Applications of Triggered Scaler Module for Accelerator Timing

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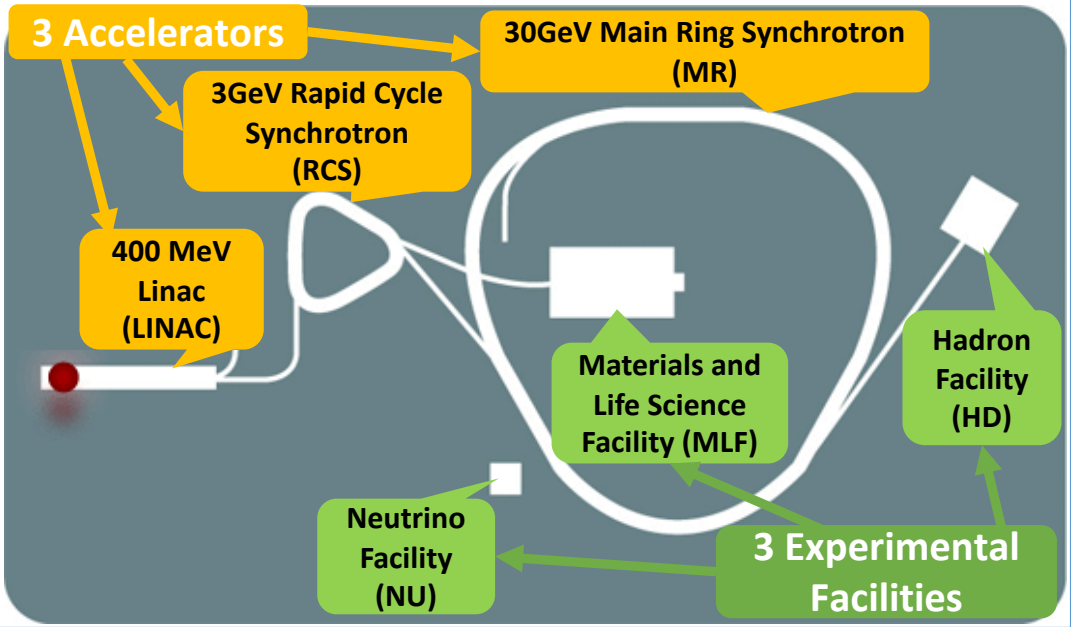
Abstract

