Review of DFH key concepts

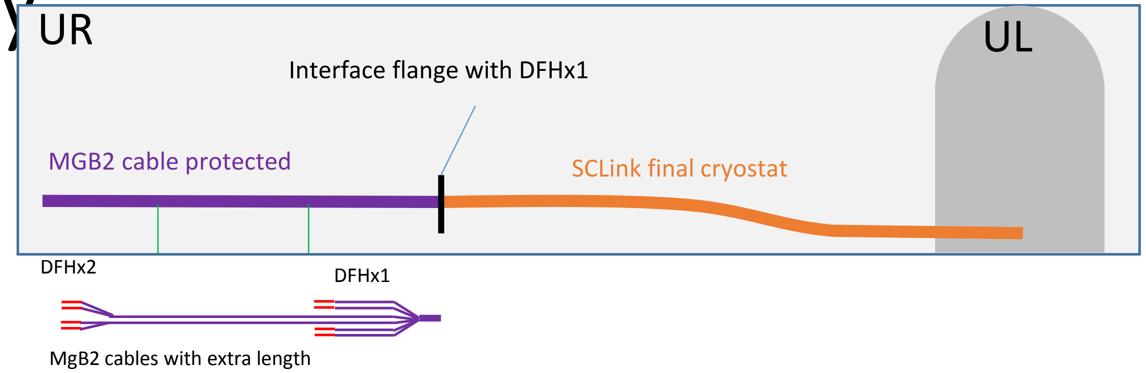
DFH-DFM meeting : 13 Feb. 2019

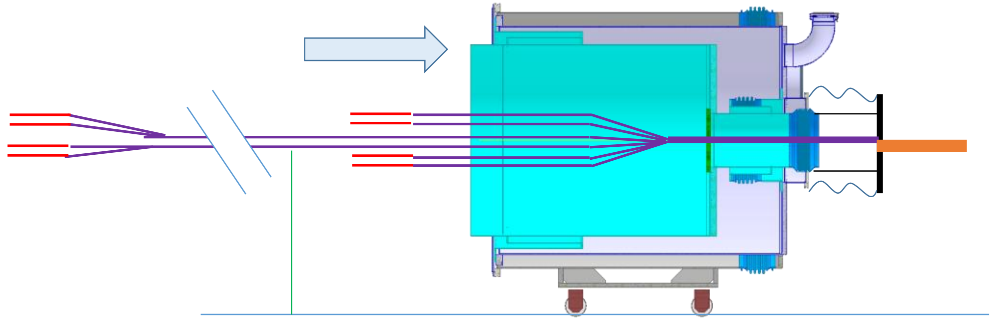
- Installation general strategy
- Leads layout in DFHx1 & DFHx2
- Splices cooling principle

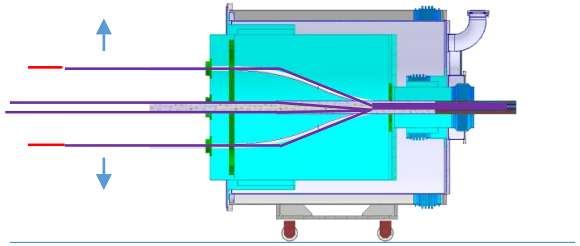
1. Installation general strategy

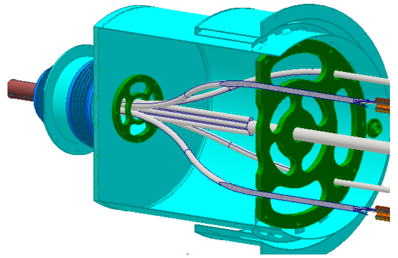
- **Option July 18. Shaping MgB2 cables in UR**
  - Test in SM18 with extra MgB2 length
  - Transport & install **compact unprepared** MgB2 cables
  - Shape, cut to length and prepare in UR

- ➔ handling of MgB2 cables in UR identified as critical
- ➔ new proposal









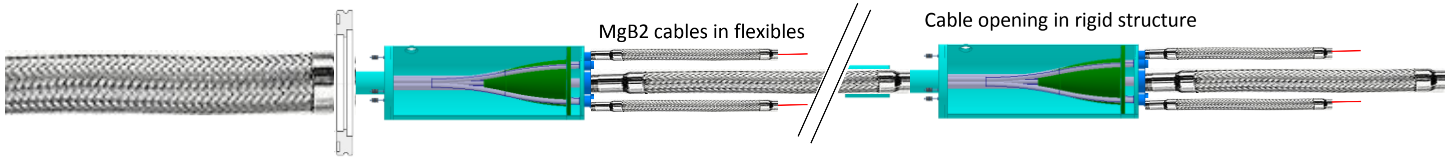
1. Installation general strategy

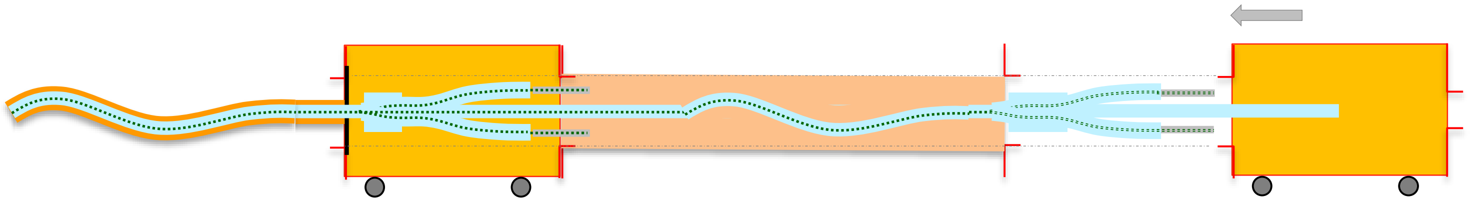
[Indico775038]

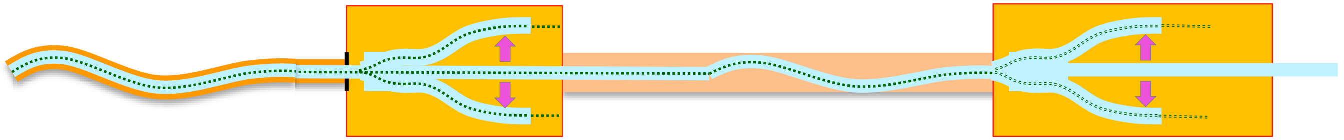
- **Option November 18 :**

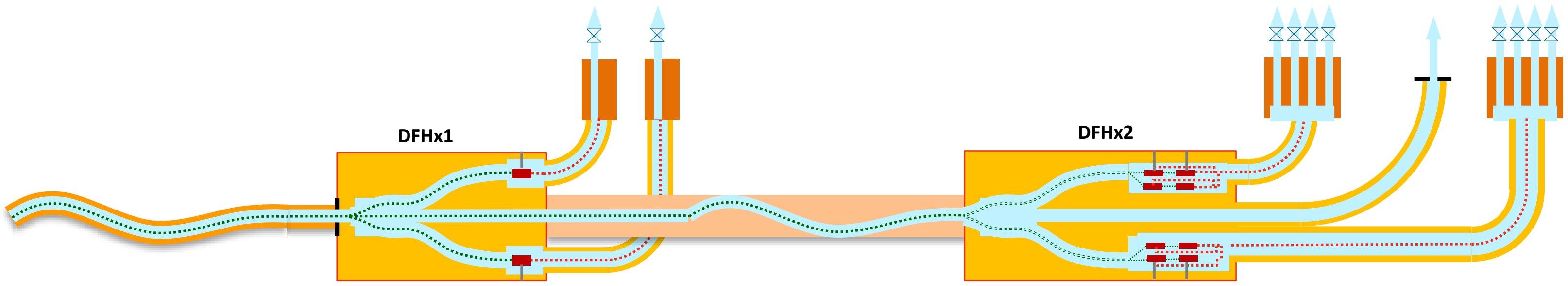
  No direct MgB2 handling

  - Insertion of MgB2 cable in SCLink
  - Pre-shape MgB2 ends in protective flexibles & reservoirs <u>in laboratory</u>
  - Test of SCLink in SM18
  - Transport configuration (on reel) with flexibles and reservoirs on
  - Deploy in the tunnel (MgB2 cable untouched)





