TIPP2023

TECHNOLOGY IN INSTRUMENTATION & PARTICLE PHYSICS CONFERENCE

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Design and Implementation of the TDAQ System for the JUNO-TAO Detector

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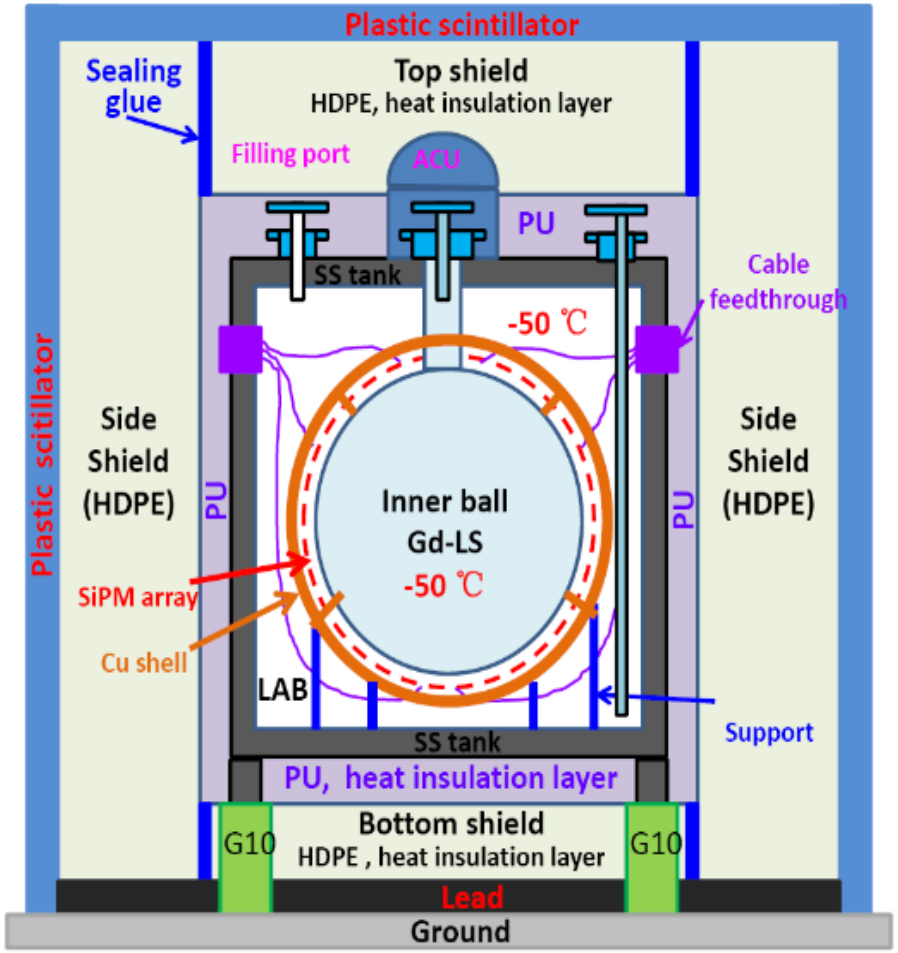
On behalf of the JUNO Collaboration

Outline

- Introduction to JUNO-TAO
- TAO TDAQ system design and implementation
  - CD trigger
  - TVT hardware trigger
  - DAQ
- Summary

JUNO-TAO

- Taishan Antineutrino Observatory (TAO), a ton-level, high energy resolution LS detector at 30 m from the 4.6 GWth core, a satellite exp. of JUNO.
- Measure reactor neutrino spectrum w/ high E resolution
  - Model-independent reference spectrum for JUNO
  - A benchmark for testing the nuclear database

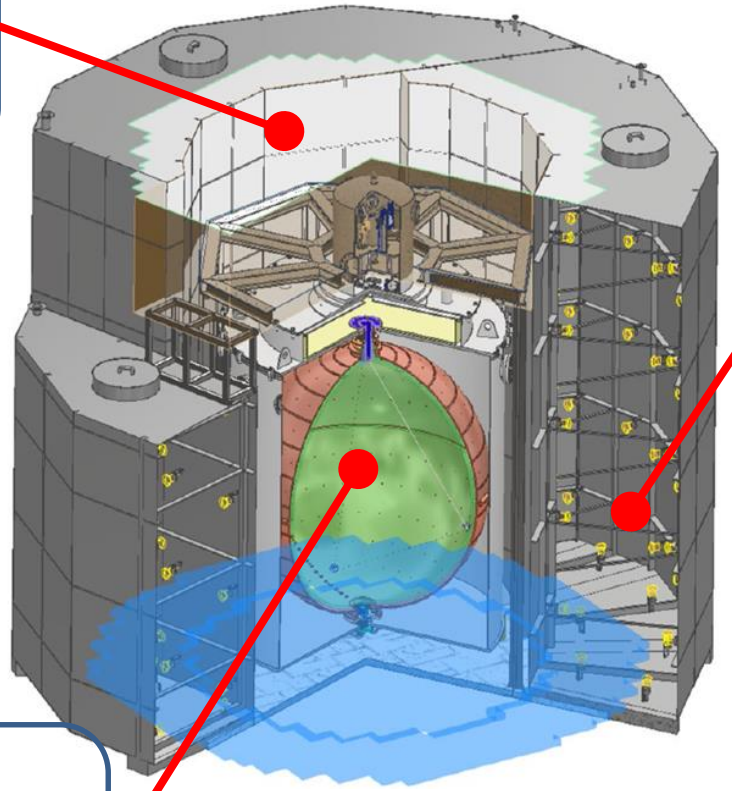


CDR: 2005.08745

TAO Detectors & Electronics

Top Veto Tracker (TVT)

- Plastic scintillator: 160 strips (4 layers)
- SiPMs at both ends: 320 tiles, 0.8 m^2



Share SiPM readout electronics

- **250/125 MHz sampling**, raw readout dominated by SiPM dark rate

Central Detector (CD)

- 2.8 ton Gd-LS
- Full coverage of SiPM (10 m^2) w/ PDE > 50%
- Operate at -50 ℃ (for SiPM dark noise reduction)
- Energy resolution <2% resolution @ 1MeV

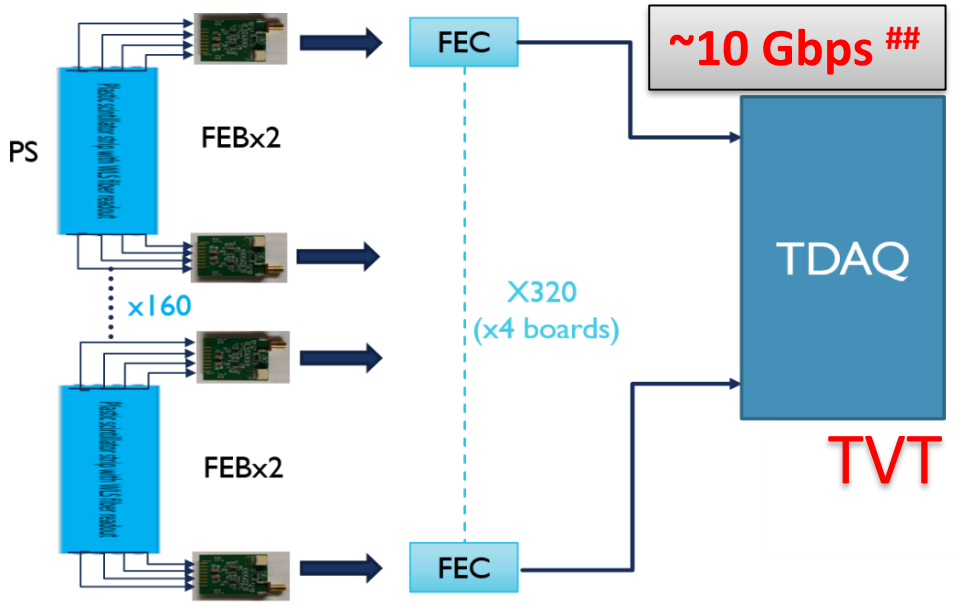
Water Tank (WT)

