Last year experiences at CERN with FPC and future perspectives

WWFPC #02, CERN, Geneva, 12-13 July 2016

eric.montesinos@cern.ch

Outline

FPC at CERN
- FPC Program at CERN
- Frequencies & Power levels
- Resources

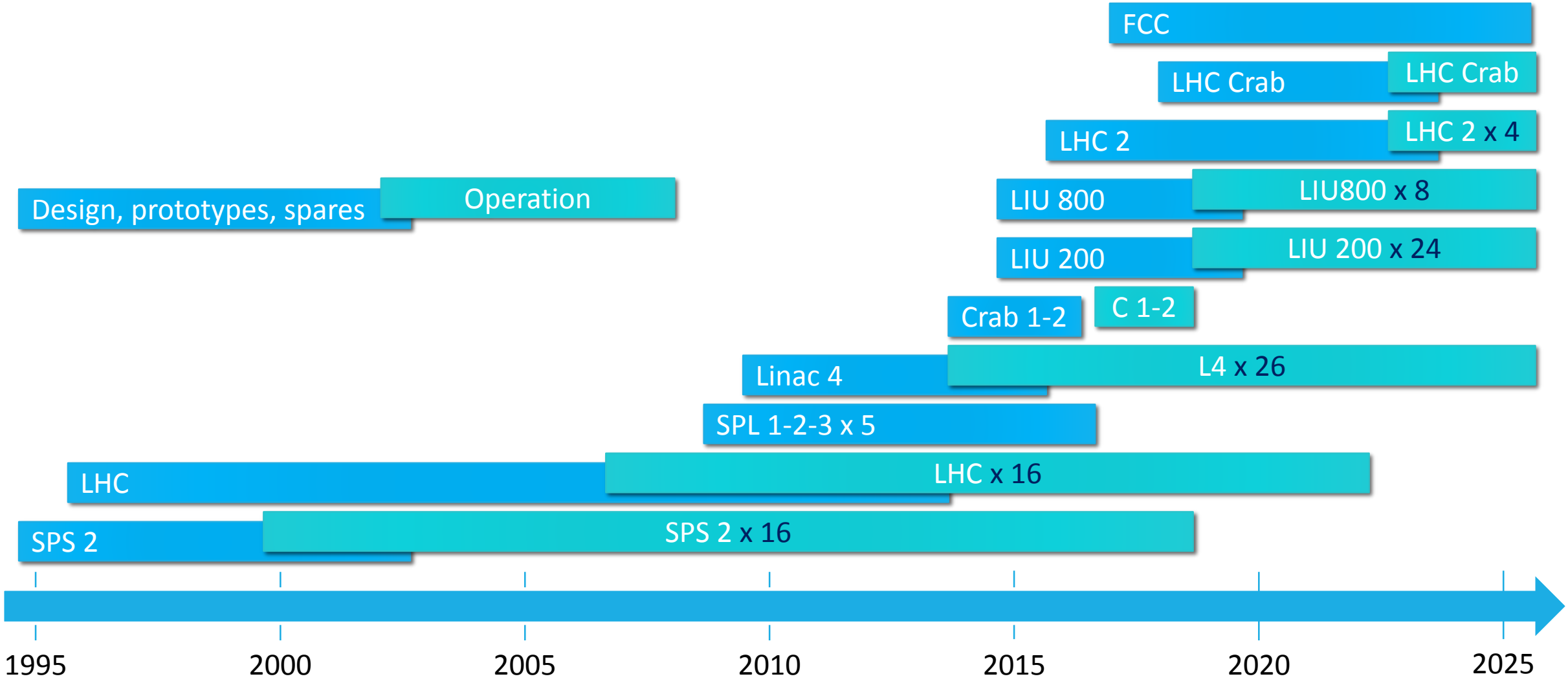
Reporting on current FPC projects at CERN
- Linac4
- SPL
- Crab Cavities
- LIU SPS 200

