The Control system of CEPC

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On behalf of Control Group, Accelerator Center, IHEP

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Outline

- Performance and Scope of the CEPC control system
- Requirement information of controlled devices
- Control system and sub-system
- Summary

Performance of the Control System

- 5bility+RT
  - ➢Stability
  - ➢Availability
  - ➢Flexibility
  - ➢Scalability
  - ➢Reliability
  - ➢Real Time

Scope of the Control System

- Control Platform
- Central Control System
- Network System
- Timing System
- Post Mortem Analysis System
- Machine Protection System
- Power Supply Control System
- Vacuum Control System
- Temperature Monitoring System
- Integration of other system: RF, Cryogenic system, Injection/Extraction system etc.
- Others

Requirement information of controlled devices

CEPC-TDR控制需求信息调查表2018.xlsx
CEPC-TDR控制需求信息调查表2018vacuum-真空.xlsx
CEPC-TDR控制需求信息调查表2018-低温 (2).xlsx
CEPC-TDR控制需求信息调查表2018-低温.xlsx
CEPC-TDR控制需求信息调查表2018-准直-王小龙.xlsx
CEPC电源与控制接口信息-20190220

CECP 直线和环高频与定时

2019.6.18

参加人员：周祖圣，马新鹏，何大勇，翟纪
徐广磊，刘智，李刚
记录：刘智

CEPC 直线提出需要定时触发信号数量统
直线：电子枪 2 路，调制器 78 路，正电子
阻尼环 Damping Ring：调制器 2 路，常温
CEPC 环高频提出需要定时触发信号数量
增强器：96 路 （ttbar+256 升级）
主环：120 路（ttbar+8 升级）
直线和环高频对定时信号的指标要求参考
增强器和主环的谐波数：需要确认。
环高频提供设备的物理布局图。
直线和环高频的本地控制基于 EPICS 自成体系，控制组提供数据库
和网络服务及本地到中控室的集成。

制需求信息调查表2018.xlsx - Microsoft Excel

PLC 为核心控制器，串口服务器和边缘交换机

真空计数字量输入（16 通道）：2160/16=135，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对真空计：2160/96=23(22.5)<2*16，需要 2 个数字量输入模块

真空阀门数字量输出模块（16）：520/16=33(32.5)，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对应阀门：520/96=6(5.4)<1*16(一个数字量输出模块通道数)

真空阀门状态回采输入模块（520*2）：520*2/16=65，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对应阀门状态回采：520*2/96=11(10.8)<1*16(一个数字量输入模块通道数)

真空计 RS232 接口对应的串口服务器：2160/16=135，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对应的串口服务器：2160/96=23(22.5)<2*16

离子泵电源 RS232 接口对应的串口服务器：8400/16=525，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对应的串口服务器：8400/96=88(87.5)<6*16

串口服务器对应需要的网络交换机（48 口的边缘交换机）：135+525=660/48=14(13.5)，此数据不可用，由于有 96 个辅助隧道，按均数，每个辅助隧道对应的边缘交换机：2+6=8<1*48

标准机柜计算，

增强器每个辅助隧道 PLC 需要 1 个标准机柜：真空计输入模块 2+真空阀门状态回采输入模块 1+真空阀门输出模块 1+通讯模块或 CPU 模块，就近几个子站组成一个系统。

每个辅助隧道串口服务器需要 3 个标准机柜：1 真空计串口服务器 2<1*4，2 离子泵电源串口服务器 6<2*4，合计 1+2=3 标准机柜

每个辅助隧道需要边缘交换机 1 个标准机柜

温度测量系统（暂以 PLC 为核心控制器），每个辅助隧道负责 34000/96=355(354.17)个测量点，按 100 点一个 PLC 子站，需要 4 个 PLC 子站即 PLC 机柜 4 个（2 个标准机柜），合计机柜 4*2=8 机柜

增强器真空控制系统和温度测量系统所需机柜：（1+3+1+8）*96=1248

Control Platform: Software

- The Choice of Control Platform
  - CERN: PVSSII/FESA (Process Visualization and Steuerung (Control) System)
  - Most of European Accelerator facilities: TANGO
  - Most of American/Asian and parts of European Accelerator facilities : ***EPICS***

Really Neat Things About EPICS

- 1. It is **free**
- 2. It is **open source**
- 3. There are **lots of users**
- 4. All a client needs to know to access data is a PV name
- 5. You can pick the best tools out
- 6. ... or build your own
- 7. The boring stuff **is already done**
- 8. There is a lot of expertise available close
- 9. A good contribution becomes **internationally** known
- 10. It doesn't matter whether you need **10 PVs or 10 Million** PVs
- Etc

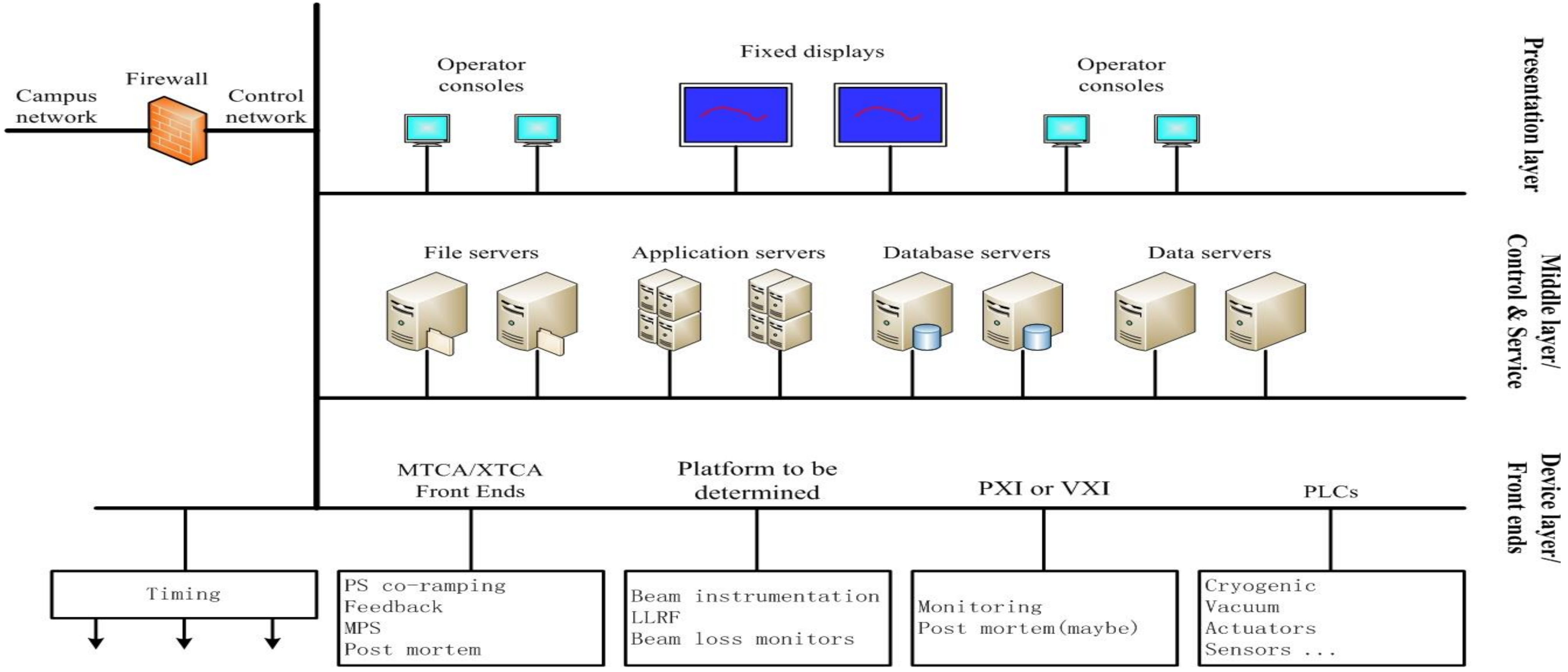
Control Platform: Software

- EPICS (Experimental Physics and Industrial Control System)
  - Open Source software toolkit
  - To create distributed soft real-time control systems
    - Particle accelerators
    - Telescopes
    - Large scientific experiments
  - Version:
    - V3.13->V3.14-->V3.15->V3.16-->V4->V7….
    - BEPCII:V3.13
    - CSNS:V3.14
    - HEPS:V3.15/V7
    - CEPC:Vxnn(X>=7)

