

~~The LHC Control System~~

CERN Accelerator Control System



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

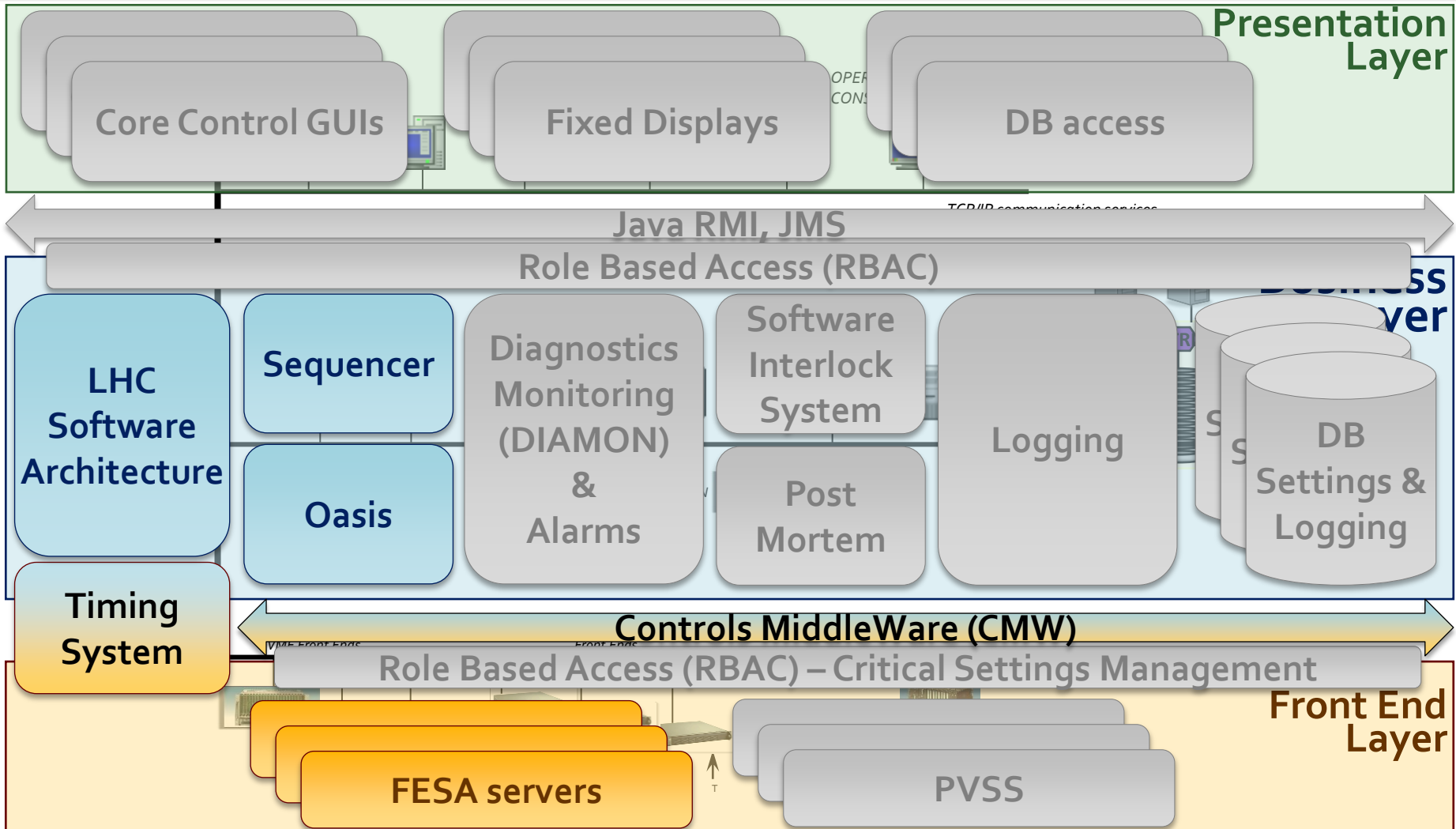
**Based on the input from M.Arruat, V.Baggiolini,
JC.Bau, M.Buttner, P.Charrue, S.Deghaye,
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J.Wozniak**

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

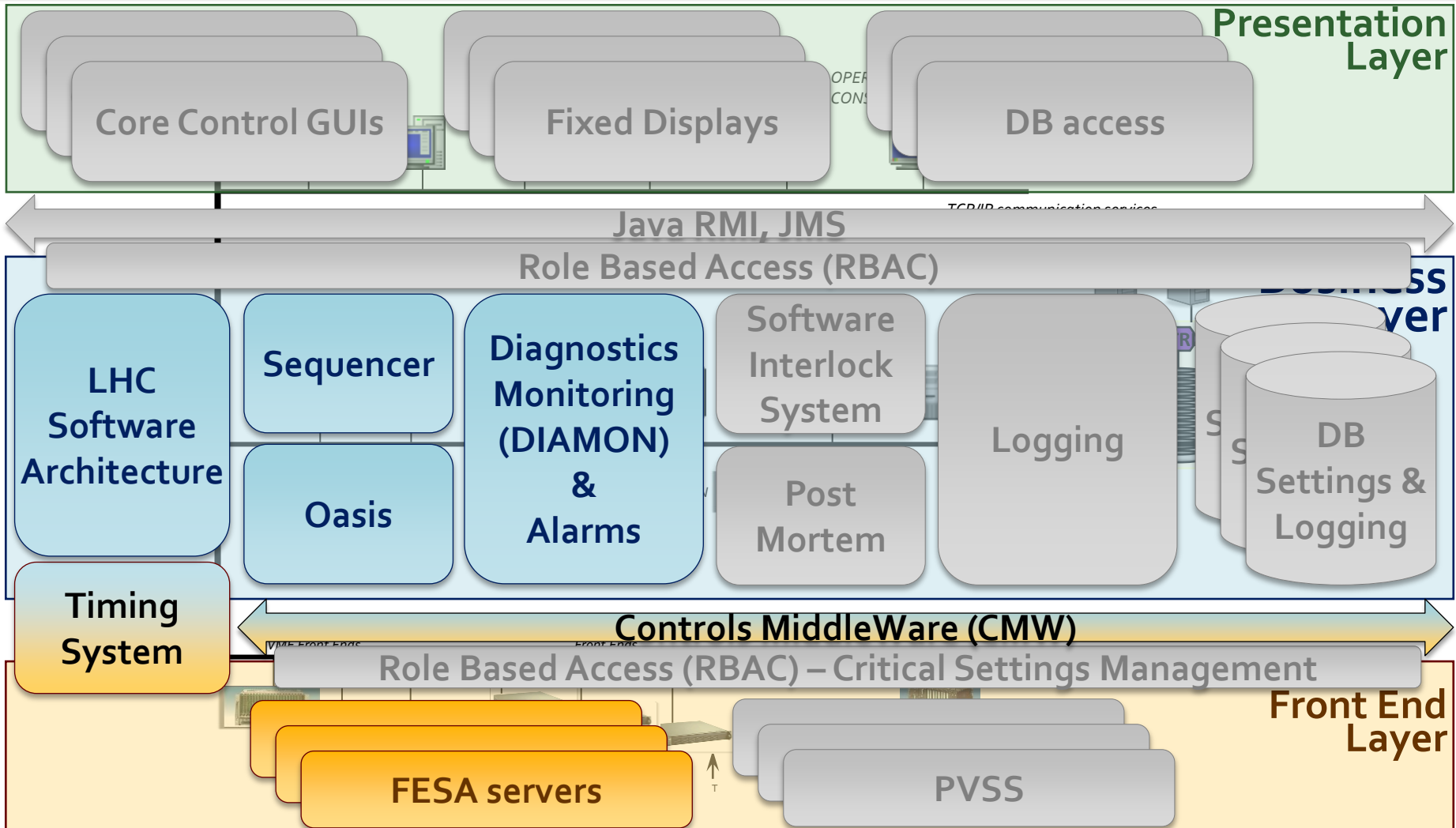
Contents

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

Key components



Key components



Diagnostic Monitoring and Alarms

Alarms

Summary of problems in single place

Huge number of SW processes

Huge number of devices

Diagnostics Monitoring



DIAGnostic MONitoring

- **Monitors** controls infrastructure
 - Computers (front-ends, servers, consoles)
 - Network
 - Software applications
- Provides **overview** of infrastructure state

DIAGNOSTIC MONITORING GUI

DMN2 console [PROD] - new configuration 1.0.13 - JURCSO as GUEST - db:all 1.0.13 - JURCSO as GUEST - db:lhc

File Edit View Help

RBA: no token Search: Name [A] Status [N] 14:21

root

- BCT
- BIC front-ends
- BLM
 - cfc-ccr-blmconc
 - cfv-sr1-blmc
 - cfv-sr1-blml
 - cfv-sr1-blmr
 - cfv-sr2-blmc**
 - cfv-sr2-blml
 - cfv-sr2-blmr
 - cfv-sr3-blmc
 - cfv-sr3-blml
 - cfv-sr3-blmr
 - cfv-sr5-blmc
 - cfv-sr5-blml
 - cfv-sr5-blmr
 - cfv-sr6-blmc
 - cfv-sr6-blml
 - cfv-sr6-blmr

cfv-sr2-blmc	cfv-sr1-blmc	cfv-sr1-blml	cfv-sr1-blmr	cfv-sr2-blmc
cfv-sr2-blml	cfv-sr2-blmr	cfv-sr3-blmc	cfv-sr3-blml	cfv-sr3-blmr
cfv-sr5-blmc	cfv-sr5-blml	cfv-sr5-blmr	cfv-sr6-blmc	cfv-sr6-blml
cfv-sr6-blmr	cfv-sr7-blmc	cfv-sr7-blme	cfv-sr7-blml	cfv-sr7-blmr
cfv-sr8-blmc	cfv-sr8-blml	cfv-sr8-blmr	cfv-sx4-blmc	cfv-sx4-blml
cfv-sx4-blmr				

cfv-sr2-blmc (BI Beam Loss Monitor VME FEC in SR2)

General Metric Services Processes Config MOTD CLIC State

Reboot SSH Restart CLIC 14:19:43 24/09/13

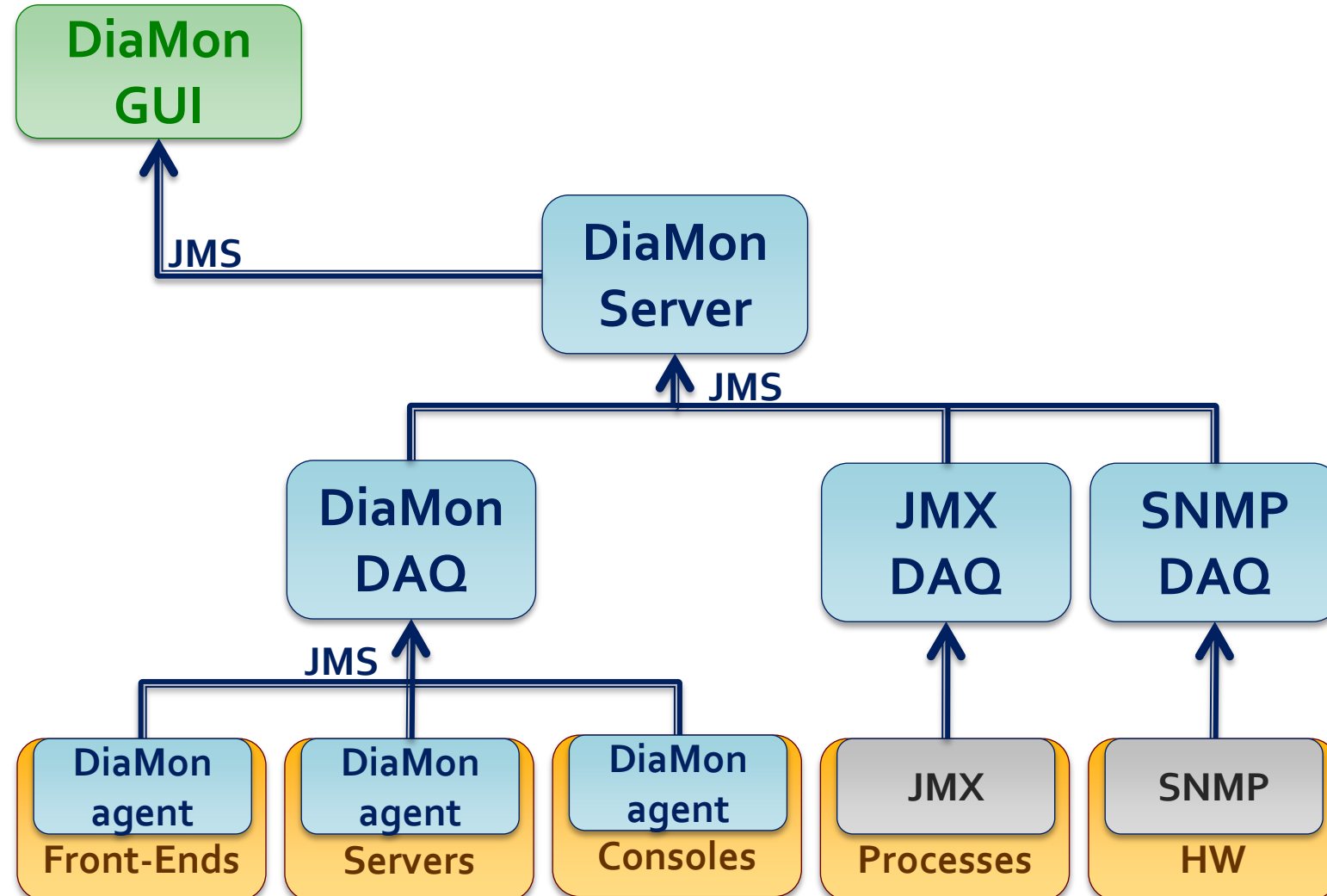
Responsible: Location: [2275](#) R-001 (BY02=SR2)

Extra info: None

Problem

Missing processes from transfer.ref: fesa2Logging, BOBR_M,

DiaMon: architecture



DiaMon: features

- Helps finding the **root cause** of the problem
- Provides **evolution history**
- Allows certain **actions**
 - restart system
 - restart process

Alarms

- **Software alarms system**
 - Problem => notification
- Does not deal with human/equipment safety
- Notifies about problems requiring **human intervention**

Alarms Console

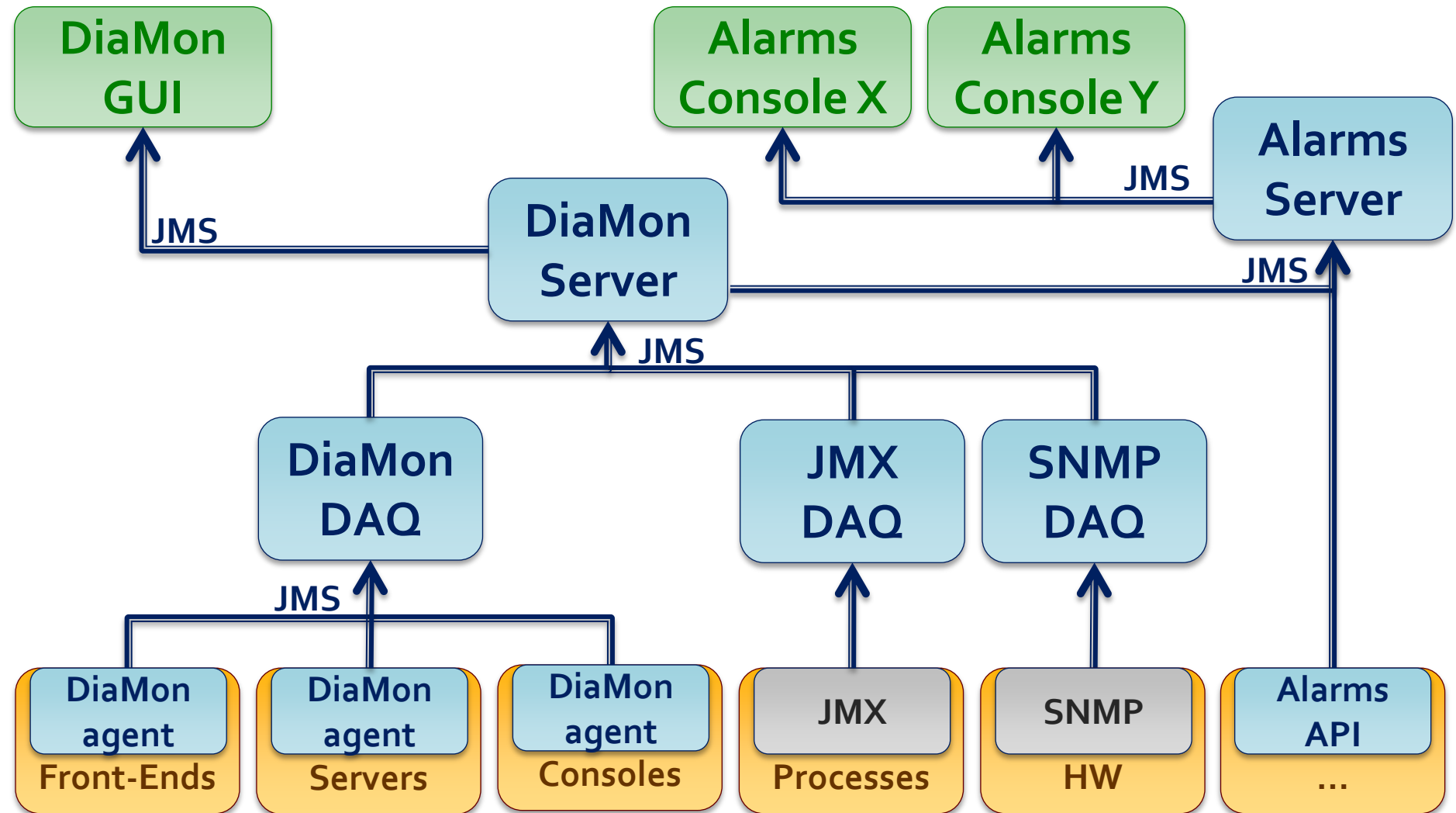
File Alarm Action View Configuration Help

