Architecture design of trigger and DAQ system for Fermilab CKM experiment

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Abstract

The Fermilab CKM (E921) experiment studies a rare kaon decay which has a very small branching ratio and can be very hard to separate from background processes. A trigger and DAQ system is required to collect all necessary information for background rejection and to maintain high reliability at high beam rate. The unique challenges have emphasized the following guiding concepts: (1) Collecting background is as important as collecting good events. (2) A DAQ "event" should not be just a "snap shot" of the detector. It should be a short history record of the detector around the candidate event. The hit history provides information to understand temporary detector blindness, which is extremely important to the CKM experiment. (3) The main purpose of the trigger system should not be "knocking down trigger rate" or "throwing out garbage events". Instead, it should classify the events and select appropriate data collecting strategies among various predefined ones for the given types of the events.

The following methodologies are employed in the architecture to fulfill the experiment requirements without confronting unnecessary technical difficulties. (1) Continuous digitization near the detector elements is utilized to preserve the data quality. (2) The concept of minimum synchronization is adopted to eliminate the needs of time matching signal paths. (3) A global level 1 trigger performs coincident and veto functions using digital timing information to avoid problems due to signal degrading in long cables. (4) The DAQ logic allows to collect chronicle records around the interesting events with different levels of detail of ADC information, so that very low energy particles in the veto systems can be best detected. (5) A re-programmable hardware trigger (L2.5) and a software trigger (L3) sitting in the DAQ stream are planned to perform data selection functions based on full detector data with adjustability.

Keywords: architecture, DAQ, trigger

1 Introduction

The CKM[1] is a Fermilab experiment to measure the branching ratio of the ultra-rare charged kaon decay $K^+ \to \pi^+ \nu\overline{\nu}$. The branching ratio of this process is on the order of 10^{-10}. This ultra-rare decay is hidden among very high rate backgrounds from decay and interaction processes. Background identification is a major challenge to this experiment.

The CKM apparatus is shown in Fig. 1. A K^+ beam of about 50 MHz enters the apparatus. About 10 MHz of K^+ will decay and the decay products will hit elements of the detectors. However, the decay $K^+ \to \pi^+ \nu\overline{\nu}$, seen in the clean signal kinematic region, is at a rate of about 1/week. The most important task for the trigger and DAQ system is not to

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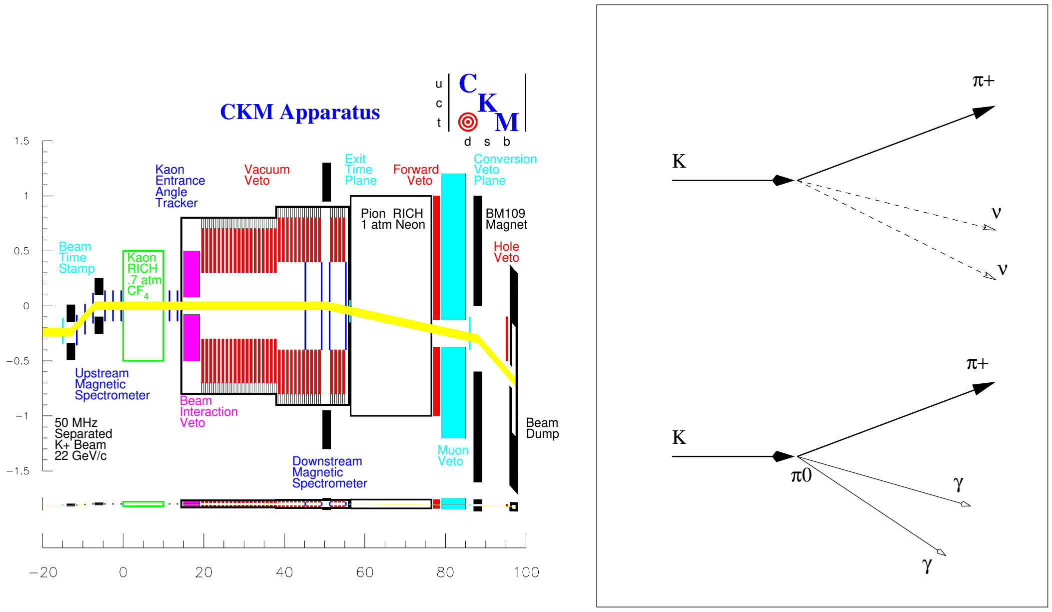

