Proposal for a test experiment to evaluate the performance of the trigger-less data-streaming type data acquisition system

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ver. April 3, 2024

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Executive Summary

We propose a parasitic test experiment with beams passing through the E73 setup at the K1.8BR beam line. The purpose of the proposed experiment is to develop a streaming-readout data acquisition (SRODAQ) system and evaluate its performance for the E50 experiment. For this, we will use our own detectors prepared downstream of the E73 setup at the request of the inquiry No.22-01-14. The E50 experiment is at the stage-1 status, and we think that the SRODAQ is one of important pieces toward the stage-2 approval, for which we are preparing TDR to be submitted in 2024. We request no extra beam time for this purpose but an opportunity to utilize the beams to be absorbed in the beam dump of the K1.8BR beam line during the E73 beam time (25 days with 80-kW proton beams on T1) approved in the last PAC meeting. We expect to test the following components on the SRODAQ system: 1) Front-End Electronics performance for steaming readout; 2) Event builder and online event filtering processes with CPU/GPU; 3) Process monitor and user interface; and 4) to accumulate unfiltered/filtered data for further developments of online processes by replaying realistic data flows. These studies with hadronic beams are of great importance not only for E50 preparation but also for serving as general-use, highly-efficient data acquisition system for communities. In this regard, the proposed experiment will be carried out in cooperation with members of the SPADI Alliance [1].

Below are the summary of request.

Beam line:	K1.8BR beam line (parasite of E73).
Beam polarity:	Negative, as E73 expects to use.
Beam momentum:	1 GeV/c, as E73 expects to use.
Beam time:	25 days, as allocated for E73. No extra beam time is requested for this experiment.

1 Introduction

We are preparing for the E50 experiment [2], which aims at measuring excited singly-charmed baryons (Λ_c^*/Σ_c^* denoted as Y_c^*) via the $\pi^- + p \to D^{*-} + Y_c^*$ reaction at the π20 beam line of the J-PARC Hadron Experimental Facility. As c quark is heavy, collective motion of a light quark pair to c (λ mode) and relative motions between light quarks (ρ mode) are disentangled [Fig. 1(a)]. This is nothing but the isotope effect. A diqaurk correlation in charmed baryons is expected to be singled out. The $\pi^- + p \to D^{*-} + Y_c^*$ reaction can populate the λ-mode excited states dominantly, which could be identified by measuring the characteristic cross-section ratio between the heavy quark spin doublet (HQ doublet) formed due to the spin-orbit interaction [Fig. 1(c)]. The decay pattern is also expected to be responsible for the internal motions of the diqaurk, as illustrated in Fig. 1(b). By means of missing mass techniques, we will measure those characteristic mass spectra of excited charmed baryons and their decay properties, such as decay branching ratios, systematically. The diquark correlation is thought to play a role in understanding the internal structure of baryons, giving a fundamenatal information on dymanics of quark clusters that are not color singlet being confined in hadrons. It is expected that the spin-spin attractive correlation between a pair of quarks is a source of the diquark condensate in highly dense matter, which might be realized in the neutron star cores. Therefore, studies of the diquark correlation are important not only in hadron physics but also cosmo-nuclear physics.

We are constructing the MARQ spectrometer for the E50 experiment. MARQ means a **M**ultipurpose **A**nalyzer to **R**esearch **Q**uark-gluon dynamics in hadrons and hadronic systems. We will employ a dipole magnet with circular magnetic poles with a diameter of 2.1 m and a gap of 1 m, for which we will modify the dipole magnet currently used for E16. We have been developing detectors that measure momentum, velocity from the trajectory and time information of each particle in the decay final state of scattered D^{*-}, as shown in Fig. 2. Since a typical cross-section of charmed baryons is as small as 1-10 nb, we will irradiate an intense pion beam of $6{\times}10^7$ per spill on a liquid hydrogen target of 4 g thickness. The reaction particle rate is expected to be as high as a few hundred million in a second. Then, the estimated data rate will be 13 gigabytes per second. We are developing the streaming-readout data acquisition system (SRODAQ) to handle such a large data flow. Because the most of data would be of less interest, we will reduce the data size by 2$\sim$3 orders of magnitude by introducing an event filtering process in the SRODAQ system. In the proposed test experiment, we will develop the SRODAQ system and evaluate its performance in a realistic experimental situation with hadronic beams.

The E50 experiment is at the stage-1 status, and we think that the SRODAQ is one of important piecies toward the stage-2 approval, for which we are preparing TDR to be submitted in 2024.

