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CRYOGENIC INSTRUMENTATION

International Workshop on Cryomodule Design and Standardization

September 4-9, 2018
BARC - Mumbai

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STFC Daresbury Laboratory (UK)

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SRF at STFC Daresbury Laboratory

- ALICE 35 MEV Energy Recovery Accelerator
  Based on 4 x 1.3 GHz SRF cavities
  (2005 – 2012)

- 1.3GHz ERL Cryomodule Collaboration for High Current and CW applications
  (STFC, Cornell, LBNL, SLAC, DESY, HZDR, TRIUMF)
  (2008 - 2013)

- SRF Crab Cavities for Hi Lumi HLC (CERN, STFC, AUP-US)
  Prototypes/ Pre Series CMs for DQW and RFD (2010 –ongoing)
  Series CMs for DQW (2020 onwards)

- ESS – High beta cavities (2015 – ongoing)

- PIP-II (2019 onwards)

Cryogenic Instrumentation

- **Introduction**
- **Thermometry**
- **Some Examples**
- **Potential R&D topics**
- **Discussion and Summary**

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Introduction

Like any other control and measurement operations in industrial or scientific environment cryogenic processes are also developed around a range of sensors and actuators.

Basic focus of the process development is on

Safety	of people, environment and equipment
Reliability	of operations, measurements
Efficiency	to keep overall costs down

Essential	Balance between automation and manual
Desirable	Seek more information, future improvements (R&D)

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Typical parameters to be measured and controlled

- Temperature
- Pressure (from Vacuum to high pressures)
- Flow
- Level
- Alignment
- Power
- Valve positions
- Measuring instruments
- ….

The technology to deal with most of the above parameters is well established, standardised with unlimited choices.

But,
Cryogenic thermometry needs special attention

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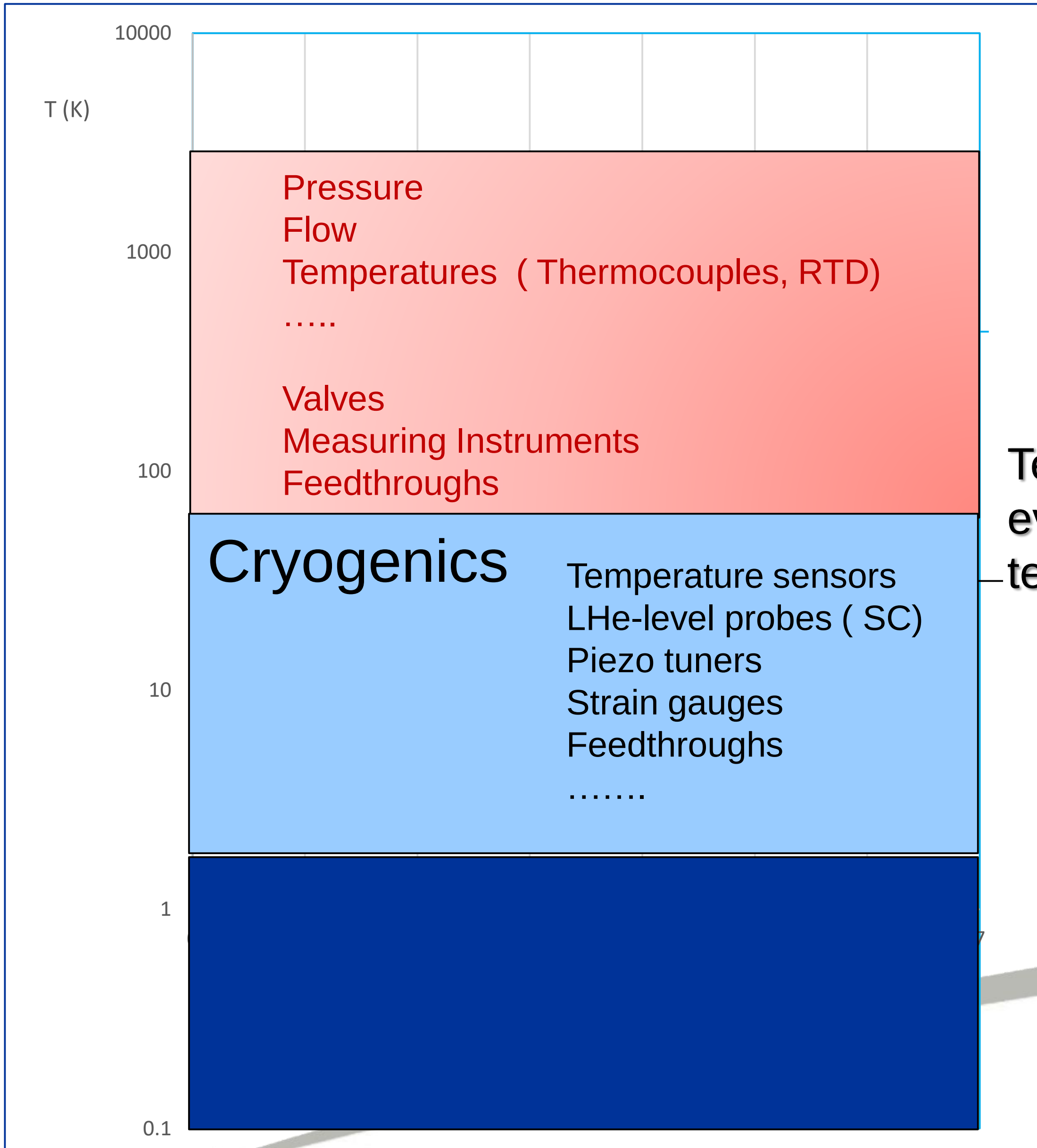
Why is Cryogenic Instrumentation different?



Technology changes every two decades in temperature

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Why is cryogenic thermometry different?

- Material properties, change drastically
- Sensitivity of conventional (Industrial) temperatures sensors (RTD, Thermocouples, …) becomes extremely poor at cryogenic temperatures (T< 50K)
- Heat Capacity (thermal mass) of material reduces by several orders of magnitude (the Debye T^3 law)

If a 1W/1s heat pulse to a 5g of copper block at 300K, it wont' even be detected
But the same heat pulse at 2K can easily create a large temperature excursion of few degrees!

Small heat leaks are the primary sources of errors in the measurements…
a heat source few nW can kill the measurements
and therefore must be identified and managed carefully

A typical PT100 (RTD) is measured using an excitation current of 1 mA/ 0.1mA
with a self heating at RT is ~ 10^{-4} W

A typical Cernox is measured using an excitation current of 10μA/ 1μA
with self heating of ~ <10^{-7} W

>> signal levels to be handled are very low and stabilities required are very high

Sources of Errors

Measurements

Very low excitation levels (1 mA, 1 mV full scale)
Stabilities required are very high (1 in 10,000)
Thermo-emf >> current reversal / ac measurements
Each sensor requires individual calibration

Well addressed by industry

All this requires special instrumentation
Lakeshore, Cryocon, OI, CEA, ……..

