~~The LHC Control System~~

CERN Accelerator Control System

Roman Gorbonosov on behalf of the
Beams Department Controls Group

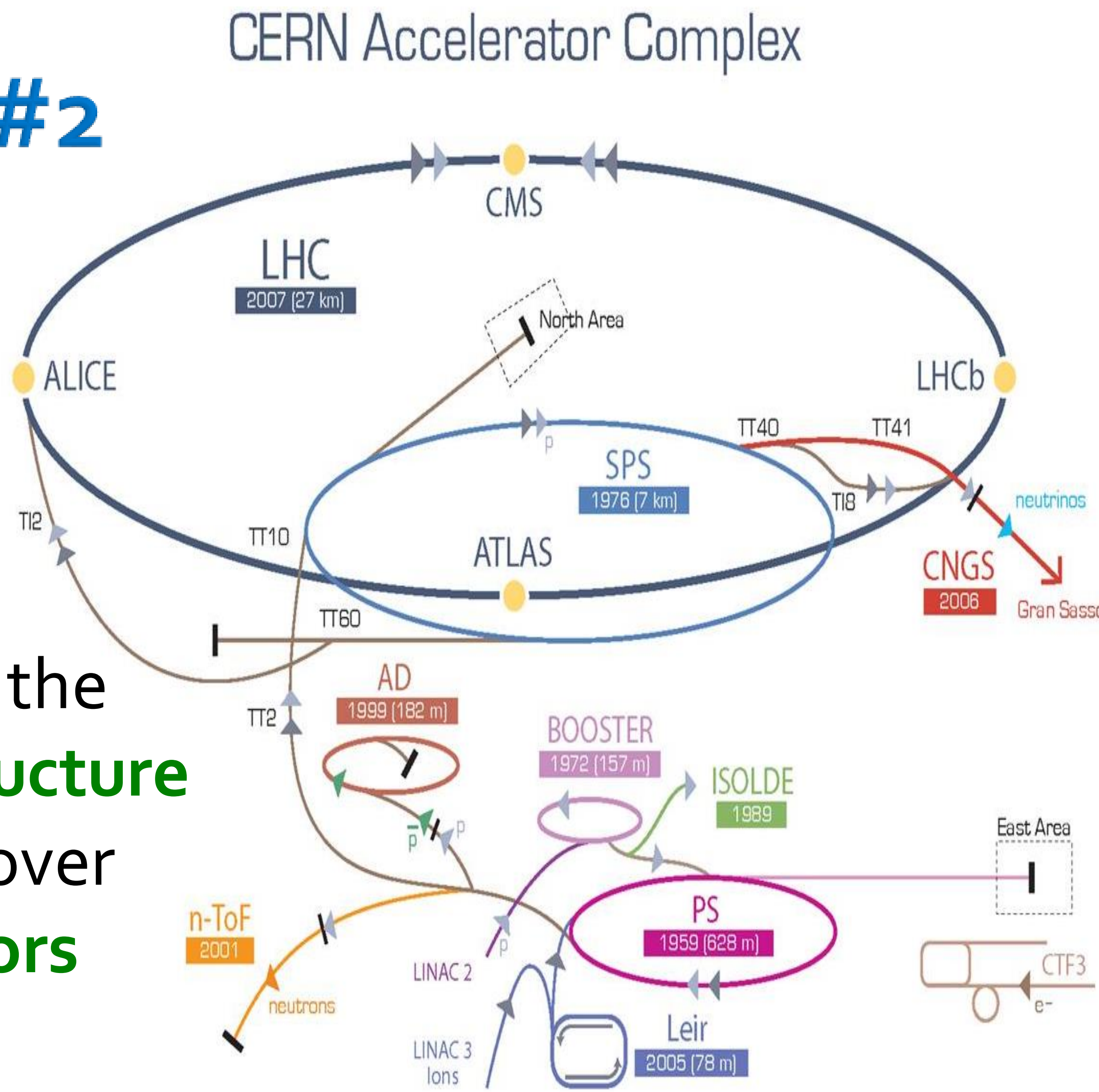
Based on the input from **M.Arruat, V.Baggiolini, JC.Bau, M.Buttner, P.Charrue, S.Deghaye, E.Hatziangeli, G.Kruk, M.Lamont, A.Radeva, U.Raich, C.Roderick, J.Serrano, W.Sliwinski, J.Wozniak**

CERN – Geneva - Switzerland
Accelerators and Technology Sector
Beams Department - Controls Group

Context is a challenge!

- Accelerate **2 beams of 2.2x10e14 (220,000,000,000,000) high energy protons** in opposite directions around a 27km ring moving at 99.9999% of the speed of light
- Through **two very narrow, very cold tubes**
- Squeeze the beams down to **16 microns**
- Collide the beams and keep them colliding for **10-15 hours**
- Keeping **beam-losses** down to a **very low level**

Challenge #2



Controls Group
is responsible for the
controls infrastructure
that is deployed over
all the accelerators
of CERN

Contents

- LHC control system requirements
- Philosophy of development
- Overview of the architecture
- Key components
- Quality Assurance (QA)
- Outlook towards the Future

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Control System Requirements

- **Provide information** about accelerator
- **Monitoring and recording**
- **Fault diagnostics**

- **Provide controls to act** on accelerator
- **Automatic process control, feedback**
- **Sequence control**

- **Prevention** of dangerous actions

- **Machine protection**

- **Cover** all **operational scenarios**
  - Commissioning (preparation, testing)
  - Physics (proton-proton, proton-ion, ion-ion)
  - Machine Development (experimenting, tuning)

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Philosophy of development

- Provide **extensible Frameworks** and **Tools**
- Develop and deploy **Generic** services
- **Applicability** to **all accelerators**
- **Quality Assurance**

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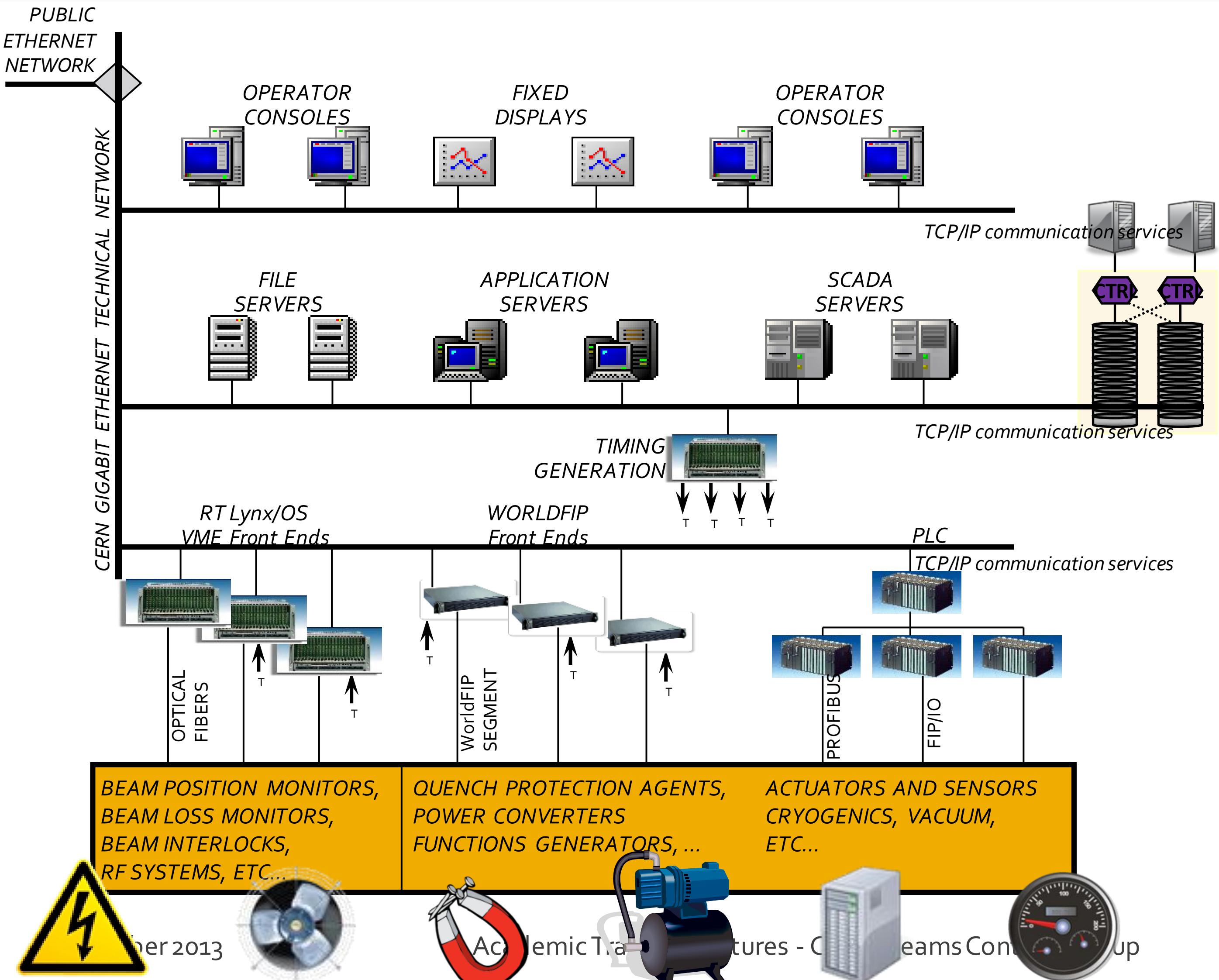
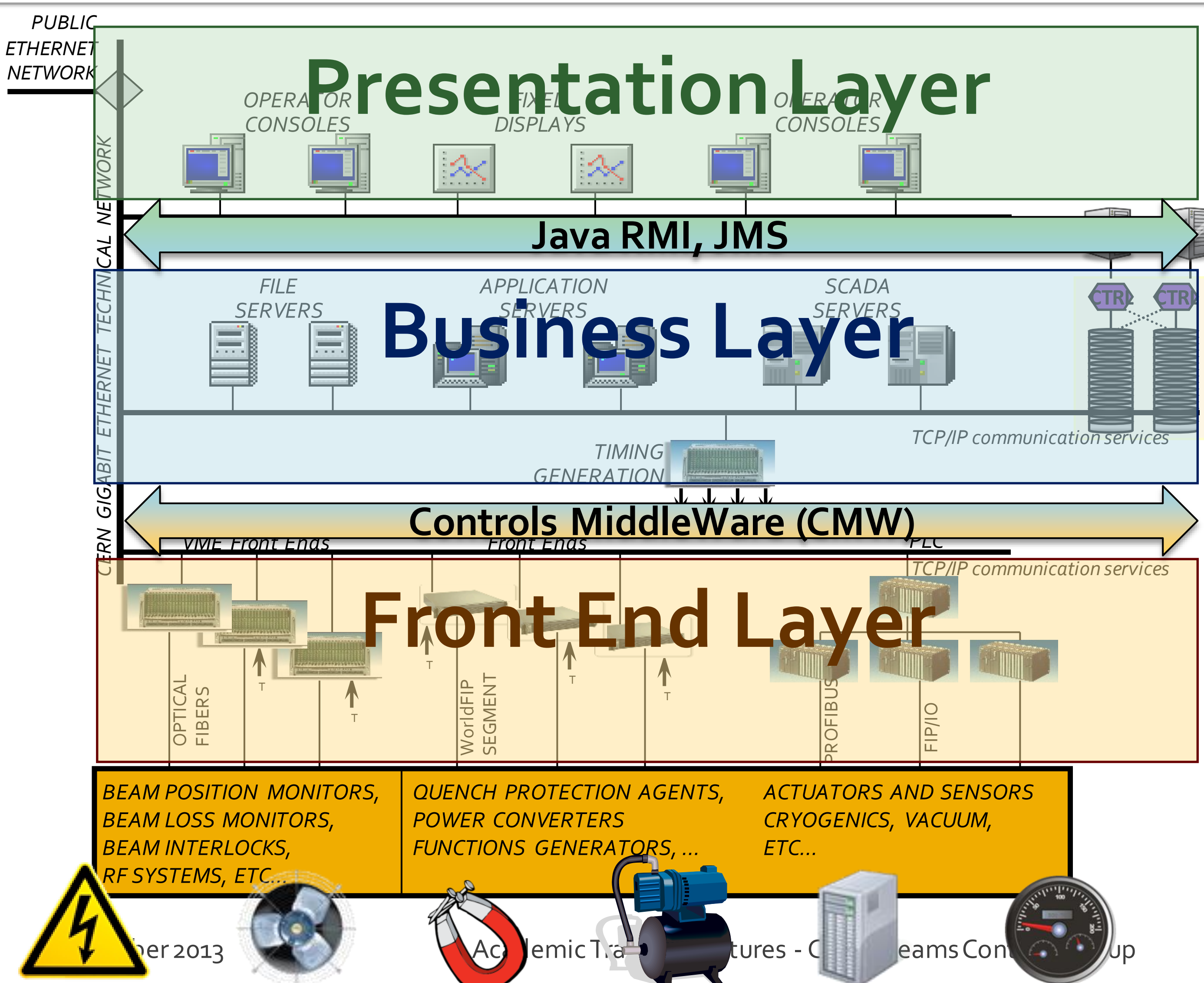
Controls HW infrastructure



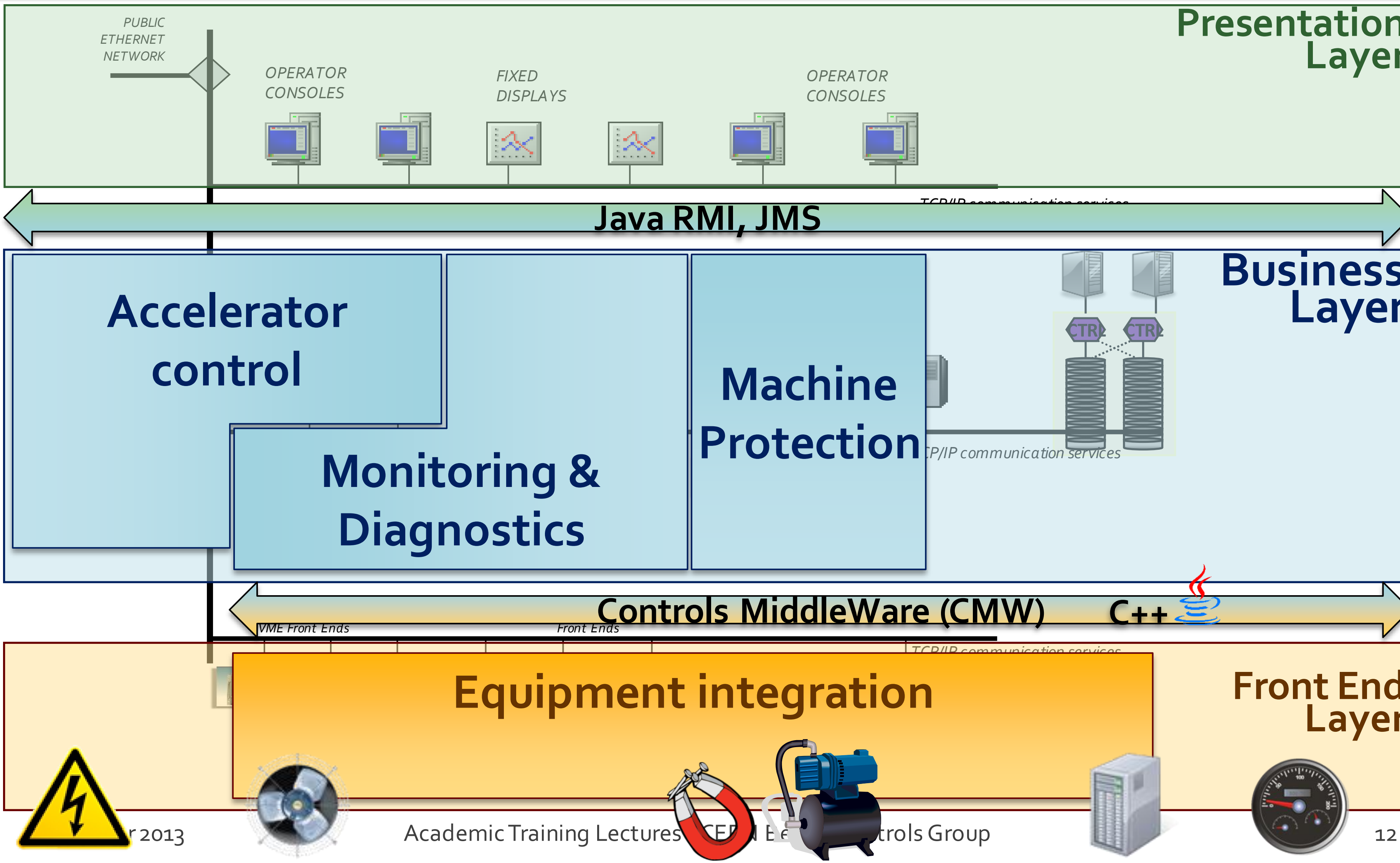
- Client Tier
  - Interactive Consoles
  - Fixed Displays
- Server Tier
  - Application servers
  - Database Servers where the setting and configuration of all devices exist
  - File Servers
  - Central Timing
- Resource Tier
  - VME crates, PC GW & PLC dealing with high performance acquisitions and real-time processing

