PAUL SCHERRER INSTITUT

PSI

FUTURE CIRCULAR COLLIDER

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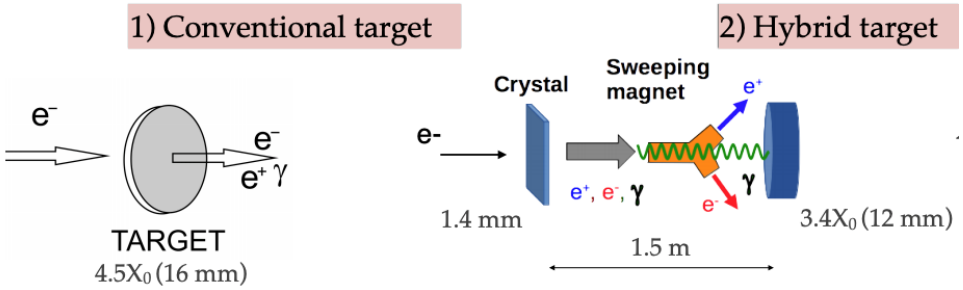
HTS solenoids for the PSI positron production project in the context of the CHART FCCee injector study

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI

31/05/22

Proof-of-concept P3 experiment



Adiabatic matching device (AMD) state-of-the-art: pulsed NC magnet

- Option 1: Improved pulsed NC magnet:
  - \+ Yield ~2.4
  - – Limited to ~100 Hz rate
  - – Uses very high voltages
- Option 2: Innovative solution: NI HTS solenoid:
  - \+ Yield 4+
  - \+ DC operation
  - \+ Non-insulated: radiation resistant

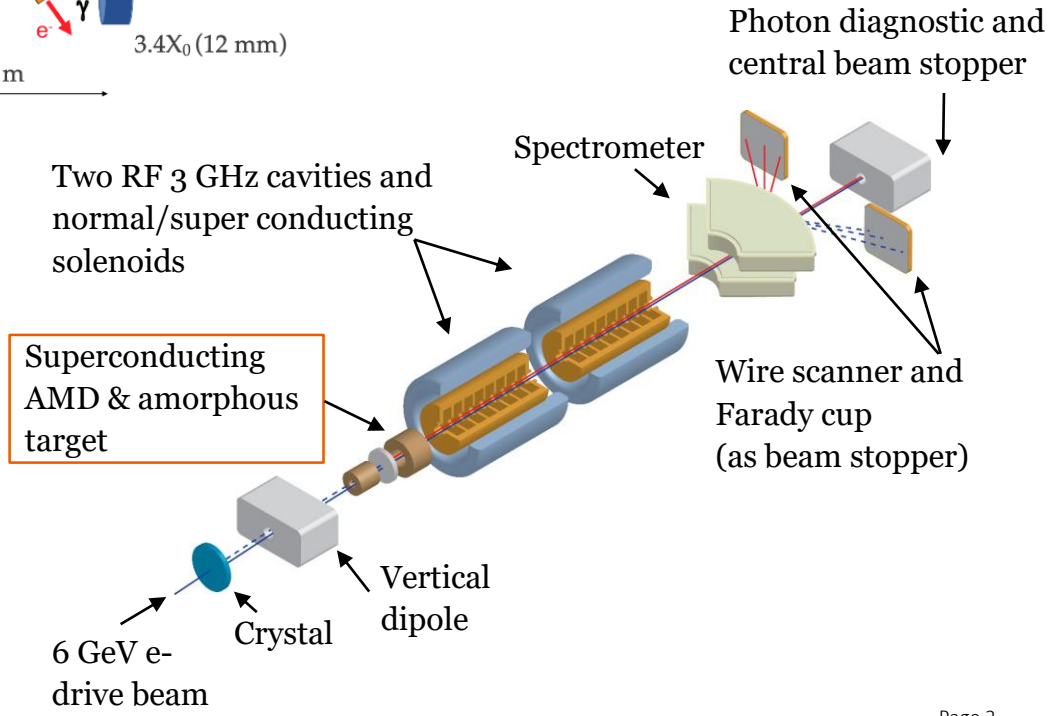


CHART2 MagDev @ PSI

"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)

CHART2 MagDev at PSI:

1) – creates magnet-development infrastructure
   – LTS (Nb3Sn) technology development for the internat. high-field magnet project
2) – HTS (REBCO) superbend demonstrator
   – bulk-HTS (REBCO) undulators
3) – HTS capture solenoid for a positron source

