# Progress in the Construction of the HFML 45 T Hybrid Magnet

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**H**igh **F**ield **M**agnet **L**aboratory (HFML-EMFL),
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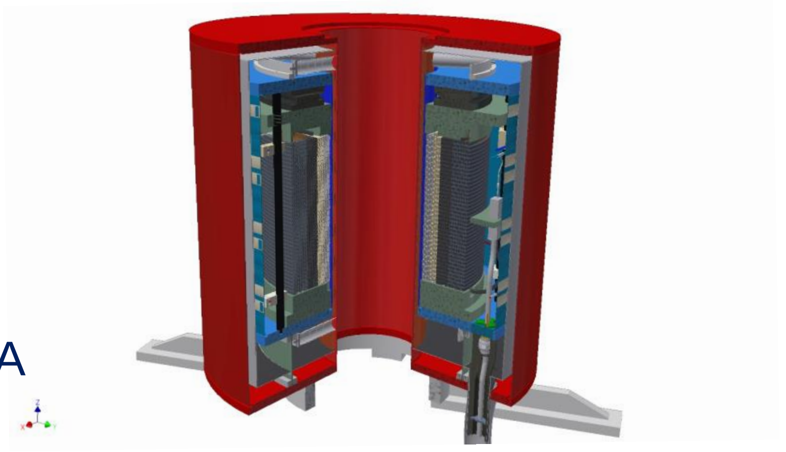
# HFML 45 T Hybrid Magnet program

- Combined on-axis field 45 T
- Resistive Florida-Bitter type **insert** magnet generates 33 T at 40 kA, 22 MW
- Superconducting $Nb_3Sn$-CICC based **outsert** magnet delivers 12.3 T at 20 kA
- Insert bore 32 mm, outsert RT bore 620 mm

