Design and Tests of the Shielded Beam Screen

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on behalf of WP12

HL-LHC annual meeting, Madrid, 16th November 2017

Design and Tests of the Shielded Beam Screen

Outline

- Concept & latest design evolution
- Nominal behaviour
    - Temperature profile simulation
    - Cryogenic tests:
        - Thermal links
        - Supporting system
        - Full system prototype
- Behaviour during quench
    - Mechanical simulations with CLIQ
    - Material characterisation: 3D printed titanium, P506 stainless steel
    - Quench tests
- Beam screen extremities and interconnection
    - Shielding in the interconnections
    - PIM
- Manufacturing status
    - Beam screen facility
    - Contract management
- Conclusions

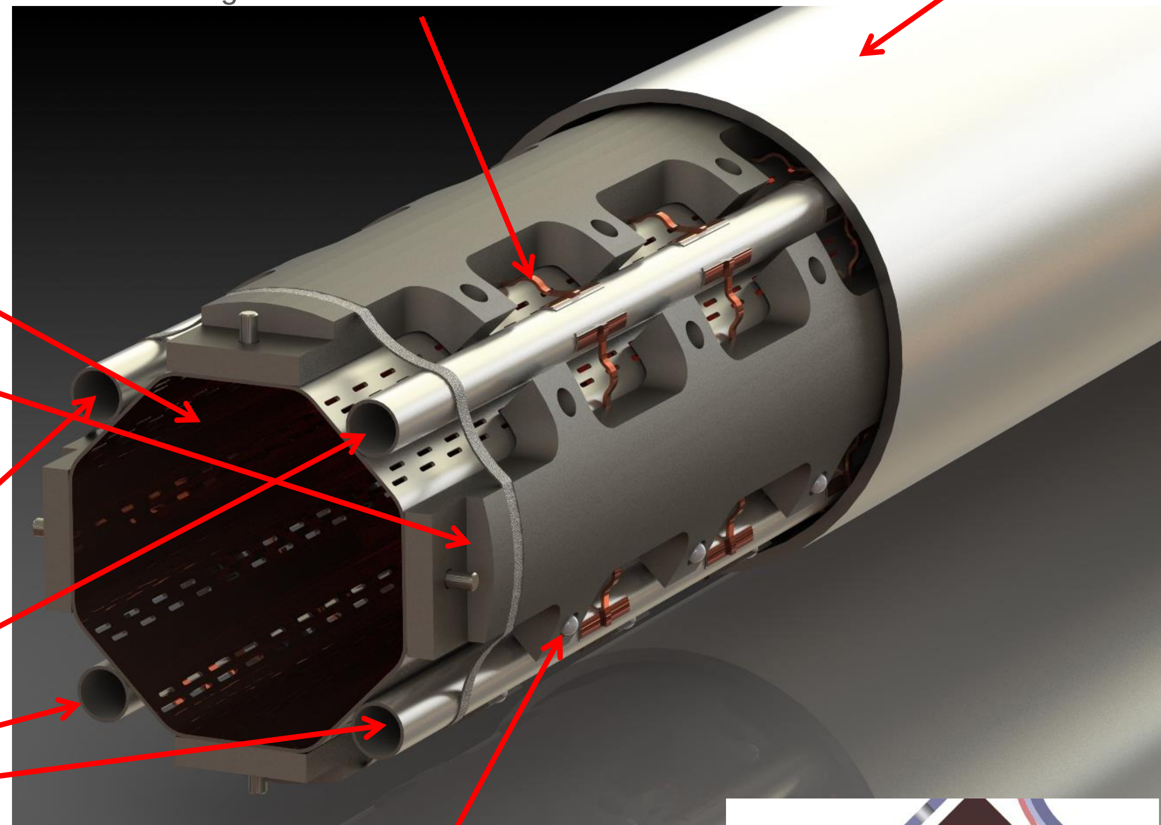
Concept

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

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

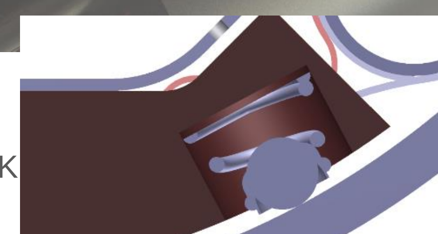
Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN

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

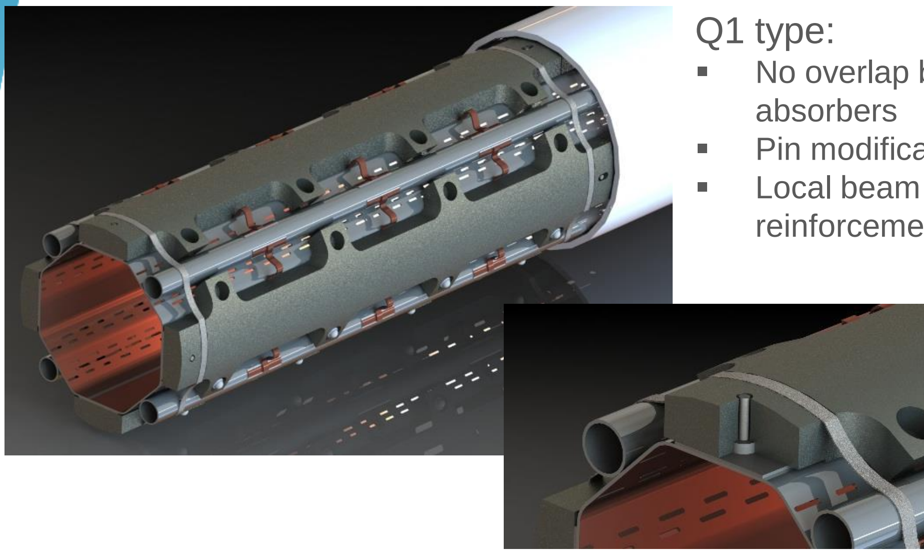


Cooling tubes:
- Outer Diameter: 10 or 16 mm
- Laser welded on the beam screen tube