Active List

▼ #	Date	Time	Building	Mnemonic	System Name	Identifier	Problem Description	Site
◇	N	13:41:36	3126	UX15	EAU_DEMI_LHC	FCUL-00013_LAR_CALOR	DEFAULT GENERAL INSTALLATION	L1
◇	03/09	21:18:38	3182	SUX1	THER_VENT_LHC	UAVX181	DEFAULT VENTILATION	L1
◇	10/09	14:29:01	3585	SX5	THER_VENT_LHC	UAVL-527	Alarm Details: THER_VENT_LHC:UAPT-204_UBRRG03:12936	L5
◇	23/09	13:42:50	3524	USC55	EAU_GLACEE_LHC	FREA-00020	System Name: THER_VENT_LHC	L5
◇	24/09	10:15:02	2395	SZU33	EAU_BRUTE_LHC	FTND-352	Identifier: UAPT-204_UBRRG03	L3
◇	24/09	10:21:09	2229	UW25	EAU_DEMI_LHC	FDED-00080_C211X	Problem Description: ALARME SEUIL POINT DE ROSEE PULSION HAUT	L2
◇	24/09	13:09:36	2280	SU2	THER_VENT_LHC	UAPT-203_UBRRG03	Alarm properties	L2
◇	24/09	13:21:37	2826	PM85	ACCE_GENERALE_LHC	YCAPG01=PM85	STATIC PROPERTIES	L2
◇	24/09	13:59:35	2280	SU2	THER_VENT_LHC	UAPT-204_UBRRG03	Fault Family: THER_VENT_LHC	L8
◇	N	14:16:37	3585	SX5	THER_VENT_LHC	F\$FSVE-00018	Fault Member: UAPT-204_UBRRG03	L2
◇	N	14:16:41	3578		ACCE_ZORA_LHC	YCPLC02=PM54	Fault Code: 12936	L5
◇	27/05	08:28:40	2285	SX2	THER_VENT_LHC	UAUX-00001	Priority: 1	L5
◇	05/06	11:49:08	2439	UA47	EAU_DEMI_LHC	FDED-00098	Reason: Temperature Point de rosee en dehors du seuil defini	L2
◇	04/07	17:00:04	2280	SU2	EAU_BRUTE_LHC	UIAO-00201_ARMOIRE_CTRL	Consequence: Mauvais fonctionnement regulation	L2
◇	27/07	08:42:40	2741	R771	EAU_DEMI_LHC	FDED-00099	Help URL: http://oraweb.cern.ch/pls/timw3/HELPALARM.AlarmForm?p_alarmid=148460&p_header=N	L4
◇	02/08	13:20:01	3125	USA15	THER_VENT_LHC	UIAO-00117	Site: L2	L2
◇	02/09	10:34:09	2285	SX2	THER_VENT_LHC	UACW2-00518	Building Number: 2280	L7
◇	03/09	06:11:14	2613	UJ63	THER_VENT_LHC	UAUQ-01635	Building Mnemonic: SU2	L1
◇	03/09	06:11:52	2748	RE78	THER_VENT_LHC	UICC-00708	Position: L2	L2
◇	03/09	07:31:10	2882	SUX8	THER_VENT_LHC	USFARPREPZ-SUX8_UOWC-816	Map Safety Zone: -1	L6
◇	03/09	15:50:40	2380	SU3	EAU_GLACEE_LHC	FTNB-301	Responsible Name: ROBIN MARTINI	L7
◇	03/09	21:18:38	3182	SUX1	THER_VENT_LHC	USFRAEXTSUX-SUX1_UOWC-114	Responsible GSM: 4609	L3
◇	10/09	15:39:32	2618	UA63	EAU_DEMI_LHC	FDED-00100	Responsible Phone: 73130	L1
◇	10/09	15:42:28	2175	SR1	THER_CLIM_LHC	UACV1-00126	Responsible Email: Robin.Martini@cern.ch	L6
◇	17/09	08:00:44	2885	SX8	SERV_EXPERIENCE_LHC	DSS_LHCB	Source Name: TIMOPALARM	L1
◇	17/09	14:44:20	2639	UA67	EAU_DEMI_LHC	FDED-00101	Source Description: Source TIMOPALARM connection failure	L6
◇	21/09	05:36:54	2618	UA63	THER_VENT_LHC	UAUT-01630	Source Responsible: MARTINI	L6
◇	23/09	09:26:29	3185	SX1	THER_VENT_LHC	UAVL-158	CATEGORIES	L1
◇	24/09	08:17:17	2480	SU4	EAU_GLACEE_LHC	UHAA402	CERN.SRVS.LHC.THER Alarms for LHC THERMIQUE	L4
◇	24/09	10:29:19	2884	SH8	THER_VENT_LHC	UAPQ881	DYNAMIC PROPERTIES	L8
◇	24/09	10:50:22	2880	SU8	THER_VENT_LHC	UAPS-807_UUDCM15	Active: Yes	L8
◇	24/09	10:51:31	2880	SU8	THER_VENT_LHC	UAVD-806_UUDCM12	Source Hostname: CS-CCR-TIM12	L8
◇	24/09	10:51:31	2880	SU8	THER_VENT_LHC	USFARHVCSB-SU8_UOWC-804	ASL_PREFIX:	L8
◇	24/09	13:40:19	3126	UX15	EAU_FLUOROCARB_LHC	FCUM-00004_TRT	EMPTY PROPERTIES	L8
◇	N	13:46:24	2280	SU2	THER_VENT_LHC	UAPE-201_P2.SU2	Action To Take:Piquet GSM:Piquet email, Building Floor, Building Room, Map Reference,	L1
◇	N	14:07:42	3118	UPX14	ACCE_GENERALE_LHC	YCPV02=UPX14	Close	L2
◇	N	14:16:18		UX15	EAU_DEMI_LHC	FCUL-00013_LAR_CALOR	DEFAULT GENERAL - FONCTION DEGRADE	L1
◇	N	14:16:47		SX1	THER_VENT_LHC	UAVL-158	[A] ALARME INSTALLATION	L1
							DEFAULT GENERAL UNITE	L2
							PORTE OUVERTE	L1
							[A] ALARME INSTALLATION	
							ALARME MANQUE TENSION UNITE VENTILATION	

