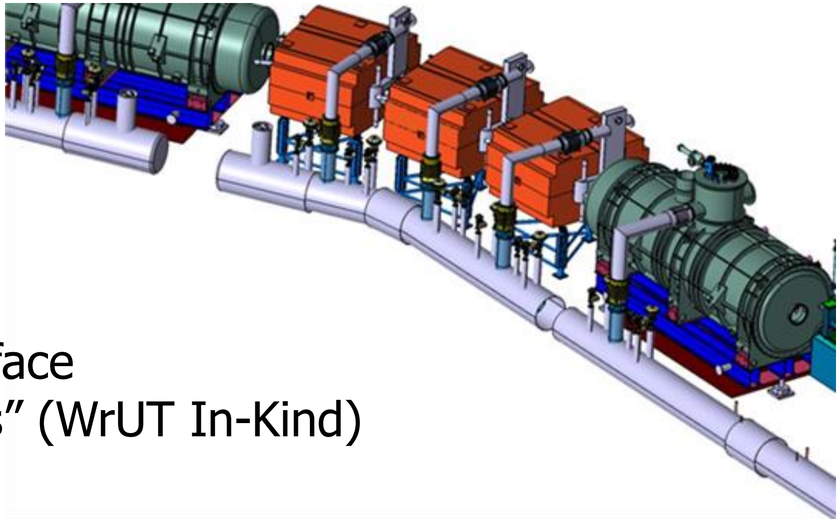
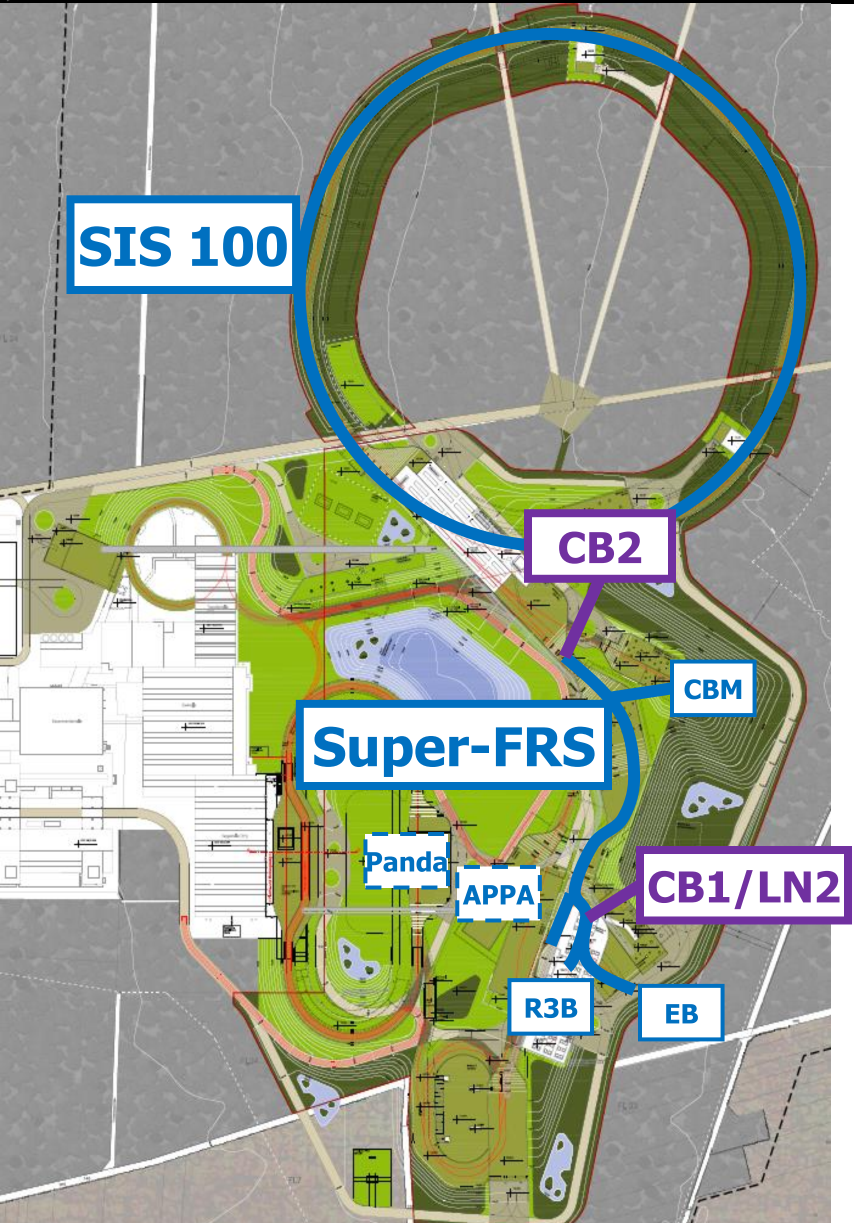
Felix Wamers, Yu Xiang (CSCY, GSI)

Cryogenics for the Super-FRS: Status and Perspective

- Introduction
- Super-FRS Cryogenics Overview
    - Operation
    - Cooldown & Warmup
    - Heat Loads
- Super-FRS Magnet Testing
    - Safety Valves and Risk Analysis
    - Cryo Jumper Connection and Interface
- WP 2.4.12 “Super-FRS Local Cryogenics” (WrUT In-Kind)
- Summary & Outlook



Introduction: Cryogenics Infrastructure for FAIR



Goals:

- SIS100 & SuperFRS for broad range of radioactive beams up to 1.5 GeV/u, and up to a factor 10000 in intensity over present
- Those beams demand strong magnetic fields combined with large momentum acceptance and thus apertures → SC Magnets

Crygenic Infrastructure for FAIR:

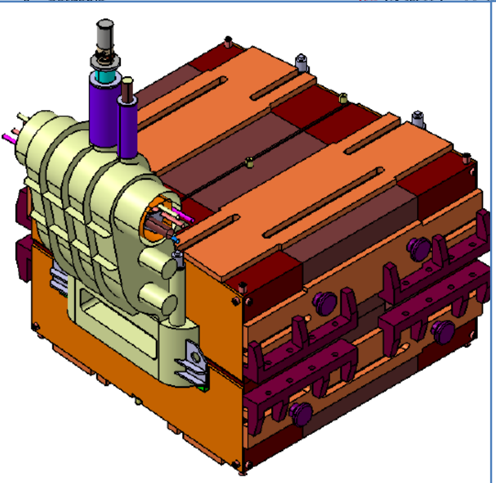
- 1 - 2 cryoplants (~ 25kW), CWU (LN2 based)
- Distribution system
- Local cryogenics SIS 100
- Local cryogenics Super-FRS
- Experiment magnets: CBM, R3B, (Panda), APPA
- Campus-wide Cryo-Control System (UNICOS)

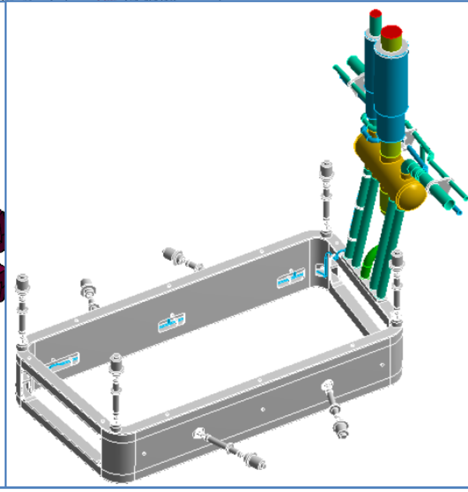
Challenges:

- Parallel operation of SIS100, SFRS, Experiments
- Large Dynamic Loads for SIS100; Large Cold-Mass / LHe Inventory of Super FRS
  - ➔ Long Cool-down / Warm-up times
- 'Broad range' of magnet types at SuperFRS
- Little beam symmetry – many cryo components

Super-FRS Cryogenics:
SFRS SC Magnets – Cryo-Relevant Properties

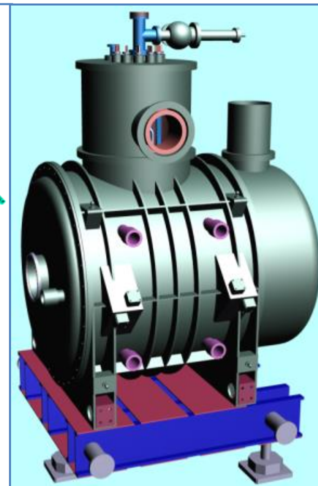
Superferric Dipole Magnets

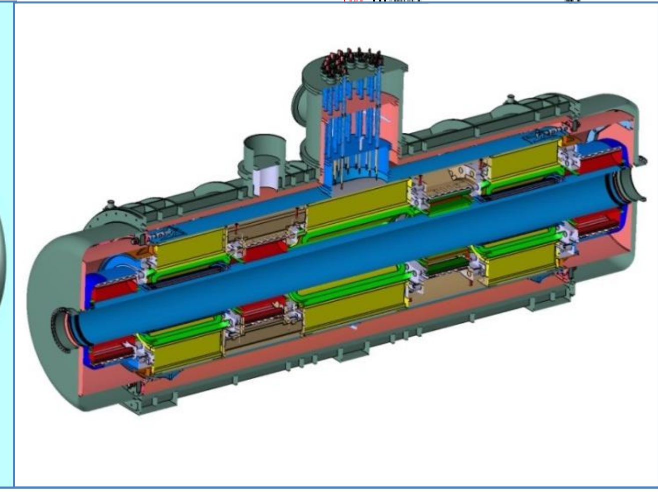




- ❖ Iron dominated, Warm iron, SC coil
- ❖ Aperture ±190mm x ±70mm
- ❖ Cold Mass: ~ 1.1 ton
- ❖ LHe Volume: ~ 22 liters
- ❖ Heat Loads: 4.3 W / 91 W / 0.028 g/s

