Data Acquisition Systems in High Energy Particle Physics: the KOTO Experiment
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Margaret Huff

KOTO is a high-energy particle physics endeavor to observe a rare decay that would provide information about the composition of the universe. The experiment hopes to measure the branching ratio of the decay in question, $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$. The standard model predicts a branching ratio of 2.8×10^{-11}. An experimentally confirmed branching ratio would be less interesting, but if it was found to be larger, it could mean that another decay process occurs in nature and the standard model should be modified.

The method to measure this branching ratio with the accuracy needed is to observe 100 decays; the experiment has to look at around 5×10^{10} decays per second total. The observation takes place at the Japan Proton Accelerator Research Complex (JPARC), in Tokai-mura, Japan. The detector consists of a Cesium Iodide crystal scintillator and phototubes; the Data Acquisition System collects the energy information from the detector and prepares it for analysis. To obtain kaons to study, a beam of protons is first accelerated into a gold target, where they create an array of less stable particles. Veto detectors sort out charged particles, since only neutral kaons take part in the KOTO decay. Veto detectors keep track of the background decay information so that it can be subtracted out from the K_L decay information. The particles that reach the main detector hit a scintillator and subsequent photomultiplier tubes. The energy information obtained from the detector can then shed light on the inner workings of the K_L decay.

The experiment hopes to obtain data that clarifies the uncertainty surrounding the decay process of $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$. It starts with just the K_L, which is composed of an anti down quark and a strange quark, and ends up with an anti down and a down quark, which is a pi zero, and neutrino and anti neutrino. The K_L decay is a weak interaction mediated by a W^- boson, and it is not a first order decay, which is why the branching ratio is so small. If K0TO measured a branching ratio higher than the one predicted, it could mean that some other process occurs in nature that is not accounted for in the standard model and that new physics is in order. One possibility is that another particle is mediating the change of a strange quark to a down quark, instead of a W^- boson. It would presumably be very heavy, since it hasn't already been observed. If such a particle did have a place in the $K_L^0 \rightarrow \pi^0 \nu\bar{\nu}$ decay, it would be a CP violating particle. Such a thing could have been involved in the change from what presumably started as an equally matter to antimatter universe to a universe with much more matter than antimatter.

The experiment's design centers on this motivation to either confirm the standard model once again or to reveal a need for new physics. A data acquisition system is required in order to store information from the decays for evaluation. The preliminary system for handling the influx of energy information is an array of custom printed circuit boards, which make sequential cuts and spread the data out for further analysis. The data acquisition system has six main components: analog to digital converters, level one boards, fanout and Master Control and Trigger Supervisor (MACTRIS) boards, level two boards, and the Banjo computing cluster. After information travels from the photomultiplier tubes in the detector, it travels to analog to digital converters that send a digitized version to the level one boards. The level one boards cut down a huge amount of data to a more manageable amount just based on the energy total of the event. If the event makes the cut then that information has to be forwarded from the ADCs to the level two boards; the Fanout crate sends this signal. The level two boards then do what is called a COE cut, which stands for Center of Energy. The momentum from a decay should all add up to zero perpendicular to the direction of motion, so when an event shows up where this is not the case, it means it could be that the neutrinos are escaping the detector unseen, which is what the experiment is interested in. If the event has the right COE, it is sent to the computing cluster, which is called Banjo. Banjo has 42 nodes and one head node, and it is connected to several disk arrays.

The project I worked on most of the summer involved the transfer of information from the level two boards after the COE cut to the Banjo nodes. The code I wrote is mostly C with a tiny bit of C++. I employed the open source packet capture library Pcap, which allows me to read data out from each individual packet (a packet holds a piece of a decay event) as it comes in. Previously, an Ethernet switch had been used to distribute pieces of decay events to the nodes so that they could be put together. To increase the speed of data transfer a different physical layer was chosen, called Infiniband, to send the right packets to the right places. Ethernet sends packets at 2 gbps while Infiniband can send them at 10 gbps. An open source library called MPI offers functions to organize the packets through Infiniband while sending or receiving them. Stephanie Su, a 2nd year grad student, wrote this part of the code. In order to make the code more efficient, the Pthreads library was used to connect my code with Stephanie's code. Threads are a parallel processing tool which splits the computer work across the different CPUs in each node, allowing the combined code to grab packets from the level two boards (through an Ethernet connection) while Stephanie's code sends them back out via Infiniband connection. This reduces waiting time between different processes in the code. So far, the code has been implemented successfully to transfer packets of energy information, but it hasn't been tested thoroughly with large amounts of packets. The next step will probably entail running the program continuously and checking to see if it can handle the uninterrupted flow of packets in and out.

References:

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