Status of beam screen, cold bore, interconnect and CWT design & production

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on behalf of WP12

HL-LHC annual meeting, Geneva, 18th November 2018

Status of cold vacuum system design & production

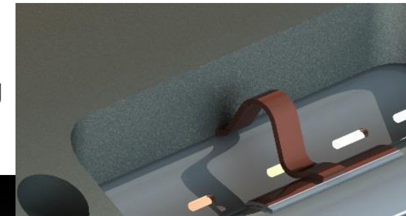
Outline

- Design update
  - Beam screen / cold bore
  - Beam screen extremities and interconnections
  - Cold/warm transitions
- Validation tests
  - Beam screen
    - Thermal: Heat transfers
    - Mechanical: Quench tests
  - PIM
- Manufacturing status
- Summary

1. Design update

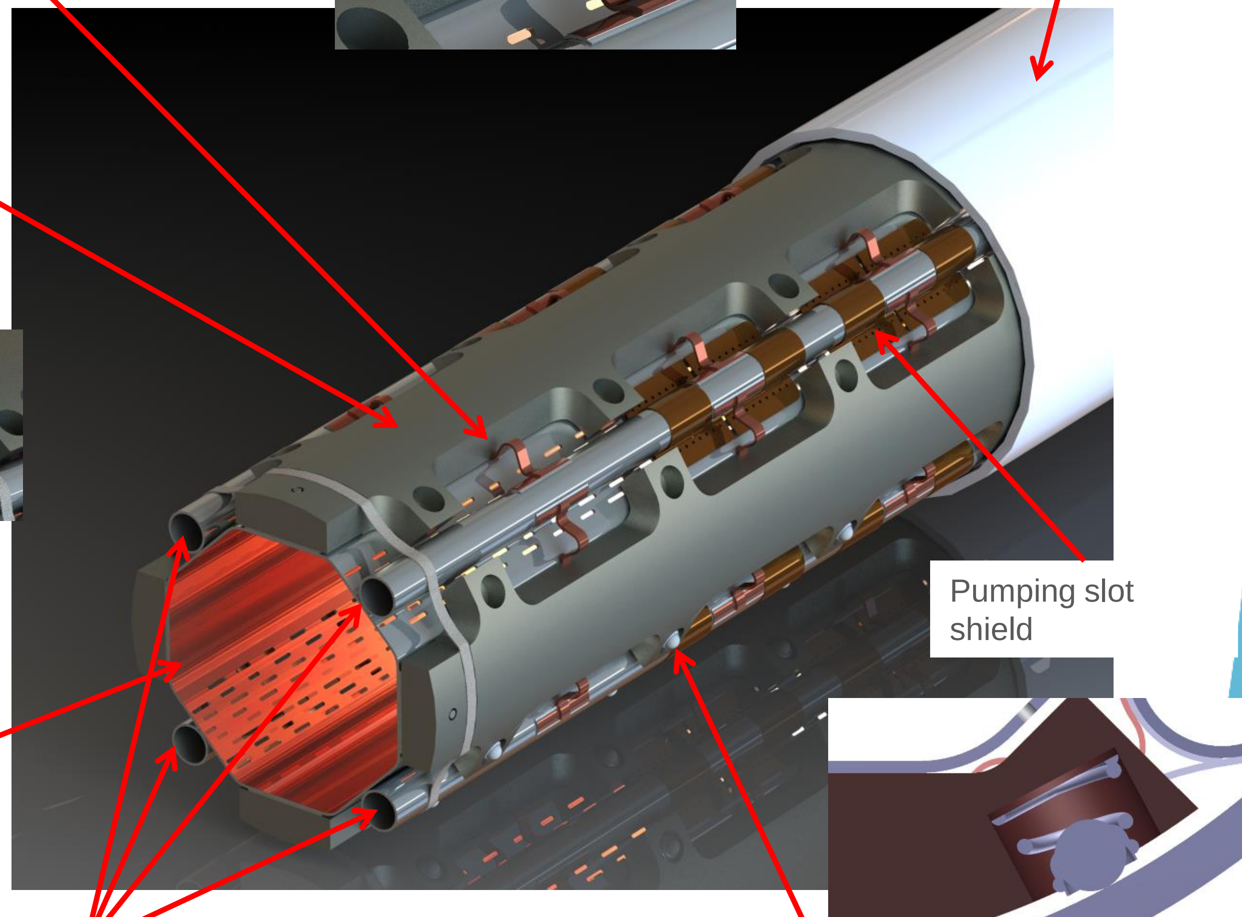
Beam screen – cold bore design

Thermal links:
- In copper
- Connected to the absorbers and the cooling tubes or beam screen tube



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
- Heat load: 15-25 W/m
- 40 cm long



Pumping slot shield

Beam screen tube (BS) at 60-75 K:
- Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H2 at 50K))
- Internal copper layer (75 μm) for impedance
- a-C coating (as a baseline) for e- cloud mitigation
- Laser treatments under investigation

Cooling tubes:
- Outer Diameter: 10 or 16 mm
- Laser welded on the beam screen tube

Elastic supporting system:
Low heat leak to the cold bore tube at 1.9K
Ceramic ball with titanium spring

Nominal behaviour

Simulations of the temperature profiles

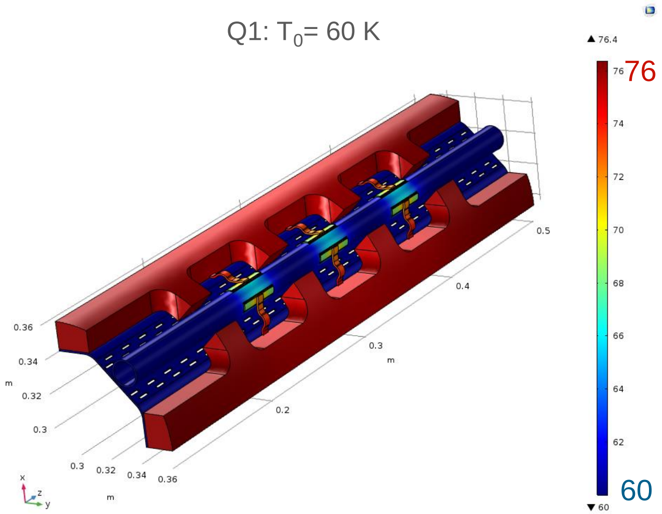
Requirements:

- 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)
- 10 layers, 0.1 mm thick, 5 mm wide

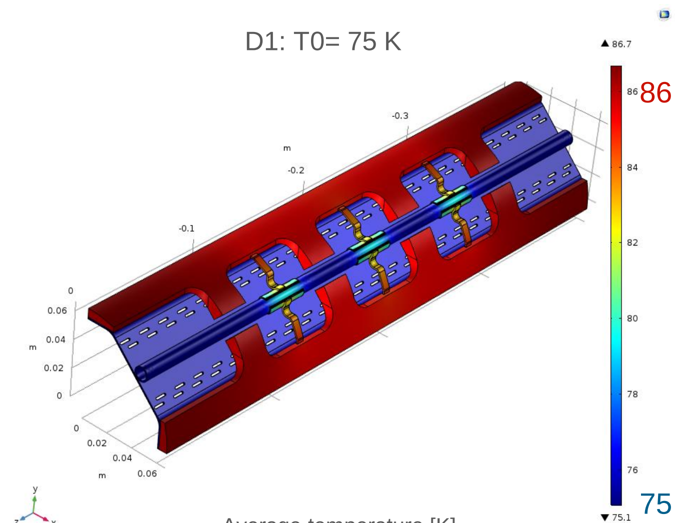
Q1: T_0= 60 K



Average temperature [K]

W-Block	Inner Cu-layer
75.8 K	60.45 K

D1: T0= 75 K

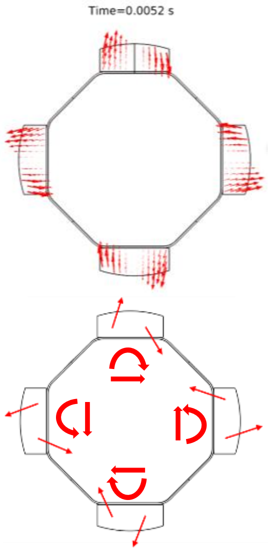


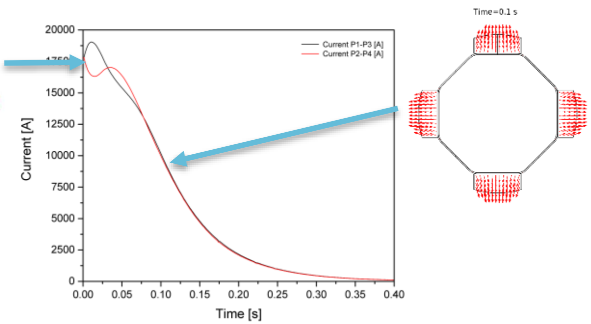
Average temperature [K]

