The vacuum control system at CERN

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TE
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Vacuum at CERN
Why accelerators need vacuum

Control System Architecture
How the vacuum control system is structured

Configuration Infrastructure
How we manage configuration and deploy our control system

Limitations to scalability
Is there any roadblock for a larger system ?

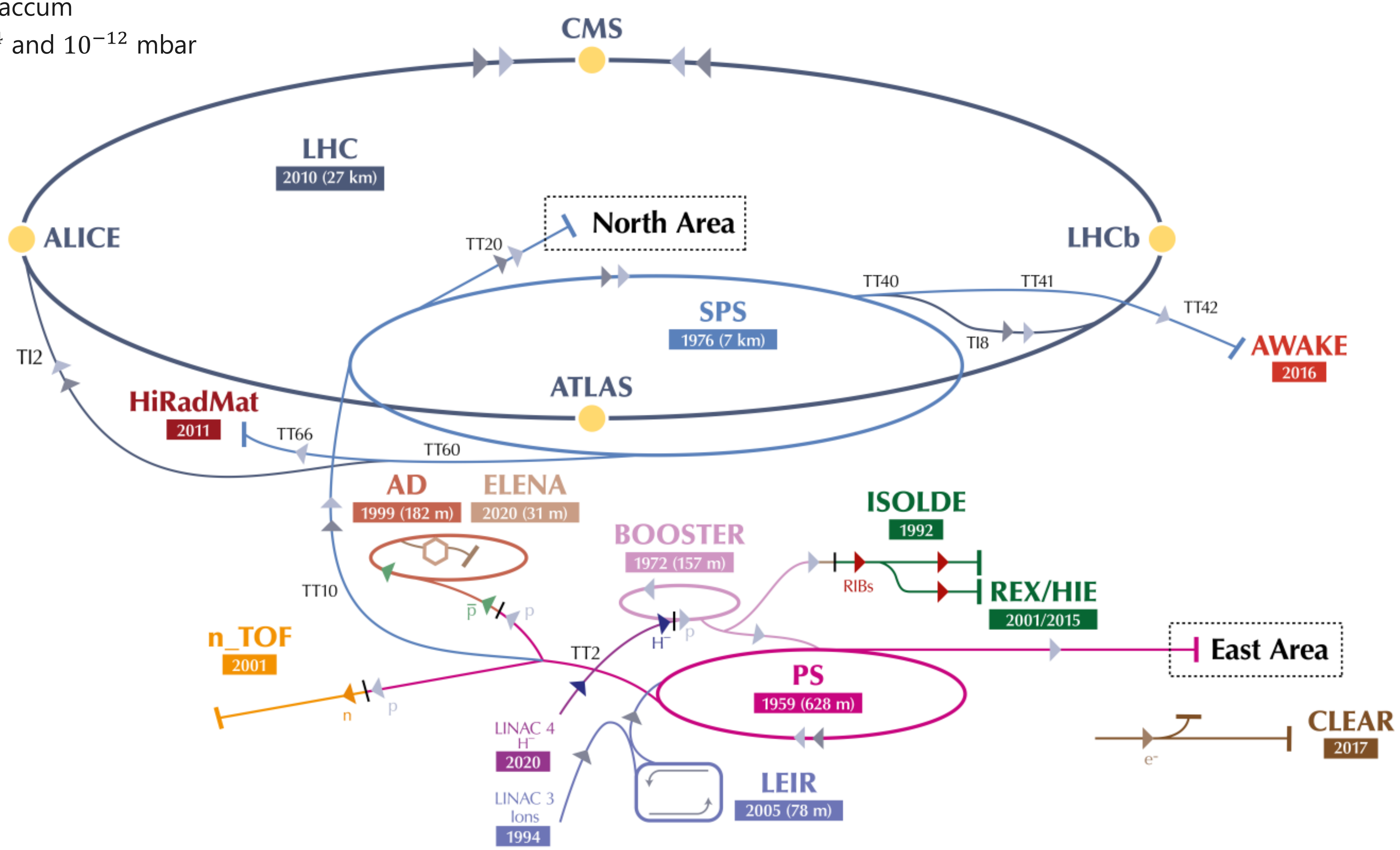
Trends and a Possible Future Architecture
What if we had to build FCC today ?

Conclusions
Key takeaways

Vacuum at CERN

127 km of lines under vaccum

Pressures between 10^{-4} and 10^{-12} mbar



Pressure on LHC beam lines is between 10^{-10} and 10^{-11} mbar

10 times less than the pressure on the moon

The Beam


HONDA
Claro
ESSO
33
citrix
HONDA
HYBRID
Red Bull
P ZERO
PIRELLI
RAUCH
telcel
Mobil 1

Gas Molecules

Beam in Vacuum

Beam Vacuum

Objective:

Reduce the interaction between the beam and residual gas molecules

- **Increased Beam Lifetime**
  Less particles lost at each turn
- **Increased Beam Stability**
  Less interference to beam dynamics
- **Increased Beam Luminosity**
  Better focused beam
- **Reduced Experiment Background noise**
  Less scattered particles

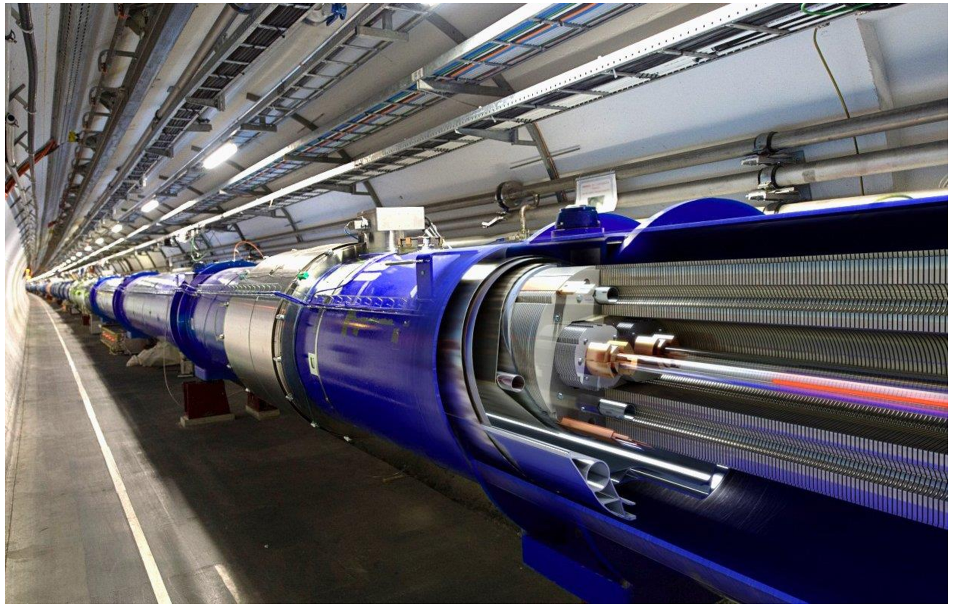
Insulation Vacuum

Objective:

