Accelerator Controls

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The CERN Accelerator School

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Agenda

The CERN Accelerator School

1. Control System Requirements
2. Implementation Philosophy
3. A bit of History
4. Hardware & Software Architecture
5. Key Components & CERN examples

Why a Control System?

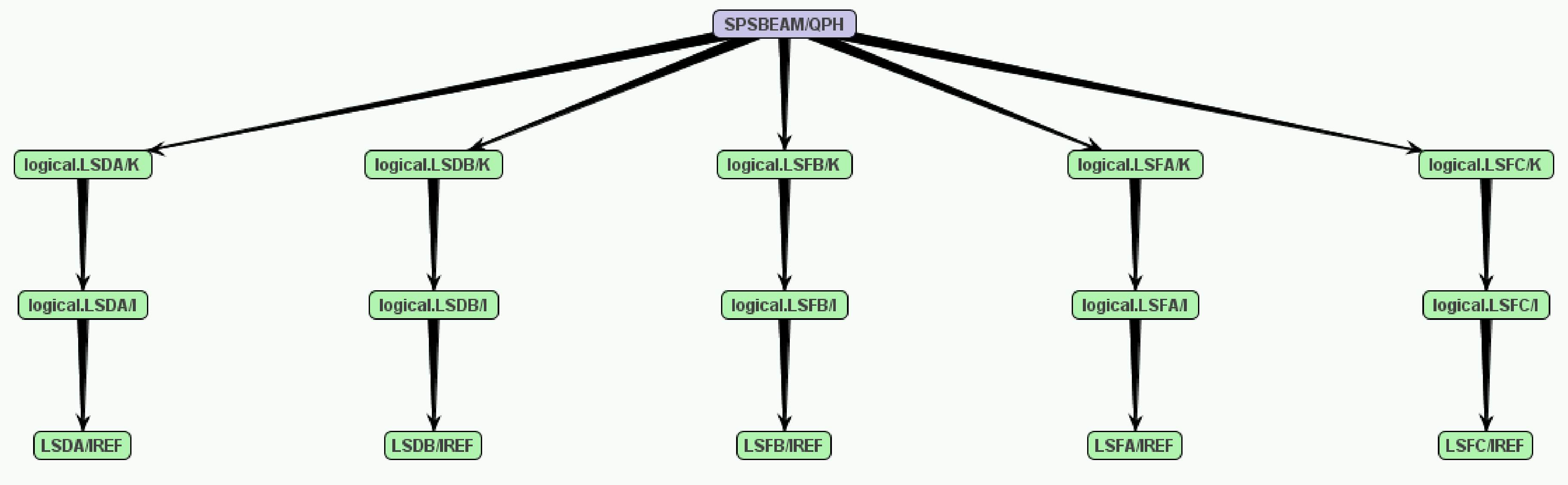
- Particle accelerators are made of many components to control and monitor the beams produced.
- The physicists and operators need to be able to remotely control and monitor these elements → this is the role of the **Control System**.
- The Control System's job is to provide to the physicists and operators a means to:
  - set reference values (aka setting) and states in active elements (e.g. power converters),
  - read instruments,
  - monitor the health of sub-systems,
  - diagnose faults,
  - etc.

Control System Requirements

Control System Key Requirements

Act on accelerator elements (settings & states)

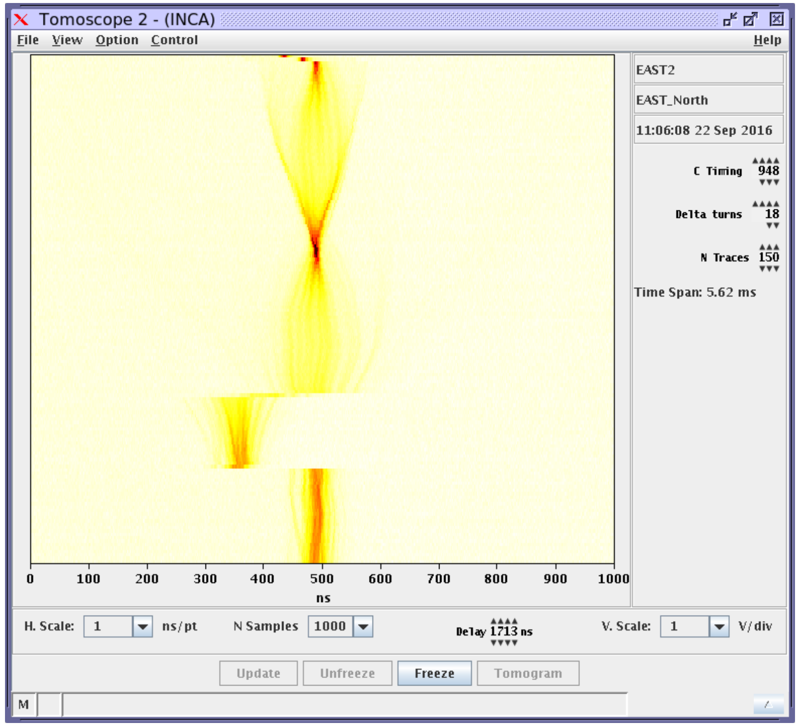
- Minimum: direct access to the hardware values
- Ideal:
  - Model-driven control to work at a higher level
  - Global transactional synchronisation



Control System Key Requirements

Monitor the elements (instruments & actuators)

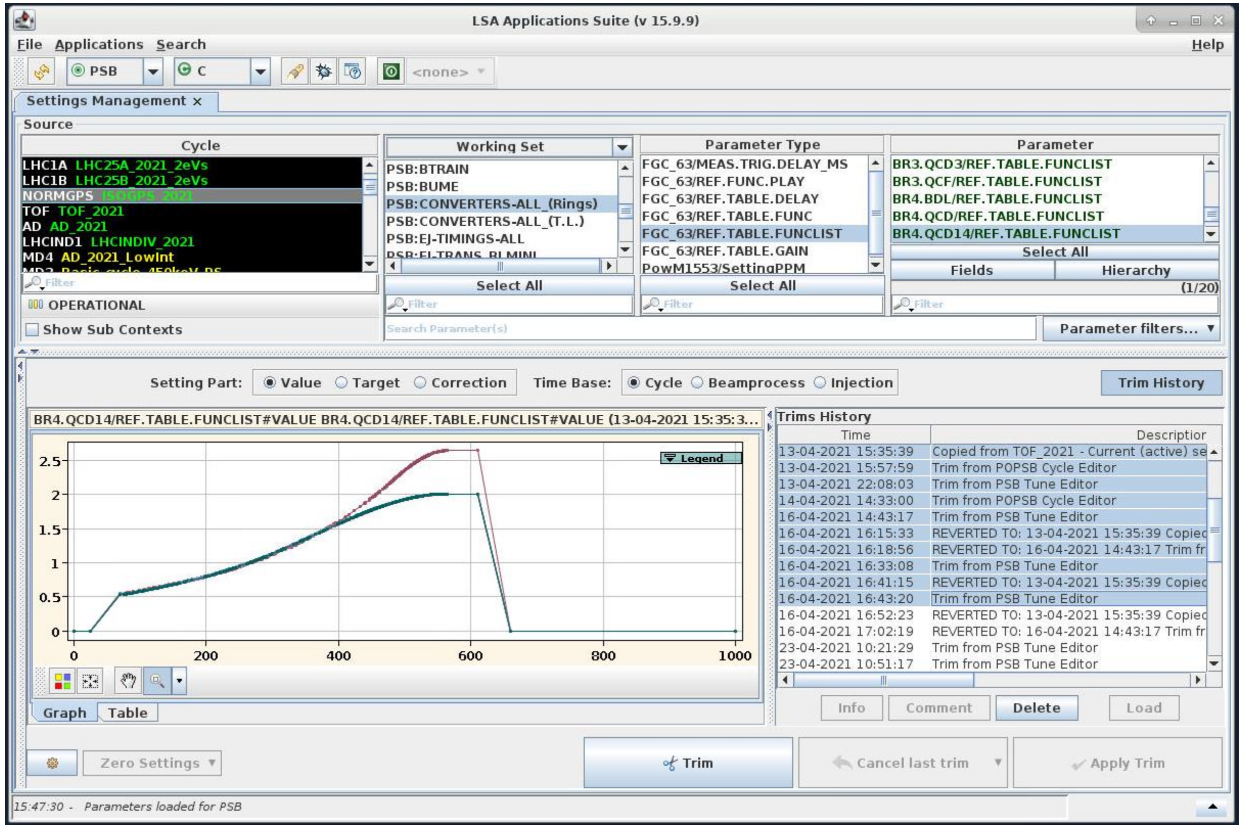
- Minimum: Display raw acquisitions
- Ideal: Time-tagged, coherent acquisition, post-processing for quick detection of abnormal situations



Control System Key Requirements

Long-Term Memory of Settings & Acquisitions

- AKA Logging
- Accelerator performance & post-mortem analysis, fine tuning of the machines
- Minimum: structured time-series in a simple format (CSV, SDDS, etc.)
- Ideal: Years of data (settings & acquisitions) with performant data extraction & analysis tools

