DFX Detailed Design

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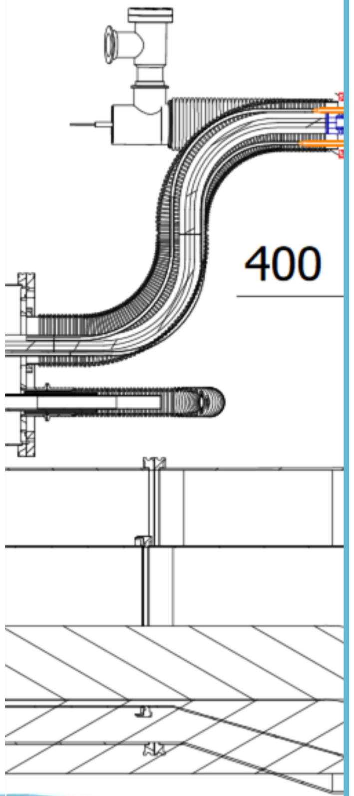
20 June. 2019

Outline

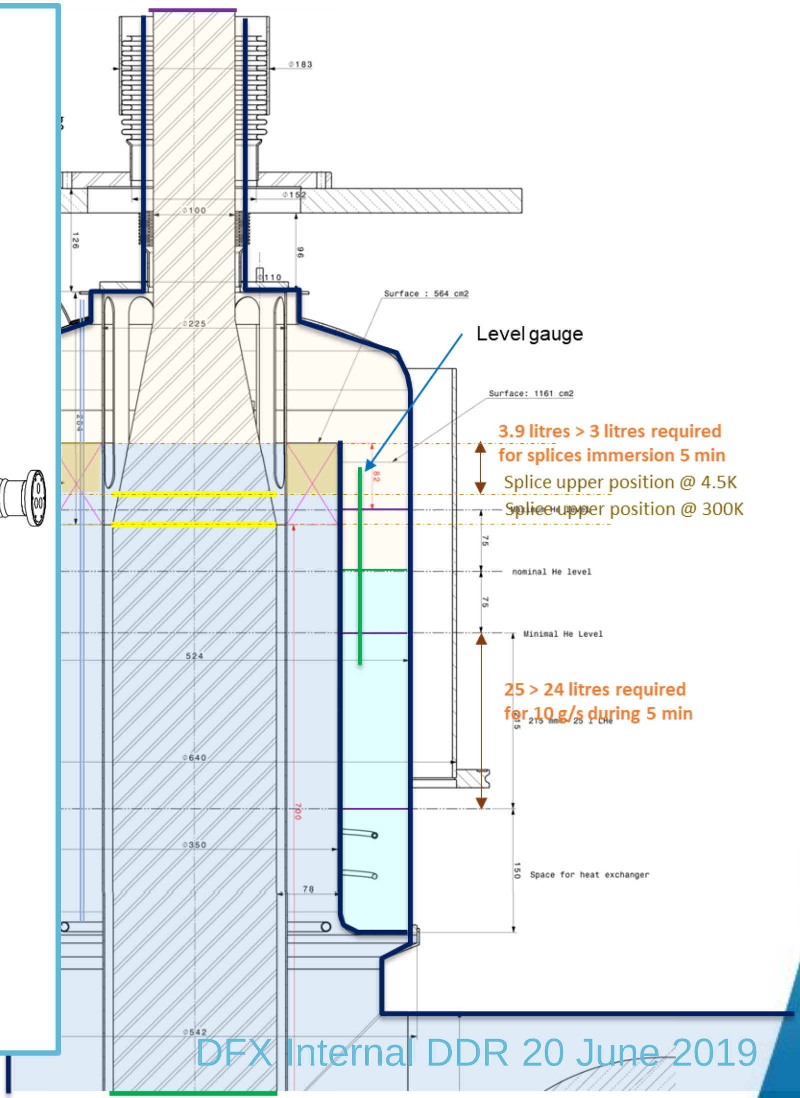
- Concept evolution since CDR
- Summary of functional fulfilment
- Detailed schematics of DFX sections
- Modes of operations and provisions
- Design studies
- Manufacturing, QA, testing and delivery
- Assembly sequences

Design Evolution since CDR:
Increased He Vapour Space and Avoiding Liquid Entrainment

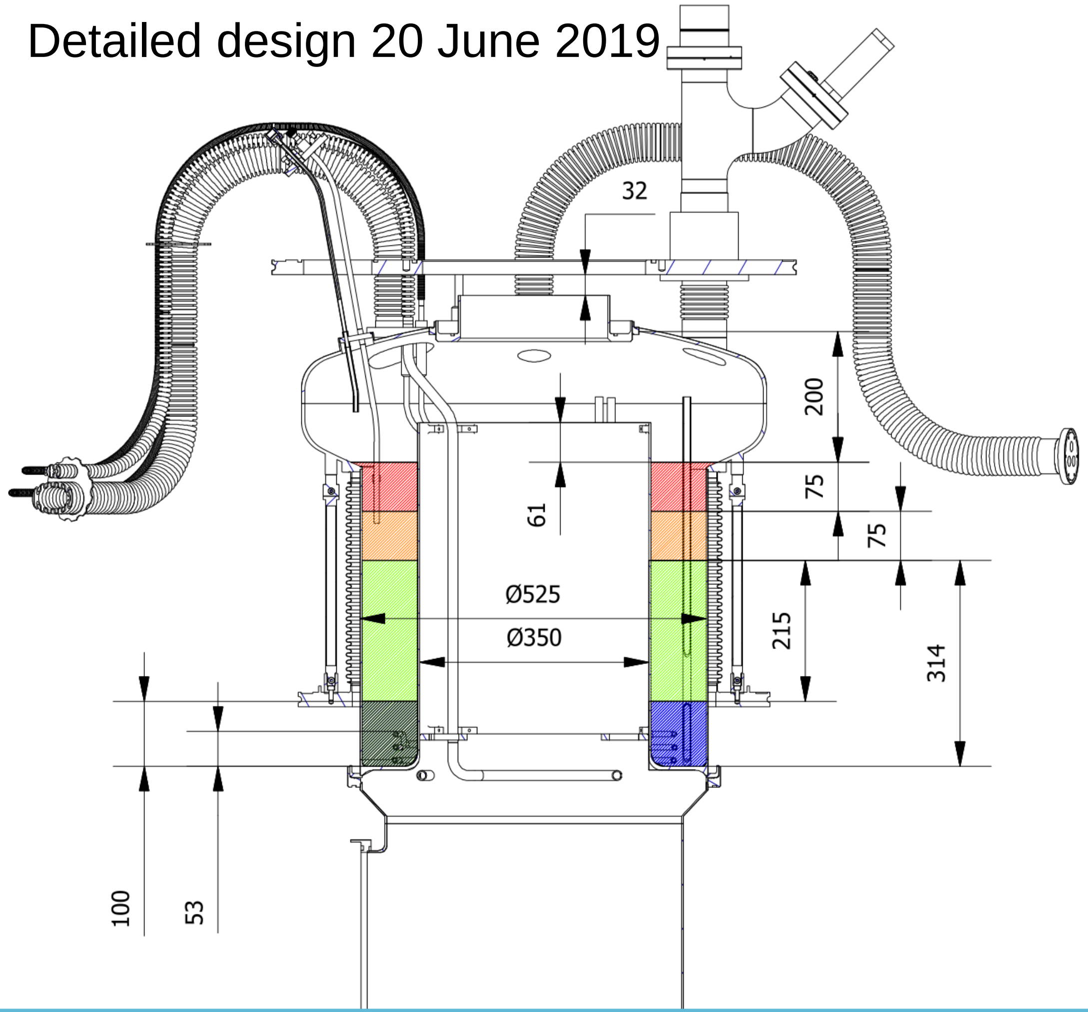
Initial concept 30 Jan 2019



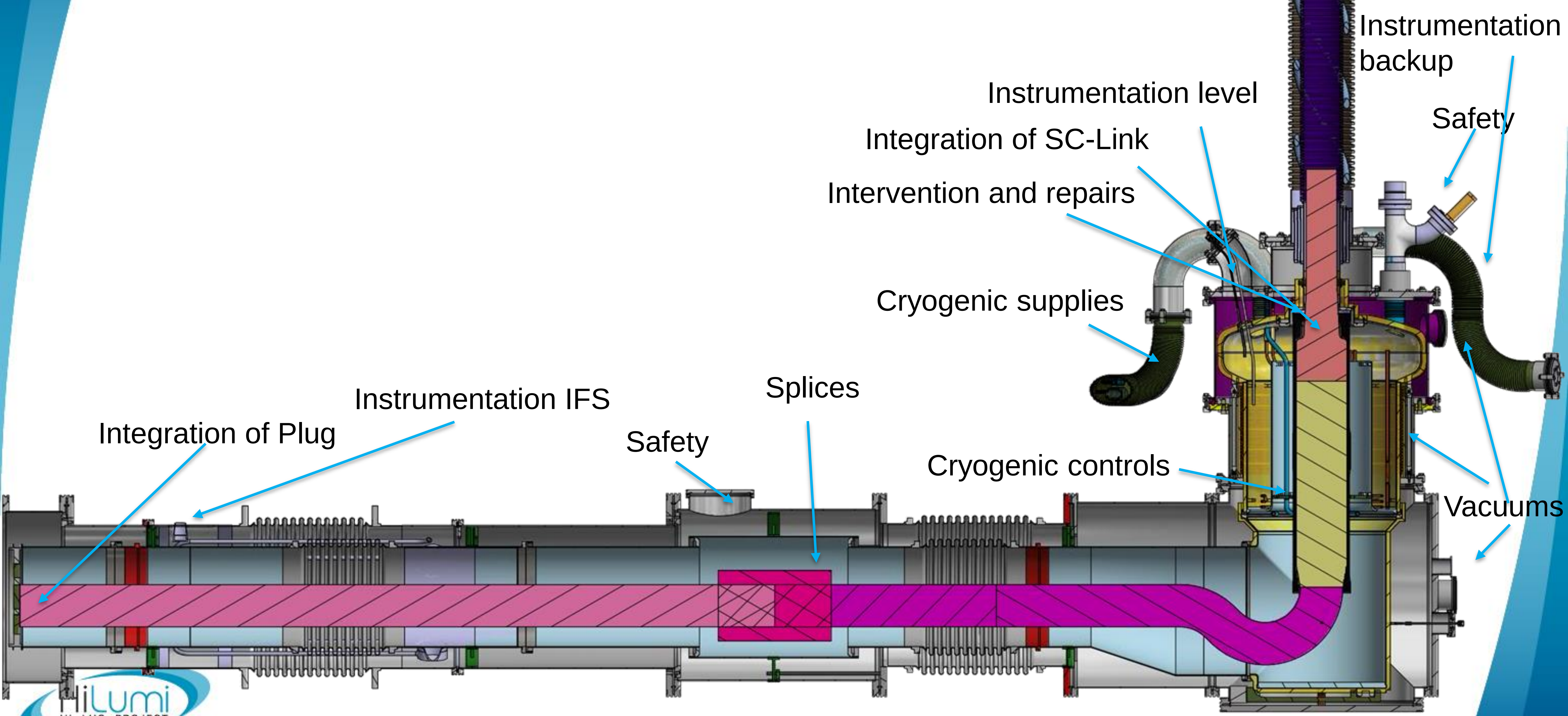
Revised concept 12 Feb 2019



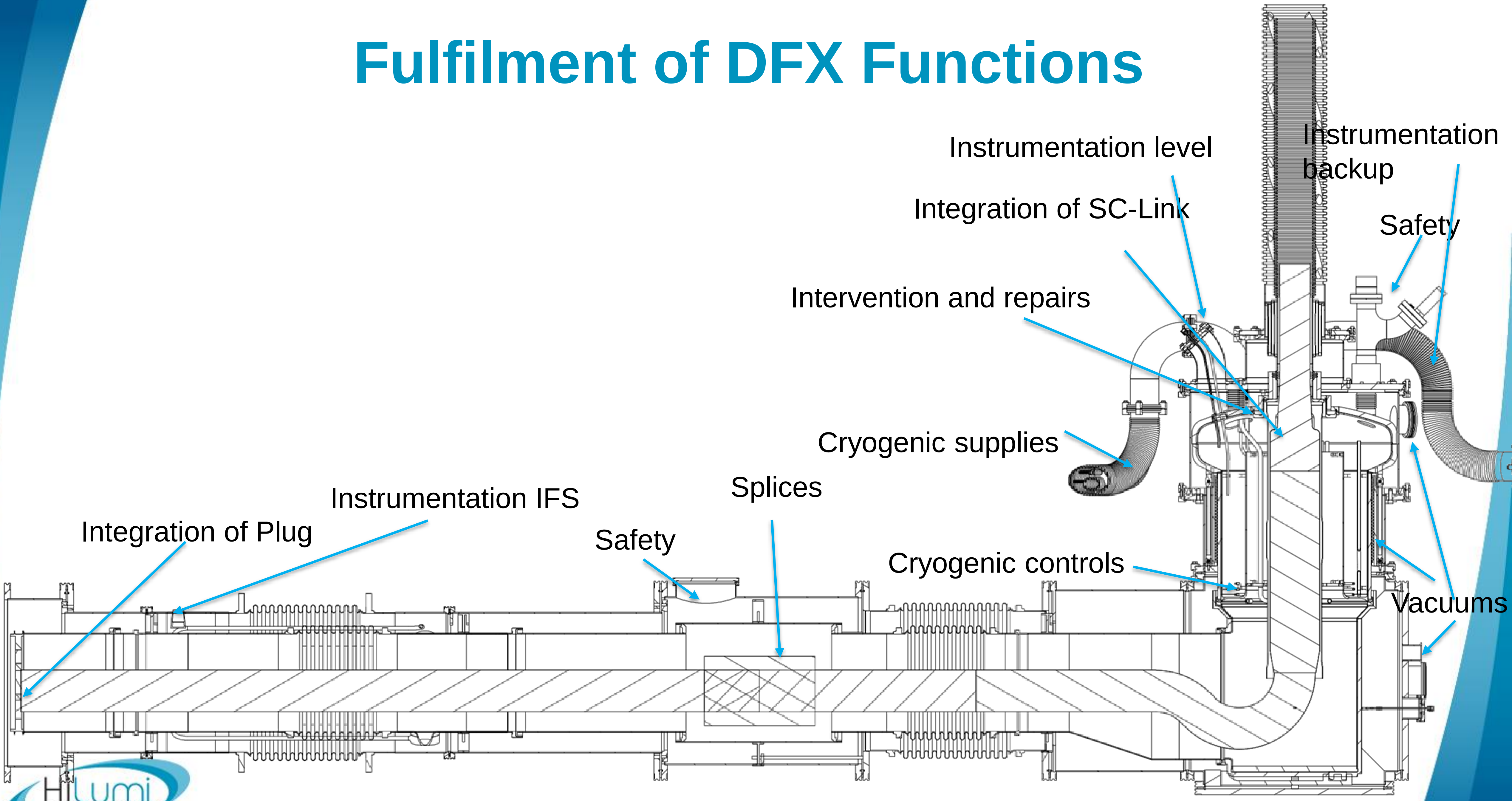
Detailed design 20 June 2019



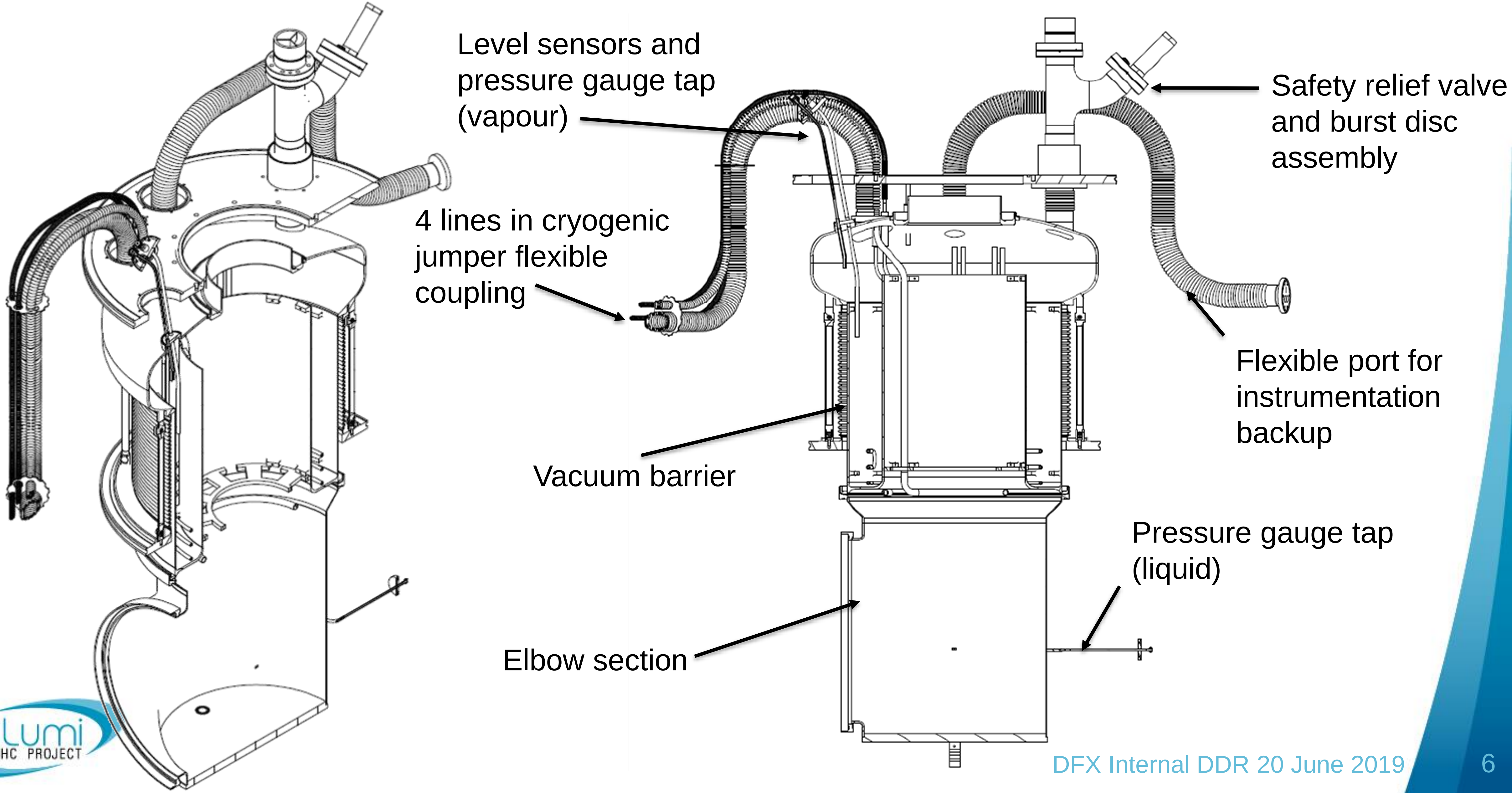
Fulfilment of DFX Functions



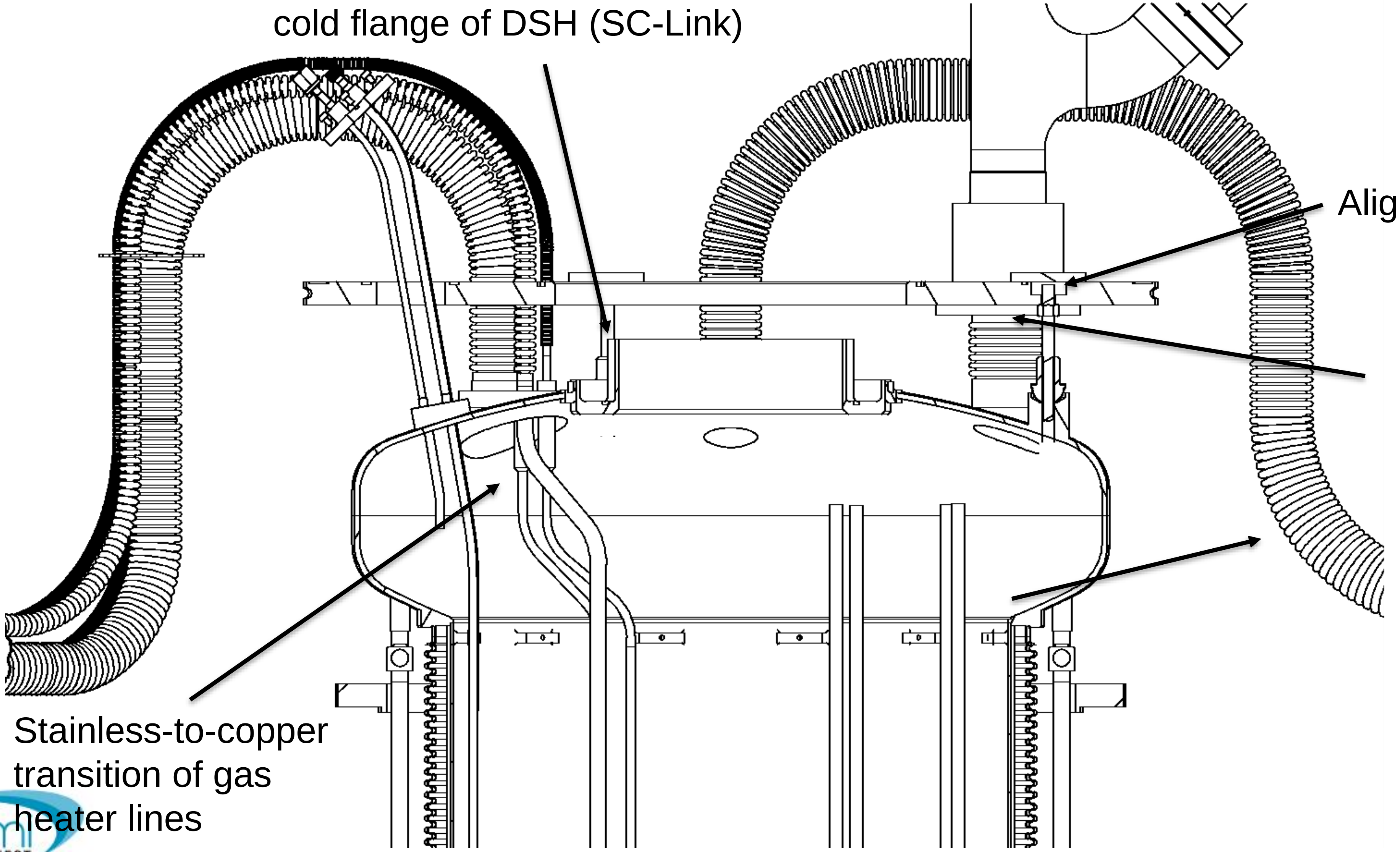
Fulfilment of DFX Functions



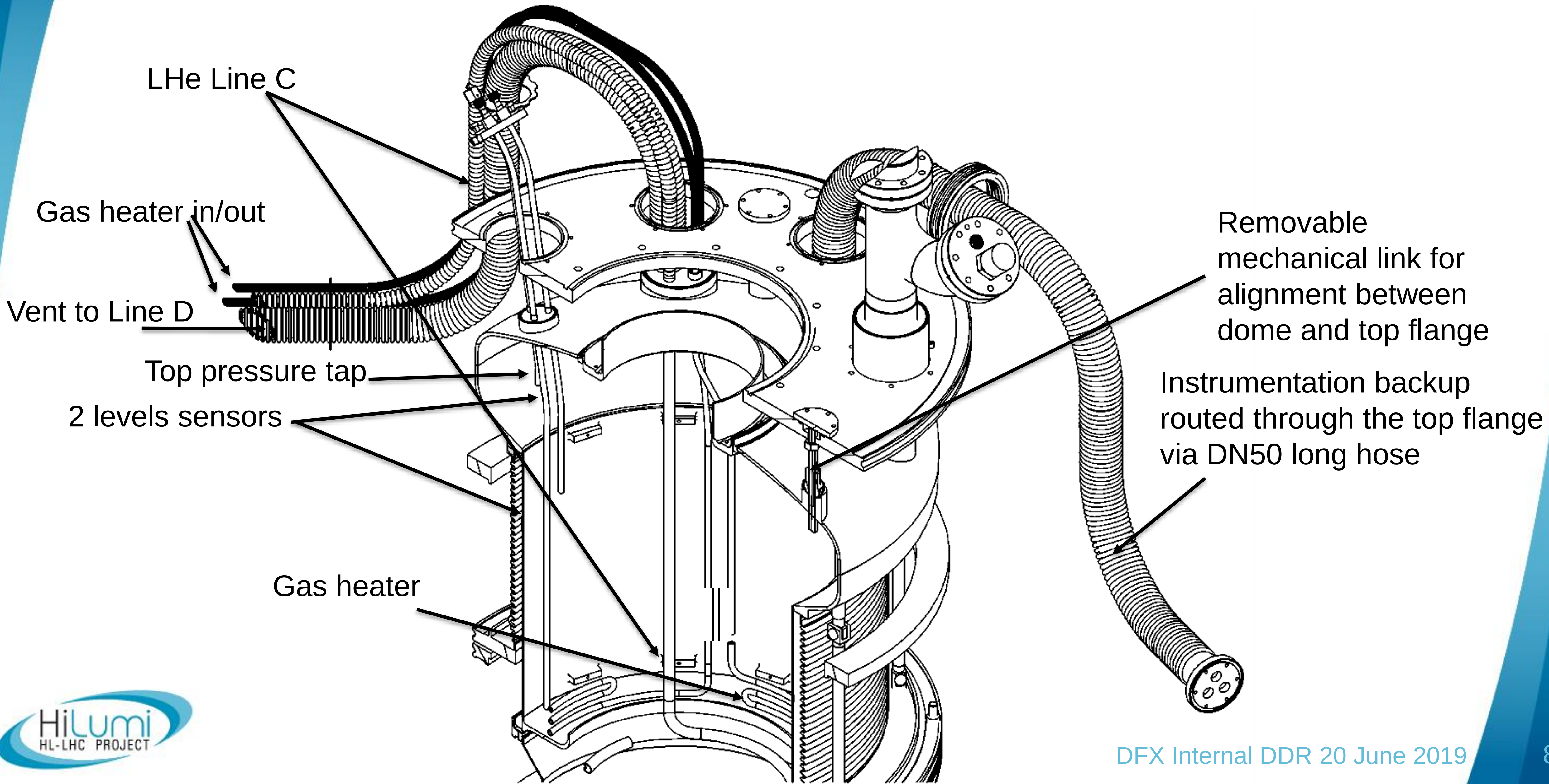
Detailed DFX Schematics: Vertical Inner Overview