Control Platform: Hardware

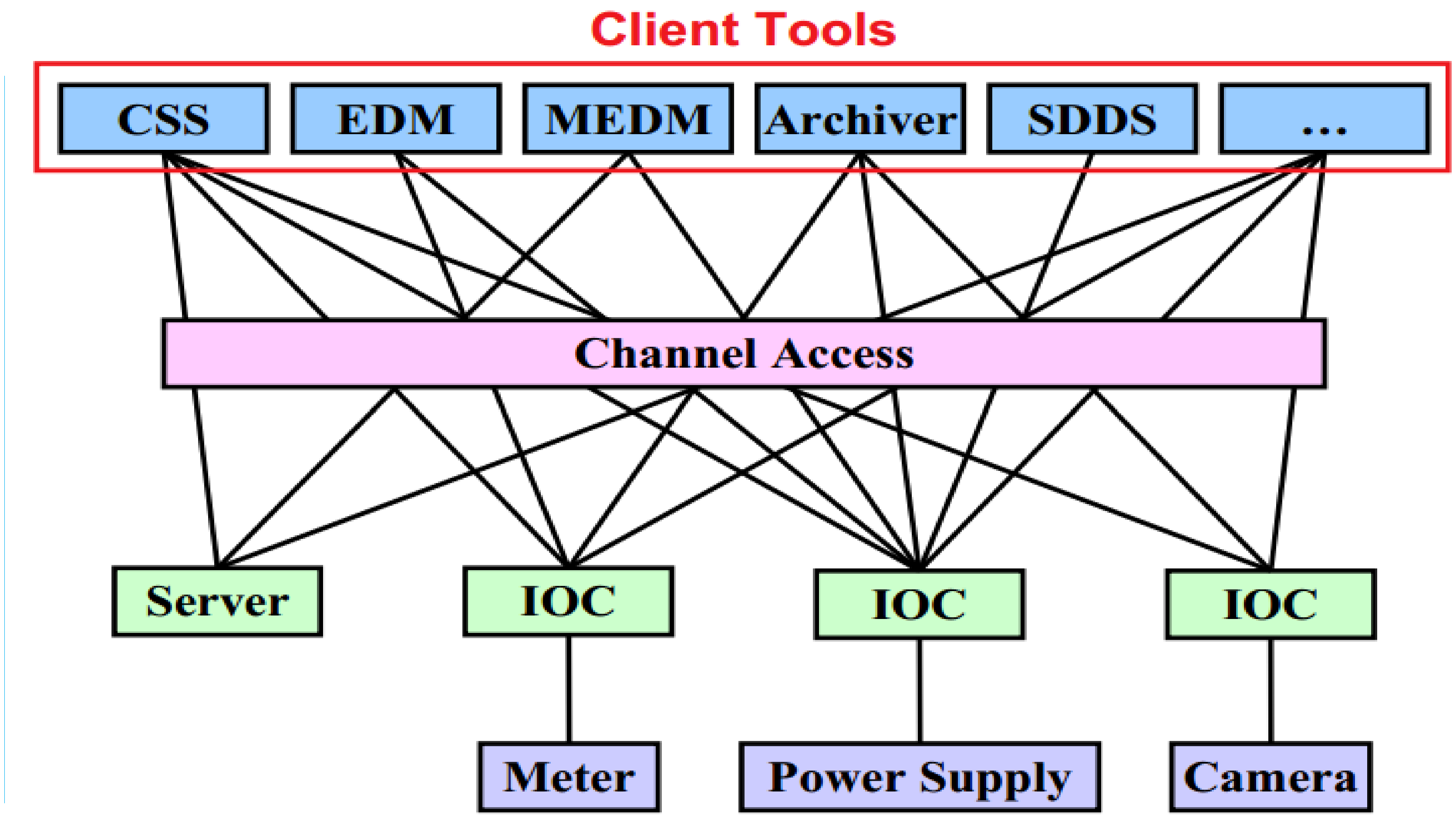
- Standardization, Modularity and Commercial products
  - PLC
  - ATCA/uTCA
  - Serial device servers
  - Blade servers
  - Motion controller/Driver
  - etc.

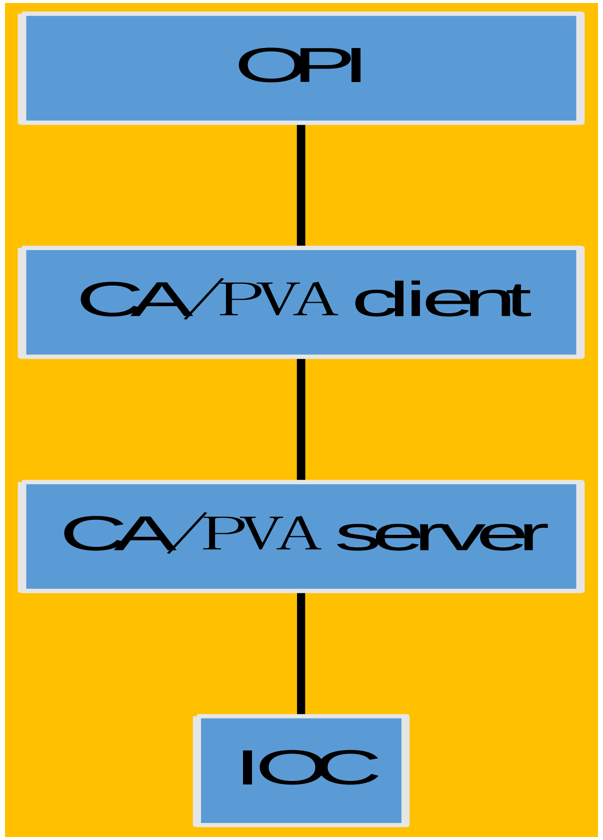
Control System and sub-system



Overall hardware architecture of the control system

Control System and sub-system



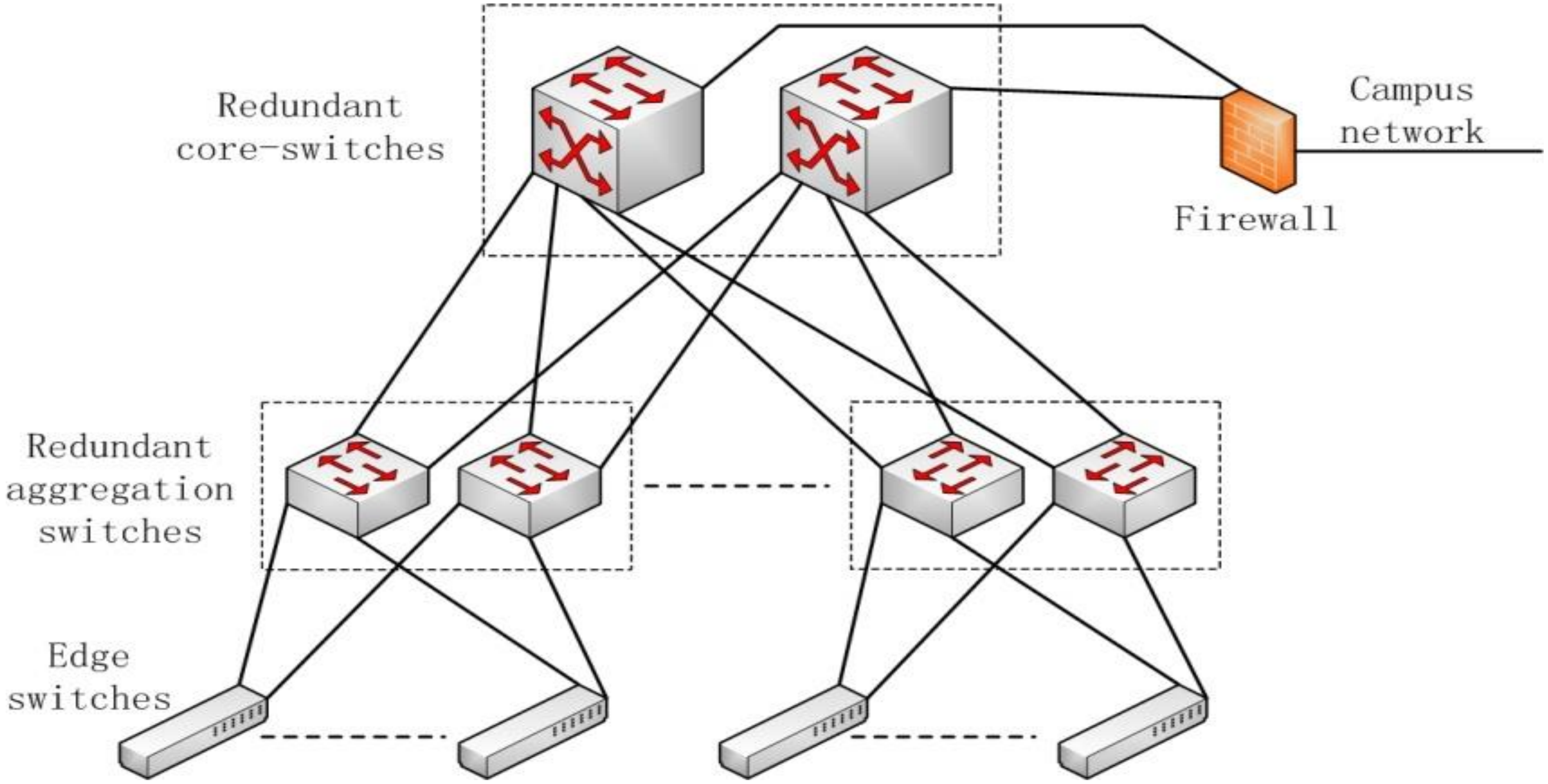


Softeware architecture of the control system

Control System and sub-system: CCS

- Central control system
  - Management and operation of IOCs/OPIs
  - Server and management of High level software
  - CA/PVA Gateway
  - CSS, caQtDM, PyDM etc
  - Data Archiver
  - Alarming system
  - Issue information of machine via instant message(weChat)
  - Machine status summary on Web
  - Elog
  - Issue tracking
  - Etc

