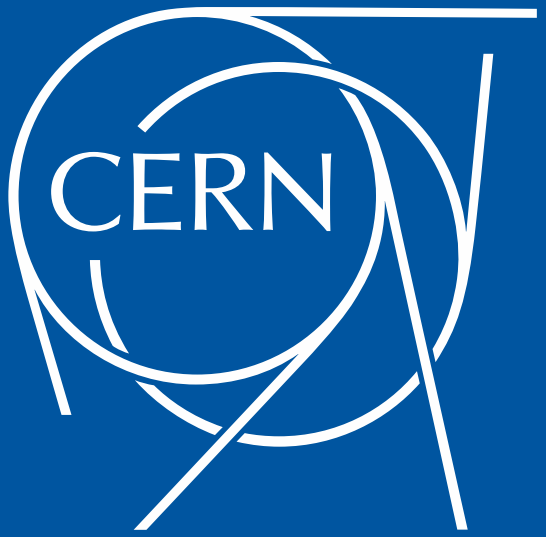
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HL-LHC instrumentation meeting
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Measurement using calibrated sensor & LHC-type electronics: cernox

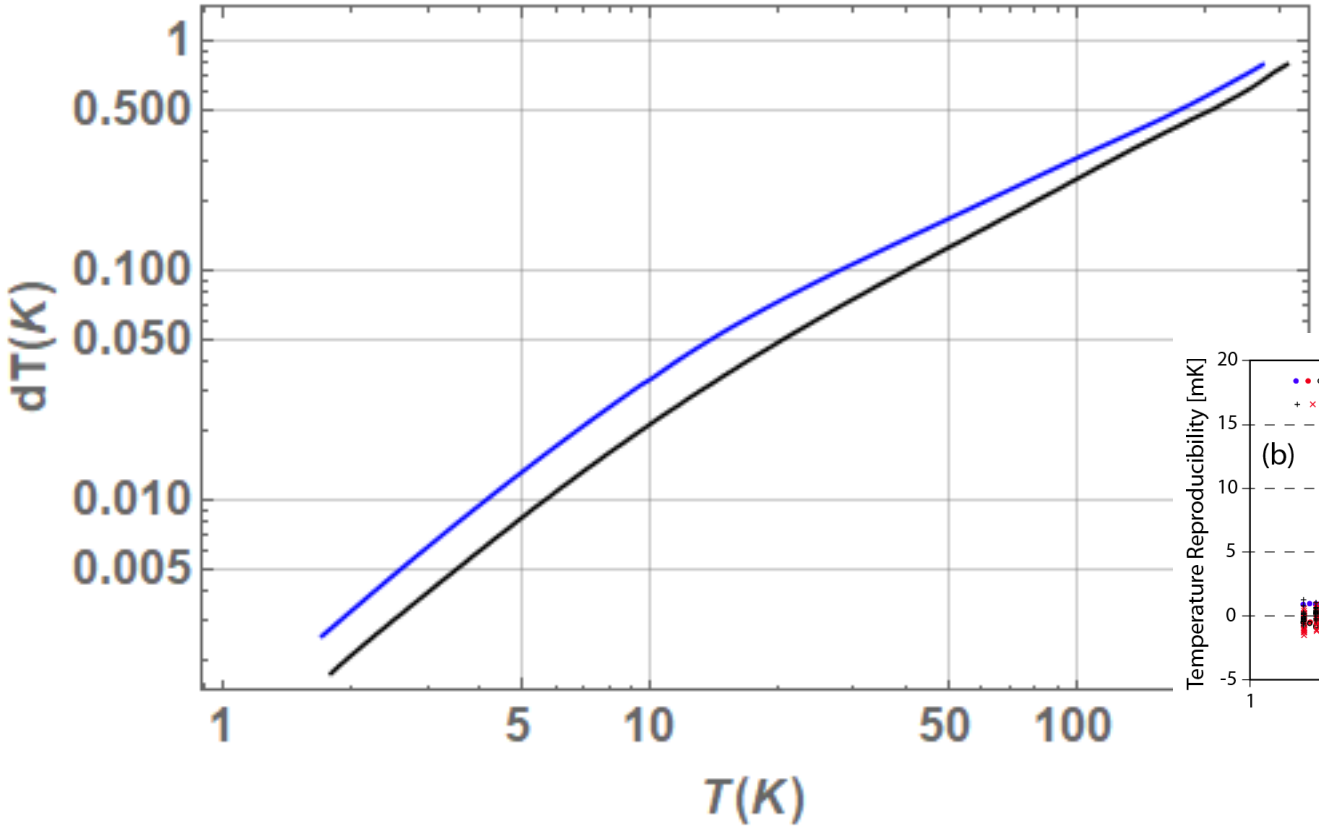
Error due to measurement uncertainty of the resistance, assumes +/- 0.25 % of measured value

