Status of the HFML-Nijmegen 45 T Hybrid Magnet

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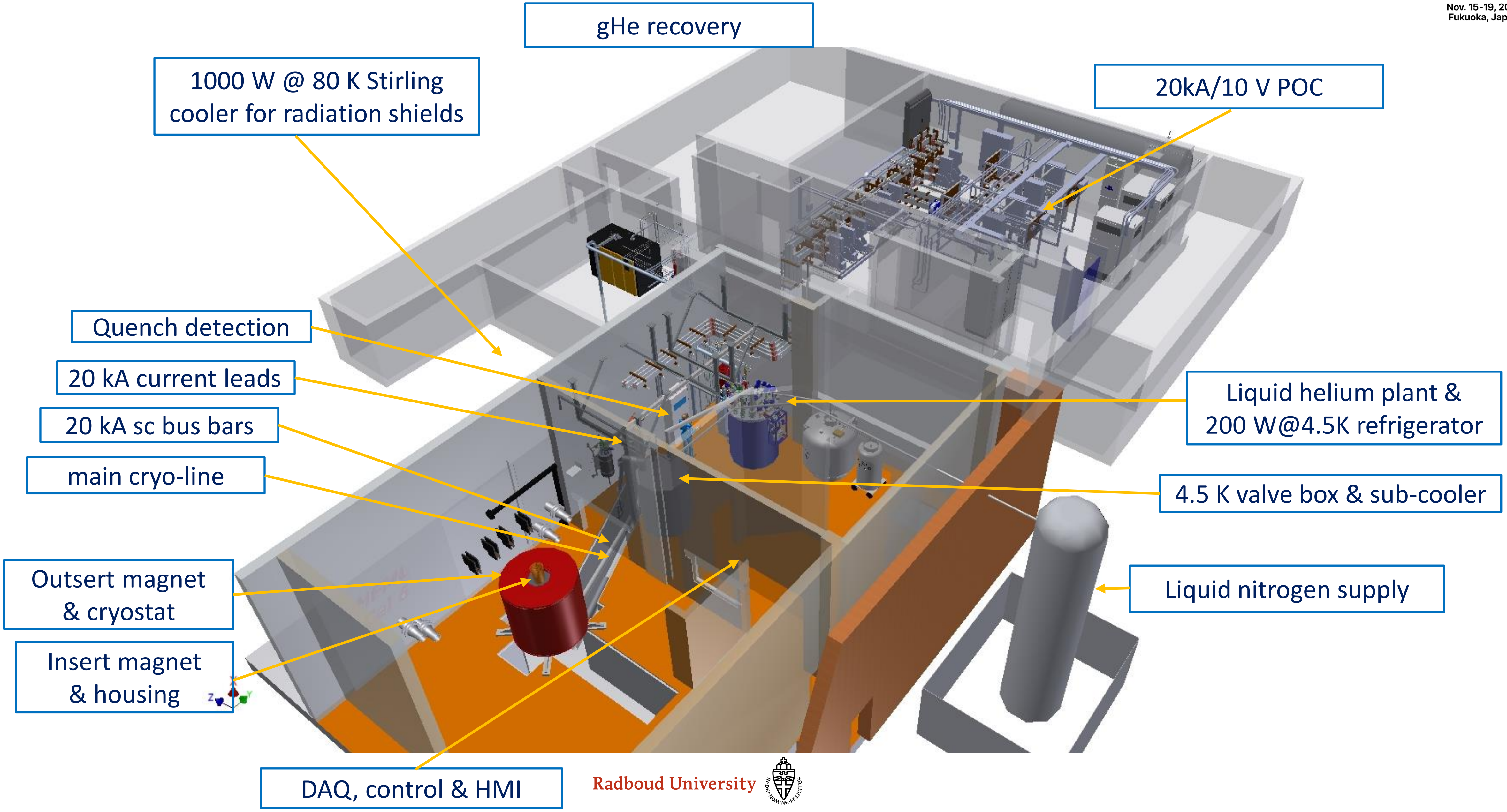
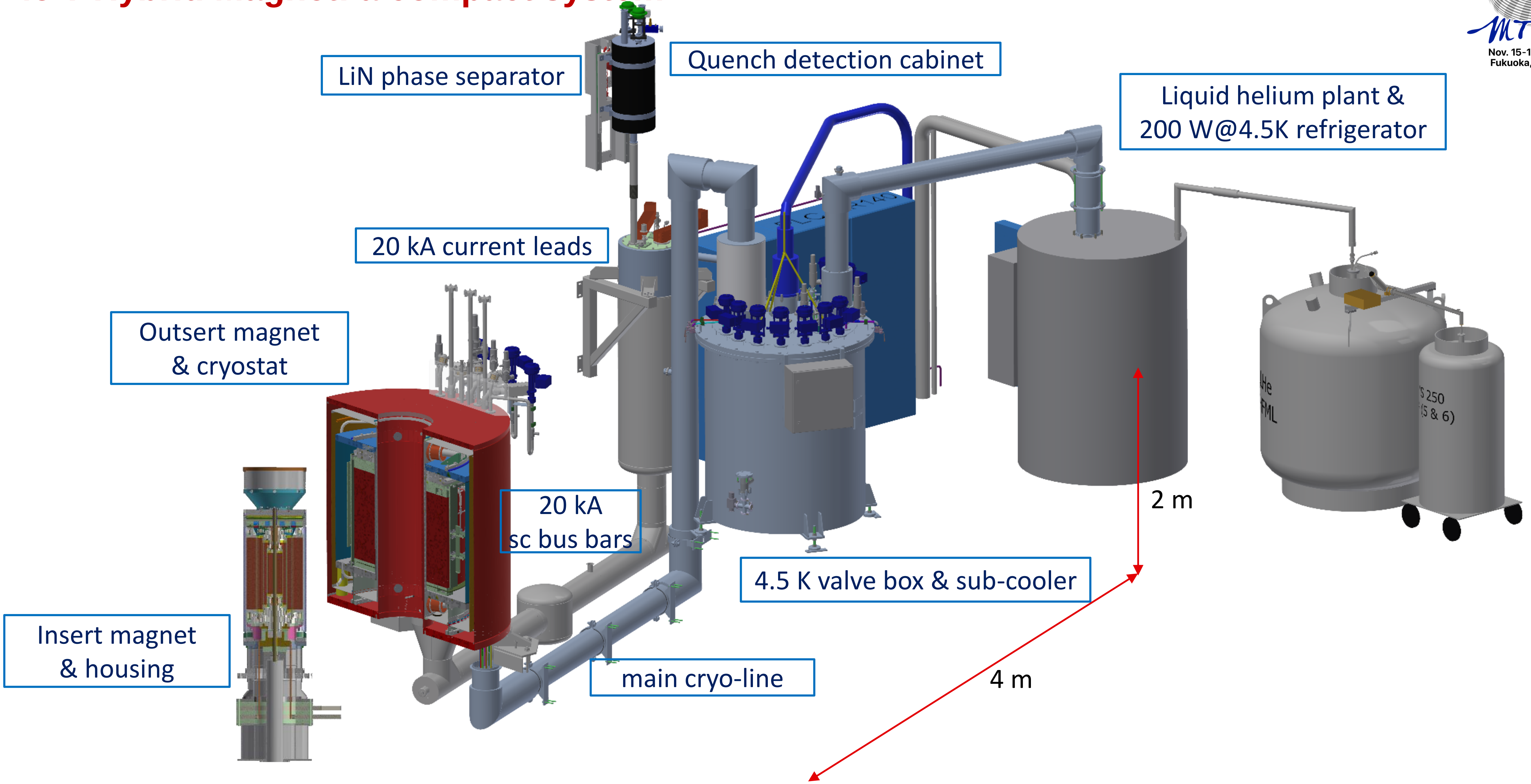
HFML Science in High Magnetic Fields | FELIX Free Electron Lasers for Infrared eXperiments | Radboud University | NWO | EMFL European Magnetic Field Laboratory | National High Magnetic Field Laboratory

