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Michal Duda, Carolin Zoller :: Magnet Section :: Paul Scherrer Institute

Test stand for superconducting magnets cooled with cryocoolers and development of cryogenic PHP at PSI

4th Superconducting Magnet Test Facility Workshop

25/04/2023

Outline

- Introduction PSI, Magnet Section and CHART
- Cryogen Free Test stand WNLA/010
- Cold tests results
- Planned upgrade
- Upcoming projects

Michal

Carolin

Paul Scherrer Institute (PSI)

- Largest research institute for natural and engineering sciences within Switzerland
- Three main fields of research: matter and materials, energy and the environment and human health
- Develops, builds and operates complex large research facilities
- Employs 2100 people
- ~2500 visiting scientists using facilities for experiments
- Part of the ETH Domain that also includes ETH Zurich and EPFL Lausanne
- Financed by the federal Government

Paul Scherrer Institute (PSI)

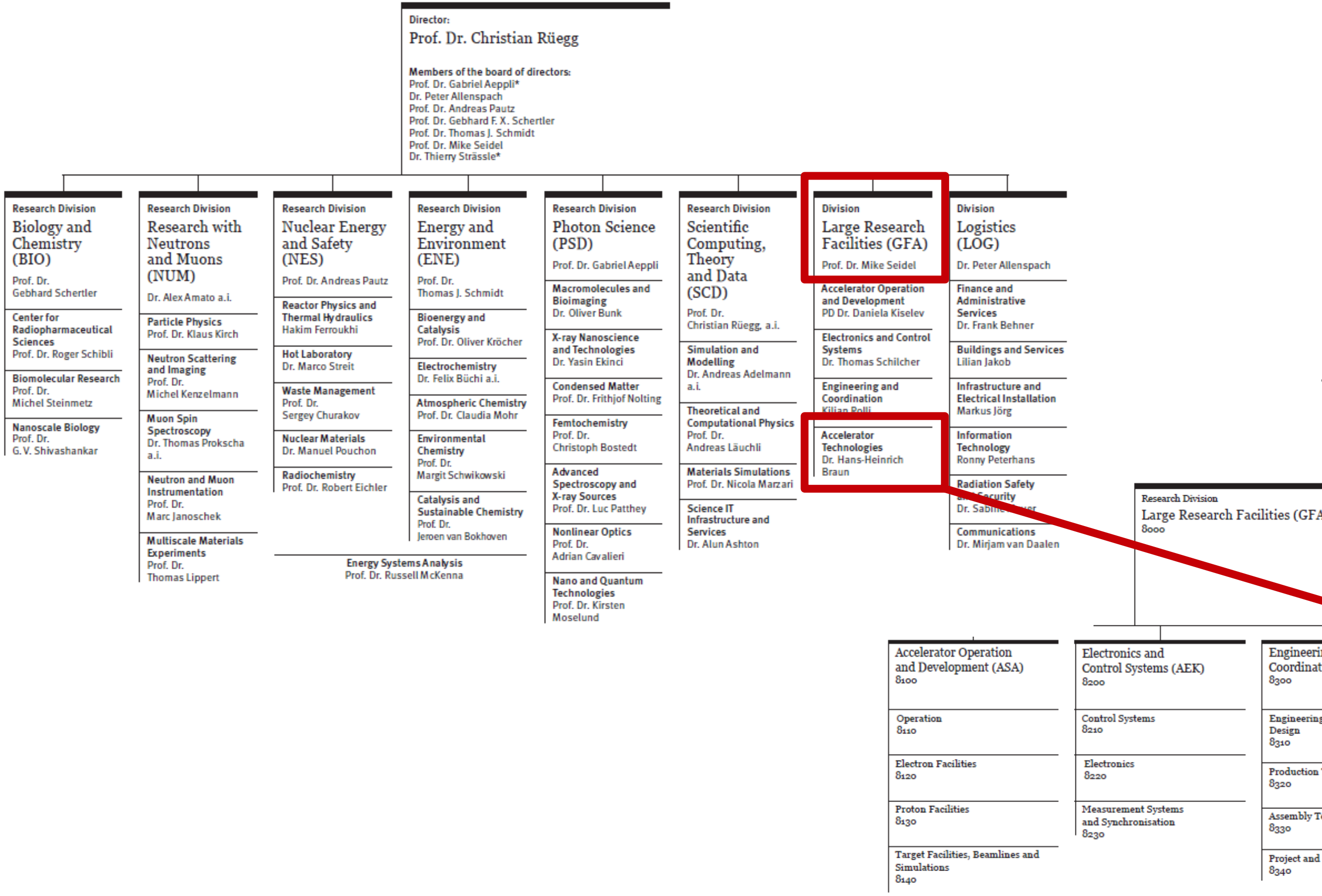
← Basel   Germany ↑   Aarau/Bern ↓   Zurich →

Magnet section at PSI

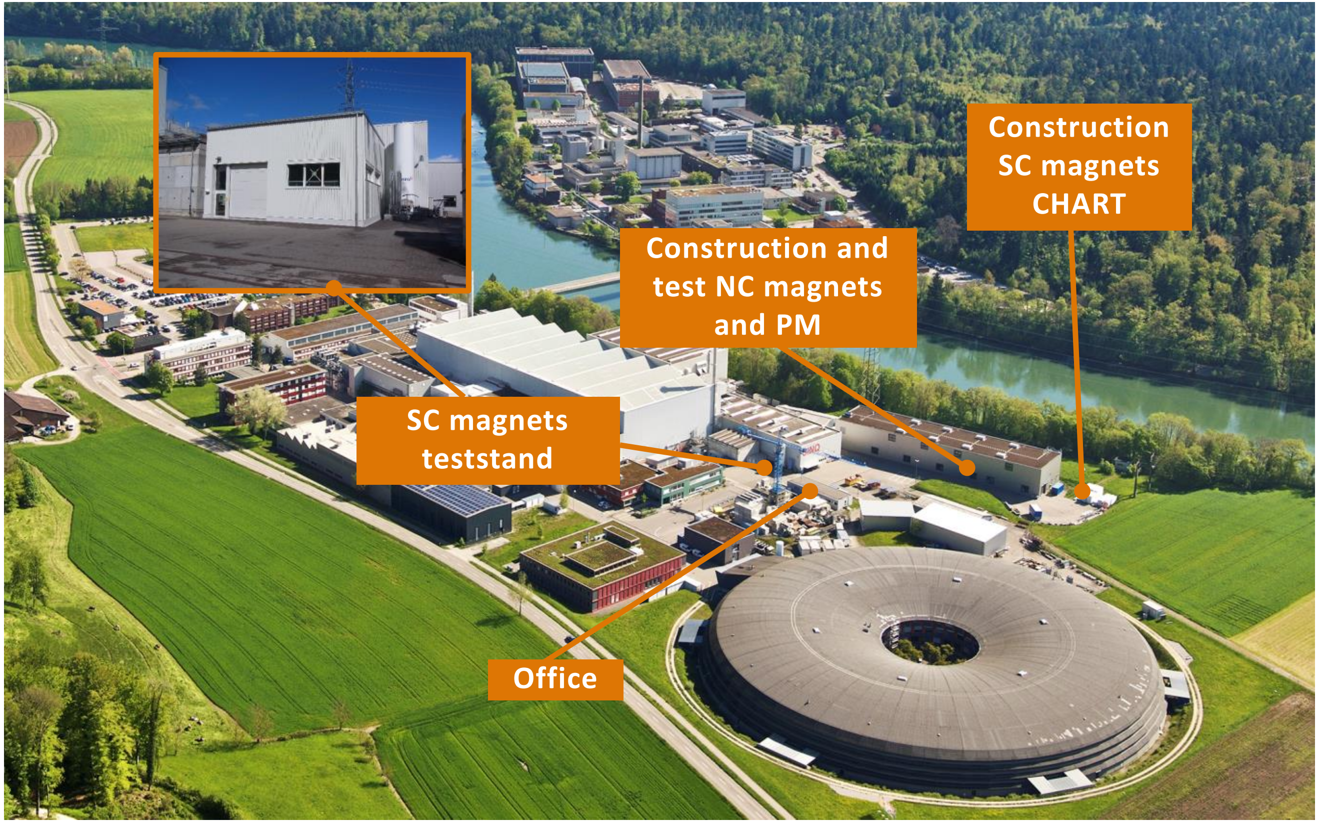
Stéphane Sanfilippo

head of the Magnet Section

23 section members



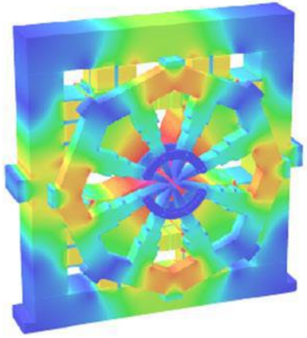
Magnet infrastructure at PSI



Magnet section activities

- activities centered around the magnets (PM, EM, SC) needed for existing and planned accelerator facilities at PSI
- magnetic and mechanical design, the construction, procurement and/or assembly of the magnets
- qualify the magnetic specifications with measurements and data analysis
- maintain and repair existing magnet assemblies at PSI
- maintain and develop magnetic measurement systems
- promote collaboration and support in our field of expertise

Construction and test EM and PM



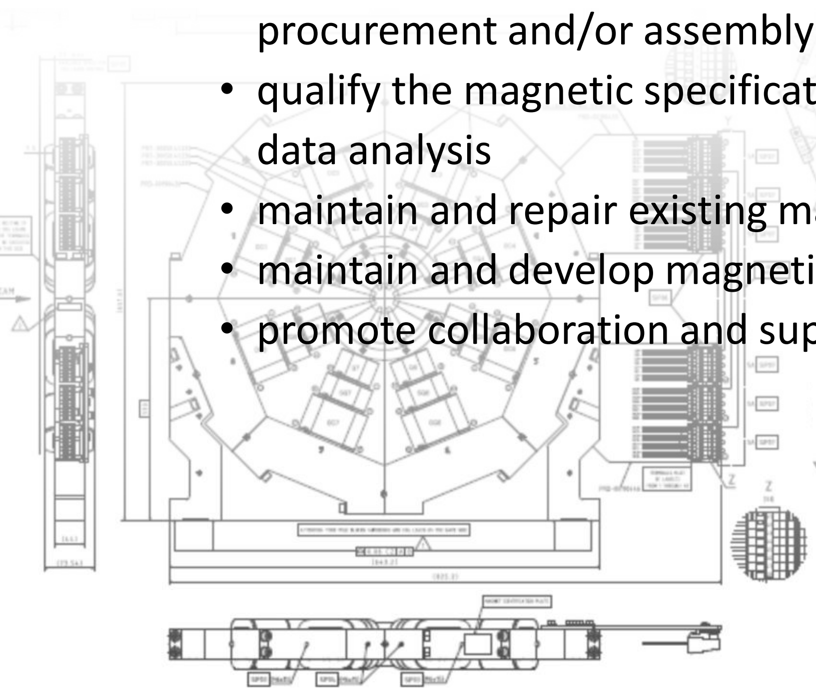


CHART @ PSI

"Swiss Accelerator Research and Technology – CHART" is a Swiss research network with PSI as a host institute and CERN, EPFL, ETHZ, and UniGE as additional members (http://chart.ch)

