

# ~~The LHC Control System~~

## CERN Accelerator Control System



**Roman Gorbonosov on behalf of the  
Beams Department Controls Group**

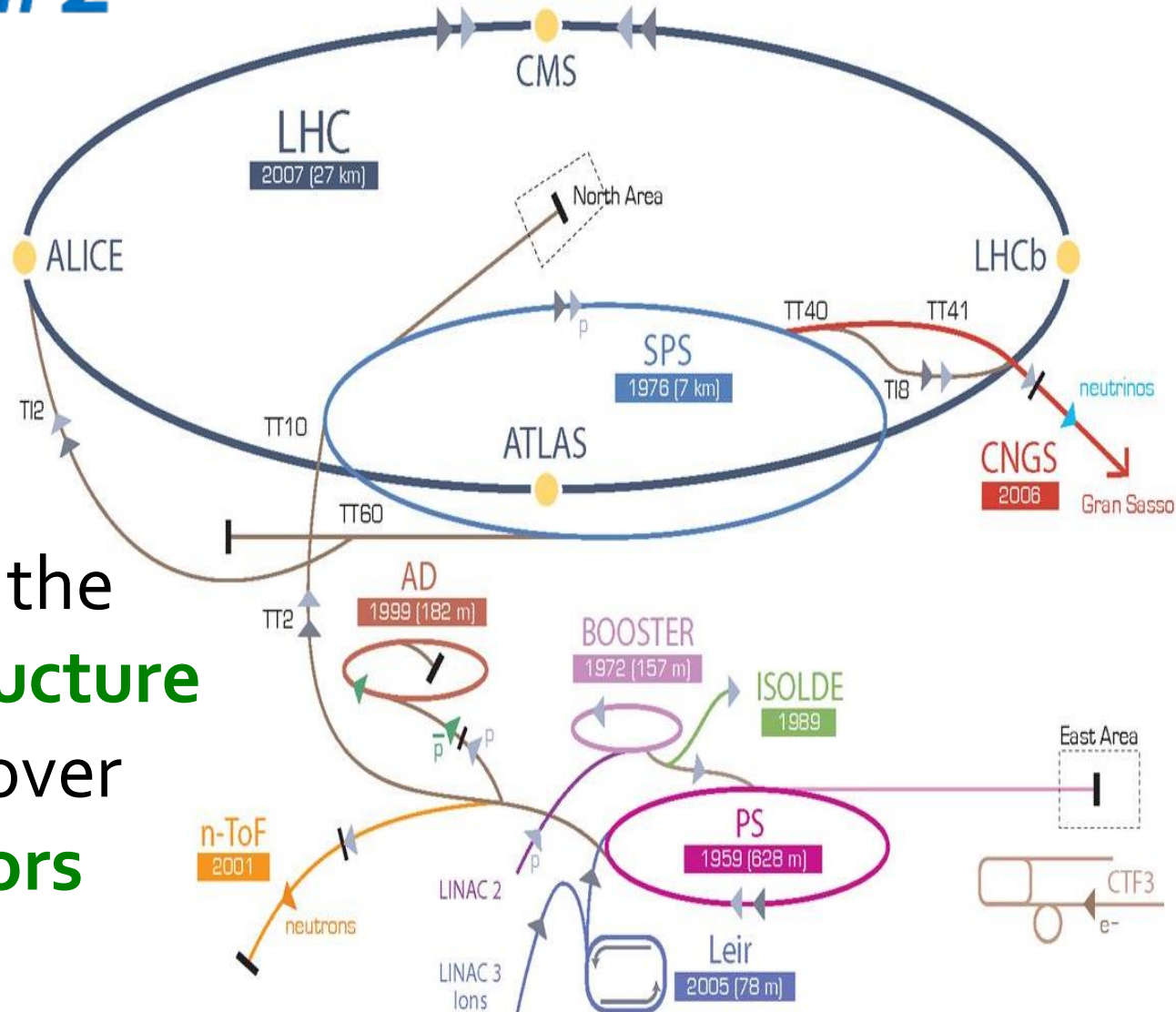
**Based on the input from M.Arruat, V.Baggiolini,  
JC.Bau, M.Buttner, P.Charrue, S.Deghaye,  
E.Hatziangeli, G.Kruk, M.Lamont, A.Radeva,  
U.Raich, C.Roderick, J.Serrano, W.Sliwinski,  
J.Wozniak**

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

# Context is a challenge!

- Accelerate **2 beams of  $2.2 \times 10^{14}$  (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

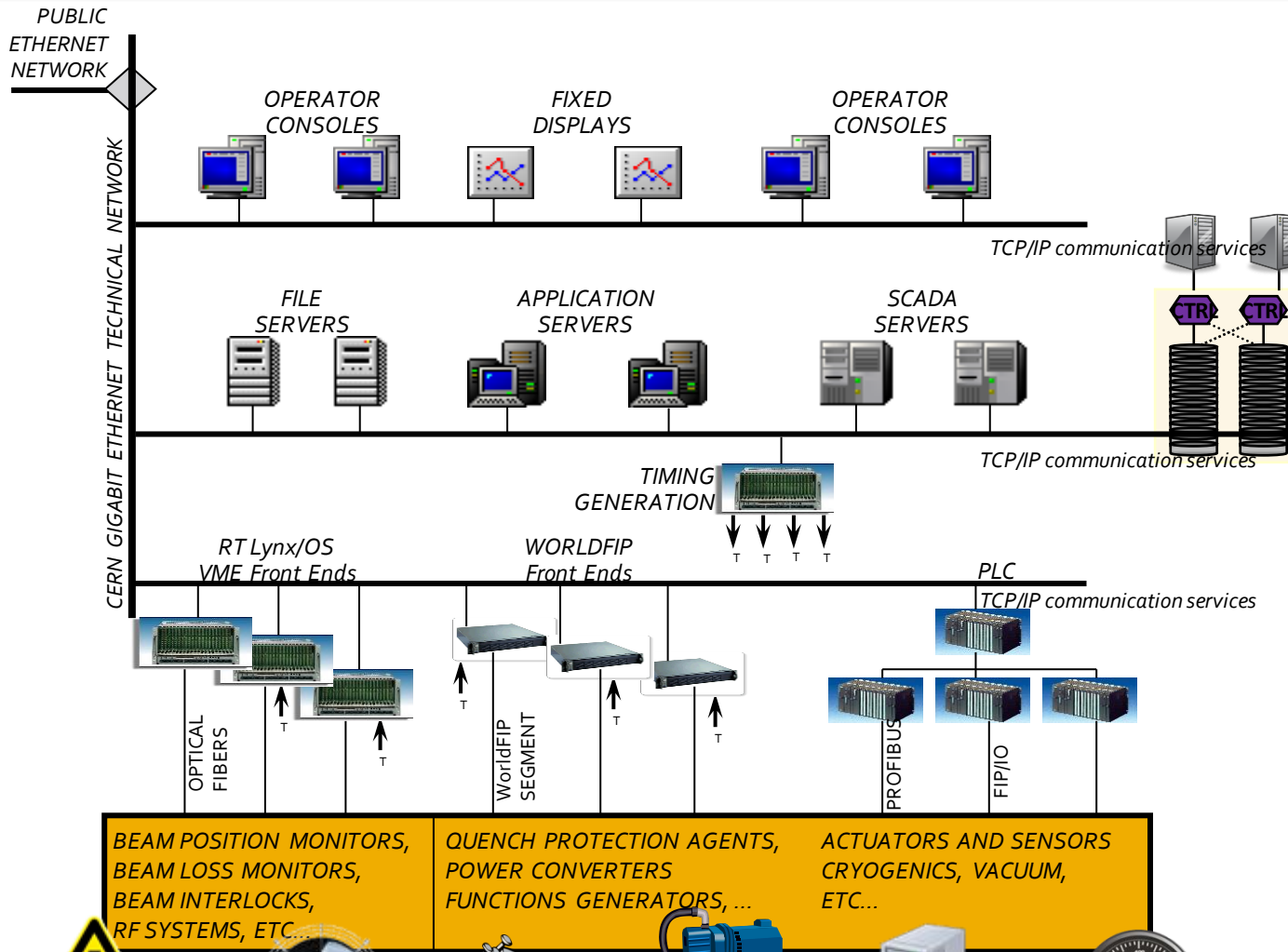
- Provide **extensible Frameworks and Tools**
- Develop and deploy **Generic services**
- **Applicability to all accelerators**
- **Quality Assurance**



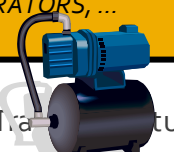
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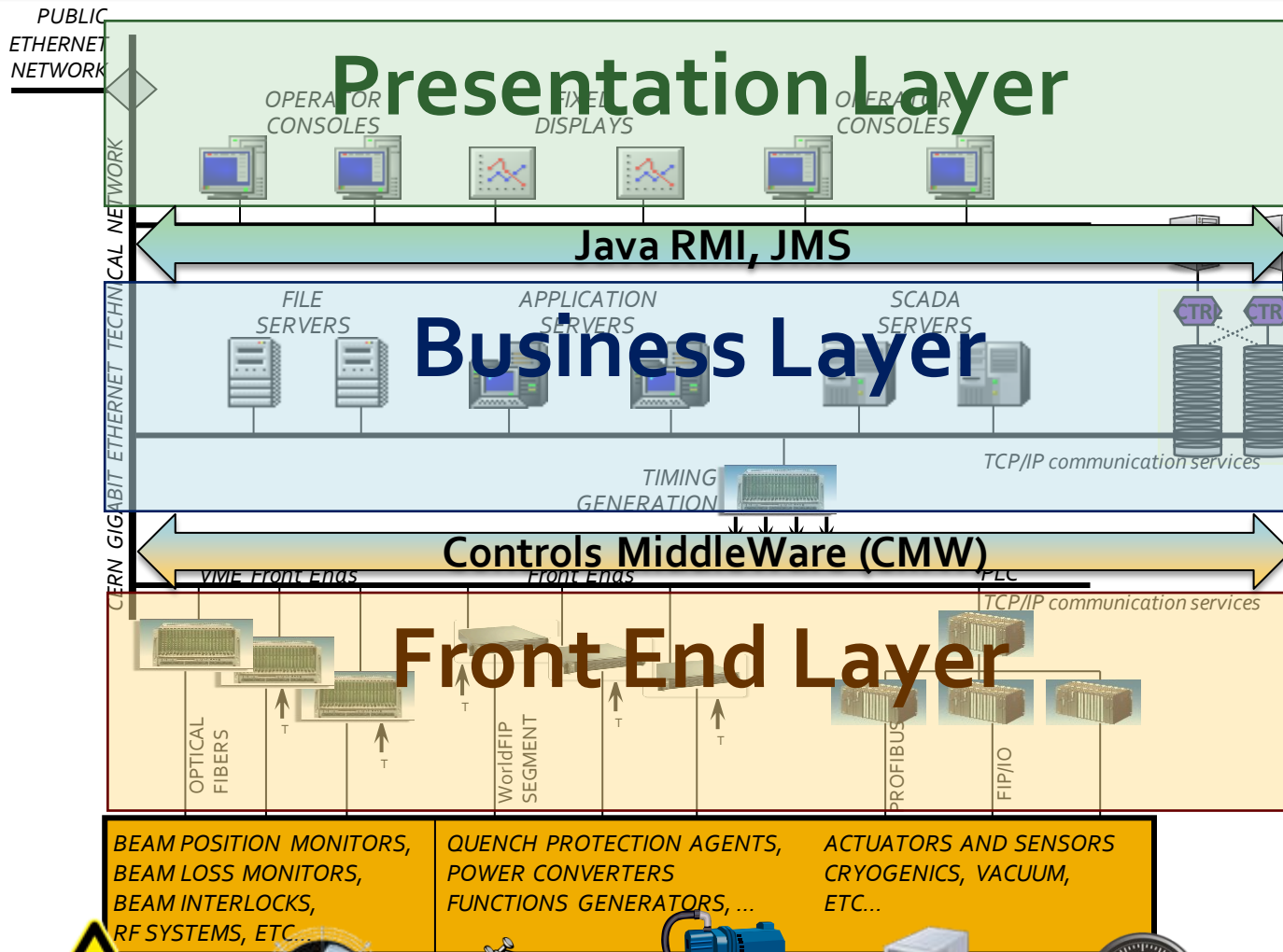
# Controls HW infrastructure