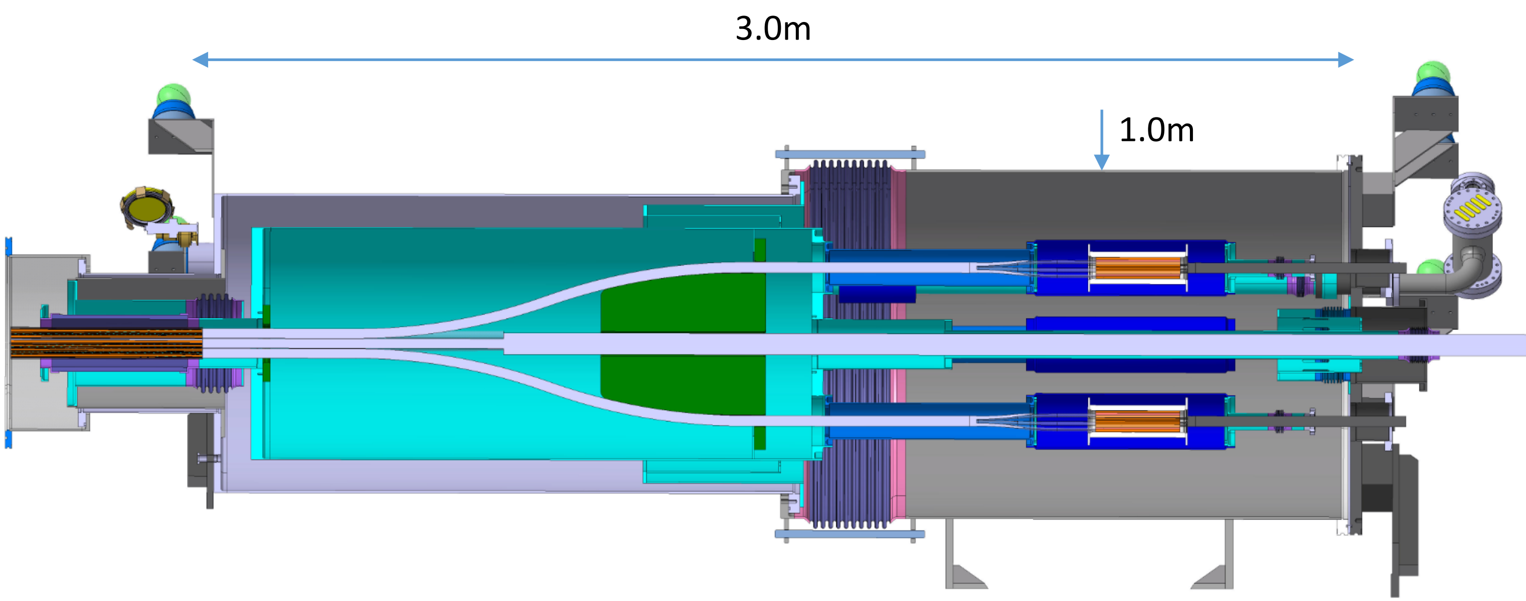




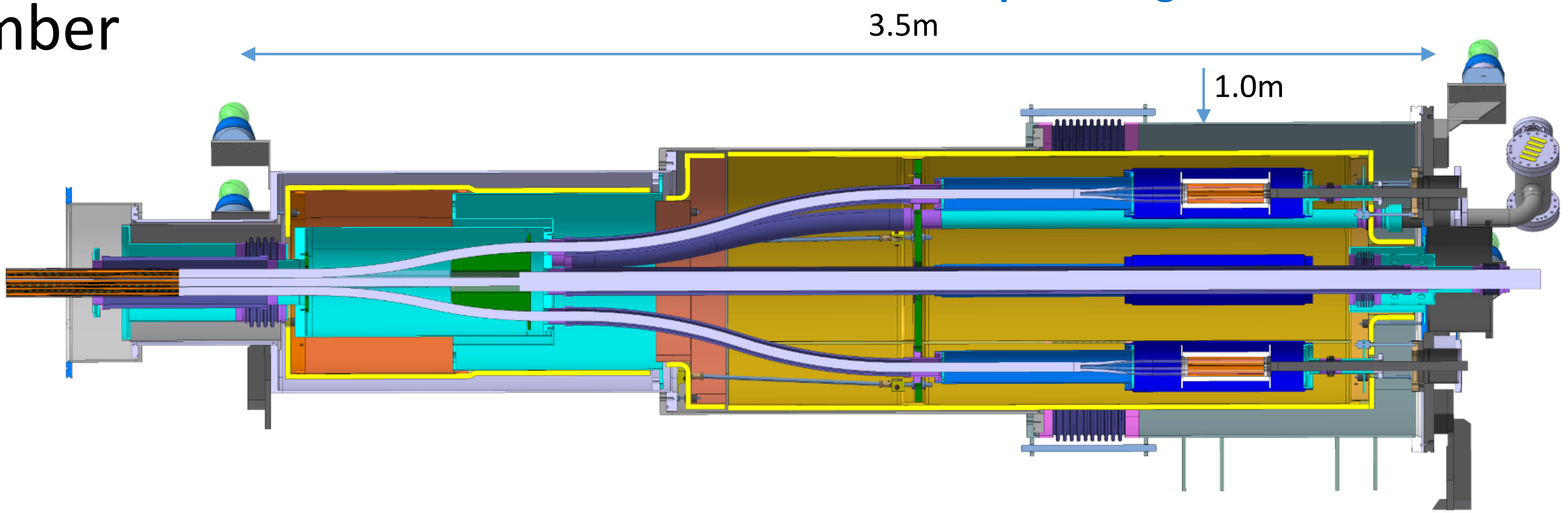
1. Installation general strategy

- **Limited handling at a cost of:**
  - Transport of bigger Reel
  - Slightly longer DFH cryostats
  - DFH mechanical assembly higher complexity
- July option not compatible with MgB2 handling limitations
- Our proposal is the November option

July Option: Shaping MgB2 cables in UR



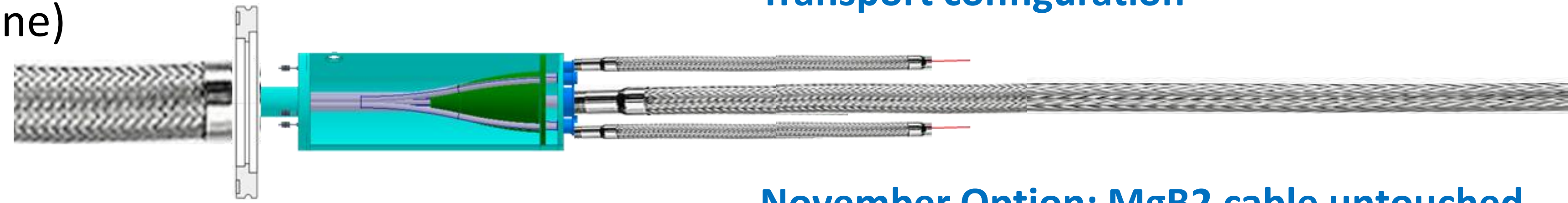
November Option: MgB2 cable untouched



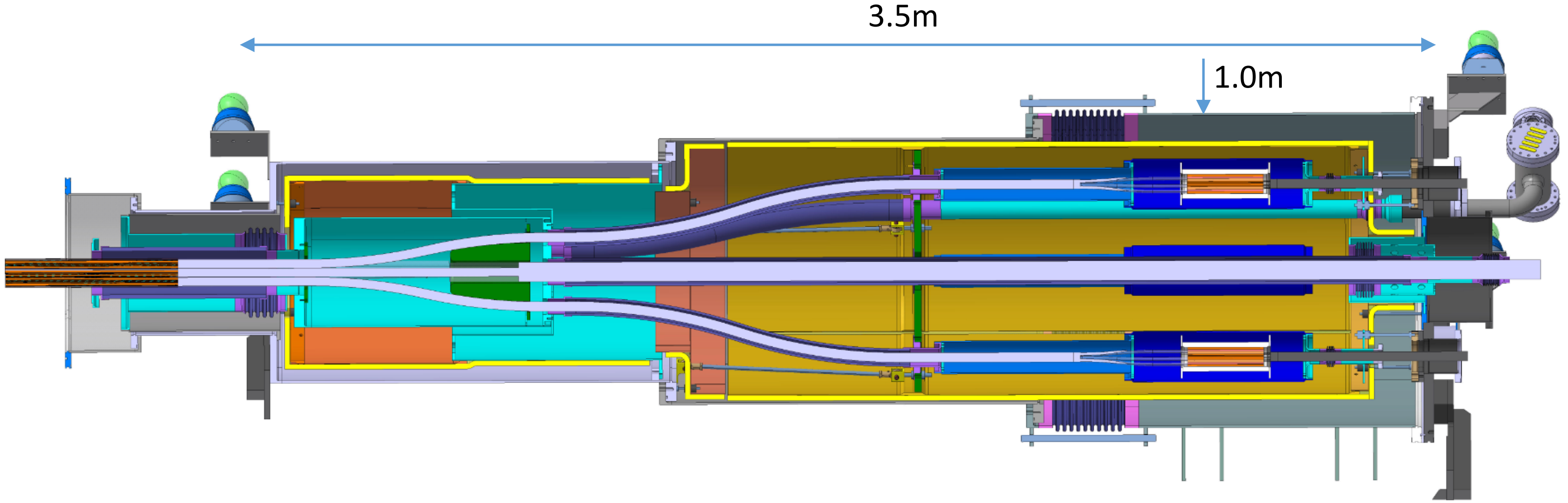
1. Installation general strategy

- No direct MgB2 handling in the tunnel has a (useful) cost
- Is this approach compatible for the cables?
- Do we go ahead with the next steps ?
  - Move on with more detailed design work
  - Prepare for a conceptual design review in march
  - DDR by May (in view of FC in June)

November Option: MgB2 cable untouched
Transport configuration



November Option: MgB2 cable untouched
Nominal configuration

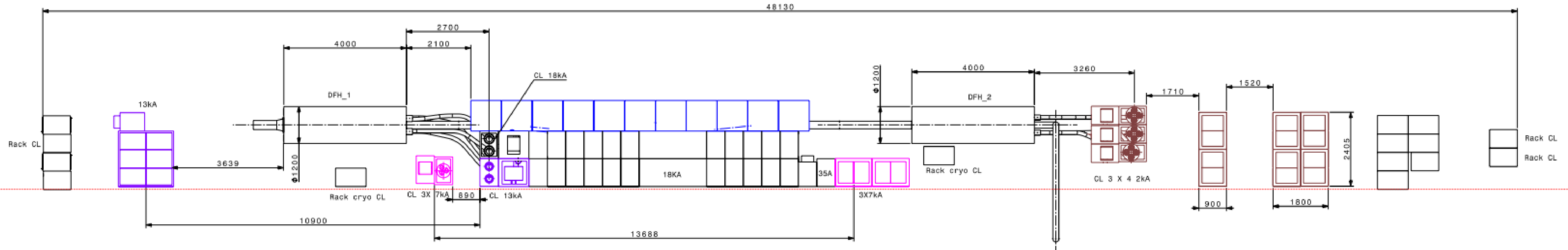


2. Leads distribution

- Initial distribution
  - DFHx1 : 2 x 18 kA + 2 x 13kA
  - DFHx2 : 3 x 7 kA + 12 x 2 kA

