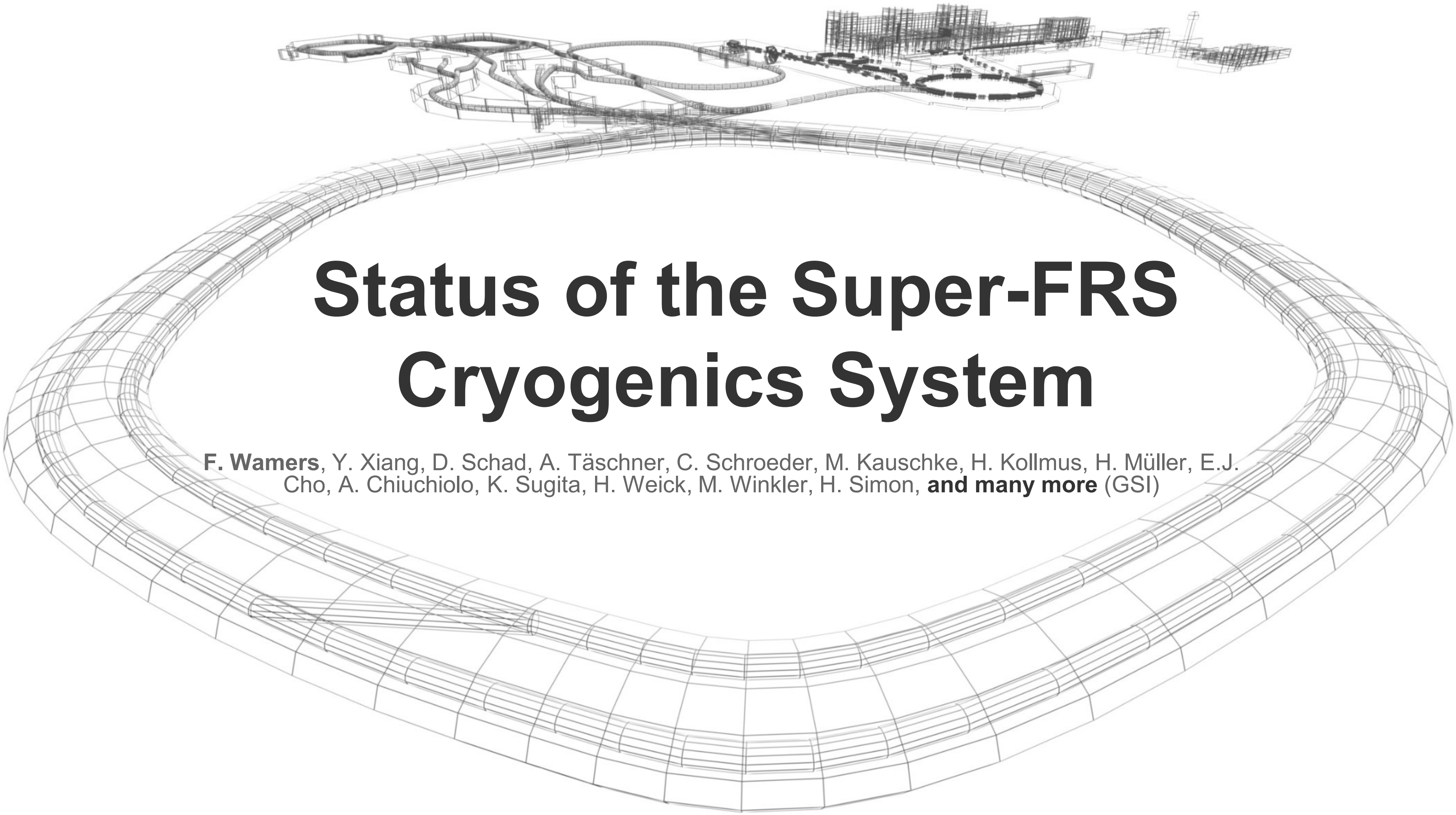
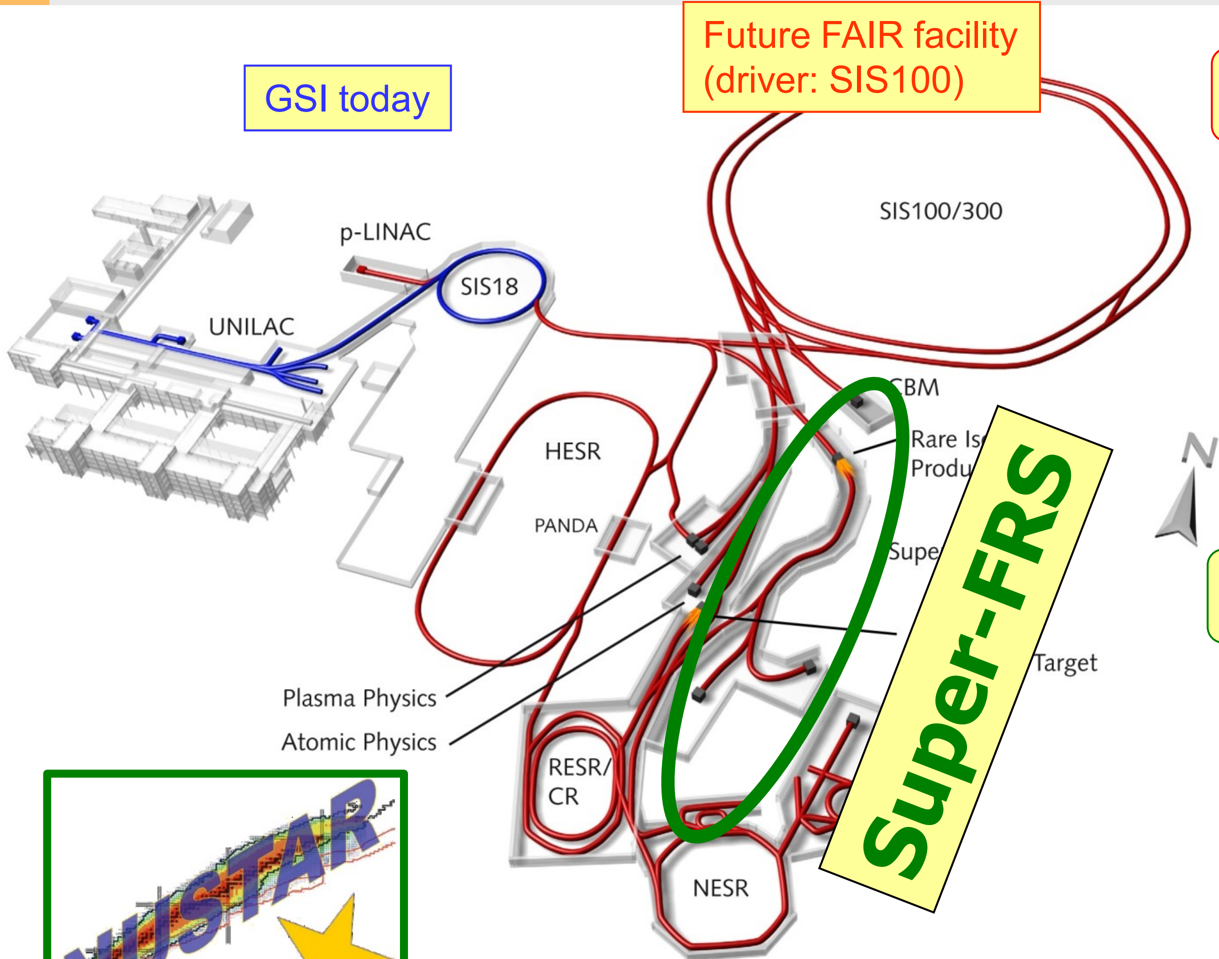


Status of the Super-FRS Cryogenics System

F. Wamers, Y. Xiang, D. Schad, A. Täschner, C. Schroeder, M. Kauschke, H. Kollmus, H. Müller, E.J. Cho, A. Chiuchiolo, K. Sugita, H. Weick, M. Winkler, H. Simon, **and many more** (GSI)

The Super-FRS @ FAIR:
Construction Site (Status May 2022)

The Super-FRS @ FAIR: A Key Device for Fundamental Research



NUclear STructure, Astrophysics, and Reactions

Primary Ion Beams

- **3.5·10^{11} ^{238}U^{28+}/s (DC)** @ 1.5 GeV/u
- **5·10^{11} ^{238}U^{28+} (pulsed)** @ 1 GeV/u
- factor **100-1000** in intensity over present

Secondary Ion Beams

- Broad range of short-lived (= “exotic”) rare-isotope beams up to **1.5 GeV/u**
- up to **factor 10 000 in intensity** over present (GSI+FRS)

→ fundamental research related to nuclear structure and reactions and nuclear astrophysics

The Super-FRS for NUSTAR: Physics with Rare-Isotope Beams

- Nuclear structure and reactions
- Nuclear astrophysics far from β-stability
- Atomic interactions of heavy ions with matter
- Application in life science and other fields