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

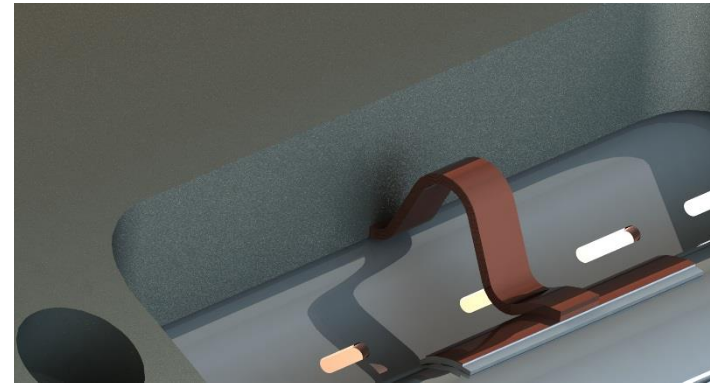


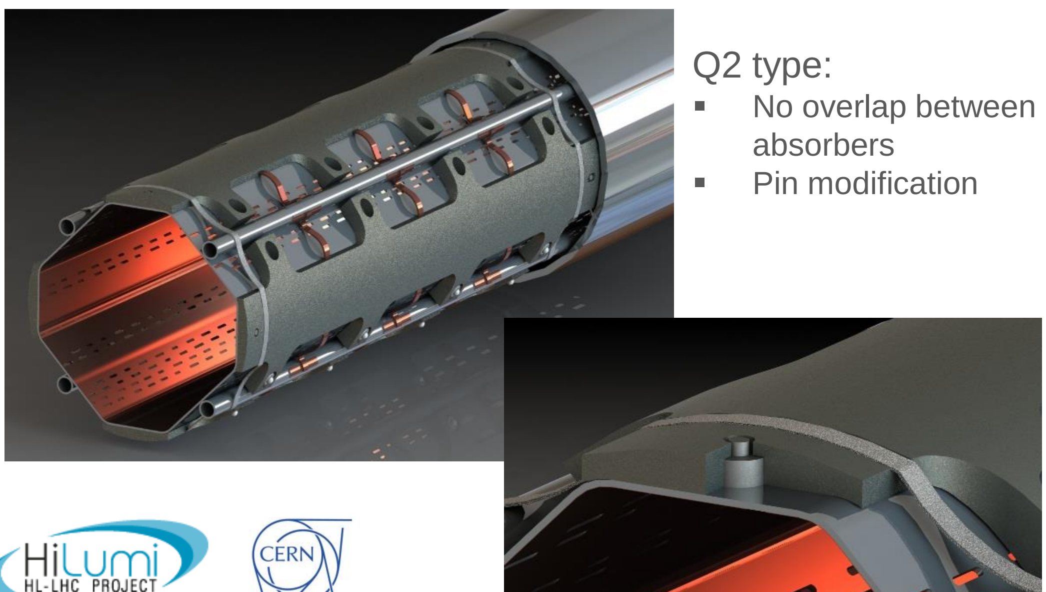
Design evolution



Q1 type:
- No overlap between absorbers
- Pin modification
- Local beam screen tube reinforcement

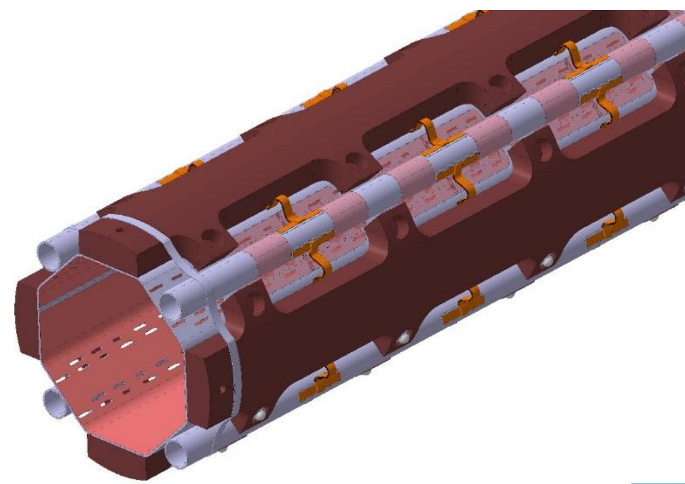
Thermal link width: 5 mm





Q2 type:
- No overlap between absorbers
- Pin modification

Pumping hole shields



Nominal behaviour

Simulations of the temperature profiles

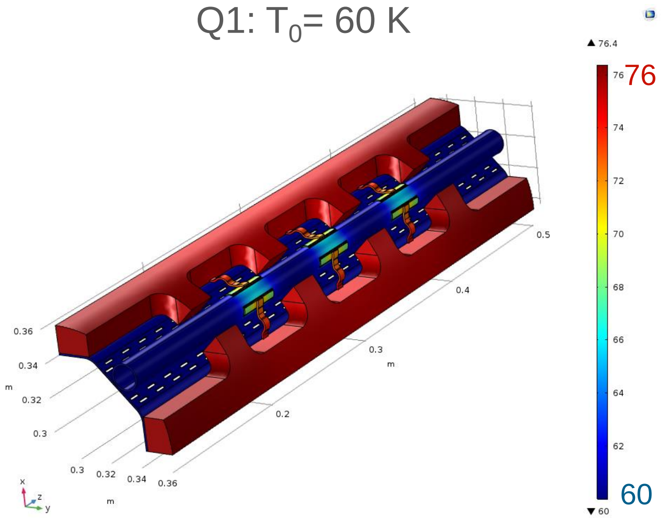
Requirements:

- 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.

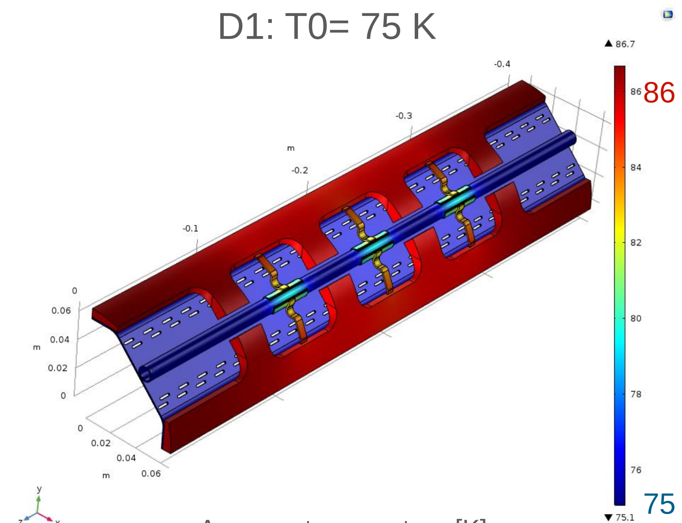
Q1: T_0= 60 K



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 of around 1 K.