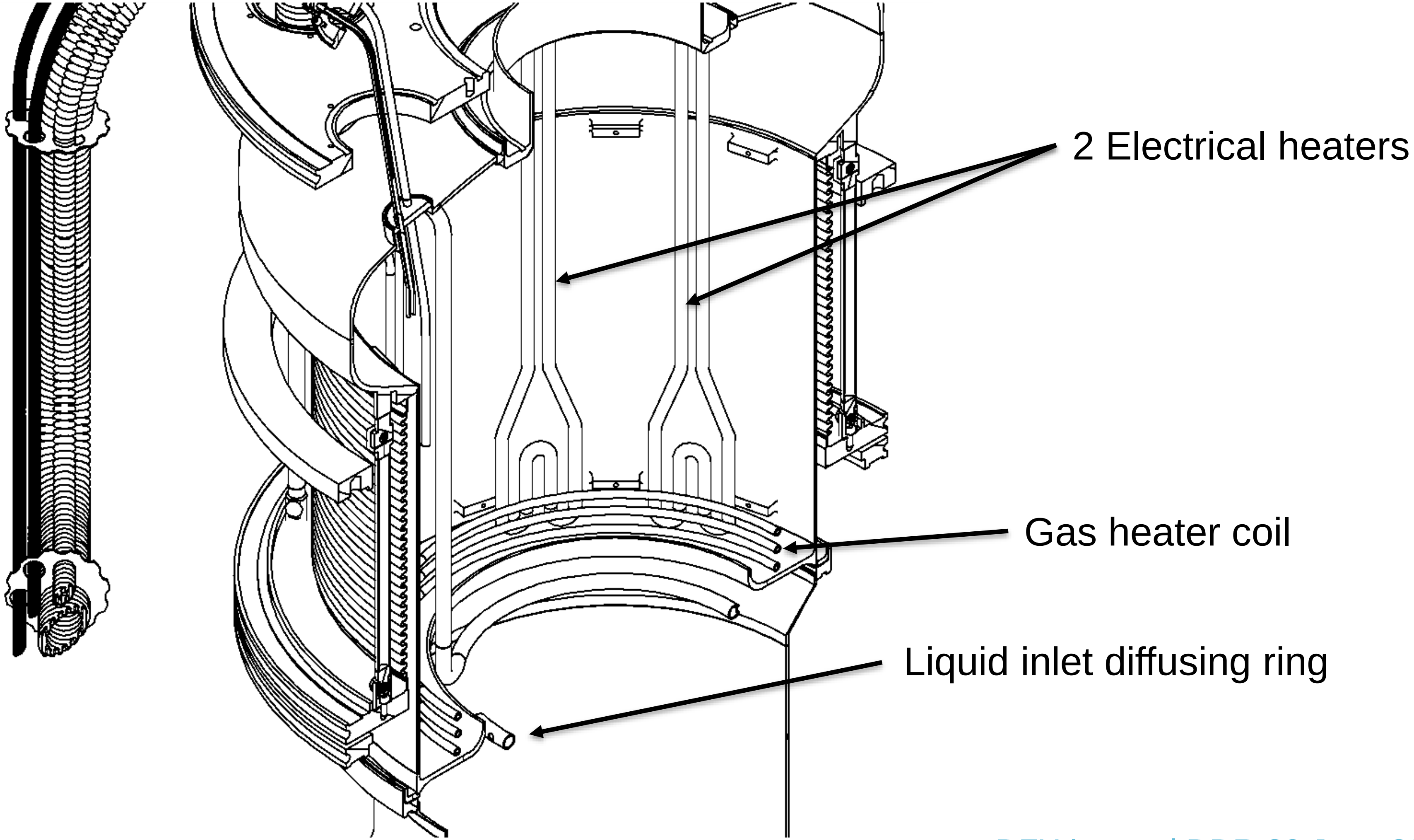
Detailed DFX Schematics: Vertical Inner Dome



Detailed DFX Schematics: Vertical Inner Interfaces



Detailed DFX Schematics: Vertical Inner LHe Fill and Heater Details



Detailed DFX Schematics: Vacuum break

Due to the shortening of the mid-section of DFX vertical, the length of the vacuum break also shorten, impacting on its contribution to the total heat load

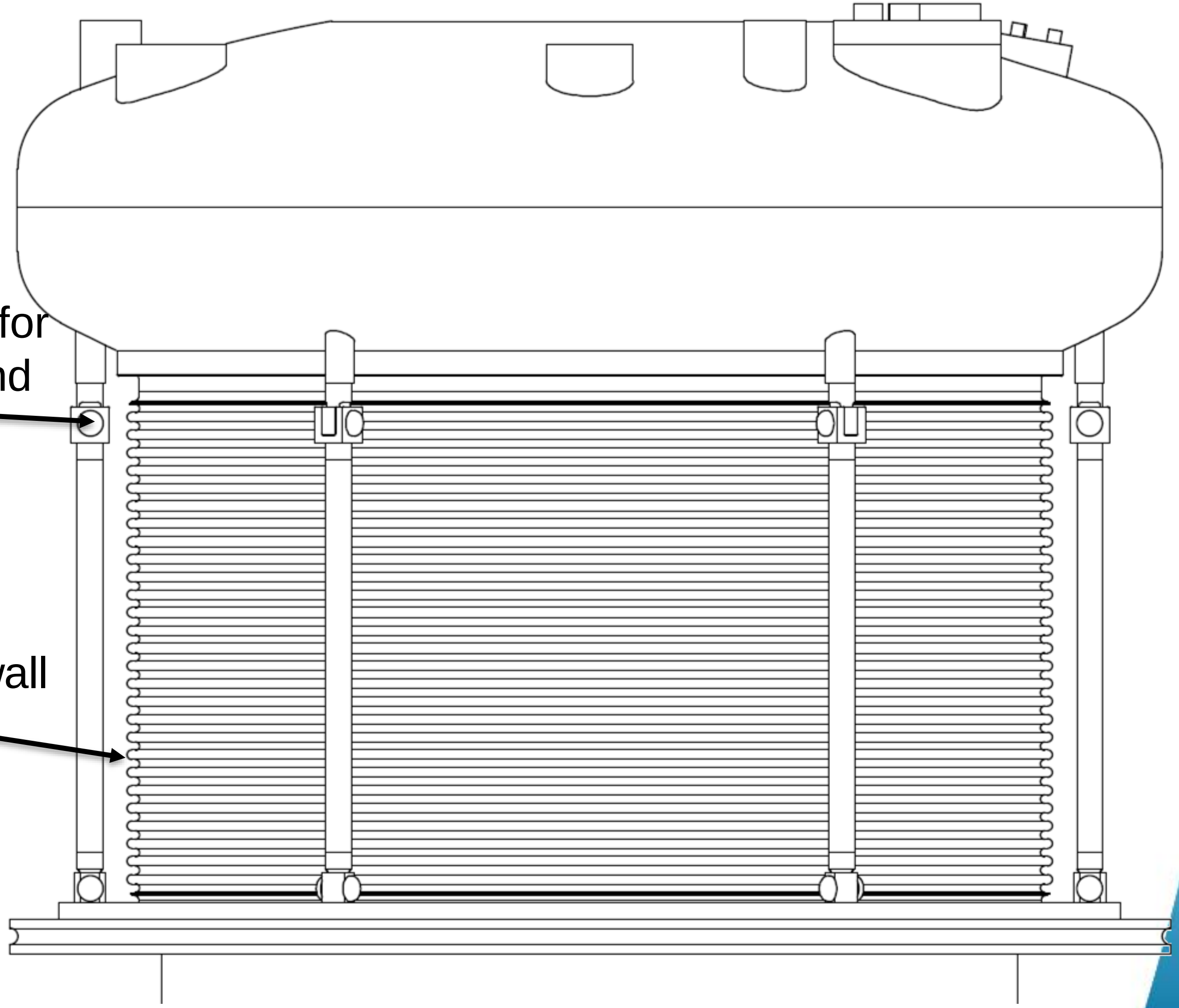
Because it has a large outer diameter (~560 mm), reducing its wall thickness made it subject to buckling

A convoluted profile was adopted to Increase the effective length whilst increasing its thickness

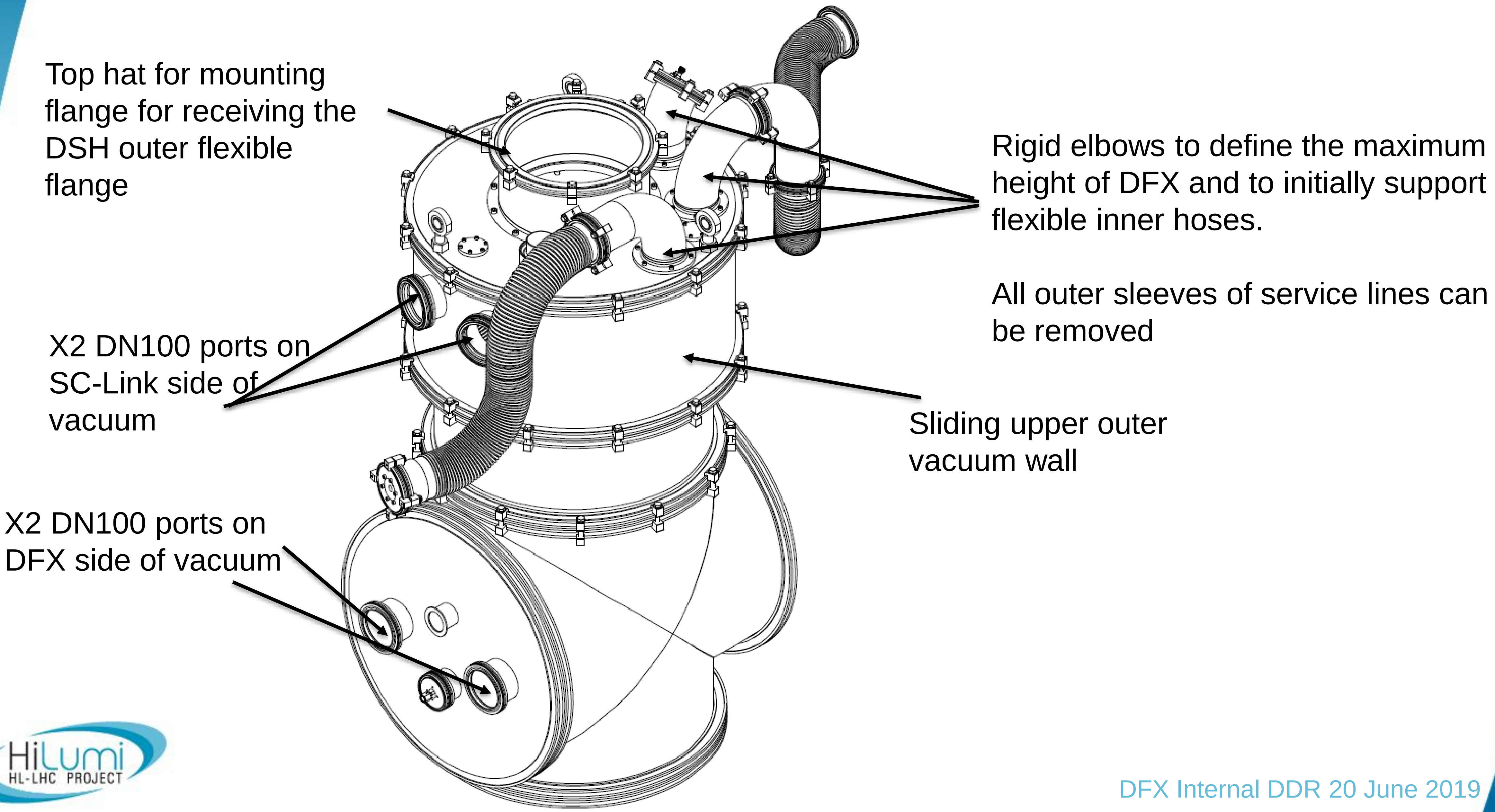
Pillars give the assembly additional rigidity forming a “cage structure” with minimal cost on heat load

Cylindrical pinned joints for installation and absorbing contraction

Convoluted wall 0.5 mm



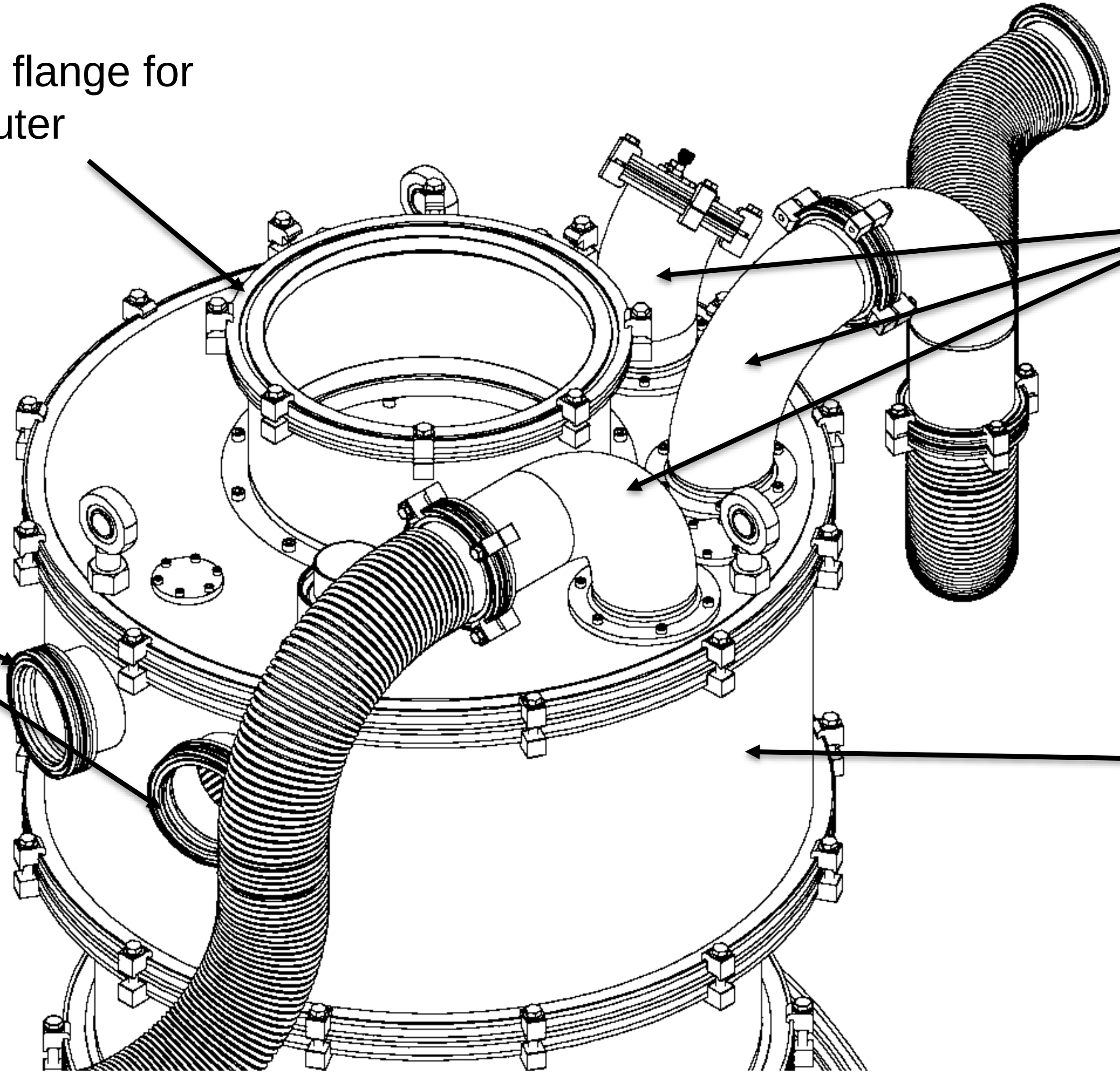
Detailed DFX Schematics: Vertical Outer – Vacuum envelope



Detailed DFX Schematics: Vertical Outer Interfaces

Top hat for mounting flange for receiving the DSH outer flexible flange

X2 DN100 ports on SC-Link side of vacuum

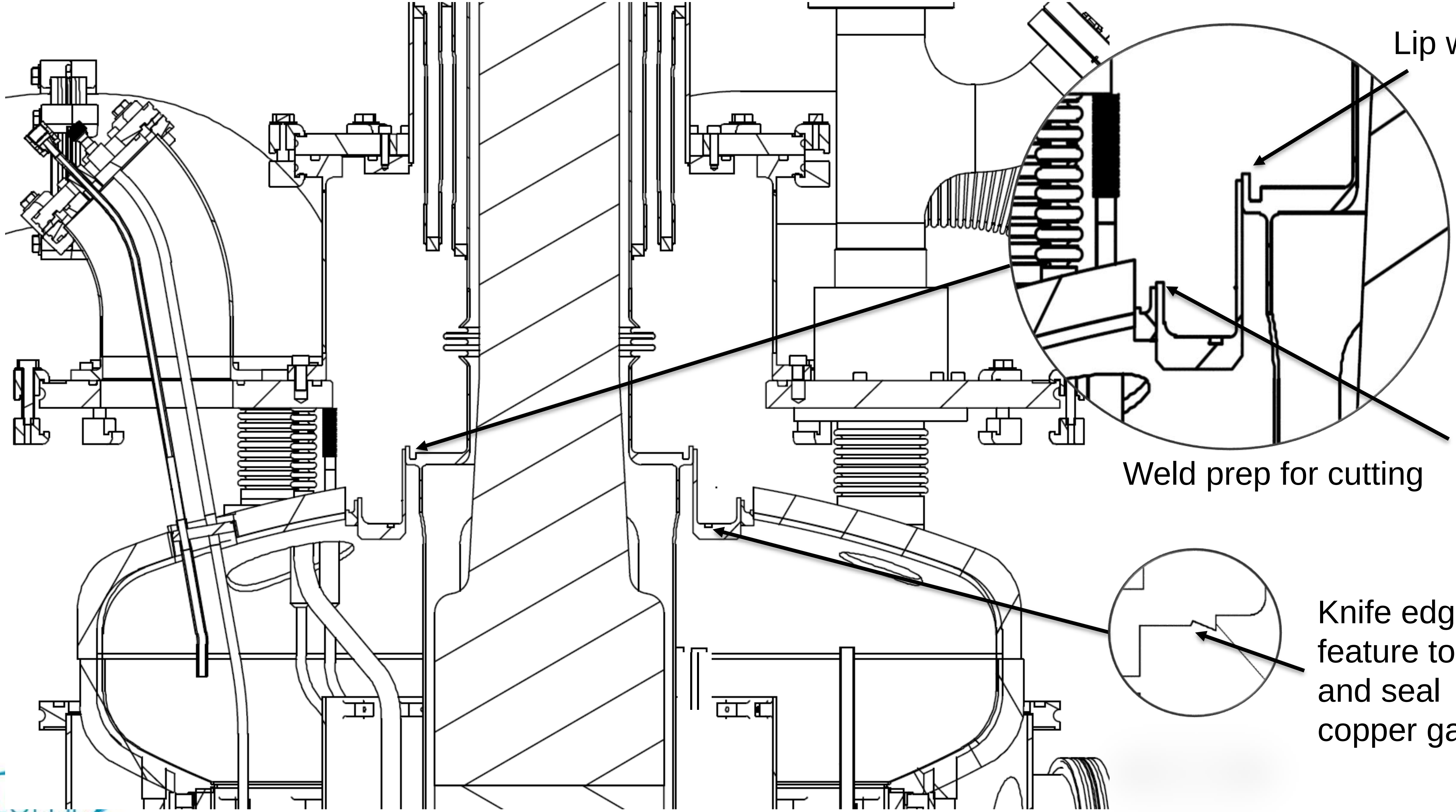


Rigid elbows to define the maximum height of DFX and to initially support flexible inner hoses.

