Vacuum connections, interfaces and technologies

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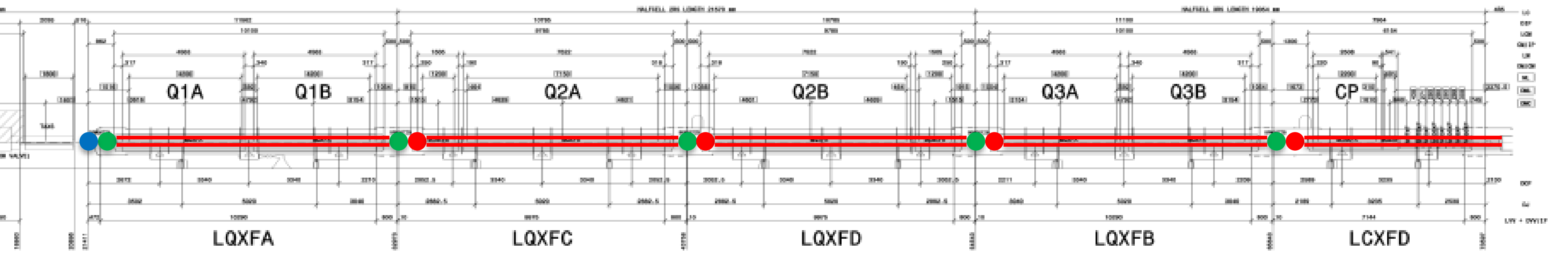
HL-LHC Inner Triplet BPMs final design review, CERN, 18th November 2020

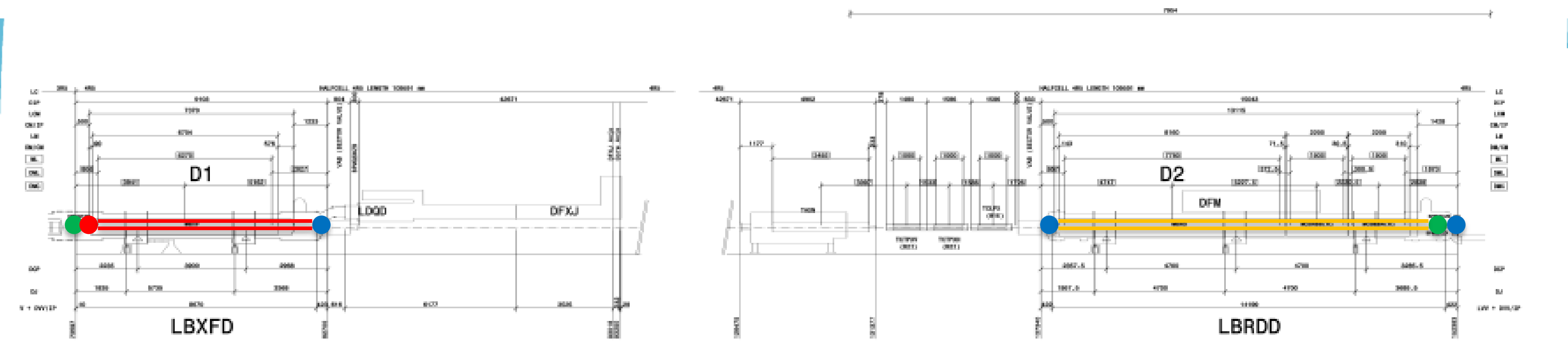
Vacuum connections, interfaces and technologies

Outline

- Beam screen design and solutions for cooling of vacuum components
  - Beam screens
  - Interconnection absorber
- Tolerances of the BPM-relevant vacuum components
- Assembly sequence of the beam screens and vacuum components
- Overview of the design and integration of welding machines
- Up-date of the implementation of memorandum EDMS 2105453
- Conclusion

HL-LHC BPM/ cold vacuum system layout





- Cold warm transition
- BPM
- Absorber in interconnection

Beam screen with shielding

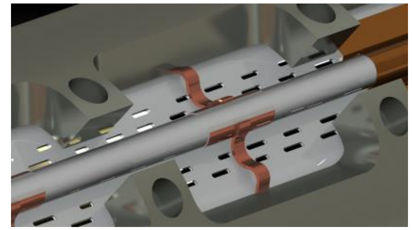
Beam screen without shielding

HL-LHC shielded beam screen

Functions:

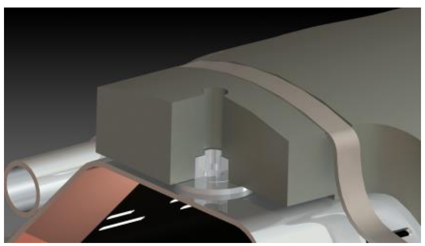
- Provide vacuum stability, control gas density
- Protect the triplet cold masses from particle collision debris

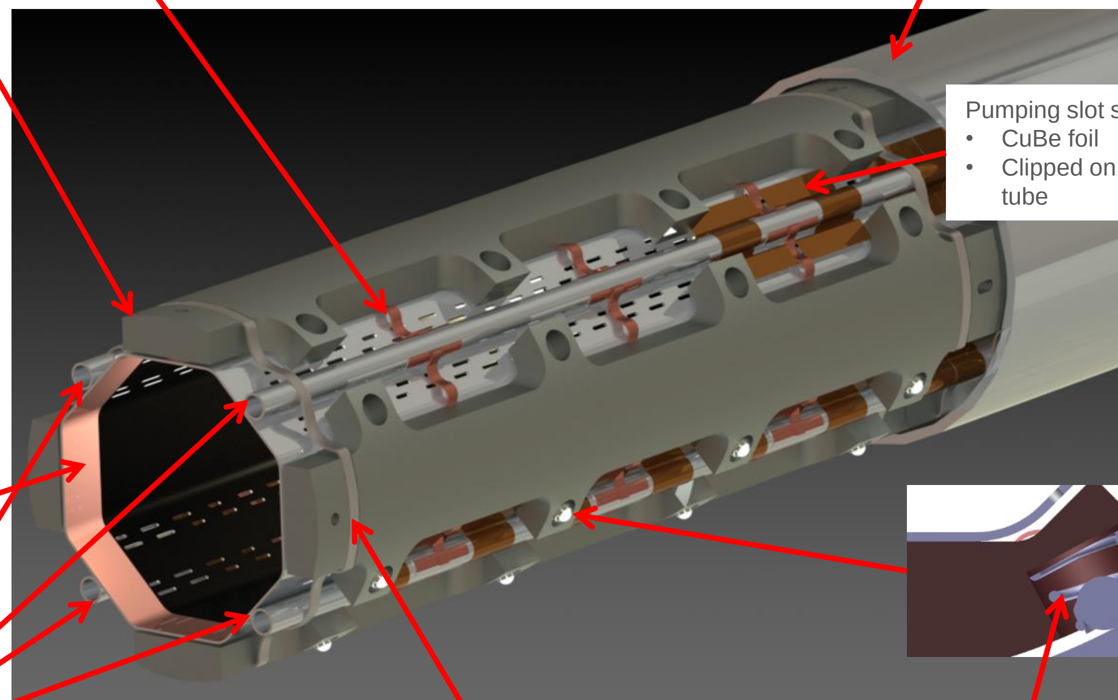
Thermal links:
- In copper (multilayer and solid part)
- Interface plates
- Connected to the absorbers and the cooling tubes



Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN

Tungsten alloy blocks:
- Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
- Mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
- 40 cm long





Pumping slot shields
- CuBe foil
- Clipped on the cooling tube

Beam screen octagonal tube (BS) at 60-75 K:
- Perforated tube in High Mn High N stainless steel (P506)
- Internal copper layer (75 μm) for impedance
- a-C coating for e- cloud mitigation
- Made of ~3m long segments

P506 cooling tubes:
- Outer Diameter: 10 mm
- Laser welded on the beam screen tube

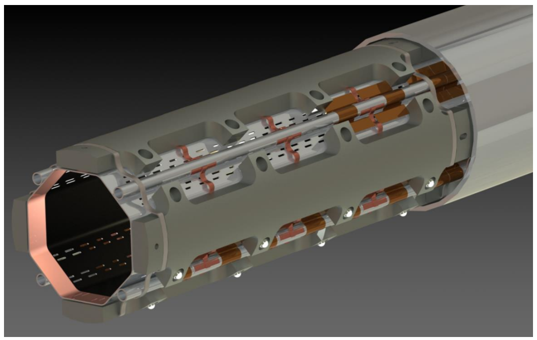
Elastic compression rings

Elastic supporting system:
- Ceramic ball and titanium spring

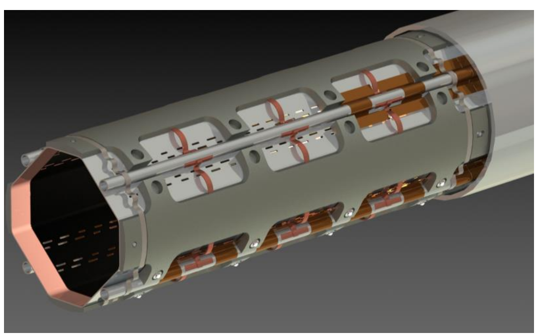
HL-LHC beam screens

3 variants:

2 shielded beam screens with different cross sections but for the same cold bore diameters



Q1 type: 16 mm thick tungsten absorber
LHCVSMSH code



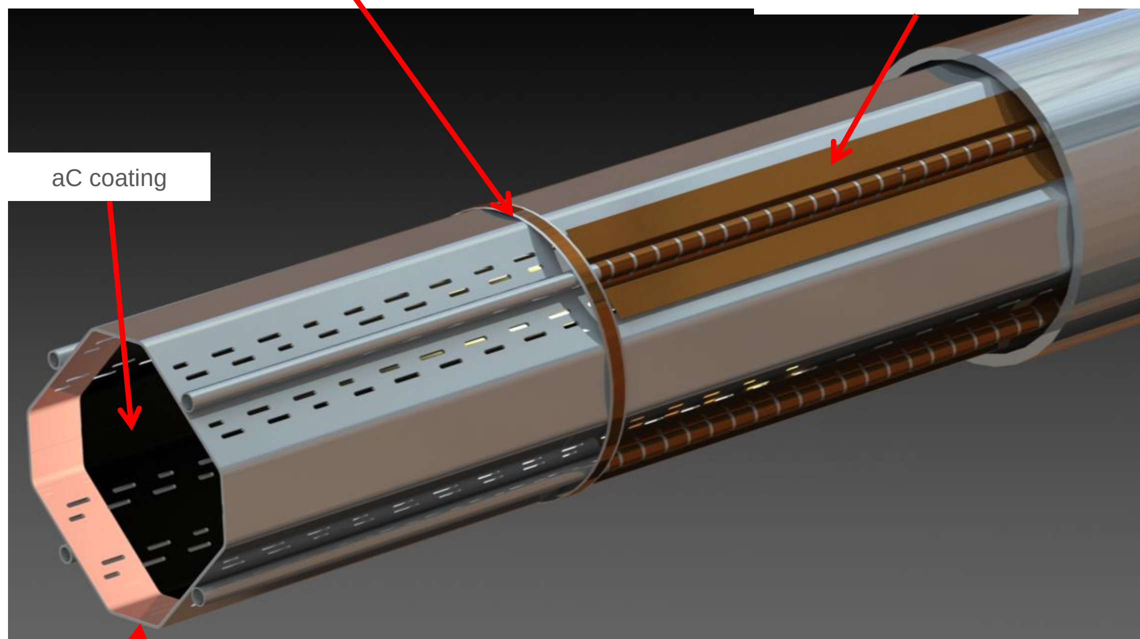
Q2 type: 6 mm thick tungsten absorber
LHCVSMSL code

1 non-shielded beam screen

Pumping slot shields
- CuBe foil
- Clipped on the cooling tube

Sliding ring

aC coating



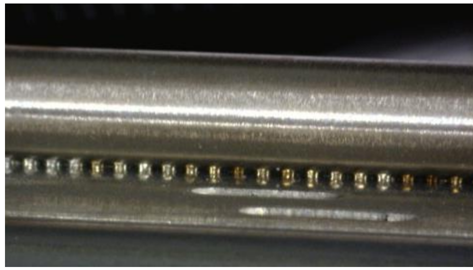
Final cross-section approved (ECR 2414836)

D2 type
LHCVSCS_ code

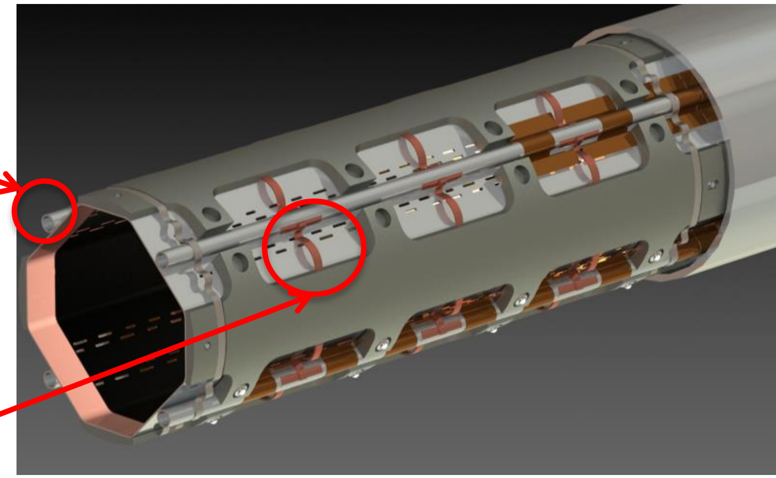
No tungsten absorber → no thermal links

Cooling of the vacuum components (1)

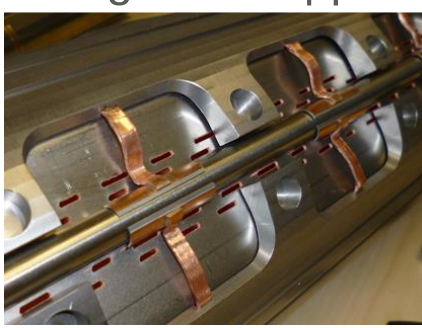
Beam screen tubes are cooled by conduction through the spot welding with the cooling tube.



Spot weld every 1 mm

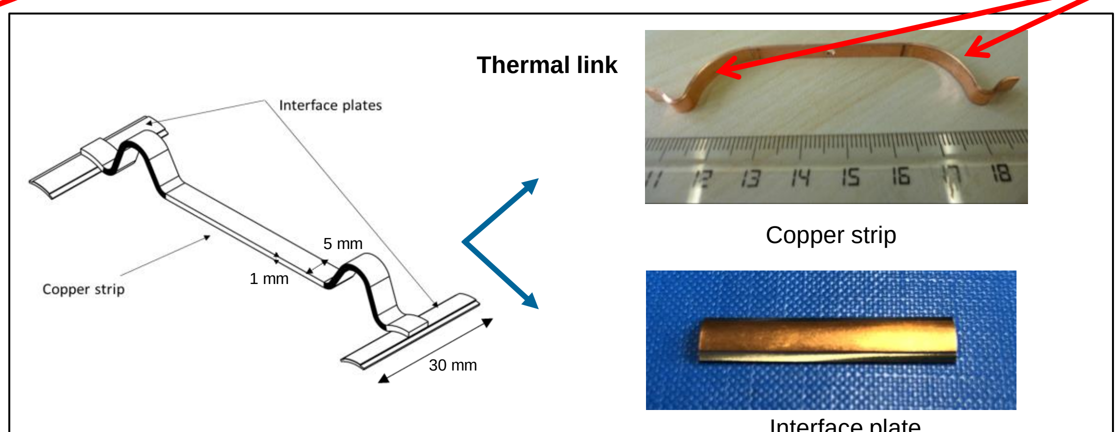


Tungsten absorbers are cooled by conduction through the copper thermal links.



3 thermal links per 40 cm long absorber

Multilayer assembly to ensure flexibility during a magnet quench



Thermal performance – beam screen (1)

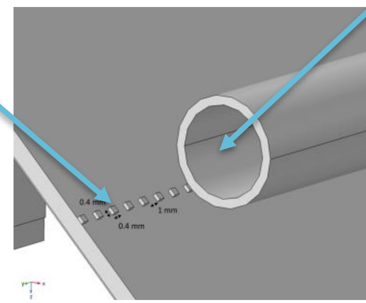
Simulations of the temperature profiles

Assumptions:

- Conservative heat loads on the beam screen tube [WP 2]: 7 W/m for Q2b, 2.16 W/m/beam for D2
- Temperature windows for the inner copper layer in the triplet: 60 – 80 K
  - Helium gradient from 60 to 75 K (from Q1 to D1) + 5 K temperature difference between helium and internal copper layer.
- Helium temperature:
  - 67 K for Q2b
  - 20 K for D2

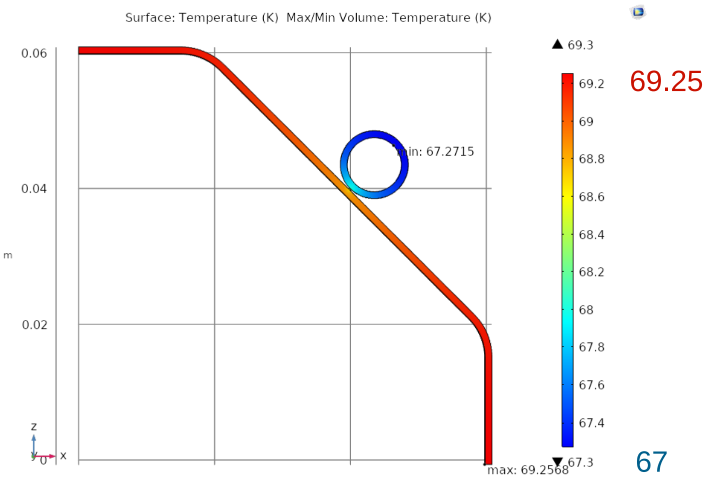
Convection coefficient: 150 W/K/m^2

Spot weld: 0.4*0.4*0.2 mm^3



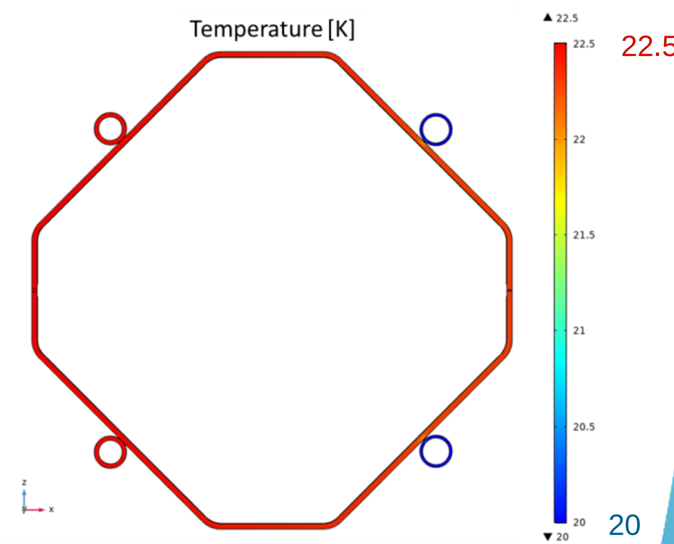
Welding model

Q2b: T_0= 67 K



Transversal temperature profile for the Q2b [K]

D2: T0= 20 K



Transversal temperature profile for the D2 [K]

→ The temperature is homogeneous in the copper layer ($\Delta T<0.5$ K)

→ Temperature difference between helium and the copper layer is driven by the spot weld thermal resistance.

→ Maximum temperature difference between helium and copper layer around 2.5 K.

Thermal performance – beam screen (2)

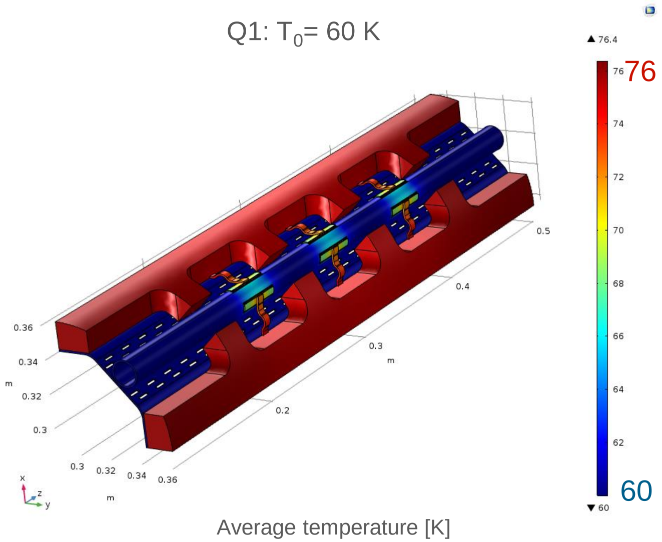
Simulations of the temperature profiles

Requirements:

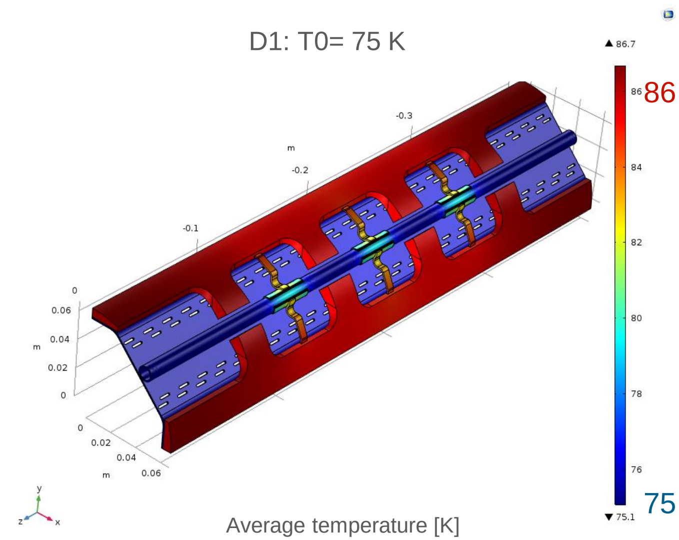
- Heat loads on the absorbers [WP 10]: 25 W/m for Q1, 15 W/m for Q2-D1
- Temperature windows for the inner copper layer: 60 – 80 K
    - ➢ Helium gradient from 60 to 75 K (from Q1 to D1) + 5 K temperature difference between helium and internal copper layer.

The heat transfer is ensured by copper thermal links:

- 6 links per blocks (40 cm long)
- 8 layers (2*0.2 + 6*0.1 mm thick), 5 mm wide



W-Block	Inner Cu-layer
75.8 K	60.45 K



W-Block	Inner Cu-layer
85.8 K	75.8 K

→ Temperature difference between helium and internal copper layer below 1 K.
→ Temperature difference between helium and absorbers around 16 K.

