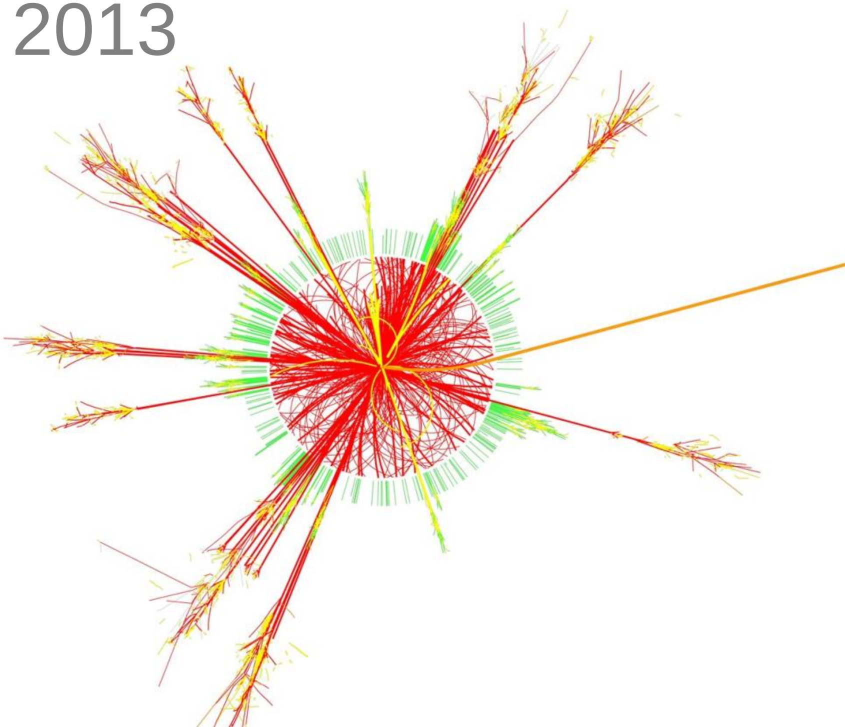
Experimental infrastructure control systems development

HEPTech Academia
2nd December 2013



CERN PH-DT
- L. Zwalinski
- G. Maire
- S. Ravat
- S. Pavis
- X. Pons

Presentation overview

- Introduction
- Detector Cooling Control Systems (CO_2 and Fluorocarbons)
- Detector Vacuum Control System
- Experimental Magnets Control Systems

PLC based Control Systems using **UN**ified **I**ndustrial **C**ontrol **S**ystem (UNICOS) of CERN

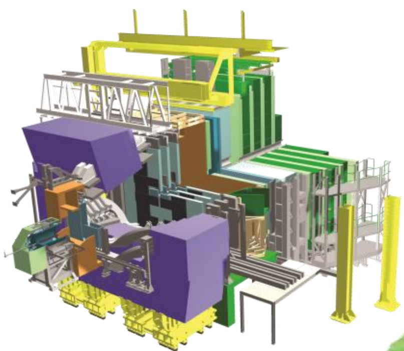
- Experimental Magnets Safety Systems
- NA62 Detector Safety System
- Roman Pots at LHC

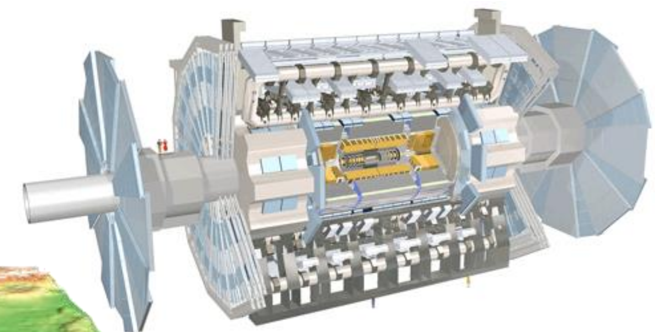
National Instruments based systems

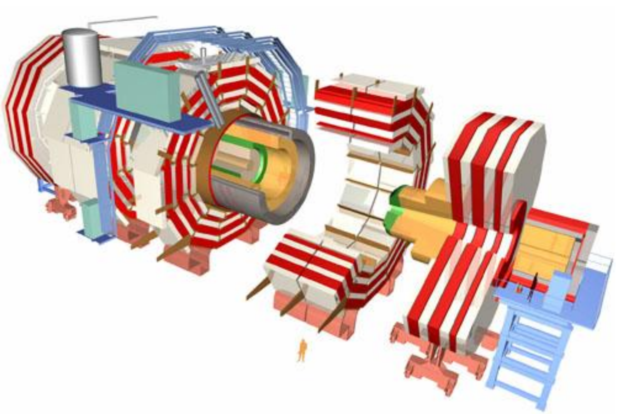
Introduction

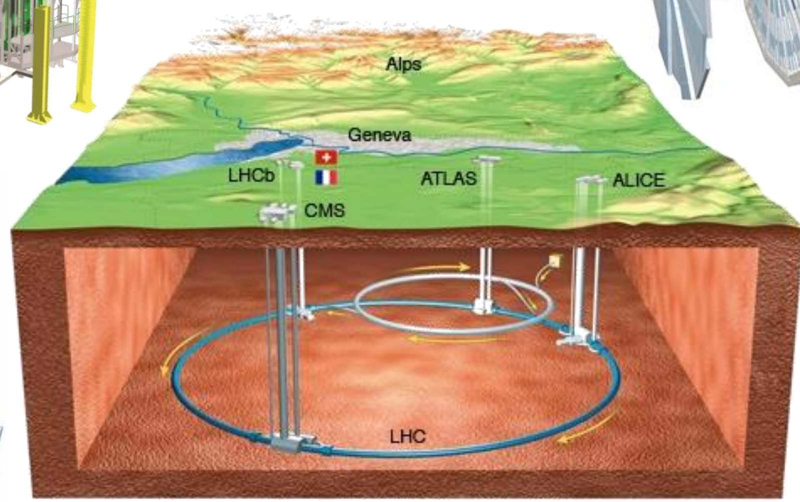
Detector Technology (DT)

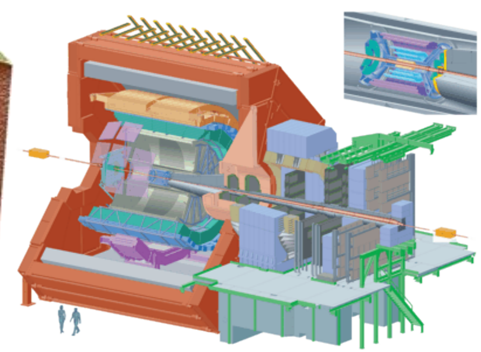
The mandate of the PH-DT group comprises development, construction, operation and maintenance of particle detectors for the experiments at CERN. The group clusters common services and infrastructure which are available to all experiments at CERN, e.g. gas system support, cooling support, thin film lab, silicon facility with bond lab, irradiation facilities, magnet support, B-field mapping, instrumentation and **controls**.