- 3 tanks, ~100 3” PMTs for each

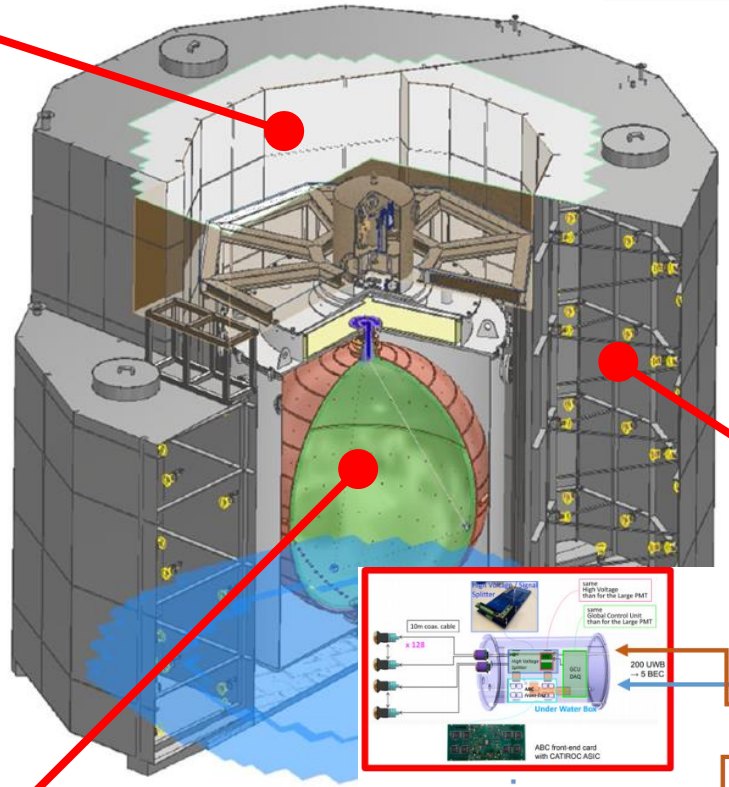
Re-use the 3” PMT electronics of JUNO

- Triggerless readout

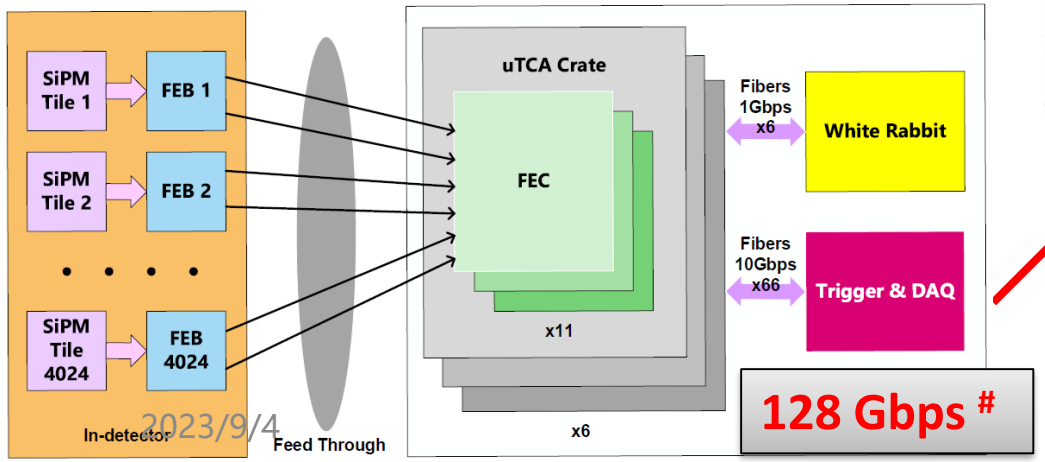
TAO TDAQ Highlights

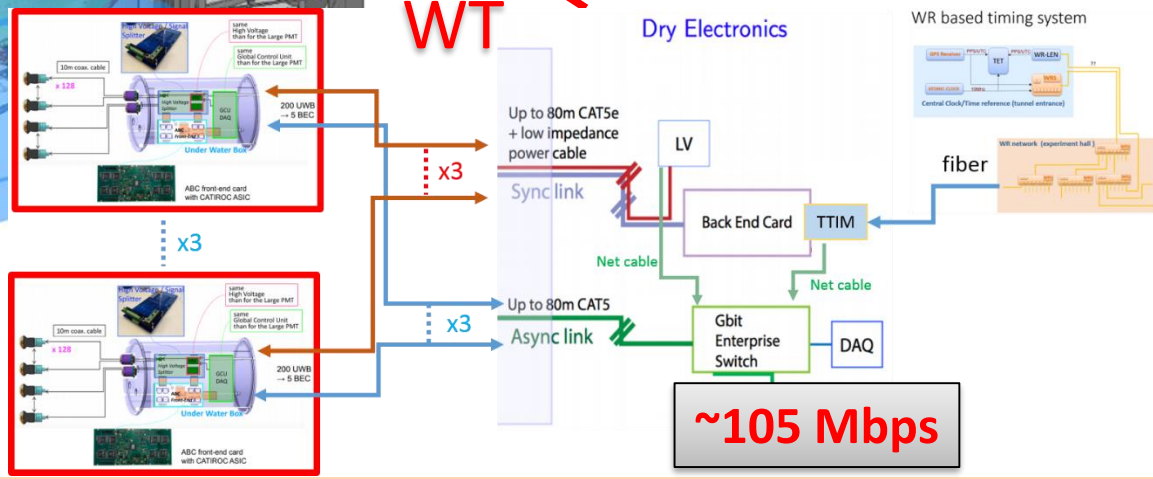


SiPM dark rate: 100Hz/mm^2 (conservative)
1.5 p.e threshold



- Readout from 3 individual detectors' electronics
- Suppress total bandwidth to **< 100 Mbps** before storage





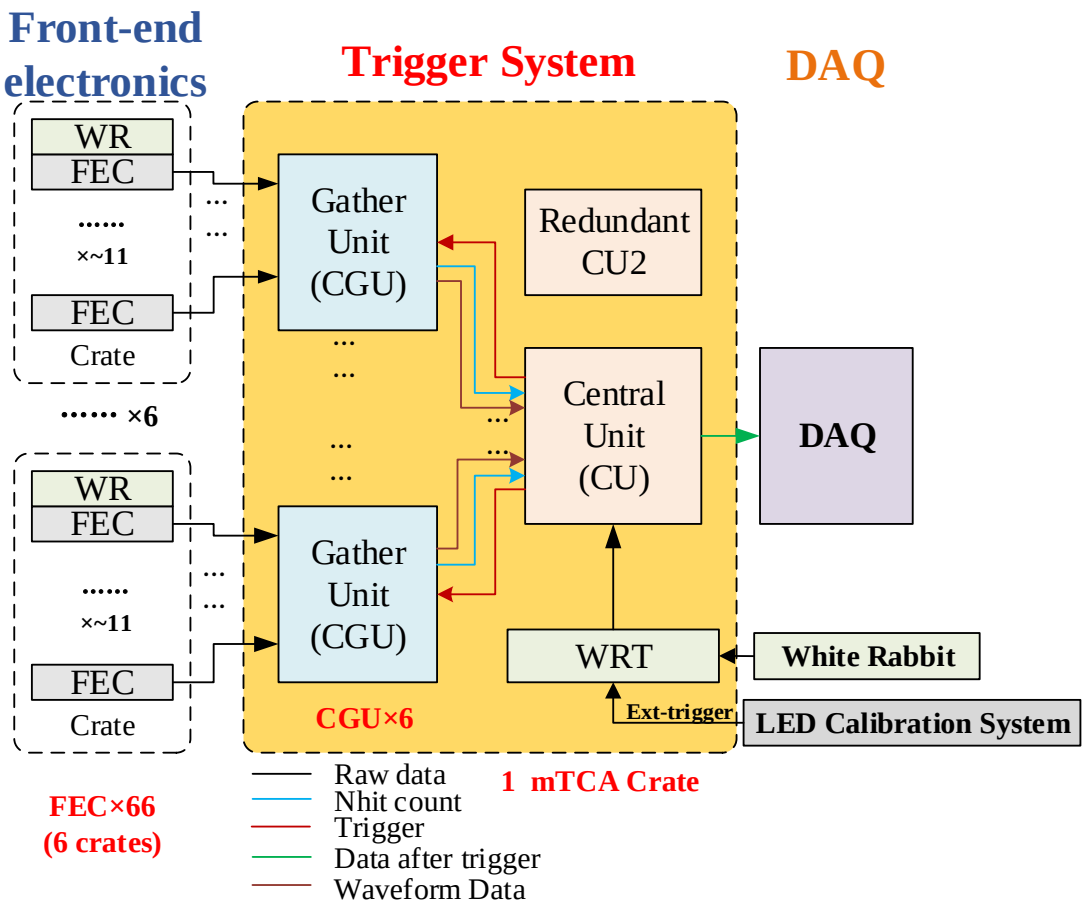
Data Suppression Strategy at TAO TDAQ

Data Stream	Raw Readout	HW trigger	DAQ Data input	SW Trigger	Compres-sion	Data Merge	Storage
CD	128 Gbps	Y	~800 Mbps	N	Y	Y	<80 Mbps
WT	~105 Mbps	N	~105 Mbps	Y	Y	Y	<10 Mbps
TVT	~10 Gbps	Y	~40 Mbps	Y	Y	Y	<1 Mbps
SUM	**~140 Gbps**		**~1 Gbps**				**<100 Mbps**

- CD trigger
- TVT hardware trigger
- DAQ

CD Trigger System Structure

- **High-performance**
  - ➢ **1GHz** hit rate
  - ➢ **128Gbps** data processing
- **Physics trigger mode: multiplicity trigger (nHit)**
- **coincident DCR < 1 Hz if nHit > 170**
- **Support External trigger for LED calibration**
- **Random/periodic trigger for diagnosis**