Thermal performance – beam screen (2)

Validation tests

Requirements:

- Temperature windows for the inner copper layer: 60 – 80 K
  - Helium gradient from 60 to 75 K (from Q1 to D1) + 5 K temperature difference between helium and internal copper layer.
- Heat transfer to 1.9 K: <500 mW/m
- Heat loads on the tungsten absorbers: 25 W/m for Q1, 15 W/m for Q2-D1

Tests at cryolab with WP9:

- 80 cm long Q2 type beam screen prototype, equipped with heaters
- Assessment of:
  - Heat transfer from the tungsten absorbers to the cooling tubes
  - Heat leak from the beam screen to the cold bore, cooled at 1.9 K

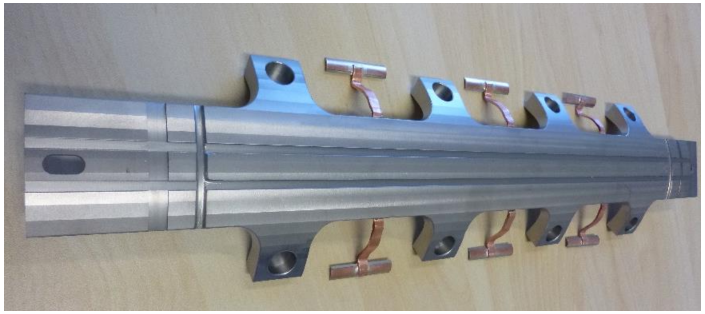
Beam screen prototype at cryolab

Thermal performance – beam screen (2)

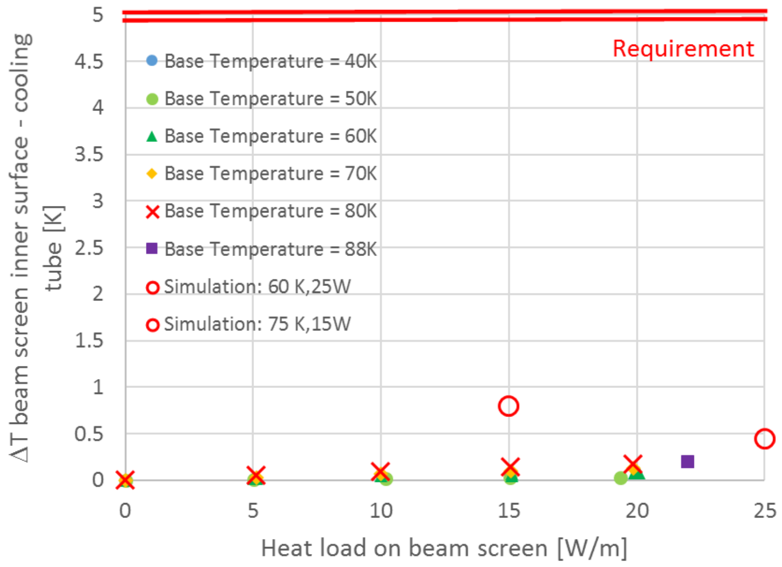
Validation tests - Heat transfer from the absorbers to the cooling tubes

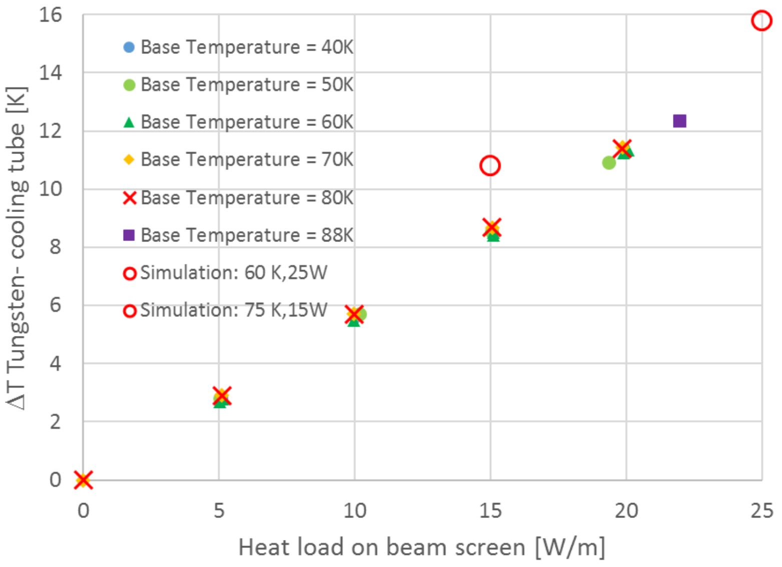
Heat load deposited in the tungsten absorbers is transferred to the cryogenic cooling circuit by thermal links:

- 3 thermal links per blocs (40 cm long),
- Copper multilayers, 10 * 0.1 mm thick, 5 mm wide
- Vacuum brazed on the absorber, interface plate welded on the cooling tube



Tungsten absorber with 3 thermal links





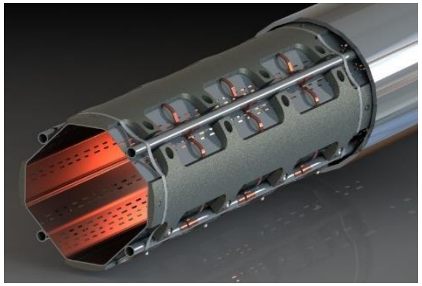
- ➢ Very good thermal decoupling between the absorbers and the beam screen tube. Temperature difference inner surface/helium well below 5K.
- ➢ Temperature of the absorbers 9 to 15K higher than the temperature of the cooling tube.
- ➢ Very good agreement between simulations and experiments.

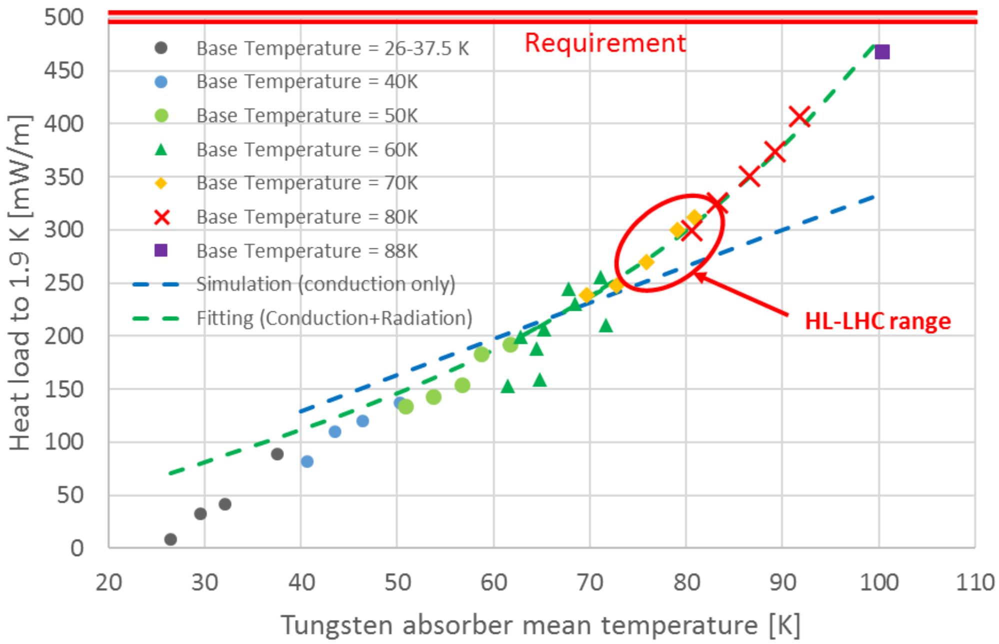
Thermal performance – beam screen (3)

Validation tests - Heat transfer from the beam screen to the cold bore

The beam screen is supported in the cold bore by sets of titanium springs and ceramic ball.
Springs are only installed in the bottom part of the beam screen.
Heat leak to 1.9 K by conduction through the supporting system and radiation.

3D printed titanium spring with ZrO2 ball


Beam screen with supports



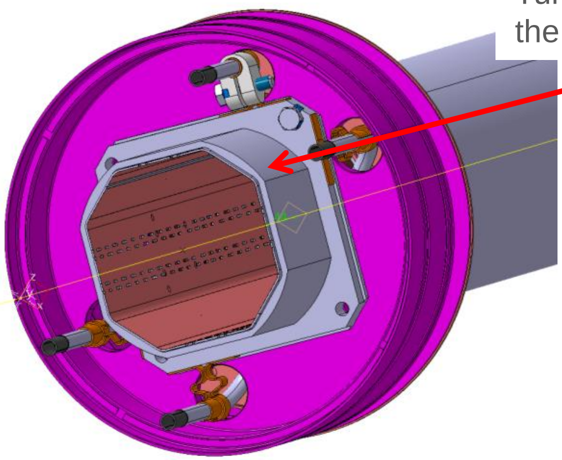
- Very good agreement between simulations and experiments.
- Heat load to the 1.9 K bath below the 500 mW/m requirement.

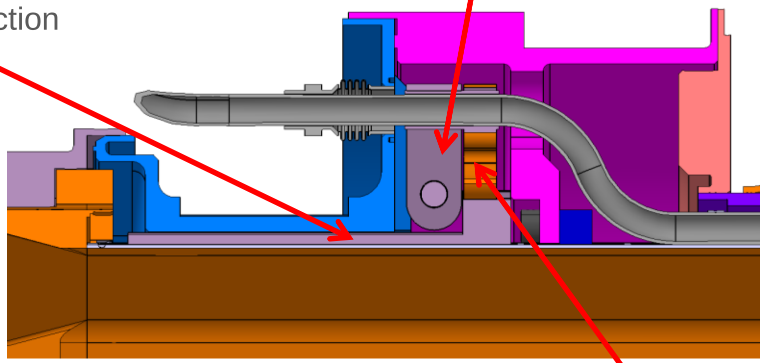
Cooling of the vacuum components (2)

Absorber in interconnections are cooled by conduction through copper thermal links clamped on the cooling tubes.

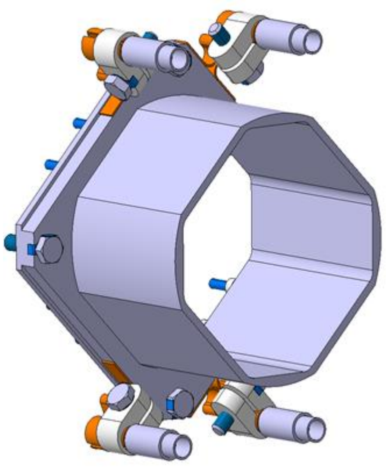
Tungsten absorber in the interconnection

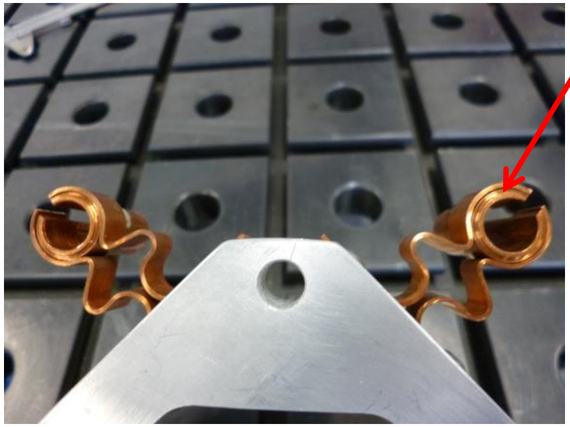
Clamp





Copper link brazed on the absorber





Absorber prototype

Thermal performance – interconnection absorber

Simulations of the temperature profiles

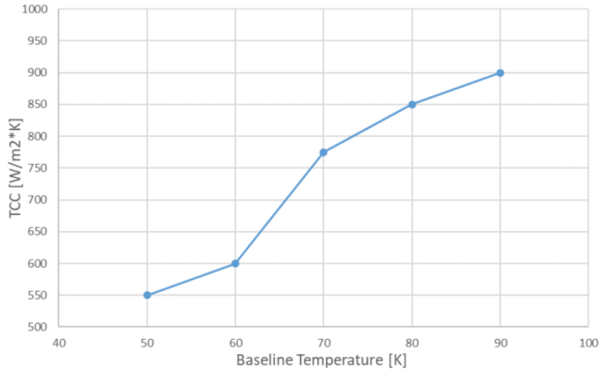
Requirements:

- Heat loads on the absorber in the interconnection [WP 10]: 2.3 W
- Temperature gradient: <20 K (similar to the absorbers on the beam screen)

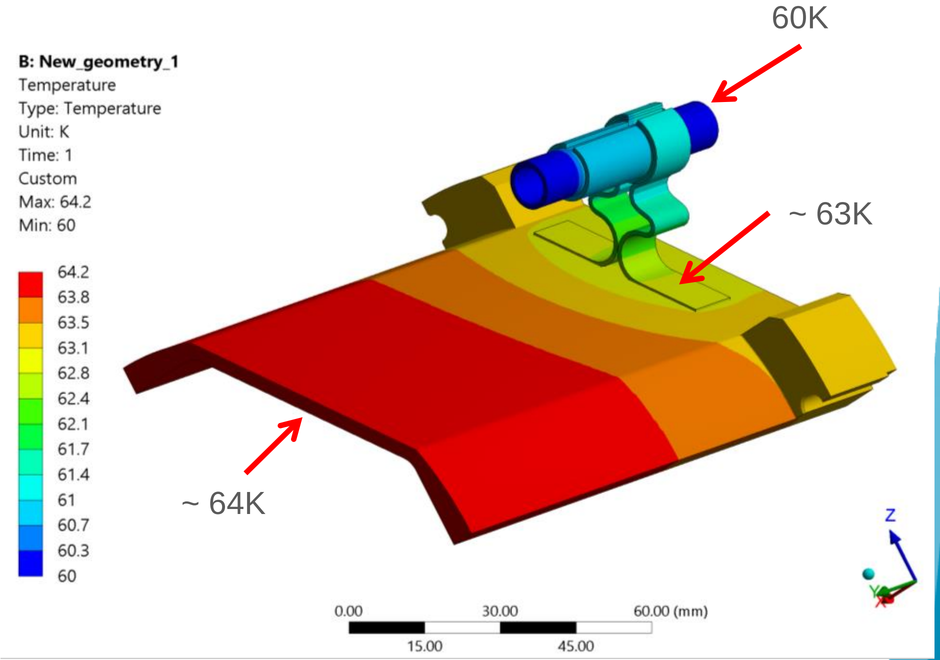
The heat transfer is ensured by copper thermal links:

- 4 links per absorber
- 1 link: 2 Strips 1 mm thick, 10 mm wide, ~30 mm long (free length)

Heat transfer driven by clamping element relying on Thermal Contact Conductance (TCC)



Heat transfer test on preliminary thermal link design



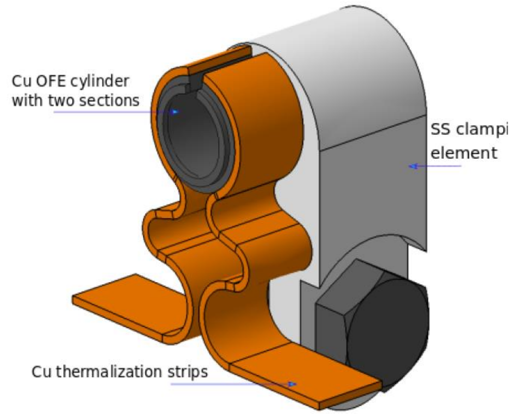
Expected temperature profile (2.7 W)

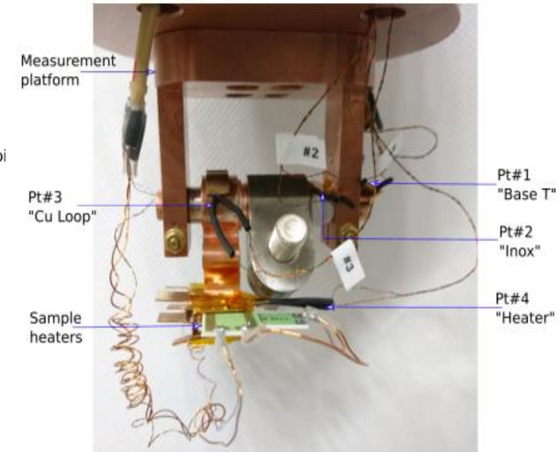
→ Expected temperature gradient below 5K.

Thermal performance – interconnection absorber

Validation tests

The temperature profile has been assessed on a prototype for different base temperatures and heating powers. Tests has been carried out at the cryolab.





Prototype and test set-up for validation tests

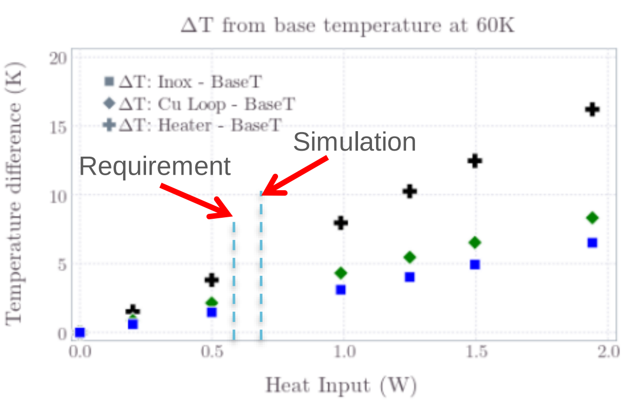


Figure 6: Temp. difference at 60 K base temp. vs. applied heat load.

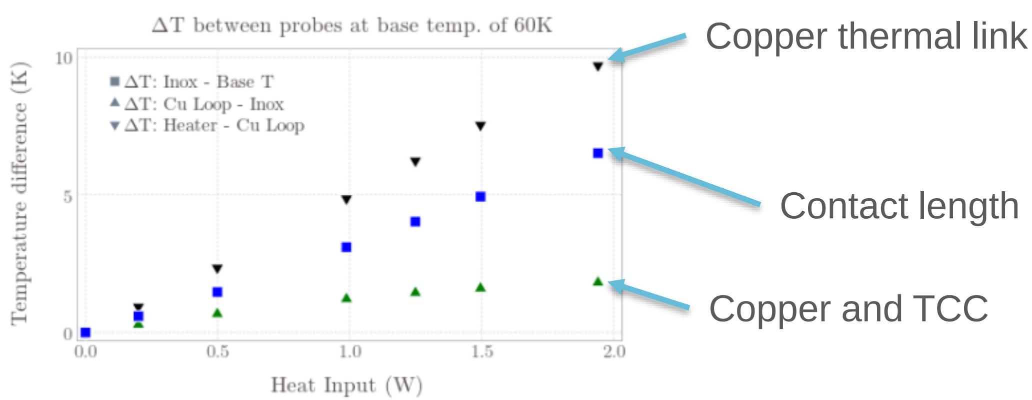


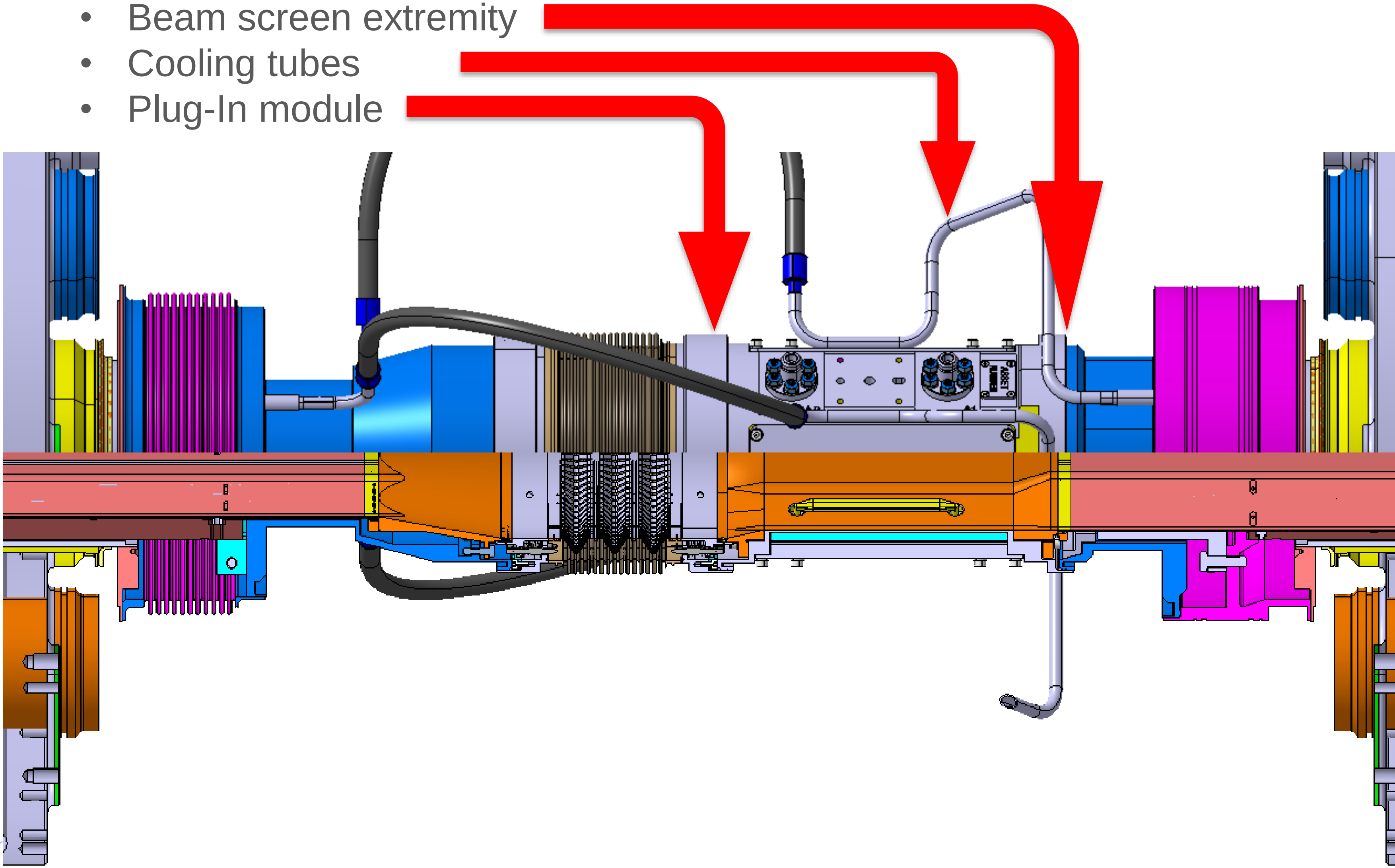
Figure 7: Temp. gradients between sensor locations at 60 K vs. applied heat load.

- The clamping device transfers efficiently the heat.
- A temperature gradient around 4 K is estimated. It is driven by the copper thermal link itself.

