LHC Cryogenics control
Technologies and industry relationships

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Objectives

– Introduce the technical choices done in the LHC cryogenics control system

– Return of experience on the established links with industry

– Illustrate a use case of *technology transfer* and their possibilities when developing control systems

Outline

- LHC Cryogenics control system
- Technical choices (Standardization)
- Industry links
- Use case: Simulation
- Conclusions

LHC Accelerator

World Largest accelerator

27km length
100m underground

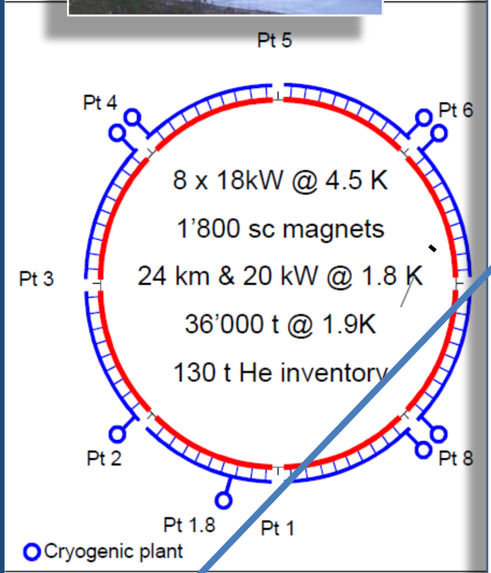
Thousands of Superconducting magnets
(1.8 x 10^9 km of superconducting filaments)

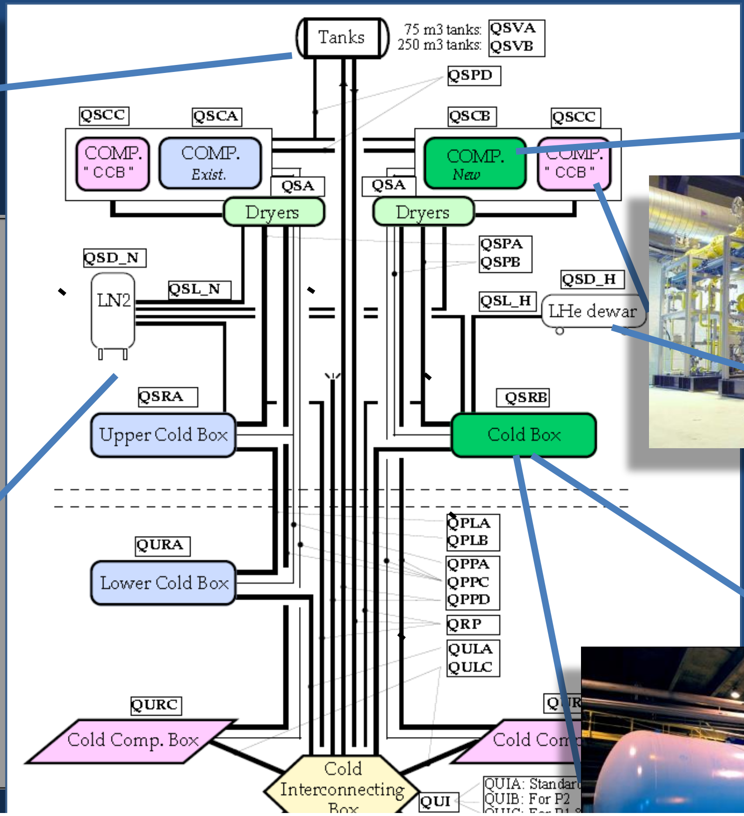
Coldest place in Universe:

-271° C

LHC Cryogenics

helium storage



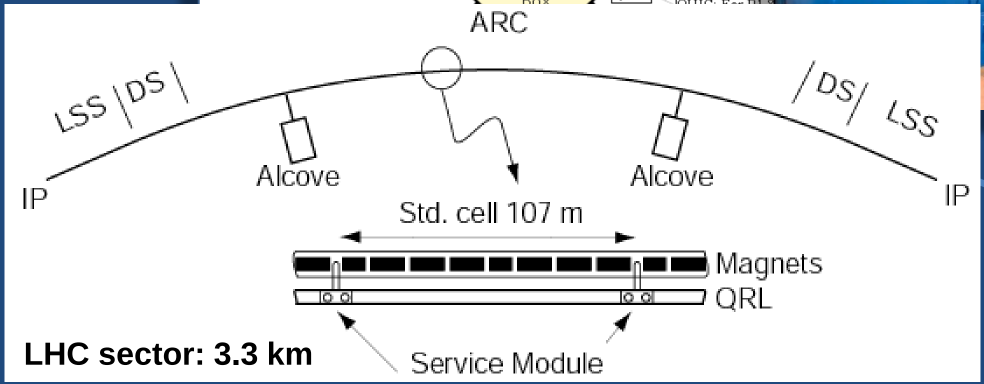


compressor stations

liquid helium storage

cold boxes

liquid nitrogen storage



LHC sector: 3.3 km

helium transfer line

Control challenges

- One of the CERN goals: maximize uptime of the instruments (accelerators, detectors,…) in order to optimize **physics data** availability

- This objective implies the maximum **availability** and optimal operation of all the auxiliary/utilities systems (e.g. cryogenics, cooling, HVAC, gas, motion, interlocks,…) -> the correspondent **control systems** must ensure this.

- What is uncommon at the LHC cryogenics control system?
  - Environment (radiation areas)
  - Large systems (highly distributed)
  - Complexity (control logic)
  - Precision (measurements)
  - Performance (regulation)

LHC cryogenics control : facts

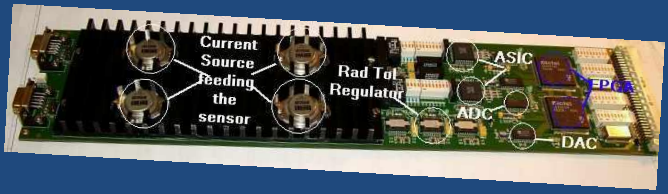
WinCC OA HMI in the CCC

- 27 km of decentralized instrumentation and control
- 50k I/O, 11k actuators, ~5k Control loops
- Control: ~100 PLCs (Siemens, Schneider),
  ~40 FECs (industrial PCs)
- Supervision: 26 SCADA servers : 1.5 million TAGS

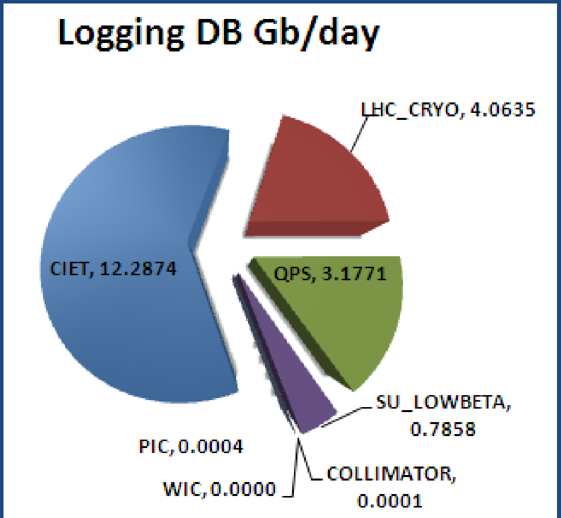
Electro-pneumatic positioner, SIPART PS2

Instruments	Range	Total
TT (temperature)	1.6- 300K	9500
PT (pressure)	0-20 bar	2200
LT (level)	Various	540
EH (heaters)	Various	2500
CV (Control Valves)	0 - 100 %	3800
PV/QV (On Off Valves)	--	2000