Short and Long Multiplets

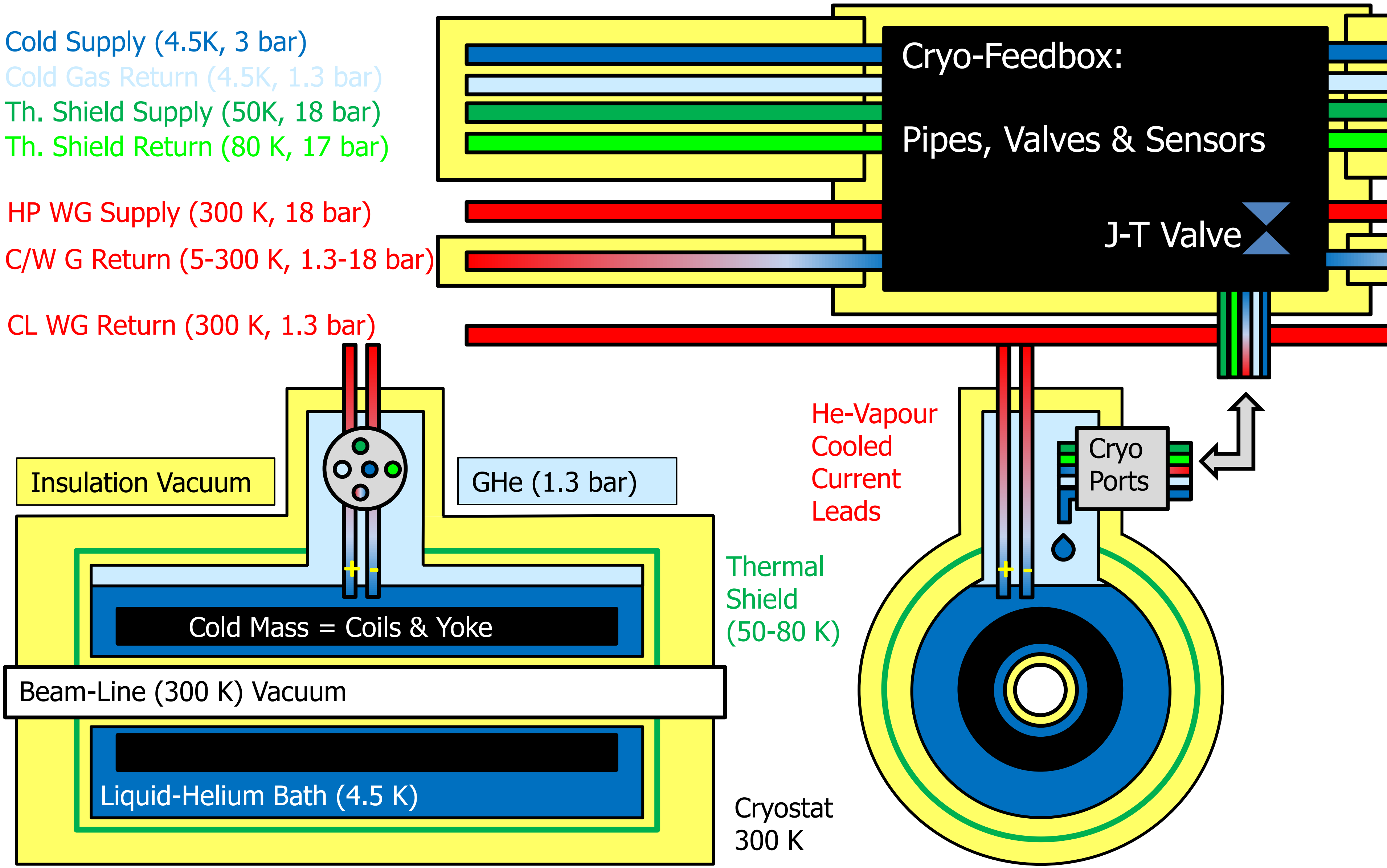




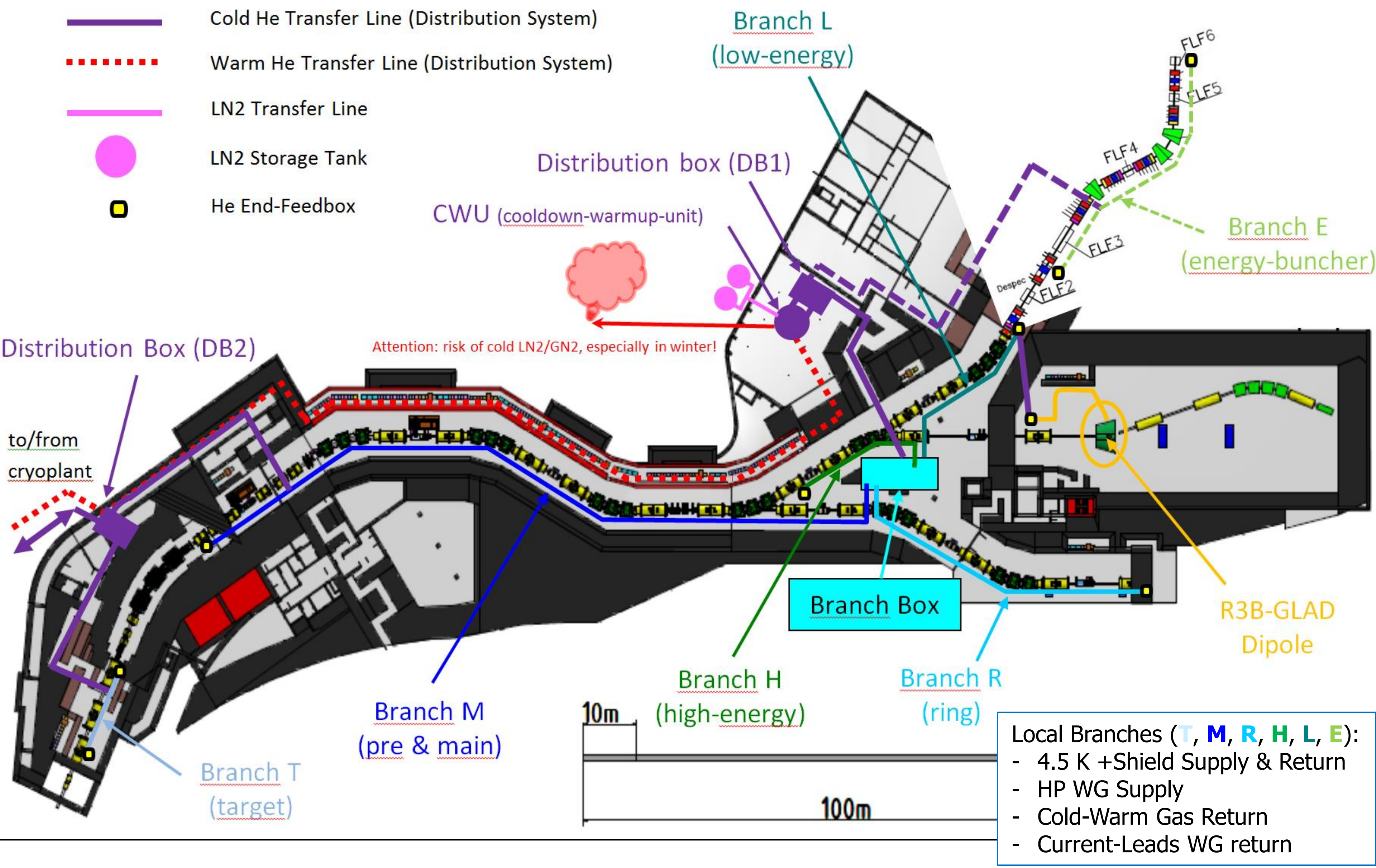
- ❖ Iron dominated, Cold iron (≈40 tons)
- ❖ Warm beam pipe (38 cm inner diameter)
- ❖ Cold Mass: up to 42 tons
- ❖ LHe Volume: up to 1300 liters
- ❖ Heat Loads: up to 15.4 W / 160 W / 0.28 g/s

- ❖ Lhe- Bath-cooled Magnets (Both Dipoles and Multiplets)
- ❖ Cooldown (1K/hr) using Gaseous Helium at ~ 12-18 bar(a) (Warm-Gas – Cold-Gas Mixing)
- ❖ LHe Filling/Operation using SC Helium at ~ 3bar bar(a) + Joule-Thomson Valve
- ❖ He-Vapour-Cooled Current Leads (300 A) at 1.3 bar (4.5 K – 300 K)
- ❖ Magnets along Super-FRS chain are supplied and cooled in parallel.