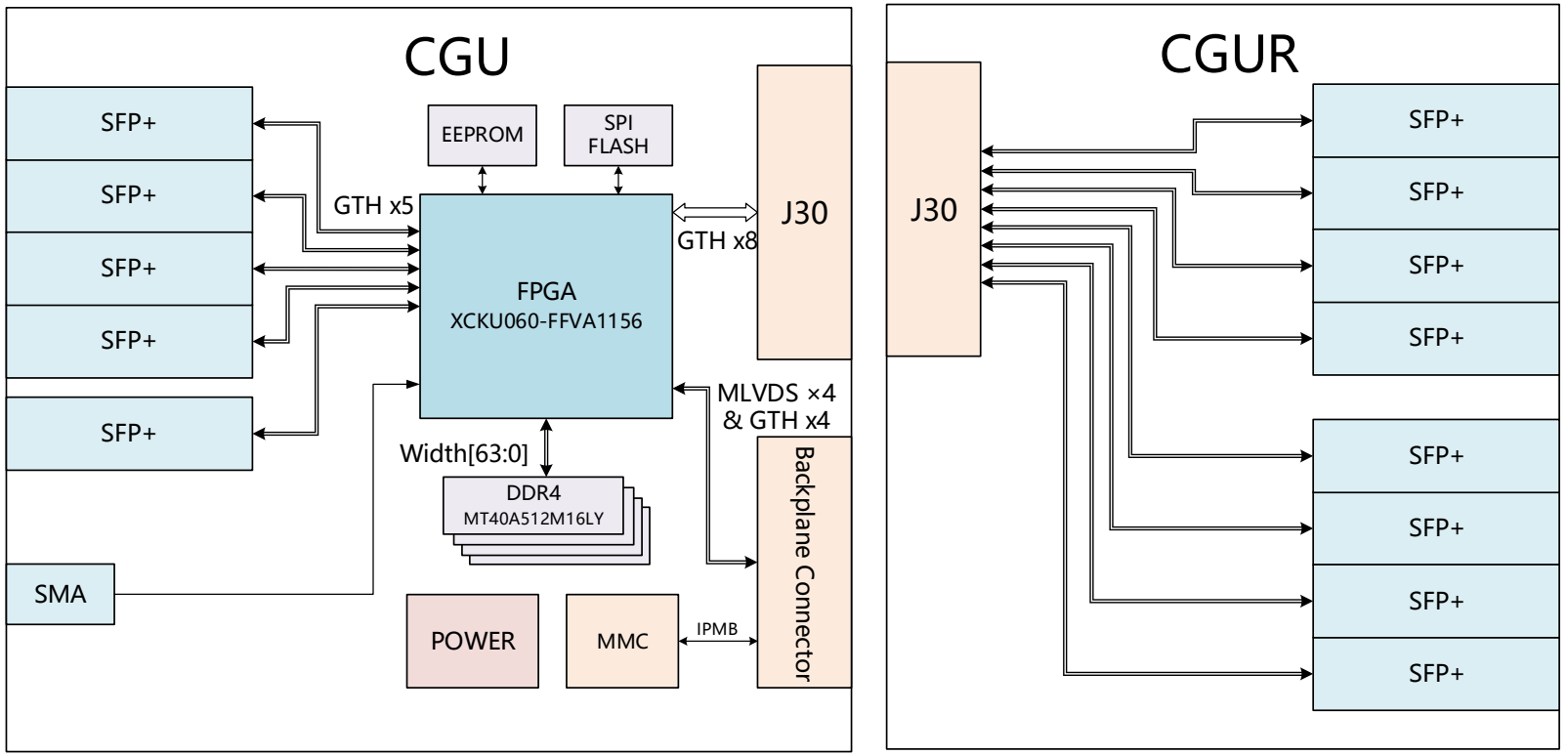


Reliable, flexible, scalable, maintainable…

Hardware Implementation

- mTCA standard: CD Gather Unit (AMC) + CD Gather Unit Rear (RTM)
- CD Gather Unit / Central Unit: **same hardware, different firmware**

- High data transmission
- Hot-swap capability
- Rear I/O
- Redundancy available



NHit Trigger Logic

nHit trigger logic

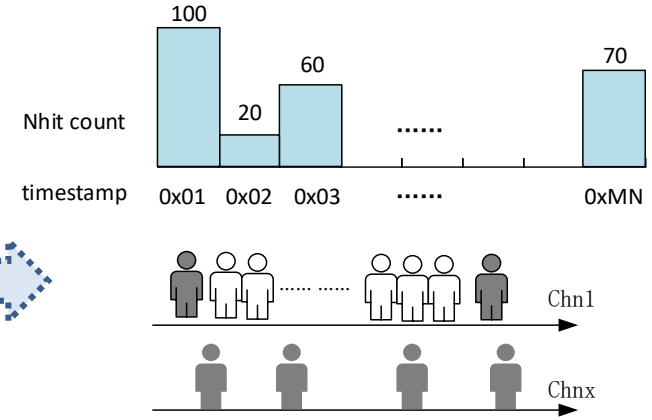
- nHit sum in slide window ≥ nHit Threshold
- Record timestamp, generate trigger
- Readout data in the window

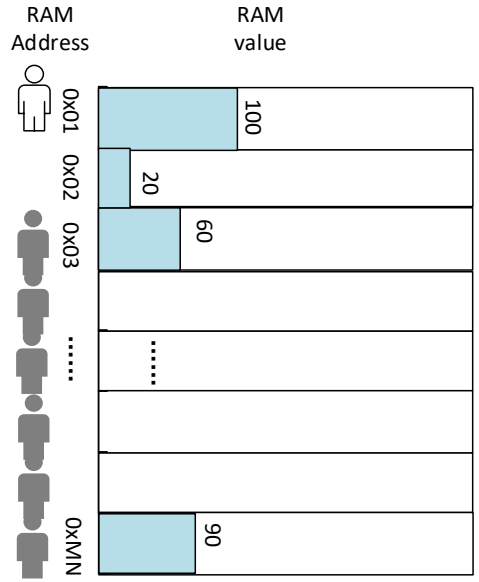
CU(Central Unit)

- CU sum the partitioned nHit
- process trigger algorithm

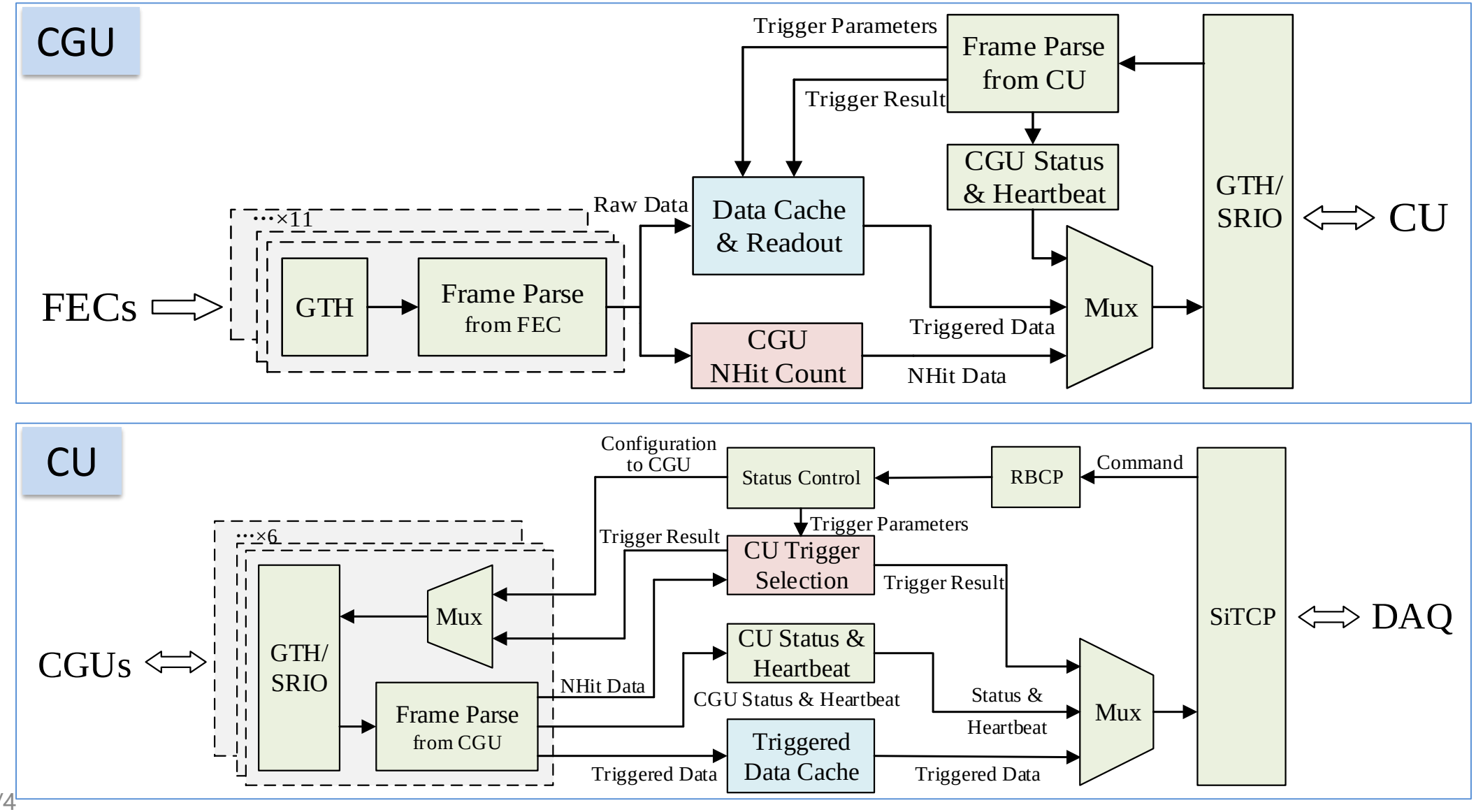
CGU(CD Gather Unit)

- Each **CGU** board count local nHit
  - parallel processing: 1 RAM for 1 FEC
- nHit count method - mapping-based approach
  - time stamp → RAM address
  - nHit count → RAM data value





