General-purpose trigger-less DAQ system for physics experiments

Contents

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Acknowledgements

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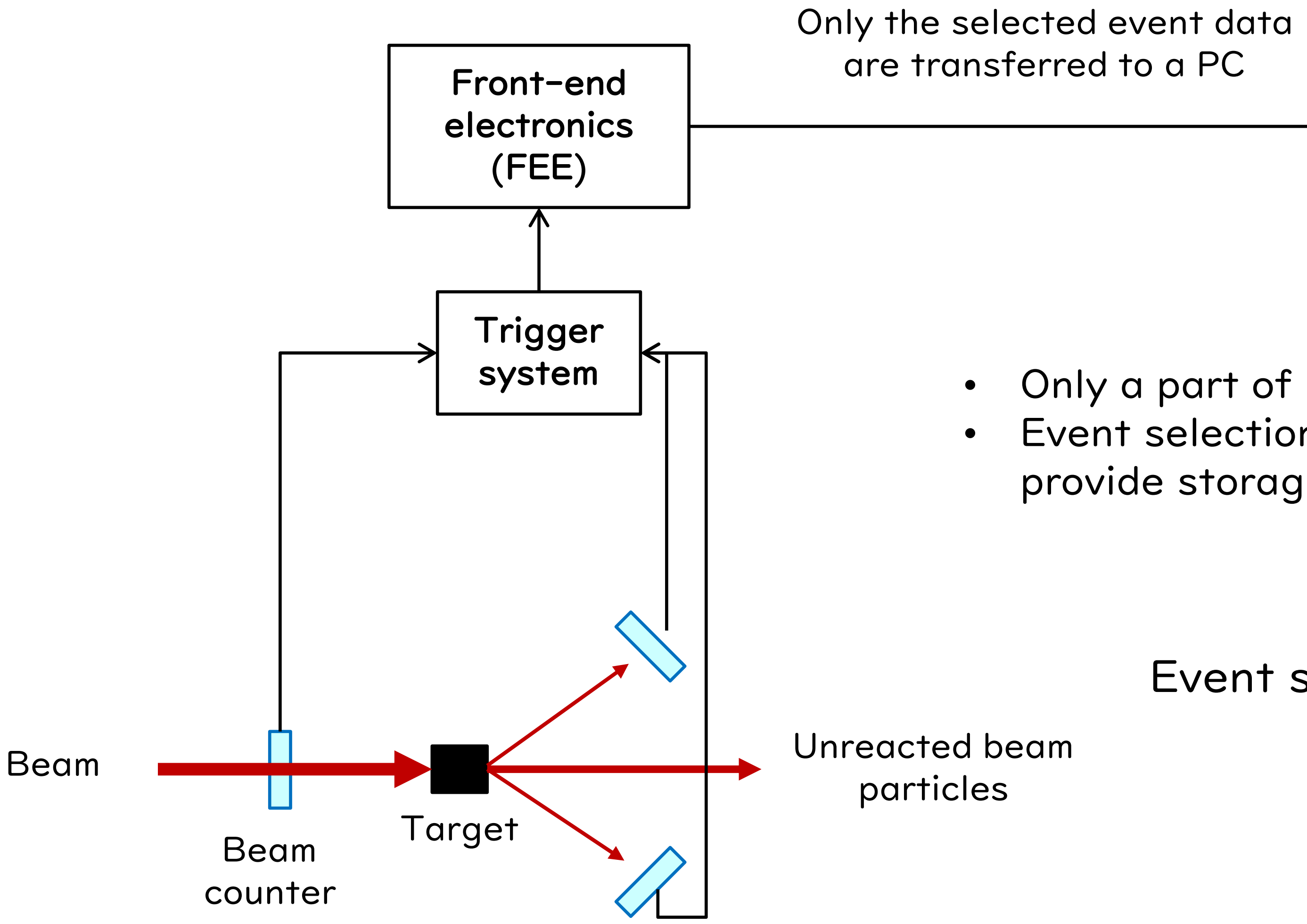
RCNP

- M. Ikeno, N. Kobayashi, H. Noumi, S. Ota, S. Ryu, K. Shirotori, K. Suzuki, T.N. Takahashi

RIKEN

- H. Baba

Hardware trigger in the PN experiments



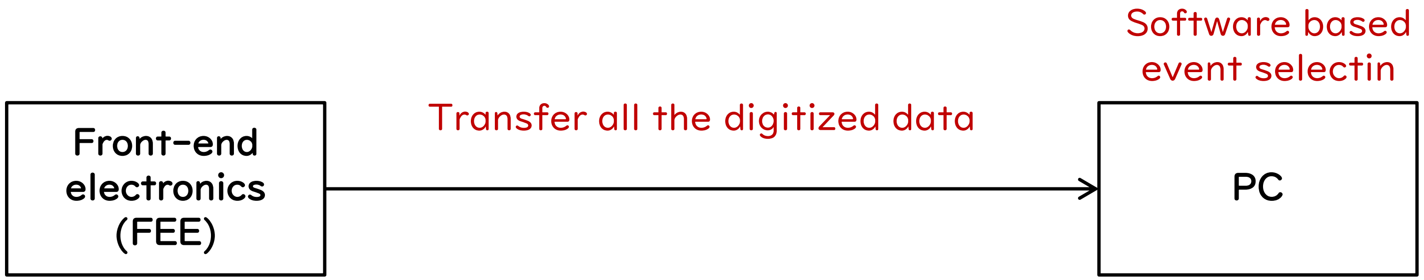
Example of a fixed target experiment

- Only a part of beam particles are reacted in the target.
- Event selection is essential since it is not realistic to provide storage to store all digitized data.

⇩

Event selection by a hardware trigger

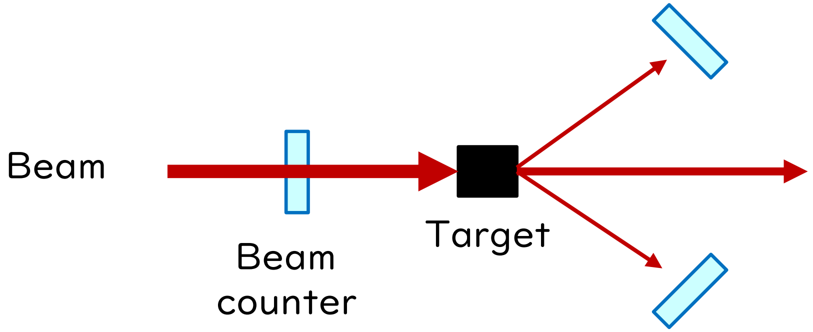
Trigger-less DAQ system in the PN experiments



- The following things have become possible thanks to the recent development of communication and information processing technology.
  - Transferring all data to a PC
  - Performing event selection using software

Trigger-less data-streaming type DAQ system

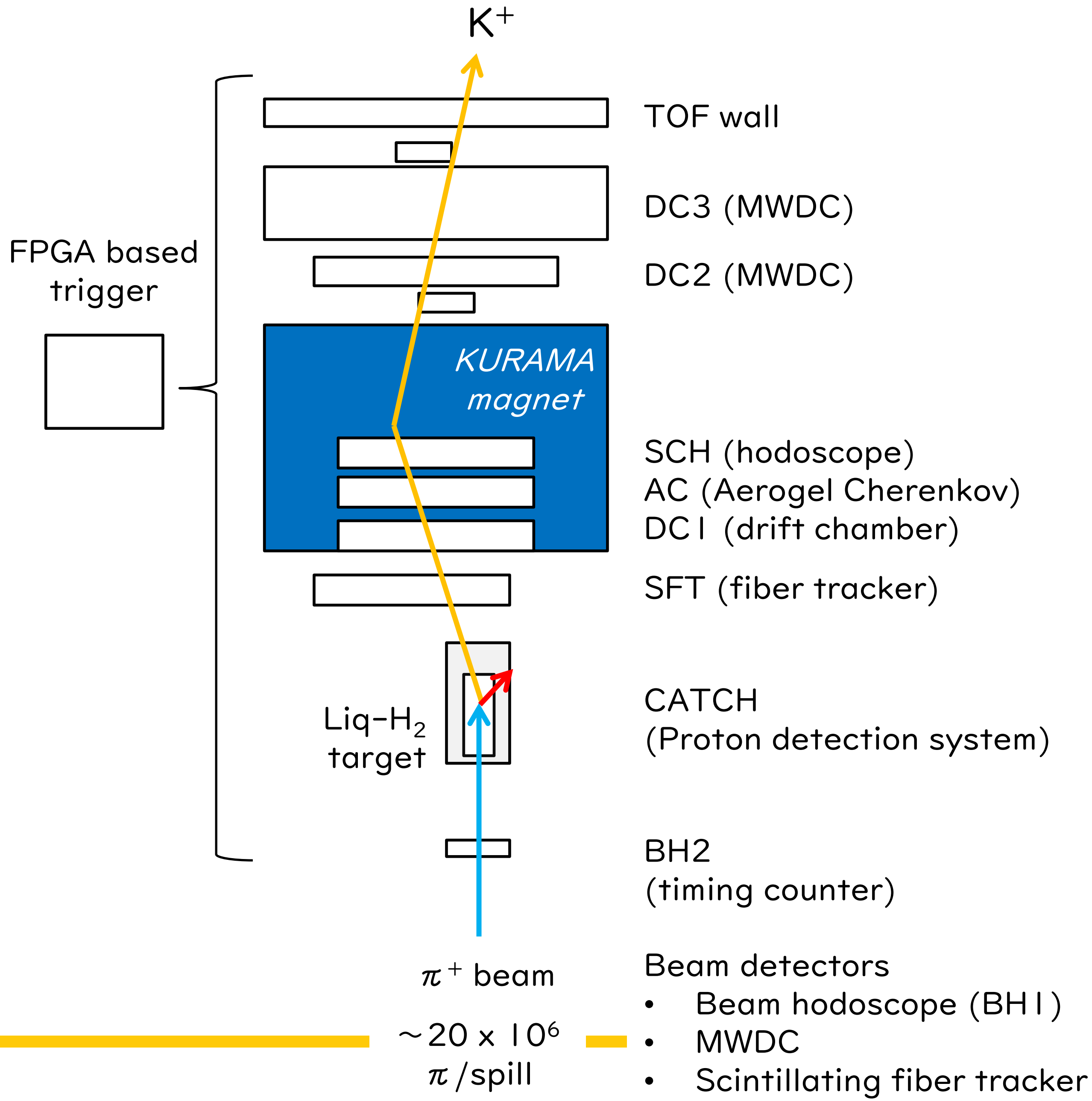
Full-streaming redout FEE
+
High-level trigger (HLT) cluster in PCs