Super-FRS Cryogenics:
SC-Magnet Cooling in a Nutshell

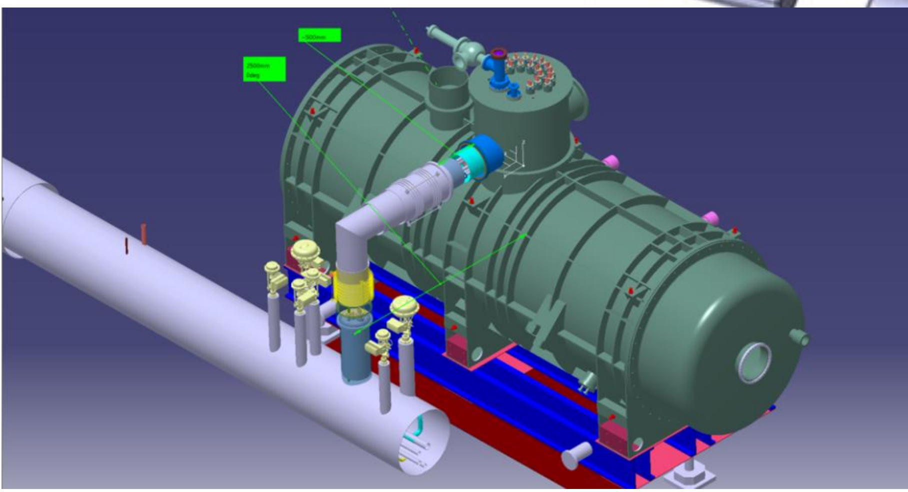


Super-FRS Cryogenics:
Layout / Routing of Helium Supply Piping

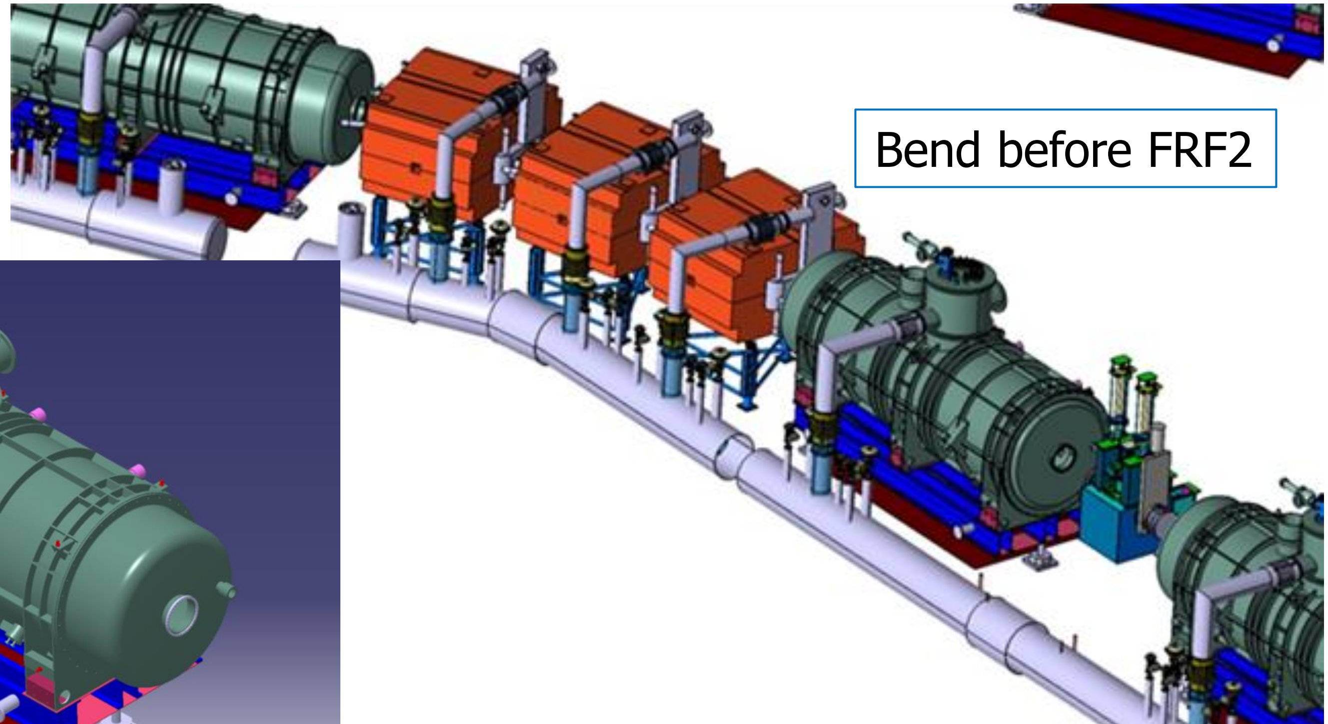


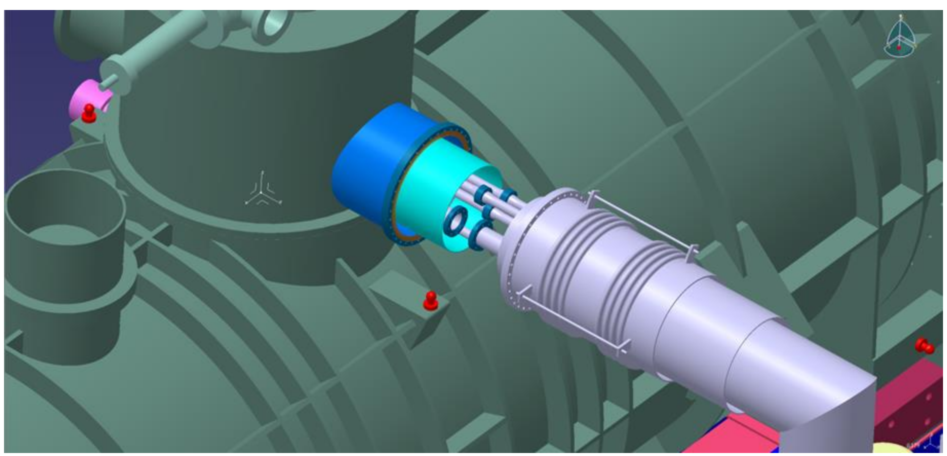
Super-FRS Cryogenics: Local Cryogenics – Snapshots DMU I

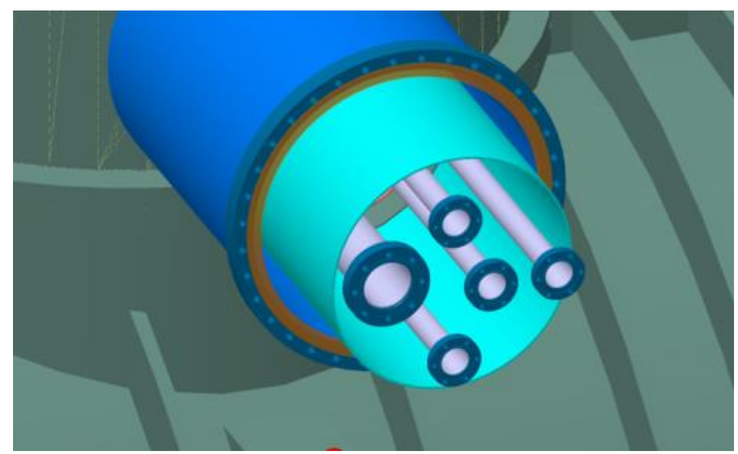
Long Multiplet connected to FB via Jumper Connection



Bend before FRF2



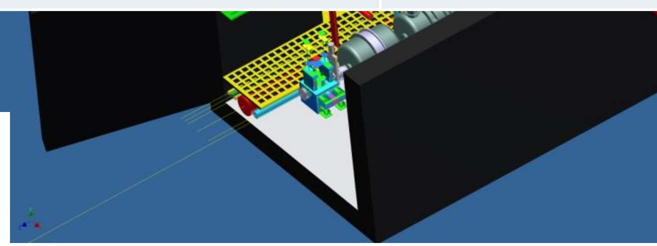




Super-FRS Cryogenics:
Local Cryogenics – Snapshots DMU II

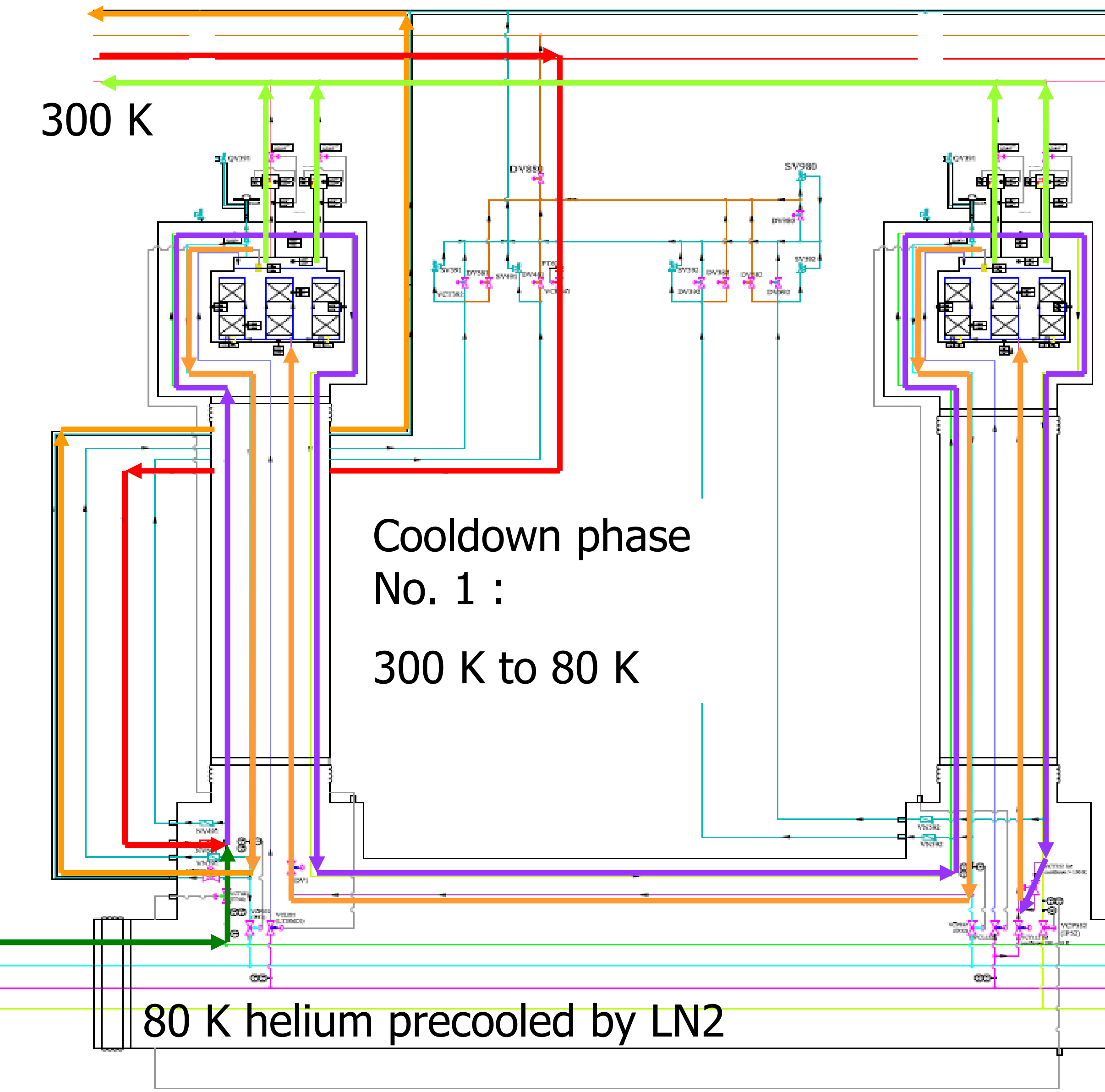
Focusing system

Feedbox Type	Number FBs	Number Magnets
Long Multiplet doublet	9	18
Long Multiplet singlet	4	4
Short Multiplet triplet	1	3
Short Multiplet quadruplet	1	4
11 Dipole triplet	1	3
9.75 Dipole triplet	7	21
EB Multiplet doublet	3	6
EB Dipole doublet	1	2
EB Dipole singlet	1	1
TOTAL	**23 + 5**	**53 + 9**

