Industrial Control at CERN

Academia-Industry Matching Event on the Mutual Impact of Industry 4.0 and High-Energy Physics

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Objectives

- Overview the **CERN organization** towards efficient Industrial controls
- Give a overview **Industrial Controls technologies** and their applicability to some **industrial control systems**
- **Advanced automation & Industry 4.0**

CERN (**C**onseil **E**uropéen pour la **R**echerche **N**ucléaire, 1954)

Yearly Budget

~1100 MCHF (~ 1000 MEUR)

Experiments financed externally.

Personnel

2500	Staff
1800	Fellows & Ass, Students
13000	Users
2000	External companies

22 Member states

Austria, Belgium, Bulgaria, Check Republic, Denmark, Finland, France, Germany, Greece, Italia, Hungary, Holland, Israel, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland, UK.

5 Observers states

EC, USA, Russian Federation, Japan, UNESCO

3 Candidate states

Serbia, Cyprus and Slovenia (pre-stage of membership)

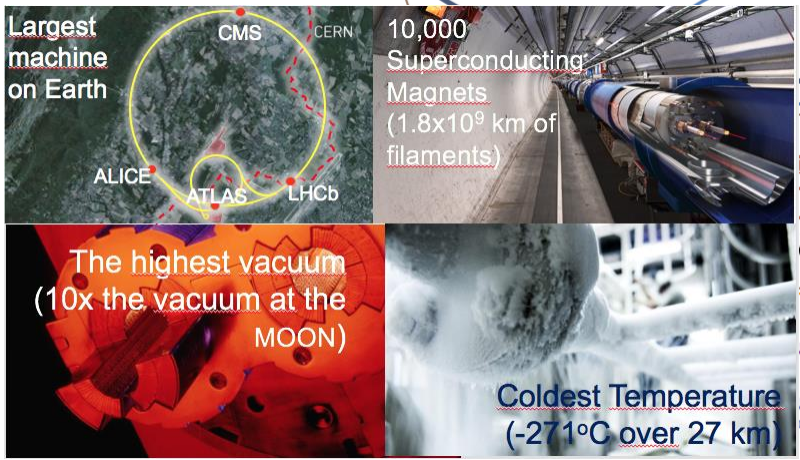
3 Associate states

Turkey, Pakistan, Ukraine and India

CERN instruments

Accelerators

Detectors



LHC

27km length

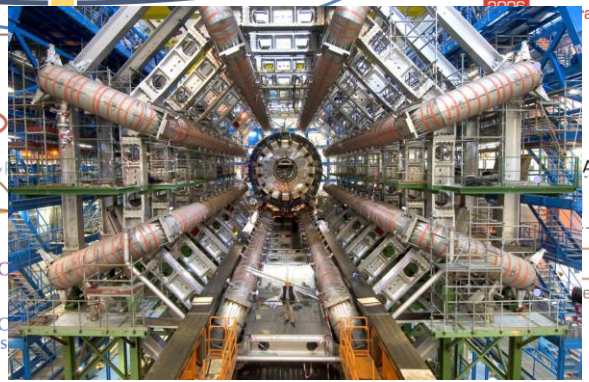
100m underground

> 1600 **Superconducting** magnets (1.8 x 10^9 km of superconducting filaments

Ultrahigh vacuum: **10^{-13} atm**

10x moon vacuum

Coldest place in Universe: ***-271° C***



ATLAS Detector

7000 tonnes, ~100 million read-out channels, 3000 km of cables

Contains 11 sub-detectors of different technologies in layer structure

Built and operated by collaboration of >3000 physicists

Industrial 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.

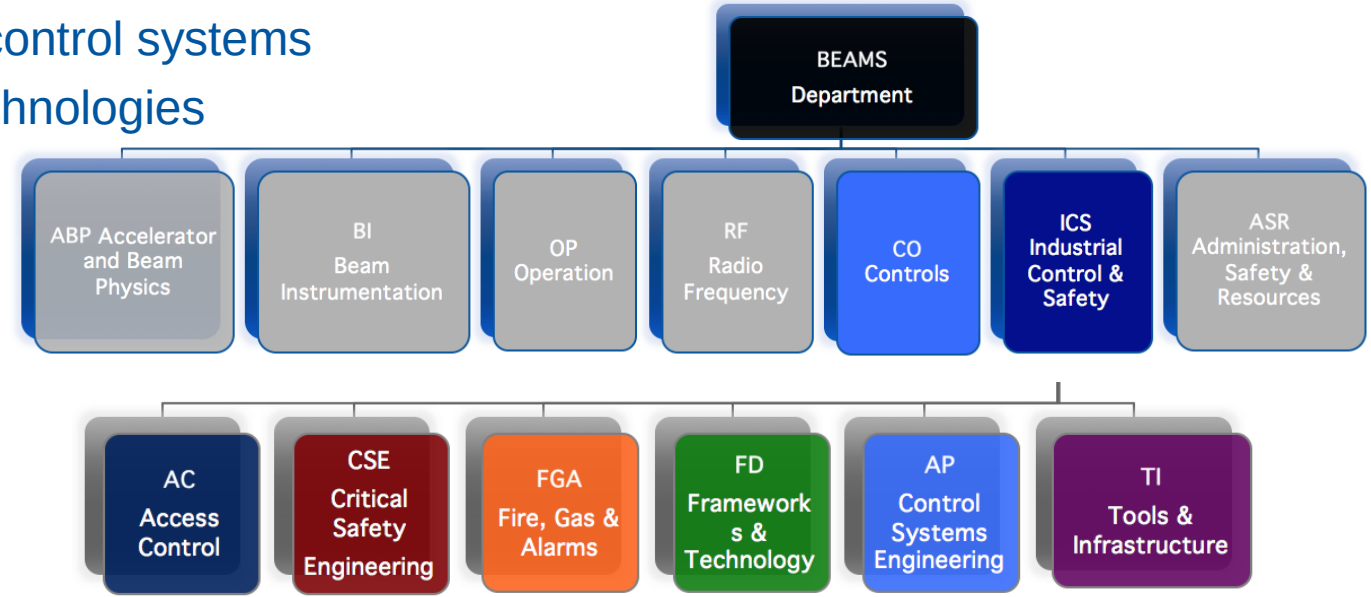
What is uncommon at the CERN accelerators control systems?

