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Status of the Detector Control System for the JUNO experiment

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(on behalf of the JUNO collaboration)

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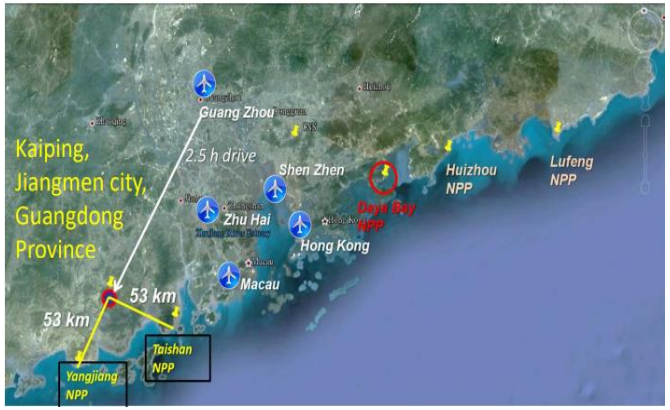
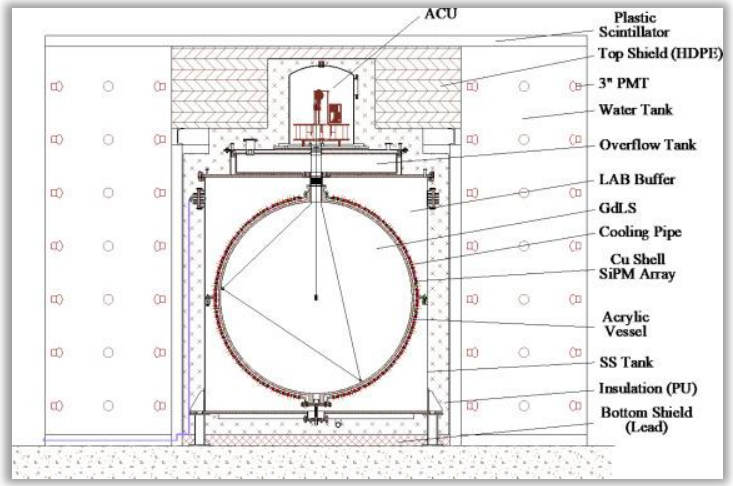
Outline

Jiangmen Underground Neutrino Observatory (JUNO)

The main mission of the JUNO is to **measure the mass ordering of neutrinos** and conduct other cutting-edge scientific research.



located in Jiangmen City, Guangdong Province, China.



[Schematic view of the JUNO detector]

- ~17612 20" PMT (CD)
- ~2000 20" PMT (Veto)

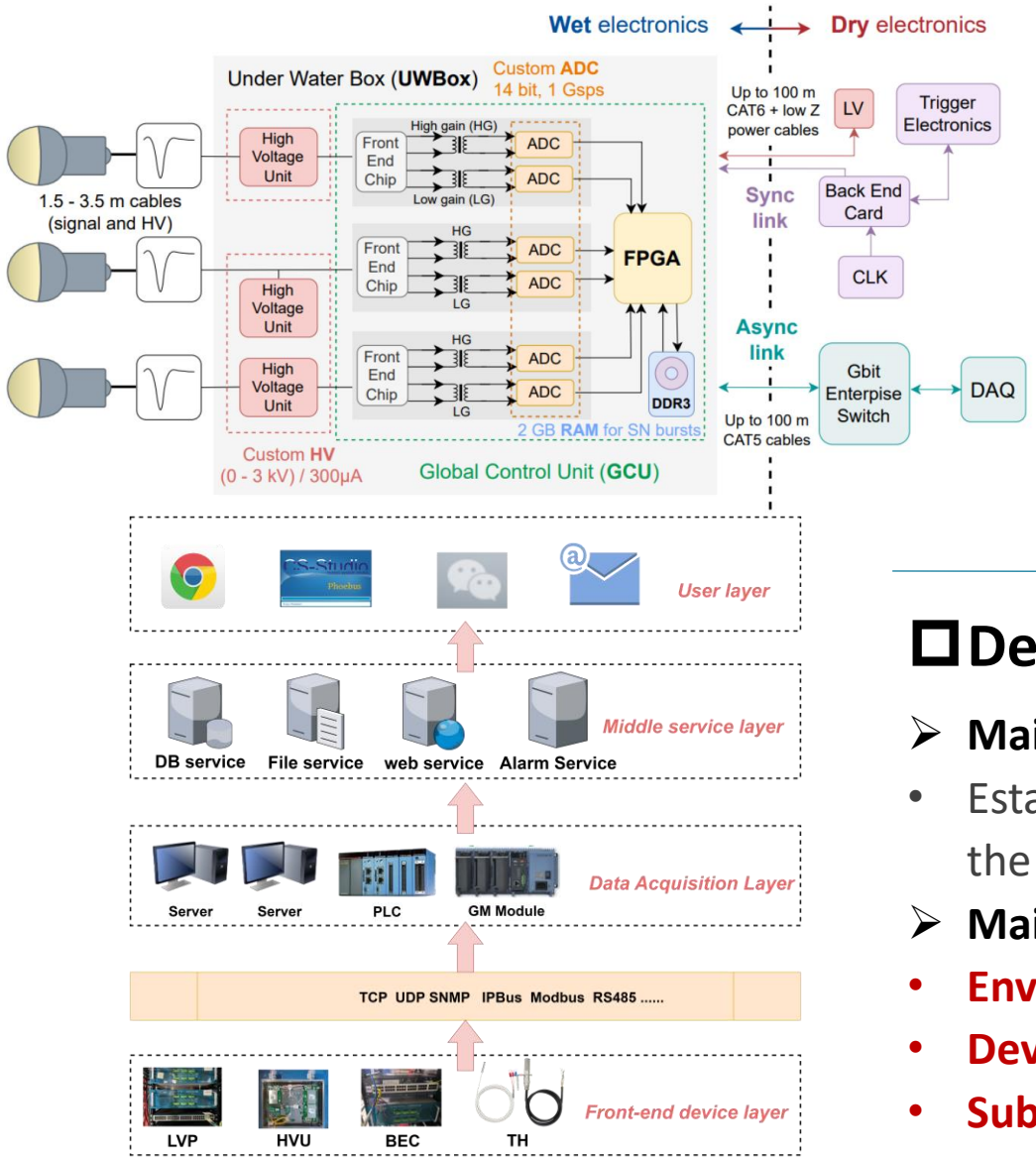
The JUNO detectors include:

- Central Detector (CD) — **CD detector**
- Water Cherenkov Detector(WC)
- Top Trackers(TT)

Veto detector

Photomultiplier Tube(PMT):
Collecting photonic signals

Requires electronics systems for management and control



☐ Readout of electronics

- **Low-Voltage Power(LVP):** Provides operating voltage for the GCU
- **Global Control Unit(GCU):** Collects PMT information.
- **High Voltage Unit(HVU):** Provides PMT working voltage.
- **Back End Card(BEC):** Provides the trigger signal.

☐ Detector Control System(DCS) of JUNO

➢ **Main tasks:**

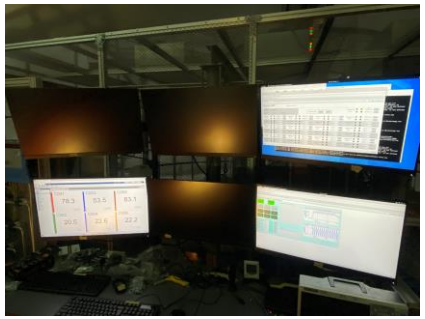
- Establish **long-term monitoring and control** of parameters affecting the performance of experimental devices.

➢ **Mainly includes:**

- **Environment:** temperature and humidity, liquid level, air pressure
- **Device:** temperature, voltage, current
- **Sub-System:** record system operation status

