Instrumentation and controls challenges

Juan Casas
CERN AT

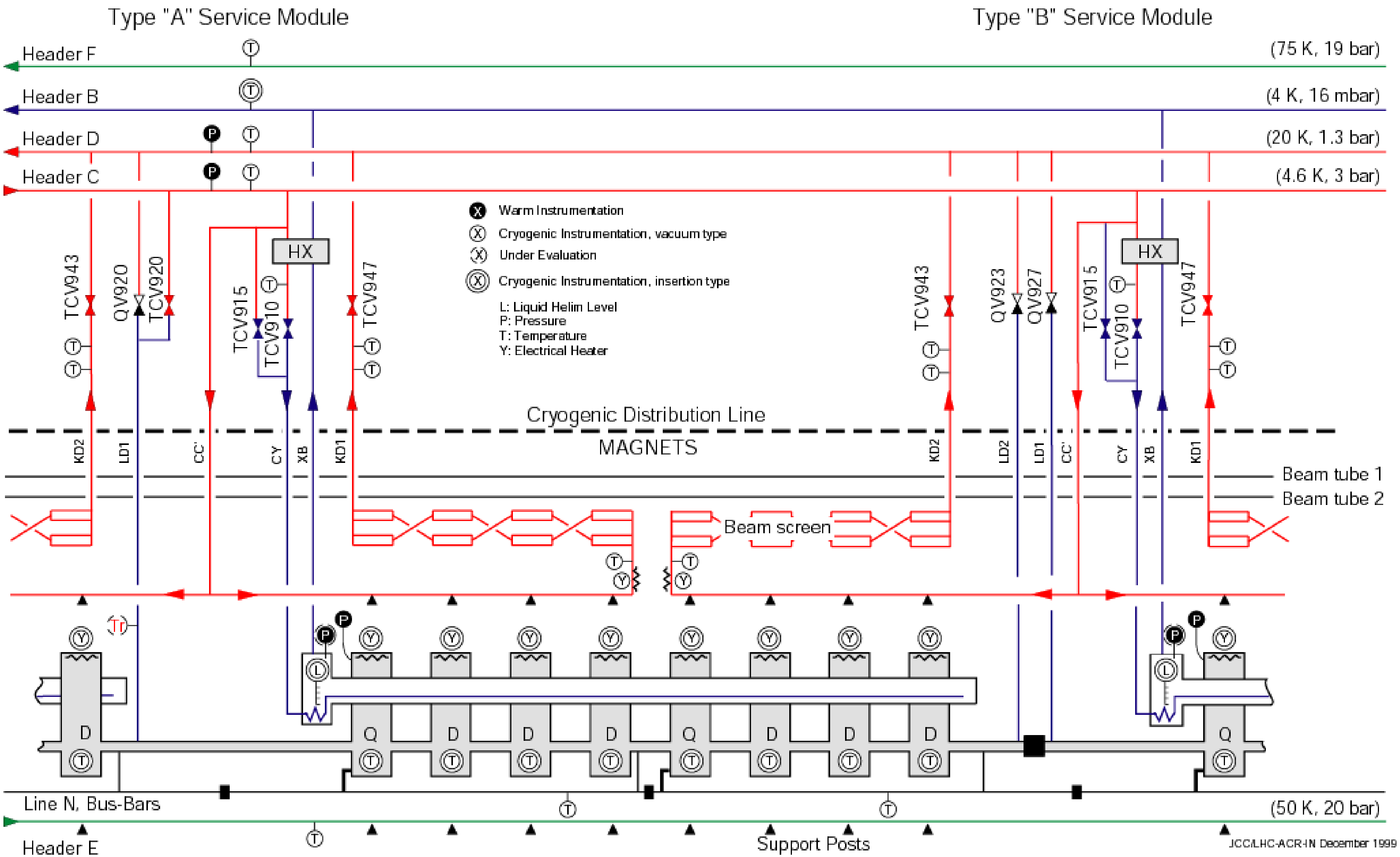
Summary

1. Main Challenges for selection, qualification, procurement and commissioning
2. LHC Instrumentation for the standard cell: Original P&ID
3. LHC Environmental Constraints
4. Hardware Selection and Qualification
5. Rad-Hard Hardware
6. Rad-Tol Electronics
7. LHC Instrumentation in Operation
8. Non Conformities
9. LHC Controls
10. Conclusion

Main Challenges

- 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.

