The CERN Cryogenic Simulation Lab:

a great support for the operators' training

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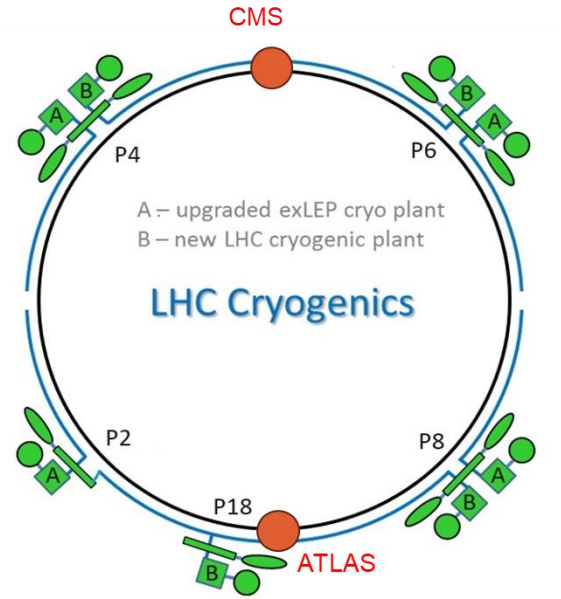
Introduction: The LHC cryo operation team

- **The LHC cryo operation is regrouping several cryogenic installations around LHC**
  - **LHC** cryogenics (8 large helium refrigerators + 8 cold compressor boxes + 27 km of cryo distribution)
  - **ATLAS** cryogenics (2 helium refrigerators + 1 nitrogen refrigerator for the ATLAS Argon Calorimeter)
  - **CMS** cryogenics (1 helium refrigerator)



- **The Operation Team :**
  - 5 engineers / referents
  - 4 point leaders (technical engineers)
  - 12 CERN operators (technicians)
  - 10 operators from subcontractors (SercAL)

➔ 22 operators with a large turn-over *(5 years contracts for CERN operators)*
with ~2 new CERN operators hired each year

Introduction: The cryo simulation lab's history

- **2005**: The original idea came from **Ph. Gayet** who was dreaming to train the future cryo operators on a simulator.
- **2006**: A PhD was launched on this topic at CERN using **EcosimPro** as commercial software.

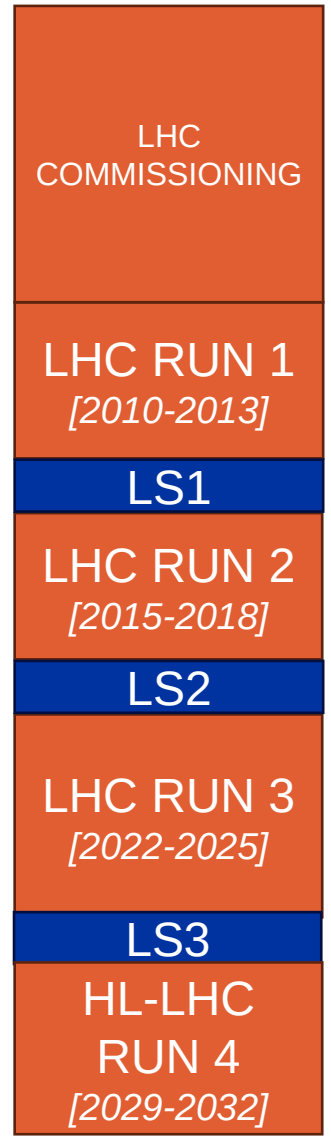
- **2007**: A first CMS cryogenic simulator was showing first positive results.
- **2009**: A first LHC cryoplant simulator (4.5 K + 1.8 K) was operational.
- **2011:** The EcosimPro cryogenic library is transferred for commercialization to EcosimPro ➔ **CRYOLIB** library
- **2012**: Some operator training sessions with the simulator are organized time to time at CERN.