Choice of wiring and sensor mounting

A range of materials is used for wiring and it is important to choose that is the most appropriate for your experiment.

Rely on local expertise, SOP.., skills and varies significantly from lab to lab

Optimised wiring for a cryostat is often the result of a compromise between the thermal and electrical requirements of the system.

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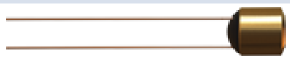
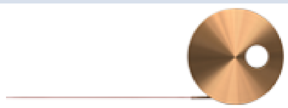
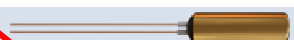
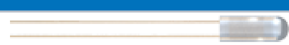
Cryogenic Temperature Sensors

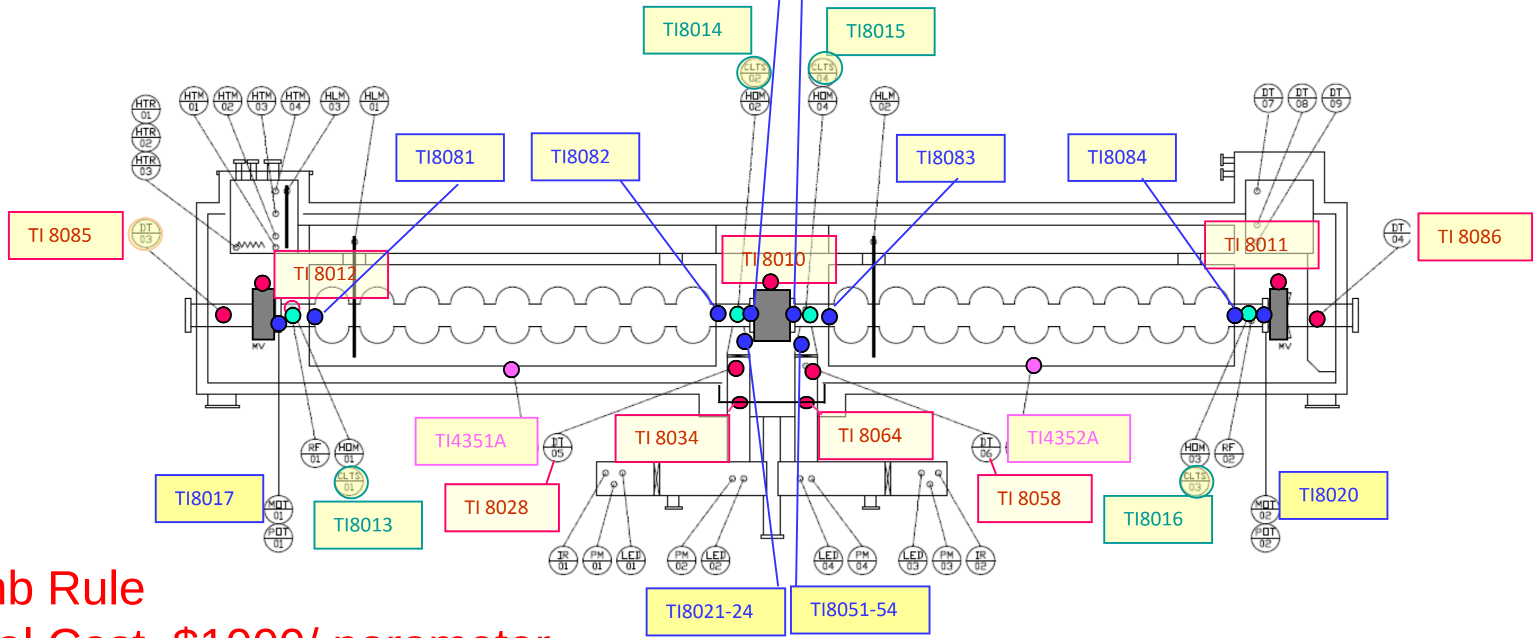
		Temperature range	Standard curve	Below 1 K	Can be used in radiation	Performance in magnetic field
Diodes						
Silicon		1.4 K to 500 K	▪			Fair above 60 K
GaAlAs		1.4 K to 500 K				Fair
Negative Temperature Coefficent RTDs						
Cernox®		0.10 K to 420 K		▪	▪	Excellent above 1 K
Germanium		0.05 K to 100 K		▪	▪	Not Recommended
Ruthenium Oxide (Rox™)		0.01 K to 40 K	▪	▪	▪	Good below 1 K*
Other						
Thermocouples		1.2 K to 1543 K	▪			Fair
Capacitance		1.4 K to 290 K				Excellent
Positive Temperature Coefficient RTDs						
Platinum		14 K to 873 K	▪		▪	Fair above 30 K
Rhodium-Iron		1.4 K to 500 K			▪	Not reccommended below 77 K
Specialty						
HR Series	HR HIGH RELIABILITY SERIES	20 K to 420 K			▪	Excellent

* RX-102B does not follow a standard response curve and is not recommended for use in magnetic fields

Electrical requirement	Typical application	Suggested solution
Current << 0.1 A Voltage < 50 V	Resistance thermometers, (4 wire)	0.1 mm hard enamelled constantan, manganin or phosphor bronze wires
Current < 2 A Voltage < 50 V	Low power heaters	Hard enamelled copper, 0.1 to 0.2 mm diameter. Below 8 K multi-filamentary superconducting wire with CuNi matrix
Current 2 to 150 A Voltage < 50 V	Superconducting magnet current leads	Many strands of hard enamelled copper wire for high temperature parts, multi-filamentary superconducting wires below 8 K. Gas cooling essential!
Current << 1 A Voltage 50 to 500 V	Piezo-electric drive	PTFE insulated copper wires (for low electrical resistance), or flexible stainless steel coaxial cables (for low heat load)
Low noise pick up	Sensitive low temperature measurements	Twisted pairs or flexible stainless steel coaxial cables
High frequency and Low loss	RF signals to/from experiment	Strip-line, twisted pairs, flexible or semi-rigid coaxial cables, stainless steel waveguides.

