

# ~~The LHC Control System~~

## CERN Accelerators Control System



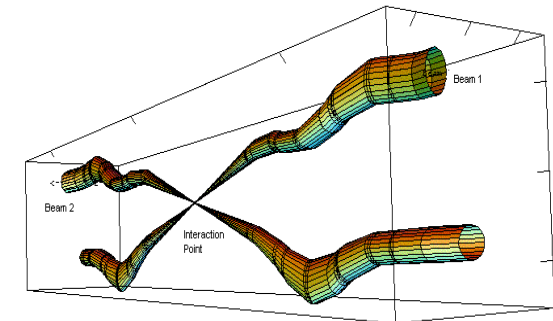
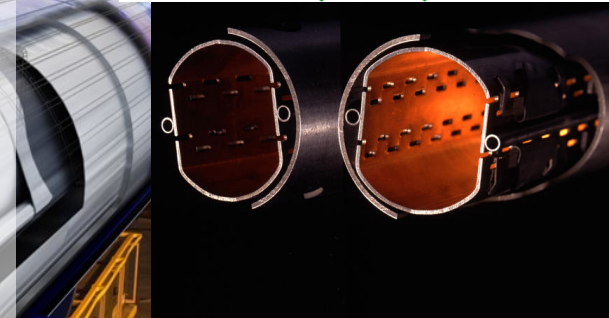
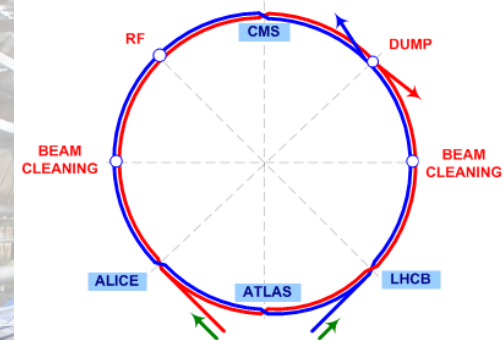
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(input from J. Wozniak, R. Steerenberg, M. Lamont,  
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**CERN – Geneva - Switzerland**  
**Accelerators and Technology Sector**

# The Challenge

- Accelerate **2 beams of  $2.2 \times 10^{14}$  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 them down to **16 microns**
- Get them to and keep them colliding for **10-15 hours**
- Keeping **beam-losses** down to a **very low level**

**THIS HAS TO BE DONE WITH THE CONTROL SYSTEM**

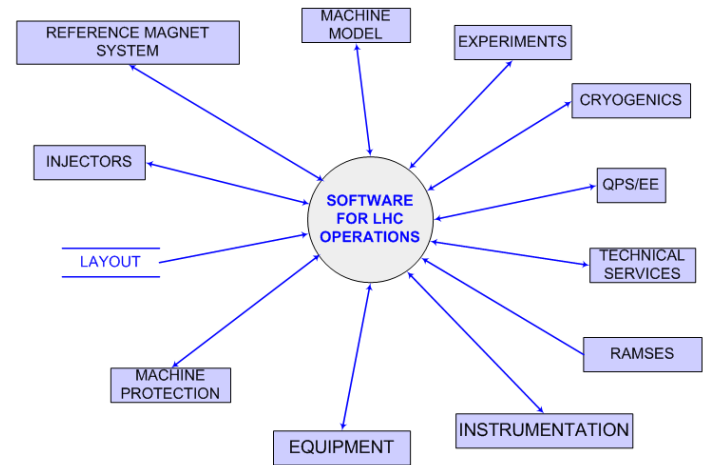


Relative beam sizes around IP1 (Atlas) in collision



# The Controls' Challenge

- **EQUIPMENT**
  - Collimators/TDI/TCDQ etc.
  - Beam Dump
  - Power converters,
  - Kickers
  - RF, TFB, LFB
  - Spectrometers & compensation
- **INSTRUMENTATION**
  - Distributed systems:
    - BLMs, BPMs,
  - Standalone:
    - BCT, BTV, AGM, BIPM, BWS, Schottky..
  - Tune, Chromaticity, Coupling
  - Luminosity monitors
  - Radiation Monitors
- **MAGNETS – RMS, errors**
- **MACHINE PROTECTION**
- **VACUUM, CRYOGENICS, QPS, EE**
- **EXPERIMENTS**



Page 1

⊗  
**Settings, functions, monitoring, display, post mortem, control, acquisition, concentration, archiving, alarms, interlocks**

⊗  
**Driving the machine through the cycle**

**Magnet errors, crossing angles, snapback, ramping, squeezing, colliding, orbit, parameter control, optimisation etc. etc.**

# High Level Control System Requirements

- Provide **controls** to operators to **act and affect changes** to the accelerator (settings management, measurements, acquisitions, ..)
- **Automatic process control, feedback** and **sequence control**

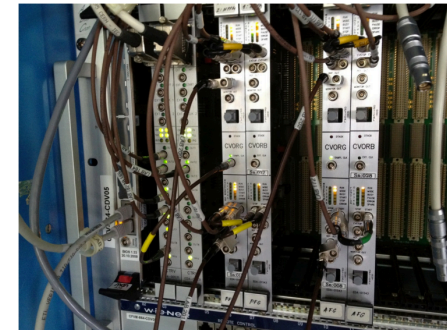
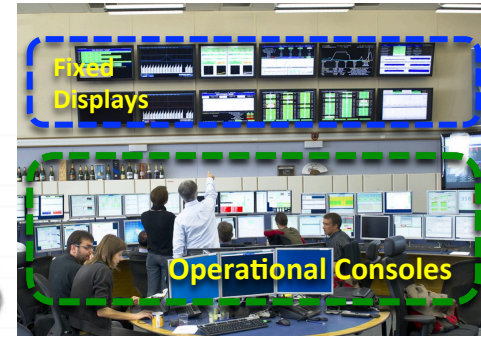
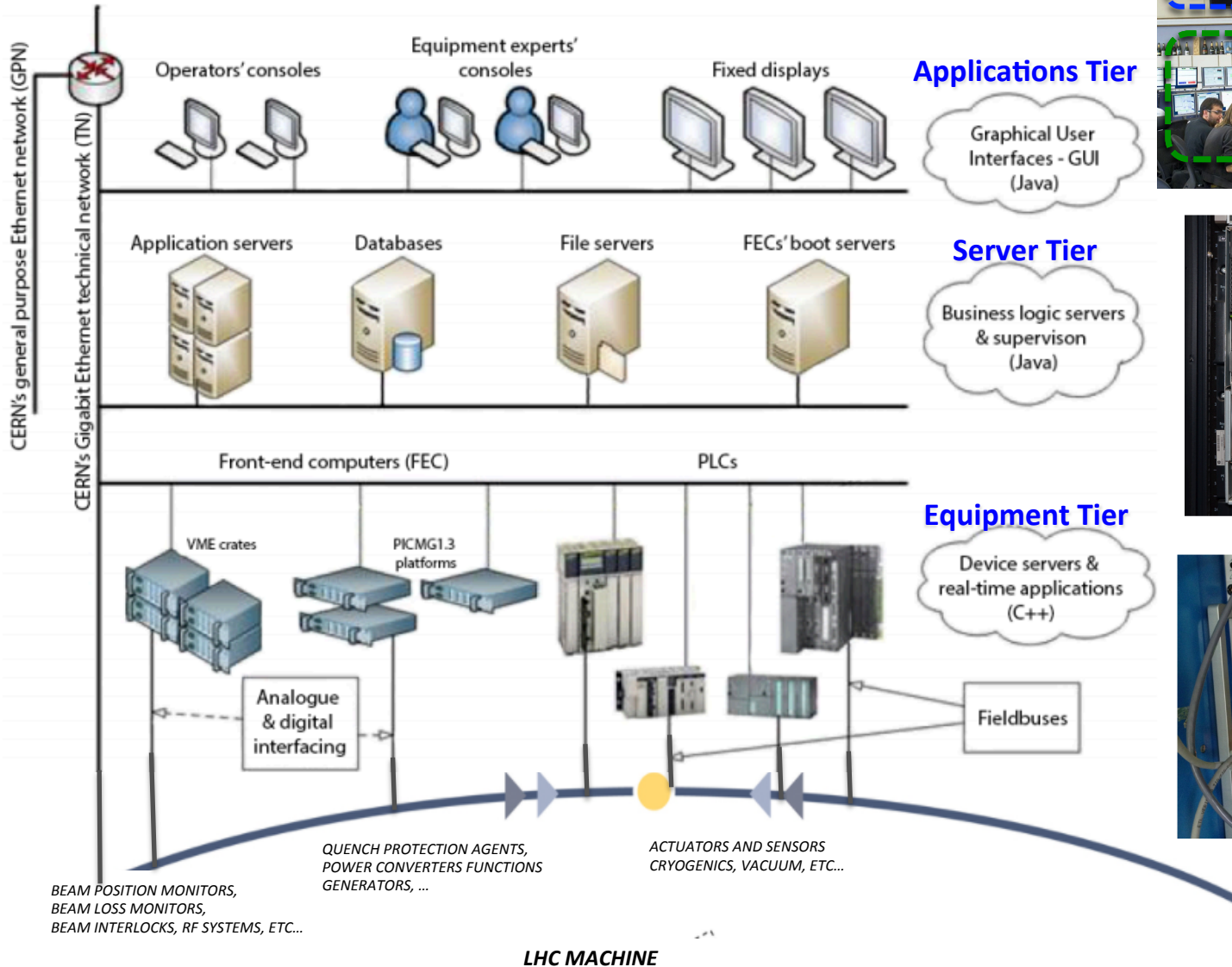
- **Display** of operator information regarding the accelerator status and beam parameters
- **Monitoring, recording and logging** of accelerator status and process parameters

- **Prevention of automatic or manual control actions which might initiate a hazard**
- **Fault diagnostics and recovery**