W-Block	Inner Cu-layer
85.8 K	75.8 K

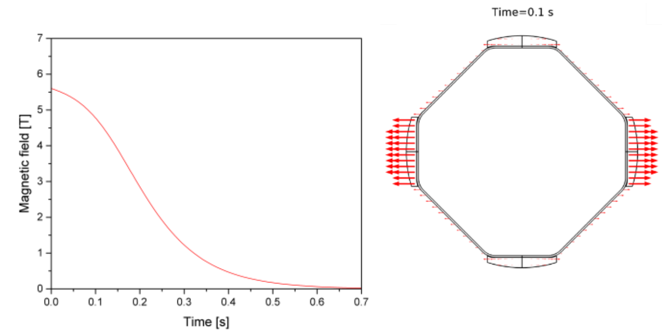
→ Temperature difference between helium and internal copper layer below 1 K.

Influence of misalignment on the behaviour during a magnet quench (1)





Current discharge (QH and CLIQ) and Lorentz's force field for quadrupoles

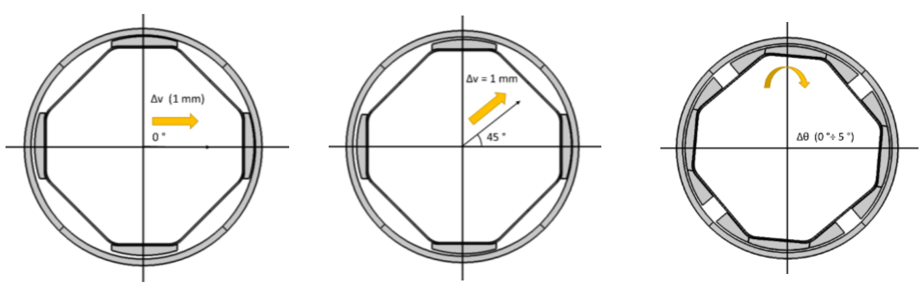


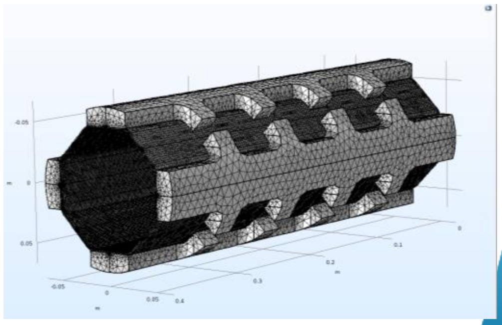
Current discharge (QH) and Lorentz's force field for dipole

→ With CLIQ discharge, internal torques and tangential forces are generated in the beam screen during the transient. No net force is observed for perfectly aligned beam screens.
→ For misaligned beam screens, disequilibrium is introduced and net forces are expected.

Misalignment and twist have been studied with 2D and 3d model.

EDMS 1966571

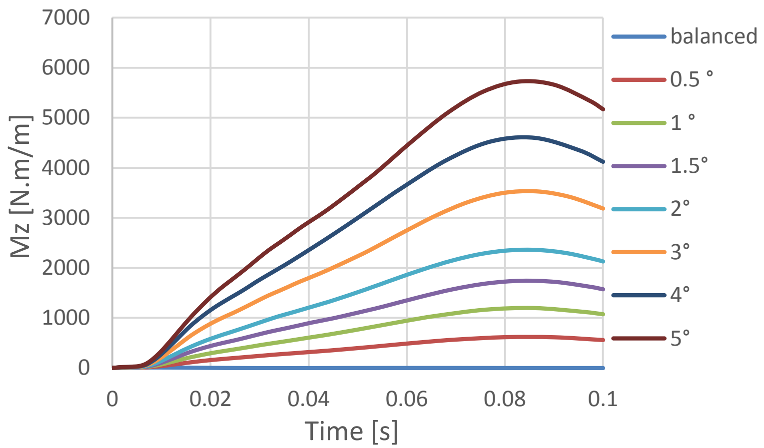




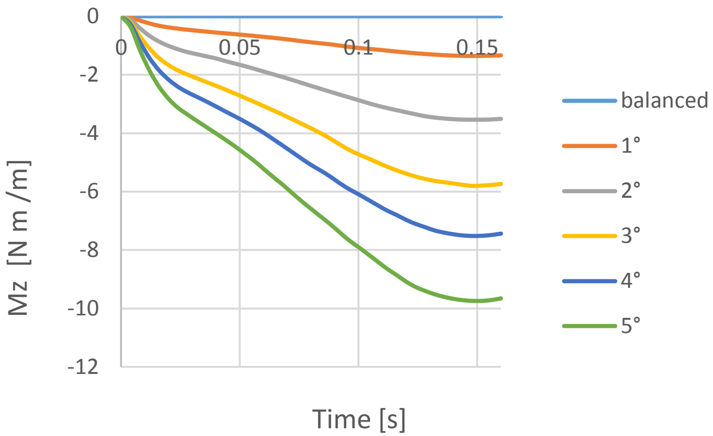
Imperfections introduced on the beam screen

Influence of misalignment on the behaviour during a magnet quench (2)

Results for an initial twist:



Net torque for Q1

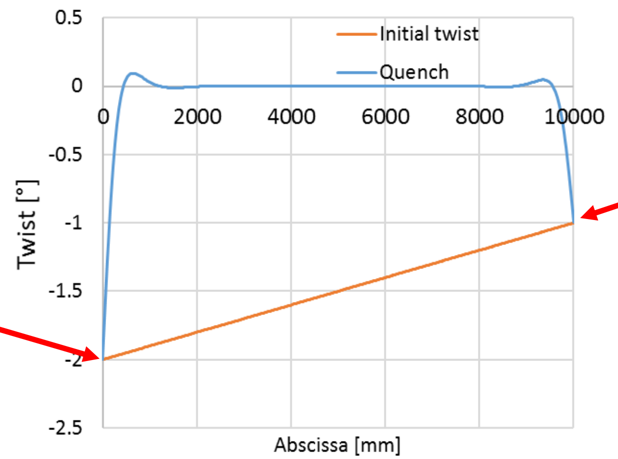


Net torque for D1

→ For D1, net torque is marginal.

→ For quadrupoles, high net torques are generated during a quench, but counterbalancing the initial twist.

→ Global effect is acceptable.



Angular deformation during a quench of a pre-twisted beam screen.

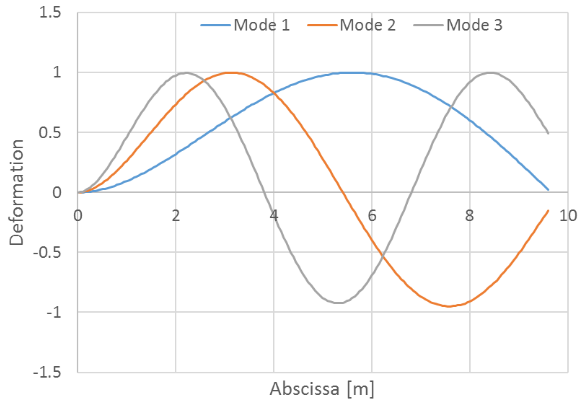
Twist of bellows: ~0.1 mrad

Maximum torque during quench @ Fixed point: ~110 N.m

Natural vibration frequencies

Natural vibrations of the beam screen have been studied, based on : (EDMS 2031211)

- beam elements
- discretized elastic supports
- beam screen bellows at one extremity