Detector Cooling – CO_2

Why do we want to use CO_2 for HEP cooling systems ?

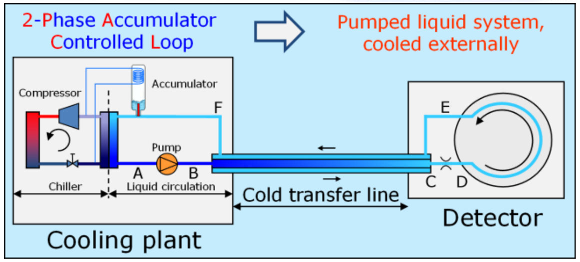
- **Significant saving of cooling hardware** (material budget) into the detector due to the physical properties:
  - large latent heat of evaporation
  - low liquid viscosity
  - high heat transfer coefficient
  - high thermal stability due to the high pressure
- Very practical fluid to work
- Practical range of the detector application -45^{0}C to +25^{0}C

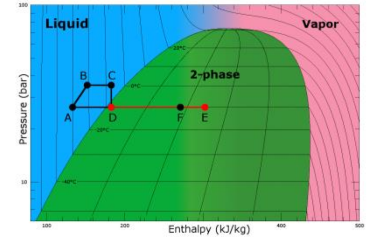
Where CO_2 cooling is currently used ?

- **AMS-TTCS** (Tracker Thermal Control System)
  Q = 150 W T = +15 ^{0}C to -20 ^{0}C
- **LHCb-VTCS** (Velo Thermal Control System)
  Q = 1500 W (2 x 750 W) T = +8 ^{0}C to -30 ^{0}C

Where it is planned to use CO_2 cooling systems ?

- At CERN:
  phase 1 upgrades: ATLAS IBL and CMS pixel phase 1
  phase 2 upgrades: under consideration
- Out of CERN:
  KEK Belle-2, ILC





Detector Cooling – CO_2

Detector Cooling – CO_2 at CERN

Experiment	Project name	PLC/DAQ Brand	Project status	Cooling power
ATLAS	SR1	Siemens	Completed	2kW
	IBL	Schneider	Under development	2x3.3kW
CMS	TIF	Schneider	Completed	8kW
	Pixel phase 1	Schneider	Under development	15kW
General purpose ATLAS & CMS	CORA	Siemens	Completed	2kW
ATLAS & Belle	MARCO	Siemens	Completed	1kW
ATLAS & CMS & LHCb ILC-PPC founded by AIDA project	TRACI	Siemens NI LabVIEW DAQ	Completed	100W

CMS TIF
- ~240 I/Os
- 1x Schneider PLC
- UNICOS framework
- WinCC OA - SCADA
- In operation

ATLAS IBL
- ~670 I/Os
- 3x Schneider PLCs
- UNICOS framework
- WinCC OA - SCADA
- Under installation

TRACI
- ~ 20 I/Os
- Siemens PLC or NI DAQ
- Portable
- 5 units in operation
- 1 unit in assembly phase

MARCO
- ~110 I/Os
- 1x Siemens PLC
- UNICOS framework
- WinCC OA - SCADA
- Local HMI
- **Movable**
- In operation

SR1
- ~140 I/Os
- 1x Schneider PLC
- UNICOS framework
- WinCC OA - SCADA
- In operation

CORA
- ~70 I/Os
- 1x Siemens PLC
- UNICOS framework
- WinCC OA - SCADA
- In operation

Detector Cooling – CO_2

Detector Cooling – CO_2 at CERN standardization approach

Mechanics:

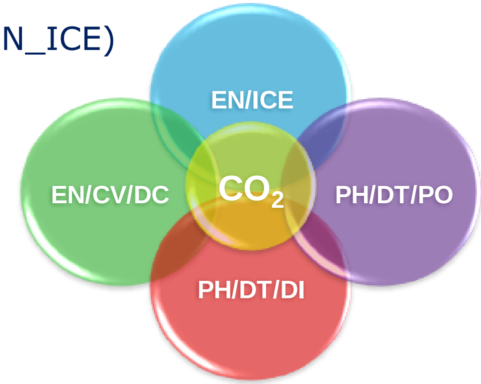
- Coherent and cost-effective development, with **standardized components**
- Use **commercial** CO_2 refrigeration **products** (but the way we operate them is different)

Control hardware:

- **Schneider PLCs** to increase maintenance capabilities of all involved teams
- **WinCC OA SCADA** system centralized on CCC Data Servers (supported by EN_ICE)
- Same electrical and control components for all cooling plants

Software:

- Develop applications with **UNICOS framework**
- Use **same control philosophy**
- Use **same safety and interlocking philosophy**



UNICOS - UNified Industrial Control System (UNICOS) of CERN EN-ICE

1) Framework supports all **three control system layers:**

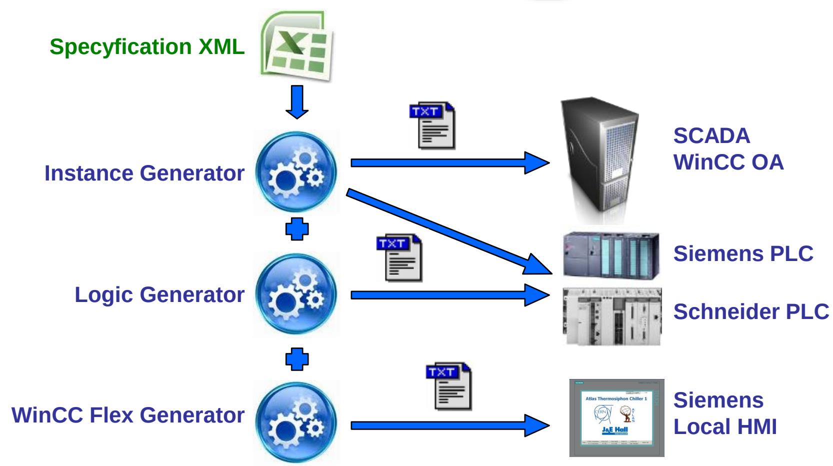
- supervision (SCADA: WinCC OA)
- control (PLC: Siemens S7 and Schneider)
- field layer