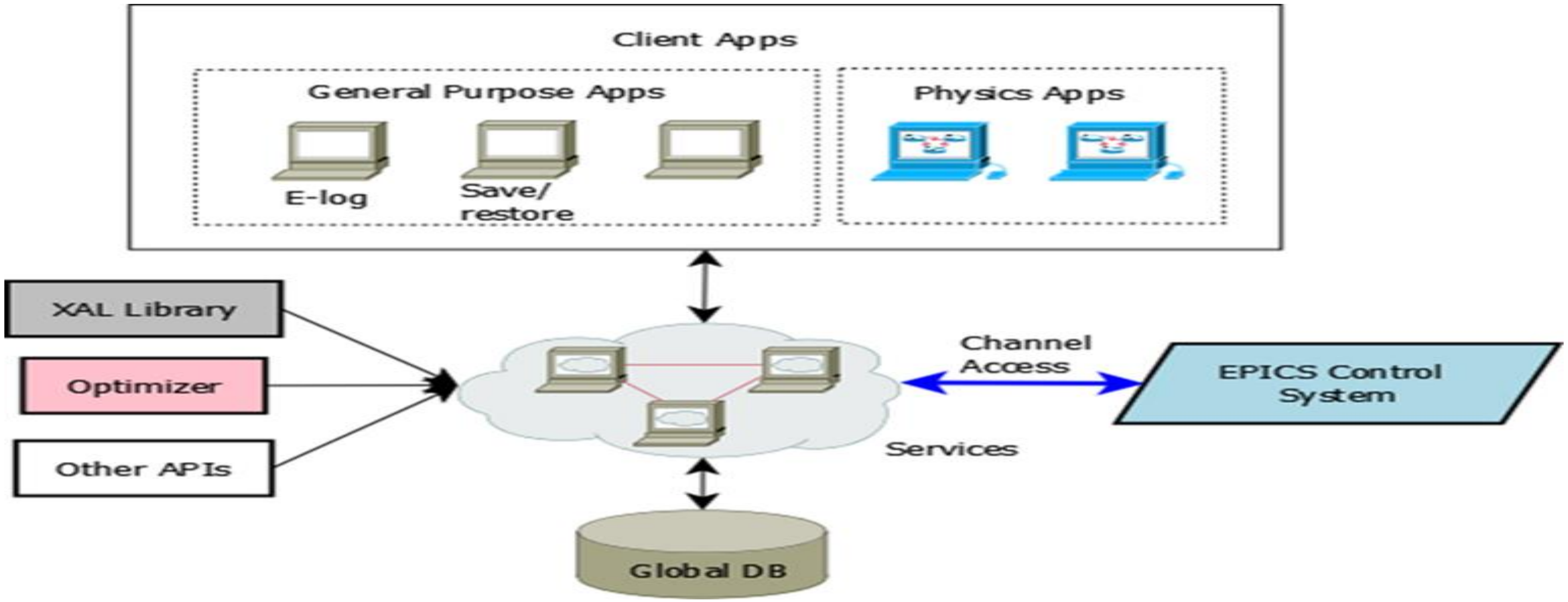
Control system and sub-system: Network



Control Network System: three layers

Control System and sub-system: Database

- Any important data throughout the entire life cycle of an accelerator should be captured systematically and stored persistently



Database software Architecture

Control System and sub-system: Database

- *Prototypes of database based on the current requirement*

① *Parameter Database*
  - Keep track of all important physics and equipment parameters consistently for an accelerator during the busy design period

② *Naming Convention Database*
  - For a large accelerator project, everything has to be named according to strict rules

③ *Magnet Database*
  - Capture and store all essential data, including a few particular magnet measurement methods

④ *Equipment Database*
  - Store all equipment including spared parts

⑤ *Lattice and Model Database*
  - Keep design lattices and their corresponding model calculation data

Control system and sub-system: PS

位 置	电源数量	安装位置	精度	接口类型
Collider	8160			
Dipole双	8	均匀		
Dipole单	162	均匀分		
Quadrupole双	192	均匀分		
Quadrupole单	920	均匀分		
	80	均匀分		
	22	均匀分		
Sextupole	896	均匀分		
	72	均匀分		
Corrector	2904	均匀分		
	2904	均匀分		

位 置	电源数量	安装位置	精度	接口类型
Booster	430			
Dipole	16	均匀分布在地上		
Quadrupole	32	均匀分布在地上		
Sextupole	32	均匀分布在地上		
Corrector	350	均匀分布在地下9		

位 置	电源数量	安装位置
Transport Line	238	
Dipole	60	均匀分布在输
	4	均匀分布在输
Quadrupole	120	均匀分布在输
Corrector	54	均匀分布在输

位 置	电源数量	安装位置	精度	接口类型
Transport Line	238			
Dipole	60	均匀分布在输运线电源厅	500ppm	以太网
	4	均匀分布在输运线电源厅	500ppm	以太网
Quadrupole	120	均匀分布在输运线电源厅	500ppm	以太网
Corrector	54	均匀分布在输运线电源厅	500ppm	以太网

位 置	电源数量	安装位置	精度	接口类型
Damping Ring	105			
Dipole	32	均匀分布在直线电源厅	500ppm	以太网
	6	均匀分布在直线电源厅	500ppm	以太网
Quadrupole	52	均匀分布在直线电源厅	500ppm	以太网
	13	均匀分布在直线电源厅	500ppm	以太网
Sextupole	2	均匀分布在直线电源厅	500ppm	以太网

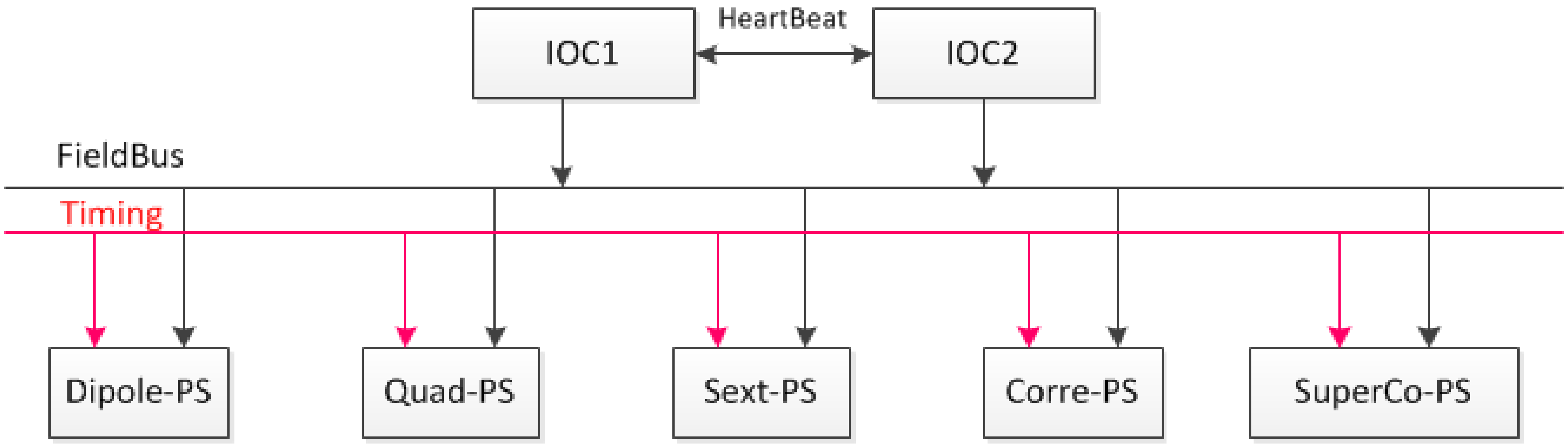
位 置	电源数量	安装位置	精度	接口类型
Linac	325			
Dipole	11	均匀		
Quadrupole	177	均匀		
Solenoids	22	均匀		
	5	均匀分布在直线电源厅	500ppm	以太网
Corrector	110	均匀分布在直线电源厅	500ppm	以太网

位 置	电源数量	安装位置	精度	接口类型
Collider	36			
超导四极磁铁	8	均匀分		
超导反校正线圈	4	均匀分布在地下对撞区电源厅	20ppm	以太网
超导反校正线圈	8	均匀分布在地下对撞区电源厅	50ppm	以太网
	16	均匀分布在地下对撞区电源厅	50ppm	以太网

Control system and sub-system: PS

- Accelerate from 10/20GeV to 120GeV.
- Magnets' power supply co-ramping within an accuracy of tens of μs.
- Two methods of PS ramping
  - Waveform can be pre-downloaded into the front end controller, then co-ramping starts with an synchronized signal.
  - Waveform can be written into the front end controller in real time with an deterministic latency.
- High reliability and high availability (Redundancy).