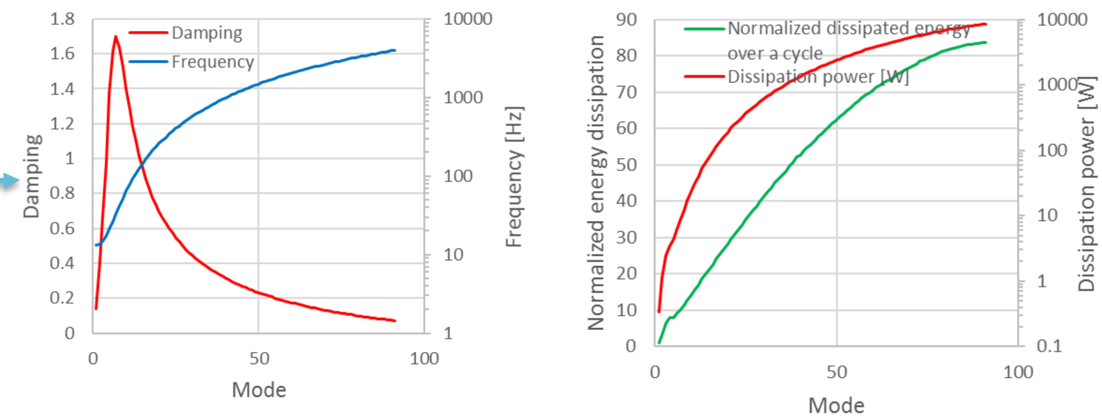
Eigen modes

	Q1 type	Q2 type
1st mode	13.2	19.5
2nd mode	13.6	20.2
3rd mode	14.9	22.5

Natural frequencies [Hz]

High damping by Coulomb friction is expected for high order modes.

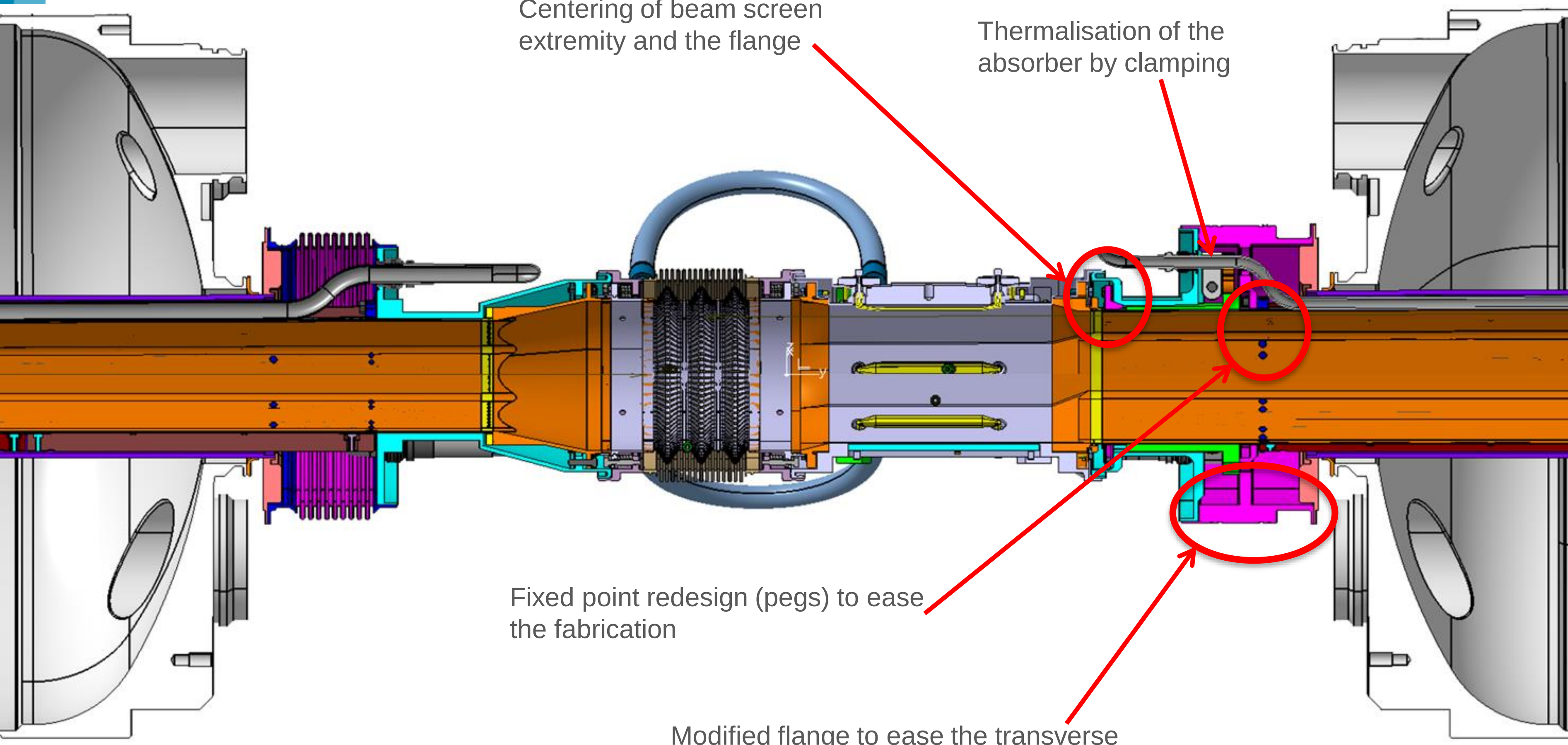
Damping = Dissipated energy over a cycle / Maximum elastic energy during the cycle



Expected damping for Q1 beam screen

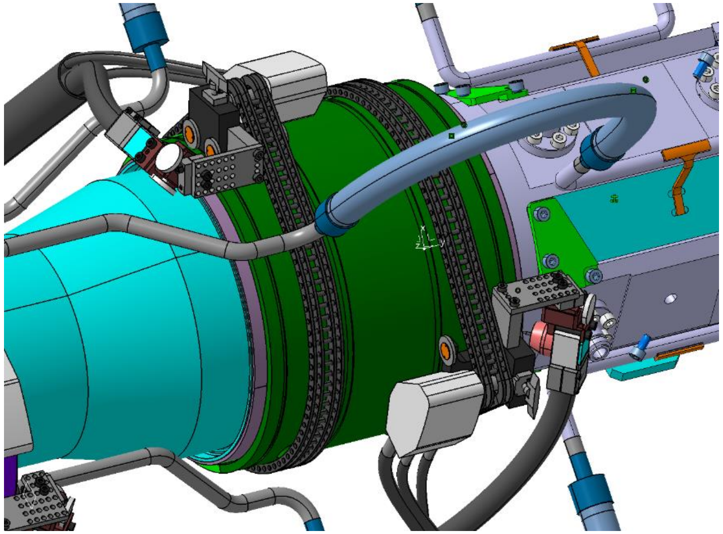
Beam screen extremities and interconnection design