- Environment (radiation areas)
- Large systems (highly distributed and/or interconnected)
- Complexity (control logic)
- Precision (measurements)
- Performance (regulation)
- Data (number and frequency)

BE-ICS (Industrial Control & Safety Systems)

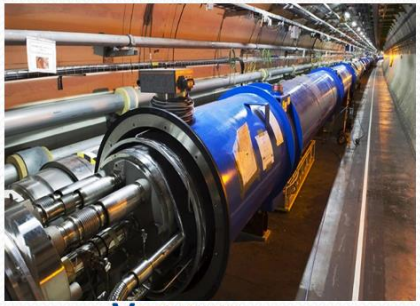
A **central group** for industrial controls serving the whole CERN community

- Development of frameworks
- Development of control systems
- Support basic technologies

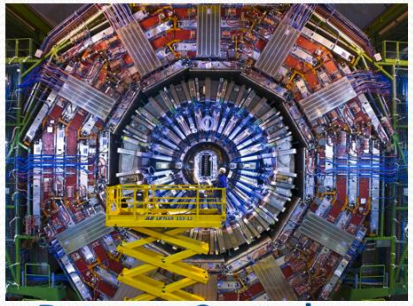


Control Systems at CERN

Cooling & Ventilation



Vacuum



Detector Controls

Electric Grid

Cryogenics

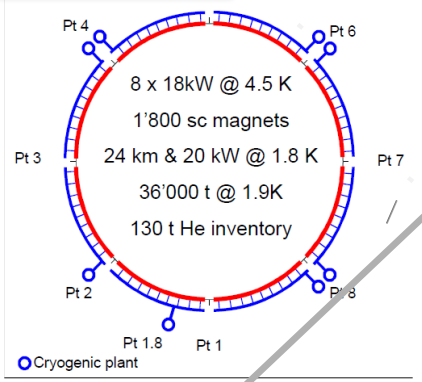
Gas Distribution

Environment & Radiation

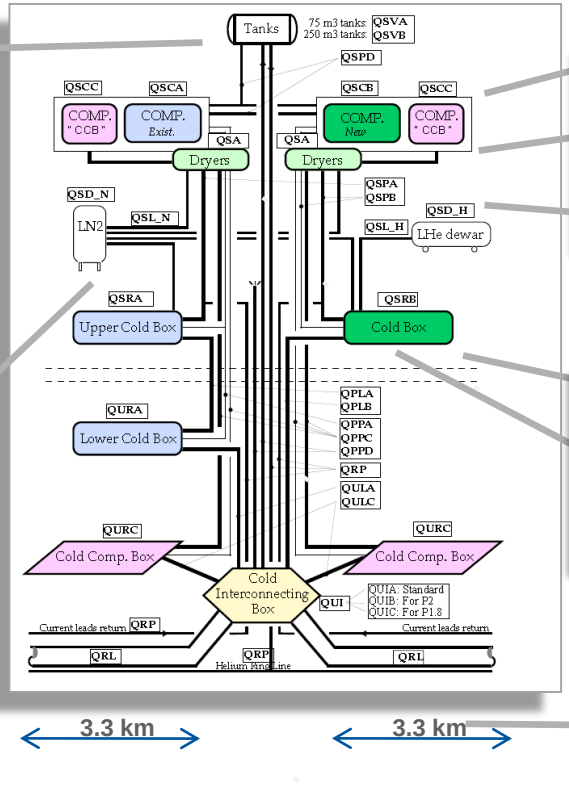
Interlocks and Safety

LHC Cryogenics (or the coldest place in universe! -271ºC)

helium storage



liquid nitrogen storage



compressor stations

liquid helium storage

cold boxes

helium transfer

LHC cryogenics control: Use case

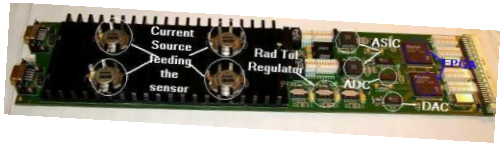
WinCC OA HMI in the CCC

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

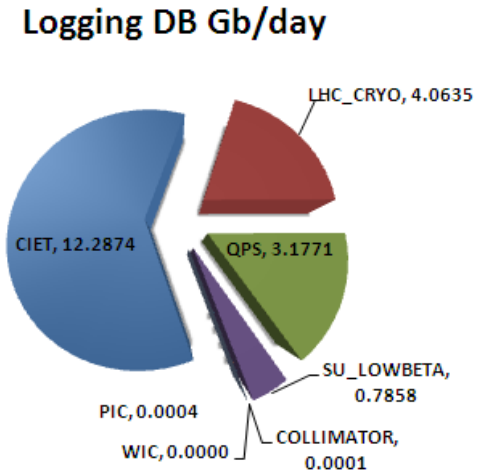
Electro-pneumatic positioner, SIPART PS2

