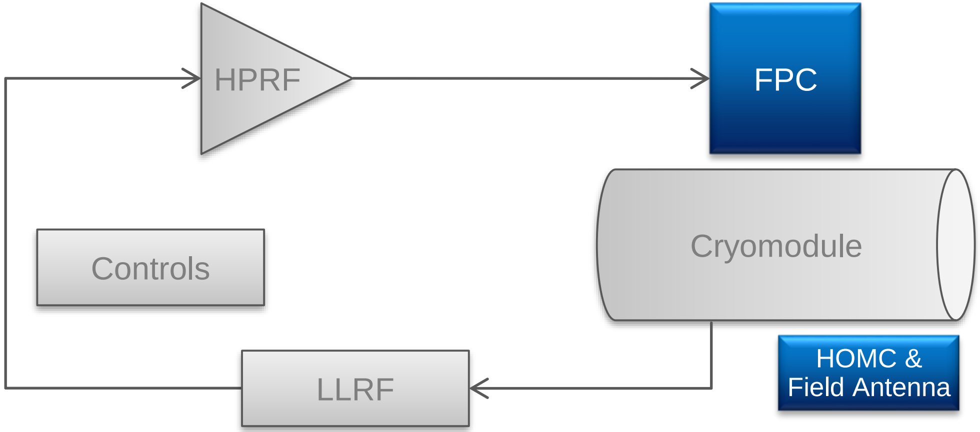
CERN FPCs & Other Couplers for HL-LHC CC

eric.montesinos@cern.ch on behalf of all teams involved

International Review of the Crab Cavity system design and production plan for the HL-LHC
19-21 June 2019
CERN

Couplers

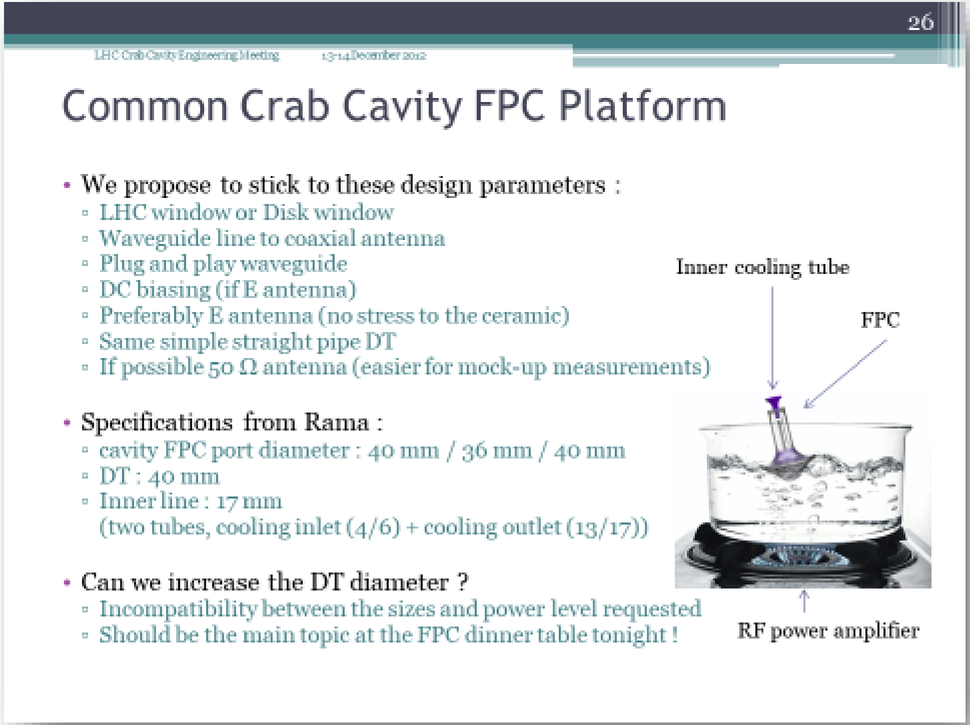
HPRF High Power RF station (including power transmission lines)
FPC Fundamental Power Coupler
HOMC High Order Modes Coupler
LLRF Low Power RF



FPC design

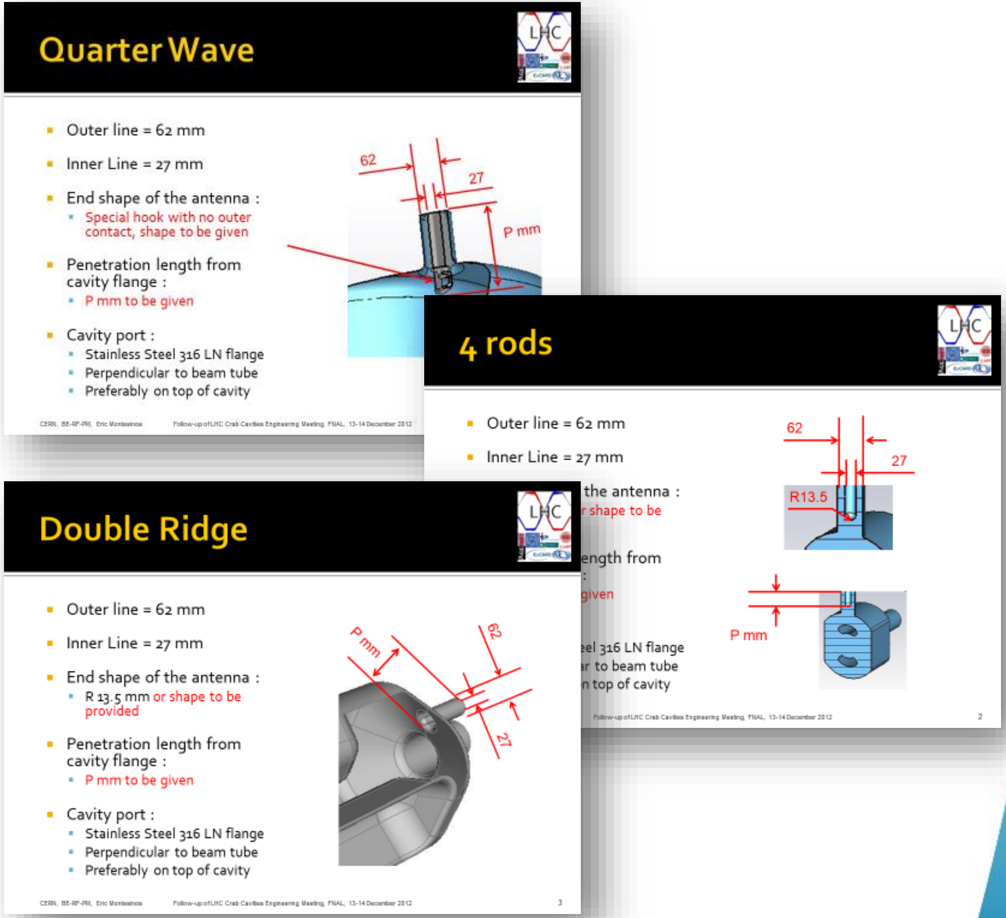
Design started in Dec 2012 at Fermilab with an interesting discussion to increase the outer diameter to its maximum

Initially, I though you were kidding me asking 100 kW in a D40/d17 mm coaxial line



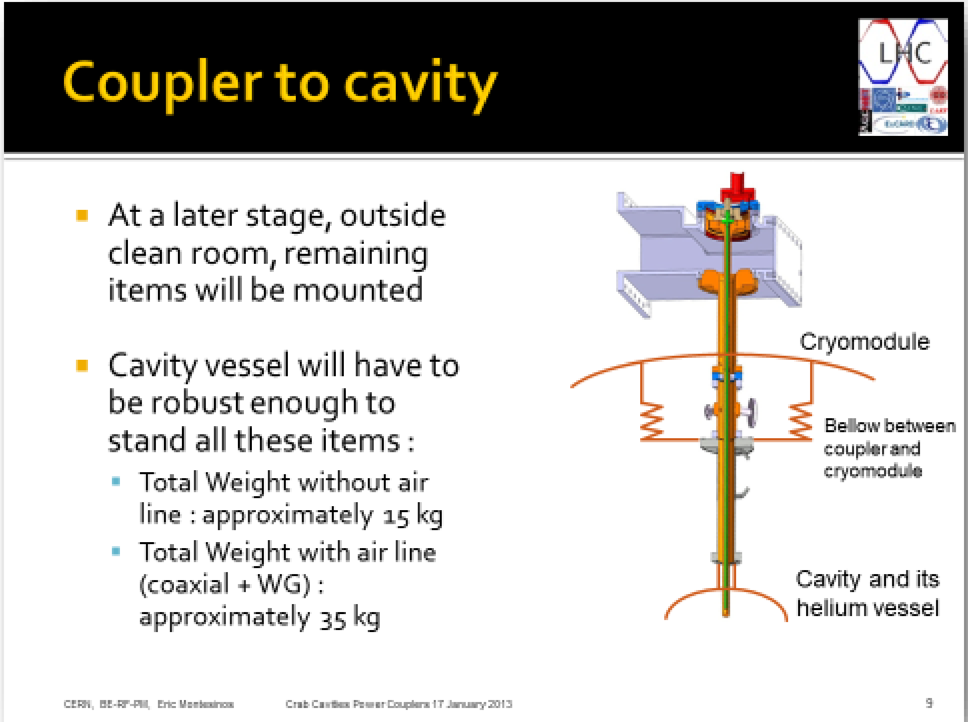
FPC design

After a long discussion, you were so kind to agree to increase to D62/d27 mm for all three designs



