

Wrocław University of Science and Technology

From Conceptual Design to Installation of the Super-FRS Local Cryogenic System at FAIR

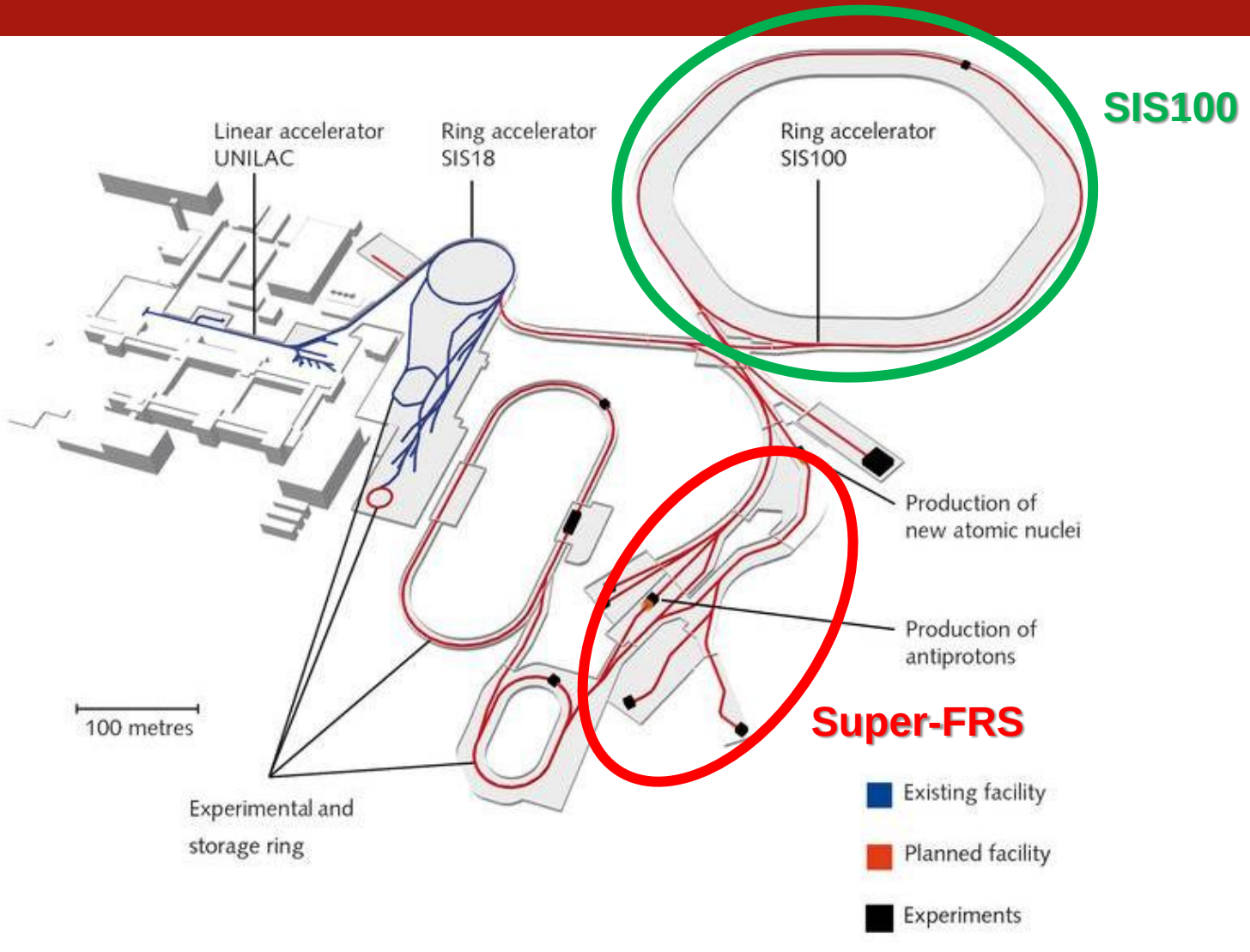
Jarosław Polinski

Co-authors:

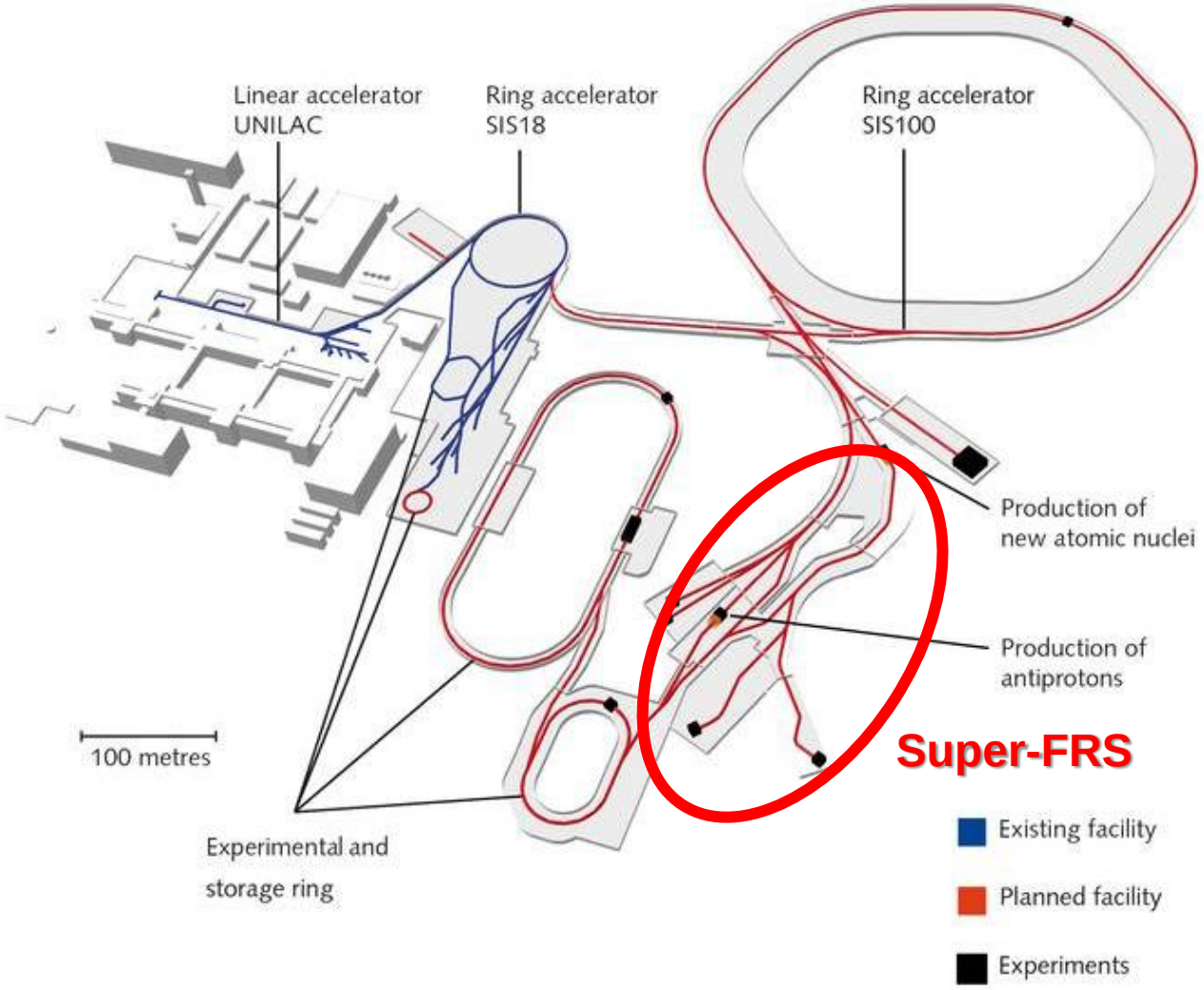
M. Chorowski, L. Pachnik, J-M. Fafara, J. Kielar, A. Piotrowska, R. Siemasz, WUST, Poland
F. Wamers, F. Dziuba, Y. Xiang – GSI, Germany
P. Grzegory, R. Płaczek, B. Kopania – Kriosystem Sp z.o.o., Poland
B. Joshi, D. Panchal, M. Thekdi – INOXCVA, India

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The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences,
21 November 202, Cracow, POLAND