Controls SW layers

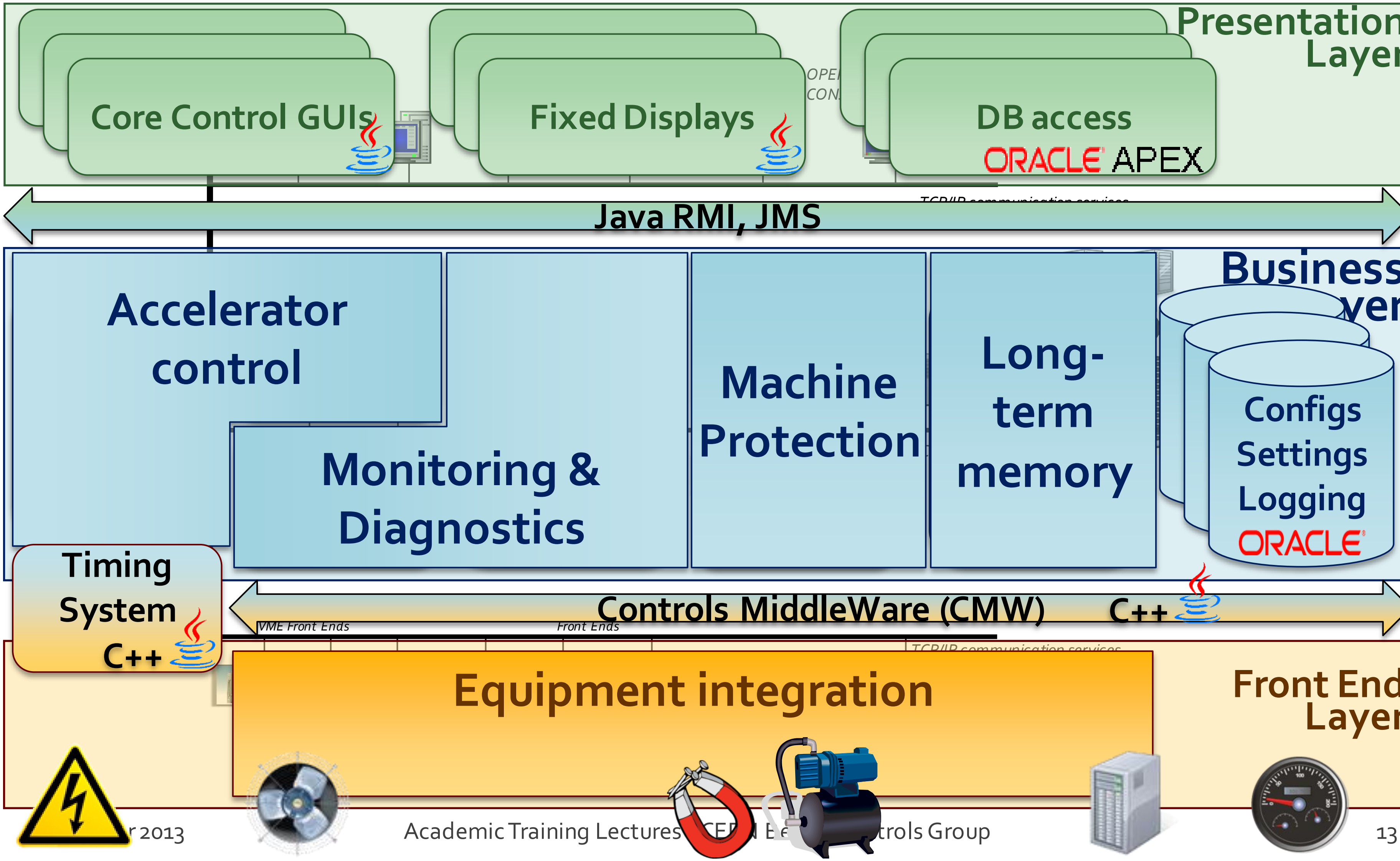


- **Presentation Layer**
  - Graphical interactive applications
  - Fixed Displays
- **Communication** via Java RMI & JMS
- **Business Layer**
  - General purpose and specific Application servers
- **Communication** via Controls MiddleWare CMW
- **Front End Layer**
  - Device servers

Controls SW Infrastructure



Controls SW Infrastructure




Fixed
Displays
CERN
Operational Consoles

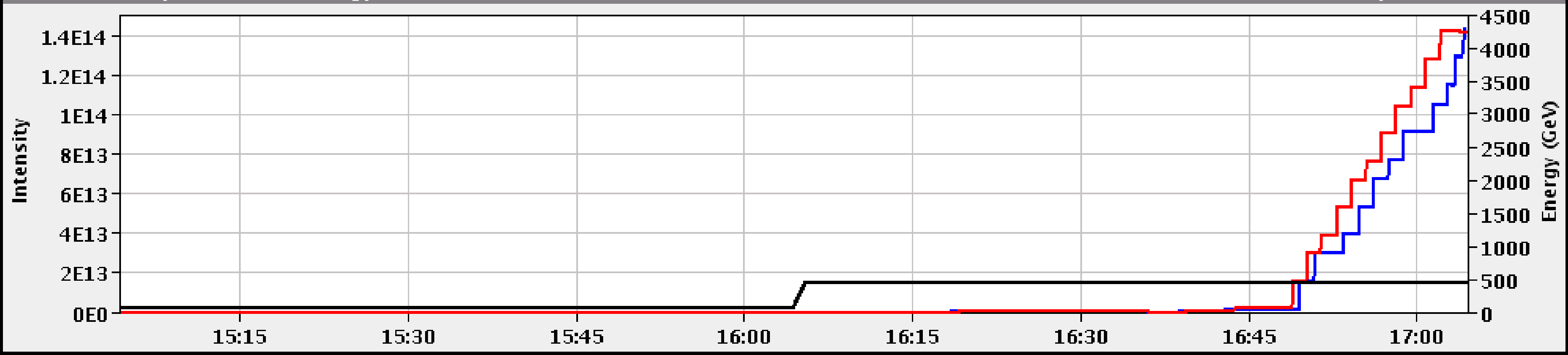
LHC Page1 Fill: 2511 E: 450 GeV 13-04-12 17:04:30

PROTON PHYSICS: INJECTION PHYSICS BEAM

BCT TI2:	7.78e+13	I(B1):	1.42e+14	BCT TI8:	0.00e+00	I(B2):	1.43e+14

TED TI2 position:	BEAM	TDI P2 gaps/mm	up: 10.68	down: 9.23
TED TI8 position:	BEAM	TDI P8 gaps/mm	up: 9.49	down: 9.53

FBCT Intensity and Beam Energy Updated: 17:04:31



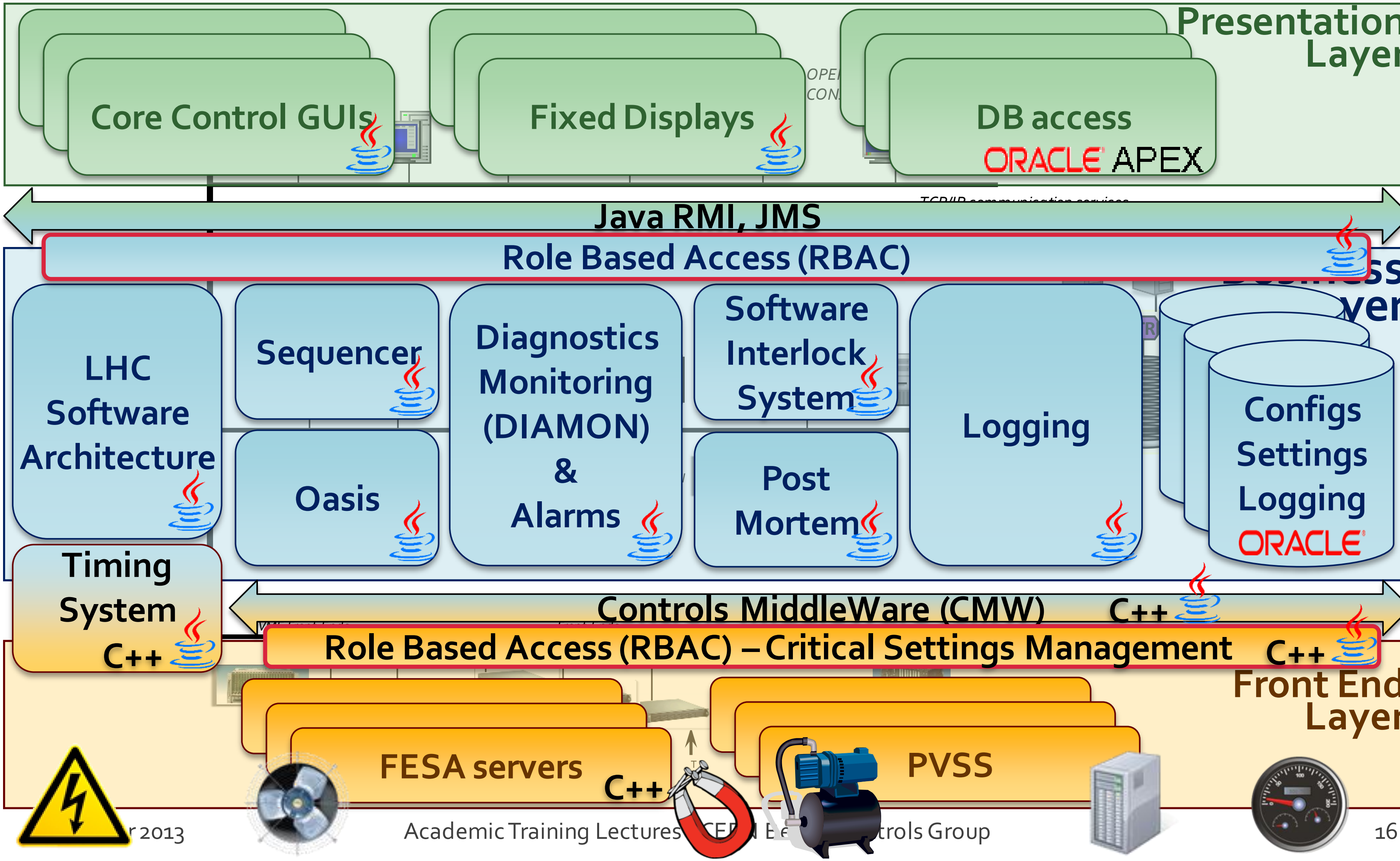
Comments 13-04-2012 16:47:56 :

fill with 1092b

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

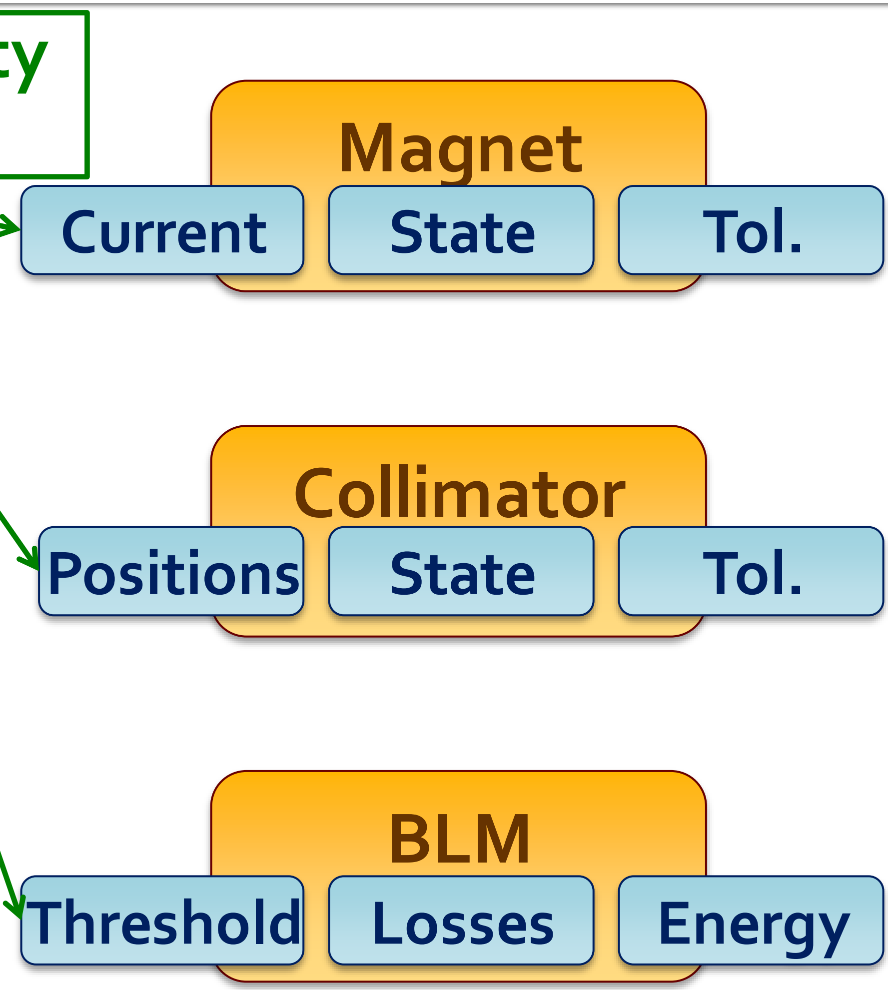
AFS: 50ns_1092b_1054_0_1032_108bpi12inj PM Status B1 ENABLED PM Status B2 ENABLED

Controls SW Infrastructure



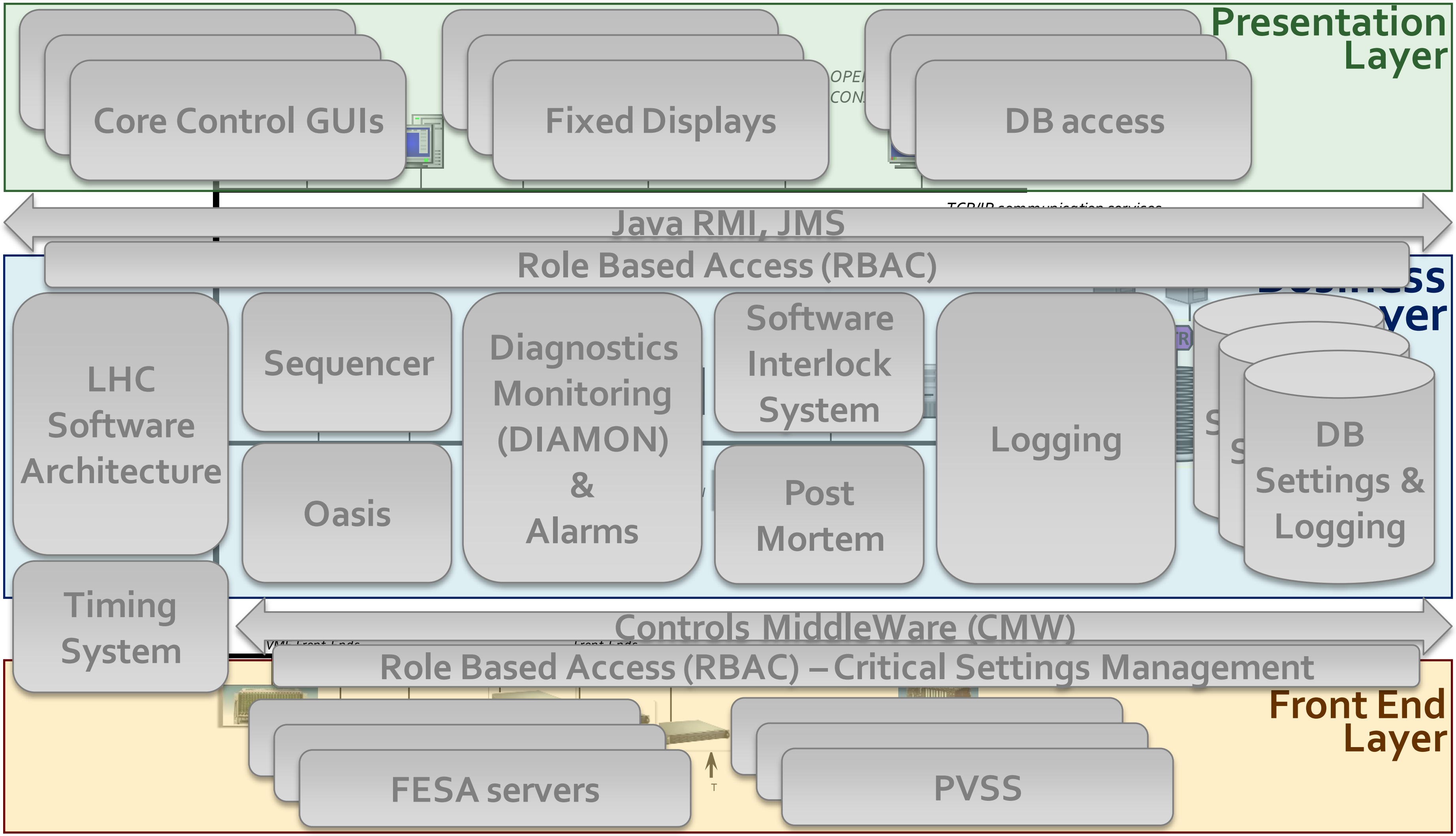
Device-Property Model

- Devices
  - Magnets
  - Collimators
  - Sensors
- Properties
  - Current, state, tolerance…
  - Positions, state, tolerance…
  - Losses…
- Strict naming convention
- Read/write properties
- Scope is wider than HW