Heavy and Super Heavy Elements

Location of drip-lines

N=Z

rp-process

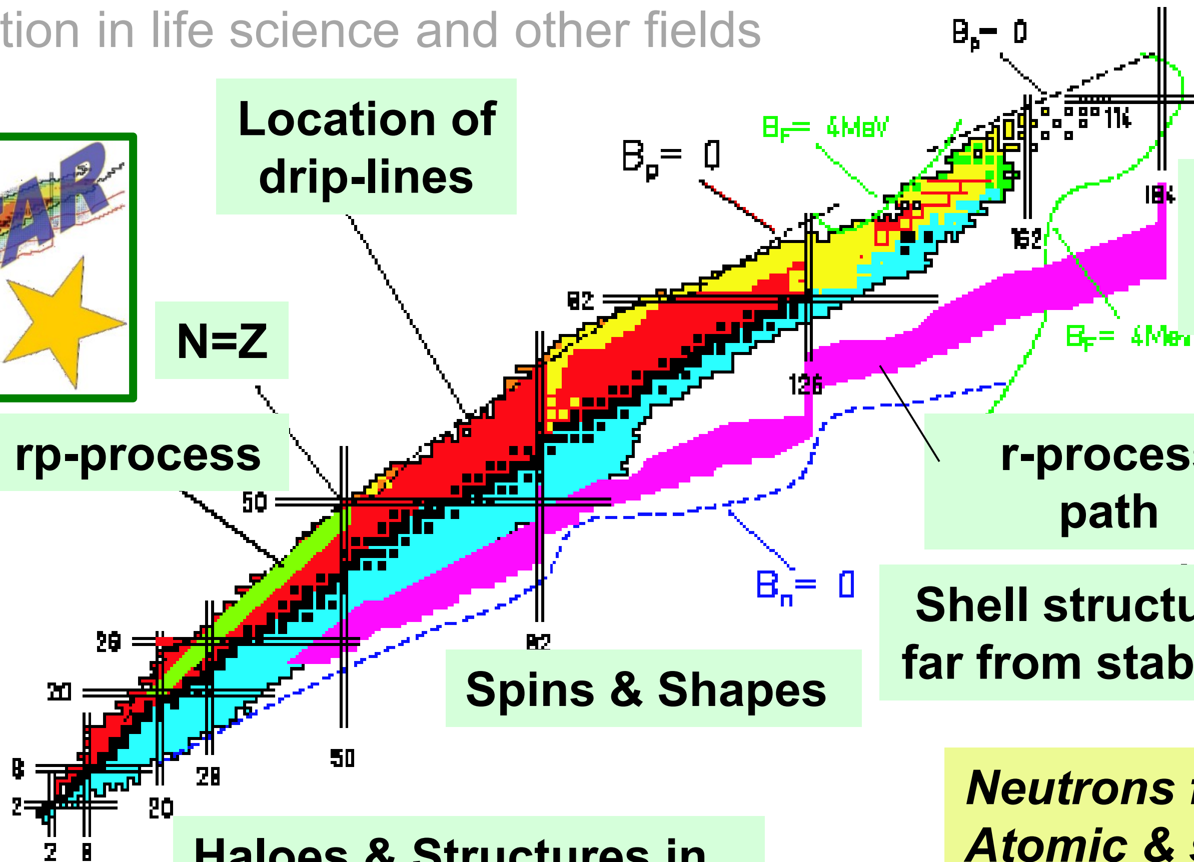
Equation of State Role of Isospin

r-process path

Shell structure far from stability

Spins & Shapes

Haloes & Structures in the Continuum

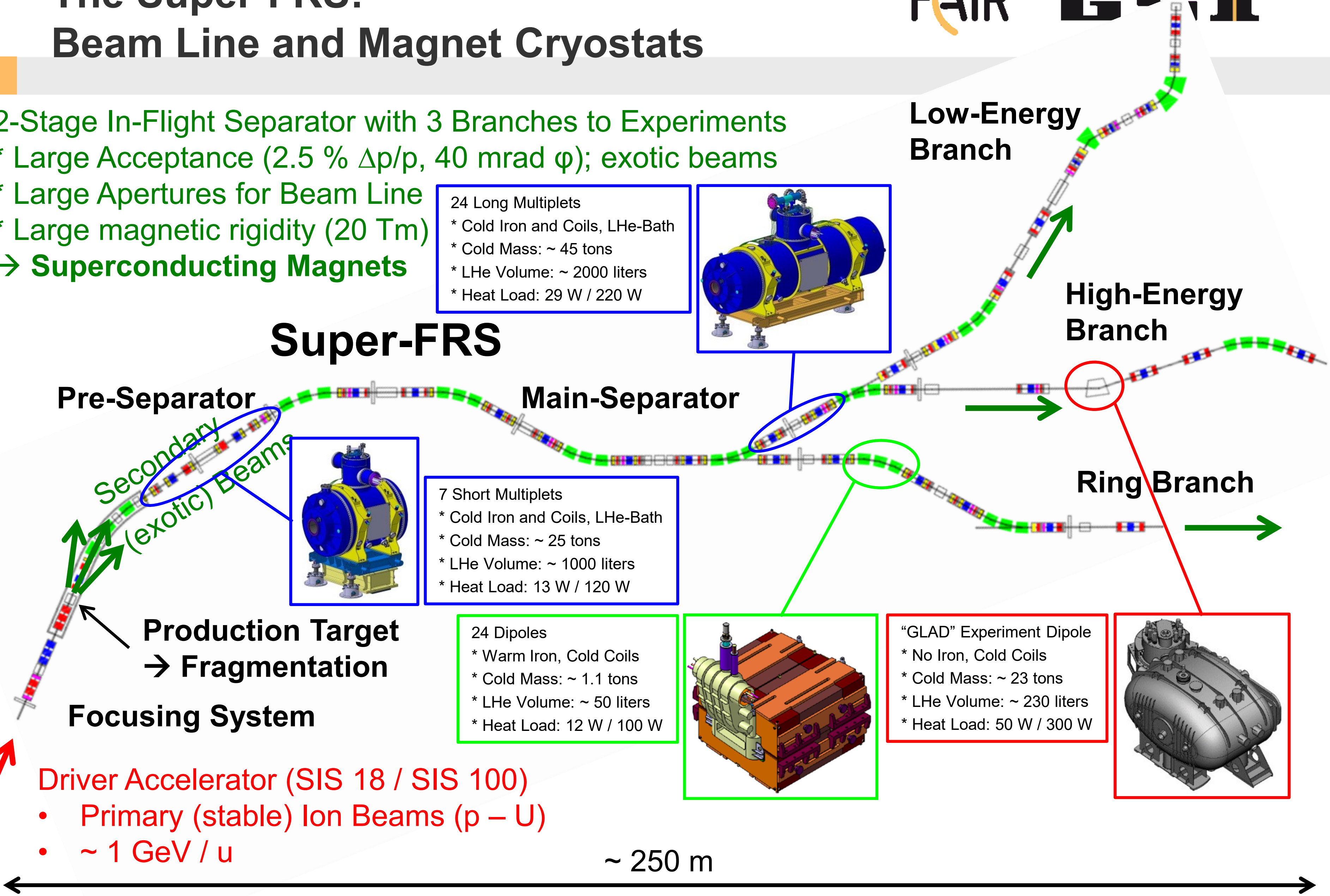


Neutrons for science
Atomic & solid state physics
Isotope production

The Super-FRS: Beam Line and Magnet Cryostats

2-Stage In-Flight Separator with 3 Branches to Experiments
* Large Acceptance (2.5 % $\Delta p/p$, 40 mrad φ); exotic beams
* Large Apertures for Beam Line
* Large magnetic rigidity (20 Tm)

→ **Superconducting Magnets**



24 Long Multiplets
* Cold Iron and Coils, LHe-Bath
* Cold Mass: ~ 45 tons
* LHe Volume: ~ 2000 liters
* Heat Load: 29 W / 220 W

7 Short Multiplets
* Cold Iron and Coils, LHe-Bath
* Cold Mass: ~ 25 tons
* LHe Volume: ~ 1000 liters
* Heat Load: 13 W / 120 W

24 Dipoles
* Warm Iron, Cold Coils
* Cold Mass: ~ 1.1 tons
* LHe Volume: ~ 50 liters
* Heat Load: 12 W / 100 W

“GLAD” Experiment Dipole
* No Iron, Cold Coils
* Cold Mass: ~ 23 tons
* LHe Volume: ~ 230 liters
* Heat Load: 50 W / 300 W

Driver Accelerator (SIS 18 / SIS 100)
- Primary (stable) Ion Beams (p – U)
- ~ 1 GeV / u

The Super-FRS s.c. Magnet Cryostats: Multiplets and Dipoles

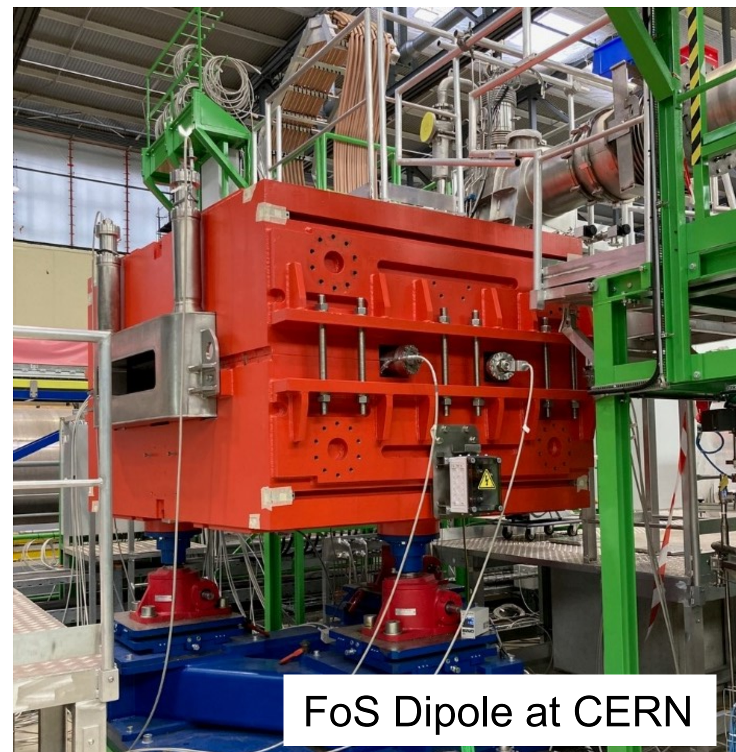
Multiplets (ASG):
- 8 short multiplets, 24 long multiplets
- up to 9 individual magnets in LM
- iron dominated, cold iron, warm beam pipe
- individual powering, I_max <300A

Status March 2023:
- 13 produced (FAT)
- 7 shipped to CERN (for SAT)
- 4 shipped to GSI (FoS-SM, FoS-LM, SM08, SM01)

Dipoles (ELYTT):
- 3 x 11, 18 x 9.75, 3 x 9.75 branched
- warm iron, s.c. coil, 50-60 tons

Status March 2023:
- 2 FoS produced (FAT), series running
- 2 shipped to CERN (for SAT)


ASG SpA in La Spezia, 24.October, 2022

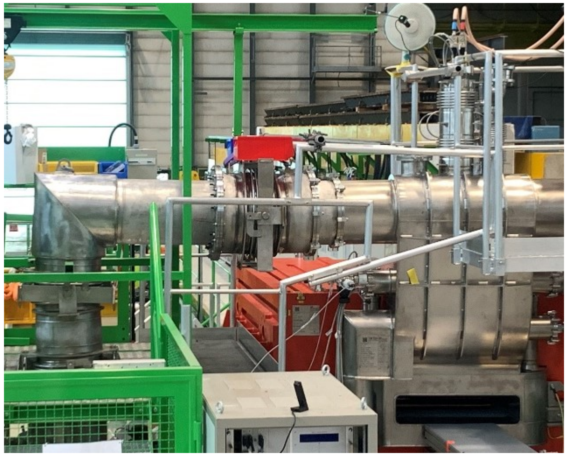

FoS Dipole at CERN

Super-FRS Magnet Testing @ CERN: Overview

3 Cryogenic Test stands in B180 at CERN

- Electrical, magnetic, vacuum, and cryogenics site-acceptance tests
- Cryo- connection via ‚Feed Box‘ and Jumper Connections
- Reception, cooldown, tests, warmup, and dispatch of 5 magnet cryostats in parallel
- Cooldown of thermal-shield- and cold-mass circuits in series (Super-FRS: parallel)