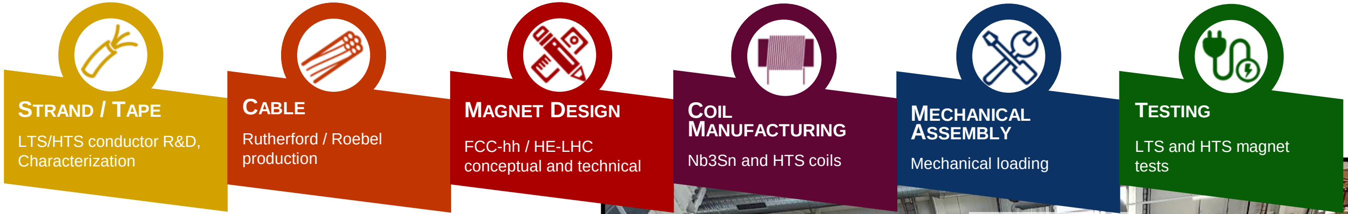
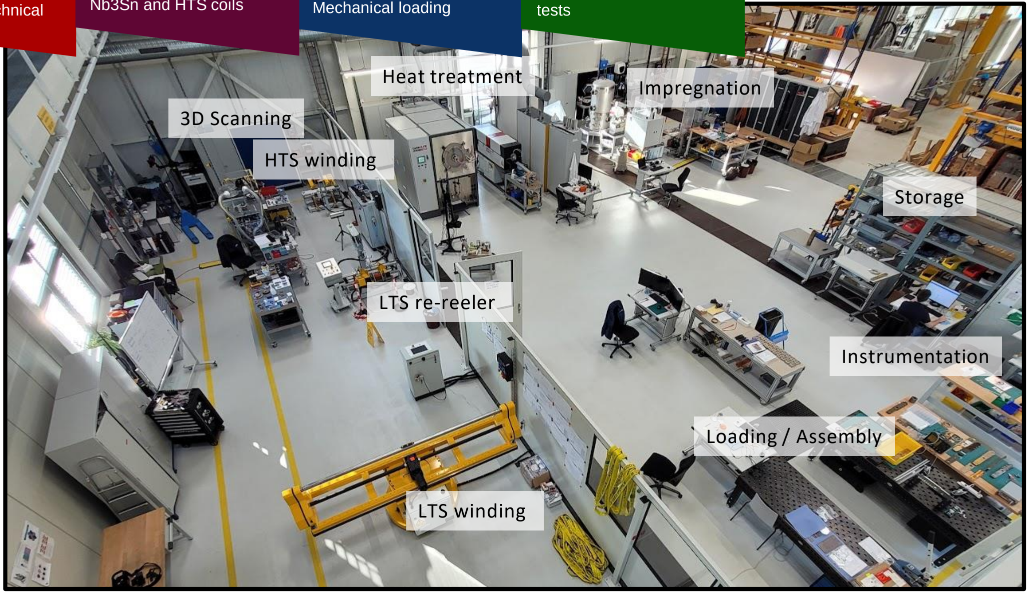
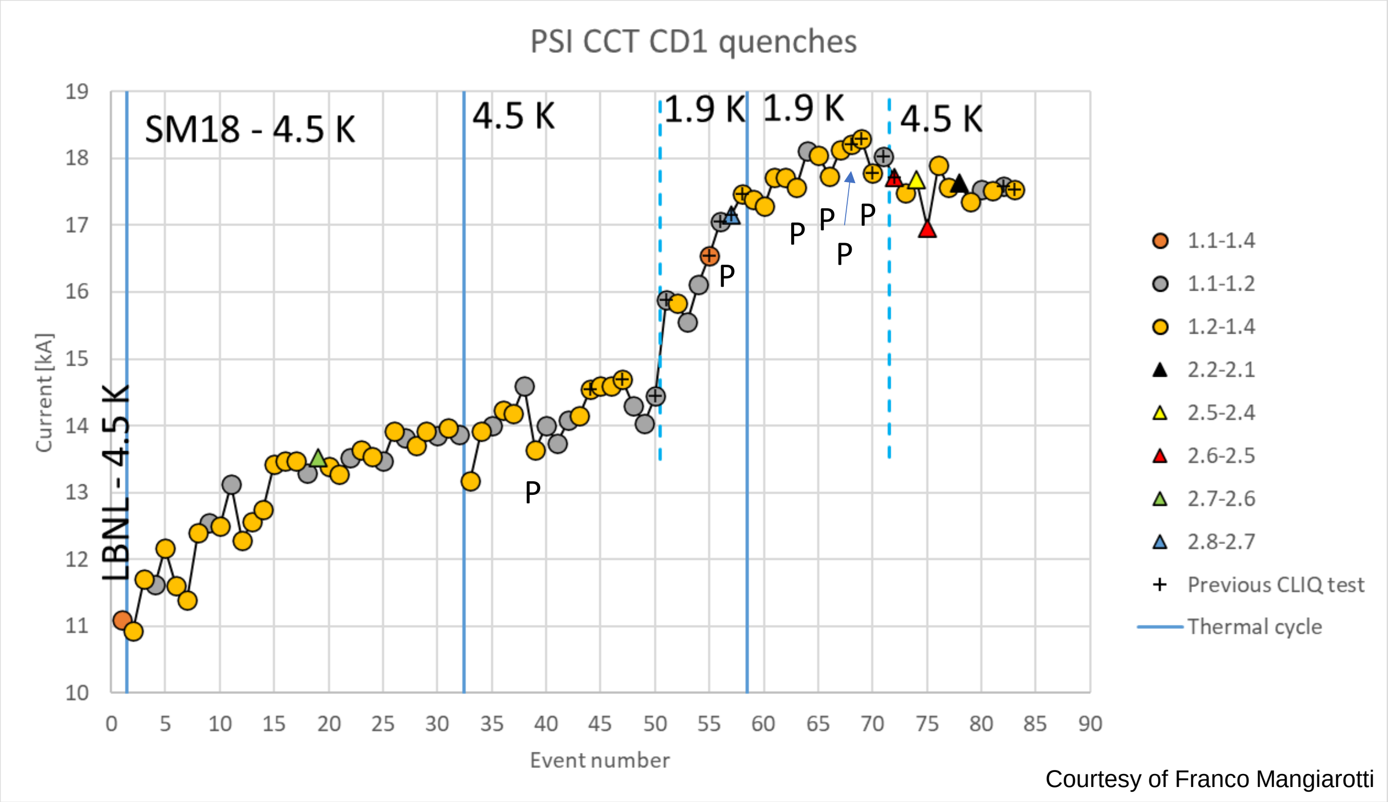


CHART MagDev @ PSI

- creates sc magnet development infrastructure
- LTS (Nb_3Sn) technology development for the international high-field magnet project
- NI HTS (REBCO) coil program
- HTS (REBCO) superbend demonstrator
- bulk-HTS (REBCO) undulators
- HTS capture solenoid for a positron source



CD1 magnet Nb3Sn CCT dipole

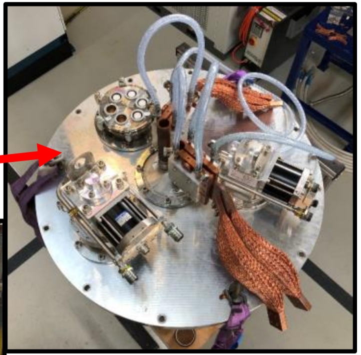


It reached **10.1 T in the bore** at 94% of Iss at 1.9 K; 9.9 T and 100% of Iss at 4.5 K

Cryogen free test stand

2kA ±10V power converter

Cryostat insert with two cryocoolers



Electronic rack
- vacuum control/monitoring
- temperature control/monitoring
- voltage signals recording
- quench detection system

Vacuum vessel
with pumps

Powering cables
(500A single cable)

Water chiller

Radiation shield with MLI

Cooling with 2 cryocoolers
- RDK-415D – two stages
- RDK-500B – single stage

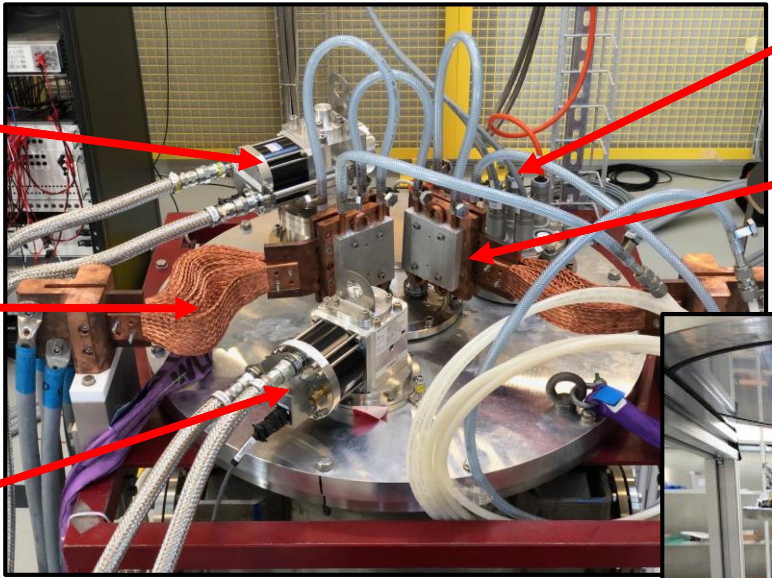
DAQ
- 2 nanovolt channels
- 64 high precision channels
- 64 fast sampling channels

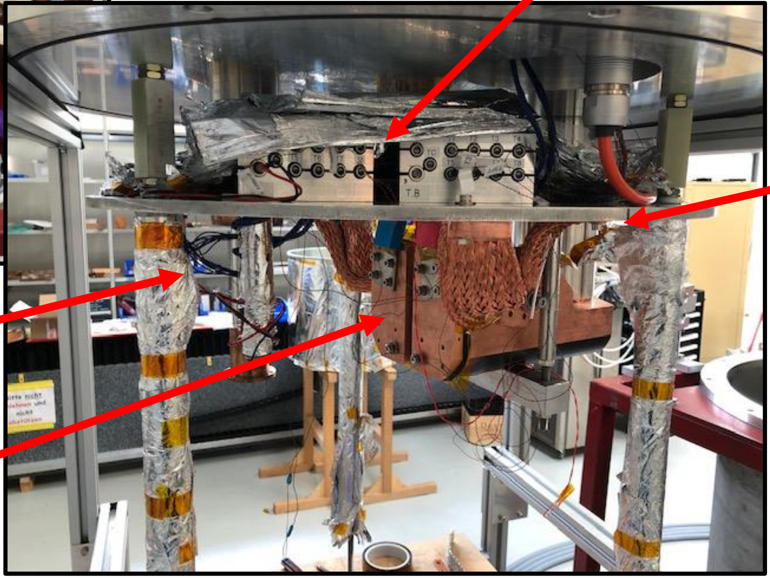
FPGA based **quench detection** system with interlock and safety matrix (CERN uQDS with PSI modification)

10+ cernox **temp sensors**

5+ **hall probes matrix** (calibrated at various temperatures up to 20T)

Cryogen free test stand insert





Cryocooler
RDK-500B

Electronic wires
feedthroughs

Water cooled
copper leads

Flexible
current leads

Instrumentation
terminals

Cryocooler
RDK-415D

Radiation
shield

V taps
connectors

Copper current
leads terminals

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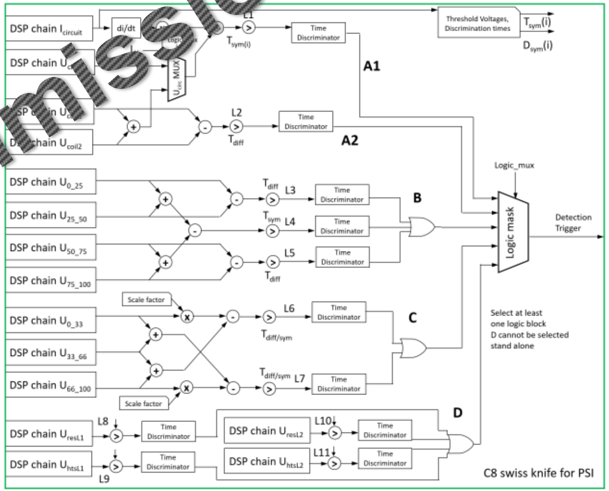
Cryogen free test stand DAQ

