Data Acquisition System Upgrade at KOTO

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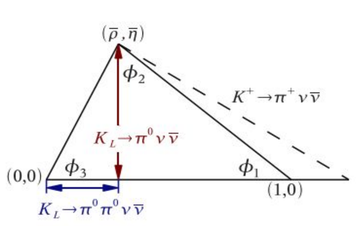
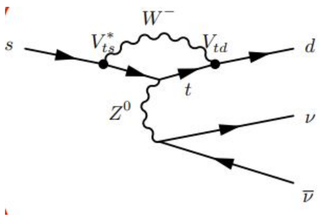
Abstract

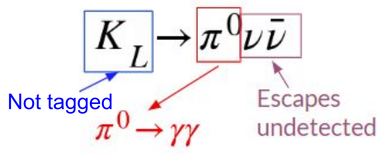
In this poster, the new KOTO data acquisition (DAQ) system upgrade is discussed. The new system is a pyramid style architecture, composed of all new homemade optical fiber centers (OFC) modules with high-speed ports which gather and build the event from over 4000 channels. It will be able to handle up to 30,000 triggers per second with minimal loss in the near future, which is a factor of six more than current rates. This will allow KOTO to handle a higher intensity KL beam, as well as open up the possibility of adding new physics triggers such as $K_L \to \pi^0 e^+ e^-$. Additionally, the new architecture simplifies our data handling and allows for greater flexibility in adding late level trigger conditions because the event building is done before the data is sent to the server. This system is robust, flexible and easily scalable in the future so that KOTO can open up our trigger to more interesting physics and provides a foundation for moving forward to KOTO Step-2.

Introduction

- KOTO searches for the ultra-rare decay, $K_L \to \pi^0 \nu \bar{\nu}$
  - $BR\left(K_L \to \pi^0 \nu \bar{\nu}\right)_{SM} = 2.94 \pm 0.15 \times 10^{-11}$.
  - Branching ratio is proportional to η.
  - Theoretical uncertainty (~2%) ⇒ sensitivity to NP!