Difficulties encountered in the past years

Conditioning processes

Future programs

FPC program at CERN

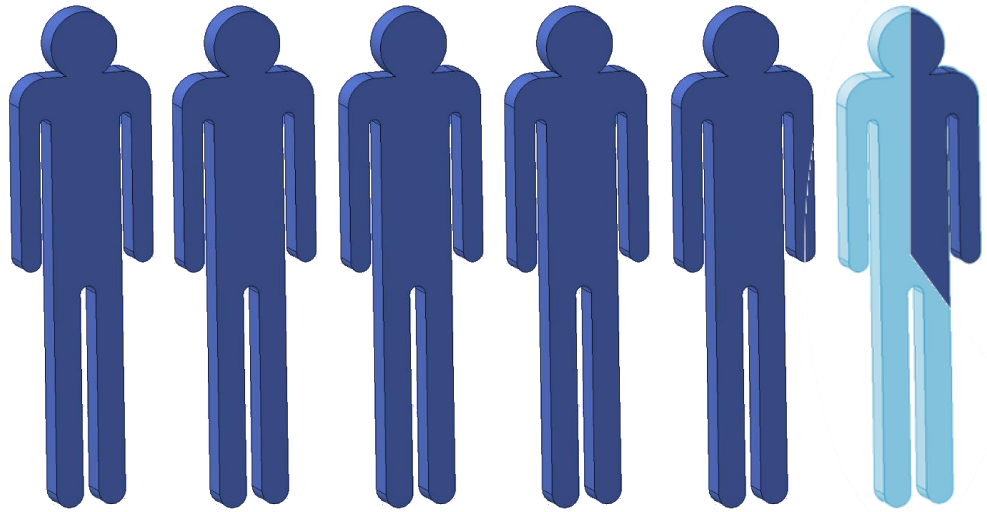


Frequencies & Power levels

Tested or Operation	Frequency [MHz]	Operation	TW [kW]	SW [kW]
SPS 2	200	CW	500	-
LHC	400	CW	550	575
ESRF-SOLEIL-APS	352	CW	300	200
SPL 1.0 – SPL 2.0	704	2 ms – 50 Hz	1000-1000	600-1000
Linac 4	352	2 ms – 1 Hz	-	900
Design & construction				
Crab	400	CW	100	100
LIU 200	200	CW	1000	-
LIU 800	800	CW	250	-
SPL 3.0	704	2 ms – 50 Hz	1500	1500
LHC 2	400	CW	600	600
LHC crab	400	CW	100	100

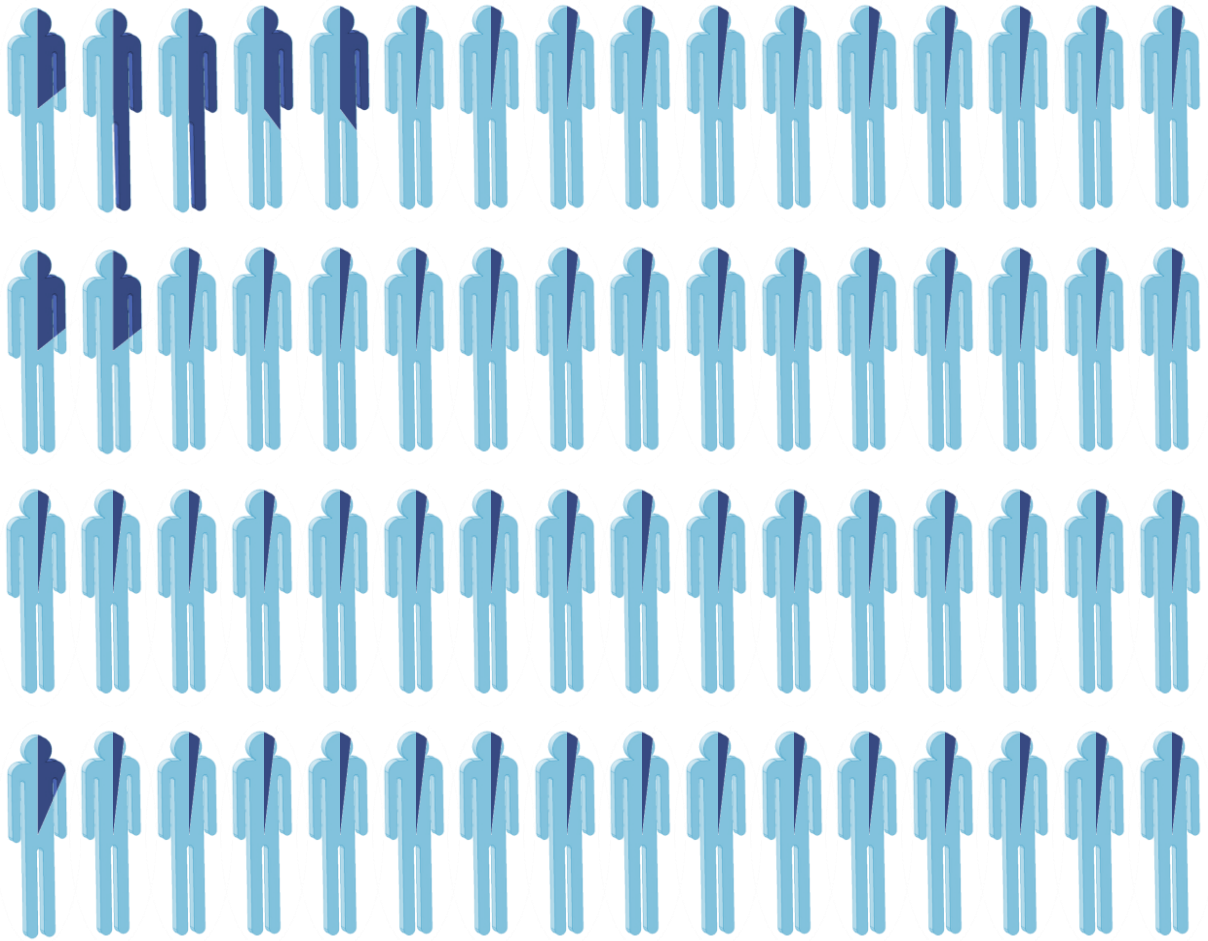
Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1