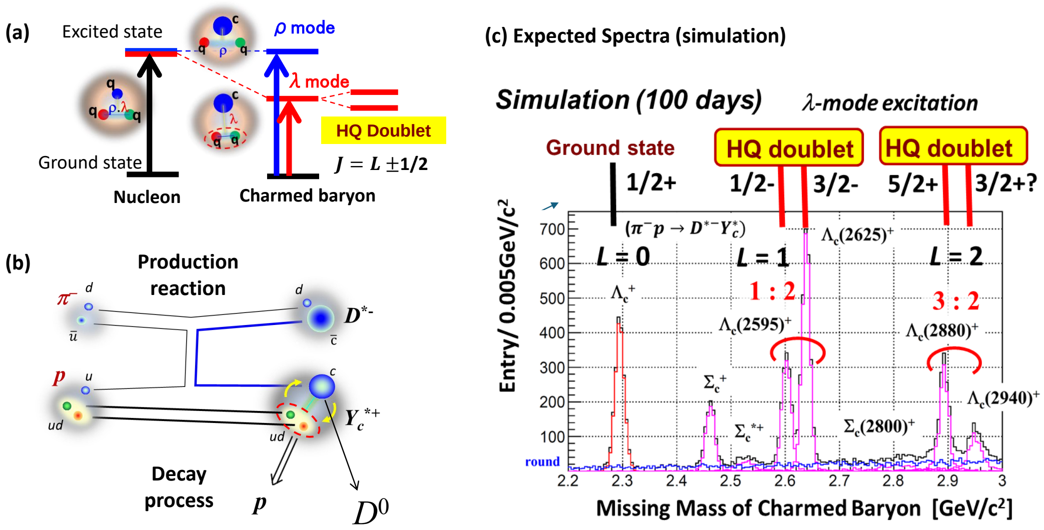

Figure 1: (a) Schemtic illustration of the isotop shift effect in excited charmed baryons. The excition energy of the λ-mode state is lower than that of the ρ-mode state. (b) quark diagram of the $\pi^- + p \rightarrow D^{*-} + Y_c^*$ reaction and a decay process expected to be dominant in a λ-mode excited charmed baryon. (c) Simulated missing mass spectrum of charmed baryon.

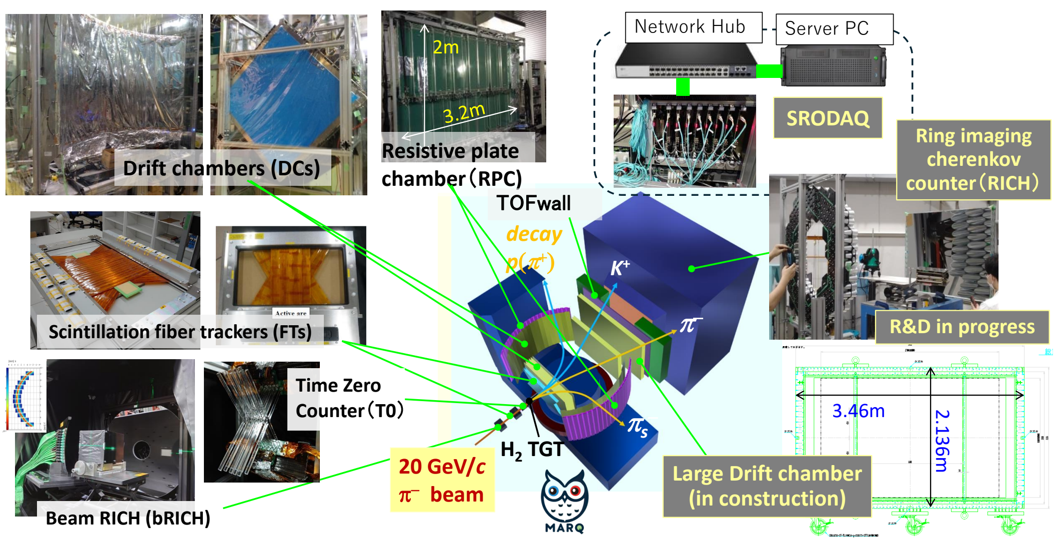

Figure 2: MARQ spectrometer used for the E50 experiment. The MARQ spectrometer is a general purpose spectrometer system to be used for various hadron spectroscopy experiments.

