Test experiment of the streaming DAQ by using hadron beam at J-PARC

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for the J-PARC MARQ collaboration,
the SPAID Alliance

Research Center for Nuclear Physics (RCNP)
Osaka University

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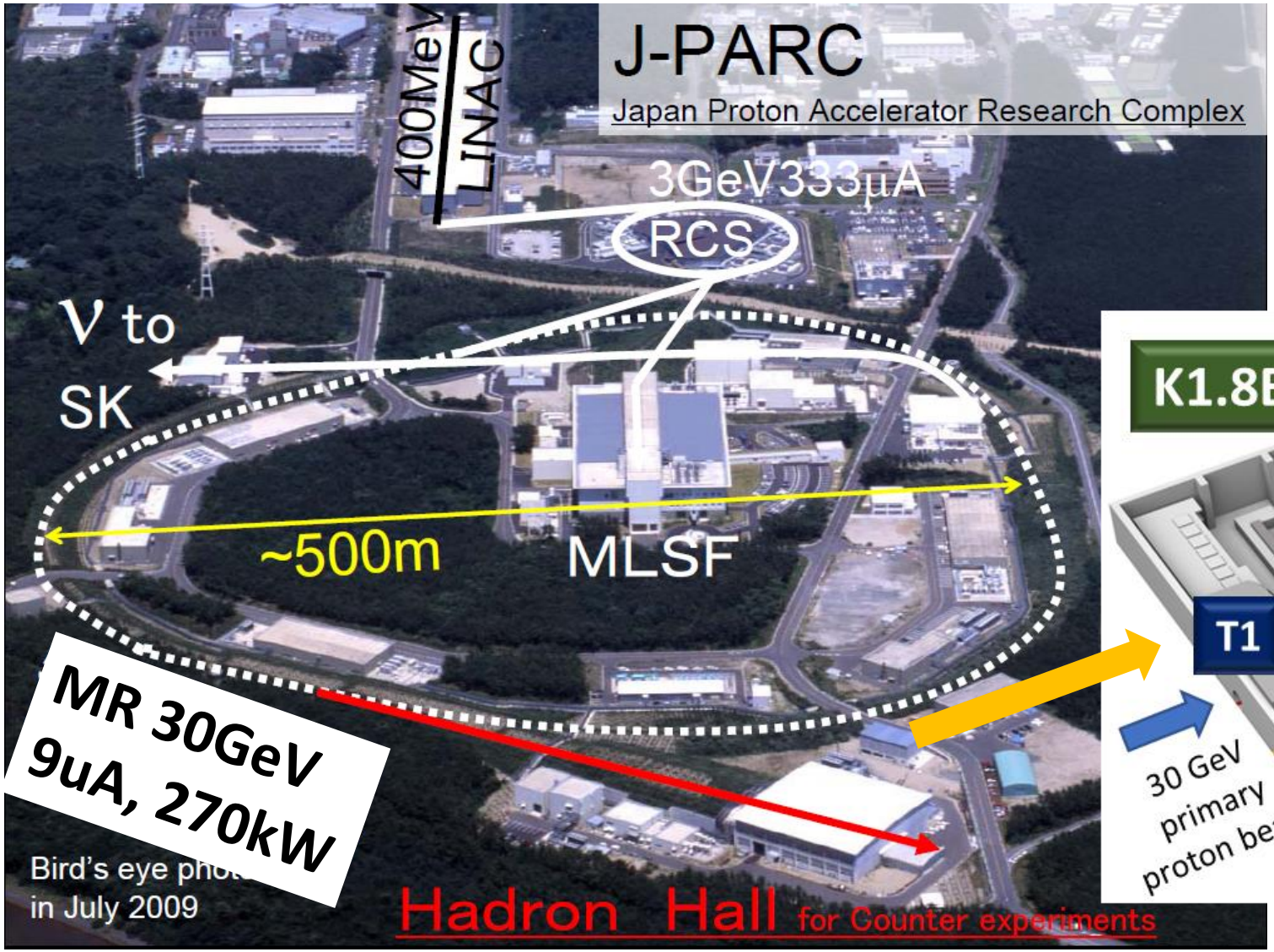
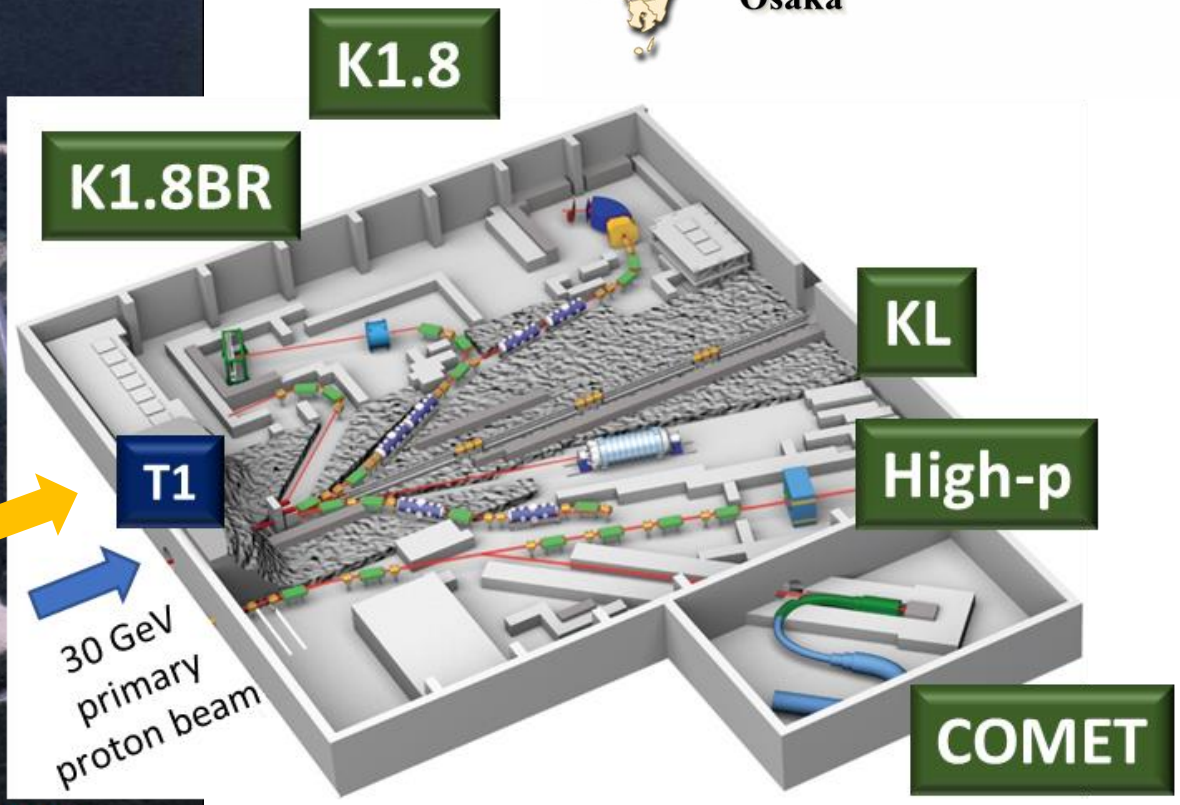
Contents

Introduction

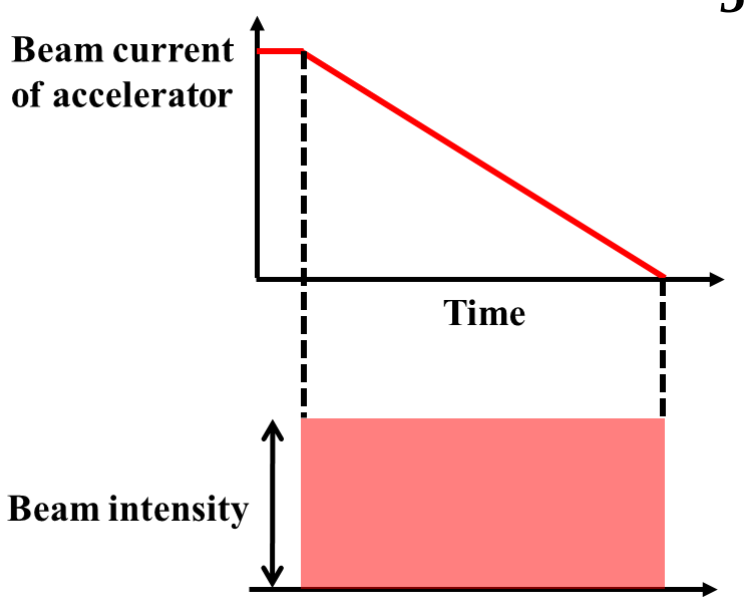
J-PARC & Hadron Experimental Facility



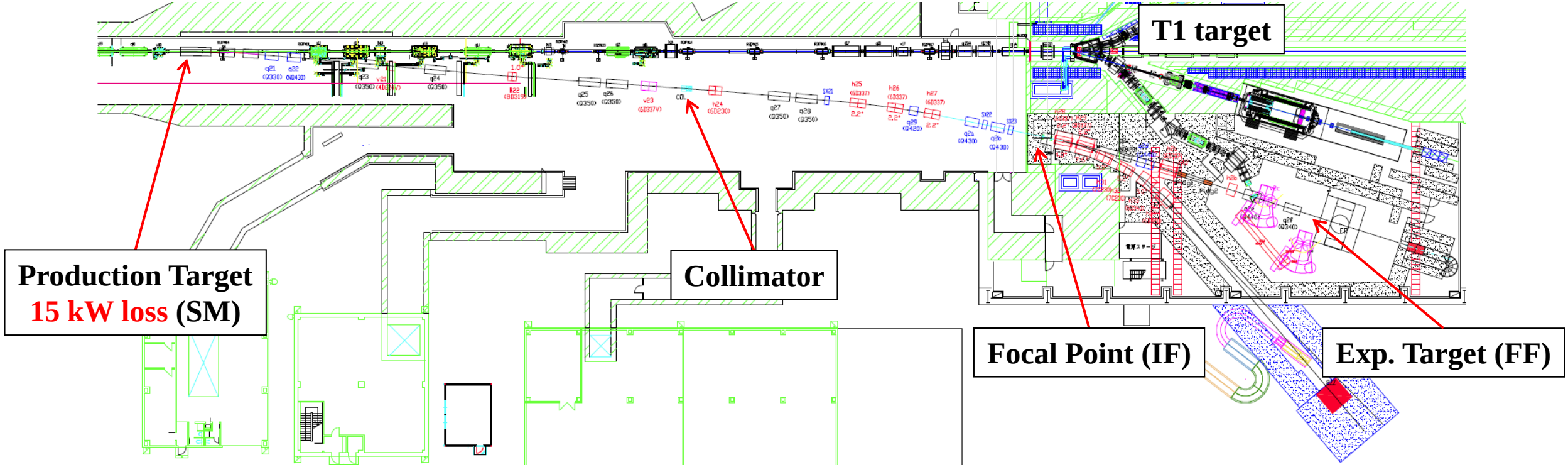


World's highest level intensity proton beam ⇒ Beam power 80 kW

High-p beam line for 2ndary beam: π20



- ∗ Slow extraction for continuous beam
  - Spill structure: 2.0 sec. extract. / 4.2 sec. cycle
- High intensity: $>10^7$ /spill for $\pi^{\pm}$, p @ 2–20 GeV/c
  - $>10^5$ /spill for K^-, anti-p
- High momentum-resolution beam: $\Delta p/p = 0.1\%(\sigma)$