64 channels high frequency (200 kS/s) DAQ NI based INCAA custom system

64 channels high precision DAQ NI PXI system

CERN uQDS system with ‘swiss knife’ firmware

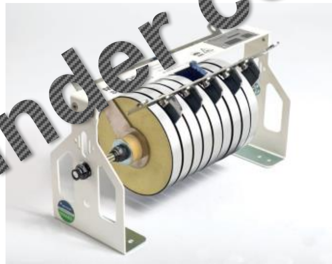


under commissioning

nanovoltmeters

temperature PID controller

mechanical switch (~4 ms ot) with varistor



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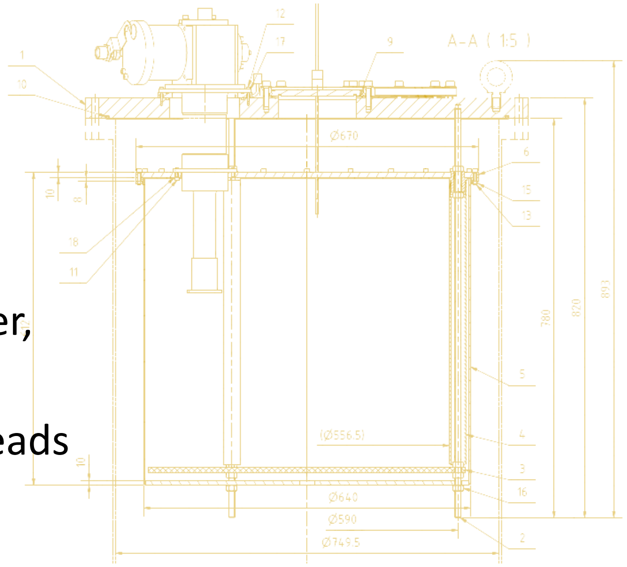
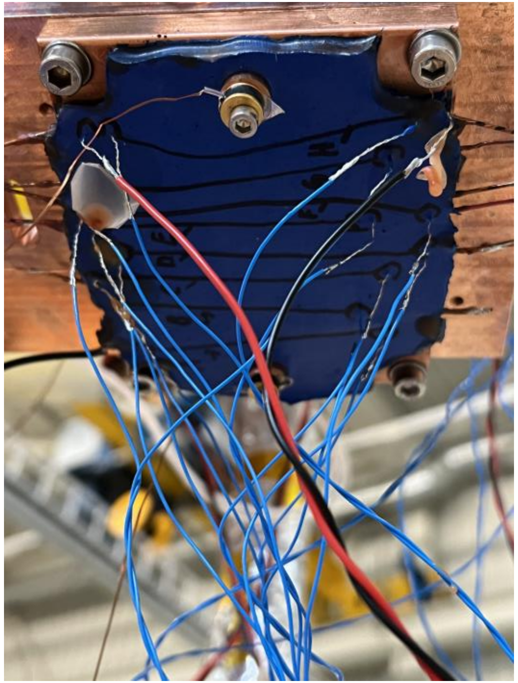
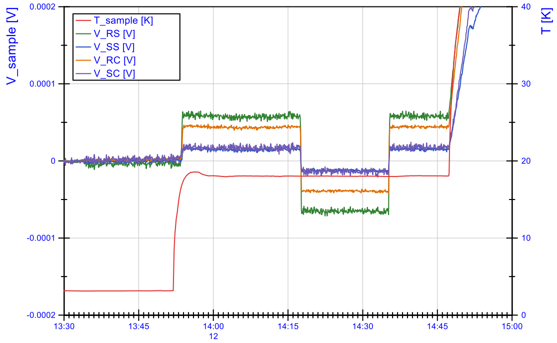
Key parameters

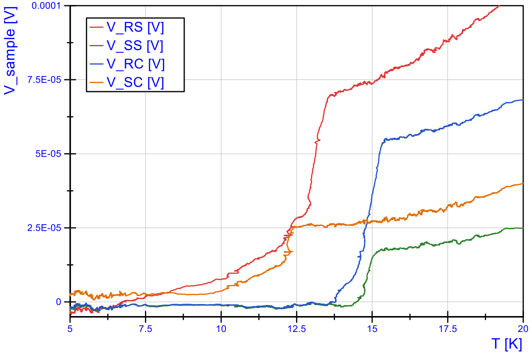


- vacuum vessel made of 316L non-magnetic stainless steel installed on non-magnetic floor
- useful volume inside the radiation shield : 630 mm diameter, 590 mm height (can be extended to 1000 mm)
- custom made conduction cooled flexible copper and HTS leads optimized for 2000 A
- cooled by two cryocoolers
  - RDK-415D – samples/coils (1.5 W @ 4.2 K and 35 W @ 50 K)
  - RDK-500B – current leads (160 W @ 70 K)
- cooling time <12h
- variable temperatures operation

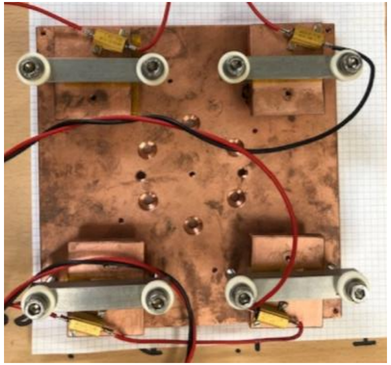
Test station capabilities various temperature tests



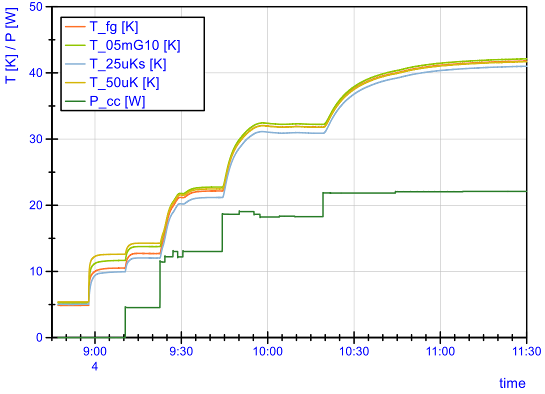




Strands in this measurement had undergone different heat treatments. During the heating cycle, they were exposed to varying amounts of oxygen at different temperatures



Thermal conductivity of different types of insulated joints



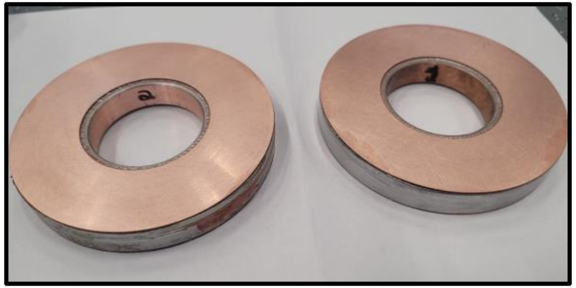
NI coils winding and soldering

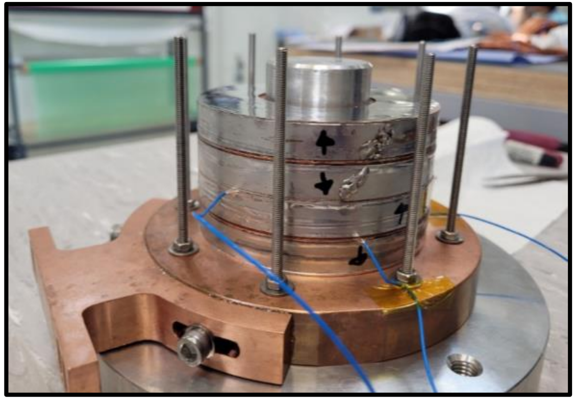
- winding setup for one or two tapes with individual tension control
- automatic application of soldering flux on each tap
- possibility of soldering the coil as it is wound
- 4 coils manufactured using different winding and soldering techniques

winding table

Stacked, single layer pancakes
Axial joints
4 coils, 12 mm SuperOx tape
Solder-potted coils
r_i 25 mm
r_o 50 mm
turns: 2 x 170
SC length: 2 x 49 m
voltage taps
hall sensors matrix

Manufacturing 2 days!





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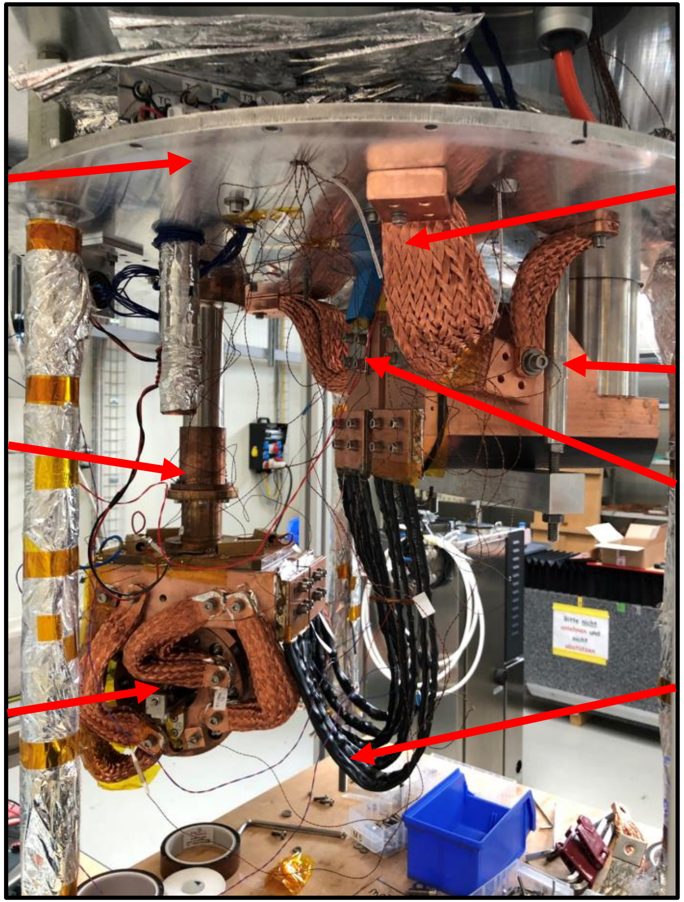
Technology Solenoid Program Milestone