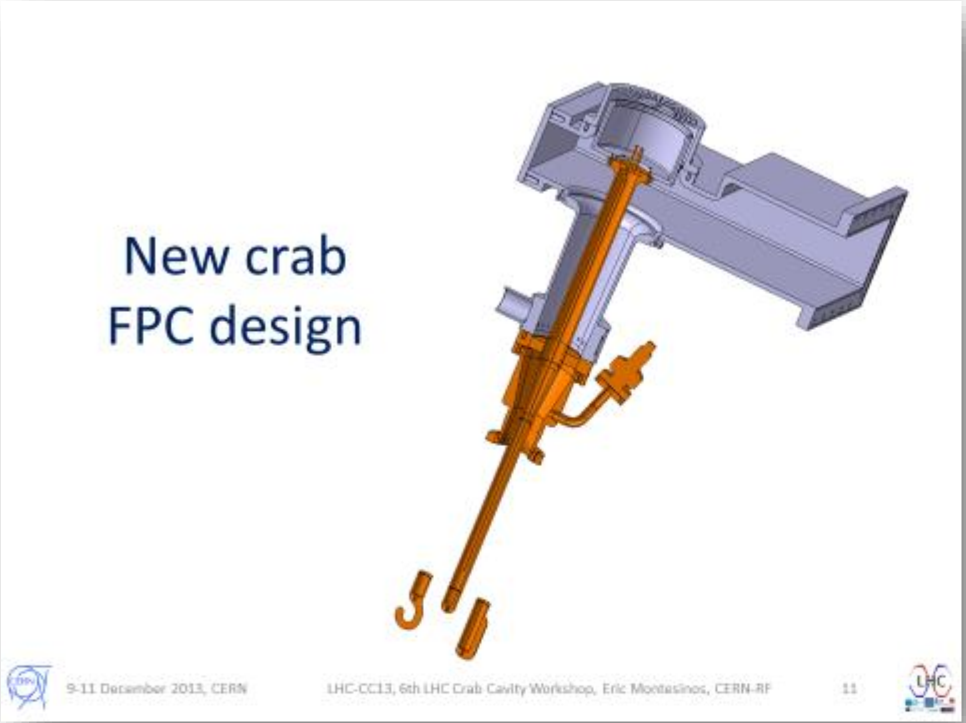
FPC design

In January 2013 we made a first proposal having a common solution for all three FPC with a clean room part and an outside clean room part



FPC design

At the end of 2013, we had a design that was almost the final version, still compatible with the three cavities



FPC design

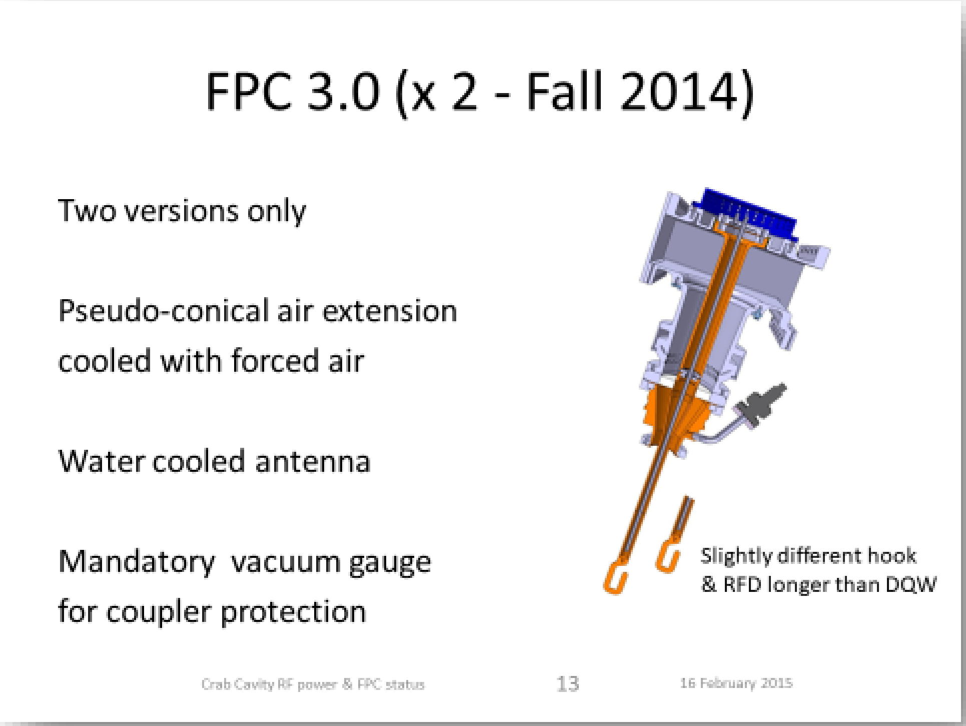
Finally, Fall 2014, Project down selected to two cavities, and we completed the two FPC designs

Fc = 400 MHz

Pmax = 100 kW average

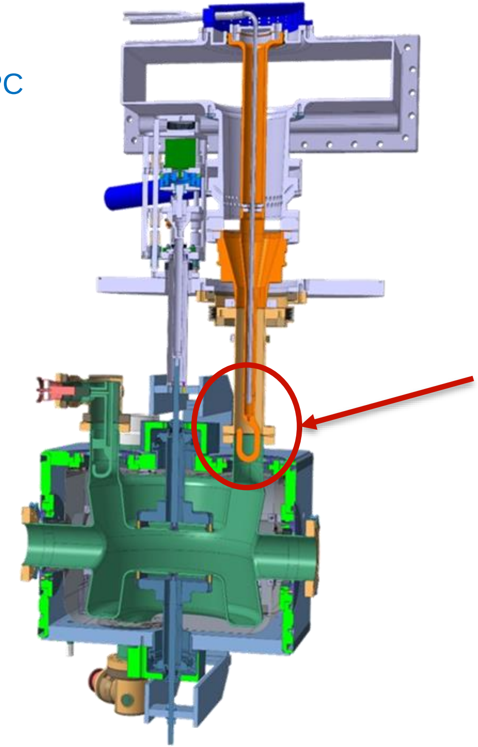
Coaxial disk window

No doorknob, coaxial to WG ensuring the matching

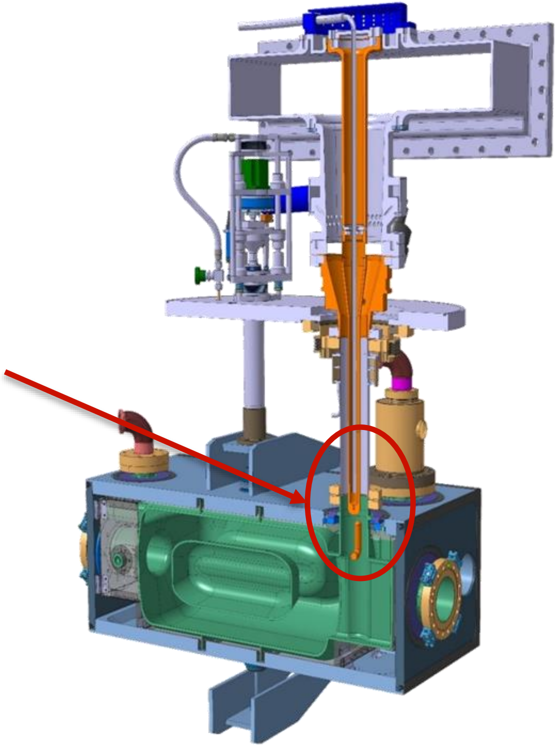


FPC design

DQW FPC



Regarding FPC the difference is only the length of the antenna and the shape of the hook

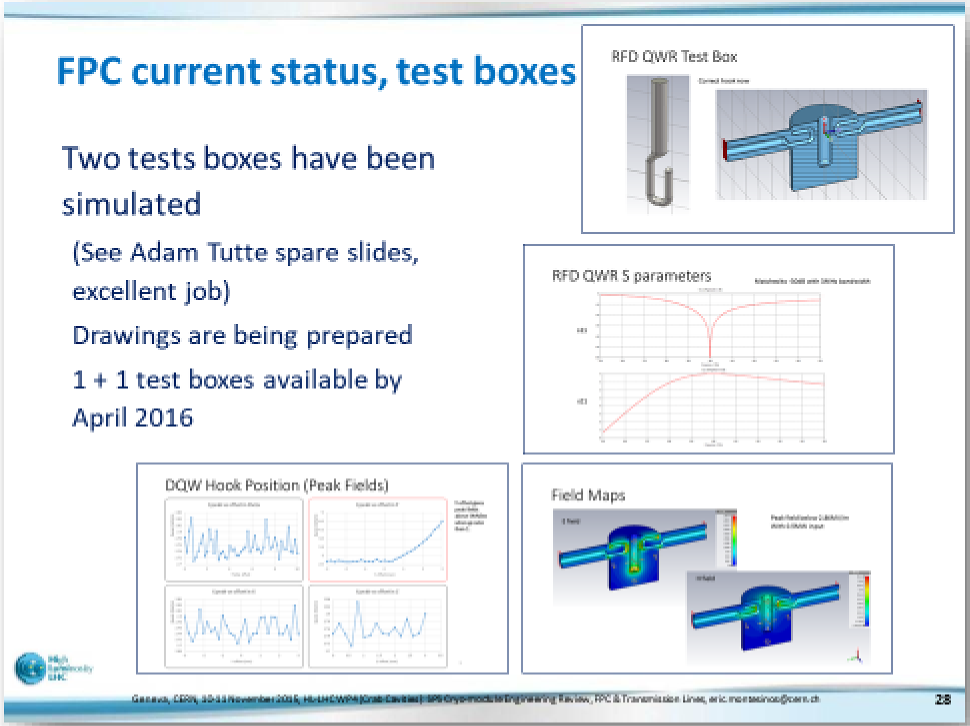


RFD FPC

FPC test box

In order to test the FPC we need a test box

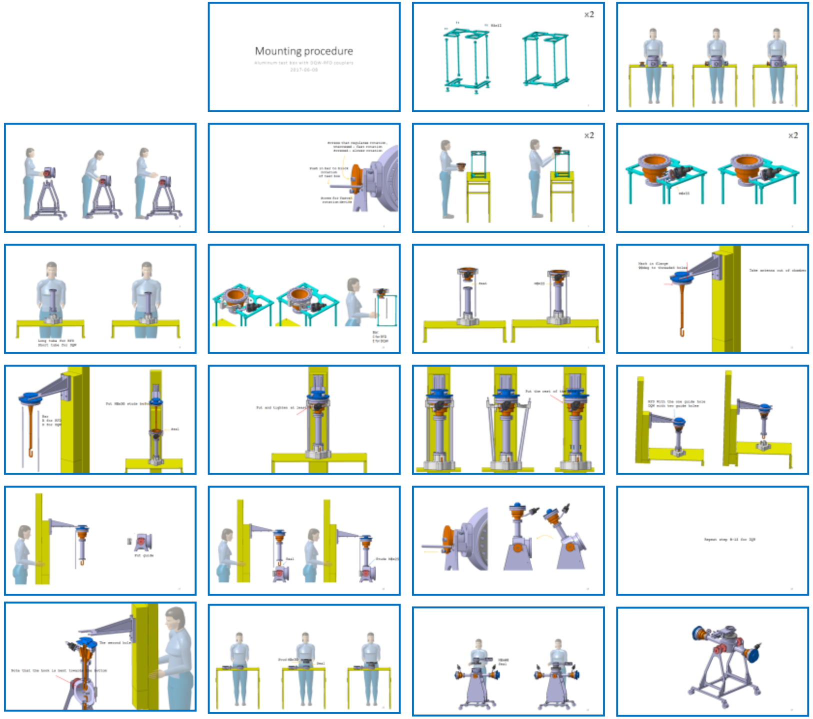
We mount face to face to FPC and the test box ensures a perfect transmission such that we can power both couplers