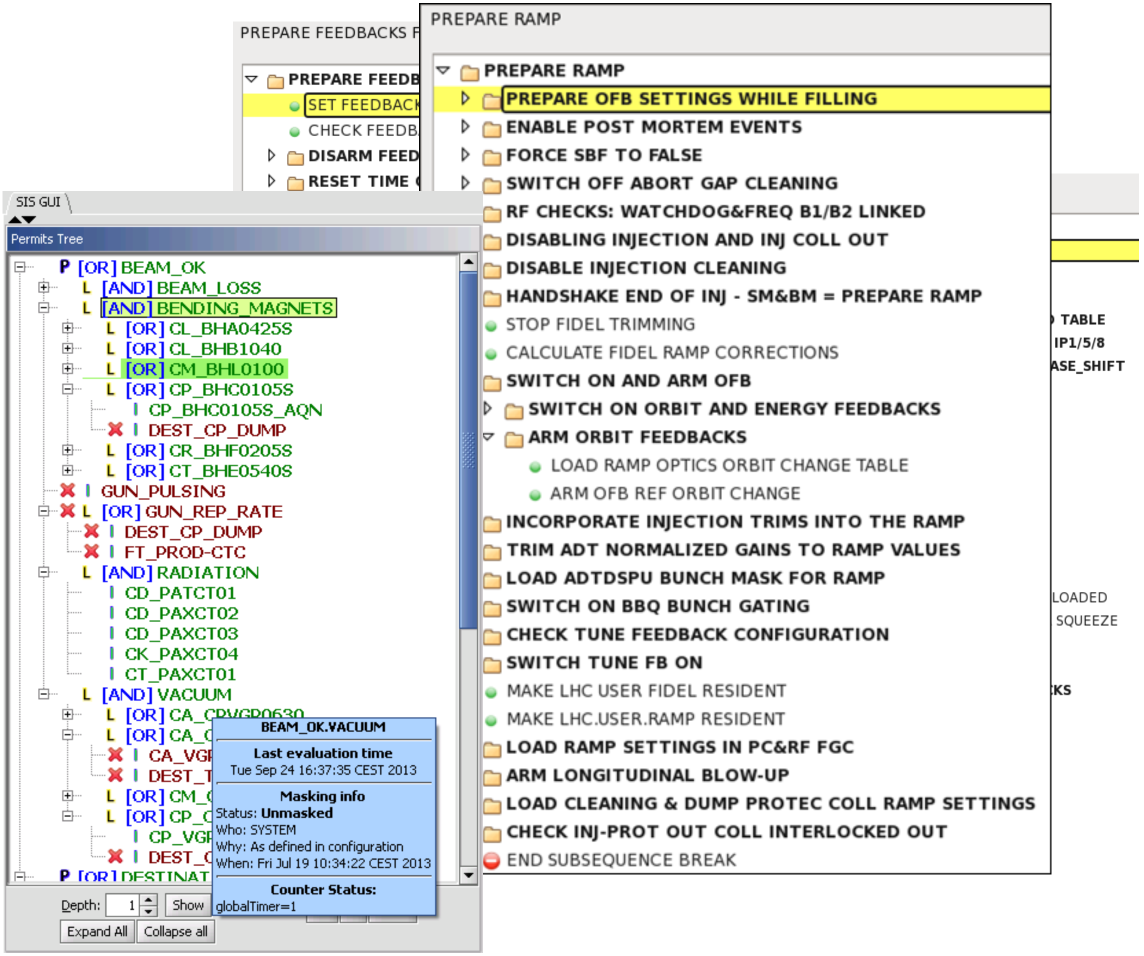


More Control System Requirements

- **Safety for machine protection & operational availability**
  - **Minimum: Machine interlock to protect the hardware**
  - **Ideal: High-level fast-reaction interlocks and role-based access to prevent the wrong action at the wrong time**

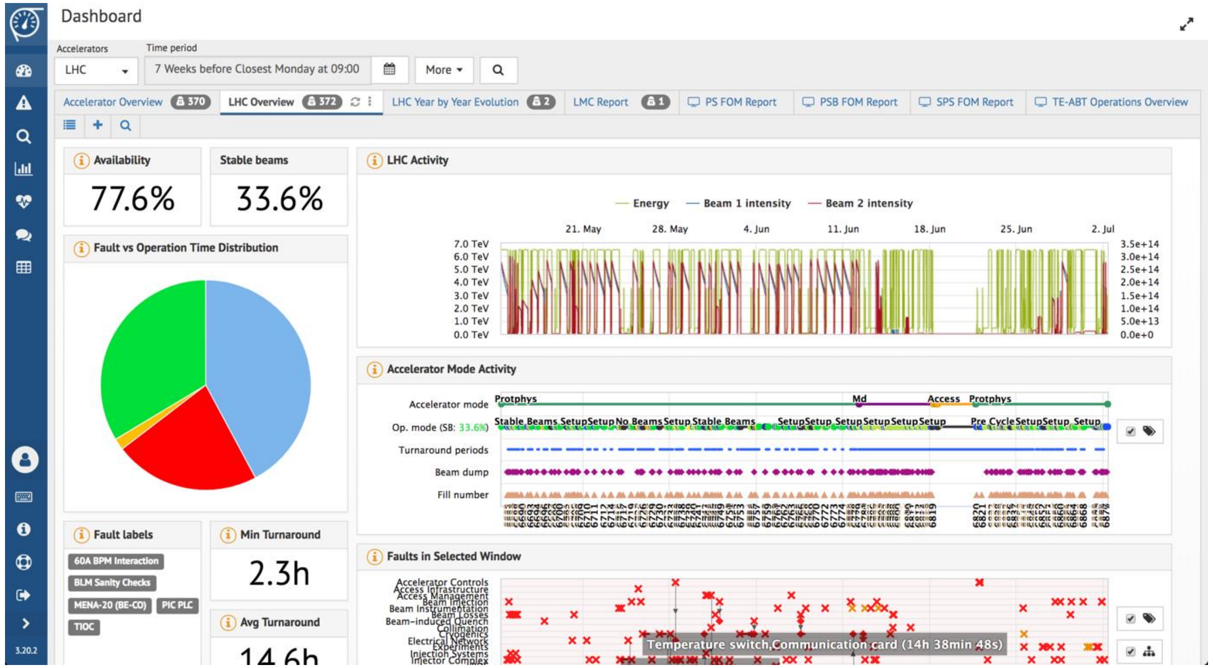
More Control System Requirements

- **Automation**
  - **Generate initial values, play sequences, feedback loops, etc.**
  - **Minimum: Non-interactive scripts**
  - **Ideal: Model-driven generation, flexible sequencer (almost like a debugger), automated actions (decision tree, machine learning)**



More Control System Requirements

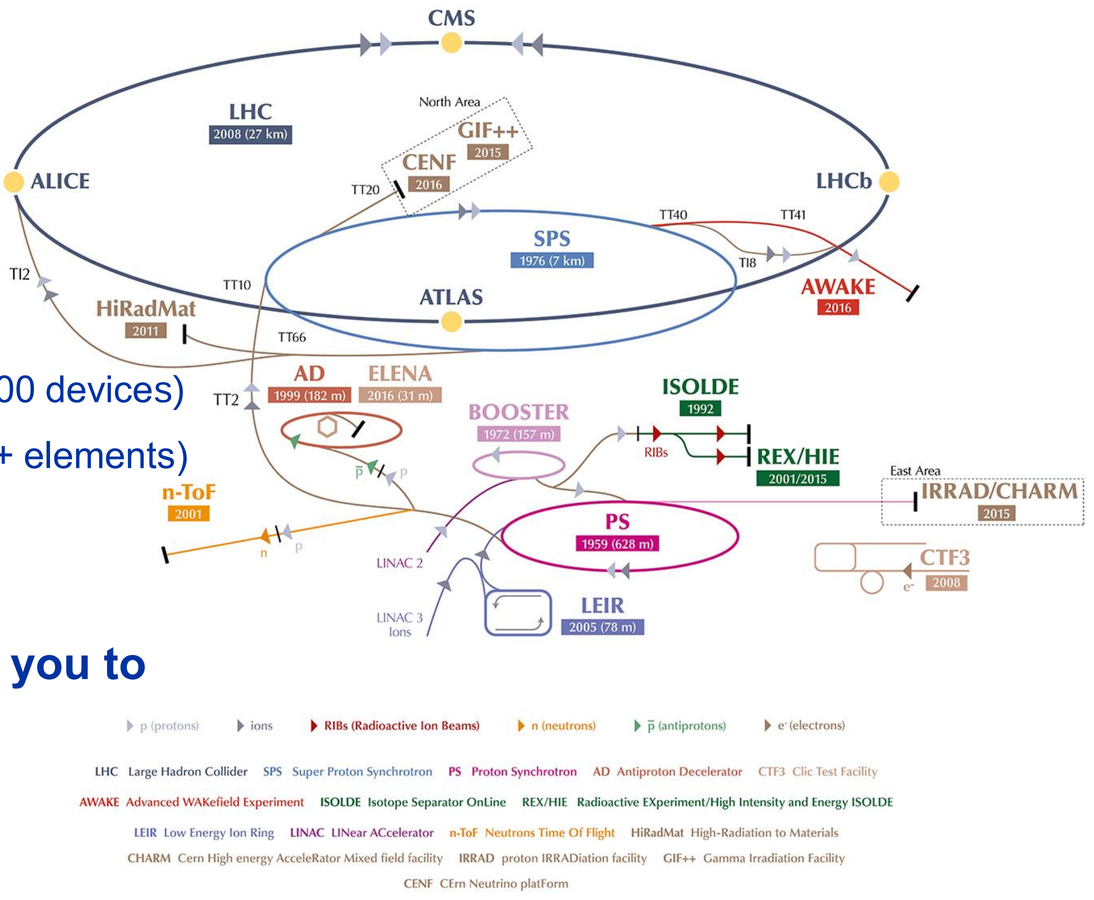
- Diagnostics
  - Detection, identification, and follow-up of problems in the controls infrastructure
  - Minimum: Non-interactive status screens
  - Ideal: Online monitoring, remote interventions (e.g. power cycle), failure prediction (Machine Learning), analysis tools