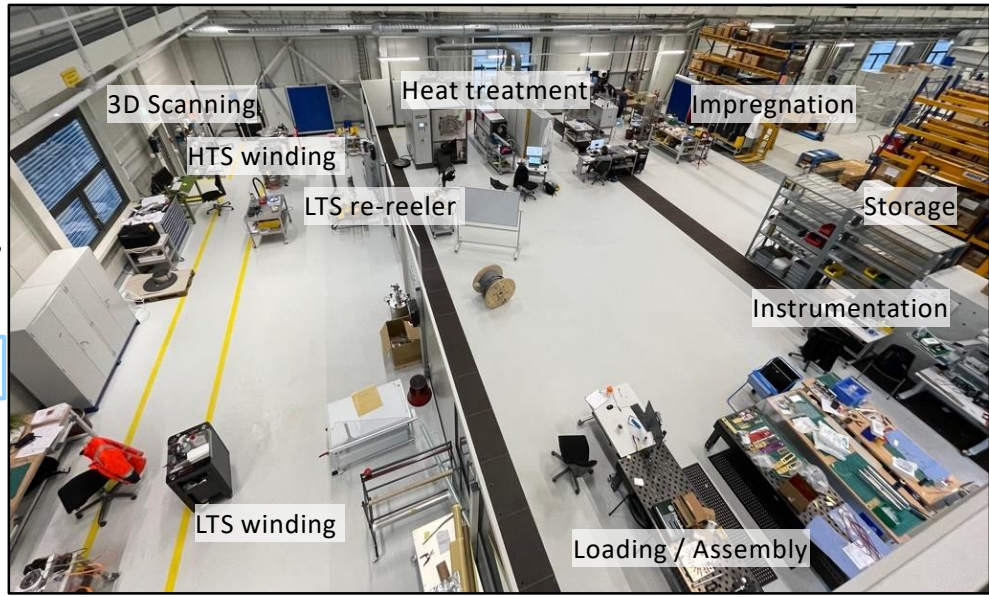
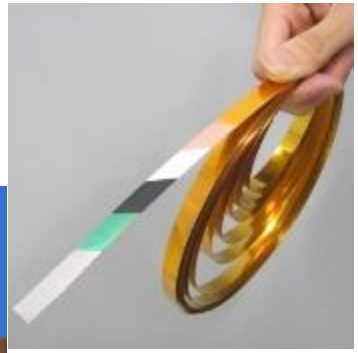


CHART MagDev: Technology Solenoid Program

- HTS tapes - great potential, but require a different approach than LTS wires
- NI coil technology license agreement with Tokamak Energy
- Rapidly develop infrastructure for HTS coil manufacturing and testing
- Stacked pancakes approach - modular!
- Aim: 4-coil stack, +16 T

ReBCO High Temperature Superconducting (HTS) Tape



tokamak energy
a faster way to fusion

Greg Brittles

Stacked, single layer pancakes
Axial joints to get current in and out

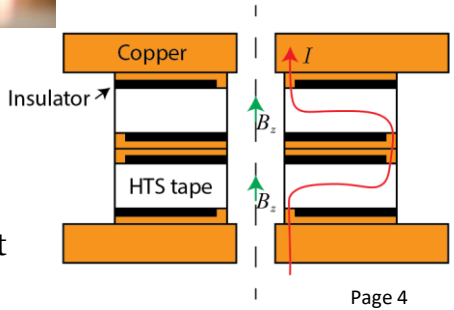
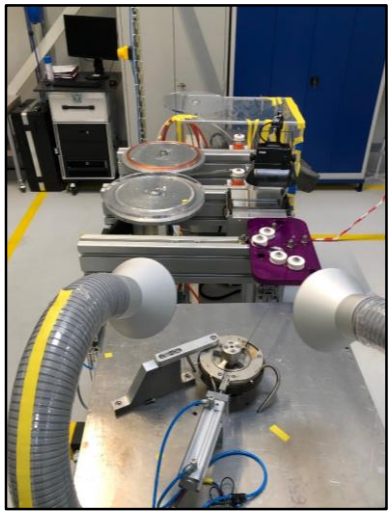


