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WORKSHOP/TUTORIALS
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JUNO DAQ Design and Status
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On behalf of the JUNO Collaboration
JUNO
https://indico.cern.ch/e/rt2024
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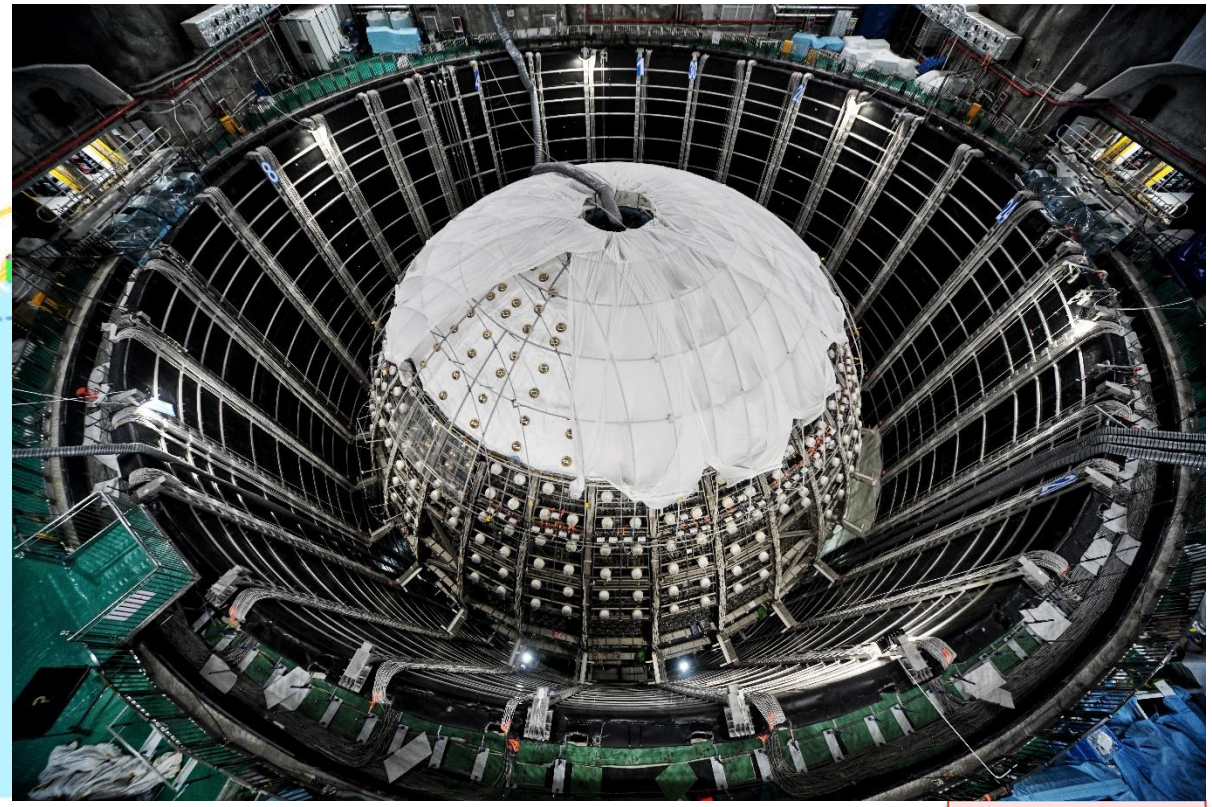
Outline

- Introduction to JUNO
- JUNO DAQ Overview
- Data Flow Software
- Online Software
- Commissioning Status
- Summary

JUNO

Jiangmen Underground Neutrino Observatory



Feb. 2024

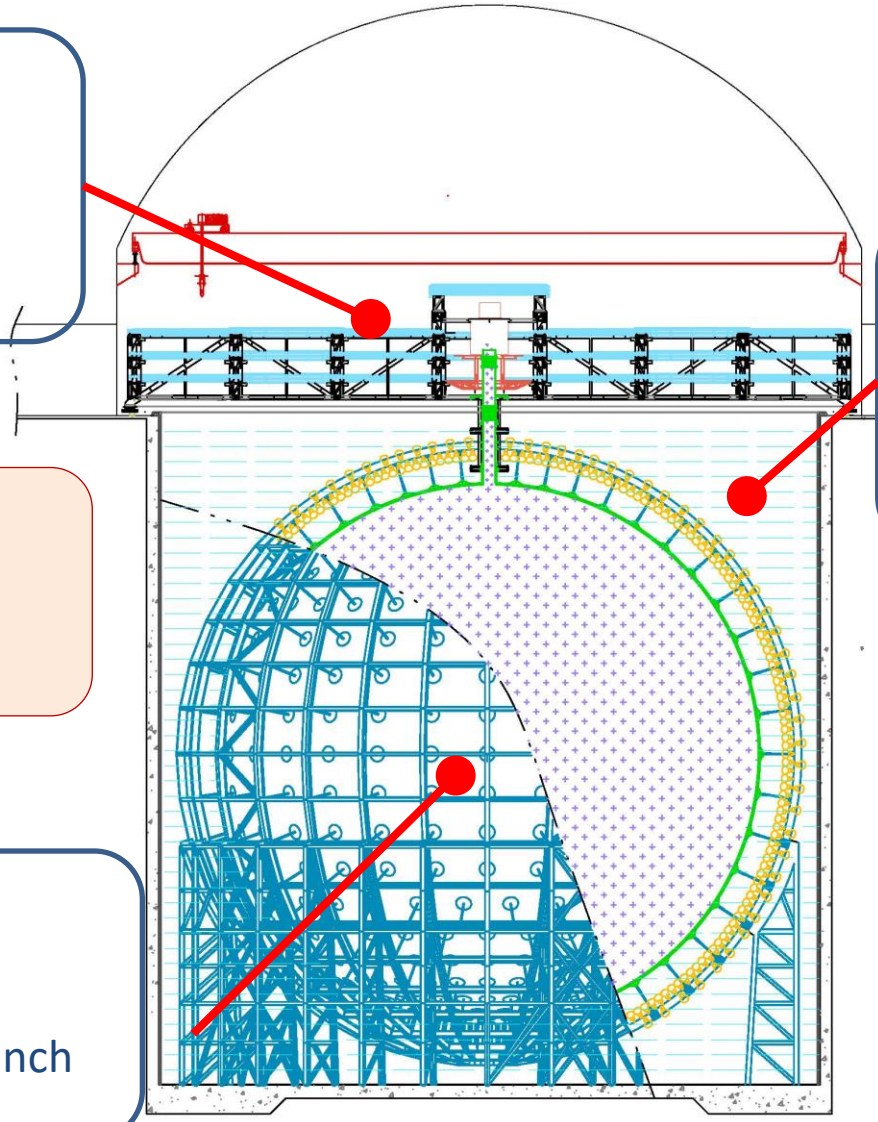
- Location optimized for neutrino mass ordering
- 700 m underground to suppress muon-induced background

J. Phys. G 43:030401 (2016)
Prog. Part. Nucl. Phys. 123, 103927 (2022)

JUNO Detectors & Readout

Top Tracker (TT)

- Plastic scintillator array from OPERA
- Local TDAQ, merged to global DAQ before storage



Water Cherenkov Detector (WCD)

- Φ= 43.5 m, H= 44 m
- 2,400 20-inch PMTs

LPMT readout

Same as CD

LPMT: 1 GS/s waveform readout with global trigger + trigger-less T/Q data

SPMT: trigger-less readout of T/Q

Central Detector (CD)

- 20 kton liquid scintillator
- Spherical acrylic vessel: Φ= 35.4 m
- 17,612 20-inch PMTs (LPMT) and 25,600 3-inch PMTs (SPMT)

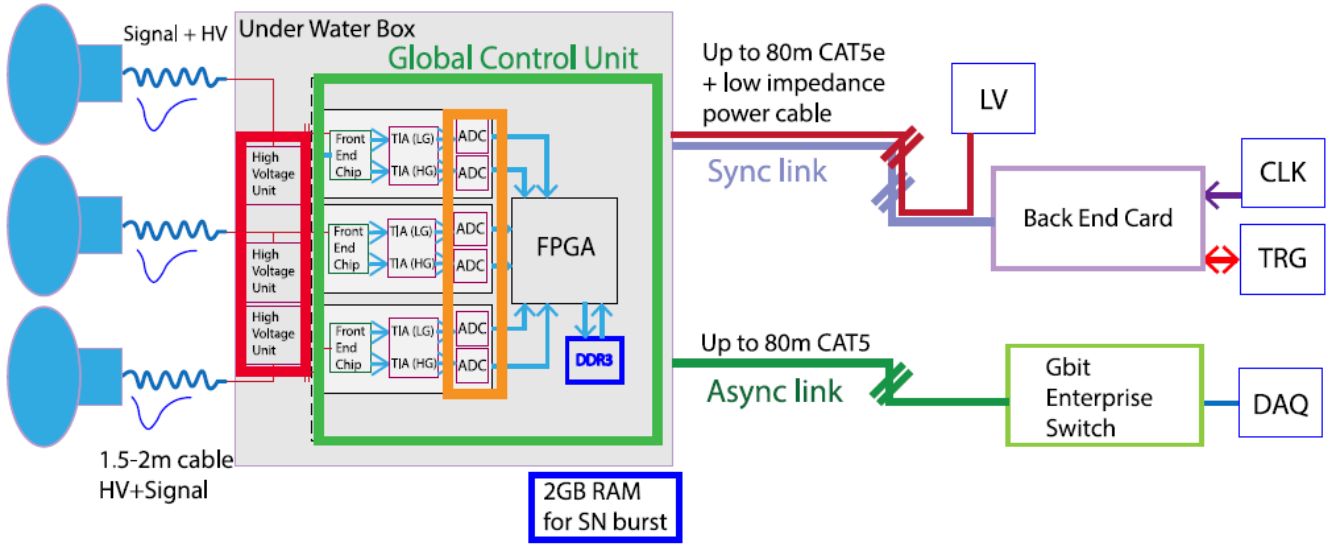
JUNO DAQ Highlights

3 channels/UWB for LPMTs of CD and WCD : ~6800 UWBs
18000 * 1GHz sample * 2 Bytes *1 us window *1 kHz trigger rate = 36 GB/s
trigger-less TQ data rate: 18000 * 30 kHz dark rate * 10 Bytes = 5.4 GB/s