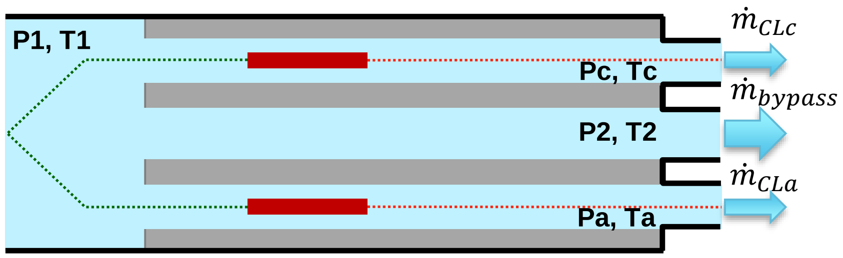
- ➔ EM issues identified

- Proposed new layout to be confirmed
  - DFHx1 : 2 x 18kA + 2 x 13kA + 3 x 7kA
  - DFHx2 : 12 x 2kA
  - **Do we go ahead with this layout for the DFH design ?**



3. Splices forced cooling principle indico786623

- 2 discussed designs
  - Splice in series with associated current lead + parallel bypass for transient and non nominal operation



Do we go ahead with this concept ?

  - Pros:
    - Abnormal splices needs **<<** CL mass flow
    - Mass flow around splice independent from local pressure drop
    - Big bypass for transients and control
  - Cons:
    - ↗ bypass flow does not increase splice flow (only inlet temperature)
    - If splices needs more than CL flow ➔ CL may be overcooled (very high margin though)

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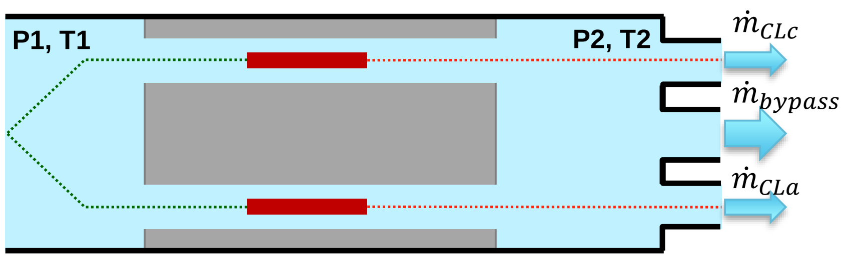
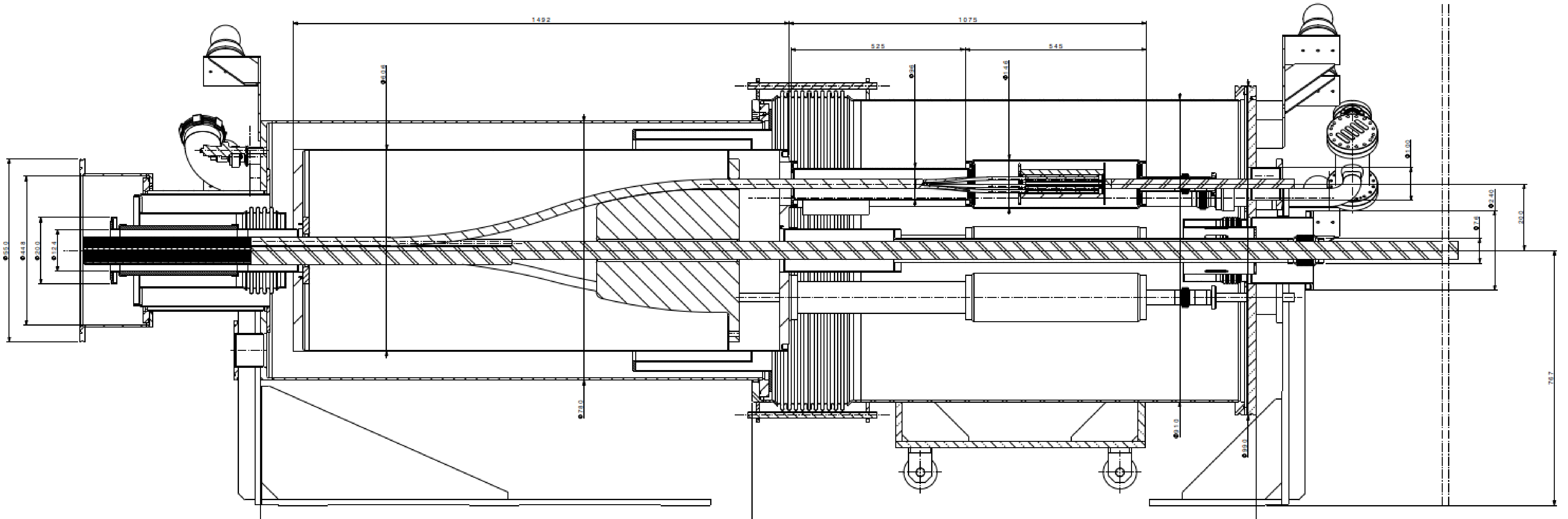
  - Splices in parallel circuits with same upstream & downstream pressures



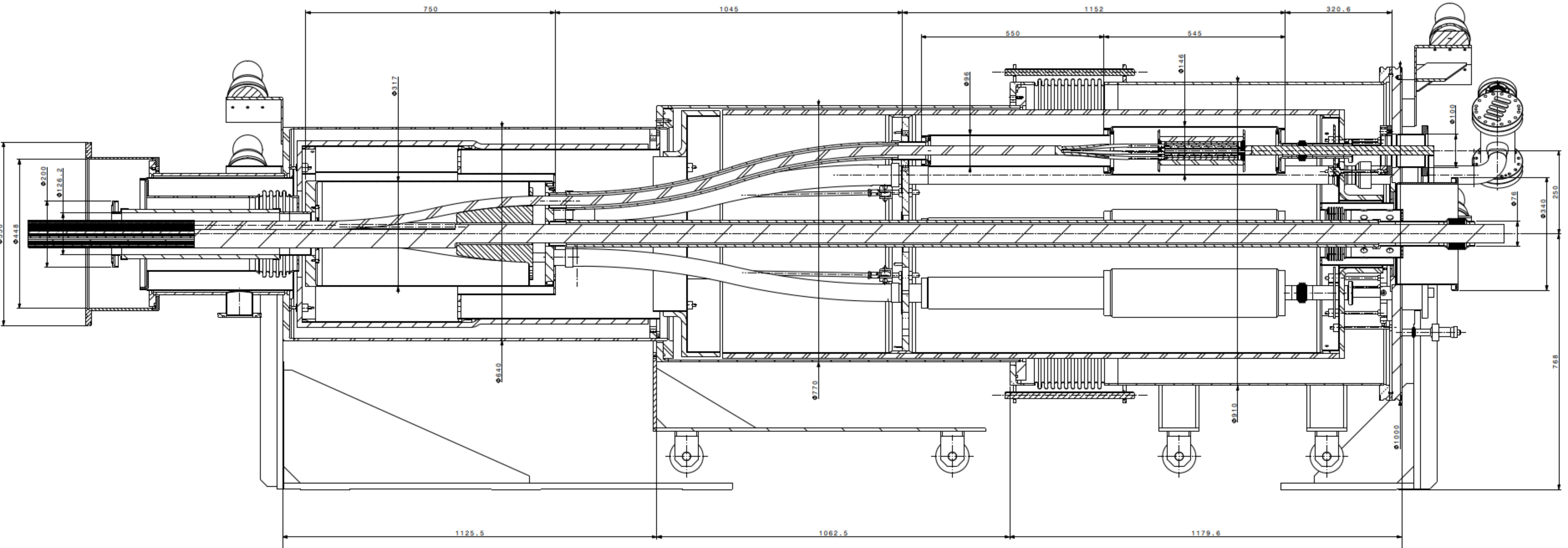
  - Pros:
    - CL flows independent from splices needs
    - ↗ Recovery line flow ➔ ↗ T_{inlet} + flow around splices (limited effect though)
  - Cons:
    - Difficult to ensure equal parallel flows
    - Limited margin to increase splice flow
    - Small flowing sections around splices may limit transient and abnormal high total flows