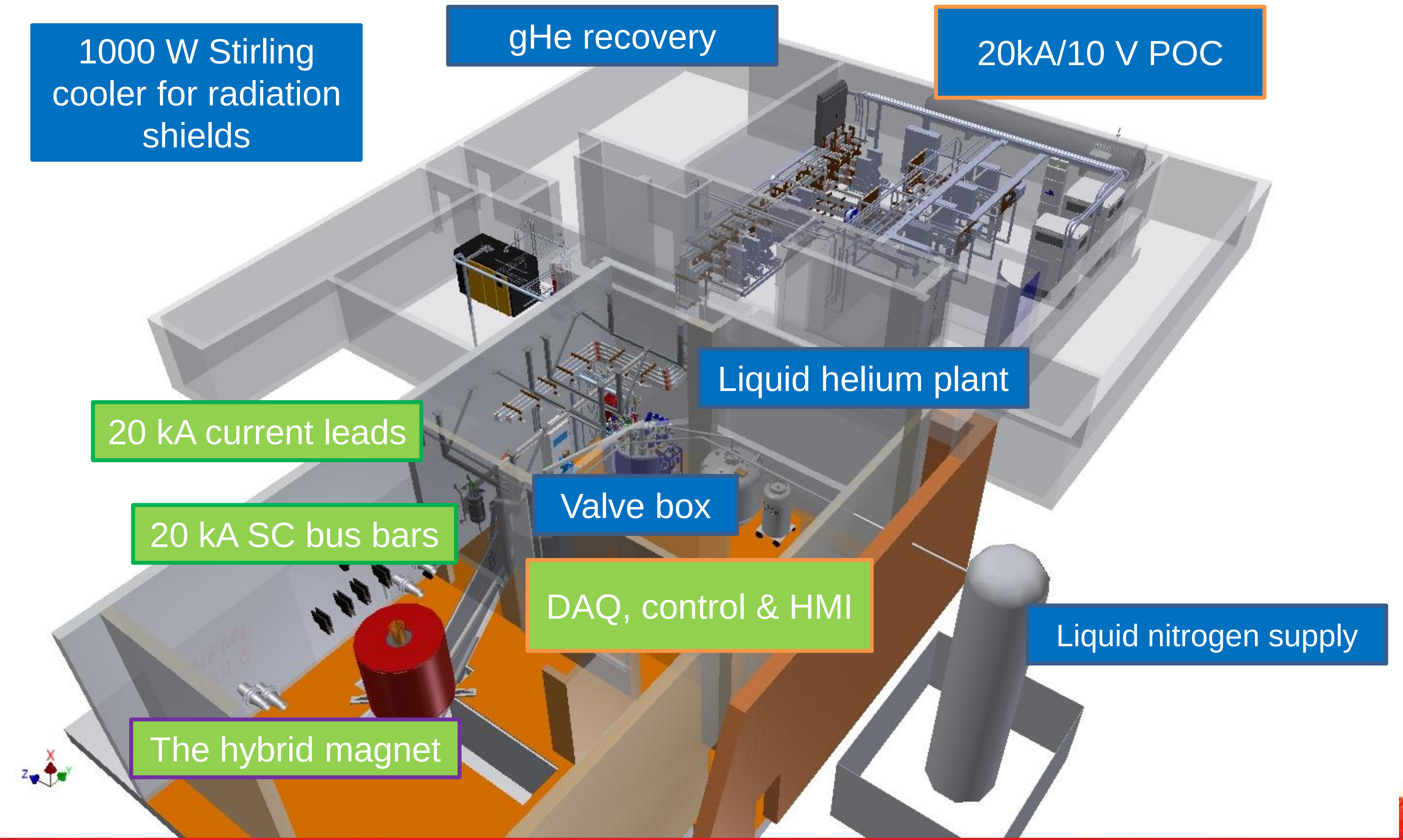


**Collaboration** with US-NHMFL (SCH program)

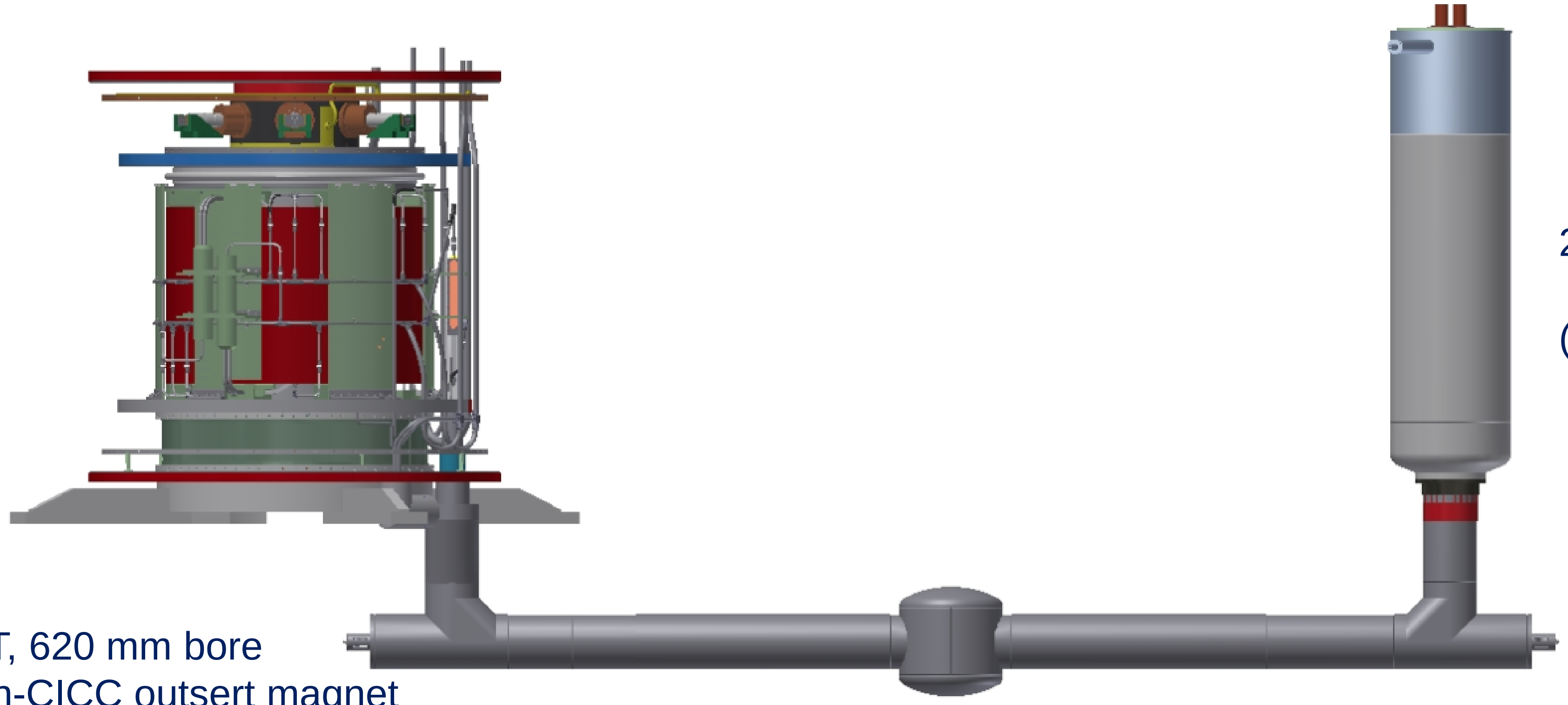
- common CICC design, outsert coil design & fabrication

- Cu-HTS current lead development

# Hybrid Magnet SYSTEM



# Superconducting outsert circuit HFML 45 T hybrid magnet



20 kA Cu-HTS current leads

(*HFML-NHMFL collaboration*)

12.3 T, 620 mm bore
$Nb_3Sn$-CICC outsert magnet

(*fabricated at NHMFL*)

4.5 meter superconducting bus bar (HFML)
(Al-stabilized NbTi-Rutherford cable)

# Outsert 20kA power converter

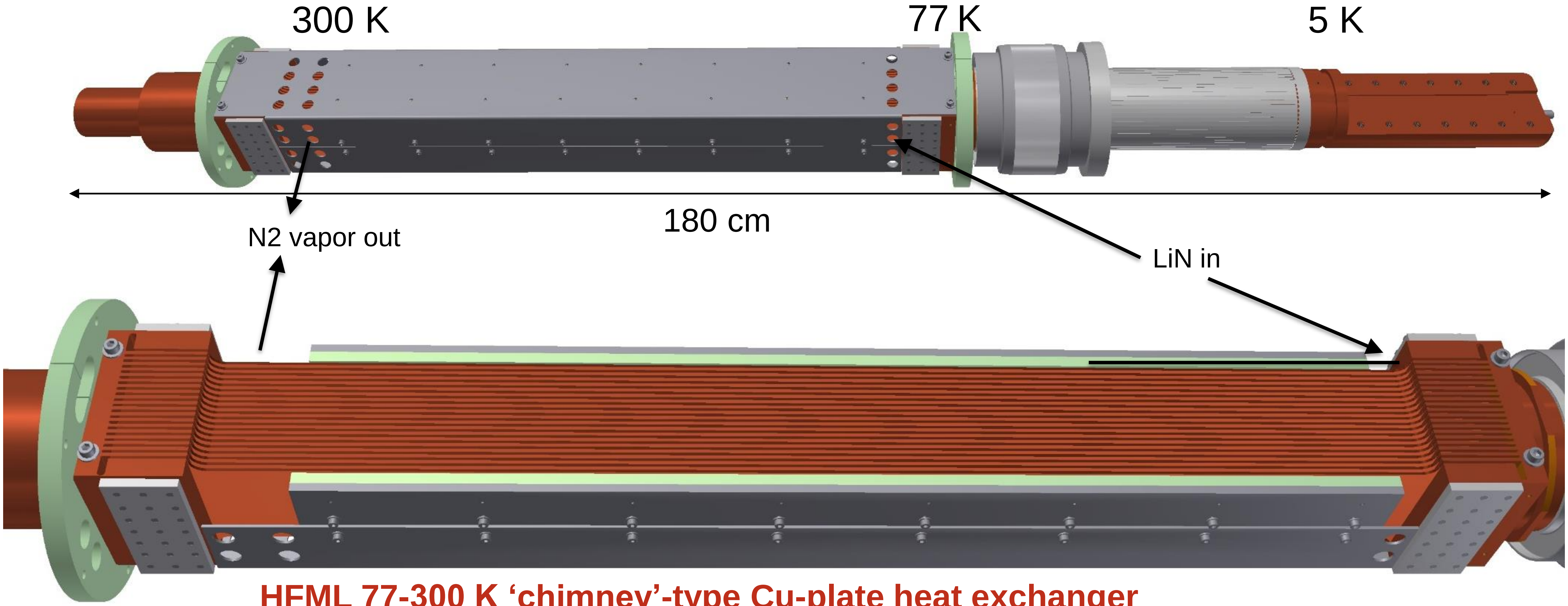
(protection breakers, dump resistors and bus bars to magnet cell)