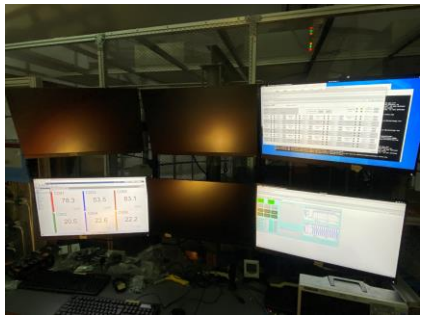
02 Design of the system

Requirement



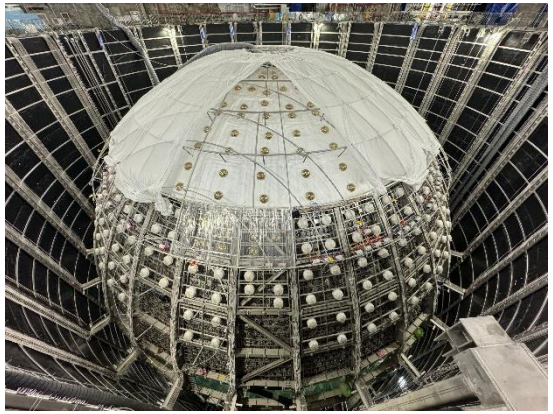
Indoor/hall environments
~200 sensors

dcs server cluster
~20 servers



LS System
~10 subsystems

320 LVPs / 160 BECs



JUNO detector

~8000 GCUs

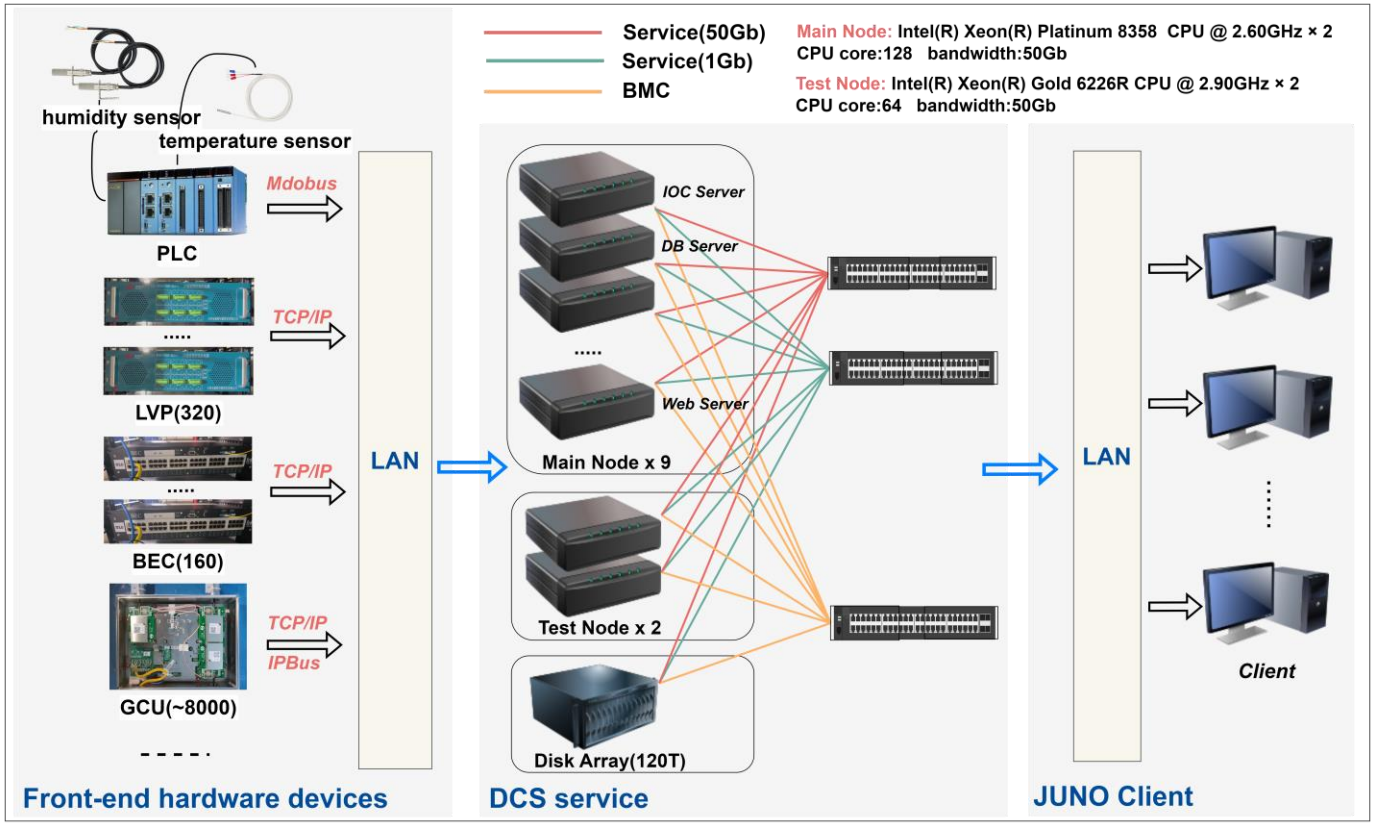
Statistical analysis of some subsystems and devices, with over 100,000 PVs requiring **read/write and monitoring**

System	Count	Main monitoring parameters	PV number
LVP	320	Temperature, Voltage, Current	~60000
BEC	160	Temperature, Voltage, Current	1600
GCU	~8000	Temperature, Voltage, Current	~80000
TH Sensor	~200	temperature and humidity	~200
LS	10	Operating parameters	~200
total		/	~145000

☐ Monitoring system requirements

- Communication with front-end devices(EPICS)
- Data readout and storage (Database)
- Operation status and data monitoring (Web)
- System operation alarm (Alarm)

System hardware architecture



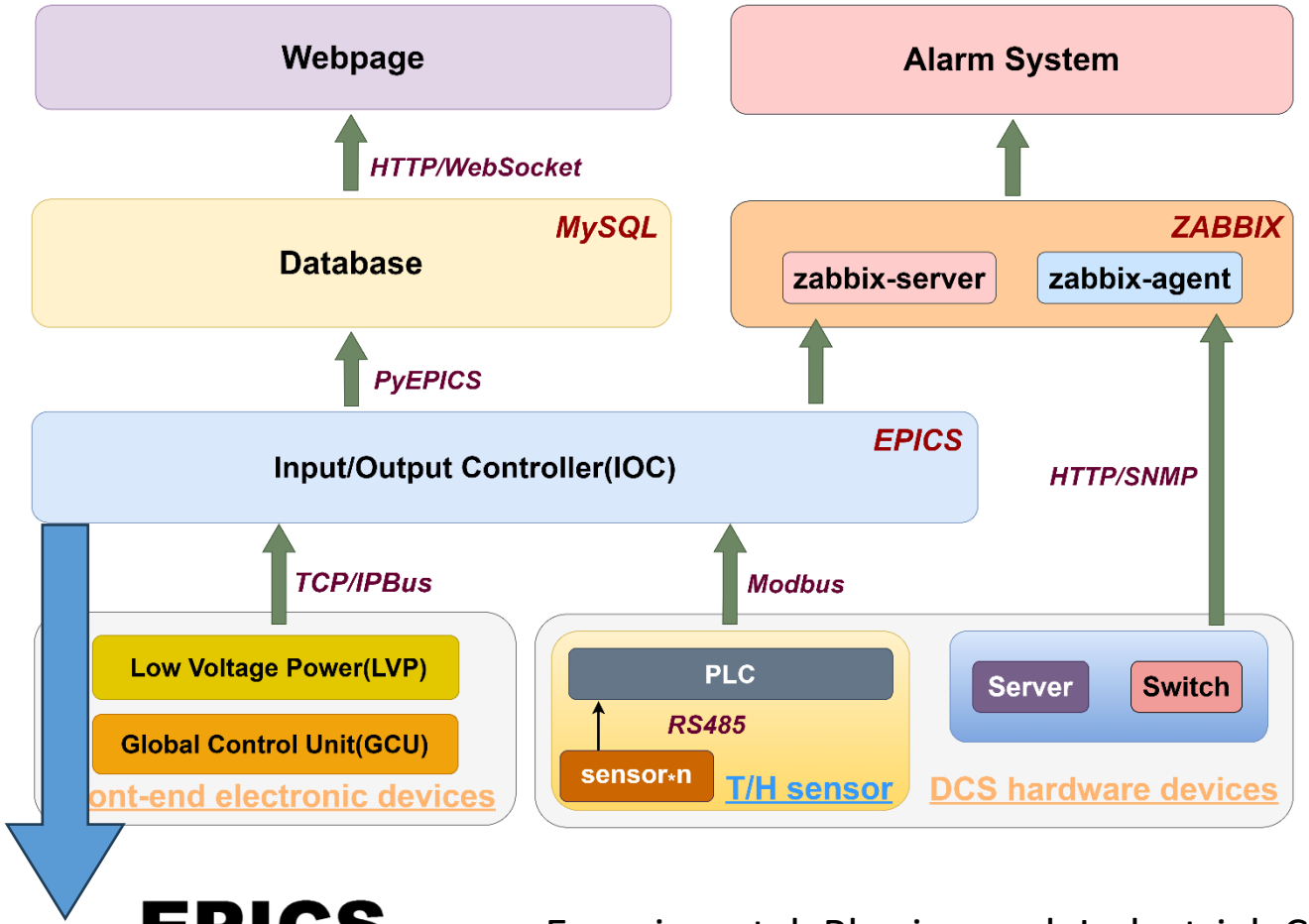
Main Node: Intel(R) Xeon(R) Platinum 8358 CPU @ 2.60GHz × 2
CPU core:128
Test Node: Intel(R) Xeon(R) Gold 6226R CPU @ 2.90GHz × 2
CPU core:64
System Version: CentOS7.9
bandwidth:50Gb/s

A large number of electronics devices require DCS for monitoring and control, such as low-voltage power supplies (LVPs), global control units (GCUs).

- **Front-end hardware devices:**
  - LVP, GCU, BEC, PLC, etc.
- **Relevant transport protocols:**
  - TCP/IP, IPBus, Modbus, SNMP, etc.
- **DCS services:**
  - IOC service
  - Database service
  - Web service
  - Alarm application

