IEEE NPSS NUCLEAR & PLASMA SCIENCES SOCIETY

ICISE CONFERENCE CENTER icise QUY NHON VIETNAM

April 22-26 2024

24th IEEE REAL TIME CONFERENCE

Quy Nhon, Vietnam

First application of a streaming-readout data-acquisition system, products of **SPADI Alliance**, to physics experiments at RCNP **towards the standardization**

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Research Center for Nuclear Physics (RCNP), Osaka University

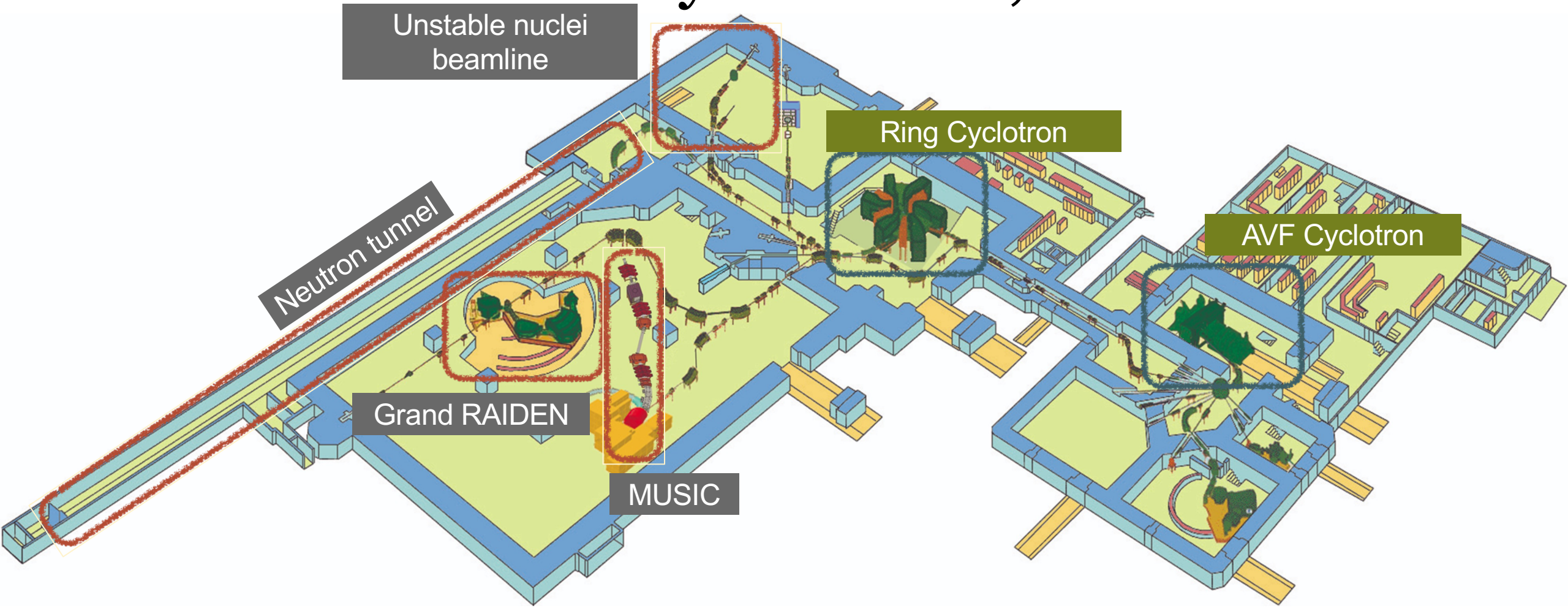
OSAKA UNIVERSITY RCNP SPADI Alliance

Collaborators

- Shinsuke OTA, Nobuyuki KOBAYASHI, Sun Young RYU, Kotaro SHIROTORI, Tomonori TAKAHASHI, Ryotaro HONDA, Yoichi IGARASHI, Hidetada BABA,Tomoaki HOTTA, Taku GUNJI, Manabu MIYABE, Hiroyuki NOUMI Masanori DOZONO, Jiawei CAI, Fumiya FURUKAWA, Hiroaki SHIBAKITA, Takayuki YANO, Shunnosuke NAGAFUSA, for SPADI Alliance

SPADI
Alliance

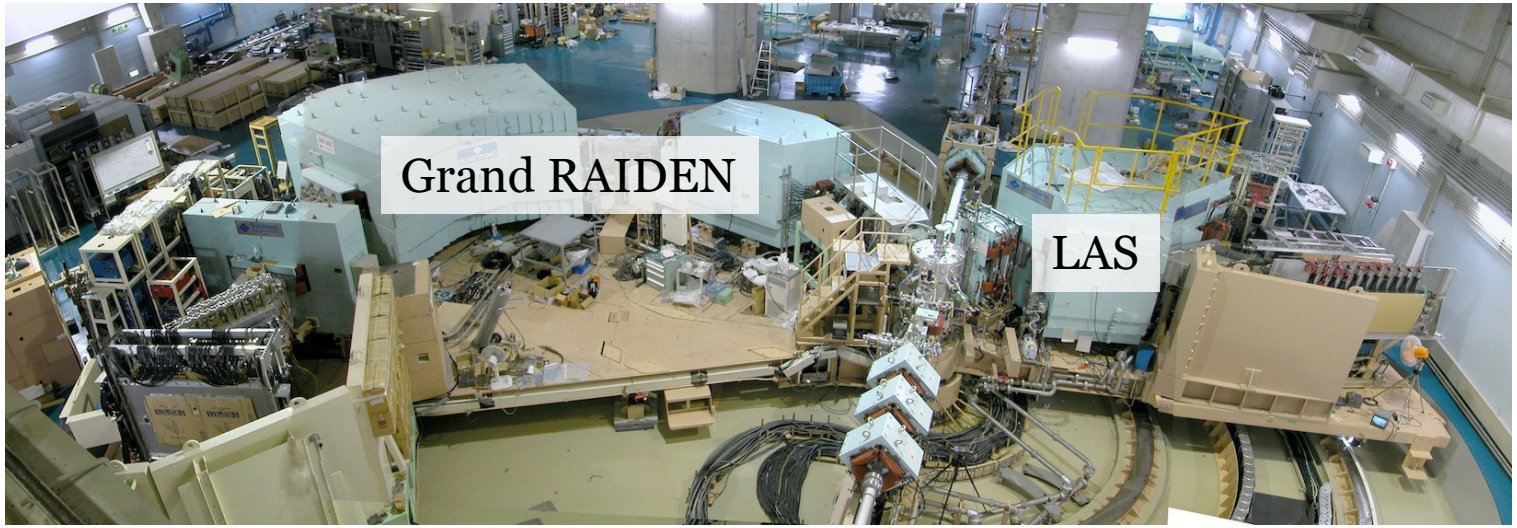
Accelerator facility in RCNP, Osaka



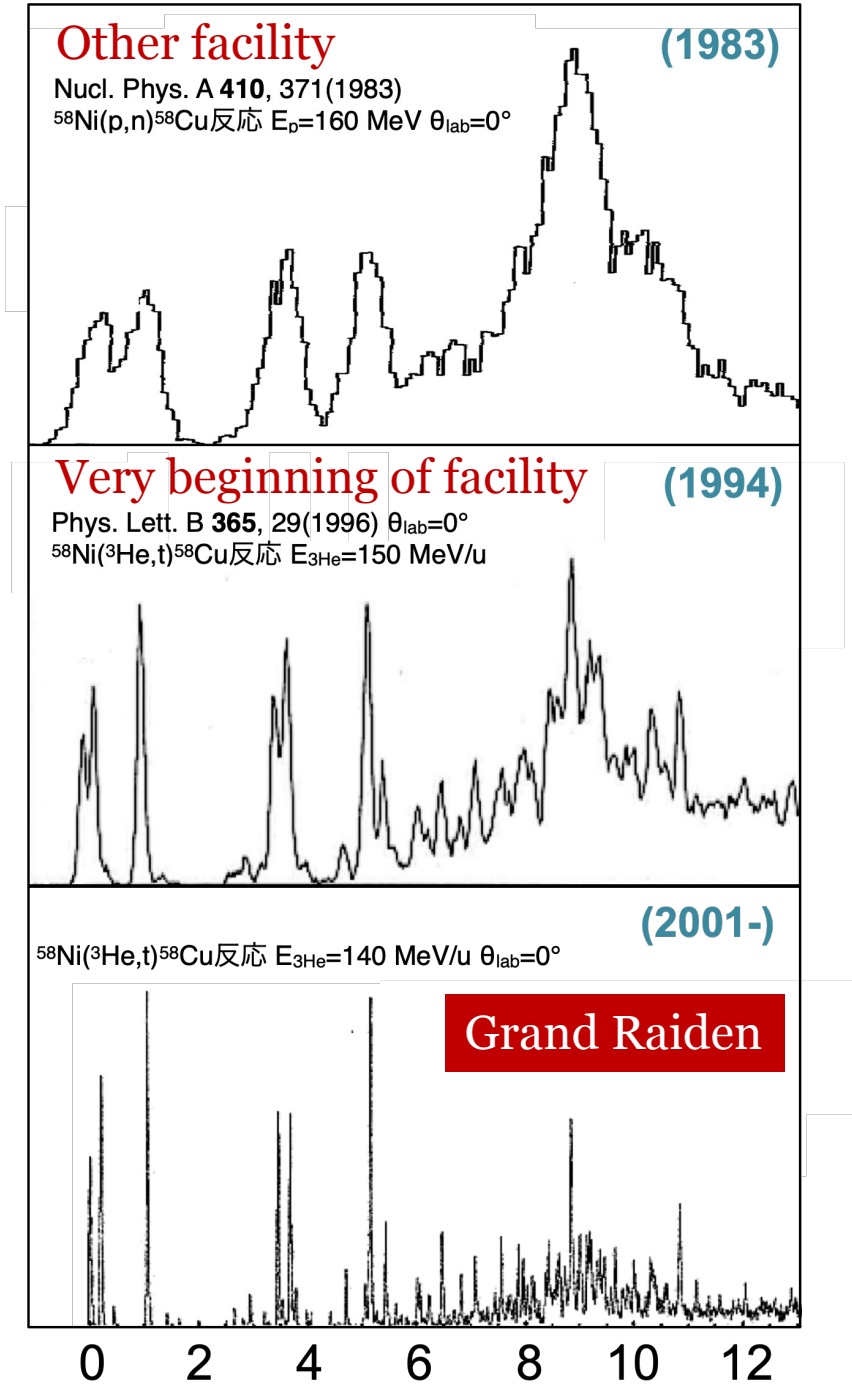
< 400 MeV proton, and < 100 MeV/u deuteron, 3He, 4He, and heavy ions

Grand RAIDEN

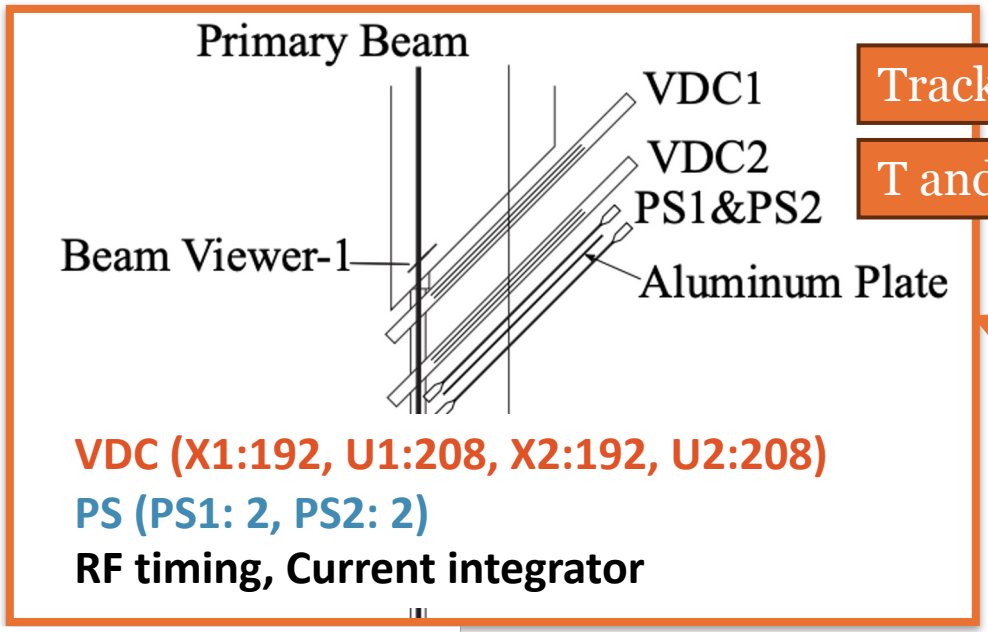
Nuclear reactions with world-best-resolution spectrometer at RCNP