(*manufactured by Ampulz B.V., The Netherlands*)

Installation, test  and commissioning
July 2015

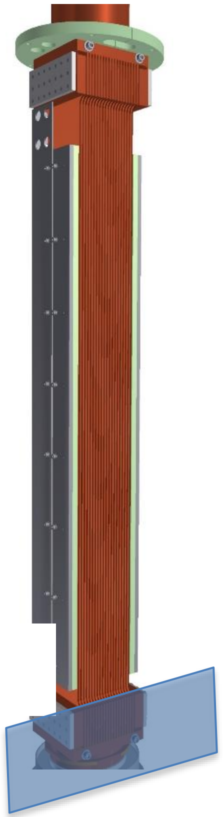
# 20kA, binary Cu-HTS (Bi2223), LiN cooled current leads

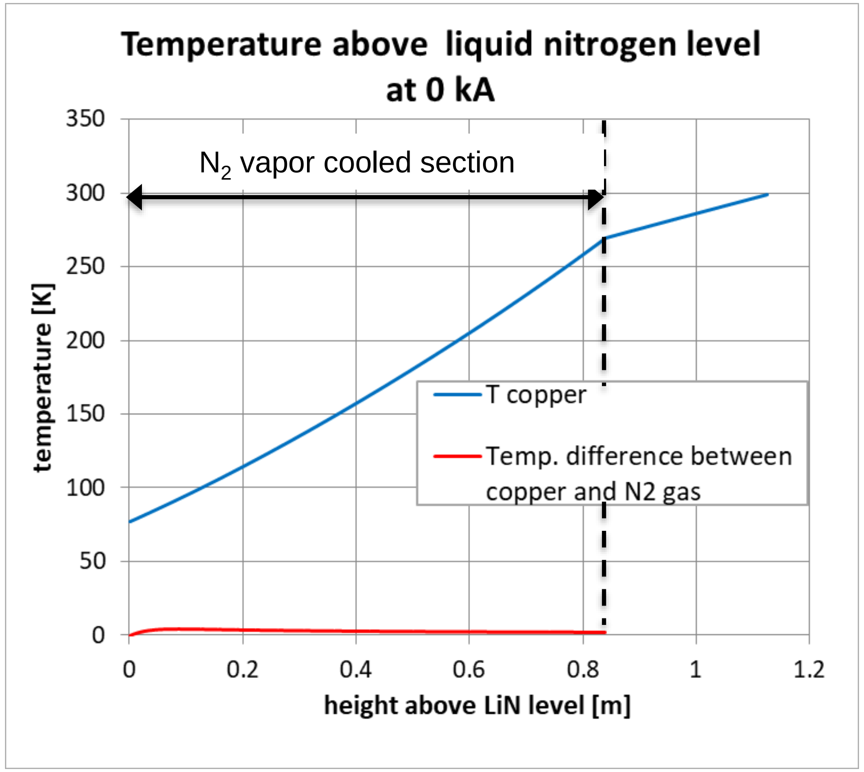
*(in collaboration with NHMFL, USA)*




HFML 77-300 K ‘chimney’-type Cu-plate heat exchanger

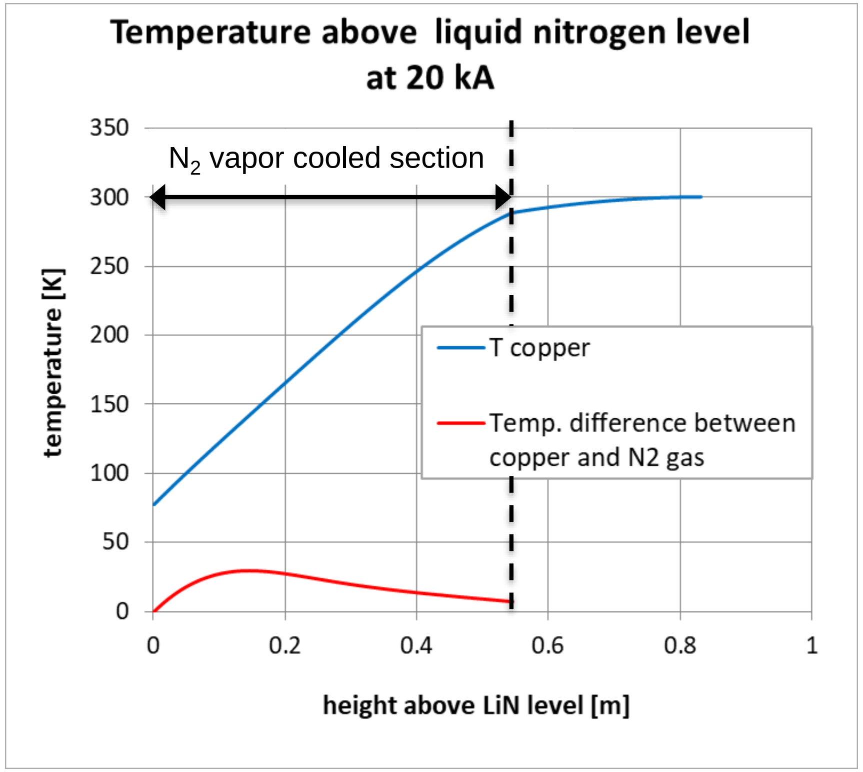
# Calculated temperature profiles resistive section (RRR ~ 5, $T_{warm}$ = 300 K)

