HL-LHC WP6a and HL-LHC-UK WP4 DFX DESIGN CONCEPT DISCUSSION

SOTON: Wendell Bailey and Yifeng Yang

Supported by Yann Leclercq, Iole Falorio, and Vittorio Parma

Contents

1. April Proposal
2. Tightening the overall design considerations/specifications for convergence with CERN
    - SC-Link handling in LHC tunnel and DFX
    - Liquid helium vessel for splice cooling and vapour generation/flow
    - Cryogenic schemes
3. Details of mechanical scheme in the DFX
4. Mechanical support and management of thermal contraction and pressure forces
5. Heater insertion

HL-LHC WP6a / HL-LHC-UK WP4
DFX Prototype Plan

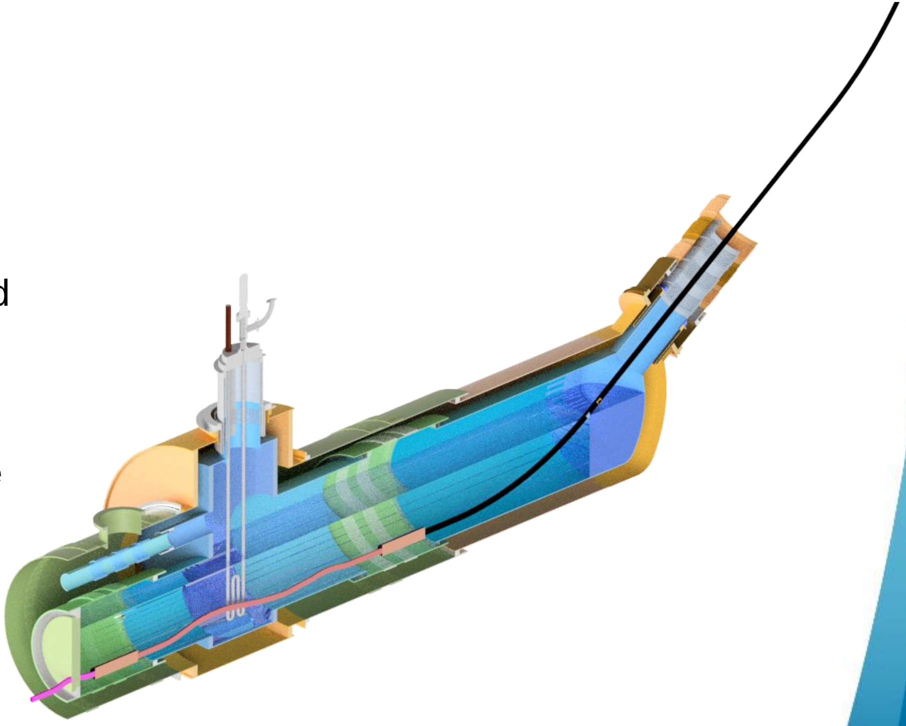
- Design, build and qualification of DFX prototype: A core activity of Task 4.2
- DFX Prototype Schedule

Function specifications	Dec 2017
Design concept (M4.3) for discussion	Mar 2018
Review of DFX prototype concept	May-Jun 2018
Finalised design concept (D4.3)	Jun 2018
Mechanical drawings (D4.4)	Aug/Sept 2018
DFX design review	Sept-Oct 2018
Component procurement (M4.6)	Nov 2018
DFX Assembly	Jun-Jul 2019
DFX qualification test and shipping (D4.6)	Oct-Nov 2019

DFX Prototype Design Concept Proposal: Apr 2018

DFX Concept

- Consists of 4 sections
- A centre hub for interfaces
- LTS/LTS splice section on the right
- SC-Link/LTS splice section on the left
- Transition section for top **angled** entry
- Recoverable splice sections for installation and maintainability
- Can be realised with a overall length of 3.5m and 0.7m OD with SC-Link/LTS splice cold-mass of nominal od of 0.25m
- **Scopes for significant length reduction**
- **Reduction of OD possible, depending on LHe level control**

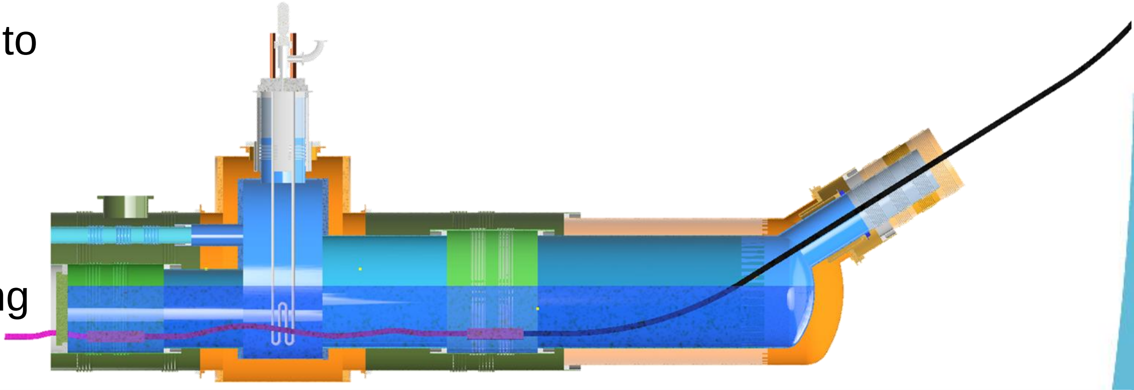


DFX Prototype Design Concept Proposal: Apr 2018

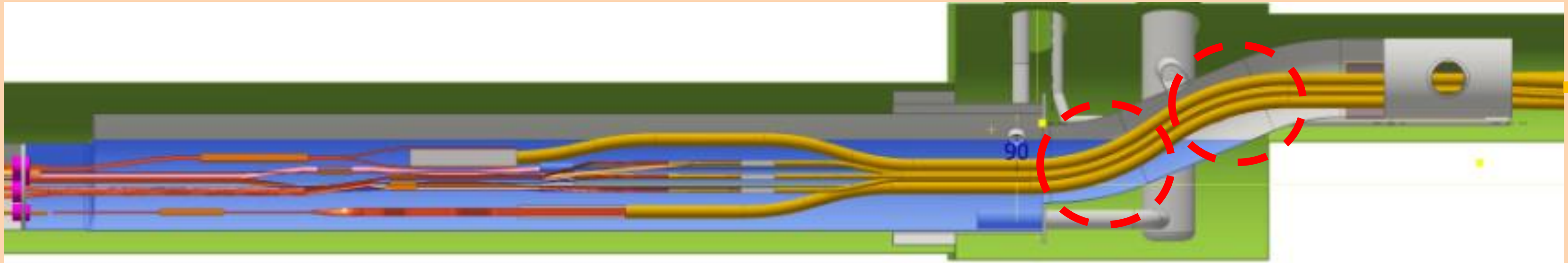
SC-Link Entry to DFX

Top Angled Entry

- Direct and continuous flow of GHe into SC-Link cryostat
- 90º bend in total
- No plug between GHe and SC-Link cryostat
- Overall DFX length of ~3.5m including a “transition” section <1.5m and a “naked” SC-Link section in FDX.



Bottom entry discounted but is it possible to have a top **horizontal** entry?



DFX Prototype Design Concept Proposal: Apr 2018

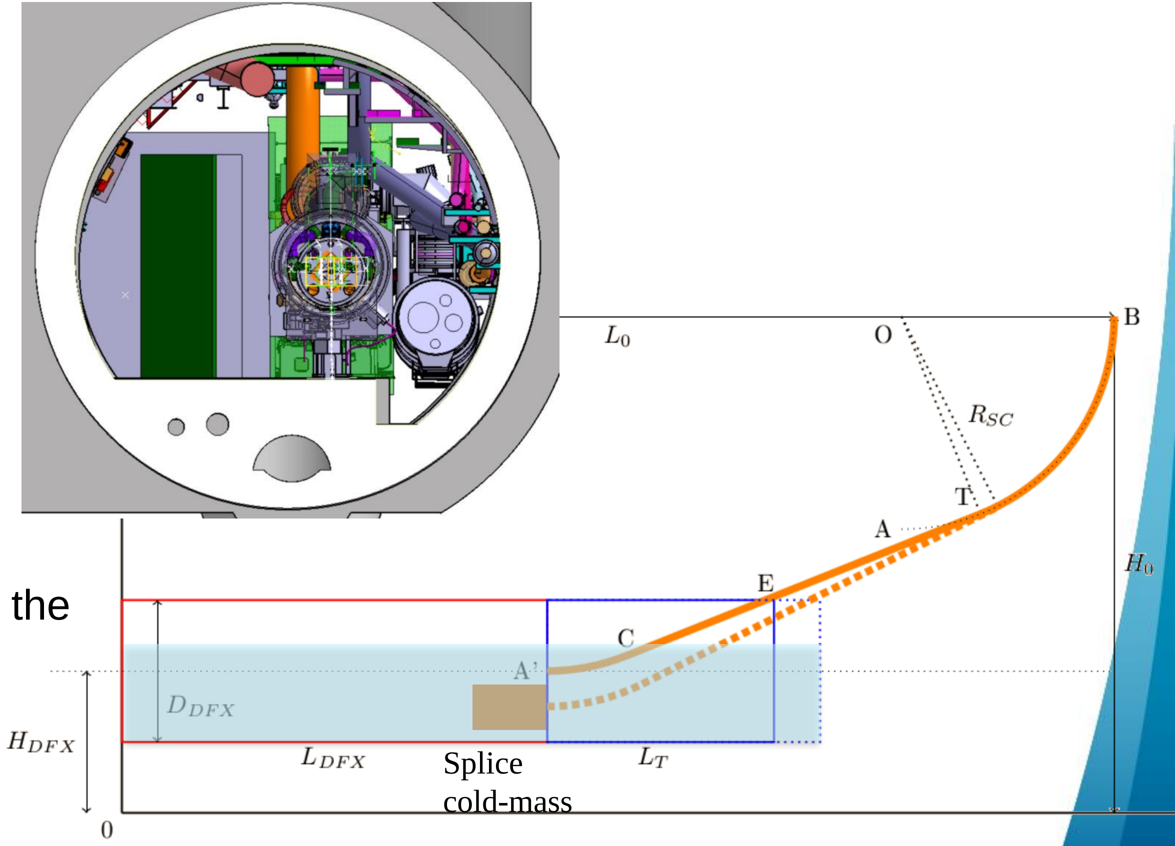
Top Angled Entry

<u>Geometry and constraints:</u>

- SC-Link bending radius
- DFX vertical location and OD relative to tunnel height
- Splice cold-mass diameter
- LHe level

<u>Advantages:</u>

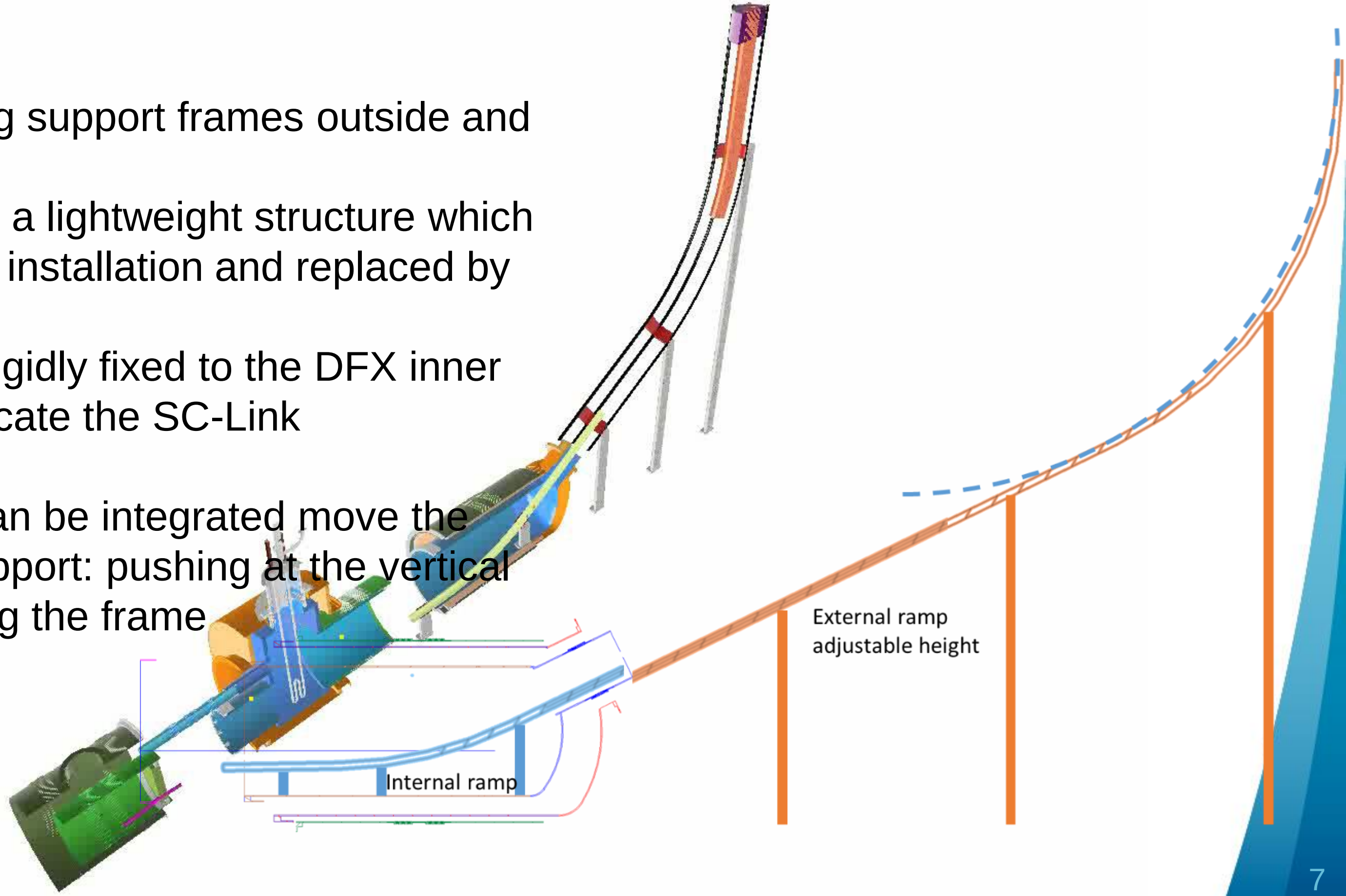
- 90º bend only without changing the sign of curvature
- Continuous GHe space into SC-Link