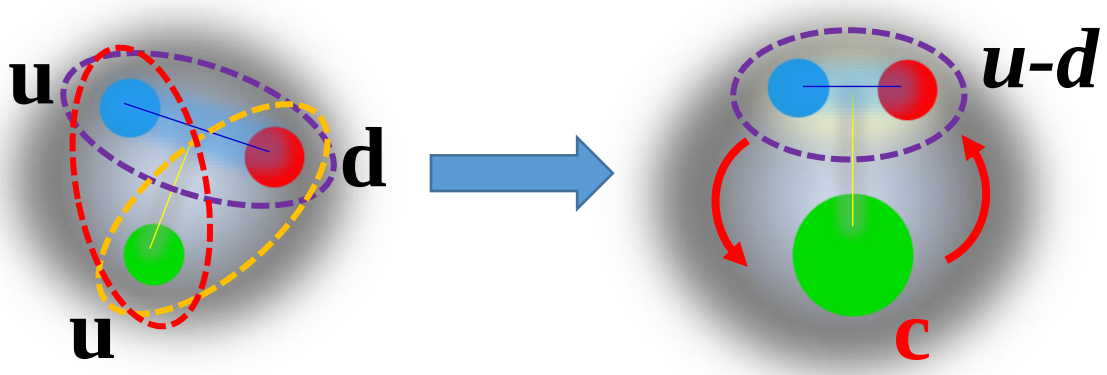


Charmed baryon spectroscopy: J-PARC E50

- **Effective degrees of freedom of hadron: Diqaurk correlation**

⇒ Internal structure of charmed baryon

Light quark baryon **Charmed baryon**



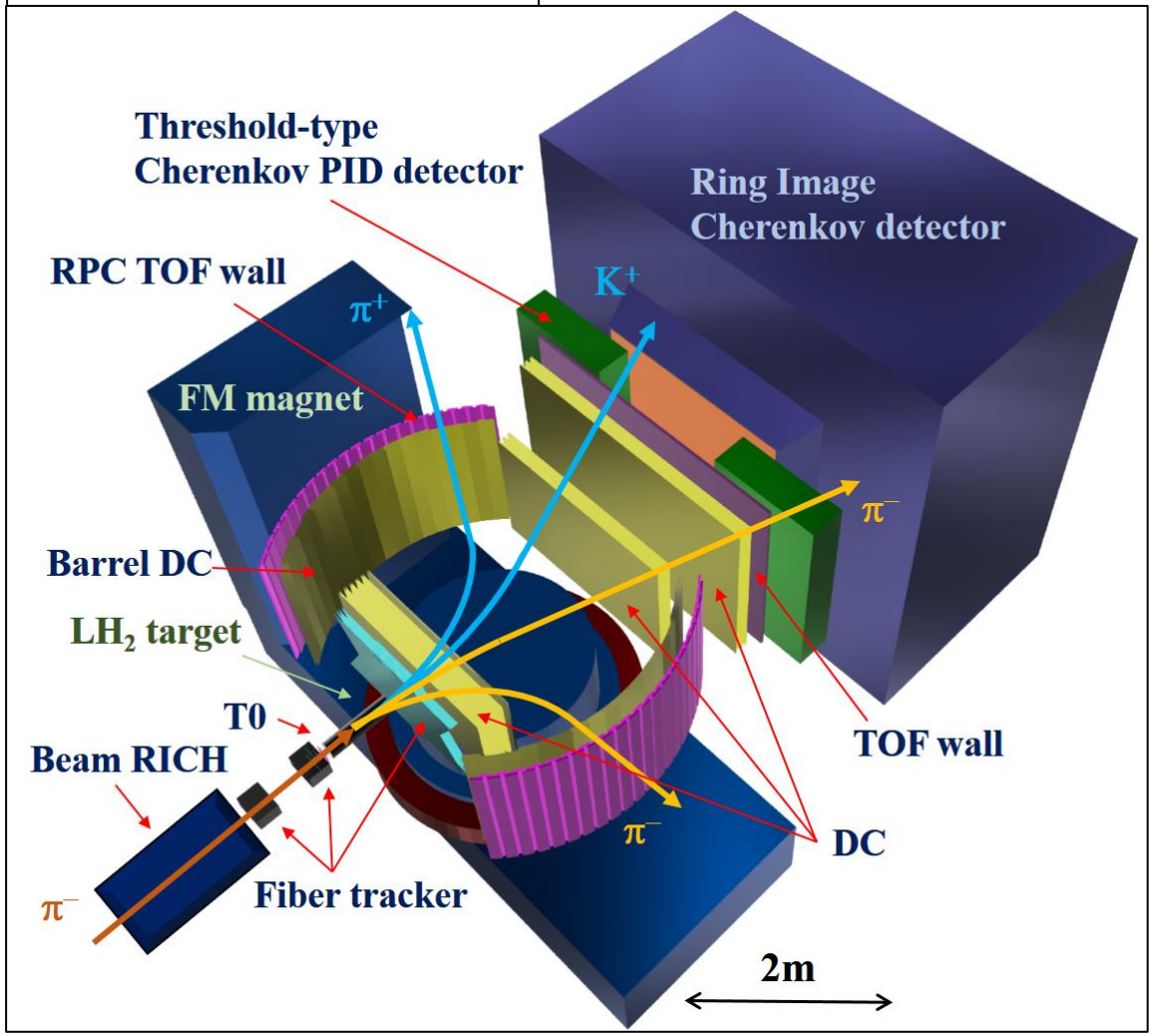
∗ Experiment: Production and decay

- **Missing mass method:** $\pi^- + p \rightarrow \boxed{Y_c^{*+}} + D^{*-}$
  - **20 GeV/c π^- beam @ 30 Mcps** $\rightarrow K^+ \pi^- \pi^-$

⇒ Construction of multi-purpose system

∗ Trigger-less streaming-readout DAQ

MARQ Spectrometer



Front-End-Electronics (FEE)

∗ Total detector channel ~30,000 ch

⇒ Streaming DAQ: Only timing data (TDC)
- FEE: 1G/10Gbps network (SiTCP)
- Timing synchronization (MIKUMARI)

- MPPC detector: ~25,000 ch
  - Scintillating fiber trackers
  - RICH, Beam-RICH, Vth AC

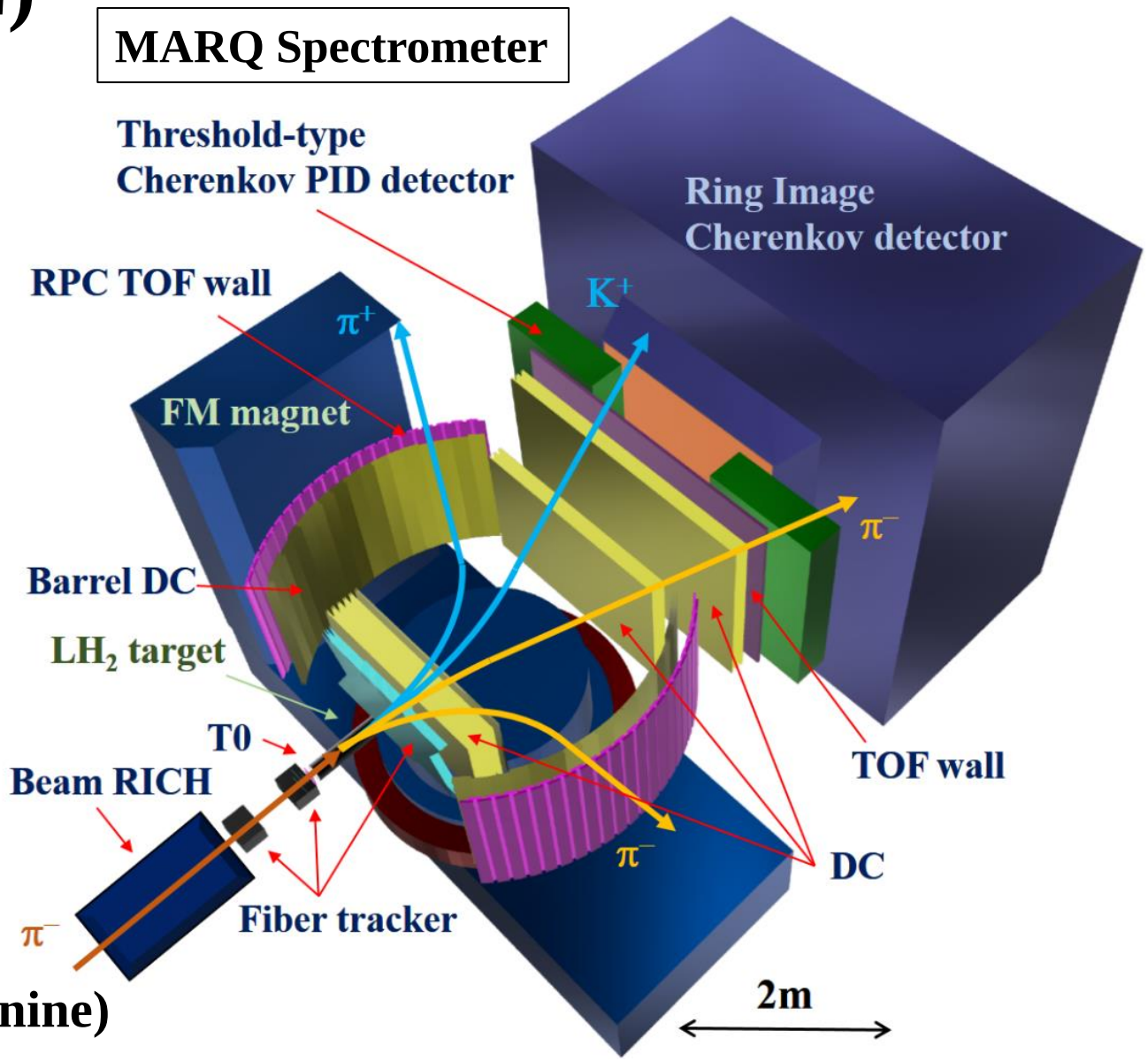
⇒ CIRASAME (ASIC: CITIROC)
- 128 ch Low-resolution TDC (ΔT_{LSB} ~ 1 ns)

- Timing detector: ~1,000 ch
  - T0, RPC, TOF: Amp/PMT + Discriminator

⇒ AMANEQ (HR-TDC mezzanine)
- 64 ch High-resolution TDC (ΔT_{LSB} ~ 20 ps)

- Drift chamber: ~4,000 ch

⇒ ASAGI(ASD) card + AMANEQ (DC mezzanine)
- ASD card 32 ch → TDC 128 ch
- Low-resolution TDC (ΔT_{LSB} ~ 1 ns)



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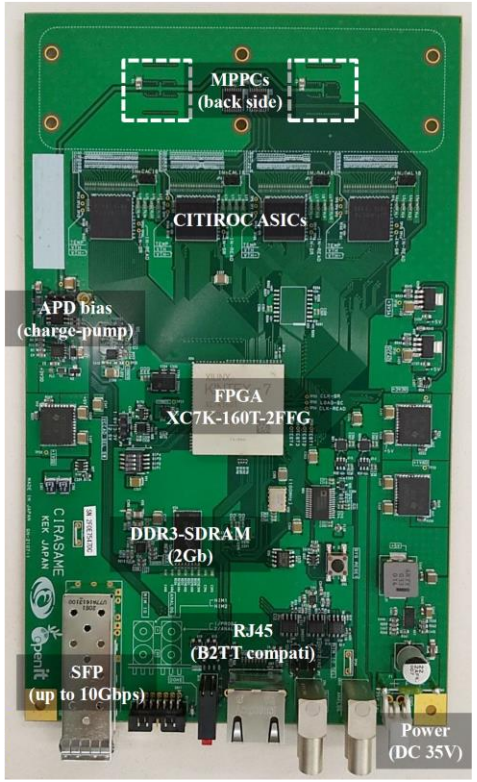
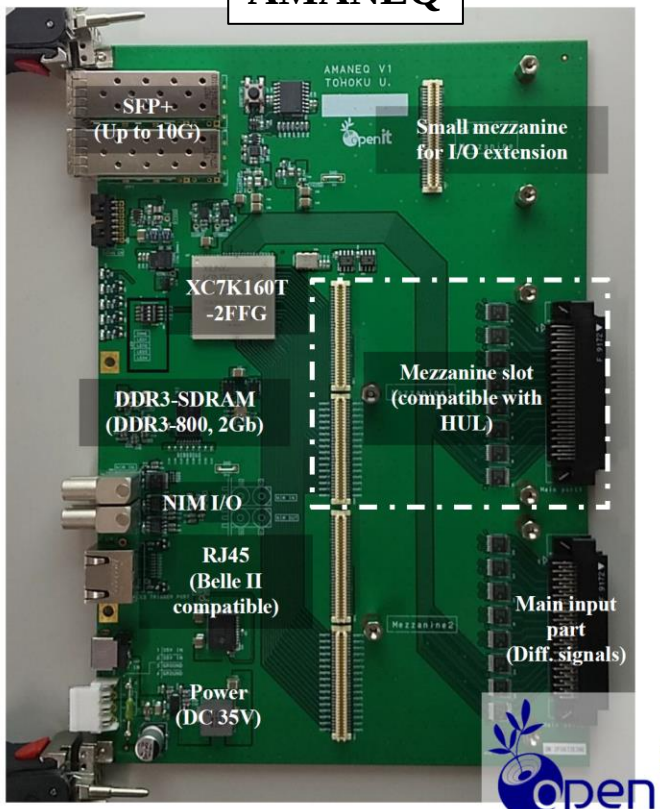
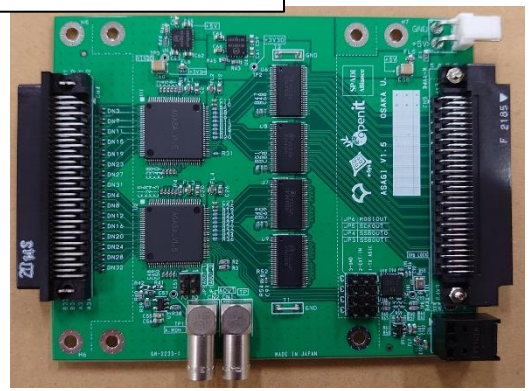
CIRASAME



AMANEQ



ASAGI ASD card



HR-TDC mezzanine

FEE features

- **Timing synchronization:**

  Heartbeat method

  - 524 μsec. period (16 bit/125 MHz)

⇒ **MIKUMARI system**

  - Local Area Common Clock Protocol (LACCP)

+ **Triger emulation mode**

Poster R. Honda

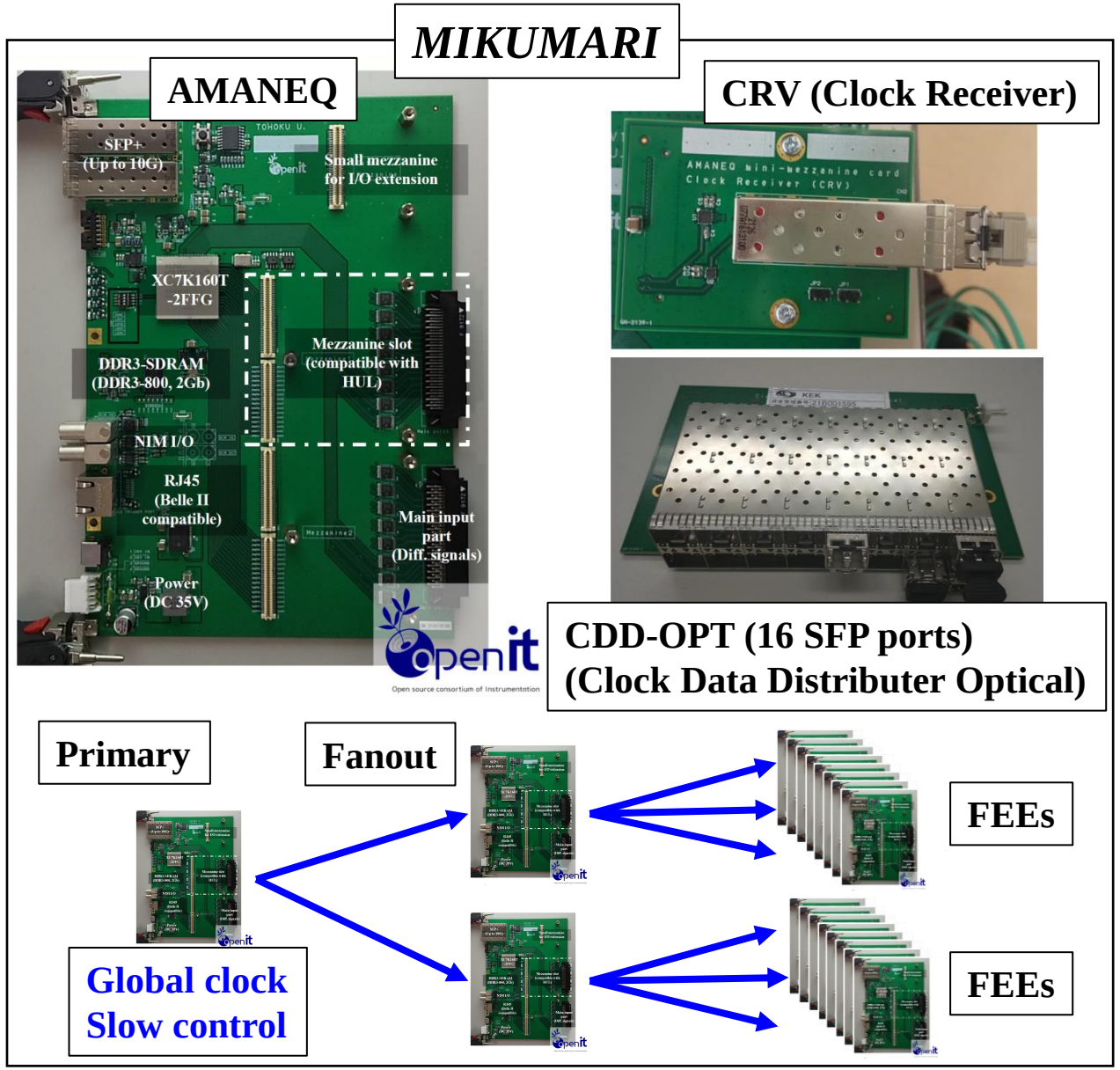
  - Accept hardware trigger
    - Only data in time window