Thermal insulation for magnets and helium distribution

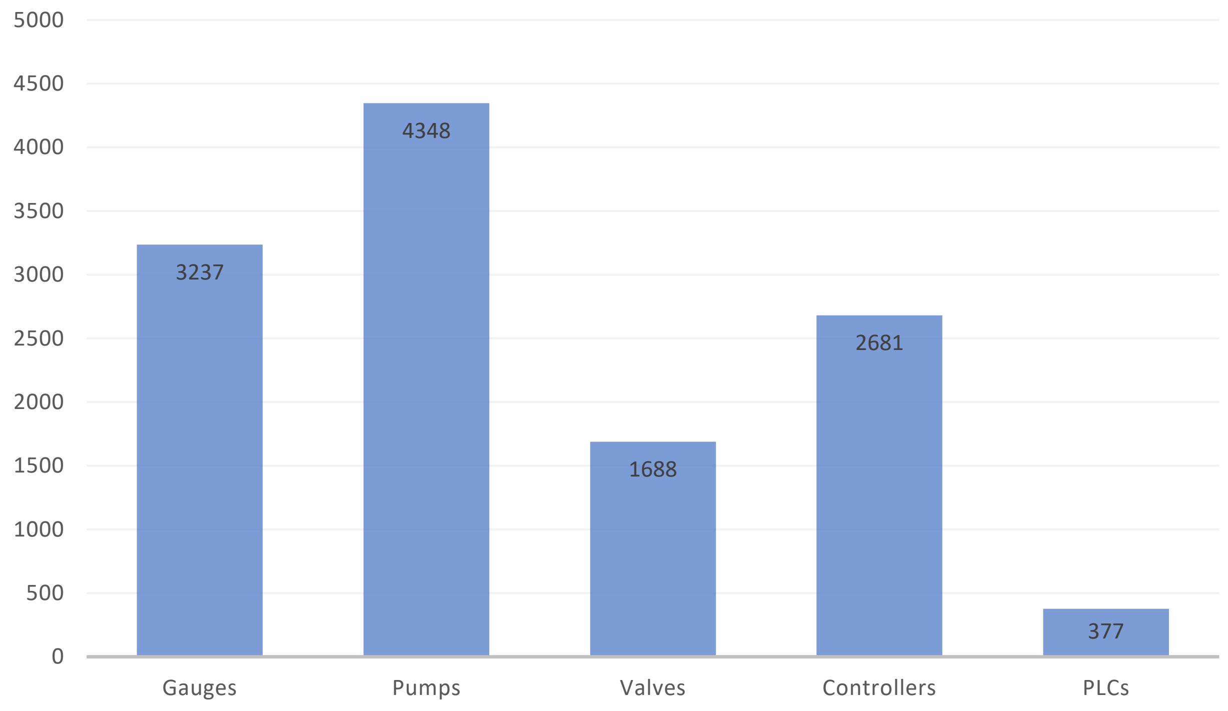
- To guide the beam, 1200 8T magnets are used
- Current of 12kA
- Superconductivity is necessary
  - 0 electrical resistivity
  - Reduced size of conductors
- Superconductivity achieved with liquid Helium
- Vacuum is used as thermal insulator for magnets and helium distribution