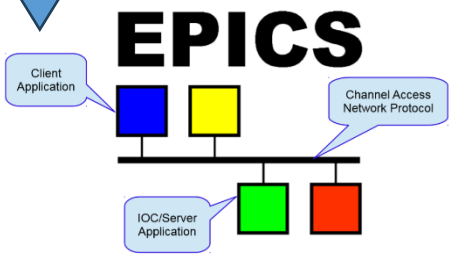
Total number of physical cores: 640

System software architecture



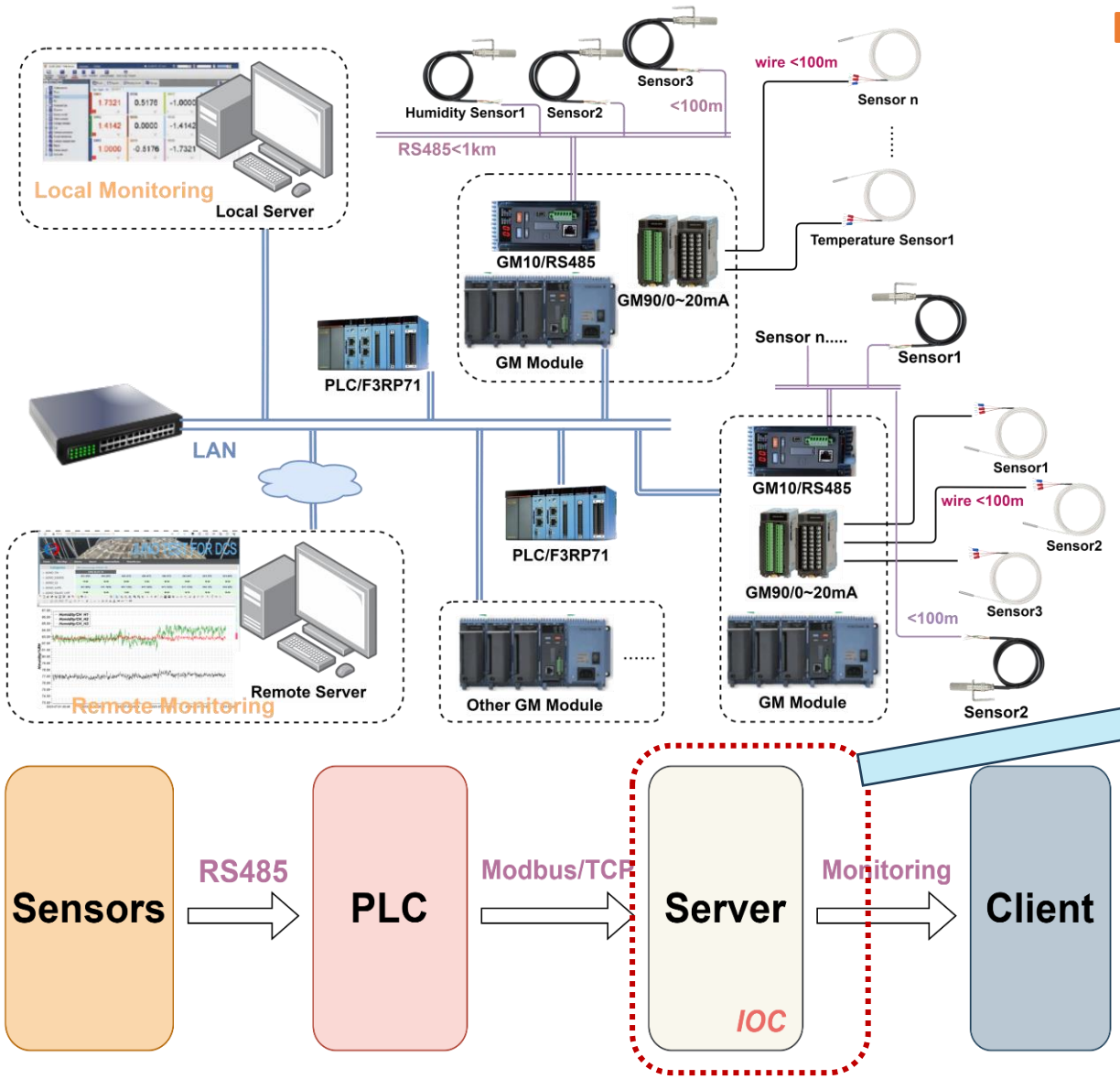
The detector control system of the JUNO (JUNO-DCS) is mainly composed of the following modules:

- **Acquisition and Communication module**
  - Realise the communication between server and front-end devices (based on EPICS).
- **Readout and archive module**
  - Data readout
  - Data archive
- **Monitoring and Control module**
  - Status monitoring
  - Data Monitoring
- **Alarm Module**



Experimental Physics and Industrial Control Systems(EPICS) is a distributed control system software development toolset.

- **Extensibility**, **portability**, **reusability** and **interoperability**.
- Communicate using **client/server** and **publish/subscribe** technologies.



Environmental Monitoring System of JUNO

Currently, the main focus is on monitoring the temperature and humidity environment in laboratories and experimental halls

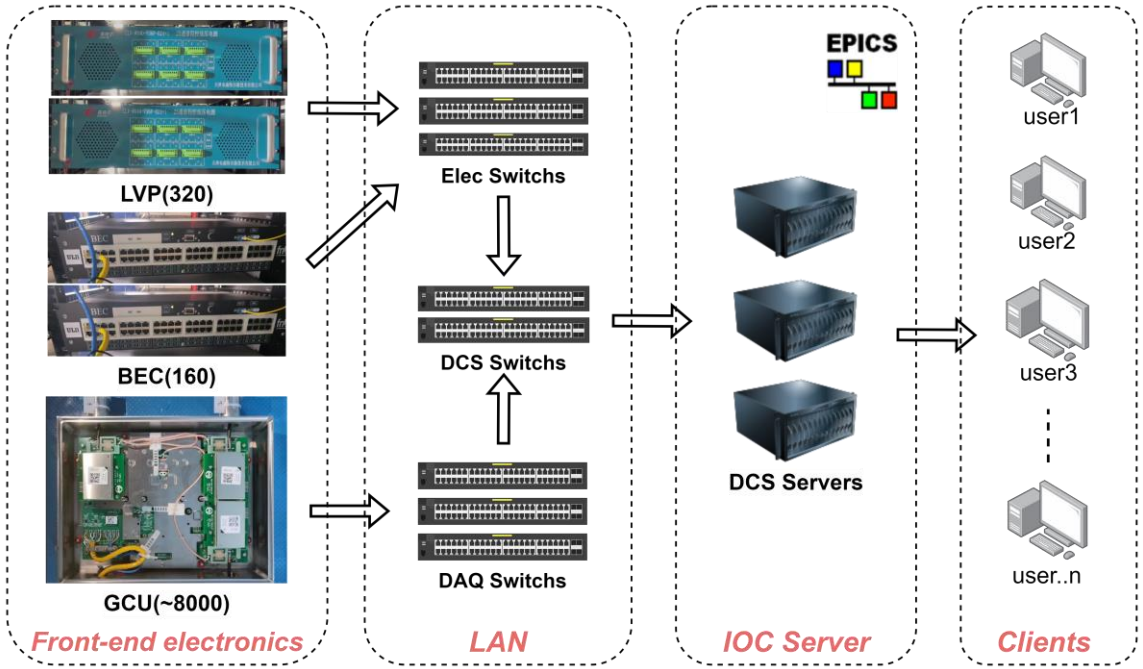
- **Sensors**
  - **Temperature sensor:** PT100 RTD type
  - **Humidity sensor:** RS485 type
- **Acquisition:** EPICS (Modbus)
  - Development of temperature and humidity IOC based on modbus protocol.

IOC Application

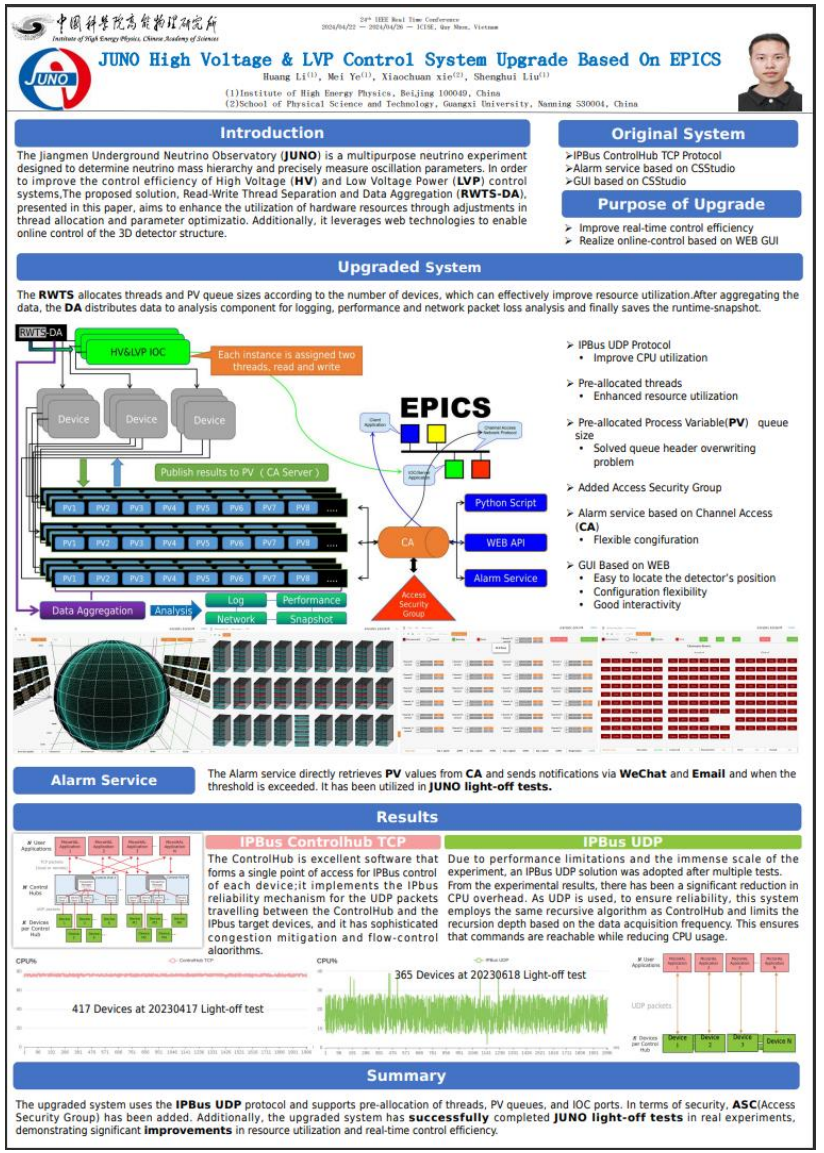
```
dbLoadTemplate("GM1-ELEC01.substitutions")
dbLoadTemplate("GM2-ELEC02.substitutions")
dbLoadTemplate("GM3-LSUD.substitutions")
dbLoadTemplate("GM4-OSIRIS.substitutions")
dbLoadTemplate("GM5-LSUP.substitutions")
dbLoadTemplate("GM6-UPROOM.substitutions")
iocInit
Starting iocInit
############################################################################
## EPICS R3.15.5
## EPICS Base built Feb 21 2023
############################################################################
iocRun: All initialization complete
epics>
```

