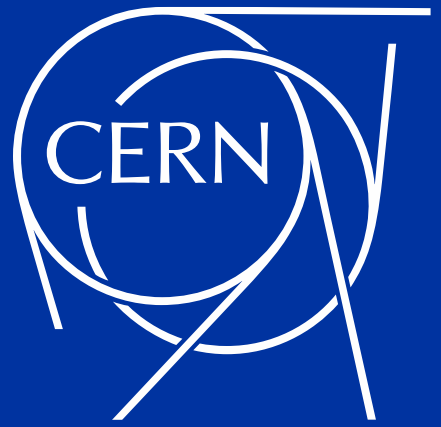

Control and monitoring of large vacuum systems for accelerators

Gregory Pigny | UHV training at CERN for Danish companies – October 5-6, 2023

Outline

- The control and monitoring of CERN’s accelerators
- Example with ELENA (Extra-Low Energy Antiproton)
- The radiation resistance of vacuum equipment
- Future needs and trend in vacuum control technology

Outline

- The control and monitoring of CERN’s accelerators
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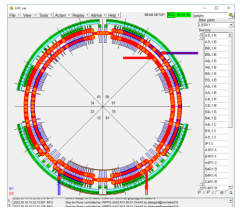
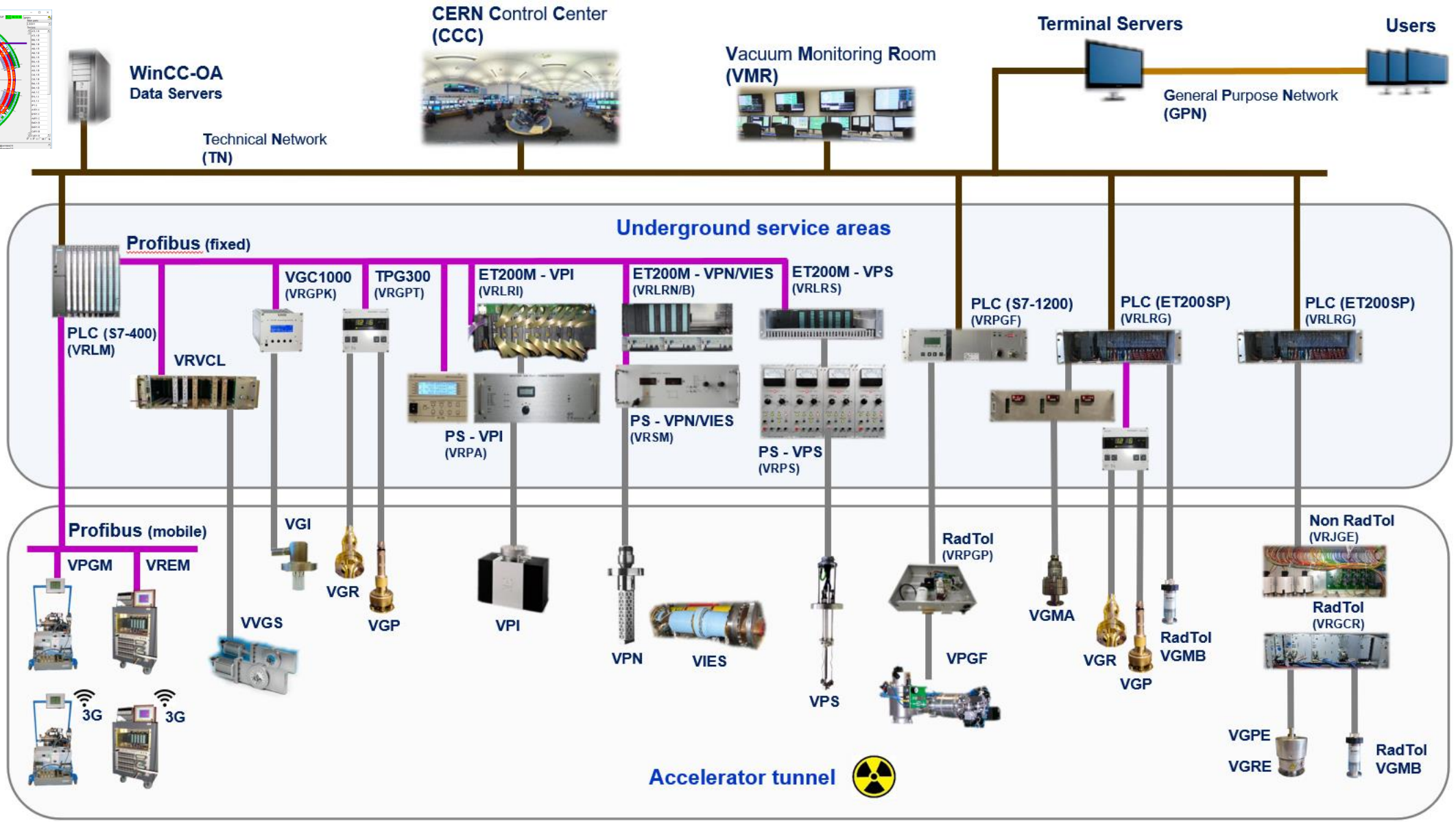
Vacuum System

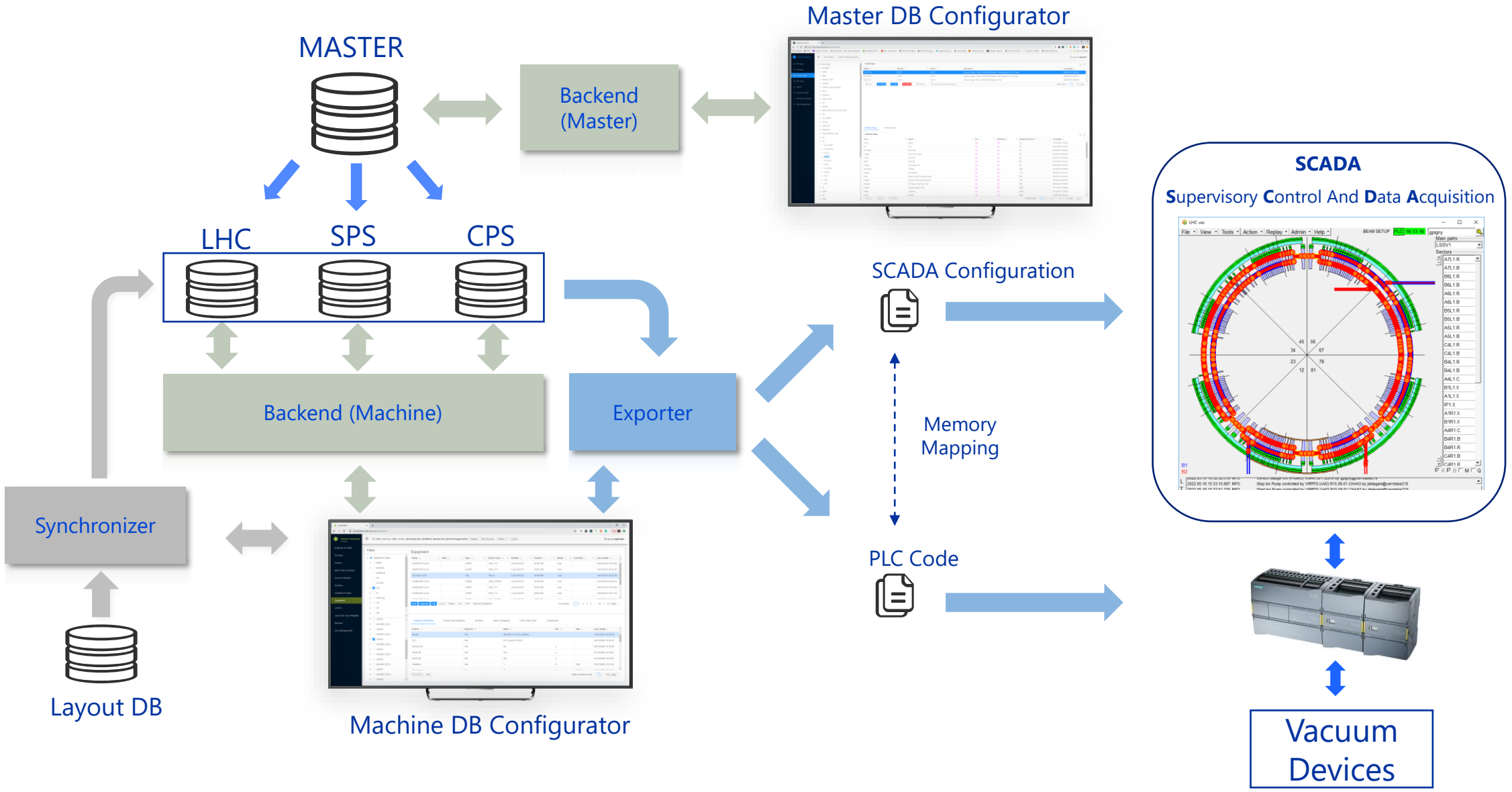
- 130km of vacuum chambers
- Pressure range from 10^{-4} to 10^{-12} mbar
- **9000** vacuum instruments to be controlled and monitored:
  - 3900 gauges
  - 520 Fixed Pumping Groups
  - 3100 Ion Pumps; 280 NEG Pumps; 270 Sublimation Pumps
  - 720 Sector Valves
  - Mobile equipment (only during Technical Stops): 176 Mobile Pumping Groups, 100 Bake-out racks
- 400 PLCs; **3000** Industrial or Custom Controllers
- 15 SCADA applications (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition)