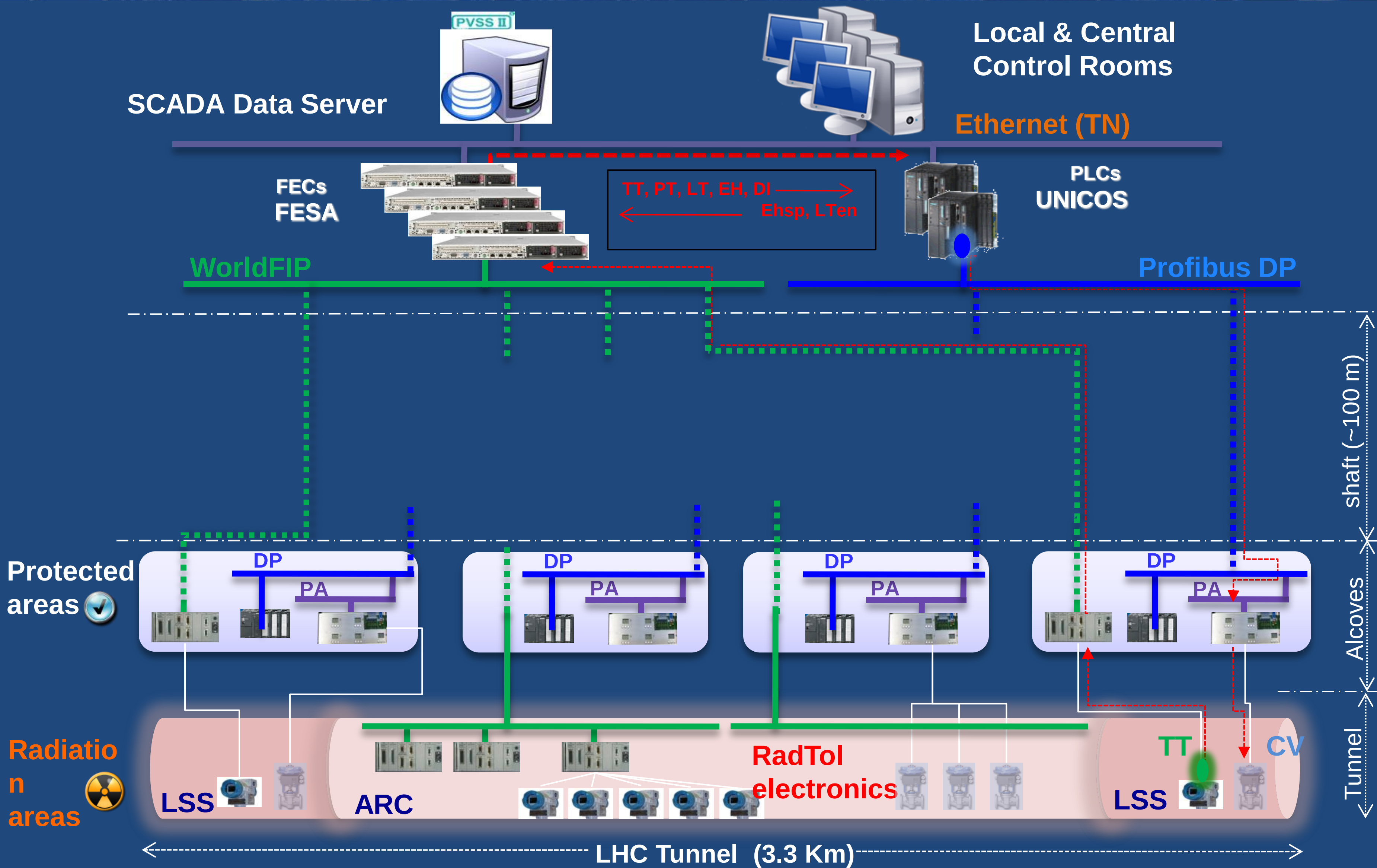
Tunnel Instrumentation



RadTol in-house electronics for signal conditioning and actuation



LHC cryo control: A sector architecture



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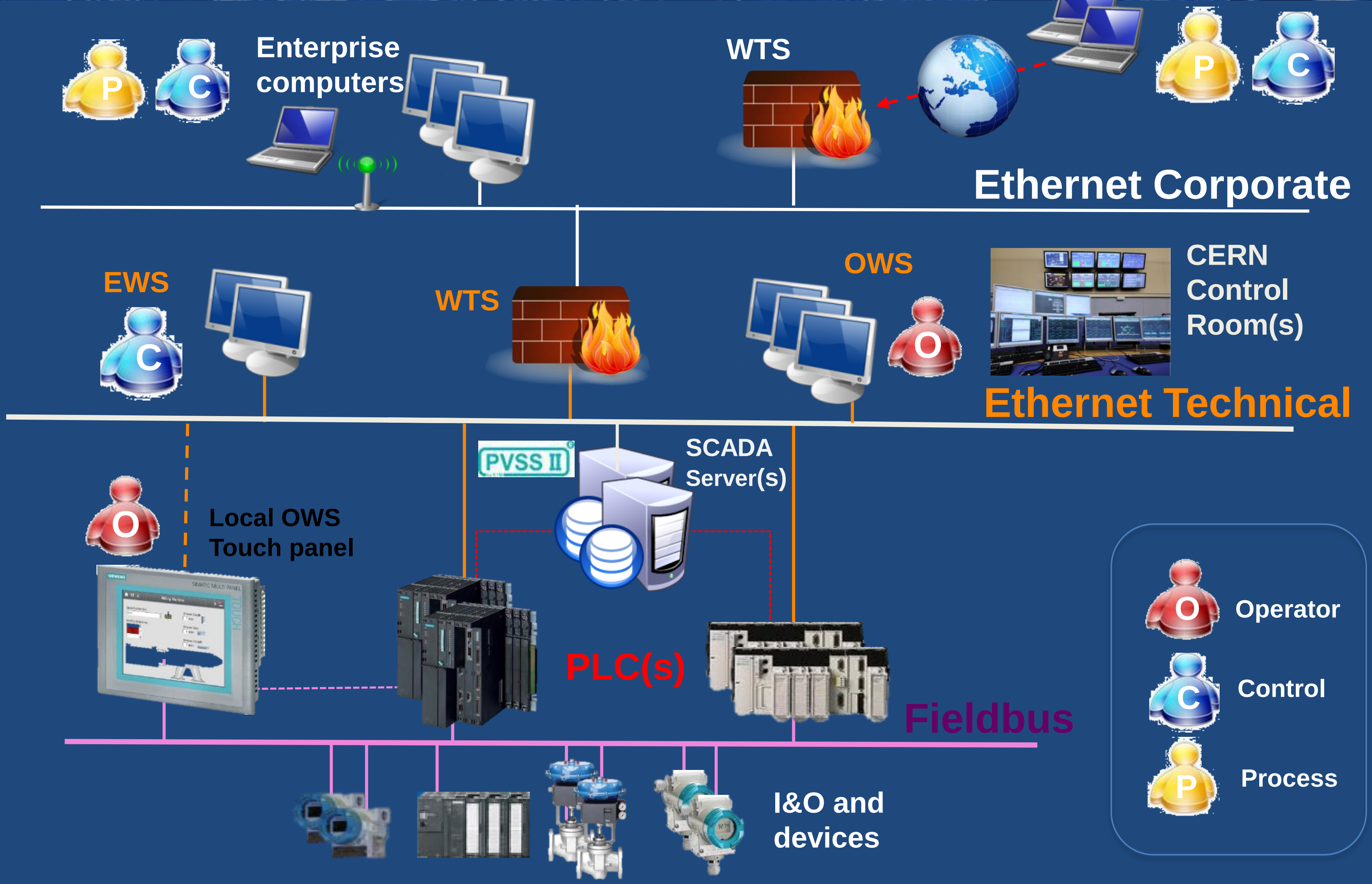
Industrial COTS

- SUPERVISION, Visualization and programming
  - SIEMENS WinCC OA (PVSS) SCADA (standard)
- CONTROL
  - SIEMENS, Schneider (standards)
  - Industrial PCs: SIEMENS IPC, Codesys
- FIELD LAYER
  - Industrial instrumentation: Sensors, actuators
  - Industrial customized actuators: Profibus PA positioners
  - Virtual instrumentation: VFT (flowmeters)
- COMMUNICATIONS
  - Fieldbuses: Profibus, WorldFIP, CAN (CERN standards)
  - Ethernet based: Profinet, Ethernet/IP

WorldFIP
EtherNet/IP
CANopen
CoDeSys
PROFINET
SIEMENS
PROFIBUS
Schneider Electric
SIMATIC
WinCC Open Architecture

