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Trigger slow control system of the Belle II experiment

C.-H. Kim [a,*], Y. Unno [a], H.E. Cho [a], B.G. Cheon [a,*], S.H. Kim [b,a], I.S. Lee [b,a], E.-J. Jang [c], S.-K. Choi [c], Y.J. Kim [d], J.K. Ahn [d], M. Remnev [e,f], A. Kuzmin [e,f], T. Koga [g], Y.-T. Lai [g], Y. Iwasaki [g], H. Nakazawa [h], D. Liventsev [i,g], M. Nakao [g,j], S. Yamada [g], R. Itoh [g], T. Konno [k], S.-H. Park [g,l], Y.-J. Kwon [l], O. Hartbrich [m], M. Ritzert [n]

[a] *Department of Physics and Institute of Natural Sciences, Hanyang University, Seoul 04763, South Korea*
[b] *Institute for Basic Science, Daejeon 34126, South Korea*
[c] *Gyeongsang National University, Jinju 52828, South Korea*
[d] *Korea University, Seoul 02841, South Korea*
[e] *Budker Institute of Nuclear Physics SB RAS, Novosibirsk 630090, Russian Federation*
[f] *Novosibirsk State University, Novosibirsk 630090, Russian Federation*
[g] *High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*
[h] *Department of Physics, National Taiwan University, Taipei 10617, Taiwan*
[i] *Wayne State University, Detroit, MI 48202, United States of America*
[j] *The Graduate University for Advanced Studies (SOKENDAI), Hayama 240-0193, Japan*
[k] *Kitasato University, Sagamihara 252-0373, Japan*
[l] *Yonsei University, Seoul 03722, South Korea*
[m] *University of Hawaii, Honolulu, HI 96822, United States of America*
[n] *University of Heidelberg, 68131 Mannheim, Germany*

A R T I C L E I N F O

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A B S T R A C T

The Belle II experiment at the SuperKEKB e^+e^- collider in KEK, Japan, started physics data-taking with a complete detector from early 2019. An online trigger system is indispensable for the Belle II experiment to reduce the beam background events associated with high electron and positron beam currents without sacrificing the target physics-oriented events. During the Belle II operation upon beam collision, the trigger system must be consistently controlled and its status must be carefully monitored in the process of data acquisition against unexpected situations. For this purpose, we have developed a slow control system for the newly developed Belle II trigger system based on the custom-made Belle II DAQ/slow control package. Around seventy thousand configuration parameters are saved in the Belle II central database server for every run when a run starts and stops. These parameters play an essential role in offline validation of the quality of runs. Around three thousand real-time variables are stored in the Belle II main archiving server, and the trend of some of these variables are regularly used for online and offline monitoring purposes. Various operator interface tools have been prepared and used. When the configuration parameters are not correctly applied, or some of the processes are unexpectedly terminated, the slow control system detects it, stops the data-taking process, and generates an alarm. In this article, we report how we constructed the Belle II trigger slow control system, and how we successfully managed to operate during its initial stage.

1. Introduction

The Belle II experiment [1] at the SuperKEKB [2] e^+e^- collider in KEK, Japan, started physics data-taking with a complete detector from early 2019. Belle II and SuperKEKB are the successors of Belle [3] and KEKB [4].

The target instantaneous luminosity of SuperKEKB is 40 times higher, and the target integrated luminosity is 50 times higher than its predecessor (Table 1). The Belle II detector is designed to cope with the increase of the event rate as well as the harsh beam background at the target luminosity. Likewise, the trigger system has been upgraded to have robustness and flexibility, and a corresponding slow control system has been prepared to ensure physics data-taking. We use a custom-developed software package for data acquisition and slow control. Especially, a custom-made network memory sharing technique is one of core technique of the package.

In this paper, we describe the trigger slow control system of the Belle II experiment. Section 2 briefly describes the Belle II detector

* Corresponding authors.
E-mail addresses: hun4341@hanyang.ac.kr (C.-H. Kim), bgcheon@hanyang.ac.kr (B.G. Cheon).

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Table 1
The KEKB/Belle achieved and the SuperKEKB/Belle II target luminosities.

	Instantaneous (10^{34} cm^{-2}s^{-1})	Integrated (ab^{-1})
KEKB/Belle	2.1	1.0
SuperKEKB/Belle II	80	50

and its trigger and slow control systems. Section 3 describes how we successfully establish the framework for the trigger slow control system. All processes for the trigger slow control system are explained in Section 4. In Section 5, we describe the operator interface tools based on the trigger slow control system framework. In Section 6, we explain how we utilize the trigger slow control system during the operation, and we summarize in Section 7.

2. Belle II experiment

2.1. Belle II detector

The Belle II detector consists, from the Interaction Point (IP) outward, of an inner silicon tracker comprising a PiXel Detector (PXD), a Silicon Vertex Detector (SVD), a Central Drift Chamber (CDC), two dedicated particle identification systems, the Aerogel Ring-Imaging CHerenkov detector (ARICH) in the forward endcap and the Time-Of-Propagation (TOP) detector in the barrel region, an Electromagnetic CaLorimeter (ECL), a superconducting solenoid for a homogeneous magnetic field of 1.5 T, and a K_L and a Muon detector (KLM). A detailed description of the Belle II detector is in Ref. [1].

2.2. Belle II trigger system

The Belle II Level 1 (L1) online trigger (TRG) is required to achieve almost 100 % trigger efficiency for $\Upsilon(4S) \rightarrow B\bar{B}$ events and nearly high efficiency for other physics processes of interest within 30 kHz maximum trigger rate under the harsh beam background environment of SuperKEKB. The readout system requires the trigger latency to be under 4.4 μs. The cross section and trigger rate of physical processes at the Belle II target luminosities are listed in Table 2.

Table 2
The total cross section from physics processes at the $\Upsilon(4S)$ energy region and expected trigger rates at the peak luminosity of 80×10^{34} cm^{-2}s^{-1} [5,6].