Vacuum Control System Architecture

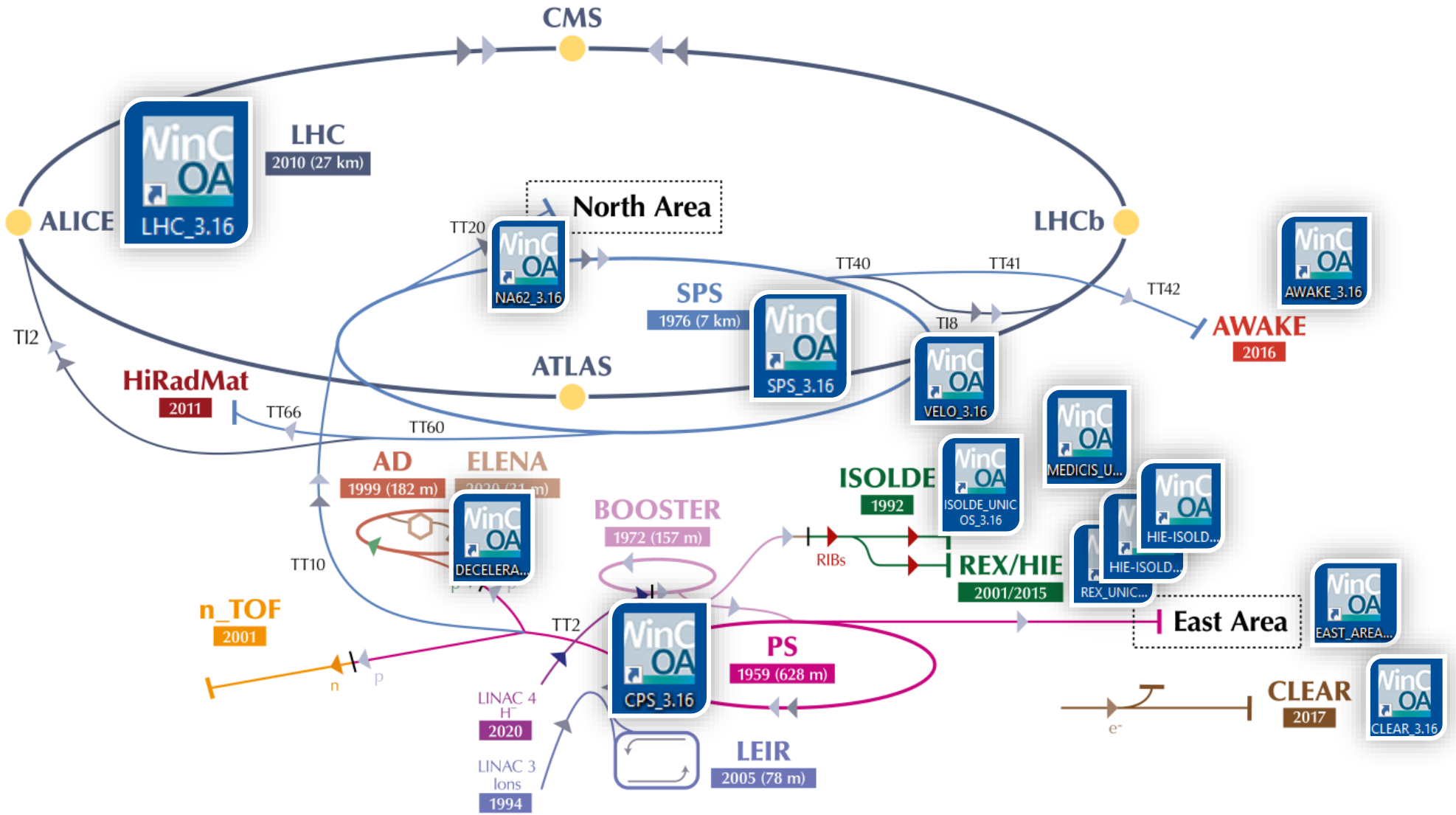




Vacuum Control Software Architecture

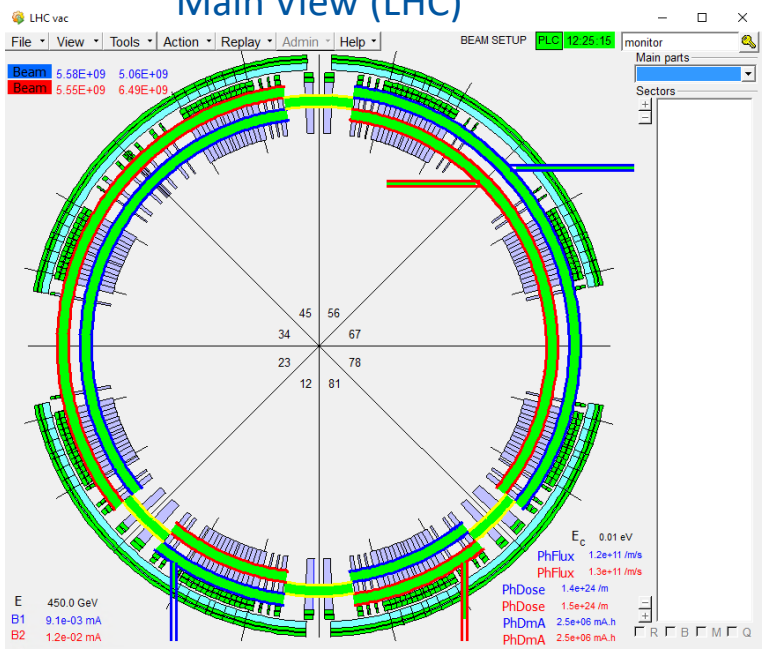


SCADA Applications (as of 2023)

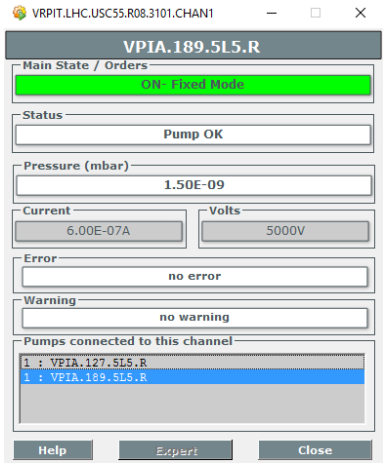


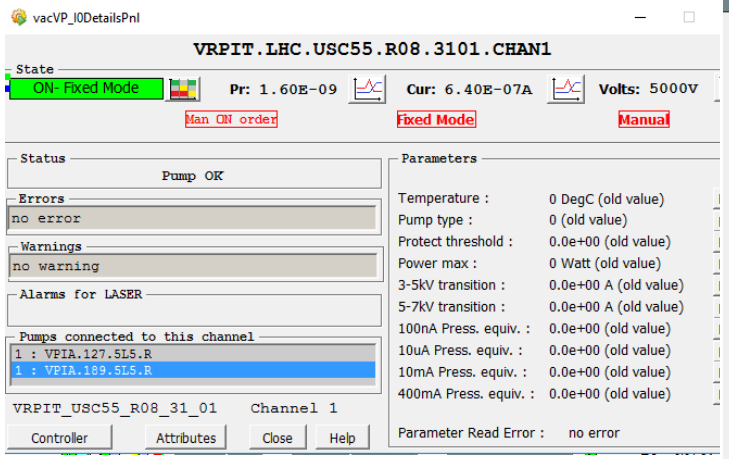
Vacuum SCADA panels and functionalities

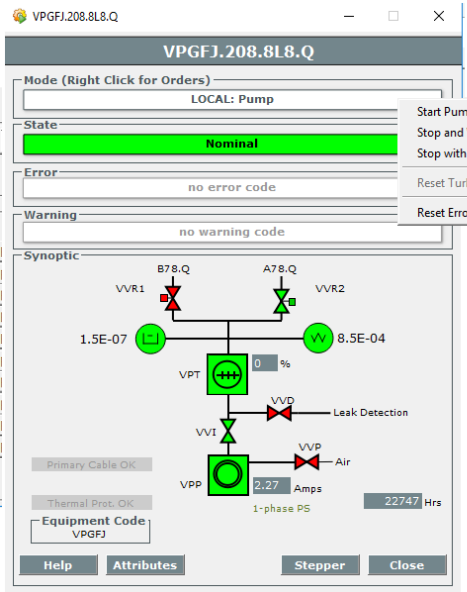
Main View (LHC)



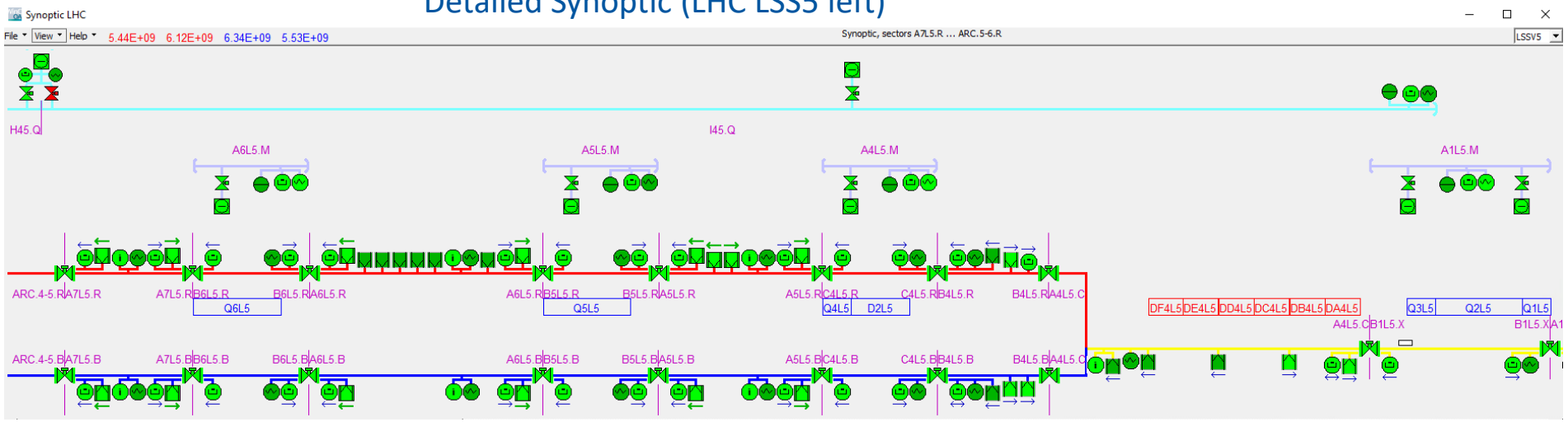
Equipment Details Panel





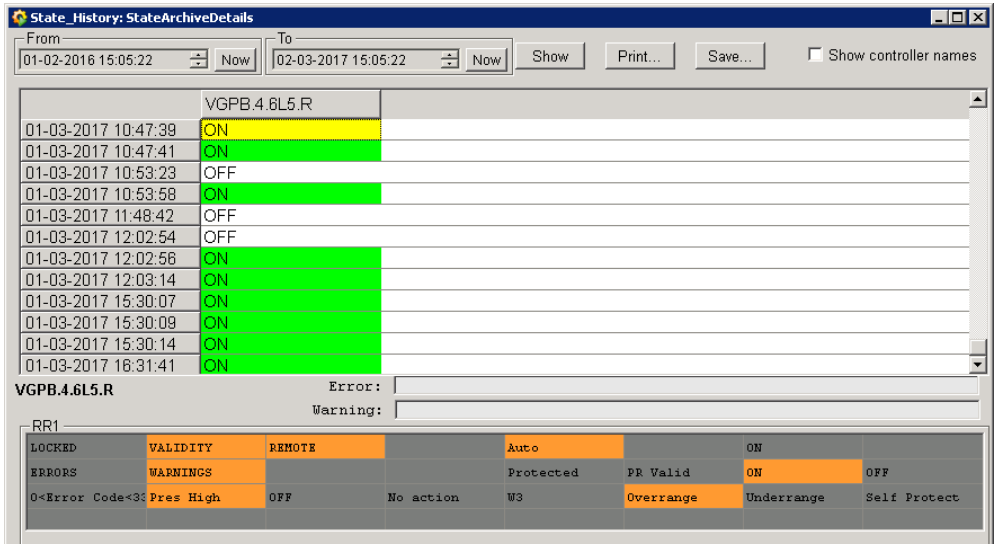


Detailed Synoptic (LHC LSS5 left)

