Les Journées Thématiques AFF-CCS au CERN
Cryogénie et Supraconductivité pour le LHC et ses détecteurs

Organisées par l'Association Française du Froid
Commission de Cryogénie et de Supraconductivité

L'instrumentation et le contrôle de la cryogénie

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- **Contraintes environnementales**
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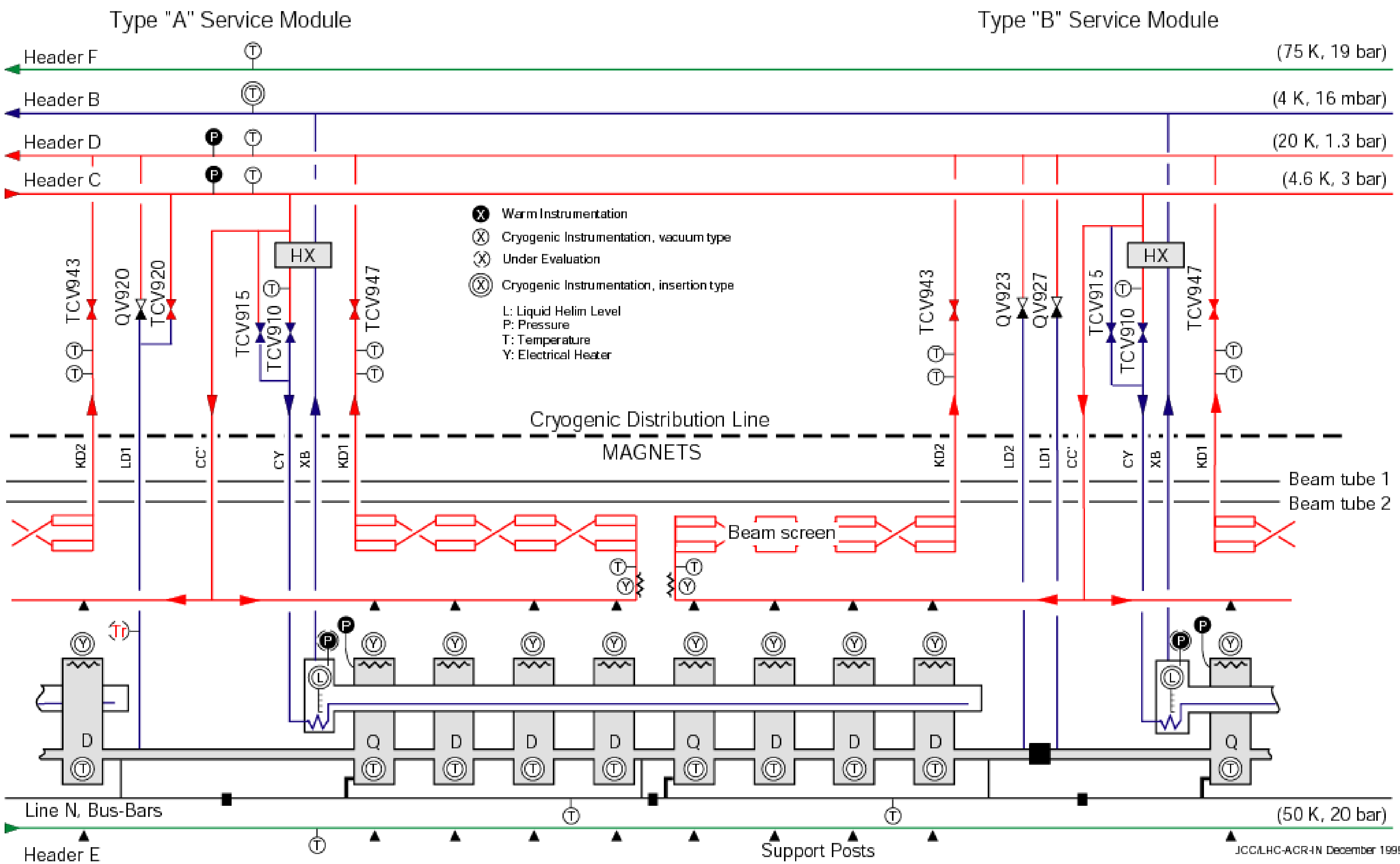
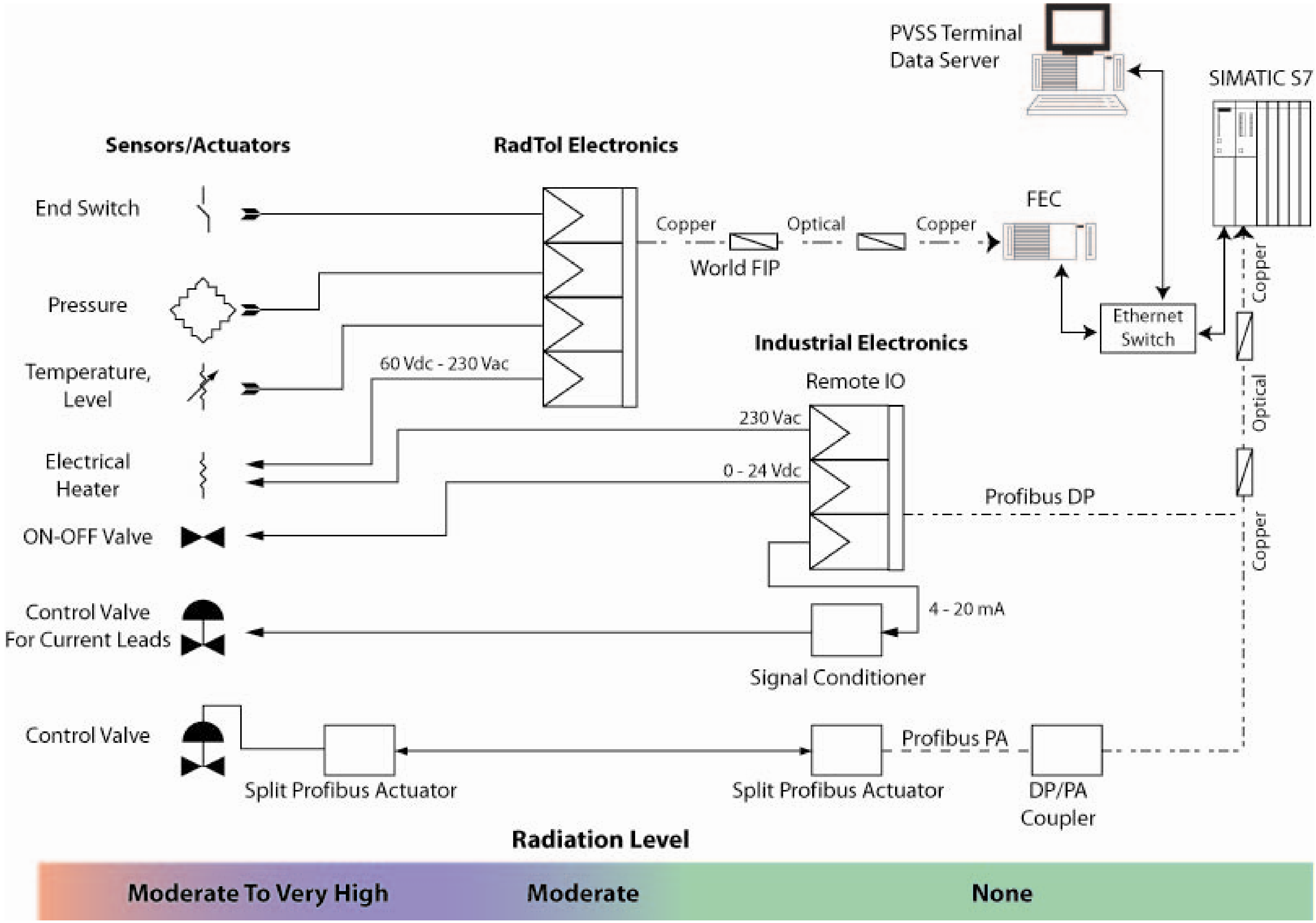
Sommaire

- The LHC instrumentation and control is distributed over the 27 km long tunnel and about 30 protected areas; requiring extensive use of fieldbus networks and scattered remote IO.
- The Radiation environment complicates significantly the selection and qualification for the LHC components installed inside the tunnel.
- Cost Mitigation requested to minimize the cabling budget imposing the procurement of radiation tolerant electronics.
- The sheer size of the LHC cryogenics is simply enormous requiring state of the art control systems for feedback closed control loops, monitoring and data storage.
- Requires a robust Quality Assurance policy.
- Automatic procedures for generation of control programs and for commissioning tasks are a necessity.