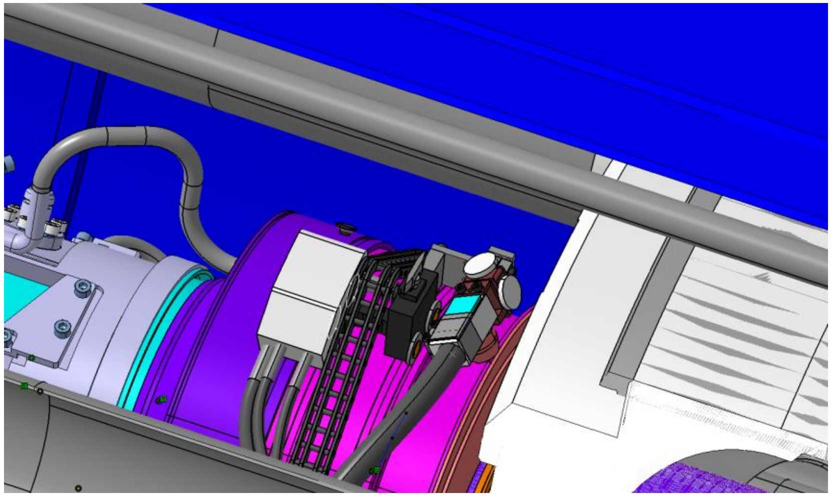
Main modifications in 2018

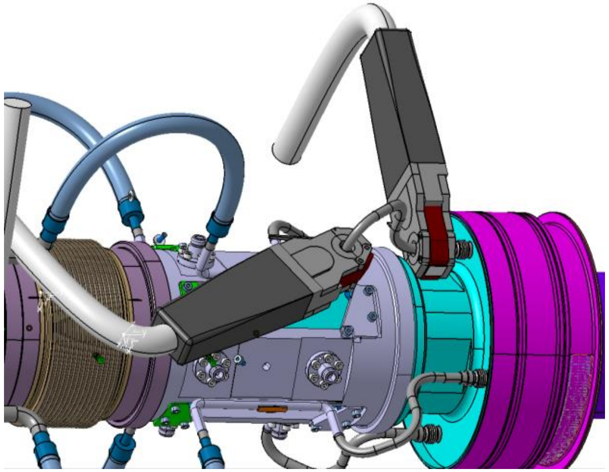


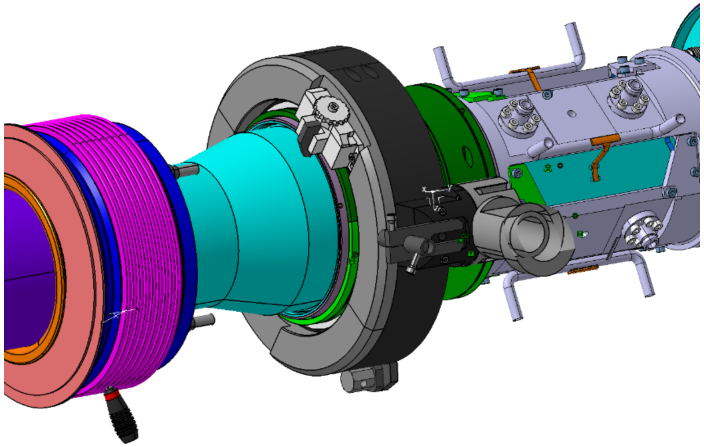
Beam screen extremities and interconnection design

Integration of welding and cutting machines


Orbital welding machine and tooling around the PIM

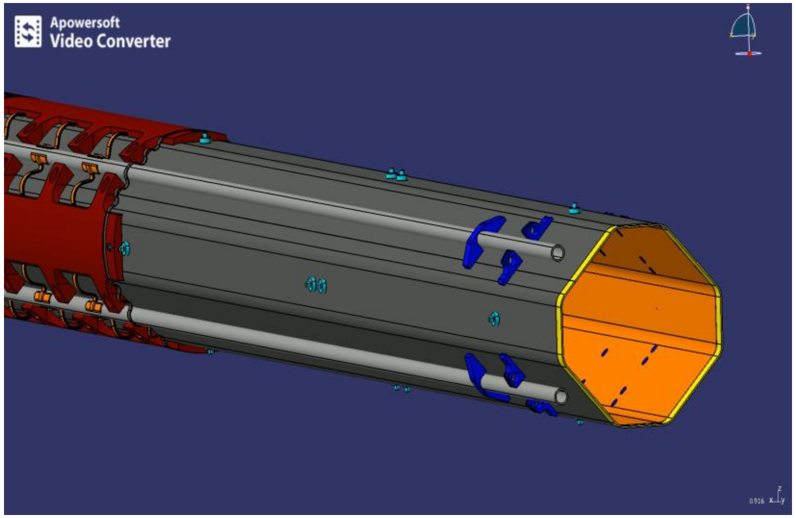

Orbital welding machine for the fixed point flange assembly


Orbital weld head

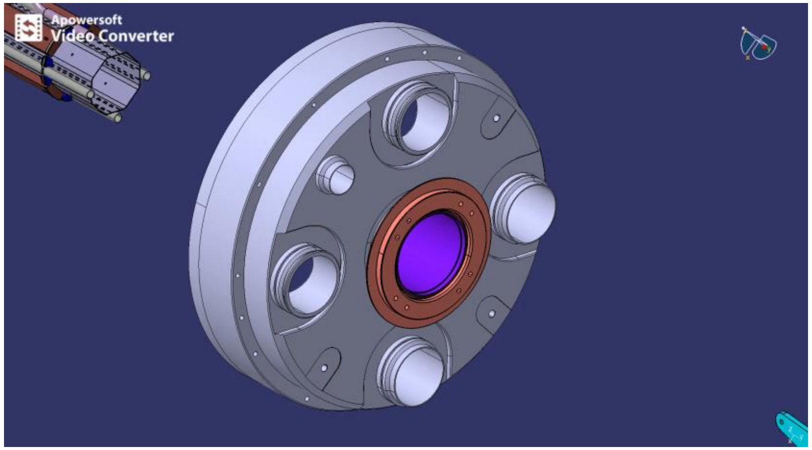

Cutting machine

Beam screen extremities and interconnection design

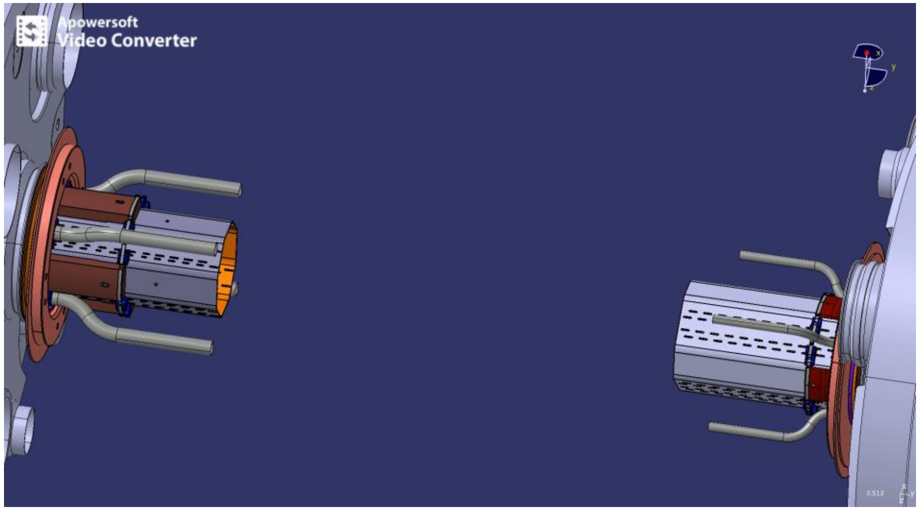
Assembly sequences



Beam screen assembly



Cooling tubes bending



Beam screen extremities and interconnection

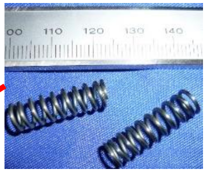
Beam screen extremities and interconnections

Interconnection module

Design of the compensation system of the beam vacuum line interconnections is reported in EDMS 2012795.

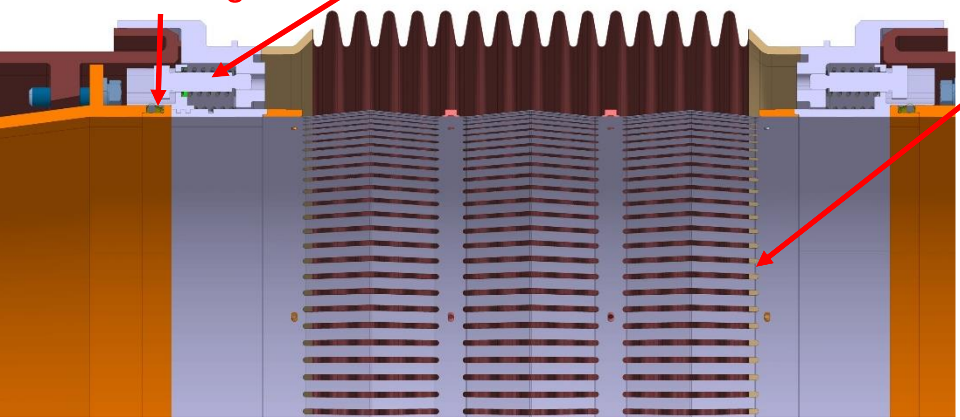
Copper Beryllium deformable RF bridge:

- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions

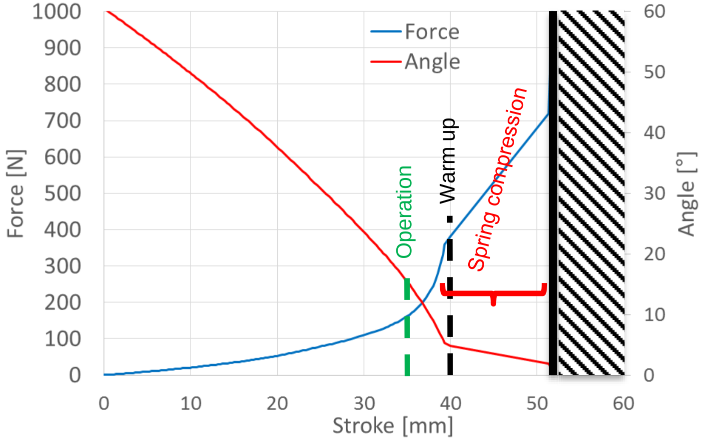


20 titanium G5 springs
(total prestress: ~360 N)