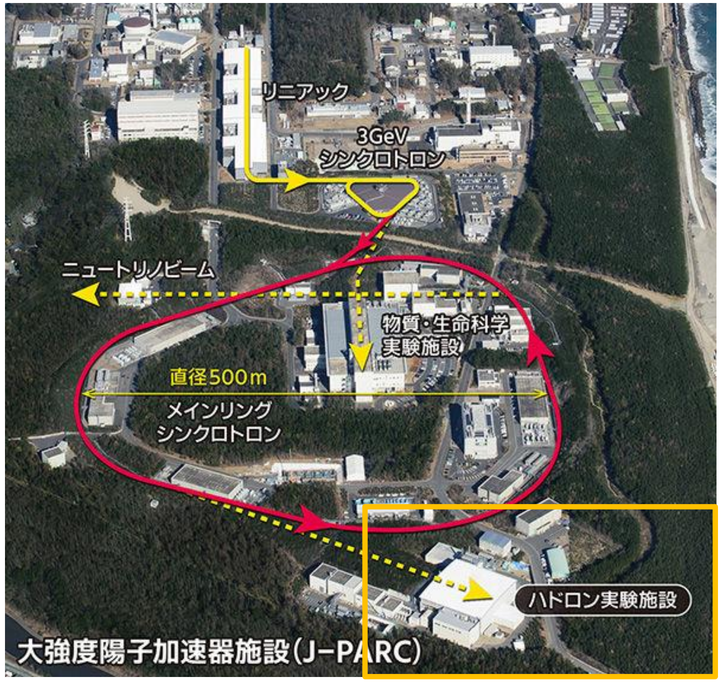
Example of a fixed target experiment

Triggered-type DAQ system
in the past J-PARC experiment

Past experiment in J-PARC hadron hall



$\Sigma^{\pm}p$ scattering experiment (J-PARC E40)



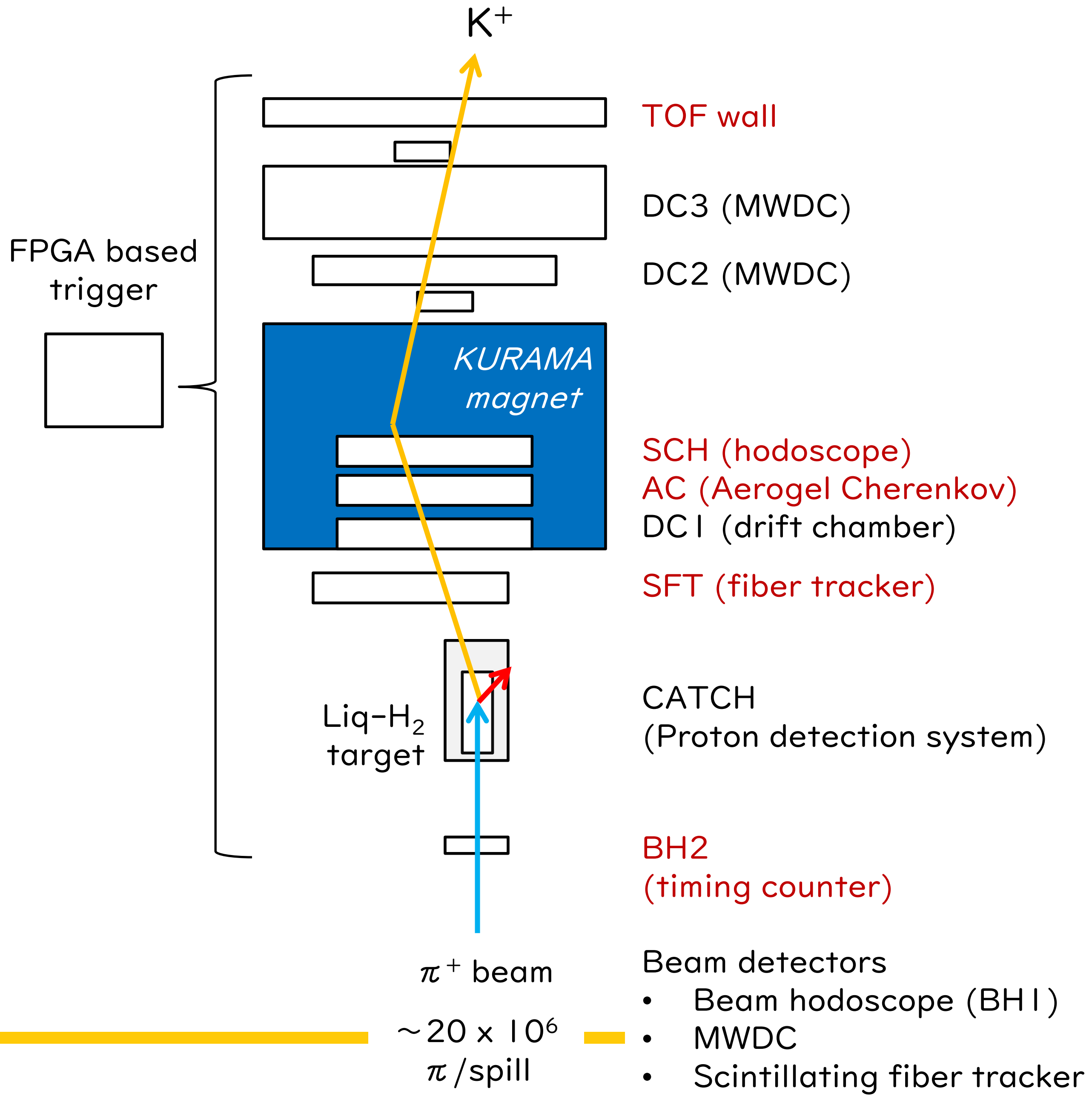
Double scattering experiment

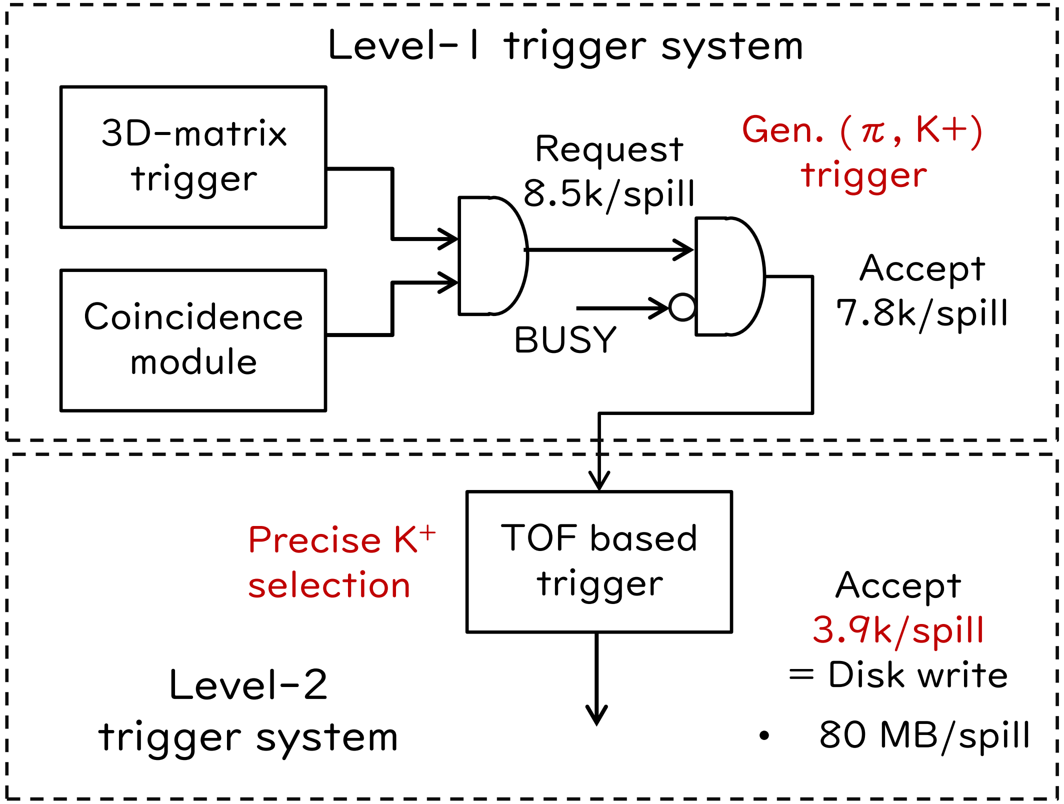
- Generate $\Sigma^{\pm}$ via $\pi^{\pm}p \rightarrow K^{+}\Sigma^{\pm}$
- Detect $\Sigma^{\pm}p$ scattering event