Cellule LHC Standard



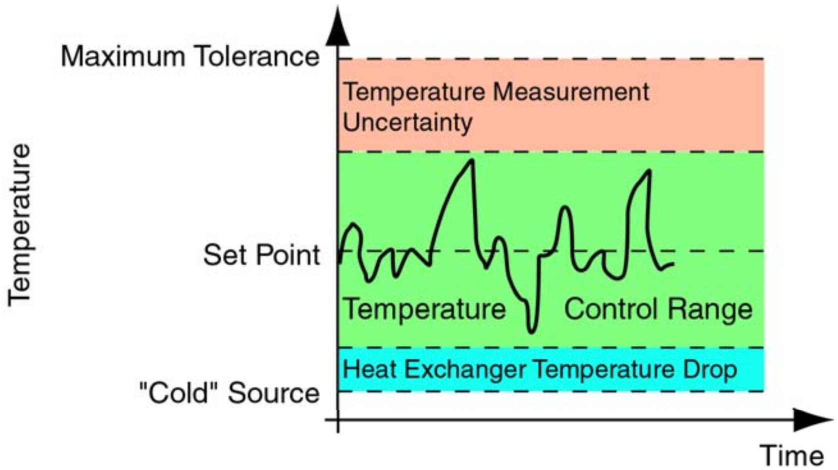
Contraintes environnementales



Sélection
Contraintes Principales

» Radiation Qualification at ambient and **cryo** conditions for tunnel equipment: sensors, actuators, electronics and fieldbus

» Temperature Readout at 1.8 K:
TARGET: +- 0.01 K (shared between sensors and electronics) over 10 years
Measurement uncertainty reduces the control range
=> Cernox from Lake Shore (USA)



» Large Series temperature calibration stations at CNRS (IPN) Orsay and CERN
Over 6000 thermometers calibrated individually in the range 1.6K to 300K
Calibration throughput: ca 200/month

» Saturated LHeII Pressure Readout at 16 kPa:
Requirement: +- 5 Pa over 10 years and Rad-Hard
NO SENSOR PASSED THE TESTS!
Selection, qualification and procurement delayed for future LHC consolidation

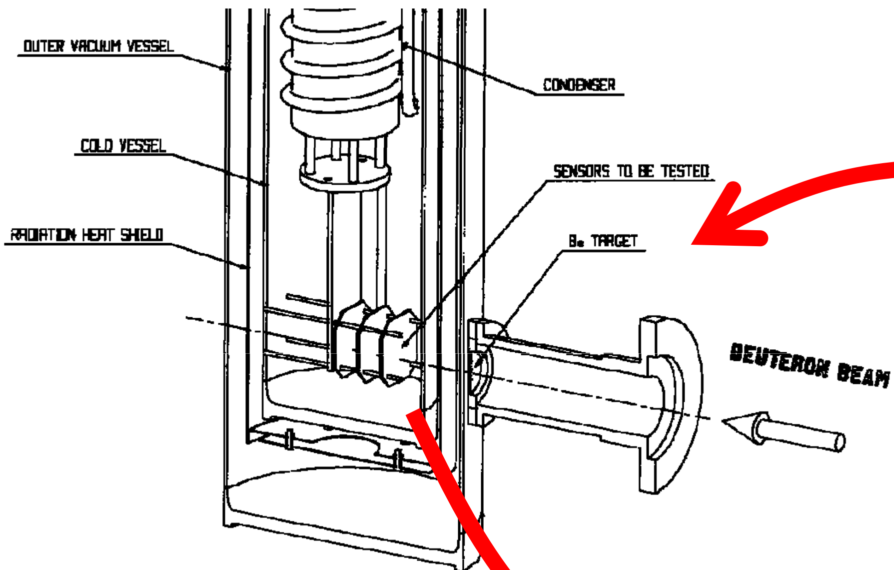
» Electrical signals for temperature and pressure sensors:
few tens of mV
required uncertainty on voltage measurement 0.4 % on readout
=> Resistance Bridge Configuration for RadTol
=> Require Rad-Tol 14-bit ADC