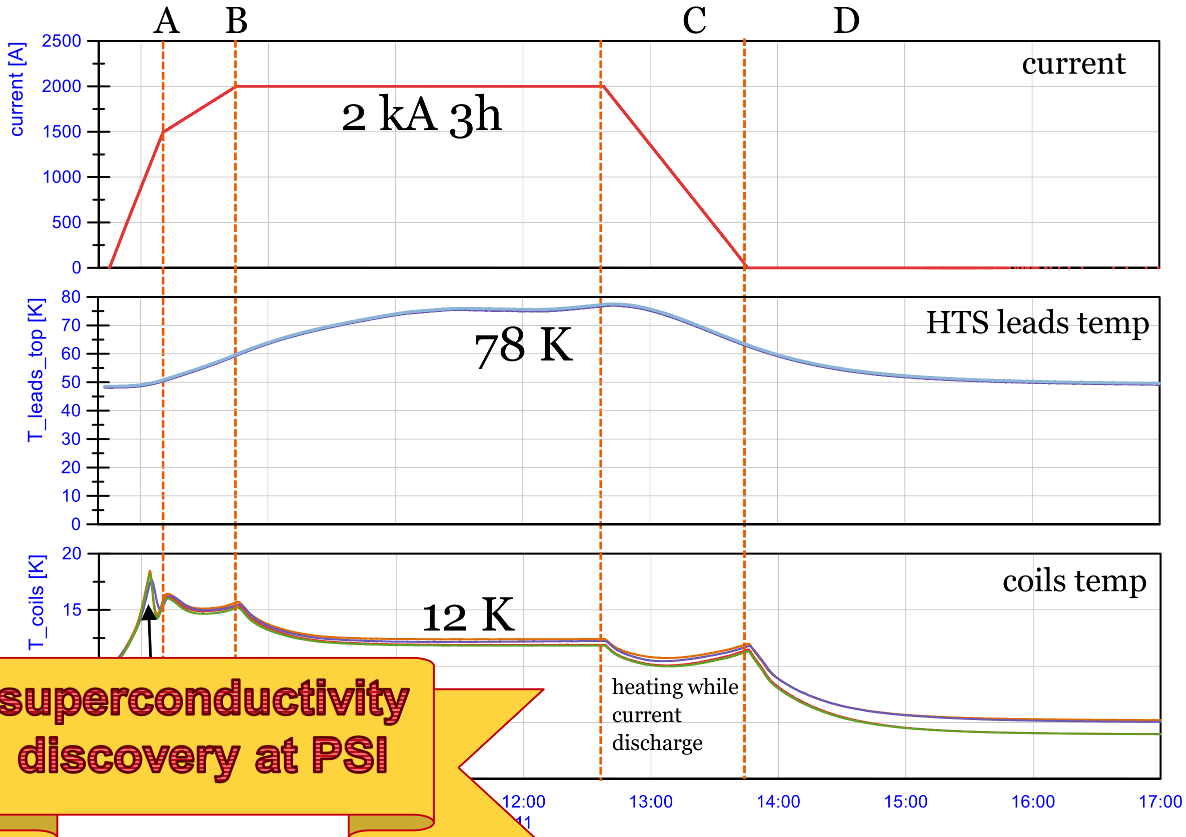
Stack of 4 NI HTS pancake coils solenoid, built at PSI and using licensed Tokamak Energy Ltd technology.

MEDUSA

Flag of Sicily



Medusa 2 kA powering results



superconductivity discovery at PSI

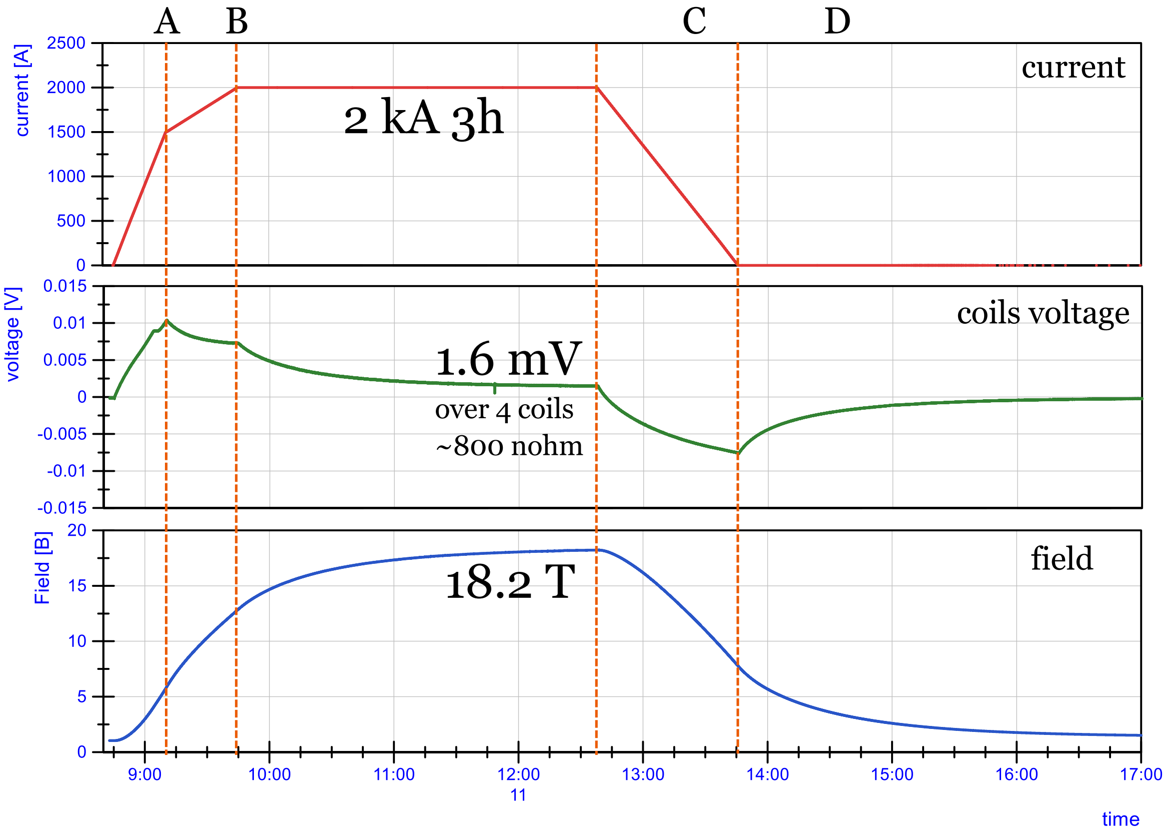
0-A:
- fast ramp up with 1 A/s
- coils temp regulated by external heaters

A-B:
- slower ramp up with 0.2 A/s to stabilize coils temperature

B-C:
- 2 kA 3h plateau
- temperature of Cu-HTS leads joint increasing because of joule heating
- coils temperature stable at 12 K

C-D:
- slow ramp down with 0.5 A/s

Medusa 2 kA powering results



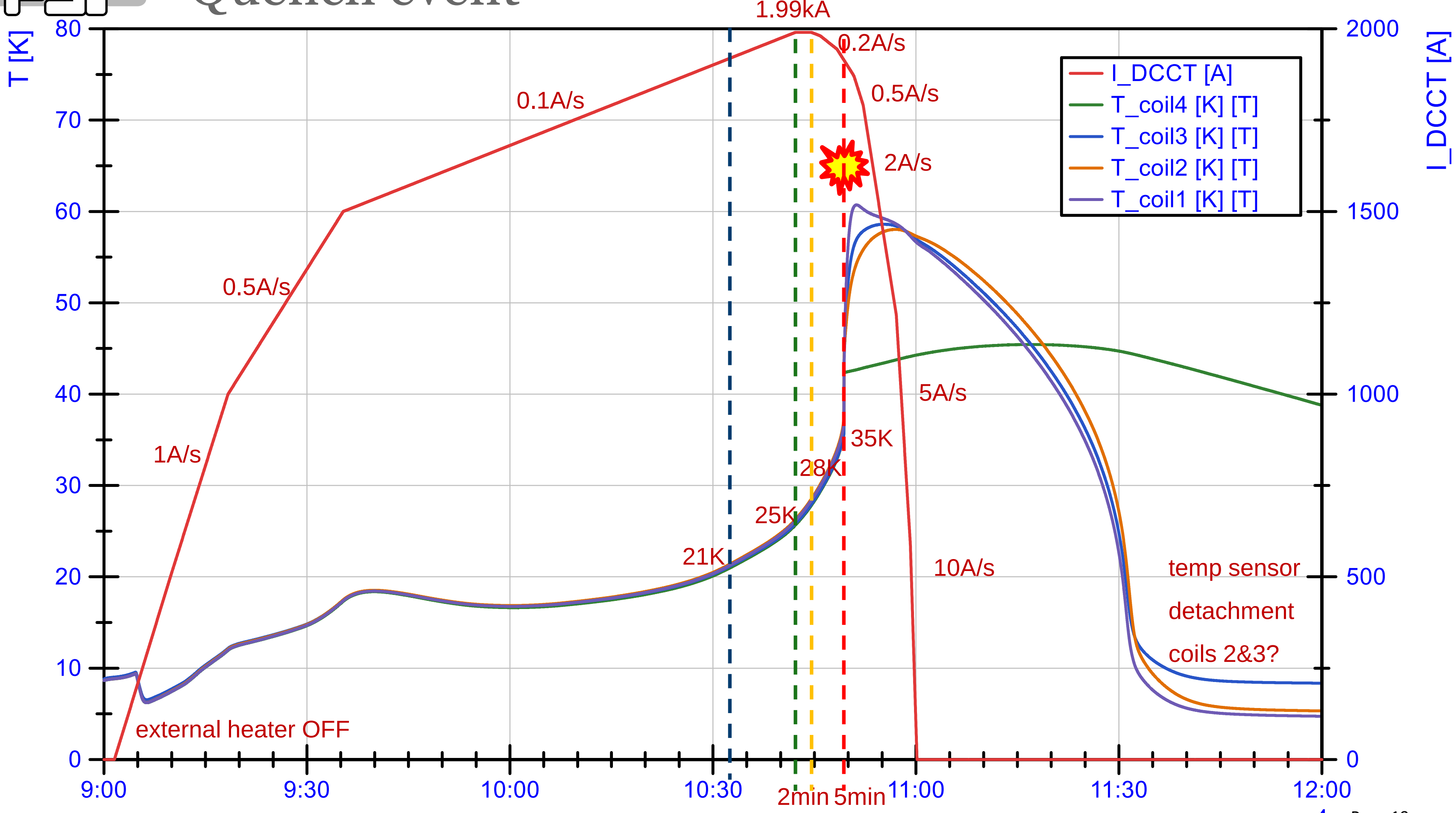
0-A:
- fast ramp up with 1 A/s
- voltage over coils increasing because of current radial path

A-B:
- slower ramp up with 0.2 A/s to stabilize coils voltage increase

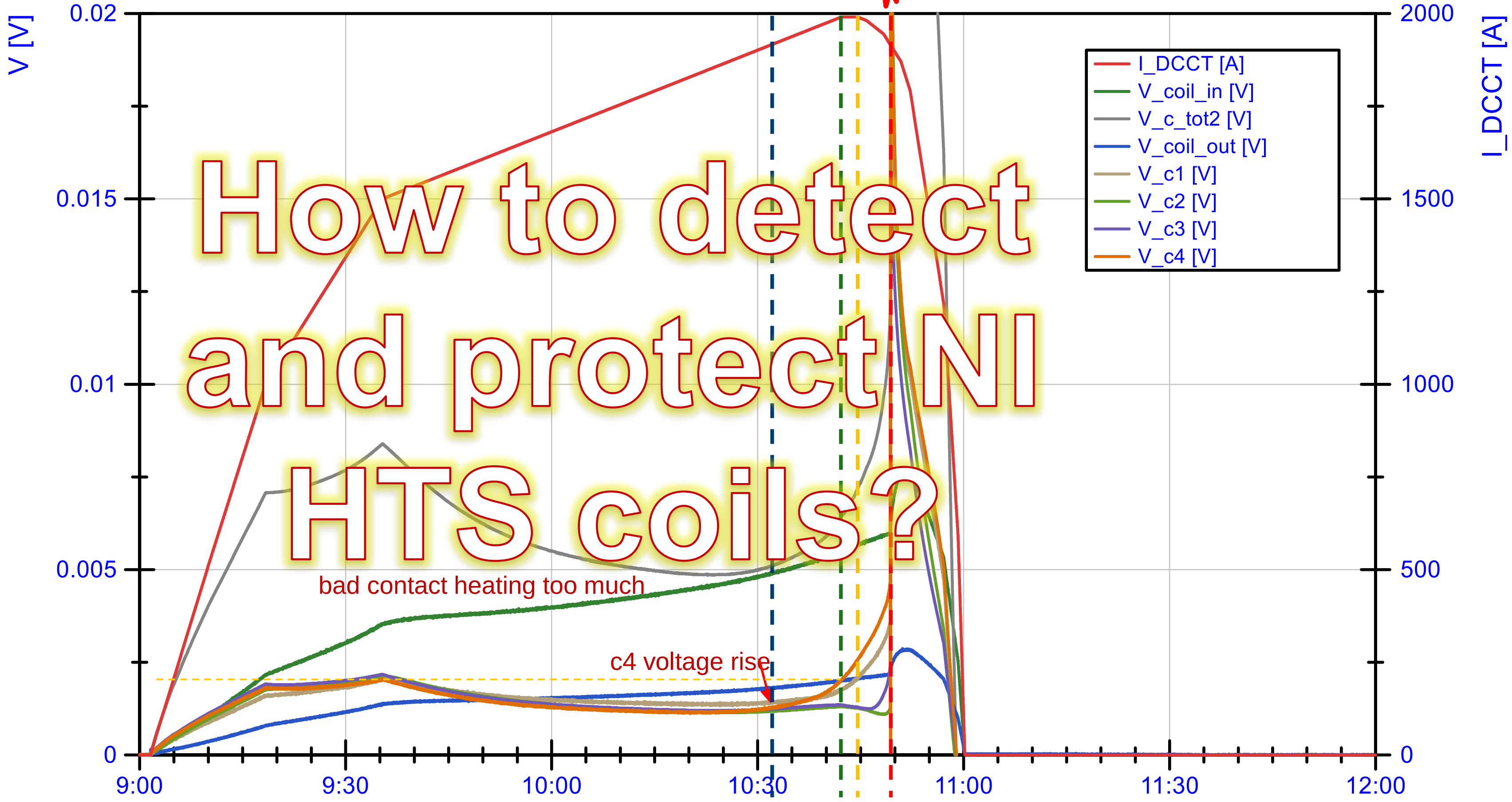
B-C:
- 2 kA 3h plateau
- coils voltage decreasing because of current redistribution
- field is increasing – not reaching saturation

