CERN

Cryolab measurement capabilities and R&D – related to MSC

Torsten Koettig on behalf of the whole Cryolab team

Outline

- Introduction
- Standard experimental infrastructure in the Cryolab
- R&D projects performed together with MSC
- Ongoing developments and new experimental systems
- Future topics
- Summary

The Cryolab team TE/CRG-CI

- 2.5 scientists
- 1 technical engineer
- 1 mechanical engineer
- 2 Fellows
- 2 PhD students
- 2-3 technical students

- 2 FSU

Cryolab projects 2019/20

35-40 short and long term projects

Technology development

- RF cavity diagnostics
- BCCCA upgrade
- Cryo - Beam Loss Monitor
- RRR thin films, strips and bulk samples
- Thermal conductivity test stand
- Thermal dilatation test stand
- HFM λ-plate seal heat inleak
- Helios refill
- LKr purity monitor NA62
- CAST
- Compass cooldown
- Rades 2 K - cavity validation
- Gas permeability
- LHC beam screen heaters
- RF surface impedance

Project driven

- HL-LHC beam screen: non-standard conditions
- HL-LHC inner triplet current feeders
- Thermal cycling of 11 T coil
- He II heat transport in Nb_3Sn cable geometries
- He II cooling simulations of Nb_3Sn coils
- LAr calorimeters high-density feedthroughs
- BPM thermal link
- Near Tc wire characterization Nb_3Sn
- FCC MLI test stand
- EASITrain - SC thin film on substrate
- DarkSide
- FCC transparent cryostat thermal performance
- LAr robot, CryFish
- Shape Memory Alloys
- ALPHA - Current leads test

Generic R&D

- Thermal mapping of SRF cavities
- Cryocooler remote cooling study
- Cryogenic force calibrator
- Sub-Kelvin cryogenic cooling study

Training and Outreach

- Cryogenic Safety courses: Fundamentals, LHe transfer, TSO
- Safety course: Self-Rescue mask
- Visits/Demonstration LN_2
- Open Days 2019
- HSSIP

projects directly linked with MSC

Standardized test stations and R&D projects

MSC related topics

Material properties	Heat transfer	Simulations
Standardized test stands ←	Materials e.g. composites	→ He II in confined geometries
New setups ←	Interfaces at low temperature	→ Metal/epoxy to He
Custom design & installation ←	Transient conditions & application	→ Thermodynamics of Quench
Novel concepts and R&D ←	Remote cooling options	→ HEX num. model to adapt to applic.

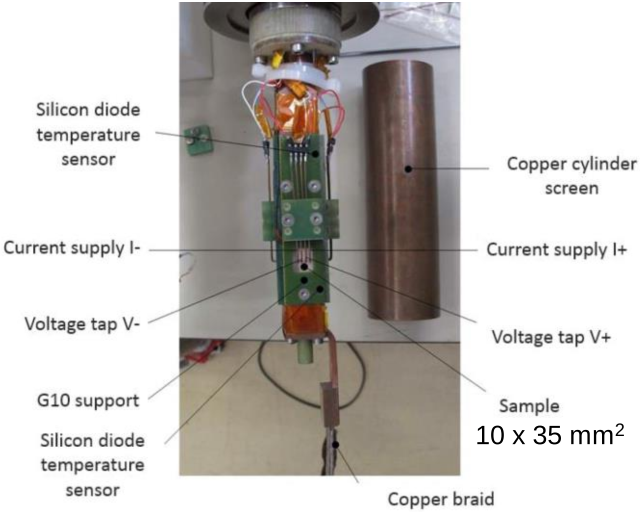
Standardized test stations

Cryolab test capabilities

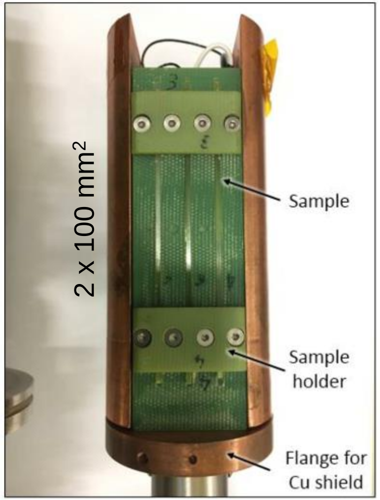
Cryolab infrastructure for tests of:

1. RRR for films, foils and bulk samples

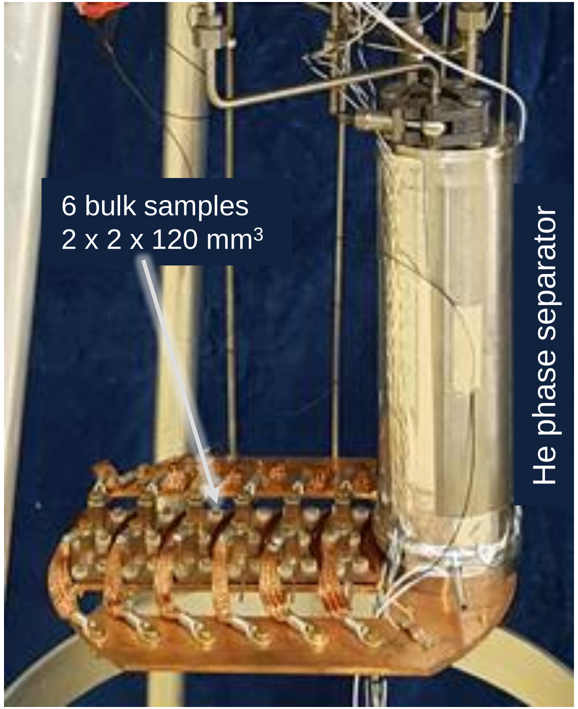
Films on substrate



Foils e.g. Quench heaters



Bulk e.g. metals, SC like Nb

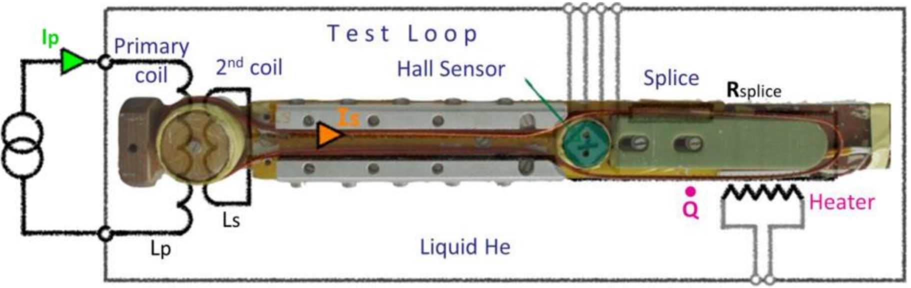


Cryolab test capabilities

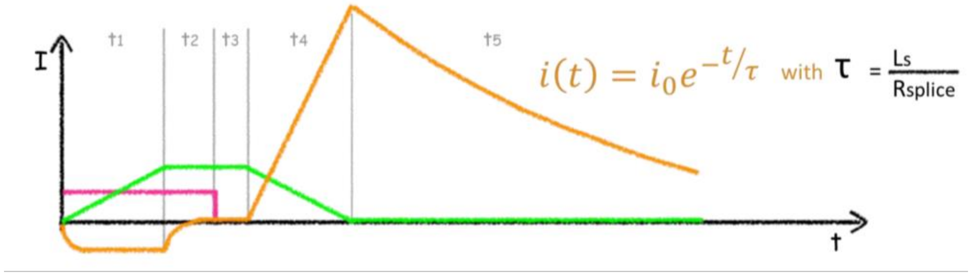
Cryolab infrastructure for tests of:

1. RRR for films, foils and bulk samples
2. SC splice resistance

Example of a SC cable with joint



Schematic of the setup

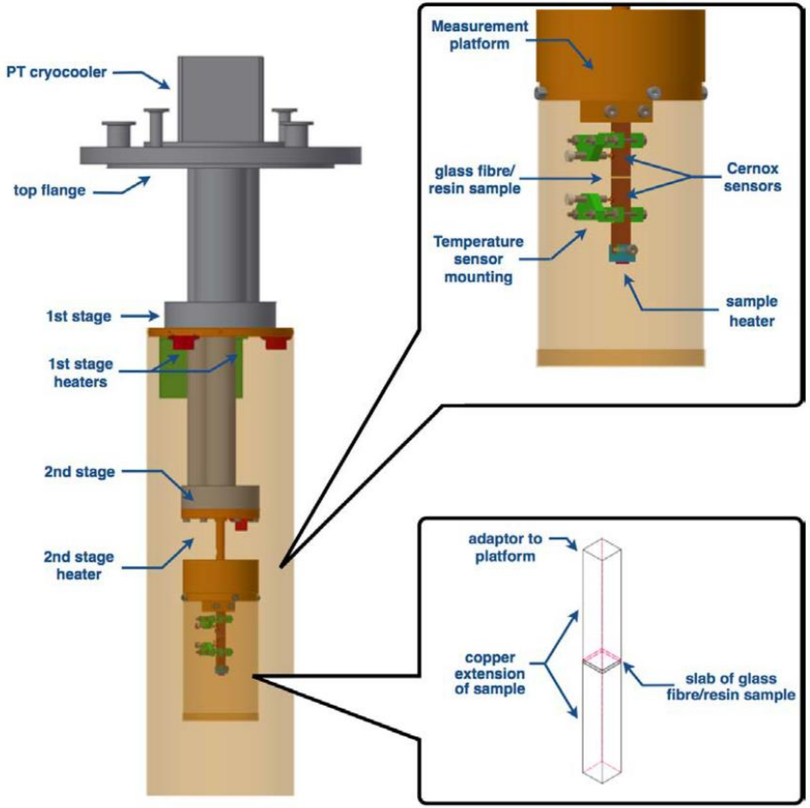


Induced current in a SC loop with a resistive connection => R ~ 1-2 nΩ

Cryolab test capabilities

Cryolab infrastructure for tests of:

1. RRR for films, foils and bulk sample
2. SC splice resistance
3. Thermal conductivity test stand
4. Thermal diffusivity test option



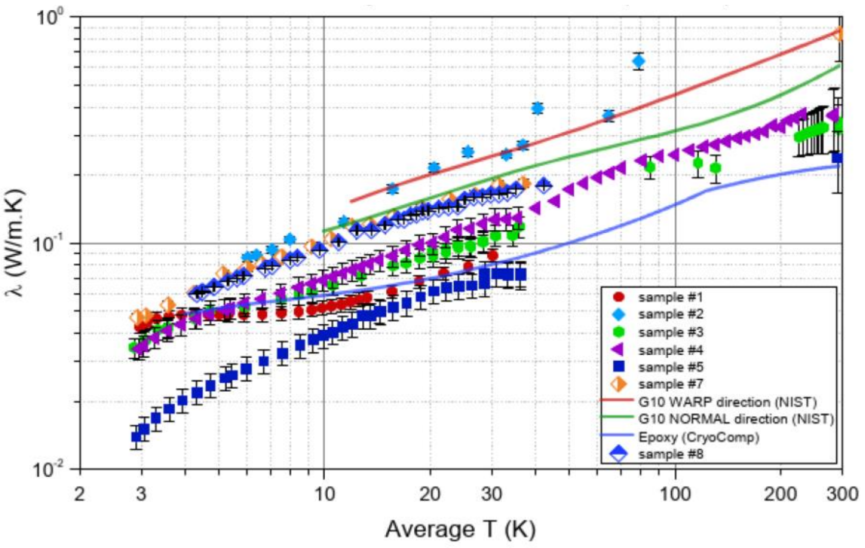
Courtesy: Patricia Borges de Sousa

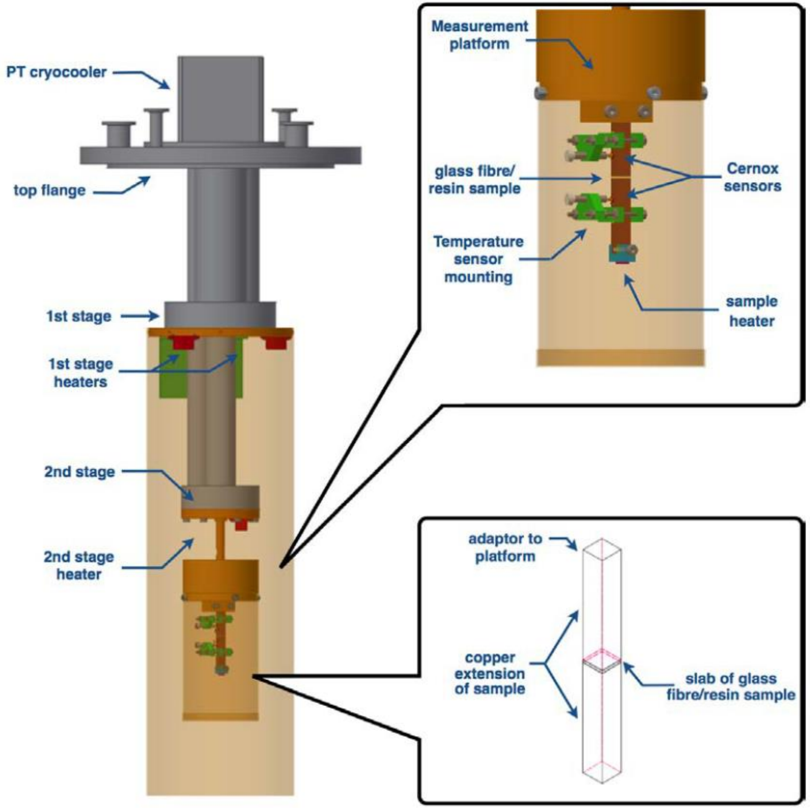
Cryolab test capabilities

Cryolab infrastructure for tests of:

1. RRR for films, foils and bulk sample
2. SC splice resistance
3. Thermal conductivity test stand
4. Thermal diffusivity test option

Thermal conductivity of different 11 T dipole impregnation samples





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Cryolab test capabilities

Cryolab infrastructure for tests of:

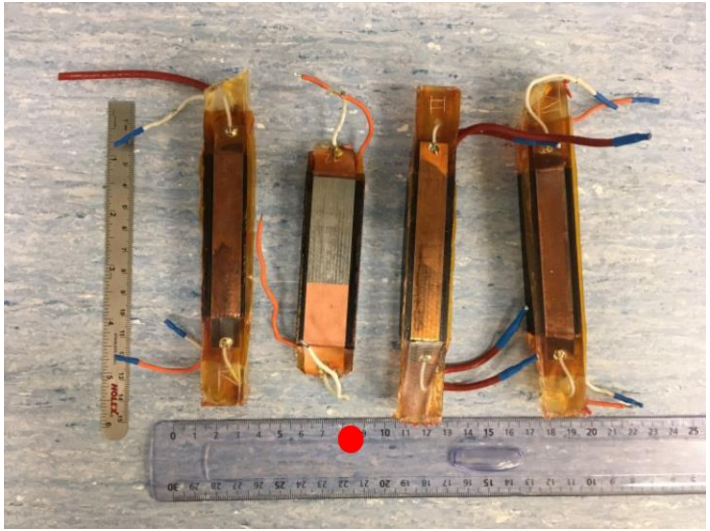
1. RRR for films, foils and bulk samples
2. SC splice resistance
3. Thermal conductivity test stand
4. Thermal diffusivity option
5. Thermal cycling (small and large scale)