p/Δp ~ 37,000



Grand Raiden



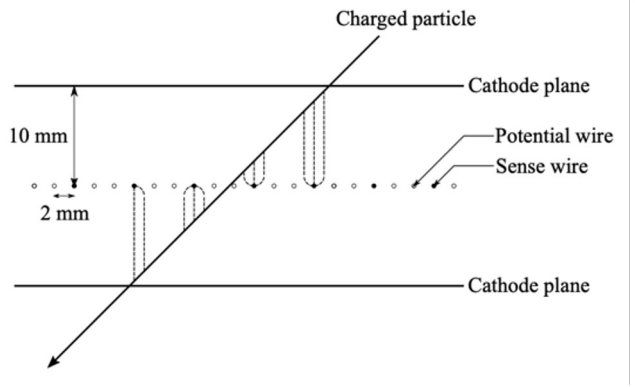
Tracking detector

T and TOT detector

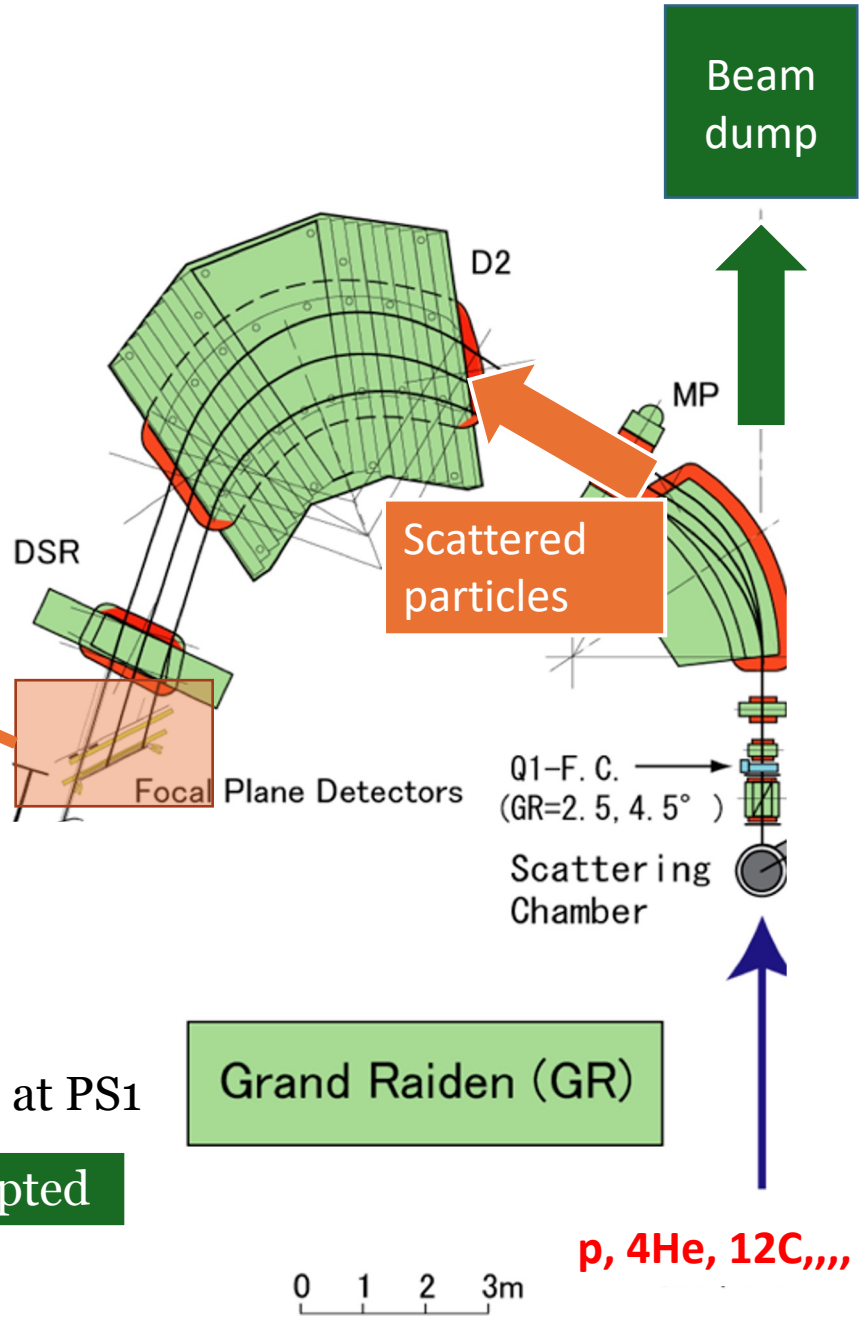
VDC (X1:192, U1:208, X2:192, U2:208)

PS (PS1: 2, PS2: 2)

RF timing, Current integrator



Requires 3 wires in each plane of VDC to deduce the position

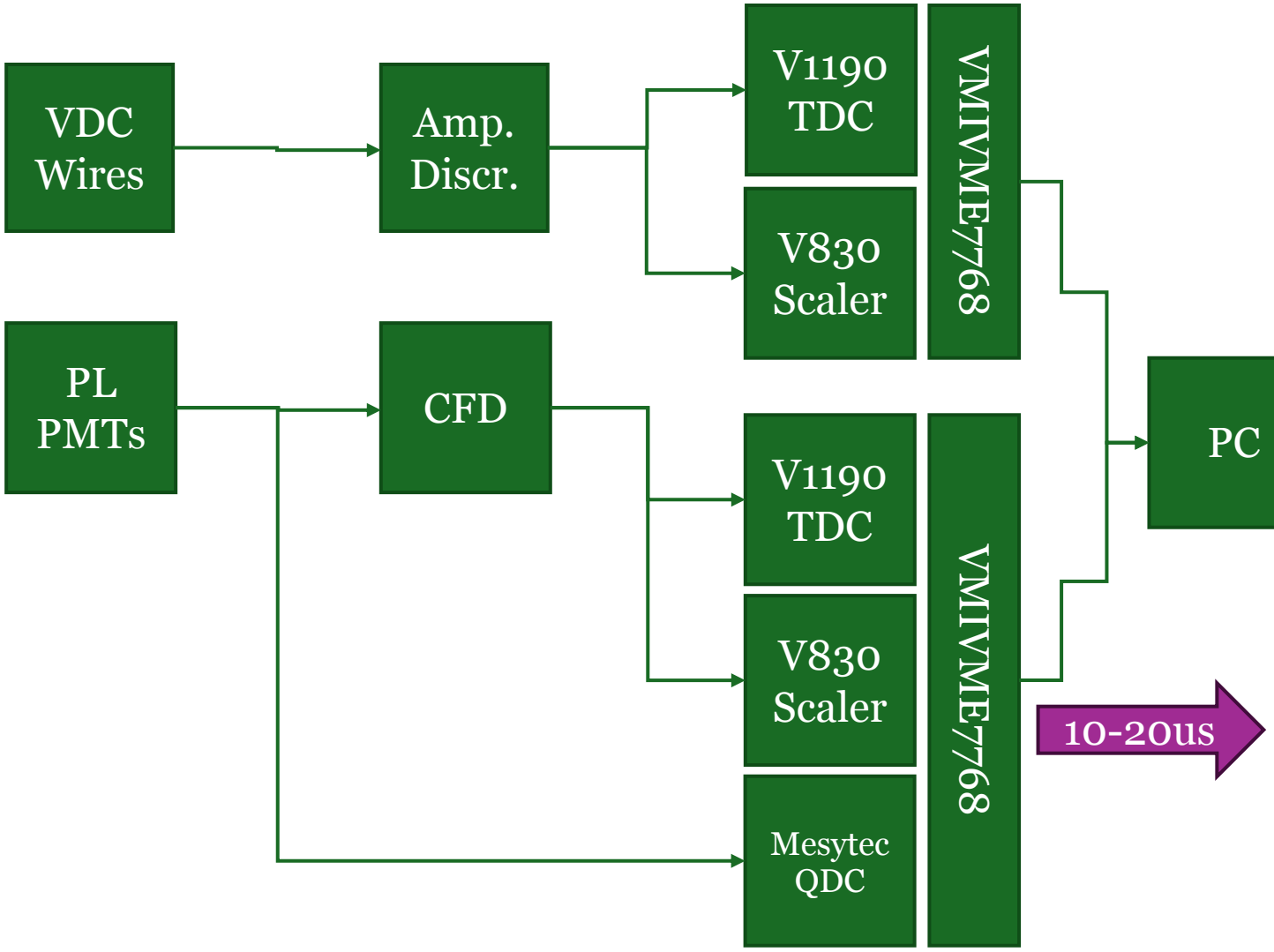


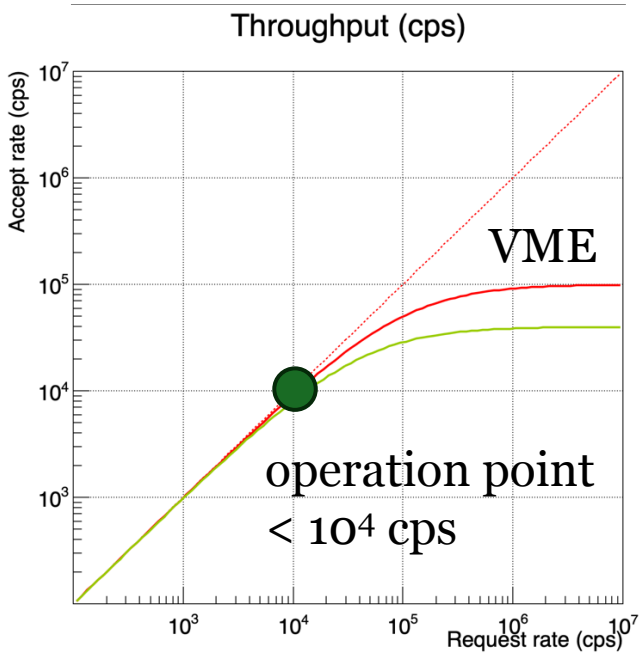
LAS also has similar detectors.

Trigger rate by PS1 == particle rate at PS1

Trigger up to 5-10 kcps can be accepted

Existing data acquisition system

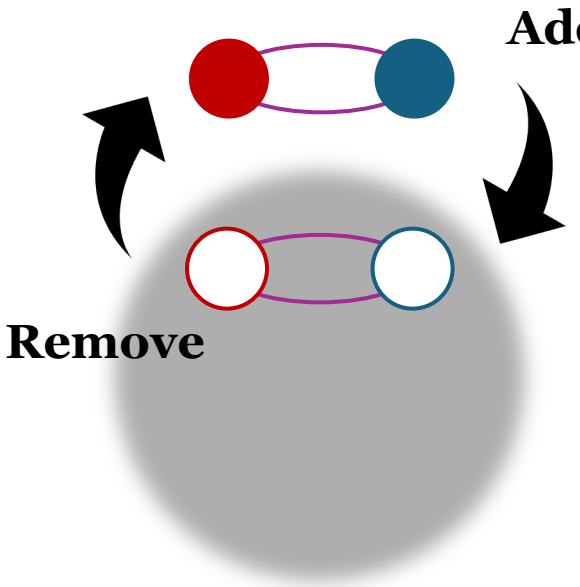


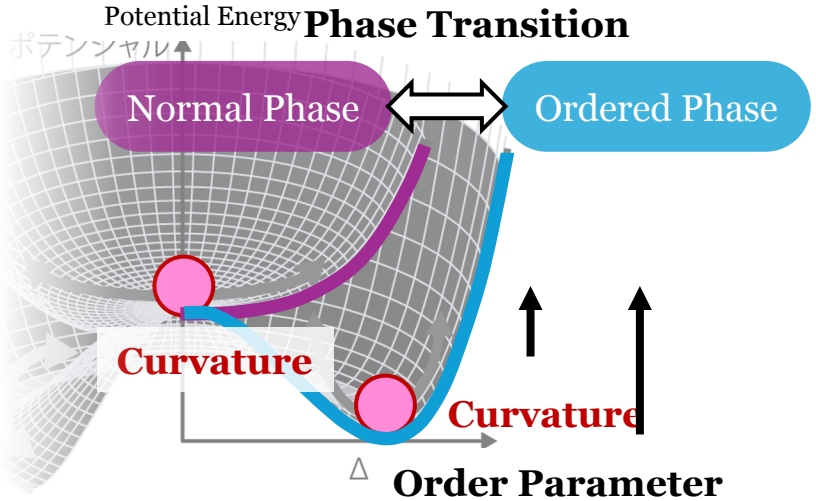


Limits bandwidth
if requires low deadtime
Maximum 50-100 kcps.

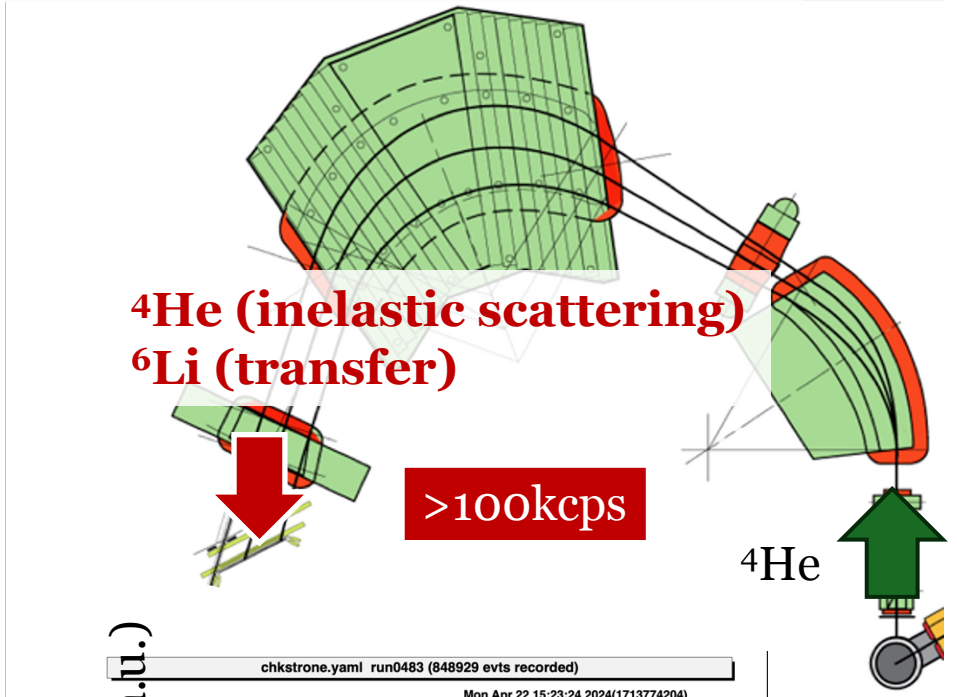
New requirements

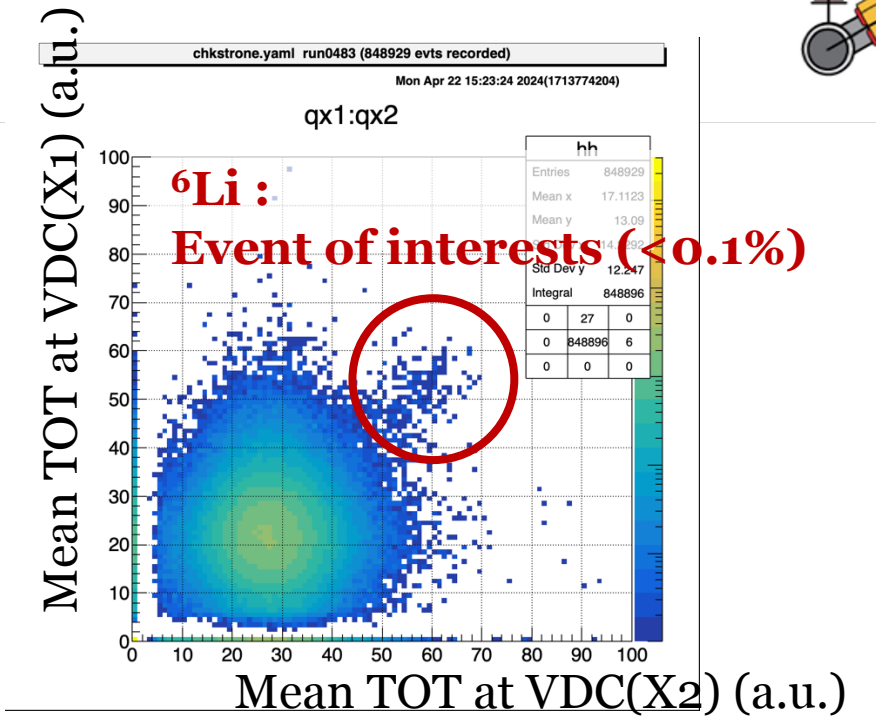
Nucleon pair transfer reaction to study the superfluidity in nuclei