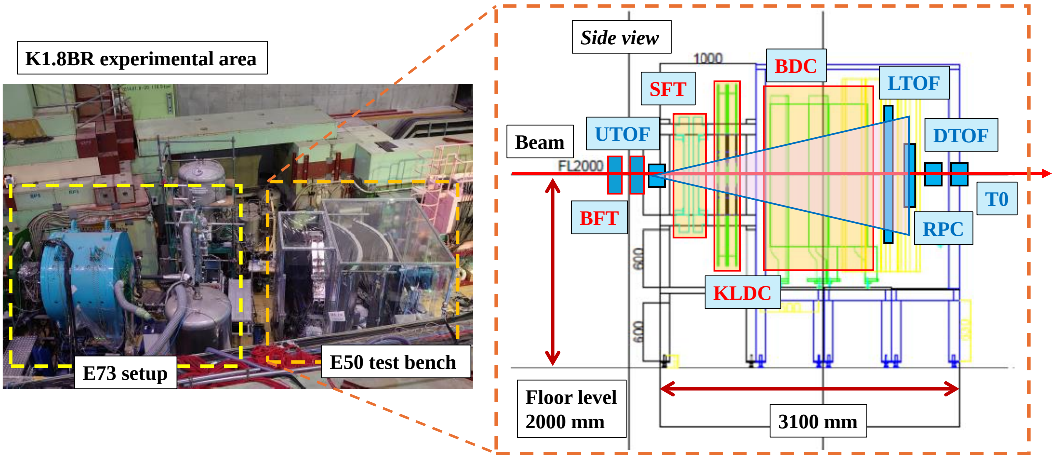

Figure 3: Setup of the detector test bench placed at downstream of the E73 detector setup.

2 Setup

2.1 Test bench

We have constructed a test bench to maintain the detector systems for the MARQ spectrometer in the K1.8BR area with the support of the EPPC office at the inquiry No. 22-01-14. The E50 experiment will be carried out at B-Line, so-called the high-momentum beam line. Since the E16 experiment is currently under commissioning at the B-line and no room to put detectors for the MARQ spectrometer, the test bench at the K1.8BR area is quite helpful and important for the preparation of the E50 experiment.

Currently, we have prepared 1400 channels of drift chambers, 2000 channels of scintillation fiber trackers, and 60 channels of timing counters made by plastic scintillators, acrylic Cherenkov radiators, and/or resistive plate chambers, as shown in Fig. 3. They are read out by the streaming-readout data acquisition (SRODAQ) system, as described in the next subsection. The number of channels is approximately 1/10 of the full setup of the MARQ spectrometer, but it would be reasonably sizable to obtain an expectation of how the SRODAQ system works.

2.2 Streaming-readout data acquisition system

The SRODAQ system is based on a parallel processing framework to handle data that is continuously sent from FEEs with a time stamp. A schematic chart of data flow in the SRODAQ system is illustrated in Fig. 4. Some of essential components have been developed. In SRODAQ, each FEE has the self-defined time domain generated by the heartbeat method [3]. The heartbeat time frame is determined by the periodic signal called the heartbeat. Since the time stamp is unique information to reconstruct an event, this time frame must be synchronized among FEEs. Thus, the MIKUMARI link technology [4] is one of the important electronics functionality, which distribute clock signal, synchronous command and timing to digitizer