Spare slides

Design MgB2 prepared in UR



Design MgB2 prepared in SM18

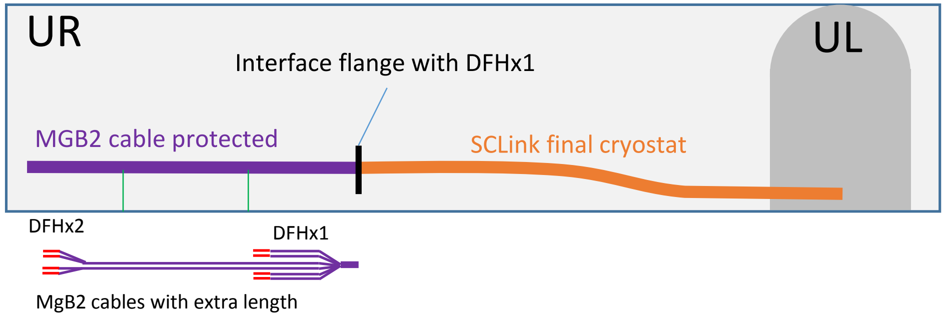


Sequence proposal

Environment : no racks installed

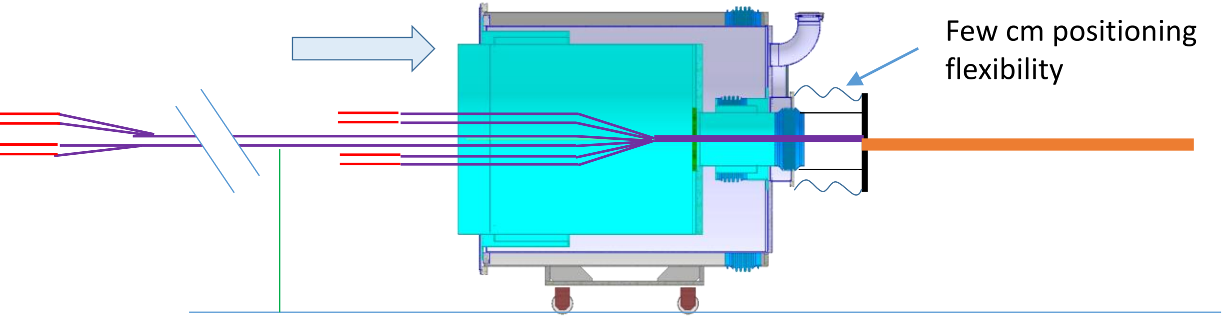
1. SCLink cables ends on supports

SCLink is pre-assembled before all other components. Fixed in position on DFX side. Interface with DFHx1 located within cm. The cable bundle is reduced to minimum diameter for transport purposes.



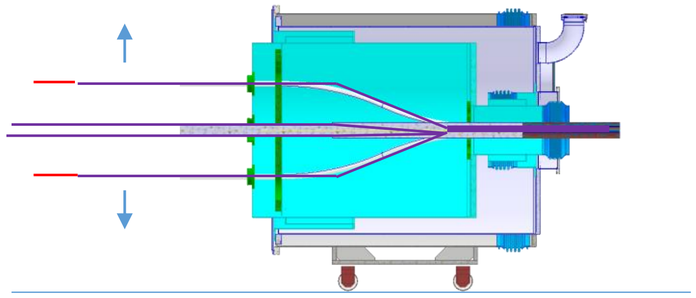
2. Insertion module 1: VV1+HeV1

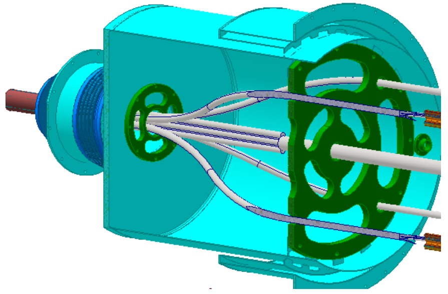
The DFHx1 module is "rolled" around the SCLink cable all the way from DFHx2.



3. Matching lead with Current lead radial positions (opening of cables bundle)

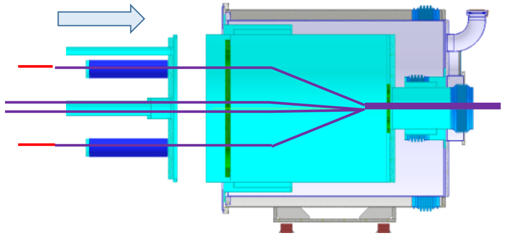
The MgB2 cables are internally routed and fixed in radial position in the DFHx1 to match the current leads interfaces. (+ installation instrumentation)





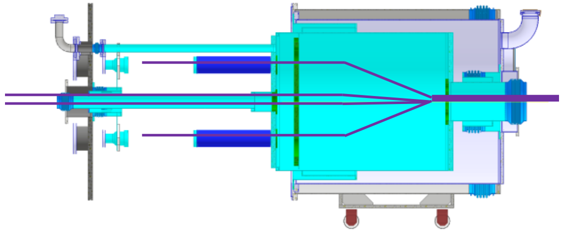
4. Insertion module 2 (sleeves opened)

Once cables are radially positioned, the internal helium vessel is closed with MgB2 extra length going out in individual tubes (to ease access to individual splice, ease welding, perform clean splice, increase & individualise turbulent flow locally at splice level).



5. Installation interfaces with current leads

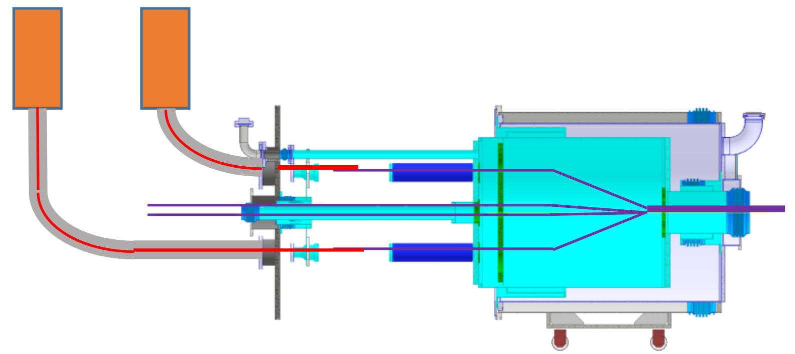
Installation of interface with DFHx2 and interface flange with current leads.



Sequence proposal

6. Assembly current leads

Racks and current leads are installed around the DFHx1. flexible ends of current leads are connected to DFHx1 interface flange.

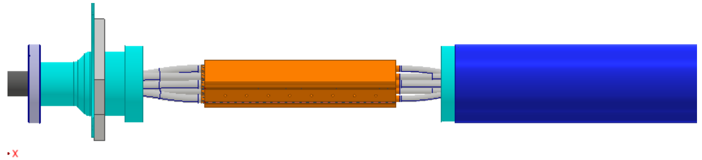


7. Adjust MgB2 leads to length

HTS end lengths of current leads are fixed, in order to face few cm positioning of the SCLink in the tunnel + solder on “fresh unsoldered MgB2 + to optimise the splice performance, it is suggested to cut the extra length of MgB2 at this stage.

8. Splice

Splices are independent (for DFHx1 18kA and 13 kA leads). Other splices can be independently protected when working around.
Installation of V-taps

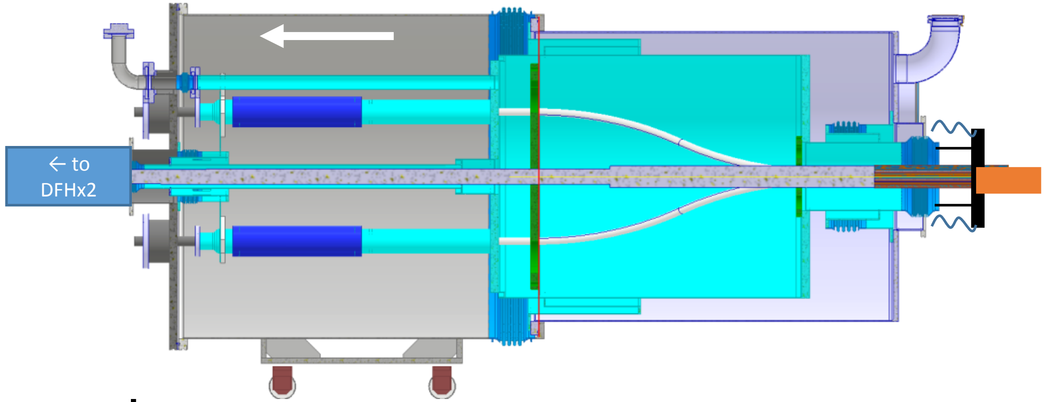


9. Close sleeves

It is suggested to use standard interconnection sleeves with standard tooling for cutting and welding.

10. Close vacuum vessel

The vacuum vessel is a sleeve itself closed with standard elastomer O-rings (LHC type connection).



11. Transient phase

The insulation vacuum is common with current leads and SCLink. Pumps and relief plates are assembled on module1.

During cool down, the internal helium vessel is fixed in the middle, splices are longitudinally fixed relatively to the helium vessels.

Thermal contraction of the cable is covered form the entry in the DFHx1. The helium vessels contractions is covered on SCLink side by bellows, on current leads side by current leads internal bellows.

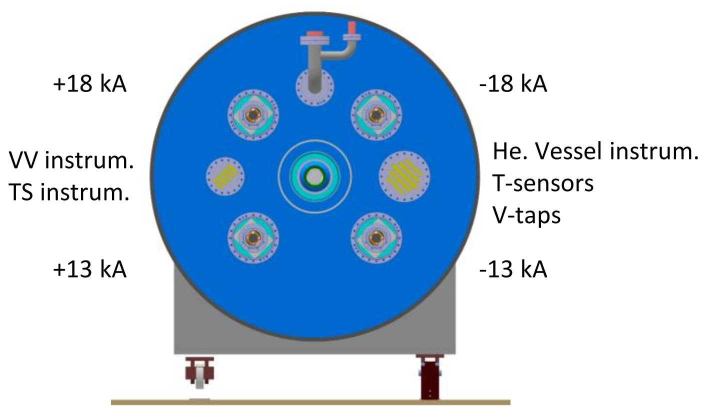
The geometry allow to individually control each mass flow around splices.