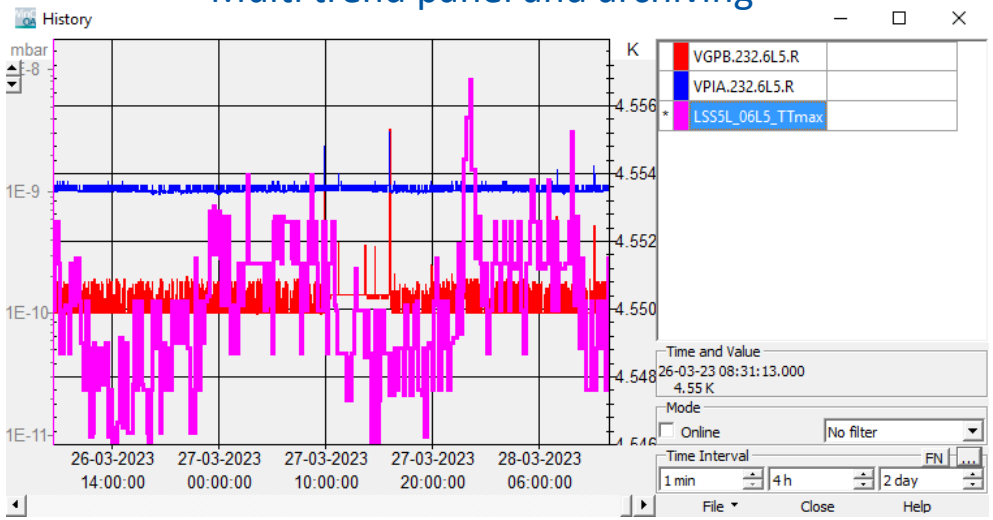


Vacuum SCADA panels and functionalities

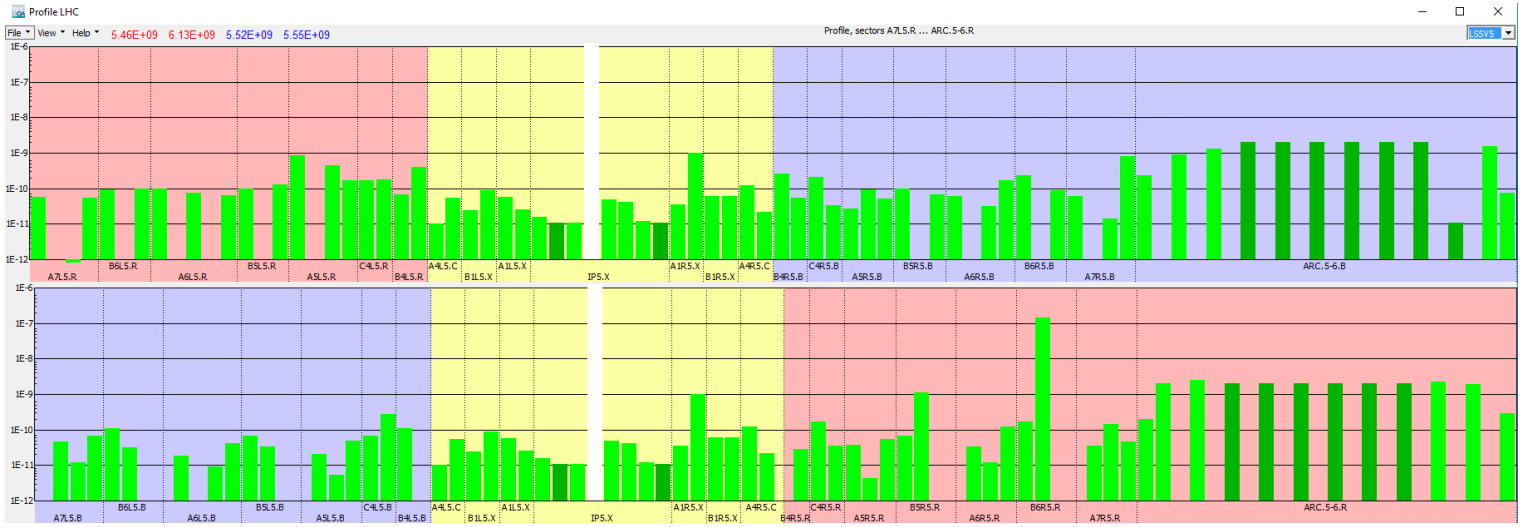
Equipment State History



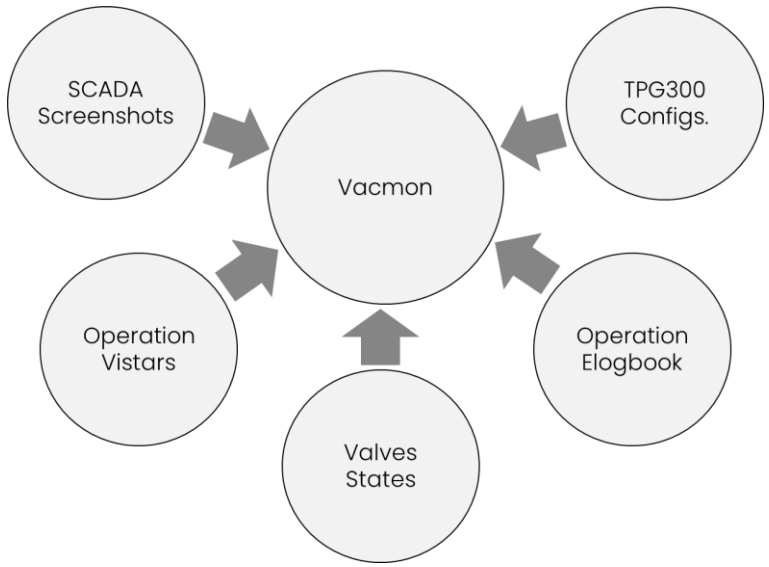
Multi trend panel and archiving



Pressure Profiles

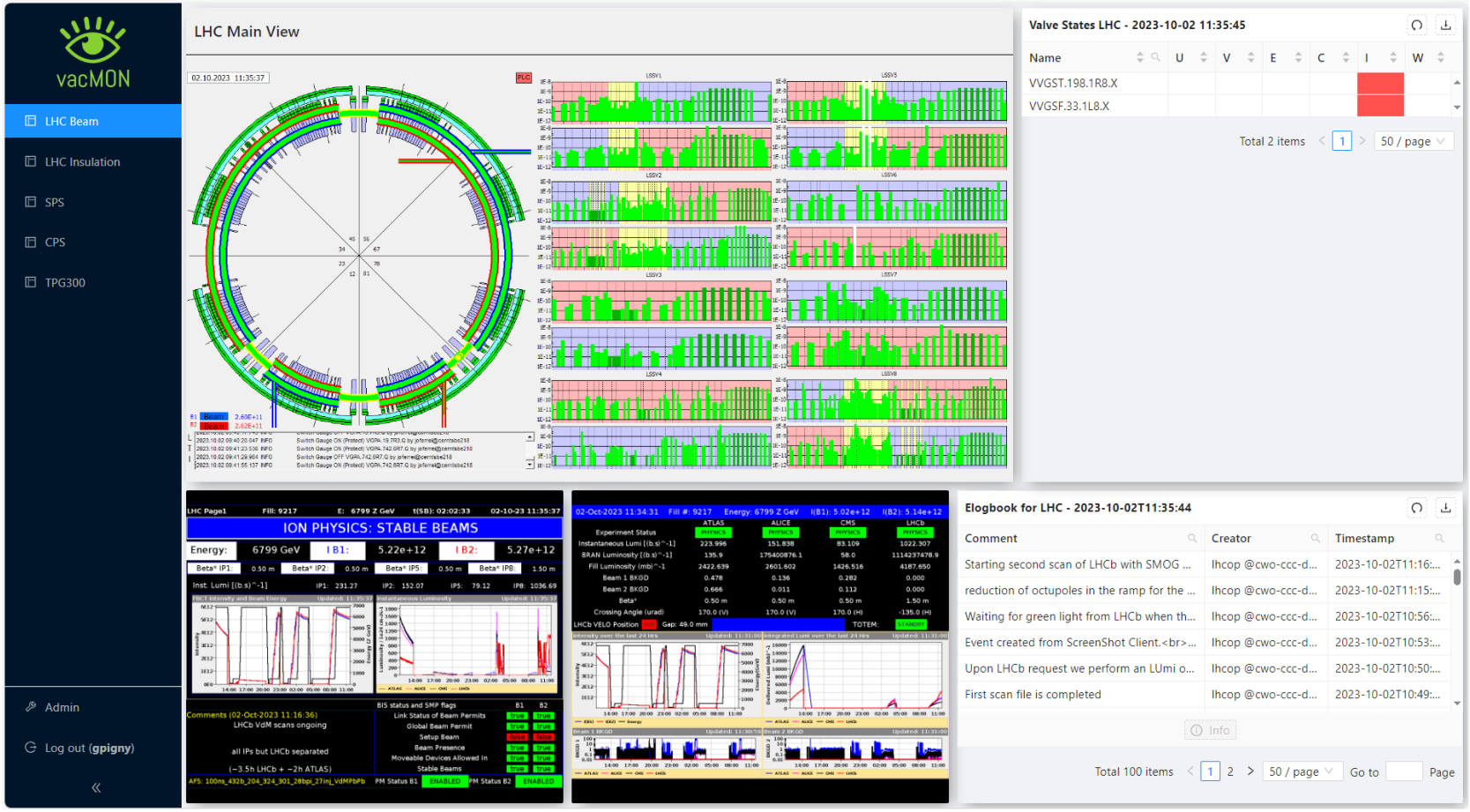


vacMON



- Gives an overview of the vacuum system and accelerators' statuses
- Web page available from any terminal or smartphone