DFX Prototype Design Concept Proposal: Apr 2018

SC-Link Deployment

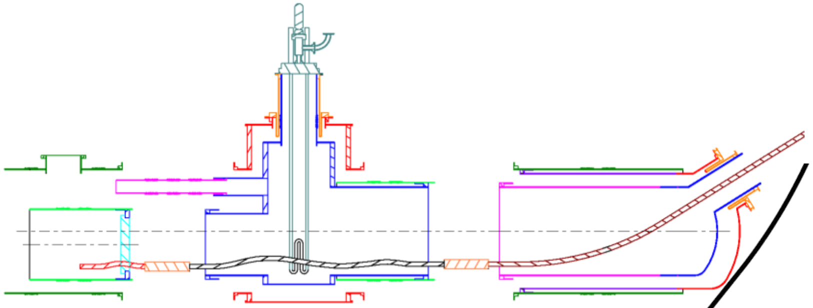
- Guided insertion using support frames outside and inside the DFX
- Outside frame can be a lightweight structure which can be removed after installation and replaced by suspending strings
- Inside frame can be rigidly fixed to the DFX inner vessel and used to locate the SC-Link mechanically
- A drive mechanism can be integrated move the SC-Link along the support: pushing at the vertical entry and pulling along the frame

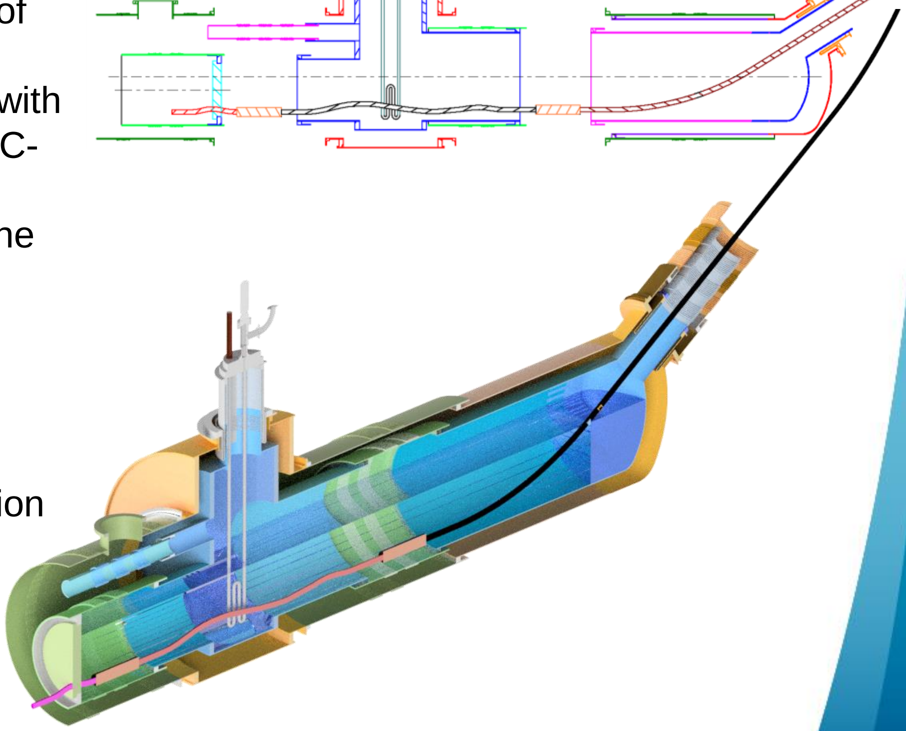


DFX Prototype Design Concept Proposal: Apr 2018

Key design consideration and features:

- Allowing SC-Link deployment with smooth cable insertion without breaching the minimum bending radius. Full mechanical support and accessibility of SC-Link during deployment
- Simplified control of helium gas (GHe) from DFX with a continuous helium vapour space from DFX to SC-Link cryostat
- Maximized liquid helium (LHe) depth for cooling the SC-Link/LTS splices while maintaining a compact overall dimension.
- Recoverable windows for LTS/LTS splicing *in situ* and maintenance of SC-Link/LTS splices
- A centre hub for mechanical underpinning, for interface integration, and for modular transportation and assembly





Towards Finalizing the Concept

Intense iterations took place since April in close collaboration with CERN colleagues

To address the questions/doubts about the initial proposal, concerning the rationale, practicality, necessity, naivety and ignorance of SOTON as an external partner

To tighten the design considerations/specifications for key aspects such as SC-Link handling, LHC tunnel constraints, interfaces, and mechanical implementations

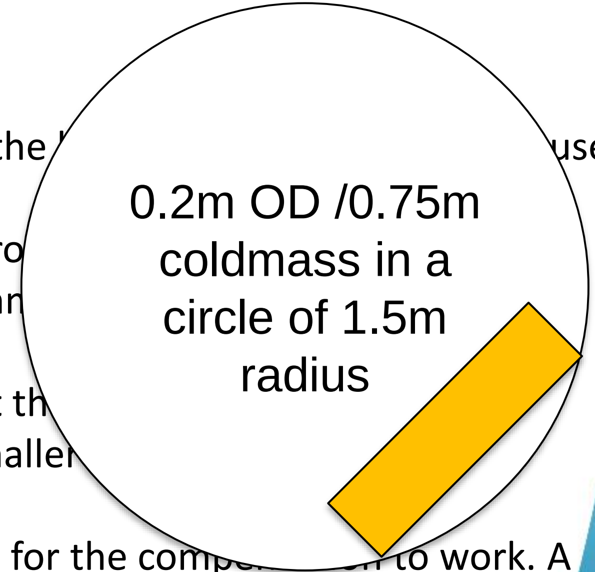
To examine the initial proposal against the tightened specifications and consider alterantives

Tightening the Design Specifications
SC-Link Cable Considerations

1. *SC-Link deployment and constraints in LHC tunnel*
    - A 90 degree bend of SC-Link is required at 1.5m bending radius
        - Vertical entry of SC-Link from UL shaft to LHC tunnel
        - Horizontal entry of LTS to D1 through plugs
    - A 1.8m vertical drop between SC-Link entry and DFX horizontal centreline to D1
    - A 7m horizontal space between SC-Link Entry to DFX to D1
    - Mechanical support for guiding the SC-Link deployment and bending in LHC tunnel
2. *SC-Link cables in DFX*
    - A vertical displacement of 300mm within DFX
        - Continuous helium vapour space from DFX to flexible cryostat
        - Sufficient margin for liquid level control
    - Allow insertion of SC-Link *in situ* and guide the bending for the height change
    - Mechanical support for guiding the SC-Link deployment and bending in DFX

Tightening the Design Specifications
SC-Link Cable Considerations

3. *Special handing for the rigid SC-Link/HTS splice section*
    - Additional space required to avoid pinching upon bending at the interface between the rigid slice coldmass and the SC-Link
    - Possible solutions
4. *Management of cable thermal contraction by DFX*
    - Compensation by DFX is unlikely to be effective/necessary for the l ... use of the accumulation of frictions and snaking in bends
    - Thus maximum compensation is for the *absolute* contraction fro ... practice at <25mm: ~18mm from 5m long copper at 0.35%, 5mn ... 0.25%.
    - The contraction will be managed by "softer" bellow sections at th ... same/similar diameters of the flexible cryostat, significantly smalle ... hence manageable for pressure conditions.
    - The SC-Link should be rigidly fixed outside the "softer" bellows for the compe... to work. A sliding section is used to allow mechanical linking after the deployment in the DFX. The gripping force is determined by the mechanical properties of the SC-Link and corresponding friction sets the elastic constant required for the bellow. (sketch in mechanical schemes)



Tightening the Design Specifications

DFX Geometry and LHC Tunnel Constraints

Main characteristics

- Modular sections for in-tunnel installation and transportation
- A hub section for structure underpinning, co-location of interfaces, and insertion/retrieval of heaters and instrumentations.
- Minimized/optimal dimensions to comply with LHC tunnel constraints and helium gas/liquid for cooling
- Inner vessel of 300mm ID between the plug and the coldmass section
  Entry section of about 500 – 600 mm OD
- An overall length less than 5.5m to comply with the length constraint of 7m between D1 and the vertical shaft

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Tightening the Design Specifications

Internal Helium Vessel

Geometry to fulfil cable bundle and splices requirements (liquid level, vapour generation)

- Liquid level below the entry point and above the top of the spliced cold mass (0 - 150 mm maximum)
- Vapour generated by heater inserted from the Hub (with reversible insertion).

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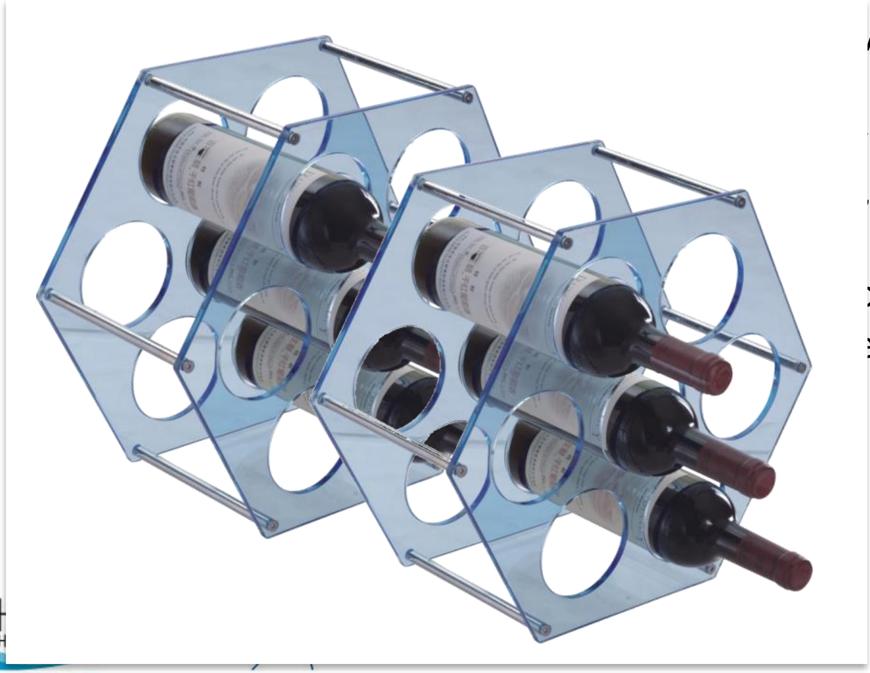

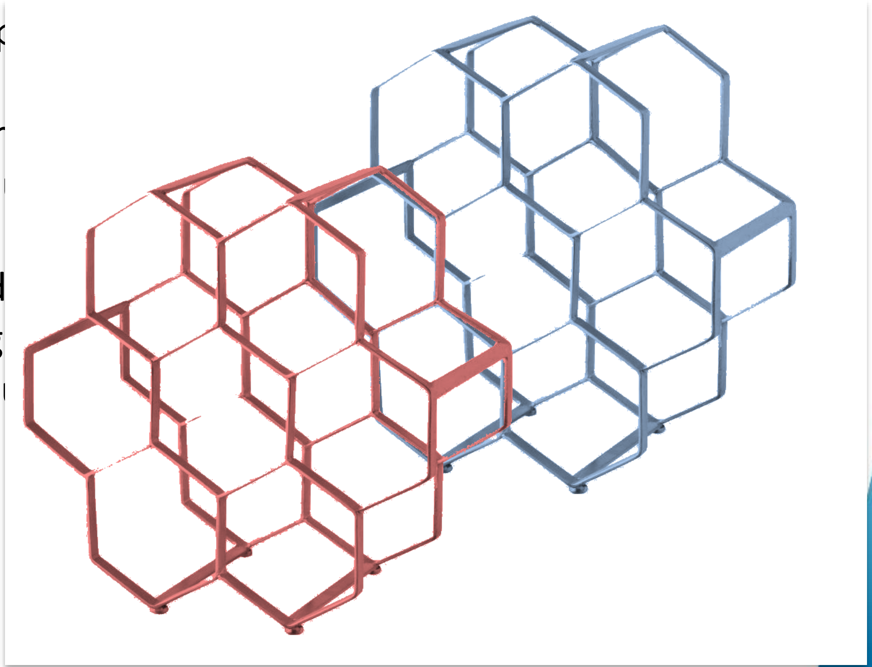

Tightening the Design Specifications
Cryogenic Schemes

- A thermal shield conductive cooled with 30 layers MLI will be installed in the DFX. A conductive cooled path could be provided to the mechanical supports too.
- The cooling source for the shield is undefined. Line D is ruled out due to lack of warm return in LHC tunnel
  - The heat load budget for the power to the 4.5K is only constrained by the condensation limitation on the 300K surfaces of the vacuum vessel. A static heat load up to 20W can be accepted
  - Possible tagging on the thermal shield of D1
- Level control = CERN standard method, tuned control margins to avoid exceeding the minimum and maximum level. CERN will also supply all gauges.
- Venting and system operation: excess vapour vent from the cold return line, heater controlled by the temperatures of GHe at exit and SC-Link splice temperature in DFH
- Over pressure vent for liquid vessel from the centre hub