CHART MagDev: Technology Solenoid Program

Commissioning of infrastructure at PSI

Winding



Tensioning system developed by Francois-Olivier Pincot, Jacky Mazet, CERN

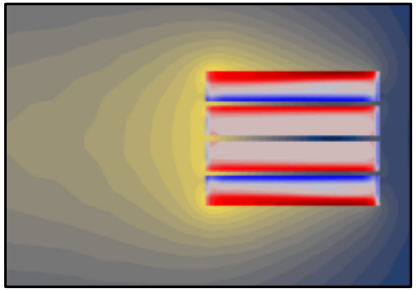
Soldering

Pre-tinning support by Davide Uglietti, PSI

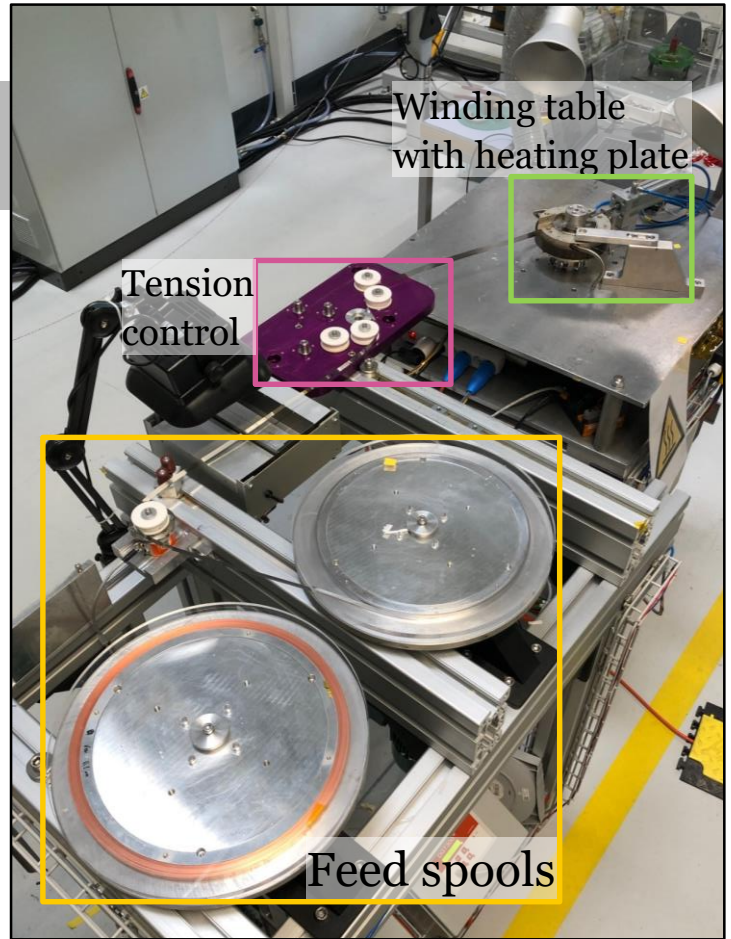
Testing

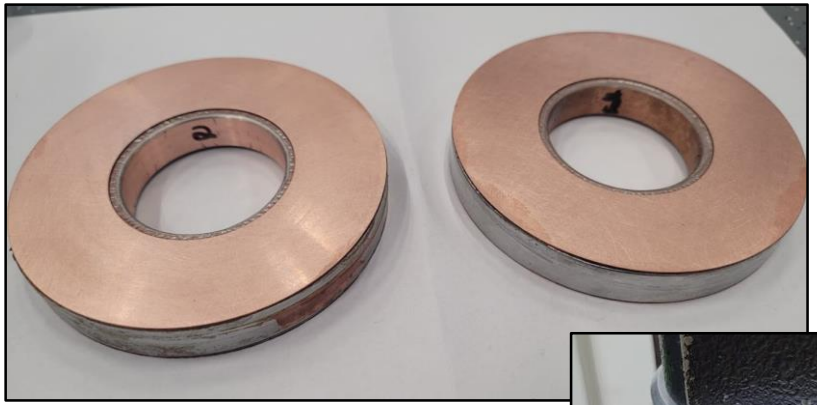
Cryogen-free test station (2 kA)

