CERN

CERN

Introduction to CERN and its Industrial Control Systems

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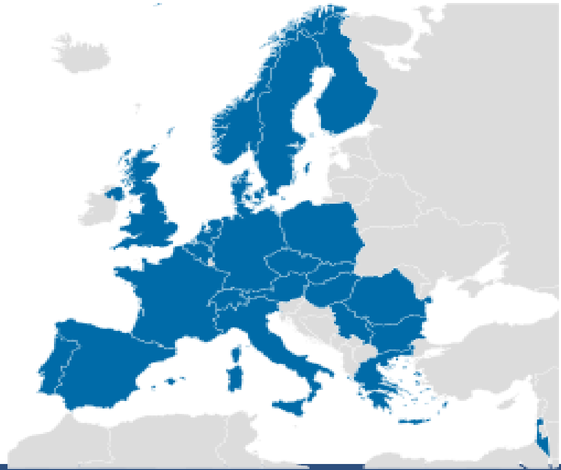
Industrial Control Systems Group of the Beams Department

Outline

- Short intro to CERN
- Industrial Controls at CERN
- CERN-Siemens/ETM partnership

CERN as Organisation

- European Organization for Nuclear Research
  - Started in 1954 to promote research on nuclear Physics in Europe and not to be left behind the US and the Soviet Union
    - Precursor of many collaboration projects that came afterwards
  - International organization
  - 22 member states (mainly Europe plus Israel)
    - Numerous associated members and observers
  - Open to worldwide scientific community: 17500 people
    - 12200 visiting scientists, 70 countries, 110 nationalities, 600 institutes
  - 2600 employees, 500 students, 800 fellows
  - Budget: 1.1 mld CHF



CERN Mission

Nuclear today? Not at all

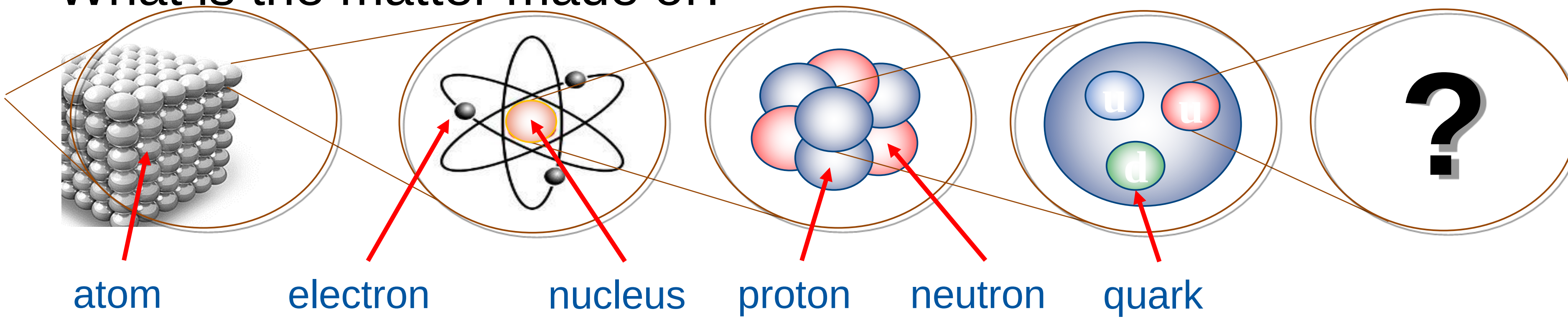
Conseil **E**uropéen pour la **R**echerche **N**ucleaire (1954)

European Laboratory for Particle Physics

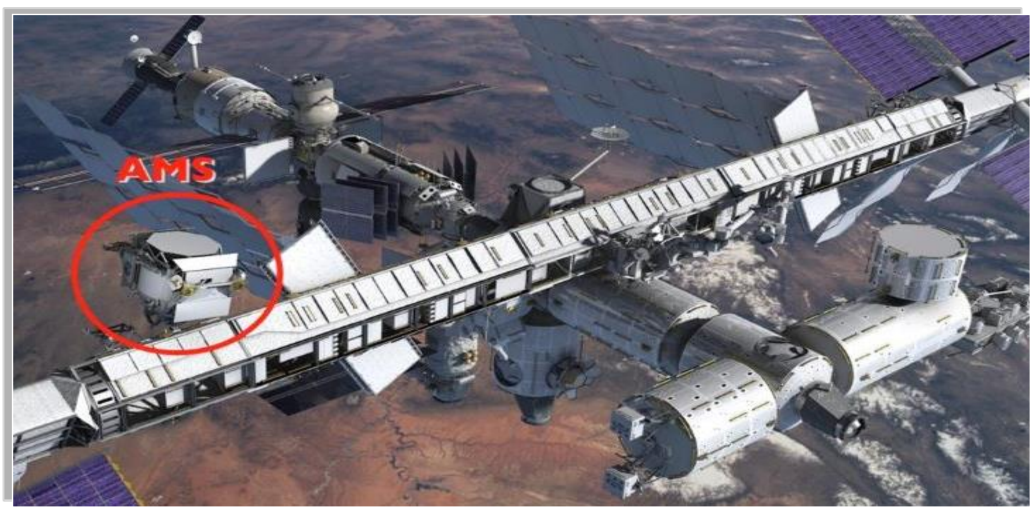
Although some short-living radioisotopes are produced for cancer treatment in the Geneva area

Fundamental research

What is the matter made of?



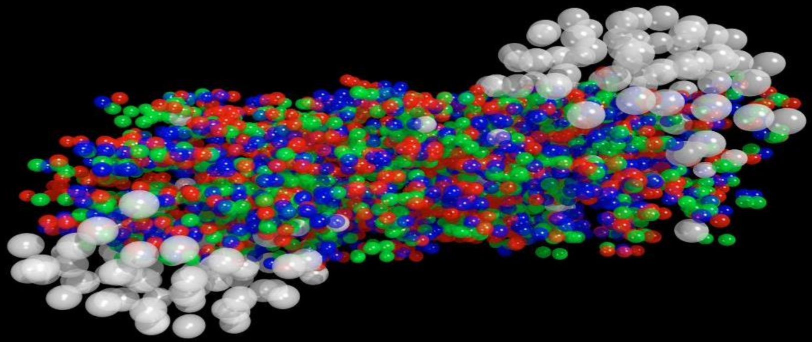
Antimatter



Higgs Boson

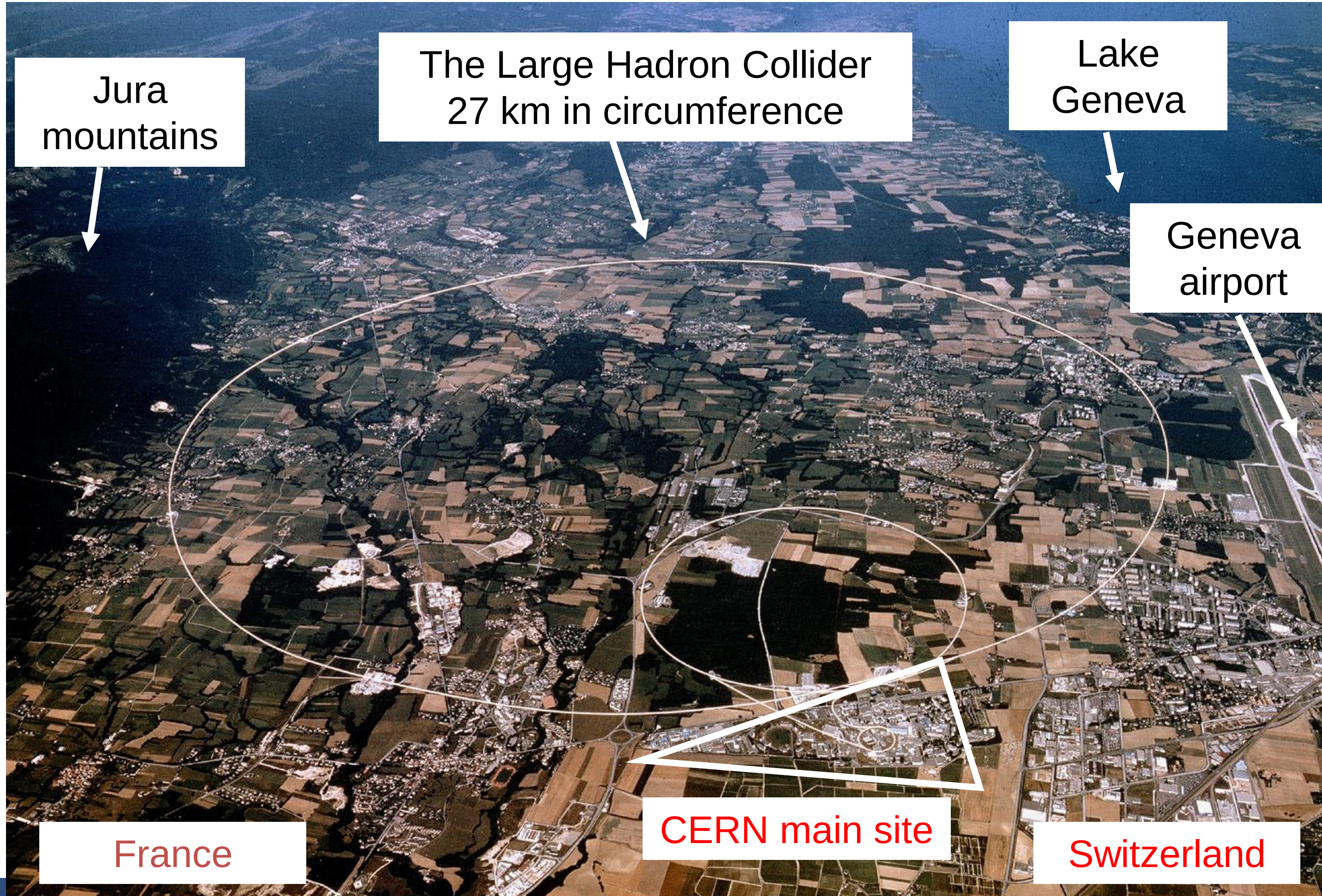
Fundamental research

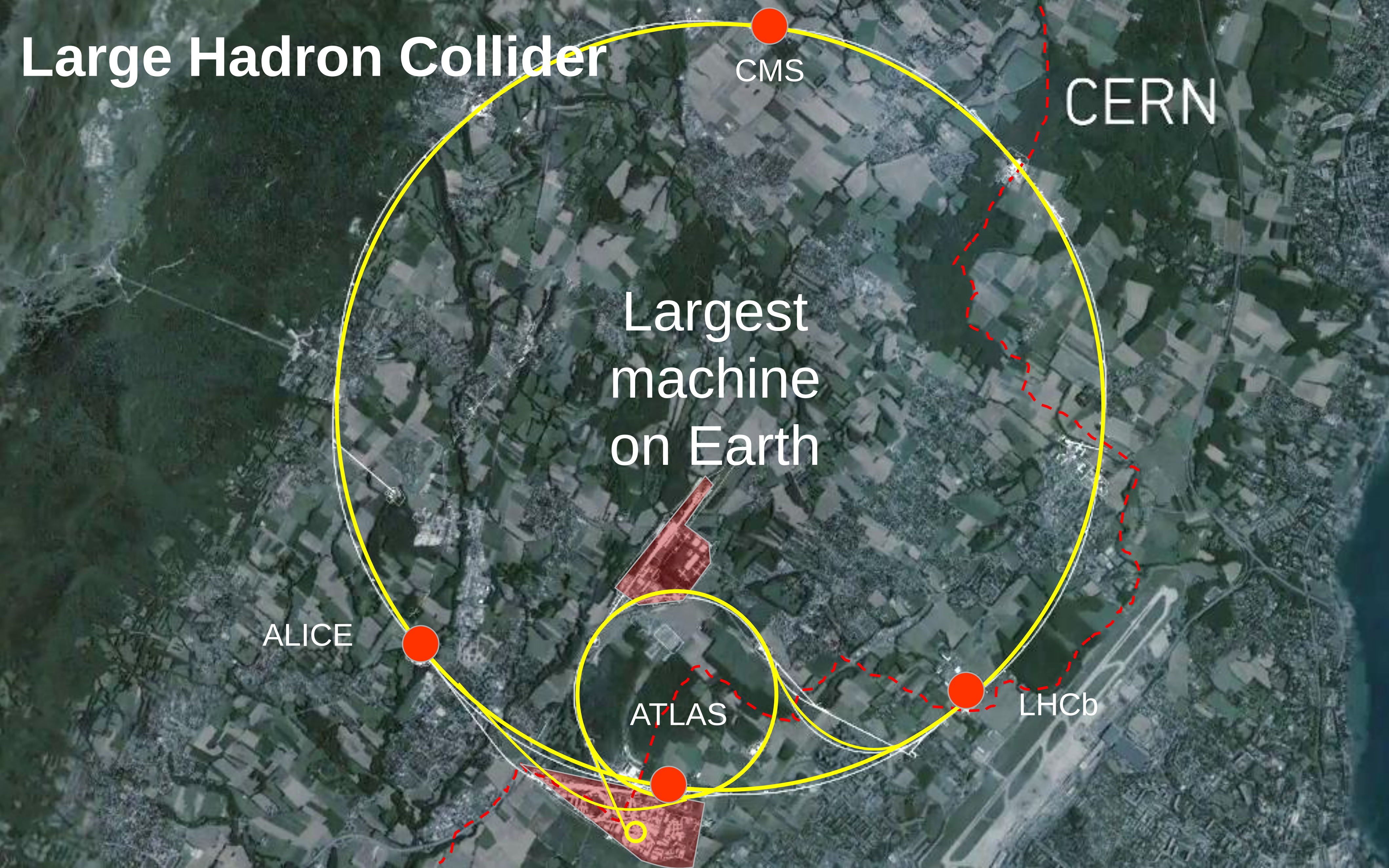
Quark-Gluon Plasma



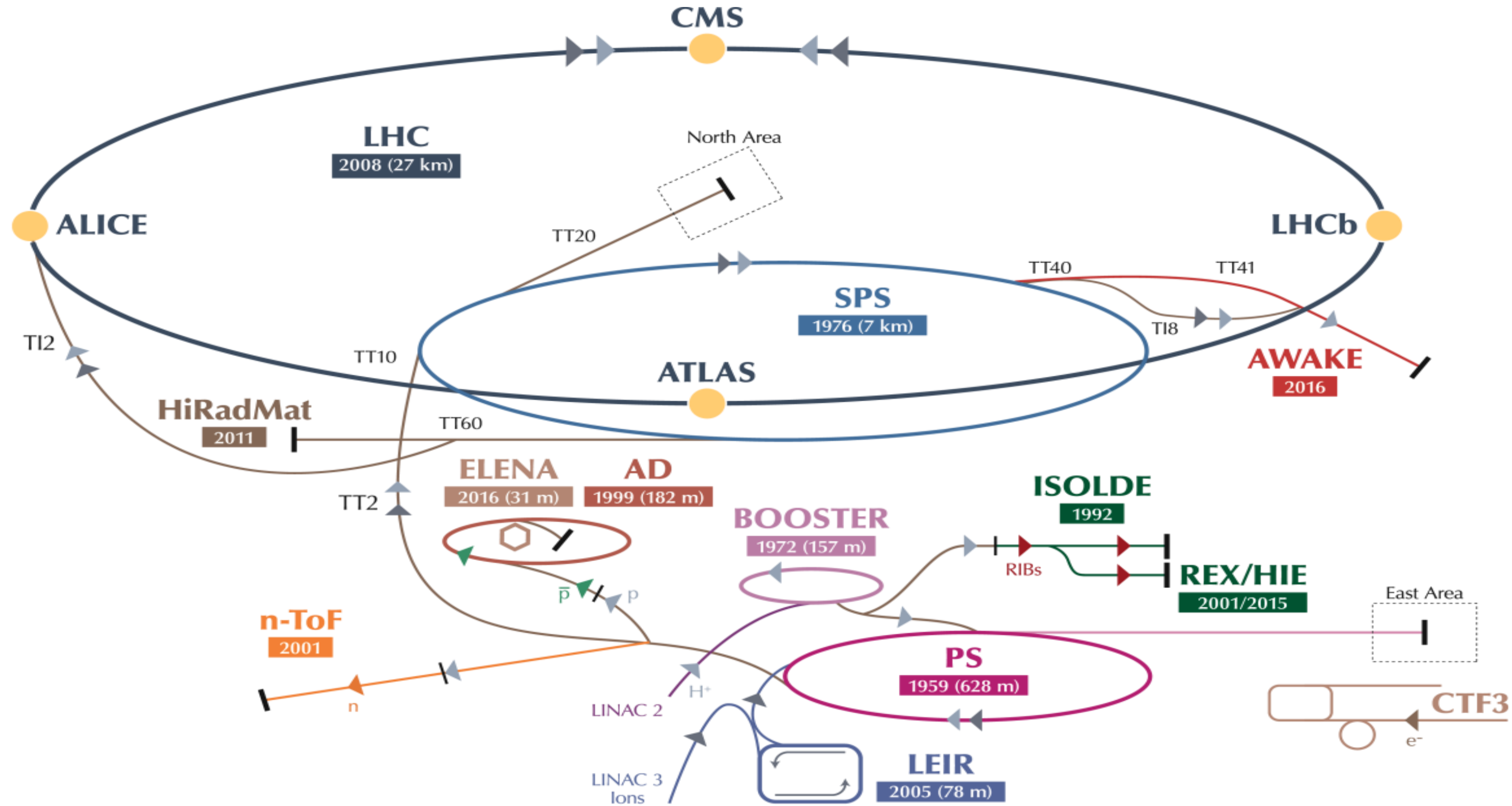
How is this done?