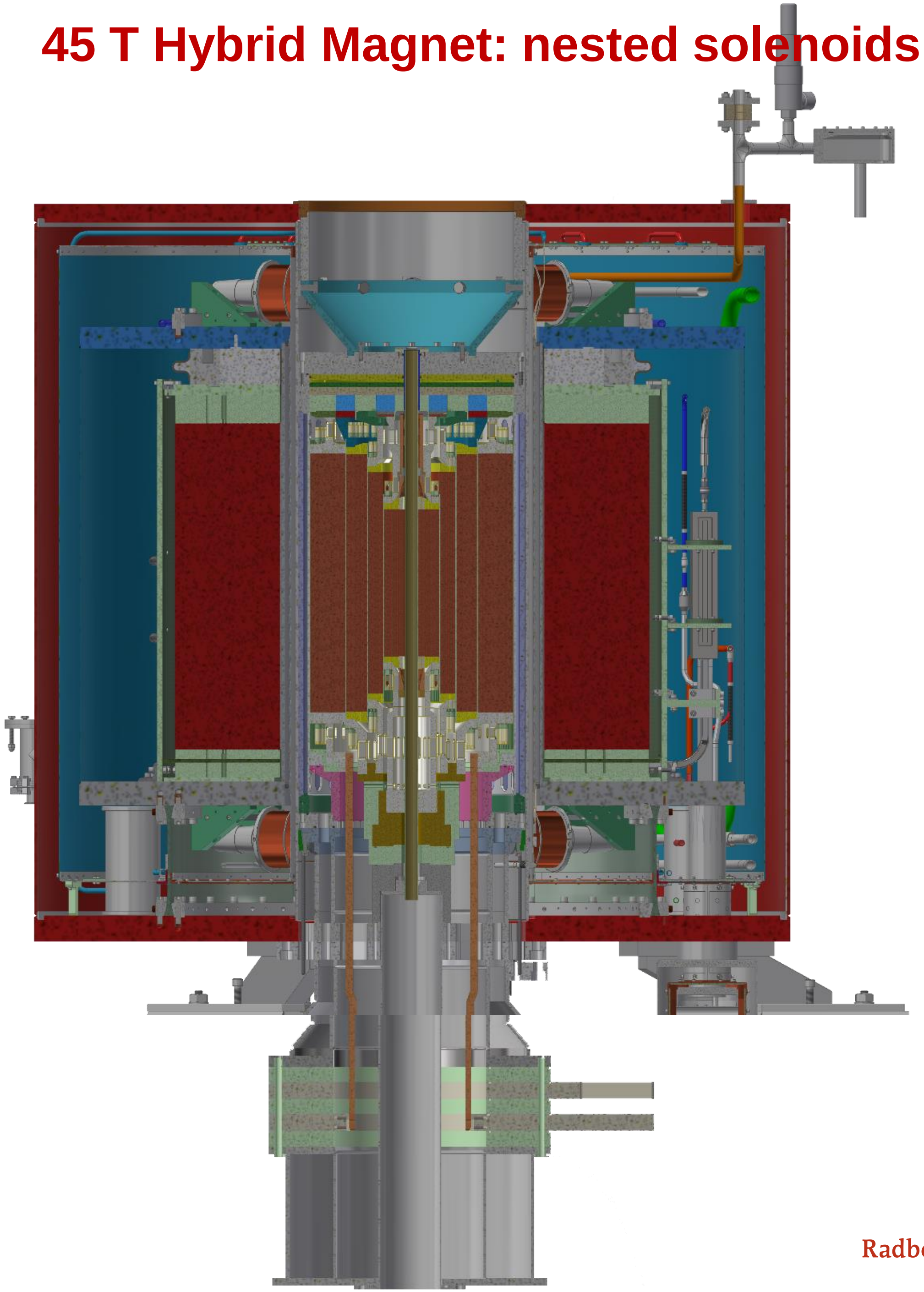
45 T Hybrid Magnet System



45 T Hybrid Magnet: a compact system



45 T Hybrid Magnet: nested solenoids



	Insert	Outsert
conductor type	Cu alloy Florida-Bitter disks	Nb_3Sn/Cu-CICC
# of nested coils	5	1 (5 sections)
operating current (A)	40,000	20,000
field contribution (T)	32.8	12.3
cooling medium	forced flow water (~ 140 ℓ/s)	forced flow supercritical helium (~ 10 g/s@6 bar)
operating temperature (K)	< 350	4.5
required power (MW)	21	0.2
stored energy (MJ)	5	55
free bore diameter (mm)	32	620

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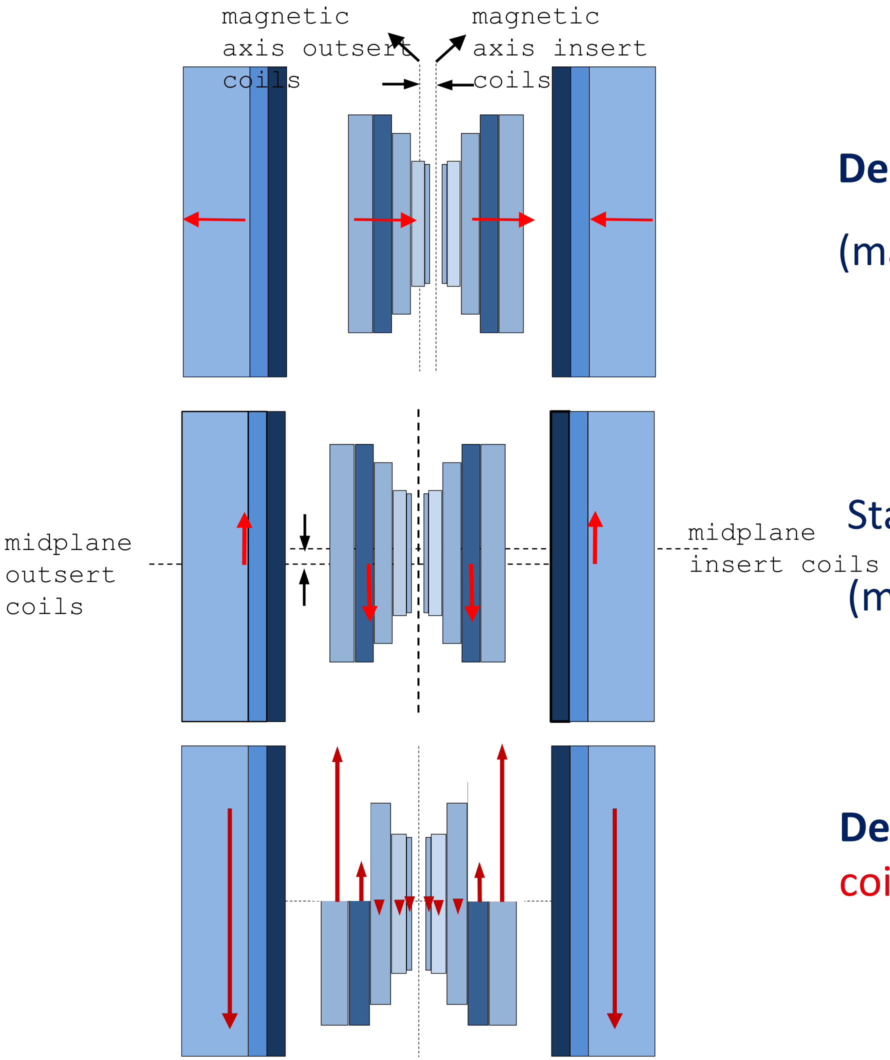
Handling Lorentz forces between insert and outsert coils



Destabilising Radial body force due to misalignment magn. axes (manufacturing tolerances): $\frac{dF_r}{dr} = 22.5$ kN/mm

Stabilising **Axial** body force due to mid-plane misalignment (manufacturing tolerances): $\frac{dF_z}{dz} = 38.5$ kN/mm

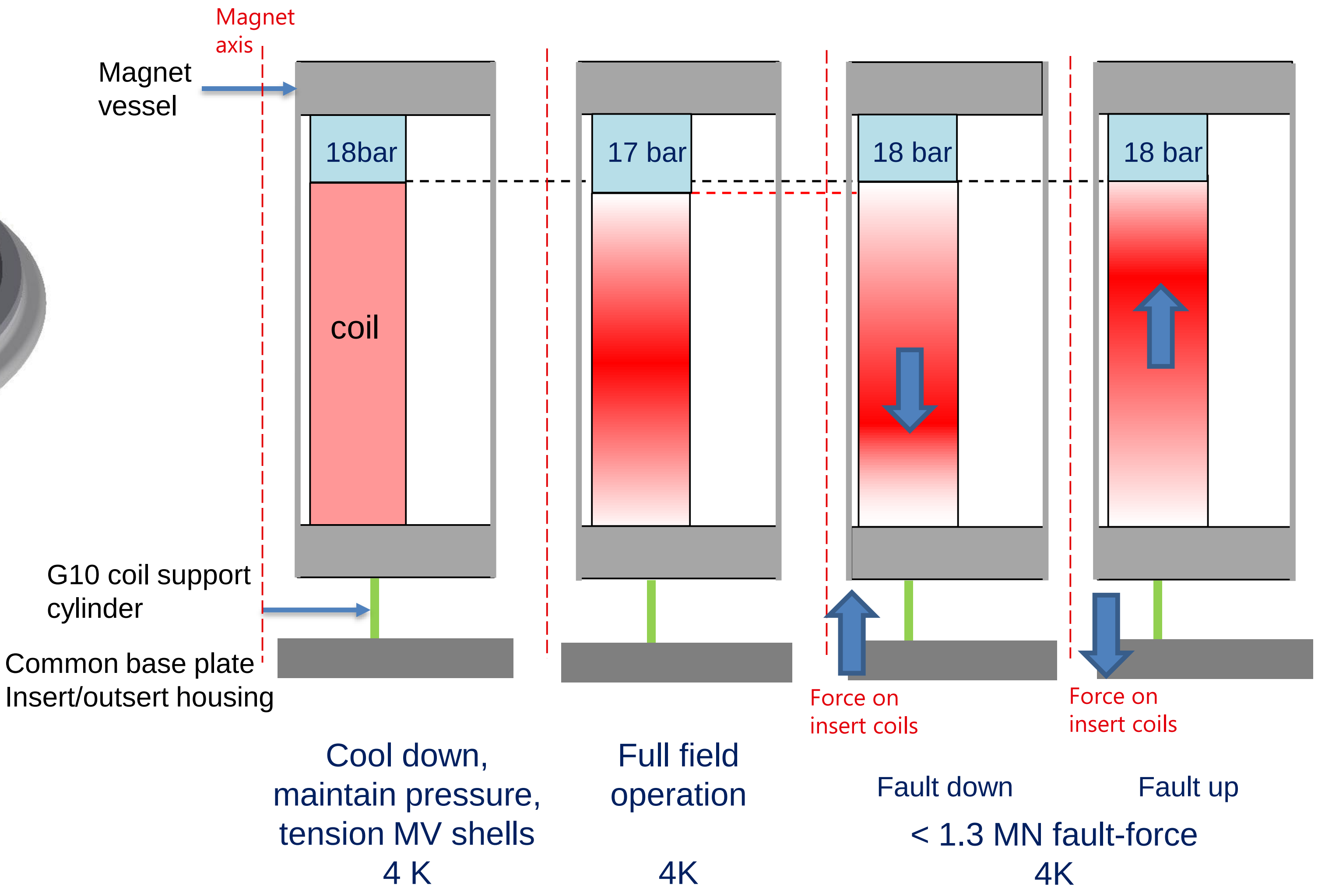
Destabilising Axial (up or down) body force during fault insert coils (e.g. mid-plane short): $F_{fz} < 1.3$ MN

