



9th HL-LHC Collaboration Meeting, Fermilab, USA
14-16 October 2019

WP4
HOM Couplers, Field Antenna and Feedthroughs Status
(& FPC and Outer Tube)

eric.montesinos@cern.ch

on behalf of all persons involved

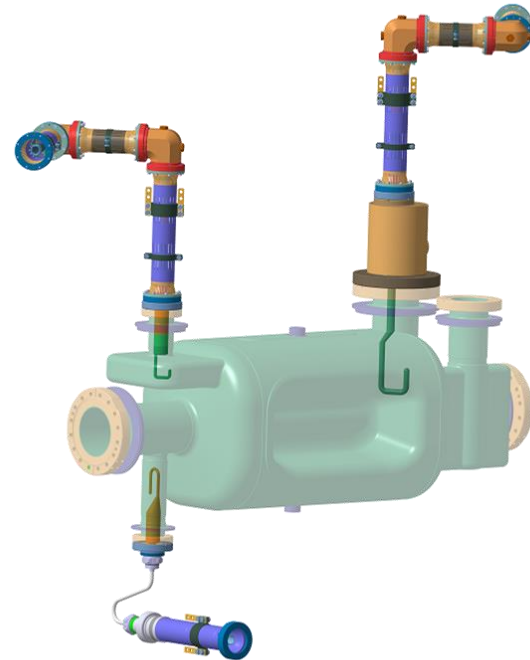
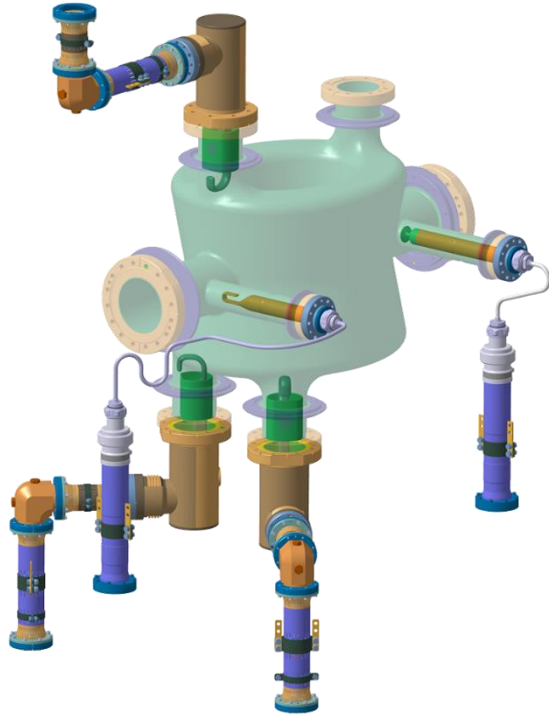
Preamble

We have a (almost) weekly vidyo meeting with US-AUP colleagues

This presentation summarizes (almost all) what is discussed there

This is the view from the CERN side of it

HOM couplers, Field Antennas, RF power lines



Schedule as per end 2018

To be provided by CERN

◆ Lines + Feedthroughs + Antennas + HOM couplers

◆ Lines

◆ Lines



◆ SPS CERN DQW proto

SPS CERN/UK RFD proto ◆

RI/CERN DQW ◆

RI/China/UK DQW ◆ ◆ ◆ ◆ ◆

AUP/TRIUMF RFD proto ◆ ◆ ◆ ◆ ◆

Schedule as per September 2019

To be provided by CERN

- ◆ Lines + Feedthroughs + Antennas + HOM couplers
- ◆ Lines + all Feedthroughs
- ◆ Lines (+ all Feedthroughs? to be decided)



◆ SPS CERN DQW proto

SPS CERN/UK RFD proto ◆


RI/CERN DQW ◆


RI/Russia/UK DQW ◆ ◆ ◆ ◆ ◆

AUP/TRIUMF RFD proto ◆ ◆ ◆ ◆ ◆

Schedule as per end 2018



3 RFD V 2 (+1) x 

3 RFD H 2 (+1) x 

All RFD HOM Couplers Series
manufactured by the US-AUP team

34 DQW 6 (+2) x 

8 x  8 x  6 + (4) x 

26 Antennas 6 (+2) x 

10 x  6 + (2) x 

Schedule as per September 2019



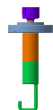
3 Antennas

2 (+1) x



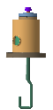
3 RFD V

2 (+1) x



3 RFD H

2 (+1) x



All RFD HOM Couplers Series
manufactured by the US-AUP team

34 DQW

6 (+2) x



8 x



8 x



6 + (4) x



13 Antennas

2 (+1) x



4 x



4 + (2) x



13 HF-HOM

2 (+1) x



4 x



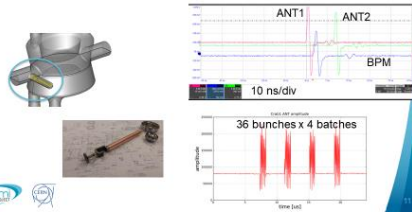
4 + (2) x



Field Antenna & HF HOM coupler

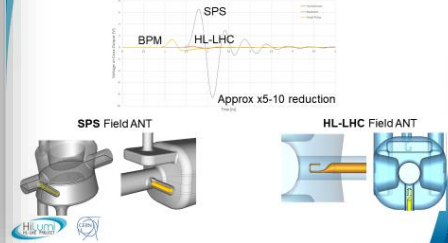
6: Field Antenna

- Strong coupling of the field antenna (like a BPM) to the beam passage instead of just measuring cavity field variation