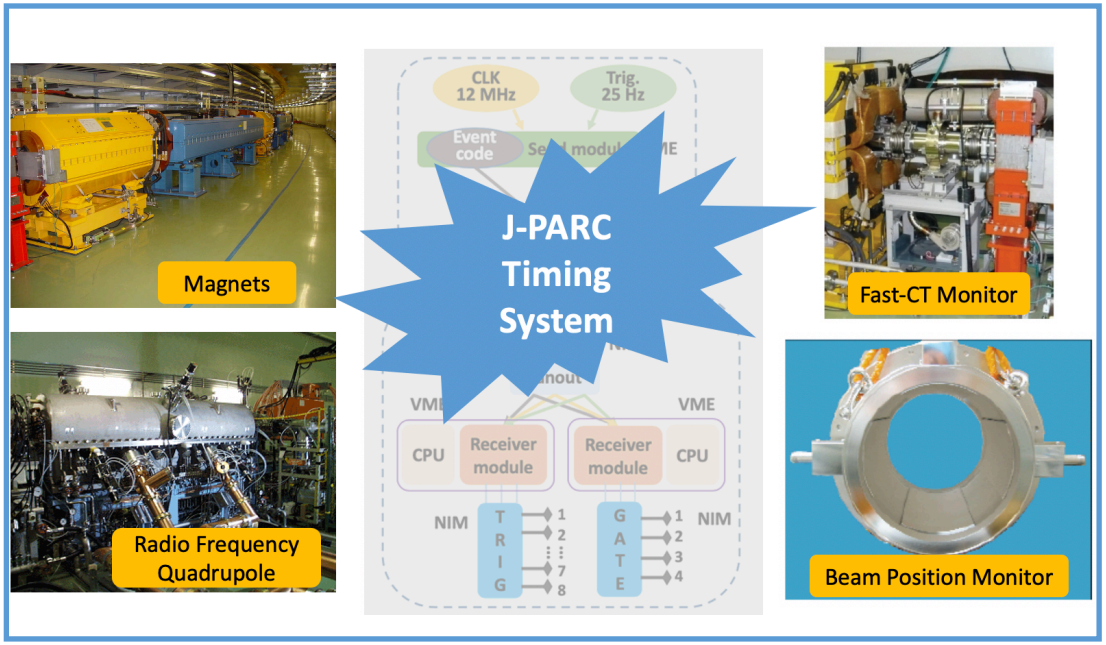
During the operation of J-PARC timing system since 2006, there were a few unexpected trigger-failure events occurred. It was difficult to find the faulty module among many suspicious modules. In order to find such a module easily, a triggered scaler module was developed as a Yokogawa PLC module. It can accept the start signal of J-PARC Main Ring (MR) slow cycle (2.48s/5.2s) and the trigger pulses of rapid cycle (25Hz), which are generated by J-PARC timing system. A scaler in the module counts number of trigger pulses during the J-PARC slow cycle and stores counts in an array. In 2018, the module was tested successfully and showed the expected performance. Two applications were developed based on the triggered scaler module. The first one, a Machine Protection System (MPS) detection, succeeded to visualize phase of a slow cycle where an MPS event occurred. The second one, an unexpected-trigger detection, was developed to detect failure events and to identify the type of failure. Both applications were tested successfully during J-PARC beam operation in June 2020, and showed that the triggered scaler module can be applied for various timing-related applications in the future. The details of the module and two associated applications will be described in the poster.

Introduction

• J-PARC



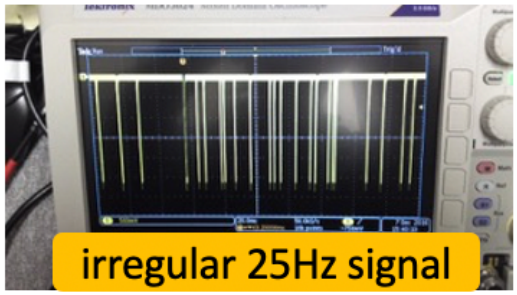
• J-PARC Timing



• Irregular Trigger Event (2017)

❖ An O/E module, which was used to send 25Hz trigger clock signals from RCS to MR, started to produce irregular signals. The irregular signals affected a critical beam diagnostic system, thus, the accelerator operation was suspended several times a day.

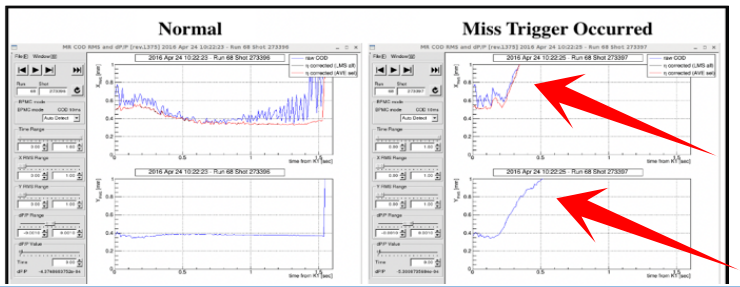
← Replaced the O/E module.



• Missing Trigger Event (2015)