Force path of support structure between insert and outsert coils as short as possible

Handling axial (fault) forces outsert

A nearly constant compressive force on the coils at 4.5 K
is maintained with a pressurised helium gas ‘bellow’ (p_{op} < 20 bar)

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



12.3 T Nb_3Sn-CICC superconducting outsert magnet

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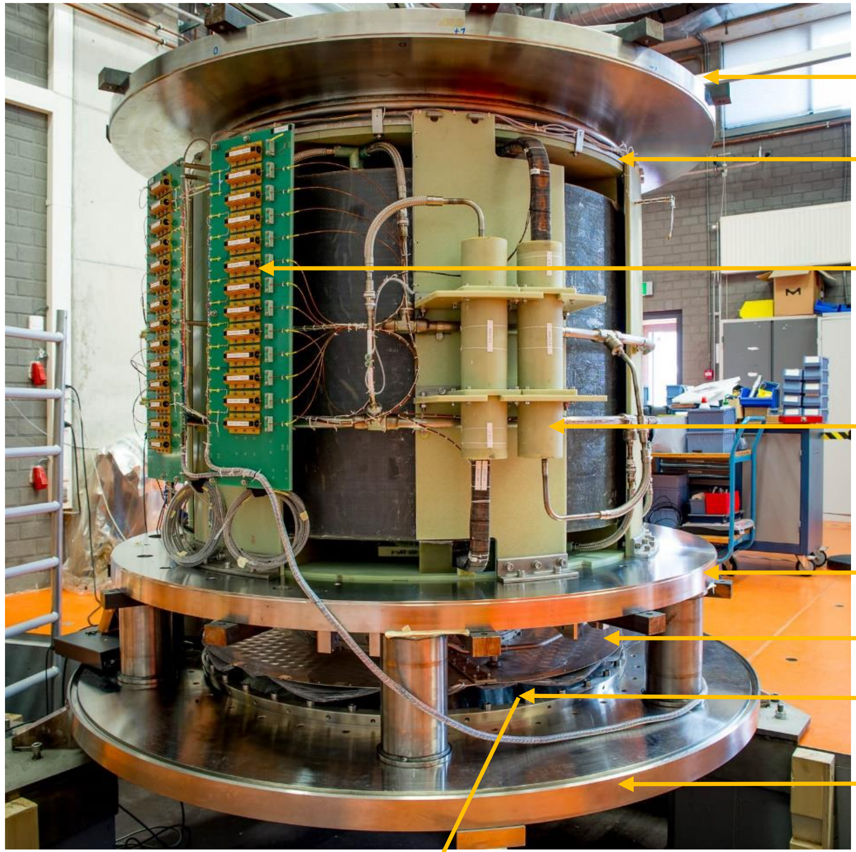

Top plate magnet vessel (1 bar He gas @ 4.5 K)

4.5K and 18 bar helium filled pre-compression 'bellow'

current limiting resistors (13 kΩ) voltage tap wiring

Section joint box

Bottom plate magnet vessel

Pillow plate bottom radiation shield

8 mm thick G10 coil support cylinder (not shown here)

Bottom plate vacuum vessel

Coil manufactured by NHMFL

Integration in cryostat well underway

All parts of cryostat manufactured

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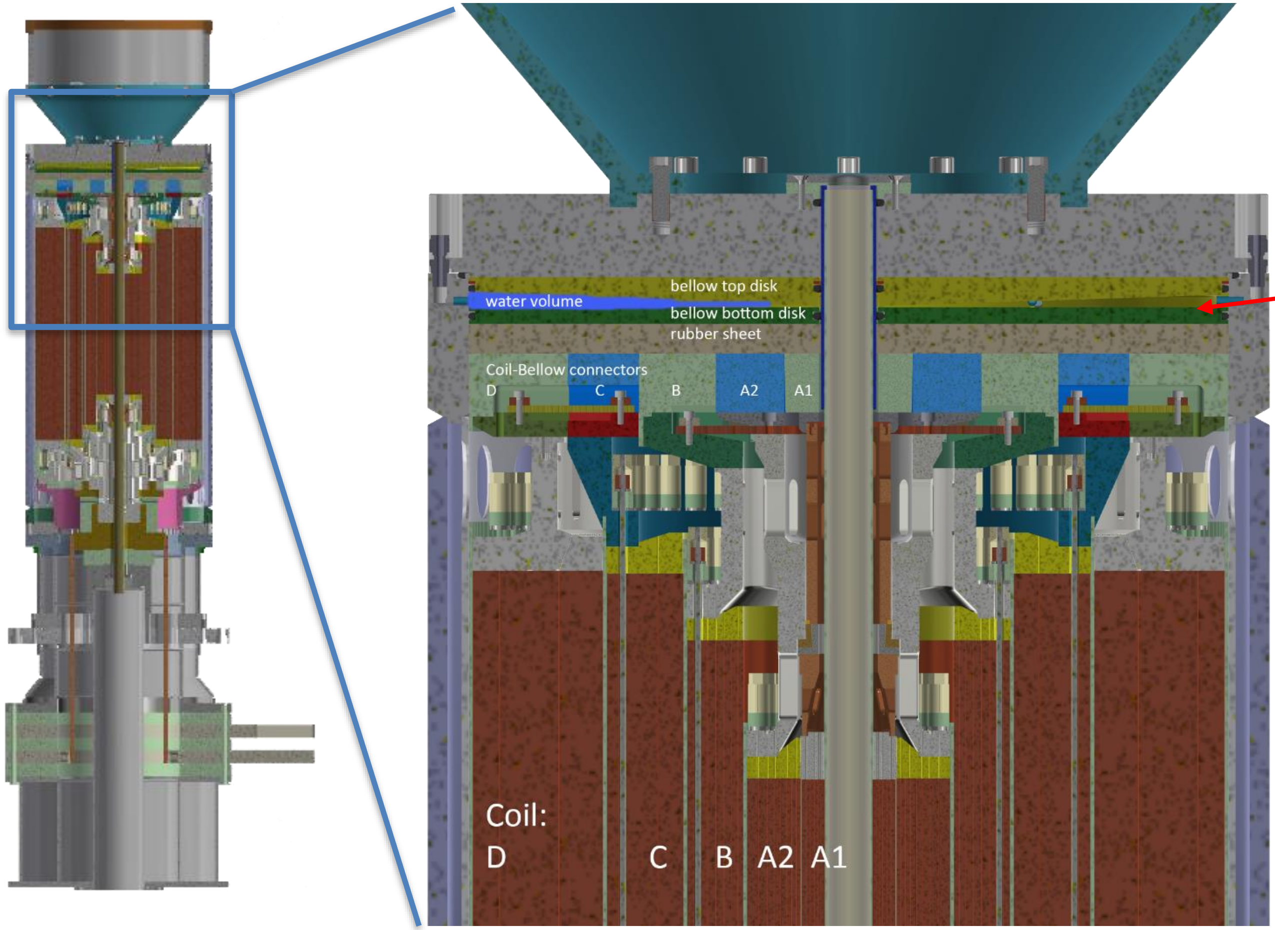
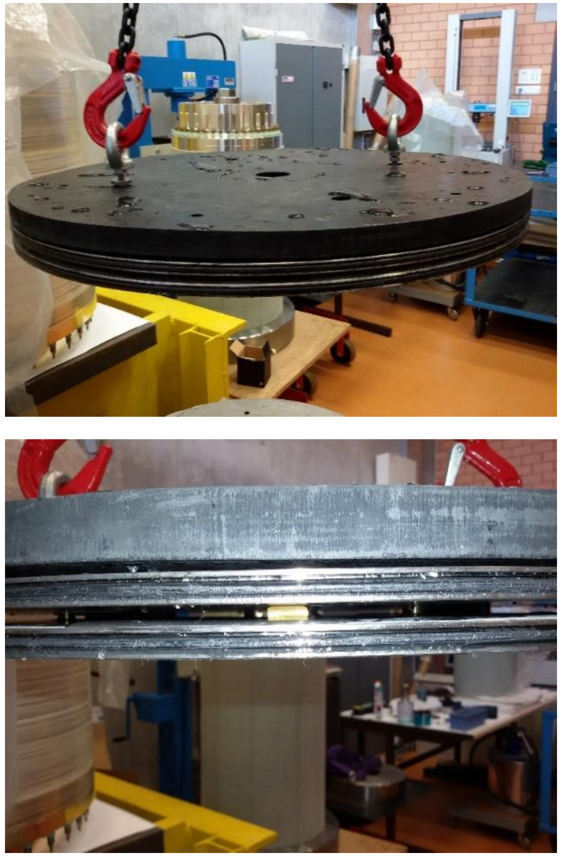
32.8 T Florida-Bitter insert magnet (40 kA, 21 MW)



100 bar hydraulic
pre-compression 'bellow'