Super-FRS Magnet Testing @ CERN: Jumpers and Heatloads



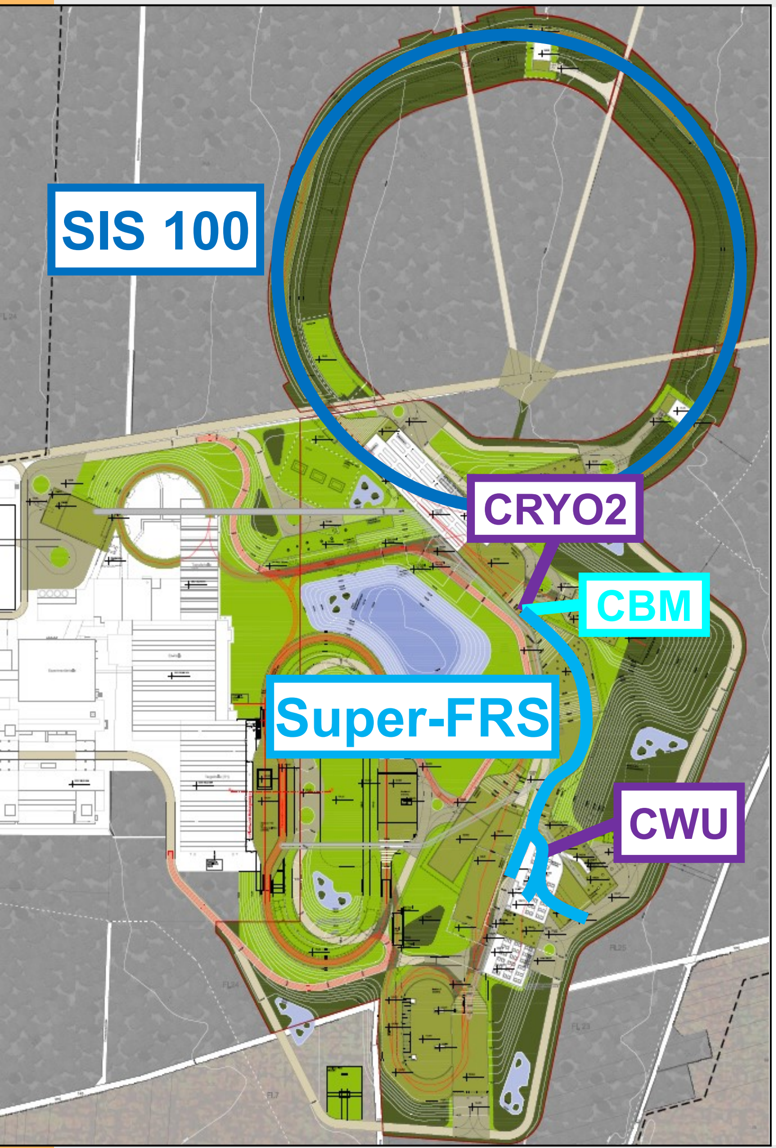
CERN Jumpers = Super-FRS prototypes
- kinematical concept
- installation & connection concept

Cryostats	4 K static loads [W]	80 K static loads [W]	CLs flow (300 A) [mg/s]
FoS-SM	13.1	70 ~ 80	~40 mg/s (2 pairs)
FoS-LM	29.3	160 ~ 180	~180 mg/s (9 pairs)
FoS-D2	12.0	80 ~ 100	~20 mg/s (1 pair)

Super-FRS s.c. Magnets:
Deliveries to GSI – Example FoS-LM

- 22 more LM expected
- pre-assembly at GSI
- intermediate storage
- > Q4 2023: transport to FAIR

The Super-FRS:
Part of the FAIR Cryogenic System



The **Super-FRS** Cryogenic System:

- 63 magnet cryostats (dipoles, multiplets, GLAD)
- ~ 410 m total beam-line length
- ~ 1500 tons total cold mass
- ~ 60000 liters total LHe volume
- ~ 2.1 kW static @ 4-5 K
- ~ 19 kW static @ 50-80 K
- ~ 9 g/s liquefaction needed (current leads)
- ~ 30 days total cool-down + filling time estimated (based on 100 kW (300-80 K) **CWU**, 7 kW (80-5 K) **CRYO2**, 50 g/s liquefaction)

Major Challenges for the **Super-FRS**:

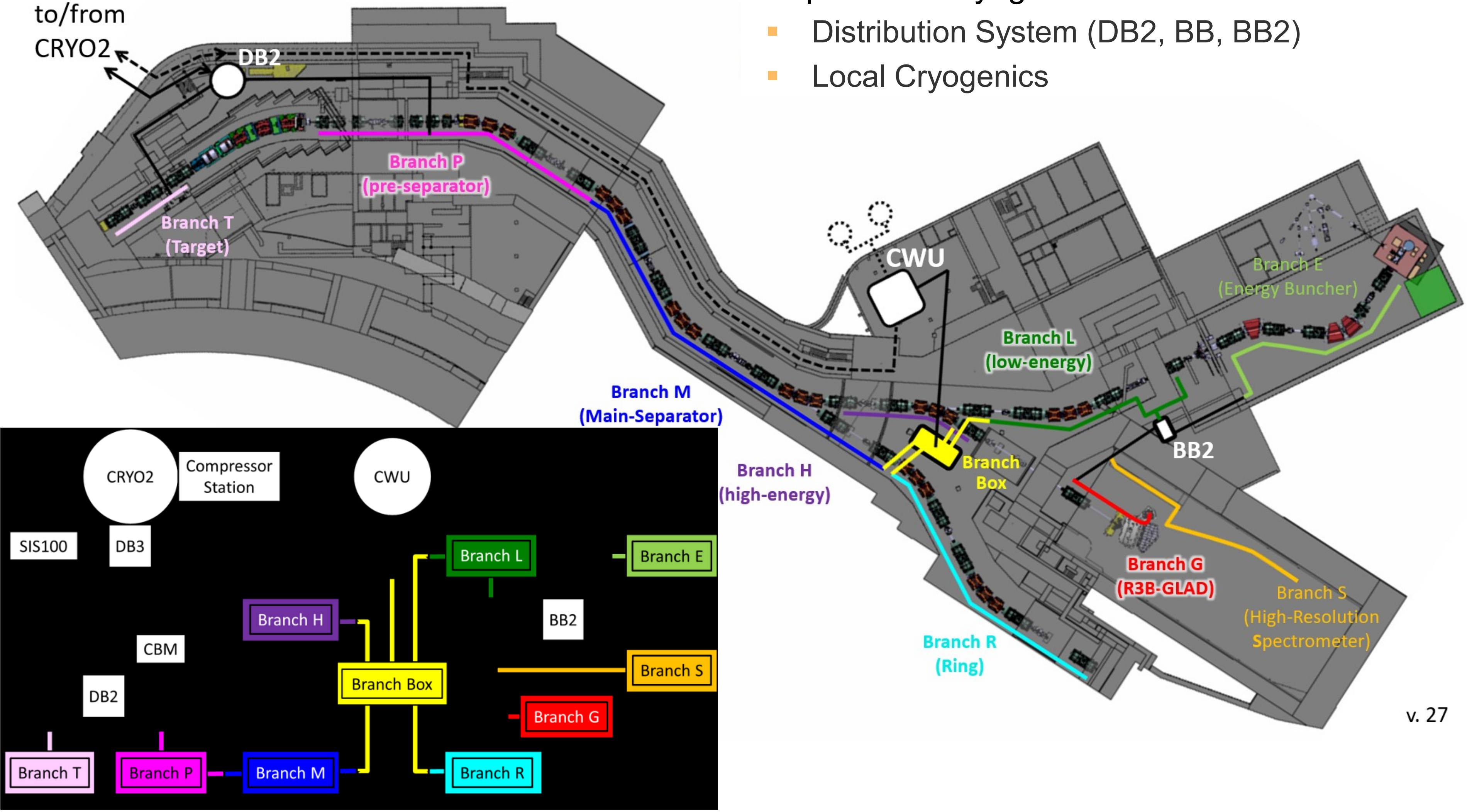
- Large cold mass, large LHe inventory, PS = 20 bar
- Broad ranges of magnet types, in terms of LHe demand (factor 40) and cooling load (factor 10)
- Little beam symmetry – many bendings, many components
- Operation / cooldown in parallel with **SIS100** and **CBM** via shared use of **CRYO2** and exclusive use of **CWU**

SIS100 Cryogenics → see presentation by M. Kauschke

The Super-FRS Cryogenics System: Buildings and Layout

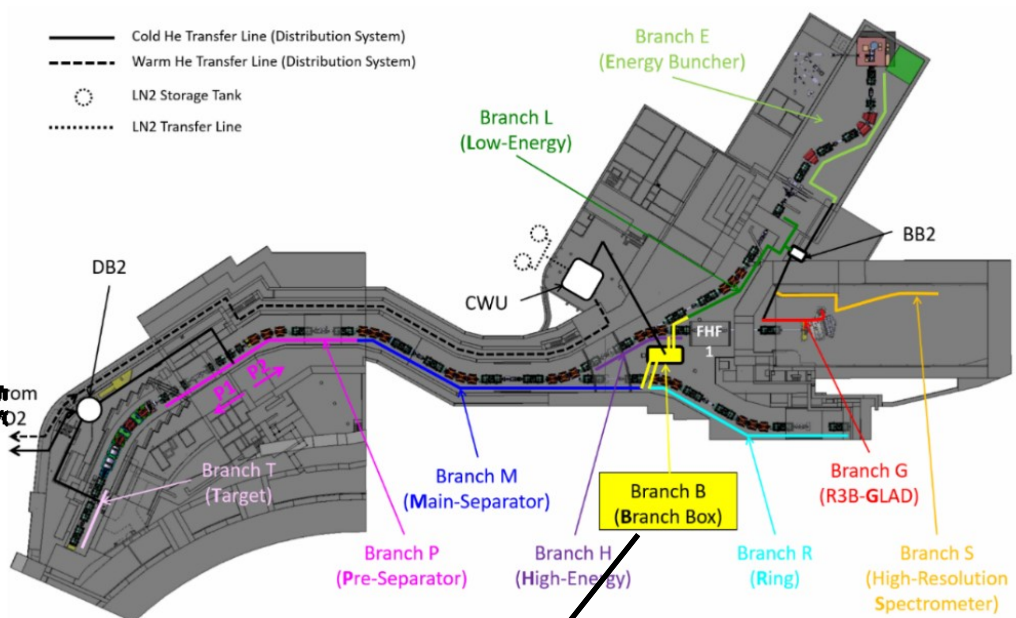
Super-FRS Cryogenics:

