig 1. Feynman diagram for the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ decay.

The standard model predicts a branching ratio of 2.43×10^{-11} for the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ decay. The experimental upper limit determined by the KEK E391a experiment is 2.6×10^{-8}. K0TO's sensitivity goal is 3×10^{-12}. A measurement of this branching ratio is sensitive to new physics, and will constrain models of such new physics according to their predictions of this branching ratio.

K0TO measures the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ decay by measuring the photons that are emitted from the most likely decay of the neutral pion. The photons are detected by CsI calorimeters which measure their energy deposits. The calorimeters then send voltages to ADC for digitization of the data. In addition to the CsI calorimeters, there are veto detectors which measure properties such as whether or not there are charged particles in the system. They are used to determine if an event doesn't match the proper decay (which contains no charged particles). The data is transferred via fiber optic cable to FPGA boards where it undergoes simple initial analysis to determine if it should be kept or discarded. The figure below (figure 2) shows the path of the data through the current version of this system.

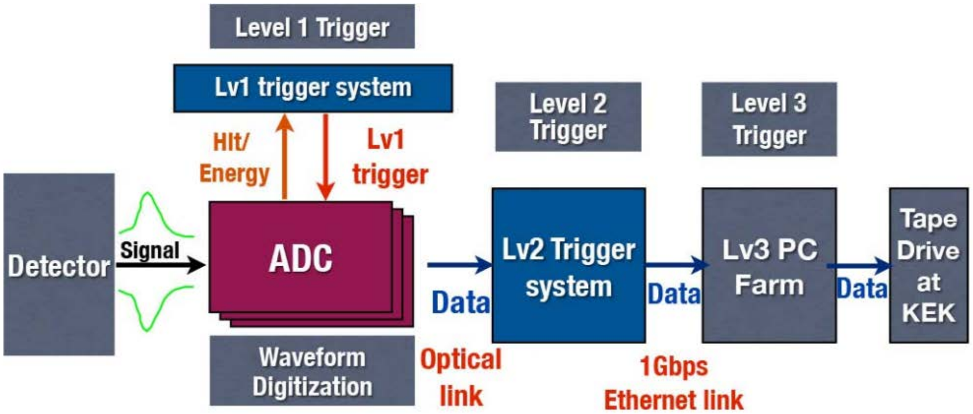

Fig 2. Schematic outline of K0TO's data acquisition system. Courtesy of Y. Sugiyama.

By using FPGAs for the Level 1 and Level 2 trigger system, cuts on the data can be made at a high rate, keeping up with the rapidity of the events detected. Once the data is digitized by the ADC, it is sent to the Level 1 trigger system. This makes a cut on the data according to the amount of total energy detected in the event. If the data passes the cut, the Level 1 system signals to the ADC to send the data to the Level 2 trigger system which then makes a cut according to a center-of-energy calculation. If the data passes the Level 2 trigger, it is sent to the Level 3 PC farm for event reconstruction and storage. Ultimately the data is written to tape at the KEK facility, also in Japan.

Currently, it appears that the choke point for this system is the Level 2 system. Data is being stored in a FIFO (First In First Out) queue which is filling up, prompting data to be dropped when this buffer is full. This loss of data will only increase as the beam power is increased in future runs. As such, the University of Michigan team is focusing on upgrades to the Level 2 system. My project concerns the initial steps in the upgrade of this trigger.

The first element of the upgrade is a switch from the VME shelf standard to the ATCA shelf standard. Shelves (or crates) are used to house the boards that contain the FPGAs and other electronics for the trigger system. The new ATCA standard will allow greater connectivity between boards of the same shelf, will support swapping of boards, will allow attachments of RTMs or Rear Transition Modules that allow greater customization of boards' connection to exterior sources, and many other improvements. As part of my project I made a document outlining the setup of the shelf manager unit for the shelves we were using, as well as preparing two of the shelves for use in testing at U of M.

The second element of the upgrade is the adaption of the Cluster On Board, or COB, for use in the K0TO data acquisition system. The COB was developed at SLAC for use in data acquisition systems. Previously, some experiments would otherwise recycle old and outdated equipment rather than design new boards. The COB allows them to purchase an up to date board that would serve their needs. The COB includes 8 Reconfigurable Cluster Elements (RCEs), each of which functioned as both a Linux computer using an ARM processor and as an FPGA. One of the group's graduate students, Stephanie Su, worked with SLAC to create some initial firmware for this device. My project was to transfer this firmware to the system at U of M, and to move development along for the course of my stay.

First, I constructed a testing environment that included an actual ADC configured to send a simulated data packet, a board to provide a clock to the ADC, and the COB in a configured

ATCA crate. I then began to implement the firmware for the COB in this system. Initially, the firmware did not work after being transferred from SLAC. This was ultimately found to be due to missing TCL files that would have to be modified to work in the U of M system. After making these modifications, I debugged the firmware using a logic analyzer tool within the firmware. After detecting logic errors in this design, I made the necessary corrections and verified that the COB could in fact receive data transmitted from an ADC. Next, I investigated the functionality of the AxiBus and AxiLite interface, which allowed for easy communication between the software running on the Linux side of the RCE, and firmware. Using this system, I was able to read out the received data, and I added in some new system resets that could be triggered from the C program running in Linux. After writing documentation describing the workings of this system and how to use it, I began investigating how to write the received data to RAM. It appears that the data does queue up and will properly transmit to the DMA engine (which is responsible for writing and reading from the system RAM), but that the DMA engine send a constant "not ready" signal. Resolving this issue will be the next step in future development.

This Level 2 system, once finished, will be much better equipped to handle the rapid stream of incoming data that will be experienced at higher beam powers. Development is moving forward at a good pace, and is expected to produce a working system having built on the progress made this summer.

Overall, this project has been an excellent experience for me both personally and professionally. I have learned about firmware design, high energy and elementary particle physics, and how to work as part of a large but tightly connected research group. I am very appreciative of this opportunity, and would like to thank Prof. Myron Campbell for the wonderful opportunity and his excellent mentorship. Thank you as well to Stephanie, Melissa, Brian, Monica, Molly, Josh, Noah, Roman, and the rest of the K0TO collaboration.

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