Custom HV (JINR) (0-3kV)/300uA

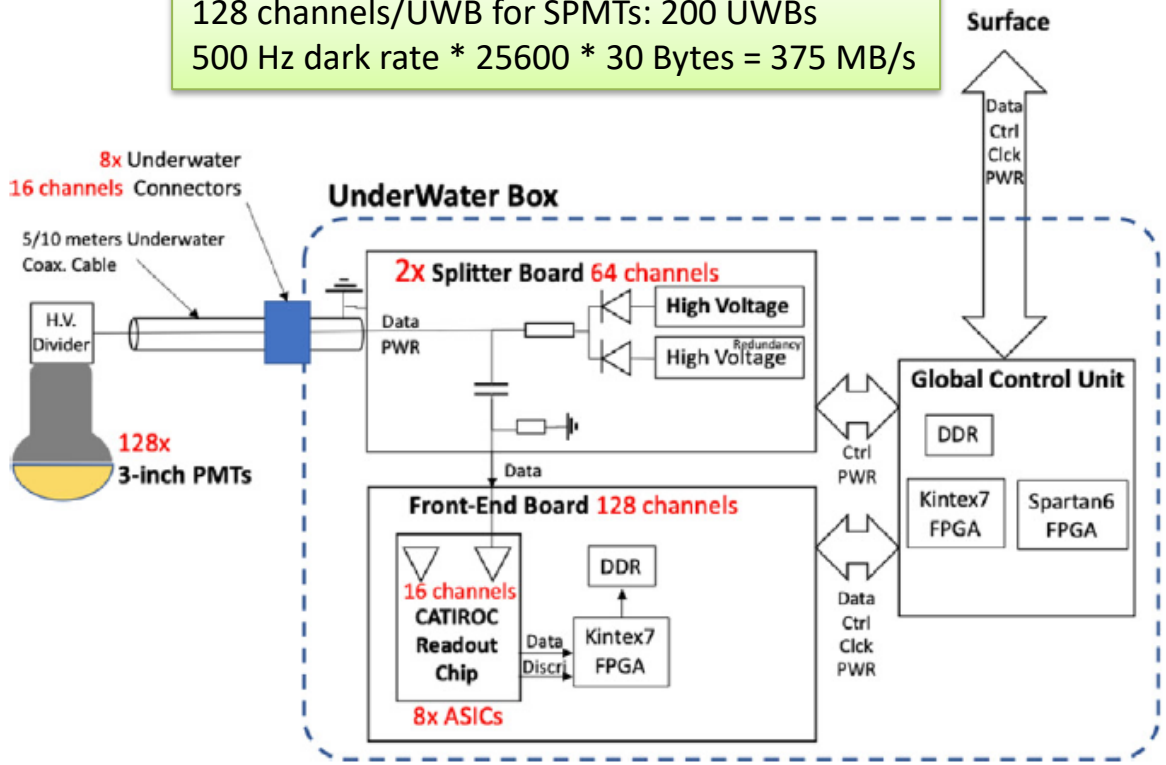
Custom ADC (Tsinghua) 12bit, 1Gsps

FPGA for Trigger and Signal Processing



Large PMT electronics scheme

128 channels/UWB for SPMTs: 200 UWBs
500 Hz dark rate * 25600 * 30 Bytes = 375 MB/s

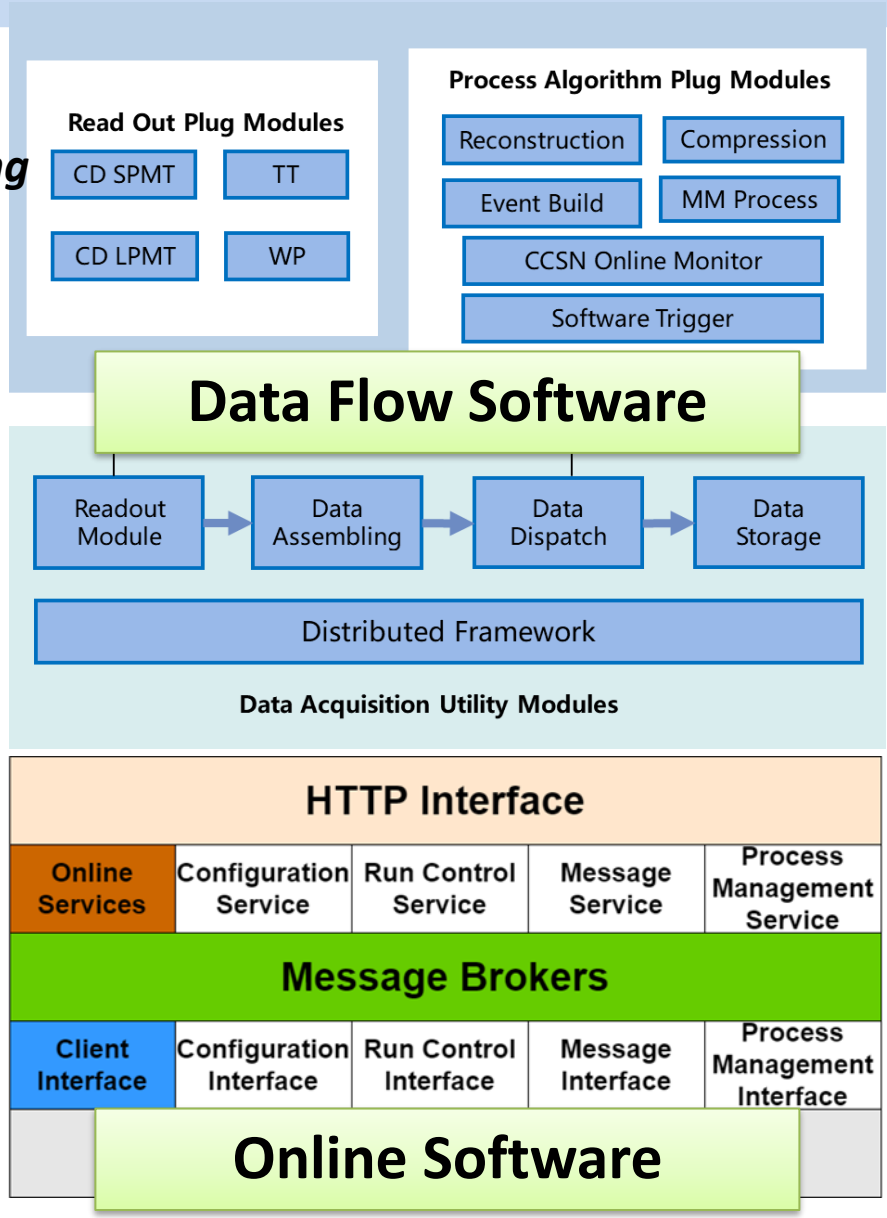


Small PMT electronics scheme

- **> 40 GByte/s** triggered waveform data and trigger-less time and charge data
- **~7000 readout links** with interface: 1 Gbps Ethernet + TCP protocol
- Process events via **Online Event Classification** to **reduce data rate by ~ 500 times**

JUNO DAQ Software Architecture

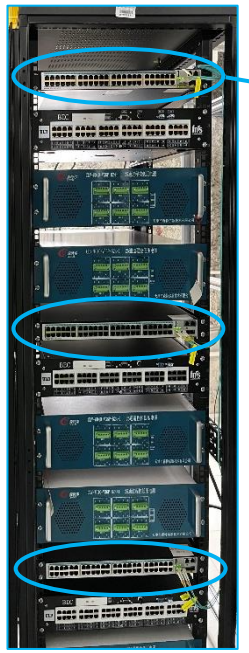
- **Radar** ***heteRogeneous Architecture of Data Acquisition and pRocessing***
  - V1: **deployed in LHAASO***, running for ~ 5 years
  - V2: **upgraded for JUNO**
- General-purpose distributed framework
  - Transport layer – ZeroMQ
  - Services – Kafka / ZooKeeper based
- Divided into two parts:
  - *Data flow software*: process data streams
  - *Online software*: management and services