LHC Dipole

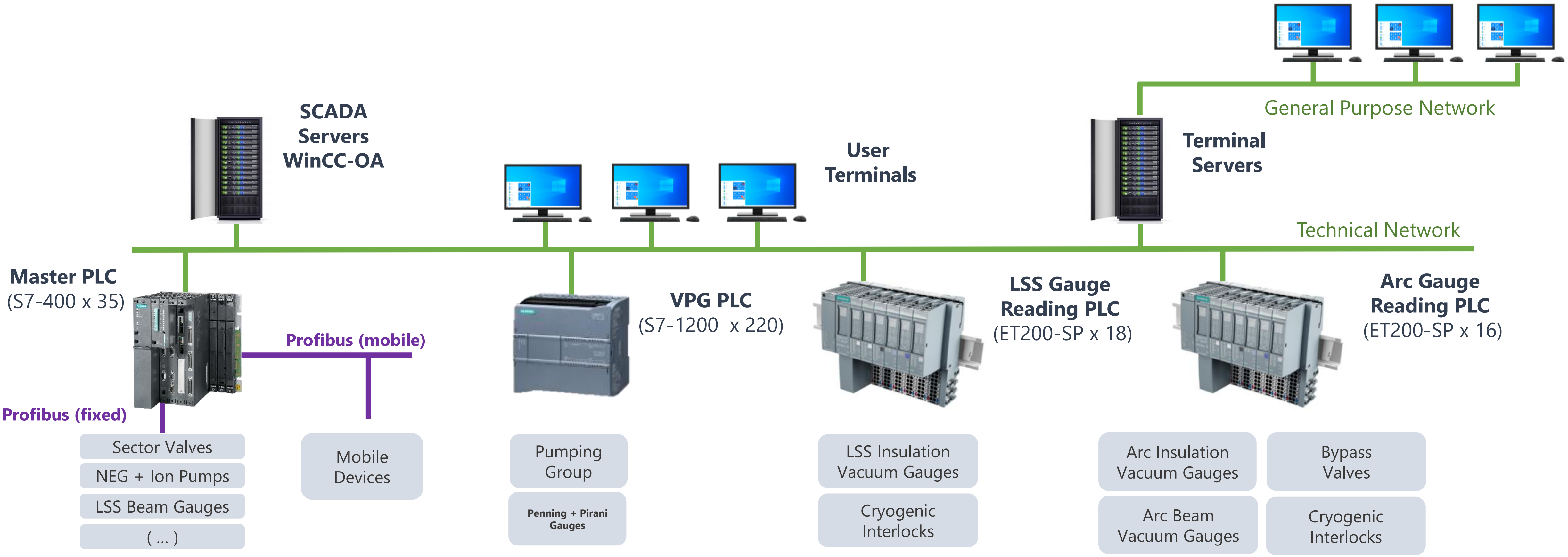


Process Equipment **numbers**

Vacuum is achieved and monitored by over 12000 pieces of control equipment

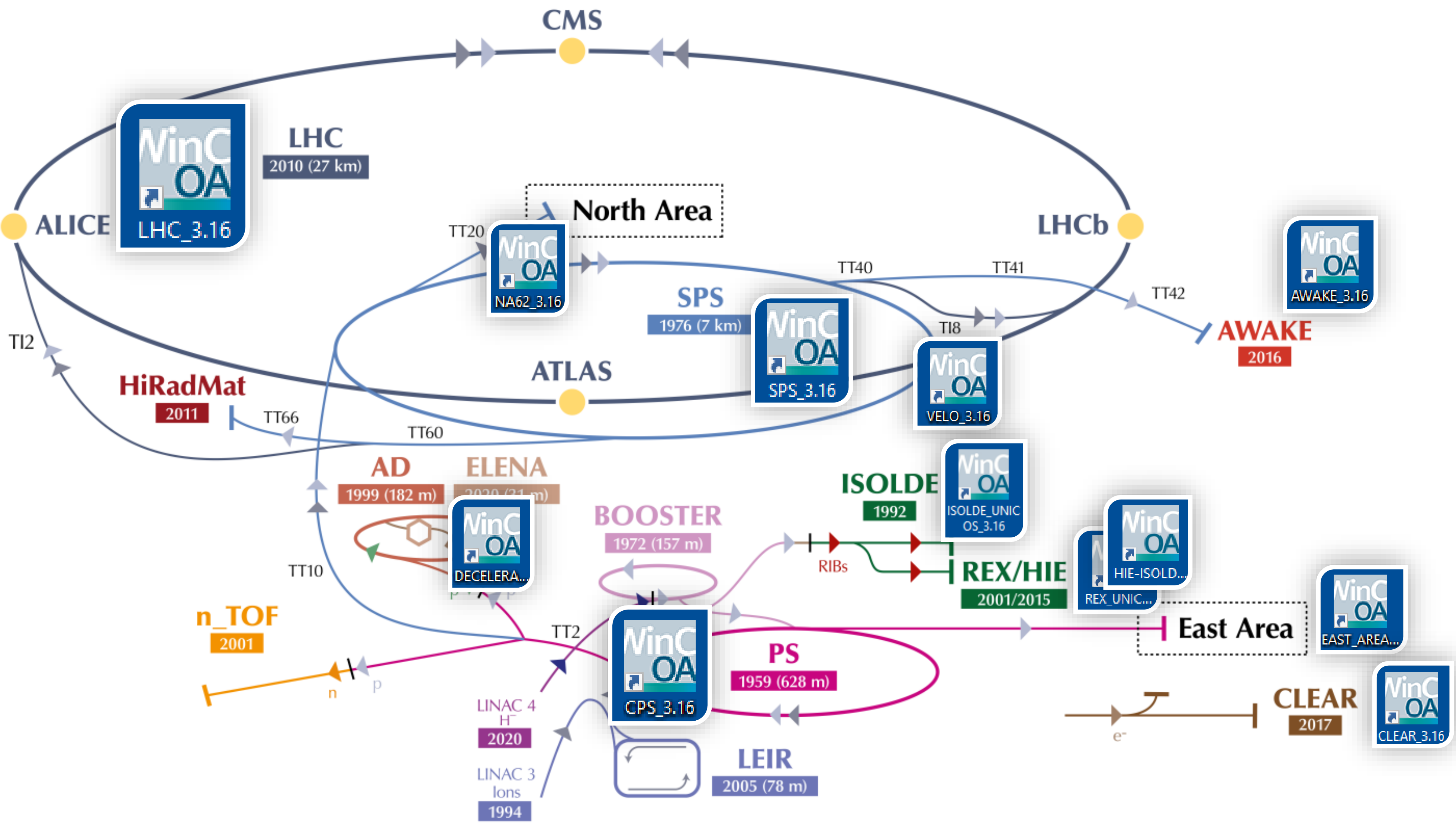


Control System Architecture



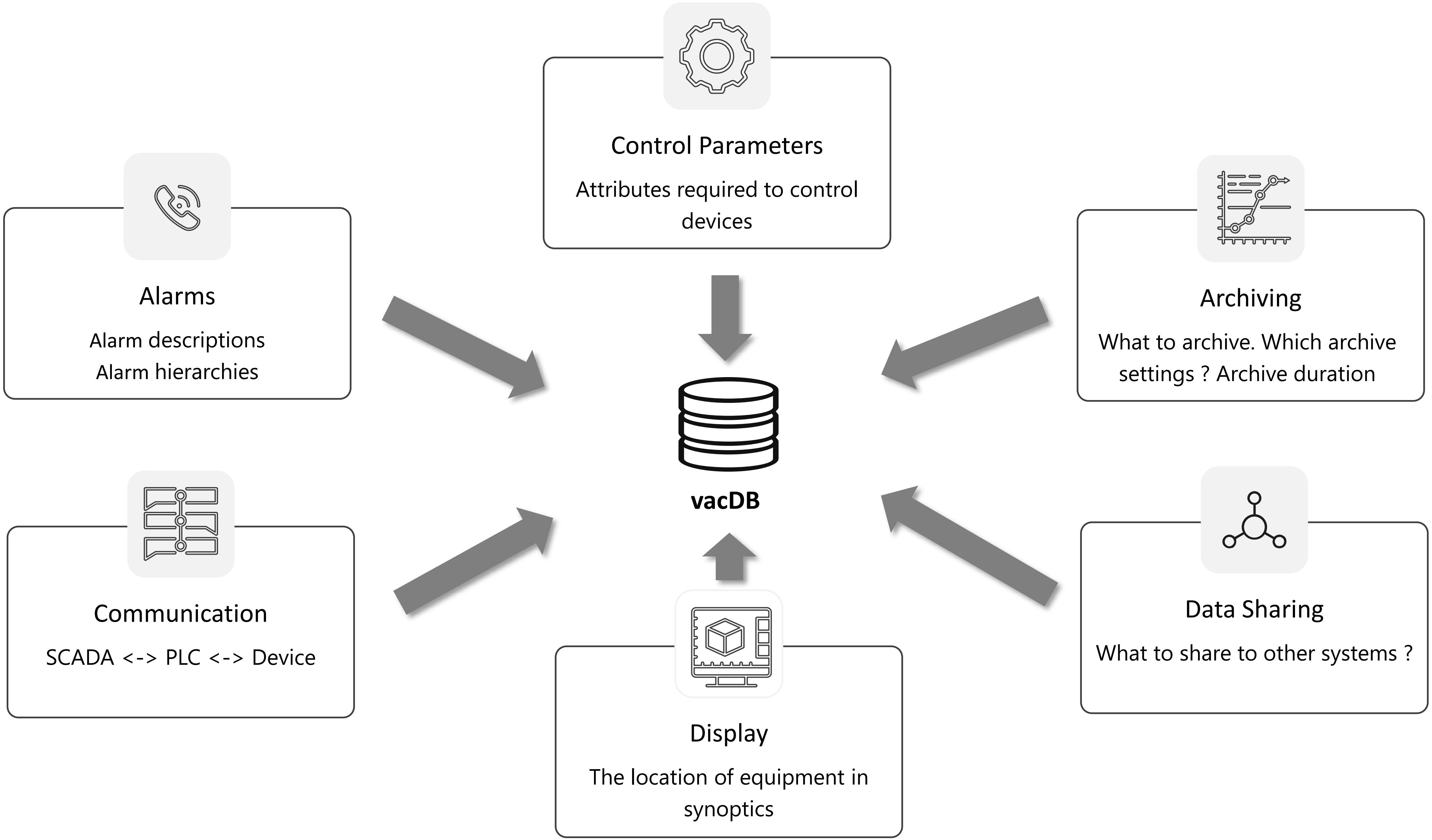
SCADA Applications

as of 2023



Configuration settings numbers

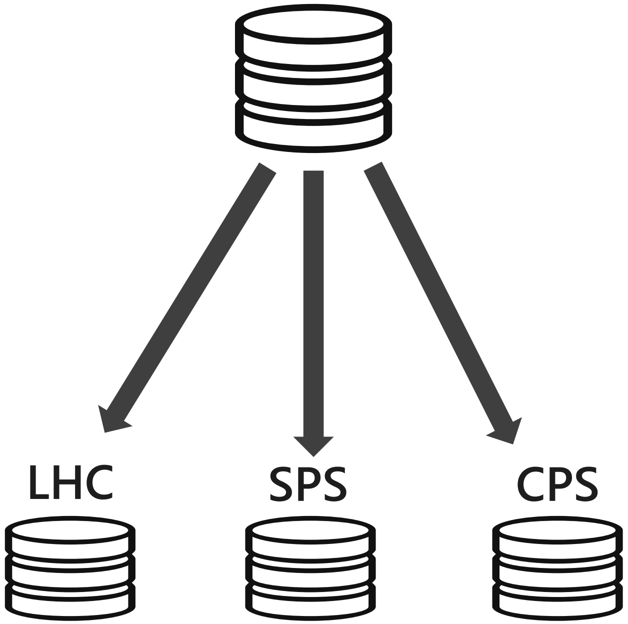
LHC	SPS	CPS
617 632	147 315	100 783


Control Parameters
Attributes required to control devices
Alarms
Alarm descriptions
Alarm hierarchies
Archiving
What to archive. Which archive settings ? Archive duration
vacDB
Communication
SCADA <-> PLC <-> Device
Data Sharing
What to share to other systems ?
Display
The location of equipment in synoptics

Vacuum Databases

Master DB

Machine DBs



Master Database

For each device type:

- Definition of Vacuum Equipment Types
- Definition of Attributes
- Definition of Default Attribute values
- Definition of Communication block
- Definition of SCADA datapoint type
- Definition of alarms produced