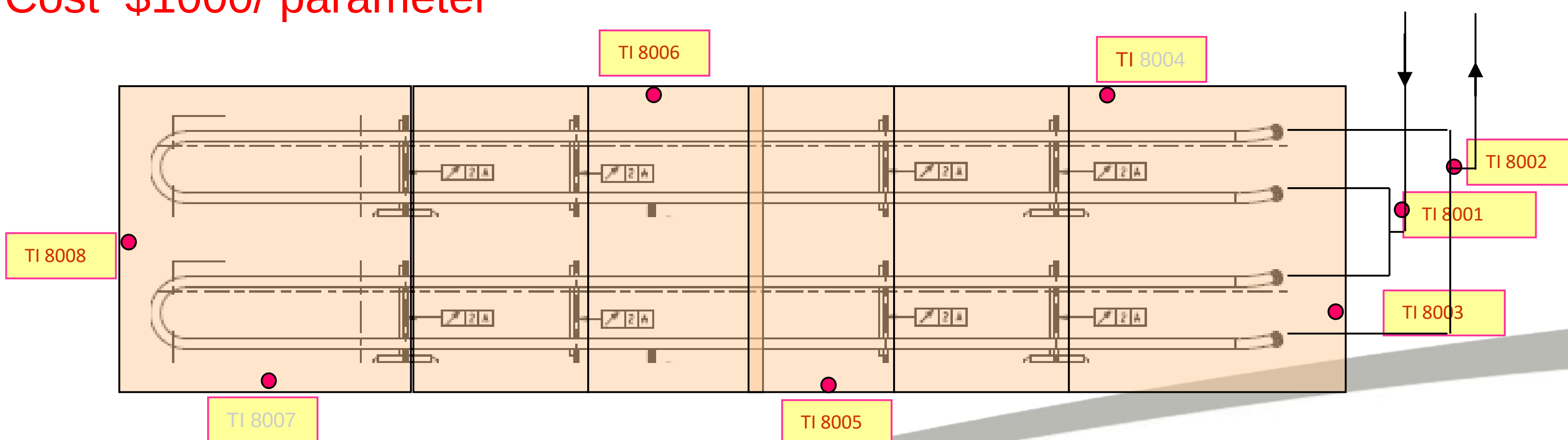
Ref: Practical Cryogenics by OI

Economics (ERL Cryomodule)



Thumb Rule

Capital Cost $1000/ parameter



PT100

CERNOX CX 1050

CLTS

Cernox

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Sensor Mounting

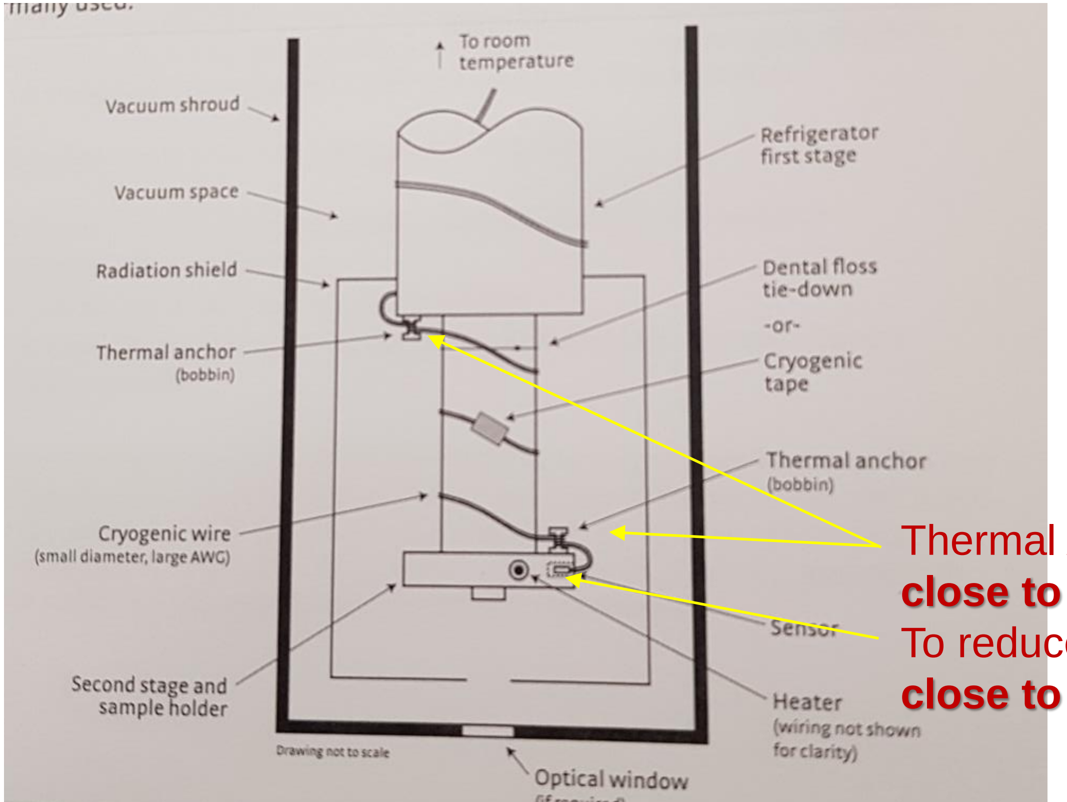

FIGURE 2-1 Typical sensor installation in a mechanical refrigerator

Heat conduction to sensing element is always higher through its leads than its interface (the bonding/ glue)

Stycast
GE varnish
Apiezon – N

Thermal Anchoring to intercept the heat flow
close to the heat sink and
To reduce measurement errors
close to the thermometer

Ref: Practical Cryogenics by OI

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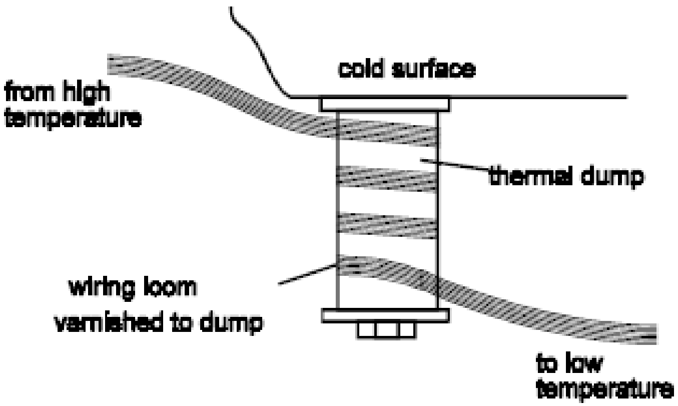
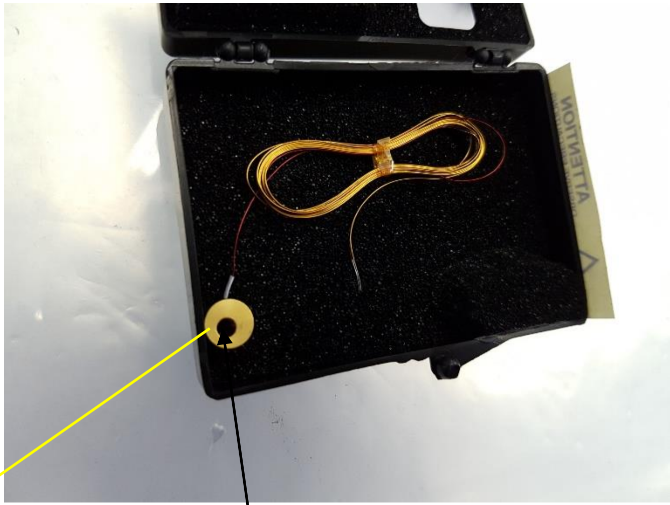
Sensor mounting