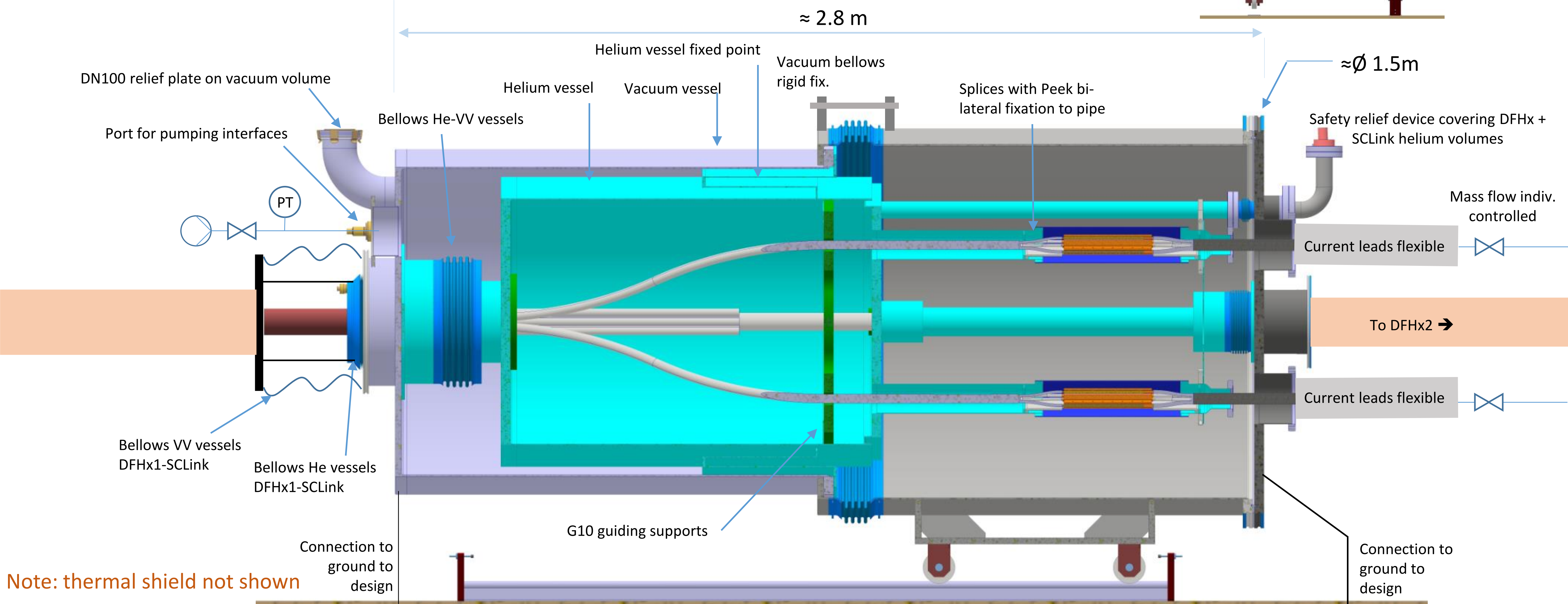
Sequence proposal

Operation:

A gaseous helium mass flow up to 10 g.s-1 enters the DFHx. The flow is separated for allowing individual splice, current leads cooling.

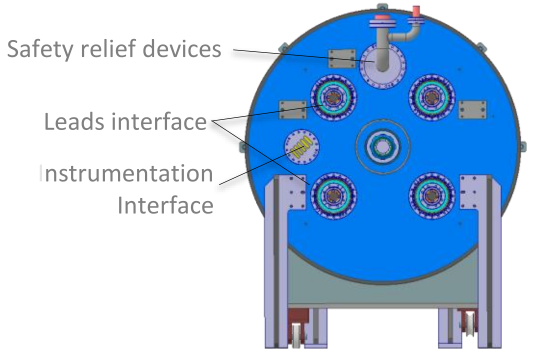
Leads are routed and fixed inside the helium vessel and longitudinally fixed at the splice level.





Note: thermal shield not shown

DFHx design proposal



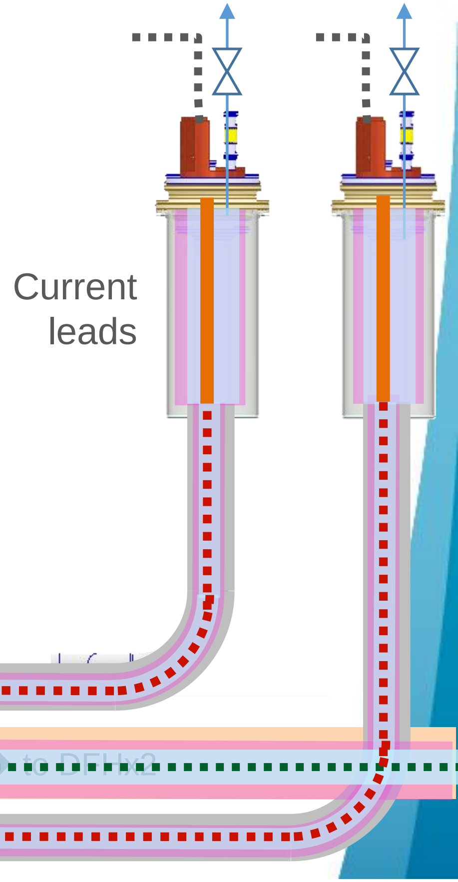
Integration & interfaces layout
- DFH in series between SCLink and current leads
- Envelope: ≈Ø1.5m x 4m on rails

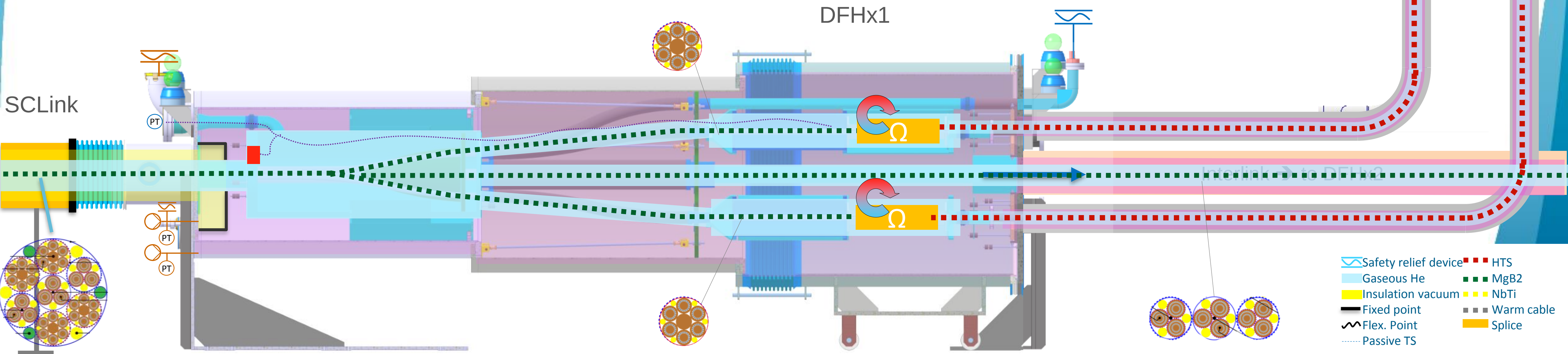
Electrical layout
- MgB2 – HTS – Current leads

Cryogenic layout
- 1 common helium volume
- Heat extracted through convective heat transfer

Insulation Vacuum layout
- Vacuum barrier at SCLink-DFHx interface

Mechanical layout
- Splices fixed to helium vessel
- Flexible structures for thermal contractions and installation

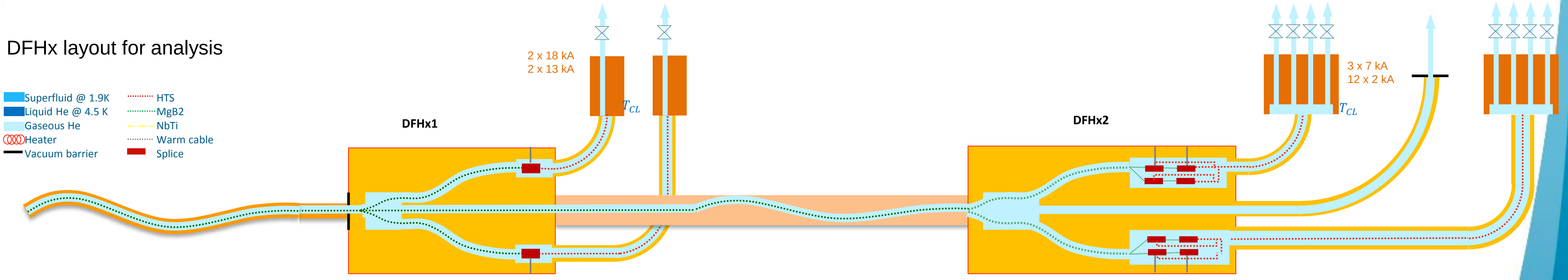




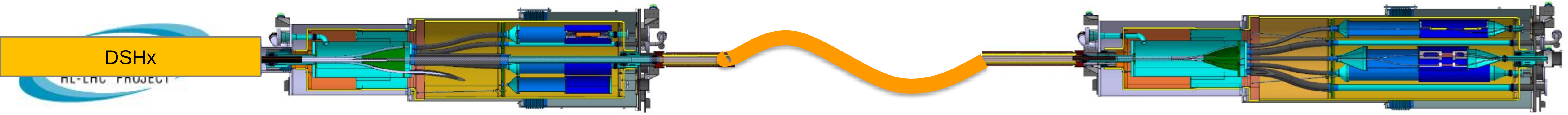
Proposed conceptual installed configuration