Standard architecture

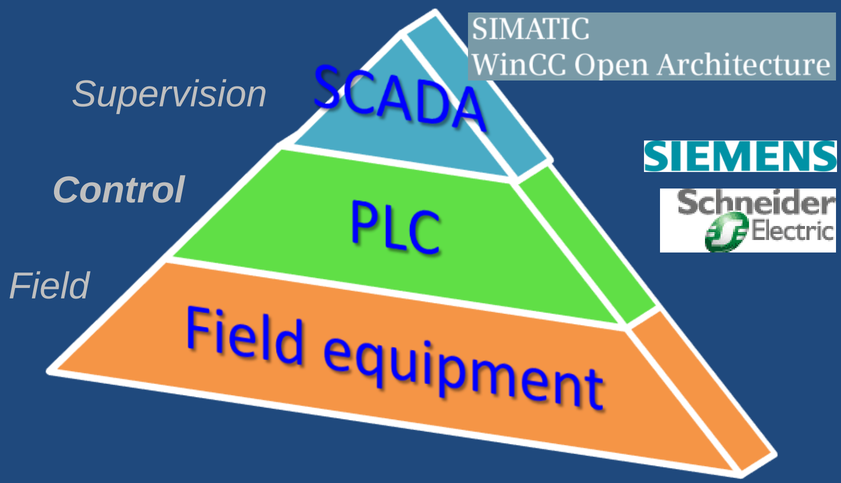


Creating standards: UNICOS

- **UNICOS** (**UN**ified **I**ndustrial **C**ontrol **S**ystem) was born at CERN as a need to develop the LHC cryogenics control system

- Framework composed of
  - Generic set of reusable devices
  - Analysis and Development method
  - Programming structure

- Based on industrial standards
  - ISA-88 / IEC-61512: Batch control
  - IEC-61499 : Distributed systems



- UNICOS benefits
  - Development (Homogenized applications)
  - Maintainable code (Original developer is not critical)
  - Unified operation in control rooms

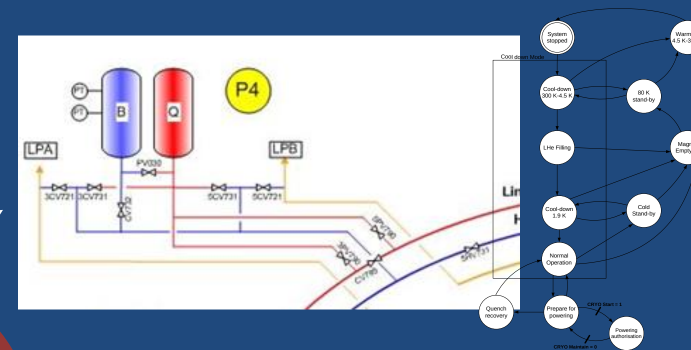
Facilitate the task of the automation engineer by allowing him/her in focusing only in the automation duty and not in the software production itself.

UNICOS Overview

I/O Channels

Field Objects *(Valves, Pumps, …)*

Process Control Objects *(Compressors, feedbox, …)*



Instances

Specifications

Logic

UNICOS

Additional services:
CMW interface
Long-Term archiving
LHC alarm system

PLC and SCADA Baseline

Instance Generator

Logic Generator

PLC and SCADA Instances

Diagnostics tools
System Integrity

Precise placeholders where the control engineer must write the process logic either automatically or manually

Standard HMI tool to create process synoptics (drag & drop)

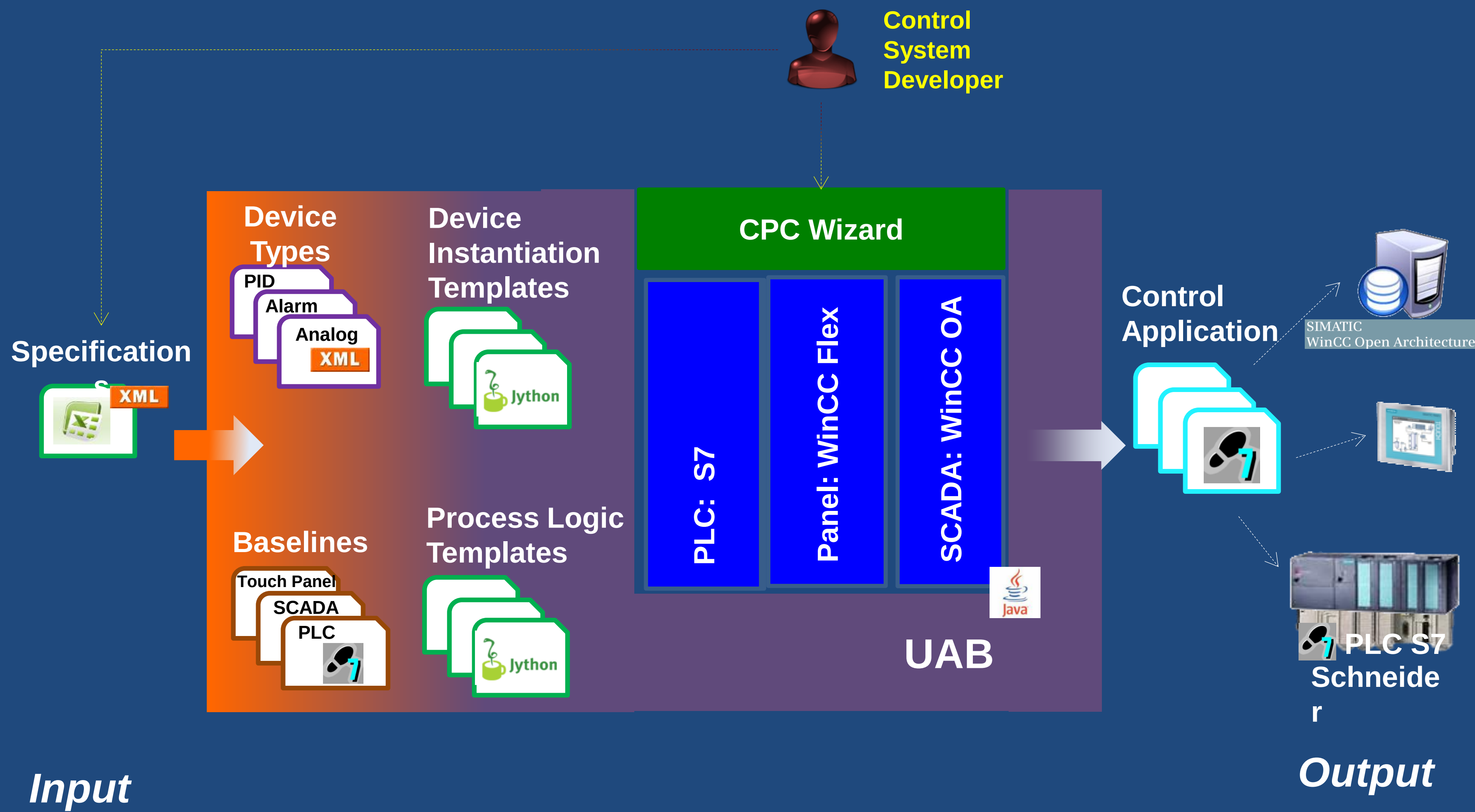
O Operator

C Control

P Process

Automatic code generation

UAB: UNICOS Application Builder



UNICOS is a CERN de facto standard

Cryogenics
- LHC accelerator & Detectors
- Experimental areas
- FRESCA2: Nitrogen

Cooling & HVAC
- Tunnels and caverns ventilation
- Machinery cooling
- Control rooms air conditioning

Interlocks
- LHC Collimator Temperature Interlocks

Motion
- ATLAS big wheels
- HTS winding machine
- AMS beam test servo systems
- LHC Elevators

Gas systems
- LHC Detector Gas
- Linac 4 hydrogen supply
- CO2 cooling plants
- CLOUD

Vacuum
- ISOLDE
- REX
- LHC Detectors: ATLAS, CMS

Detector Controls
- Magnet Control system
- ECAL detector cooling
- CMS tracker thermal screen
- ALICE Cooling water valves

Outline

1. LHC Cryogenics control system
2. Technical choices (Standardization)
3. Industry links
4. Use case: Simulation
5. Conclusions

Experience with suppliers

- More than 12 years of experience with market leader suppliers
  - There is not a perfect supplier but a satisfactory supplier
  - Lack of competition between suppliers is not healthy… as long as you can afford it.
  - Despite being a rather conservative technology segment, the supplier must follow tendencies
  - A strong and reactive technical team must be behind the curtains
  - Key is not having a supplier but a **partner**

Industrial Partners

Integrators: GTD Systems and Software Engineering

- LHC cryogenics project (initial budget ~ 6 MCHF)
- First implementation of the software framework

Others involved along the project:

