# Data acquisition system for the J-PARC E36 experiment

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***Abstract*—An experiment to test Lepton Flavor Universality (LFU) using a precise measurement of the decay width ratio of the two-body kaon decays with a positron and a muon (J-PARC E36), completed data-taking in December 2015. The experiment was performed on the K1.1BR beam-line at the Japan Proton Accelerator Research Complex (J-PARC). We developed and constructed a data acquisition (DAQ) system for this experiment. The DAQ system had to integrate several traditional and also recent types of readout systems to satisfy the experimental requirements. We used an event synchronization method by distributing the event identifying number, called the event-tag, and a common network to integrate the different types of readout systems. The entire DAQ was very stable during the experiment data-taking with 10 % dead-time at a trigger rate of 250 Hz.**

## I. INTRODUCTION

An experiment to test Lepton Flavor Universality (LFU) using a precise measurement of the decay width ratio $R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ (J-PARC E36)[1], completed data-taking in December 2015. The experiment was performed on the K1.1BR beam-line at the Japan Proton Accelerator Research Complex (J-PARC)[2] Hadron Hall. The K1.1BR beam-line is a low momentum $K^+$ beam line for stopped $K^+$ measurements. The aim of the experiment is achieving to determine $\Delta R_K/R_K$ with precision of the order $10^{-3}$.

### A. Detectors of J-PARC E36 experiment

The E36 detector system employed a 12 sector iron-core superconducting spectrometer for the momentum analysis of the charged particles from the decays. The $K^+$ beam was slowed down by a degrader and stopped in a position-sensitive fiber target. The fiber target identifies the $K^+$ stopping position and the outgoing lepton track. Decay leptons from the target are tracked and momentum-analyzed using a spiral fiber tracker (SFT) and three multi-wire proportional chambers (C2, C3, C4) in each toroidal sector. $\gamma$-rays from the radiative decays, are detected by a CsI(Tl) photon detector (PD) which covers the target with 75 % of the total solid angle. The detector system has three types of the particle identification (PID) detectors of TOF, Aerogel Cherenkov counters (AC) and Lead Glass counters (PGC) to discriminate $K^+ \to e^+\nu(K_{e2})$ and $K^+ \to \mu^+\nu(K_{\mu2})$ decays. The PID detectors are located in each toroidal sector. Fig. 1 shows the schematic view of the J-PARC E36 detector.

## II. REQUIREMENTS AND OUR SOLUTION

The J-PARC E36 detector was constructed by upgrading the KEK-PS E246 detector used for the KEK-PS, by inheriting some part of the elements along with their readout. The experiment decided to use the inherited detector elements, because their performance and characteristics are well known. The inherited detectors ware also very cost-effective. The same time new modern readout devices were developed and incorporated in the new detector. Thus, the data acquisition (DAQ) system had to integrate several traditional and recent types of readout systems. Moreover, the DAQ system required simpleness and easy maintenance for development and be managedement by a few people. Based on these experimental requirements, we built the DAQ system using the comprehensible network based DAQ software and the comprehensible trigger/event-tag handling system.

## III. READOUT DEVICES

The DAQ system has three types of the readout interface, TKO, VME, and the standard network. TKO is a KEK local standard DAQ readout system developed for 1990's experiments. TKO is used to read the high-resolution TDCs for the time-of-flight (TOF) counters and ADC for the aerogel cherenkov counters. A multi-crate TKO system can be integrated by a VME system. A VME controller can read all the TKO crates via a special bus line. VME is used to read ADC and TDC for many types of counters. We used CAEN V792 for reading ADC and VT48 for TDC. VT48 is a 0.625 ns resolution multi-stop TDC developed at TRIUMF. VME is also used to read waveforms of the PD by VF48 FADC. VF48 is a 10 bit FADC module developed at TRIUMF, which can sample data up to 60 MHz . We used a 25 MHz sampling frequency to read the PD. A network oriented SiPM readout board [3] was used to read the MPPC signals of the fiber target and SFT. The board has two SiPM front-end ASICs named EASIROC (developed by Omega IN2P3) and ADCs and multi-stop TDCs. The board has an FPGA based controller and an FPGA based TCP/IP network engine [4]. Therefore, this board can send its recorded data to the network by itself without requiring any