And many more…

Controls Complexity

- **Many requirements from physicists and operators**
- **Accelerators made of many elements**
  - Early accelerators, e.g. CERN Proton Synchrotron (PS), were small (< 5’000 devices)
  - Latest accelerators, e.g. LHC, are much more complex to operate (30’000+ elements)
- **The Control System’s job is to hide the complexity and help you to do your job as efficiently as possible.**

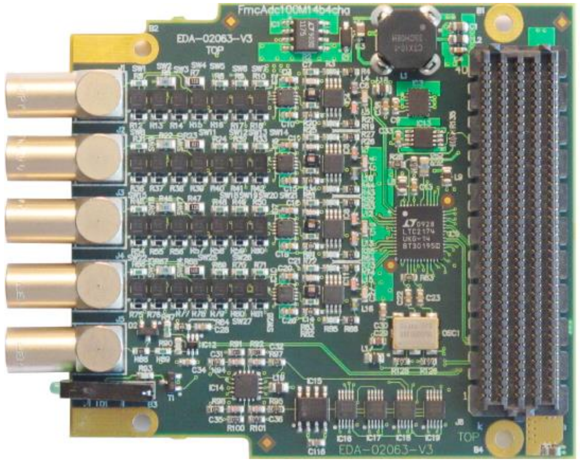


Implementation Philosophy

Implementation Philosophy - Hardware

As much as possible:

- **Apply vertical industrial control system solutions**
  - PLCs for industry-like process control (electricity, cooling & ventilation, vacuum, cryo)
- **Restrict home-made HW development to specific applications**
  - Beam optics controls (i.e. all power converters),
  - Injection and Extraction systems,
  - Beam instrumentation,
  - RF,
  - Collimation,
  - Timing Systems,
  - Etc.



Don’t Reinvent The Wheel !!

- **Base the HW architecture on available standards and Commercial Off-The-Shelf (COTS)**
  - Standards for complex embedded I/O systems with high performance demands
  - COTS electronic modules for generic features (CPUs, serial controller boards, ADCs, etc.)
  - Standard fieldbuses for applications requiring real-time features and radiation hardness (e.g. WorldFIP), and less stringent applications (Profinet/Ethercat)
  - Standards for cost-effective I/O systems for networking (fieldbus controllers)
  - GPS for time stamping and overall accelerator synchronization
  - COTS desktop PCs & servers for control rooms and application servers

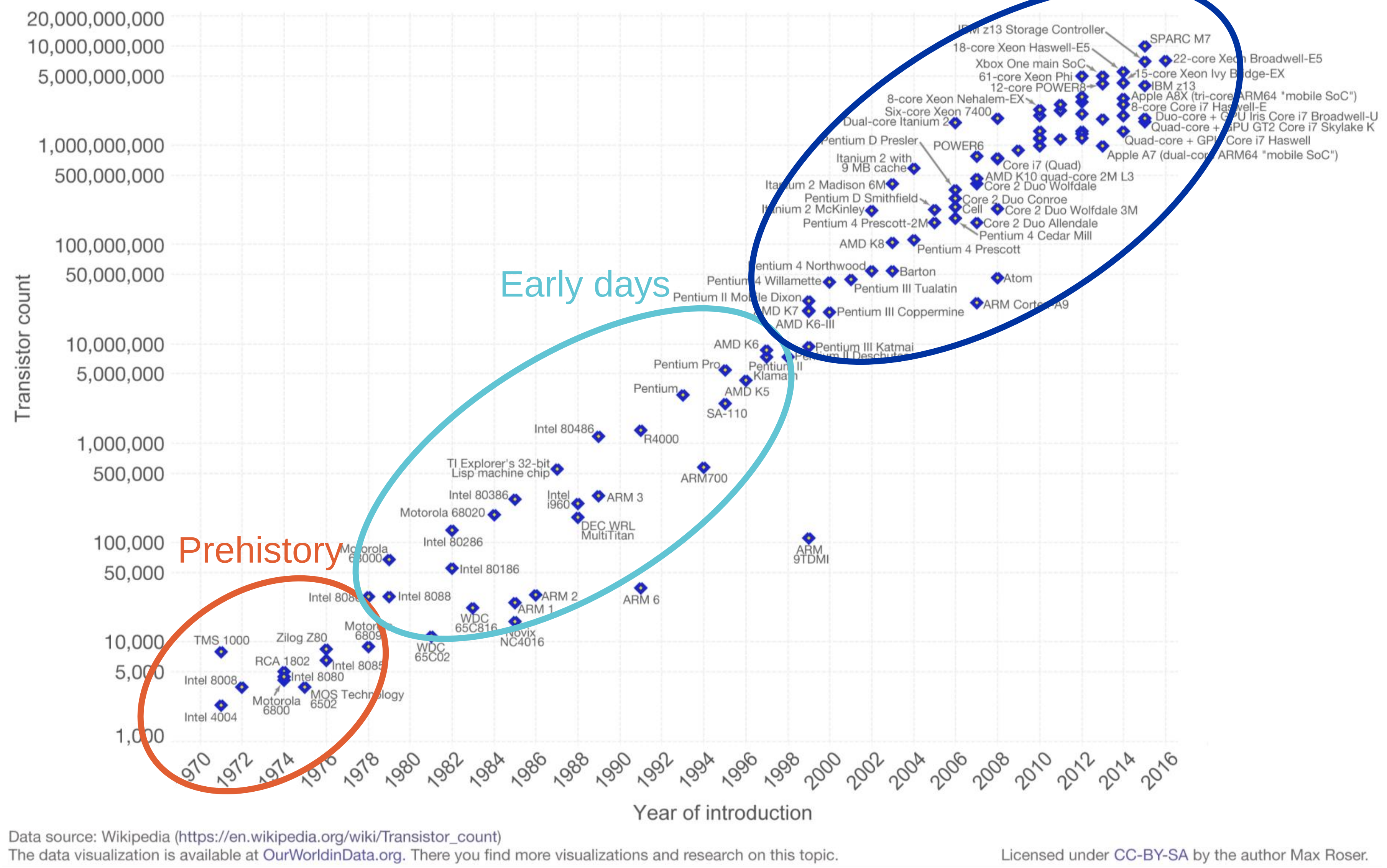
Implementation Philosophy - Software

As much as possible:

- **Apply vertical industrial control system solutions**
  - Supervisory Control and Data Acquisition Systems (SCADA) for commands, graphical user interfaces, alarms, etc. of industrial systems
- **Rely on common technologies and tools**
  - Important for aspects such as recruitment, education & training
  - DBs & Storage solutions (e.g. Hadoop)
  - Communication protocols
  - Monitoring solutions used in the industry (e.g. ICINGA)
- **Privilege Open-Source Software**
  - Avoid vendor lock-in
  - Control license cost
  - Manage the Total Cost of Ownership (TCO)

