Wrocław University of Science and Technology

Innovative Engineering Solutions and Current Implementation Status of the SIS100 Local Cryogenic System at FAIR

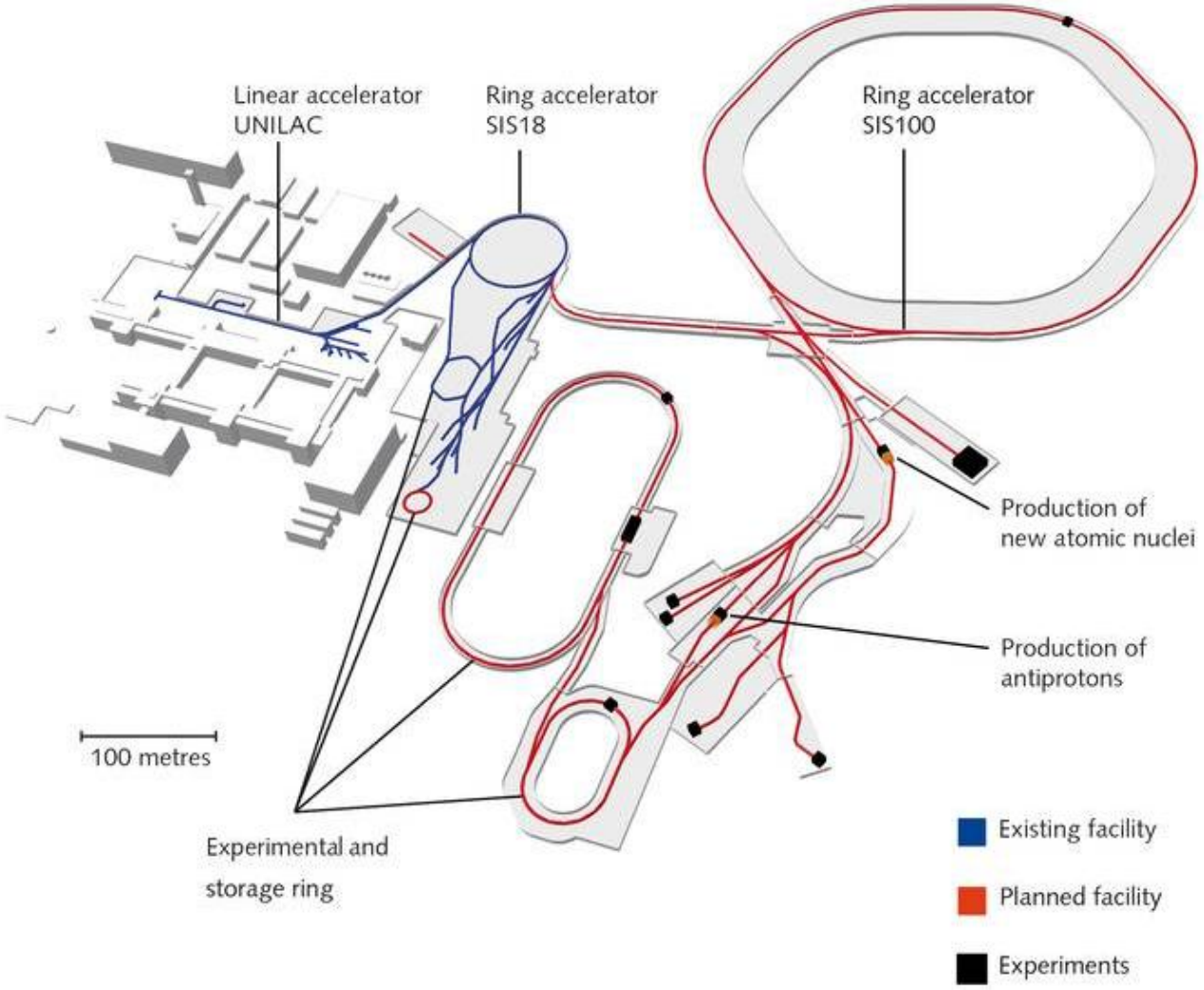
Jarosław Polinski

Co-authors:

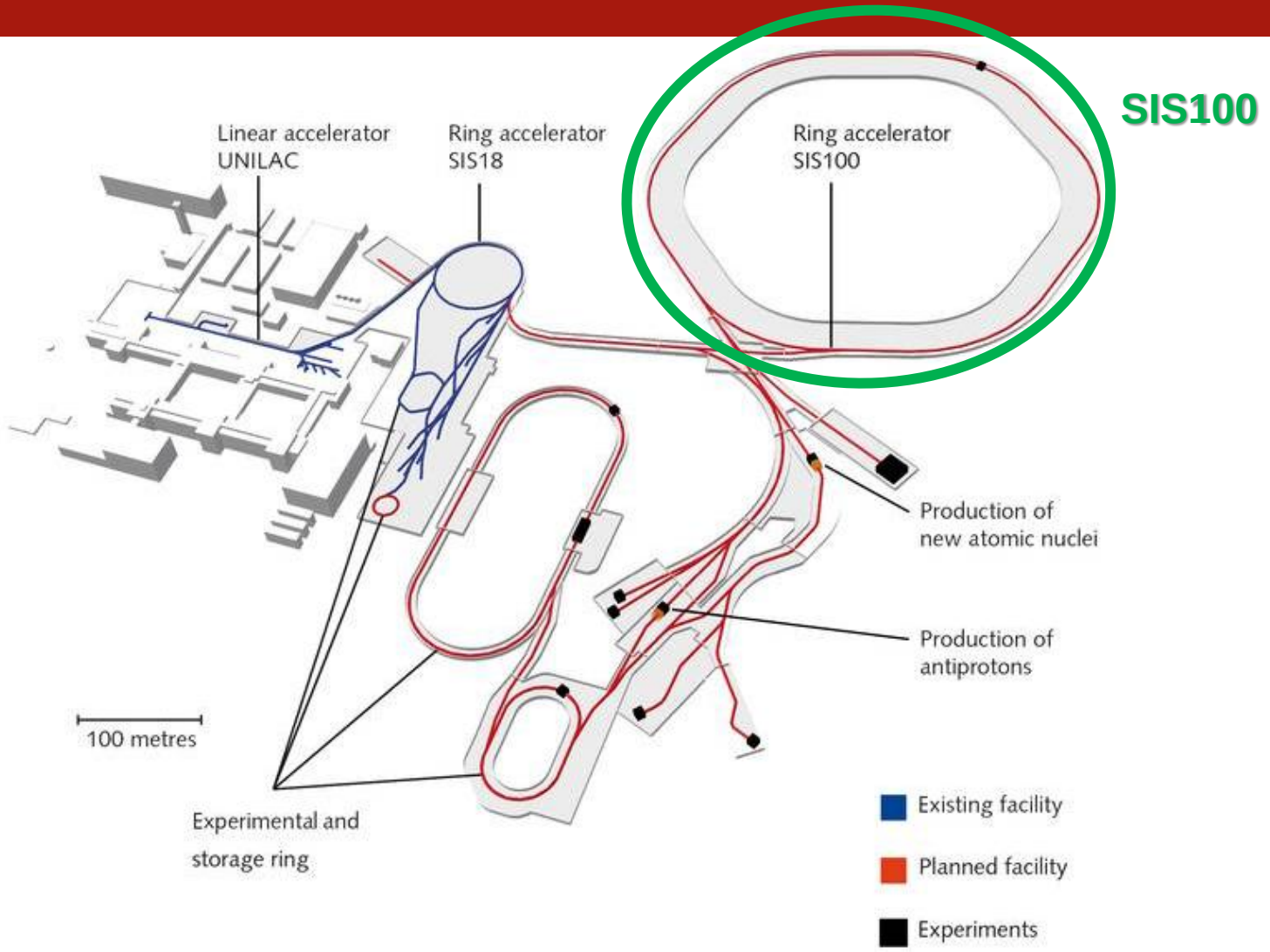
M. Chorowski, A. Iluk, M. Stanclik – WUST, Poland
T. Eisel, M. Kauschke, B. Streicher – GSI, Germany
P. Grzegory, G. Michalski, K. Zawada – Kriosystem Sp z.o.o., Poland
B. Joshi, D. Panchal, M. Thekdi – INOXCVA, India

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21 of Nov 2026, Cracow, POLAND

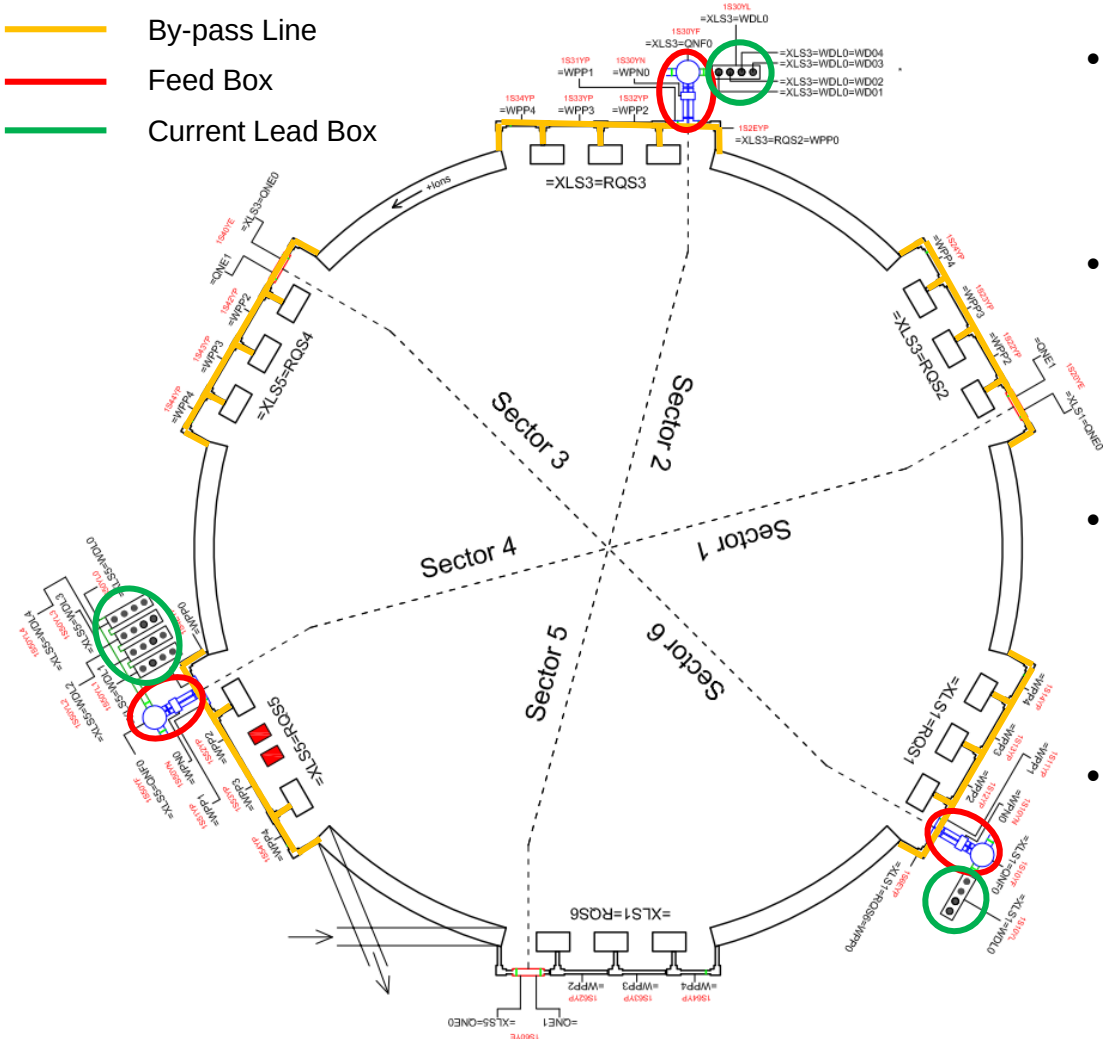
Overview of the FAIR accelerator complex