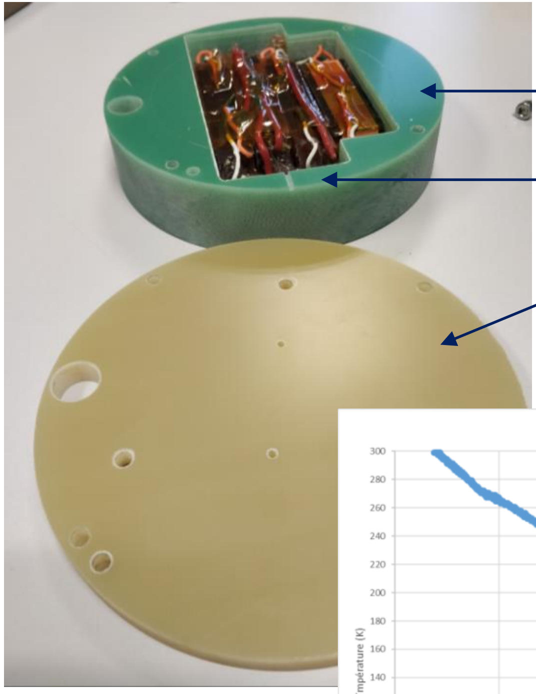
→ next 2 slides

Felix Wolf

Nb_3Sn small scale samples thermal cycling to 2 K

- 4 samples to be cooled down
- Immersion in He II
- Warm up to 4.2 K => 293 K

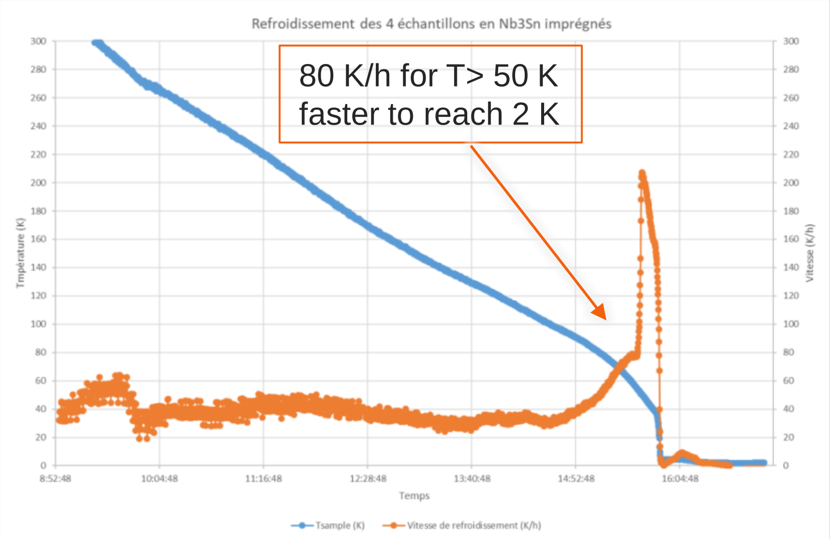




Sample box in G10

TT in sample space

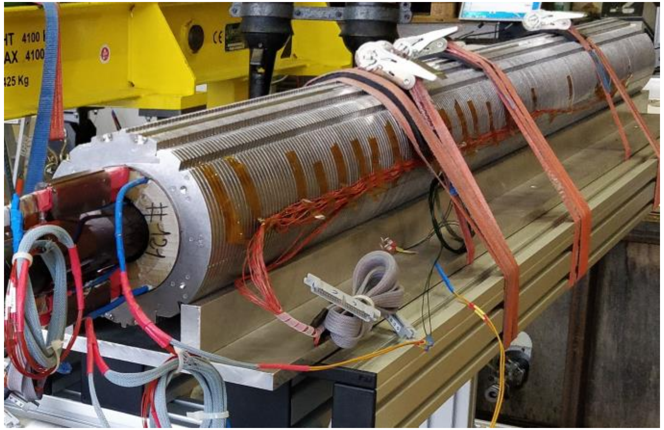
Cover to protect from He gas stream

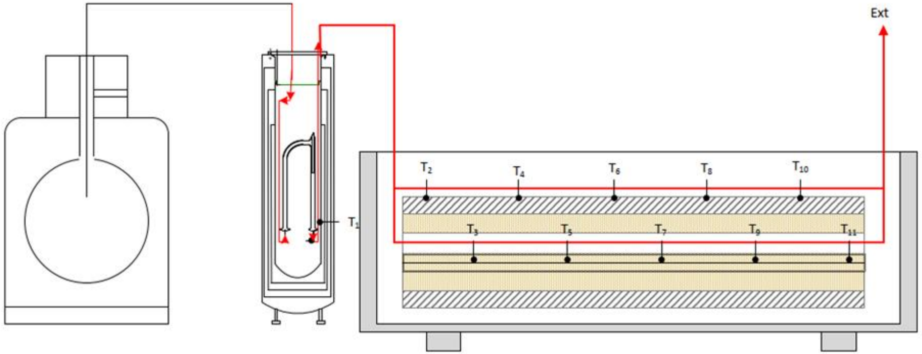


Thermal cycling 11 T coil thermal cycling 10 x to 80 K in GN_2

Evaluation of the effect of thermal cycling on impregnated Quench heater insulation to the coil and the respective resistance (SP07)

- 10 thermal cycles to 80 K in GN_2 atmosphere
- Controlled ΔT during magnet cooldown
- Insulation resistance measurement after each cycle 660 V, 2 min





- Setup of a gas distribution system, guaranteeing the max. thermal gradient across the magnet of 50 K (100 K) and cooldown in 24 h.
- 10 thermal cycles have been performed while staying within the maximum allowed temperature gradients.
- No thermal degradation has been identified by MSC.
- Humidity and temperature influence during the insulation tests => MSC
- EDMS: 2150812 /2332230

Cryolab test capabilities

Cryolab infrastructure for tests of:

1. RRR for films, foils and bulk samples
2. SC splice resistance
3. Thermal conductivity test stand
4. Thermal diffusivity option
5. Thermal cycling (small and large scale)

R&D:

A) Thermal dilatation, classic and laser based system
B) Near T_c test stand for SC wires
C) T_c of SC films on Cu substrate (cavities)

Dilatation test stands in the Cryolab

Number	Setup	Sample dimensions	Temperature in K	Remarks
1	Pyrex cryostat insert	50 mm x 8 mm x 8 mm	293 K reference, 78 K and 4.2 K	Requires LN_2 or LHe
2	Laser based cryostat insert	80 mm x 15 mm x 15 mm	5 K to 293 K continuous	Requires LHe 5 samples measured for MSC
3	Laser based interferometer R&D	All dimensions up to: 200 mm x 70 mm x 50 mm Max. 18 mm dx from edge	8 K to 293 K continuous	Sample in vacuum Cryocooler based Laser beam distance 21 mm

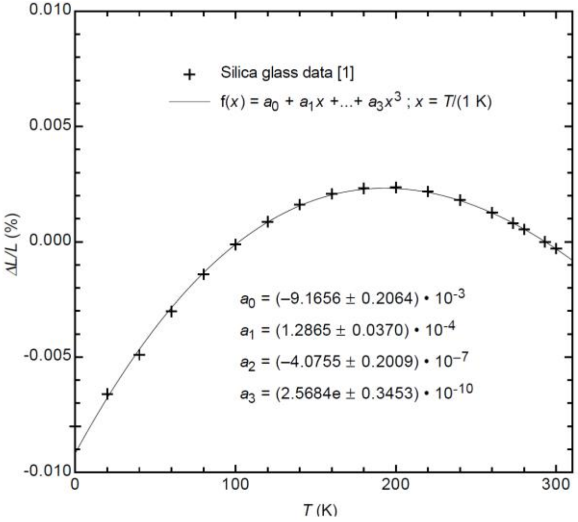
The Laser dilatometer #3 (based on a cryocooler) is a completely new developed dry experimental station, and is under commissioning in the Cryolab right now.

The goal is to have a versatile measurement setup esp. in terms of sample dimension and composition.

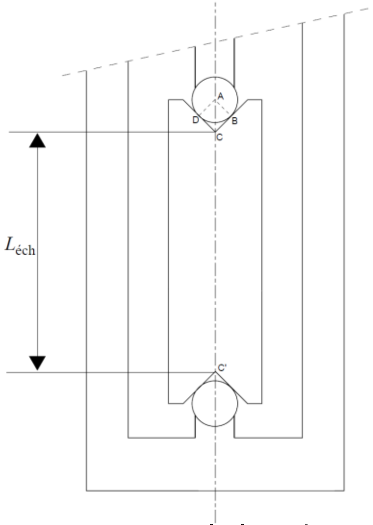
Dilatation test stand – Pyrex insert

Old system => cryostat insert

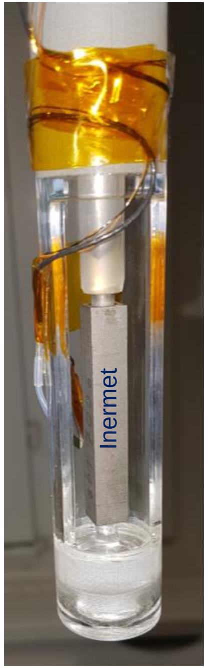
Measurement points: 293 K reference, 78 K LN_2 and 4.2 K LHe



Reference material used for calibration of the glass insert (NIST)

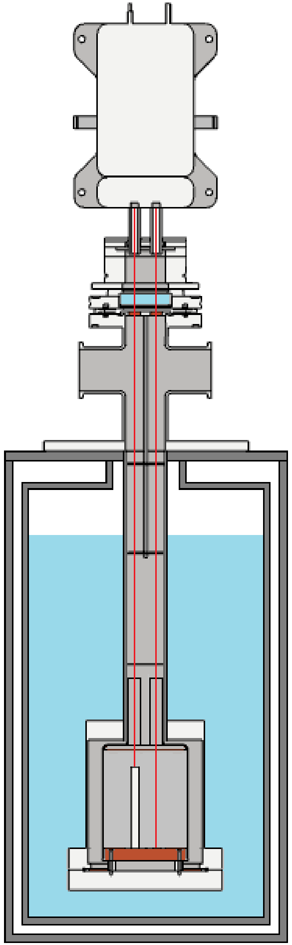


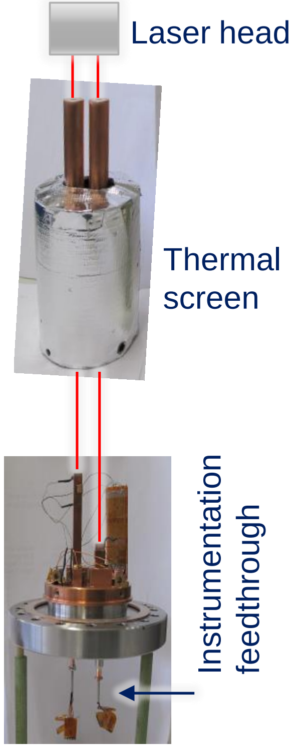
50 mm sample length with special interfaces



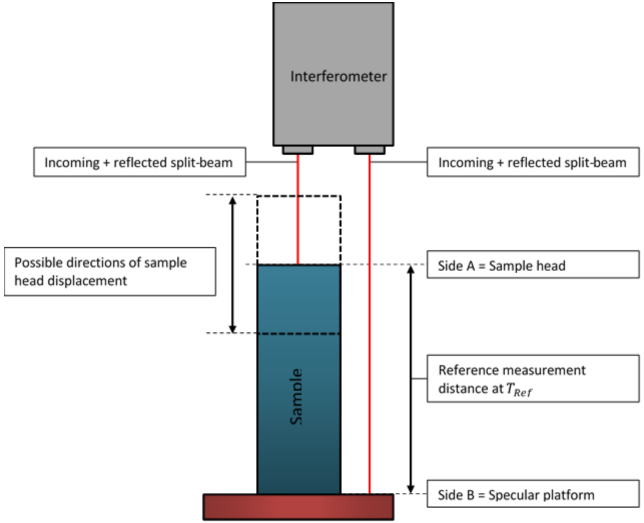
Measurements: Inermet, Ultem 1000, G10 II and ⊥

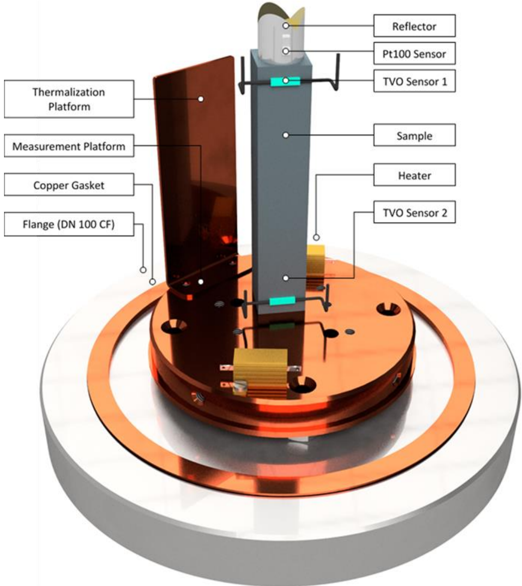
Dilatation test stand laser interferometer cryostat





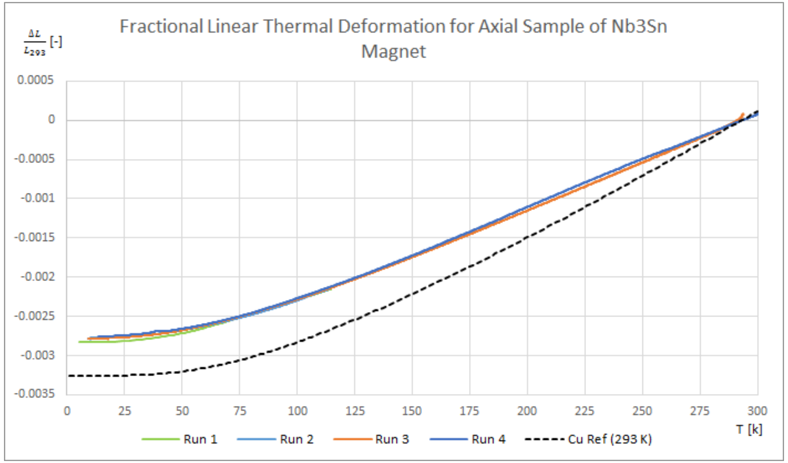
- Measurement with LN2 or LHe
- Sample in vacuum
- Cu shield + MLI around sample platform ensures $T_{Environment} \sim T_{Sample}$
- Reduction of the viewing factor at platform screen
- Temperature uniformity by thermal screen
- Experimental platform enables samples: 80 mm x 15 mm x 15 mm

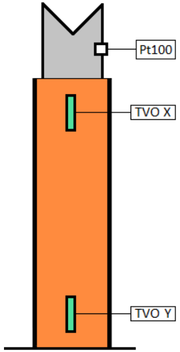




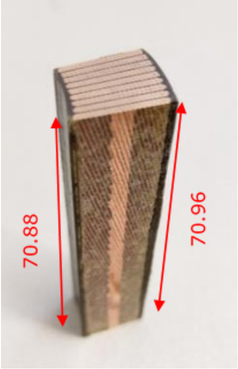
Matthias Michels

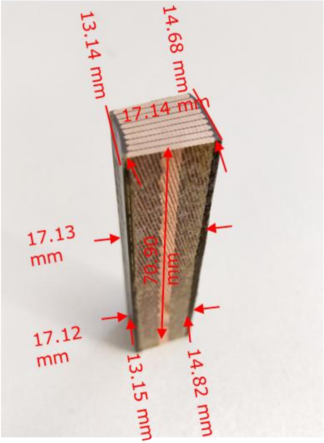
Dilatation test stand – results Nb_3Sn samples





Axial direction





Courtesy: Remy Kriboo, Flory ten Broeke

Matthias Michels

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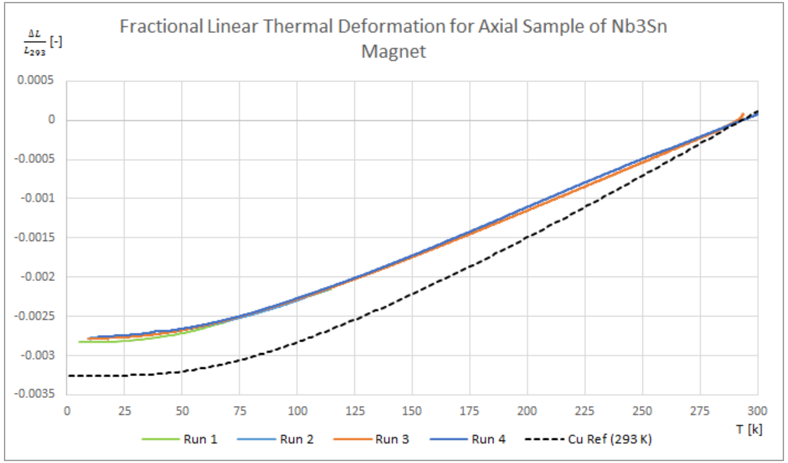
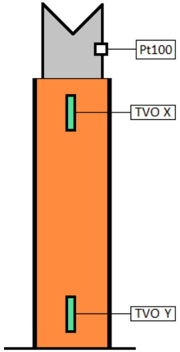
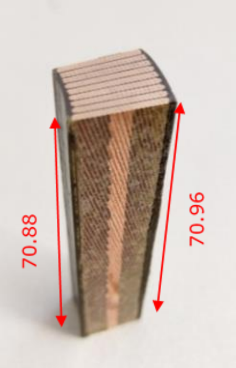
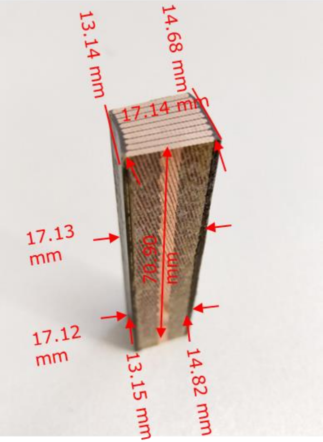
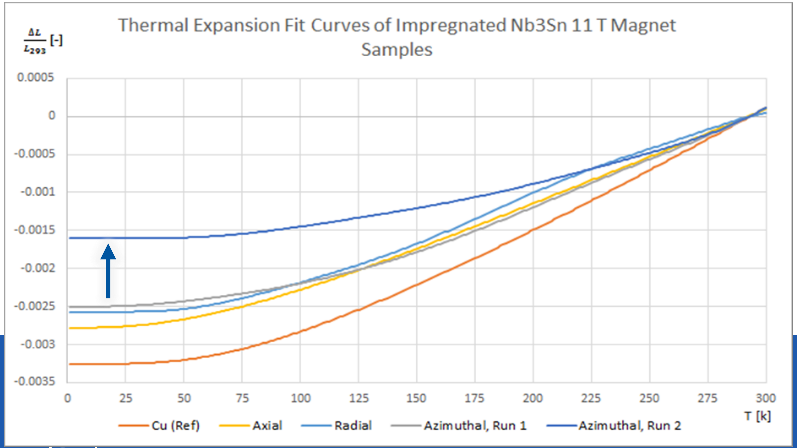