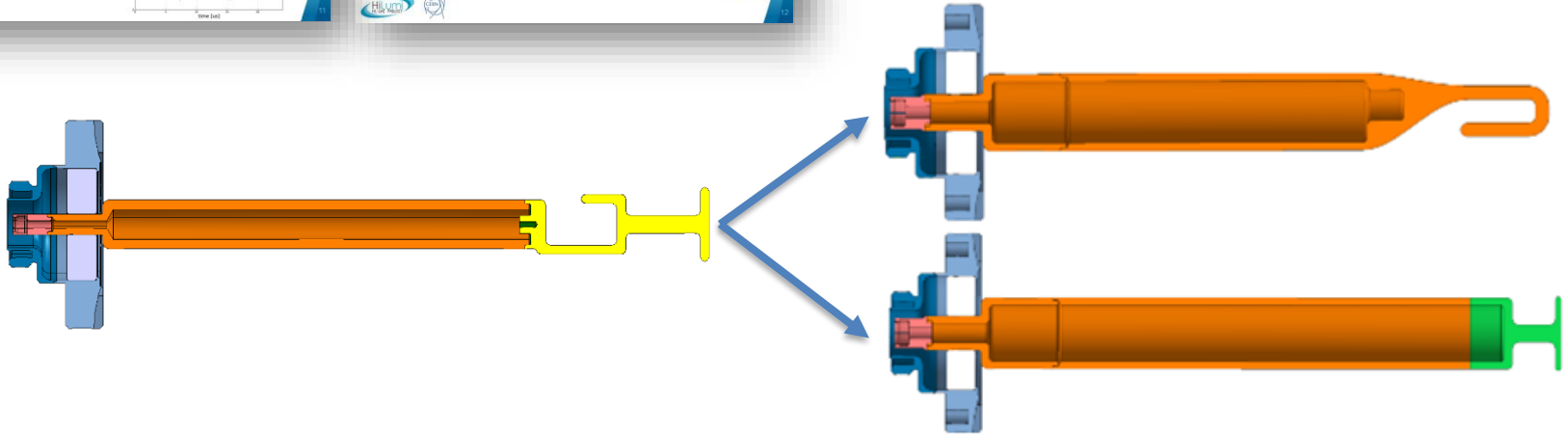
Direct Beam Coupling Mitigation

- Design change for field antenna adopted for HL-LHC to minimize this effect by approx. $\times 10$



As Rama explained yesterday, we are 'concern #6'

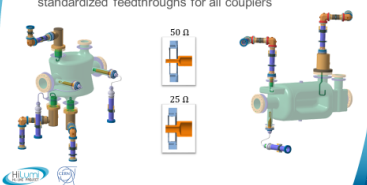
To solve it we had to move from 'all in one Field Antenna & HF HOM' to one Field Antenna & one HF HOM coupler



Feedthrough : 50 Ohm to 25 Ohm

7: RF Feedthroughs

- Vacuum leaks at 2K experience during SPS solved with re-design for window brazing
- Feedthrough impedance used for SPS 38 Ω ! Ideally 50 Ω , decision to go for 25 Ω for robustness & standardized feedthroughs for all couplers



The diagram shows two types of RF feedthroughs. On the left, a 50 Ω feedthrough is shown with a blue and yellow assembly. On the right, a 25 Ω feedthrough is shown with a similar but slightly different assembly. The 25 Ω version is noted as being chosen for robustness and standardization.



In addition to the coupling mitigation, we are also 'concern #7' I endorse it, as this is because of my fear of transportation



Transportation : 50 Ohm to 25 Ohm

With all the transportations we will have, we can reasonably expect some shocks



Series cryomodules

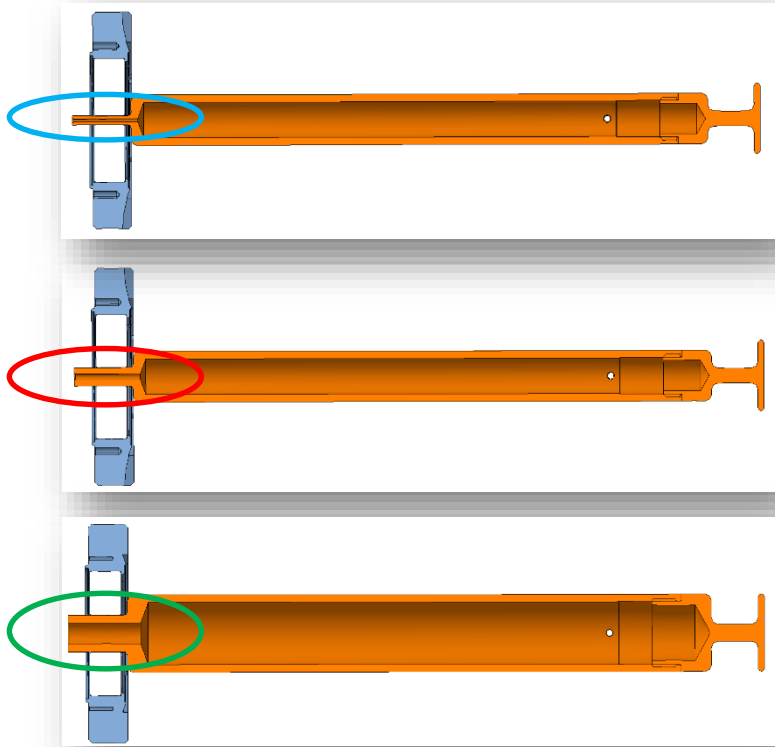
Components (FPC, beam screen, RF links, ...)