- 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



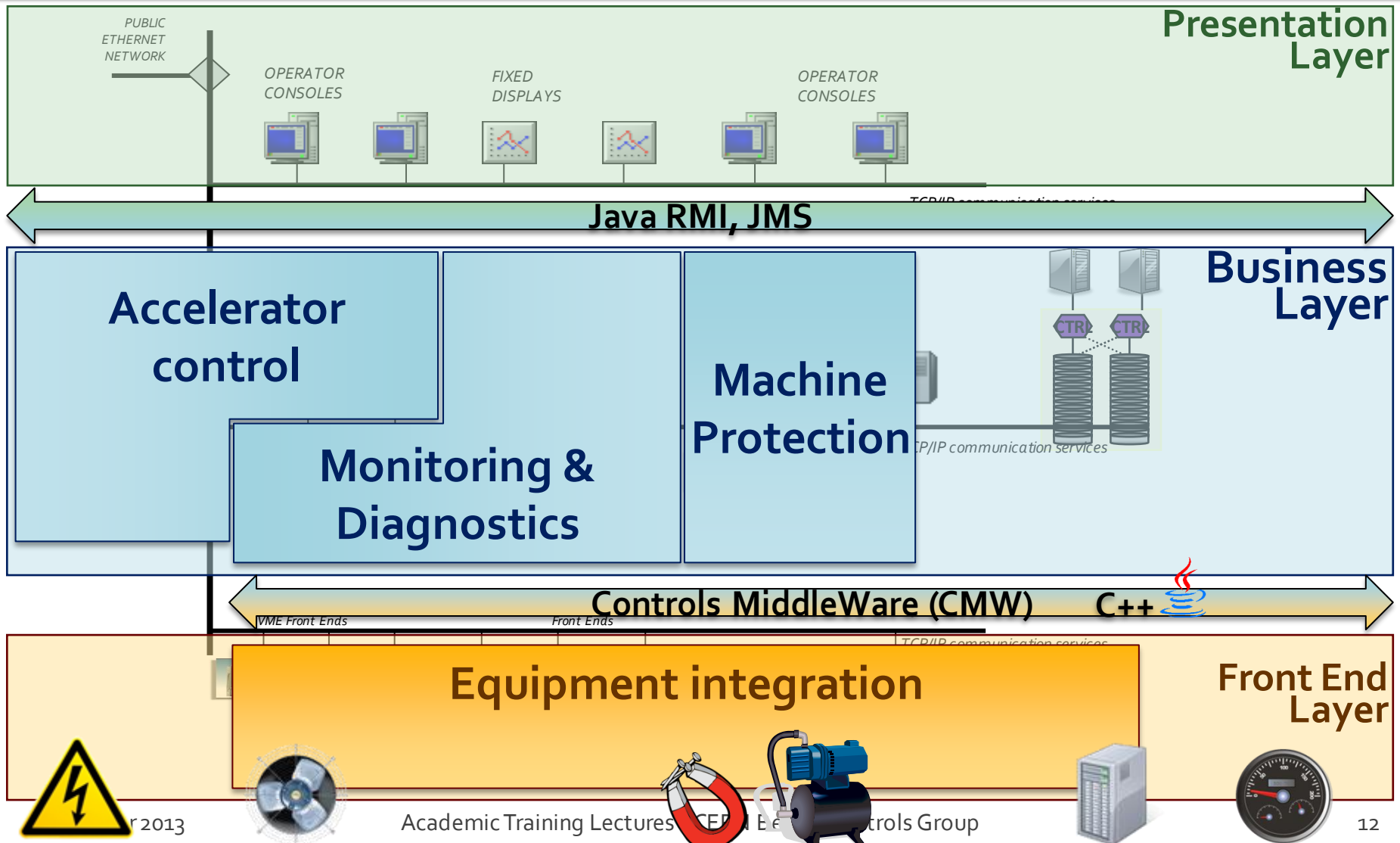
# Controls SW layers



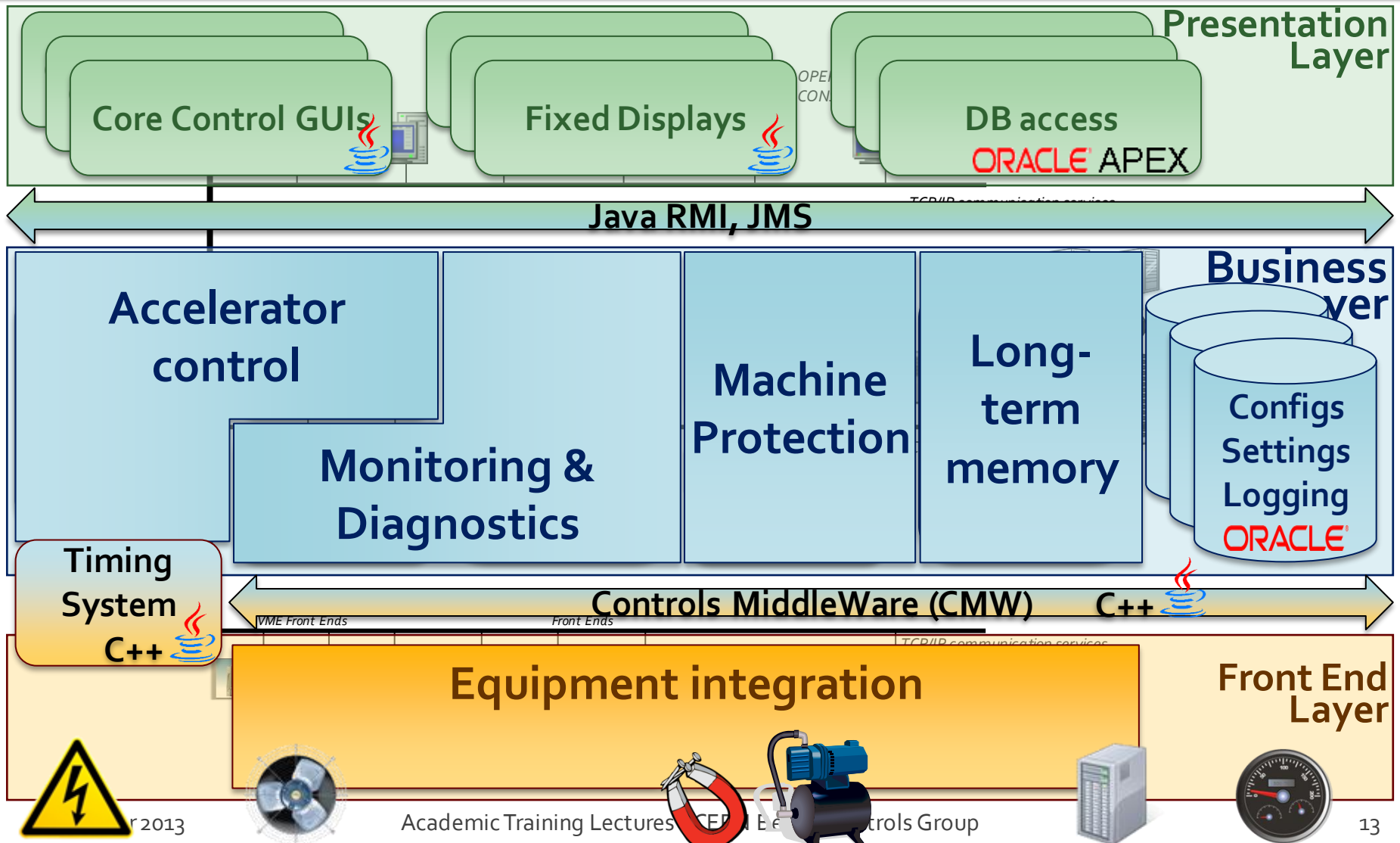
- **Presentation Layer**
  - Graphical interactive applications
  - Fixed Displays
- **Communication via Java RMI & JMS**
- **Business Layer**
  - General purpose and specific Application servers
- **Communication via Controls MiddleWare CMW**
- **Front End Layer**
  - Device servers



# Controls SW Infrastructure



# Controls SW Infrastructure



Fixed  
Displays



Operational Consoles



# PROTON PHYSICS: INJECTION PHYSICS BEAM

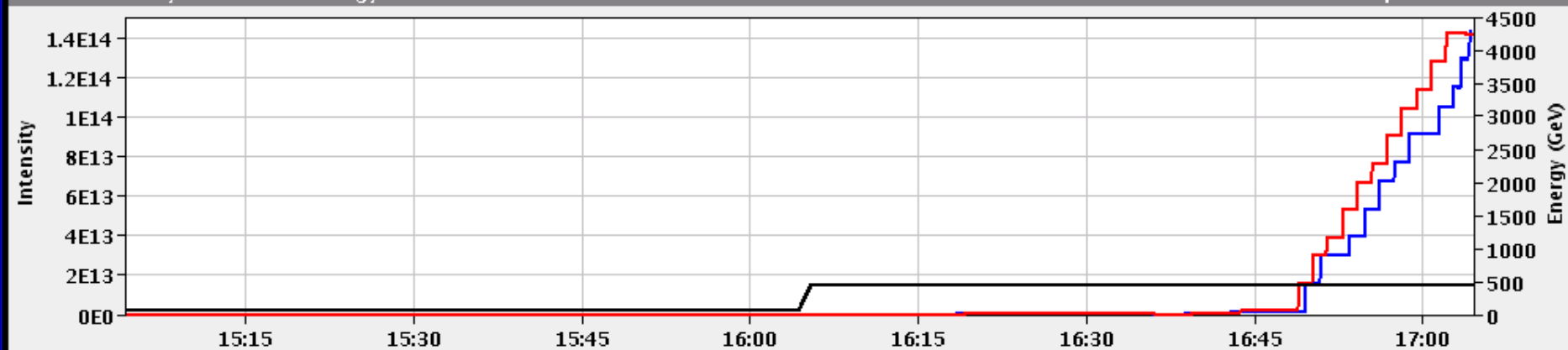
**BCT TI2:** 7.78e+13    **I(B1):** 1.42e+14    **BCT TI8:** 0.00e+00    **I(B2):** 1.43e+14

**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

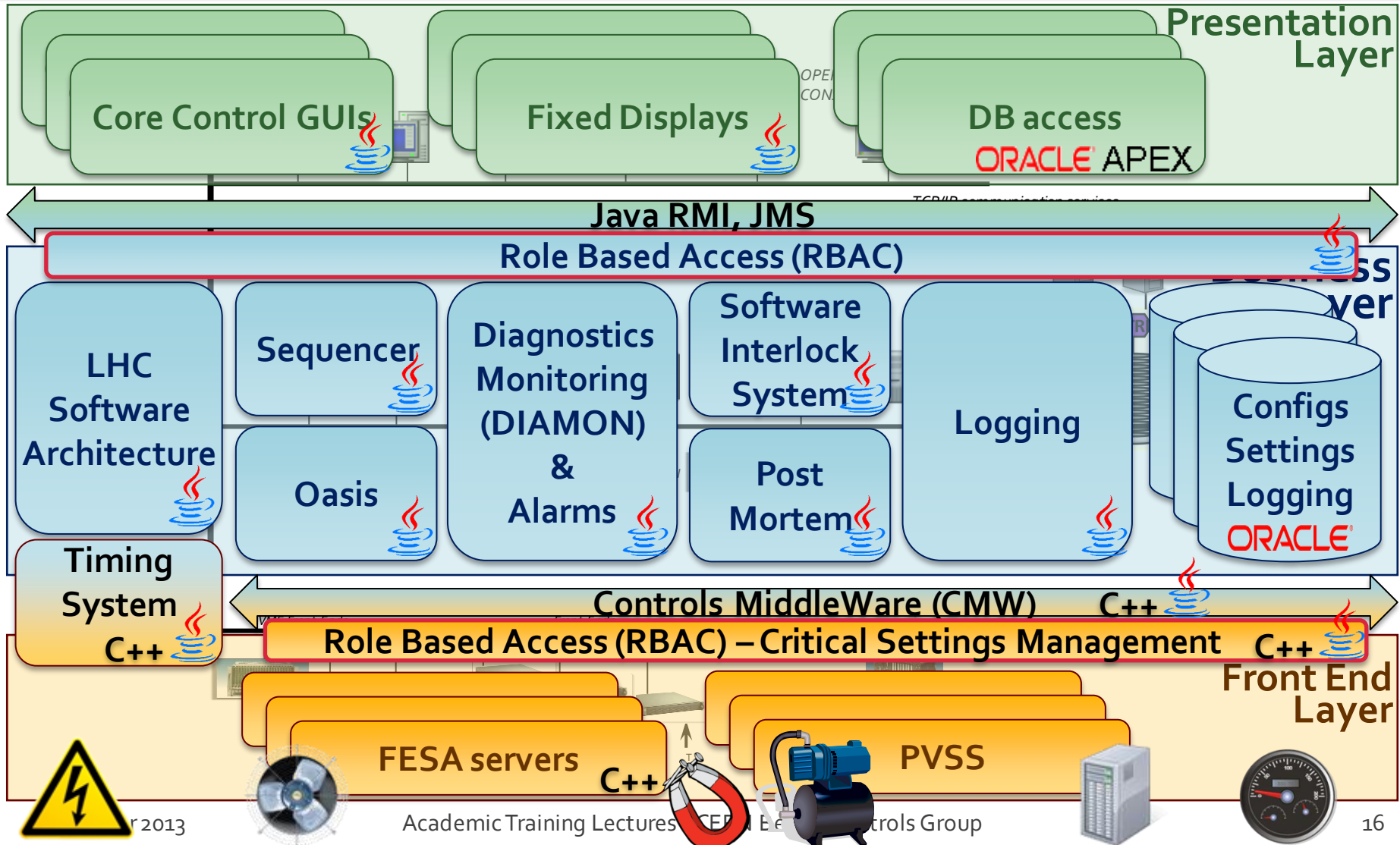
PM Status B1

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

Device + Property  
=> IO-point

Current

State

Tol.

Magnet

Positions

State

Tol.