- Mitigates end-turn issues
- Sustains axial fault forces

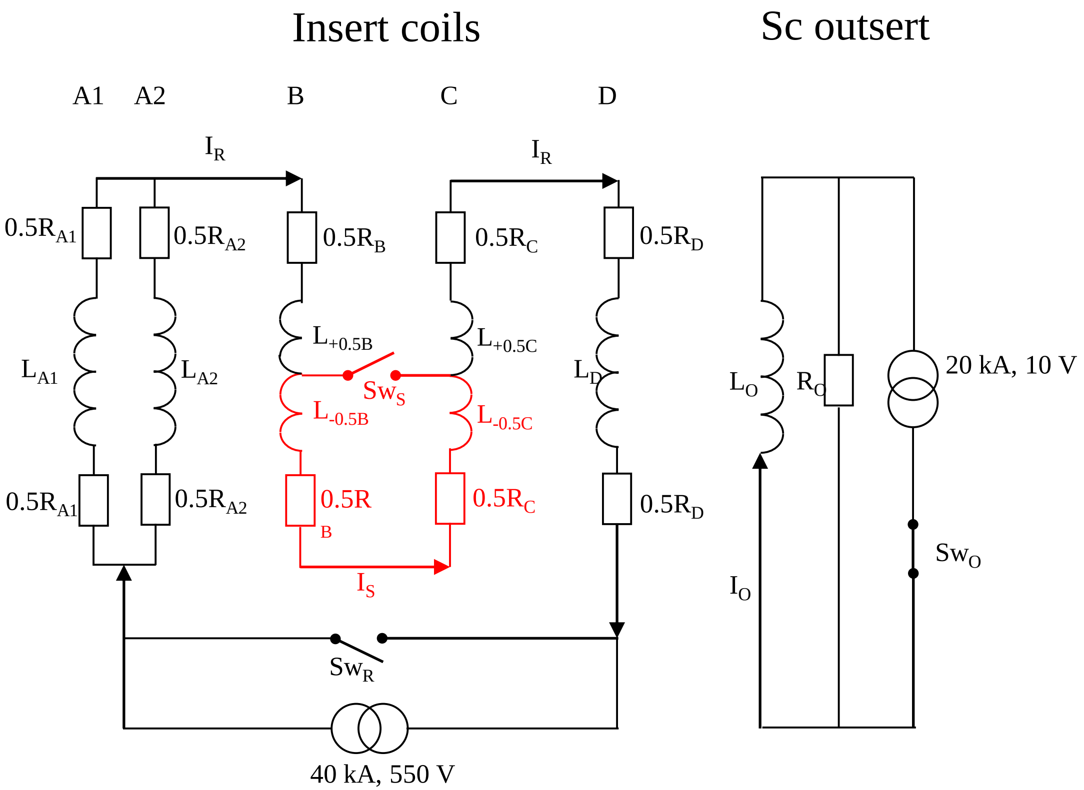
All insert coil and housing components manufactured

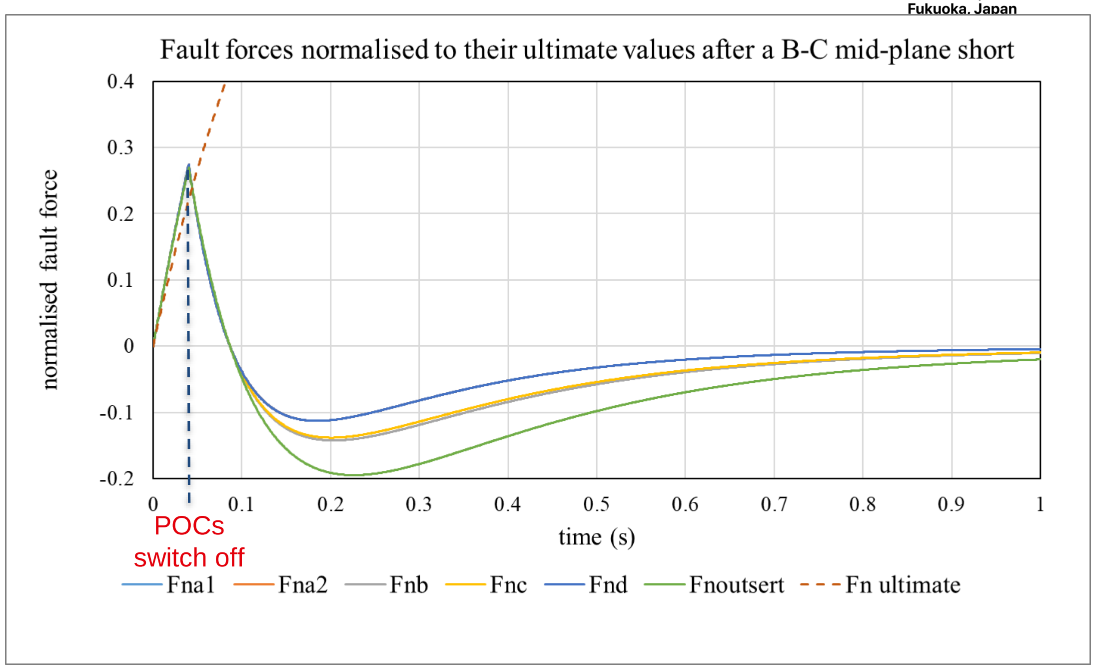


Mock-up test hydraulic bellow

IEEE Trans. Appl. Supercond. vol. 28 (2018) 4902304
IEEE Trans. Appl. Supercond. vol. 30 (2020) 4300204

Axial fault forces (e.g. B-C mid-plane short after insert's coil failure)





PROPERTIES INSERT COILS					
	A1	A2	B	C	D
operating current (kA)	13	27	40	40	40
current density (A/mm²)	603	345	214	111	95
power density (W/mm³)	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 B-C coils at mid-plane (kN) (No protective actions)	
A1	83
A2	600
B	-1032
C	-1829
D	1274
Outsert	903

Provided coil protection systems work properly:

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

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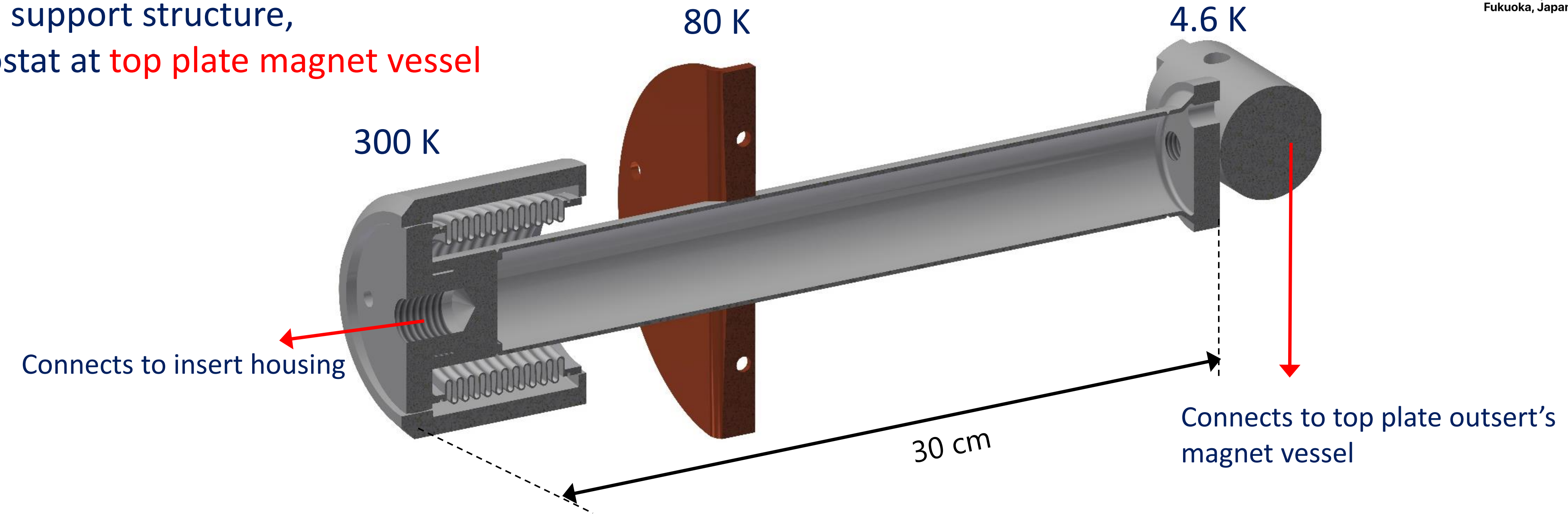
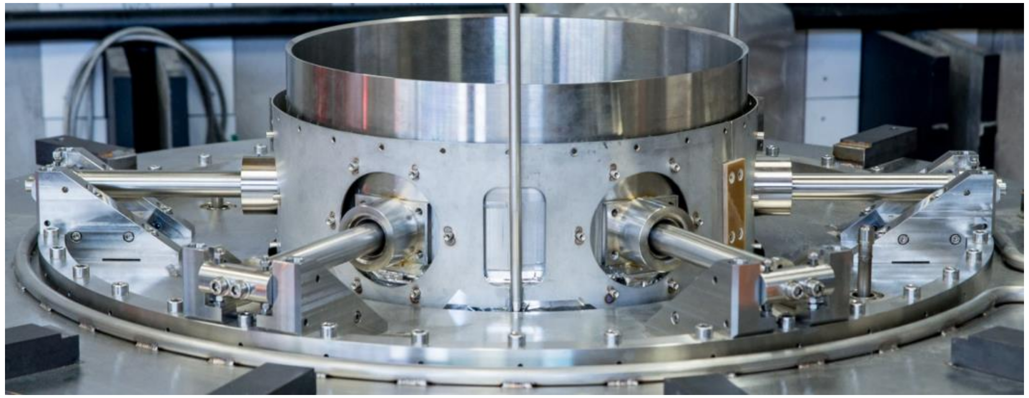
Handling radial misallignment forces