- Siemens, Schneider, Arc Informatique, ETM

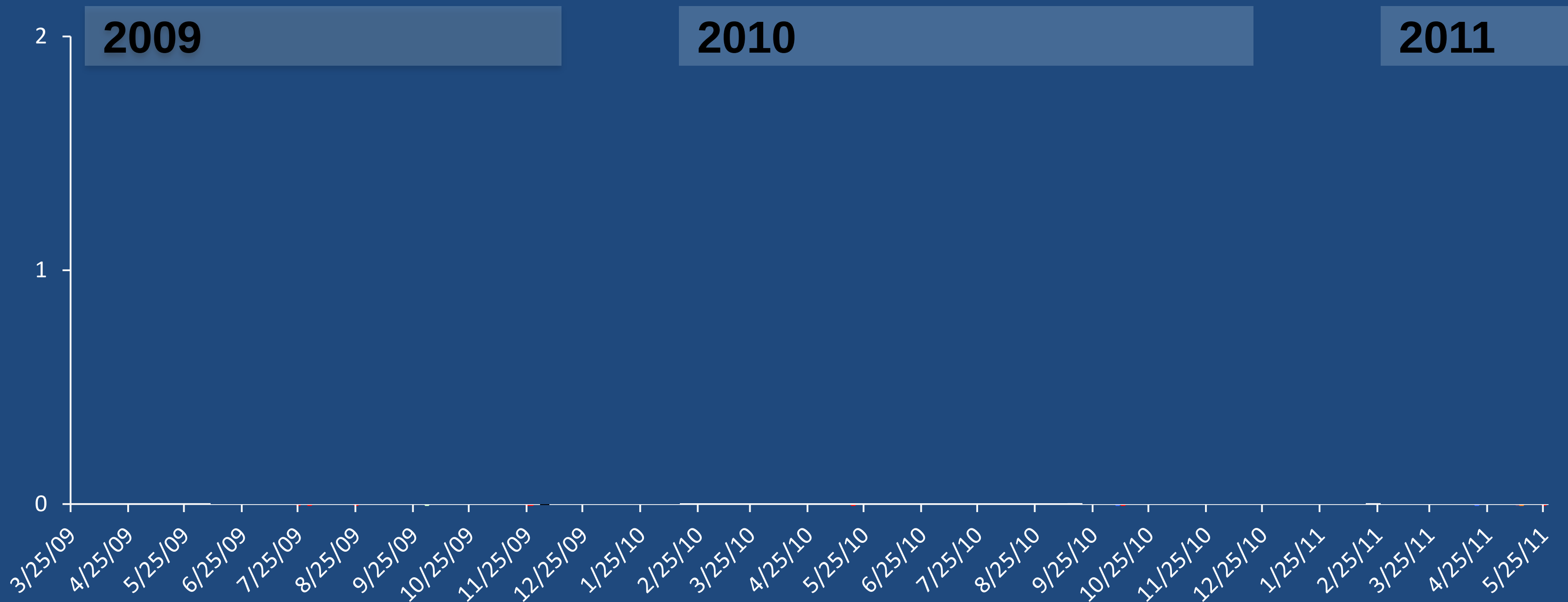
CERN Suppliers: SCHNEIDER & SIEMENS*

- Not simply suppliers but partners: Collaboration
  - Annual meetings at CERN and their headquarters
  - Technology roadmap
  - CERN requirements (limitations, missing functionalities,…)
  - Beta testers: e.g. TIA portal, M580, Ethernet/IP

*Reinforced by the presence of SIEMENS (and ETM) in the Openlab.

Fast troubleshooting

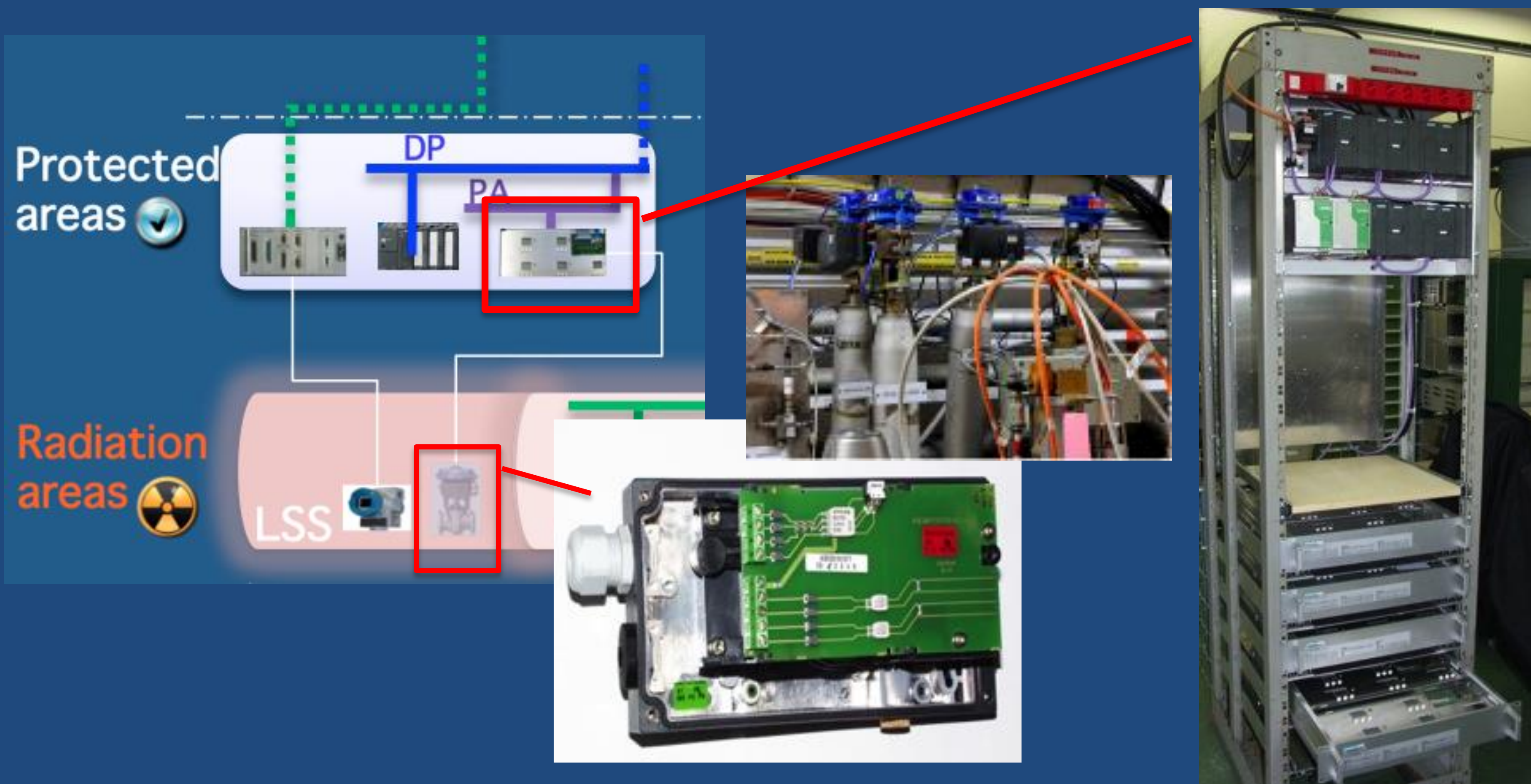
2009-2011 PLC CPU Schneider failures



- **Known RAM default (6)**
- **SEU Suspicions (3)**
- **Coprocessor Error (1)**
- **No Explanation (1)**
- **Double connection to CPU (1)**
- **New TAG RAM writing (2 same CPU)**