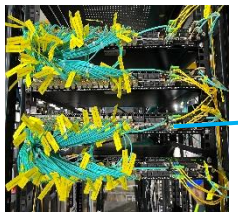


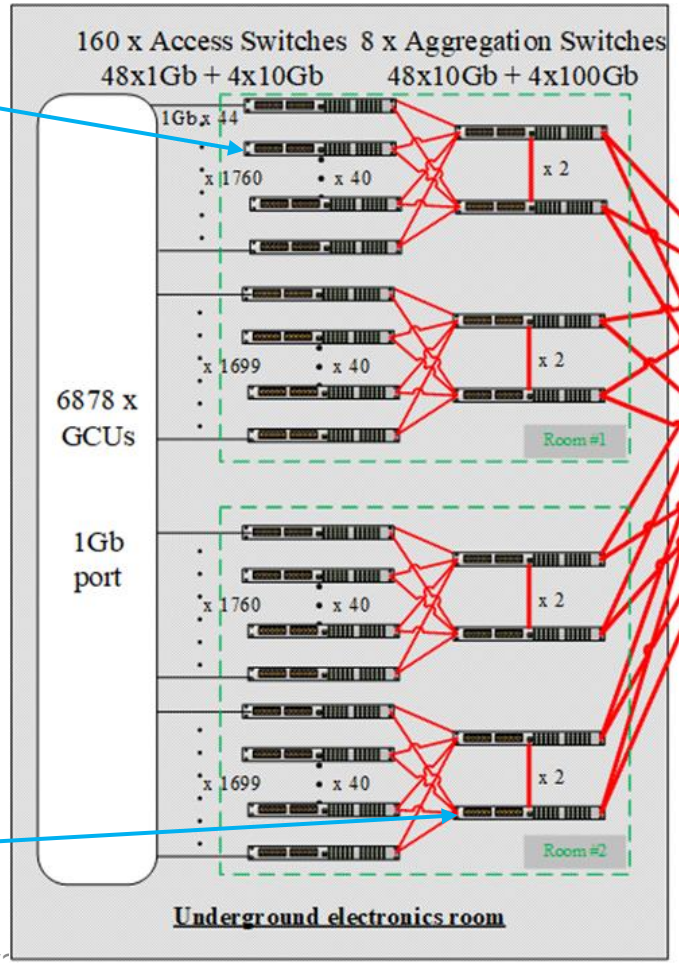
* Large High Altitude Air Shower Observatory

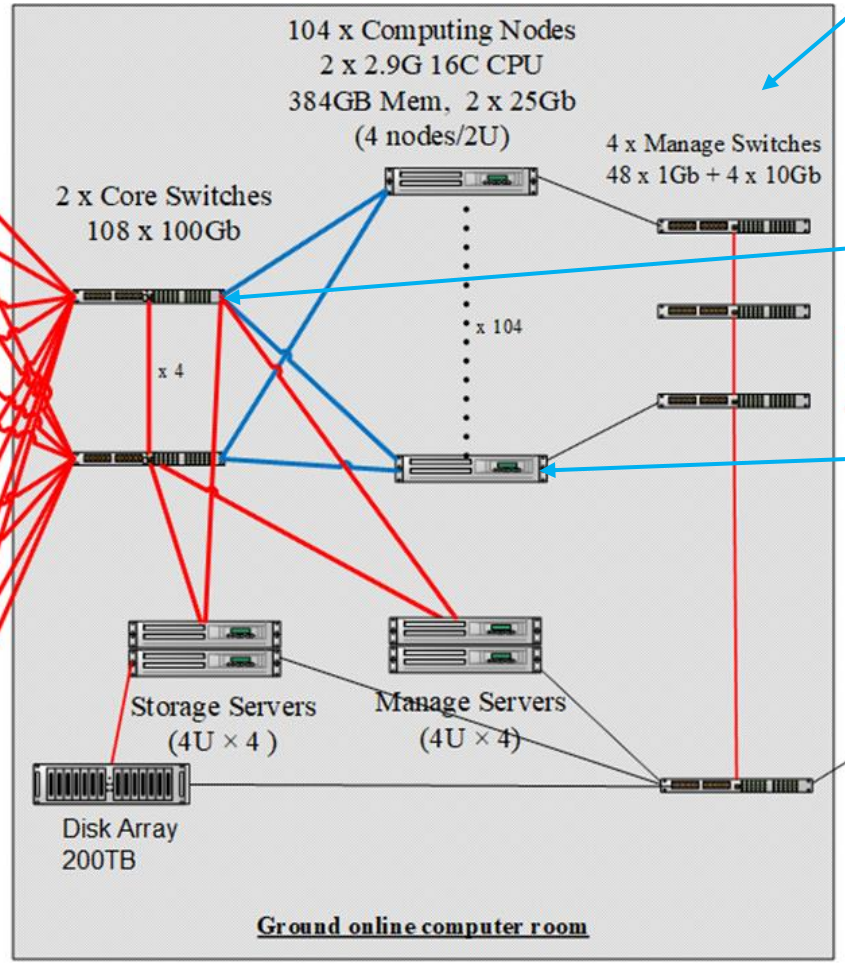
Hardware Implementation

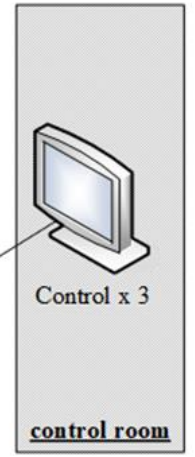
- Most onsite devices deployed for over a year, used for onsite testing
- **Network dual redundancy design** to avoid single point of failure











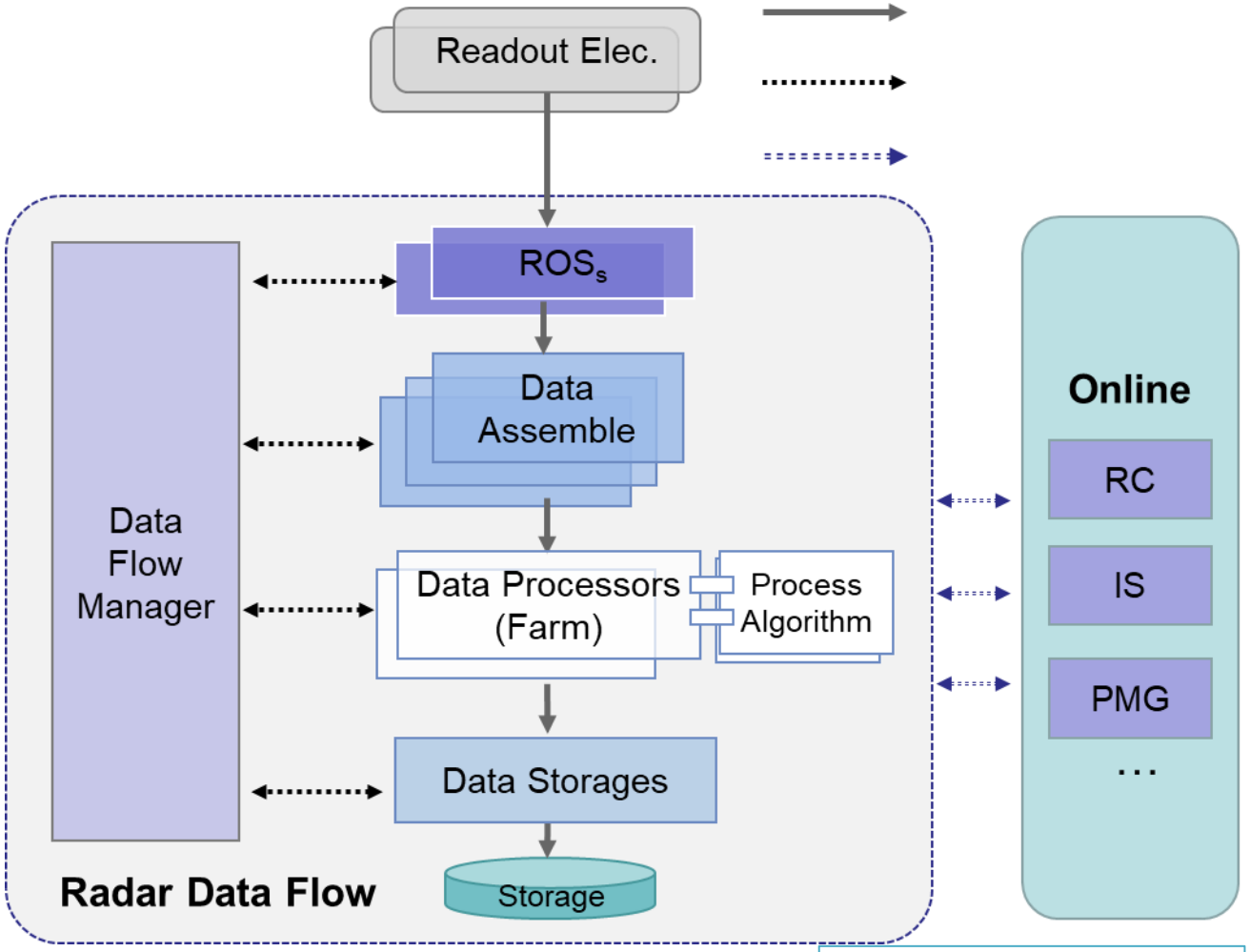
JUNO DAQ Hardware Deployment

1Gb
10Gb
4x25Gb to 100Gb
100Gb

Total CPU cores: 3328
Computing node：

- CPU: Intel(R) Xeon(R) Gold 6226R CPU(16 cores) @ **2.90 GHz x 2**
- Memory: **384 GB**
- Network: 2x2**5 Gb/s** uplink