2) The package of **programming tools** includes:

- baseline library (with modular PID algorithm)
- code generator
- skeleton templates and example of objects list

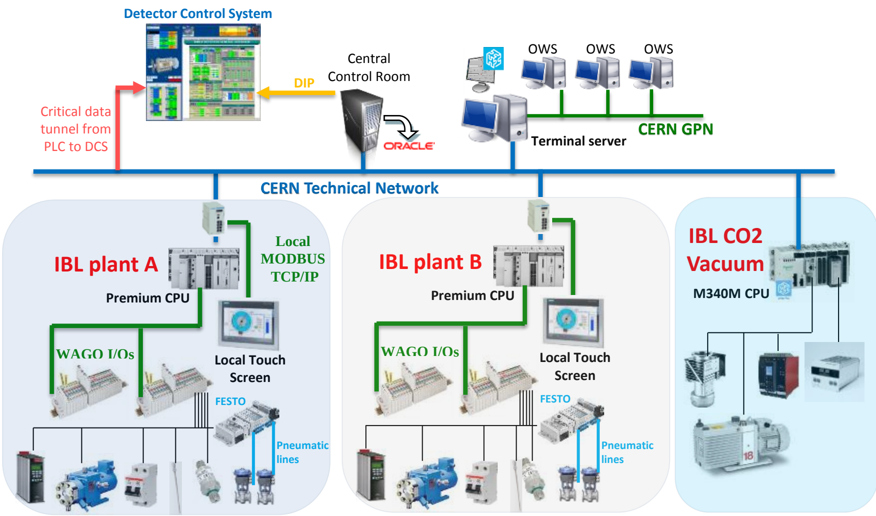
3) **Object definitions** provided by UNICOS are split into:

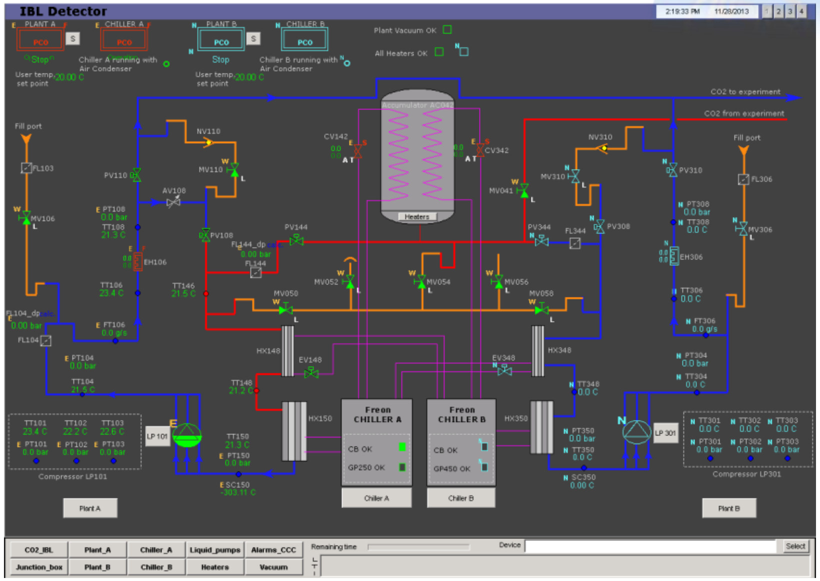
- I/O Objects *(Digital Input, Digital Output, Analog Input)*
- Field Objects *(OnOff, Analog, AnaDig, Controller, etc.)*
- Process Control Objects *(PCO).*



Detector Cooling – CO_2

Detector Cooling – CO_2 at CERN, ATLAS IBL





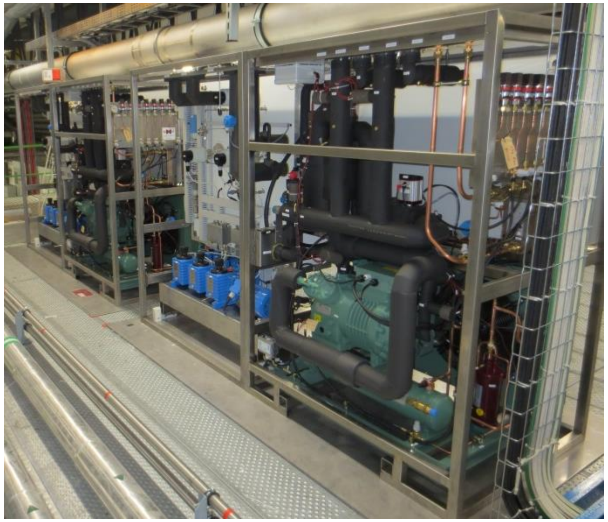
Main purposes:

- Cool down ATLAS Insertable B Layer detectors (IBL) to **-40ºC** using evaporating CO_2

System components:

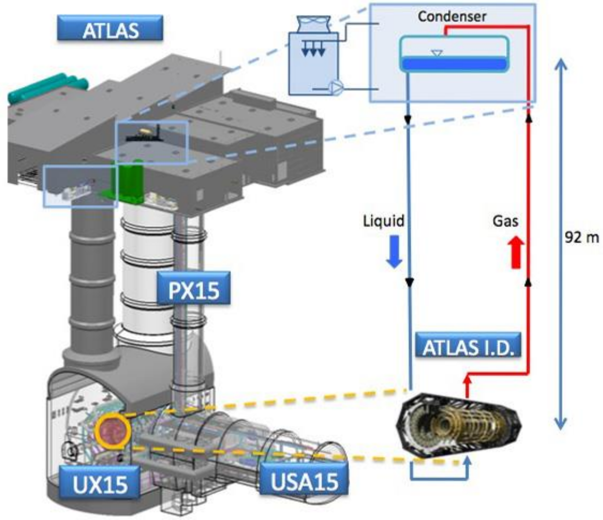
- 3 independent Schneider PLCs:
  - ❑ 1xPremium for IBL-A,
  - ❑ 1xPremium for IBL-B
  - ❑ 1xM340 for Vacuum system

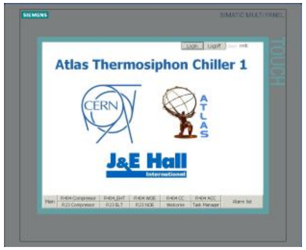
  } all running UNICOS framework
- WinCC OA SCADA system
- Local Touch Screens