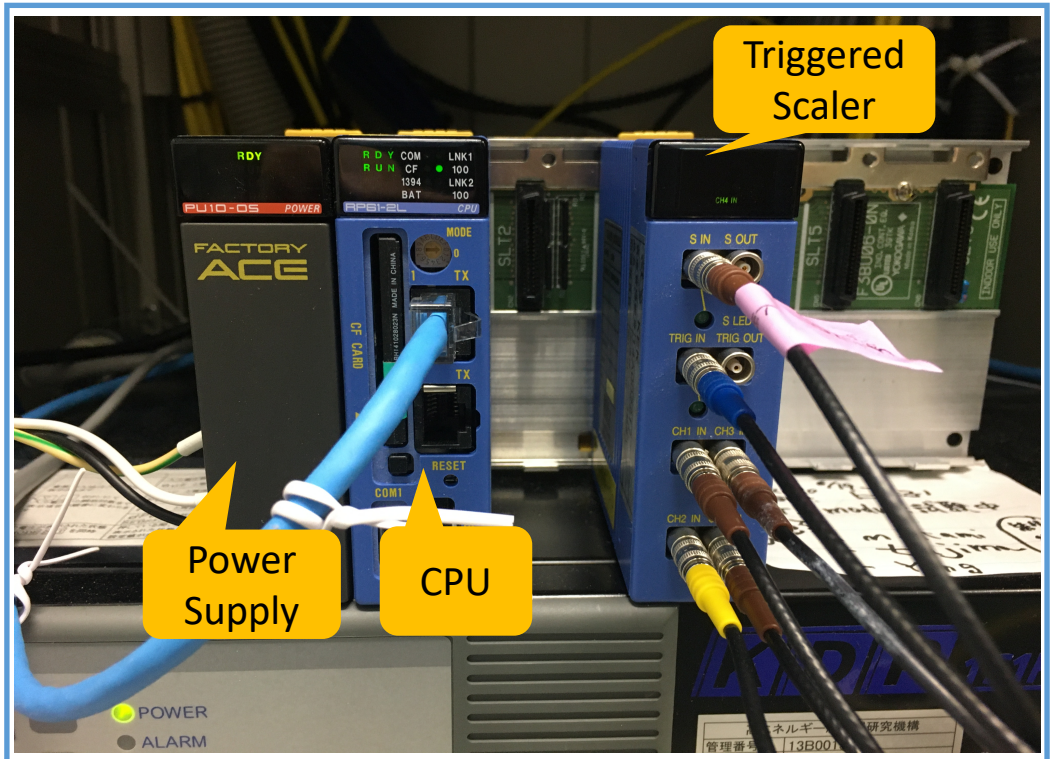
❖ Occasional beam loss was observed during the beam delivery to Hadron Facility. Such event appeared a few times per month. In May 2016, cause of these events were finally identified as momentary errors in a timing receiver module for one of MR steering magnets. Later survey showed that the errors were caused by external common mode noises.

← Added ferrite cores to metal cables.