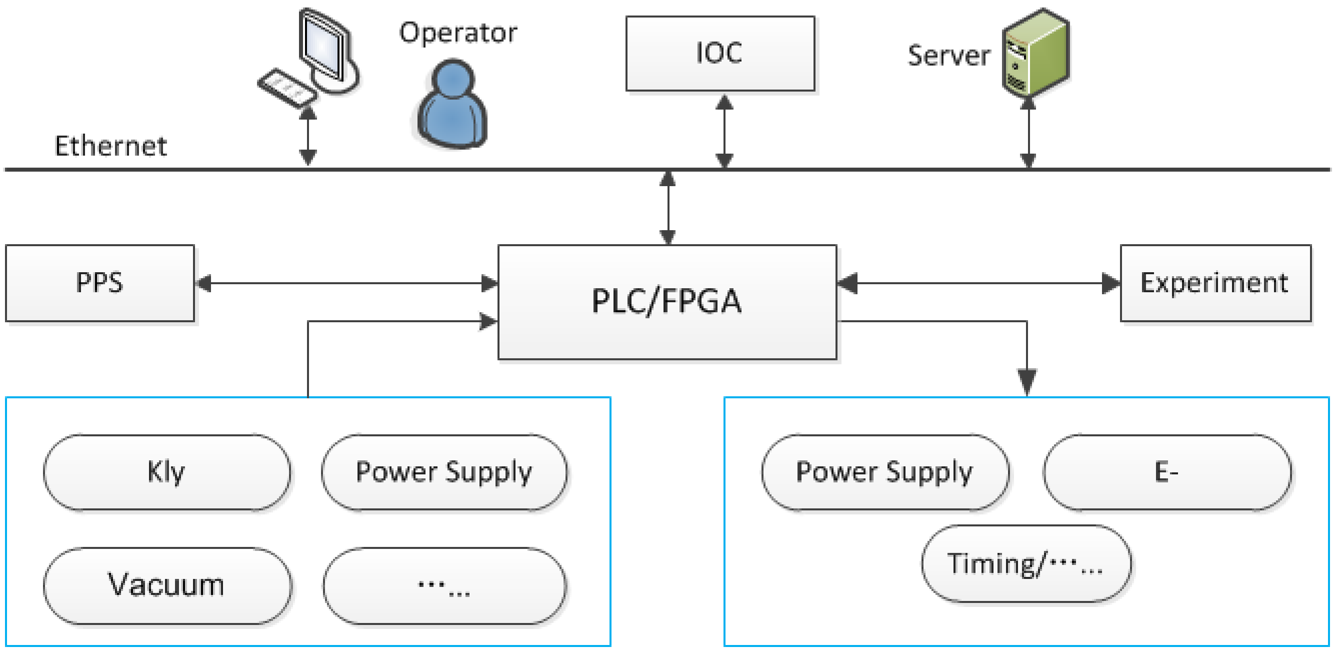
Control system and sub-system: PS



Redundant IOCs for power-supply controls

Control system and sub-system: MPS

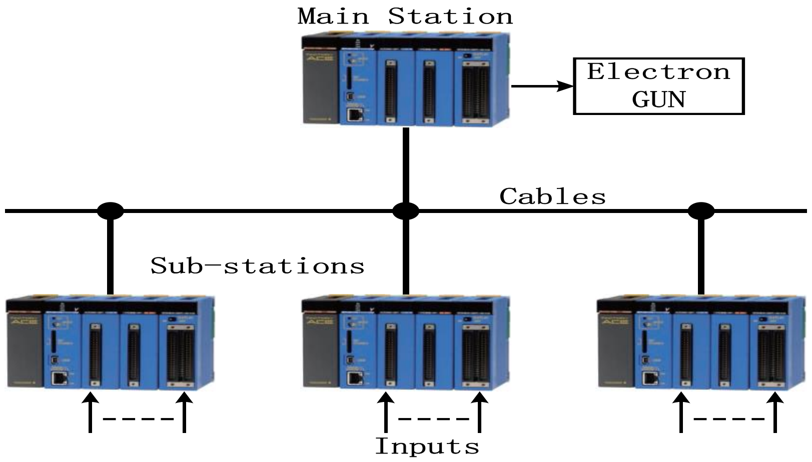
- Tightly related to the accelerator design
- Stop beam or steer beam to dump, when key device or sub-system is a fault or abnormal
- Generally, the structure of MPS=EPS (PLC)+FPS (FPGA)



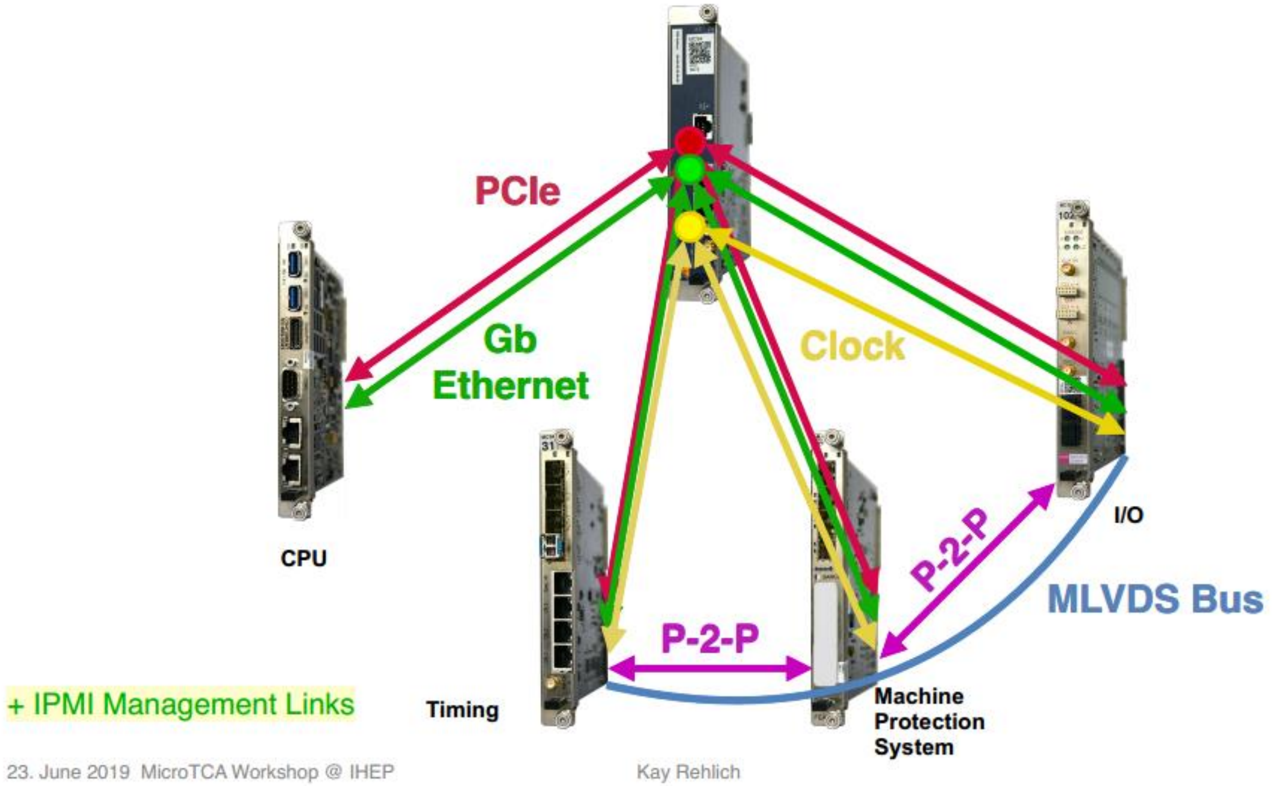
The MPS Architecture of CEPC

Control system and sub-system: MPS

- PLC for slow inputs, a response time of tens of ms is defined.
  - The actuators are RF power ramp down and shutdown of electron gun.
  - Preliminary name : Equipment Protection System (EPS).
- FPGA for fast inputs, a response time of tens of micro seconds is defined.
  - The actuators are RF power off and shu
  - Preliminary name : Fast Protection Sys
- Individual systems for loose couplin