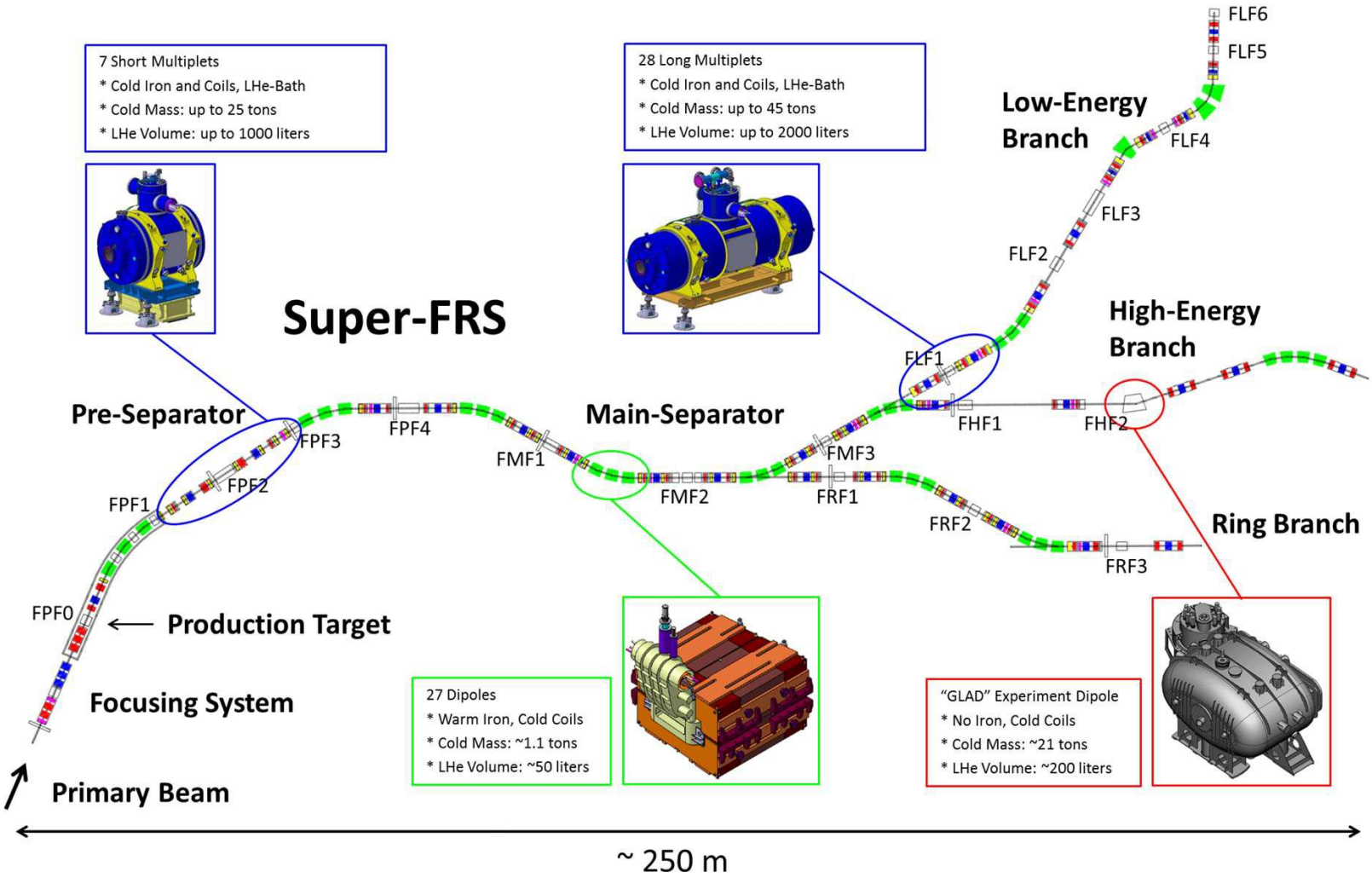
Outline of the FAIR accelerator complex



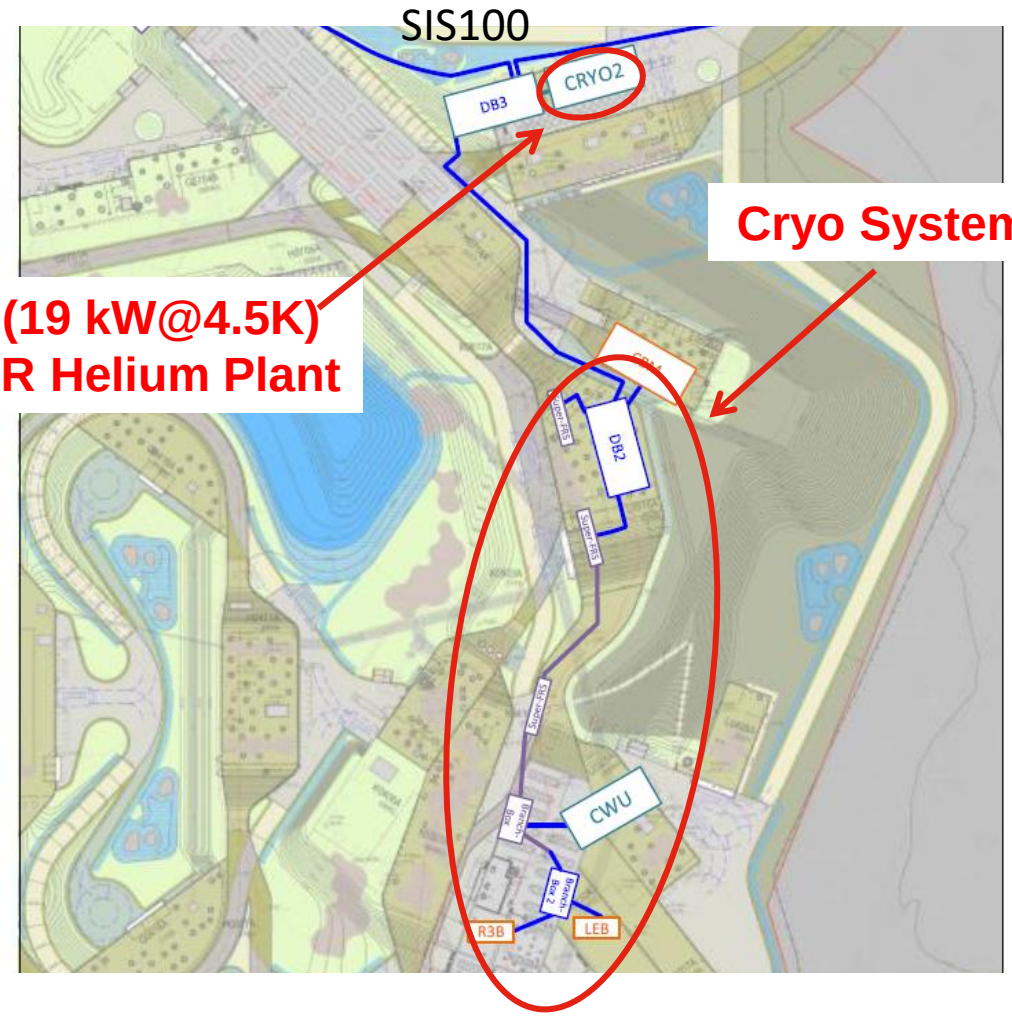
Outline of the FAIR accelerator complex



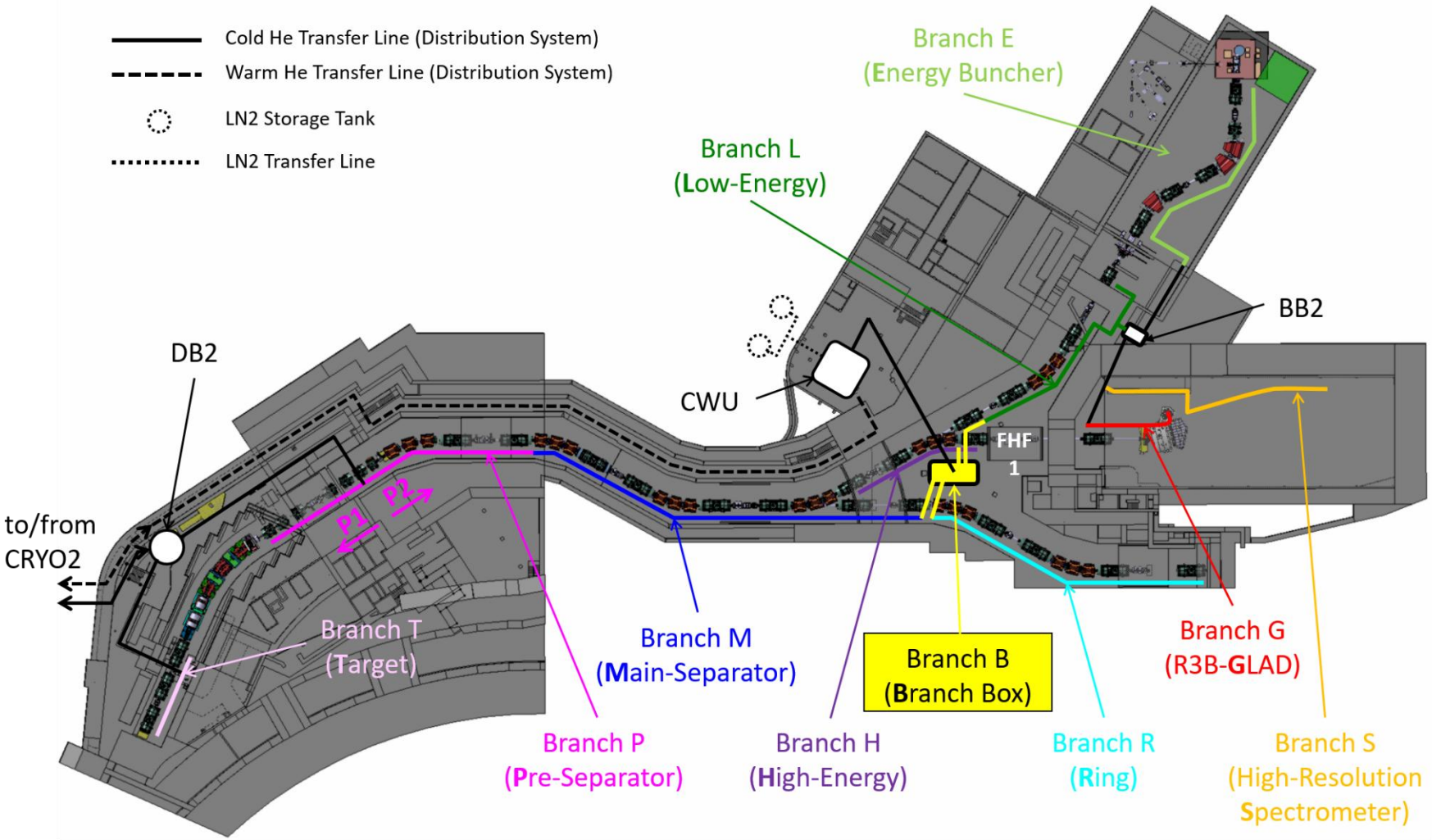
Outline of the Super-FRS



Layout of the FAIR Cryogenic System



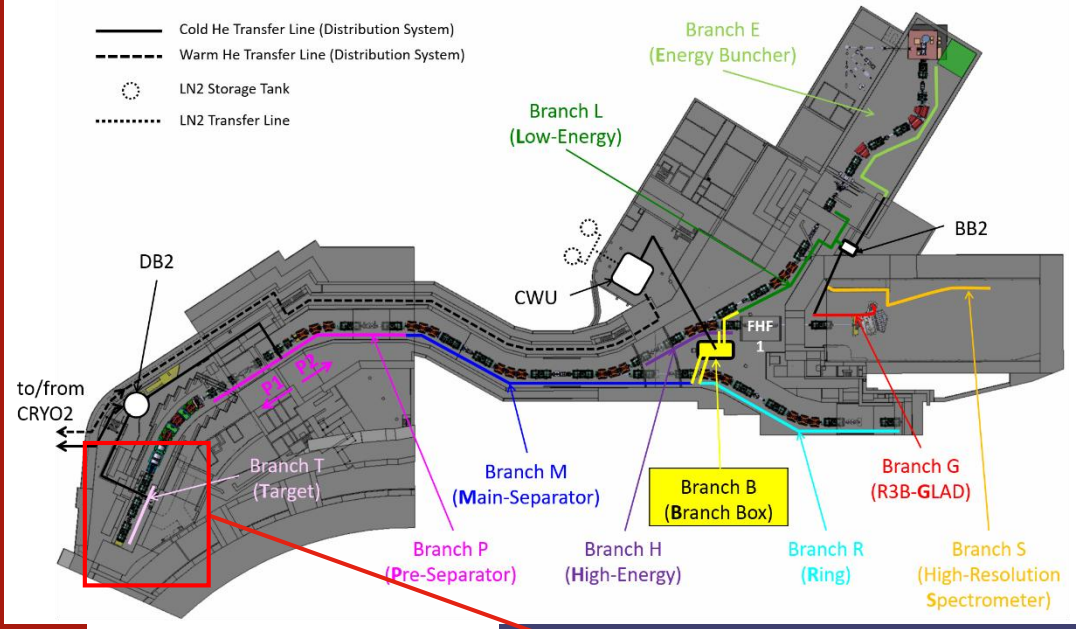
Layout of the Super-FRS Local Cryogenic System

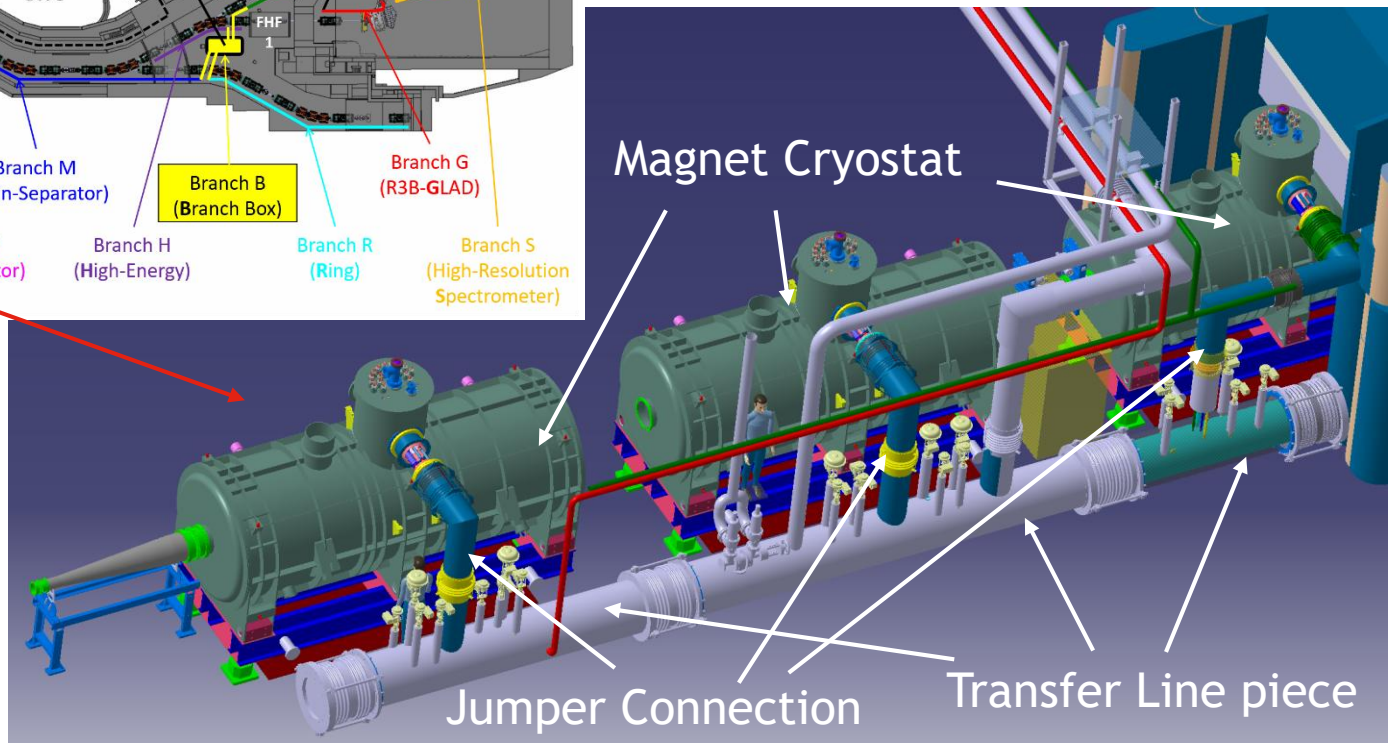


Challenges in design, construction and operation of cryogenic system for superconducting accelerators

