DFX studies

DFX team: Y. Leclercq, C. Ortiz Ferrer, V. Parma, J-B. Deschamps
WP6a : cold powering – WP Leader: A. Ballarino

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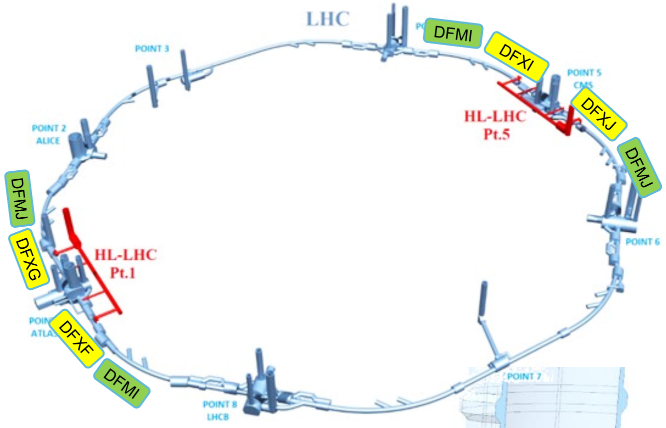
Introduction

- Aim: present the preliminary ongoing studies on the DFX:
  - Clarify requirements
  - Identify enabling technologies, technical challenges, system interfaces
  - Plan next steps and identify missing input
- The studies presented here are conceptual and likely to evolve with the evolution of requirements and engineering design

- Outline
  - Context
  - Identify requirements
  - Preliminary concepts

Context

- Each IP1 and IP5 sides equipped with 1 DFX + 1 DFM
- DFX basic functions:
  - Electrical interface between SC Link and triplets string (Q1-D1) through D1 cryostat
  - Supply cryogenics to the SCLink



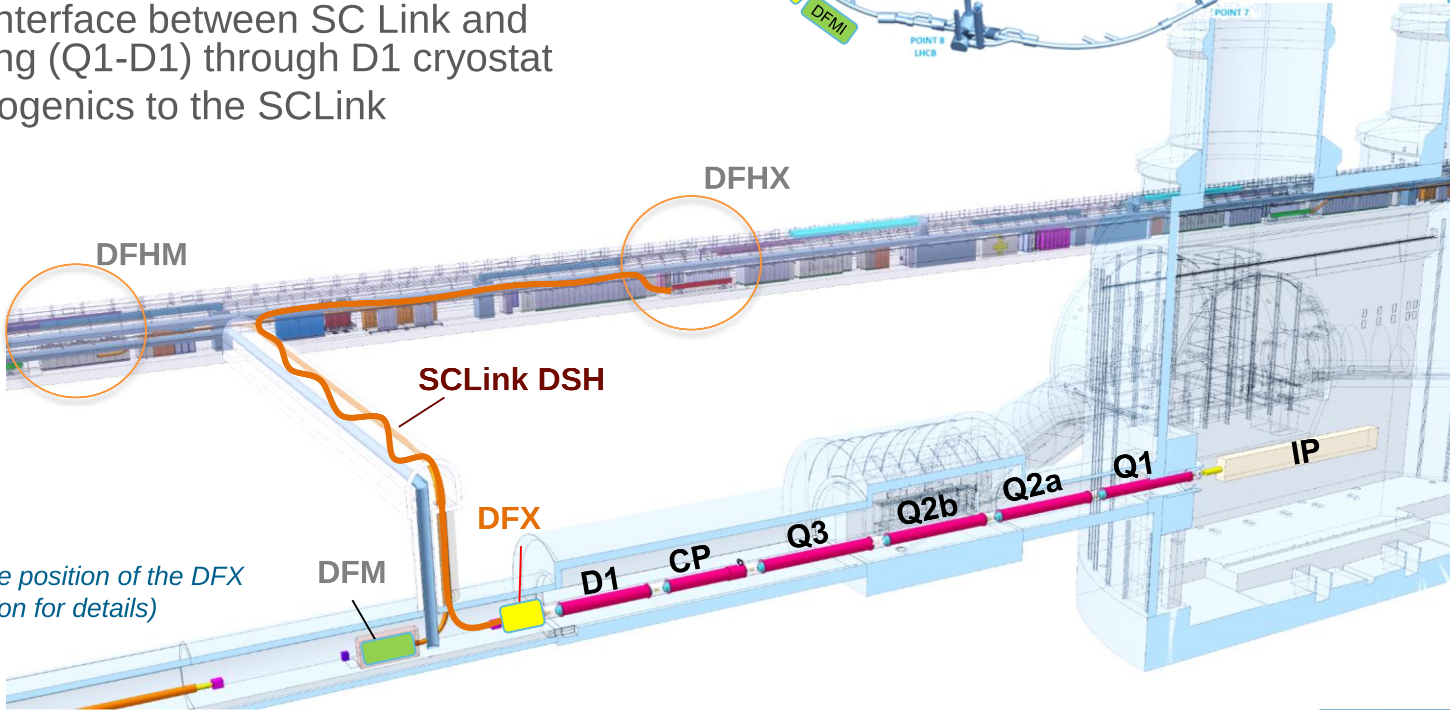


Illustration of the position of the DFX (not latest version for details)

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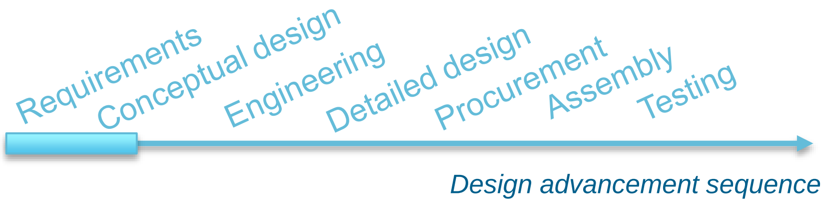
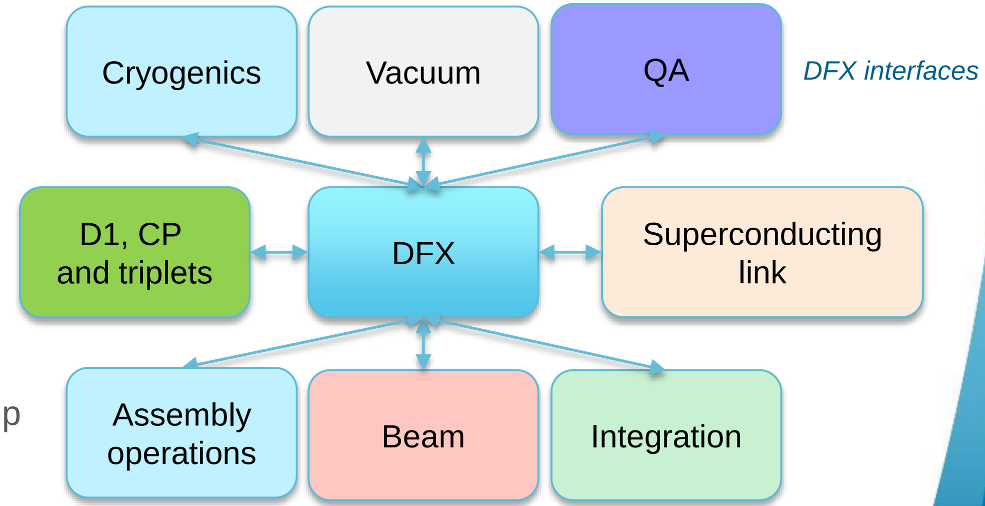
DFX studies: early design phase