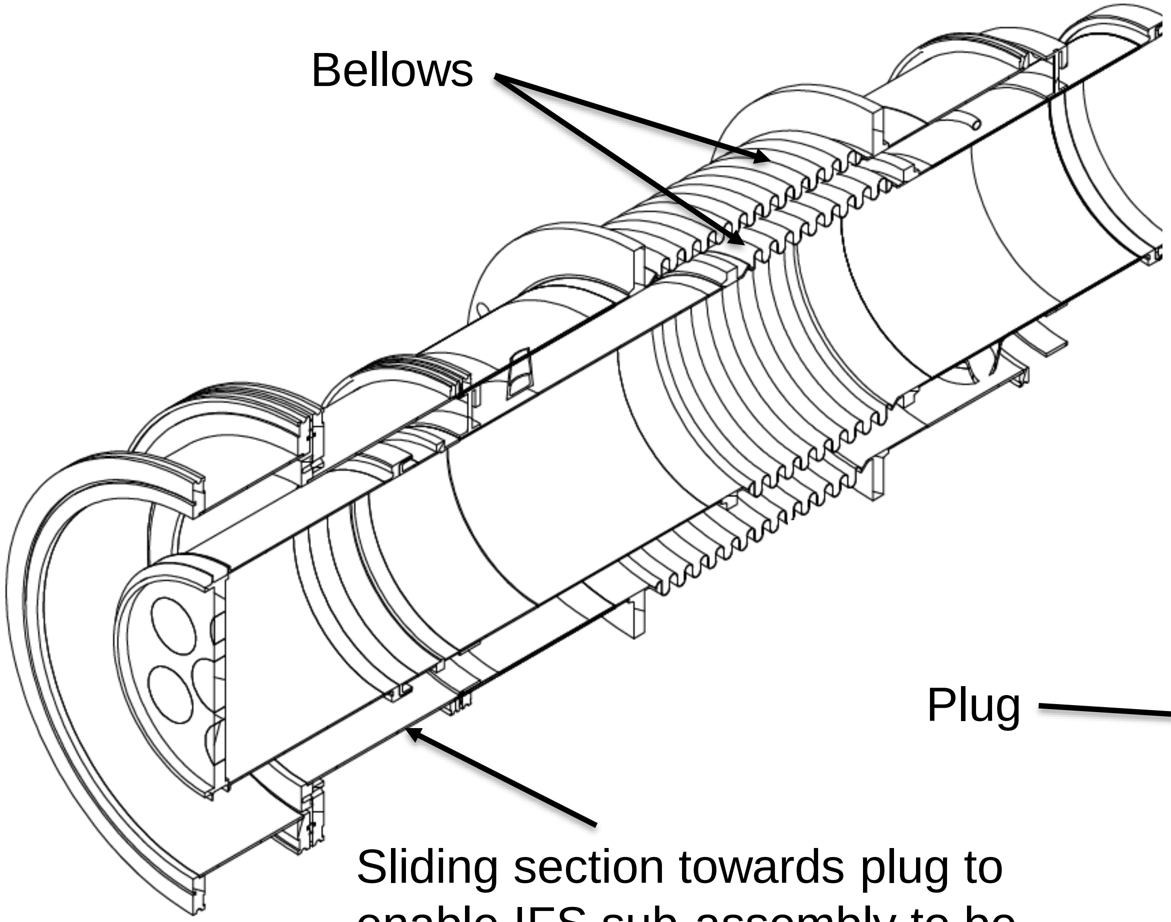
All outer sleeves of service lines can be removed

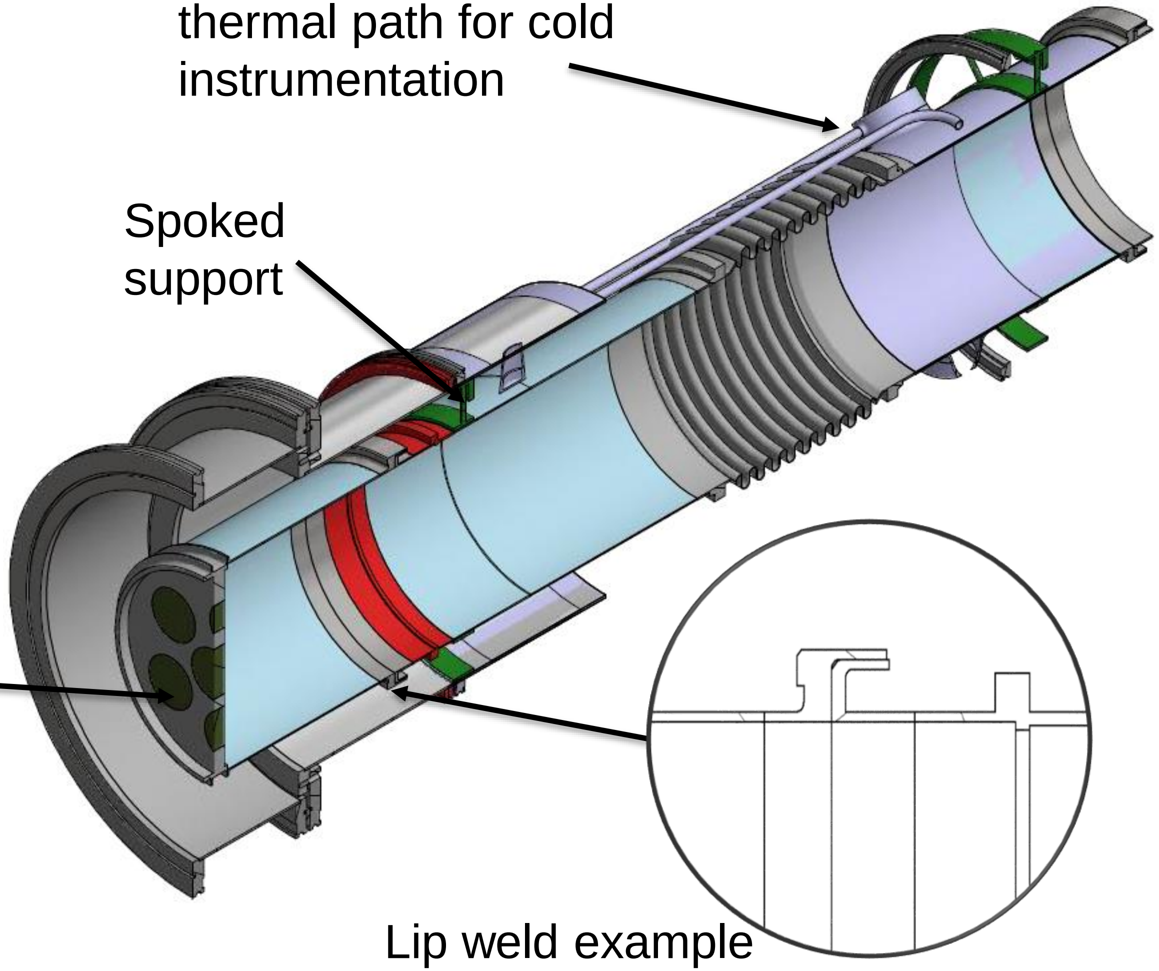
Sliding upper outer vacuum wall

Detailed DFX Schematics: Vertical inner to SC-Link

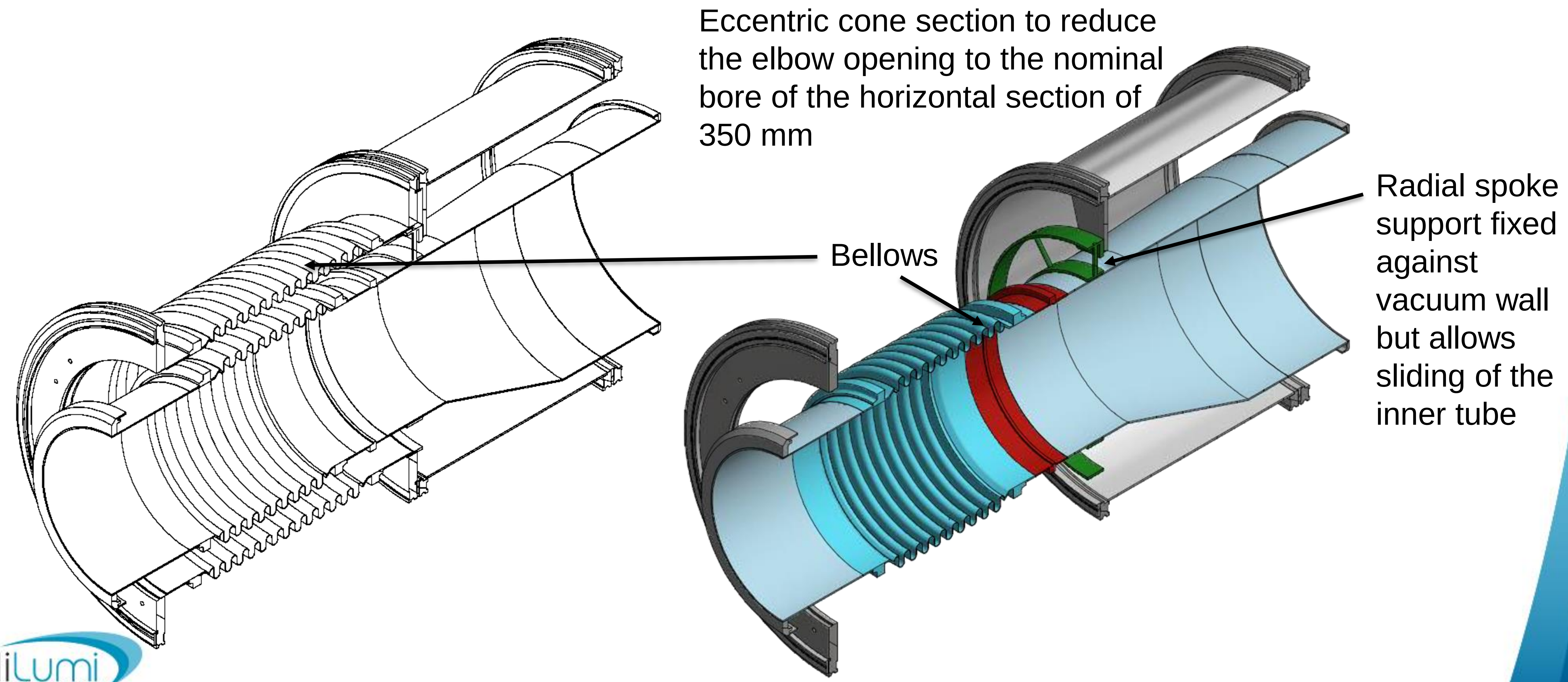


Detailed DFX Schematics: Horizontal Section 1 – IFS sub-assembly and plug





Detailed DFX Schematics: Horizontal Section 2 at SC-Link End

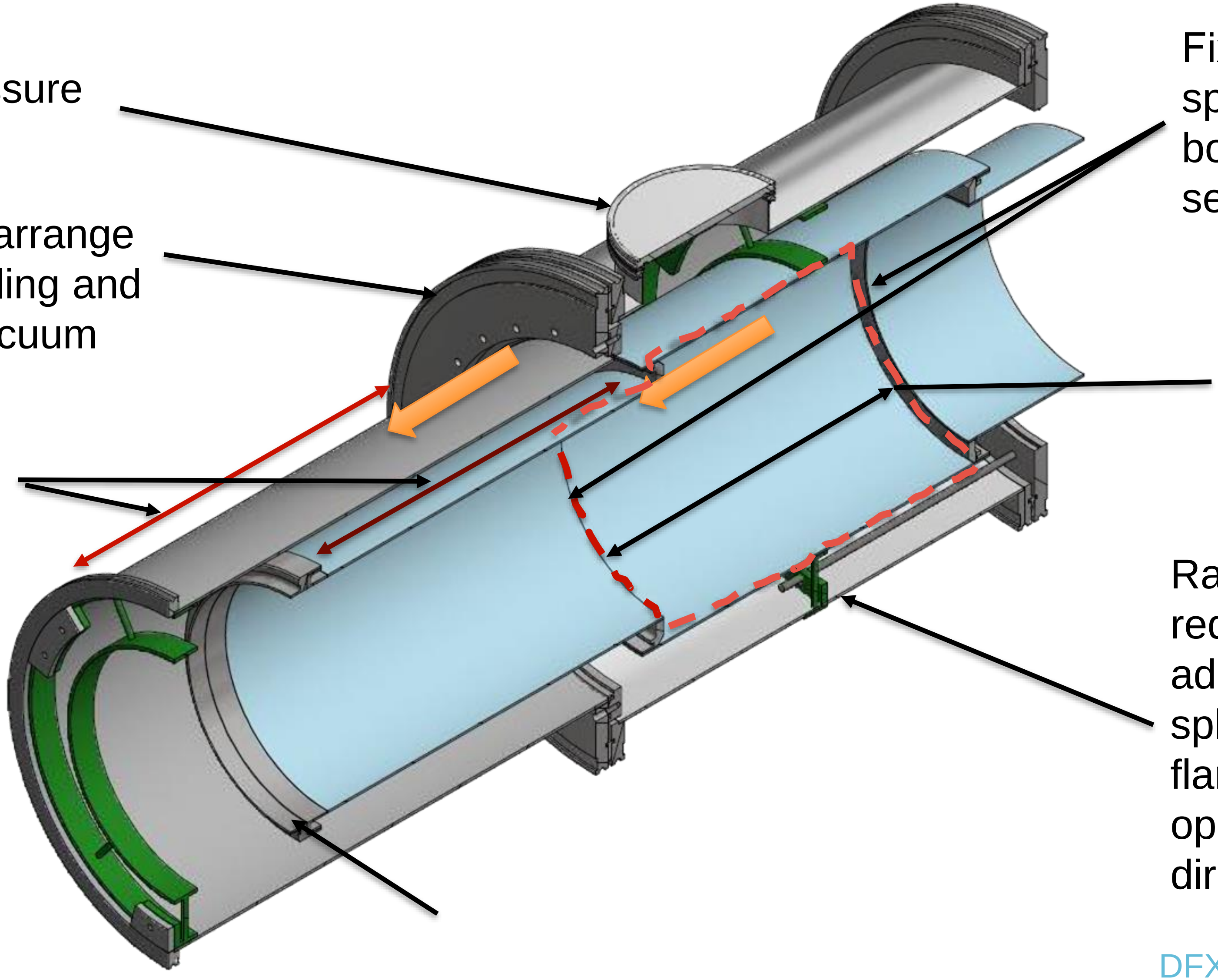


Detailed DFX Schematics: Horizontal Section 3 – Splice box

Standard DN200 vacuum overpressure plate

Floating flange arrange to allow decoupling and sliding of the vacuum wall

Reservation for parking tubes when splices exposed



Fixing “ears” to support the splices in this located within the bore of the neighbouring tubes sections

Red dashed zone = reservation for splice

ID = 425mm
length 500mm

Radial spoke support required to support the additional weight of the splices and fixed to the flange on the side opposite to sliding direction via studs

Modes of Operations and Safety

- Commissioning:
  - Differential pressure of 1atm across the vacuum barrier
  - Venting of GHe from DFX to Line D in cooling down
- Nominal operations
  - 1.3bar LHe feed from Line C
  - Nominal currents in SC-Link, plug, and LTS bus-bars
- Controls
  - GHe flow rate into DSH for DFH splice temperature and current lead temperature
  - LHe level
- Abnormal conditions
  - Stop of LHe supply for 10min at $5gs^{-1}$ or 5min at $10gs^{-1}$
  - Safety device triggered at 2.5bar in liquid vessel

Design Studies

- Mechanical
  - Vacuum scenarios
  - Pressure scenarios
  - Differential thermal contraction
  - Static loads
- Thermal
  - Conduction heat loads
  - Radiation heat load

Design Studies: Vacuum Scenarios

The feature most susceptible to collapse under different vacuum conditions is the vacuum break; thus required further study

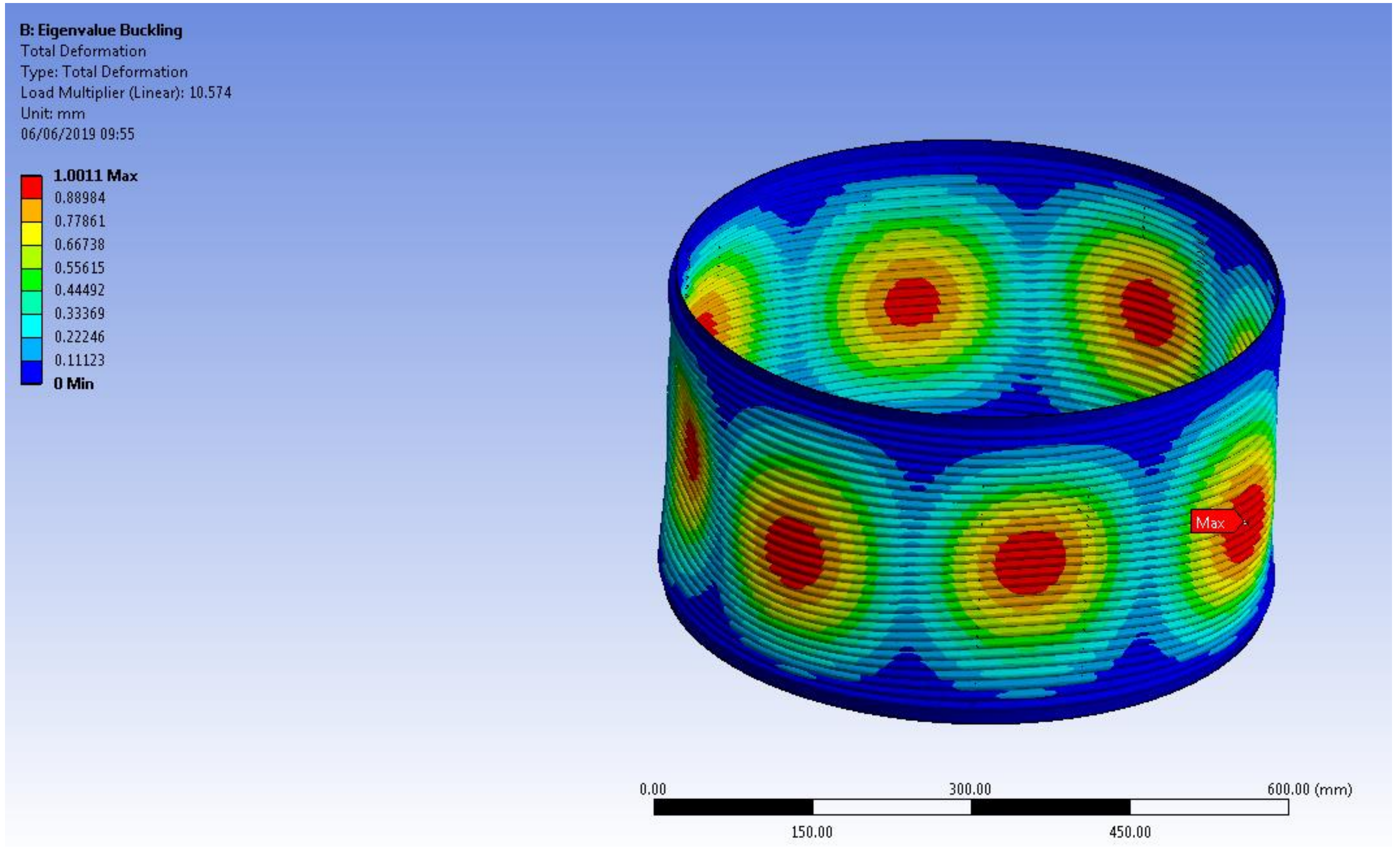
Eigenvalue buckling function deployed in ANSYS to inspect behaviour in under 2 conditions to obtain the load factor

- External pressure 1 bar, (i.e. Loss of vacuum in SC-Link side, whilst preserving the vacuum in DFX side)
- Internal pressure 1 bar, (i.e. Loss of vacuum in DFX side, whilst preserving the vacuum in SC-Link side)

Vacuum break consist of fully convoluted wall to add inherent stiffness, whilst providing licence to reduce the wall thickness to manage heat leak

Design Studies: Vacuum Scenarios

A convoluted 0.5mm thick vacuum membrane is able to withstand the pressure differential with a satisfactory load factor



<u>Conditions and parameters</u>

External pressure = 1 bar
Thermal conditions = +22 ^{o}C

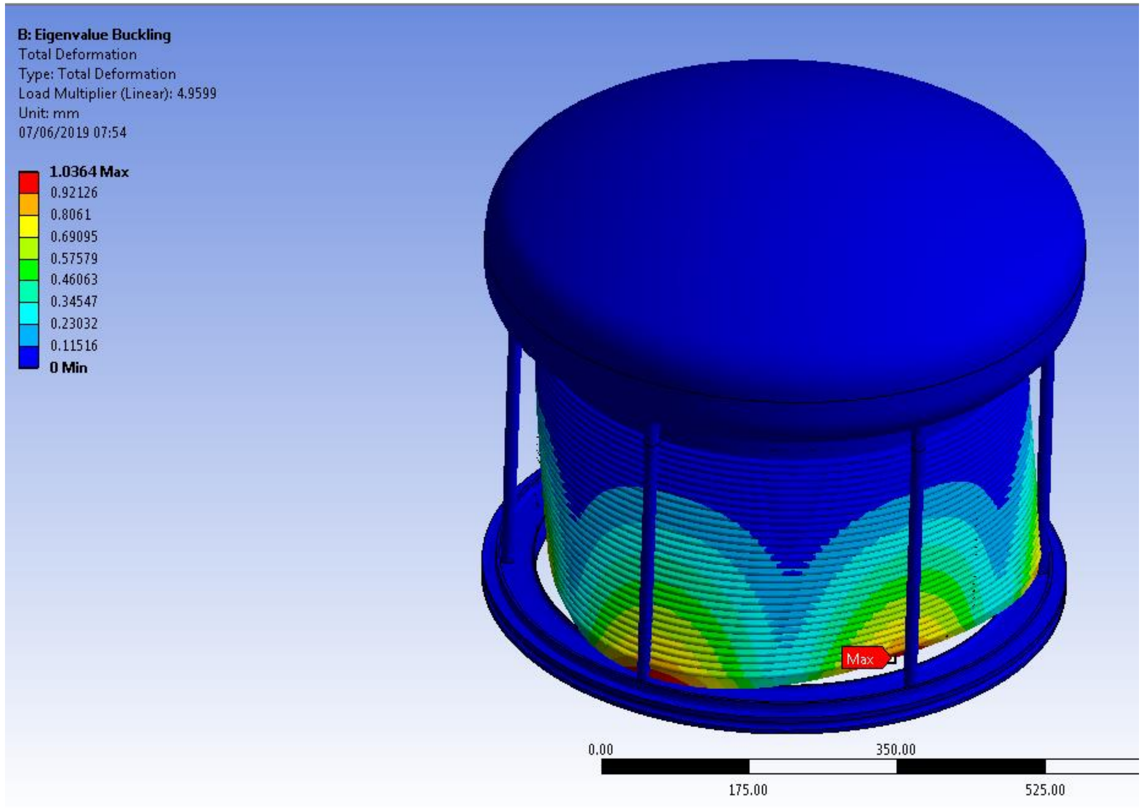
Wall thickness of convolutions = 0.5 mm
Rigidly at both ends

LOAD FACTOR = 10.57 = Safe

Design Studies: Vacuum Scenarios

Integration of vacuum break with real flanges and domes

Rigid studs between the dome and the room temperature flange do not provide a sufficient load factor for the 0.5 mm convoluted vacuum membrane



<u>Conditions and parameters</u>

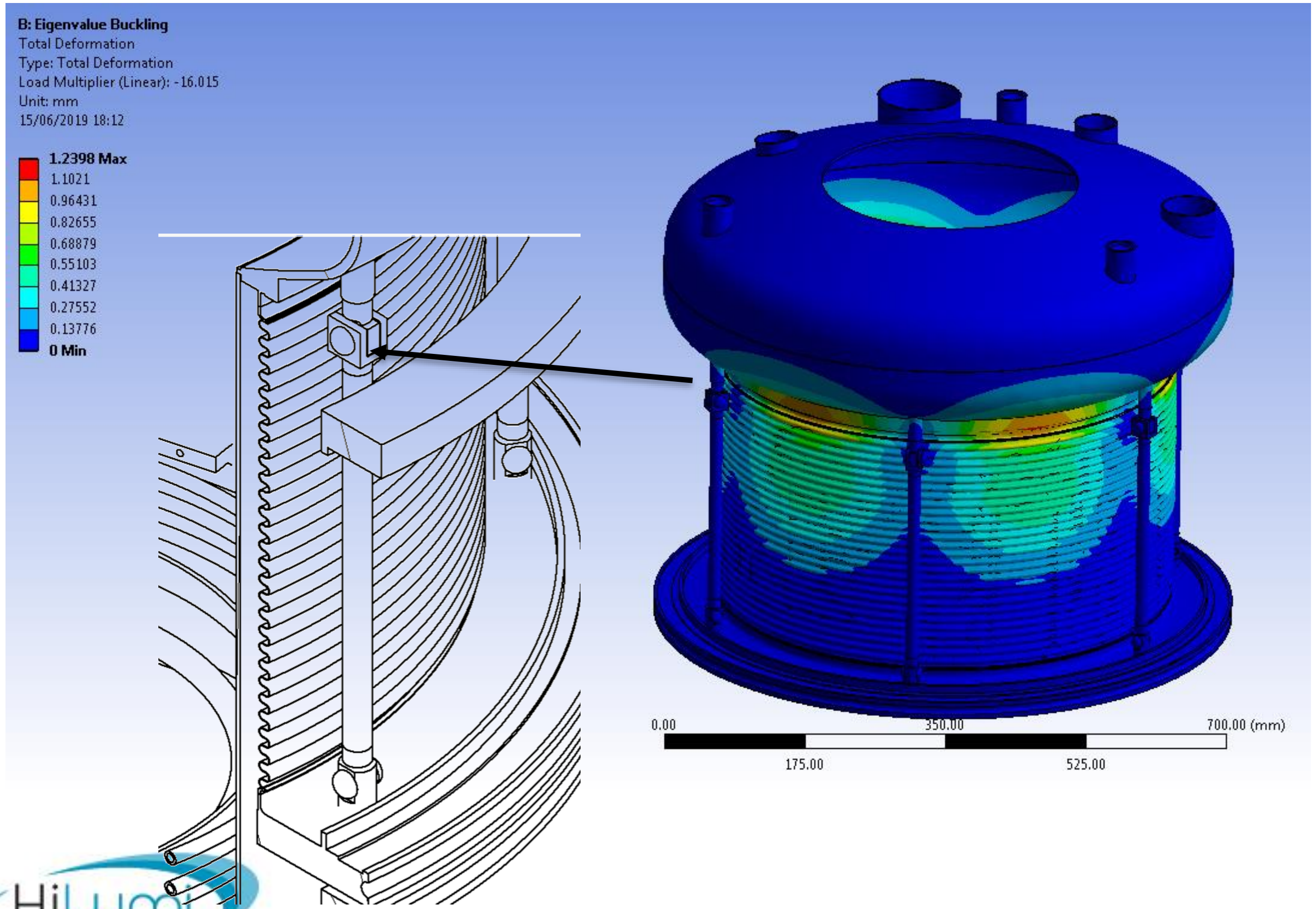
External pressure = 1 bar
Thermal conditions = +22 ^{o}C