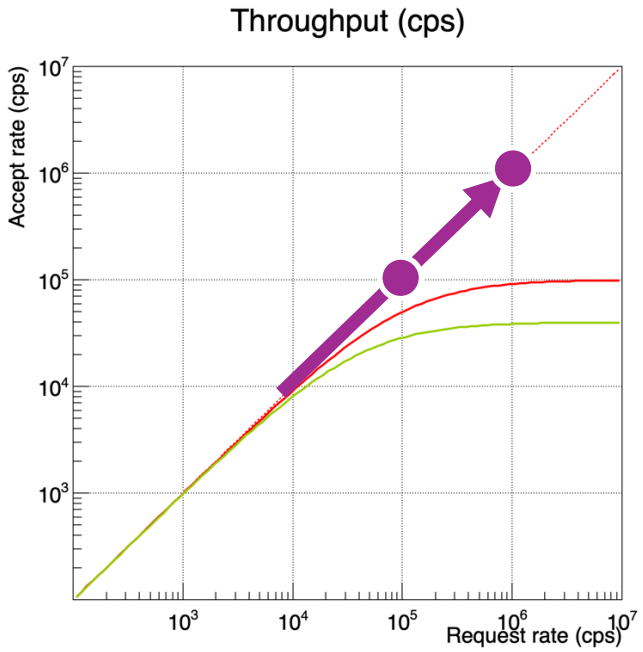


$$\langle \mathrm{BCS}|P^{\dagger}|\mathrm{BCS}\rangle = \frac{\Delta}{G}.$$

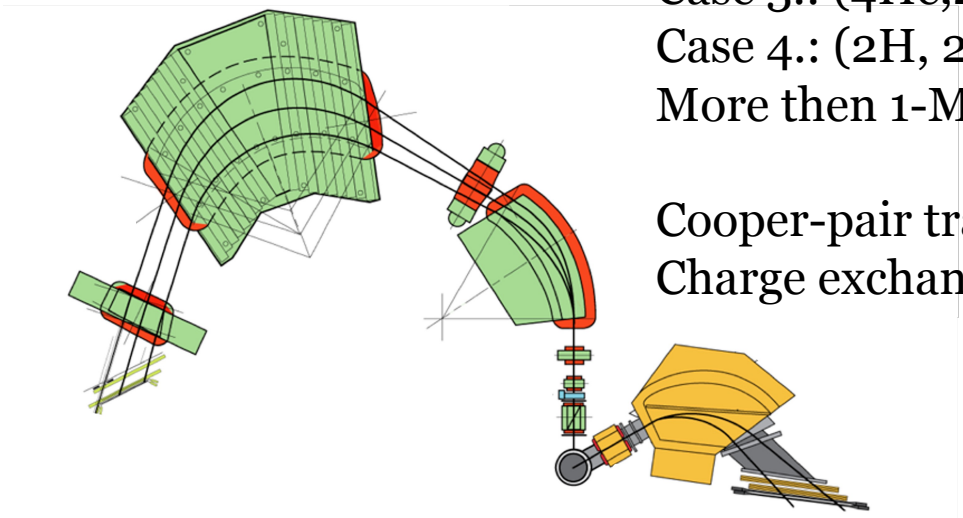




Requirements from similar experiments



Case 1. : (4He,6He) with large background from 4He elastic scattering
Case 2. : (4He,6Li) with large background from 4He inelastic scattering
More than 100-kcps particles are observed.



Case 3.: (4He,2p) with large background by break up
Case 4.: (2H, 2p) with large background by break up
More then 1-Mcps particles will be observed.

Cooper-pair transfer => Superfluidity
Charge exchange =>Noble Nuclear structure

In any case, small S/N ratio (<0.1%) expected.
Trigger rate becomes more than 100 kcps.
Complicated hardware trigger is required.
Difficult to handle conventional data acquisition system.

Any solution?

922 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 70, NO. 6, JUNE 2023

Streaming DAQ Software Prototype at the J-PARC Hadron Experimental Facility

Tomonori Takahashi, Ryotaro Honda, Youichi Igarashi, and Hiroshi Sendai

PTEP Prog. Theor. Exp. Phys. **2021** 123H01(20 pages)
DOI: 10.1093/ptep/ptab128

Continuous timing measurement using a data-streaming DAQ system

Ryotaro Honda[1,*], Takashi Aramaki[2], Hidemitsu Asano[3], Takaya Akaishi[4], W. C. Chang[5], Youichi Igarashi[1], Takatsugu Ishikawa[6], Shunsuke Kajikawa[2], Yue Ma[3], Kei Nagai[5,7], Hiroyuki Noumi[8], Hiroyuki Sako[9], Kotaro Shirotori[8], and Tomonori Takahashi[3]

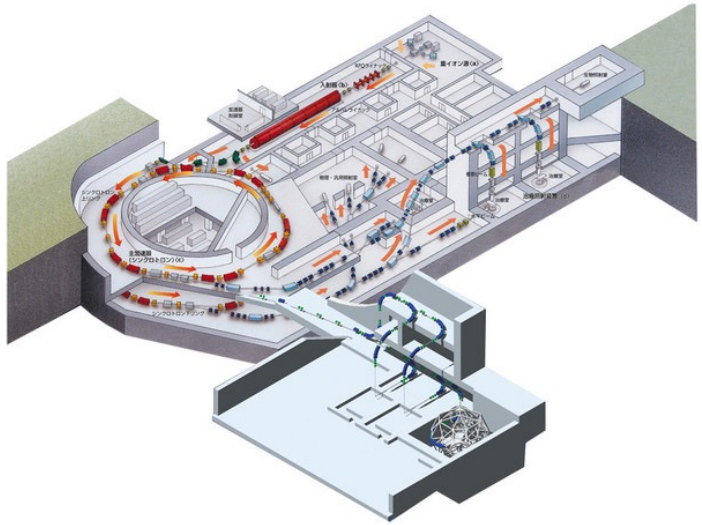
These are developed for J-PARC experiment.
Can we use them in RCNP???

Accelerator for Nuclear Physics in Japan

J-PARC
Z=0,1
MIP

RCNP
Z=0-30
0.1<β<0.7

Accelerator upgraded
10 times intensity



HIMAC
Z=0-54
0.01<β<0.7

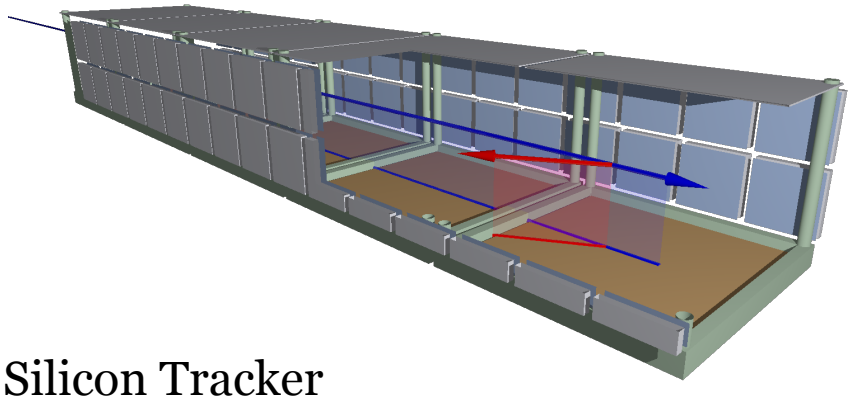
RIBF
Z=0-82
0.01<β<0.7

RHIC, LHC, EIC…

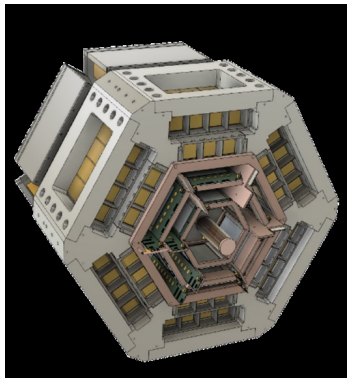
FRIB, …

Near-Future devices

Active Target TPC
20000 ch 12 bit 50 MS/s => 12 Tbps
600 ch 12 bit 30MS/s => 0.2 Tbps

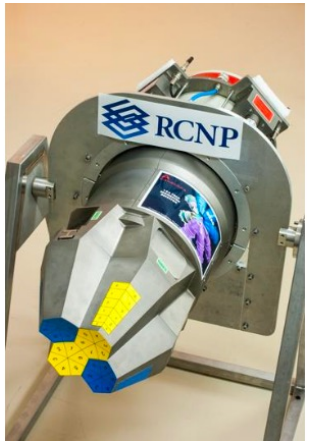


Silicon Tracker
20000 ch 12 bit 30 MS/s => 7.2 Tbps



Courtesy of H. Baba

Segmented Germanium
~2000 ch 16 bit 100 MS/s => 3.2 Tbps



Courtesy of
Y. Yamamoto (RCNP)

64ch 12bit 50MS/s ~ 40 Gbps
64ch 16bit 100MS/s ~ 100 Gbps

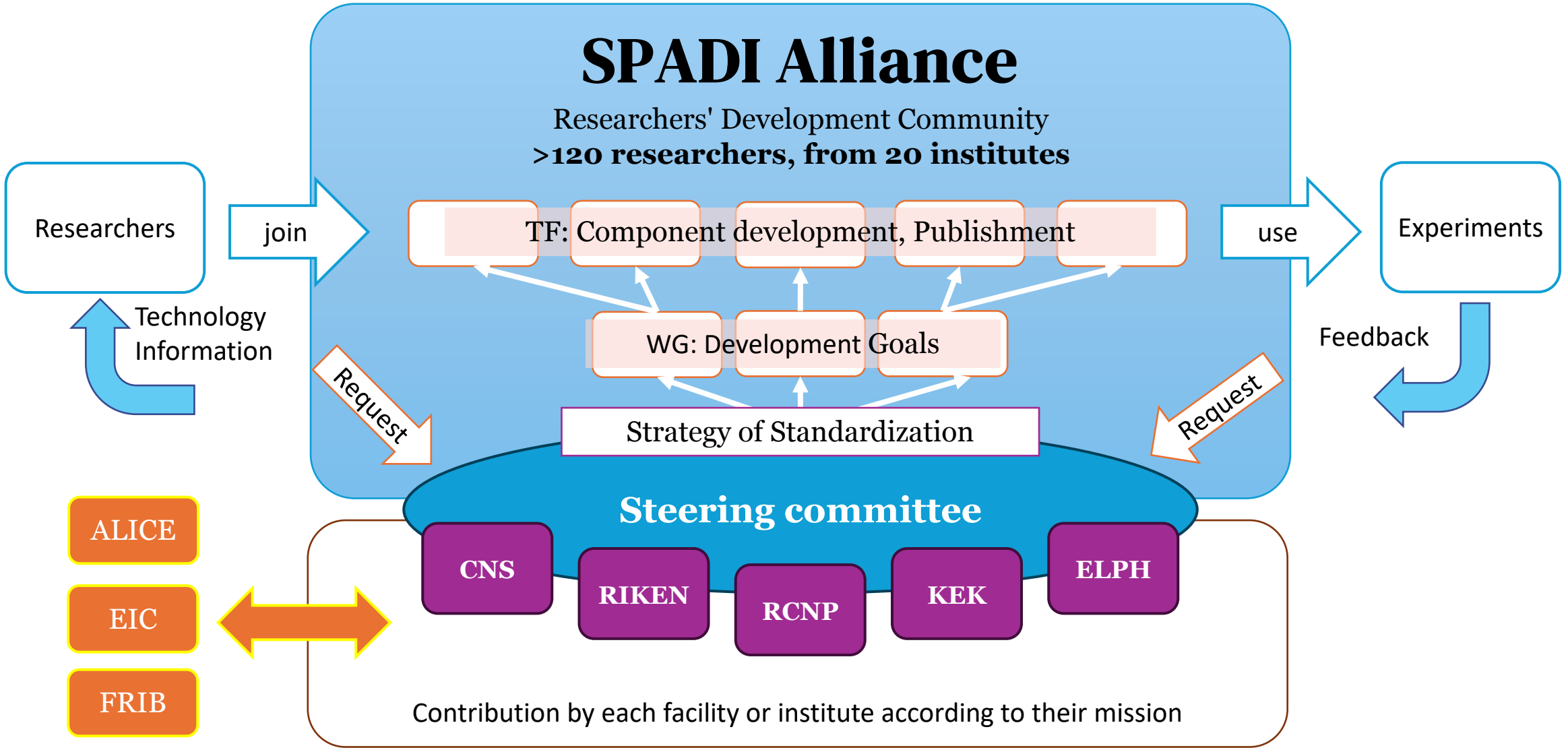
Each group has small number of core member.
Independent DAQ development is difficult.