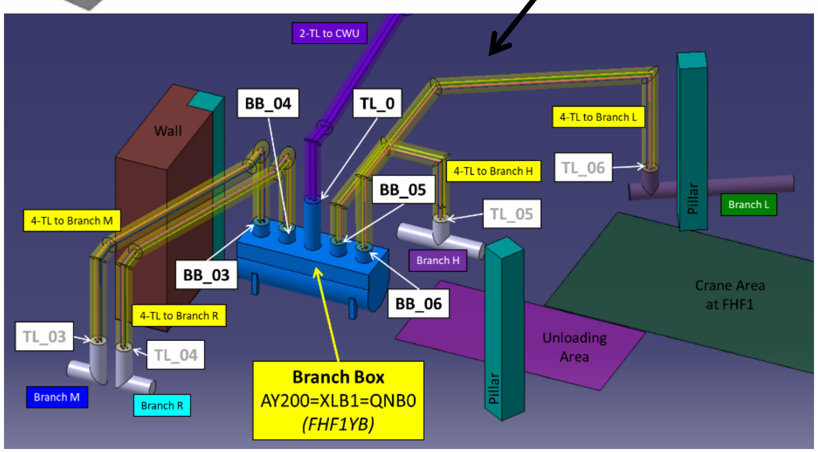
- Distribution System (DB2, BB, BB2)
- Local Cryogenics



v. 27

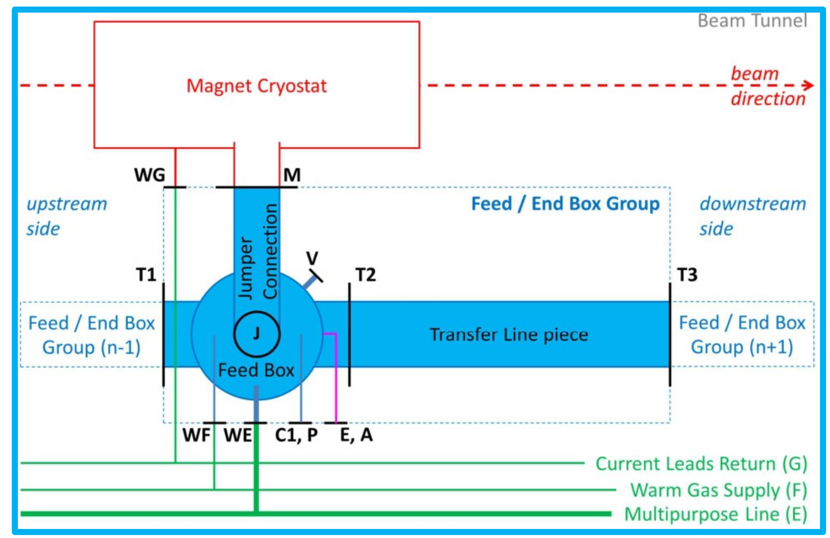
The Super-FRS Cryogenics System: Concept and Structure





Branch Box & its environment

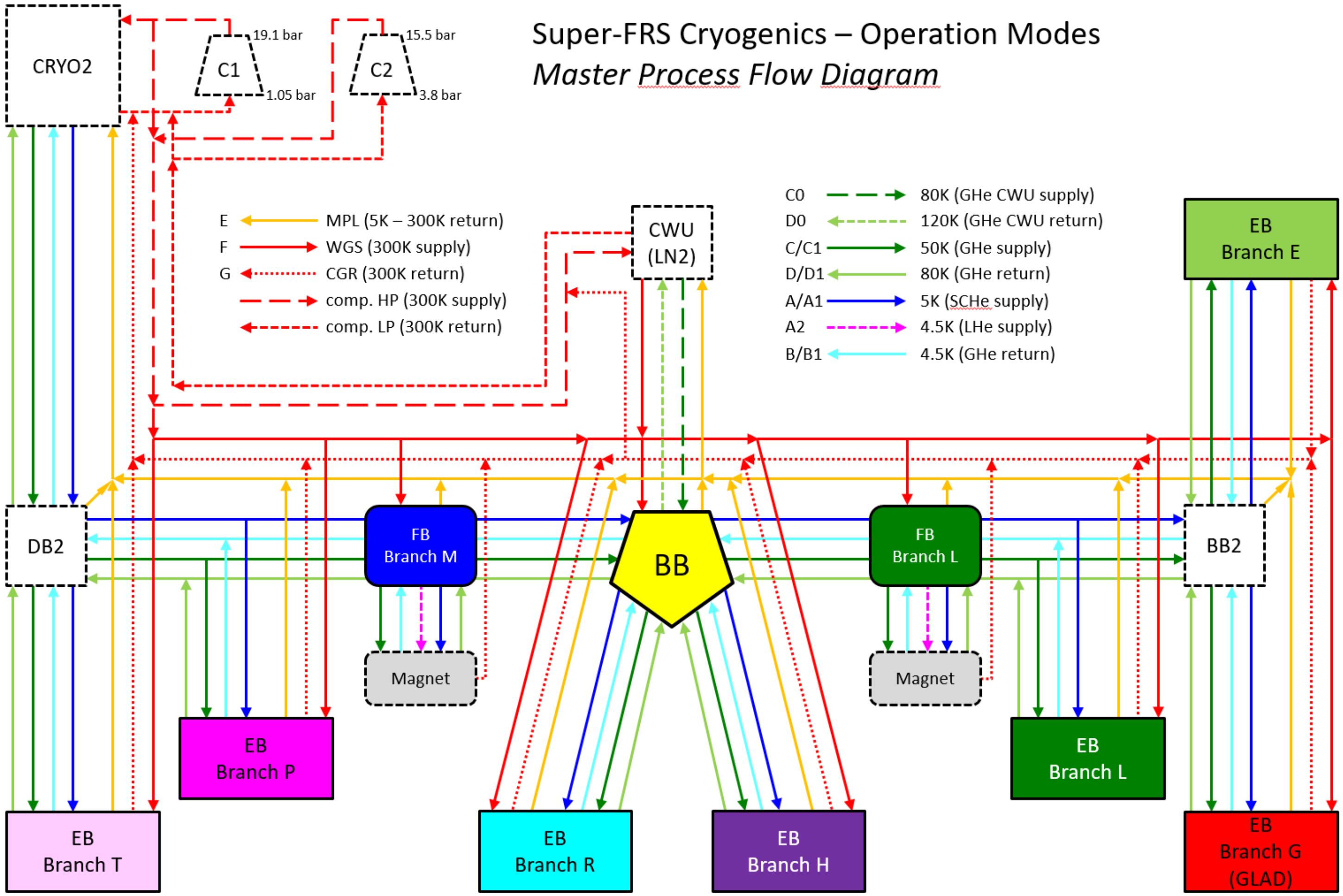
Feed Box group:
= Feed Box (or End Box)
+ Transfer Line (4 headers)
+ Jumper (5 headers, to magnet)



- **Distribution Box 2** (DB2, link to CRYO2, link to CBM)
- **Branch Box** (BB, central distribution, link to CWU)
- **Branch Box 2** (BB2, secondary distribution)

- **8 Branches of Feed Box groups** (Feed Boxes, End Boxes, Transfer Lines, Jumpers), in parallel to the beam line and the magnet cryostats
- **3 Auxiliary Cryogenic Piping lines** (per Branch)

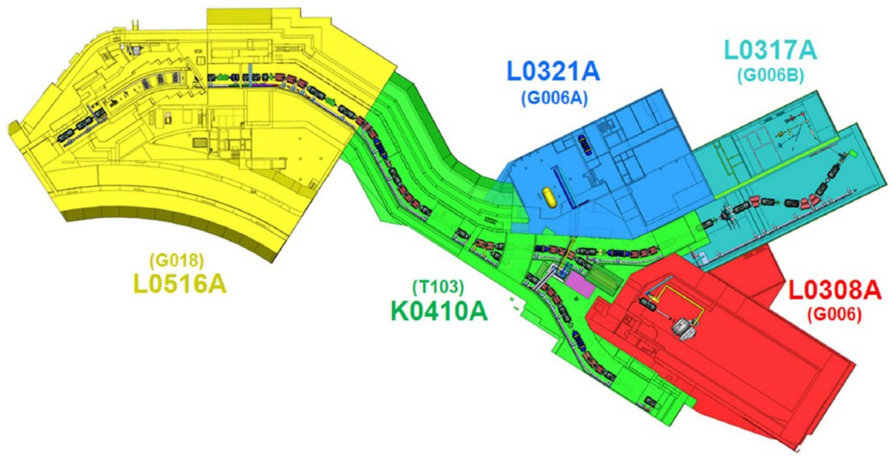
The Super-FRS Cryogenics System: Operational Flow Scheme



DB2: CRYO2 operation of CBM (not shown), independent of Super-FRS cooldown, operation, and/or warmup
BB: parallel & independent operation (CRYO2) or cooldown/warmup (CWU) of Branches R, H, and L, to provide large flexibility for beam operation of the threes Super-FRS beam branches
BB2: parallel operation of Branches G and E, depending on beam operation for HE- and/or LE-experiments of NUSTAR

The Super-FRS Local Cryogenics: Specific Design Challenges

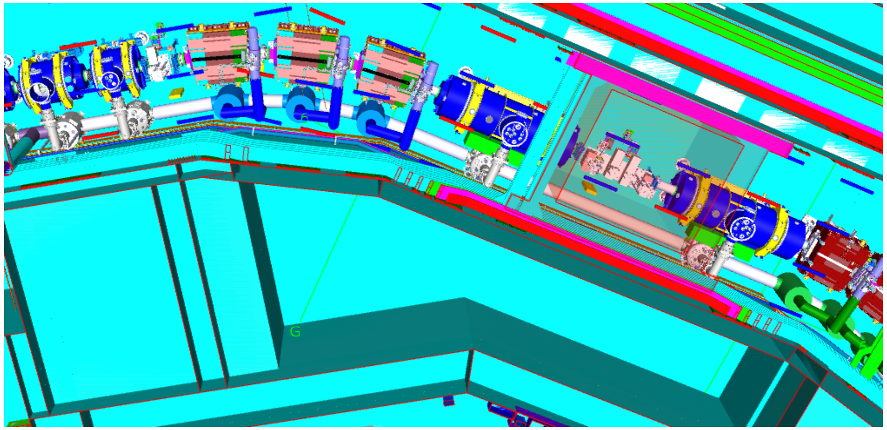
- Radiation harshness (neutrons)