- **Streaming TDC**

  - Leading edge & Time-Over-Threshold(TOT) or Both Leading & Trailing edge

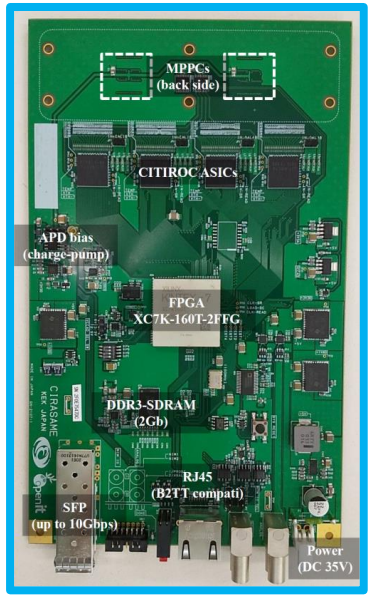
- **Other functions**

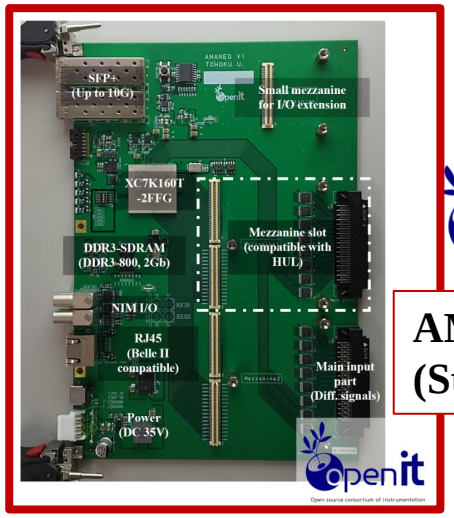
  - Scaler function: RBCP (UDP) port
  - TOT hardware filter in streaming TDC
  - Throttling functions
  - DDR3-SDRAM implementation (homework)



MARQ DAQ scheme

CIRASAME (MPPC readout)





AMANEQ (StrTDC)

Schema of the DAQ system

Clock/command/timing distribution (MIKUMARI)

AMANEQ

Master clock

Hardware

Software

CIRASAME

Network switch

Fiber tracker

RICH

Timing counter

RPC

Drift chamber

AMP

AMP

ASD

ASAGI card

FPGA based HR-TDC

CITIROC + TDC

CITIROC + TDC

HR-TDC

HR-TDC

LR-TDC

5.6 Gb/s

4.0 Gb/s

0.6 Gb/s

0.5 Gb/s

1.0 Gb/s

Heartbeat method

Sampler

Local filter

Global filter

Computer

Load balance

Storage

Storage

Server PC

Reduce the data rate to

FairMQ + redis

- Process monitor and control via in-memory type DB.
- Automatic topology generation

NestDAQ

- **Beam intensity ~30 Mcps (60 M/2.0 sec. spill, 4.2 sec. cycle)**

⇒ **~1.5 Mcps reaction rate (4 g/cm^2 LH_2 target)**

- **Total expected data rate: ~13 GB/sec. (~100 Gbps during extraction)**

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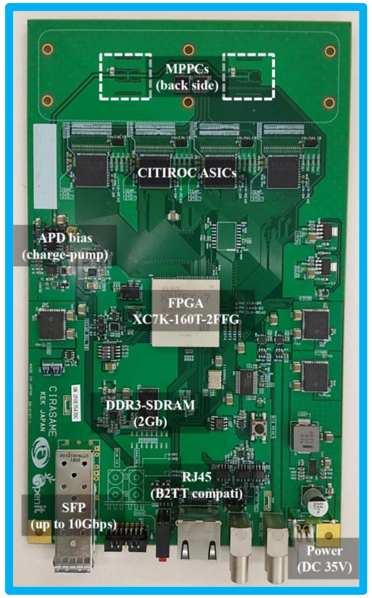
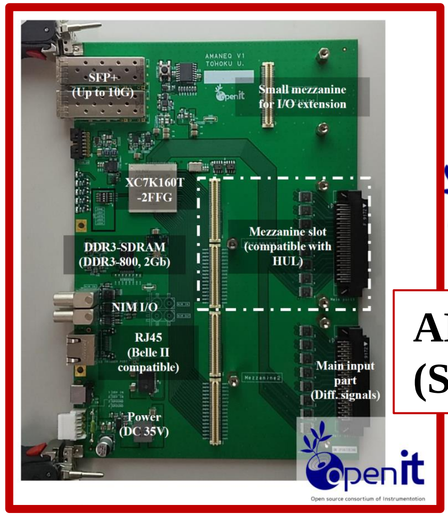
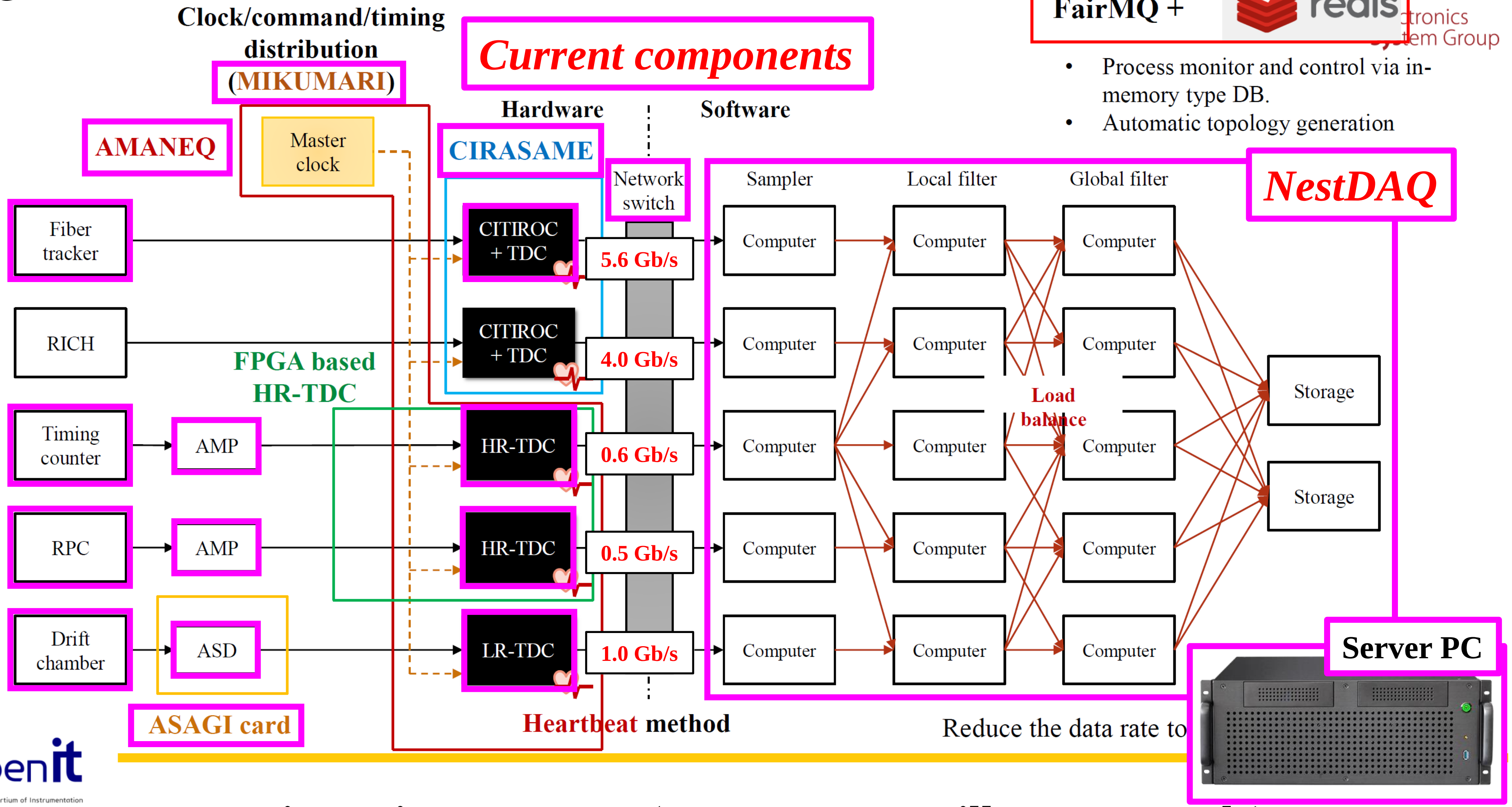




AMANEQ (StrTDC)

FairMQ + redis

- Process monitor and control via in-memory type DB.
- Automatic topology generation



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Evaluation of the streaming-readout DAQ system

Test experiment at J-PARC

SPADI Alliance

Purposes of test bench study: J-PARC T103

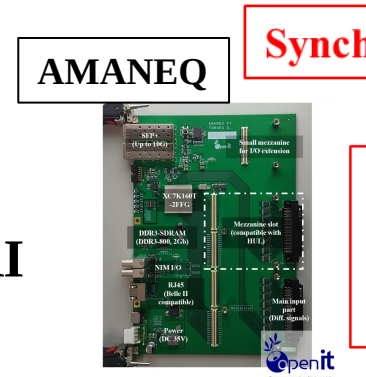
- **Streaming DAQ performance evaluation by using actual hadron beam**
  - **Full FEE operation**
    - Streaming TDC: AMANEQ
    - MPPC specified FEE: CIRASAME
    - Timing synchronization: MIKUMARI
  - **NestDAQ full processes**
    - Event finding and online data selection
    - Scaler and data monitoring function
  - **Network and multiple PC configuration**

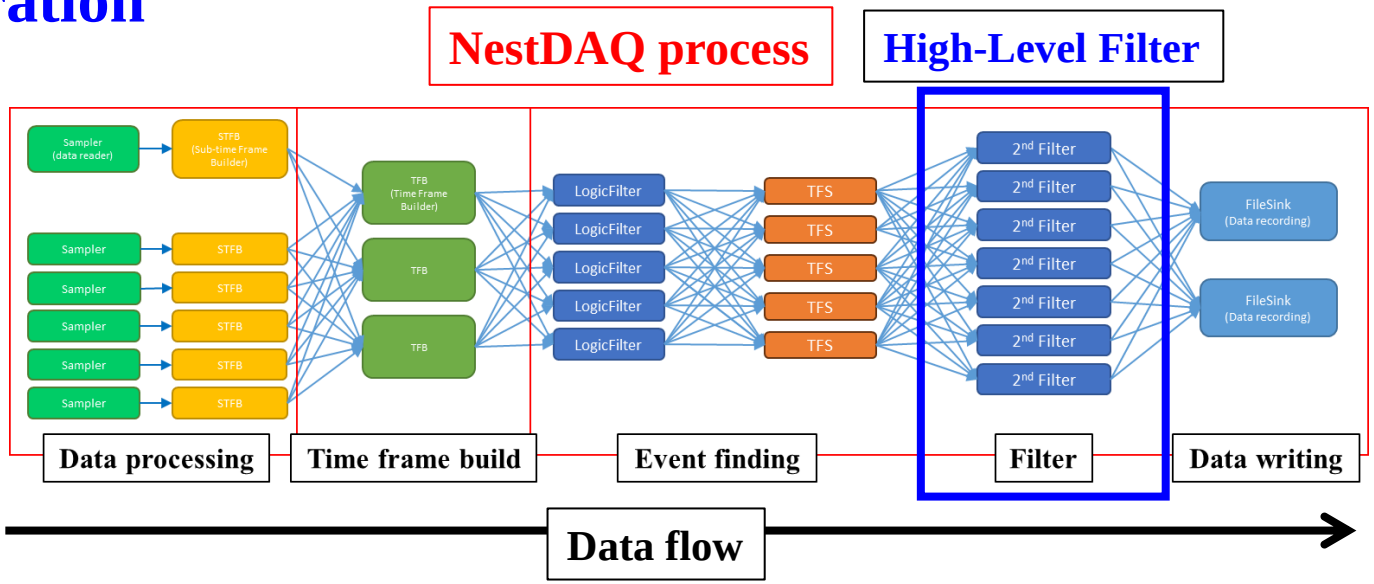
⇒ **DAQ system integration test**

- Smaller scale than actual setup
- Test High-Level Filter (“Trigger”)