SPADI Alliance

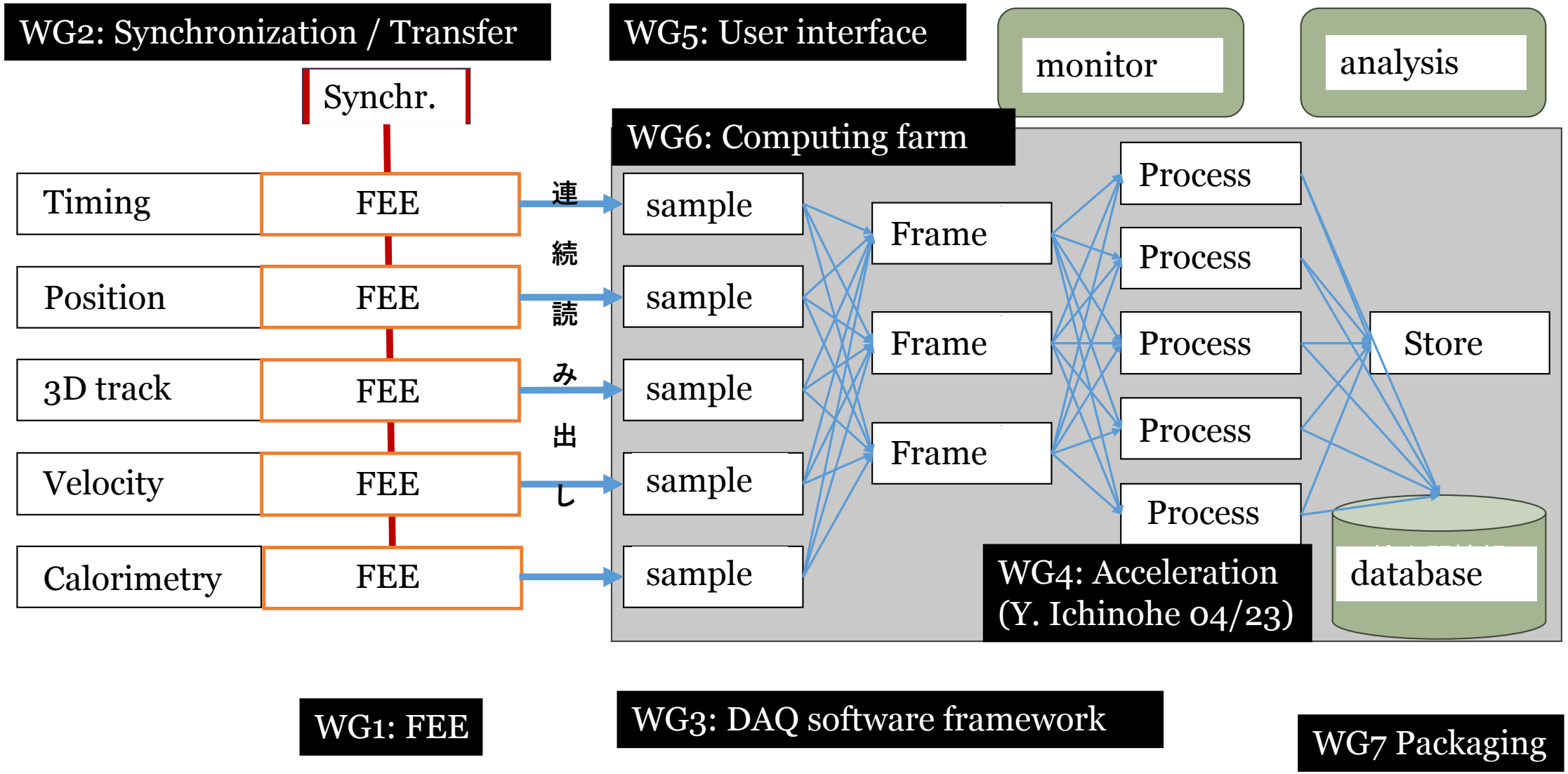
Signal processing and data acquisition infrastructure alliance

toward the standardization for sustainable developments

A new type of collaboration

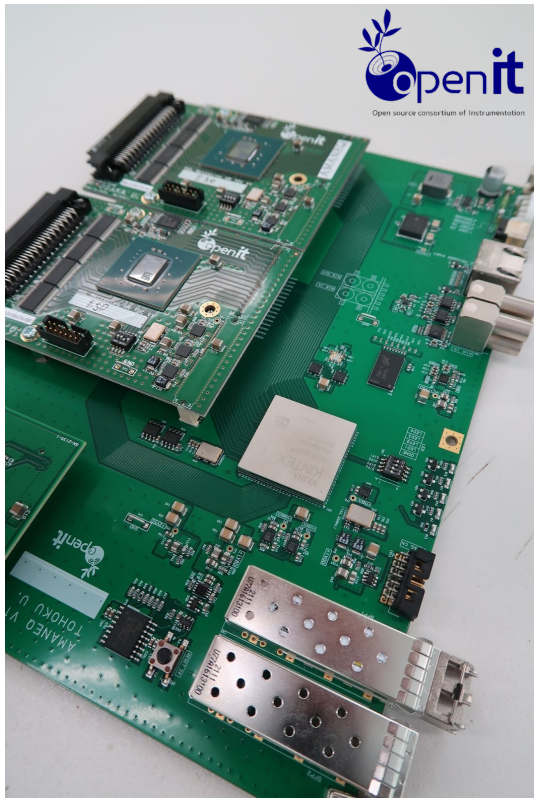


One streaming DAQ system



Part of FEE underdeveloped

Slope ADC : T. Takahashi (04/26)

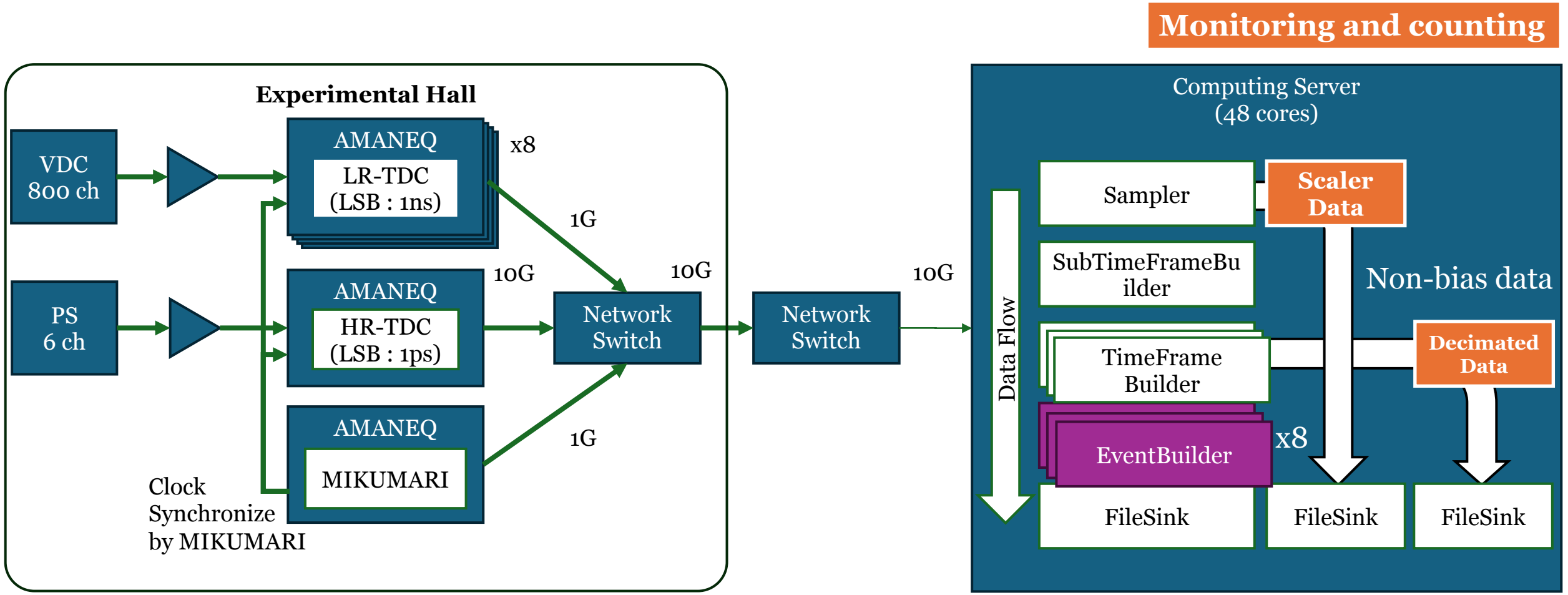


AMANEQ: R. Honda et al.
(General purpose TDC)

SAMIDARE: SPADI Alliance
(TPC readout with SAMPA)

MIRA: H. Baba et al
(Waveform digitizer for Si)