DAQ trigger: Beam π x scattered K^+

- Identification of K^+ was a key

Past experiment in J-PARC hadron hall

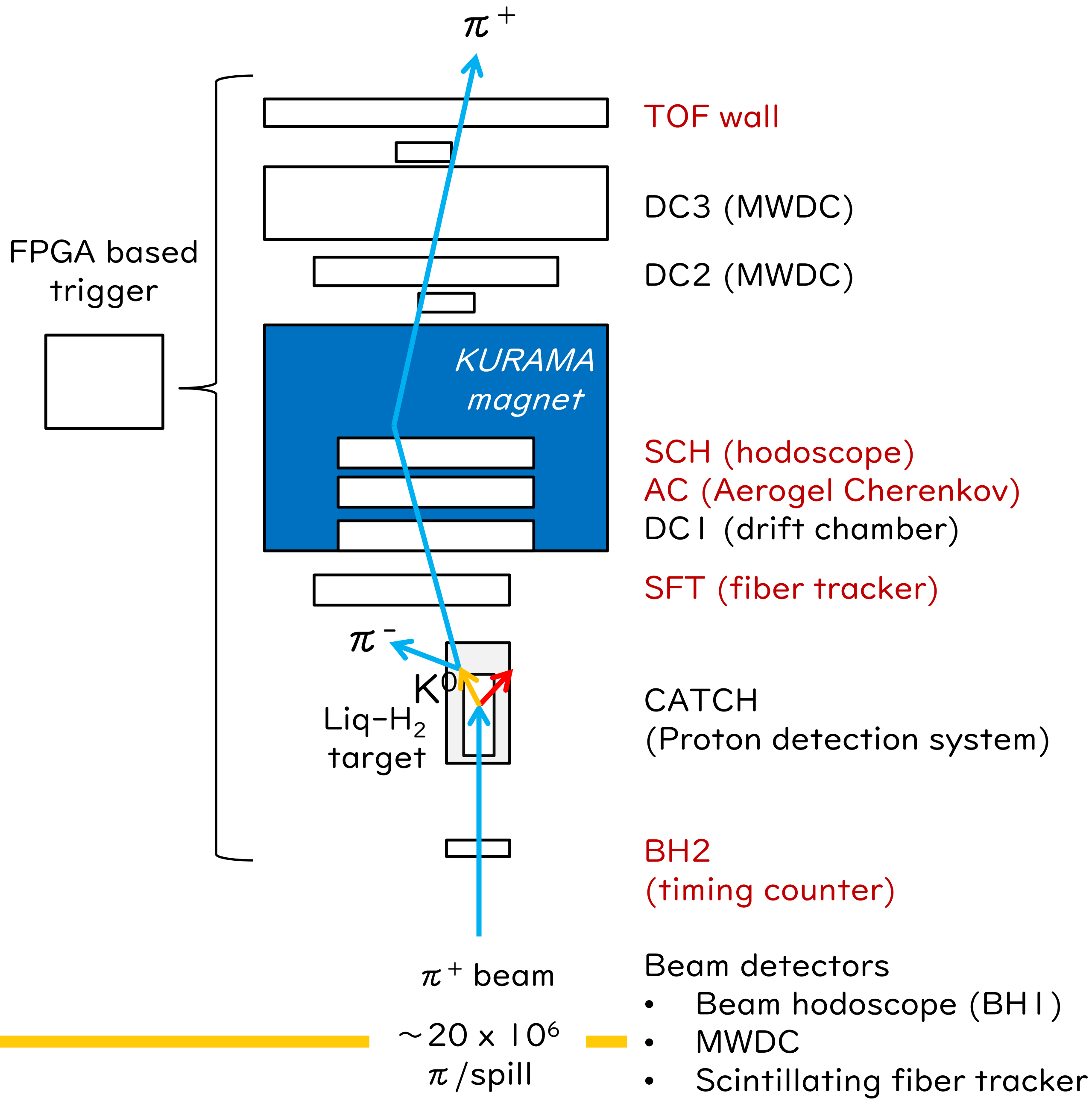




Breakdown of acquired data

- No KURAMA track **40%** (1.56k)
- Scattered particle found (2.34k)
  - π like 9.8%
  - K^+ like 4.4% (170)
  - p like 38.9%
  - Unknown 6.8%

Past experiment in J-PARC hadron hall



Byproduct channel

- Generate Λ via $\pi^- p \rightarrow K^0\Lambda$
- Detect Λp scattering event

This channel was almost rejected by the trigger since π^+ is background from the view point of K^+ identification

Limitation of the hardware trigger system

E40 level-1 trigger system was simple extension of the NIM module-based trigger system.
FPGA was used but basic concept of the trigger logic was just a logic coincidence.

- Unrealistic to include slow detectors (drift chamber)
- Simultaneous identification of K^+/K^0 was impossible for us at that time

OK!
Let's introduce a high-performance trigger system used in the collider experiments!

But it is not an easy way…

- Such the trigger system requires dedicated data links to gather hit information from FEE
  - Replacement of all FEEs is necessary to accept such the trigger module
- Development of the FPGA based complex trigger logic takes long time
  - It does not meet with the situation of short-span experiments

Belle-II UT3
(trigger logic module)

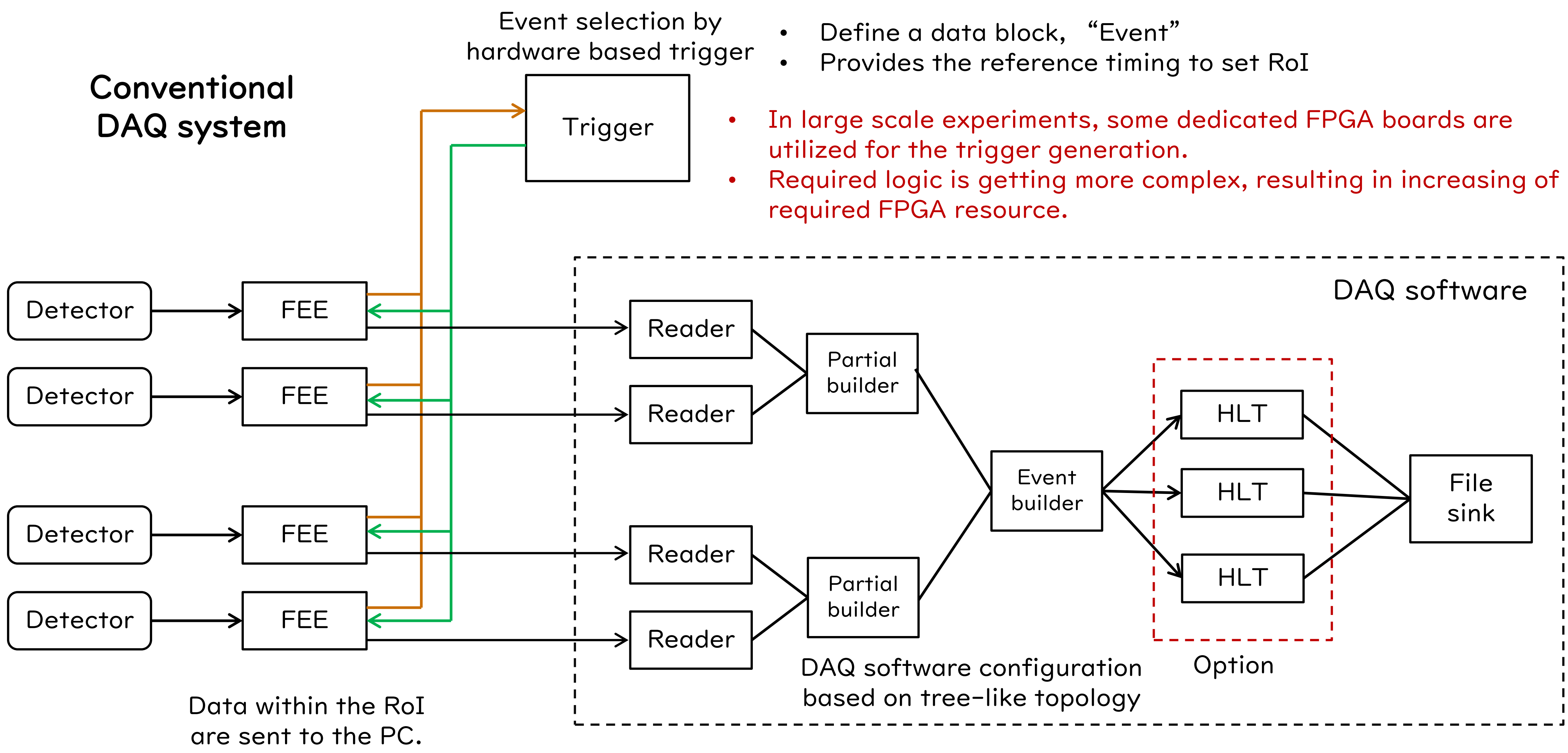
Toward a trigger-less data-streaming DAQ system

Overview of the conventional DAQ system

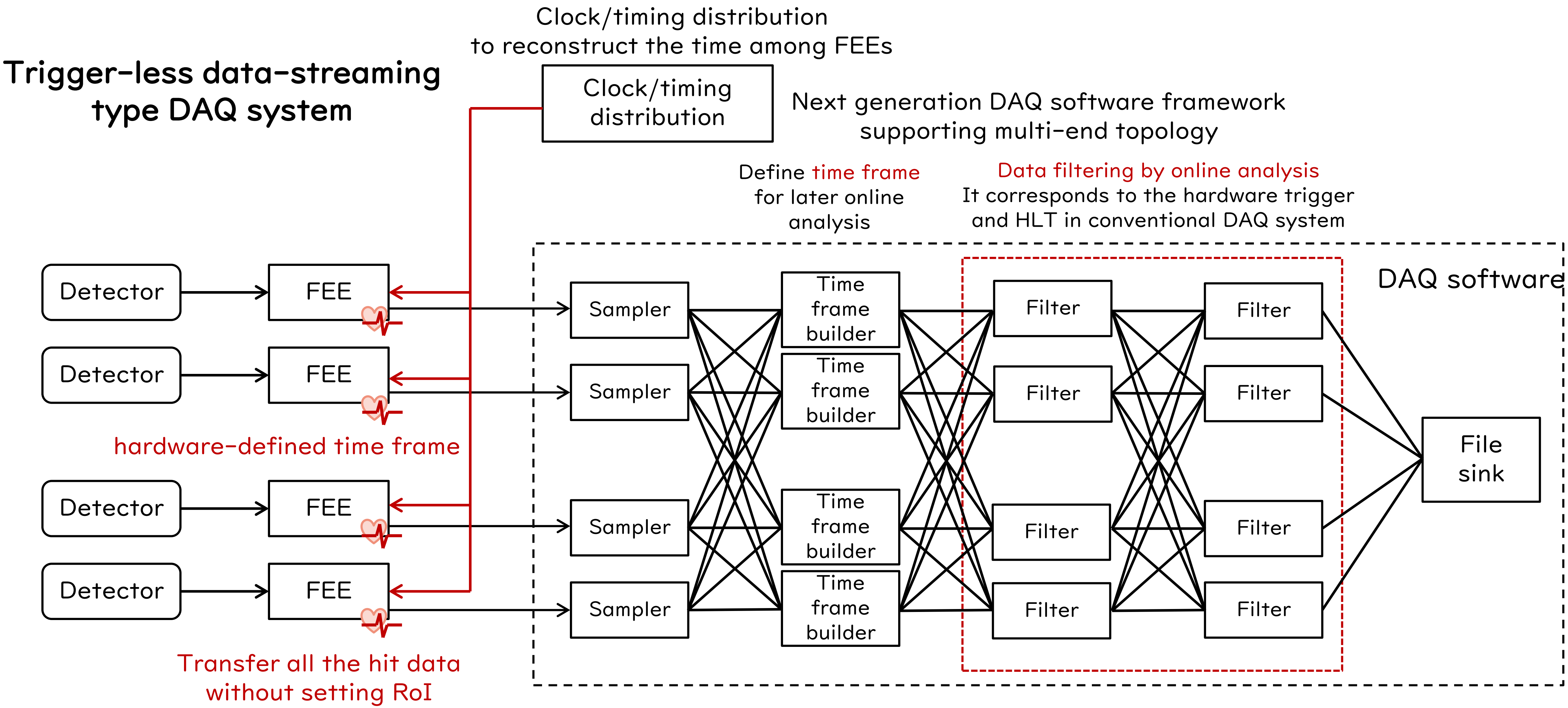
Conventional DAQ system

- Define a data block, "Event"
- Provides the reference timing to set RoI

- In large scale experiments, some dedicated FPGA boards are utilized for the trigger generation.
- Required logic is getting more complex, resulting in increasing of required FPGA resource.



Toward trigger-less data-streaming DAQ system



We would like to develop and standardize
the trigger-less DAQ system for various experiments.