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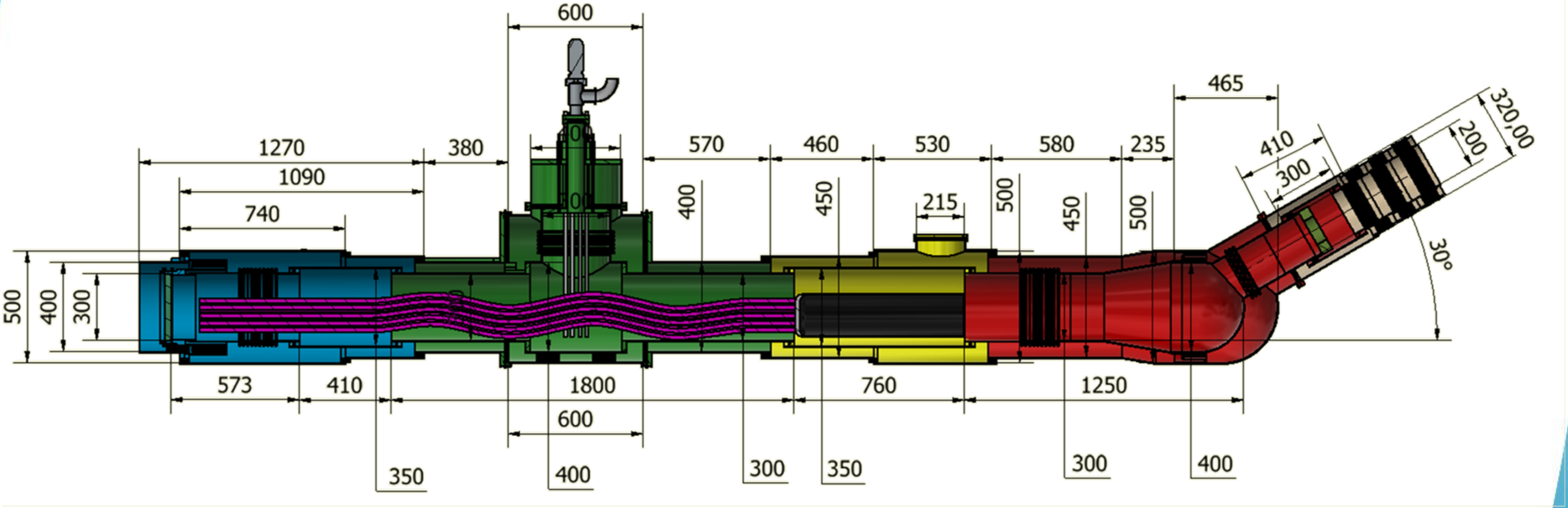
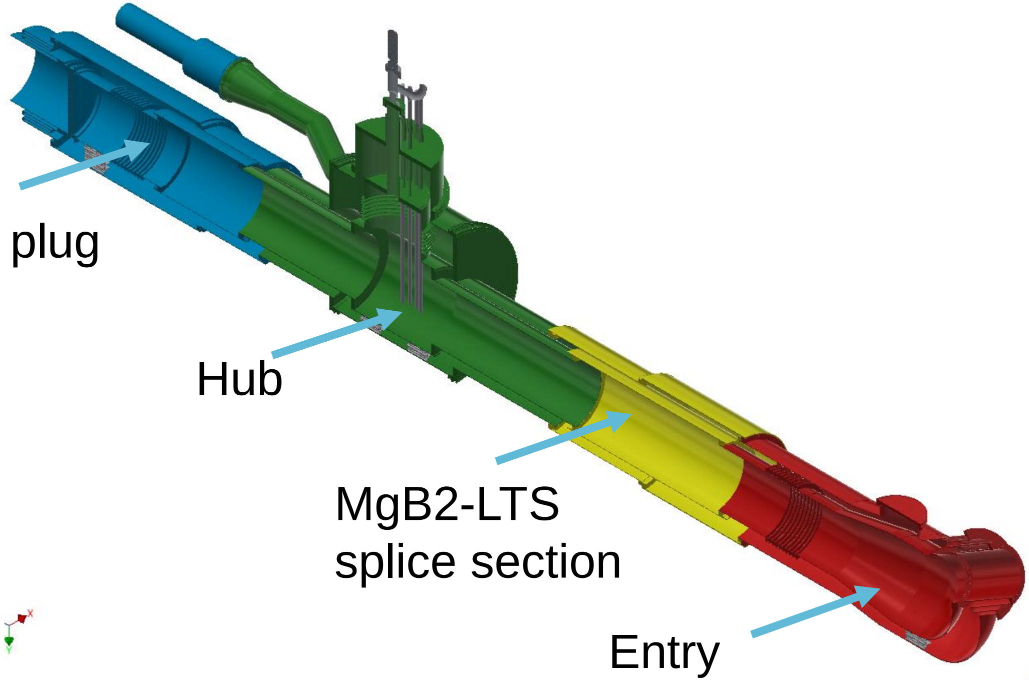
Mechanical Schemes of Revised Concept

Revised proposal
Overview



Mechanical scheme in the DFX CONCEPT



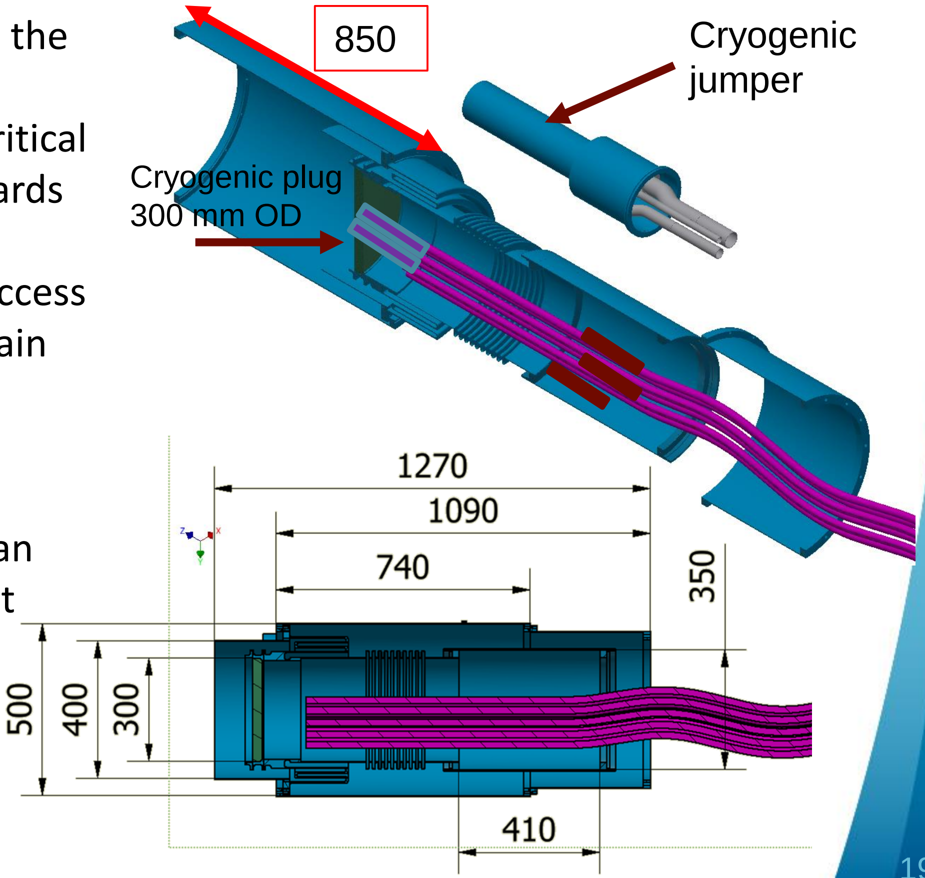
The basic construction of DFX consists of 4 sub-sections:

1. LTS splice-cryogenic plug
2. Hub
3. MgB2-LTS splice section
4. Entry section

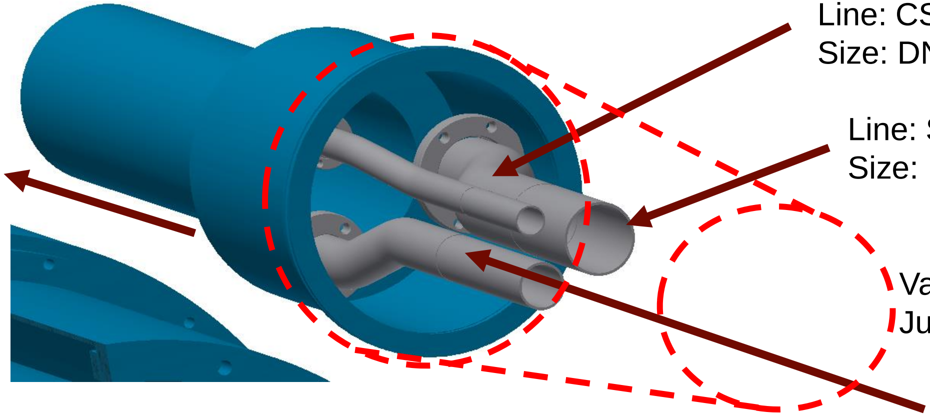
1. LTS-cryogenic Plug Section

Revised proposal
Sub-section 1. LTS splice-cryogenic plug - Overview

- Primary function to support and provide access to the cryogenic plug and the LTS splices.
- Plug = 300 mm, and defines the volume of supercritical helium on the D1 side. The vacuum envelope towards D1 is 400 mm OD.
- The use of “slide apart” vacuum sleeves provide access to the re-weldable preps of the helium vessel to gain access to the LTS splices
- Overall minimum length~1300 mm (with marginal savings on height and length to gain)
- The sliding vacuum tube moving to the length mean that the cryogenic diodes will need to be spaced at least 850 mm from the end of the plug



Revised proposal
Sub-section 1. LTS splice-cryogenic plug - Jumper



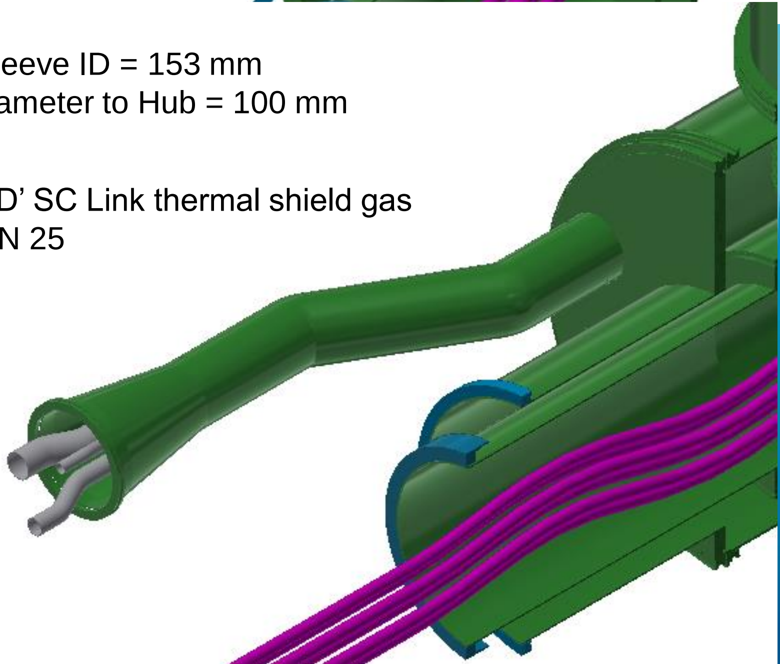
Line: CS (helium supply)
Size: DN 12

Line: SD (DFX gas return)
Size: DN 40

Vacuum sleeve ID = 153 mm
Jumper diameter to Hub = 100 mm

Line: DD’ SC Link thermal shield gas
Size: DN 25

- An elbowed entry required (as shown) to avoid obstruction to the sliding vacuum sleeve
- Maximum diameter of jumper that can connect horizontal through side flange is 100 mm OD
- A solution could be to make a connection via an appendix leaving the Hub (as shown) that has an enlarged section later to make connection via CF flanges



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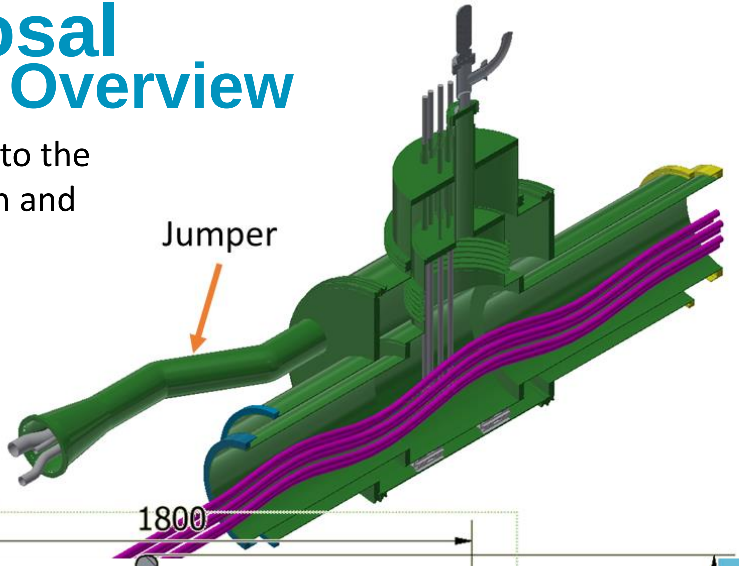
2. The Hub

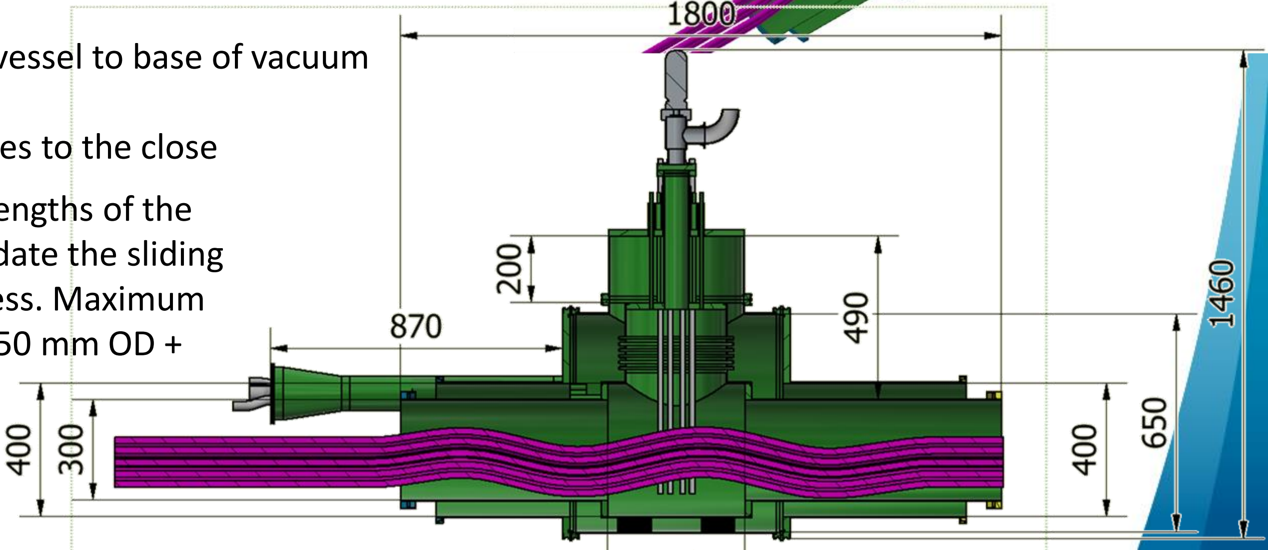
Revised proposal
Sub-section 2. Hub - Overview

- Primary function of this section is to provide a service point to connect to the cryogenic jumper, insert heaters for vapour generation, instrumentation and pressure relief safety devices
- The connection of the jumper to the Hub is made at the side
- Assembly sequence:

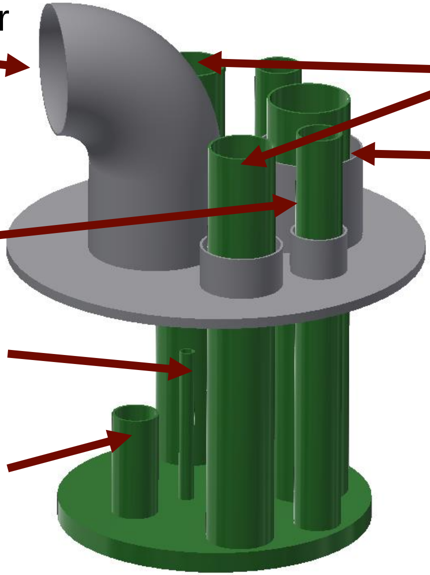
1. Fully weld the helium inner vessel (including the neck) and insert from one side into Hub vacuum outer tube
2. Lift, support and weld the service flange to the neck to the neck
3. Lower and fix the base of the helium vessel to base of vacuum vessel with fixed feet supports
4. Fit vacuum flanges with extended tubes to the close

Total length of the Hub dictated by the lengths of the cantilevered tubes needed to accommodate the sliding vacuum sleeve approach to provide access. Maximum length = 1800 mm, maximum height = 650 mm OD + turret height