Modeling

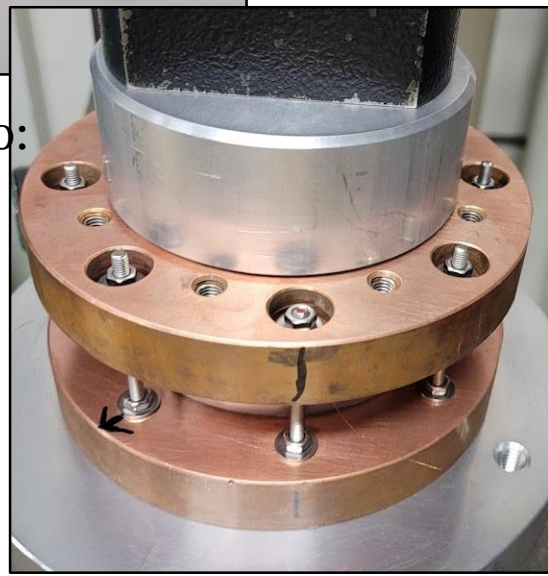


Winding and stacking



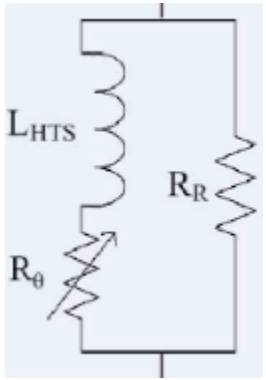


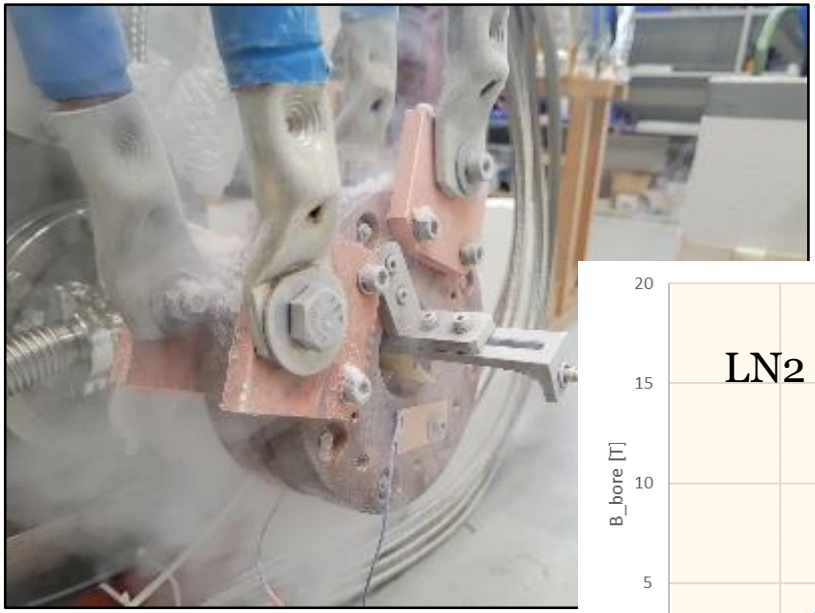
Manufacturing ready to go:
1 coil takes 2 days



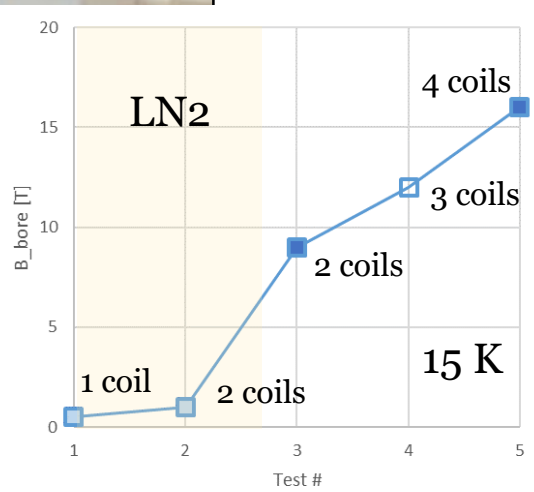
NI HTS coil behavior and test program

- NI coil can be represented by inductor and resistor in parallel
- During ramping, current will flow in the radial direction
- Time constant L/R





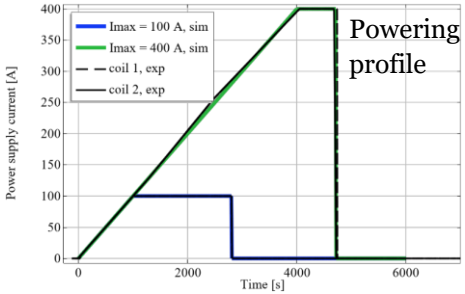
Test in LN2 up to 1.3 T for 2 stack to verify soldering technique and +16 T model at 20 K for 4-stack