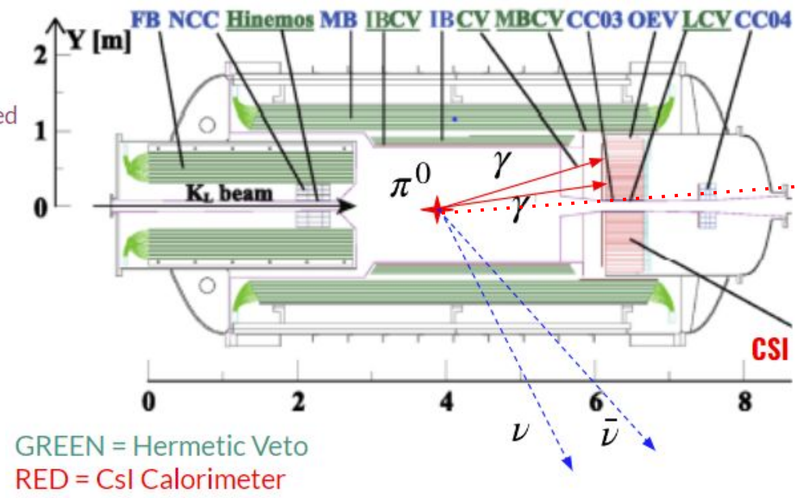


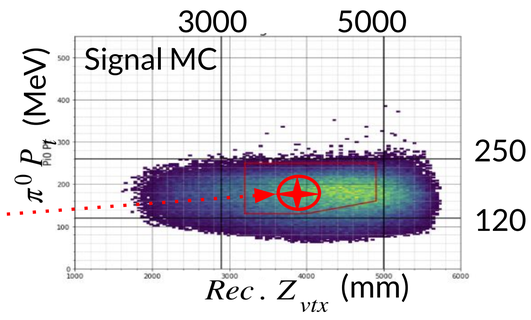


Measurement Principle

VETO SYSTEM

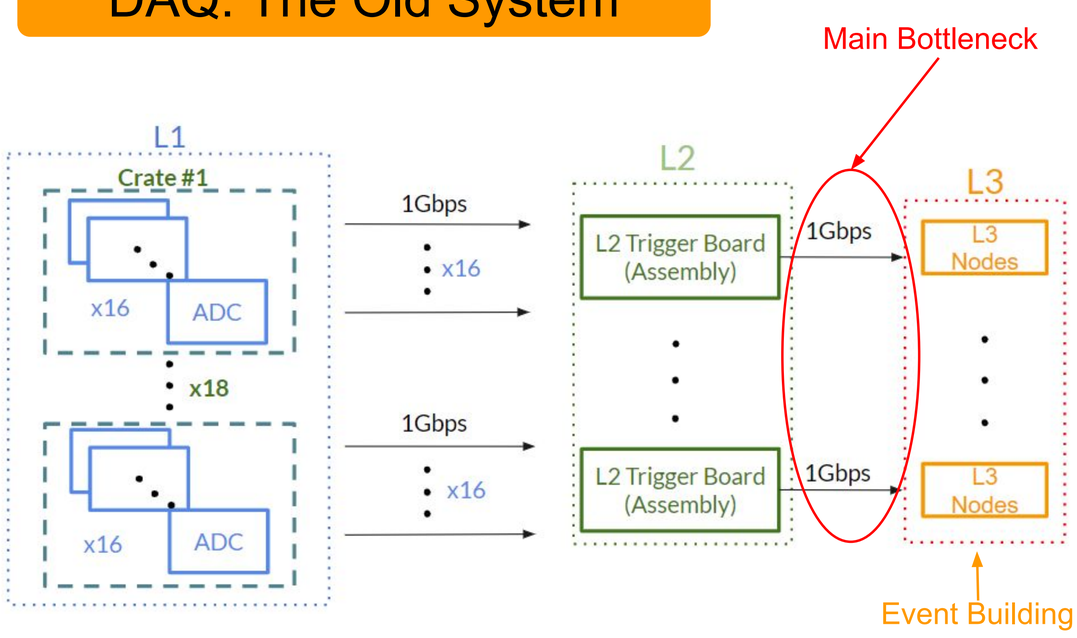
Surround the decay volume with an efficient hermetic veto system.





- Two photons in the CsI have a high transverse momentum from missing particles.
- Reconstruct the decay vertex assuming the pion mass.

DAQ: The Old System



The Bottleneck

We cannot read and write simultaneously at our L2 Trigger Board. For each spill, the L2 Trigger Board will accumulate the data and during spill-off, the module will push out all of that data. The output for each board is only a single 1Gbps line. This limits the total throughput to 10-15k triggers per spill.

Overview

Our Data Acquisition System consists of nearly 4,000 independently read out channels. There is a spill-like data structure where beam comes and goes in two seconds intervals.

The current trigger rate is ~10,000 triggers per spill corresponding to a beam intensity of 60kW. Accelerator upgrades will push the beam intensity towards 100kW meaning we expect nearly a factor of two increase in trigger rates. The Level 2 Boards, which perform the data assembly for a crate, cannot perform at such high rates.

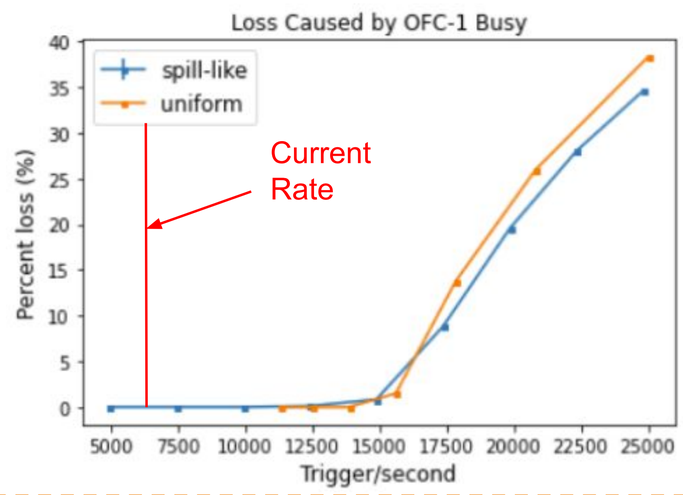
The Level 3 Nodes must finish the event building, as each one receives only a single crate of data.