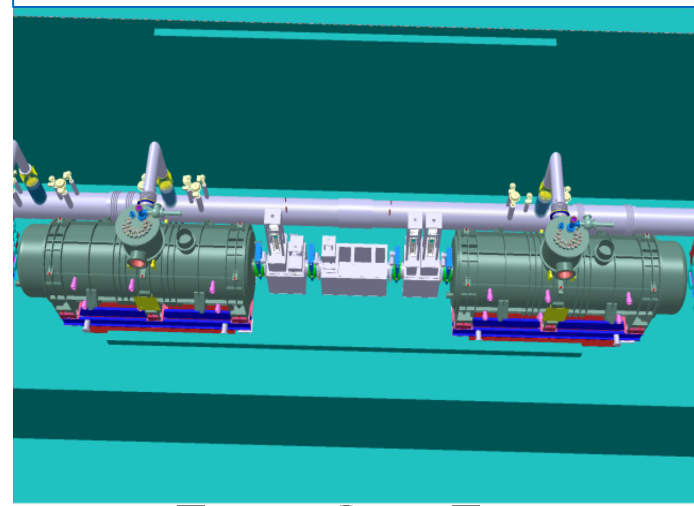


FHF1

Super-FRS Cryogenics:
Cooldown of two long multiplets from 300 K to 80 K



Long MP Dublett, e.g., at FPF4



Cooldown phase No. 1 :

300 K to 80 K

80 K helium precooled by LN2

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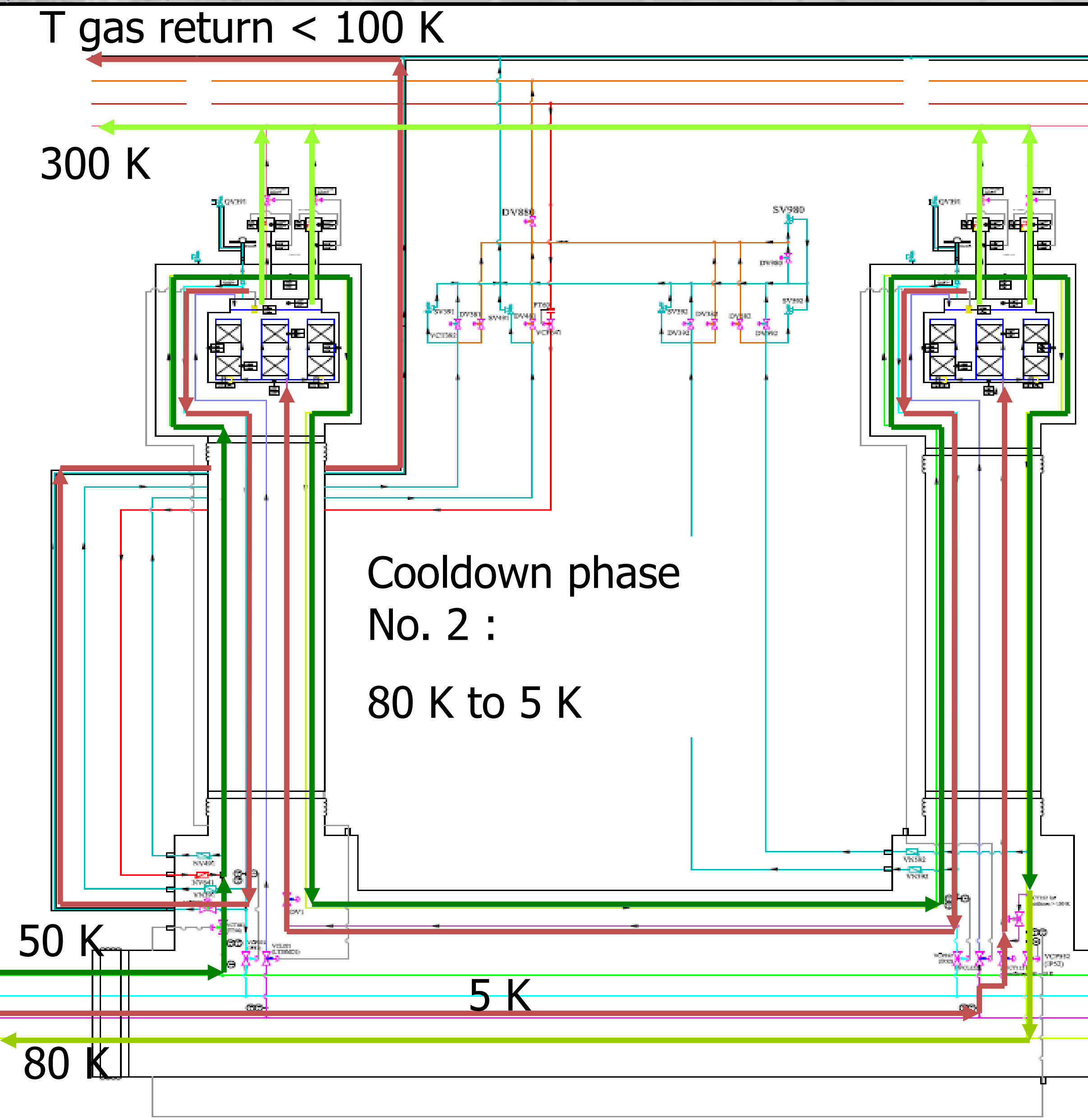
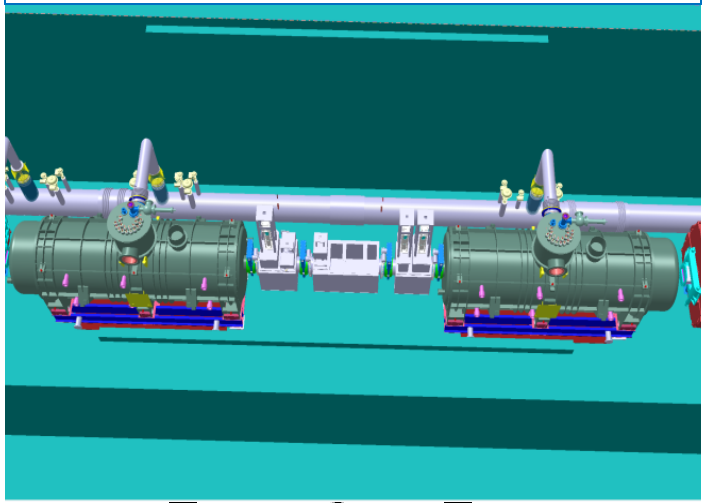
Super-FRS Cryogenics:
Cooldown of two long multiplets from 80 K to 5 K



Long MP Dublett, e.g., at FPF4



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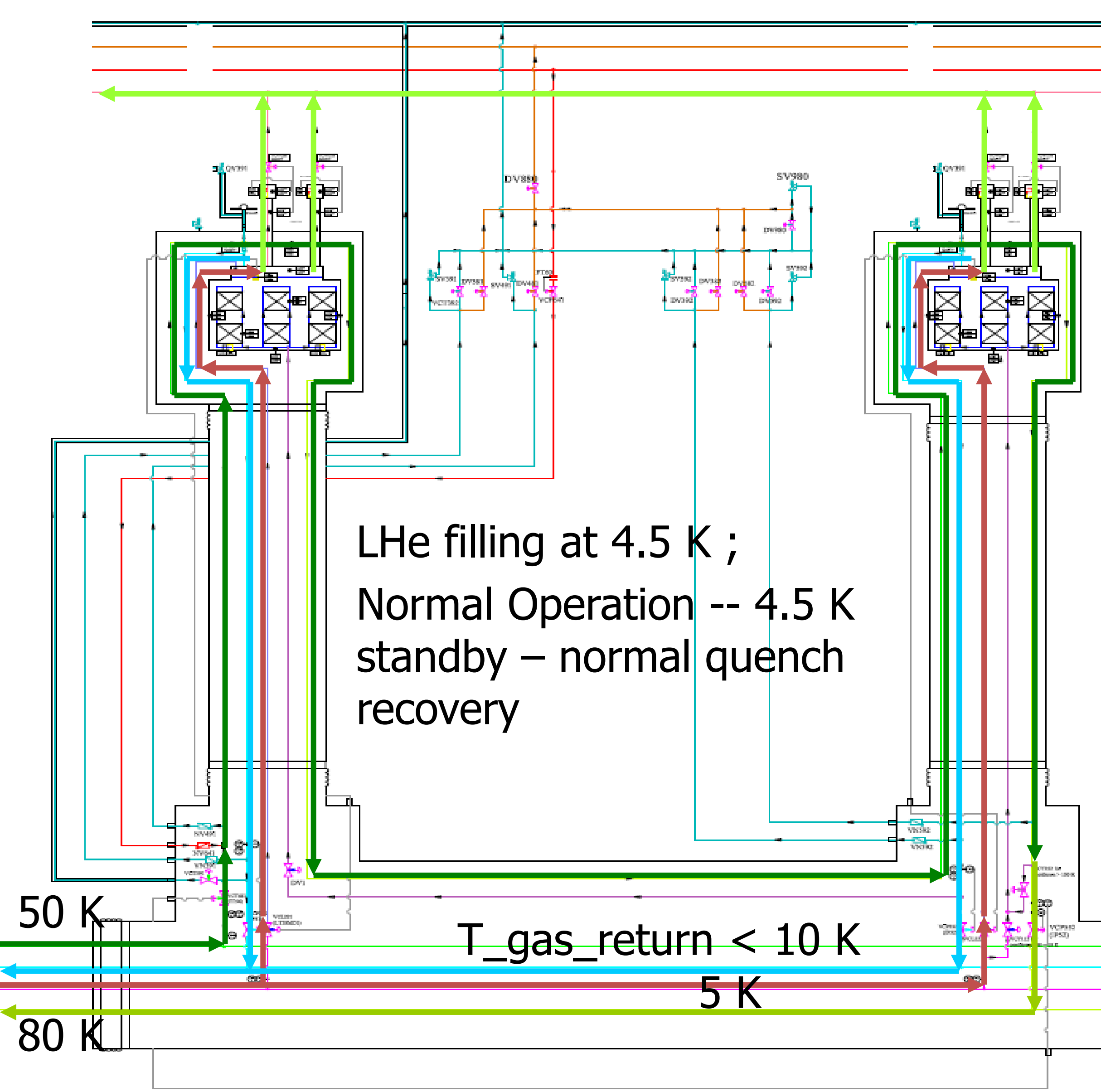
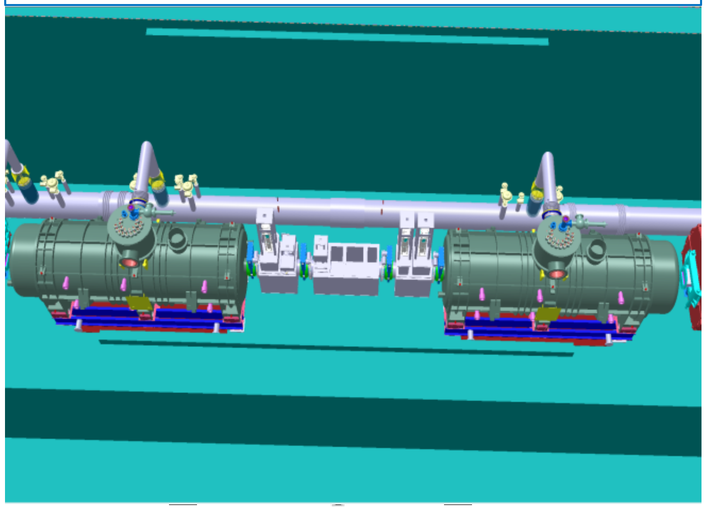
Super-FRS Cryogenics:
LHe Filling and normal operation of two long multiplets