Thermal Anchoring to intercept the heat flow

close to the heat sink and

To reduce measurement error

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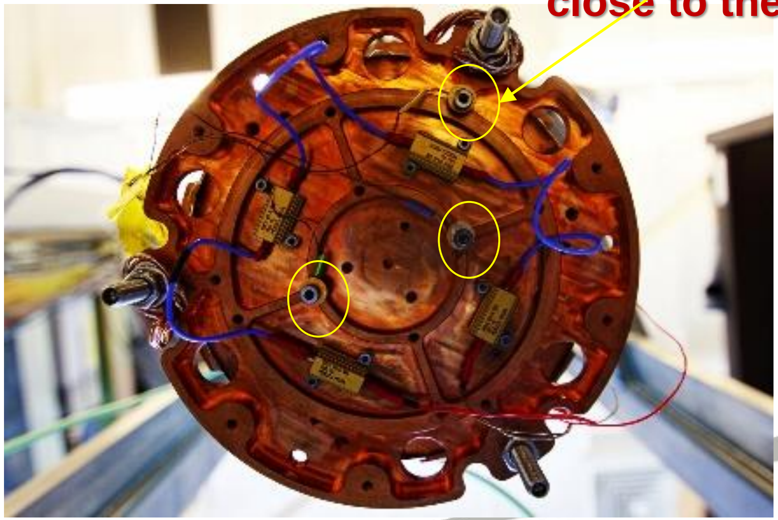
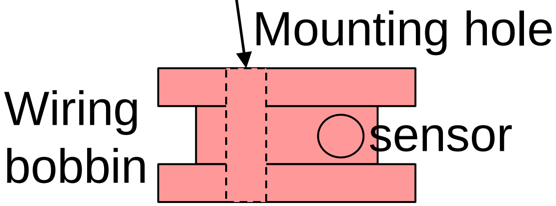


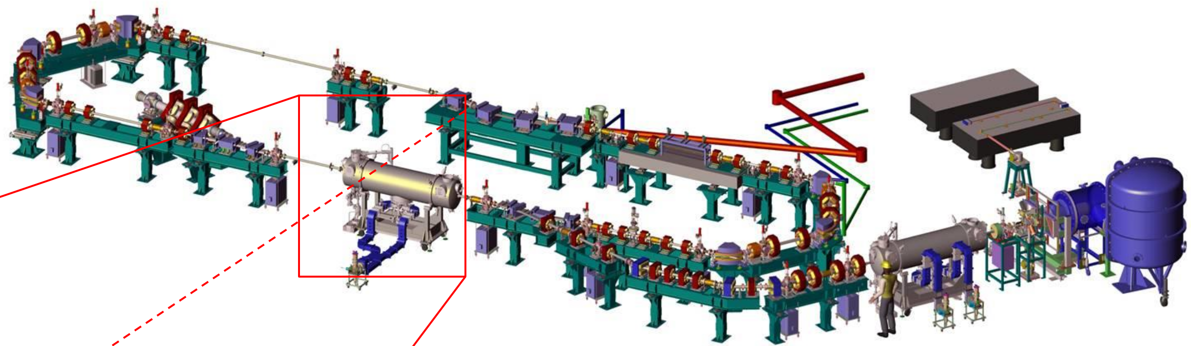


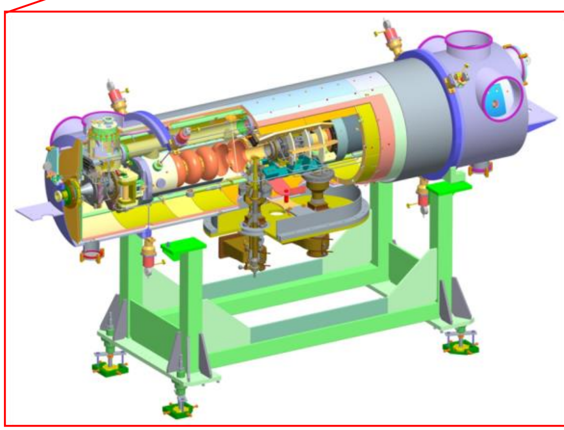

Manganin
Twisted pair
Ribbon

(Tekdata)

Example : ERL Cryomodule

Accelerator and **L**asers
in **C**ombined **E**xperiment





- Dimensioned to fit on the ALICE ERL facility at Daresbury:
  - Same cryomodule footprint.
  - Same cryo/RF interconnects.
  - 'Plug Compatible' with existing cryomodule

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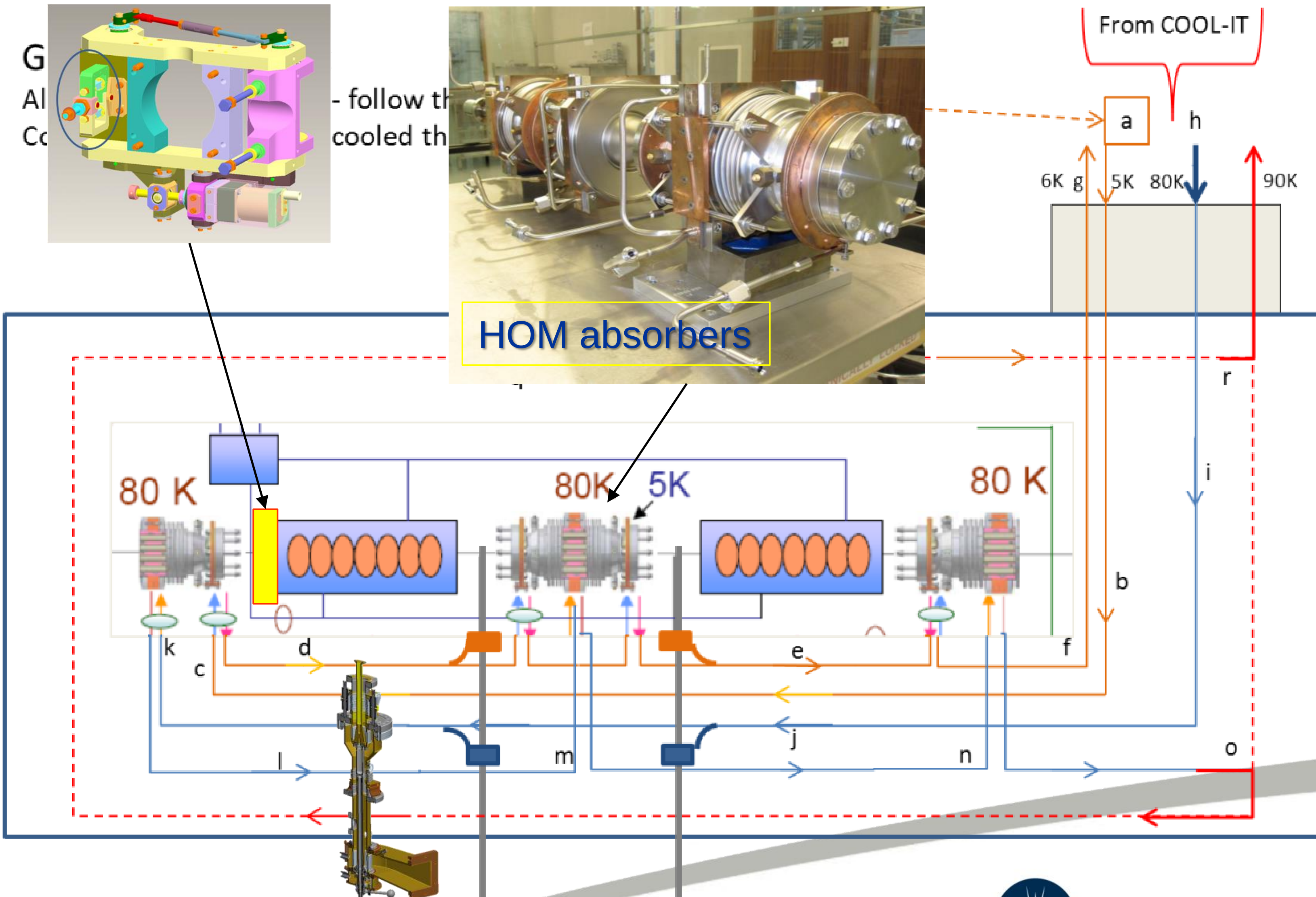
ERL Cryomodule