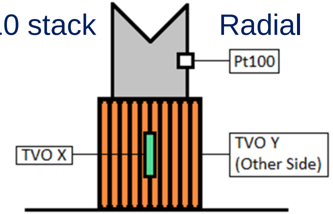
Axial direction

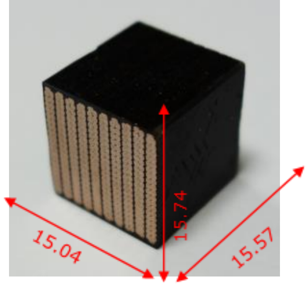




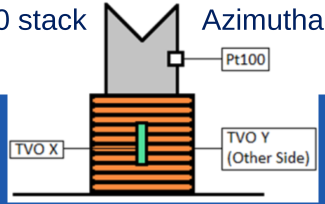


10 stack Radial





10 stack Azimuthal



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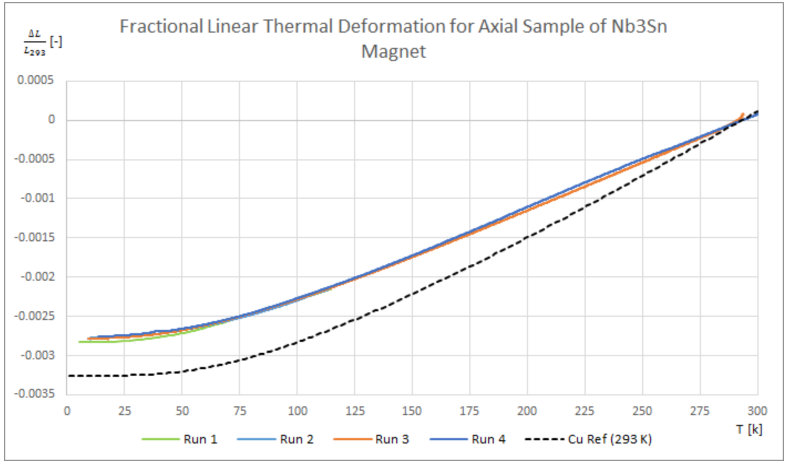
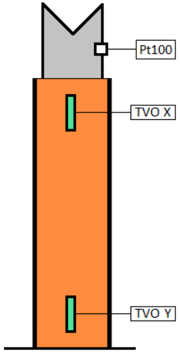
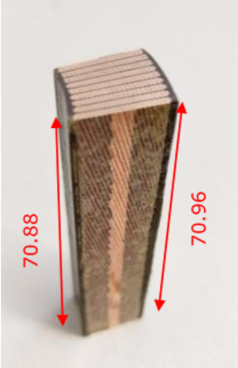
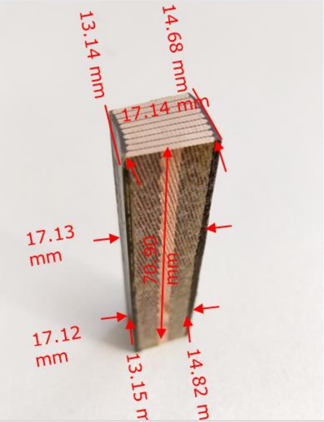
Dilatation test stand – results Nb_3Sn samples

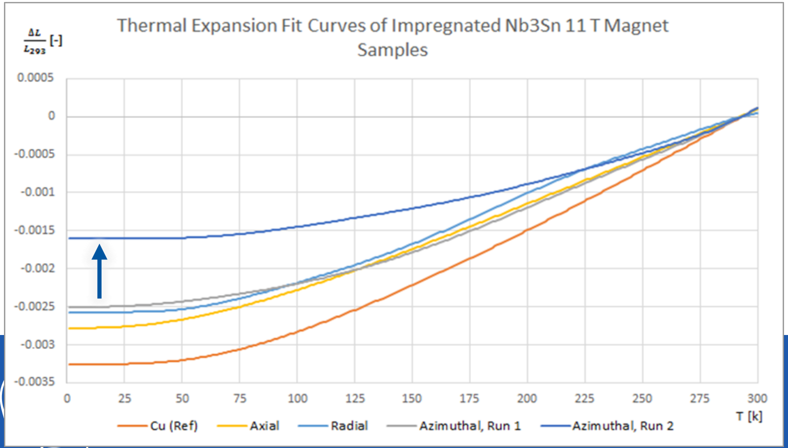




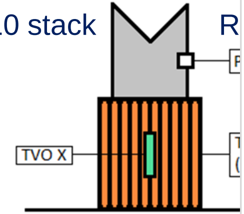
Axial direction



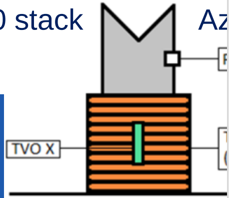


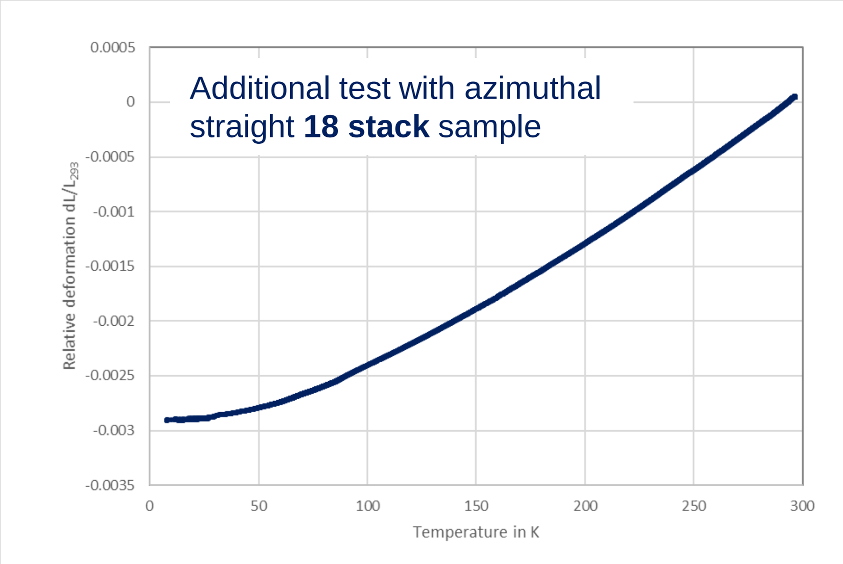


10 stack

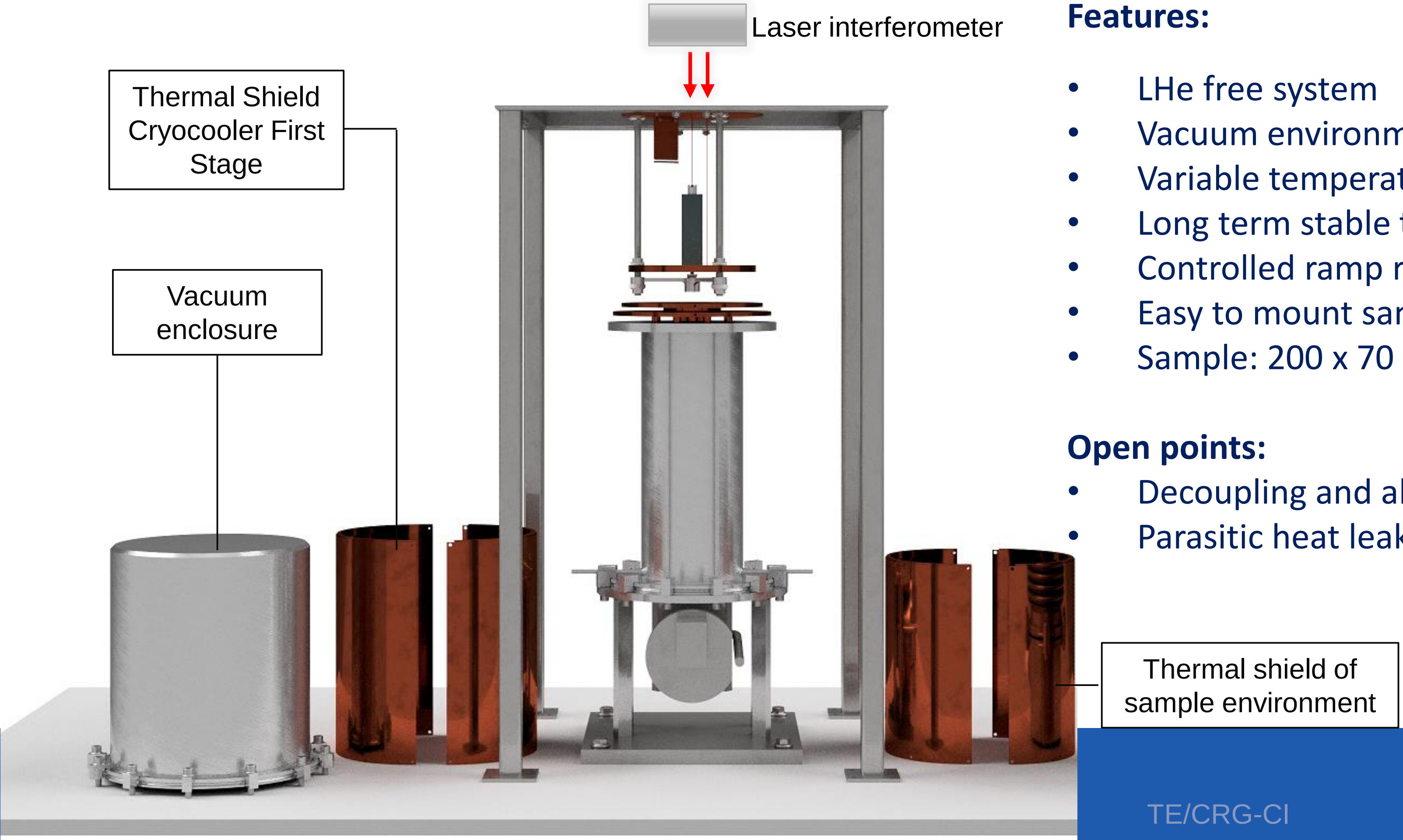


10 stack





Upgrade dilatation test stand to cryocooler and laser



Features:

- LHe free system
- Vacuum environment
- Variable temperature 8 K to 293 K
- Long term stable temperature
- Controlled ramp rates
- Easy to mount sample
- Sample: 200 x 70 x 50 mm^3

Open points:

- Decoupling and alignment
- Parasitic heat leaks

Courtesy: Remy Kriboo, Flory ten Broeke

Finished R&D topics:

- Near T_c characterization of Nb_3Sn wire

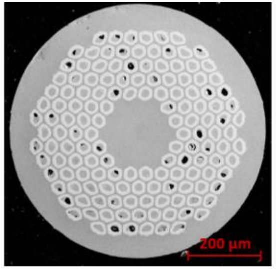
  (mechanical stress applied at room temperature)

Patrick Ebermann

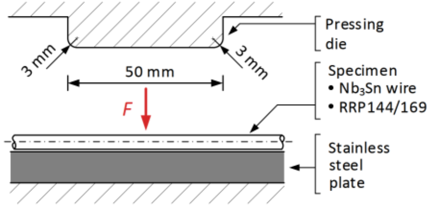
A) Near Tc test stand for I_c measurement of reacted Nb_3Sn wire

PhD topic of Patrick Ebermann: “Analysis of electrical degradation by measuring I_c as a function of transversal stress applied at room temperature:

- **Wire** with adapted setup in **CryoLab**
  - In collaboration with CERN-TE-CRG-CI

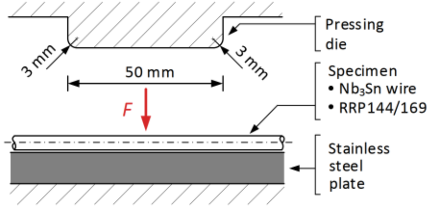


Cryogenic test 1 =>



1st compression force applied at room temperature

=> Cryogenic test 2 =>

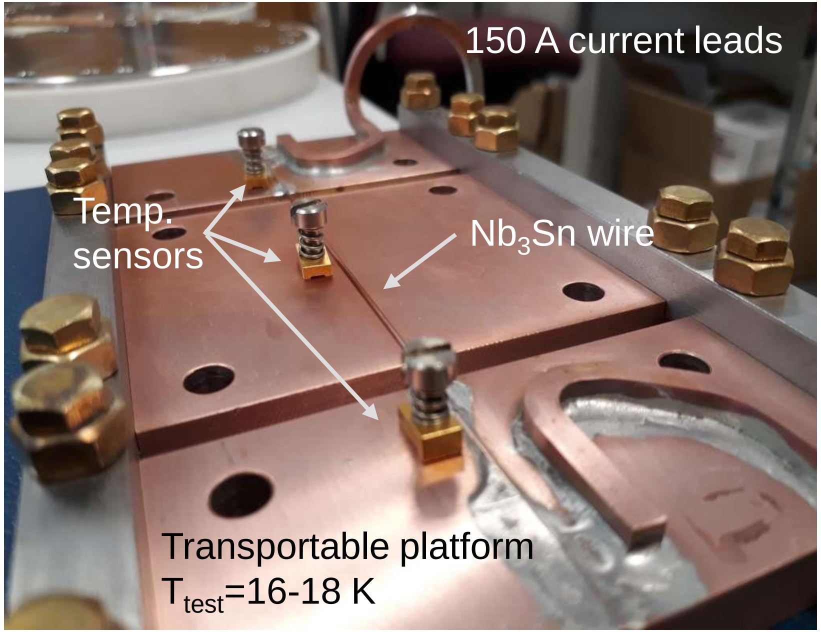


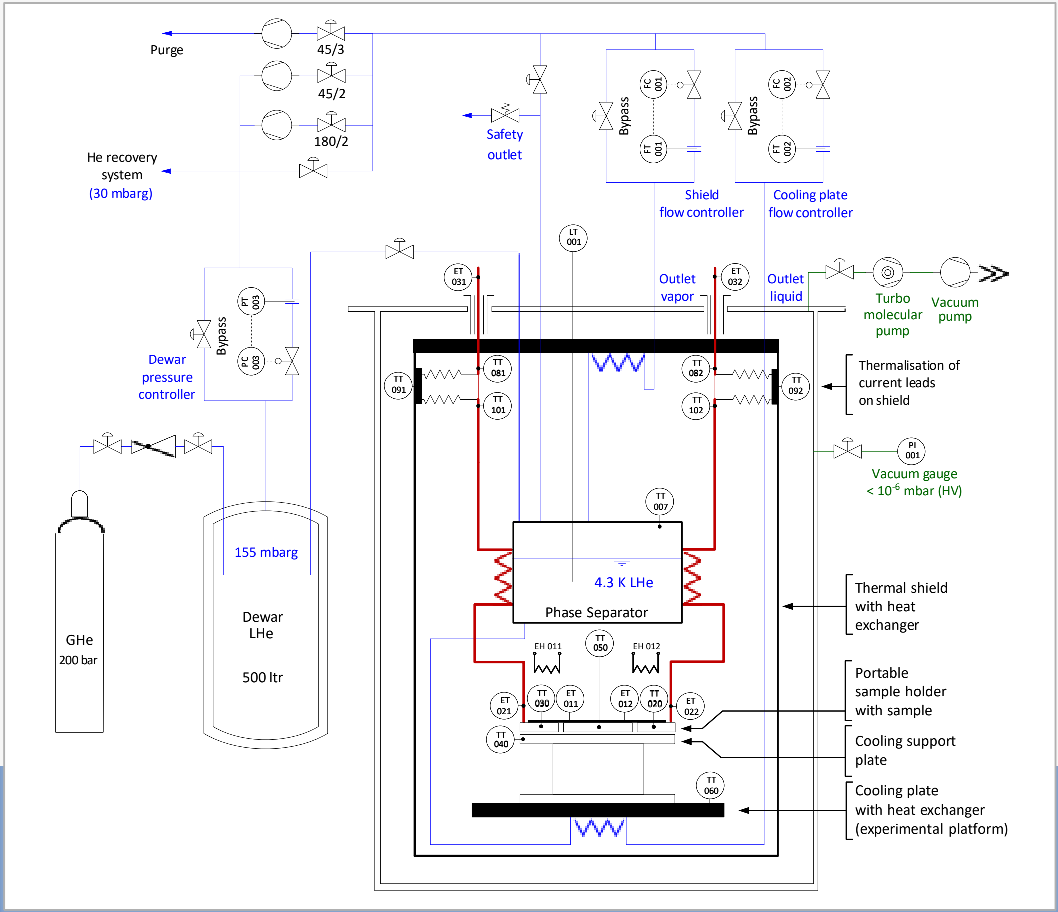
2nd compression force applied at room temperature

A) Near Tc test stand for I_c measurement of reacted Nb_3Sn wire

PID of the Near Tc test stand, P. Ebermann

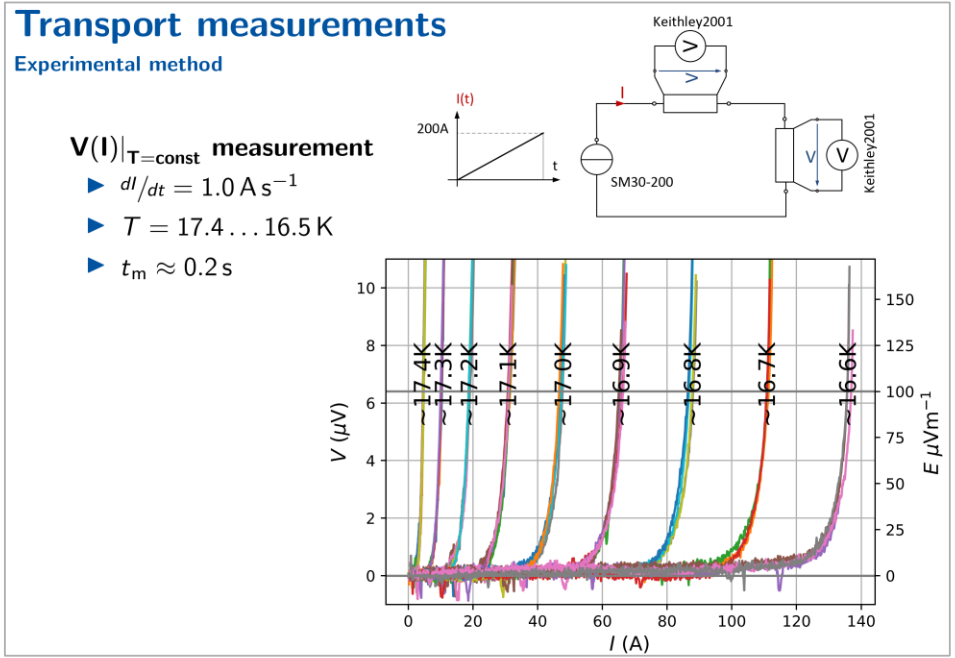
Demountable sample holder thermalized at 16 -18 K with dT=0.1 K





A) Near Tc test stand for I_c measurement of reacted Nb_3Sn wire

Keep T_{sample} constant



Courtesy: Patrick Ebermann, Irreversible degradation of superconducting Nb_3Sn wires and cables caused by transverse stress at room temperature.