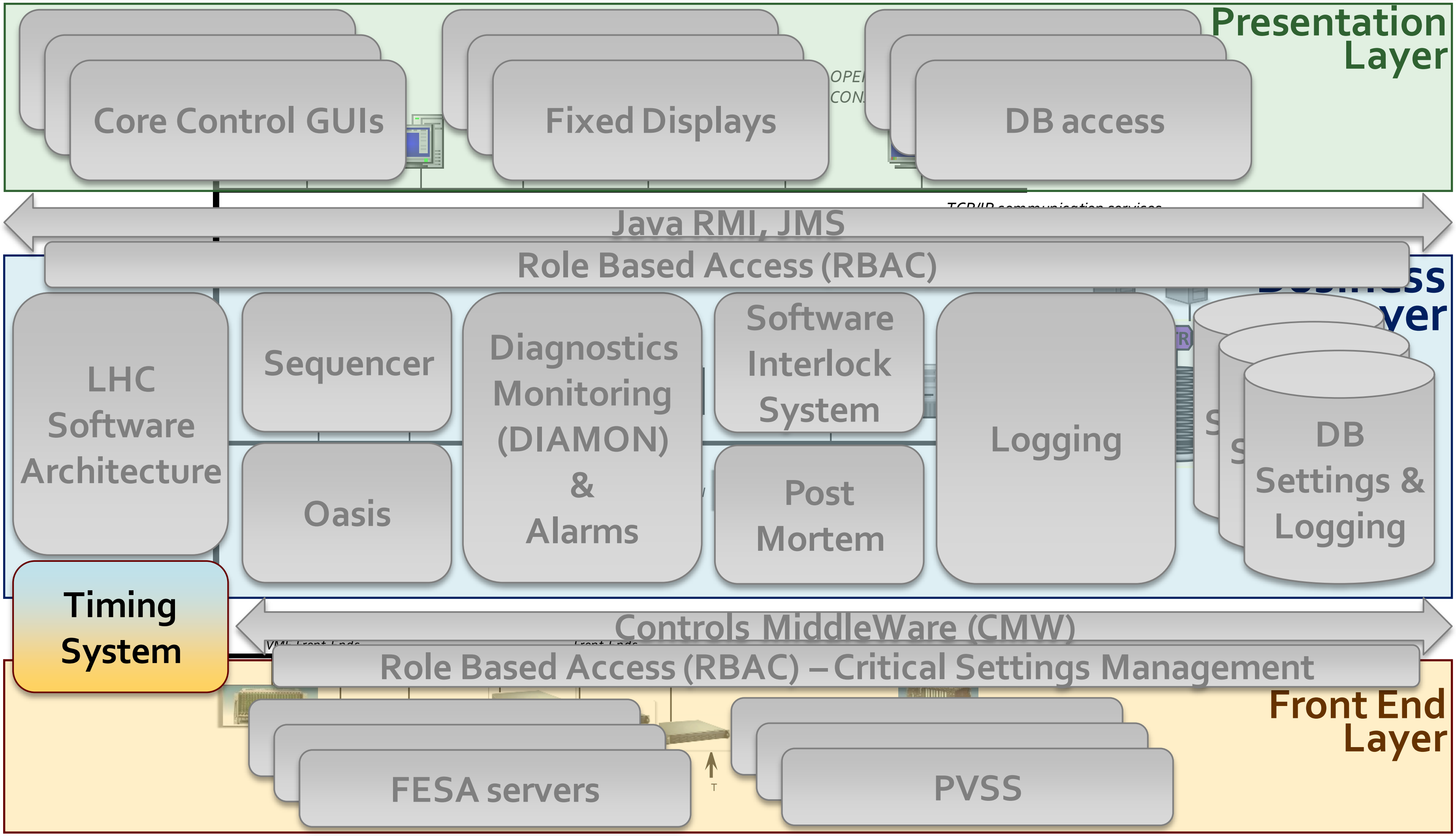


Contents

Key components



Key components: Timing System



Timing System

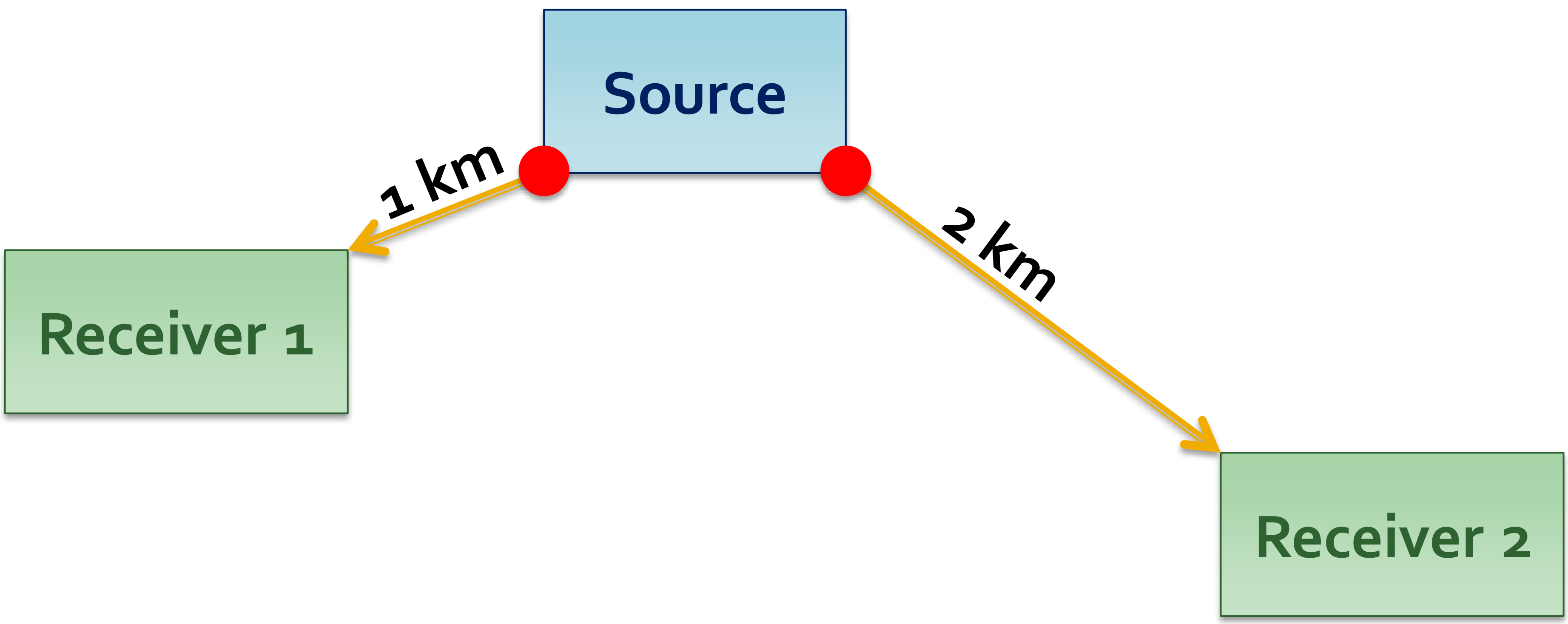
- Have many systems acting in **sync**
  - ex. synchronously ramp up LHC magnets

- Provide a **common notion of time** in distributed system - to make sense of acquired data
  - LHC: data timestamps have 1 μs precision

TIME and SYNCHRONIZATION
are very IMPORTANT everywhere

Timing System: challenges

- Compensate the transmission delay from the source to receivers



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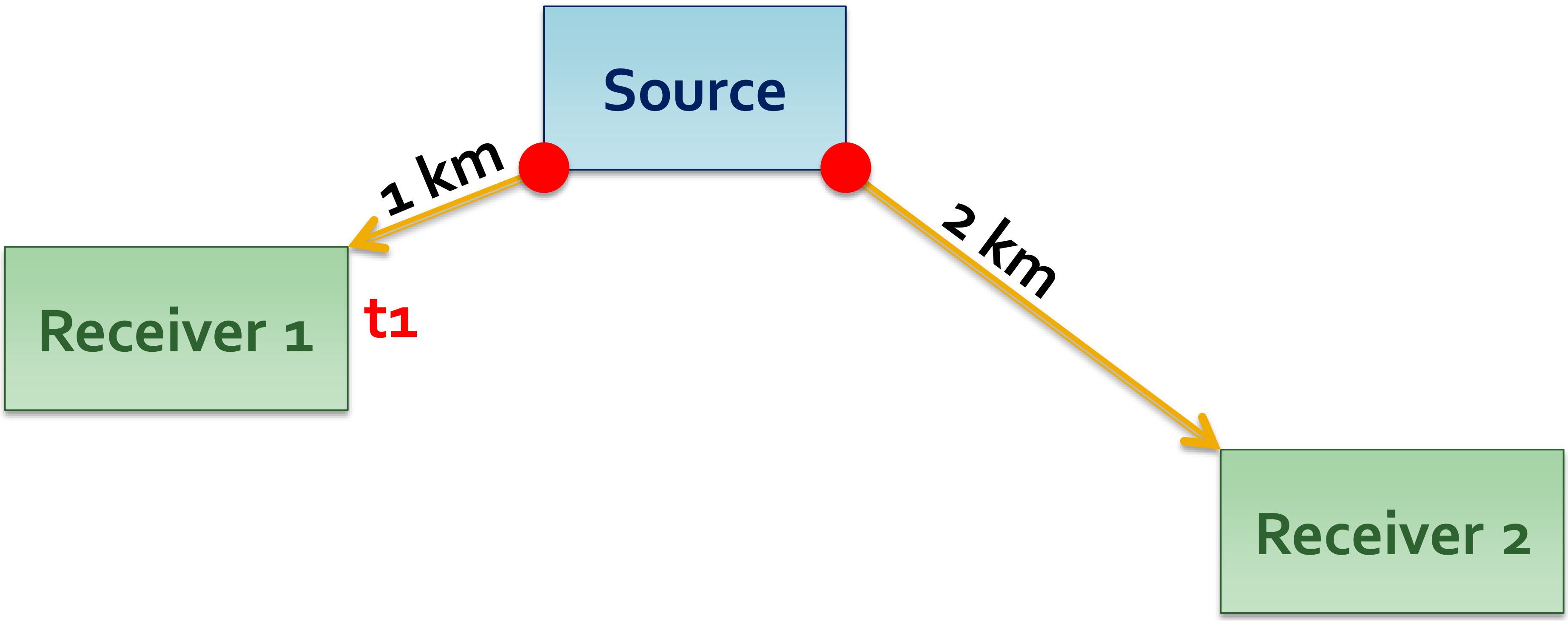

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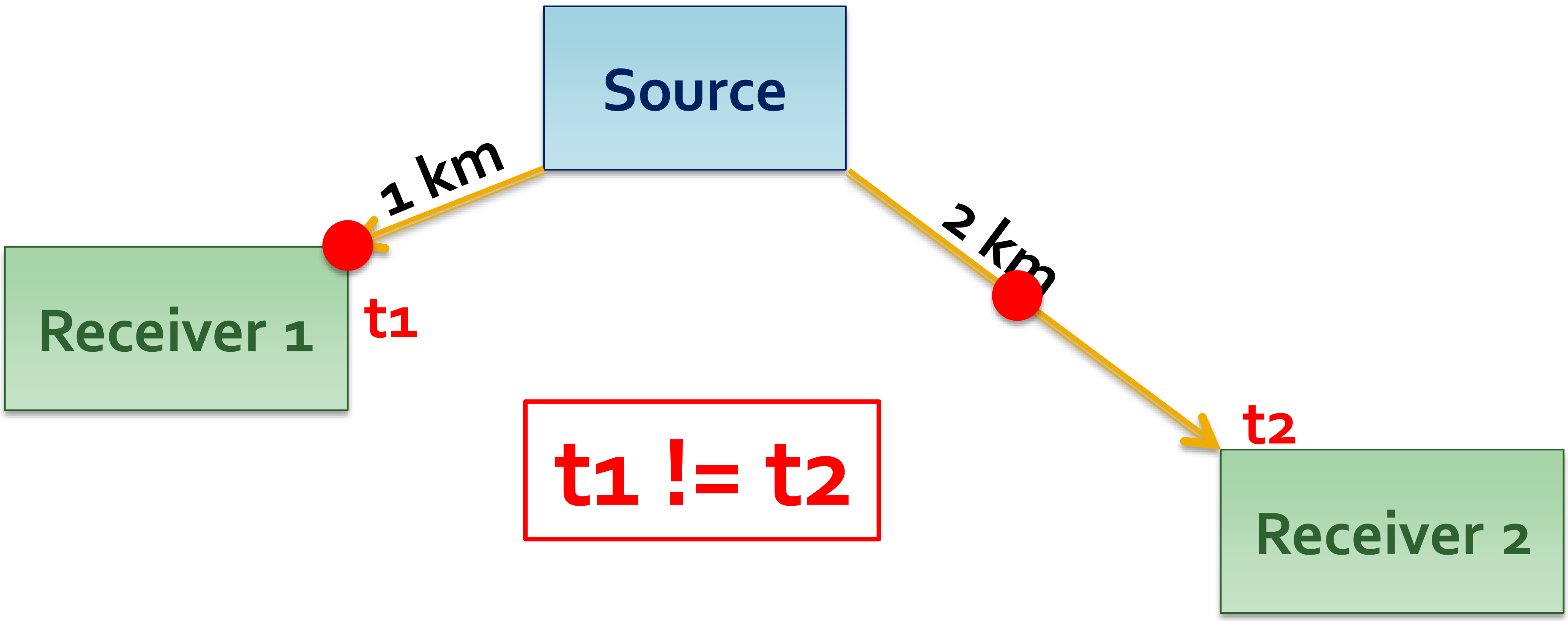
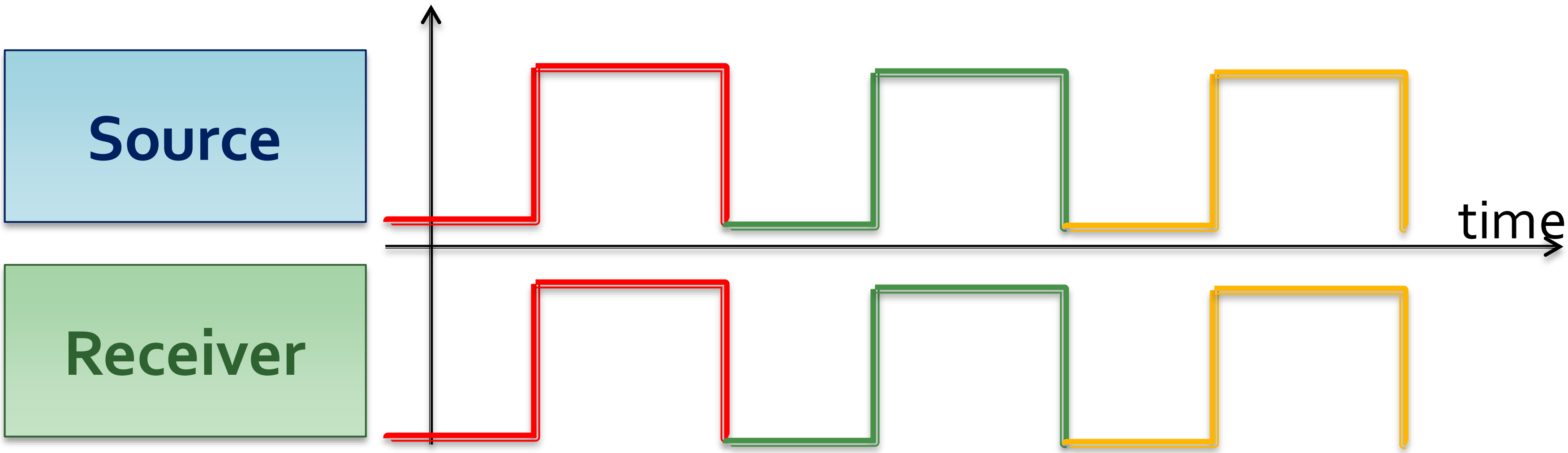