Tolerances of the BPM-relevant vacuum components

In the triplets, BPM have interfaces with:

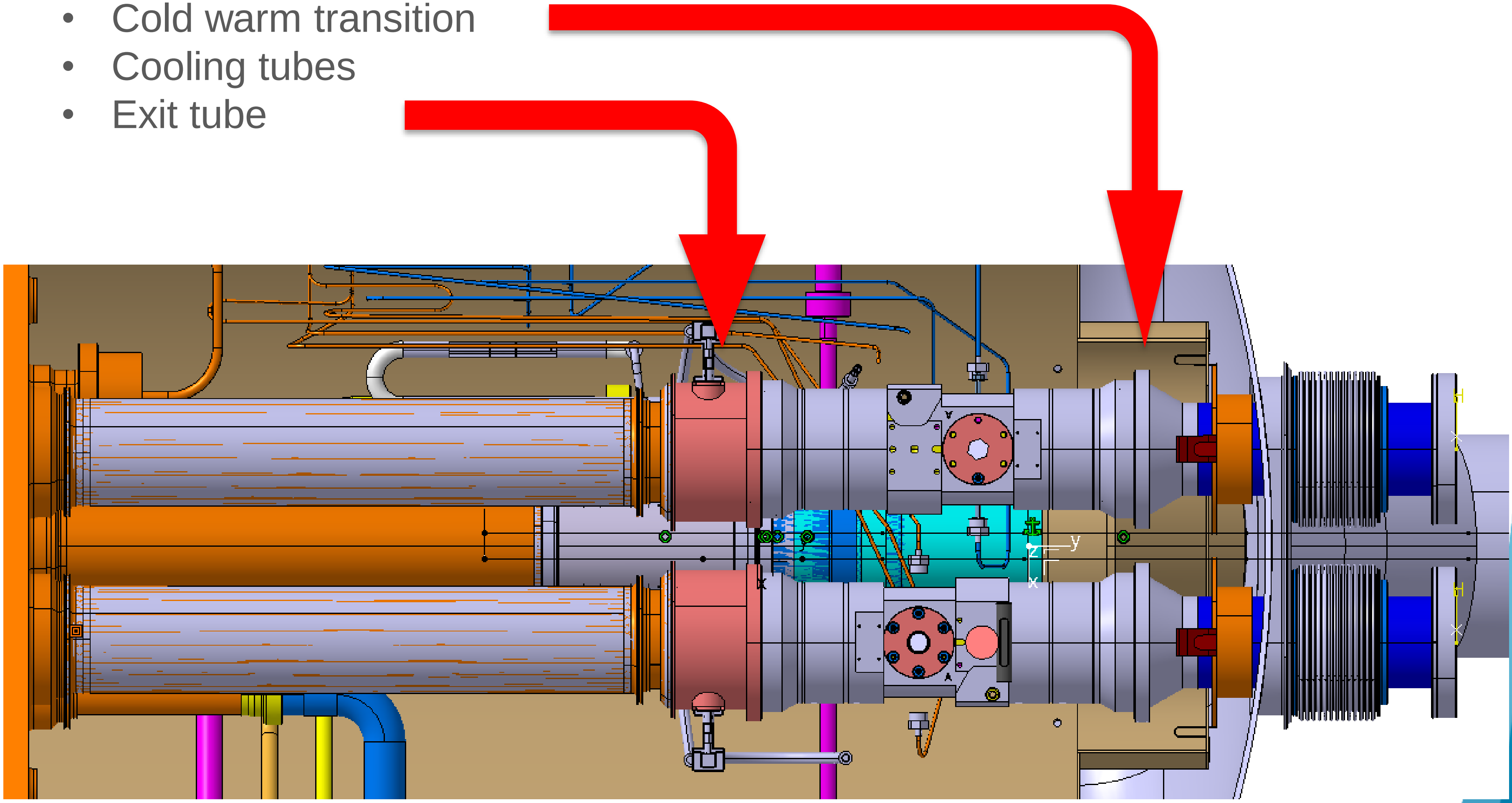
- Beam screen extremity
- Cooling tubes
- Plug-In module



Tolerances of the BPM-relevant vacuum components

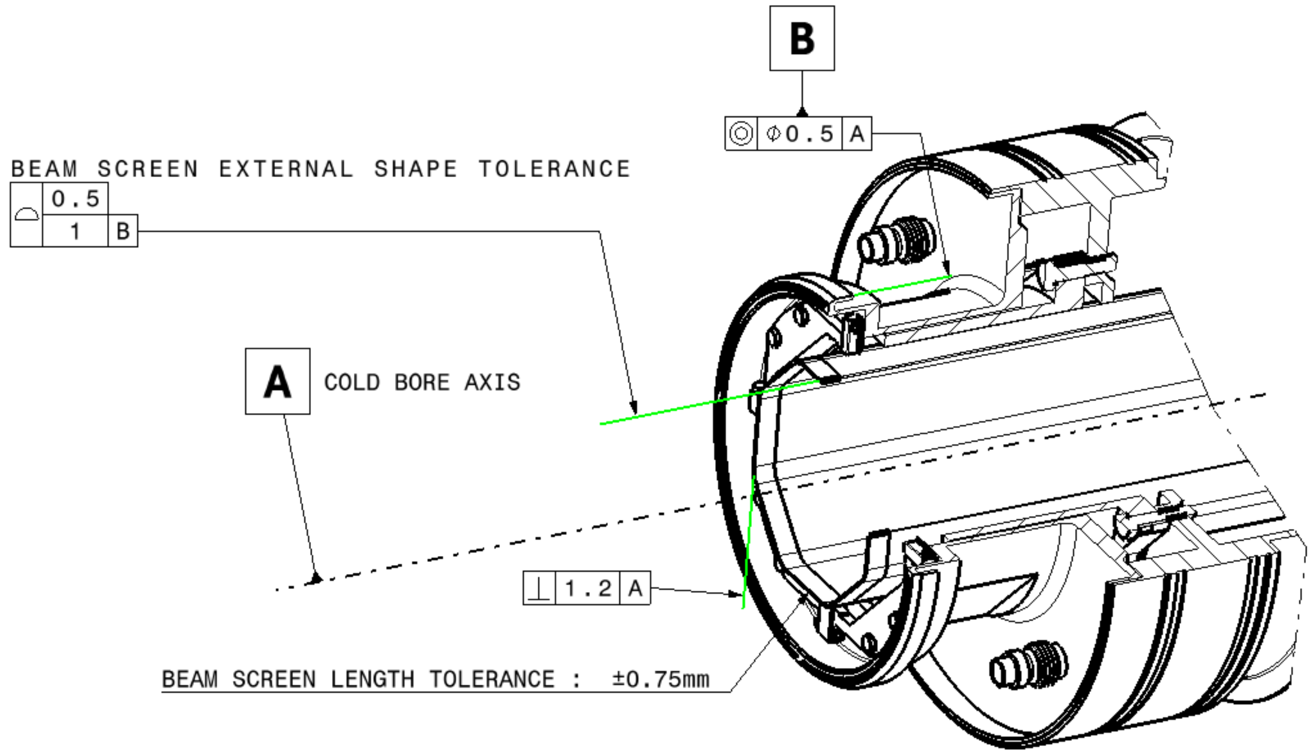
In the D2, BPM have interfaces with:

- Cold warm transition
- Cooling tubes
- Exit tube



Drawings for D2 beam screen extremities are not available.
Same tolerancing as the triplet will be applied.

Tolerances of the beam screen extremity and end flange



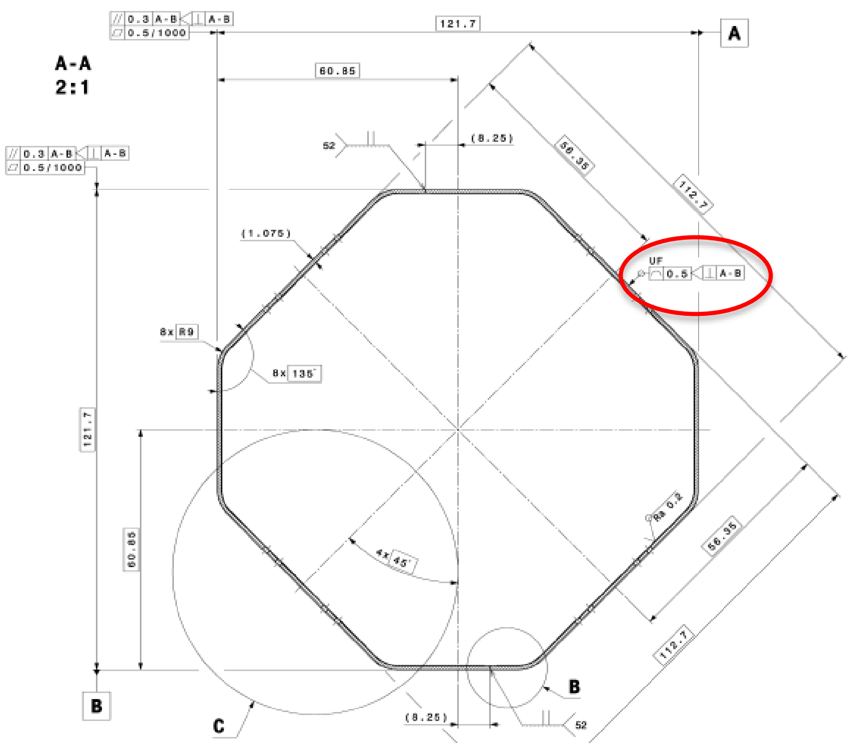
- Coaxiality of the flange w.r.t. cold mass: ϕ 0.5.
- On the beam screen extremity, a shape tolerance of 0.5 mm (+/- 0.25) is applied as well as an equivalent "coaxiality" of 0.5 mm (+/- 0.25) with respect to the end flange.

WGA, 6th March 2019

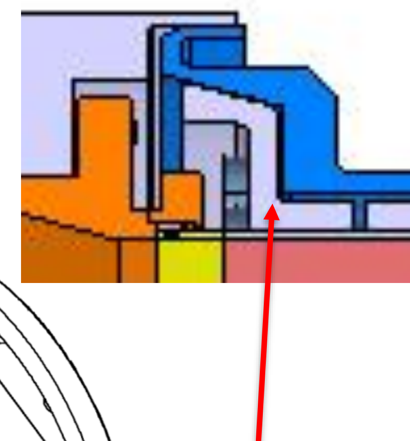
Tolerances of the beam screen extremity

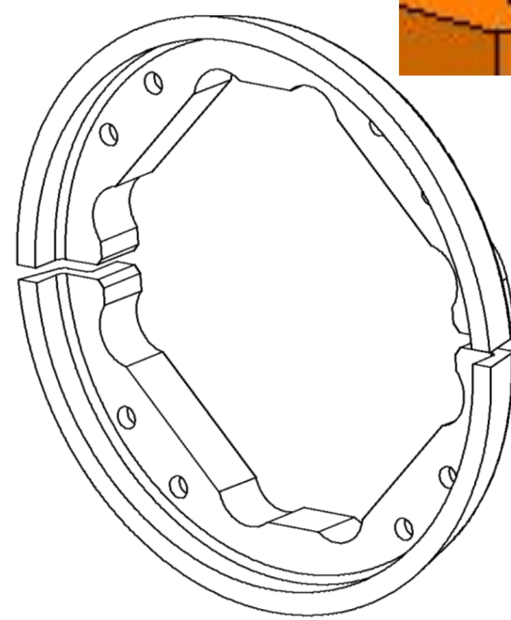
A shape tolerance of 0.5 is specified on the beam screen cross-section.
A half ring pair with conical shape is used to:

- Resize the beam screen extremity
- Center the beam screen extremity with respect to the end flange



Q2 type beam screen cross section



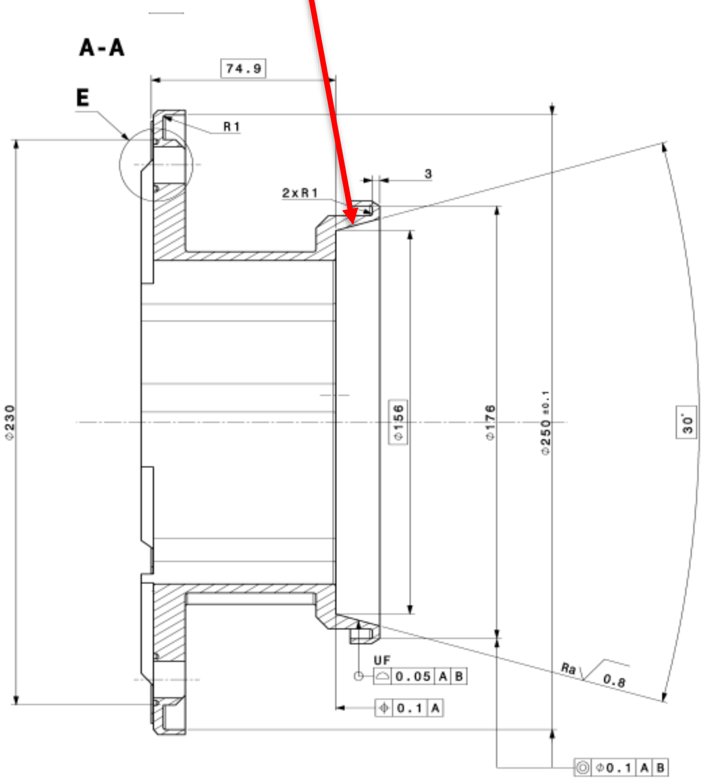


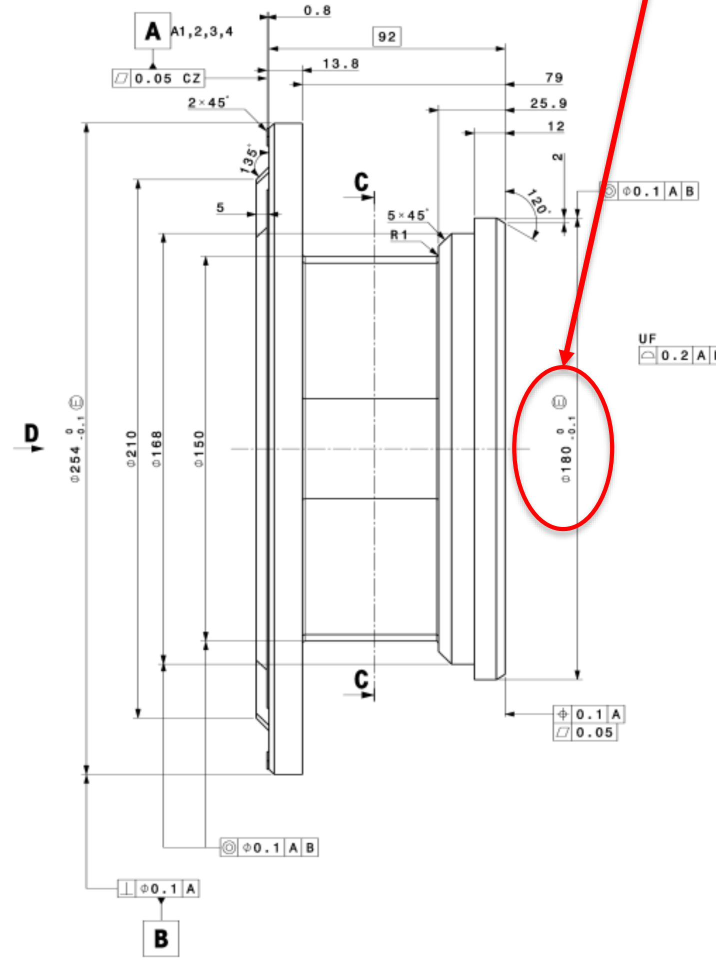
Half rings

Tolerances of the end flange

Conical shape for the centering

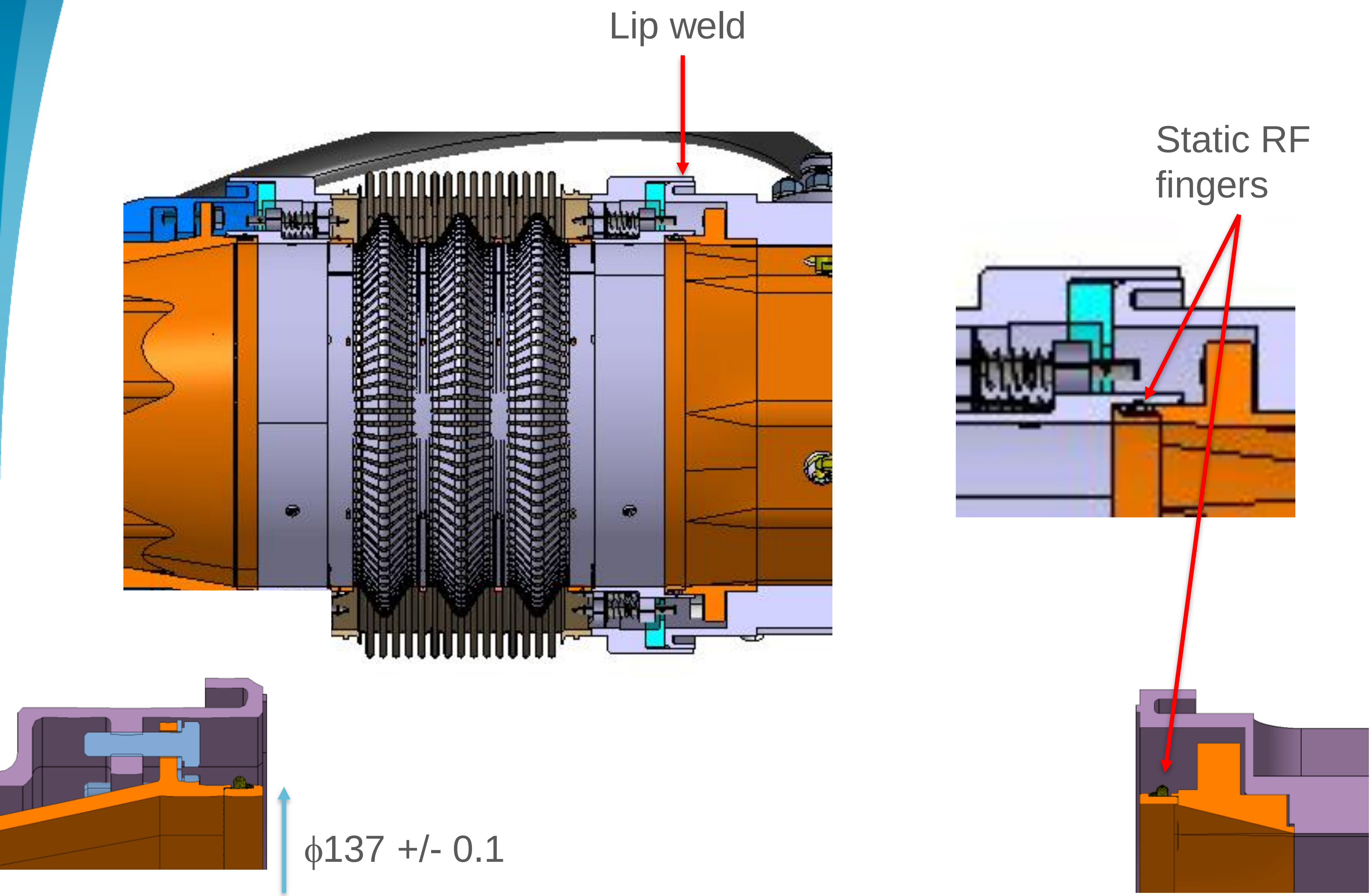
A dimension of 180 -0.1/0 specified for the male lip



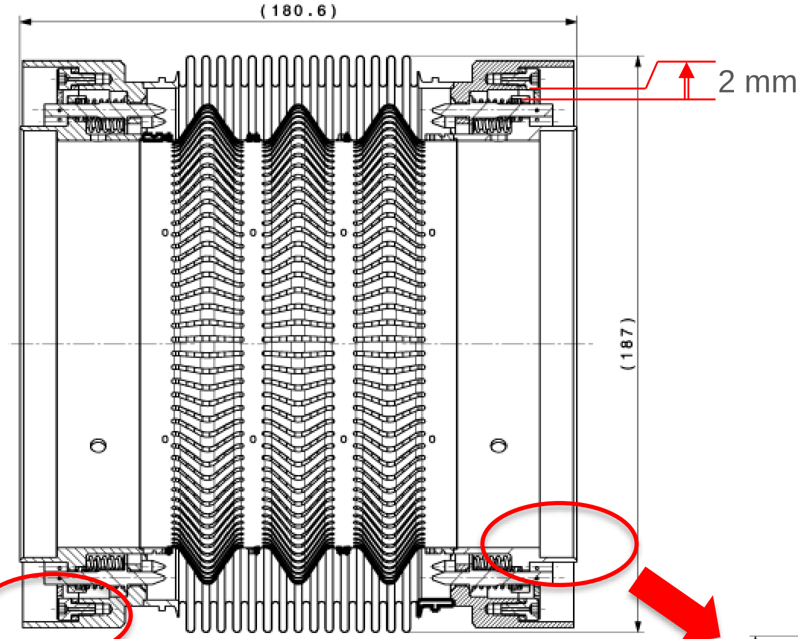


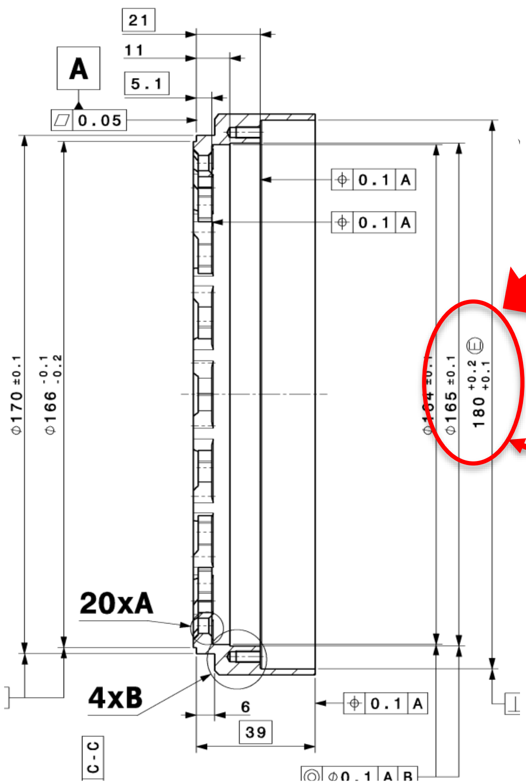
As a general rule a tolerance of -0.1/0 is specified on the male weld lip.

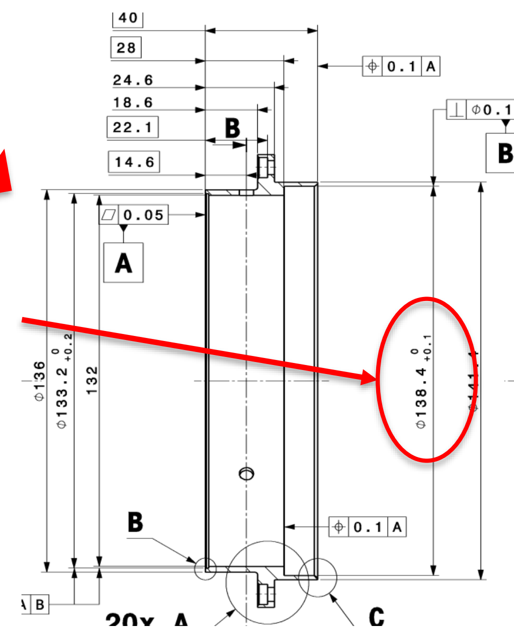
Interface PIM - BPM



Tolerances of the PIM







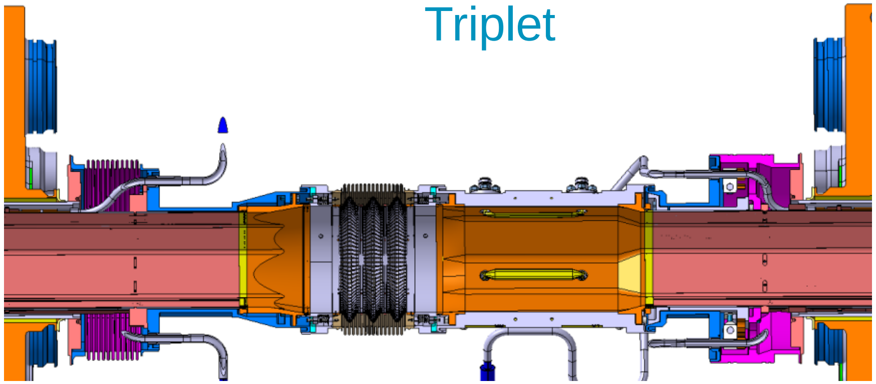
A dimension of 138.4 0./+0.1 specified for the copper insert.

A dimension of 180 +0.1/+0.2 specified for the female lip

As a general rule a tolerance of +0.1/+0.2 is specified on the female weld lips.