Revised proposal
Sub-section 2. Hub turret – Alternative layout

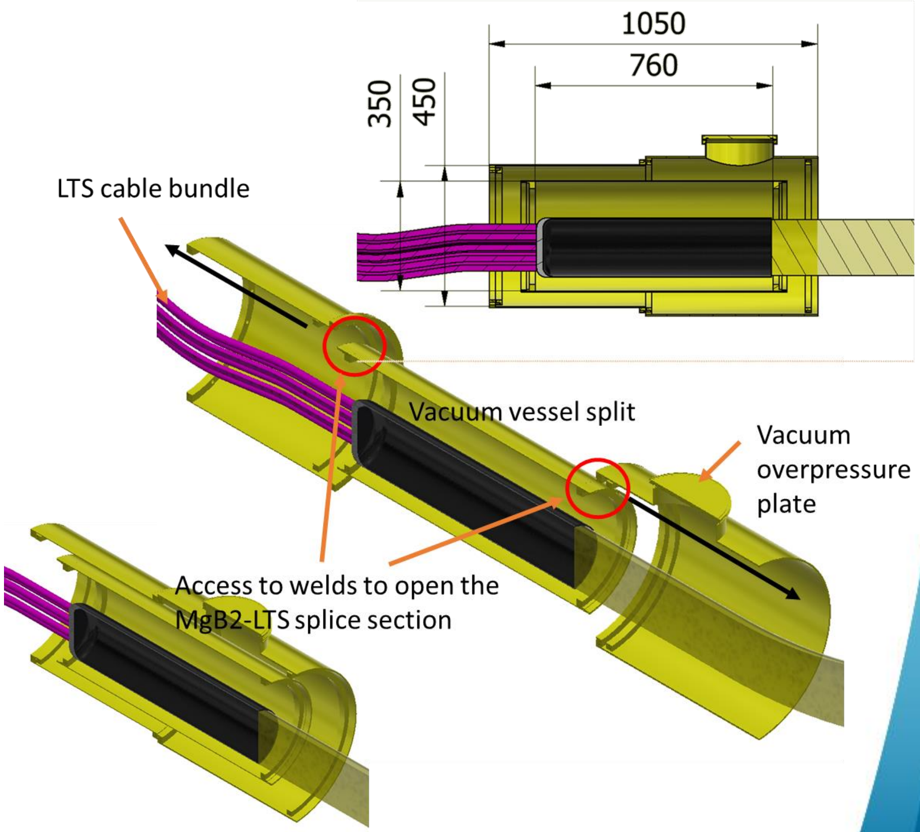


- The revised scheme shows better grouping of similar components to minimise the number of welds
- Emphasis placed on providing a single flange for entry of all serviced required.
- Given the current information that gas supply for the SC Link shield is not required, the diameter of the jumper can be further reduced, and could be switched with the diameter reserved for pressure relief (Ø75 mm).
- Presenting the jumper interface to mimic a vacuum insulated transfer line, could simplify the insertion of liquid fill and return lines whilst utilising top entry
- The size of the service neck is currently 300 mm, with an option to increase to 400 mm if the number/size of heaters and instrumentation increases

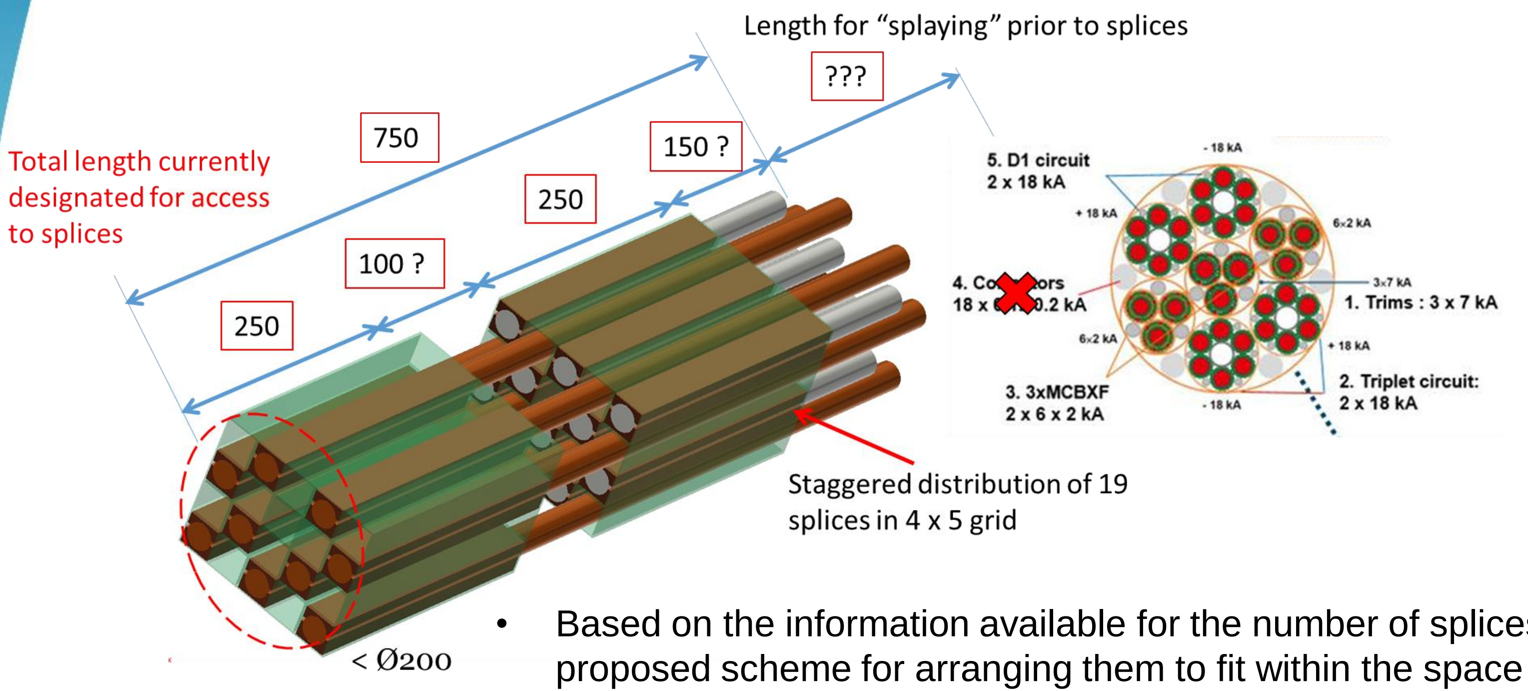
3. MgB_2-LTS Splice Section

Revised proposal
Sub-section 3. MgB2-LTS splice section - Overview

- Primary function of this section is to provide a space to accommodate and access the MgB2-LTS splices and the least obstructive location to locate the vacuum overpressure plate
- Remedial access provided by the “slide apart” vacuum sleeves to gain access to the splices.
- Current allocation for length of slices = 760 mm. Decision on whether this is sufficient space to be made during discussion.
- Maximum diameters of this section of the DFX = 350 mm (in the location of the splices) and 450 mm (vacuum envelope)



Revised proposal
Sub-section 1. LTS splice-cryogenic plug - Overview

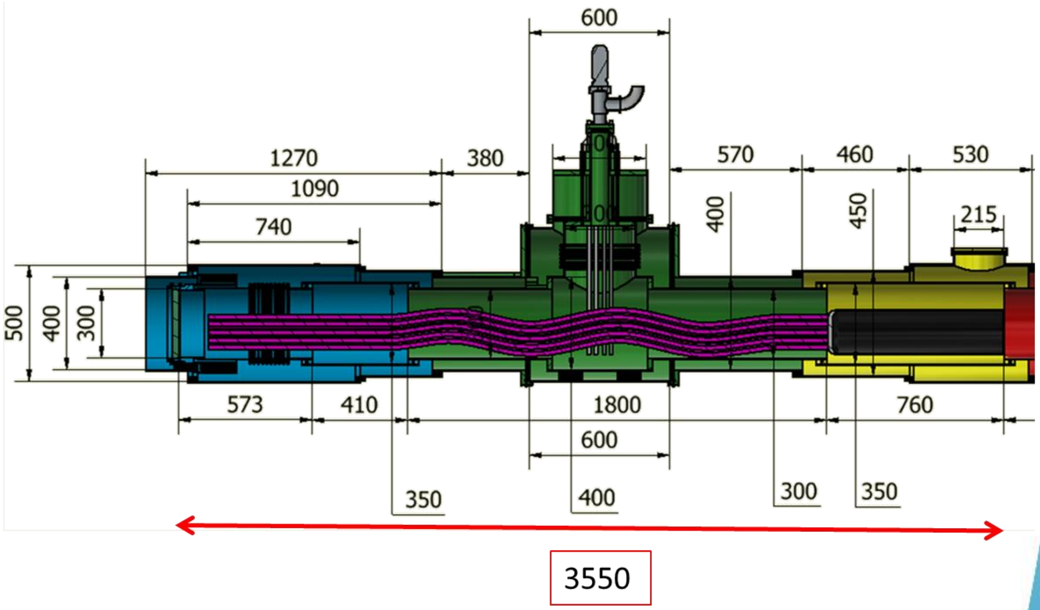


- Based on the information available for the number of splices (19?), a proposed scheme for arranging them to fit within the space allocated is shown
- The illustration of the splice block holder could be improved by replacing the green boxes with frames either end fixed together with studding

Revised proposal
Sub-section 1-3 Fixed length

The total length of sub-sections 1-3 can be fixed at 3550 mm. It can be assumed that only marginal gains (< 5 %) can be achieved by making small adaptions to further reduce the total length

This provides a common basis upon which to fairly compare the impact on length and height of the changes made to sub-section 4 (Entry Section) and the trajectory of the SC Link leaving the shaft and entering the DFX module in the slides that follow



4. SC-Link Entry Section Iterations on Alternatives

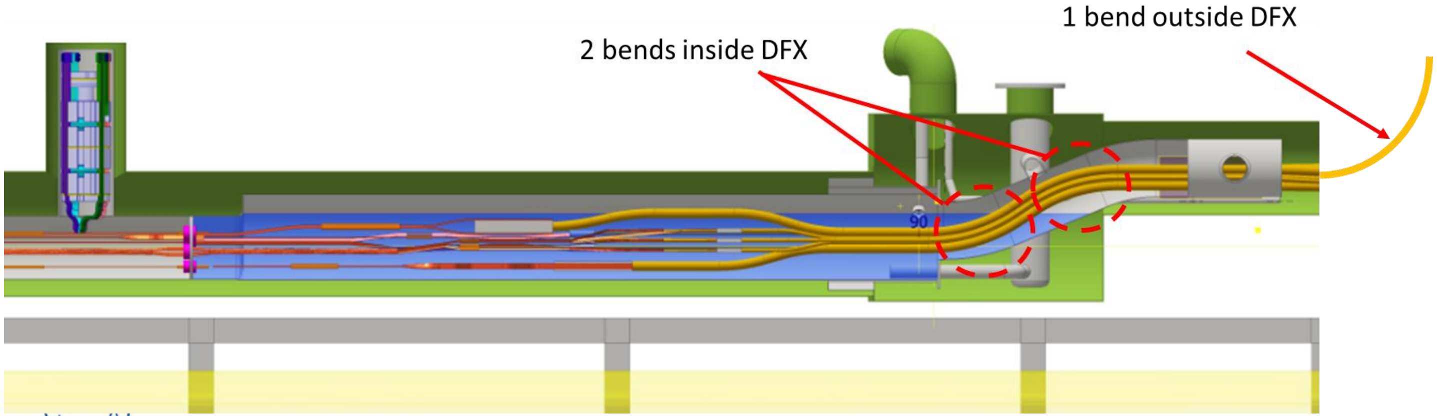
Revised proposal

4.1 – Horizontal “high level” entry with 1 bend outside DFX, 2 bend inside

This scheme already developed for other cables:

Parametric studies required to check its suitability for the SC Link:

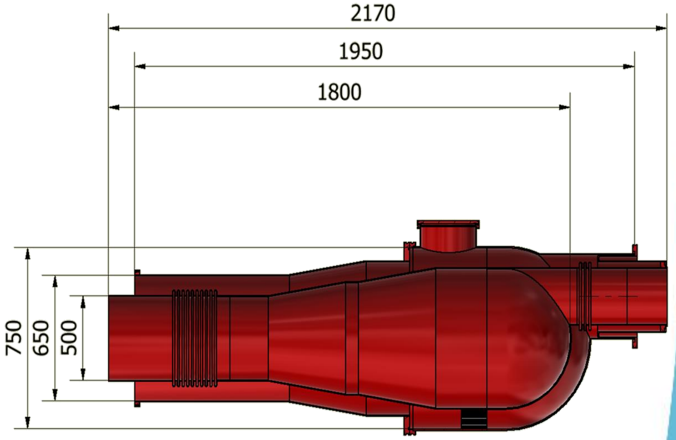
- The ability to achieve the double-bend within the remaining vertical height remaining (300 mm).
- Ensure the minimum bend radius is always satisfied and its impact of the length of DFX
- Consider the leading end of the SC link (splices = LTS length) contained in a rigid tube during insertion into the DFX
- Can the double-bend be achieved inside a **closed** tube that forms the bend but allows safe passage
- How would tooling and mechanical support could be deployed

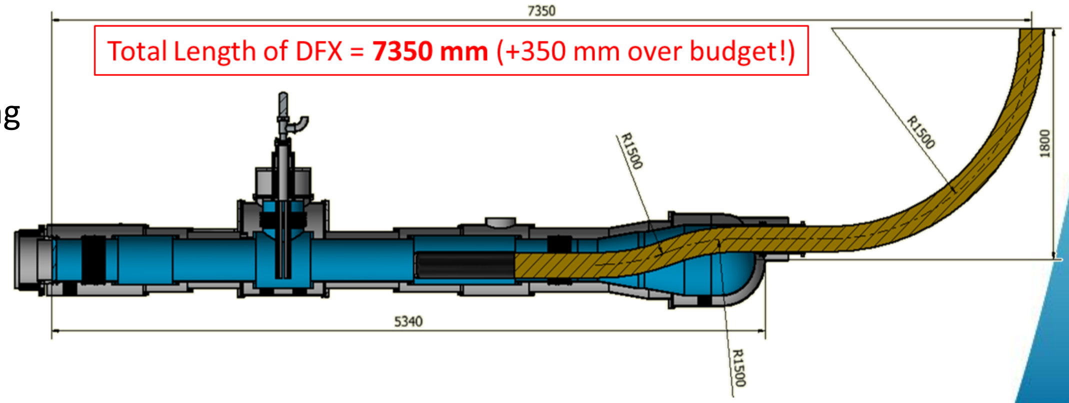


Alternative 1

4.1 – Horizontal “high level” entry with 1 bend outside DFX, 2 bend inside

- The design of an Entry Section to join to sub-sections 1-3 and satisfy the requirements on bending radius and drop in height is 1800 mm between the end of the helium vessel coupling to the sub-section 3 and the dome end.
- The additional length between the dome end and the shaft (2100 mm) comprises of 1500 mm for the cable to transition from vertical-horizontal in the first bend and 600 mm of straight length to pass through the horizontal neck and provide some additional length to perform the double bend.
- The diameter of the inner helium and outer vacuum vessels must also increase to achieve the double bend within the 300 mm drop, particularly to avoid the horizontal turret filling with liquid.
- A radial increase is required to shift the entry turret upwards, but the diameters of the concentric tubes increases in both direction.