Specialized HW developments

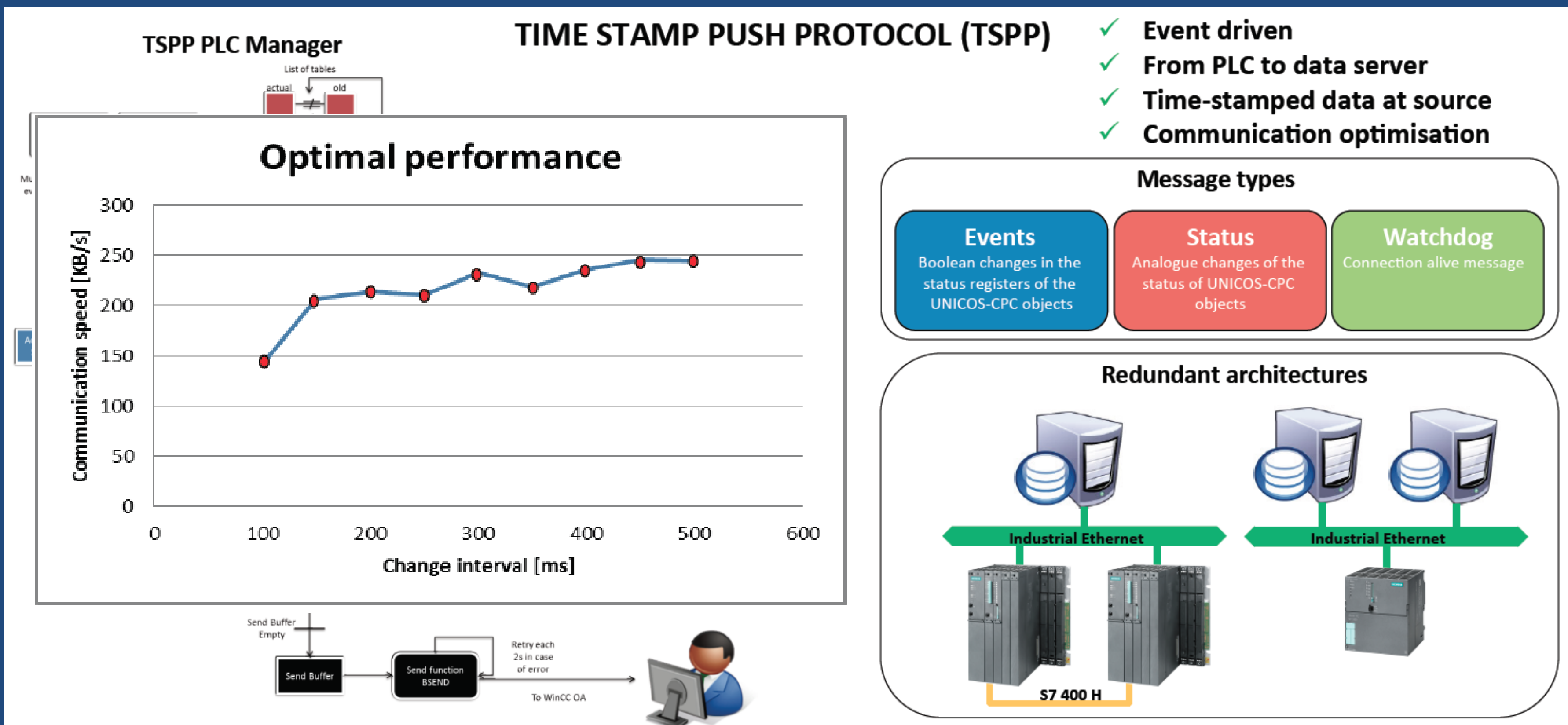
Innovation capacity to answer our needs
(e.g. SIPART positioners split in the tunnel by SIEMENS)



Specialized SW developments

Flexibility to answer our needs

Development of the TSPP (Time-Stamp Push Protocol) both in the Modbus and Siemens S7 drivers at the PVSS SCADA (ETM - SIEMENS)



Risk is always present

- **CENELEC** Standards are mandatory under European Commission directives for any applications in the European Union by state-owned and/or public utility companies.
  - *EN 50170, March, 1996 (Fieldbuses Standardization rules)*
  - Fieldbuses: P-NET, WorldFip and Profibus

- WorldFIP was selected at CERN because of the good performance of its nodes under radiation

  Deployed in many LHC installations:
  - Cryogenics, Power Converters, Quench Protection, Beam Instrumentation, Radiation Monitoring, Survey

- Alstom phased out WorldFip in 2009

- In-source the technology at CERN

Outsourcing

- **In-house**
  - My business is really different !!!
  - In-house technicians and engineers gets more knowledgeable about the plants
    - Incremental improvements
    - Troubleshooting problems
  - TCO: Total Cost of Ownership

- **Outsourcing**
  - Acquiring the skilled staff (no long-term commitments)
  - Replacing an individual is costless than in-house
  - Are you the appropriate partner?

Outsourcing

- A third concept: hybrid
  - Mission-critical engineering skills in-house
  - General purpose services outsourced

- Challenge
  - What is critical and what is general purpose?

- Outsourcing is possible but under certain conditions: **Hybrid** solution
  - Mission-critical stays at home (UNICOS framework)
  - Use clearly defined contracts (UNICOS projects)
    - Specifications
    - Standardization by frameworks
    - Deliverables reviewed by skilled in-house employees
  - Chose reliable and established providers (more than one!)

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Why Dynamic Simulation?

- Allows a better understanding of the process
- Dynamic process plant verification & optimization

Process Knowledge

- Offline tests of improved regulation (e.g. PID tuning)
- New control algorithms application (e.g. model embedded based)

Advanced Control

Training of operators

- Complex and critical plants do not allow training online
- High operator turnover requires appropriate training

Virtual Commissioning

Off-line commissioning reduces drastically the real commissioning effort

Process Knowledge : Cryogenics

- CERN developed a cryogenic library with the commercial simulation software **EcosimPro** (Empresarios Agrupados)
  - Cryogenic equipments modelled by DAEs. (Differential-Algebraic Equations)
  - Components: valves, HX, turbines, pipes, tanks, compressors, phase separators, ...

- Under a special Spanish programme of industry support to Science the library was the object of a technology transfer to EA International (2011)