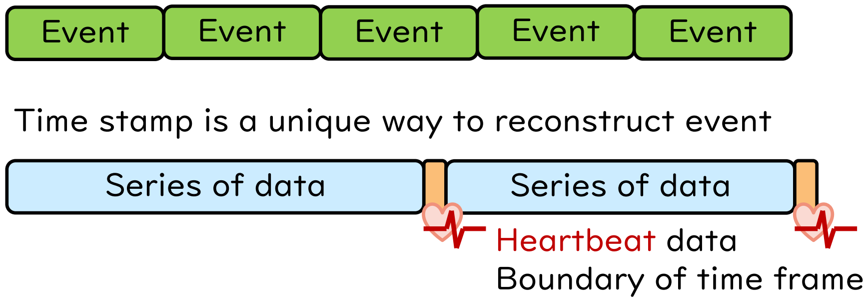
Key technologies for high-resolution streaming TDC

Define the time frame

From taking a picture to recording a video

Trigger

Trigger-less



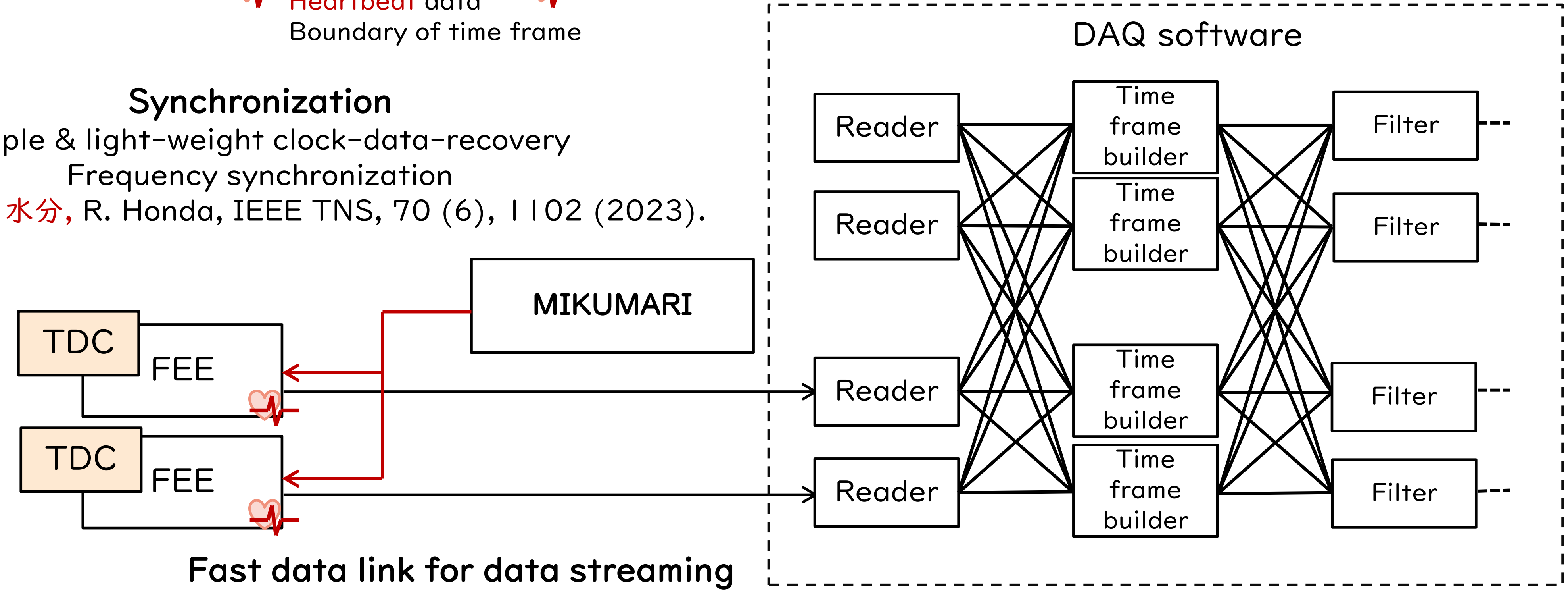
HDDAQ
DAQ-Middleware

NestDAQ

Support multi-end topology for load balancing

Synchronization

Simple & light-weight clock-data-recovery
Frequency synchronization
(MIKUMARI: 水分, R. Honda, IEEE TNS, 70 (6), 1102 (2023).



Fast data link for data streaming
(10Gbps Ethernet)

NestDAQ software

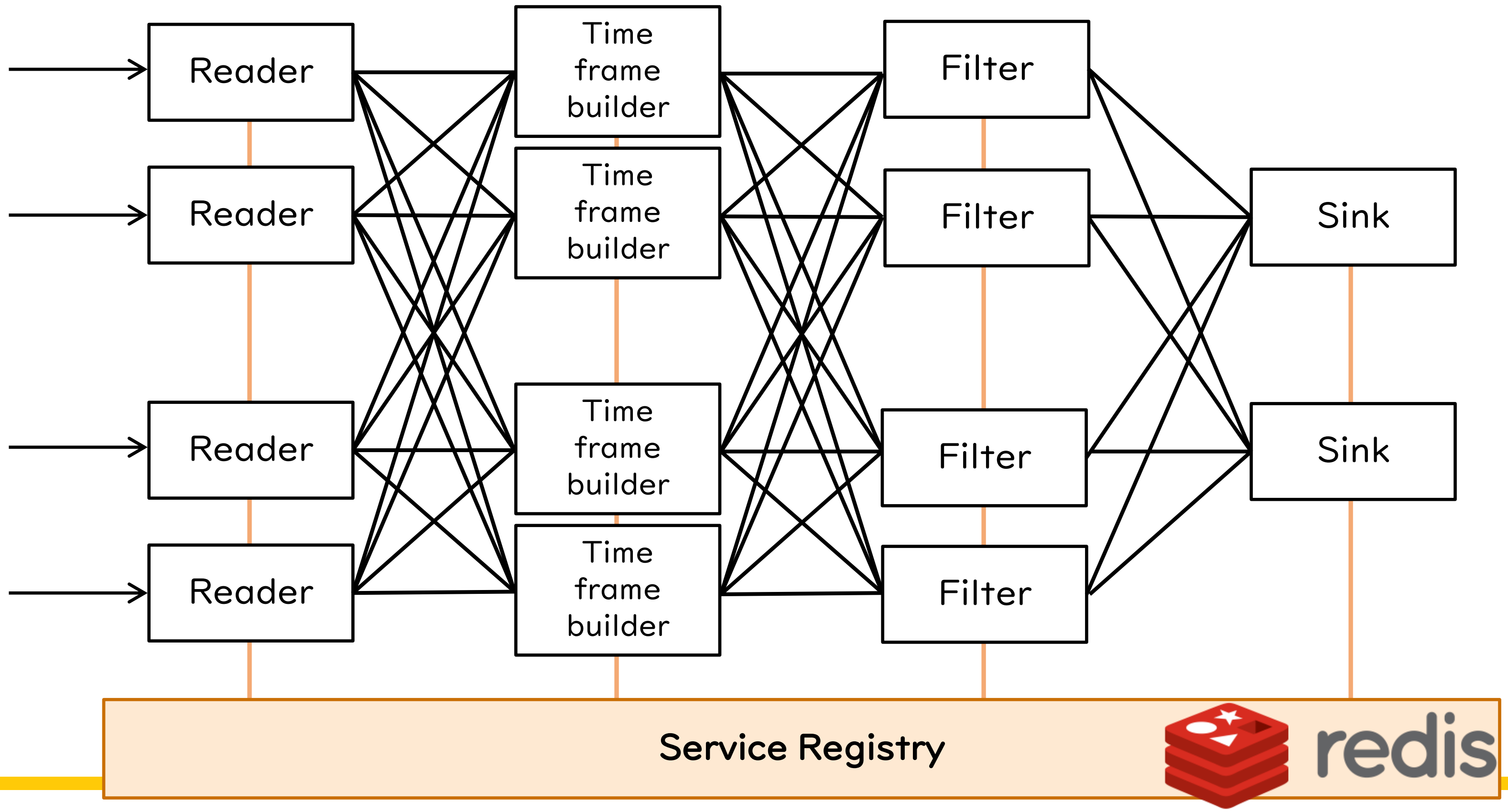
FairMQ, https://github.com/FairRootGroup/FairMQ

NestDAQ, https://github.com/spadi-alliance/nestdaq
T.N. Takahashi, IEEE TNS 70 (6), 922 (2023)

FairMQ based DAQ software frame work
- Entire control using service discovery by redis data base
    - Semi-automatic topology generation

Multi-end connection topology
- 1-to-n, m-to-1, n-to-m among processes

Load balancing
(Round robin)



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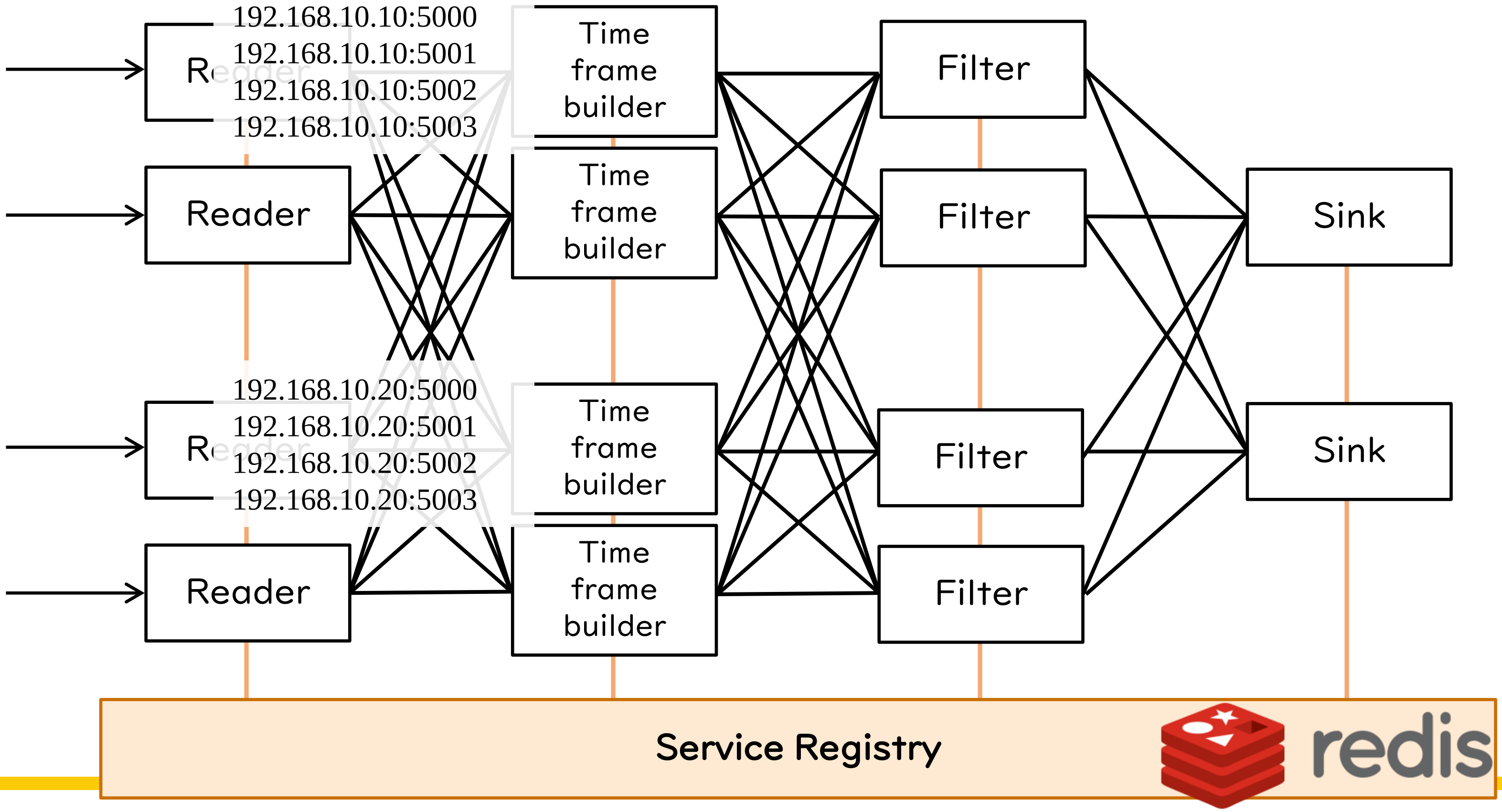