LHe filling at 4.5 K ;

Normal Operation -- 4.5 K standby – normal quench recovery

Long MP Dublett, e.g., at FPF4



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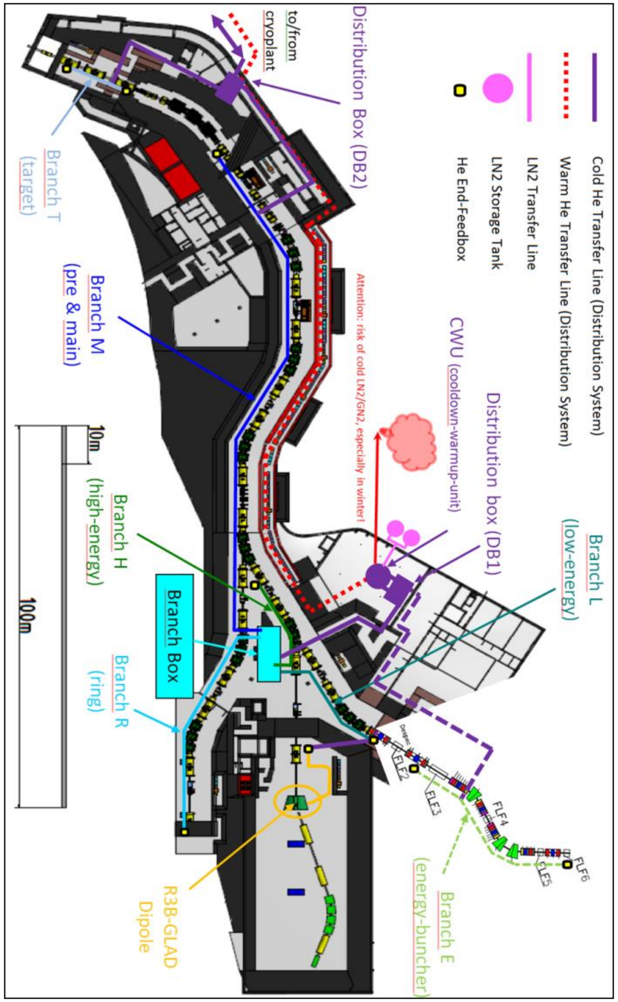
Super-FRS Cryogenics:
Summary 1: Cold Mass, LHe Inventory



Super-FRS machine	Pre- and main-separator; Ring-branch; HE-branch; LE-branch up to DESPEC)			R^{3}B experime nt	EB (C-shape)	EB (C-shape)		
SC magnets	Dipole	Long Multi-plet	Short Multi-plet	GLAD Dipole	Dipole (30°)*	Quad-rupoles **		
Number []	24	24	7	1	3	9		
Cold mass in individual cryostats [tons]	1,1	42	15	21 [0)]	2,7	22	**Total cold mass with EB [tons]**	**Total cold mass without EB [tons]**
Sum of cold mass of all magnets with same type [tons]	26,4	1008	105	21	8,1	198	**1367**	**1076**
LHe volume in individual cryostats [litres]	50	1300	900	460 [0)]	18	450	**Total LHe volume with EB [litres]**	**Total LHe volume without EB [litres]**
Sum of LHe volume of all magnets with same type [litres]	1200	31200	6300	460	54	4050	**43264**	**36560**

For reasonable cooldown times (~2 weeks) of the 1100-1400 tons cold mass from 300 K to 80 K (40 K delta T of cooling flow) a LN2-based pre-cooler (CWU) is envisaged.

Super-FRS Cryogenics: Summary 2: Cool-Down / Warm-Up Time

Three Cooldown Scenarios: Full Super-FRS, without EB, only HE Branch

Table 2: Cooldown of the Super-FRS machine from 300 K to 5 K.

Cooldown scenarios	No.1	No.2	No.3
Cold mass in one cooldown batch [tons]	all Super-FRS magnets including EB	all Super-FRS magnets without EB of 290 tons cold mass	all Super-FRS magnets without Ring-, LE-branch and EB
	1367	1076	689
LN2-precooler Capacity (CWU) for cooldown of Super-FRS from 300 K to 80 K [kW]			**80**
Cooldown enthalpy (SS304) from 300 K to 80 K [GJ] A)	111.8	88.0	56.3
Cooldown time to 80 K [days]	**16.2**	**12.8**	**8.2**
Available capacity from Cryoplant at 4.5 K for cooldown of Super-FRS from 80 K to 5 K [kW]			**7,0**
Cooldown enthalpy (SS304) from 80 K to 5 K [GJ]	8,4	6,6	4,3
Cooldown time from 80 K to 5 K [days]	**13.9**	**10.9**	**7.0**

Table 3: Liquid-helium filling of the Super-FRS machine.

Cooldown scenarios	No.1	No.2	No.3	Current leads cooling flow (100%) for full current [g/s]	6.9
Available liquefaction capacity from Cryoplant [g/s]			50 *)		
Liquid helium volume to be filled [litres]	43264	36560	24410	Current leads cooling flow (60%) for zero current [g/s]	4.1
Time for LHe filling [days]	**4.1**	**3.4**	**2.3**	P_GHe_after JT [bar]	Vapor quality_after JT []
T_SchHe_before JT [K]	**6.0**	P_SchHe_before JT [bar]	4.0	1.30	0.68

*) FAIR CryoPlant preliminary specification

Table 4: Total cooldown time including the liquid helium filling of the Super-FRS machine.

Cooldown scenarios	No.1	No.2	No.3
Cold mass in one cooldown batch [tons]	all Super-FRS magnets including EB	all Super-FRS magnets without EB of 290 tons cold mass	all Super-FRS magnets without Ring-, LE-branch and EB
	1367	1076	689
Total Cooldown time including LHe filling [days]	**34**	**27**	**17**

FAIR Cryoplant Capacity:

CWU Power (300K-80K): 80 kW
Cryoplant Power (80K-4.5 K): 7.0 kW
Cryoplant Liquefaction Rate: 50 g/s

Resulting Total Cooldown Time including LHe Filling:

34 d 27 d 17 d

Super-FRS Cryogenics:
Summary 3: Total Heat Loads

Table 10: Total heat loads budget for the Super-FRS magnets and infrastructure.

	Heat loads budget of Super-FRS machine including EB			Heat loads budget of Super-FRS machine without EB		
Static heat loads	4.5 K [W]	50 K to 80 K [W]	Liquefaction [g/s]	4.5 K [W]	50 K to 80 K [W]	Liquefaction [g/s]
Magnet cryostats	596	7487	6.9	519	6639	6.5
Local cryogenic distribution	796	5226		683	4465	
Total	**1391**	**12713**		**1202**	**11104**	
with design factor of 1.5	**2087**	**19069**	**10.3**	**1803**	**16656**	**9.7**

For the full Super-FRS, we expect (static) operation loads onto the Cryo-Plant(s) of about