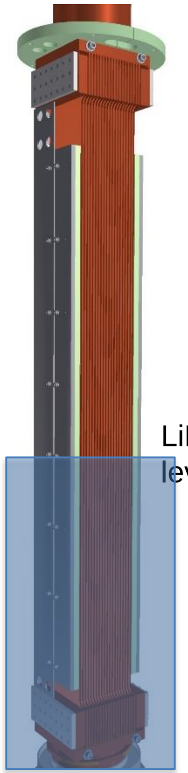



I = 0 kA

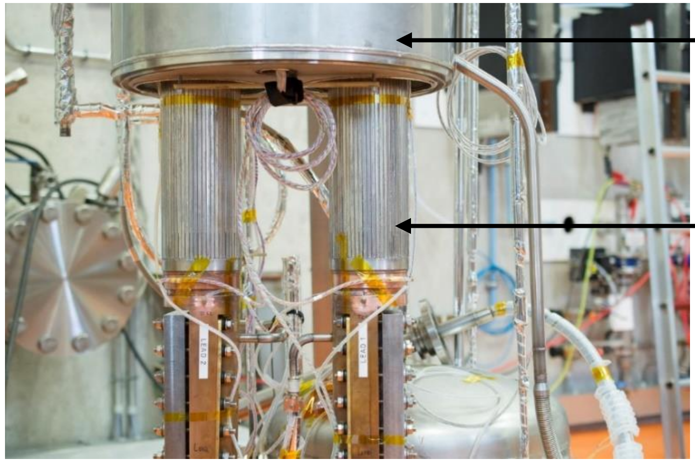
Pcold = 167 W/lead
Pwarm = 335 W/lead



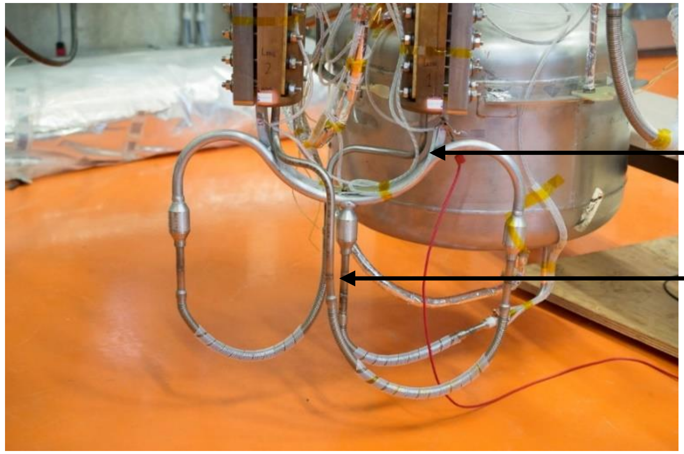

I = 20 kA
$V_{resistive}$ = 47 mV
Pcold = 620 W/lead (14 litre LiN/h)
Pwarm = 2 W/lead

# 20kA Cu-HTS, LiN cooled current leads



LiN vessel Cu-HEX

BiSrCaCuO(2223) section



Al stabilized NbTi jumper

Supercritical helium cooling channel @ 6 bar, 5 K

Test  and commissioning 2018
Ready for integration into CL cryostat

# Cryogenic components

Aluminium 20 kA bus bars

Cryo-line to Stirling cryo-cooler

Current leads location

Cryo-line valve box - magnet cryostat

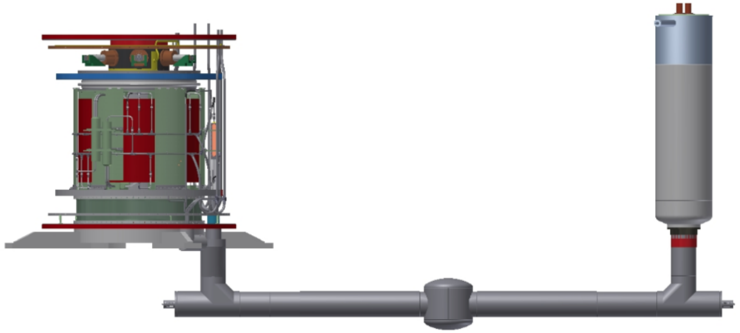
Valve & distribution box

Helium refrigerator/ liquefier in operation

All components ready for testing and integration

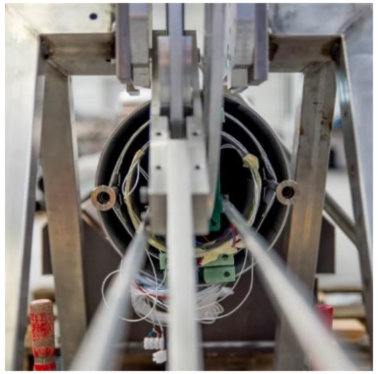
# Superconducting bus bars between current leads and cryostat

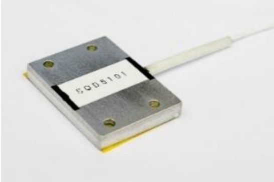
*(in collaboration with Cryoworld B.V., the Netherlands)*