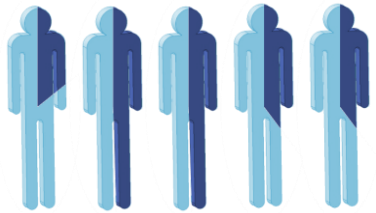
Resources

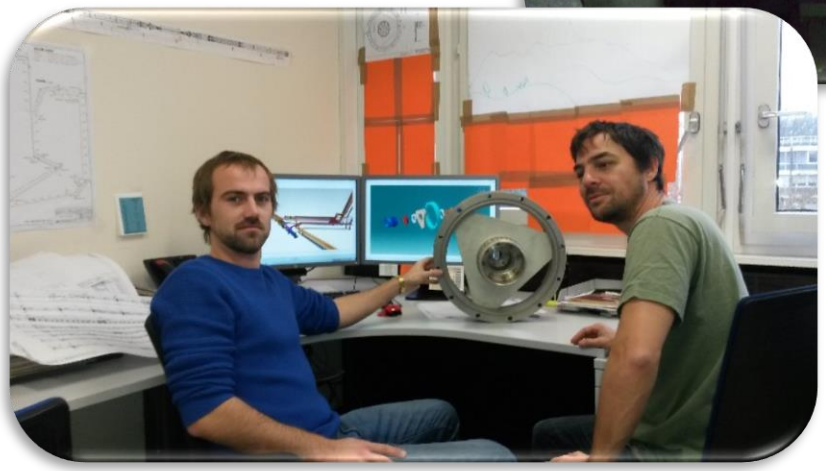
Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1



Resources

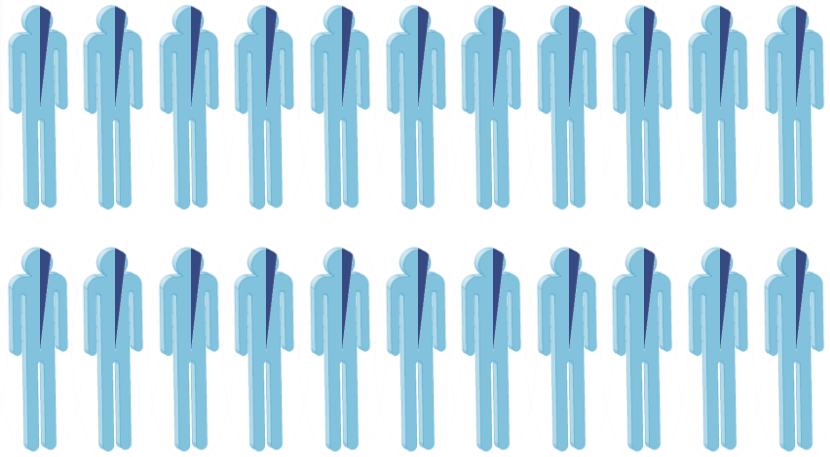
Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.1
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1

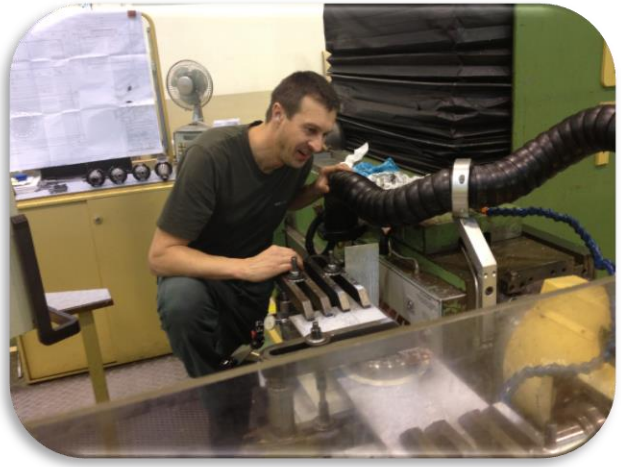




Resources

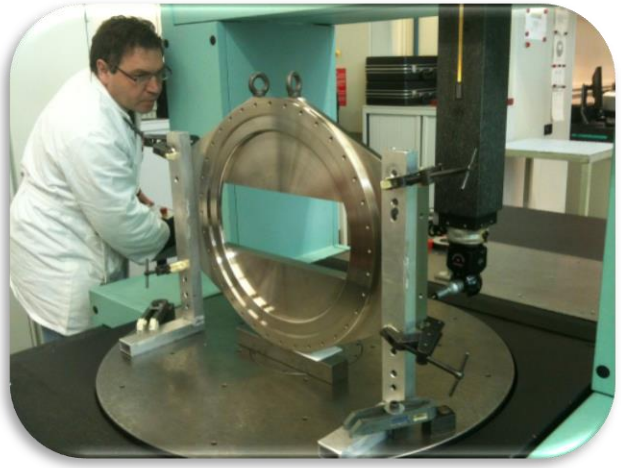
Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.1
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1