Wall thickness of convolutions = 0.5 mm
Stainless steel pillars = 12 mm OD x 2 mm wall

LOAD FACTOR = 4.96 = on the limit
LOAD FACTOR 5 = lower limit

Design Studies: Vacuum Scenarios

Use of cylindrical pin joints increases the load factors to a satisfactory level



<u>Conditions and parameters</u>

External/internal pressure = 1 bar
Thermal conditions = -269 ^{o}C

Wall thickness of convolutions = 0.5 mm
Stainless steel pillars = 16 mm OD x 1.2 mm wall

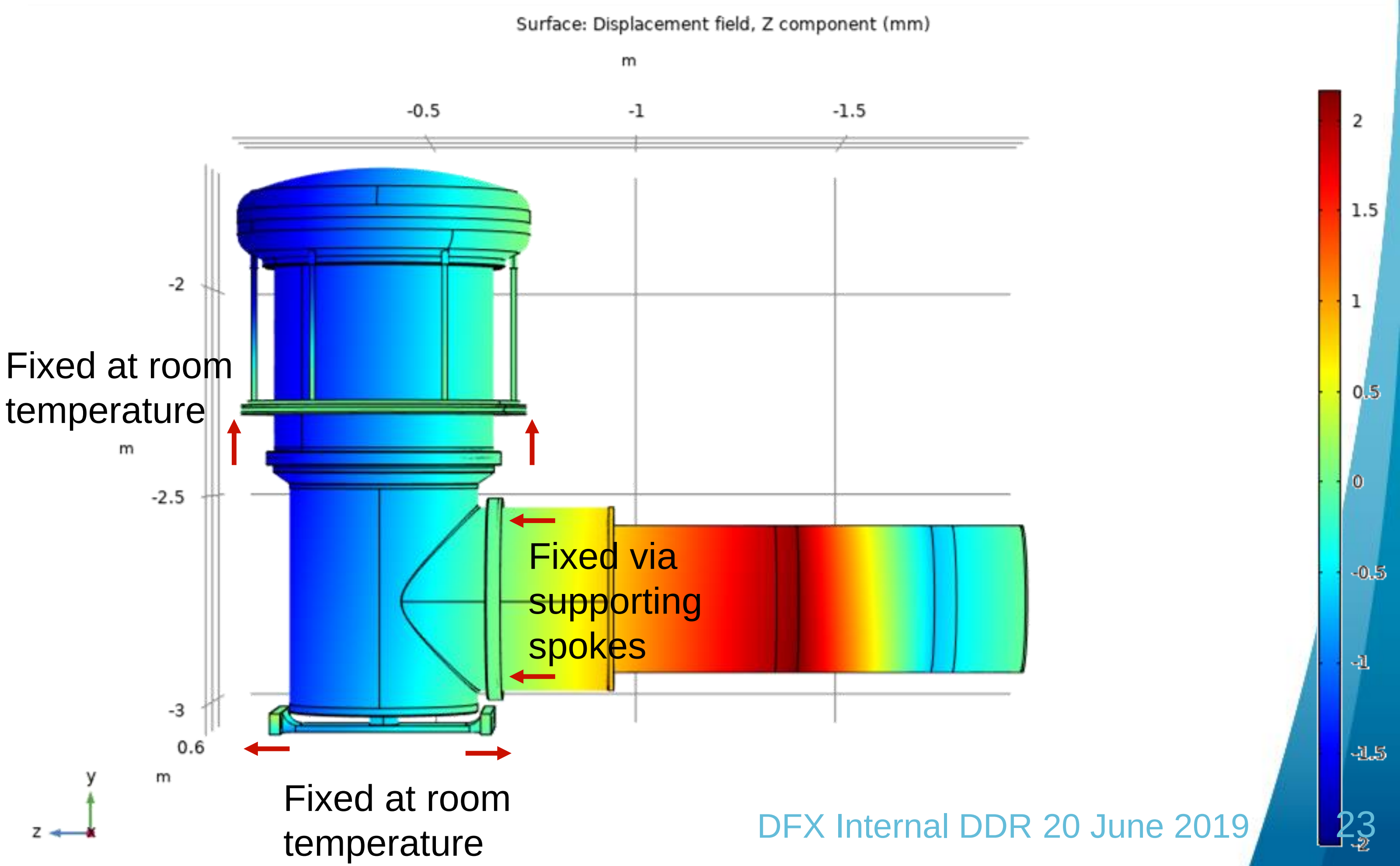
LOAD FACTOR = 14.7 = external pressure
LOAD FACTOR 16.0 = internal pressure

Design Studies: Thermal Contraction

The longitudinal contraction of the horizontal section are taken up by the bellows (90N/mm)

Horizontal support for the vertical section located symmetrically without imposing differential constraints

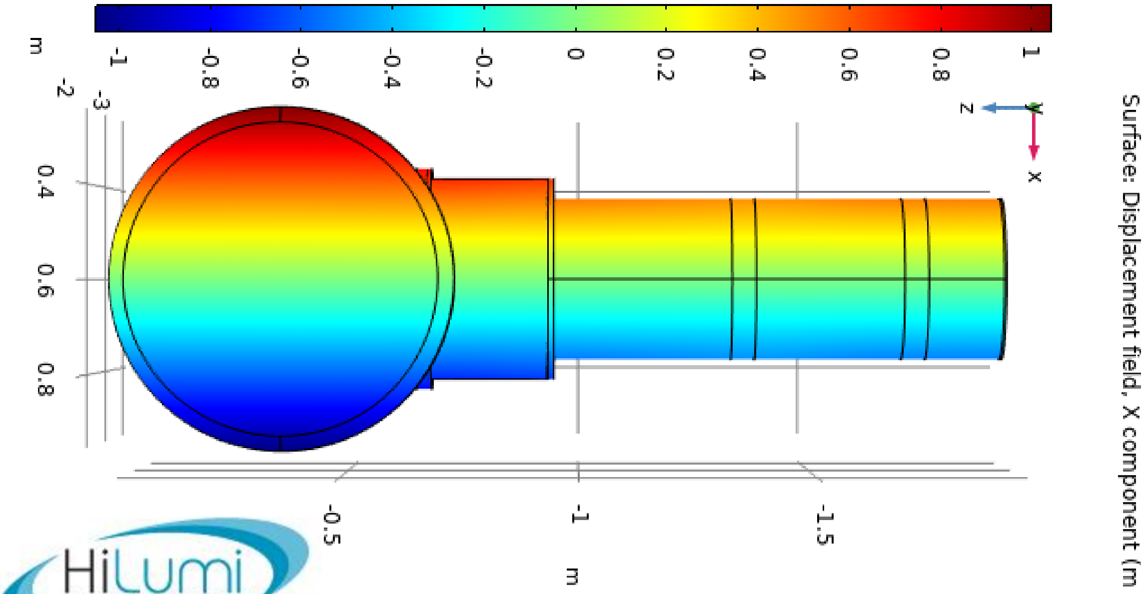
The outer boundary of the vertical vessel contracts 1.3mm in the horizontal direction

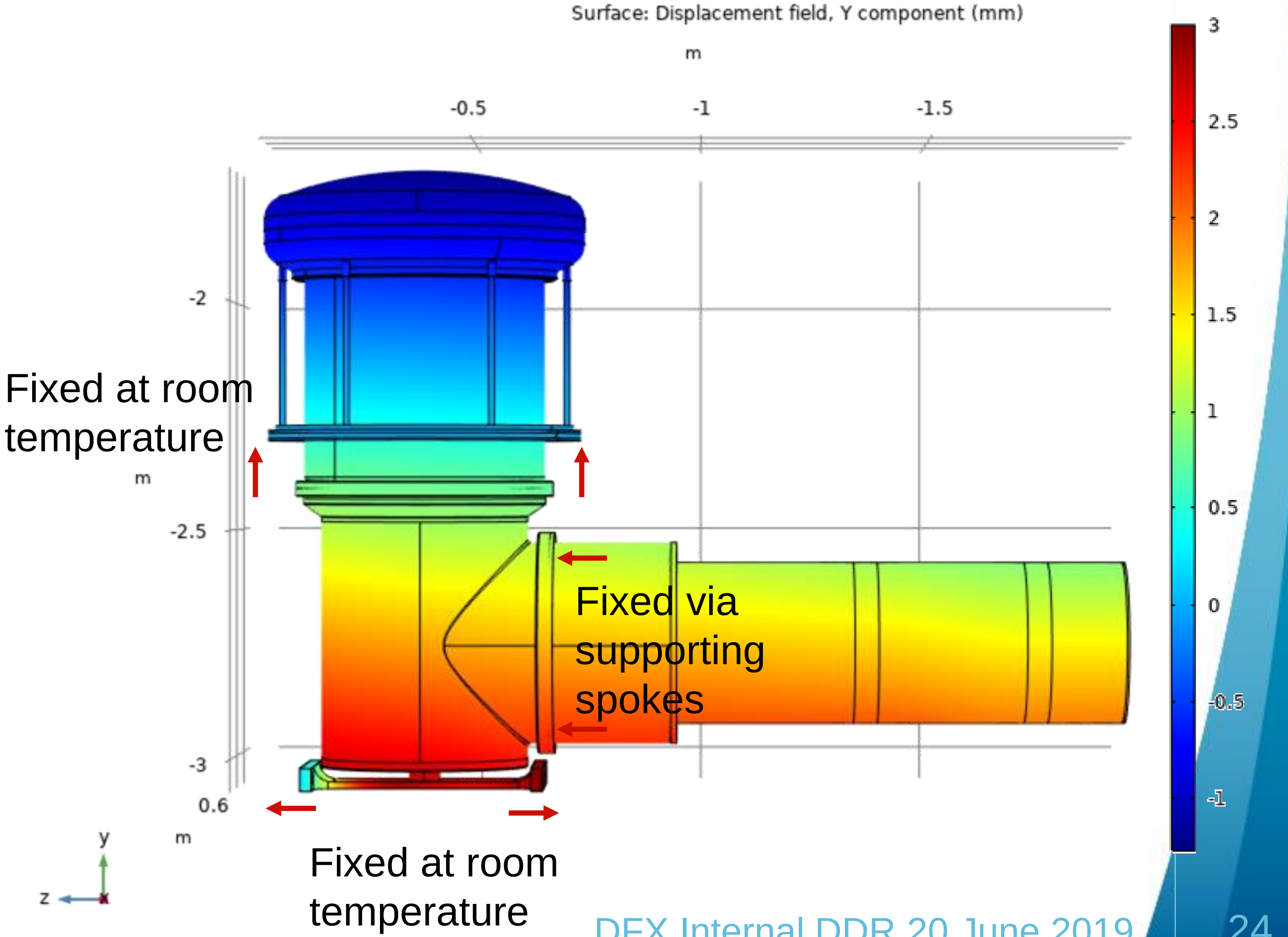


Design Studies: Thermal Contraction

The vertical section contracts 3mm vertically towards the room temperature plane of the vacuum break

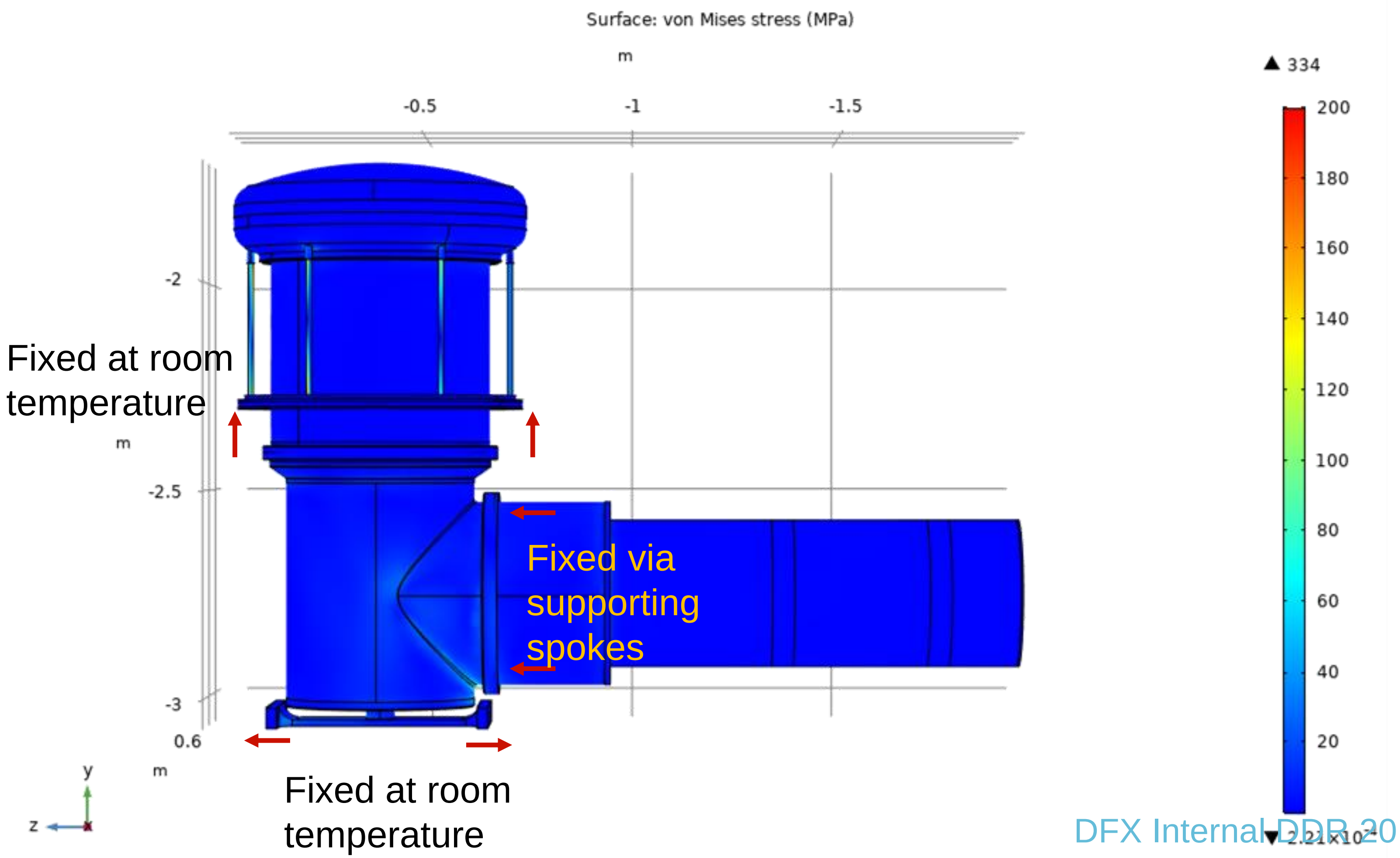
The vertical section contracts 1mm in the transverse horizontal direction towards the longitudinal axis





Design Studies: Thermal Contraction

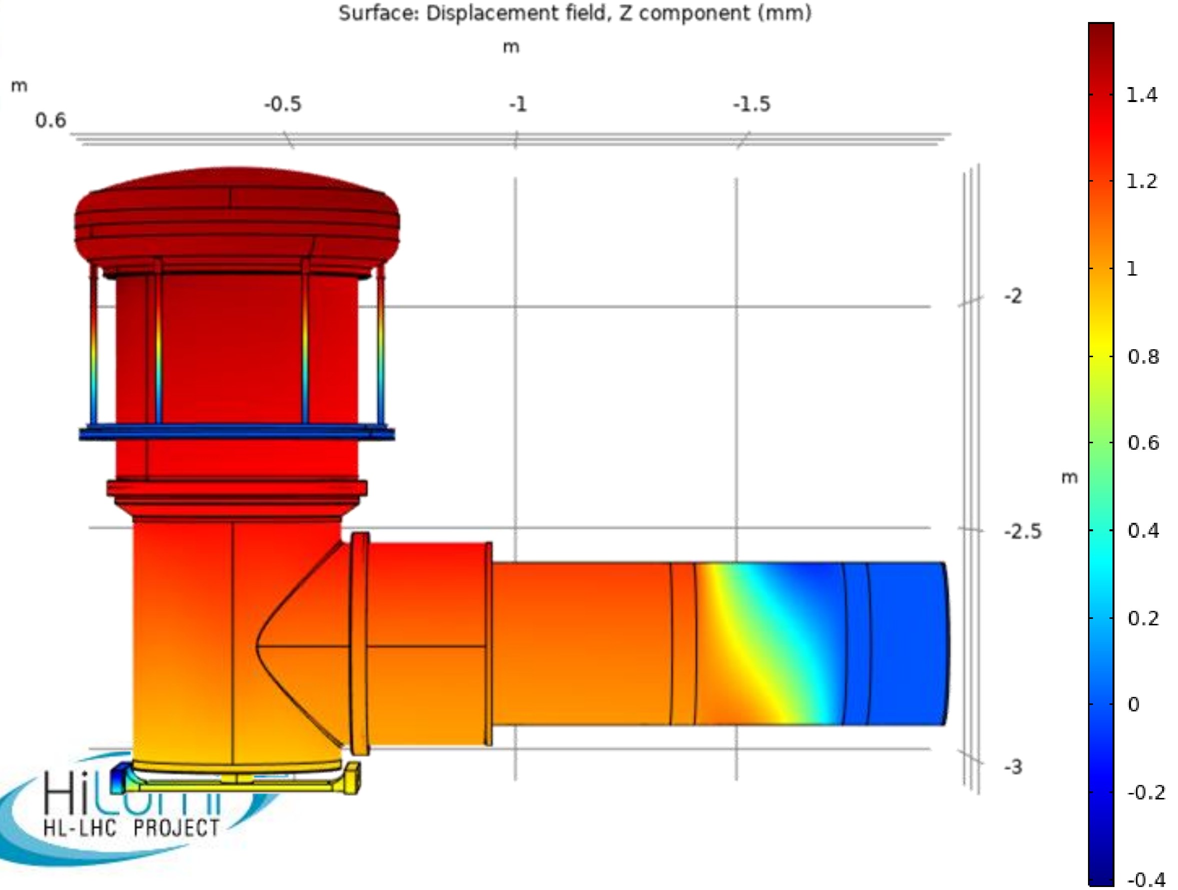
Stress not an issue

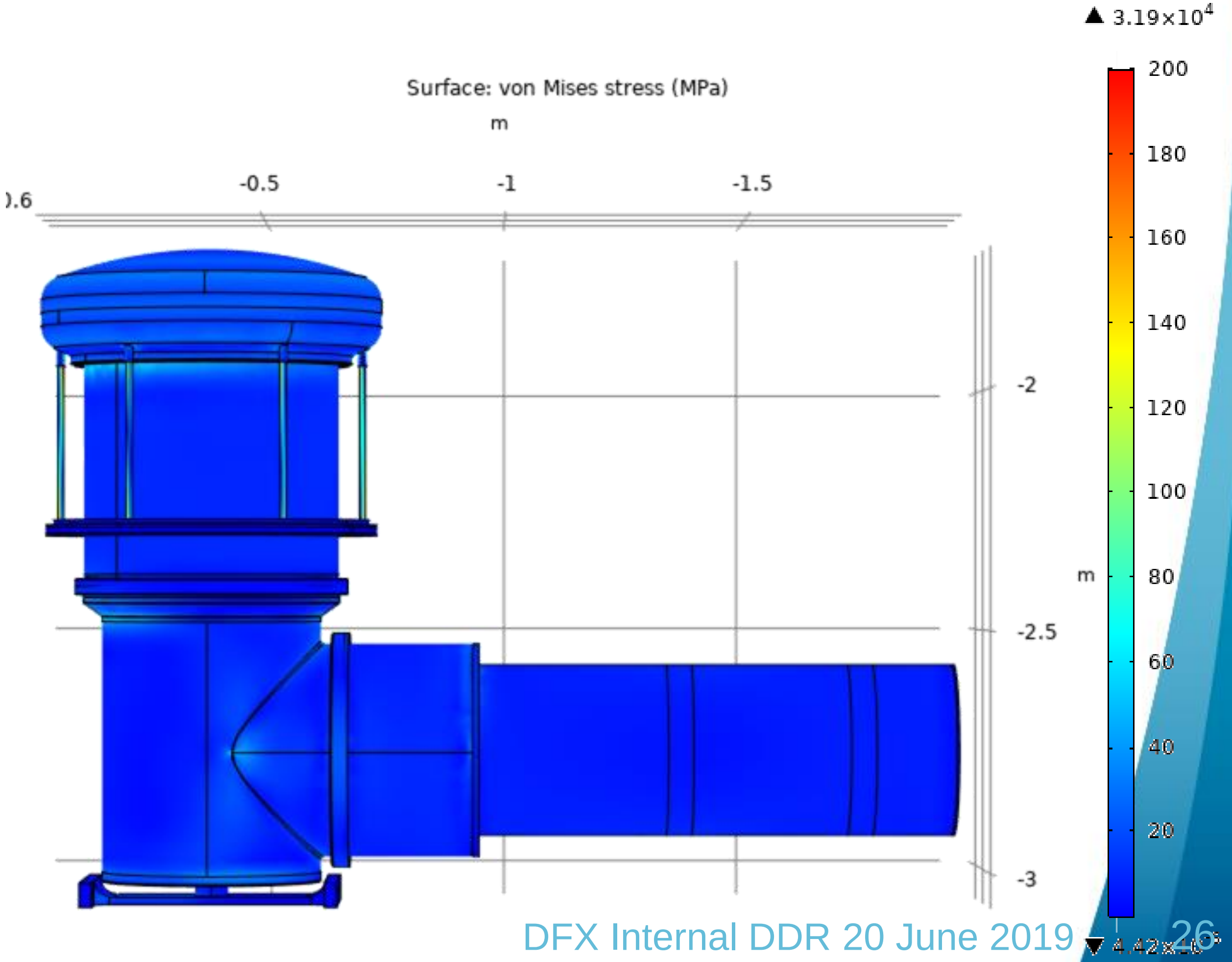


Design Studies: Pressure Scenarios: 1.3bara

At the nominal working pressure of 1.3bara and with the horizontal support, the bellow results in a longitudinal expansion of ~1.3mm at the outer border of the vertical section, which almost compensates the thermal contraction perfectly