Very compact radial support structure,
6 spokes inside cryostat at top plate magnet vessel

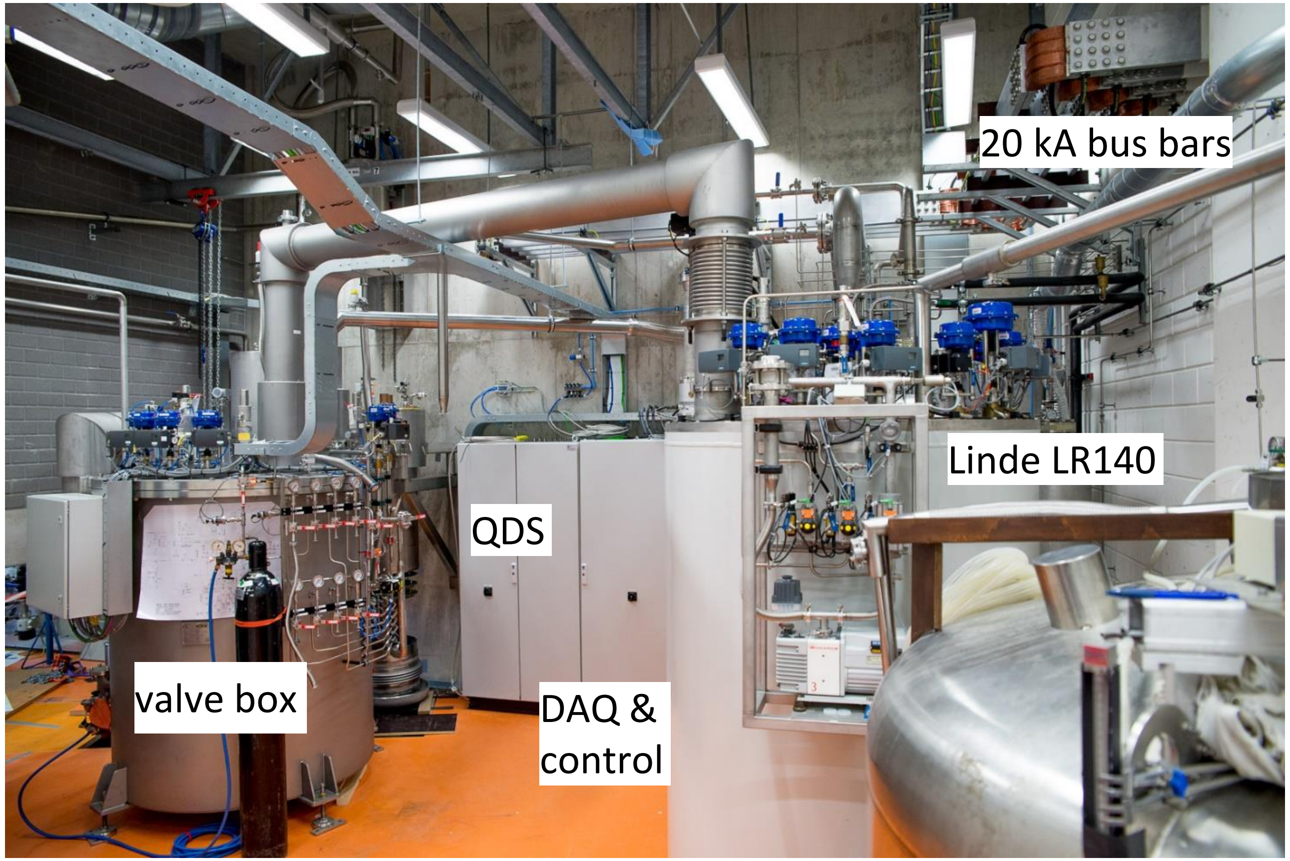


Radial stiffness 6 spokes = 381 kN/mm (angle independent)
Radial off-set force /mm misalignment: 22.8 kN/mm
Heat loads 6 spokes: 24 W @ 80 K, 1.2 W @ 4.6 K
Fixation to insert's housing at outsert T = 90 K (pre-cooled state)



Radial support at bottom plate magnet vessel : G10 support cylinder (radial stiffness > 780 kN/mm)

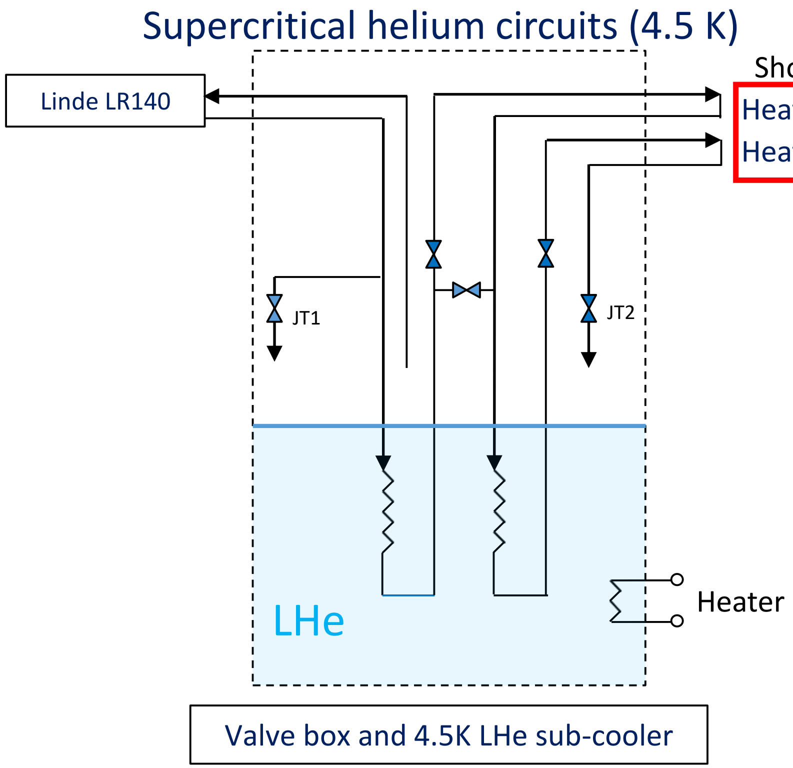
Cryogenic systems operational

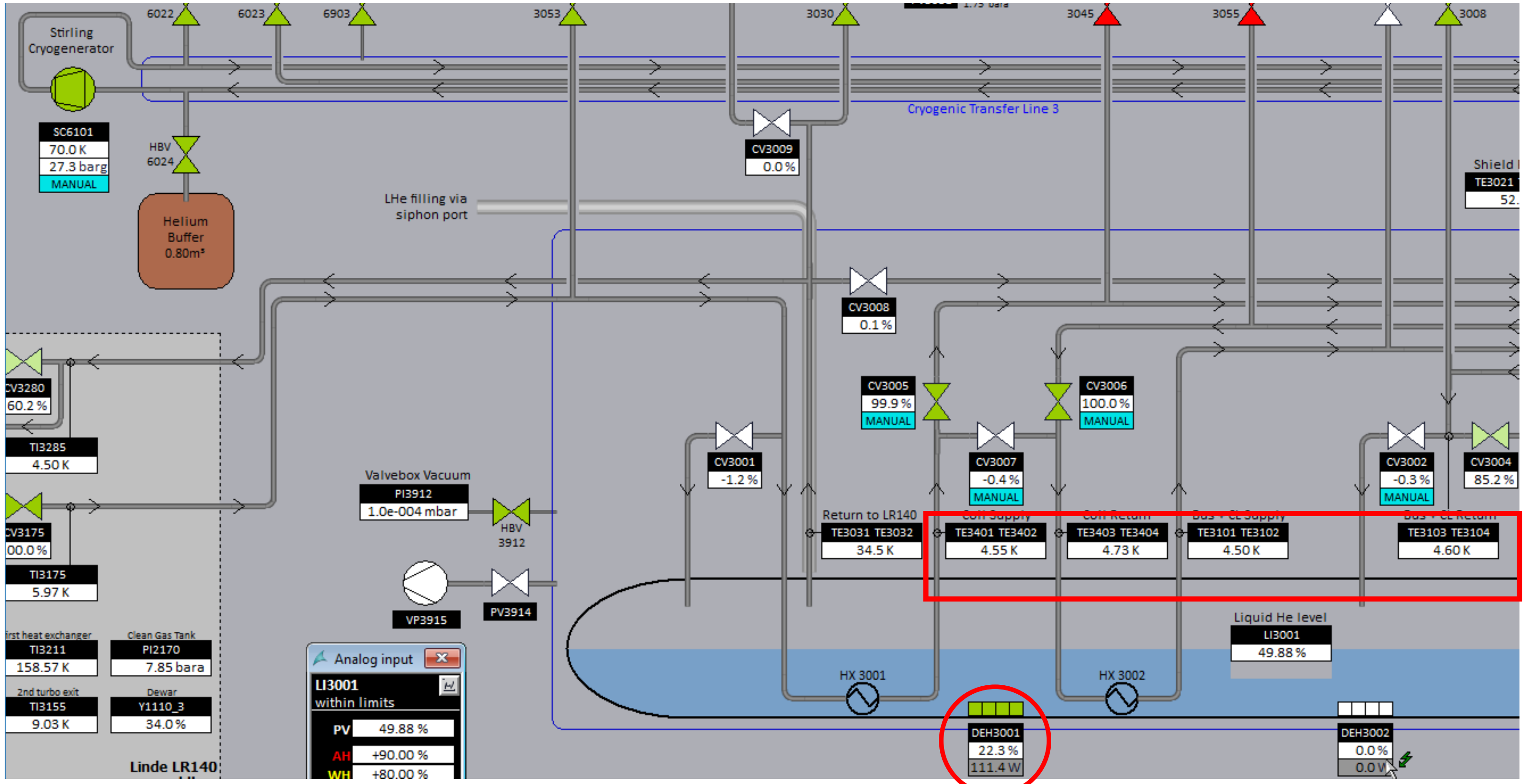


Cryo-room with main cryogenic equipment, control cabinets, current lead cryostat

Stirling cryo-cooler and distribution box (1000 W @ 80 K, 20 bar gHe, cryo-fan forced flow)