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

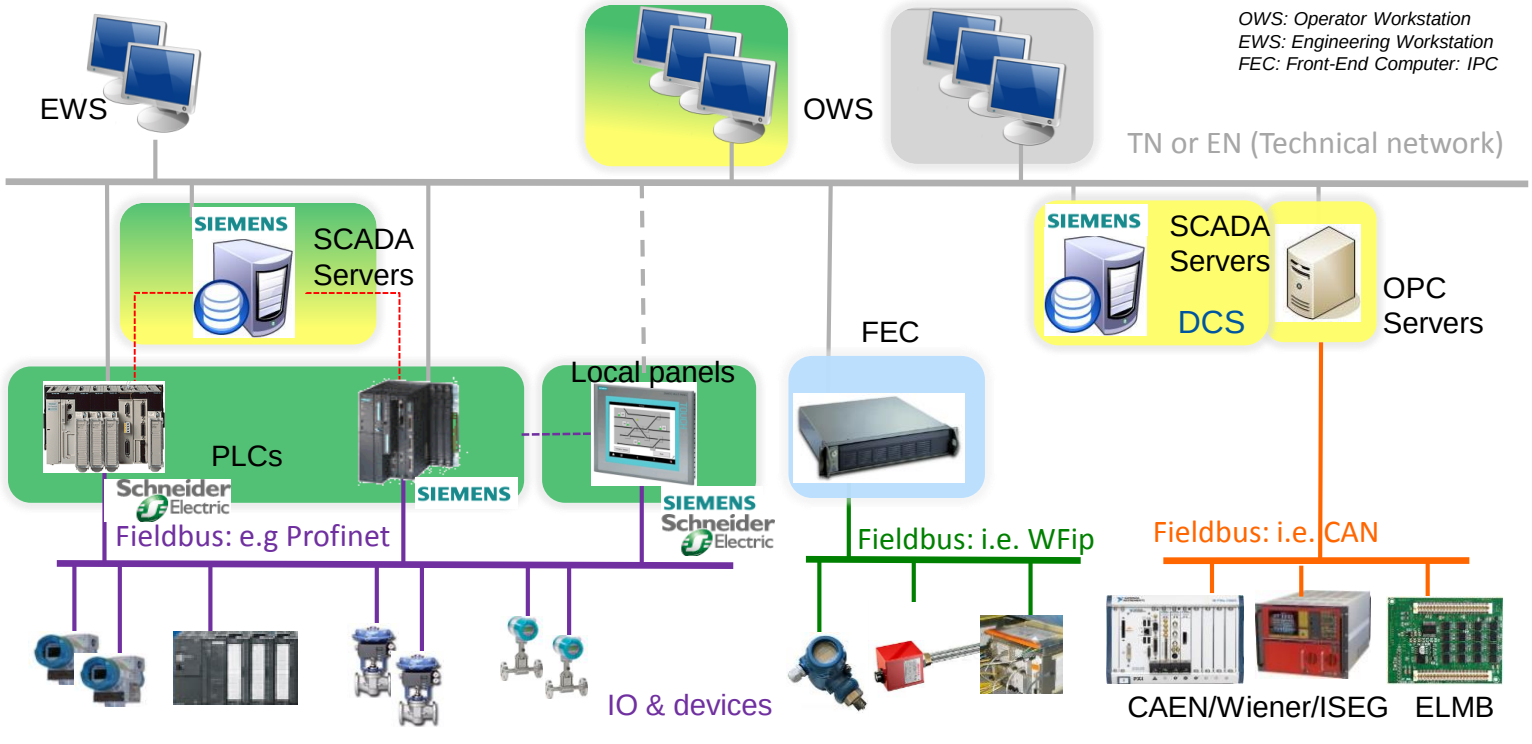


RadTol in-house electronics for signal conditioning and actuation



Industrial Controls Architecture

Frameworks:
- UNICOS
- JCOP
- FESA (BE-CO)

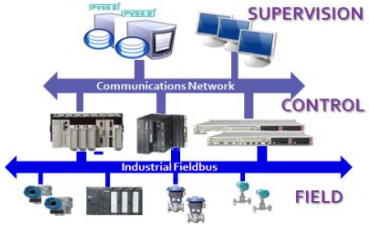


600 SCADA Applications
400 Industrial PCs
10 RAC Oracle Servers
200 TB stored per year

600 PLCs
200 OPC UA Servers
90 FECs

Hundreds of PS
Hundreds of Fieldbuses
Thousands of intelligent instruments
10 M Hardware I/O