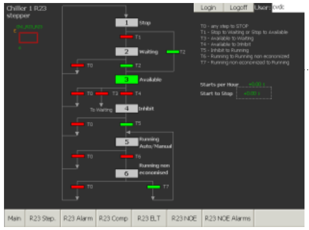


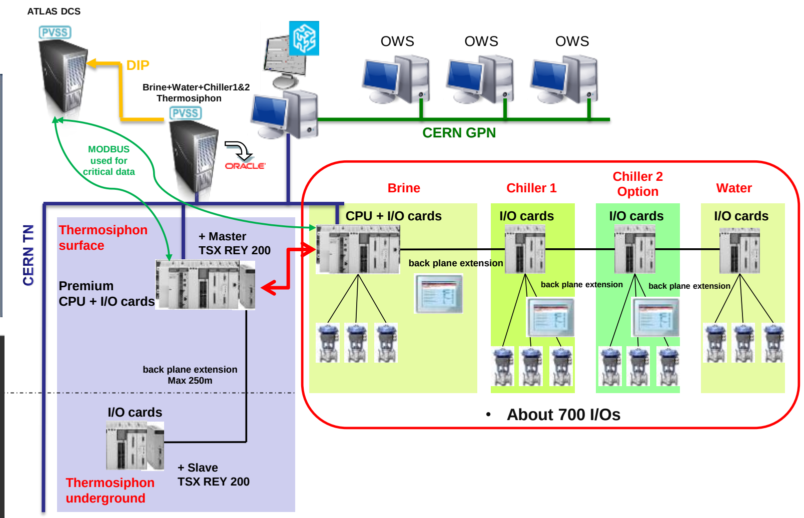
Detector Cooling – ATLAS Thermosiphon

Detector Cooling – Thermosiphon, ATLAS Inner Detector



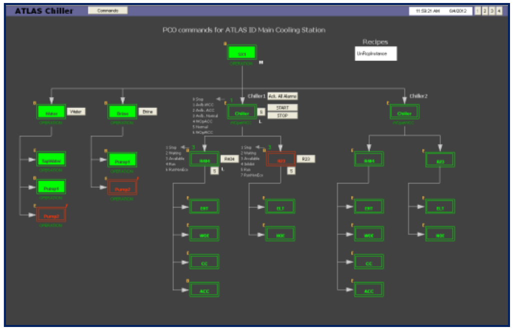






Main purposes:

- Cool down ATLAS silicon detectors (Pixel and SCT) to **-20⁰C** using perfluoropropane (C3F8)
- Replace existing oil-free compressors

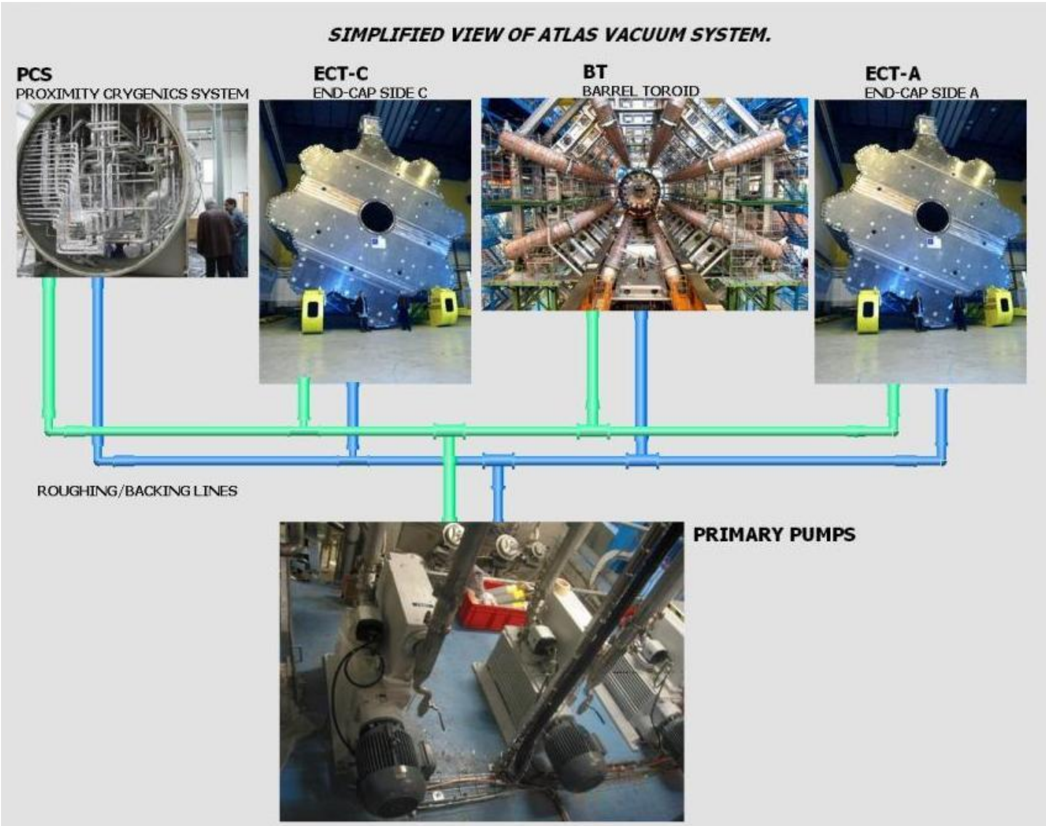


System components:

- 2 independent Schneider PLCs one for Thermosiphon and one for Chiller+Brine+Water system
- UNICOS framework
- WinCC OA SCADA system
- Chiller designed and constructed by external company, **software fully done by CERN.**