- Guidelines for the assembly:
  - MgB2 cable protected at all times
  - MgB2-HTS splices fixed to He vessel
  - Orientate angularly the MgB2 leads to the corresponding HTS leads

DFHx layout for analysis

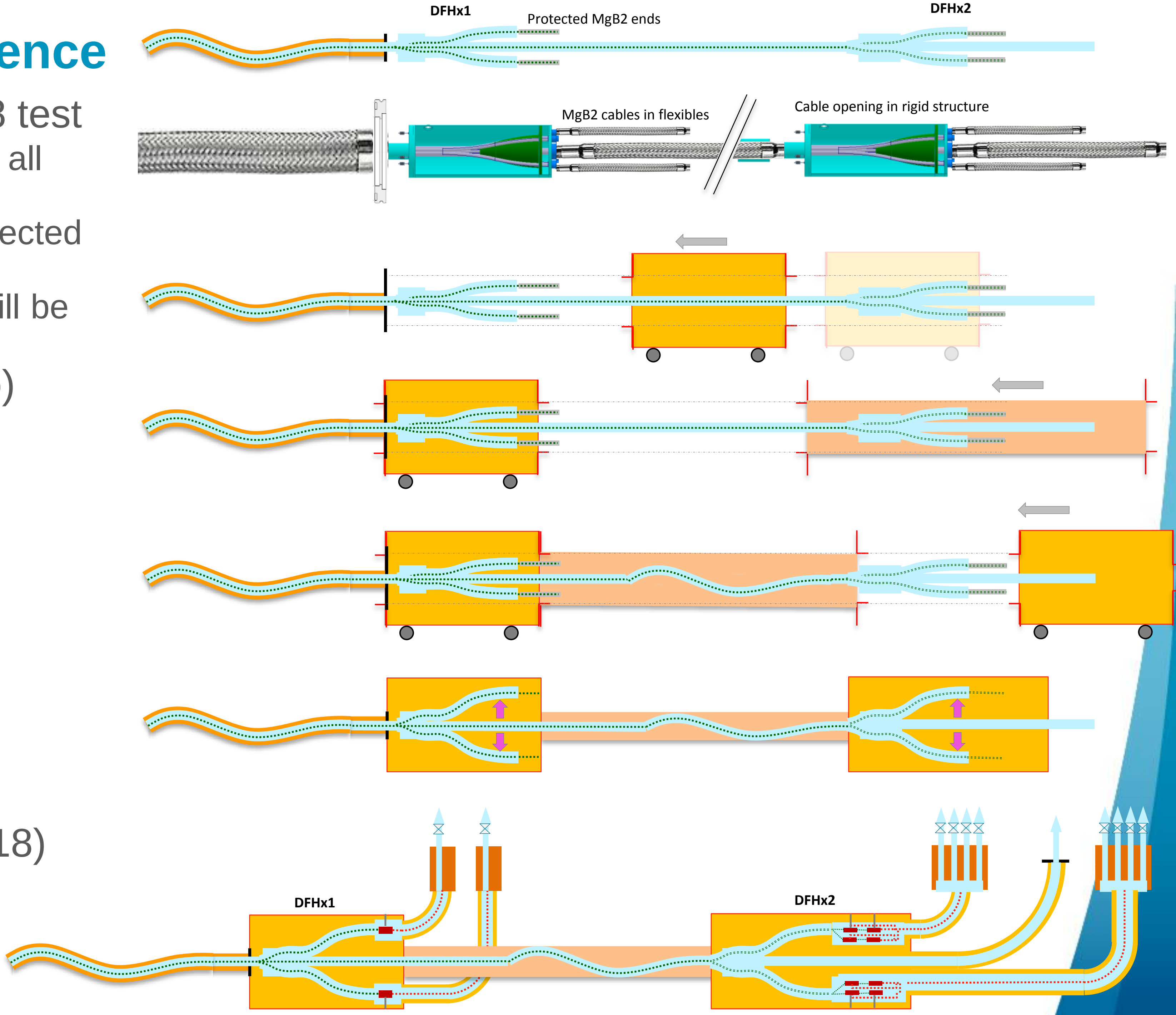


DFHx 3D pre-design for illustration

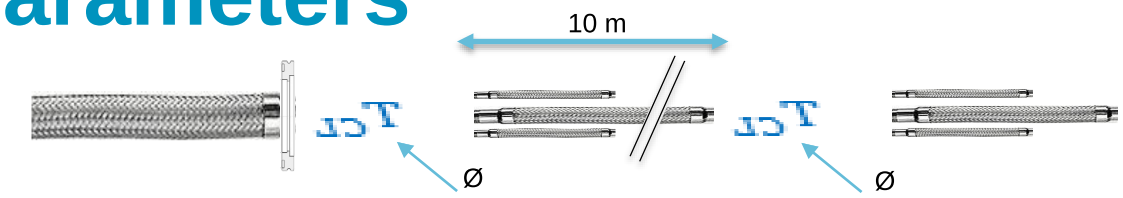


Proposal installation sequence

- SCLink end preparation for SM18 test
  - He vessels pre-mounted once for all before SM18 test
  - Only MGB2 ends (temporary protected are visible)
  - Only final welds around splices will be further performed
- SM18 test installation (DFH proto)
  - 90% of He vessels are done
  - Insertion DFHx1 VV
  - Insertion of Interlink
  - Insertion of DFHx2
  - Opening of flexibles **+ angular orientation**
  - Splicing + Current leads
- Transport configuration
  - Procedure backward
  - 2 x 1m rigid section
- SCLink installation (same as SM18)

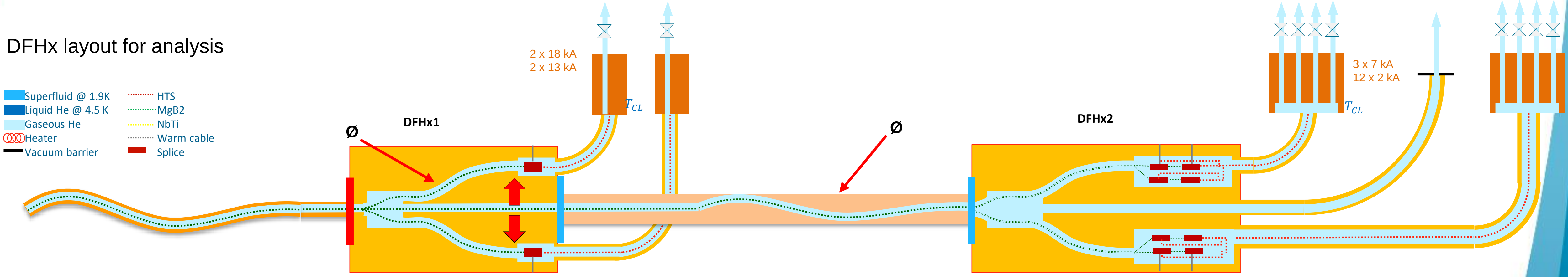


Key influencing parameters

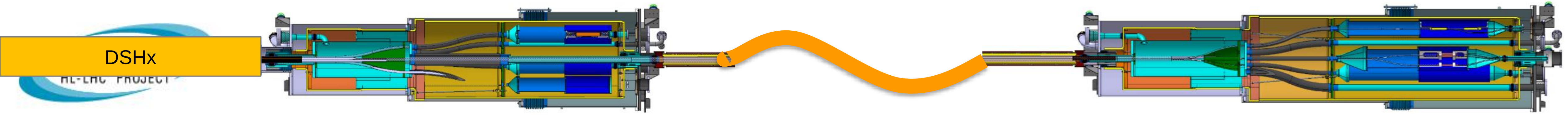


- The pre-opening of the MgB2 cables directly influences:
  - The rigid boxes 10m distant to be installed in the turret for transport
  - The SCLink vacuum jacket interface flange diameter
  - The openings in the vacuum vessels
    - ➔ increase radial distance to splices ➔ length of DFH due to bending radius of MgB2
  - The interlink vacuum jacket ID (could use it for waving only inner pipe)
- Today orders of magnitudes:
  - DFHx length ≈ 4m (bending radius 1.5m)
  - DFHx Vacuum vessels OD ≈ up to 1.5m
  - Interlink OD ≈ 400mm

DFHx layout for analysis



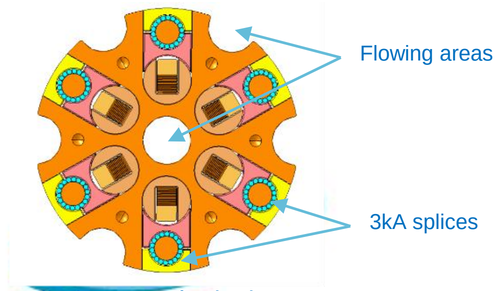
DFHx 3D pre-design for illustration



Needs to cool/maintain a 18kA-splice temperature within spec.