Overview of the FAIR accelerator complex



FAIR SIS100 Local Cryogenic System

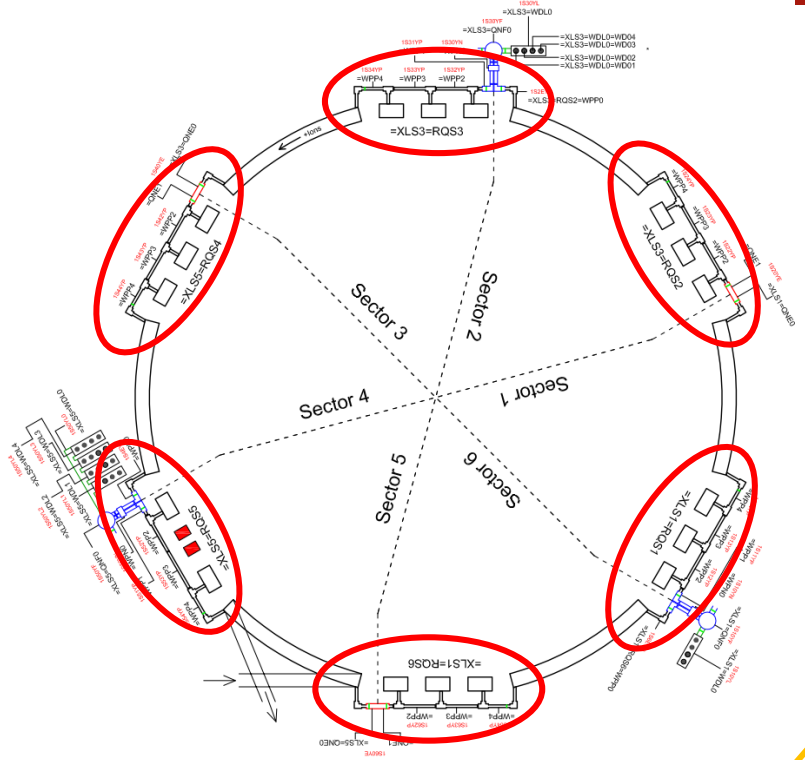


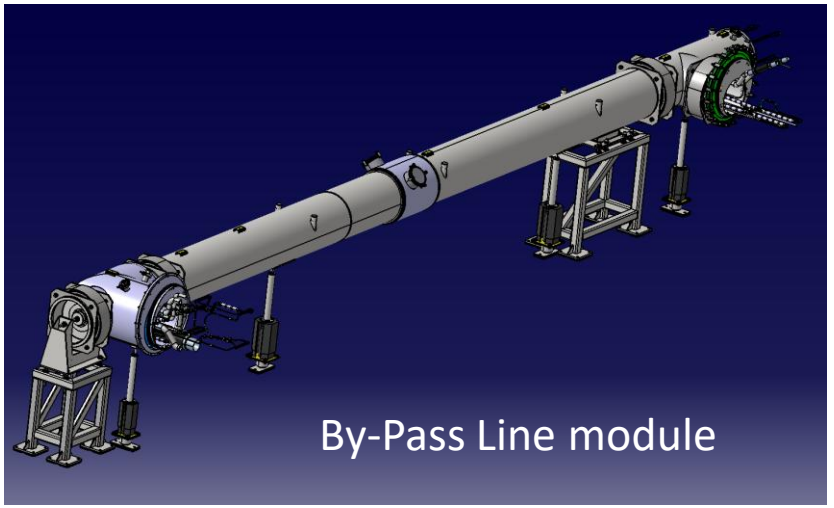
- The SIS100 ring consists of six cold arcs containing superconducting magnets.
- The cold arcs are interconnected by six **Cryogenic Bypass Lines (BPLs)**, with a total length of 288 m.
- Each **Feed Box (FB)** supplies two adjacent SIS100 ring sectors with cryogenic helium and electrical power.
- The **Current Lead Boxes (CLBs)** provide the electrical transition between conventional conductors and superconducting busbars.

Functions of the SIS100 Local Cryogenic System

- Supplies liquid and cold gaseous helium to the SIS100 superconducting magnets.
- **Distributes electrical current to power and control the magnets through four pairs of superconducting busbars.**
- Protects the magnet process pipes against excessive pressure.
- **Isolates the magnets from externally induced mechanical loads.**
- Measures and controls helium flow through the process pipes.

Local cryogenic system of FAIR SIS100

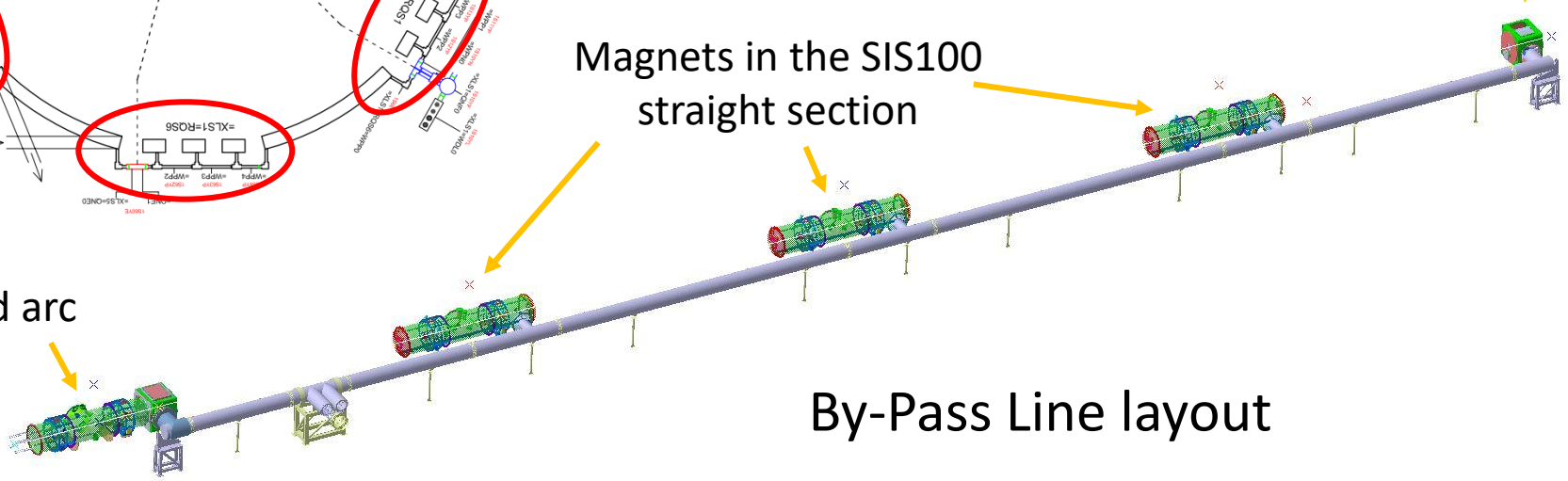




Cold arc

Magnets in the SIS100
straight section

Cold arc

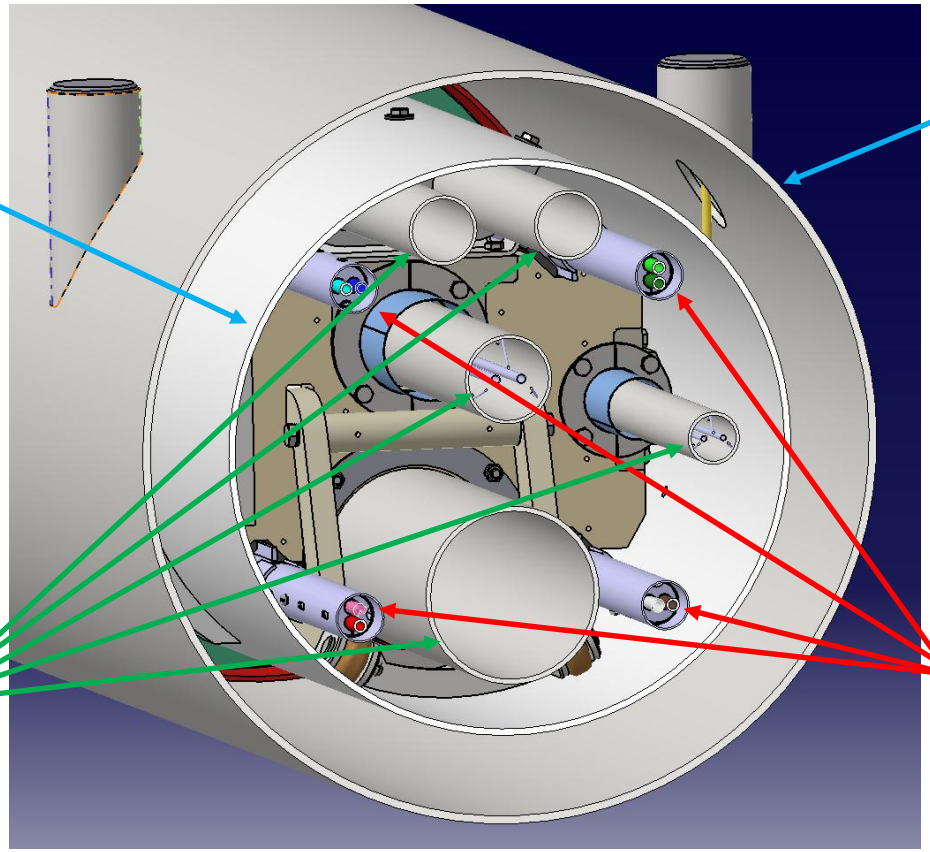


By-Pass Line layout

BPL design – internal structure

Cross-section of the Cryogenic By-Pass Line

Thermal Shield (TS): temperature 80 K



Vacuum Vessel (VV): temperature 293 K

Process Pipes (PP): 5 pipes providing helium (4K and 50K) to the magnets

Superconducting Busbars (BB): Four pairs of NbTi conductors operating at approximately 4 K