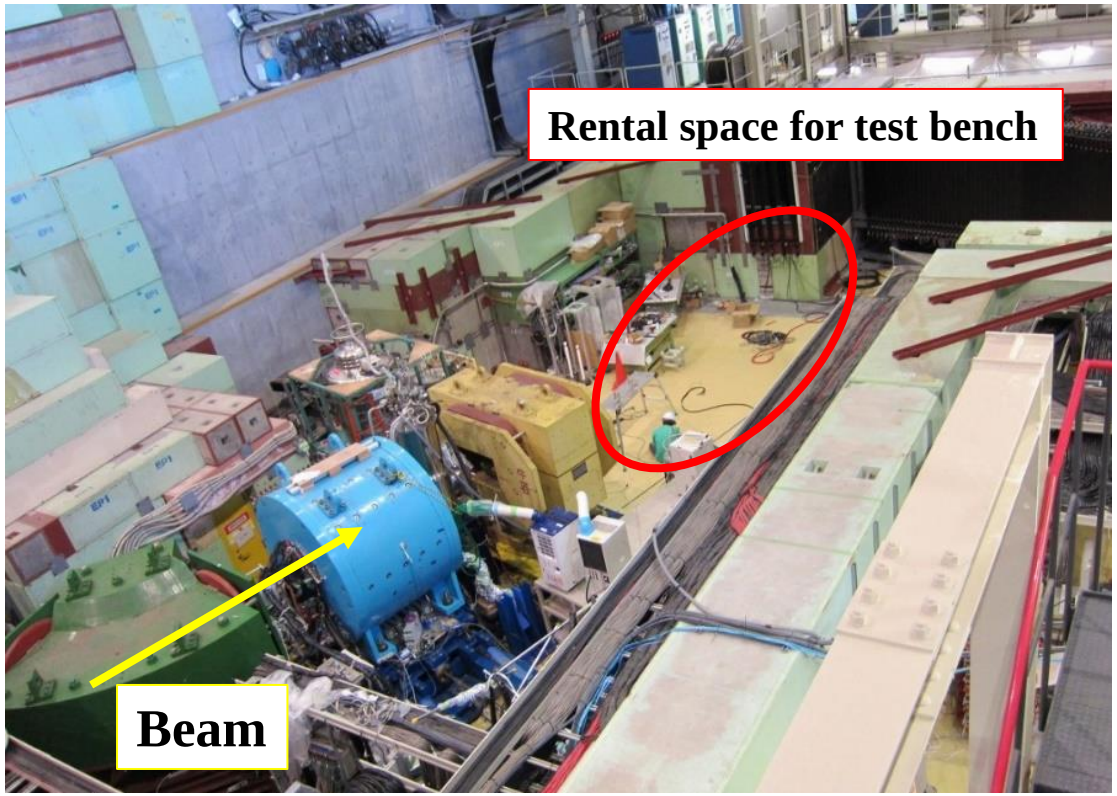
∗ Parasite experiment at J-PARC

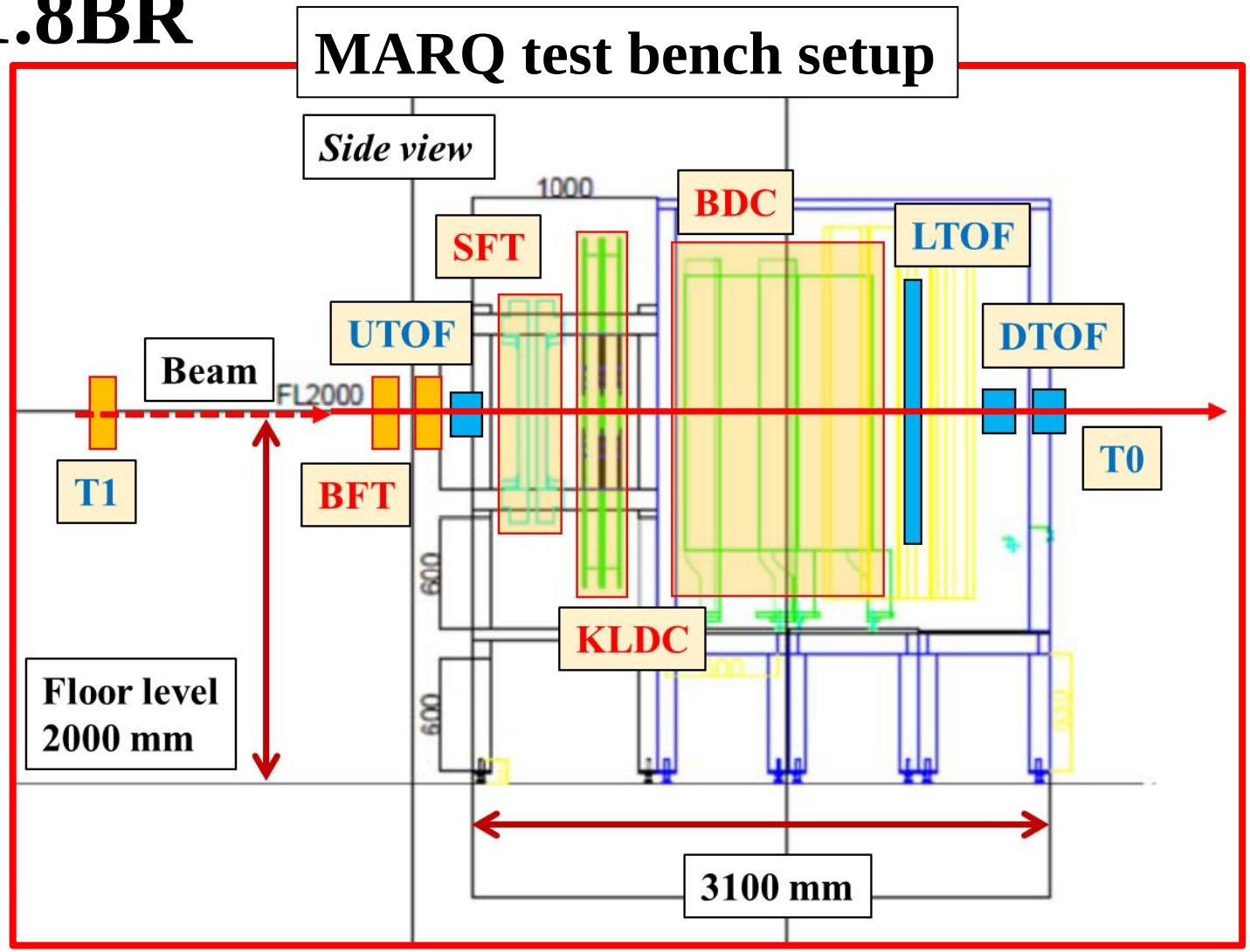
- Lifetime measuring of ${}^{3}_{\Lambda}\mathrm{H}$





Test bench at J-PARC K1.8BR





- Beam condition for test bench

⇒ ~1 M/spill (all charged particles) @ 1 GeV/c

  - 2.0 sec. extraction (4.2 sec. cycle)

- ϕ~300 mm(σ) beam size

∗ Construction from actual detectors

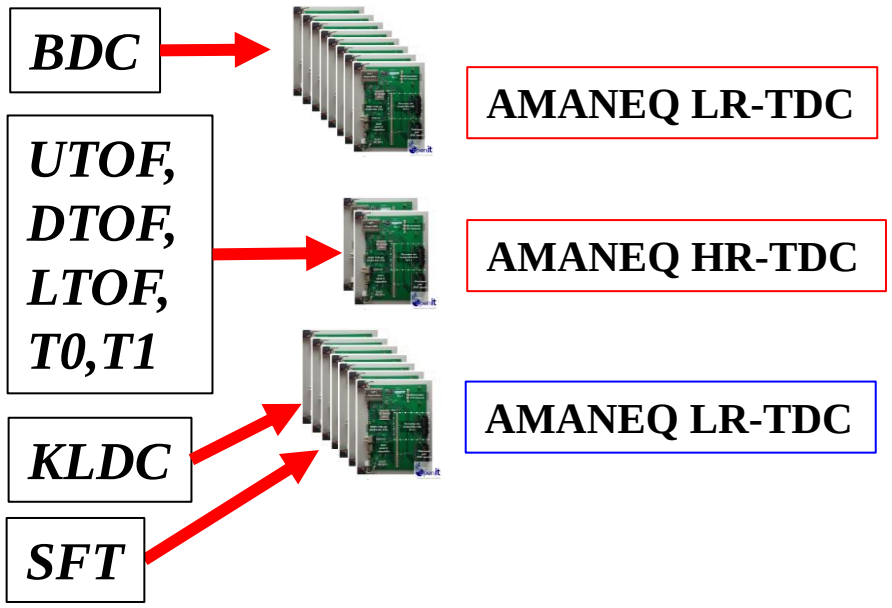
- Trackers: BFT, SFT, KLDC, BDC
- Timing detectors: UTOF, LTOF, DTOF, T0, T1

DAQ node connection

Total 39 nodes w/ 4,142 channels

Det.	FEE	# of Mod.	# of Ch
	MIKUMARI	4	128
TOF	AMANEQ HR-TDC	2	128
DC	AMANEQ LR-TDC	15	1920
Fiber	CIRASAME	18	2304

Data 10G
Data 1G
MIKUMARI

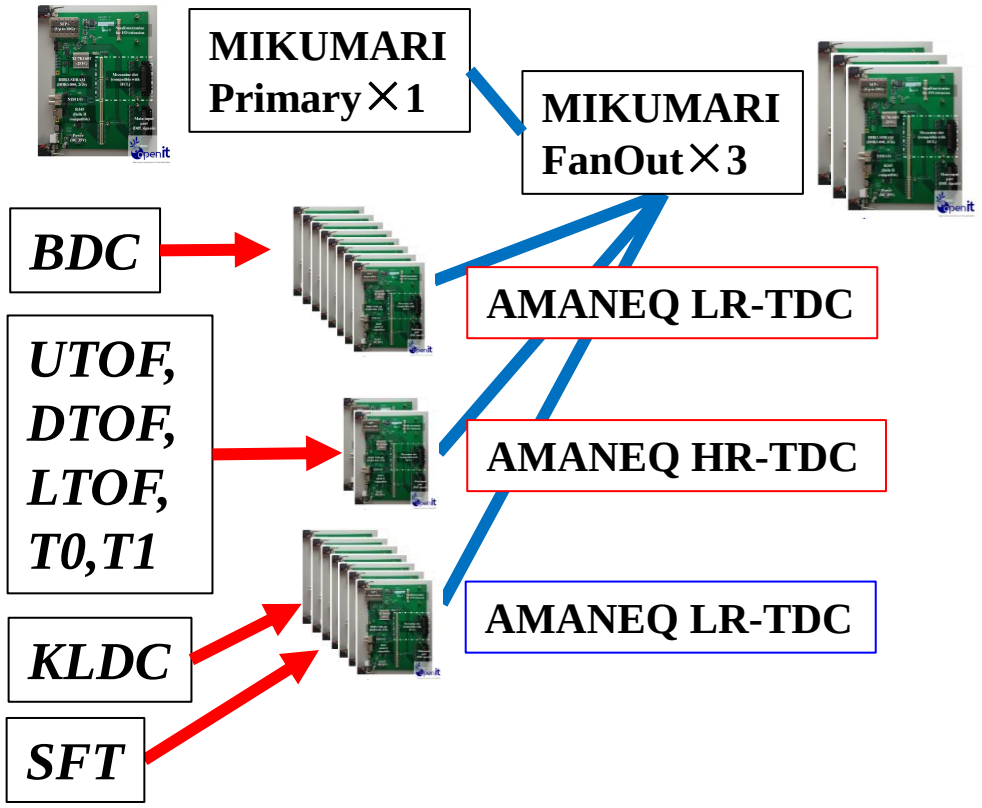


∗ AMANEQ(SrTDC×17, MIKUMARI Prim×1 + FanOut×3)×21, CIRASAME×18

- Upstream (SFT&BFT&KLDC): 25 nodes
- Downstream (BDC&TOFs): 10 nodes

“Scalability” for various experiments

DAQ node connection



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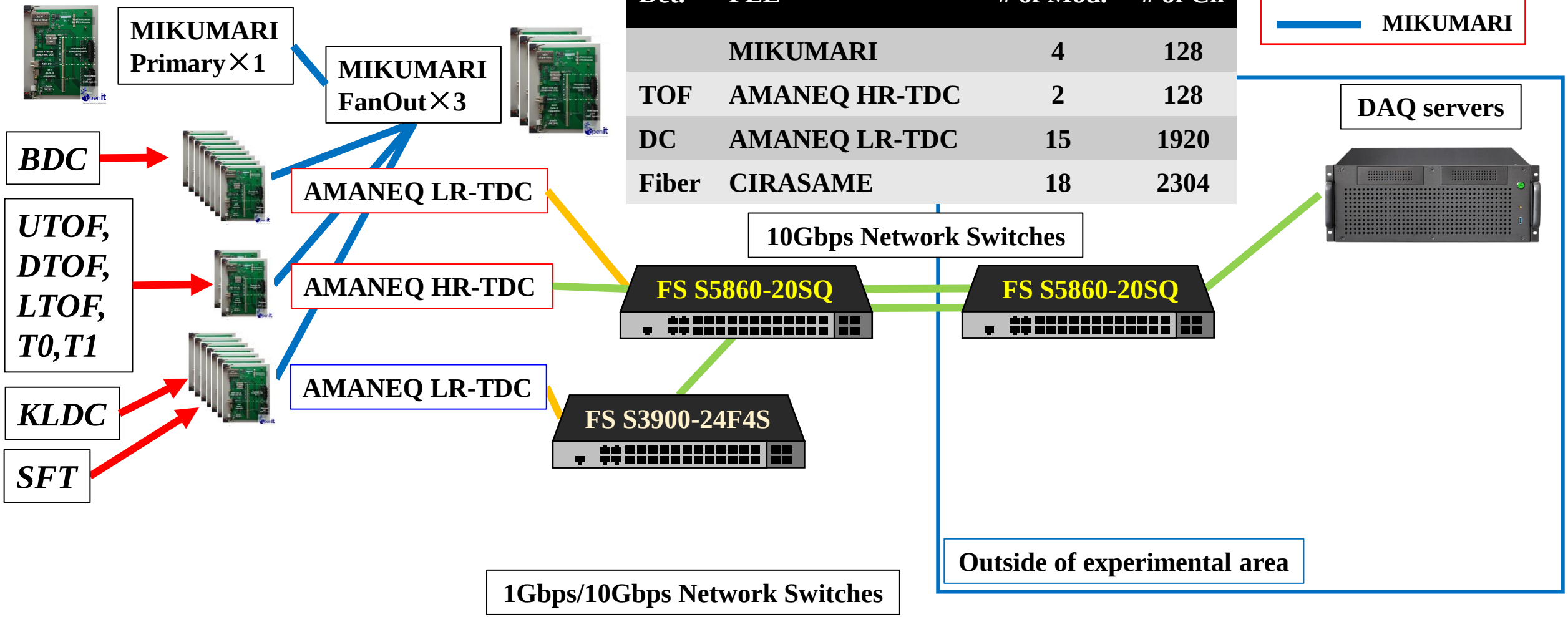

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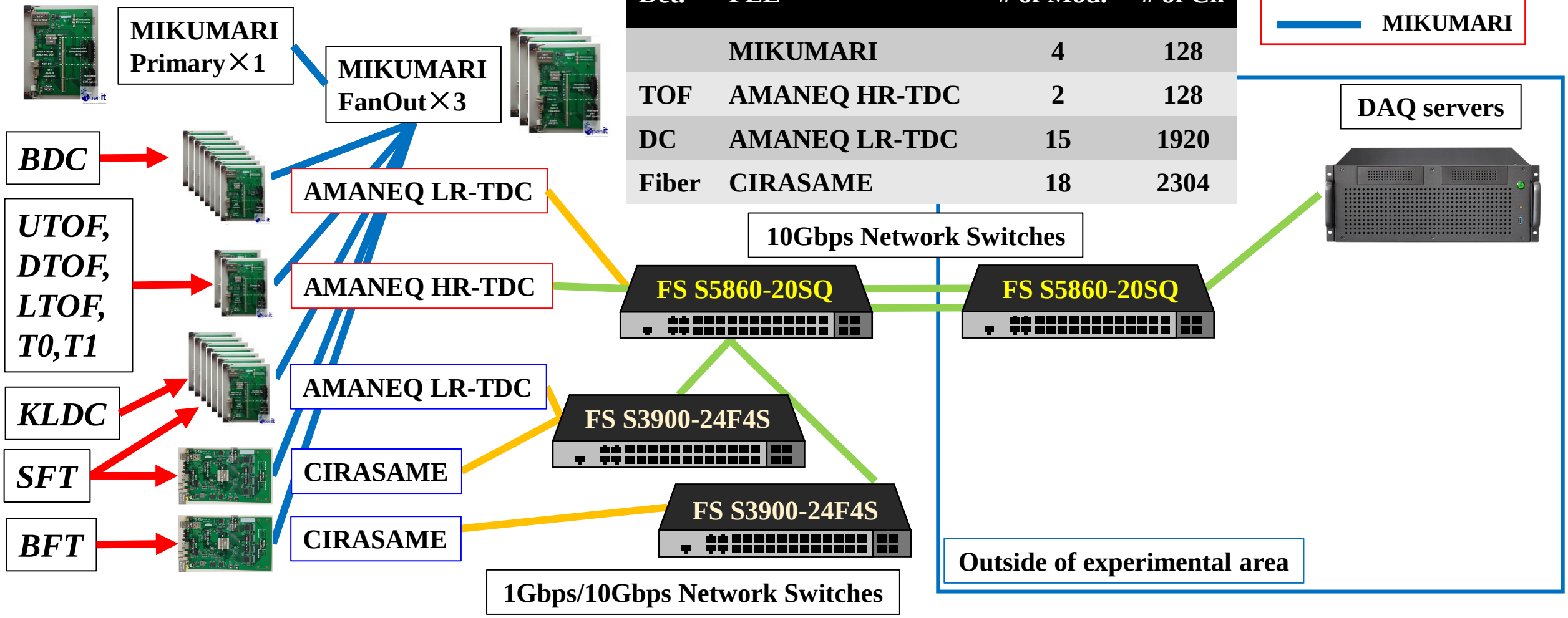