CERN: European Centre for Particle Physics




Large Hadron Collider
CMS
CERN
Largest
machine
on Earth
ALICE
ATLAS
LHCb

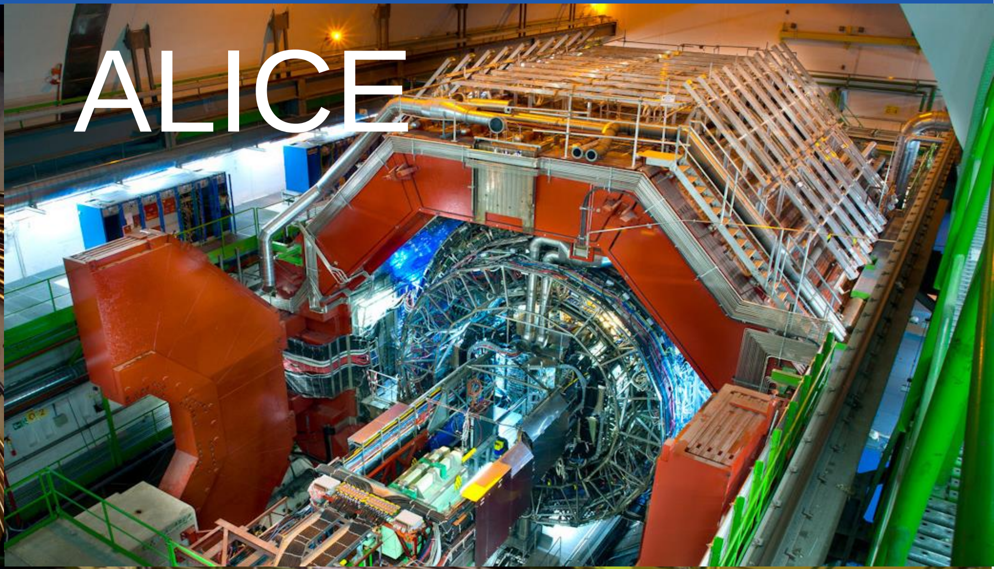
Accelerator Complex

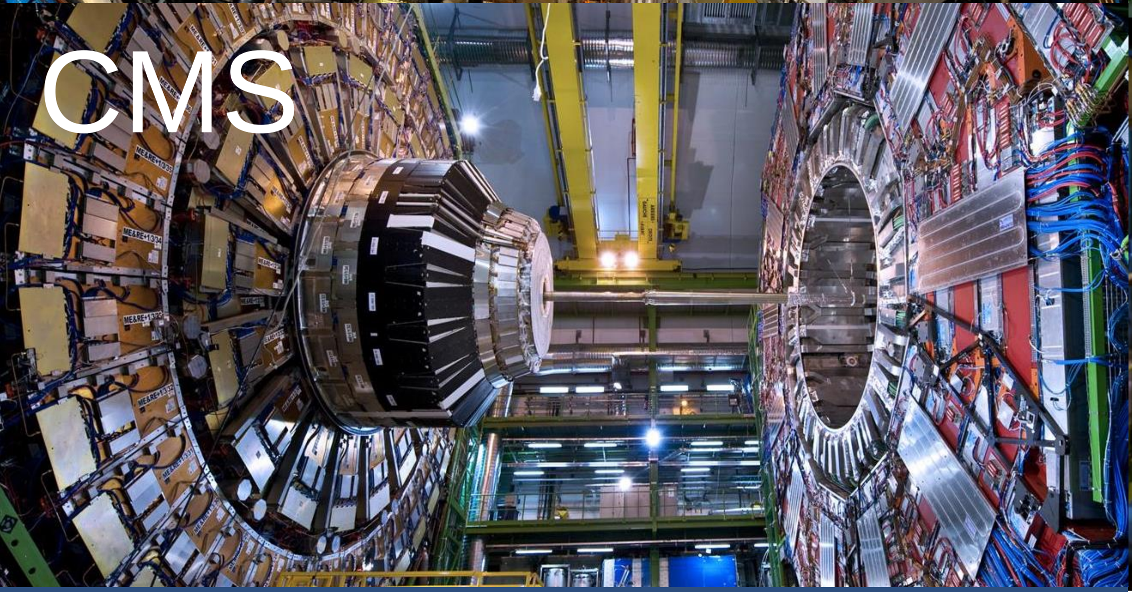


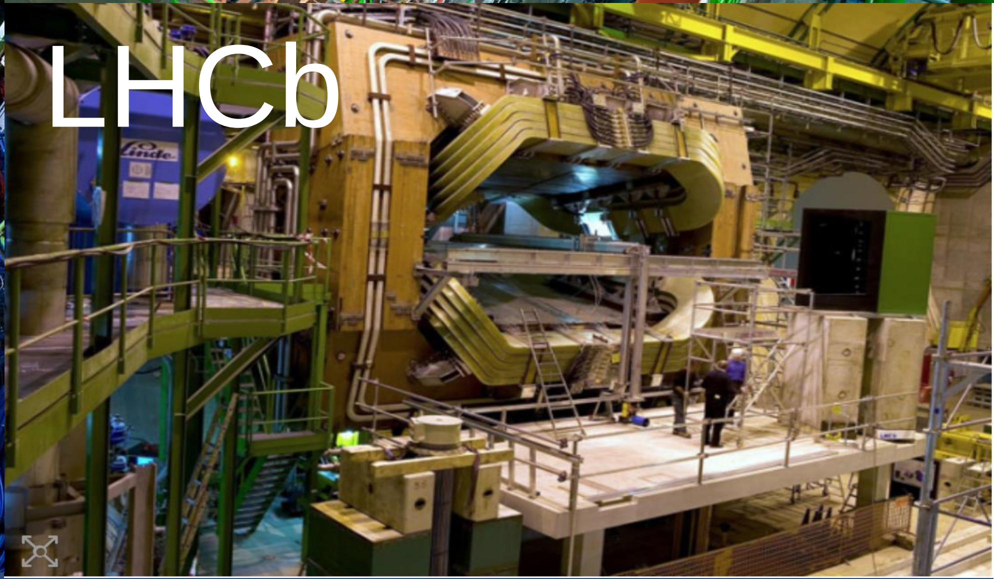
▸ p (protons) ▸ ions ▸ RIBs (Radioactive Ion Beams) ▸ n (neutrons) ▸ p̄ (antiprotons) ▸ e- (electrons) proton/antiproton conversion proton/RIB conversion

LHC Large Hadron Collider **SPS** Super Proton Synchrotron **PS** Proton Synchrotron **AD** Antiproton Decelerator **CTF3** Clic Test Facility
AWAKE Advanced WAKefield Experiment **ISOLDE** Isotope Separator OnLine **REX/HIE** Radioactive EXperiment/High Intensity and Energy ISOLDE
LEIR Low Energy Ion Ring **LINAC** LINear ACcelerator **n-ToF** Neutrons Time Of Flight **HiRadMat** High-Radiation to Materials

LHC Particle Detectors





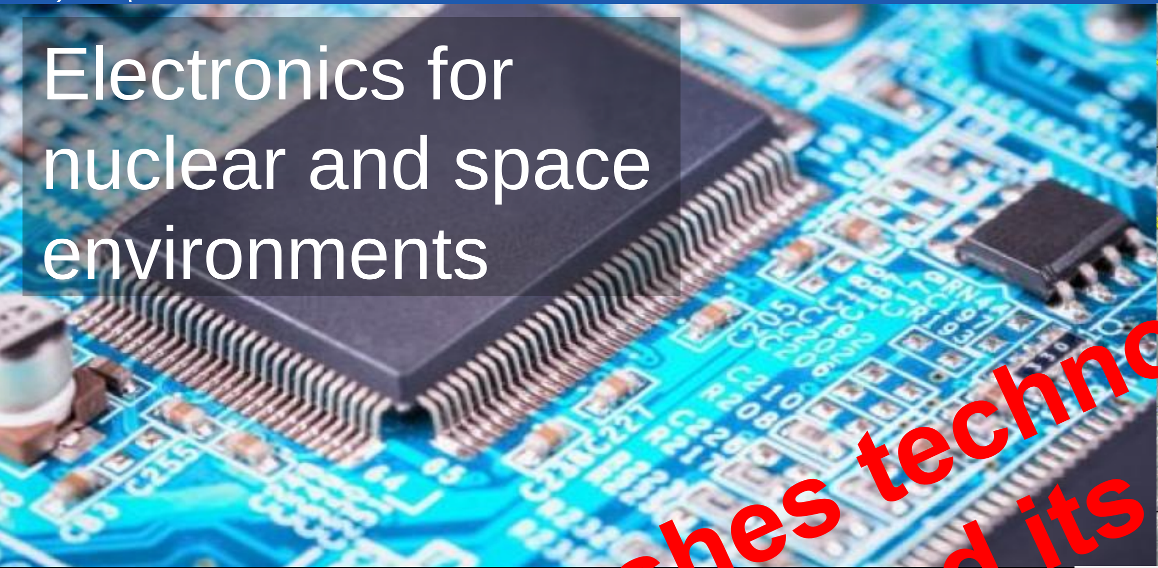


How everything fits together?

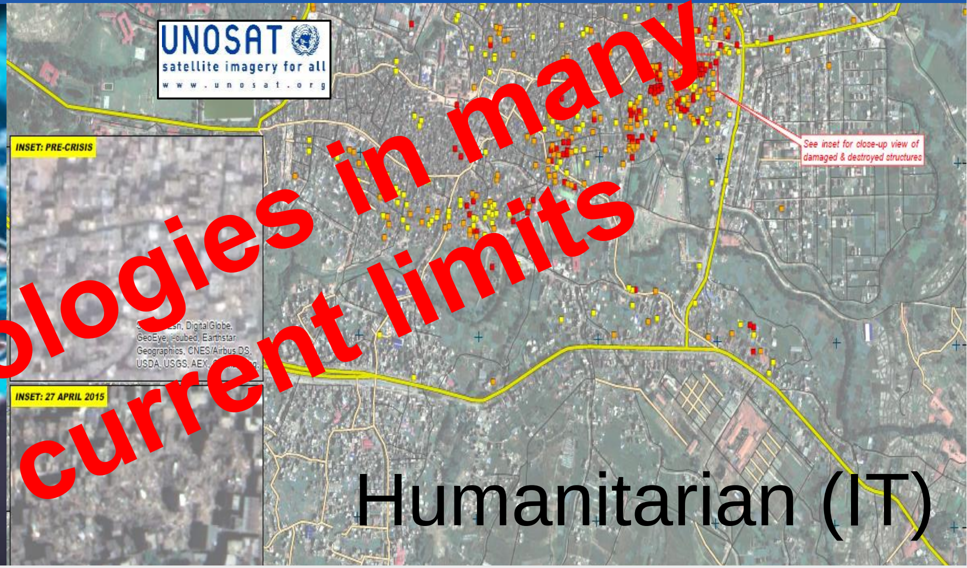
But that’s not all…

Spinoffs

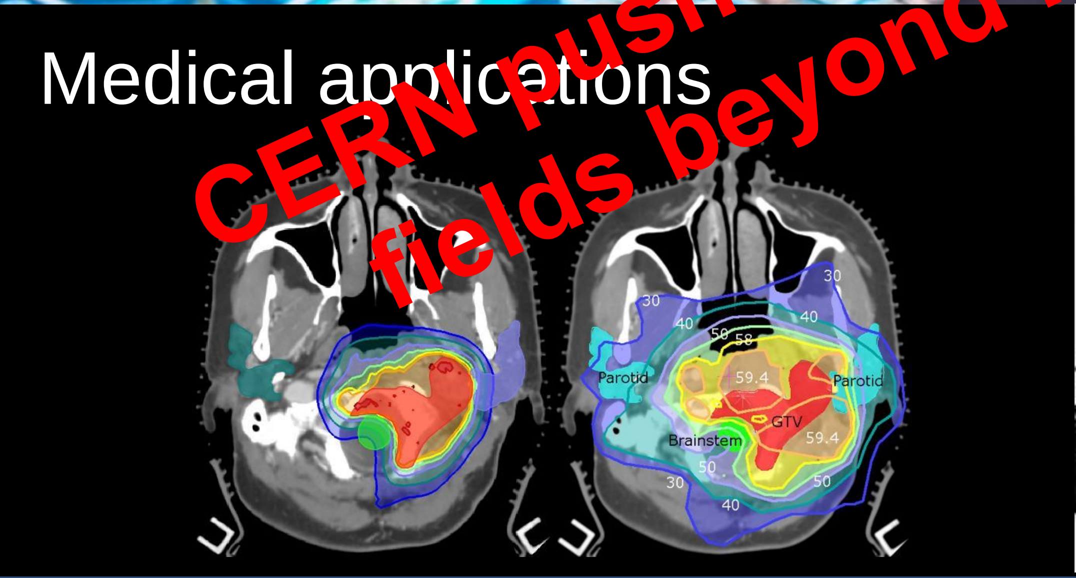
Electronics for nuclear and space environments



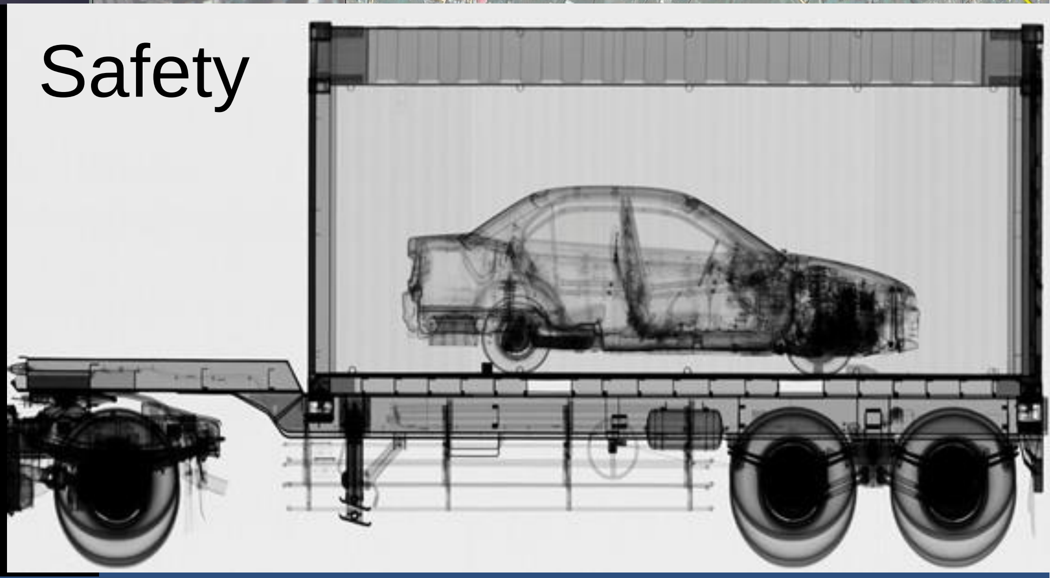
Humanitarian (IT)