BPL design – internal structure

View of the Cryogenic By-Pass Line during assembly

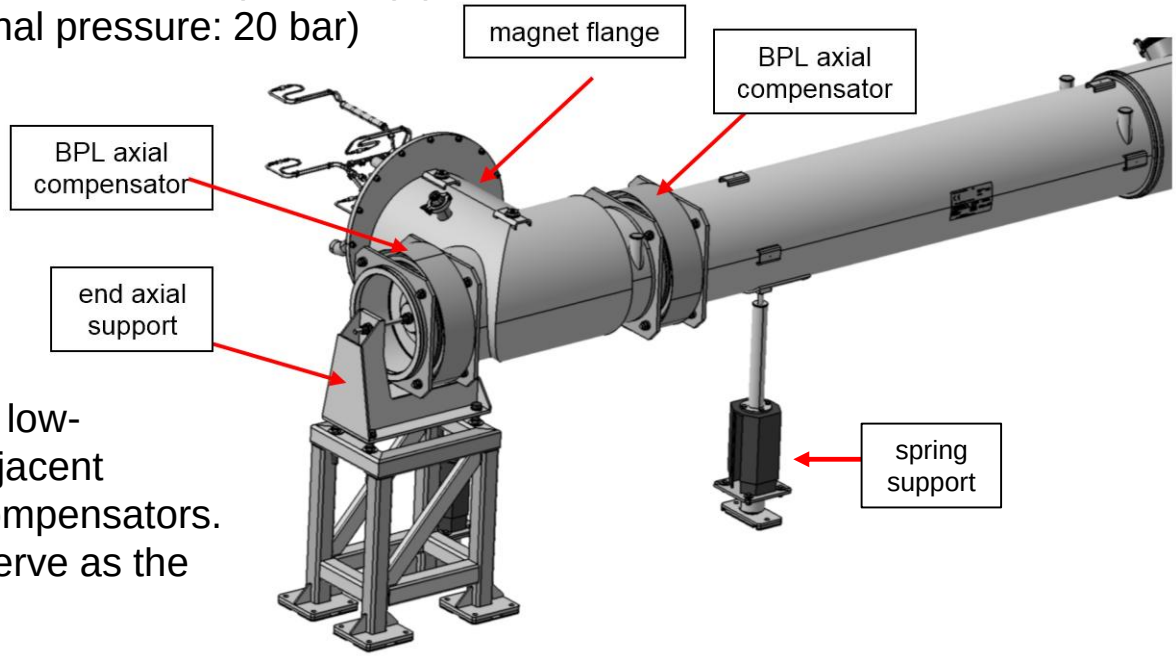


BPL design – floating external supports

The position of each superconducting magnet must be adjusted with an accuracy of 0.1 mm along the entire 1.1 km SIS100 ring. To maintain this precision, significant mechanical loads must not be transferred from the BPL to the magnets.

The BPL is subjected to several mechanical loads:

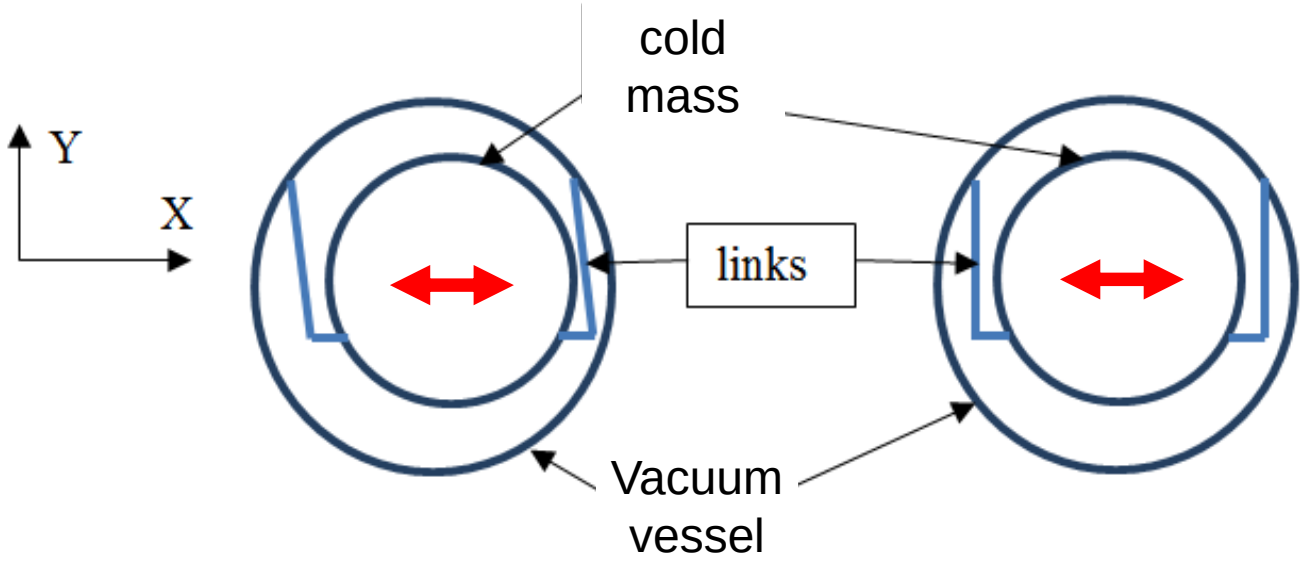
- External atmospheric pressure.
- Forces caused by thermal contraction of the process pipes.
- Internal helium pressure (nominal pressure: 20 bar)



The BPL is primarily supported by low-stiffness spring supports, while adjacent sections are separated by axial compensators. The flanges at magnet interface serve as the only fixed points of the BPL.

BPL design – floating internal supports

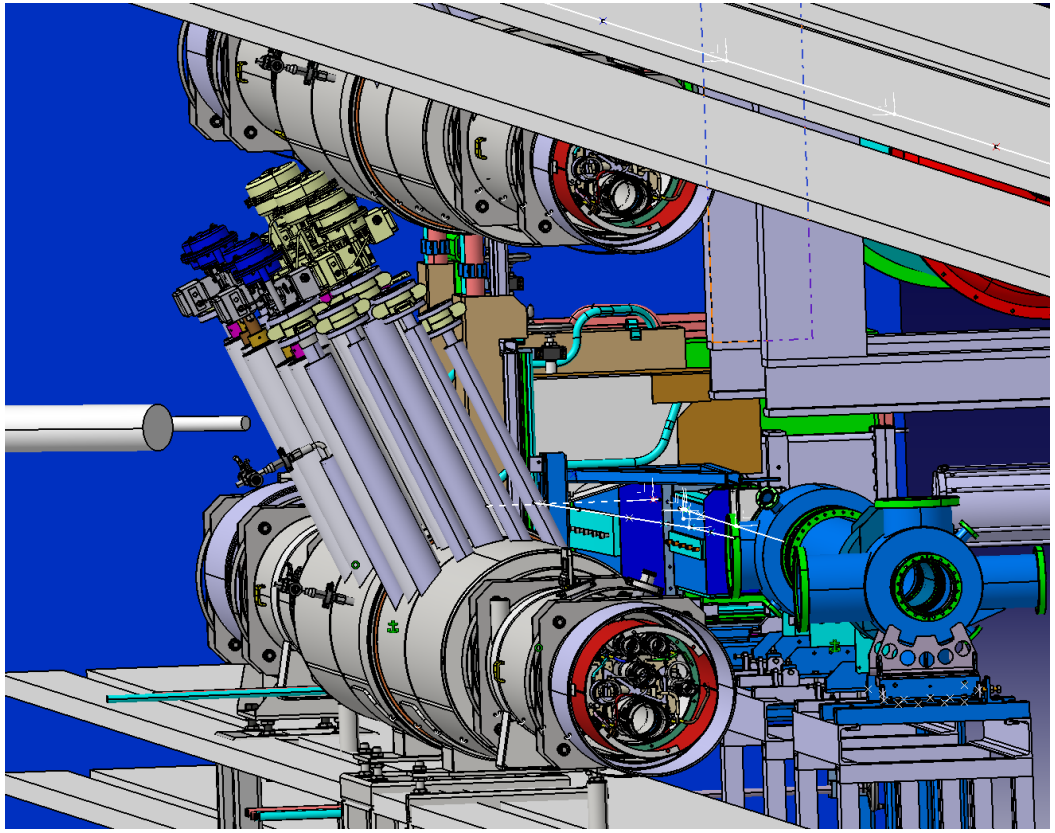
An innovative internal suspension system was developed to minimise the mechanical loads transferred to the superconducting magnet structures.
Unlike conventional sliding supports, which primarily accommodate longitudinal displacement, the BPL support system must allow cold-mass movement in both longitudinal and transverse directions.
Therefore, the internal cold mass of the BPL is supported by a floating suspension system rather than conventional sliding supports.



BPL Design – integration in a congested environment

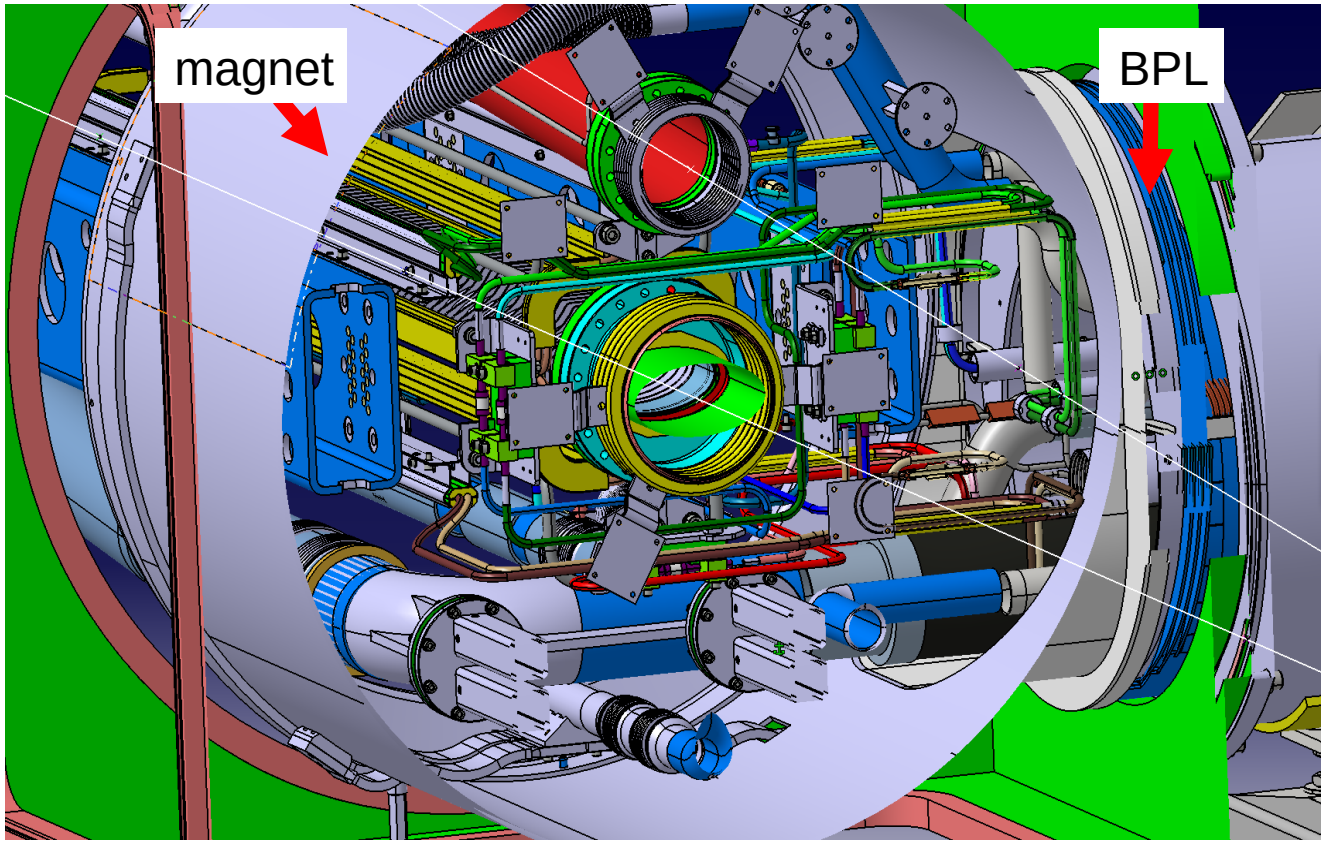
The BPL modules must be integrated into an already defined and highly constrained accelerator tunnel environment:

- The space allocated to the BPL was defined before the detailed design phase and proved insufficient.
- Other accelerator components have higher integration priority, making modifications difficult.
- The limited space in the tunnel makes on-site assembly particularly challenging.



Real environment of the End Box BPL module

BPL design – magnet interfaces

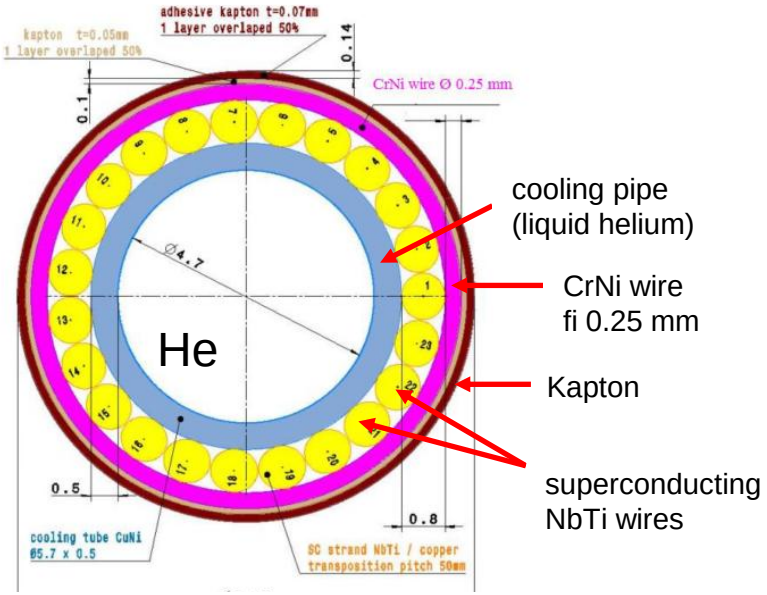


- The magnet design was finalised before the BPL design
- The BPL process pipes and superconducting busbars must fit within the existing magnet structure.

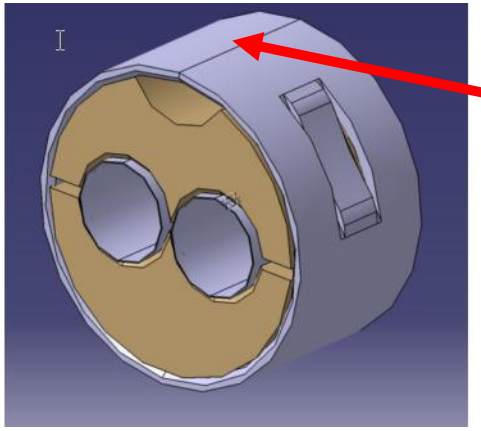
Superconducting cables (Bus Bars)

Bus Bar clamping system requirements:

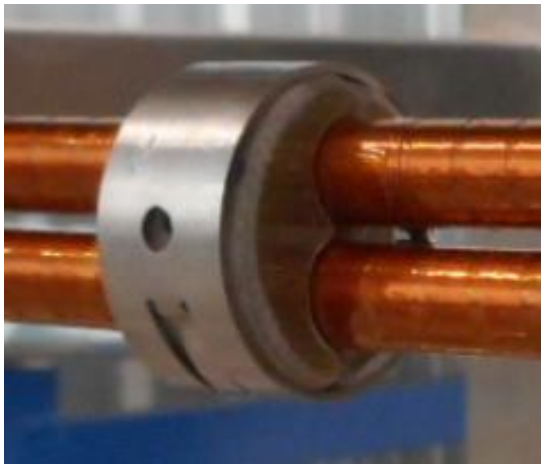
- AC current 13 kA
- Lorentz force per unit length: 3.81 kN/m
- Approximately 18,000 clamps are required for the SIS100 BPL system, making simplicity and cost-effectiveness essential.



Cross-section of a Nuclotron-type NbTi Superconducting Bus Bar



The final version of the Bus Bar clamps



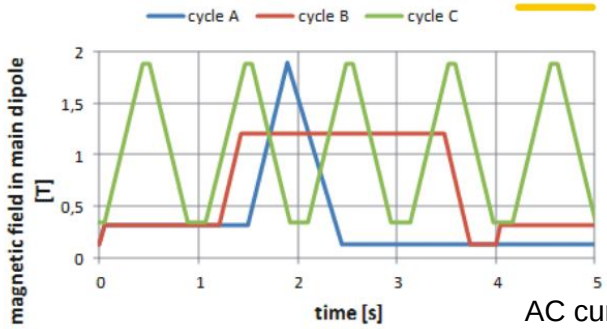
The real BB clamp

Electromagnetic Cross-Talk between Bus Bars

Requirement:
To ensure precise magnet control, a **13 kA AC** current in one pair of superconducting busbars must induce no more than **100 mA** in another pair through electromagnetic cross-talk over the entire SIS100 ring.

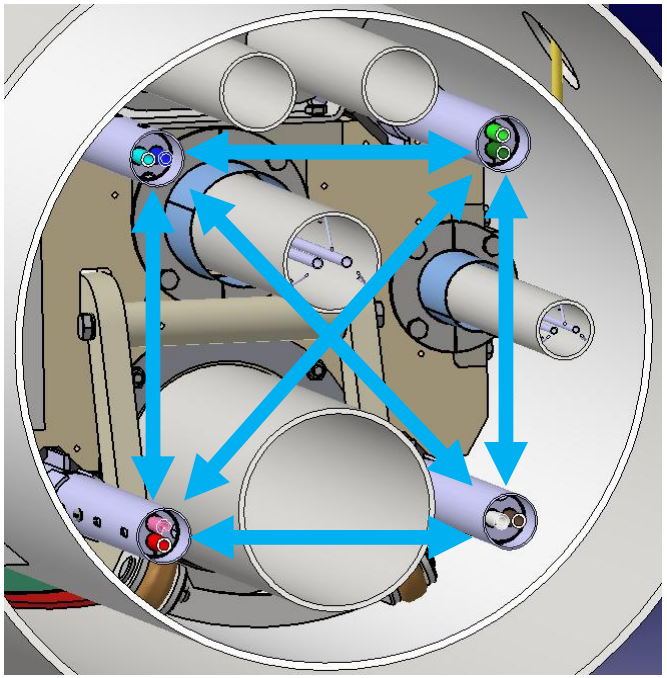
Design solutions:

- Clamping the two Bus Bars of each pair together to minimise their external magnetic field.
- Maximising the distance between individual busbar pairs.
- Optimising the relative orientation of the busbar pairs through controlled twisting.