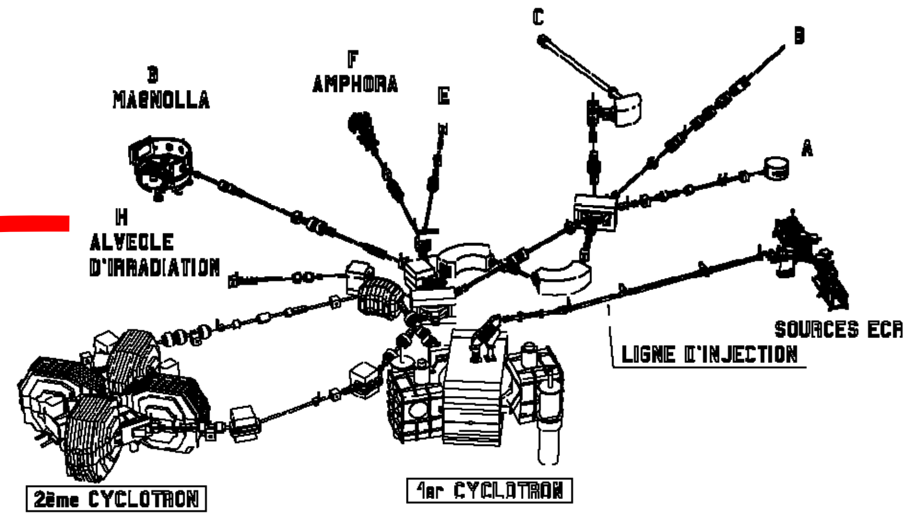
Equipements RadHard / RadTol

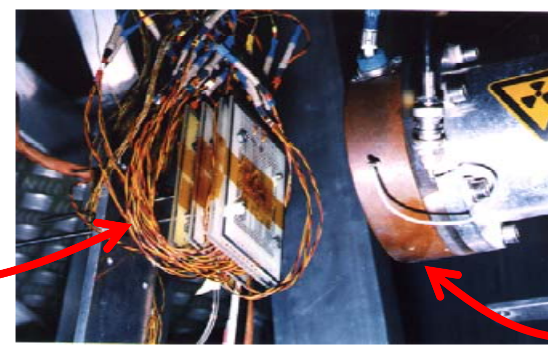
Sensor	Location	Qty	Type
Lhe Level Gauge	Lhe-II phase Separator, DFB, Stand Alone Magnets	528	Superconducting Wire
Pressure Sensor	Magnets, QRL, DFB	694	Strain Bridge
Pressure Sensor	RF Cavities	8	Profibus PA
Thermometers		9564	
	Current Leads	3300	Pt 100
	QRL, Magnets, RF, etc	5400	Cernox
	QRL, Magnets, RF, etc	336	Pt 100
	Electrical Heaters	528	Pt 100 & Type-J thermocouple
GH/GL/PS Signals	ON-OFF Valves and Pressure Switches	1152	Mechanical Switch
Actuator	**Location**	**Qty**	**Type**
Control Valves	QRL	1436	Profibus PA
Control Valves	Current Leads	1184	Analogue
ON-OFF Valves	QRL	374	Pneumatic
Quench Valves	QRL	342	Pneumatic
Electrical Heater	All	2462	Electrical resistor
Electronics	**Location**	**Qty**	
Crate (Cabinet)	Under main dipole, protected areas	853	Mechanical Assembly
Power Source Card	Crate	1184	COTS based Design
Temperature - Pressure Card		4502	
Sc Level Crad		413	
Digital In Card		317	
FIP comm card		1266	

About 20 % of the sensor channels are not equipped with dedicated conditioning electronics; either for redundancy or cost savings.

RadHard: Qualif





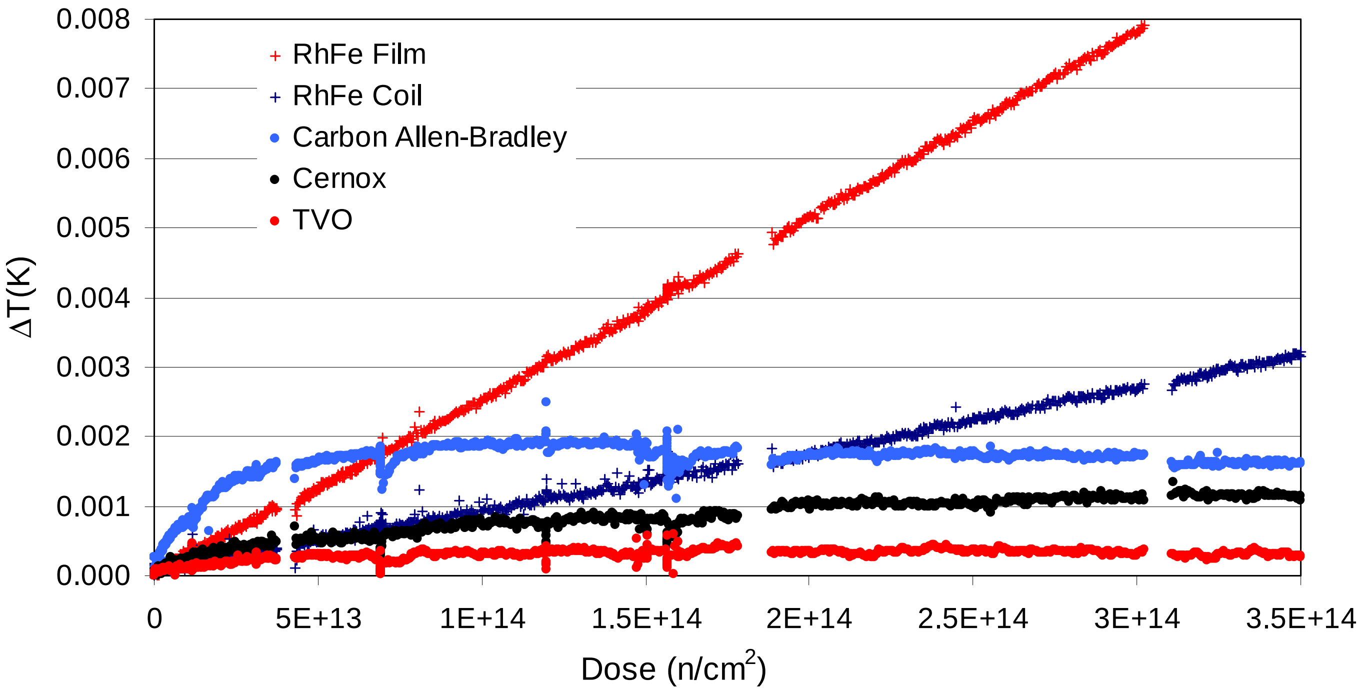


Be Target

Tests Performed on:
Temperature Sensors
Cryo-pressure Sensors
LHe Level Gauges (sample test)

Tests carried at SARA (Grenoble) and CERI (Orleans)

RadHard: Résultats



Radiation Hardness is better for “amorphous materials”

» Arc @ dipole: 4 10^{12} n/cm2

» Arc @ Quad: 10^{13} n/cm2

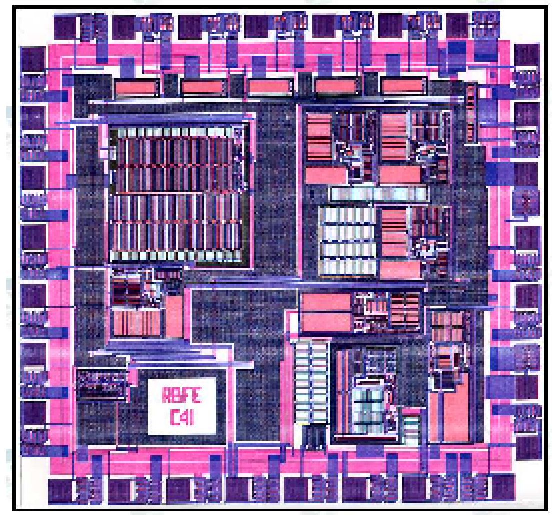
» DS: 10^{13} to 10^{15} n/cm2

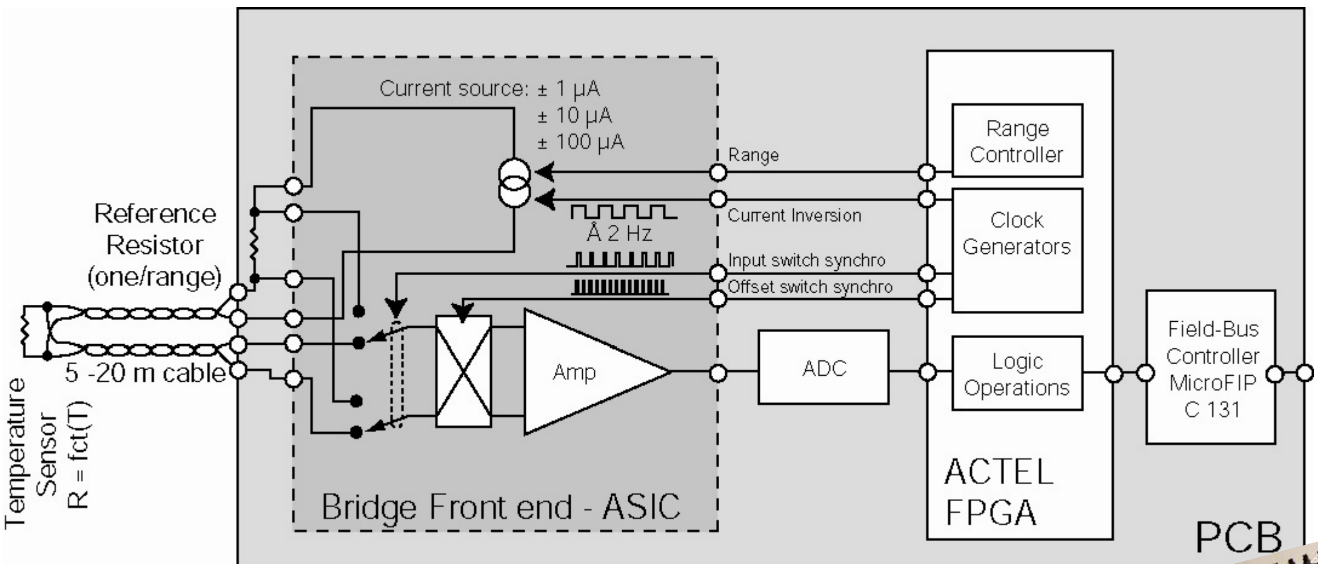
» LSS: > 10^{13} to **VERY HIGH** n/cm2

NOTE sub-mK on-line measurement accuracy during irradiation
=> IT WAS A WORLD PREMIERE!