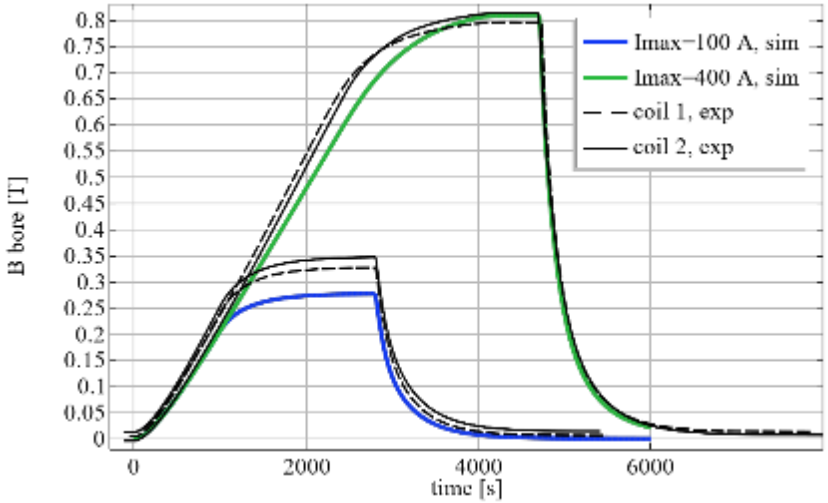


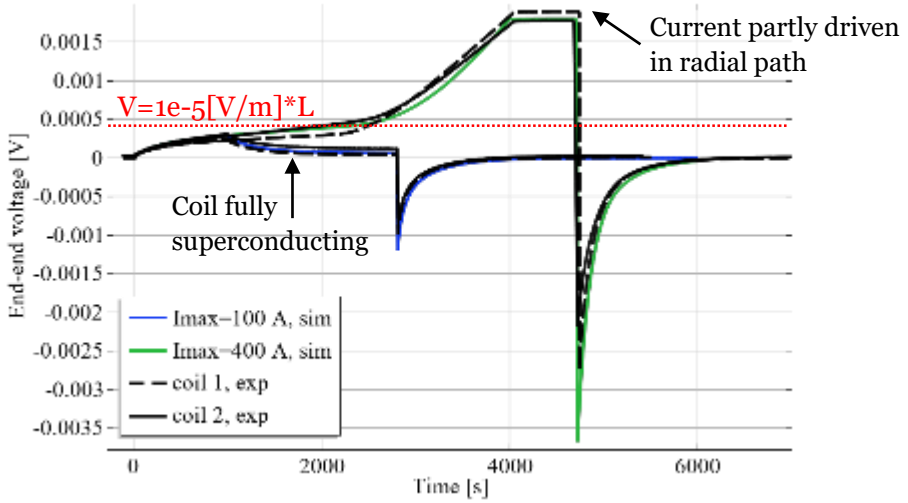
Tests program and milestones

Single coil in LN2 compared with model

- each coil tested at LN2 first to verify its performance
- very good agreement between model and experiment
- excellent stability above critical current (~200% of Ic)







1 fit parameter: turn-turn contact resistance. 1 ohm*cm2

2 kA cryogen-free test station at PSI

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

Vacuum chamber
with pumps (not visible)

Radiation shield with MLI

2kA power converter

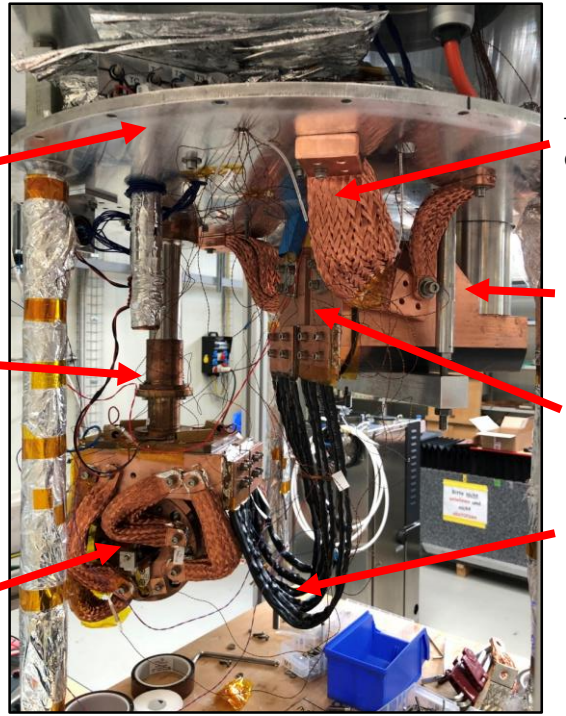
Water chillers
(for compressors and power converter)

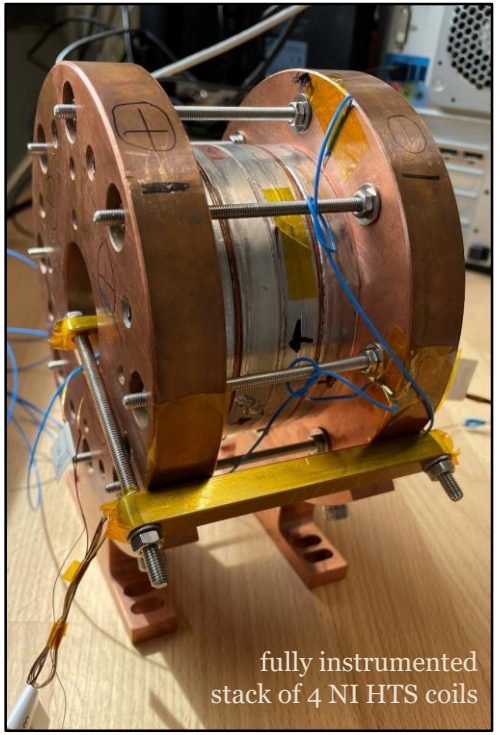
Cryostat insert with two cryocoolers

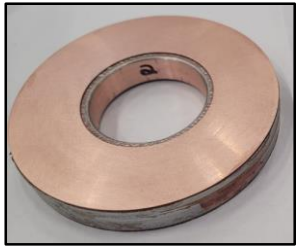
Power cables
(500A single cable)

Cryogen-free test setup

- Successful test in cryogen-free test station of 4-stack HTS NI solenoid, built in-house at PSI and using licensed Tokamak Energy Ltd technology.