Application for the physics experiment (^{4}He,^{6}Li) at RCNP

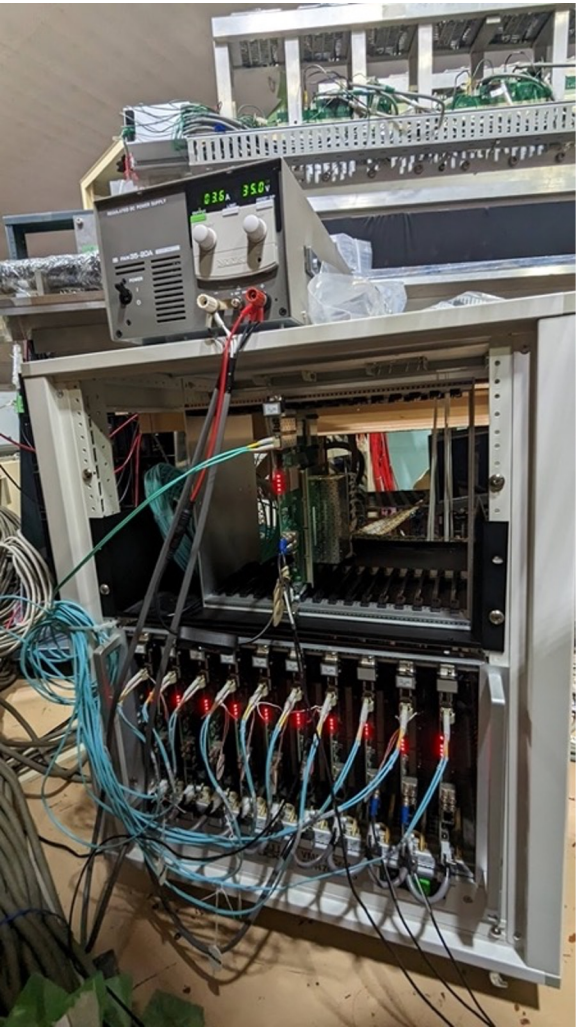


AMANEQ / MIKUMARI : R. Honda on 04/25

NestDAQ framework : Y. Igarashi on 04/23

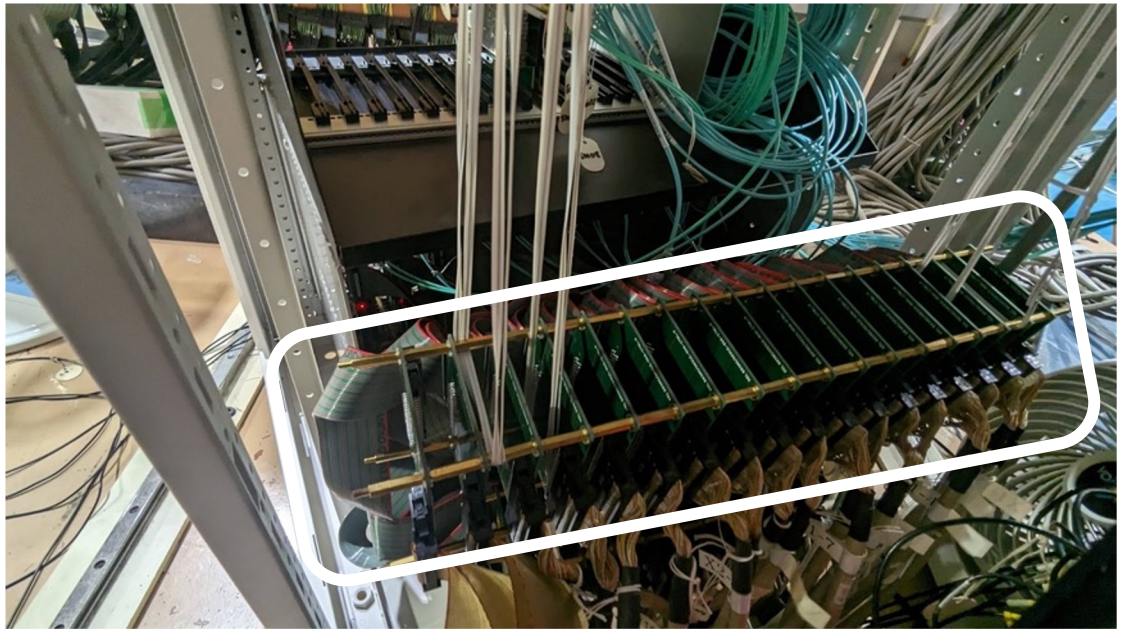
Needs standardization …

Focal plane

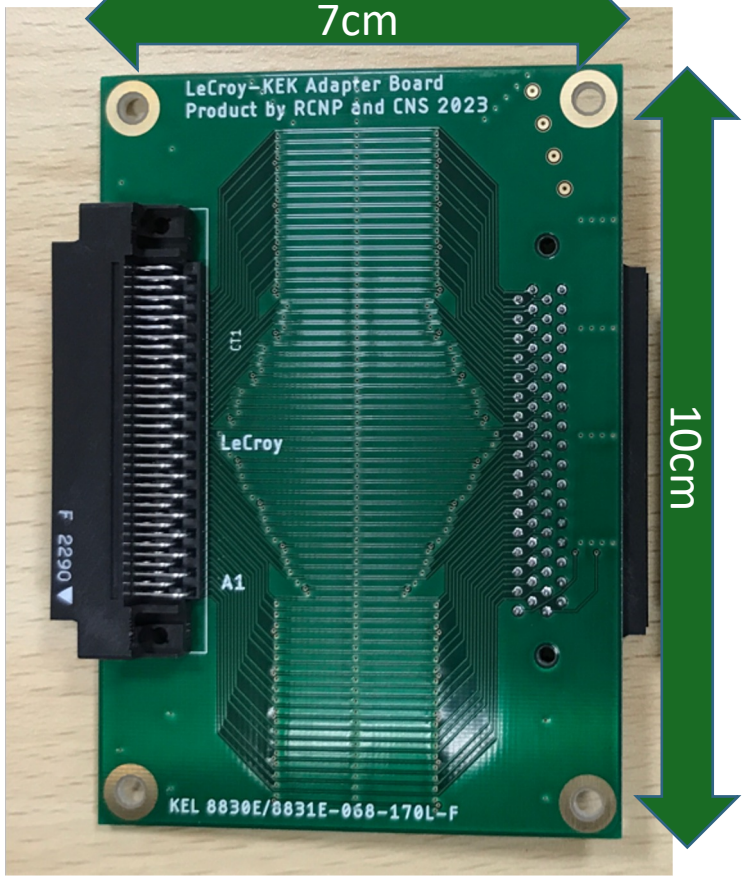


Pitch converter is needed to adapt the AMANEQ TDC

VDC	▶		P-C	AMANEQ
Plastic	NIM-LVDS	QTC	P-C	AMANEQ



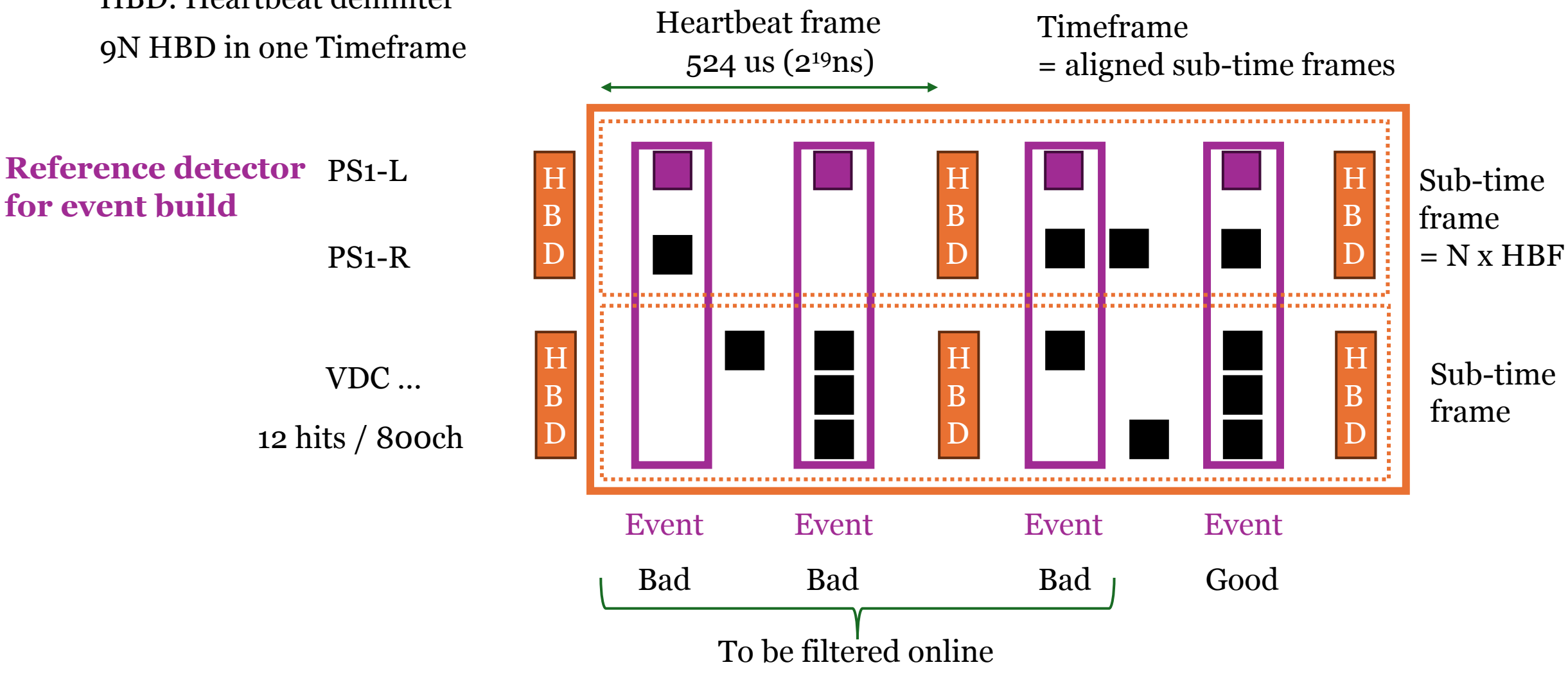
Pitch converter
1…32 <-> 3…34
35..66 <-> 37…68
(CNS/RCNP)



Data structure and Event building

HBD: Heartbeat delimiter

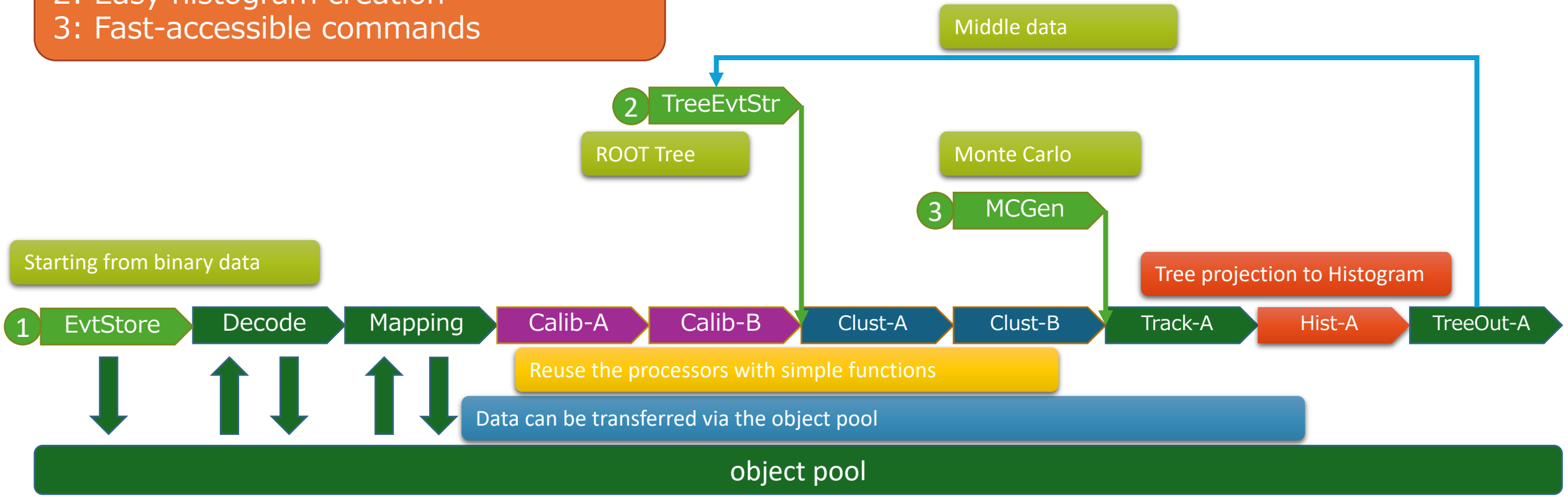
9N HBD in one Timeframe



ARTEMIS (Analysis Framework)

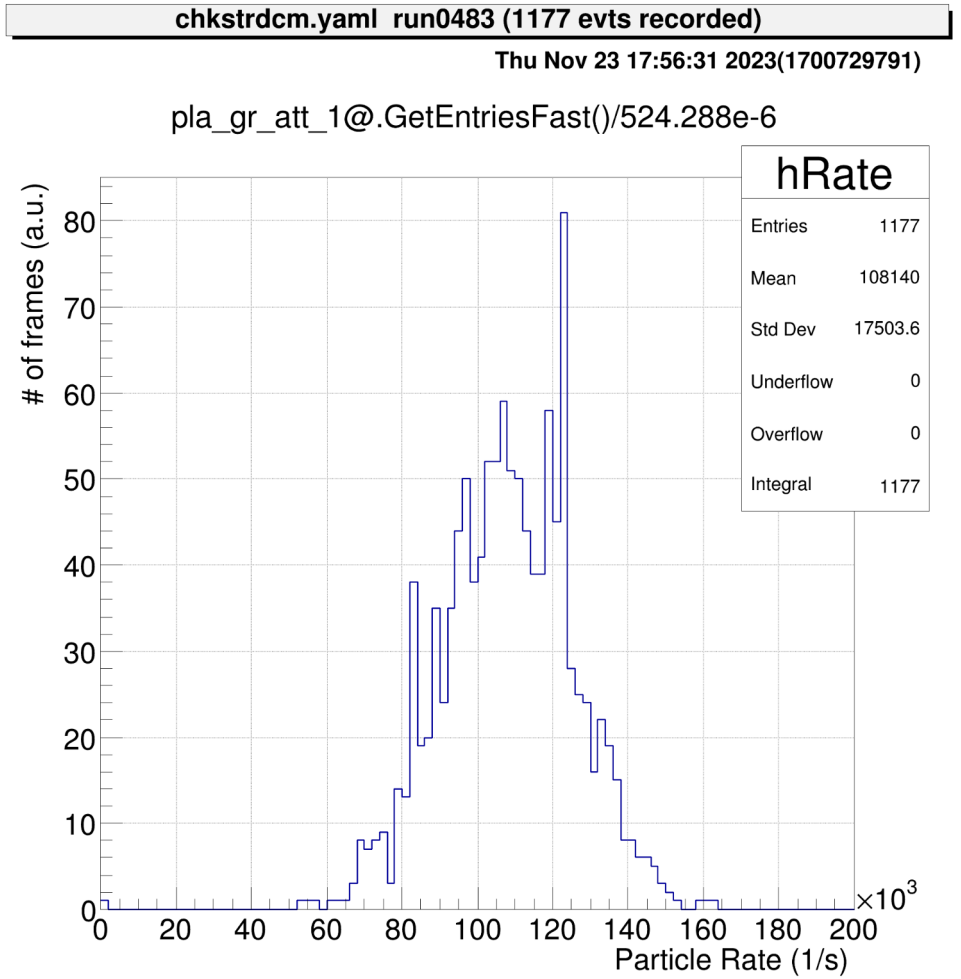
A ROOT Extension with Modular processors for Instant Switching

1: Instant Switching Modular Processors
2: Easy histogram creation
3: Fast-accessible commands