- **2015**: The simulator was officially integrated in the LHC cryo operator training program

- **2019**: Major refactoring of the code and architecture *(use of OPC-UA & Python)*

- **Today (2024):**
  - The simulator is used all along the year with the new operators
  - Simulator is also used as refresher for other operator time to time

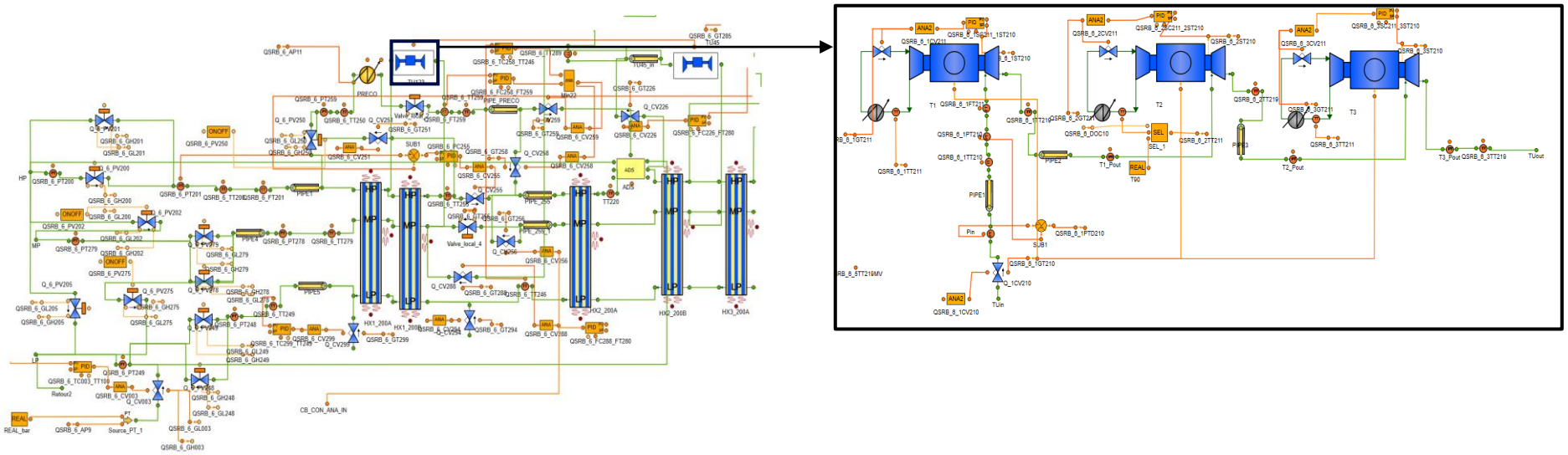
➔ It took a long time to make benefit of it (~10 years) but it is today a **fundamental tool** in our operator training program and we aim to expand its usage in the coming years !



How does the simulator work today ?

1. The process model is built under EcosimPro software using the CRYOLIB library

- Make use of an object-oriented approach to model and couple all cryo equipment to be simulated
- EcosimPro is then generating a standalone executable to run the simulation embedding an OPC-UA server to exchange data



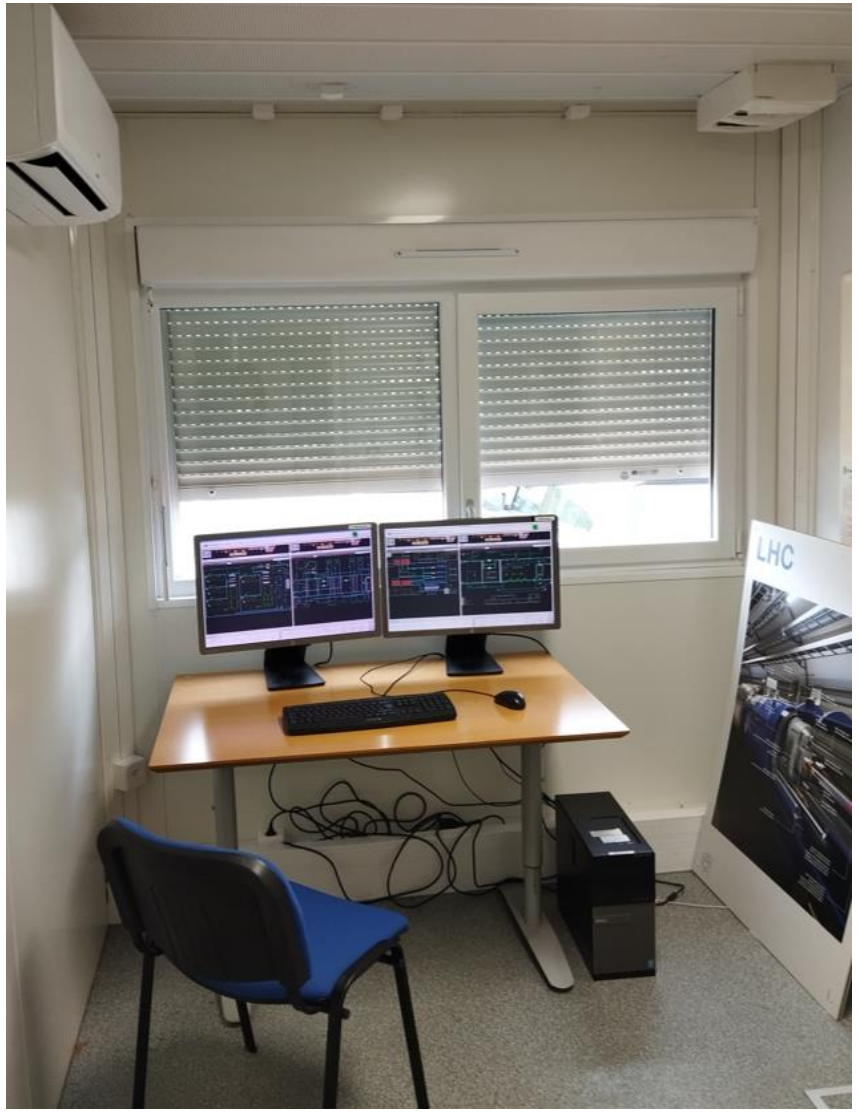
2. The real control system driving the cryo installation is duplicated on similar hardware