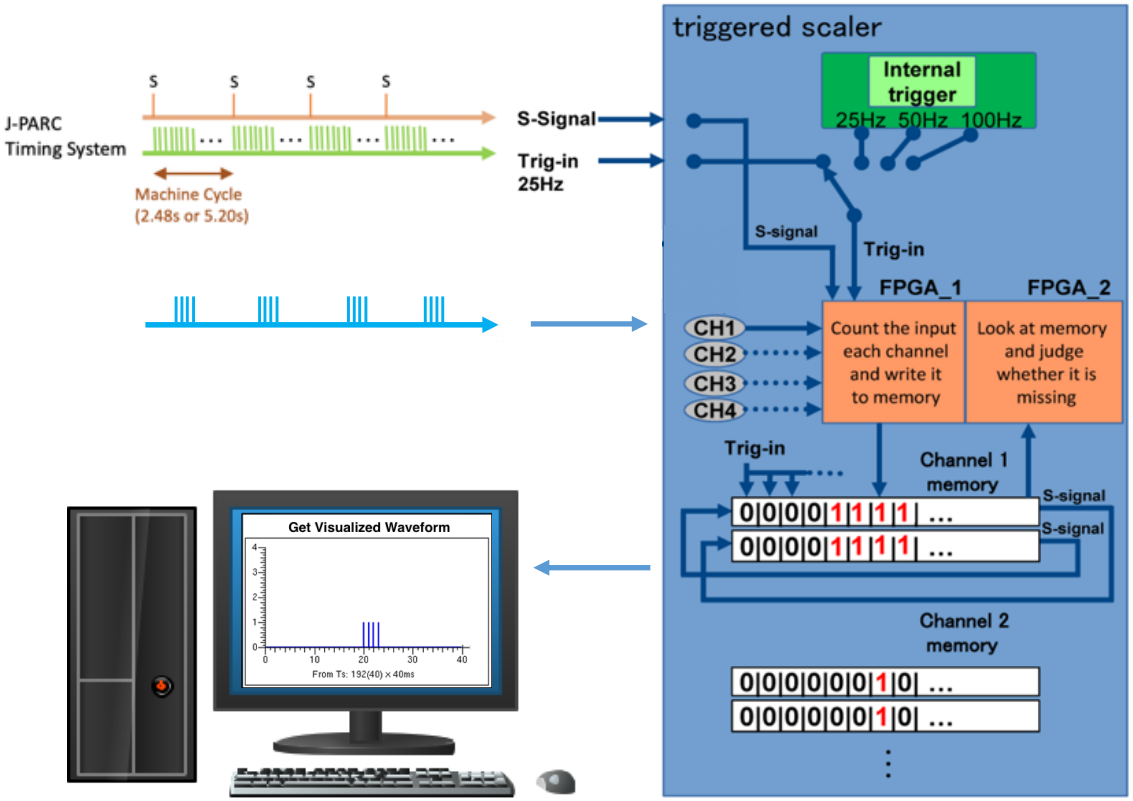
Triggered Scaler Module

• Outside Setup



- ❖ Triggered scaler module: A Yokogawa PLC-type module (Standard I/O form in J-PARC MR).
  - ❖ Designed for reading back signals generated by J-PARC timing system.
  - ❖ It requires two kind of reference signals: “S IN” (start signal of slow cycle) and “TRIG IN” (start signal of rapid cycle).
  - ❖ It has four input channels and each of them has dual memory buffers (16 bit x 192 cells x 2).
- ❖ CPU module: Linux and EPICS are running on it.

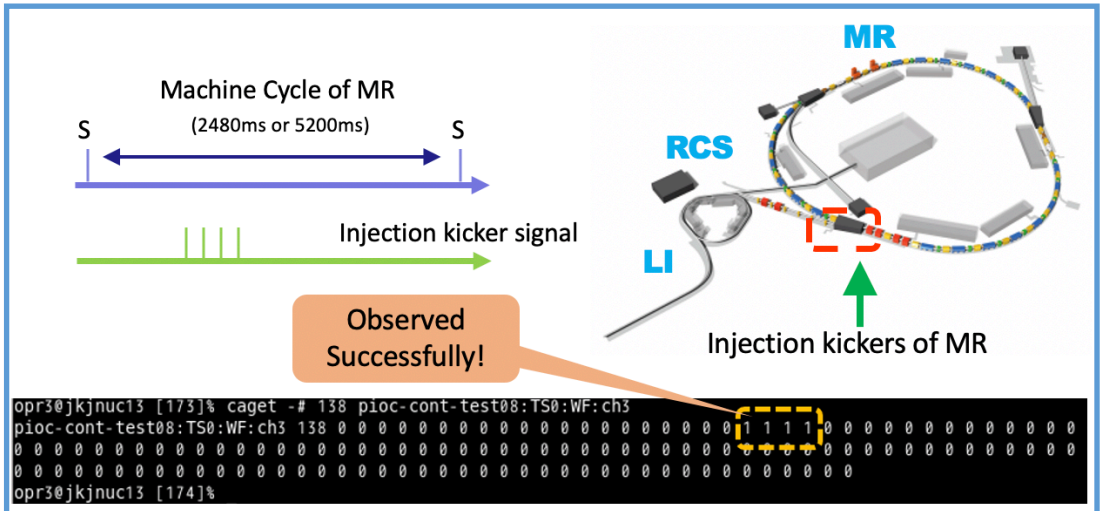
• Inside Working Principle



- ❖ In principle, the triggered scaler module works as a scaler module with four channels.
- ❖ There are two FPGA logics inside the module.
  - ❖ One is to count number of input pulses in 25Hz (40ms) and store the counts in a memory buffer.
  - ❖ Another one is to read the memory buffers, and judge whether there is an unexpected failure event.