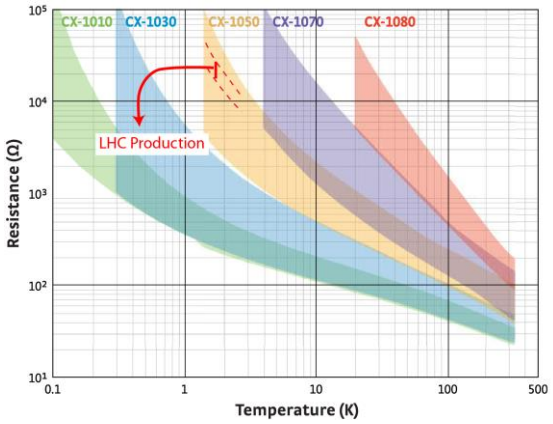
Blue: sensor with “low” resistance (standard spec CX-1050, 5.55 kΩ @ 1.7 K)

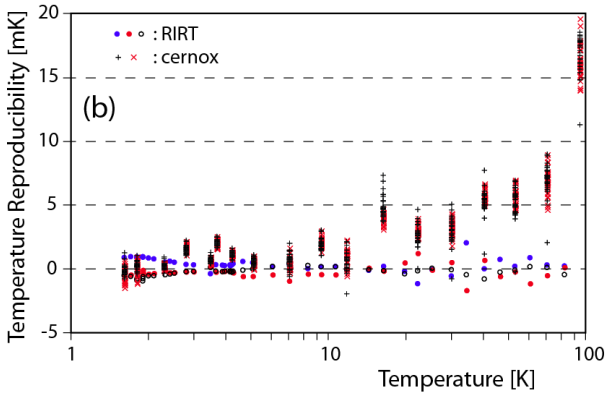
Black: LHC resistance range (LHC spec CX-1050, 5.55 kΩ @ 21.0 K)

Narrow resistance range @ 1.7 K => 22.5 kΩ ± 5.5 kΩ

Error is dominated by WFIP electronics







Measurement using non-calibrated sensor & LHC-type electronics: cernox

By using:

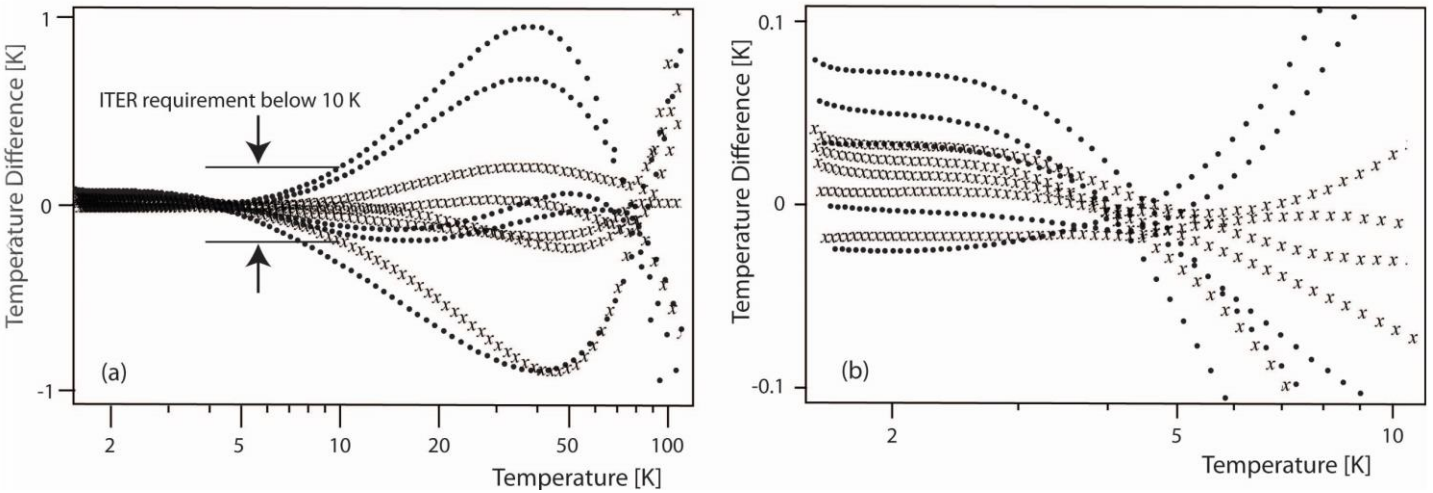
- Sensors within the same resistance range as the LHC “library”
- Three data points supplied by Lake Shore
  {resistance, temperature} @ 4.2, 77 & 300 K