- PLCs (Schneider) + Supervision Data Server (WINCCOA) + operation console

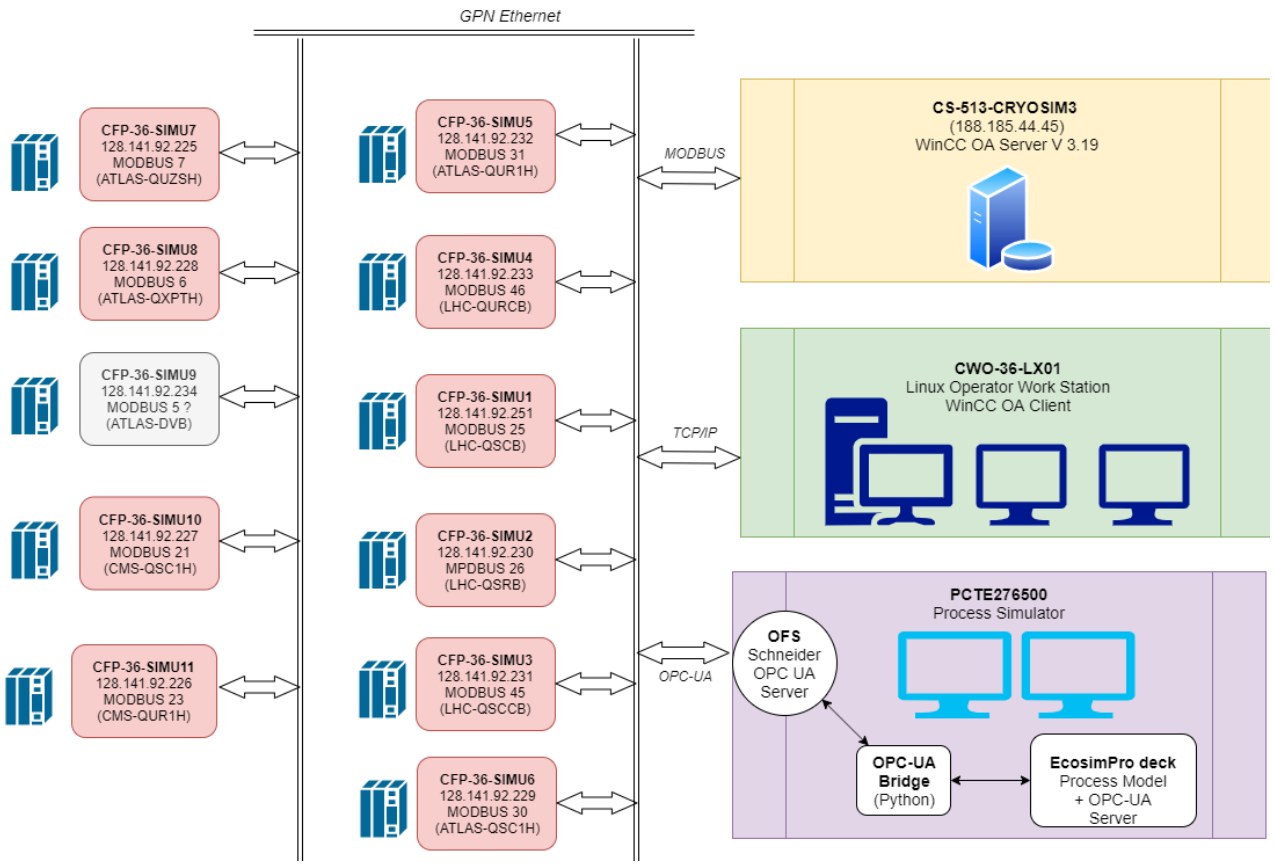
3. A Python software ensures the OPC-UA communication between the PLC and the model, reusing UNICOS *(CERN control standard)*

To what the cryo simulator looks like ?