Industrial Controls Technologies



SUPERVISION, Visualization and programming

- WinCC OA (PVSS) SCADA (standard)
- Legacy systems: PCVue32, FactoryLink, WinCC

CONTROL

- SIEMENS, Schneider (standards)
- Industrial PCs: SIEMENS IPC, Kontron

FIELD LAYER

- Industrial instrumentation: Sensors, actuators
- Industrial customized actuators: Profibus PA positioners
- Home made electronics: ELMB, Signal Conditioners (CRYO), Power supplies

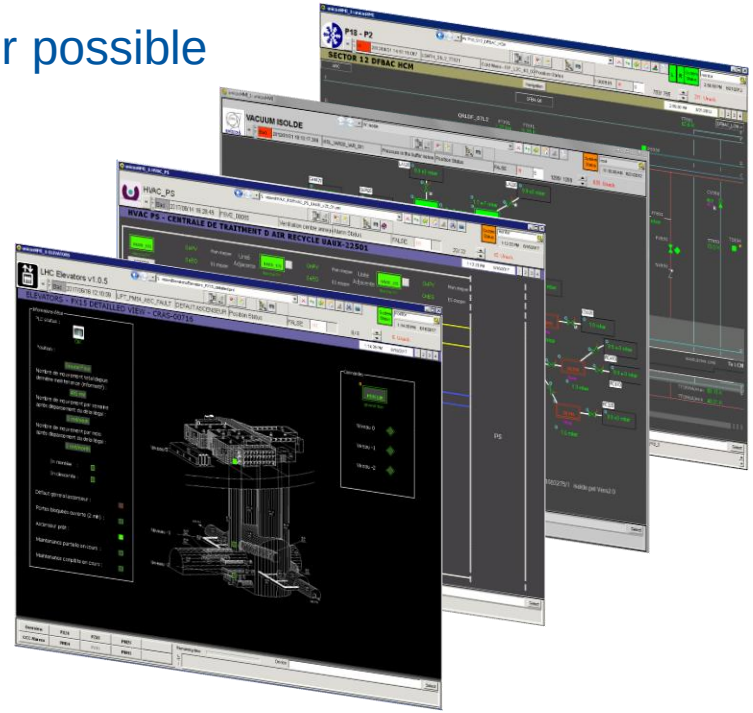
COMMUNICATIONS

- Fieldbuses: Profibus, WorldFIP, CAN, Profinet, Ethernet/IP
- In house developments: White rabbit
- OPC

Industrial Controls: Standards & Frameworks

- Off-the-shelf components (COTS) whenever possible
- Standardization (ISA, IEC)
- Frameworks
  - **JCOP**: A homogeneous way to build the detector control systems
  - **UNICOS**: A unified way to build process control systems

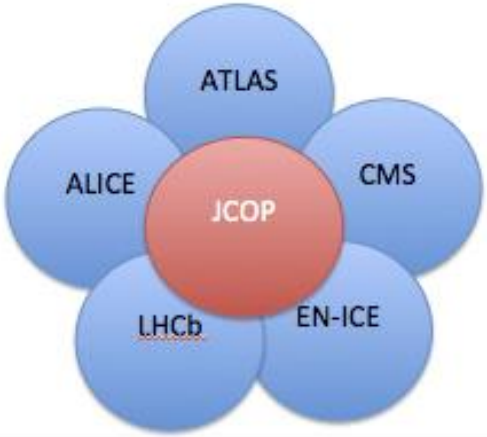
- **Homogenization**
  Cryogenics, Vacuum, HVAC, Electricity…



JCOP (JOINT CONTROLS PROJECT)

- Started in 1998
- Collaboration between the Experiments and the central controls team (nowadays BE-ICS)

- Major subprojects:
  - WinCC OA based framework
  - Experiments' Gas Control Systems
  - Detector Safety Systems



Coordinates all the work done by BE-ICS for the experiments

The DCS of the four LHC Experiments is done in common in the frame of the JCOP

Courtesy of F. Varela

Industrial Partners & Collaborations

(some examples…)

Integrators

- **GTD Systems**: LHC cryogenics project (initial budget ~ 6 MCHF)
- **Assystem**: Industrial controls support contract

Suppliers

- Siemens, Schneider,: PLCs; ARC *Informatique*, ETM (Siemens): SCADA; *Empresarios Agrupados:* Industrial modeling and simulation.

Academia

- **UVA** (University of Valladolid, Spain): modelling & simulation, PLC embedded controllers (MBPC)
- **BME** (Budapest University of Technology and Economics), **EPFL** (Lausanne): Formal methods applied to PLC code verification