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FairMQ based DAQ software fra

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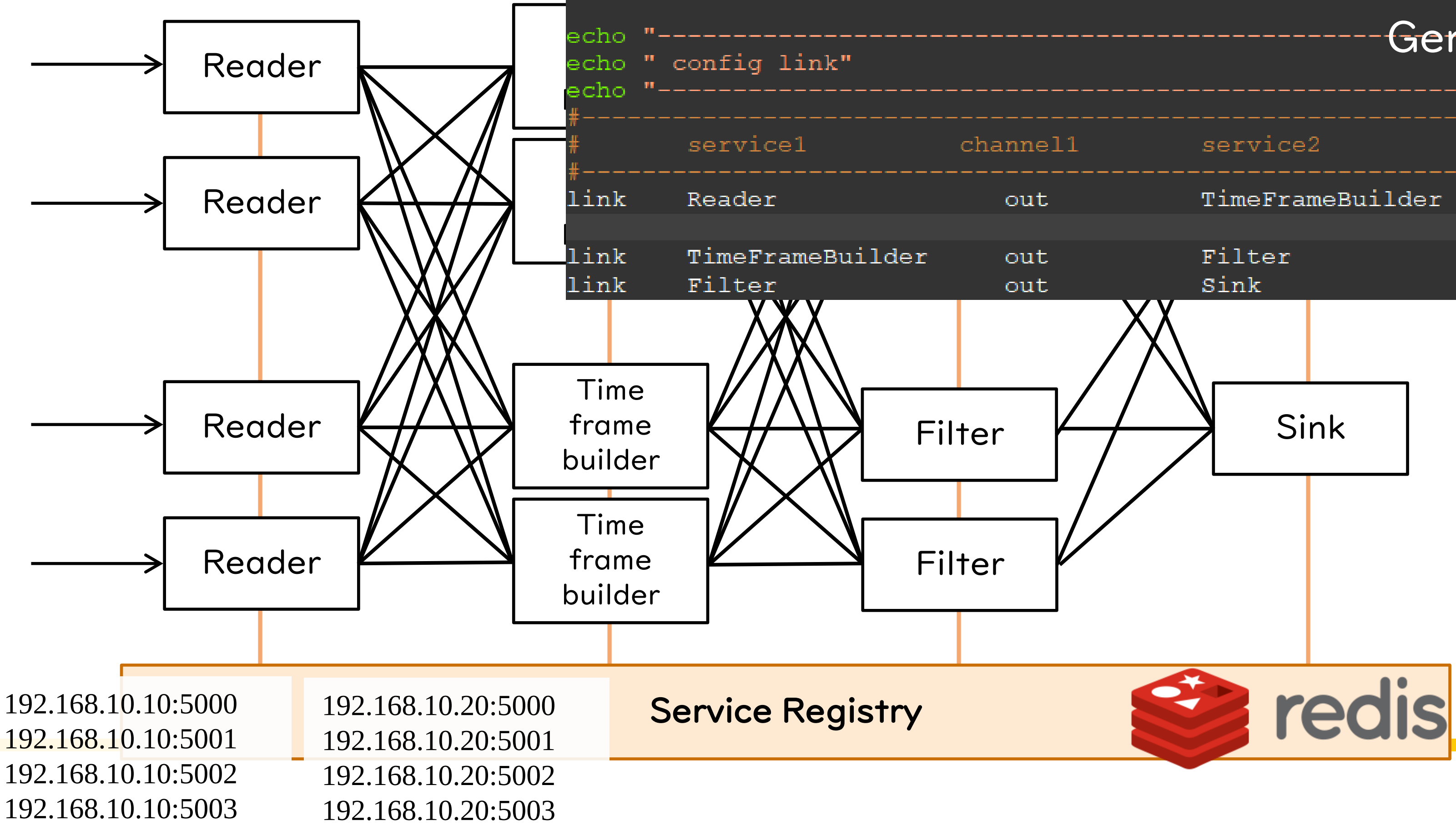
Multi-end connectio

- 1-to-n, m-to-1, n-t

```
#--------------------------------------------------------------------------
#            service                  channel           options
#--------------------------------------------------------------------------

# Reader
endpoint      Reader                  out              type push  method bind

# tf
endpoint      TimeFrameBuilder        in               type pull  method connect
endpoint      TimeFrameBuilder        out              type push  method connect autoSubChannel true

# filter
endpoint      Filter                  in               type pull  method bind
endpoint      Filter                  out              type push  method connect autSubChannel true

# Sink
endpoint      Sink                    in               type pull  method bind

echo "------------------------------------------------------------------------"
echo " config link"
echo "------------------------------------------------------------------------"
#--------------------------------------------------------------------------
#       service1            channel1          service2           channel2
#--------------------------------------------------------------------------
link     Reader                  out          TimeFrameBuilder   in

link     TimeFrameBuilder        out          Filter             in
link     Filter                  out          Sink               in
```

Generated with only these descriptions!



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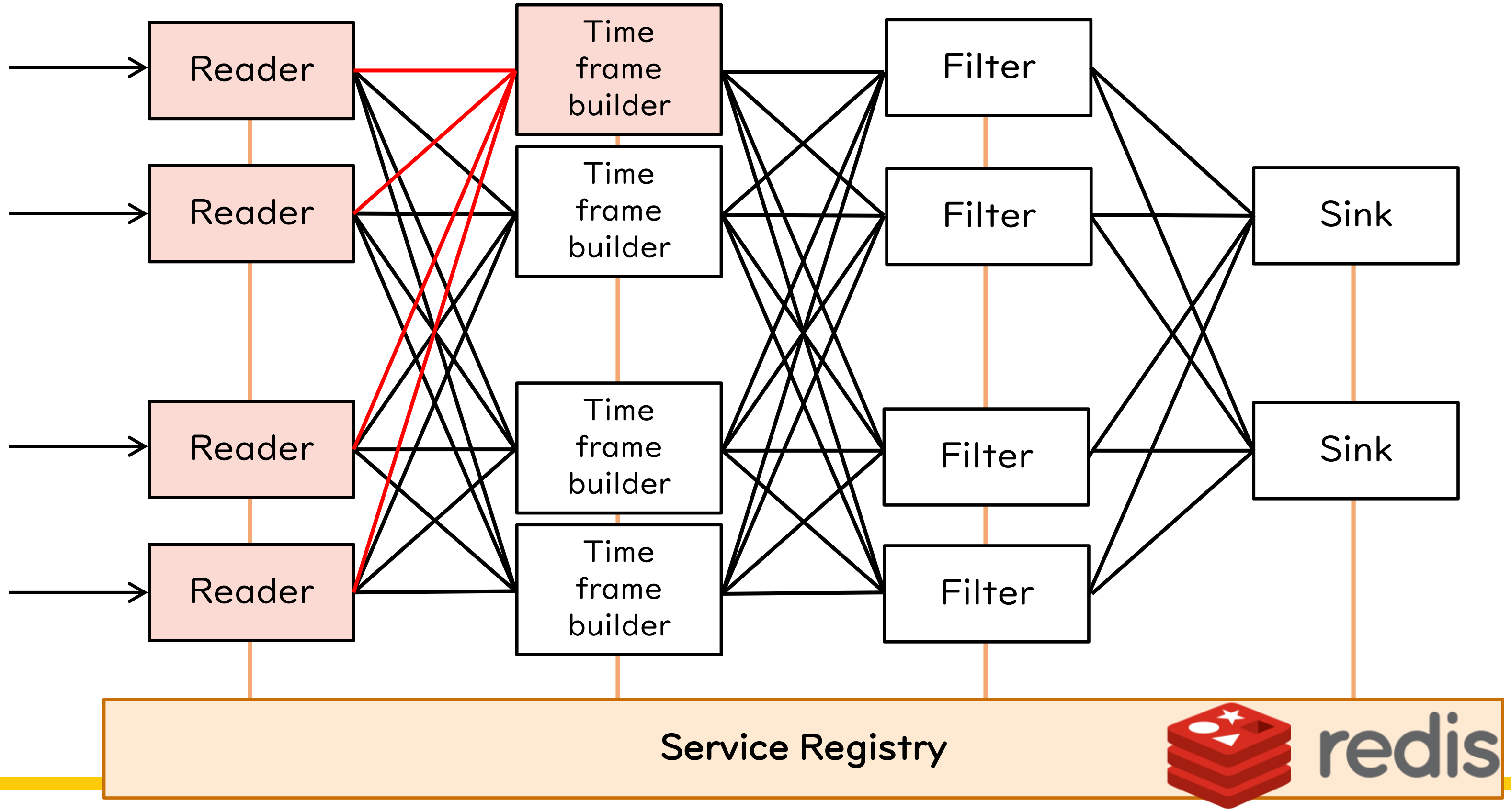