PV readout

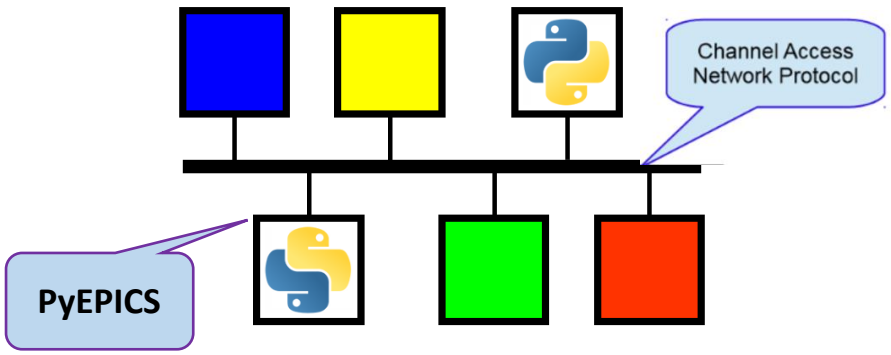
```
[root@xiaohui GM10_JUNO]# caget JUNO:JM:ELEC01:TEMP:1:1
JUNO:JM:ELEC01:TEMP:1:1        21.1
[root@xiaohui GM10_JUNO]# caget JUNO:JM:ELEC01:TEMP:1:2
JUNO:JM:ELEC01:TEMP:1:2        21.4
[root@xiaohui GM10_JUNO]# caget JUNO:JM:ELEC01:H:1
JUNO:JM:ELEC01:H:1             71.7
[root@xiaohui GM10_JUNO]# caget JUNO:JM:ELEC01:H:2
JUNO:JM:ELEC01:H:2             73.1
```



See poster for details @ Huang Li



- **Front-end hardware devices:**
  - HVU, BEC, LVP, etc
- **Acquisition:** EPICS (TCP/IP and IPBus)
  - Development of IOC for LVP and BEC based on **TCP/IP** protocols
  - Development of IOC for HVU based on **IPBus and UDP** protocols



PyEPICS:

- PyEpics is a **Python interface to the EPICS Channel Access (CA) library** for the EPICS control system.

Provides the main functions:

- caget(): get a pv value
- caput(): set the value of a PV
- cainfo(): query the information of a PV
- caget_many(): get the value of a Pvlist
- caput_many(): set the value of a Pvlist

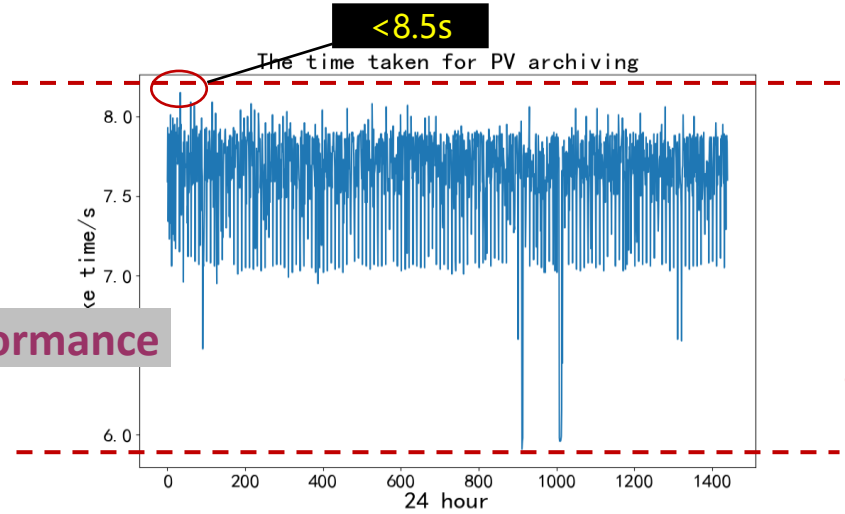
Among them, caget_many() has better performance when getting a large number of PVs.

PV read test of caget function

Number of IOC	Number of PV	Reading time/s	Single PV read time /ms	Average CPU overhead
1	1000	27.07	27.07	7.25%
1	10000	274.83	27.48	15.88%
1	50000	1423.13	28.46	17.03%
1	100000	2935.67	29.35	29.35%

PV read test of caget_many function

Number of IOC	Number of PV	Reading time/s	Single PV read time /ms	Average CPU overhead
1	1000	0.32	0.32	2.83%
1	10000	3.19	0.31	10.52%
1	50000	14.52	0.29	13.06%
1	100000	27.33	0.27	13.87%



The functions provided by PyEPICS use the CA protocol to establish a connection with the PV **to read, write and monitor the PV**.

Database Cluster Design

Main tasks

- Meet the storage of massive experimental data and monitoring data in experimental operation.

Framework:

- MySQL Cluster + MySQL Route

Implementation:

- Read/Write Separation, Real-time Disaster Recovery, Failover

- **Routing node:**

Forward read and write requests

- **SQL Node:**

Process client requests

- **Data Nodes:**

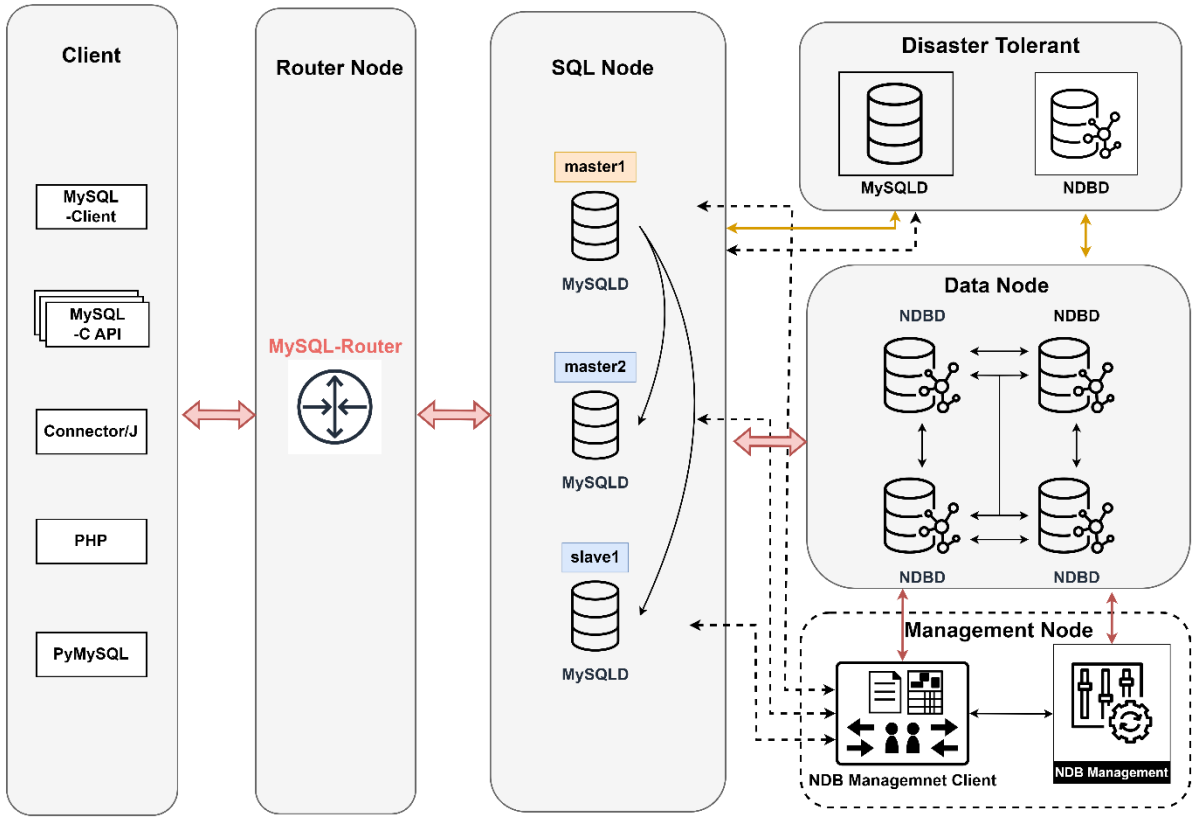
Store data and provide data services

- **Backup Node:**

Enabling failover and data backup

- **Management Node:**

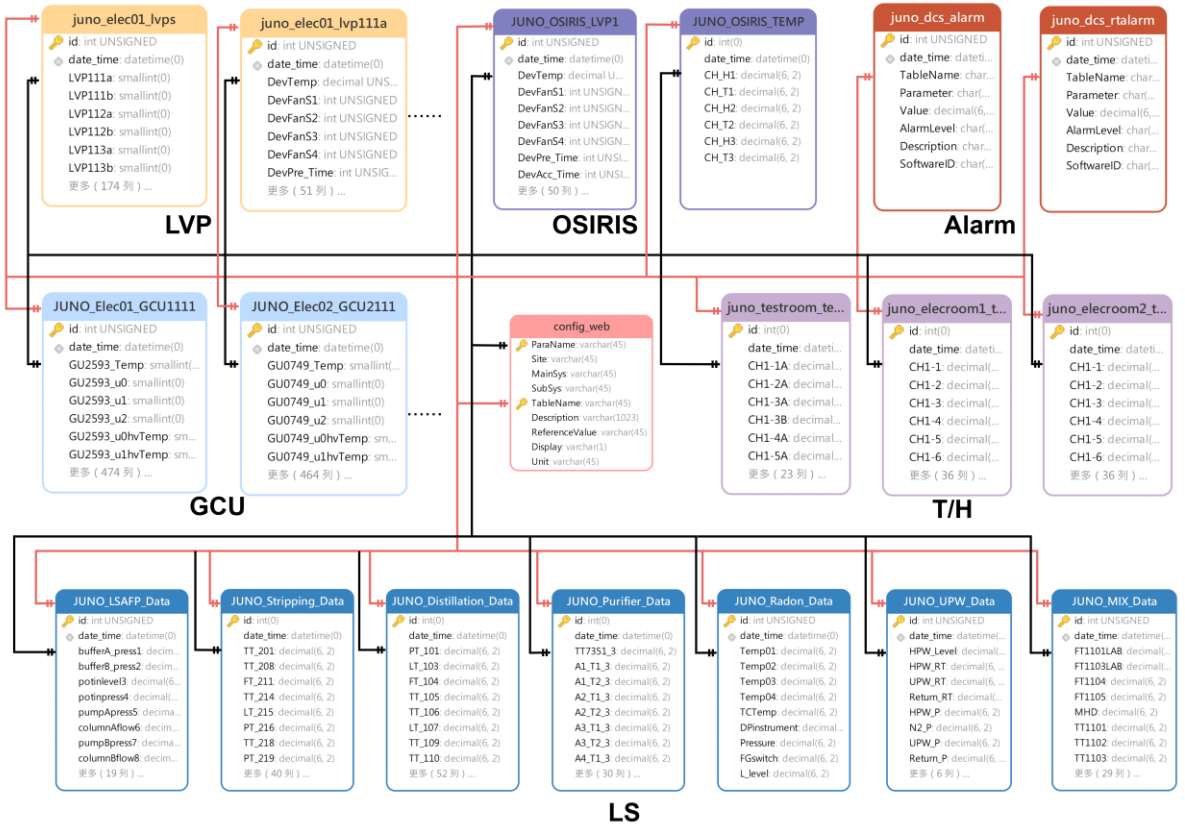
Manage database clusters



Node classification	version	port
Router node	mysql-router8.0.26	7001，7002
SQL node	mysql-cluster-data-node8.0.26	3306
Data node	mysql-cluster-data-node8.0.26	1186
Backup node	mysql-server8.0.26	1186，3306
Management Node	mysql-cluster-management-server8.0.26	1186