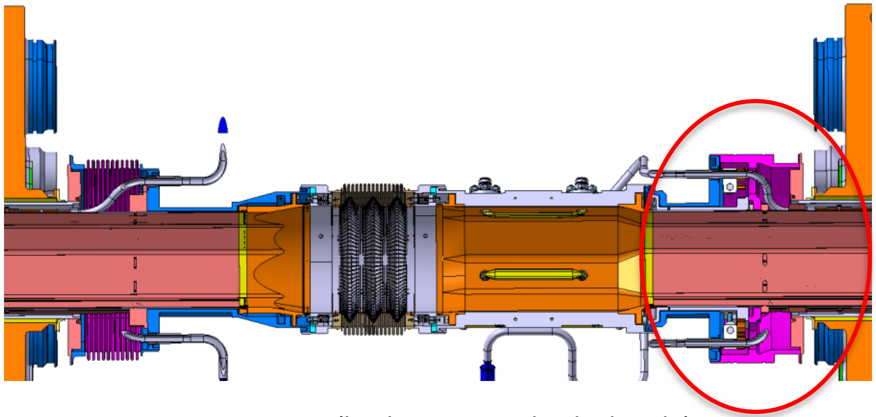
Assembly sequence of the beam screen and vacuum components

Triplet



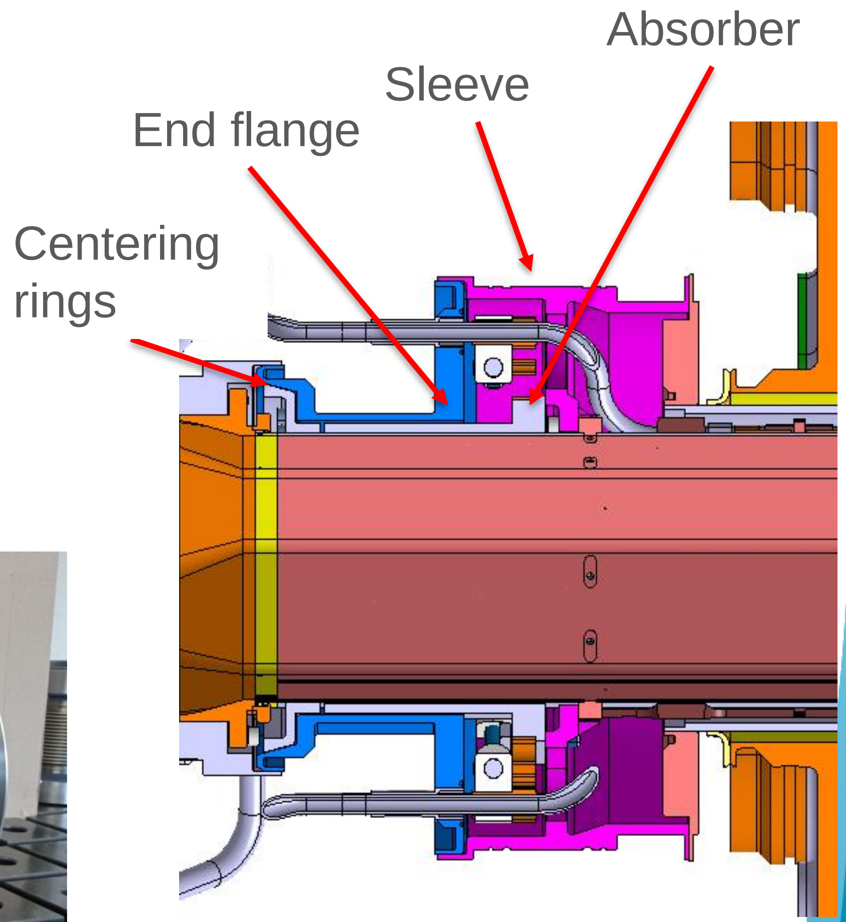
1. Beam screen manufacturing:
    1. Beam screen assembly
    2. aC coating
    3. Storage
2. Beam screen insertion
    1. Bending of the cooling tubes (fixed point side)
    2. Insertion in the cold mass
    3. Bending of the cooling tubes (sliding side)
    4. Fixed point assembly
    5. Sliding point assembly
3. BPM mounting
    1. BPM positioning and welding
    2. Cooling tube connections

Fixed point assembly



Beam vacuum line interconnection in the triplet

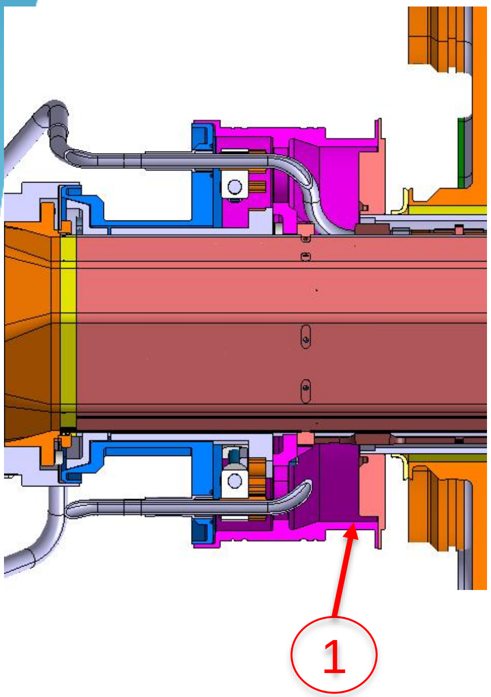
Prototypes of fixed point components



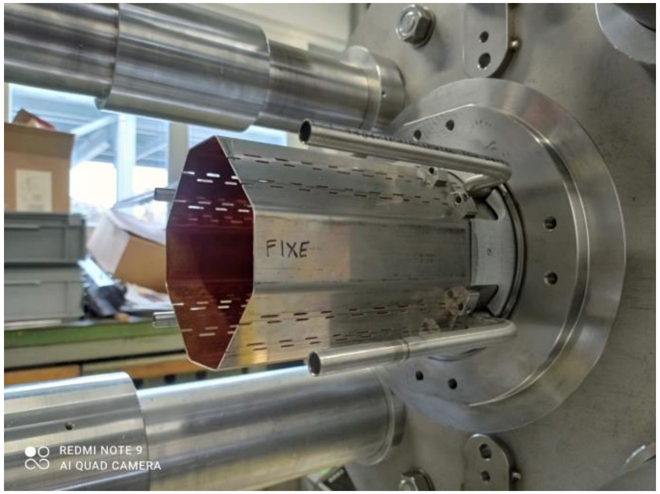
Fixed point assembly

Fixed point assembly

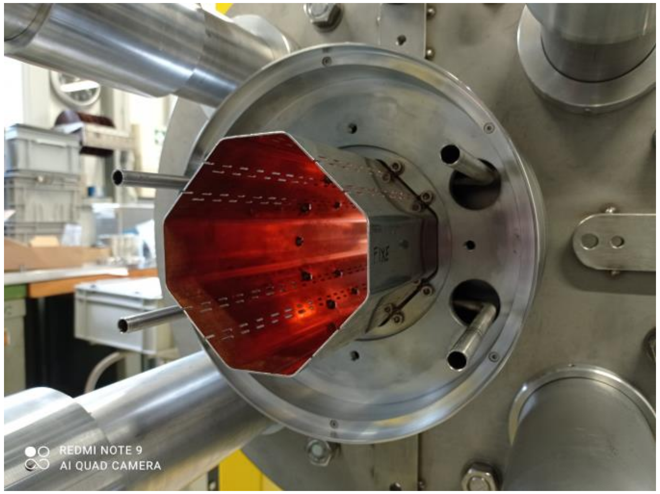
Assembly principle:



1. Mount the sleeve on the “salmon” fixed pegs and temporary fix it to the cold bore flange



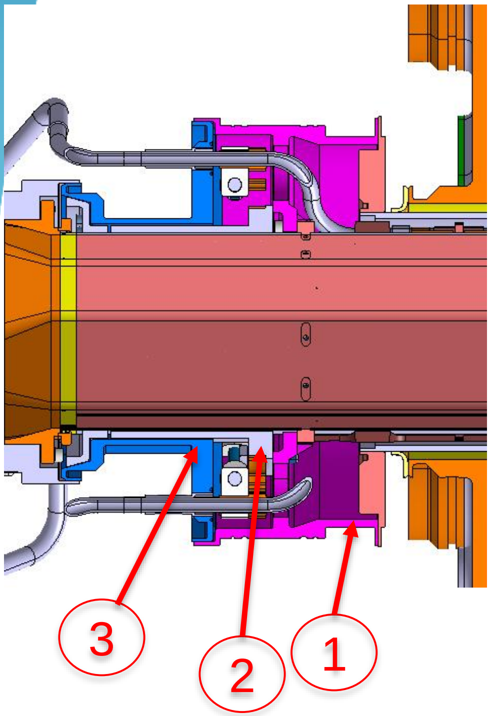
Inserted beam screen



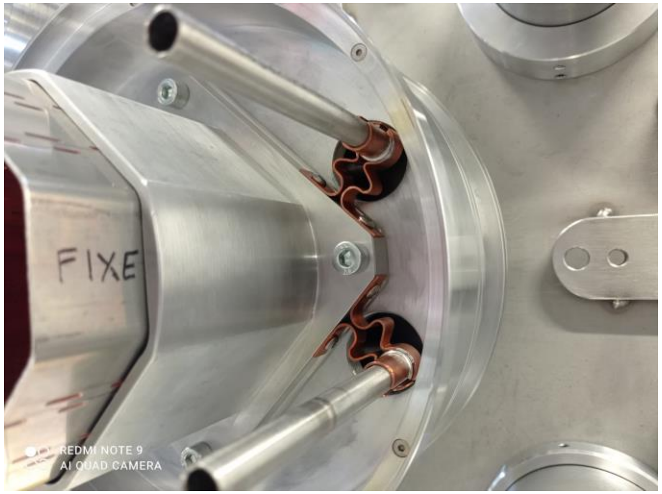
Sleeve assembly

Fixed point assembly

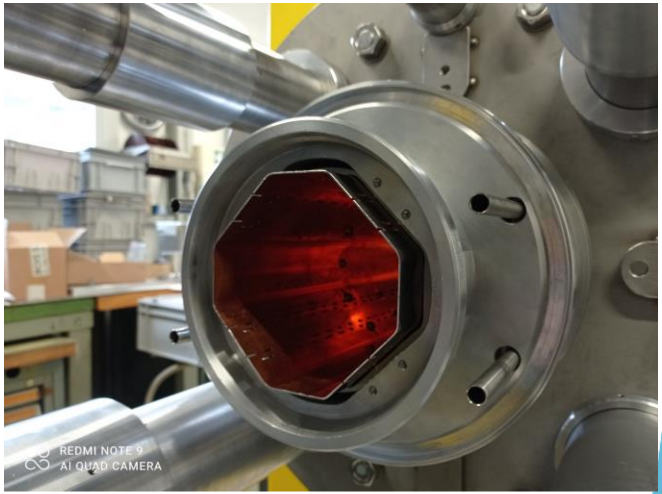
Assembly principle:



2. Install the absorber (screwed on the sleeve)
3. Install the end flange



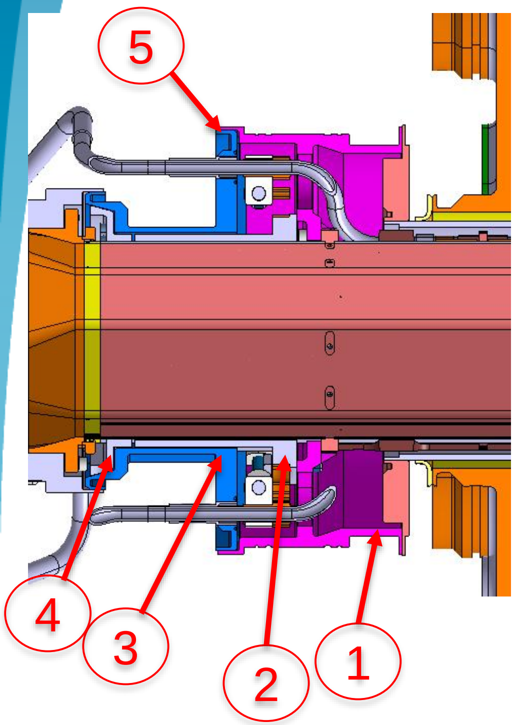
Installed absorber



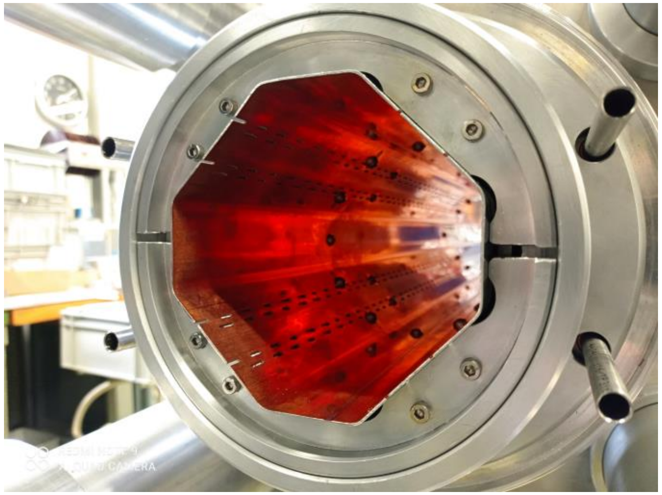
Installed end flange

Fixed point assembly

Assembly principle:



4. Mount and adjust the centring rings between the end flange and the beam screen
5. Weld the end flange to the sleeve

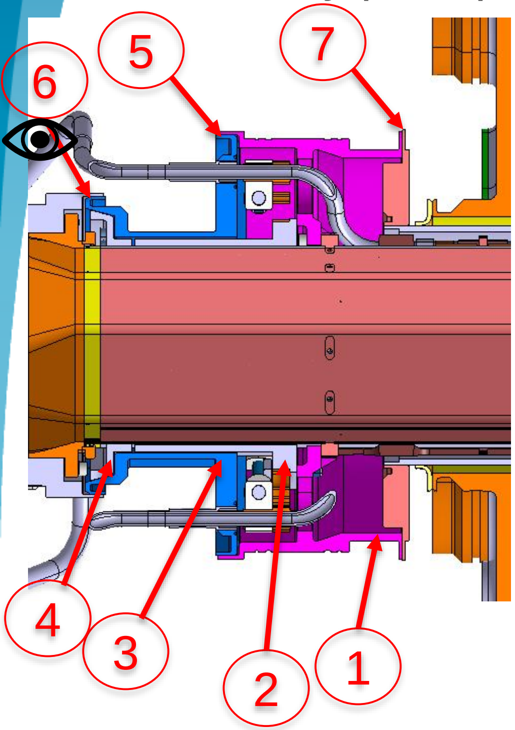


Installed centring rings

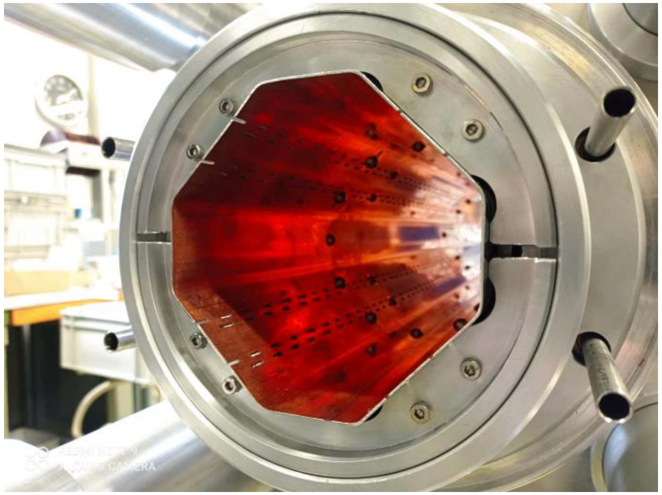
Installed end flange

Fixed point assembly

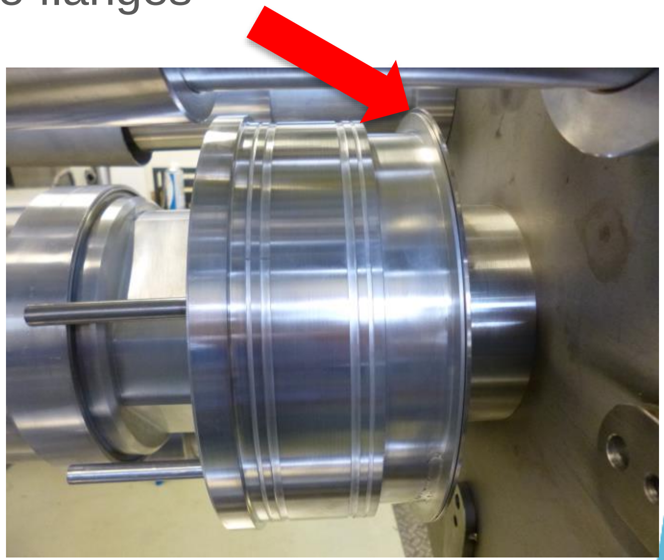
Assembly principle:



6. Check position of the end piece flange and adjust it if necessary
7. Weld the cold bore/sleeve flanges

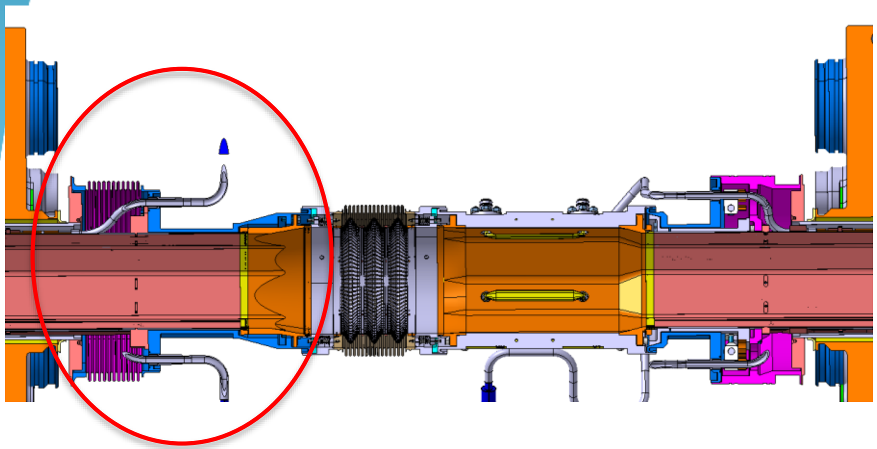


Installed centring rings

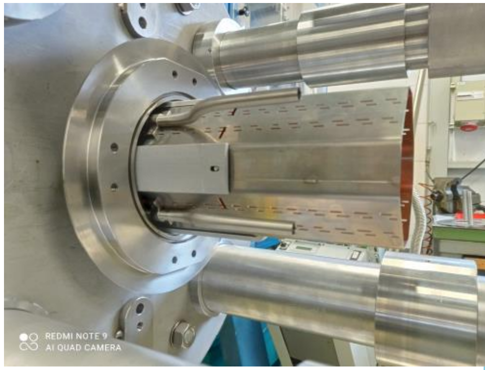


Installed end flange

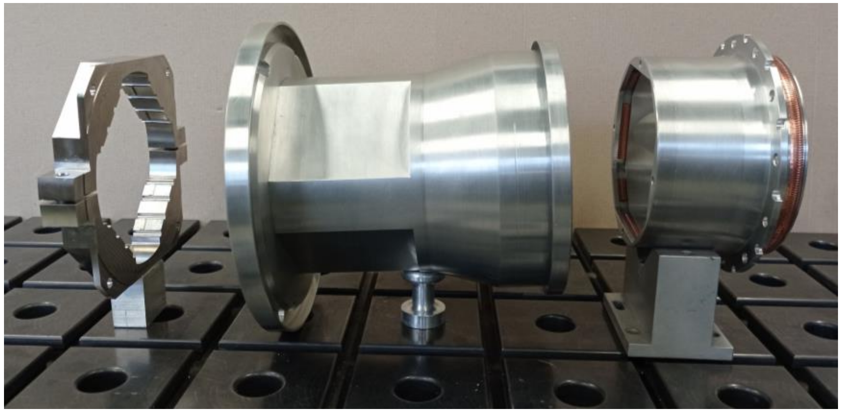
Sliding point assembly



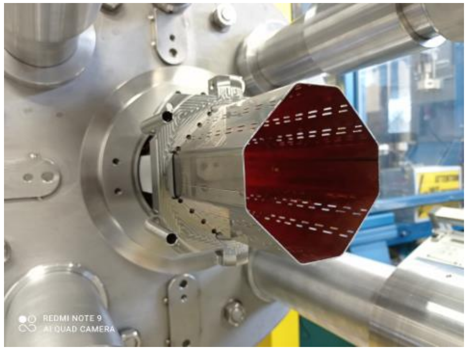
In-situ cooling tube bending



Beam screen extremity after cooling tube bending



Prototypes of fixed point components

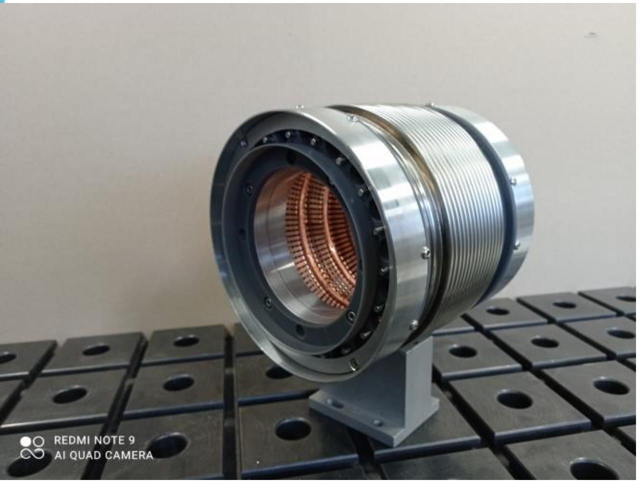


Fixed point assembly

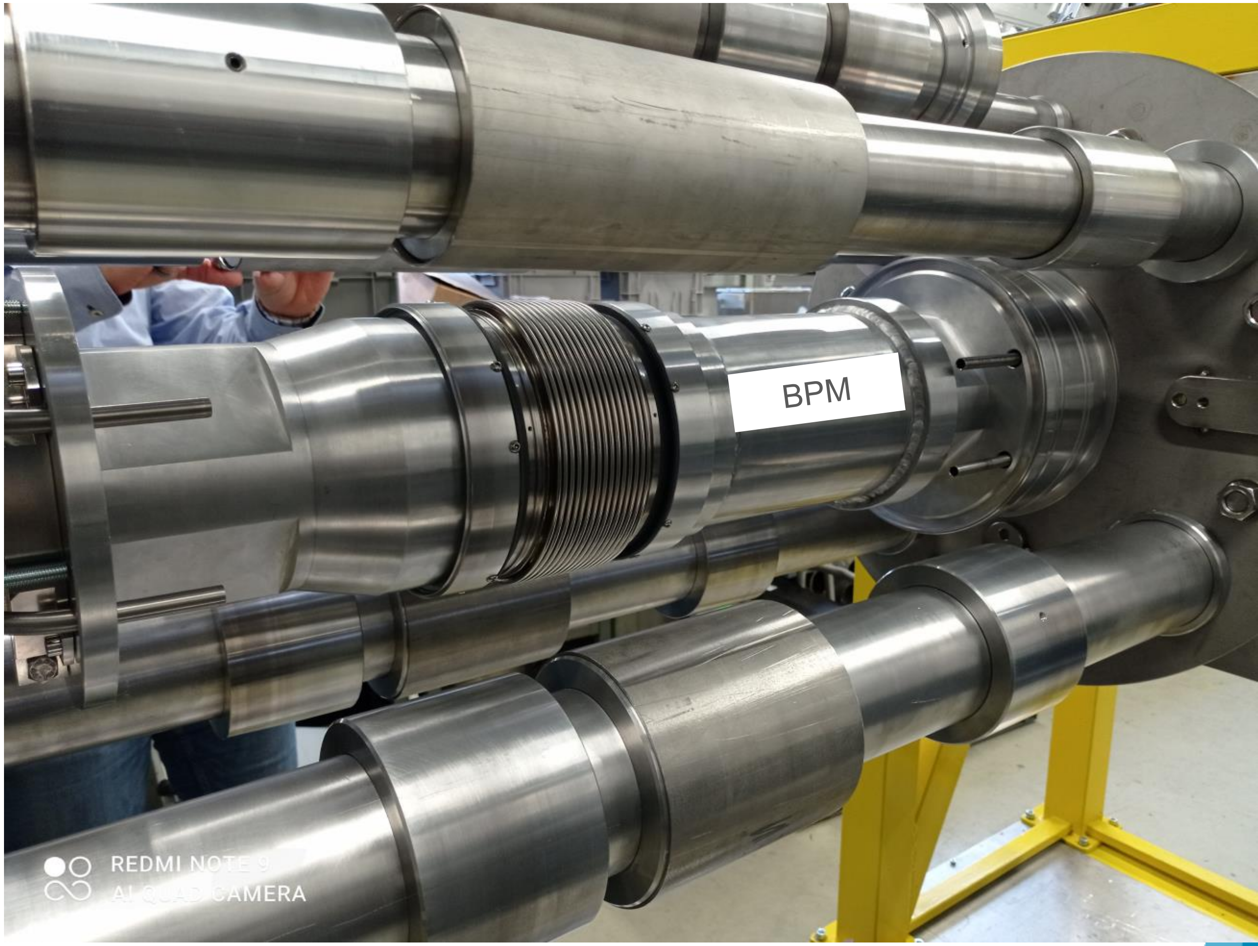
End flange and insert assembly

Beam vacuum line interconnection

Triplet interconnection mock-up



PIM prototype with Deformable RF bridge



Beam vacuum line assembly

If more representative BPM prototype is available, it can be integrated in the mock-up.