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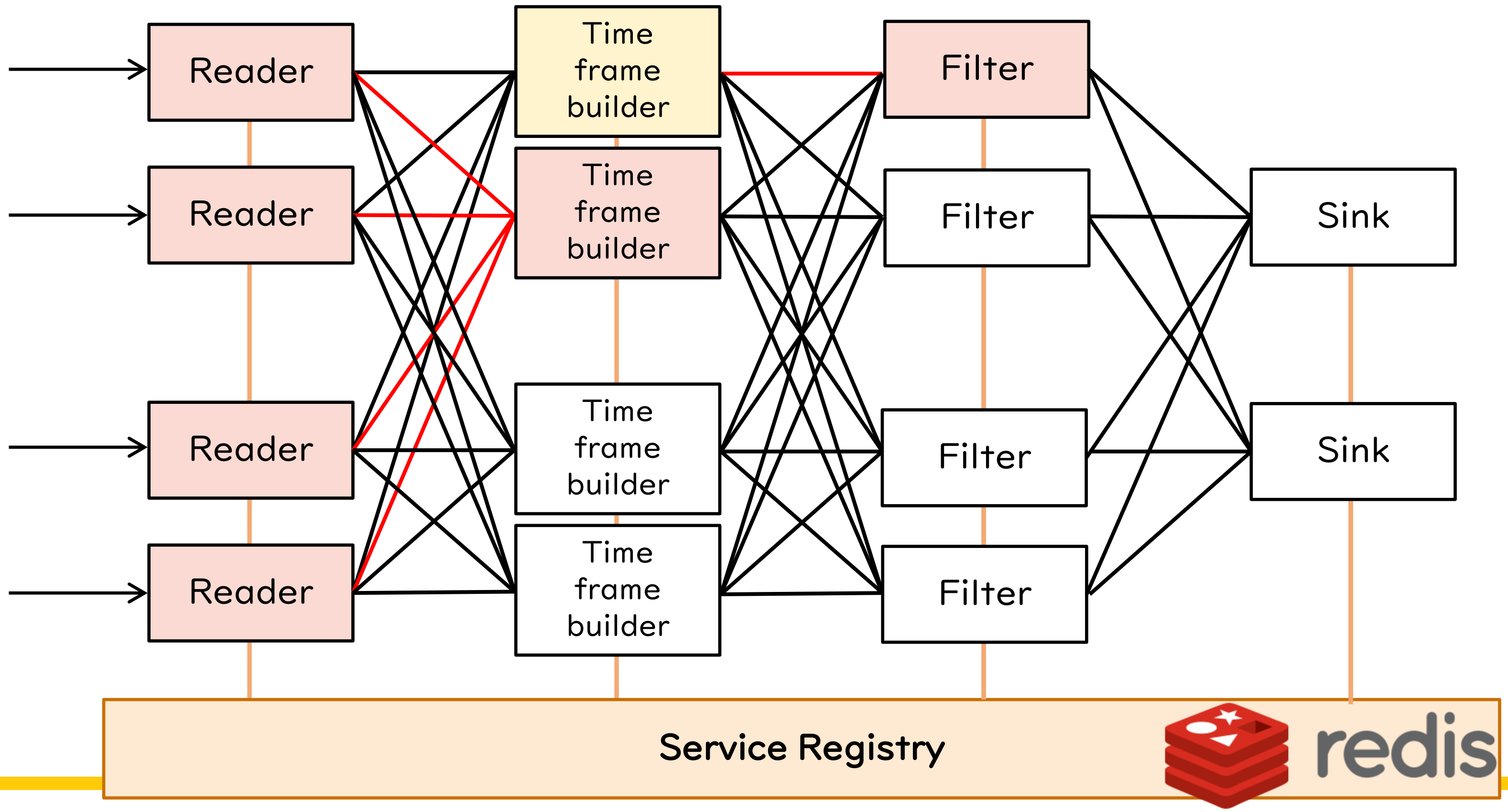

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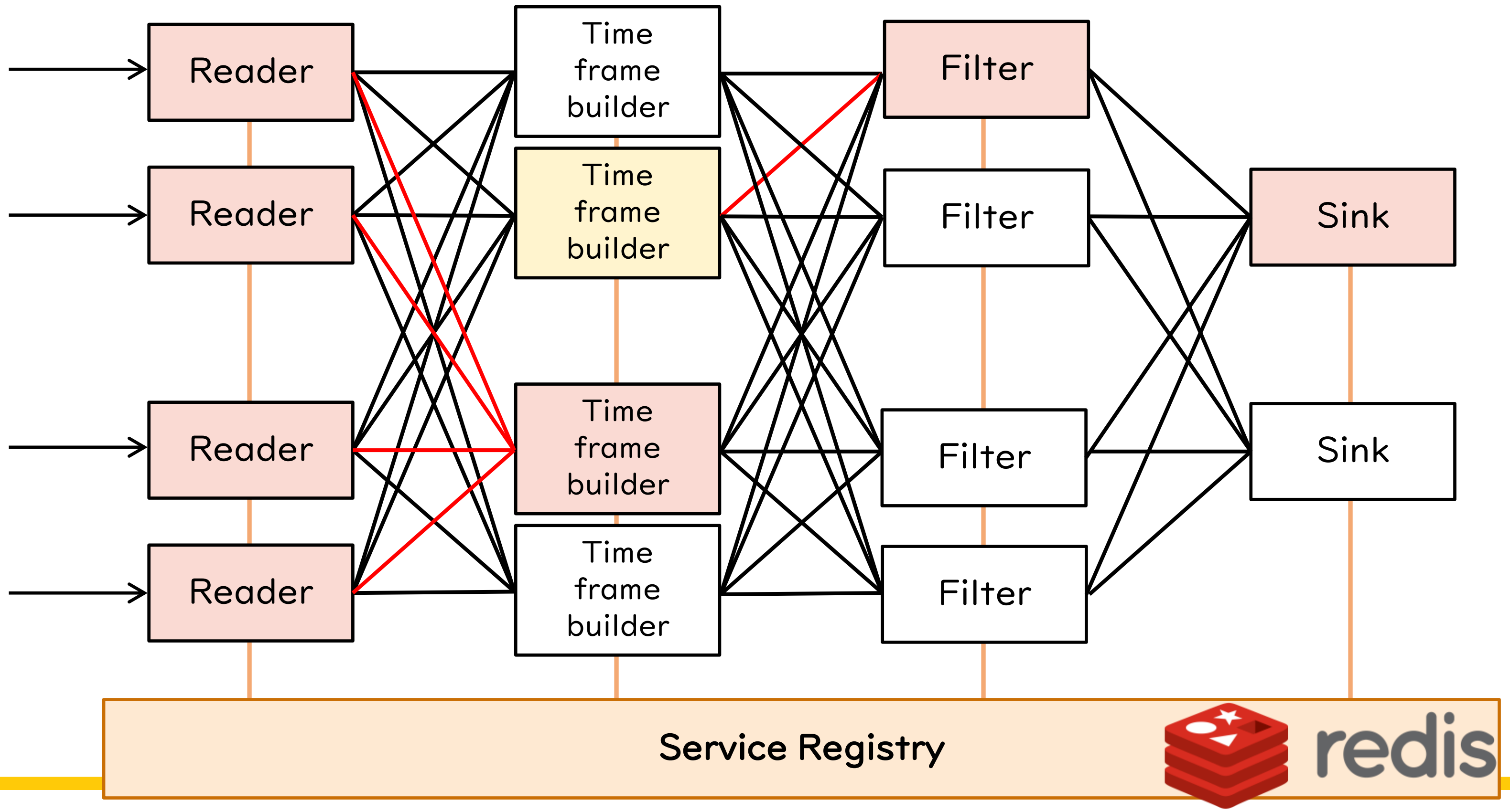
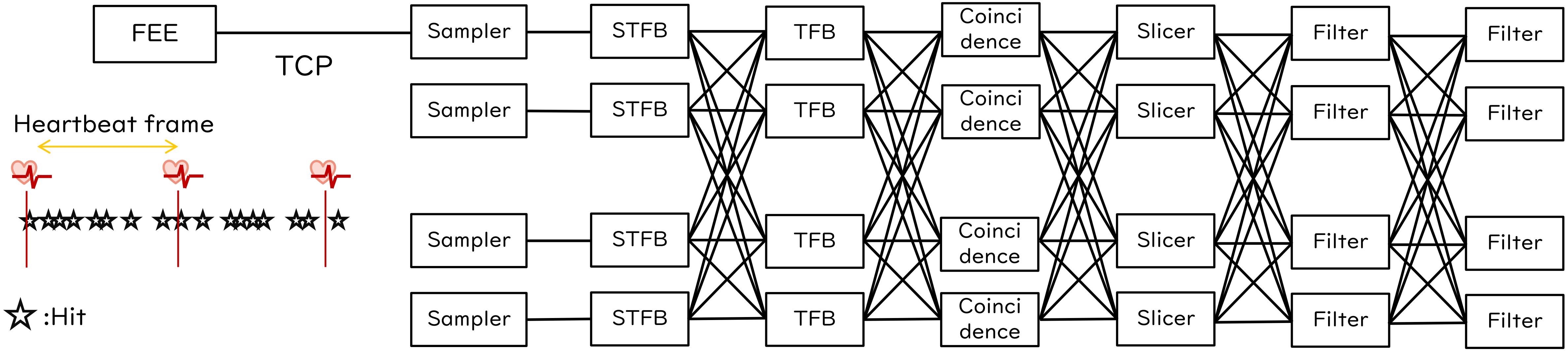
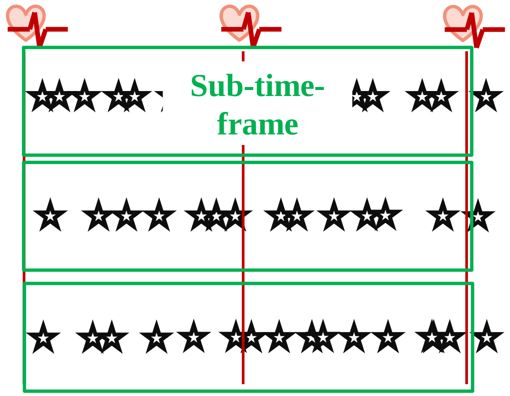


Present our DAQ scheme

- Data structure starts from the heartbeat frame (524us length) defined by FEE. It is transformed to event based data fragments through Coincidence and Slicer processes.
- Filter analyzes data with the same way that of T-DAQ.





- Build a sub-time-frame containing some heartbeat frames.