Medical applications



Safety



CERN pushes technologies in many fields beyond its current limits

Spinoffs

Web@30

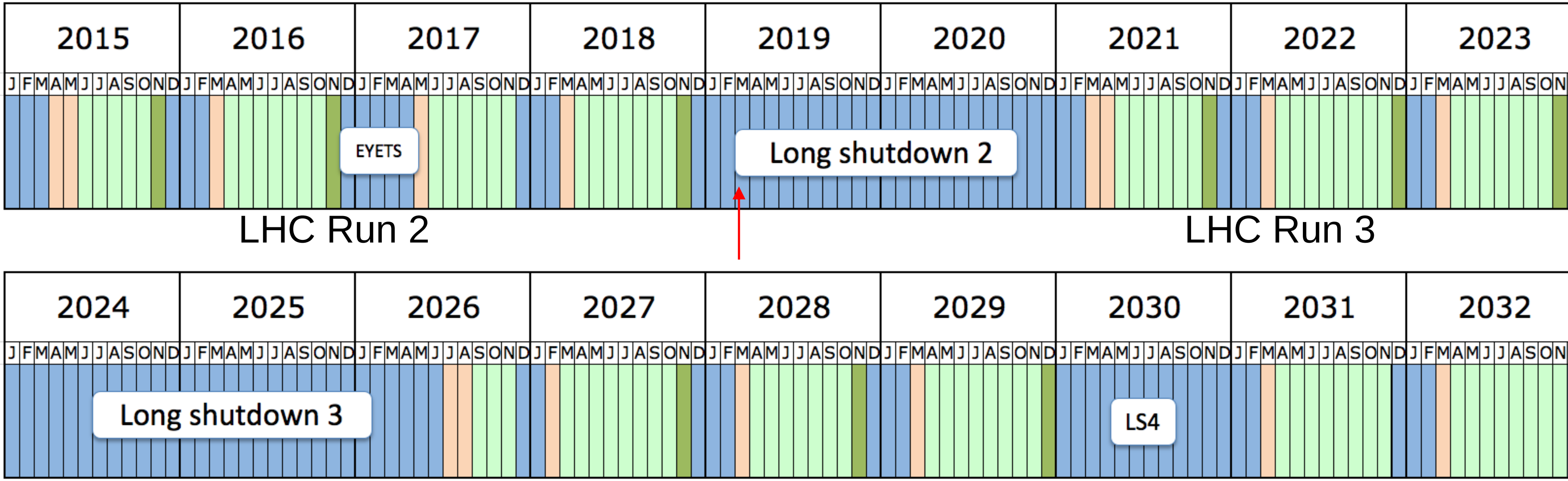
1989 - 2019

http://cern.ch/web30

12 March 2019

Looking ahead

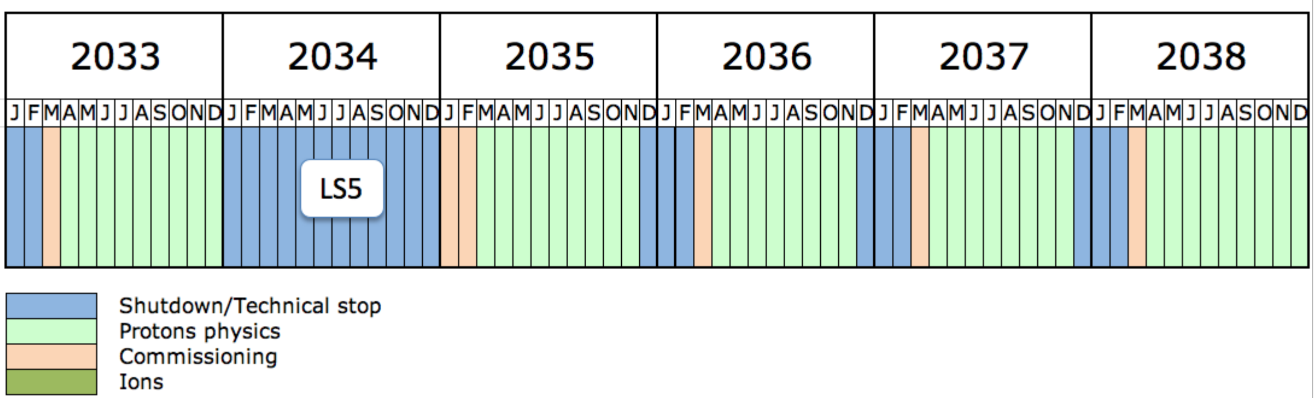
LHC future

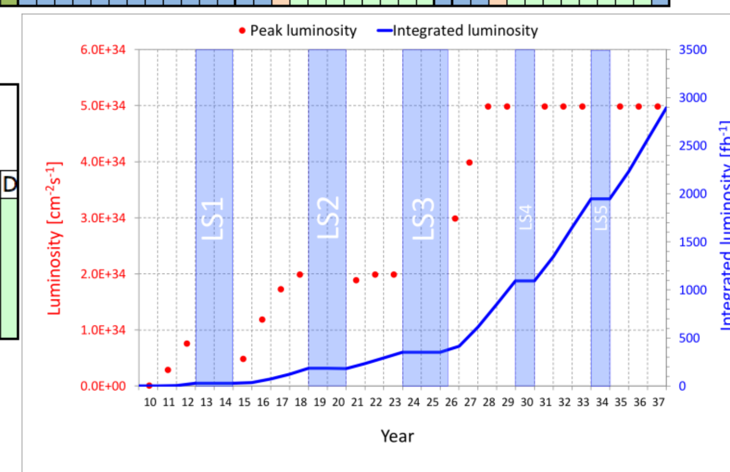


LHC Run 2

LHC Run 3

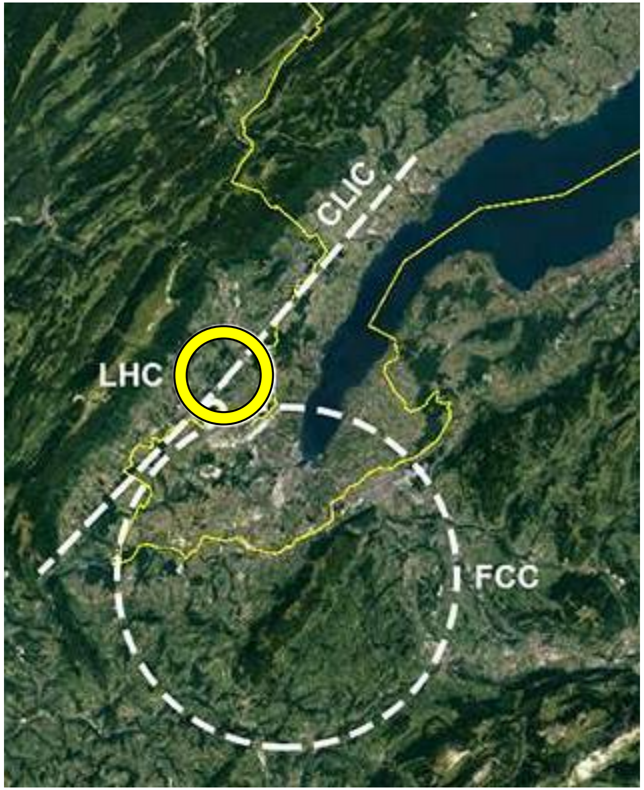
HiLumi LHC





What's beyond?

- Proposals for the future colliders at CERN
  - Compact Linear Collider (CLIC)
    - Conceptual study
    - 11-50 km linear, 3 TeV; in stages
    - ~2035?
  - FCC (Future Circular Collider)
    - Conceptual study
    - 100 km, 100 TeV
  - Projects are complementary
    - SPS→LEP→LHC→….

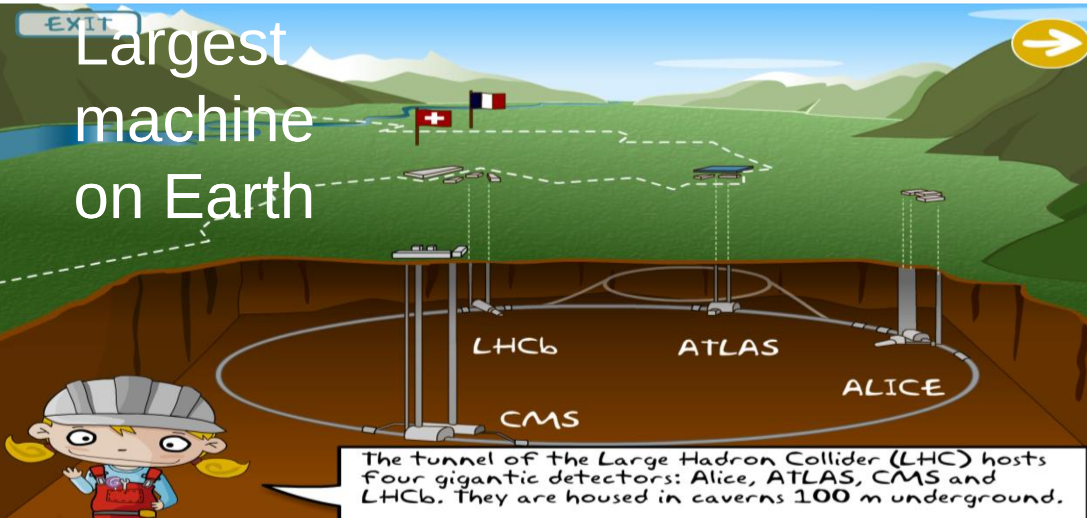


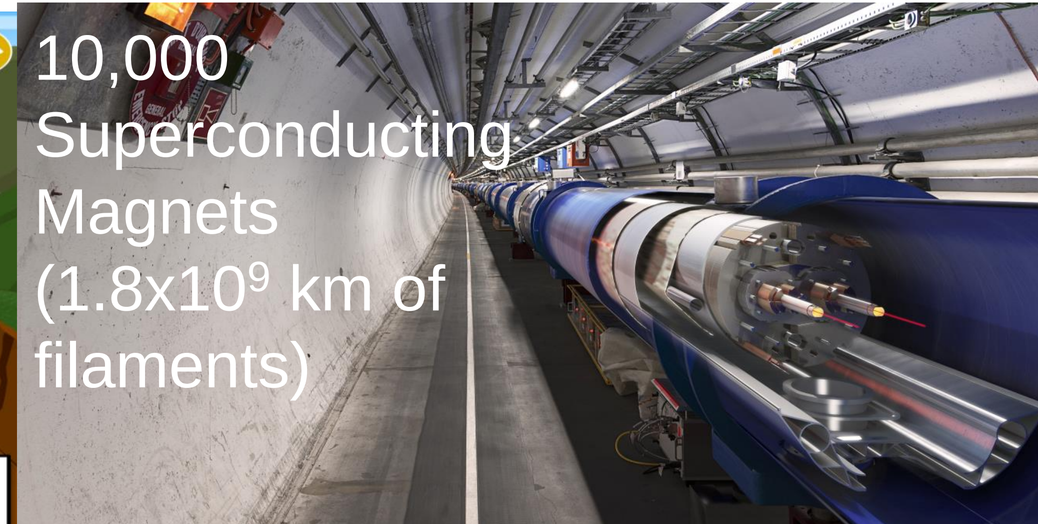
- Update of the European Strategy for Particle Physics
  - Guide the direction of the field to mid-2020 and beyond
  - May 2019 (The Open Symposium)
  - January 2020 (The Strategy Drafting Session)