18 kW @ 4.5 Refrigerators

Compressor station

Storage

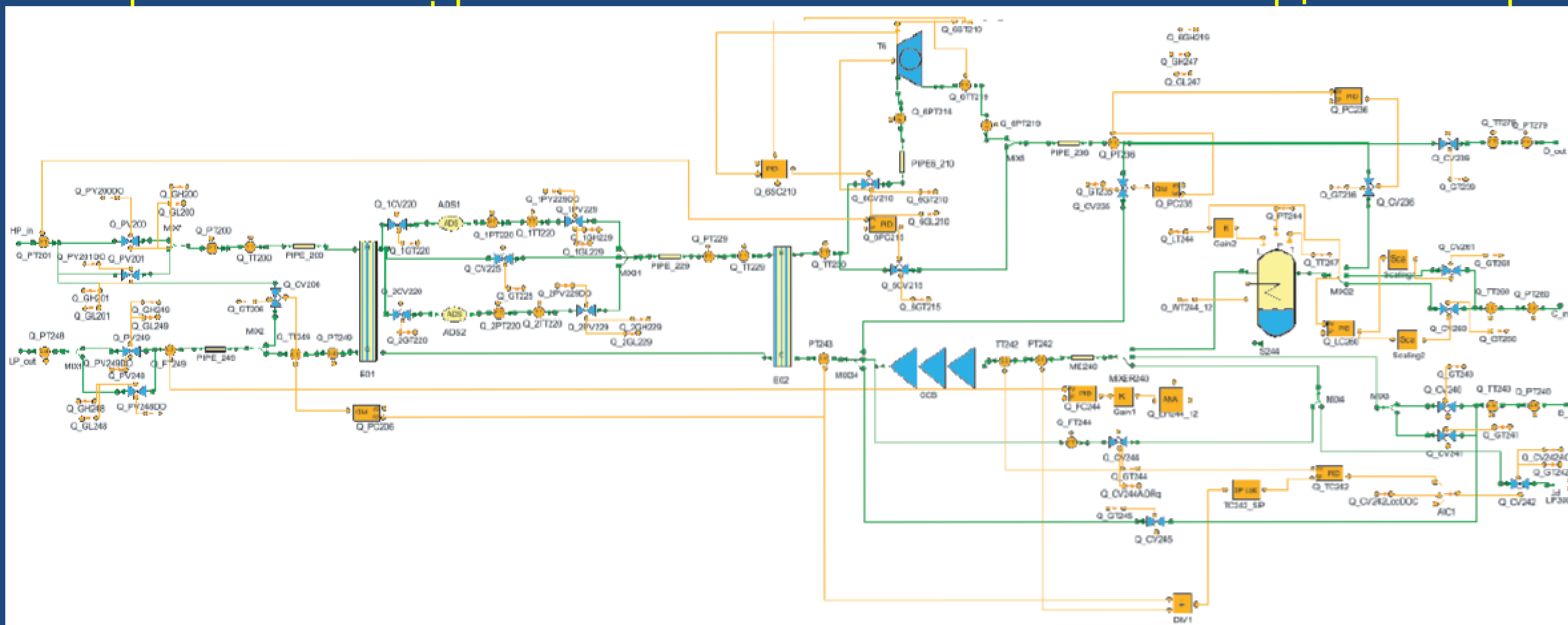
LHC Superconducting magnets

1.8 K refrigeration unit

Warm Compressors

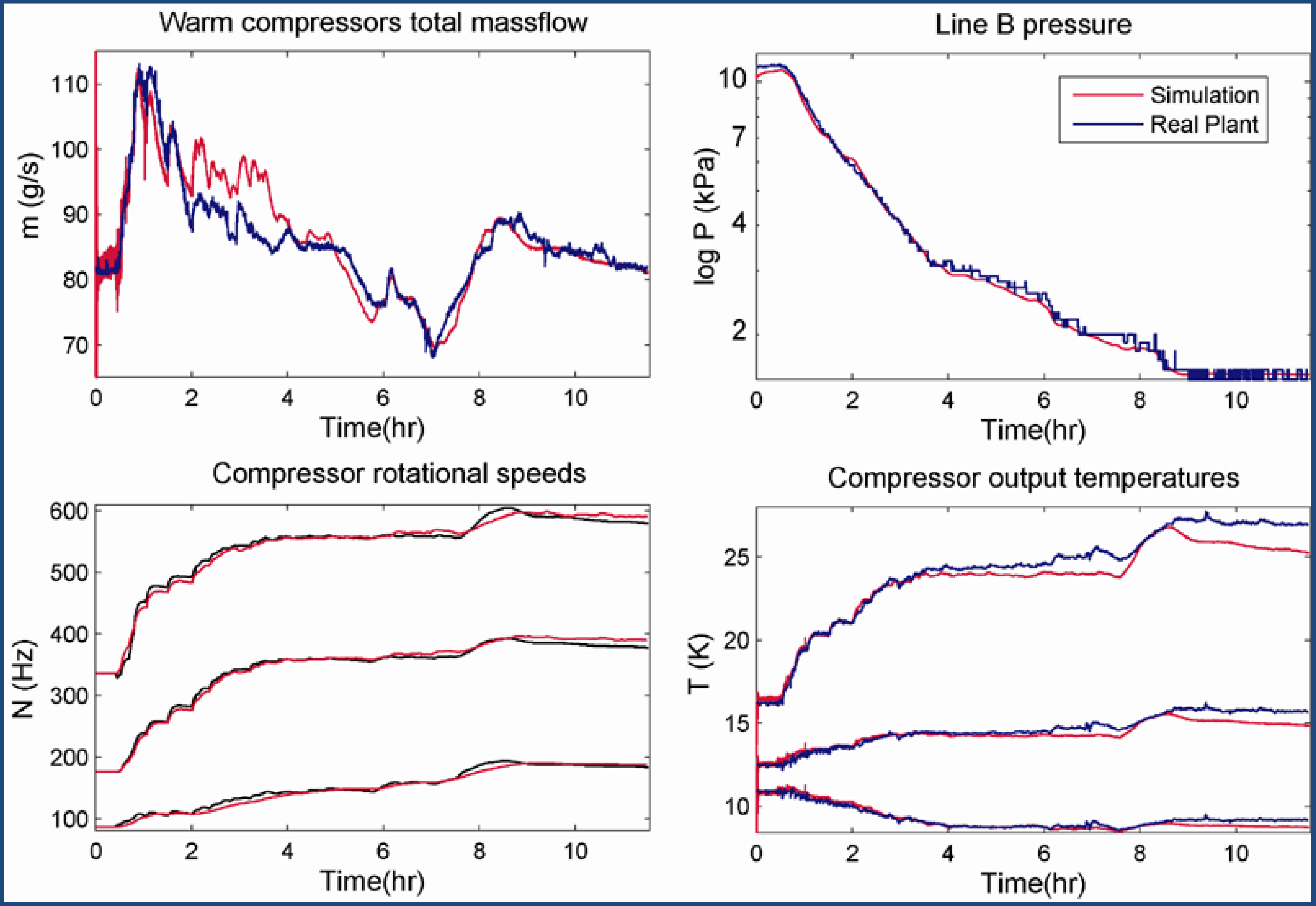
1.8 K Refrigerator

QUIC /QRL



Courtesy of Benjamin Bradu

Simulation results

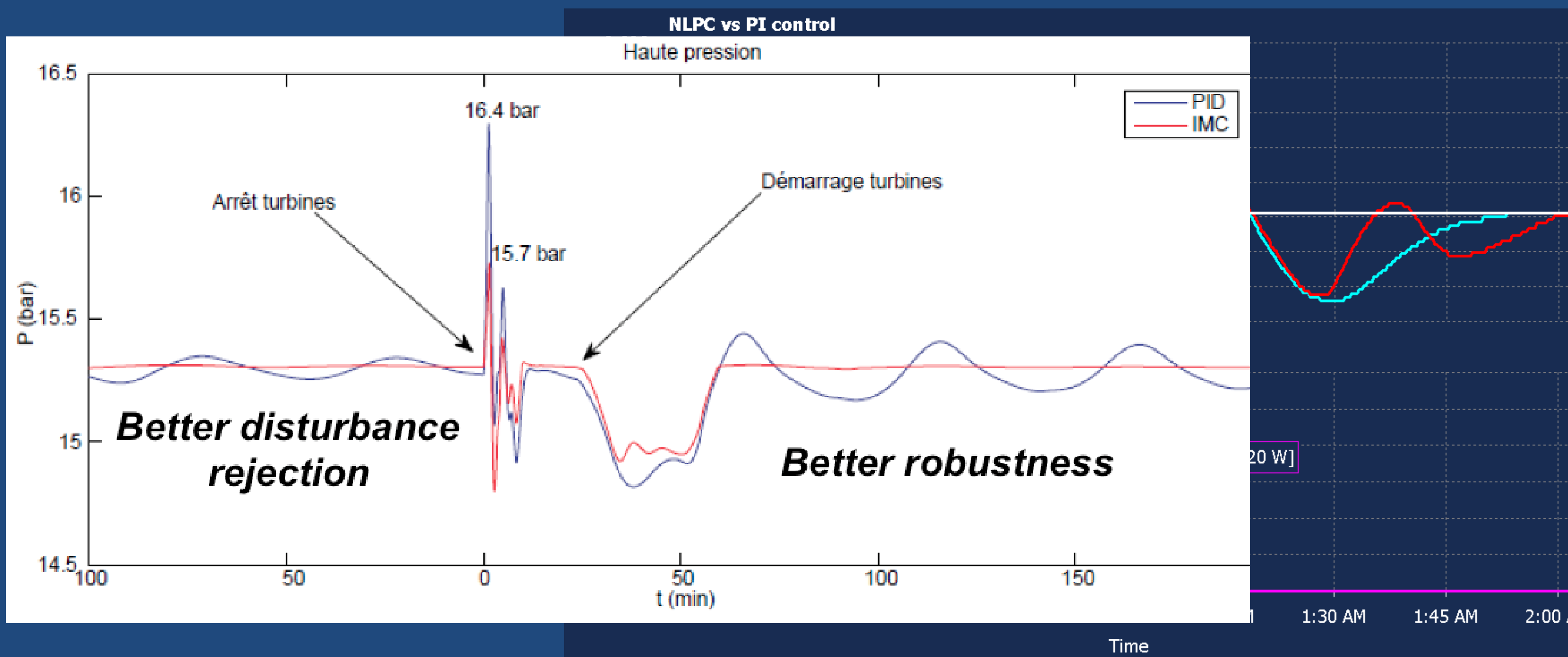


Courtesy of Benjamin Bradu

Feedback Control

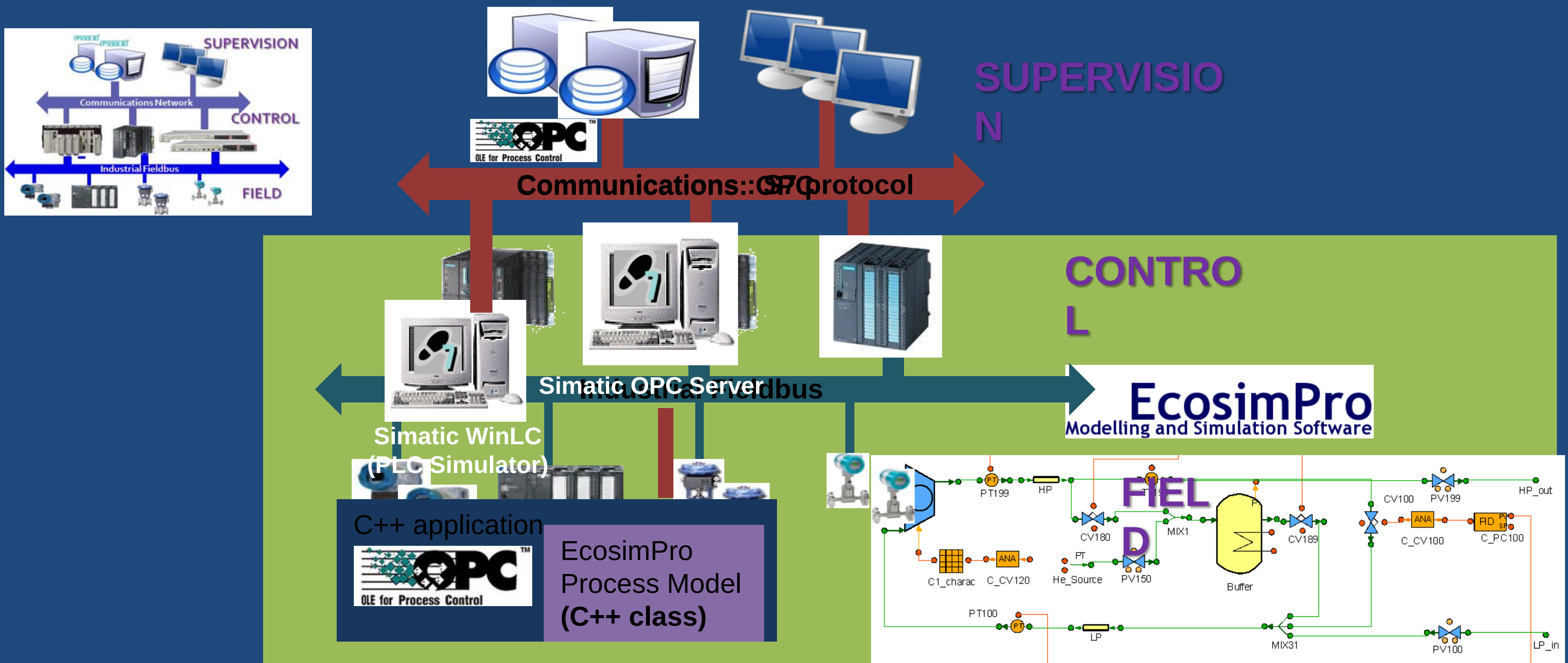
- Simulation is used to improve regulation algorithms (e.g. IMC vs PID) or just tuning of the controllers (e.g. PID tuning)

- Highly nonlinear processes, modeling and simulation is used to offline investigate the feasibility of advanced control algorithms (e.g. **Model based predictive control**)



Testing and Commissioning

- Standards
  - ANSI/ISA-62381-2011 (IEC 62381 Modified)
  - SAT and FAT activities are vital when delivering the final control system
- Virtual commissioning
  - Simulation techniques (static and dynamic)



CERN Industrial control architecture vs Simulation