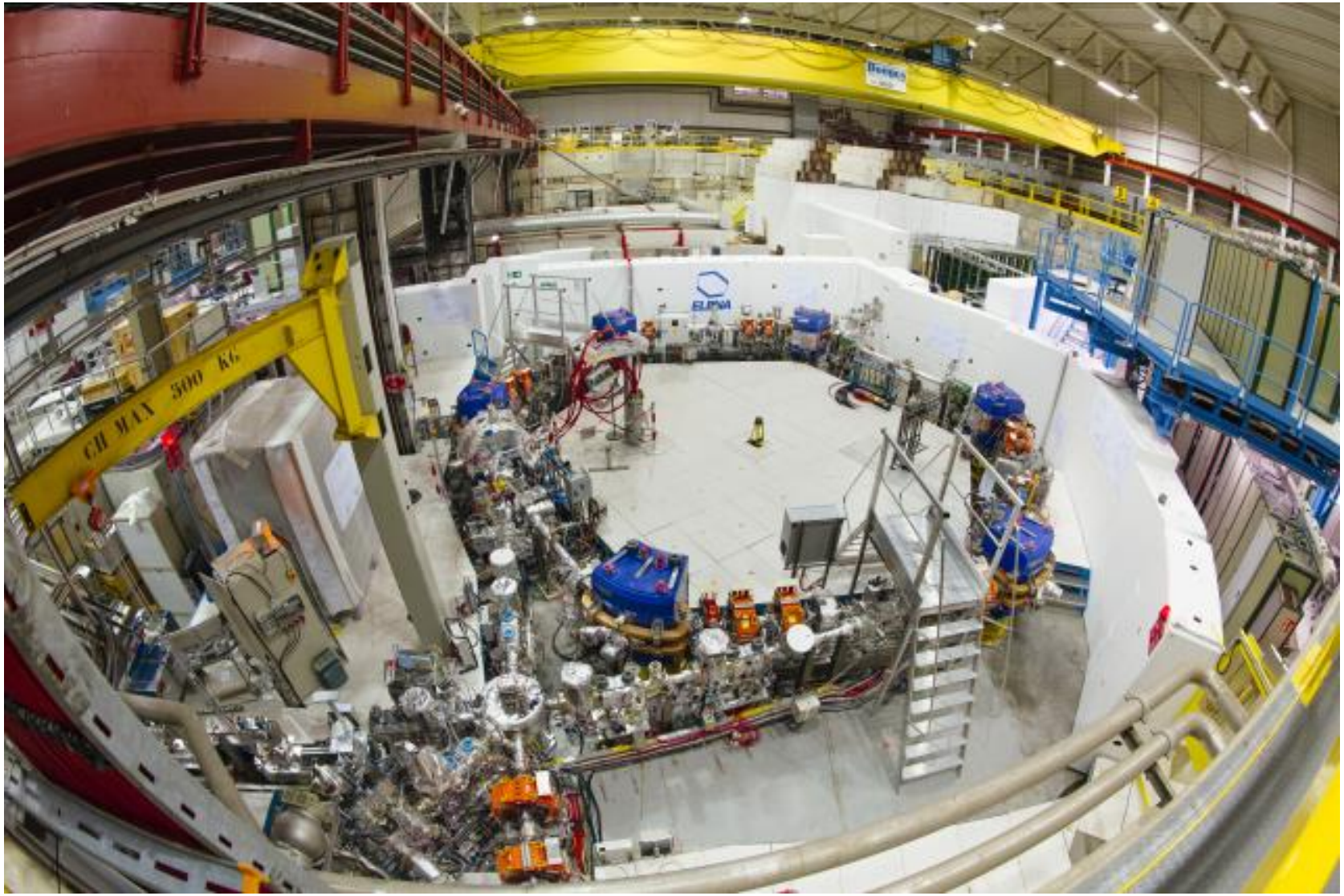
vacMON for LHC



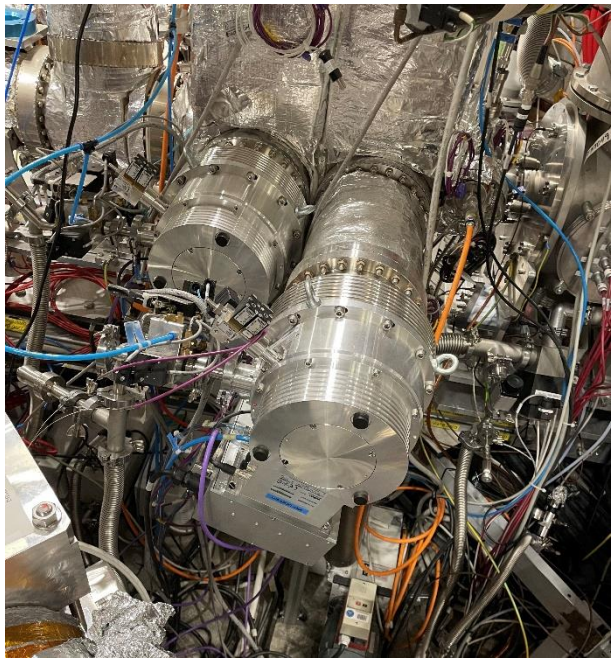
Outline

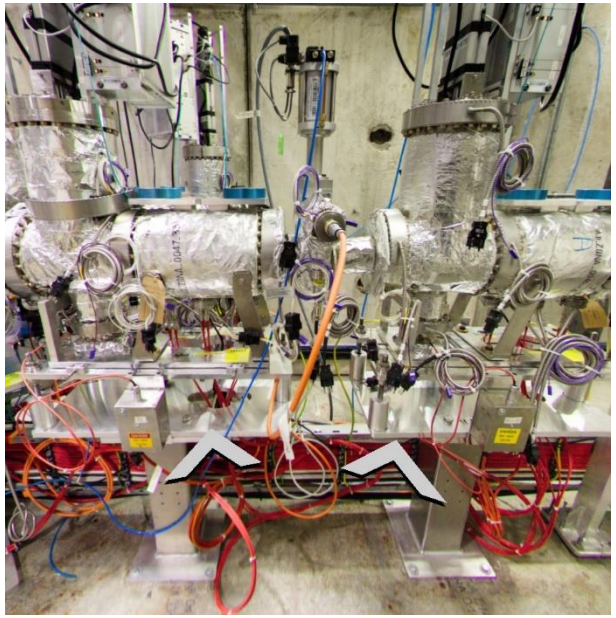
- The control and monitoring of CERN’s accelerators
- Example with ELENA (Extra-Low Energy Antiproton)
- The radiation resistance of vacuum equipment
- Future needs and trend in vacuum control technology

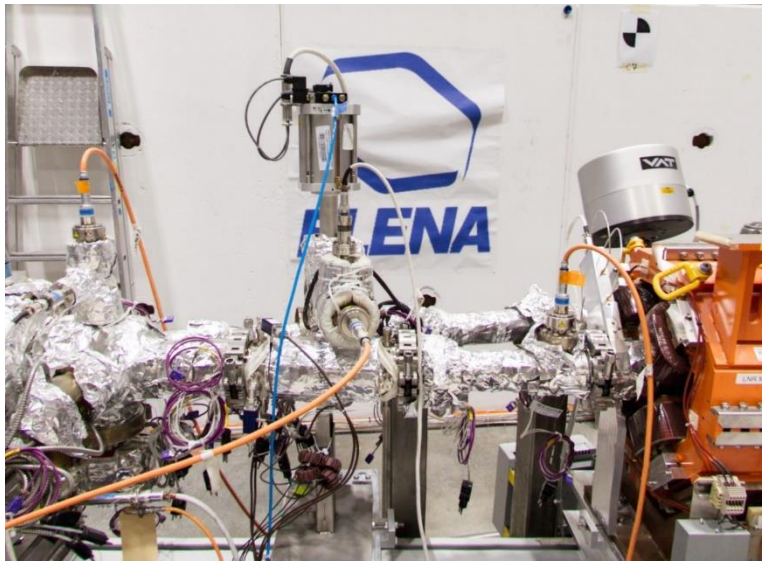
ELENA (Extra-Low Energy Antiproton)