- Ensure safe, stable and reliable cryogenic operation of superconducting magnets and RF cavities.
- Support various operating modes, from cooldown preparation and controlled cooldown to nominal operation.
- Select appropriate materials and instrumentation considering mechanical, thermal, vacuum and radiation resistance requirements.
- Provide high-performance thermal insulation to minimize refrigeration power consumption and ensure operational stability.
- Optimize the mechanical design to balance thermal performance and structural stability.
- Implement overpressure protection using both active systems (sensors, control systems and control valves) and passive devices (safety valves and pressure relief devices).
- Enable efficient and reproducible industrial production.
- …

Initial Conceptual Layout of a Super-FRS Local Cryogenic Branch

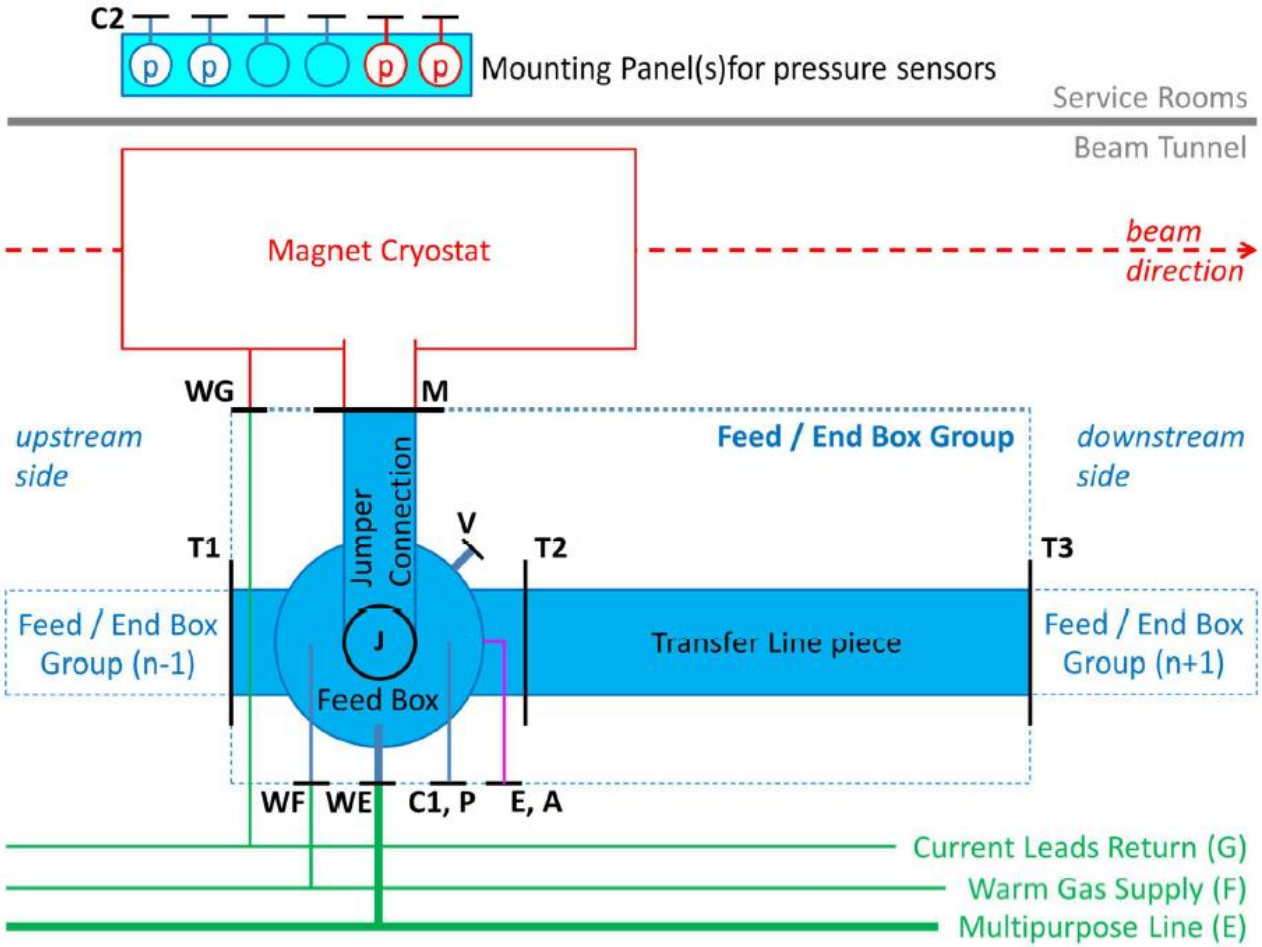




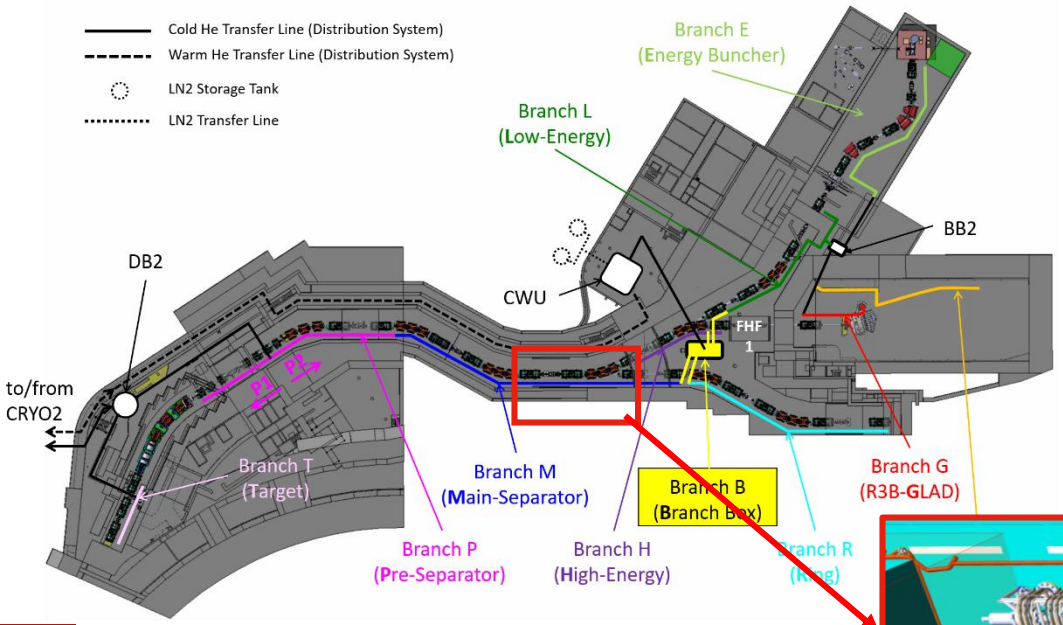
Disadvantages of the Initial Super-FRS Local Cryogenic System Concept

- Each magnet cryostat requires a uniquely designed transfer line section.
- Complex, non-standardized manufacturing and logistics processes.
- Increased risk of design and manufacturing errors.
- Limited flexibility in the installation sequence.

Schematic of the Super-FRS Feed Box and End Box Group



Final Conceptual Layout of a Super-FRS Local Cryogenic Branch



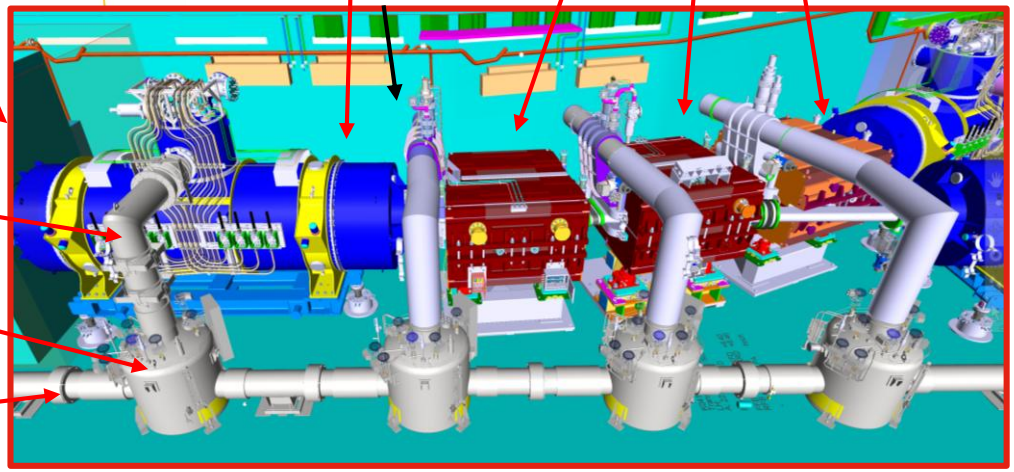
Multiplet Magnet Cryostat

Diploe Magnet Cryostat

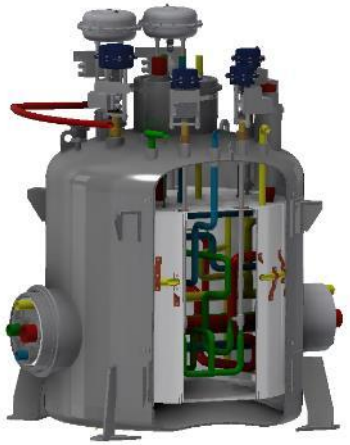
Jumper Connection

Feed Box

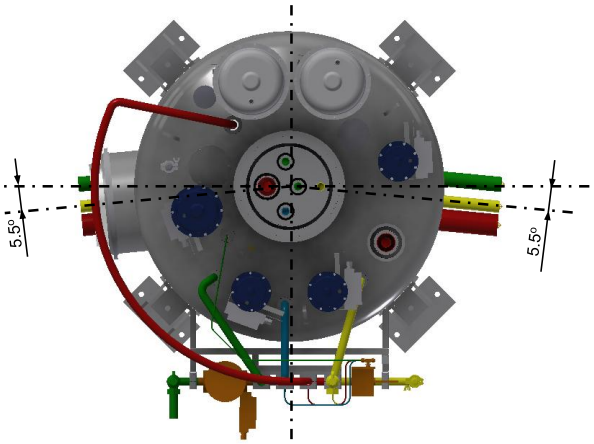
Transfer Line piece



Super-FRS Local Cryogenic System - Component Types



Standard and Branch End Multiplet FBs
0 degree Dipole FBs
(2 types - 38 pcs)



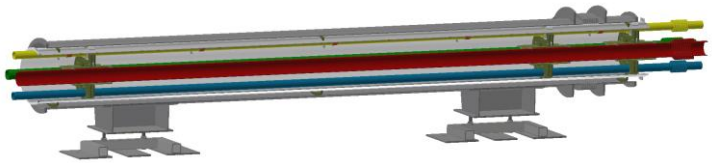
11 and 9.5 degree Dipole FBs
(3 +1 types, 24 pcs)



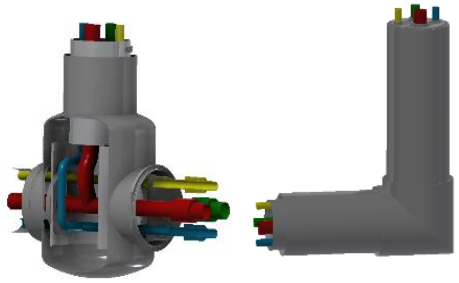
End Box
(2 types, 6 pcs)



1L and 3L Jumper Connections
(15 types, 62 pcs)



4-ch Transfer Line pieces
(9 type, 44 pcs)