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Conclusions

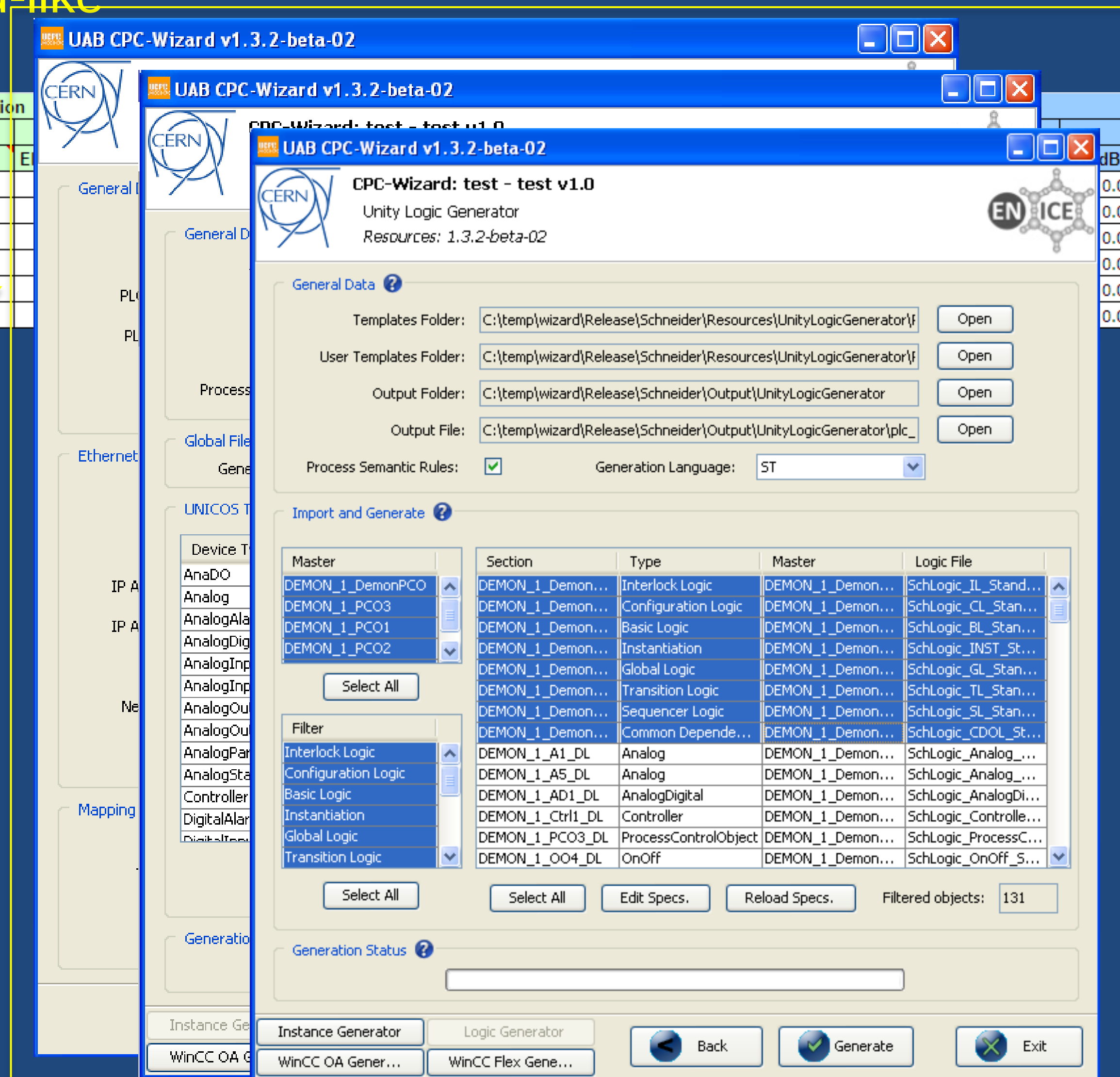
- LHC Cryogenics Control System
  - Heterogeneous large control system
  - Critical to the LHC availability
- Technologies
  - Industrial COTS use
  - *Standardization* by frameworks: UNICOS
- Industry
  - *Partnerships*
  - Outsourcing: Hybrid solution
  - Technology transfer: Simulation

Questions

Developing apps workflow

- The specification is device instance oriented
- The creation is wizard-like

DeviceIdentification	DeviceDocumentation
Name	Description
QSDN_4_1TT4001	Vessel 1- Heater section1-Temp. control
QSDN_4_AI1	SPARE
QSDN_4_1TT4002	Vessel 1- Heater section2-Temp. control
QSDN_4_1TT4003	Vessel 1- Heater section3-Temp. control
QSDN_4_1LE400	Vessel 1- LN2 Level
QSDN_4_1PT400	Vessel 1- LN2 Vessel Pressure



Training of operators

Types of Process Training Simulators (PTS):

- FSS : Full scale/scope simulators: replica of the CCR (Central Control Room)
- MFDS: Model Forward for Design Simulators. Only process but no the CCR environment.