Stress well contained

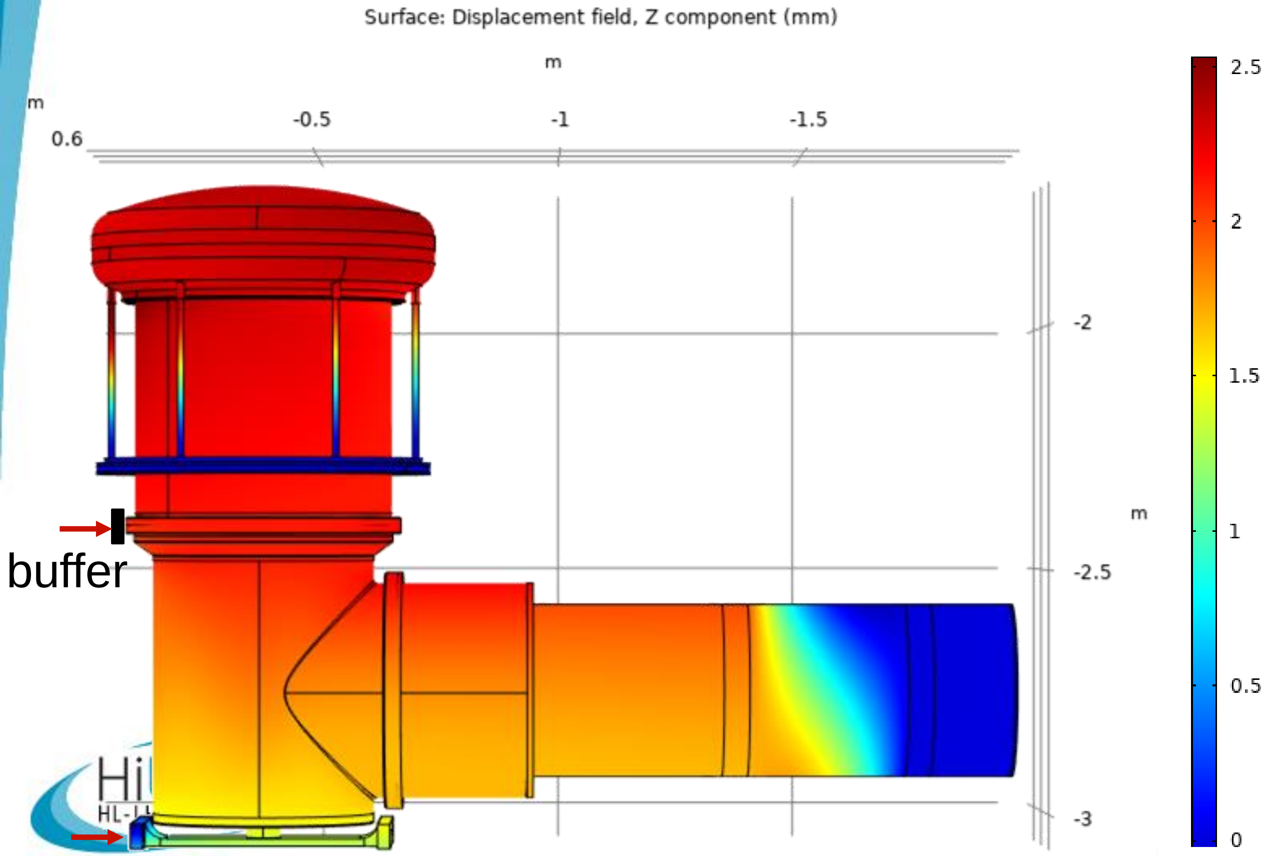


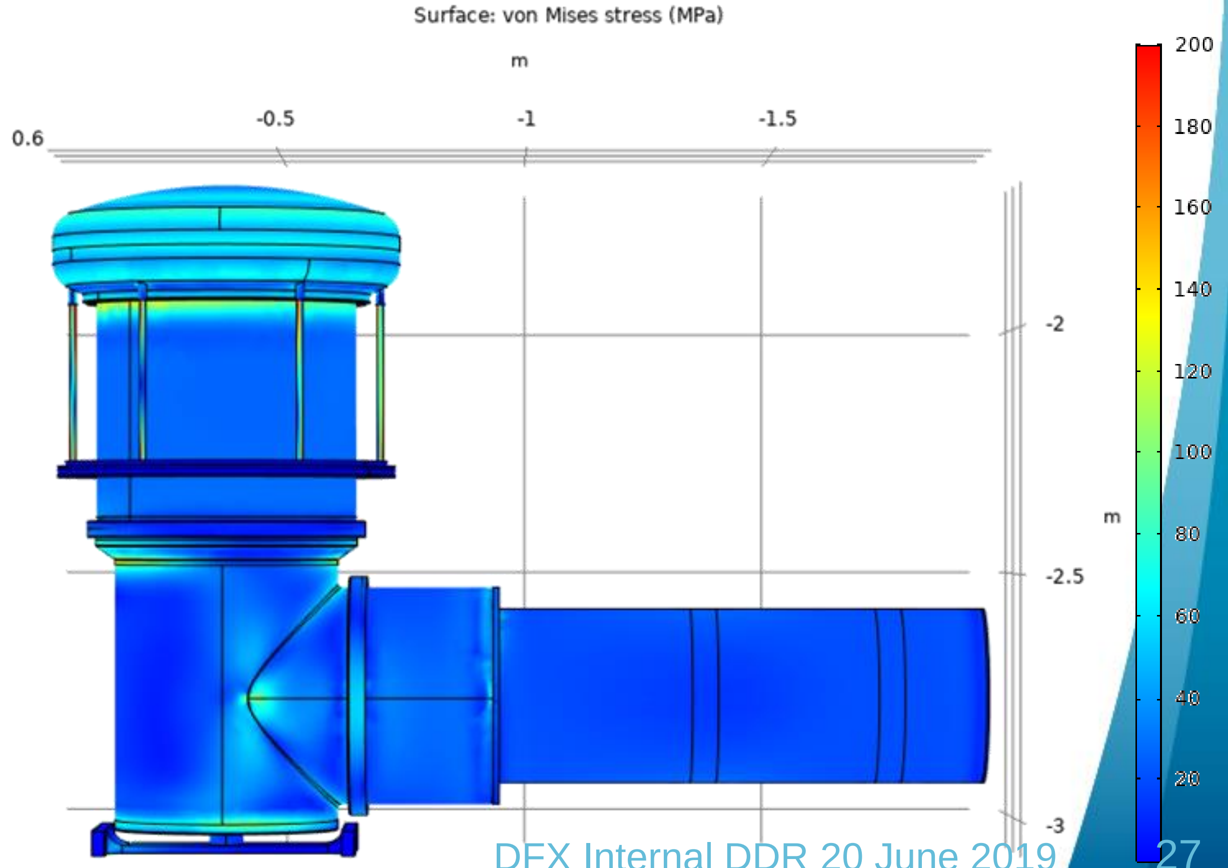


Design Studies: Pressure Scenarios: 3.5bara

At the PED test pressure of 3.5bara, the vertical vessel needs a buffer to limit the bending moment by stopping the longitudinal expansion at 2mm. The buffer is fixed on the vacuum vessel with a nominal clearance of 2mm, which will be confirmed by the mock-assembly test

Mostly bending stress and kept within 130MPa with the buffer





Design Studies: Heat Loads

- Structural
  - Heat conduction by the vacuum break: 3.7W
  - Heat conduction by supporting studs: 2.8W
- Mechanical Support:
  - Heat conduction by spokes 1.4W
  - Heat conduction by horizontal support: 2.3W
- Instrumentations:
  - Heat conduction1-3W
- Radiation (<10m^2) cold area
  - <15W
- Total: <30W

Manufacturing

- Materials: SS316L for Co<0.1%
- Components
  - Mostly tube sections with welded flanges
  - Elbows
  - Domes
  - Bellows
- Sub-assemblies
  - Vertical upper vessels (inner and outer)
  - IFS sub-assembly

QA Plan

- Pressure qualification at required level (3.5bar) of all the parts and components of the DFX liquid helium vessel as a part of component procurement QA. The parts include all the cold tube sections with welded flanges required for integration.
- Pressure qualification at the required level for the DFX sub-assemblies (upper vertical inner vessel and IFS) as a part of the sub-assembly procurement. The sub-assemblies covers all the welded interfaces including the cryolines, safety devices, guiding tubes for level sensors, IFS etc. The interfaces to the SC-Link and lower vertical elbow will be blanked.
- Cryogenic shock test, vacuum tightness test, and pressure verification of mock assembled DFX module. The welding to be performed by CERN during LHC tunnel integration will be clamped via metal O-rings.
- Independent welding method qualification for the welding to be performed in situ by CERN in the LHC tunnel. Sample welding will be made according the mechanical design approved by CERN. The welded samples will be pressured tested and cut, if necessary re-welded and retested.

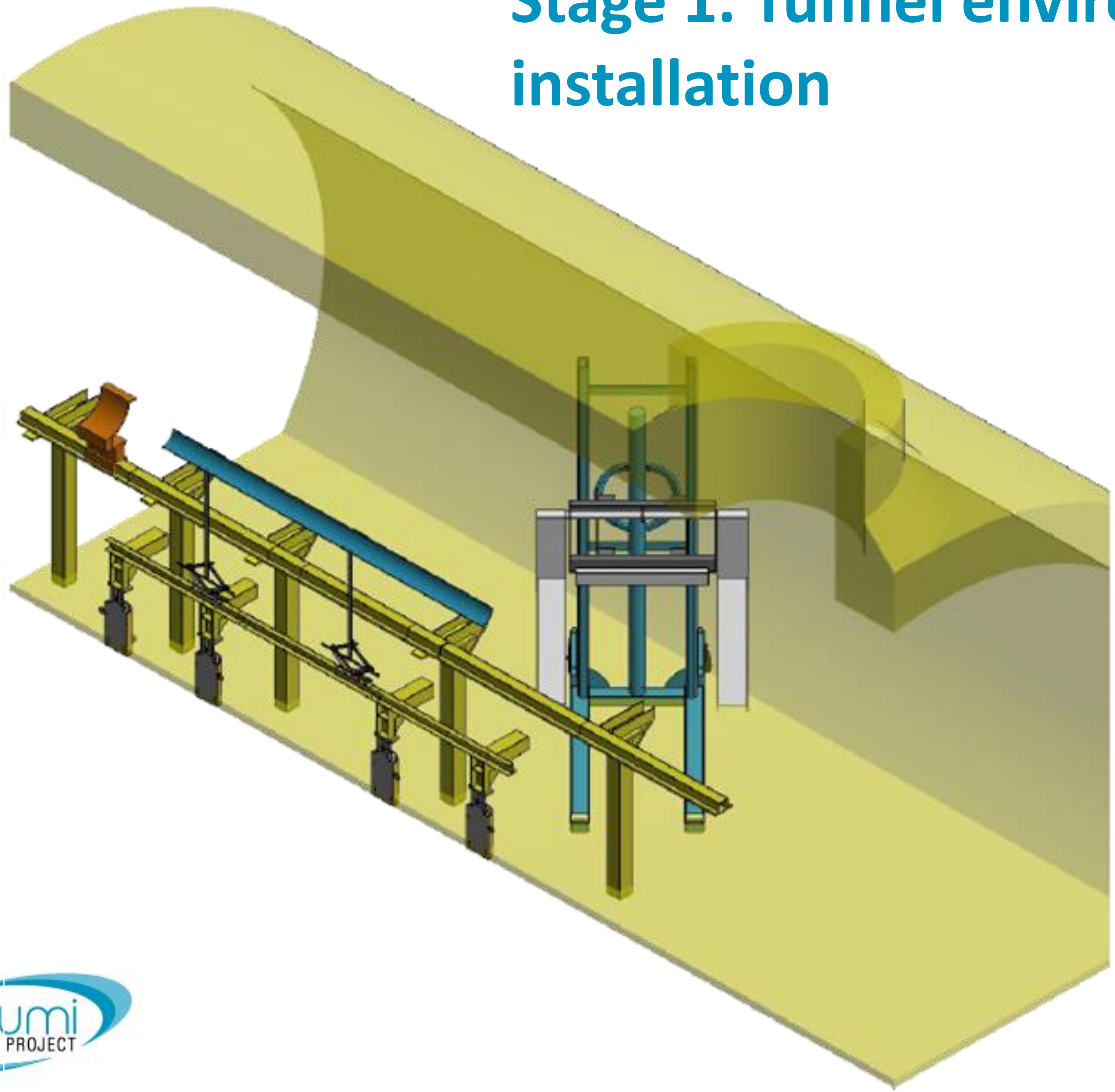
Testing and Delivery

- Cold vessels assembled by clamping together the metal gasket provisions
- Contained in the fully assembled vacuum vessels
- Vacuum tightness test, cryogenic shock test, and pressure test at 3.5bara in the cold vessel
- Mechanical and displacement measurements for the management of thermal contraction and pressure load

Assembly in Five Stages

- Stage 1: Assembling the horizontal section at the plug end
- Stage 2: Assembling the vertical DFX and integrating of the SC-Link
- Stage 3: Assembling the horizontal section at the SC-Link end
- Stage 4: Splicing LTS bus-bars
- Stage 5: Finishing the assembly with the splice window closed

Stage 1. Tunnel environment – Preparation for installation

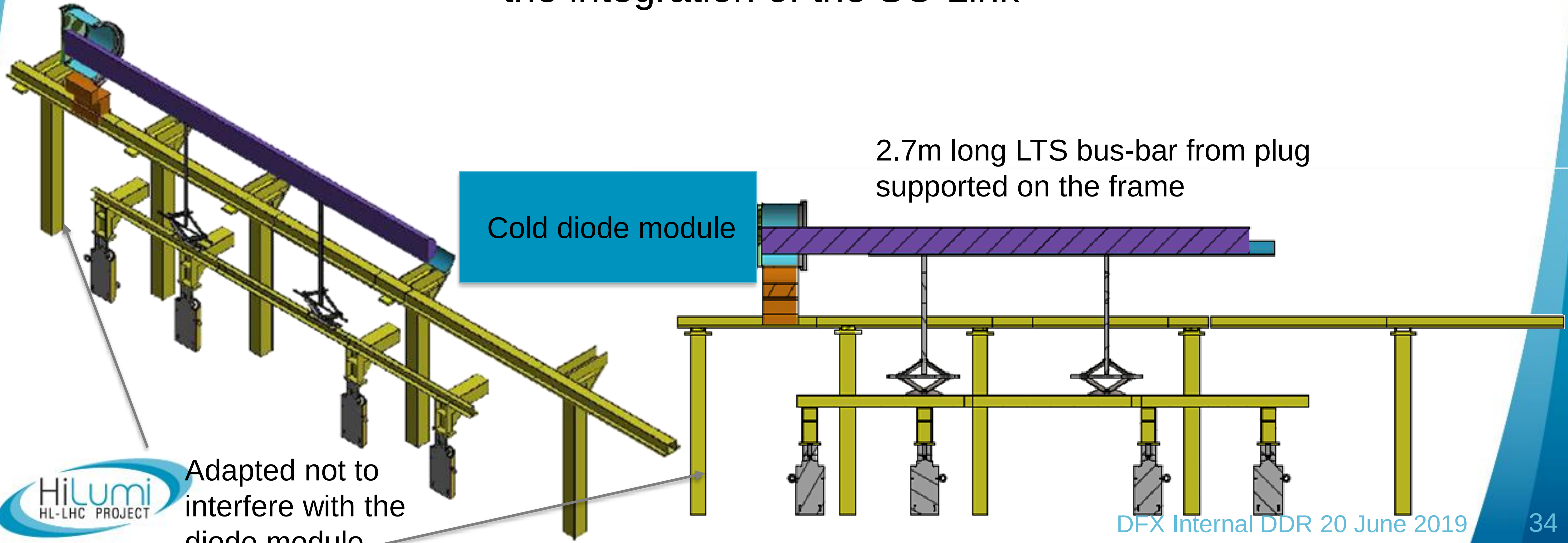


No beamline in position

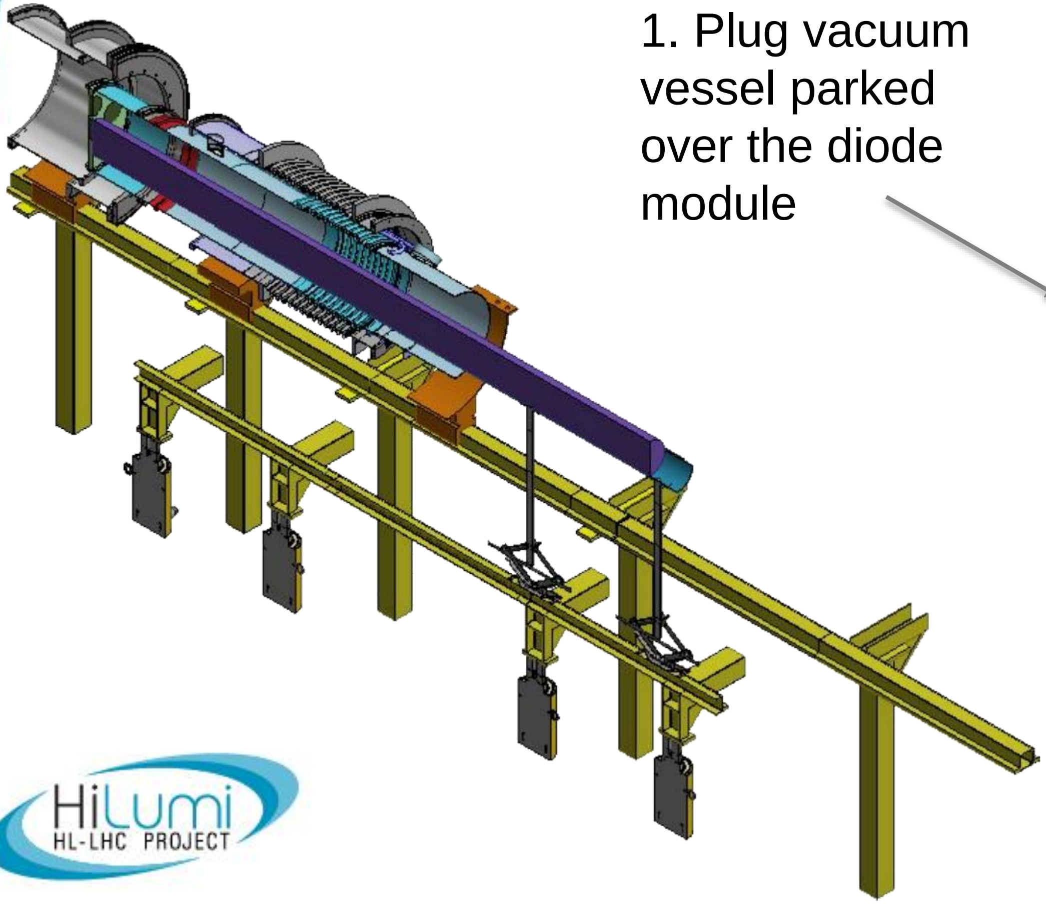
Lifting and support frame work indicatively illustrated in this sequence and to be studied further by CERN.

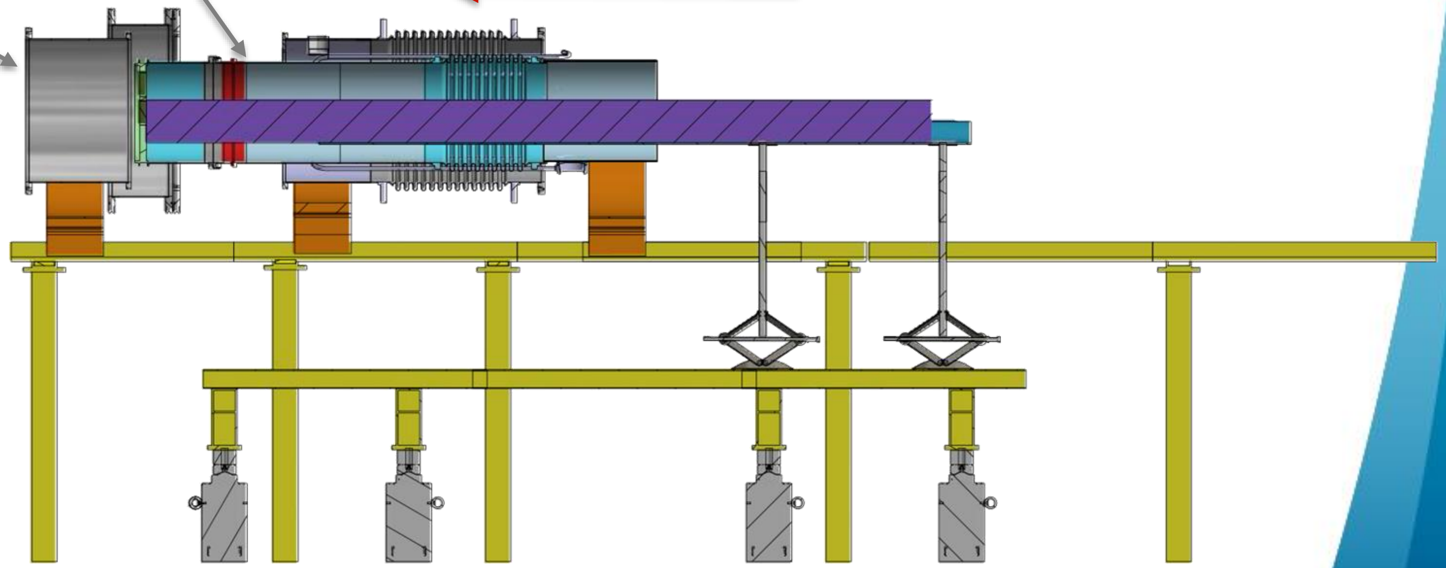
Stage 1 – Assembling the horizontal section at the Plug End

Starting position assuming the installation of the cold diode module with the plug prior to the integration of the SC-Link

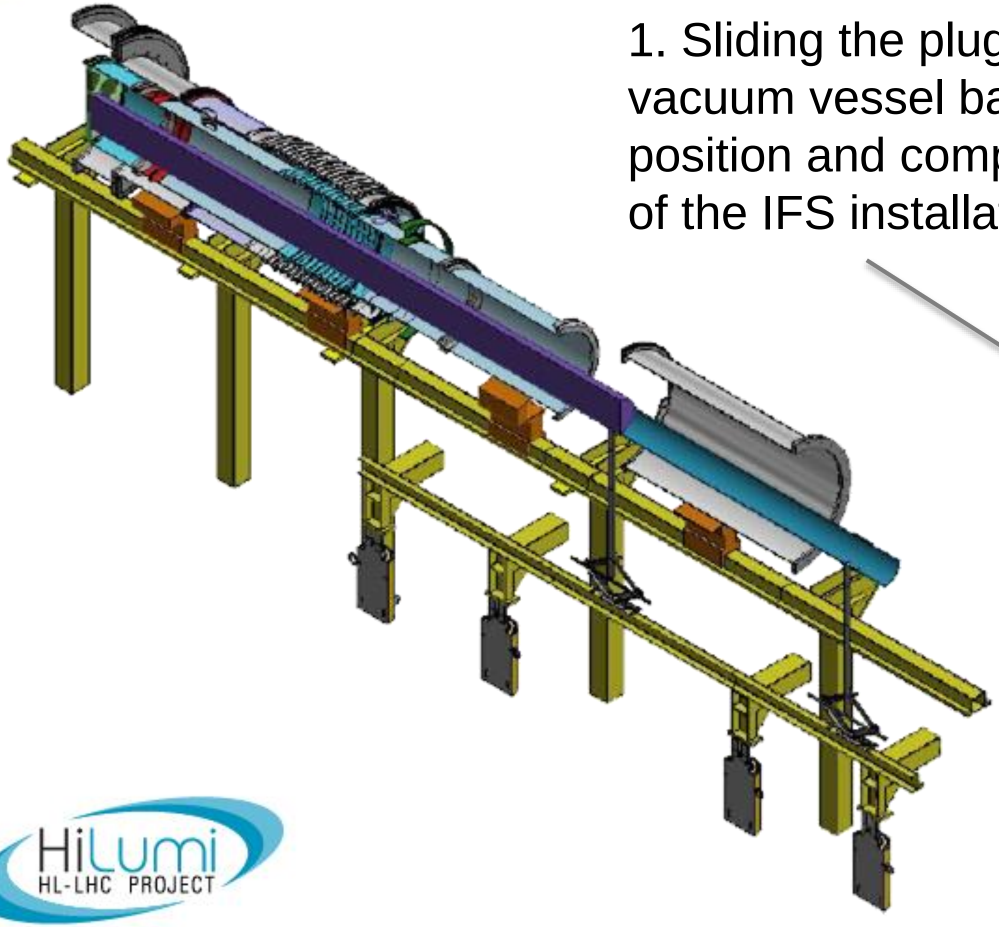


Stage 1.1 – Installation of the IFS sub-assembly to the plug





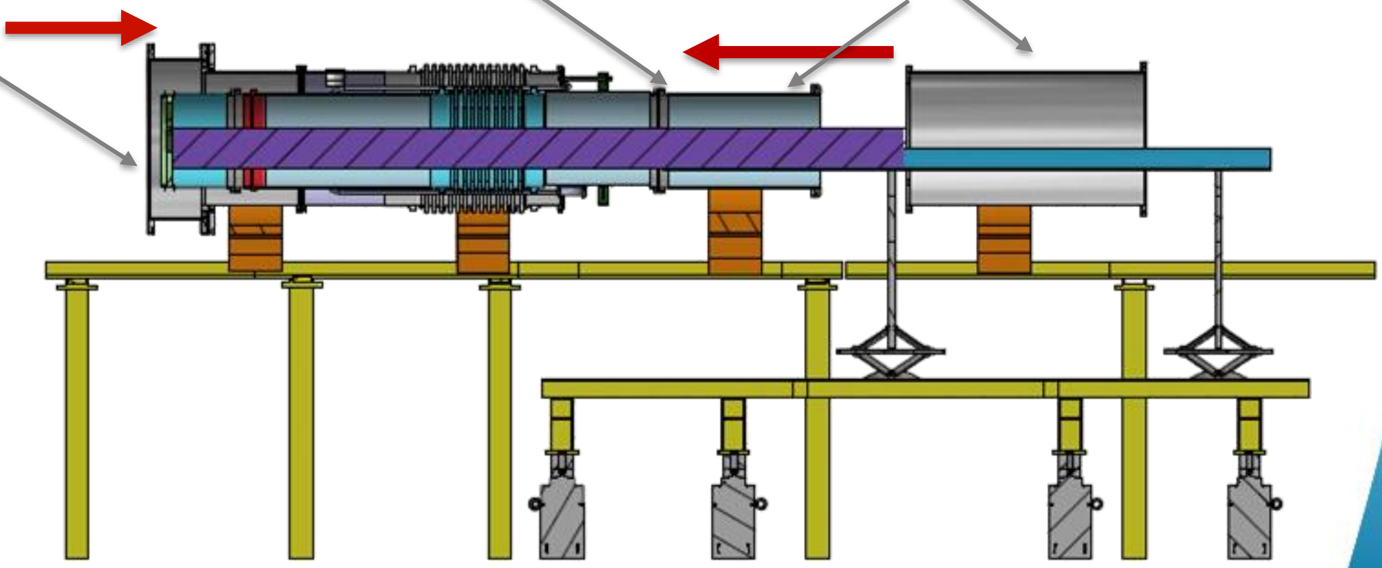
Stage 1.2 – Installation of the parking extension for parking the sliding splice section