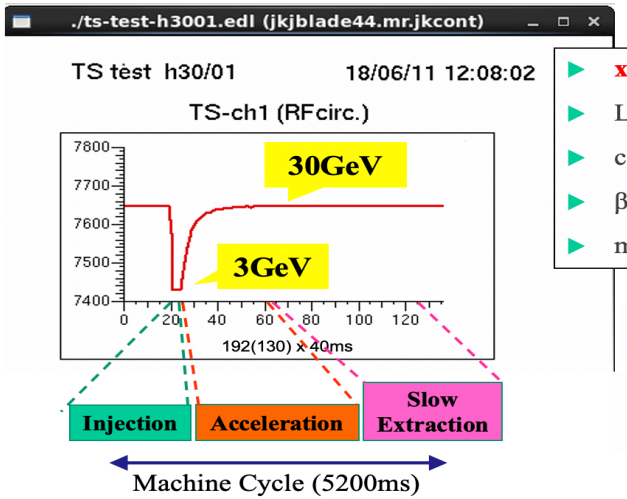
Performance of Triggered Scaler Module

• Measurement of an Injection Kicker Signal



- ❖ In 2018, we measured a typical timing signal: a trigger for MR injection kickers.
  - ❖ In each J-PARC slow cycle, the injection kicker receives four trigger signals from RCS for MR injection.
- ❖ We successfully observed four successive “1” values in the memory-buffer of the module.

• Measurement of an RF Signal



- ▶ x : RF signal (counts / 40 ms)
- ▶ L : Circumstance of MR (1567.5 m)
- ▶ c : speed of light (299792458 m/s)
- ▶ β : Relative speed
- ▶ m_0c^2 : Proton rest mass (0.938 GeV)

$$\beta = \frac{v}{c} = \frac{x}{0.040} \cdot \frac{L}{c}$$

$$E = \frac{m_0c^2}{\sqrt{1-\beta^2}} - m_0c^2$$

RF parameters			Number of counts in 40ms bin	
Energy (GeV)	RF (MHz)*	One turn (μs)	Expected	Observed
30	1.7205	5.231	7647	7647
3	1.6717	5.384	7429	7429

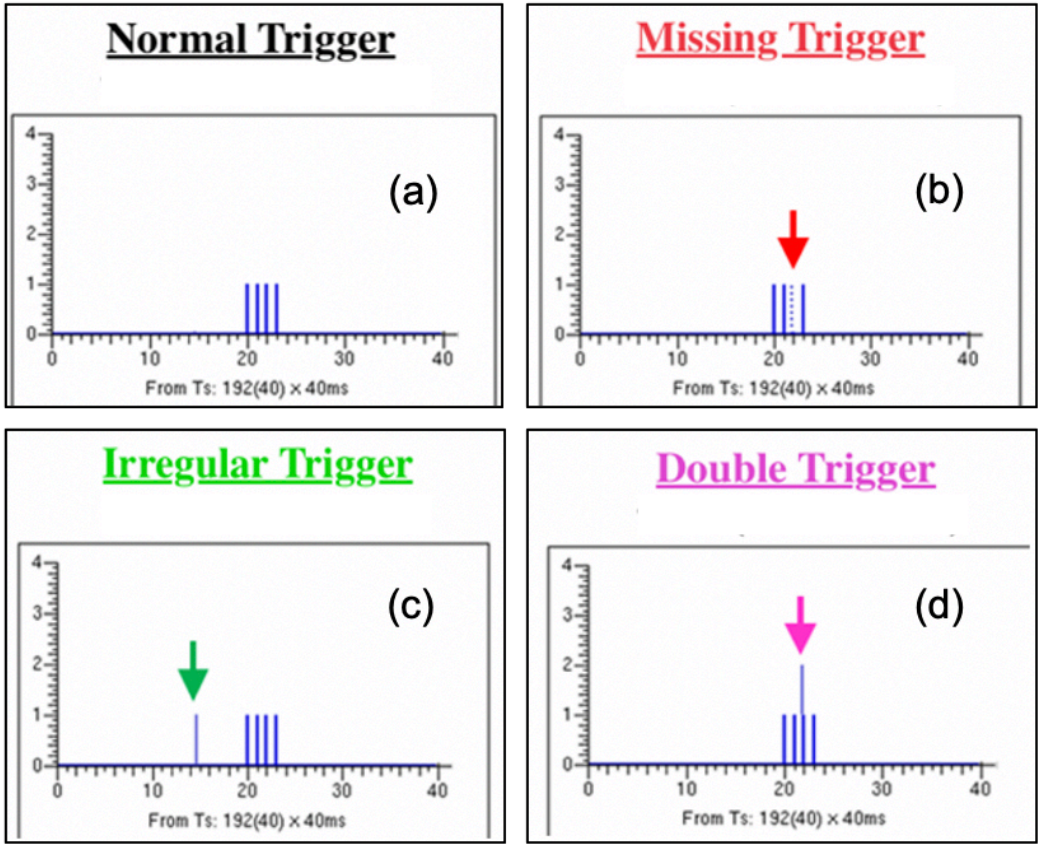
- ❖ We measured an RF signal (MR circulation signal), which is generated by a Low-Level Radio Frequency (LLRF) system.
- ❖ When the beam energy was 3 GeV and 30 GeV, 7429 and 7647 were observed, respectively.
- ❖ The observed counts are consistent to the Relativistic theory.