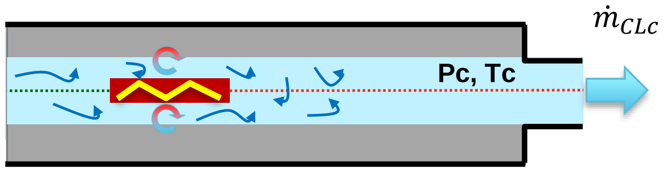
- Exercise with (very) preliminary design of 18kA splice
- Various configurations:
  - 3 gas temperatures: 10, 15 & 20 K
  - 4 splice resistances :
    - R_{3kA}=10, 25, 50 & 100 nΩ
    - Corresponds to
    - R_{18kA}=1.5, 4.2, 8.3, 16.7 nΩ
  - Constants : I=18 kA, P=1.1 bara

- Observations:
  - The helium gas temperature has limited influence on the ΔT between gas and splice surface
  - ➔ T_{GHE} has direct influence on T_{splice}
  - **For low $\dot{m}_{CL}$, high T_{GHE} and very high R_{18kA} , the splice temperature remains below 25K.**
  - **➔ The splice will very most likely never need higher mass flow than current leads**
  - **= the current lead mass flow is limited to CL needs**
    (for HTS flexible < 15m)



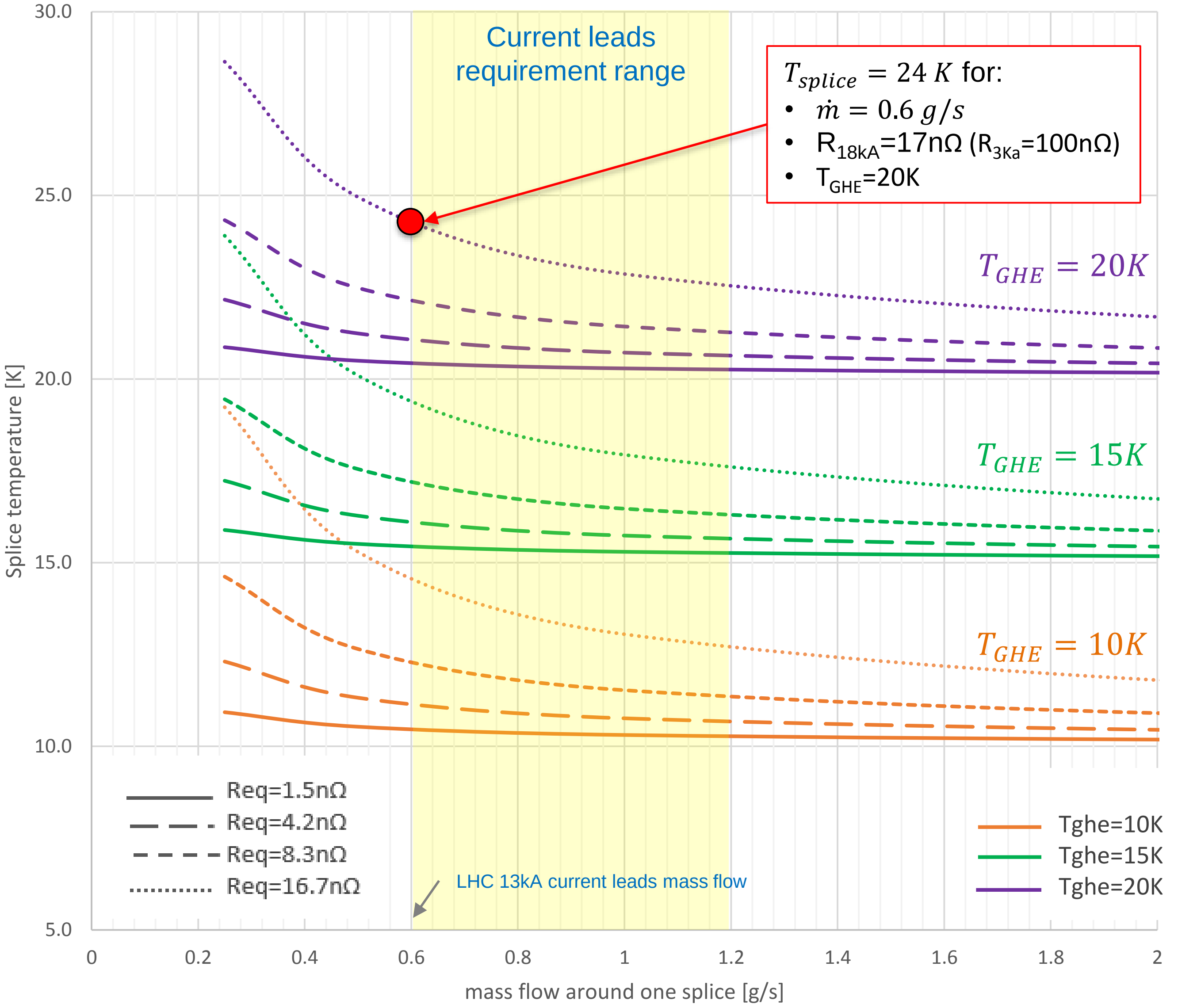
Preliminary early design MgB2-HTS

SPLICE PROPERTIES	Unit	Value
Splice length	[mm]	220
Flowing area Equivalent diameter	[-] [mm]	6 x ½ DN10 + central DN10 DN20
Deq	[mm]	20
Heat transfer area	[mm²]	27600
Dissipated power - Current - 3kA Resistance	[W] [kA] [nΩ]	From 0 to 5 W 6 X 3 From 10 to 100

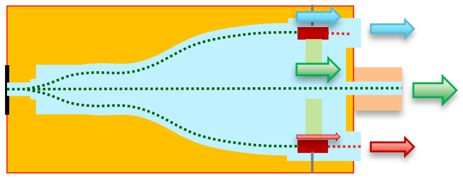


Note: $T_{bottom\ CL}$ increases by 0.5 K @ 0.5g/s mass flow per meter of HTS flexible length
Ex: $L_{flexible\ HTS}$= 5 m, $\dot{m}_{CL} = 0.5\ g/s$
➔ $T_{bottom\ CL}$ =T_c+3 K

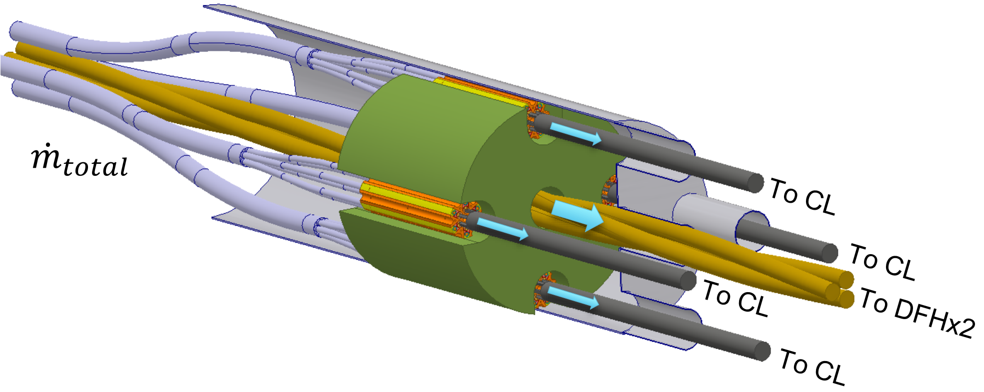
Splice temperature for various gaseous temperatures and splice resistances

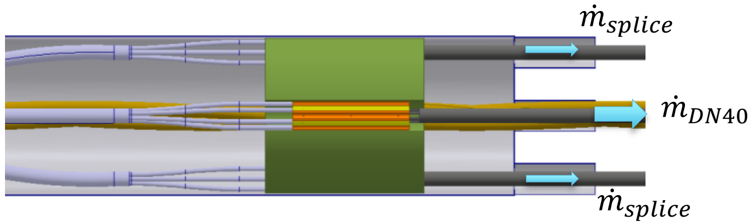


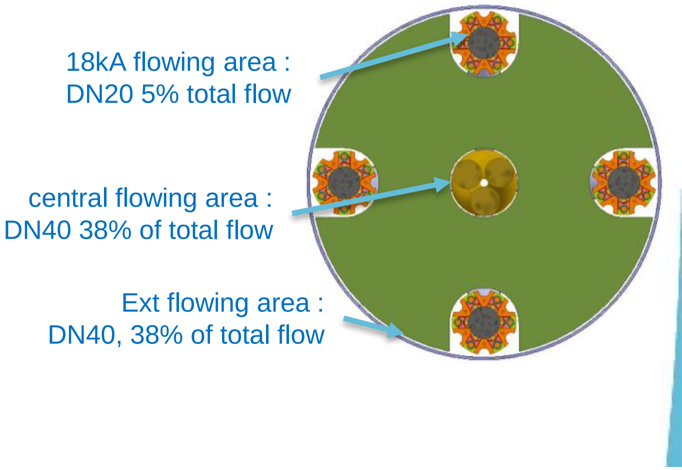
Hydraulic studies for parallel flow options



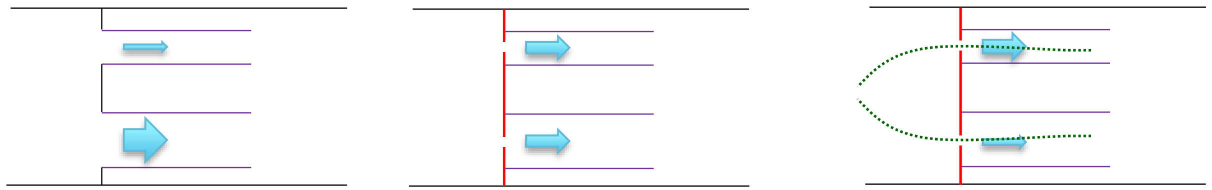
- Exercise with DFHx1 and 18kA splice preliminary design: 4 x 18kA splice + 1 path for DFHx2 leads