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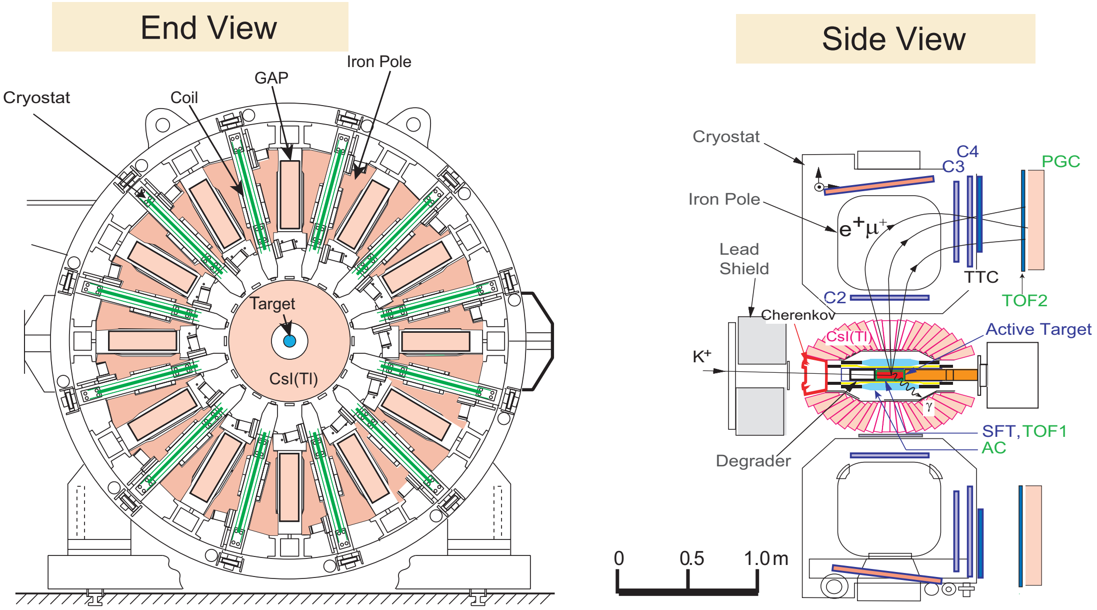

Fig. 1. The schematic view of the J-PARC E36 detector

additional controller. The board is a KEK-VME module and receives power and trigger information from the KEK-VME timing signal bus. KEK-VME is a local extension of VME32 [5]. TABLE I shows the various detectors and their readout devices.

TABLE I
J-PARC E36 DETECTORS AND THEIR READOUT DEVICES

| Detector | Num. of channels | ADC | TDC |
|---|---|---|---|
| Beam Hodo-scope | 24 | — | TRIUMF VT48 |
| Fitch Cherenkov | 28 | — | TRIUMF VT48 |
| TOF Counter | 72 | CAEN V792 | TKO HR-TDC |
| Trigger Counters | 17 | CAEN V792 | TRIUMF VF48 |
| Lead Glass Counter | 84 | CAEN V792 | TRIUMF VF48 |
| Gap Veto Counter | 12 | CAEN V792 | TRIUMF VF48 |
| Aerogel Cherenkov | 24 | TKO ADC | TRIUMF VT48 |
| MWPC | 496 | TKO ADC | — |
| Spiral Fiber Tracker | 128 | Network EASIROC board | |
| Fiber Target | 256 | Network EASIROC board | |
| CsI(Tl) Photon Detector | 768 | TRIUMF VF48 | |

## IV. DAQ NETWORK

We used PC based VME single board computers GeFanuc[1] V7768 and XVB602 as a controller for VME and TKO. The V7768 has a 2.16 GHz Core2 Duo processor and a Tundra Universe-II VME bridge. The XVB602 has a 2.53 GHz Core i7 processor and a Tundra Tsi148 VME bridge. A PC which has a Xeon E5-1650 v2 6-core processor and a 12 TB RAID storage disk connected by iSCSI, was used for the central DAQ computer. This DAQ computer collected all the data from the DAQ subsystem and built events and store them to the storage. The DAQ computer also controls all the DAQ subsystem. All the VME controllers and the DAQ computer were connected to a common 1 Gbps network switch via 1 Gbps Ethernet. The EASIROC board were connected with the same network switch via 100 Mbps Ethernet. Fig. 2 shows the configuration of DAQ network.