Figure 1: CKM Apparatus, the $K^+ \to \pi^+ \nu \overline{\nu}$ signal and the $K^+ \to \pi^+ \pi^0$ background.

just collect good events, but is to collect enough information of the background processes so that nearly none of the background events can be mis-interpreted as $K^+ \to \pi^+ \nu \overline{\nu}$ signal in the entire two years data taking time.

Therefore, the electronic system must function reliably. Timing and analog signal paths must be kept as short as possible before digitization. The number of necessary time matching signal pairs must be minimized. Digital designs are preferred for trigger systems due to the high reliability requirement.

In CKM experiment, the most important background decay is $K^+ \to \pi^+ \pi^0$, in which the π^0 further decays into two photons. These photons should be detected by one of the photon veto detectors: the Vacuum Veto, the Forward Veto or the Hole Veto. If the veto detectors fail to see both of the photons, the event may be mis-interpreted as $K^+ \to \pi^+ \nu \overline{\nu}$ signal (see Fig. 1).

One of the many possibilities for a veto detector element to fail to detect a photon is temporary blindness of the element due to previous activities. A detector element and its DAQ channel are temporarily dead after being hit by a particle. The channel recovers after certain amount of time. During the recovery time, it functions with reduced performance and may fail to detect a photon. Therefore, one must collect a short detector history record just before a possible decay one wants to study in order to assure the detector is alive.

2 Architecture Design

The block diagram of the CKM trigger and DAQ system is shown in Fig. 2. We will discuss the design considerations.

A clock signal is distributed in the system via the CLK link. This is a signal and the only signal requiring well time delay control and monitor in the entire system. Time stamps are kept in the system by counting the time reference signal. The reset and check signals for the time stamps are distributed via the same cable. All the other commands such as triggers are separately digitally issued in advance of the execution time and then are executed when the

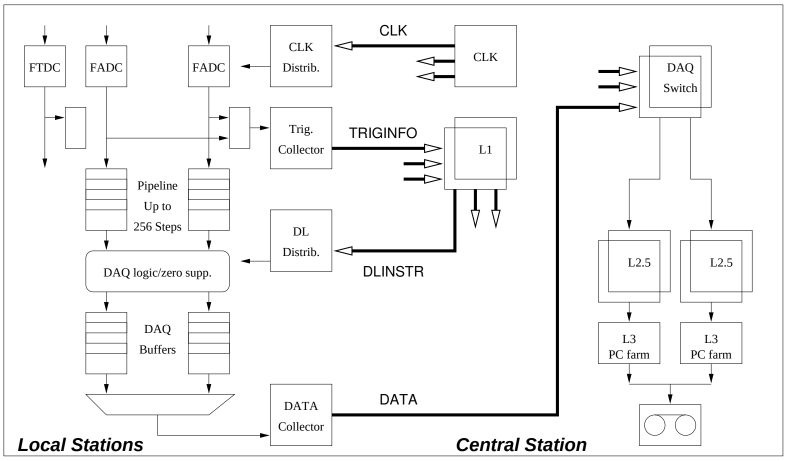

Figure 2: Block Diagram of CKM Trigger and DAQ System

local time stamp counter matches the execution time. Clearly, there is no other time matching pair signals needed anywhere in the system, which one may call “minimum synchronization”. Cable, module changing or temperature variation will not cause any timing mismatch problems.

The digitizations of time and charge signals are placed as close to the detector as possible. The FTDC and FADC devices produce a digital number for each detector channel every clock cycle. The digital data are pushed into pipeline and branched out for the level 1 trigger.

The CKM apparatus is more than 100 m long and its trigger decisions are made with timing and charge information from separated detectors. So the digital trigger approach is naturally chosen to avoid losing information through long cable transmission.