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Message for Standardisation

Consideration to sensor mounting and thermal anchoring should be given at the mechanical design stage
Cavity- helium vessel, couplers, shields, ……..

- Clearly specify/define locations
- Provide suitable mounting holes/clamps for sensors, bobbins, wiring

In most of the cased these sensors are glued to the surface with Stycast, GE Varnish, Apiezon grease, Indium….

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Vertical Test Facility at Daresbury

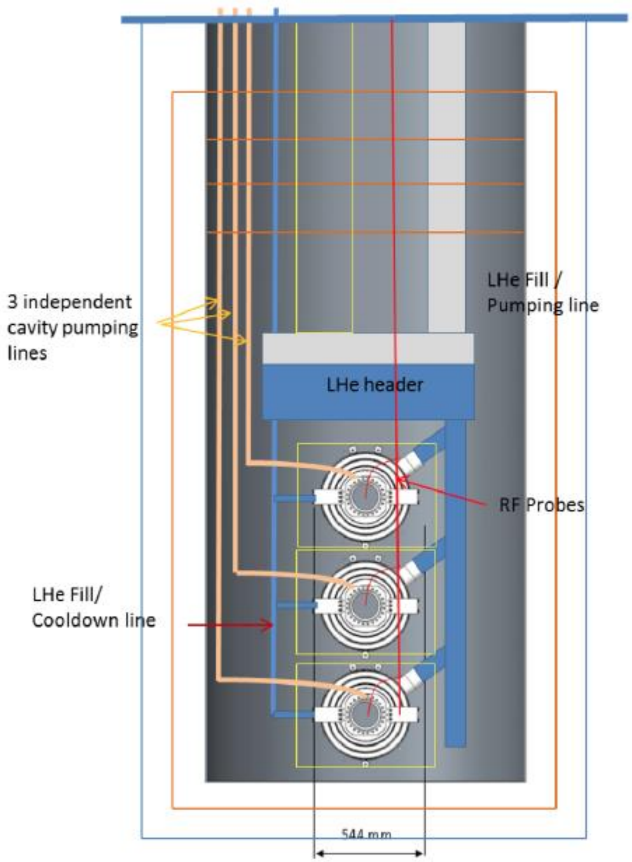
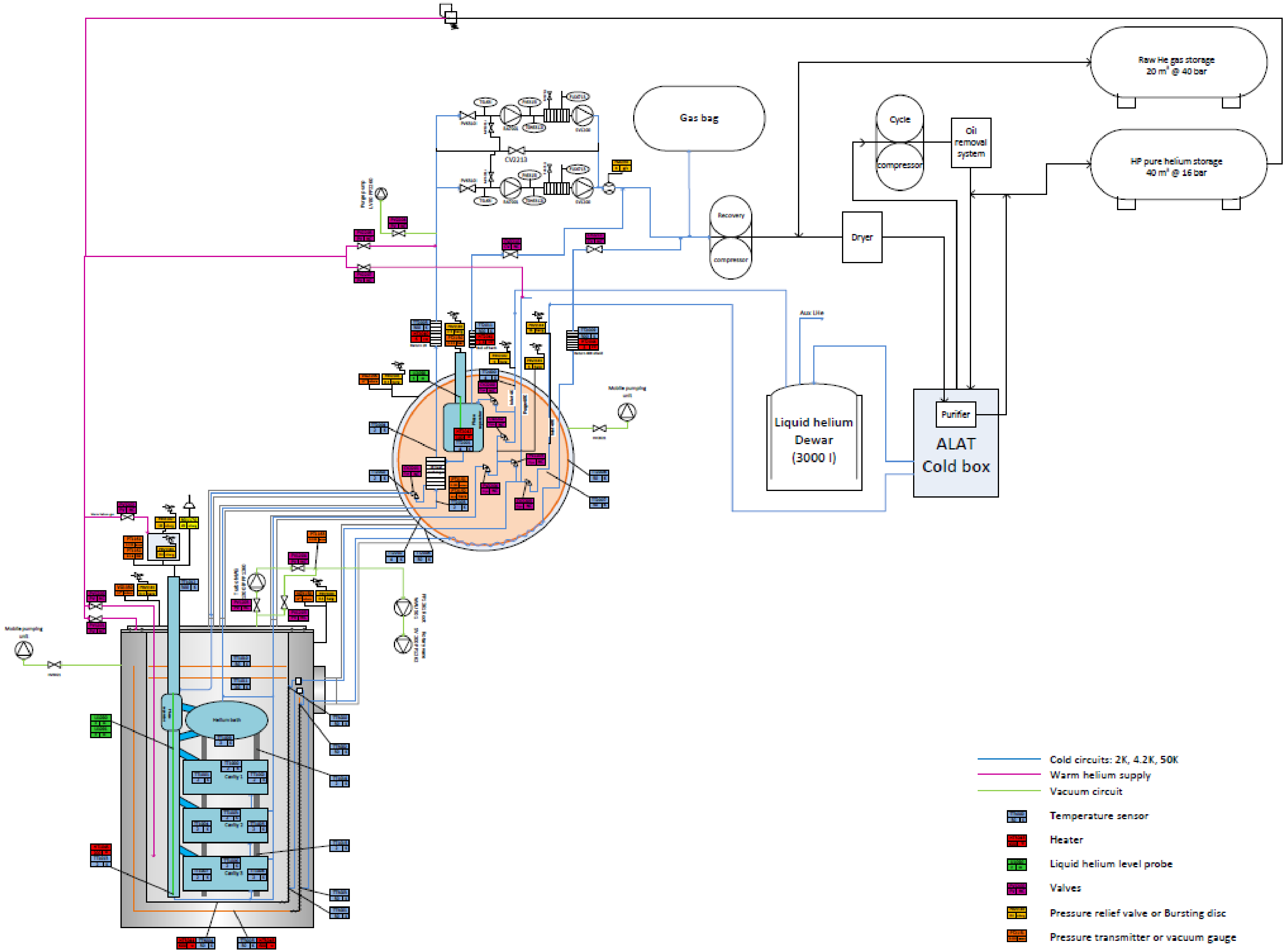