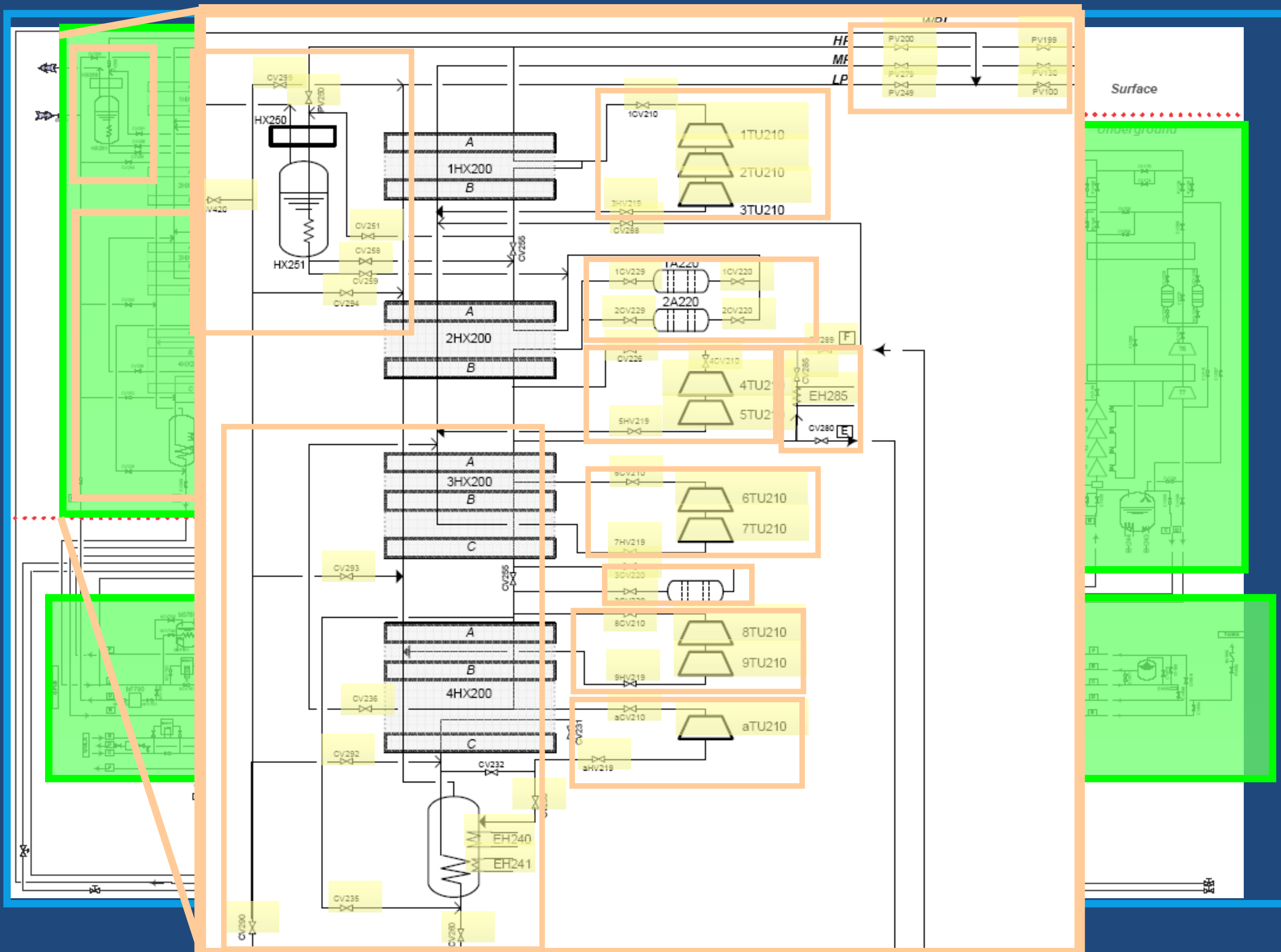
FSS becomes particularly useful:

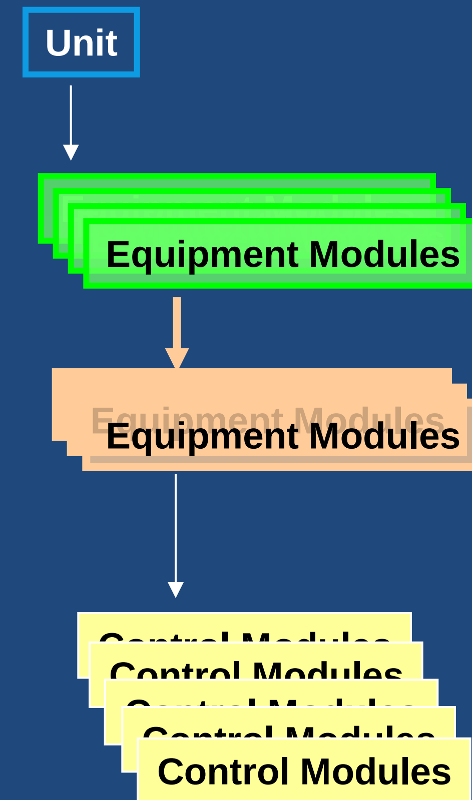
- Complex and critical plants do not allow “hands-on” on place
- High operator turnover requires appropriate training
- Long periods of shutdown (e.g. LHC 2013-14)

The operator sits in a “virtual” control room that emulates the real one. The experts/trainers can have full access to any action on the simulated process and may recreate malfunction or instruments failure to check the responsiveness of the operators.

CERN CRYO Virtual Control Room

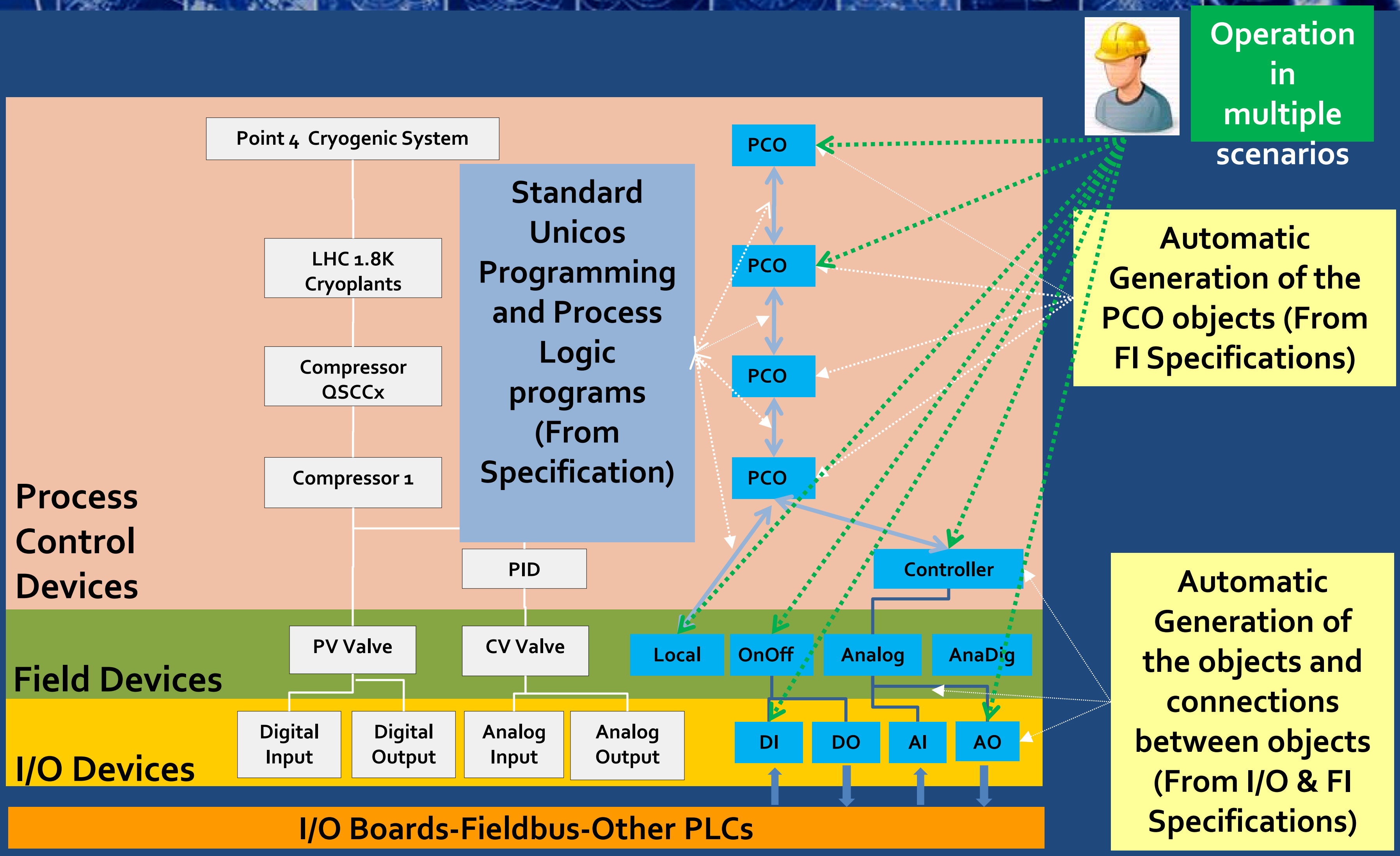
Process Analysis: Decomposition





IEC 61512-1
Physical model

Process vs. control Architecture



Control layers integration