Test & commissioning valve box - refrigerator - cryogenic control

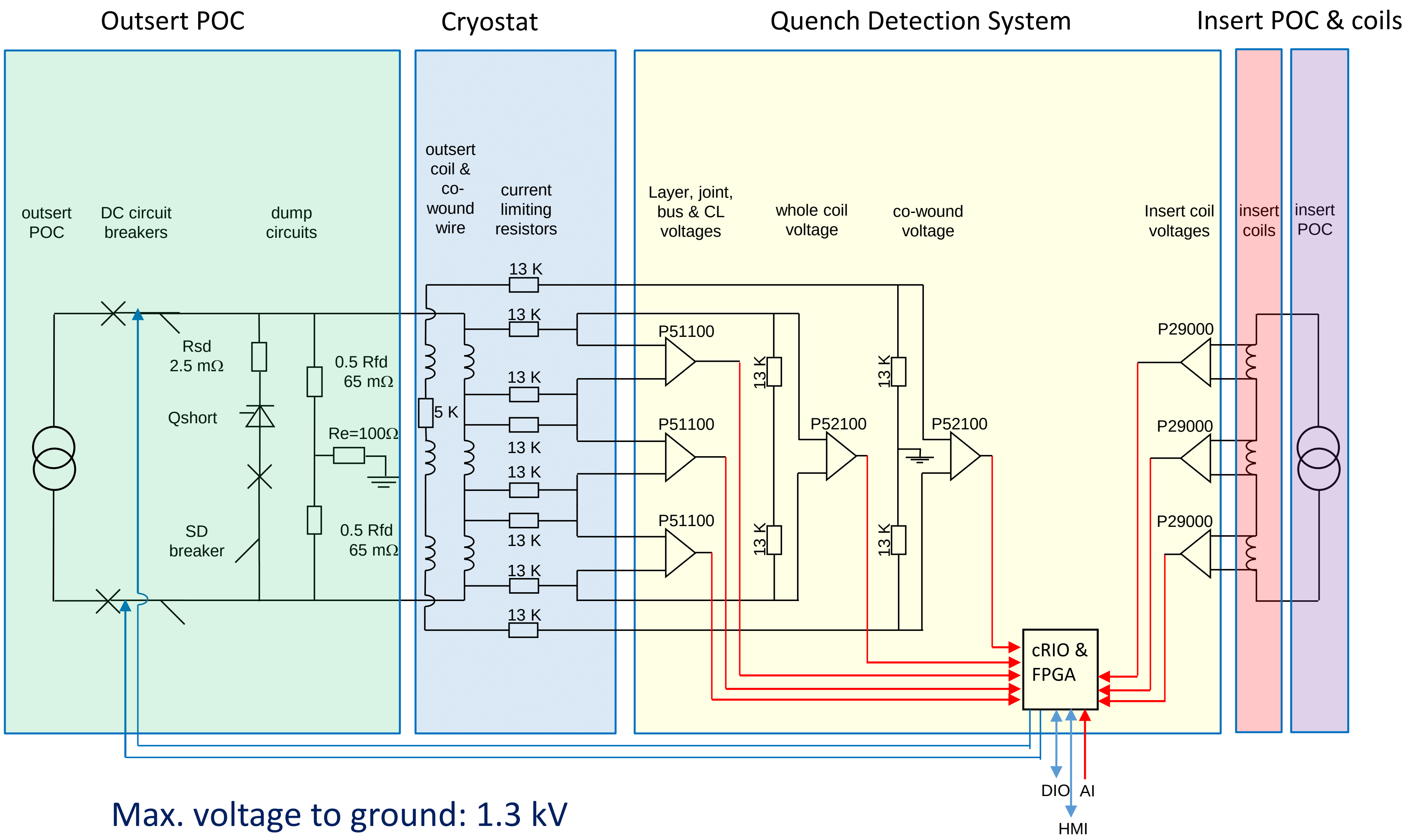




Test configuration valve box & sc He circuits

- cooling power @ constant level
- cool-down characteristics
- representative heat loads
- mode switching at quench (heat, pressure)
- safety & control system

Quench Detection System

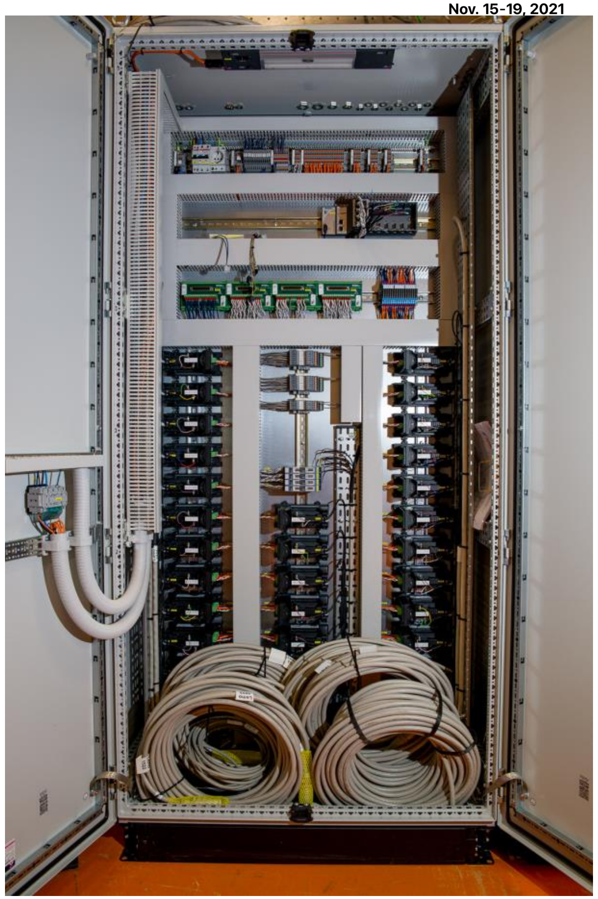


Max. voltage to ground: 1.3 kV

Commercial Knick isolation amplifiers

Labview controlled NI-cRIO (FPGA, RT & HMI)

Test & commissioning well underway



QDS cabinet with isolation amplifiers and NI-cRIO & FPGA

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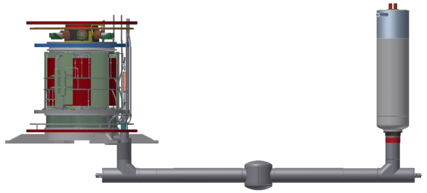
Superconducting circuits connected



20 kA Cu/HTS current leads commissioned

Mounted & electrically connected
current lead cryostat

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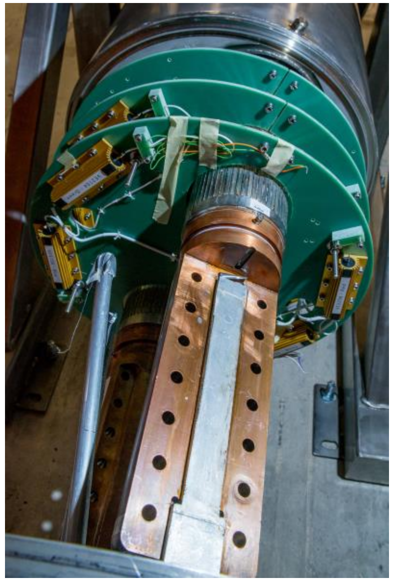
20 kA sc bus bar