System under commissioning

Detector Vacuum - ATLAS Vacuum System

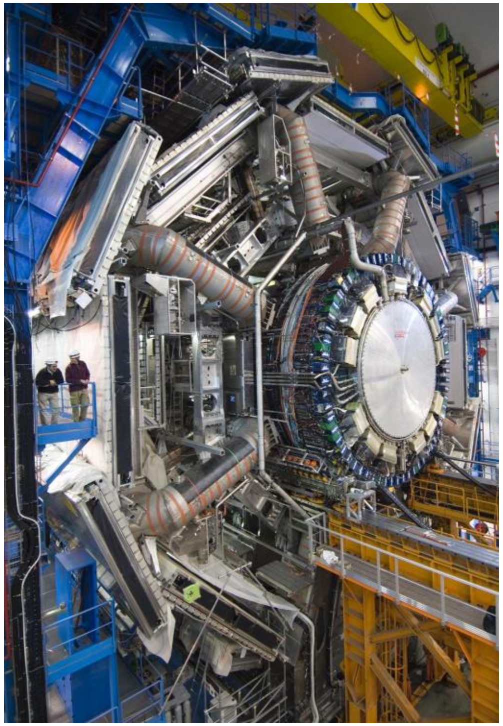


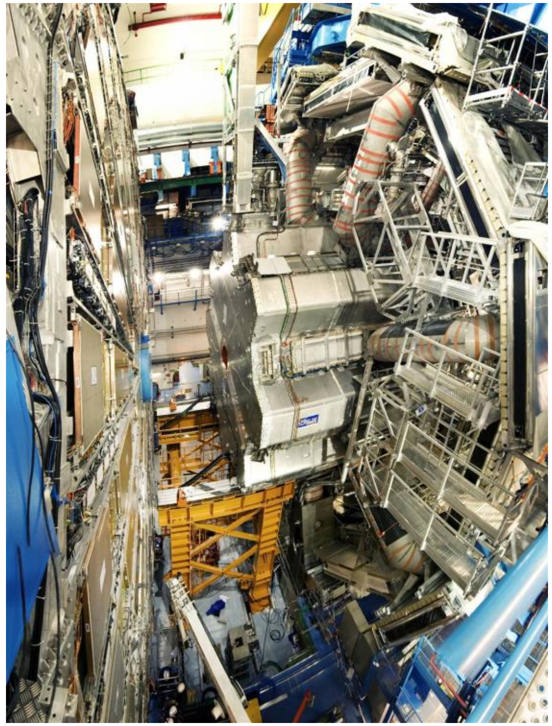
Vacuum for ATLAS Magnet operation:

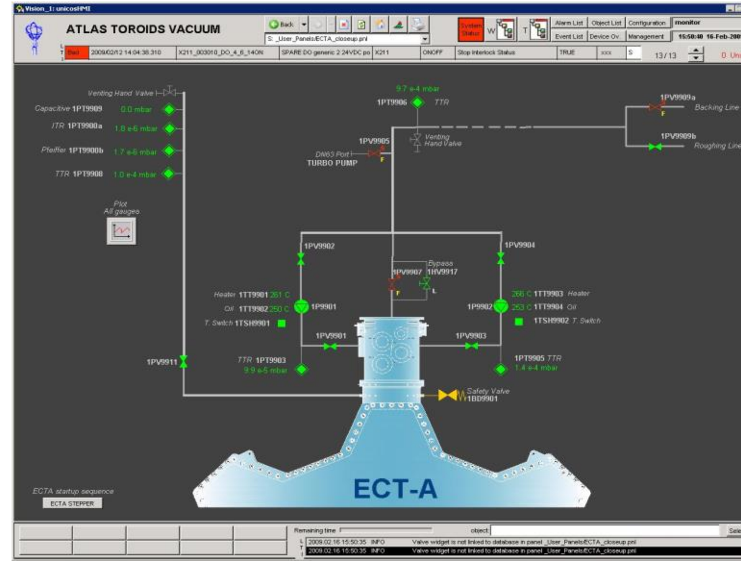
- ***Barrel Toroid***:
  - 56km of **superconductor wires**
  - 8 cold masses (**5K**), total surface 1100m^2
  - 8 vacuum vessels with a total volume of **310m^3** and surface 1200m^2
- ***End Cap Toroid***:
  - cold masses (5K), total surface 900m^2
  - vacuum vessels with a total volume of **220m^3** and surface 400m^2
- ***Total with PCS:***
  - **800 m^3** volume to be kept at 10^{-4} mbar or less
  - 2000 m^2 of "dirty" surface to outgas
- ***Vacuum Heater System:***
  - **750kW electrical power** dissipated over the Toroids surface in case of vacuum break

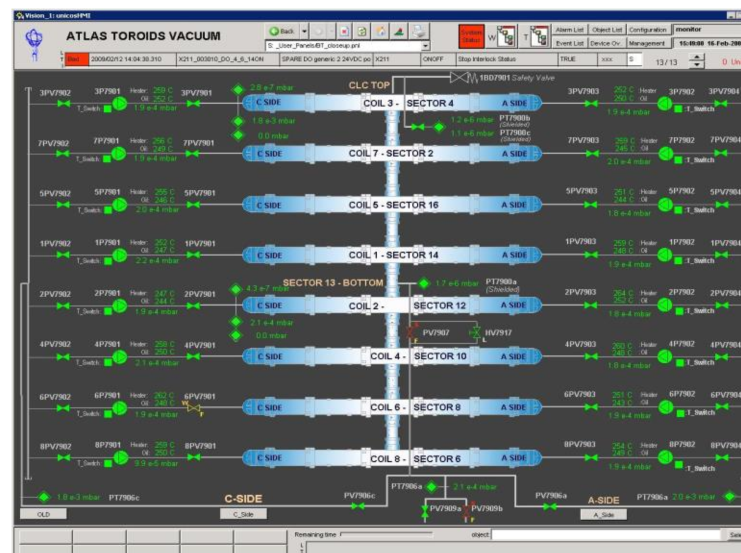
Our responsibility: instrumentation and controls

Detector Vacuum - ATLAS Vacuum System









- ❑ Schneider PLC + WinCC OA SCADA
- ❑ UNICOS framework
- ❑ I/Os: 180 AI, 260 DI, 320 DO

Hardware data:

- 21 diffusion pumps
- 5 primary pumps
- 60 valves
- 60 vacuum pressure readings
- 60 temperature readings
- 4 control racks
- 1 power cabinet

MCS Magnet Control System

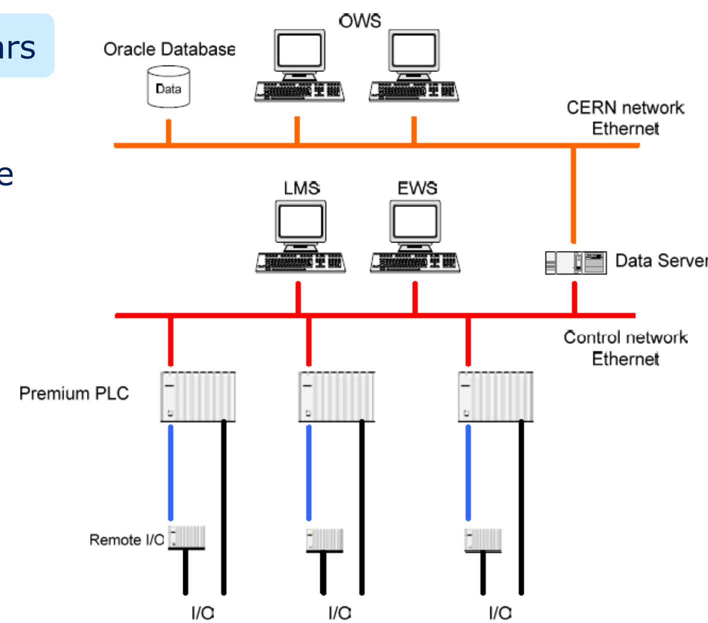
Magnet Control System - Continuously running at CERN since 6 years