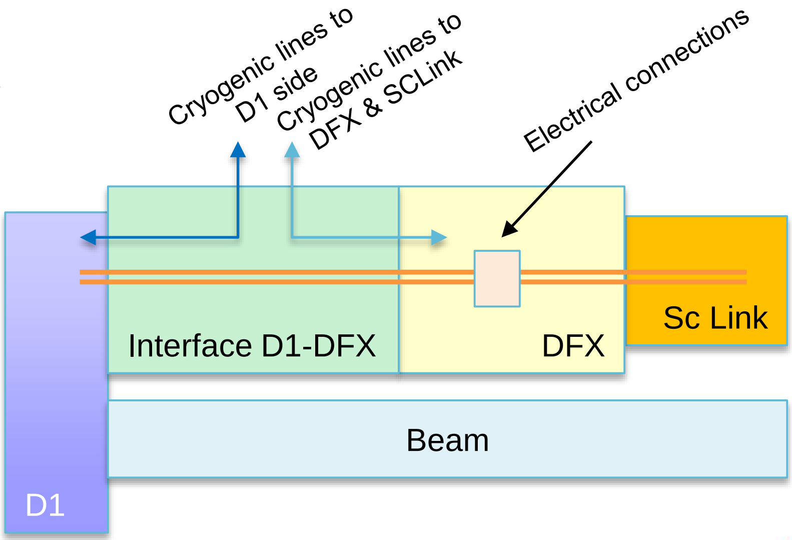
- Status of the DFX design phase:
  - Definition of requirements: on-going
  - Conceptual design: on-going
  - Setting-up of team (who does what?): in progress
- Identification of:
  - Main options for conceptual design
  - Technical challenges
  - Interfaces
  - System responsibilities
  - Pending information
- Enabling technologies needed:
  - Splices between superconductors: to start
  - Plugs: development laboratory being set-up (SMI2), insourcing of existing knowledge, R&D and prototyping: starting





Identify key requirements

- **S#1: Transfer current between SC-Link and D1-side**
  - Physically route and orientate cables through the DFX
  - Ensure and control the cooling capabilities along the path SCLink-D1
  - Perform reliable electrical connections
- **S#2: Supply the SCLink in cryogenics fluids**
  - Transfer a cryogenic line from the jumper to the SCLink thermal shield
  - Provide gaseous helium at 4.5K at the required mass flow for cables cooling
- **S#3: Be compatible with integration, installation and maintenance constraints**
  - Limit envelope size to transport constraints
  - Fit the maximum physical envelope at final position
  - Ensure compatibility with close equipment over life time
  - Optimise the quantity of work to be done in the tunnel
  - Ensure proper access during maintenance operations
- **S#4: Optimise the physical interface with D1 and SCLink**
  - Ensure a shared connection to the jumper
  - Provide cables in superfluid helium environment to D1
  - Minimise transferred mechanical loads from vacuum
- **S#5: Be reliable, maintainable and safe over the life time**
  - Ensure that design allows needed qualifications before installation
  - Mitigate the identified risks
  - Allow required redundancies, spares and maintenance operations
  - Ensure life-time of all components



Specifications are not totally detailed today but enough to identify key technical challenges, main conceptual designs and pending information