Data Flow Software

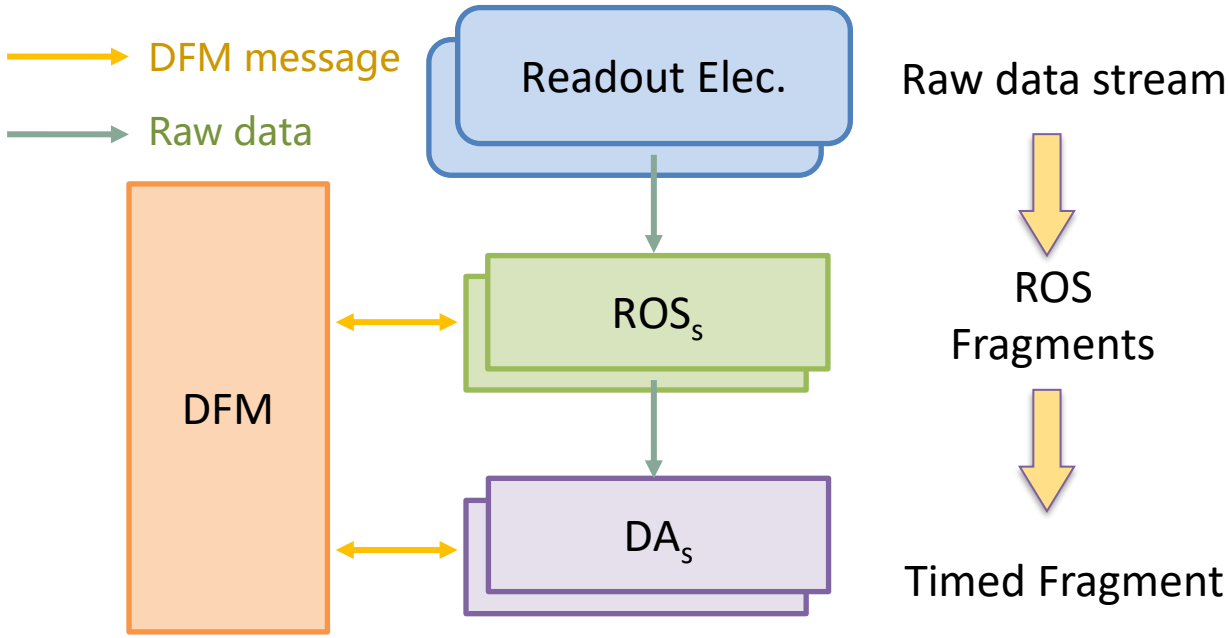


- **ROS:** ReadOut System
- **DA:** Data Assemble
- **DP:** Data Processor
- **DS:** Data storage

Radar data flow

- **Lightweight** structure
- ROS + DA + DP + DS
- **Plug-in modules design** for ROS & DP
- Integrate customized readout / processing modules

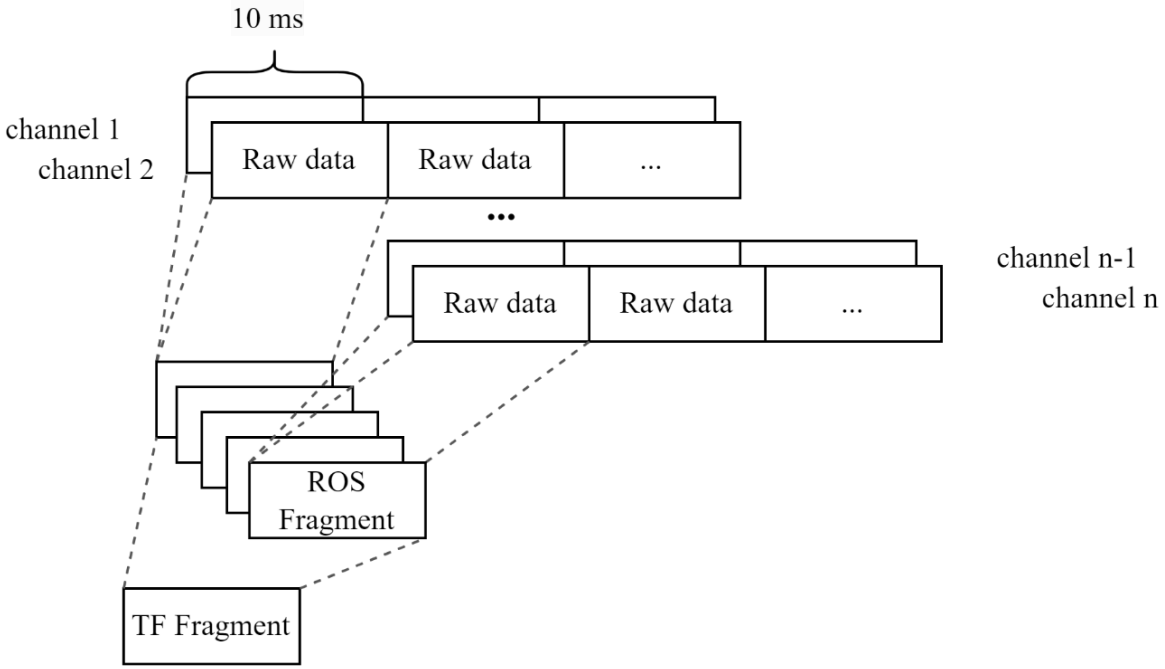
JUNO DAQ Data Assemble



Raw data stream

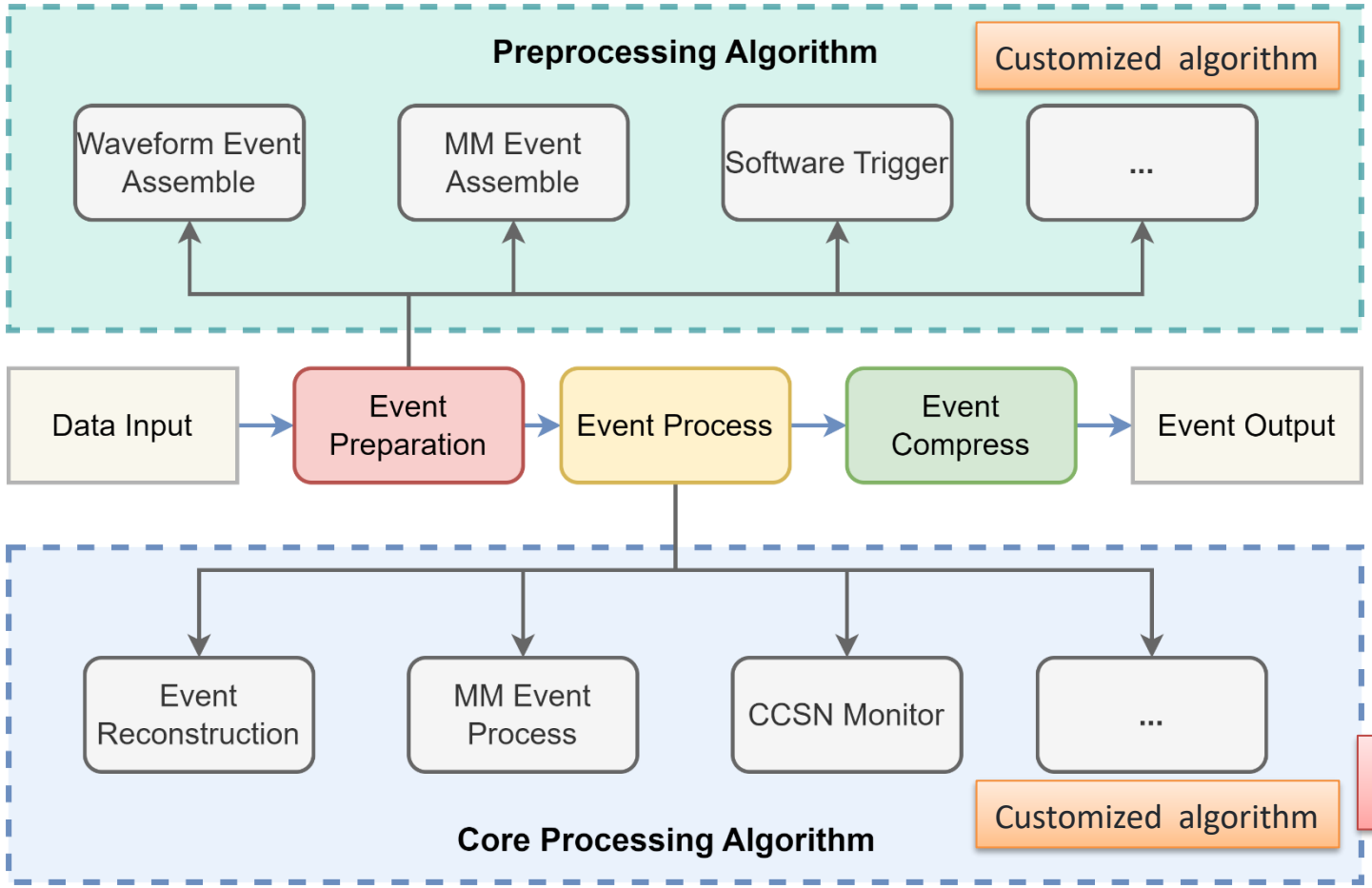
ROS Fragments

Timed Fragment



- Support data assembled **by ID or timestamp**
- Uniform processing both triggered and trigger-less data
- 2 level assemble by time fragments – ROS + DA