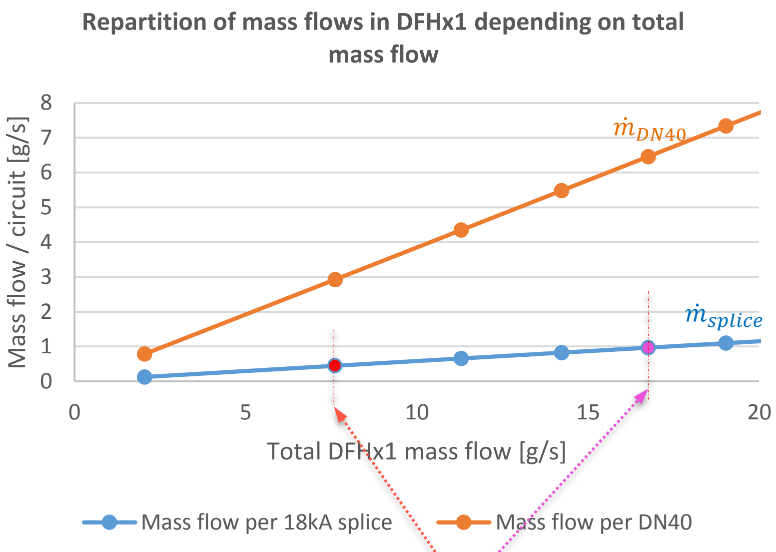






- Observations:
  - Most of the flow goes to the biggest Deq circuit
    - ≈20% to the 4 splices (5% each) , ≈80% to central outer circuits
  - ➔ Install upstream orifices for similar parallel mass flows (common practice)
    - Order of magnitude : Ø10 mm ➔ **Integration of upstream orifices unreliable around MgB2 cables** (various Ø, Kapton, solder geometry)





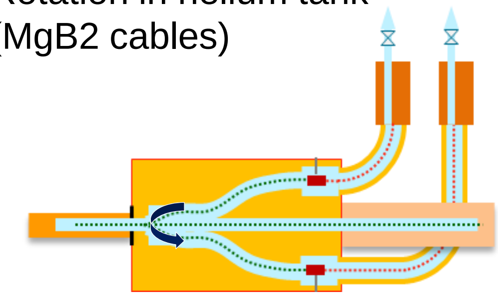
0.5 g/s around one splice ➔ **total 7 g/s**
1.0 g/s around one splice ➔ **total 17 g/s**

- **What if:**
  - **➔ A limited diffirence between parallel circuits implies high mass flows unbalance** (higher R, Kapton, solder)
    - One splice sub-hole is blocked ➔ Atr reduced by 15% ➔ Q reduced by 15%: Non critical
    - One splice is warmer ➔ ΔP increase ➔ local mass flow decreases further
    - One splice needs twice more heat extraction ➔ total mass flow +150%
    - Support and flowing areas obstructions not perfect ➔ mis balance between hydraulic parallel circuits

Starting data :
- Bending radius : 1000 mm
- Interlink diameter : 250 mm
- MgB2 opening in surface

How to match angularly MgB2 and HTS cables ?

Rotation in helium tank (MgB2 cables)



+500 mm length or +200 mm diameter for
Helium tank
DFH
MgB2 cables (+500 mm length in any case)

- Need to close Helium tank in UR
- In DFHx1, manipulation problem for other cables (depend of layout)
- Only very local guide for cables
- How to be sure to not rotate the cable in the link ?
- MgB2 manipulation in situ
- Complicated manipulation due to bad access

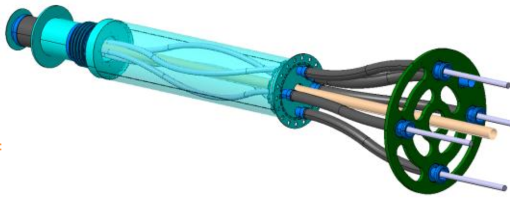


Illustration – rotation 0°

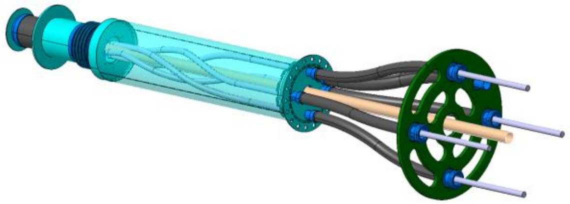
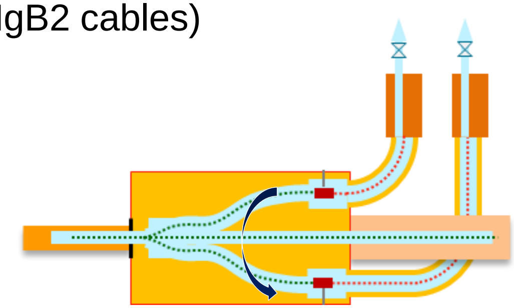


Illustration – rotation 180°

Rotation with internal flexibles (MgB2 cables)



+1000 mm length for
DFH
MgB2 cables

- Instrumentation and safety flexible will be also rotated
- Cables are protected during rotation

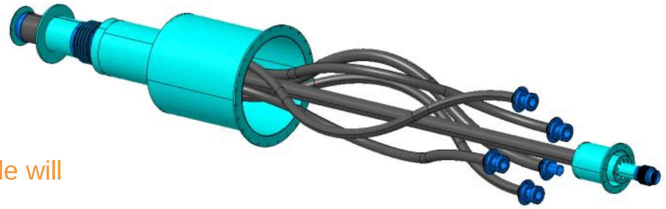


Illustration – rotation 0°

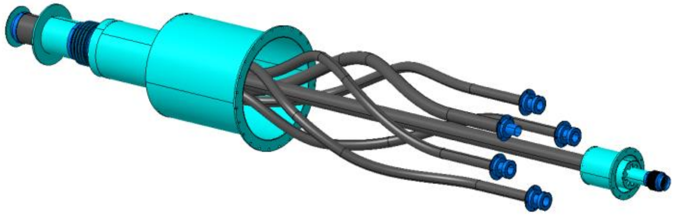
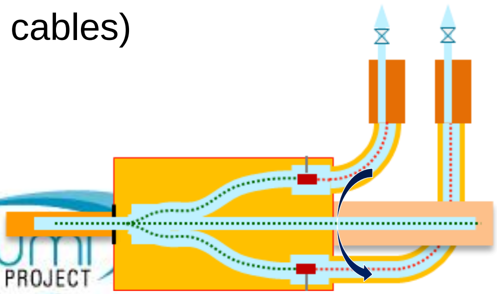


Illustration – rotation 180°

Rotation with external flexibles (HTS cables)



+ 4000 mm length for
HTS cables

- No impact on DFH enclosure
- Need to have a rotatable output flange
- Cables are protected during rotation
- Possible impact on integration

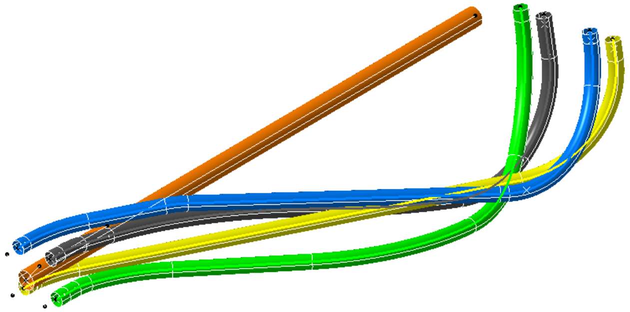
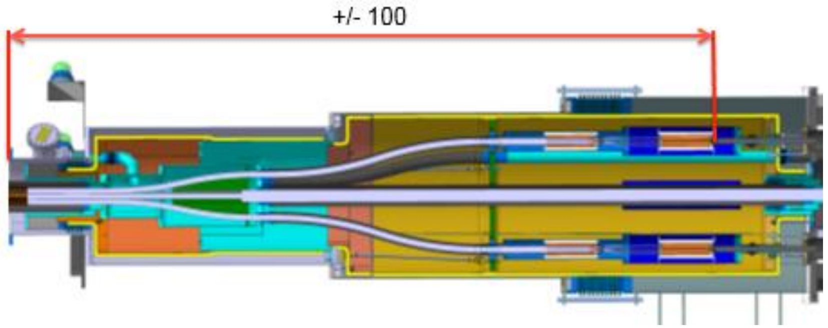


Illustration – rotation 180°

Main points to be confirmed to develop final design

Points to be confirmed	Priority	Needs	Chosen data	Consequences
Leads distribution output	**1**	Chosen layout		Start new 3D design
Splices cool-down	**2**	Chosen solution (individual or parallel cooling)		DFH enclosure MgB2 cable manipulation Angular matching between MgB2 and HTS
Bend radii in DFH	**3**	Radius for each cable (MgB2, HTS, 18, 7 and 2kA)	R=1000 for single 18kA HTS and MgB2 R=500 for single 7, 2kA HTS and MgB2	DFH enclosure Angular matching between MgB2 and HTS MgB2 cable manipulation
MgB2 cable manipulation	**4**	Opening in UR or SM18 ?	In SM18	For R=1000, DFH length + 1000 mm (wrt to UR solution) Angular matching between MgB2 and HTS Spool compatibility
		Tolerance of MgB2 installation position	 Tolerance : +/- 100 mm	DFH length + 200 mm HTS length + 200 mm
Angular matching between MgB2 and HTS	**5**	Location of matching	Matching thanks internal flexibles (MgB2 cables)	For R=1000, DFH length + 1000 mm (wrt to UR solution) Angular matching between MgB2 and HTS Spool compatibility
			Matching thanks external flexibles (HTS cables)	For R=1000, HTS length + 4000 mm DFH output flange rotatable