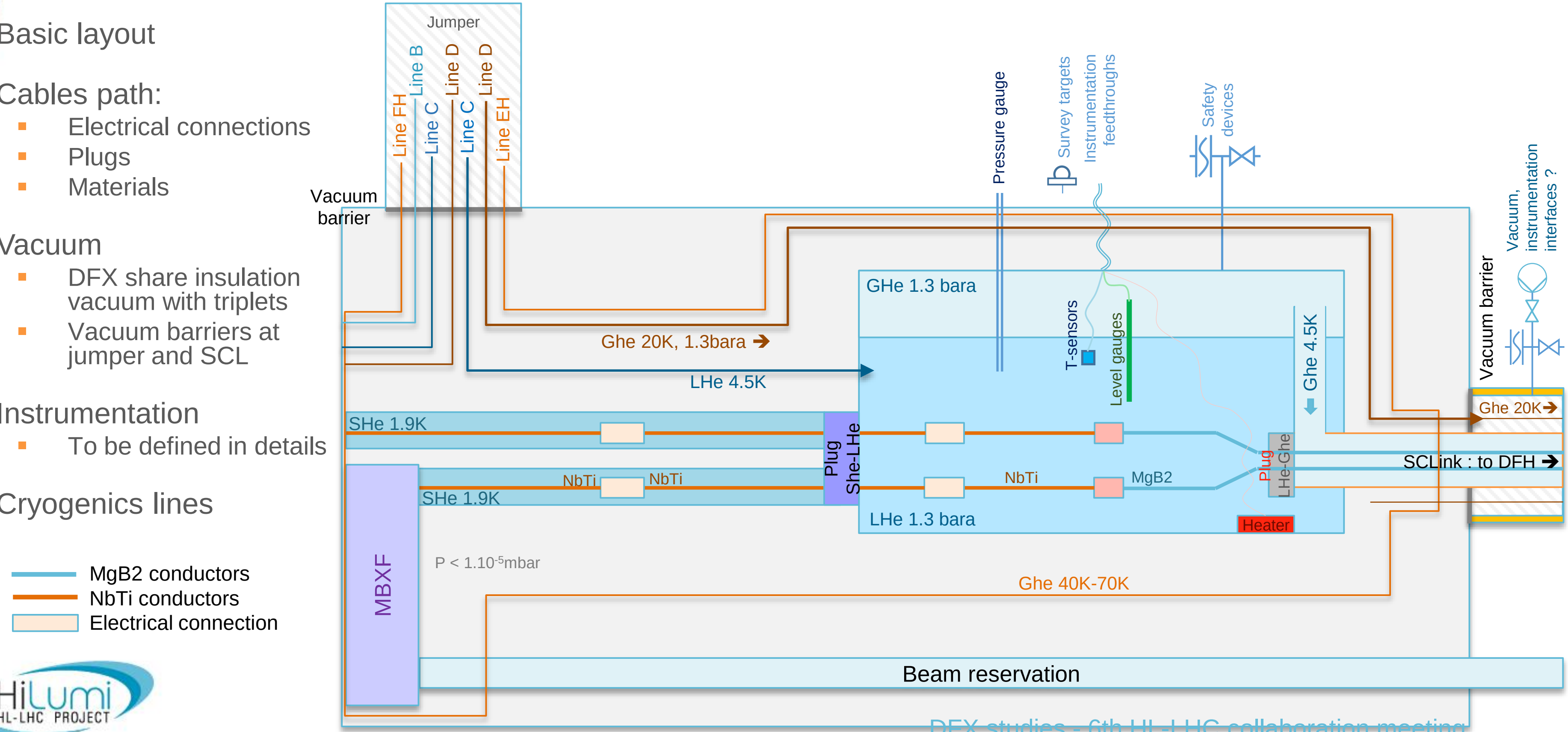
Conceptual design

- Sufficiently well known boundary conditions used for the conceptual design study:
  - Cables and electrical connections:
    - Estimation of flexibility of the superconducting link and individual cables
    - Estimation of number and types of cables to connect in the DFX
    - Electrical connection technology
    - Cables material
  - Cryogenics:
    - Available cryogenic lines with pressures and temperatures
    - Helium phase in pipes connecting the DFX
    - The SCLink assumed to have thermal shield
  - Integration:
    - Beam envelope
    - Envelope at final position
    - Envelope for transport (try to stay within D1 envelope)

- Key preliminary questions:
  - Beam pipe inside OR outside the cryostat ?
  - Jumper fixed to D1 OR to the DFX ?

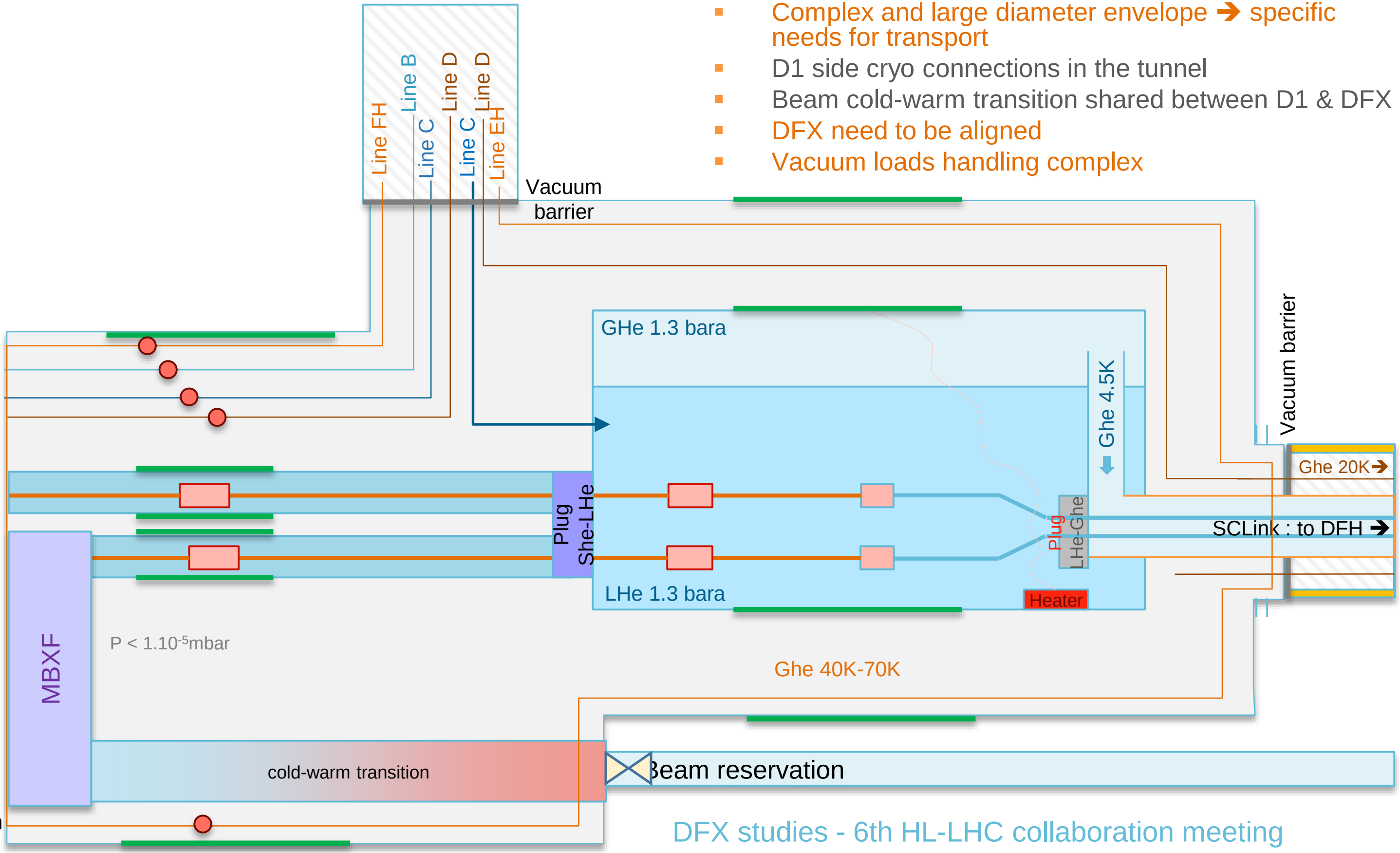
4 Conceptual designs : common features

- Basic layout
- Cables path:
  - Electrical connections
  - Plugs
  - Materials
- Vacuum
  - DFX share insulation vacuum with triplets
  - Vacuum barriers at jumper and SCL
- Instrumentation
  - To be defined in details
- Cryogenics lines