Timing System: challenges

- Compensate the transmission delay from the source to receivers
- Keep clocks of the nodes in sync



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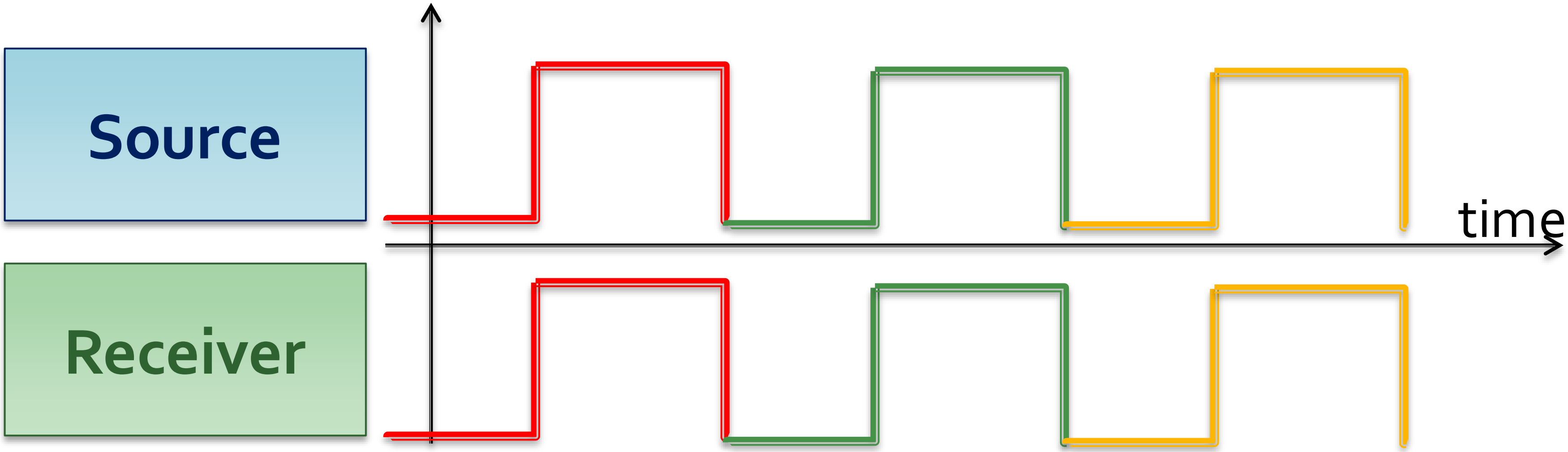

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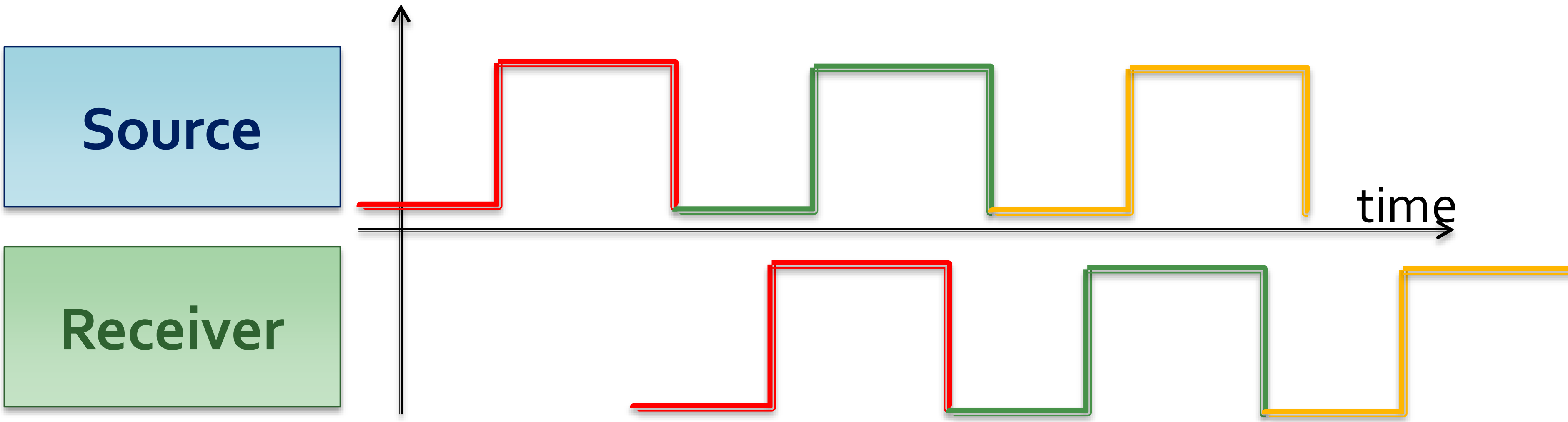

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- Compensate the transmission delay from the source to receivers
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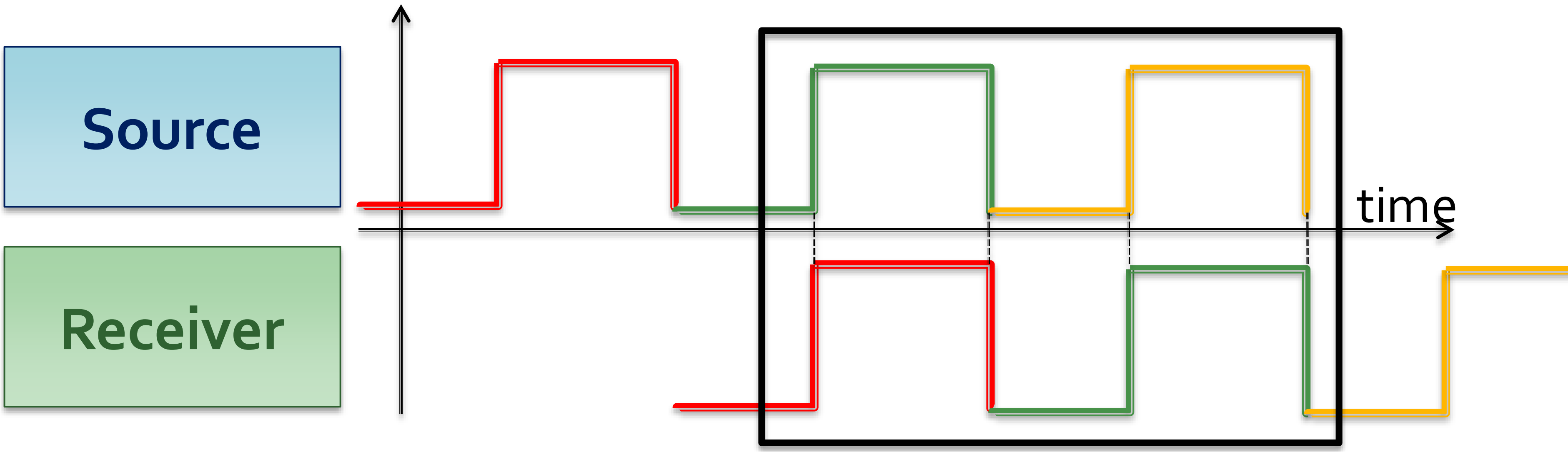
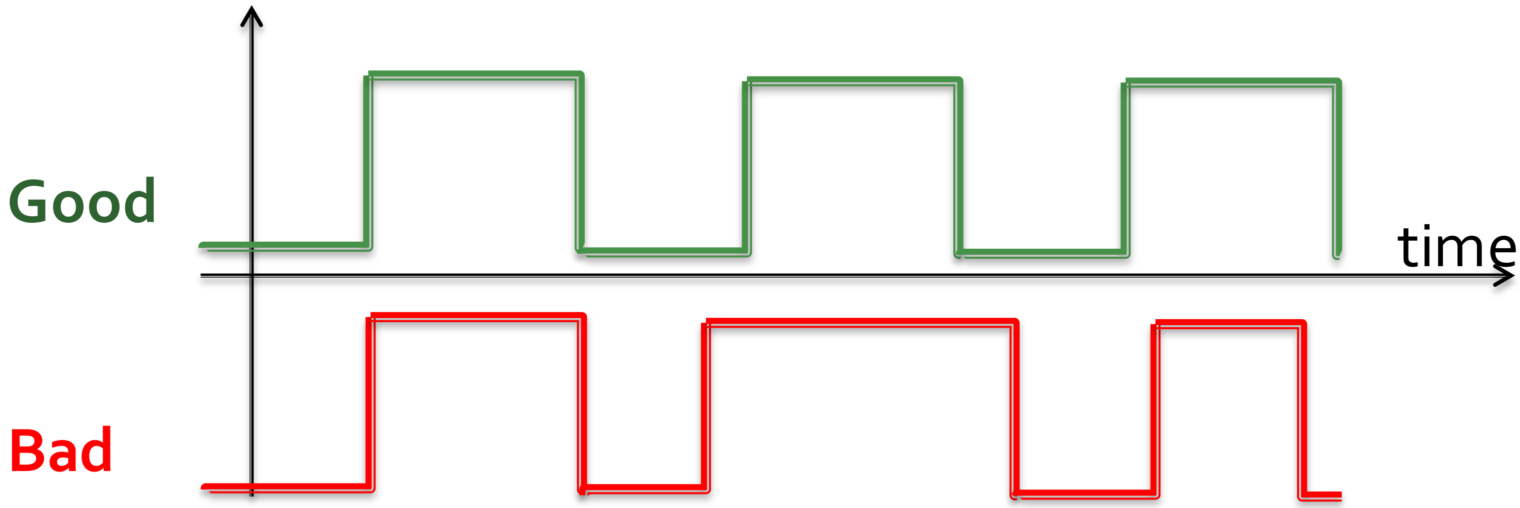


Timing System: challenges

- Compensate the transmission delay from the source to receivers
- Keep clocks of the nodes in sync
- Generate very good periodic clock at the source



LHC Timing System: today

- Event-based timing system
- Dedicated network
- Manually calibrated (hardcoded delays)
- 2 source nodes (active + hot spare)
- ~1000 receiver serving ~8000 clients

LHC Timing System: future

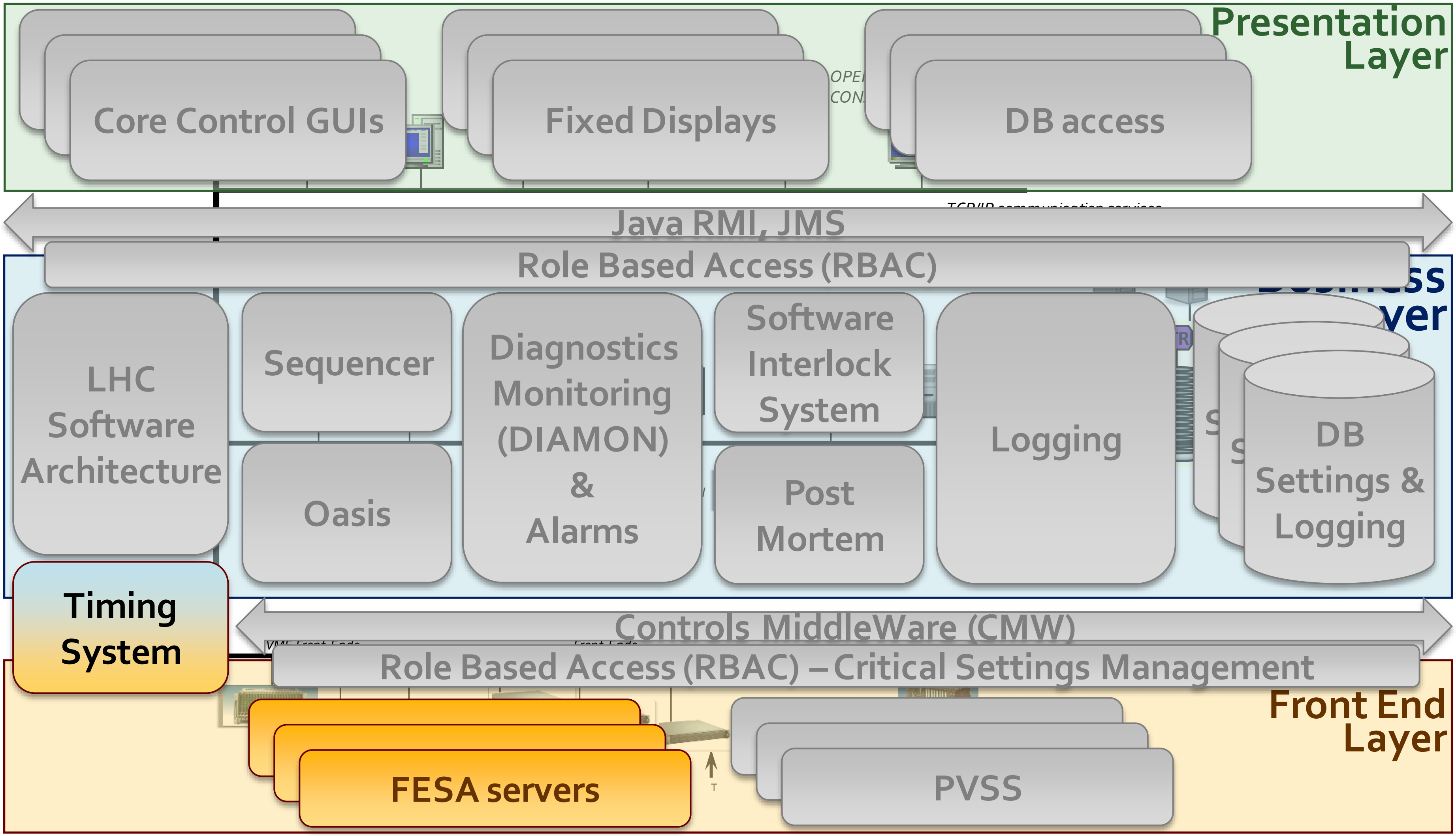
- Switch to WhiteRabbit
  - Time-based timing system
  - Automatically synchronized “common time”
  - Ethernet-based
  - Deterministic
  - Reliable: redundant both for topology and data
  - Initiated and developed in CERN
  - Open standard