Collimator

Threshold

Losses

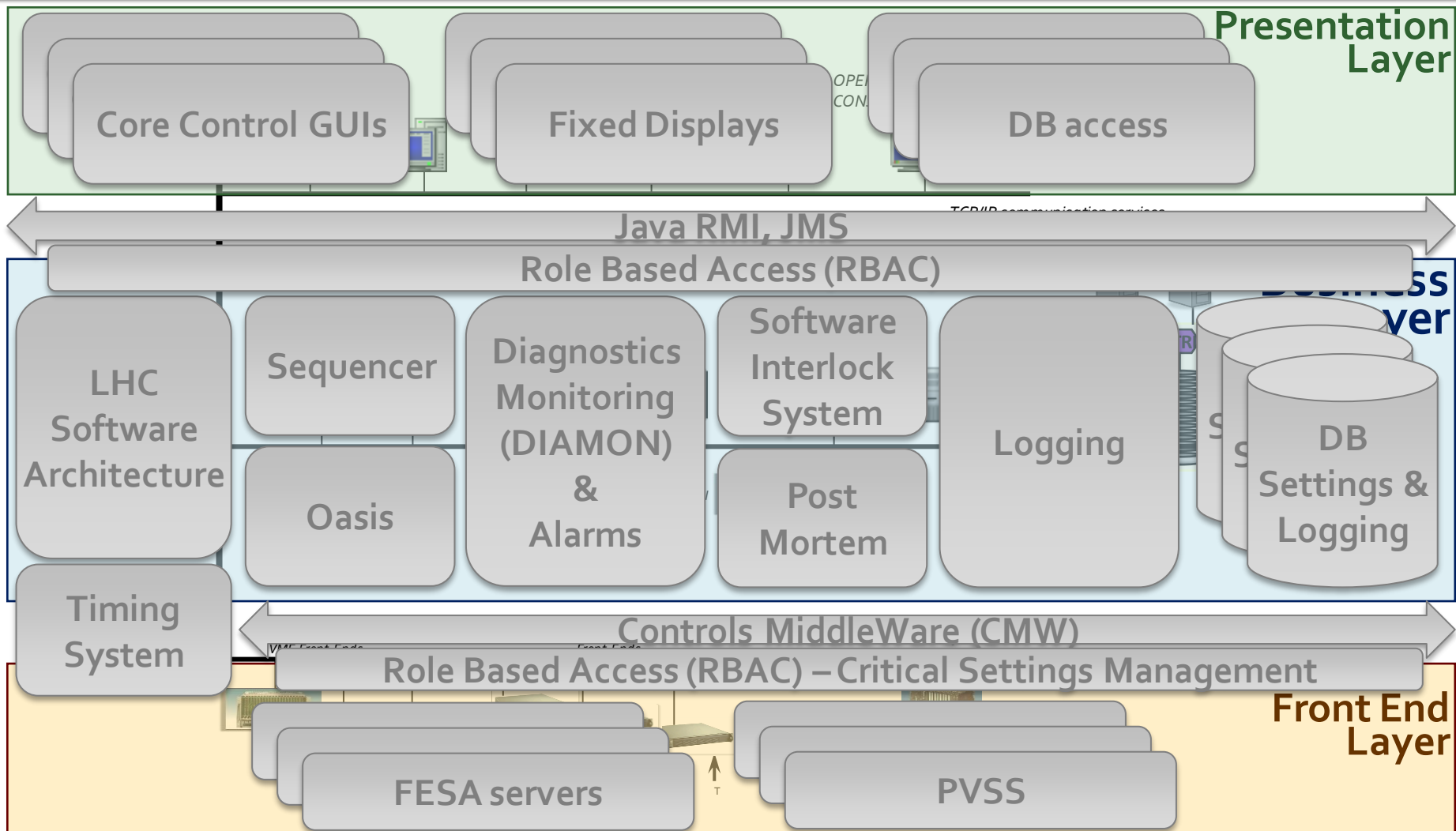
Energy

BLM

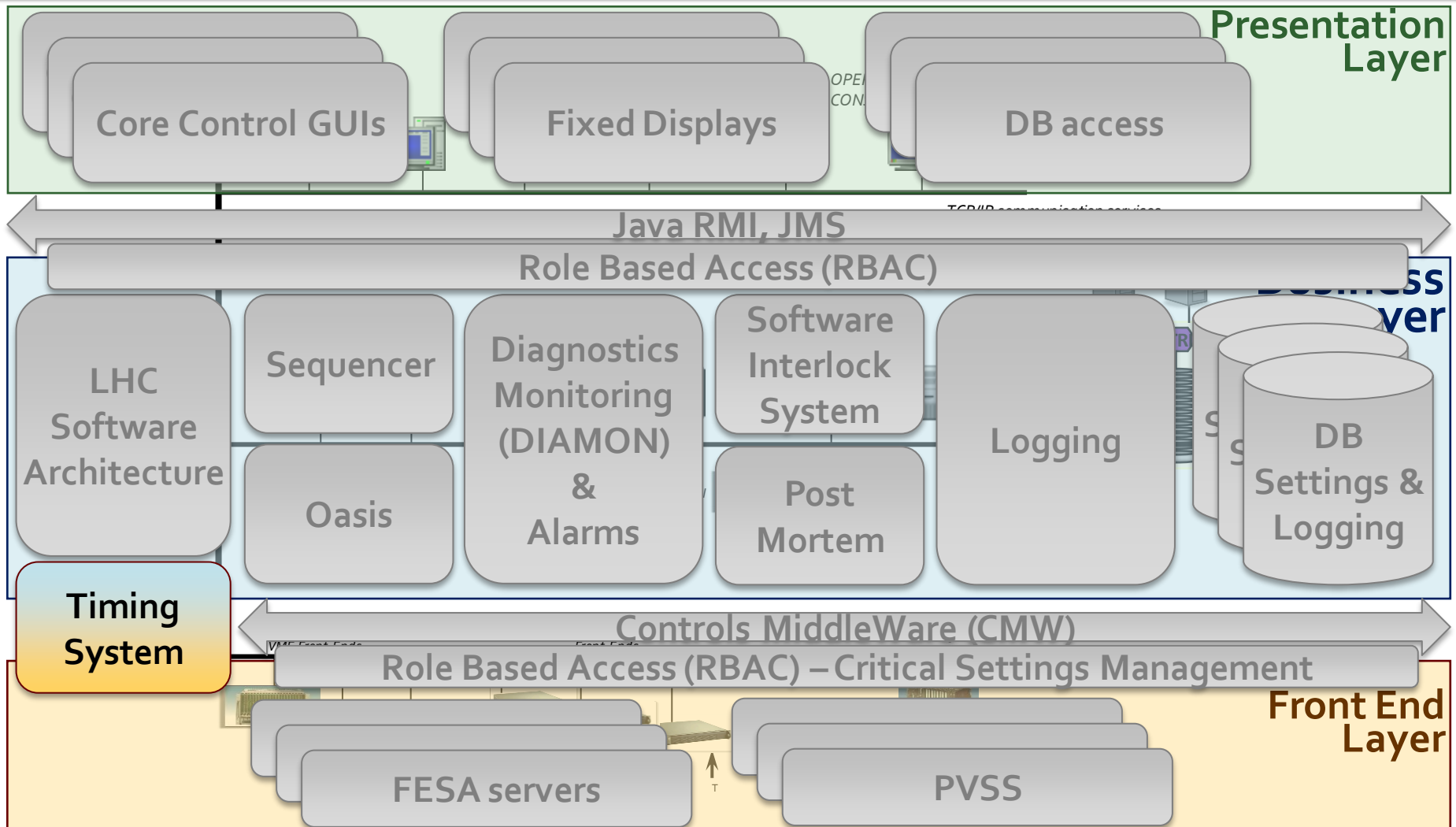
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# Key components



# Key components: Timing System



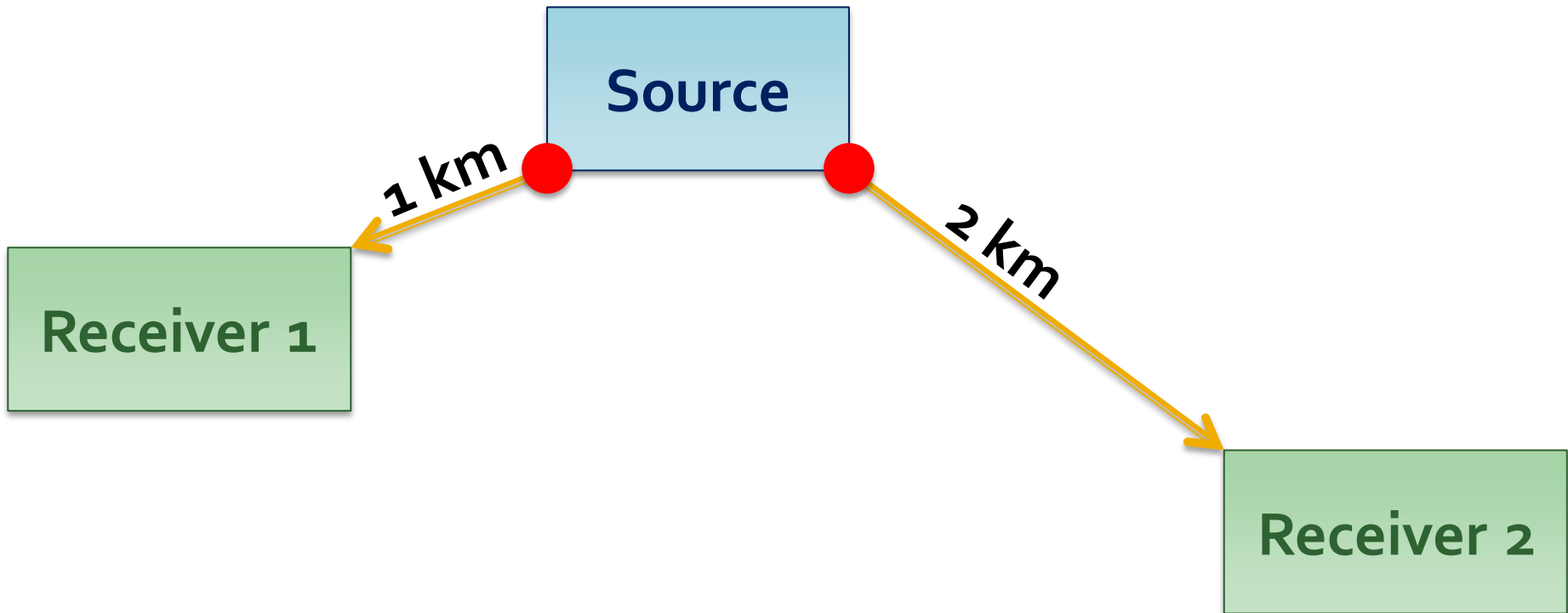
# Timing System

- 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  $1 \mu\text{s}$  precision

**TIME and SYNCHRONIZATION  
are very IMPORTANT everywhere**

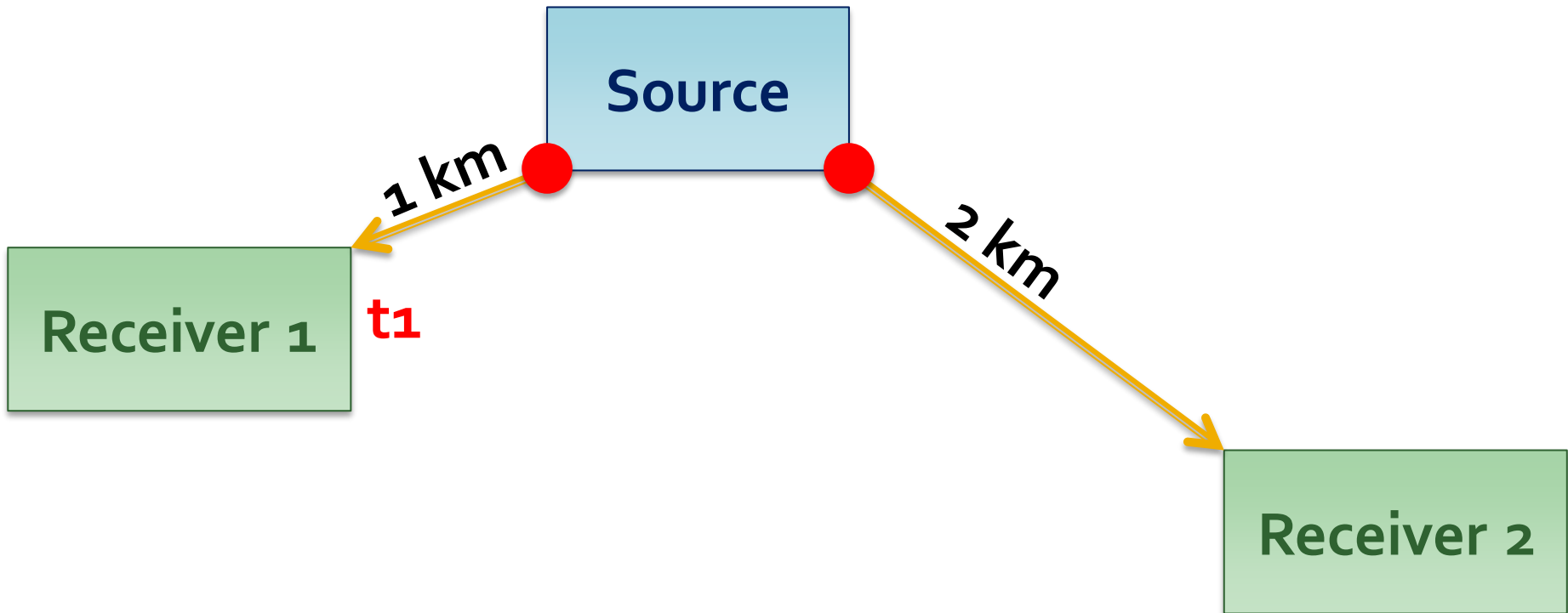
# Timing System: challenges

- Compensate the transmission delay from the source to receivers



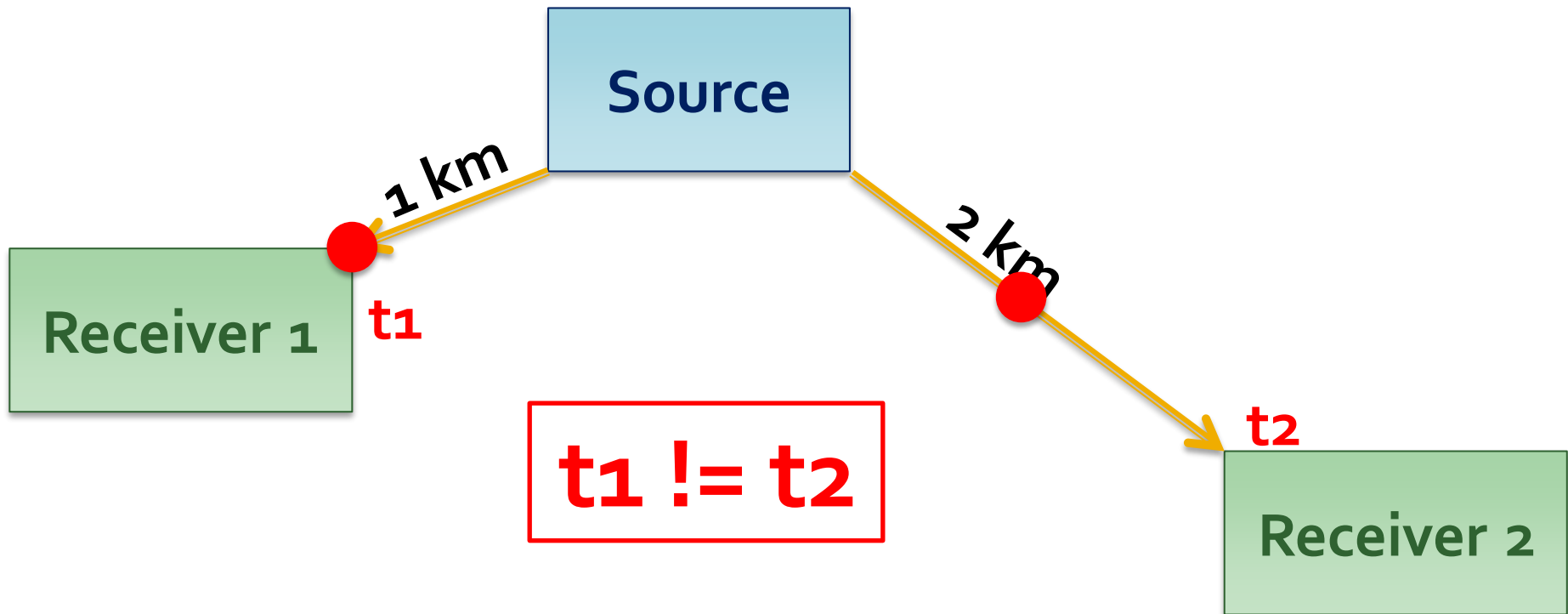
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# Timing System: challenges

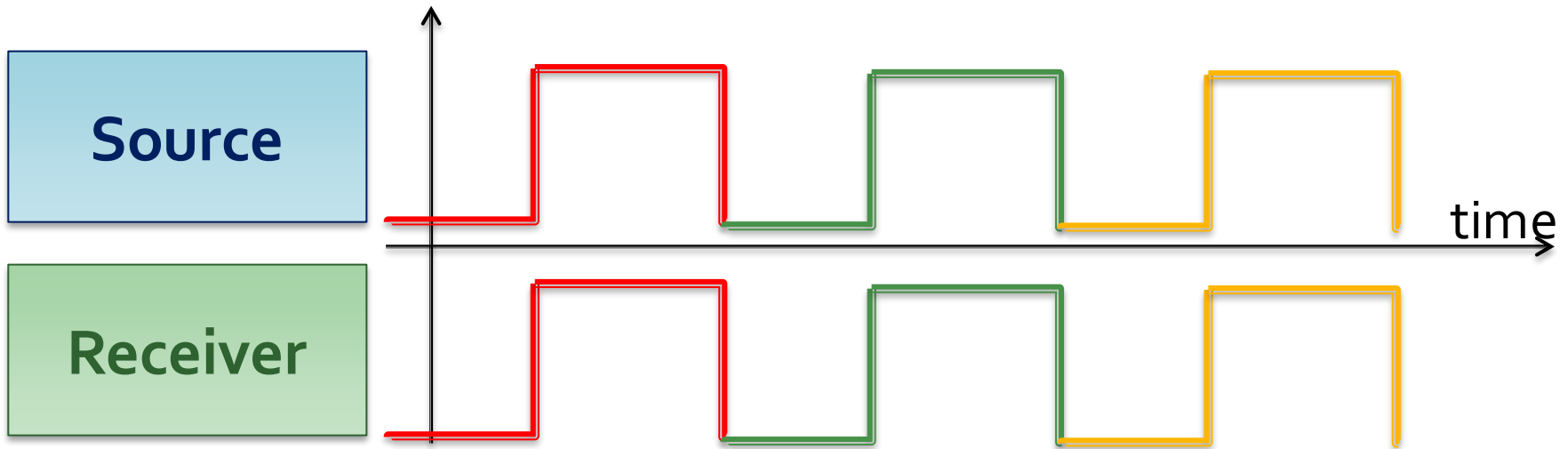
- Compensate the transmission delay from the source to receivers