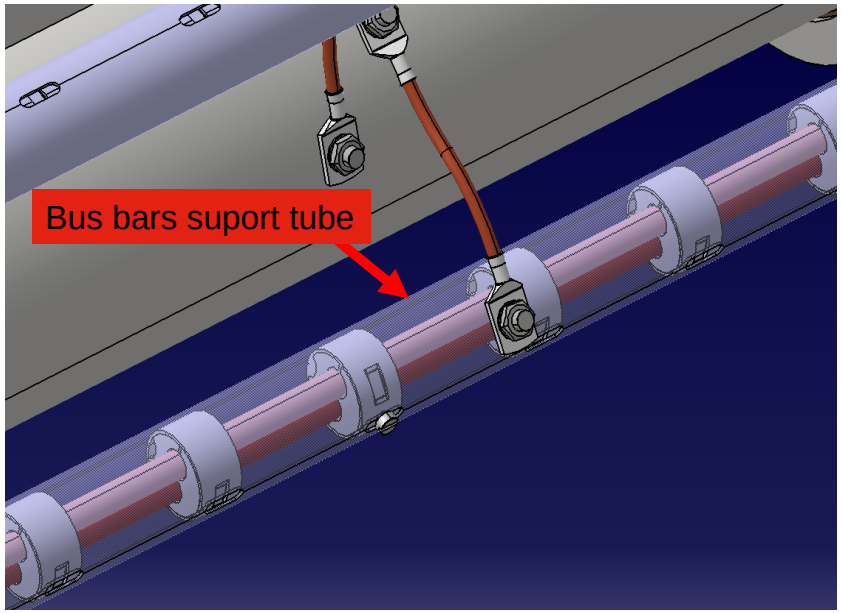
AC current cycles in Bus Bars

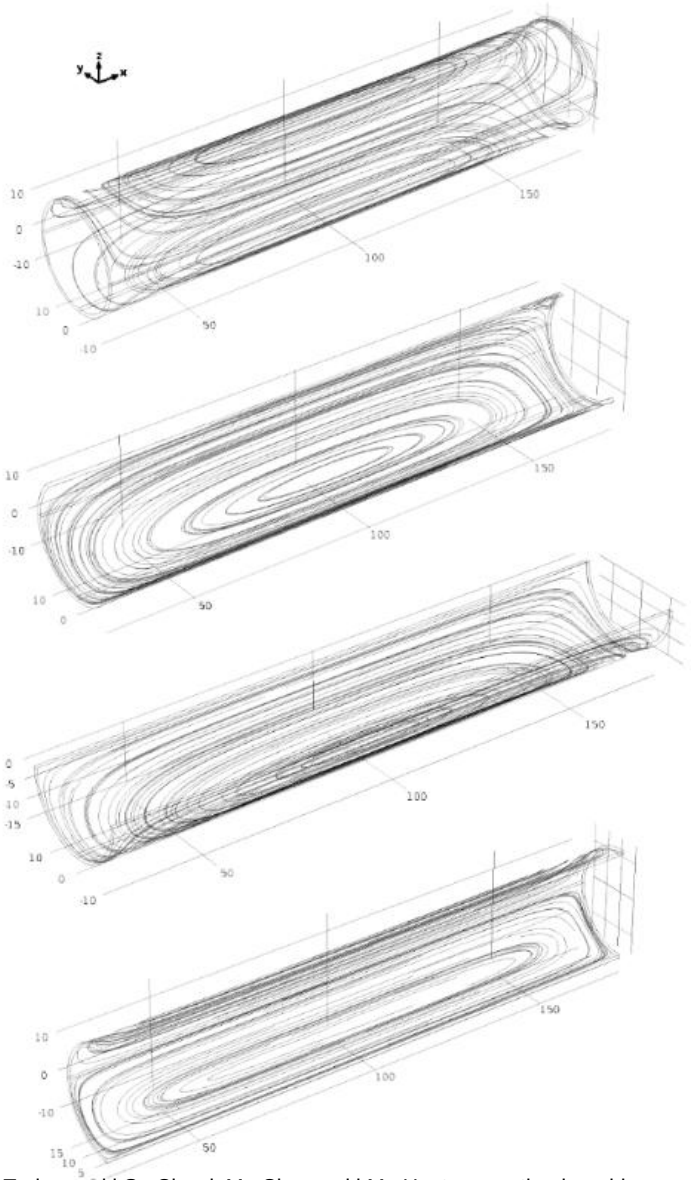
A: Proton cycle (5 s)
B:RIB cycle U28+ (4 s)
C: triangular cycle U28+ (1.029 s)



Eddy Current Losses in the Bus Bar Support Tube

Electromagnetic simulations were performed to evaluate heat generation caused by eddy currents in the mechanical support tube of the superconducting busbars.





Tomków Ł., Trojanowski S., Ciszek M., Chorowski M., Heat generation by eddy currents in a shell of superconducting bus-bars for SIS100 particle accelerator at FAIR

View of streamlines of Eddy currents for (top to bottom): full shell, split shell at angle 45 °, 0 °, 90°

Thermal contraction compensation of Bus Bars

A dedicated **compensation system** was developed to accommodate the thermal contraction of Bus Bars within the 12.9 m-long BPL modules



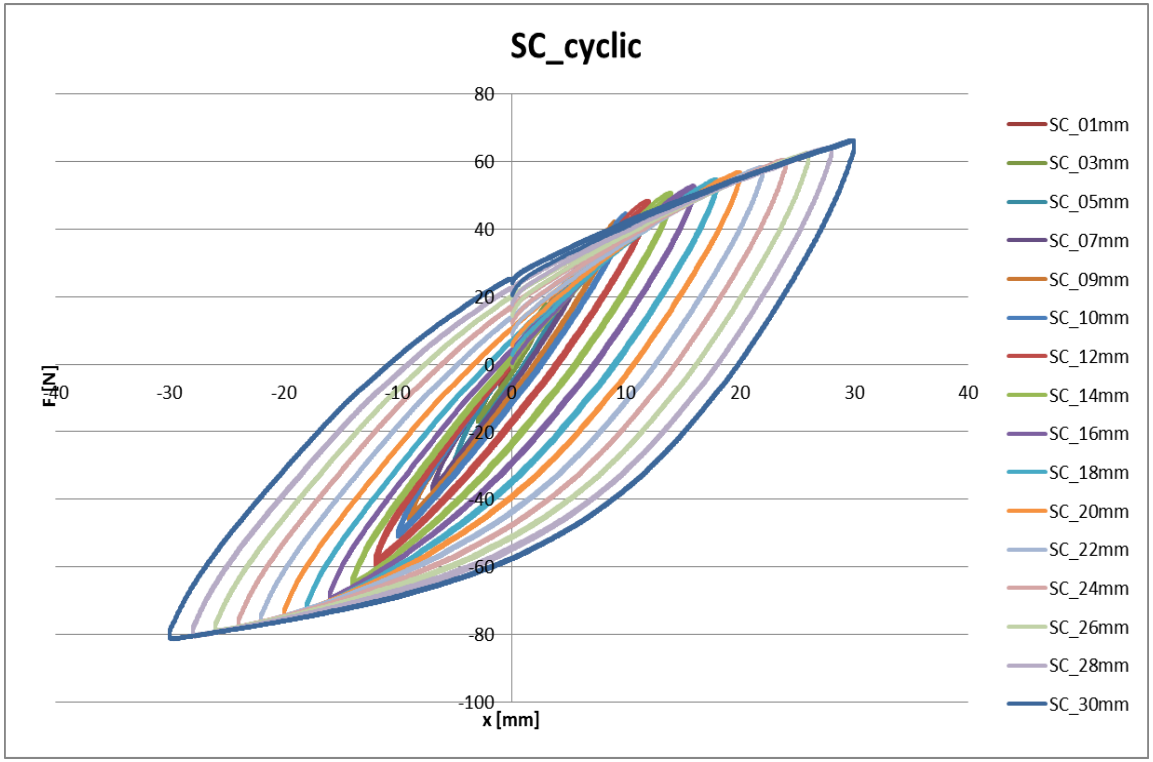
Bus Bars thermal compensation loop

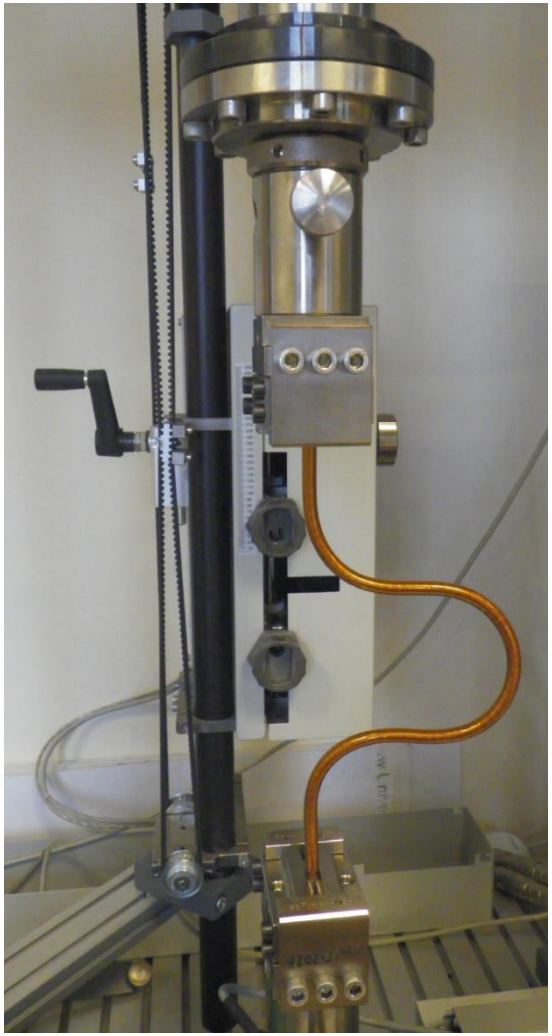


Bus Bar compensation loop tests at liquid nitrogen

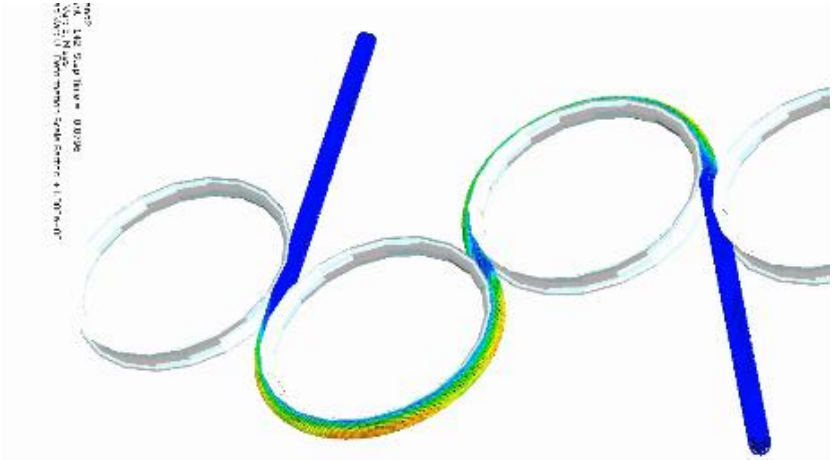
Mechanical tests

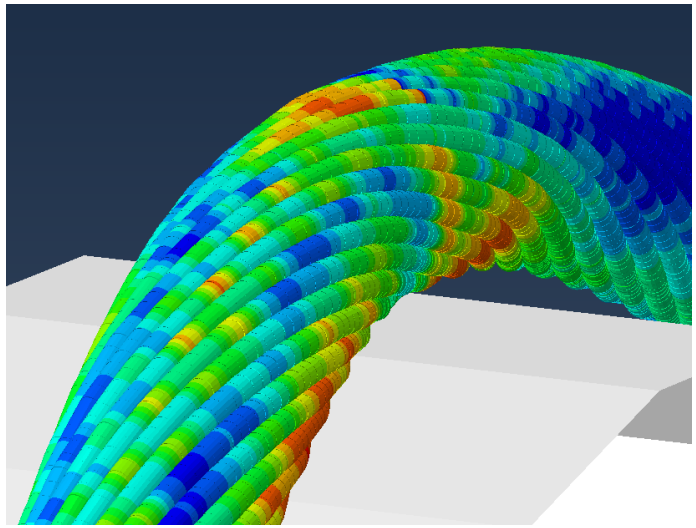
The **mechanical hysteresis** of the Bus Bar compensation loops was experimentally investigated..