Firmware Design and Implementation

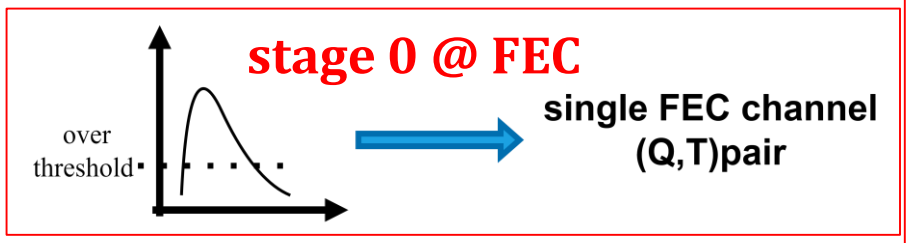


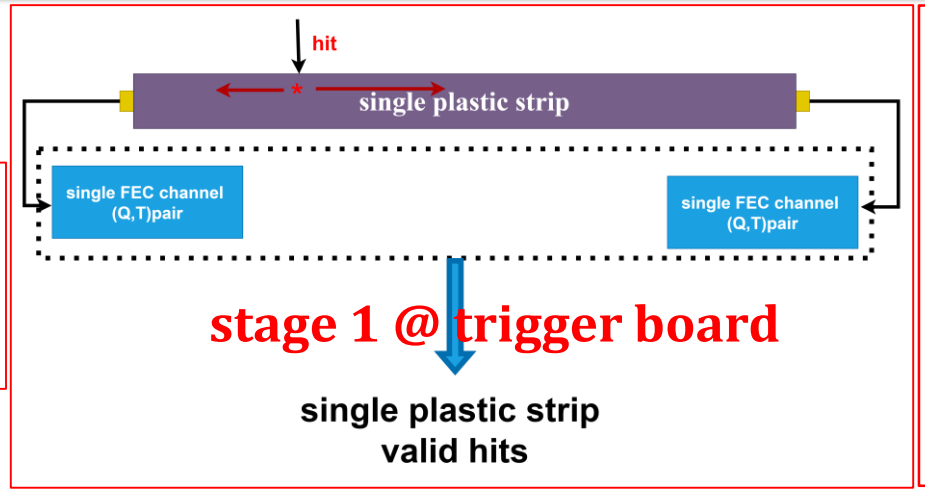
- CD trigger
- **TVT hardware trigger**
- DAQ

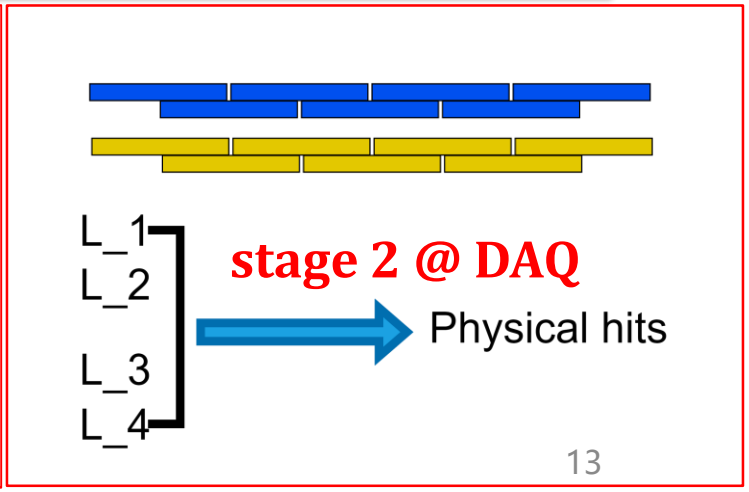
TVT Trigger Definition

- SiPM DCR: ~50 kHz/mm2 @25℃
- Muon rate: ~32 Hz/Strip (strip size: 0.2 x 0.2 m^2, muon flux 80 Hz/m^2)
- Natural radioactivity: ~1 kHz/Strip

- stage 0: waveform -> (Q,T) pair @threshold 0
- stage 1: coincidence of 2 ends in single strip -> window @threshold 1
- Stage 2: coincidence of layers -> window @ multiplicity threshold

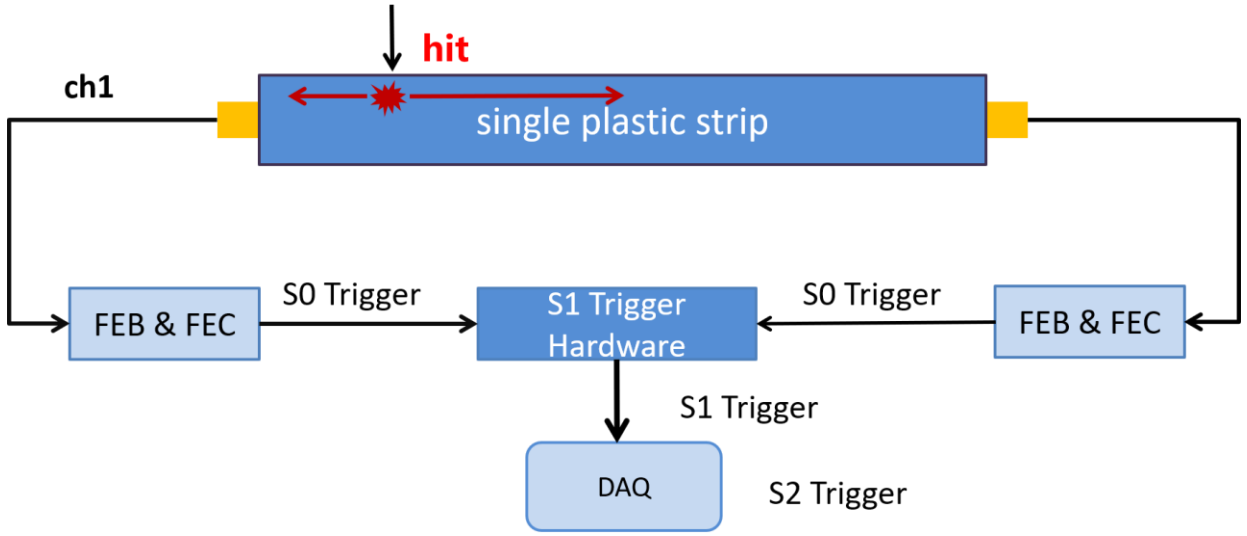


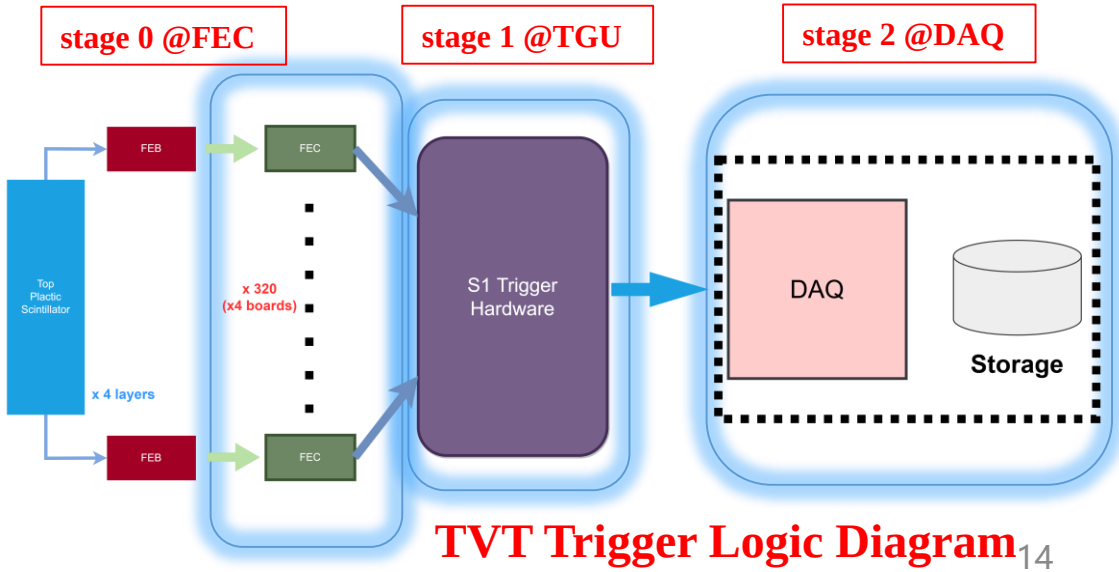




S1 Hardware Trigger Requirements

- **Bandwidth**
  - ➢ **FEC -> trigger system: ~10 Gbps ***
  - ➢ **trigger system -> DAQ: ~40 Mbps ****
- **Algorithm: coincidence trigger**
  - ➢ **utilize the coincidence in both charge & timing from dual-ends to reject DCR**