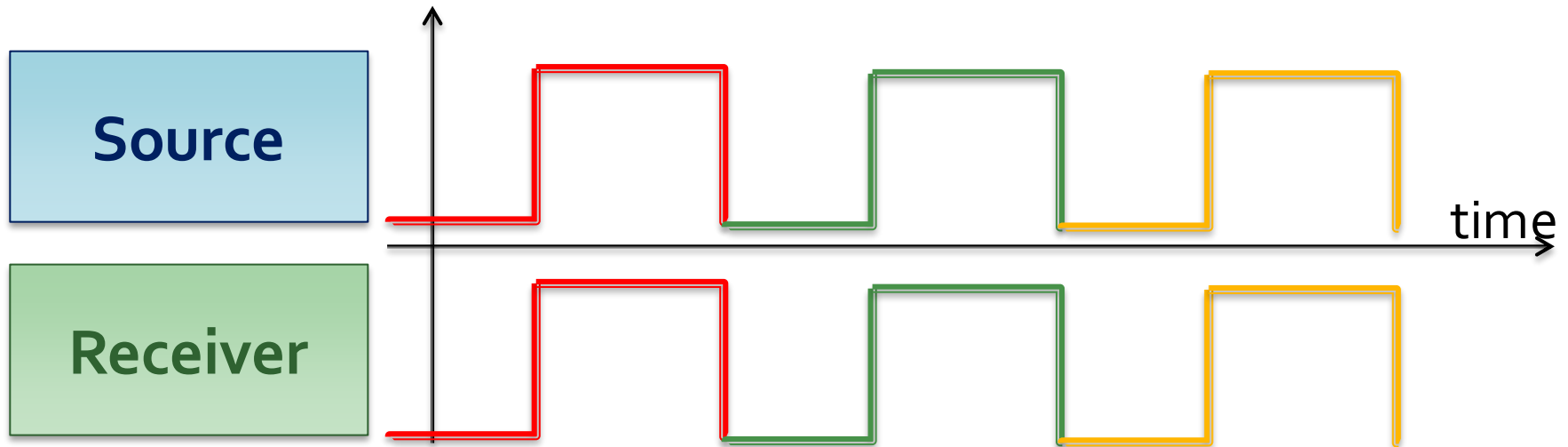
# Timing System: challenges

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



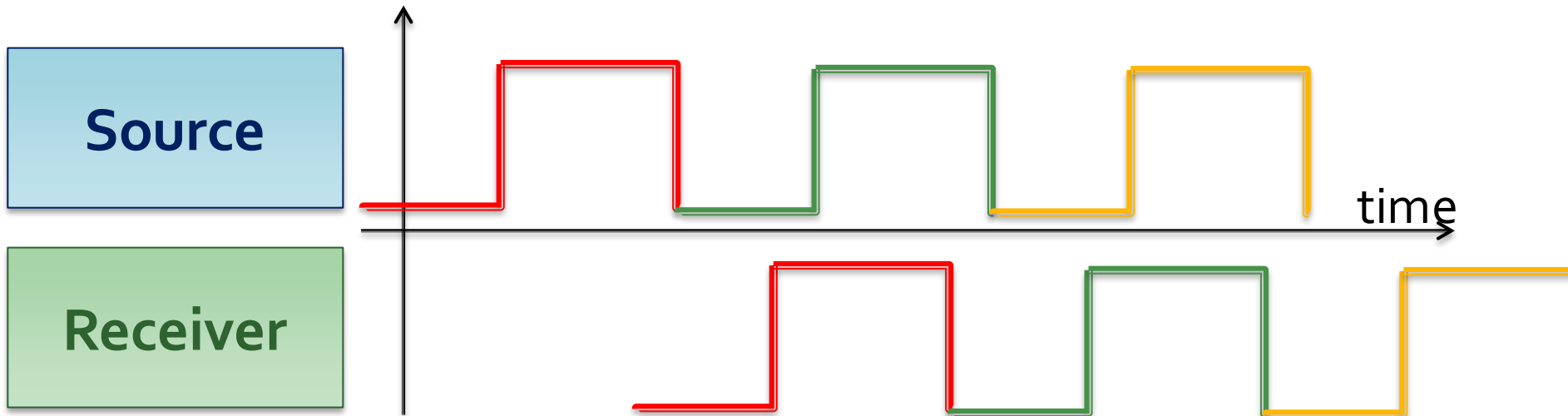
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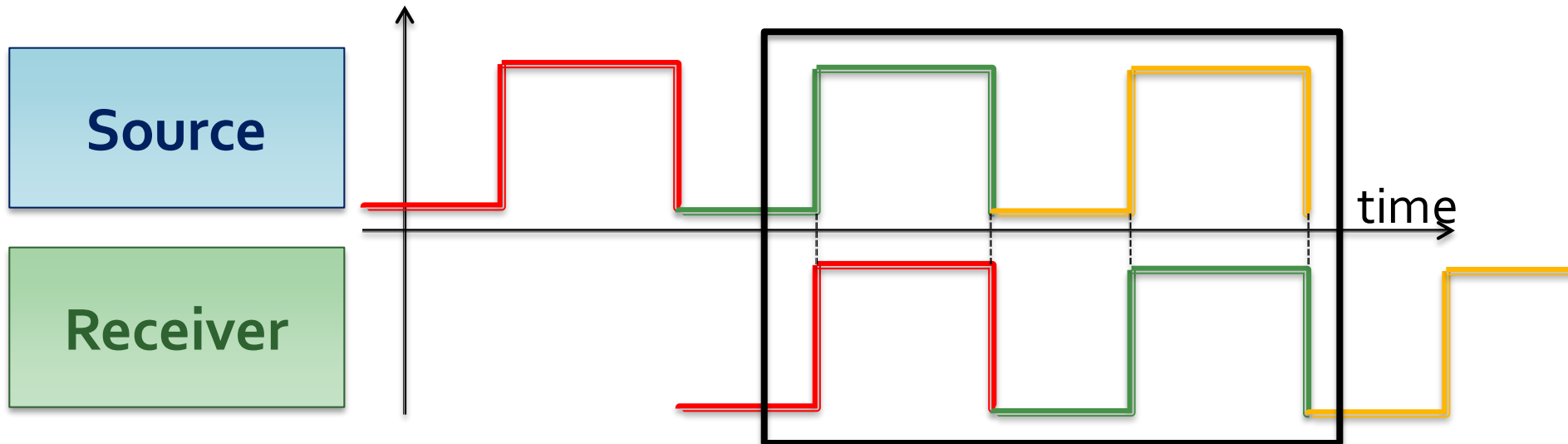
# Timing System: challenges

- Compensate the transmission delay from the source to receivers
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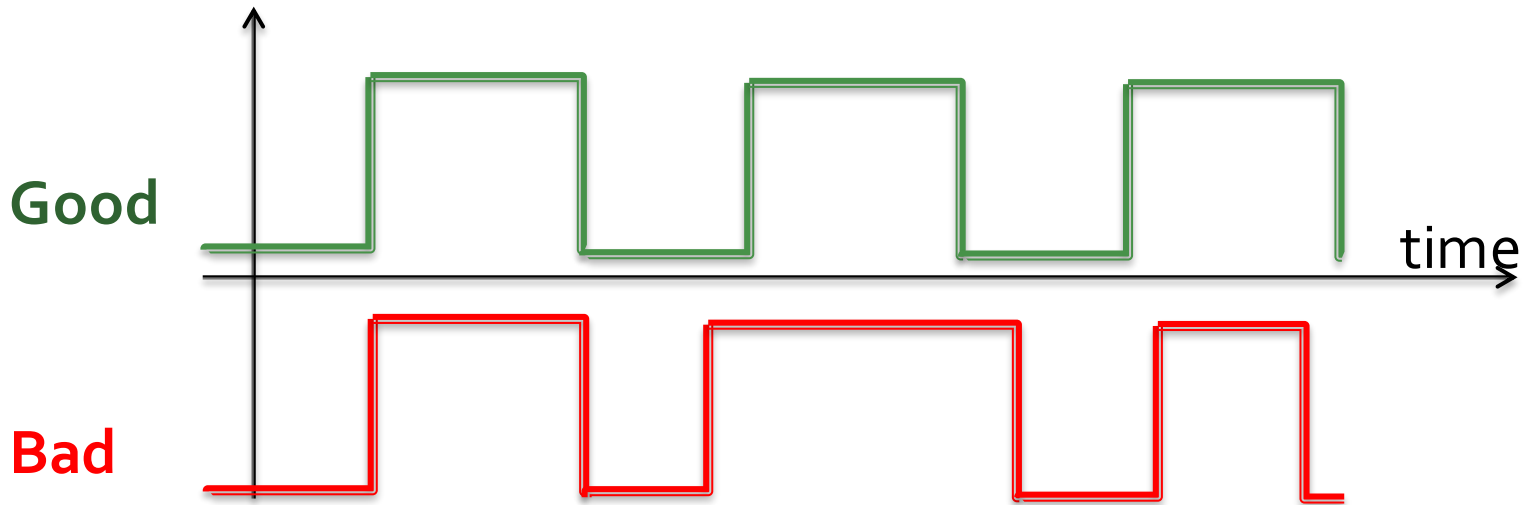
# Timing System: challenges

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



# 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

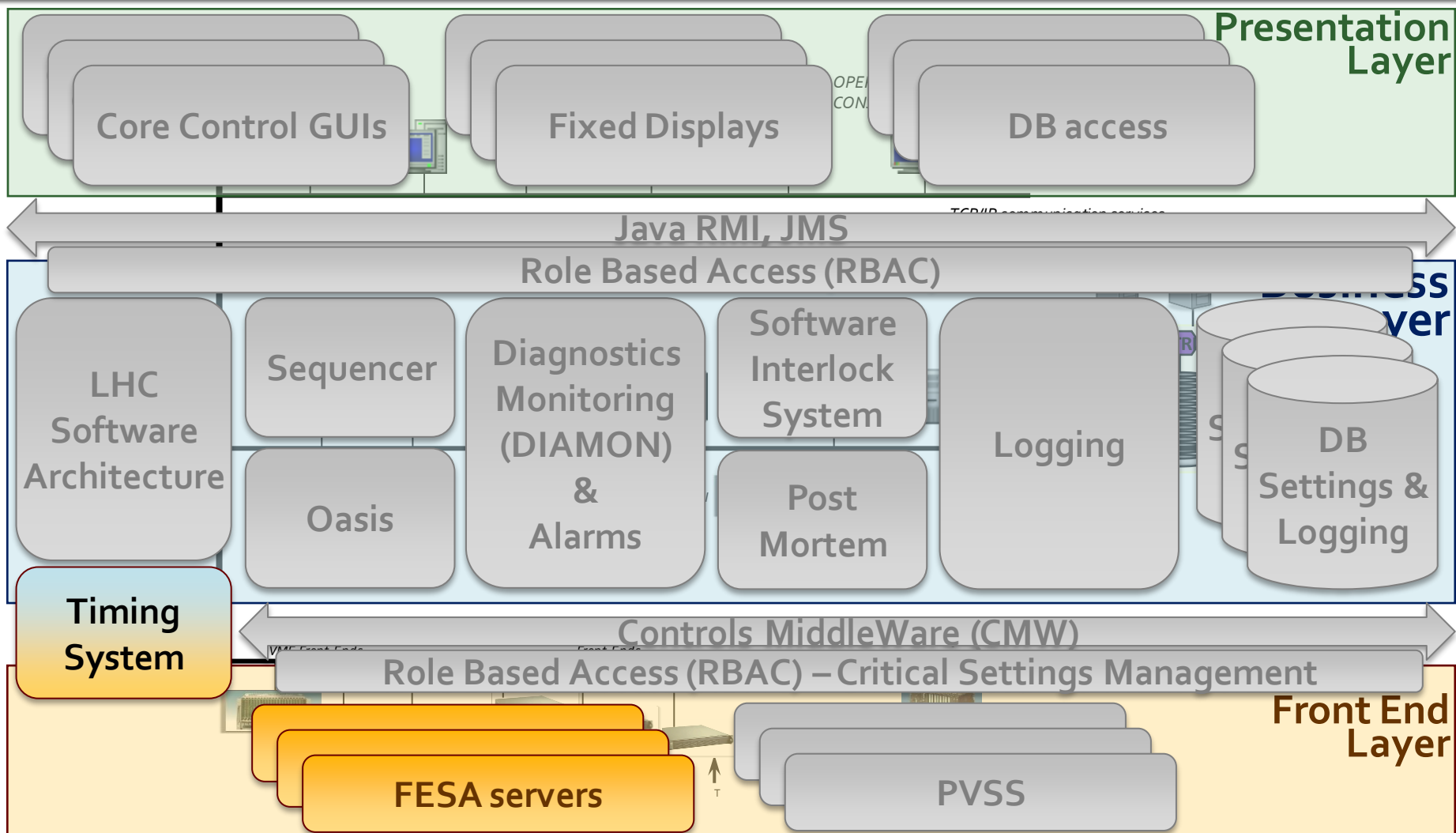
# Open Source Hardware

- 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](http://www.ohwr.org)