Revised proposal

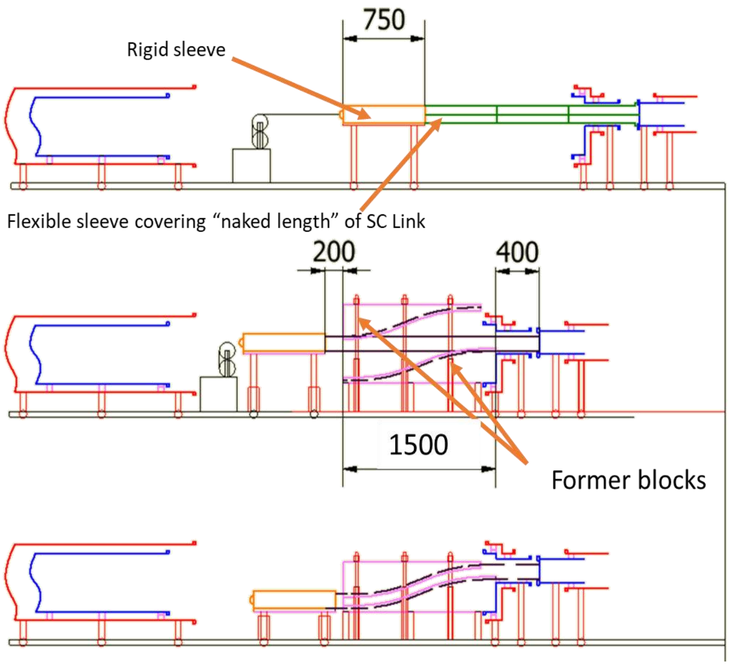
4.1 – Horizontal "high level" entry with 1 bend outside DFX, 2 bend inside

Given the length of the rigid sleeve and it tendency to bridge and tip over the curvatures needed to form the double-bend in the naked length, it was considered impractical (due to dimensions) and risky (due to access to view to rely on a "closed tube" to perform this process

A bending method providing open access was derived:

1. SC Link in horizontal orientation and entry sections containing the inner and outer turrets are passed over rigid sleeve (orange) and naked length in flexible sleeve (green)

2. Setup former blocks (top and bottom with the profile of the double-bend). Three flexible sleeves (manufactured as clam shells) removed. 400 mm extra required to pass through the turret and provide a lead length at the start of the former blocks. 200 mm required to prevent "pinching" at the rigid sleeve-cable intersection

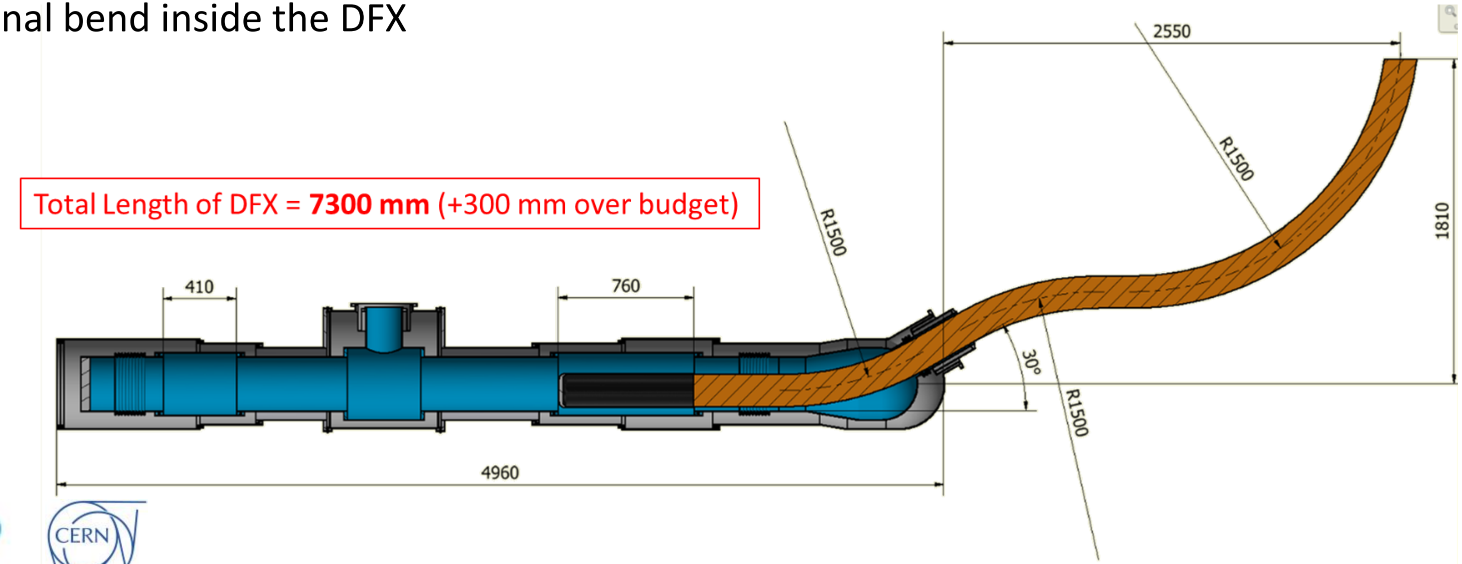


3. Cable compressed by manually controlling hydraulic pistons, whilst the rigid sleeve moves downwards to remain horizontal with the end it is joined to and being compressed

Alternative 2

4.2 – Angled entry, 2 bends outside, 1 bend inside – Overview

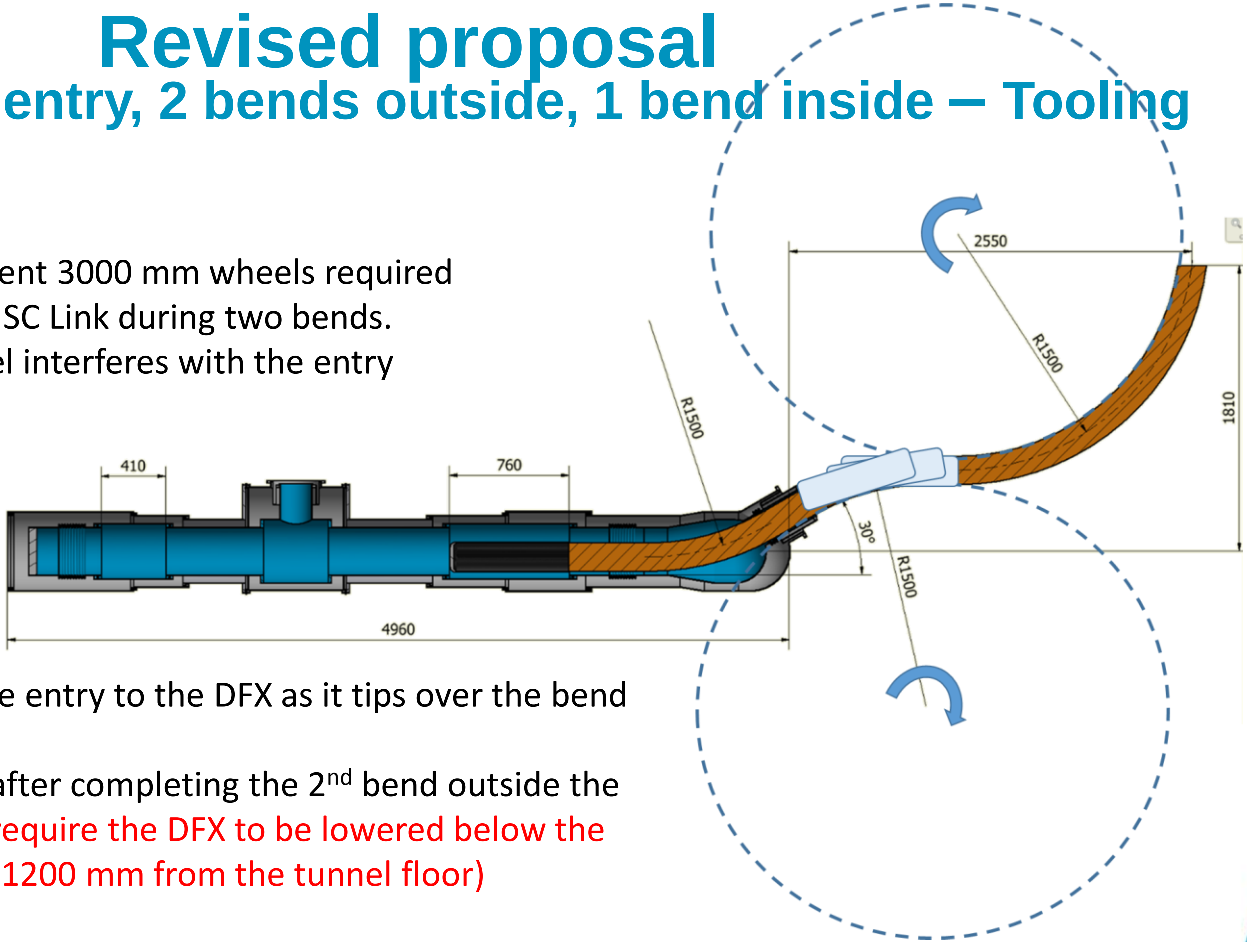
- Moving one of the two bends previously conducted inside the DFX to outside is attractive and introduces a horizontal length that can longitudinal displacement of the shaft position
- Before considering tooling, the concept is over-budget in length by 300 mm
- 2550 mm required to perform 2 bends outside the DFX, 1200 mm to complete the final bend inside the DFX



Revised proposal

4.2 – Angled entry, 2 bends outside, 1 bend inside – Tooling

- Round dash circles represent 3000 mm wheels required to shape and support the SC Link during two bends. Setup of the second wheel interferes with the entry section

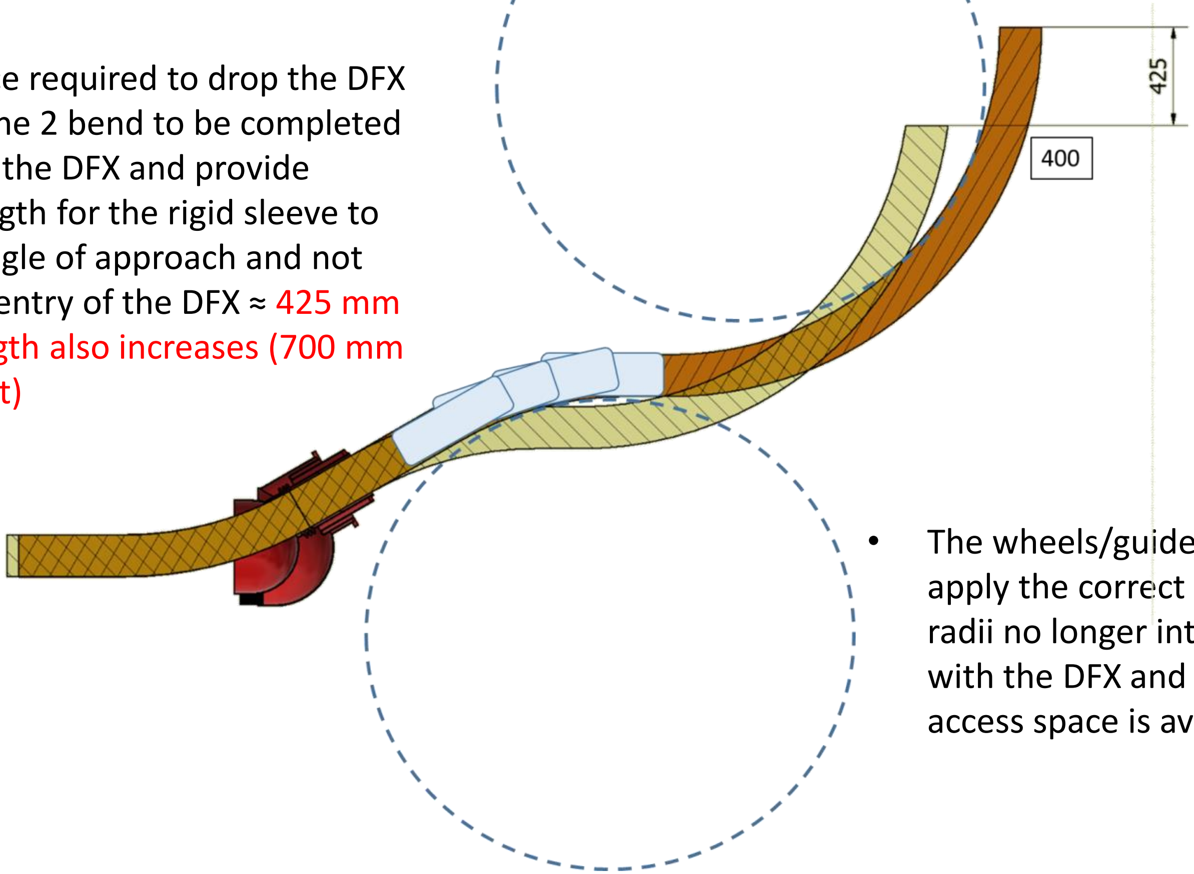


- Rigid sleeve will foul at the entry to the DFX as it tips over the bend radius
- A longer straight section after completing the 2nd bend outside the DFX is required. This will require the DFX to be lowered below the current baseline height (~1200 mm from the tunnel floor)

Revised proposal

4.2 – Angled entry, 2 bends outside, 1 bend inside – Tooling

- The distance required to drop the DFX to enable the 2 bend to be completed external to the DFX and provide enough length for the rigid sleeve to conform angle of approach and not foul at the entry of the DFX ≈ 425 mm
- Overall length also increases (700 mm over budget)