A) Near Tc test stand for I_c measurement of reacted Nb_3Sn wire

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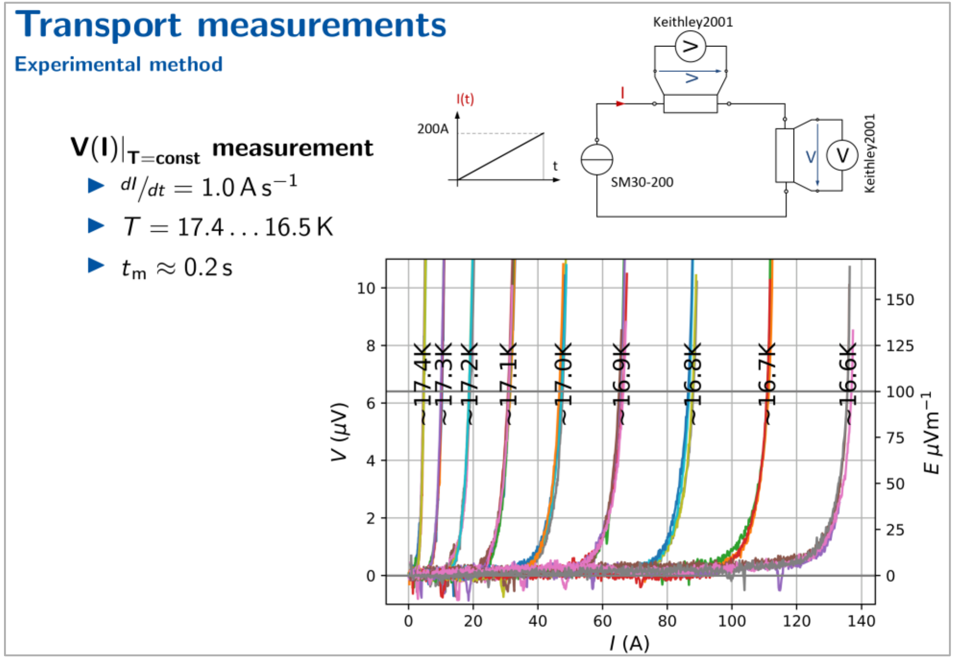
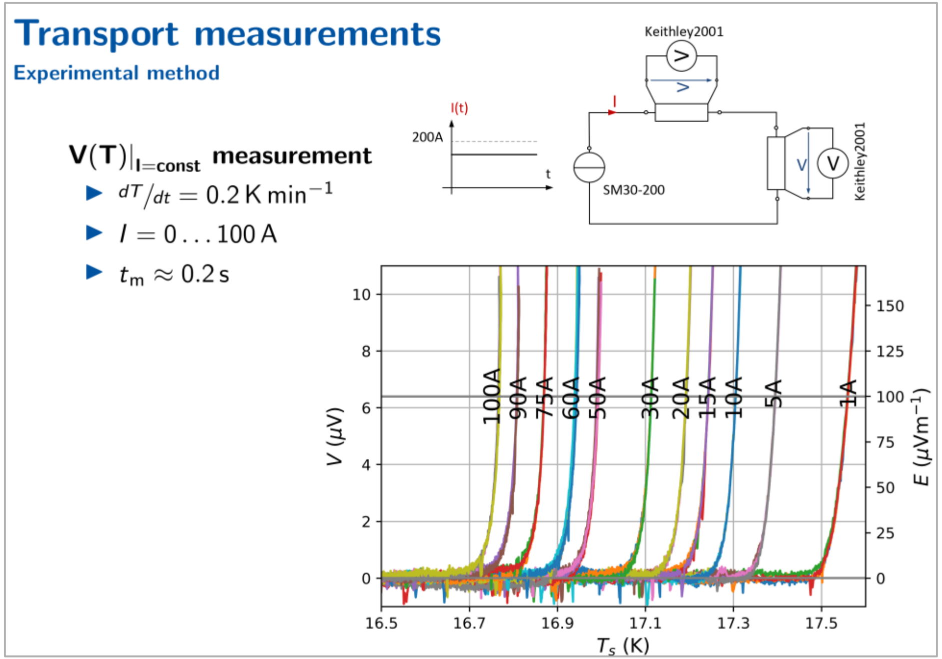


Controlled ramping T_{sample}



Courtesy: Patrick Ebermann, Irreversible degradation of superconducting Nb_3Sn wires and cables caused by transverse stress at room temperature.

A) Near Tc test stand for I_c measurement of reacted Nb_3Sn wire

Feasibility shown:

- Test near Tc (16 K-18 K) possible
- Dismountable support allowing for room temperature stress application
- Heat loads are reasonable (CL 150 A) at 50 K and 15 K
- Possible to test with a cryocooler system

Finished R&D topics:

- Near T_c characterization of Nb_3Sn wire
- HIE ISOLDE thermalisation of RF cable and coupler

HIE-ISOLDE RF cable temperature distribution

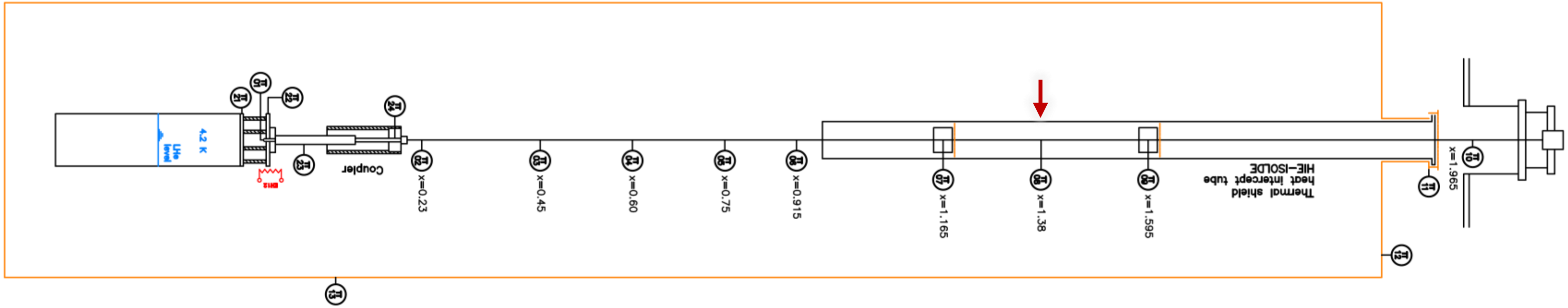
Established thermal mockup of HIE-ISOLDE semi rigid RF cable thermalisation from 293 K to 4.2 K incl. RF coupler and its antenna

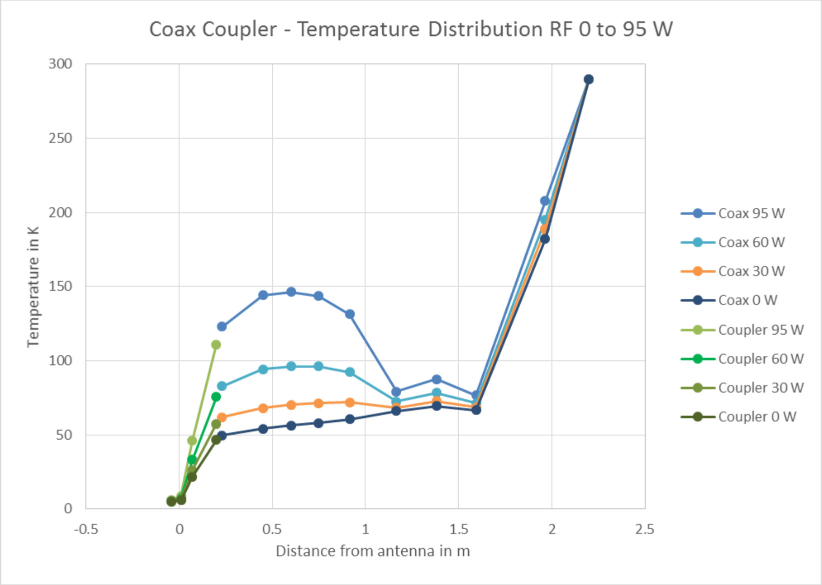
- Actively stabilized thermal shield
- 4.2 K coupler interface
- 13 Pt100 sensors at screen and RF cable
- 4 TVO at coupler and LHe reservoir
- Heat meter at the cavity interface to calibrate after RF power tests

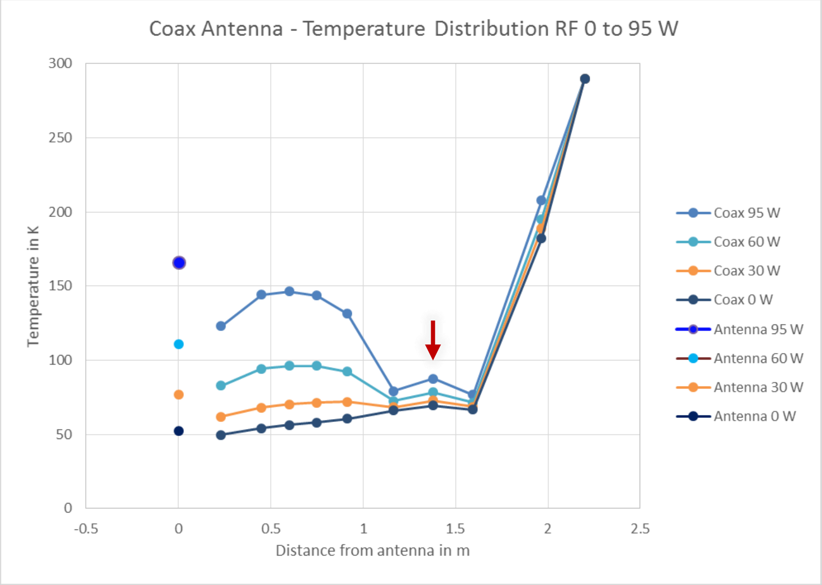
Results:
No thermal run-away observed in the tested set-up with RF power up to 95 W for 24 h
=> heat load to cavity in that case 0.8 W

Heat intercept of RF coax cable at thermal shield temperature effective, see TT8 at 1.38 m

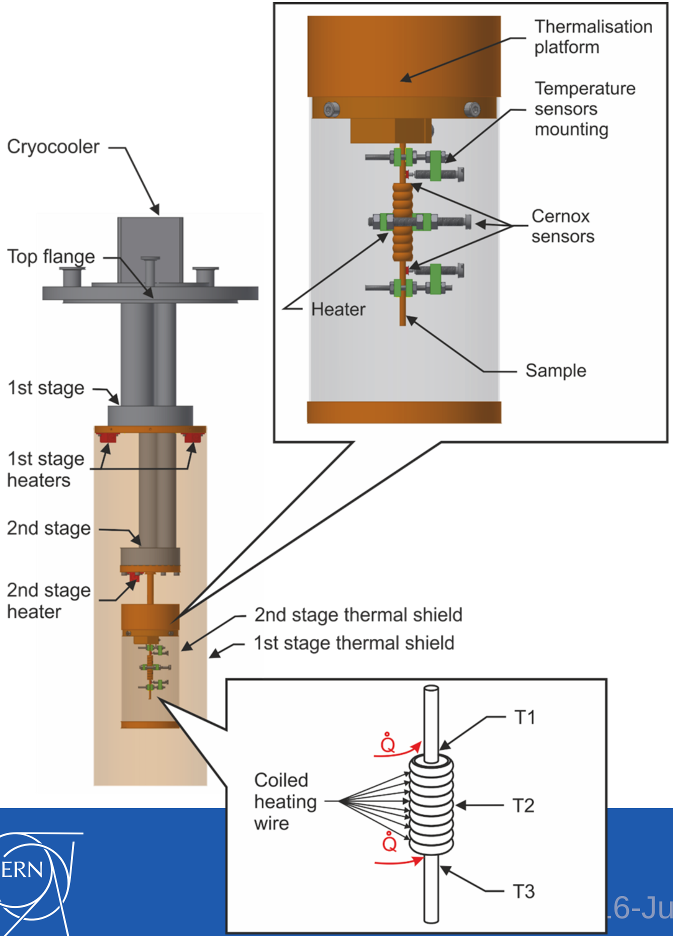
HIE-ISOLDE RF cable temperature distribution

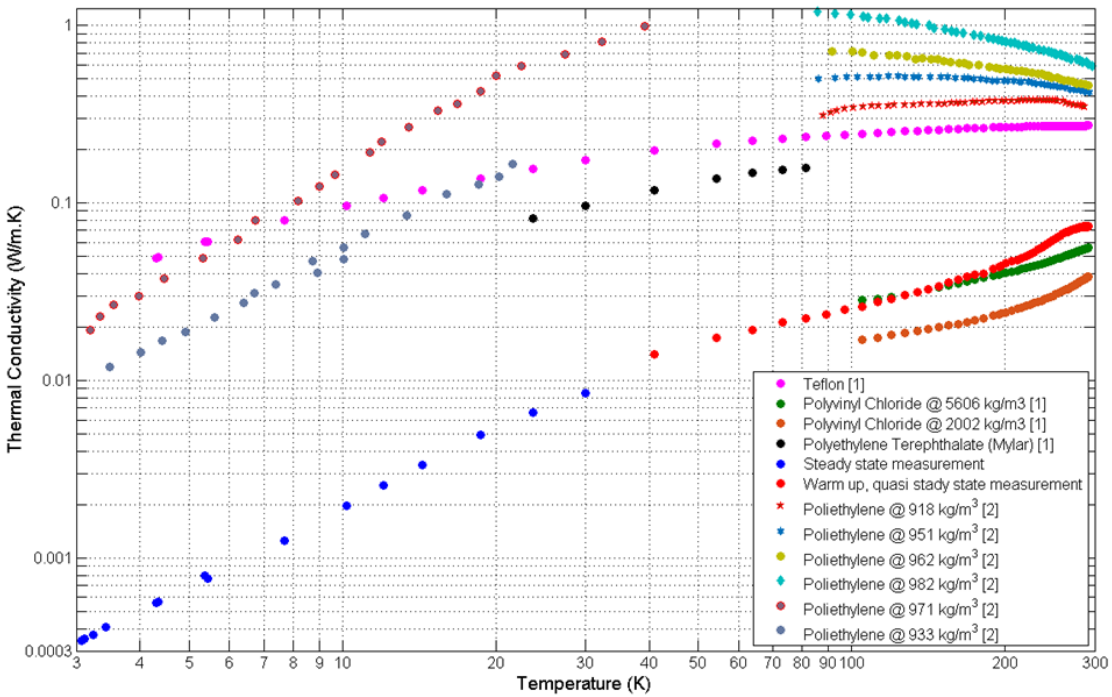






HIE-ISOLDE RF cable transverse thermal conductivity



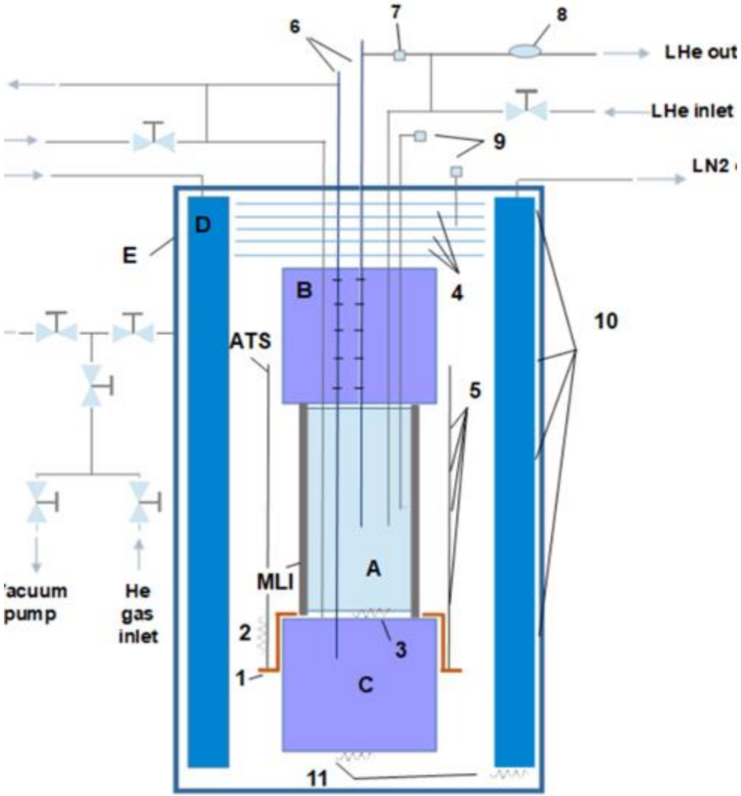


[1] http://cryogenics.nist.gov/MPropsMAY/materialproperties.htm
[2] Perepechko, Low temperature Properties of Polymers