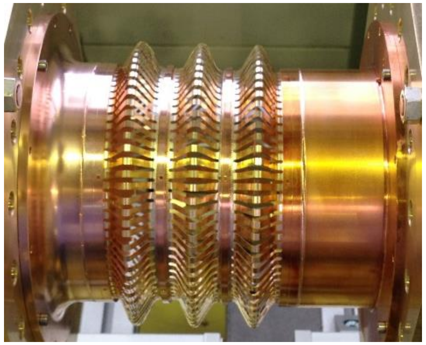
Static RF fingers



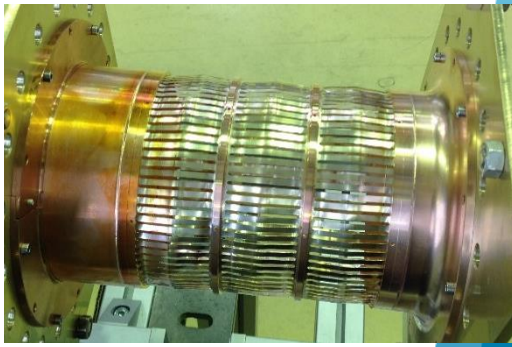
Longitudinal constraint, due to the finger extension limitation, is reduced thanks to the static RF fingers and the springs.



Expected behaviour and working conditions of the RF bridge



as installed

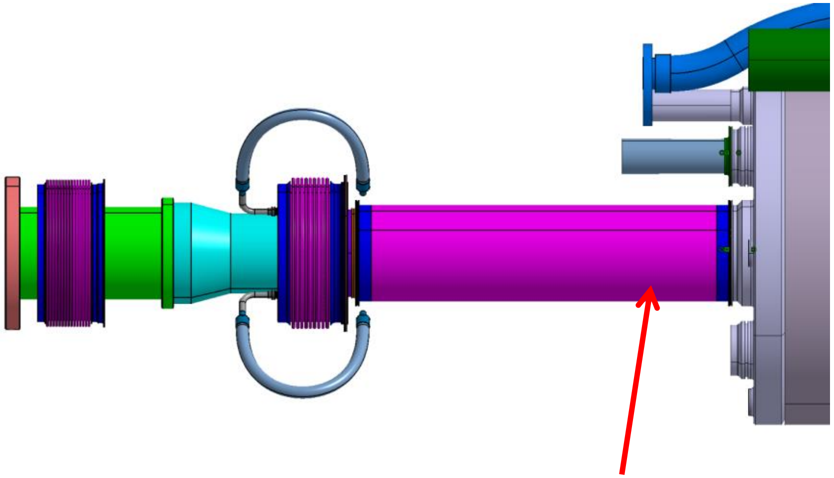


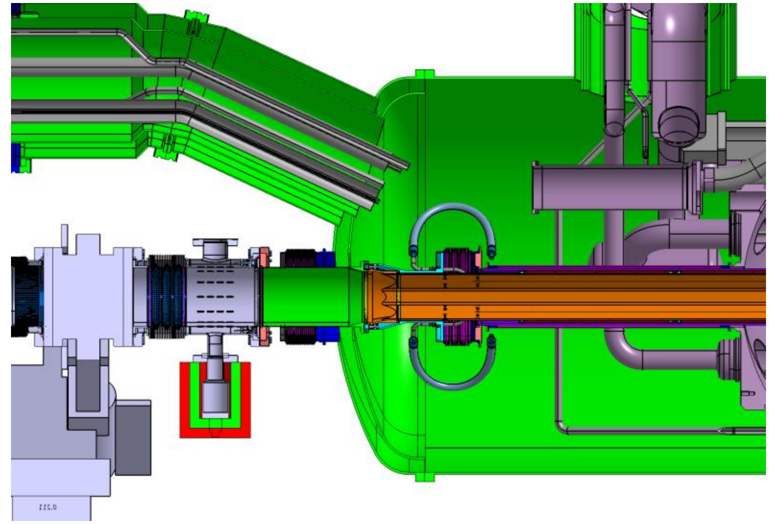
in operation

Deformable RF fingers

Cold/Warm transitions

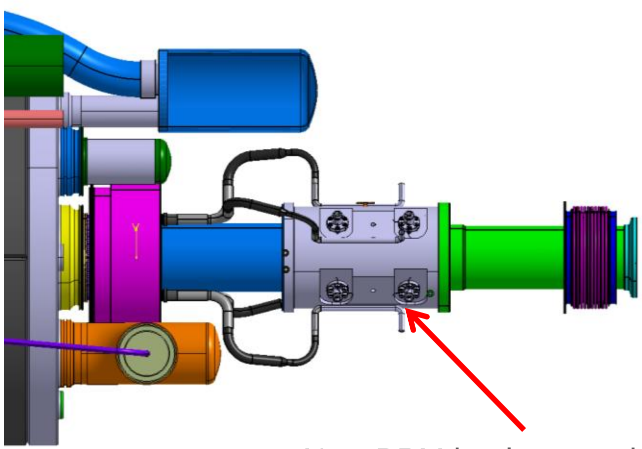
D1 C/W transition

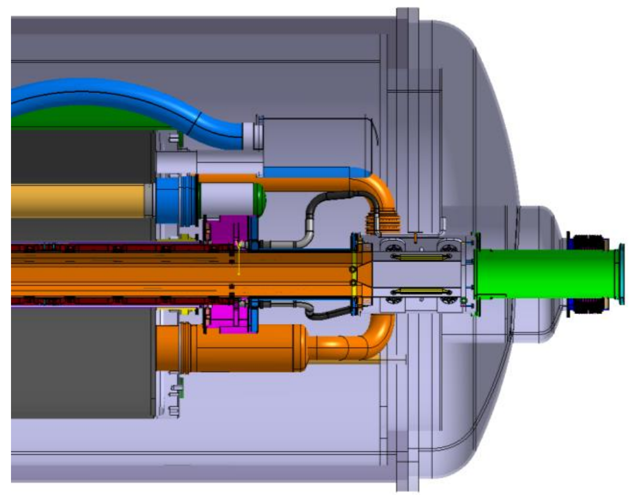




Helium vessel extension

Q1 C/W transition





New BPM implemented

Study of temperatures profiles and heat transfer ongoing.

2. Validation tests

Thermal validation of the shielded beam screens

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

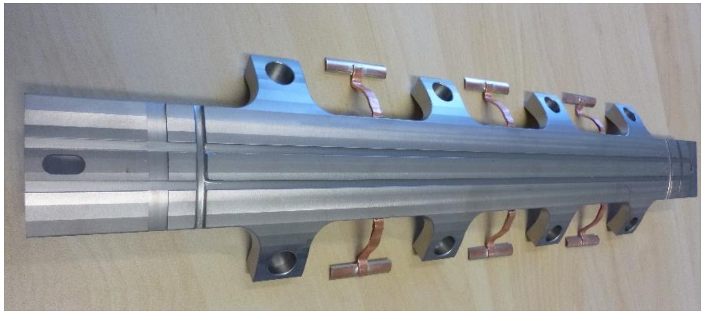
Details in the talk "Thermal qualification of the HL-LHC beam screens for the inner triplets, Patricia Tavares, Torsten Koetting, Wednesday PM.