Machine Databases

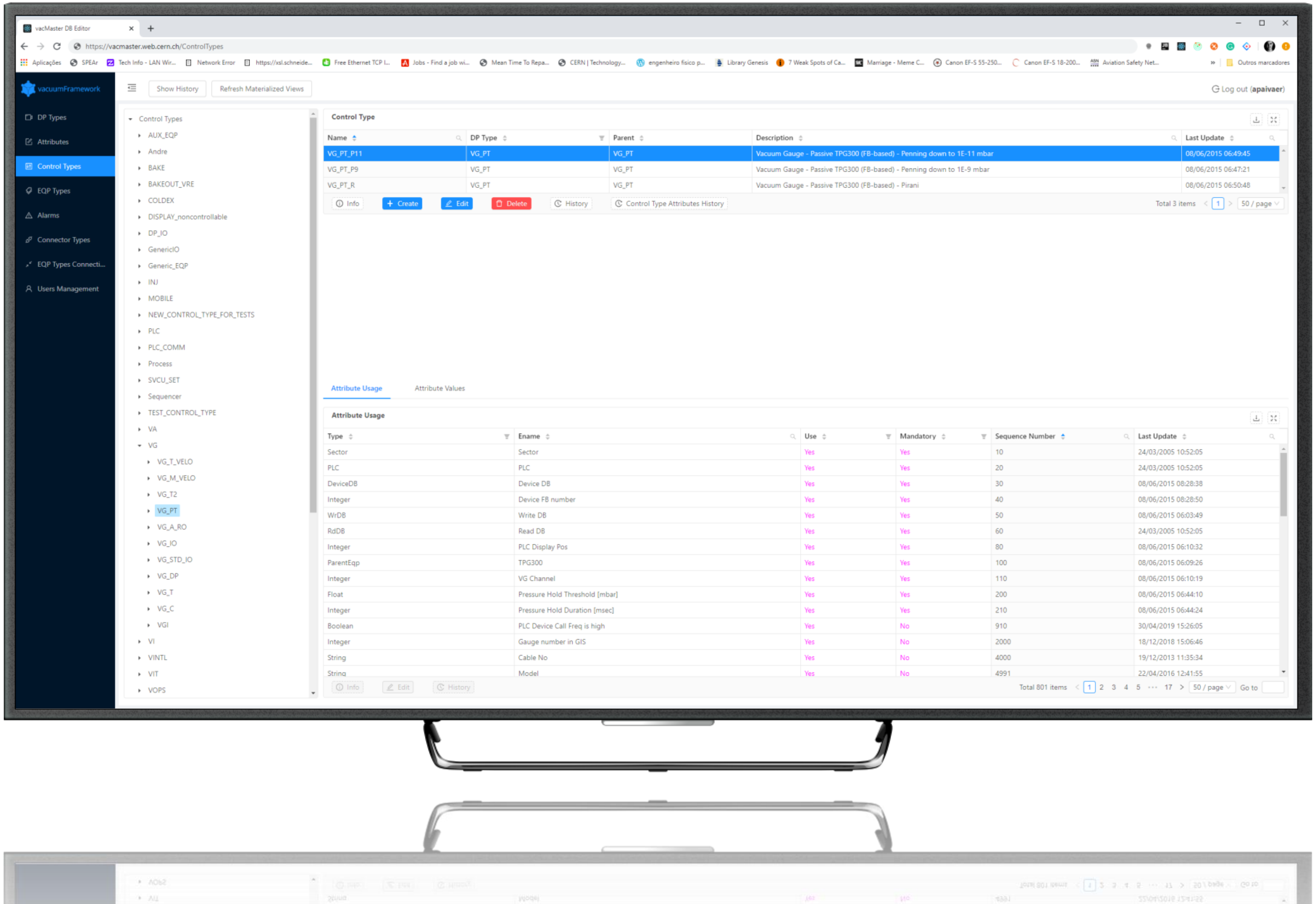
Instantiation of equipment
Specification of equipment attributes
Specification of archiving settings
Specification of data sharing