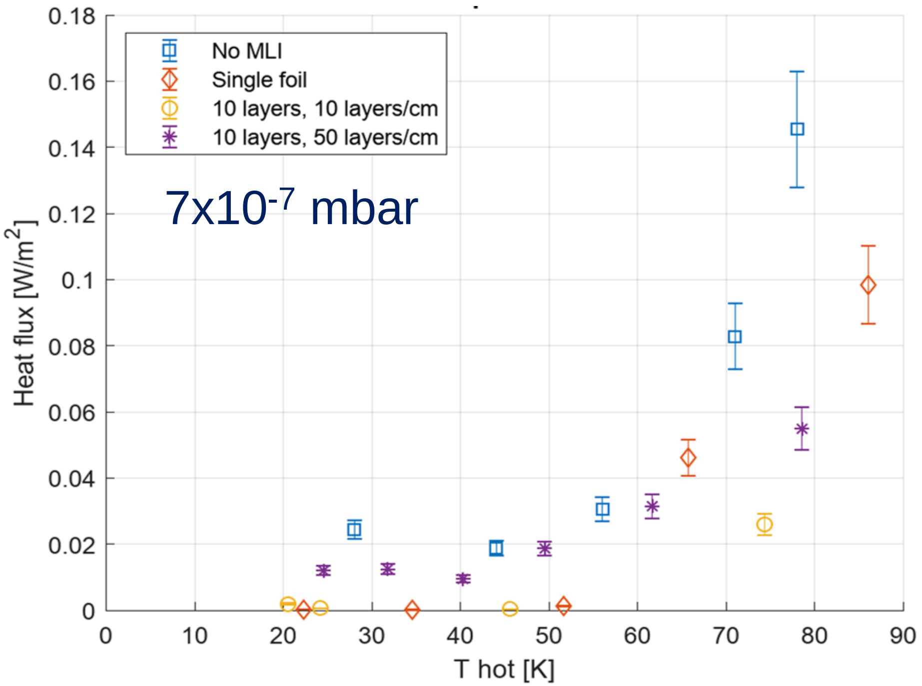
Finished R&D topics:

- Near T_c characterization of Nb_3Sn wire
- HIE ISOLDE thermalisation of RF cable and coupler
- MLI thermal performance as fct. (T_{warm} and p_{vac})

MLI performance test stand => host and support

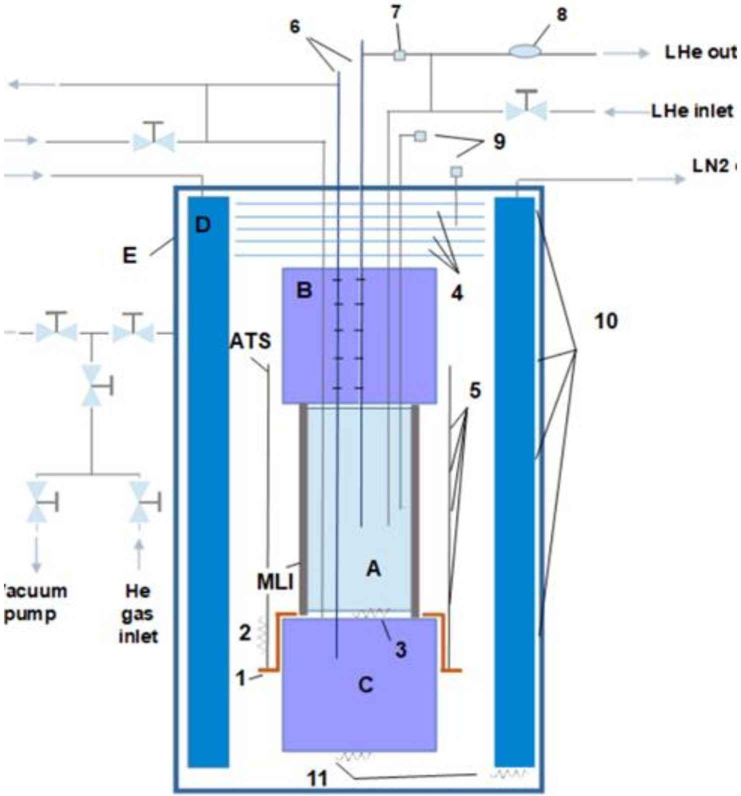


Vacuum and He degraded vacuum conditions
Different MLI configurations

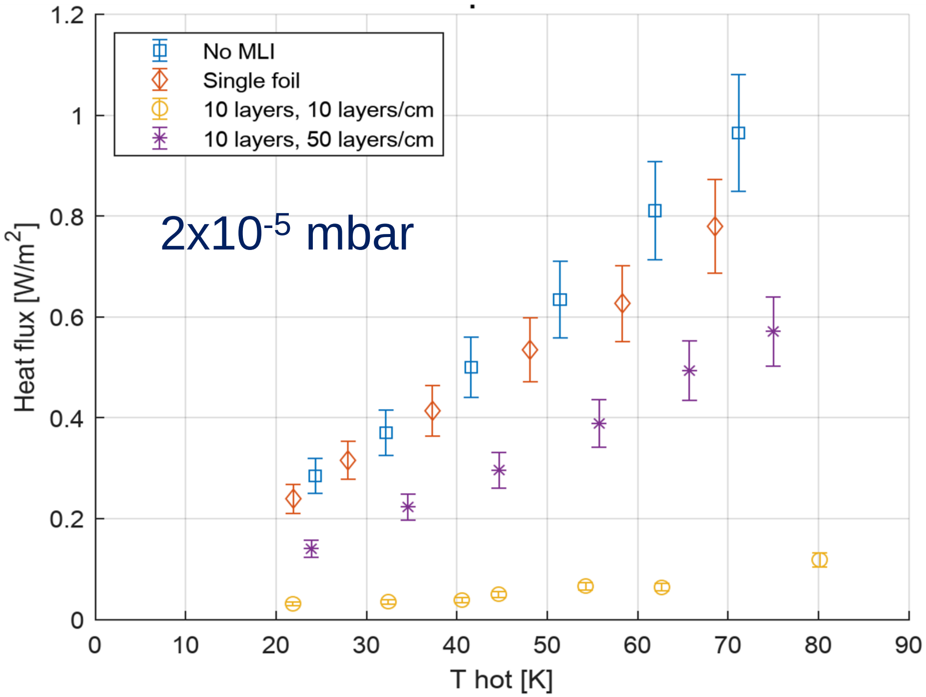


Courtesy: Valentina Venturi

MLI performance test stand => host and support



Vacuum and He degraded vacuum conditions
Different MLI configurations

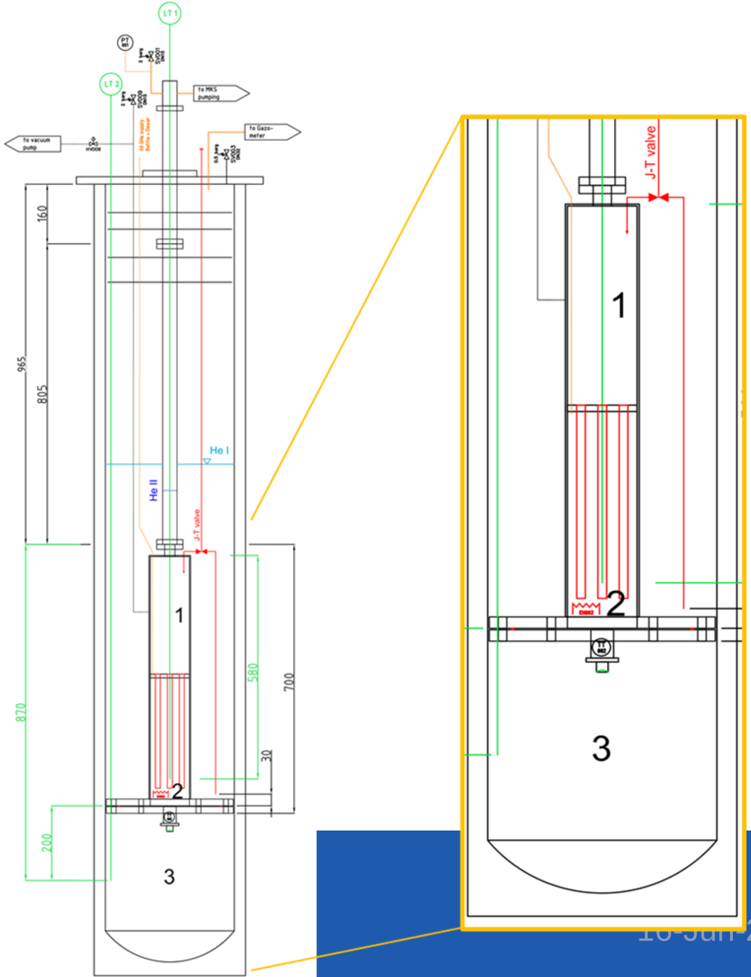


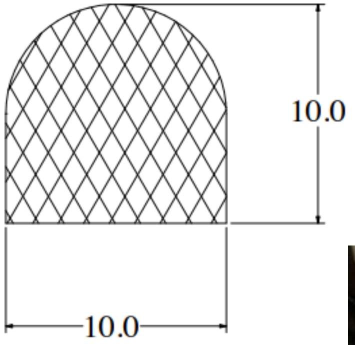
Courtesy: Valentina Venturi

Finished R&D topics:

- Near T_c characterization of Nb_3Sn wire
- HIE ISOLDE thermalisation of RF cable and coupler
- MLI thermal performance as fct. (T_{warm} and p_{vac})
- HFM Lambda plate seal – thermal heat leak

HFM lambda plate seal test - heat load He I to He II



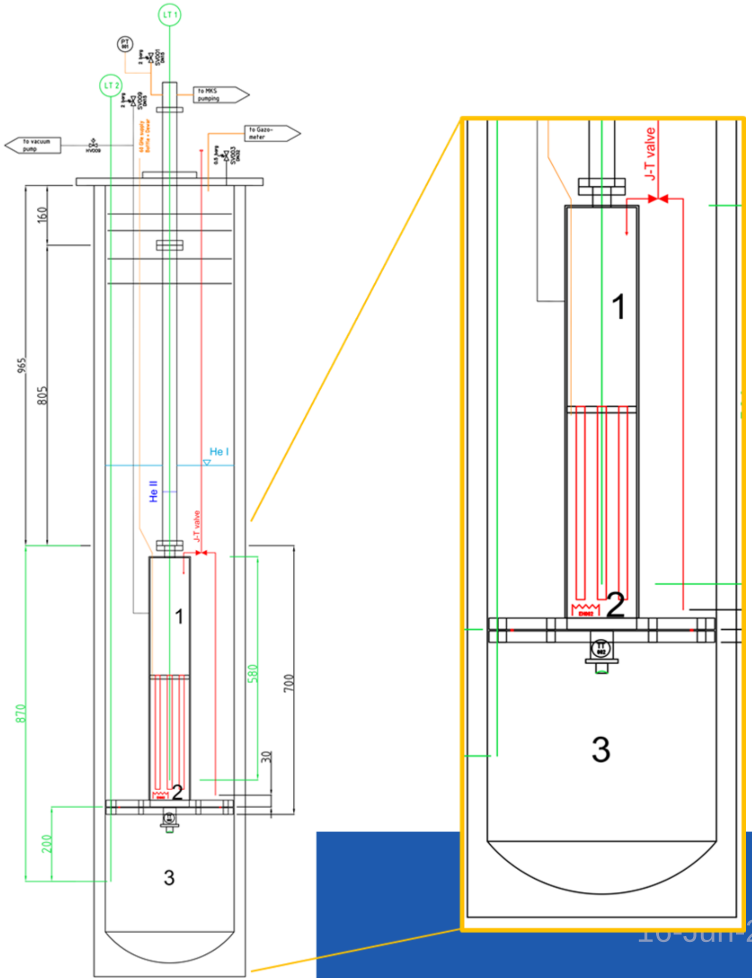


D-shape profile
silicone based
choice tested

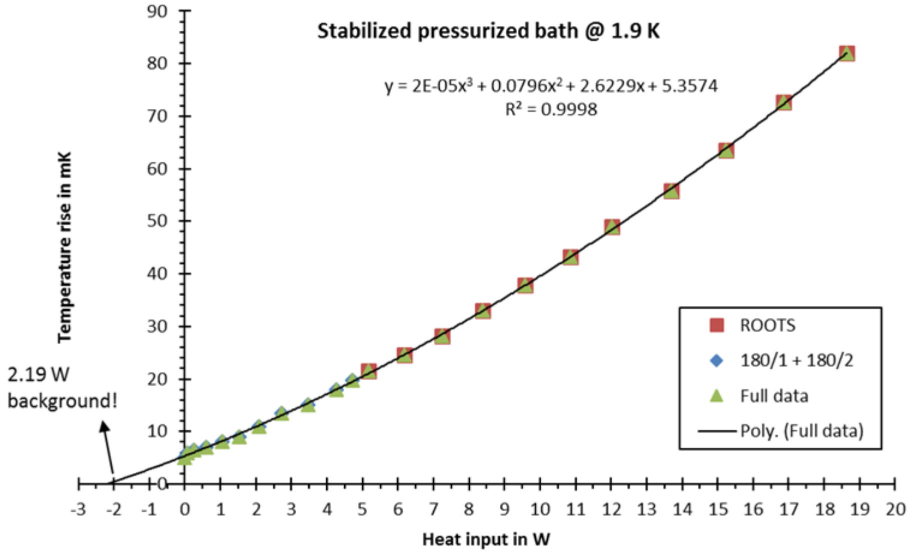
EDMS: 1845733 v.1

Arnaud van de Craen

HFM lambda plate seal test - heat load He I to He II



Heat meter calibration with Indium seal



Silicone seal showed similar results of 2 W like In

EDMS: 1845733 v.1

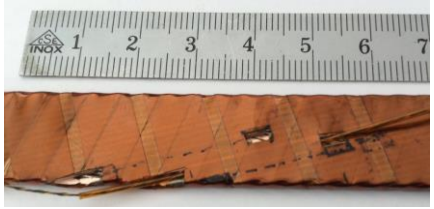
R&D topics

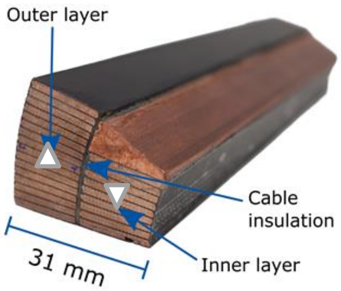
- Thermal performance of He II cooled magnet coil samples

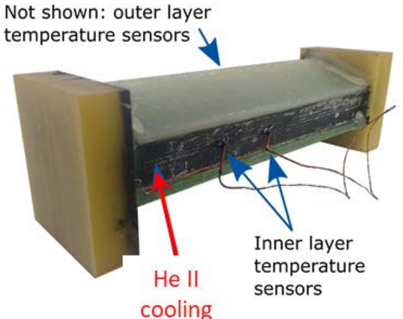
Thermal performance of He II cooled NbTi & Nb_3Sn coil samples