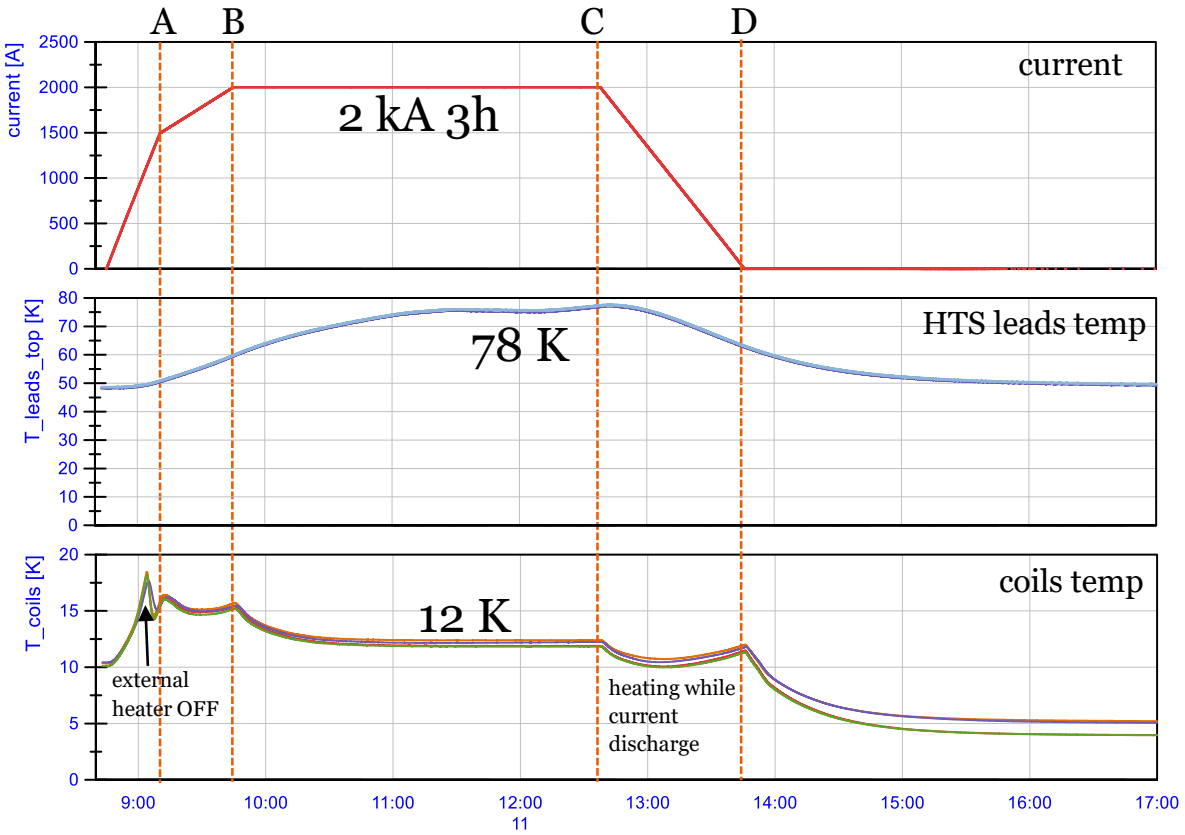




Diameter: 100 mm
Aperture: 50 mm

SC type: ReBCO
tapes: 2
turns: 2 x 170
SC length: 2 x 49 m

4-stack 10+ K test results



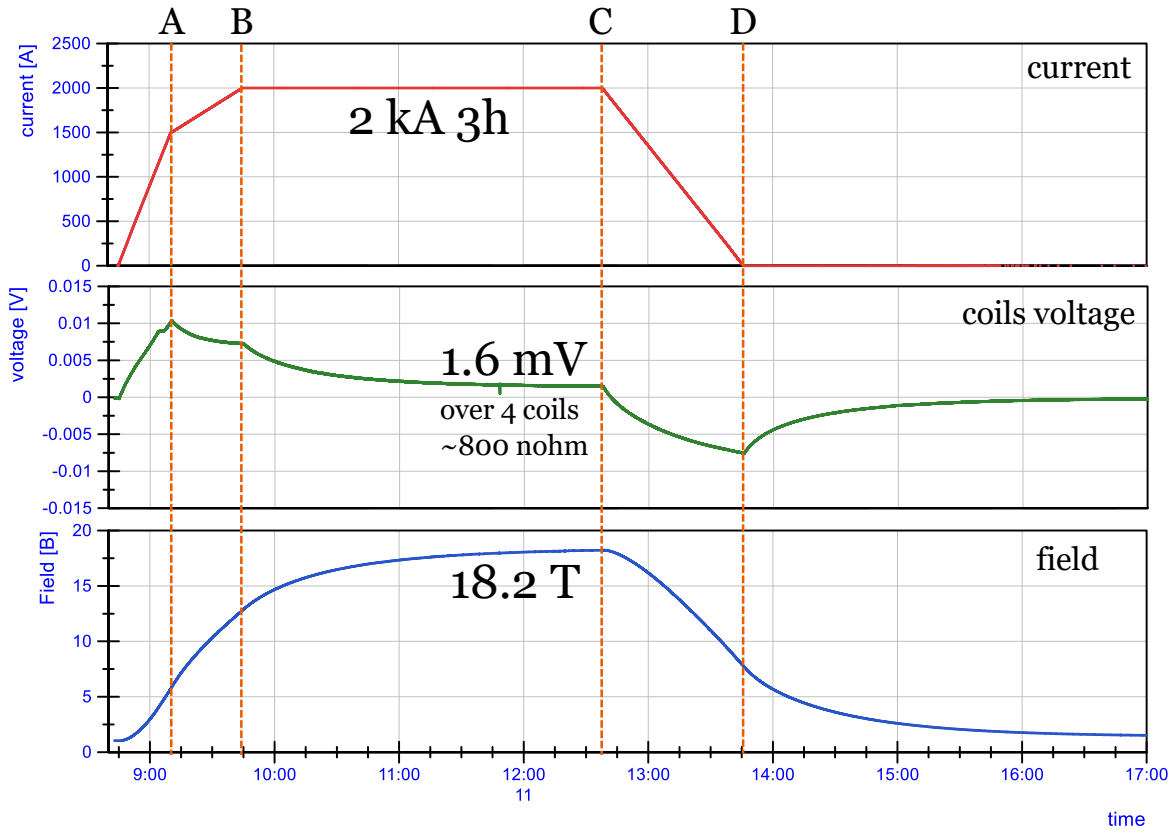
0-A:
- fast ramp up with 1 A/s
- coils temp regulated by external heaters