C-D:
- slow ramp down with 0.5 A/s to avoid quench back

Quench event

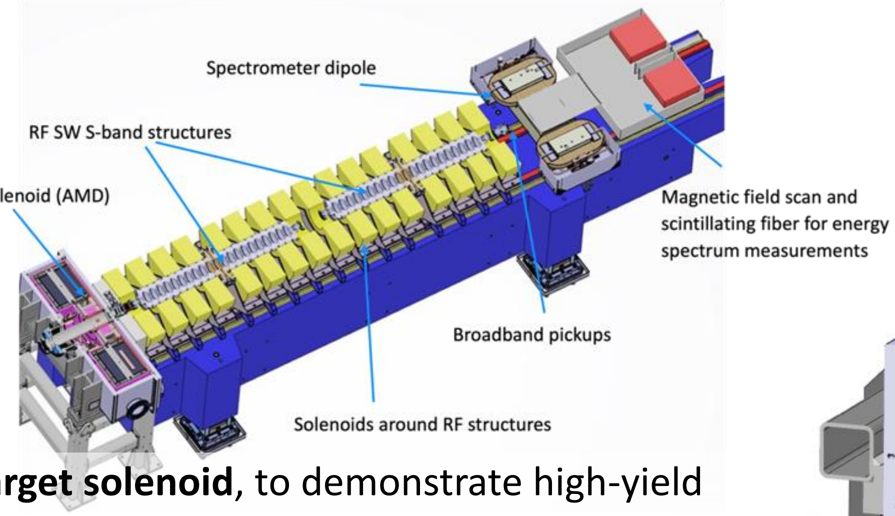


Quench event



How to detect and protect NI HTS coils?

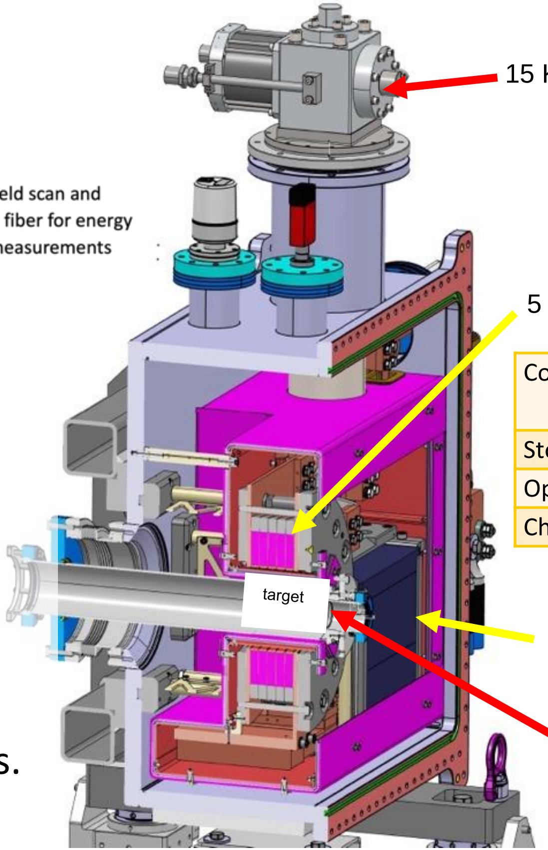
P3 FCCee Injector Study PSI Positron Production



HTS NI target solenoid, to demonstrate high-yield positron source concept

- stable DC operation,
- high thermal conduction due to solder impregnation to extract heat deposited in coils,
- radiation robustness due to absence of insulators.

Manufacturing Q3'23-Q2'24
Experiment at PSI's SwissFEL 2025/26



Coil diameter	122 mm inner 219 mm outer
Stored energy	331 kJ
Operating current	1.17 kA
Charging constant	11 hours

Courtesy J. Kosse, T. Michlmayr, H. Rodrigues

Summary part one

- PSI new approach for superconducting materials and small demonstrator magnets test stand: cryogen free
  - variable temperatures (3 – 100+ K)
  - flexibility of tested items:
    - enabling technologies (impregnations, thermal conductivity, etc.)
    - wire/cables/tapes characterization (RRR, Tc, etc.)
    - small magnets demonstrators (LTS and HTS)
  - energy consumption optimization
- Max operating current 2 kA (+-10 V)
- Quench detection system based on FPGA electronic
- Protection by fast mechanical switch and dump varistor (1 kV)
- Plans for future:
  - optimize cooling paths for existing insert
  - mm anti-cryostat
  - new cryostat 10 kA
  - superconducting transformer powering

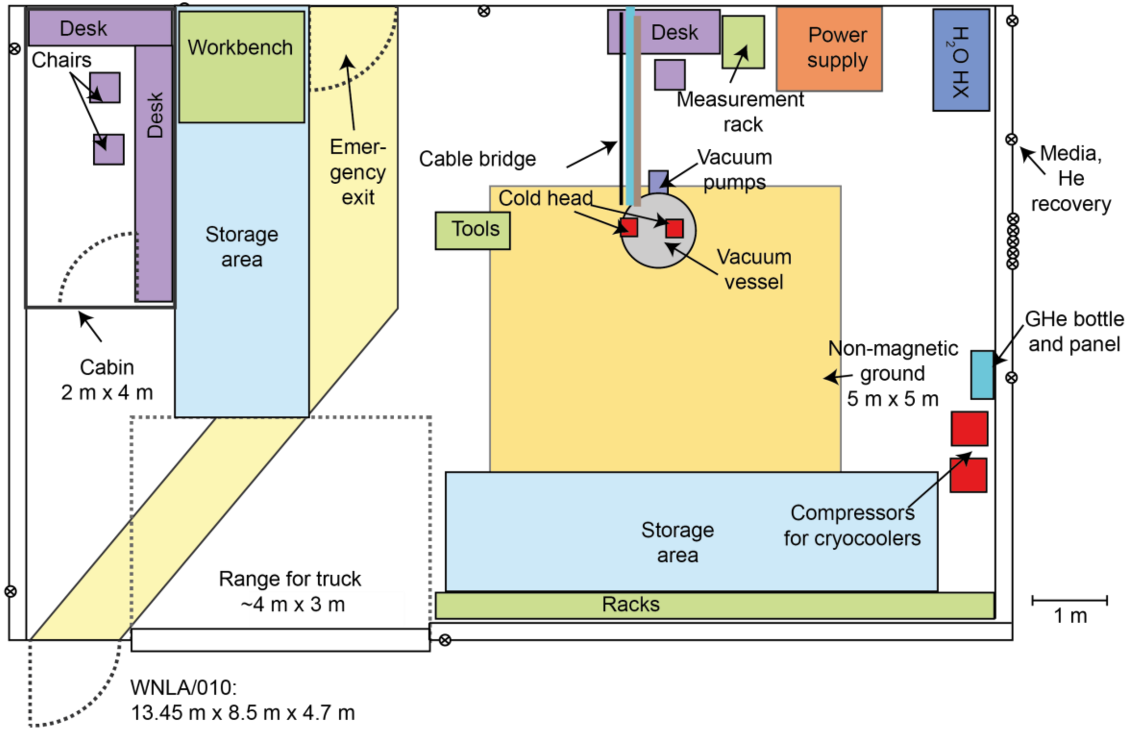
Outline

- Introduction PSI, Magnet Section and CHART
- Cryogen Free Test stand WNLA/010
- Cold tests results
- Planned upgrade
- Upcoming projects

Michal

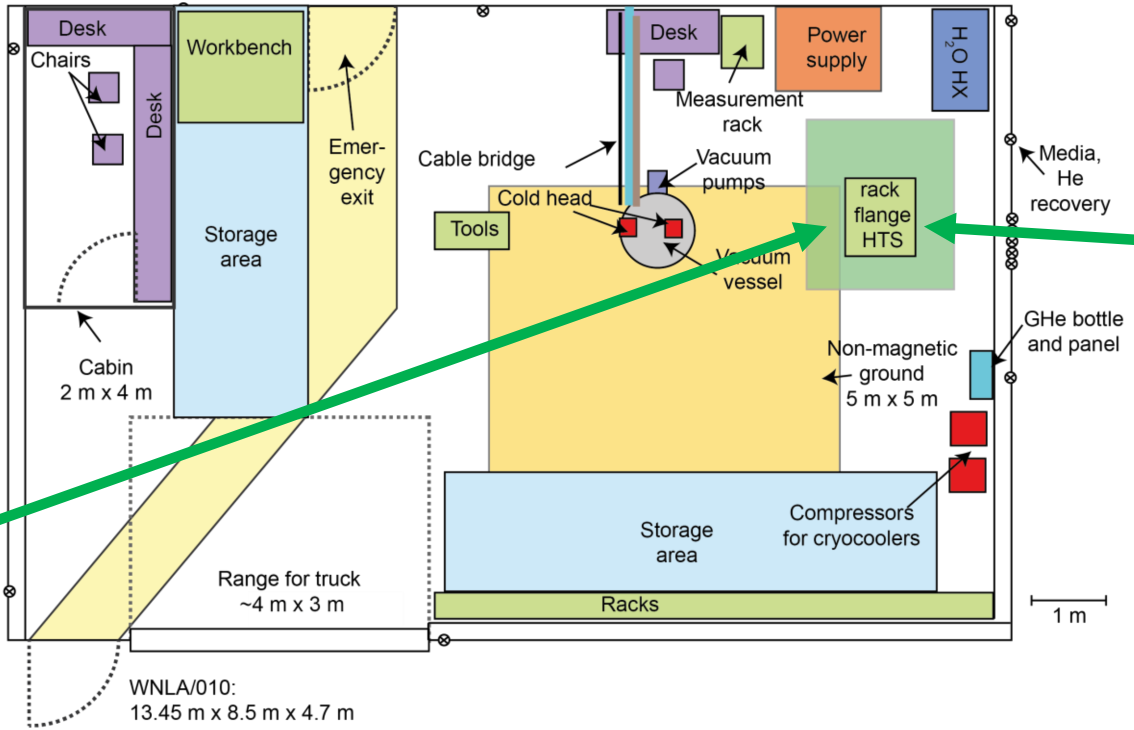
Carolin

Test stand - now

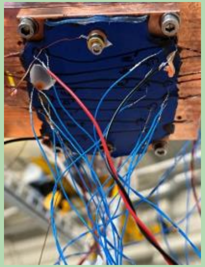


Test stand - now

Space! Noise!