See presentation of Kurt Artoos and Thomas Jones "Transport Aspects"
See presentation of Luca Dassa "Technical Specifications and Guidelines for Compliance with CERN Safety Rules"
See presentation of Eric Montesinos "CERN FPC & Other couplers for HL-LHC CC"
See presentation of Germana Riddone "Vacuum for HL-LHC CC"

HiLumi HL-LHC PROJECT CERN

OC. International review of the HL-LHC Crab Cavity system, 19/06/2019

Transportation : 50 Ohm to 25 Ohm



Ideal design D39.7/d3.1 ; $Z = 50 \Omega$

$$Z_{ceramic} = \frac{60}{\sqrt{\epsilon_r}} \ln \left(\frac{D}{d} \right) ; Z_{ceramic} \sim 20 \ln \left(\frac{D}{d} \right)$$

Crab SPS design D39.7/d6 ; $Z = 38 \Omega$

In order to make it much more robust, Rama had the clever idea to propose 25 Ω

Crab design D40/d12 ; $Z = 24 \Omega$

Transportation : 50 Ohm to 25 Ohm

Courtesy Eduardo, Ofelia and team

Moving from 50 Ω to 25 Ω is not an easy decision as it impacts a lot of modifications on all devices

Ceramic sizes

Titanium flanges size

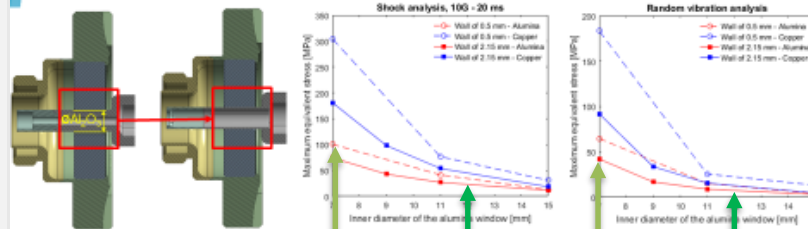
Cavity flanges size

This was finally agreed by all actors, including US-AUP

Transport analyses

Qualitative evaluation of the maximum **stress** for different diameters of the alumina window and thicknesses of the copper wall – **Shock and random vibration*** (truck transport) analyses.

Maximum equivalent stress



Moving from d6 to d12 reduces more than twice the stress

- Increasing the diameter of the alumina window decreases the maximum stress in both the copper and the alumina.

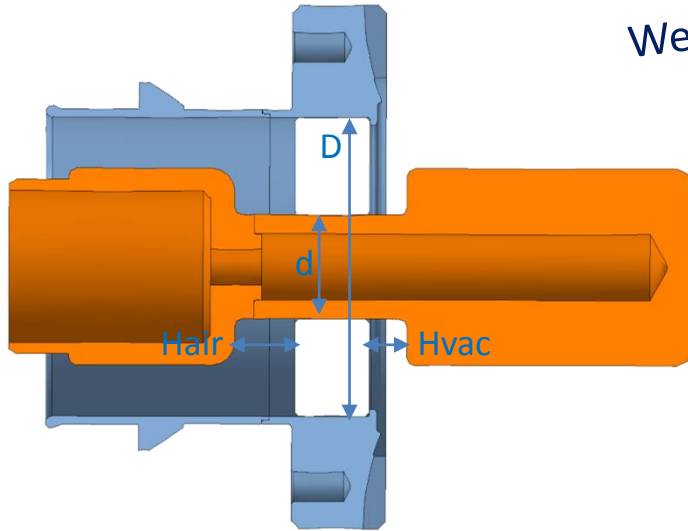


*PSD extracted from ASTM D4169

5/03/2019, E. Canc

Eduardo did simulations showing that the stress in the ceramic is largely decreased with 25 Ω feedthroughs

Feedthroughs optimization



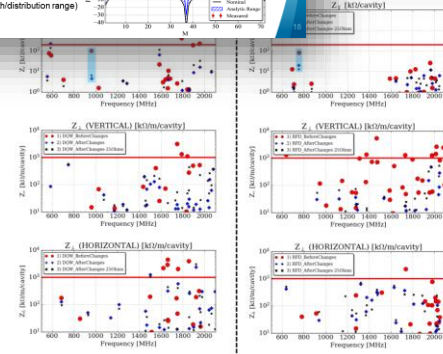
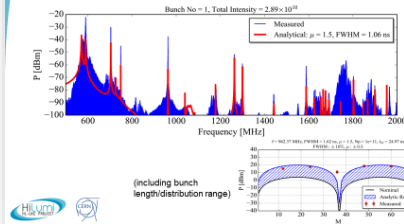
Devil is in the details, so everything is carefully adjusted in order to provide a wideband and robust 25Ω feedthrough

- D has been increased to 40.0 mm
- d has been slightly increased to 14.0 mm
- Hair has been calculated taking into account fabrication constraints (EBW#1 and EBW#2) and RF optimization
- Hvac has been calculated taking into account solidity with respect to transport and RF optimization

We are also concern #12

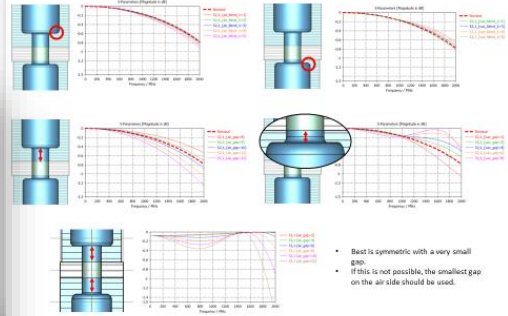
12: Impedance

- Integrated max HOM power measured < 3 W. More than 75% from ~960 MHz as expected
- Overall HOM power & scaling to the HL-LHC looks reasonable, some deviations related to lack of accurate beam profile