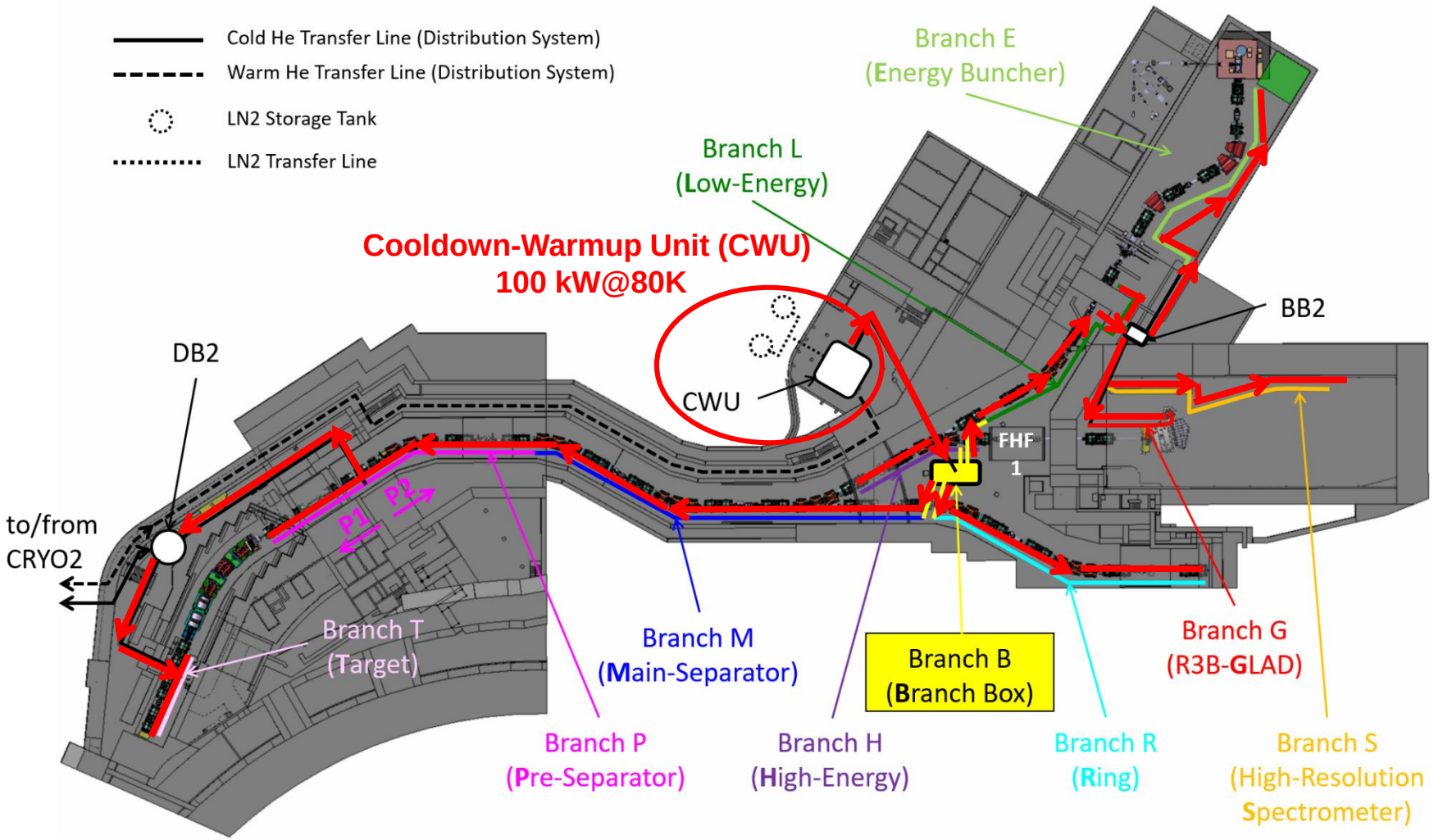


Complex TLs: T and L-conn.
(2+2 type, 5+5 pcs)

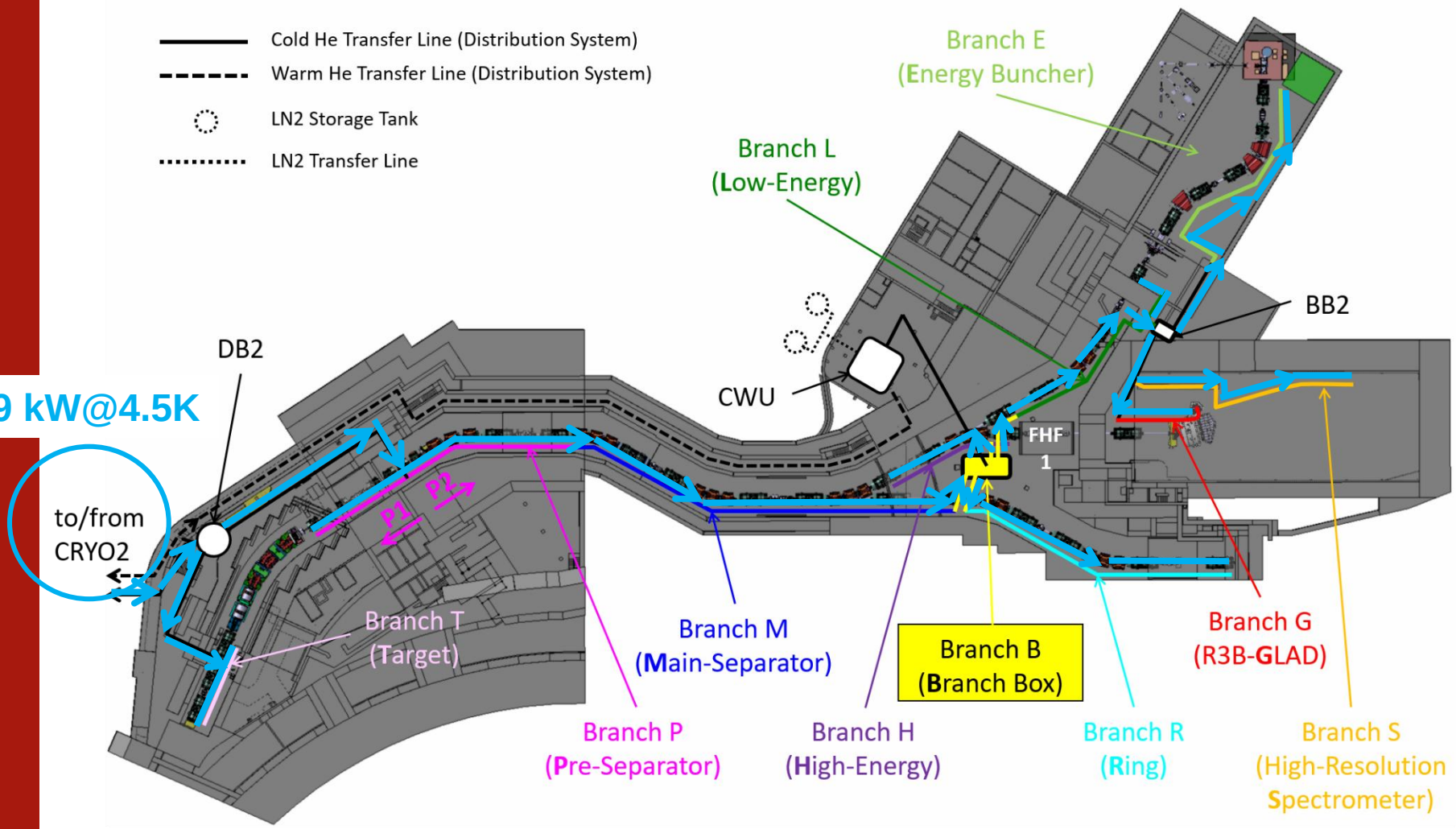
Super-FRS Local Cryogenic System - Operating Modes

- Cooling down of the magnet cryostats,
- Filling of the magnet vessels with LHe ,
- LHe bath temperature and liquid level stabilization during powering of the magnets,
- Magnet quenches and other hazardous events,
- Warming up/cooling down of all or group of Branches,
- Warming up/cooling down of individual cryostats
- … – 17 operating modes in total.

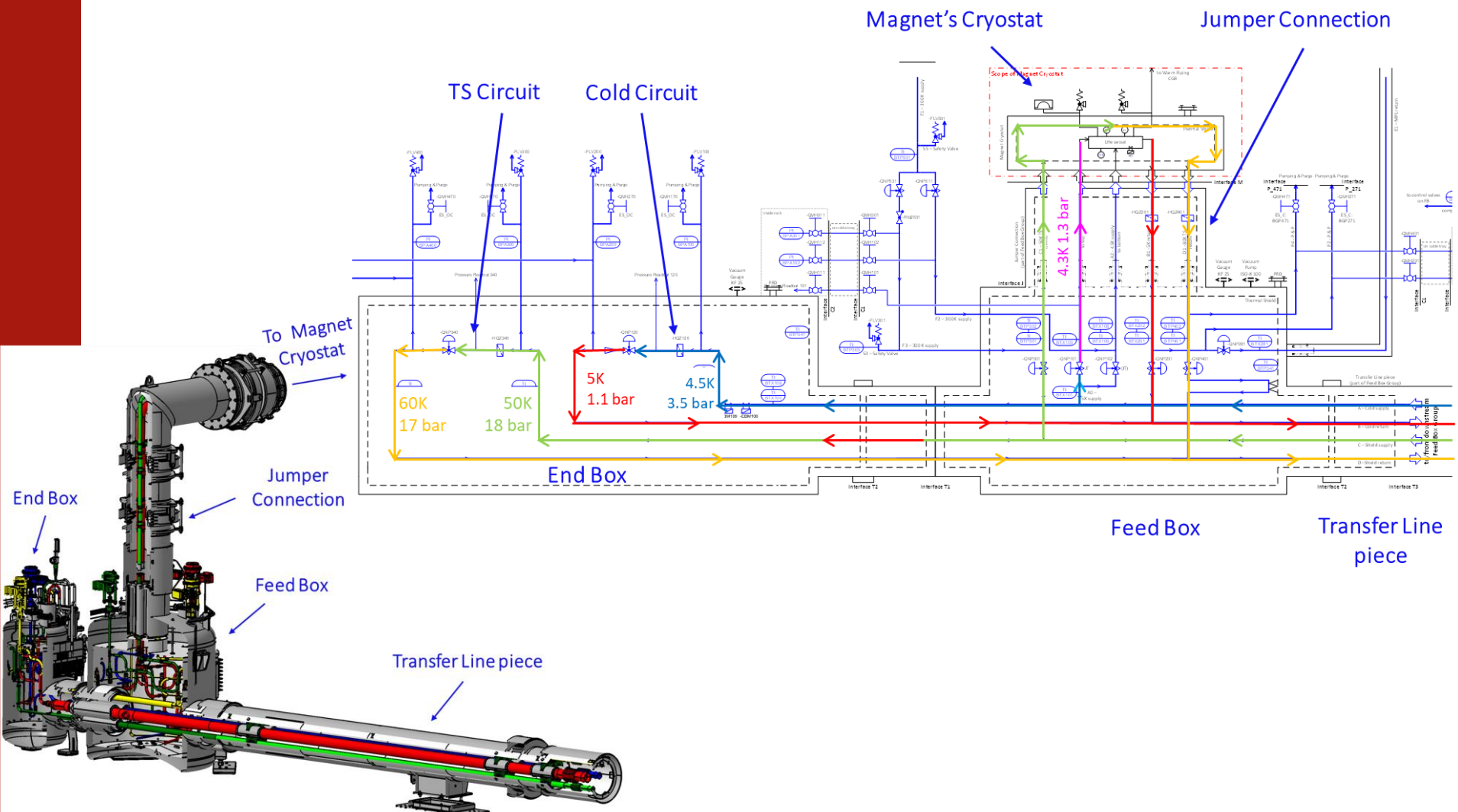
Super-FRS Cooldown from 300K to 80K and Warmup using the CWU