SC coil samples from prototype magnets are tested in pressurized He II

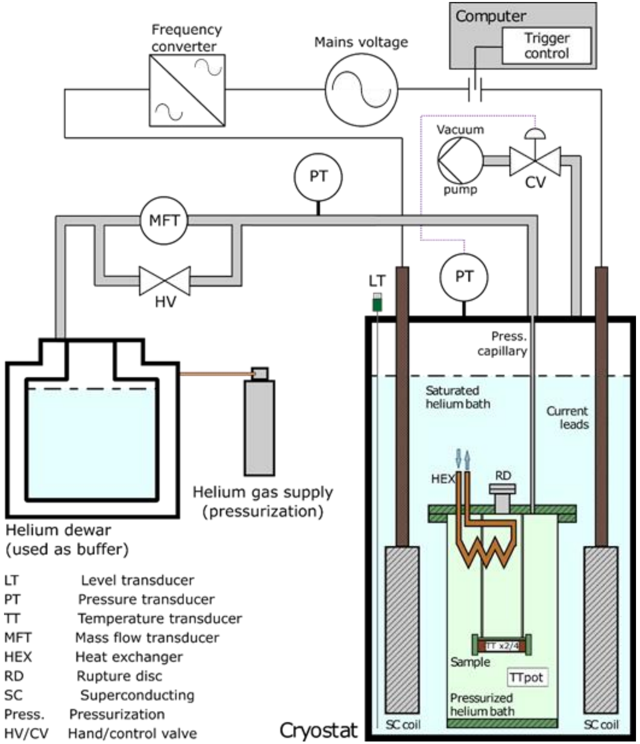
NbTi cable

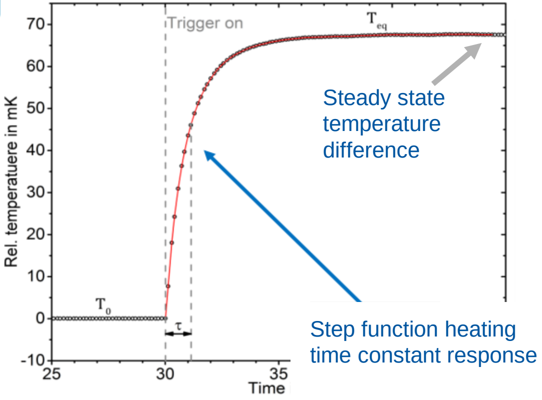






Sample: LARP 007, tested in MQXFS3
conductor type RRP108/127 => MQXF coil



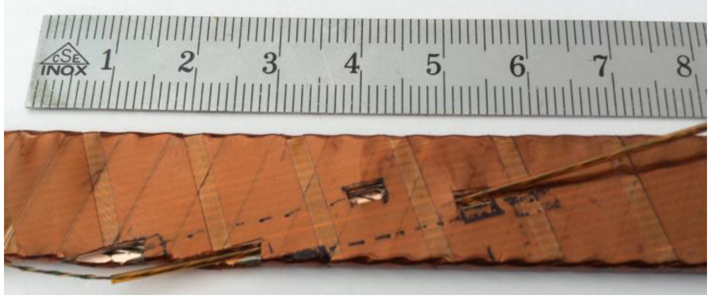


Evaluation of the step heating response:

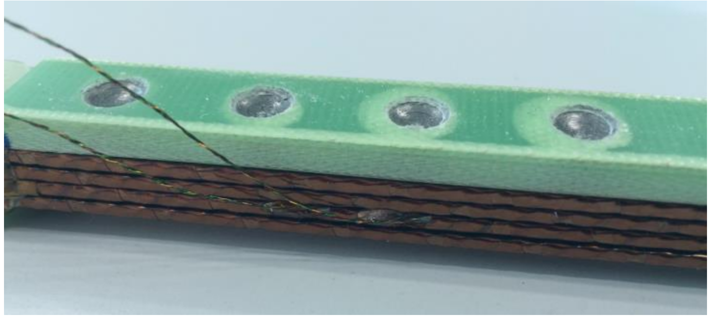
- Steady state => R_{th}
- Transient => $R_{th} \cdot C = \tau$
- Num. simulations

Courtesy: Rob van Weelderen, Tiemo Winkler, Mario Grosso, Kirtana Puthran, Lise Eder Murberg

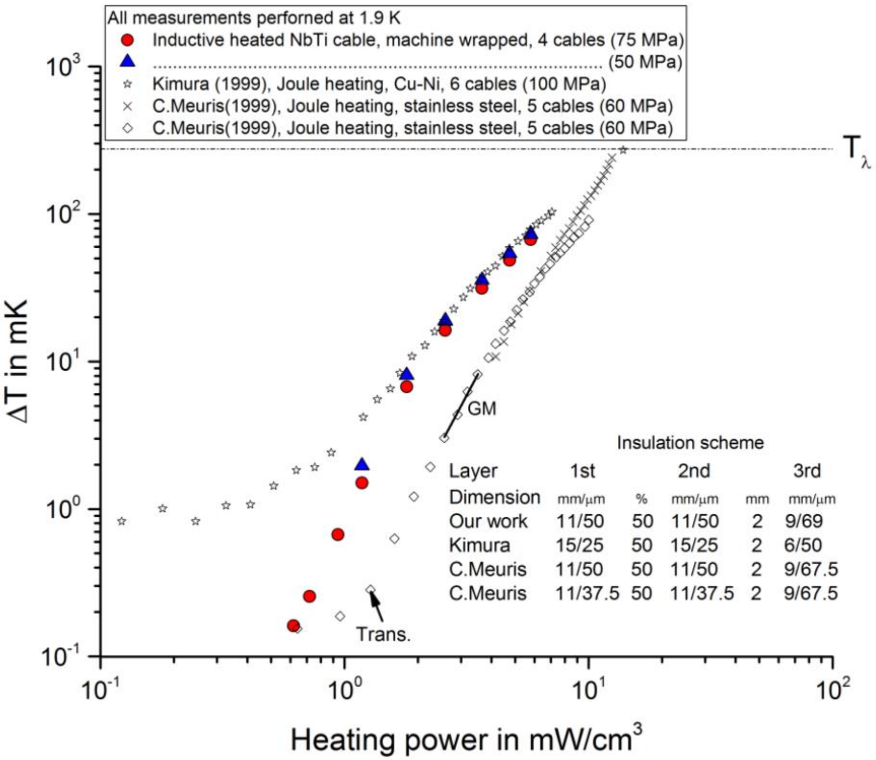
Thermal performance of He II cooled NbTi coil-pack samples



Original machine wrapped cable
Instrumentation in removed strand



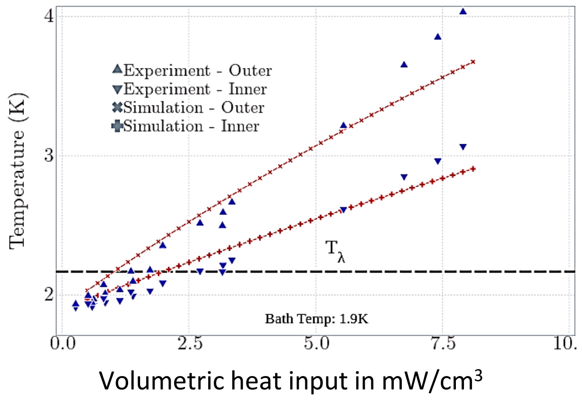
Mechanical compression of 50 and 75 MPa



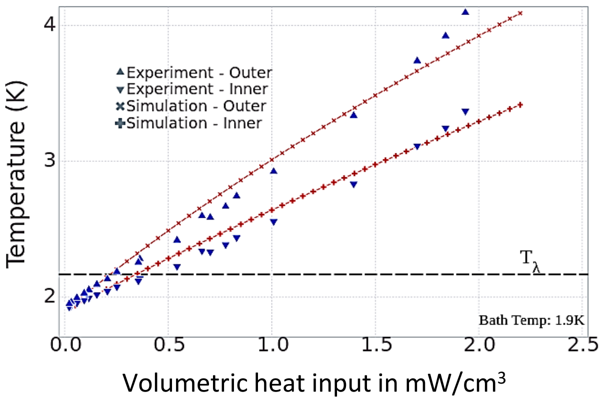
Courtesy: Tiemo Winkler, Jens Schundelmeier Rob van Weelderen

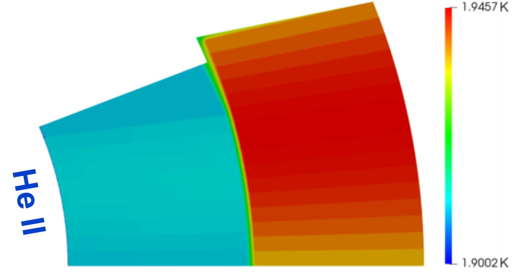
Thermal performance of He II cooled Nb_3Sn coil samples

Steady state temp. **D11 T** sample

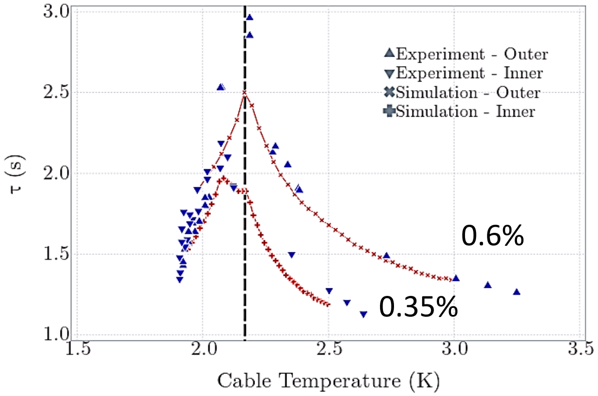


Steady state temp. **MQXF** sample

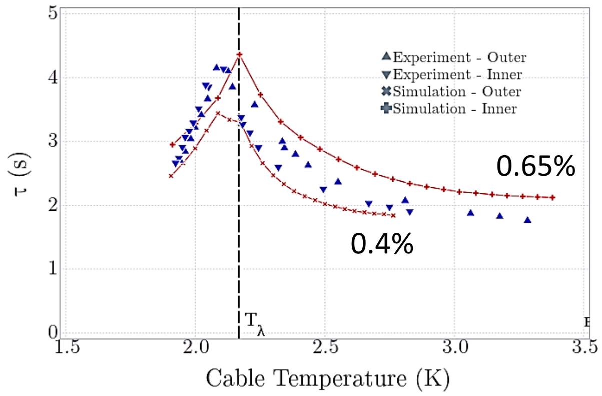




Time constant **D11 T** sample



Time constant **MQXF** sample



- Predicted He porosity 0.35-0.65% in the sample
- Sample preparation for new D11T in progress (latest design)
- To approach predicted operational heat loads on the magnets.

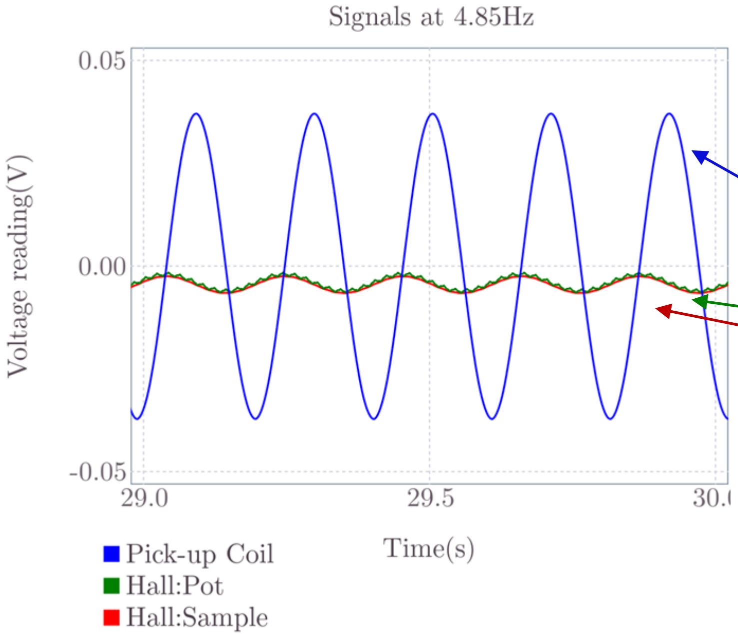
a) Exploring thermal behaviour at higher heat loads by using an external heater and/or

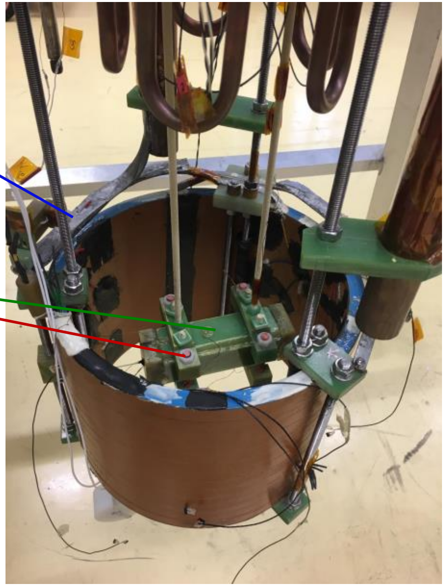
b) Variable frequency current source ν< 50 Hz

Courtesy: Rob van Weelderen, Tiemo Winkler, Mario Grosso, Kirtana Puthran, Lise Eder Murberg

Thermal performance of He II cooled Nb_3Sn coil samples

Effect of magnetic field penetration and frequency dependency of the AC magnetic field.





Courtesy: Rob van Weelderen, Kirtana Puthran, Lise Eder Murberg

Thermal performance of He II cooled Nb_3Sn coil samples

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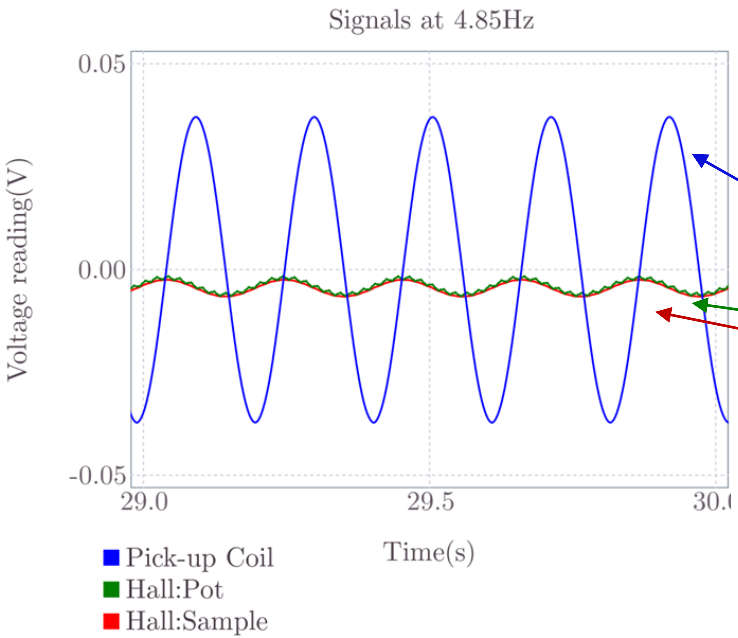