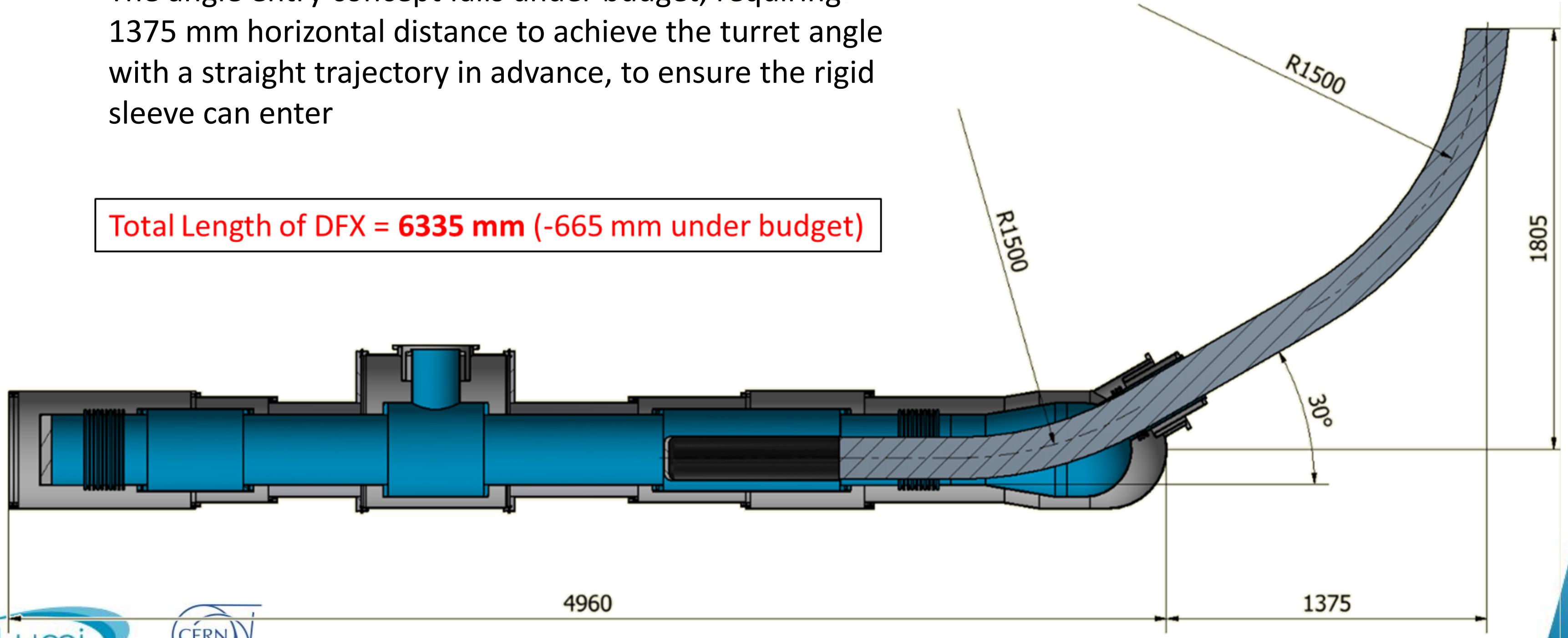


- The wheels/guides used to apply the correct bending radii no longer interfere with the DFX and some access space is available

Revised proposal
4.3 – Angled entry, 90 degree total bend – Overview

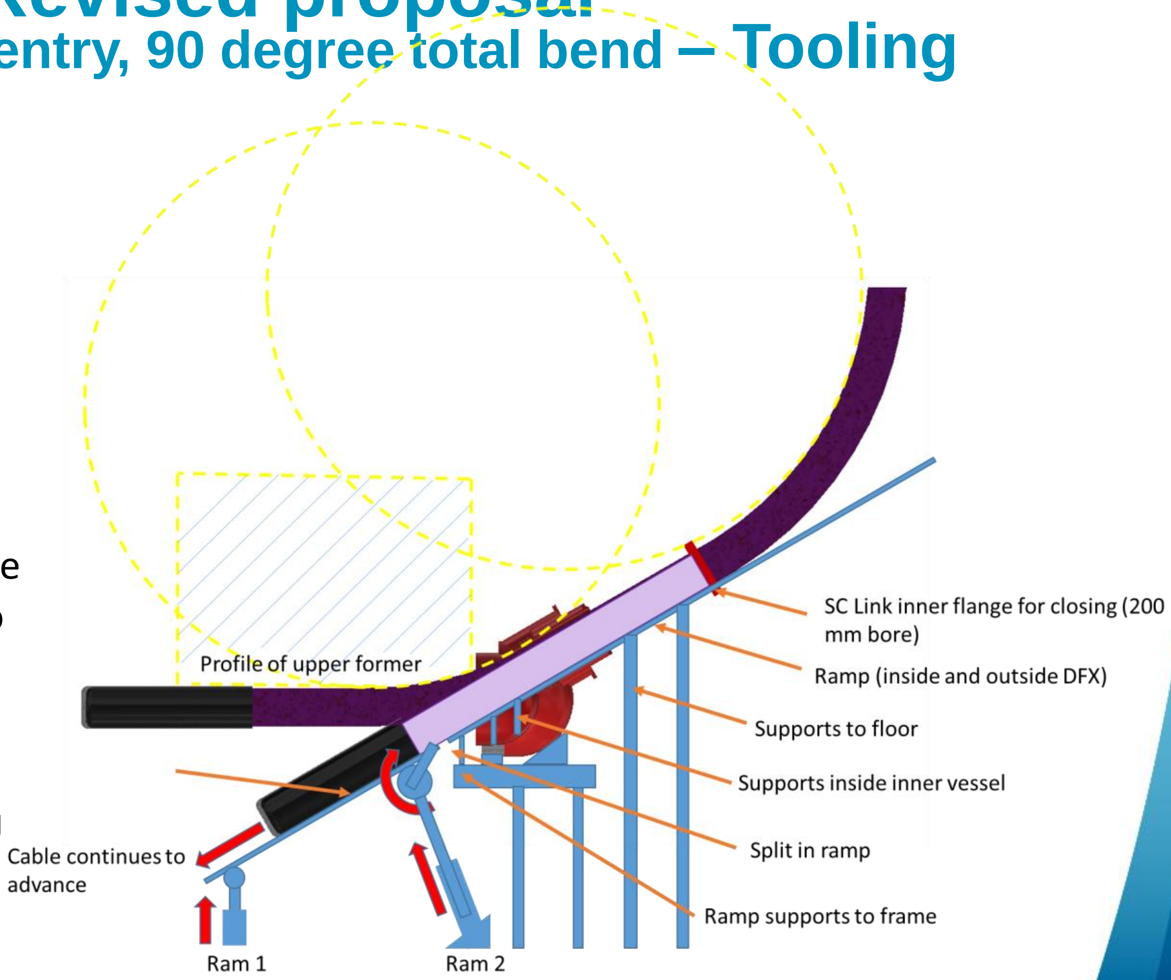
- The angle entry concept falls under budget, requiring 1375 mm horizontal distance to achieve the turret angle with a straight trajectory in advance, to ensure the rigid sleeve can enter

Total Length of DFX = **6335 mm** (-665 mm under budget)



Revised proposal
4.3 – Angled entry, 90 degree total bend – Tooling

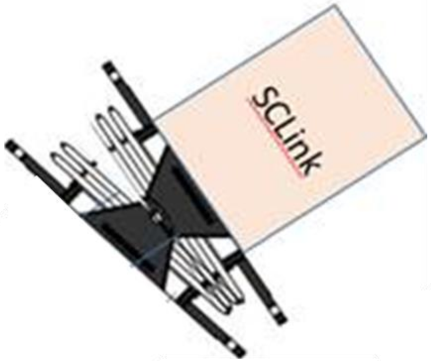
- For insertion, the rigid sleeve must pass completely through the entry section as shown.
- Supports setup to match the same angle as the turret
- Tooling setup to support the rigid section as it advances and is fully support
- Mechanics bend the rigid sleeve and part of the naked length to apply the bending against a former
- Rest of helium vessel slid over supported cable to weld in-situ



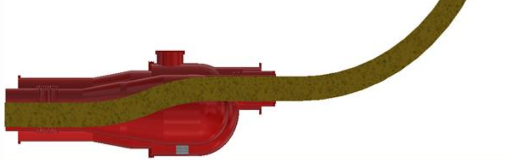
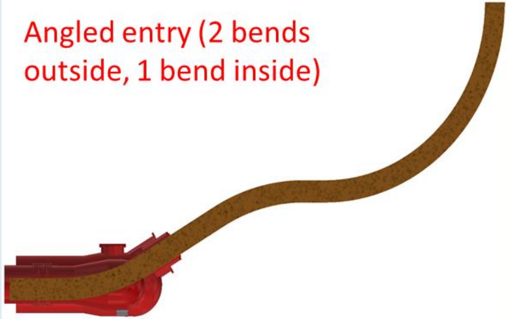
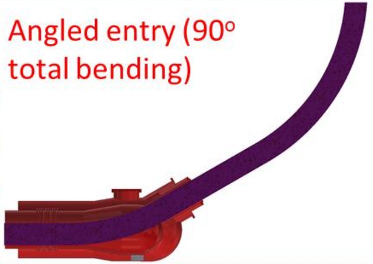
Revised proposal

4.3 – Angled entry, 90 degree total bend: flexibility in entry angle

- In order to accommodate variance in the shaft position in different tunnels, a hinged type bellows could be considered and integrated into in the entry section to allow some adaptation of the angle of entry, **leading to tolerances in overall length**



Revised proposal
Summary of Entry Section Alternatives

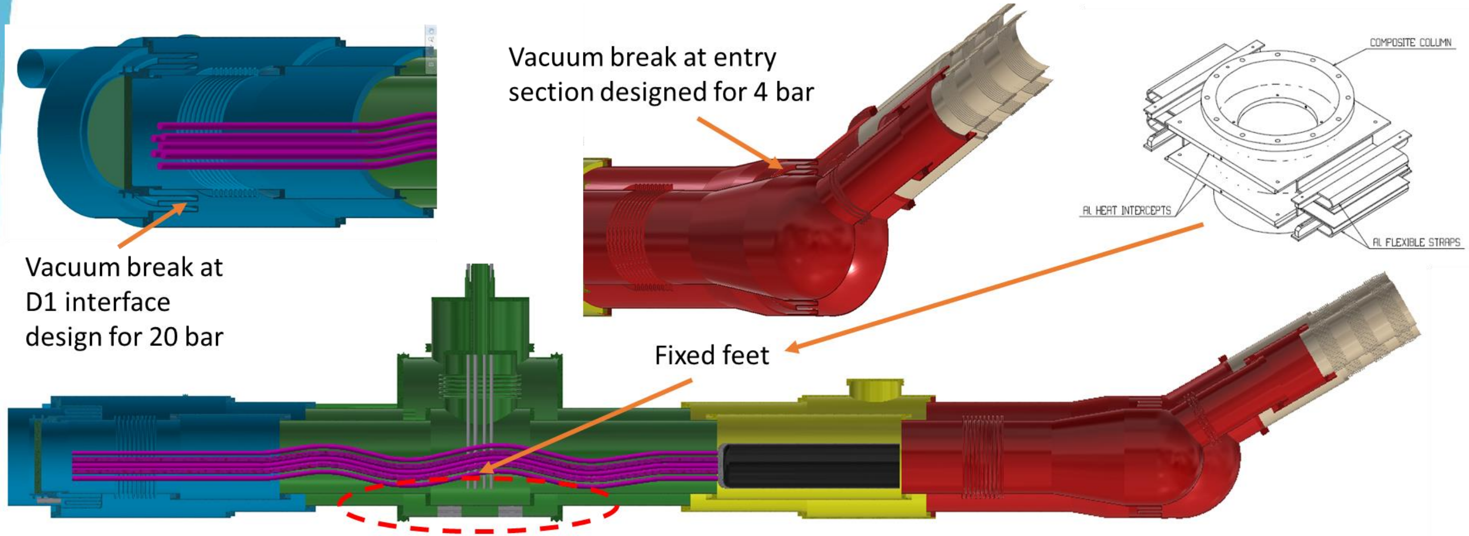
	Horizontal entry (1 bend outside, 2 inside)	Angled entry (2 bends outside, 1 bend inside)	Angled entry (90^{o} total bending)
			
PROS	• Most adaptable to different shaft positions • Link can be inserted and the double bend applied while static and decoupled from the cable travel • Larger OD can accommodate a larger liquid head and greater tolerance for level control	• Reasonably adaptive to different shaft positions	• Under budget in length (665 mm) • Least amount of bending applied • Smallest entry section for moving and handling • Extended ramp runs straight into the DFX to continue cable support from the shaft exit
CONS	• Large OD tubes (approaching 750 mm) in entry section that will need to custom made • Over budget in length (350 mm)	• Does not satisfy height limit applied • DFX must be dropped by at least 425 mm to make this a feasible option • Over budget in length (700 mm) • Extra external tooling required in addition to the supports and actuation required to perform the final bend inside the DFX section	• Fixed angle of entry turret makes it the least adaptive to civil engineering tolerances • Semi-complex tooling required to safely achieve final bend

5. Mechanical Supports

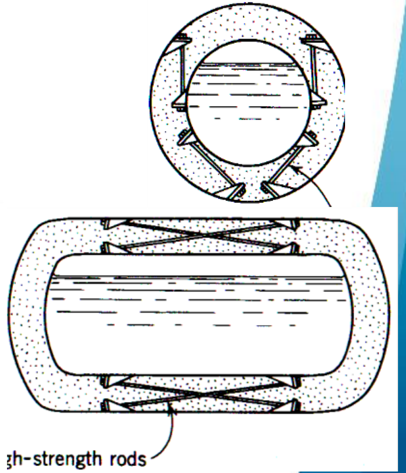
Revised proposal

Mechanical support and management of thermal contraction and pressure forces – Supports and vacuum breaks

- Fixed feet located at the Hub – a key structure that requires support due to the cantilevered sections protruding off the section of helium vessel located inside
- Design of foot based on similar design to the “plate and column” design already used by CERN: Optimised for DFX by,
  - i) couple to a supply of cold gas to improve heat interception
  - ii) simplify design and reduce wall thicknesses to contend with much smaller loads
- Heat load main issue: might necessary to combine with classical methods



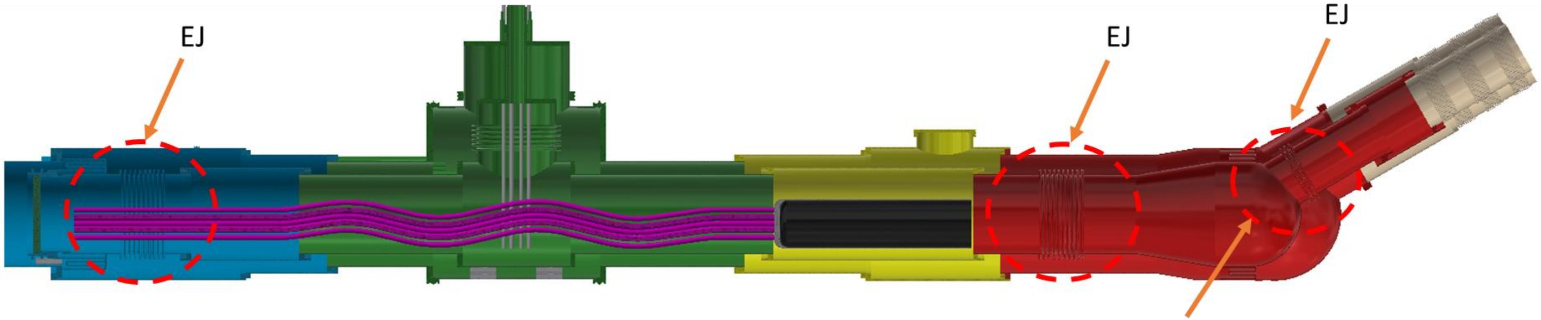
Classical inner vessel suspensions



Revised proposal

Mechanical support and management of thermal contraction and pressure forces – Expansion joints

- By rigidly connecting the inner vessel to the outer at the three locations we can locate expansion joints (EJ) to accommodate the contraction forces and displacement
- Taking the entire length (7000 mm) of the DFX into our assumptions, each of the large EJ’s need to accommodate ~ 10 mm each. Apply some margin = 20 mm each
- EJ to be included in sections where the diameters do not exceed 300 mm, to ensure that EJ’s with a spring stiffness < 20 N/mm and able to withstand 4 bar can be deployed.