RRR, thermal conductivity, etc.



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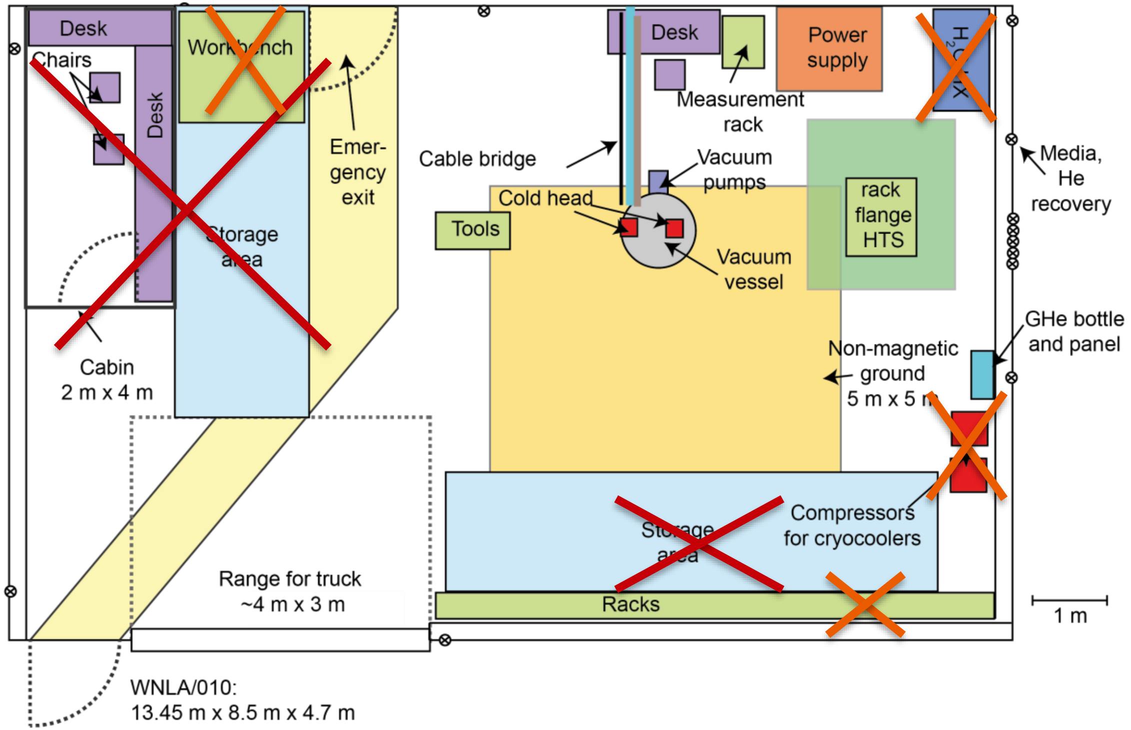
Test stand – (re-)move parts

Space! Noise!



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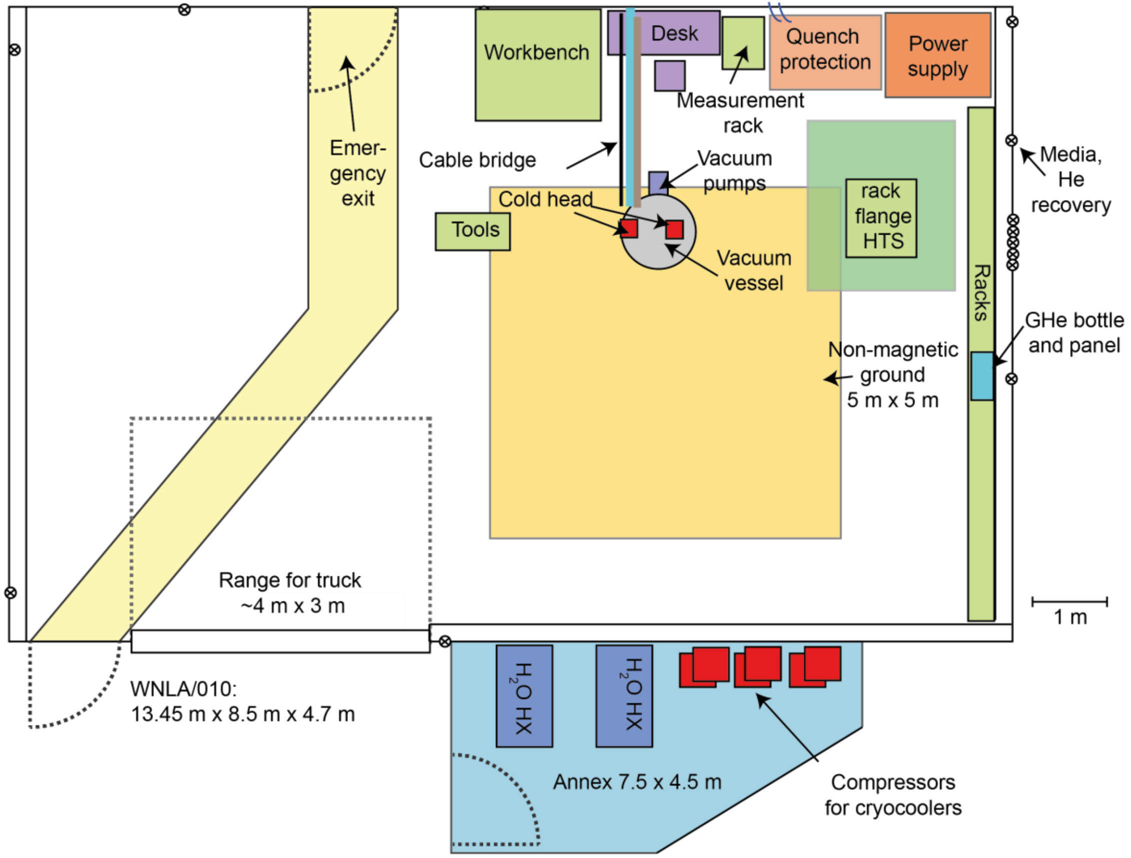
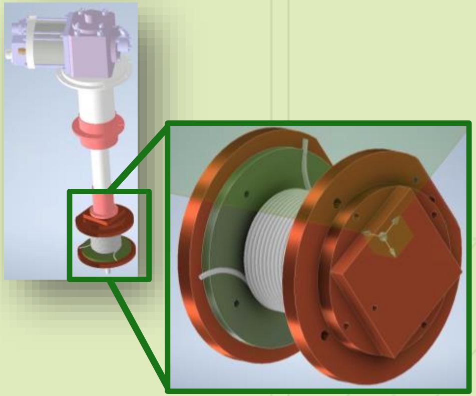
Test stand – planned annex for noisy components



Test stand – new projects from 2023

Innovation Fostering in Accelerator Science and Technology (I.FAST)



https://ifast-project.eu/home

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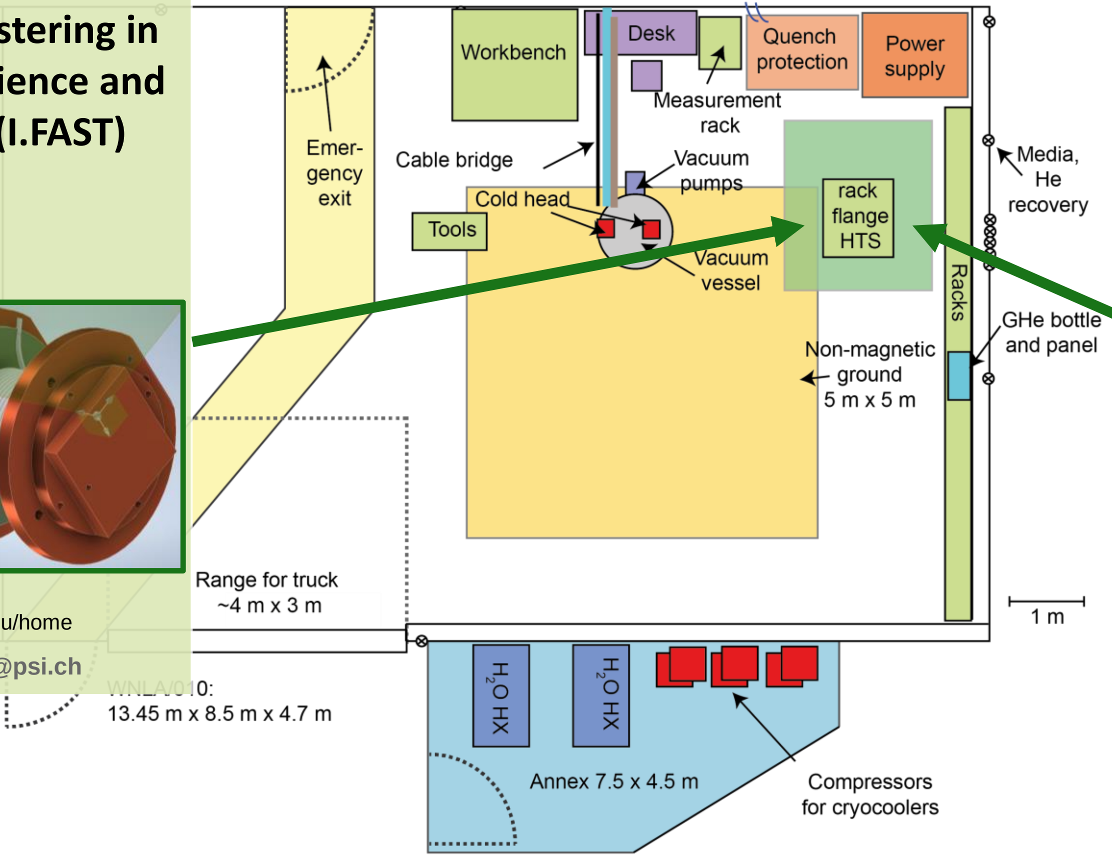

+ Team

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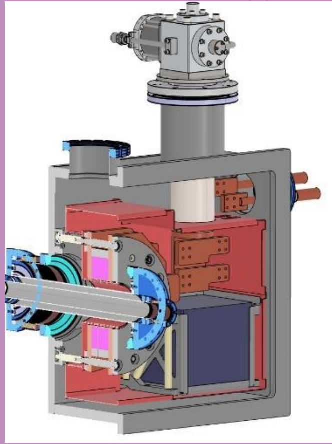
Test stand – new projects from 2023

FCCee Injector Study: P³ (PSI Positron Production)