HEP Institutes

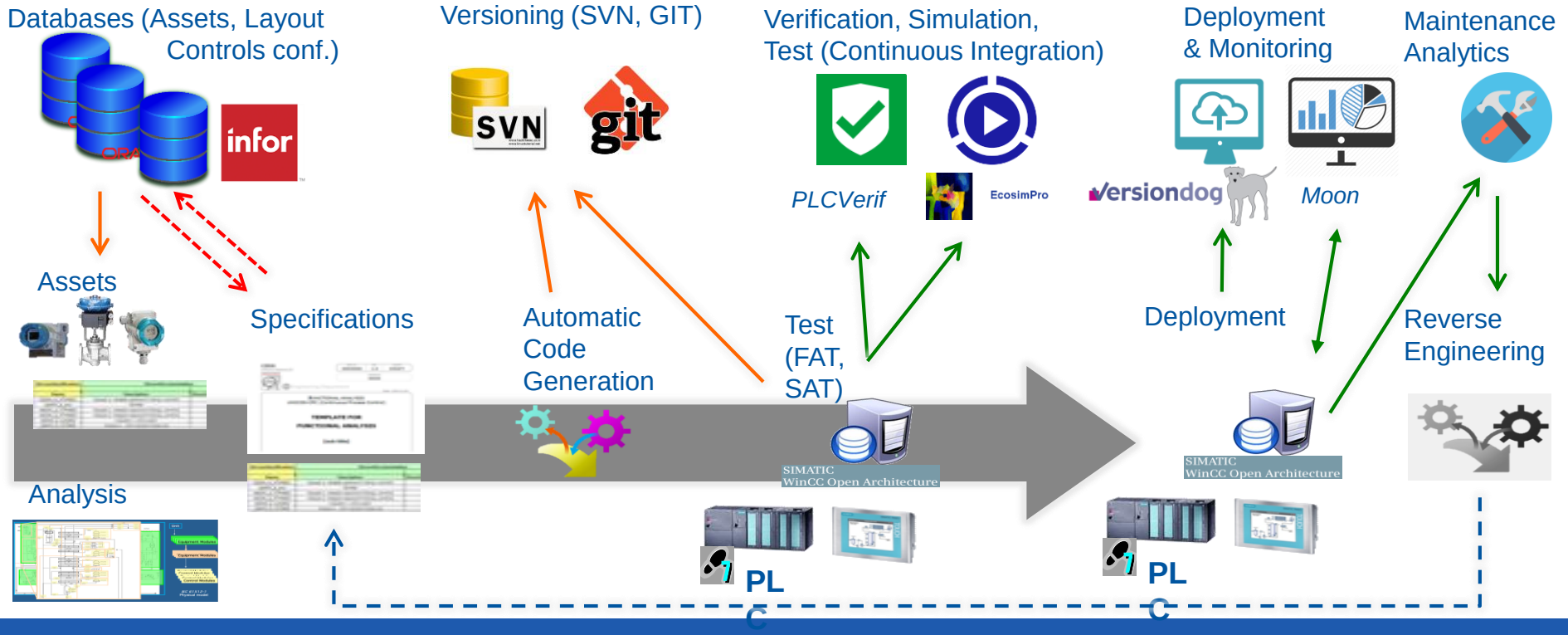
- GSI, ITER, ESO, SOLEIL, MPI…

Industrial controls & Industry 4.0

- Mostly relevant to discrete products and their manufacturing – assembly lines, machines, and robots. In a process plant : **processing equipment**
- **Additional sensors** deployed to enable online **monitoring** of **equipment** (‘things’)
- The Industrial Internet of Things (**IIoT**): industrial-strength networks and cyber-physical security.
- **Analyze the raw data:** process monitoring or **anomaly** detection: **Big data**.
- **Information exchange** over the entire lifecycle of a product: convergence of OT and IT.
- **Digital twins** fostering fabrication and performance

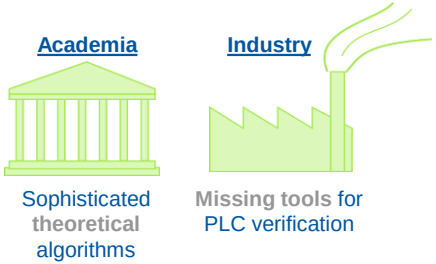
- Industrial controls and drives: The future will bring more effective industrial controls and drive technologies that will **reduce process variability** while ensuring **safety** and **security**

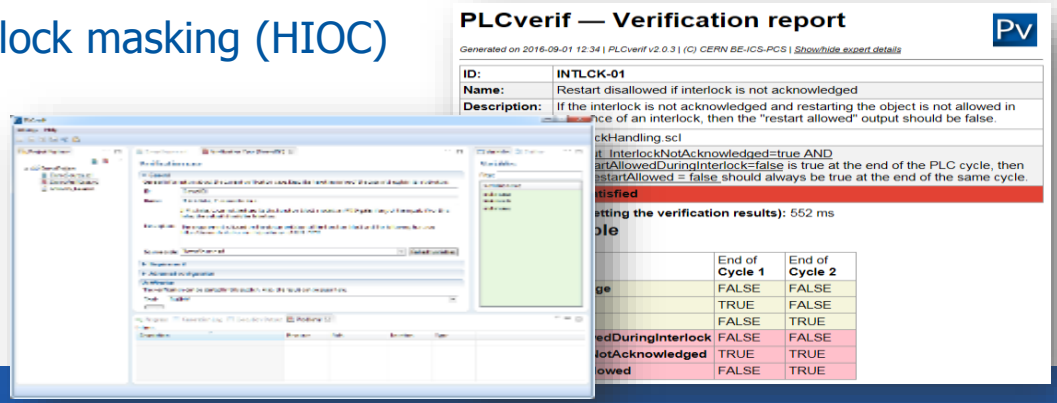
OT and IT convergence (Project Life cycle)