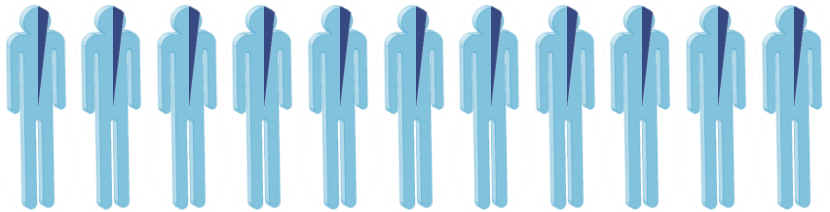


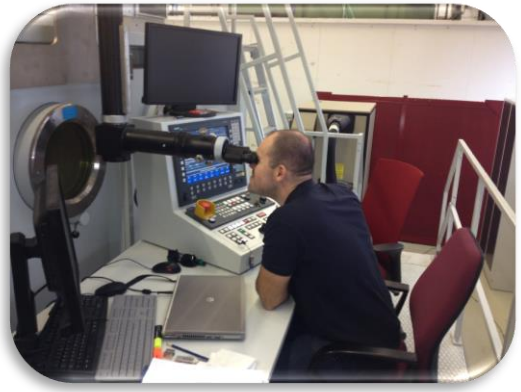


Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1

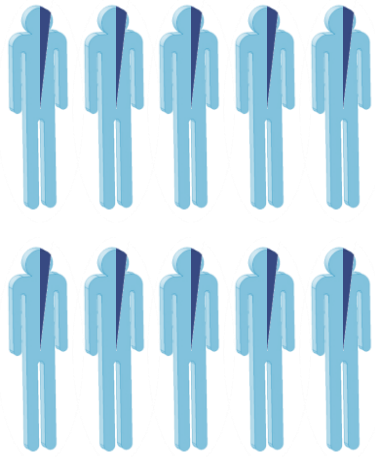






Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1

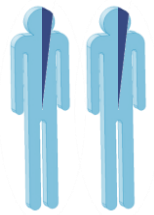


Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1

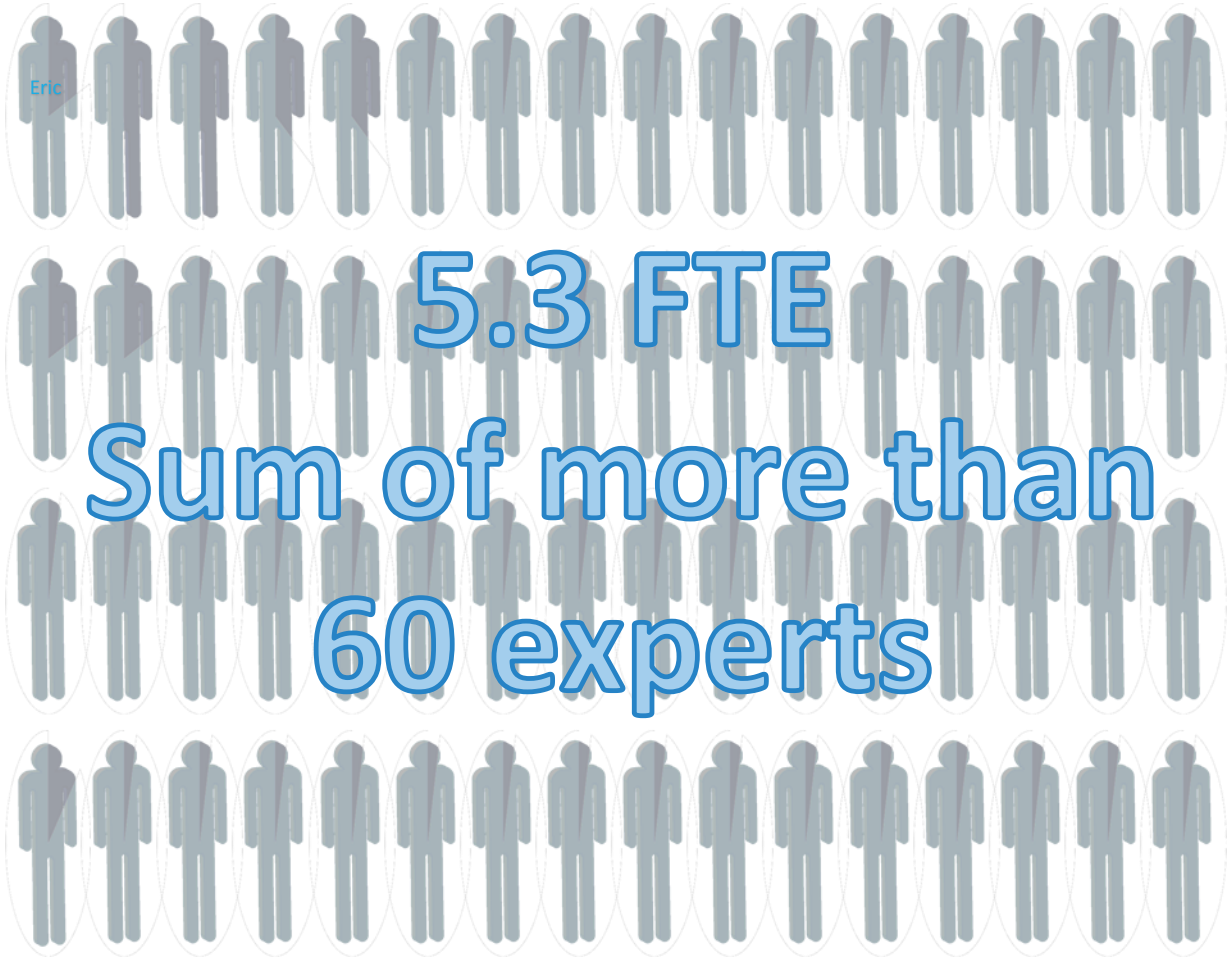
Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1