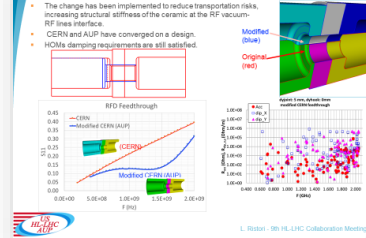
J. Mitchell (CERN, BE-RF-PM)

More detailed PU study with equal spacing



Design of Feedthrough for Dampers

- HOMs feed-thru RF design change 50 Ohm \rightarrow 25 Ohm
- The change has been implemented to reduce transportation risks, increasing structural stiffness of the ceramic at the RF vacuum-RF loss interface.
- CERN and AUP have converged on a design.
- HOMs damping requirements are still satisfied.



HL-LHC

L. Ristori - 9th HL-LHC Collaboration Meeting

Zenghai and Jamie verified that this new impedance is still compatible with requirements, and RF optimization of the feedthrough was done taking it into account

Feedthroughs optimization



Thickness of the inner tube is a key parameters

1.5 mm is ok

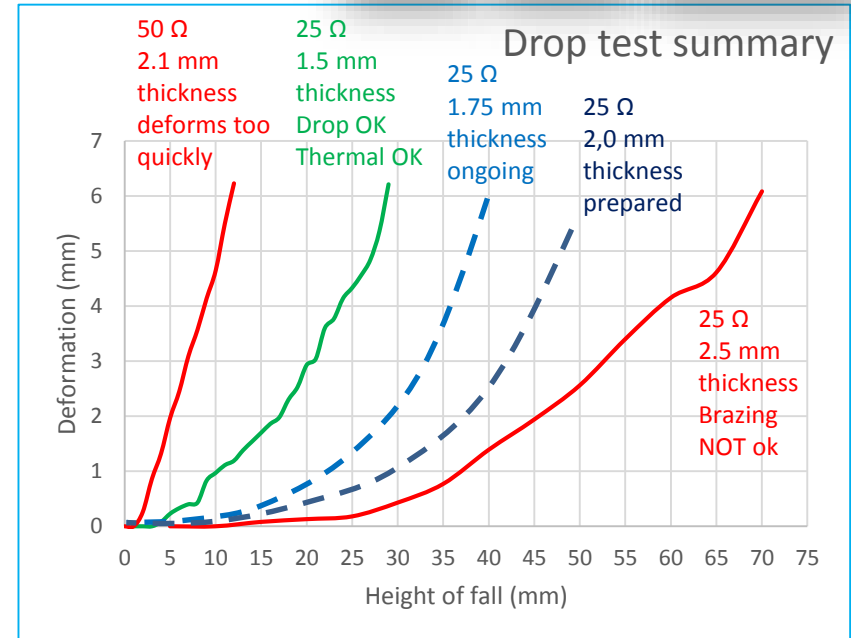
1.75 mm is being tested

2.0 mm is being prepared

2.5 mm failed, brazing was not ok

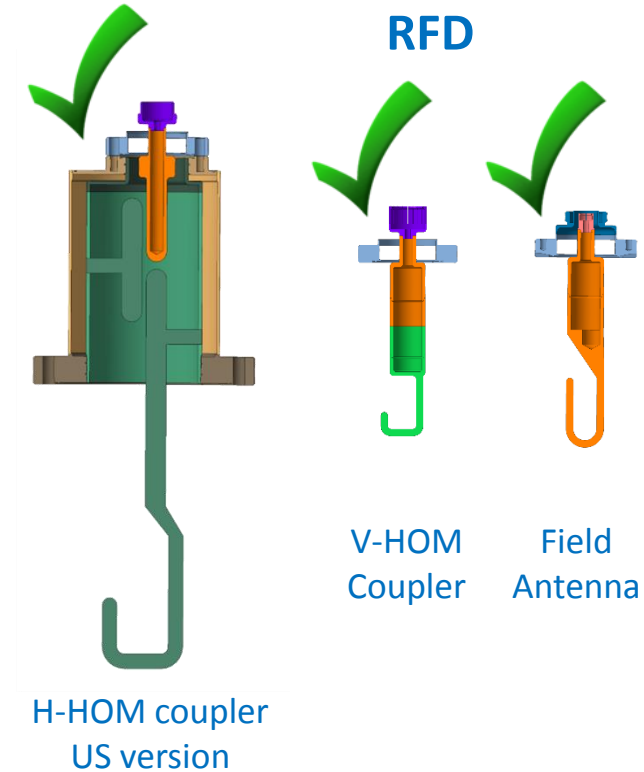
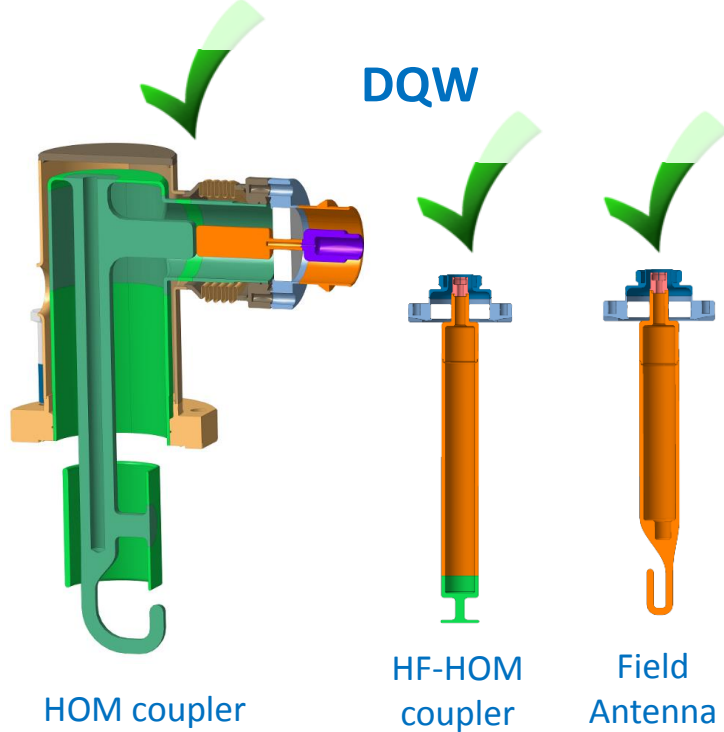
Thermal tests are performed before drop tests