A bit of History

Moore's Law


Modern days
Early days
Prehistory
Transistor count
Year of introduction
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.
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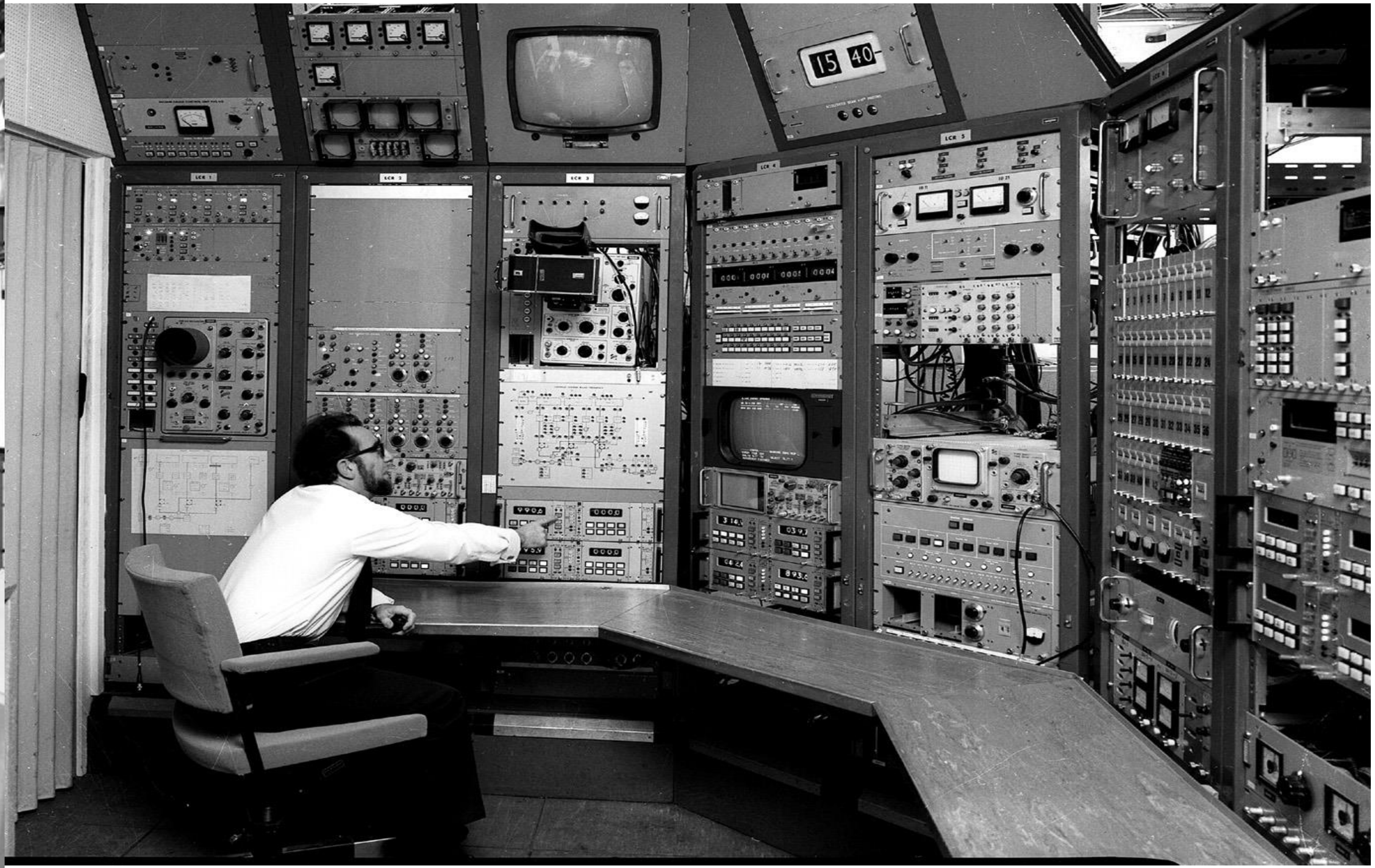
Control System Prehistory

- **Accelerators are small and overall less complex (e.g. no superconducting magnets)**
  - No more than a few thousands of devices to control
- **No computing infrastructure and limited possibility to model**
- **Actuator and monitors are physically in the local control rooms (e.g. buttons, knobs, analogue oscilloscopes, etc.)**

Control System Prehistory



The Early Days

Beginning of remote controls

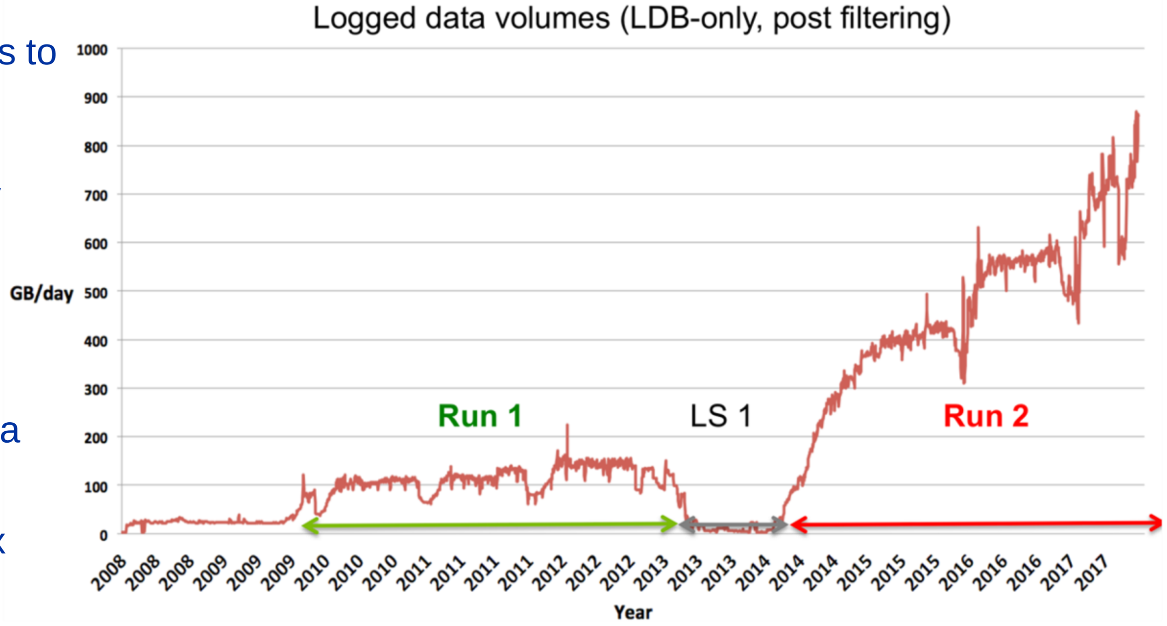
- **Still limited by the available performance**
- **Lack of standards and common frameworks → more DIY and custom solutions**
- **Emergence of several controls solutions, aiming at different types of accelerators (at first)**
  - EPICS (driven by US labs),
  - Tango (driven by ESRF (Fr) – synchrotron light sources)
  - CERN[1]

[1] non-exhaustive list

Modern days

- **Hardware has become powerful**
  - E.g. embedded systems at CERN in late 90s had **64 MB of RAM**; Nowadays, they have **8 GB**
  - Most of the needs are covered
  - Yet, users want more and more data (turn-by-turn acquisitions, big-data solution for the long-term storage, etc.)

- **Software industry has become a major actor worldwide.**
  - We can rely on many readily available technologies that open the doors to much more powerful systems



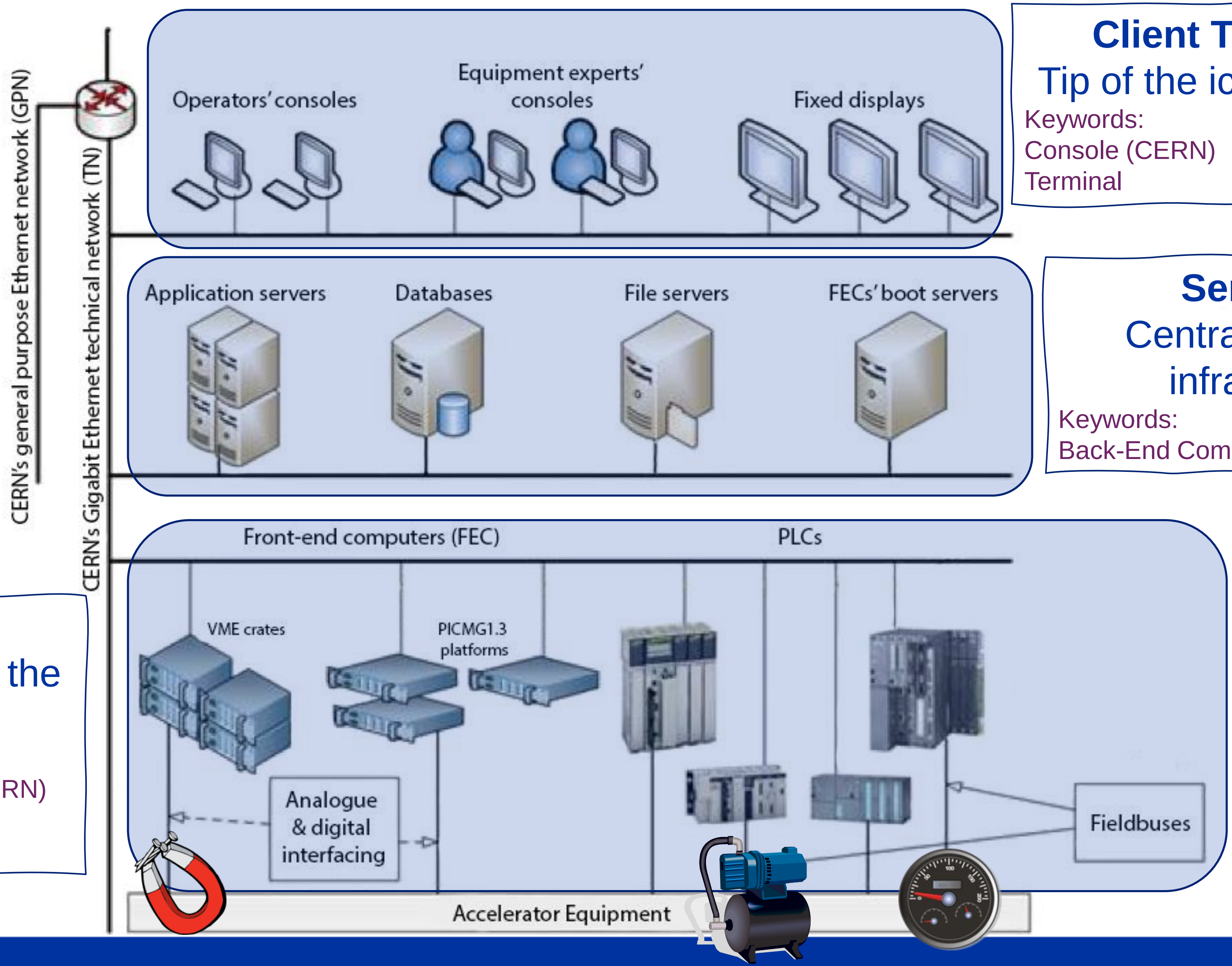
- **We still need to integrate and customise them to the very specific domain of particle accelerator controls**
  - Not all solutions are appropriate;
    Need to remember accelerator controls ≠ selling plane tickets
  - Mastering the different solutions with their evolution, limitations, etc. is a major challenge
  - The rhythm of updates is no longer under our control. E.g. recent Linux CentOS changes