Physics process	Cross section (nb)	Rate (Hz)
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$	1.1	880
$e^+e^- \rightarrow q\bar{q}$	3.4	2700
$e^+e^- \rightarrow \mu^+\mu^-$	1.1	880
$e^+e^- \rightarrow \tau^+\tau^-$	0.9	720
Bhabha[a]	44.0	350[c]
$\gamma\gamma$[a]	2.4	19[c]
$e^+e^- \rightarrow e^+e^- + 2\gamma$[ab]	13.0	10,000[d]
Total	1.1	~15,000

[a] $\theta_{lab} \geq 17°$.
[b] $p_t \geq 0.1$ GeV.
[c] Pre-scaled by factor of 1/100.
[d] Estimated from the Belle level 1 trigger rate.

A schematic overview of the Belle II hardware trigger system is shown in Fig. 1. There are four sub-trigger systems, which are the CDC trigger, the ECL trigger, the TOP trigger, and the KLM trigger. The CDC trigger provides two- and three-dimensional (2D and 3D) charged track information [7]. The ECL trigger provides total energy, cluster information, and Bhabha identification information of electromagnetic particles [5,8]. The TOP trigger provides precise timing and hit topology information. The KLM trigger provides muon track information [6].

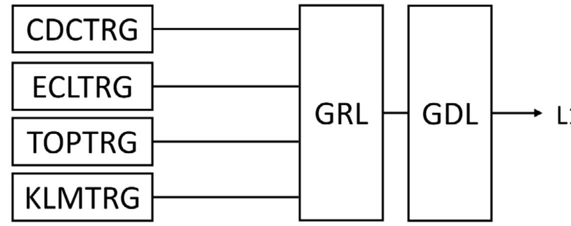

Fig. 1. A schematic overview of the Belle II trigger system [6]. The trigger system consists of the CDC/ECL/TOP and KLM triggers. The GRL collects all signals from each sub-trigger and delivers its matching information output to the GDL. The GDL generates a final decision with the matching information and sub-trigger outputs. L1 is the final level 1 trigger decision.

The Global Reconstruction Logic (GRL) generates matching information based on all the sub-trigger outputs. The matching information and sub-trigger outputs are delivered to the Global Decision Logic (GDL), and the GDL makes the final trigger decision, called the L1 decision. Finally, the L1 decision is forwarded to the Belle II Data AcQuisition (DAQ) system [9]. For stable operation of the trigger system upon beam collision, a reliable controlling and monitoring system is mandatory.

2.3. Belle II DAQ system

Each of the Belle II sub-detector systems has its front-end electronics (FEE) readout system, which, except PXD, sends data to the unified back-end readout system. The back-end system consists of readout boards called COmmon Pipelined Platform for Electronics Readout (COPPER) [10] and readout servers [11]. The COPPERs receive sub-detector front-end data, including trigger data through "Belle2link" [12] which utilizes Xilinx Rocket I/O for high-speed serial data transfer. The bandwidth of the Belle2link is up to 3.125 Gbps. The estimated event size from the FEE is 100 kB and 1 MB for the non-PXD detectors and the PXD, respectively [9].

At the designed luminosity of 80×10^{34} cm^{-2}s^{-1}, the expected average trigger rate is 20 kHz, so we set 30 kHz as a designed trigger rate for the DAQ system conservatively [9].

2.4. Belle II slow control system

The primary tasks of the Belle II slow control systems are to manage operations of sub-systems, to provide and store configuration parameters to sub-systems, and to collect status and environmental conditions of sub-systems. In order to accomplish these tasks, three fundamental sub-components have been developed; run control, log collector, and operator interface [13]. Four core techniques are used to build the components; the network communication based on EPICS [14] and NSM2 [15], databases based on PostgreSQL [16], the Graphical User Interface (GUI) based on the Control System Studio (CSS) [17] and Process Variable (PV) [18] archiving via EPICS archiver appliances [19]. The Belle II DAQ/slow control software package, named "daq_slc", contains all components. Each component is briefly explained below.

First, network communication between slow control processes is handled via EPICS and a software package named "Network Shared Memory 2 (NSM2)", a software library that enables the synchronization of the shared memory on each node using UDP and TCP communications over the network [9]. The synchronization interval usually several seconds [13]. The NSM2 is a custom-made tool for network communication by the Belle II collaboration. The NSM2 is an advanced version of NSM [15], which was used at the Belle experiment. A daemon process called "nsmd2" takes care of all communication over the network segments [13]. Based on NSM2, we prepared NSM2 nodes, which are building blocks of the network communication between sub-systems through the daemon process. An NSM2 node reads some values from a hardware system, converts it to NSM2 format, and distributes it to the Belle II network. The NSM2 makes it possible for each operator to control systems remotely with minimized interference with each other. Belle II ARICH slow control system uses a particular type of NSM2 node, which is suitable for high voltage control [20]. Belle II SVD slow control system case, network communication is based on EPICS [21]. Different from ARICH and SVD case, the trigger slow control system uses NSM2.

Second, the PostgreSQL database management system is used for managing configuration parameters and logging information [13].

Third, GUI tools are based on the Control System Studio (CSS), which is an Eclipse-based tool for creating control systems [17]. The CSS is originally designed for EPICS variables, but it also accepts NSM2 variables through a custom plugin on the CSS and an interface process, named nsm2socket [13]. A GUI can communicate with NSM2 nodes via a single TCP/IP connection to the nsm2socket [13].

The last one is the EPICS archiver appliance, which is an implementation of an archiver for EPICS control system [19]. The EPICS archiver appliance records the history of PVs in real-time. In order to record the history of NSM2 variables, a process called "nsm2cad" converts NSM2 variables to EPICS PVs because the EPICS Archiver Appliance can record EPICS PVs only [18].