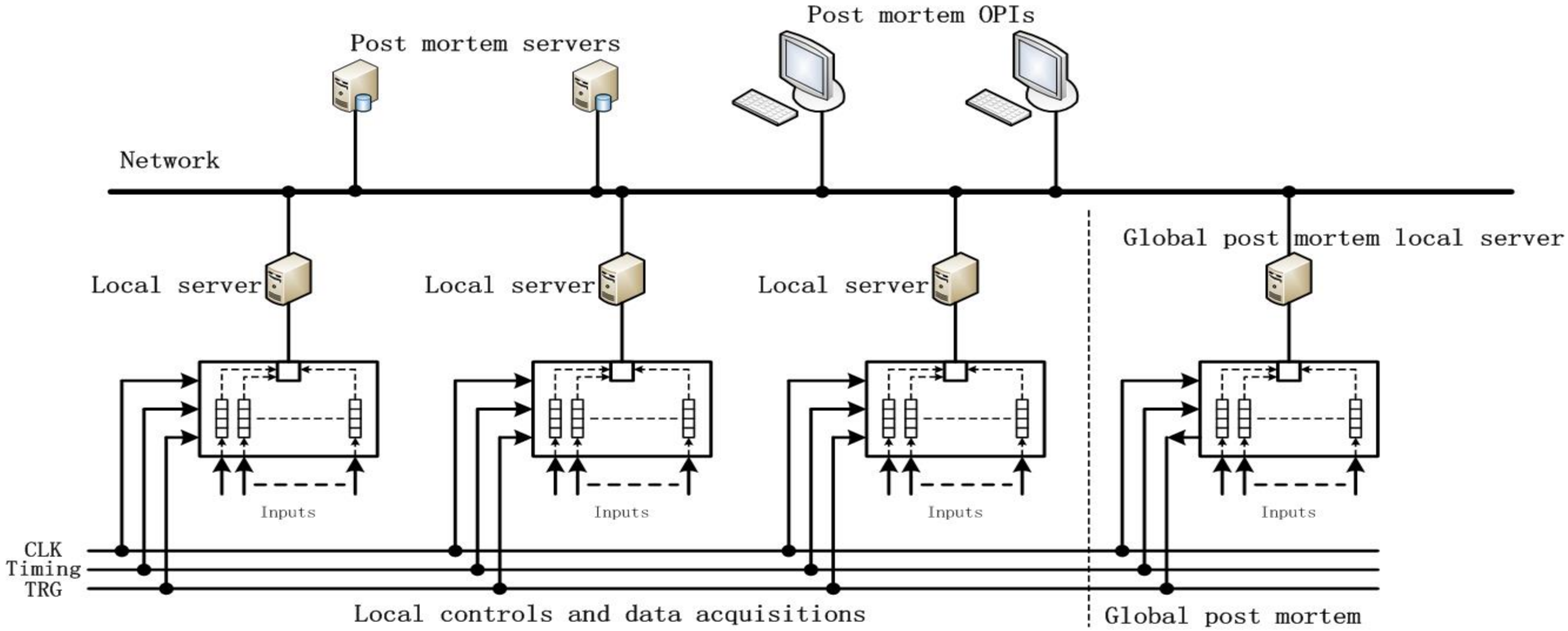
EPS based on PLC



Control system and sub-system: Post Mortem Analysis

- For fast and accurate fault diagnostics.
- Both hardware and software works.
- Tightly related to the devices’ controls.
- Accurate timestamp needed.
- Global trigger, global clocks, global timing, analysis software …

Control system and sub-system: PMA



Preliminary design of post mortem analysis

Control system and sub-system: Vacuum CS

A	B	C	D	E	F	G	H
系统名称	被控设备	与控制接口设备/传感器	指标需求	区域（位置：直线、阻尼环、输运纟	数量	连接电缆芯数	接口类型
真空系统	真空计	真空控制器	测量极限:10^{-11}mbar	直线/阻尼环/输运线	620	2(铜线)	RS485，继电器接点
				增强器	2160	2(铜线)	RS485，继电器接点
				对撞机	4320	2(铜线)	RS485，继电器接点
	真空阀门	阀门控制器	全金属气动阀门PLC	直线/阻尼环/输运线	38	6(铜线)	24V开关量
				增强器	520	6(铜线)	24V开关量
				对撞机	1040	6(铜线)	24V开关量
	真空盒、波纹管、光子吸收器	Pt温度传感器(三线制/四	0.5度	直线/阻尼环/输运线	500	2(铜线)	
				增强器	34000	2(铜线)	
				对撞机	68000	2(铜线)	
	离子泵	离子泵电源	5kV	直线/阻尼环/输运线	1430	2(铜线)	RS485
				增强器	8400	2(铜线)	RS485
				对撞机	22300	2(铜线)	RS485