Database Table Structure Design

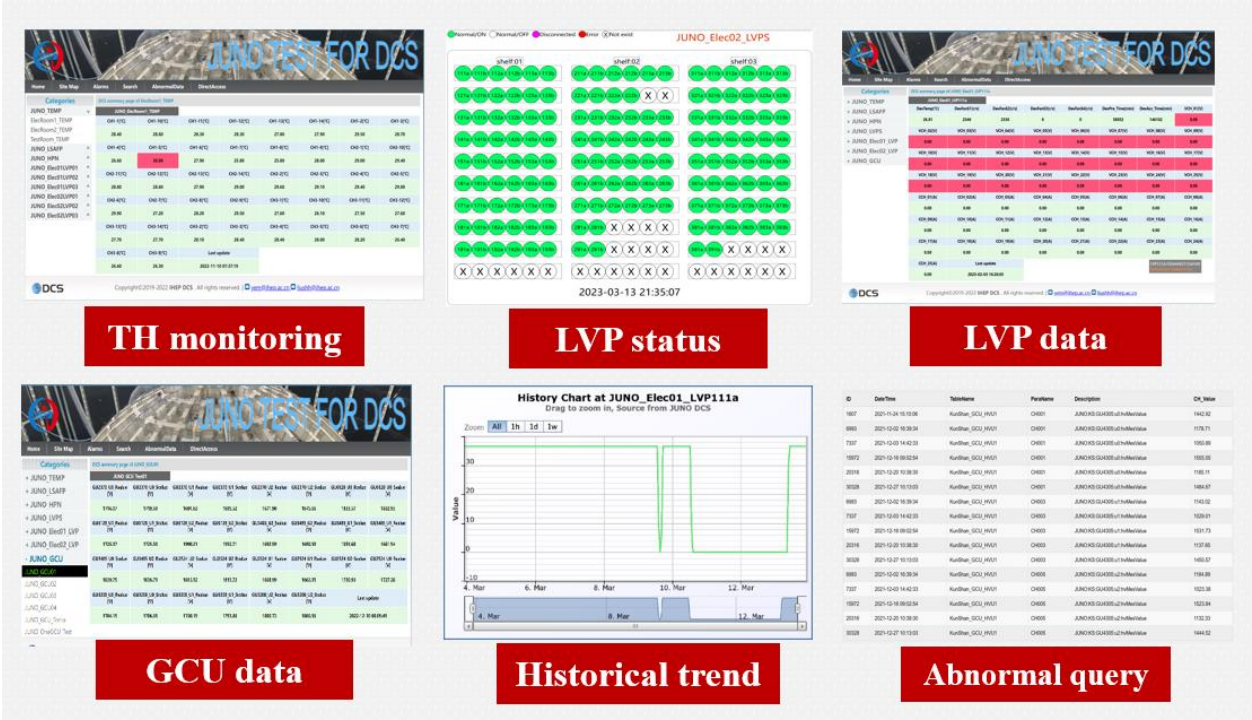
- **Channel Data Table**
  - Records the data of the channel
- **Device status table**
  - Records the operation status of the device
- **Alarm table**
  - Records abnormal data and device information
- **Configuration Table**
  - Records configuration information

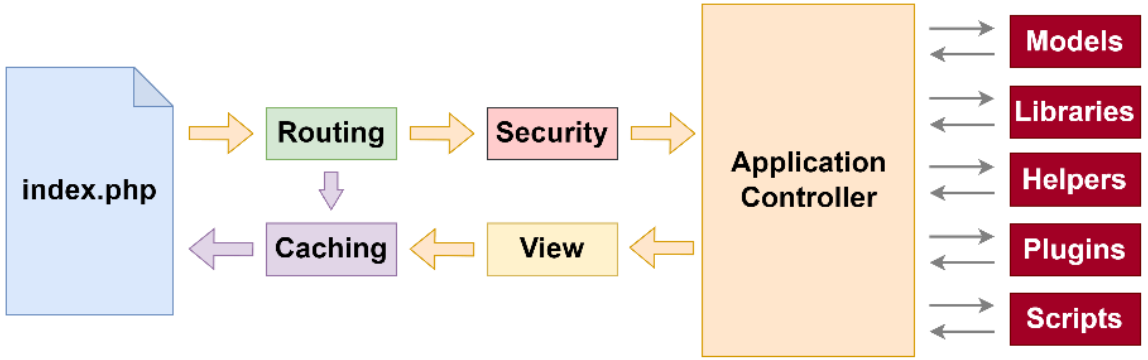


Device/System	Number	PV number	Table Number	archiving period	Bytes archived/times	Total archived Bytes/1min
LVP	320	~60000	320	1min	194 Byte	62080(~62KB)
BEC	160	1600	160	1min	41 Byte	6560 (~6.6KB)
GCU	~8000	~80000	8000	1min	41 Byte	328000(~328KB)
TH	~200	~200	10	1min	/	590 Byte(~0.6KB)
LS	10	~200	10	10s	~1100 Byte	6600(~6.6KB)
Total	/	~145000	~10000	/	/	~405KB(~0.41MB)

Data monitoring webpage

- **Framework：** ***CI (CodeIgniter)***
  - CodeIgniter is a set of application development frameworks and toolkits for PHP web developers.
- **Development Language:** PHP
- **Application Interface:** MySQLi
- **Data Interaction:** AJAX
- **Implementation:**
  - Device status display
  - Channel data display
  - Historical data query
  - Abnormal data retrieval