OK… this is really to what it looks like…



Cryo Simulation Lab architecture



3 independent simulators are available :

- **The LHC cryo simulator**
  - ✓ 4.5 K cryoplant coupled to the 1.8 K ref system
- **The ATLAS cryo simulator***
  - ✓ Main Refrigerator at 4.5 K + Toroid distribution
- **The CMS cryo simulator***
  - ✓ 4.5 K cryoplant + magnet distribution

Hardware used in the cryo simuation lab :

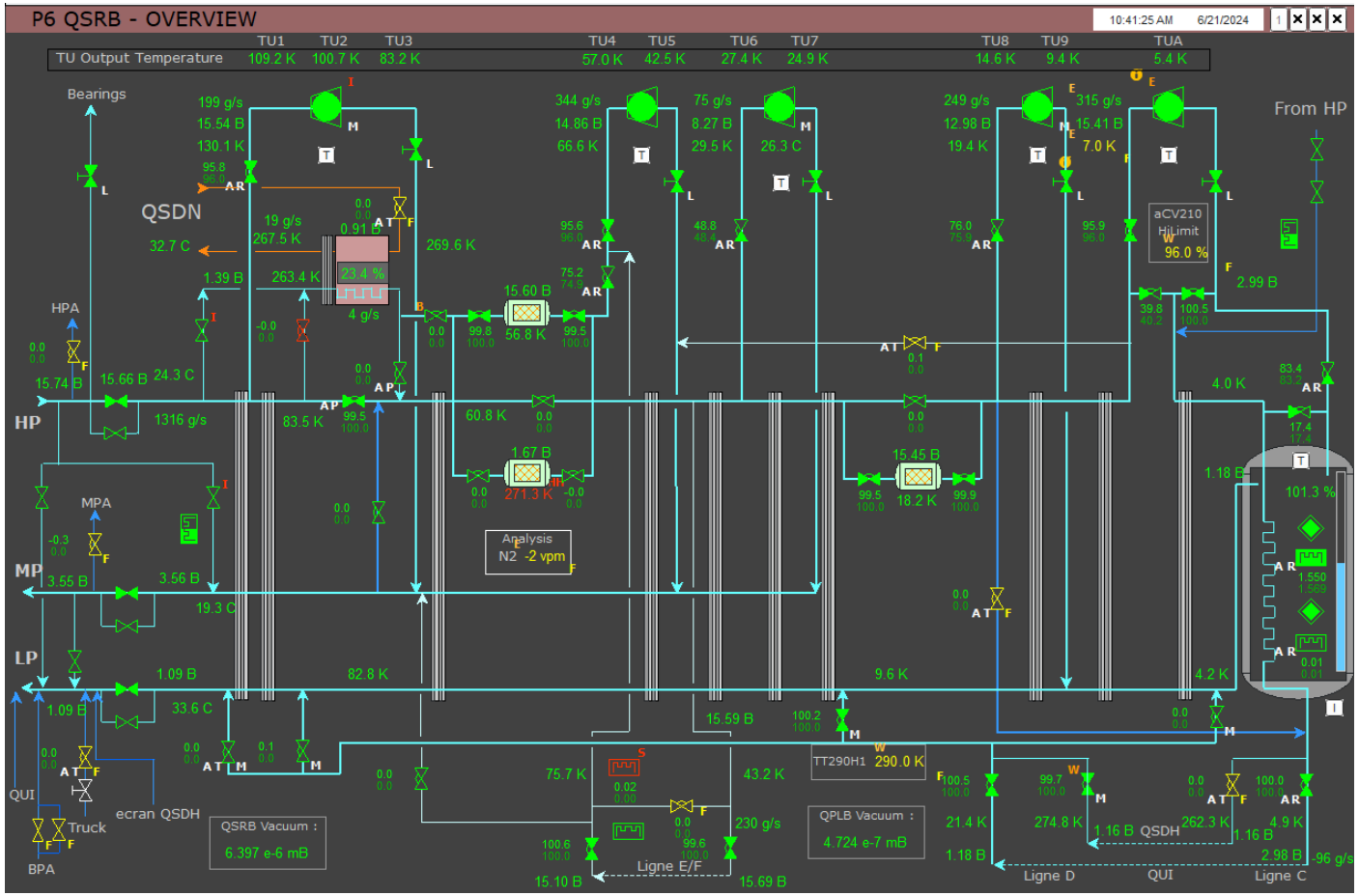
- 1 SCADA Data Server (WINCCOA)
- 1 Linux Operator Work Station
- 1 Windows computer for the process simulation
- 10 Schneider PLC (4xLHC + 4xATLAS + 2xCMS)