Applied formal methods

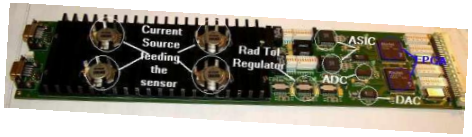
- **Formal verification** of PLC code: **PLCVerif**
  - Mathematically sound methods to check the correctness of plans / implementations. E.g. Model checking
  - Tool reengineering project started (funded by CERN KT)
- **Used in real-life projects** (to complement testing)
  - At CERN: SM18 projects, B311 Switchboard, AWAKE
  - Outside of CERN: ITER interlock masking (HIOC)
- **Collaborations**
  - TU Budapest, EPFL
  - Siemens US (Openlab)

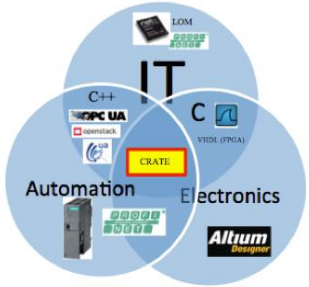




Courtesy of D. Darvas

IIoT (Industrial IoT)





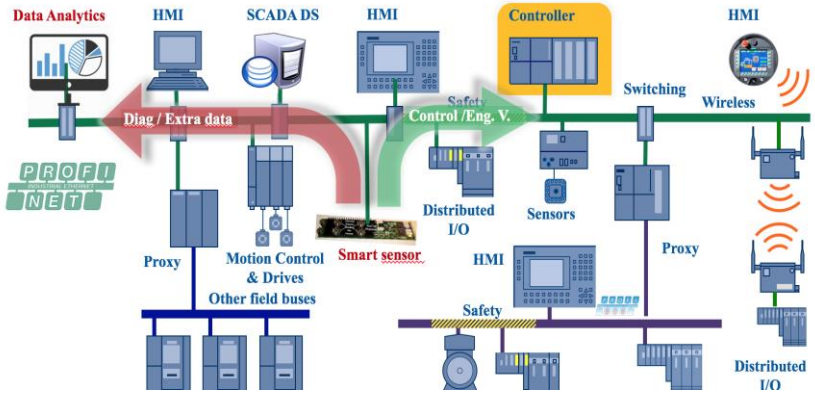
IIoT equipped sensors

Cryogenics instrumentation electronics cards design (high precision)

IIoT architectures

Fully integrated within industrial fieldbuses (e.g. Profinet)

- Profinet RT for control purposes (engineering values)
- OPC-UA for sensor diagnostics (data analytics)