Vacuum Gauge：7000

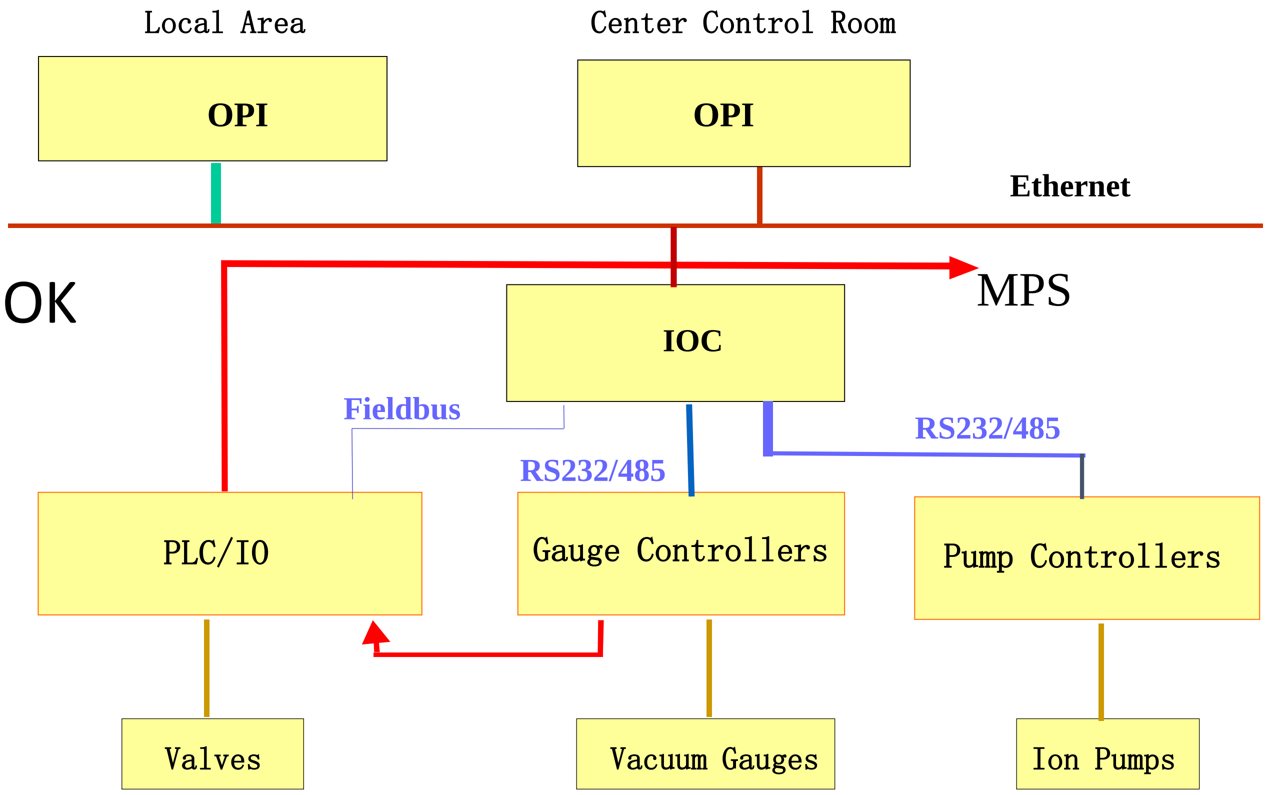
Valve：1598

Ion pump：32130

Temperature sensor：102500

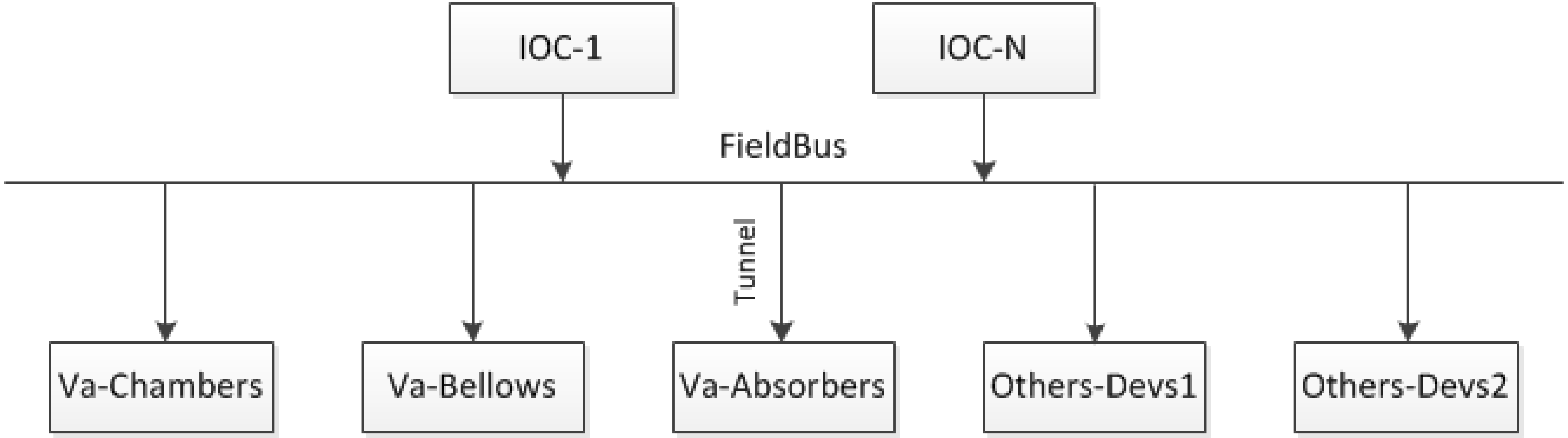
Control system and sub-system: Vacuum CS

- Monitor
- Interlock policy
  - Voting scheme： Close Valve
  - Closed state of NO Contact： OK



Control system and sub-system: TM

- TM: Temperature Monitoring
- Quantity: 100,000+(Vacuum devices)
- Others: … …



Control system and sub-system: Timing

系统区分	定时信号需求数量	性能要求	备注
束测（TTL信号）	10664路	抖动<50ps	BPM、profile、DCCT、工作点测量、BCM、束流损失
束测（RF信号）	5030路	抖动<0.5ps, <1ps, <5ps	BPM、profile、DCCT、工作点测量、BCM、束流损失
电源	860路	抖动<5ns	Booster 、Dipole、Quadrupole、Sextupole、Corrector等磁铁电源
直线加速器 阻尼环 输运线	404路	抖动<50ps或者20ps	回旋频率、注入频率、触发信号
直线和环高频	301路	抖动<20ps	增强器和主环的谐波数有待确认

Control system and sub-system: Timing

- An maximum distance of about 50 km (about half ring).
- Latency change due to temperature variations(compensation)
- An accuracy of tens of ps
- Precise timestamp will be provided.

Control system and sub-system: Timing

Event timing system

- Swiss Light Source (SLS)，1999年， Specially designed for the accelerator
- Commercial products, widely used in many accelerators, such as BEPCII, CSNS and so on

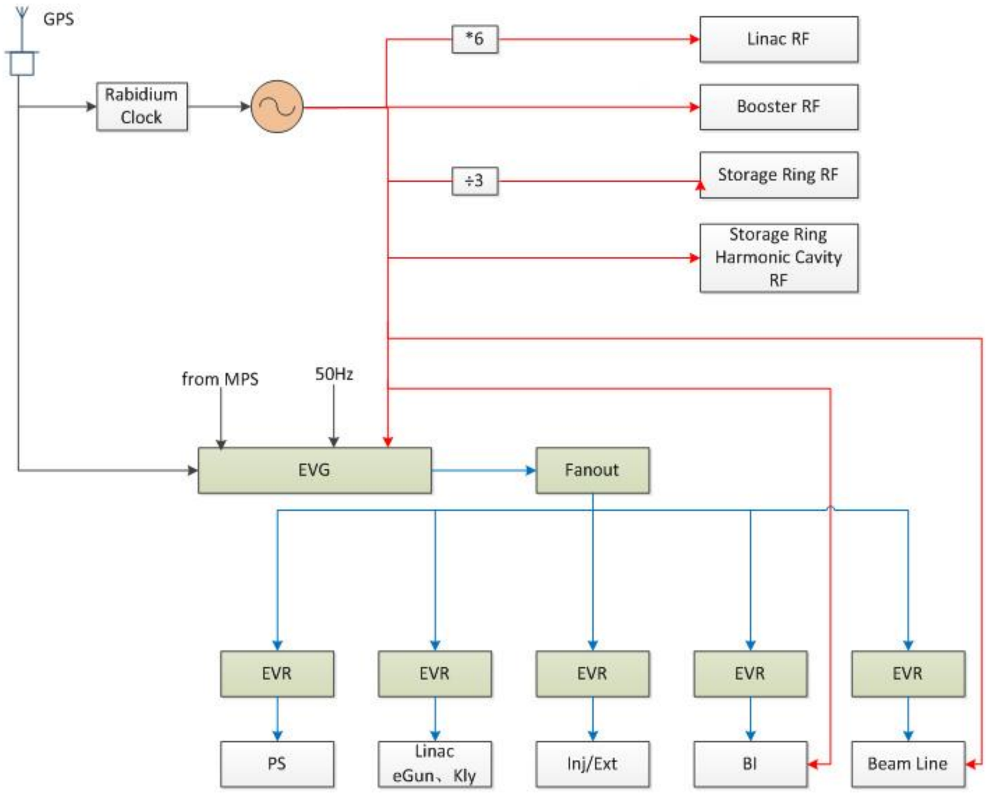
- The MRF Timing system originally developed for the Swiss Light Source (SLS), Paul-Scherrer Institut in 1999
- First commercially available timing system for particle accelerators
- Current users include
  - SLS, PSI
  - Diamond Light Source Ltd., U.K.
  - SSRF, Shanghai, China
  - Australian Synchrotron
  - ALBA, Spain (Tango)
  - Elettra, Trieste, Italy (Tango)
  - BEPCII, Insitute for High Energy Physics, Beijing, China
  - LCLS, Stanford Linear Accelerator Center, USA
  - KEK, Japan
  - FERMI, Trieste, Italy (Tango)
  - TLS, Taiwan
  - NSLS II, Brookhaven, USA
  - PAL-XFEL, Pohang, South Korea
  - LANSCE upgrade, Los Alamos, USA
  - FRIB, Michigan, USA
  - MAX IV, Sweden
  - SwissFEL, PSI
  - STFC, Daresbury
  - ESS, Sweden
- Most of the sites listed above are using EPICS

EPICS

Control system and sub-system: Timing

The basic structure of Timing System

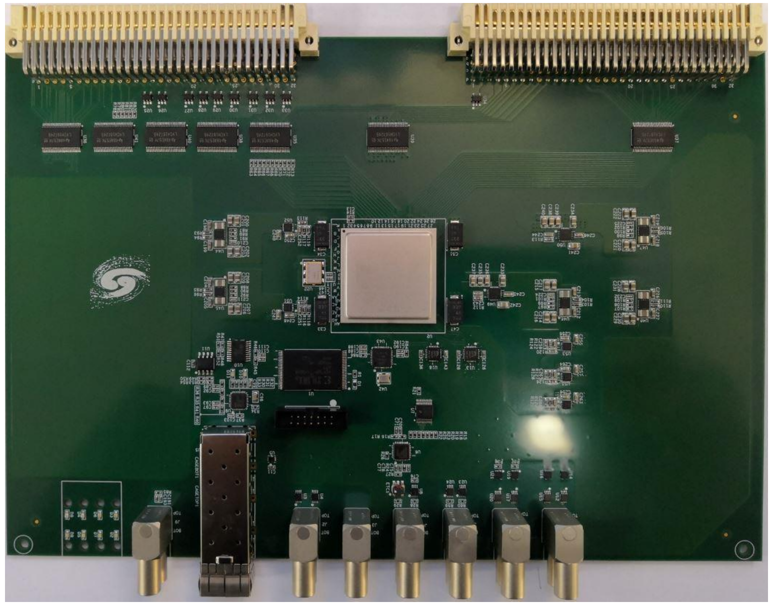
- Event timing system and RF transmission system
- Event timing system: Trigger signal and Low frequency clock signal
- RF transmission system: Transmit high stability RF signal