Rate Test

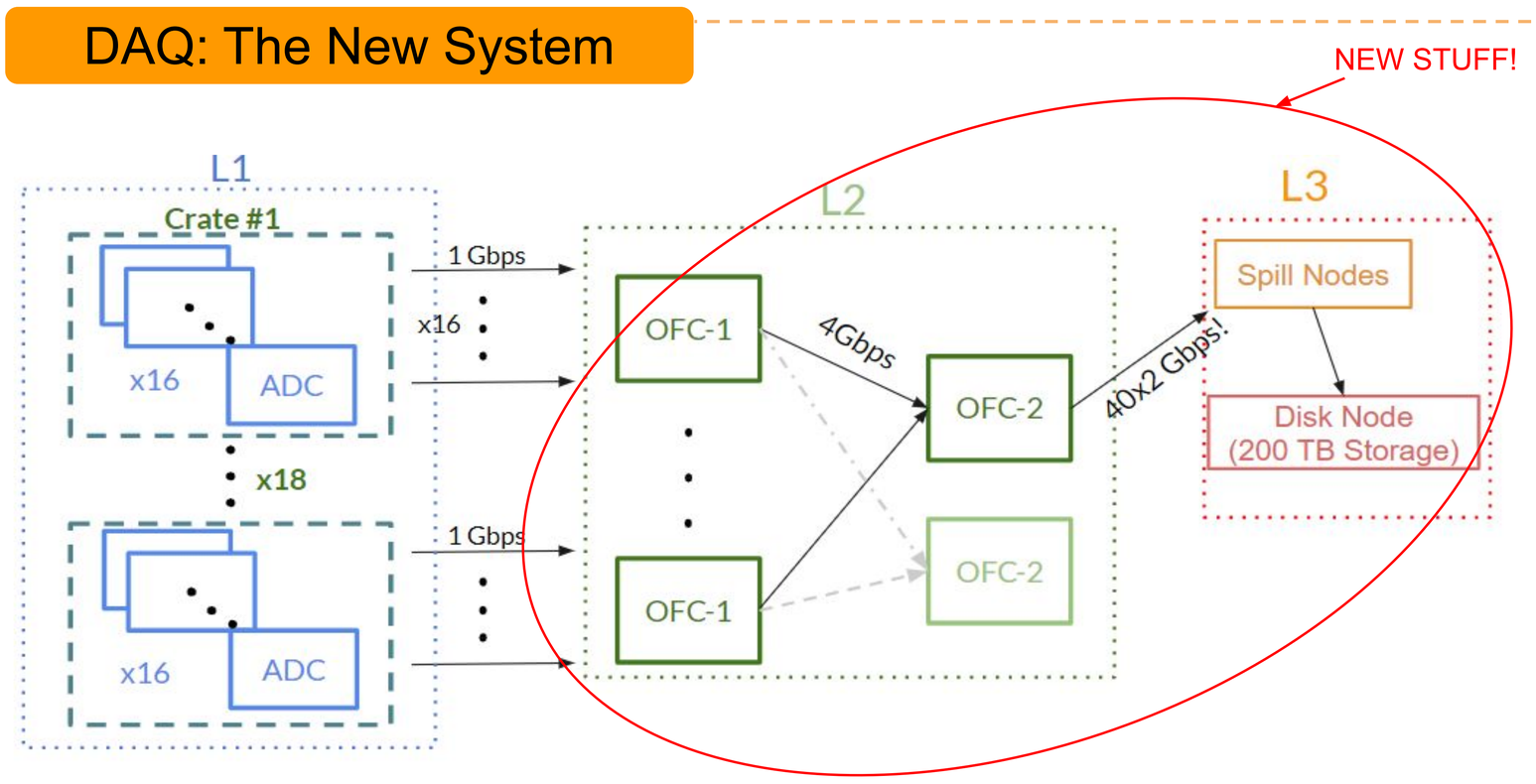
- The OFC-1 can handle rates of 15k triggers per second with less than 1% loss.
- It can handle more than twice the current data rate.

The New Bottleneck

It is caused by the OFC-1 output being limited to 4Gbps. Here in Chicago, this bottleneck was tested to see what the maximum throughput of the system is.



DAQ: The New System



Overview

The new DAQ system employs a pyramid-style structure which greatly simplifies the data-handling. The data for each crate will be assembled in OFC-1, and the entire event will be assembled in the OFC-2 before it ever reaches Level 3. This simplification of data handling allows us the flexibility to perform late level trigger in order to reduce output data rates.

The new optical fiber center modules (OFC's) have a hugely improved throughput relative to the old Level 2 modules. This means our maximum throughput increased from 10-15k triggers per spill, to 30k (60k) triggers per spill with one (two) OFC-2 modules. That increase in throughput will give KOTO the ability to open up our physics trigger and take more interesting data like $K_L \to \pi^0 e^+ e^-$.

Lastly, this system is expandable. By inserting a second OFC-2, the max throughput will double. Furthermore, if we ever need to increase our trigger rates even more than a factor of six, we can either add more OFC-1 or OFC-2 to the system to further improve the throughput. This means this DAQ system is robust to any future changes, and it provides a foundation to build upon moving towards KOTO-2.

OFC-1

OFC-1 consists of an Arria 5 FPGA, and 18 SFP I/O (5Gbps). Most are used for the 16 ADC module output per crate, and only two are available for output.

OFC-2

OFC-2 is a major step up from the OFC-1. The FPGA is a Stratix X with 8GB of high bandwidth on chip memory. There are 9 QSFP I/O which are tested at 40Gbps each.

Summary

The KOTO DAQ required a major upgrade due to upcoming increases in beam power. The new system includes two new Chicago made modules to improve the data throughput by a factor of four. Not only that, the upgrade simplifies the DAQ architecture by implementing a pyramid-style structure. This opens up the level 3 for more complicated late stage trigger decisions, and allows KOTO to study more interesting physics trigger. Moving forward, this DAQ system will be able to handle upwards of 30k triggers per second with minimal loss, while being scalable and robust as the collaboration moves towards the development of KOTO-2.