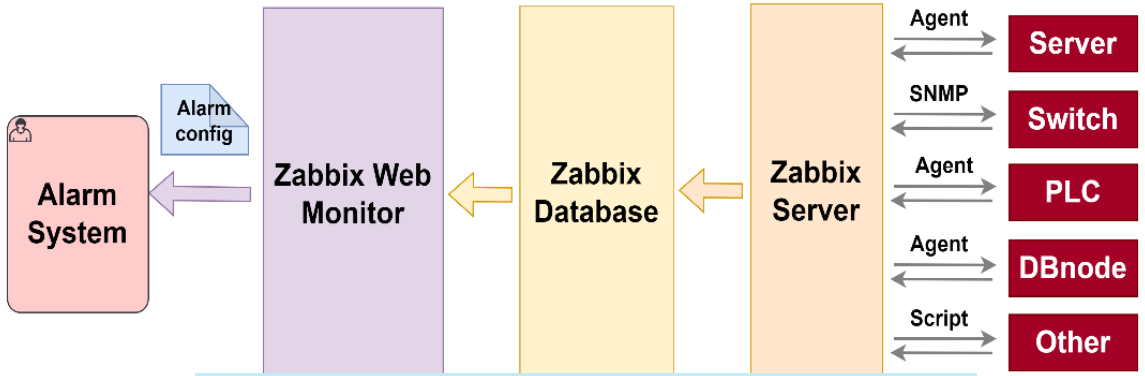


PHP Open Source CI Modelling Framework

Lightweight
Low-code
Excellent performance

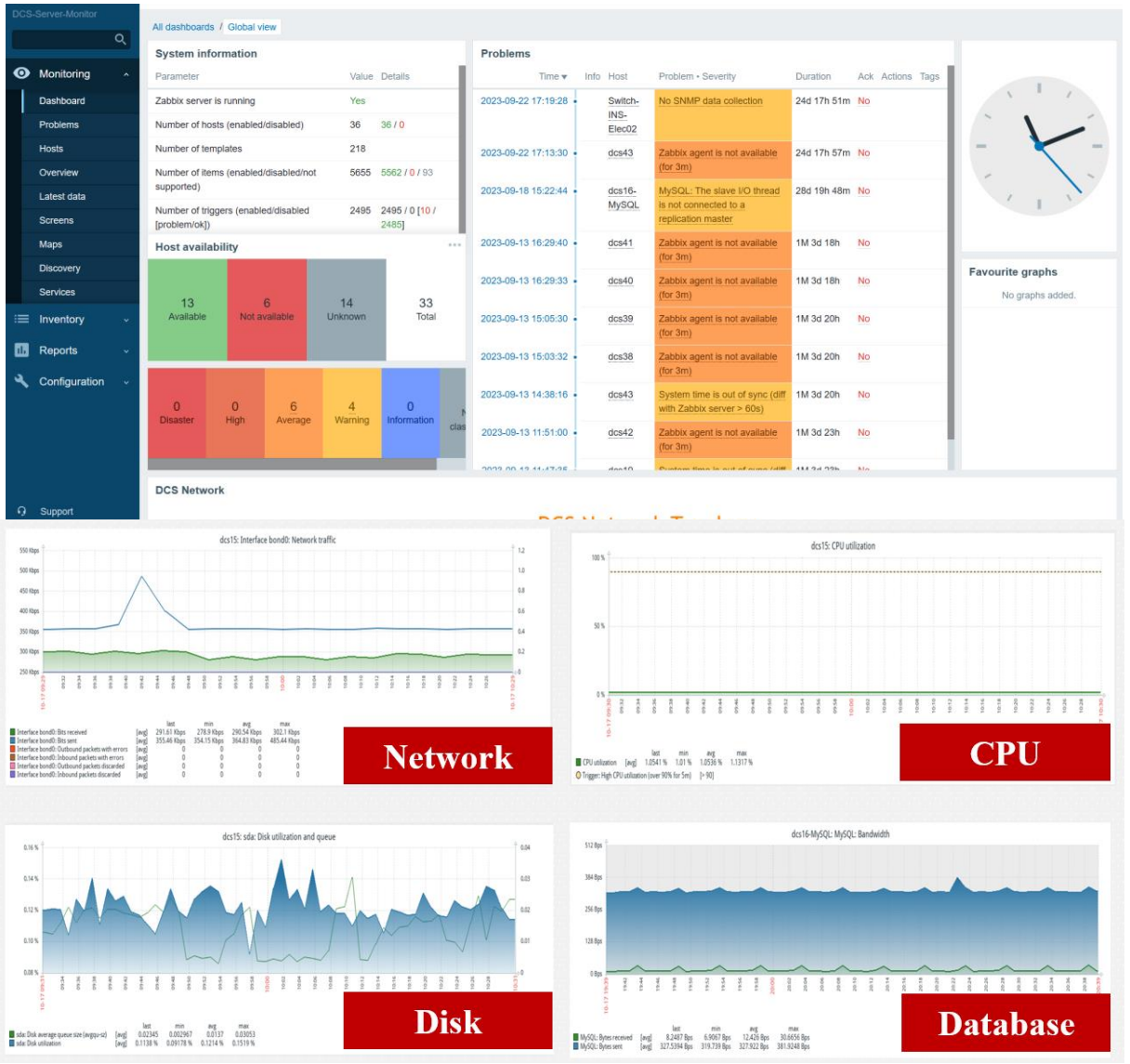
Device Monitoring System

- **Purpose:**
  - To monitor the DCS servers, switches, and other front-end hardware devices.
- **Platform:** ***Zabbix5.0 LTS***
- **Monitoring device :**
  - Servers, Database, Switches, Storages, PLCs
- **Monitoring items:**
  - Network status, CPU overhead, network bandwidth, etc.
- **Alarm:** Web/Email/Wechat



ZABBIX-based device monitoring system

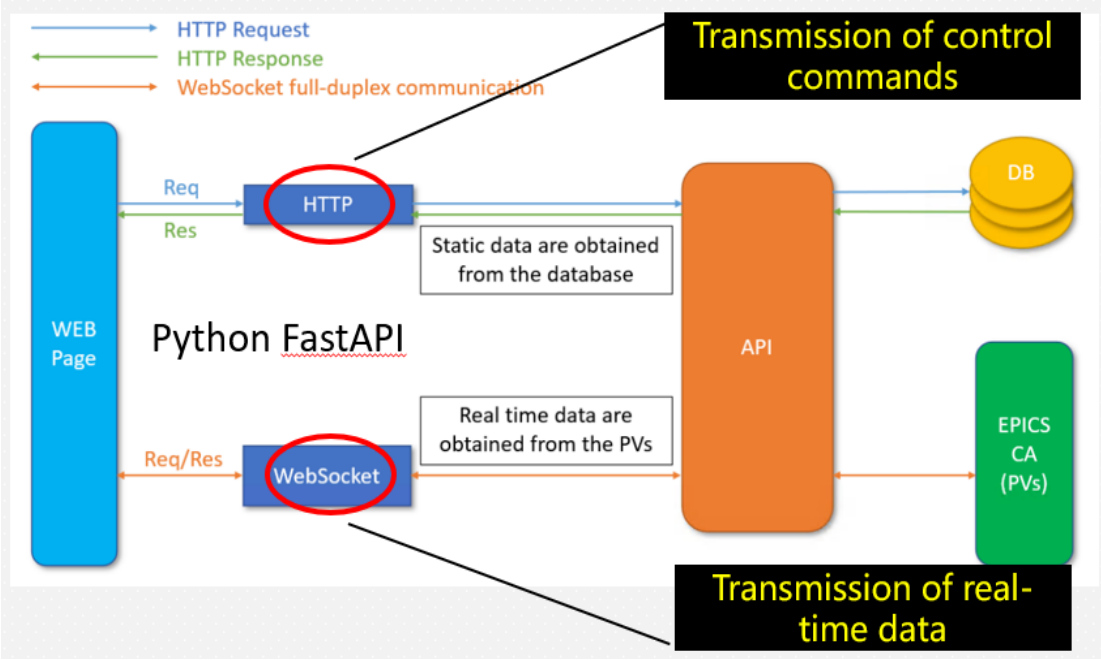
Open Source ***Simple configuration*** ***Highly integrated***

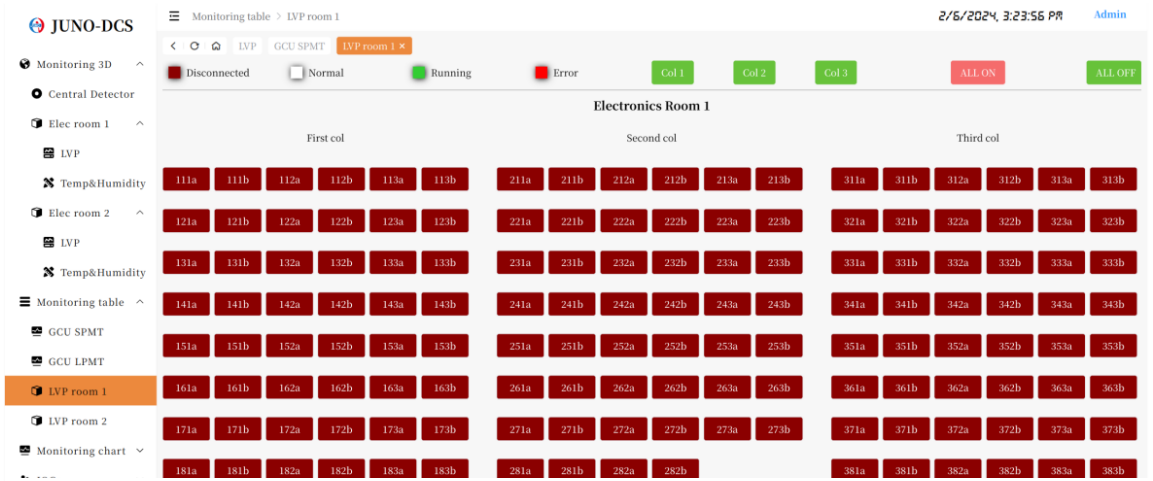


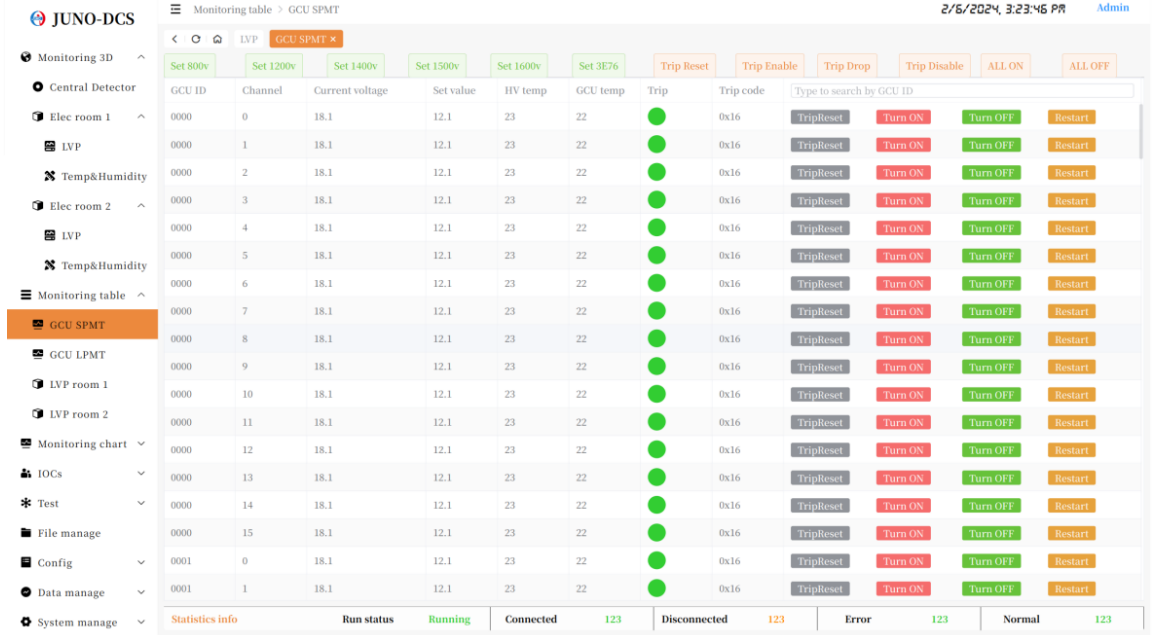
Control (web-based)

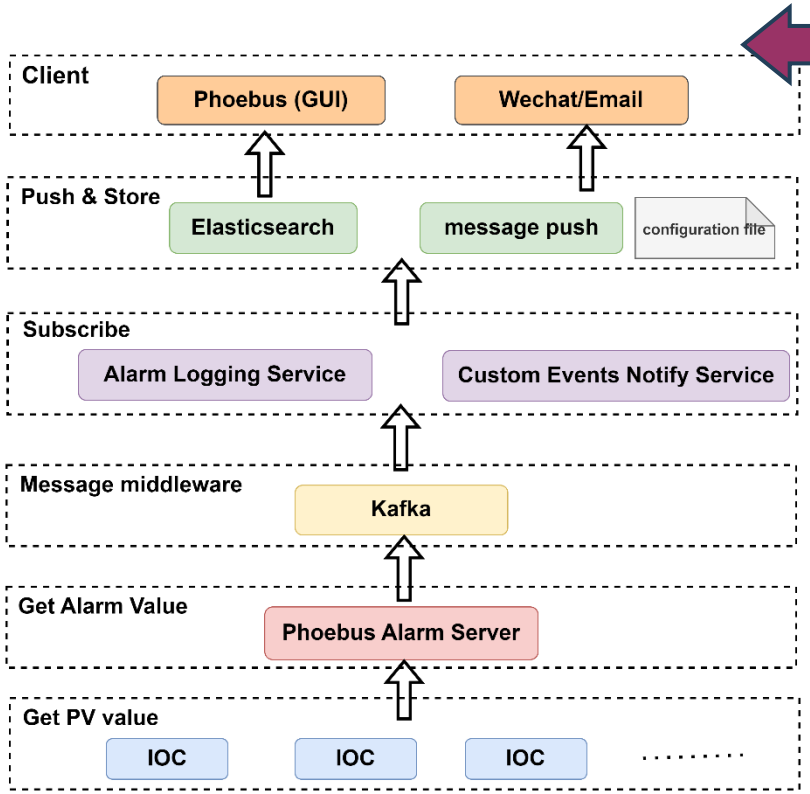
Front-end device control (web-based)