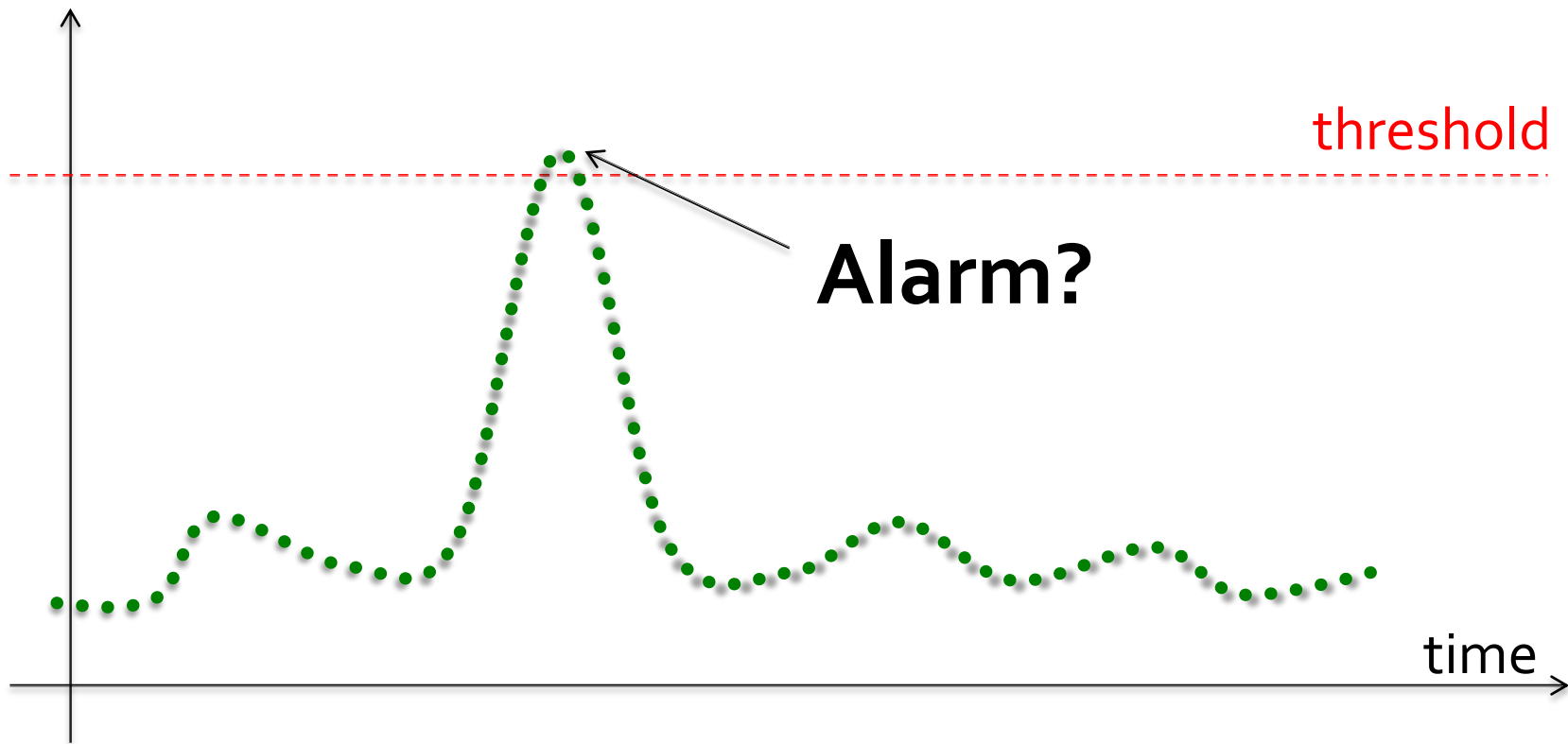
Active: 36 M: 299 I: 29 H: 0

DiaMon & Alarms: architecture



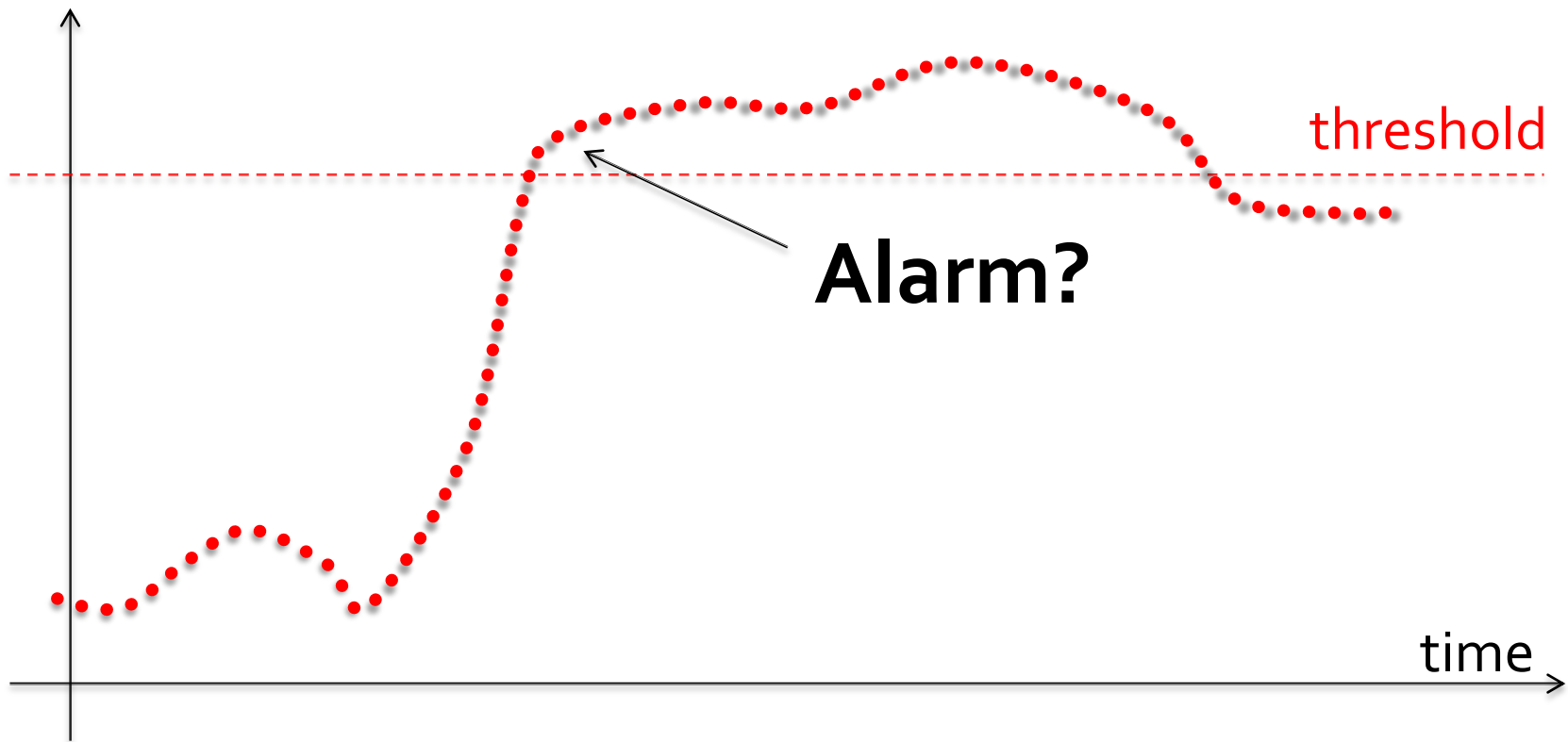
Alarms: features

- **Relevant** alarms only



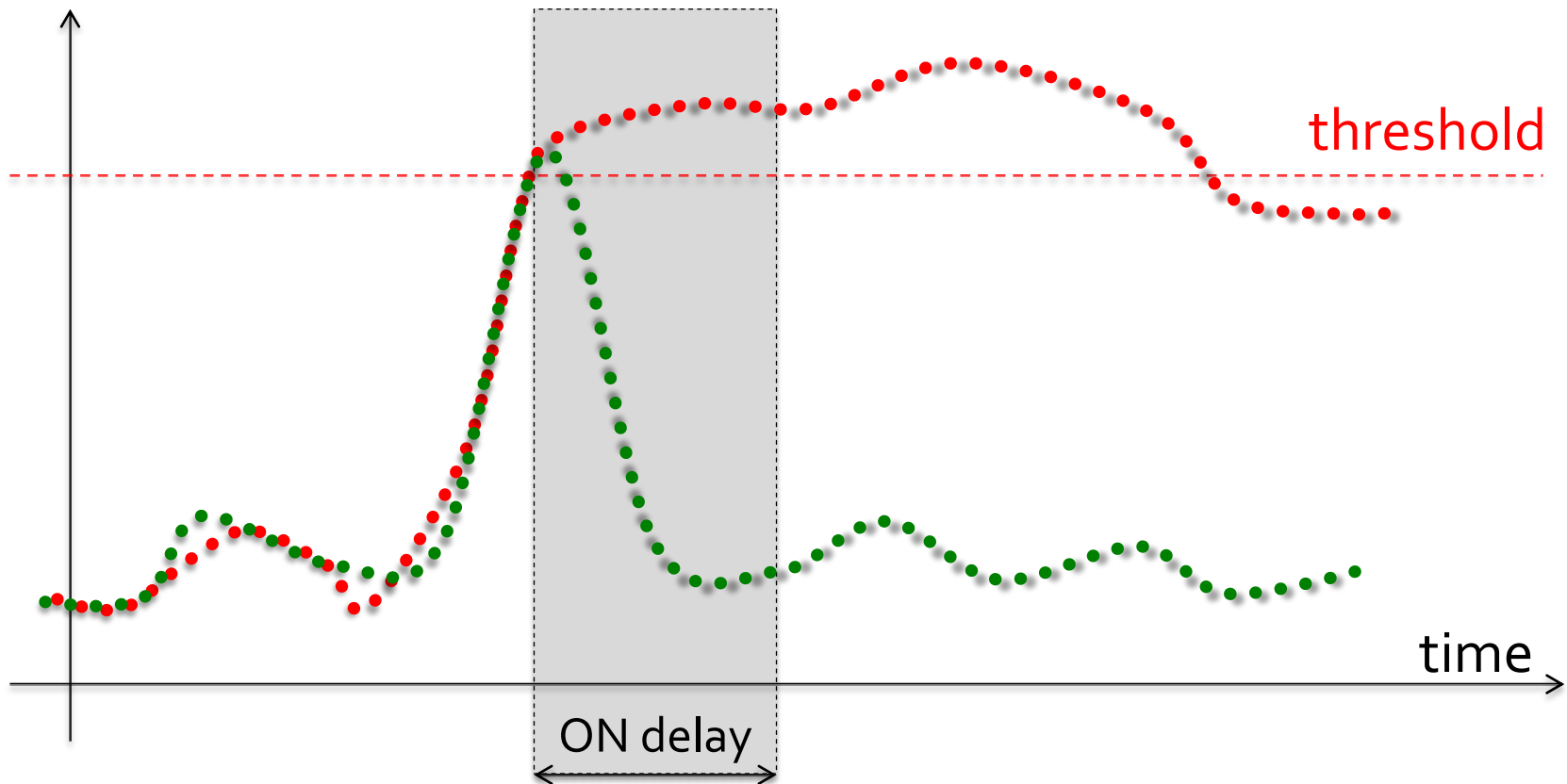
Alarms: features

- **Relevant** alarms only



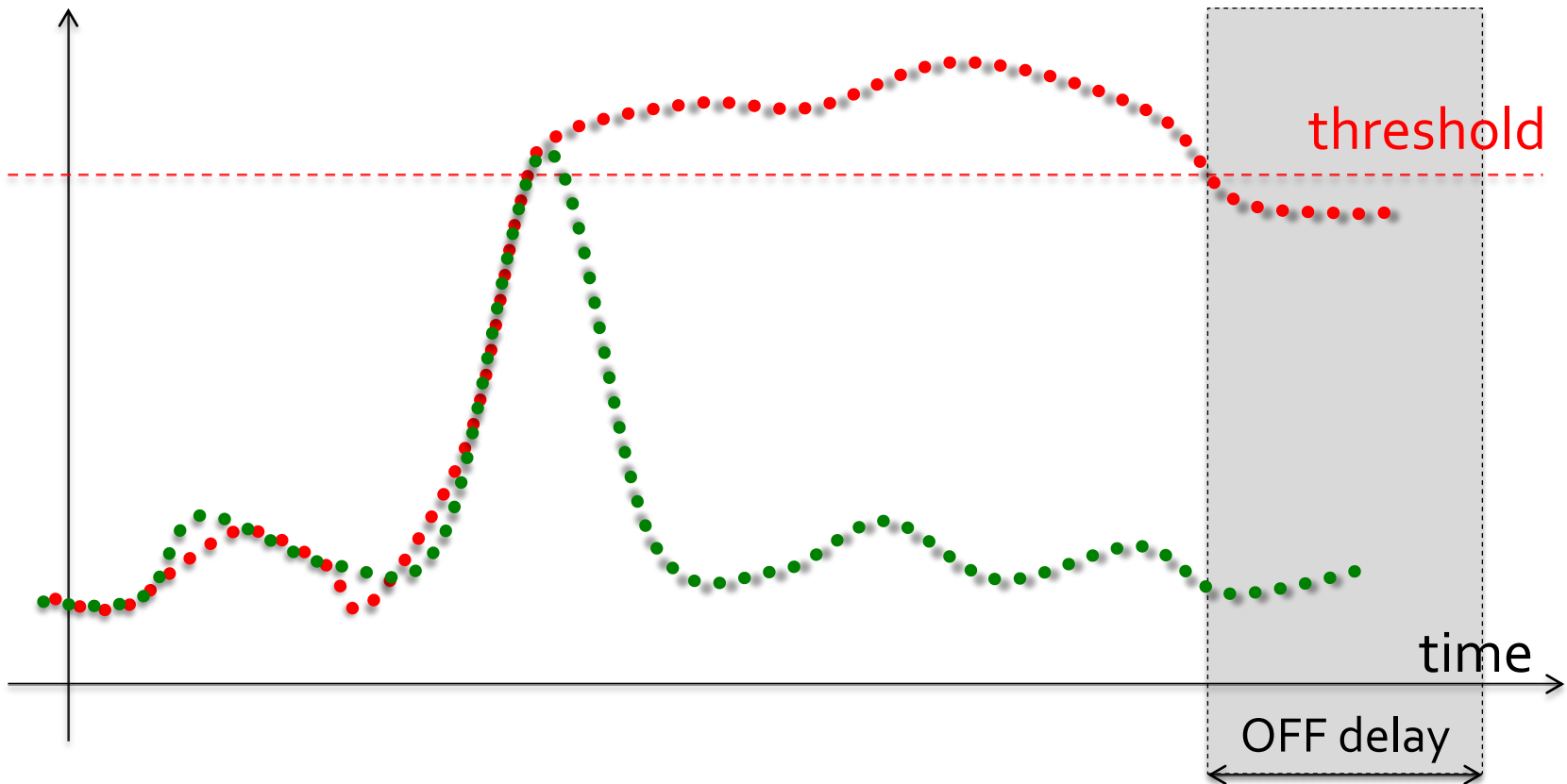
Alarms: features

- Relevant alarms only



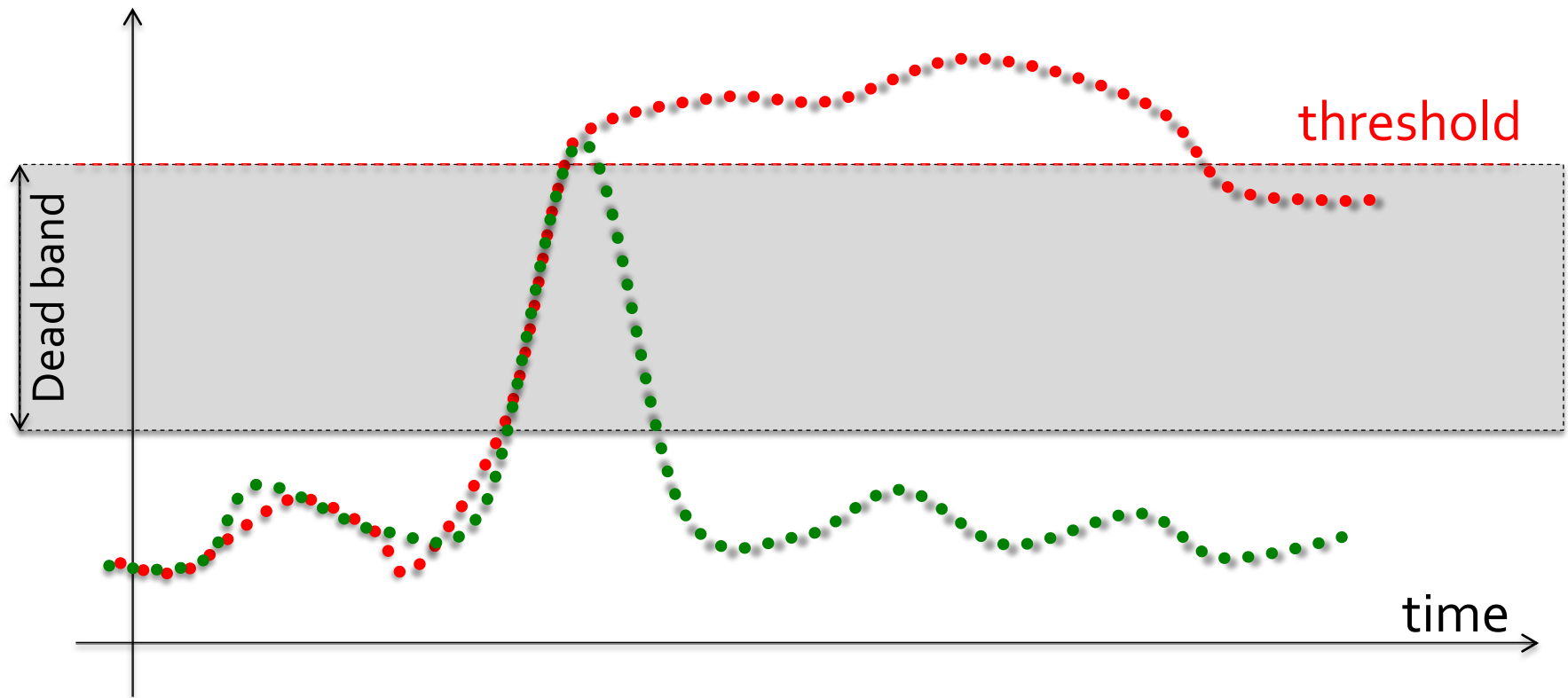
Alarms: features

- **Relevant** alarms only



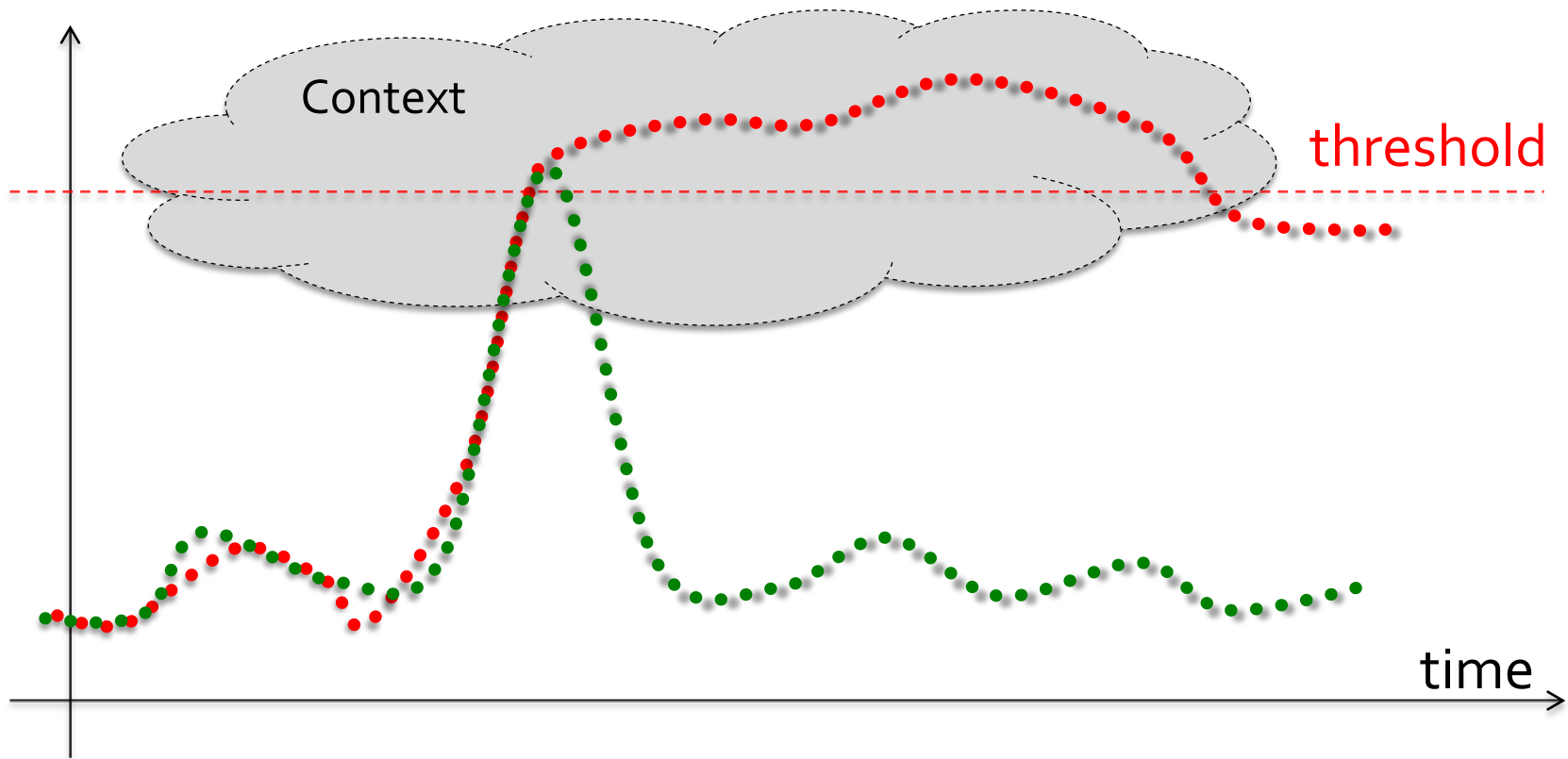
Alarms: features

- **Relevant** alarms only



Alarms: features

- **Relevant** alarms only



Alarms: features

- **Relevant** alarms only
 - Quality of raised alarms
 - Dependent on clients: ex. different accelerators
- Alarms **history**
- **Maps** alarms **to people** and **possible actions**
- Alarms **priority**

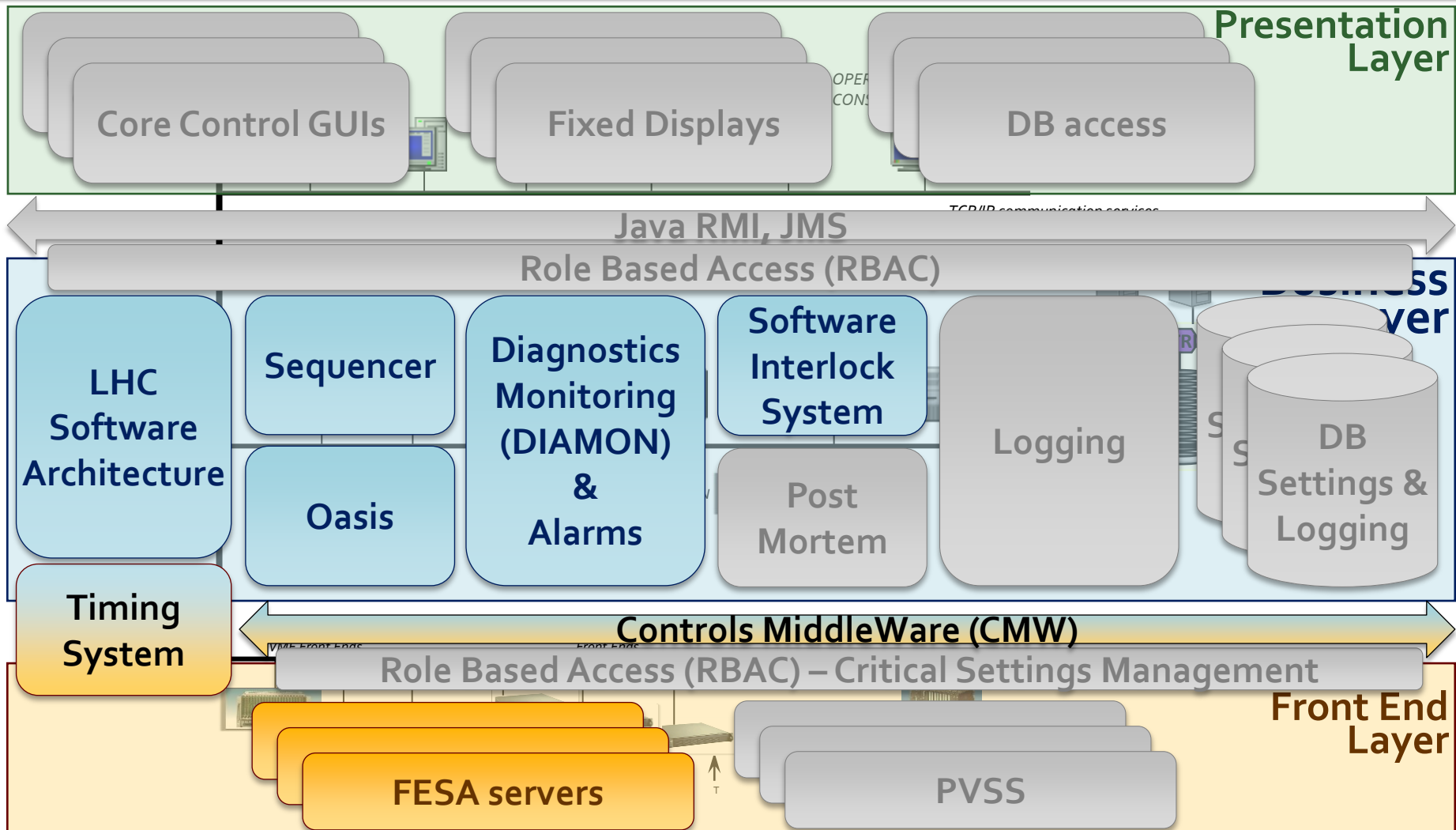
DiaMon & Alarms: today

- Diagnostic Monitoring
 - Metrics from >2000 computers
 - ~10 M updates / day
- Alarms
 - ~200 K alarm definitions (80'000 for LHC)
 - ~150 alarm events / minute

DiaMon & Alarms: future

- Extend monitoring to process internals
 - JMX metrics
 - Periodic sanity checks
- Automatic alarms analysis
 - Frequent, oscillating alarms => contact expert
 - Long-standing alarms => reconsider alarm