Actively cooled Al-stabilized NbTi Rutherford cable
(CERN-ATLAS ECT grade, 5T, 4.2 K, 60 kA )

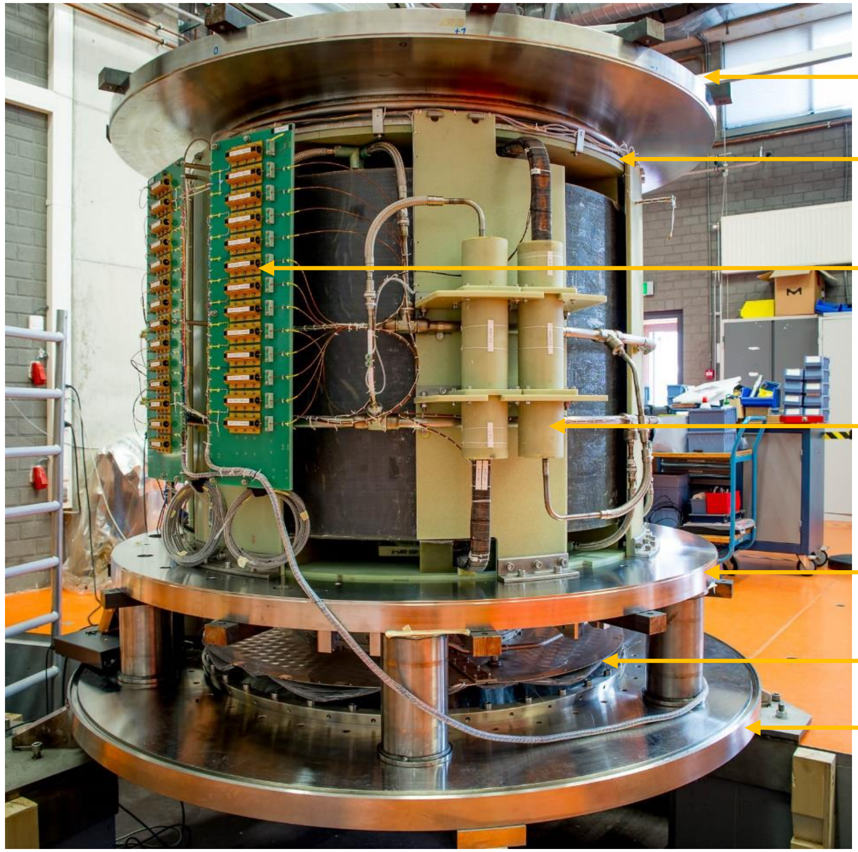
Thermal strain relief





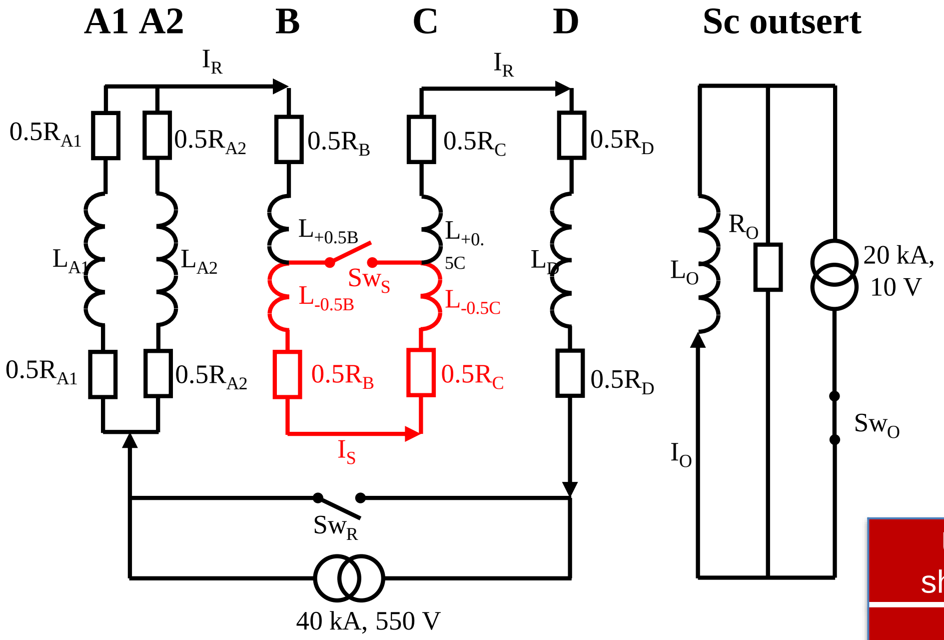
**S**uperconducting **Q**uench **D**etector (developed at CERN)