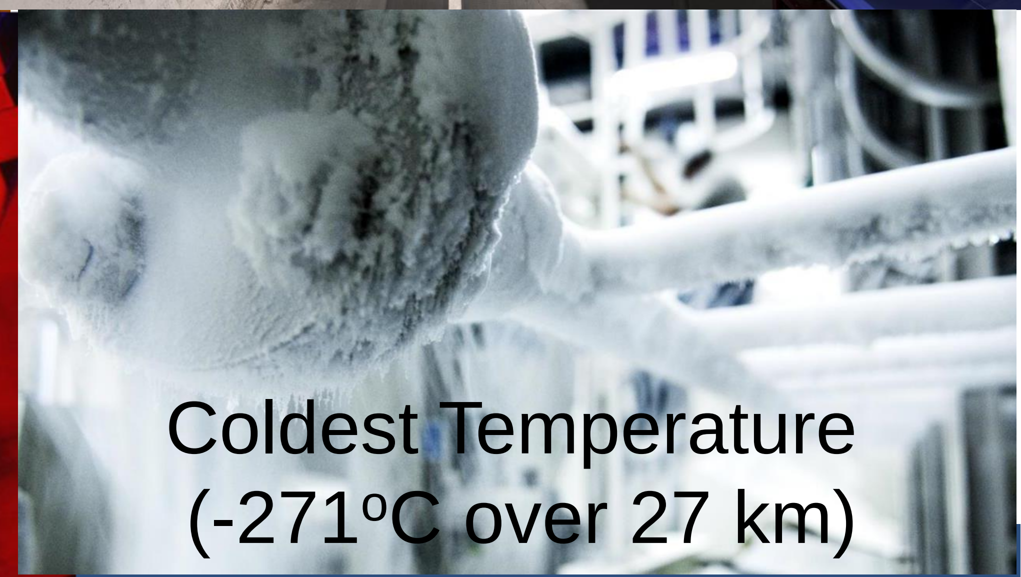
CERN Industrial Controls

LHC: world largest particle accelerator

27 km, 100m underground, Four major detectors: ALICE, ATLAS, CMS and LHCb

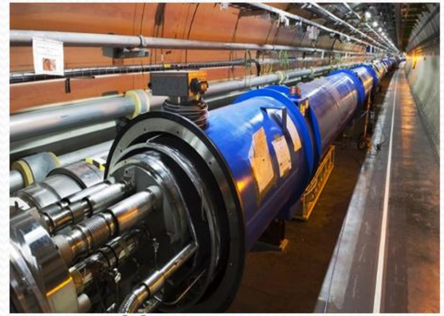






Industrial Controls at CERN


Cooling & Ventilation

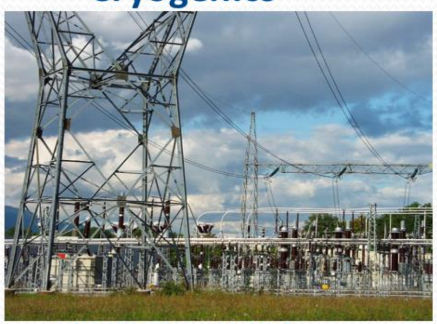

Vacuum


Detector Controls


Cryogenics


Gas Distribution


Environment & Radiation


Electric Grid

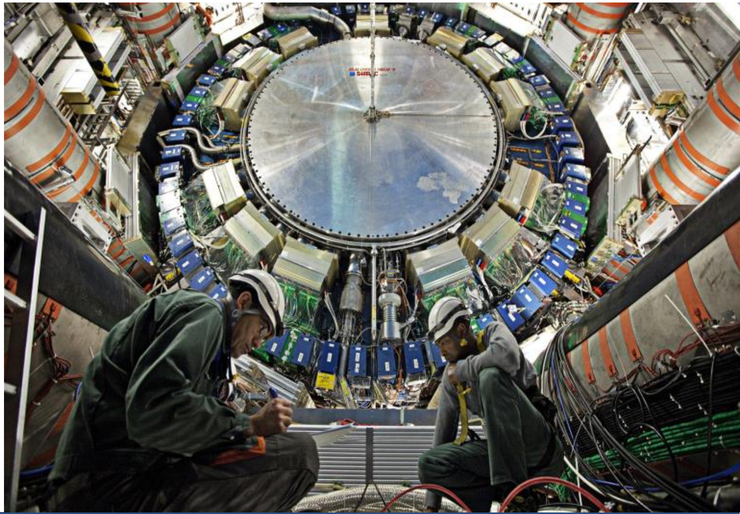

Interlocks and Safety


..and many others

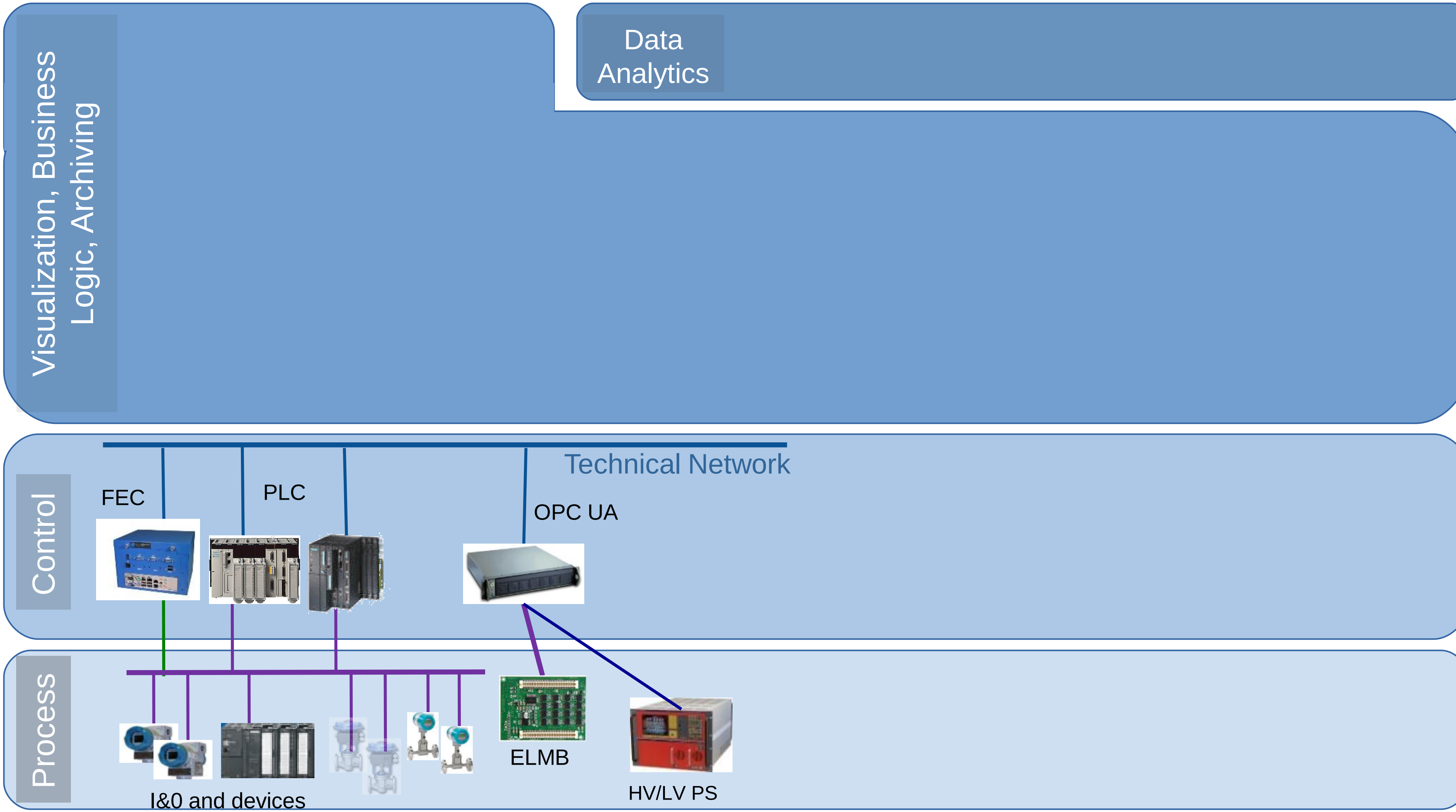
Industrial Control challenges

- **Goal**: maximize and optimize **physics data-taking by maximizing uptime and optimal operation of detectors, accelerators and technical infrastructure**

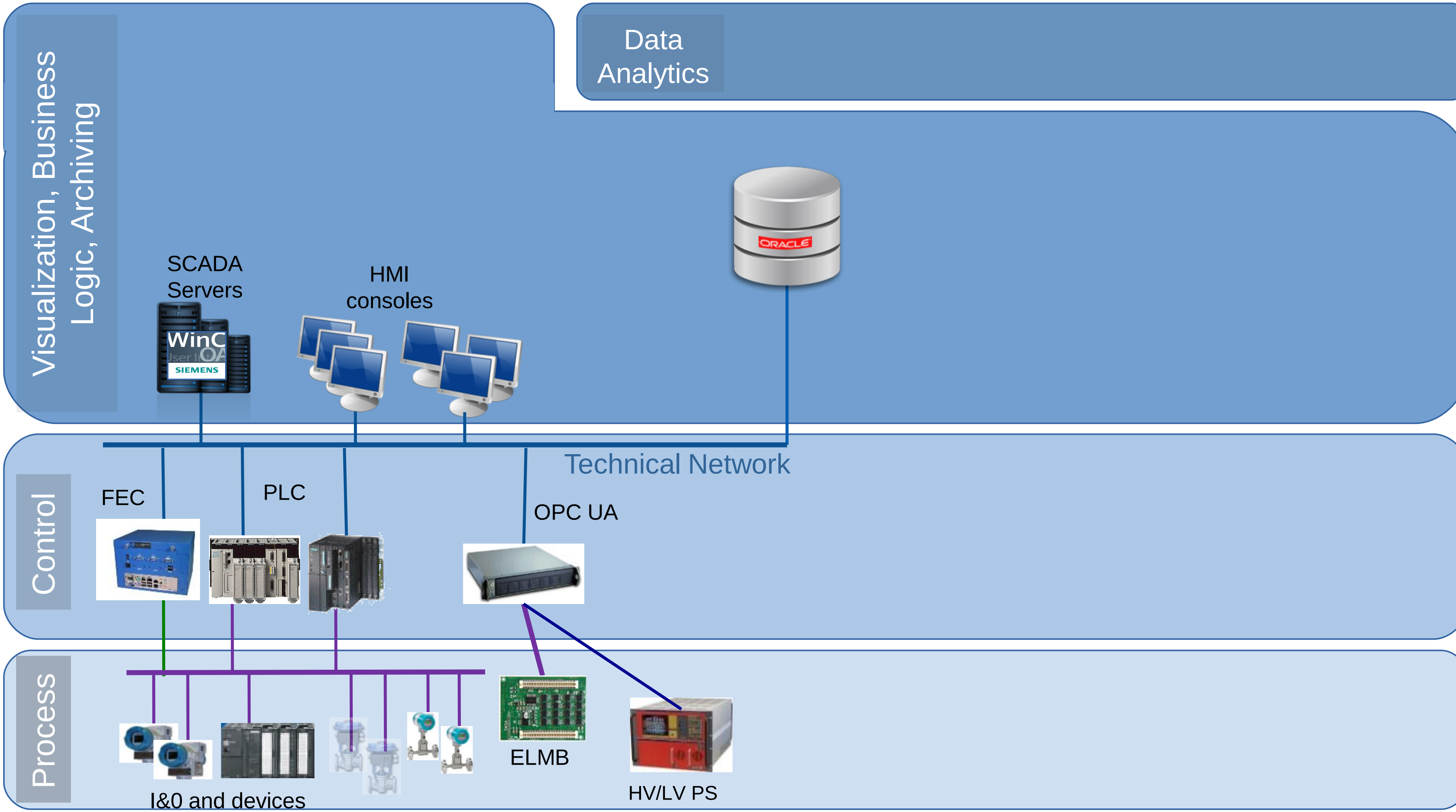
- Additional specific requirements:
  - Environment:
    - radiation areas, strong magnetic field up to 4T
  - Unprecedented number of I/O
    - (3 M h/w channels in ATLAS)
  - Data volumes and rates
    - (e.g. QPS 200.000 changes/s)
  - Large distributed and interconnected systems
  - Complexity (control logic, multiple technologies)
  - Highly de-centralized instrumentation (>27 km)
  - CERN electrical grid ~ Canton of Geneva