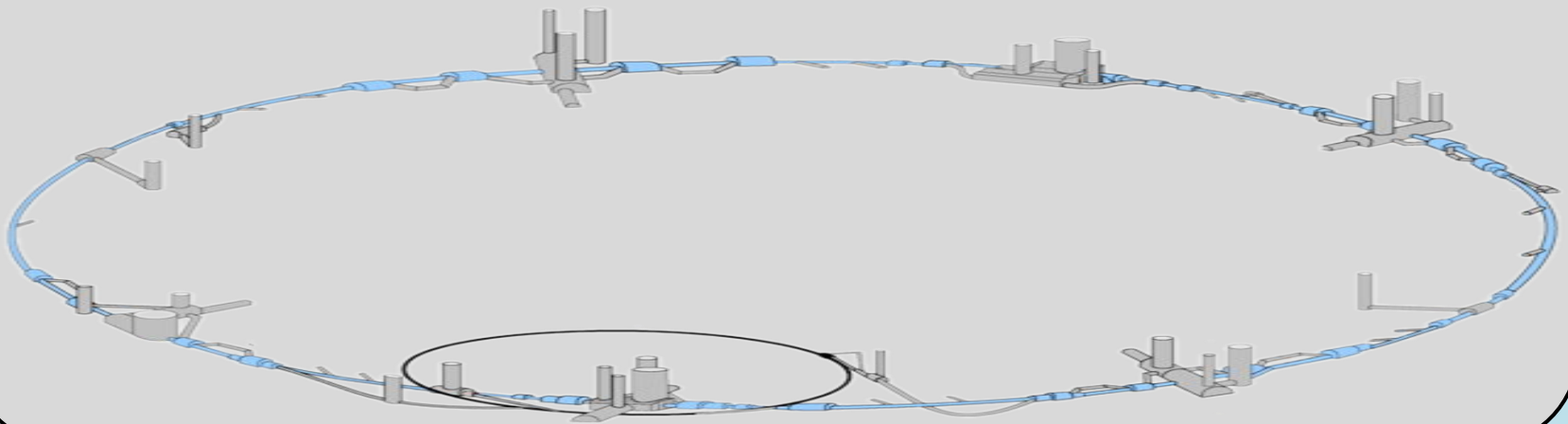
Key components: SIS



Machine Protection: birds-eye view

Software Interlock System

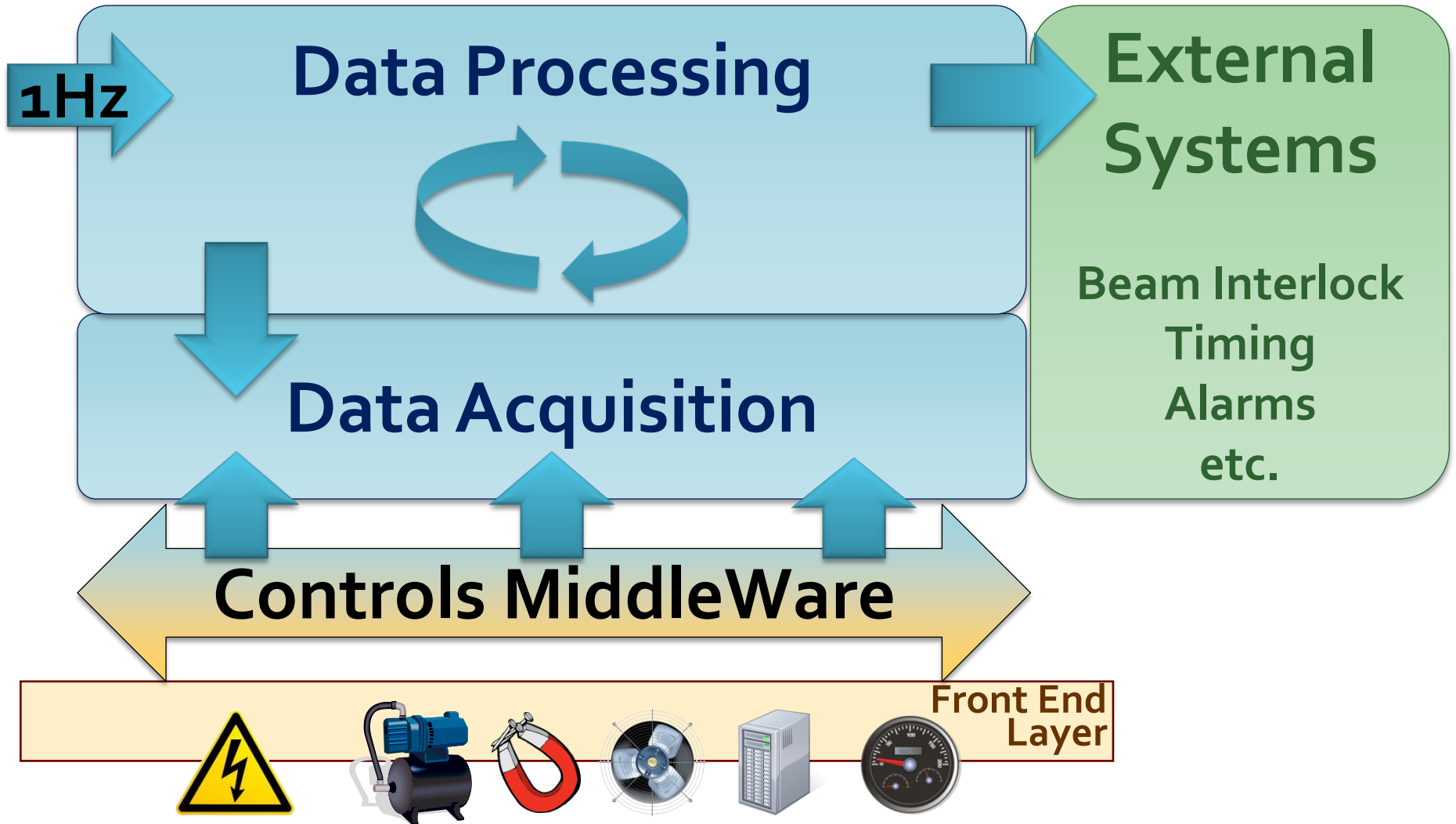
Hardware Machine Protection



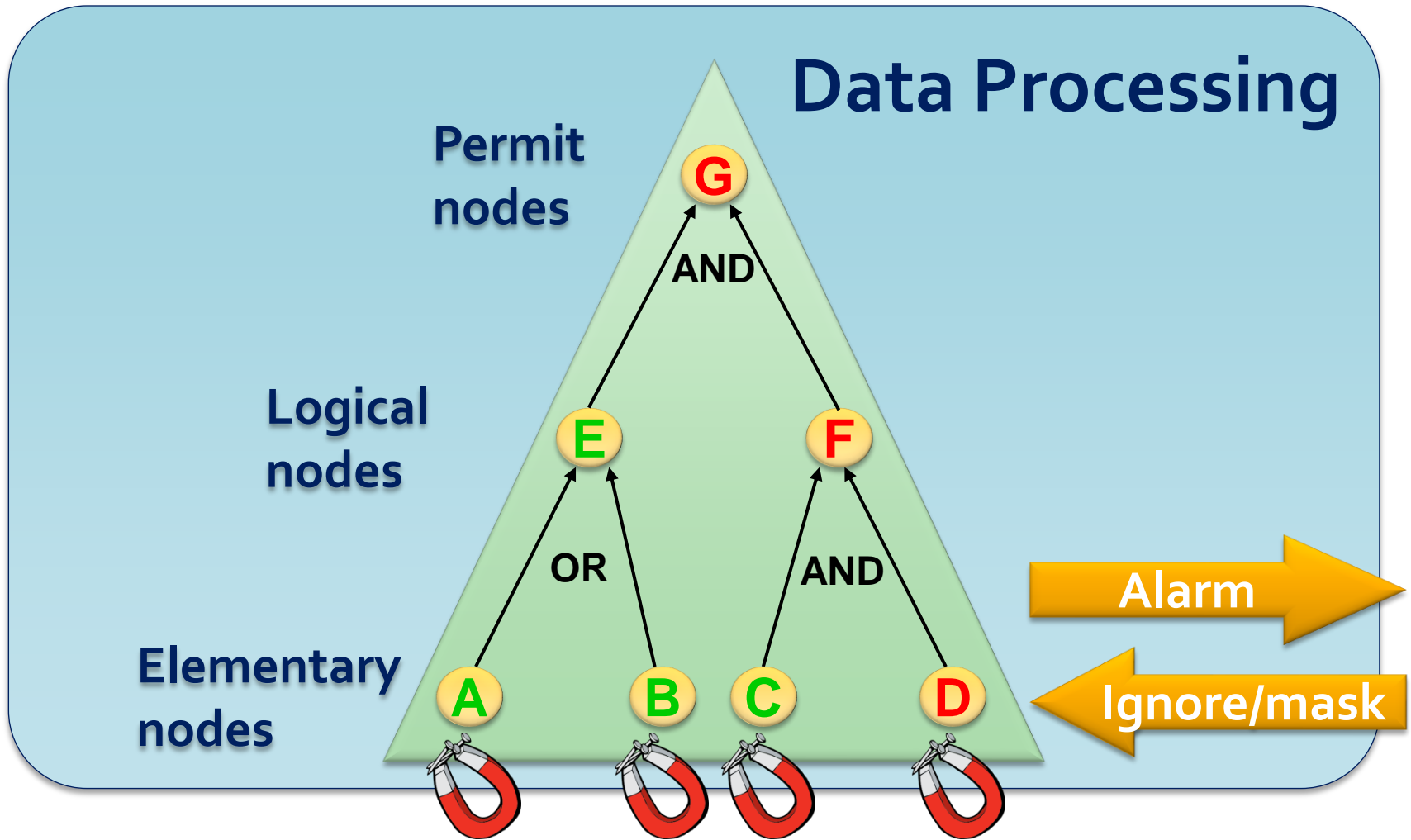
Software Interlock System (SIS)

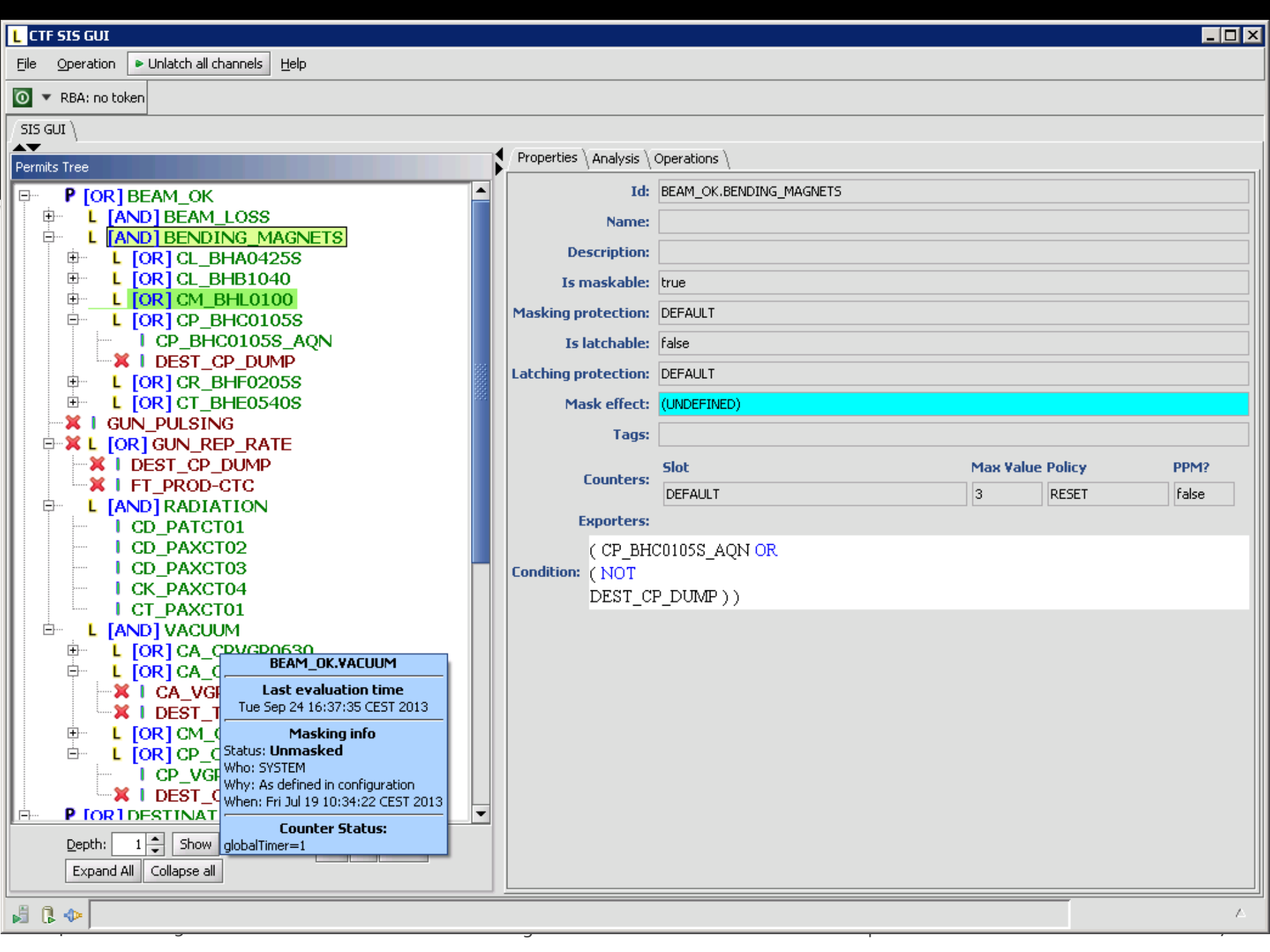
- **Surveys** the state of key LHC components
- **Acts** if necessary
 - **abnormal situation** \Rightarrow **beam dump**
- Part of overall **Machine Protection**

SIS: architecture



SIS: implementation





SIS GUI

Permits Tree

- P [OR] BEAM_OK
 - L [AND] BEAM_LOSS
 - L [AND] BENDING_MAGNETS
 - L [OR] CL_BHA0425S
 - L [OR] CL_BHB1040
 - L [OR] CM_BHL0100
 - L [OR] CP_BHC0105S
 - I CP_BHC0105S_AQN
 - I DEST_CP_DUMP
 - L [OR] CR_BHF0205S
 - L [OR] CT_BHE0540S
 - I GUN_PULSING
 - I GUN_REP_RATE
 - I DEST_CP_DUMP
 - I FT_PROD-CTC
 - L [AND] RADIATION
 - I CD_PATCT01
 - I CD_PAXCT02
 - I CD_PAXCT03
 - I CK_PAXCT04
 - I CT_PAXCT01
 - L [AND] VACUUM
 - L [OR] CA_CPMGD0630
 - L [OR] CA_C...
 - I CA_VG...
 - I DEST_T...
 - L [OR] CM_C...
 - L [OR] CP_C...
 - I CP_VG...
 - I DEST_C...
- P [OR] DESTINAT...

Properties Analysis Operations

Id: BEAM_OK.BENDING_MAGNETS

Name:

Description:

Is maskable: true

Masking protection: DEFAULT

Is latchable: false

Latching protection: DEFAULT

Mask effect: (UNDEFINED)

Tags:

Counters:	Slot	Max Value Policy	PPM?	
	DEFAULT	3	RESET	false

Exporters:

Condition: (CP_BHC0105S_AQN OR DEST_CP_DUMP)

BEAM_OK.VACUUM

Last evaluation time
Tue Sep 24 16:37:35 CEST 2013

Masking info
Status: Unmasked
Who: SYSTEM
Why: As defined in configuration
When: Fri Jul 19 10:34:22 CEST 2013

Counter Status:
globalTimer=1

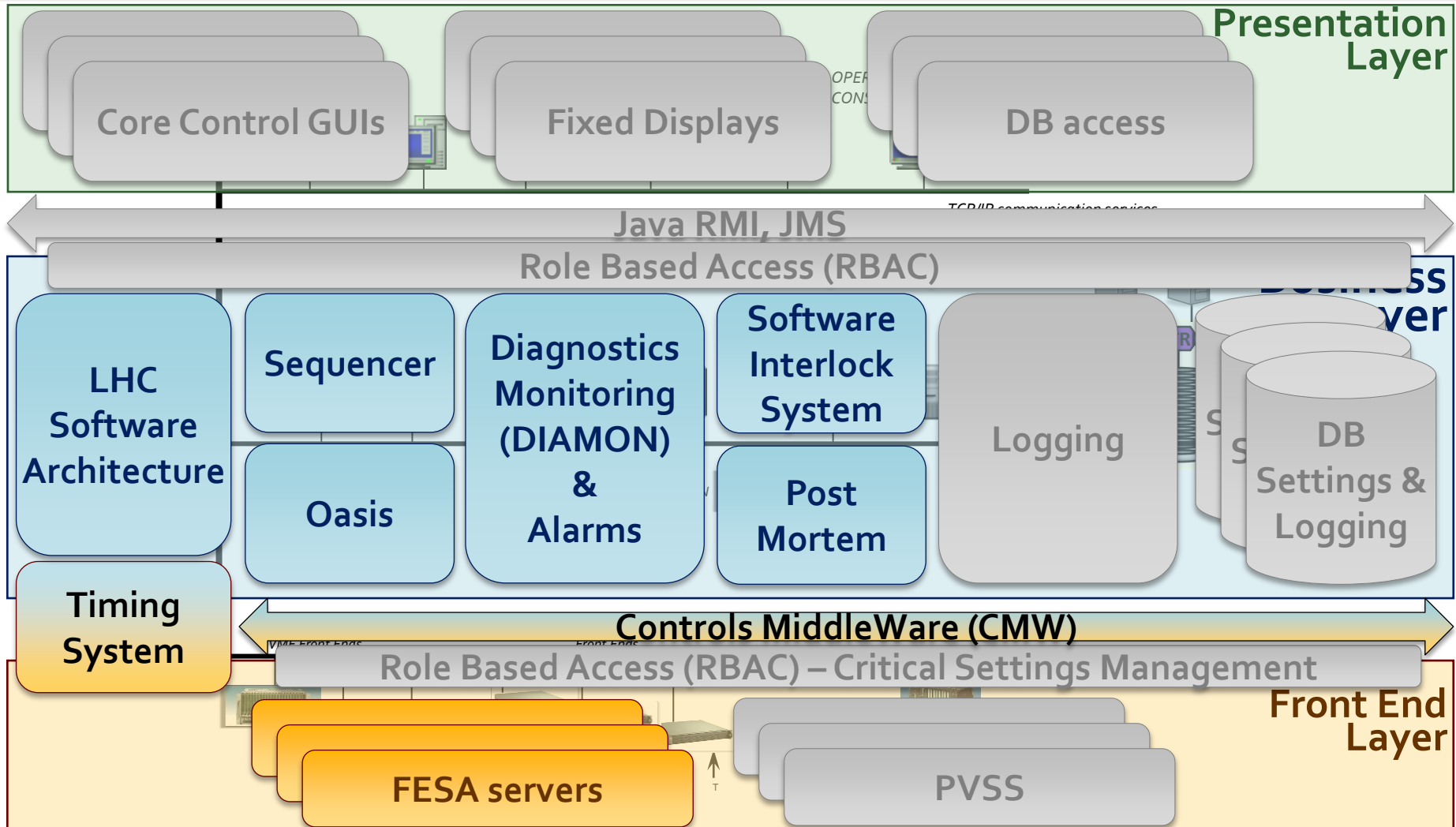
SIS: features

- **Domain conditions** representation
- **Complex** condition **logic**
- Provides the operations with condition calculation **diagnostics**
- **Extensible**
- **Deterministic** and highly **reliable**