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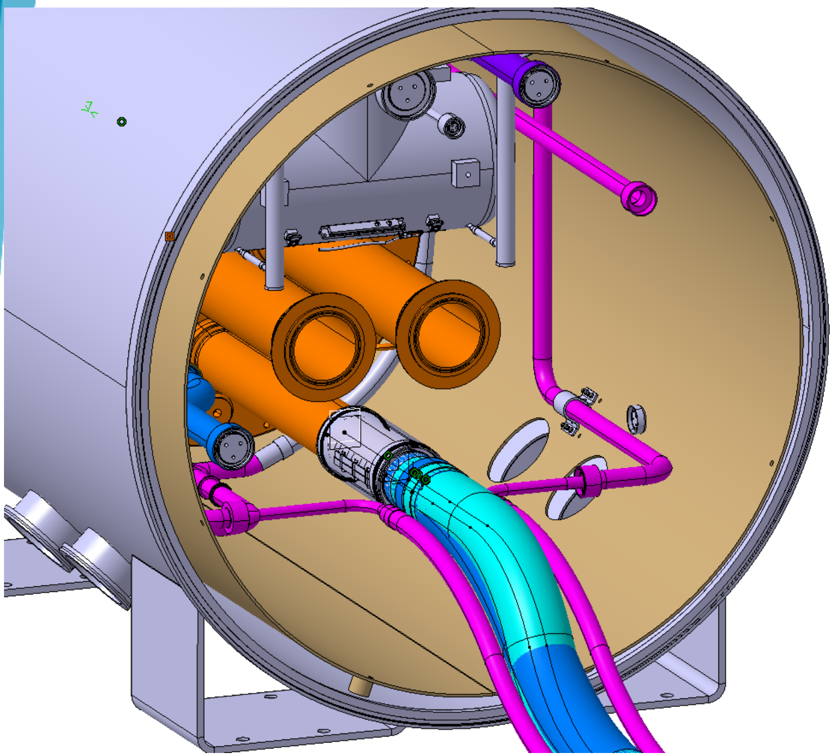
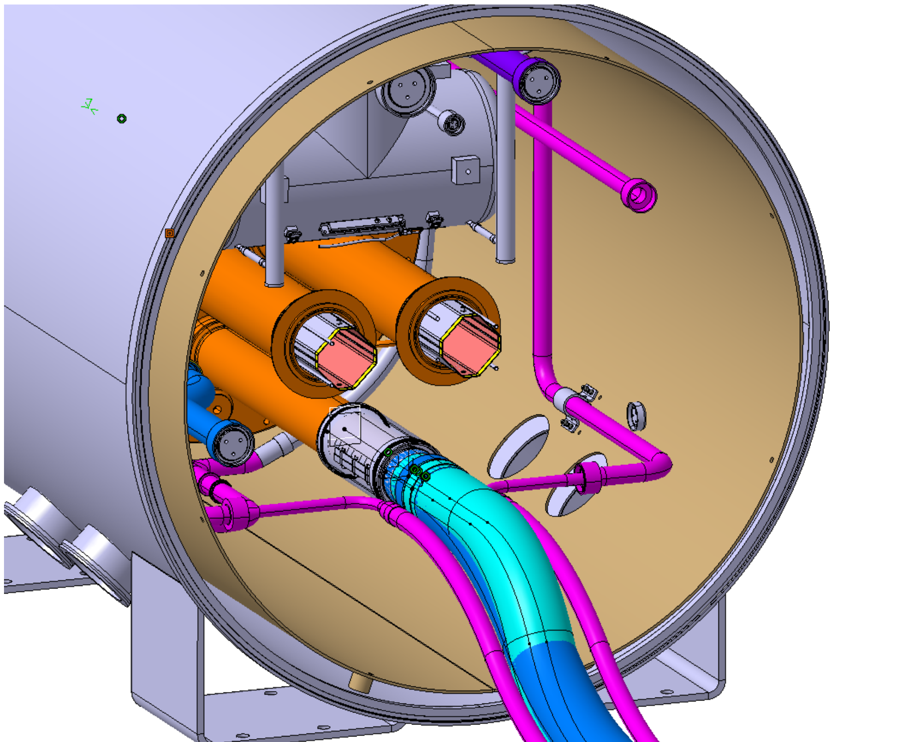
Assembly sequence of the beam screen and vacuum components

D2

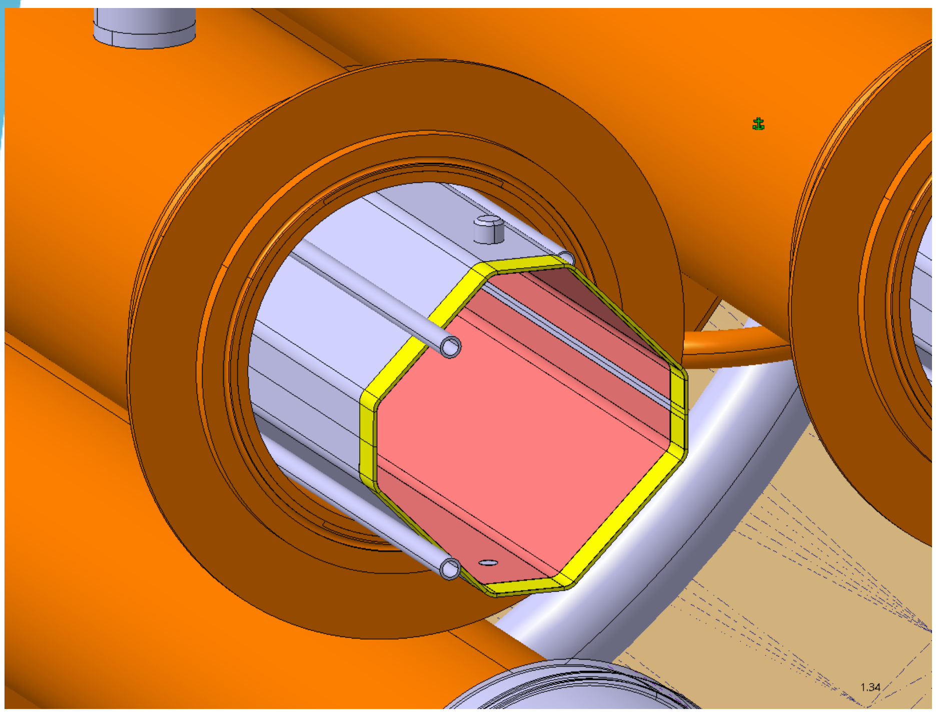


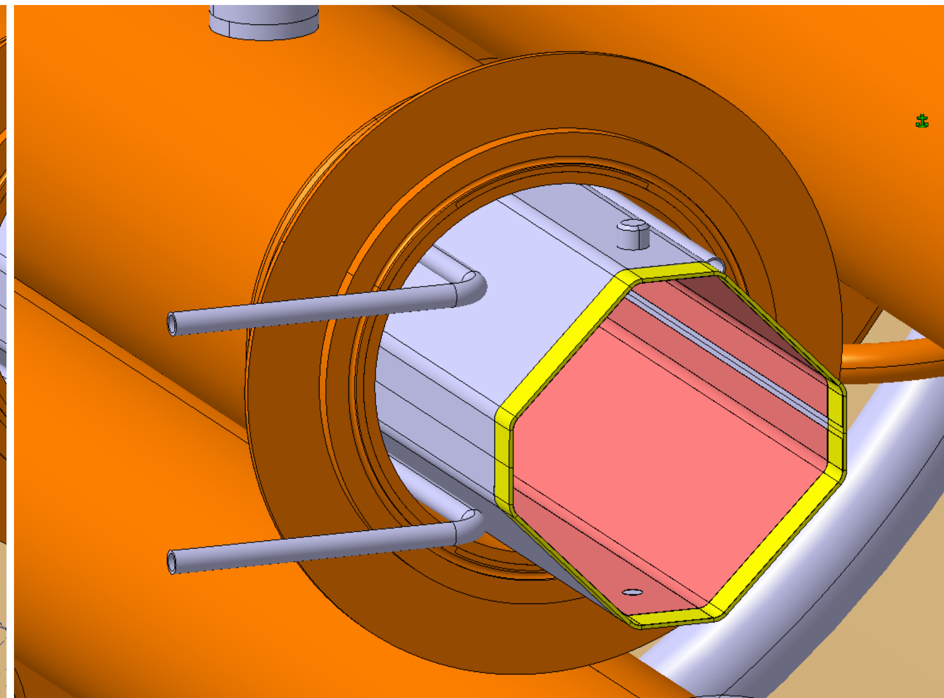


Beam screen insertion

Assembly sequence of the beam screen and vacuum components

D2

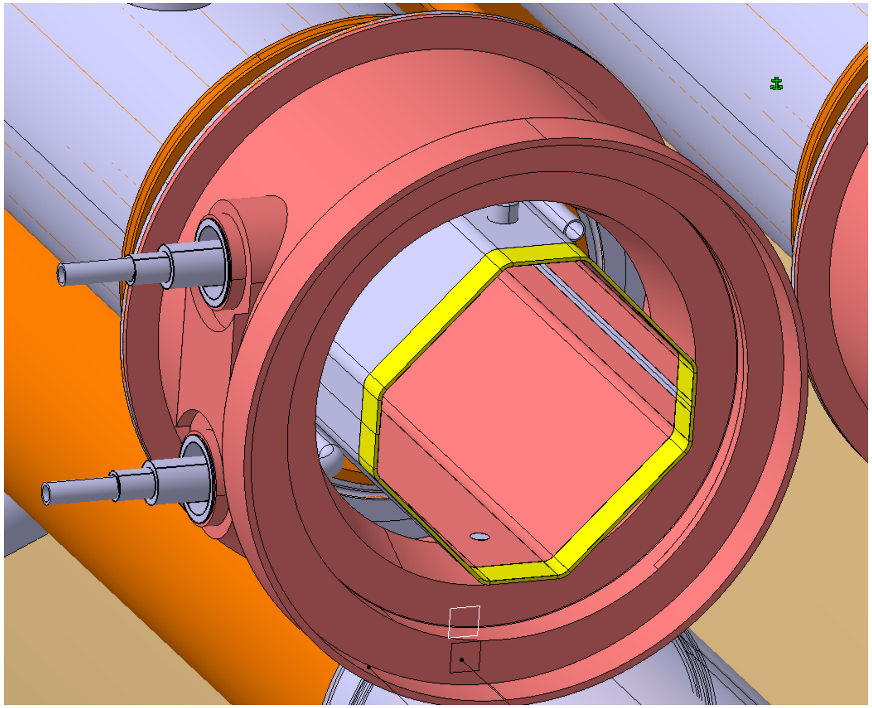




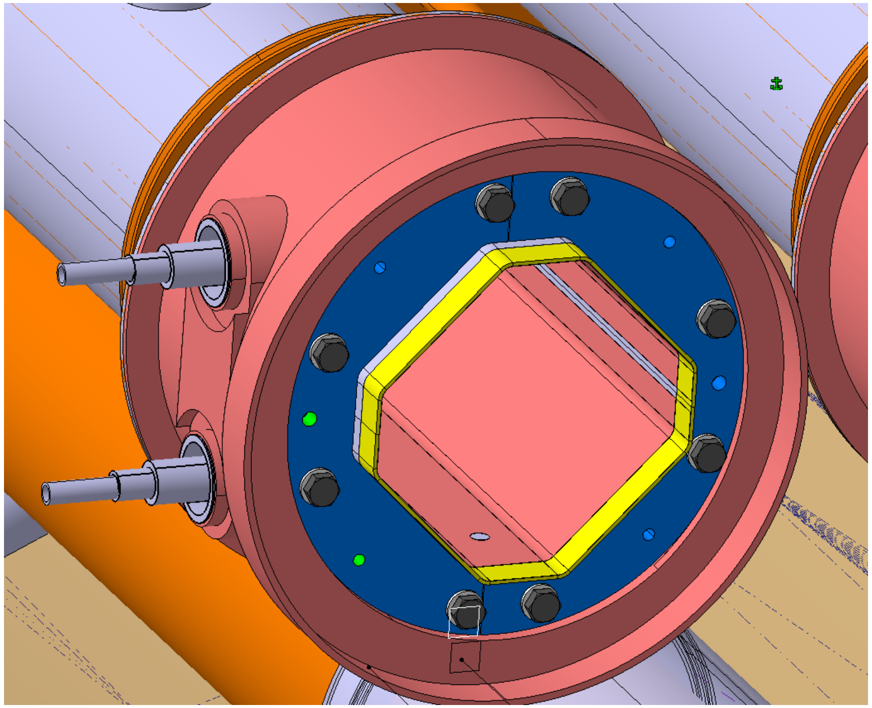
Cooling tube bending

Assembly sequence of the beam screen and vacuum components

D2



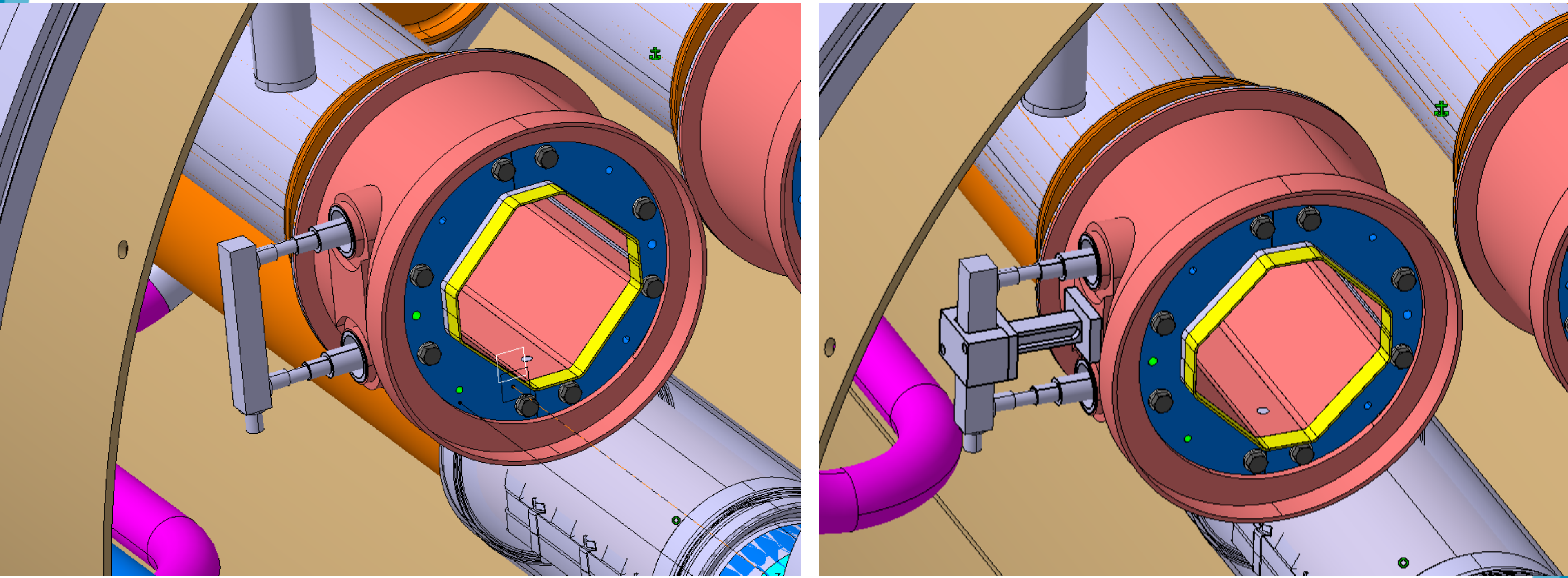
Exit tube assembly



Centering ring assembly

Assembly sequence of the beam screen and vacuum components

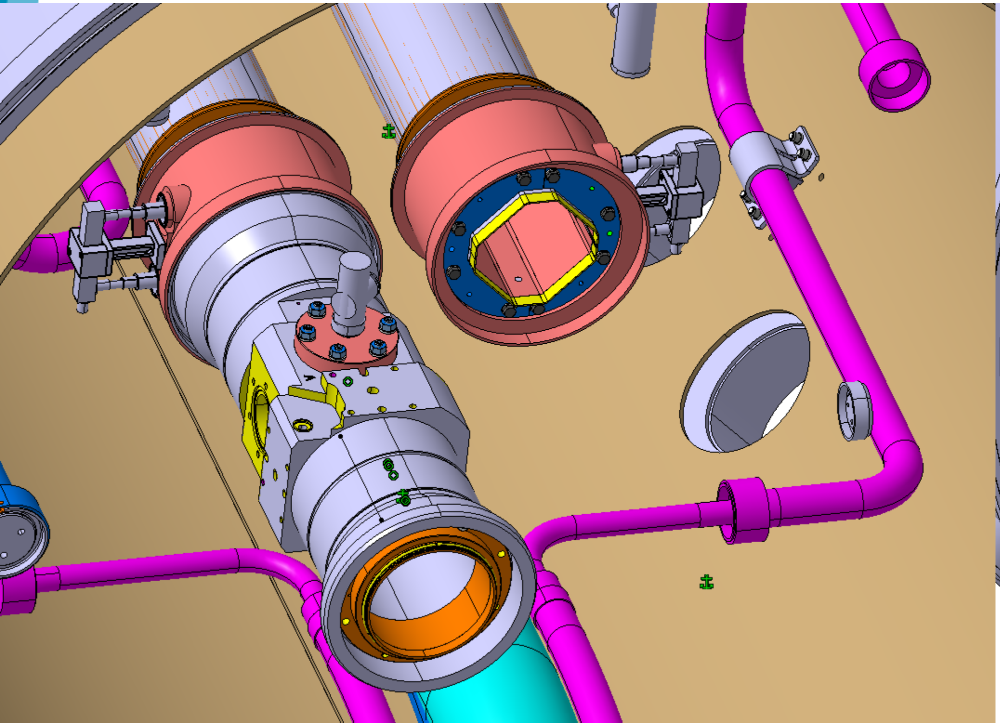
D2



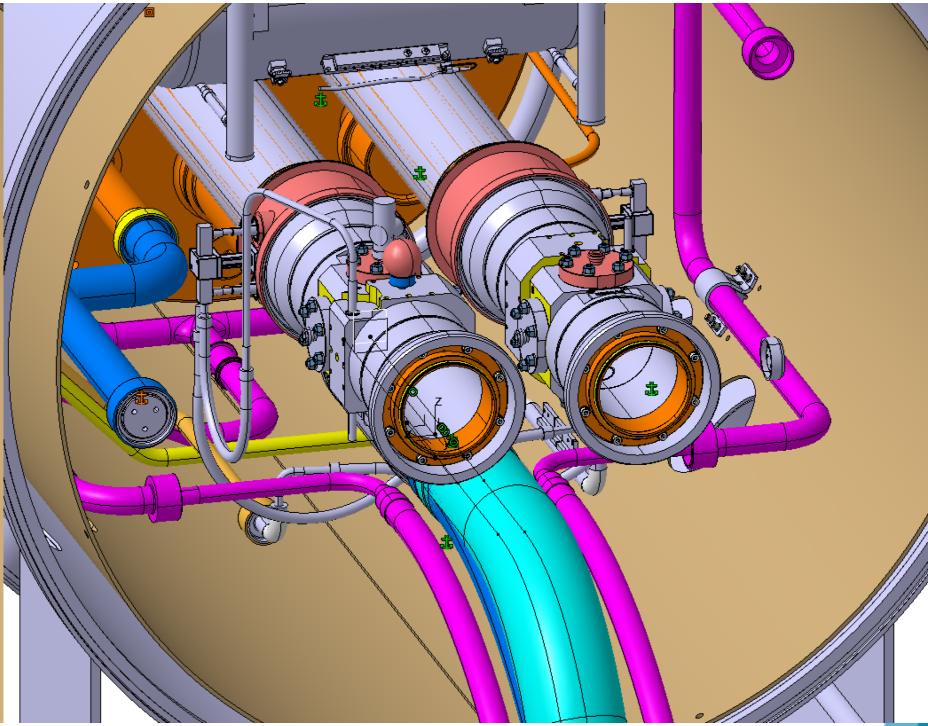
Feedthrough, exit tube and collector welding