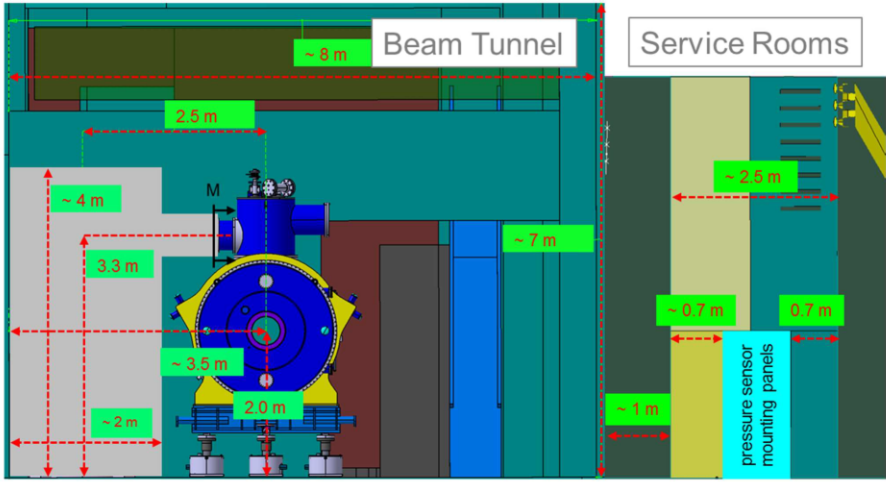


Branch Name	Branch ID	Super-FRS Building	Dose Rate (µGy/h)	Dose per Year (kGy)	Dose per 20 Years (kGy)
Target	T / 1	L0516A (G018)	≤ 5 x 10^5	~ 2.2	~ 43
Pre-Separator	P / 2	L0516A (G018)	≤ 5 x 10^7	~ 220	~ 4300
Main-Separator	M / 3	K0410A (T103)	≤ 5 x 10^5	~ 2.2	~ 43
Branch Box	B / 0	K0410A (T103)	≤ 5 x 10^3	~ 0.022	~ 0.43
Ring	R / 4	K0410A (T103)	≤ 5 x 10^3	~ 0.22	~ 4.3
High-Energy	H / 5	K0410A (T103)	≤ 5 x 10^5	~ 2.2	~ 43
Low-Energy	L / 6	K0410A (T103)	≤ 5 x 10^4	~ 0.22	~ 4.3
Energy Buncher	E / 7	L0317A (G006B)	≤ 5	~ 2.2 x 10^{-5}	~ 4.3 x 10^{-4}
R3B-GLAD	G / 8	L0308A (G006)	≤ 500	~ 2.2 x 10^{-3}	~ 4.3 x 10^{-2}

2-200 kGy/year → avoid active electronics in beam tunnel
→ electro-mechanical valve positioners
→ capillary pipes to pressure sensors in remote racks
→ radiation-hard materials

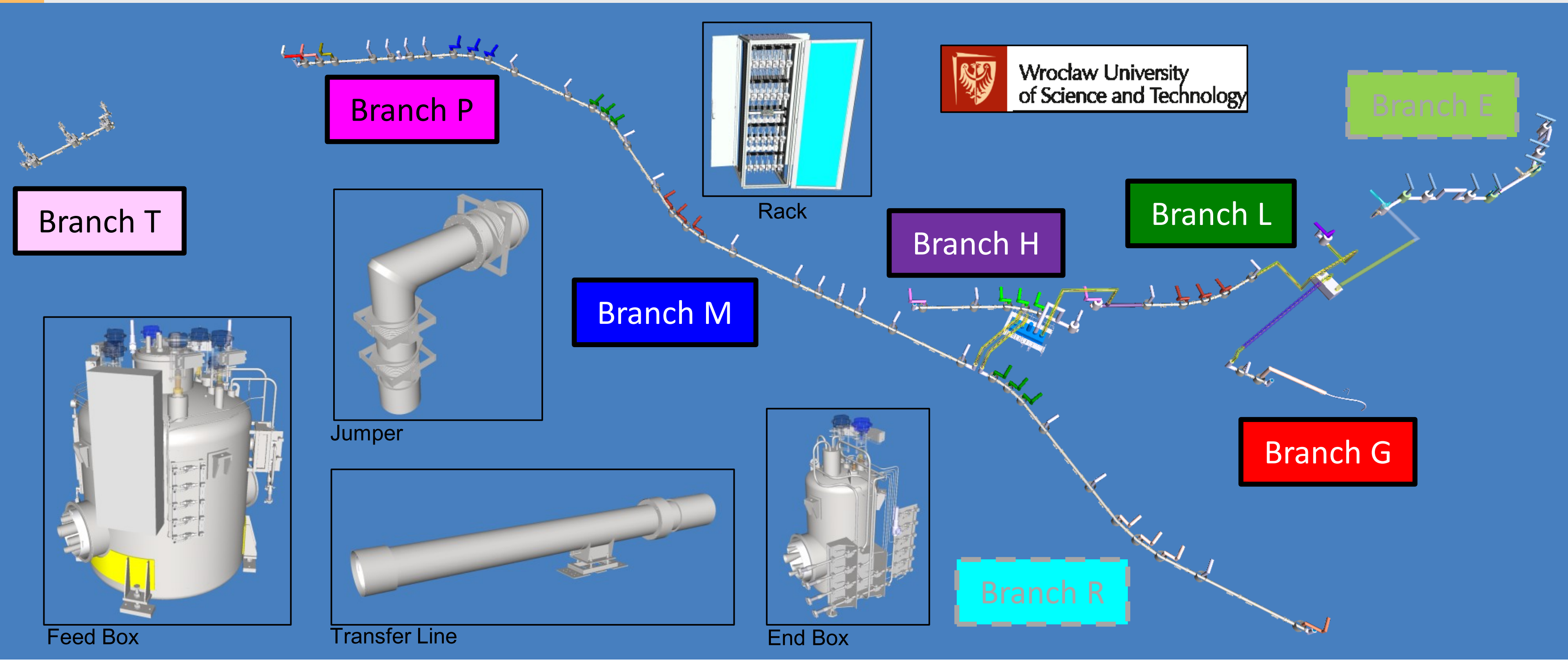
- Tight spaces for installation





→ 'slim' design and good logistics

The Super-FRS Local Cryogenics: Conceptual Design of Branches

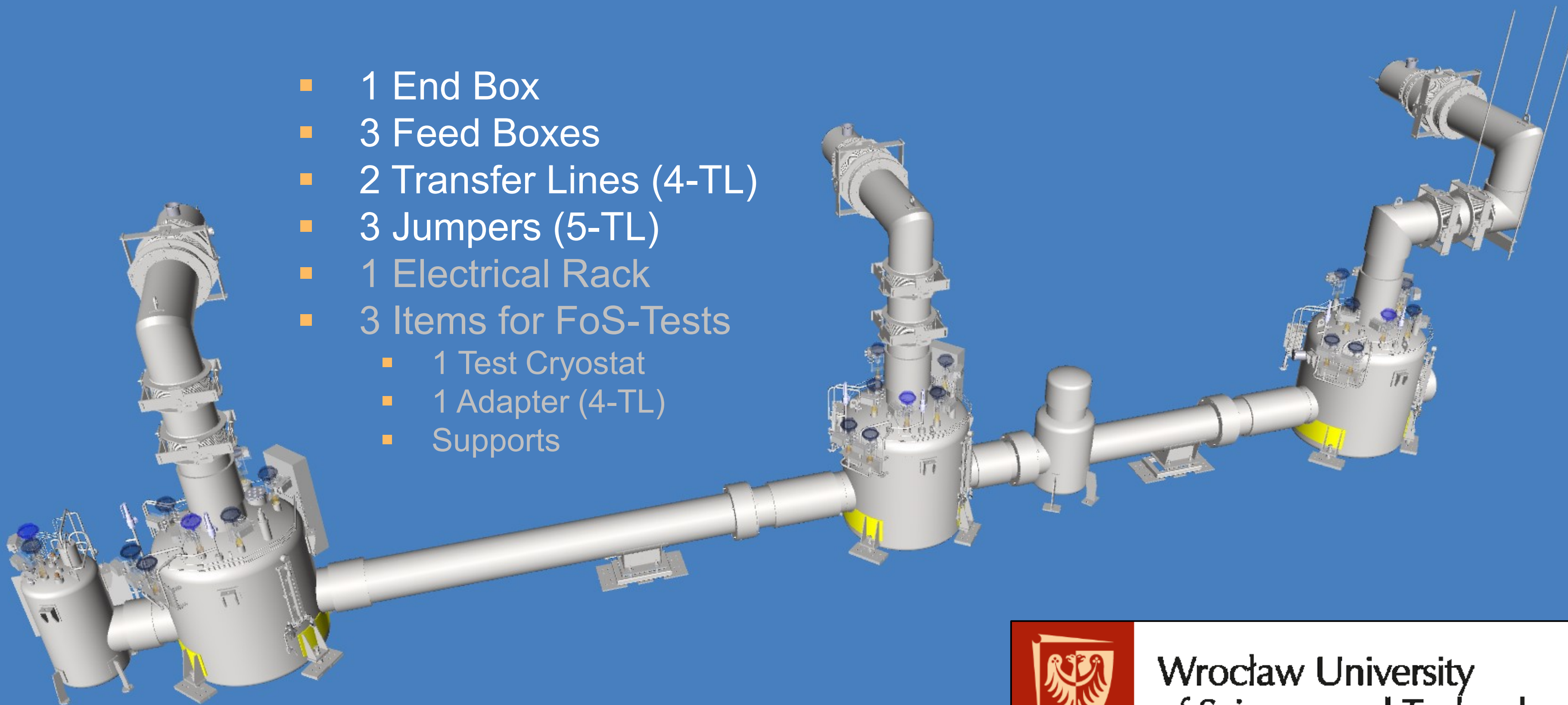


Conceptual Designs (CDR)

- Multiplet Feed Boxes (standard) (completed)
- Multiplet Feed Boxes (Branch-End) (completed)
- Dipole Feed Boxes (completed)
- End Boxes (nearly final)
- Transfer Line Pieces (nearly final)
- Branch Hydraulics, Thermics, and SVs (nearly final)
- Jumper Connections (nearly final)
- Branch Mechanics and Electrics (in progress)
- FoS-Test Equipment (in progress)
- NUSTAR – HEC (GLAD connection) (in preparation)
- NUSTAR – LEC (Energy Buncher) (postponed to 2024 – not needed for FS, but for FS++)

The Super-FRS Local Cryogenics: Conceptual Design of Branch T

- 1 End Box
- 3 Feed Boxes
- 2 Transfer Lines (4-TL)
- 3 Jumpers (5-TL)
- 1 Electrical Rack
- 3 Items for FoS-Tests
  - 1 Test Cryostat
  - 1 Adapter (4-TL)
  - Supports