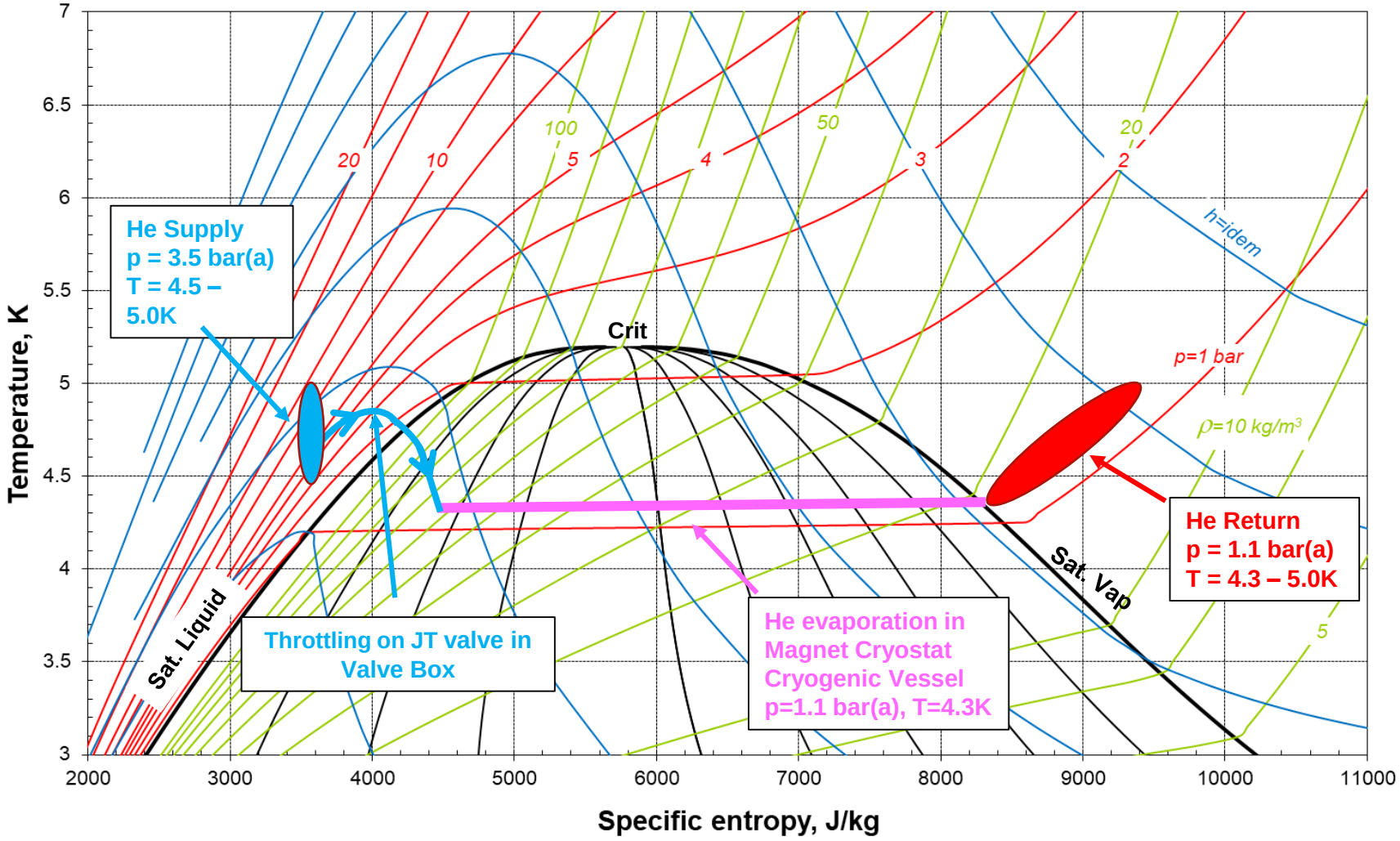
Super-FRS Cooldown from 80K to 5K and Nominal Operation using CRYO2



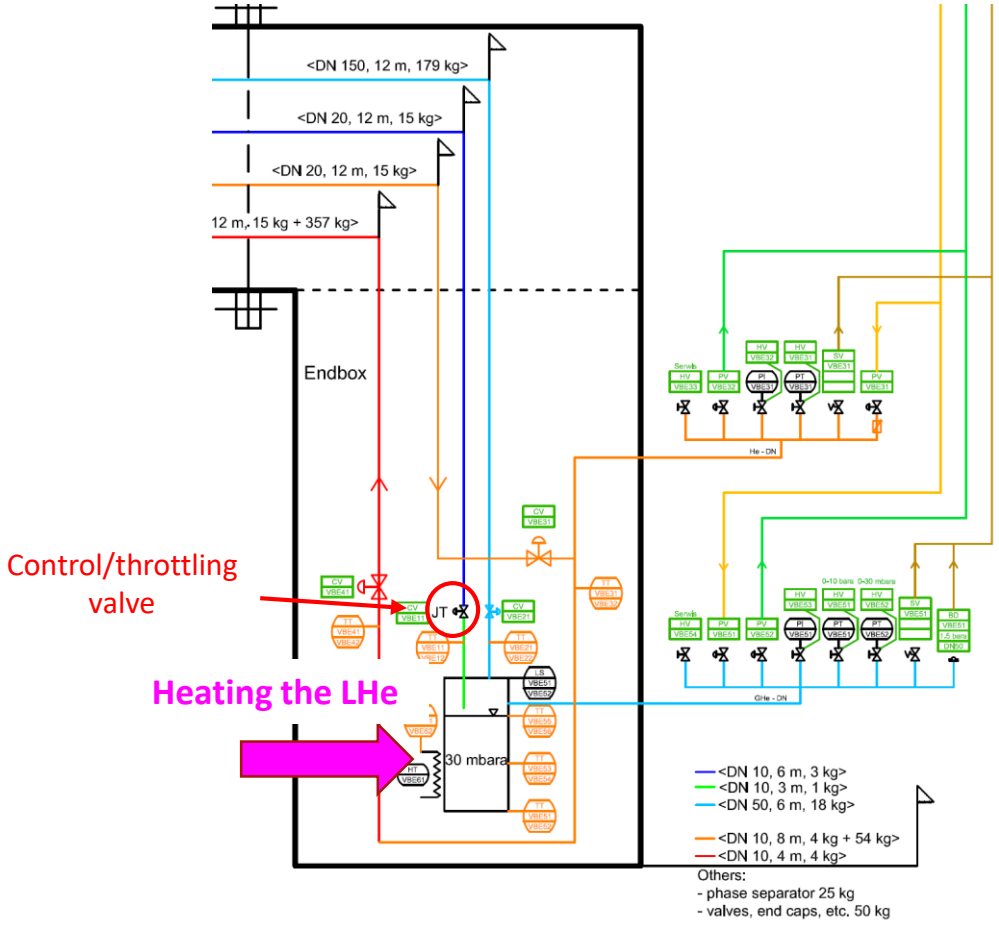
Nominal Operating Mode of a Super-FRS Branch