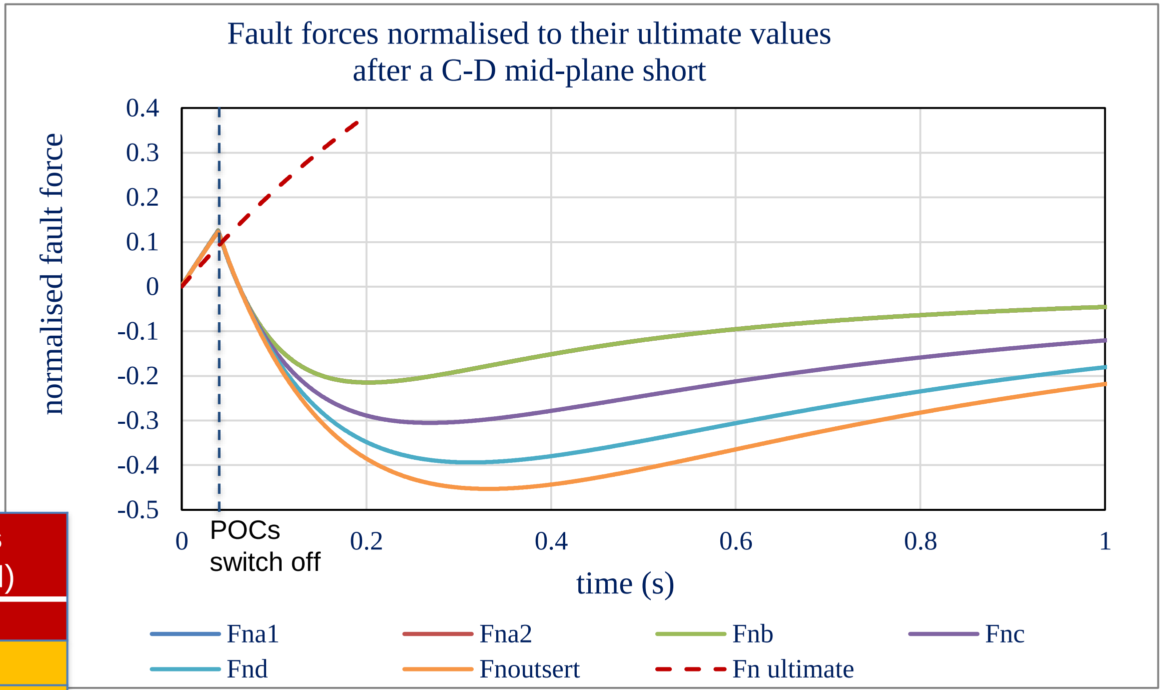
# 12.3 T $Nb_3Sn$-CICC superconducting outsert magnet




Coil manufacturing by NHMFL completed in 2018
Integration in cryostat well underway
All parts of cryostat have been manufactured

# Axial fault forces after insert coil failure *(Presented Tue-Po2.15-03)*




| PROPERTIES INSERT COILS | | | | | |
|---|---|---|---|---|---|
| | A1 | A2 | B | C | D |
| operating current (kA) | 13 | 27 | 40 | 40 | 40 |
| current density ($A/mm^2$) | 603 | 345 | 214 | 111 | 95 |
| power density ($W/mm^3$) | 9.9 | 3.1 | 1.2 | 0.23 | 0.17 |
| uncooled heating rate (K/s) | 2868 | 900 | 338 | 67 | 50 |
| voltage drop (V/winding) | 2.0 | 2.0 | 2.7 | 1.6 | 2.1 |

| Ultimate static fault forces shorted coils at mid-plane (kN) | | |
|---|---|---|
| | B-C | C-D |
| A1 | 83 | -54 |
| A2 | 600 | -389 |
| B | -1032 | -1383 |
| C | -1829 | 1694 |
| D | 1274 | 2988 |
| Outsert | 903 | -2856 |

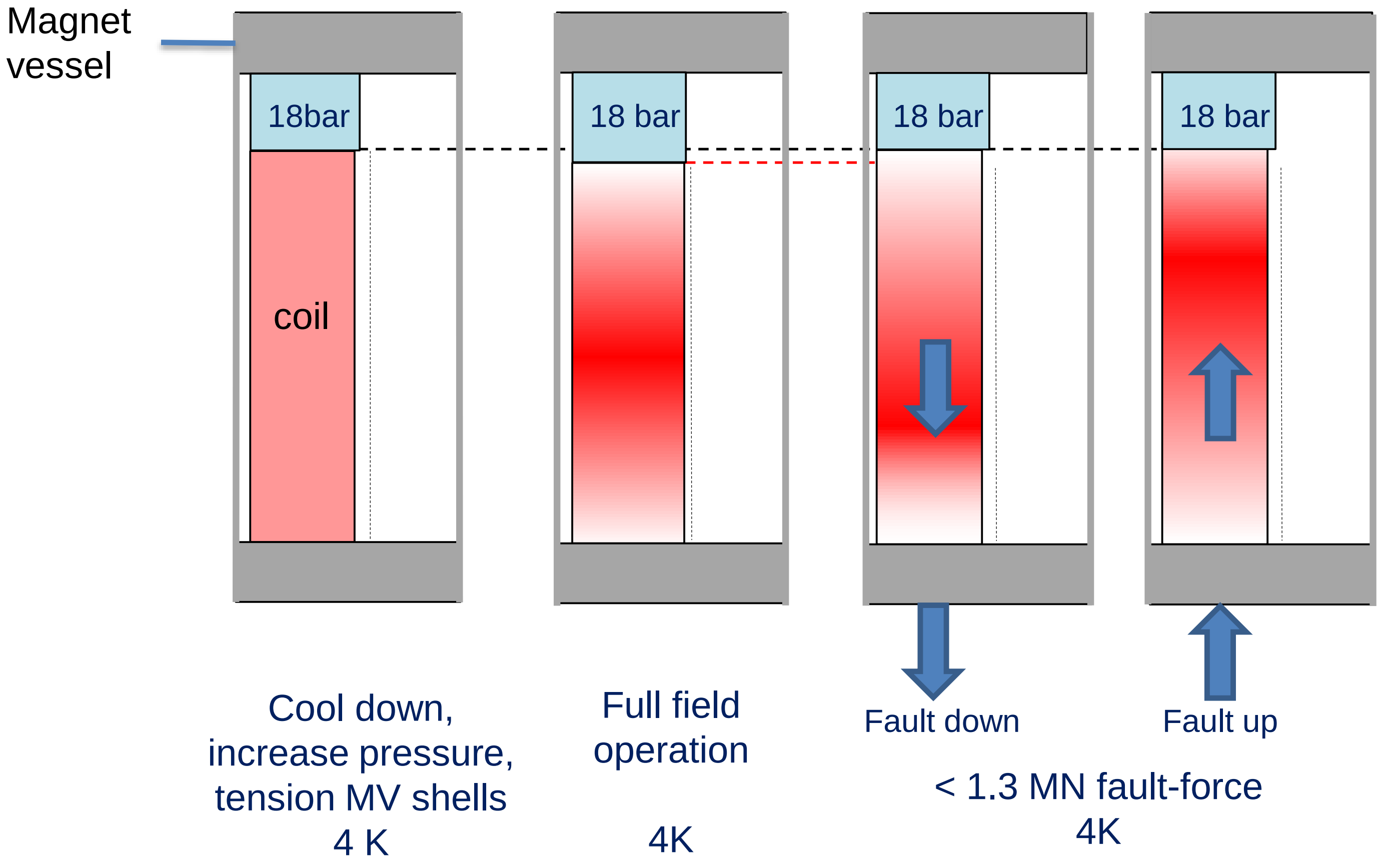
If coil protection systems work properly:

- Fault forces stay well within 50% of ultimate
- Fault forces change sign = direction

# Axial support handling fault forces outsert:  HFML approach

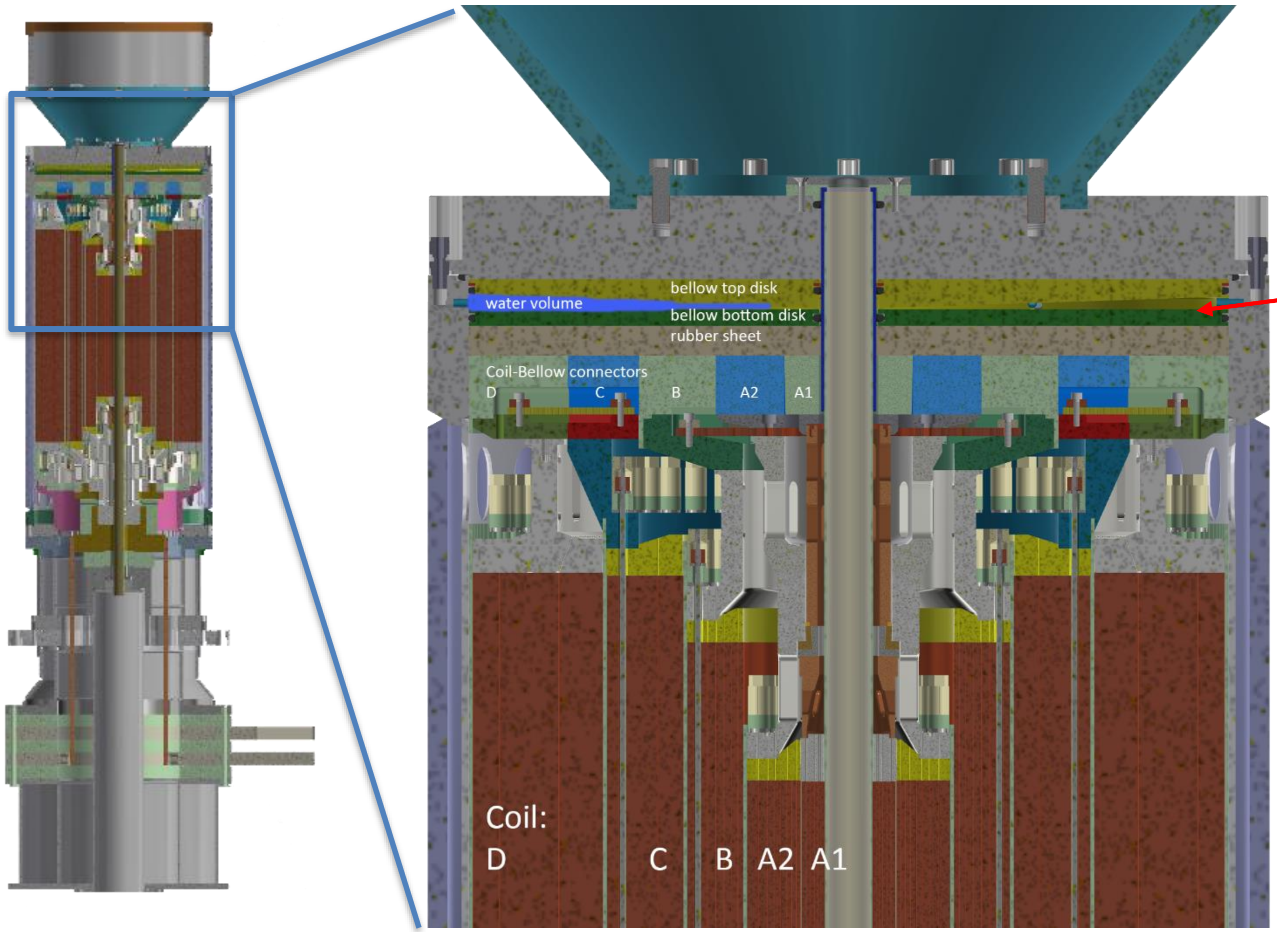
During an insert fault a constant stress in inner & outer shell of Magnet Vessel  at 4.5 K is maintained with a pressurised helium gas bellow ( $p_{op}$ < 30 bar)


Force constant: 73 kN/bar
Axial stiffness: 17 kN/mm
Lateral stiffness: 1.2 MN/mm
Minimum gas volume: 7 $dm^3$