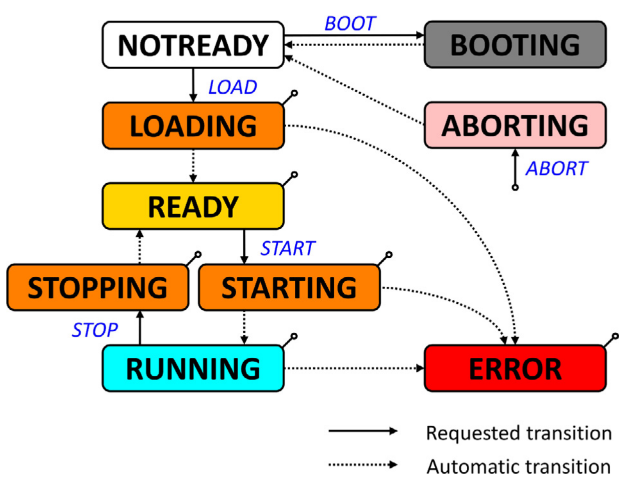

Fig. 2. Run control state diagram [13]. This diagram shows how the Belle II experiment handles a run. The round boxes denote the status of an NSM2 node, and the texts outside of the boxes are requests. A node status can be checked and changed by operators. The ABORTING state is reached from LOADING/READY/STOPPING/STARTING/RUNNING/ERROR states by an ABORT request (Lines with small circles connect the states to the ABORT request line).

The run control system manages the DAQ systems and sub-detector systems via NSM2 to follow the state diagram shown in Fig. 2 [13]. The run control requests (requested by operators) and the run control states are listed in Tables 3 and 4, respectively.

3. Trigger slow control system framework

The stable operation of the trigger system is essential for the steady data acquisition of the Belle II experiment. The trigger slow control system makes it possible to operate the trigger system efficiently and stably. In order to cooperate with the rest of the slow control system, the trigger slow control system is constructed upon the Belle II common daq_slc framework, described in Section 2.4. The primary tasks of the trigger slow control system are shown below.

(a) Makes logs of problematic events and sends it to the central logging server.
(b) Saves experimental parameters automatically at every run start and stop.
(c) Provides real-time monitoring plots.
(d) Takes local run data.
(e) Troubleshooting.

Table 3
List of run control requests.

Request	Meaning
LOAD	Load parameters
START	Start a run
STOP	Stop a run
ABORT	Abort the state transition and reset the state
BOOT	(Re)initialize the system

Table 4
List of run control states.

State	Meaning
NOTREADY	Parameters are not loaded yet
LOADING	Parameters are being loaded
READY	Ready to start a run
STOPPING	Run is being stopped
STARTING	Run is being started
RUNNING	Run is ongoing
ERROR	Problem detected
ABORTING	Abort sequence is ongoing
BOOTING	(Re)initialization is ongoing

In order to accomplish these tasks, the trigger system is connected to the Belle II main run control, central database, and archiver servers. Fig. 3 shows the connections between the trigger system servers, and to the main run control server.

To communicate through NSM2, we run several NSM2 nodes on the servers of the trigger system. The NSM2 nodes collect values from sub-trigger systems and convert them to NSM2 variables. NSM2 variables are then converted into three formats: configuration database, archiver, and operator interface format (Fig. 4). The purpose of the configuration database format is to put experimental parameters from hardware to the configuration database server and vice versa. The goal of the archiver format is to save the trend of the values and view their history later. The operator interface format aims to display values of interest on an operator panel or change hardware settings from an operator panel. We will explain each part further in the following subsections.

3.1. Configuration database

A run-recording process automatically stores 67,662 experimental parameters to the central database server by run number when a run starts/ends. The parameters are mainly firmware versions and setting parameters. Some slow control settings, such as NSM2 port settings and including/excluding NSM2 nodes in run control (RC) scheme information, are also stored.

The GDL bits are stored: the input bits, the final trigger decision output bit, the output bits of PSNM (Pre-Scale aNd Mask), and administrative bits. The sub-trigger rates processed by GRL are stored. The CDC trigger bits are stored: the track segment finder (TSF), the event timing finder (ETF), and the 2D/3D tracking information [6]. The ECL trigger bits are stored: the trigger cell (TC) noise, TC noise fitting parameter, FADC Analysis Module (FAM) pedestals, FAM rates, FAM temperature, the Trigger Merger Module (TMM) temperature, and the ECL Trigger Master (ETM) physics bits [5,8].

We use the stored parameters to validate the run quality. A log-collecting process automatically gathers the status of the NSM2 nodes and sends it to the central database server. We can check when problems happened and chase the origin of them with the collected logs.

We can also manually save sets of experimental parameters to the central database server, and NSM2 nodes can retrieve them. An example is given in Section 5.1.