JUNO DAQ Data Processing



2-stage data processing:

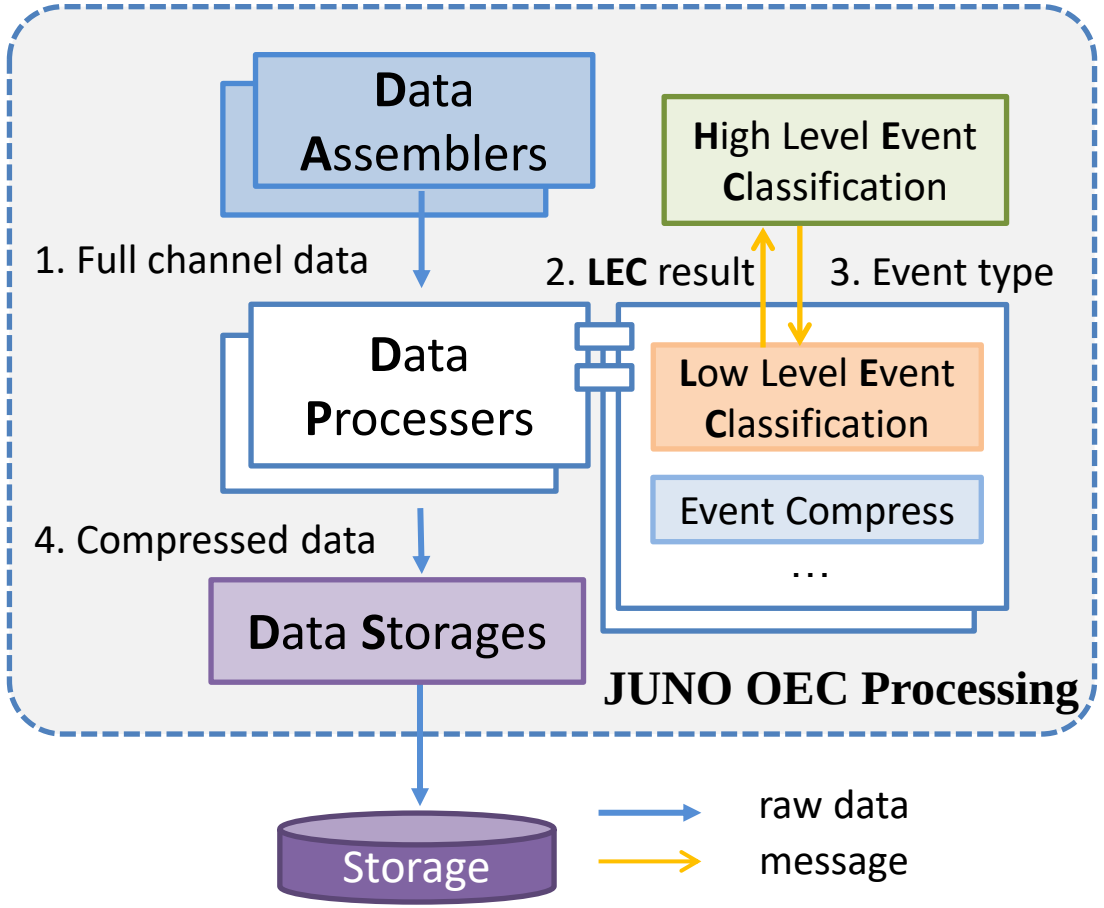
- Data preparation / preprocessing
- Core event processing algorithms

- Support parallel processing
- **Processing interface provided**
- **Plugin algorithm** deployment

Data processing is flexible, configurable

- **CCSN:** Core Collapse SuperNova
- **MM:** Multi-Messenger

Online Event Classification



Raw data stream
~ **40 GB/s**

OEC

Data to storage
~ **60 MB/s**

OEC

Including two levels:
- Distributed parallel computing (LEC)
- Global serialized computing (HEC)

OEC Adaptor

Interlayer between DAQ and offline
— Reuse offline software online

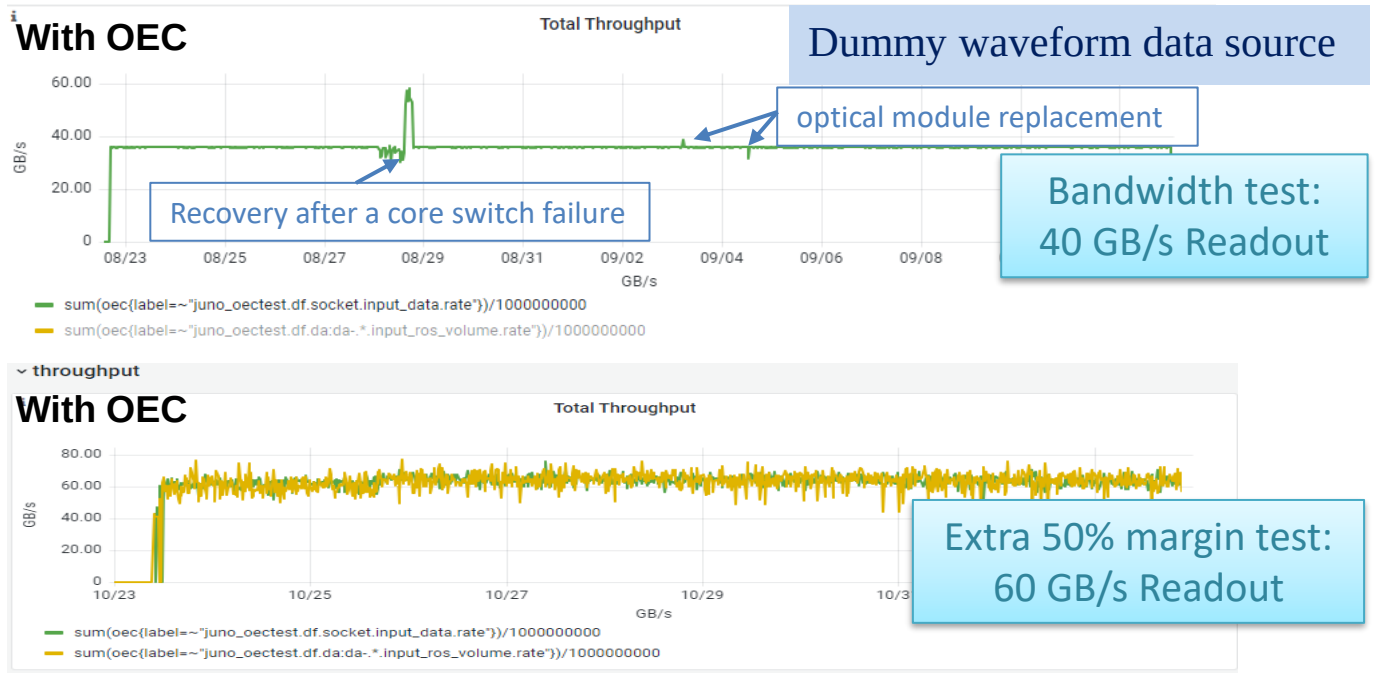
- OEC based on online reconstruction – **suppress waveform data**
- **Offline code directly embedded**, making development and deployment easier