1. Leak test
2. Keep the feedthrough under vacuum
3. Submerge the feedthrough slowly in liquid nitrogen
4. For **120 seconds** leave the piece
5. Slowly lift up the piece emptying any excess liquid
6. Submerge the feedthrough slowly in warm water
7. For **120 seconds** leave the piece
8. Slowly lift up the piece emptying any excess liquid
9. Repeat **5 times** steps 3 to 8
10. Leak test

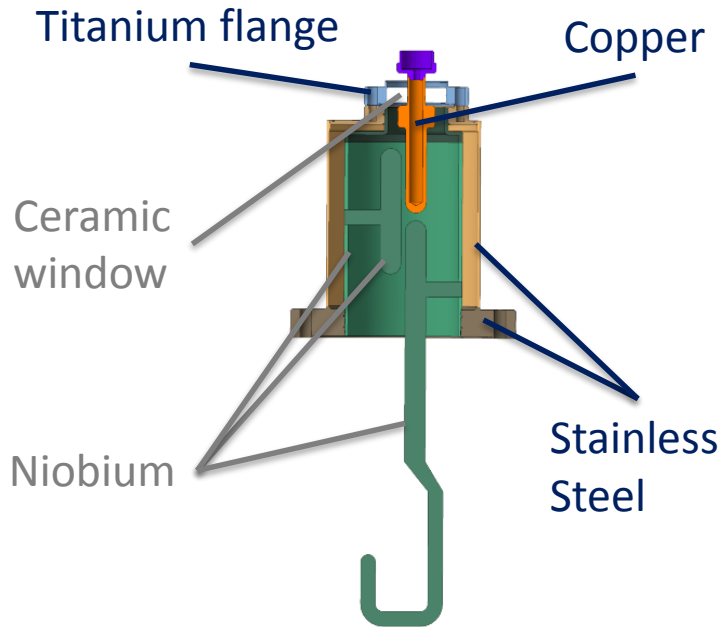


Frida and Sonia did drop tests that showed that moving to 25 Ω is not the only parameter, the thickness of the tube is also important and must not be too large