LHC Standard Cell Intrumentation

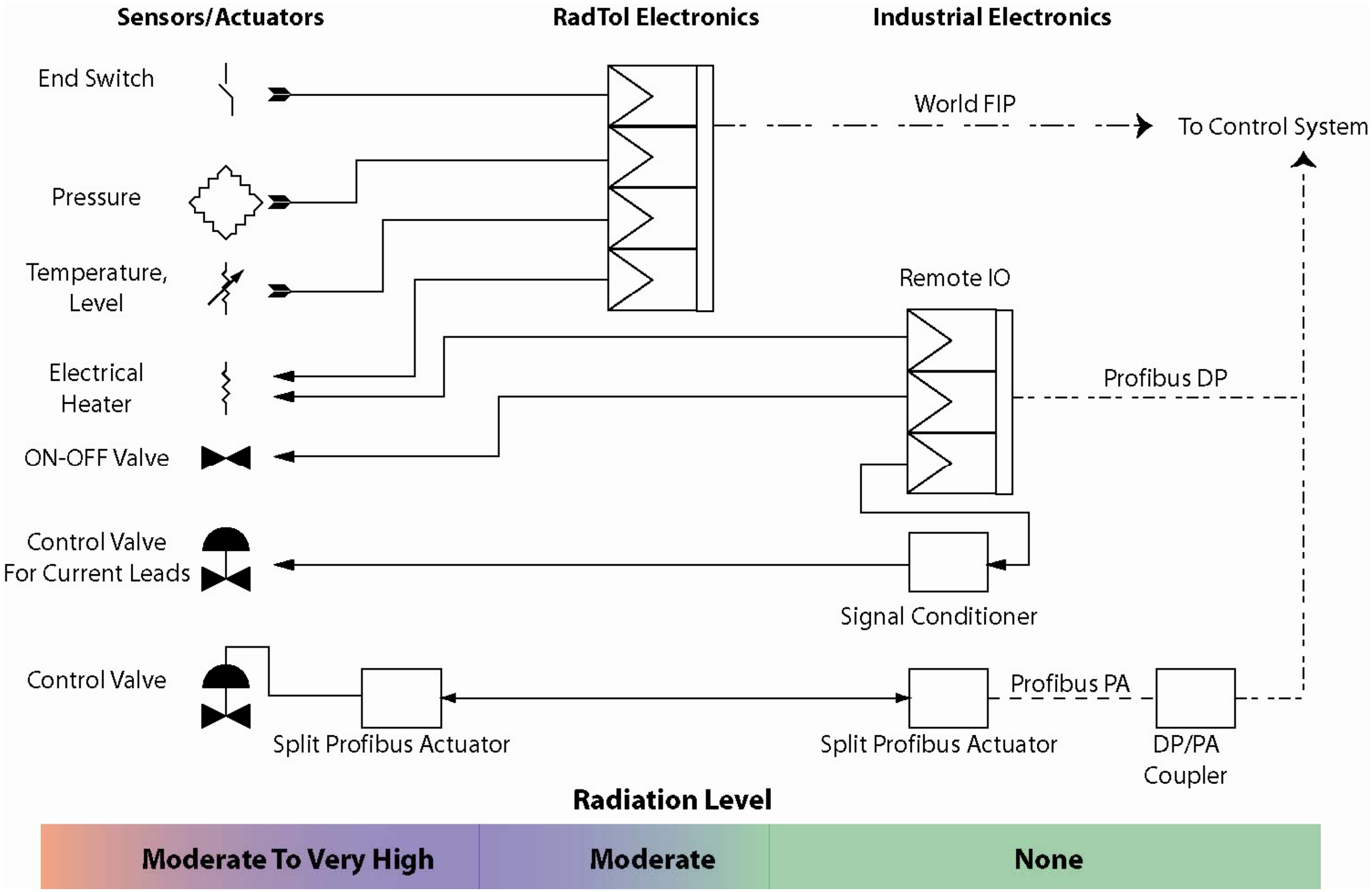


LHC Environmental Constraints

LHC environment is industrial in what concerns:

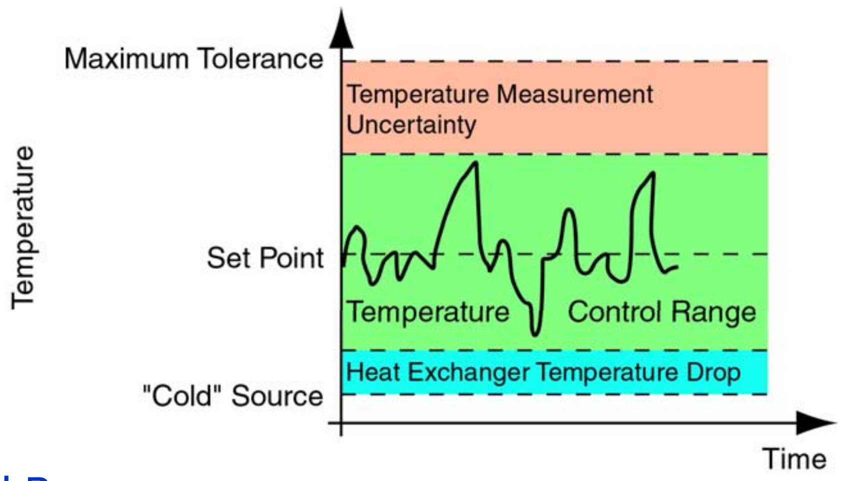
temperature, humidity, electromagnetic noise, …

But very HOSTILE close to the beam in what concerns RADIATION



Hardware Selection and Qualification

- The most stringent LHC requirements are:
  - Radiation Qualification at ambient and **<u>cryo</u>** 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)
  - Capability to performs large series calibrations with unprecedented metrological quality (see spot)



  - Saturated LHeII Pressure Readout at 16 kPa:
    Requirement: +- 5 Pa over 10 years and Rad-Hard
    <u>NO SENSOR PASSED THE TESTS</u>!
    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

Rad-Hard/Tol Hardware

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.

Rad-Hard Hardware

Temperature: 1.6 to 300 K: Cernox; Lake Shore(USA)
Individual Calibration Otherwise +- 0.15 K (see fig)
50 to 300 K: Platinum 100 Ohm

Pressure: Metal-Thinfilm strain gauge on metal; Baumer (CH)

LHe level Gauges: Superconducting wire; Cryogenic Limited (UK)

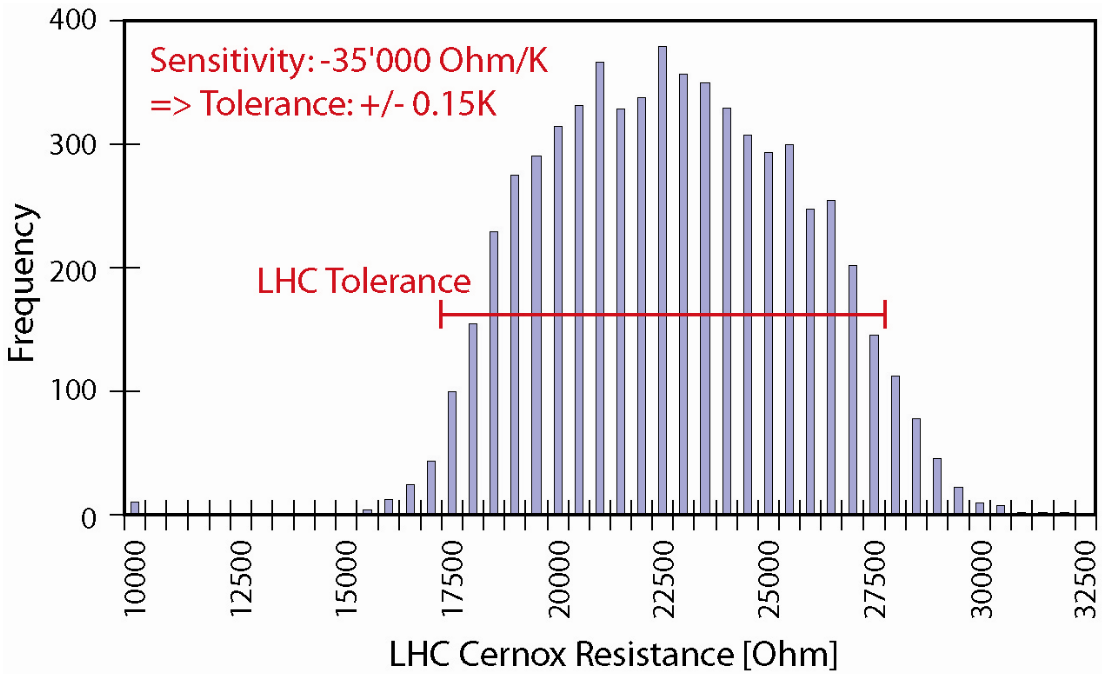
Intelligent Valve Positionner: Sipart PS2-PA; Siemens (GE)
CERN specific split design with electronics outside radiation area