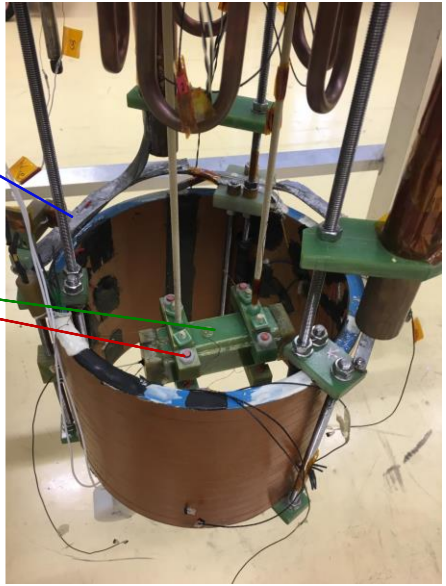

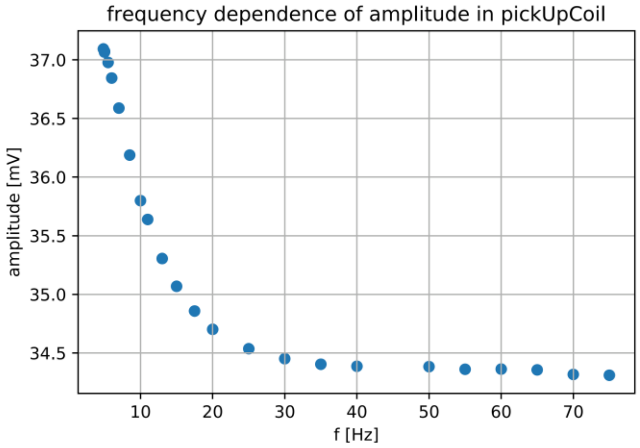

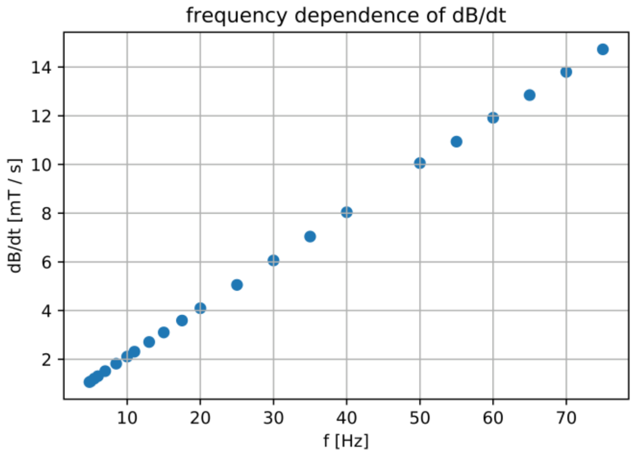

Courtesy: Rob van Weelderen, Kirtana Puthran, Lise Eder Murberg

Thermal performance of He II cooled Nb_3Sn coil samples

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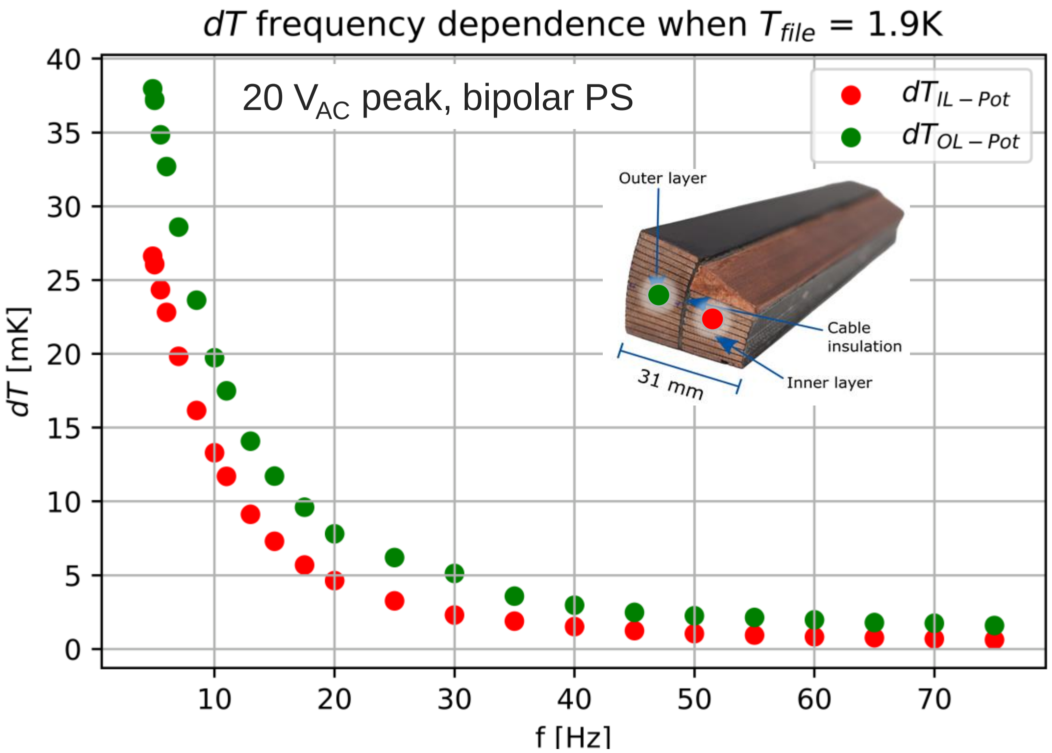
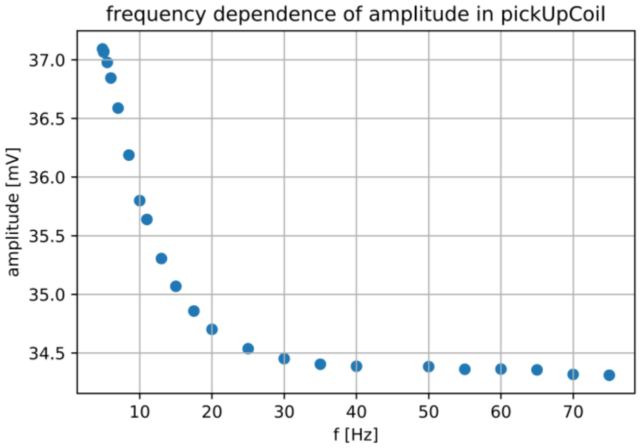
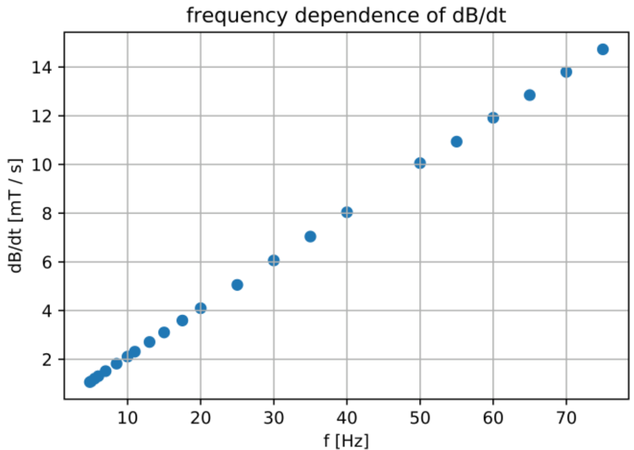






Courtesy: Rob van Weelderen, Kirtana Puthran, Lise Eder Murberg

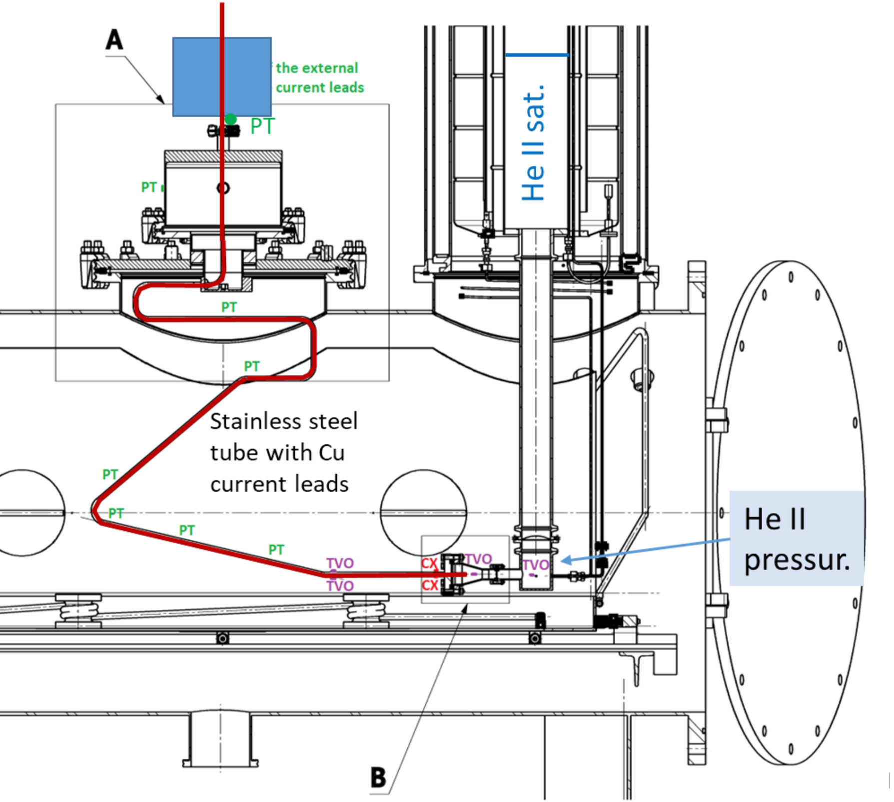
R&D topics

- Thermal performance of He II cooled magnet coil samples
- Thermal performance of HL-LHC Inner Triplet Current Feeders

Thermal validation: HL-LHC Inner Triplet Current Feeders

- Mock-up measurement setup
- K-mod configuration
- 2 x 10mm^2 Cu cable (Kapton insulated in stainless steel tubes)
- Equivalent thermal path like in HL-LHC
- Thermal performance validation
  - Temperature feedthroughs to outside
  - Heat load to 1.9 K pressurized bath
  - Cooldown behavior and thermal stability

Thermal validation: HL-LHC Inner Triplet Current Feeders



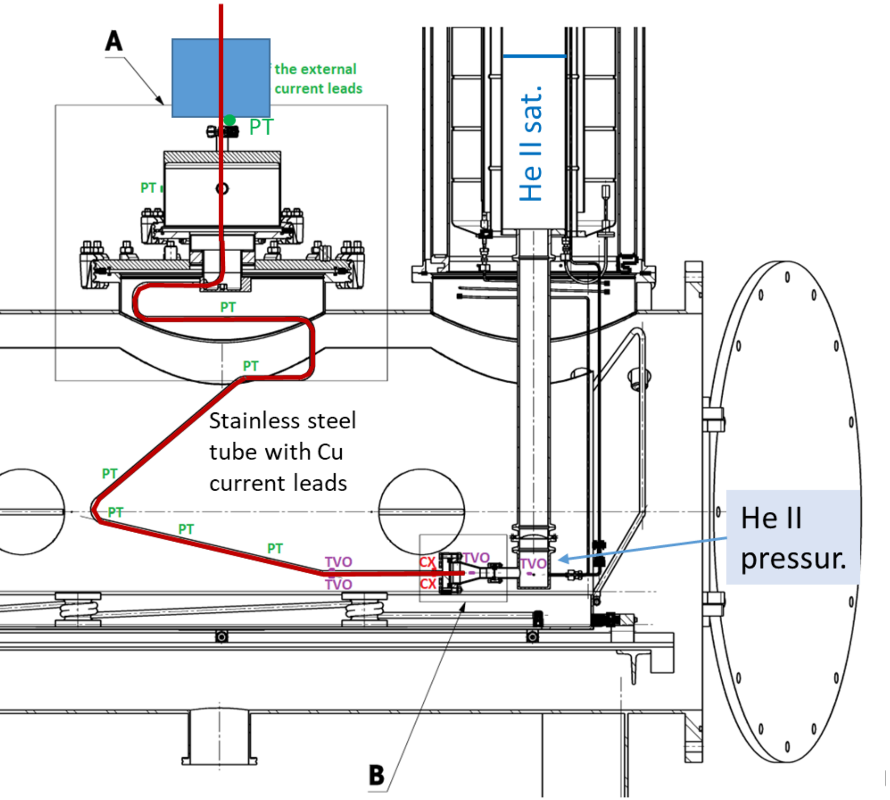
- Mockup of electric current feeders 35 A_{AC}
- Equivalent thermal path like in the application => K-mod
- Feeder connection from room temperature flange directly to He II bath.

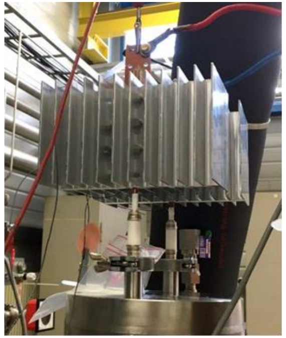
Goals:

- Feedthrough temperature
- Temperature profile
- Thermal stability
- Heat inleak into 1.9 K LHe
- Electrical tests with CERN colleagues

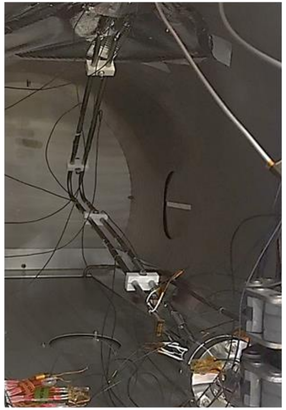
Courtesy: Joanna Liberadzka

Thermal validation: HL-LHC Inner Triplet Current Feeders





Detail **A**, warm feedthrough



Detail **B**, double feeder

Results

Warm end temperatures with and w/o HX and electrical current 25 A DC:

Case	Air temp [K]	Avg. lead temp [K]	T difference [K]
No HX 0 A	292.78	291.74	**-1.04 ± 0.03**
No HX 25 A	291.71	292.78	**1.07 ± 0.03**
HX 0 A	292.76	292.60	**-0.16 ± 0.03**
HX 25 A	293.05	293.56	**0.51 ± 0.03**

dT is important for dew point in the LHC tunnel air

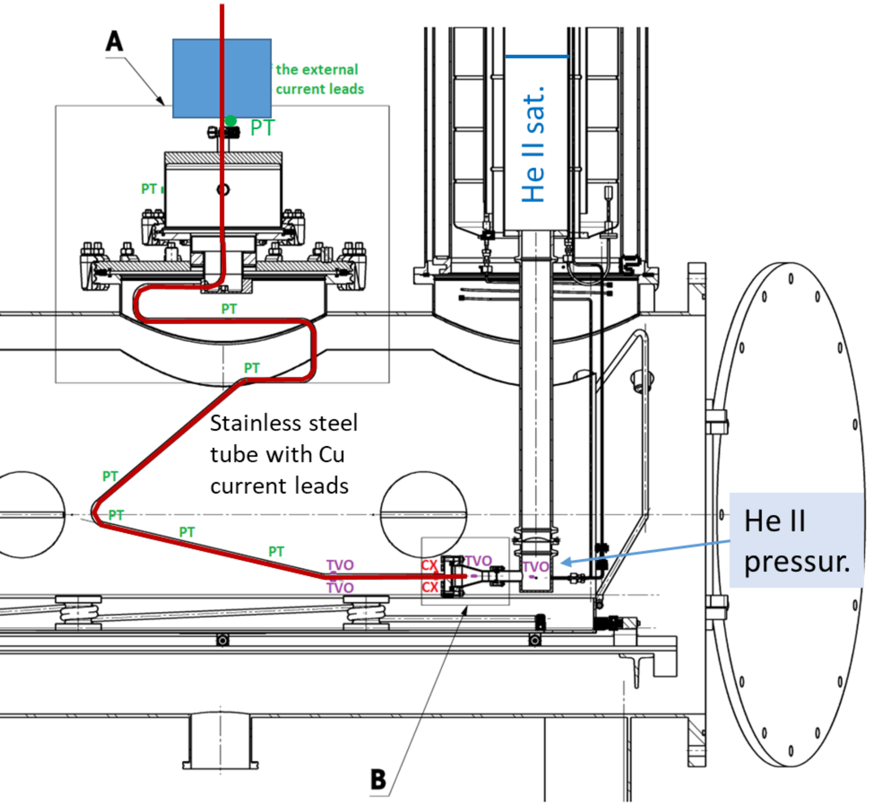
Heat input to the He II system (2 leads):

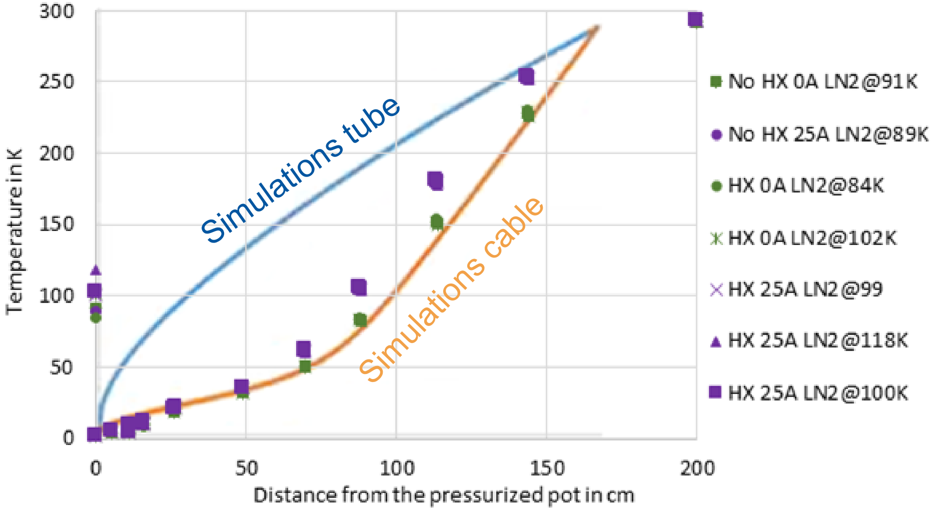
Configuration	Total heat input [W]
HX 0 A	**2.39 ± 0.07**
HX 25 A	**2.60 ± 0.07**

Simulation expected Q=1.9 W

Courtesy: Joanna Liberadzka

Thermal validation: HL-LHC Inner Triplet Current Feeders





Courtesy: Joanna Liberadzka

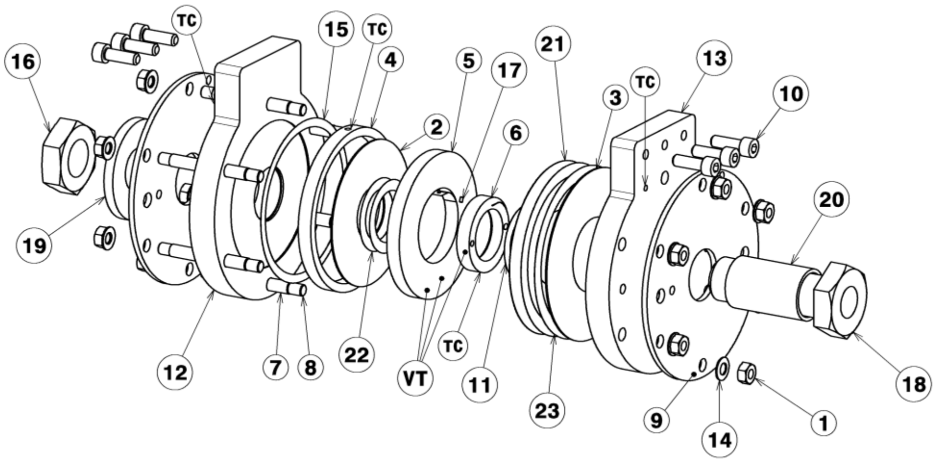
TE/MPE-EE: Electrical tests with pulses up to 7 kA were successful in the Cryolab setup, see EDMS: 2332911 v.1