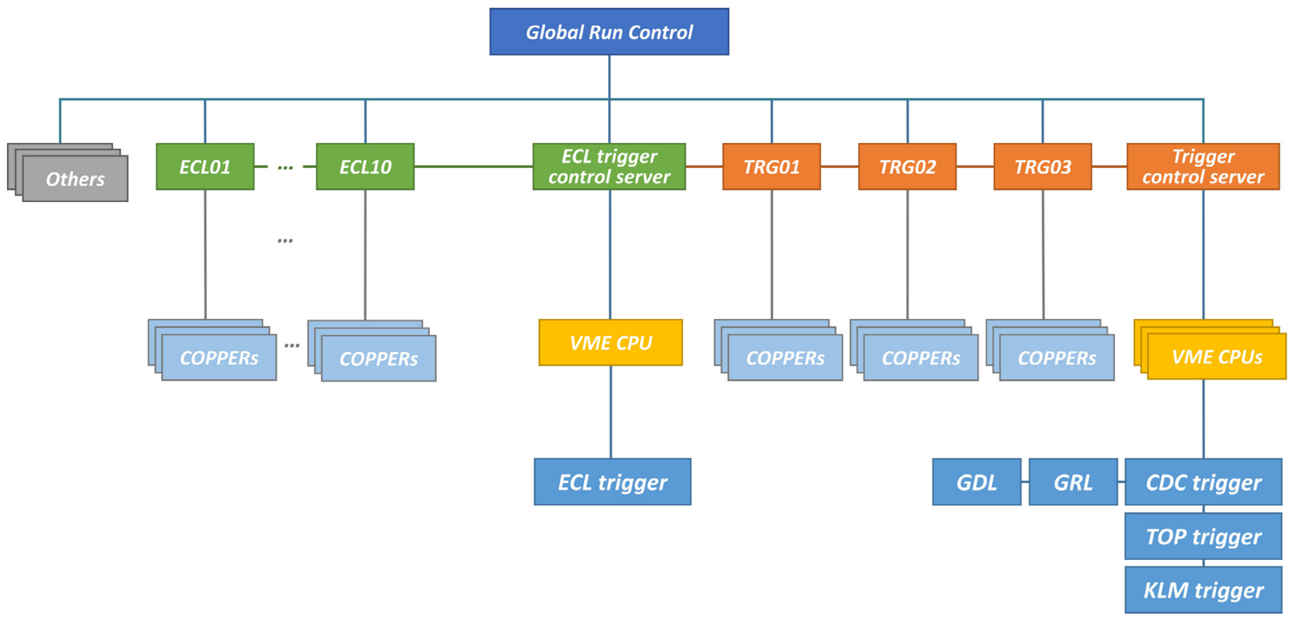

Fig. 3. The trigger slow control system server structure. This diagram shows how the trigger slow control related servers are connected to the Belle II network. "Others" in the gray-colored box denote servers related to other sub-detectors; PXD, SVD, CDC, ARICH, TOP, and KLM. The TRG01/02/03 and the ECL01 to 10 servers are COPPER control severs. All the sub-trigger except the ECL trigger is connected to the trigger control server via corresponding VME CPUs. The ECL trigger system is connected to the ECL trigger control server via a VME CPU. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

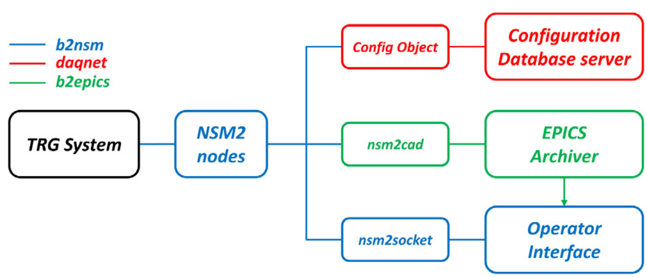

Fig. 4. NSM2 nodes are connected to three network lines: b2nsm, daqnet, and b2epics. The b2nsm is for NSM2 communication, the daqnet is for connections to the database server, and b2epics is for EPICS PVs. "Config object", which is a C++ object of an NSM2 node, converts NSM2 variables to suitable for the configuration database format. "nsm2cad" and "nsm2socket" are explained in the previous section.

3.2. Archiver

We archive 3303,[1] EPICS PVs to the Belle II main archiver server[2] These are mainly variables to judge the stability of trigger systems such as the temperatures of modules, the pedestal levels, the luminosity, and the trigger rates.

The GDL bits are archived: the input bits, the final trigger decision output bit, the output bits of PSNM, and administrative bits. The sub-trigger rates processed by GRL are archived. Track rate from IP and track rate outside IP, which the CDC generates, are archived. The ECL trigger bits are archived: TC noise, pedestal, hit-rate, FAM board temperature, TMM board temperature, ETM physics bit, and accelerator/detector luminosity. TOP L1 trigger rates are archived. KLM L1 trigger rates are archived.

Some of them are plotted on CSS and monitored by trigger experts during a run in real-time.

[1] The Belle II archiver server is capable of storing 80,000 values. The trigger group have 5000 slots.
[2] The default archiving period is 10 s, and the minimum period is 1 s.

3.3. Operator interface tools

User-friendly, intuitive, and reliable GUI is highly required for stable operation. We use CSS, which is widely used in the high energy physics community. NSM2 variables can be read/written on CSS by nsm2socket process and CSS NSM2 plugin. They convert the NSM2 variables to be handled by CSS. We show a few examples of frequently used operator interface panels in Section 5 in detail.

- The trigger local run control panel
- The trigger main control panel
- The Level 1 trigger plot
- The GDL main panel
- The ECL trigger panels

4. Implementation of the trigger slow control system

Fig. 5 shows all processes for the trigger slow control system. The processes are coded with the daq_slc package. Each process in the figure is explained below [13].

- Ready signal NSM2 node
  The ready signal NSM2 node on the ECL trigger control server collects all signals necessary for generating the ECL trigger ready signal. The ready signal NSM2 node on the trigger control server collects all signals necessary for generating the final integrated trigger ready signal, including the ECL trigger ready signal.
- runcontrold
  This daemon process makes it possible for NSM2 nodes to be included in the RC scheme, which is described in Fig. 2. If a node is declared to be included in the RC scheme, a status of the node can affect a run directly.
- runrecordd
  This daemon process automatically saves experimental parameters of NSM2 nodes to the central database server when a run starts and stops. The stored information can be used to validate the run by comparing the condition of starting and stopping moments of the run.