Design being finalized with a common feedthrough

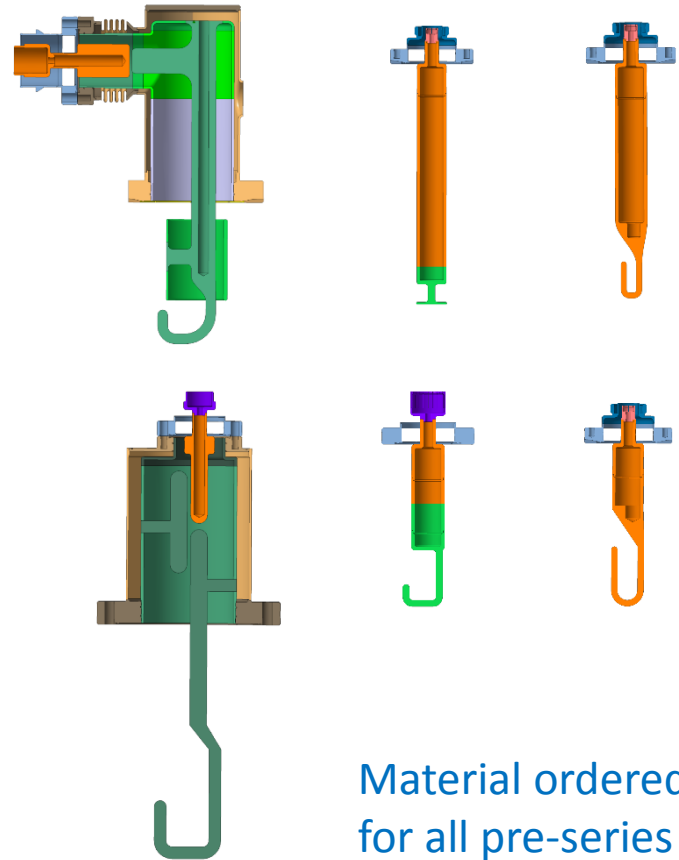


Raw material ordered



Material ordered and delivered














Material ordered not yet delivered



Material ordered
for all pre-series

Schedule as per September 2019

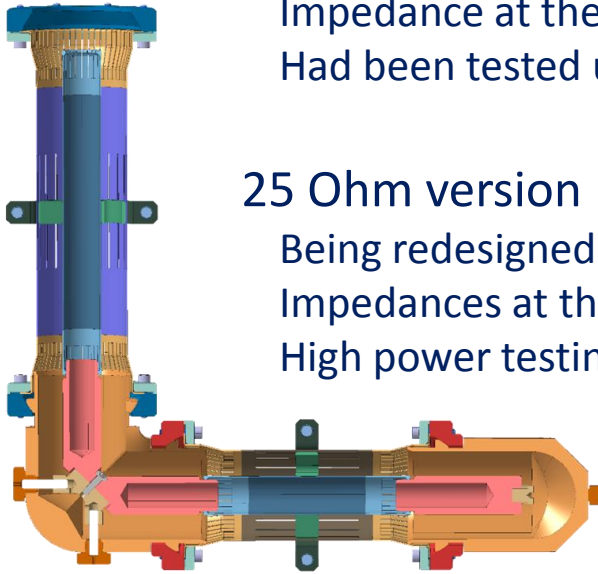


3 antennas	2 (+1) x							
3 RFD V	2 (+1) x							
3 RFD H US _{version}	2 (+1) x							
			All RFD HOM Couplers Series manufactured by the US-AUP team					
34 DQW	6 (+2) x		8 x		8 x		6 + (4) x	
13 Antennas	2 (+1) x		4 x		4 + (2) x		Collaboration with Russia being prepared	
13 HF-HOM	2 (+1) x		4 x		4 + (2) x			

RF Power transmission lines

50 Ohm version

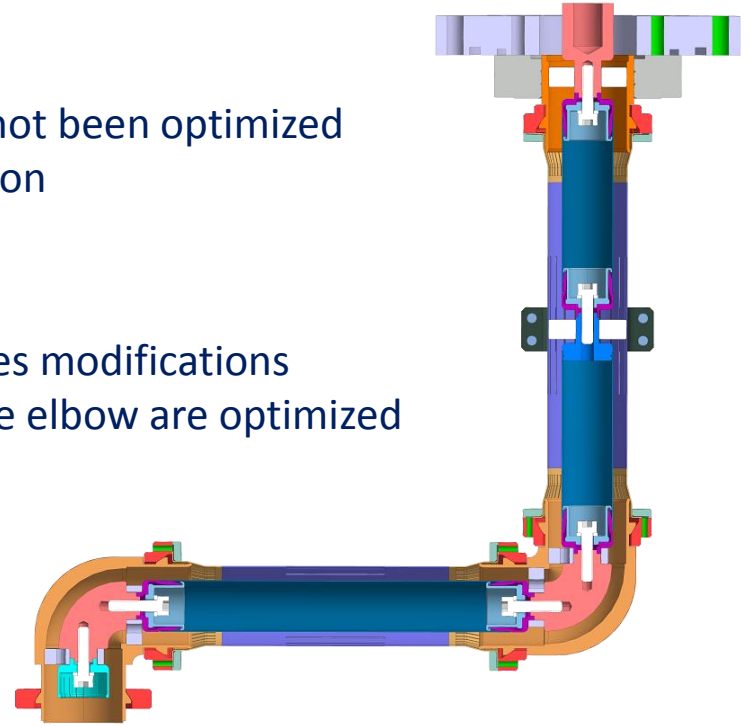
Impedance at thermal anchor level had not been optimized
Had been tested up to 16 kW full reflection



50 Ohm version, tested up to 16 kW CW under vacuum

25 Ohm version

Being redesigned for 25 Ohm, this induces modifications
Impedances at thermal anchor and of the elbow are optimized
High power testing being prepared



25 Ohm version, must also sustain 4 kW full reflection, i.e. 16 kWp to do so, elbows are being redesigned

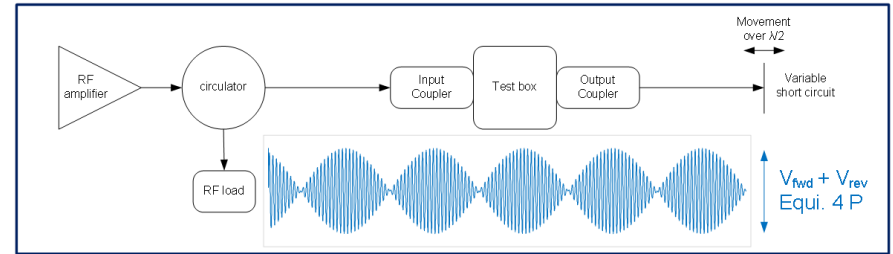
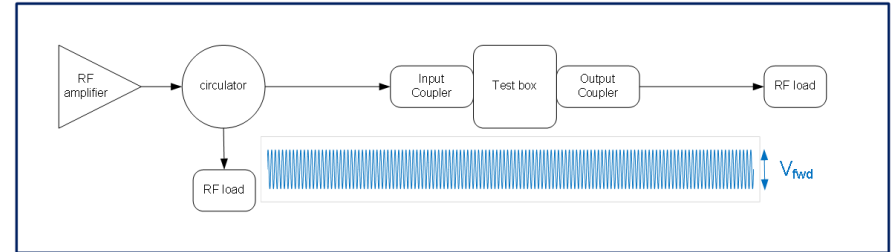
RF Power transmission lines

Power lines have to be powerful as if for any reason the load is removed or broken, they will locally be exposed to an equivalent of 4 times the power