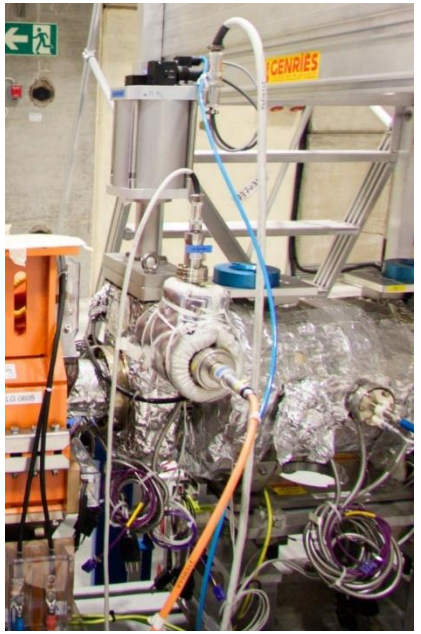


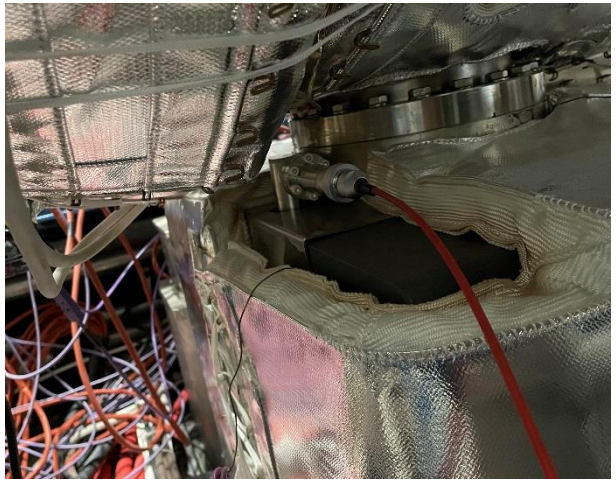
ELENA – Some vacuum equipment

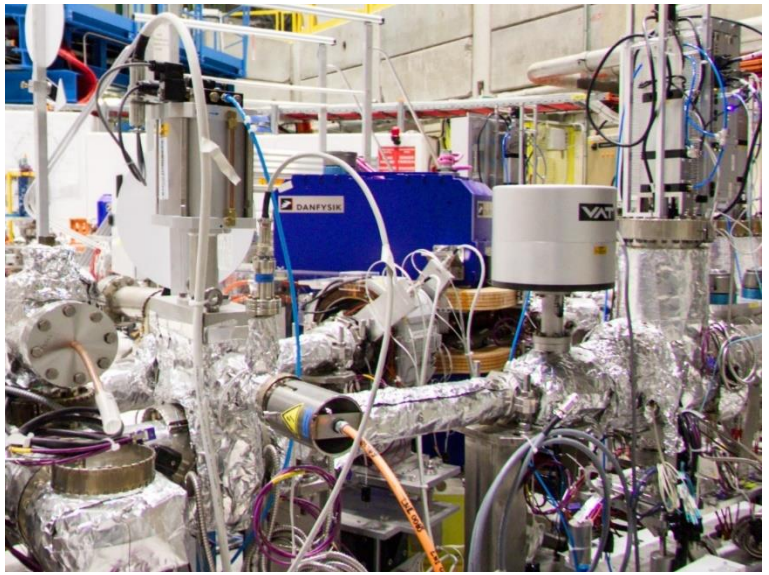


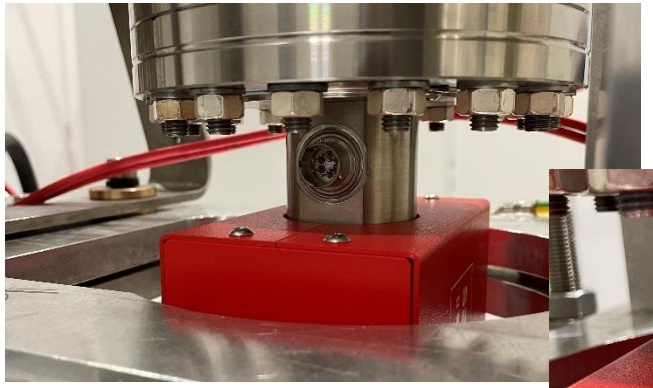


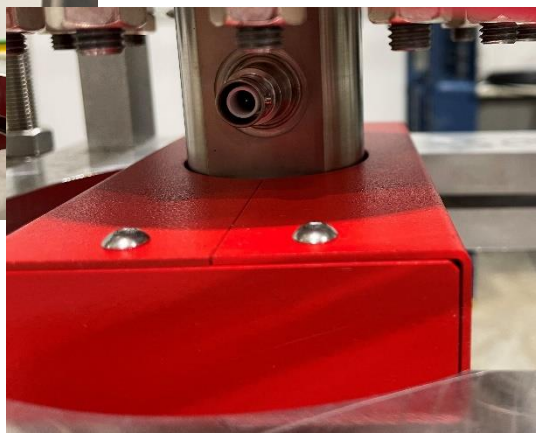






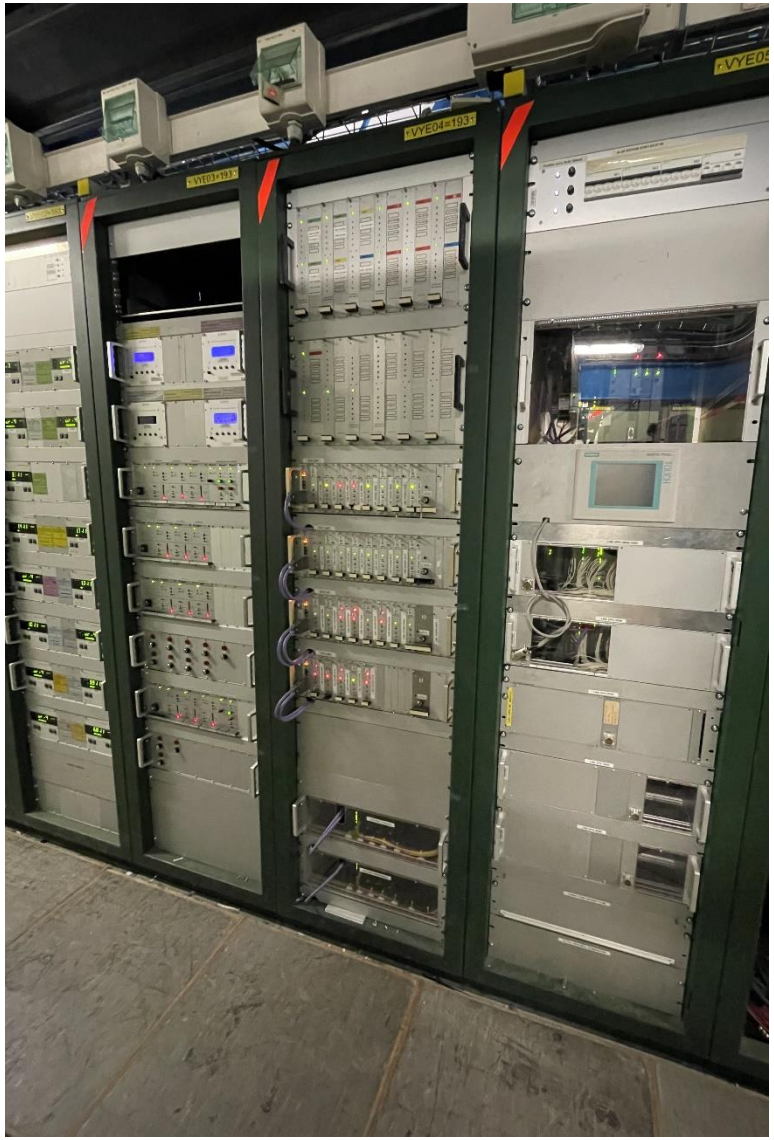




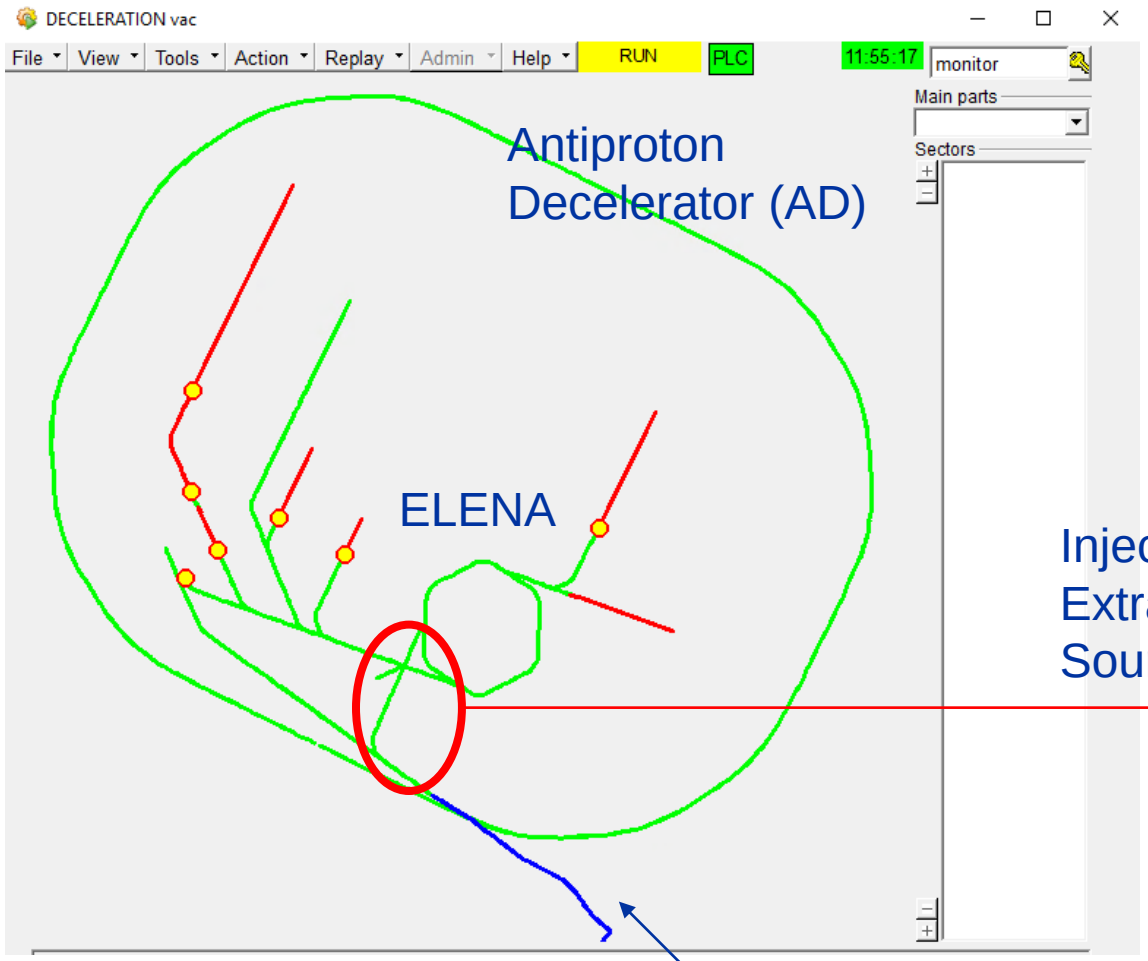


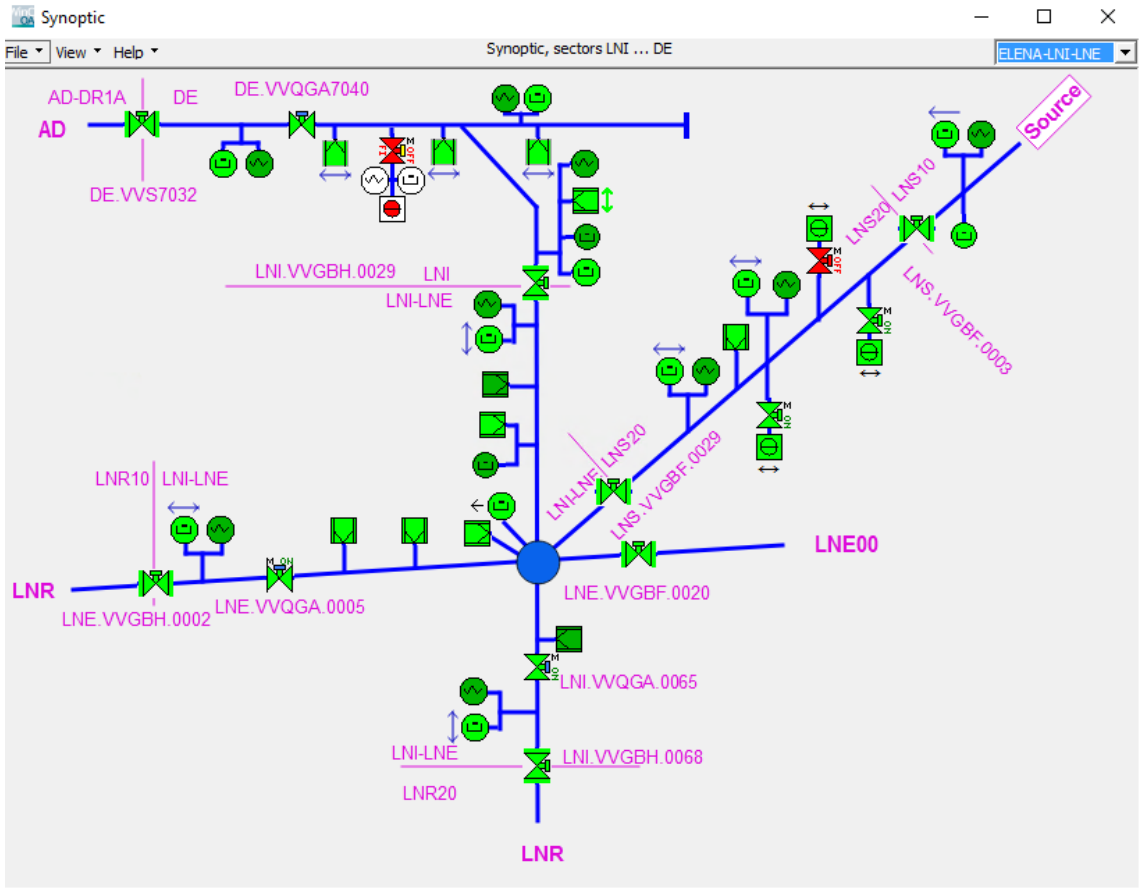
ELENA – Racks and controllers

ELENA – Racks and controllers

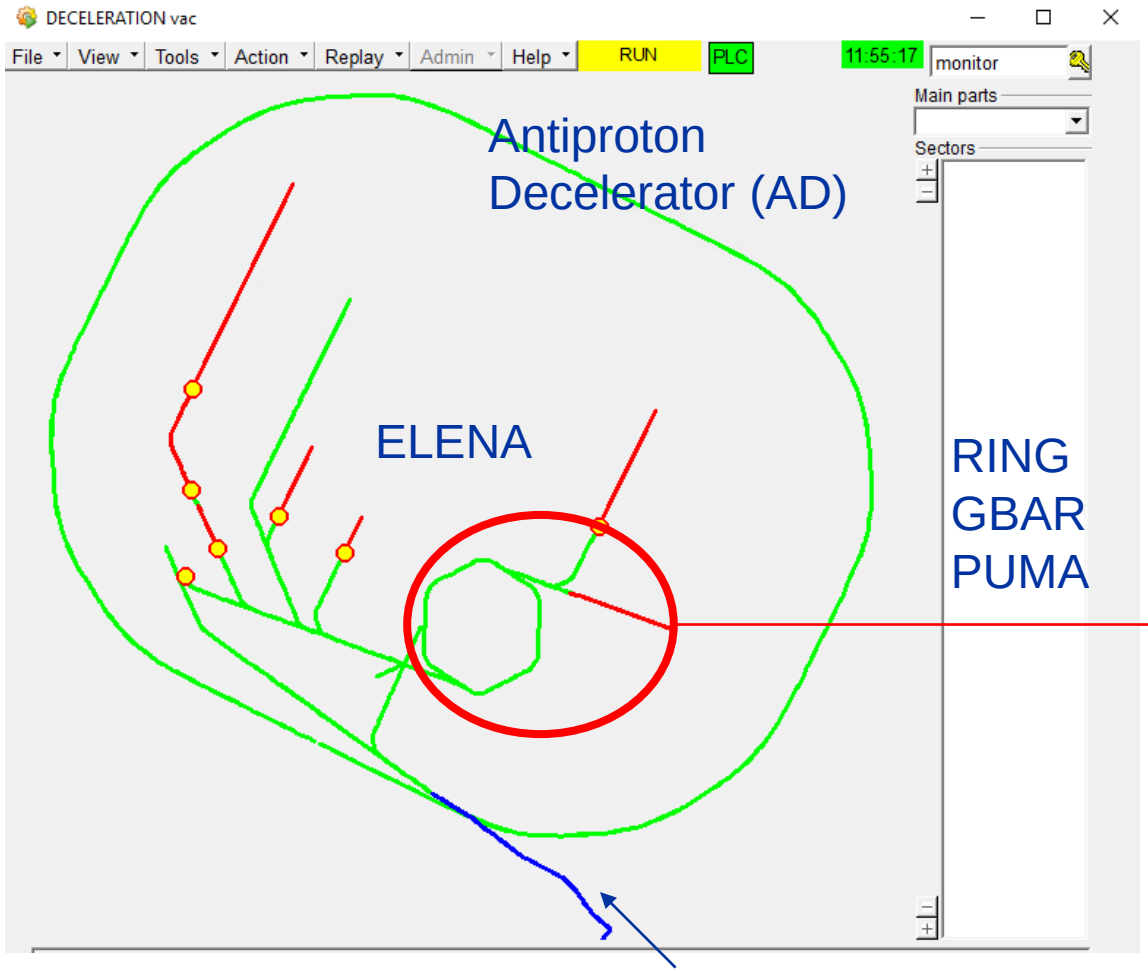


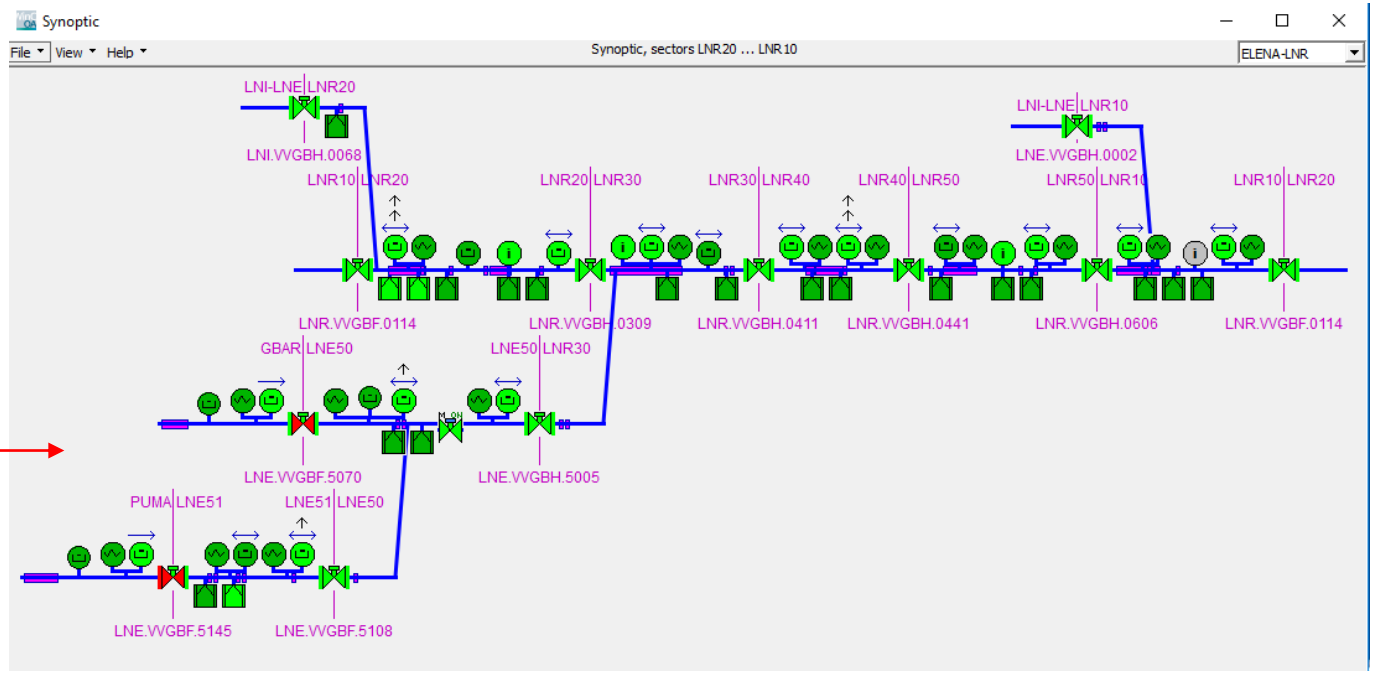
ELENA – SCADA (Injection, Extraction and Source)