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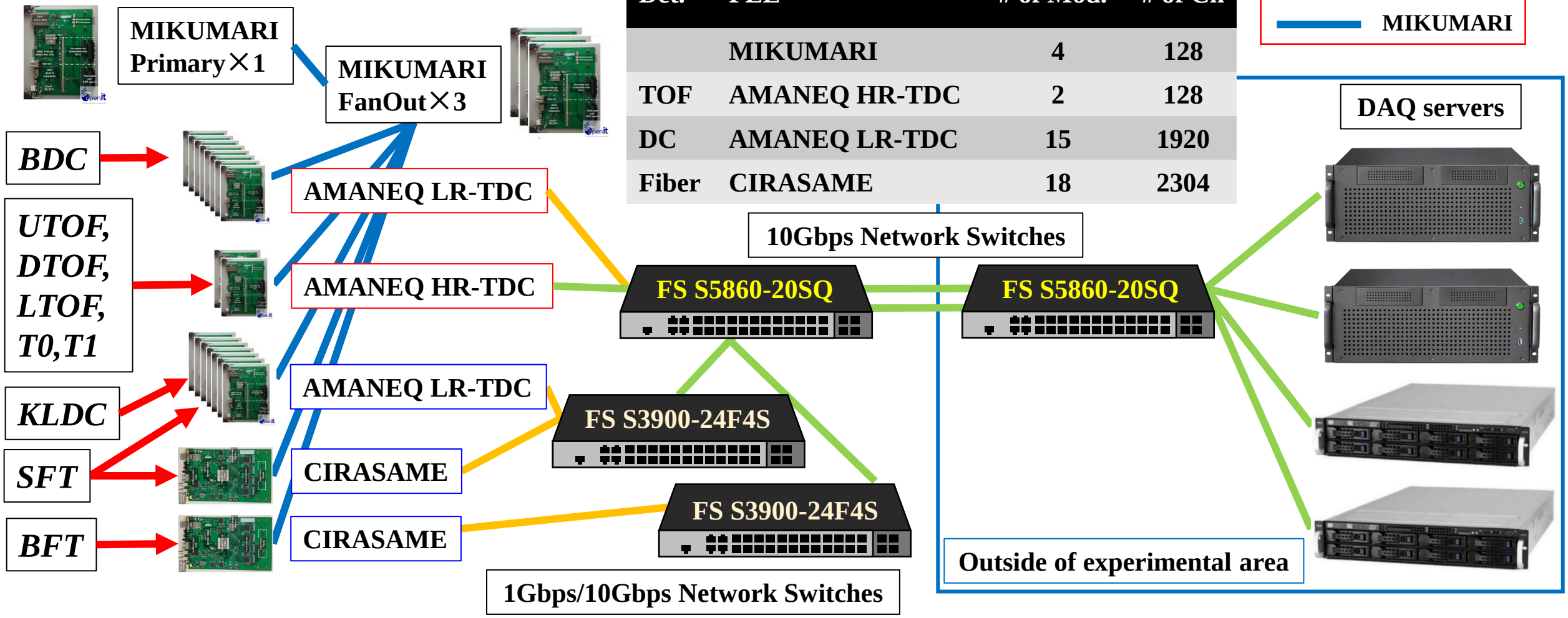

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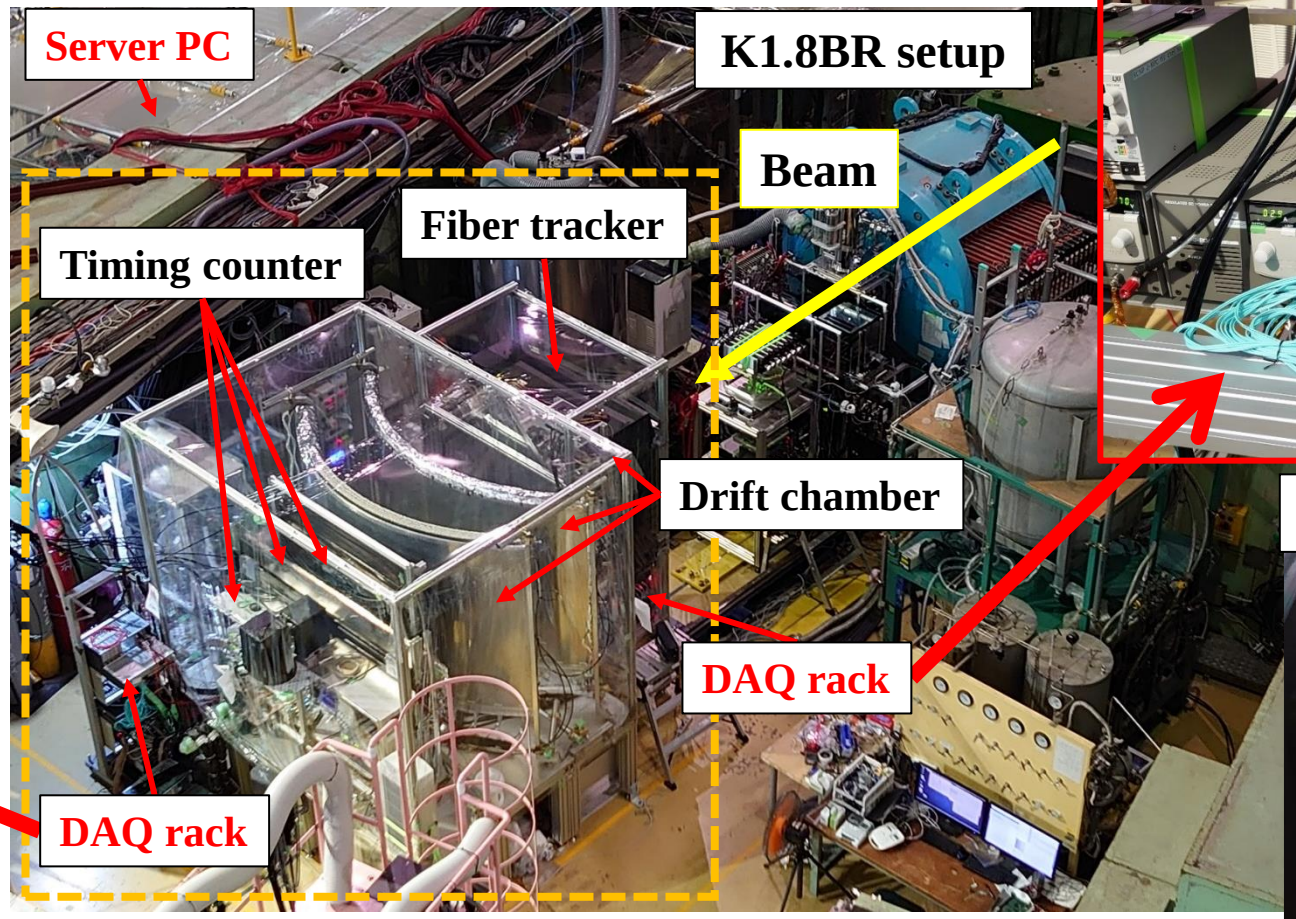
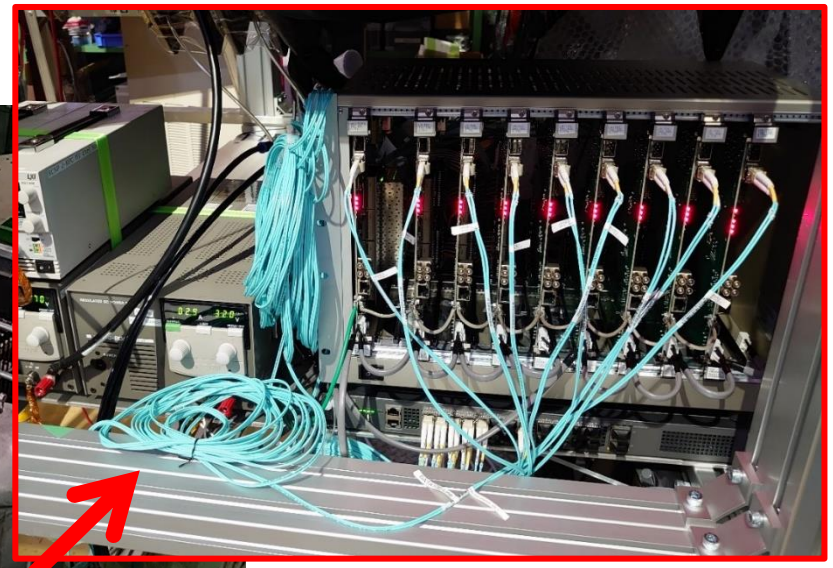
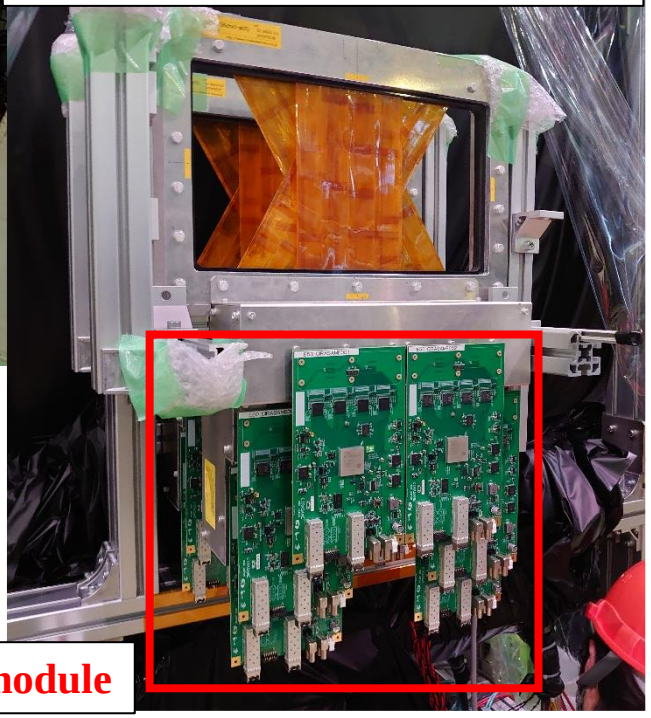
"Scalability" for various experiments

Test bench photos



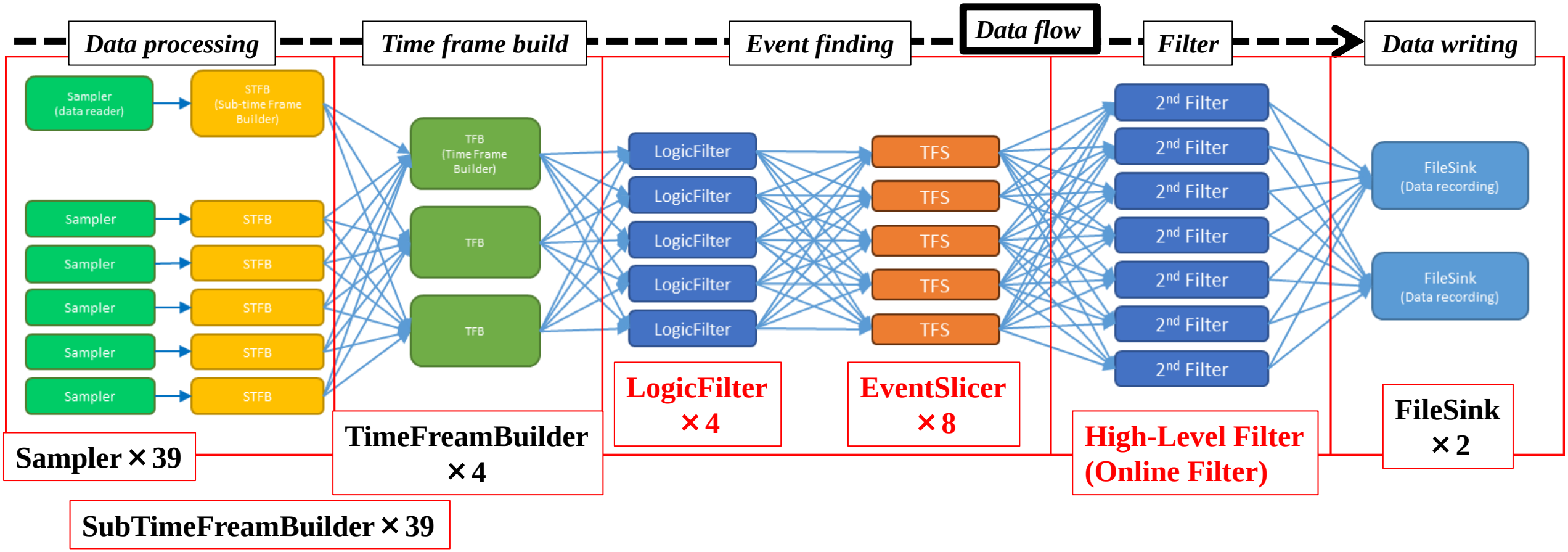


Fiber tracker & CIRSAMAE



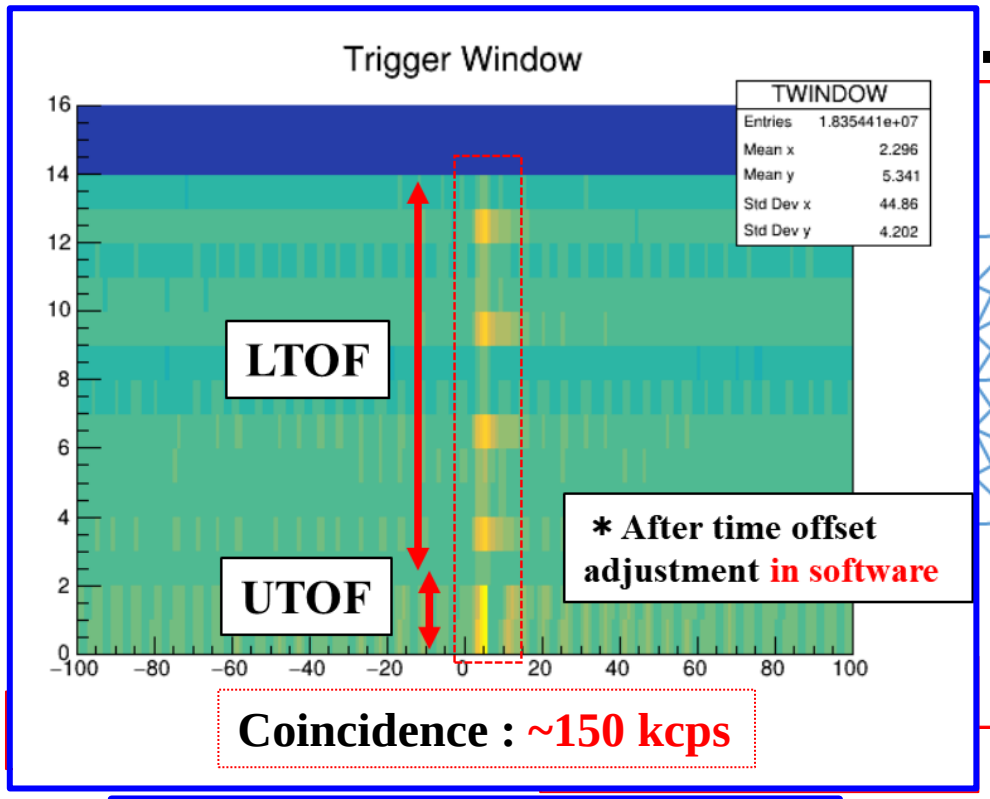
* **Standard nuclear physics experiment scale (Much compact !)**
  - >4,000 channel redout w/ various detectors
- **Data flow ~180 MB/s (~1.4 Gbps) (averaged in 4.2 sec. cycle)**
  - **Beam extraction (2.0 sec.): ~260 MB/s (~2.1 Gbps)**