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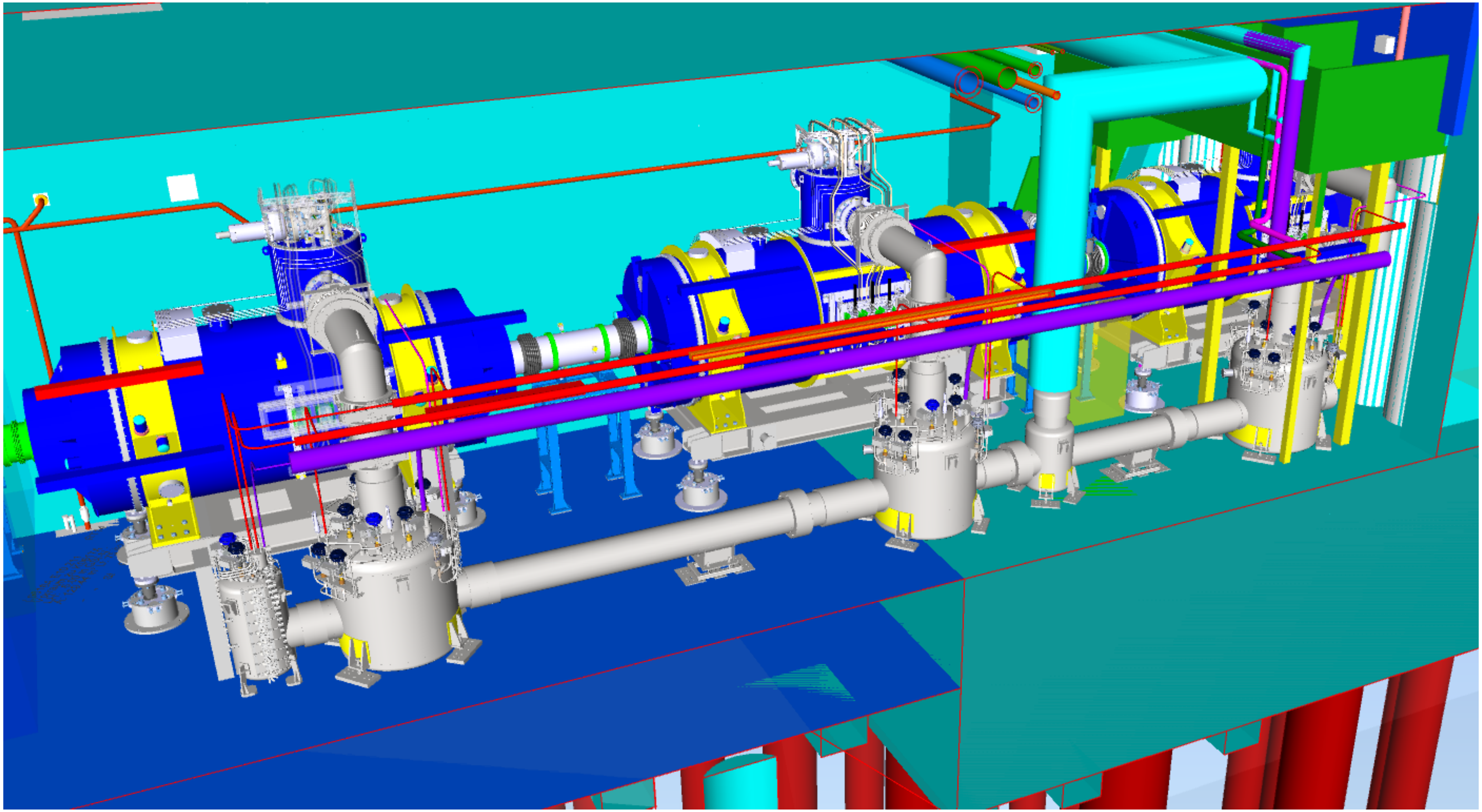
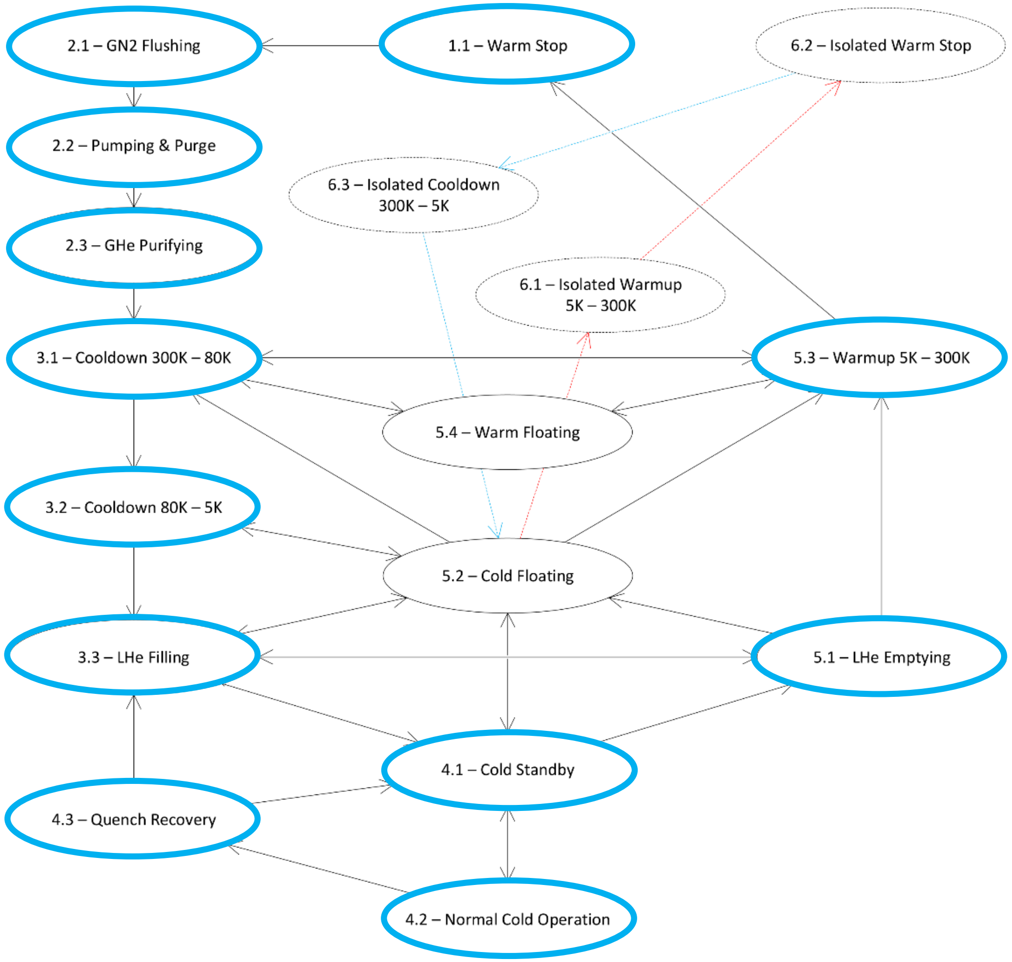
Branch T = FoS Branch for entire Super-FRS Local Cryogenics system

The Super-FRS Local Cryogenics: Branch T in Beam Tunnel

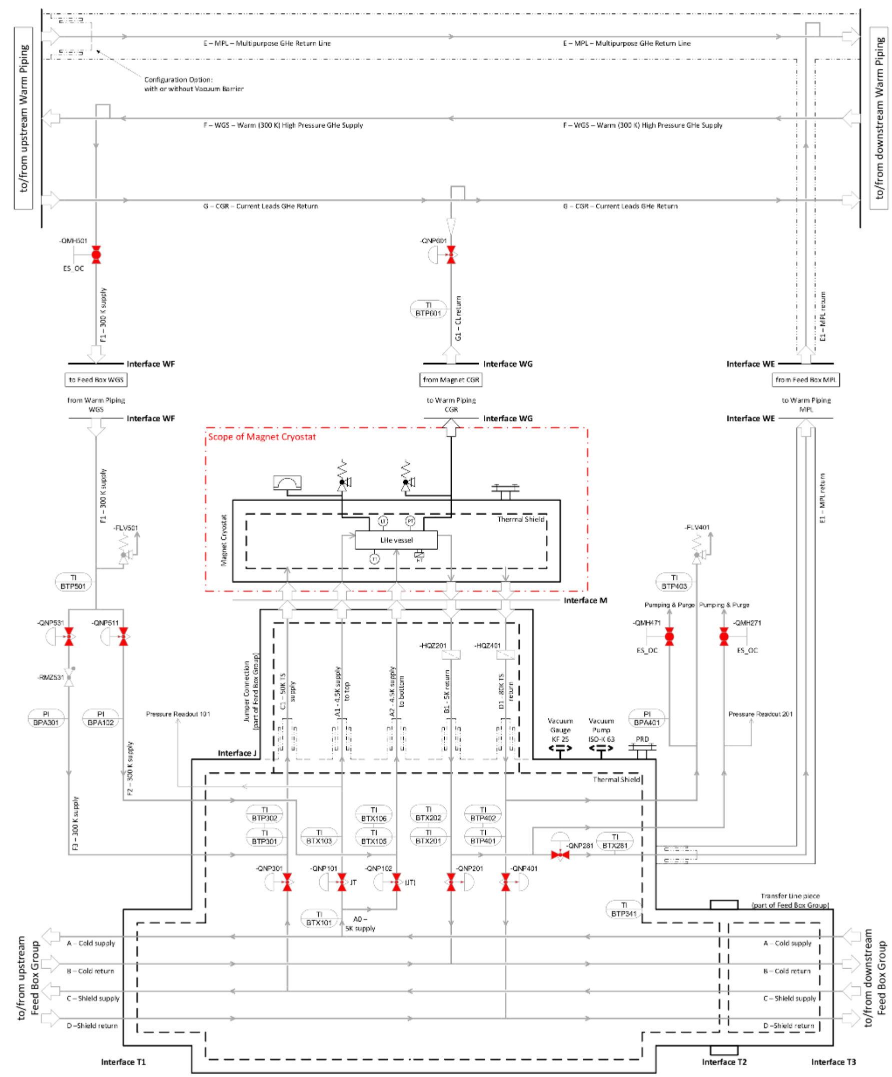


3D model: Beamline + Magnets + Cryo within Building

The Super-FRS Local Cryogenics: Feed Box + Magnet Operation



Operation Mode: 1.0 – Warm Stop



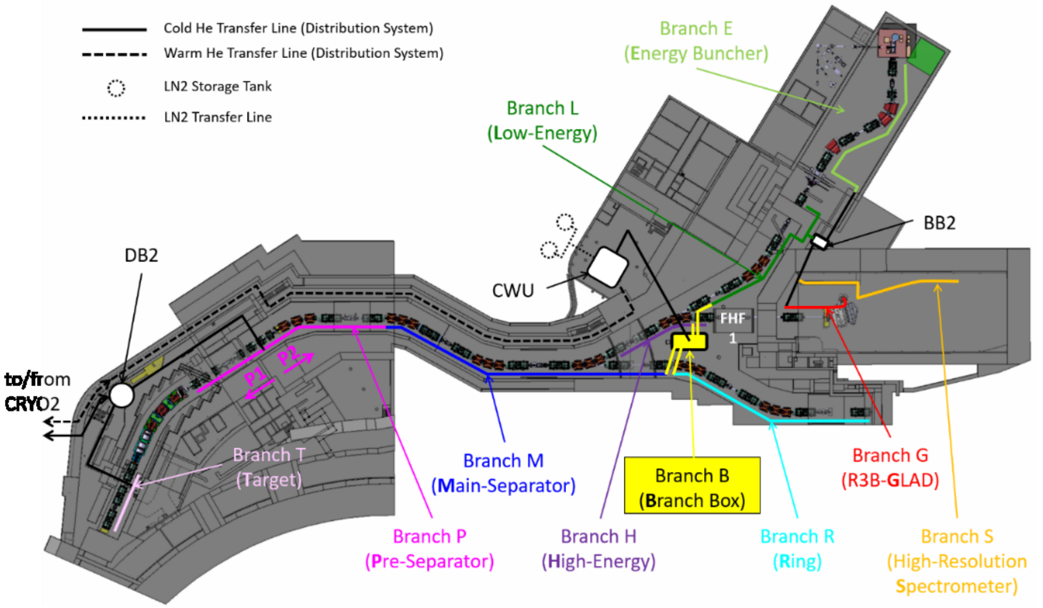
- Complex operational scheme for Feed Boxes + Magnets
- Many boundary conditions / interlocks in order to protect magnets from damage
- Main future challenge: establish TS+CC cooldown in parallel