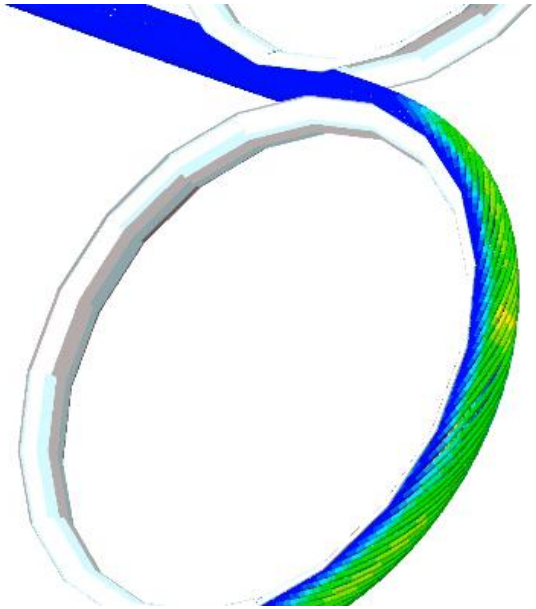




FEM of Bus Bar bending

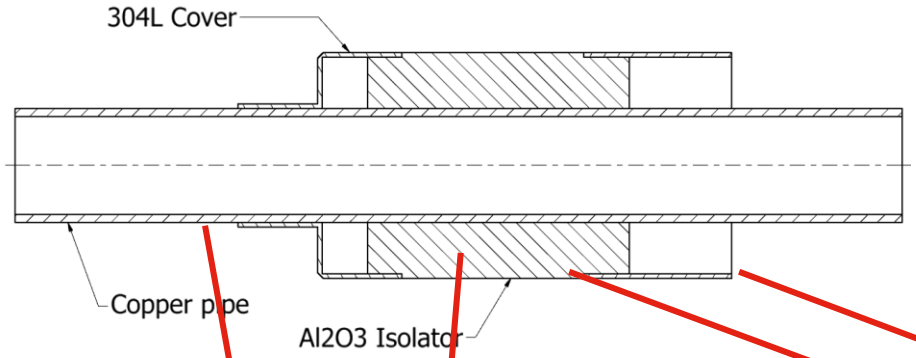




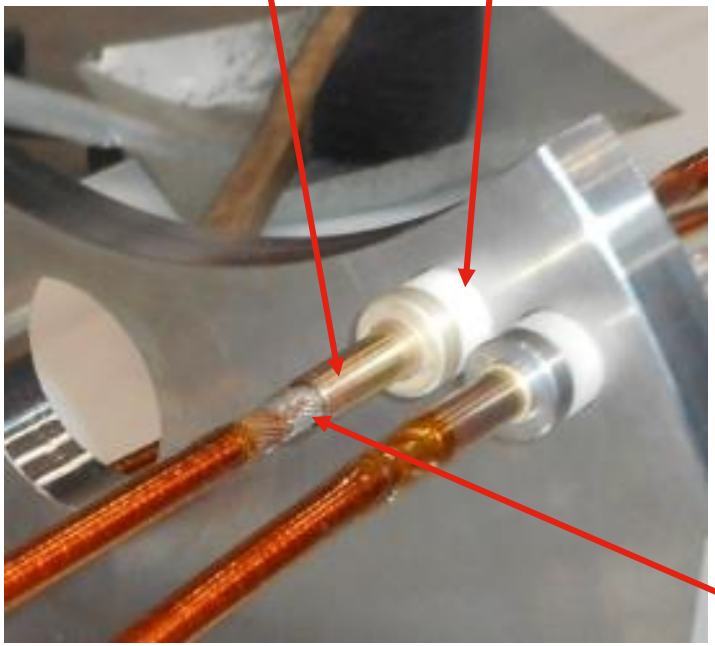


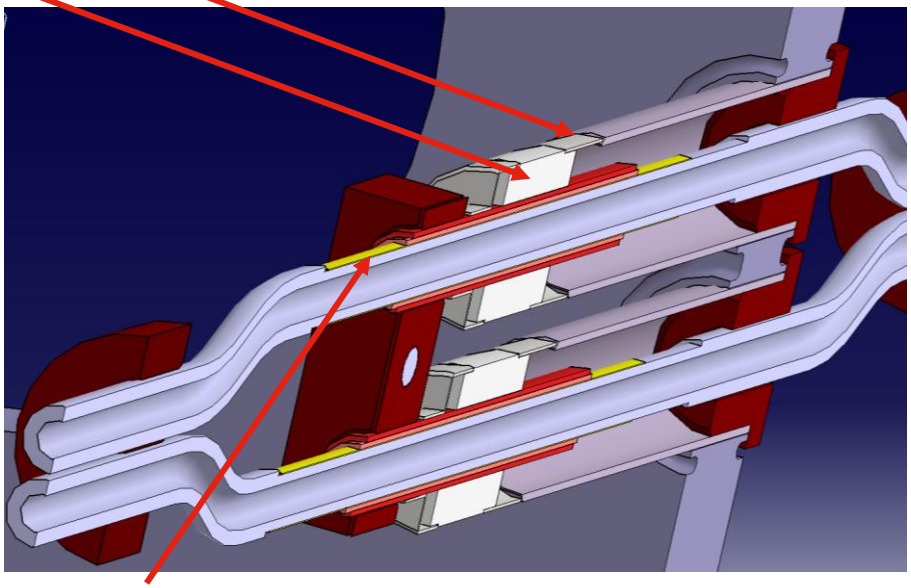
Bending proces of the superconducting cable - FEM simulation

Vacuum Barrier feedthroughs



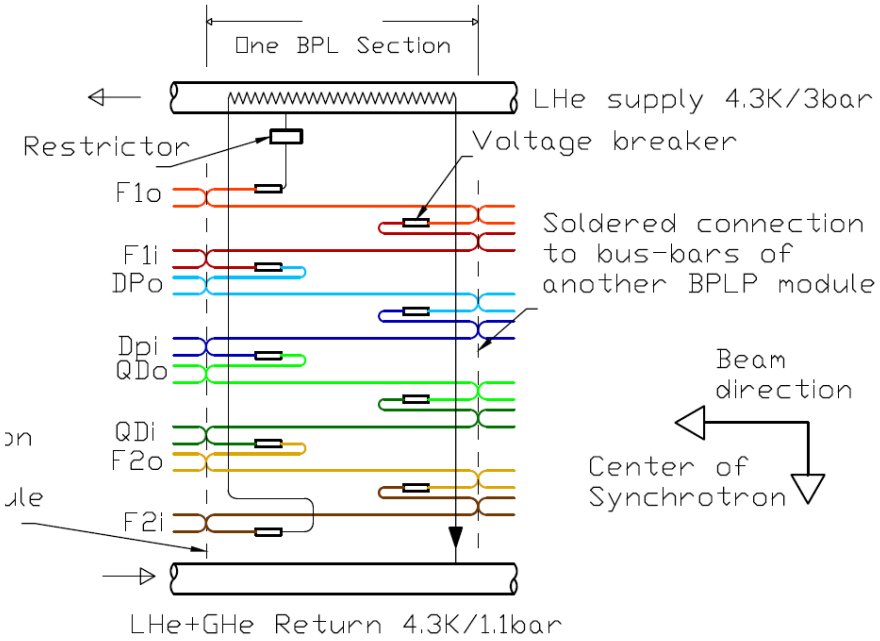
Vacuum Barrier feedthrough
for the Bus Bars



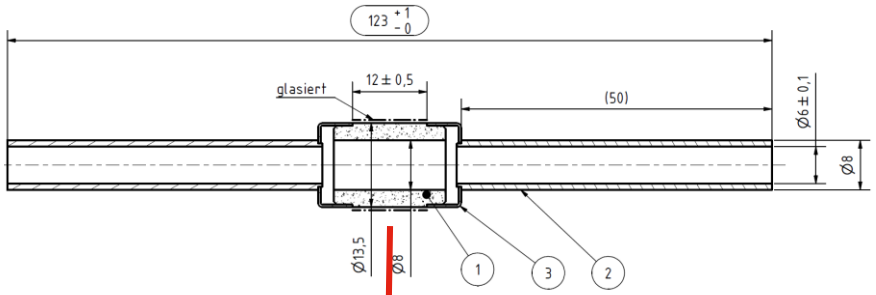


Vacuum-tight solder

Voltage Breakers



Hydraulic – electric scheme of Bus Bars in BPL module



Voltage Breaker design



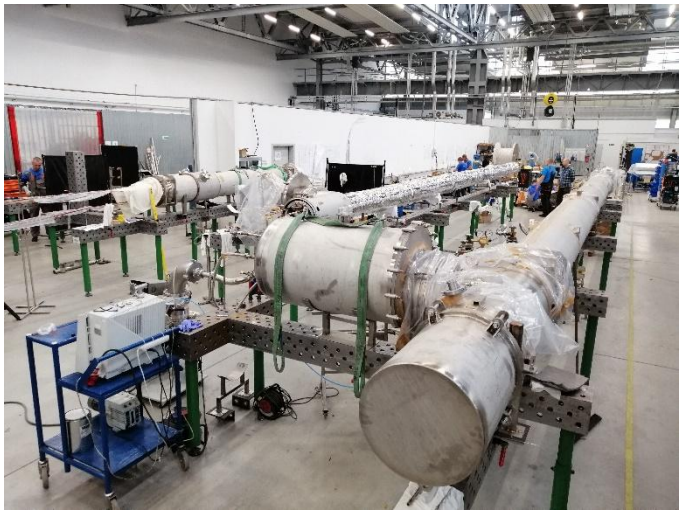
Voltage Breaker view

Within each BPL module, eight electrical circuits share a common hydraulic circuit for helium flow.
Voltage breakers provide electrical isolation between the individual circuits while maintaining hydraulic continuity.