N. Vallis, “PSI The P³ experiment: a Positron Source Demonstrator for FCC-ee”, 2022

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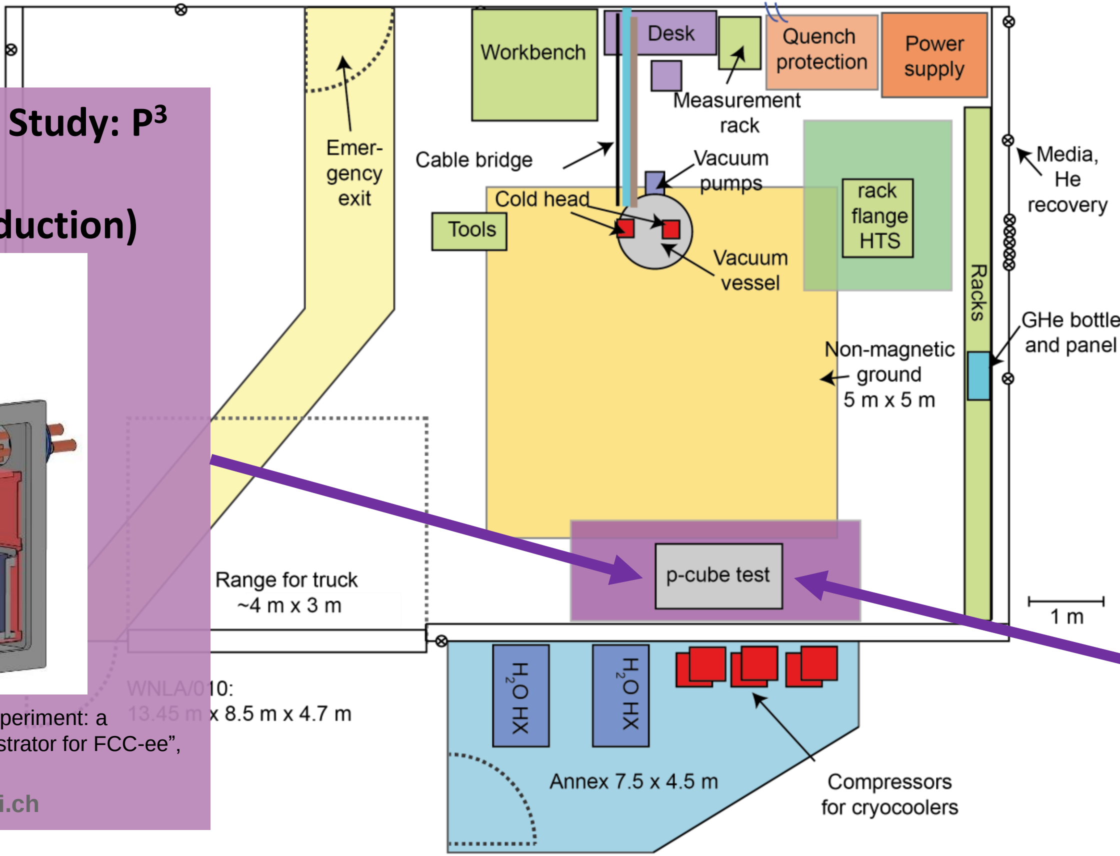

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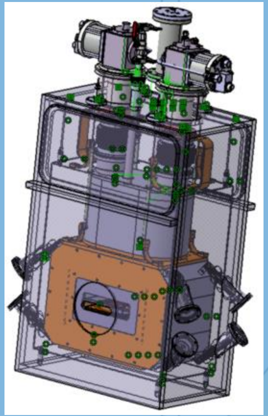
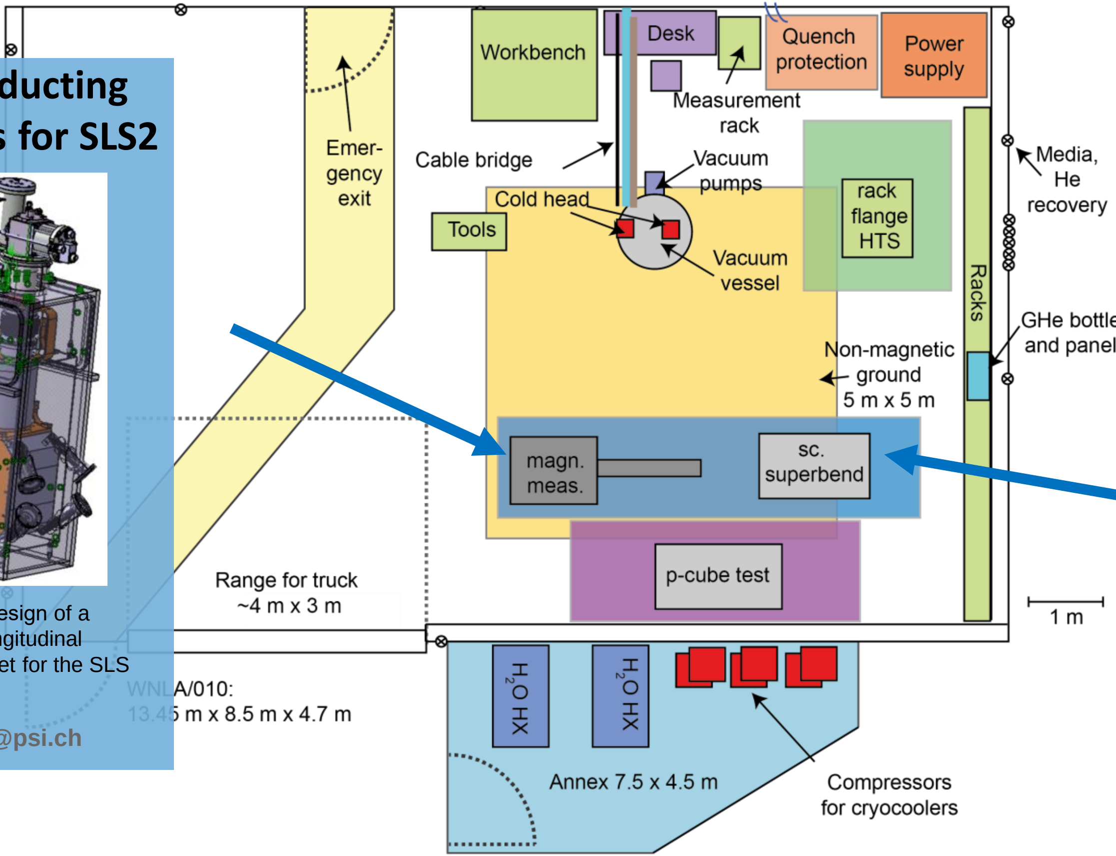
Test stand – new projects from 2023

Superconducting superbends for SLS2



C. Calzolaio et al. “Design of a Superconducting Longitudinal Gradient Bend Magnet for the SLS Upgrade”, 2016

ciro.calzolaio@psi.ch



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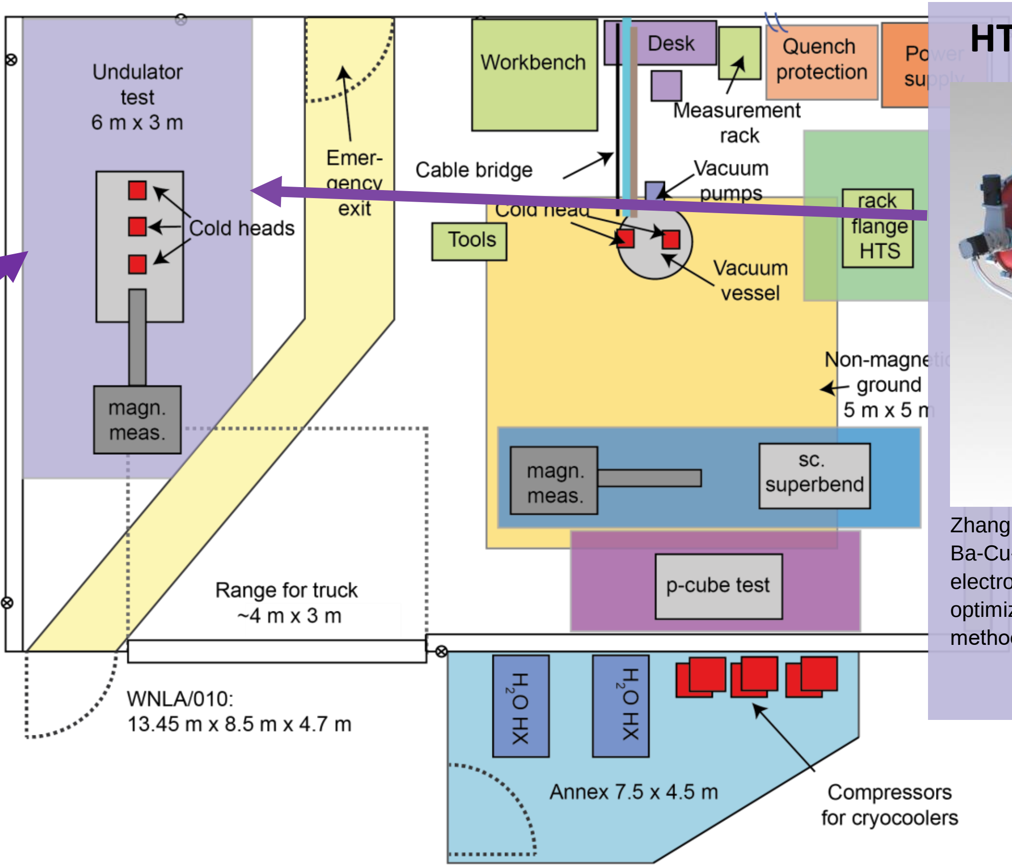
Test stand – new projects from 2023



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HTS undulator for SLS2

Zhang et al., “Fully-staggered-array bulk Re-Ba-Cu-O short-period undulator: large-scale 3D electromagnetic modelling and design optimization using A-V and H-formulation methods”, 2021

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Test stand – new projects from 2023

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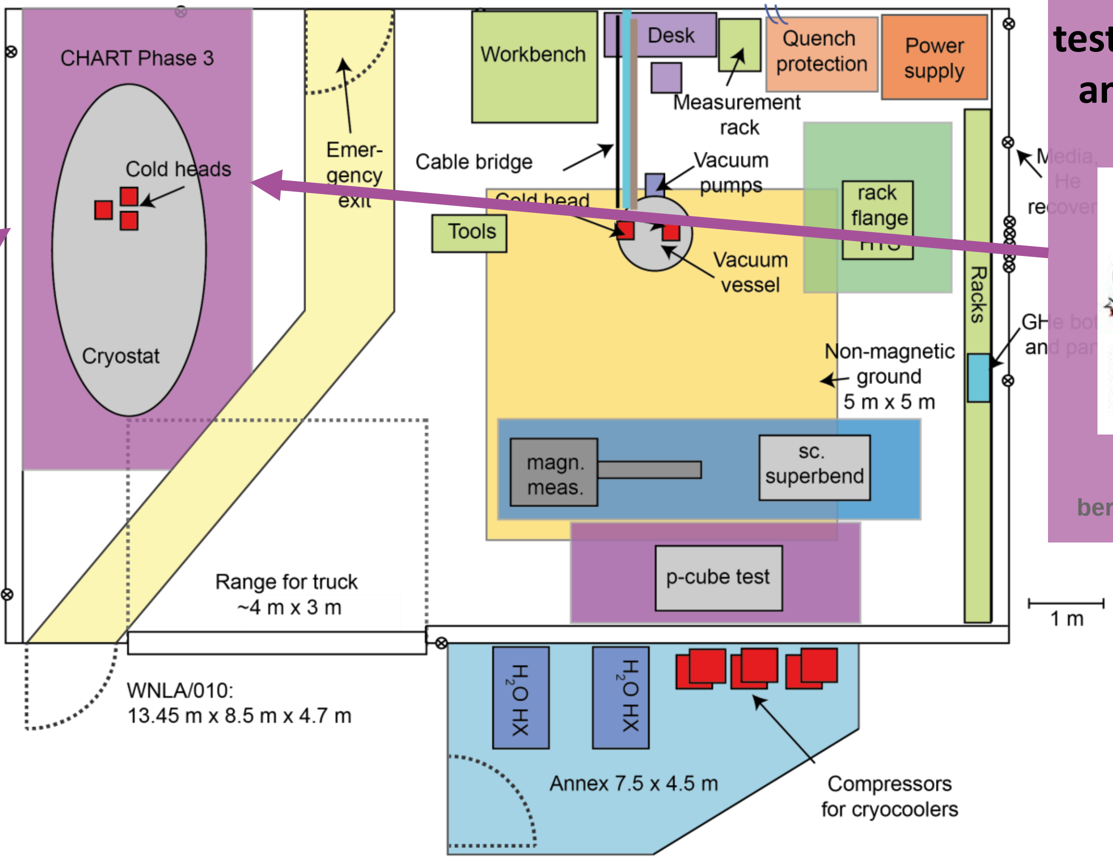