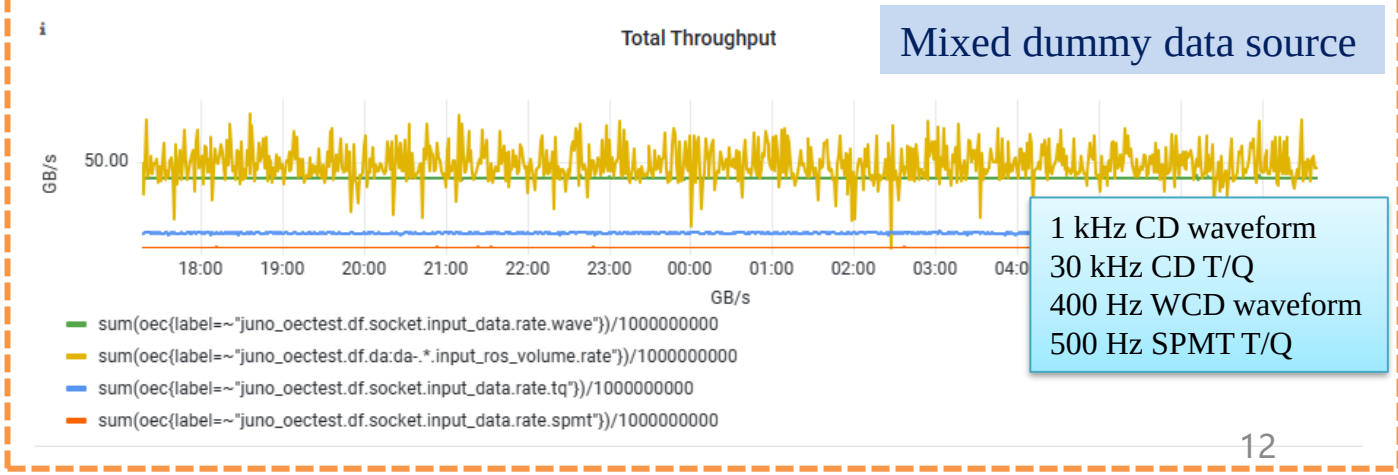
Performance Verification

Data source	15 nodes
ROS Num	30 processes / **15 nodes**
DP Num	40 processes / **40 nodes**
DA Num	80 processes / **40 nodes**
DS/DFM	**1 nodes**
Channel Num	17612 (CD waveform)
OEC Alg	V 0.2.8 / V 0.2.11
Event Rate	1 kHz / 1.5 kHz

- Performance test with baseline OEC algorithm
- Mix data source test
- Continuous running for weeks

Run stably with OEC, with 50% performance margin
Room for integrating more customized algorithms

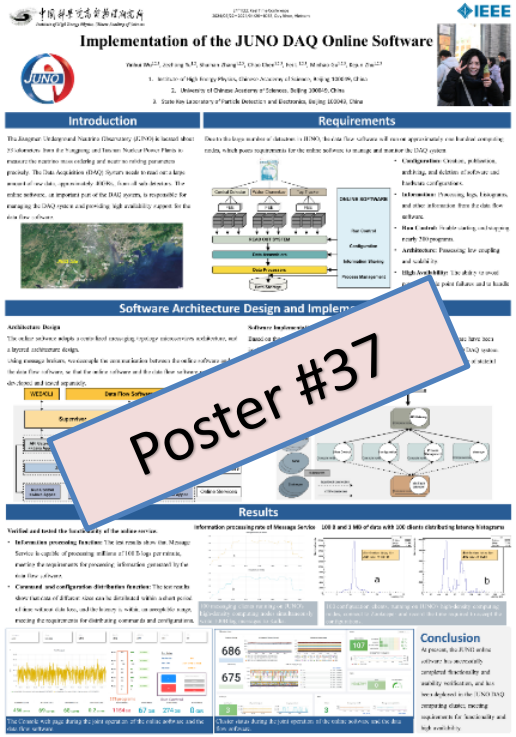




Online Software Overview

Online Software: provide management, interfaces and services

Online Software					
	HTTP Interface				
	Online Service	Configuration Service	Run Control Service	Message Service	Process Management Service
	Message Brokers				
	Client Interface	Configuration Interface	Run Control Interface	Message Interface	Process Management Interface
Data Flow Software					



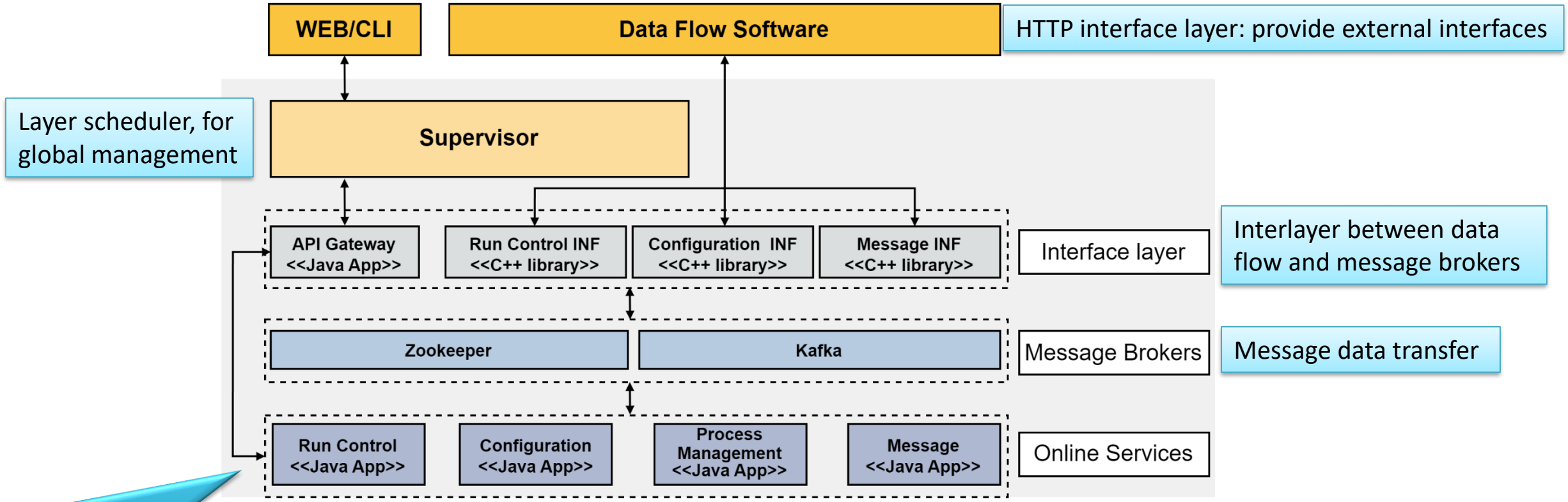
- Microservices architecture
- Kafka / ZooKeeper based services
- Kubernetes managed **containerized operation** (online + data flow)
- **Failover mechanism** design based on Kubernetes
- Feature-rich interface design

30 years running for JUNO lifetime

Reliable for supernova detection

Online Software Architecture

- Centralized messaging topology: message brokers – **decouple online and data flow**
- Microservices: keep independence between services
- Layered design – **interface, message, online services and supervisor**



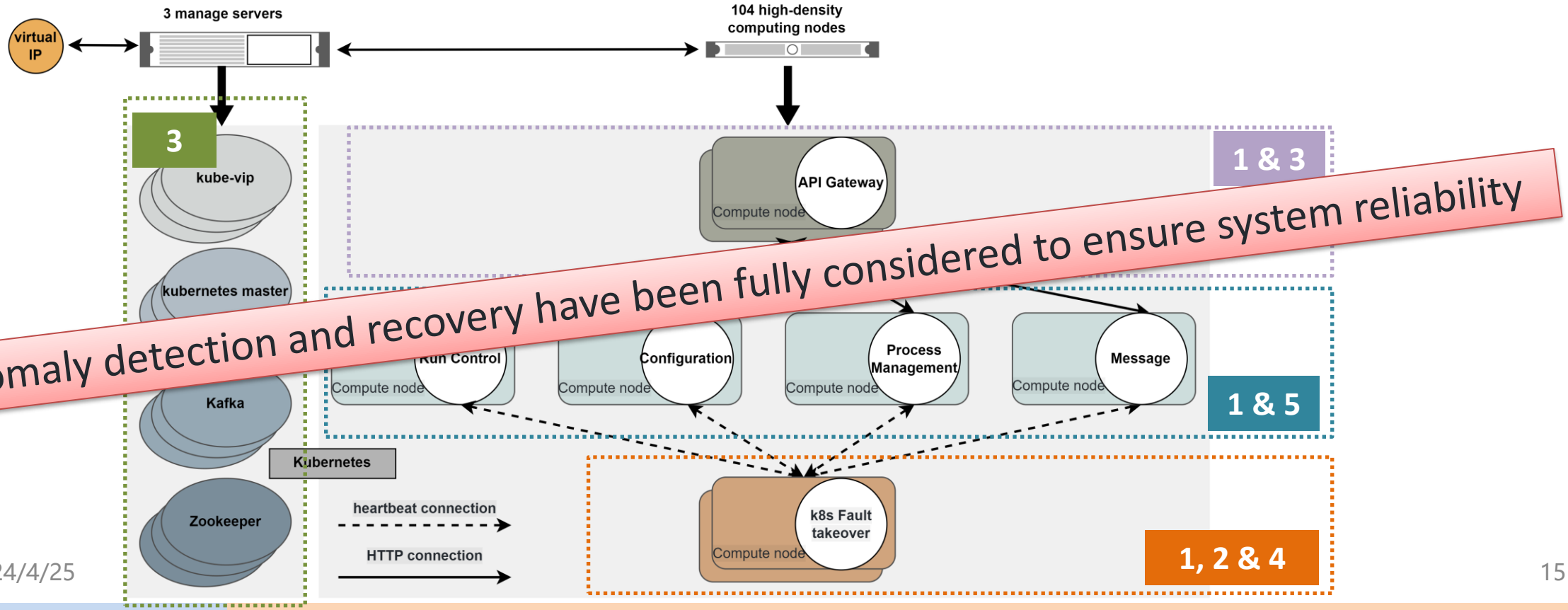
Online Software Reliability Considerations