- **Framework：** Vue3+TypeScript
- **Protocol：** WebSocket & HTTP
- **Advantage：**
  - Fast Response
  - Simple page
  - Integrated monitoring and control









IOC Device Alarm Architecture

Based on EPICS

☐ **Main task:**

Alerts for abnormal channel data

☐ **Alarm levels:**

NO_ALARM, MINOR, MAJOR,INVALID

Non-IOC Device Alarm Architecture

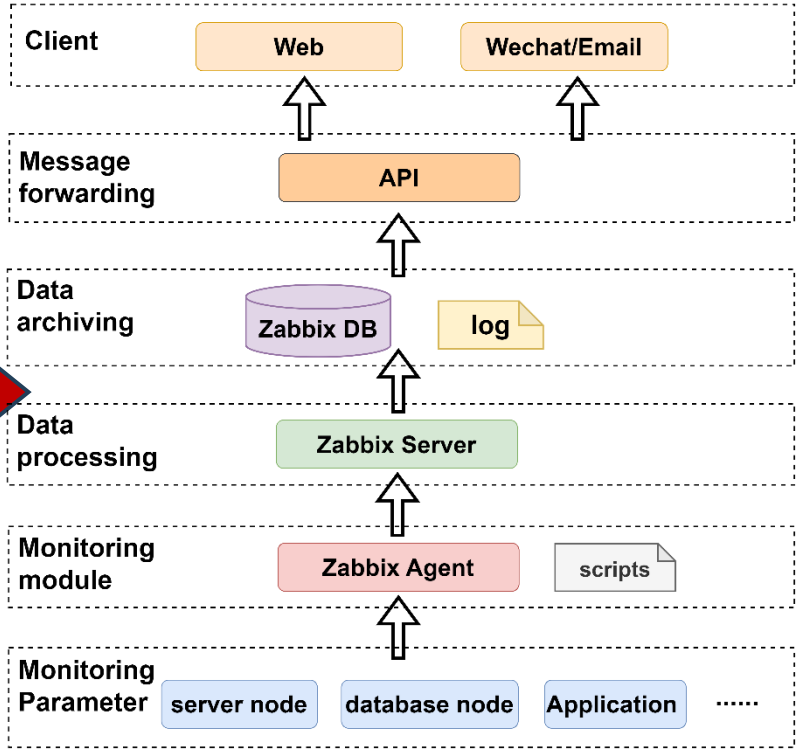
Based on ZABBIX

☐ **Main task:**

Alerts for abnormal conditions in devices, applications, etc.

☐ **Alarm level:**

No alarm, Warning, Average, High



Monitoring target	Monitoring parameters
IOC device	Data of the device channel

Monitoring target	Monitoring parameters
Server node	Connection, Network, Bandwidth, CPU, Memory, Disk
Database node	Database status, threaded, throughput, buffer pool usage
Front-end device	Status of device communications
Process	Program status, timed tasks

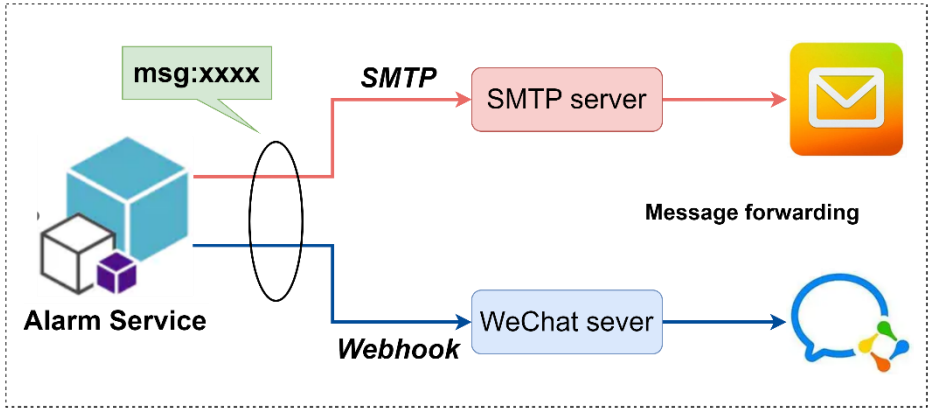
Alarm Message Format Definitions

Alarm occurrence：

- Alarm Host: the host of the alarm
- Alarm Address: IP address of the alarm device
- Alarm Time: the time when the alarm occurs
- Alarm Level: the level of the alarm
- Alarm Message: Alarm message
- Alarm Item: Alarm channel or variable
- Alarm Details: Alarm values
- Current Status: Current status
- Event ID: The event ID of the alarm

Alarm clearance:

- Consistent with the above.



Alarm occurrence

PROBLEM Status Report	
Alarm Host	TAO-Temp
Alarm Address	127.0.0.1
Alarm Time	2023-09-01 17:37:16
Alarm Level	High
Alarm Message	TAO_Channel16 Temperature anomaly
Alarm Item	TAO.channel16
Alarm Details	Channe16 Temperature : 39.6℃
Current Status	PROBLEM : 39.6℃
Event ID	6658

Alarm clearance:

OK Status Report	
Recovery Host	TAO-Temp
Recovery Address	127.0.0.1
Recovery Time	2023-09-01 17:43:06
Recovery Level	High
Recovery Information	TAO_Channel16 Temperature anomaly
Recovery Item	TAO.channel16
Recovery Details	Channe16 Temperature : 29.7℃
Current Status	OK : 29.7℃
Event ID	6658

04 System operational test

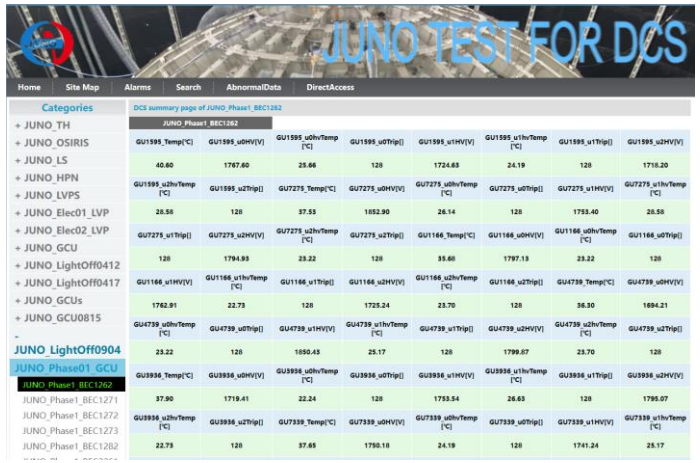
Simulation test

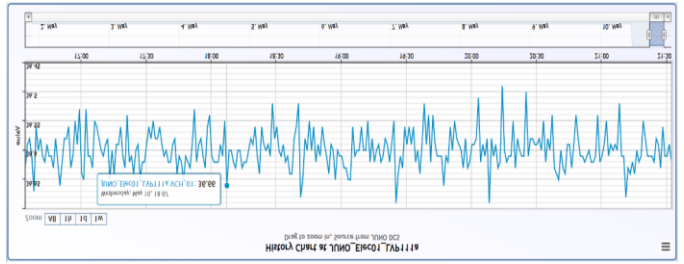
Test purpose

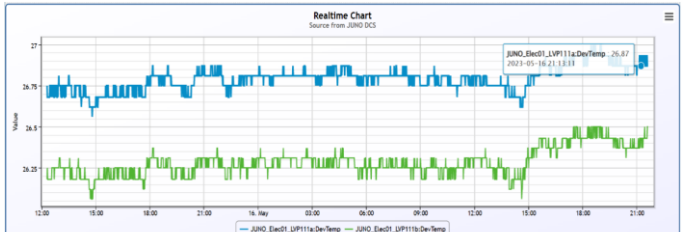
To verify if the monitoring webpage can withstand concurrent access pressure.