Nominal behaviour

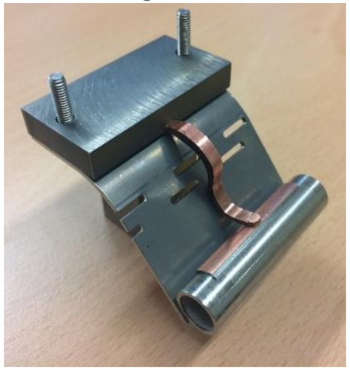
Cryogenic tests* (1)

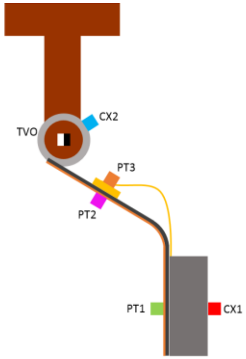
Heat transfer from the absorbers to the cooling tubes

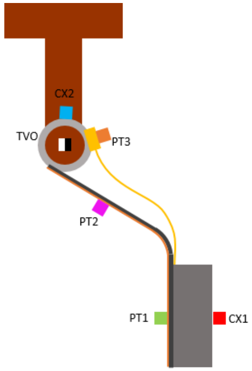
Tests of the thermal links:
- Two thermal link configurations have been tested.
- Tests have been carried out with 3 mm wide thermal links.
- Some geometrical parameters have been optimised based on FE simulations.
- Base temperature from 50 to 80 K, equivalent heat load up to 25 W/m

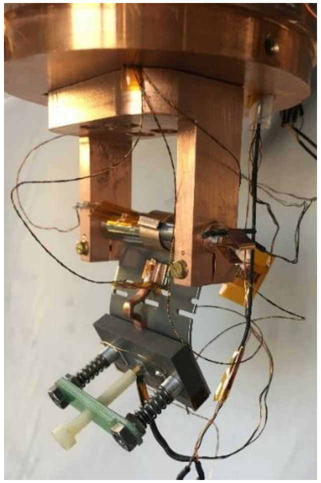
Configuration #1

Configuration #2



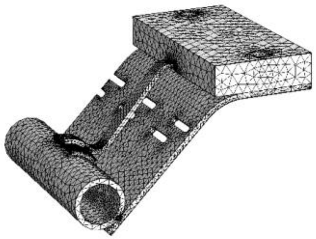


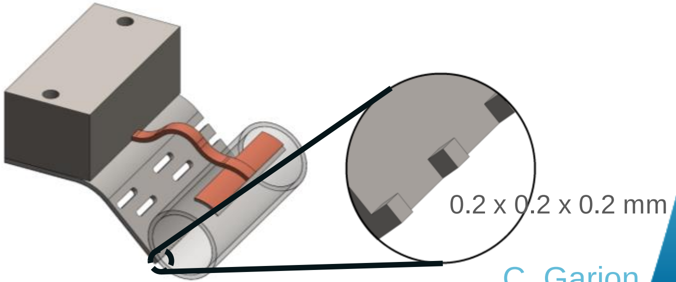




Instrumented sample

Thermal simulations of the thermal links:
- Temperature dependant thermal conductivity
- Weld properly modelled

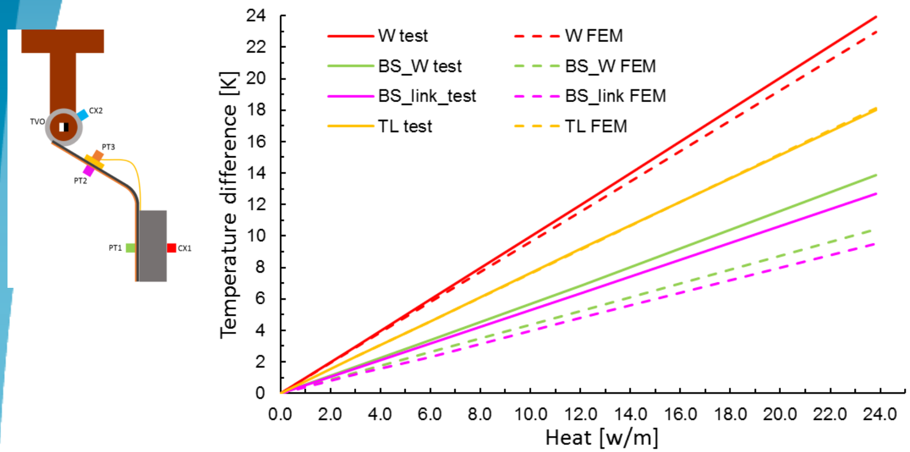


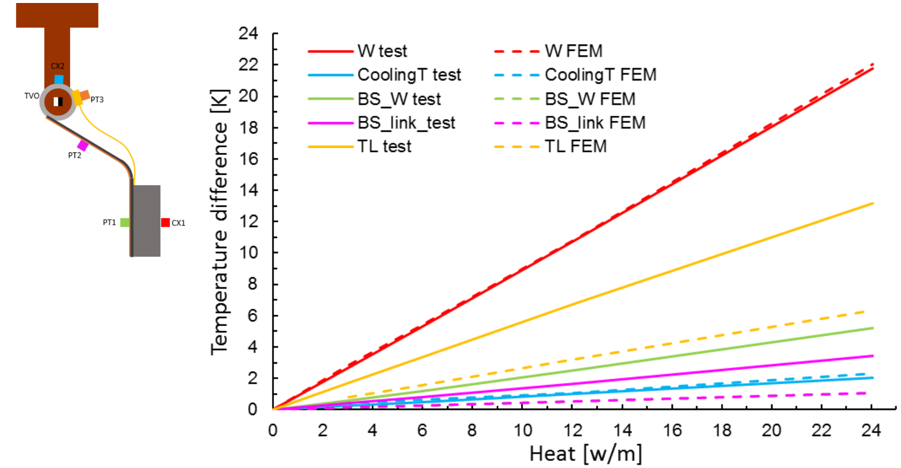


*In collaboration with WP 9

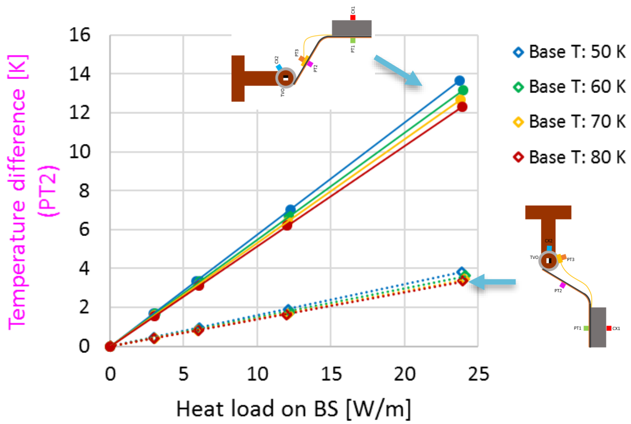
Nominal behaviour

Cryogenic tests* (1)





Temperature differences w.r.t. a coolant at a base temperature of 70 K and a contact pressure W/BS of 3430 Pa (Q2)



Measurements on the beam screen under contact pressure of 3430 Pa

→ Good agreement of the simulations with the measurements.
→ Low influence of the base temperature (in the range 50-80 K): < 1K @ 25 W/m for configuration #2
→ Temperature difference between helium and beam screen below 4 K @ 25 W/m (2K @ 15 W/m).
→ Low influence of the contact pressure: < 1 K @ 25 W/m

→ Final design is 6 copper thermal links per absorber, 5 mm wide connected to the cooling tubes.