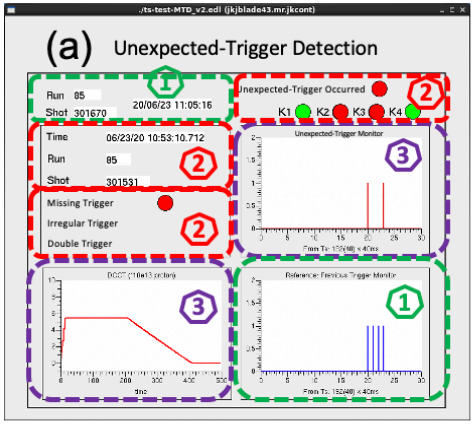
• Discussion

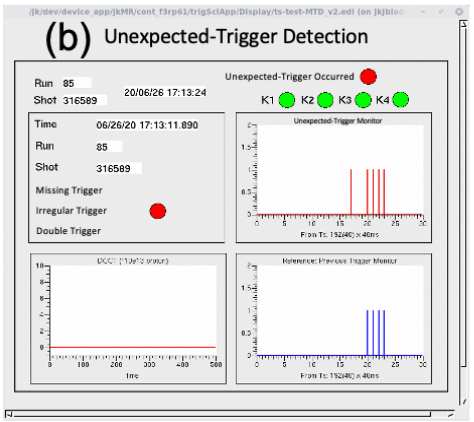
- ❖ The measurement of the injection kicker signal showed that the triggered scaler works as we expected and can be used to construct the read-back system of J-PARC timing in the future.
- ❖ The measurement of the RF signal showed that the triggered scaler can read back not only for timing signals, but also for RF signals. It is worth noting that the module is useful to visualize various timing-related signals.

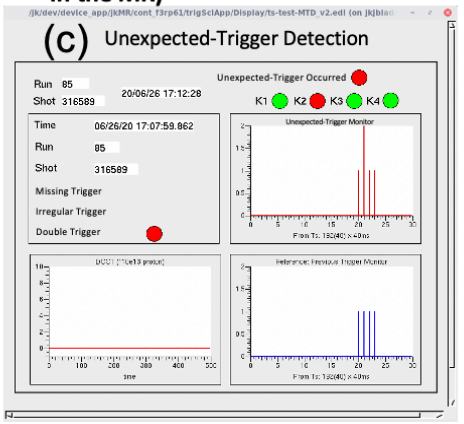
Applications Based on Triggered Scaler Module