Failure Detection

Heartbeat Detection
1. Inter-Process: Based on ZooKeeper
2. Inter-Node: Based on ICMP Protocol

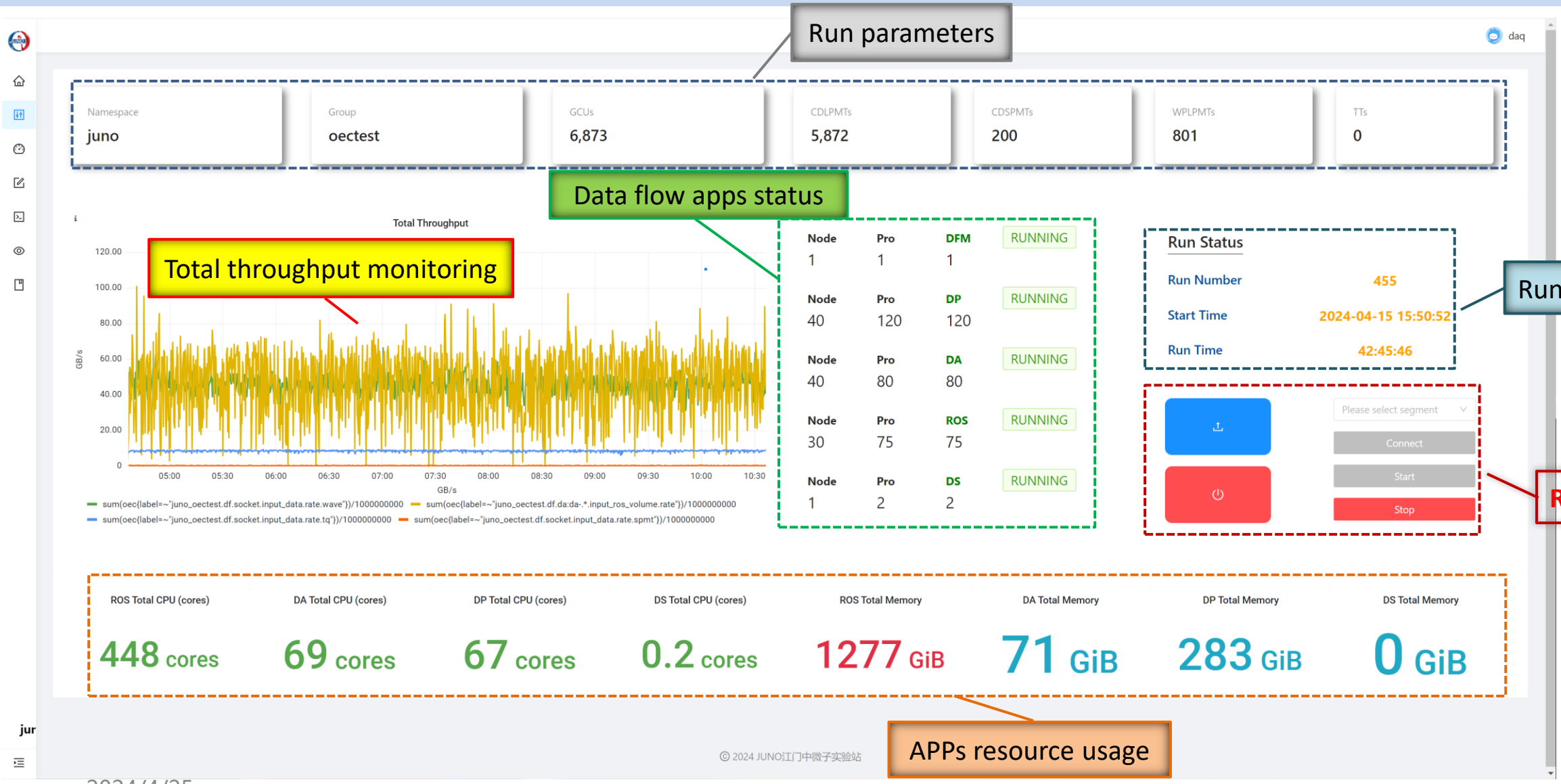
Failover

3. Redundancy + Master-Slave Election
4. Takeover scheme based on Kubernetes
5. Solutions for rapid restart of services

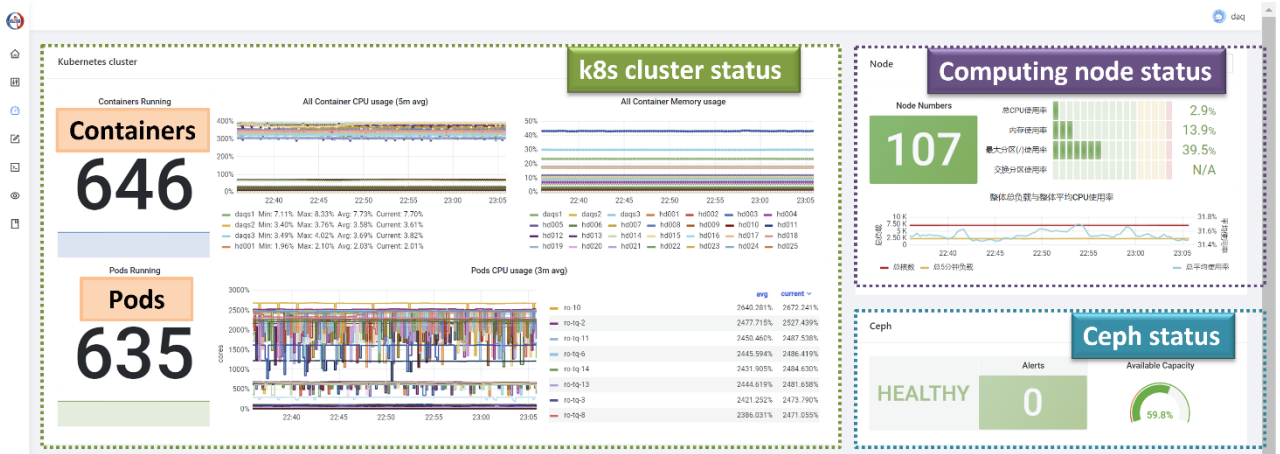


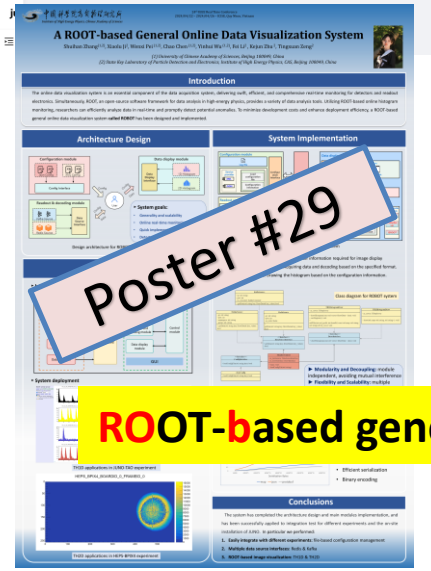
Anomaly detection and recovery have been fully considered to ensure system reliability