Thermal validation of the shielded beam screens

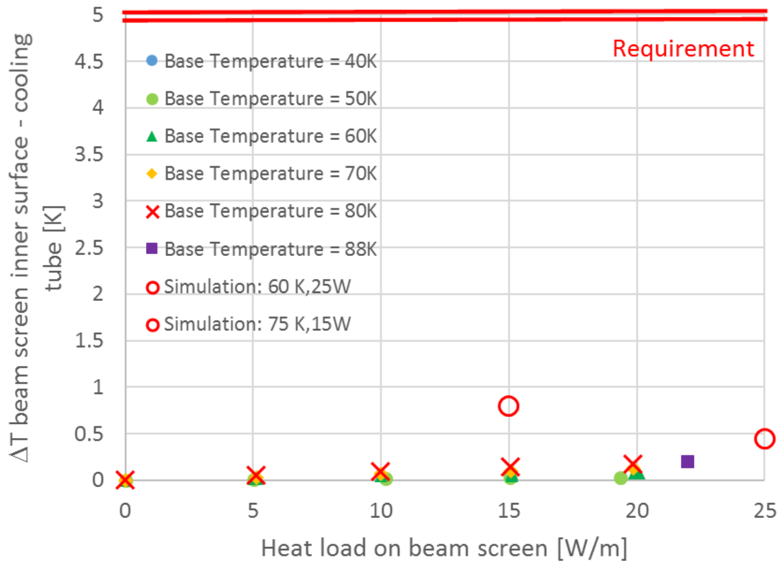
Heat transfer from the absorbers to the cooling tubes

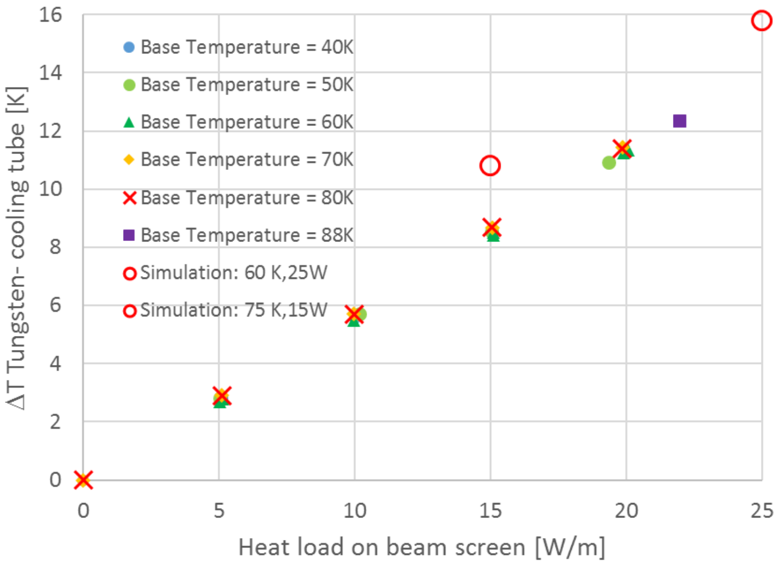
Heat load deposited in the tungsten absorbers is transferred to the cryogenic cooling circuit by thermal links:

- 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





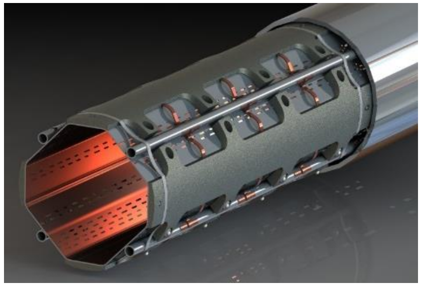
- ➢ Very good thermal decoupling between the absorbers and the beam screen tube. Temperature difference inner surface/helium well below 5K.
- ➢ Temperature of the absorbers 9 to 15K higher than the temperature of the cooling tube.
- ➢ Very good agreement between simulations and experiments.

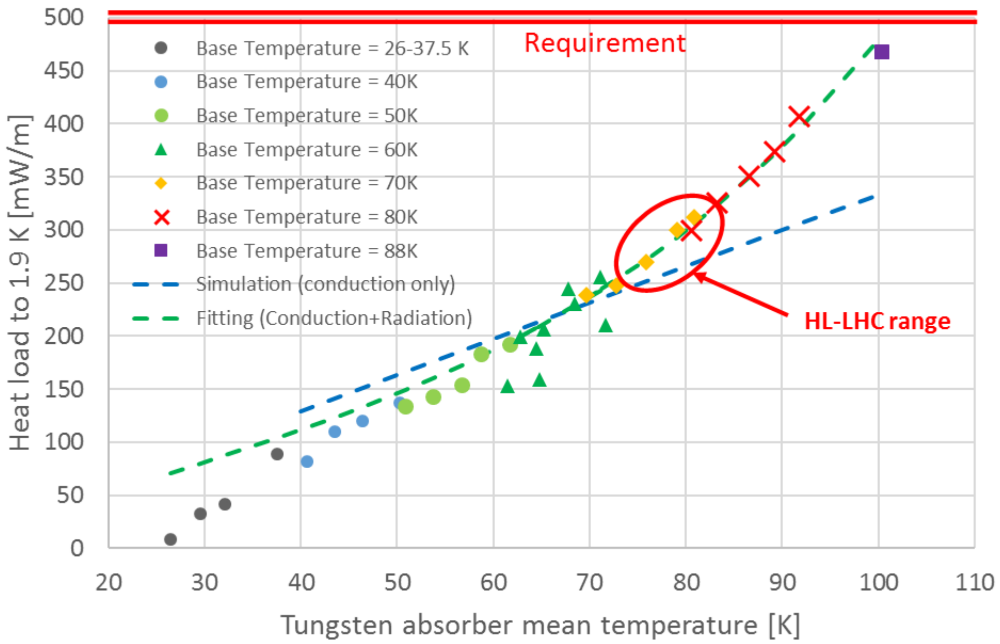
Thermal validation of the shielded beam screens

Heat transfer from the absorbers to the cooling tubes

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.

Mechanical validation of the shielded beam screens

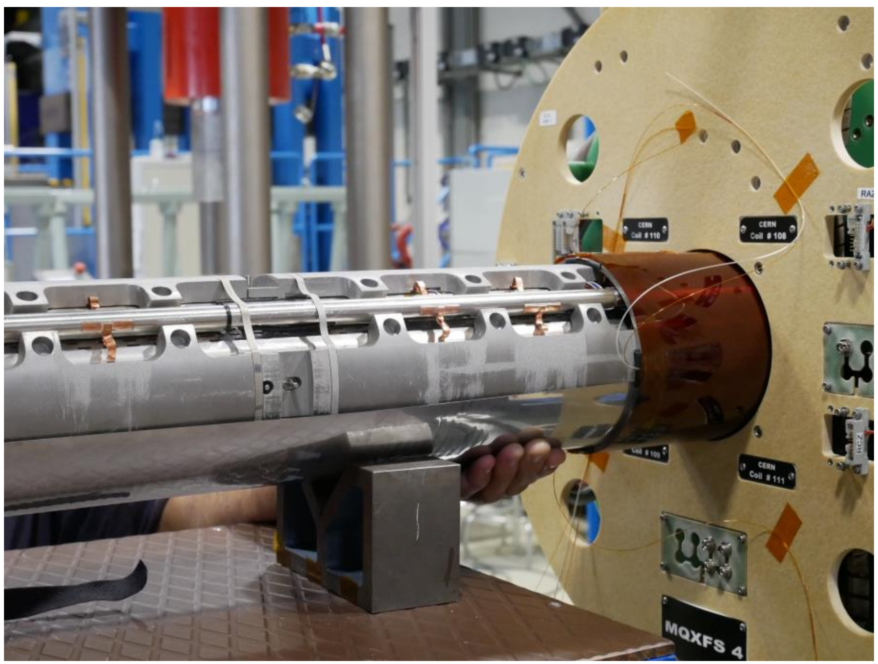
Requirement: The shielded beam screen must withstand the Lorentz forces induced by Eddy current during a quench.

Quench tests with WP3:

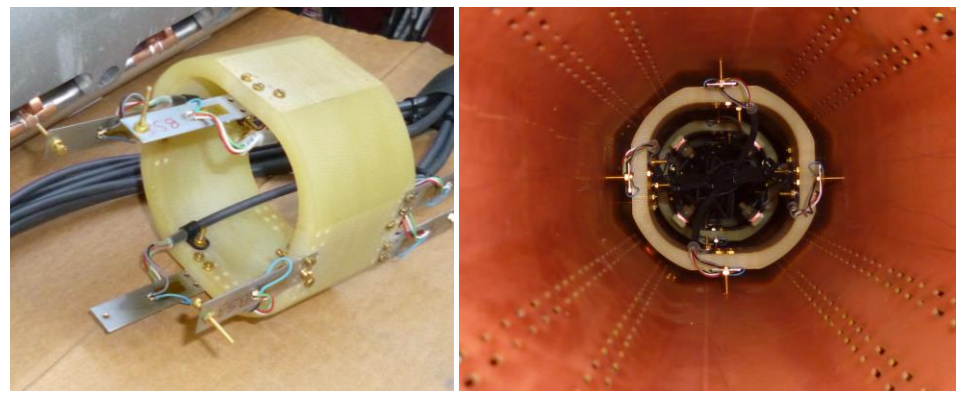
- Q1 model (MQXFS4)
- Tests at 1.9 K.