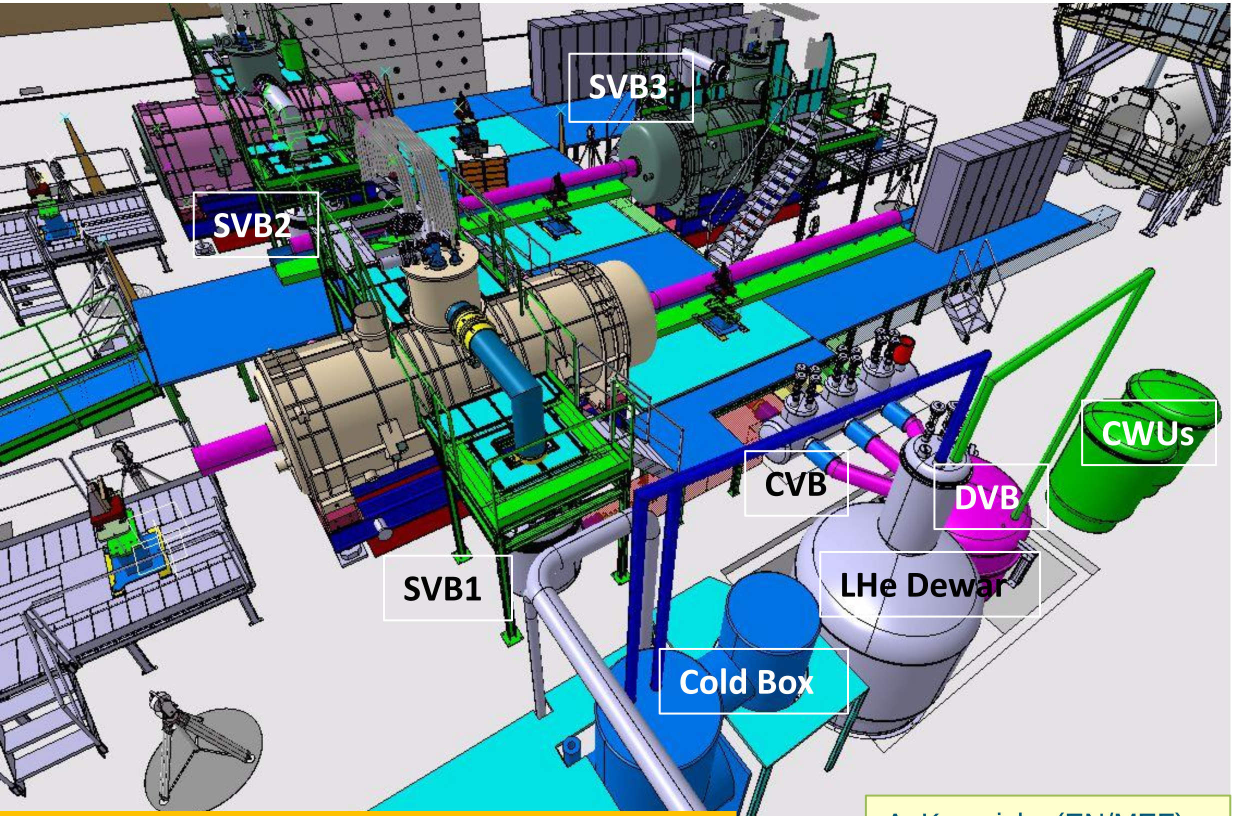
1.4 kW @ 4.5 K,
13 kW @ 50 K – 80 K
6.9 g/s (Liquefaction)

Magnet-Testing @ CERN Overview

Super-FRS Multiplet and Dipole Magnets to be tested in B180 @ CERN, during 2017-2020

B180 Cryo-Infrastructure (currently being refurbished)

- ColdBox,, Lhe Dewar, 1+1 LN2 Precoolers, Distribution System, Controls
- Three test-stations for parallel operation of up to three magnets



H. Derking, A. Perin, L. Serio (CERN)

A. Kosmicky (EN/MEF)
L. Stewart (TE/CRG)

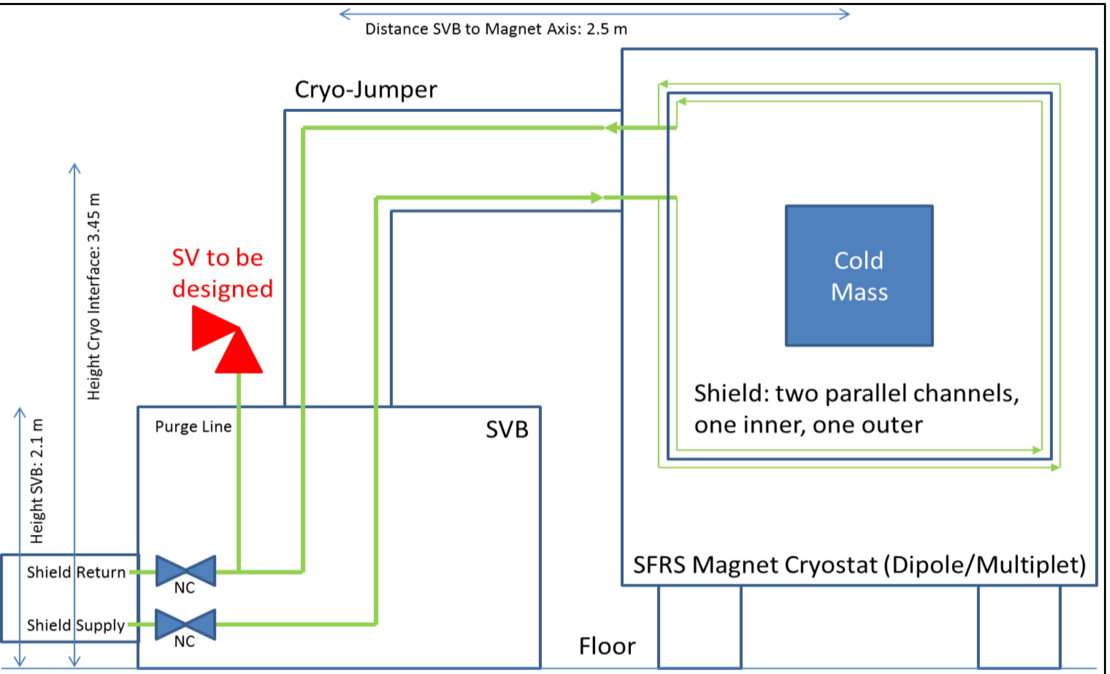
Strong involvement of CSCY in SFRS Magnet Testing @ CERN

- Jumper-Connection Design Study
- Cryo-Interface Specification

- Reaction-Forces Analysis
- Cryo-Process Specification
- Safety-Valves Spec. & Risk-Analysis

- Design & Procurement of three JCs for SFRS Testing at CERN

Magnet-Testing @ CERN:
Sizing of Thermal-Shield Safety Valves



Safety Valves for the Thermal-Shield Circuit between Magnets and CERN Feedboxes:

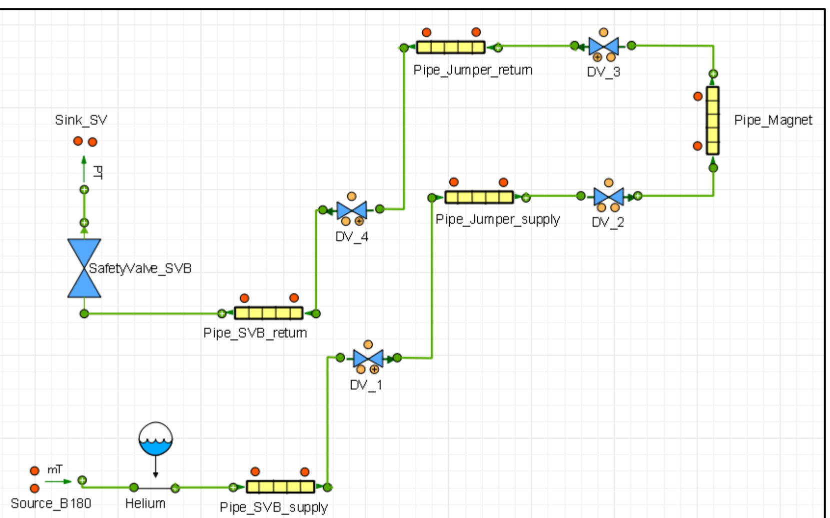
- Sizing and Pressure-Drop calculations
  → Comply with EN 4126 and EU PED.
- Hazard Scenario: Loss of Insulation Vacuum (5 kW/ m2)
- Static and Dynamic (EcosimPro) Calculations.

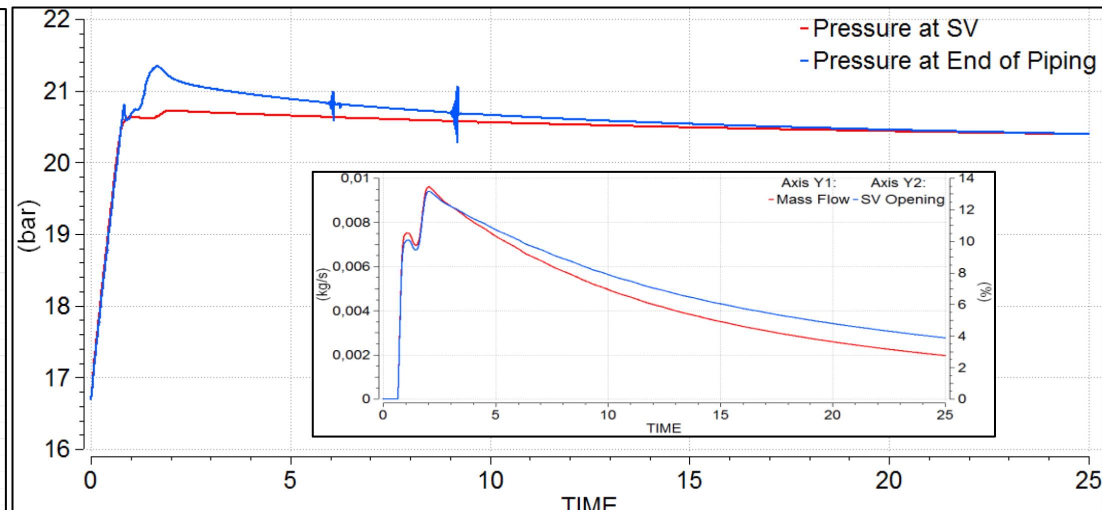
→ ~ 9 g/s peak mass-flow rate

→ max. pressure within 110% limit (21.9 bara)

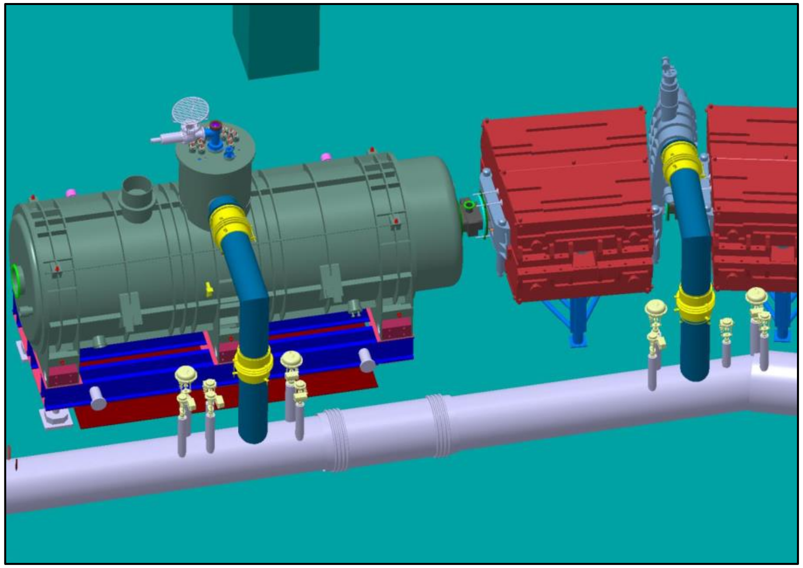
→ pressure drop along relief line > 3% PS = 570 mbar