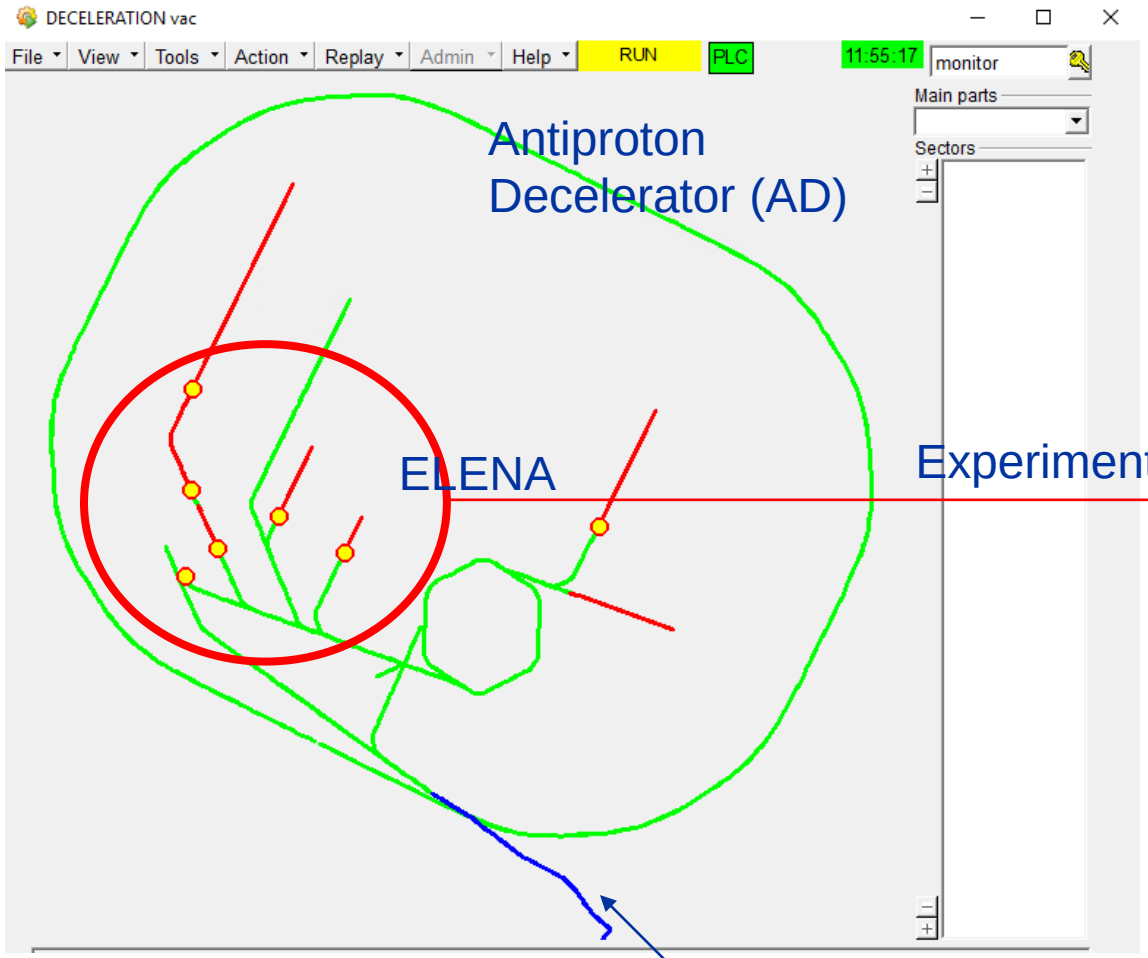
ELENA – SCADA (RING, GBAR, PUMA)

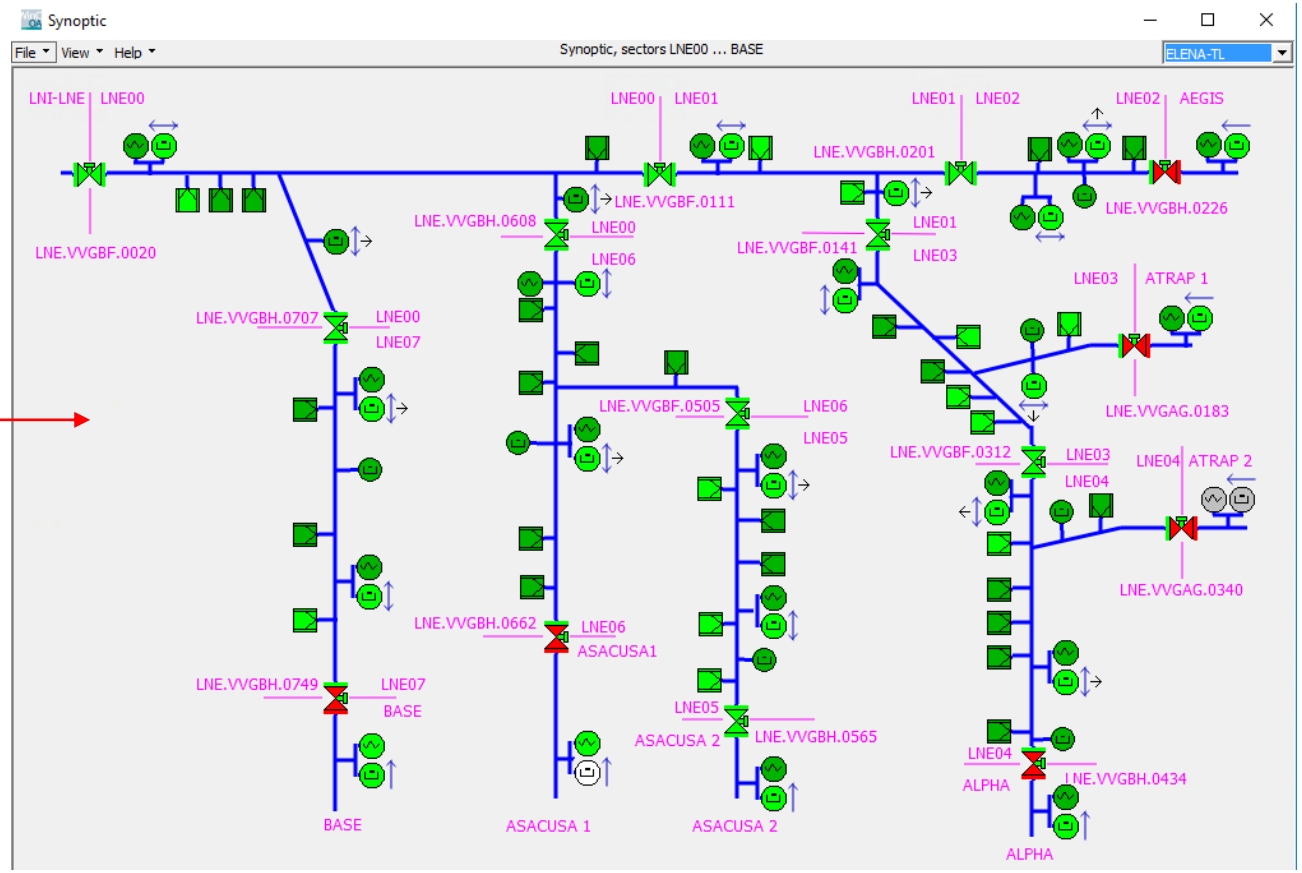




Beam from Proton
Synchrotron (PS)

ELENA – SCADA (BASE, ASACUSA, ALPHA, ATRAP, AEGIS)





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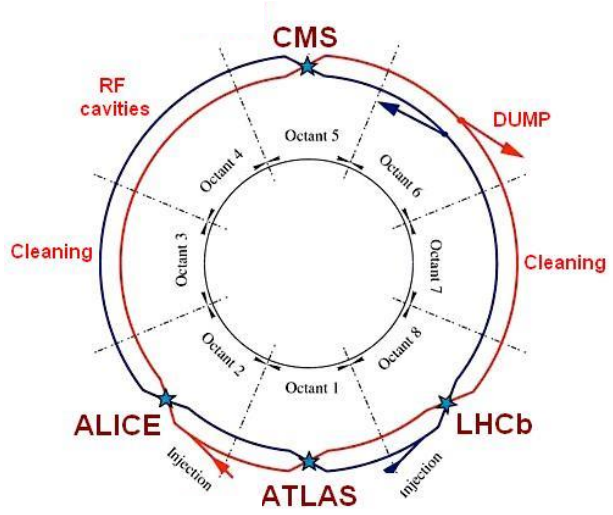
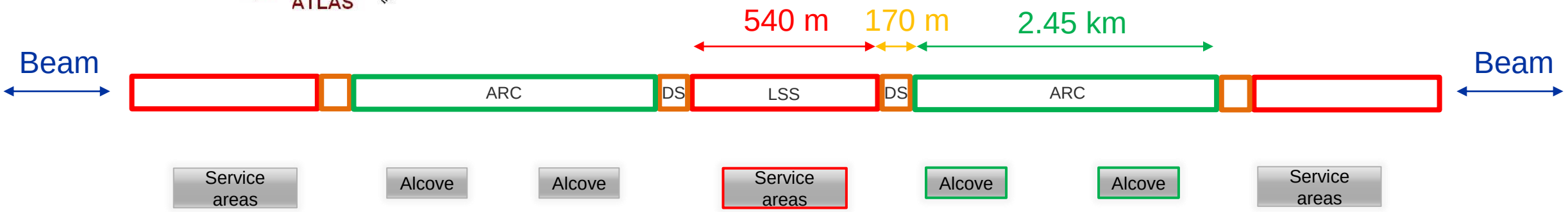
Radiation levels for HL-LHC



Dispersion **S**uppressor (up to 1 kGy/y)

- Radiation Tolerant electronics installed in the tunnel
- Non-radiation tolerant controllers installed in protected service areas
- Cable length up to **600** m



Long **S**traight **S**ection (up to 100 kGy/y)

- Only passive components
- Controllers installed in protected service areas
- Cable length up to **400** m

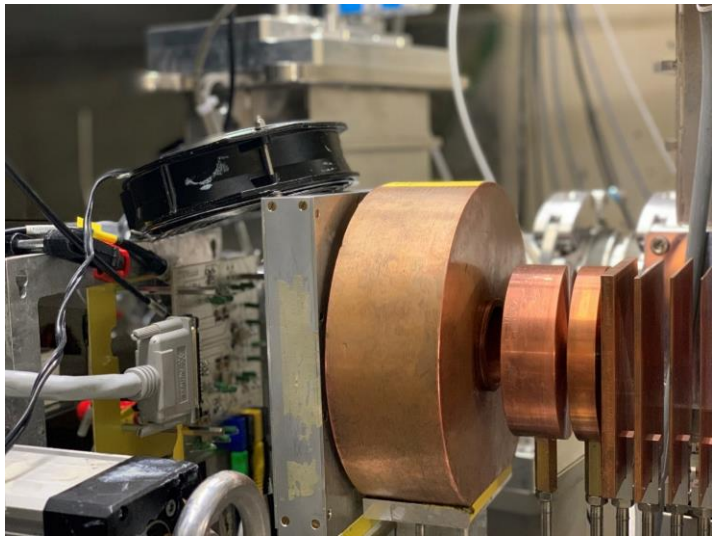
ARC (up to 14 Gy/y)

- Radiation Tolerant electronics installed in the tunnel
- Non-radiation tolerant controllers installed in the protected alcoves
- Cable length up to **1** km

Radiation tests on electronics

- **Component level test**: off-the-shelf component (COTS) batches are tested for radiation tolerance at **PSI** (**P**aul **S**cherrer **I**ntitute), external facility in Switzerland with proton beam