Present our DAQ scheme

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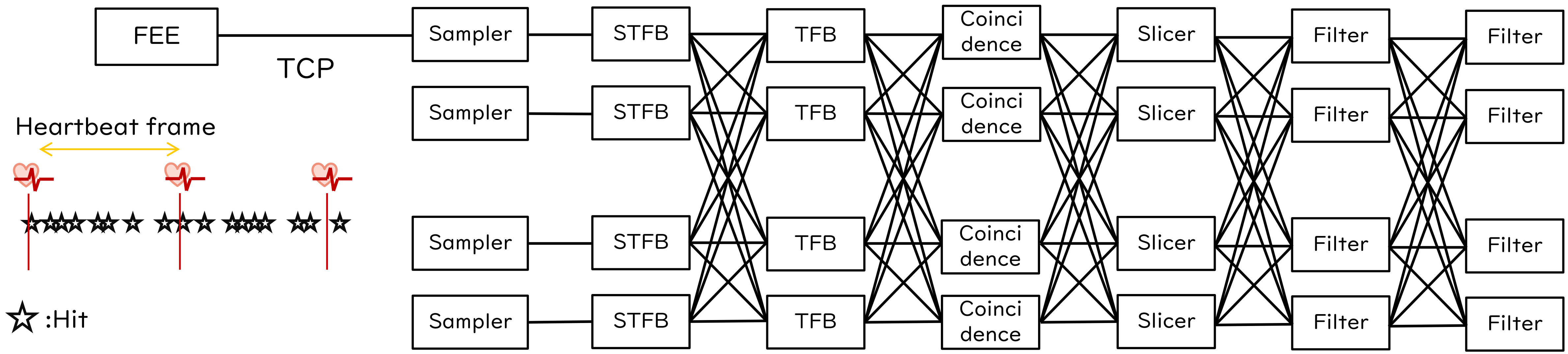

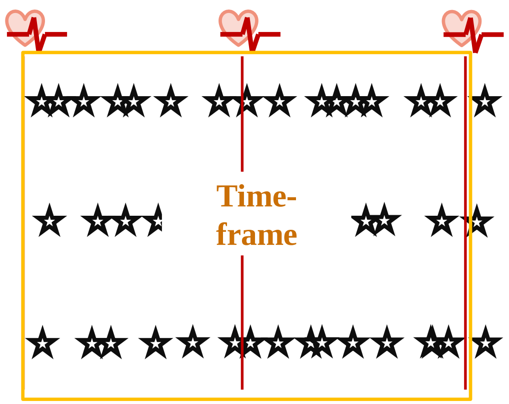

- Build a time-frame which has SFTs.

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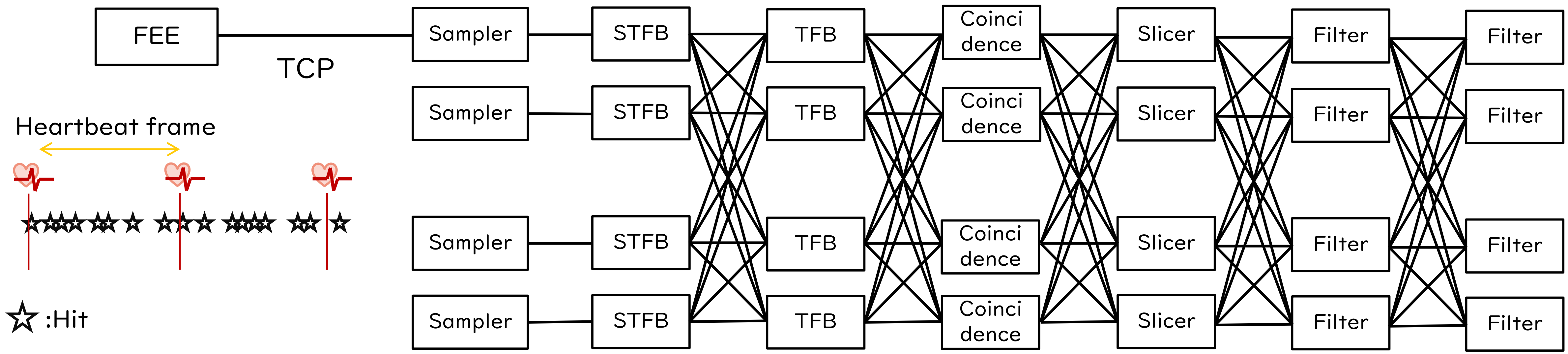
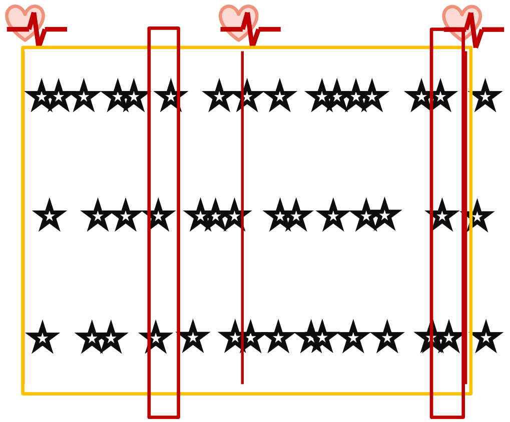


- Apply coincidence logic among fast detectors



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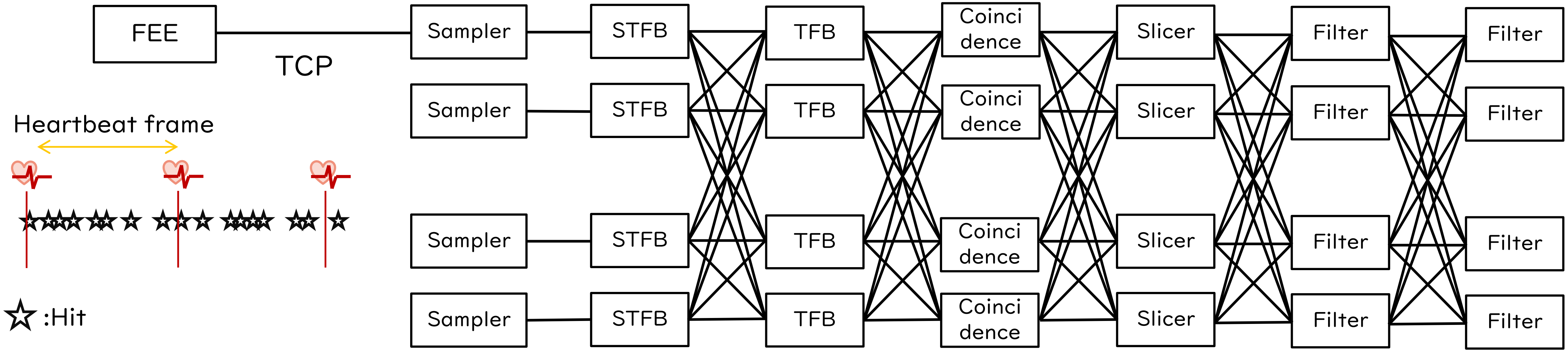
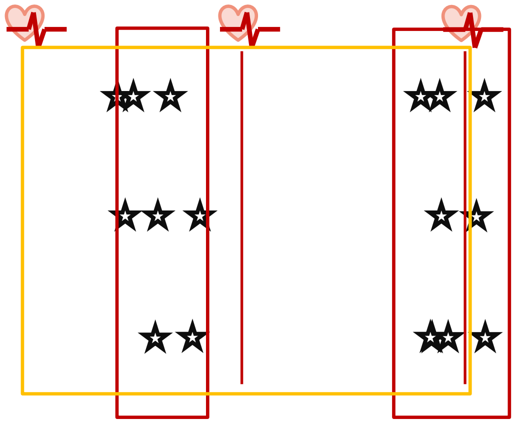
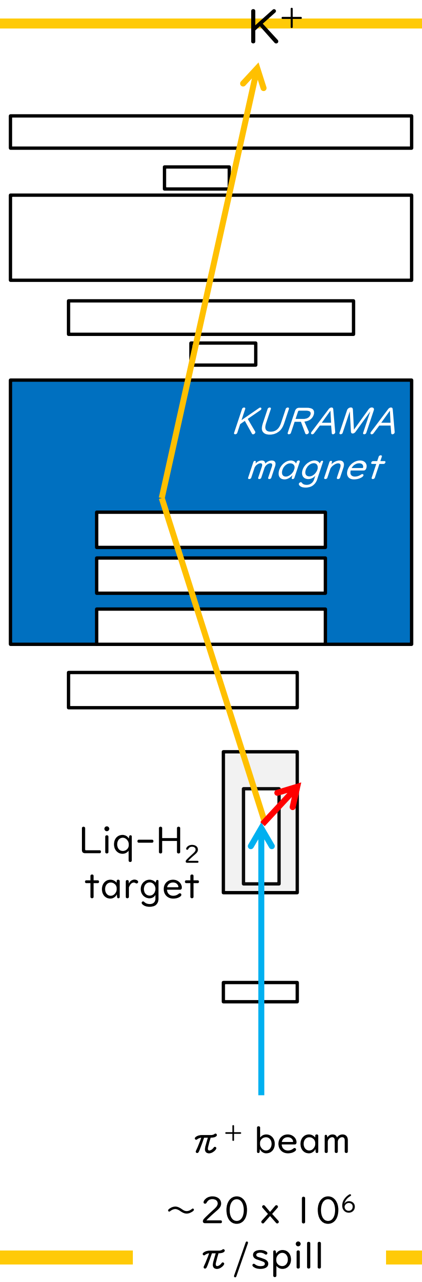


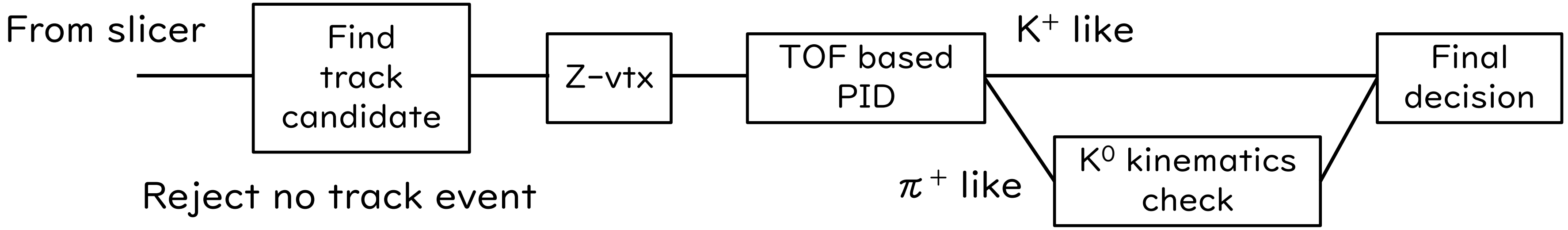
- Slice data based on the coincidence trigger.
- It corresponds basic data fragments (≒ Event) to be filtered later.