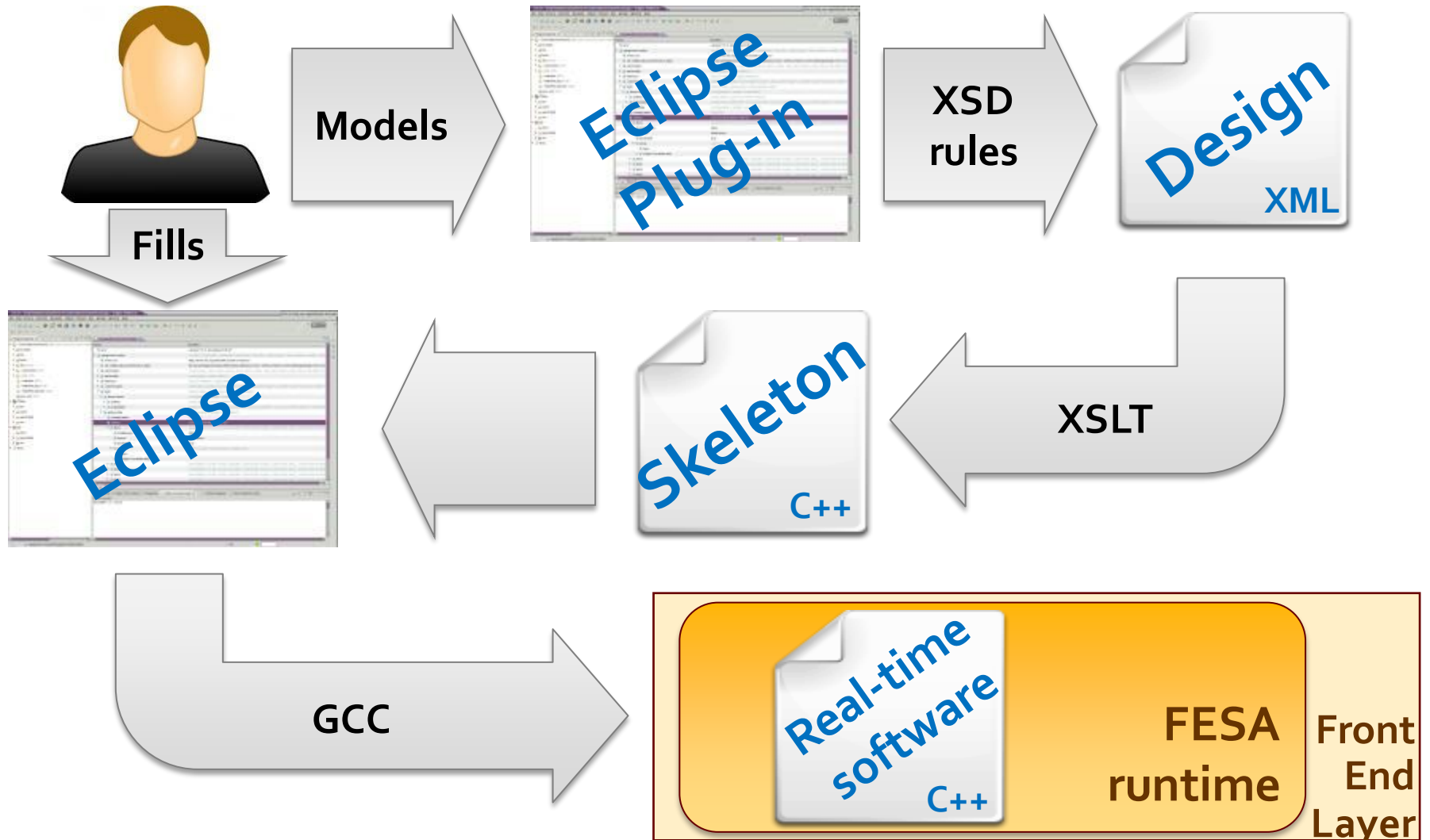
# Key components: FESA



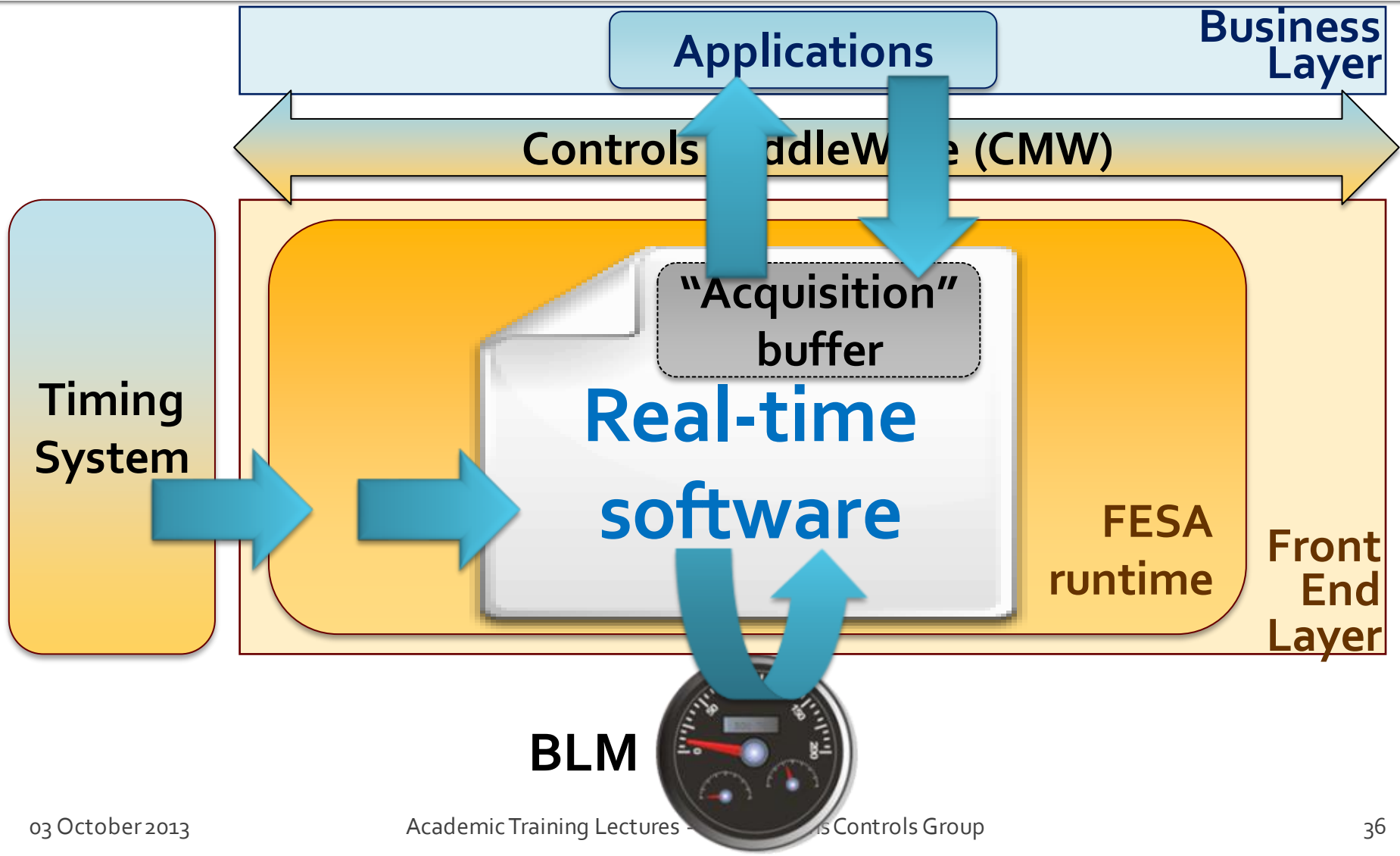
# Front End Software Architecture

- 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



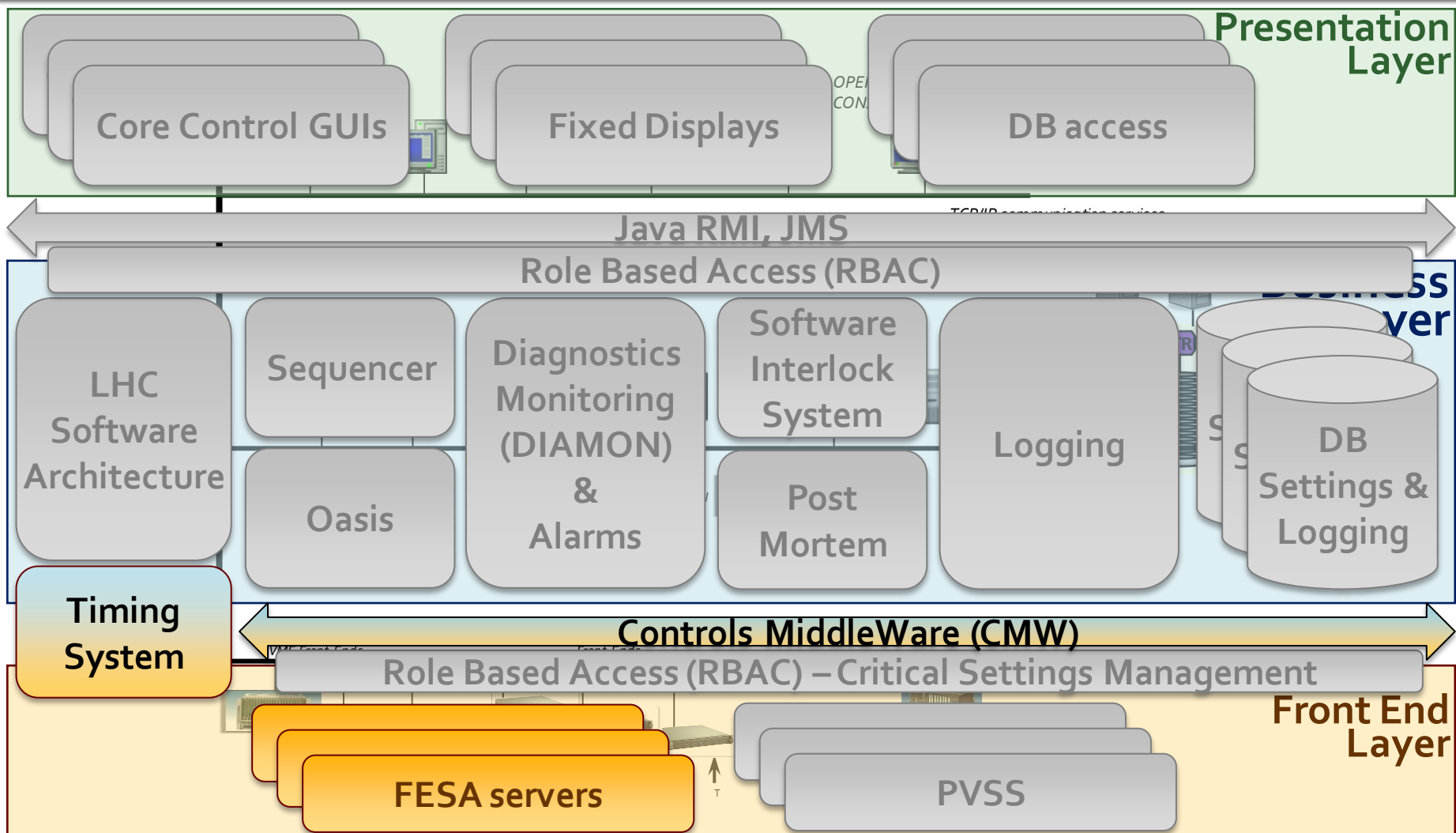
# FESA: features

- **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

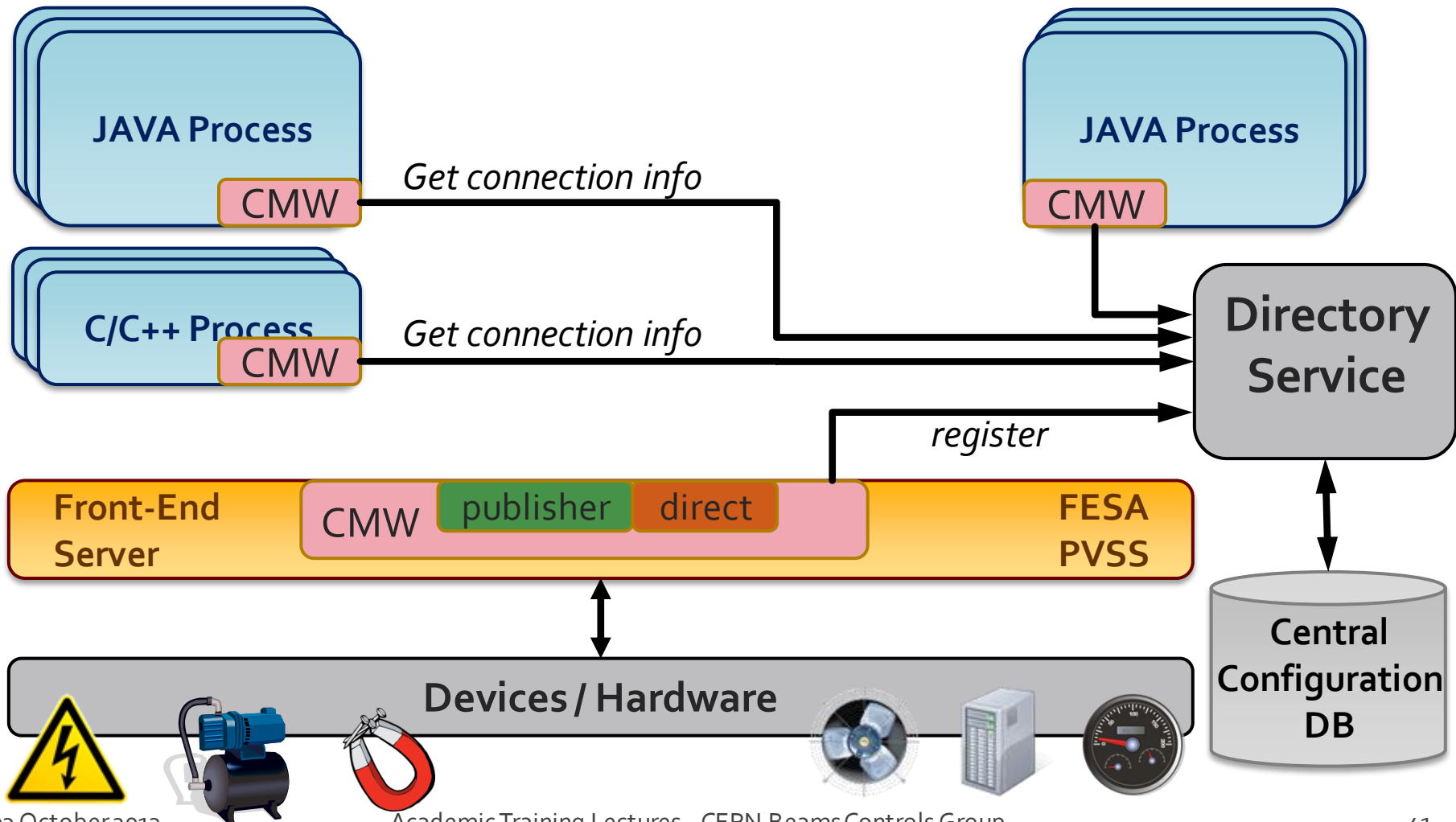


# Controls MiddleWare (CMW)

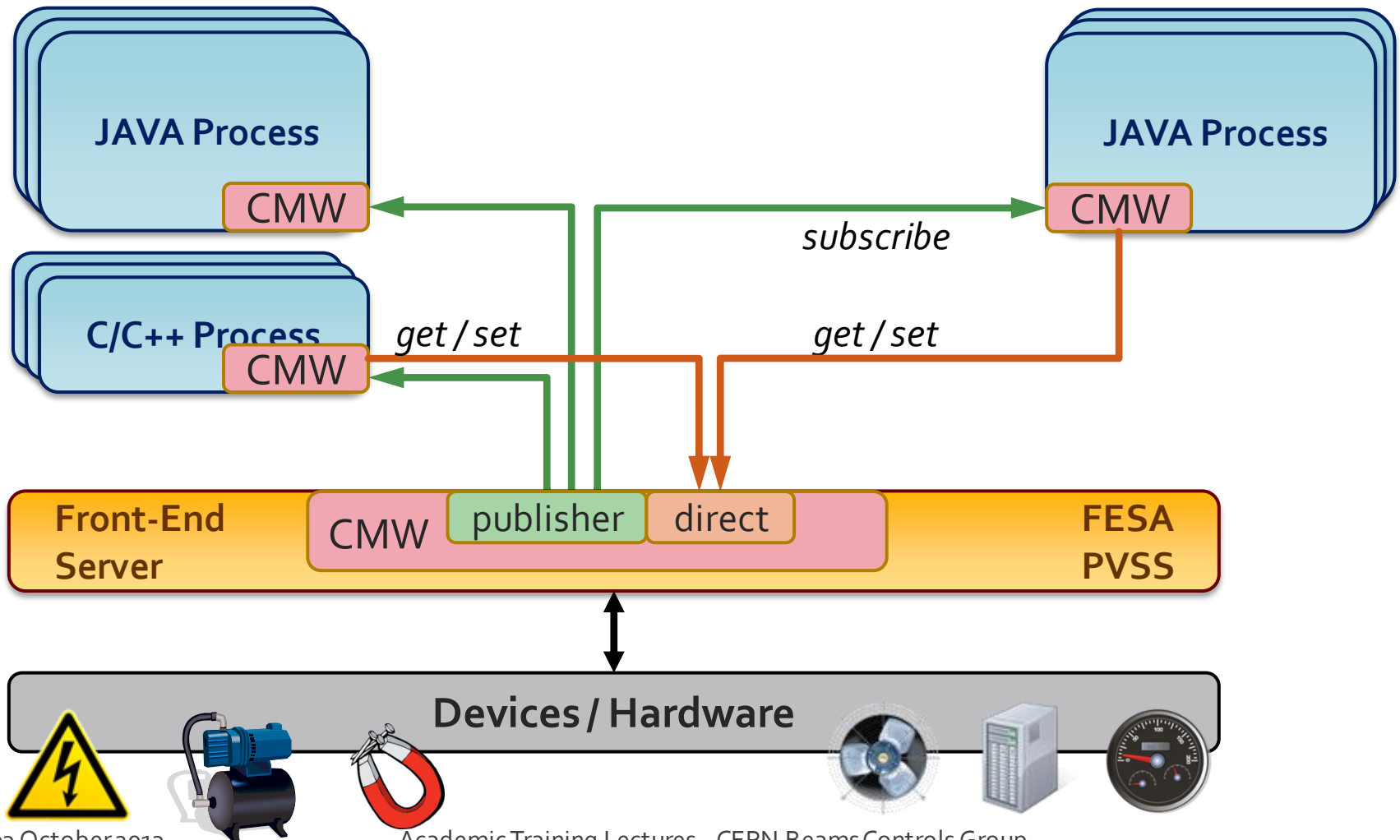
- Core **communication** layer => **critical**
- Collection of software **components & services**
- Communication => **device-property model**
- Operations: **GET, SET, SUBSCRIPTION**
- Widely deployed for **all CERN accelerators**