Open Source Hardware

- Initiated by CERN (BE/CO/HT)
- Inspired by Open-Source Software
  - Hardware designs and documentation are publically accessible
  - Knowledge dissemination
  - Improved hardware quality
  - No vendor-lock
  - Re-usage of designs

www.ohwr.org

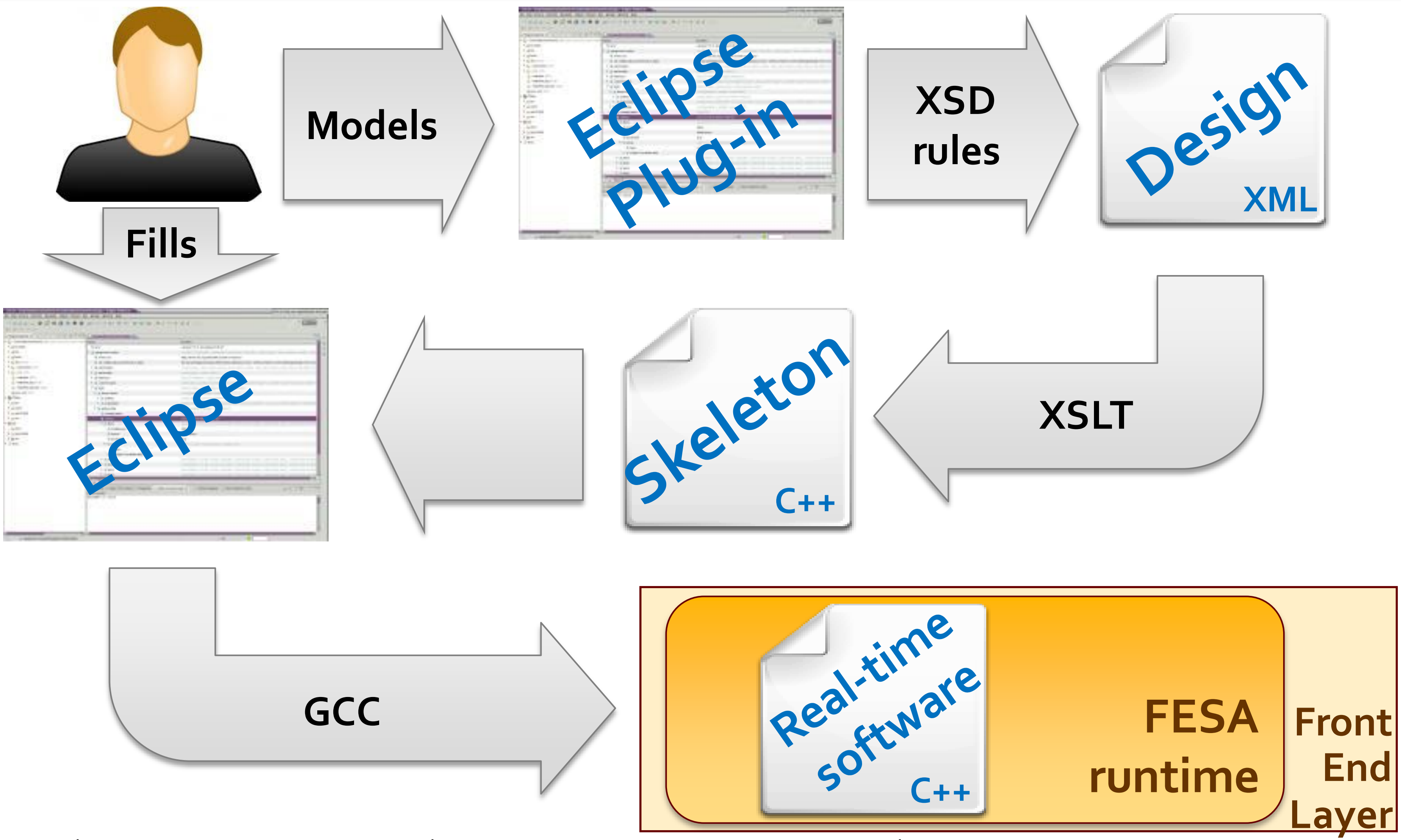
Key components: FESA



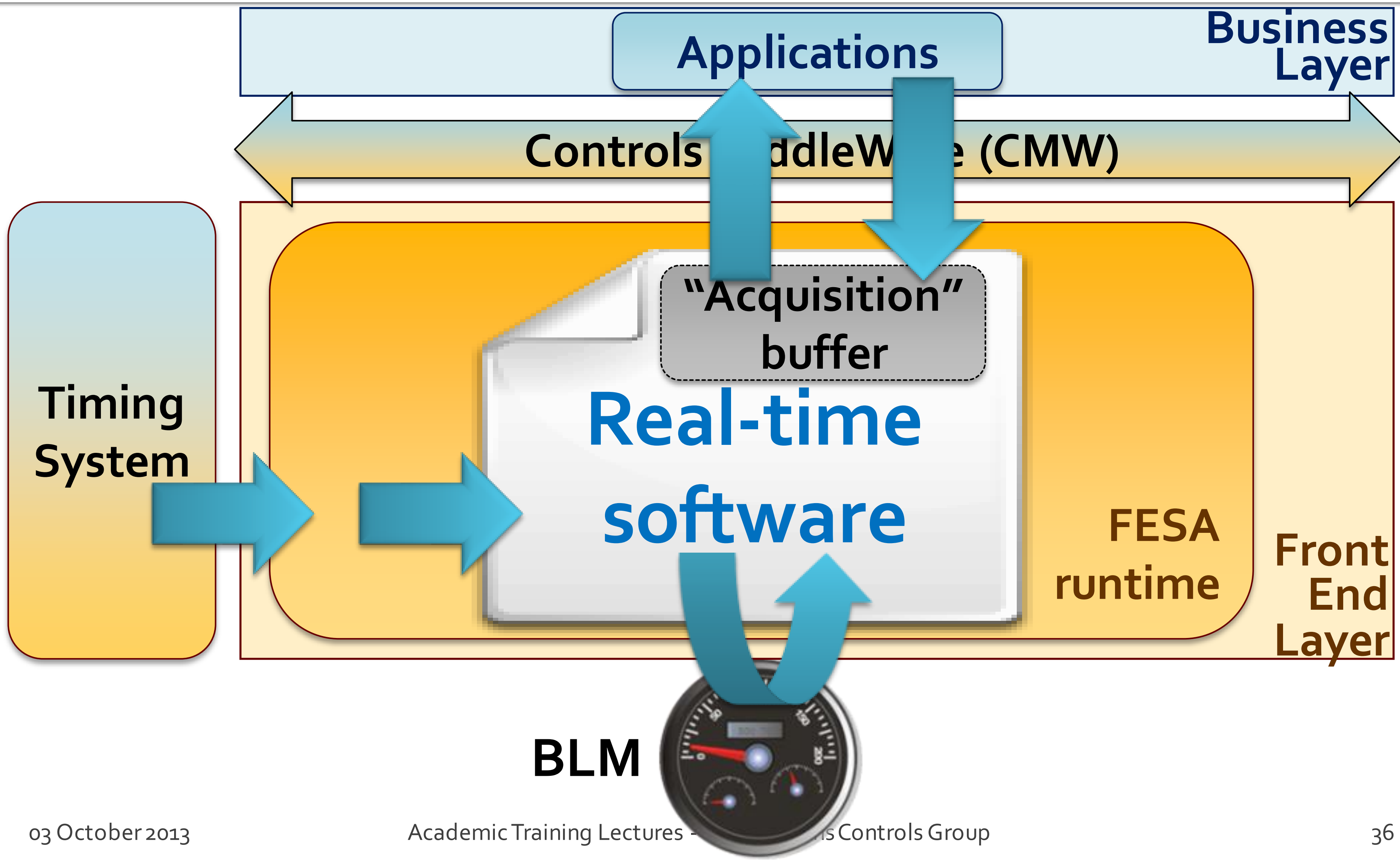
Front End Software Architecture

- Framework to develop **real-time** software to control equipment
- **Integrates the equipment** into Control System
- Equipment => **device-property model**
- **Common model** for software structure
- Allows developer to **focus on HW-specific logic**
- **Saves** developer's **time**
- **Standard** approach to develop Front-End Software **for all accelerators**

FESA: development workflow



FESA: runtime



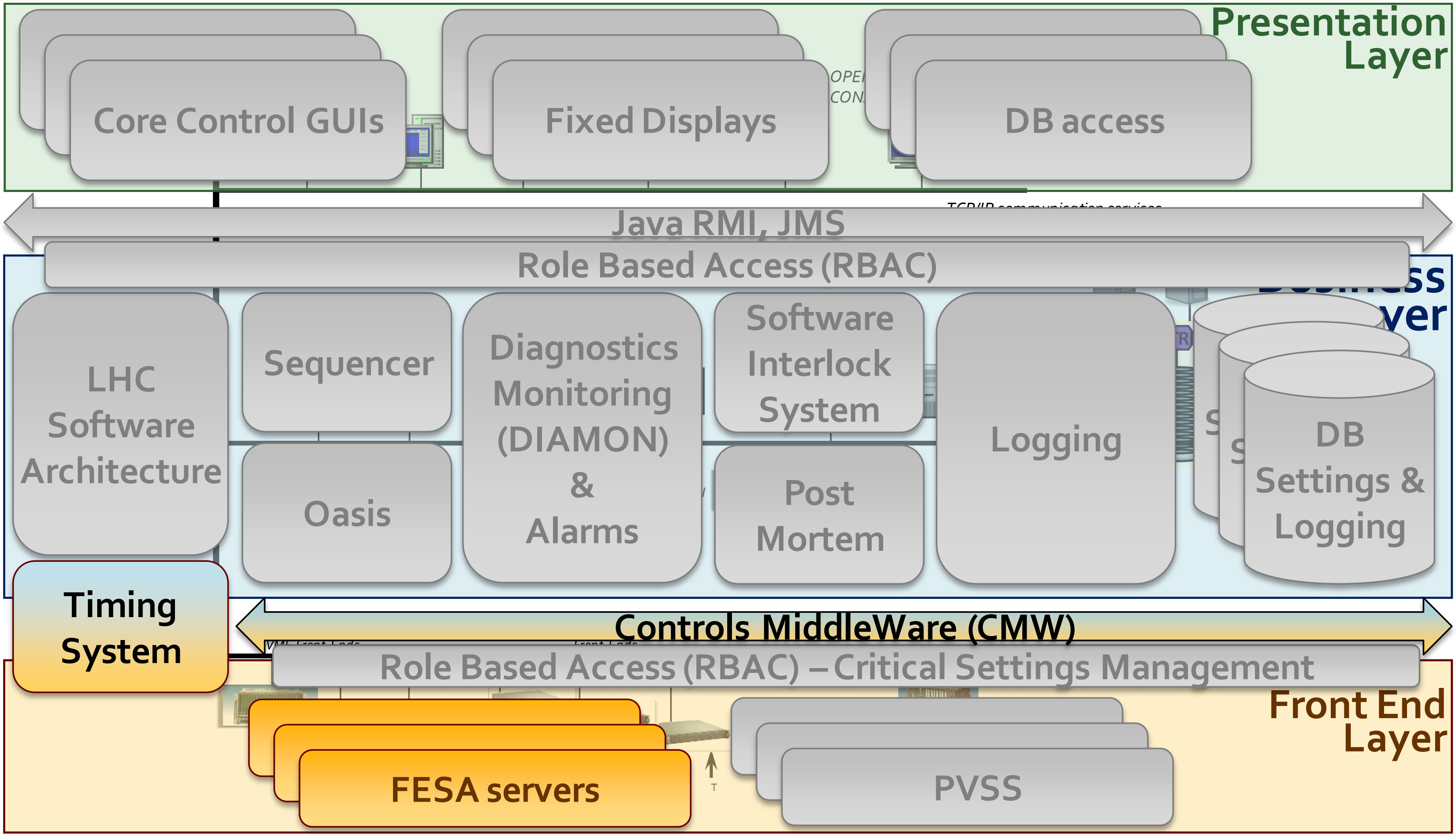
FESA: features

- **Simplifies** the development
- **Consistent**: across all equipment software
- **Satisfies** equipment groups
  - Working with many devices
  - Devices generate a lot of data
  - Strong real-time constraints

FESA: today

- **~100 developers** from 16 equipment groups
- **~600 device types** (~200 in LHC)
- **~55000 devices** (~25000 in LHC)
- **~1000 Front-Ends** (~500 in LHC)
- **Exportable**: used in GSI (Darmstadt)