**Under upgrade – should be finalized by the end of this year*

What is simulated, and what is not?

- **What is simulated ?**
  - Helium rotating machines

  (warm compressors, turbines, cold compressors)
  - Main helium circuits and volumes
  - Heat exchangers
  - Phase separators
  - Actuators (valves and heaters)
  - Sensors (temperature, pressure, massflow)
- **What is NOT simulated ?**
  - Impurities in helium
  - Electrical supplies
  - Vacuum systems
  - Oil, water, nitrogen circuits
  - Purge and secondary circuits used for maintenance and manual operations



A LHC main cold box at 4.5 K

How do we train the CERN cryo operators ?

- **New operators are receiving a set of training sessions for 1 year in parallel of their integration in a local cryogenic operation team before being qualified for 24h/24h shift alone.**

- **Training sessions are organized in 9 blocks:**

1. Integration and introduction to LHC cryogenics with its detectors and CERN controls → 1 simu session= 4 hours
2. 4.5 K refrigeration light theory
3. Practice on Simulator - Discovery and familiarization → 3 simu sessions = 12 hours
4. Specific trainings (Compressors, Turbines, storage, Distrib, RF, Vacuum…)
5. Practice on simulator - Standard operation in LHC and Detectors → 5 simu sessions = 20 hours
6. Light theory on 2 K refrigeration (LHC)
7. Practice on simulator – cold compressors and special operations in detectors → 5 simu sessions = 20 hours
8. Transient operations and special configuration, planning organization…
9. Final sessions for autonomous shift qualification → 1 simu session = 2 hours

➔ **Total of 15 simulator sessions (~60 hr in total) over the year for a new operator**

A typical simulation session (4hr) for operator training

1. **As introduction, the simulator session objectives are clearly stated to the trainee and the potential differences with the real plant are also reminded (~25 min)**
   - E.g.1: Discovery of a transient operation following a procedure for the first time
   - E.g.2: Failure scenario to evaluate the reaction of the operator.
   - E.g.3: Replay a difficult transient for improvement or refreshment.
2. **The simulator is initialized to a predefined state by the instructor (~5 min)**
   - E.g.1: The cryoplant is entirely stopped at ambient temperature and depressurized.
   - E.g.2: The cryoplant is running in steady-state operation during beam operation.
3. **Simulation is starting and the trainee follows the instructions given by the instructor (~3 hr)**
   - E.g.1: Find and follow a dedicated procedure / transient sequence.
   - E.g.2: Just monitor the cryoplant and pay attention to any abnormal behaviour, react if needed (explaining why).
4. **Debriefing of the trainee (~30 min)**
   - Discuss about what was learnt, if the session was useful and if the initial objectives were achieved.
   - Discuss about the potential differences between the real plant and the simulation.

Examples of predefined scenarios

- **Standard scenarios**
  - Starting of a compression station and cooldown of a cold box alone (with or without LN2 precooler)
  - Cold box parameter tuning during a significant heat load variation (HP, turbines, various setpoints, etc.)
  - Adsorber switch and launch of the adsorber regeneration of the disconnected one (LHC only)
  - Pumping down from 300 mbar to 16 mbar with cold compressors (LHC only)
  - Reconnection of the cold compressor box to the pumping line at 30 mbar “on the fly” (LHC only)

- **Failure scenarios**
  - Turbine trip (various types) – eventually starting of LN2 precooler if needed in case of TU123 trip
  - Degradation of the coldbox power due to a forgotten actuator in manual mode (or broken sensor)
  - Oscillatory behavior due to badly tuned PID controller (or a suddenly noisy sensor)
  - Restart in degraded mode after a major failure to recover helium inventory
  - General management of the cryogenic system after a magnet slow discharge (ATLAS and CMS only)