SIS: today

- Deployed practically for all accelerators
- SIS for LHC has
 - ~2700 subscriptions
 - ~5200 elementary / ~800 logical / 8 permits
- SIS for SPS is used to save energy
 - Up to 200'000 euro/year

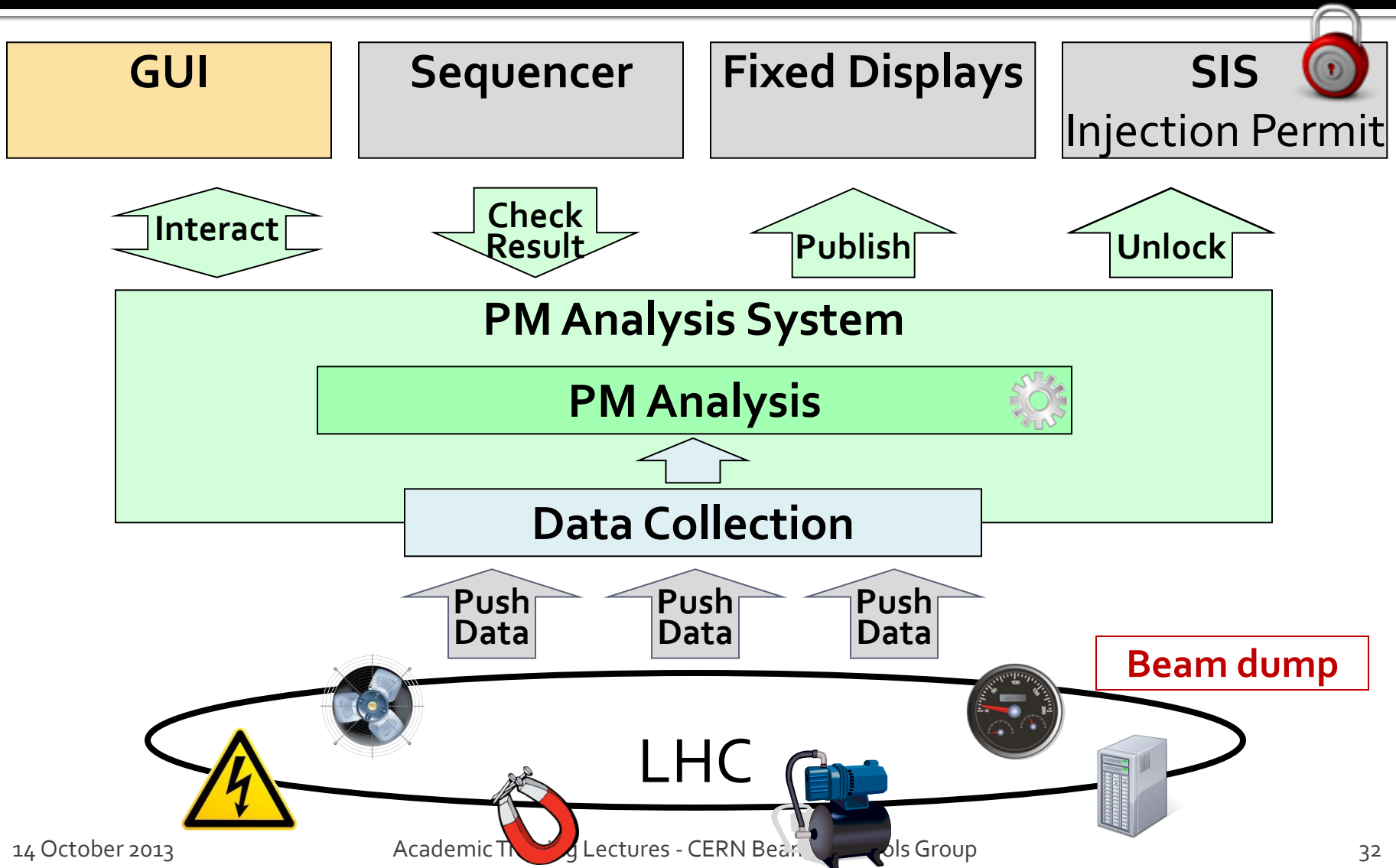
Key components: Post-Mortem



Post-Mortem Analysis (PMA)

- Detects the cause of the beam dump
- Checks if all the protection equipment behaved as expected
- Decides if it safe to continue the operations
- Blocks the next injection otherwise
- Part of overall **Machine Protection**

PMA: workflow



PMA: LHC Page 1

LHC Page1

Fill: 973

E: 3567 GeV

21-03-2010 08:16:27

BEAM SETUP: RAMP DOWN

Energy:

3567 GeV

I(B1):

5.40e+08

I(B2):

0.00e+00

Post Mortem Information

PM event ID: Sun Mar 21 07:59:45 CET 2010

PM event category: EMERGENCY_DUMP

PM event classification: MULTIPLE_SYSTEM_DUMP

PM BIS Analysis result: PM BIS Analysis result: First input change detected: USER_PERMIT: Ch 12(PIC_MSK):

PM comment: LBDS dumped due to missing vacuum information

Comments 21-03-2010 08:06:06 :