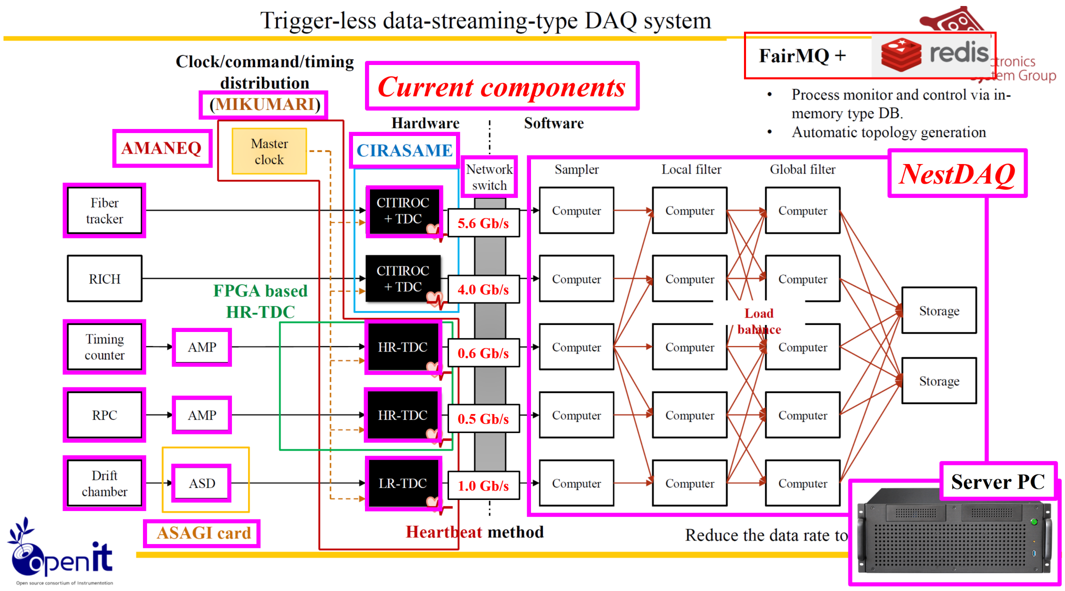

Figure 4: Schematic illustration on signal and data processing in the streaming-readout data acquisition system.

modules, and thus the clock frequency synchronization is achieved among FEEs. A software framework, NestDAQ [5], has been developed, which employs FairMQ [6] and redis [7] to monitor and control processes via an in-memory type database. In NestDAQ, the sampler process collects signal data from each digitizer. The sub-time frame builder process creates a time-series dataset for a single digitizer module. The time frame builder process rearranges a time-sliced dataset over all the digitizer modules. A simple filter process is prepared, in which a specified signal logic condition between specified digitizer modules within a time frame can be used as a kind of software "trigger" to reduce the data size by discarding a time frame dataset with an unsatisfied "trigger" condition. Recently, we introduced an event builder, in which an event dataset is reconstructed, and more complicated analysis could be developed for further event selection. The FileSink process records dataset passing through filter processes. The network configuration of the SRODAQ system is illustrated in Fig. 5. FEE modules and PC servers are connected via optical fiber network cables with high-speed network protocols. For the proposed experiment, we prepared two servers of the AMD EPYC 7313P 16-core 3.0 GHz with 64GB memory and the AMD EPYC 74F3 24-core 3.2 GHz, 64GB memory for task sharing in the streaming-readout data processing, as shown in Fig. 6.

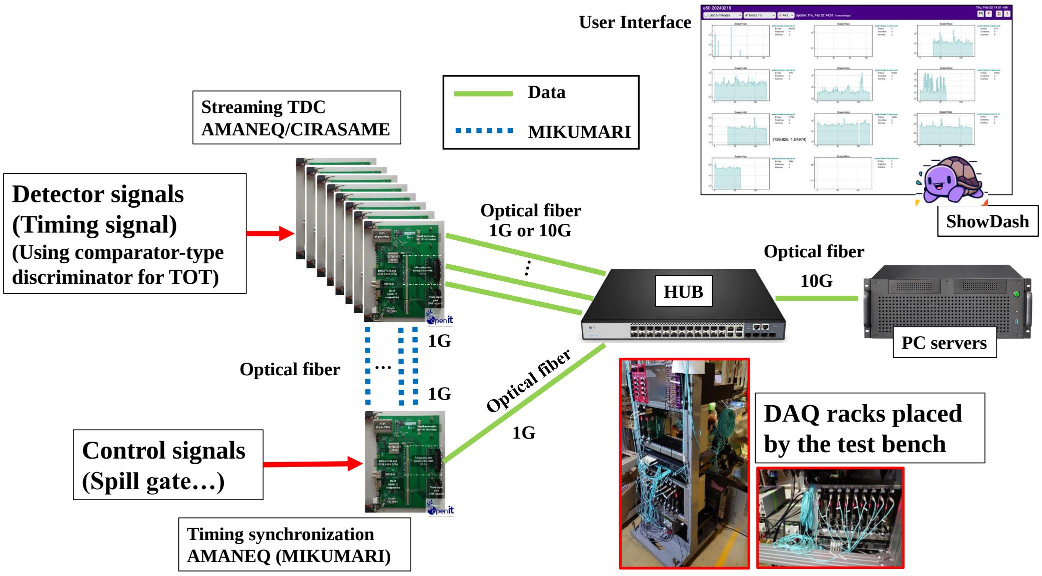

Figure 5: Network configuration of the SRODAQ system for the proposed test experiment.