Thermodynamic processes in the Feed Box+ Magnet's Cryostat cold circuit

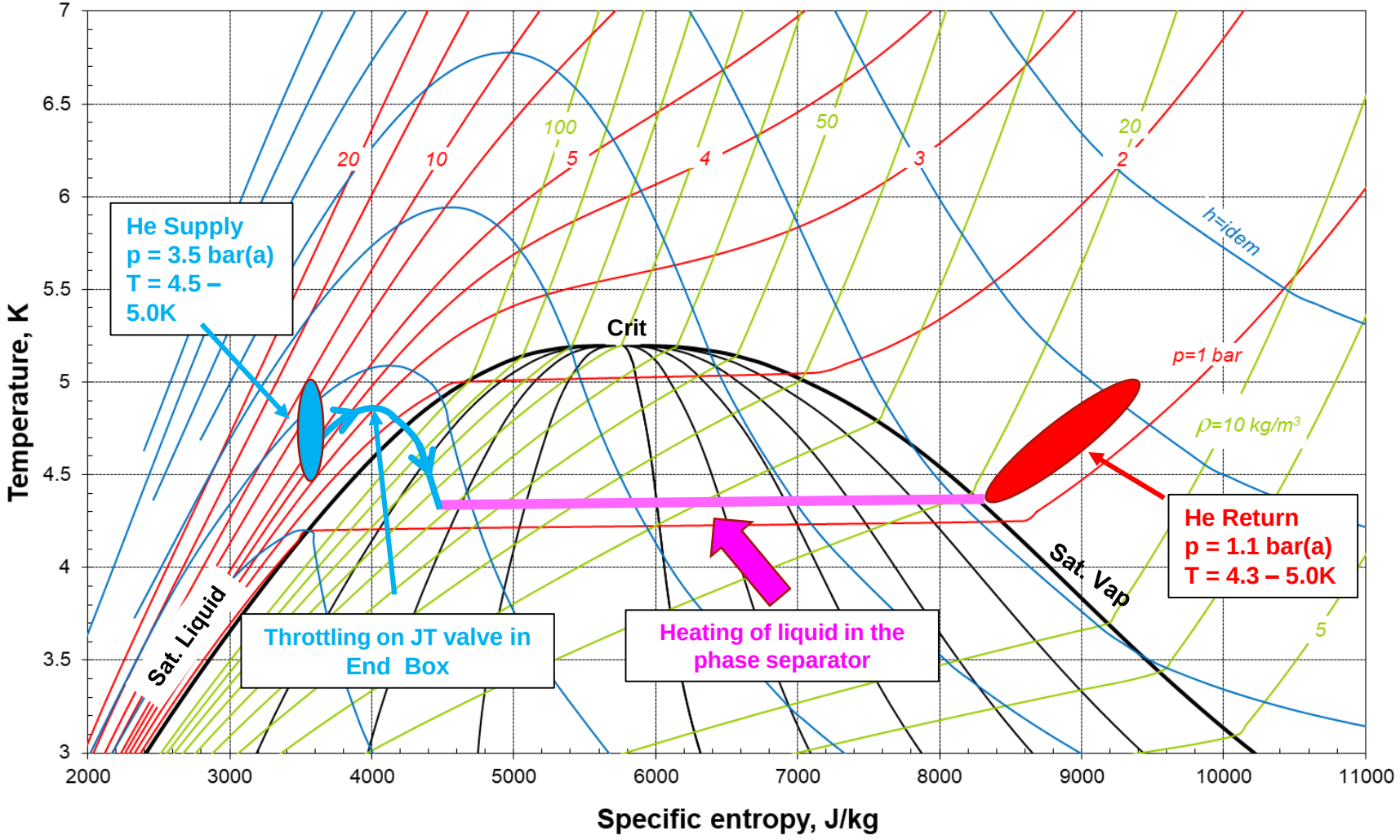


Role of the End Box in Cryogenic Systems

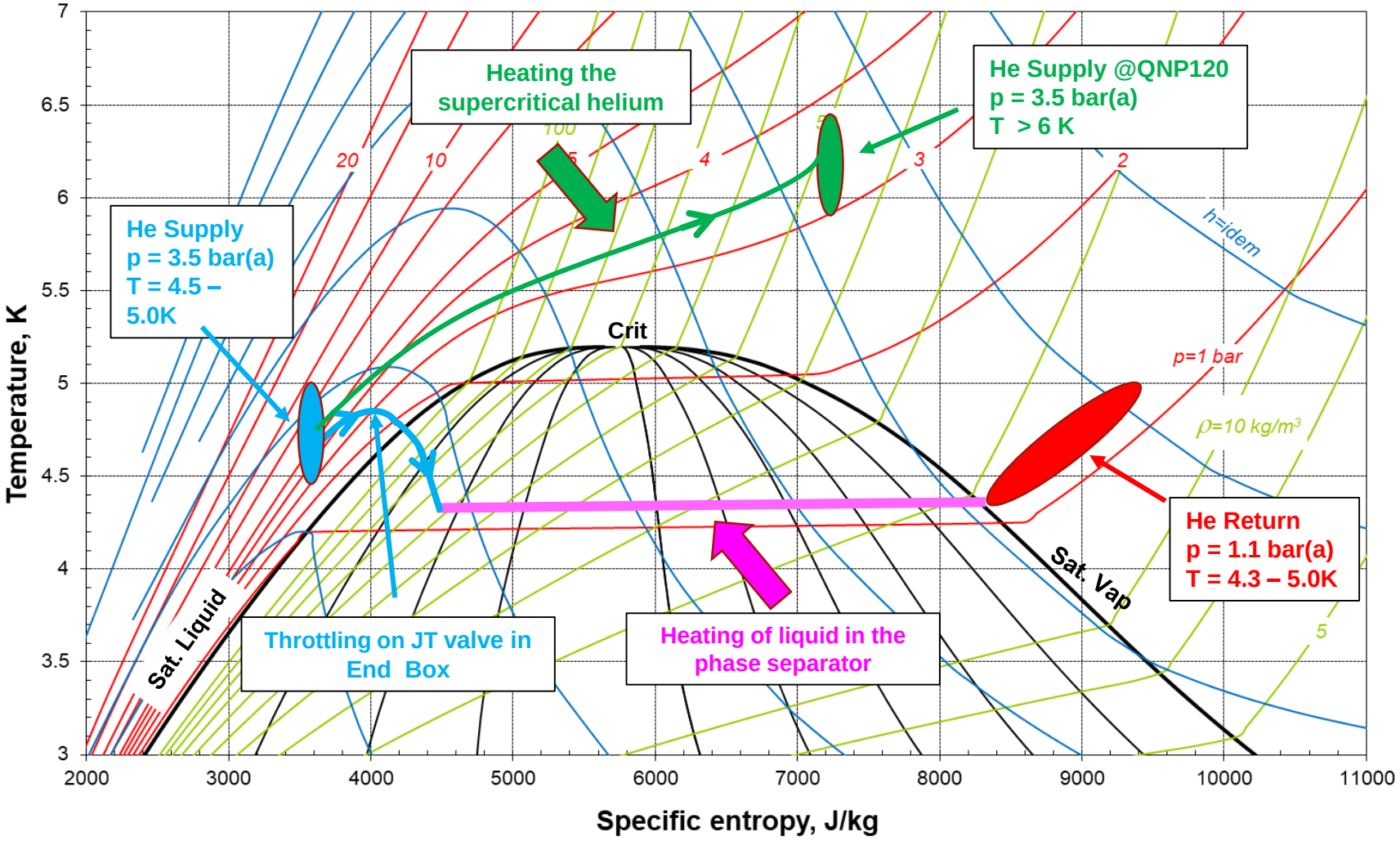


PolFEL End Box P&ID

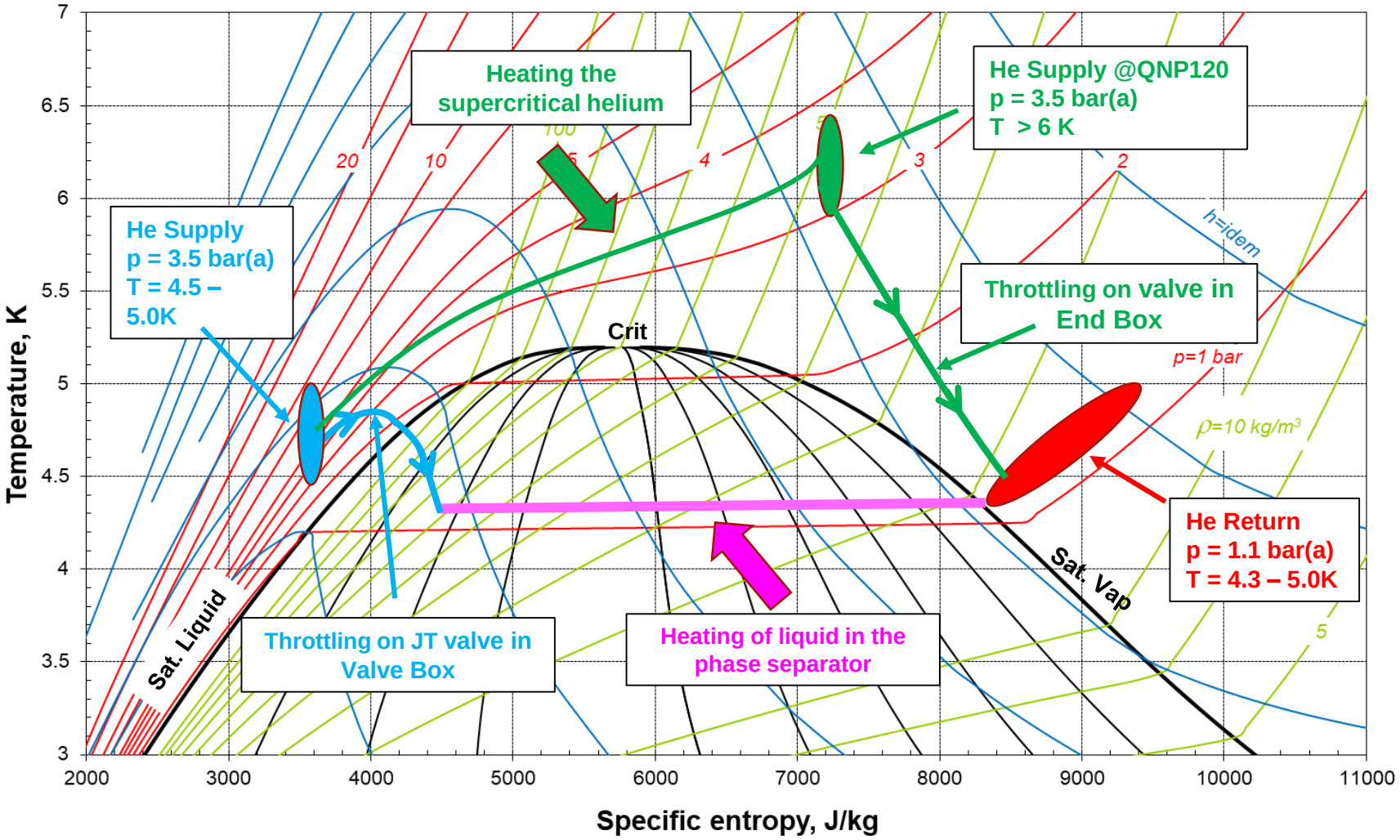
End Box role in the cryogenic systems



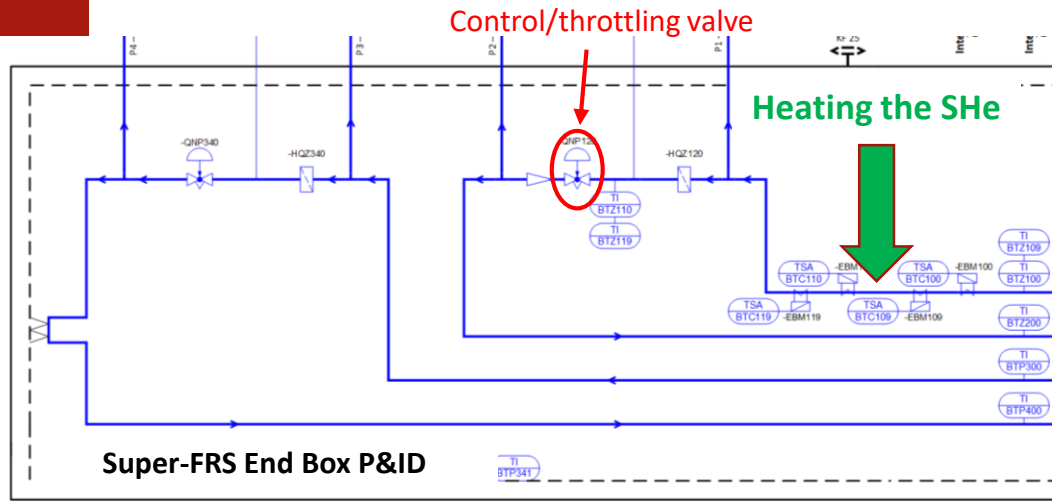
End Box role in the cryogenic systems



End Box role in the cryogenic systems



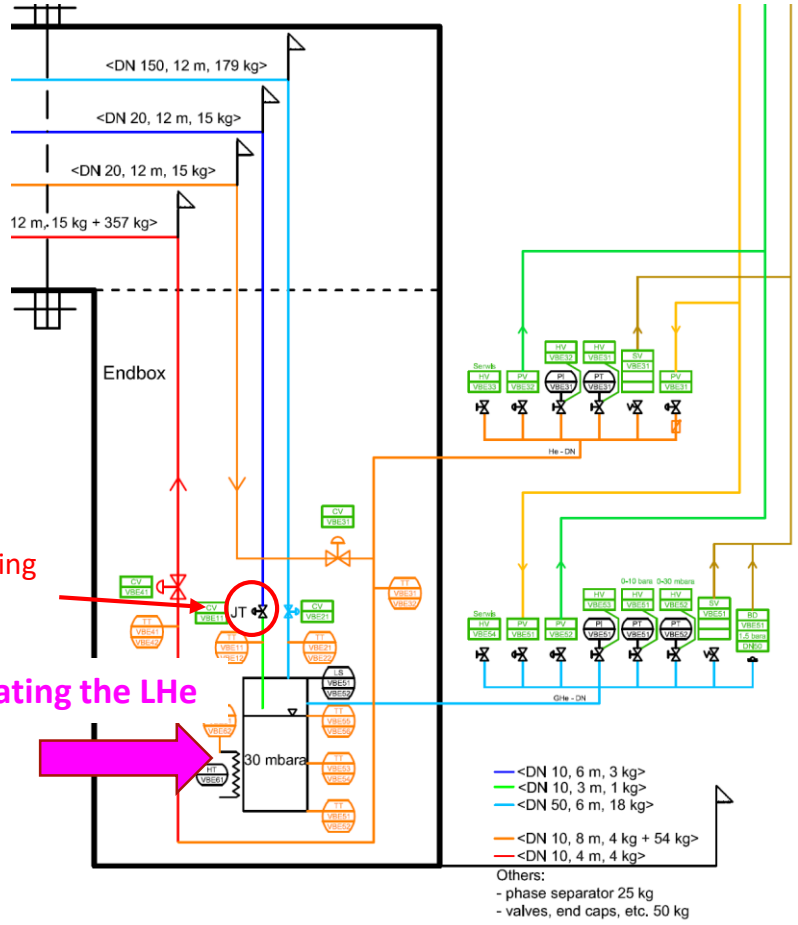
End Box in Super-FRS Local Cryo



Super-FRS End Box P&ID

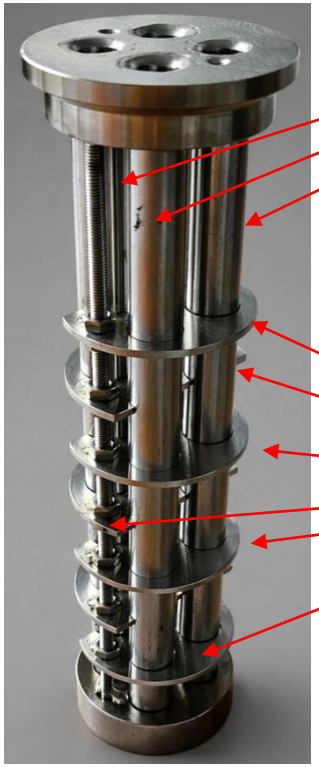
The Super-FRS End Box **does not include**:

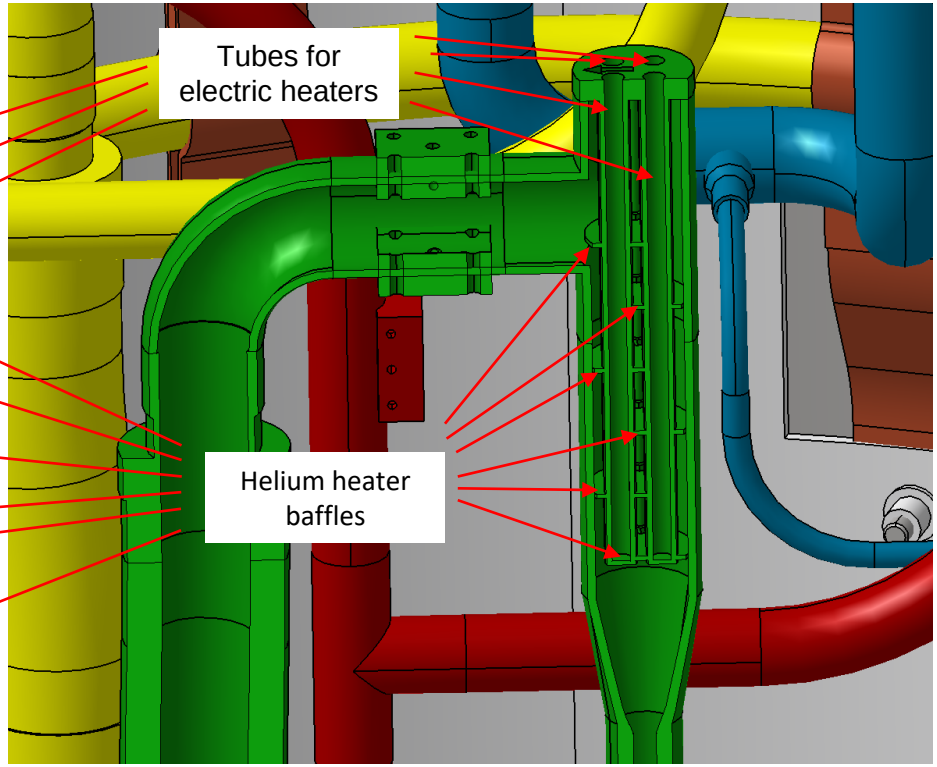
- A high-pressure, PED-certified phase separator vessel.
- A liquid level sensor with a cryogenic electrical feedthrough.
- A redundant liquid level measurement system based on hydrostatic differential pressure (two pressure transducers).
- At least two additional temperature sensors.
- A precise heater control system