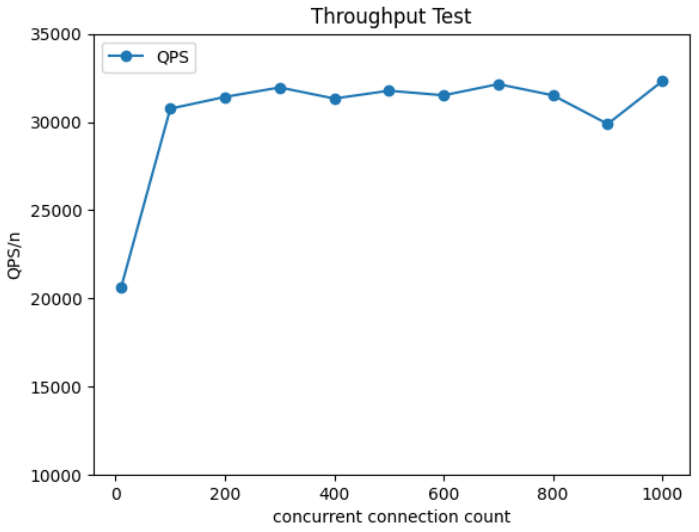
Test metrics

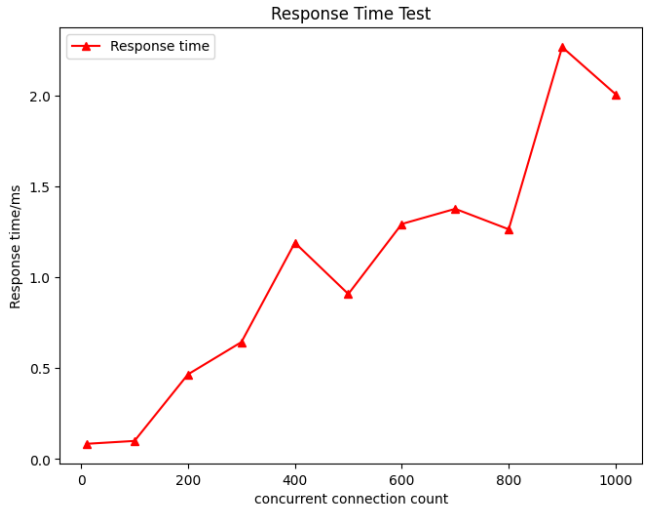
metrics	explain
Response time	the response time from sending a request to receiving it
Concurrent users	the number of users accessing the website at the same time
Throughput	the number of requests processed in a given period of time
Error rate	the percentage of requests that fail
Resource Utilisation	CPU and memory utilisation











Test Conclusion

Large number of concurrent connections (<1000)
Response time **<3ms**
Throughput **>20000**
CPU overhead between **50~60%**

Remote webpage are capable of meeting system monitoring requirements.

04 System operational test

Onsite test

LPMT Onsite Test (09/2023) (ONSITE)

- **Devices:** 1768 GCUs
- **Process:**

IOC application, data archiving (0.05Hz), alarm service

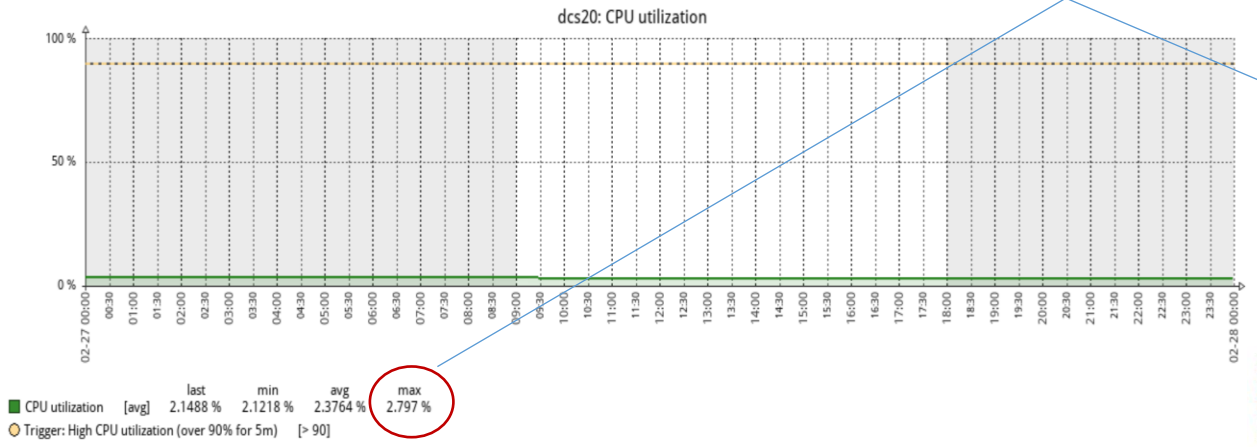
- **Result:**

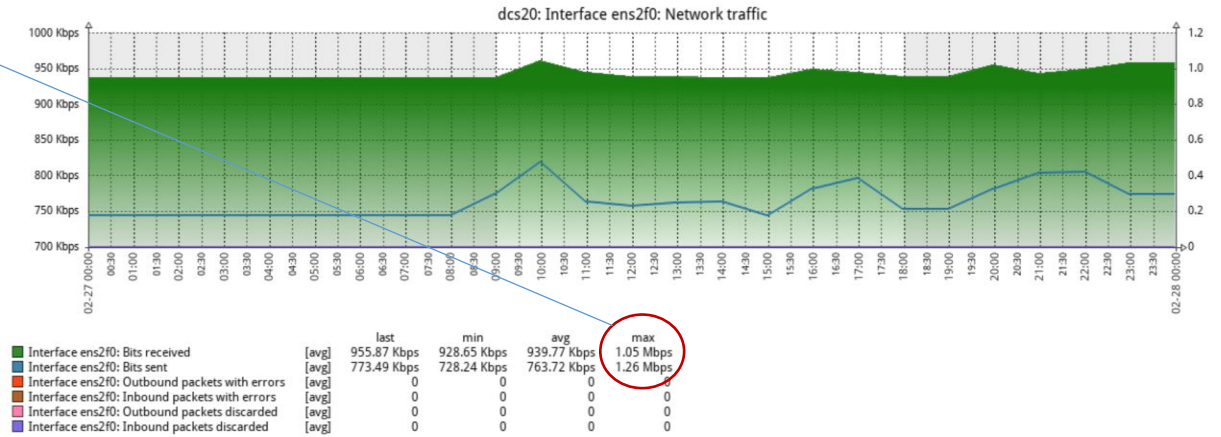
The system is running stably, and data archiving and monitoring have been completed.

Date	Round	BEC_Number	GCU_Number	GCU_PV
2023/9/4	1	10	155	gcuTemperature
	2	8	342	hvMesValue
	3	10	446	hvTemperature
	4	15	449	hvTripStatus
	5	12	376	.....

During the test:

- CPU Utilization（max）: ~2.8%
- Network traffic:
- Sent(max):1.05Mbps
- Received(max):1.26Mbps





04 System operational test

On-call

Remote on-call

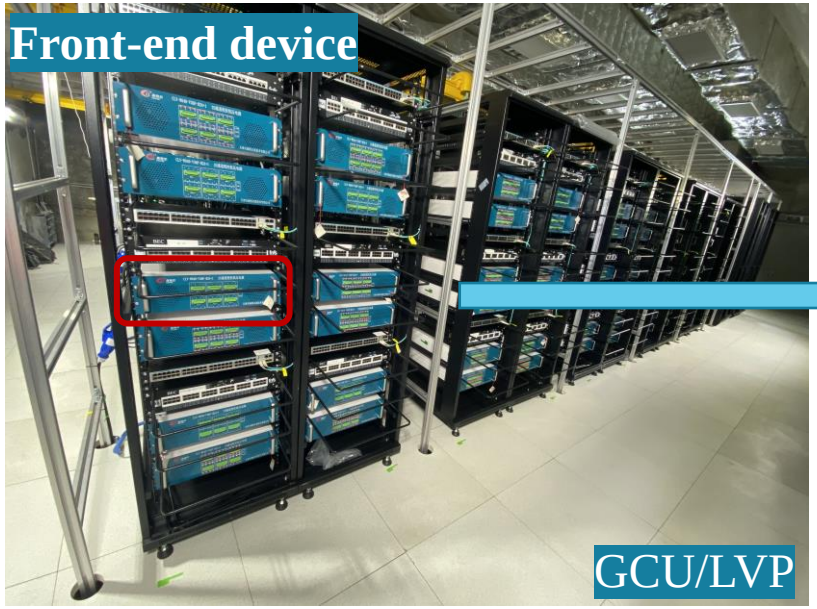
- **Tasks:**
  - The device runs without load, monitoring the system and device operating status
- **length of time：** 1 month
- **Implementation:**
  - Data archiving and monitoring alarms

发生故障：Unavailable by ICMP ping

发件人： 657993055@qq.com

收件人： 657993055@qq.com "刘生辉"<liushh@ihep.ac.cn>

PROBLEM Status Report	
告警主机	PLC-Elec01
告警别名	PLC-Elec01
告警地址	10.3.198.246
告警时间	2023.09.25 07:22:35
告警等级	High
告警信息	Unavailable by ICMP ping
告警项目	icmpping
问题详情	ICMP ping: Down (0)
当前状态	PROBLEM: Down (0)
事件ID	4604



Temperature, Voltage, Current and other parameters…

LVP数据告警['JM01:LVP063']

发件人：DCS告警 <[redacted]m>
时　间：2024年2月8日（星期四）上午6：46
收件人：DCS告警 <[redacted]>

邮件可翻译为中文 立即翻译

LVP数据告警['JM01:LVP063']

报警时间：2024.02.08-06:46:45
设备编号：['JM01:LVP063']
设备位置：JUNO_Elec01_LVP212a
通道状态：温度异常
通道值：{'DevTemperature': 84.75}
响应操作：关闭整台电源

响应结果：[1]

LVP数据恢复['JM01:LVP063']

发件人：DCS告警 <[redacted]m>
时　间：2024年2月8日（星期四）上午6：47
收件人：DCS告警 <[redacted]>

邮件可翻译为中文 立即翻译

LVP数据恢复['JM01:LVP063']

恢复时间：2024.02.08-06:47:16
设备编号：['JM01:LVP063']
设备位置：JUNO_Elec01_LVP212a
通道状态：温度恢复
通道值：{'DevTemperature': 20.75}

响应操作：值班人员请检查!

The alarm system is running stably and is being gradually upgraded and optimized.

05 Summary and Plan

☐ Summary:

The detector control system based on EPICS for JUNO has been implemented.

✓ **Readout**

- Communication between the server and front-end hardware devices has been achieved through EPICS

✓ **Archiving**

- Designed a distributed database cluster and database table architecture, and completed data archiving.

✓ **Monitoring**

- Developed a web monitoring page based on the MVC framework.

✓ **Alarm**

- Implemented subscription to abnormal information using ZABBIX and Kafka

☐ Plan:

- Integrated monitoring and control through web pages, and optimized system configuration and alarm services.
- By integrating machine learning and other technologies, upgraded the automation of the O&M system to reduce on-call tasks.

Thank you!

Status of the Detector Control System for the JUNO experiment