⇒ Possible to find an approximation function without performing a calibration

⇒ Error dominated by spread of sensor characteristics

Work was performed by CERN for ITER that accepted much larger uncertainty than the LHC case.

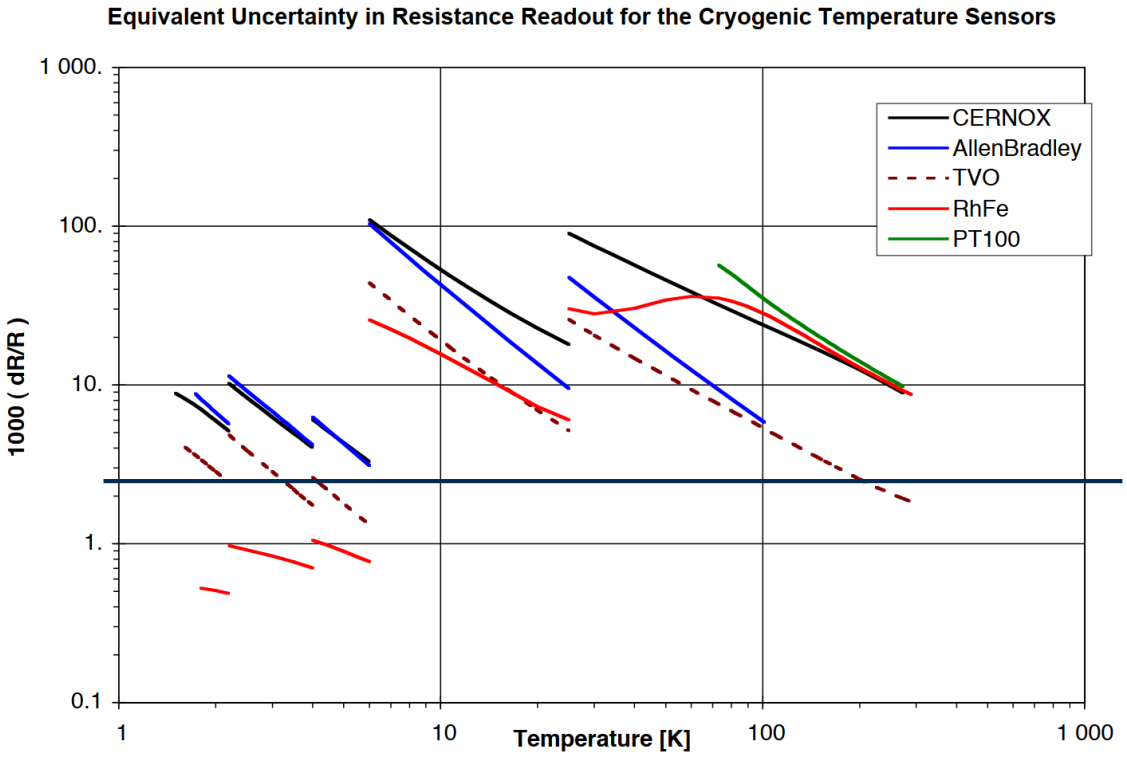
- ITER intend to use the cernox sensors with this approximation



LHC requirements & its consequence on electronics accuracy

The figure below shows the MINIMUM required accuracy on the measurement of resistance for various type of resistance based sensors to satisfy the accuracy requirements of the table (LHC requirements 1999 era).