vacCC Master

The metadata editor

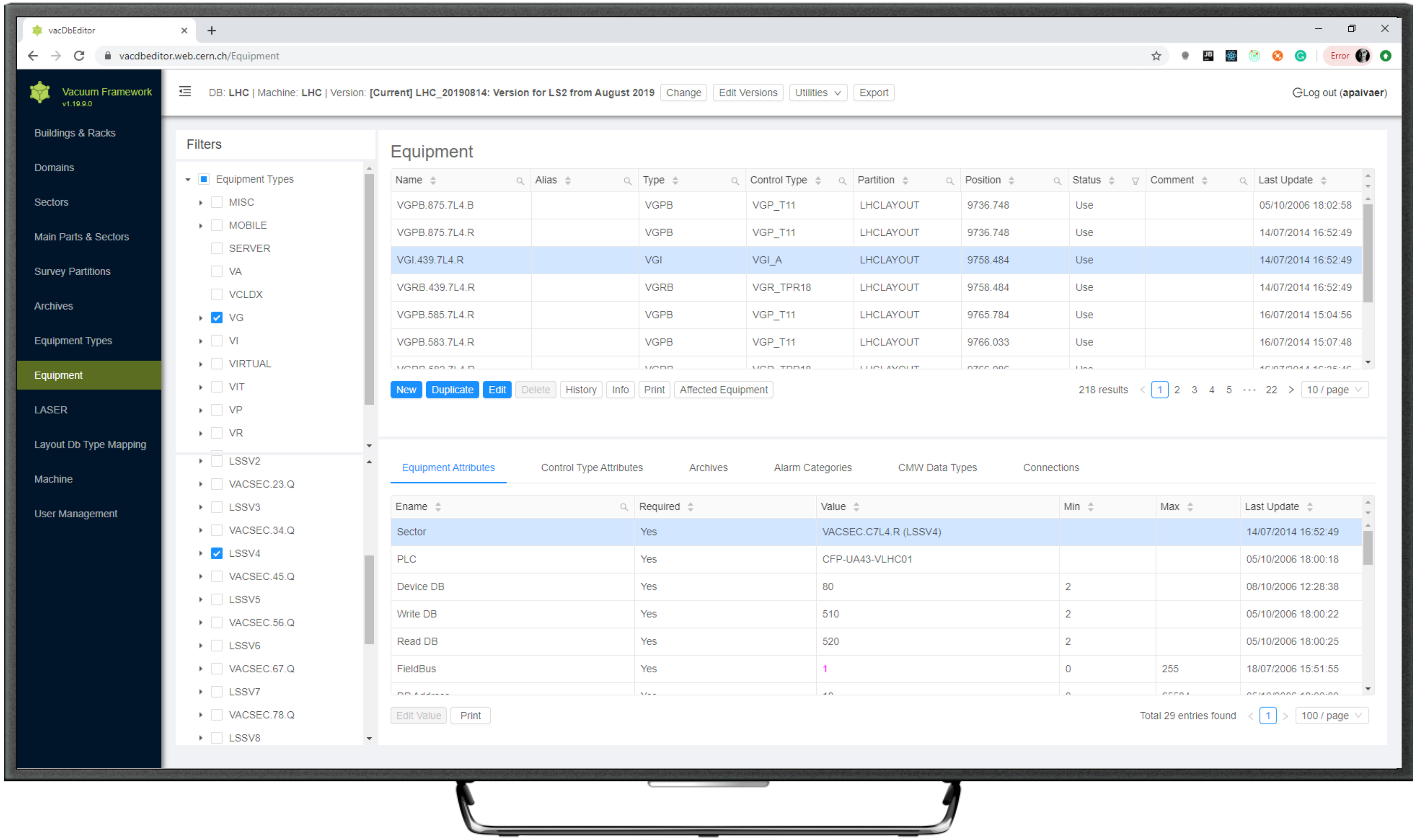
Used by SCADA developers

Definition of defaults for each eqp type



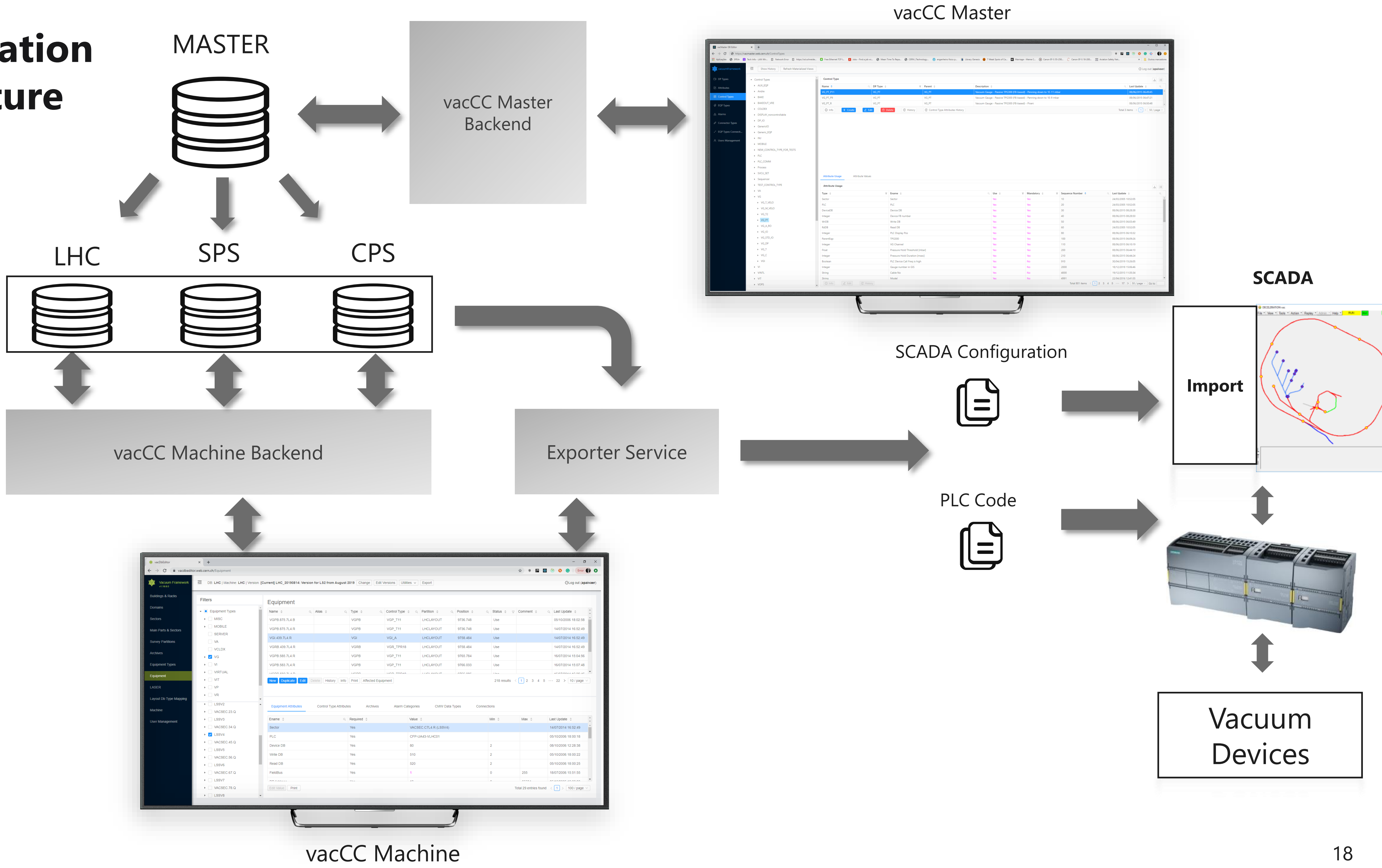
vacCC Machine

- The editor for the machine databases
- Allows integration of equipment in the control system by non software experts
- Full traceability



Configuration Architecture

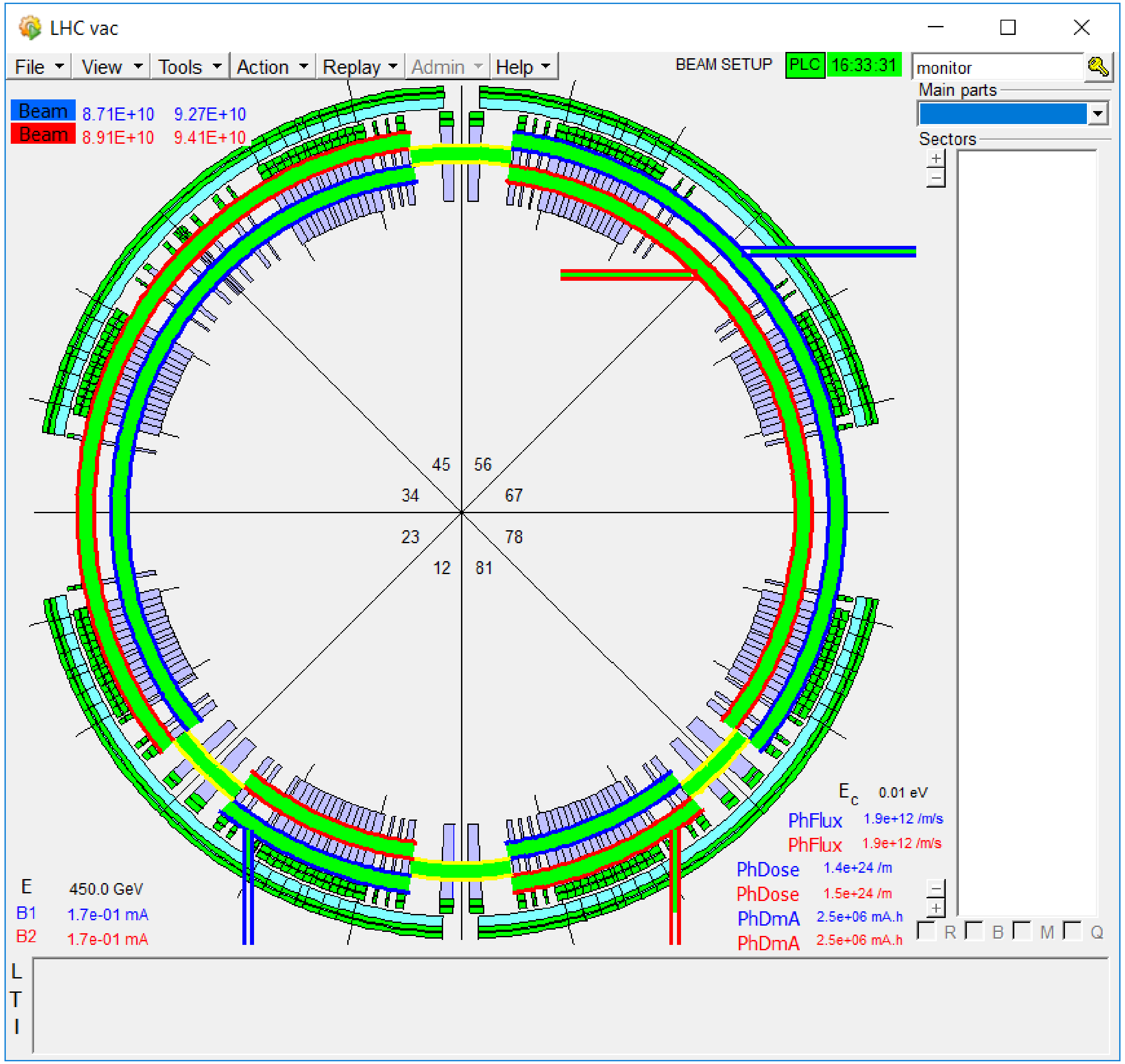
Data flow



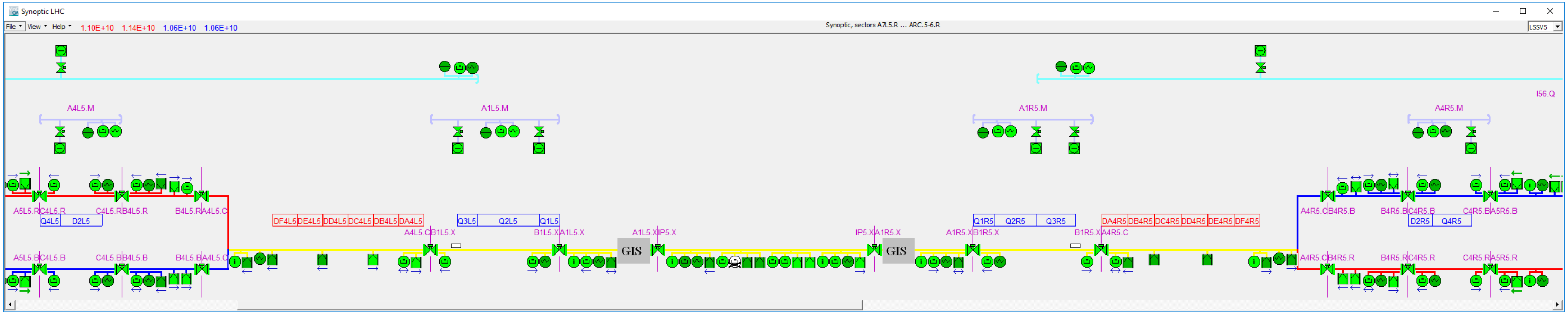
Advantages of Database-Driven Configuration Engineering Tools

- **Cross-layer consistency**
  - Changes of parameters are propagated to all relevant layers of the control system
- **Data integrity**
  - Configuration integrity and consistency done by defining rules for data validation and constraints
- **Assessibility**
  - Multiple people can work in the configuration of the control system at the same time
- **Versioning**
  - Have different versions of the control system ready in advance according to the needs of operations
- **History**
  - Log every change. Know what changed, when it changed and who changed what.