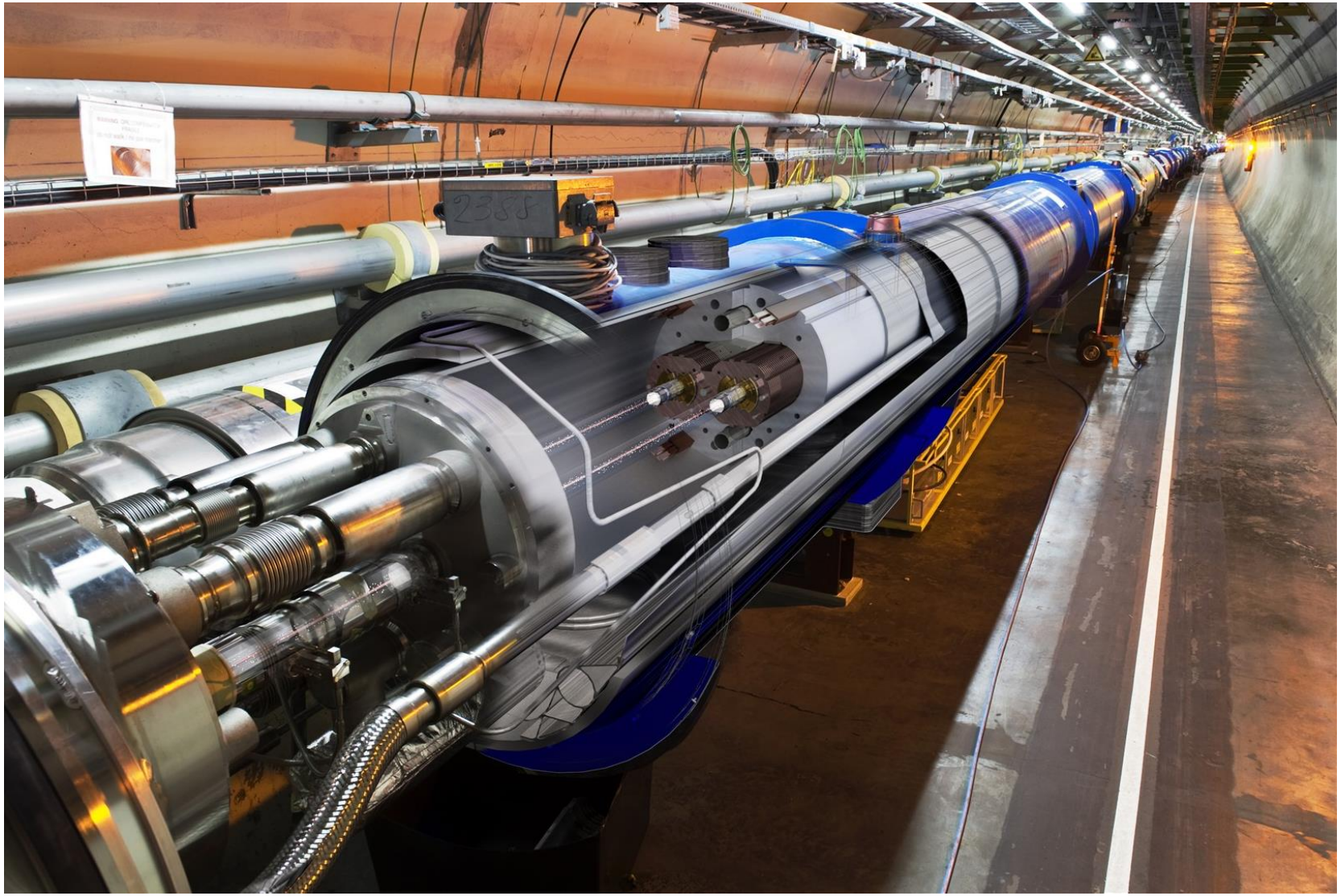
Conclusion & perspectives

- **A real-time cryogenic simulator is used to train the CERN cryo operators**
  - On LHC, ATLAS and CMS cryogenic systems
  - Dynamic model build with EcosimPro/CRYOLIB and connected to a duplicate of the real control system
  - Each new operator follows ~15 simulation sessions during its first year, inside his training program

- **A minimum maintenance is needed to keep the simulator up to date**
  - Follow versions of Windows, EcosimPro, Python, OPC, etc.
  - Update of PLC programs and synoptics in case of significant changes on the real installations (typically, between each LHC run every 4 years)

- **Perspectives**
  - Existing models of ATLAS and CMS cryogenics are under upgrade to be fully operational
  - More sophisticated scenarios with predefined “back doors” to simulate failures are under study

Questions ?



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