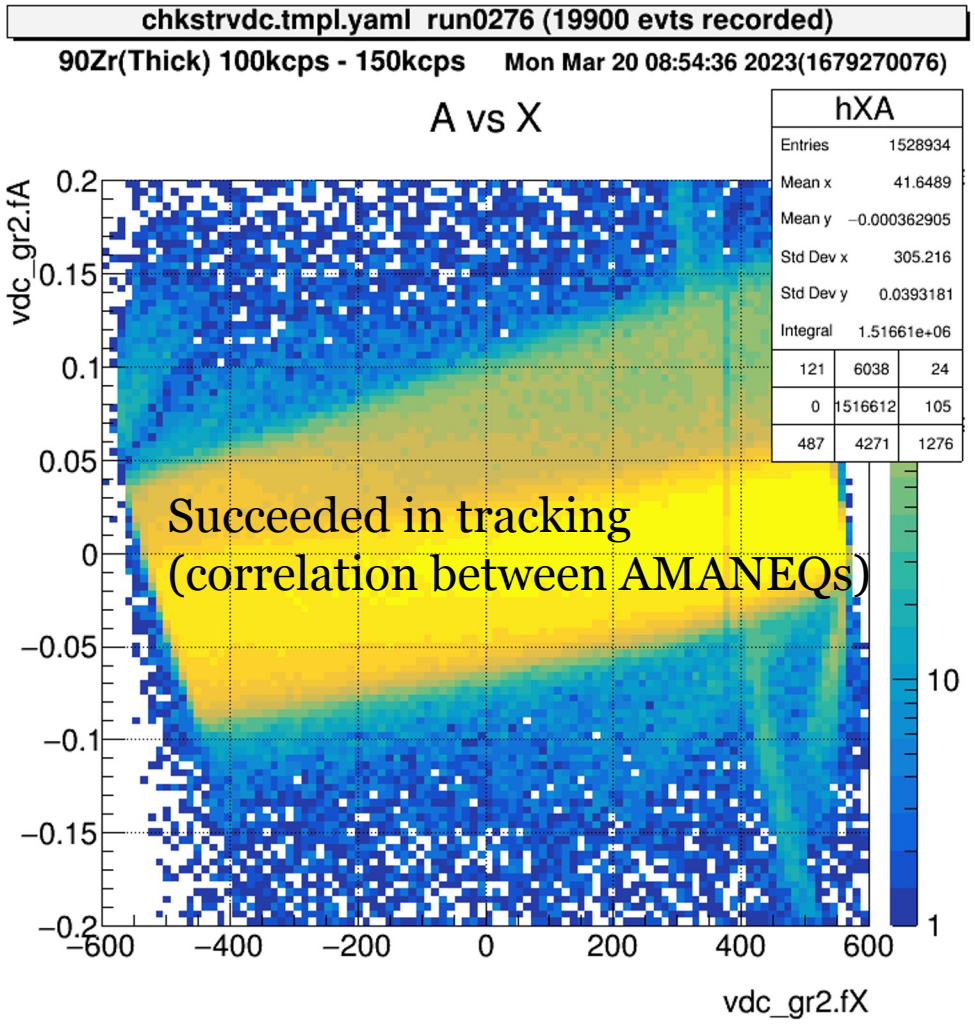


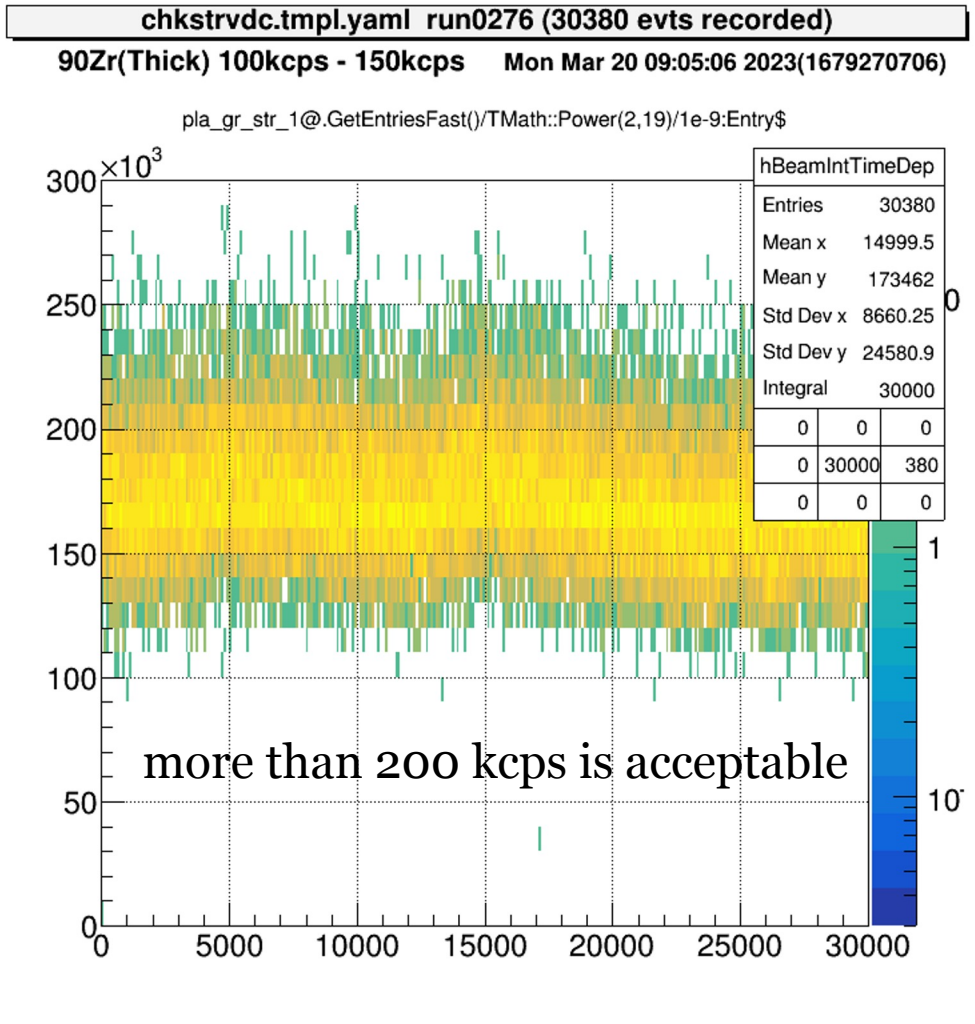
Trigger equivalent rate

- Number of hits per heartbeat frame gives an estimation of event rate.
- Trigger rate == Event rate
  - >100 kcps was achieved
- Throughput ~ 300 Mbps
  - Limited by luminosity (beam intensity x target thickness) at this moment.

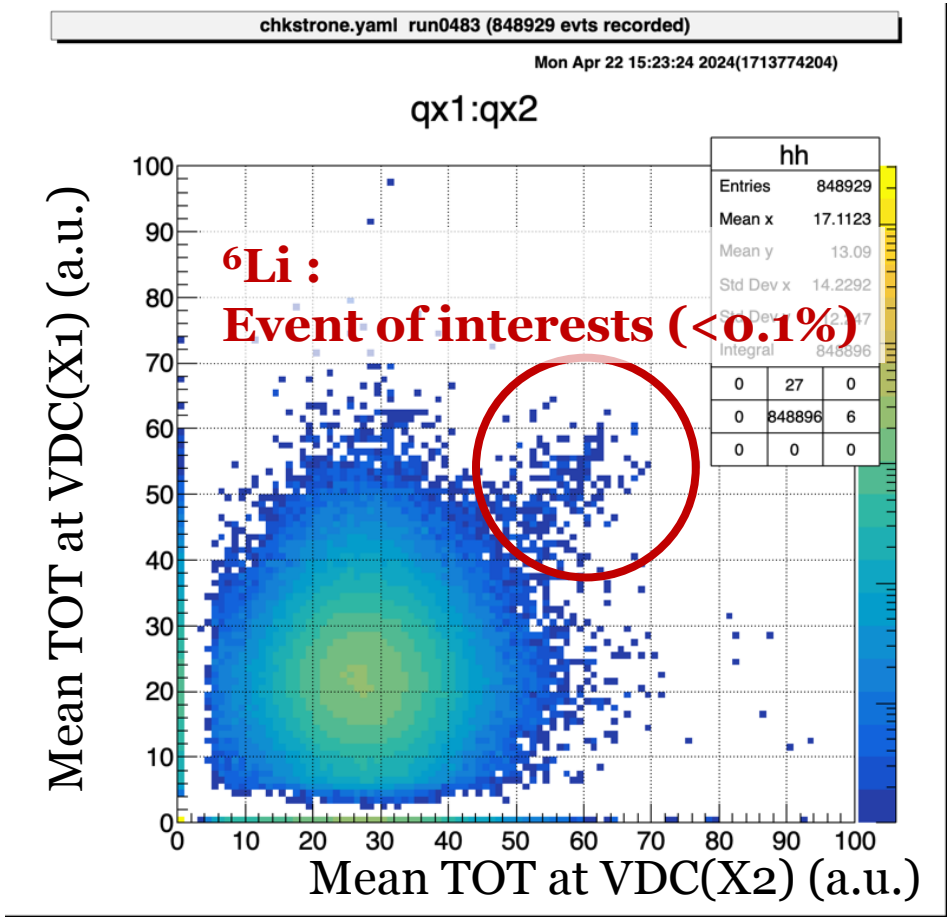


Higher throughput is achieved





Needs more development : online filter

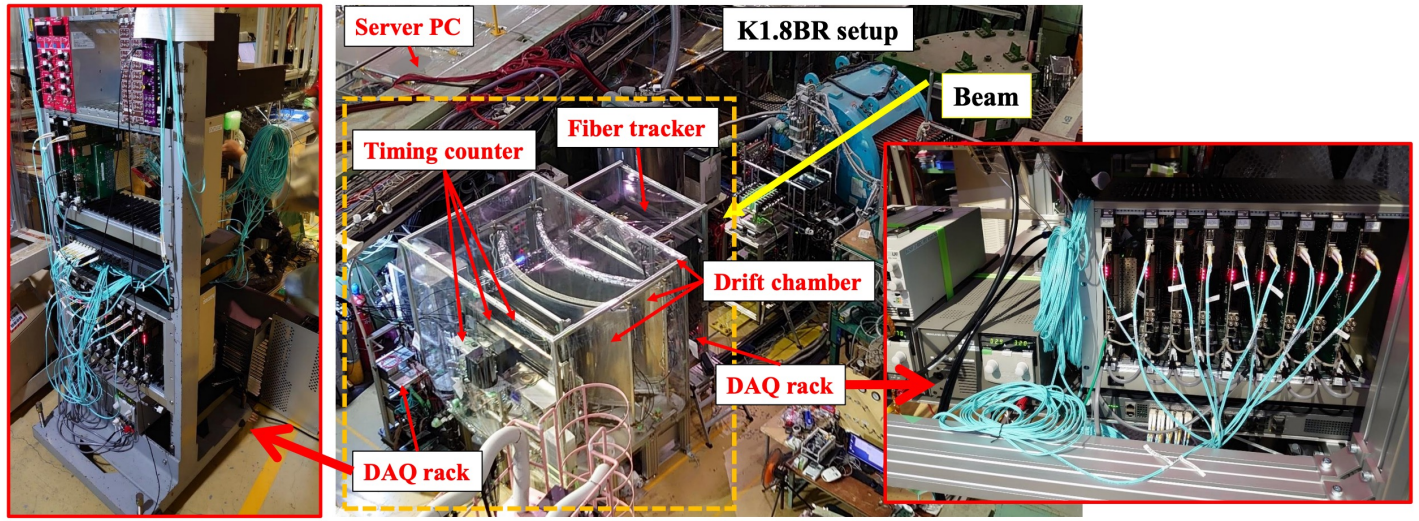


- Data can be recorded but with S/N < 0.1%
- Consume the storage and analysis time by meaningless data…
  - ex.) 17 TB for 5 days
- Online filtering is strongly required.
  - Particle identification
  - Tracking and vertex reconstruction
  - Physics observables

Back to J-PARC, and …?

Ongoing experiments

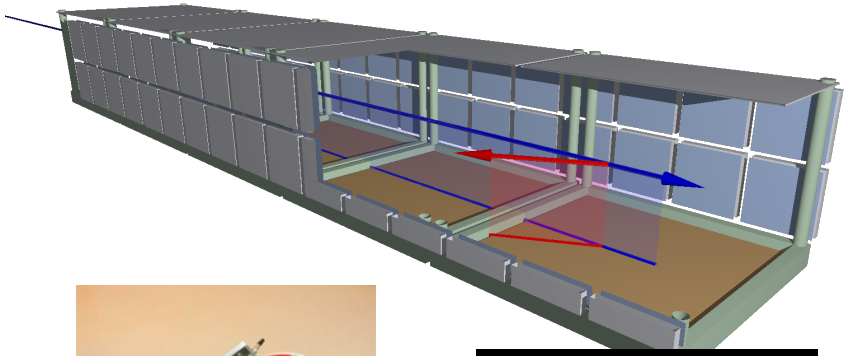
Test bench photo: 2023 June beam time

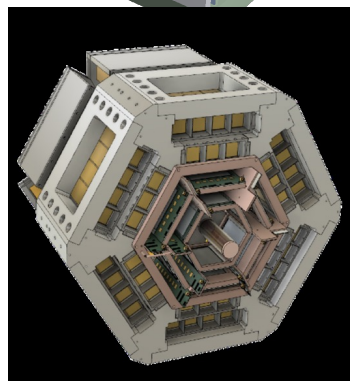


- **Detector channels: ~2000 ch (DC ~1500 ch, Fiber ~400 ch, Counter ~60 ch)**
- **DAQ: AMANEQ×20 (Streaming TDC×17 + MIKUMARI×3)**
- **Data taking PC server×1**

⇒ Standard nuclear physics experiment scale (much compact rack size)

Courtesy of K. Shirotori
Experiment (T103) with the same DAQ system is ongoing now!!
10 times larger throughput (> 3Gbps).