RadTol: Design

- Analog Readout based on:
- a comparison bridge providing excellent performance against TID and temperature effects
- a quarter micron ASIC using IBM technology
- COTS for OP-Amps, ADCs, DACs and passive components
- Anti-fuse FPGAs with triplicated logic
- Micro FIP C131 WorldFIP bus controller

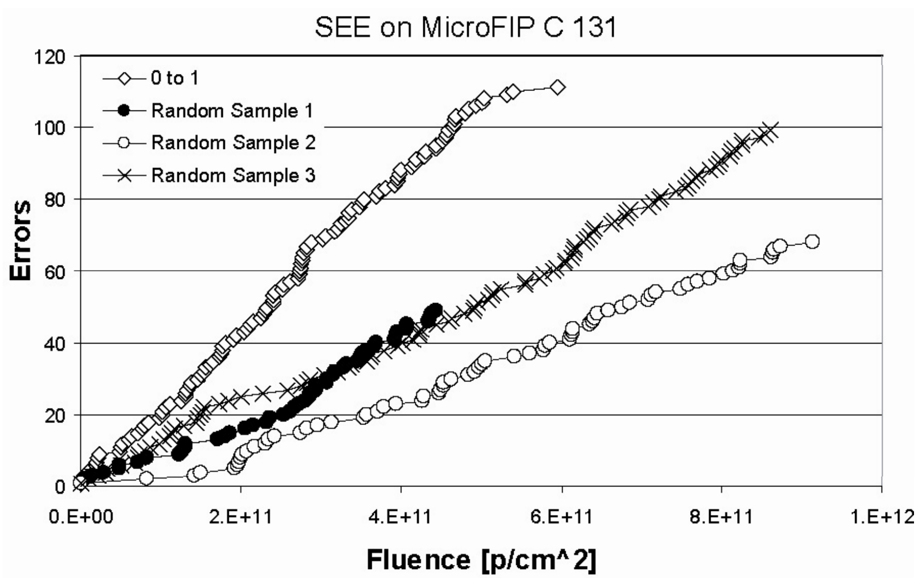


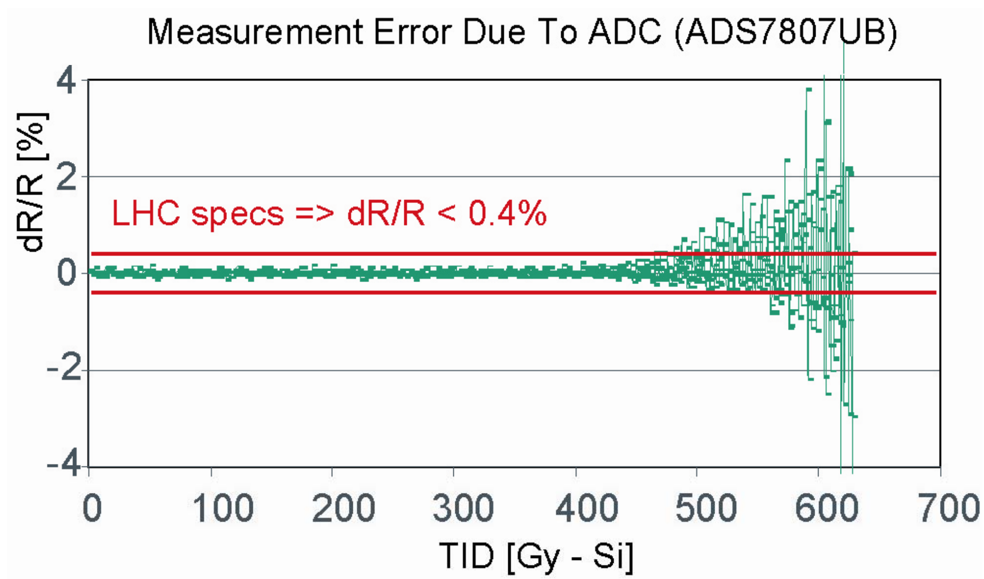


RadTol: Tests

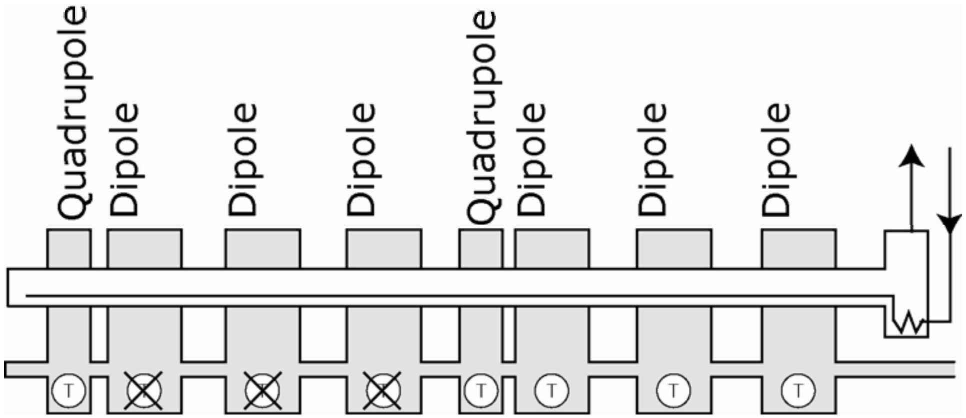
- **Digital Circuits are sensitive to SEE and "most" SEE can be corrected by using appropriate algorithms**
  SEE Effects probability depend "0" to "1" or "1" to "0"
- **All circuits are degraded by Total Integrated Dose (TID)**
  The most "fragile" circuit used is the ADC that limits the Radiation Tolerance to about 400 Gy
- **Tests are done with very high dose rates**
  => Annealing will certainly improve the actual radiation tolerance of the LHC electronics

CERN: TCC2 area (presently dismantled) for LHC like radiation on complete systems
PSI (CH) and Louvain (BE) for fast particles or SEE on particular Integrated Circuits
ITN (PT) for neutron damage on analog electronics and sub-systems





Thermométrie LHeII de Précision



LHC cell: "Isothermal" over 107m

⇒ **Temperature reproducibility typ. Better than 0.01 K**

In-situ calibration is unfeasible within the control requirements (0.01 K)