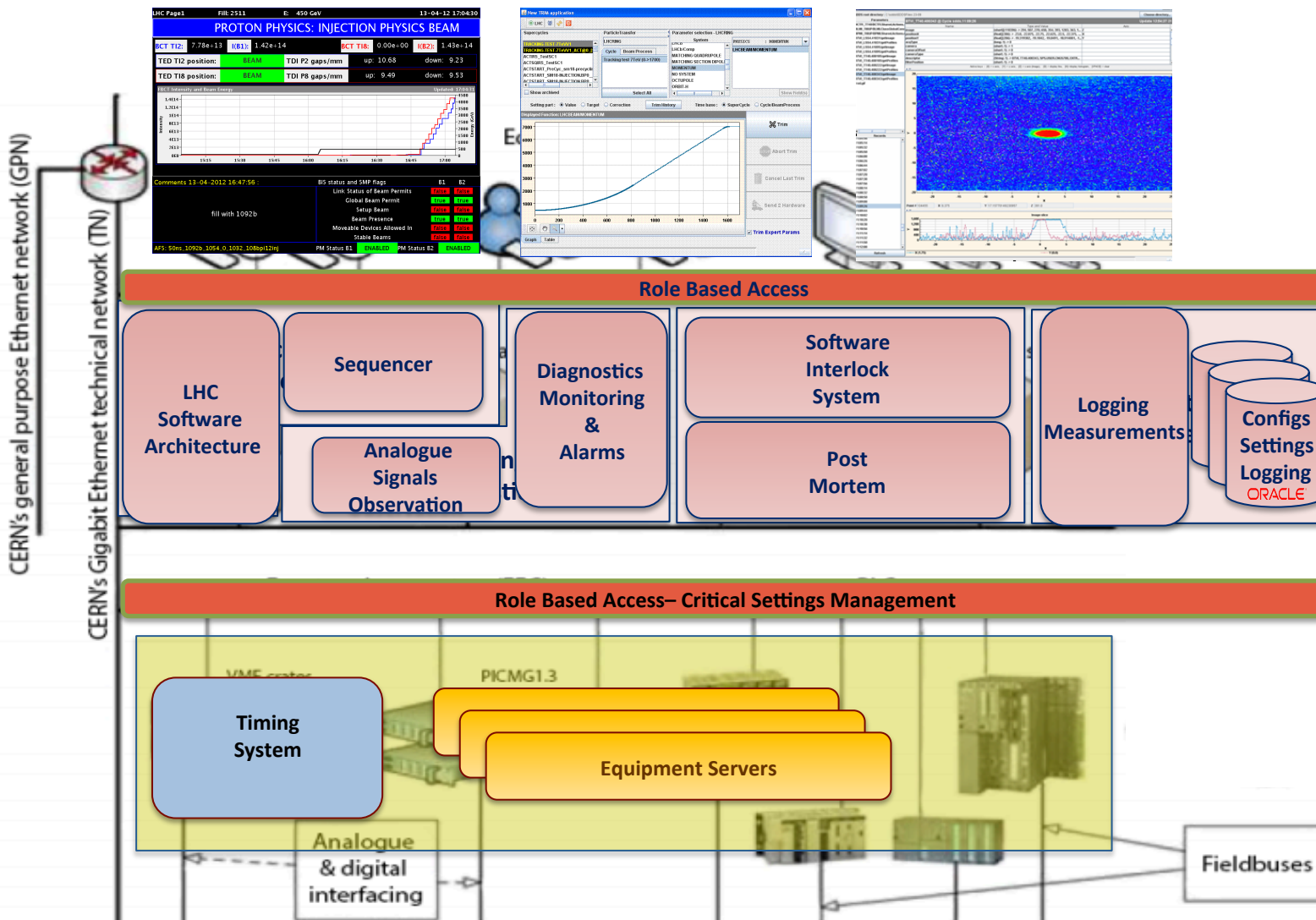
- **Machine protection - Detection of onset of hazard and automatic hazard termination (i.e. dump the beam ), or mitigation (i.e. control within safe operating limits)**

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

# Control System Architecture



# Control Software Architecture

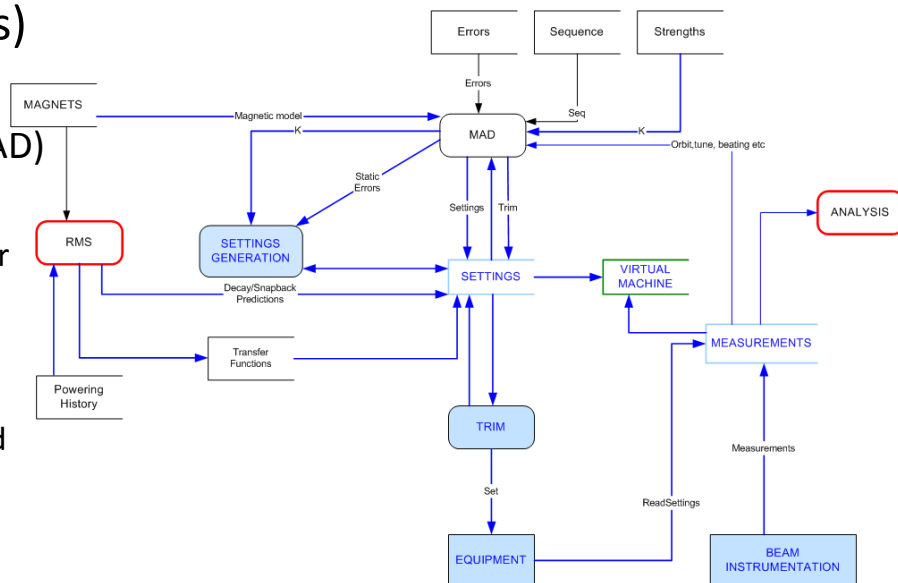


# LHC Settings and Cycles

- The LHC is **Event Driven** and not Timing Driven
  - The Injector Complex is timing driven (repetition of cycle with pre-defined length)
  - The LHC cycle contains **Beam Processes** (pre-cycle, injection, ramp, squeeze, etc.) that are in principle not time limited
  - Each Beam Process contains **settings** for all devices and all beam processes are linked
  - **The Sequencer** walks efficiently and securely through all steps in the beam processes and execute the pre-defined commands and checks

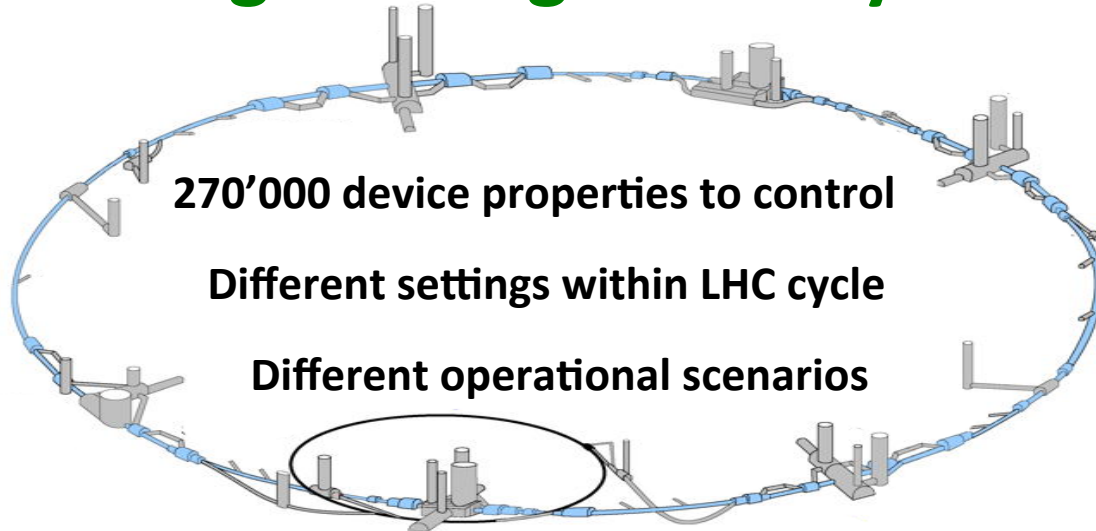
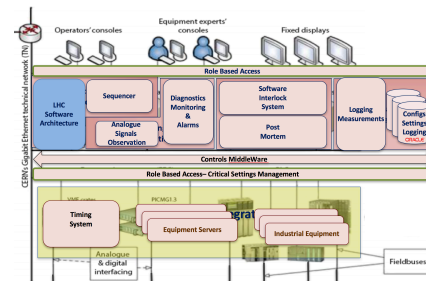
- The LHC is Model Using High Level (physics) Parameters

- **Settings Generation** from theoretical model (MAD)
- **Setting Management** is done:
  - Through **dedicated application software** (single or multiple parameters/hierarchies)
  - **Semi-automatic** through feed-forward (FIDEL) and feedback (e.g. orbit, tune)
  - **Protected** through **Role Based Access Control** and **Critical Setting management** to minimize undesired/mistakenly parameter changes



# LHC Software Architecture (LSA)

## Settings Management System



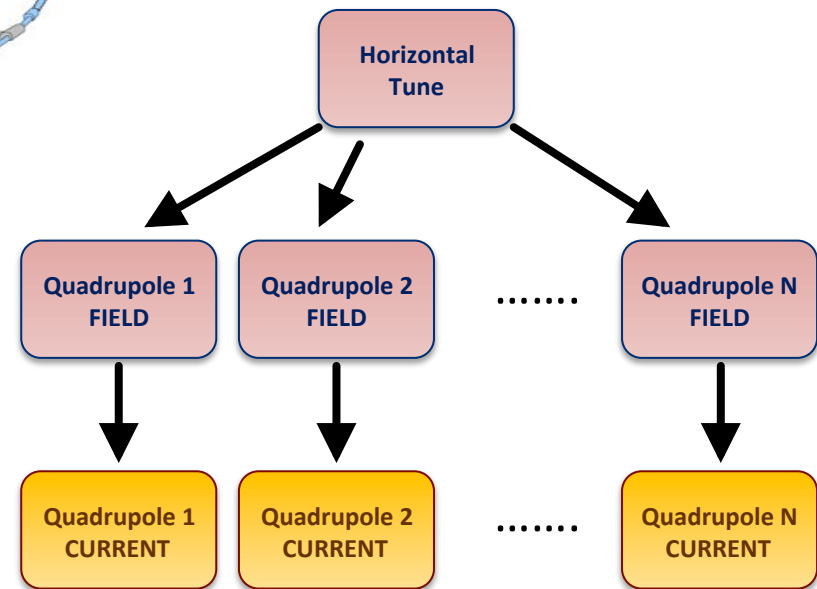
270'000 device properties to control

Different settings within LHC cycle

Different operational scenarios

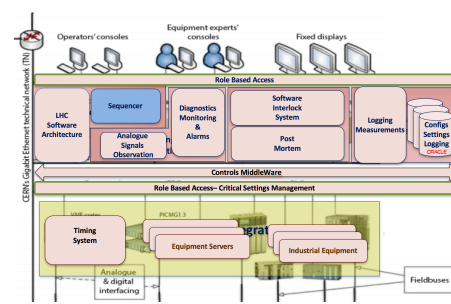
**Translation** of high-level accelerator parameters to low-level device properties

- Used in 6 accelerators:
- LHC, SPS, LEIR, PS, PSB, ISOLDE
  - **Exportable:** used in GSI
- > ~150 M of settings
- ~ 1M lines of code