Mounted & electrically connected
superconducting Al-stabilized NbTi bus bar



Soft soldered joints
current leads-bus bar

Soft soldered joints
bus bar-coil terminals

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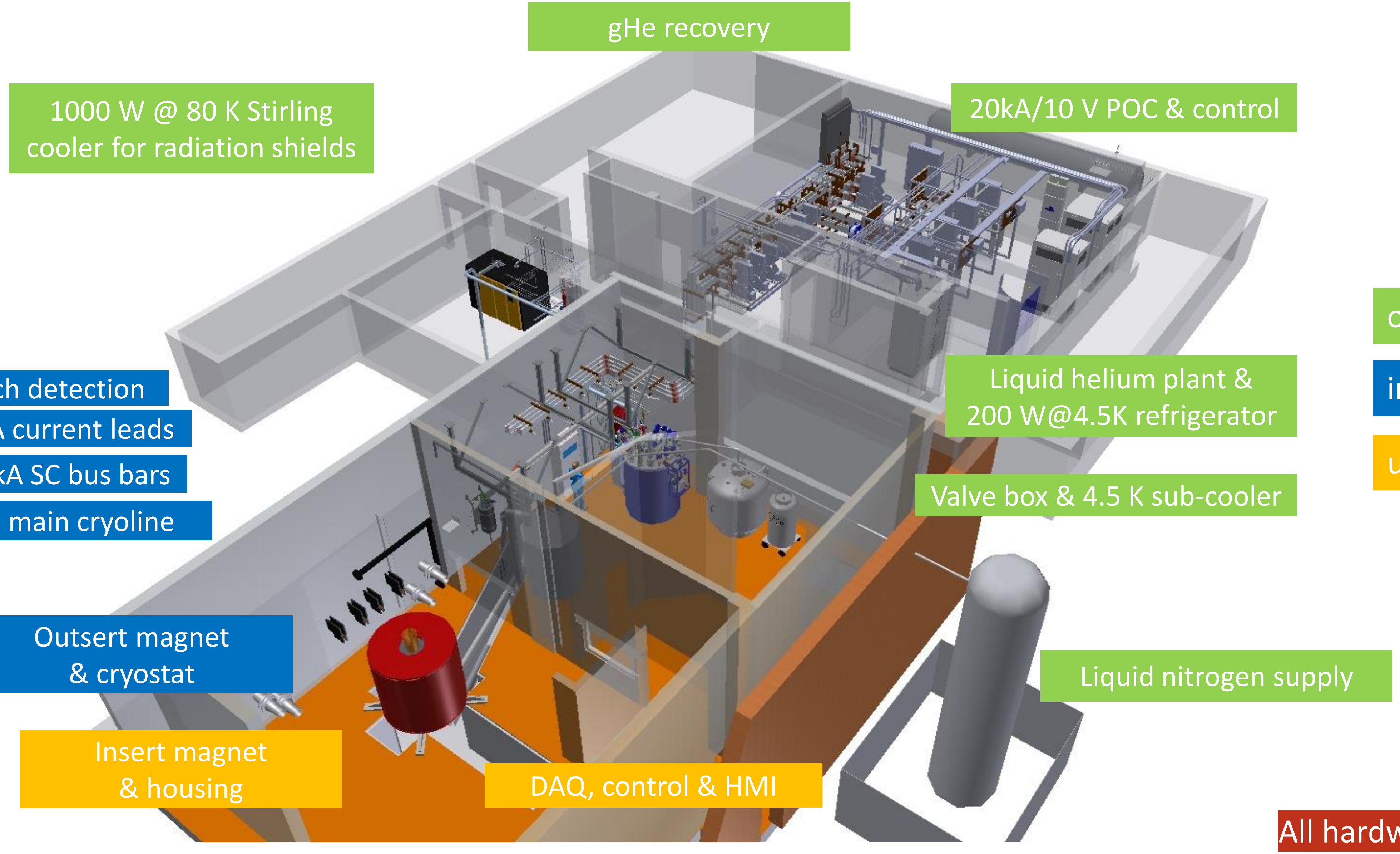
45 T Hybrid Magnet System readiness



operational

integration stage

under construction

All hardware delivered

Acknowledgements

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NWO

EPSRC
Engineering and Physical Sciences Research Council

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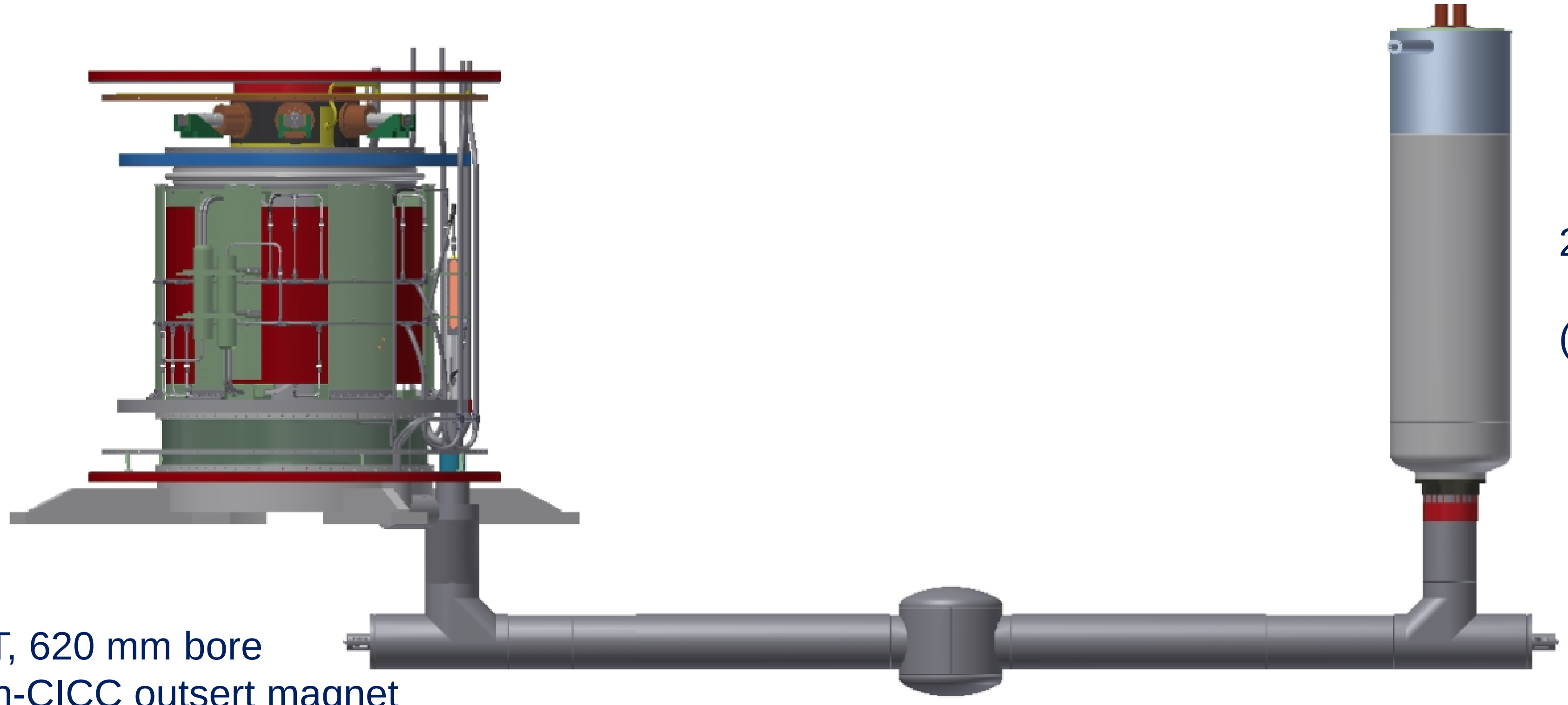
EMFL
European Magnetic Field Laboratory

Superconducting outsert circuit 45 T hybrid magnet



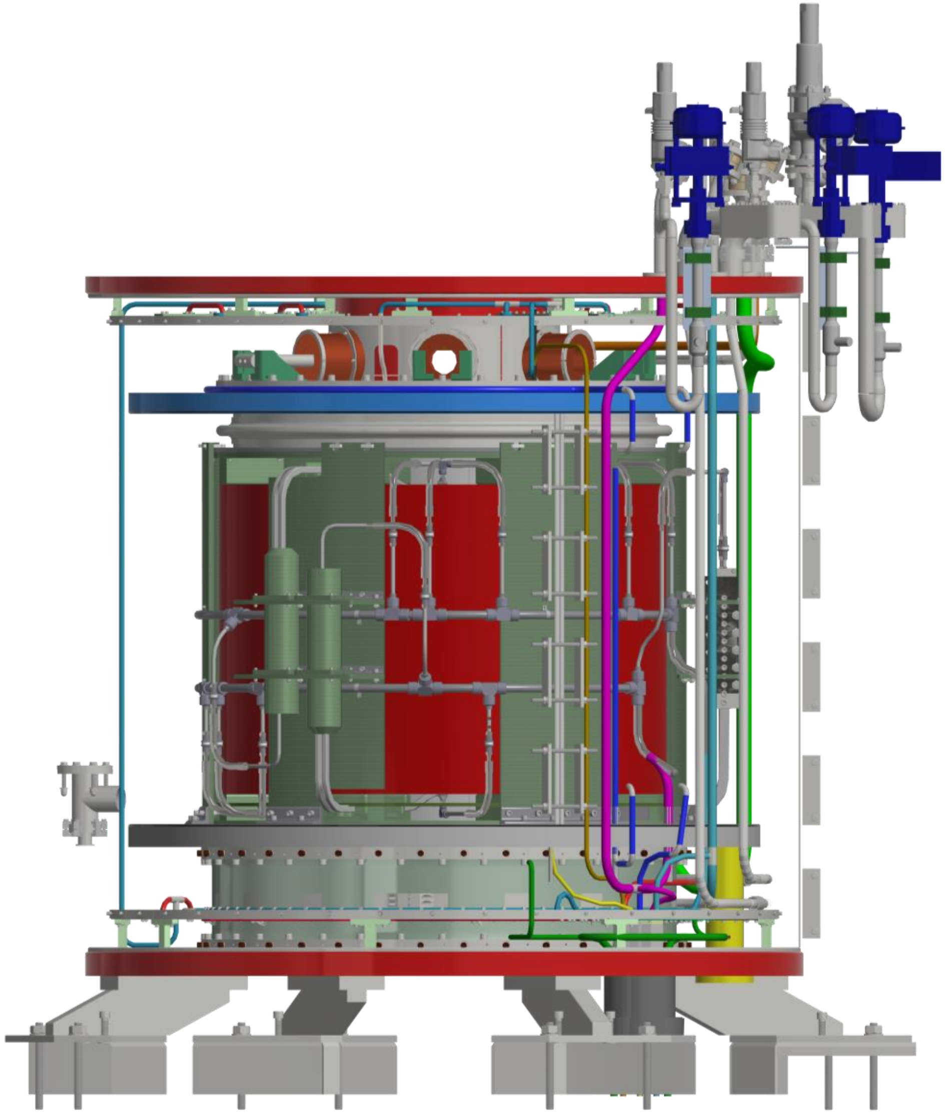
20 kA Cu-HTS current leads

(*HFML-NHMFL collaboration*)