FPC test box

As Crab is with high gradient, we needed to take care of the FPC in clean room from the first day, including assembly on the test box

We first prepared all actions on a flip book, we trained ourselves on mock-ups outside clean room



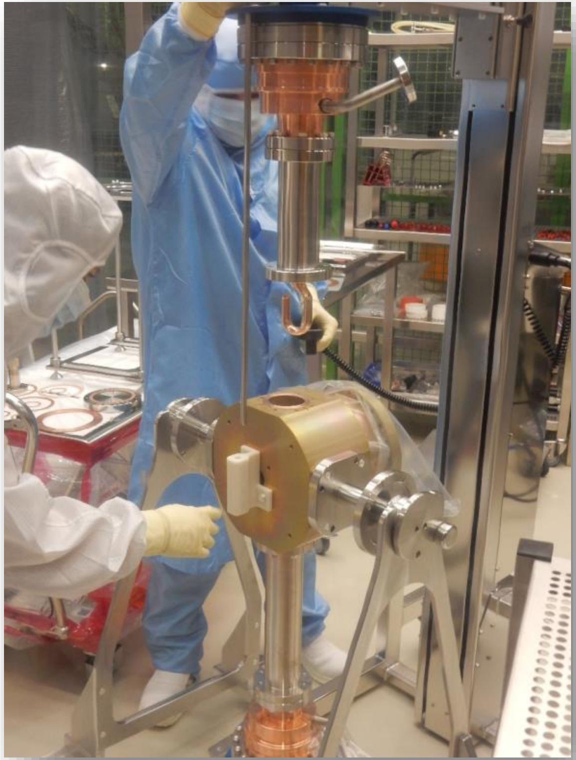
FPC test box

During the assembly in clean room, we learnt a lot on many details, and we improved our processes and tooling

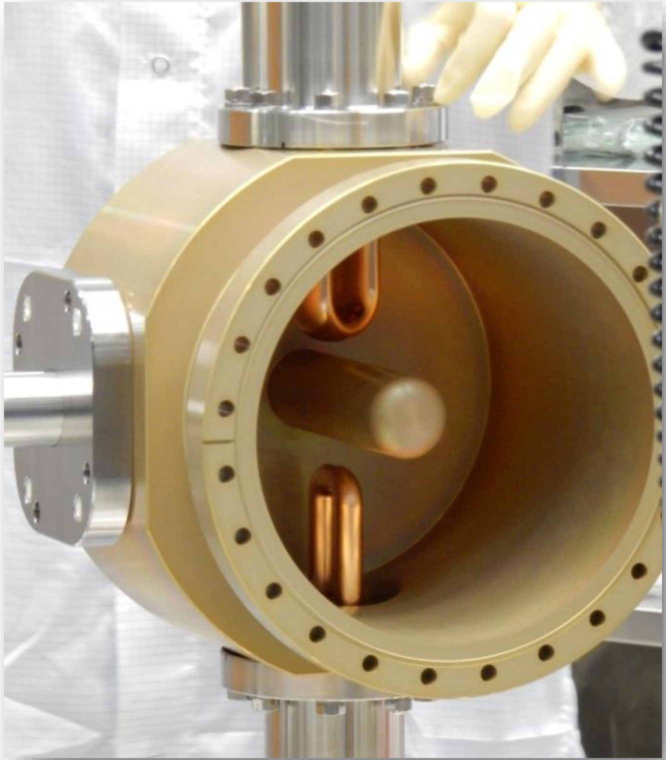
We 3D printed several tools in Acura 25 that allows to avoid polluting the items

FPC test box

FPC test box

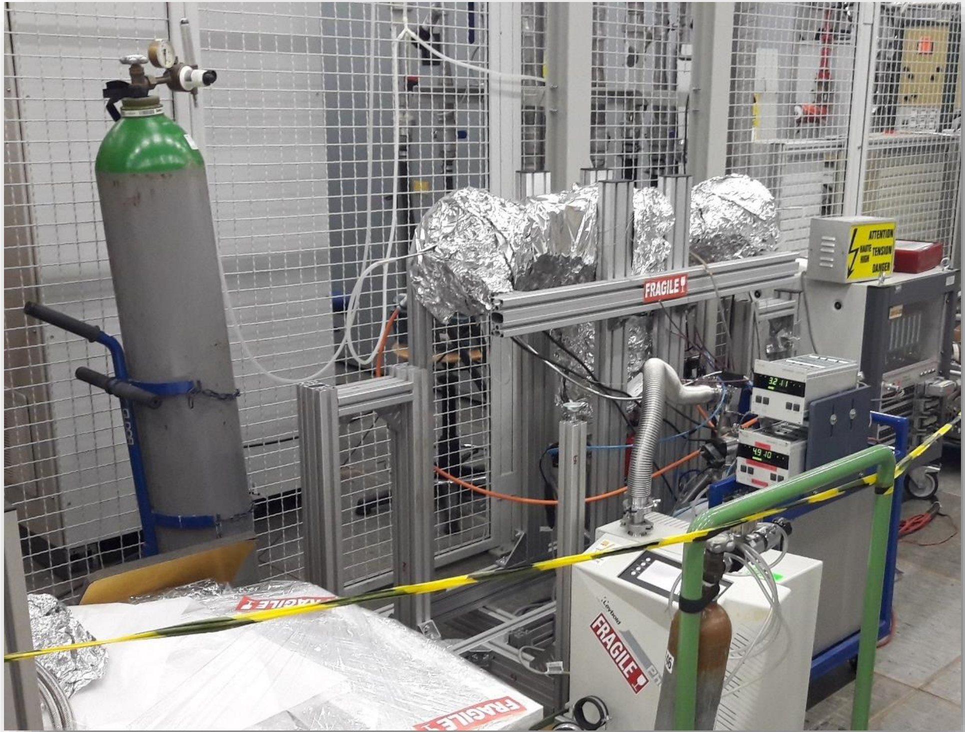


FPC test box



FPC tests

Following the experience with all the couplers we built over the last decades, we learnt that a well done bake out process considerably helps to speed up the RF processing time



FPC tests

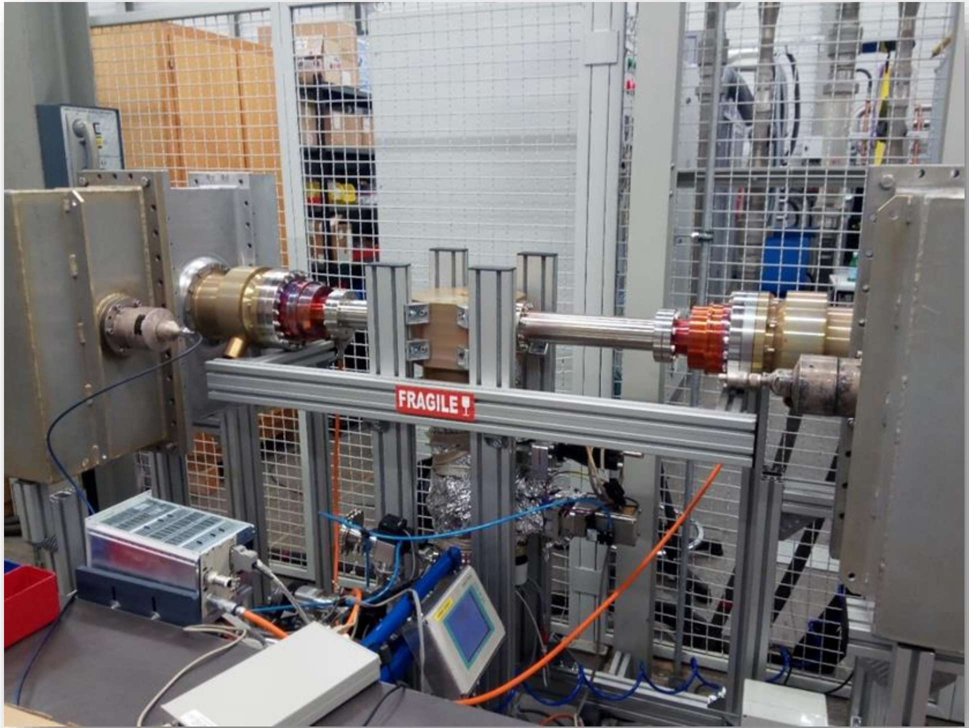
Two couplers face to face have been processed

- TW 75 kW 10 ms @ 52.6 Hz
- TW 46 kW CW

We also processed them at the same values in SW, full reflection all phases

To date we processed

- 2 x DQW (in SPS test)
- 1 x RFD & DQW



FPC outer line

Despite we did it with all our couplers, copper coating was always a challenge

This one was as always, complex before being successful

We launched a study in order to define the best way to build it, the consolidated design will be ready for the next couplers

Assembly in clean room

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

We again did the same preparatory work, with flip-book and training on mock-ups taking into account recommendations form the Clean Room review

Assembly in clean room

We then assembled the two DQW FPC from their test box to their cavities in SM18 clean room

All went very smoothly

Assembly in clean room

Once they have been assembled, the frame with two cavities is moved outside the SM18 clean room