Figure 2. Cryostat schematic

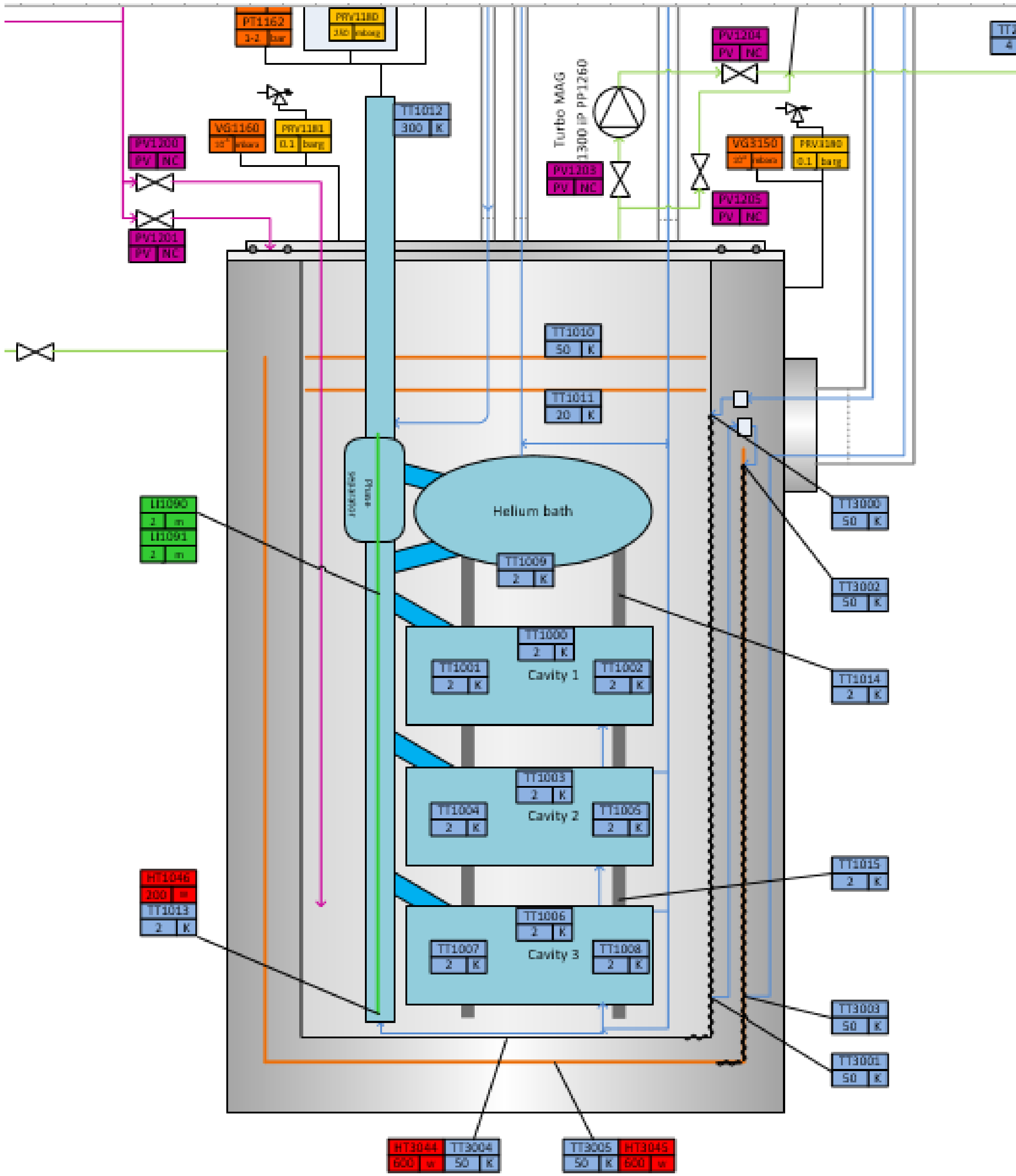
Figure 3. CAD of CSI

Figure 4.

P&ID (Process and Instrumentation Diagram)



P&ID



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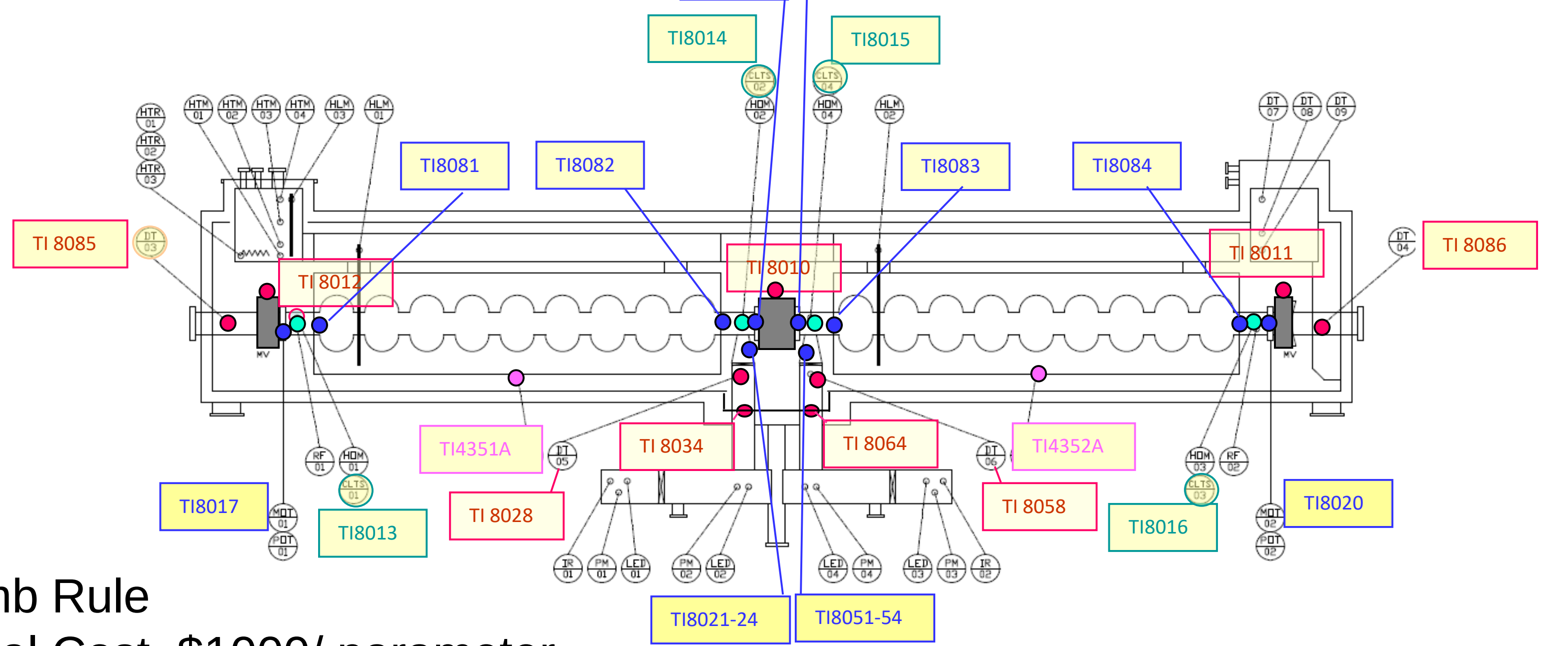
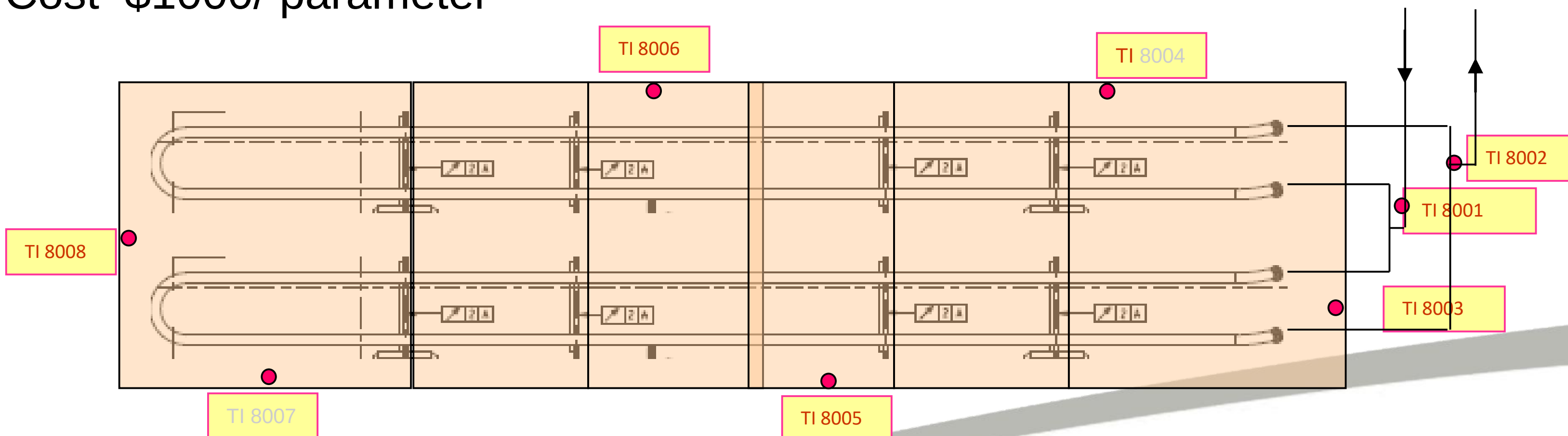
Essential vs Desirable