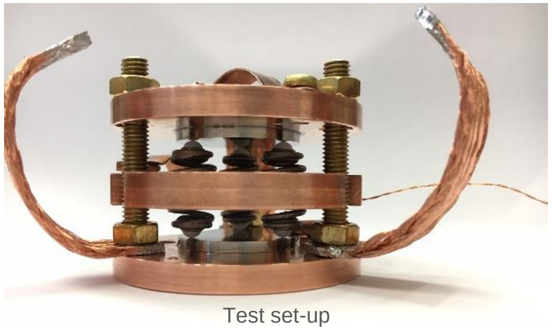
*In collaboration with WP 9

Nominal behaviour

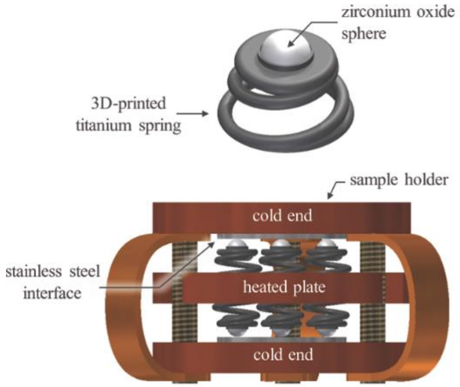
Cryogenic tests* (2)

Heat load to the cold bore through the supporting system

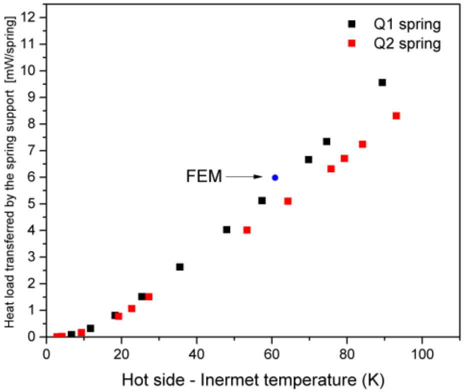
3D printed titanium spring with ZrO2 ball



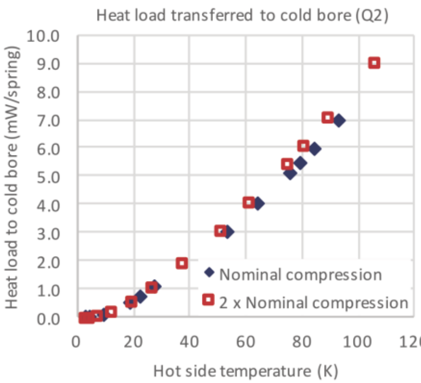
Test set-up



Test principle



Heat load transferred by the spring support



Influence of the spring compression

→ Heat load around 5 to 8 mW/spring for absorber temperature between 60 to 90 K.

→ Low influence of the compression: ~10 % for twice the nominal load

Expected heat load from the beam screen to the cold bore below 500 mW/m (cryogenic budget):

- 320 mW/m for Q1
- Between 260 to 300 mW/m from Q2a to D1

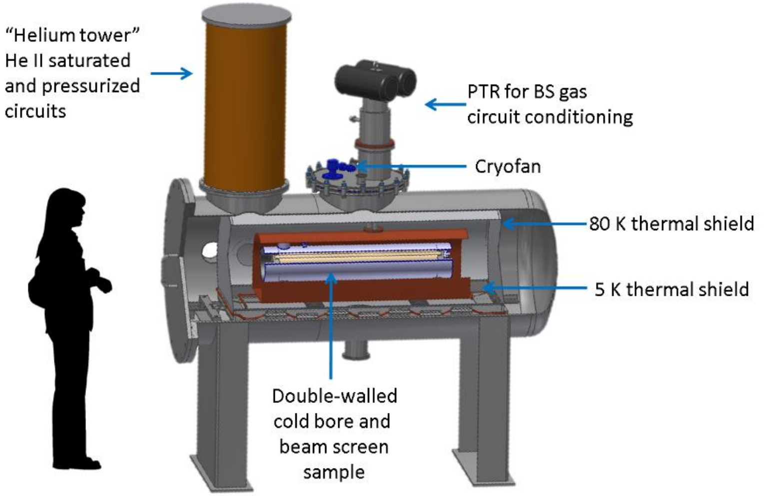
*In collaboration with WP 9

Nominal behaviour

Cryogenic tests* (3)

Heat transfer on a 80 cm long prototype:

- Heat load to the cold bore
- Heat transfer from the absorber to the cooling tubes



Cryogenic test bench

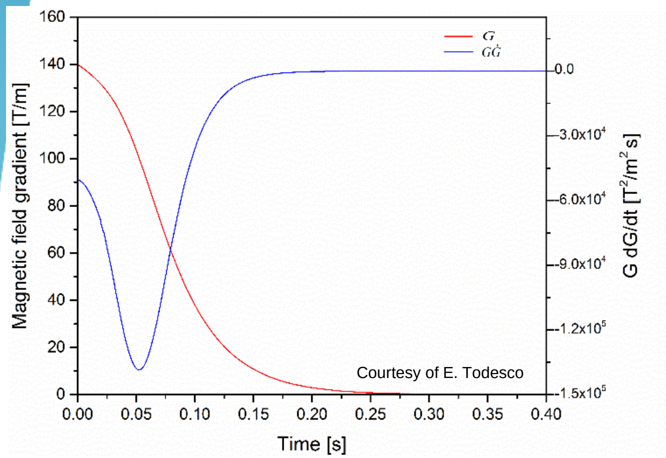
Beam screen prototype

First cryogenic test on the 80 cm long Q2 type beam screen prototype by the end 2017.