Resources

Activities	5.3 FTE year
RF Design	0.2
Mechanical Design	1.8
Raw material	0.05
External machining pilot	0.5
Internal machining	1.0
Surface treatments	0.1
Brazing	0.2
Titanium sputtering	0.1
BE welding	0.1
Metrology	0.05
Assembly	0.5
Vacuum tests	0.1
RF Conditioning	0.5
Clean room assembly	0.1



Linac4 windows

1 MW @ 352 MHz – 2 ms – 1 Hz (2 kW average)

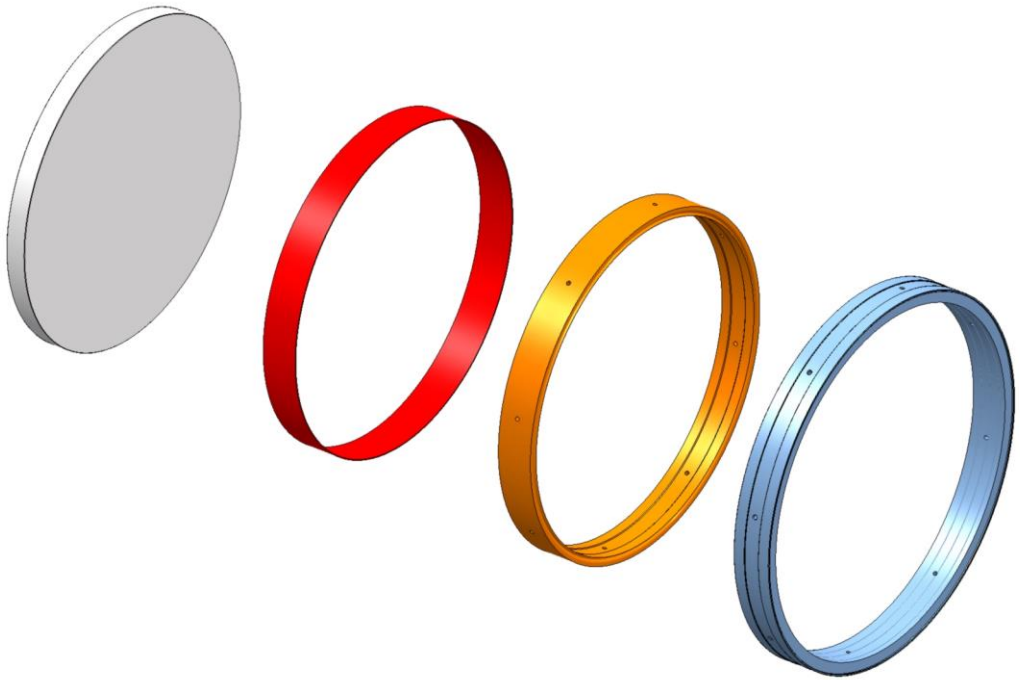
upgradable to 2 ms – 50 Hz (100 kW average)

Initially we asked companies to build it

- Too expensive
- Too long delivery delays
- Too ‘big’ devices

We designed a compact and quite simple solution

- One large disk window
- Helicoflex seals
- Two WG2300 to cylindrical transitions
- Transistion ‘coolable’ with air or water if needed