By-Pass Line production









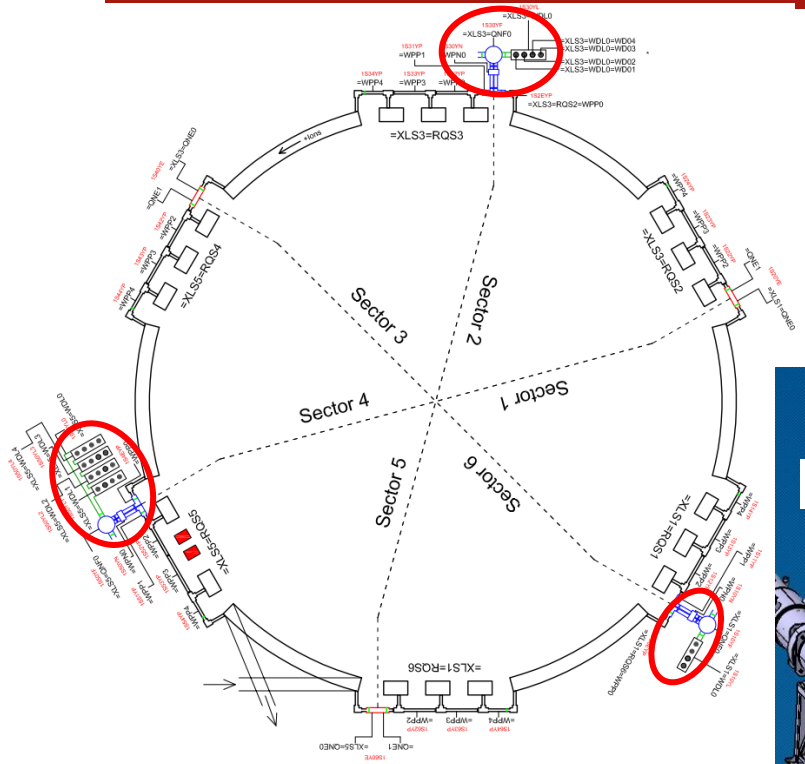




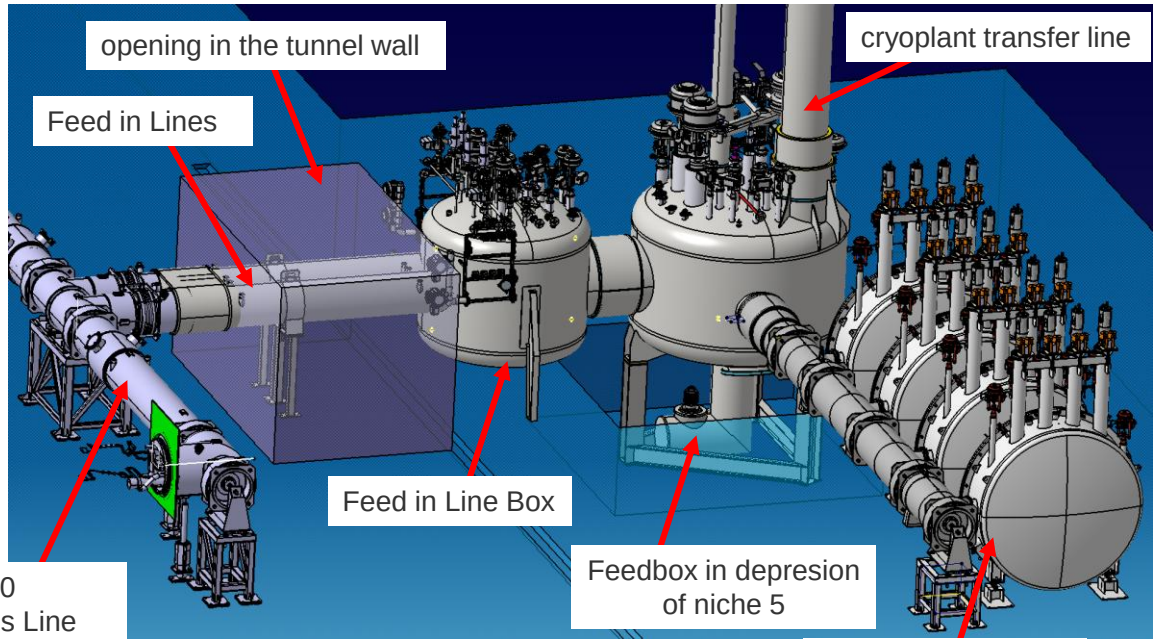
By-Pass Line installed in the SIS100 tunnel



he SIS100 Local Cryogenic System at FAIR

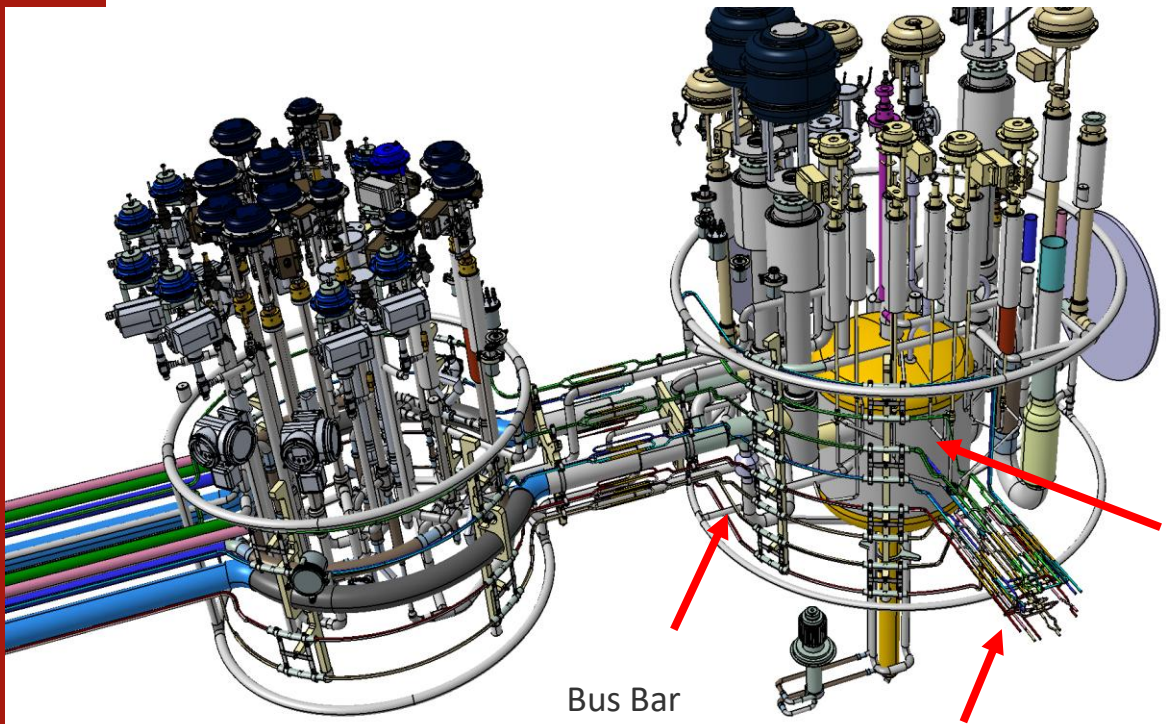


Feed Box + Current Lead Boxes



SIS100 Feed Boxes

Internal structure of Feed Box

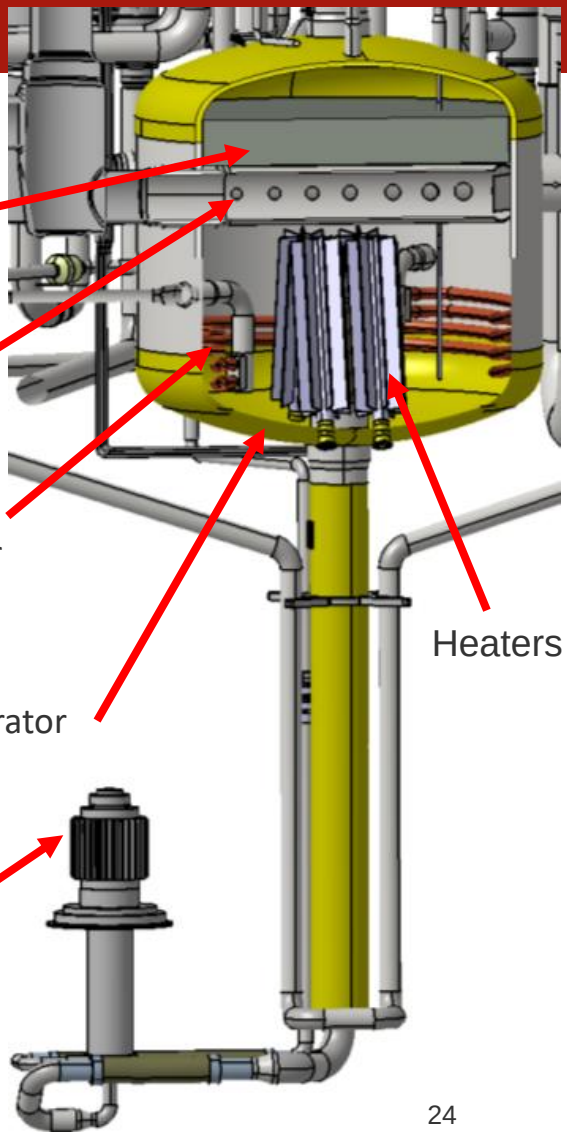


Feed-In Line Box

Bus Bar system

Feed Box

Connection to Current Lead Box(es)