# 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

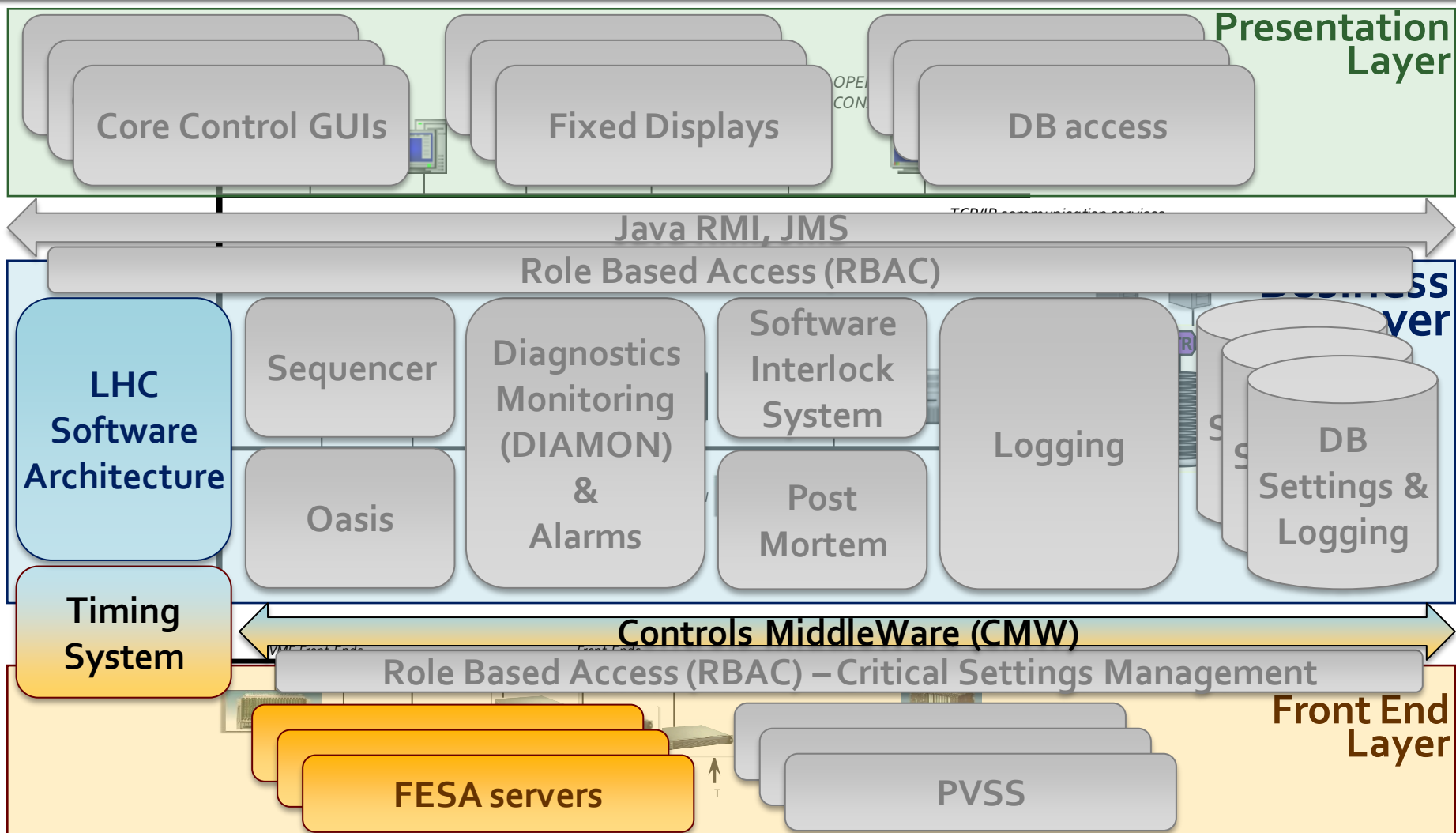
# CMW: features

- **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

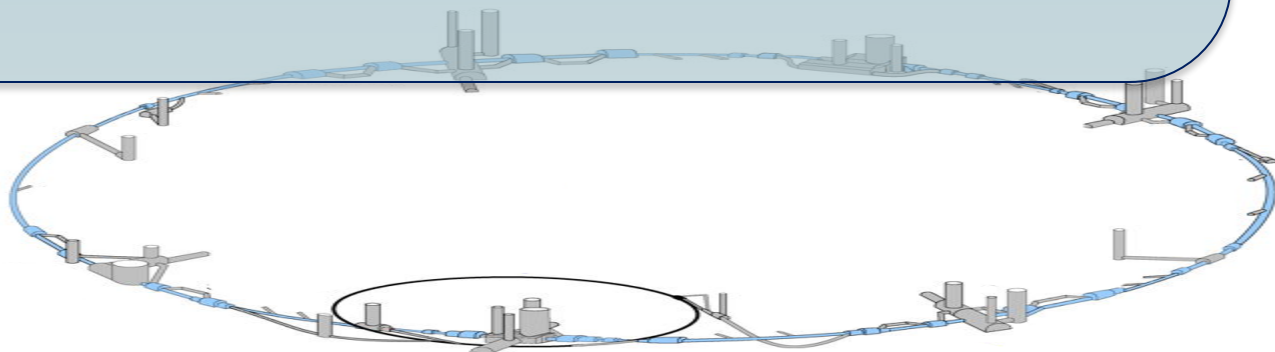
**LSA**

270'000 device properties to control

Different settings within LHC cycle

Different operational scenarios

150'000'000 of settings



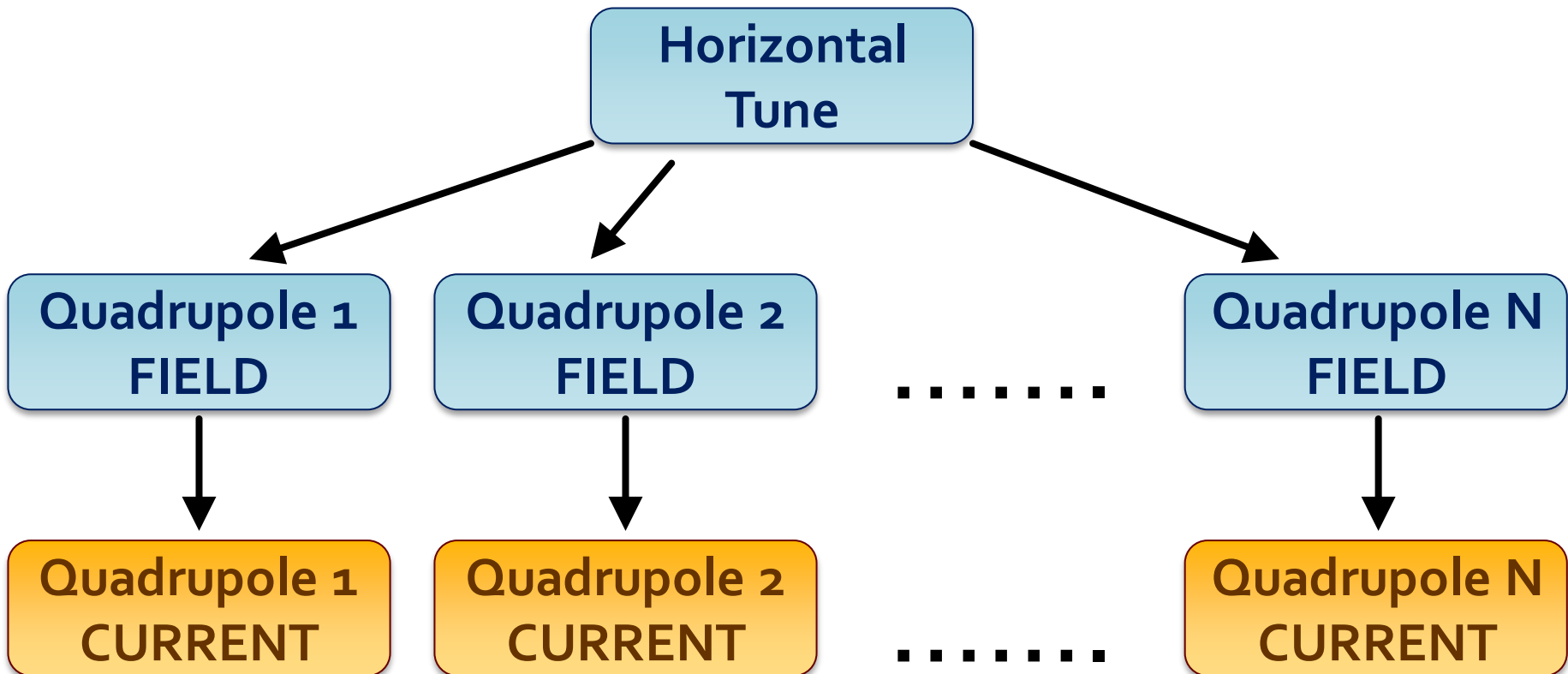
# LSA: requirements / expectations

- **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

LSA Applications Suite - version 0.7.4

File Applications Search Options Help

LHC OP BP RBA: no token

Trim Editor (Beta Version) x

Beam Process: BI-START-SQUEEZE-2011-ACTUAL System: SKEW SEXTUPOLES Type Group: KNOB Parameter: LHCBEAM1/QH\_TRIM