Thought experiment



If this system had been used in the E40 experiment…

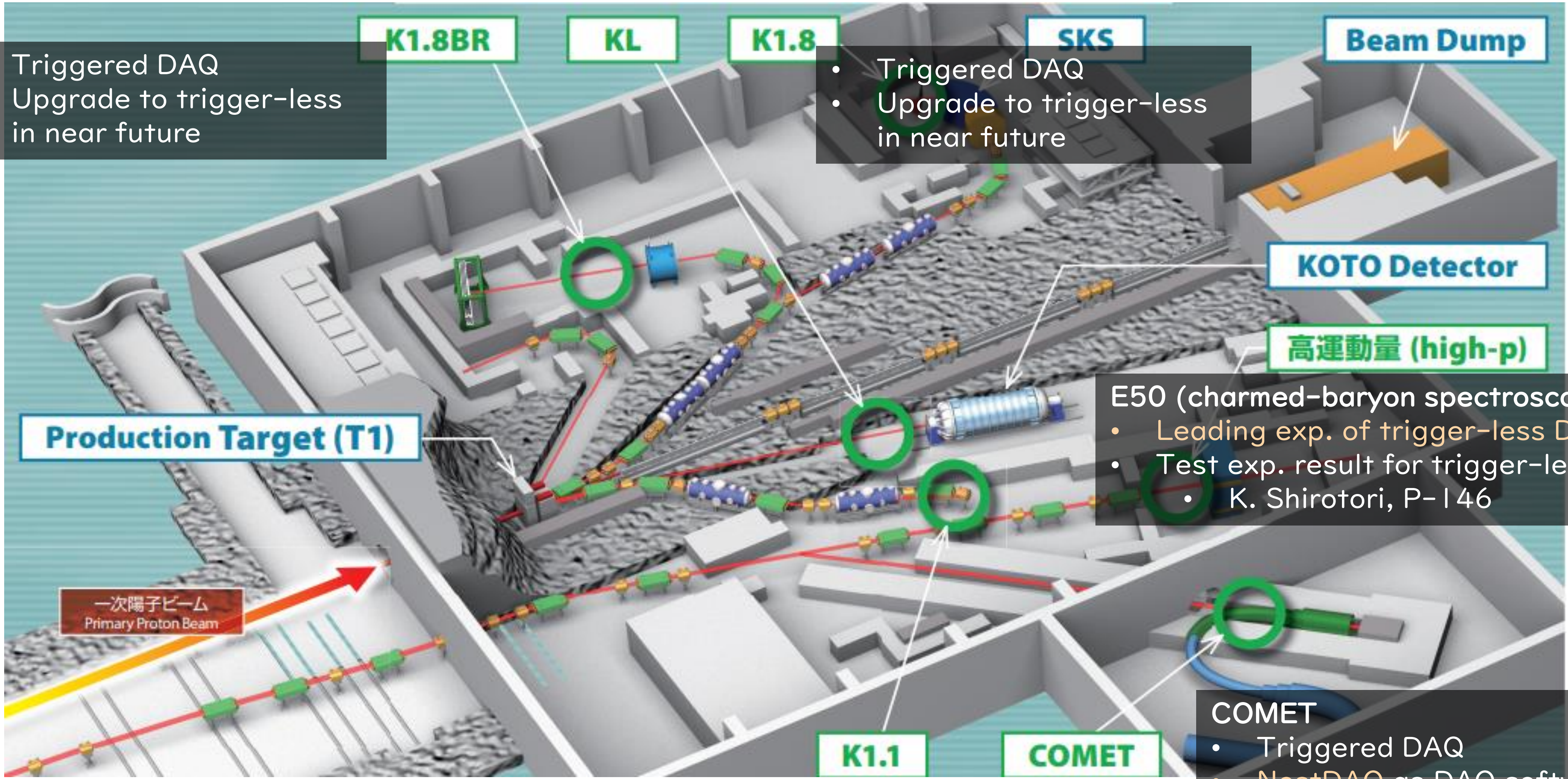


- Slow detectors join to the trigger logic.
  - It was impossible in the actual E40 experiment
  - It will allow us to suppress the beam background by using z-vtx information.
- Decision process can be switched based the PID results.
  - K^0 channel, which was rejected in the actual E40, can be survived in principle.

Flexibility and scalability are feature of the trigger-less DAQ system.
It provides a new choice for the DAQ system for the physics experiments.

Implementation in J-PARC experiments and in other facilities

Implementation in hadron facility



- Triggered DAQ
- Upgrade to trigger-less in near future

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- Upgrade to trigger-less in near future

E50 (charmed-baryon spectroscopy)@ π20

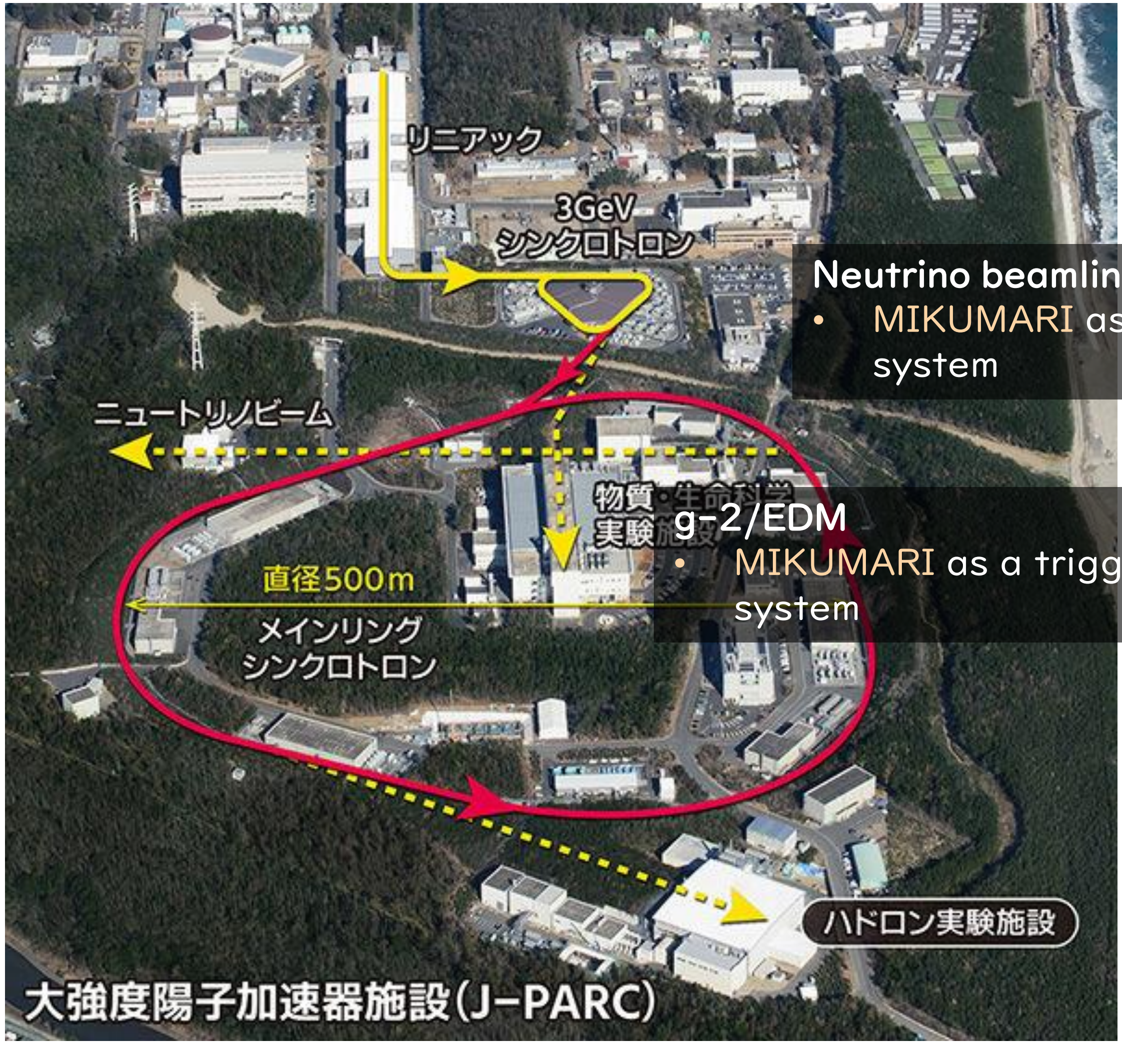
- Leading exp. of trigger-less DAQ
- Test exp. result for trigger-less DAQ
  - K. Shirotori, P-146

COMET

- Triggered DAQ
- NestDAQ as DAQ software

We are planning to introduce the trigger-less DAQ system
into new beamlines constructed in the hadron facility extension project

Implementation in J-PARC



MIKUMARI: Link protocol for clock synchronization

Neutrino beamline

- MIKUMARI as a timing distribution system

g-2/EDM

- MIKUMARI as a trigger distribution system

Replacement of DAQ-middleware with NestDAQ

NestDAQ is an abstract of DAQ software

Standardization of the trigger-less DAQ system

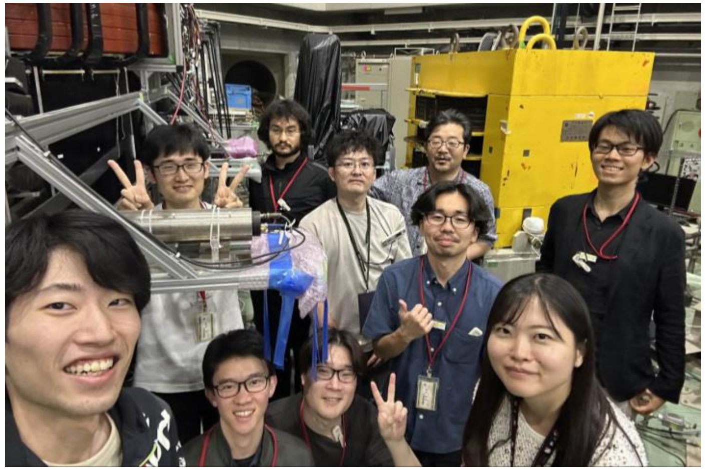
Standardize the developed DAQ system under the SPADI alliance
Use the same system in different facilities

SPADI Alliance
Signal processing and data acquisition infrastructure alliance

J-PARC hadron T103

RCNP Grand RAIDEN

RARIS (ELPH) BL monitor



Standardization of DAQ makes it easier for people and instruments to move around.
Develop and maintain the DAQ system throughout our research field

Summary

- The general-purpose trigger-less DAQ system is under development as the next generation DAQ system
  - Features: flexibility and scalability
  - It relieves us from the development of the complex hardware trigger system

- Three key technologies for the trigger-less DAQ system
  - Clock synchronization (MIKUMARI, LACCP)
  - Fast data link
  - DAQ software framework (NestDAQ), which supports
    - Multi-end connection topology
    - Load balancing

- Thought experiment: If this system had been used in the E40 experiment…
  - Slow detectors can join to the trigger logic; it was impossible for the simple coincidence based trigger system
  - K^0 channel, which was rejected in the actual E40, can be survived in principle.

- Standardization of the developed DAQ system is ongoing under the SPADI alliance

Why trigger-less DAQ system?

Background

- High-intensity (luminosity) beams require more complex trigger logic due to the increase of accidental background.
    - Excellent trigger systems using FPGAs have been successfully used in large-scale experiments, but it is unlikely that the same thing can be done in small- and middle-scale experiments.
    - Barriers to entry for FPGA are high due to its high-education cost, and it is critical for shared beamlines. The detector setup and the trigger logic frequently change experiment by experiment.

Merit

- The fully-software-based trigger logic allows us to include multi-channel slow detector such as wire chambers to the trigger; this is almost impossible for the conventional NIM module based trigger system.
- Software is easier to develop and debug than FPGA firmware, leading to user entry.

The trigger-less DAQ system has advantages for small- and middle-scale experiments,
and of course for large-scale experiments.
Stop the Galapagosization (independent evolution) of DAQ systems in each facility and concentrate development resources.