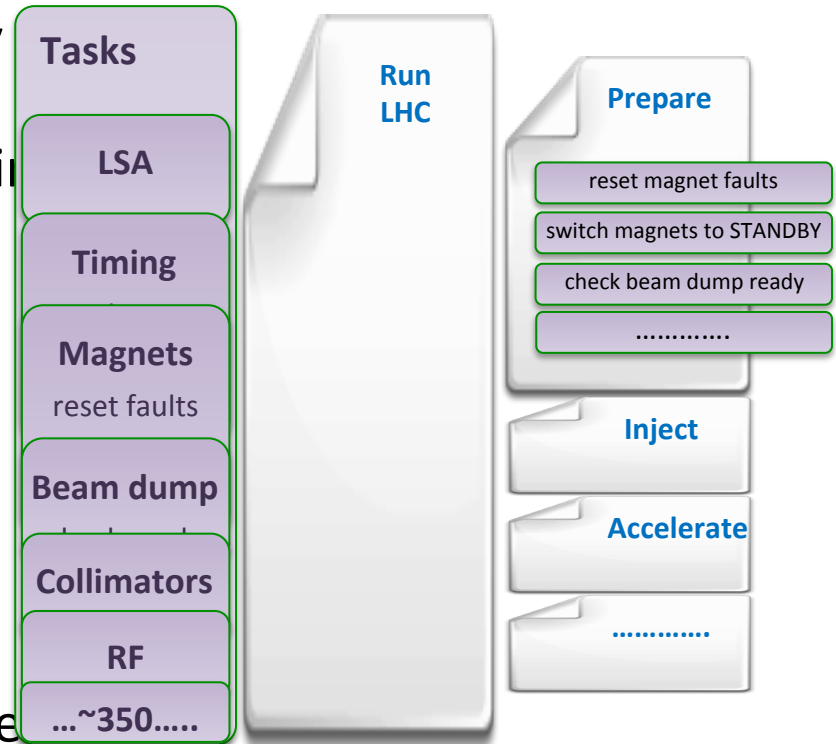




# Sequencer



- **Automates** execution of **sequences of tasks**
  - Check the values of devices
  - Ask the control system to load the settings
  - Wait for the equipment to be ready
- **Operators** memory
- **Reliable** execution and error reporting
- **Safe** mode
  - run-through automatically
  - run until task
  - step task-by-task
- **Expert** mode
  - skip task
  - jump to task
- ~ 1250 sequences for LHC Beam Operation
- ~ 350 tasks types
- LHC main sequence: ~1100 tasks in total

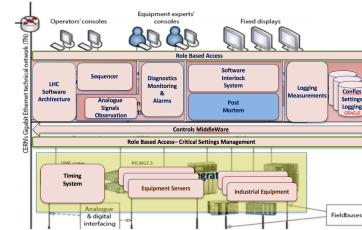


# LHC Machine Protection

- LHC relies on an Important and **Complex Machine Protection System** (MPS)
  - Protect machine against damage from power of the beams
  - In case MPS is triggered, efficient diagnostics through post-mortem data analysis is of prime importance

# Post-Mortem Analysis

- Part of overall **Machine Protection**
- 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
- 4 mission critical LHC applications
  - LHC Beam Dump Analysis
  - External Post-Operational Check
  - Injection Quality Check
  - Powering Event Analysis
- 2 GB per LHC Beam Dump



LHC Page1      Fill: 973      E: 3567 GeV      21-03-2010 08:16:27

**BEAM SETUP: RAMP DOWN**

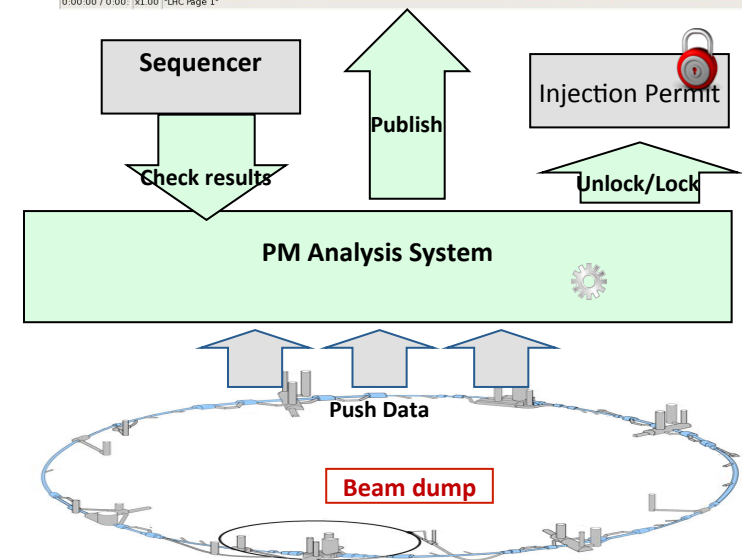
Energy: 3567 GeV    I(B1): 5.40e+08    I(B2): 0.00e+00

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 :	BIS status and SMP flags	B1	B2
Beam dumped	Link Status of Beam Permits	false	false
Triplets tripped	Global Beam Permit	false	false
Ramp down and reinject	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

0:00:00 / 0:00:00 : x1.00 "LHC Page 1"



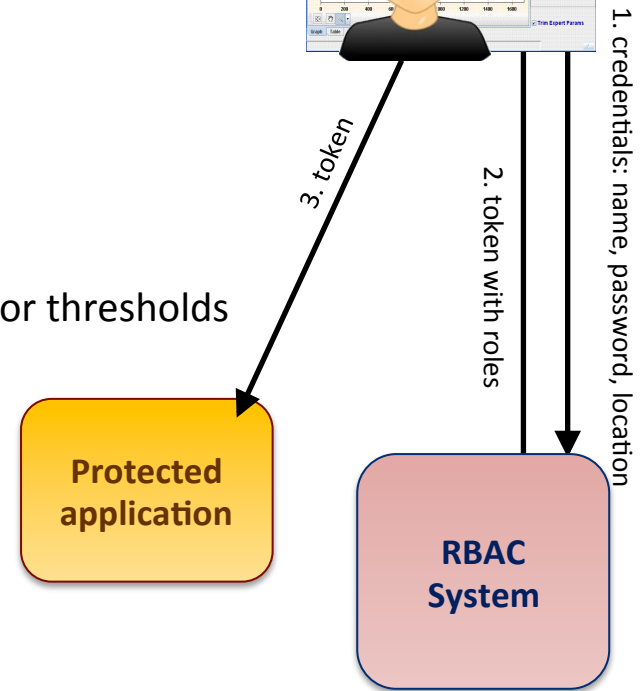
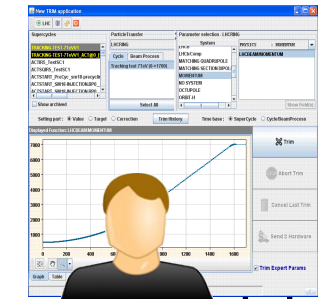
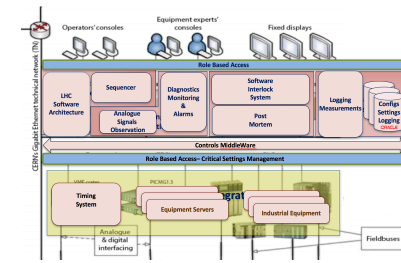
# Role Based Access & Critical Settings

- **Role Based Access**

- **Protects the action** (unauthorized access), not the value
- Authentication & Authorization
- Permission definitions
  - Who, what, when, from where
- RBAC protects all the LHC equipment
- ~500'000 permission definitions
- ~500 users

- **Critical Setting Management**

- **Protects the value**, not the action, ex. BLM, BPM, collimator thresholds
- Only experts can modify the value
- Digitally signed values
- 100 critical value types => 1500 properties

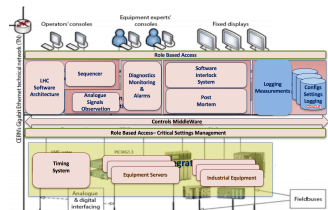


1. credentials: name, password, location

# Understanding the LHC

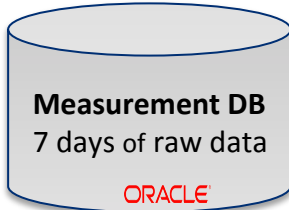
- LHC operation relies heavily on **Logging** and **Post-Mortem** data
  - For trouble shooting
  - For machine performance analysis
  - To enhance machine performance and to understand beam dynamics issues, high volume data observation systems (ADT/ObsBox data) provide valuable input
  - For data analysis, long-term storage and efficient retrieval of data are key

# Measurement & Logging System

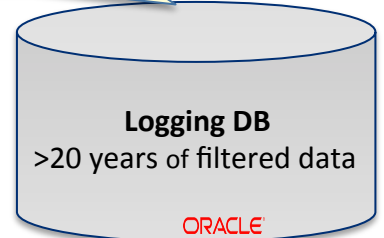


- **Storage** for beam & equipment data beyond LHC lifetime
  - No experiments' data

~ 1000 clients  
~ 5 million extraction requests/day

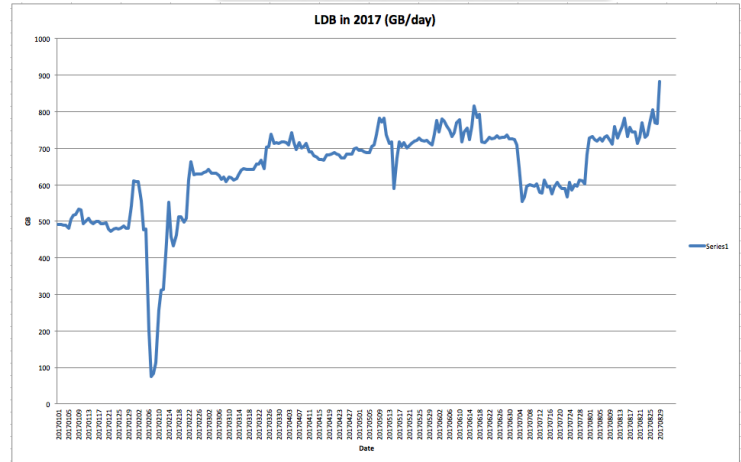
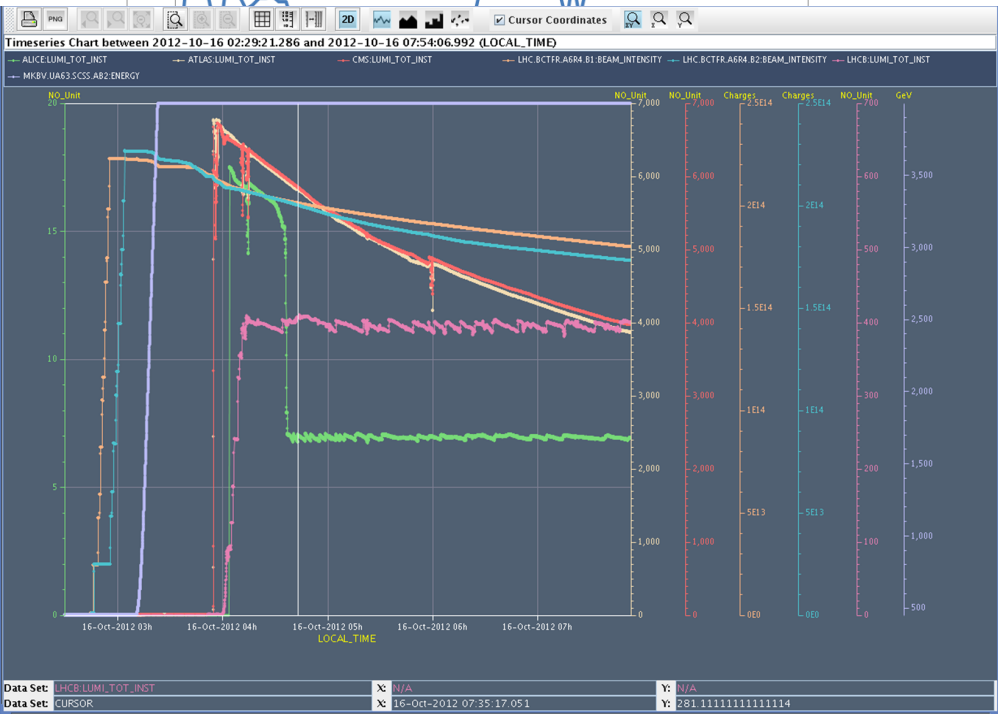
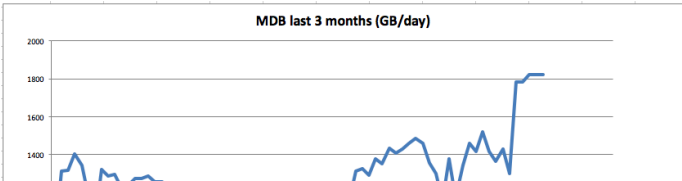