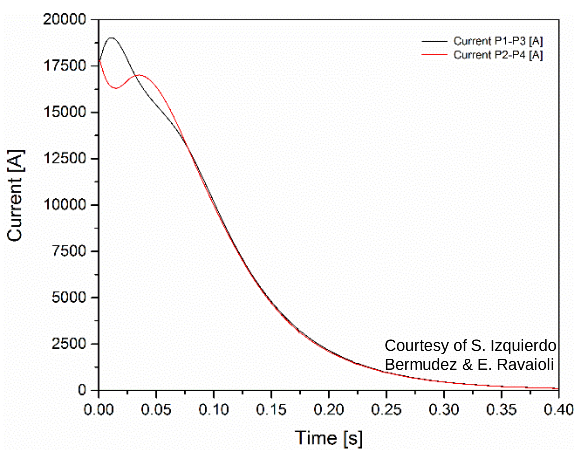
*In collaboration with WP 9

Behaviour during a magnet quench

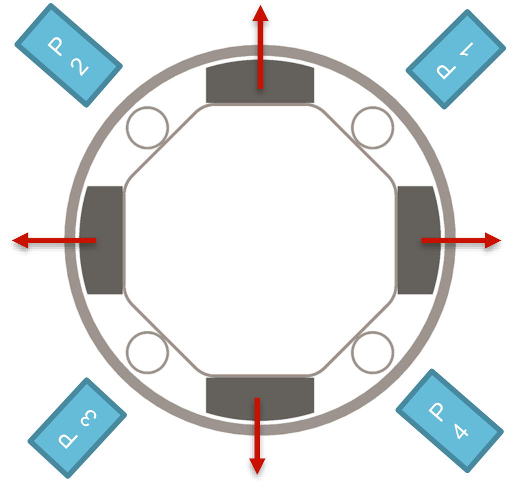
Impact of CLIQ



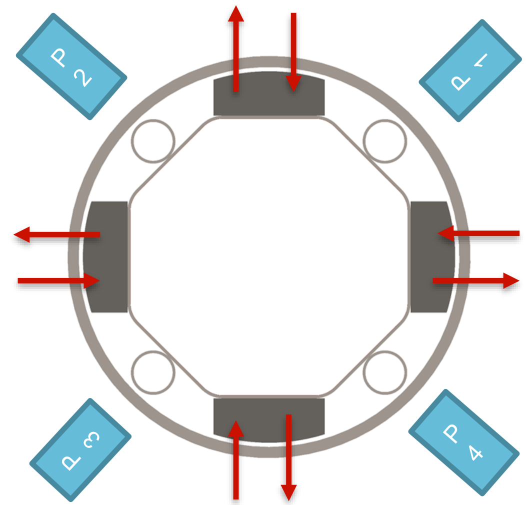
Magnetic field decay with quench heaters



Current decay with CLIQ discharge



Expected forces in red



Specific Lorentz forces reads:

$$f \propto \frac{G\dot{G}}{\rho} r^3$$

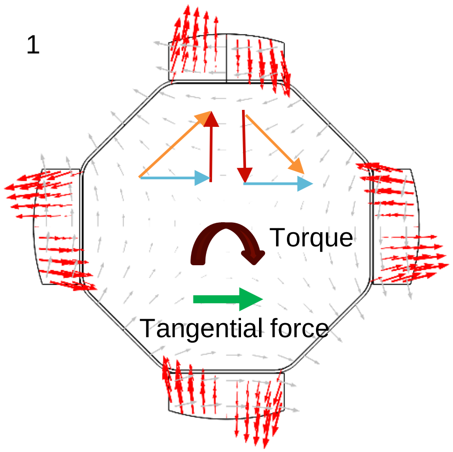
- → Lorentz forces driven by GG' product
- → Lorentz forces acting on the beam screen are pointing toward the cold bore
- → Lorentz forces are maximum after 50 ÷ 60 ms.

$\dot{G}$ has opposite sign in the first phase of the CLIQ discharge!
Therefore, opposite forces are expected in the same component.

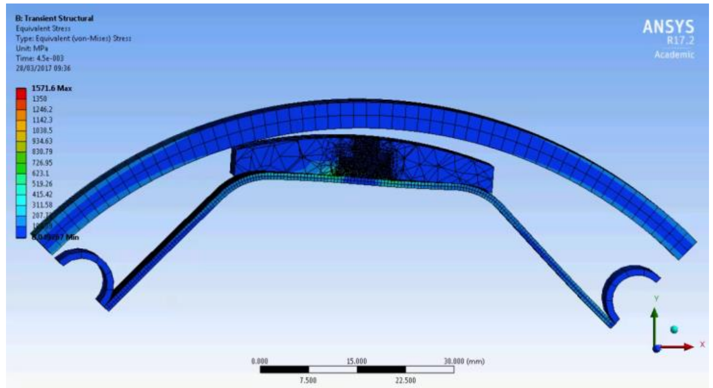
Behaviour during a magnet quench

Impact of CLIQ

1

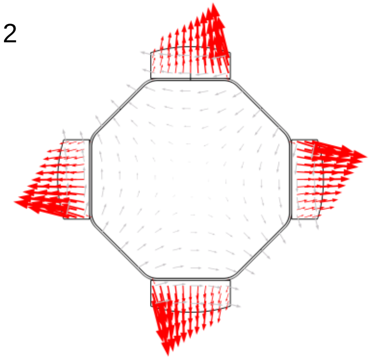


Force distribution



Deformation during the first phase

2



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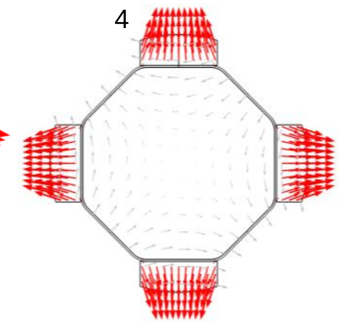
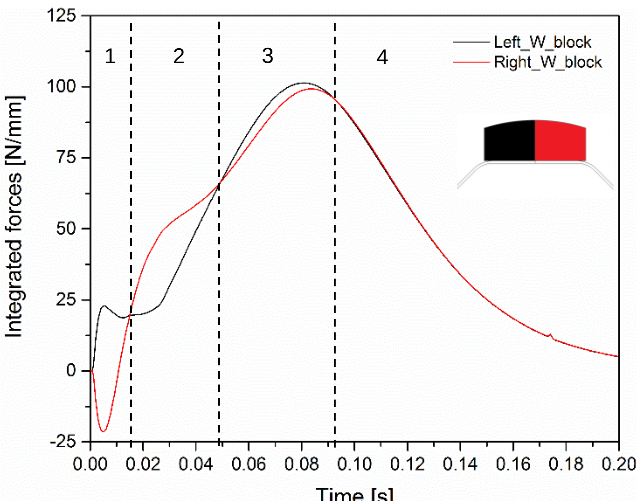




Integrated forces induced in half W block

Phase 1: Most critical!!

component	Q1		Q2	
	Torque [N m/W block]	Tangential force [N/W block]	Torque [N m/W block]	Tangential force [N/ W block]
Cold bore	250	3400	250	3400
Heat absorber	280	4200	150	2200
Octagonal pipe	80	1600	230	3800