NestDAQ configuration

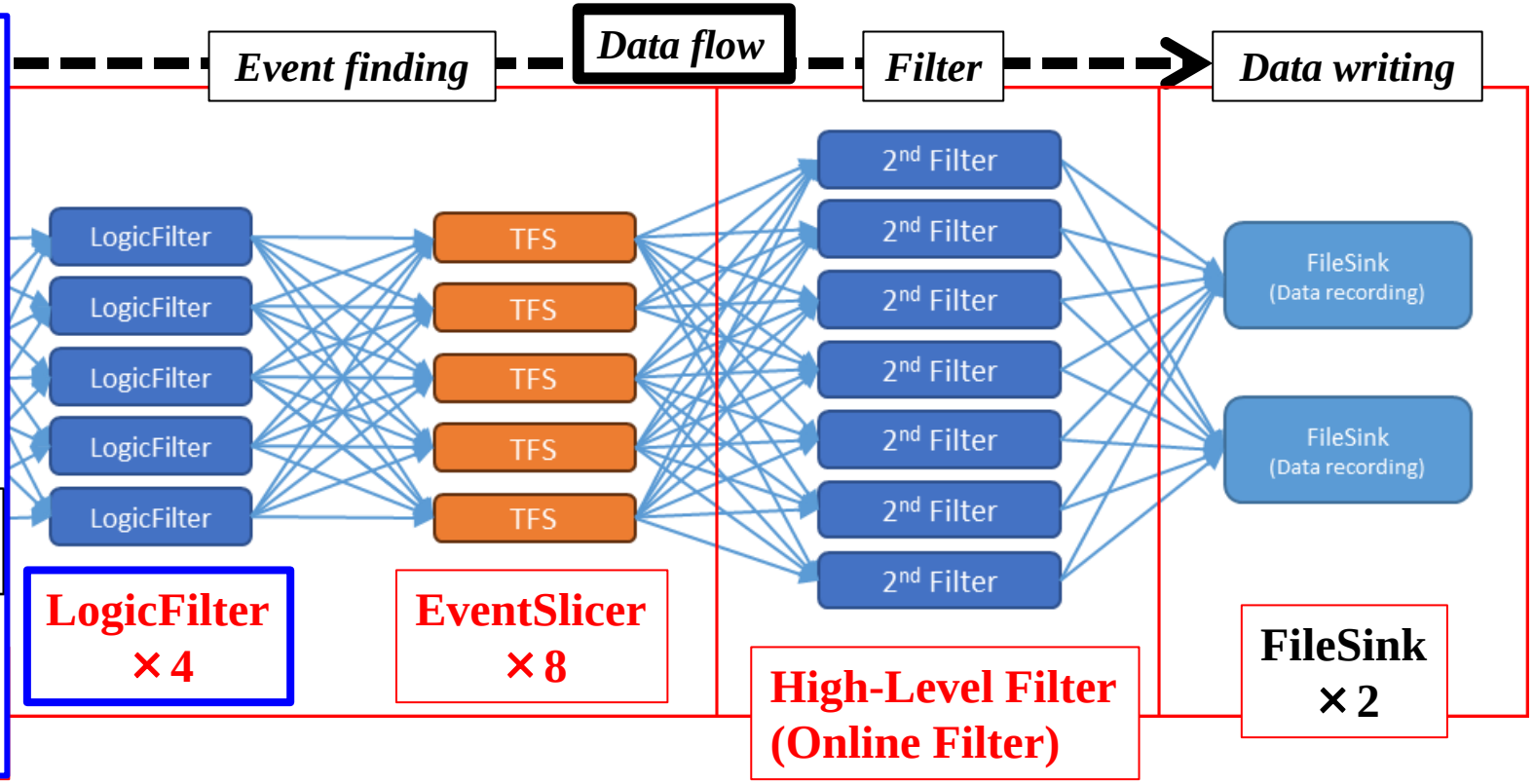


- **Filtered data** + **No filter data (w/ Pre-scaler function)**
  - **No Filter**: Sampler → STFB → TFB → FileSink
  - **Filtered**: TFB → LogicFilter → EventSlicer → High-level Filter → FileSink

NestDAQ configuration



Coincidence timing finding



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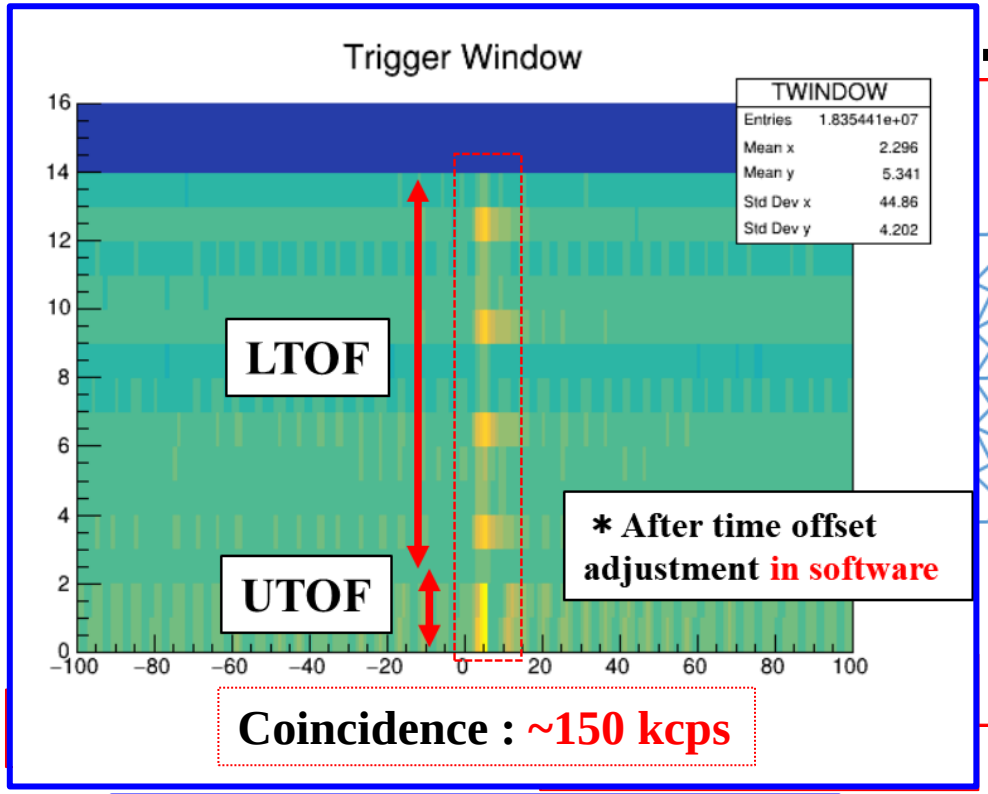
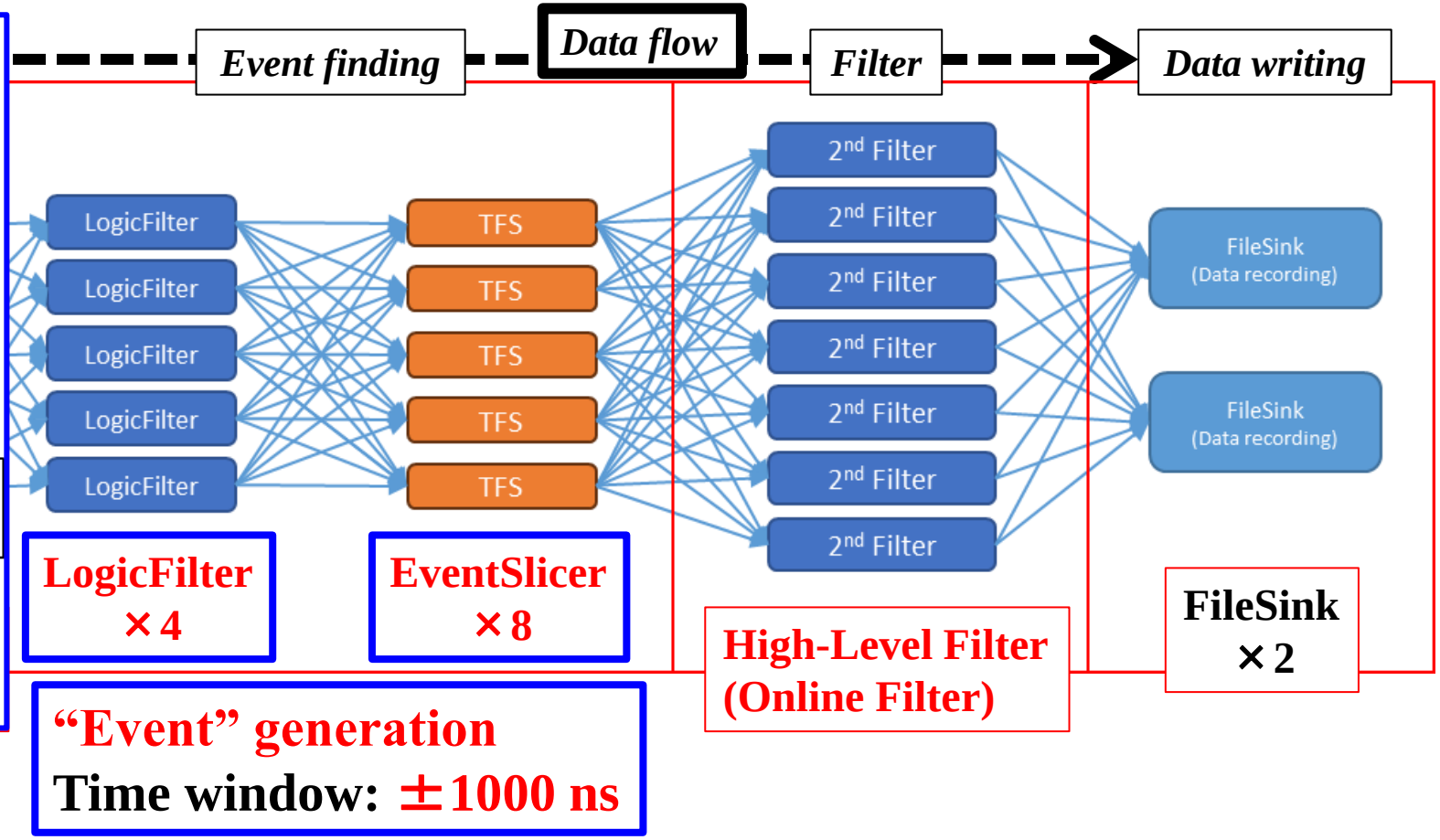


Coincidence timing finding



"Event" generation
Time window: ±1000 ns

- Filtered data + No filter data (w/ Pre-scaler function)
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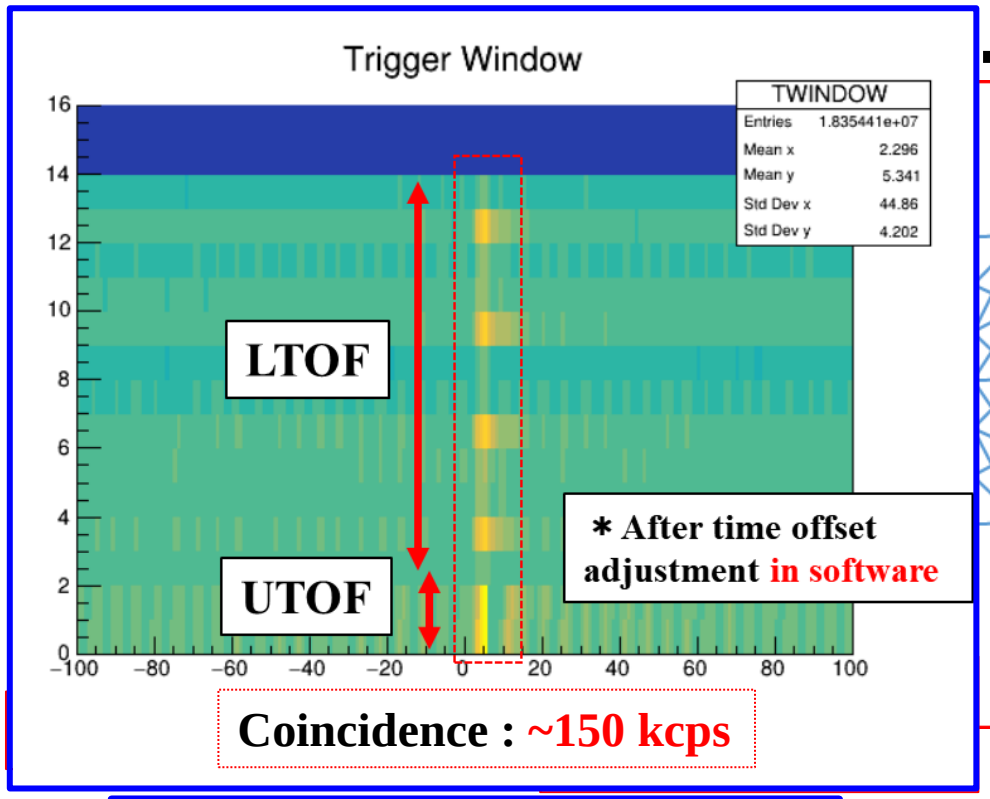
NestDAQ configuration