Linac4 windows

1 MW @ 352 MHz – 2 ms – 1 Hz (2 kW average)

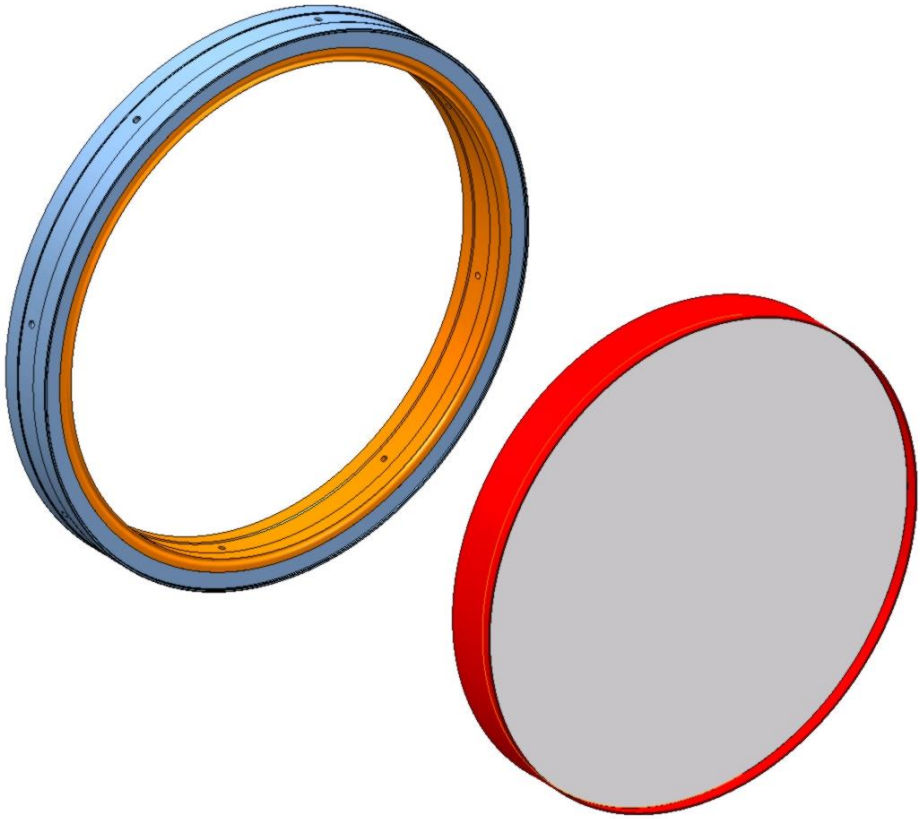
upgradable to 2 ms – 50 Hz (100 kW average)

Initially we asked companies to build it

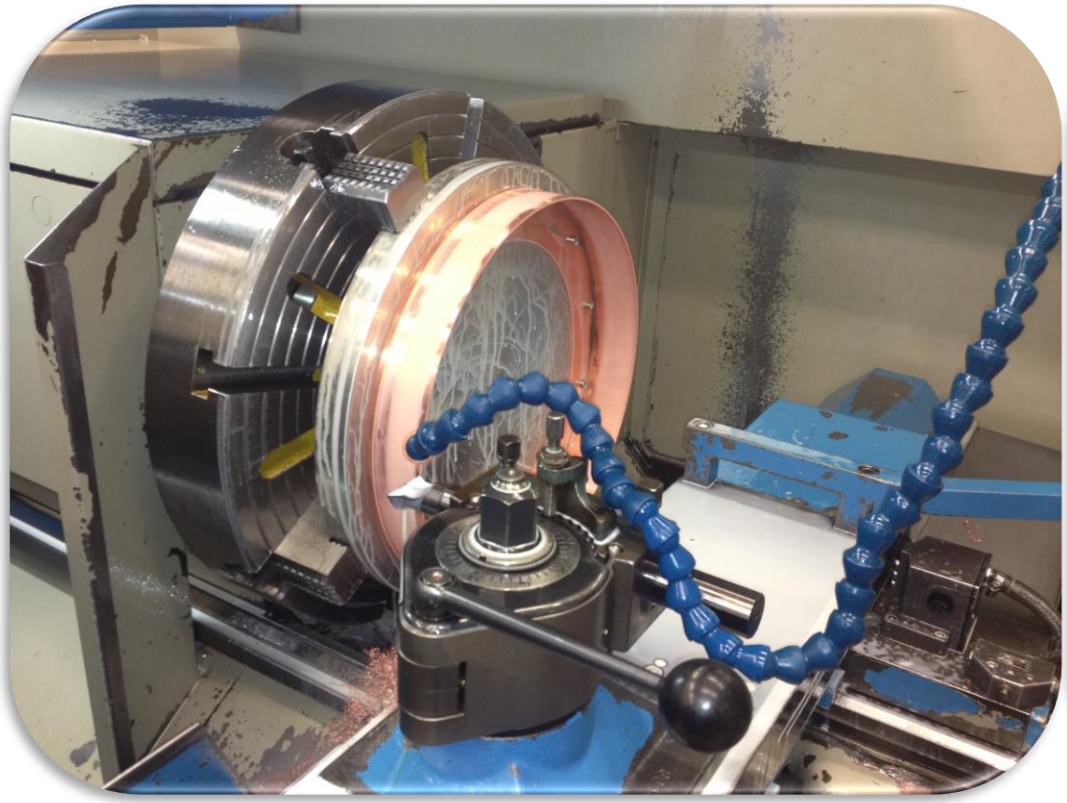
- Too expensive
- Too long delivery delays
- Too ‘big’ devices