50 years of technology evolution

High-Level Architecture

of a modern control system

High-Level Hardware Architecture



Client Tier

Tip of the iceberg

Keywords:
Console (CERN)
Terminal

Server Tier

Central computing infrastructure

Keywords:
Back-End Computer (BEC) (CERN)

Resource Tier

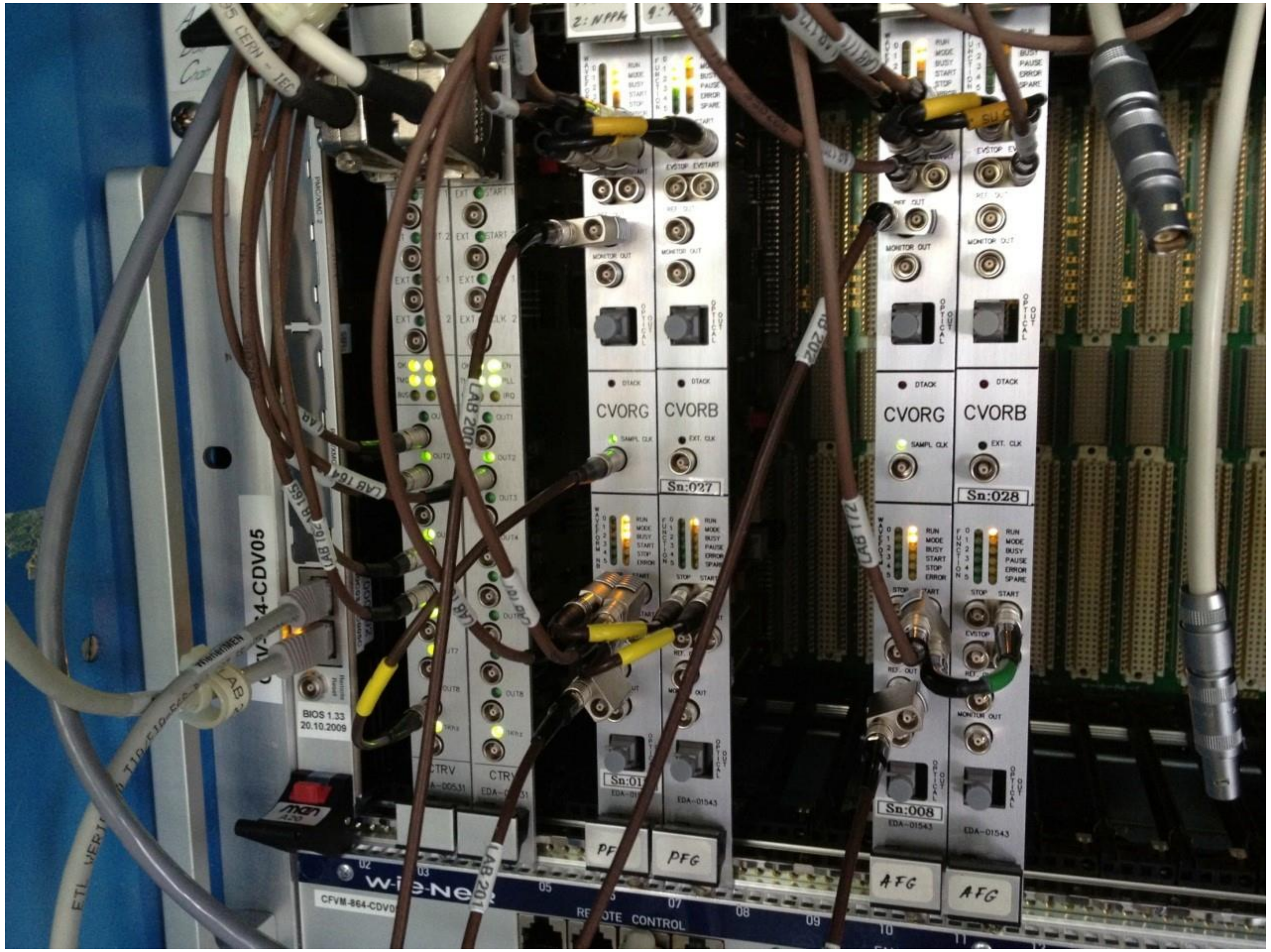
Electronics close to the accelerator

Keywords:
Front-End Computer (FEC) (CERN)
I/O Controller (IOC) (EPICS)
Device Server (Tango)

High-Level Hardware Architecture

Resource Tier

- **Open enclosures**
  - Easy access
  - Better cooling and power available
  - But expensive
- **Closed enclosures**
  - Possible for simple functions (e.g. fieldbus control)
  - Cost effective; when deployed in big number, e.g. LHC power converter control gateways

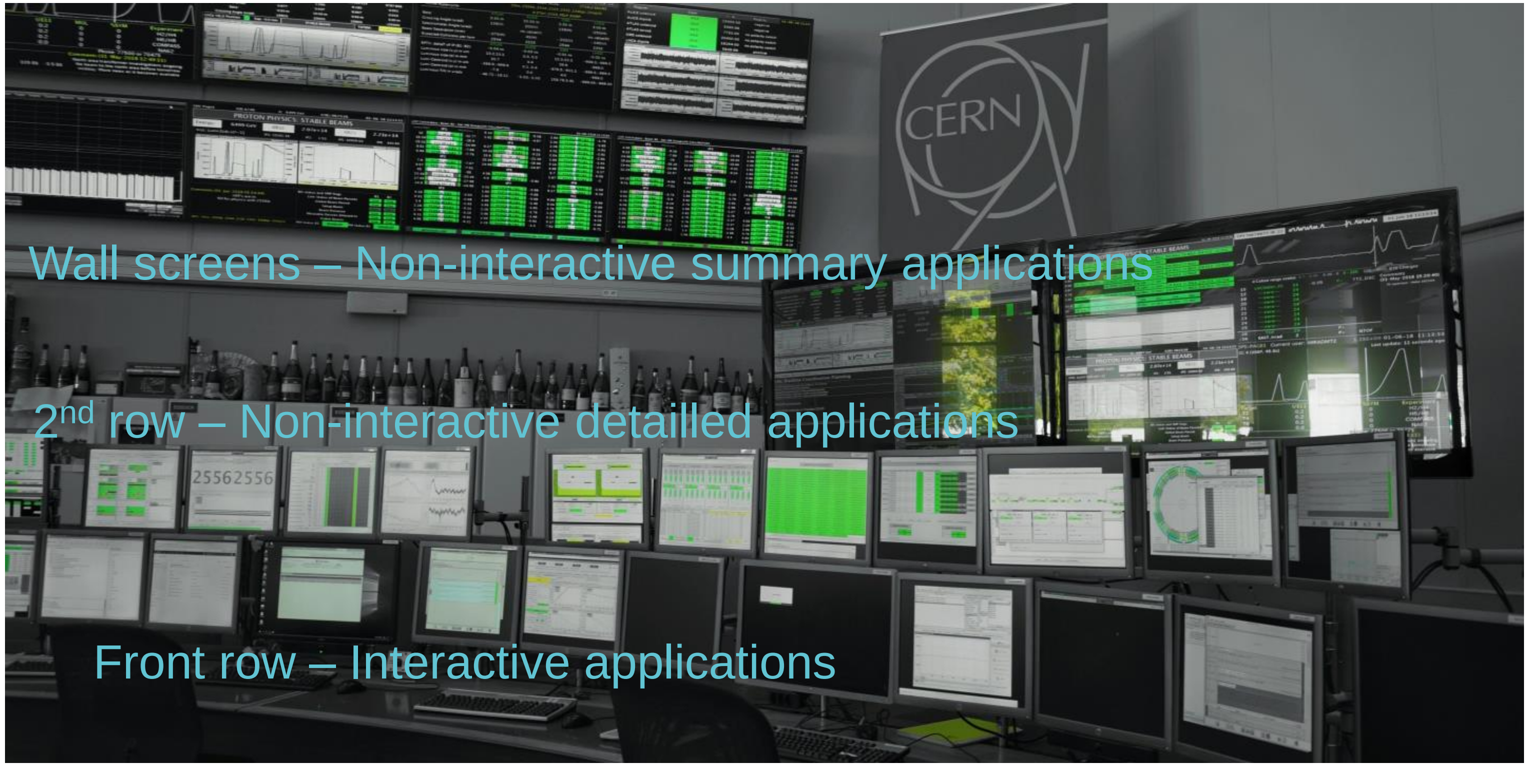


High-Level Hardware Architecture

Middle Tier

- IT Computer centre type of hardware
- High-density
- Highly available (redundancy and hot-swap)