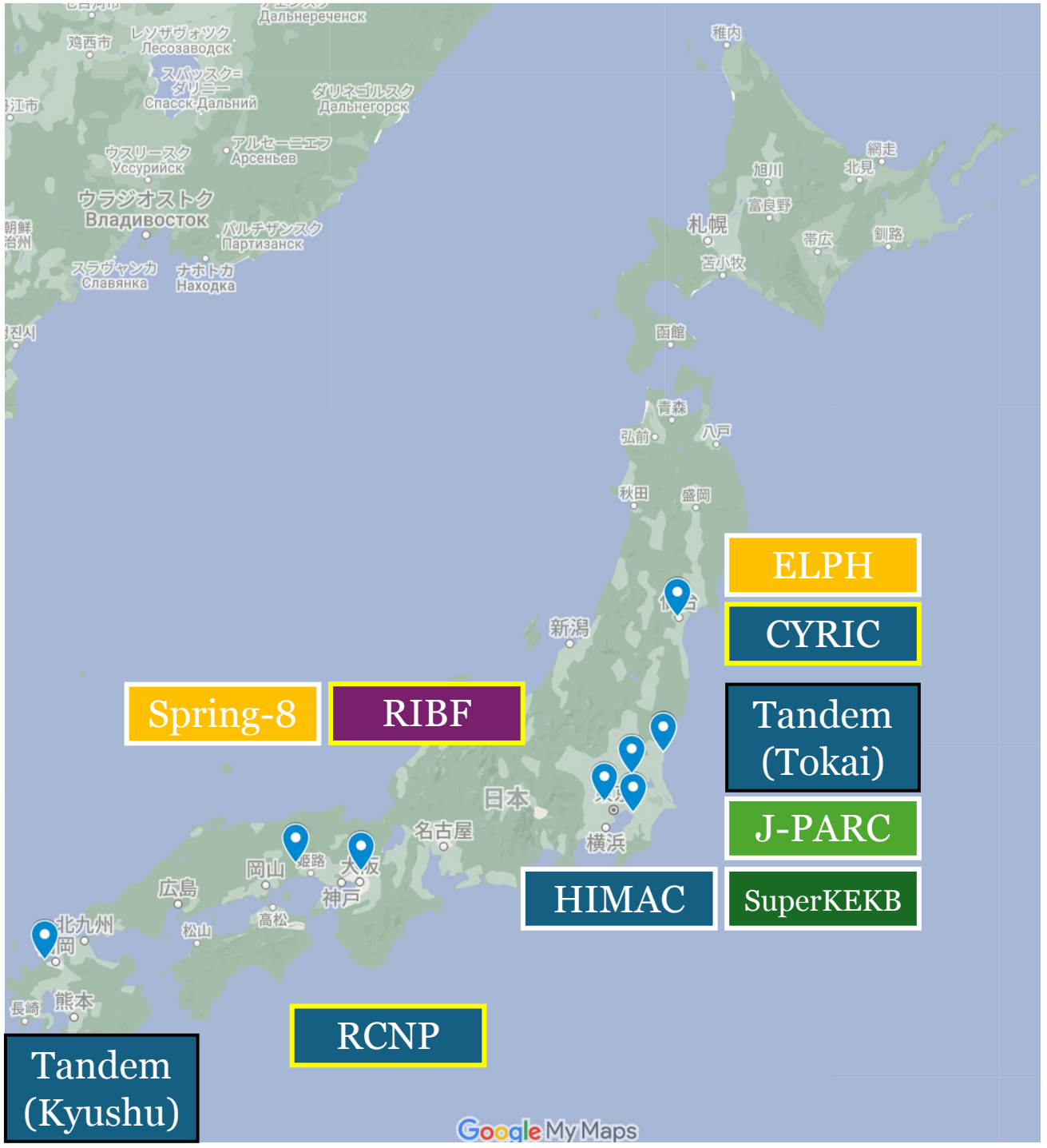
Treatment of higher-throughput (>>1Tbps) is under discussion.

Summary

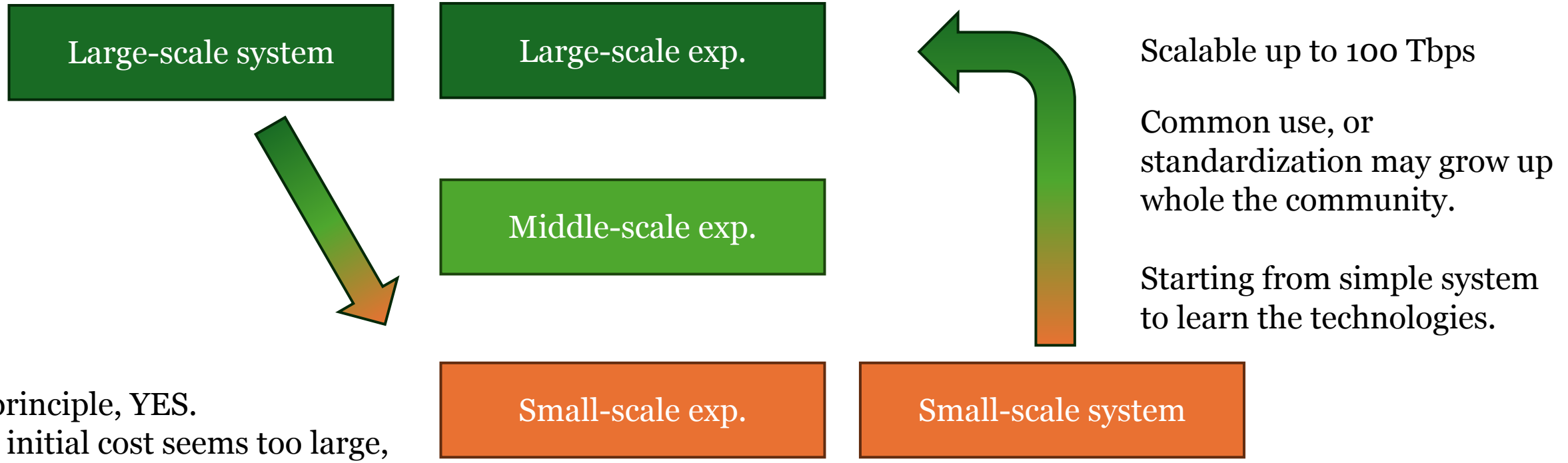
- New scheme of the data acquisition is commonly required in nuclear and hadron experiments in Japan
- **SPADI Alliance** are formed in Japan, aiming at constructing and distributing a common data acquisition system including hardware and software.
  - Standardization of the system is important for sustainable development and exchange the knowledge and technique
- **An application of streaming data acquisition system at Grand RAIDEN in RCNP** has been done.
  - 40 times speed up compared to existing system
  - New experiment is becoming possible to be performed.
- Same scheme was and is **being applied to an experiment at J-PARC**
  - This is the first step of the standardization
- Developments of online filters and higher-throughput data transfer scheme are required.
- Please contact us if you are interested in!

Situation in Japan

- Not only the large-scale experiments but also the small-size experiments
- Variety of the beam species, the beam energies, the targets and the measured reaction products
- Variety of the lifetime of the experimental setup from one day to several months (or more)
- **Frontend electronics : commercial and designed**
- **Localized DAQ software (and hardware) and analysis tools**



A large thing will serve for a small one...?
大（だい）は小（しょう）をかねる?



Scalable up to 100 Tbps

Common use, or standardization may grow up whole the community.

Starting from simple system to learn the technologies.

In principle, YES.
But initial cost seems too large, setup, configuration and/or operation are also difficult WITHOUT knowledge and technique.

Both views and requirements are important for the common-use scalable system

Stating from the small, scalable system in cooperation with researchers from different institutes

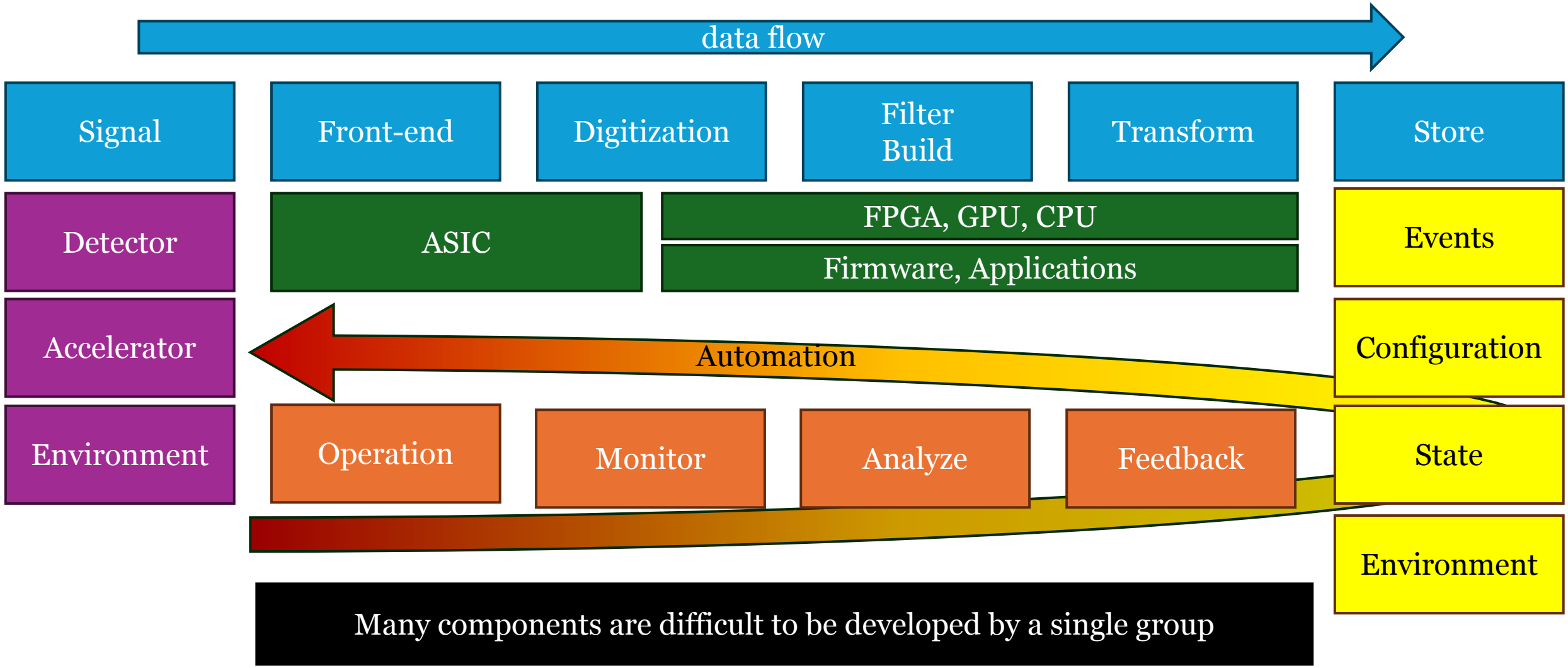
Feature of each facility

	RIBF	RCNP	J-PARC	
Accelerator	Cyclotron	Cyclotron	Synchrotron	
Beam	Heavy ion (Z<92)	Light to medium	Meson / Hadron	
Velocity (β)	0.1 < β < 0.7	0.1 < β < 0.7	β > 0.9	
Intensity	10^7 cps	10^{10}-10^{12} cps	10^7 cps	
Measure beam?	Yes	No	Yes	
Reaction rate	10^3 cps	10^4 cps	10^3 cps	
Detection rate	10^6 cps	10^4 cps	10^6 cps	Beam/react.
Energy deposit	2 - >100000	2 - 3000	1	MIP = 1
# of Ch in Std Sys.	200	2500	25000*	* HD spectrometer
User DAQ	Yes	Yes	Rarely	
Life cycle	2 weeks	2 weeks	> 1 month	

FRIB

EIC, sPHENIX, ..

Develop components



Working groups and Task forces

WG1
Frontend Electronics

Streaming type
Charge ASD board
Voltage ASD board
WF Digitizer board
Control Firmware dev.

WG2
Clock synch. / Data Transfer

General Clock Synch.
High throughput
Intra-board transfer

WG3
Acquisition software framework (NestDAQ + …)

Streaming type
FairMQ-based Scalable DAQ
Sampling, Time frame build, ~~Event build, Monitoring…~~
Format

WG4
Event processing

Acceleration using GPU/FPGA
Zero suppression
Calibration, Clustering, Tracking, PID,

WG5
User Interface

Control, Monitor, Configure,

Trial with
SlowDash

WG6
Computing infrastr.

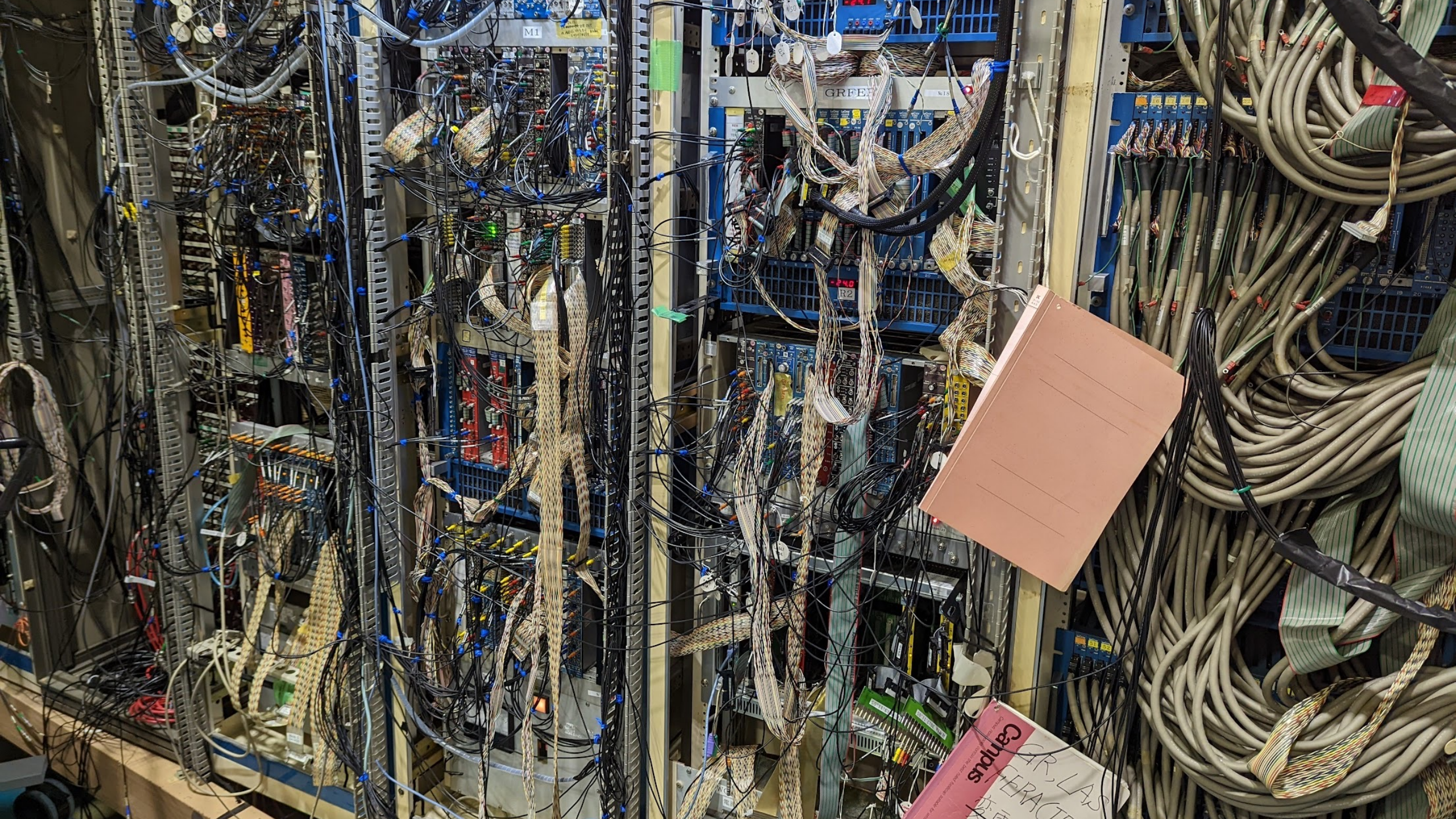
High throughput
Large volume
Flow and Archive
Power consumption
Interconnect
Networking
…