PolFEL End Box P&ID

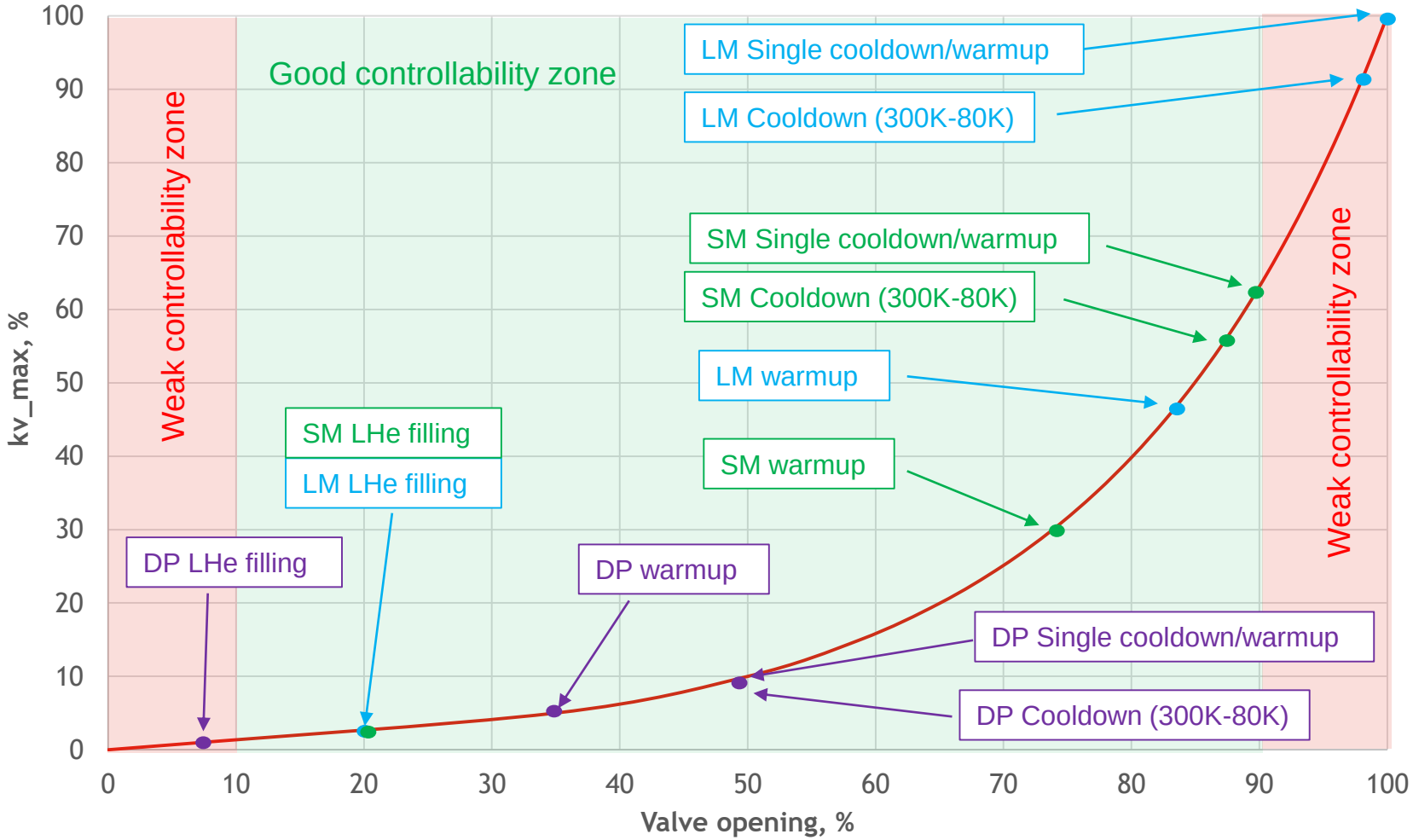
End Box heater design



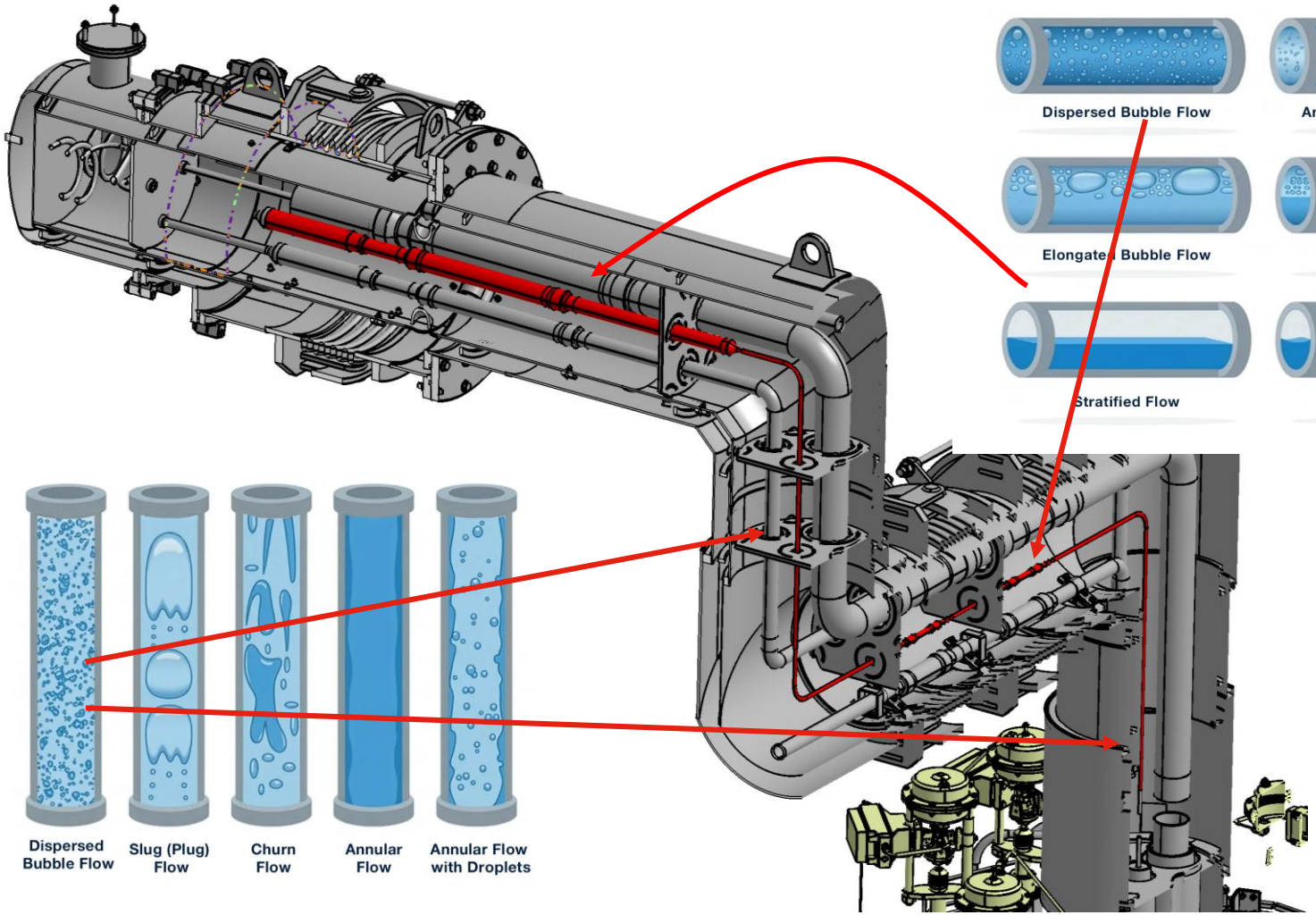




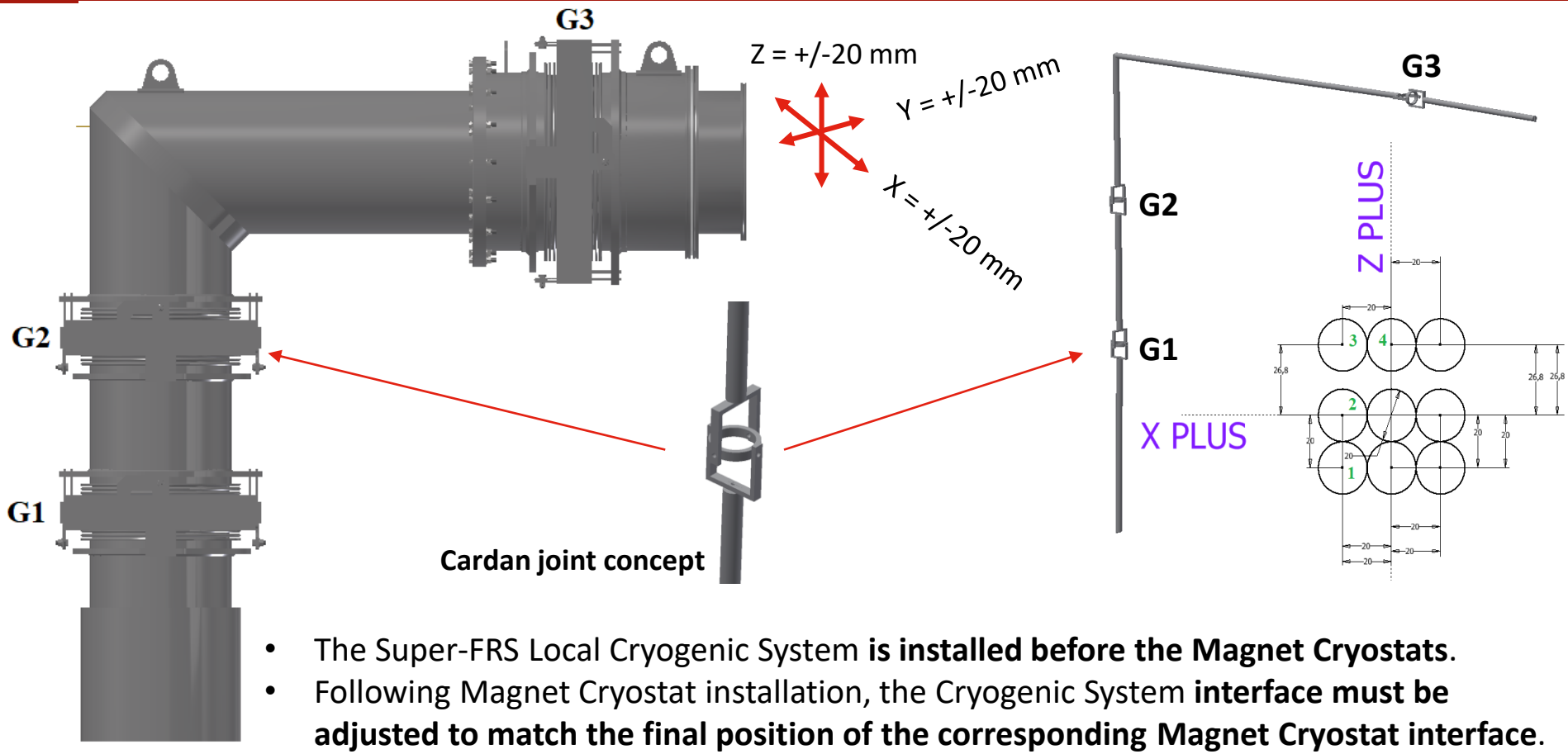
Cool-down valve sizing results



Jumper Connection's Line A1 sizing

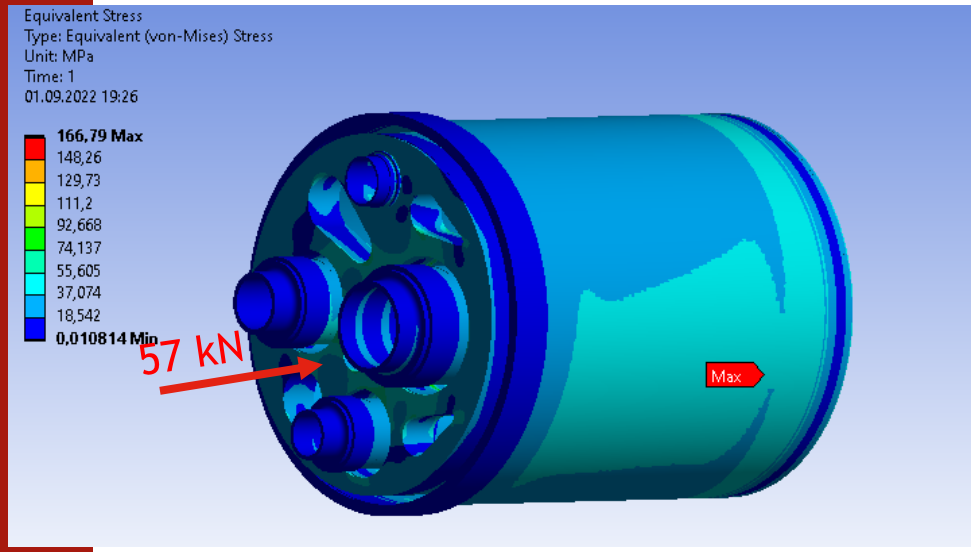


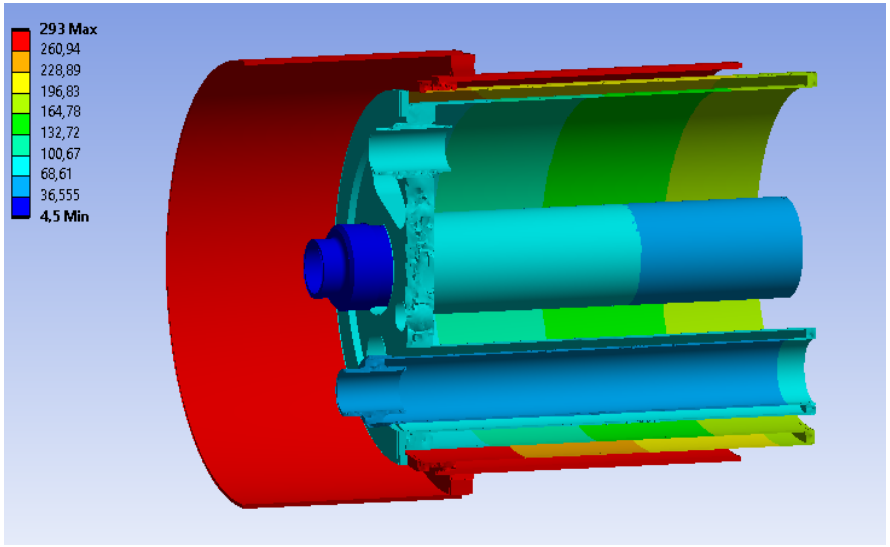
Jumper Connection adjustability



- The Super-FRS Local Cryogenic System **is installed before the Magnet Cryostats**.
- Following Magnet Cryostat installation, the Cryogenic System **interface must be adjusted to match the final position of the corresponding Magnet Cryostat interface**.
- The Jumper Connection design allows interface displacement of **±20 mm along each axis without compromising the insulation vacuum**.

Thermo - mechanical optimization - Fix supports

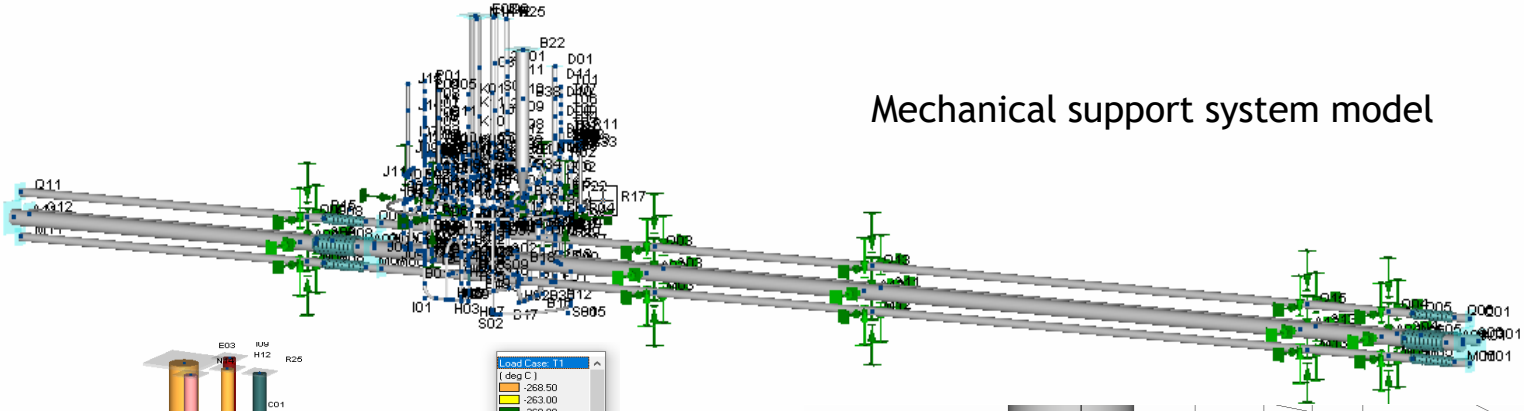




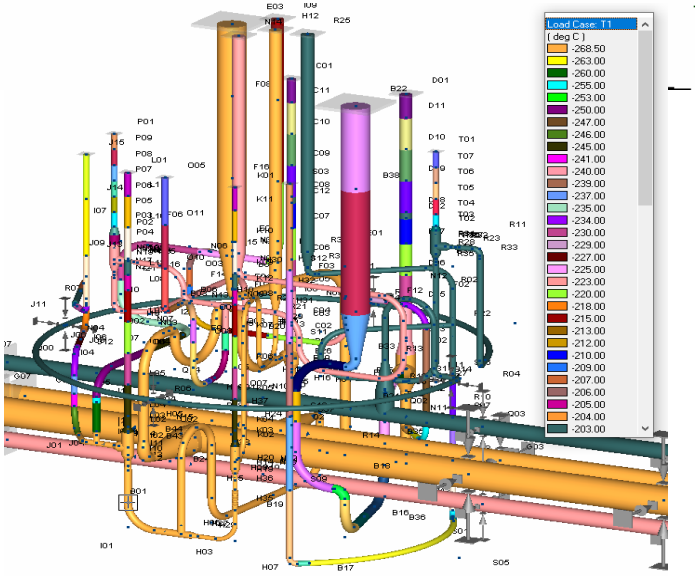
Stress distribution
15 load cases analysed

Temperature distribution

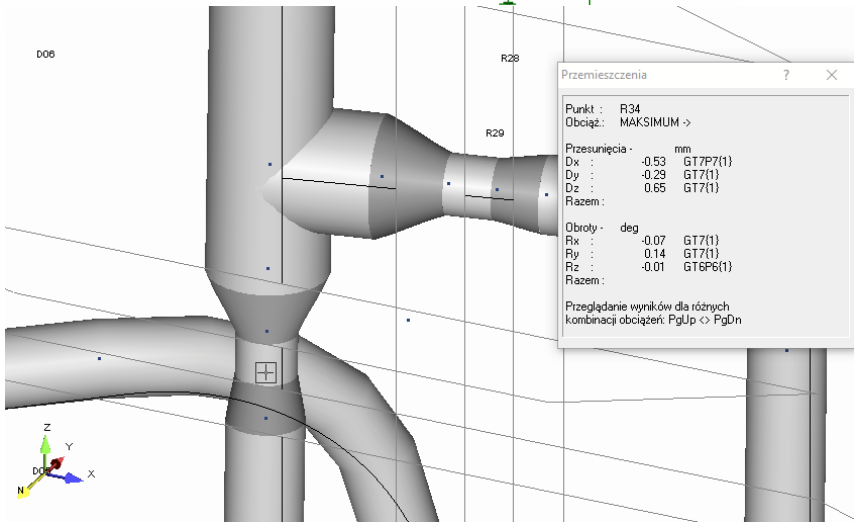
Flexibility Analysis of the Hydraulic System



Mechanical support system model

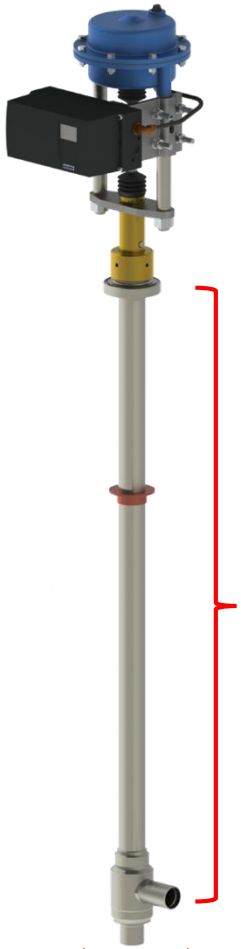


Thermo-mechanical model
(7 load cases analyzed)



Control Valve head displacement

Cryogenic valves deflecton





Valve Body after stress relief



Valve Body re-welded to the Vacuum Vessel

Production of Branch T components at INOX, India – Aug. 2023 – Sept 2024



Branch T components delivered to FAIR in Nov 2024

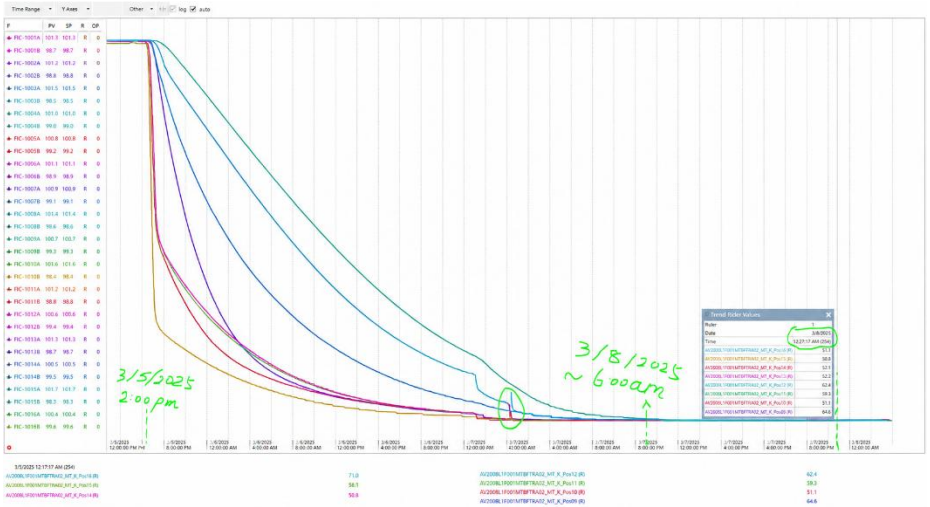