Filter ~ 95 % reduction



~ 11TB / week (1.5TB/day)  
~ 71e9 data points/day (4e9 in 2014)

~ 1.5M signals archived  
~ 20k device properties  
~ 1 TB/day  
~ 1 PB of archived data



- Allows **analysis of accelerator behaviour** over long periods of time

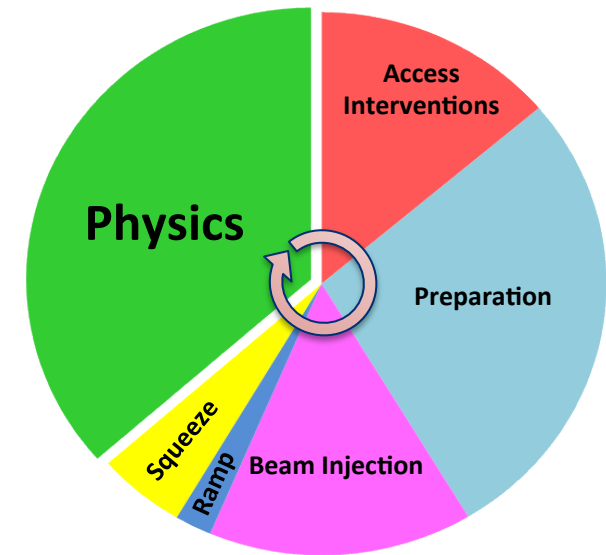


# Towards LHC Performance Improvement

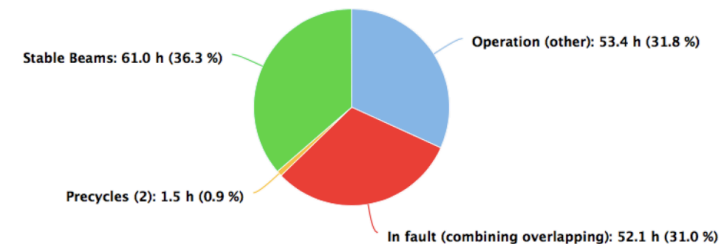
“Integrated Luminosity is important, hence machine/beam availability is key”

## Physics time maximization

- LHC procedures optimization through better tools
  - Recent automation of Hardware Commissioning steps and validation have made this process much more efficient (**~ 1 months → 2 weeks**)
- Control System fault minimization



## Time distribution



# Accelerator Fault Tracking

“Why are we not doing Physics when we should be?”  
 “What can we do to increase machine availability?”

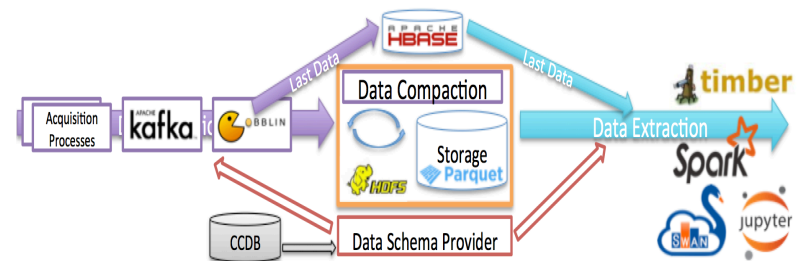
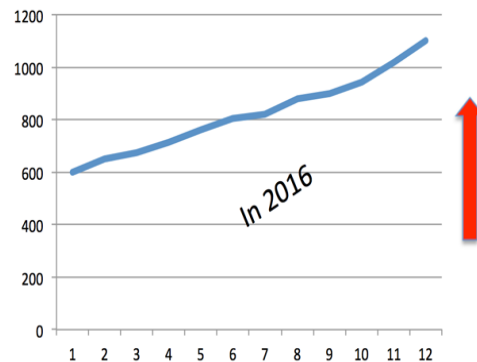
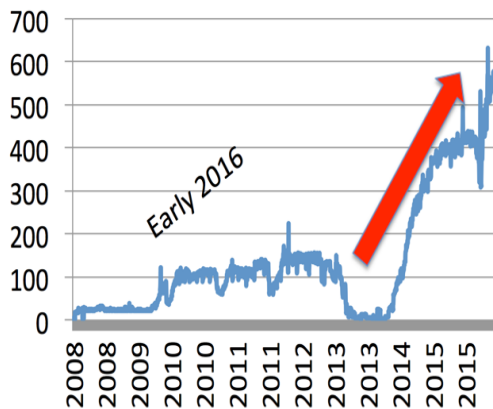
- Coherent data capture: 830 faults recorded for LHC helping areas for improvements
- Detailed fault classification and analysis for equipment groups
- Covers CERN’s entire injector complex





# Towards BIG Data

- Current data throughput rates in the existing Logging system approach 1 TB / day and are expected to continue to increase in the coming years
- The next generation Logging System is being developed
- Based on modern "Big Data" technologies (Hadoop, Kafka, Spark)
- Built on open source components and libraries
- Aims to answer the needs to store more data, & to be able to efficiently analyse it using the languages of choice by data experts



# The LHC has a very Modular Distributed Control System

- Performs **mission-critical tasks**
  - 70'000 equipment processes on ~2000 front ends machines
  - ~2000 programs running on 550 servers
  - 500 different GUIs and ~300 server programs
  - **Developed by ~100 people from 16 different groups**
  - 1100 Java executable
  - **~10M lines of code**
  - **1PB of archived data**
- Big (>1000) user community
- It **evolves** constantly

# BACK UP SLIDES

# Upcoming Topics

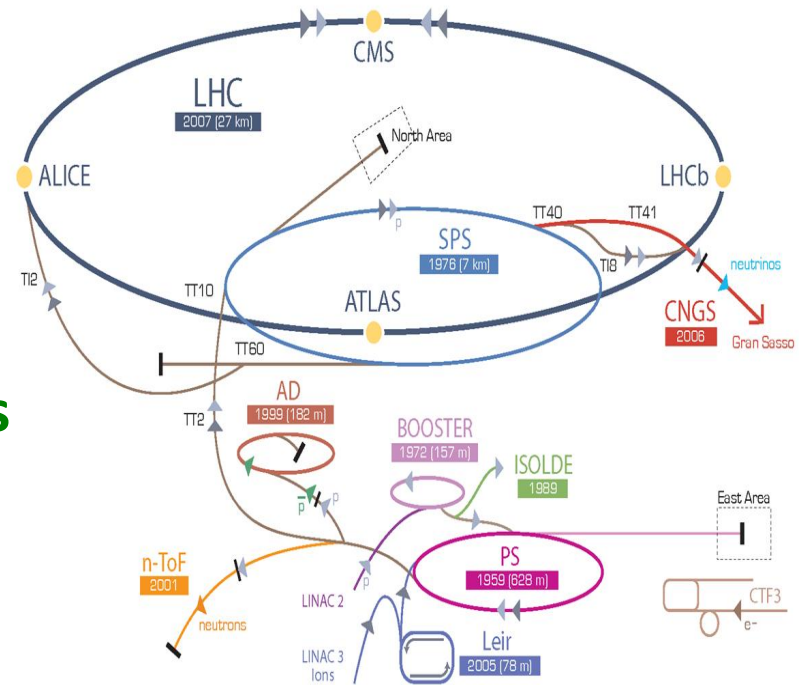
- Levelling / Anti-levelling
  - With the performance increase and also in view of the HL-LHC luminosity levelling becomes important
  - Depending on the type of levelling the control process can be complex
    - Beam separation → “easy”, routinely used
    - Crossing angle → “demanding”, being exploited today
    - $\beta^*$  → “challenging”, under development to be used in the coming years
- New developments of more complex controls system components required/ongoing to link seamlessly existing systems in the machine together (e.g. orbit, collimators, optics, machine protection, ....)
- All these upcoming work can be achieved with efficient collaborations of experts, operators and developers across the accelerator sector

# Additional challenge

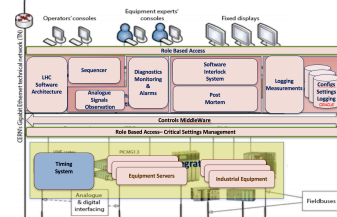
The **same controls infrastructure** is deployed on **all CERN accelerators**