Electrical Heater:
- Wire-wound; Sfernice (FR)
- Cartridge; Rotfil (IT)

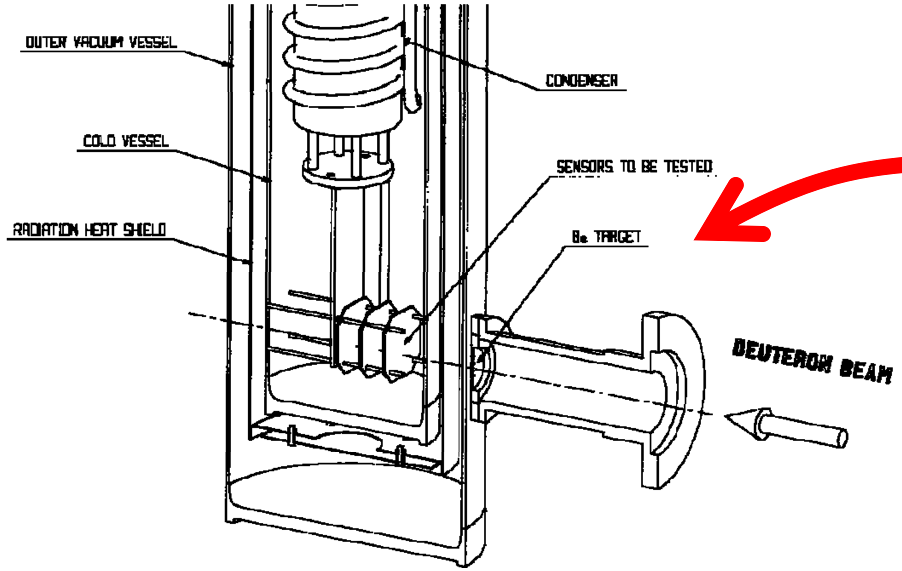
Standard Industrial Equipment:
- ON-OFF Pneumatic Actuators
- Valve Manifolds
- ...

UNDERLINED: Equipment Qualified for Radiation

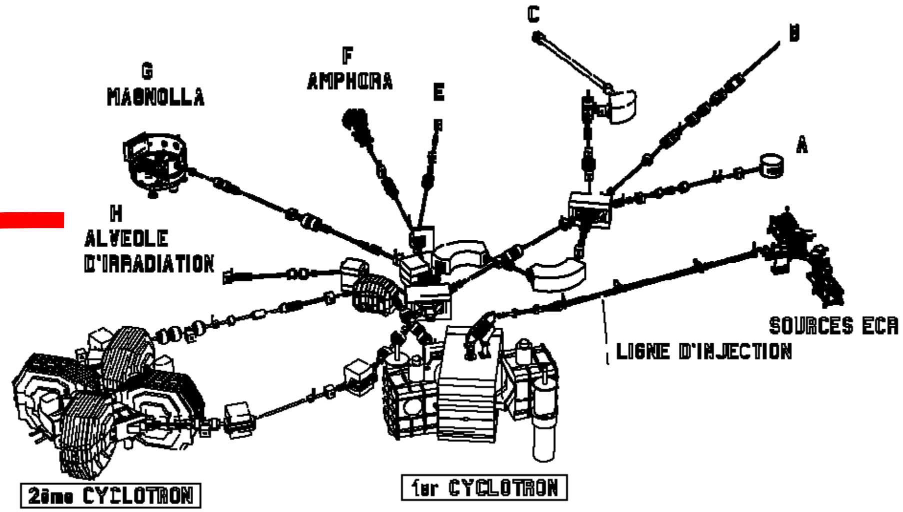
Radiation Qualification is not always required: list of materials can be sufficient in particular for passive devices.



Rad-Hard Hardware: LHe Radiation Tests



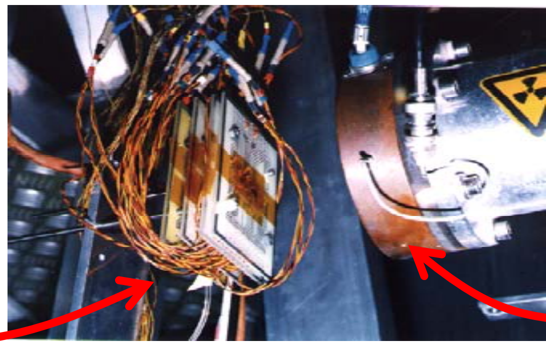
1.8 K Cryostat



SARA Cyclotron

Beam: deutons (20 MeV, 6 μA)

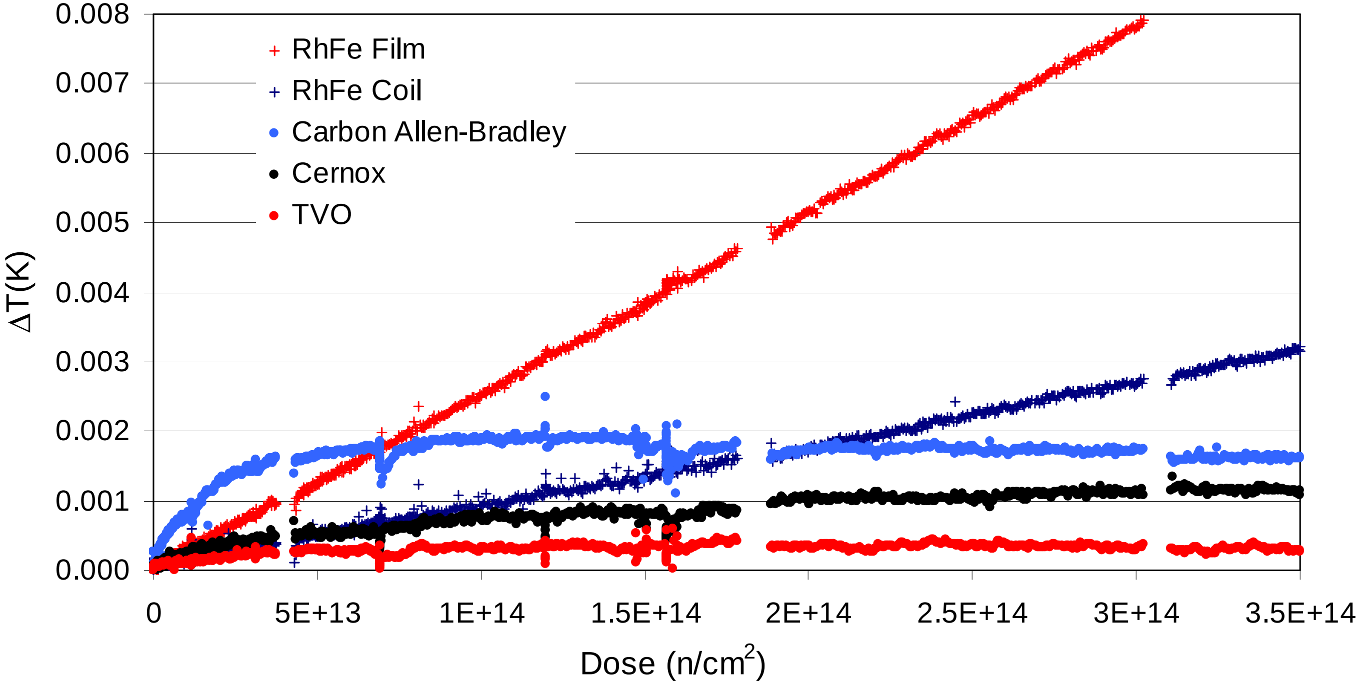
Tests Performed on:
Temperature Sensors
Cryo-pressure Sensors
LHe Level Gauges (sample test)