Budget savings required the reduction of acquisition channels

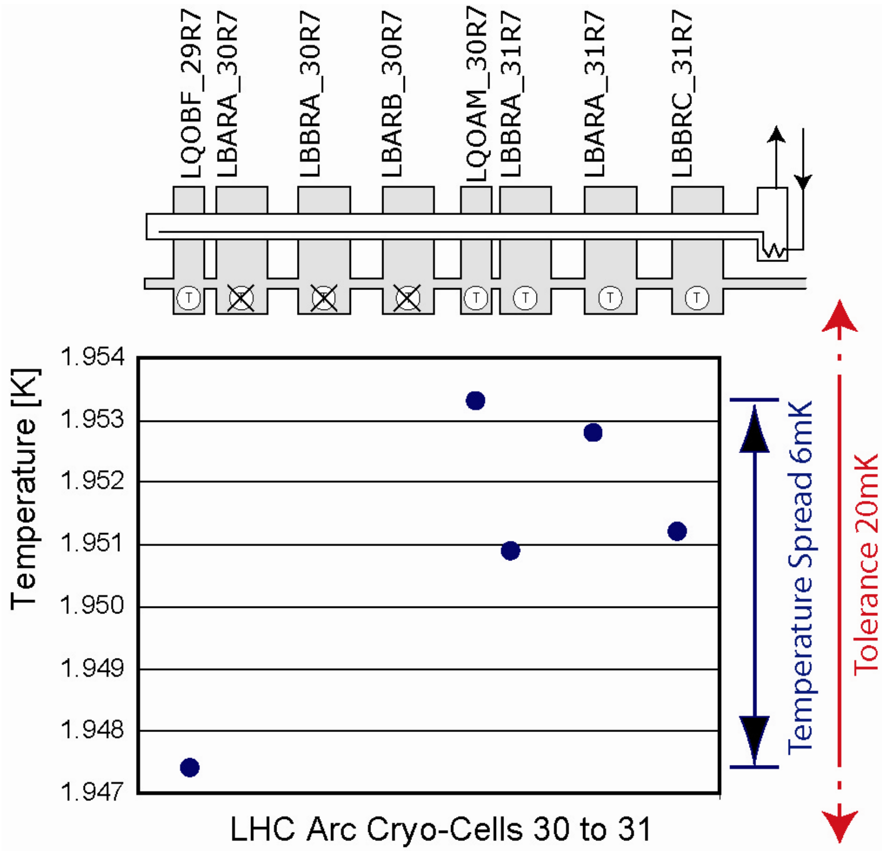
⇒ **Reproducibility of many thermometers cannot be assessed**

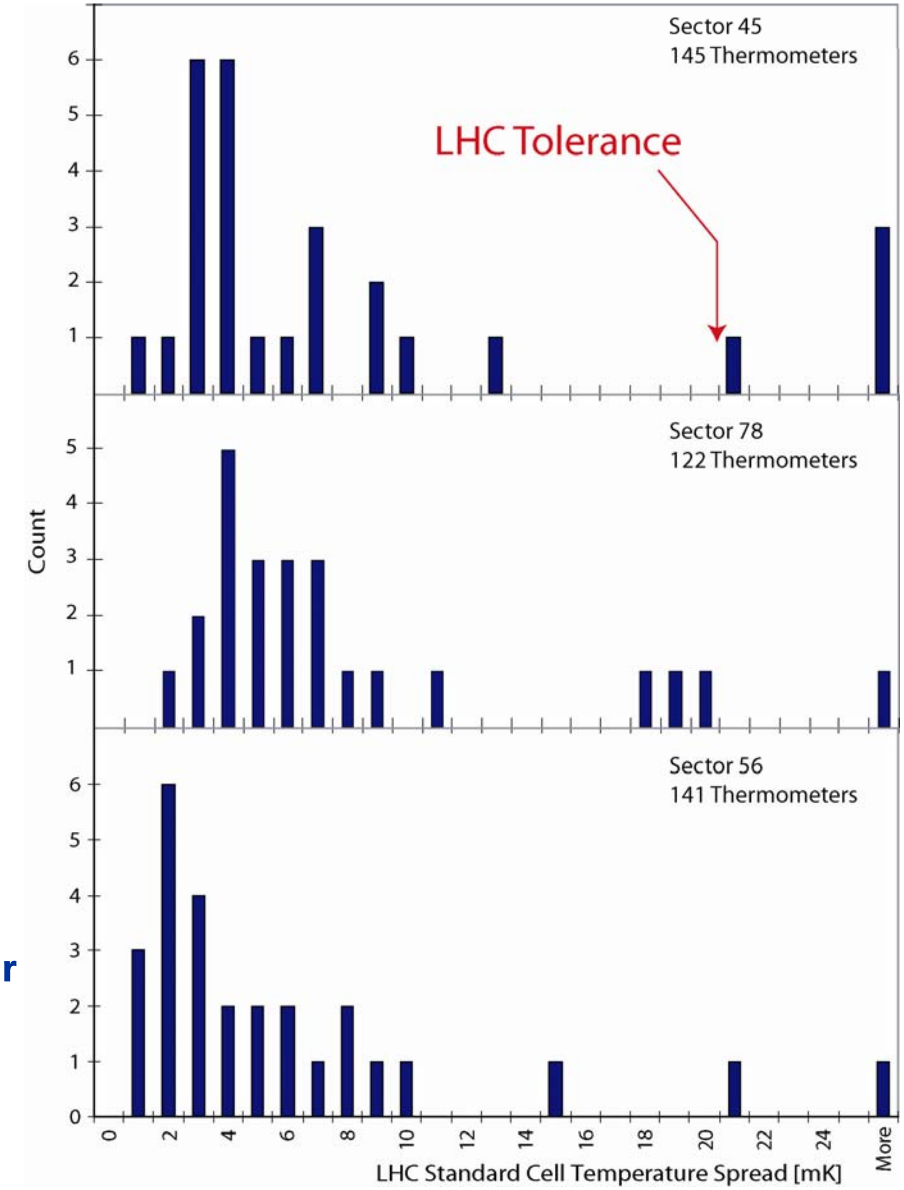
Nevertheless over 400 temperature measurements have been checked for 3 sectors

⇒ **Less than 2% of channels are outside requirements**

⇒ **1st time that +/- 0.01K reproducibility has been obtained without in-situ calibration!**