## Important Technical Challenges

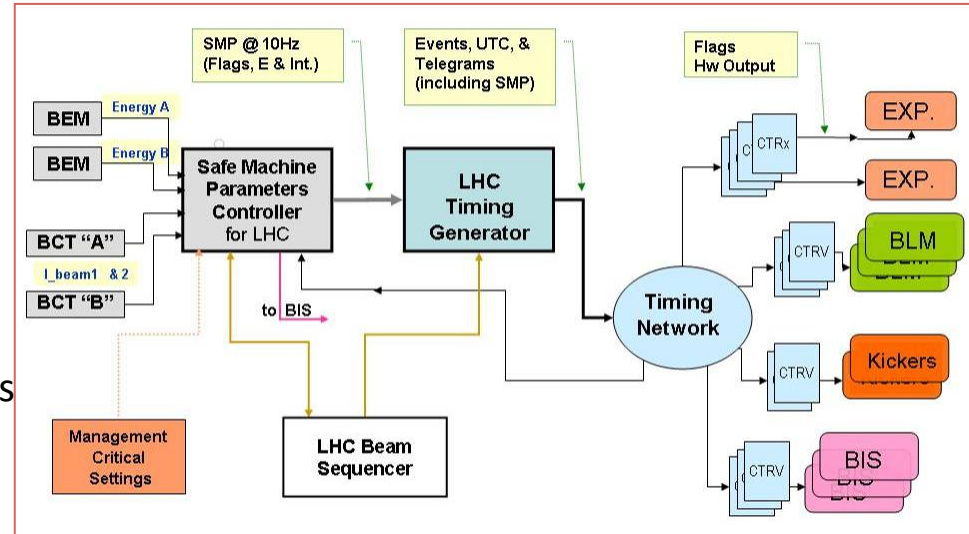
- Highly exposed, critical operational services
- Serves dissimilar set of users, commonality vs. customisation
- Complex dependencies
- Challenging integration, difficult maintenance
- Technical errors  $\Leftrightarrow$  high impact
- Stability vs. fast turn around
- High reliability and availability



# LHC Timing System



- Event-based timing system
- Dedicated network
- Active and hot spare nodes
- Manually calibrated
- Have many systems acting in **sync**
  - synchronously ramp up LHC magnets
  - ~1000 receivers serving ~8000 clients
- Provides **common notion of time** in distributed systems - to make sense of acquired data
  - LHC: data timestamps have 1  $\mu$ s precision



## Distribution of critical parameters over the Timing network

- Beam Energy,
- Safe Beam Flags,
- ...

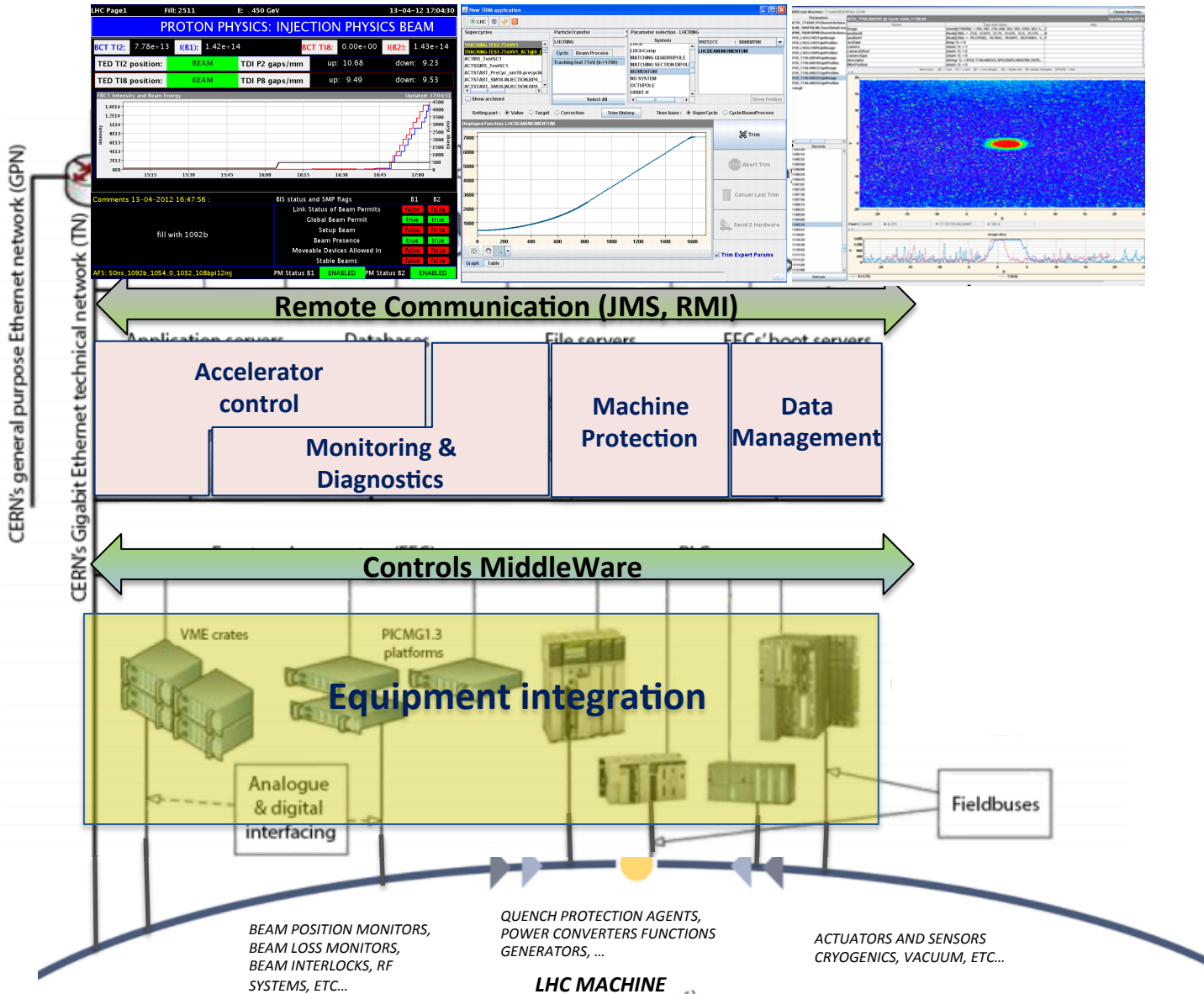
## Interfaces with

- Kicker systems (BEM)
- BCT system
- BLM system
- Experiments
- Beam Interlock System.

# Philosophy of development

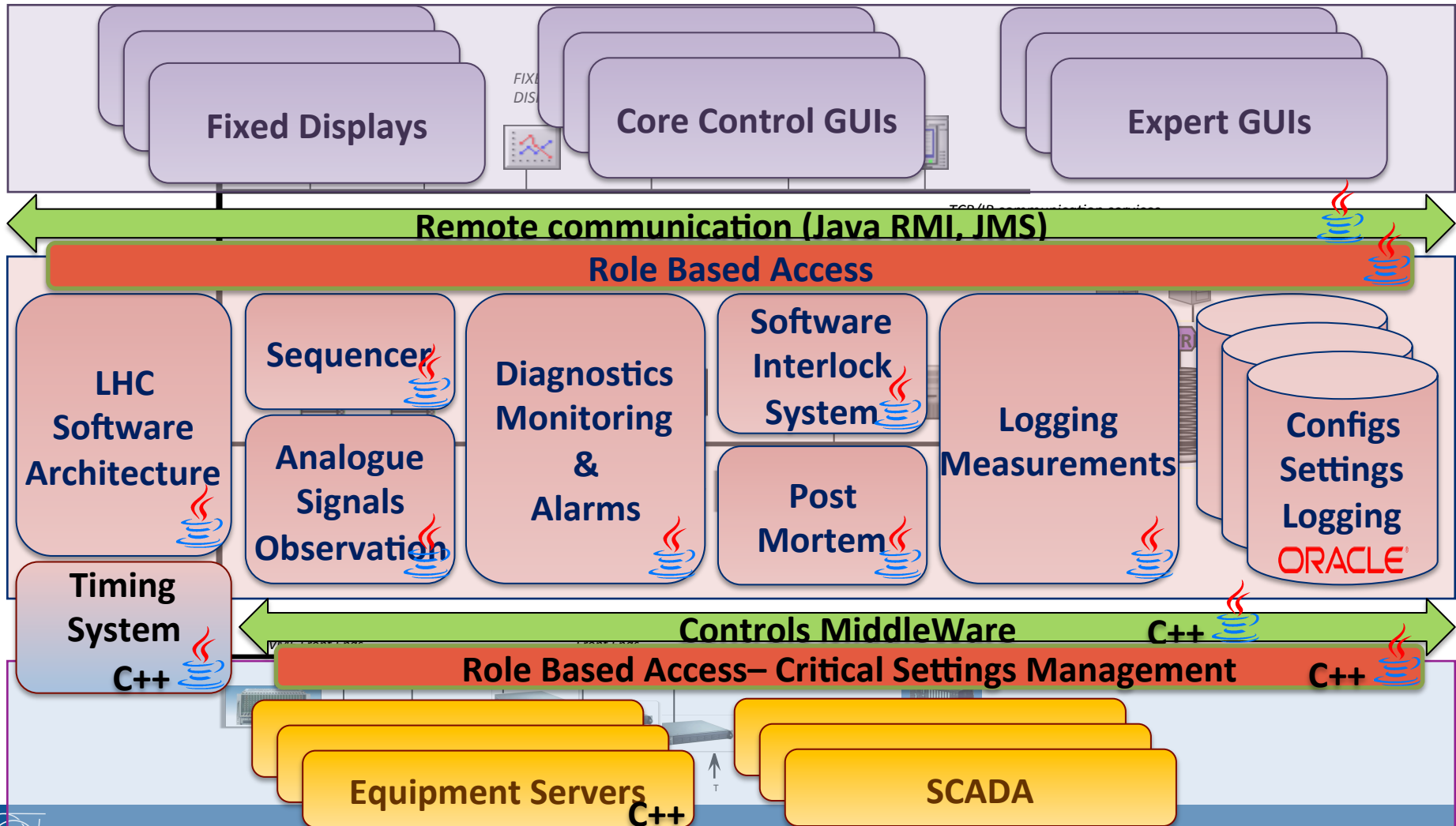
- Provide **extensible Frameworks** and **Tools**
- **Domain experts** fill in the domain-specific knowledge
- Develop and deploy **Generic** services
- **Applicability** to all accelerators
- Thorough **Quality Assurance**
- Successful and efficient **collaboration**
  - with equipment groups and operators
  - with other laboratories (FermiLab, GSI, ESRF, ITER, MedAustron, Dubna)