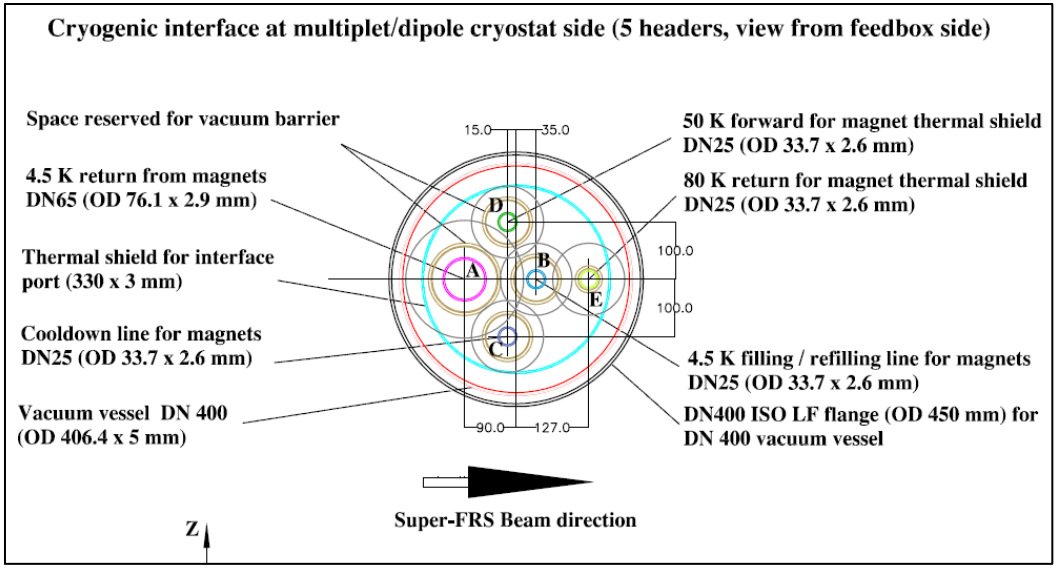
→ Redesign Dipole Shield-Circuit and/or extra SV at SVBs in B180 @ CERN

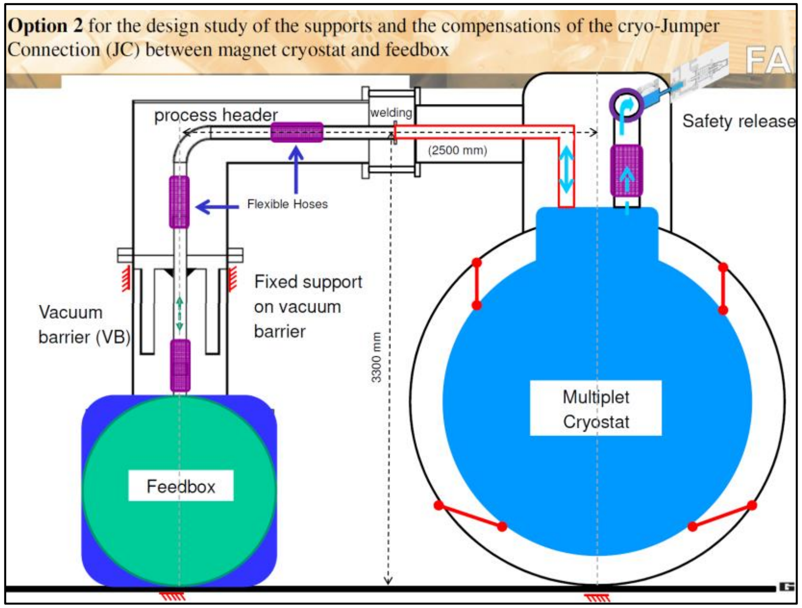




Magnet-Testing @ CERN: Design-Study for the Cryo-Jumpers Connections





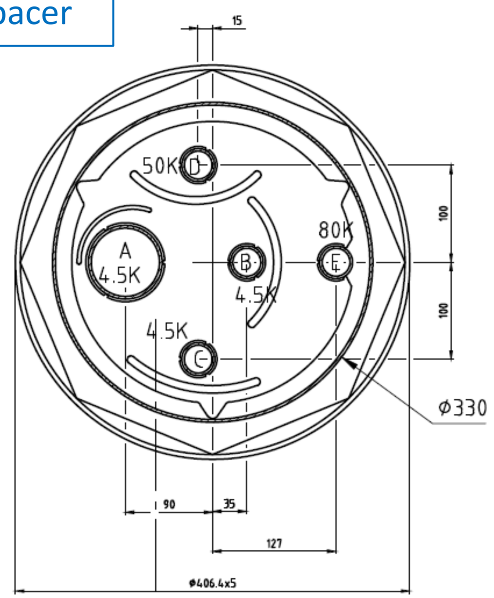


Goals for the external study at Cryotherm:
Suggest a JL Design fulfilling the desired mechanical, hydraulic, and thermal specs:

- +/-20 mm installation tolerance
- minimize forces on cold mass and FB
- keep heat in-leaks low enough
- keep pressure drop (cool-down) low enough
- coupling and dimensioning of the cryostat (and shield-lines) safety valves

Magnet-Testing @ CERN: Cryo-Interface Design Study

Spacer



Design Study by Cryotherm Company:

- Design of Jumper-Line as such until vacuum barrier to feed box (similar to KIT, Fermilab)
- Suggestion of two different options in terms of alignment and shrinkage compensation via hoses
- Concept for process lines and SV line in cryostat
- Calculation/estimation of reaction forces onto cold mass during cool-down and feedbox due to loss of vacuum
- Pressure drop and heat in-leak calculations
- Sizing for LHe-vessel and shield-line safety valves

Magnet-Testing @ CERN: Cryo-Interface Definition

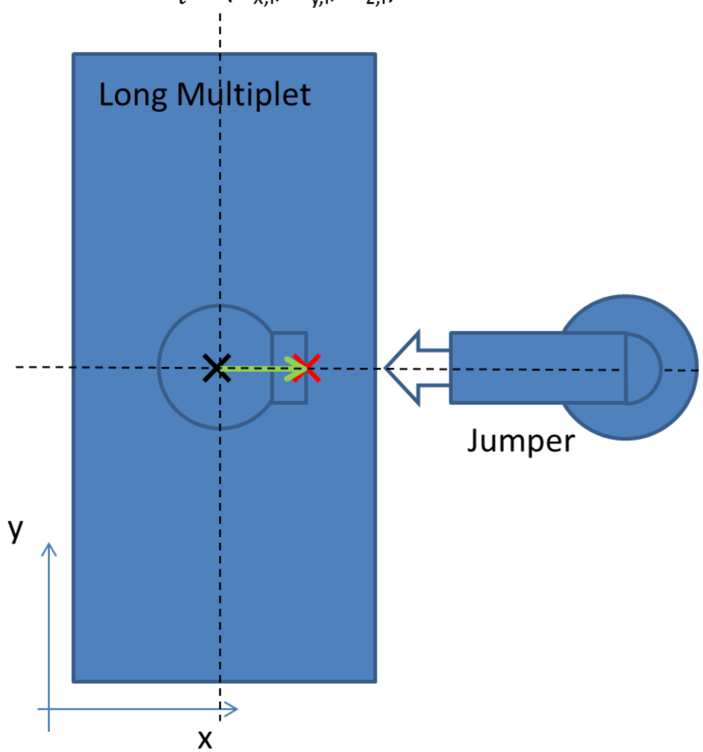
Definition of Magnet-Cryo Interface via Fixed Reference Points on Floor

View From Top

✕ $= \overrightarrow{X_i} = (x_i, y_i, z_i) = (x_i, y_i, 0)$.

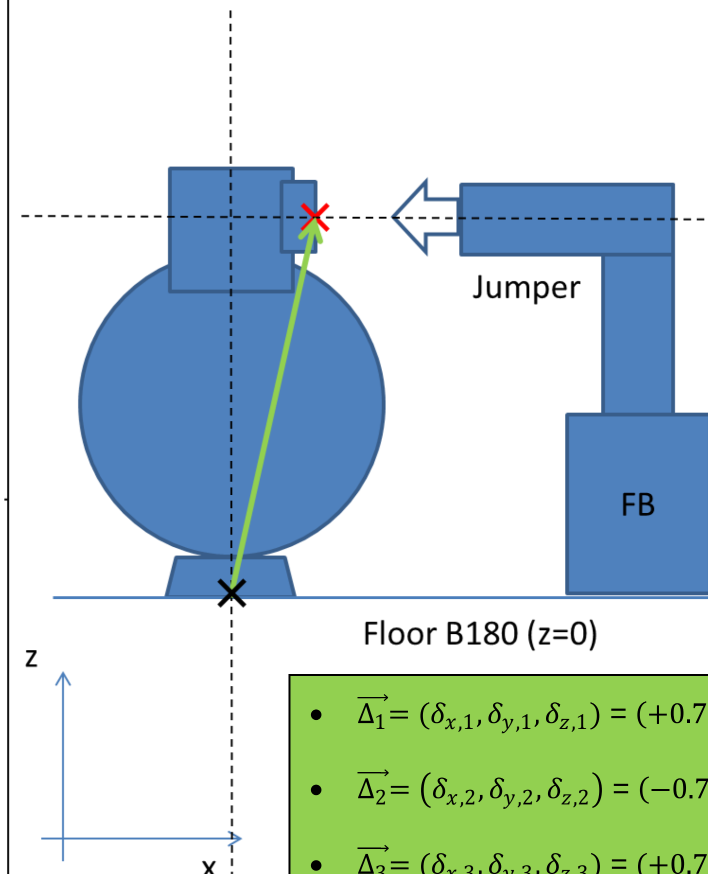
✕ $= \overrightarrow{R_i} = (r_{x,i}, r_{y,i}, r_{z,i}) = \overrightarrow{X_i} + \overrightarrow{\Delta_i}$
$= (x_i+\delta_{x,i}, y_i+\delta_{y,i}, z_i+\delta_{z,i})$.