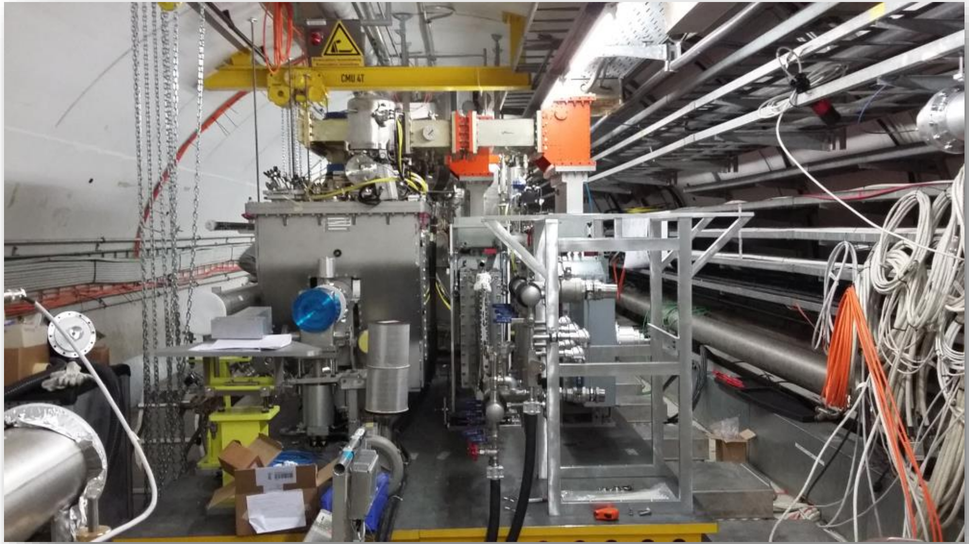
(*metallic wheels on metallic rails, no dust*)

HL-LHC FPC

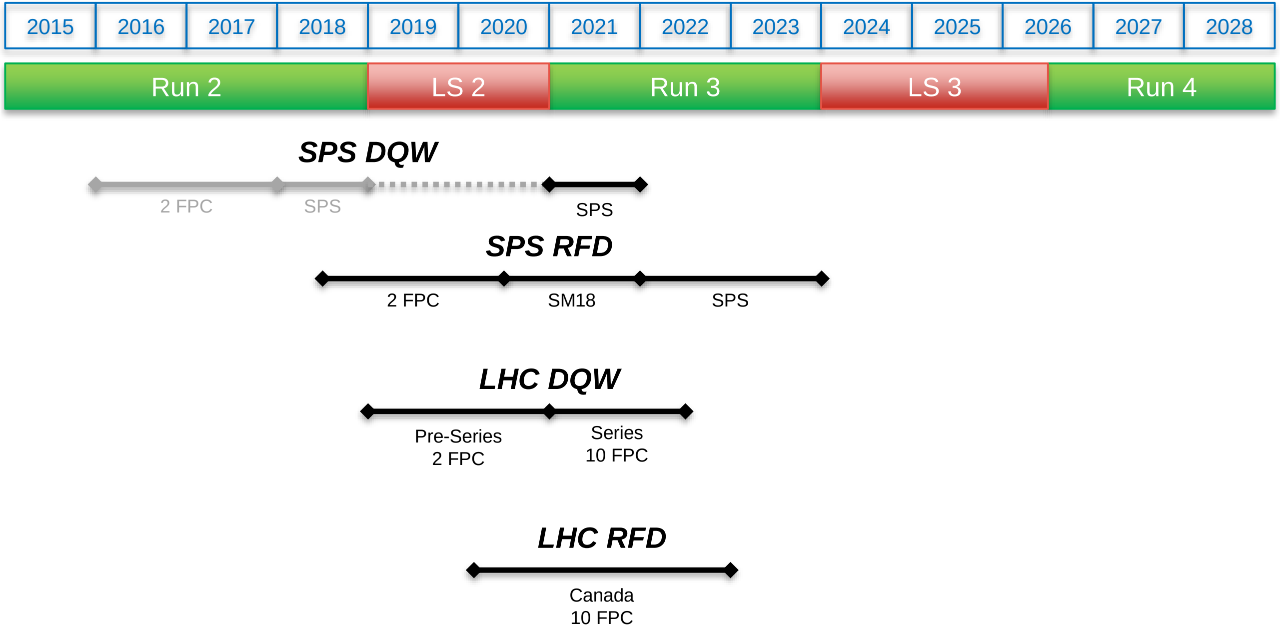
SPS test was very useful to validate the design

As everything went very well with the FPC during all the SPS tests, we decided to **keep the design as it is**

We already launched the series production of all FPC in order to stick to the planning and to deliver FPC to all Collaborations in due time

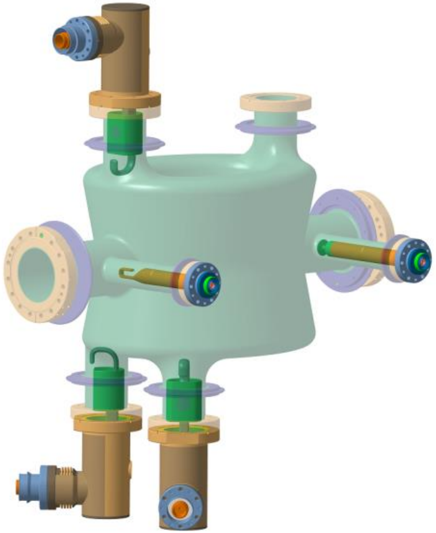


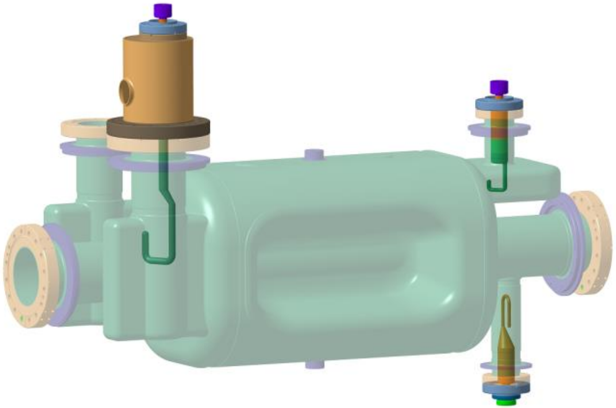
FPC timeline



HOM Couplers & Field Antennas

DQW HOM Couplers and Field Antenna and their ‘ancillary (the DQW cavity)’

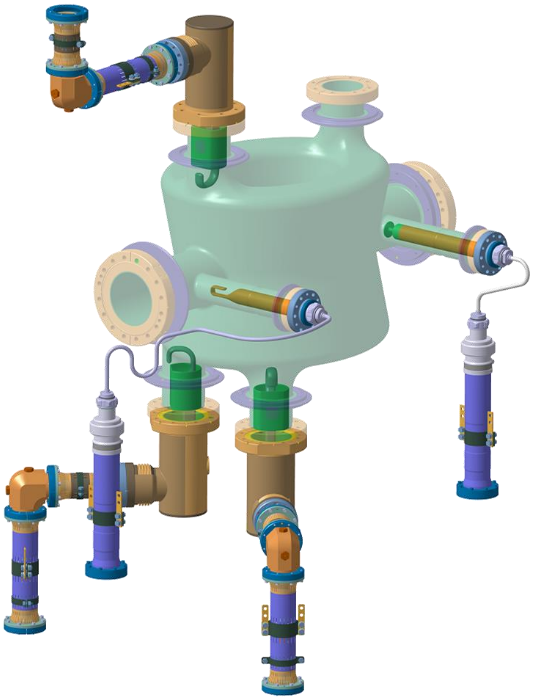


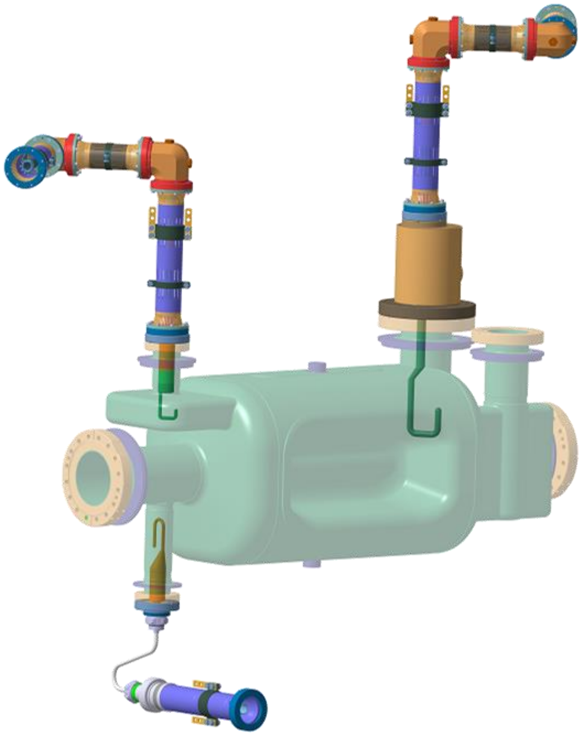


RFD HOM Couplers and Field Antenna and their ‘ancillary (the RFD cavity)’

HOM Couplers & Field Antennas

DQW HOM couplers and their RF power lines

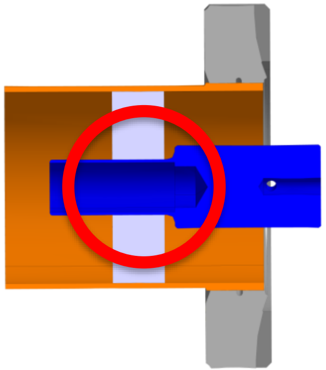




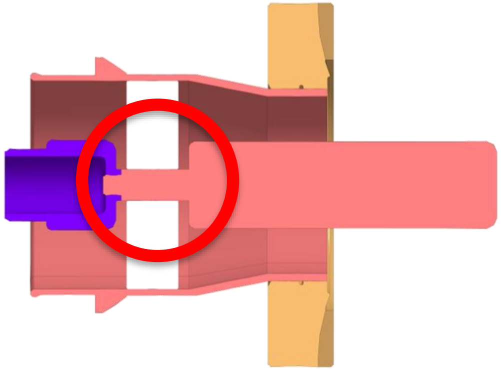
RFD HOM couplers and their RF power lines

HOM Couplers & Field Antennas feedthroughs

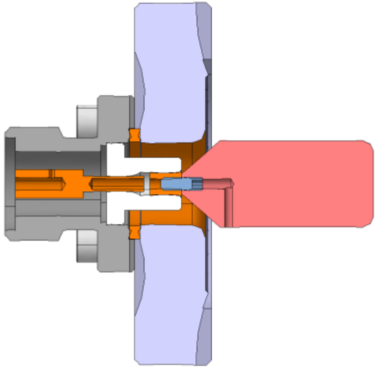
$$Z_{ceramic} = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right) \; ; \; Z_{ceramic} \sim \; 20 \ln\left(\frac{D}{d}\right)$$