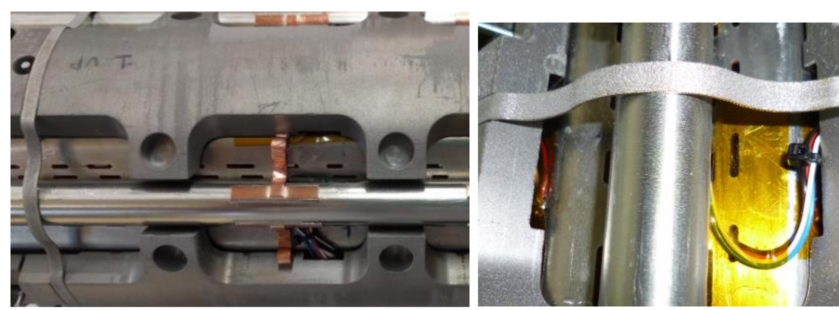
→ Copper layer and thermal links scaled to get similar Lorentz forces.

- First test on modified Q1 beam screen prototype, 2 m long.
- Strain measurements on the cold bore by optical fibers.
- Strain measurements on the beam screen by strain gauges.
- Measurement of the displacements of the beam screen and absorbers.
- Tests carried out with CLIQ at -30% and +25% of nominal, in term of (dI/dt)*I



Beam screen insertion in the MQXFS 4

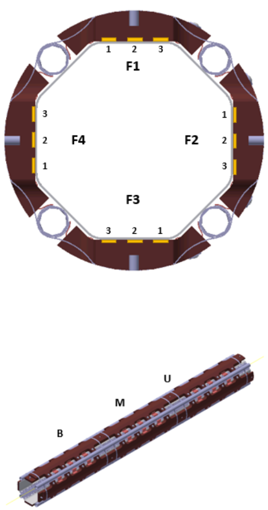

Instrumentation for displacement measurements

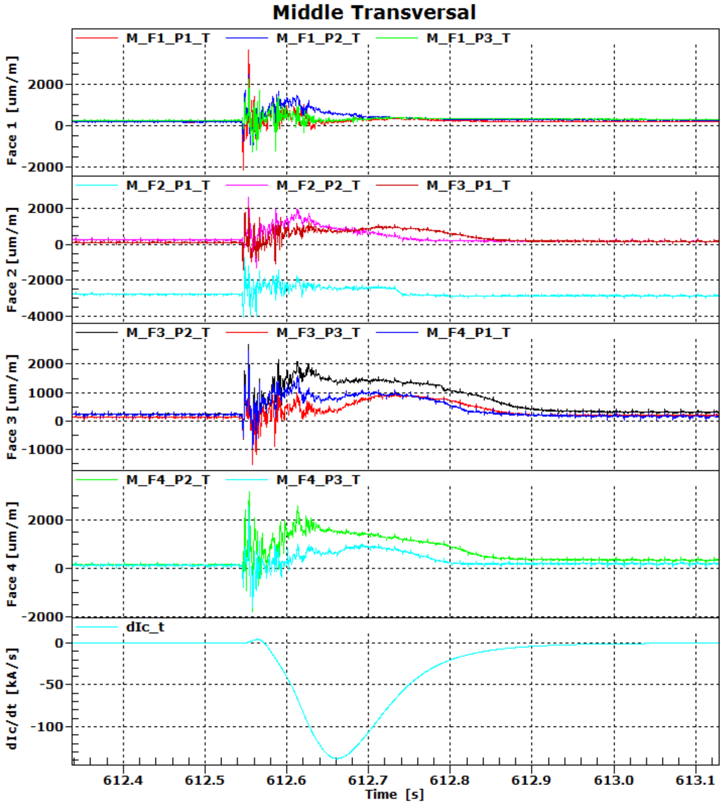

Strain gauges on the beam screen tube underneath the absorbers

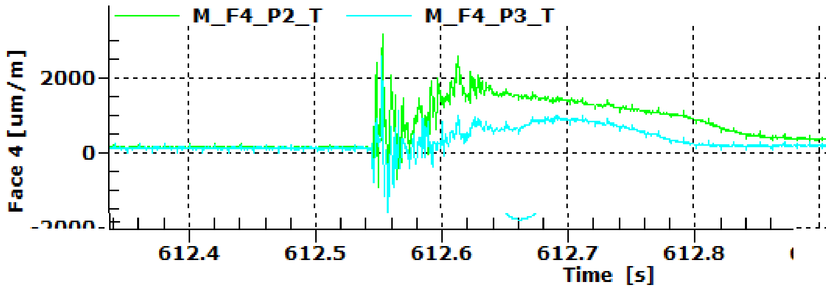
Mechanical validation of the shielded beam screens

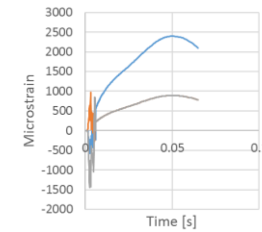
First results (18.5 kA)

Beam Screen Transversal Strains

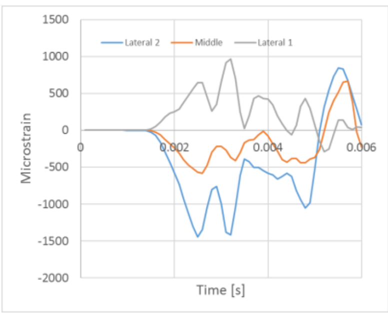


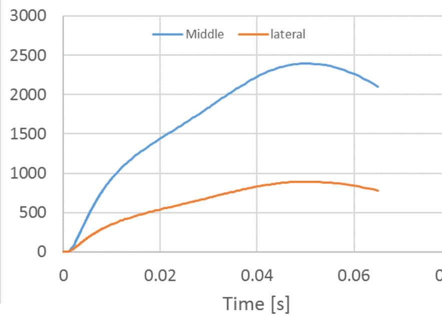






Simulated simplified behaviour based on decoupling CLIQ, QH





- Beam screen withstand 25 quenches, up to ultimate current.
- Elastic overall behaviour of the beam screen.
- Detailed analysis of the test data to be done.

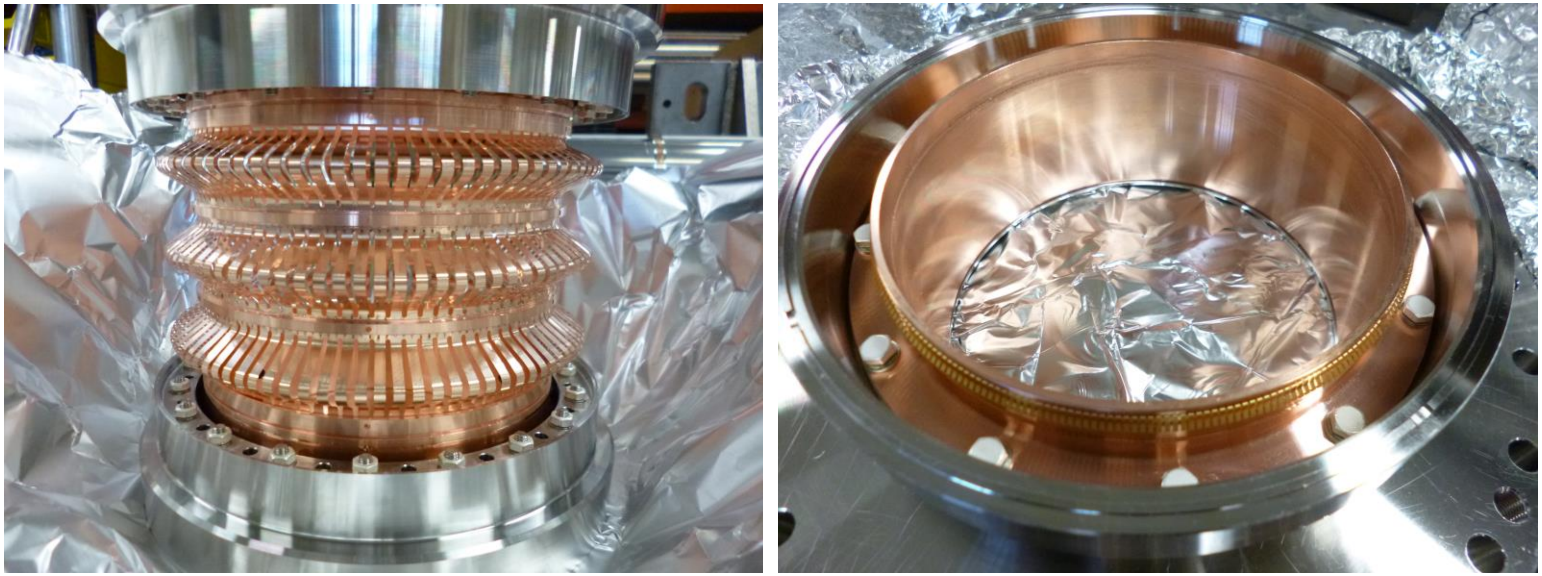
Mechanical and RF validations of the PIM