WG7
Packaging

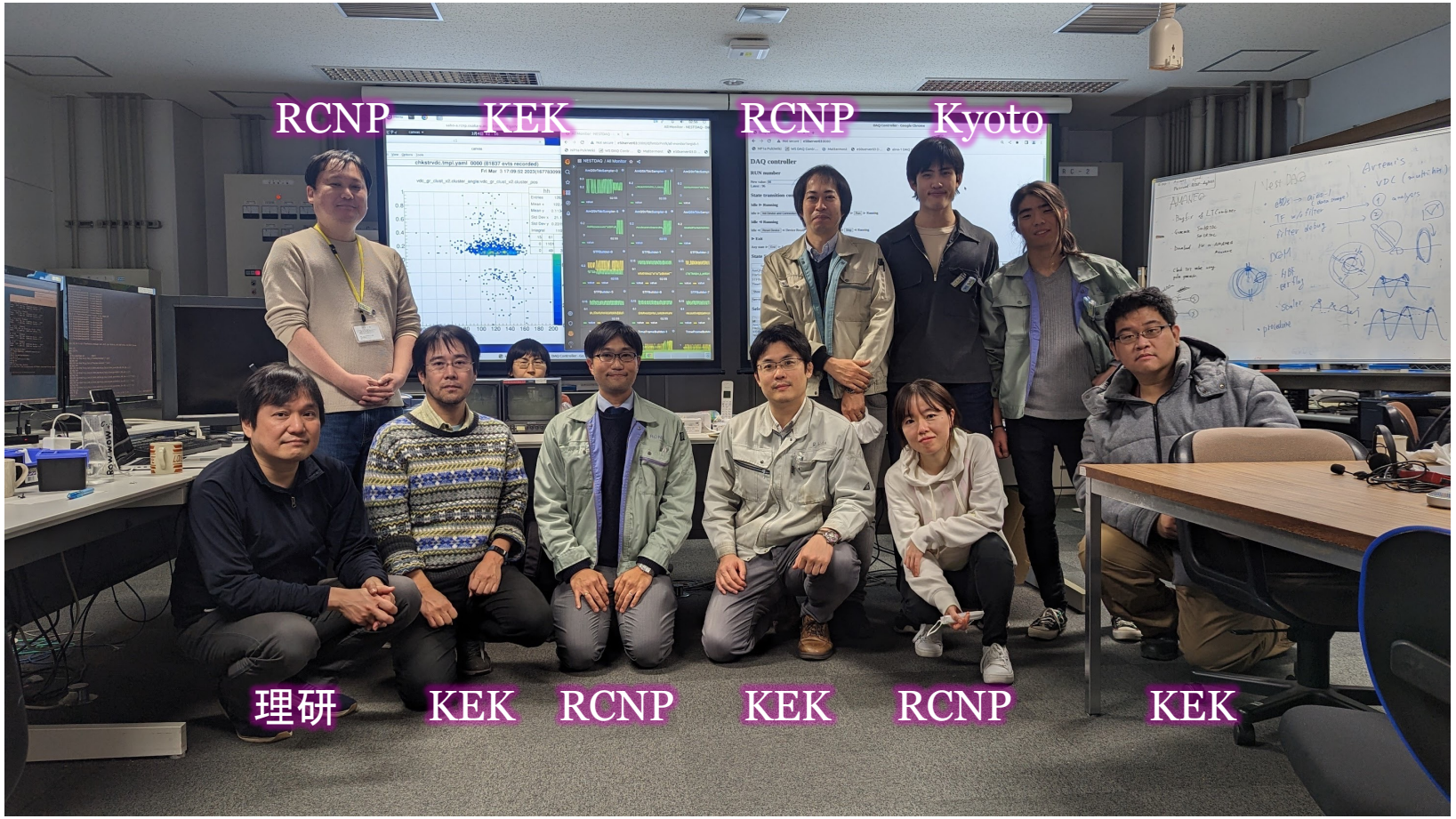
Standalone system
Popularization
Standardization
Market research
User feedback

Analysis

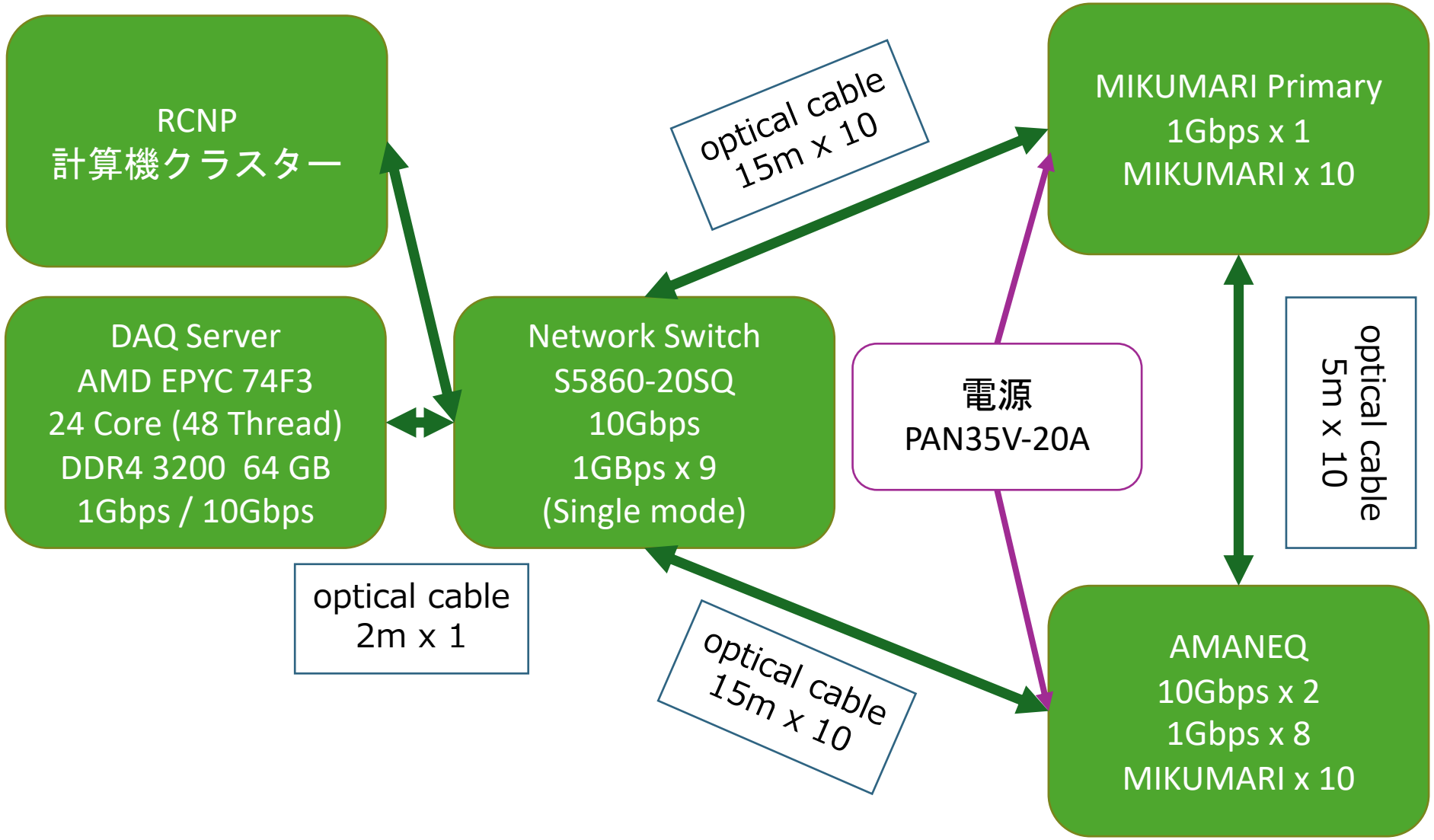
Trial with
Artemis

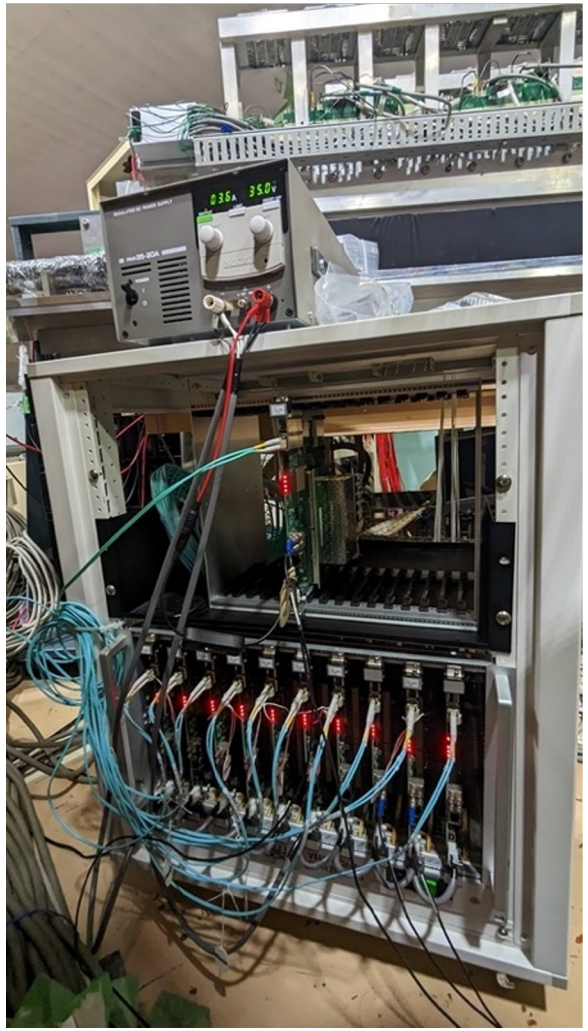

M1
R2
Canpus

Collaboration photo

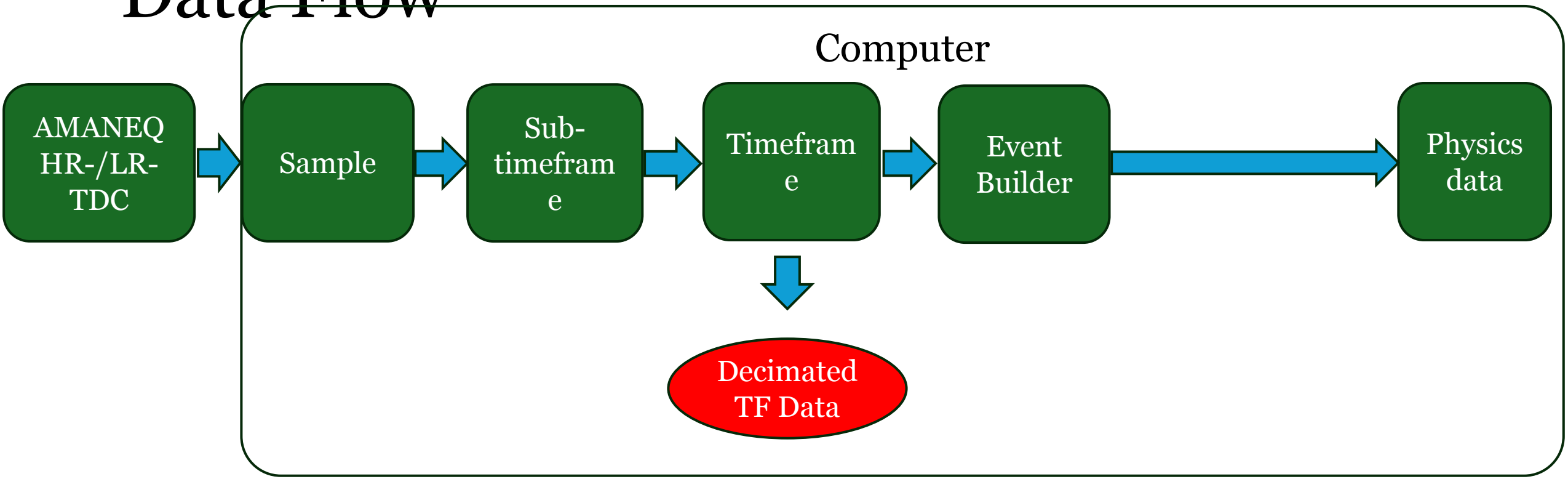


Devices


RCNP
計算機クラスター
DAQ Server
AMD EPYC 74F3
24 Core (48 Thread)
DDR4 3200 64 GB
1Gbps / 10Gbps
Network Switch
S5860-20SQ
10Gbps
1GBps x 9
(Single mode)
optical cable
15m x 10
optical cable
2m x 1
optical cable
15m x 10
電源
PAN35V-20A
MIKUMARI Primary
1Gbps x 1
MIKUMARI x 10
optical cable
5m x 10
AMANEQ
10Gbps x 2
1Gbps x 8
MIKUMARI x 10



Data Flow



Now inserted filter after the EventBuilder

- Detector
- Sampler
- EventBuilder
- Disk

TimeFrameBuildPlayer is Data Replayer.
Raw data are unprocessed data acquired in an experiment and have a TimeFrame structure.