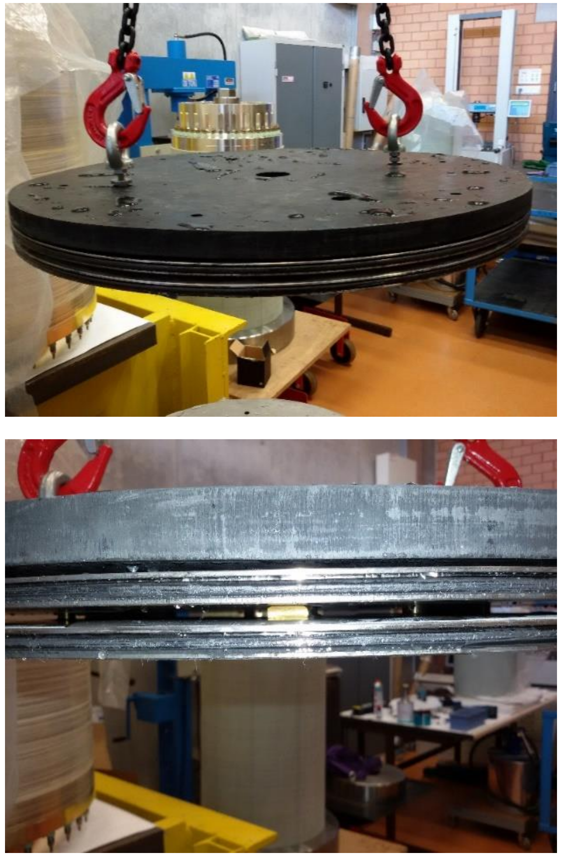
# 33 T Florida-Bitter insert magnet (40 kA, 22 MW)

*(presented Tue-Po2.15-02)*




100 bar hydraulic pre-compression 'bellow'

- Mitigates end-turn issues
- Sustains axial fault forces



Mock-up test hydraulic bellow

All insert coil components being purchased

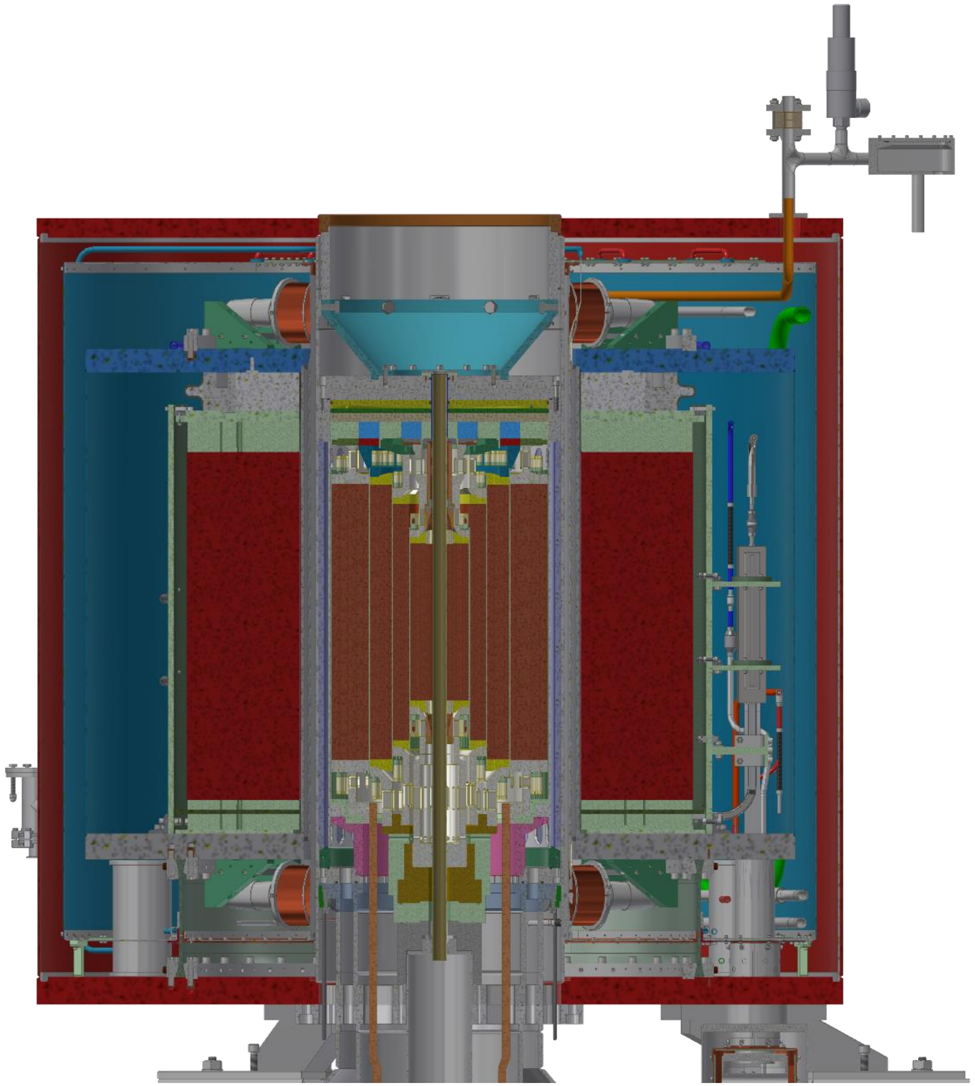
## Summary

Key components for the outsert magnet nearly ready for integration

Insert components are being purchases or manufactured

Control & monitoring systems in production
(quench detection, cryogenics, magnet operation)

Commissioning expected to start mid 2020



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**HFML**

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**Technical Advisory Committee**

H. ten Kate (UT-CERN), A. Bonito-Oliva (F4E), P. Bruzzone (EPFL/CRPP) and U. Wagner (CERN)

| | Insert | Outsert |
|---|---|---|
| operating current $I_i$ , $I_o$ (A) | 40,000 | 20,000 |
| contribution to central field (T) | 32.7 | 12.3 |
| free RT bore diameter (mm) | 32 | 600 |
| expected # powering cycles | 30,000 | 3,000 |
| cooling medium | forced flow water (~ 140 l/s) | forced flow supercritical helium (~ 11 g/s@5 bar) |
| operating temperature $T_{op}$ (K) | < 360 | 4.6 |
| self inductance (mH) | 5 | 266 |
| mutual inductance (mH) | 11 | 11 |
| (dump) resistance $R_i$ , $R_o$ (m$\Omega$) | 15 | 130/2.5 |
| decay time constant ($L/R$) (s) | 0.3 | 2.0/106 |
| required power (MW) | 21.5 | 0.2 |
| stored energy (MJ) | 5 | 55 |