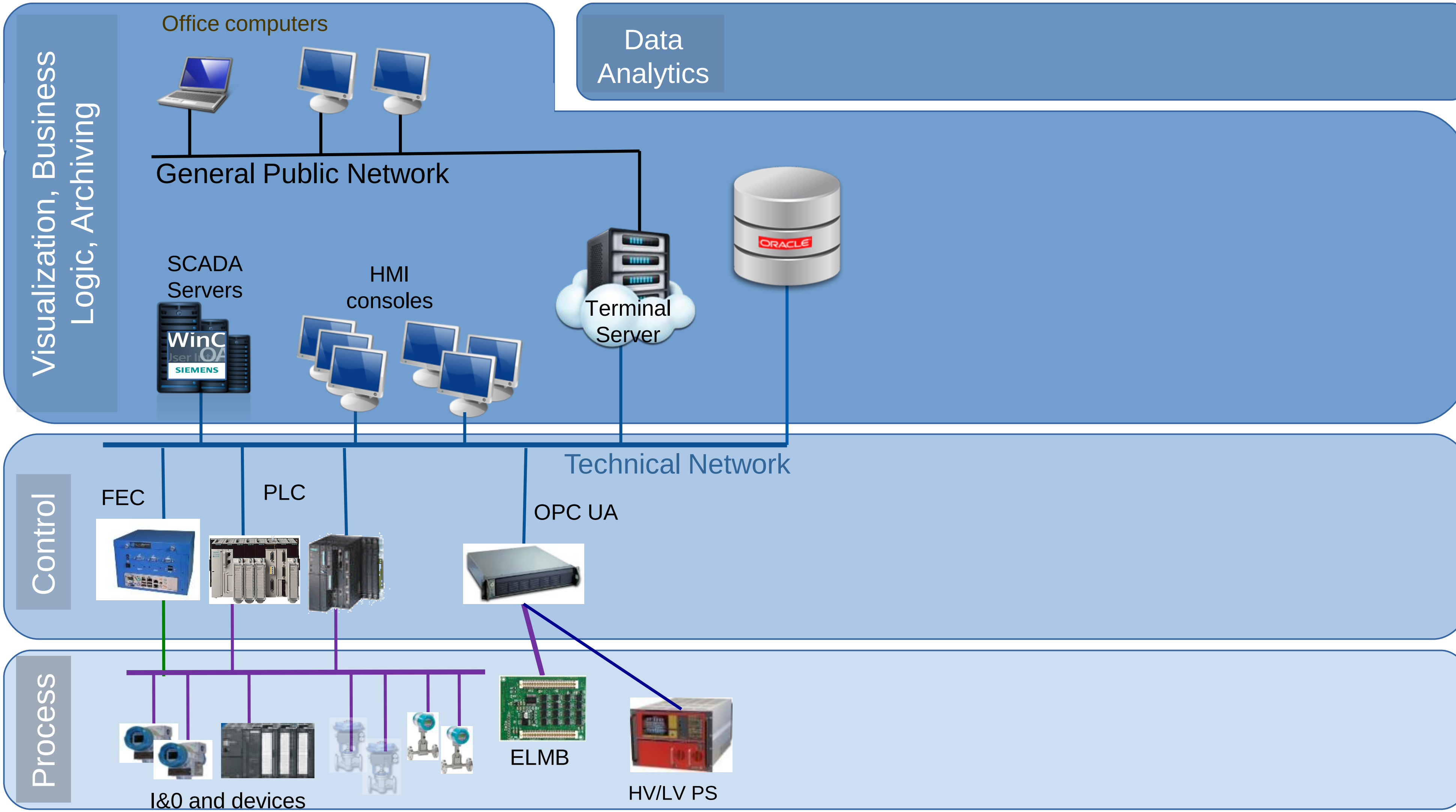
Architecture



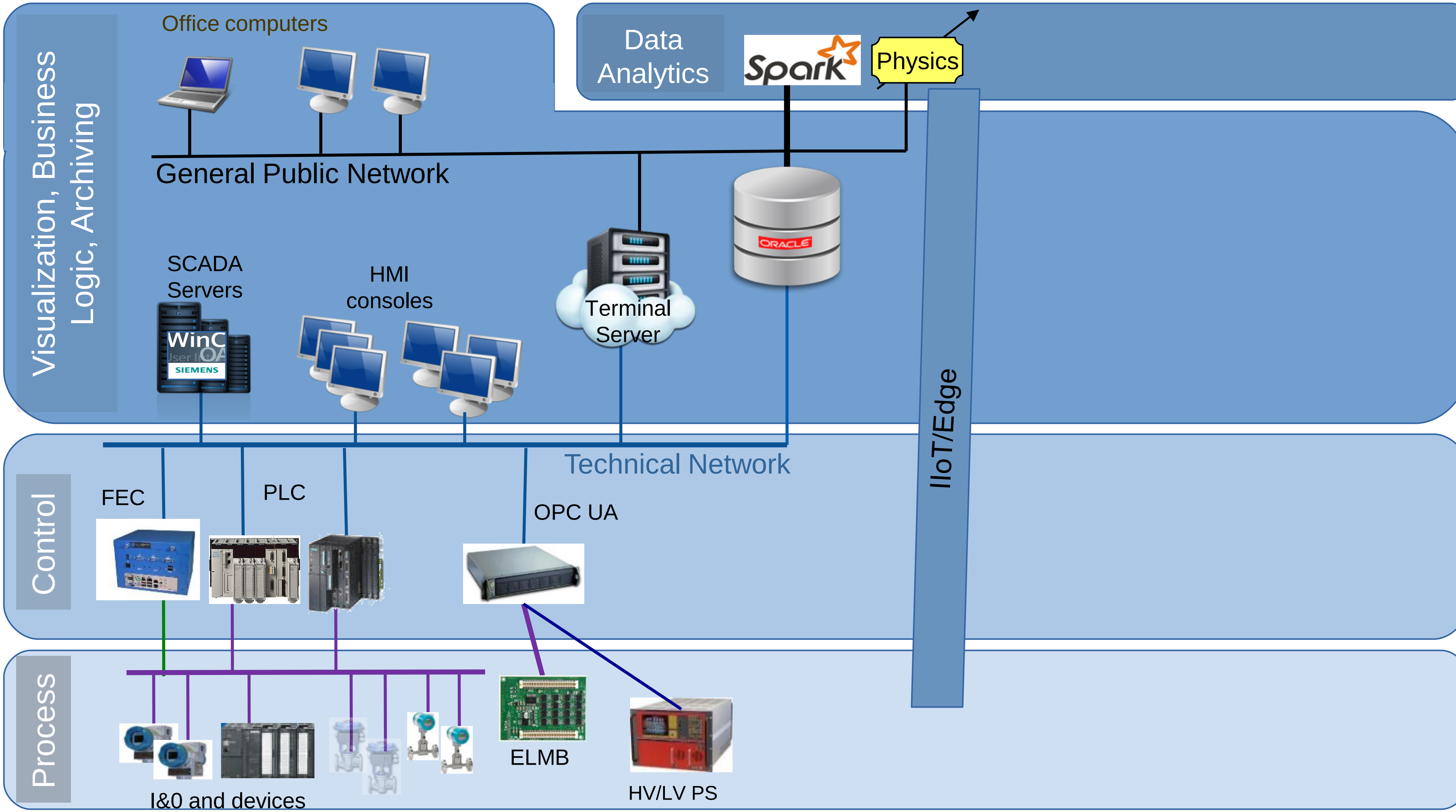
Architecture



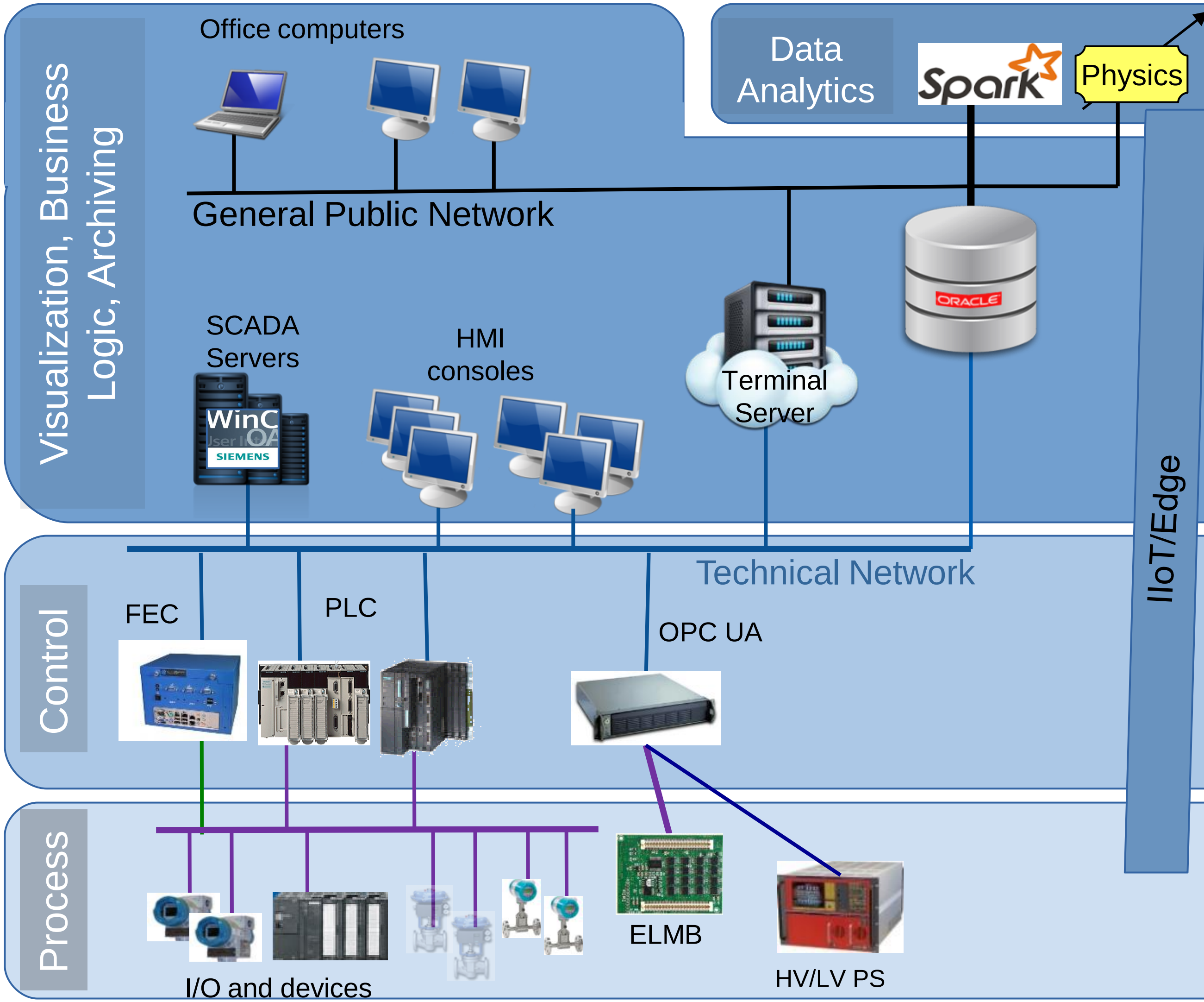
Architecture



Architecture



Architecture & Figures



Anomaly detection, fault prediction, root-cause analysis

850 SCADA Applications
400 Industrial PCs
10 RAC Oracle DBs
200 TB stored per year

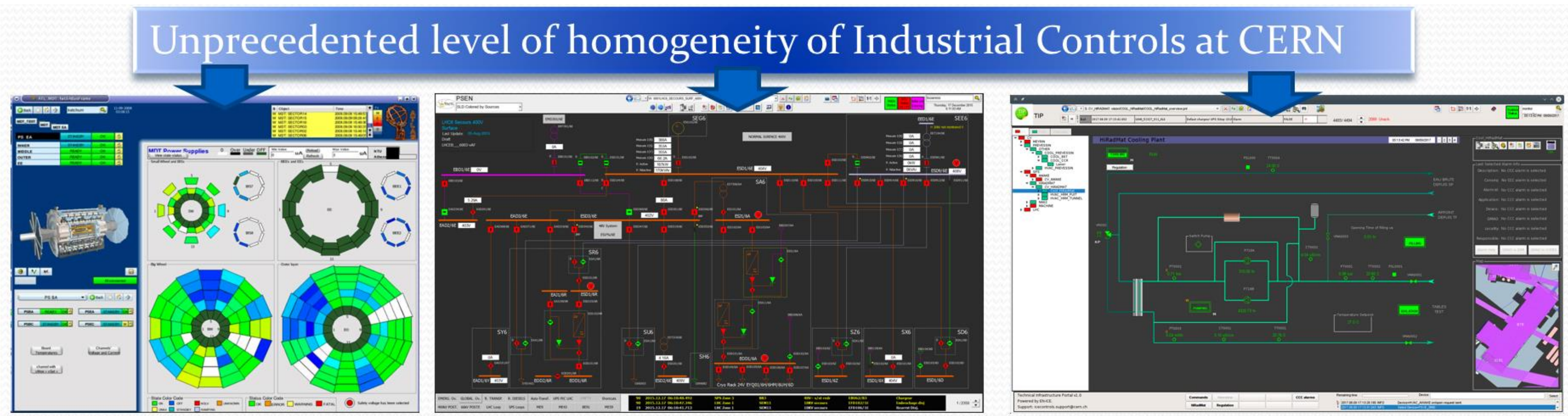
600 PLCs
200 OPC UA Servers
60 RT Front-End Computers (Industrial PCs)

Hundreds of Power Supplies
Thousands of Fieldbuses
10 M Hardware I/O

Approach to Industrial Controls

ATLAS Embedded Local Monitor Board

- Use of Industrial (COTS) solutions whenever possible
  - Custom radiation-tolerate electronics and middleware
- Standardization at all layers of the controls chain (also ISA, IEC)
  - Restricting the number of technologies and protocols
- Development of generic Industrial Controls Frameworks
  - **J**oint **CO**ntrols **P**roject (**JCOP**) and **UNICOS**
- ~850 industrial controls applications were developed using these frameworks



ATLAS | CERN Electrical Grid | Cooling & Ventilation

Standardized Technology Stack

SUPERVISION, Visualization and programming

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

CONTROL

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

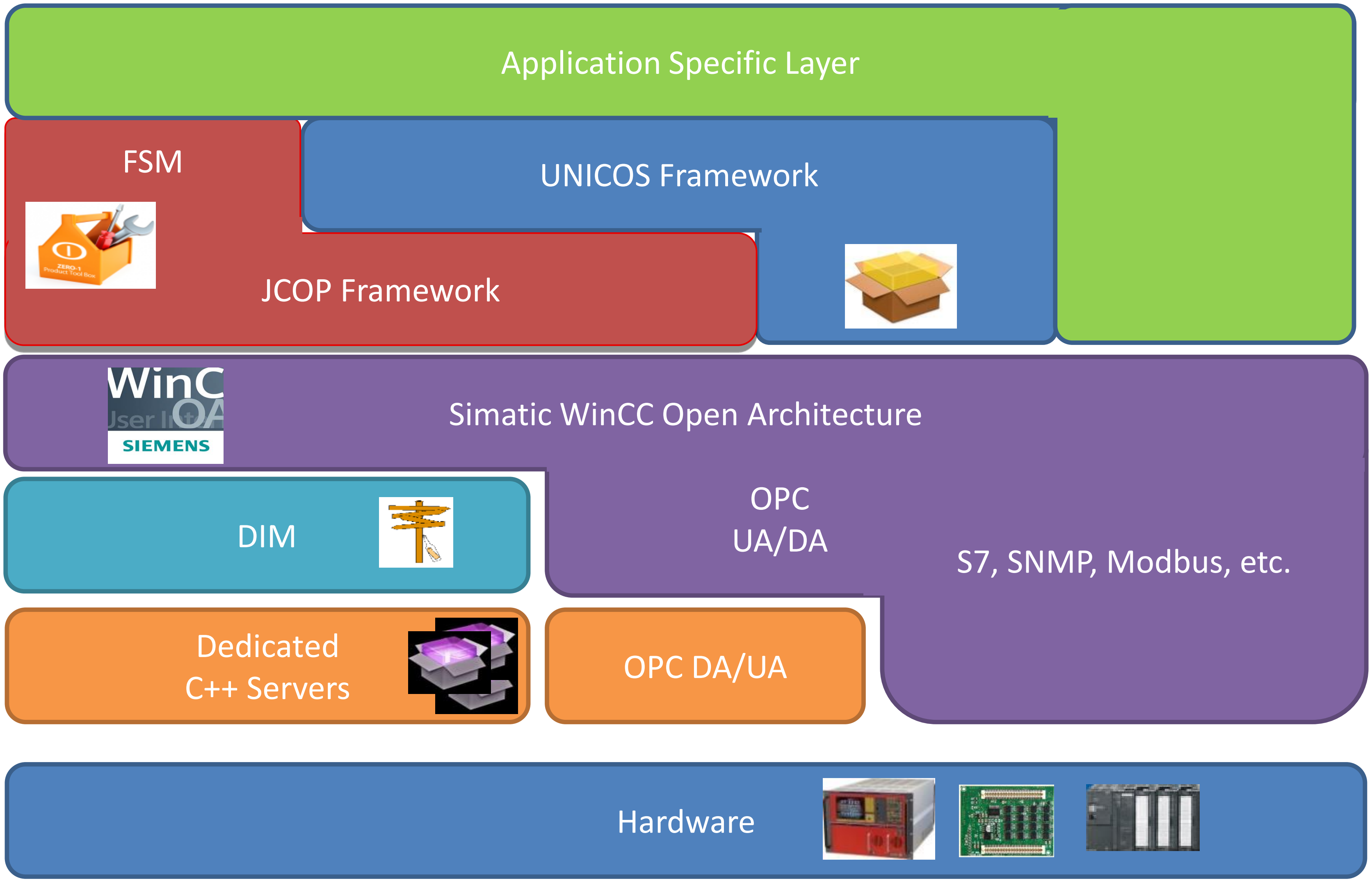
FIELD LAYER

- 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

ICS Building Blocks



WinCC OA as key in element in the standardization of CERN Industrial Control Systems

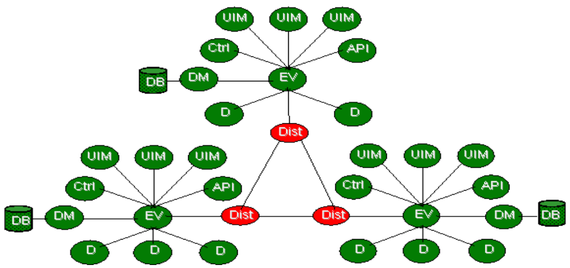
SCADA evaluation

- Selection of technologies for the LHC era
  - Started in 1996
  - Use of industrial products/standards
  - Many technologies evaluated
  - SCADA, middleware, fieldbuses, PLCs, etc

- SCADA evaluation
  - Extensive market survey (hundreds of SCADA, 40 companies contacted for specs)
  - Evaluation 1997-99 (>10 man-year effort, 6 products evaluated)
  - Very long list of criteria
  - PVSS (WinCC OA) selected in year 2000 after CERN tender
    - Since 2007: PVSS II -> WinCC Open Architecture

Why WinCC OA ?

- Scalability
  - Large Distributed Systems
  - Millions of I/Os
  - Datapoints: Structured tags
  - High troughput



- Openness
  - CTRL, C++ API
  - API Managers, Drivers, CtrlExt, EWO

- Multiplatform

- Partnership with the company

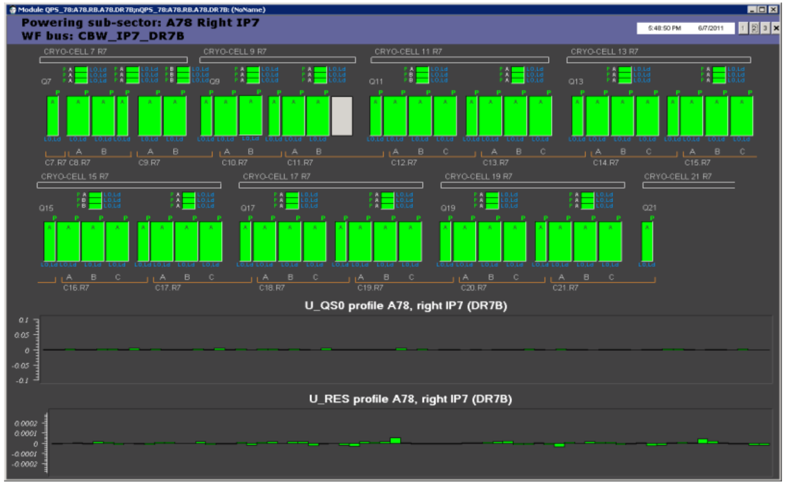
WinCC OA-based Control systems at CERN

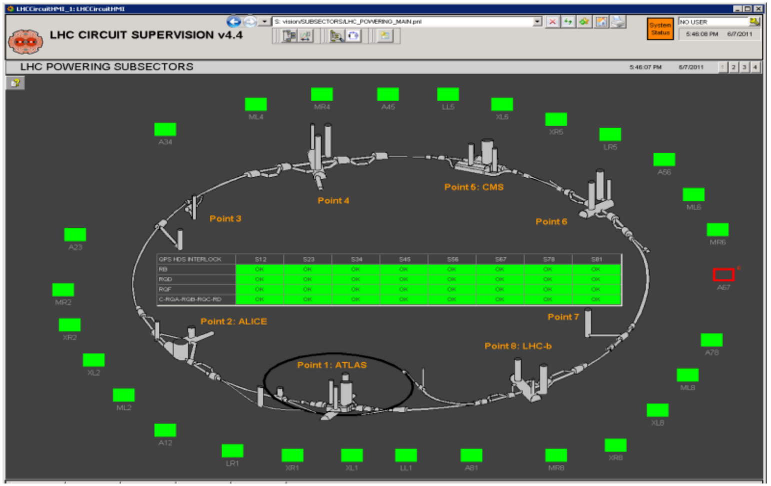
Projects: the LHC

- Cryogenics and instrumentation
  - 11k actuators, 5k control loops
  - 50k I/O tags, 100 PLCs, 40 FECs
  - 26 SCADA servers, 1.5 M tags
- Vacuum
- Magnet Protection Systems
- Powering and interlocks

LHC: 9’600 Magnets for Beam Control

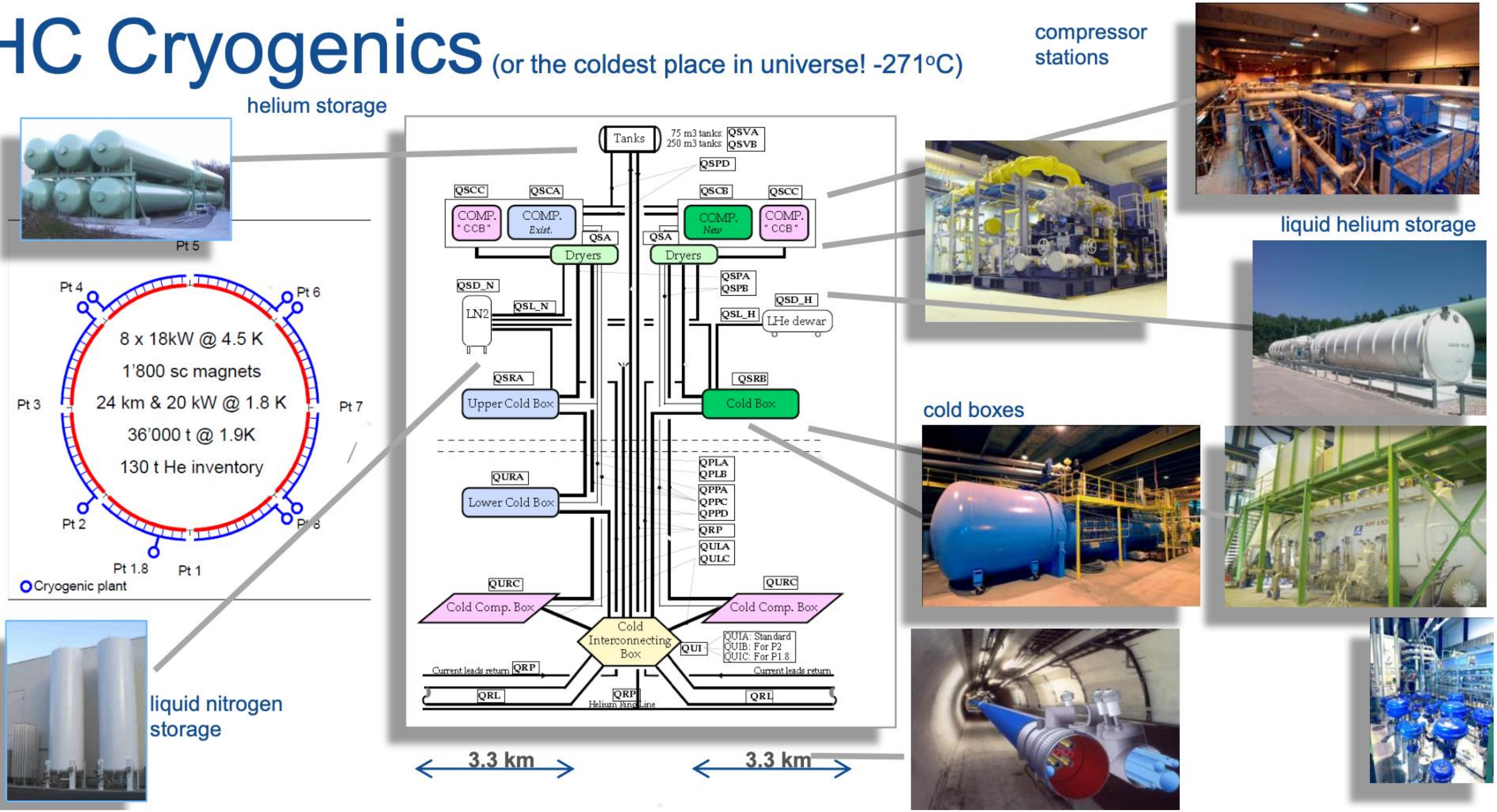
1232 superconducting dipoles for bending: 14m, 35t, 8.3T, 12kA