Concept #1 : Jumper fixed to DFX / Beam out of the vacuum vessel

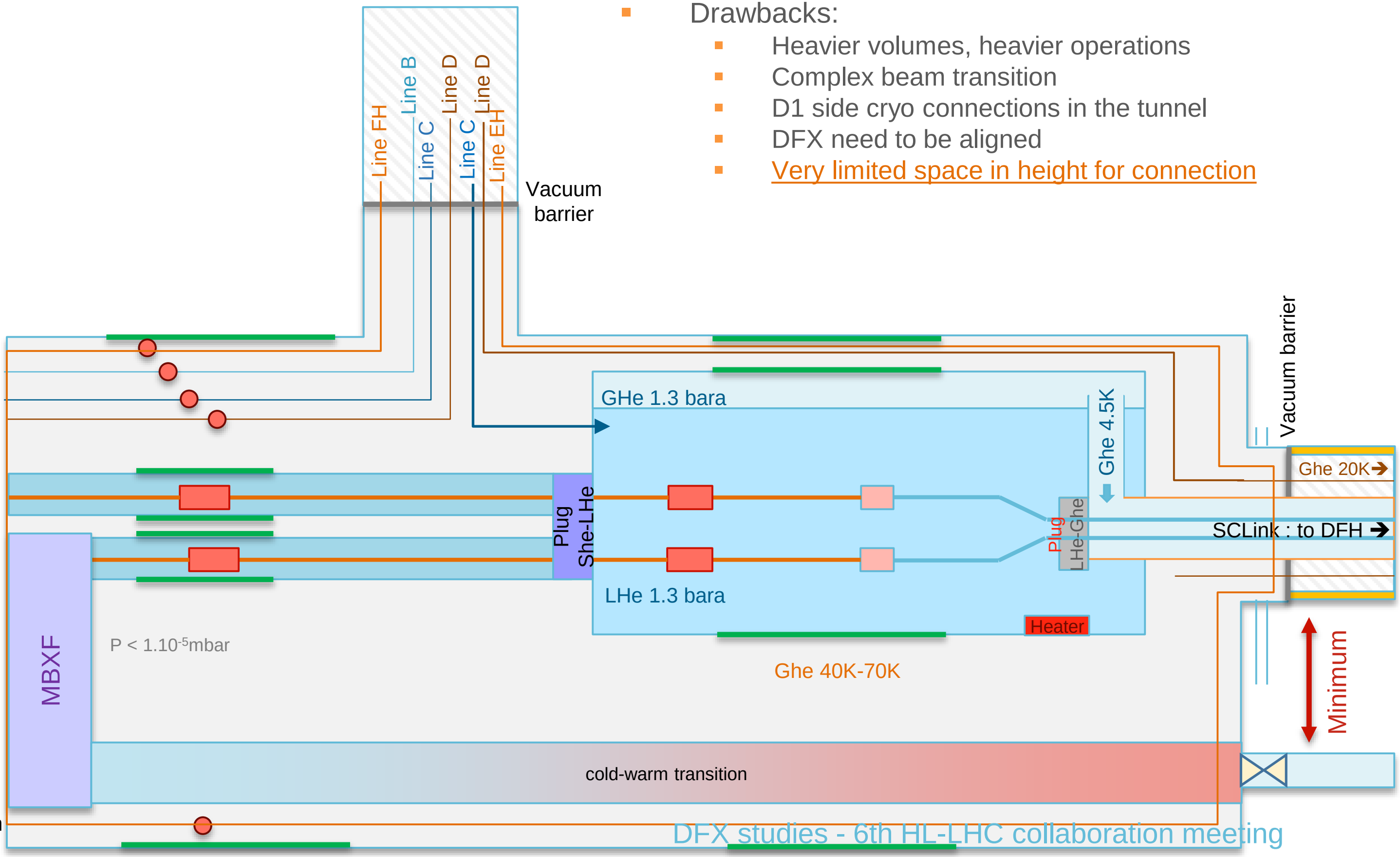
- Advantages:
  - Standard bellows access for brazing and piping welding
  - Cryogenic connections to DFX, SCLink on surface
  - DFX has more height ➔ optimise level control
- Drawbacks:
  - Complex and large diameter envelope ➔ specific needs for transport
  - D1 side cryo connections in the tunnel
  - Beam cold-warm transition shared between D1 & DFX
  - DFX need to be aligned
  - Vacuum loads handling complex



Values are expressed for steady-state operation
Interfaces with D1 are not represented

Concept #2 : Jumper fixed to DFX / Beam inside the vacuum vessel

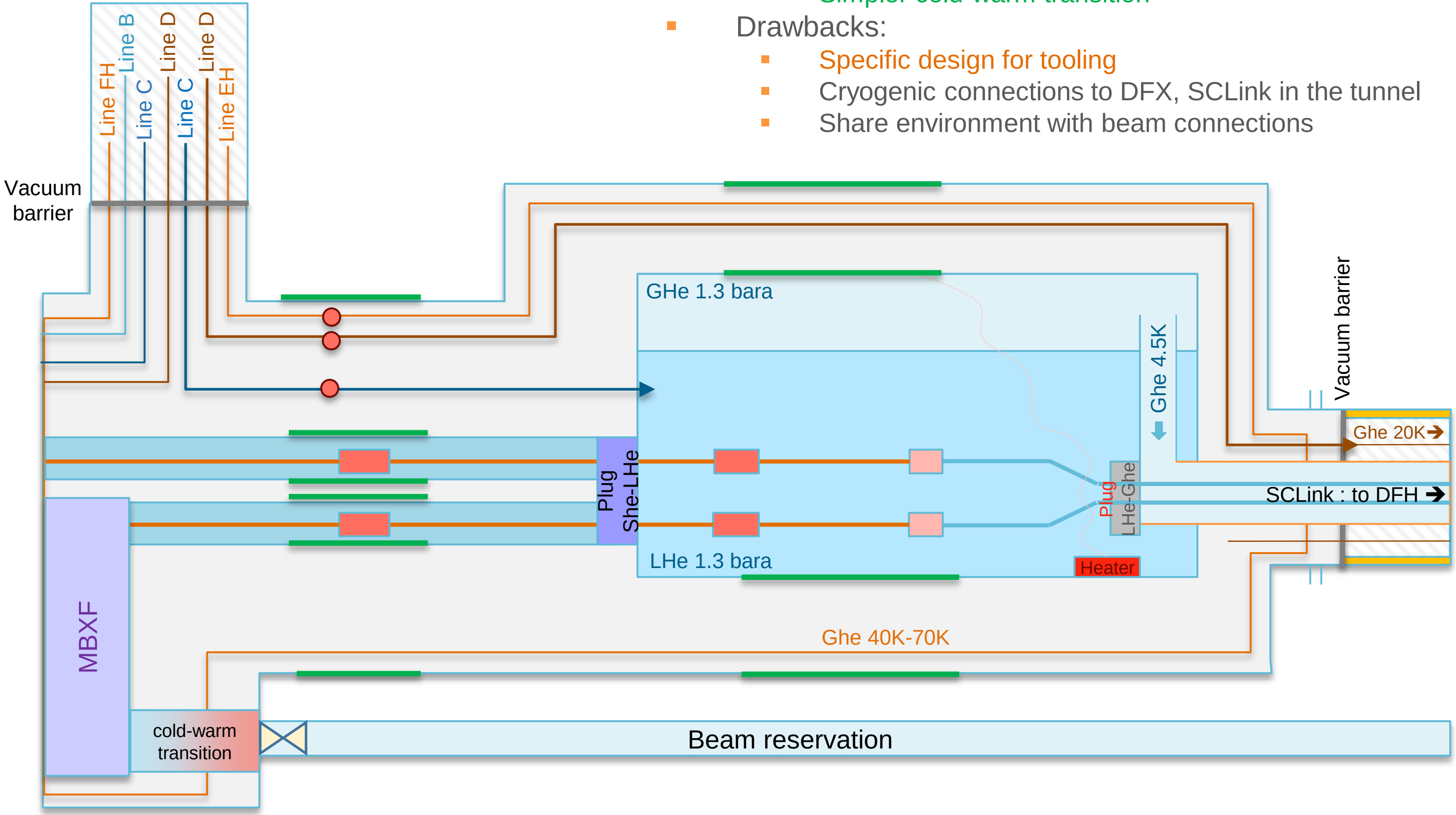
- Advantages:
  - Standard bellows access for brazing and piping welding
  - Cryogenic connections to DFX, SCLink on surface
  - Standard envelope
  - Vacuum loads easy to handle
- Drawbacks:
  - Heavier volumes, heavier operations
  - Complex beam transition
  - D1 side cryo connections in the tunnel
  - DFX need to be aligned
  - Very limited space in height for connection