The Super-FRS Local Cryogenics: Project Status & Outlook

Branches of Feed Box groups (WUST in-kind)
- Standard CDRs (close-to-final: April 2023)
- Contract Branch T (planned: 05/2023)
- CDR Branch G (planned: 10/2023)
- Contract rest FS scope (planned: 10/2023)
- Final Designs (FDR) (planned: 2023 - 2024)
- Installations (planned: 04/2024 – 06/2025)

Branch Box (industry tender)
- Tendering: running since 07/2023
- Contract: planned 03-04/2023
- Design: planned 11/2023
- Production: planned 10/2024
- Installation: planned 12/2024

Auxiliary Cryogenic Piping (industry tender)
- Tendering: start planned 04/2023
- Contract: expected 09/2023
- Design: expected 12/2023
- Production: expected 01-06/2024
- Installation Branches: expected 04-09 / 2024
- Installation Branch B: expected 01/2025 (after BB)

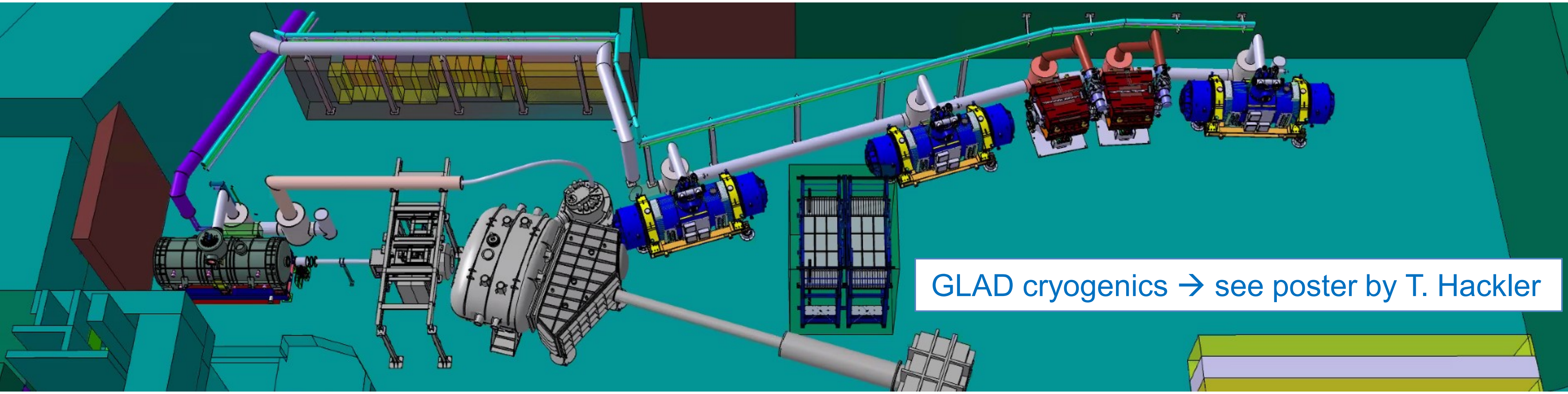


Outlook (basic schedule)
- Design: 2021 → 2023
  - Tendering: 2023→2024
- FDR+Production: 2023 → 2025
  - FOS-Testing: 2024
- Installation: 2024 → 2025
- Commissioning: 2026
- Start Beam Operation: 2027

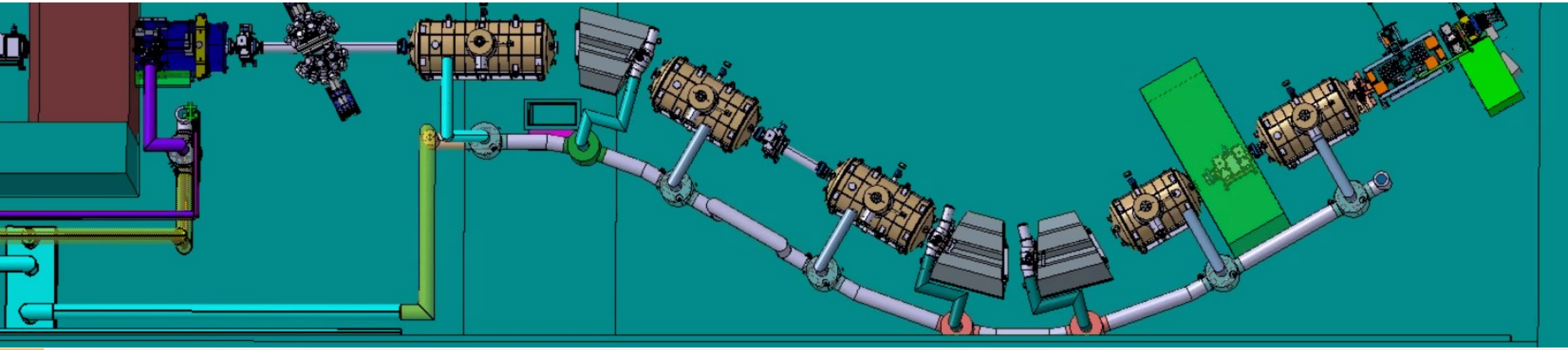
Outlook – Upcoming Design Work NUSTAR Branches G and E

Layout in HE-Cave (Branch G) (and future Branch S)

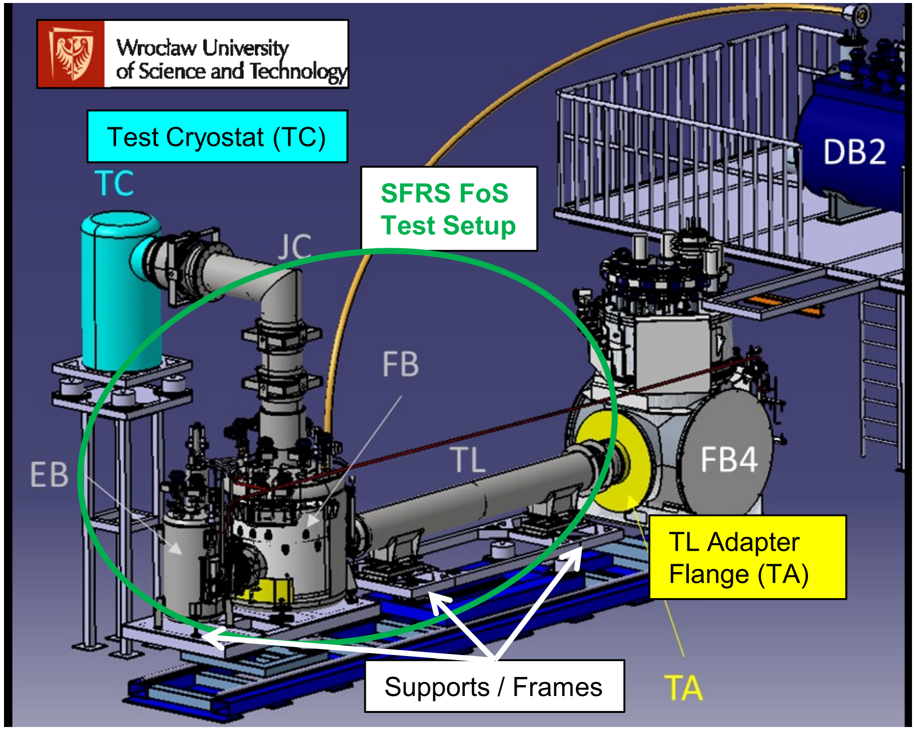
- TODO: final P&ID and specification of GLAD-FB and the flexible TL – July 2023

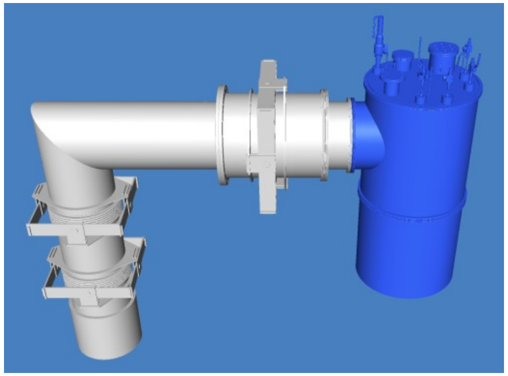


- Layout in LE-Cave (Branch E)
  - TODO: a) Magnet cryo-interface b) Local Cryogenics geometry confirmation – 2024



Outlook – FoS-Testing at GSI: Branch T Components





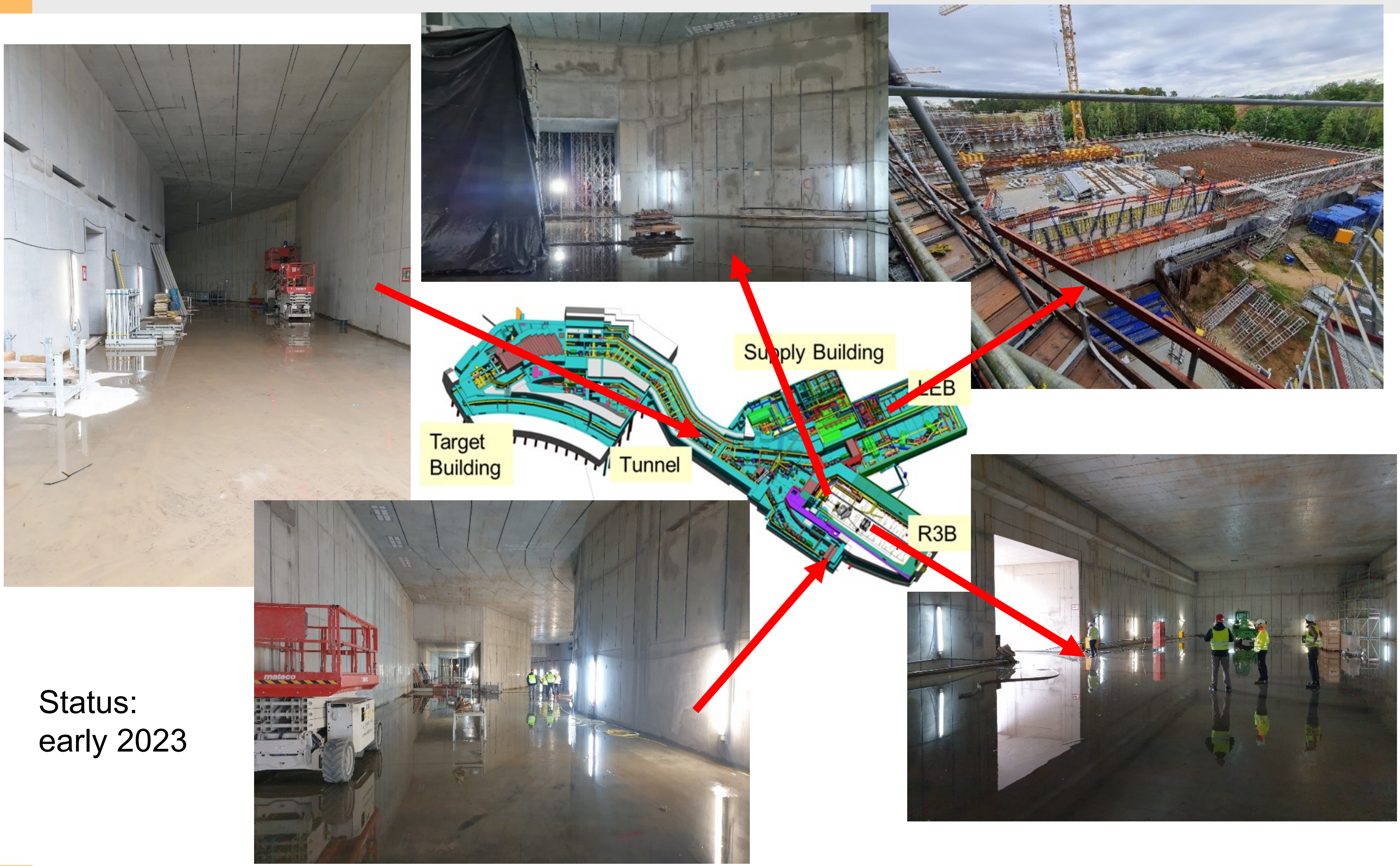
Test Cryostat (TC)
(a ‚magnet-dummy‘, connected to a Jumper)