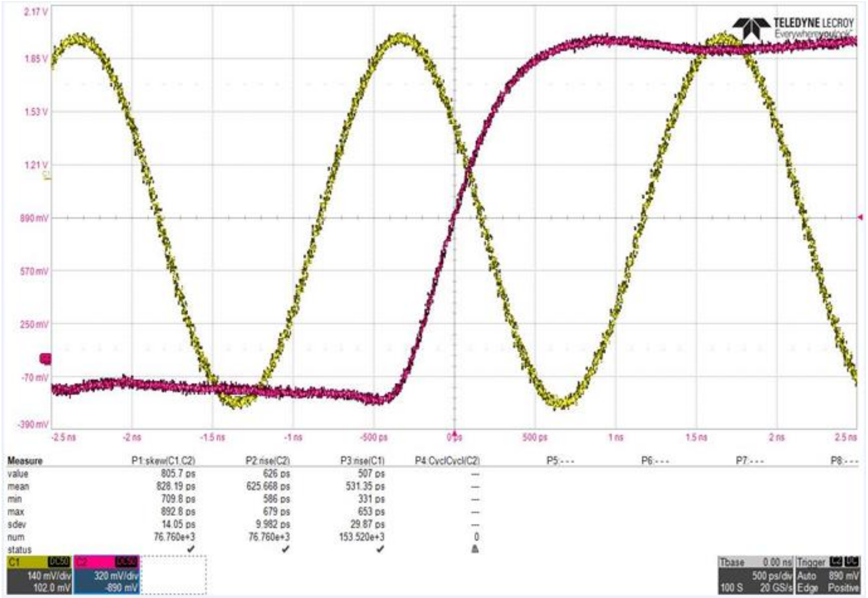


Red line: RF transmission system

Blue line: Event Timing System

Control system and sub-system: Timing





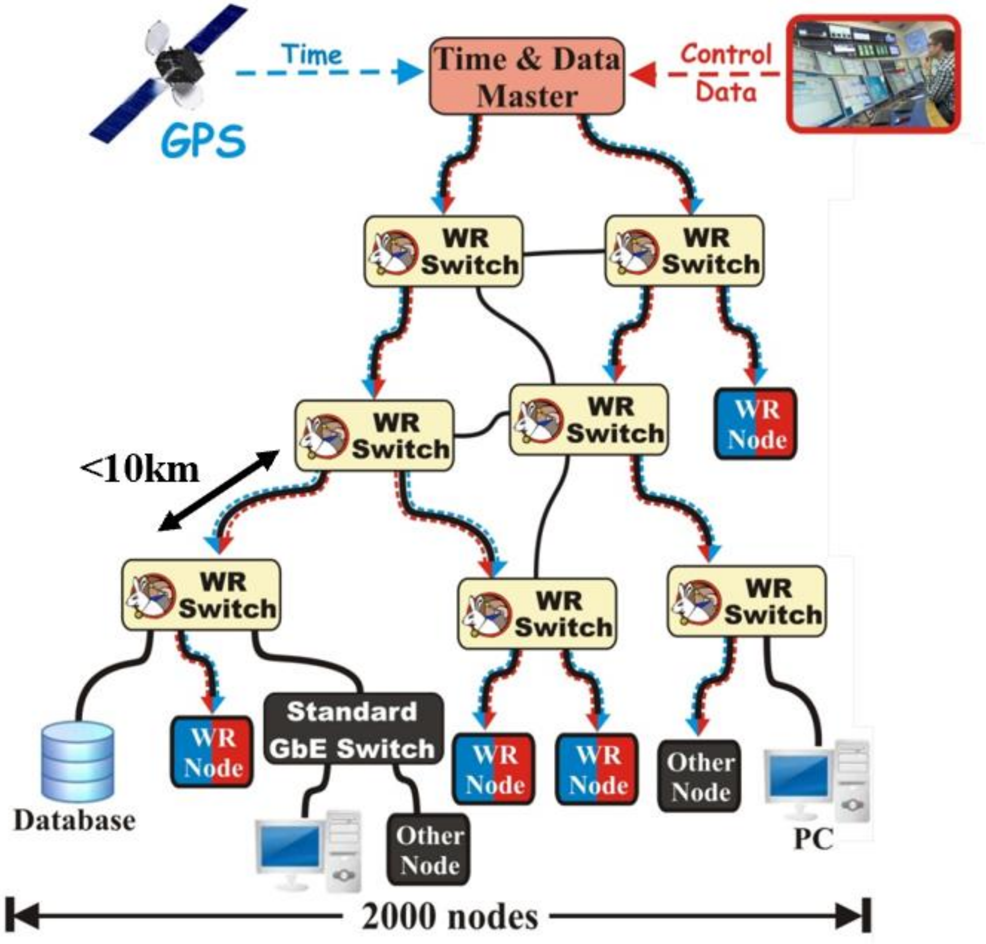
Fine Step: 5ps

Jitter<15ps

Control system and sub-system: Timing

Alternative Plan: WhiteRabbit

- CERN and GSI initiative for control & timing
- Based on well-established standards
  - Ethernet (IEEE 802.3)
  - Bridged Local Area Network (IEEE 802.1Q)
  - Precision Time Protocol (IEEE 1588)
- Extends standards to provide
  - Sub-ns synchronisation (included in IEEE 1588)
  - Deterministic data transfer
- Initial specs: links ≤10 km & ≤2000 nodes



Control system and sub-system: Timing

- EVG/EVR Timing System
  - Trigger
  - RF reference
  - Precise timestamping
- EVG/EVR：Broadcast
- Site：APS、SLS，BEPCII，CSNS，SSRF，etc
- Support
  - Commercial products
  - EVG/EVR of SSRF
  - Homemade I/O and delay board

V.S

- White Rabbit Timing System
  - Precise timestamping
  - Trigger
  - RF reference
- Master/Slave: Bi-directionality
- Site：CERN、GSI、ESRF、Spring-8、SHINE、LHAASO、German Stock Exchange，etc
- Support
  - OpenHareware+Commercial products

Routine control and design considerations

- Integration of other system control, such as RF, Cryogenic system, etc.
- Video monitoring.
- … …

To integrated into the control system, the following rules must be observed:

1. Consistent with version of EPICS
2. Interface to CA/PVA of EPICS
3. Reserve Hardware Interface
4. Agree with other standards of control system

Cooperation: Different Division of IHEP

Cooperate with other accelerator complex (CSNS, HEPS,BEPC..)

- Management and design of Database(HEPS)
- Issue information(CSNS)
- Etc

Cooperation: Database

- *Database based on the user's requirement*

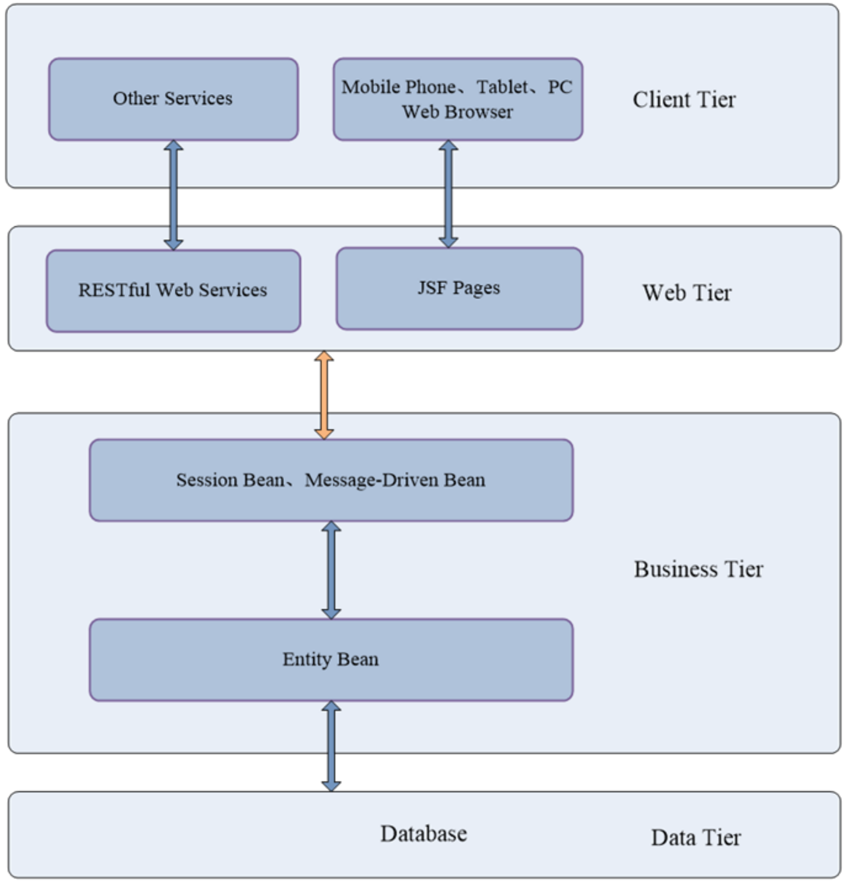
Parameter Database
Magnet Database
Lattice and Model Database
Log and trouble tracking
Management of Cable and device
Configuration of Security database
Etc..