High-Level Hardware Architecture



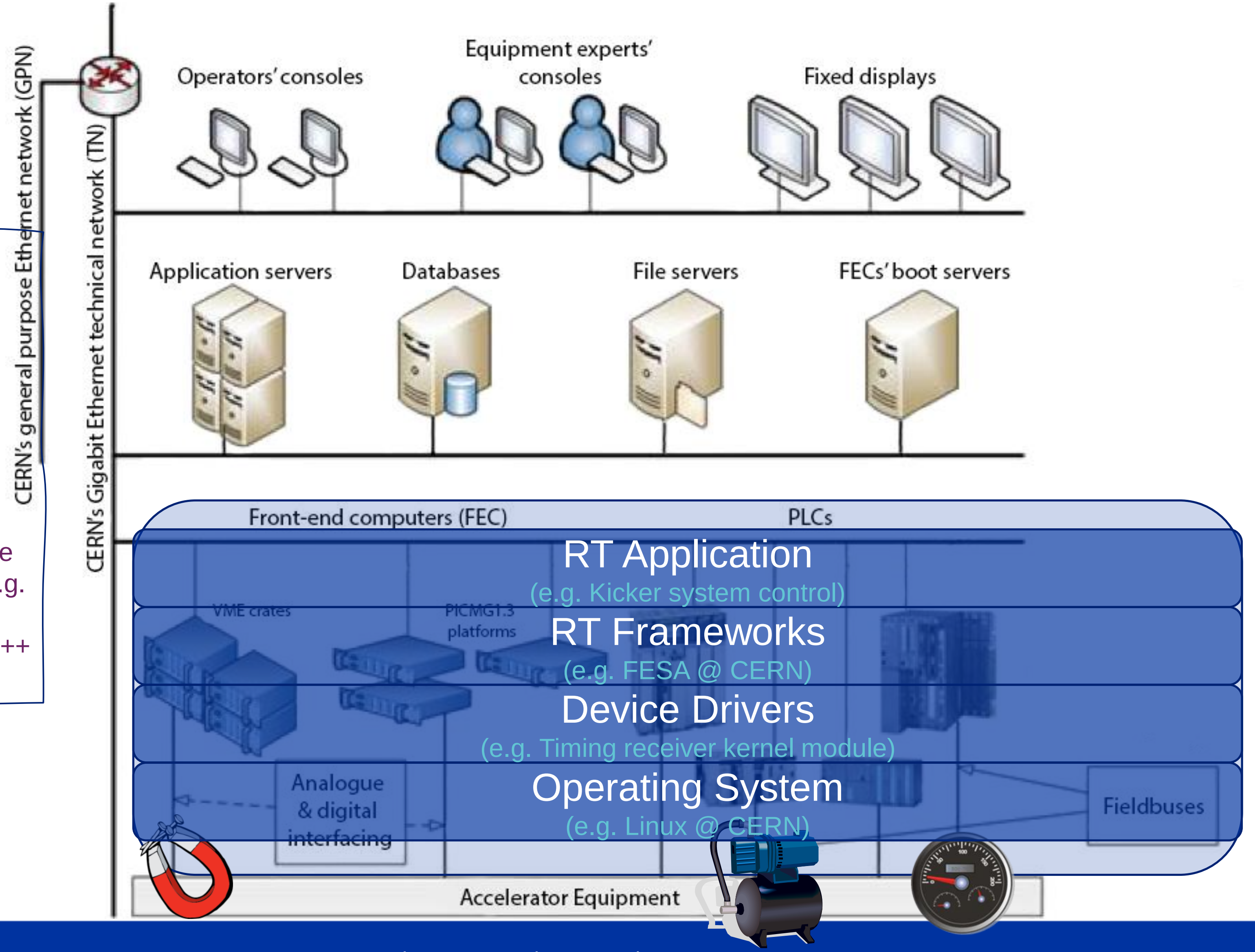
Control Room Computers

- As much as possible COTS desktop PCs but MTBF requirements might be difficult to satisfy
- Users expect modern reactive GUIs
- Several layers of screens to have as much data as possible available

High-Level Software Architecture

Front-end Tier
Real-time control and acquisition

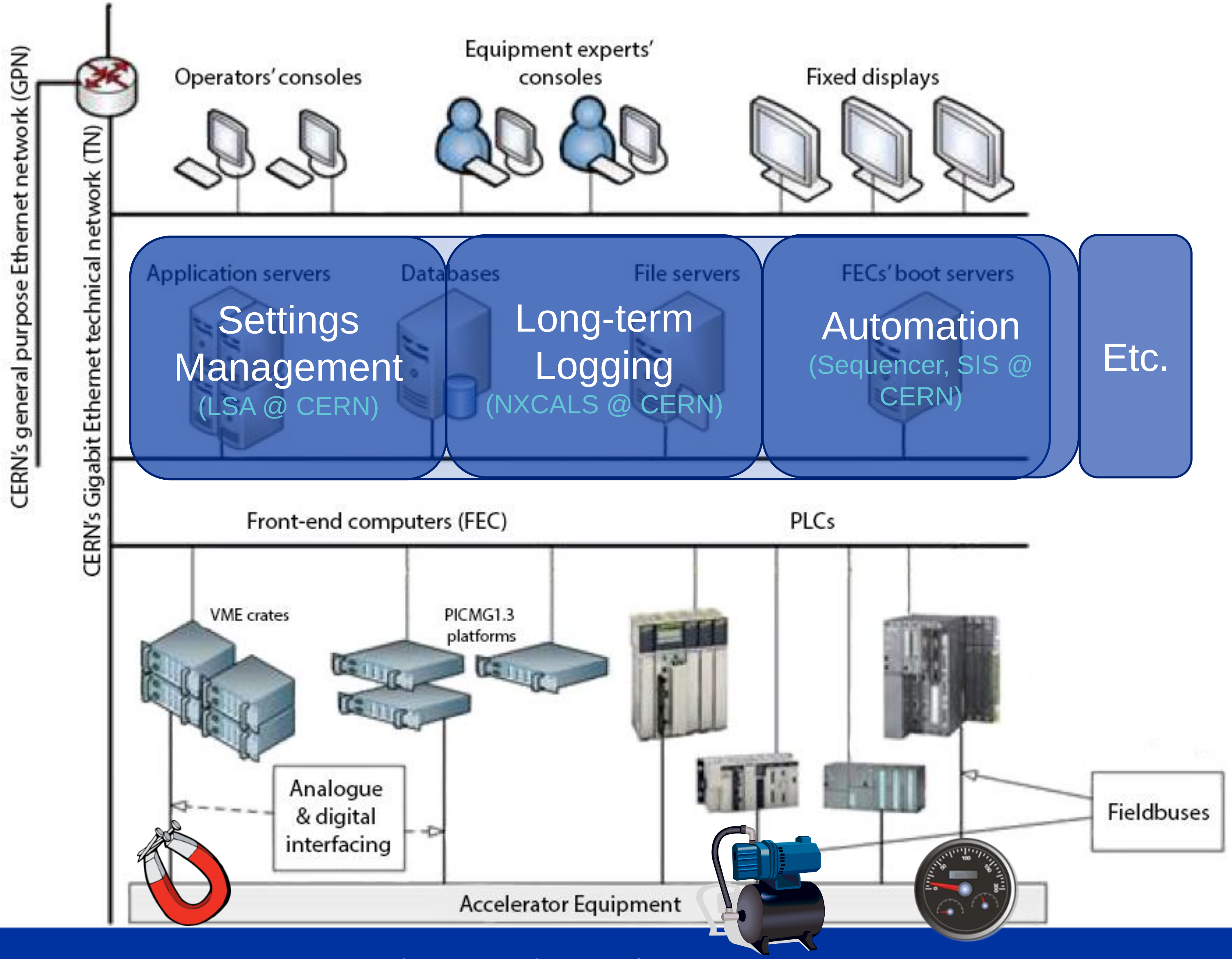
- Limited, local scope
- Fast reaction possible (interrupts)
- Limited computing power (compared to other tiers)
- Equipment processing to provides a high-level view of the hardware
- Real-time (RT) applications relies on frameworks, which capture the recuring aspects (react to events, publish new data, etc.) E.g. FESA @ CERN, POGO with Tango
- Based on technologies closed to the hardware (C for drivers, C++ for RT, etc.)