This happened in 1996 with a SPS test of a LHC cavity

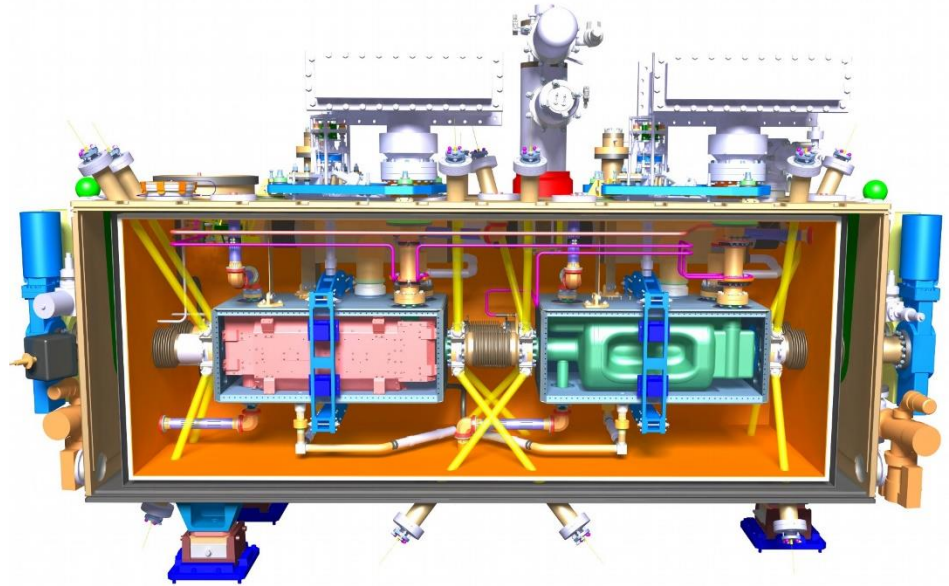
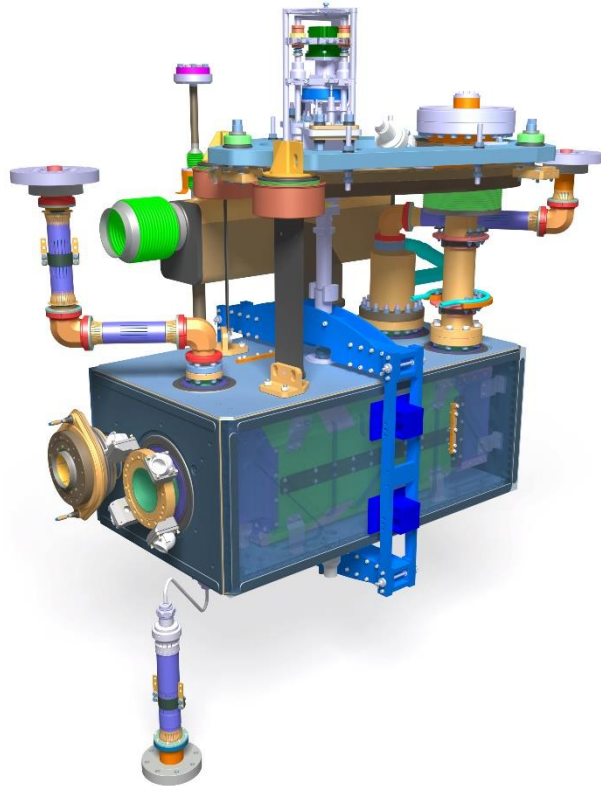
We had to open the cryomodule and to exchange the cables connecting the HOM couplers to external world

In addition, RF power lines are additional impedances mismatch added to the HOM impedance network, so they must be as well designed as possible



Usually we explain full reflection with an amplifier as a source and a load, here the source is the HOM coupler and the beam

RF Power transmission lines



No one will agree that we ask to open the cryomodule to exchange a cable, reason why we are designing these 'too big' RF power lines

FPC

SPS Tests has demonstrated the good design of the FPC 'ancillary' (not a concern #14)

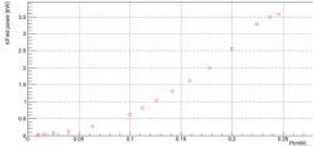

We are on track for the next two cryomodules to be equipped

2 RFD + 2 DQW FPC being prepared for RF processing on their test boxes

14: RF Power

- Only notable issue with RF power was linearity at low power (< 5 kW). Added to specification for HL-LHC amplifiers (now SSPA)
- Rest of the RF chain validated

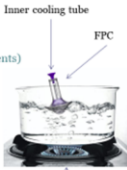
Surface-BA6



HL-LHC International Review of Crab Cavity System Design 21

Common Crab Cavity FPC Platform

- We propose to stick to these design parameters :
 - LHC window or Disk window
 - Waveguide line to coaxial antenna
 - Plug and play waveguide
 - DC biasing (if E antenna)
 - Preferably E antenna (no stress to the ceramic)
 - Same simple straight pipe DT
 - If possible 50 Ω antenna (easier for mock-up measurements)
- Specifications from Rama :
 - cavity FPC port diameter : 40 mm / 36 mm / 40 mm
 - DT : 40 mm
 - Inner line : 17 mm
 - (two tubes cooling inlet (4/6) + cooling outlet (13/17))
- Can we increase the DT diameter ?
 - Incompatibility between the sizes and power level requested
 - Should be available in the FPC dinner table tonight!



We have been quite quick to design and construct the FPC

Please keep in mind that we are designing and producing quite a large number of these FPC, and this Crab one in an evolution of the SPL FPC

Do you remember that in December 2012 you asked to provide 100 kW CW through a 40/17 mm line ?