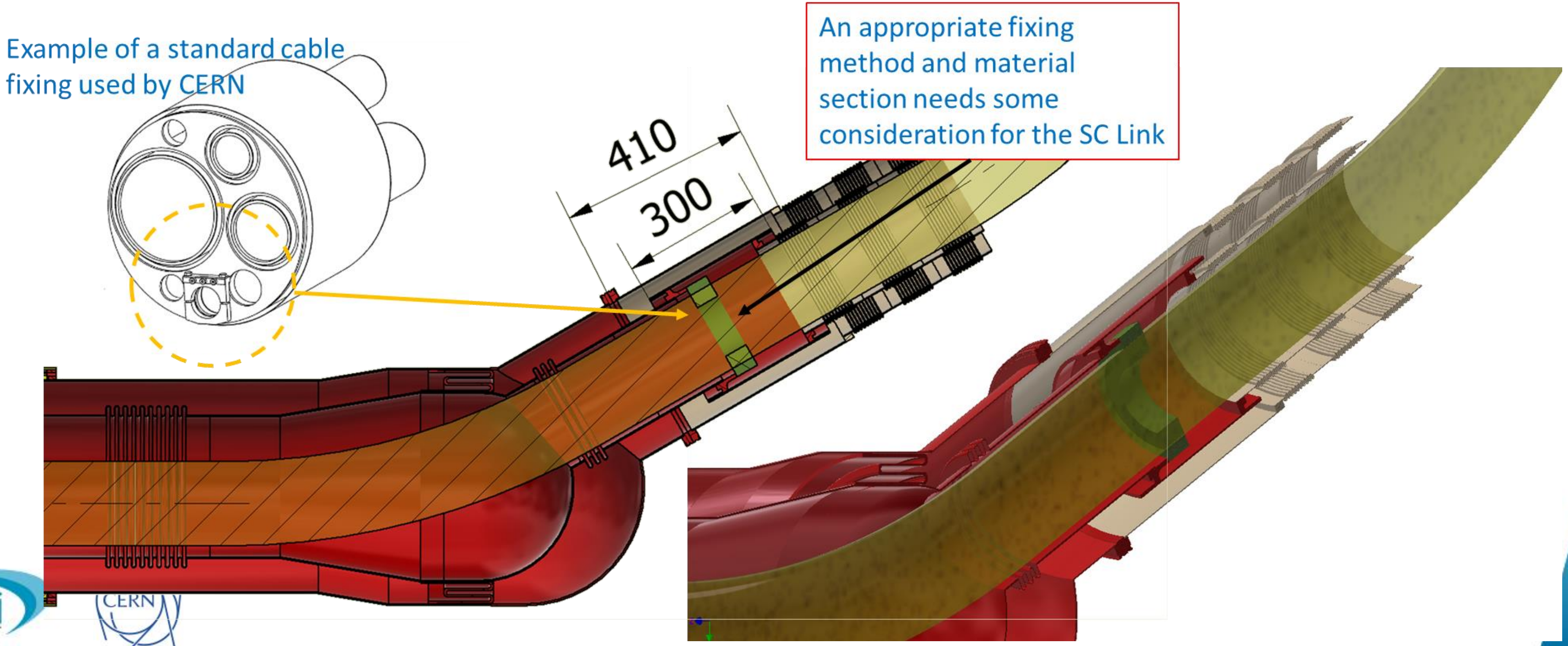
Waving in the LTS cables provide enough slack to take up the contraction in the cable between the plug and fixed point of the cable

Small EJ located in the angled turret to relieve bending forces that may develop during cool-down.

Revised proposal

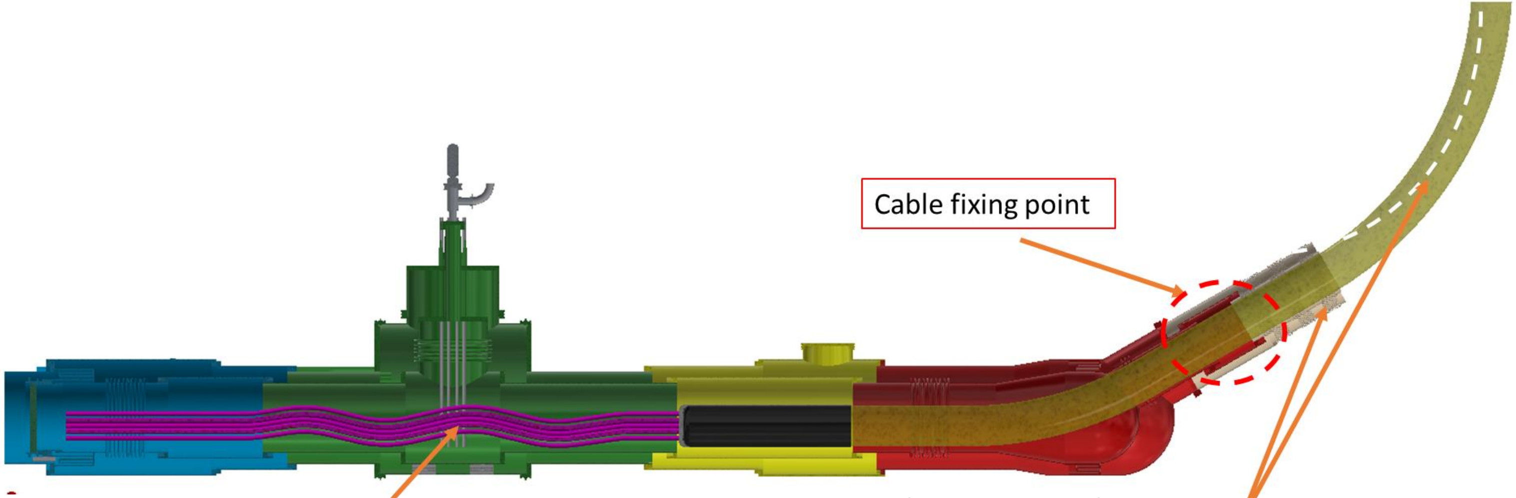
Mechanical support and management of thermal contraction and pressure forces – Cable fixing

- To manage the differential contraction between the cable and its flexible outer over the length of SC Link leaving the mouth of the shaft (2500 mm), the cable should be fixed, (ideally in the turret neck before the short EJ positioned in the neck).



Revised proposal

Mechanical support and management of thermal contraction and pressure forces – SC Link and cables



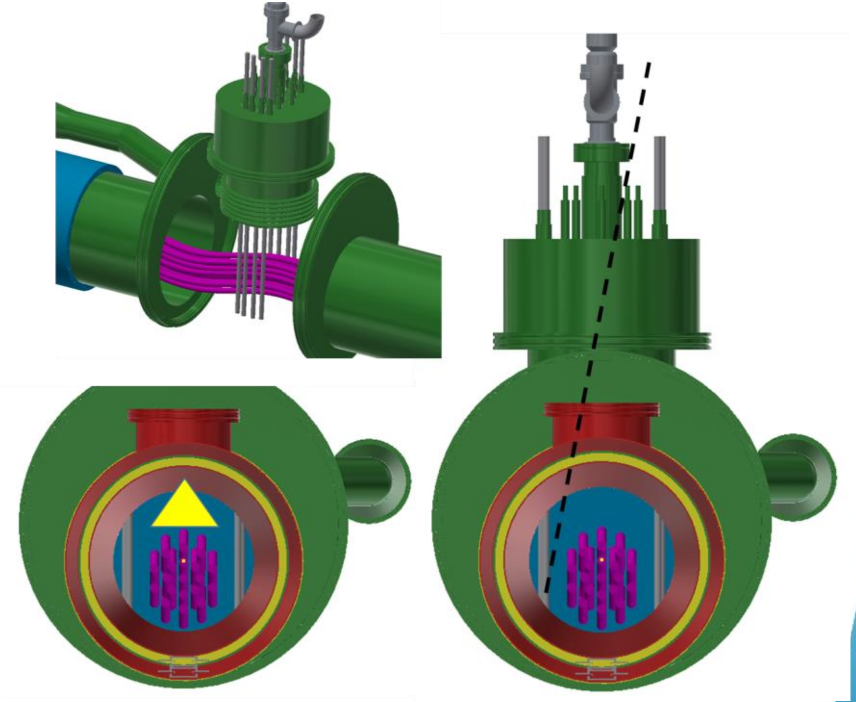
Waving in the LTS cables provide enough slack to take up the contraction in the cable between the plug and the fixed point in the entry

- The length of cable in its flexible tubing outside DFX will want to shorten during cooling.
- The composition and snaking of the cable strands, friction at the cable-flexible interface, and potential locking of the cable near the shaft entry make it hard to predict the behaviour of this length.
- Safe strategy to used the EJ in the neck to compensate for enough contraction (~25 mm with in built margin)

Revised proposal

Heater insertion

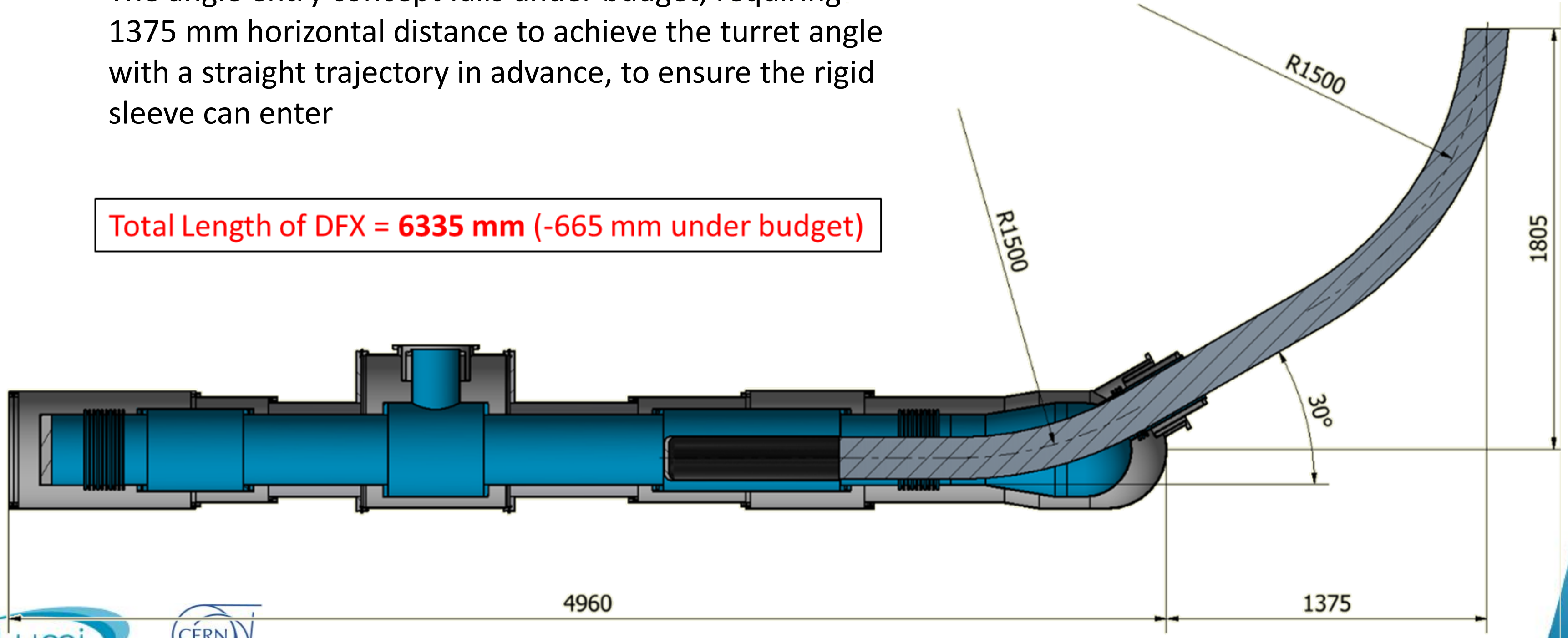
- Vapour generated by a set of heaters located in the Hub
- Vapour space in DFX is the volume in the long vessel between the liquid level and the top of the vessel between 0 – 100 mm)
- The length of heater must ensure it can be inserted and retrieved within the headroom available (1800 mm).
- A large 300 mm bore entry into the helium vessel at the Hub enables the heaters to be located towards the periphery of the tube to avoid interfering with the LTS cable bundle
- If the diameter or number of heater increases, the following strategies could be deployed to ensure insertion and:
    a. A cone to deflect the path of the heater pass the cable bundle during insertion
    b. Inclined heater entry ports



Finalised Concept?