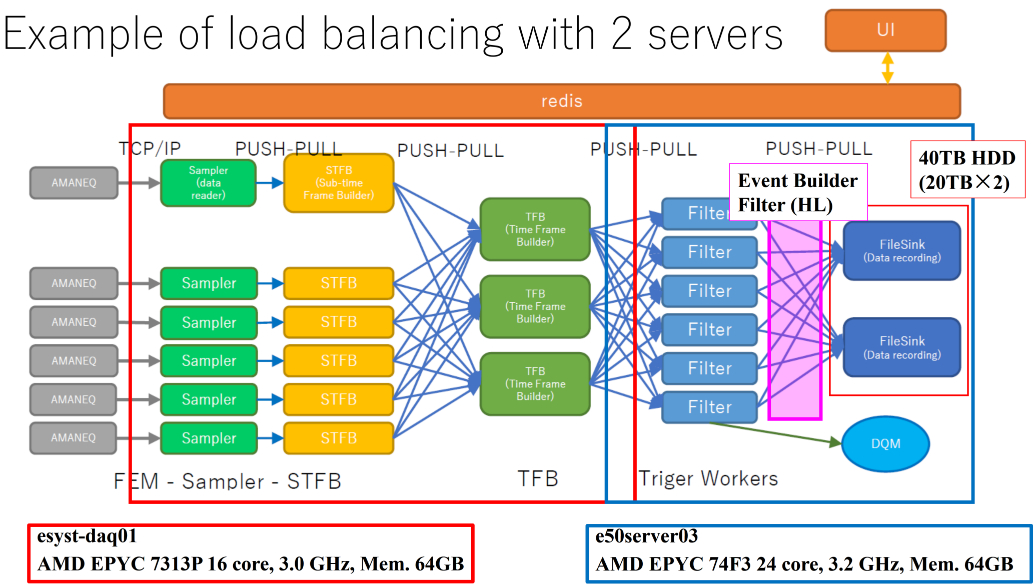

Figure 6: An example of load balancing with 2 PC servers. Task sharing in the streaming-readout data processing will be performed.

3 Experimental Plan

We will study the following items.

1) Front-End Electronics performance for the streaming readout.
2) Event builder and online-event-filtering processes with CPU/GPU.
3) Monitor process/ User Interface.
4) Accumulate unfiltered/filtered data for further developments of online processes that can be "replayed" later to simulate the realistic data flows.

In study item 1), we will test a new FEE module, CIRASAME. The CIRASAME is an FEE module for SiPM containing a Time-to-Digital Coverter, which will be used for scintillating fiber trackers and RICH detectors of MARQ. Now, both AMANEQ and CIRASAME used in MARQ are ready for a deployment. Recently, new protocol called LACCP (Local Area Common Clock Protocol) was developed and the first beam test will be conducted. Since the MIKUMARI link technology provides only the frequency synchronization, another protocol is essential to complete the clock synchronization. This protocol is able to automatically adjust the time stamp with 100-200 ps accuracy in each FEE by calculating the time offset coming from the transmission delay. The FPGA firmware includes all the functionalities necessary for actual experiments. From a DAQ FEE perspective, this beam test is an important milestone, as it deploys essentially all foreseen components and therefore many new key feature can be tested in a realistic condition.

In study item 2), we will test a filter process. For this, an event-builder process was introduced in the NestDAQ framework. We will analyze the event data so as to make a decision to record or discard the event data. In SRODAQ, we will be able to record all the event data, including so-called beam-through events that do not take place in any reaction with the target nuclei. We, however, will reduce these events in order to save resources for data storage. This is going to be a critical issue with the full-scale setup. It is therefore of vital importance to test it.

We will improve a monitoring process and user interfaces to control/monitor DAQ status, change/monitor operation conditions/statuses of detectors/FEE modules, and so on [study item 3)].

Since FEE has become a production specification, the data obtained in this test experiment is simulated data for the actual experiment. By taking advantage of the feature of streaming readout and leaving unbiased (unfiltered) data [study item 4)], we will develop the algorithm for not only beam event removal mentioned above but also further intelligent event analysis programs to filter out specified physics processes.

From the comprehensive evaluation by the study items 1)–4), we plan to prove that the SRODAQ system can acquire data stably even under high loads. Our goal is to achieve stable operation of the SRODAQ system while solving problems that can be identified in the test bench setup of the MARQ spectrometer with realistic beam situations.