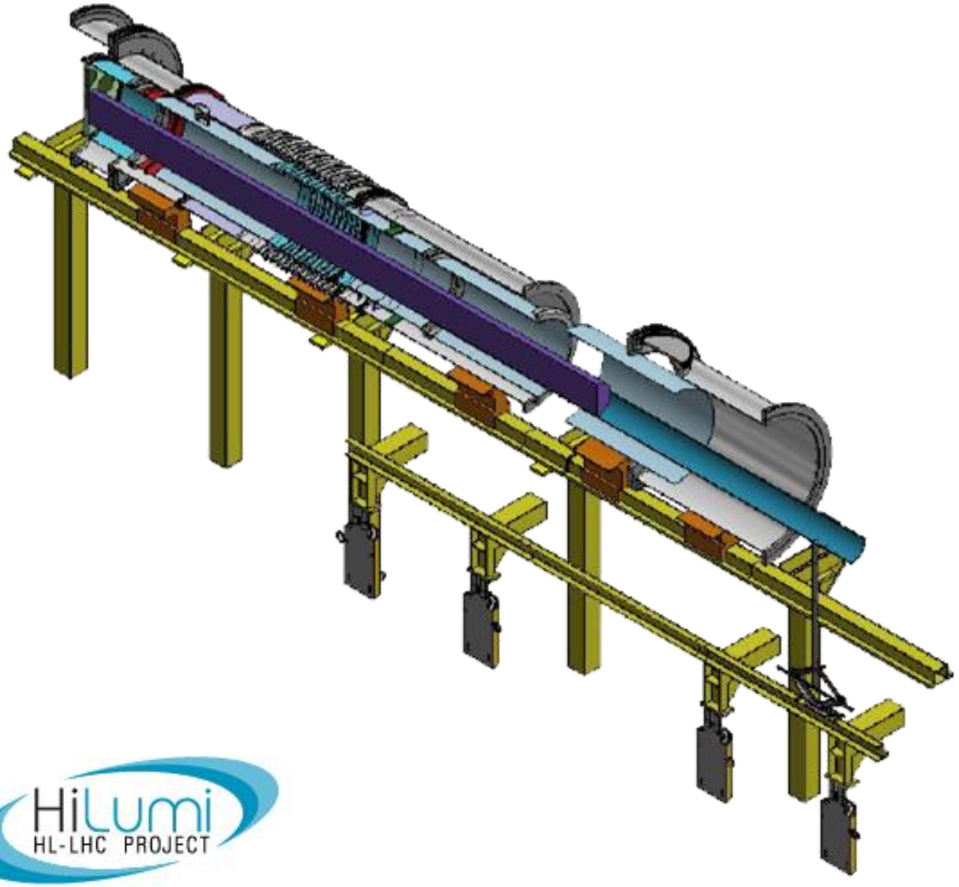
1. Sliding the plug vacuum vessel back in position and completion of the IFS installation

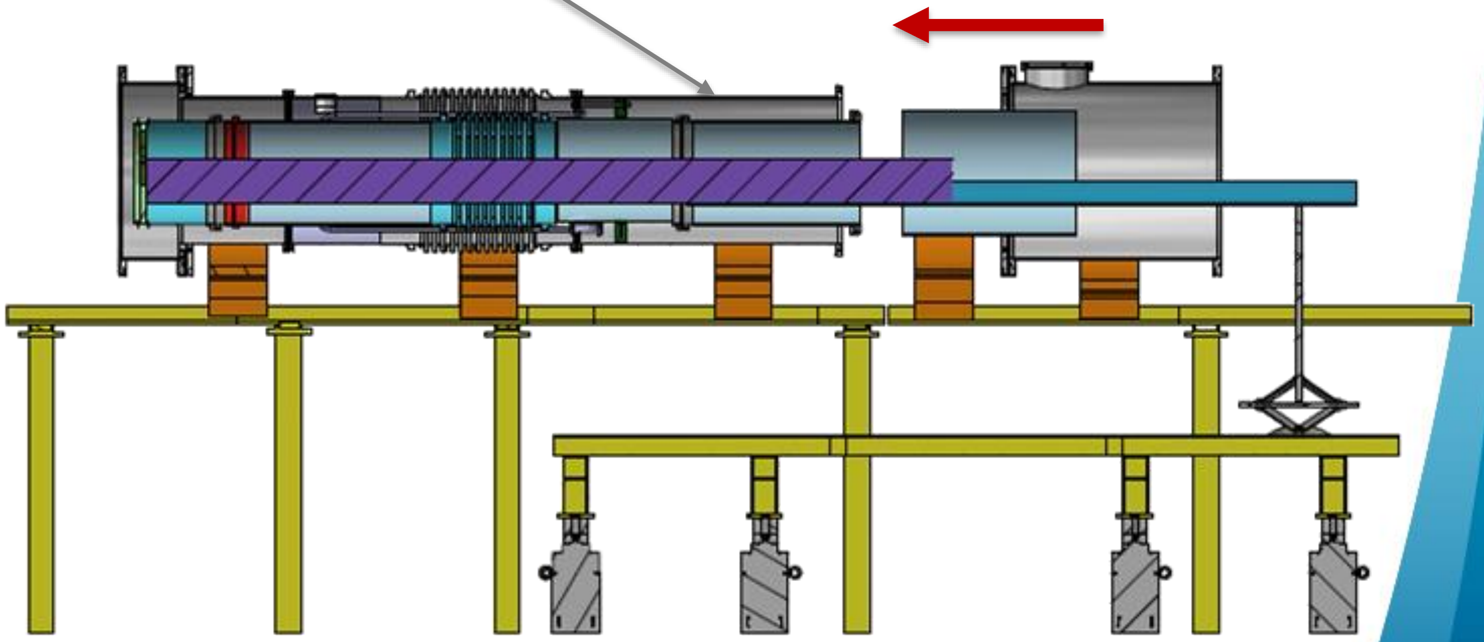
3. Weld in situ #W2

2. Insertion of the parking extension

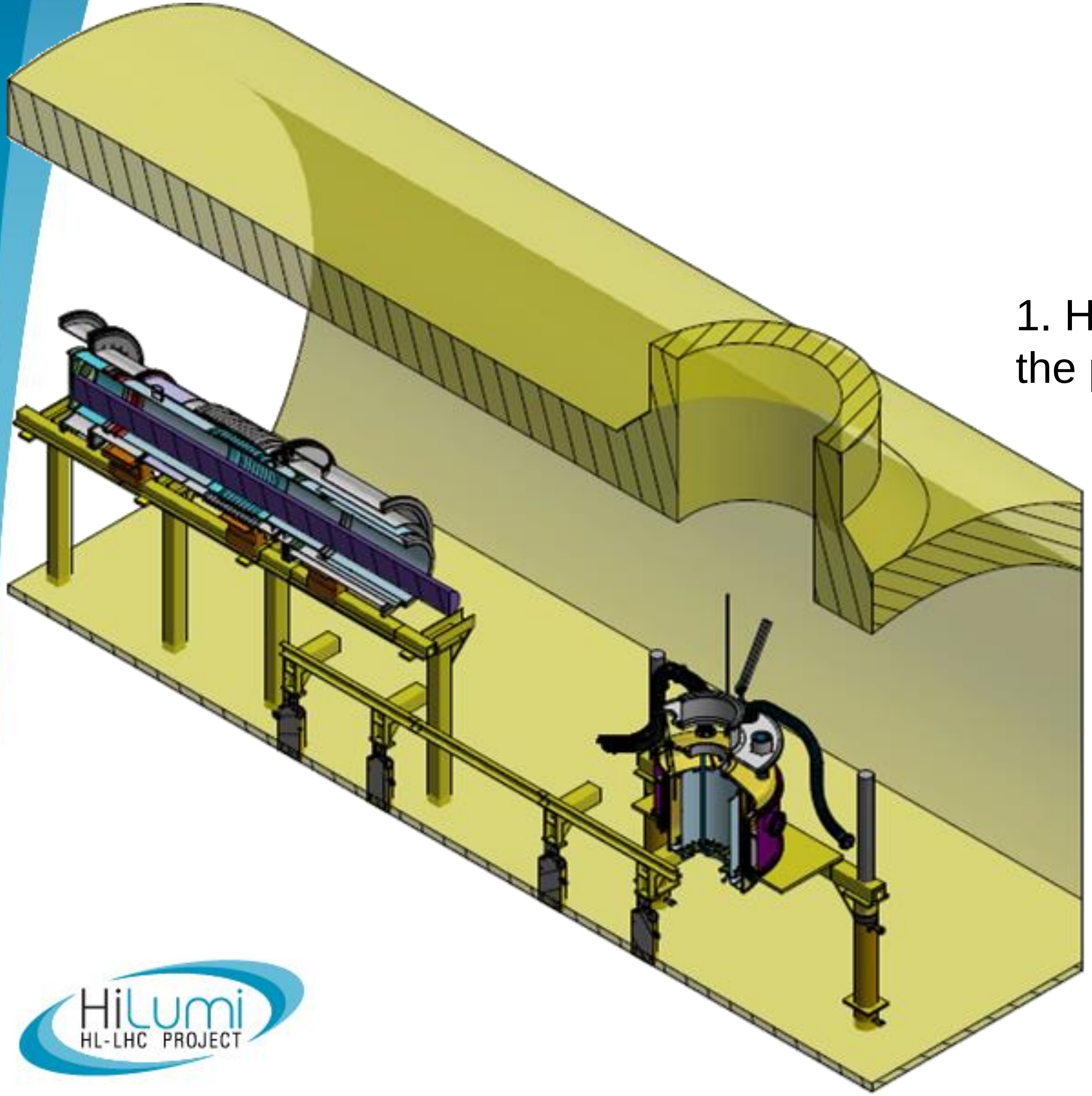


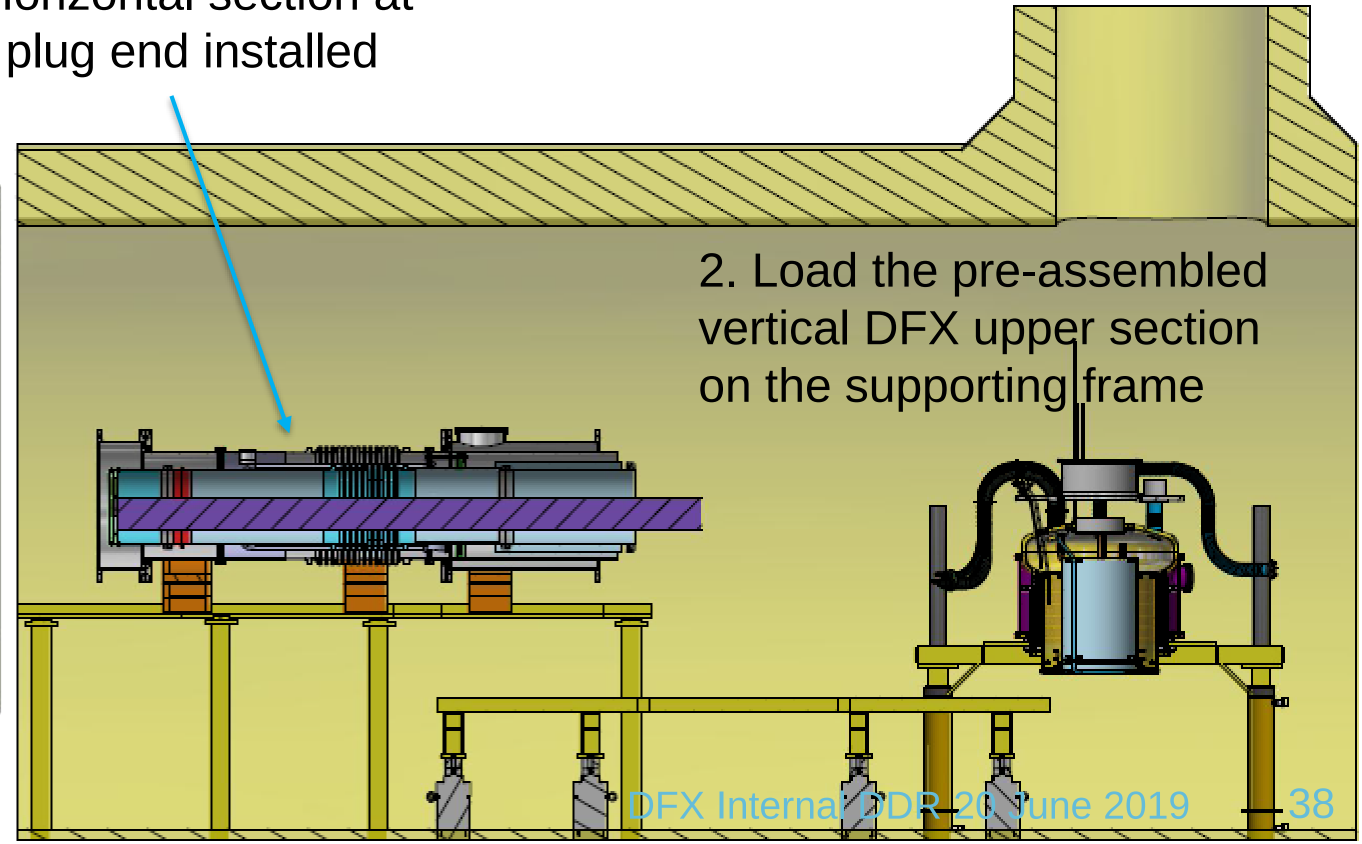
Stage 1.3 – Parking of the sliding splice section



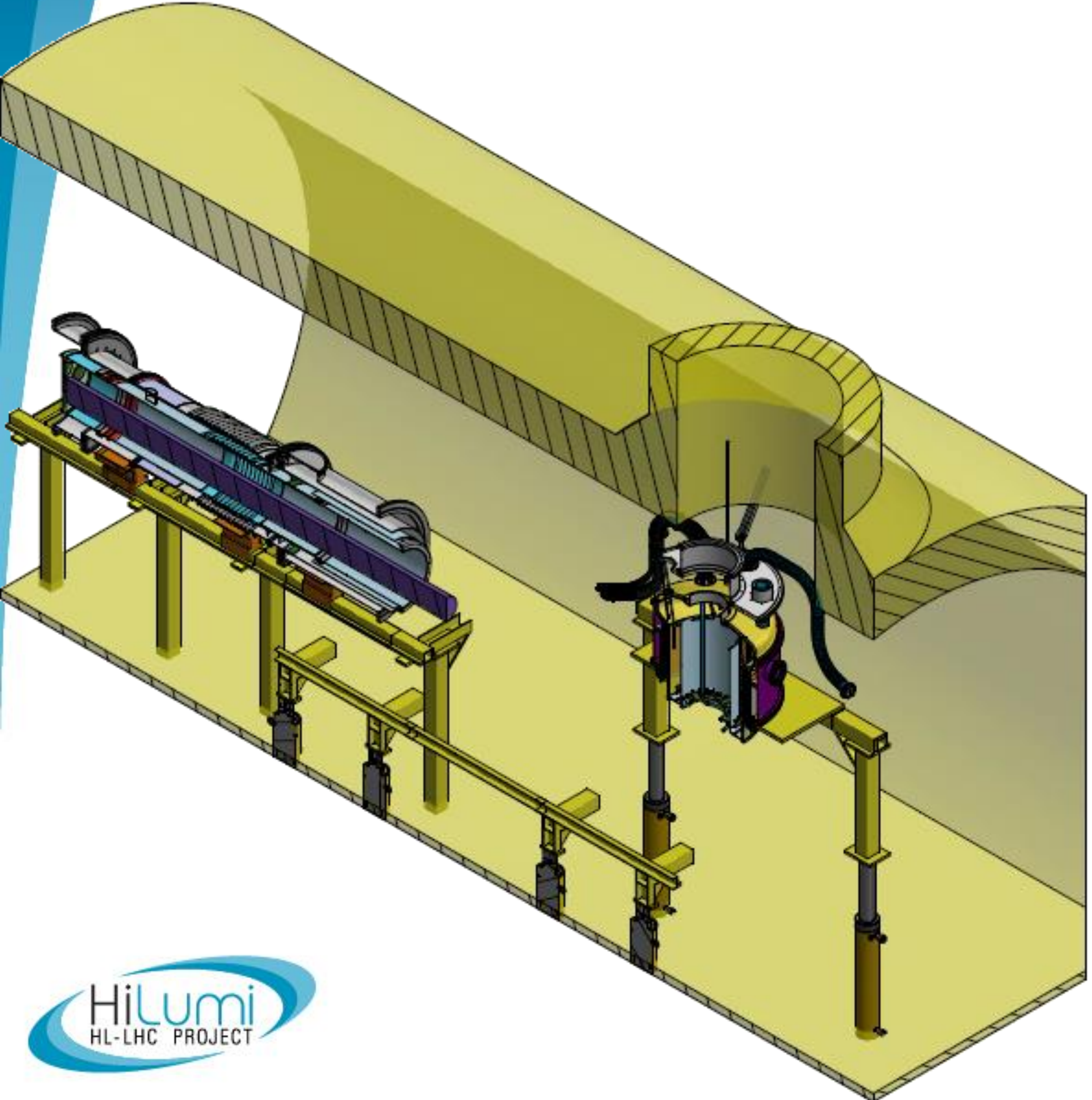


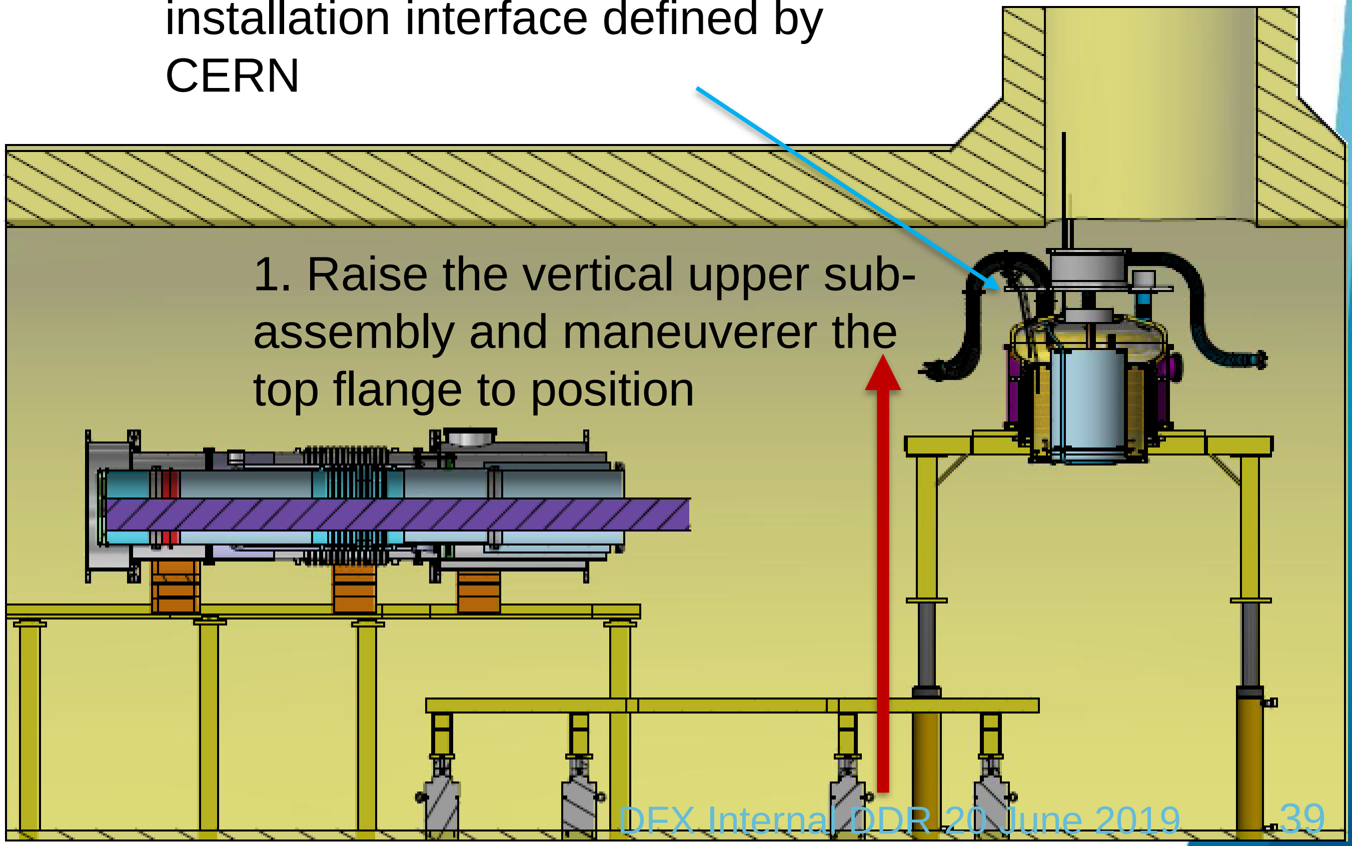
Stage 2 Assembling the vertical DFX and integrating of the SC-Link





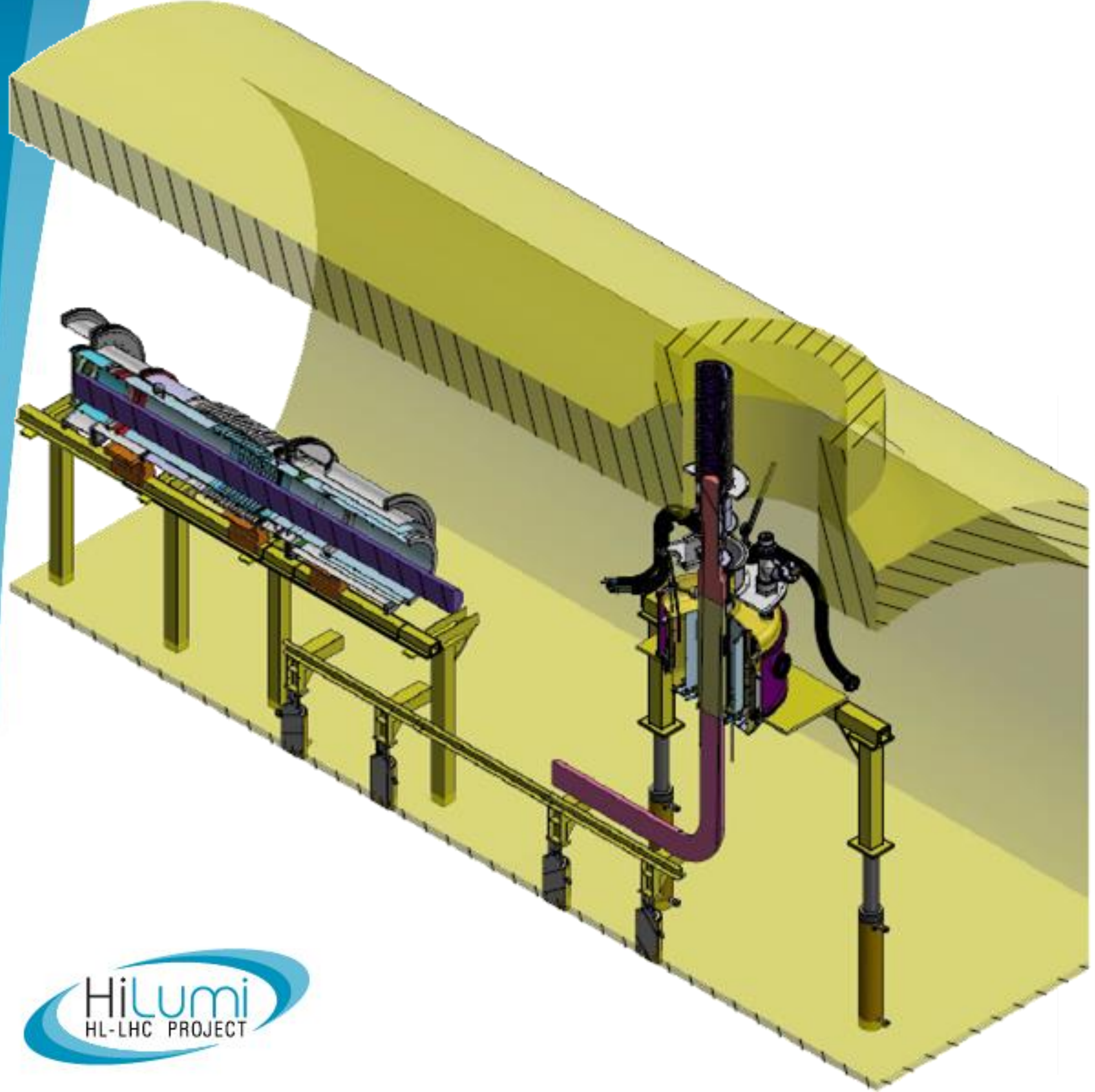
Stage 2.1 Fix the top flange to CERN defined interface position