LEP & LHC



Crab v1
wrong design
with rod instead tube
cracks during vertical tests



Low power

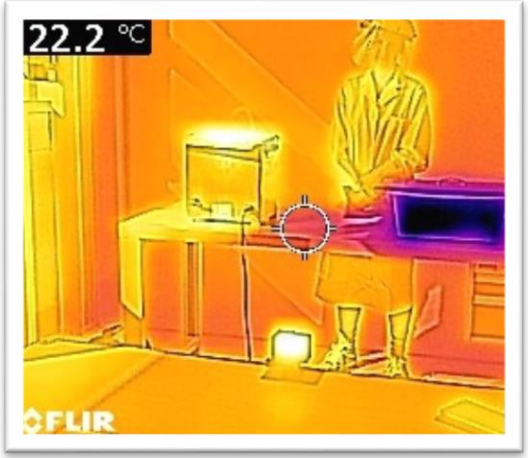
Feedthrough thermal test

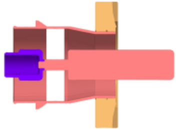
1. Leak test
2. Keep the feedthrough under vacuum

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

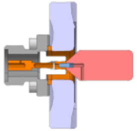
9. Repeat ***5 times*** steps 3 to 8

10. Leak test





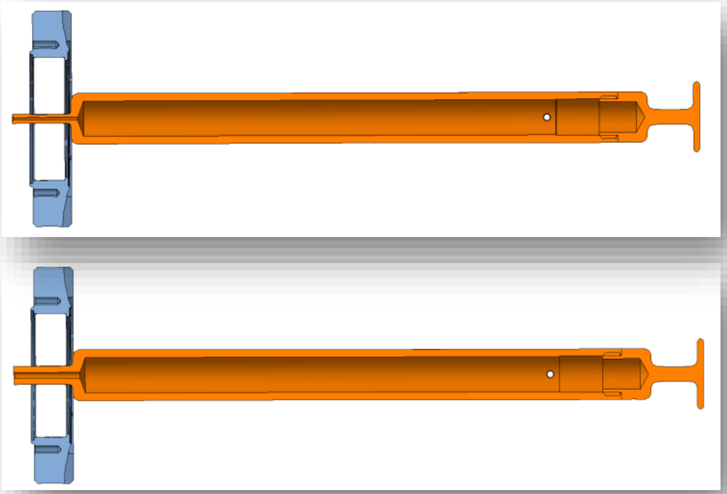
Crab v1 ✗



Low power ✓

Validated for SPS test
With power limitations ok as it was not intended to have high power

HOM Couplers & Field Antennas feedthroughs



Ideal design D39.7/d3.1 ; Z = 50 Ω

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

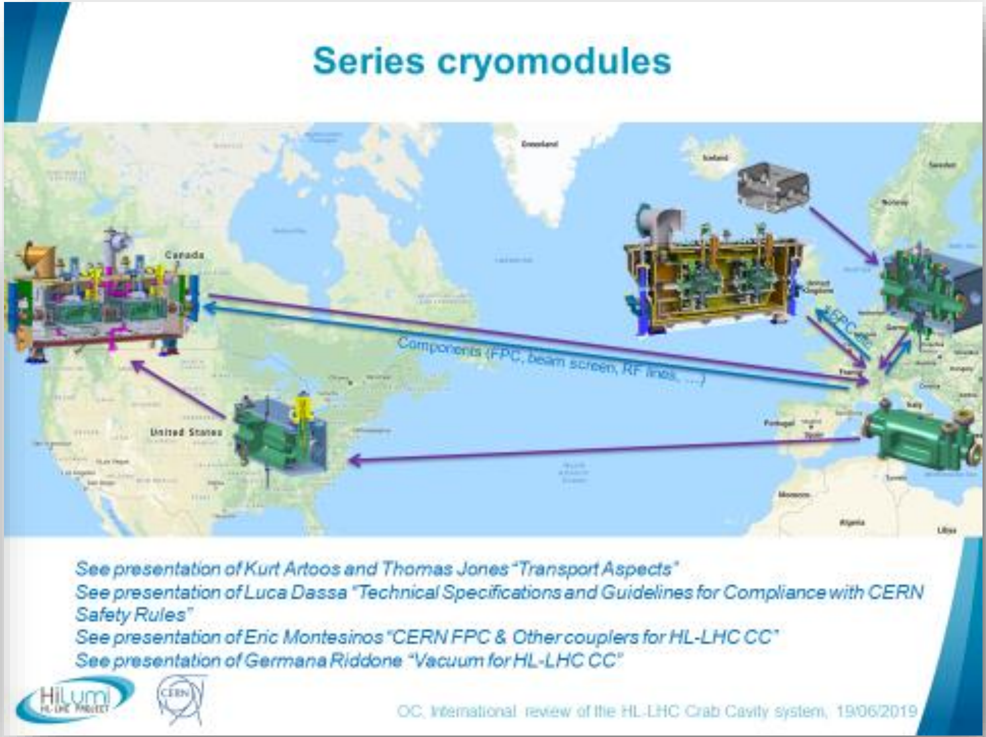
Crab design D39.7/d6 ; Z = 38 Ω

We started looking at a new design with copper tubes as inner lines, keeping in mind copper diameter and thickness through the ceramic
We agreed with Rama not to stick to 50 Ω even at a cost of some additional reflections for HOM, but…

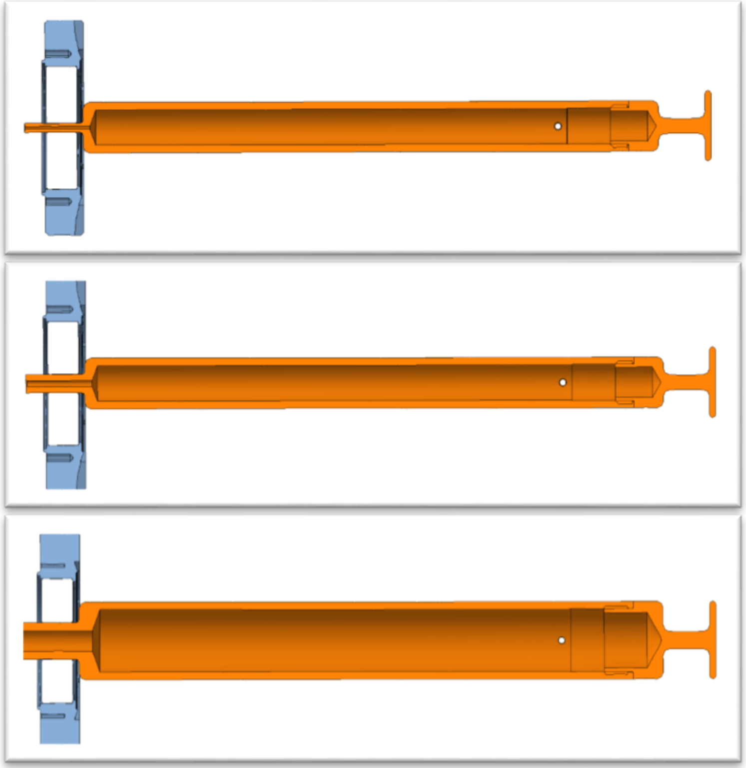
I started to be scared by … this

And by … that

What Ofelia and Marco showed yesterday is not to reassure me…



HOM Couplers & Field Antennas feedthroughs



Ideal design D39.7/d3.1 ; Z = 50 Ω

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

Crab design D39.7/d6 ; Z = 38 Ω

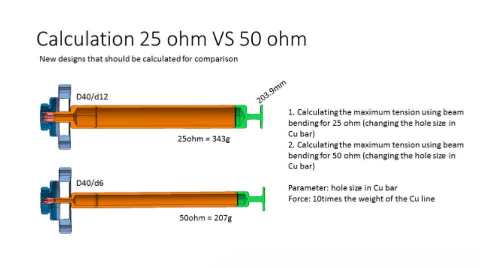
In order to make it much more robust,
Rama had the clever idea to propose 25 Ω