12.3 T, 620 mm bore
Nb_3Sn-CICC outsert magnet

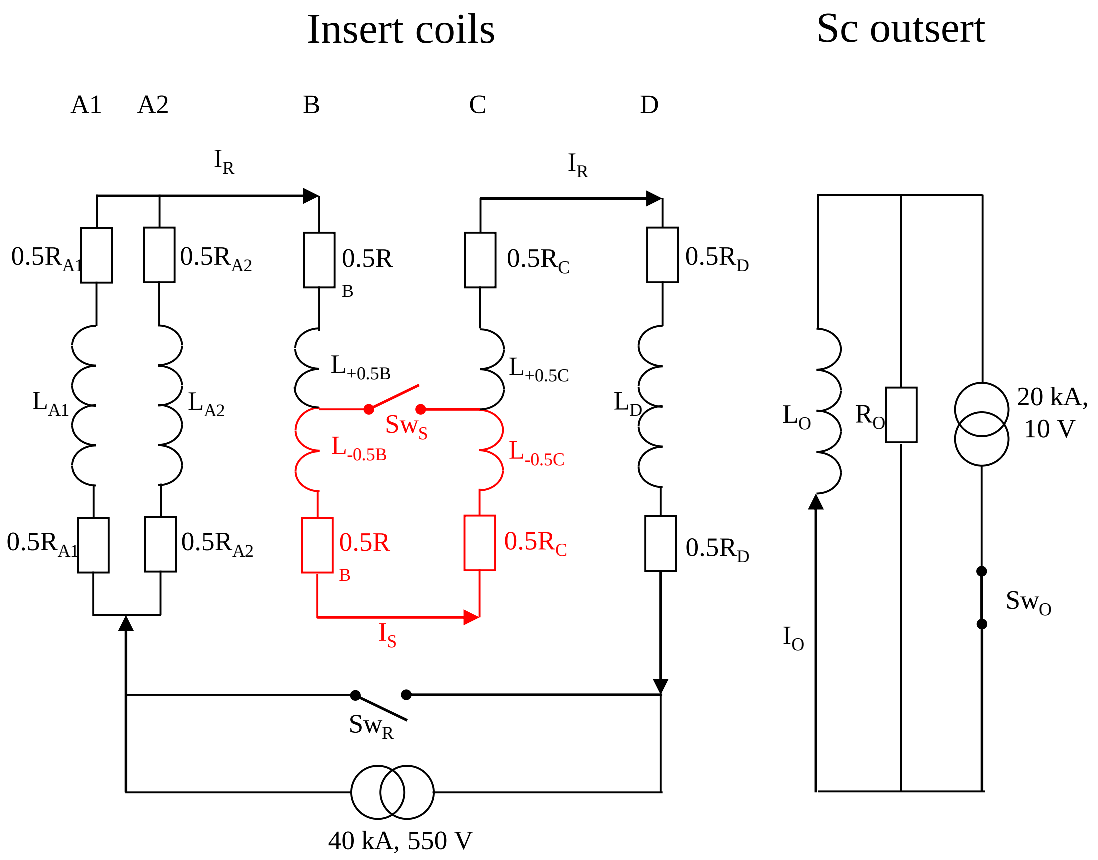
(*fabricated at NHMFL*)

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

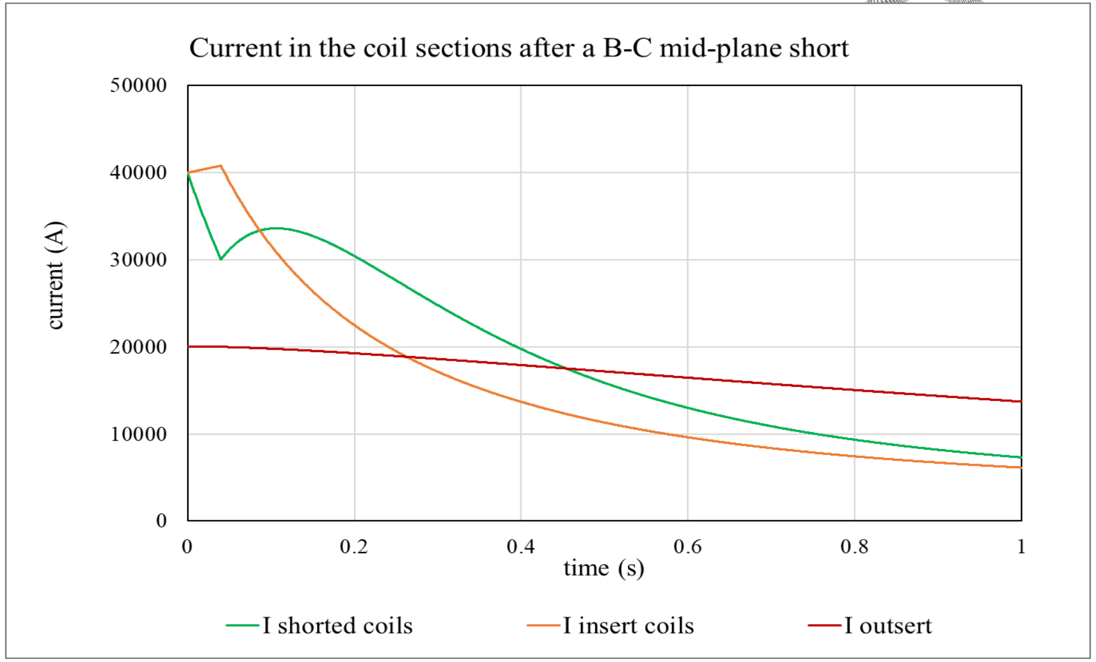


20kA power converter, protection breakers, dump resistors and bus bars to the magnet cell (Vonk B.V.)

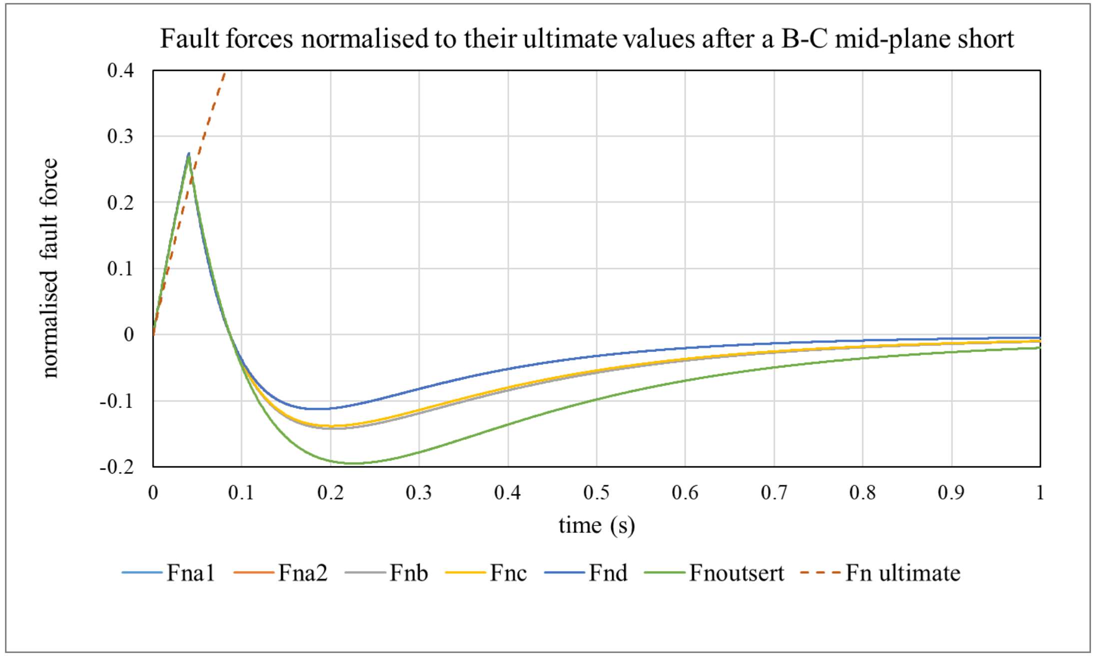
Installed, tested and commissioned



Insert coils
Sc outsert
A1
A2
B
C
D
I_R
I_R
0.5R_A1
0.5R_A2
0.5R B
0.5R_C
0.5R_D
L_+0.5B
L_+0.5C
L_A1
L_A2
L_D
Sw_S
L_-0.5B
L_-0.5C
0.5R_A1
0.5R_A2
0.5R B
0.5R_C
0.5R_D
I_S
Sw_R
40 kA, 550 V
L_O
R_O
20 kA, 10 V
Sw_O
I_O



Current in the coil sections after a B-C mid-plane short
current (A)
time (s)
I shorted coils
I insert coils
I outsert



Fault forces normalised to their ultimate values after a B-C mid-plane short
normalised fault force
time (s)
Fna1
Fna2
Fnb
Fnc
Fnd
Fnoutsert
Fn ultimate

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