Thermométrie LHeII de Précision





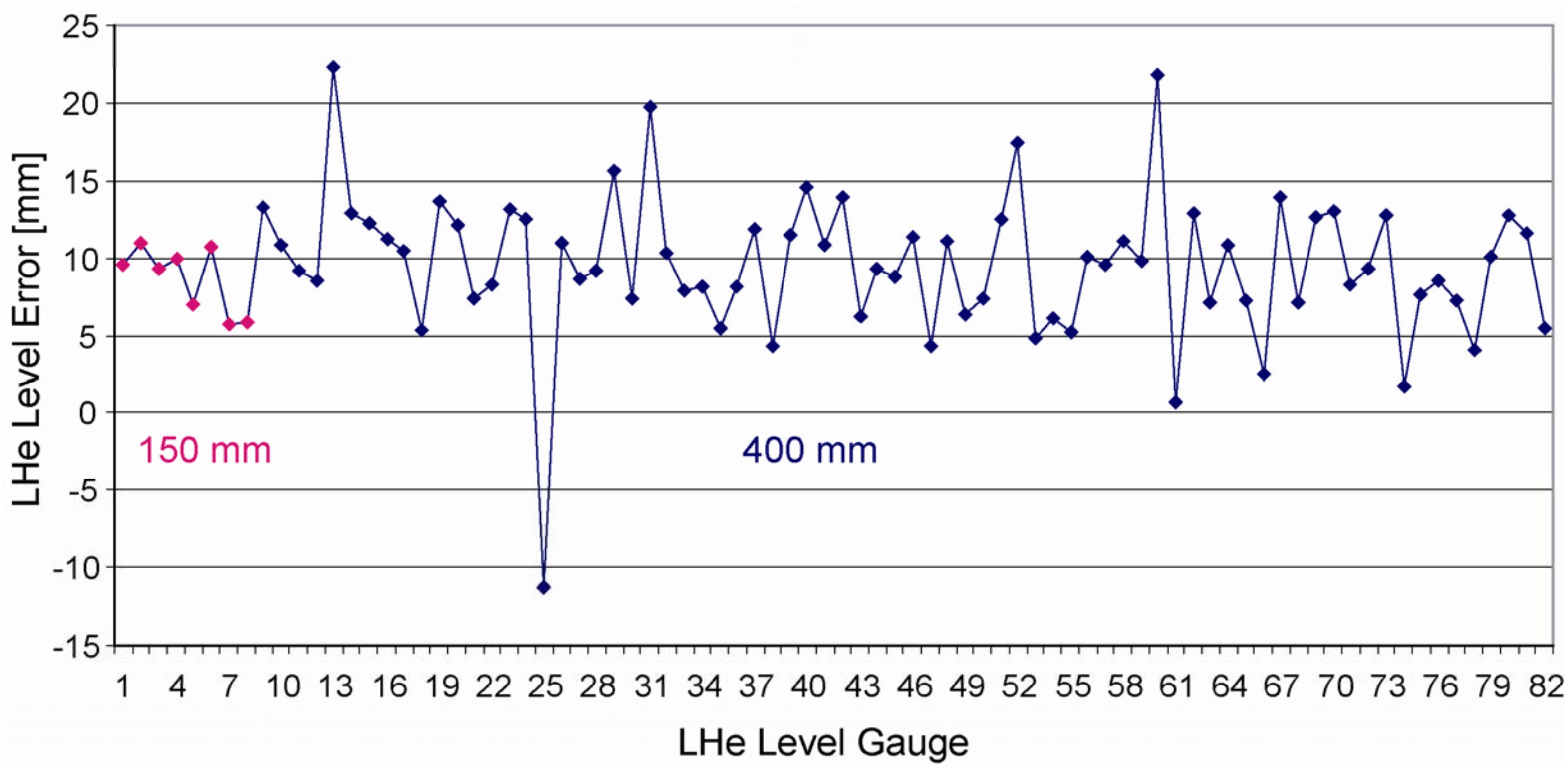
Cells with "large" spread can be due to:

- **Mismatch Magnet – Thermometer serial number**
- **Cells with Cryo-"problems"**
- **Calibration**

Jauges de Niveau LHe

Delivered gauges had inappropriate insulating material for radiation
=> Gauges reworked
=> AFTER Mechanical tolerances severely degraded

HTS current leads require very tight level regulation (< 10mm)
=> Individual Calibration
=> Without Individual Calibration the Level was mostly underestimated (typ. by 10mm)



Jauges de Niveau LHe Aimants Singuliers

Constrained GHe exhaust on LHe gauge holder

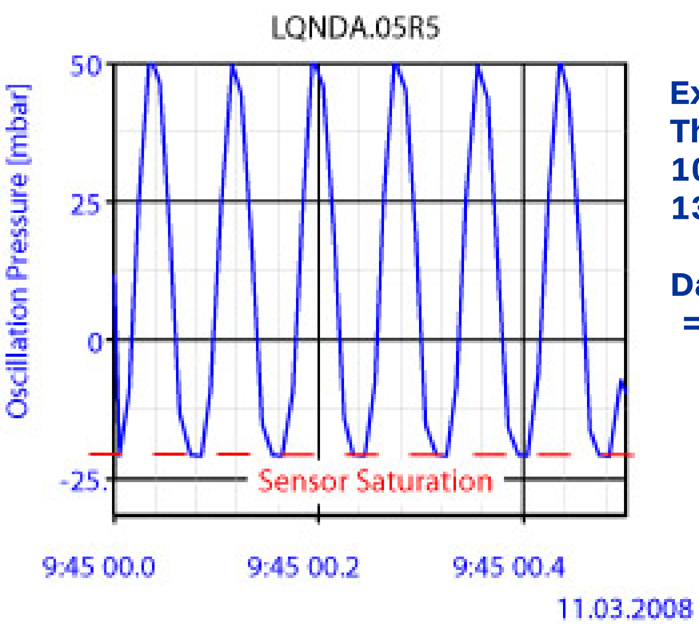
⇒ **LHe evaporation inside holder increases pressure head**

⇒ **LHe level pushed down compared to magnet**

⇒ **30mm systematic underestimation due to thermal conduction**

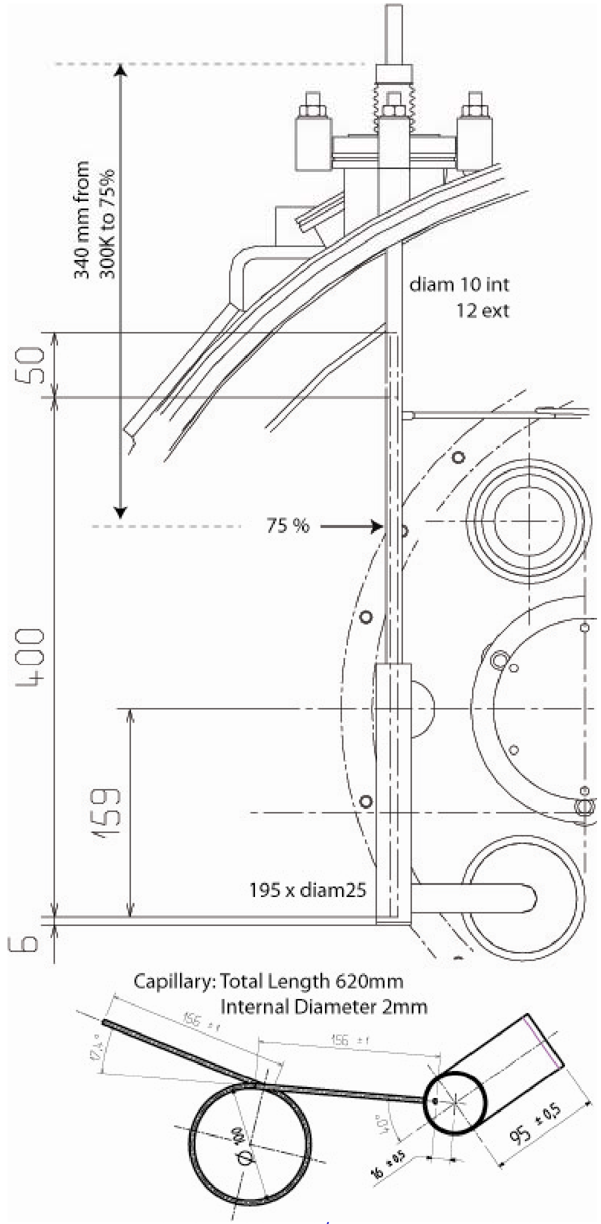
For some magnets the level readout is further decreased or lost:

- **Unexpected additional heat loads (Thermoacoustic oscillations, …)**
- **Exhaust capillary blocked**
- **…**



Example for Q5R5:
Thermo-acoustic oscillation
100 mbar p-p
13 Hz

Damping element added
=> Apparently solved



Non Conformités

Non conformities can occur at any step from delivery to commissioning.