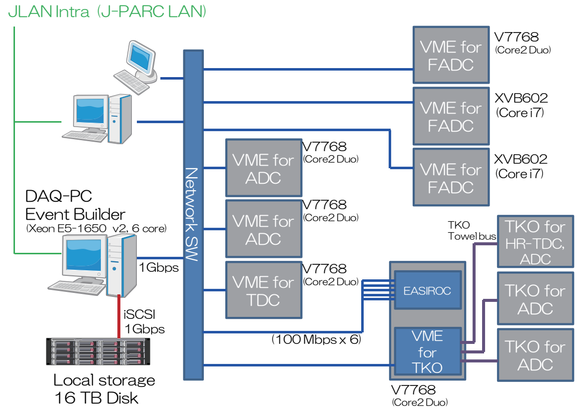

Fig. 2. The DAQ network of the E36

## V. NETWORK DAQ SOFTWARE

A network based DAQ software was developed for J-PARC Hadron Hall experiments. It was developed with a “comprehensible” theme. The DAQ works cooperatively with many simple single function processes. The DAQ has two transport ways named “message path” and “data path”. The message path connects with all DAQ processes and controls the processes. The data path is used for event data-taking. The front-end process works on the sub DAQ computer such as a VME controller and takes data from the front-end A/D devices, and sends it to the event builder. The event builder collects all the data fragments and builds them and sends them to the event distributor. The event distributor has two data output ports the recorder port and the monitor port. The event distributor distributes the built event data to the both data ports. The recorder port sends the complete event data. However the

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[1] This company’s VME products moved to Abaco Systems

monitor port skips sending an event data when the receiver process is not ready. The data can be transported smoothly by this criterion without any blocking by heavy analysis tasks. Both ports can send the event data to many processes. The multiple analysis processes connect with this port at the same time. The recorder process recodes the received event data in the storage. The controller process controls all the DAQ process using the message path. The front-end process works on each VME controller. The event builder, the event distributor, the recorder and the controller processes work on the DAQ computer. And the message daemon which consist of the message path, works in each computer. Fig. 3 shows the structure and components of the network based DAQ software.

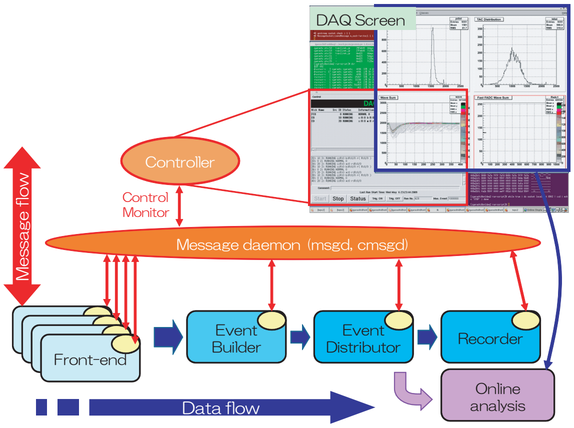

Fig. 3. Structure of the network based DAQ software. Round squares and ovals mean DAQ processes. Arrows between the round squares mean the TCP/IP communication for the data stream (data path). Arrows between the ovals mean the TCP/IP communication for the control (message path).

## VI. EVENT SYNCHRONIZATION

The unique event number named "event-tag" is distributed to all the front-end devices with a trigger signal to identified the event. The event-tag is managed by the Master Trigger Module (MTM). MTM is a unique trigger source and it handles the trigger-busy sequence. DAQ subsystems, TKO, VME and KEK-VME have the receiver modules (RM) which can receive the trigger and the event-tag. These control signals are transported via a pair of CAT6 STP cables with a LVDS signal level. The 20 bit event-tag is encoded and sent to the RM via a serial line. The data fragments can be identified by this event-tag. The repeater module can multiply the receiver destination. Fig. 4 shows the event synchronization modules and the configuration structure.

### A. Event synchronization for unsupported devices

The VF48 FADC module works with pipe-line readout. However, this module has no interface to receive the event-tag. Therefore, the event-tag is encoded as an analogue signal by the DAC plug on the VME-RM module. The VME-RM module consists of a RM mezzanine card and a general purpose VME FPGA board. The VME FPGA board has two mezzanine slots. One slot is used for the RM mezzanine card, the other slot is free for the standard configuration. Hence, its free slot can be used to generate a signal for the front-end devices which is not supported for the RM interface. Three channels of the FADC take the encoded event-tag signal when the PD signals arrive. The event-tag can be decoded from the encoded event-tag signal in the event data.