Phase 2: Less severe than phase 1

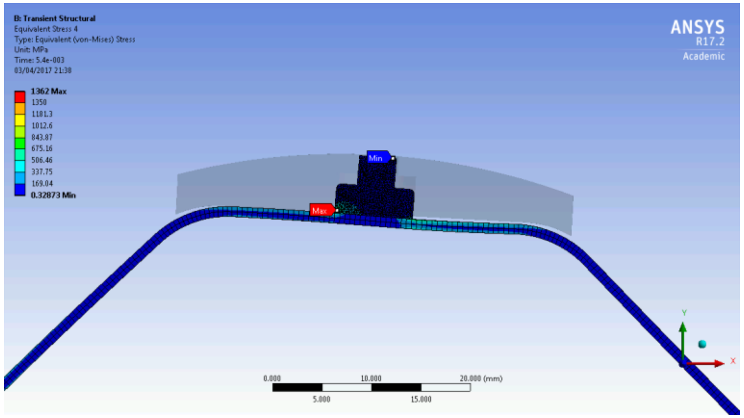
Phase 4: Less severe than without CLIQ

E.g. Fy for the tungsten block: $Q1_{NO\ CLIQ}$ ~230 [N/mm] > $Q1_{CLIQ}$ ~200 [N/mm]

Behaviour during a magnet quench

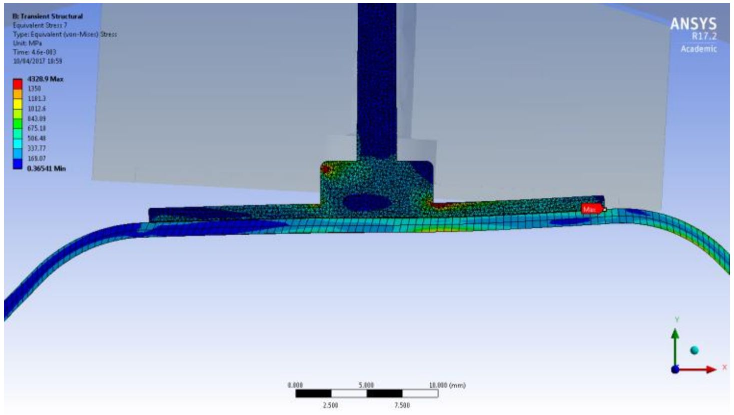
Impact of CLIQ

Q2:



→ Pin modification

Q1:



→ Pin modification

→ Local reinforcement of the beam screen

CLIQ phase 1

Component	Material	Elastic limit [MPa]	Q1			Q2		
			$F_{y\ max}$ [N/mm] -per eight-	σ_{max} [MPa]	δ_{max} [mm]	$F_{y\ max}$ [N/mm] -per eight-	σ_{max} [MPa]	δ_{max} [mm]
Cold bore	Ss 316 LN	860 (at 4 K)	12	620	1.35	12	280	1.0
Heat absorber	Inermet	1284 (at 77K)	22	650	-	11	400	-
Octagonal pipe+ Cu layer	Ss P506	1350 (at 50 K)	5.3	850	-	14	450 (1250 loc.)	-
Pin	Ss P506	1350 (at 50 K)	-	> 1350 (loc.)	-	-	1000 (loc.)	-

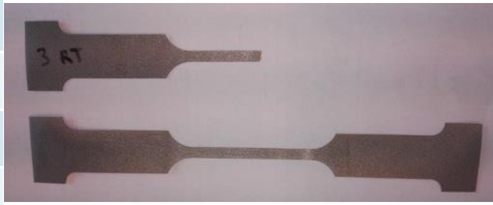
Behaviour during a magnet quench

Material characterisation

Tensile tests on thin 3D printed titanium sample (RT and 77 K)

Sample	Rm [MPa]	A [%]	Emod [GPa]	Rp2 [MPa]
Supplier #1	975.65	1.54	98.20	939.40
Supplier #1 HIP	864.46	0.66	97.40	851.20
Supplier #2	809.40	0.69	81.16	801.43
Supplier #2 HIP	753.55	1.41	84.07	729.08
Reference	900	10	110	830

Test results at room temperature



Tensile and damage evolution tests on P506 samples and welded pins

- Test campaign on samples to assess the ductile damage evolution in P506 at cryogenic temperature.
→ Analysis of local damage propagation with or without initial defects.

- Test campaign on welded pins to assess the strength and optimize welding parameters

Behaviour during a magnet quench

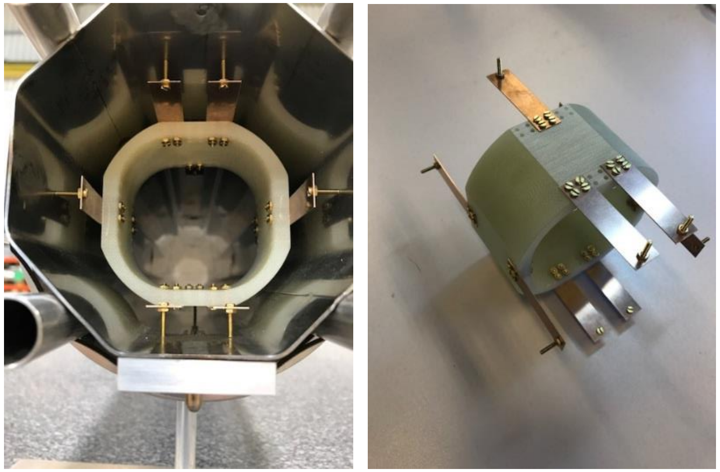
Quench tests

Tests with CLIQ discharge on Q1, Q2:

- Tests at 1.9 K.

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

- First test on modified Q1 prototype (end 2017/early 2018).
- Strain measurement on the cold bore by optical fibers.
- Measurement of the displacements of the beam screen and absorbers.