Crab design D40/d12 ; Z = 24 Ω

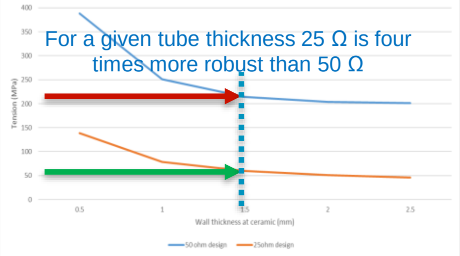
Feedthroughs 25 Ω

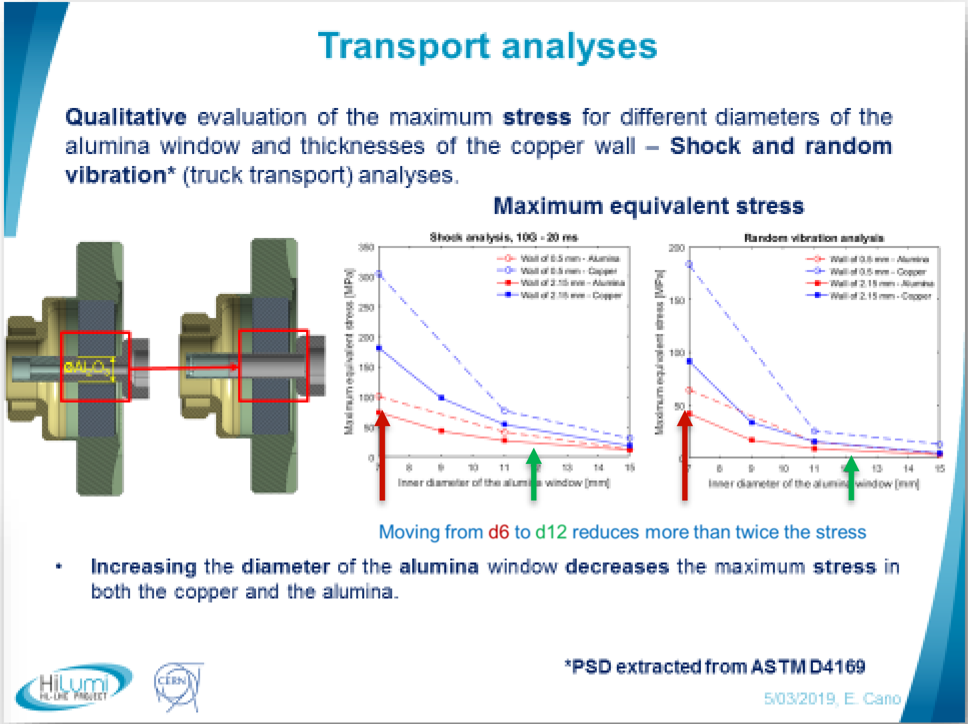
Courtesy Eduardo

In order to check it we did simulations and 25 Ω is with no doubt more robust



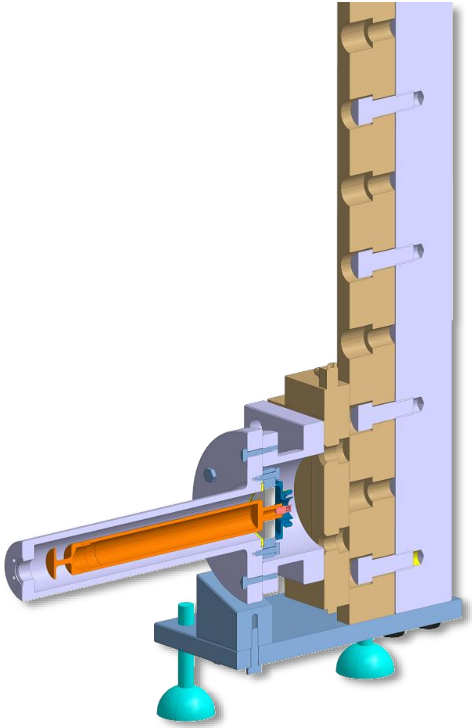
Courtesy Frida

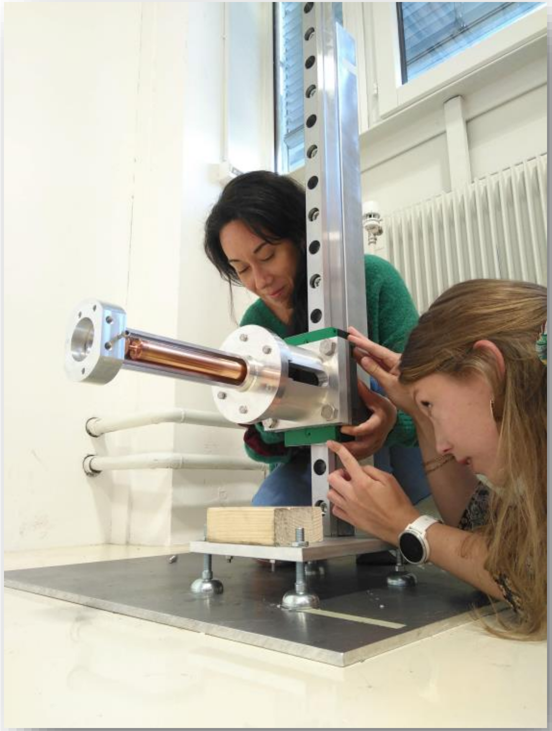




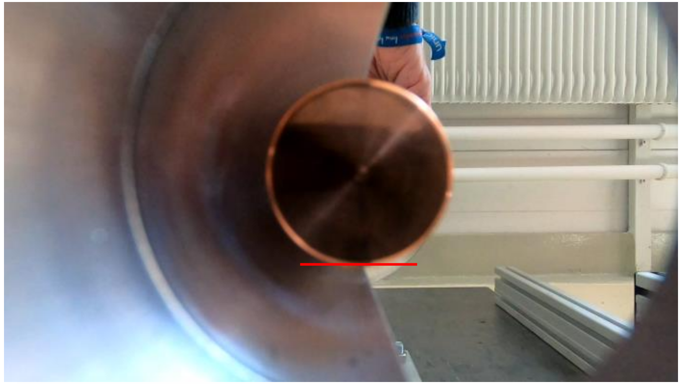
Feedthroughs 25 Ω

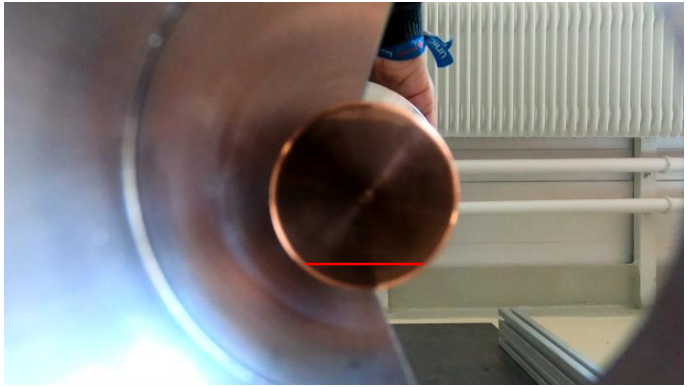
We also did some tests to have ‘a feeling’ of the shocks and how the increase of diameter is really better despite the increase of weight

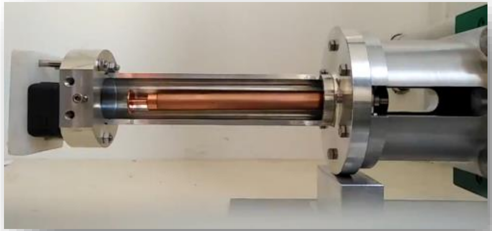




Feedthroughs drop test







10 cm
Drop
test

20 cm
Drop
test

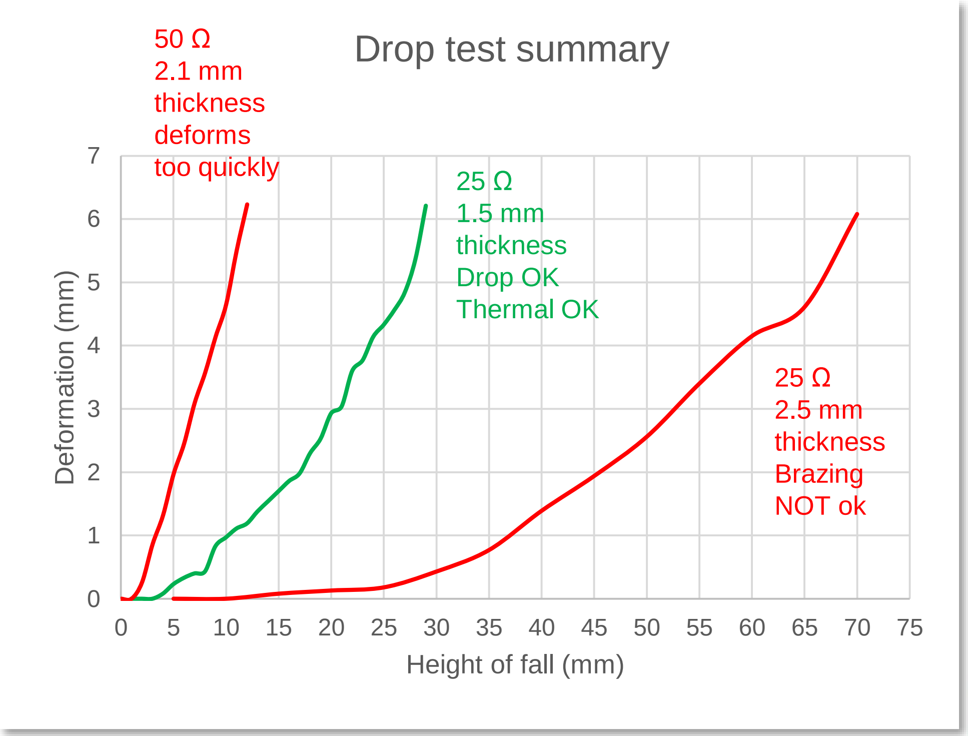
Frida and Sonia tried to destroy the feedthrough, even if the ceramic did not brake
it deformed such that it will be un-usable for RF purposes

Feedthroughs 25 Ω

The thickness of the copper tube is a key parameter

- Too thick, we cannot braze it
- Too thin it will not reinforce the feedthrough enough

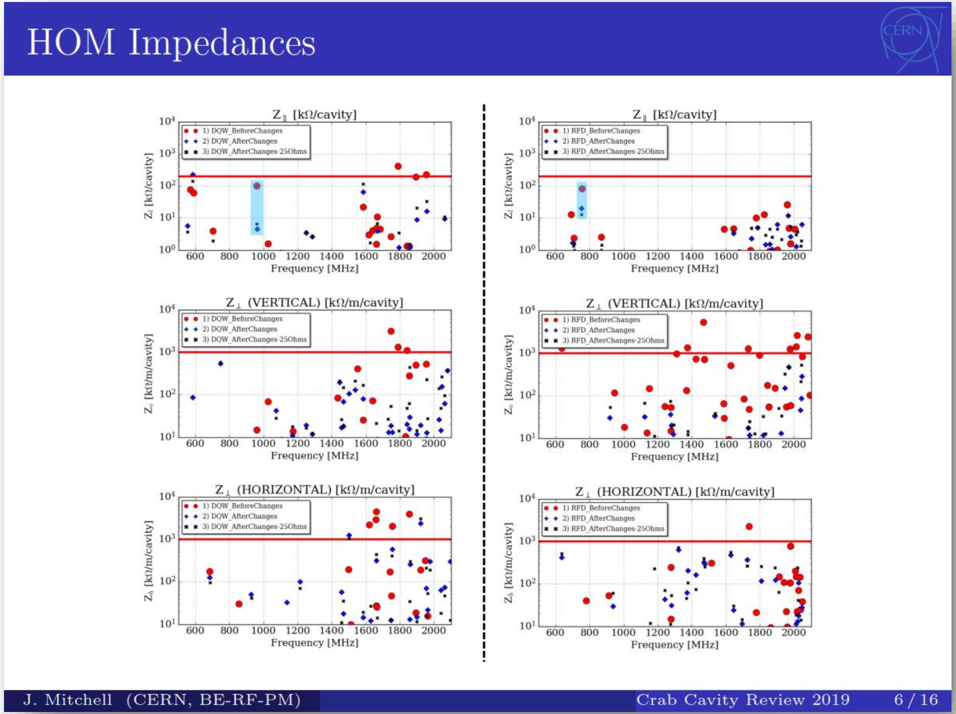
Even with a thicker copper tube, 50 Ω feedthrough is more sensitive