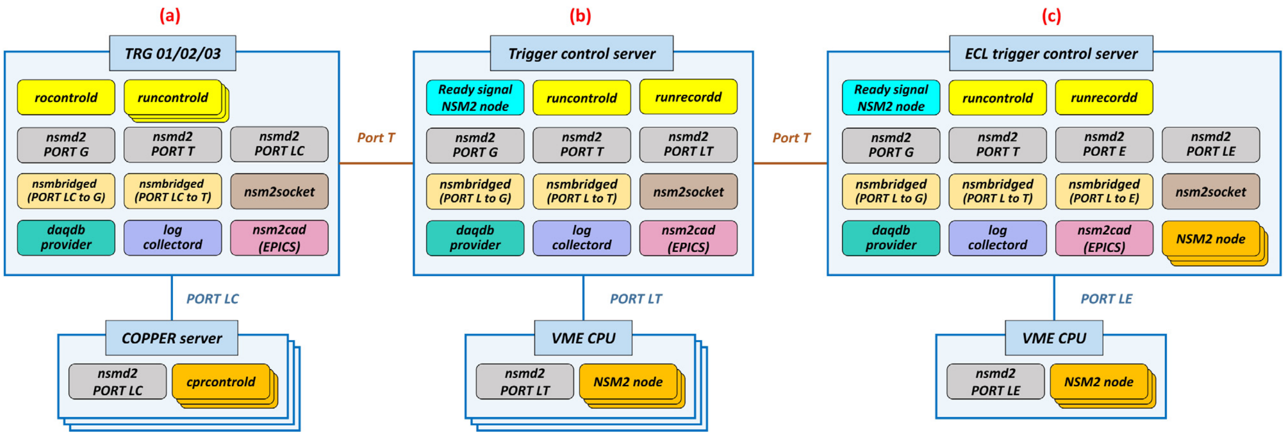

Fig. 5. Schematic of the trigger slow control processes. (a) Each TRG 01 and 02 server has 6 COPPER servers. TRG 03 server has 2 COPPER servers. There are three "runcontrold" on TRG 01 server. Each TRG 02 and 03 server has a single "runcontrold". (b) There are 16 NSM2 nodes on 7 VME CPUs in total. (c) There are 6 NSM2 nodes on the ECL trigger control server and 3 NSM2 nodes on a single VME CPU. (PORT G, T, E, LT, LE, and LC means PORT Global, Trigger, ECL, Local Trigger, Local ECL trigger, and Local COPPER.).

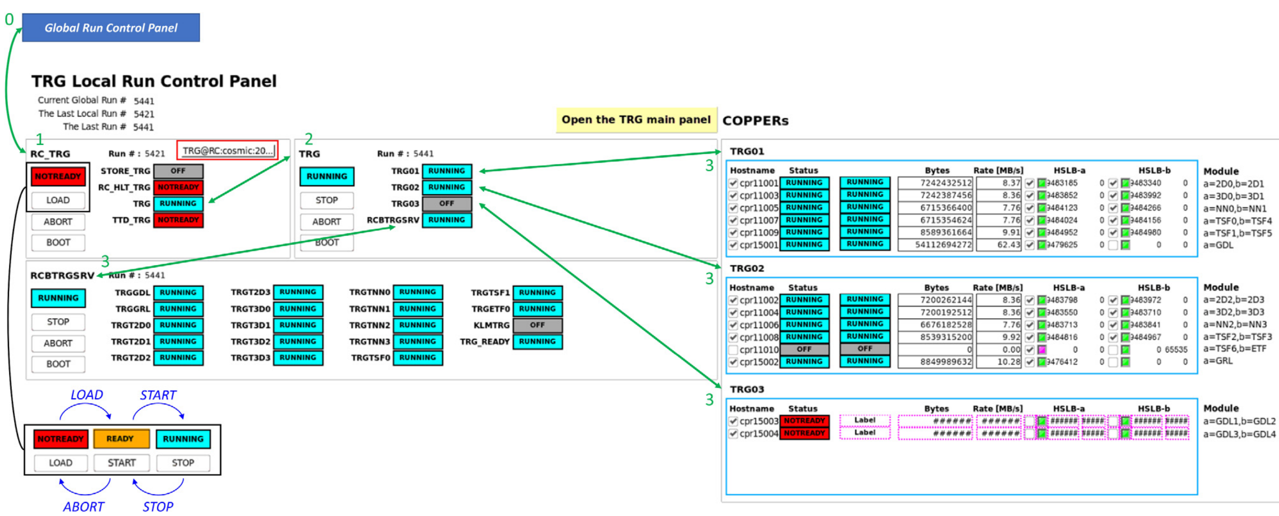

Fig. 6. The trigger local run control panel. The left-bottom side black box show how clicking the request button changes the status display box and the text of the request button itself. Numbers in the figure represent the hierarchical structure in the run control system. If a level of an RC unit receives and executes a request, all active lower levels of RC units also execute the same request. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

- rocontrold
  This daemon process controls trigger read-out.
- nsmd2
  This daemon process takes care of all communication over the network level [13]. For example, nsmd2 with port LT takes care of all network communication between the trigger control server and the corresponding vmecpus.
- nsmbridged
  This daemon process gives network communication between two different NSM2 networks with different port numbers. For example, nsmbridged (LT to G) is a bridge between nsmd2 (LT) and nsmd2 (G).
- nsm2socket
  This process converts NSM variables to suitable for operator interfaces.
- daqdbprovider
  The Belle II central database server is not directly connected to local networks. This daemon connects the local server to the main database server.
- logcollectord
  Logs are collected to the Belle II central database server by this daemon process.
- nsmd2cad
  This daemon process converts NSM variables to EPICS Processed Variables (PV).
- NSM2 nodes
  NSM2 nodes are fundamental building blocks of collecting information and sending commands to the sub-trigger modules.
- COPPER control nodes (cprcontrold)
  COPPER control nodes are fundamental building blocks of collecting information and sending commands to the read-out boards.

5. Trigger slow control panels

5.1. Local run control panel

We regularly take a local run data set for steady improvement of the trigger system, such as calibration or new firmware confirming purposes. For taking a local run data set easily, the trigger local run control panel is prepared (Fig. 6). Before a run, an operator can change experimental parameters according to the purpose of the run by using the dropdown button in the red squared box. By clicking the load button, a pre-saved set of experimental parameters on the central database server is loaded. During a run, status of COPPERs, such as the sizes of the total stored data (bytes) and data-storing rates, are displayed.