Beam dumped
Triplets tripped
Ramp down and reinject

BIS status and SMP flags

B1

B2

Link Status of Beam Permits

false false

Global Beam Permit

false false

Setup Beam

true true

Beam Presence

false false

Moveable Devices Allowed In

false false

Stable Beams

false false

LHC Operation in CCC : 77600, 70480

PM Status B1

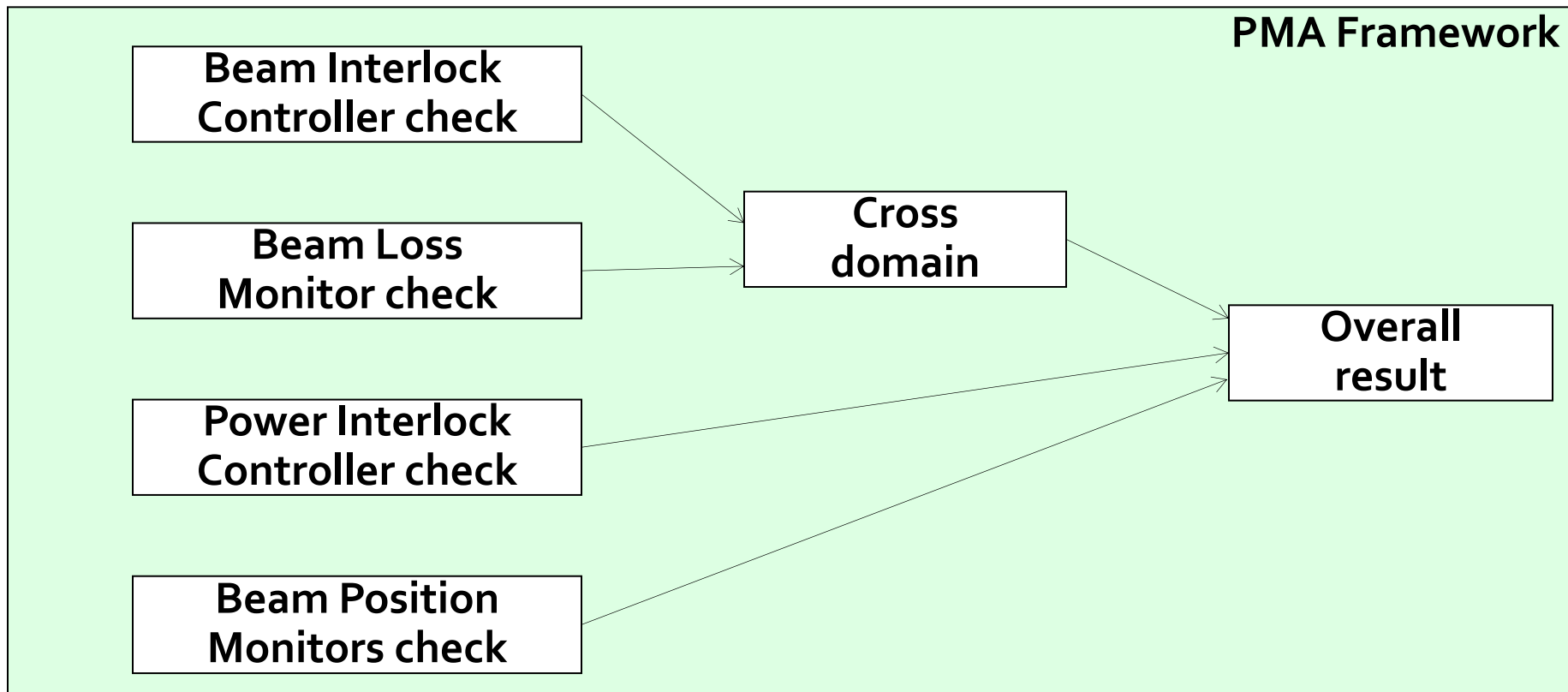
ENABLED

PM Status B2

ENABLED

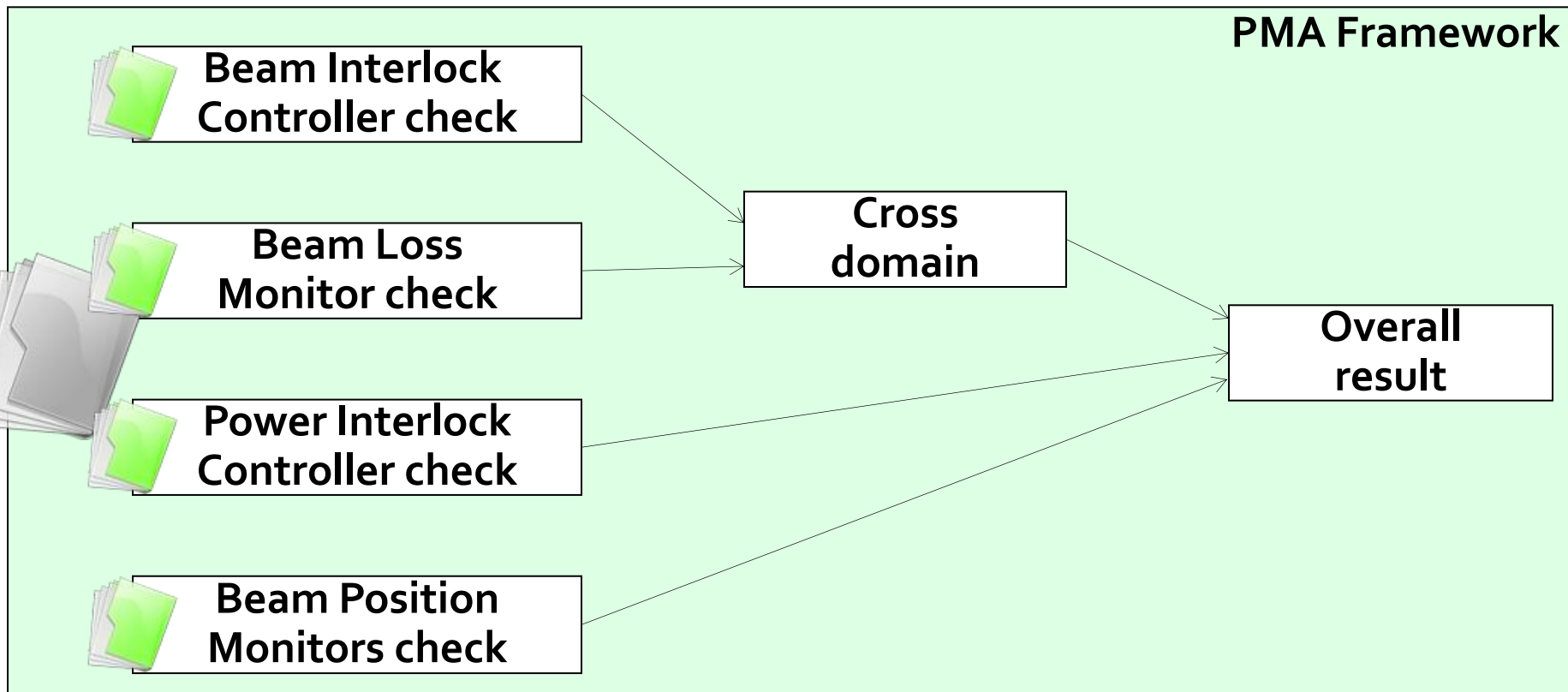
PMA: implementation

- Analysis is based on a graph of analysis modules



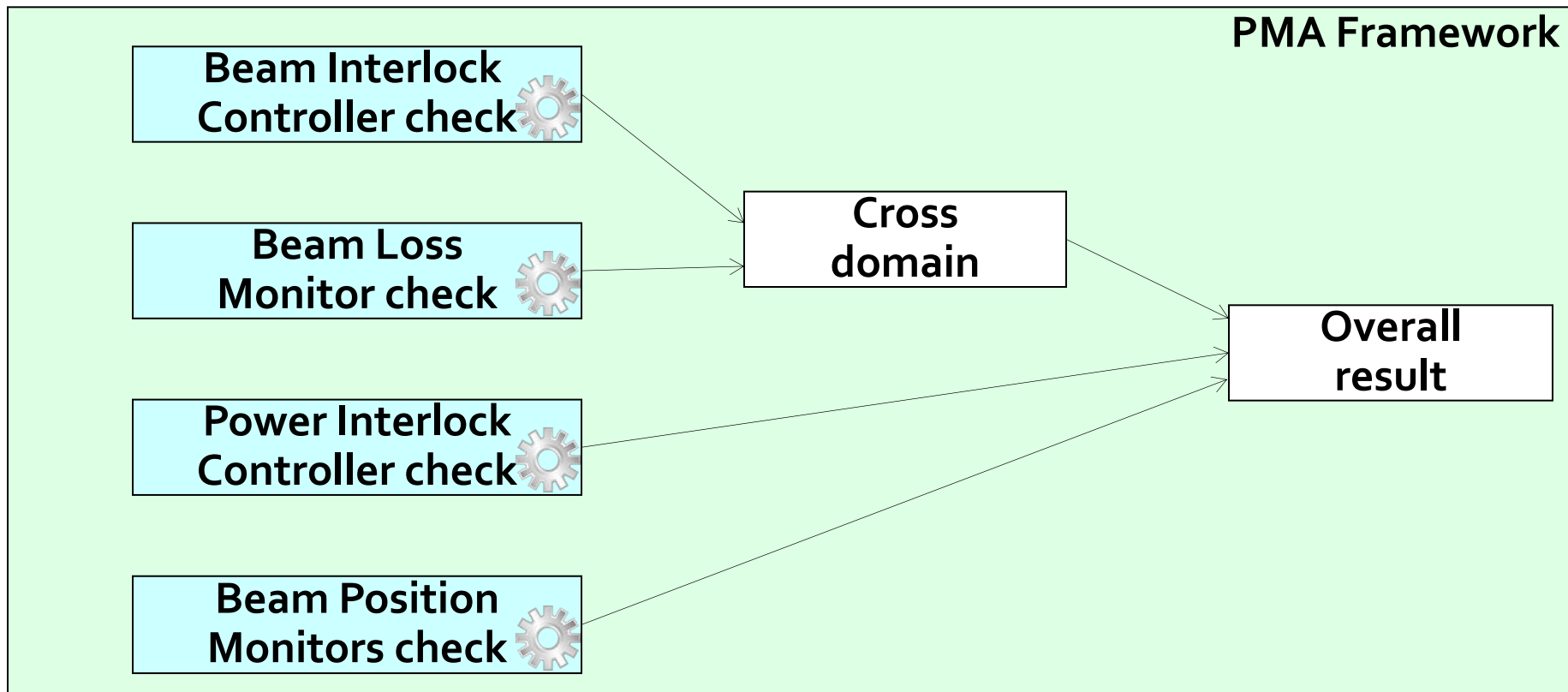
PMA: implementation

- Analysis is based on a graph of analysis modules



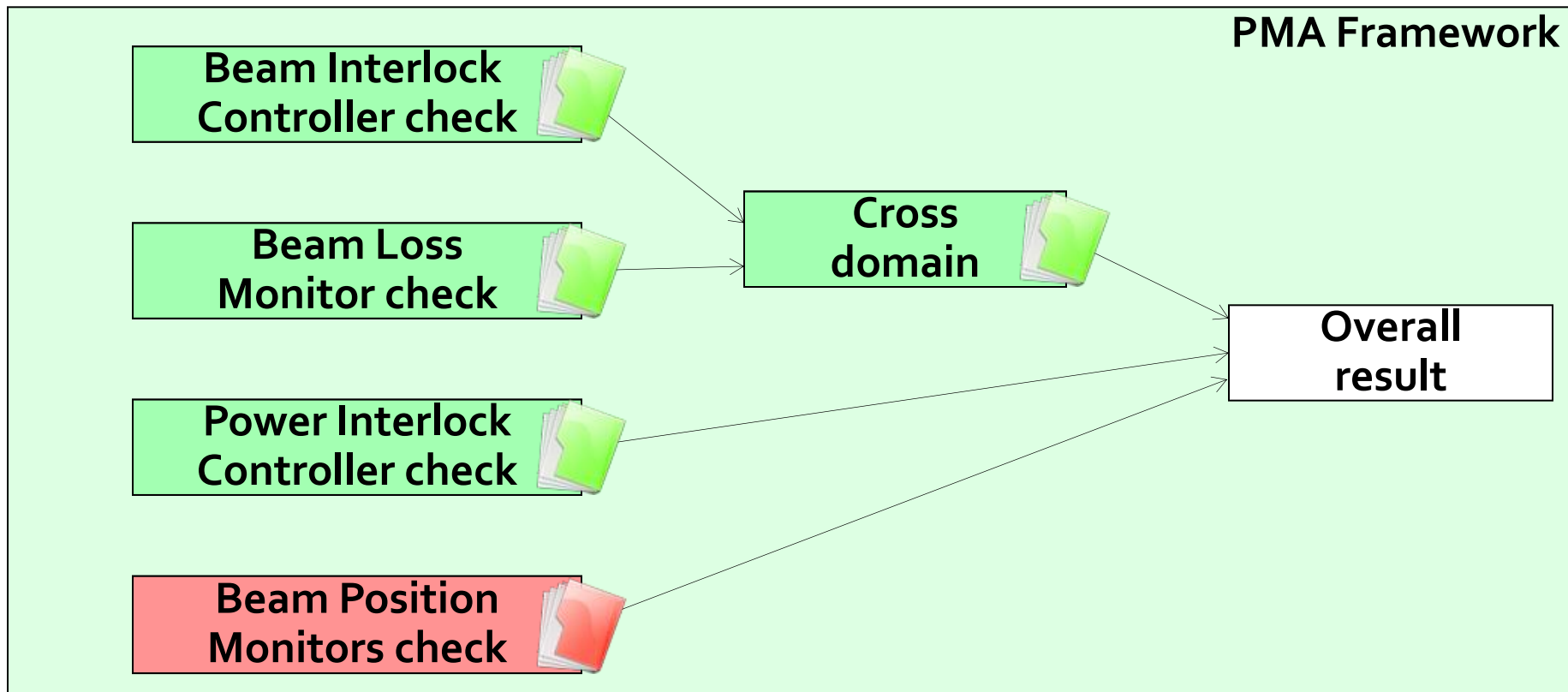
PMA: implementation

- Analysis is based on a graph of analysis modules



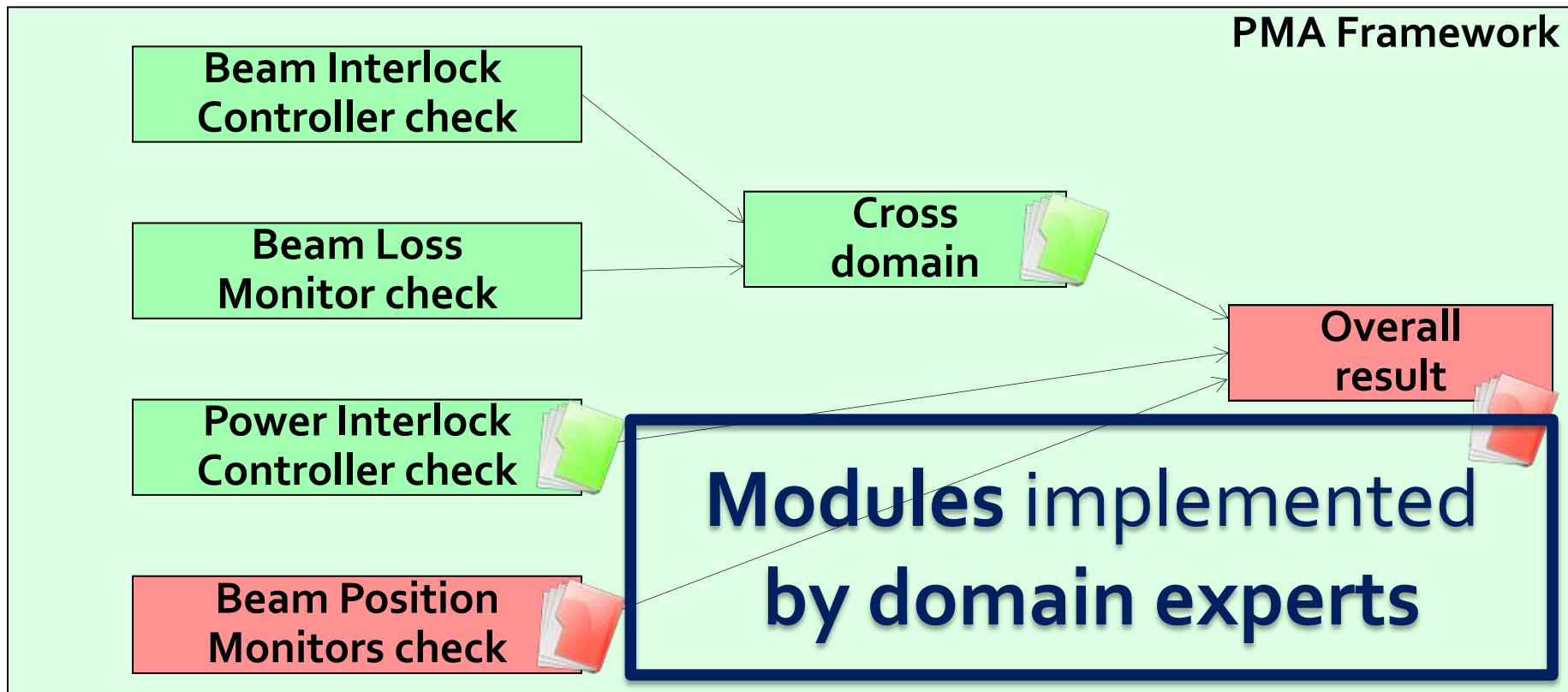
PMA: implementation

- Analysis is based on a graph of analysis modules



PMA: implementation

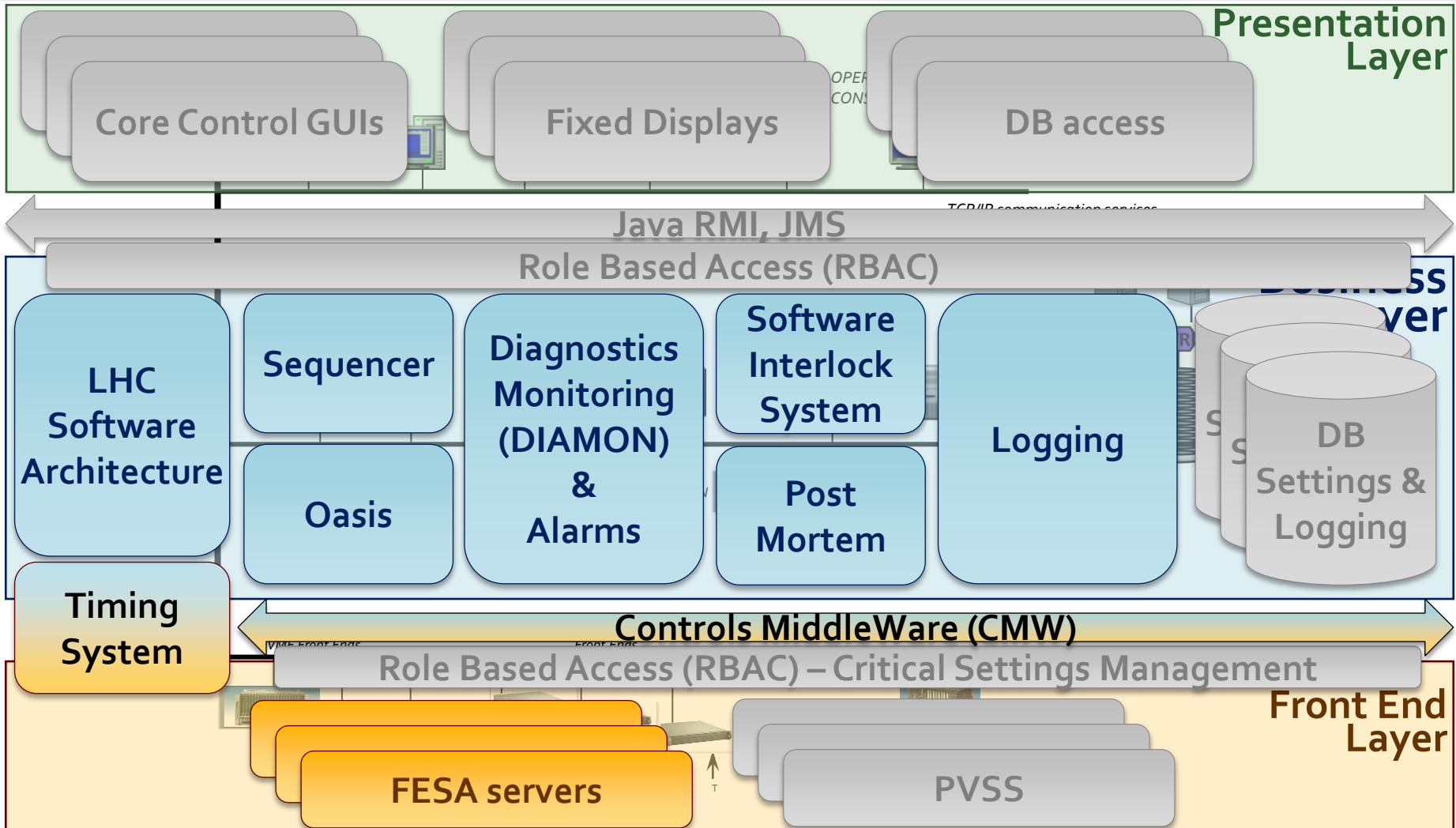
- Analysis is based on a graph of analysis modules

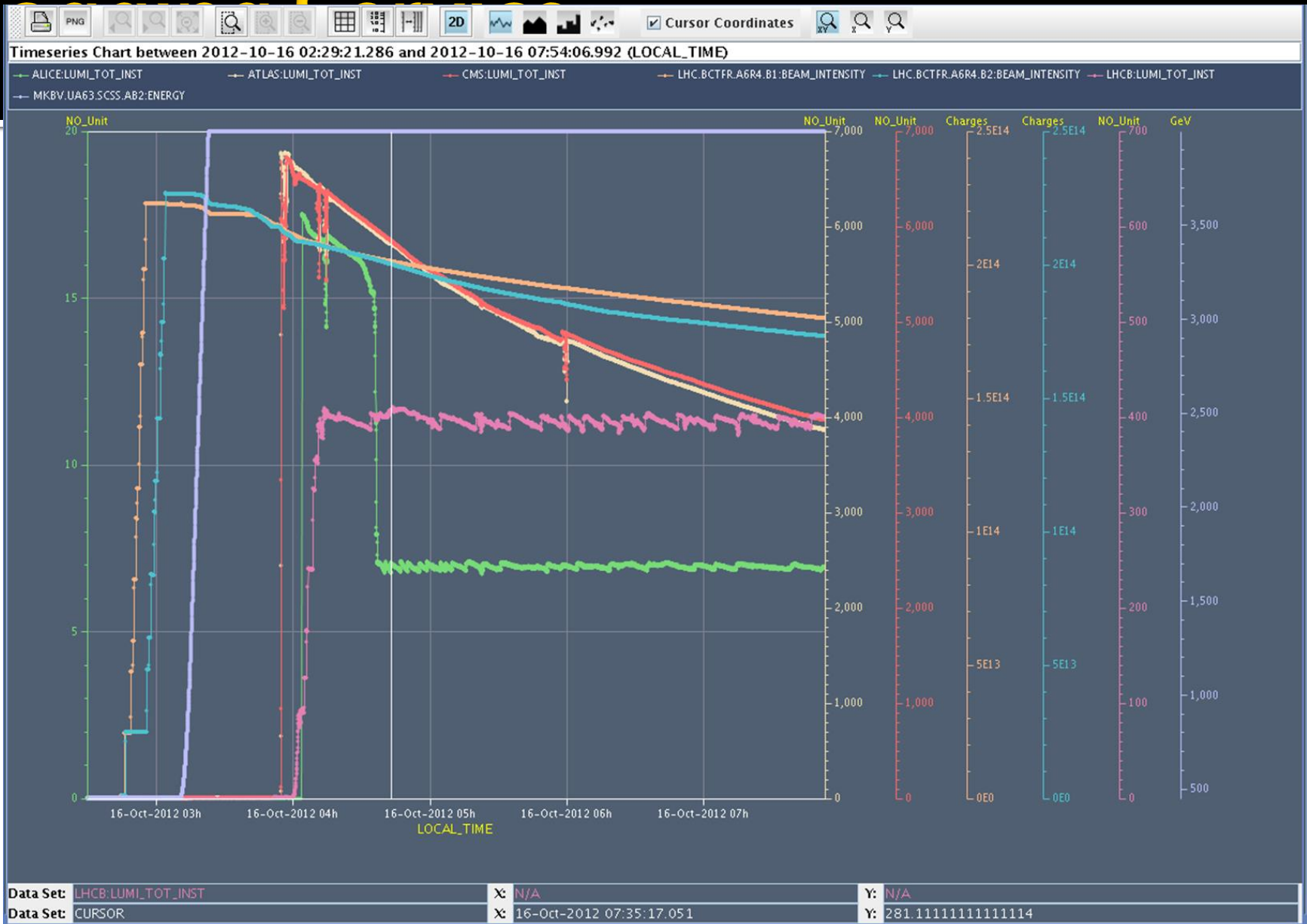


PMA: today

- 4 mission critical LHC applications
 - LHC Beam Dump Analysis
 - eXternal Post-Operational Check (XPOC)
 - Injection Quality Check (IQC)
 - Powering Event Analysis
- 45 analysis modules
- 10 module developers from different teams
- 2 GB per LHC Beam Dump

Key components: Logging

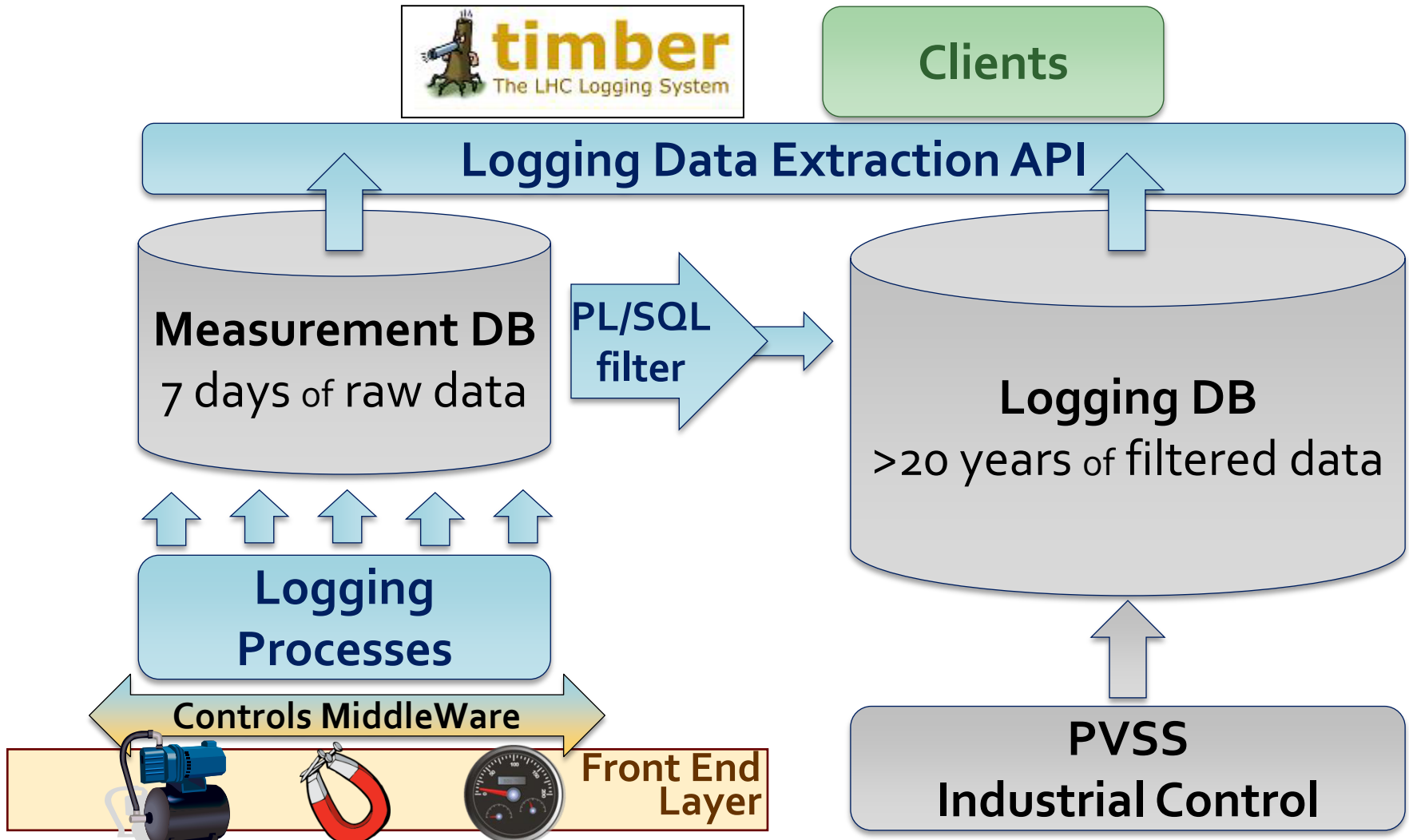




Logging Service

- **Storage** for beam & equipment data beyond LHC lifetime (>20 years)
 - Does not store experiments' data
- **Online** storage (Oracle DB, RAC-based)
- Allows **analysis of accelerator behaviour** over **long periods of time**