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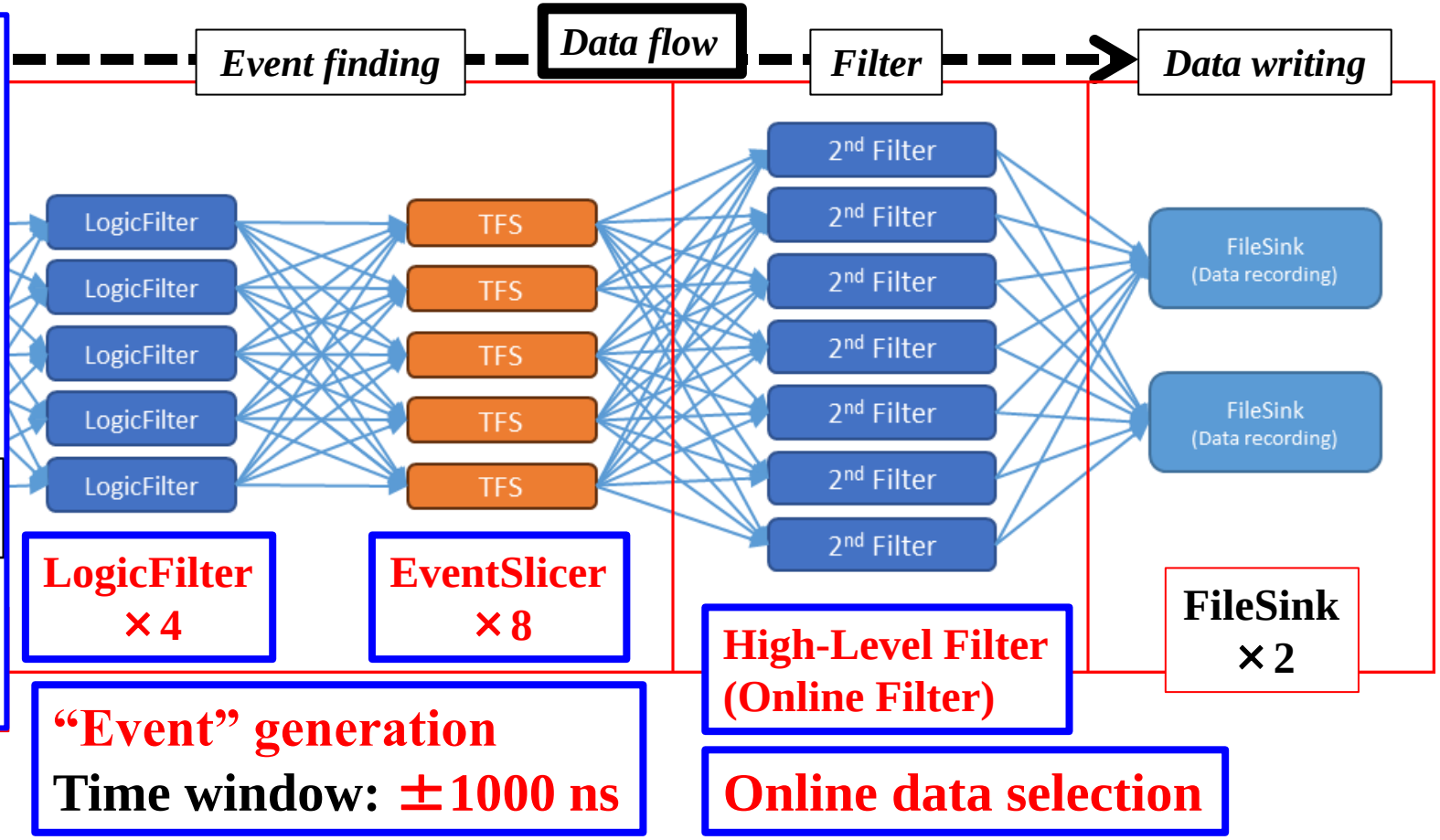

"Event" generation
Time window: ±1000 ns

Online data selection

- Filtered data + No filter data (w/ Pre-scaler function)
  - No Filter: Sampler → STFB → TFB → FileSink
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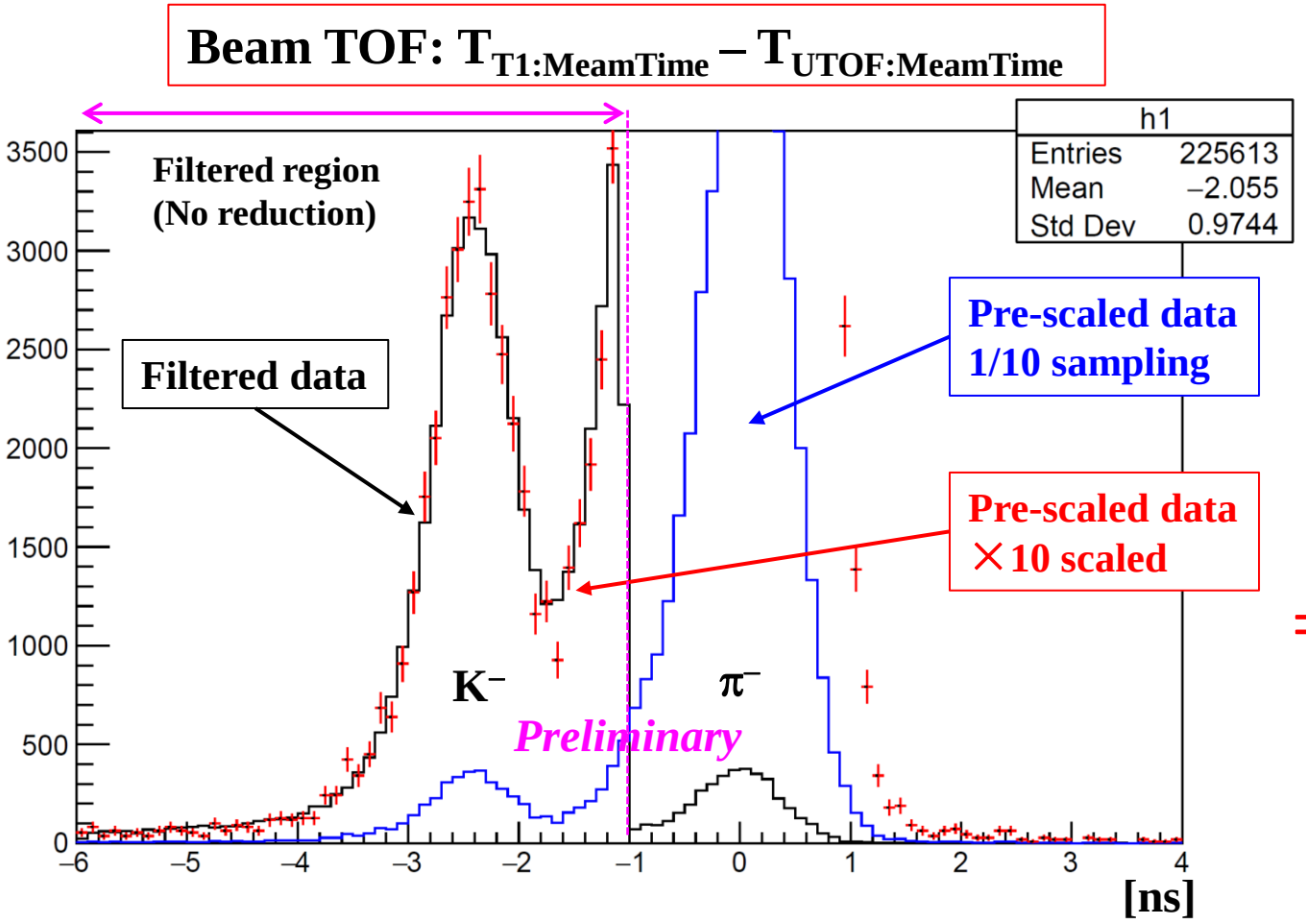
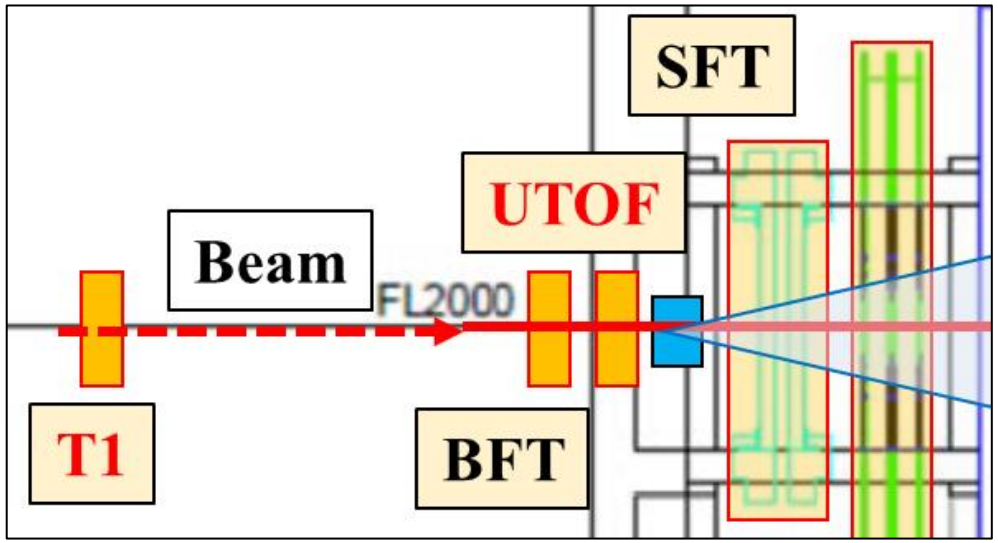
High-level Filter: Online data selection

- **Beam TOF filter: K^- beam selection**
  - **Beam TOF (5-m distance): $\Delta T \sim 2.4$ ns for π^- & K^-**

∗ Online check of Beam TOF filter ⇒ OK





∗ Filter evaluation *Poster F. Furukawa*

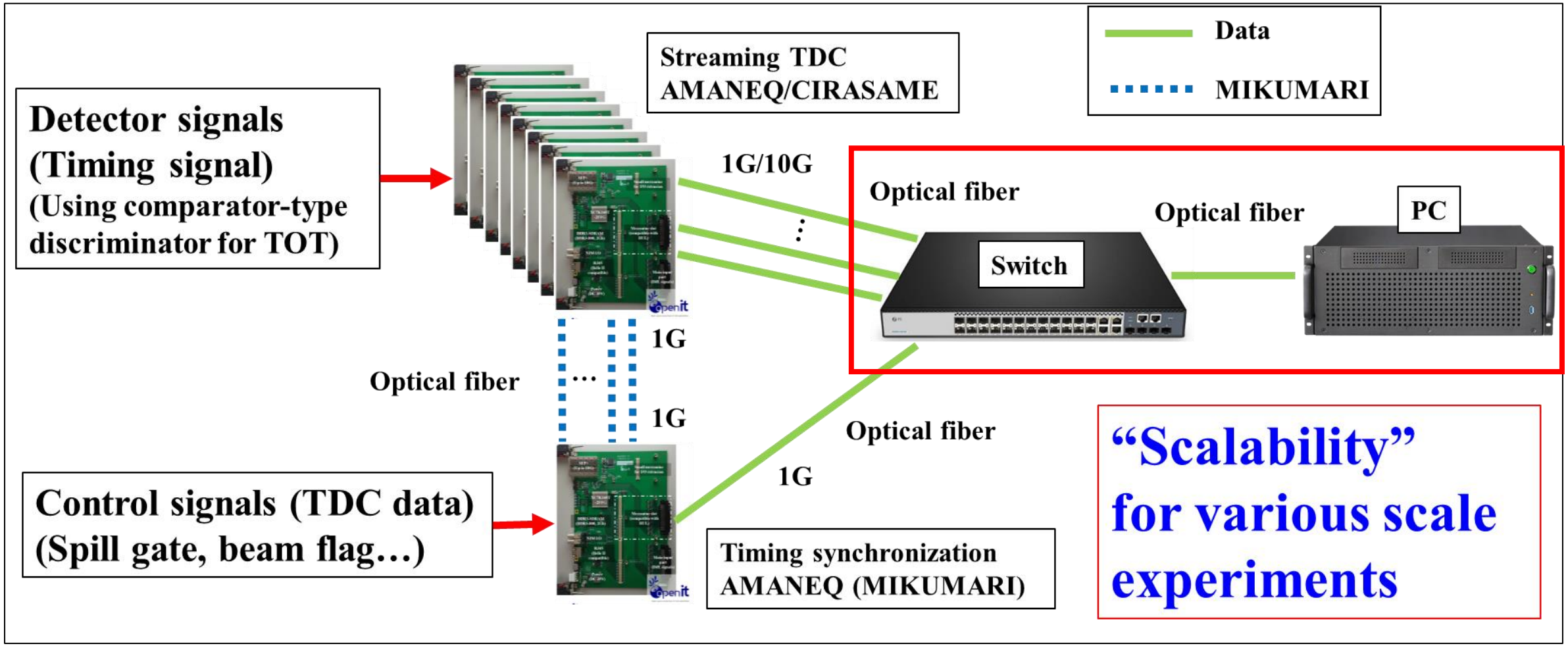
- **Data throughput and calculation time**
- **# of High-level Filter processes**

⇒ Study by "Data re-player"

- **TOF timing**
- **DC hit pattern and correlation**
- **DC cluster/tracking**

Multiple PC study

- **Flexibility and scalability: Configuration of PC and NestDAQ processes**
  - **1 PC ⇒ 5 PCs: PC×2 – PC×2 – PC×1 configuration**
    - **Sever PCs and normal desktop PCs**