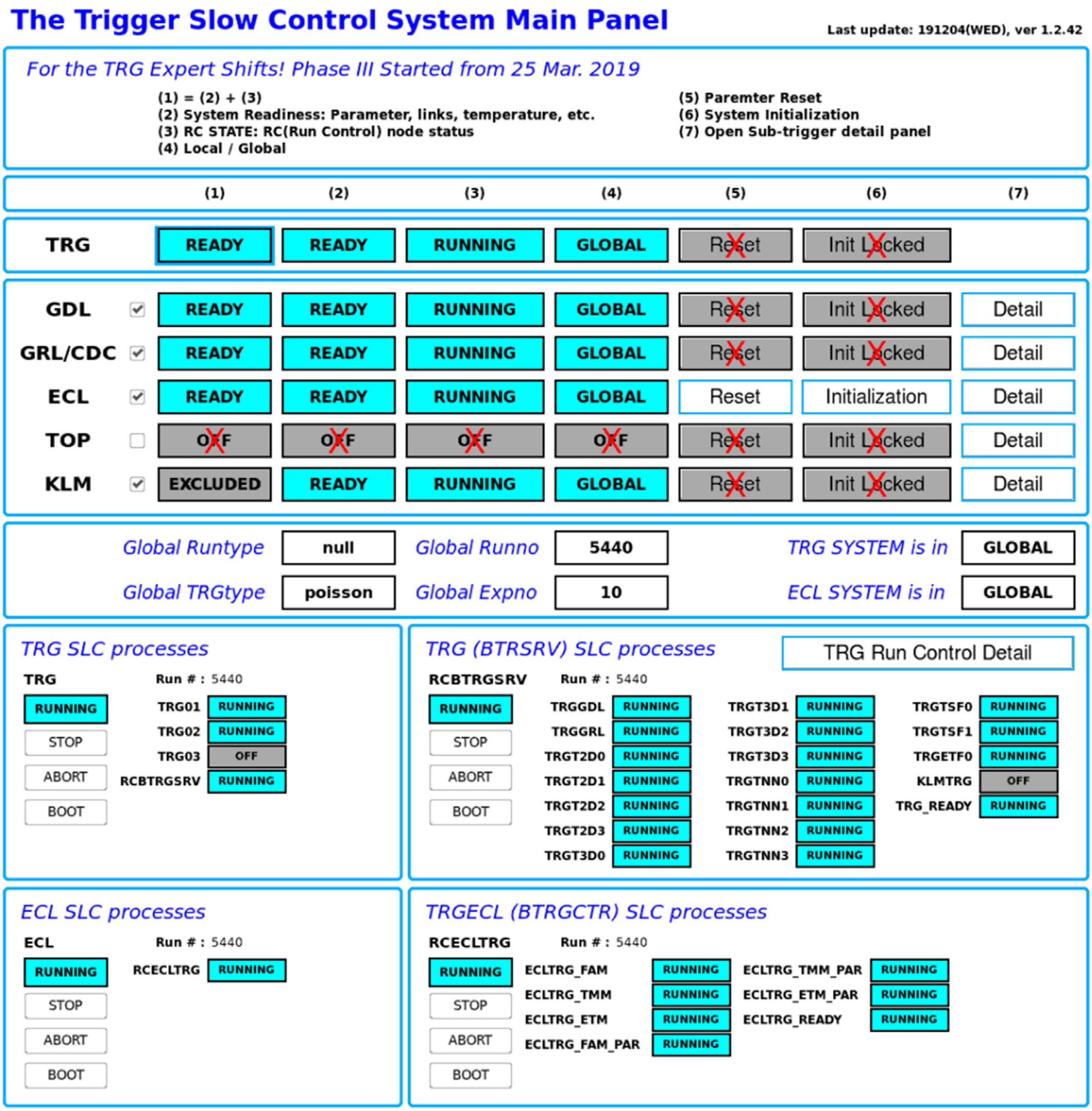

Fig. 7. The trigger main control panel in operation. If a run is stable, all run related parts are shown in light-blue color. The KLM trigger and TRG03 are excluded in this example of a test run for maintenance. Depending on purpose of a test run, we can easily exclude/include sub-triggers and COPPER control servers. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

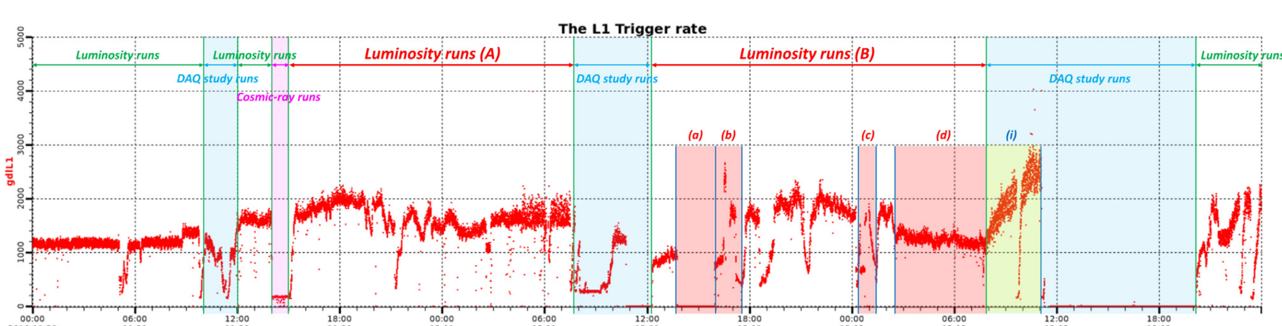

Fig. 8. The L1 trigger plot. A screen shot of the L1 trigger archived PV displayed on CSS. The x-axis is time, and the range is between November 30, 2019, 00:00 JST and December 3, 2019, 00:00 JST. The unit of the y-axis is hertz (Hz). The L1 trigger rate is between 1 kHz and 2 kHz during physics runs.