# Control Software Architecture



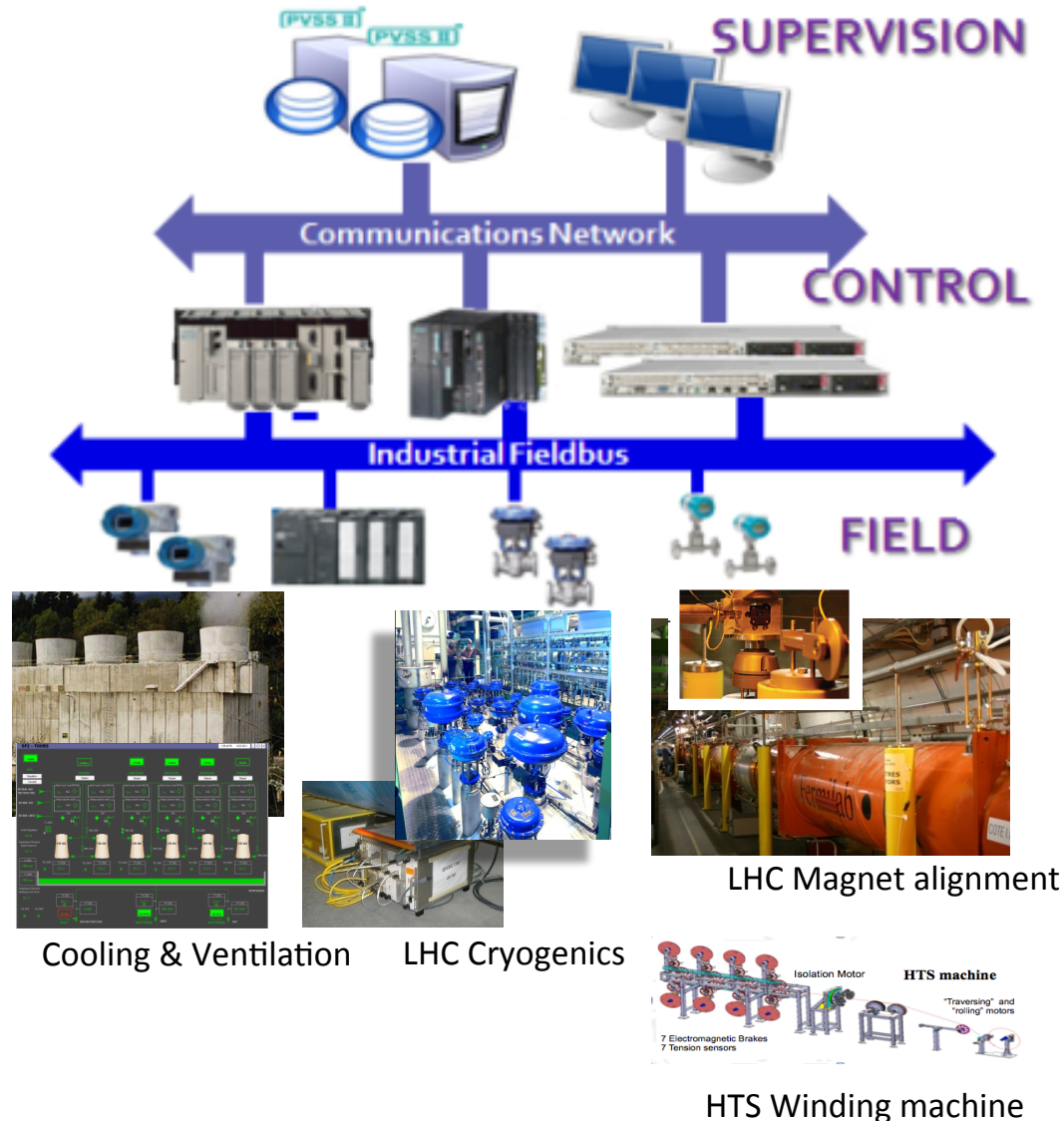


# Controls SW Infrastructure

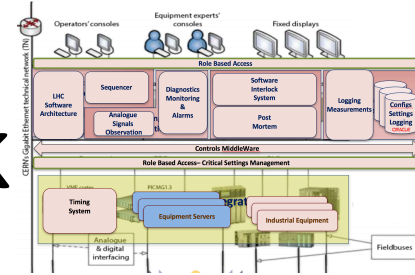


# Industrial Process Control System

- Process Control application framework **UNICOS**
  - PLC or PAC-based applications
  - UNICOS proposes a method to design and develop the control application which will run in commercial off-the-shelf products
- **JCOP FRAMEWORK**
  - Common Framework of tools and core components
  - Device modelling, configuration, monitoring, alarms, etc
  - Main users are software developers and LHC experiments
  - Large software system
  - Users >750 History: 14 years
  - Many external contributions: e.g. experiments

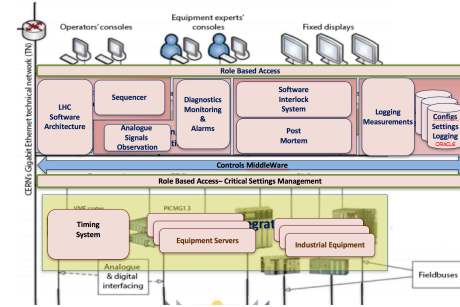


# Front End Software Framework



- **Standard** software framework to develop **real-time** Front-End Software to control **all accelerators** equipment
- Hides the complexity of the controls infrastructure, **simplifies** the development, allows equipment experts to **focus on their HW-specific logic**
- **~100 developers** from 16 equipment groups
- **~700 hardware device types** (~200 in LHC)
- **~70000 devices** (~25000 in LHC)
- **~1000 Front-Ends machines** (~500 in LHC)
- **Exportable**: used in GSI (Darmstadt)

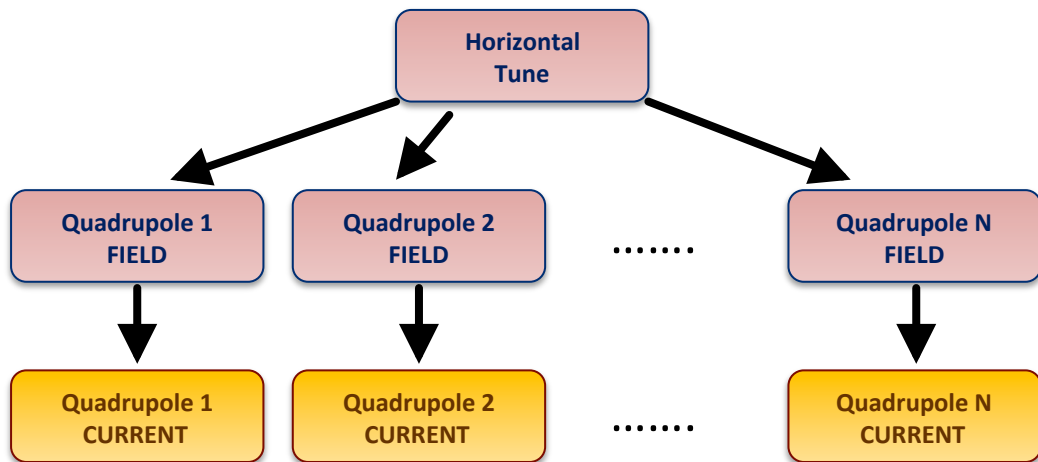
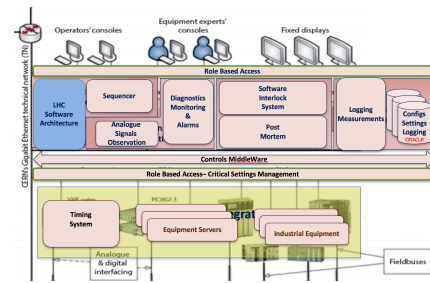
# Controls MiddleWare



- Reliable decentralised core **communication** layer based on ZeroMQ
- Collection of software **components & services**
- Operations: **GET, SET, SUBSCRIPTION**
- Widely deployed for **all CERN accelerators**
- Provides **comprehensive diagnostics**
  
- **4'200 Front-End servers** processes
- **85'000** (incl. SCADA) **devices**
  - **85'000 devices**
  - **2'000'000 equipment controllable properties**
- 2 Directory Servers for device information how to connect
- **Exportable**: used in GSI (Darmstadt)

# LHC Setting Management

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



- 6 accelerators:
  - LHC, SPS, LEIR, PS, PSB, ISOLDE
  - **Exportable**: used in GSI
- > 200 HW types
- > 150 M of settings
- ~ 200 client applications
- ~ 1M lines of code

# LSA Parameter Hierarchy

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

The diagram shows a hierarchical structure of parameters. The root node is LHCBEAM1/QH\_TRIM, which branches into 16 children. Each child node further branches into three intermediate nodes, which then branch into a final set of four leaf nodes. The leaf nodes are labeled with 'RPMBB.UA' followed by a unique identifier and 'MREF'.

Child	Intermediate 1	Intermediate 2	Leaf
RQTF.A56B1/K1	RQTF.A56B1/K_SMOOTH	RQTF.A56B1/I	RPMBB.UA63.RQTF.A56B1/MREF
RQTD.A67B1/K1	RQTD.A67B1/K_SMOOTH	RQTD.A67B1/I	RPMBB.UA67.RQTD.A67B1/MREF
RQTF.A81B1/K1	RQTF.A81B1/K_SMOOTH	RQTF.A81B1/I	RPMBB.UA87.RQTF.A81B1/MREF
RQTF.A67B1/K1	RQTF.A67B1/K_SMOOTH	RQTF.A67B1/I	RPMBB.UA67.RQTF.A67B1/MREF
RQTD.A23B1/K1	RQTD.A23B1/K_SMOOTH	RQTD.A23B1/I	RPMBB.UA27.RQTD.A23B1/MREF
RQTD.A45B1/K1	RQTD.A45B1/K_SMOOTH	RQTD.A45B1/I	RPMBB.UA47.RQTD.A45B1/MREF
RQTF.A12B1/K1	RQTF.A12B1/K_SMOOTH	RQTF.A12B1/I	RPMBB.UA23.RQTF.A12B1/MREF
RQTD.A34B1/K1	RQTD.A34B1/K_SMOOTH	RQTD.A34B1/I	RPMBB.UA43.RQTD.A34B1/MREF
RQTD.A81B1/K1	RQTD.A81B1/K_SMOOTH	RQTD.A81B1/I	RPMBB.UA87.RQTD.A81B1/MREF
RQTF.A78B1/K1	RQTF.A78B1/K_SMOOTH	RQTF.A78B1/I	RPMBB.UA83.RQTF.A78B1/MREF
RQTF.A45B1/K1	RQTF.A45B1/K_SMOOTH	RQTF.A45B1/I	RPMBB.UA47.RQTF.A45B1/MREF
RQTD.A78B1/K1	RQTD.A78B1/K_SMOOTH	RQTD.A78B1/I	RPMBB.UA83.RQTD.A78B1/MREF
RQTD.A12B1/K1	RQTD.A12B1/K_SMOOTH	RQTD.A12B1/I	RPMBB.UA23.RQTD.A12B1/MREF
RQTF.A23B1/K1	RQTF.A23B1/K_SMOOTH	RQTF.A23B1/I	RPMBB.UA27.RQTF.A23B1/MREF
RQTD.A56B1/K1	RQTD.A56B1/K_SMOOTH	RQTD.A56B1/I	RPMBB.UA63.RQTD.A56B1/MREF
RQTF.A34B1/K1	RQTF.A34B1/K_SMOOTH	RQTF.A34B1/I	RPMBB.UA43.RQTF.A34B1/MREF