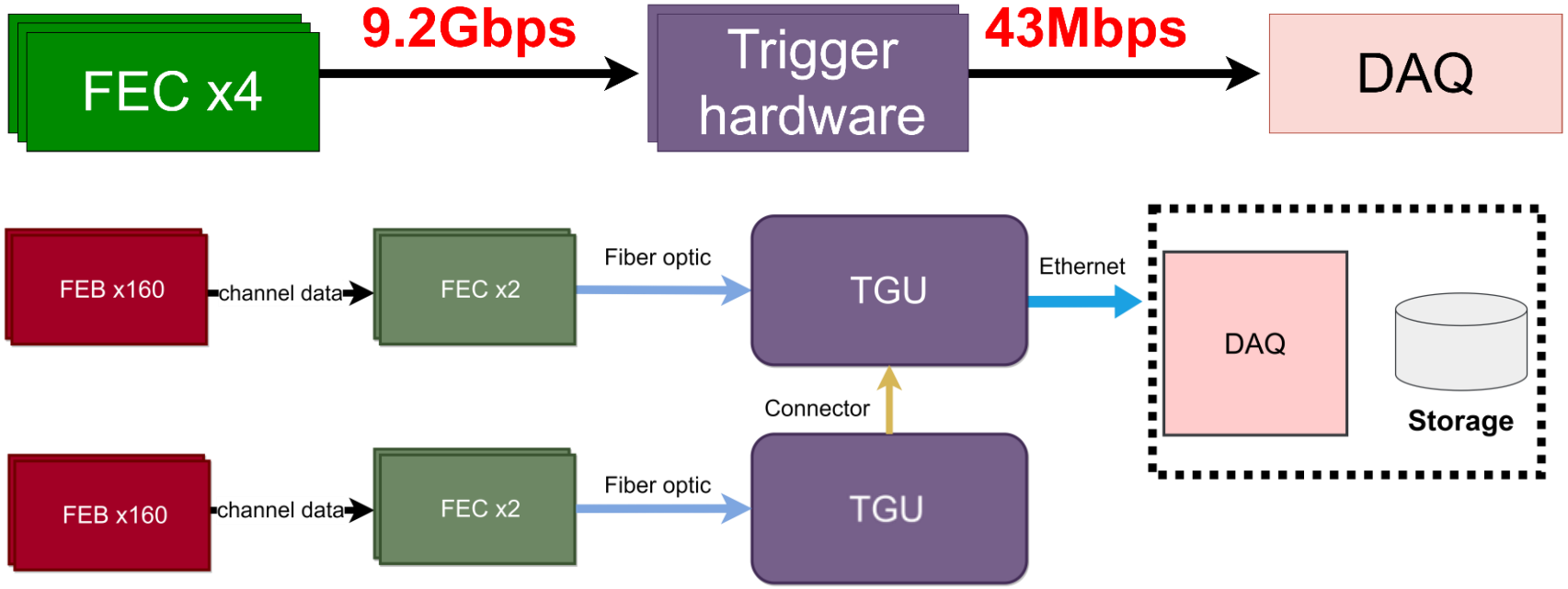


TVT Trigger Logic Diagram

*DCR: ~0.22 MHz/channel @1.5 p.e.
**mostly from natural radioactivity

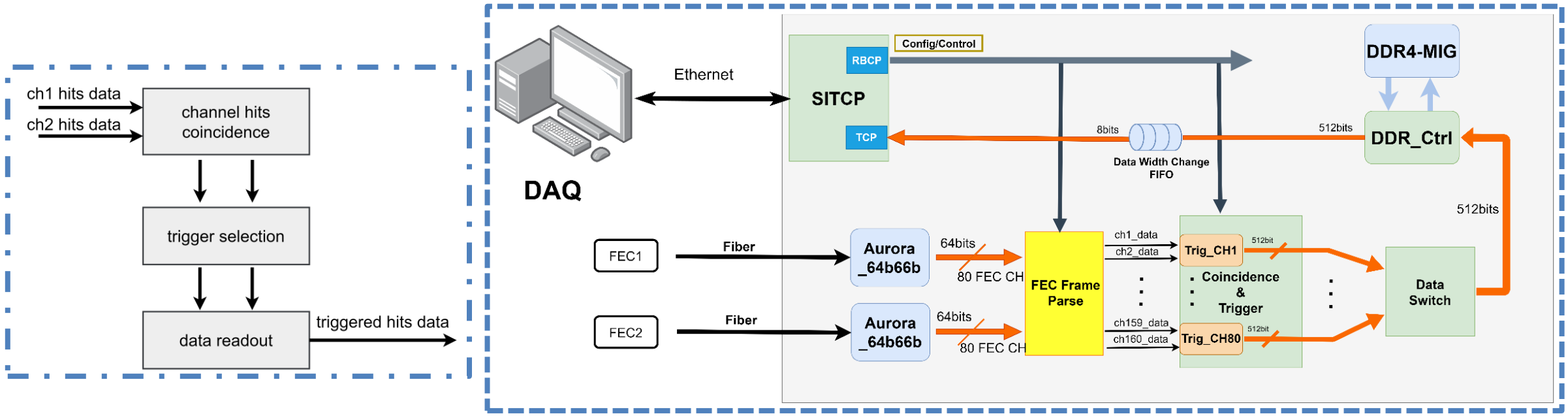
Hardware Design

- **TVT trigger system use same hardware board as CD, different firmware**



TVT: top veto tracker
TGU: TVT gather unit
FEB: front end board
FEC: front end controller

Firmware Design and Implementation



*ch1、ch2:the channels of a single plastic strip

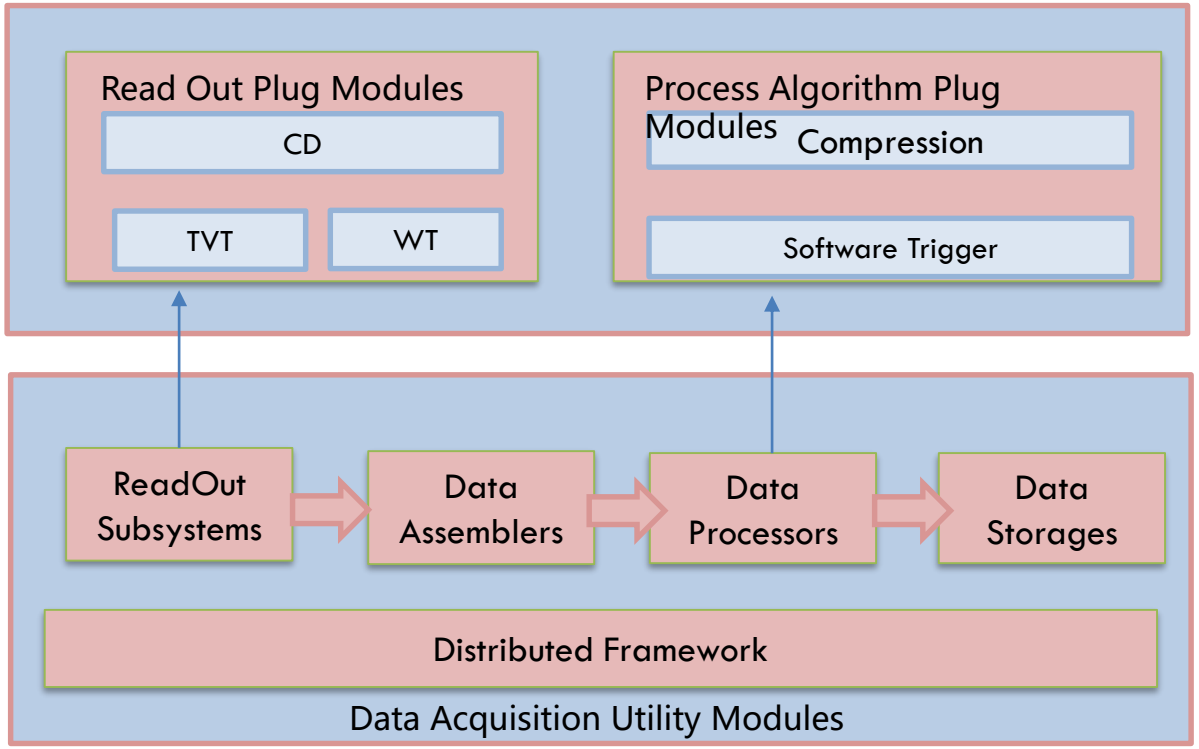
Trigger Processing Flow

Logic Diagram

- CD trigger
- TVT hardware trigger
- **DAQ** Design and Implementation

JUNO/TAO DAQ Architecture Design

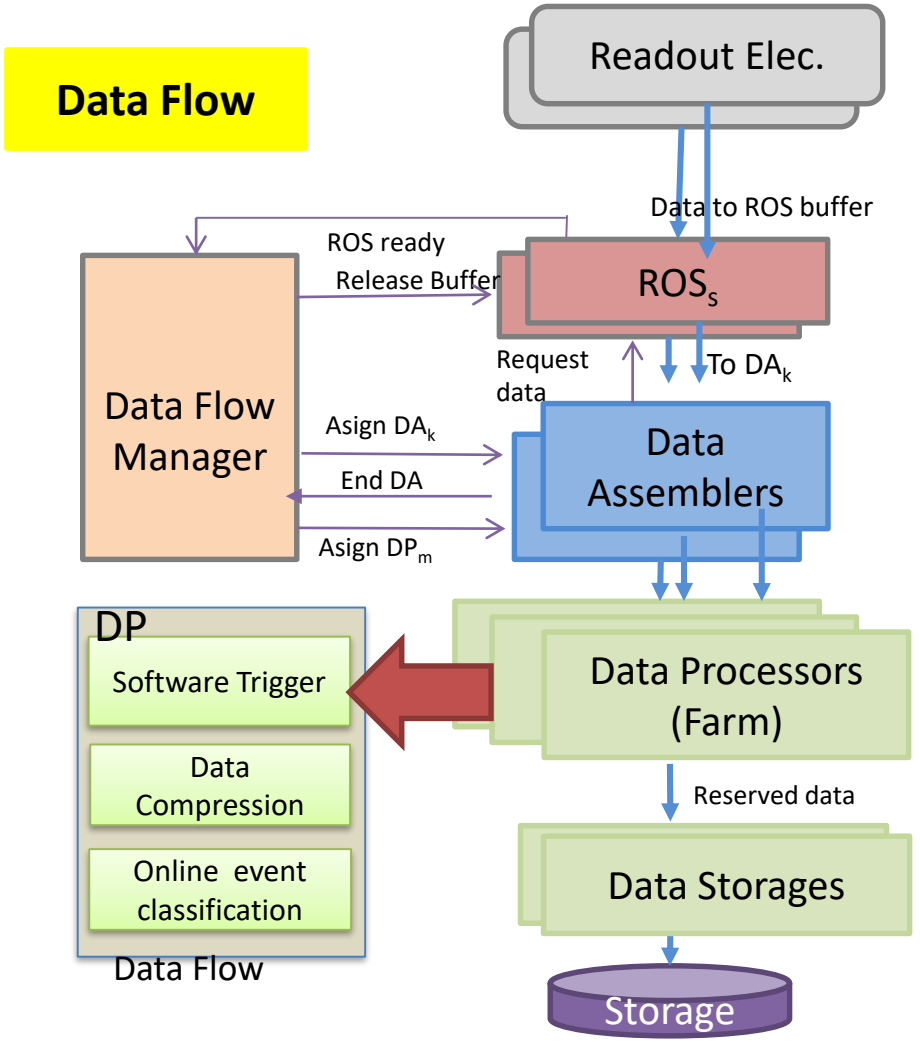
- JUNO and TAO share same DAQ architecture
  - ➢Share data file format and data transfer system
  - ➢Integrated monitoring
- Distributed framework
- Plug-in modules design