Assembly sequence of the beam screen and vacuum components

D2



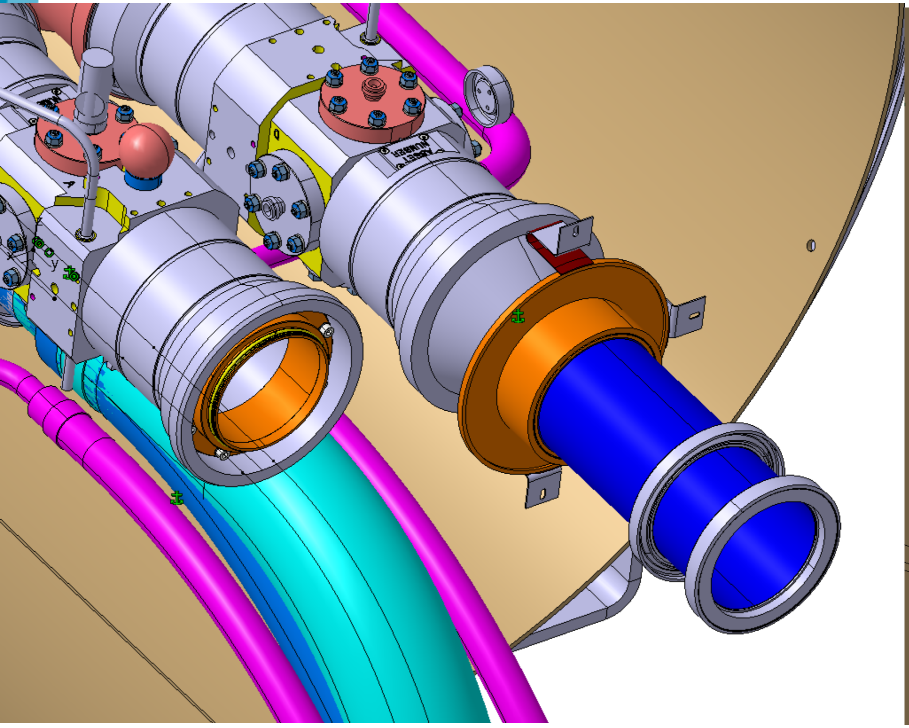
BPM welding



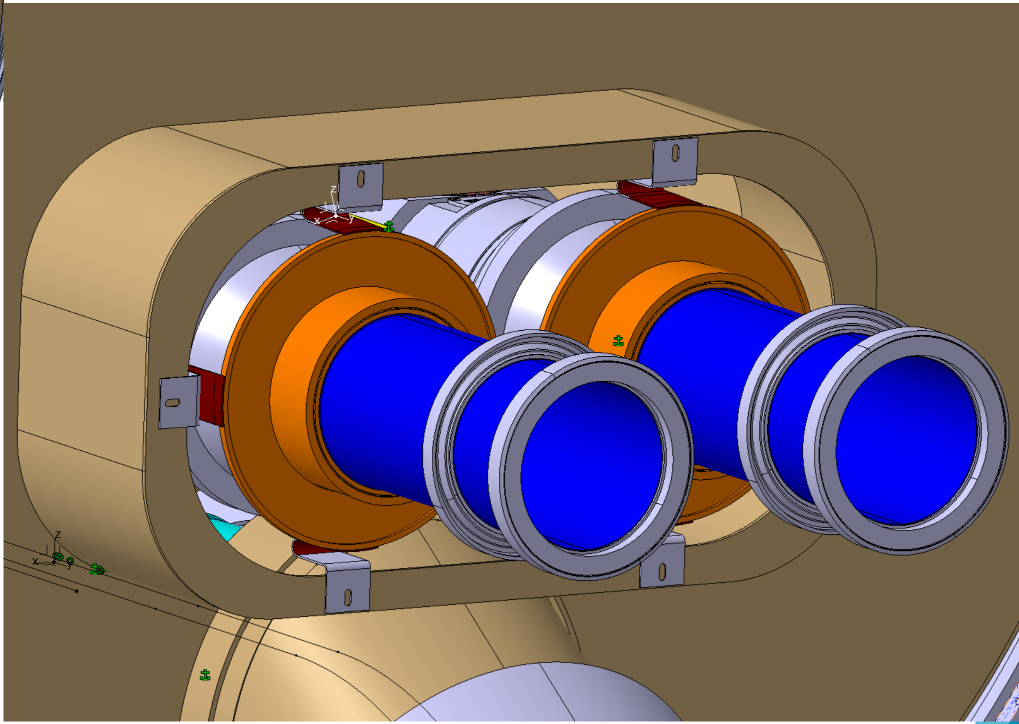
Cooling tube welding

Assembly sequence of the beam screen and vacuum components

D2



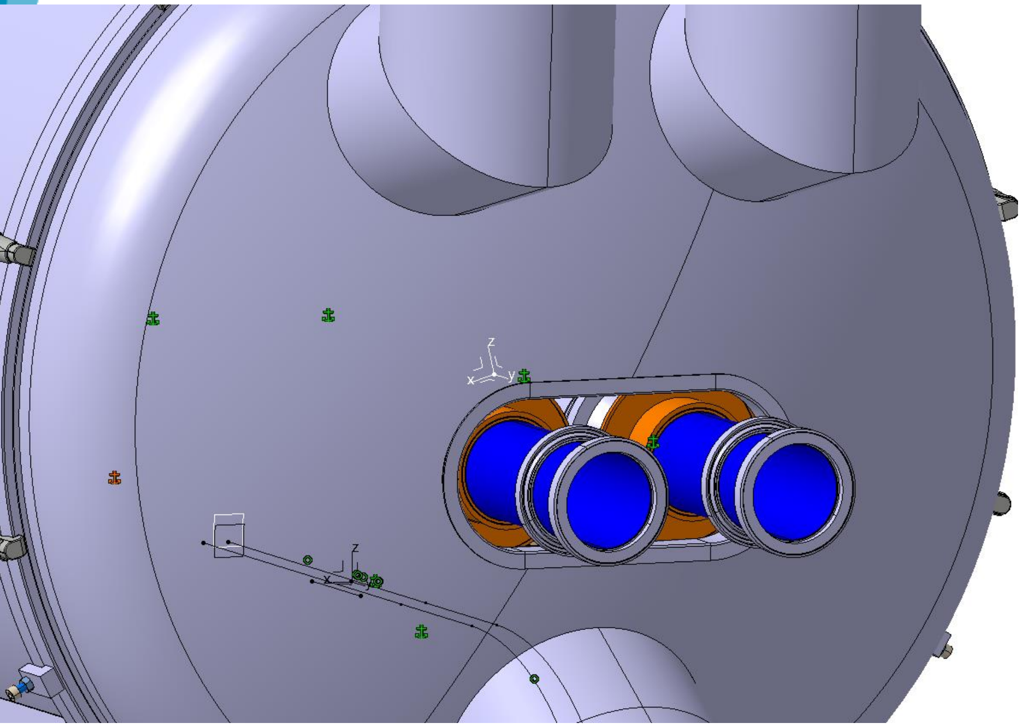
Cold warm transition welding



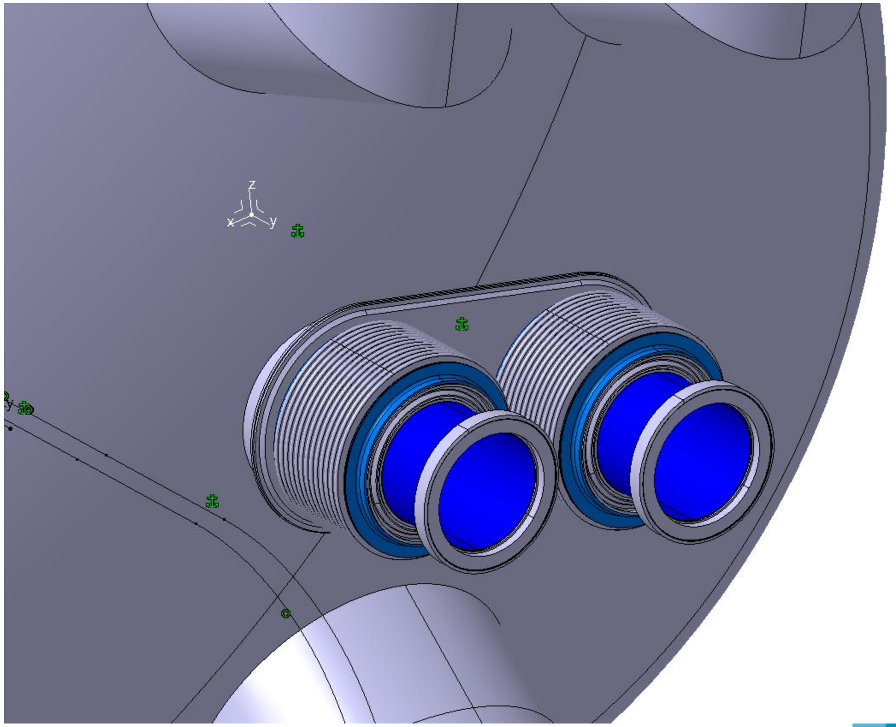
Thermal shield assembly

Assembly sequence of the beam screen and vacuum components

D2



End cover assembly



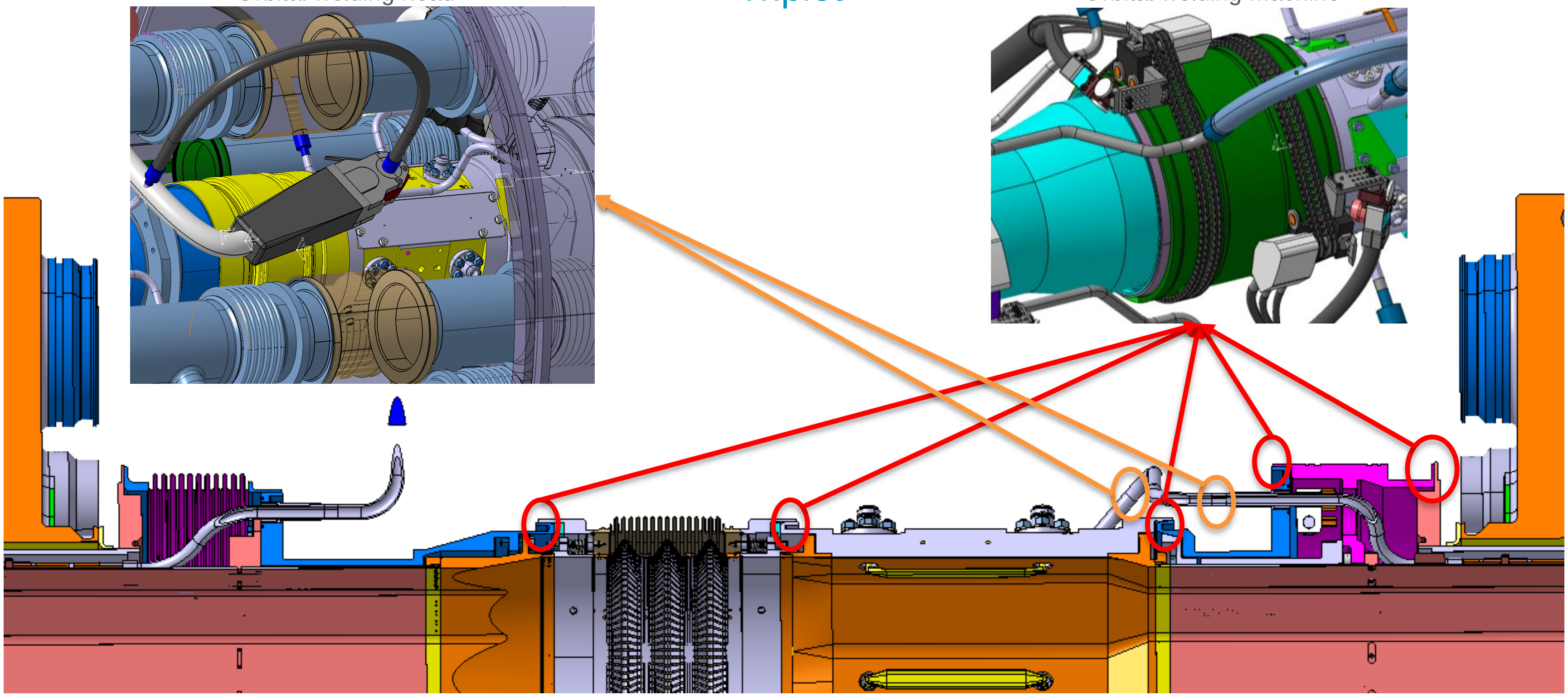
Bellows welding

Integration of welding machines

Orbital welding head

Triplet

Orbital welding machine



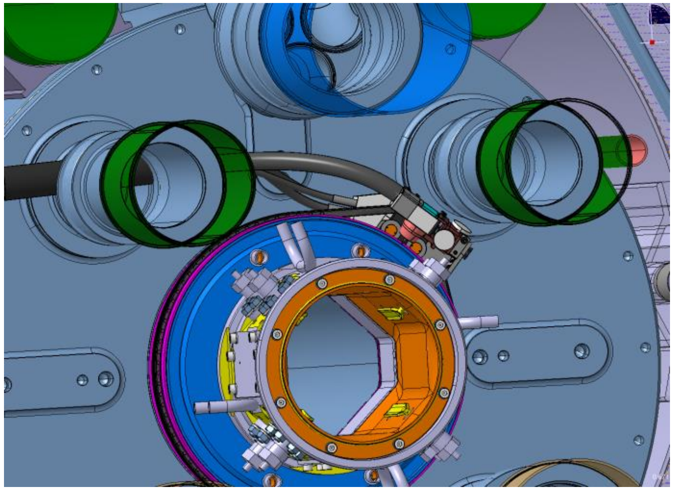
Automatic orbital welding is the baseline.

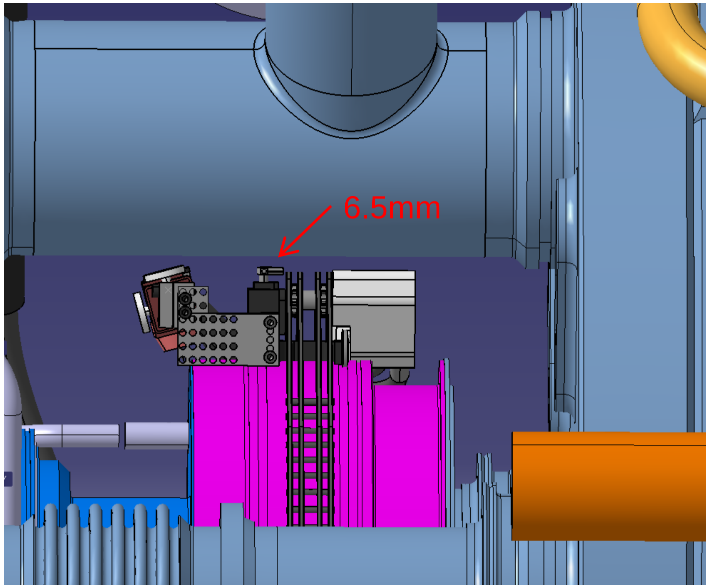
ST references:

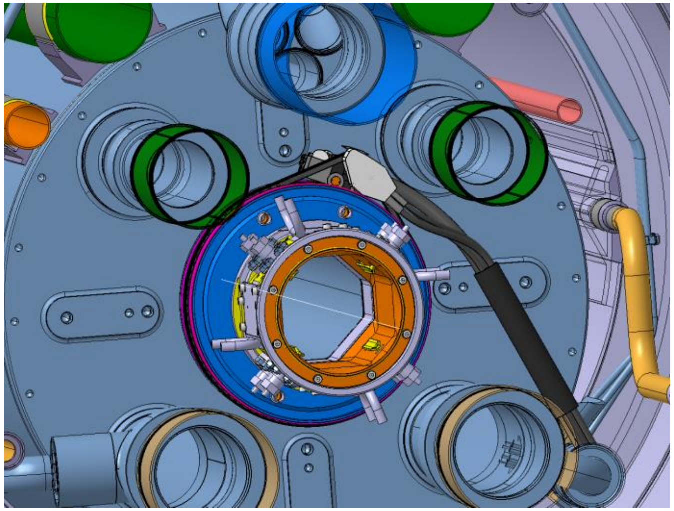
- ST0726478 LSS5R machine integration study
- ST1000412 remontage outils de Q1 a D1
- ST1013646 REMONTAGE RIGHT Q1-D1

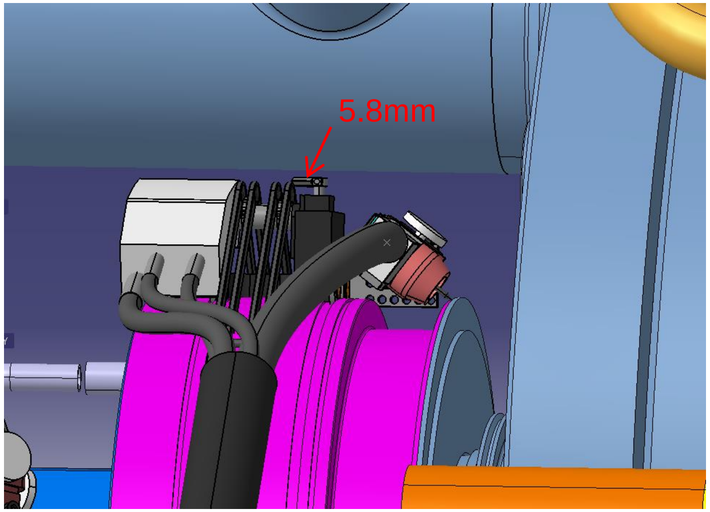
Integration of welding machines

Triplet – Sleeve welding





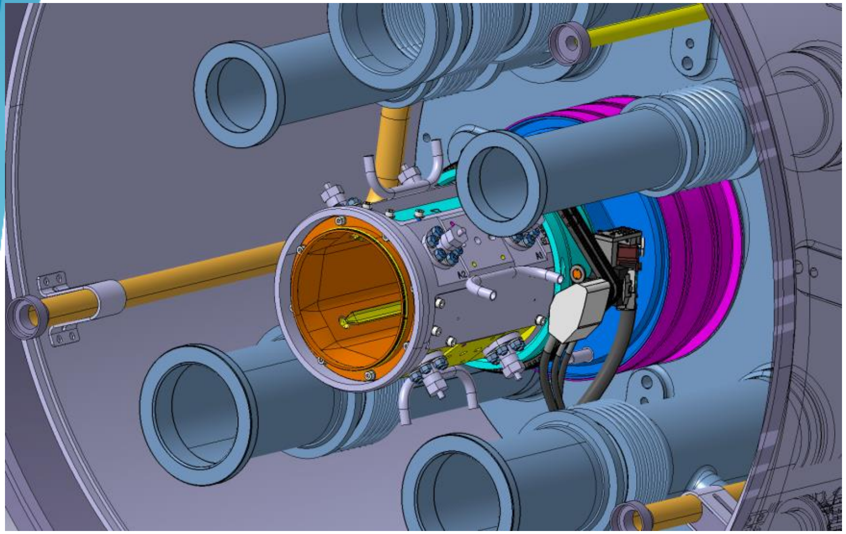


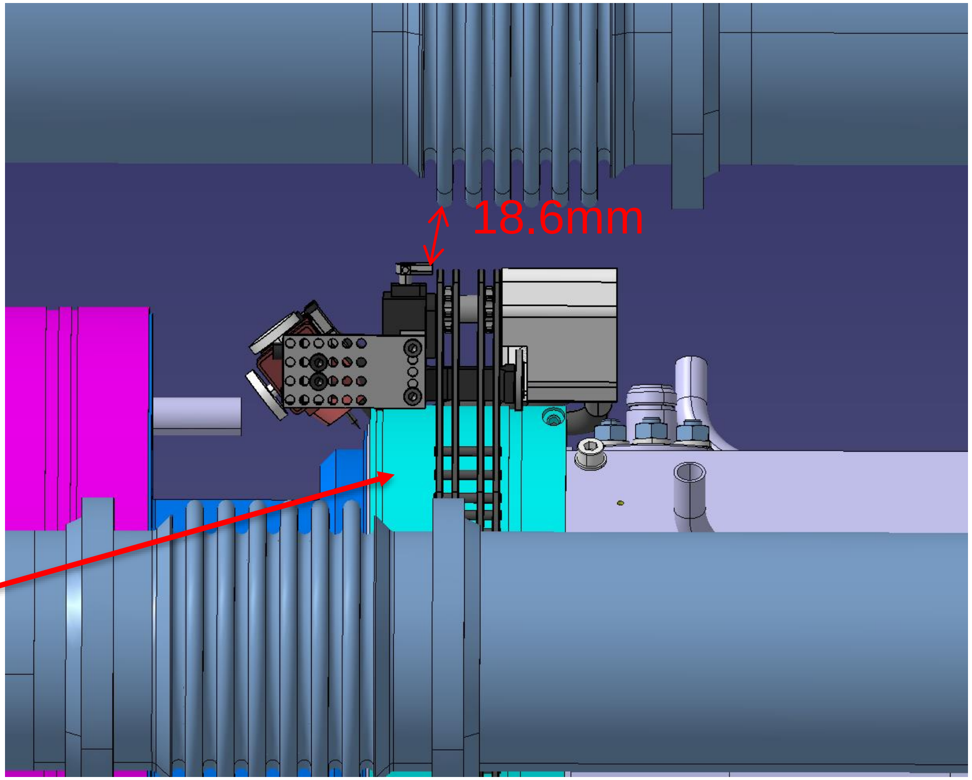


Orbital welding machine around the sleeve

Integration of welding machines

Triplet – BPM welding



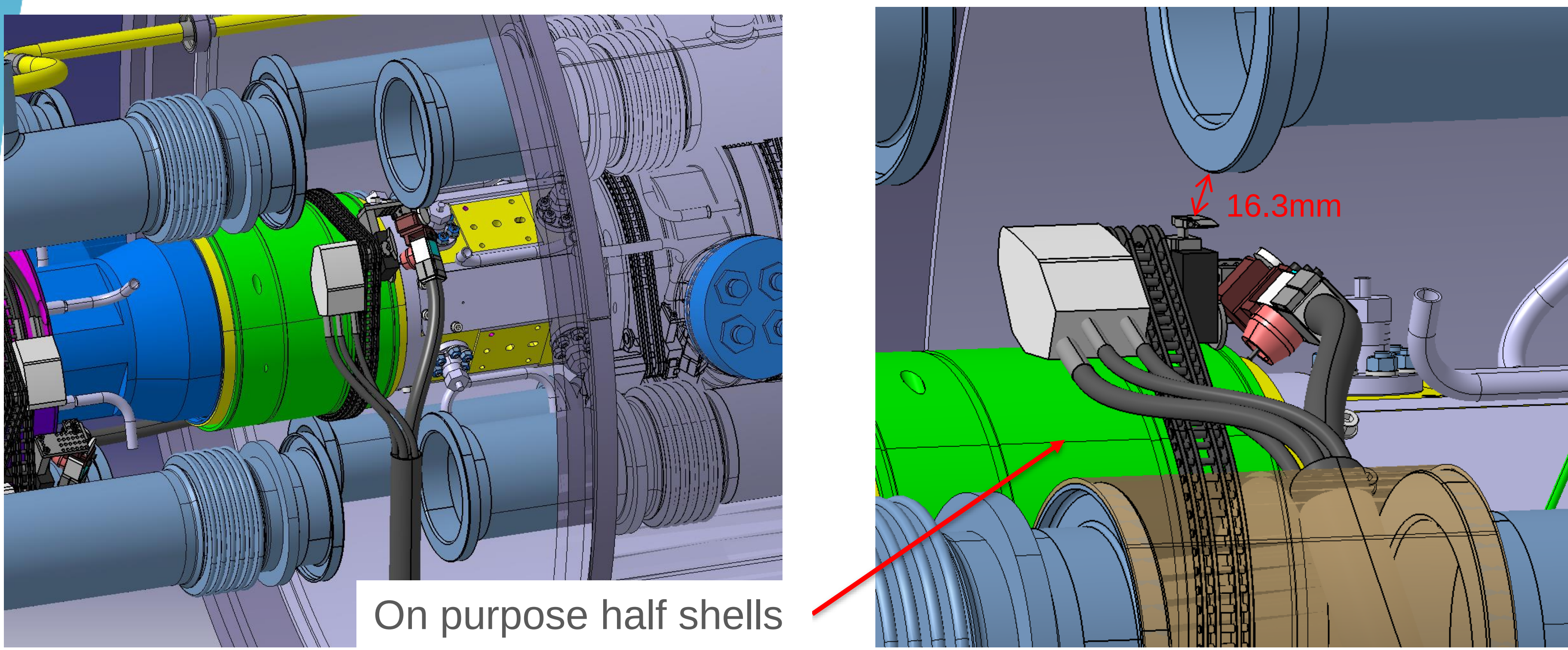


On purpose half shells

Orbital welding machine and tooling around the BPM

Integration of welding machines

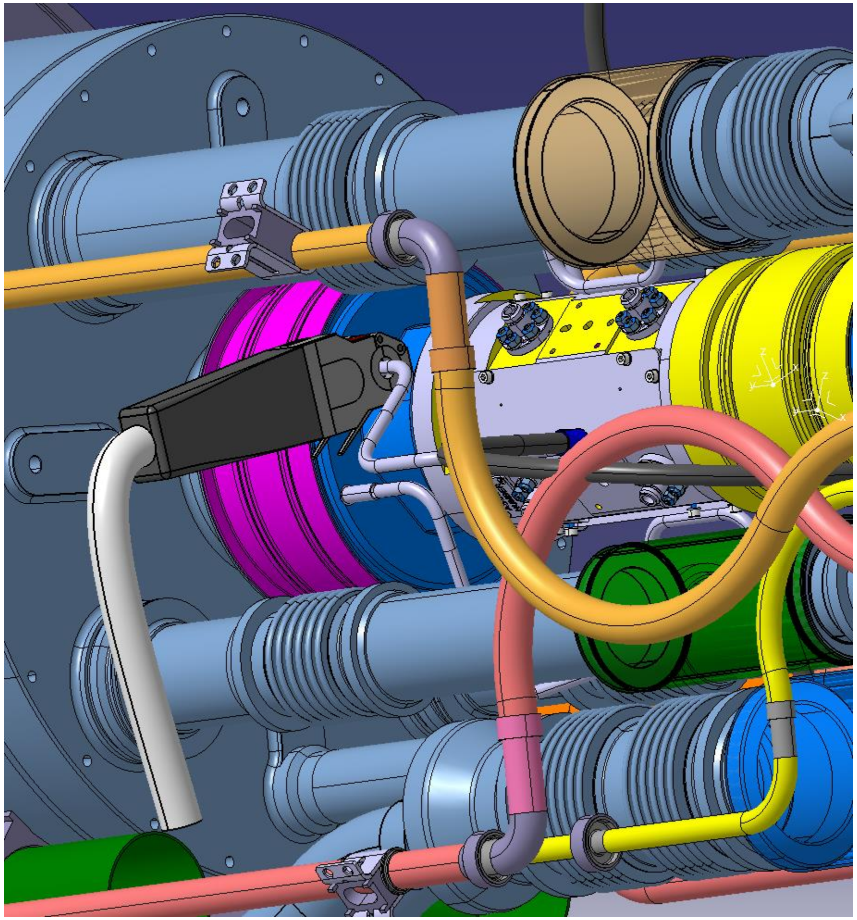
Triplet – PIM welding



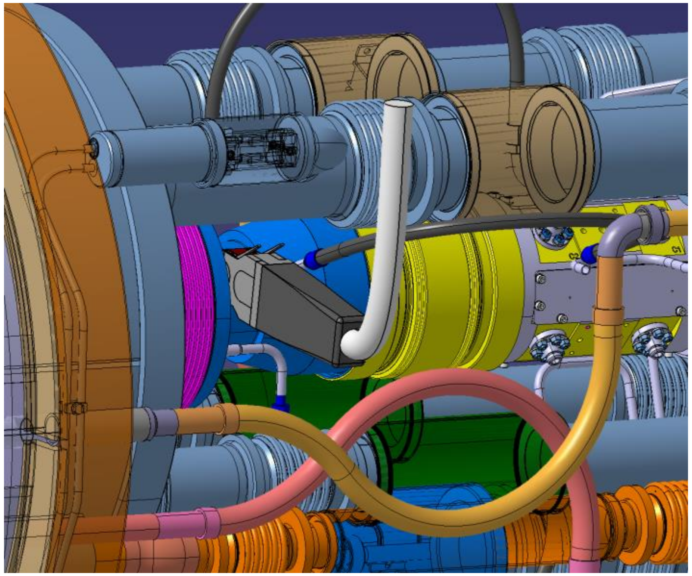
Orbital welding machine and tooling around the PIM