Parameter Hierarchy

Parameter: LHCBEAM1/QH\_TRIM Hierarchy: DEFAULT

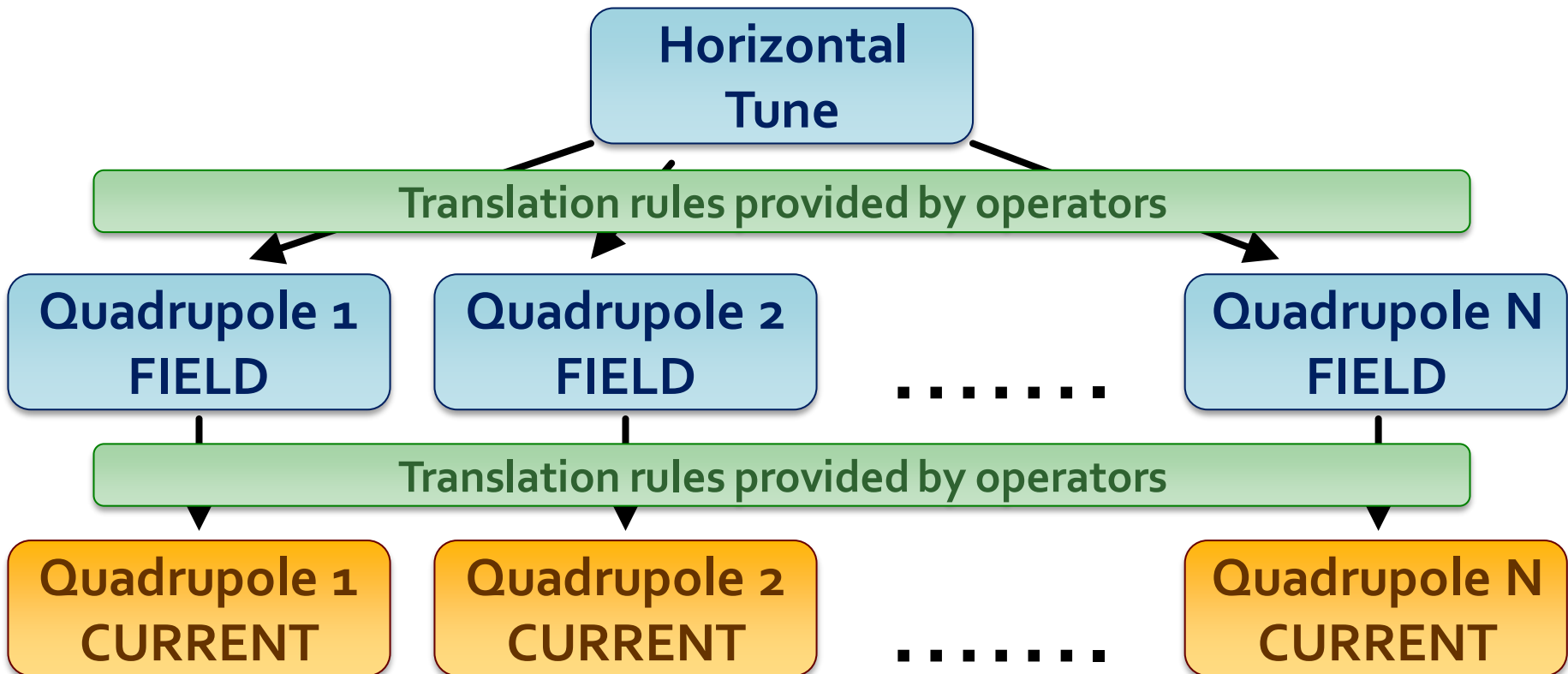
```
graph LR; Root[LHCBEAM1/QH_TRIM] --> C1[RQTF.A56B1/K1]; Root --> C2[RQTD.A67B1/K1]; Root --> C3[RQTF.A81B1/K1]; Root --> C4[RQTF.A67B1/K1]; Root --> C5[RQTD.A23B1/K1]; Root --> C6[RQTD.A45B1/K1]; Root --> C7[RQTF.A12B1/K1]; Root --> C8[RQTD.A34B1/K1]; Root --> C9[RQTD.A81B1/K1]; Root --> C10[RQTF.A78B1/K1]; Root --> C11[RQTF.A45B1/K1]; Root --> C12[RQTD.A78B1/K1]; Root --> C13[RQTD.A12B1/K1]; Root --> C14[RQTF.A23B1/K1]; Root --> C15[RQTD.A56B1/K1]; Root --> C16[RQTF.A34B1/K1]; C1 --> I1[RQTF.A56B1/K_SMOOTH]; C1 --> I2[RQTF.A56B1/I]; C1 --> I3[RPMBB.UA63.RQTF.A56B1/REF]; I1 --> L1[RQTF.A56B1/I]; I2 --> L1; I3 --> L1; C2 --> I4[RQTD.A67B1/K_SMOOTH]; C2 --> I5[RQTD.A67B1/I]; C2 --> I6[RPMBB.UA67.RQTD.A67B1/REF]; I4 --> L2[RQTD.A67B1/I]; I5 --> L2; I6 --> L2; C3 --> I7[RQTF.A81B1/K_SMOOTH]; C3 --> I8[RQTF.A81B1/I]; C3 --> I9[RPMBB.UA87.RQTF.A81B1/REF]; I7 --> L3[RQTF.A81B1/I]; I8 --> L3; I9 --> L3; C4 --> I10[RQTF.A67B1/K_SMOOTH]; C4 --> I11[RQTF.A67B1/I]; C4 --> I12[RPMBB.UA67.RQTF.A67B1/REF]; I10 --> L4[RQTF.A67B1/I]; I11 --> L4; I12 --> L4; C5 --> I13[RQTD.A23B1/K_SMOOTH]; C5 --> I14[RQTD.A23B1/I]; C5 --> I15[RPMBB.UA27.RQTD.A23B1/REF]; I13 --> L5[RQTD.A23B1/I]; I14 --> L5; I15 --> L5; C6 --> I16[RQTD.A45B1/K_SMOOTH]; C6 --> I17[RQTD.A45B1/I]; C6 --> I18[RPMBB.UA47.RQTD.A45B1/REF]; I16 --> L6[RQTD.A45B1/I]; I17 --> L6; I18 --> L6; C7 --> I19[RQTF.A12B1/K_SMOOTH]; C7 --> I20[RQTF.A12B1/I]; C7 --> I21[RPMBB.UA23.RQTF.A12B1/REF]; I19 --> L7[RQTF.A12B1/I]; I20 --> L7; I21 --> L7; C8 --> I22[RQTD.A34B1/K_SMOOTH]; C8 --> I23[RQTD.A34B1/I]; C8 --> I24[RPMBB.UA43.RQTD.A34B1/REF]; I22 --> L8[RQTD.A34B1/I]; I23 --> L8; I24 --> L8; C9 --> I25[RQTD.A81B1/K_SMOOTH]; C9 --> I26[RQTD.A81B1/I]; C9 --> I27[RPMBB.UA87.RQTD.A81B1/REF]; I25 --> L9[RQTD.A81B1/I]; I26 --> L9; I27 --> L9; C10 --> I28[RQTF.A78B1/K_SMOOTH]; C10 --> I29[RQTF.A78B1/I]; C10 --> I30[RPMBB.UA83.RQTF.A78B1/REF]; I28 --> L10[RQTF.A78B1/I]; I29 --> L10; I30 --> L10; C11 --> I31[RQTF.A45B1/K_SMOOTH]; C11 --> I32[RQTF.A45B1/I]; C11 --> I33[RPMBB.UA47.RQTF.A45B1/REF]; I31 --> L11[RQTF.A45B1/I]; I32 --> L11; I33 --> L11; C12 --> I34[RQTD.A78B1/K_SMOOTH]; C12 --> I35[RQTD.A78B1/I]; C12 --> I36[RPMBB.UA83.RQTD.A78B1/REF]; I34 --> L12[RQTD.A78B1/I]; I35 --> L12; I36 --> L12; C13 --> I37[RQTD.A12B1/K_SMOOTH]; C13 --> I38[RQTD.A12B1/I]; C13 --> I39[RPMBB.UA23.RQTD.A12B1/REF]; I37 --> L13[RQTD.A12B1/I]; I38 --> L13; I39 --> L13; C14 --> I40[RQTF.A23B1/K_SMOOTH]; C14 --> I41[RQTF.A23B1/I]; C14 --> I42[RPMBB.UA27.RQTF.A23B1/REF]; I40 --> L14[RQTF.A23B1/I]; I41 --> L14; I42 --> L14; C15 --> I43[RQTD.A56B1/K_SMOOTH]; C15 --> I44[RQTD.A56B1/I]; C15 --> I45[RPMBB.UA63.RQTD.A56B1/REF]; I43 --> L15[RQTD.A56B1/I]; I44 --> L15; I45 --> L15; C16 --> I46[RQTF.A34B1/K_SMOOTH]; C16 --> I47[RQTF.A34B1/I]; C16 --> I48[RPMBB.UA43.RQTF.A34B1/REF]; I46 --> L16[RQTF.A34B1/I]; I47 --> L16; I48 --> L16;
```

Children Parents

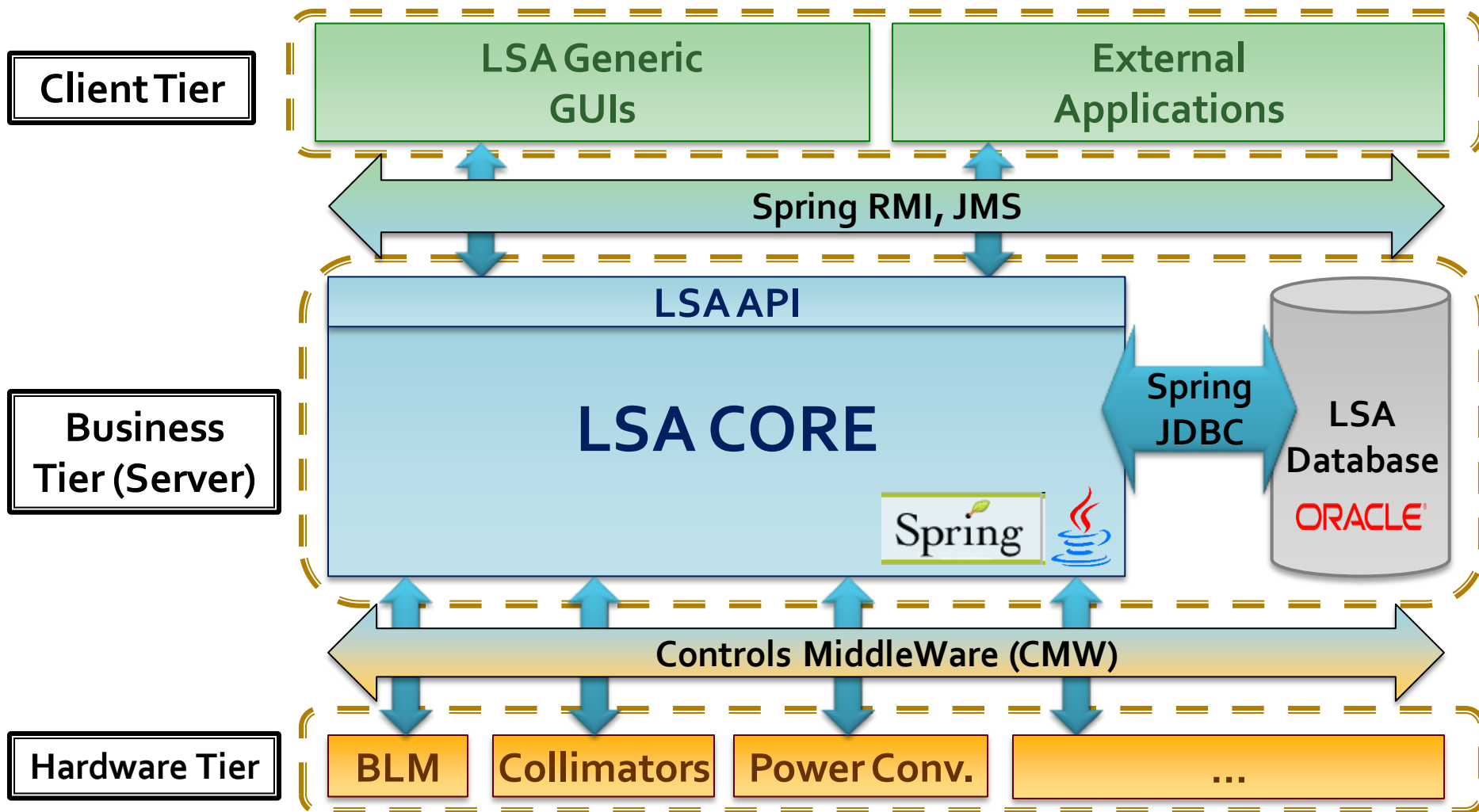
Close

# LSA: implementation

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



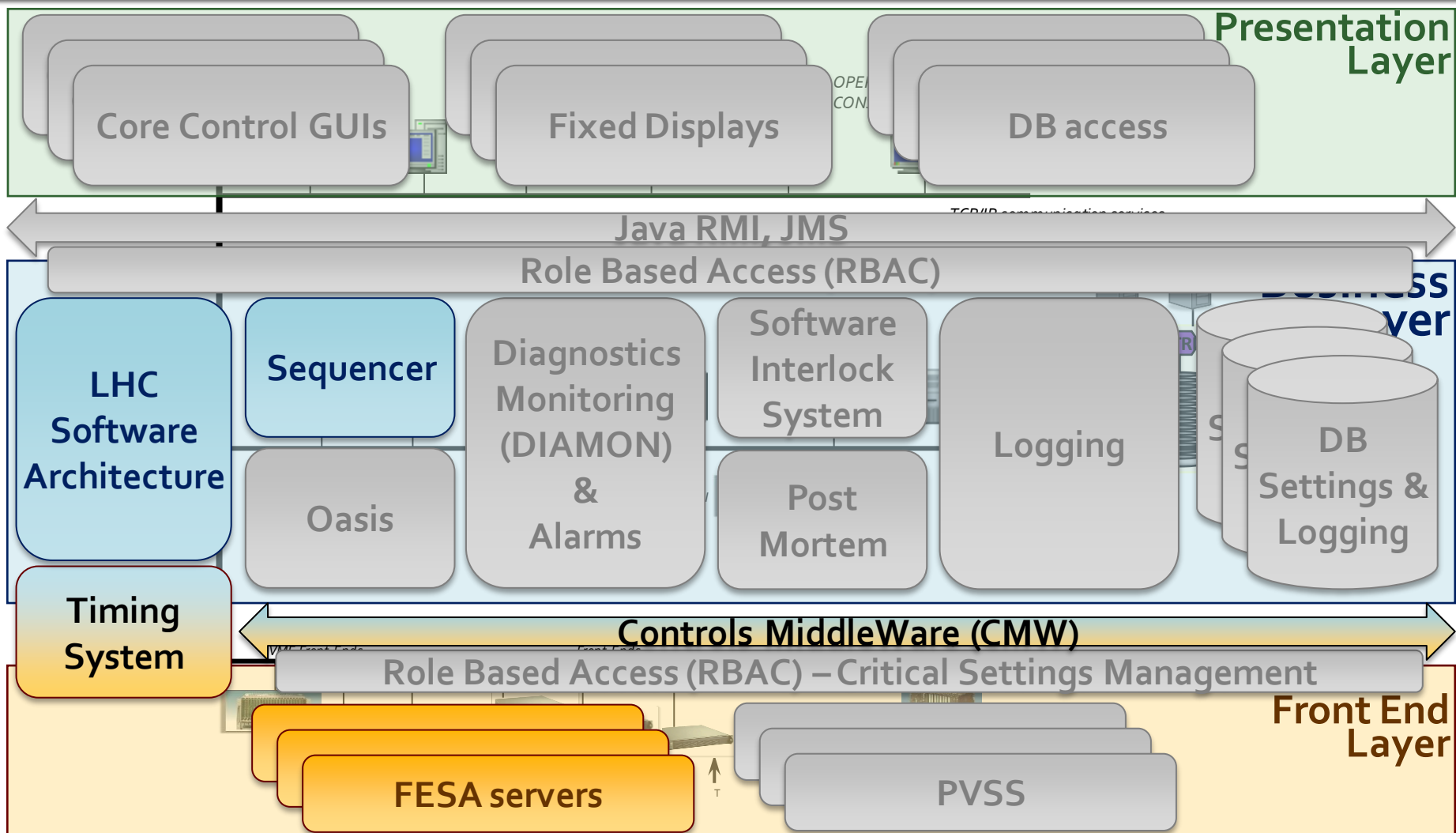
# LSA: architecture



# 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

## Tasks

### LSA

### Timing

send event

### Magnets

reset faults  
check state  
set state

### Beam dump

check ready

### Collimators

### RF

...~350.....