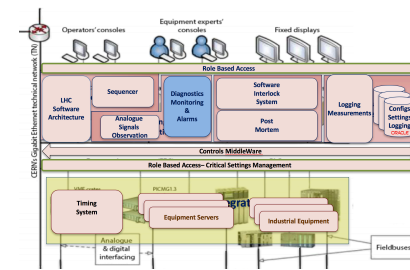
Children Parents

Close

12:42:40 - Loading hierarchy of LHCBEAM1/QH\_TRIM

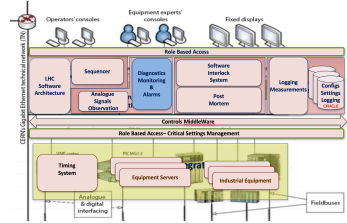
# Diagnostic Monitoring

- **Monitors** controls infrastructure
  - Computers (front-ends, servers, consoles)
  - Network
  - Software applications
- Provides **overview** of infrastructure state
- Helps finding the **root cause** of the problem
- Provides **evolution history**
- Allows certain **actions**
  - restart system
  - restart process
- Metrics from >2000 computers
- ~10 M updates / day



Name [A]	Status [N]
cfv-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-sr8-blmc	
cfv-sr8-blml	
cfv-sr8-blmr	
cfv-sx4-blmc	
cfv-sx4-blml	

# Alarms

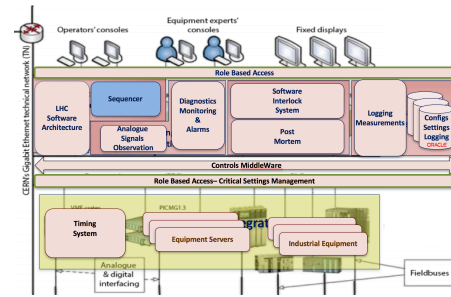


- **Software alarms system**
  - Problem => notification
- Does not deal with human/equipment safety
- Notifies about problems requiring **human intervention**
- **Maps alarms to people** and **possible actions**
- **Relevant** alarms only
  - Depends on accelerators
- Alarms **history**
- Alarms **priority**
- **~200 K alarm definitions**
  - 80'000 for LHC
- **~150 alarm events/min**

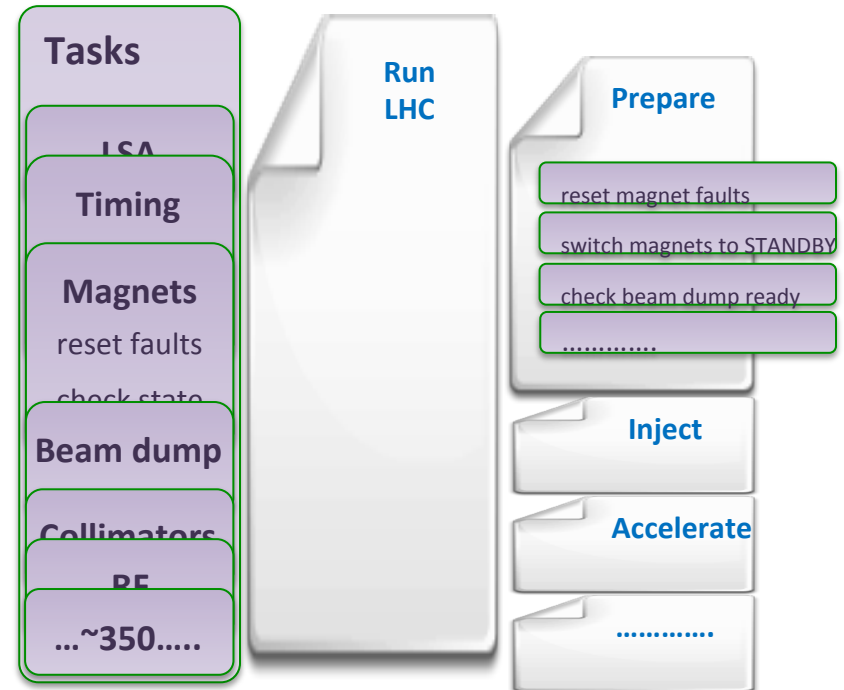
Y #	Date	Time	Building	Mnemonic	System Name	Identifier	Problem Description	Site
N	13:41:36	3126	UX15	EAU_DEMI_LHC	FCUL-00013_LAR_CALOR		DEFAULT GENERAL INSTALLATION	L1
03/09	21:18:38	3182	SUX1	THER_VENT_LHC	UAVX181		DEFAULT GENERAL INSTALLATION	L1
10/09	14:29:01	3555	SXS	THER_VENT_LHC	UAVL-527		DEFAULT GENERAL INSTALLATION	L1
23/09	13:42:50	3524	USX55	EAU_GLACEE_LHC	FREA-00020		DEFAULT GENERAL INSTALLATION	L5
24/09	10:15:02	2395	SZU93	EAU_BRUTE_LHC	FTND-952		DEFAULT GENERAL INSTALLATION	L2
24/09	10:21:09	2229	UW25	EAU_DEMI_LHC	FDDE-00080_C211X		DEFAULT GENERAL INSTALLATION	L2
24/09	13:09:36	2280	SU2	THER_VENT_LHC	UAPT-203_UBRRG03		DEFAULT GENERAL INSTALLATION	L2
24/09	13:21:37	2826	PM85	ACCE_GENERALE_LHC	YCARG01-PM85		DEFAULT GENERAL INSTALLATION	L2
24/09	13:59:35	2280	SU2	THER_VENT_LHC	UAPT-204_UBRRG03		DEFAULT GENERAL INSTALLATION	L2
N	14:16:37	3585	SXS	THER_VENT_LHC	F3FSVE-00018		DEFAULT GENERAL INSTALLATION	L5
27/05	08:28:40	2285	SX2	THER_VENT_LHC	USCL002-PM54		DEFAULT GENERAL INSTALLATION	L2
05/06	11:49:08	2439	UA47	EAU_DEMI_LHC	UAUX-00001		DEFAULT GENERAL INSTALLATION	L4
04/07	17:00:04	2280	SU2	EAU_BRUTE_LHC	UIAO-00201_ARMOIRE_CTRL		DEFAULT GENERAL INSTALLATION	L2
27/07	08:42:40	2741	R771	EAU_DEMI_LHC	FDDE-00099		DEFAULT GENERAL INSTALLATION	L7
02/08	13:20:01	3125	USA15	THER_VENT_LHC	UIAO-00117		DEFAULT GENERAL INSTALLATION	L1
02/09	10:34:09	2285	SX2	THER_VENT_LHC	UACW2-00518		DEFAULT GENERAL INSTALLATION	L2
03/09	06:11:14	2613	UJ63	THER_VENT_LHC	UAUQ-01635		DEFAULT GENERAL INSTALLATION	L6
03/09	06:11:52	2743	REF8	THER_VENT_LHC	UICC-00703		DEFAULT GENERAL INSTALLATION	L7
03/09	07:31:10	2882	SUX8	THER_VENT_LHC	USFARPREP2-SUX8_UOWC-816		DEFAULT GENERAL INSTALLATION	L6
03/09	15:50:40	2380	SU3	EAU_GLACEE_LHC	FTNB-301		DEFAULT GENERAL INSTALLATION	L3
03/09	21:18:38	3182	SUX1	THER_VENT_LHC	USFRAEXTSUX-SUX1_UOWC-114		DEFAULT GENERAL INSTALLATION	L1
10/09	15:39:32	2618	UA63	EAU_DEMI_LHC	FDDE-00100		DEFAULT GENERAL INSTALLATION	L6
10/09	15:42:28	2175	SRI1	THER_CLIM_LHC	UACV1-00126		DEFAULT GENERAL INSTALLATION	L7
17/09	08:00:44	2855	SXS	SERV_EXPERIENCE_LHC	DSS_LHC6		DEFAULT GENERAL INSTALLATION	L8
17/09	14:44:20	2659	UA65	EAU_DEMI_LHC	FDDE-00010		DEFAULT GENERAL INSTALLATION	L6
21/09	05:36:54	2618	UA63	THER_VENT_LHC	UAUT-01630		DEFAULT GENERAL INSTALLATION	L6
23/09	09:26:29	3155	SX1	THER_VENT_LHC	UAVL-158		DEFAULT GENERAL INSTALLATION	L1
24/09	08:17:17	2480	SU4	EAU_GLACEE_LHC	UHA4402		DEFAULT GENERAL INSTALLATION	L4
24/09	10:29:19	2884	SH8	THER_VENT_LHC	UAAPQ881		DEFAULT GENERAL INSTALLATION	L4
24/09	10:50:22	2880	SU8	THER_VENT_LHC	UAPS-807_UUDCM15		DEFAULT GENERAL INSTALLATION	L8
24/09	10:51:31	2880	SU8	THER_VENT_LHC	UAUD-806_UUDCM12		DEFAULT GENERAL INSTALLATION	L4
24/09	10:51:31	2880	SU8	THER_VENT_LHC	USFARHVCSB-SU8_UOWC-804		DEFAULT GENERAL INSTALLATION	L6
24/09	13:40:19	2156	UX15	EAU_FLUOROCARB_LHC	FCULM-00004_TRT		DEFAULT GENERAL INSTALLATION	L1
N	13:46:24	2280	SU2	THER_VENT_LHC	UAPE-201_P2_SU2		DEFAULT GENERAL INSTALLATION	L2
N	14:07:42	3118	UX14	ACCE_GENERALE_LHC	YCPV02-UPX14		DEFAULT GENERAL INSTALLATION	L1
N	14:16:18	UX15	EAU_DEMI_LHC	FCUL-00013_LAR_CALOR			DEFAULT GENERAL INSTALLATION	L1
N	14:16:47	UX1	THER_VENT_LHC	UAVL-158			DEFAULT GENERAL INSTALLATION	L1



# Sequencer



- **Automates** execution of **sequences of tasks**
  - Check the values of devices
  - Ask the control system to load the settings
  - Wait for the equipment to be ready
- **Operators** memory
- **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



- ~ 1250 sequences for LHC Beam Operation
- ~ 350 tasks types
- LHC main sequence: ~1100 tasks in total