Values are expressed for steady-state operation
Interfaces with D1 are not represented

Concept #3 : Jumper fixed to D1 / Beam outside the vacuum vessel

- Advantages:
  - D1 cryo connections done and tested on surface
  - Smaller overall diameter, easy to transport, open for access
  - Vacuum loads shared between D1 and DFX
  - No need for precise alignment
  - Simpler cold-warm transition
- Drawbacks:
  - Specific design for tooling
  - Cryogenic connections to DFX, SCLink in the tunnel
  - Share environment with beam connections



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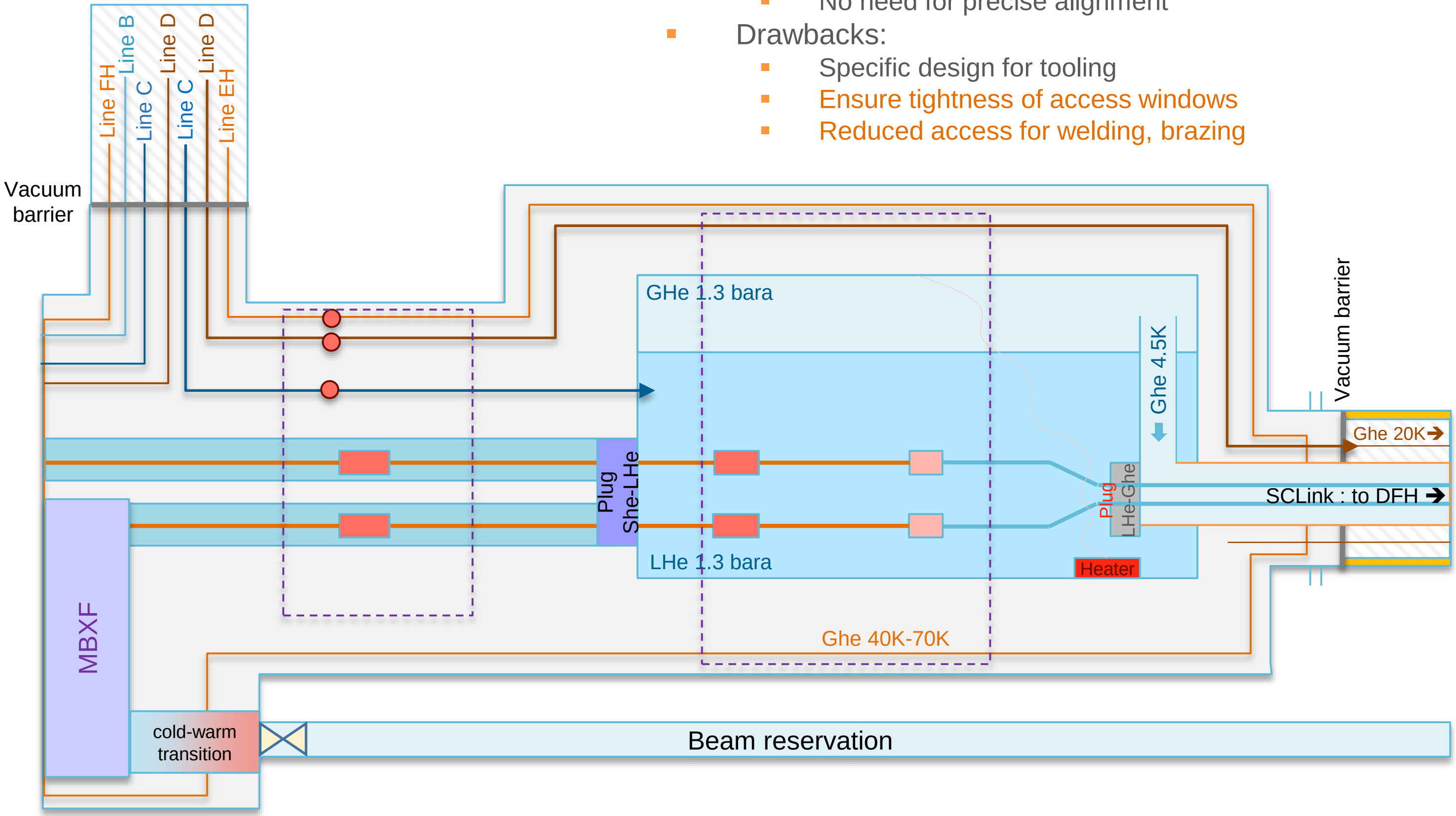
Concept #4 : Jumper fixed to D1 / Beam outside the vacuum vessel.

- Advantages:
  - Vacuum loads handling
  - No support
  - D1 cryo connections done and tested on surface
  - Smaller overall diameter
  - Easy to transport, open for access
  - No need for precise alignment
- Drawbacks:
  - Specific design for tooling
  - Ensure tightness of access windows
  - Reduced access for welding, brazing