- **Unexpected-Trigger Detection (Using Injection Kicker Signal)**









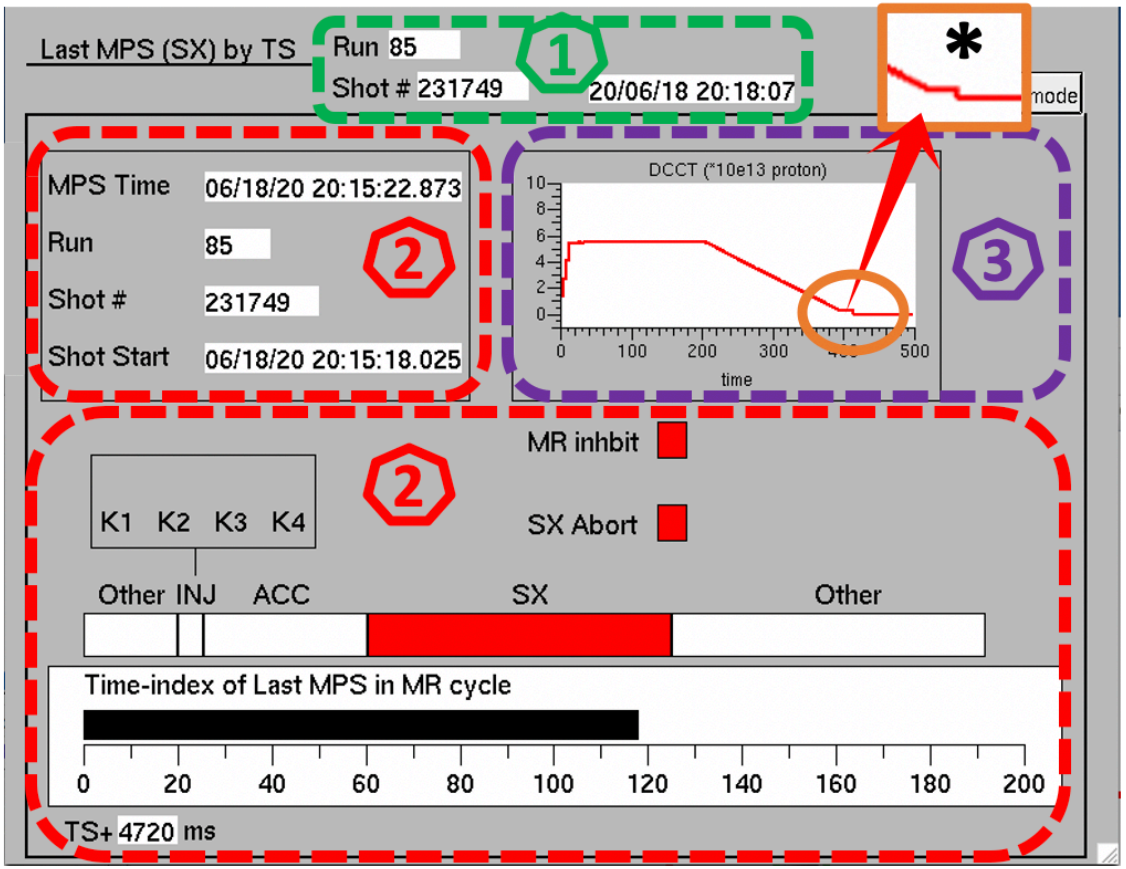
1) Live data
   - Time stamp, Run-number, Shot-number
   - Trigger pattern (data of the triggered scaler's memory buffer)
2) Detected unexpected-trigger event
   - Time stamp, Run-number, Shot-number
   - Identified type (one of three)
   - (Dis)appearance of four injection triggers
3) Saved parameters at the unexpected-trigger
   - Saved unexpected-trigger pattern
   - Saved DCCT waveform (beam current in the MR)

- There are three possible failure events of the injection kicker signal ((a) is the normal trigger waveform).
  - (b) Missing trigger event
  - (c) Irregular trigger event
  - (d) Double trigger event
- These trigger-failure events, not preferable for accelerator operation, are called "unexpected-trigger events".