The digitized data generated by the FTDC and FADC are summarized in the local station and are sent to the central station through the TRIGINFO link. Based on the trigger information from various detectors, the level 1 trigger subsystem (L1) makes data selection decisions and issues down load instructions which are sent to the local stations via the DLINSTR link.

The down load instructions are not simply trigger signals, they are digital commands instructing the DAQ logic to move the data into the DAQ buffer with different levels of detail. The data stored in the DAQ buffer are then collected and sent to the central station via the DATA link.

Through the DAQ switch, data of same event from different detectors are placed together. With the full data, further event selection algorithm can be applied in the L2.5 trigger system. The L2.5 is a collection of FPGA based trigger modules. The logic in these devices can be reprogrammed while the modules are installed in the system. In the L2.5 system here, data of all detector channels are available for the event selection. This allows the maximum flexibility of trigger adjustment in the hardware trigger stage.

Each L2.5 module sends out information of the selected events (and short summaries of events not selected) into a machine in a PC farm. The PC farm makes the level 3 (L3) event selection. Again, this trigger stage sees full data. The PC farm allows experimenters to run more complicate event selection algorithm which L2.5 can not run in a hurry. The data selected by the PC farm are then recorded in the massive storage media.

In order to understand detector temporary blindness, as mentioned before, one must collect a short detector history record just before a possible decay one wants to study. This can

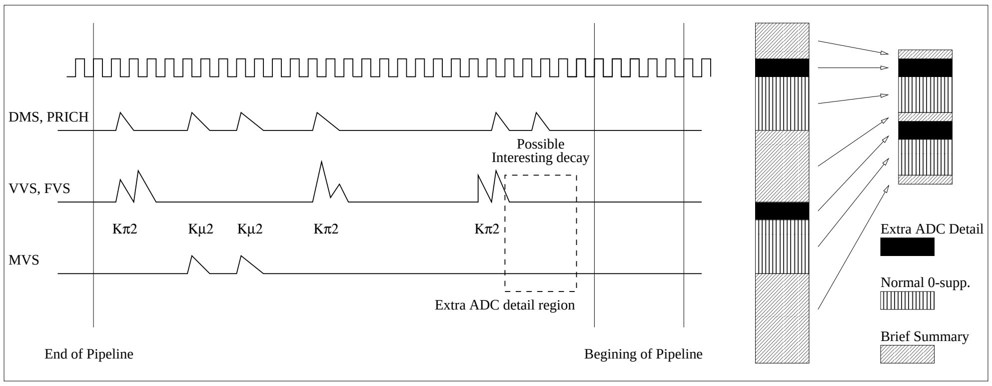

Figure 3: CKM "Event"

be shown in Fig. 3. An event in CKM is actually a time interval.

In most portion of the time interval, zero-suppression will be applied to the ADC (and TDC) data to reduce the data volume. While around the possible interesting decay, ADC data with full detail, i.e., without zero-suppression of all channels will be recorded, so that particle hits with lowest energy can be detected. In fact, in CKM experiment, none of the detector hits should be completely ignored. The hits in the events not accepted by the trigger systems and the hits far away from the interesting events are still useful for detector monitoring, which is vital to the success of CKM experiment. Data of these hits are briefly summarized and recorded as shown in right hand side of Fig. 3.

Note that the events selected by the trigger and DAQ system are not merely $K^+ \to \pi^+\nu\overline{\nu}$ signals. Most of "events" selected and recorded are known to be background with some possibilities of mis-interpretation, such as missing one photon in $K^+ \to \pi^+\pi^0$ decays. The purpose to collect the background is to understand the behavior of the background so that the final $K^+ \to \pi^+\nu\overline{\nu}$ signal quality is assured.

3 Summary

In the CKM experiment (in fact, in many HEP experiments), the following concepts are true:

- **Collecting background is as important as collecting good events.**
- **A DAQ "event" should not be just a "snap shot" of the detector. Instead, it should be a short history record of the detector around the candidate event.**
- **For trigger system to "throw out garbage events" is not valid anymore.**

Reliability of the system and quality of the data are the main focus of the design consideration. We believe that the architecture design described in this document will fulfill the requirement of the experiment without confronting unnecessary technical difficulties.

References

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