Feedthroughs 25 Ω

Jamie's talk on Thursday morning

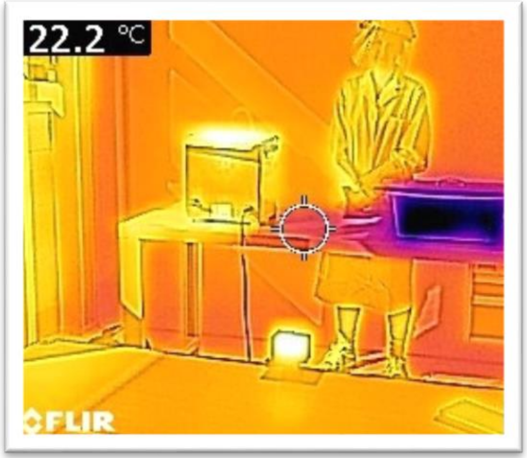
Finally we also checked RF behaviour of the HOM couplers that validated the option

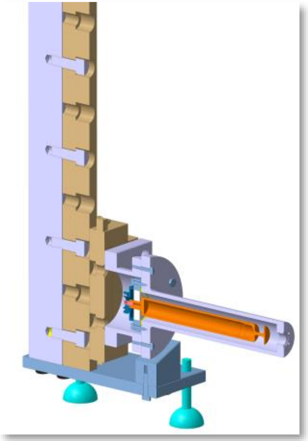


Feedthroughs 25 Ω

We finally did again the thermal shock test with the selected feedthrough design, and it passed successfully

Kurt and his team (thanks in advance!) (Kurt's talk Friday morning) will make the full mechanical analysis in order to define the limits to be imposed during the transportation of the devices



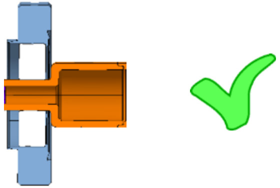


1. Leak test
2. Keep the feedthrough under vacuum

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



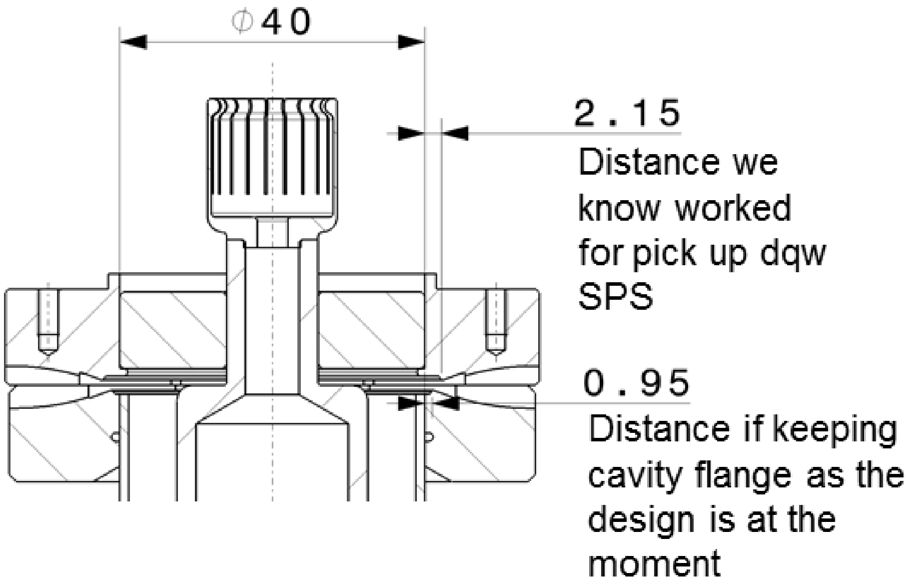
HL-LHC Crab 25 Ω

Custom DN 40 flange

In order to help with the 25 Ω design, we asked to increase the outer diameter of the ceramic to 40 mm, this was the maximum available with respect to integration of the components in the cryomodule

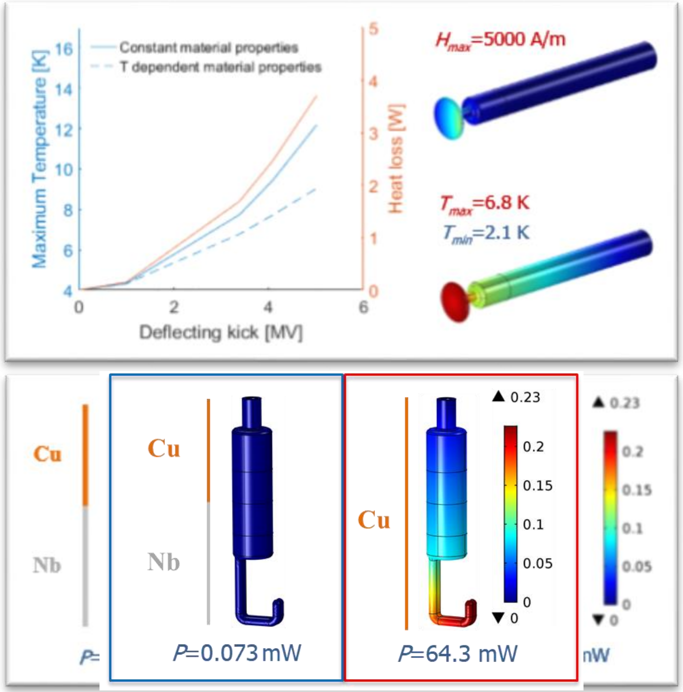
To minimize the stress given to the ceramic, we then asked to move the vacuum knife to a larger diameter

Even if we already successfully operated this CF Ti (feedthrough) vs CF StSt (Cavity) with the DQW-SPS cavities, we will make deeper tests to re-validate this option



End tip in Niobium

Looking at the power losses, Eduardo and Ofelia found out that DQW HF-HOM mushroom and RFD V-HOM hook should be made in Niobium in order to minimise heat loss

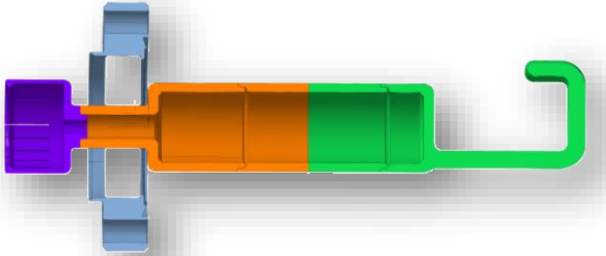


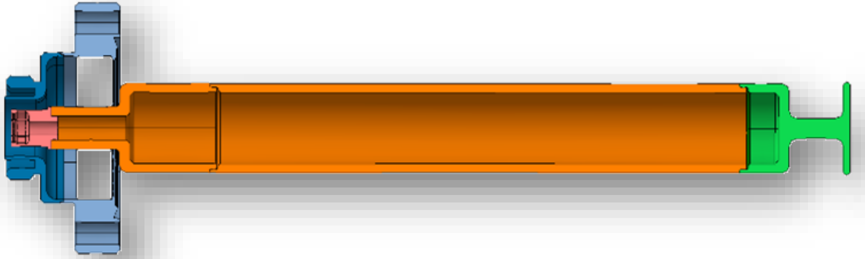
Some simulations extracted from the very well written report of Eduardo and team that will be presented at the next SRF19
AN INSIGHT ON THE THERMAL AND MECHANICAL NUMERICAL EVALUATIONS FOR THE HIGH-LUMINOSITY LHC CRAB CAVITIES
showing the need of Niobium end tip of DQW HF-HOM and RFD V-HOM

End tip in Niobium

Said and his team designed a specific Niobium/Copper interface that will later be EBW to Copper/Copper and Niobium/Niobium

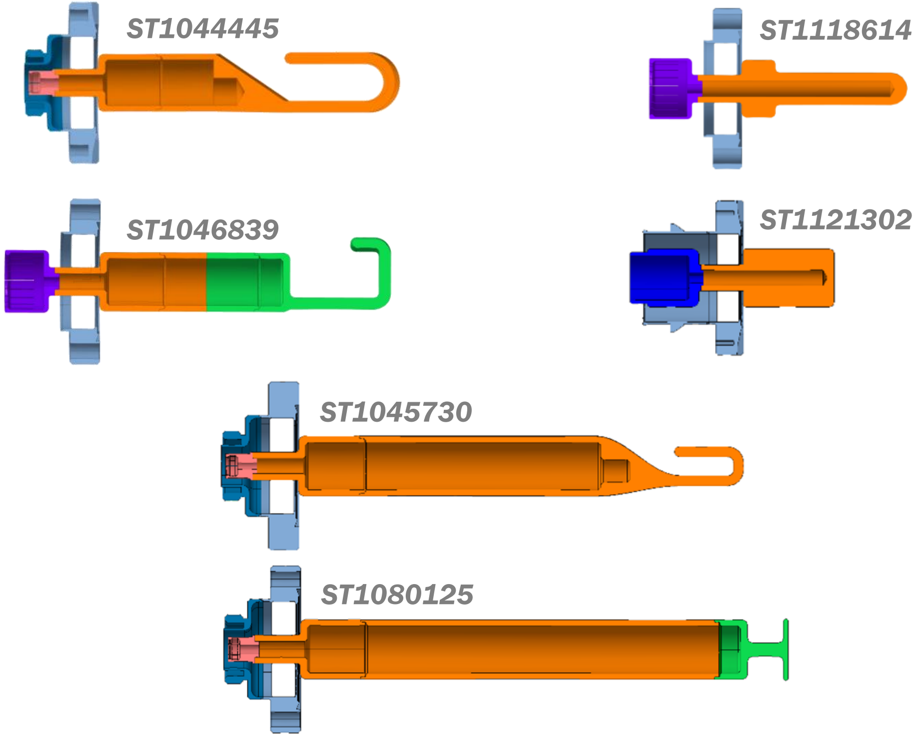
Doing so, we minimize the risk of difficult EBW with expensive items