- The angle entry concept falls under budget, requiring 1375 mm horizontal distance to achieve the turret angle with a straight trajectory in advance, to ensure the rigid sleeve can enter

Total Length of DFX = **6335 mm** (-665 mm under budget)

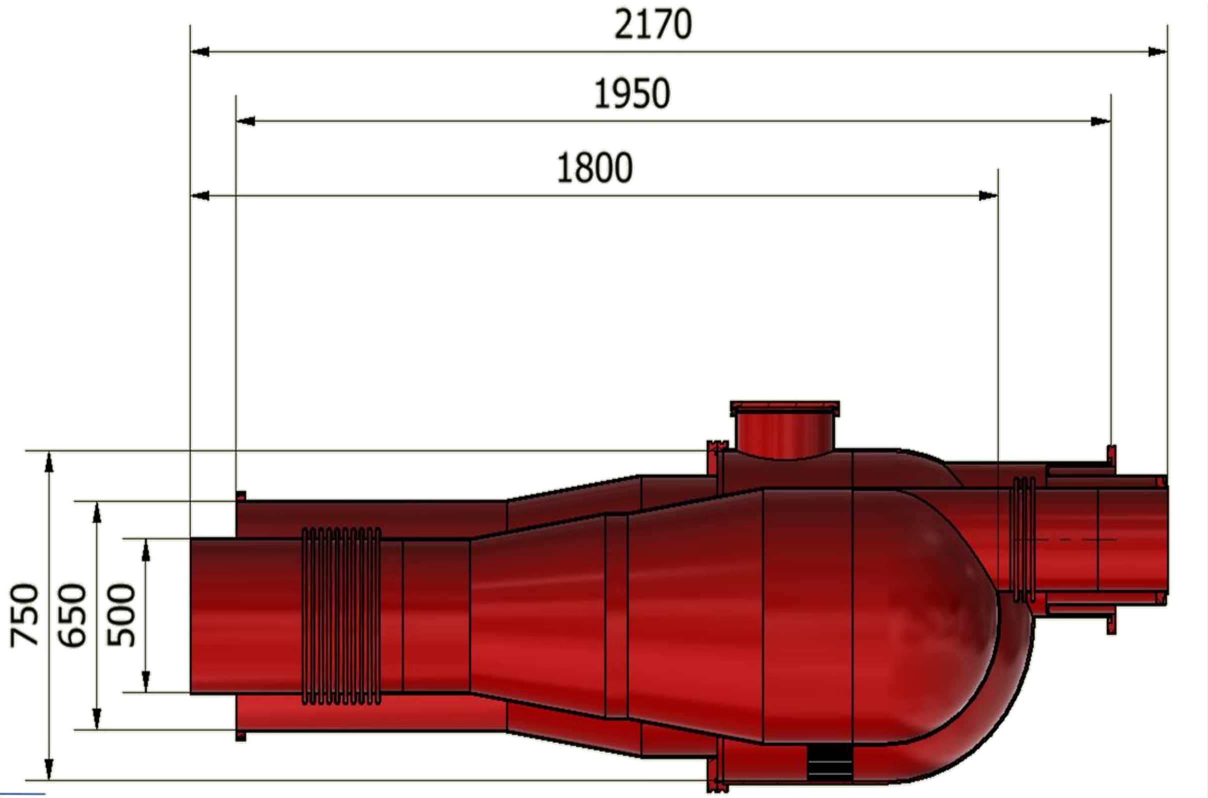


Next Step Mechanical drawings (D4.4) Sept 2018

Detailed mechanical design of the cryostat as a pressure vessel (modelling and standard)
Detailed design of mechanical support (total forces, flexibility and heat load)
Supporting frames and SC-Link deployment (integration team)
Details of the interfaces

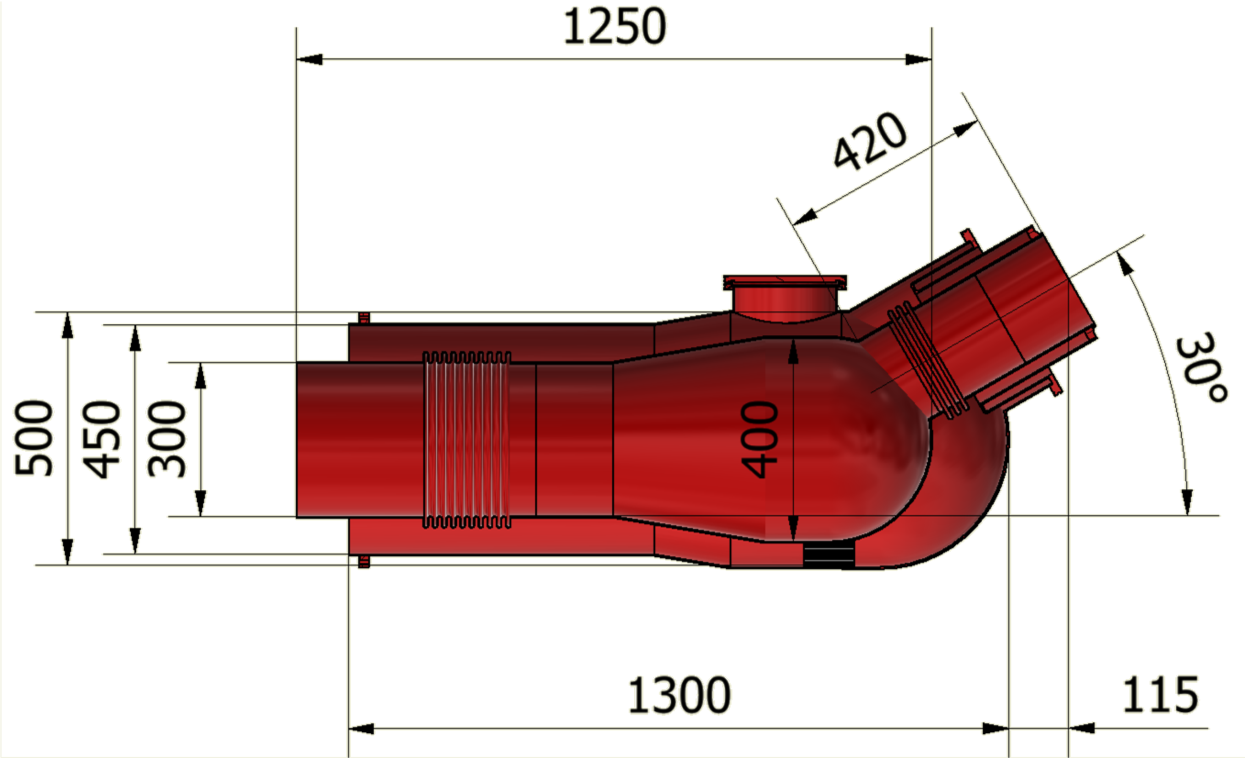
Revised proposal

Spare slides



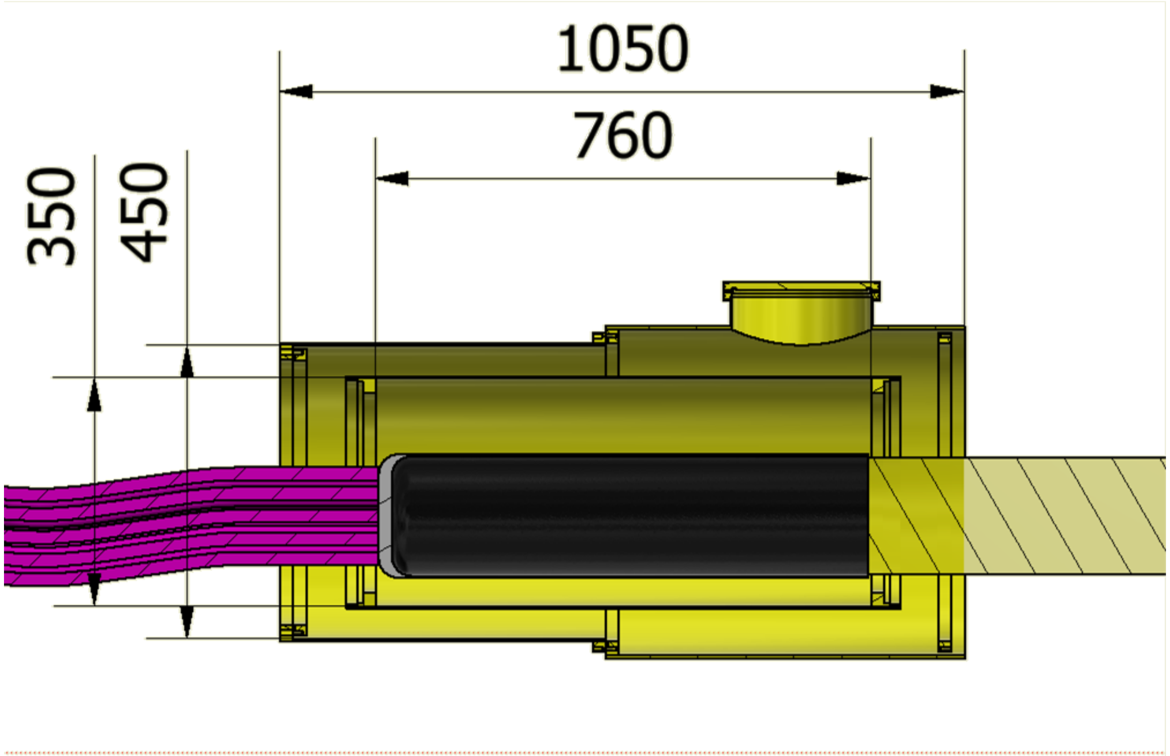
Revised proposal

Spare slides



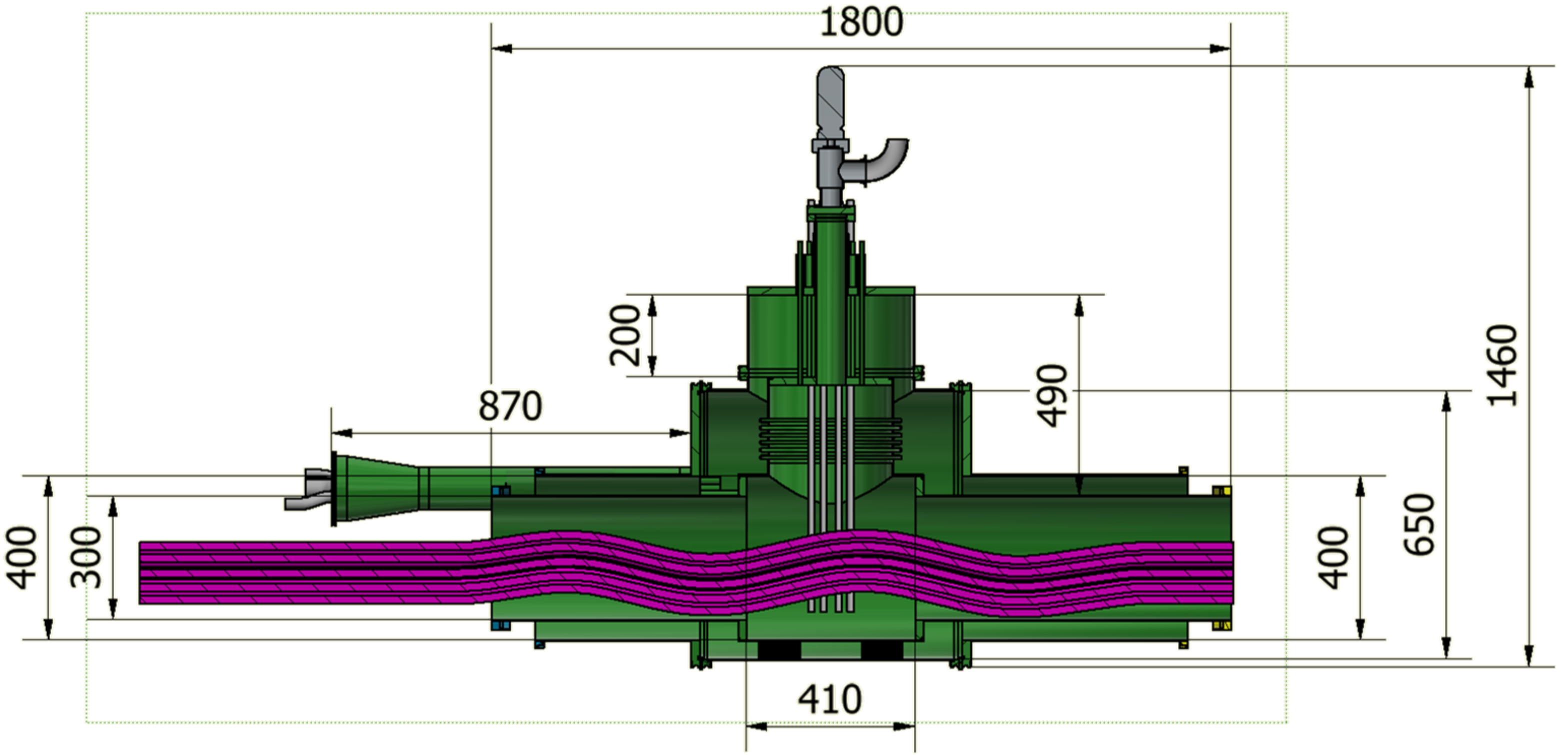
Revised proposal

Spare slides



Revised proposal

Spare slides



Revised proposal

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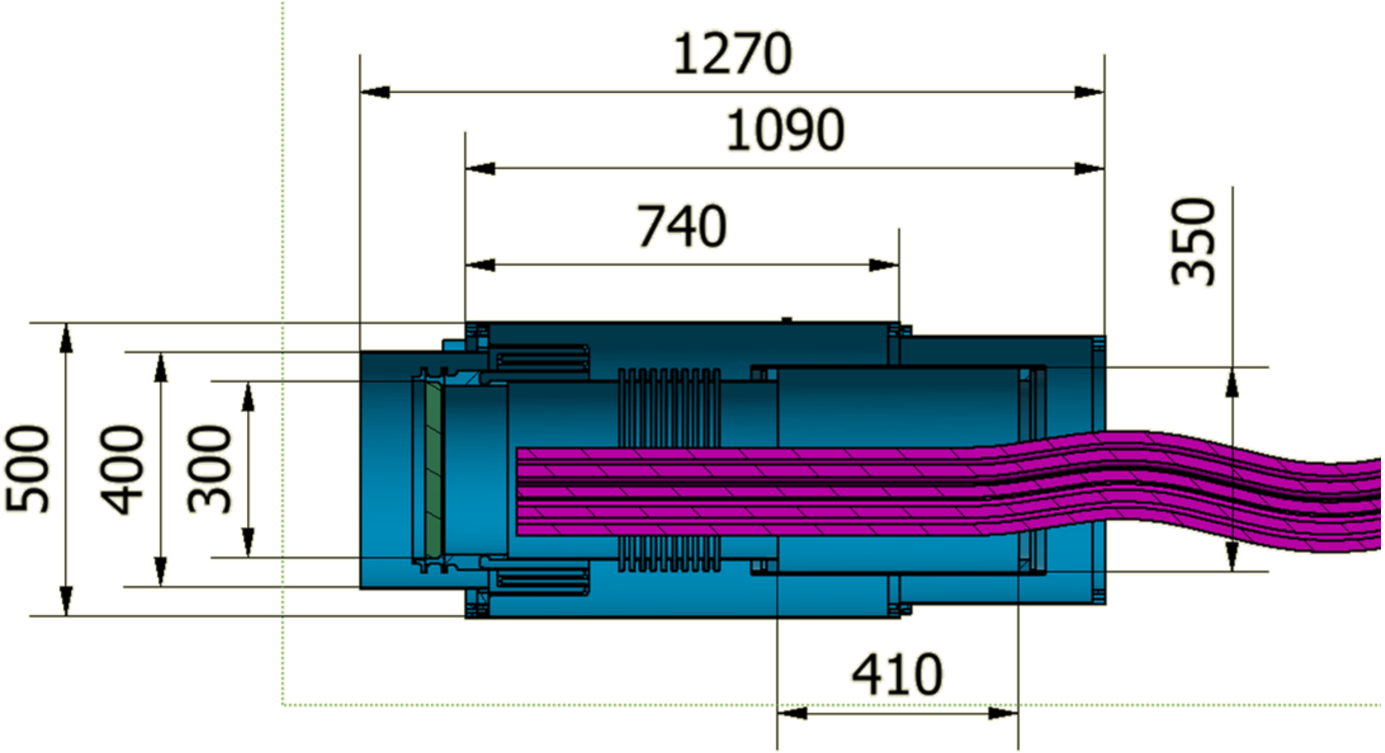

Revised proposal

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