Same as concept#3 with all rigid structure and access windows

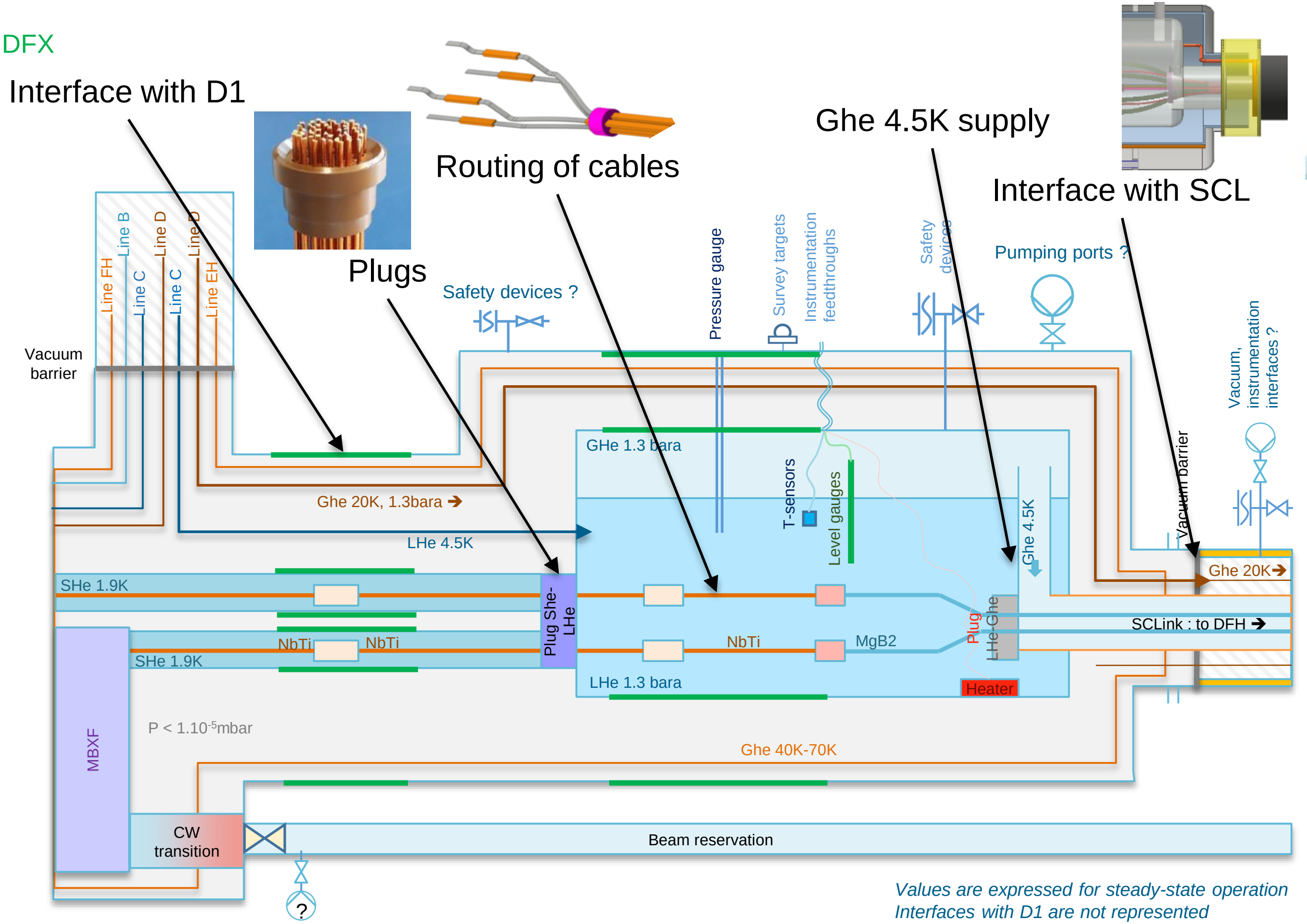


Conceptual design

- Decision to go into details with concept#3
- Identification of technical challenges

Smaller, lighter components
Vacuum loads shared between D1 and DFX
No need for precise alignment
Simpler cold-warm transition

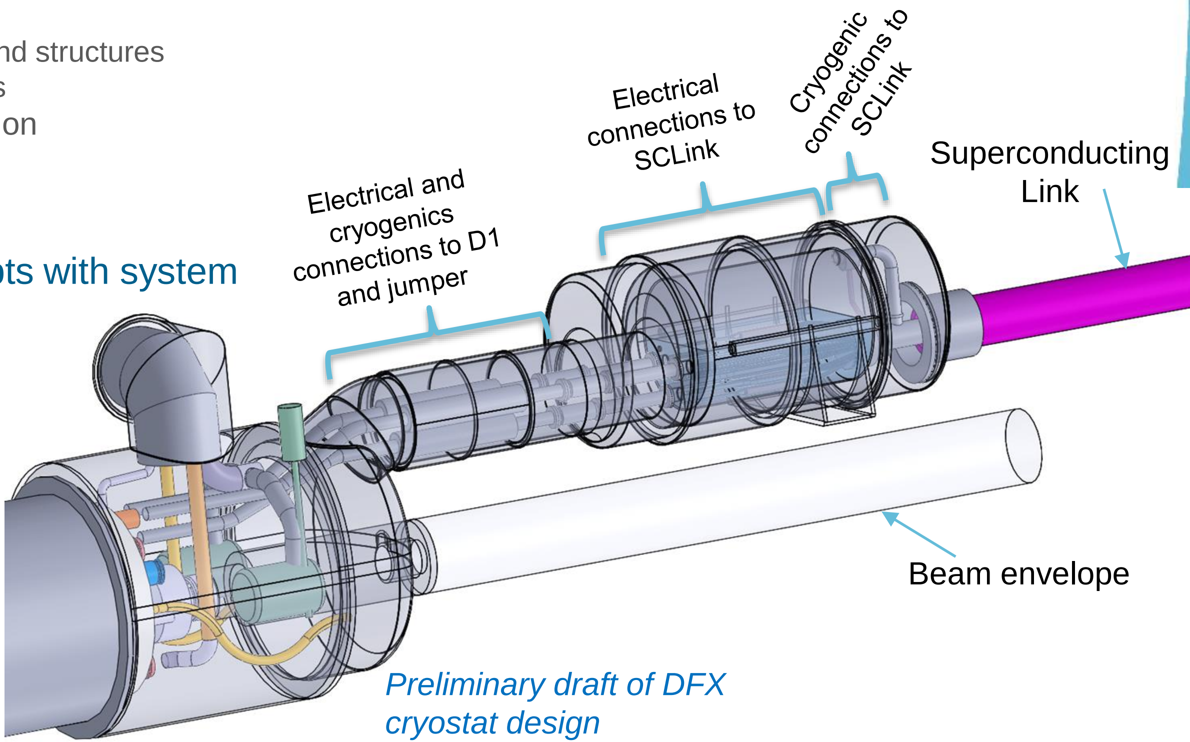
1-5 (1-bad : 5-excellent)	W	#1	#2	#3	#4
S#1 transfer current					
Routing	3	4	1	5	3
Ensure cooling of connections	5	5	2	5	5
Reliability of electrical connection	5	5	5	5	5
S#2 Supply SCL in cryo. Fluids					
TS connection to SCL	3	4	2	4	4
Supply 4.5K Ghe	5	5	3	5	5
S#3 Integration, installation, maintenance					
Envelope size for transport	3	1	3	5	5
Envelope size at nominal position	3	1	3	5	5
Compatibility with environment	5	3	4	4	4
Quantity of work in the tunnel	3	2	2	5	3
Ensure maintainability	5	4	2	5	2
S#4: Interface D1 and SCL					
Connection to jumper	3	3	1	4	1
Cables in SHE	3	4	4	4	4
Minimise transferred mechanical loads	3	1	4	4	5
S#5: Safety and Quality					
Testability before installation	4	2	2	3	3
Risk mitigation	5				
Volumes for spares, redundancy	4	3	1	4	2
		190	152	256	215



Values are expressed for steady-state operation
Interfaces with D1 are not represented