Logging: architecture



Logging: today



~ 1000 clients
~ 5 million extraction requests / day

Logging Data Extraction API

~ 95 % data reduction
Millions of recs / min

Measurement DB
7 days of raw data



Logging DB
>20 years of filtered data

Logging Processes

~ 250'000 device properties
~ 5.5 billion records / day
~ 2 TB / week throughput

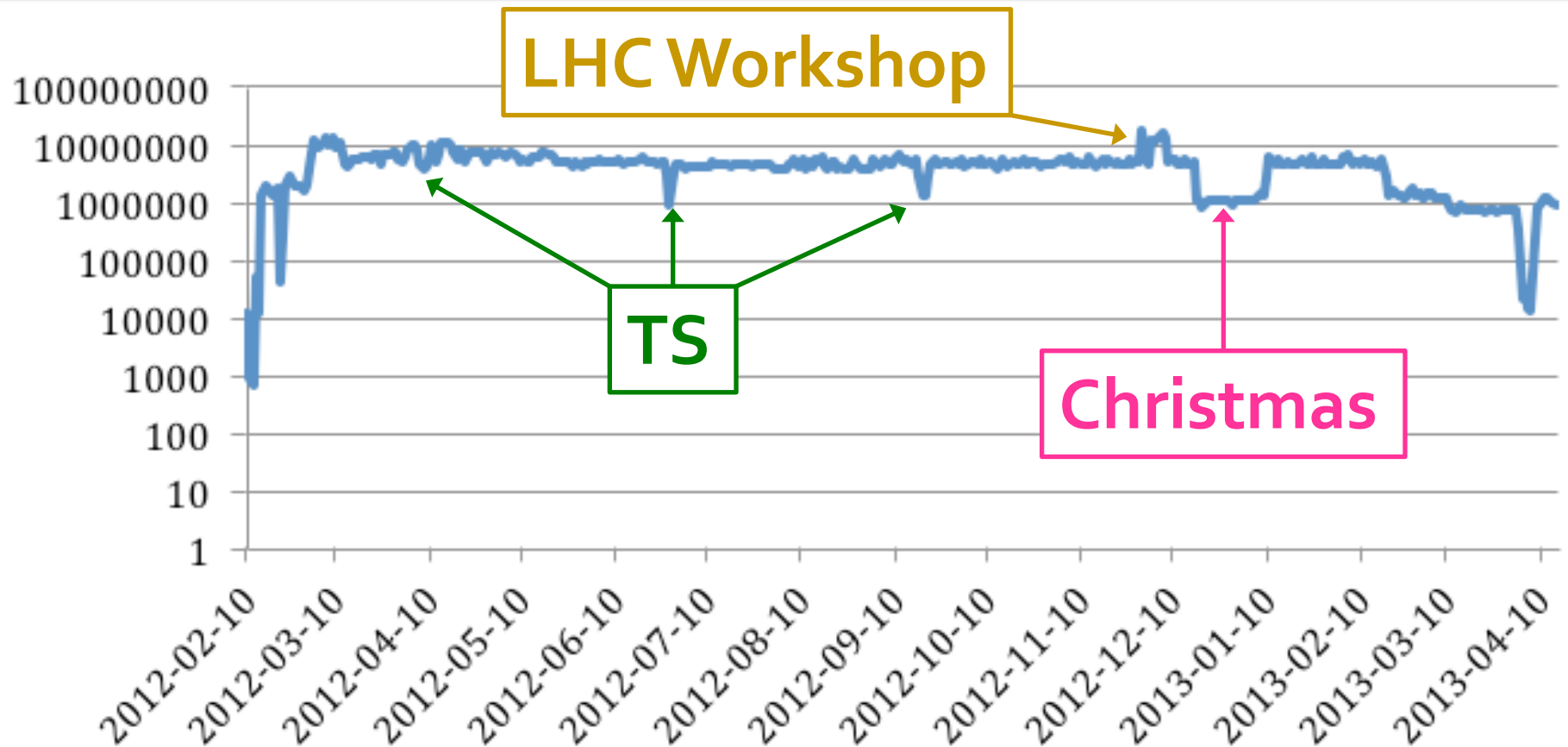
Controls MiddleWare



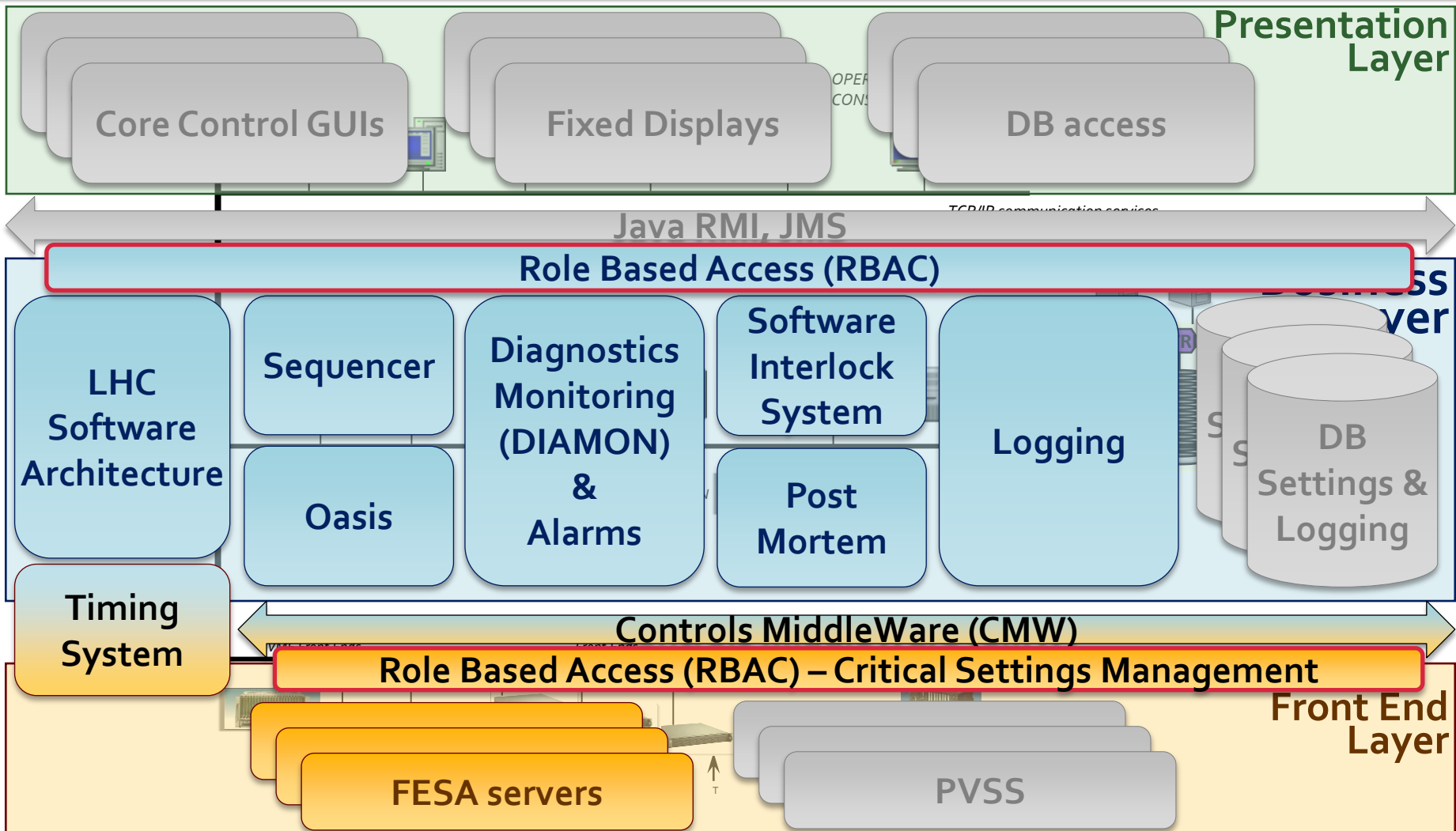
~ 1 million device properties
~ 4 billion records / day
~ 1 TB / week stored
~ 170 TB stored now

Industrial Control

Logging: daily extraction requests



Key components: RBAC - MCS



Role Based Access Control (RBAC)

- **Protect** against unauthorized access
- Access audit
- Integrated with all 3 layers
 - front-end, business, presentation

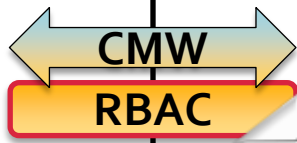
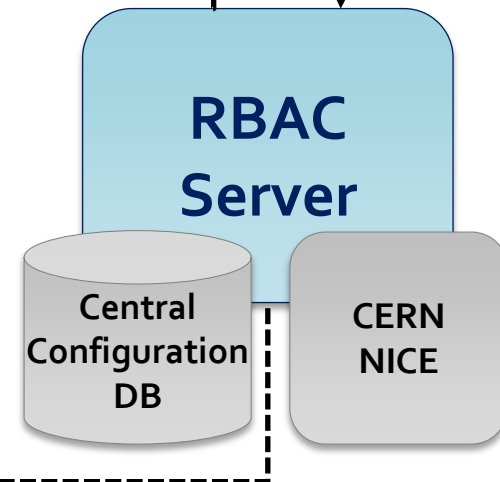
RBAC: HW and SW protection



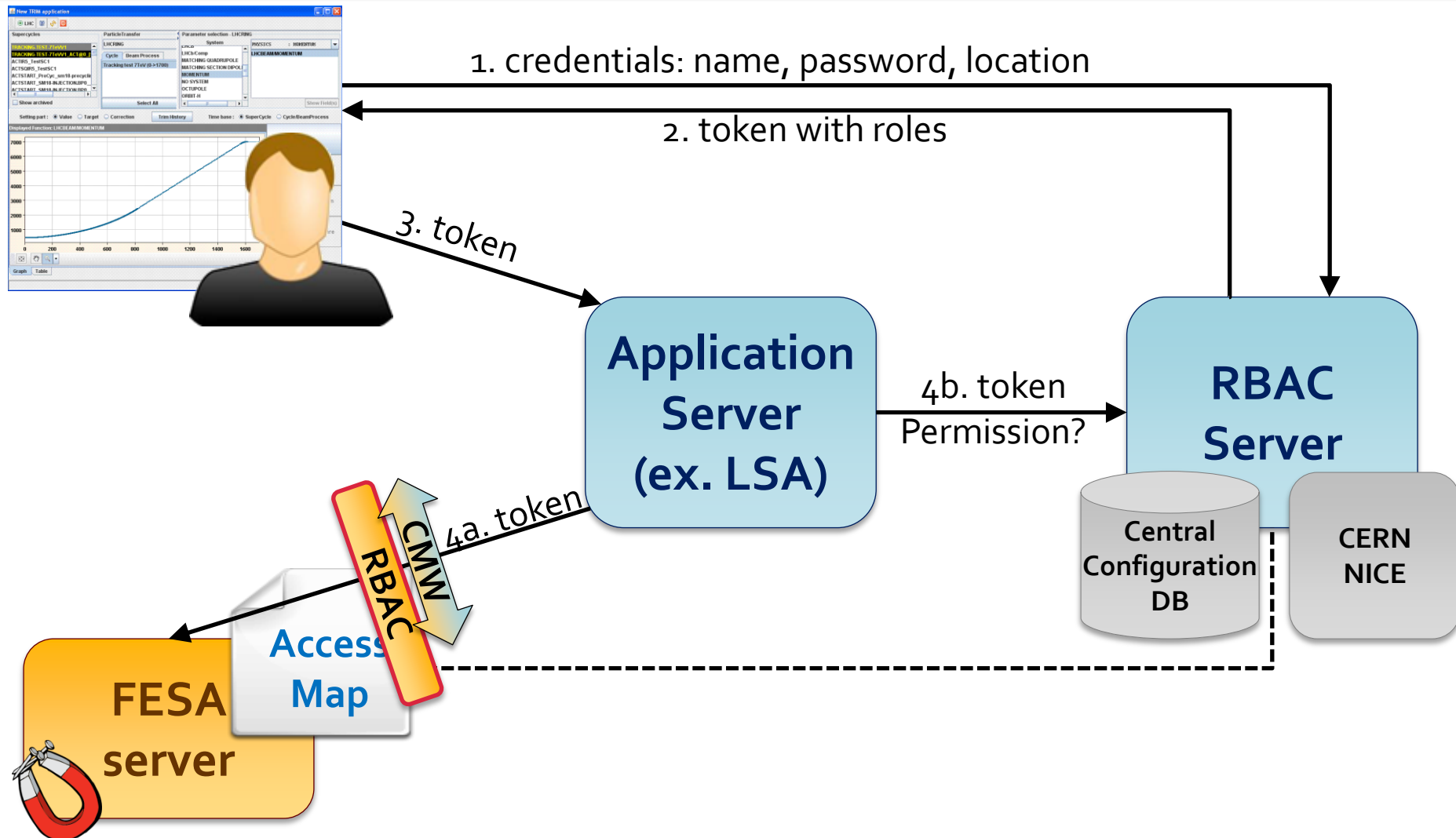
1. credentials: name, password, location

2. token with roles

3. token



RBAC: HW and SW protection



RBAC: features

- Authentication
- Authorization
 - Business layer
 - Front-End layer
- Permission definitions
 - Who, what, when, from where
- Flexibility
 - Login-by-location
 - Temporary permissions
 - Operational-mode dependent

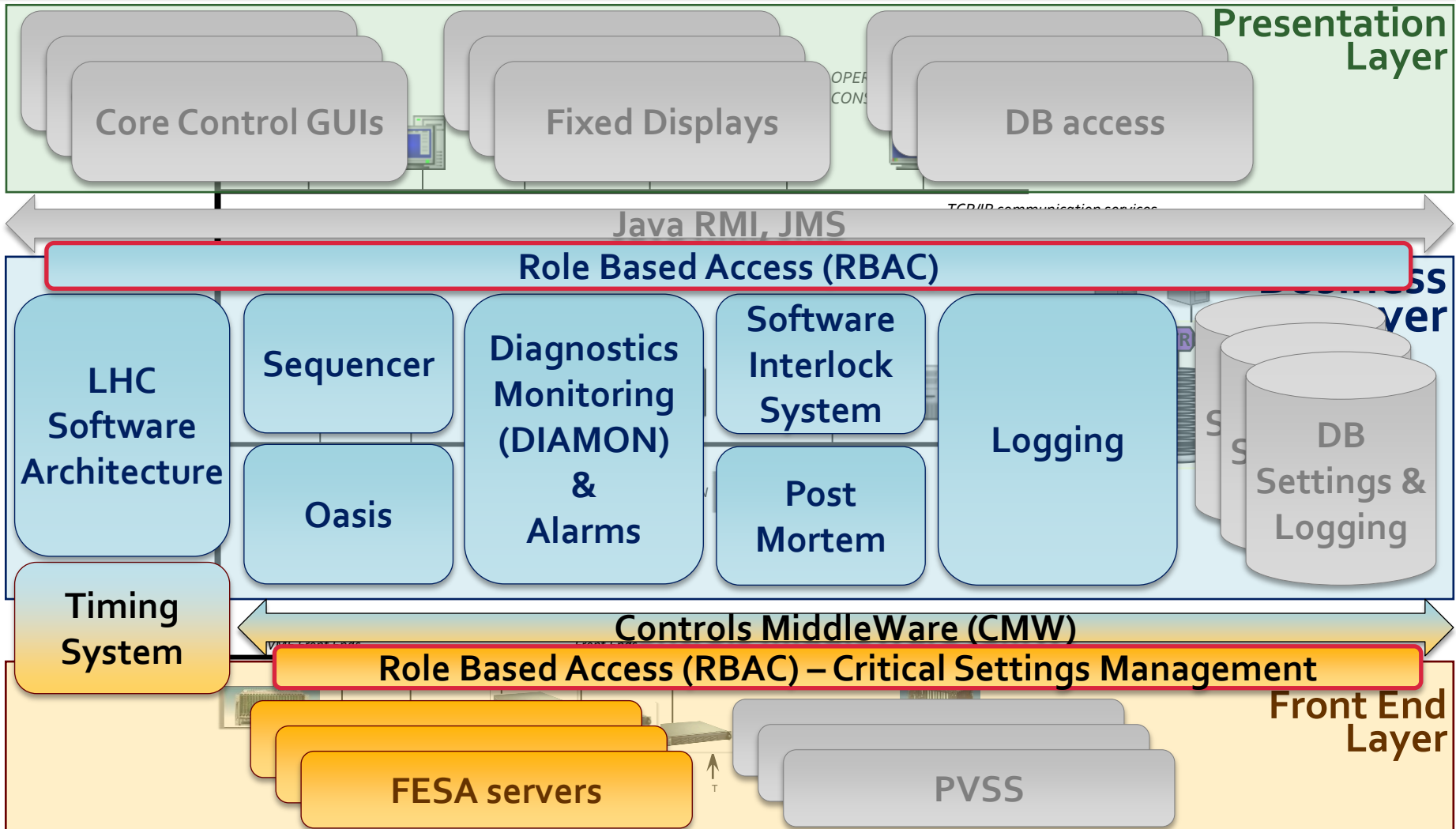
RBAC: today

- RBAC protects all the LHC equipment
- ~500'000 permission definitions
- ~500 users