From 2025:
test stand for sc. LTS and HTS magnets for CHART

Swiss Accelerator Research and Technology

https://chart.ch/

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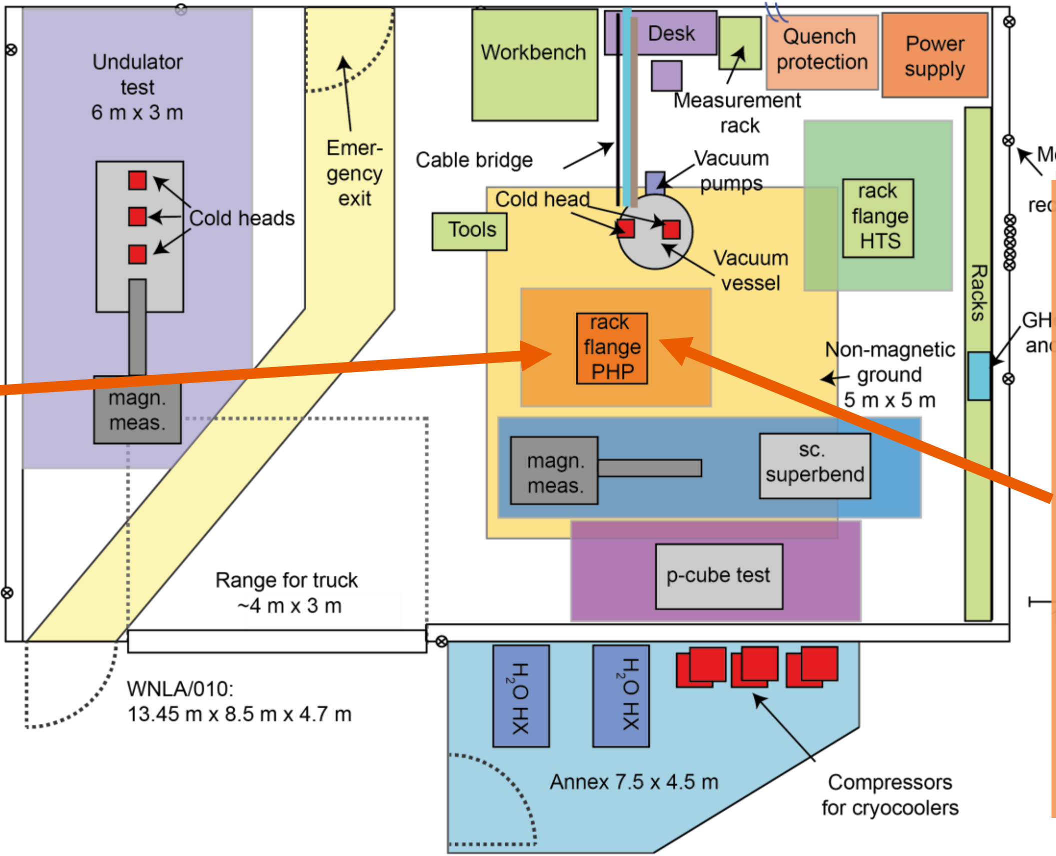
Test stand – new projects from 2023

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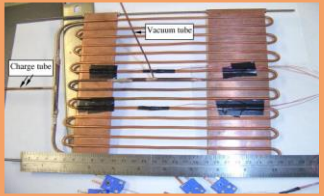
Development of cryogenic pulsating heat pipes (PHP)



Jiao, A. et al, "Experimental investigation of cryogenic oscillating heat pipes", 2009

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VDL

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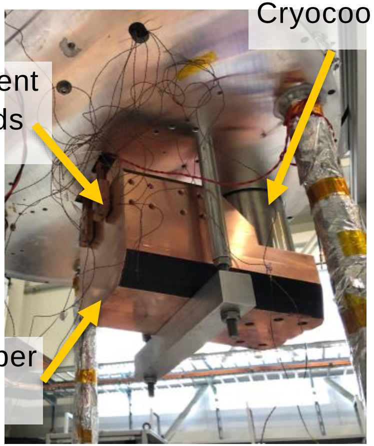
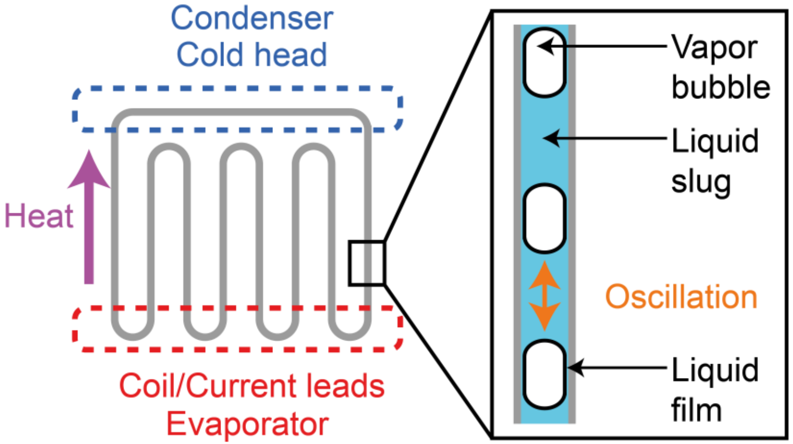
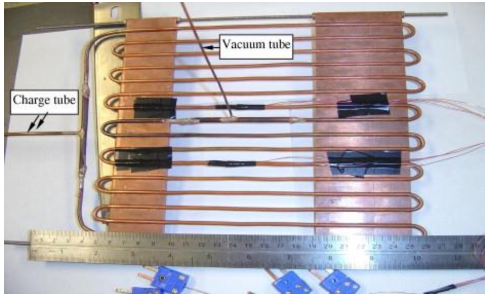
Cooling of sc. magnet without LHe bath

- Challenge: Transport heat efficiently from sc. component to cryocooler



Test 2 kA current leads

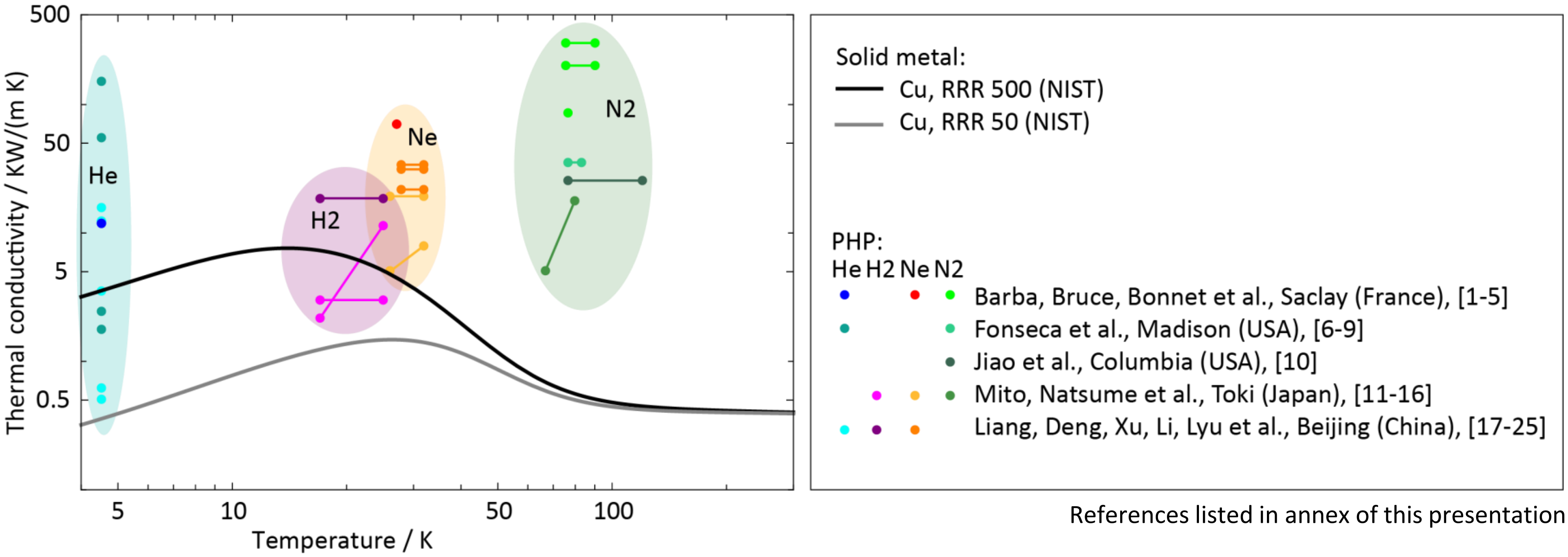




Nitrogen PHP in Laboratory
(Jiao et al., https://doi.org/10.1016/j.ijheatmasstransfer.2009.03.013.)

→ Replace of conventional copper thermal links with pulsating heat pipes (PHP) filled with cryogenic fluid

Thermal conductivity of PHP for cryogenic application



References listed in annex of this presentation

- Helium PHP for LTS application
- Neon PHP (theoretically also hydrogen and nitrogen PHP) for HTS application

Summary

- **Magnet infrastructure** at PSI for permanent, electro- and superconducting magnets
- Trend for new projects to use **sc. magnets cooled with cryocoolers** (saving energy)
- **Test stand for cryocooled sc. magnets** at PSI continuously evolved since 2018
- **Ongoing upgrade** of test stand for new projects, e.g. P^3, LTS superbend and HTS undulator for SLS2
- **Cryogenic pulsating heat pipes** (PHP) promising alternative to copper connection between sc. magnet and crycooler

Wir schaffen Wissen – heute für morgen

We create knowledge today – for use tomorrow

Thank you for your interest.

References Saclay, France

[1] Bonnet F, Gully P, Nikolayev V. Development and test of a cryogenic pulsating heat pipe and a pre-cooling system. In: Advances in cryogenic engineering, vol. 1434; 2012. p. 607–14.

[2] Romain Bruce, Maria Barba, Antoine Bonelli, Bertrand Baudouy, Thermal performance of a meter-scale horizontal nitrogen Pulsating Heat Pipe, Cryogenics, Volume 93, July 2018, Pages 66-74

[3] Barba, M., Bruce, R., Bouchet, F., Bonelli, A. & Baudouy, B. Thermal Study of a one-meter long Neon Cryogenic Pulsating Heat Pipe. IOP Conf. Series: Materials Science and Engineering 502 (2019). (doi.org/10.1088/1757-899X/502/1/012152)

[4] Bruce, R., Barba, M., Bouchet, F., Bonelli, A. & Baudouy, B. Transient thermal behavior of a neon Pulsating Heat Pipe (PHP). IEE Transactions on Applied Superconductivity, Volume 29, Issue 5 (2019). (doi.org/10.1109/TASC.2019.2902978)

[5] Maria Barba, Romain Bruce, Florent Bouchet, Antoine Bonelli, Bertrand Baudouy, Effect of the thermo-physical properties of the working fluid on the performance of a 1-m long cryogenic horizontal pulsating heat pipe, International Journal of Heat and Mass Transfer, Volume 187, 2022, 122458, https://doi.org/10.1016/j.ijheatmasstransfer.2021.122458.

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