Main purposes:

Provide the **process controls** needed to execute automatically the **various running modes** of the magnet system in the LHC experiment magnets (**ALICE, ATLAS, CMS, LHCb**)

Requirements:

- The system must be able to perform, on demand, **automatic operational sequences** on the magnet (subsystem tests...)
- **Communication** Interface with Power Converter
- **Adaptation of the current** in the magnet according to external conditions (level of helium in the tank, etc...)
- **Regulation of the helium flow** in the "Current Leads" as a function of the magnet current
- Information **exchange between MCS** and other sub-systems such as vacuum or cryogenic installation
- **Monitoring of all critical parameters** in the coil (temperatures, strain gauges, displacement...)
- Calculation of non linear sensor correction



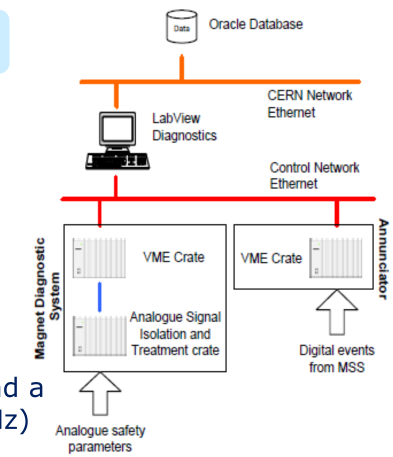
- ❑ Schneider PLC
- ❑ WinCC OA - SCADA
- ❑ UNICOS framework
- ❑ **I/Os for 4 experiments**
  2754 Analog Input
  48 Analog Output
  860 Digital Input
  320 Digital Output

MSS Magnet Safety System

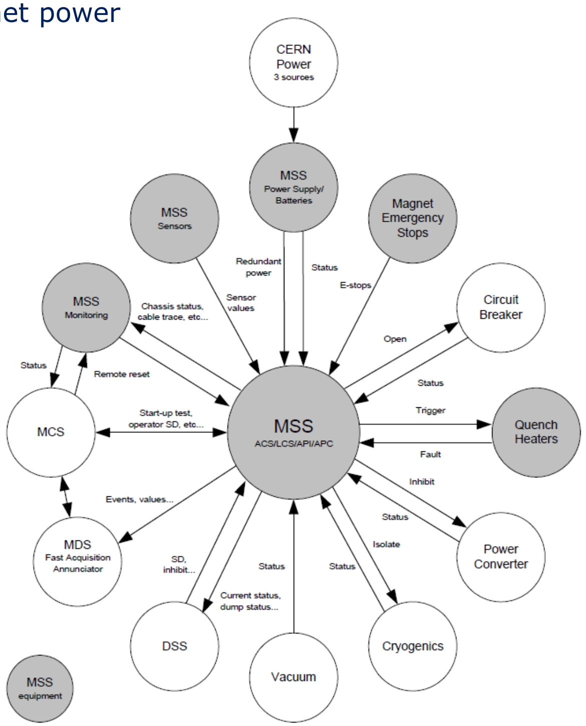
Magnet Safety System - Continuously running at CERN since 6 years, development started in 1998

Home made, no industrial systems available on the market.

- **Main purposes:**
  - **Protect** LHC experiment magnets (ALICE, ATLAS, CMS, LHCb)
  - **Interact** with LHC machine
  - **Identify** a causes of an abnormal magnet stop:
    - The **Annunciator** is a *fast digital data` acquisition* with a resolution of 1ms
    - The **Magnet Diagnostic System** (MDS) is a *slow data acquisition* at a rate of 1Hz and a post-mortem file after a magnet quench (1mn before and 5mn after at a rate of 100Hz)
  - **Magnet control -** continuous measurements => analyse => send orders to magnet power supply, cryogenic and quench heaters



- **Main system components:**
  - **An Analog interface ACS** containing the safety measurement channels, deciding whether a safety parameter has been exceeded, thus generating an alarm. Detections are made with **3 purpose-built signal condition modules:**
    - A dual/differential voltage detection module - DVM
    - A dual bridge measurement module -DBQD
    - A dual resistive measurement module - DRM
  - **A logical decision unit LCS** determining the current machine status based on received parameters and alarms. The main electronic card of this unit is the Hard-wired Logic Module based on **ALTERA FPGA**.
  - **An application interface API/APC (DI/DO interface)** between the logic unit and the actual machine which is the magnet with services. This interface controls main breakers, quench heaters, power converter, etc.



MSS2 Magnet Safety System 2

Why MSS2 needed?

- Some **components are obsolete**
- **Simplification required** to comply with any magnet type (superconducting or warm magnet)

What's NEW?

- **Replacement of Altera FPGA by a Compact RIO from National Instruments**
  (This industrial unit is a reconfigurable embedded system containing a **processor running a real-time operating system** (RTOS), **FPGA**, and **interchangeable industrial I/O modules**.)
- Simplified structure:
  - Design of new Analog cards
  - Treatment of Analog signals (LCS) done in the Compact RIO,
  - Annunciator will be include in the Compact RIO Controller.