Sensor Under Test

Be Target

Rad-Hard Hardware :
Thermometer Radiation Effects



- 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

➢ Radiation Hardness is better for "amorphous materials"

Rad-Tol Electronics

Radiation Tolerant Electronics shall be used in the LHC tunnel (apart the Long Straight Sections)

Why? : Cost of Cabling & Signal Integrity

Expected Total Integrated Dose (TID) over a 10 year lifespan:
10 to 50 Gy (5 E11 to 2.5 E12 neutron/cm^2)
Although for DS 1 & 5 doses could increase x 40

Radiation causes:

- Shifting of analog electronics characteristics (gain, offset, etc.)
- Single Event Effects (SEE) in digital circuits

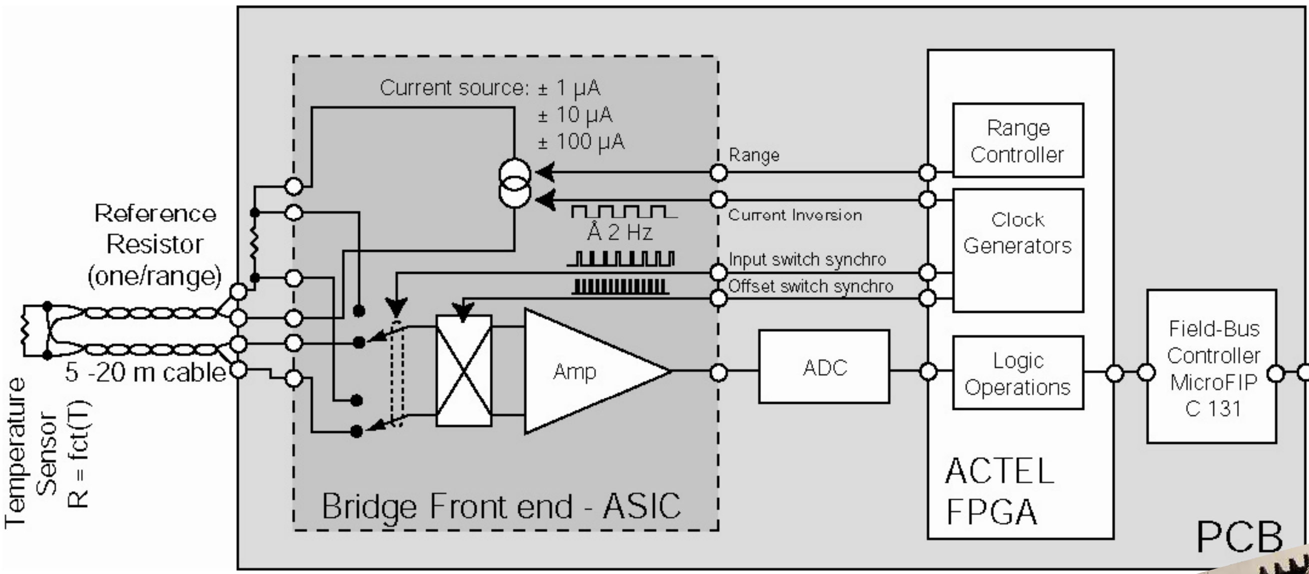
Irradiation testing were carried at:

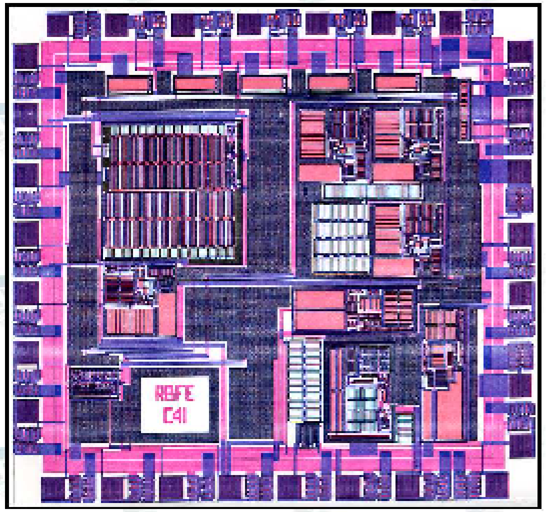
- ➢ CERN: TCC2 area (presently dismantled) for LHC like radiation on complete systems
- ➢ PSI (CH) and Louvain (BE) for fast particles or SEE on particular Integrated Circuits
- ➢ ITN (PT) for neutron damage on analog electronics and sub-systems

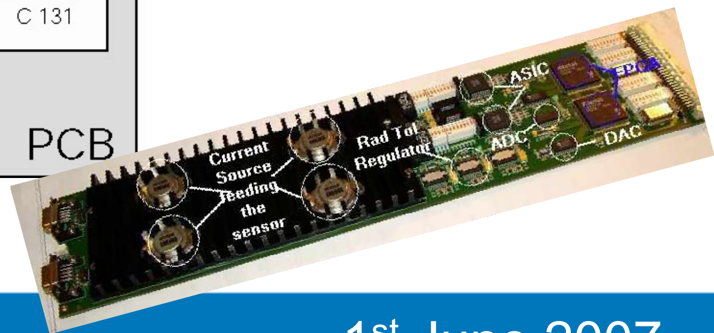
Rad-Tol Electronics: Front End Design

Analog Readout based on:

1. a comparison bridge providing excellent performance against TID and temperature effects
2. a quarter micron ASIC using IBM technology
3. COTS for OP-Amps, ADCs, DACs and passive components
4. Anti-fuse FPGAs with triplicated logic
5. Micro FIP C131 WorldFIP bus controller

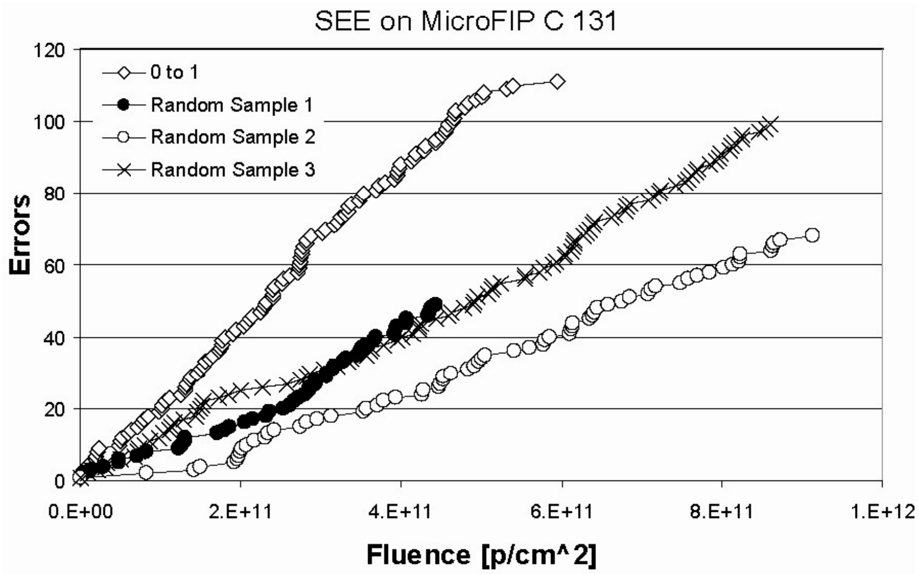


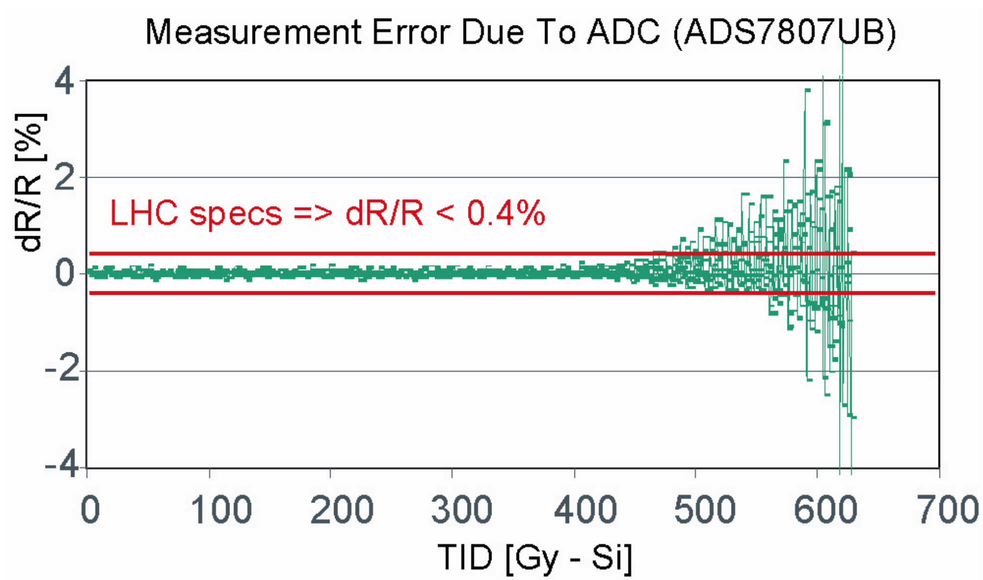




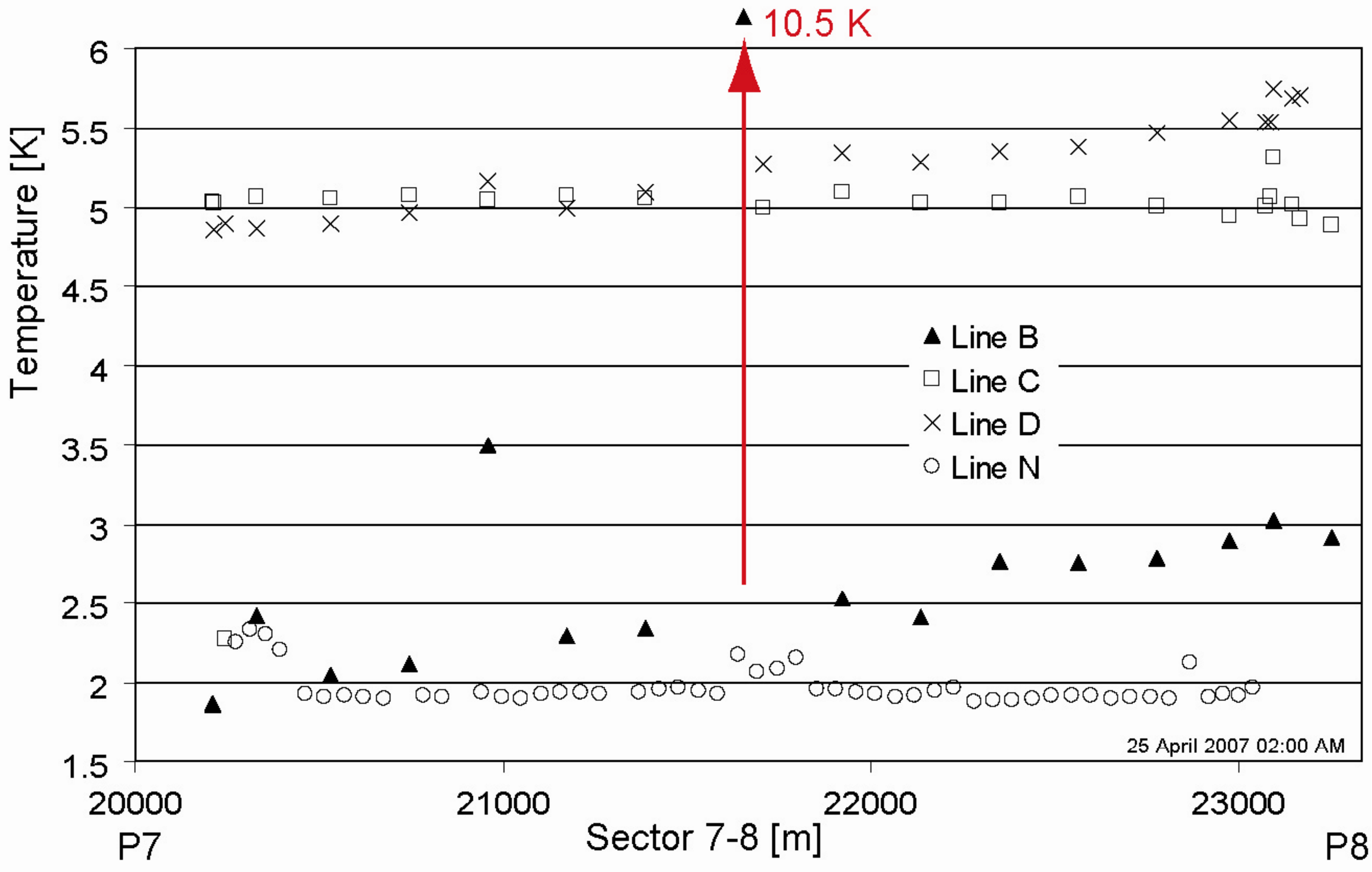
Rad-Tol Electronics: Radiation Tests

- 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 may improve the actual radiation tolerance of the electronics





LHC Instrumentation in Operation:
LHC Thermometry in Sector 78

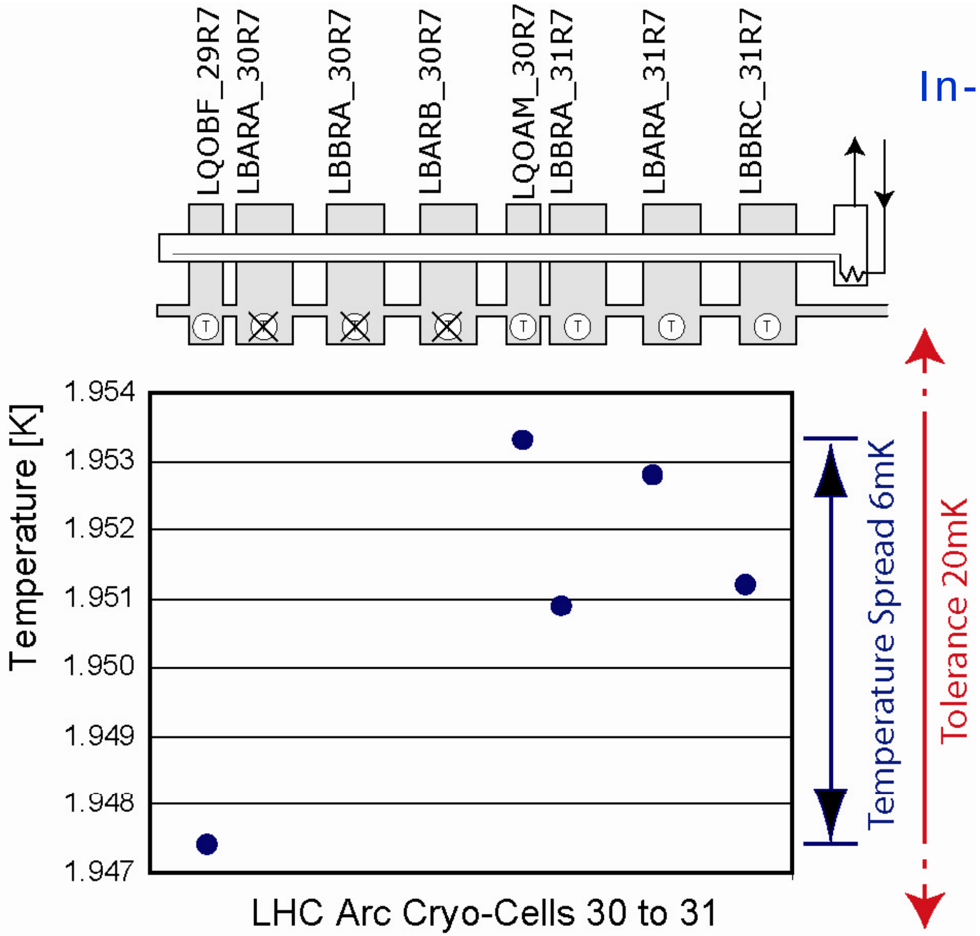


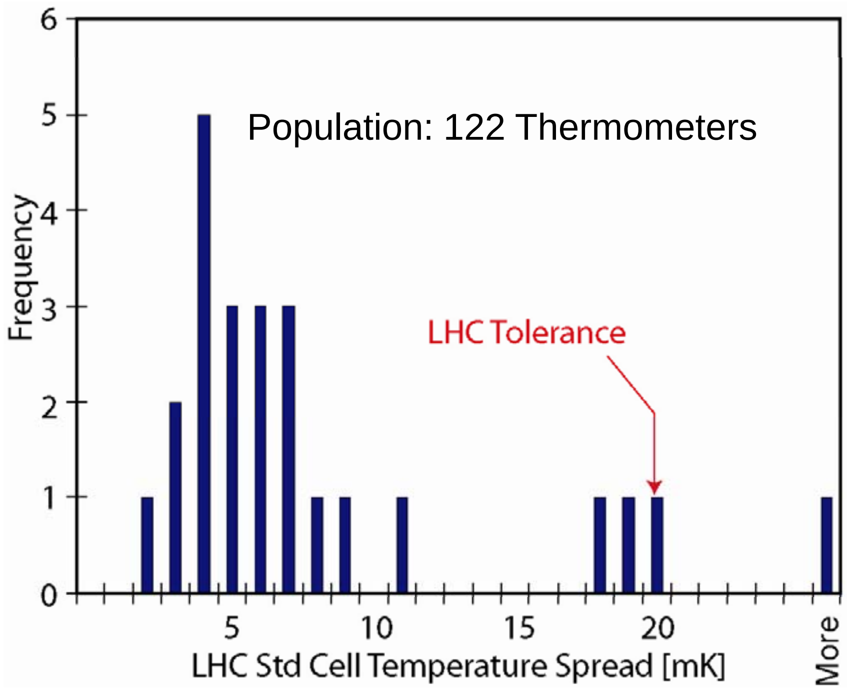
LHC Instrumentation in Operation: LHe-II Thermometry

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)





High Values for Temperature Spread due to High Thermal Loads or Instabilities at the "ends" of S78 (in particular R7)

Data from 25 April 2007 03:00 AM

Non Conformities

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
- Apart thermometers and heater all instruments can be replaced
  => 100% operational status can be obtained
- 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.