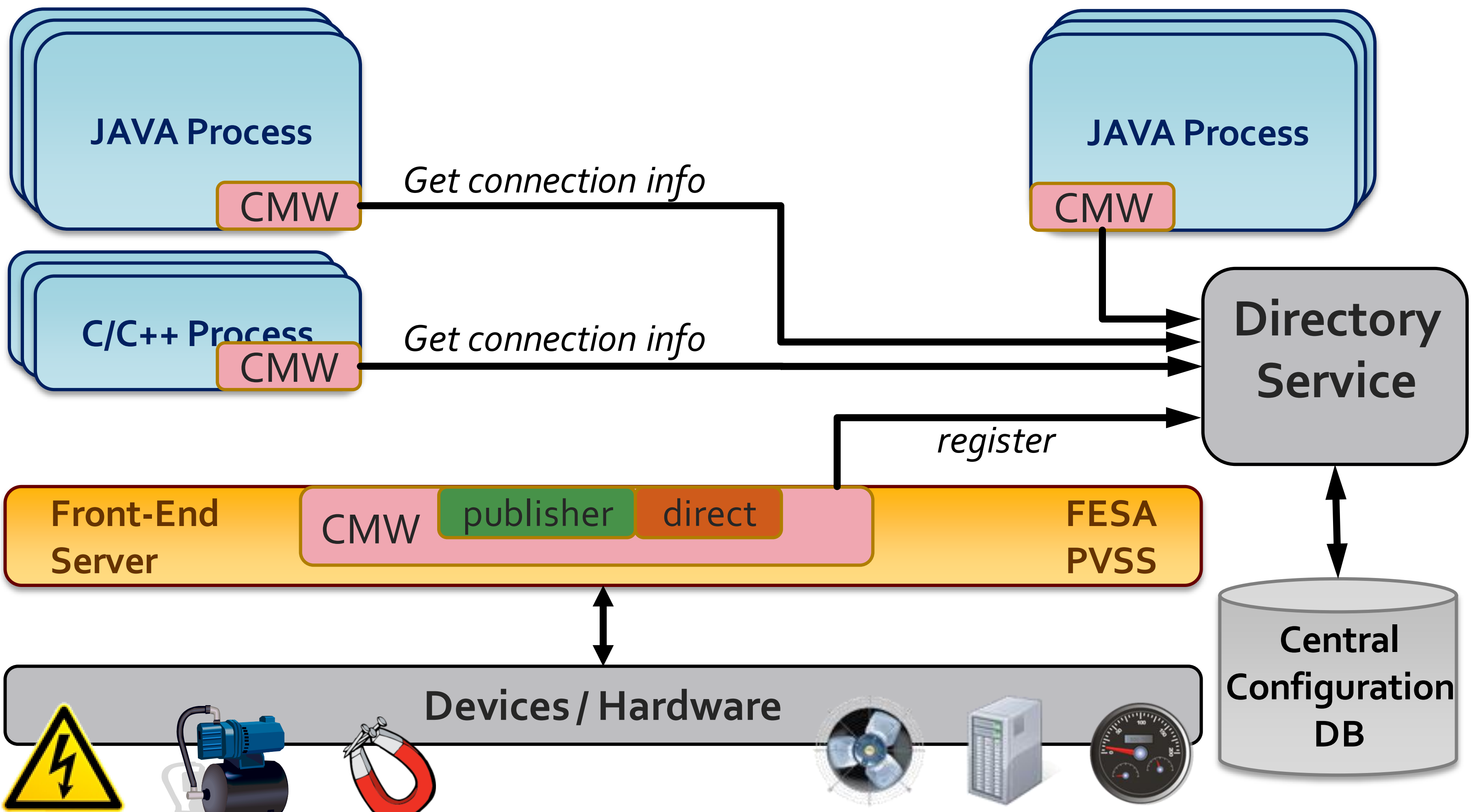
Key components: CMW



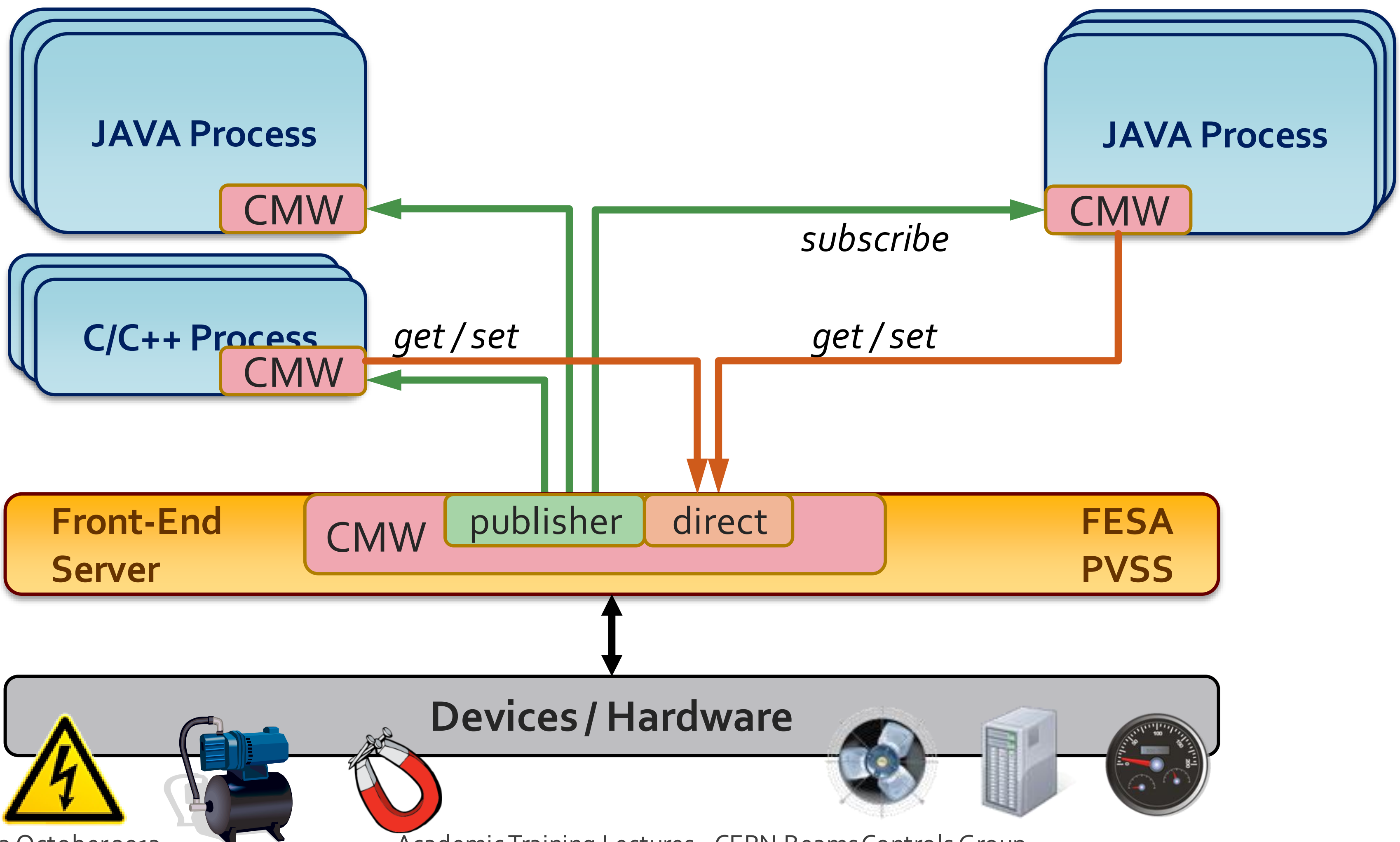
Controls MiddleWare (CMW)

- Core **communication** layer => **critical**
- Collection of software **components** & **services**
- Communication => **device-property model**
- Operations: **GET**, **SET**, **SUBSCRIPTION**
- Widely deployed for **all CERN accelerators**

CMW: architecture



CMW: architecture



CMW Remote Device Access

- Client & server libraries (C++, Java)
- (was) CORBA-based => moving to ZeroMQ
- Decentralized (no brokers, etc) => scalable
- Directory Service is clustered

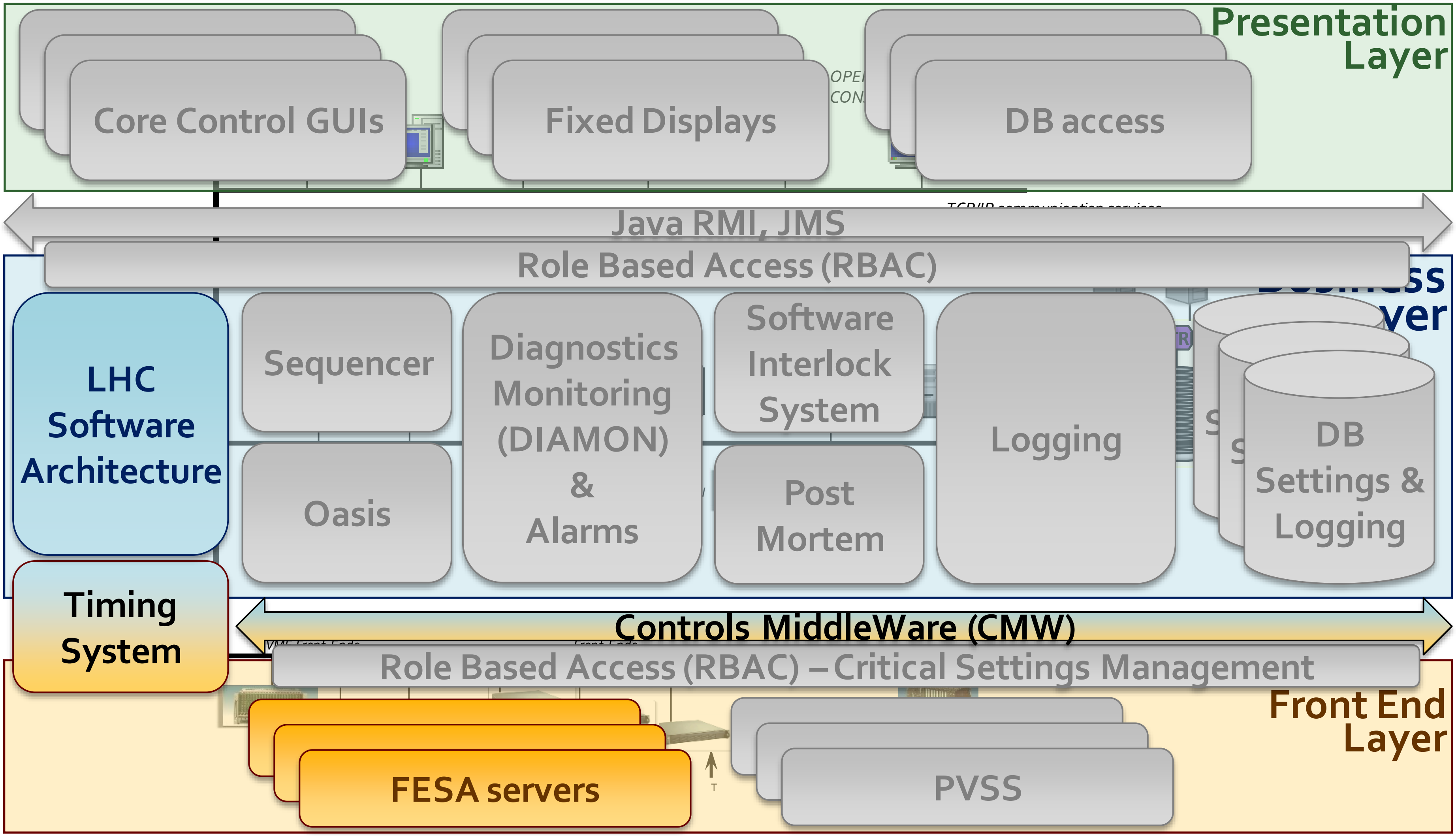
CMW: features

- **Reliable communication** in distributed system
- **Integrated** with all the platforms
  - Linux / Windows (x32 / x64), LynxOS
  - FESA, PVSS, FGC
  - C++, Java
- Provides **comprehensive diagnostics**

CMW: today

- **4’000 Front-End servers** (processes)
- **85’000** (FESA + PVSS) **devices**
  => **2’000’000 properties**
- 2 Directory Servers (clustered)
- **Exportable**: used in GSI (Darmstadt)

Key components: LSA



LHC Software Architecture (LSA)

- **Settings Management System**

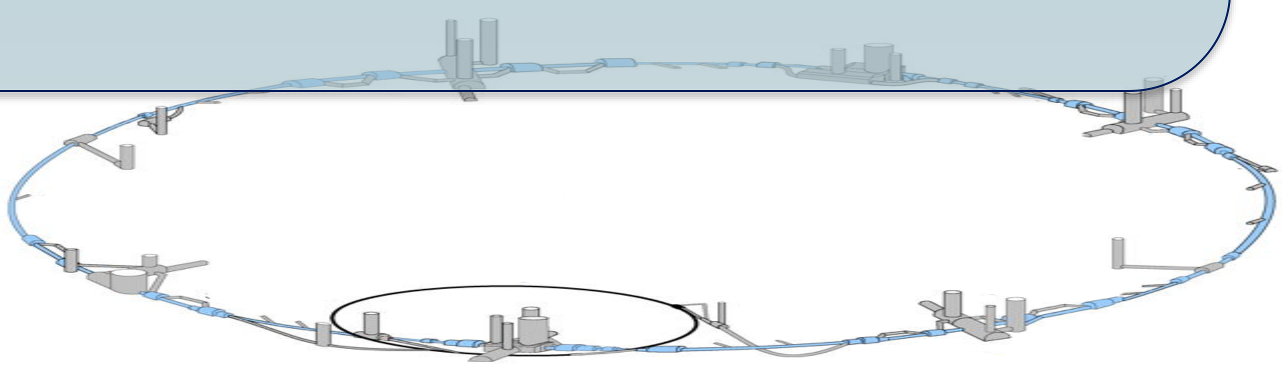
LSA

270’000 device properties to control

Different settings within LHC cycle

Different operational scenarios

150’000’000 of settings

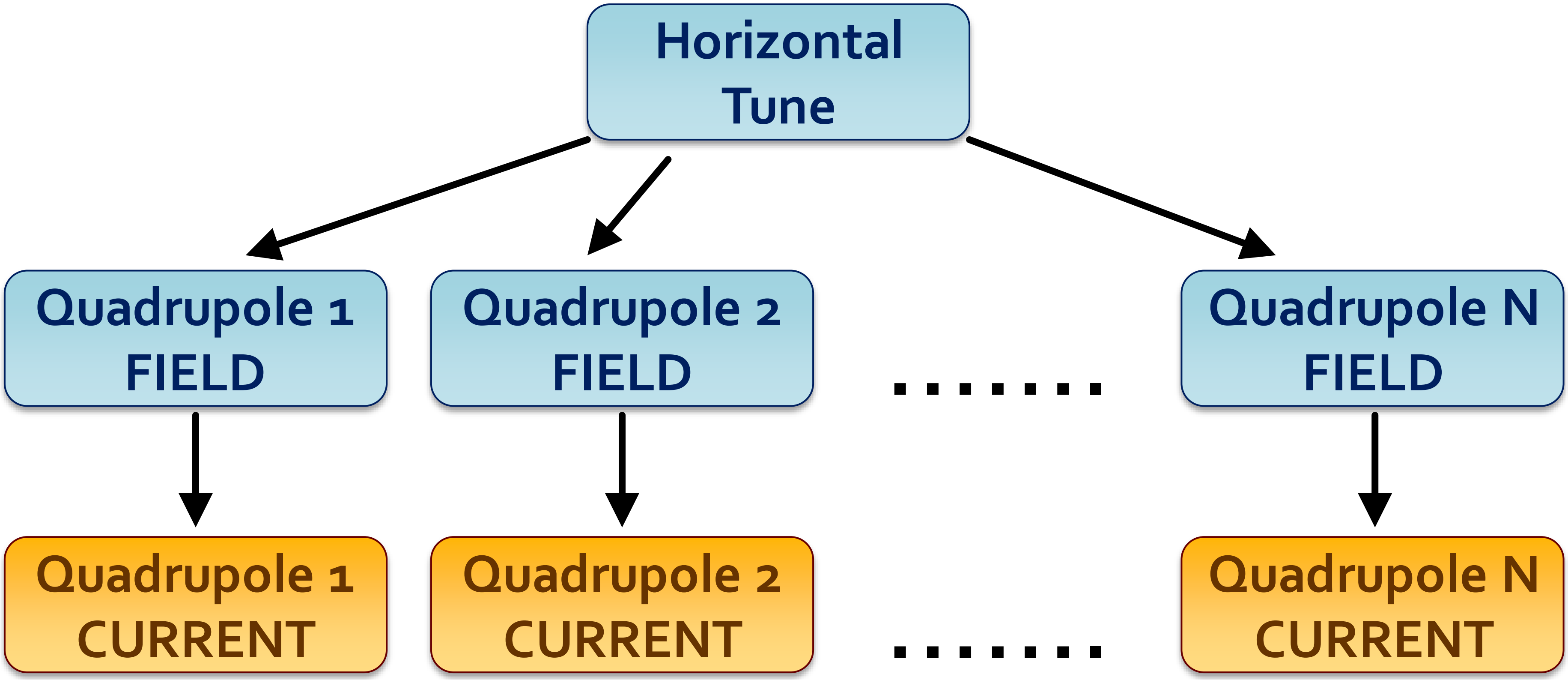


LSA: requirements / expectations

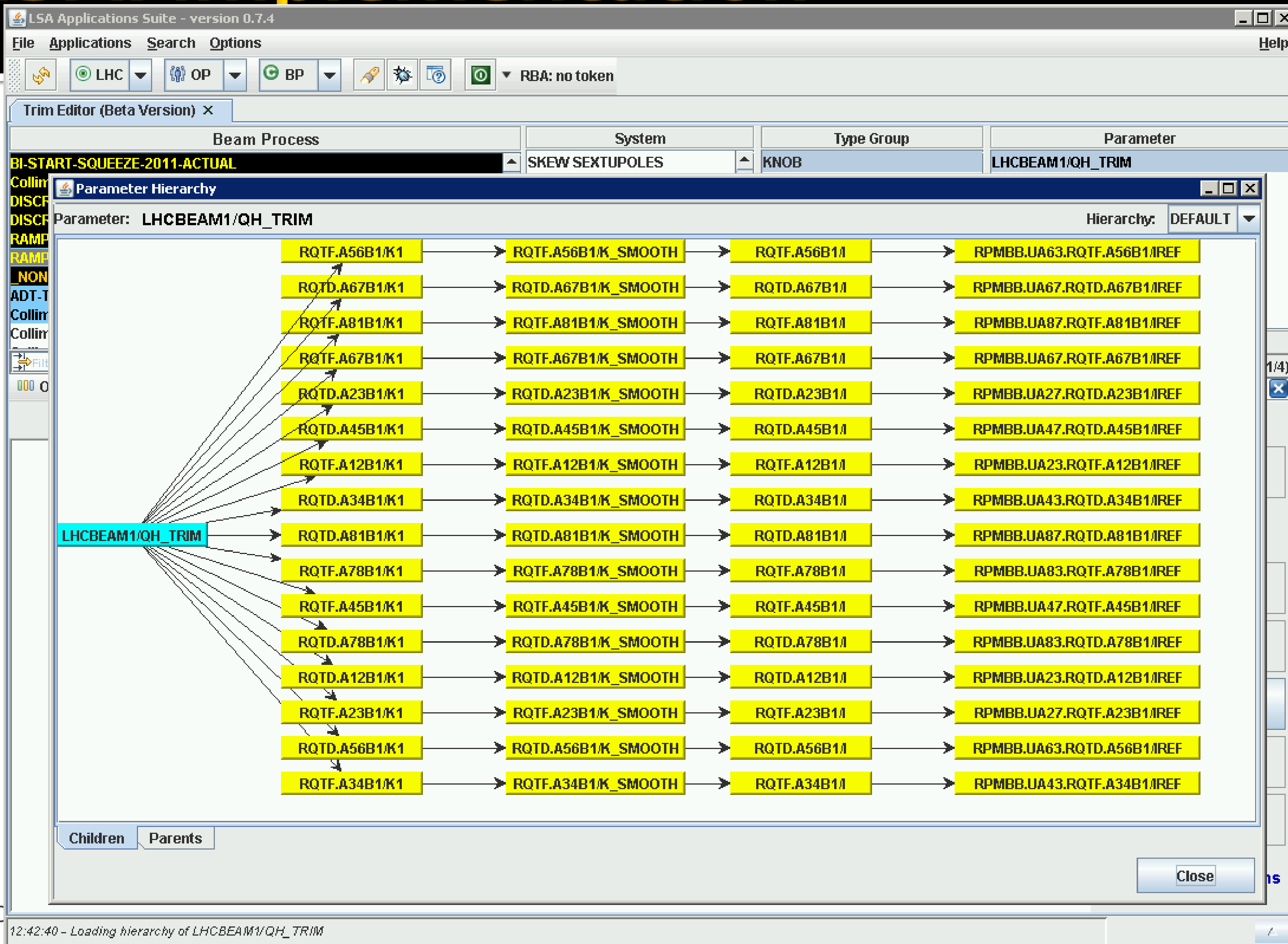
- **Settings Management System**
  - Generation of initial settings based on optics
  - Storage/modification of settings for all devices
  - Coherent modifications of settings
  - Settings versioning
  - History of changes and rollback
- Communication with the hardware
  - Deals with different hardware types and interfaces