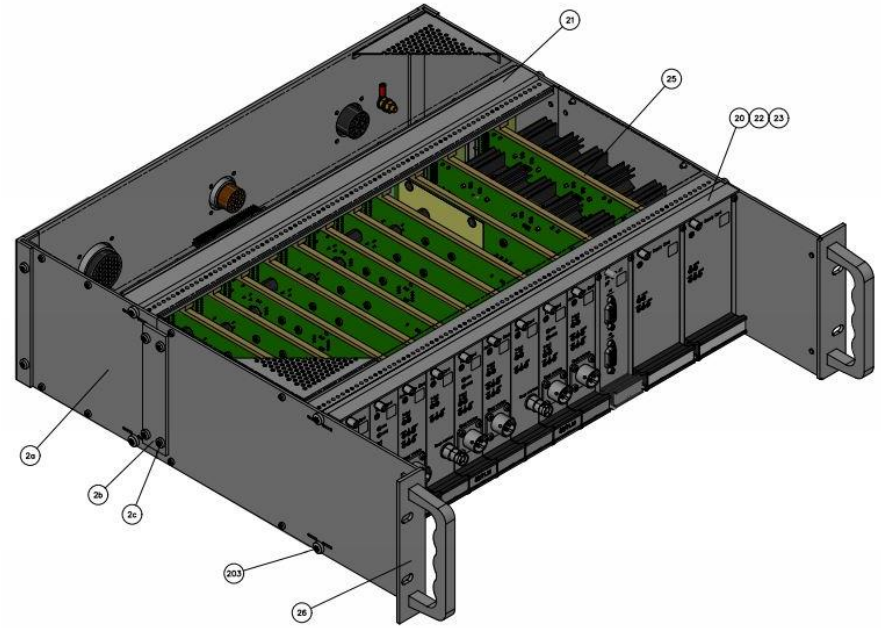
- **System level test**: Successfull batches tested at PSI are used to manufacture the electronic cards which are tested at **CHARM** (**C**ern **H**igh energy **A**ccele**R**ator **M**ixed field) facility with mixed field more representative of the real environment in the accelerators' tunnel



Component level test at PSI

System level test at CHARM

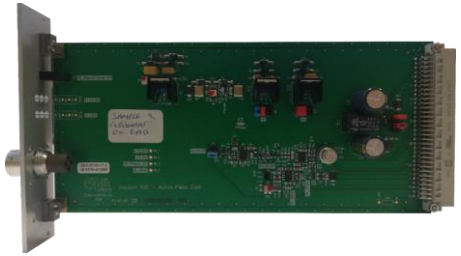
Radiation Tolerant Electronics for vacuum gauges



Penning

Pirani

Piezo



- Production, testing and calibration of **1300** cards and **180** crates before 2026 (LS3)

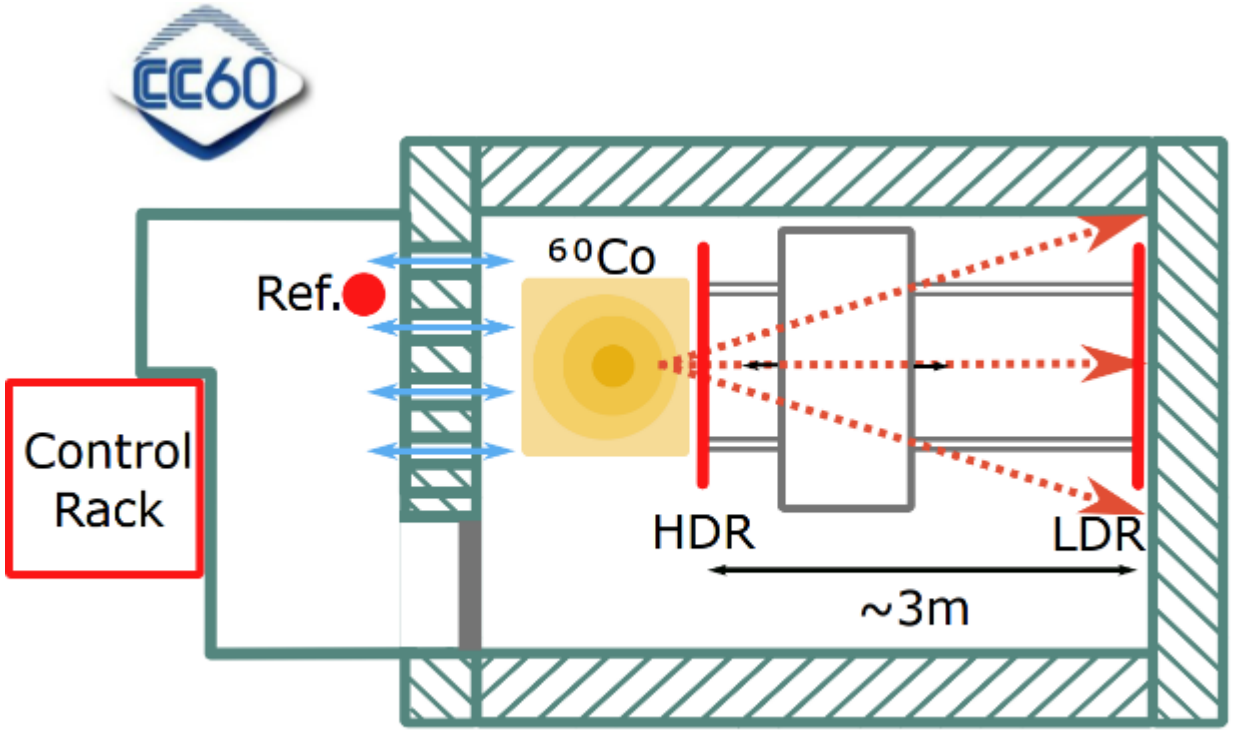
By-Pass valve local control

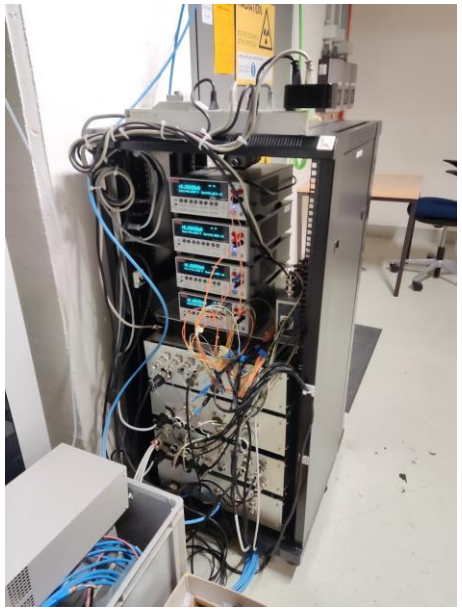
Profibus Active Termination

Power Supply

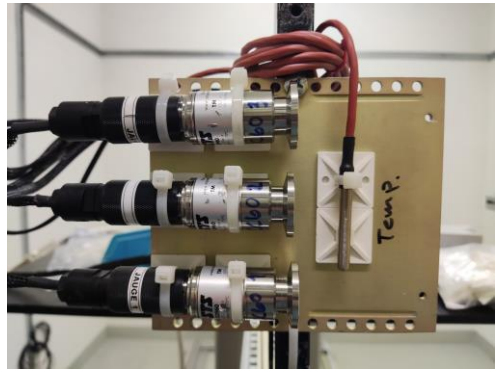
Radiation tests on vacuum gauge

- Both component and system level tests can also be performed with Gamma at **CC60** (**C**ERN **C**obalt-**60**)
  - Pro: no material activation, flexibility
  - Cons: less representative of the real conditions in the accelerators compared to CHARM