- **LHe level gauges and pressure transducers: forbidden internal wire insulation material found during destructive sample tests**
  => All the production was repaired
- **LHe level gauges fabrication tolerances are worse than expected as found by X-ray tests and field measurements**
- **Temperature sensors are fragile and damage rate depend on the mechanical complexity of the sensor "host":**
  For the cold-masses and QRL the rate of damaged sensors are respectively 3% and <1%
- **Unforeseen operational status during software commissioning can also damage equipment:**
  one such event concerned the accidental powering of electrical heaters

- **Overall non conformities are well under control and the present status for the instrumentation is adequate for the LHC operation.**

Contrôles LHC

- The LHC control is based in the UNICOS framework, it provides:
- the Programmable Logic Controllers (PLC) and associated hardware
- Programming rules and code library for common objects (valves, analog inputs, etc)
- Automated tools for writing control code
- Gateways based in an industrial pc for WorldFIP based signal conditioners
- Control level communication via Ethernet between gateways <-> PLC and PLC <-> PLC
- Event driven communication protocol between PLC <-> SCADA
- SCADA based in PVSS with generic widgets, look and feel and shared data server.

- The control system is:
- clustered (refrigerators, interconnection boxes, cold-compressors, etc)
- distributed (tunnel, over 3.3 km for each sector)

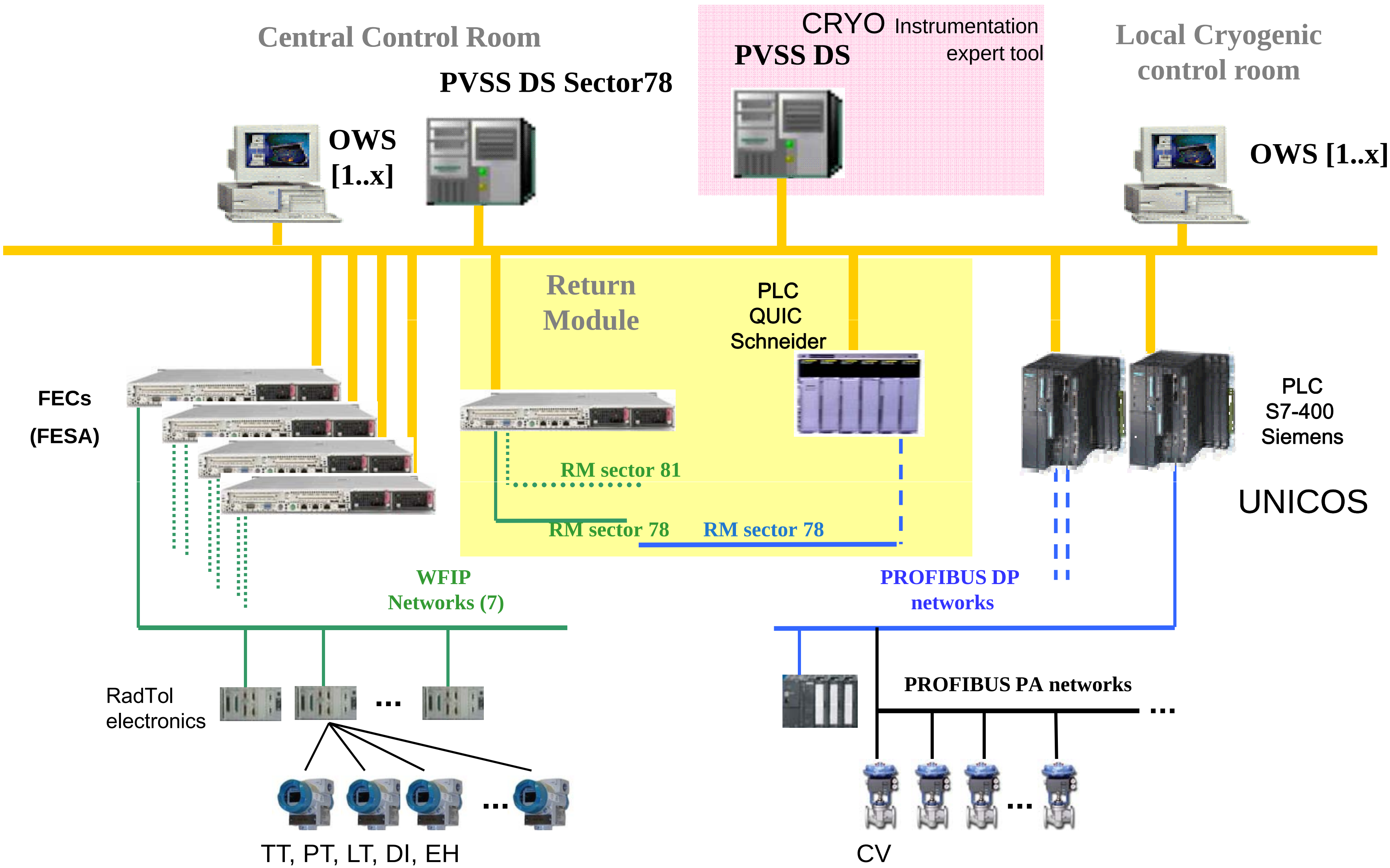
- WorldFIP gateways provide the instrumentation engineer with a dedicated diagnostics and configuration interface

Contrôles LHC
Taille

	Tunnel	4.5 Refrigerator	Cold Compressor	QUI	Common	TOTAL
Analog Inputs	12136	5216	2640	1128	216	21336
Analog Outputs	4856	1140	608	292	112	7008
Digital Inputs	4536	8100	3984	1144	592	18356
Digital Outputs	1568	956	1184	232	272	4212
Closed Loop Controllers	3680	548	328	100	48	4704
						55616