Where it will be implemented:

1st **M1**- detector electronic test stand with a beam and magnetic field

2nd **COMPASS** experiment

DSS Detector Safety System for NA62

Detector Safety System for NA62

Purpose: ensure the protection of the experiment's equipment

Requirements:

- Reliable, simple, robust, and 100% available.
- Able to take immediate action to protect equipment.
- **Maintainable** over the lifetime of the experiment.
- **Flexible** and easily configurable.
- Supervised via **WinCC OA**

Innovative solution:

- **Replace** LHC Solution by **National Instruments cRIO**

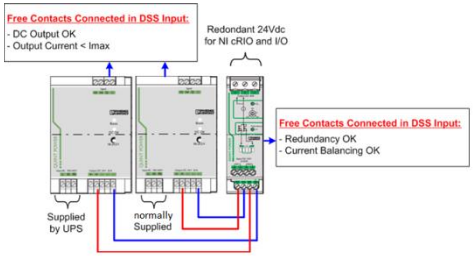
✓ As cRIO is FPGA based there is no need of redundancy => **cost reduction**

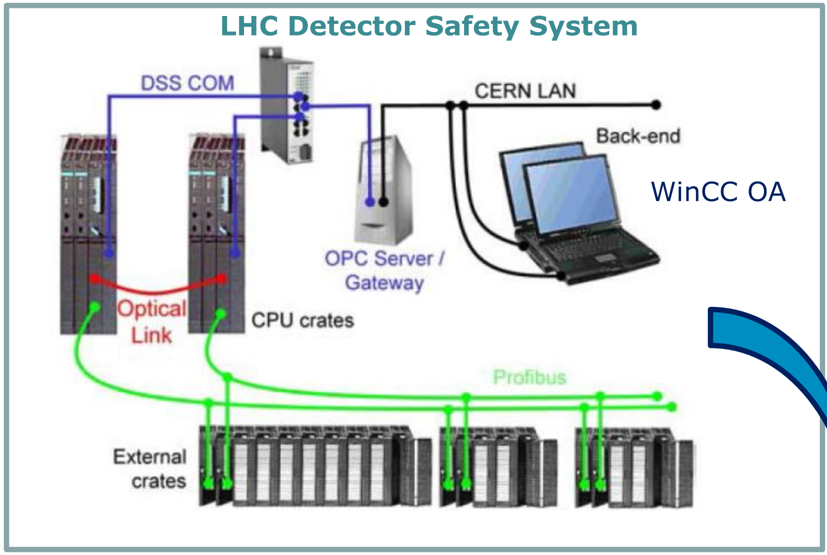
✓ **Development time reduction** =>indeed only safety matrix programming is needed

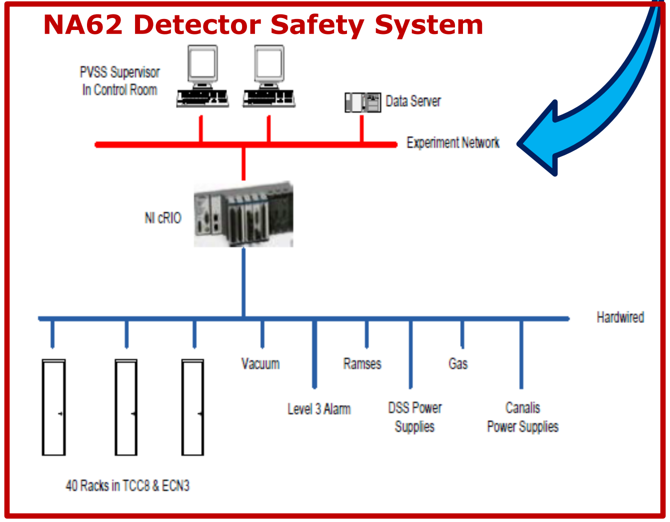
✓ **Faster process treatment** (less than 1ms, i.e. around 20ms for the PLC).

The safety matrix in the cRIO controller is programmed in an FPGA and the **data exchange with the supervisor is made with a real time processor** via a communication bus (Modbus TCPIP). Thus any communication problem between the supervisor and the real time processor of the cRIO does not affect the safety system.

24V DC Redundant power supply

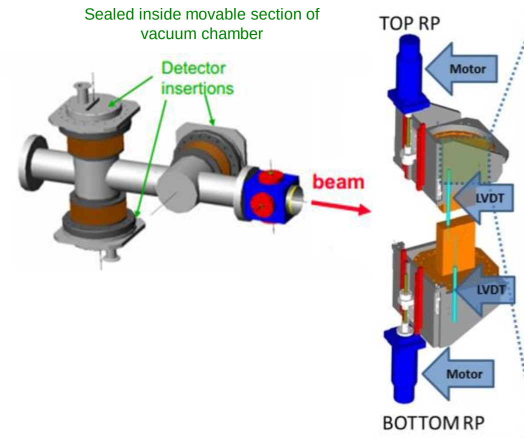






Roman Pots at LHC

Roman Pots at LHC –movement control system for detector positioning



Used for: ATLAS-ALFA and TOTEM

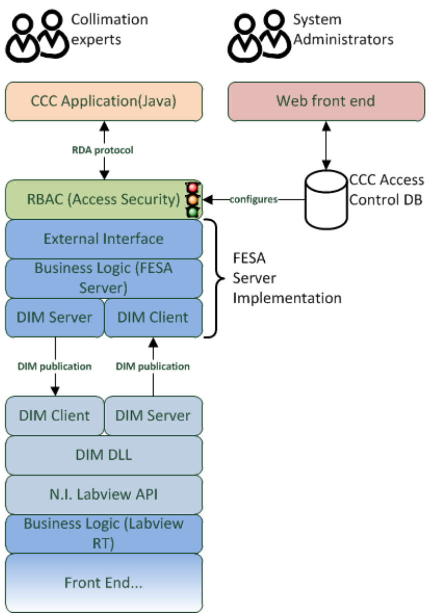
Purpose: ensure and survey detector position every 20ms with accuracy of 15um

Requirements:

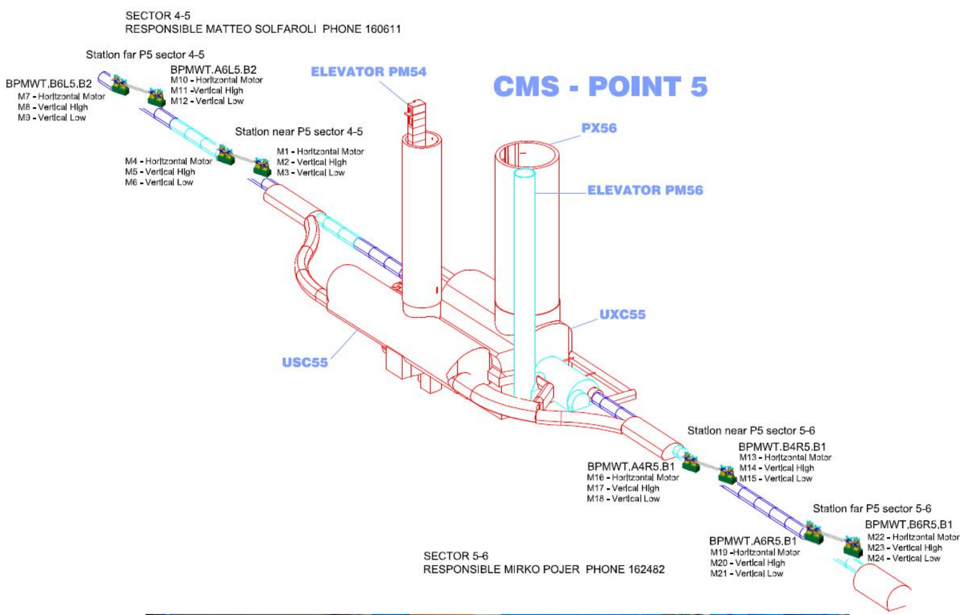
- If detector move too close to the beam, detector safety system sends the interlock signal to the LHC to triggers **the beam dump**.
- Control has to be considered as a **subset of LHC collimation control**
- **HMI interface** has to be integrated with LHC CCC
- When there is beam in the machine, the Roman Pots should be limited to their retracted position for all machine modes except for **Stable Beams**.