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

4-stack 10+ K test 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

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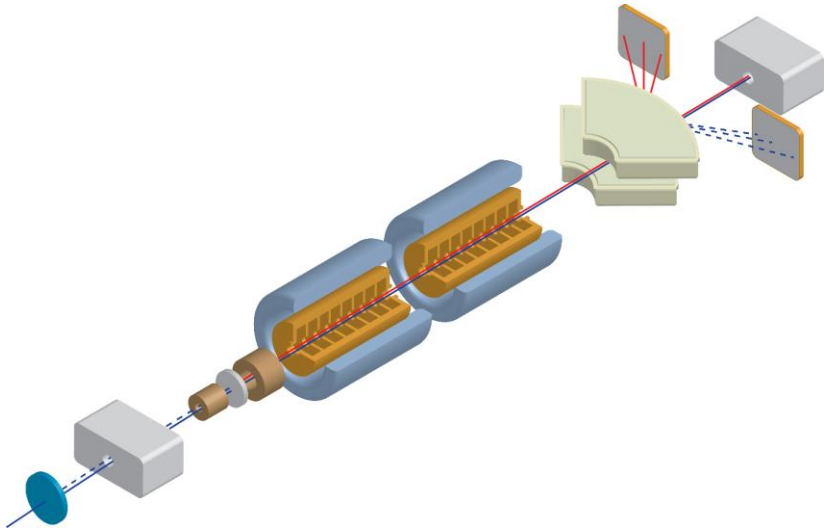
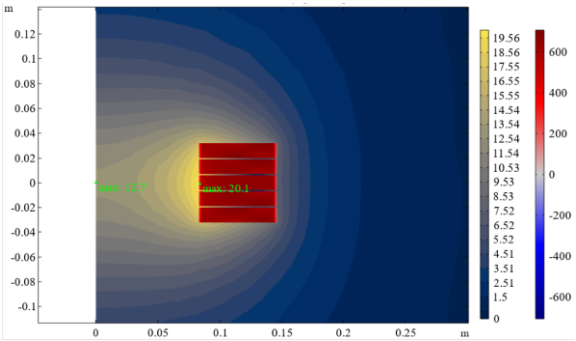
   - bulk-HTS (REBCO) undulators
3) – HTS capture solenoid for a positron source



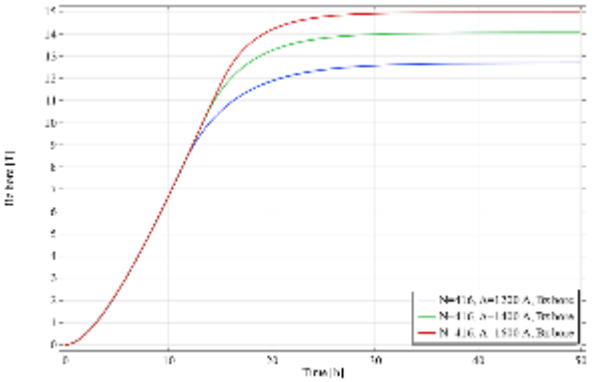
NI HTS AMD 5-stack concept

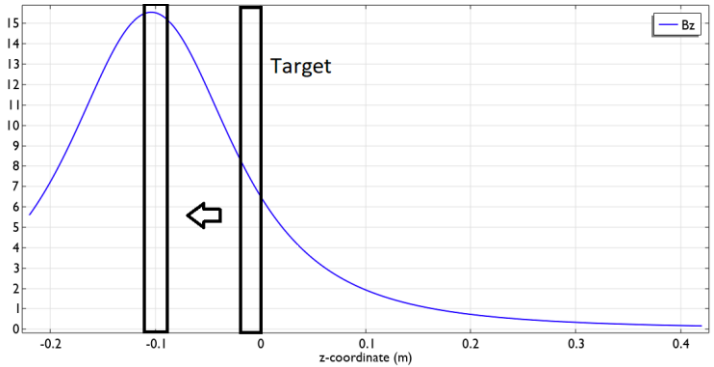
- J 630 A/mm2
- R_i 72 [mm]
- R_o 146 [mm]
- W 12 [mm]
- Spacing 1 [mm]
- Top 20 [K]