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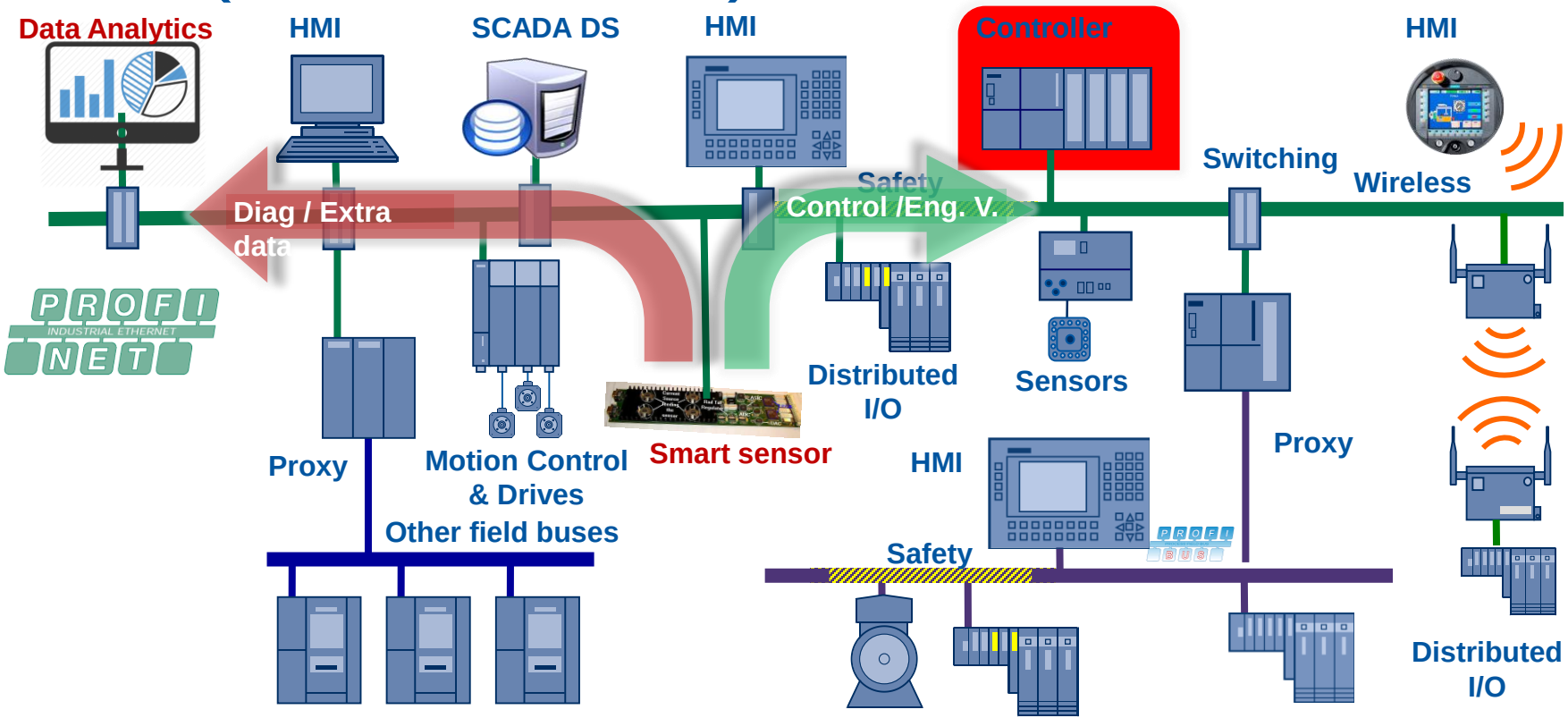
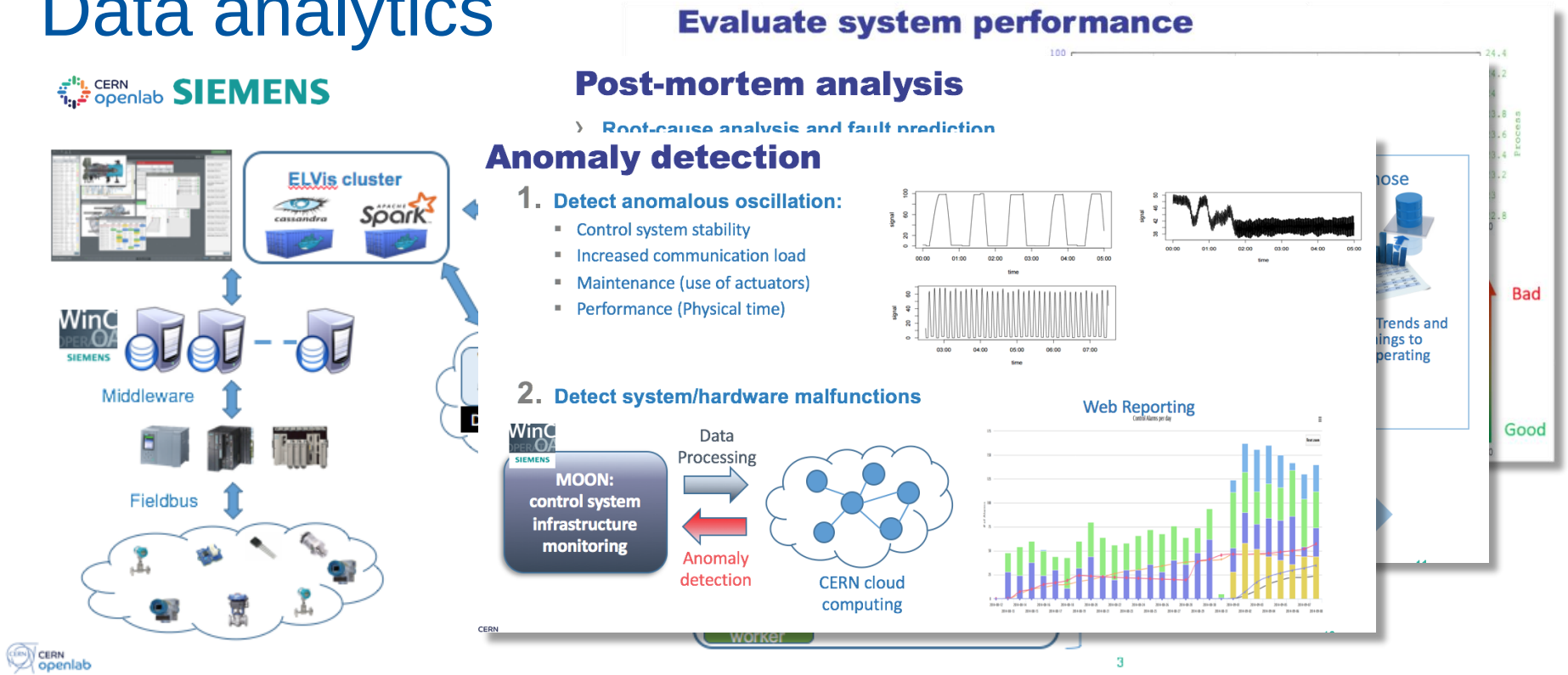


Data analytics



Courtesy of F. Tilaro (Openlab)

Increase SECURITY

Cybersecurity at CERN relies on three principles

- Device registration, inventory and traffic auditing.
- Network segregation : Separate networks for production, development and major experiments.
- Device isolation through control sets: PLC devices are only allowed to speak to trusted equipment (SCADA servers, monitoring equipment…)

Robustness of PLCs, IoT devices and other equipment

- CERN collaborated with *ANSSI (FR) / **BSI (DE) on an open-source initiative for an ISA-99 compliant robustness fuzzing platform (implemented by AMOSSYS). The platform will be released to the public domain early 2018 Q2.