DFX studies : First draft of concept#3

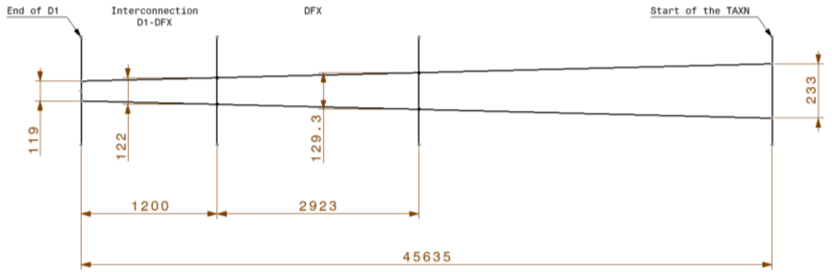
- Specifications are not all defined but:
  - Enough to start working on concepts
  - Enough to identify technical challenges
    - Plugs
    - SCL interface
    - Study physical accesses and structures
    - Dimension cryogenics lines
  - Enough to list pending information
    - Cables layout
    - Vacuum equipment
    - Instrumentation
- Next step: discuss these concepts with system responsible



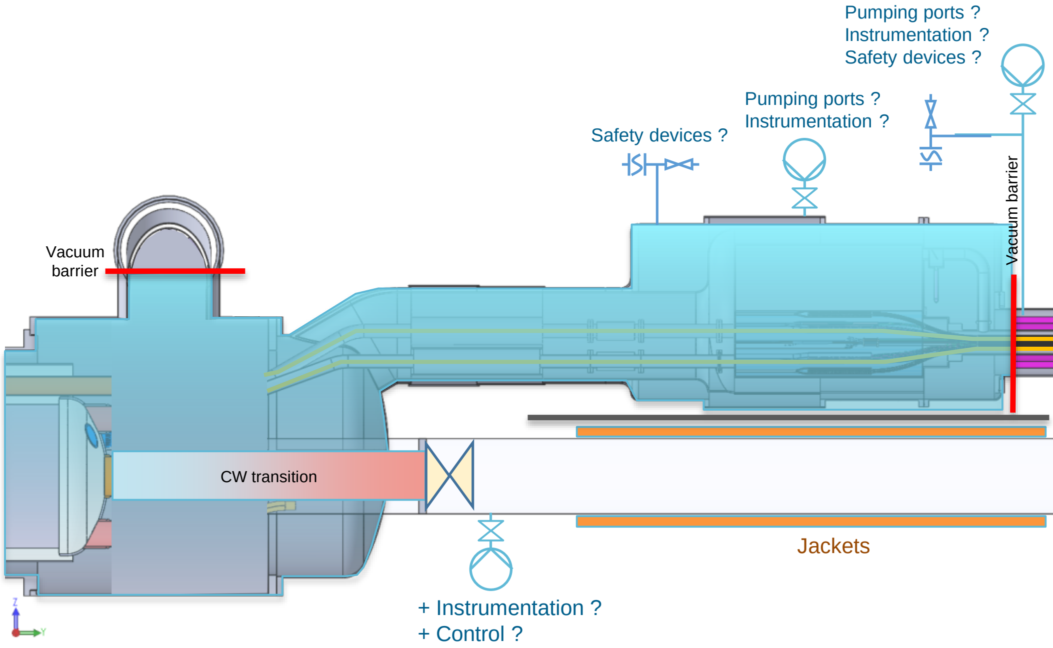
Preliminary draft of DFX cryostat design

DFX: vacuum and beam related studies

- Concept :
  - same vacuum for triplets and DFX
  - Vacuum barriers at Jumper and superconducting link
- Vacuum equipment
  - DFX: need for pumping station to be discussed
  - DFX vacuum vessel protected by DN200 on D1 ?
  - SCLink: needs for pumps, instrumentation, safety devices ?
- Beam reservation
  - Cold-warm transition at the end of D1
  - Control, pumps
  - Warm tube
  - Shielding ?
  - Jackets integration
- To be studied in details and discussed with system responsible



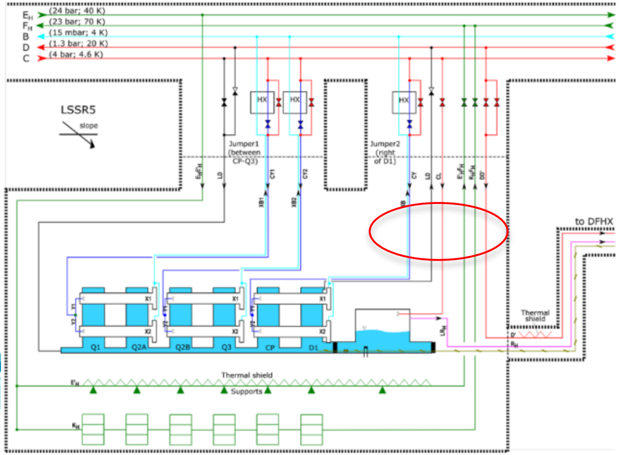
Beam aperture evolution

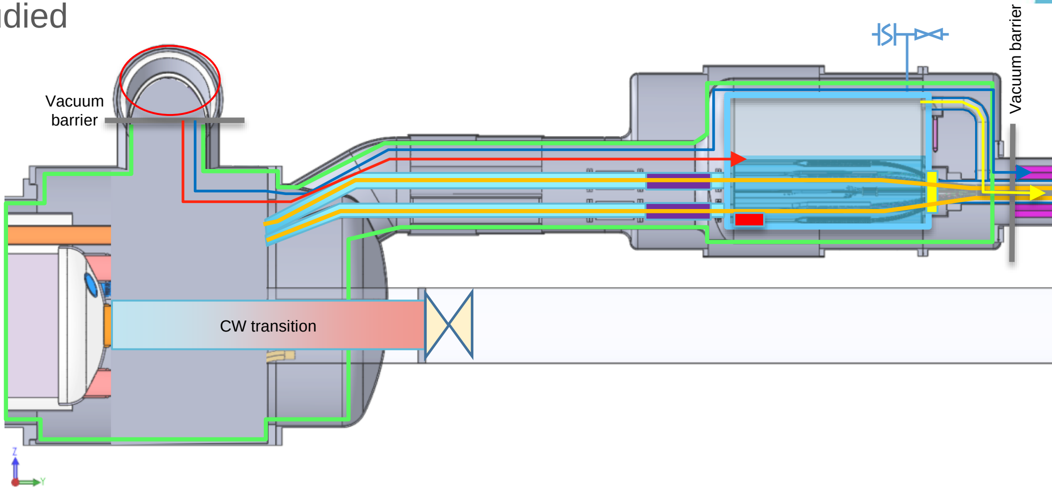


DFX: Preliminary cryogenics studies

- Thermal shield in series
  - Additional heat loads, pressure drop to be studied
- Helium vessel:
  - Two phase LHe-Ghe at 1.3 bara nominal, 2.5 bara max
  - Estimation of volumes: ≈ ∅0.6m x 1.2m
- Plugs
  - SHE-LHE: 20 bara relative pressure
  - LHE-GHE: high conductance transition
  - Leak tightness and heat loads to be studied
- Piping and jumper
  - Integration of jumper: to be studied
  - 20K line to the SCLink thermal shield: mass flow to be confirmed
  - 4.5K LHe line to the DFX + heaters : ≈10 g/s
- Instrumentation and safety devices
  - To be defined with cryogenic expert : P gauge, Level gauge, T-sensor, Heaters, redundancy / maintainability
  - Common safety devices for SCLink helium volume and DFX helium vessel to be discussed.