JUNO/TAO DAQ System is divided into Data Flow and Online

Data Flow Software

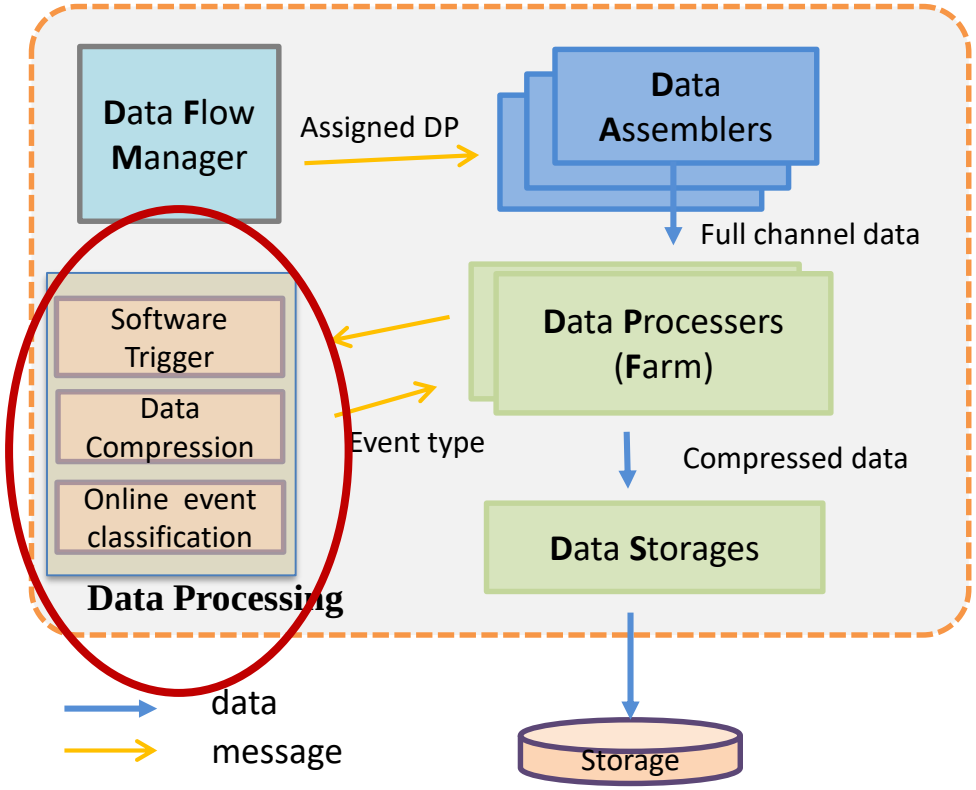
- Support triggered/triggerless data stream
- data assembling by ID or timestamp
- Online data processing interface provided
- Modular design



Online Data Processing

	DAQ input rate	DAQ output goal (limited by network)
JUNO	400 Gbps	500 Mbps
TAO	~ Gbps	<100Mbps

- **Parallel online processing**
  - Interface provided
  - Customized processing can be integrated
  - Algorithm can be provided by different experts

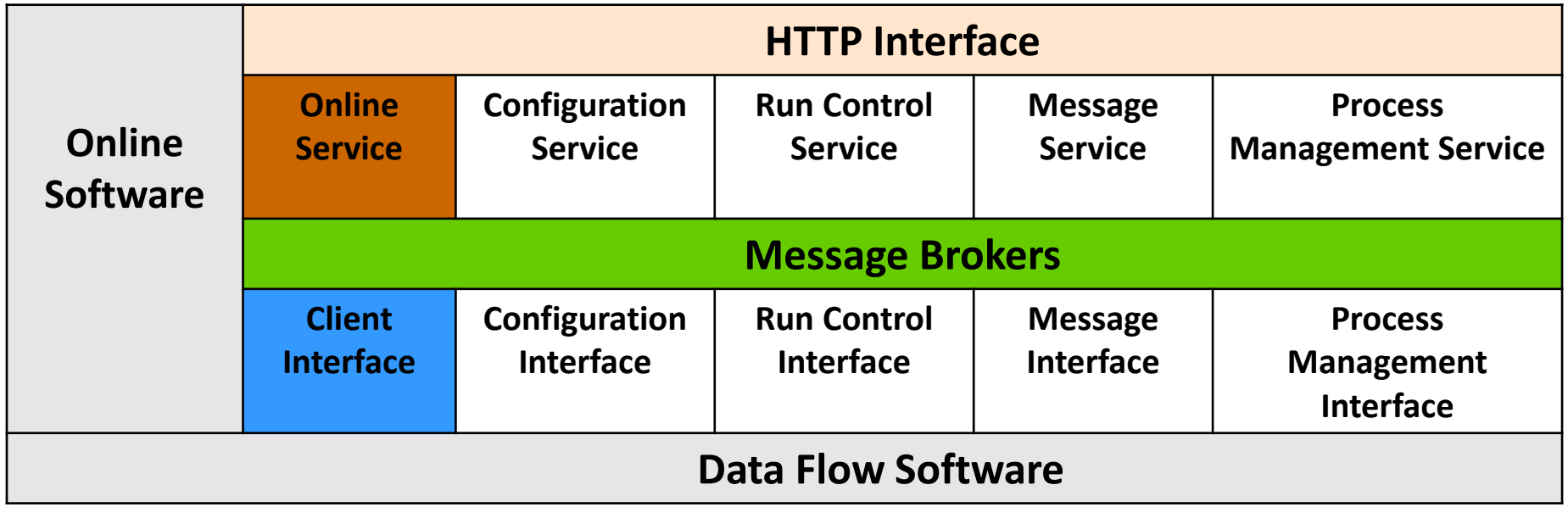


Provides high-performance real-time online data processing interfaces

Split the data stream based on timestamps – parallel processing

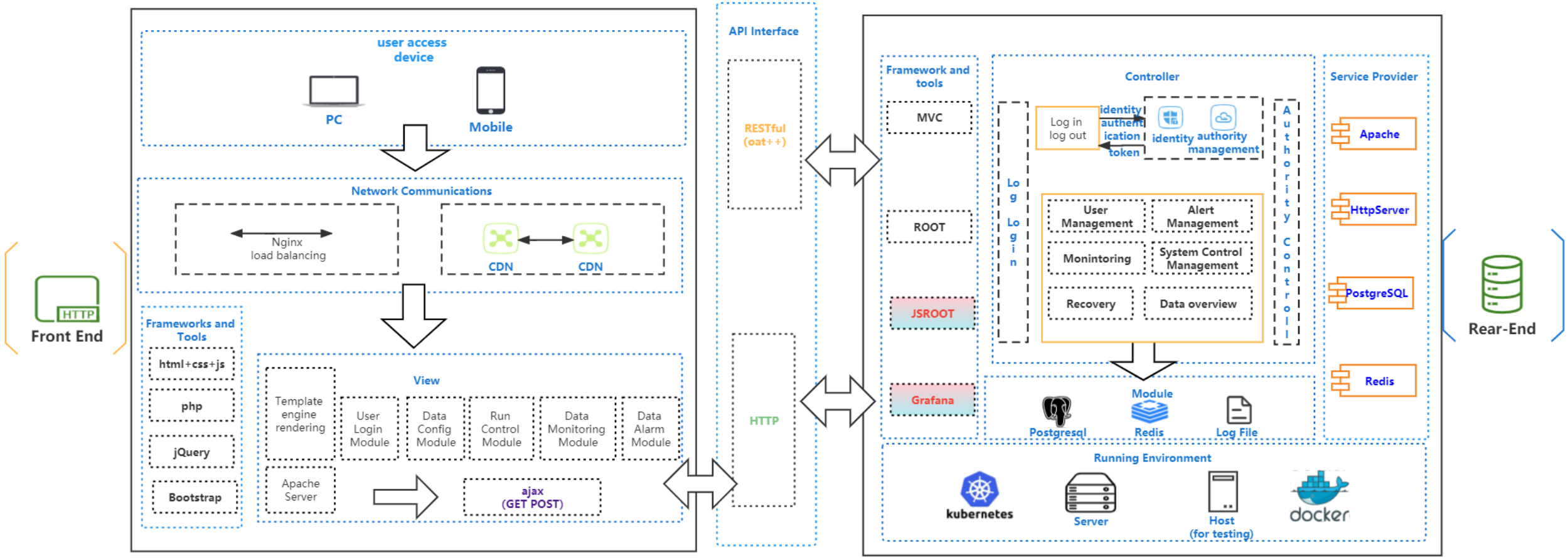
Online Software

Online Software: provide various interface and services



- Redis based services
- Run in k8s managed containers.
- Web based GUI
- Detection tool for exception diagnosis