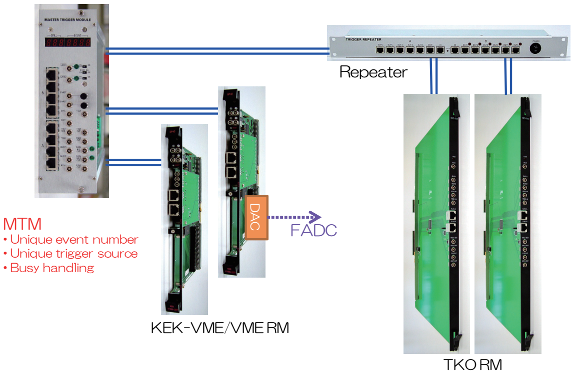

Fig. 4. Event synchronization modules for the different readout DAQ subsystems

TABLE II
DAQ SUBSYSTEMS AND THEIR DEAD-TIME

| Subsystem | Device | Typcal Data size (Bytes) | Dead time ($\mu$s) |
|---|---|---|---|
| TKO | ADC, HR-TDC | 800 | 400 |
| VME1 | TDC (V1190) | 860 | 200 |
| VME2 | ADC (V792) | 930 | 200 |
| VME3 | ADC (V792) | 190 | 40 |
| VME4 | FADC (VF48) | 25000 | 20 |
| VME5 | FADC (VF48) | 19000 | 20 |
| VME6 | FADC (VF48) | 35000 | 20 |
| EASIROC board 1 | ADC, TDC | 800 | 12 |
| EASIROC board 2 | ADC, TDC | 740 | 12 |
| EASIROC board 3 | ADC, TDC | 590 | 12 |
| EASIROC board 4 | ADC, TDC | 600 | 12 |
| EASIROC board 5 | ADC, TDC | 610 | 12 |
| EASIROC board 6 | ADC, TDC | 600 | 12 |

## VII. PERFORMANCE AND STABILITY

The DAQ system was very stable during the experiment data taking. We encountered a few troubles from the old ADCs and power supply breaking. The event slip occurred a few times a week. The FADC halted a few times a month. However the DAQ software did not crash without human mis-operation. The typical data size and the typical dead-time of the DAQ subsystems are summarized in TABLE II. The slowest part was readout of TKO ADCs, which took 400 $\mu$s. This part determined the total dead-time. The typical trigger rate in the experimental physics run was 250 Hz, The DAQ system worked with around 10 % dead-time.

## VIII. SUMMARY

An experiment to test LFU completed data-taking in December 2015. We developed a DAQ system to integrate the multi-generational readout devices using a standard network for the experiment. We used a network based DAQ system and a comprehensible event synchronization system. The entire DAQ system worked stably during the experiment data-taking with 10 % dead-time with a trigger rate of 250 Hz.

## ACKNOWLEDGMENT

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## REFERENCES

[1] S. Shimizu, *et al.*, “Measurement of $\Gamma(K^+ \rightarrow e^+\nu)/\Gamma(K^+ \rightarrow \mu^+\nu)$ and Search for heavy sterile neutrinos using the TREK detector system”, *Proposal for J-PARC 50 GeV Proton Synchrotron, P36*, Jun. 2010 [Online]. Available: http://trek.kek.jp

[2] The Joint Project Team of JAERI and KEK, “The Joint Project for High-Intensity Proton Accelerators”, *KEK-PREPRINT-1999-4*, Jul 1999

[3] R. Honda *et al*, ”The development of the multi PPD readout electronics with EASIROC and SiTCP”, *PoS (PhotoDet 2012)*, 031

[4] T. Uchida, “Hardware-Based TCP Processor for Gigabit Ethernet”, *IEEE Trans. Nucl. Sci.*, 55, No. 3, (2008), 1631

[5] Y. Igarashi *et al.*, “A Common Data Acquisition System for High Intensity Beam Experiments”, *IEEE Trans. Nucl. Sci.*, 52, (2005), 2866