Mechanical tests with offsets (longitudinal and transverse).

RF tests:

- With/without bellows
- In nominal or with misalignment configurations

Module ready for tests to be done with BE/RF and BE/ABP.



Deformable RF bridge prototype

3. Manufacturing

Manufacturing status

Beam screen facility

Beam screen facility under construction:

- Laser welding machine commissioned
- Cold test bench under manufacturing
- Welding bench commissioned for LHC type beam screen (to be updated for HL-LHC type)
- Assembly, insertion, aC coating benches to be designed

Laser welding machine and welding bench

Manufacturing status

Component procurement

Contract management:

- High Manganese High Nitrogen stainless steel for beam screens and cooling tubes: Received.
- Cooling tubes: Received.
- Co-lamination: Received.
- Beam screen punching, forming and welding:
  - IT-4395 done. Discussions ongoing.
  - Expected first beam screen tube: End 2019.
- Tungsten absorbers:
  - Qualification of 4 suppliers done (EDMS 1973451).
  - IT in preparation. To be sent by the end 2018, FC: March 2019.
  - Pre-series: Summer 2019.

Manufacturing status

Component procurement

Contract management:

- Thermal links:
  - Interface plates:
    - Co-laminated strip ordered (March 2019).
    - Copper scrapping tests ongoing: mechanical or etching.
  - Copper links:
    - two assembly technologies considered: vacuum brazing, US welding.
    - IT early 2019.

- Ti springs & rings:
  - MS: ongoing (options of 3D printing or classical manufacturing methods).
  - IT: early 2019, Pre-series: September 2019.

- Pumping slot shields:
  - Design to be finalized.
  - Price inquiry to be done mid/end 2019.

Manufacturing status

Component procurement

Contract management:

- Cold bore
  - Raw material:
    - First bars in October 2018.
    - Next batch: March 2019.
  - Machining:
    - Contract approved by FC, being placed.
    - Pre-series: End March 2019.

Cold bore manufacturing

4. Summary

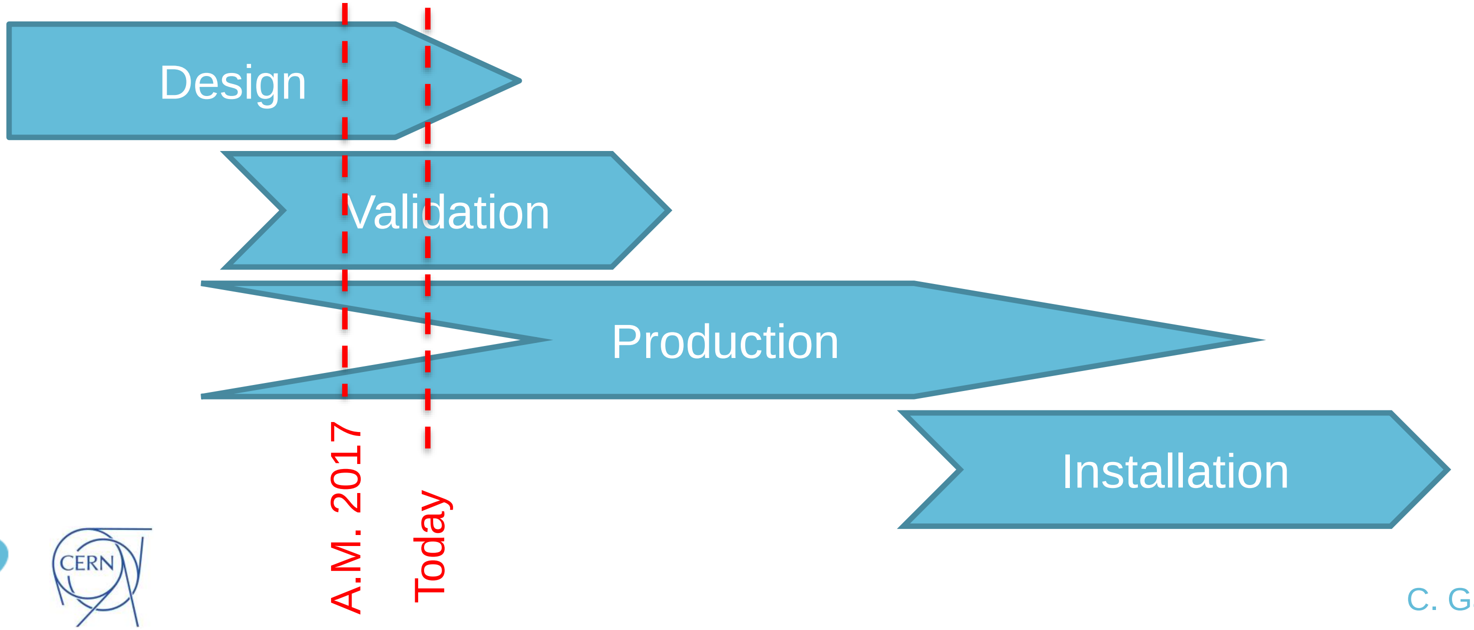
Summary

Thermal and mechanical studies of the beam screen – cold bore system have been carried out.
Additional mechanical studies (misalignment, vibrations) have been done in 2018.

Validation tests are ongoing:

- Thermal tests on a complete beam screen prototype have been successfully done. Very good results, in agreement with simulations, have been obtained.
- Quench tests have just been done on a Q1 beam screen prototype. First hints indicate that the beam screen integrity is preserved and quench tests have been passed successfully.
- RF bridge module prototype is ready for mechanical/RF validation tests.

Contracts for manufacturing of main components are being placed.
The construction of the beam screen finishing facility is ongoing.
Discussions with WP3 on the assembly sequence have started.

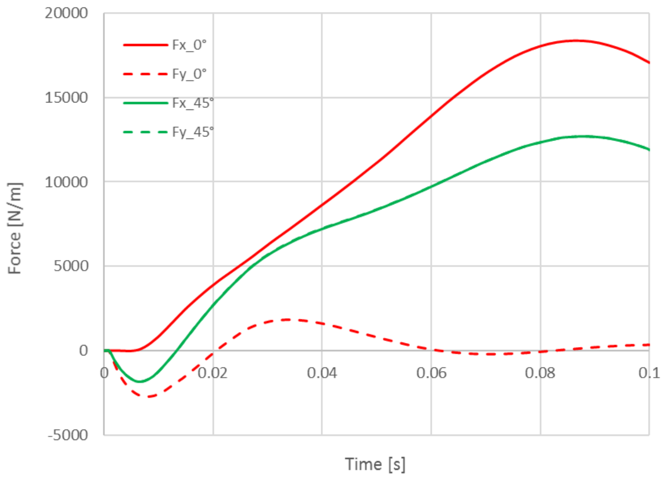


Thank you for your attention

Many thanks to WP3, WP9, EN/MME and all VSC team for their significant, valuable and important contributions.

Influence of misalignment on the behaviour during a magnet quench (3)

Results for a transverse misalignment:



Net force for Q1 and 1 mm offset

→ Initial transverse offset is increase during a quench until the beam screen goes in contact with cold bore (nominal expected behaviour).