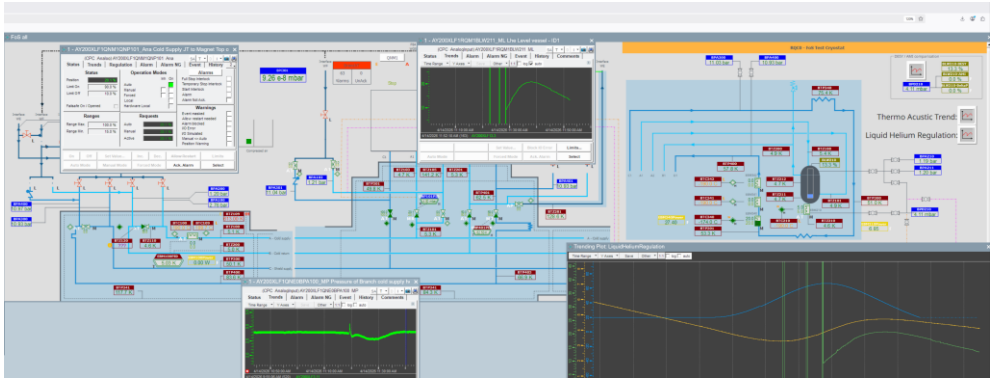
Branch T First of Series (FoS) tests (March 2025)



Branch T FoS components during the functional tests



FoS cool-down profile



View of the test control panel

Branch T installation

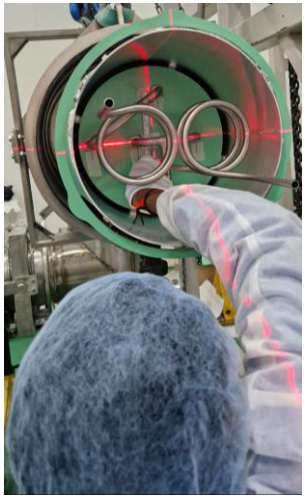


Connection of the Branch T to the Magnet Cryostat



Branch P – production, delivery, SAT tests and installation





Production at INOX India





Production at KrioSystem



Delivery and SAT test at FAIR



Installation in the Super-FRS tunnel

Summary

- As part of Poland's in-kind contribution to the FAIR facility, Wrocław University of Science and Technology (WUST) designed the entire Super-FRS Local Cryogenic System.
- The project required the integration of complex functional and material requirements, supported by expertise in mechanical engineering, fluid dynamics, cryogenic heat transfer, instrumentation, control systems and automation.
- The components for Branches T and P, including a total of 15 Feed Boxes, associated Jumper Connections and Transfer Line sections, and two End Boxes, were manufactured by INOX India and Kriosystem Poland under WUST supervision.
- Following delivery and successful First-of-Series testing, Branch T has been fully installed in the Super-FRS tunnel and is awaiting cold commissioning.
- First-of-Series testing of Branch P components has also been successfully completed. Delivery of the remaining components and installation activities are currently in progress.

Thank you for your attention