LSA: implementation

- **Translation** of high-level accelerator parameters to low-level device properties



LSA: implementation



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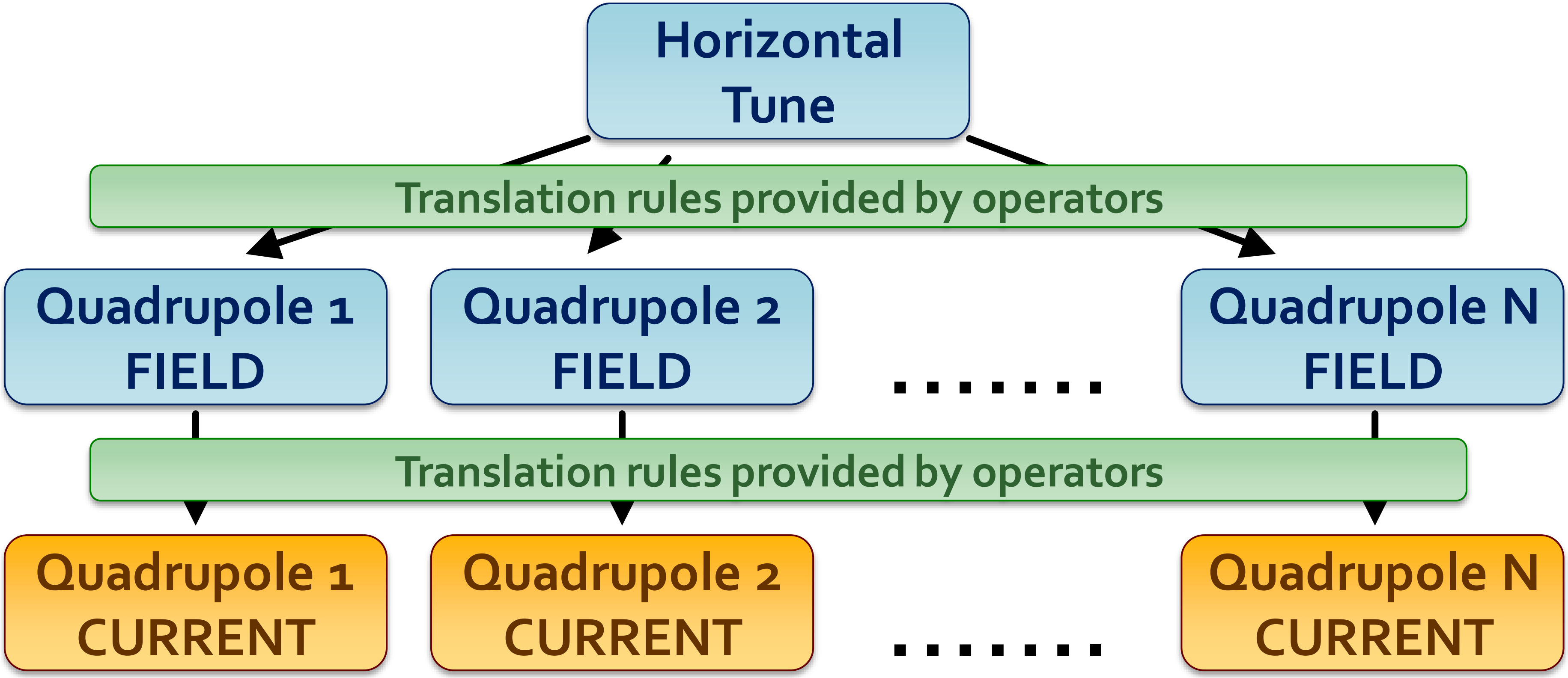
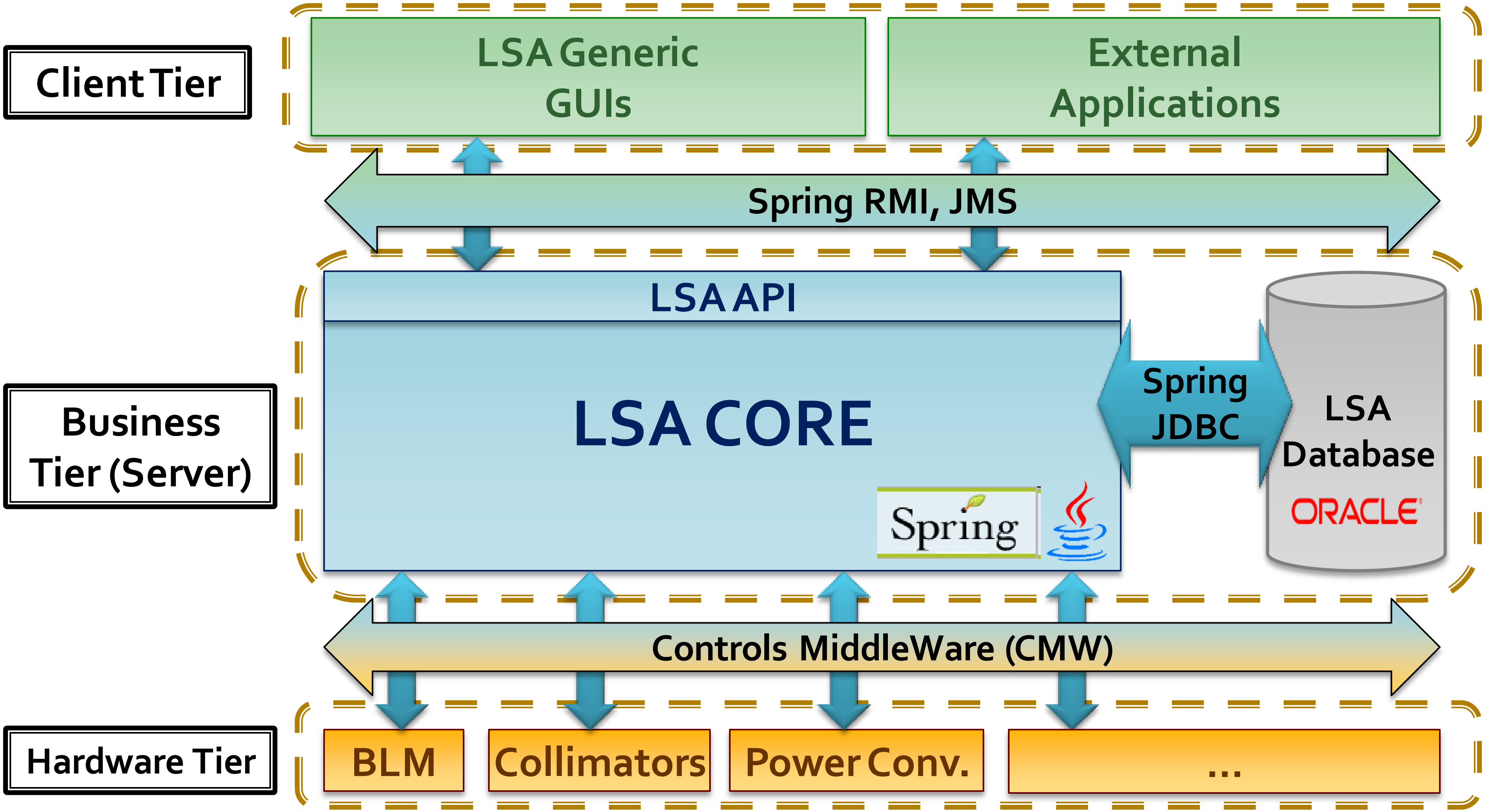


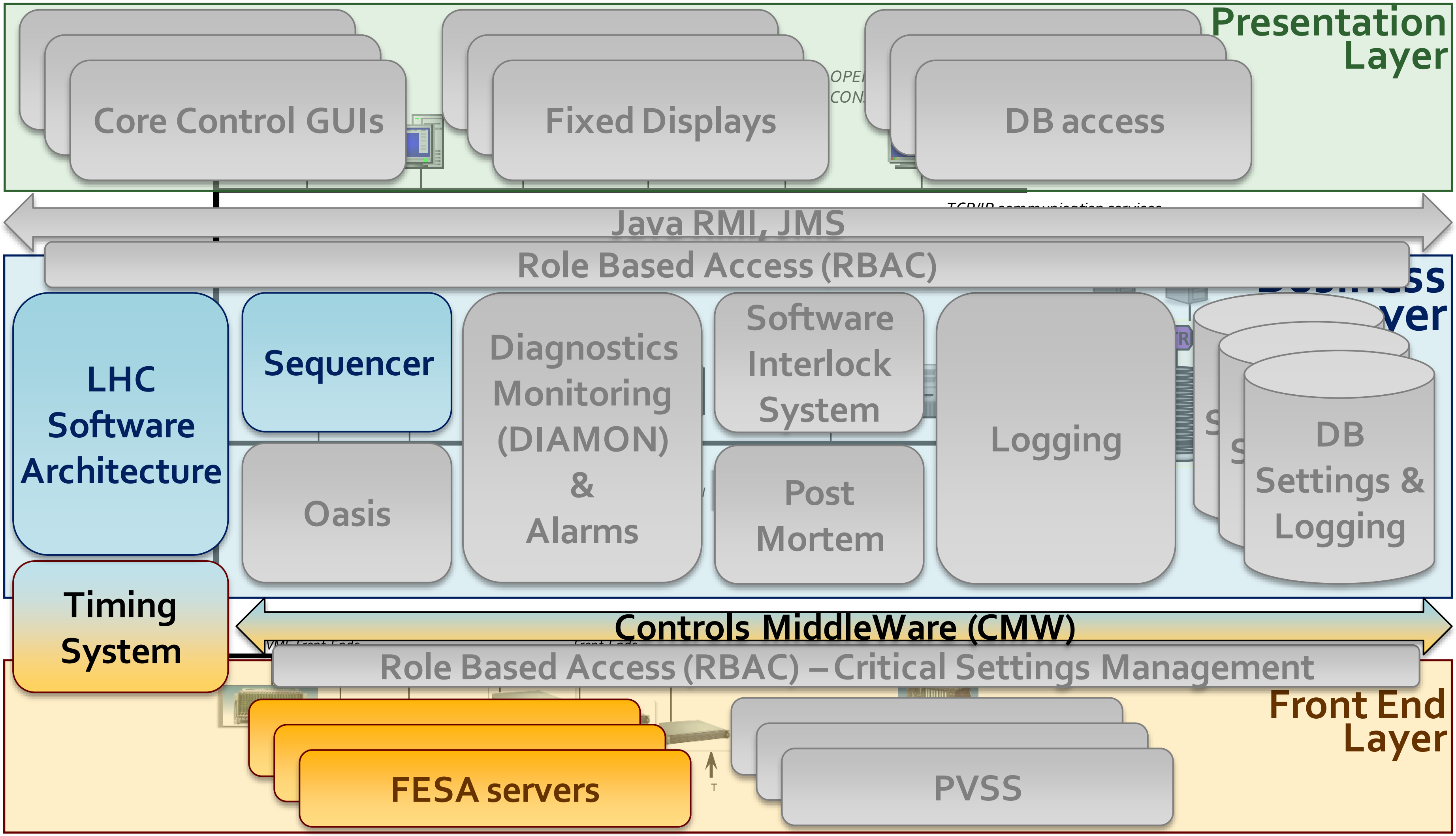
LSA: architecture



LSA: today

- **Shared** between Controls and Operations
- 6 accelerators:
  - LHC, SPS, LEIR, PS, PSB, ISOLDE
  - **Exportable**: used in GSI (Darmstadt)
- > 200 HW types
- > 270 K device properties managed
- > 150 M of settings
- ~ 200 client applications
- > 1M lines of Java code