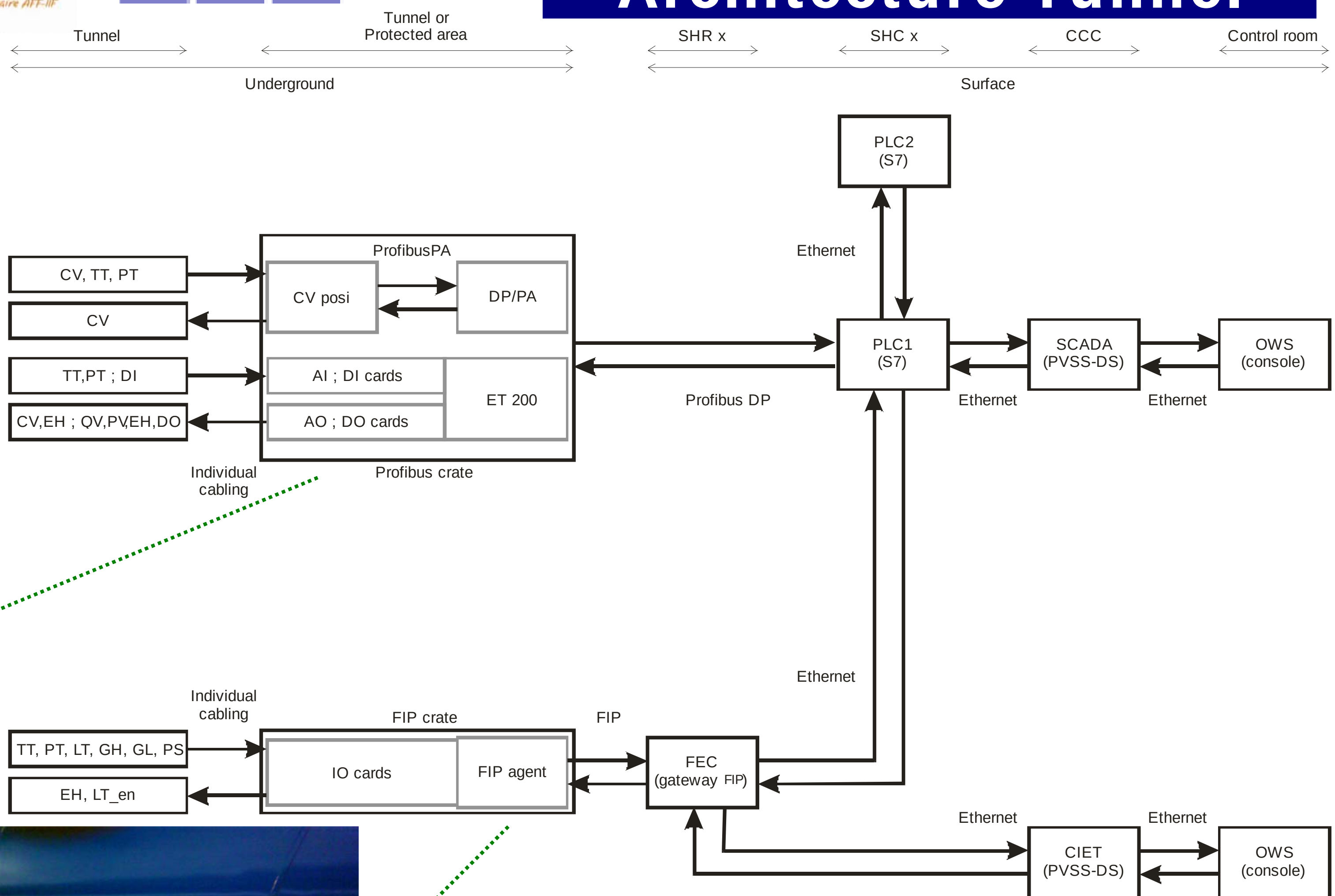
- **The Control system for the LHC cryogenics (excluding the refrigerators for the LHC experiments) is huge with more than 50’000 IO channels.**
- **The tunnel represent about 50% of the analog channels and about 75% of the closed control loops.**
- **At a refrigerator point it is installed: a cluster of PLCs (each dealing with a cryogenic sub-system) that communicate via a technical Ethernet network and share the SCADA system**
- **Hardware requirements are different for clustered and distributed controls. Clustered systems are delivered with a complete instrumentation ready to be connected to the respective PLC inputs/outputs**

Contrôles LHC Architecture

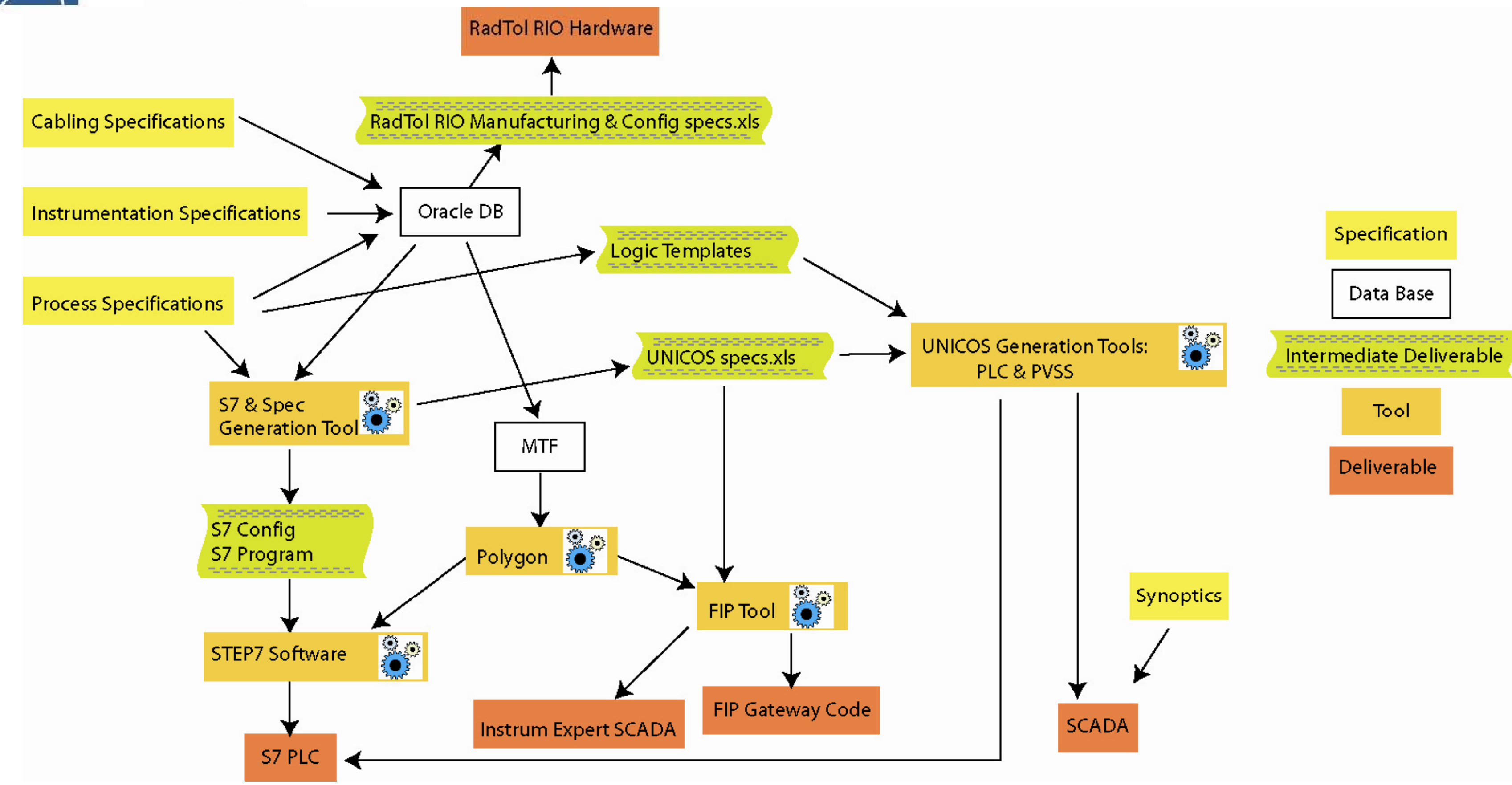


Courtesy E. Blanco

Contrôles LHC Architecture Tunnel



Contrôles LHC Production Soft



We rely extensively on databases for (1) manufacturing files for the Rad-Tol hardware and (2) software production.

Databases provide a robust environment to improve coherence between software parameters, actual equipment characteristics (type, calibration,..) and SCADA

The main drawback is that minor modifications are very cumbersome

Conclusions

The instrumentation and control system has been commissioned in cold conditions for sectors 78, 45 and 56.

The thermometer channels performance is within the expectations in spite of a very ambitious goal in what concern targeted uncertainty and large scale deployment. Previously, such an uncertainty was obtained within a laboratory environment or with a much smaller facility.

The QA procedures for main component manufacturing permit to track the correspondence between main assembly and sensor serial number; this is required for individually calibrated instruments.

The control system is operational: it has been able to cope with all the controlled variables but as any new project there are still some bugs to be corrected in order to improve the overall performance.

The database environment used for defining the control system is very reliable and it provides a robust frame for long term operation, the related maintenance tasks and eventual upgrades. However in the initial commissioning phase it lengthens significantly small corrections or improvements as many pieces of code need to be created and then loaded into the controllers.

The next challenges are to verify the performance of the instrumentation in what concerns immunity against electromagnetic noise when all LHC systems are operational and against the background radiation that will be present once the particles beam starts circulating.