# Sequencer 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 OF

MAKE LHC.USER.INJECTION RESIDENT

LOAD INJECTION REF ORBIT FOR OF

SET ACTIVE ORBIT INDEX

CALC ACTIVE BEAM PROCESS OPTIC

SET ACTIVE BEAM PROCESS OPTICS

DRIVE TUNE FB SETTINGS FOR INJE

SWITCH FEEDBACK STATE TUNE\_B1 O

SWITCH FEEDBACK STATE TUNE\_B2 O

MAKE LHC.USER.INJECTION RESIDENT

LOAD FEEDBACK INJECTION SETTING

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

INATION 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

LOAD REF ORBITS FOR THE SQUEEZE

SET ACTIVE ORBIT INDEX 0

LOAD REF orbit for squeeze

CHECK REFERENCE ORBIT CORRECTLY LOADED

LOAD ORBIT AND OPTICS TABLE CHANGE FOR SQUEEZE

LOAD OFB REF ORBIT CHANGE

55

SWITCH ON ORBIT AND ENERGY FEEDBACKS

LOAD TUNE FB FOR SQUEEZE

LOAD SQUEEZE 2011 PC TABLES SEGMENT

FEEDBACKS ARMED

CHIRP AND QFB OFF

STATE/BEAM\_MODE = SQUEEZE

LOAD ART TBL (33) EVT

Beam Controls

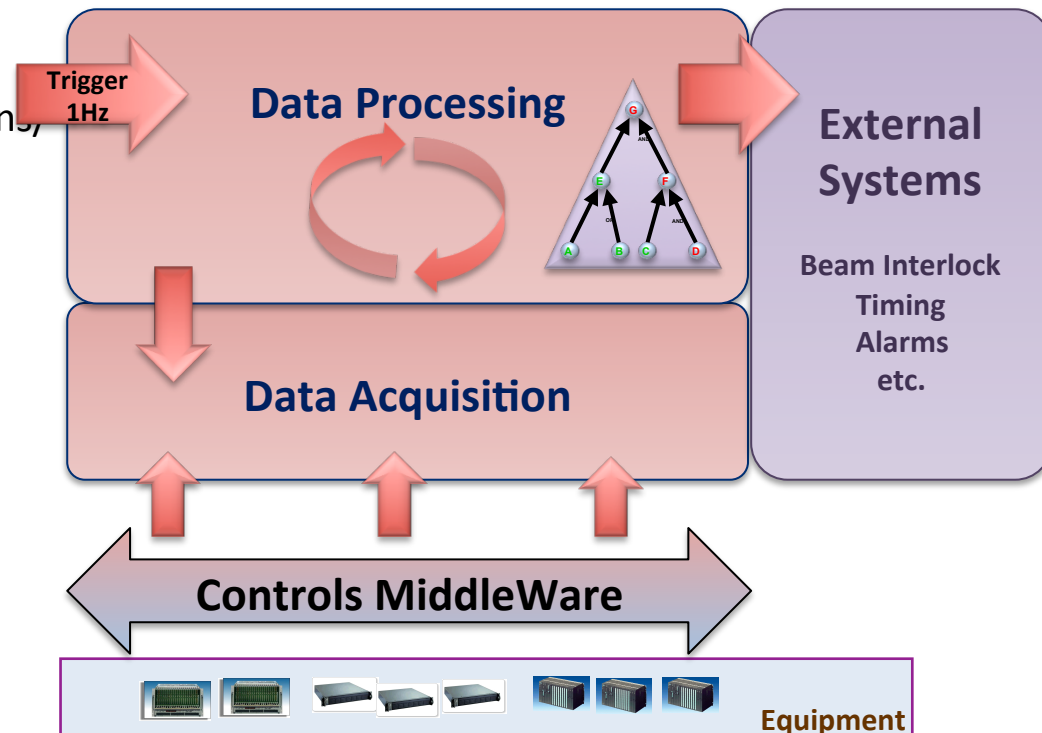
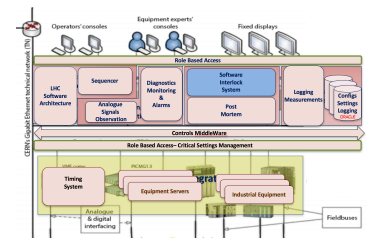
1st Sep. 2012

34

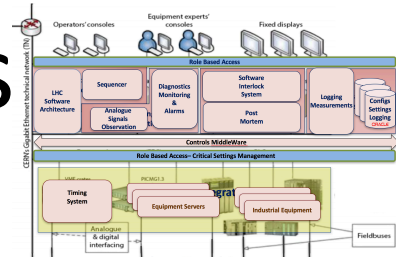


# Software Interlock System

- Part of overall **Machine Protection**
- **Surveys** the state of key LHC components using **complex** condition **logic**
- Provides the operations with condition calculation **diagnostics**
- Extendable - add/modify/remove conditions, reactions
- **Deterministic** and highly **reliable** system
- **Acts** if necessary
  - **abnormal situation**  $\Rightarrow$  **beam dump**
- Deployed practically for all accelerators
- LHC has
  - ~2700 subscriptions
  - ~5200 elementary values
  - ~800 logical channels
  - 8 permits

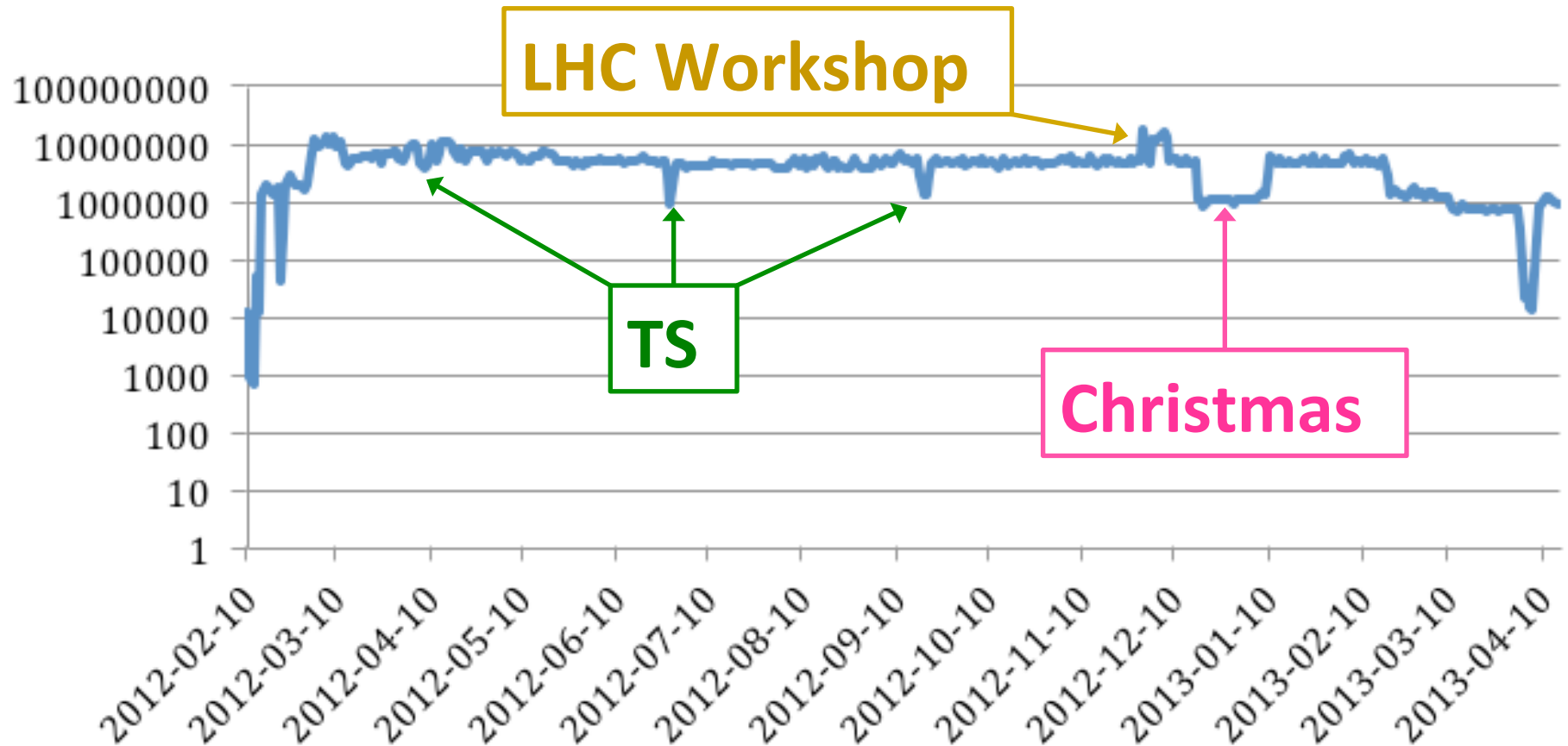


# Management of Critical Settings



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

# Logging: daily extraction requests



# LHC's Figure of MERIT

- Peak luminosity is important

$$LUMINOSITY = \frac{N_{event/sec}}{\sigma_r} = \frac{N_1 N_2 f_{rev} n_b}{4\pi\sigma_x \sigma_y} F$$

- Integrated Luminosity, hence machine/beam availability is key

$$L = \int L dt$$

# LHC Future Timing System



- Move to WhiteRabbit technology
  - Time-based timing system
  - Automatically synchronized “common time”
  - Ethernet-based deterministic solution for  $\sim 0.5$  ns accuracy and  $< 10$  ps precision reliable data delivery among a few thousand nodes over large distances (tens of kilometers)
  - Reliable: redundant both for topology and data
  - Initiated and developed in the Controls group
  - Open Source Hardware and Software

# White Rabbit CERN Users

- ATLAS
  - Synchronisation of seismic measurements (M.Guinchard, Nov-Dec. 2015)
- General Machine Timing system upgrade in the Antiproton Decelerator and the ELENA ring
- Beam Instrumentation
  - Time-stamp events based on a reference clock that will be received by WR
- Btrain over White Rabbit on CERN CO wikis (CERN access only)
  - Magnetic field measurement and distribution of the data in real-time
- LHC Instabilities Trigger Distribution
  - Instability diagnostics
- ProtoDUNE - CERN Prototype of DUNE
  - SM-18: Magnetic field measurement and distribution of the data in real-time
- SPS RF distribution over White Rabbit
- **CNGS** Timing for neutrino measurements (2012-2014)



# White Rabbit Non CERN Committed Users

- **Arkus, Japan**
- **Cherenkov Telescope Array**
- **China Spallation Neutron Source Institute of High Energy Physics Chinese Academy of Sciences - CSNS, Beijing, China**
- **CHIRON-IT, The Netherlands**
- **Culham Centre for Fusion Energy**
- **DESY, Germany**
- **DLR (German Aerospace Center, Institute for Technical Physics)**
- **EISCAT, Sweden**
- **EPFL, ESPLAB Switzerland**
- **GSI, FAIR facility**
- **ESS Bilbao, Spain**
- **JINR (Russia)**
- **Fermilab, USA**
- **Paris Observatory**
- **MIKES (Centre for metrology and accreditation, Finland)**
- **LHAASO ( Tsinghua University, China)**
- ....