- An unexpected-trigger detection application has been developed.
  - It was tested using a dummy signal, and the result showed that the application detected all of the unexpected-trigger events.
  - Then, the application was tested with the real injection kicker signal during J-PARC beam operation in June 2020. The result showed that no unexpected-trigger event was detected.

Applications Based on Triggered Scaler Module

• Machine Protection System (MPS) Detection



- ❖ MPS is a fast interlock system to stop accelerator operation safely.
- ❖ To analyze an MPS event, we often need to know which machine phase (Injection phase/ Acceleration phase/ Slow extraction phase) the MPS occurred.
- ❖ To visualize phases of accelerator in which an MR MPS event generated, an MPS detection system has been developed.
- ❖ The system was tested during the J-PARC beam operation in June 2020, and the MPS-abort event was detected successfully.

1) **Live data**
   - Time stamp, J-PARC operation parameters (run number, shot number)
2) **Detected MPS event**
   - Time stamp, J-PARC operation parameters (run number, shot number, shot start number)
   - The visualized phase and time-index of the last MPS event in the last slow cycle
3) **Saved parameters at the MPS event**
   - Saved DCCT waveform (Beam current in MR)

* The fluctuation was caused by MPS event

Discussion & Summary

• Advantages & Disadvantages

❖ **Advantages**

- ✓ **Portability. The triggered scaler module is a PLC-based module. it is small in size and convenient to move.**
- ✓ **Extendibility. Since PLC-type is one of standard I/O forms in J-PARC, the module can be easily extended and applied to many places.**

❖ **Disadvantages**

- ○ **The setup of the system is not portable (connected with J-PARC archiver system).**
- ○ **Only tested in J-PARC MR (slow cycle machine).**
- ○ **Not customize with additional I/O modules yet.**

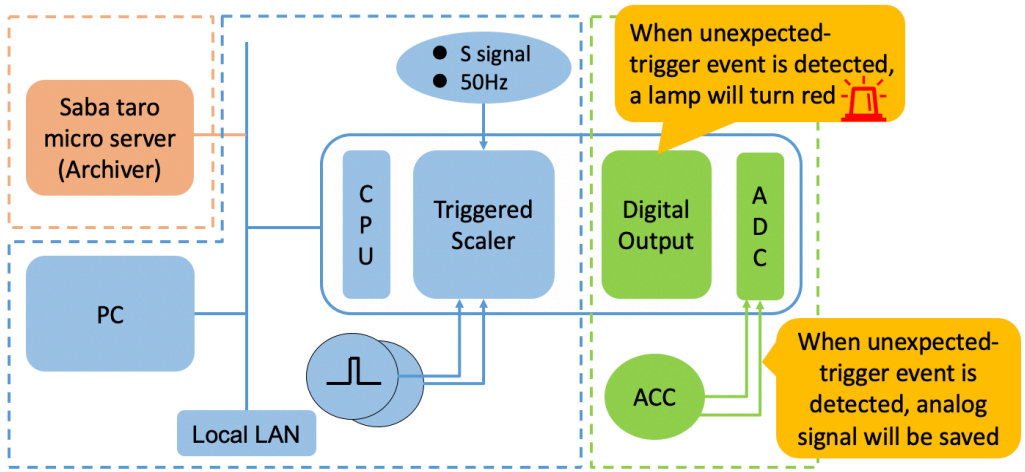
• Future Plans

❖ **Introduce an archiver with a micro server to make the system more portability.**

❖ **Firm up the hardware and software.**

❖ **Add additional I/O modules to make the system multifunctional.**

➢ **An example of adding additional I/O modules:**



❖ **Test in the rapid cycle machine.**

• Summary

❖ **A triggered scaler module was designed to get read-back signals of J-PARC timing system. The module was tested using accelerator signals, and it showed expected perform.**

❖ **Two applications have been developed based on the module and tested successfully during J-PARC beam operation in June, 2020. The applications will be used for J-PARC MR beam operation after January, 2021.**

❖ **In order to realize more functionality and to be tested in other accelerators, the system will be firmed up and additional I/O modules will be added in the following year.**