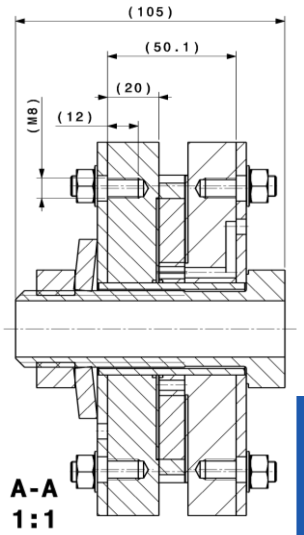
R&D topics

- Thermal performance of He II cooled magnet coil samples
- Thermal performance of HL-LHC Inner Triplet Current Feeders
- HTS small coil test

Variable temperature cryostat setup for HTS small test coils

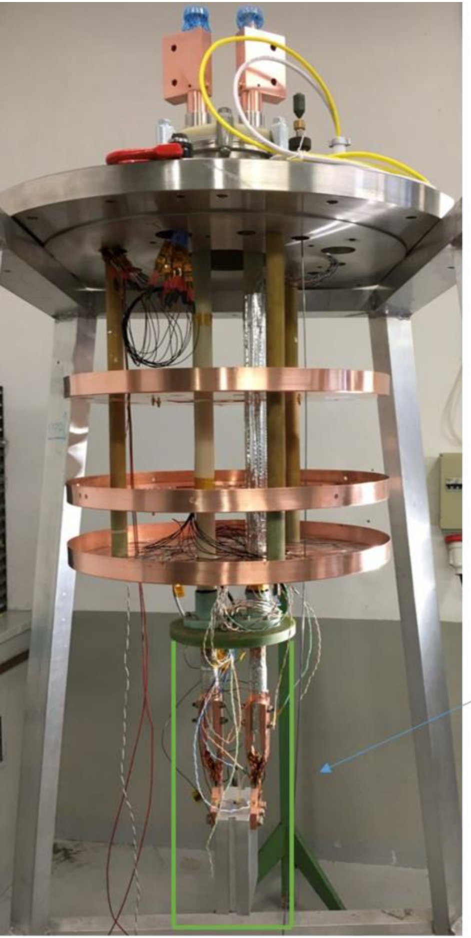
- Test stand to determine the performance of novel HTS solenoids
- Non-metallic cryostat insert
- Operating temperatures at 4.2 K, 20 K … 80 K => LN_2 or LHe or He vapor
- Long ramp duration (stable for up to 6 h)
- 2 kA current leads => in-house build to fit the gas cooling insulated loop
- Vehicle for MSC to test new technologies (like partial or non-insulated coils)

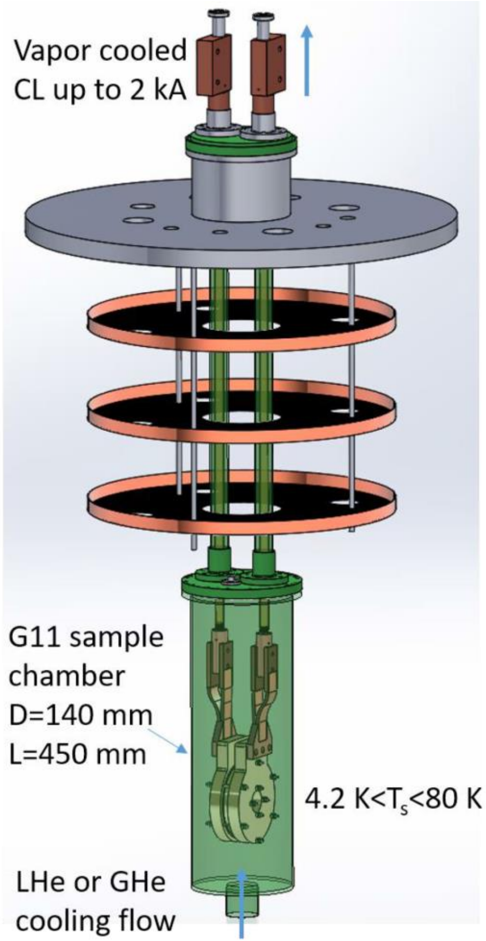




Drawings courtesy: D. Schoerling

Vapor cooled non-magnetic cryostat setup, 2 kA current leads





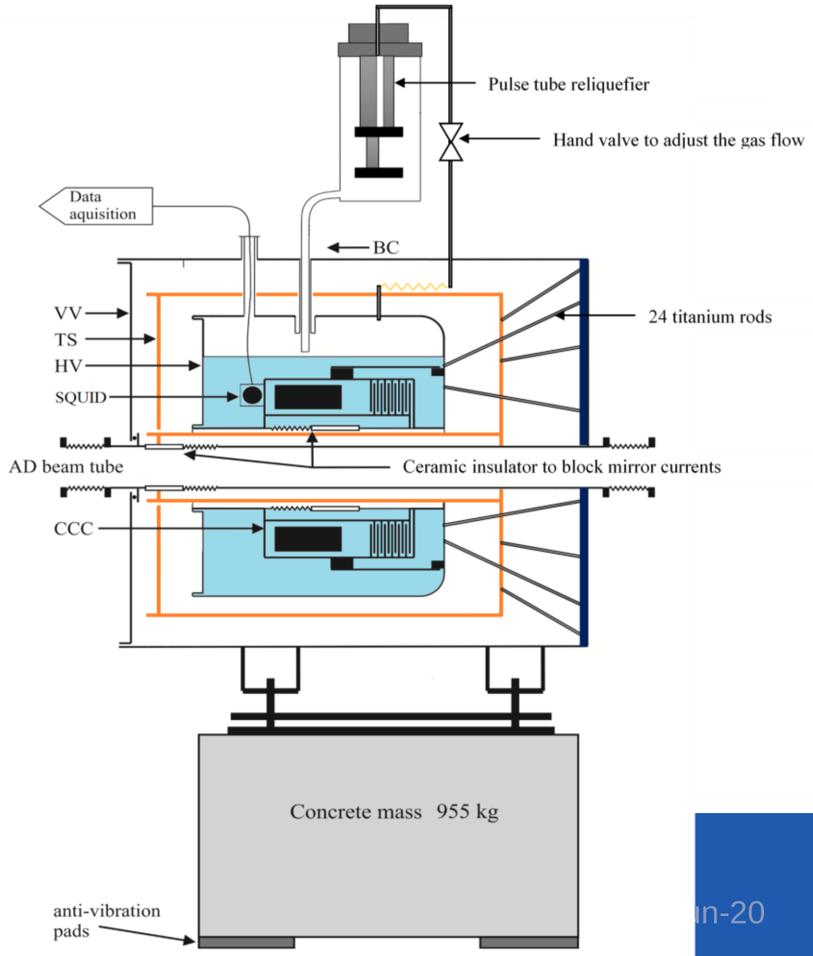
- Test of small HTS coils
- Controlled inter-turn resistance
- Temperature steps 4.2 K < T< 80 K
- Adapted current leads for max. 2 kA
- Fully non magnetic insert (Quench)
- Glass epoxy chamber with temperature stabilization for several hours
- Cryo system is commissioned

Courtesy: Joanna Liberadzka

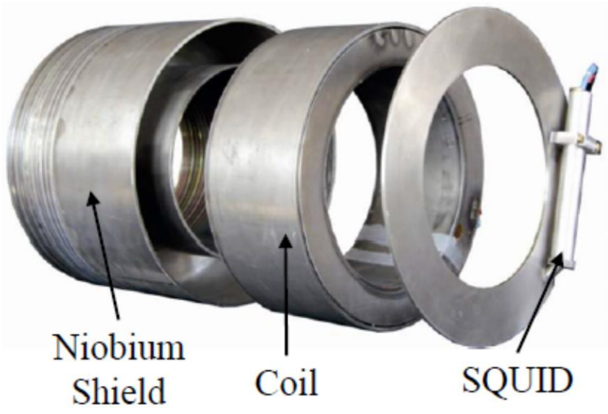
R&D - possibly interesting for MSC

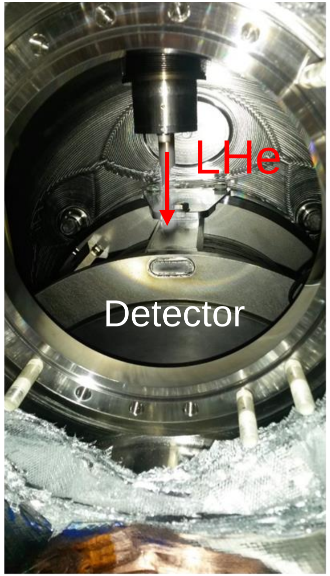
- Remote cooling with He fluid circuits

LHe zero boil off cryostat for the Antimatter Factory (BCCCA)



Detector with SC shield and SQUID sensor measuring the antiproton beam current.

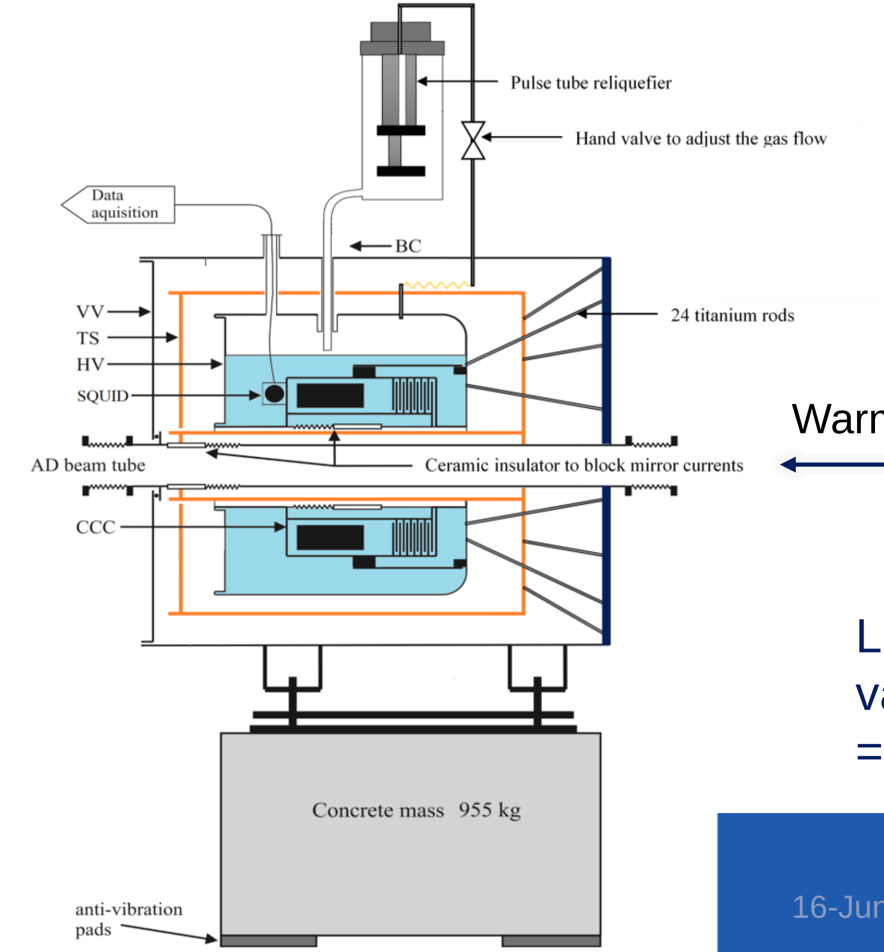




Inner vessel

Courtesy: Miguel Abreu Fernandez, Jocelyn Tan, Andrew Lees

LHe zero boil off cryostat for the Antimatter Factory (BCCCA)



- Stand alone cryo system
- Complex design with ceramic breaks
- Q<1.2 W available cooling power

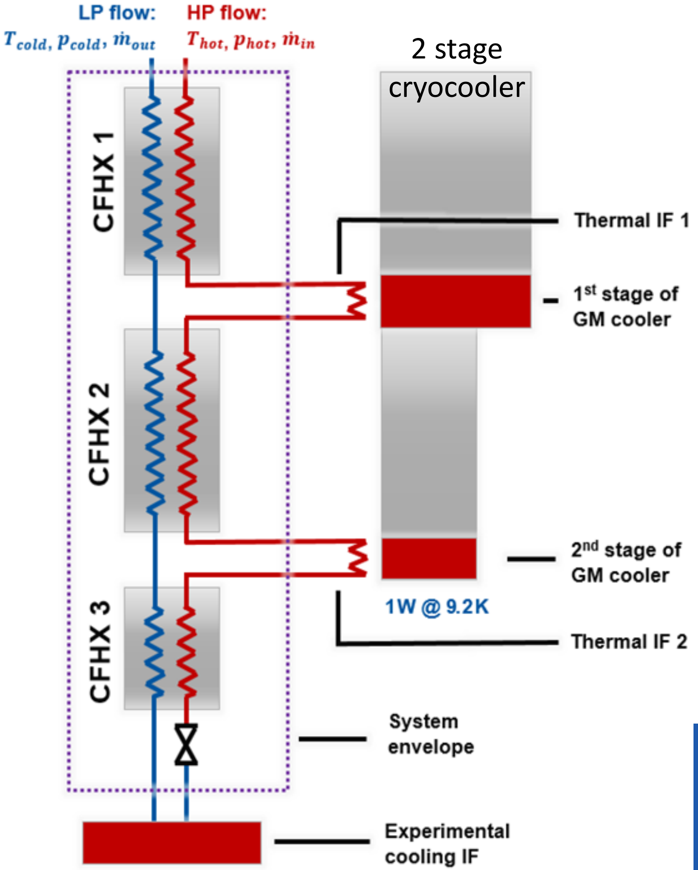
Warm bore cryostat for Antiproton beam pipe

Low values of: vibration, dT and magnetic field variations are crucial
=> paved the way to remote cooling circuit R&D

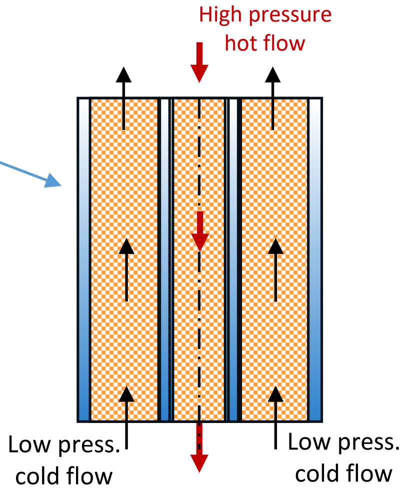
Courtesy: Miguel Abreu Fernandez, Jocelyn Tan, Andrew Lees

Helium remote cooling circuit R&D

Research goal: Protect the experiment from cryocooler influences (vibration/mag. disturbance) or separate the cryocooler from harsh environment (radiation/mag. field).



- Novel HEX design
- Enhanced tube in tube geometry
- Highly compact geometry
- High effectiveness of the HEXs is key for system performance
- Design code
- Adaptable to various applications



Results:

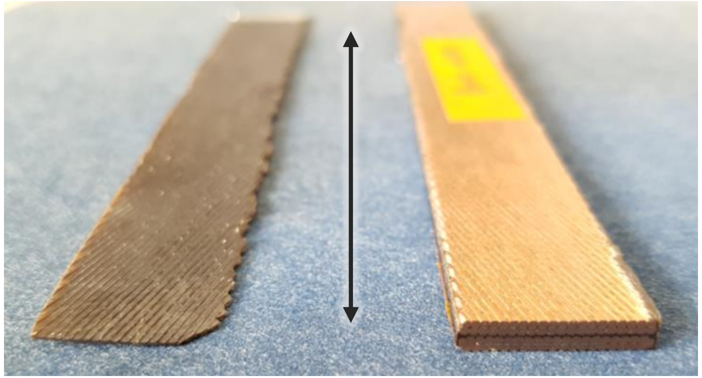
- Performance is tested in between 293 K to 50 K,
- CFHEX 1 achieved 94.6 % overall effectiveness, which will enable an increased cooling performance of the circulation loop compared to the cryocooler alone.

Courtesy: Aleksandra Onufrena

New / further topics

- Thermal conductivity of coil impregnation and a double Rutherford cable with one impregnation layer axial direction:

MQXF impregnation and a double cable structure



- Emissivity of materials at $T \leq 4$ K

- Vacuum break at non-standard geometries and higher than 4 K temperatures

Summary

- Capabilities of the Cryolab and its personnel for tests and projects,
- R&D in the range between 25 mK to 1.5 K to room temperature,
- Staff is guiding the young generation of scientist and engineers in their projects
- Our work is free of charge
- We are interested to participate in the R&D of MSC
- Goal is to further improve our testing capabilities and perform R&D together with you

Cryolab capabilities document: https://edms.cern.ch/document/2384399/1