We designed a compact and quite simple solution

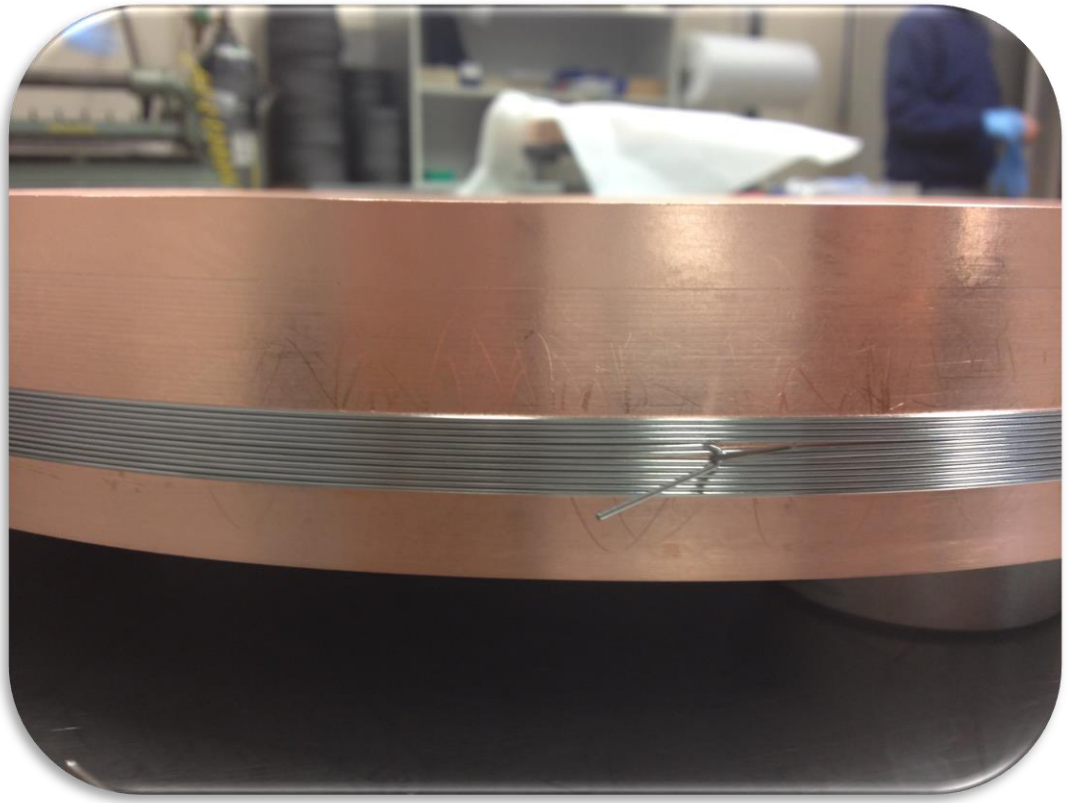
- One large disk window
- Helicoflex seals
- Two WG2300 to cylindrical transitions
- Transistion ‘coolable’ with air or water if needed