Displacement measurement tooling (Courtesy Oscar Sacristan De Frutos)

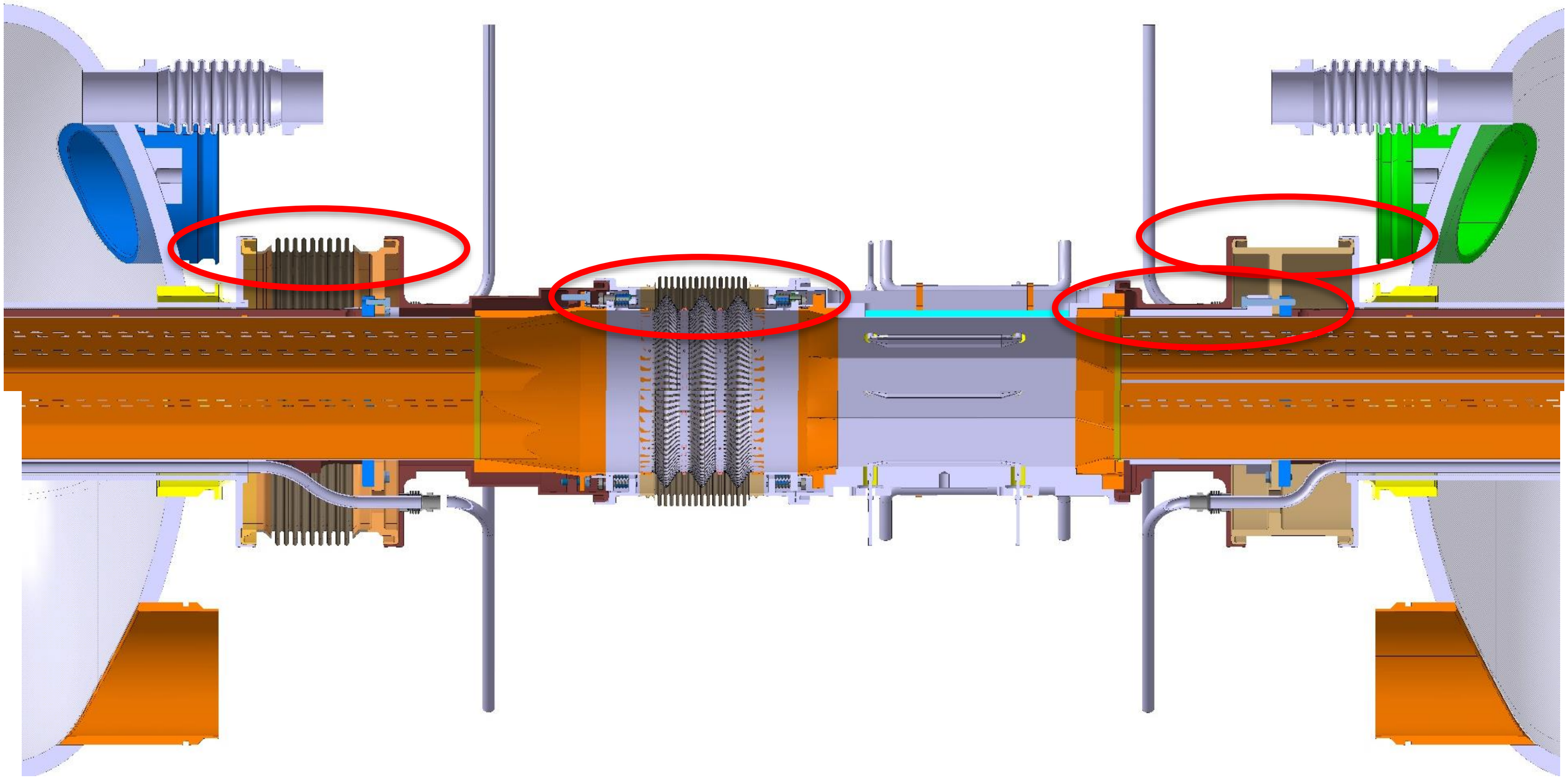
Modified absorbers

Beam screen tube

Beam screen extremities and interconnections

Layout

0/90° cut



+/-45° cut

- More compact components (transversally)
- Longer absorber at the beam screen extremities
- Update of the interconnection module design

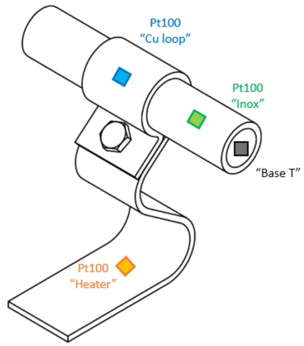
*BPM model provided by WP 13

Beam screen extremities and interconnections

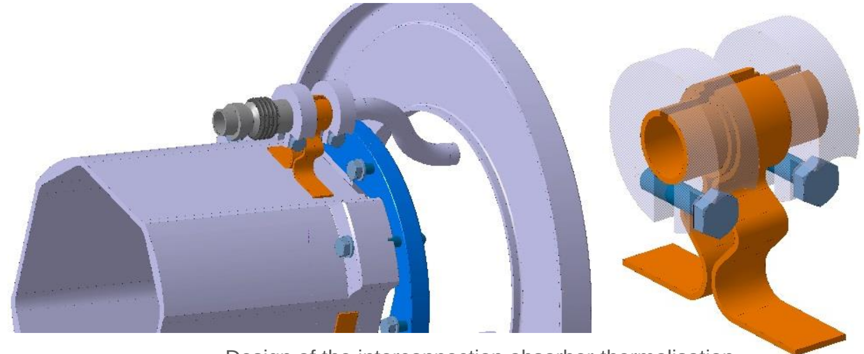
Shielding in the interconnections

Heat load on the tungsten absorber in the interconnection: ~ 5W

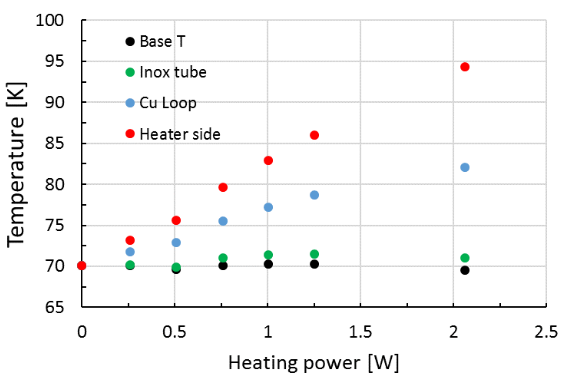
Heat transfer driven by clamping element relying on Thermal Contact Conductance (TCC)

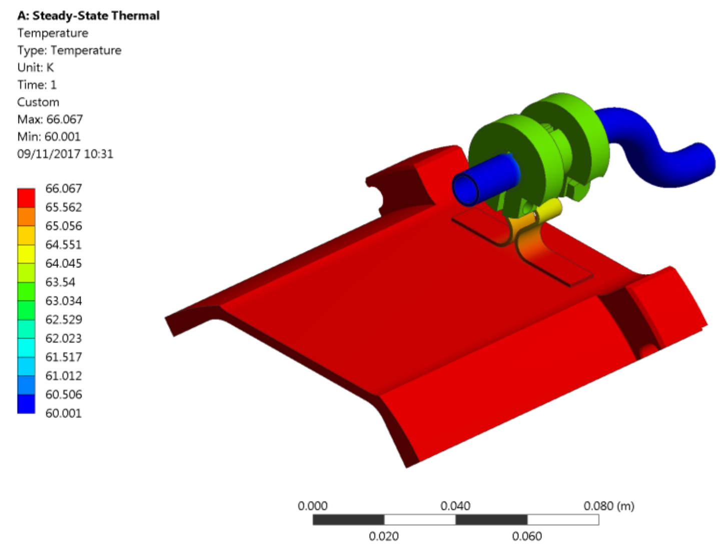


Heat transfer test on preliminary thermal link design



Design of the interconnection absorber thermalisation





Expected temperature profile

Temperature measurement and fitting with the numerical simulations lead the TCC assessment.