High-Level Software Architecture

Business Tier
General purpose services & Specific business logic

- Broader scope; able to coordinate the entire accelerator
- Powerful computers
- Less reactive (network) and at a higher-level of abstraction
- Based on technologies that are better suited for high-level business logic (e.g. Java)



High-Level Software Architecture

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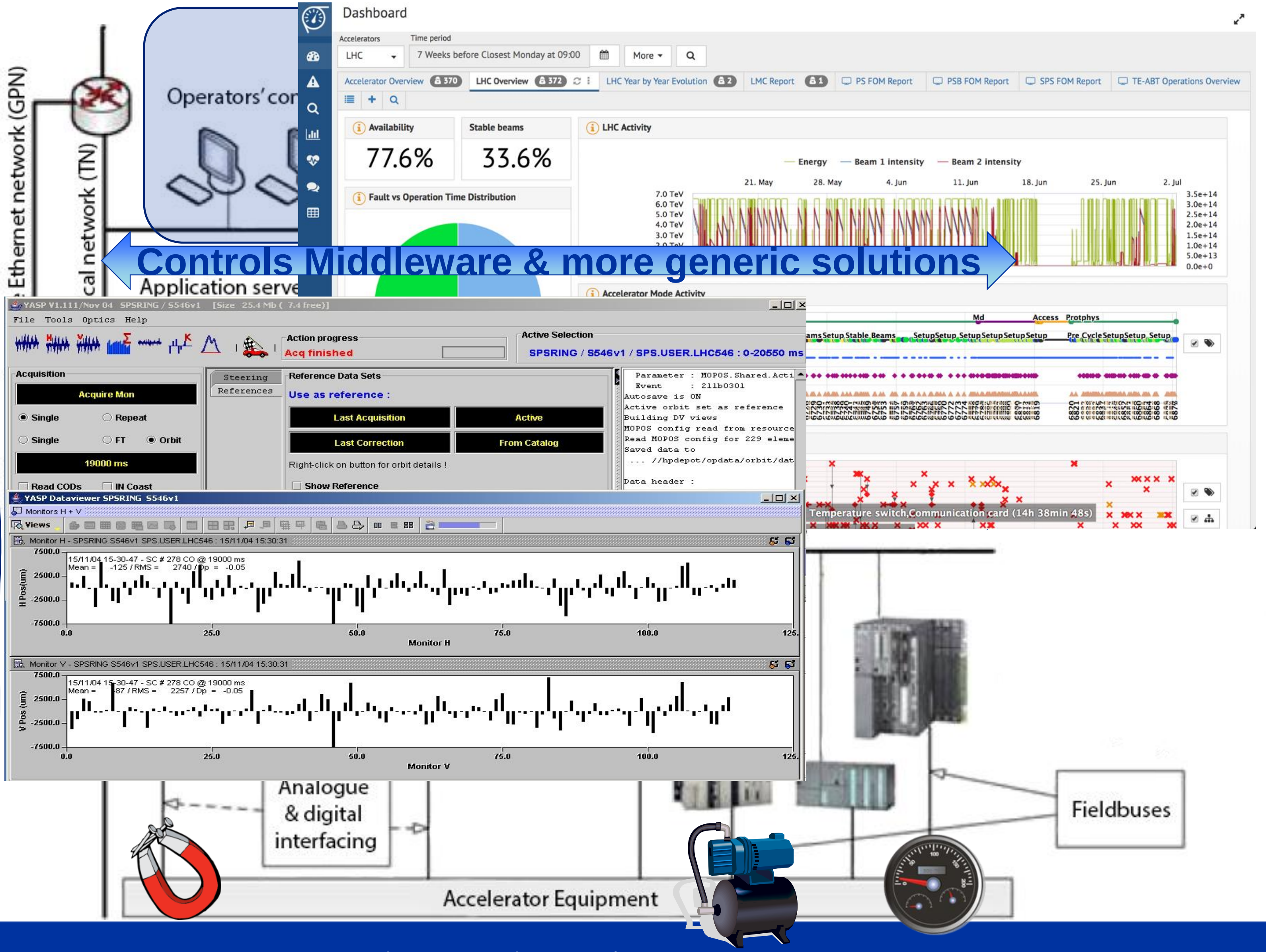
Presentation Tier
Graphical applications

Different technologies available
- ➢ Java Swing, Java FX
- ➢ Qt, PyQt
- ➢ Web ecosystem (Angular, View.js, etc.)

Keywords:
Graphical User Interface (GUI)
Human-Machine Interface (HMI)
Command-line interface (CLI)

Communication

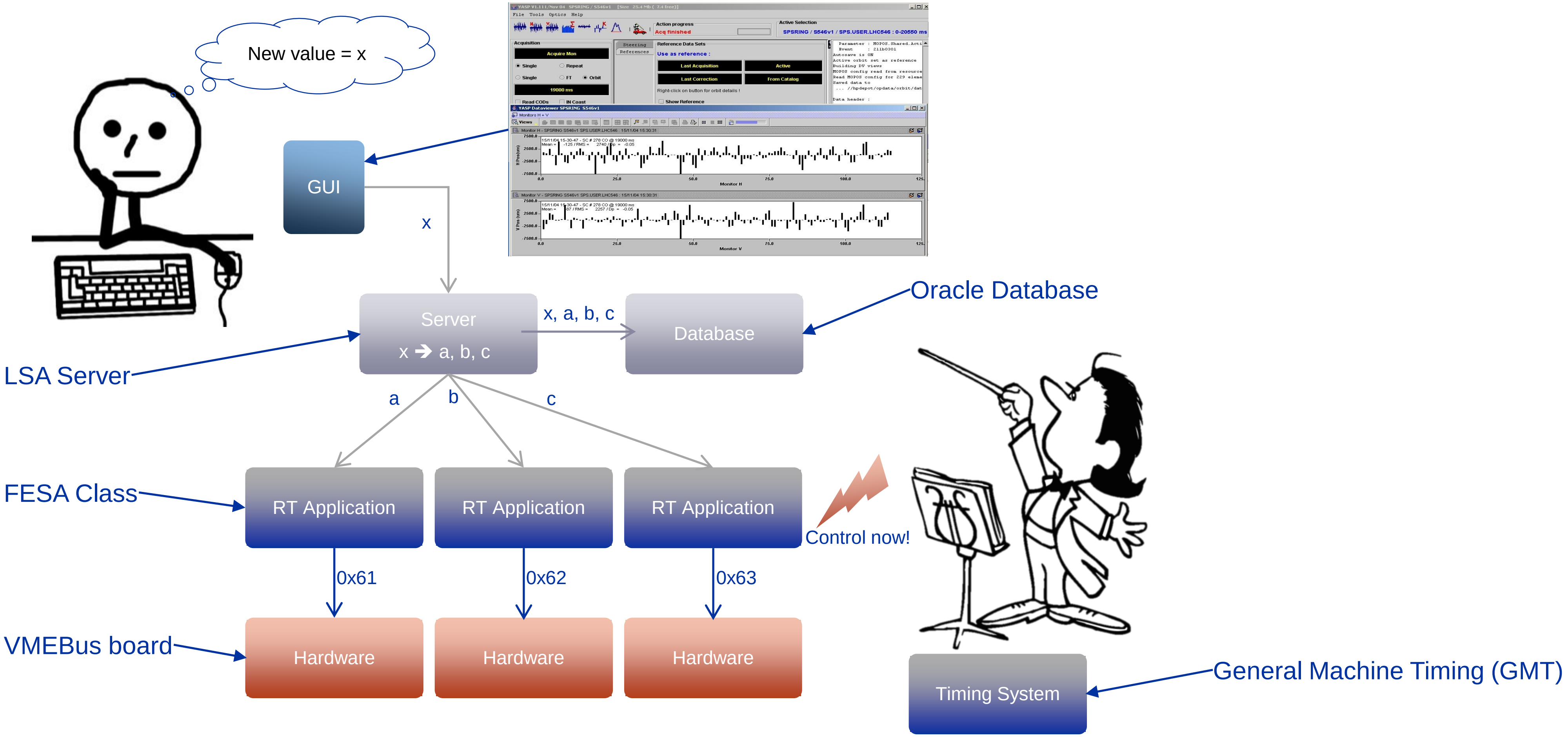
- ➢ Accelerator-specific protocols for the lower layers
  - ➢ Channel Access (EPICS)
  - ➢ CMW (CERN)
- ➢ Potentially, more generic technologies for the higher layers
  - ➢ RMI/JMS
  - ➢ REST API
  - ➢ gRPC
  - ➢ …