LHC Controls

The LHC control is based in the UNICOS framework, it provides:

1. the Programmable Logic Controllers (PLC) and associated hardware
2. Programming rules and code library for common objects (valves, analog inputs, etc)
3. Automated tools for writing control code
4. Gateways based in an industrial pc for WorldFIP based signal conditioners
5. Control level communication via Ethernet between gateways <-> PLC and PLC <-> PLC
6. Event driven communication protocol between PLC <-> SCADA
7. 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

LHC Controls: Channel Count

	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

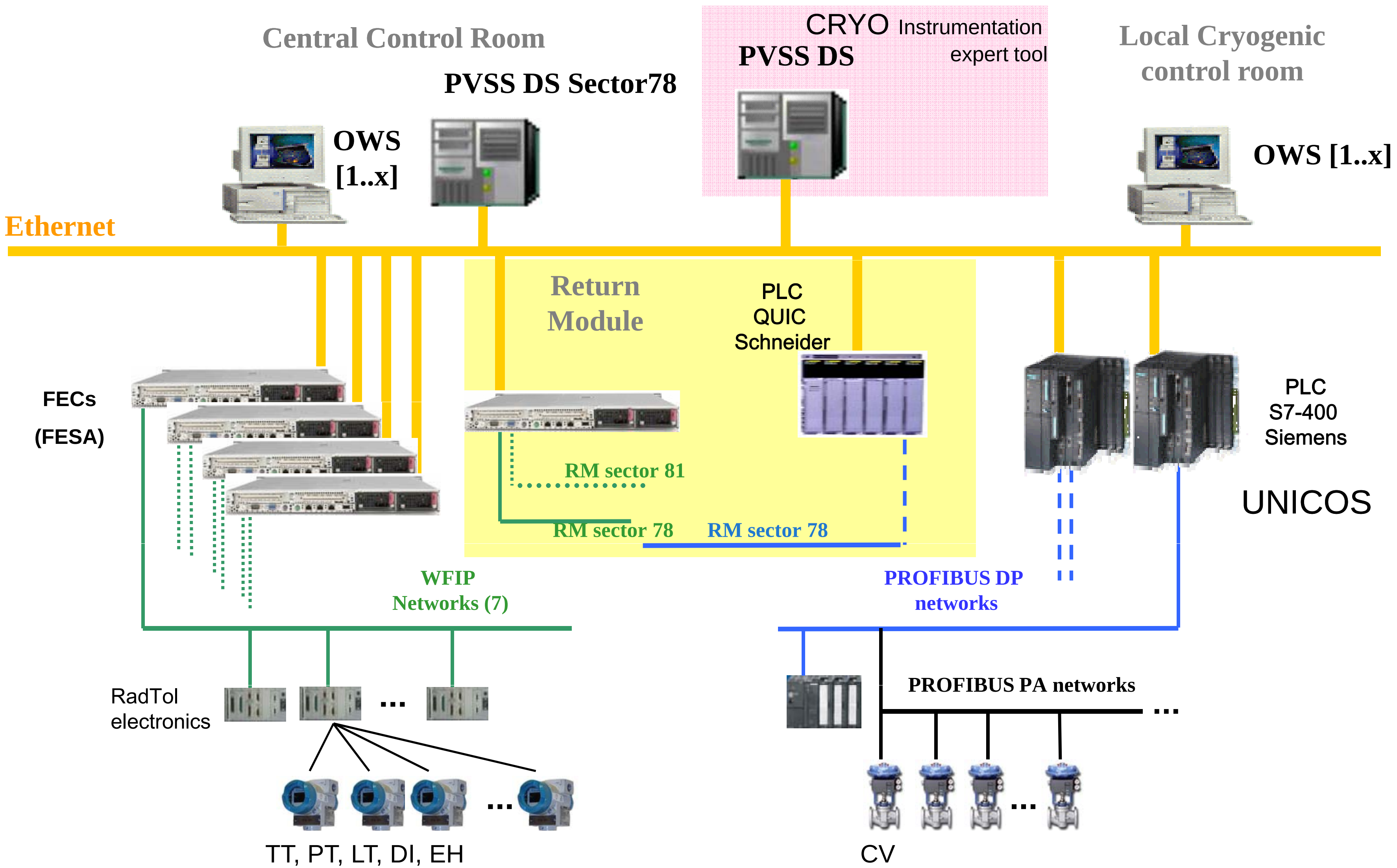
The Control system for the LHC cryogenics (excluding the refrigerators for the LHC experiments) is huge with more than 60'000 IO channels.