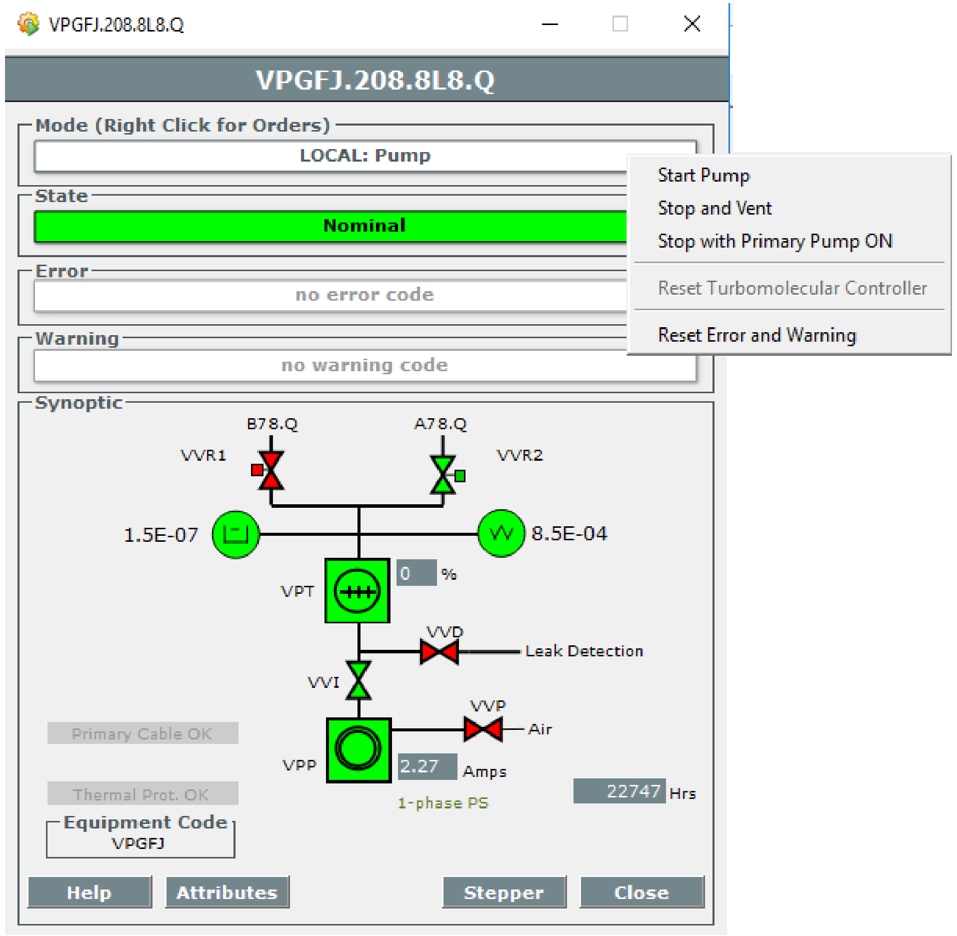
SCADA
User Interface



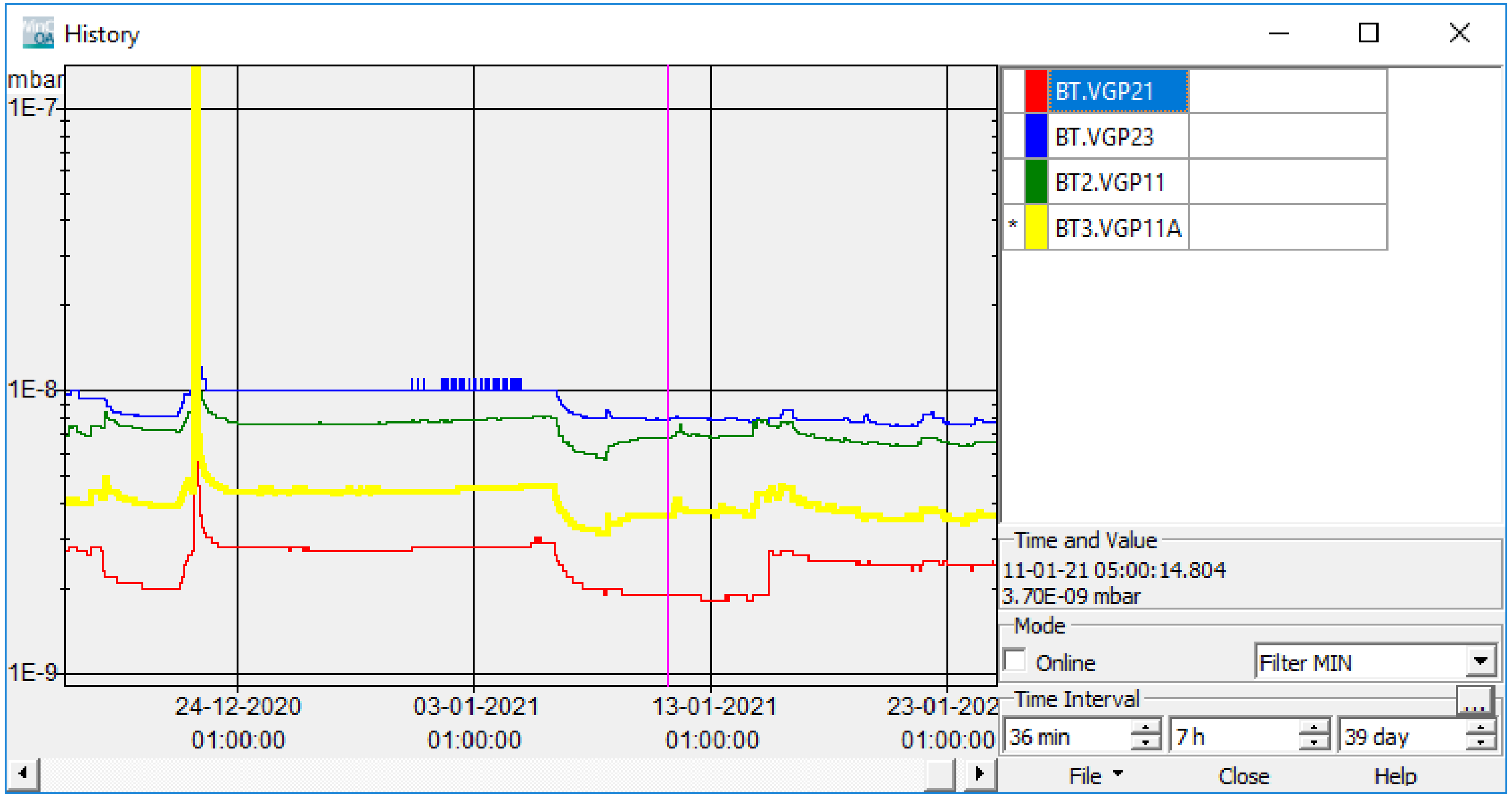
Automatic Synoptic Drawing



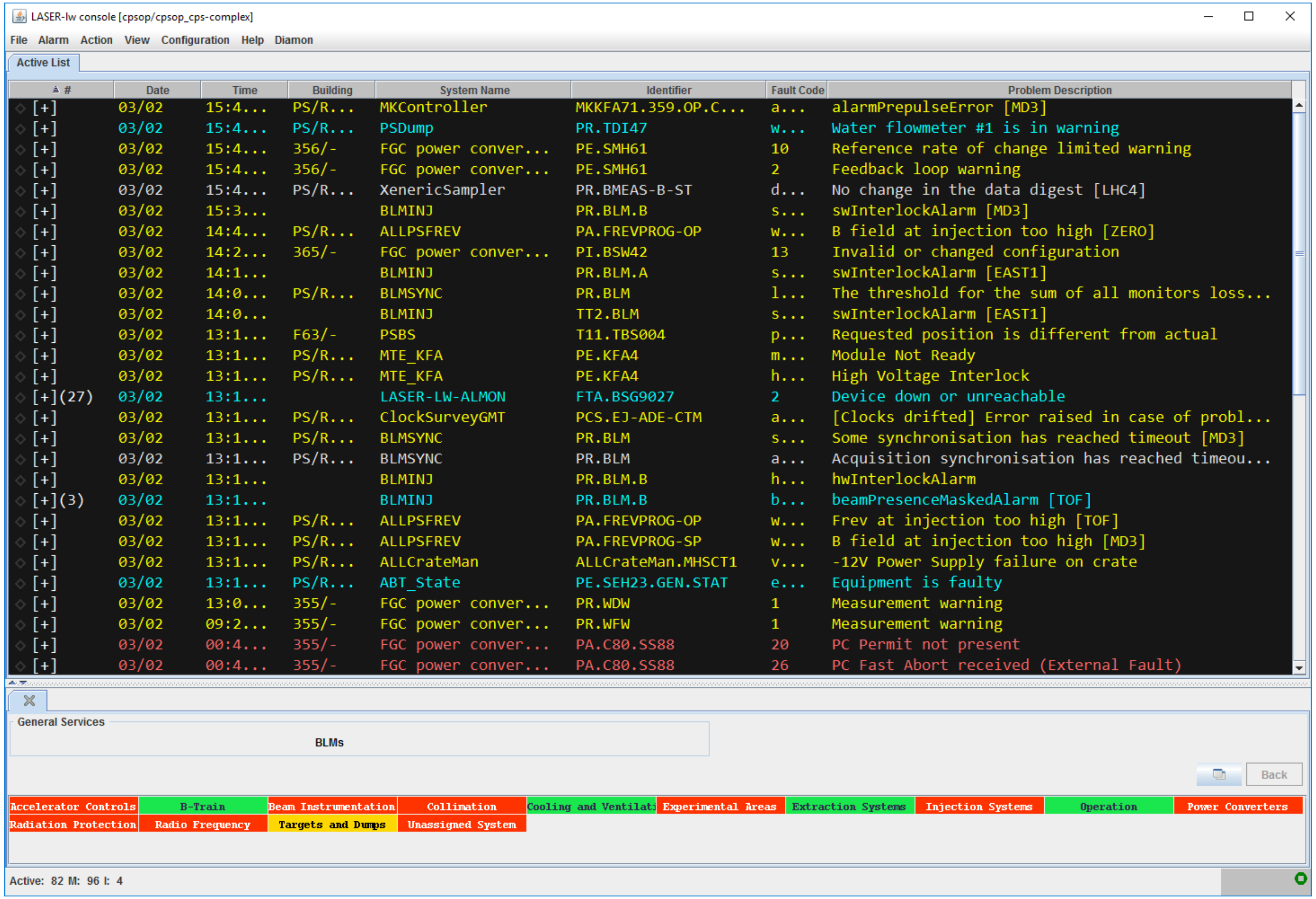
Equipment Details Panel



Archiving


History
mbar
1E-7
1E-8
1E-9
24-12-2020
01:00:00
03-01-2021
01:00:00
13-01-2021
01:00:00
23-01-202
01:00:00
BT.VGP21
BT.VGP23
BT2.VGP11
* BT3.VGP11A
Time and Value
11-01-21 05:00:14.804
3.70E-09 mbar
Mode
Online
Filter MIN
Time Interval
36 min
7 h
39 day
File
Close
Help

Alarms


LASER-lw console [cpsop/cpsop_cps-complex]
File Alarm Action View Configuration Help Diamon
Active List
Date Time Building System Name Identifier Fault Code Problem Description
[+] 03/02 15:4... PS/R... MKController MKKFA71.359.OP.C... a... alarmPrepulseError [MD3]
[+] 03/02 15:4... PS/R... PSDump PR.TDI47 w... Water flowmeter #1 is in warning
[+] 03/02 15:4... 356/- FGC power conver... PE.SMH61 10 Reference rate of change limited warning
[+] 03/02 15:4... 356/- FGC power conver... PE.SMH61 2 Feedback loop warning
[+] 03/02 15:4... PS/R... XenericSampler PR.BMEAS-B-ST d... No change in the data digest [LHC4]
[+] 03/02 15:3... BLMINJ PR.BLM.B s... swInterlockAlarm [MD3]
[+] 03/02 14:4... PS/R... ALLPSFREV PA.FREVPROG-OP w... B field at injection too high [ZERO]
[+] 03/02 14:2... 365/- FGC power conver... PI.BSW42 13 Invalid or changed configuration
[+] 03/02 14:1... BLMINJ PR.BLM.A s... swInterlockAlarm [EAST1]
[+] 03/02 14:0... PS/R... BLMSYNC PR.BLM l... The threshold for the sum of all monitors loss...
[+] 03/02 14:0... BLMINJ TT2.BLM s... swInterlockAlarm [EAST1]
[+] 03/02 13:1... F63/- PSBS T11.TBS004 p... Requested position is different from actual
[+] 03/02 13:1... PS/R... MTE_KFA PE.KFA4 m... Module Not Ready
[+] 03/02 13:1... PS/R... MTE_KFA PE.KFA4 h... High Voltage Interlock
[+](27) 03/02 13:1... LASER-LW-ALMON FTA.BSG9027 2 Device down or unreachable
[+] 03/02 13:1... PS/R... ClockSurveyGMT PCS.EJ-ADE-CTM a... [Clocks drifted] Error raised in case of probl...
[+] 03/02 13:1... PS/R... BLMSYNC PR.BLM s... Some synchronisation has reached timeout [MD3]