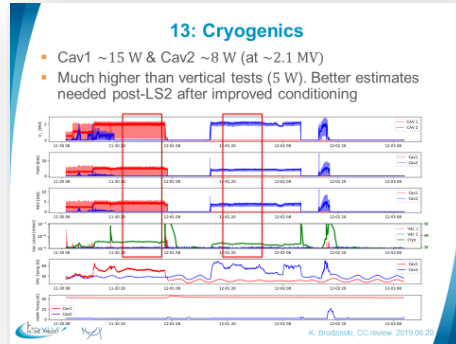
Fortunately we had a dinner at 'Two Brothers' and we agreed there a 62/27 mm line

FPC Outer Tube

Perhaps linked to 'concern #13'

Being redesigned with two anchors positioned such that there is a monotonous thermal path

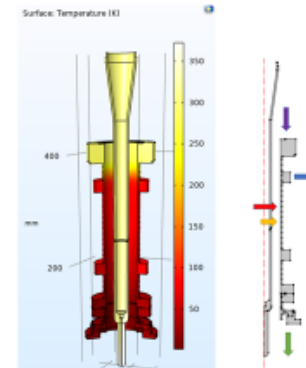
Feasibility of a gold-gold being studied (if not possible, will be gold-copper, as we did for the SPS test)



Courtesy Joanna, Ofelia and team

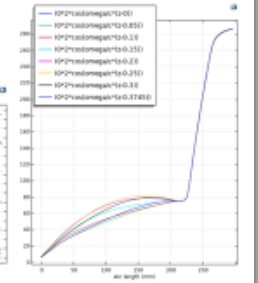
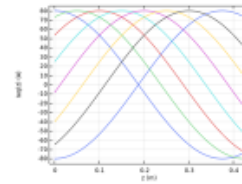
FPC RFD, example of results

- Coating: 15 μm copper+ 1 μm gold
- One thermalisation point at 75 K
- RF power: 40000 W



Temperature distribution considering RF current travelling wave

RF current travelling wave (function maximum move from 0 to a half of wavelength)



Heat loss considering RF current travelling wave

move	Q _{bath} [W]	Q _{rad} [W]	Q _{heat} [W]	Q _{rem} [W]
0	5.00	-8.82	-39.50	45.12
0.05	8.17	-7.54	-39.43	43.80
0.1	8.82	-6.06	-40.61	42.84
0.15	4.62	-5.51	-42.05	42.94
0.2	5.07	-6.59	-42.80	44.12
0.25	4.76	-7.91	-42.56	45.51
0.3	5.88	-9.00	-41.03	46.14
0.3745	5.00	-8.83	-39.50	45.13



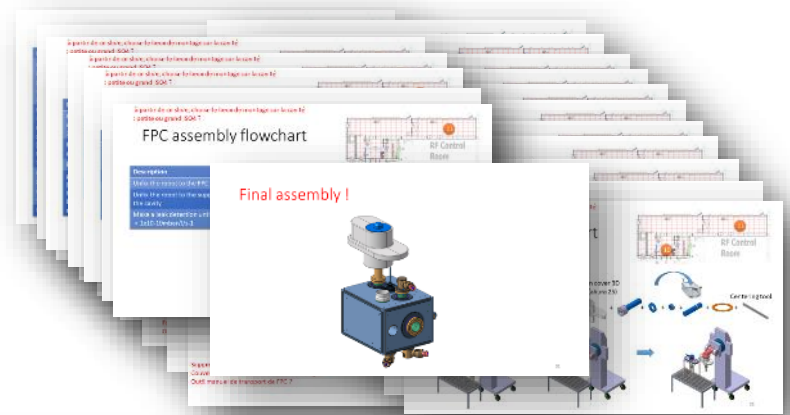
Assembly in clean room

Once the FPC have been RF processed, we assembled them in clean room

We will take advantage of the experience gain with the first DQW cryomodule

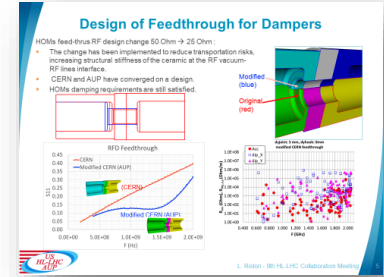
We upgraded our flip-book, and we are also upgrading our tooling

We also started to work on the test boxes we want to qualify the HOM couplers





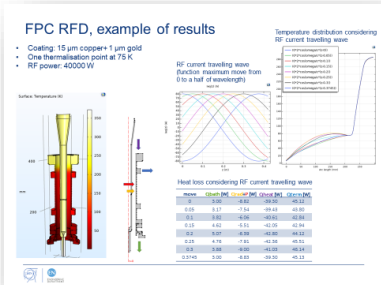
All difficulties we have to avoid/cure
(impedances, transport,...)
not easily identifiable at a first glance



WP4 RF team
(CERN + US-AUP)



Nice (innocent)
HOM couplers



Still to be done

Complete the 3D and 2D drawings for DQW

Study how to qualify a 25 Ω system and build qualification tools

Order specific 25 Ω cables and loads

Prepare Clean Room assembling tooling (taking advantage of experience gained with DQW SPS test)

Ensure a correct Quality Management

Conclusion

We induced some delay due to the 25 Ohm design

We now have a solid feedthrough design that successfully passed thermal and drop tests (transport)

This design is common to all our couplers and antennas

We launched the production of the RFD couplers

DQW modifications to 25 Ohm are almost done and construction will be launched very soon

We stick to a delivery of RFD by end May 2020, and DQW by end July 2020

RF power lines modifications are being done

FPC are on track



Thanks once again to the management for the support

Thanks to all people involved doing a fantastic job !

We are eager to continue working on this exciting project