Management of Critical Settings

- **Protects the value**, not the action
 - BLM, BPM thresholds
 - Collimator thresholds
 - SIS configuration
- Only experts can modify the value
- All the operators can use this value
- Digitally signed values
- 100 critical value types => 1500 properties

Key components



Contents

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- Key components
- **Quality Assurance (QA)**
- Outlook towards the Future

Highly modular distributed system

Big developer community

■ Front-End Layer (C/C++)

- 85'000 devices controlled by 2000 different machines
- 600 different device types (FESA, PVSS, FGC)
- Developed by 100 people from 16 different groups

■ Business and Presentation Layer (Java)

- 400 different GUIs and 100 server applications
- Up to 600 processes on 400 machines
- Developed by ~100 people from 10 different groups

■ Control system performs **mission-critical tasks**

■ Control system must **evolve**

Quality Assurance is essential

Development
Process

+

Integration
Testing

+

Deployment
Strategy

Control System **Quality Assurance**

Quality Assurance is essential

Development
Process

+

Integration
Testing

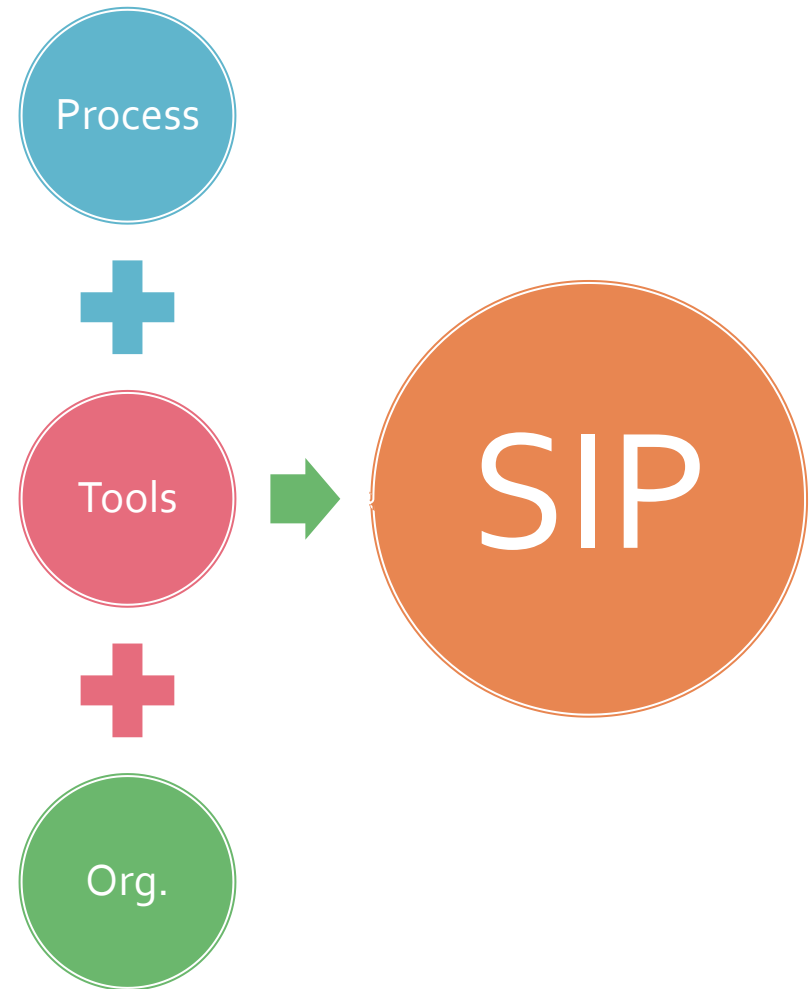
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Deployment
Strategy

Control System **Quality Assurance**

Software Improvement Process (SIP)

- Development process
 - Recommended / mandatory activities and deliverables
- Tools
 - Support the process by automating as much as possible
- Organization
 - Officially allocate time
 - Dedicated QA days
 - Follow up progress



SIP: activities and tools

- Common code style (Eclipse IDE)
- Dependency analysis (Eclipse plugin)
- Unit testing (JUnit, Mockito, Clover)
- Static code analysis (FindBugs, PMD, Sonar)
- Code reviews (FishEye + Crucible)
- Continuous Integration (Bamboo)
- Issues tracking & planning (JIRA + Greenhopper)
- Documentation (Confluence Wikis)
- Agile development methodologies

Links to project pages

Beams Department Controls Group	espace.cern.ch/be-dep/CO
Timing System	wikis.cern.ch/display/HT(/Timing+Software) www.ohwr.org(/projects/white-rabbit/wiki)
Front-End Software Architecture	wikis.cern.ch/display/FESA3
Controls MiddleWare	wikis.cern.ch/display/MW
LHC Software Architecture	wikis.cern.ch/display/LSA
Sequencer	wikis.cern.ch/display/SEQ
Open Analog Signal Information System	wikis.cern.ch/display/OASIS
Diagnostics Monitoring & Alarms	wikis.cern.ch/display/ADM laser-alarms.web.cern.ch/laser-alarms/
Software Interlock System	wikis.cern.ch/display/SIS
Post-Mortem (Analysis)	wikis.cern.ch/display/PMS(/Documentation)
Logging Service	wikis.cern.ch/display/CALS
Testbed	wikis.cern.ch/display/CSTBF

Quality Assurance is essential

Development
Process

+

Integration
Testing

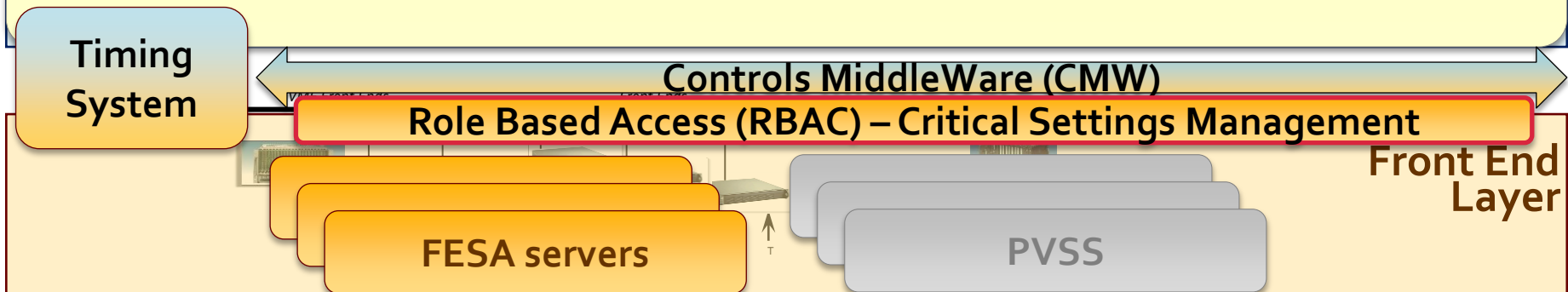
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Deployment
Strategy

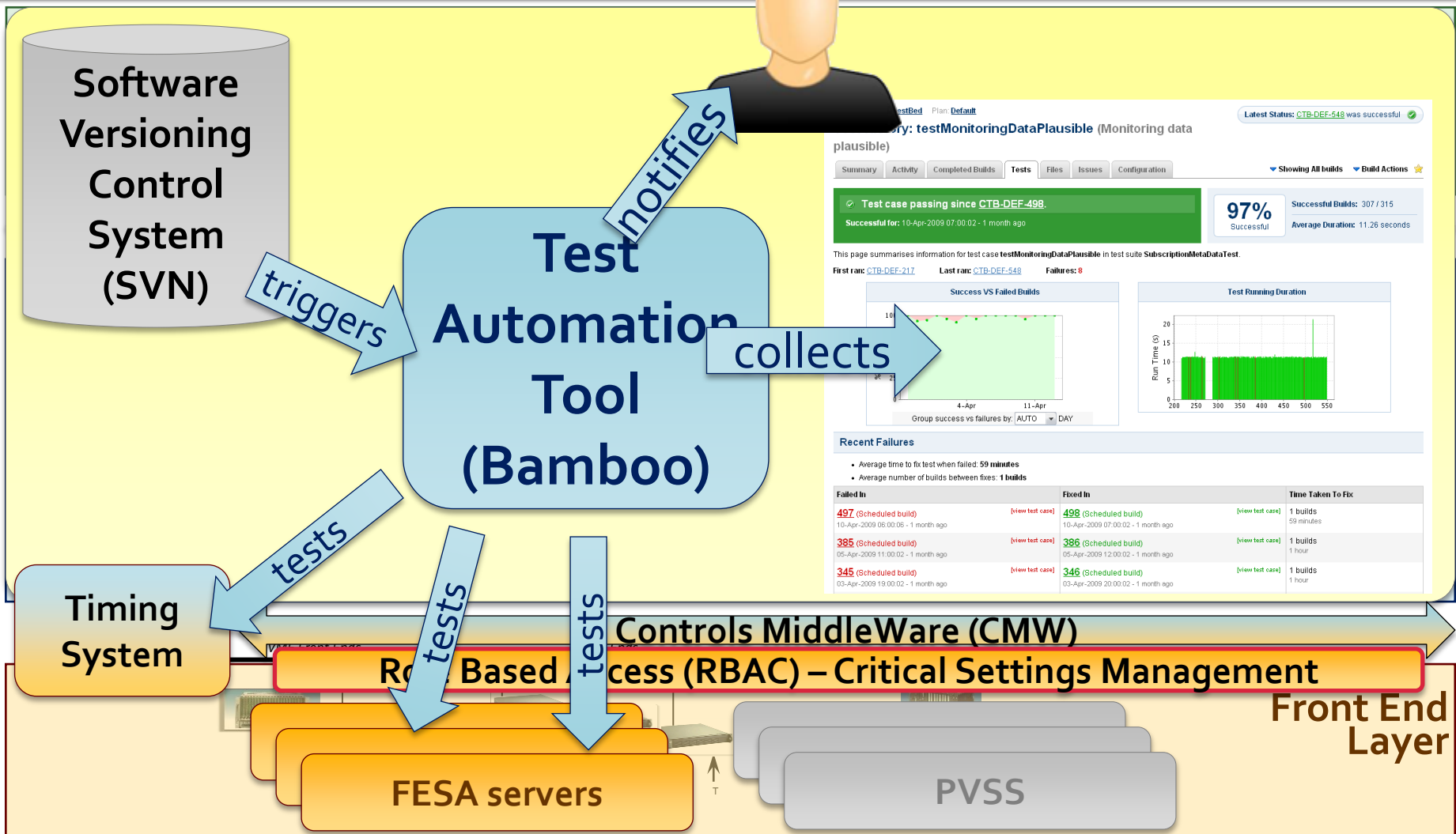
Control System **Quality Assurance**

Integration testing: Testbed

- Test the core components of the control system together
- Validate new versions of the control system before deployment
- Automation



Integration testing: Testbed



Quality Assurance is essential

Development
Process

+

Integration
Testing

+

Deployment
Strategy

Control System **Quality Assurance**

Deployment: Smooth Upgrades

- **Official approach**
 - **Analyze** the **impact** of a change upfront
 - **Backward compatible** upgrades if possible
 - Non-backward compatible upgrades only with **careful coordination** and follow-up
 - Big changes on central systems only during shutdown
- Other ingredients to **smooth upgrades**:
 - **Planning** before starting development work
 - **Quality Assurance** (development + integration testing)
 - Deploy upgrades first for accelerators that need them
 - **Means** to quickly **roll-back** in case of problems

Contents

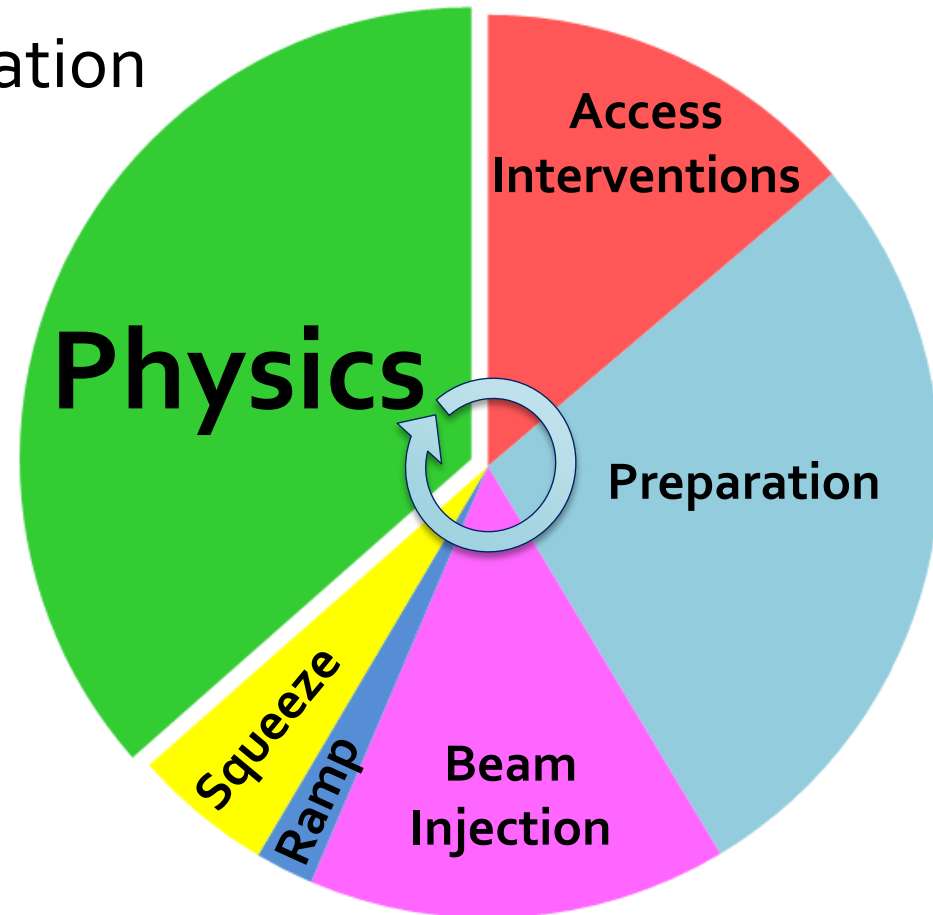
- LHC control system requirements
- Philosophy of development
- Overview of the architecture
- Key components
- Quality Assurance (QA)
- Outlook towards the Future

Consolidation and new functionality

- Control System **consolidation**
- **Common analysis framework** for logged data
- LHC Hardware Commissioning analysis **automation**
- **Technology** replacement
 - Future Front End hardware platform technology
 - Investigations regarding future software technologies
 - Timing => WhiteRabbit, Middleware => ZeroMQ

LHC performance improvement

- “Physics” time maximization
 - LHC procedures optimization
=> provide tools
- Control System fault minimization



Accelerator downtime minimization

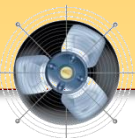
- Early warning system, **problem anticipations**
 - Monitoring
 - Sanity checks
- Improve **first-line problem analysis**
 - Runtime dependency analysis
 - Which expert to call
- Improve **smooth upgrades**
 - Better tools to show what has changed
 - Tools to help **backward-compatibility assurance**

CERN Accelerator Control System

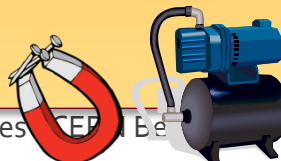
- **150** server applications
 - **400** different GUIs
 - Up to **600** processes on **400** machines
 - Developed by **~100** people from **10** different groups
-
- **85'000** devices controlled by **2000** different machines
 - **600** different device types (FESA, PVSS, FGC)
 - Developed by **100** people from **16** different groups



2013



Academic Training Lectures CERN Beam Controls Group



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CERN Accelerator Control System

- **Strategy** behind development:
 - We provide extensible frameworks/tools
 - Clients fill in the domain-specific knowledge
- Clear **guidelines**
 - Coherent model: device-property
 - Architecture and technology choices
- Thorough **Quality Assurance**
- Successful and efficient **collaboration**
 - with equipment groups and operators
 - with other laboratories (FermiLab, GSI, ESRF, etc.)