Thumb Rule
Capital Cost $1000/ parameter



PT100

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Cernox

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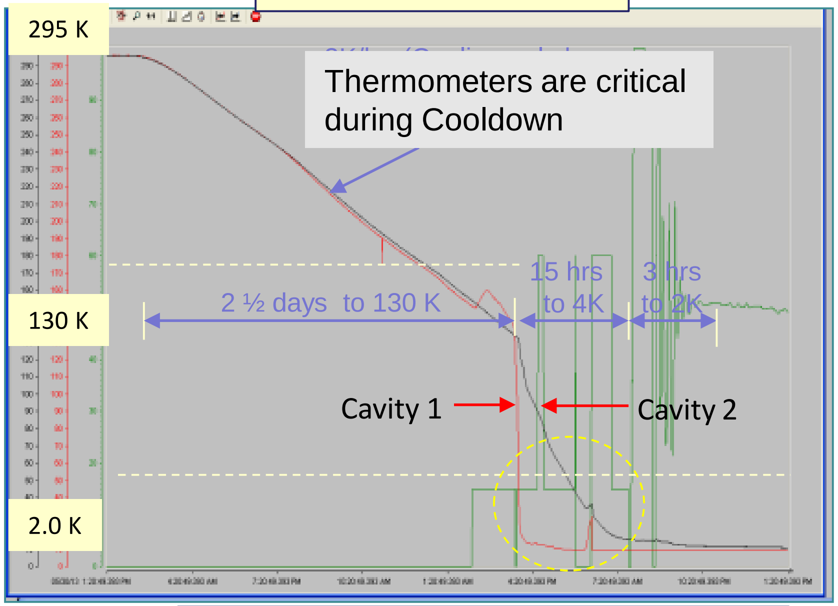
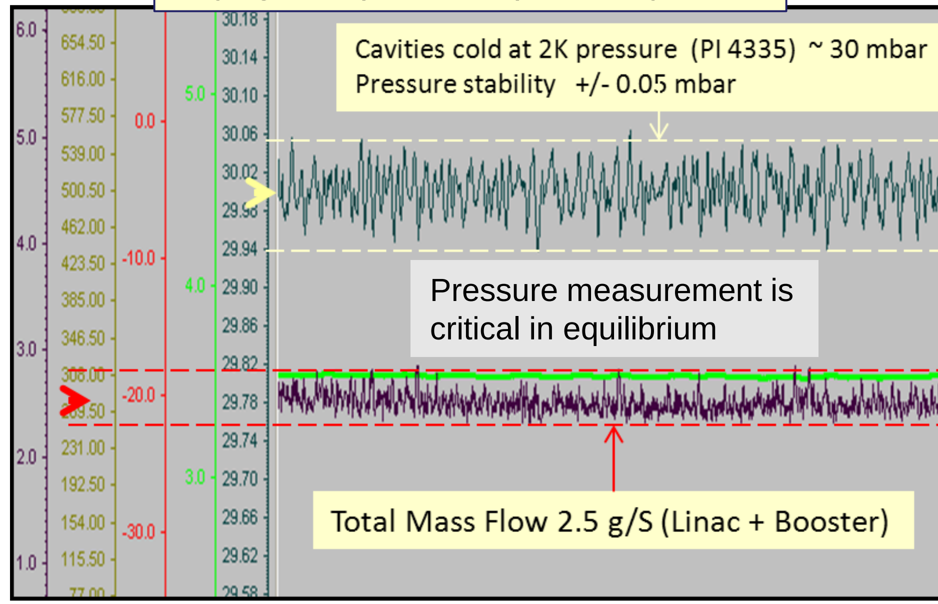
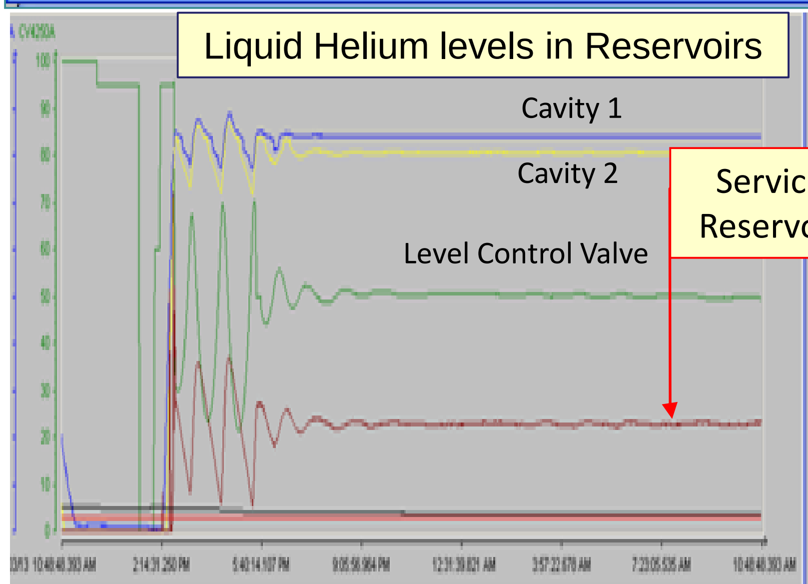
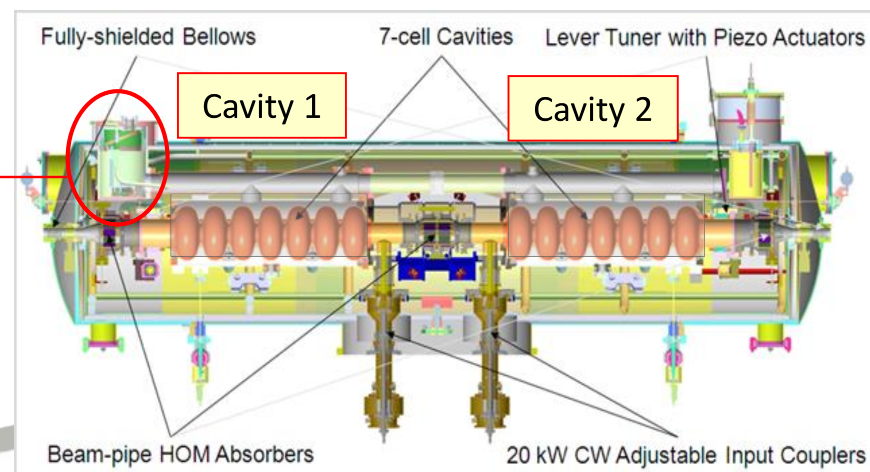
Cryogenic Performance