4 Schedule

According to the beam time schedule from April, 2024 before summer shutdown, 25-days beam time will be allocated in the up-coming run (14^{th} April 2024 – 28^{th} May 2024) for the E73 experiment, where the E50 test bench is currently set up. We will conduct the test according to the schedule of the E73 experiment. Therefore, we request a parasitic use of beams passing through the E73 setup. We request no extra beam time for the proposed experiment. 24-hour shift will also be scheduled to conduct the experiment when the E73 group use beam longer than a day.

Run schedule of the E73 experiment is planned in three periods as follows.

A. Commissioning run at the beginning of the beam time.

B. Full detector system calibration runs using helium(^{4}He) and hydrogen targets.

C. Production run using helium(^{3}He) target.

Experimental periods and run plan of both E73 experiment and E50 test bench are summarized in Table 1.

4.1 Studies in schedule A

The E73 commissioning run is allocated from 8^{th} to 14^{th} in April. The E73 group use 1-shot operation beams for checking their detectors and DAQ in the primary beam line commissioning by the hadron experimental facility group. We will conduct the commissioning of the E50 test bench detectors and the SRODAQ system by using beams passing through the E73 setup.

4.2 Studies in schedule B

Full detector calibration runs for the E73 experiment is allocated in two period, from 15^{th} to 17^{th} and 19^{th} to 20^{th} in April. A stable beam condition is expected during calibration runs using ^{4}He and hydrogen targets so that we will test the operation of the streaming readout FEEs and the performance of event builder and online-event-filtering processes with CPU/GPU with realistic hadronics beams. Usefulness of the newly developed monitor process and the user interface can be evaluated. Those studies correspond to the study items 1), 2) and 3) explained in Sec. 3. Then, we will select the candidates of data-taking filtering conditions for a long period run.

4.3 Studies in schedule C

The E73 production run is allocated from 26^{th} in April to 22^{nd} in May. Related to study items 1) and 2), we will take data with fixed conditions for evaluating the stability over a long period and trend of the SRODAQ system conditions such as data flows and error rates of FEE and efficiencies of the filter process. For evaluating the performance of the filter algorithm, we will test several patterns of the filters which are needed to be developed during the beam experiment because we don't have data before the test. The development of the filter needs the studies including many test data taking during the realistic beam irradiation. It is also important to study how to create filters in a real time during the beam experiment. For further intelligent event analysis to filter out specified physics processes, it is necessary to accumulate enough reaction data. Corresponded to study items 4) explained in Sec. 3, accumulated both unfiltered and filtered data will be used for further developments of online processes that can be "replayed" later to simulate the realistic data flows. Therefore, in order to conduct those studies, we need data taking over a long period of several days under several different conditions.

In addition, in order to evaluate unexpected errors in FEE and DAQ software, it is necessary to take data over a long period because the error rate is not high. It is an important study for evaluating the performance of the newly developed FEE and SRODAQ system.

In the current situation, there are still no experts who can smoothly launch the SRODAQ system. The test experiments are not only for developing the components of the SRODAQ system, but also for training persons who will work for the newly developed DAQ system.

Table 1: Schedule of the E73 experiment and E50 test run plan.

Schedule	Period	E73 run plan	E50 test run plan
A	8^{th}–4^{th} Apr.	Commissioning	Commissioning
B	15^{th}–17^{th} Apr., 19^{th}–20^{th} Apr.	Calibration run	Study items 1), 2), 3)
C	26^{th} Apr.–22^{nd} May.	Production run	Study items 1), 2), 4)

References

[1] SPADI Alliance, `https://www.rcnp.osaka-u.ac.jp/~spadi/`

[2] H. Noumi *et al.*, J-PARC Proposal E50, ‘’Charmed Baryon Spectroscopy via the (π, D^{*-}) reaction" (2012).

[3] R. Honda *et al.,* "Continuous timing measurement using a data-streaming DAQ system", Prog. Theor. Exp. Phys. 2021 Issue 12, 123H01 (2021).

[4] R. Honda, "New Clock Distribution System Based on Clock-Duty-Cycle-Modulation for Distributed Data-Aquisition System", IEEE Transactions on Nuclear Science, Vol 70-6, 1102-1109 (2023)

[5] T.N. Takahashi, R. Honda, Y. Igarashi, H. Sendai, "Streaming DAQ Software Prototype at the J-PARC Hadron Experimental Facility ", IEEE Transactions on Nuclear Science, Vol 70-6, 922-927 (2023).

[6] FairMQ, [online] Available: `https://github.com/FairRootGroup/FairMQ`.

[7] Redis, [online] Available: `https://redis.io`.