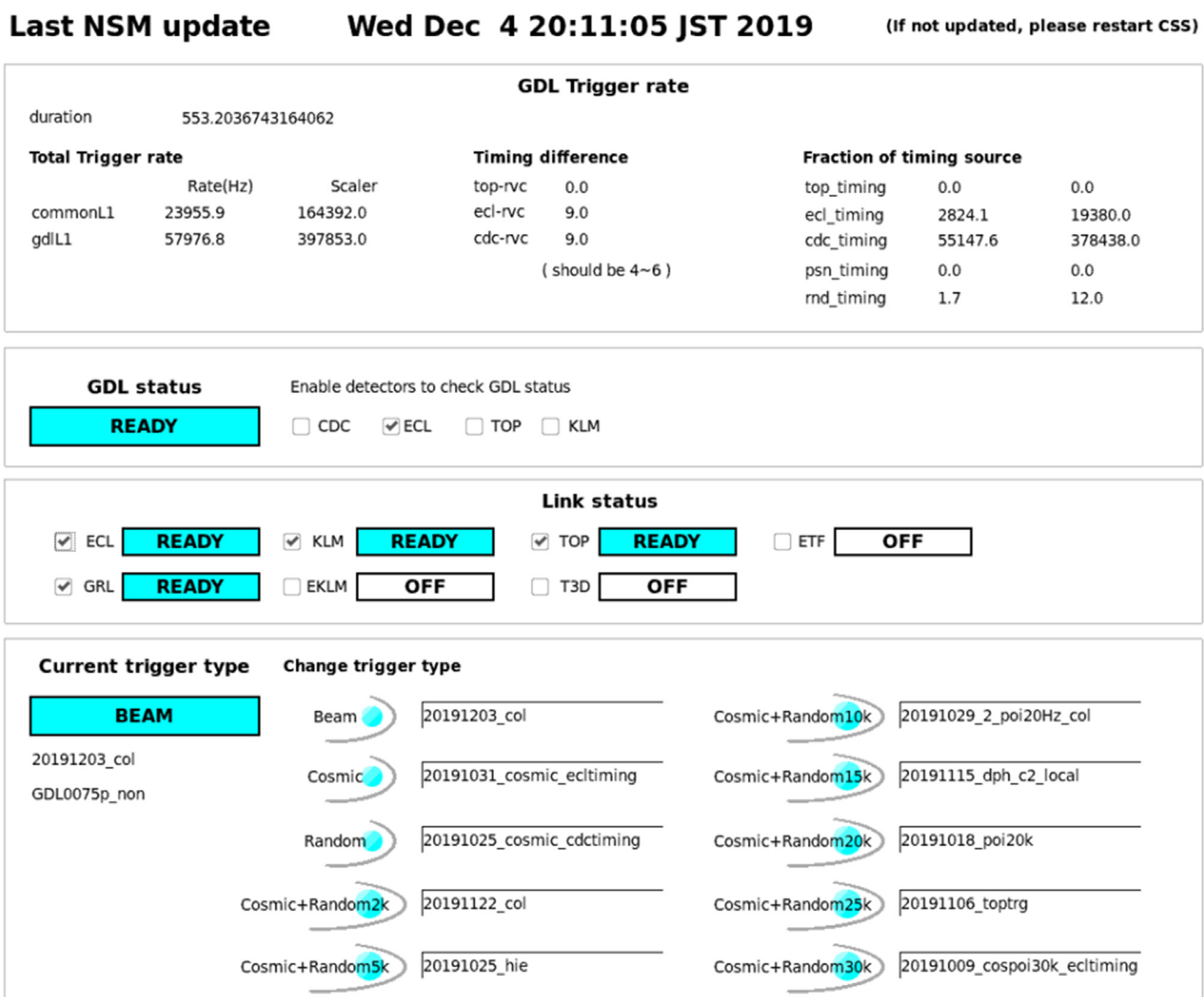

Fig. 9. The GDL detail main panel. The first block shows several real-time trigger rates. The following two blocks are for checking the GDL status. Sub-trigger status and link status can be included/excluded to generate the GDL status with checkboxes. The last block is for setting the trigger type. Trigger type and related parameters can be changed with the ellipse-shaped button.

5.2. *Main control panel*

Fig. 7 is a screenshot of the trigger main control panel in a test run during a stable operation. Trigger experts utilize this panel mainly for monitoring the trigger system status. All run related boxes are shown in light-blue color if everything works well during a physics run. When the trigger slow control system detects a problem, it automatically stops the run and shows which parts have the problem on the main panel.

The third block is for integrated trigger information, and the fourth block is for sub-trigger information. Except for the TOP trigger, all sub-triggers are included in the trigger RC scheme (Fig. 2). The TOP trigger group has a slow control tool that is not based on the Belle II slow control framework, yet. It will also be converted and included in the trigger main RC scheme. The fifth block gives run information: global run type, trigger type, run number, and experimental number. The sixth to ninth blocks correspond to Fig. 3. Trigger experts can use these blocks in the same way as controlling the trigger local run panel.

We also prepared a read-only version of the panel for the Control Room (CR) shift crew members who are the main operators of the Belle II data taking. Opening detail panels and the trigger local run control panel, and reset/initialization buttons are deactivated, but an alarm exists in this version.

5.3. *Level 1 trigger rate plot*

The level 1 trigger is the final output of the trigger system, and its rate can be used as one of the direct indicators of the trigger system, so it should be archived and monitored. Fig. 8 is a screenshot of the L1 trigger rate plot. If the rate suddenly drops or soars without a corresponding change in accelerator conditions, it is suspected that the trigger system has a problem. Then, the CR shift crew members should stop a run and call a trigger expert shift crew member. The DAQ study runs are mainly for DAQ study, and also for each sub-detector study. During the cosmic-ray runs, the GDL parameter setting is different from the parameters for the physics (luminosity) runs, so the L1 trigger rate is noticeably different from that of physics runs. The luminosity runs in the period (B) are relatively less stable than the luminosity runs in the period (A) because several problems ((a) to (d)) happened in the period (B).

(a) No L1 trigger rate, due to beam problem.
(b) The GDL timing problem happened.
(c) Same as (b)
(d) Sudden decrease of the L1 trigger rate.

In the period (i), ECL expert did local run study in order to chase the origin of (d).