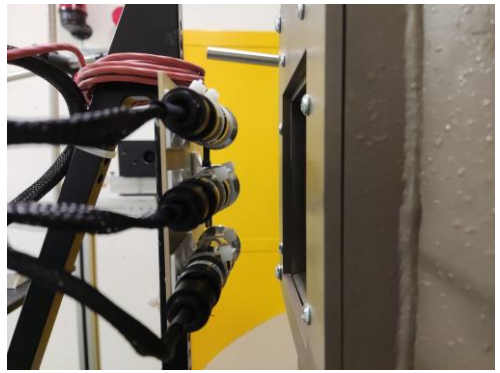




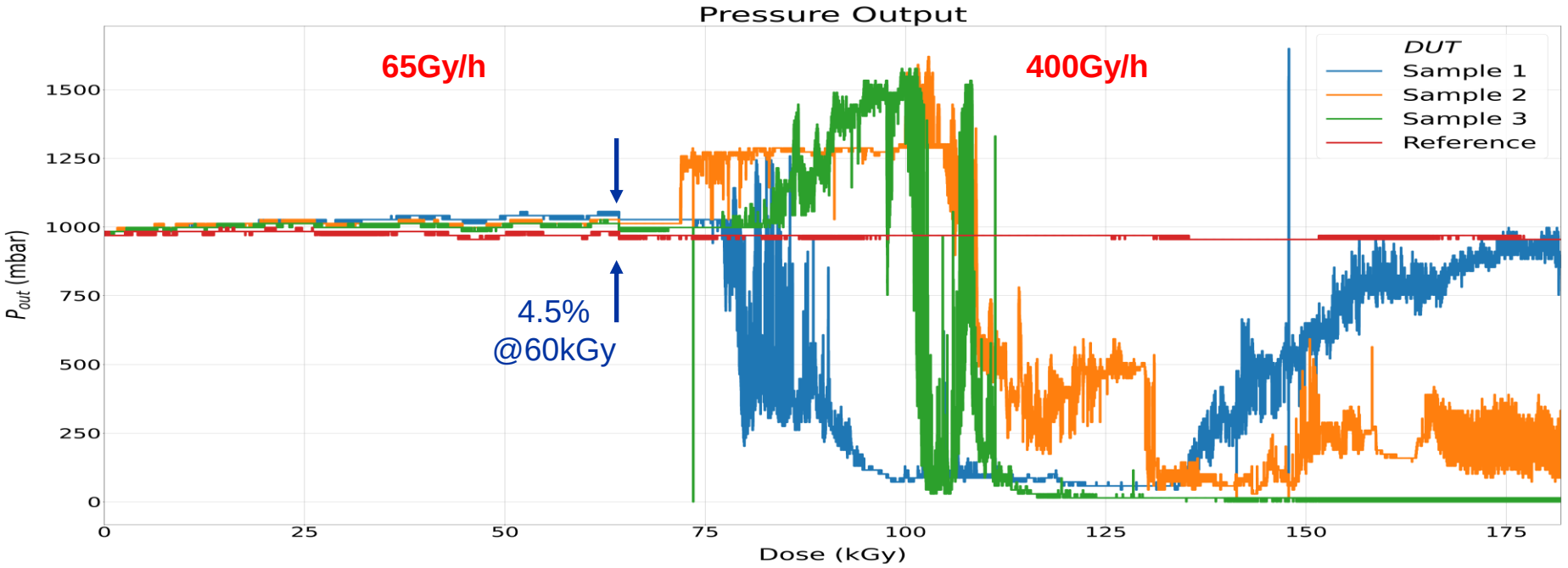
Data acquisition rack

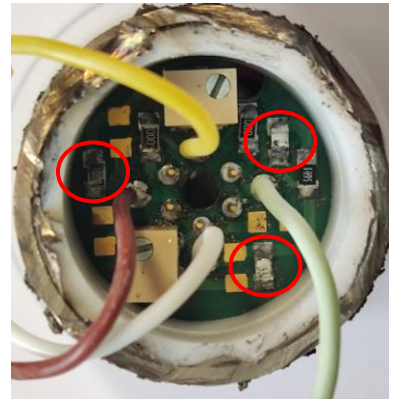


Piezo-resisitive gauges and source



Passive Piezo-resistive gauge

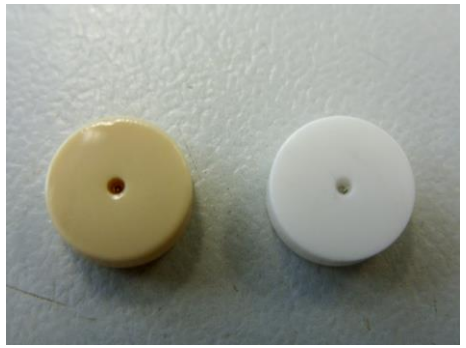




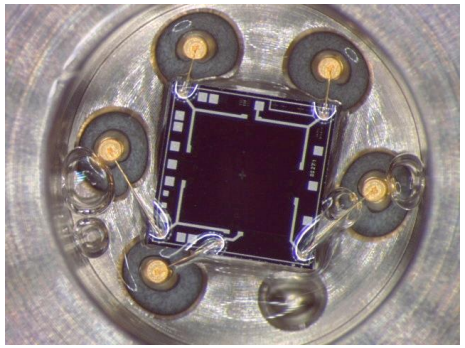
Bridge resistances affected

Stainless steel membrane in normal condition

Membrane removed
Discoloration of sintered ceramic



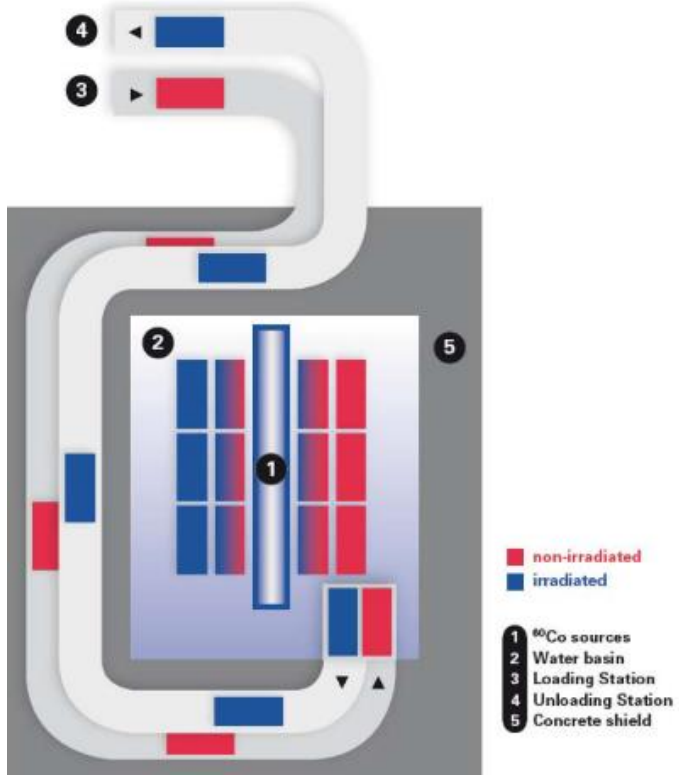
Comparison of sintered ceramic



Chip no abnormality
Viscosity of oil seems unchanged

Radiation tests on materials

- **Gamma irradiation** of vacuum devices in the **MGy** range to study and validate there tolerance
  - Irradiation performed in **external facilities** (e.g. BGS, Steris)
  - Pre/Post irradiation tests performed at CERN (and external laboratory for eleastomer characterization)



BGS facility conveyor

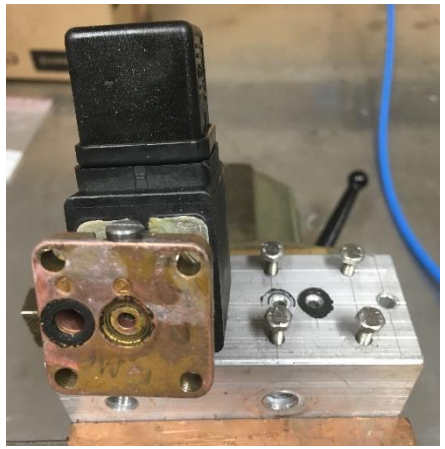
Electro-pneumatic devices

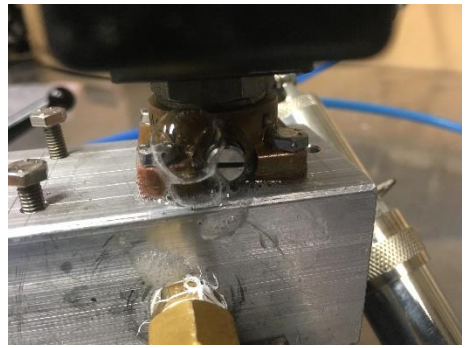
Vacuum assemblies with O-rings

Electropneumatic devices

Electropneumatic motor failed at 5MGy due to brittle blades and affected grease.

Piezo-electric distributor failed at 0.5MGy due to the piezo-electric element and leaking degraded body gaskets.





Electro-pneumatic distributor failed after 0.5MGy due to leaking degraded O-rings.

- Radiation tolerant seals and O-rings
- Radiation tolerant grease and oil
- Radiation tolerant cables and connectors

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(Vacuum) Control Hardware – needs in view of HL-LHC

- **Irradiation facility**
  - Proton, neutron, gamma facilities for material and electronics irradiation

- **Radiation tolerant instruments and material**
  - Gauges (Piezo-resitive)
  - Elastomer EPM/EPDM (O-ring)
  - Grease and oil

- **Cables and connectors**
  - Signal (LV, HV) and power cables and connectors, for (non)radiative environments

- **Electronics**
  - PCB production and assembly
  - Radiation tolerant components
    - FPGA, uC, DC/DC converter, ADC/DAC

- **Controllers**
  - Chassis assembly (mechanical, cabling)
  - PLC modules, protection circuits, control and power modules

Vacuum Control Software maintenance - Outsourcing

- **SCADA Applications (every 3 to 5 years)**
  - WinCC-OA 3.16 (3.19)
    - QT version
    - Microsoft Visual Studio
    - Data Server Operating System
    - Terminal Server Operating System
- **Web Applications (every 3 years, should occur in 2024)**
  - Backend Services
    - JDK
    - Spring Boot
  - FrontEnd
    - Javascript
    - React – Ant-design
- **Logging Infrastructure (every year)**
  - FileBeat, Logstach, Elastic, Kibana
- **Monitoring Infrastructure (every year)**
  - Grafana, Prometheus

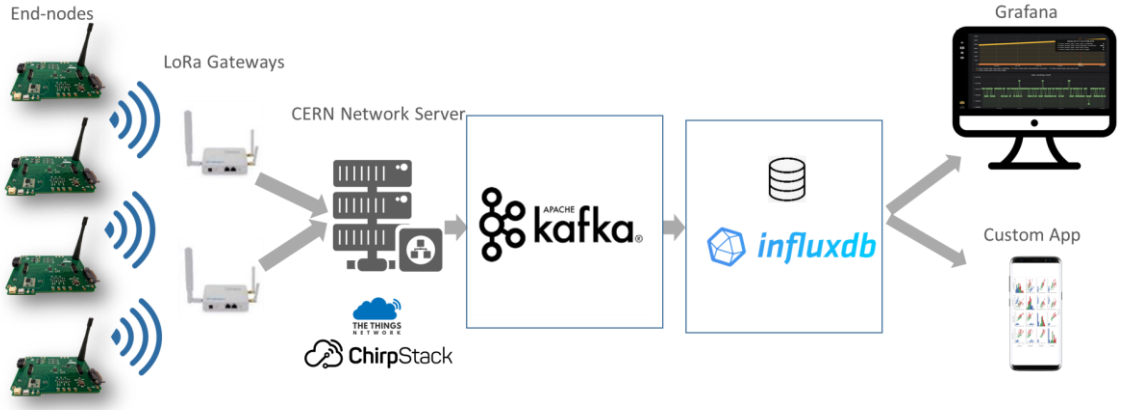
Wireless communication in the accelerators

- **Wireless technologies allow:**
  - Quick connectivity
  - Easy installation and upgrade
  - **Reduction of the cabling cost**

- **Wireless network (IoT)**
  - LoRaWAN (Long Range Wide Area Network) already implemented at CERN
  - Mainly for monitoring, predictive maintenance
  - Very limited and non-real time

- **Industrial wireless network (IIoT)**
  - Real time communication, reliability
  - For monitoring and control
  - WorldFIP Wireless: ongoing studies at CERN

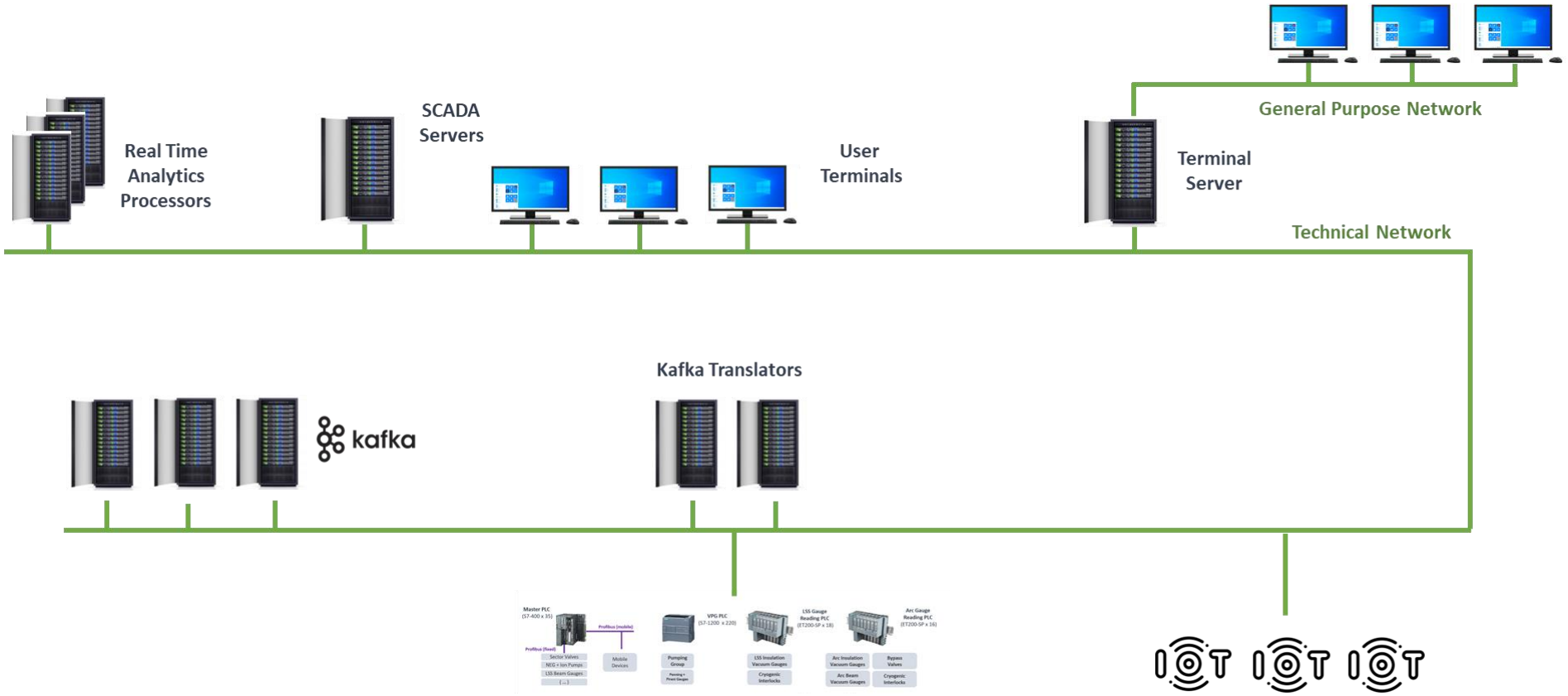
- **Radiation tolerance**
  - Both wired and wireless filedbuses imply local radiation tolerant electronics
  - Challenge in term of reliability



LoRaWAN used for radiation monitoring along the accelerators
Courtesy of S. Danzeca

Streaming architecture

- **Increasing number of devices and amount of data**
  - **Data pipeline –** allows to move large amounts of data between the different parts of the control system
  - **Advanced real time data analytics** – increasingly important on large scale systems with huge amounts of data to analyze
  - **Integration of IoT devices**
  - **And more**



Thank you for your attention!

Questions?