- 3.2 km tape



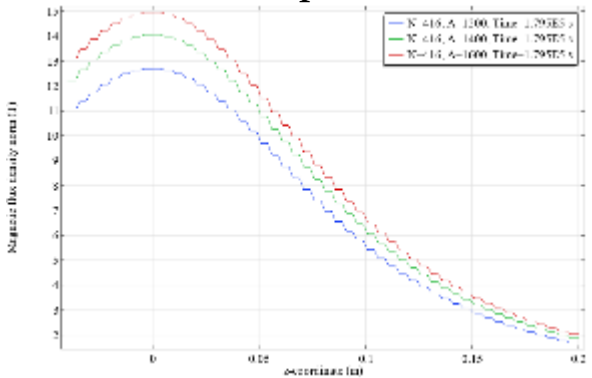
powering



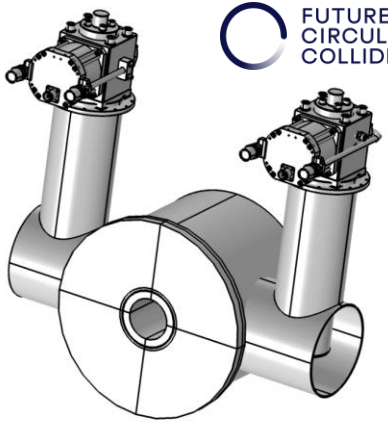


See details about yield optimalisation in Yongke ZHAO presentation

field profile



NI HTS AMD solenoid proposal

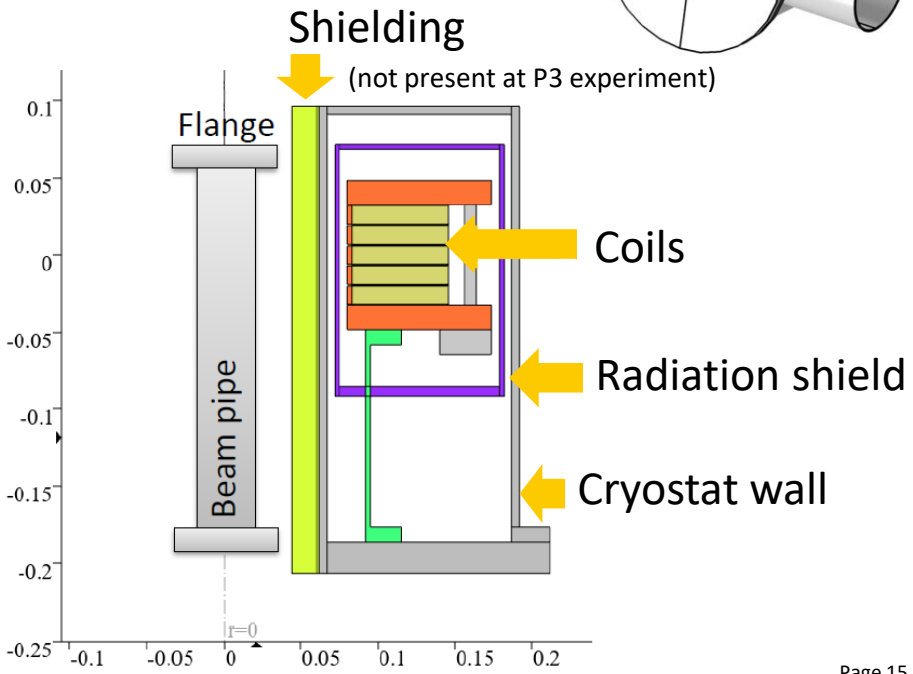


Some of the FCC-ee requirements are not present in the P3 experiment:

- A much lower energy deposition in target is expected thus **no cooling needed**

- **An aperture of 72 mm** optimized to fit the CF40 flanges (69.9 mm) of the beam pipe, and to satisfy the radiation shielding for FCC

- **No need of shielding** - heat load and long-term radiation damage studies – see details in Barbara Humann talk



Summary

- Licensed NI HTS coils technology transfer from Tokamak Energy Ltd to PSI was very successful
- 2 kA cryogen free test station fully commissioned and operating
- Successful test of 4-pancake HTS NI solenoid, **built in-house at PSI reached 18.2 T** field in bore during the 3 h test heating up to less then 12 K
- Future plans:
  - stack of 4 coils 24 h plateau test scheduled in June
  - stack of 5 coils tests later this summer
  - scale-up of demonstrated technology for positron source experiment

Acknowledgements
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