Solution:

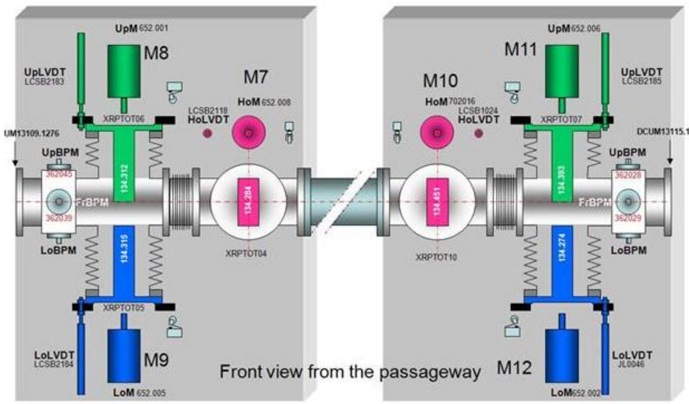
- Each pot is moved using a **step counting motor**
- Position information is provided by means of **stopper switches** and Linear Variable Differential Transformer LVDT
- **A tensioned spring** attached to each Roman Pot and compensation bellows connected to the beam vacuum provide a simple means of pot retraction
- **FPGA cards housed in a PXI crate** handle interlock decisions based on the readout from the switches and LVDT.
- Software running on a **PXI Real Time** (RT) controller controls the stepper motor and communicates with the FPGA cards to feed back position and status information to the upper control system layers.
- Note that the **FPGA** cards make interlock decisions and execute corresponding actions **autonomously;** they have no dependency on the software running in the RT controller.

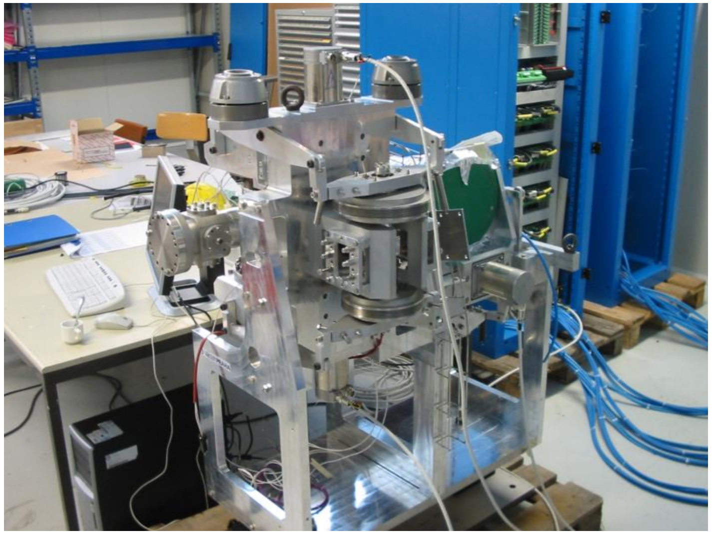


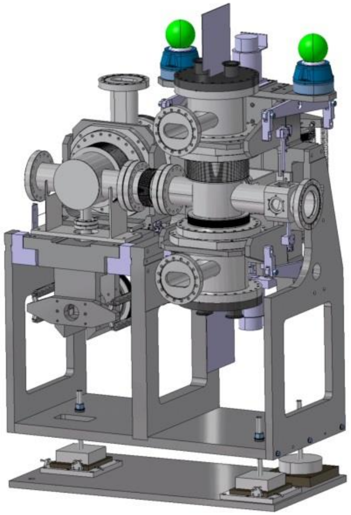
Roman Pots at LHC - TOTEM



TOTEM







Conclusions

On the road ahead would be good, both from the technical aspects (new technologies) and projects:

- Try always to use standard industrial components if fulfils your requirement
- Try to develop a standard framework suitable for Your organization, it will safe a time on development and simplify maintenance
- Collaboration with industry on the custom software development for their equipment can be a success

References:

- L.Zwalinski, J.Daguin, J.Godlewski, J.Noite, M.Ostrega, S.Pavis, P.Petagna, P.Tropea, B.Verlaat
  "***THE CONTROL SYSTEM FOR THE CO2 COOLING PLANTS FOR PHYSICS EXPERIMENTS***" ICALEPCS 2013
- B. Farnham, S. Ravat, F. Ravotti, M. Deile, P. Fassnacht, O.O. Andreassen, I. Atanassov, J. Baechler, B. Copy, S. Franz, S Jakobsen, F.L. Rodriguez, X. Pons, E. Radermacher, S. Redaelli, M. Dutour
  "***A MOVEMENT CONTROL SYSTEM FOR ROMAN POTS AT THE LHC***" ICALEPCS 2013
- S. Ravat, X. Pons, L. Deront, A. Kehrli
  "***A SAFETY SYSTEM FOR EXPERIMENTAL MAGNETS BASED ON COMPACTRIO***" ICALEPCS 2013
- G. Maire, A. Kehrli, S. Ravat
  "***THE DETECTOR SAFETY SYSTEM OF NA62 EXPERIMENT***" ICALEPCS 2013
- G. Maire, A. Kehrli, M. Pezzetti, S. Ravat
  "***EVALUATION AND IMPLEMENTATION OF ADVANCED PROCESS CONTROL WITH THE COMPACTCRIO MATERIAL FROM NATIONAL INSTRUMENTS***" ICALEPCS 2013
- G. Maire, G. Olesen, E. Sbrissa
  "LHC Experiments "Magnets Control Project" MT 19 - Session: Protection System; Program Number: THA03PO07