→ $= \overrightarrow{\Delta_i} = (\delta_{x,i}, \delta_{y,i}, \delta_{z,i})$.



View From Side

(The $\overrightarrow{X_i}$ still need to be agreed with CERN)



- $\overrightarrow{\Delta_1} = (\delta_{x,1}, \delta_{y,1}, \delta_{z,1}) = (+0.75\, m, 0, 3.30\, m)$,
- $\overrightarrow{\Delta_2} = (\delta_{x,2}, \delta_{y,2}, \delta_{z,2}) = (-0.75\, m, 0, 3.30\, m)$,
- $\overrightarrow{\Delta_3} = (\delta_{x,3}, \delta_{y,3}, \delta_{z,3}) = (+0.75\, m, 0, 3.30\, m)$.

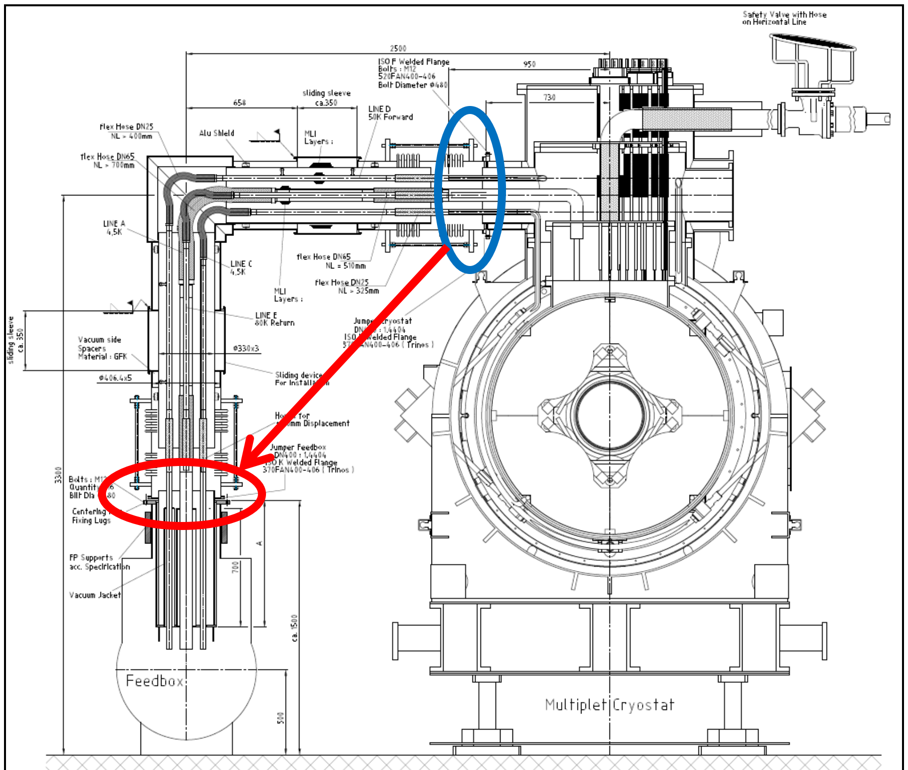
Magnet-Testing @ CERN:
Cryo-Interface Change Request

26.06.2015: CERN-GSI Collaboration Committee Meeting

- PDR (and documents) for SFRS multiplets not before end 2015

→ Definition (Fixing) of magnet-cryo interface at the moment too risky / not possible

→ Change Request for moving the interface to the jumper-feedbox connection



Consequences:

- The interface Feedbox (CERN) to Jumper (GSI) needs to be fixed
- The Magnet Cryo Connections (flanges, piping) need to be fixed
- GSI (CSCY) will procure the jumpers and ship them to CERN

PSP 2.4.12 – Super-FRS Local Cryogenics "Project Cockpit" (2005)

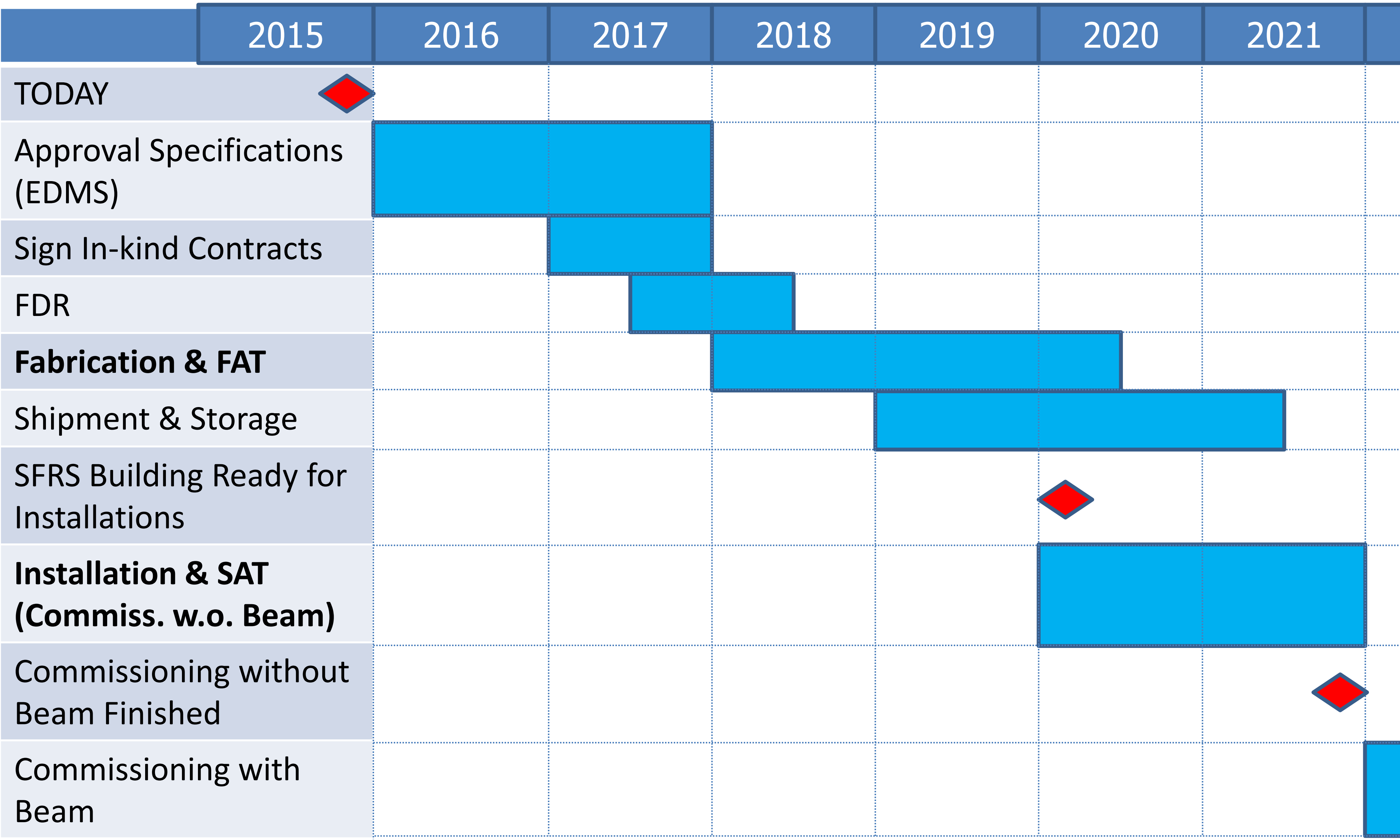
PSP-Code	Beschreibung	
2.4.12	**Cryogenics (Local)**	
2.4.12.1	Helium distribution box	1
2.4.12.2	Feedbox (without end-box integrated) for dipole stages	8 + 2 (EB*)
2.4.12.3	Feedboxes for Multiplet stages	15 + 3 (EB)
2.4.12.3.1	Feedbox (without end-box integrated) for multiplet stages	8 + 1 (EB)
2.4.12.3.2	Feedbox (with end-box integrated) for multiplet stages	7 + 2 (EB)
2.4.12.4	Cryogenic transfer line in sections [m]	~75 m
2.4.12.5	Warm helium/quench gas return piping [m]	3x (340 + 60 (EB)) m
2.4.12.6	Safety valves	For each FB, BB, HPWG supply
2.4.12.7	Instrumentation setups	For each FB: 38 + 8 (EB) units
2.4.12.8	Feedbox control system	For each FB: 38 + 8 (EB) units

*The EB is NOT part of the Modularised Start Version (MSV). It is NOT part of the WrUT In-Kind.

PSP 2.4.12 – Super-FRS Local Cryogenics Current Scope & Priorities

PSP	Name	Explanation	Comment
.3 .2	Feedboxes Multiplets Feedboxes Dipoles	All Feedboxes (FB), including the Jumper-Connections (JC) to the Magnets	Includes parts of .6 (Safety Valves), .7 (Instrumentation Setups), and .8 (Feedbox Control System)
.1	Helium Distribution Box	Branch Box (BB) (connection between main and SFRS branches and DB1)	Includes parts of .6, .7, and .8
.4	Cryogenic Transfer Line	Connection lines between Branch Box and FBs of individual SFRS branches	
.5	Warm Return Piping	- Warm Gas supply to FBs - Current Lead WG return - Cooldown & Quench gas return (multipurpose line)	Includes parts of .6, .7, and .8

PSP 2.4.12 – Super-FRS Local Cryogenics Milestones & Suggested Scheduling



Conclusions

Summary
- Super-FRS Local Cryogenics: Working Principle & Design
  - Magnet Properties
  - Cooldown&Operation Principles
  - Integral Machine Characteristics
- Super-FRS Magnet-Testing @ CERN
  - Jumper-Connection and Cryo-Interface
  - Safety Valves
  - Magnets' Thermal-Shield Piping Design
- Super-FRS Local Cryogenics: Schedule and Planning
  - Contents of WP 2.4.12
  - Suggestions for Milestones and Planning

Outlook
- Fruitful Collaboration with our WrUT In-Kind Partners!

Acknowledgements
- CSCY: M. Kauschke, H. Kollmus, A. Taeschner, ...
- PBMT: E.J. Cho, H. Mueller, P. Schnizer, ...
- CERN: H. Derking, A. Perin, A. Henriques, L. Serio, ...