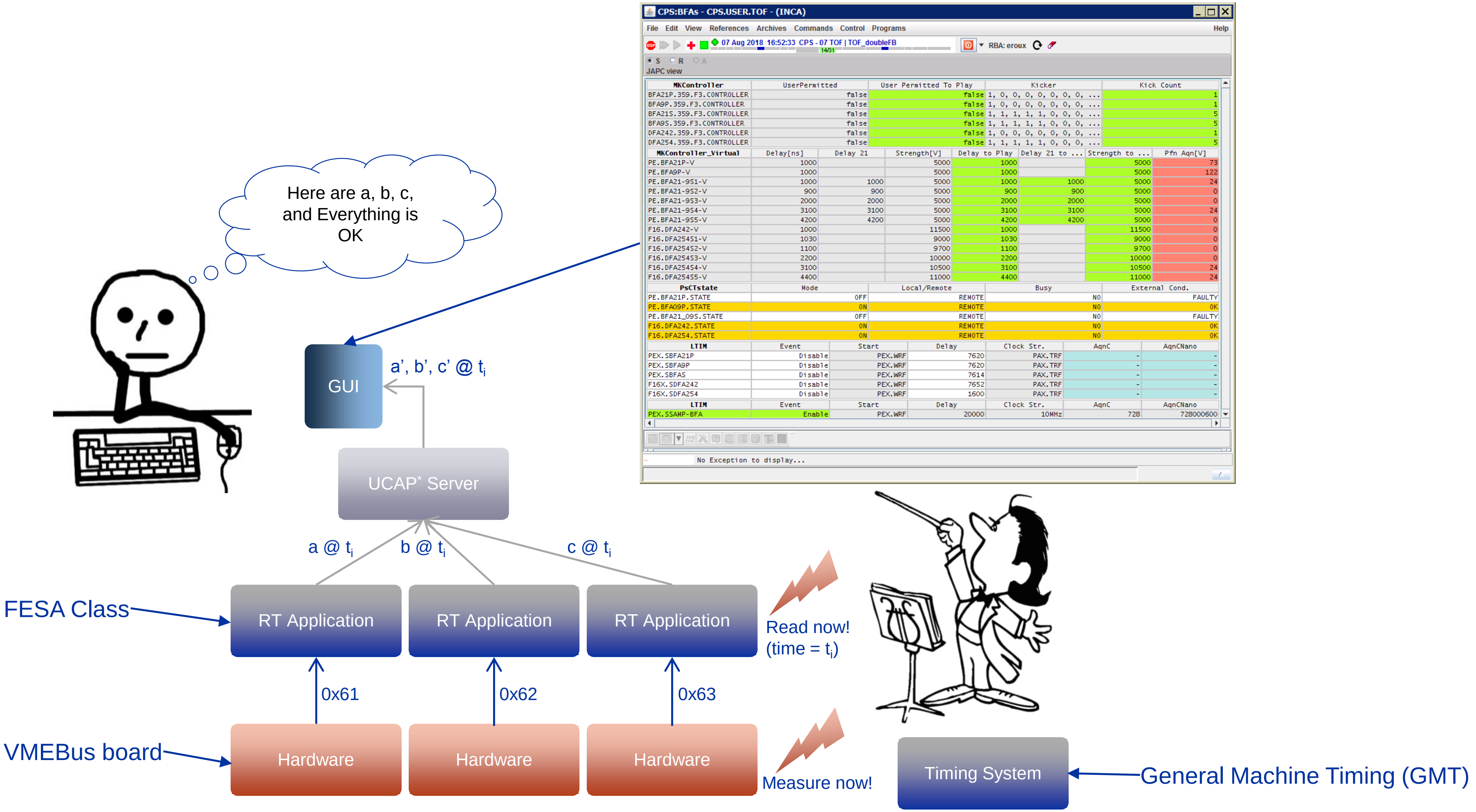
Key Components

A few examples from CERN Control System

CERN Example 1 – Control

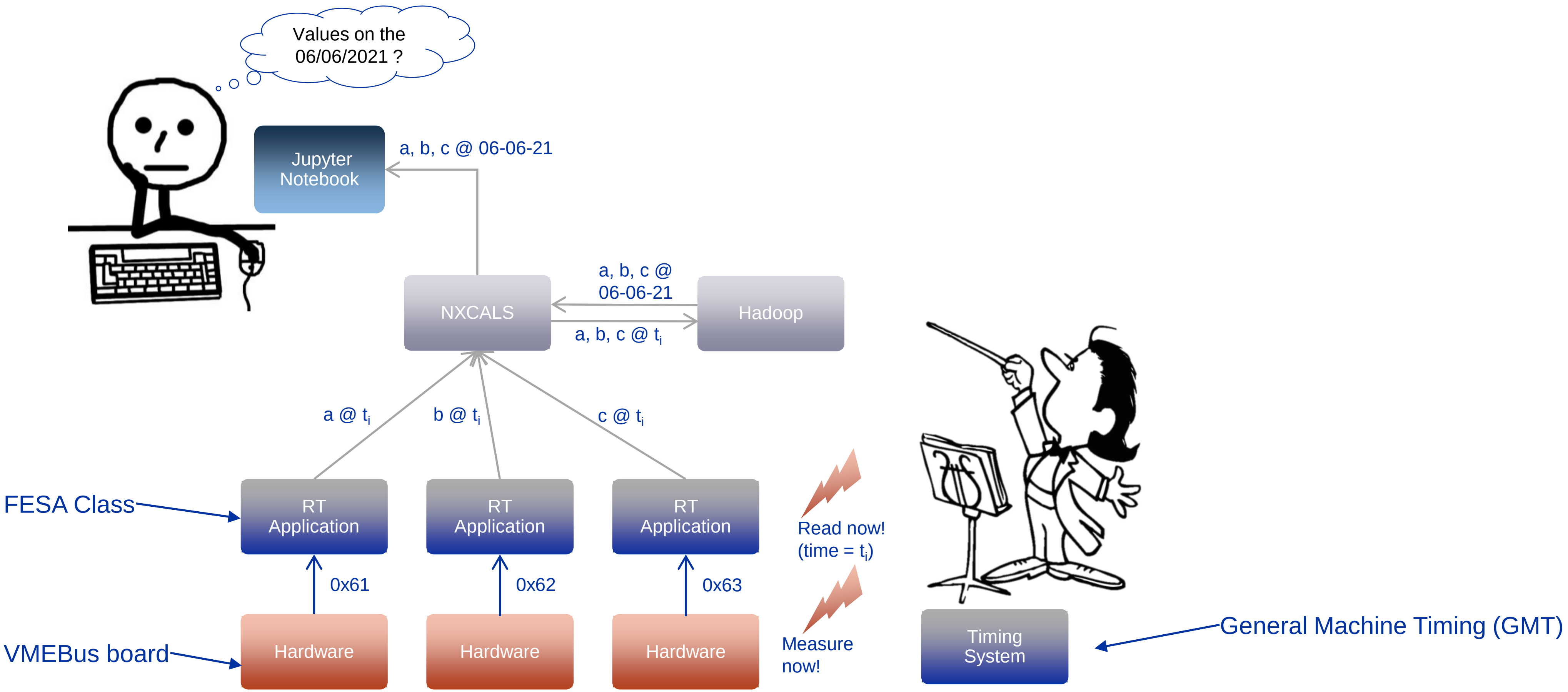


CERN example 2 – Monitoring



*UCAP: Unified Controls Acquisition & Processing framework

CERN example 3 – Logging



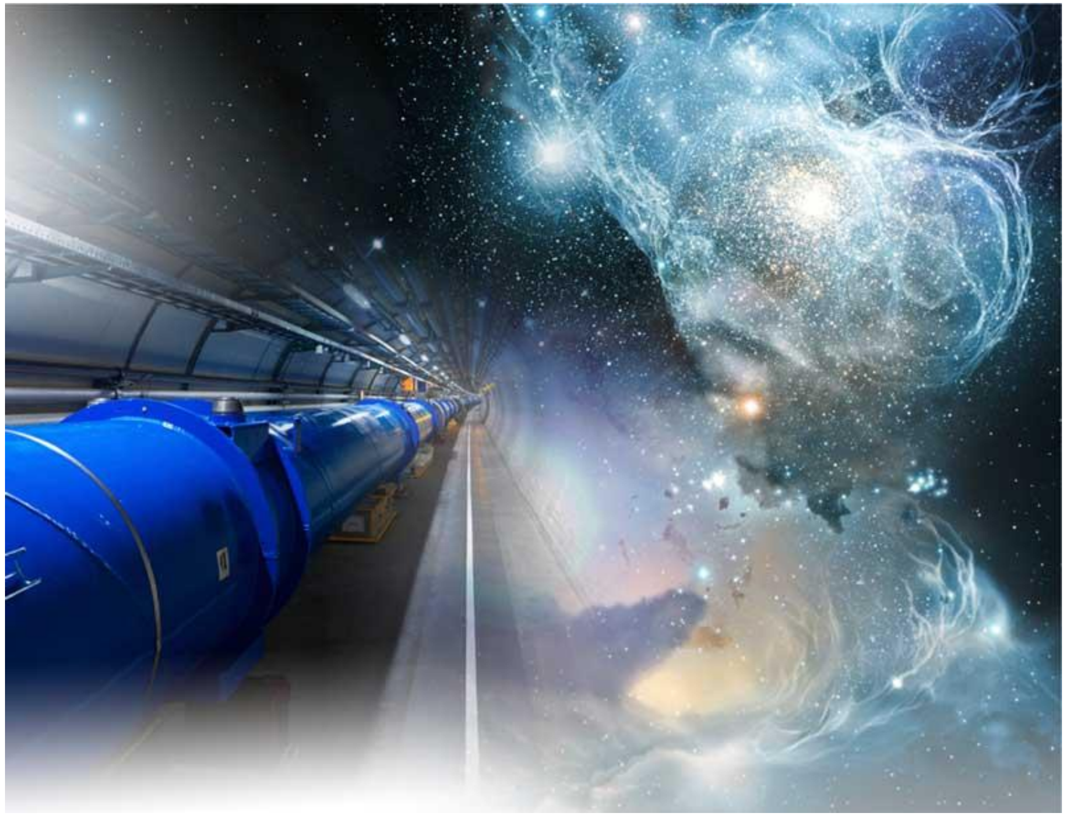
Want to know more?

CERN Beams Department (https://beams.cern/)

Introduction to BE-CO Control System, 2019 Edition, S. Deghaye & E. Fortescue, CERN, 2020. (https://cds.cern.ch/record/2748122)

Tango Controls (https://www.tango-controls.org/)

EPICS (https://epics-controls.org/)



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