[+] 03/02 13:1... PS/R... BLMSYNC PR.BLM a... Acquisition synchronisation has reached timeou...
[+] 03/02 13:1... BLMINJ PR.BLM.B h... hwInterlockAlarm
[+](3) 03/02 13:1... BLMINJ PR.BLM.B b... beamPresenceMaskedAlarm [TOF]
[+] 03/02 13:1... PS/R... ALLPSFREV PA.FREVPROG-OP w... Frev at injection too high [TOF]
[+] 03/02 13:1... PS/R... ALLPSFREV PA.FREVPROG-SP w... B field at injection too high [MD3]
[+] 03/02 13:1... PS/R... ALLCrateMan ALLCrateMan.MHSCT1 v... -12V Power Supply failure on crate
[+] 03/02 13:1... PS/R... ABT_State PE.SEH23.GEN.STAT e... Equipment is faulty
[+] 03/02 13:0... 355/- FGC power conver... PR.WDW 1 Measurement warning
[+] 03/02 09:2... 355/- FGC power conver... PR.WFW 1 Measurement warning
[+] 03/02 00:4... 355/- FGC power conver... PA.C80.SS88 20 PC Permit not present
[+] 03/02 00:4... 355/- FGC power conver... PA.C80.SS88 26 PC Fast Abort received (External Fault)
General Services
BLMs
Back
Accelerator Controls
B-Train
Beam Instrumentation
Collimation
Cooling and Ventilati
Experimental Areas
Extraction Systems
Injection Systems
Operation
Power Converters
Radiation Protection
Radio Frequency
Targets and Dumps
Unassigned System
Active: 82 M: 96 I: 4

WinCC-OA Limitations to Scalability

(known) factors that may eventually limit our current architecture

Source: https://www.winccoa.com/documentation/WinCCOA/3.18/en_US/Installation/Operating_Conditions.html

Devices and datapoint elements

Maximum number of datapoint elements: ~16M

Implications on memory and CPU load

LHC: currently at 400.000

Memory and CPU

Average CPU load by event manager should be < 20%

Summarized average CPU of all WinCC-OA processes (drivers, event, data, ctrl) should be < 50 %

LHC Total CPU load < 3% / Event Manager Load 10% on single core

LHC currently at 14GB/256GB memory usage

Number of PLC Connections

Maximum number of 512 connections per system

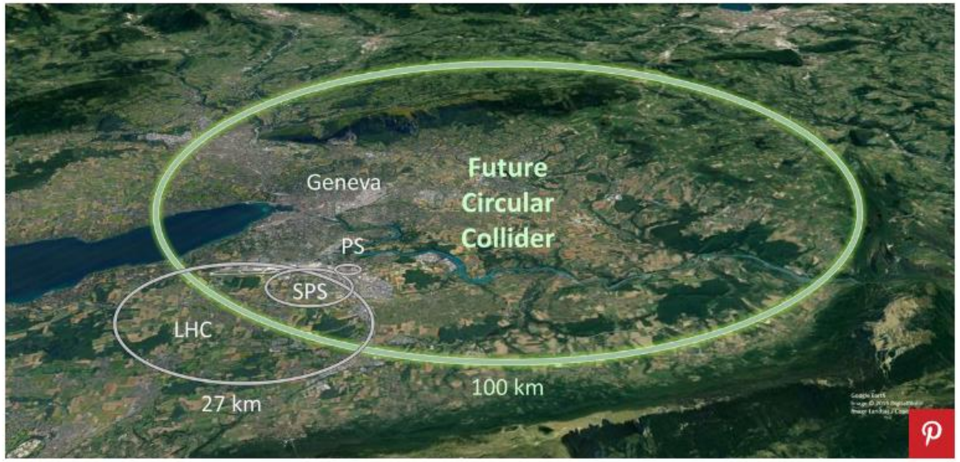
LHC currently with 300 connections

Scientists Are Planning a New Particle Collider That Absolutely Dwarfs the LHC

The proposed Future Circular Collider will be around ten times as powerful as the Large Hadron Collider.