Online Monitoring System Design

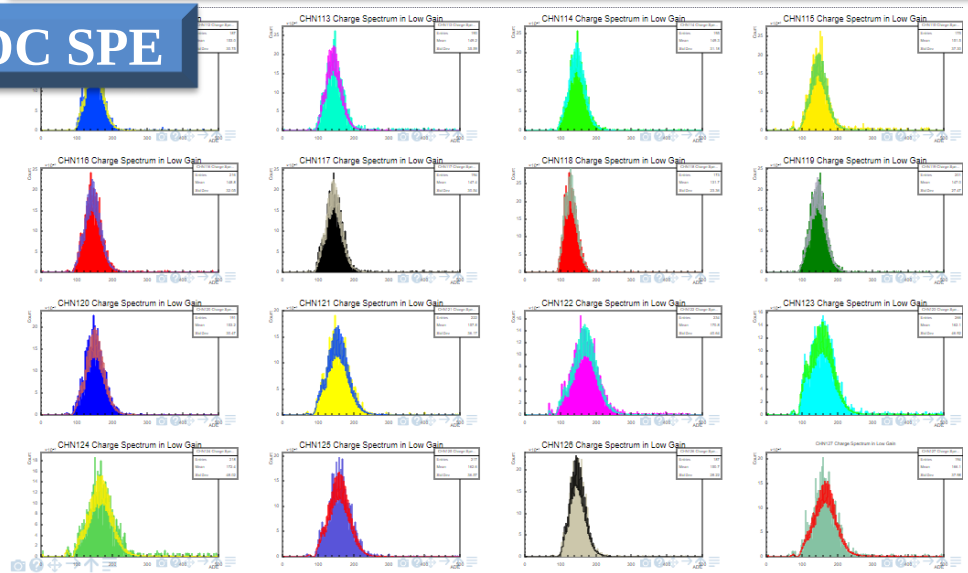


MVC based: modular design - low coupling, reusable, easy to deploy and upgrade

Online Monitoring for Data Quality

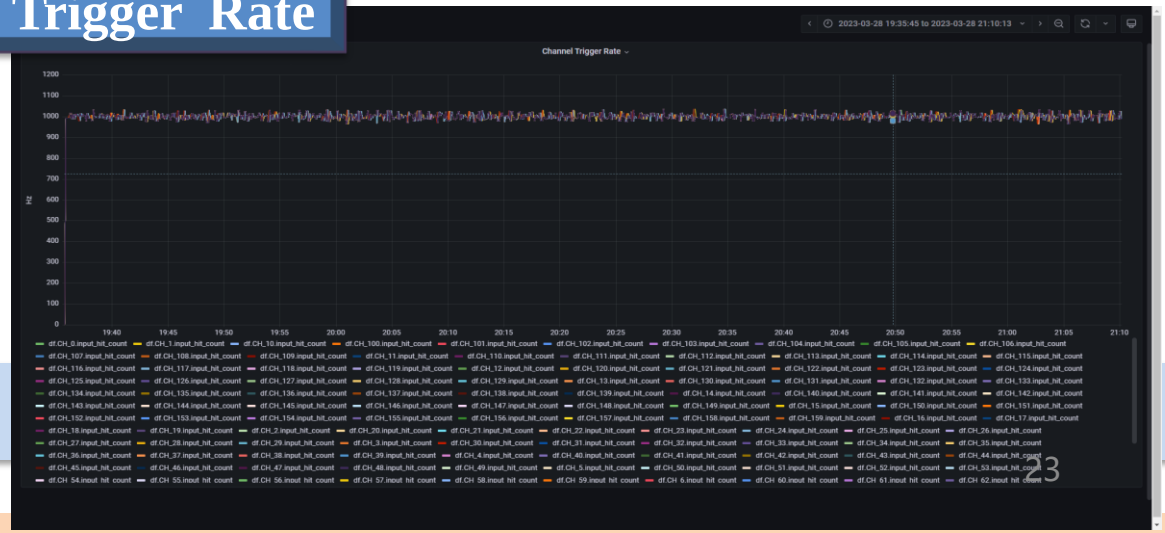
- **ROOT & JSROOT**
  - Visualization and data analysis tool
  - Expert user friendly
- **Redis & Prometheus & Grafana**
  - Complete monitoring and visualization solutions
  - Rich variety of charts and dashboards
  - Support for viewing history

ADC SPE

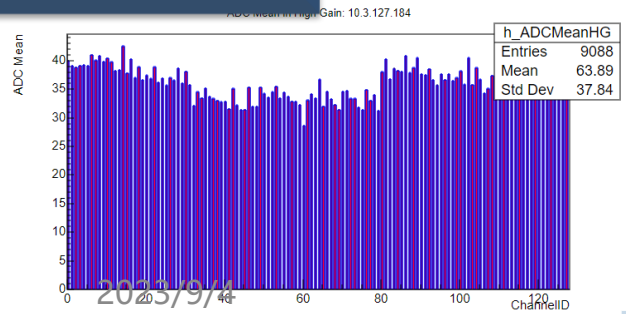


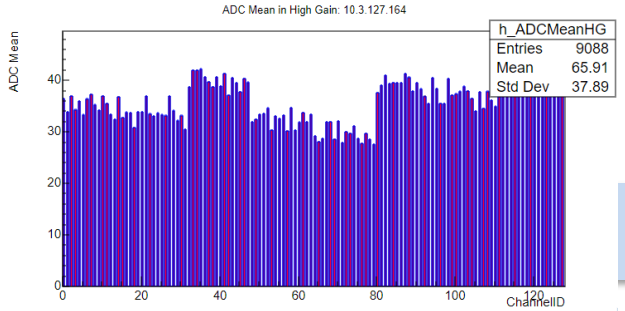
DCR monitor

Trigger Rate



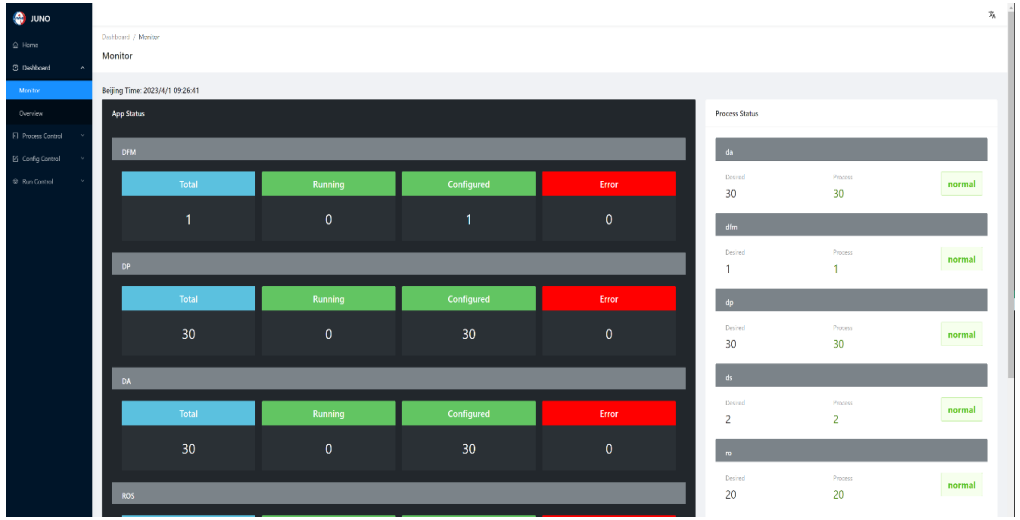
ADC MEAN





Online Monitoring for DAQ Running Status

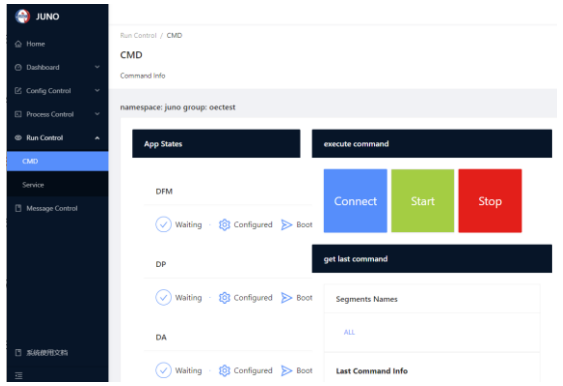
- **DAQ working status**
  - APP, process, system running status…
  - Memory and CPU usage of each process
- **DAQ Data Flow status**
  - Throughput, process rate, counter, buffer usage..