Demister pad

2-phase He inlet

Cu heat exhanger

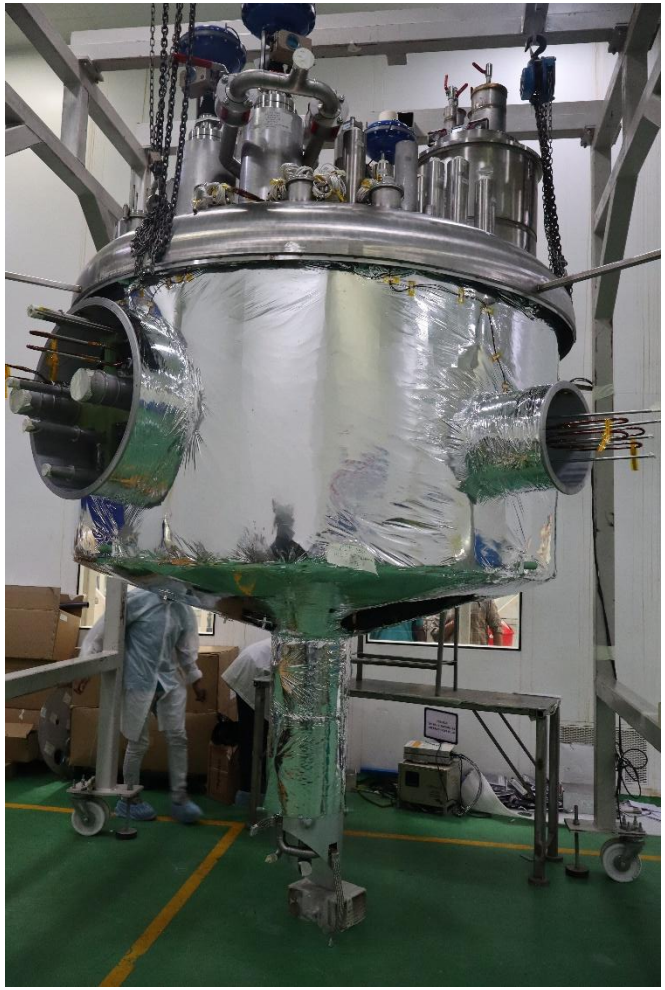
Phase separator

Heaters

Helium circulation pump

Feed Box manufacturing at INOX India





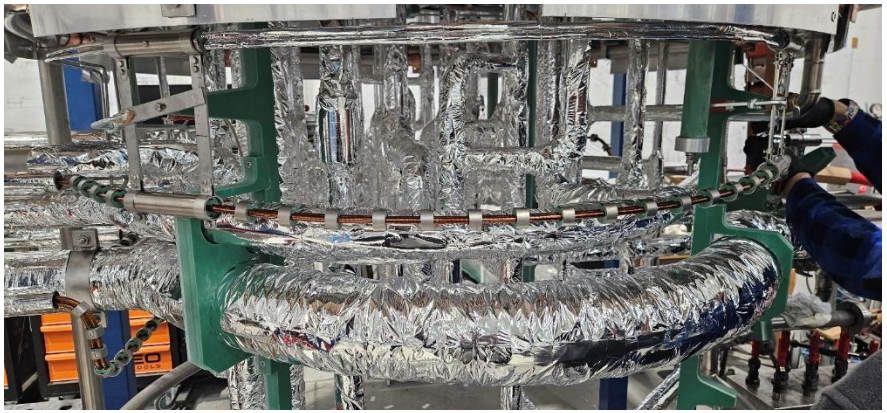
Feed Box manufacturing at INOX India





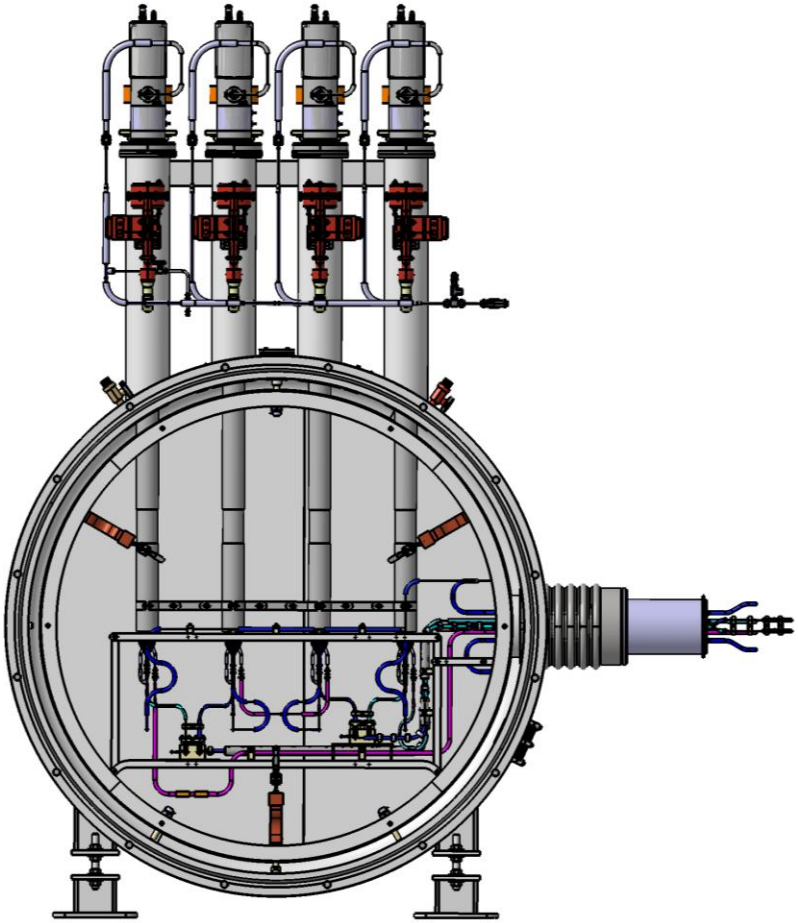
Feed-In Line Box manufacturing at KrioSystem, Poland







Current Lead Boxes

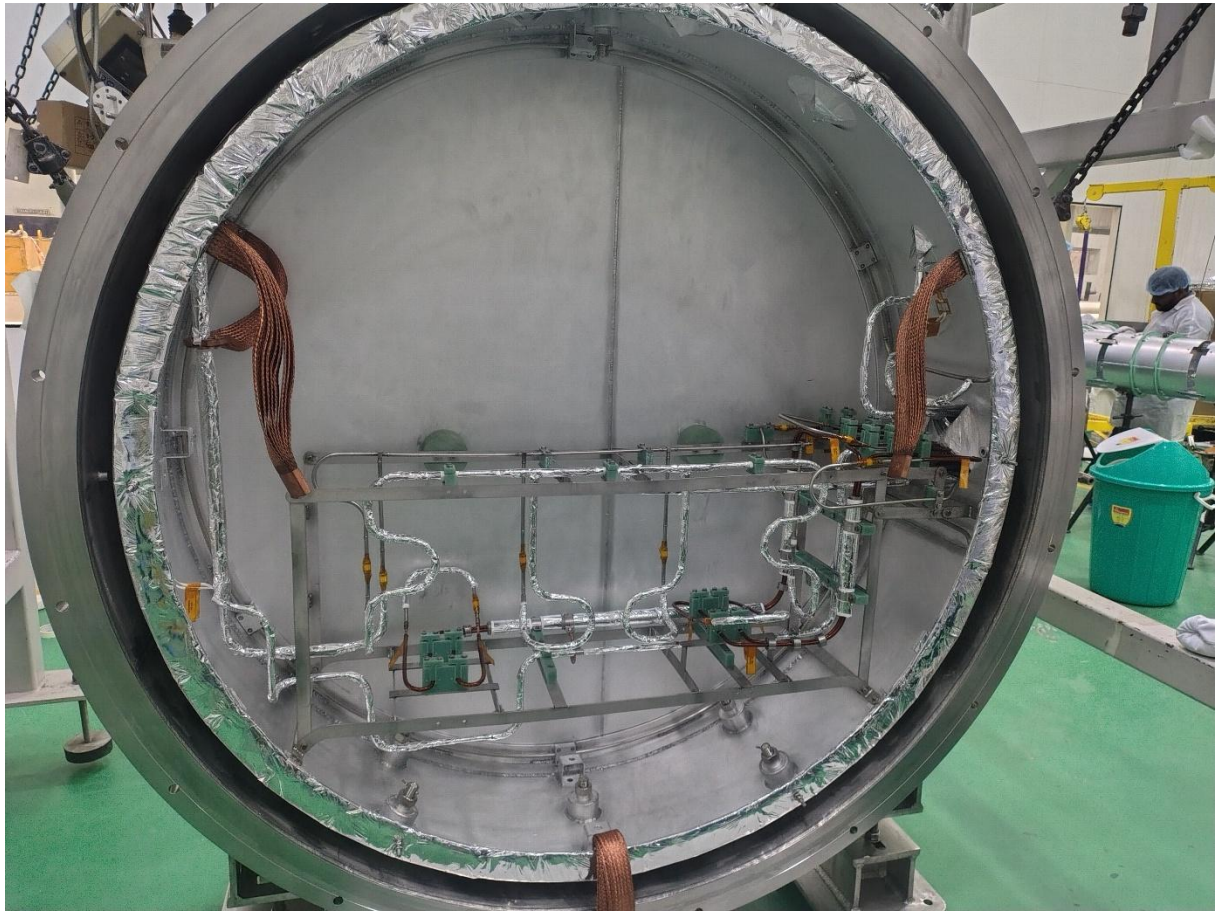


Current Lead Box design



Current Leads installation at GSI

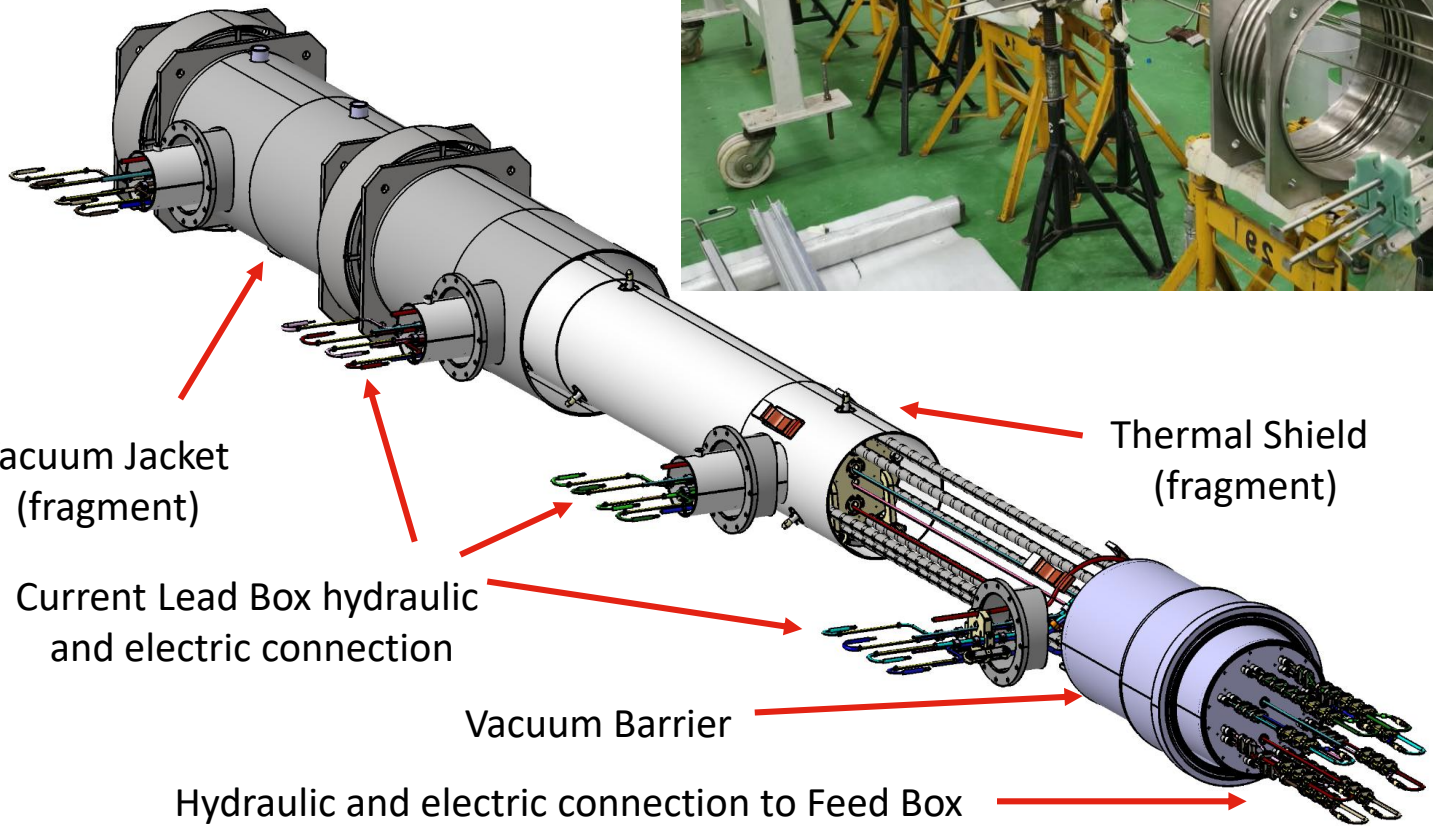
Current Lead Boxes manufacturing at INOX India





Current Lead Boxes Link manufacturing at INOX India





Summary

- The SIS100 Local Cryogenic System at FAIR combines the distribution of cryogenic fluids (liquid and cold gaseous helium) with the transmission of high electrical currents through superconducting busbars.
- The design phase, spanning more than ten years, and the subsequent manufacturing phase, lasting over three years, involved numerous complex engineering challenges.
- All 27 Cryogenic Bypass Line modules have been manufactured and installed in the SIS100 tunnel. System integration will begin following the delivery of the remaining components.
- The Feed-In Line for Sector 3 has been delivered, while the corresponding Feed Box is undergoing Factory Acceptance Testing (FAT) at the manufacturer's facility.
- Four Current Lead Boxes have been delivered and have successfully passed FAT. One additional unit is ready for dispatch, while the final unit is still under production at INOX, India. Manufacturing of the Current Lead Box Links also remains to be completed.
- The two remaining Feed Boxes have been ordered by FAIR and will be manufactured by Kriosystem, Poland.
- All manufacturing activities, Factory Acceptance Tests (FAT), Site Acceptance Tests (SAT), installation and subsequent system integration are supervised by WUST in close collaboration with GSI, FAIR, INOX India and Kriosystem, Poland.

Thank you for your attention