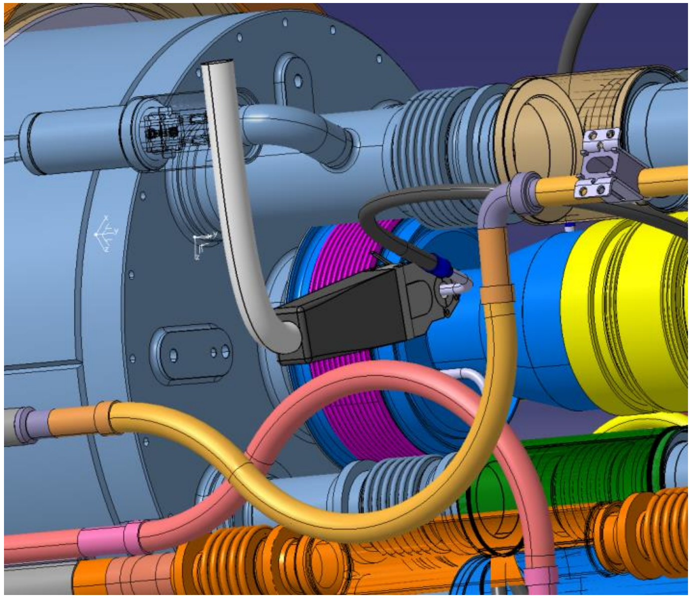
Integration of welding machines

Triplet – cooling tubes



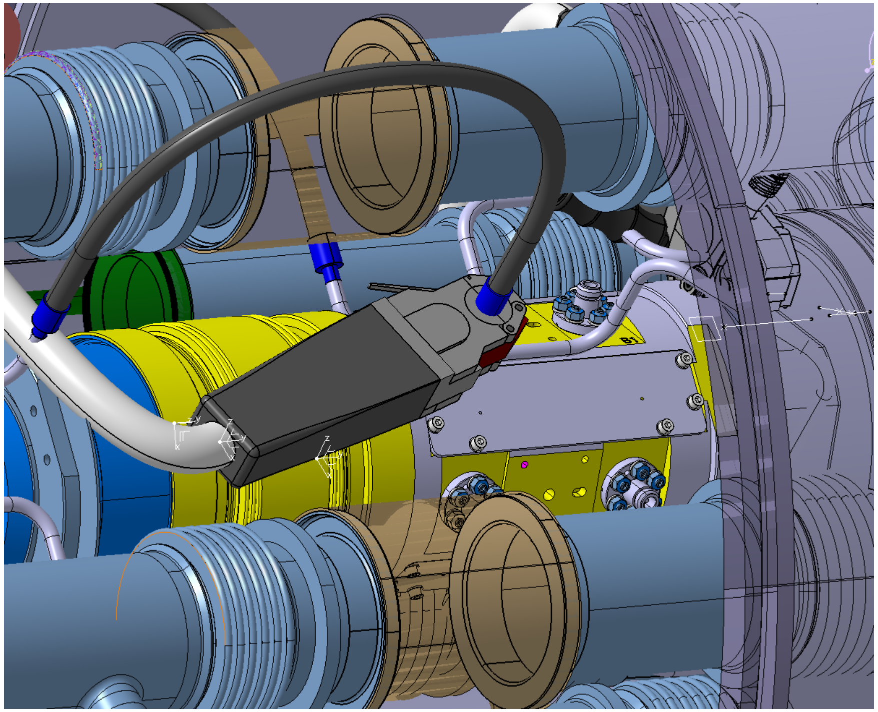
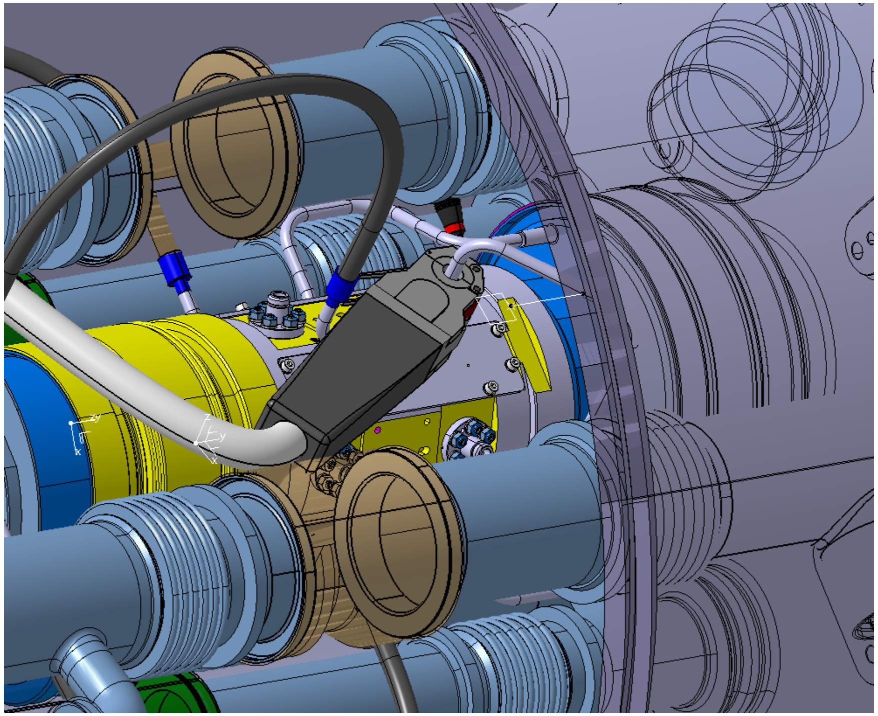
Orbital welding head at the cooling tube exit





Integration of welding machines

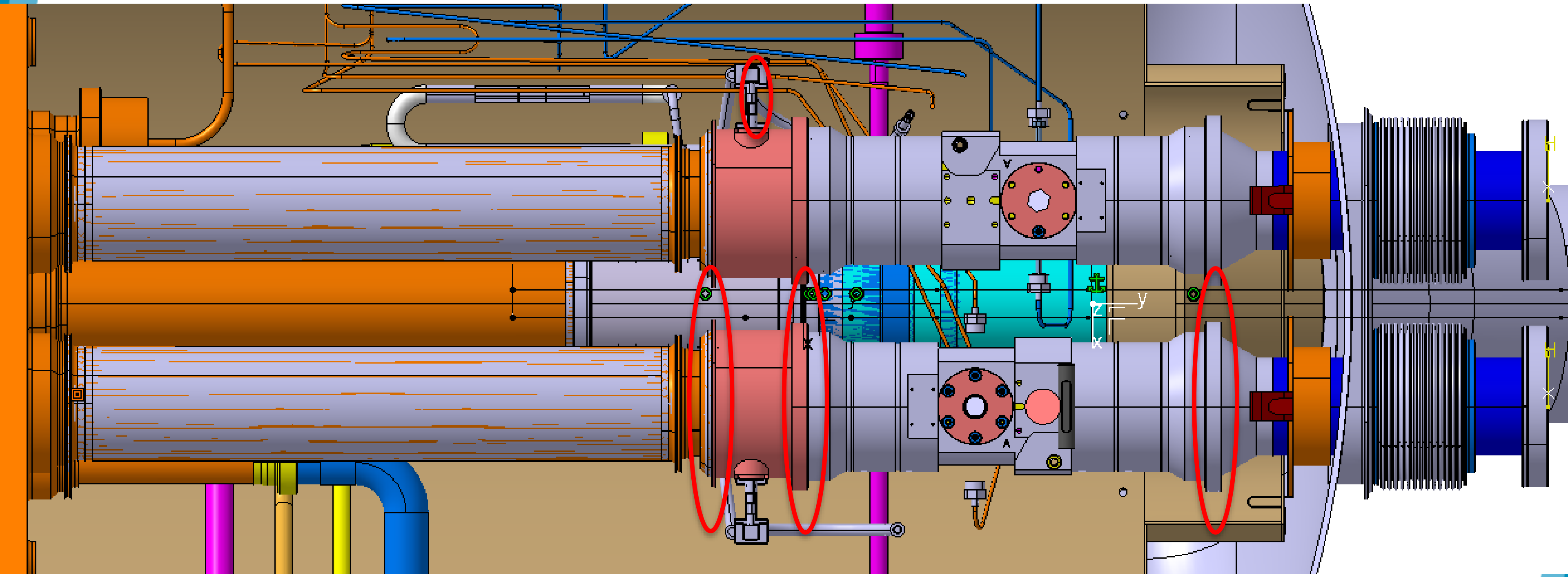
Triplet – cooling tubes

Orbital welding head for the cooling tube piping

Integration of welding machines

D2



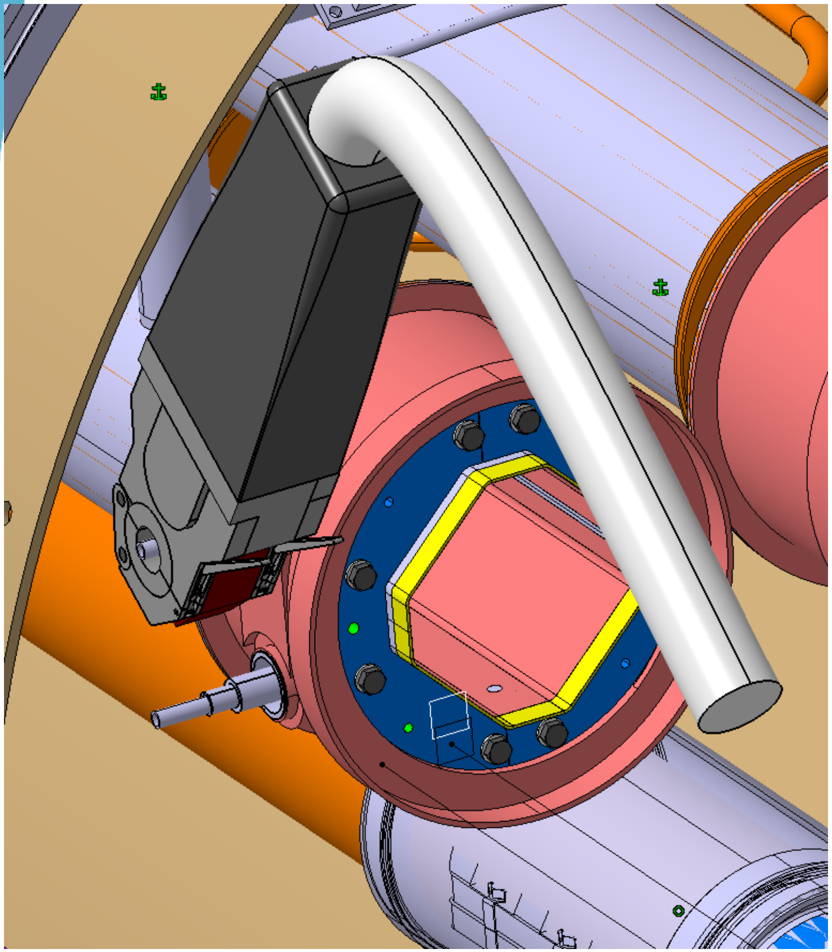
Automatic orbital welds are the baseline.

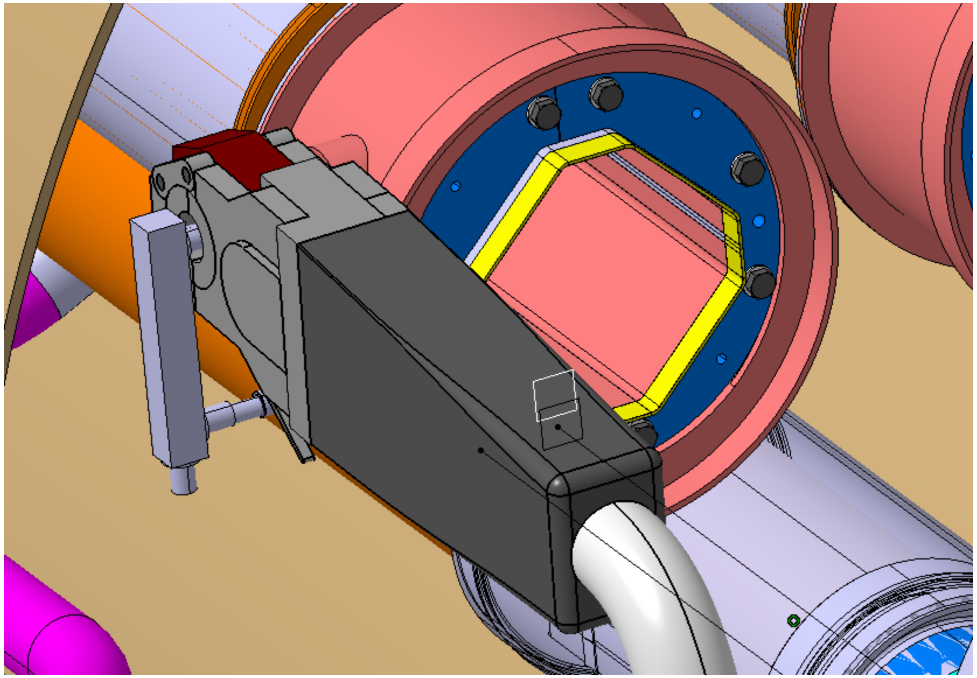
ST references:

- ST0947311 LBRDD Cryoassembly
- ST1087032 REMONTAGE D2 ligne 1 et 2

Integration of welding machines

D2

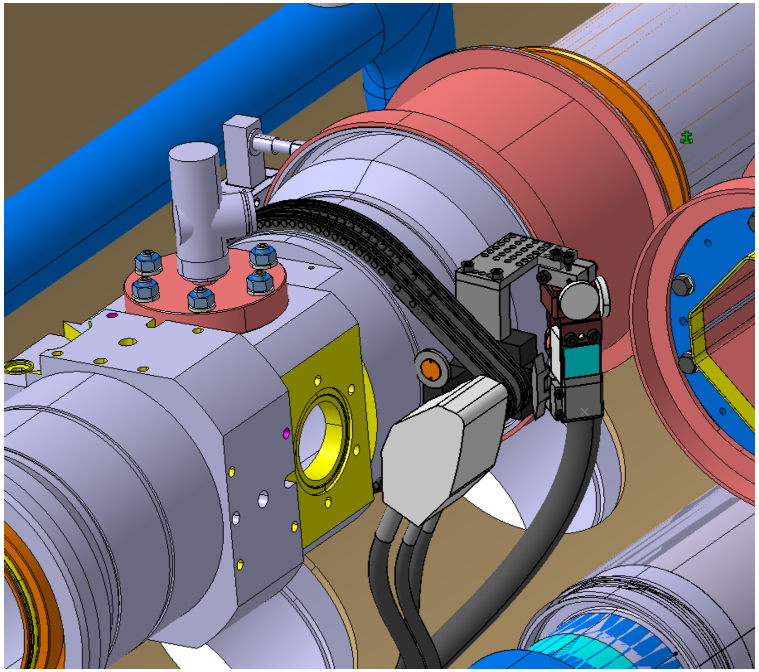


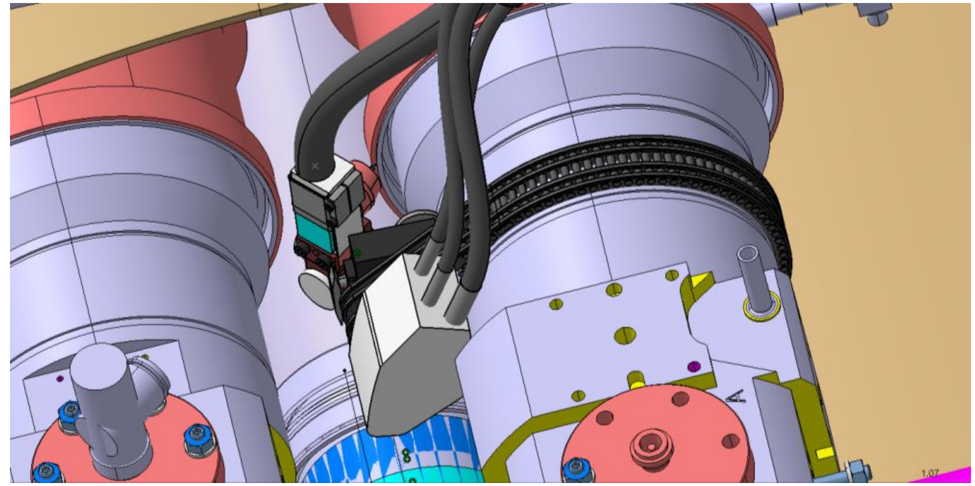


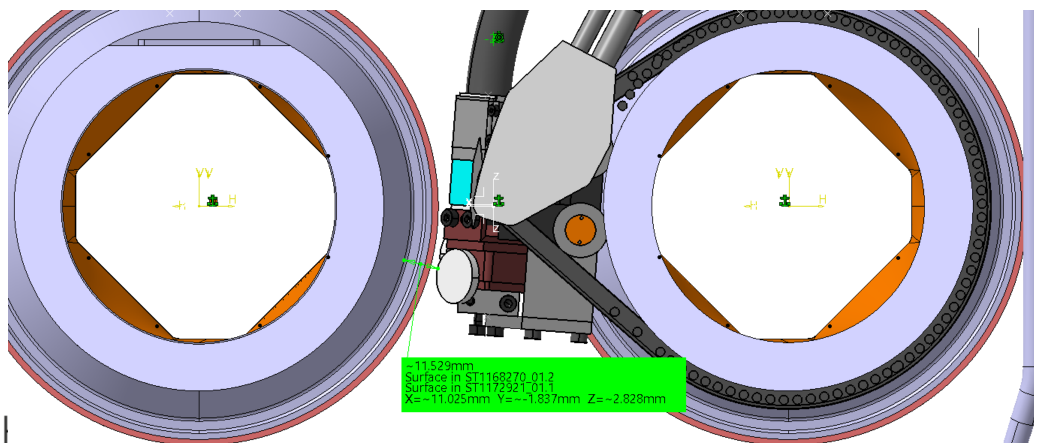
Orbital welding head for the cooling tube exit and piping