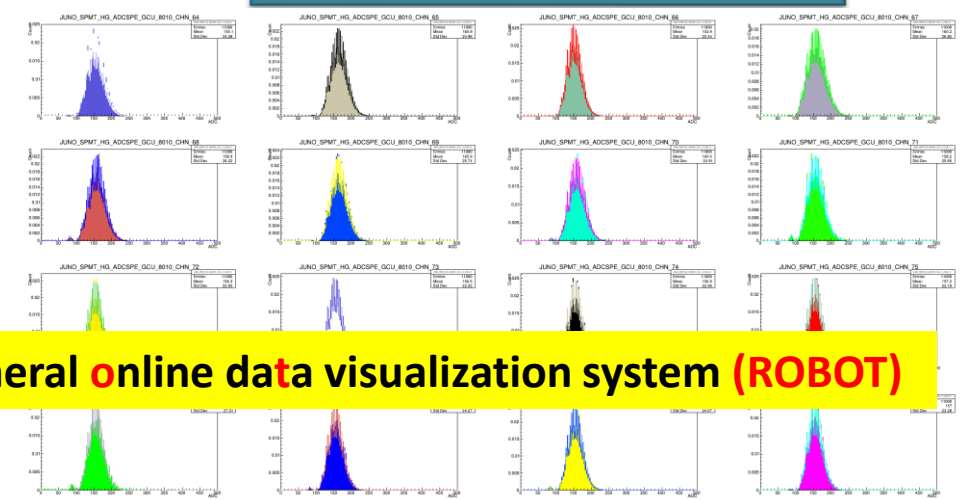
DAQ Console GUI



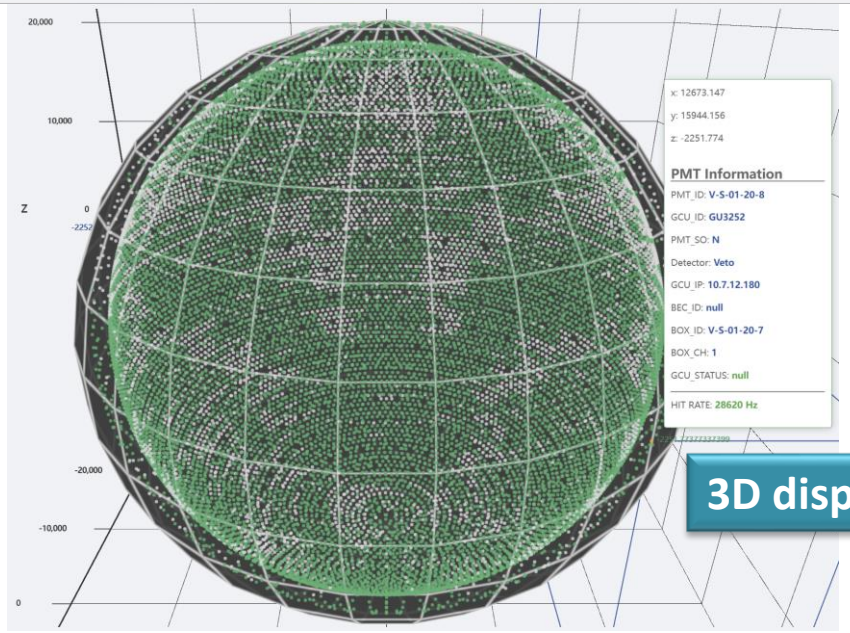
Visualization Monitoring



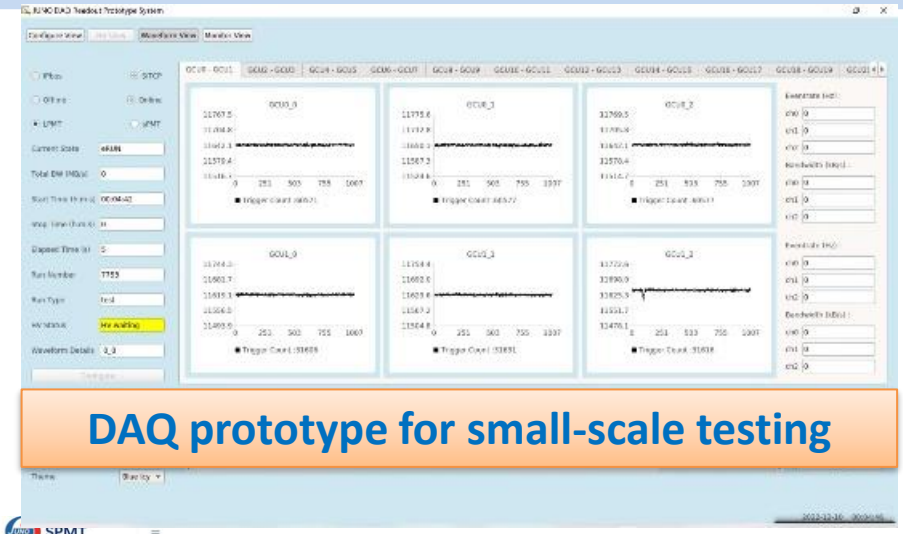




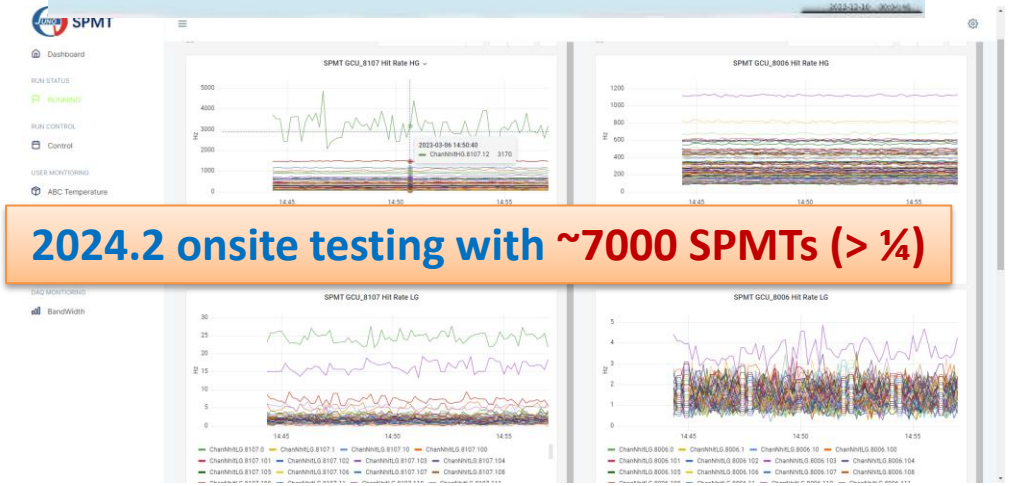
ROOT-based general online data visualization system (ROBOT)



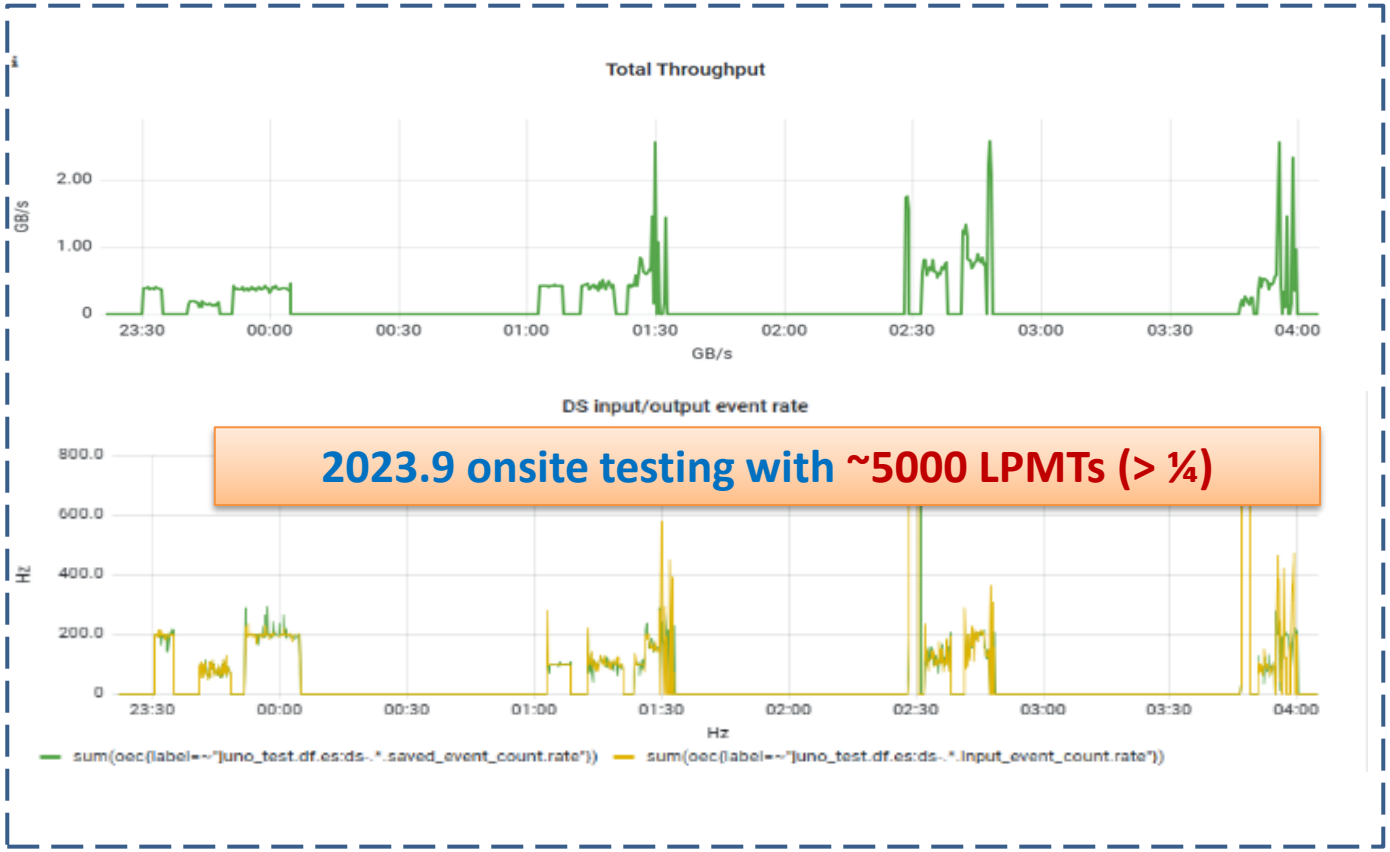
On-site Commissioning Status



DAQ prototype for small-scale testing



2024.2 onsite testing with ~7000 SPMTs (> ¼)



2023.9 onsite testing with ~5000 LPMTs (> ¼)

The detector installation has finished ~ 70%, DAQ provided stable and reliable data-taking for on-site detector readout chain commissioning tests.

Summary

- Develop JUNO DAQ based on our **Radar platform**
- The entire system has been **containerized running** for over half year
- Run stably **with online event classification** based on dummy data source
- Performance **meet JUNO requirement**, with 50% margin
- On-site detector installation readout chain commissioning tests ongoing
- **Stability & reliability consideration** in hardware and software
- Next: upgrade data flow software to handling exceptions with minimum data loss

Thanks!