Cryogenics layout: Courtesy TE-CRG



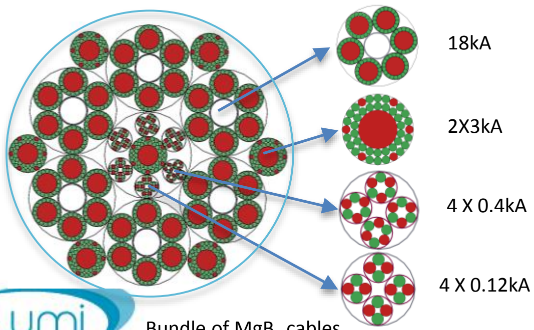


DFX: Preliminary electrical studies

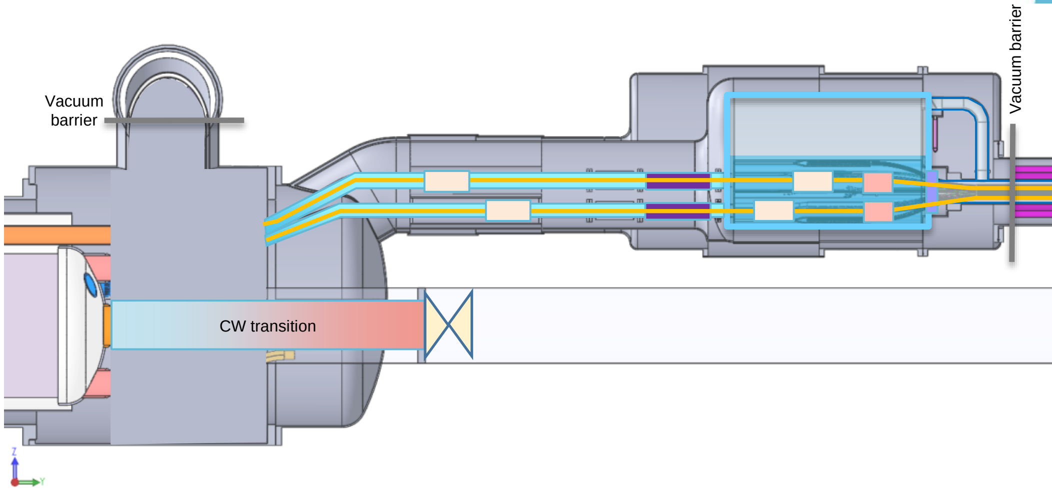
- Up to about 40 conductors from 0.12 kA to 18 kA
- MgB2-NbTi connection performed and tested in the surface:
  - Immersed in LHe
  - Maintainable in the tunnel
- NbTi - NbTi electrical connections in the tunnel:
  - Well known and reliable operation
  - Staging
  - Immersed in LHe or SHe

- Stable information we need to proceed
  - Conductors type and number
  - Required accesses and dimensions for MgB2-NbTi connection, maintenance
  - Cables interfaces including NbTi extremities
  - Final start and end routing locations
- On going work:
  - Study principles for plugs, cables routing, tooling, required access
  - Study integration of NbTi-NbTi connections

Illustration of a preliminary design of a type of cables bundle
Courtesy TE-MSC-SCD



Bundle of MgB_2 cables
ØEXT ≈ 65 mm



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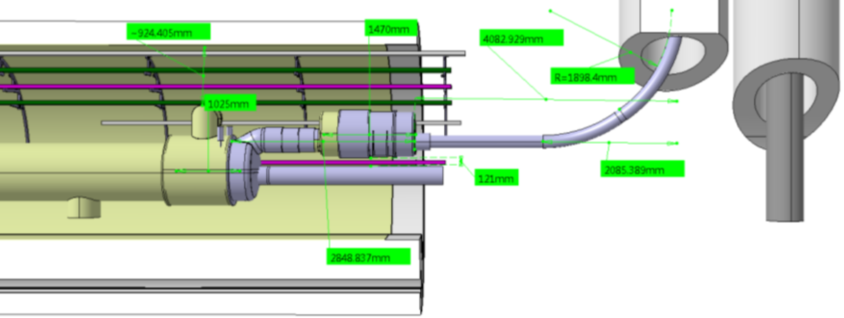
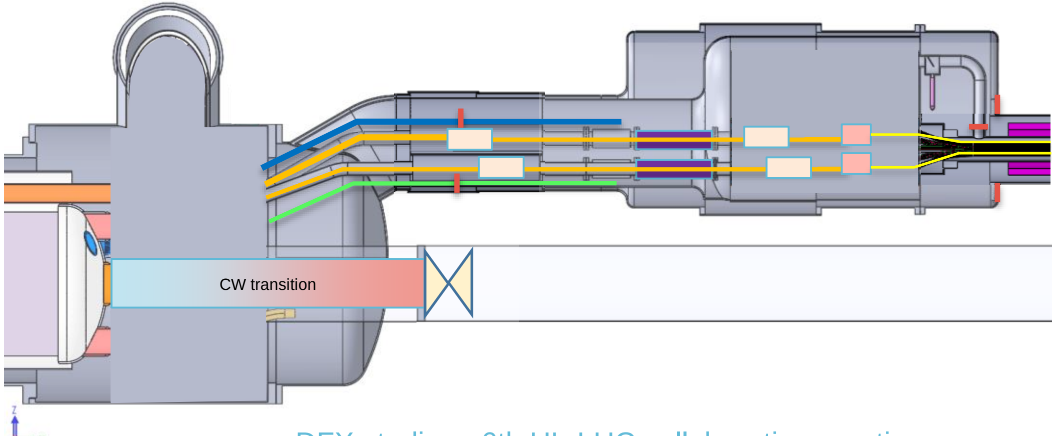
DFX: Preliminary integration studies

- Identification of a conceptual design on the paper
  - Upcoming discussions with cryogenics experts:
    - Pre-size piping, helium vessel
    - Instrumentation
  - Vacuum
    - Detail and identify required equipment
  - Triplets, SCL
    - Gather information on cables and location
- Next steps
  - ➔ integrate D1-DFX interface
  - ➔ validate feasibility of transport
  - ➔ integrate pre-sized piping
  - ➔ detail structures, opening systems
- Possible installation procedure

First draft of DFX integration in the tunnel





Summary

- Studies so far are enabling the identification of requirements, system interfaces, and boundary conditions for the design of the DFX
- Conceptual studies have helped identify technical challenges as far as the sufficiently well known boundary conditions allow
- These concepts can now trigger technical discussions with the system responsible involved and enable design work to proceed
- The development of plugs, an enabling technology, is starting
- Advanced design and engineering studies have to start early 2017

Illustration of a possible design for the superconducting link extremity