Standard 25 Ω feedthrough

We design all HOM Couplers and Field Antennas to be with the same 25 Ω feedthrough to the biggest extend possible

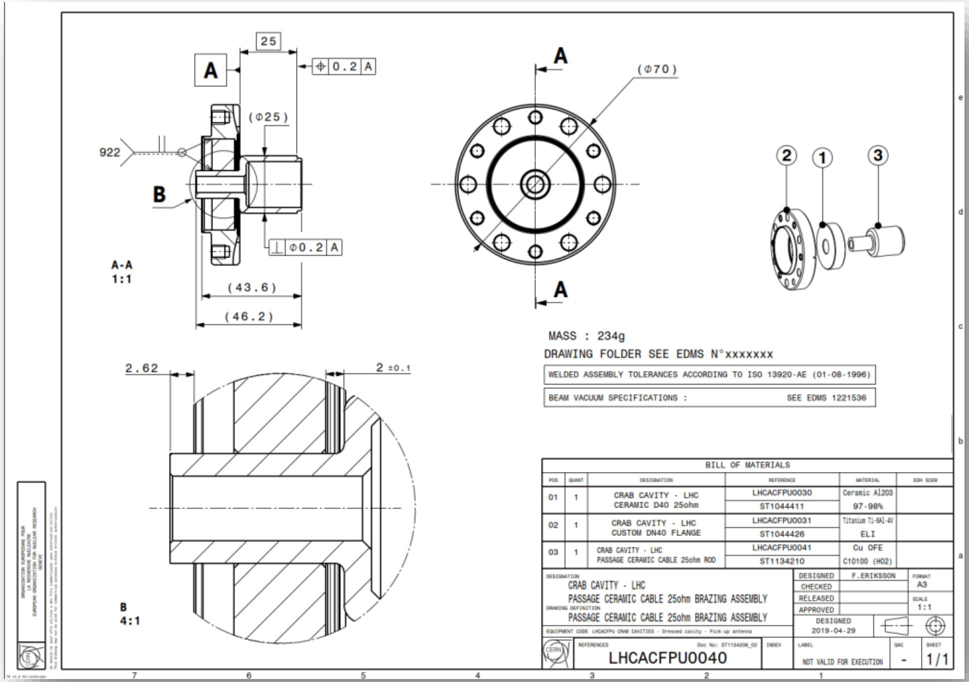


Standard 25 Ω feedthrough

We now have a robust feedthrough design validated with thermal shock test

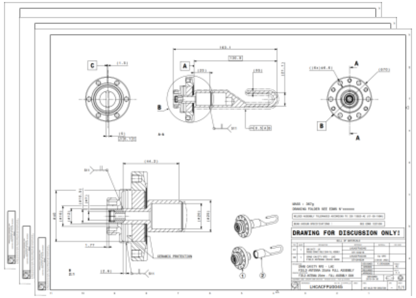
AND

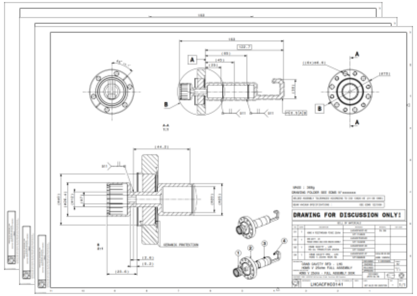
with drop test

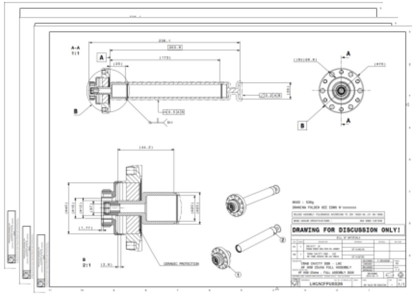


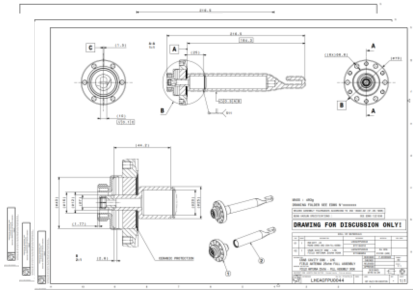
Standard 25 Ω feedthrough

Several details still need to be validated, however we already produced 3D and 2D models that are compatible with all solutions such that we were able to launch the purchase of raw material in order to keep the construction feasible within our tight schedule







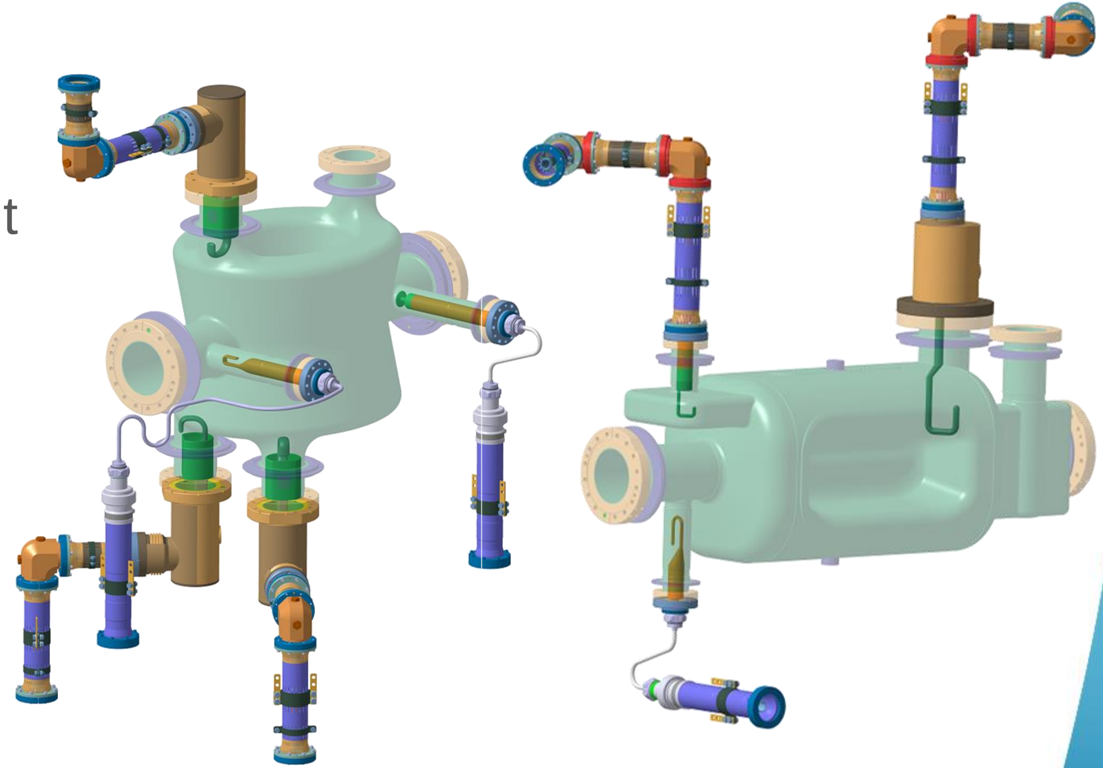


Coaxial lines

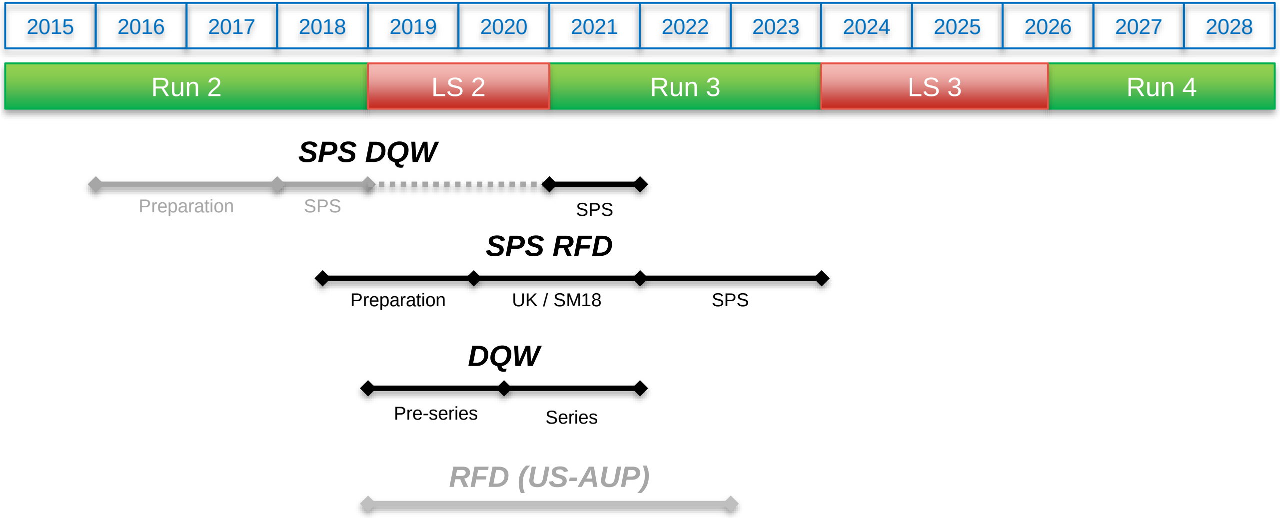
We have not yet worked out details of the coaxial lines

This will be done very soon

We already contacted cables suppliers and they are working on it as well



HOM Couplers and Field Antennas



Weekly Vidyo meetings CERN/US-AUP to share concerns and proposals

Conclusion

FPC have proven to operate as expected

We launched the series production

Outer FPC lines to be improved, task already ongoing

HOM couplers in SPS have been to specification

Issues with feedthroughs solved

New 25 Ω concept, necessary, validated (RF + mechanical)

New 25 Ω design almost complete, almost all raw material ordered

Will be very challenging to stick to schedule, we are doing our best

Thanks to all colleagues involved with the SPS FPC, HOMC and Field Antenna devices (special thanks to Antoine, Seb, Frida, Sonia, Jamie, Ofelia, Kurt, Eduardo, Said, BE-RF-PM team & all MME teams)

Thanks to Rama and Ofelia (WP4 leaders), to RF management, to BE management and to HL-LHC management for supporting us with this very exciting (and very challenging) project

We (BE-RF-PM & MME teams and all associated colleagues from many groups) are eager to provide HL-LHC with fantastic Couplers