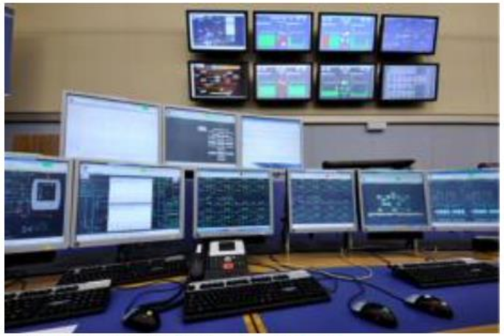


LHC Cryogenics

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



LHC Cryogenics Controls



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

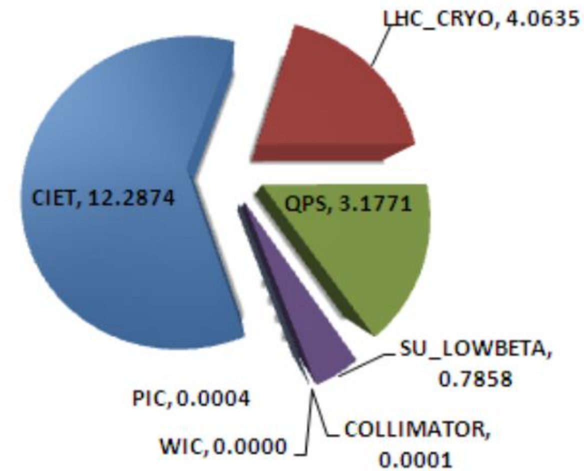
Electro-pneumatic positioner, SIPART PS2

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

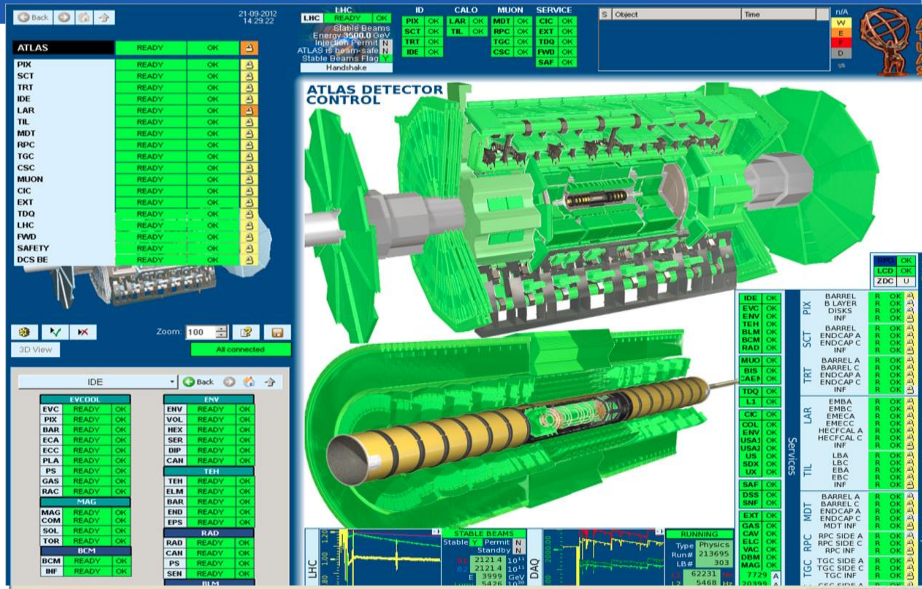
RadTol in-house electronics for signal conditioning and actuation

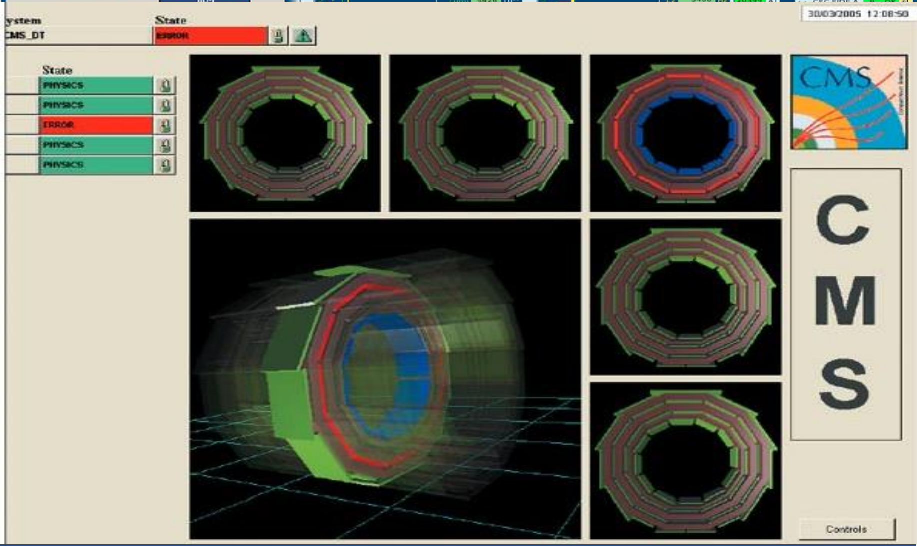
Logging DB Gb/day



Projects: Experiments

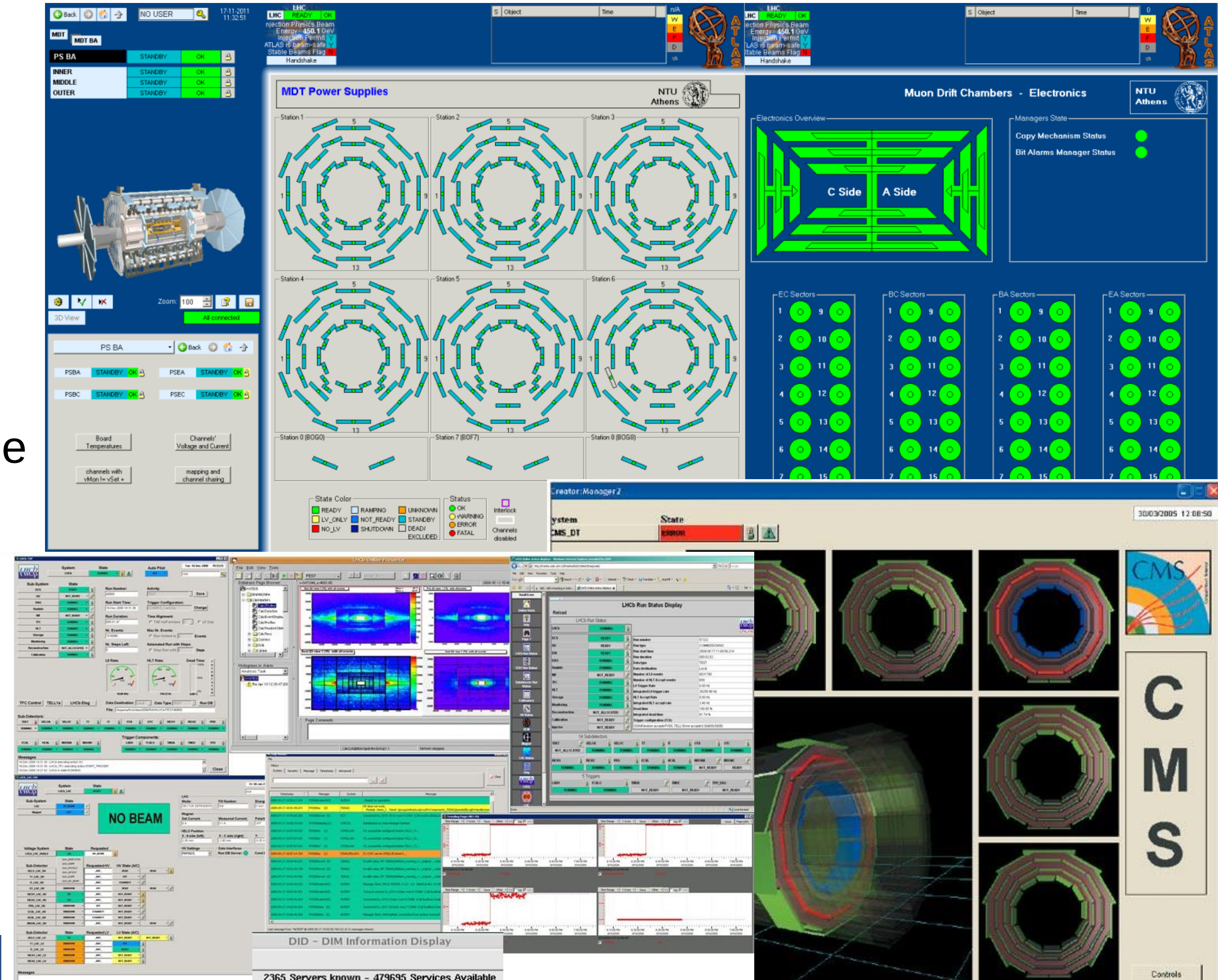
- A variety of Control Systems
  - Detector Control Systems
  - Run Control Systems
  - Detector Safety Systems
  - Gas Control Systems
  - Magnet Control Systems
  - Vacuum Control Systems
- For
  - The 4 LHC experiments
  - Smaller experiments COMPASS, NA62
  - Low-energy experiments: ISOLDE
  - Other experiments: CAST, CLOUD



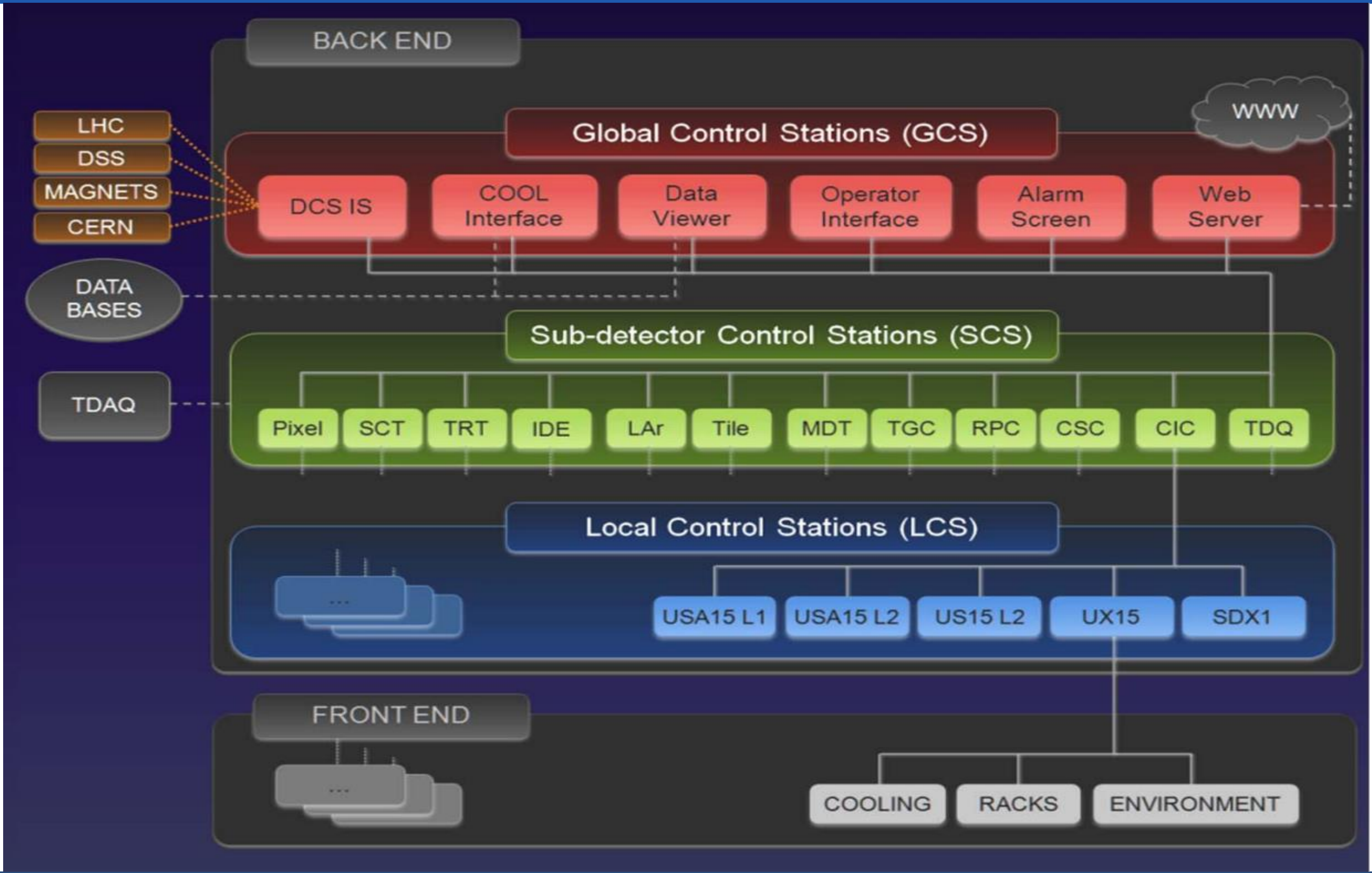


Detector Control System

- Up to 160 Interconnected WinCC OA Systems
- Up to 3 M I/O
- Up to 10 M variables (dpes)
- Common Oracle Database
- Synchronized through FSM and Expert System
- A single non-experience operator