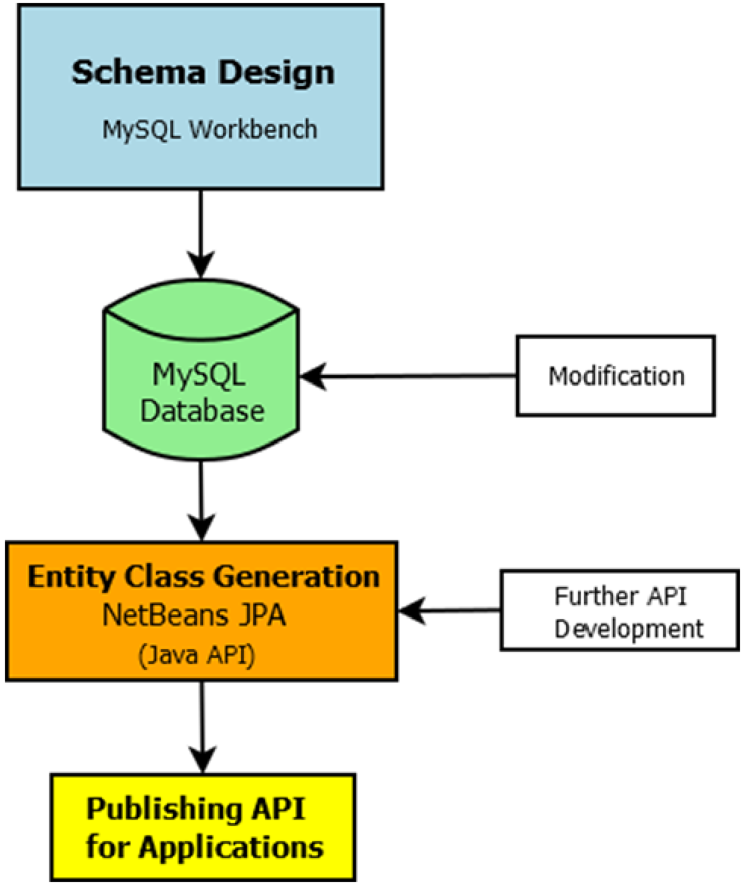
Naming Convention Database
Equipment Database
Management of File
Alignment Database
Alarm database
MPS and interlock database

More and more Database will be designed with the progress of the Project

Cooperation: Database

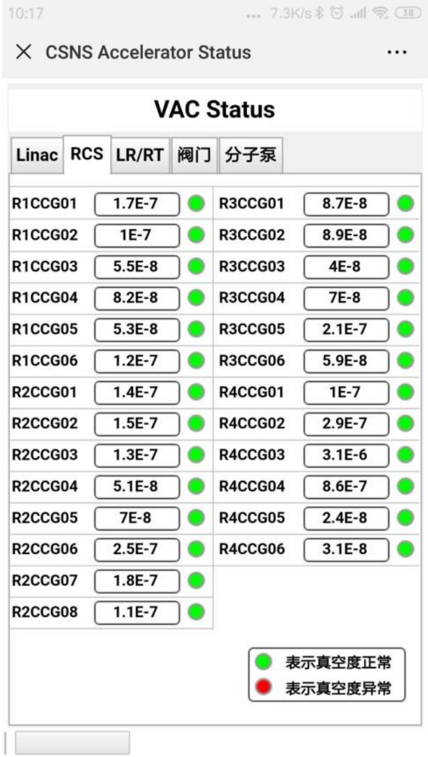
- *The structure of RDB database*

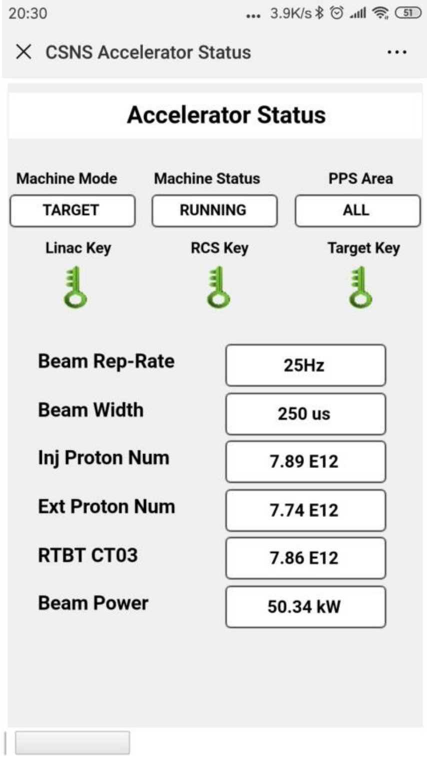


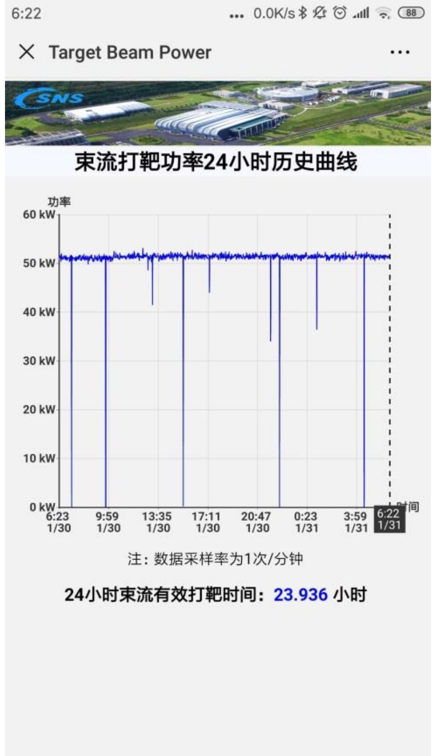


Cooperation: Issue information

- *Based on Wechat*







Cooperation: IHEP and Company

Cooperate with company (Cosylab, Geekoo,..)

- Mini workshop of CEPC control system

Control Cooperation Group

20200603

视频会议方式：ZOOM：731 236 4513

会议时间：12:30~14:00

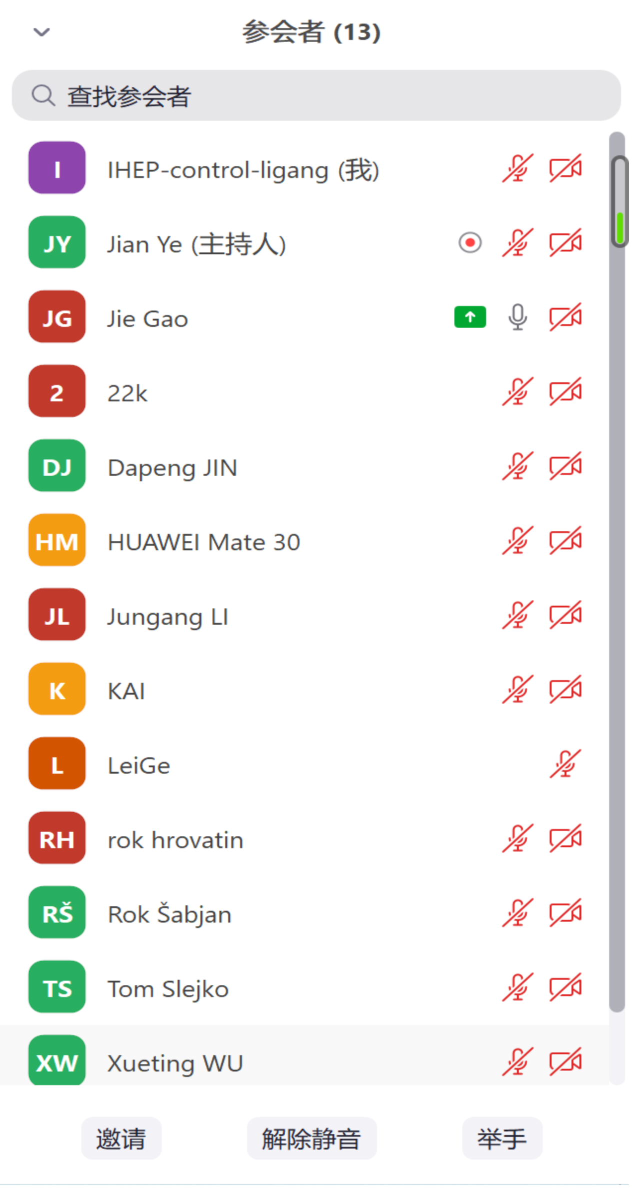
Convener: Prof. Jie Gao

1、the Status and Progress of CEPC   Prof. Jie Gao

2、CEPC-Large Experimental Facilities: Cosylab Experience   Rok Sabjan & Tom Slejko

3、基于 White Rabbit 同步技术的商业化产品介绍   Dr. Kai Zheng（更鼓电子）

4、Discussion



Summary

- More detailed requirements should be further clarified, with the progress of CEPC TDR

- EPICS：Cooperate closely with EPICS community and company

- New technique: IoT/AI/machine learning in control system

Thanks a lot!