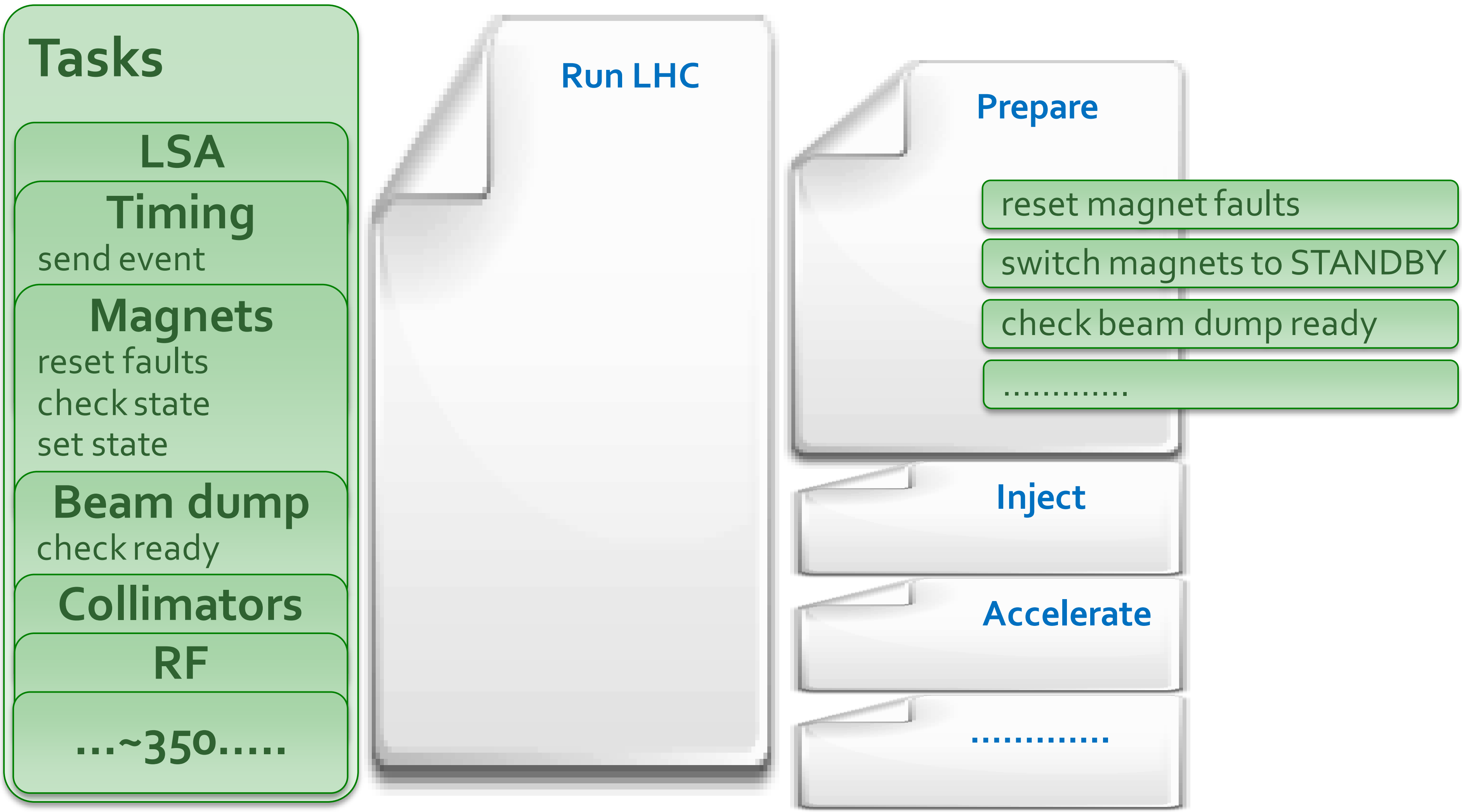
Key components: Sequencer



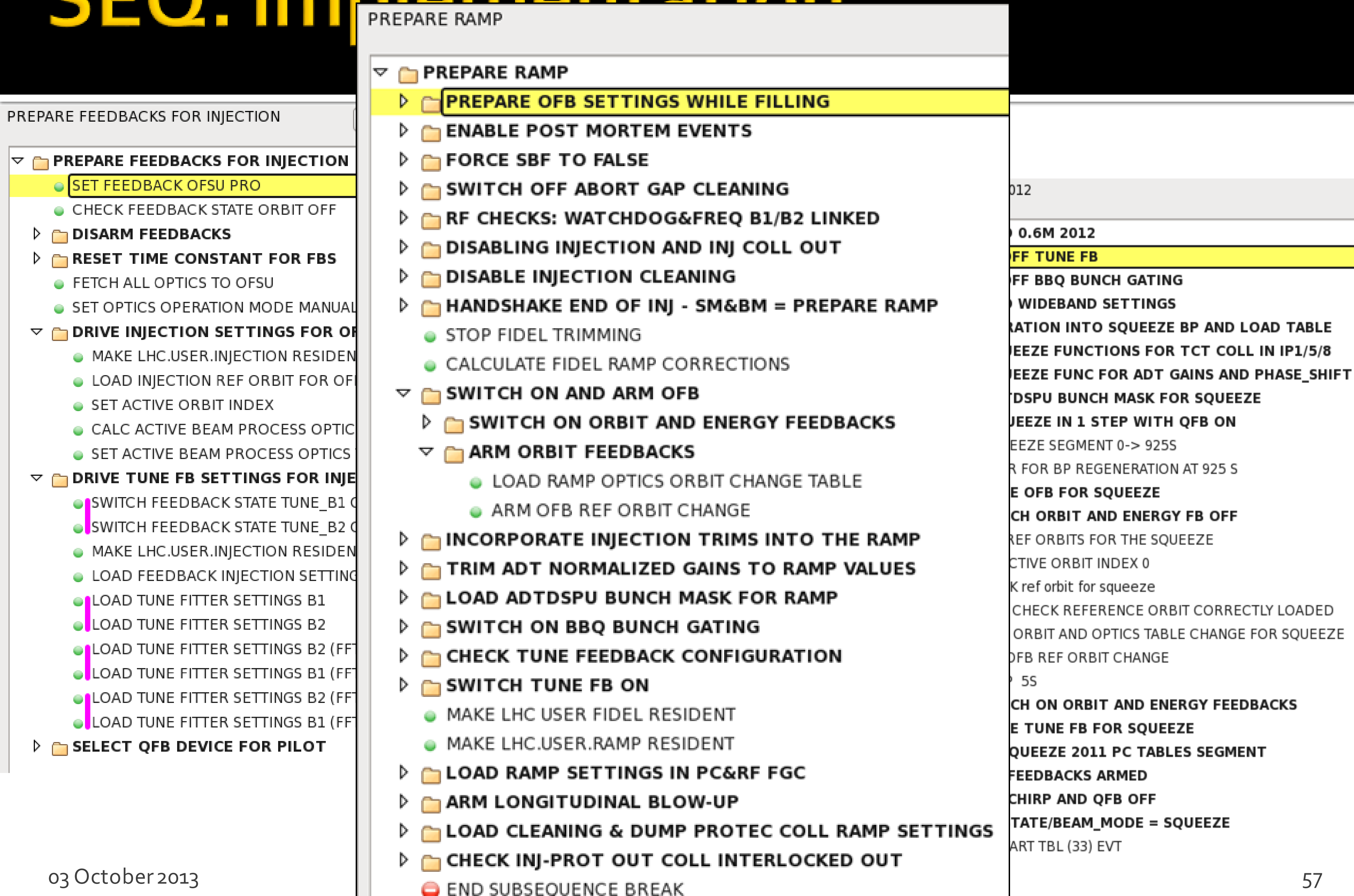
Sequencer

- **Automates** execution of **sequences of tasks**
  - Check a device property has certain value
  - Ask LSA to load the settings
  - Wait for the equipment to be ready
- **Guides operators**
  - Operators' external memory

SEQ: implementation



SEQ: implementation



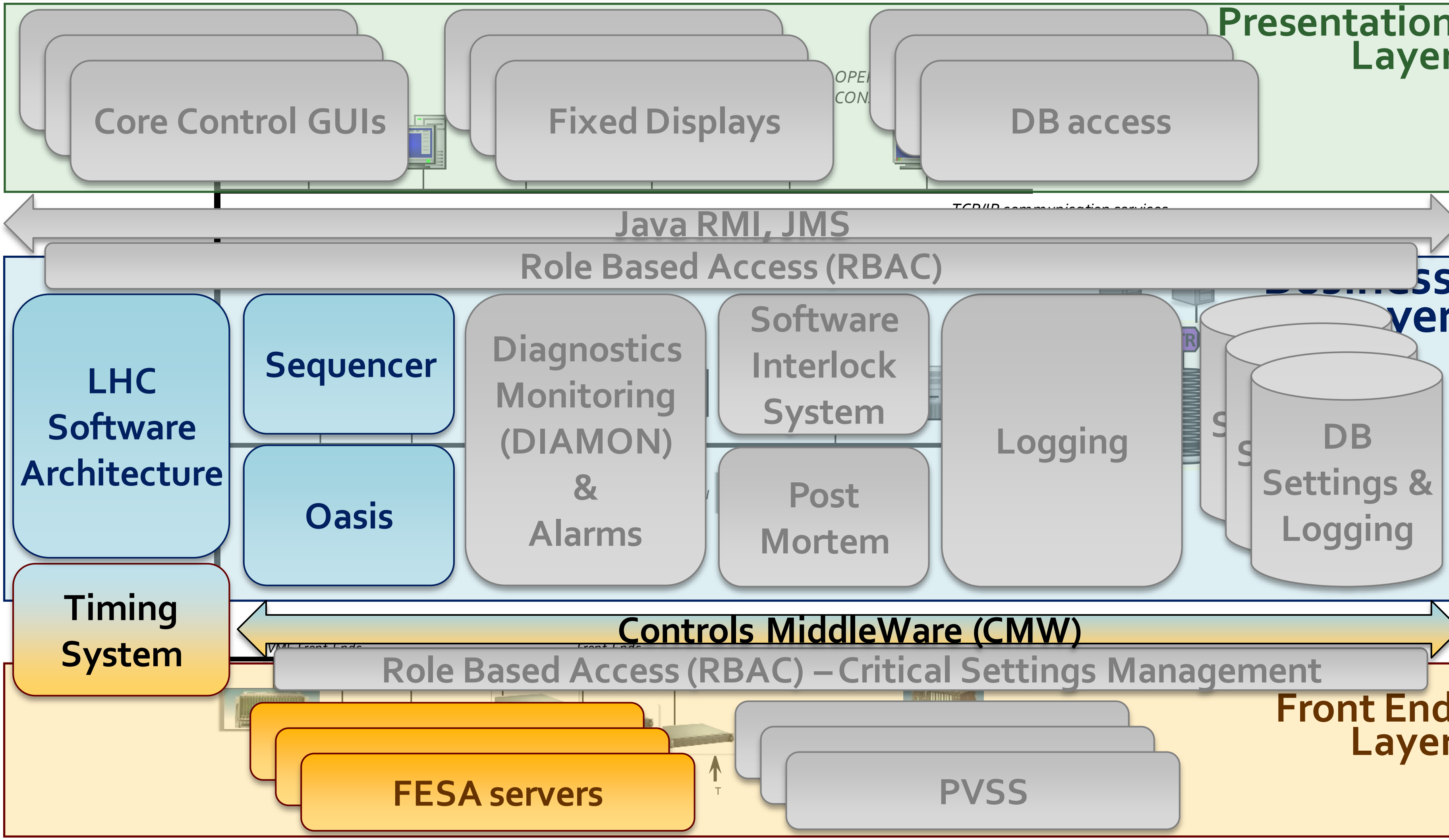
SEQ: features

- **Reliable** execution and error reporting
- **Safe** mode
  - run-through automatically
  - run until task
  - step task-by-task
- **Expert** mode
  - skip task
  - jump to task
- Parallel task execution
- Sequence editing

SEQ: today

- Collaboration with operators and domain experts
- Used in LHC (and other accelerators)
- ~ 1250 sequences for LHC Beam Operation
- ~ 350 tasks types
- LHC main sequence: ~1100 tasks in total

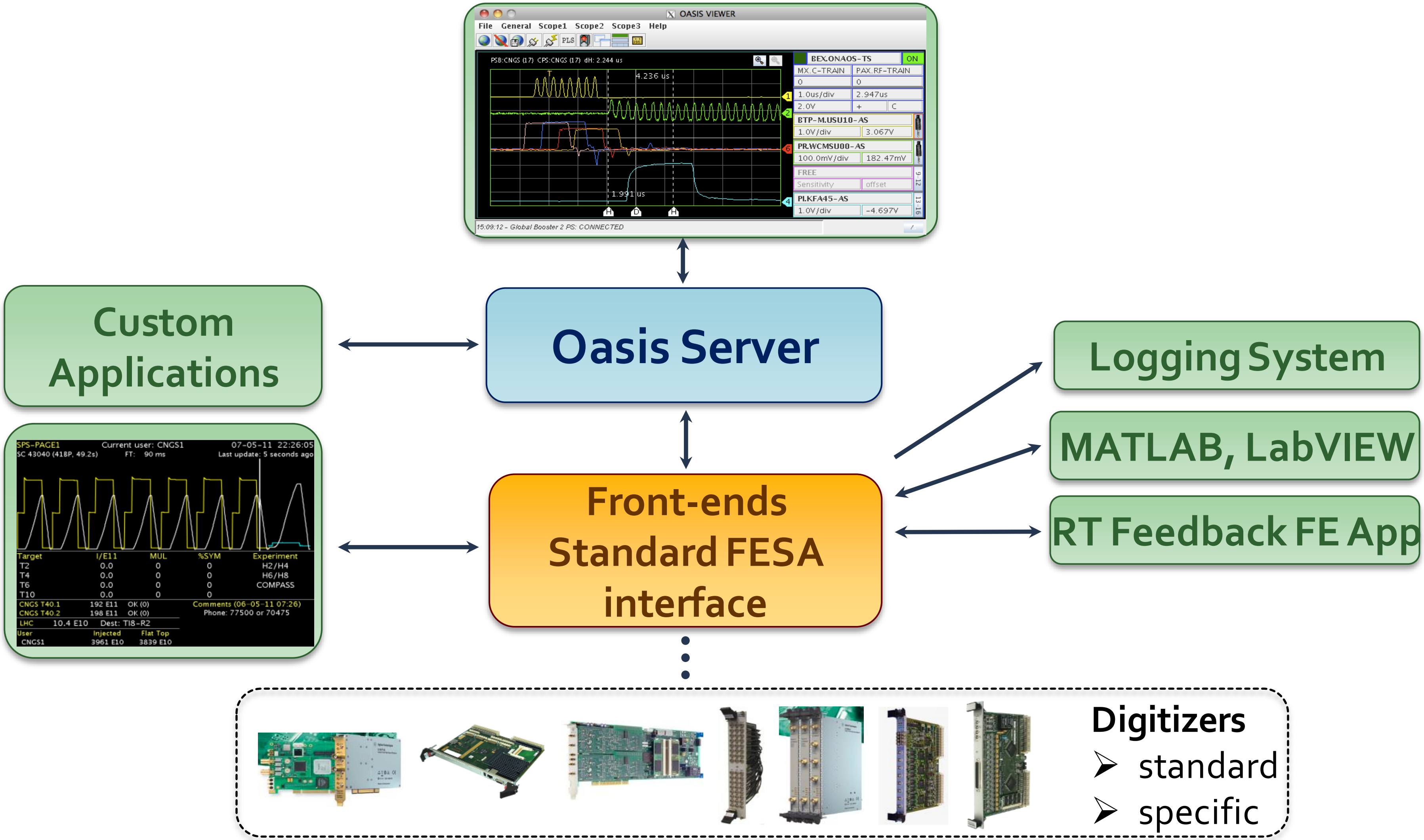
Key components: OASIS



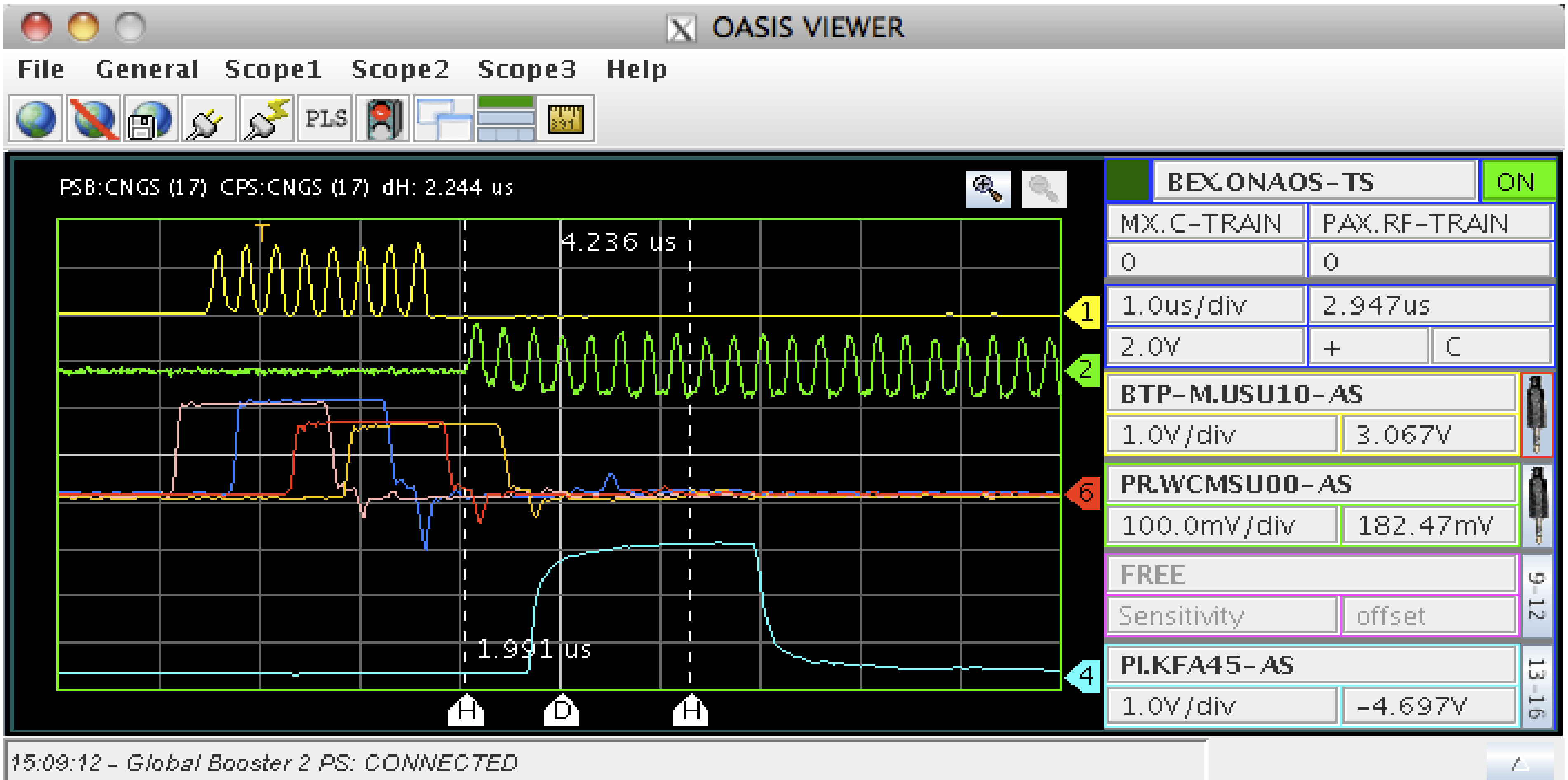
Open Analog Signal Information System

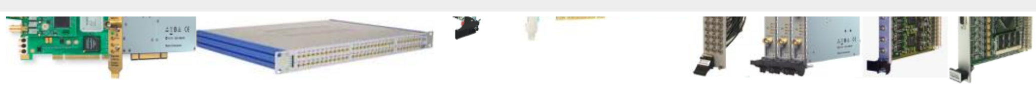
- Analog signal **acquisition** and **digitalization**
- Analog signal **visualization** (**correlation**)
- Full **vertical system**
  - Hardware, Front-Ends, Application server, GUI
- **Standard independent infrastructure** to digitize, transport and visualize
- Invaluable **diagnostics tool**

OASIS: architecture



OASIS: architecture





e.g. RF, BI

OASIS: today

- ~100 front-ends (18 in LHC)
- ~500 digitizers (60 in LHC)
- 200 kHz → 8 GHz
- ~5000 signals (~200 in LHC)
- 80'000 signal acquisition requests per year

That’s it for today: questions?