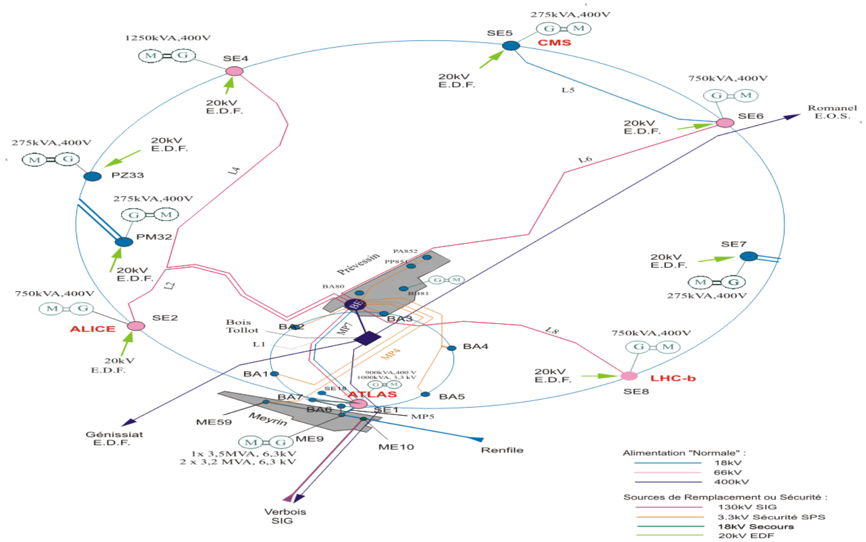


Distributed Supervision Architecture in ATLAS

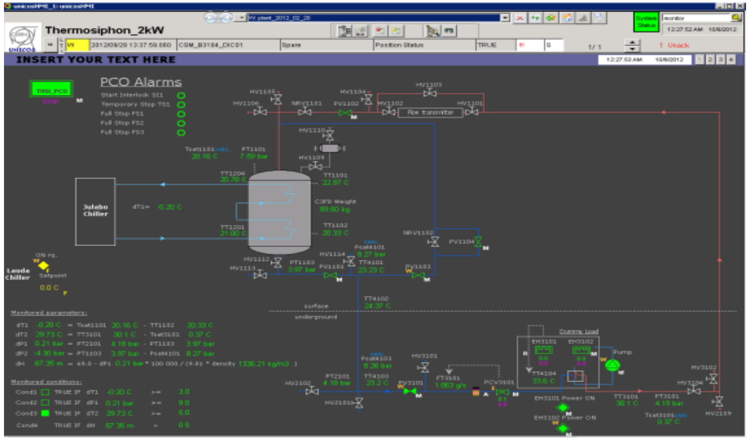


Projects: Technical Infrastructure

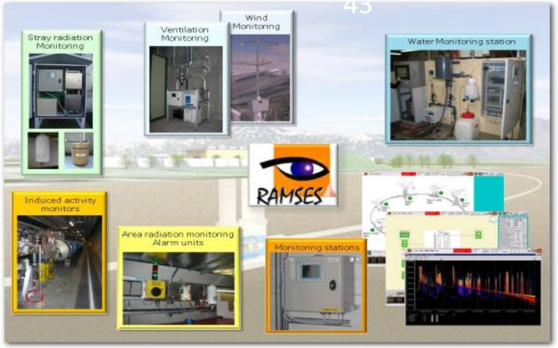
- Electrical network



- Cooling and Ventilation



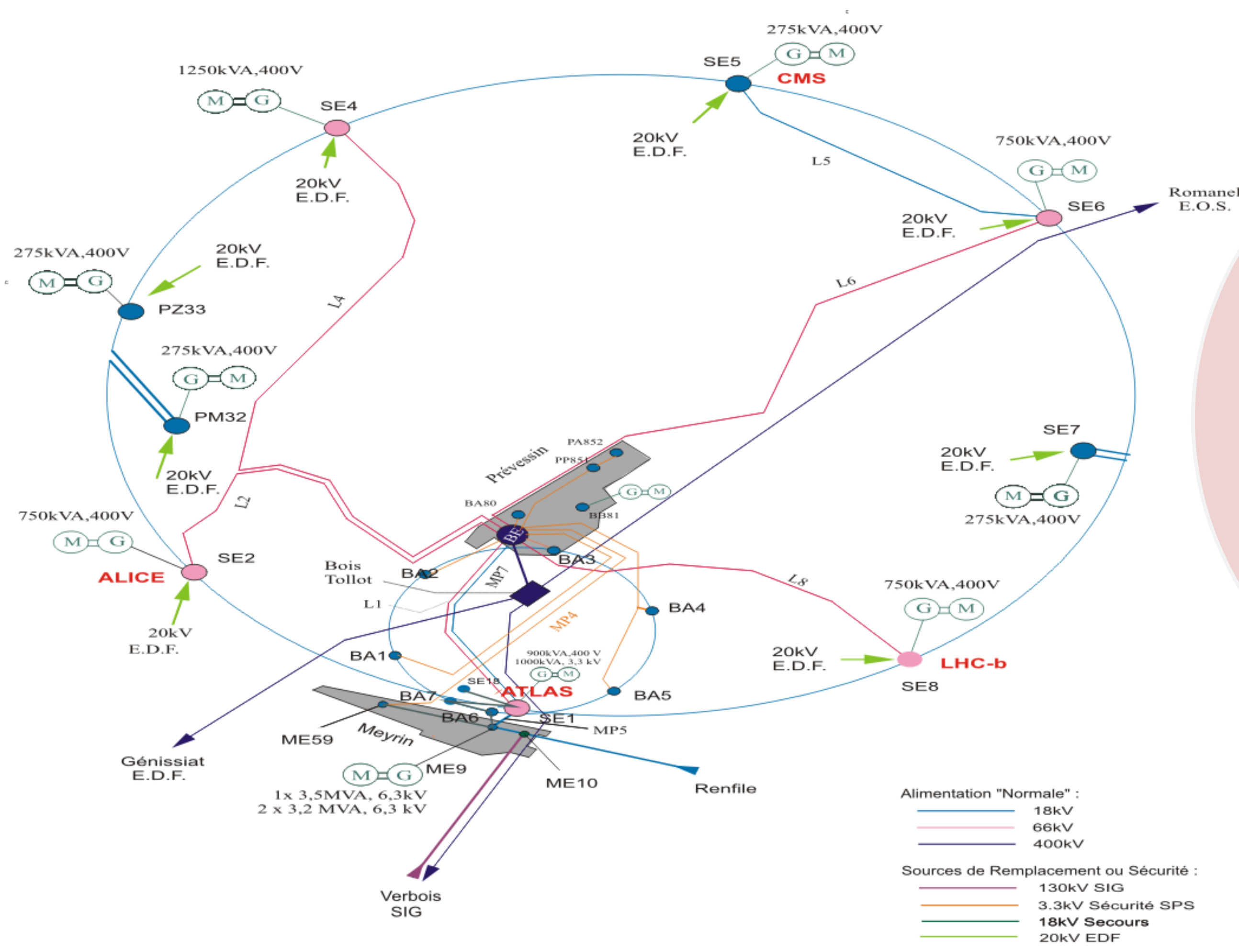
- Radiation and Environment Monitoring

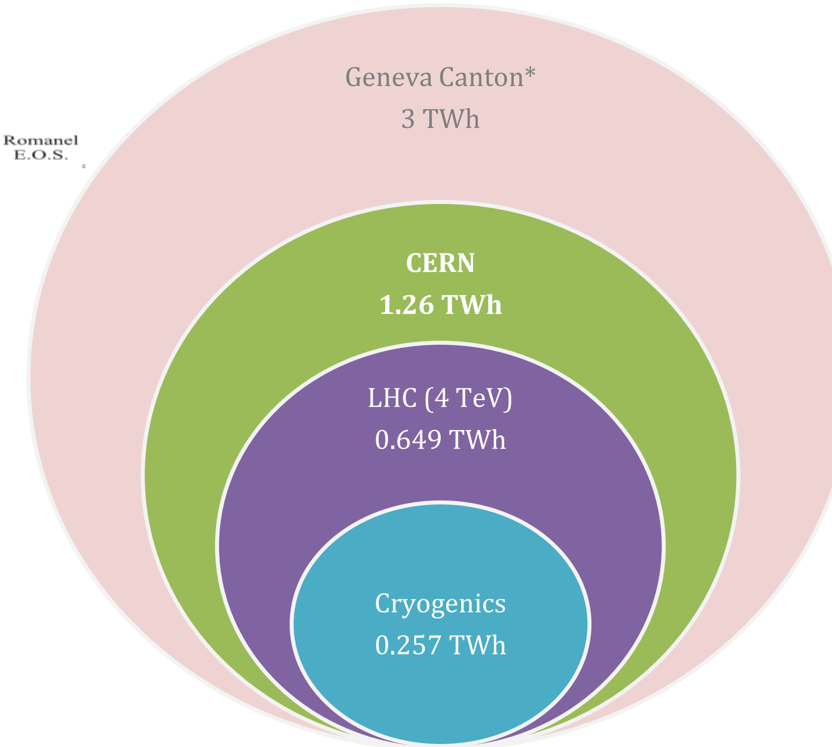


- Geometry and alignment

- Testbench systems

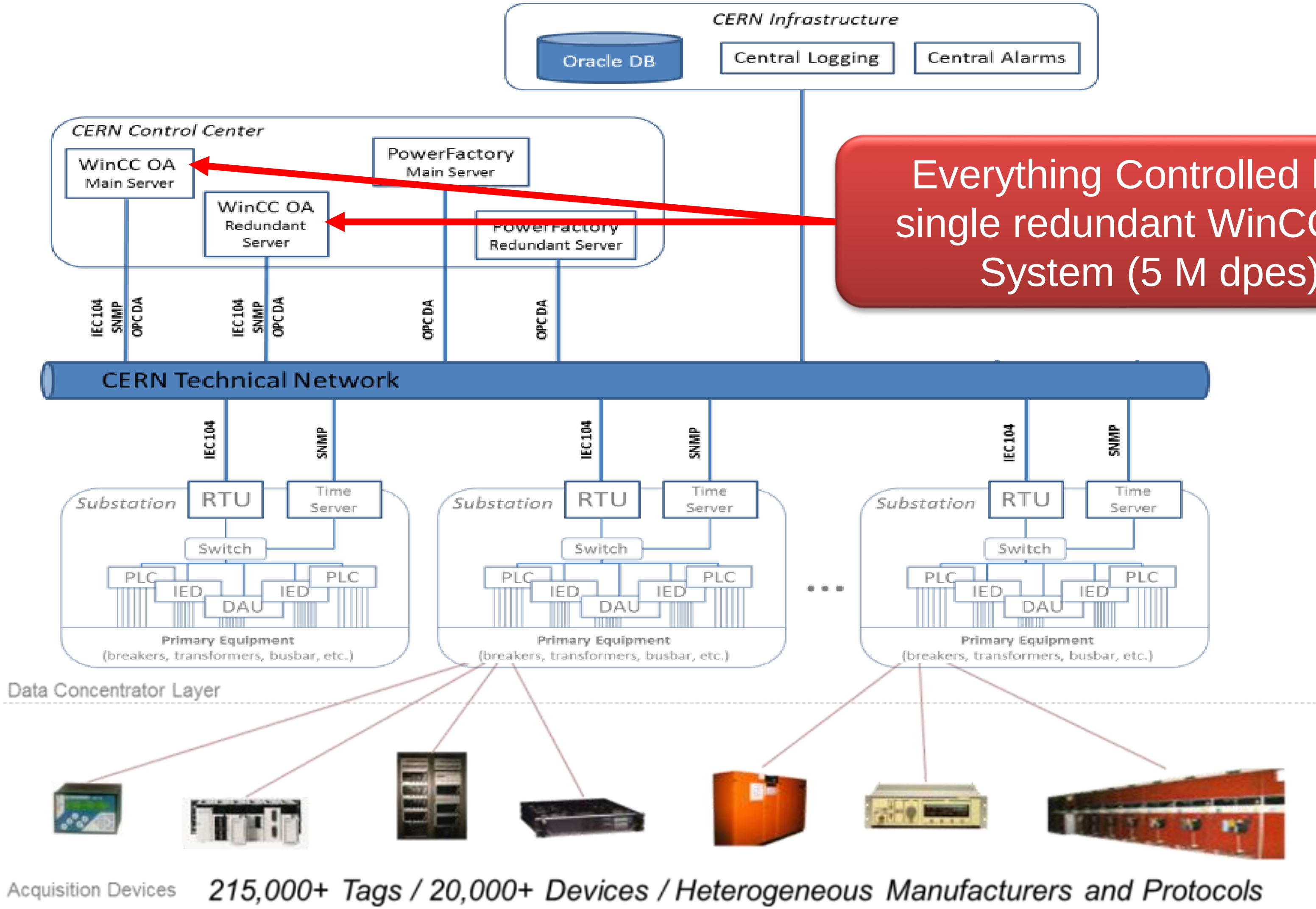
CERN Electrical Network





2012 Yearly Consumption

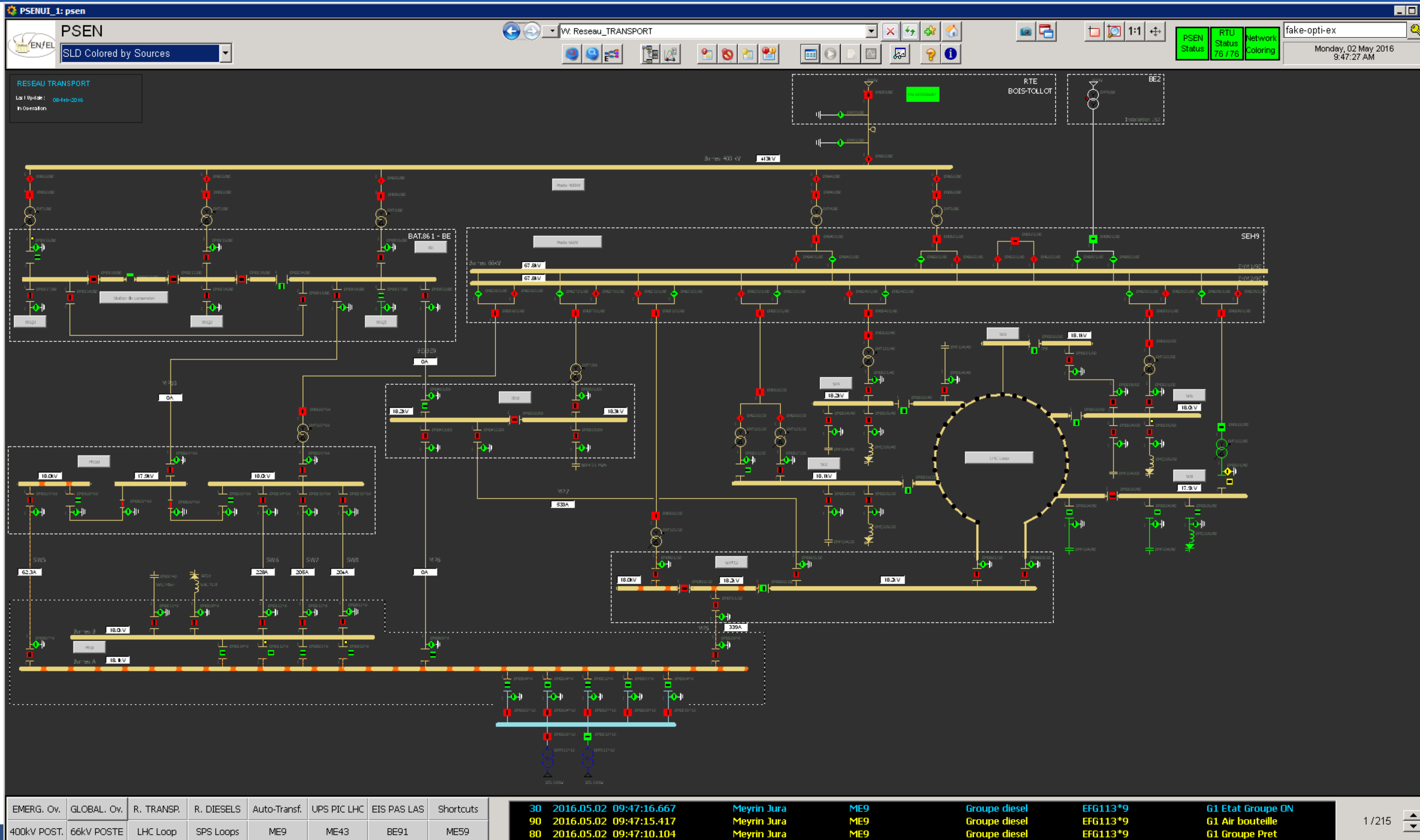
WinCC OA for Electrical Distribution



Everything Controlled by a single redundant WinCC OA System (5 M dpes)

215,000+ Tags / 20,000+ Devices / Heterogeneous Manufacturers and Protocols

WinCC OA HMI for Electrical Grid



20 years of Successful Partnership

Long-term partnership

- Different collaboration models with Siemens & ETM
  - CERN specifications + feedback
  - Joint Workshops (with source code)
  - Openlab
- Many results
  - WinCC OA Distributed Systems
  - WinCC OA Oracle Archiver optimization
  - WinCC OA User Interface technology (Qt based), WebUI, CTRL++
  - WinCC OA Driver development (Modbus, S7)
  - ML applied to ICS
  - Distributed Complex Event Processing
  - PLC Security
- Current work
  - Next Generation Archiver
  - Industrial Edge & Device Monitoring
- Reference site and visit organisation for potential customers
- Regular follow up meetings
  - Annual meetings to review roadmaps, get information about new products and releases (Nuremberg, Eisenstadt)
  - Regular meetings to follow up on support issues

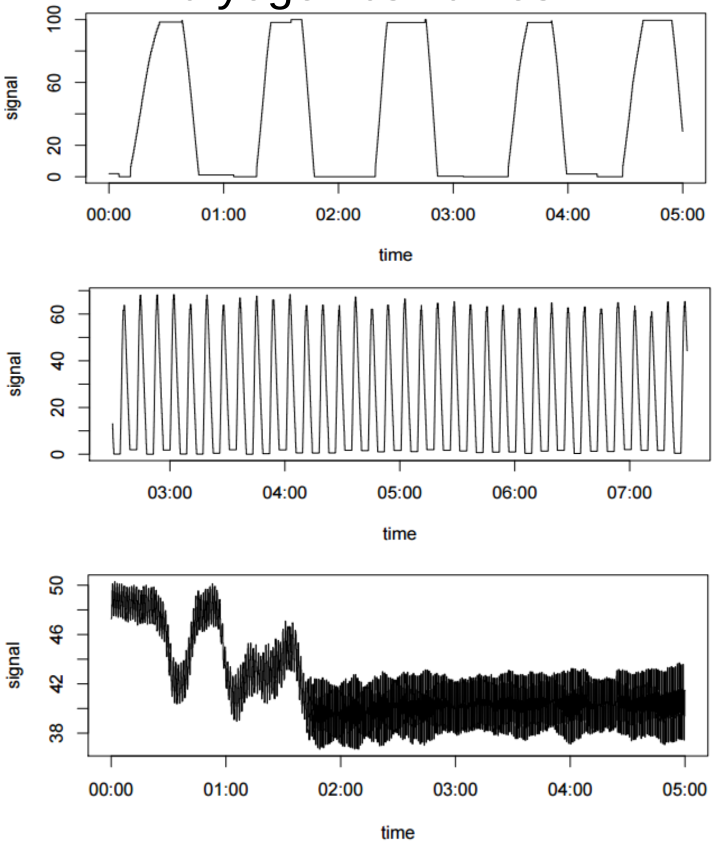
Ongoing and future Challenges

Ongoing and Future Challenges

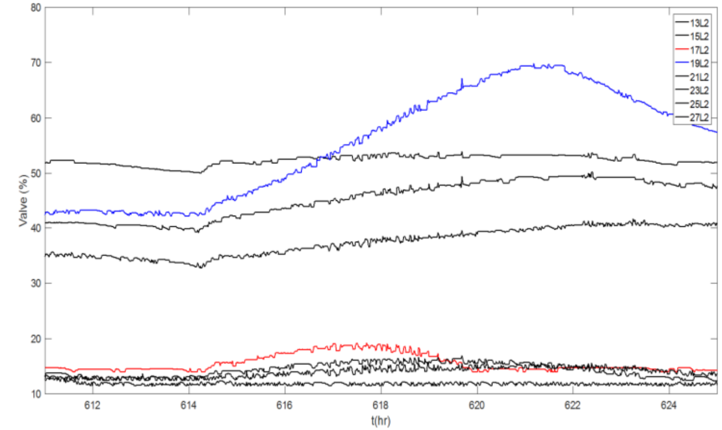
- Migration of Archiving from Oracle to Influx DB and PostgreSQL/Timescale DB
- Integration of Machine Learning and AI to reduce operation and maintenance cost:
  - Predictive maintenance
  - System Optimization
  - Smarter control system that can guide operators in the event of problems or to take automatic corrective actions
- Integration of Industrial Edge and IoT devices