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

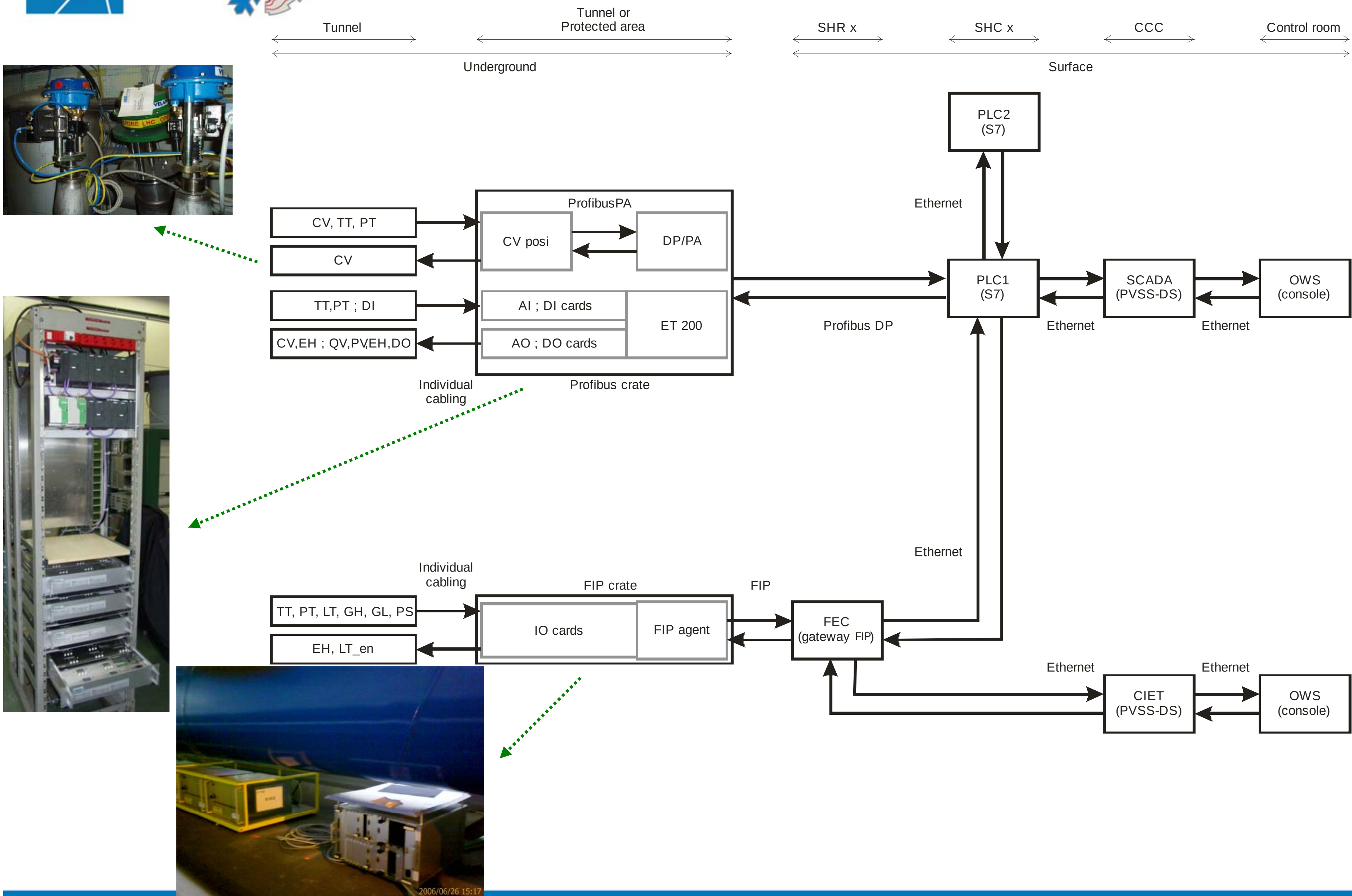
Hardware requirements are different for clustered and distributed controls. Clustered systems are delivered with a complete instrumentation ready to be connected to the respective PLC inputs/outputs

LHC Controls: Architecture

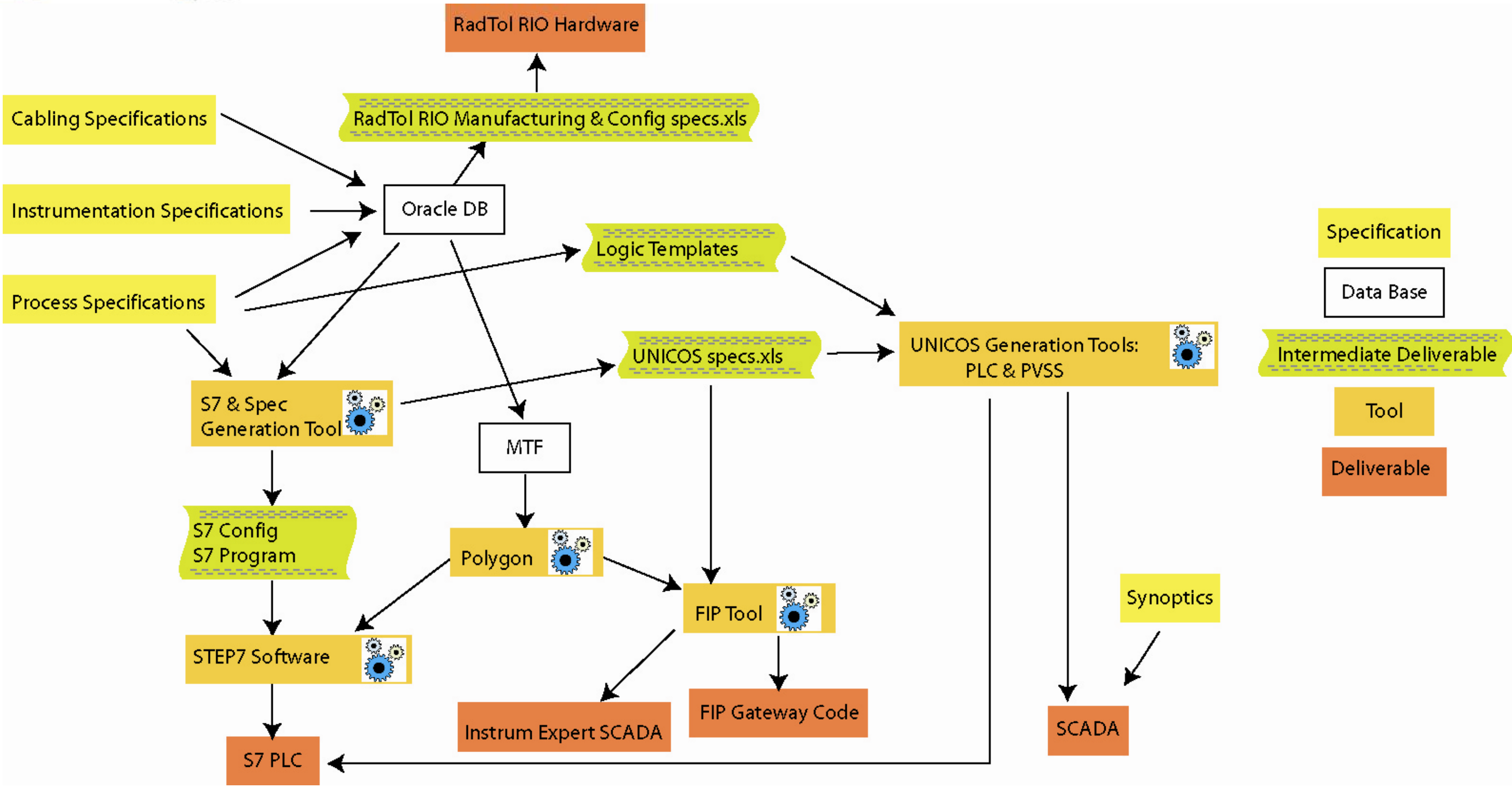


Courtesy E. Blanco

LHC Controls: Tunnel Architecture



LHC Controls: Tunnel Software Generation



- 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 for sector 78 and for the QRL in sector 81.

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: for the first sector 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 and the related maintenance tasks. 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.