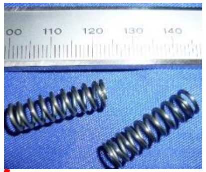
→ The installation of tungsten absorber in the interconnection is possible

Beam screen extremities and interconnections

Interconnection module

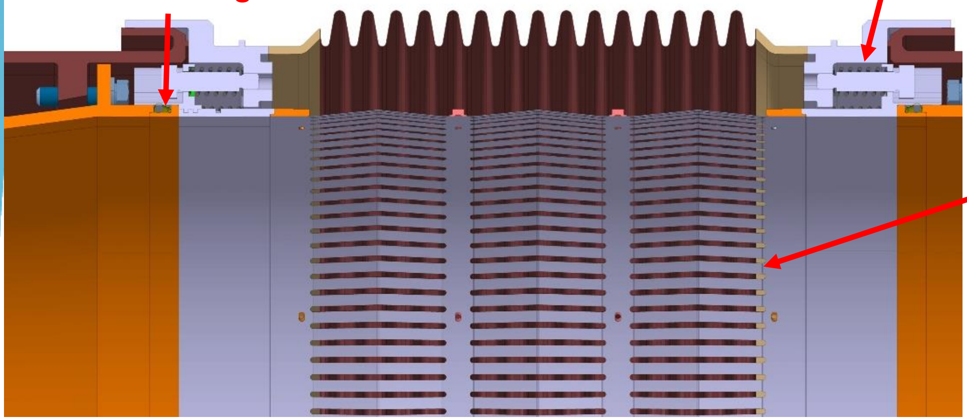
Copper Beryllium deformable RF bridge:

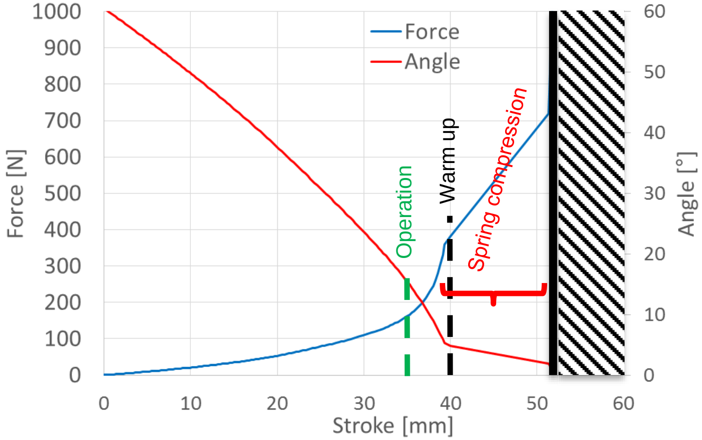
- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions



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

Static RF fingers

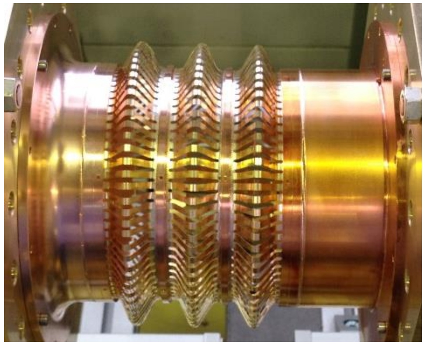




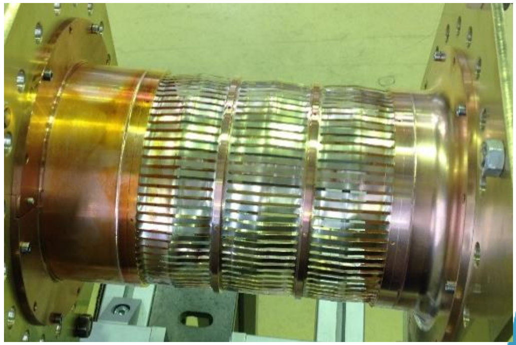
Expected behaviour and working conditions of the RF bridge

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

Full interconnection module prototype under manufacturing.
Mechanical and RF tests will be done, in particular the RF performance with transversal offset will be assessed (early 2018).



as installed



in operation

Deformable RF fingers

Manufacturing status

Beam screen facility

Beam screen facility under construction:

- Gantry crane installed and commissioned
- Laser welding machine to be received end November
- Cold test bench under refurbishment
- Welding bench (EN/MME) installed in February 2018 for LHC type beam screen (to be updated for HL-LHC type)
- Assembly, insertion benches to be designed

Beam screen manufacturing

Manufacturing status

Component procurement

Contract management:

- High Manganese High Nitrogen stainless steel for beam screens and cooling tubes: Received
- Cooling tubes:
  - Reception next week
  - Reception tests: End 2017
- Co-lamination:
  - Delivery: Q4 2017
- Beam screen punching, forming and welding
  - New market survey for 6m long unit ready to be sent
  - Finance committee Mid 2018
  - 316LN prototype: March 2019
  - First beam screen tube: Mid 2019
- Tungsten absorber:
  - Qualification of 4 suppliers ongoing
  - Contract placement before end 2018

Manufacturing status

Component procurement

Contract management:

- Cold bore
  - Raw material:
    - Contract placement: end 2017
    - Delivery: Mid 2018 (urgent prototypes on existing blanket contract)
  - Machining:
    - Qualification of a second bidder ongoing
    - Contract placement: March 2018

Conclusions

Thermal and mechanical studies of the beam screen – cold bore system have been carried out.

Thermal tests to assess the heat transfer to the cryogenic system and the cold bore have been successfully carried out. Thermal test on a complete beam screen prototype is in preparation for end 2017/early 2018.

A design evolution, compatible with the CLIQ protection system, has been proposed. First quench test planned for early 2018.

Design of the beam vacuum line interconnection has been significantly improved. RF bridge module prototype is in fabrication.

Contracts for manufacturing of main components are being placed.

The construction of the beam screen finishing facility is ongoing.