Temperature Range	1.6-2.2 K	2.2-4 K	4-6 K	6-25 K	20-300 K
Uncertainty [K]	± 0.01	± 0.02	± 0.03	± 1	± 5



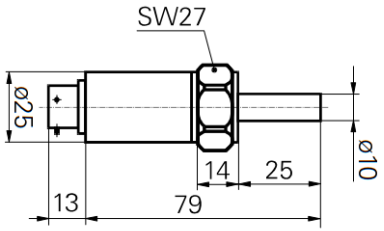
0.25% reading accuracy WFIP

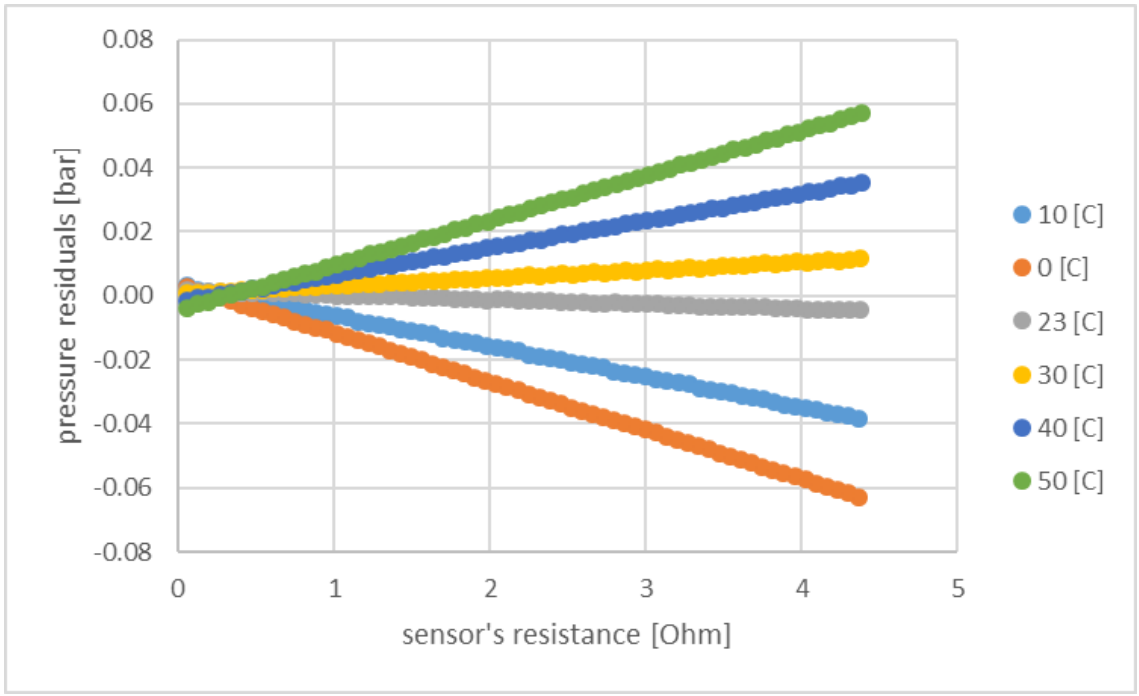
Measurement of pressure

All pressure sensors are accessible and therefore exchangeable.

- Absolute LHC pressure sensors provided by Baumer (CH), resistive bridge
  Procurement OK but minimum order qty about 50 units

Manufacturer	Model	Type	Range	Max P	Burst pressure	Accuracy
Baumer	PDAS/404772 A240	absolute	0-4 bar	5 bar	10 bar	0.4 % FS
Baumer	PDAS/404772 A320	absolute	0-20 bar	32 bar	64 bar	0.4 % FS





Final Comments

What we would expect as technical requirements:

Project	Technical Contact	Instrument Type	Environment	Physical Unit	Measurement Range	Output Range	Temperature Range [K]	Pressure Range [bar]	SubRange 1	Accuracy SubRange 1	Subrange 2	Accuracy SubRange 2	SubRange 3	Accuracy SubRange 3	Expected Date for Delivery	Quantity	
		Thermometer, Pressure, Conditioner..	Cryo, Fluid, Ambient, Vacuum, Radiation..	K, Pa, ..		If applicable	Working Range	Working Range		% or absolute		% or absolute		% or absolute	yyyy.mm		
FCM_SCCL Feedbox	U. Wagner	Thermometer	Vacuum	K	4.0-325		4.5-325		4.0-10.0	0.01 K	10.0-50.0	0.1 K	50.0-325	1.0 K	2011-05	8	ta
FCM_SCCL Feedbox	U. Wagner	Thermometer	Ambient	K	220-325		270-310		220-325	0.5 K					2011-06	3	
FCM_SCCL Feedbox	U. Wagner	Thermometer	Ambient	K	220-325		270-310		220-325	0.5 K					2011-06	2	
FCM_SCCL Feedbox	U. Wagner	Pressure	Ambient	bar abs	0-20		~~0-20~~	0-20	0-20	0.04 bar					2011-06	8	
FCM_SCCL Feedbox	U. Wagner	Pressure	Ambient	mbar abs	0-1000			0-1.3		5% of value					2011-06	1	
FCM_SCCL Feedbox	U. Wagner	Differential pressure	Ambient	mbar	0-300			0-20	0-20		0-300				2011-06	2	
FCM_SCCL Feedbox	U. Wagner	Differential pressure	Ambient	mbar	0-60			0-20	0-60		0-300				2011-06	1	
Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	Item deleted	
FCM_SCCL Feedbox	U. Wagner	Level	Cryo	mm	0-500		4.4-5.0	1.2-1.3	0-500						2011-06	1	

Final Comments

Technical requirements: LHC example for temperature sensors

Table 11.12: Cryogenic instrumentation inventory

Sensor type	Quantity	Redundancy	RadTol quantity
Temperature CX	4,500	1,153	3,347
Temperature Pt100	2,400		450
Pressure Low	230		230
Pressure Mod/High	900		900
Level Gauges	300		300
Electrical Heater	2,500		2,000

Table 11.12 from “LHC Design Report” CERN-2004-003

Table 11.13: Measurement uncertainty requirements versus temperature.

Temperature Range	1.6-2.2 K	2.2-4 K	4-6 K	6-25 K	20-300 K
Uncertainty [K]	± 0.01	± 0.02	± 0.03	± 1	± 5

1.6 to 2.2 K Temperature Range

Location	Uncertainty [K]	Quantity	
Cold mass	0.01	1969	State of the art
Bus bar	0.05	910	Necessary for assessing filling of bus bars, might change if single outlet capillary is blocked Sensors should be redundant Not necessary if several capillaries are used in parallel
TCV910-HX	0.02	264	Used for calculating JT gas fraction (flash)

2.2 to 4 K Temperature Range

Location	Uncertainty [K]	Quantity	
Cold mass	0.02	1969	Used for liquid filling control
Bus bar	0.05	910	
TCV910-HX	0.02	264	Used for calculating JT gas fraction (flash)
Header B	0.03	132	

4 to 6 K Temperature Range

Location	Uncertainty [K]	Quantity	
Cold mass	1	1969	
Bus bar	1	910	
Header B	0.03	132	
Header C	0.03	132	
Header D	1	132	
Beam screen	0.05	1365	Outlet of beam screen goes to low temperature in the absence of beam

25 to 50 K Temperature Range

Location	Uncertainty [K]	Quantity	
Cold mass	5	1969	
Bus bar	5	910	
Header B	5	132	
Header C	5	132	
Header D	5	132	
Beam screen Outlet	5	910	Leak monitoring of TCV943 & TCV947

50 to 300 K Temperature Range

Location	Uncertainty [K]	Quantity	
Cold mass	5	1969	
Bus bar	5	910	
Header B	5	132	
Header C	5	132	
Header D	5	132	
Header E	Class B	132	Pt100
Header F	Class B	132	Pt100
Beam screen Outlet	5	910	Leak monitoring of TCV943 & TCV947

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