## Run LHC

## Prepare

reset magnet faults

switch magnets to STANDBY

check beam dump ready

.....

## Inject

## Accelerate

.....



# SEQ: implementation

## PREPARE FEEDBACKS FOR INJECTION

- PREPARE FEEDBACKS FOR INJECTION
  - SET FEEDBACK OFSU PRO
    - CHECK FEEDBACK STATE ORBIT OFF
  - DISARM FEEDBACKS
  - RESET TIME CONSTANT FOR FBS
    - FETCH ALL OPTICS TO OFSU
    - SET OPTICS OPERATION MODE MANUAL
  - DRIVE INJECTION SETTINGS FOR OFB
    - MAKE LHC.USER.INJECTION RESIDENT
    - LOAD INJECTION REF ORBIT FOR OFB
    - SET ACTIVE ORBIT INDEX
    - CALC ACTIVE BEAM PROCESS OPTICS
    - SET ACTIVE BEAM PROCESS OPTICS
  - DRIVE TUNE FB SETTINGS FOR INJECTION
    - SWITCH FEEDBACK STATE TUNE\_B1 OFF
    - SWITCH FEEDBACK STATE TUNE\_B2 OFF
    - MAKE LHC.USER.INJECTION RESIDENT
    - LOAD FEEDBACK INJECTION SETTINGS
    - LOAD TUNE FITTER SETTINGS B1
    - LOAD TUNE FITTER SETTINGS B2
    - LOAD TUNE FITTER SETTINGS B2 (FF)
    - LOAD TUNE FITTER SETTINGS B1 (FF)
    - LOAD TUNE FITTER SETTINGS B2 (FF)
    - LOAD TUNE FITTER SETTINGS B1 (FF)
  - SELECT QFB DEVICE FOR PILOT

## PREPARE RAMP

- PREPARE RAMP
  - PREPARE OFB SETTINGS WHILE FILLING
    - ENABLE POST MORTEM EVENTS
    - FORCE SBF TO FALSE
    - SWITCH OFF ABORT GAP CLEANING
    - RF CHECKS: WATCHDOG&FREQ B1/B2 LINKED
    - DISABLING INJECTION AND INJ COLL OUT
    - DISABLE INJECTION CLEANING
    - HANDSHAKE END OF INJ - SM&BM = PREPARE RAMP
      - STOP FIDEL TRIMMING
      - CALCULATE FIDEL RAMP CORRECTIONS
  - SWITCH ON AND ARM OFB
    - SWITCH ON ORBIT AND ENERGY FEEDBACKS
      - ARM ORBIT FEEDBACKS
        - LOAD RAMP OPTICS ORBIT CHANGE TABLE
        - ARM OFB REF ORBIT CHANGE
    - INCORPORATE INJECTION TRIMS INTO THE RAMP
    - TRIM ADT NORMALIZED GAINS TO RAMP VALUES
    - LOAD ADT DSPU BUNCH MASK FOR RAMP
    - SWITCH ON BBQ BUNCH GATING
    - CHECK TUNE FEEDBACK CONFIGURATION
    - SWITCH TUNE FB ON
      - MAKE LHC USER FIDEL RESIDENT
      - MAKE LHC.USER.RAMP RESIDENT
    - LOAD RAMP SETTINGS IN PC&RF FGC
    - ARM LONGITUDINAL BLOW-UP
    - LOAD CLEANING & DUMP PROTEC COLL RAMP SETTINGS
    - CHECK INJ-PROT OUT COLL INTERLOCKED OUT
      - END SUBSEQUENCE BREAK

012

0.6M 2012

FF TUNE FB

FF BBQ BUNCH GATING

WIDEBAND SETTINGS

ATION INTO SQUEEZE BP AND LOAD TABLE

SQUEEZE FUNCTIONS FOR TCT COLL IN IP1/5/8

SQUEEZE FUNC FOR ADT GAINS AND PHASE\_SHIFT

DSPU BUNCH MASK FOR SQUEEZE

SQUEEZE IN 1 STEP WITH QFB ON

SQUEEZE SEGMENT 0-> 9255

R FOR BP REGENERATION AT 925 S

ARM OFB FOR SQUEEZE

SWITCH ORBIT AND ENERGY FB OFF

REF ORBITS FOR THE SQUEEZE

ACTIVE ORBIT INDEX 0

ARM ref orbit for squeeze

CHECK REFERENCE ORBIT CORRECTLY LOADED

ORBIT AND OPTICS TABLE CHANGE FOR SQUEEZE

OFB REF ORBIT CHANGE

55

SWITCH ON ORBIT AND ENERGY FEEDBACKS

ARM OFB FOR SQUEEZE

SQUEEZE 2011 PC TABLES SEGMENT

FEEDBACKS ARMED

CHIRP AND QFB OFF

STATE/BEAM\_MODE = SQUEEZE

START TBL (33) EVT

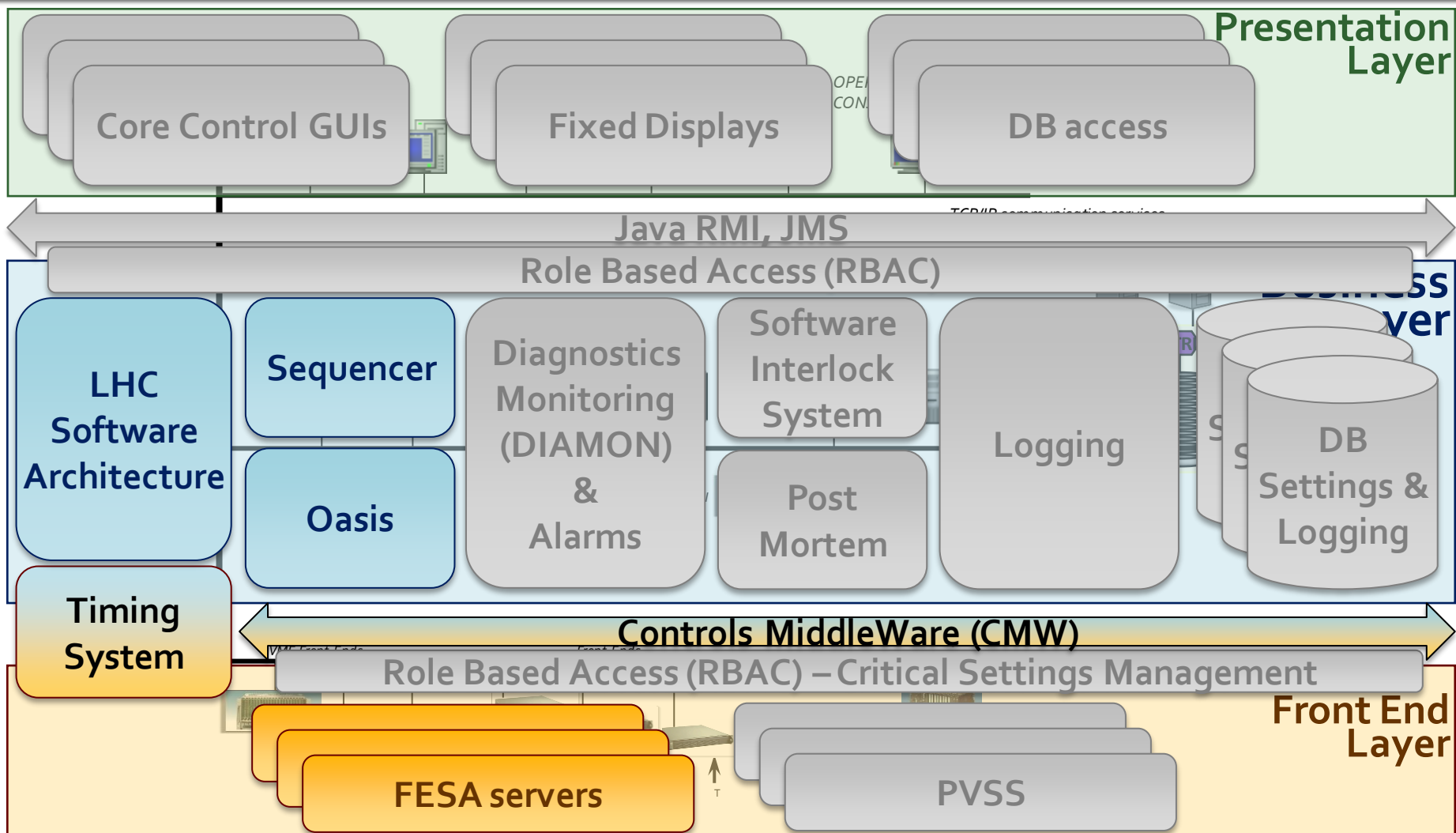
# SEQ: features

- **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

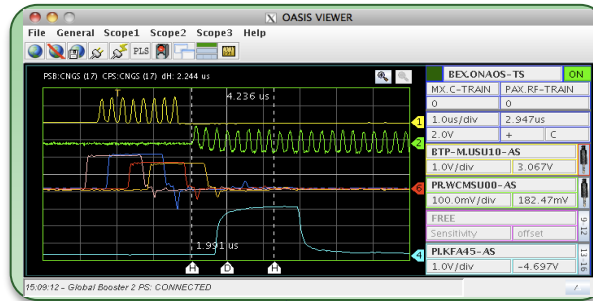
# Key components: OASIS



# 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**

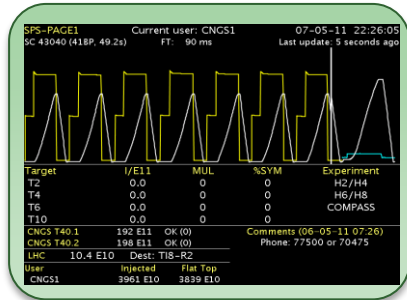
# OASIS: architecture



Custom Applications

Oasis Server

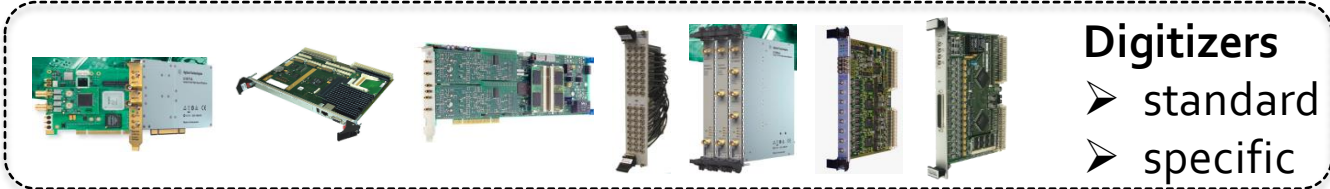
Logging System



Front-ends  
Standard FESA  
interface

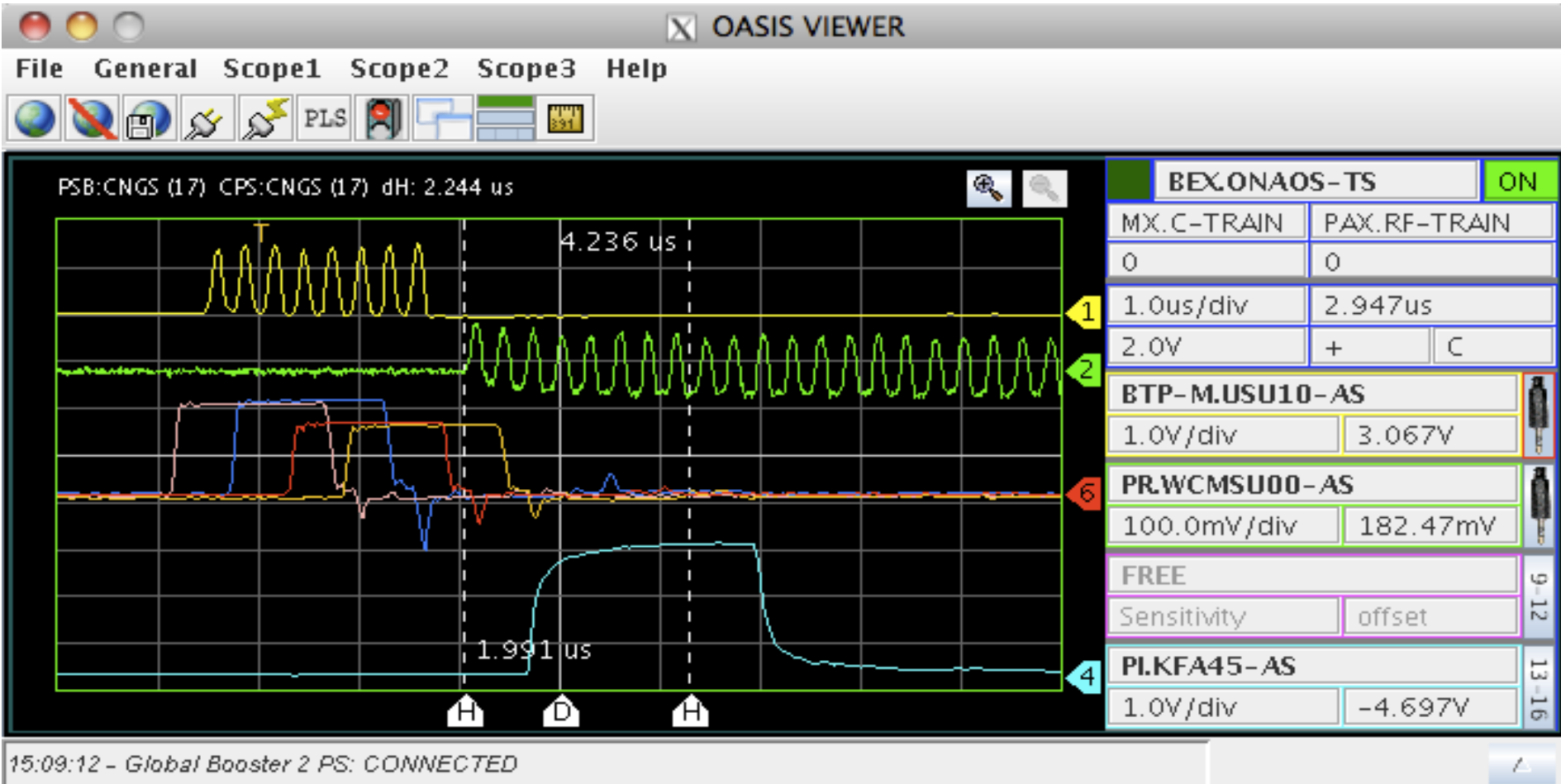
MATLAB, LabVIEW

RT Feedback FE App



Digitizers  
 ➤ standard  
 ➤ specific

# 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?