BY AVERY THOMPSON PUBLISHED: JAN 16, 2019

SAVE ARTICLE



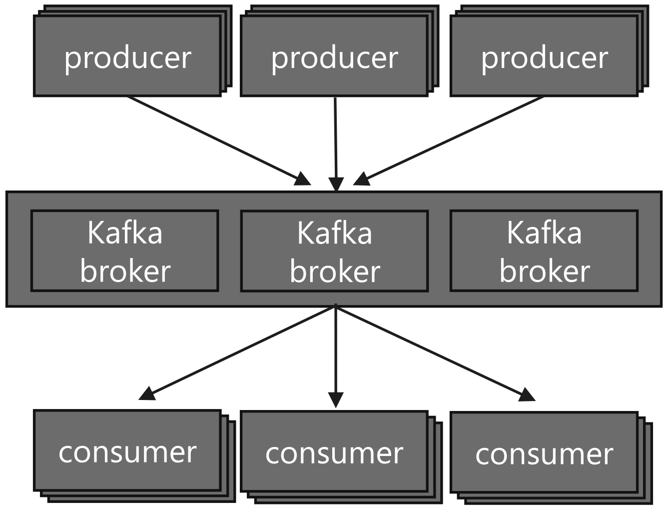
CERN

Scaling to FCC

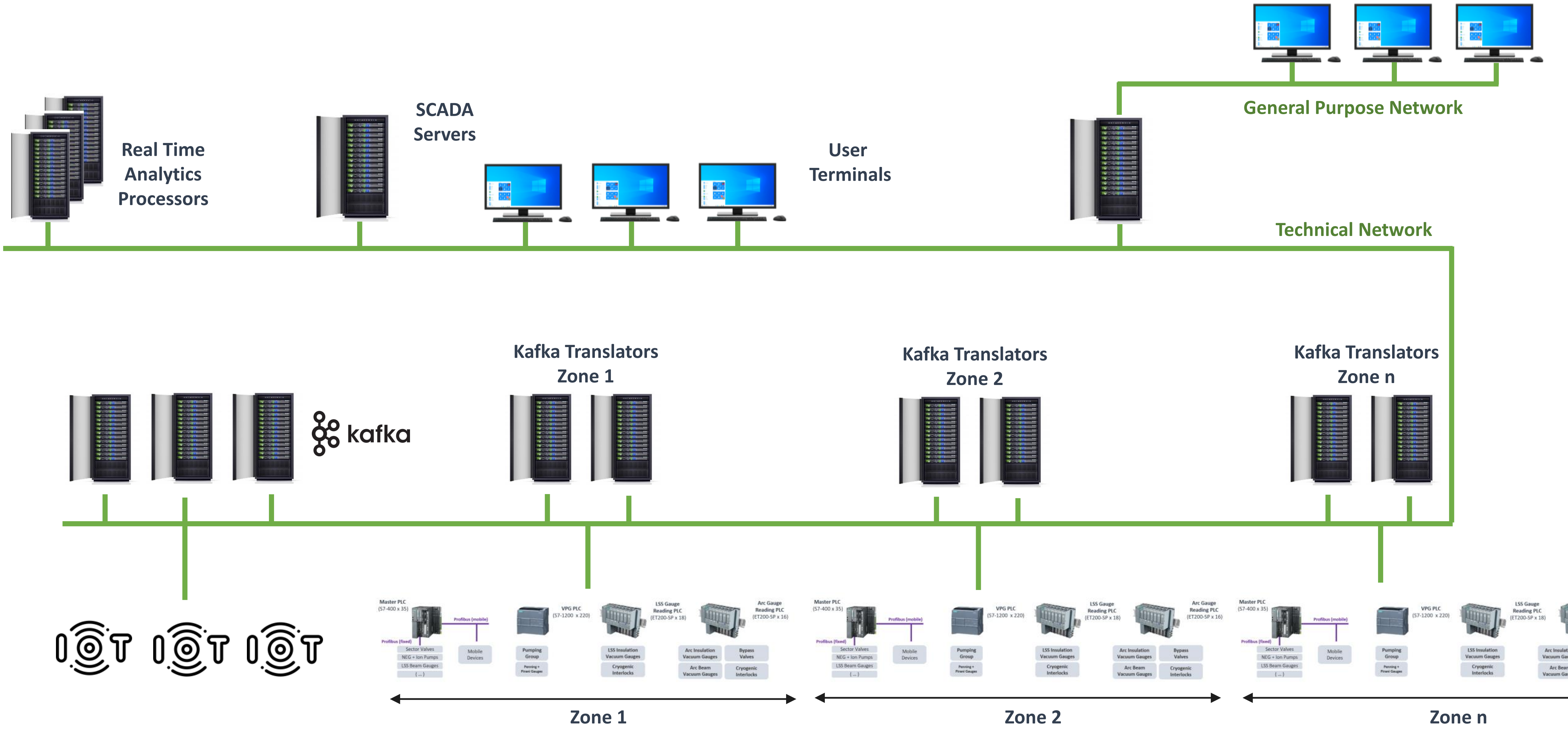
- **Scaling our current architecture to an accelerator the size of FCC won't work**
  - FCC planned size is roughly 4 times that of LHC
  - WinCC-OA is limited to 512 PLC connections
    - LHC has 300 PLCs x 4 = 1 200 PLCs – too many connections
- **(New) trends have to be considered for future control system architectures**
  - Integration of IOT devices
  - Advanced real time data analytics – increasingly important on large scale systems with huge amounts of data to analyze
  - Data pipelines – provide robust ways of moving large amounts of data between the different parts of the control system

Kafka

- **Distributed streaming platform**
- **Publish/subscribe messaging system based on topics**
- **High Throughput / Low latency**
    - Hundreds of thousands of messages per second on a single broker
- **Scalable without compromising performance**
    - Designed to scale horizontally by adding more brokers to the cluster
    - Topic partitioning – distribute data across multiple brokers
- **Highly available and Fault-tolerant**
    - Automatic Failover
    - Topic replication
- **Ecosystem of pre-made connectors, allowing to integrate kafka with a multitude of systems**
    - https://docs.confluent.io/kafka-connectors/self-managed/kafka_connectors.html#kafka-connectors



Control System Architecture



Conclusion

- **Database-driven Configuration Engineering tools are essential to manage large-scale control systems:**
  - Provide a centralized location for storing and managing equipment configurations, making it easier to maintain and update control systems
  - Allow for more efficient collaboration between multiple teams working on different aspects of a control system
  - Improve the reliability and safety of control systems by ensuring that equipment configurations are consistent and correctly applied in the relevant layers
  - Allows operators to track and monitor changes made to control system parameters, providing a clear audit trail of modifications
- **Distributed streaming technologies can help us evolve our control system architecture:**
  - Provide greater scalability, enabling control systems to handle larger and more complex deployments
  - Enable real-time analytics, allowing for more proactive and predictive maintenance strategies
  - Open up new possibilities for integrating different types of equipment and technologies, improving interoperability and reducing vendor lock-in

Thank you !