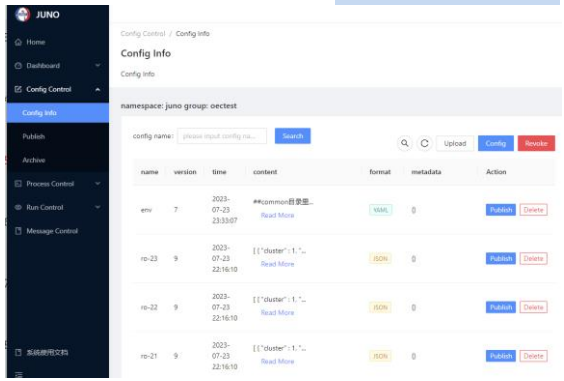
DAQ Web GUI

DEMO

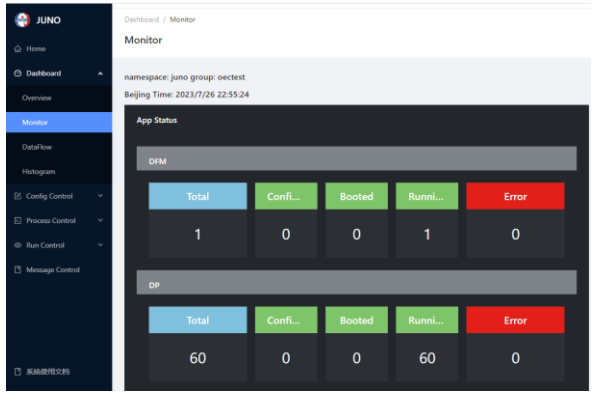
Data flow monitoring



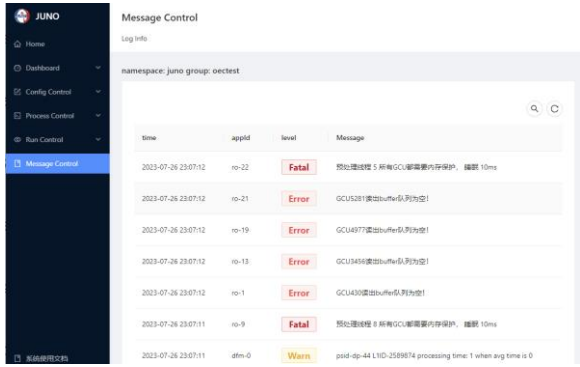
Run control



Configuration



Process info

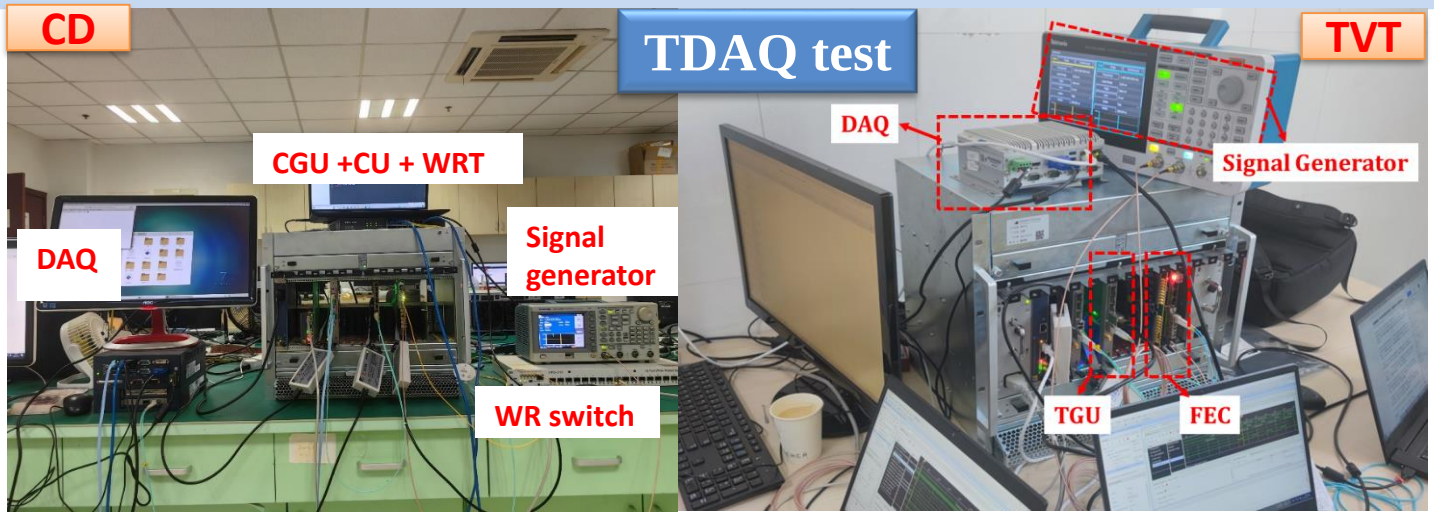


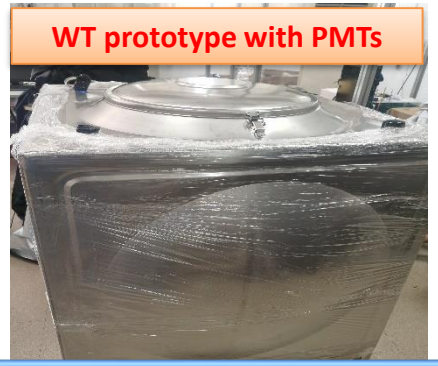
Log message

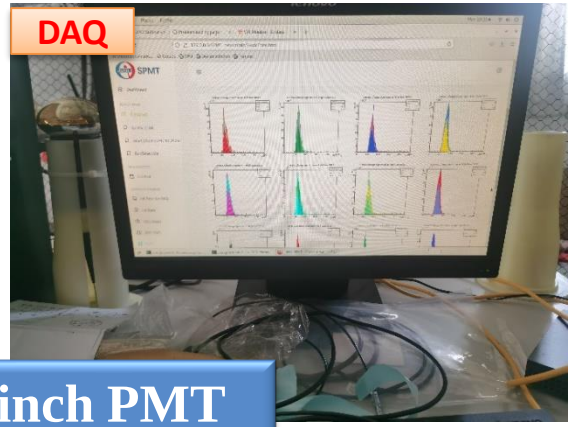
All the monitoring modules will be integrated into DAQ web GUI – control and monitor remotely

TAO TDAQ Current Status

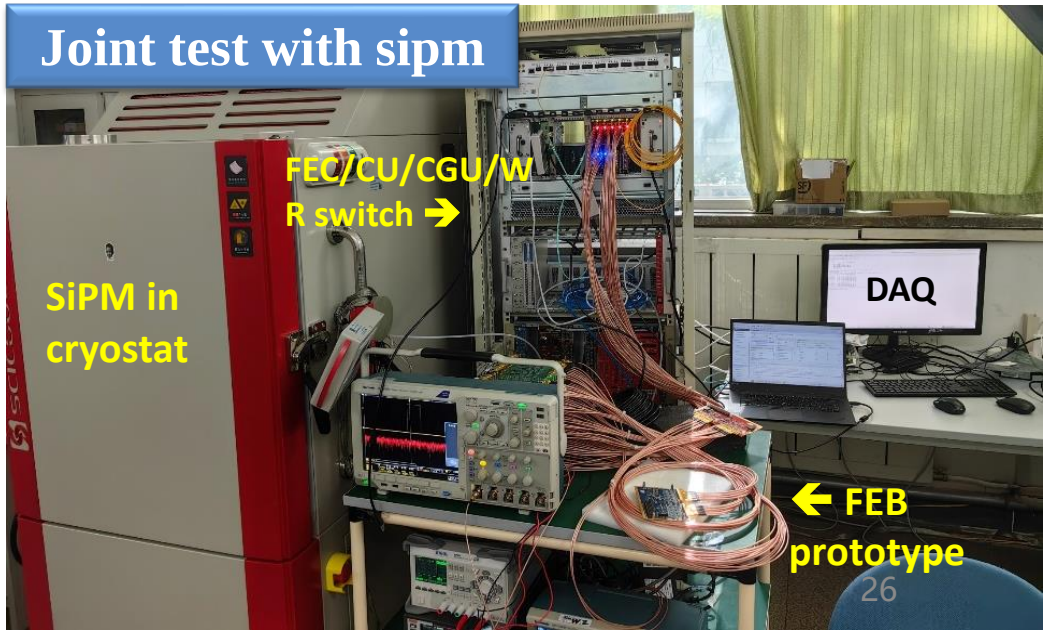
- **Major development work completed**
  - ➢ Key modules verified
  - ➢ Self-developed hardware all ready
- **Whole chain tests has started**
- **Will be fully ready at end of 2023**







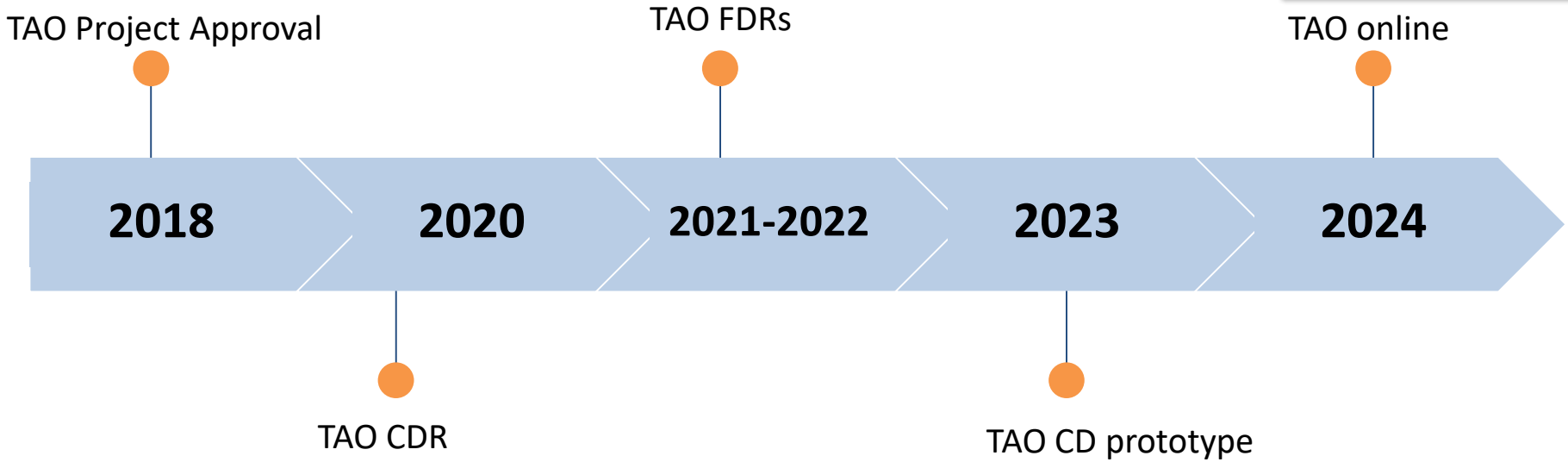
Joint test with WT 3-inch PMT



Summary

- **Design and build a pure digital TDAQ system for JUNO-TAO**
- **Trigger algorithms on FPGA + compression strategies on CPU**
  - ➢Reduce data rate *O* (100Gbps) -> < 100Mbps

Expected time for TAO be **online at 2024**



Thanks!