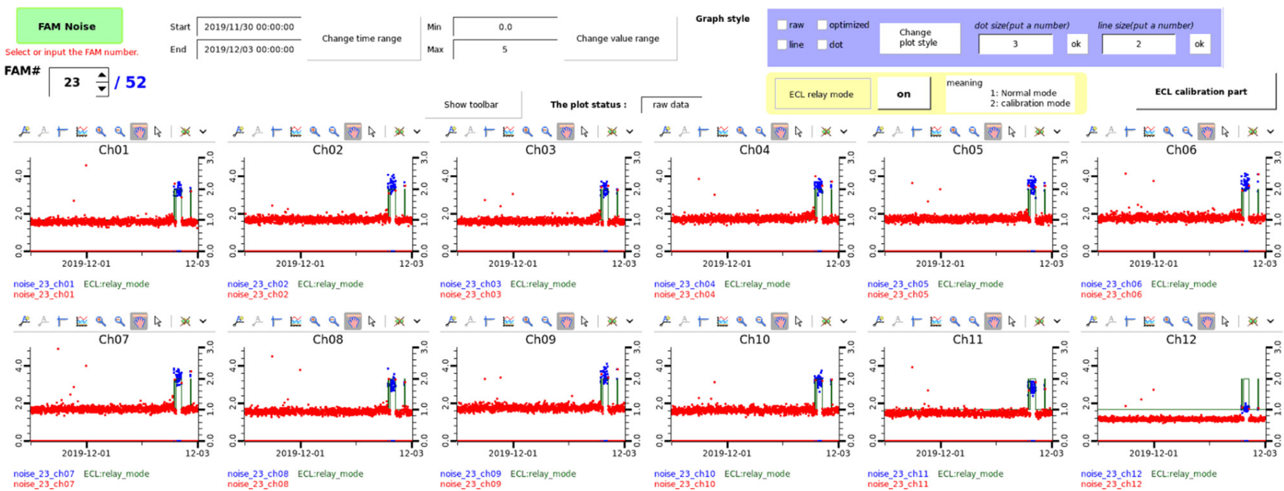

Fig. 10. The FAM module noise monitoring panel. The *x*-axis is time: the range is between November 30, 2019, 00:00 JST and December 3, 2019, 00:00 JST, same as Fig. 8. The left-hand side *y*-axis is for noise value (red/blue dots), and the unit is ADC count (1 ADC count corresponds to 5.25 MeV). The right-hand side *y*-axis denotes the ECL operation modes (green line, 1: the normal mode, 2: the local work mode). With the normal setting, the FAM noise level is near 2 ADC counts (red dots), and with the local work setting, the FAM noise level is between 3 and 4 ADC counts depending on the local study (blue dots). The channel 12 is a null-channel. We can change the range of x and y axes, and style of both of the plots by the corresponding setting interface on the panels. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.4. GDL panel

Fig. 9 is the GDL main panel. Sub-trigger rates and link status of data-taking are displayed on the GDL main panel. With this panel, we can set several GDL parameters for specific purposes such as physics (beam) run, cosmic-ray run, test runs with a random (Poisson) trigger rate, and a cosmic-ray + random trigger rate. We can test the DAQ system stability with an increased random trigger rate.

5.5. ECL trigger panels

The ECL trigger system consists of 3 sub-modules, which are the FADC Analysis Module (FAM), the Trigger Merger Module (TMM), and the ECL Trigger Master (ETM) [5,8].

Fig. 10 is a FAM noise monitoring panel and the plots in the figure are based on archived PVs. This figure shows an example of how we exploit the trigger slow control system in real use. There are also other panels showing the FAM pedestal, hit-rate, average hit-rate, the TMM temperature, and the ETM physics bits plots. We use all these plots for operating the ECL trigger system stably. Especially, FAM hit-rates and average hit-rates PVs are utilized not only by the trigger group but also by the SuperKEKB side for beam tuning. Additionally, the ECL trigger slow control system provides an automatic parameter setting function depending on run condition [22].

6. Trigger slow control in operation

A read-only version of the trigger main panel and the L1 trigger rate plots are used by CR shift crew members. If a run stops automatically by the trigger slow control system or CR shift crew members find a problem in the trigger side with the operator interfaces, they contact the trigger expert shift crew members by internal chat or a phone call.

If a trigger expert shift crew member finds a problem or gets a message/phone call from CR shift crew members, the trigger expert first checks which part shows the problem and follows recovery procedures. If the problem is due to the slow control system itself, the trigger expert can easily recover whole processes on the trigger control servers, COPPER control servers, and all sub-servers of both of them by scripts (Fig. 3). If the problem is due to a sub-trigger system, the trigger expert can follow the troubleshooting procedure provided by the corresponding sub-trigger group. If the trigger expert cannot recover the systems by following the procedures, then the real expert of the sub-trigger is called.

7. Summary

The trigger slow control system has been developed based on the Belle II DAQ/slow control software package. The successful development of the trigger slow control system verifies that the package is an effective tool for controlling real electronics. The trigger slow control system stores configuration parameters into the Belle II central database server for every run start and stop, and EPICS PVs into the Belle II main archiver server every default period of 10 s. Shift crew members can detect problems by intuitive GUI panels and try a recovery procedure when a problematic situation occurs. During the initial running period of Belle II, we have steadily refined the system based on operation experiences. The stable operation of the trigger system is crucial for the efficiency of data taking. The slow control system made it possible to stably operate the trigger system during the last 2019 autumn run and following runs in 2020.

CRediT authorship contribution statement

C.-H. Kim: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Visualization, Validation. **Y. Unno:** Software, Writing – review & editing. **H.E. Cho:** Validation. **B.G. Cheon:** Writing – review & editing, Supervision, Funding acquisition. **S.H. Kim:** Software, Validation. **I.S. Lee:** Writing – review & editing, Software, Validation. **E.-J. Jang:** Software, Validation, Visualization. **S.-K. Choi:** Validation. **Y.J. Kim:** Software, Validation. **J.K. Ahn:** Validation. **M. Remnev:** Software, Validation, Writing – review & editing. **A. Kuzmin:** Software. **T. Koga:** Software, Validation, Visualization, Writing – review & editing. **Y.-T. Lai:** Software, Validation, Visualization. **Y. Iwasaki:** Software, Project administration. **H. Nakazawa:** Software, Validation, Visualization, Writing – review & editing. **D. Liventsev:** Software. **M. Nakao:** Conceptualization, Software, Writing – review & editing, Supervision. **S. Yamada:** Software. **R. Itoh:** Software. **T. Konno:** Conceptualization, Methodology, Software. **S.-H. Park:** Software, Validation. **Y.-J. Kwon:** Validation. **O. Hartbrich:** Software, Writing – review & editing. **M. Ritzert:** Software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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