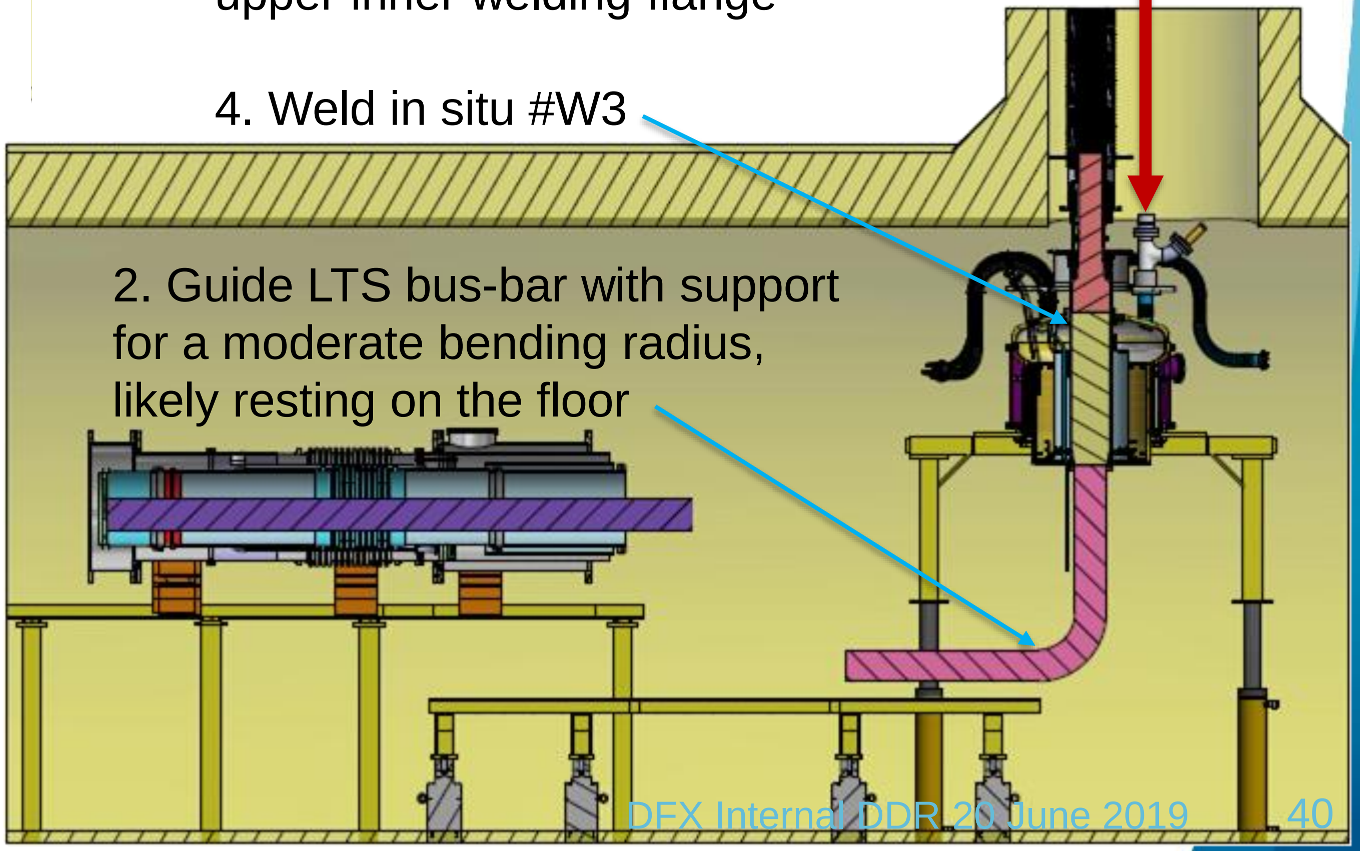




2. Fix the top flange using supporting mechanisms installed on the shaft by CERN. This is the installation interface defined by CERN

Stage 2.2 Insertion of SC-Link and integration with the vertical DFX upper section





1. Insertion of SC-Link with DFH from the shaft

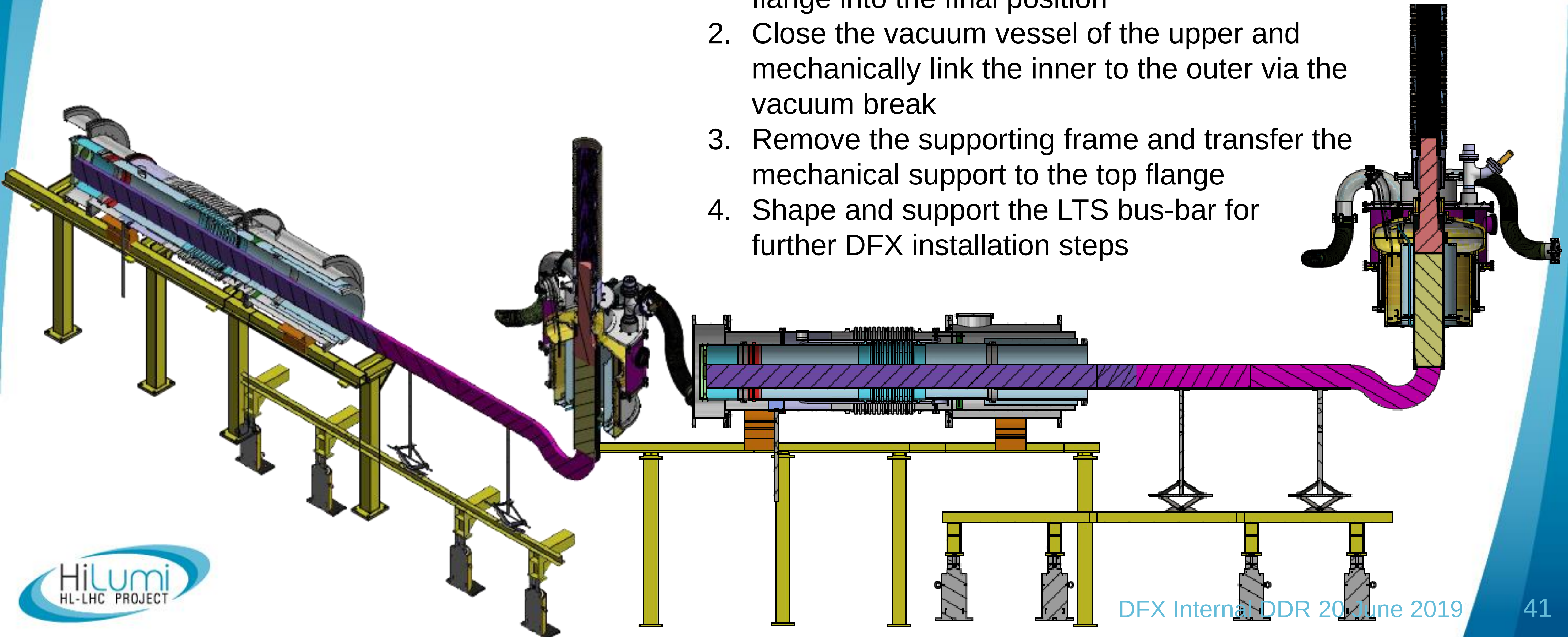
2. Guide LTS bus-bar with support for a moderate bending radius, likely resting on the floor

3. Position the top of the rigid splice section for welding to the vertical DFX upper inner welding flange

4. Weld in situ #W3

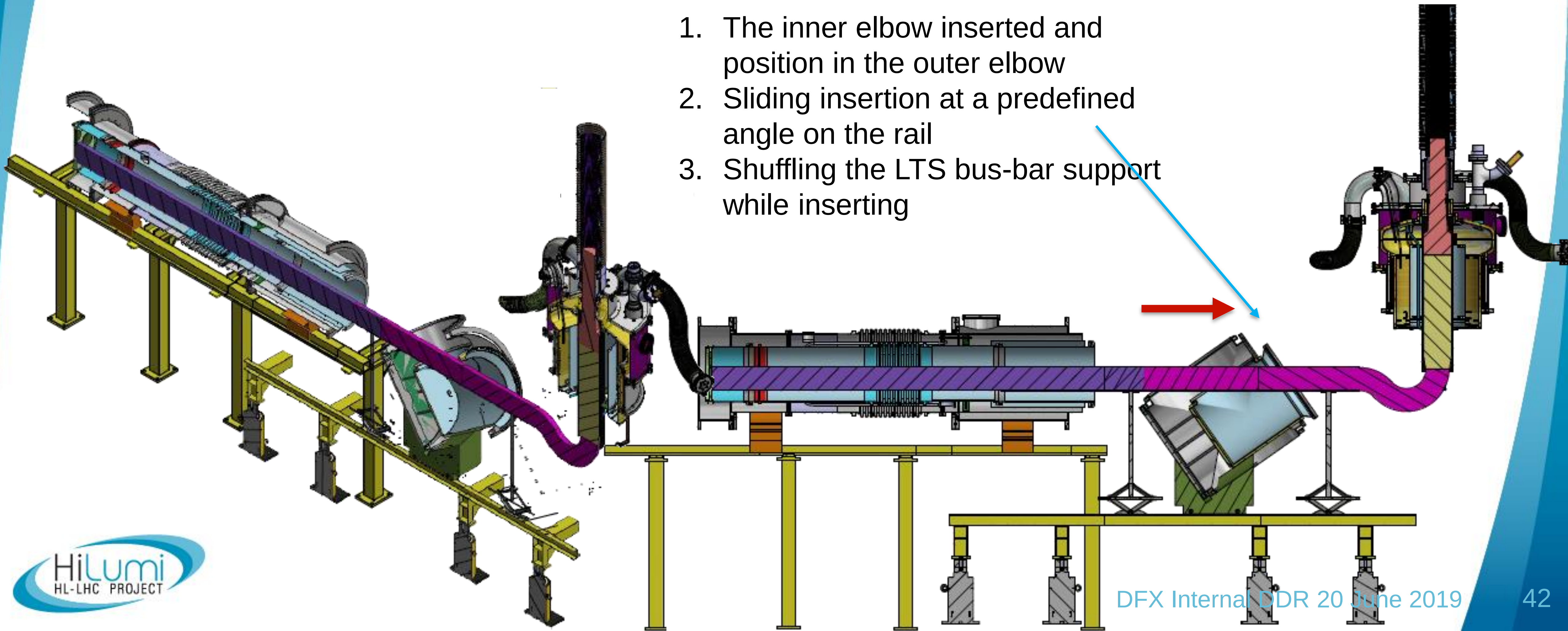
Stage 2.3 Completion of vertical DFX upper assembly and shaping the LTS bus-bar

1. Move the inner vessel up 80mm towards the top flange into the final position
2. Close the vacuum vessel of the upper and mechanically link the inner to the outer via the vacuum break
3. Remove the supporting frame and transfer the mechanical support to the top flange
4. Shape and support the LTS bus-bar for further DFX installation steps



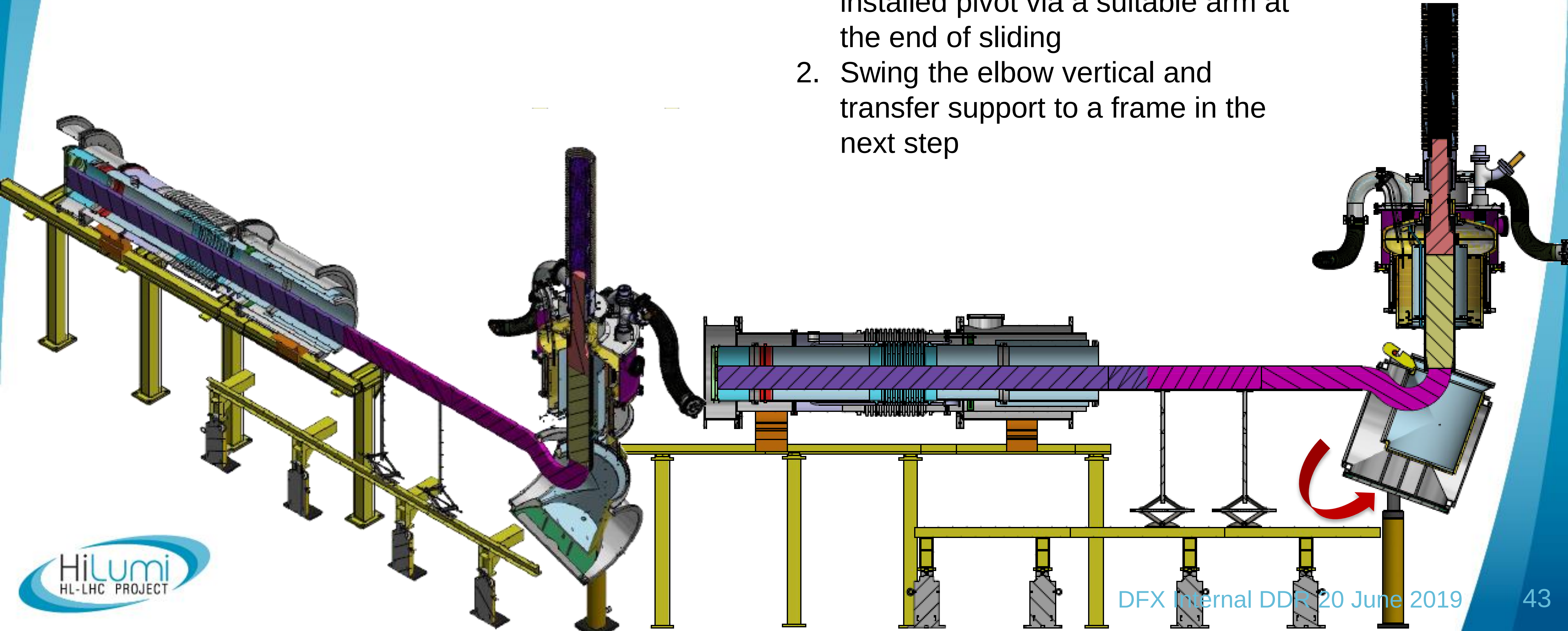
Stage 2.4 Insertion of the vertical DFX lower elbows

1. The inner elbow inserted and position in the outer elbow
2. Sliding insertion at a predefined angle on the rail
3. Shuffling the LTS bus-bar support while inserting

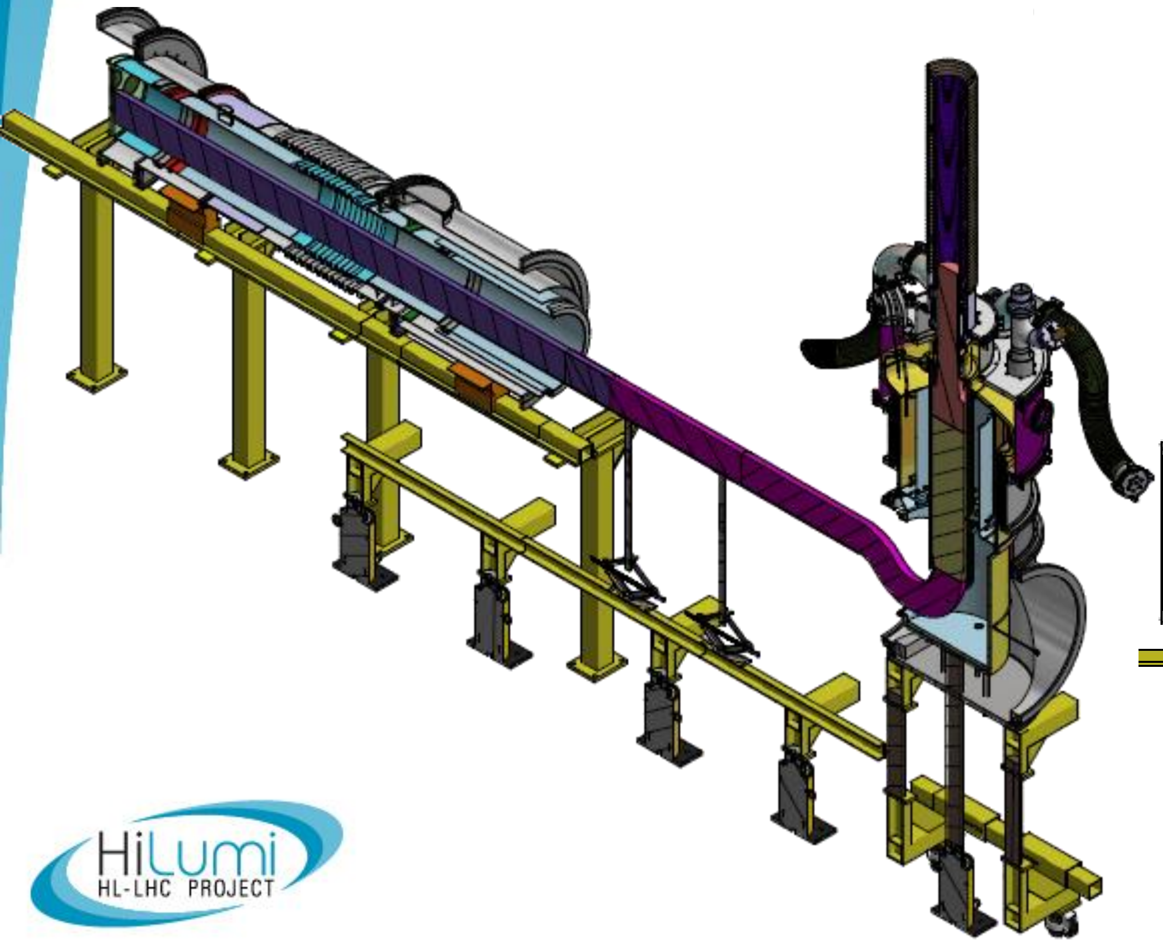


Stage 2.5 Swing the elbows into vertical position

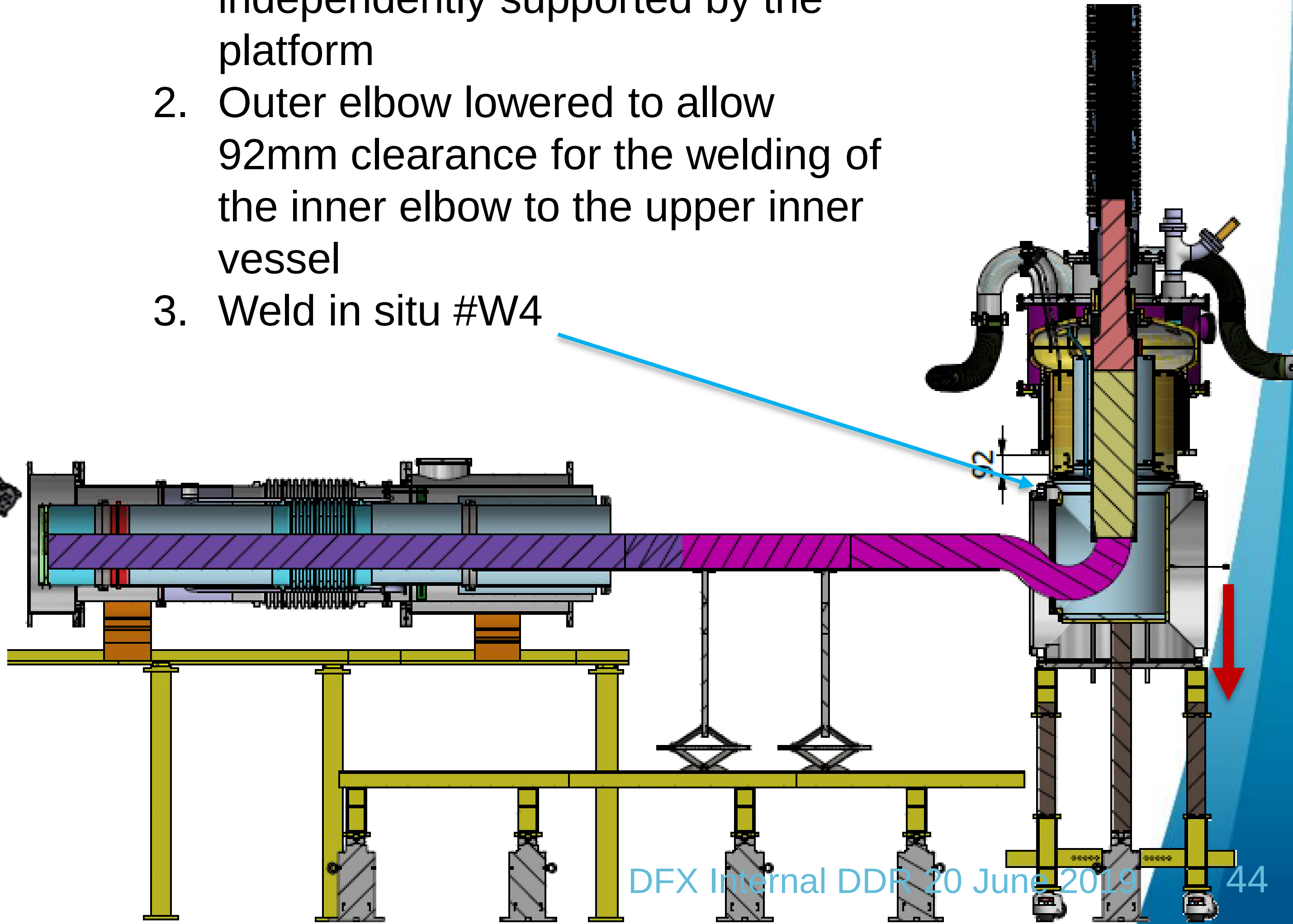
1. Engage the elbows to a pre-installed pivot via a suitable arm at the end of sliding
2. Swing the elbow vertical and transfer support to a frame in the next step



Stage 2.6 Welding of the inner elbow



1. The inner and outer elbows independently supported by the platform
2. Outer elbow lowered to allow 92mm clearance for the welding of the inner elbow to the upper inner vessel
3. Weld in situ #W4