ANSSI Agence nationale de la sécurité des systèmes d'information

Bundesamt für Sicherheit in der Informationstechnik

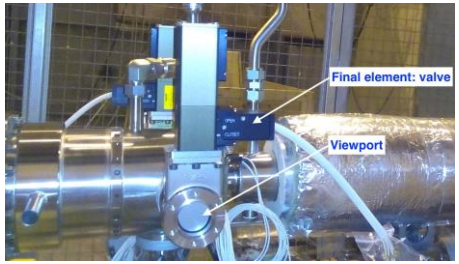
* Agence nationale de la sécurité des systèmes d'information (France)
** Bundesamt für Sicherheit in der Informationstechnik (Germany)

Courtesy of B. Copy

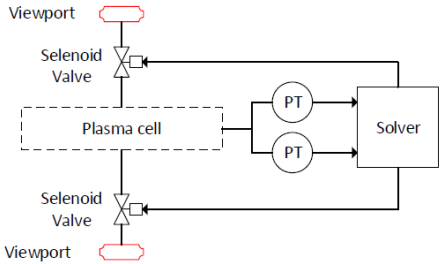
Increase SAFETY

Safety Instrumented Systems engineering

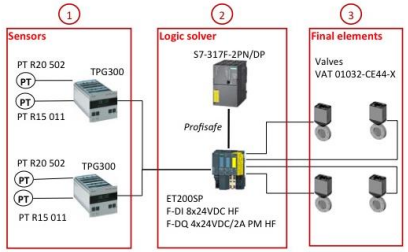
AWAKE Plasma cell



AWAKE Plasma cell (viewports)

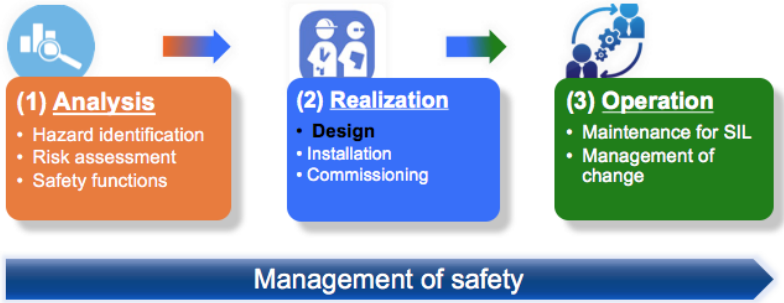


Safety Instrumented Function Loop



Safety Instrumented Function architecture

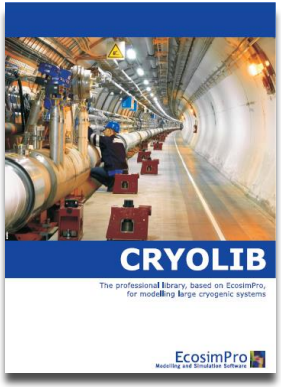
Standards



Modeling & Simulation: Digital twin

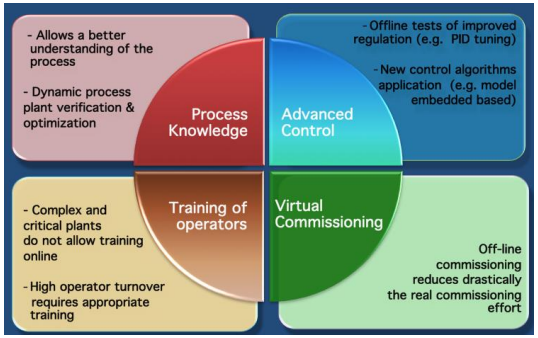
CERN developed a cryogenic library with the commercial simulation software **EcosimPro** (*Empresarios Agrupados*): Cryogenic equipment modelled by DAEs. (Differential-Algebraic Equations)

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



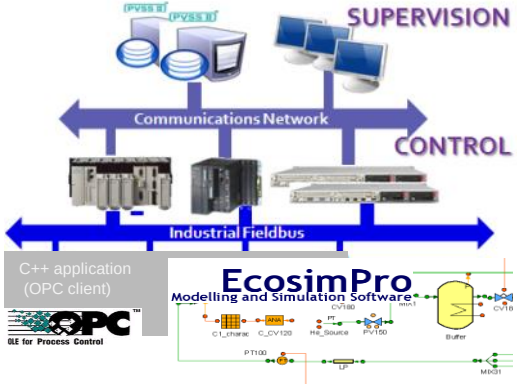
18 kW @ 4.5 Refrigerators

Compressor station



Adopting the **Virtual Commissioning** concept reduces installation launch time and increase the control system quality by testing, validating, and debugging the system before physical commissioning

HIL: Hardware in the loop



Conclusions

- Sound base of standardized industrial control systems
- Large installations usually well instrumented
- Extensive experience with fieldbuses
- Already large experience OT & IT convergence
- Large amount of data available
- Valuable partners identified

- But LHC will be there for 20 more years…
- Evolution will naturally integrate Industry 4.0 concepts
- A exciting period in front of us!

Acknowledgements & Credits

Material extracted from several sources:

- CERN documentation
- BE-ICS group (Industrial Controls & Safety Systems)
- CERN equipment groups (e.g. Cryogenics, QPS…)
- CERN LHC experiments
- JCOP project
- UNICOS project

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CERN

CERN, 2018