- ~ 50 liters LHe
- ~ 1800 mm height
- ~ 600 mm diameter
- Instrumentation

GSI cryo test facilities → see poster by C. Schroeder

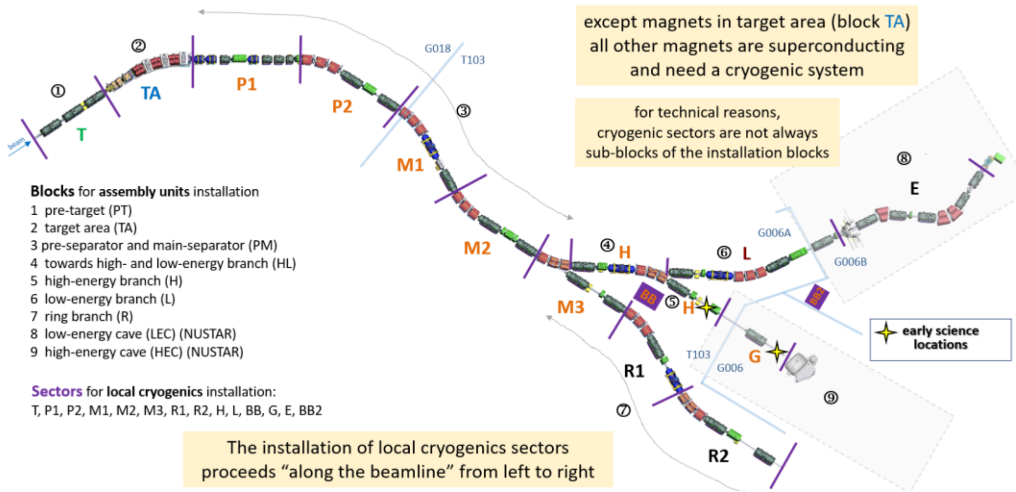
- FoS-test scope: Part of Branch T
  - Transfer Line, Multiplet-Feed Box, End Box, Jumper Connection, Electrical Rack
  - Installation and alignment training, cryo-controls, cryo-performance validation
- FoS-test equipment
  1) Support Frames
  2) Adapter Flange to FB4
  3) Test Cryostat

Outlook – Installation:
Super-FRS Civil Construction Progress



Status:
early 2023

Outlook – Installation: Local Cryogenics Logistics

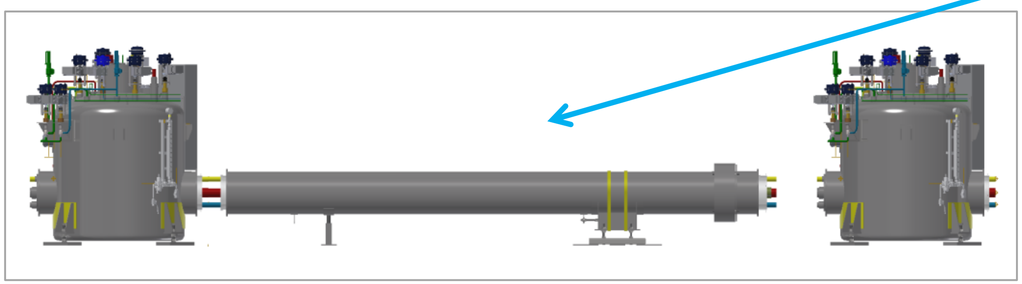


Basic Scheme: LocalCryo „Sectors“ in installation „Blocks“ (N Sectors per Block, M Magnets per Sector)

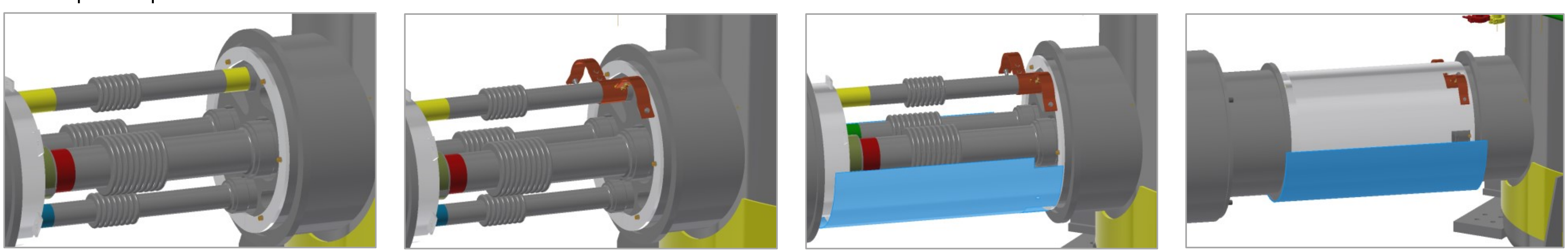
1) Building and TGA ready
2) Installation of Auxiliary Cryogenic Piping (walls, ceilings) for entire „Block“
3) „Blueline“ ready
   1) Sector (1 to N): Feed Boxes, Transfer Lines, Jumpers
      1) Feedbox (1 to M): Connection of Magnet cryostats to Jumpers

Basic Schedule:

1) Branch T: April 2024++
2) Branch P+M: June 2024++
3) Branch Box: December 2024
4) Branches H+L+G: January 2025++



Example/Snapshots of FeedBox – TransferLine interconnection works



Outlook – Commissioning: Basic Plan for 2025 – 2026

- Mechanical completion (external providers) – until early 2025
  - installations, anchoring, NDTs, CPLs
- Mechanical completion (GSI+FAIR) – 2025
  - grounding, cabling, capillaries, compressed air, etc.
- Hardware commissioning – 2025 until early 2026
  - verification of all capillary and electrical connections
  - valves and instruments adjustments
  - insulation vacuum, control system, first pumping&purge
- Remote Cryo commissioning (CRYO2 only) – 2026 til early 2027
  - Local Cryogenics only (Boxes & Lines)
    - DB2 + Branch T
    - Branches P+M + Branch Box
    - Branch H
    - Branch L + BB2
    - Branch G + GLAD
  - Local Cryogenics + Magnet Cryostats + Dry Run
  - Full Super-FRS for SIS18 pilot beam

Summary

- The Super-FRS @ FAIR will be the ‚working horse‘ for the NUSTAR science community

- The Super-FRS s.c. magnet cryostats are being produced (ASG, ELYTT), being tested (at CERN), and being delivered to GSI

- The Super-FRS is part of the FAIR cryogenic system
  - Ccold mass ~1500t; LHe inventory ~60m³
  - Cooldown & warmup via CWU, cold-operation via CRYO2
  - Complex geometry, space constraints, radiation-harsh environment

- The Super-FRS cryogenic system = Distribution System + Local Cryocenics Branches
  - Distribution System (CRYO2, CWU, Local Cryogenics) = DB2, BB, and BB2
  - Local Cryogenics = 6 + 2 + 1 Branches of interconnected FBs (62+1), EBs (7), TLs (~300 m), and JCs (to supply the s.c. magnets)
  - Auxiliary Cryogenic Piping (3 parallel process headers)

- Branch Box and Auxiliary Cryogenic piping are / will be industry tenders to reach installation by end of 2024 / mid 2025

- The Local Cryogenics Branches are being provided by Polish inkind partner (WUST)
  - The CDRs are mostly finished; Branch T is being tendered until May 2023 and will serve as a FoS Branch
  - Remaining tenders, FDRs, and manufacturing will run on a just-in-time base from 2023 until end of 2024
  - Branch T FoS-components (FB, EB, TL, JC) will be tested at the STF at GSI

- Commissioning and Start of Operation
  - Branch-wise Installation, 2024 – 2025. Mechanical completion targeted for 2025.
  - Commissioning planned for 2026. Start using CRYO2 only.
    - First: Local Cryogenics without magnets; Second: Local Cryogenics including magnets.
  - Start of Beam Operation (NUSTAR Early-Science at Super-FRS) 2027
    - CWU commissioning together with magnet cryostats, as soon as they are

Acknowledgements

- GSI & FAIR
  - Y. Xiang, D. Schad, A. Weber, A. Täschner, I. Remolina, M. Herber, C. Schroeder, B. Streicher, T. Eisel, M. Kauschke, H. Kollmus
  - H. Müller, E.J. Cho, M. Michels, F. Greiner, R. Jäger, V. Velonas, F. Käther, K. Sugita, A. Chiuchiolo
  - J. Kurdal, N. Kurichiyanil, A. Krämer
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  - T. Hackler, D. Körper
  - A. Bergmann, M. Schmidt, V. Ricciardi, M. Winkler, H. Simon
  - H. Marcocelli, M. Marenich, J. Bittner, H. Reich
- WUST
  - J. Polinski, A. Iluk, L. Pachnik, D. Chadaj, R. Siemasz, J. Kielar, J. Niechcial, P. Wojcik, M. Chorowski
- Kriosystem
  - G. Orlowski, P. Grzegory, et al.
- CERN
  - A. Perin, H. Derking, G. Rolando, Th. Dupont, G. Riddone, et al.
- CEA
  - C. Mayri, R. Carbonell, et al.

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KrioSystem CRYOGENICS IS OUR PASSION

Thank You