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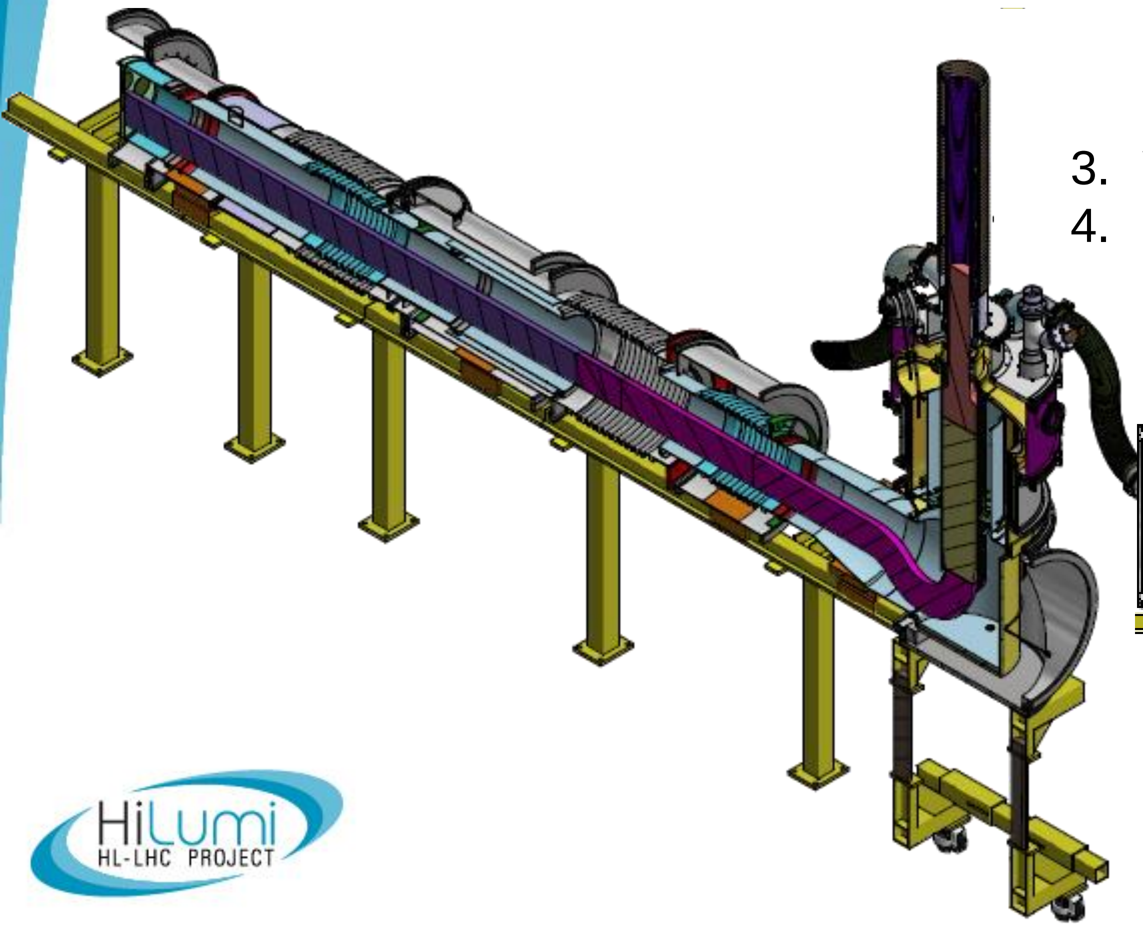
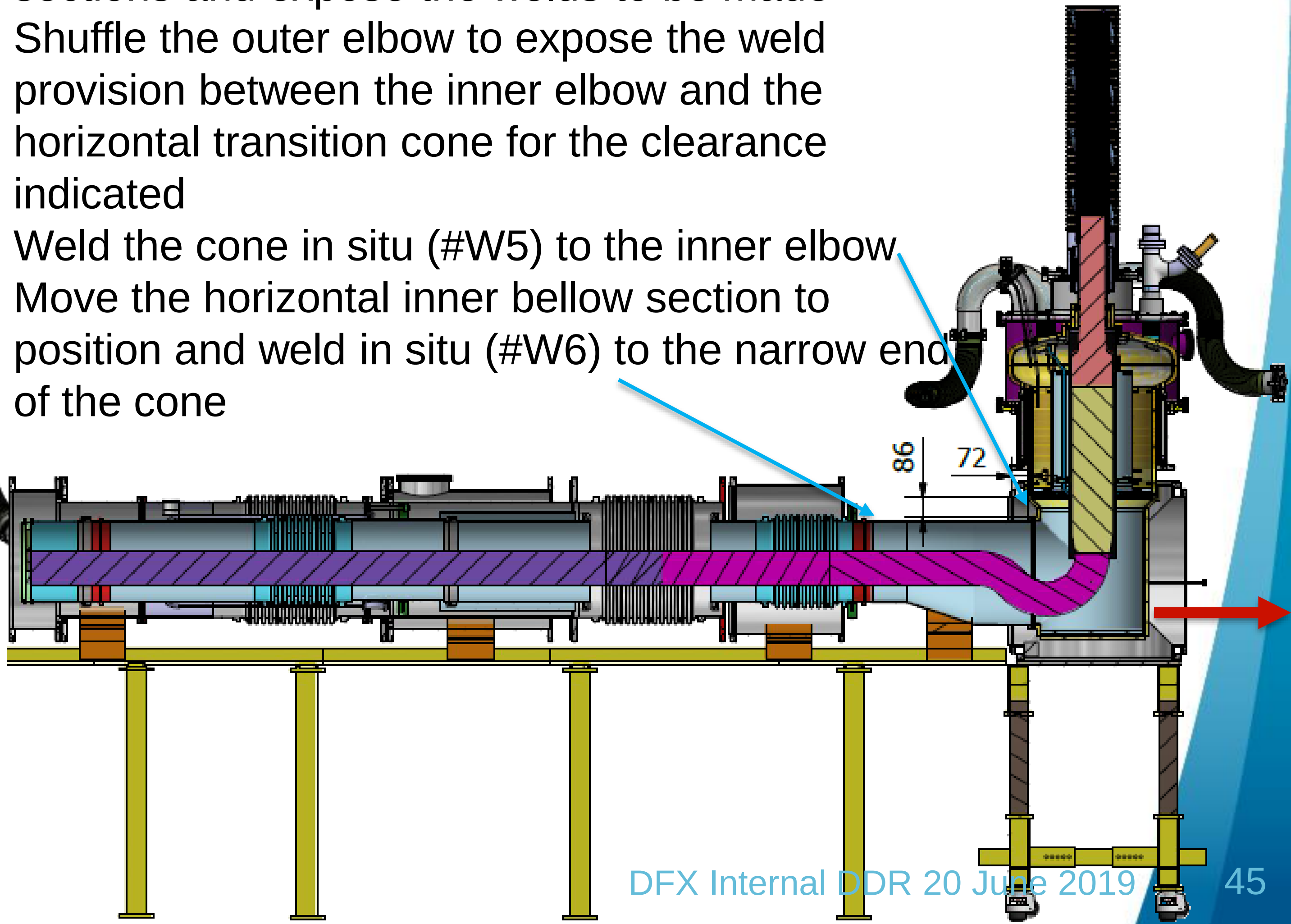
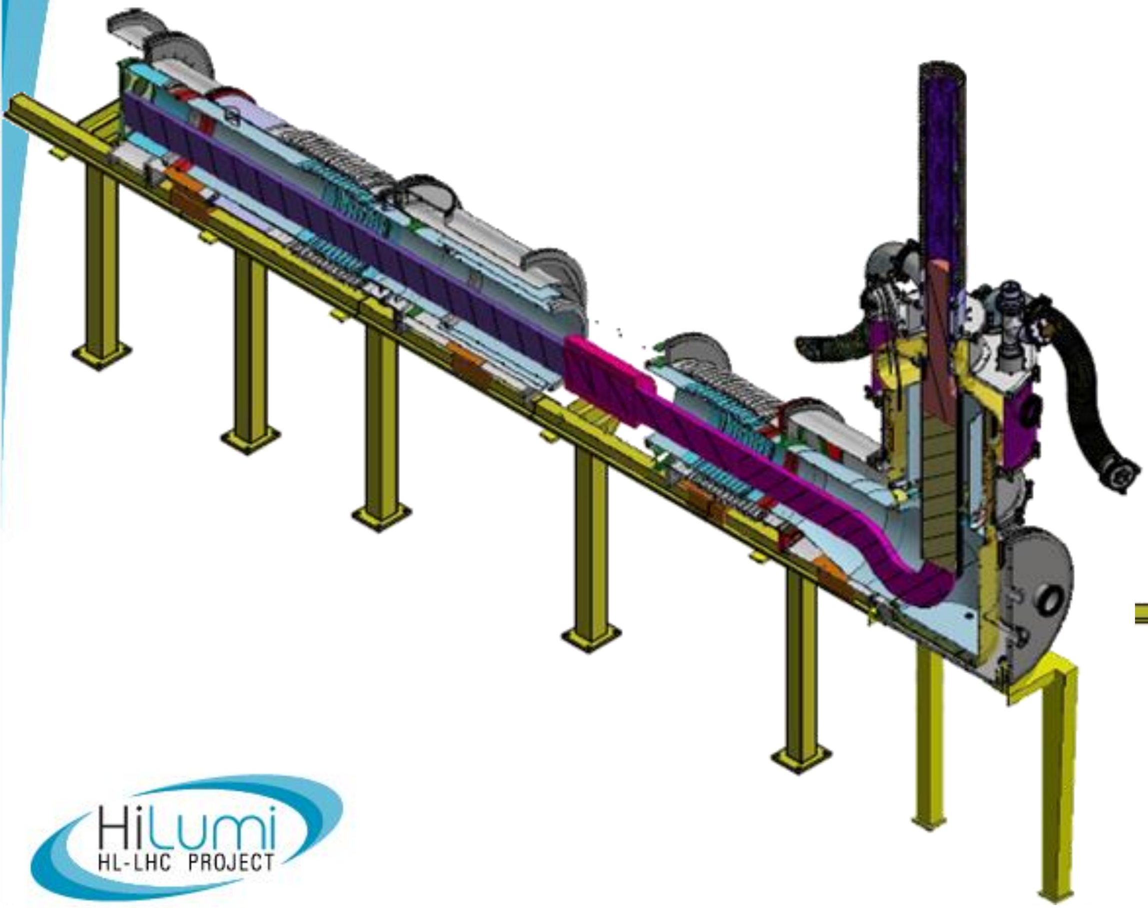
Stage 3 Assembling the horizontal section at the SC-Link end

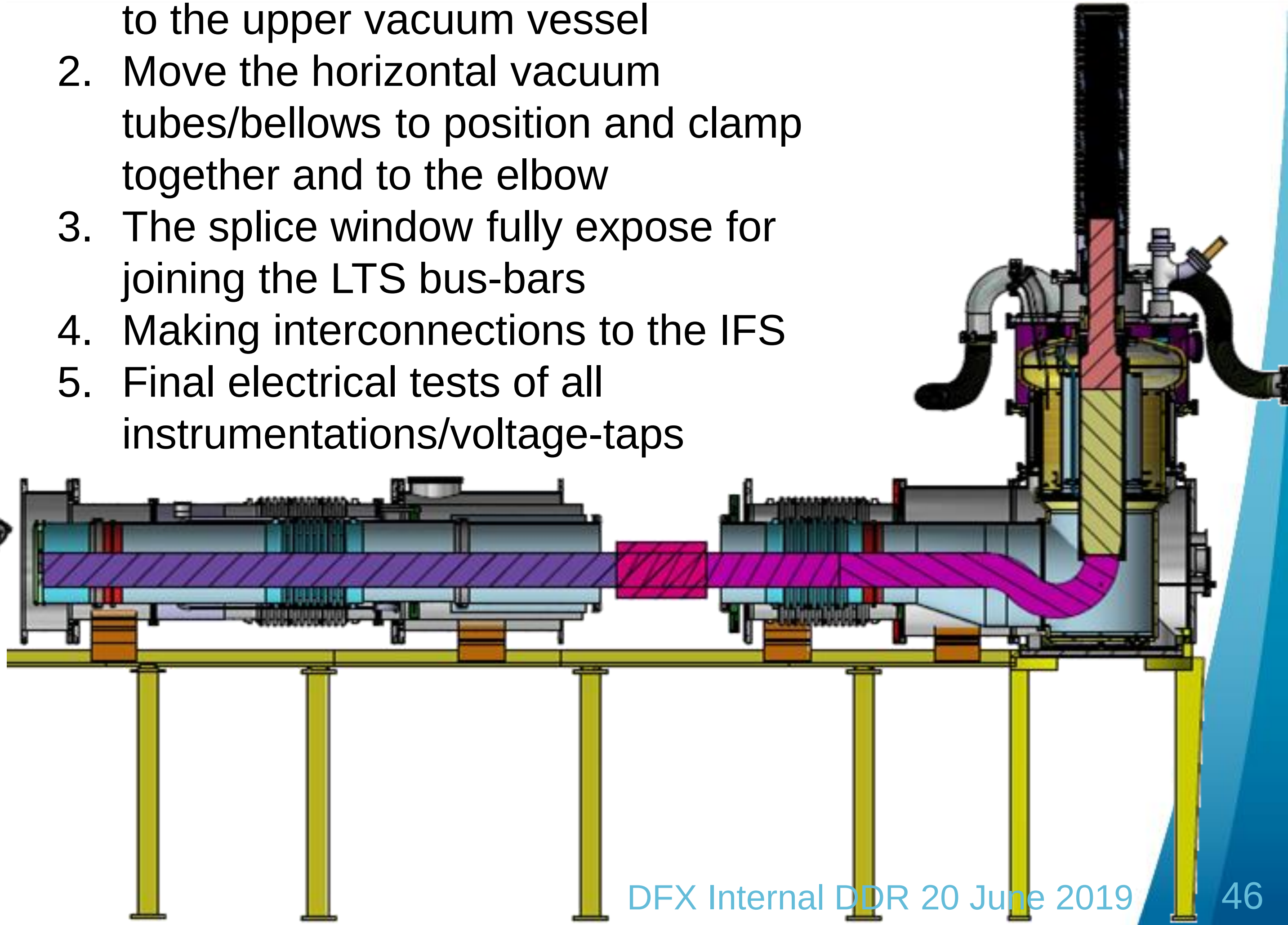


1. Sliding in the rest of the horizontal inner and outer sections and expose the welds to be made
2. Shuffle the outer elbow to expose the weld provision between the inner elbow and the horizontal transition cone for the clearance indicated
3. Weld the cone in situ (#W5) to the inner elbow
4. Move the horizontal inner bellow section to position and weld in situ (#W6) to the narrow end of the cone



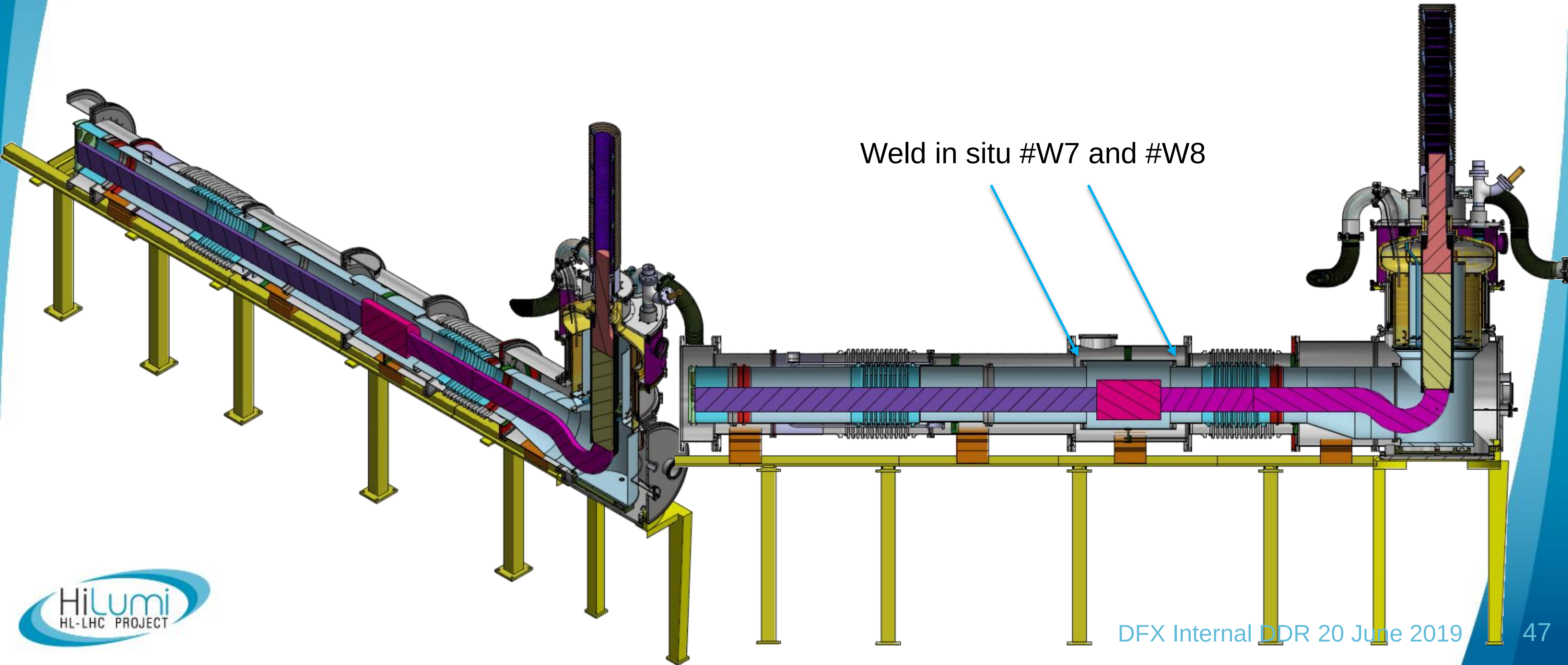
Stage 4 Splicing LTS bus-bars





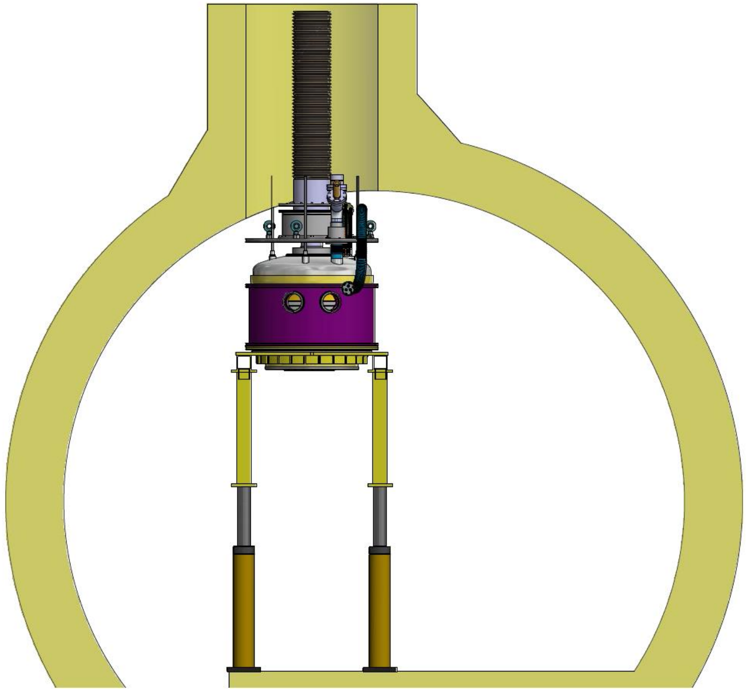
1. Move the outer elbow back and clamp to the upper vacuum vessel
2. Move the horizontal vacuum tubes/bellows to position and clamp together and to the elbow
3. The splice window fully expose for joining the LTS bus-bars
4. Making interconnections to the IFS
5. Final electrical tests of all instrumentations/voltage-taps

Stage 5 Closing the splice window to complete the DFX assembly and SC-Link/Plug integration

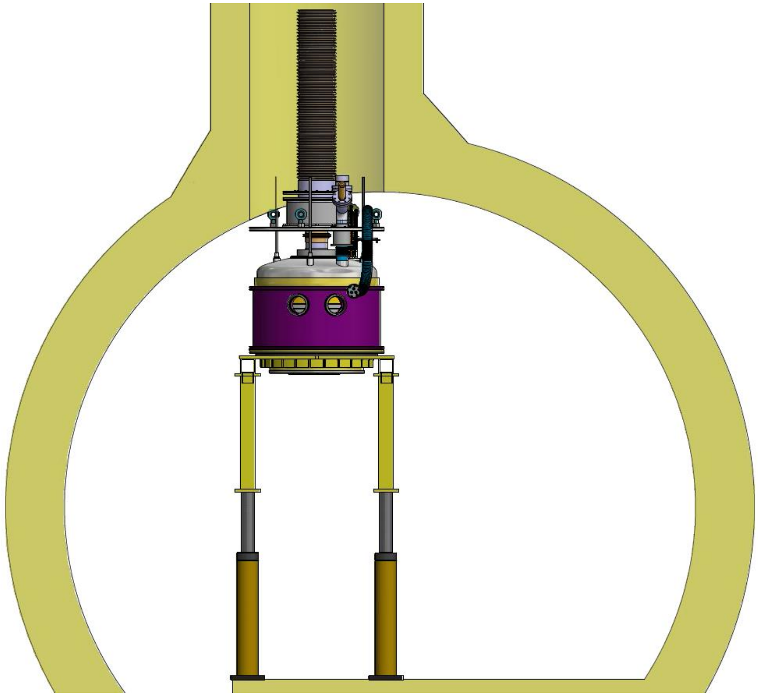


Thank you for your attention

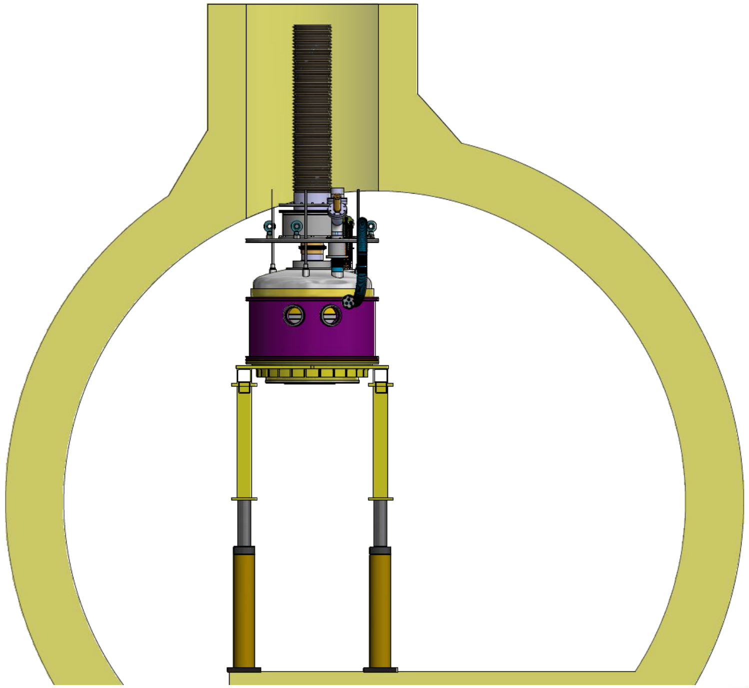
Detailed DFX Schematics: Lowering and raising



Fully assembled

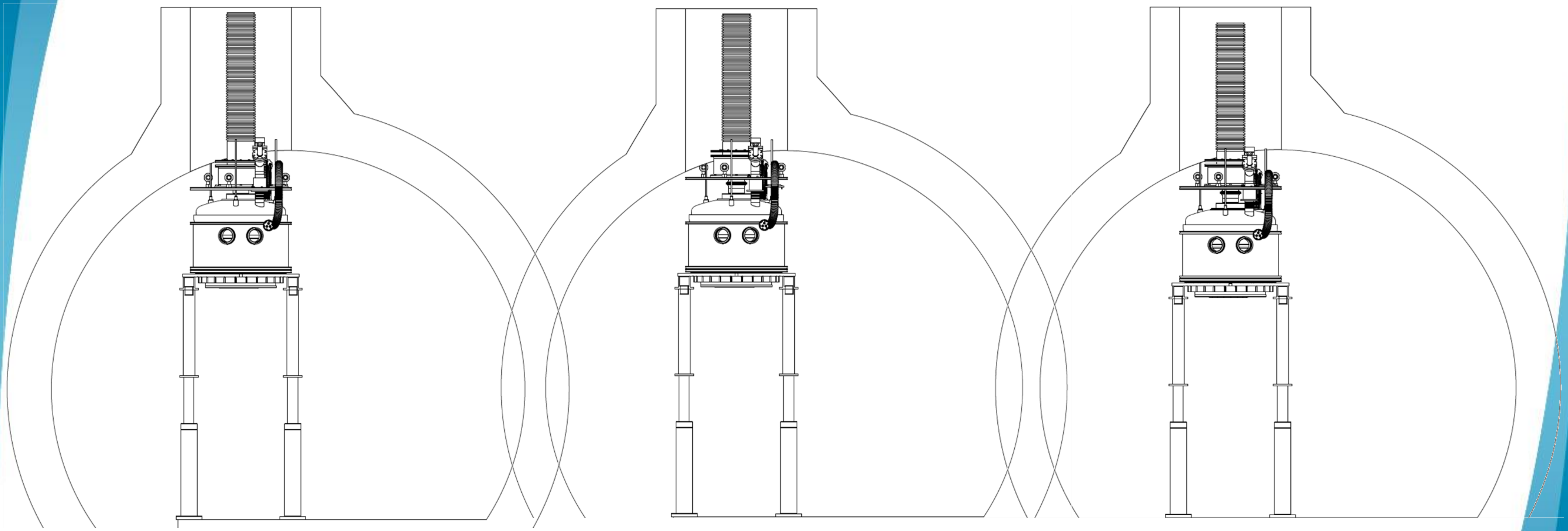


Top flange raised



Inner vessel lowered

Detailed DFX Schematics: Lowering and raising



Fully assembled

Top flange raised

Inner vessel lowered

Detailed DFX Schematics: Lowering and raising