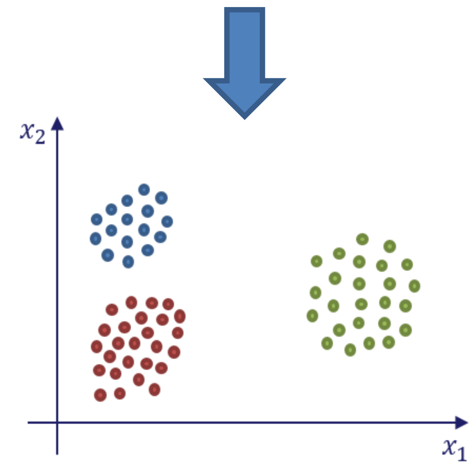
Some selected ML results (1/4)

Abnormal Oscillation of cryogenics valves



Anomaly Detection

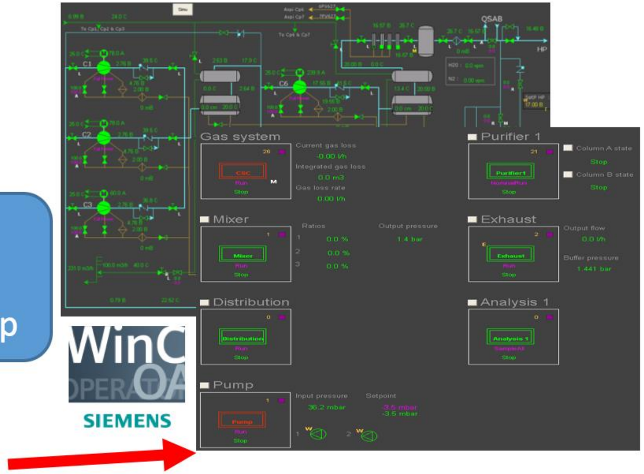




Some selected ML results (2/4)

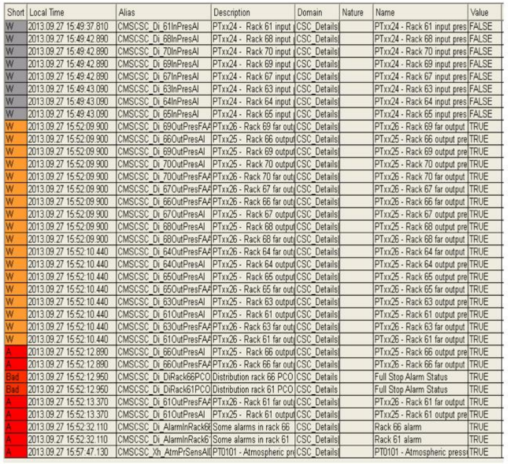
Root-cause analysis in the event of major events (Alarm flood)

Misleading feedback!
Actual problem in the distribution and not in the Pump



Fault in the distribution system

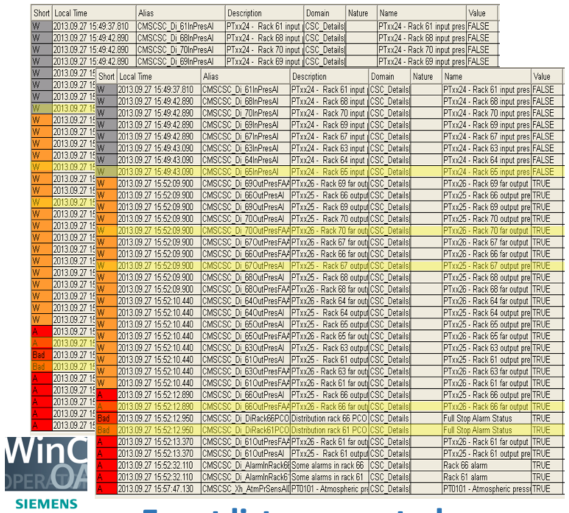
Domino effect



Short	Local Time	Alias	Description	Domain	Nature	Name	Value
W	2013.09.27 15:49:37.810	CMSCSC_Di_61InPresAl	PTxx24 - Rack 61 input	CSC_Details		PTxx24 - Rack 61 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_68InPresAl	PTxx24 - Rack 68 input	CSC_Details		PTxx24 - Rack 68 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_70InPresAl	PTxx24 - Rack 70 input	CSC_Details		PTxx24 - Rack 70 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_69InPresAl	PTxx24 - Rack 69 input	CSC_Details		PTxx24 - Rack 69 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_67InPresAl	PTxx24 - Rack 67 input	CSC_Details		PTxx24 - Rack 67 input pres	FALSE
W	2013.09.27 15:49:43.090	CMSCSC_Di_63InPresAl	PTxx24 - Rack 63 input	CSC_Details		PTxx24 - Rack 63 input pres	FALSE
W	2013.09.27 15:49:43.090	CMSCSC_Di_64InPresAl	PTxx24 - Rack 64 input	CSC_Details		PTxx24 - Rack 64 input pres	FALSE
W	2013.09.27 15:49:43.090	CMSCSC_Di_65InPresAl	PTxx24 - Rack 65 input	CSC_Details		PTxx24 - Rack 65 input pres	FALSE
W	2013.09.27 15:52:09.900	CMSCSC_Di_69OutPresFAA	PTxx26 - Rack 69 far out	CSC_Details		PTxx26 - Rack 69 far output	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_66OutPresAl	PTxx25 - Rack 66 output	CSC_Details		PTxx25 - Rack 66 output pre	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_69OutPresAl	PTxx25 - Rack 69 output	CSC_Details		PTxx25 - Rack 69 output pre	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_70OutPresAl	PTxx25 - Rack 70 output	CSC_Details		PTxx25 - Rack 70 output pre	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_70OutPresFAA	PTxx26 - Rack 70 far out	CSC_Details		PTxx26 - Rack 70 far output	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_67OutPresFAA	PTxx26 - Rack 67 far out	CSC_Details		PTxx26 - Rack 67 far output	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_66OutPresFAA	PTxx26 - Rack 66 far out	CSC_Details		PTxx26 - Rack 66 far output	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_67OutPresAl	PTxx25 - Rack 67 output	CSC_Details		PTxx25 - Rack 67 output pre	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_68OutPresAl	PTxx25 - Rack 68 output	CSC_Details		PTxx25 - Rack 68 output pre	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_68OutPresFAA	PTxx26 - Rack 68 far out	CSC_Details		PTxx26 - Rack 68 far output	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_64OutPresFAA	PTxx26 - Rack 64 far out	CSC_Details		PTxx26 - Rack 64 far output	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_64OutPresAl	PTxx25 - Rack 64 output	CSC_Details		PTxx25 - Rack 64 output pre	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_65OutPresAl	PTxx25 - Rack 65 output	CSC_Details		PTxx25 - Rack 65 output pre	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_65OutPresFAA	PTxx26 - Rack 65 far out	CSC_Details		PTxx26 - Rack 65 far output	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_63OutPresAl	PTxx25 - Rack 63 output	CSC_Details		PTxx25 - Rack 63 output pre	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_61OutPresAl	PTxx25 - Rack 61 output	CSC_Details		PTxx25 - Rack 61 output pre	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_63OutPresFAA	PTxx26 - Rack 63 far out	CSC_Details		PTxx26 - Rack 63 far output	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_61OutPresFAA	PTxx26 - Rack 61 far out	CSC_Details		PTxx26 - Rack 61 far output	TRUE
A	2013.09.27 15:52:12.890	CMSCSC_Di_66OutPresAl	PTxx25 - Rack 66 output	CSC_Details		PTxx25 - Rack 66 output pre	TRUE
A	2013.09.27 15:52:12.890	CMSCSC_Di_66OutPresFAA	PTxx26 - Rack 66 far out	CSC_Details		PTxx26 - Rack 66 far output	TRUE
Bad	2013.09.27 15:52:12.950	CMSCSC_Di_DiRack66PCO	Distribution rack 66 PCO	CSC_Details		Full Stop Alarm Status	TRUE
Bad	2013.09.27 15:52:12.950	CMSCSC_Di_DiRack61PCO	Distribution rack 61 PCO	CSC_Details		Full Stop Alarm Status	TRUE
A	2013.09.27 15:52:13.370	CMSCSC_Di_61OutPresFAA	PTxx26 - Rack 61 far out	CSC_Details		PTxx26 - Rack 61 far output	TRUE
A	2013.09.27 15:52:13.370	CMSCSC_Di_61OutPresAl	PTxx25 - Rack 61 output	CSC_Details		PTxx25 - Rack 61 output pre	TRUE
A	2013.09.27 15:52:32.110	CMSCSC_Di_AlarmInRack6	Some alarms in rack 66	CSC_Details		Rack 66 alarm	TRUE
A	2013.09.27 15:52:32.110	CMSCSC_Di_AlarmInRack6	Some alarms in rack 61	CSC_Details		Rack 61 alarm	TRUE
A	2013.09.27 15:57:47.130	CMSCSC_Xh_AtmPrSensAl	PT0101 - Atmospheric pr	CSC_Details		PT0101 - Atmospheric press	TRUE

Alarms flooding

Some selected ML results (3/4)



Event lists generated by the same fault

Data

Analyze

Identify and detect fault / abnormal pattern for Diagnosis and Prognostics

Learn

Provide experts with Root-cause and Gap Analysis using Rules and Patterns Mining

Diagnose

Forecasts, Trends and Early-Warnings to increase Operating Hours

Sequence: Confidence: 83.3 % / Appearance count: 5

CMSCSC_Di_62PRegAl | Alarm Unacknowledged | Rising

Sequence: Confidence: 100.0 % / Appearance count: 6

CMSCSC_Di_62PRegAl | Alarm Unacknowledged | Rising
CMSCSC_Di_62PRegAl | Position Status (HH-LL) | Rising
CMSCSC_Di_YC60995 | Auto Off/Close Request Status | Falling
CMSCSC_Di_YC60995 | Auto On/Open Request Status | Rising
CMSCSC_Di_YC60995 | Off/Closed Status | Falling
CMSCSC_Di_YC60995 | On/Opened Status | Rising
CMSCSC_Di_YC60995 | Output Order Value Status | Rising

Pattern AA B A A B → **Alarm**

X T C D F A A E D N D B K D F A A B K D

Achievements:

- ✓ Identification of the root of the problem
- ✓ Algorithm learns patterns and use them to forecast possible faults
- ✓ Early warning to operators to intervene

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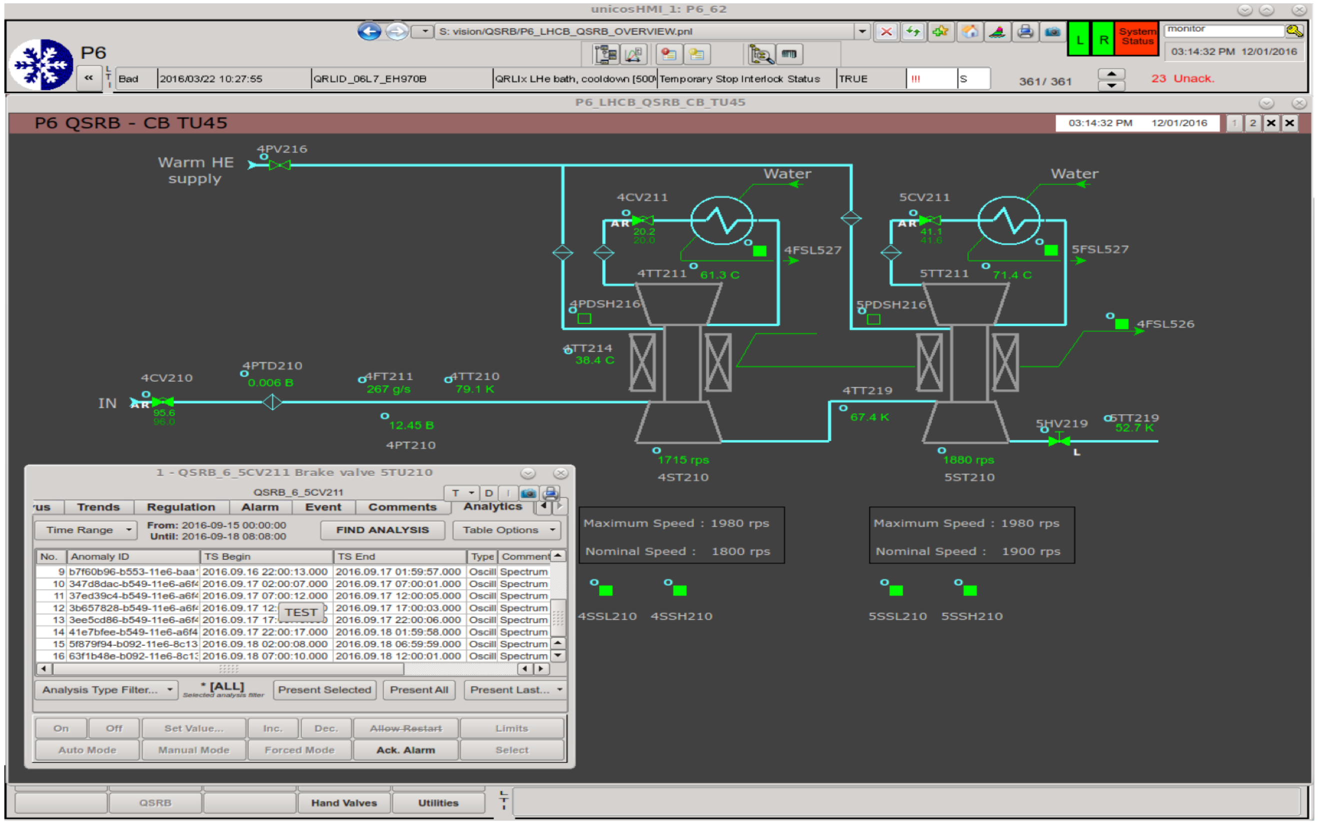
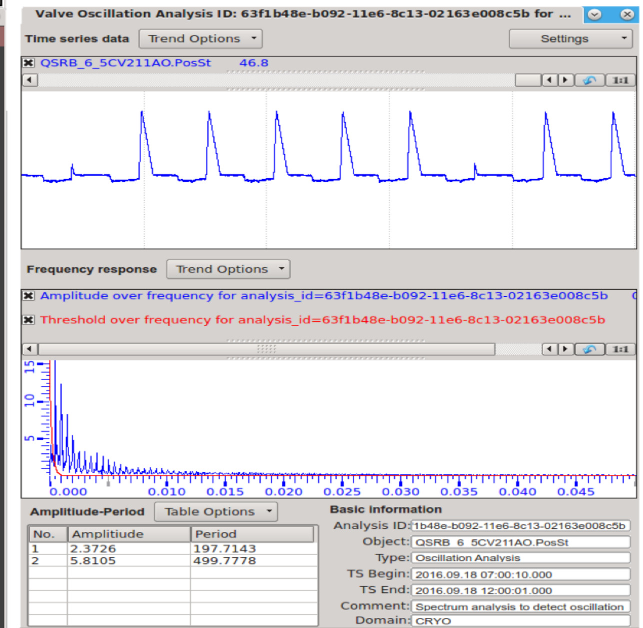
Some selected ML results (4/4)

Visual feedback and alarms in WinCC OA as result of ML analysis





Status: Working prototype

Credits:

- Industrial Controls Systems Group
- LHC Experiments

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Industrial Control Systems Group - Beams Department