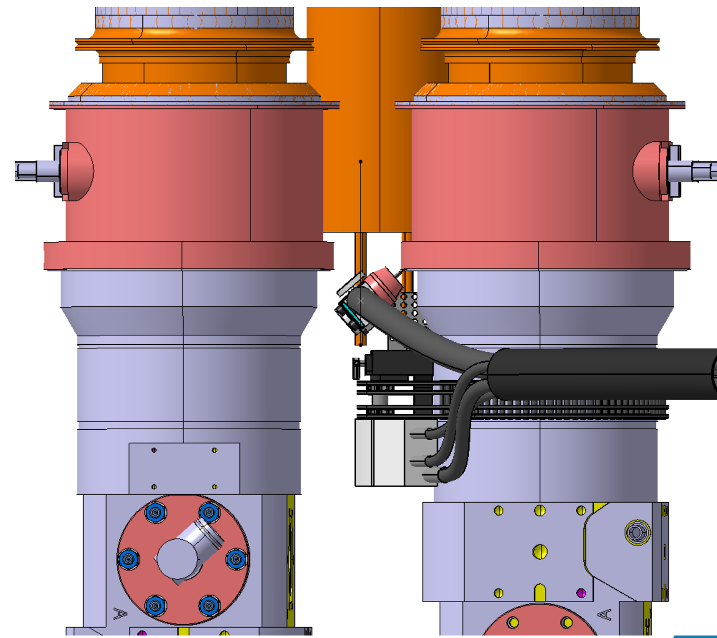
Integration of welding machines

D2



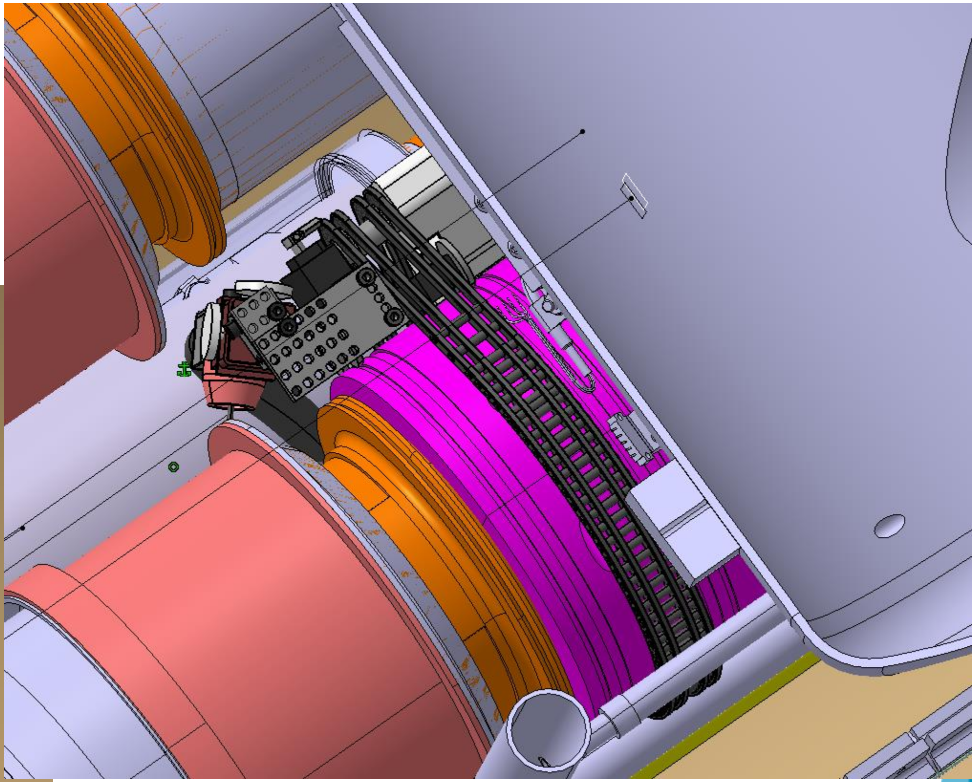


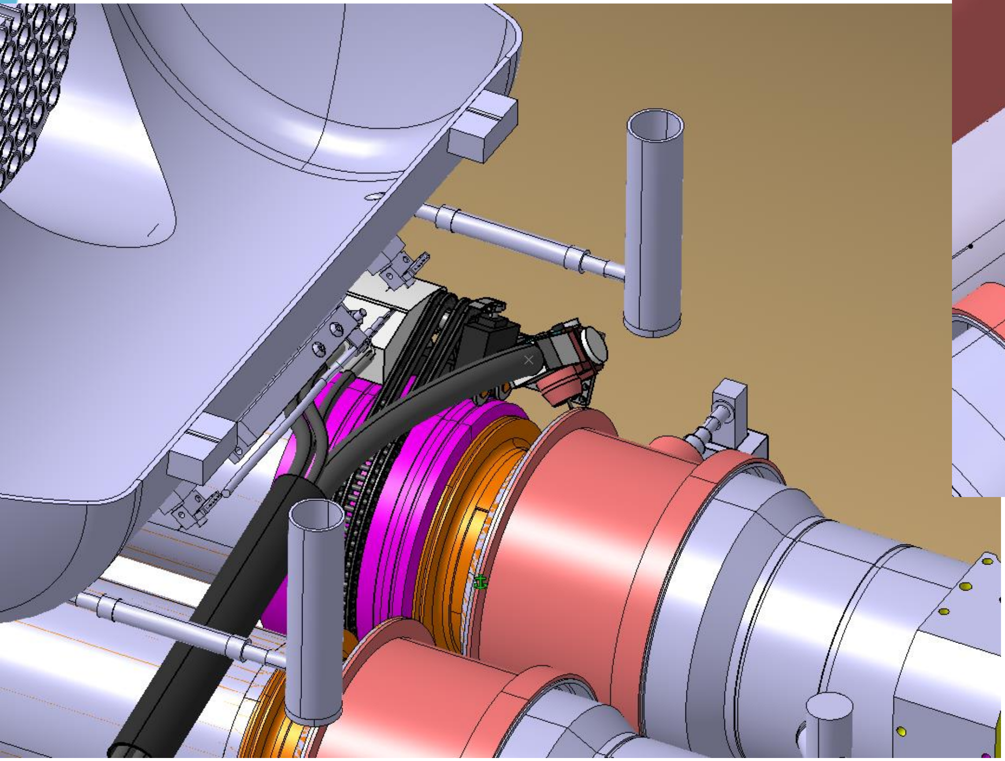




Integration of welding machines

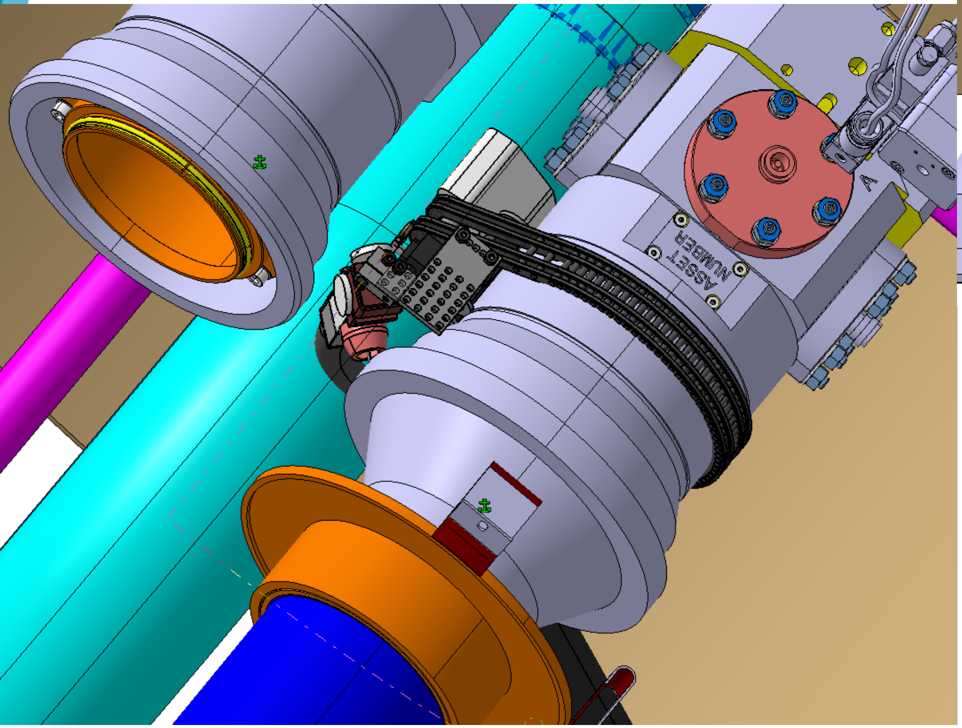
D2

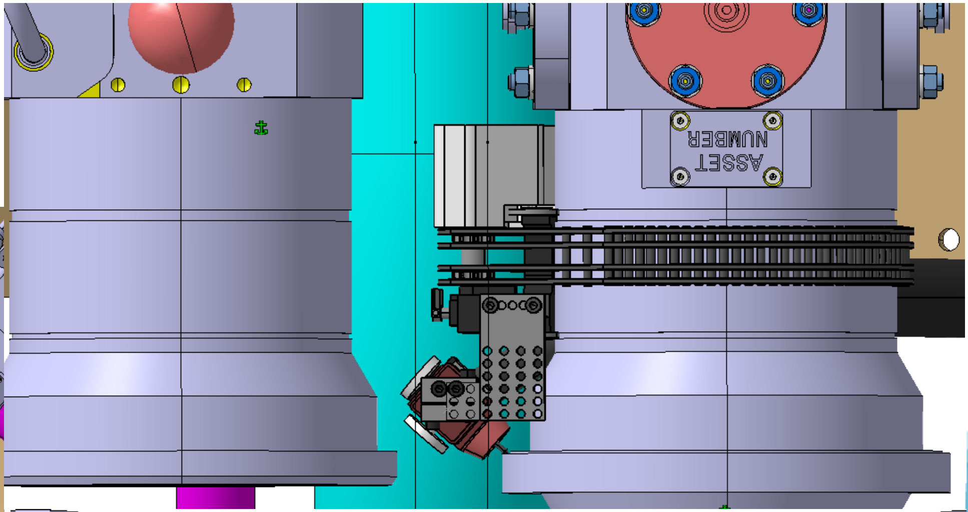


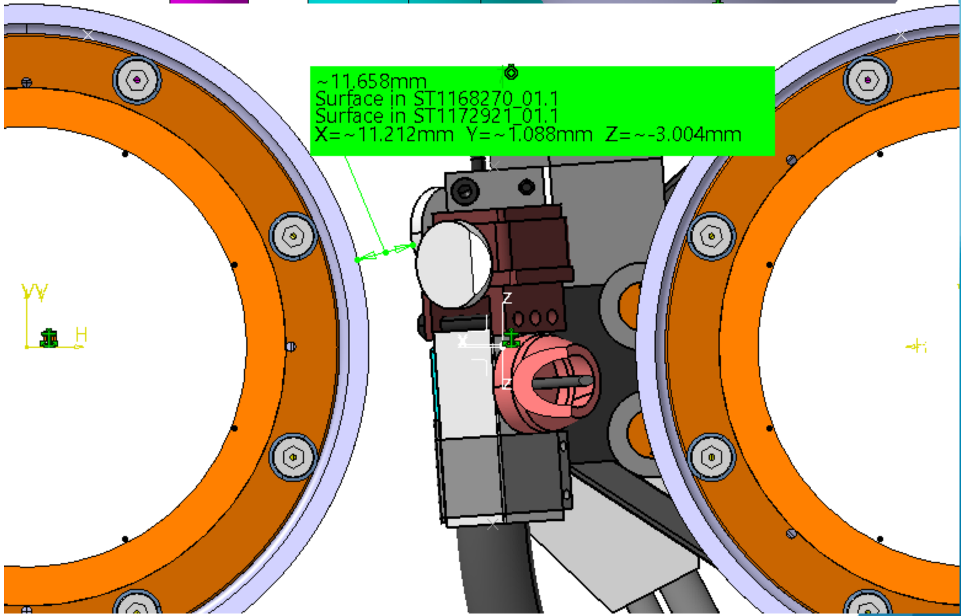


Integration of welding machines

D2







Up-date of the implementation of memorandum EDMS 2105453

EDMS no. 2105453 v.1.0

MEMORANDUM

Date: 11.11.2019

To: Group leaders of BE-BI, TE-VSC, TE-MSC, EN-SMM and WP3, WP12, WP13, WP15 leaders

From: Gerhard Schneider BE-BI-ML

Cc:

Subject: **Responsibility share between BE-BI, EN-SMM TE-VSC and TE-MSC for the assembly of HL-LHC Inner Triplet and D2 Cryogenic Beam Position Monitors**

Abstract:

In the framework of the HL-LHC Inner Triplet production, a total of 4 BPMQSTZA for Q1, 20 BPMQSTZB for Q2A to D1 and total 8 BPMs for D2 of types BPMQWBZA and BPMQWBZB will be installed, aligned, welded, leak checked and documented. According to the present baseline, this work is performed after the magnet cold mass insertion in its cryostat including all cryogenic lines with magnet and cryogenic instrumentation assembled. The space required for the welding and cutting machines must be agreed upon and shown on the relevant integration drawings.

The routing of the pre-bent semi-rigid coaxial cables must also be agreed upon, and the cable mounting feasibility has to be studied in the framework of the cryostat interface meetings https://indico.cern.ch/category/9521/ .

This memorandum outlines the agreed work share and interfaces of this installation where

- WP13 (BE-BI) is the global responsible for BPM installation
- WP12 (TE-VSC) is responsible for the welding, based on similar orbital welds required for the vacuum system on each Cryomagnet
- WP3 (TE-MSC) is responsible for the management of interfaces with the cryostat, cold mass and cryogenic piping inside the cryo-assembly
- WP15 (EN-SMM) is responsible for the alignment

The figures shown in this document are based on the BPMQSTZB which represents 20 out of 32 BPMs. The principle of alignment and welding is however for all BPMs the same.

3. Responsibility share of the deliverables and developments prior to BPM installation

BE-BI (WP13)

- Supply a dummy BPM for BPM integration tests
- Supply of the design for the pre-bent, semi-rigid coaxial cables for integration into the service module drawings
- Supply of cleaned, copper and aCarbon coated fully tested (mechanical tolerances, vacuum leak-checked, RF characteristics) BPMs with agreed surfaces for welding
- Supply of tooling for installation, alignment and BPM leak tests
- Supply and installation of the pre-bent, semi-rigid coaxial cables
- Procedure of the BPM assembly

TE-VSC (WP12)

- Supply of the flexible cooling connection tubes between the BPM towards the beam screen and the BPM flexible cooling connection towards the subsequent magnet. The cost will be shared between WP12 and WP13, each 50%.
- Development and documentation of the welding parameters, including the cooling tube connections, for welds 1 to 5. The cost of these welds will be shared for
  - weld 1, as a fraction of total 5 orbital V-line welds, hence 20% for WP13, 80% WP12
  - welds 4 and 5: each 50% WP12 and WP13
  - welds 2 and 3 performed in the tunnel during magnet connection: 100% WP12
- Supply and operation of all welding machines for welds 1 to 5 including tooling. Same split as for the development and documentation.
- Supply of stay clear envelopes to the integration team for welding machines including those for the cooling tube welds. Related cost payed by WP12.
- Final leak check tools such as cap the opposite side of the vacuum line, leak detector and piping from the magnet to the leak detector. Related cost payed by WP12.
- Final beam vacuum system conditioning such vacuum or specific sealed gas atmosphere. Related cost payed by WP12.
- BPM specific welding tests in representative environment supplied by WP3. Related cost payed by WP13.

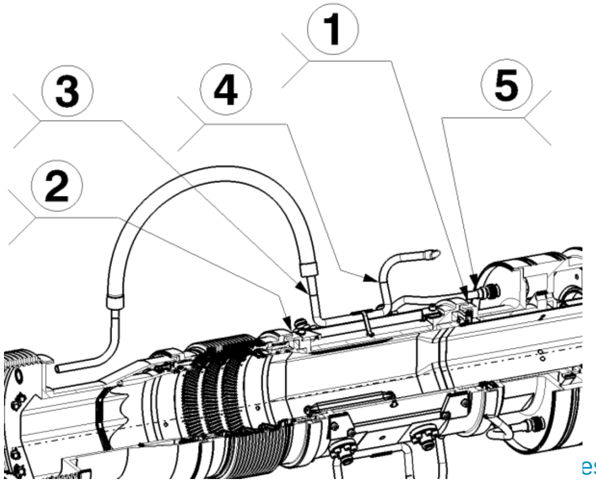
As a summary:

- WP13 procures and installs with the support of WP15 (survey) the BPM
- WP12 makes the different welds and their validation

Up-date of the implementation of memorandum EDMS 2105453

TE-VSC (WP12)

- Supply of the flexible cooling connection tubes between the BPM towards the beam screen and the BPM flexible cooling connection towards the subsequent magnet. The cost will be shared between WP12 and WP13, each 50%. → Not started
- Development and documentation of the welding parameters, including the cooling tube connections, for welds 1 to 5. The cost of these welds will be shared for → Discussion initiated with EN/MME for the welding development
    - weld 1, as a fraction of total 5 orbital V-line welds, hence 20% for WP13, 80% WP12
    - welds 4 and 5: each 50% WP12 and WP13
    - welds 2 and 3 performed in the tunnel during magnet connection: 100% WP12
- Supply and operation of all welding machines for welds 1 to 5 including tooling. Same split as for the development and documentation. → Welding machines available (see next slide)
- Supply of stay clear envelopes to the integration team for welding machines including those for the cooling tube welds. Related cost payed by WP12. → Several iterations done
- Final leak check tools such as cap the opposite side of the vacuum line, leak detector and piping from the magnet to the leak detector. Related cost payed by WP12. → Just started
- Final beam vacuum system conditioning such vacuum or specific sealed gas atmosphere. Related cost paved bv WP12. → Defined: under N2 atmosphere
- BPM specific welding tests in representative environment supplied by WP3. Related cost payed by WP13. → To be done

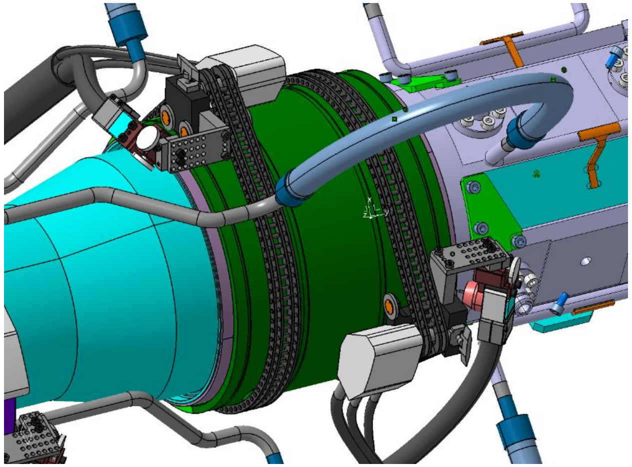


Status of welding machines

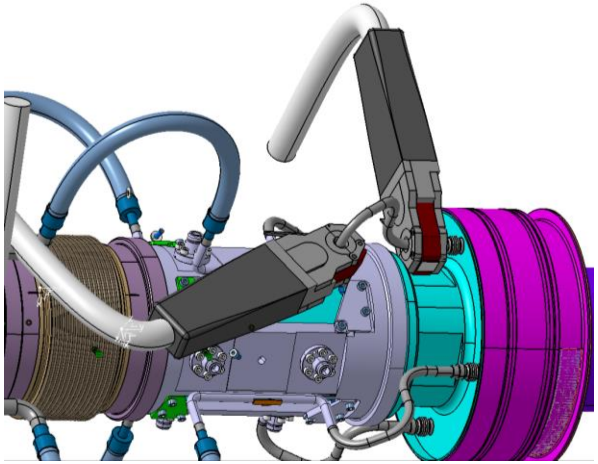
Welding machines for BPM welding:

- Closed head:
  - 1 new compact AMI head purchased.
  - 5 other available heads (suitability to be checked).
  - 3 sources available (maintenance to be done).
  - Specific clamps might be needed for specific tube diameters.

- Open head:
  - 2 LORA head available (maintenance to be done)
  - 1 Orbital machine available (working but obsolete)
  - 1 Orbital machine purchased



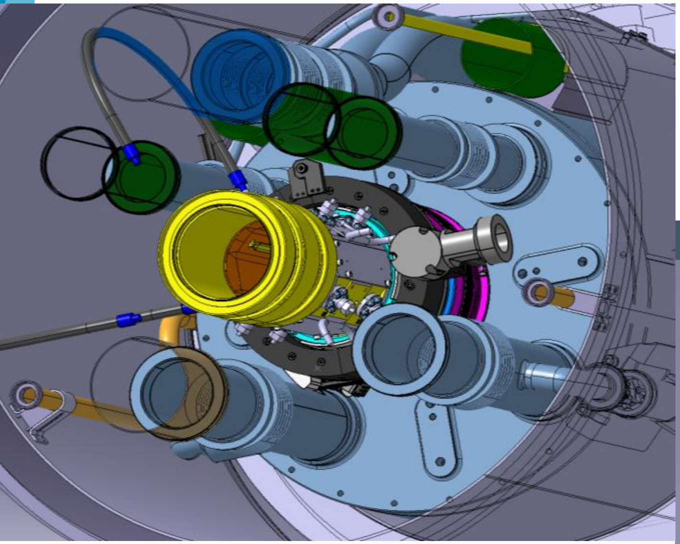
Orbital welding machine and tooling around the PIM

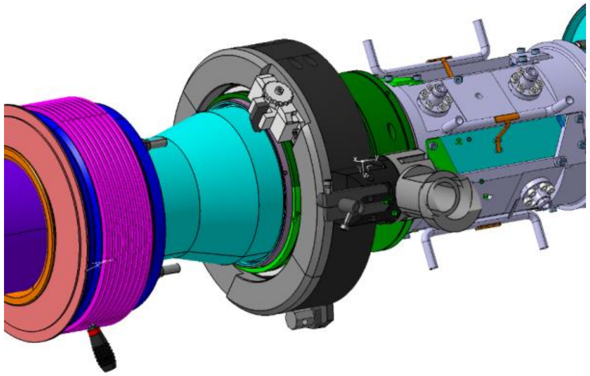


Orbital weld head

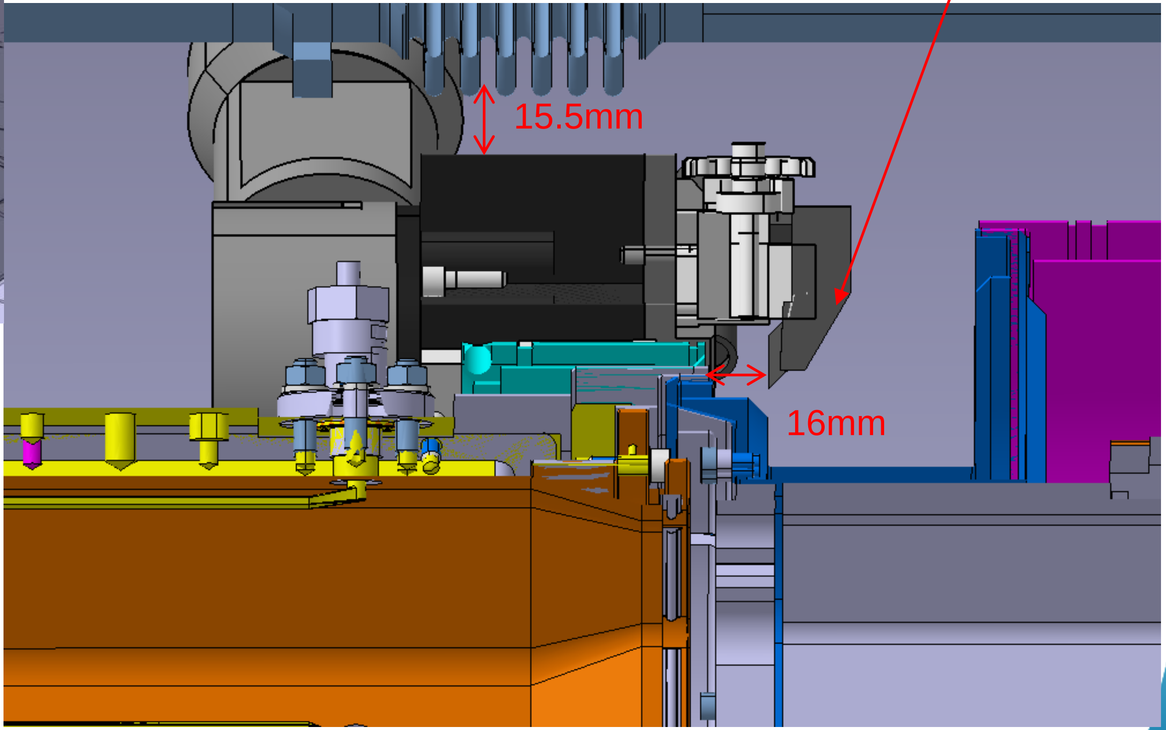
Status of cutting machines

The cutting machine is for illustration only. It is scaled from the existing ones (TE-MSC) but not available.
Today, no budget in WP12 is foreseen neither for the study/development nor procurement and operation of these cutting machines.





Cutting tooling to be modified



Conclusion

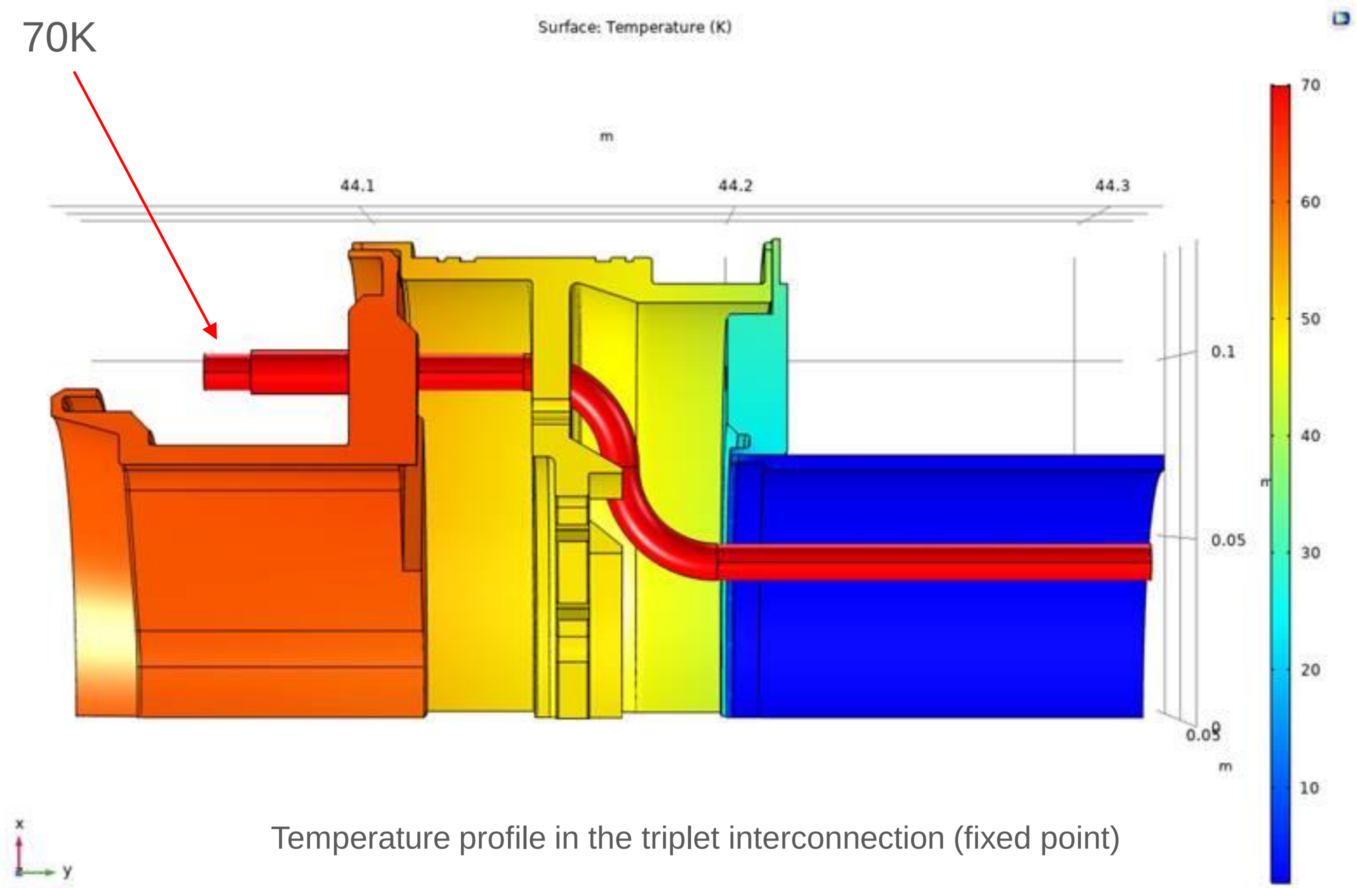
The design of the HL-LHC beam screens is completed.
The cooling of the absorbers in the triplet is ensured by copper thermal links either welded or clamped on the cooling tubes.
The heat transfer performance has been assessed by simulations and validated by cryogenic tests.

Design of the triplet beam screen extremity components is completed.
Prototypes have been done and validated on a representative interconnection mock-up.
Design of the D2 extremities is still ongoing.

Interfaces with BPMs (triplet and D2) are defined and agreed.

WP12 is responsible for the BPM welding activities.
Integration of the welding machines is done. Further iterations most likely will be required.
Welding machines are available.
Welding study (parameters, residual deformation) will start next year.

Heat load on the 1.9K cold bore



Temperature profile in the triplet interconnection (fixed point)

Heat load from the interconnection to the 1.9K cold bore is around 3W per interconnection.