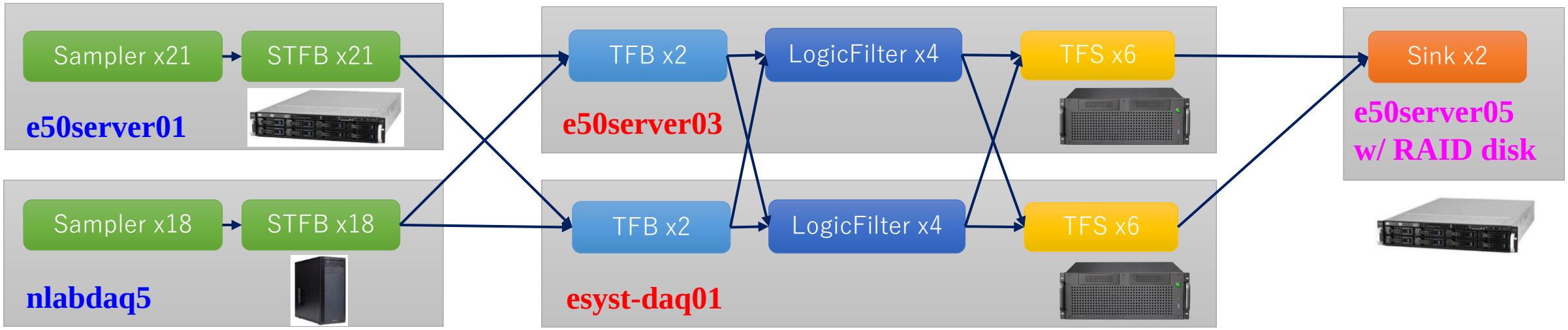


Multiple PC configuration: Check scalability

- **Load balance adjustment for 2PC – 2PC – 1PC configuration**
  - **Low load process: Sampler, STBF, Sink ⇒ Low performance PCs**
  - **High load process: EventSlicer > LogicFilter > TFB ⇒ High performance PCs**
  - **Highest load process: High-level filter ⇒ To be processed by other PCs**

- **Data rate ~9.2 Gbps ⇔ 10G network limit**
  - **Generated by detector noise and MPPC dark current**

PC×5: FEE data processing PC×2 + Data processing PC×2 + Data writing PC×1



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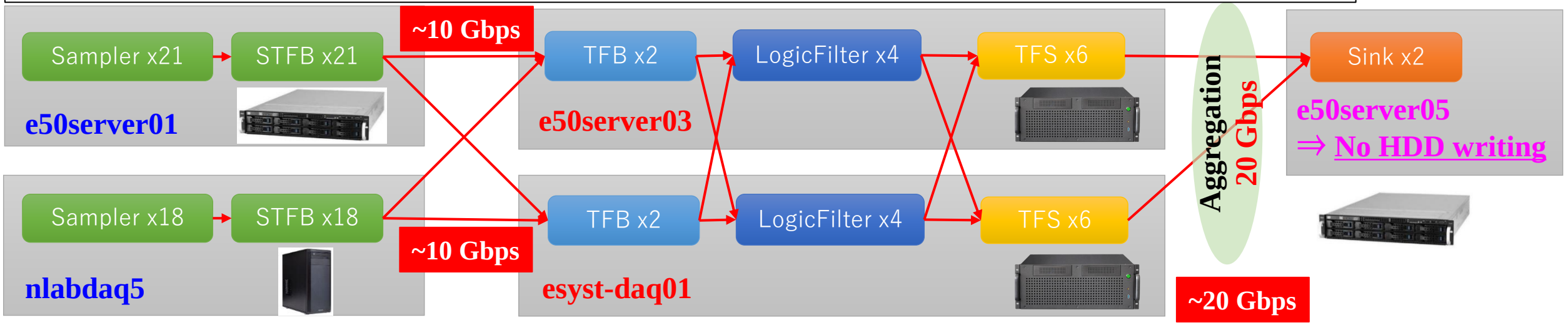
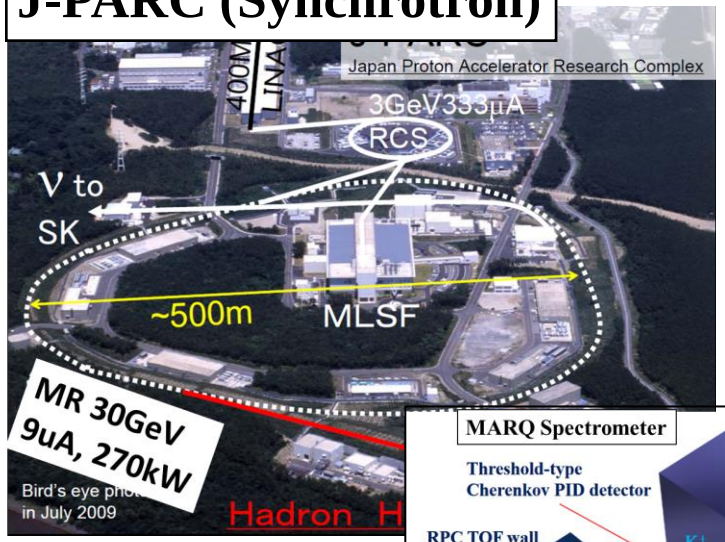


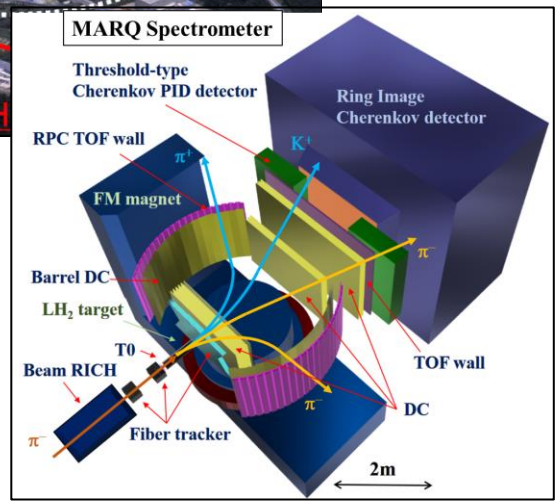
Outlook and Summary

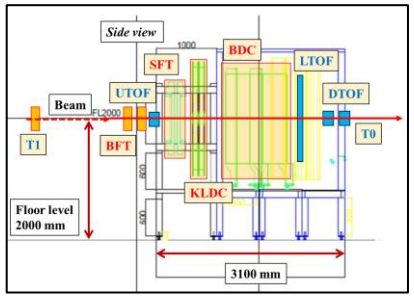
Accumulating experiences as SPADI Alliance activity

∗ Implementation in various experiments: J-PARC, RCNP, RARiS…

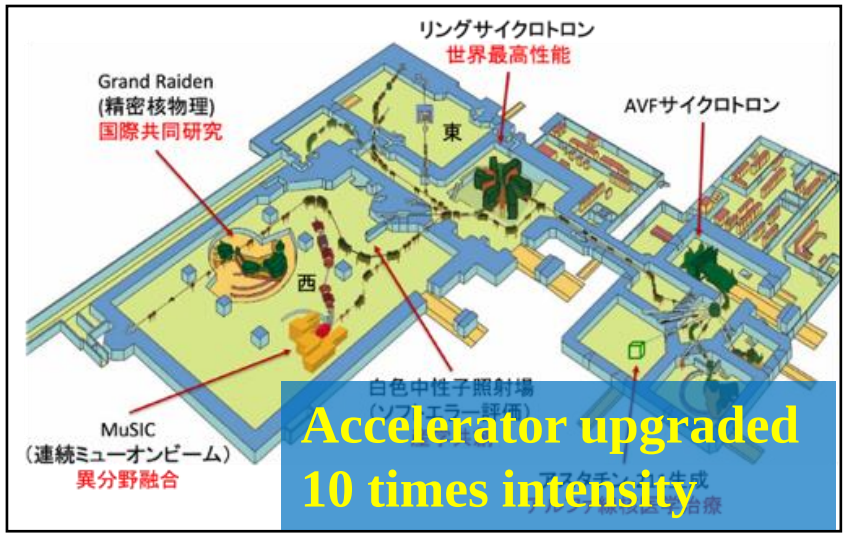
J-PARC (Synchrotron)

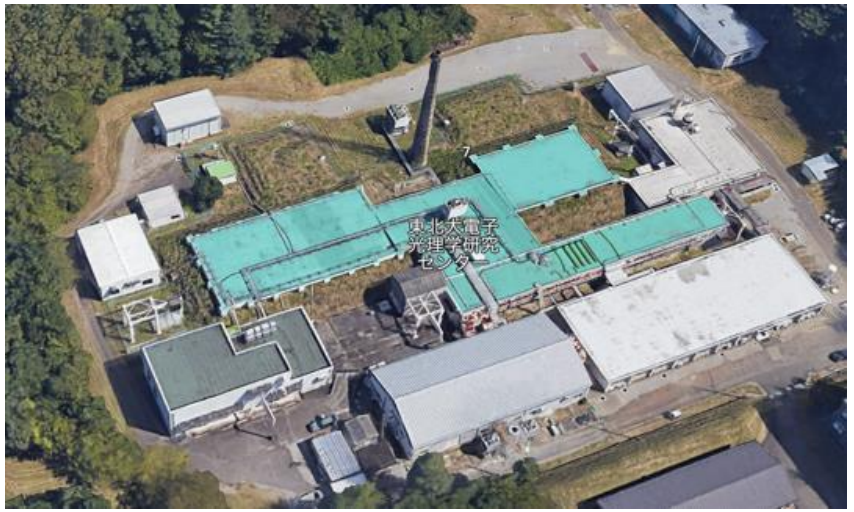






T103 Test bench & MARQ





RCNP (Cyclotron)

Grand Raiden DAQ upgrade

- DAQ Commissioning
  - S. Ota, N. Kobayashi *et al.*
- E585
  - S. Ota, M. Dozono *et al.*

Talk S. Ota
Poster N. Kobayashi

RARiS (Synchrotron)

Beam Profile Monitor development

Poster R. Kino

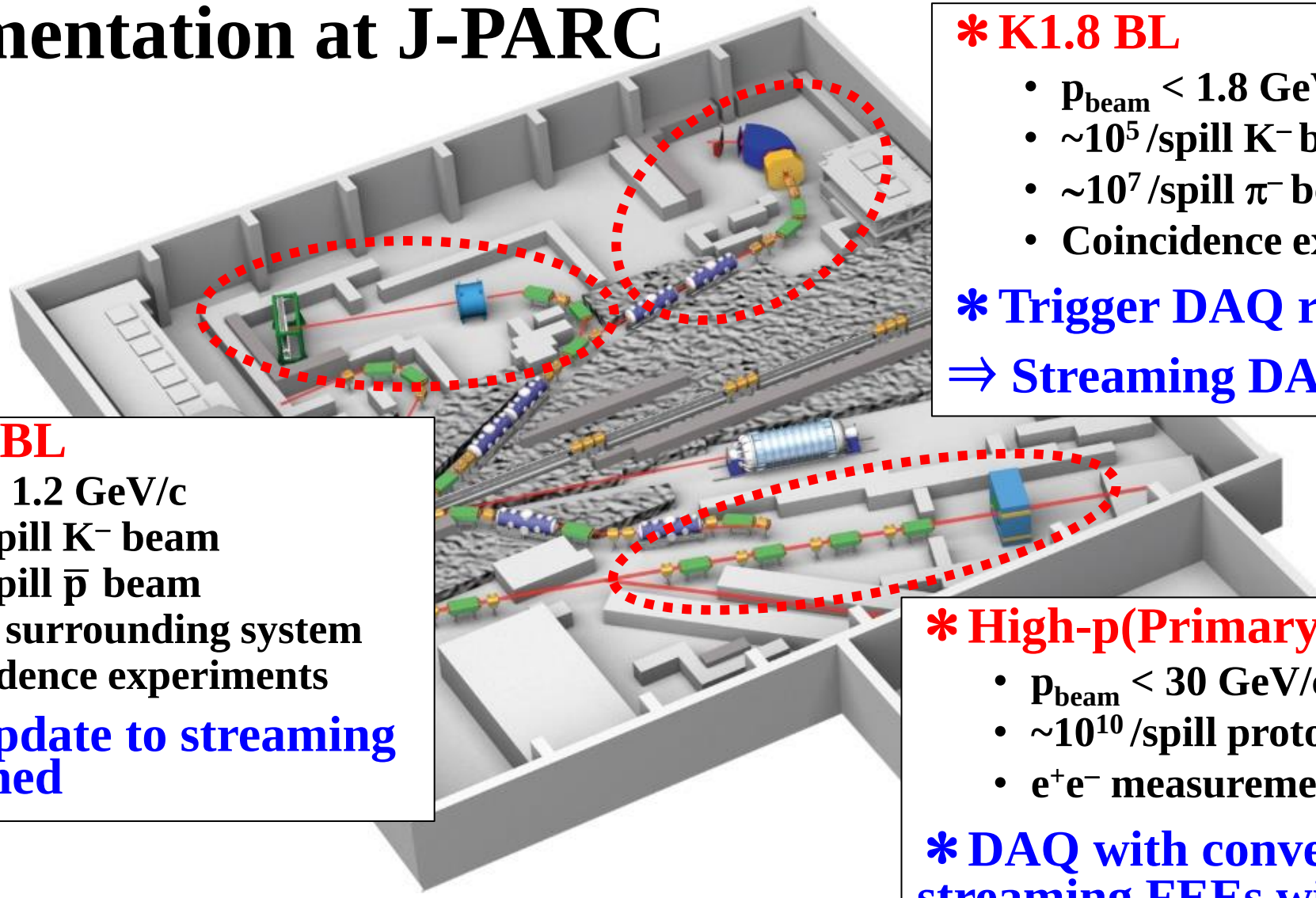
- S. Nagao, R. Kino *et al.*

NKS DAQ upgrade

- M. Kaneta *et al.*

Poster M. Kaneta

Implementation at J-PARC



∗K1.8 BL

- p_{beam} < 1.8 GeV/c
- ~10^5 /spill K^- beam
- ~10^7 /spill π^- beam
- Coincidence experiments

∗Trigger DAQ ready

⇒ Streaming DAQ

∗K1.8BR BL

- p_{beam} < 1.2 GeV/c
- ~10^5 /spill K^- beam
- ~10^5 /spill $\bar{p}$ beam
- Target surrounding system
- Coincidence experiments

∗Major update to streaming DAQ planned

∗High-p(Primary p beam)

- p_{beam} < 30 GeV/c
- ~10^{10} /spill proton beam
- e^+e^- measurement by specific trigger

∗DAQ with conventional and streaming FEEs with trigger

⇒ Full streaming DAQ(?)

∗Streaming DAQ implementation planned in hadron experimental facility

Summary

SPADI Alliance

- **Streaming DAQ performance evaluation by actual hadron beam**
  - **Full FEE operation and NestDAQ processes**

⇒ Full DAQ system test successfully done.

  - **Smaller scale than actual MARQ spectrometer setup**

- **Construction of DAQ system: Ordinary nuclear experiment scale setup**
  - **~4,000 channel redout w/ drift chambers, scintillating fiber trackers and timing detectors**

- **Successful implementation of High-Level Filter process to NestDAQ**
  - **Beam TOF filter for selecting K^- beam event**

⇒ Data re-player study is ongoing.

- **Implementation in various experiments**
  - **J-PARC, RCNP, RARiS…**

⇒ Accumulating experiences as SPADI Alliance activity