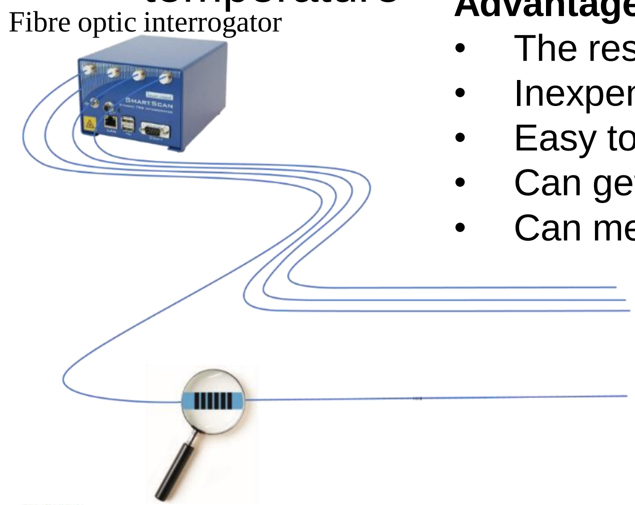




Cryogenic temperature sensor based on Fibre Bragg Grating

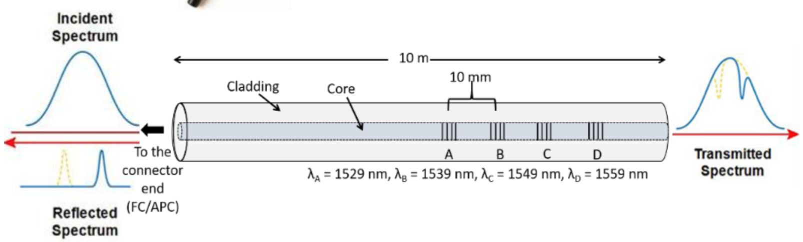
Good for measuring temperature profile

- Wavelength shift is influenced by both strain and temperature



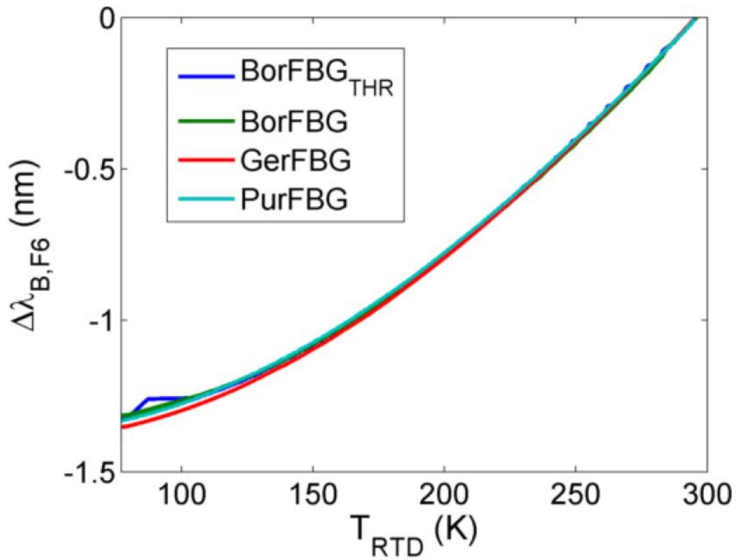
Advantages:

- The response time is superior than thermistors or ordinary Platinum resistors
- Inexpensive and robust
- Easy to install
- Can get the exact position (sub-mm range),
- Can measure temperature between - 140° C to 600° C.



Relation between wavelength and temperature:

$$\Delta\lambda_B = \lambda_B(\alpha + \xi + (1 - P_e)(\alpha_{sub} - \alpha))\Delta T$$



Thermo-optic coefficient of the FBG will not change, however, the thermal expansion properties will change

E S de L Filho et. al, *Optics Express*, vol 22 No. 22, 2014

Cryogenic temperature sensor based on Fibre Bragg Grating

- It has been used for T > 40 K
- Will be very economic and simple
- FPG technology must be explored for measuring temperature profiles (e.g. quench detection)
- R&D needed to extend the temperature range for SRF applications

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Remarks and Summary

- As far as possible keep the process simple
- Use well demonstrated industrial components and processes to keep the cost down with high reliability
- Identify what is essential/ desirable (*R&D vs Operations*)
- Consider redundancies (*Replacement of sensors not possible*)
- In SRF based accelerators temperatures sensors are critical for cool-down, warm –up, interlocks….
- At equilibrium temperatures vapour pressure is the best indicator of temperature

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Remarks and Summary

- Cryogenic Instrumentation is similar except for thermometry and few other devices that actually operate in cryogenic environment.
- Careful consideration must be given to wiring and sensor mounting at the design stage
- Several devices/ components could not covered in the presentation due to time limitations …
  Feedthroughs, SC level probes, Cold valves, etc.

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Questions / Discussion