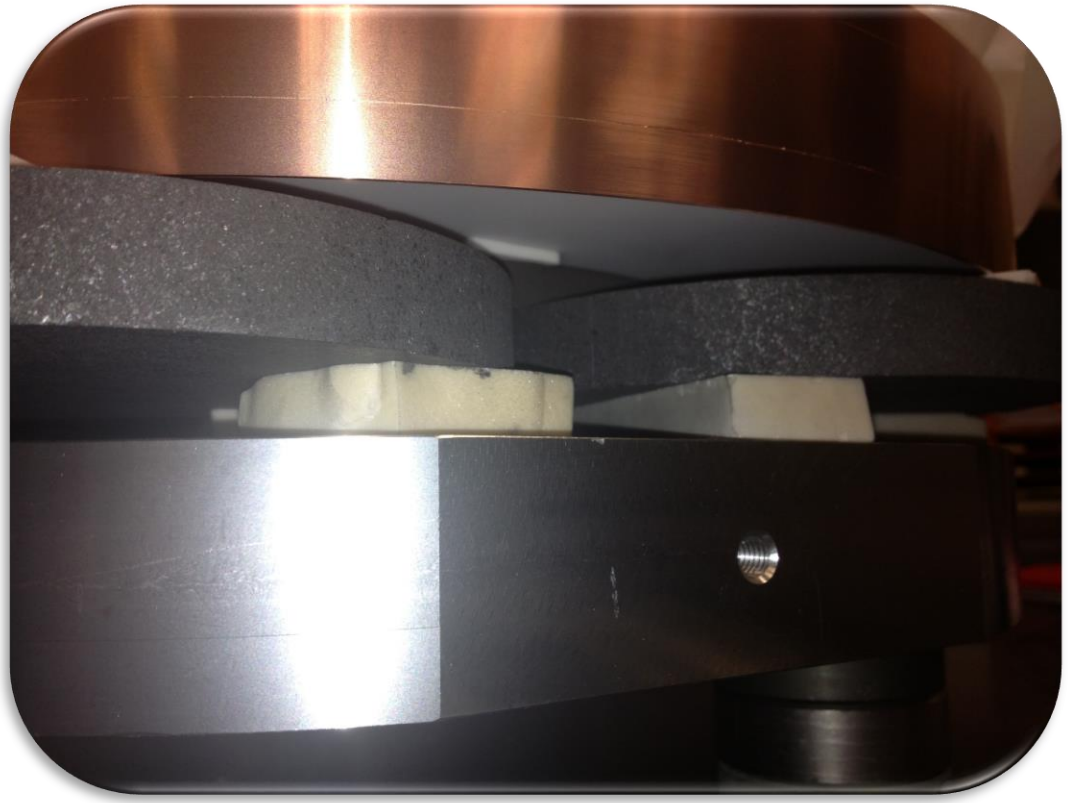
Linac4 copper for ceramic



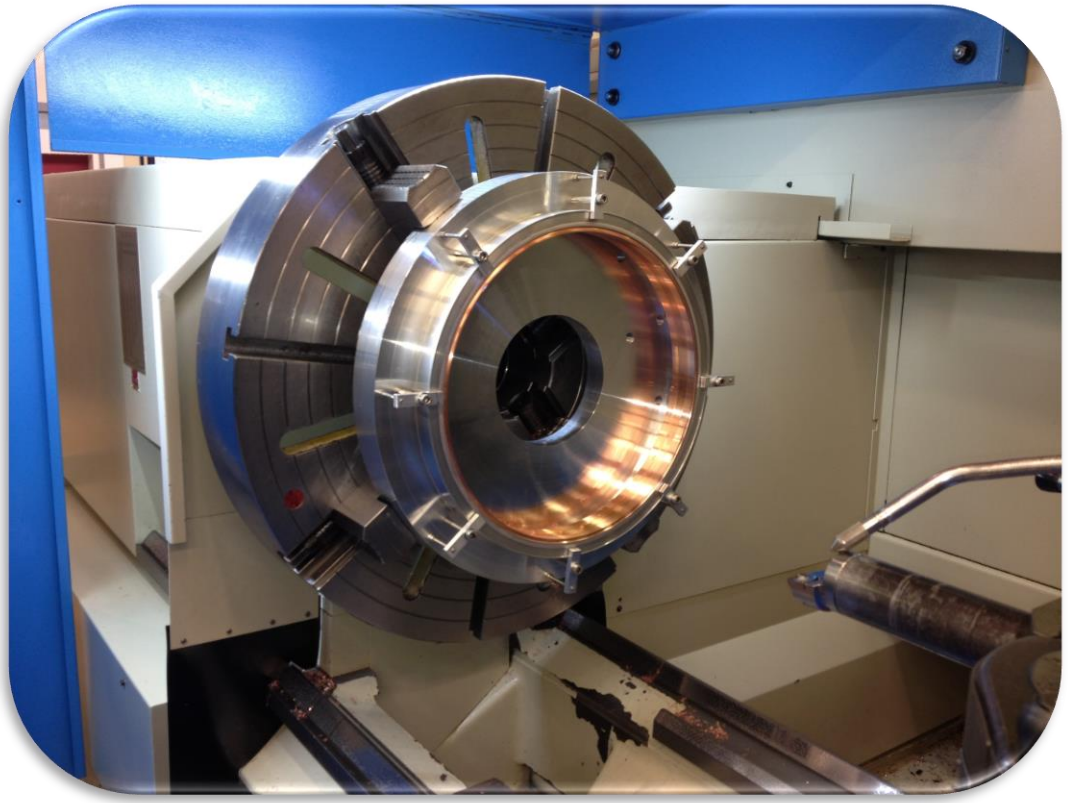
Linac4 preparation of brazing



Linac4 ceramic brazing

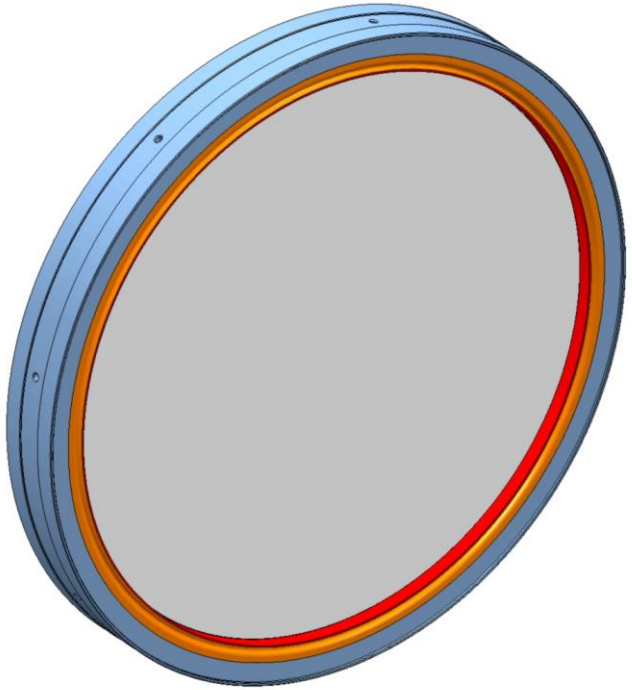


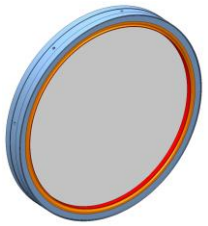
Linac4 Stainless steel + copper ring



Linac4 Stainless steel + copper ring

Linac4 windows EBW





Linac4 windows Ti sputtering

At cern we apply TiOx sputtering against multipactor

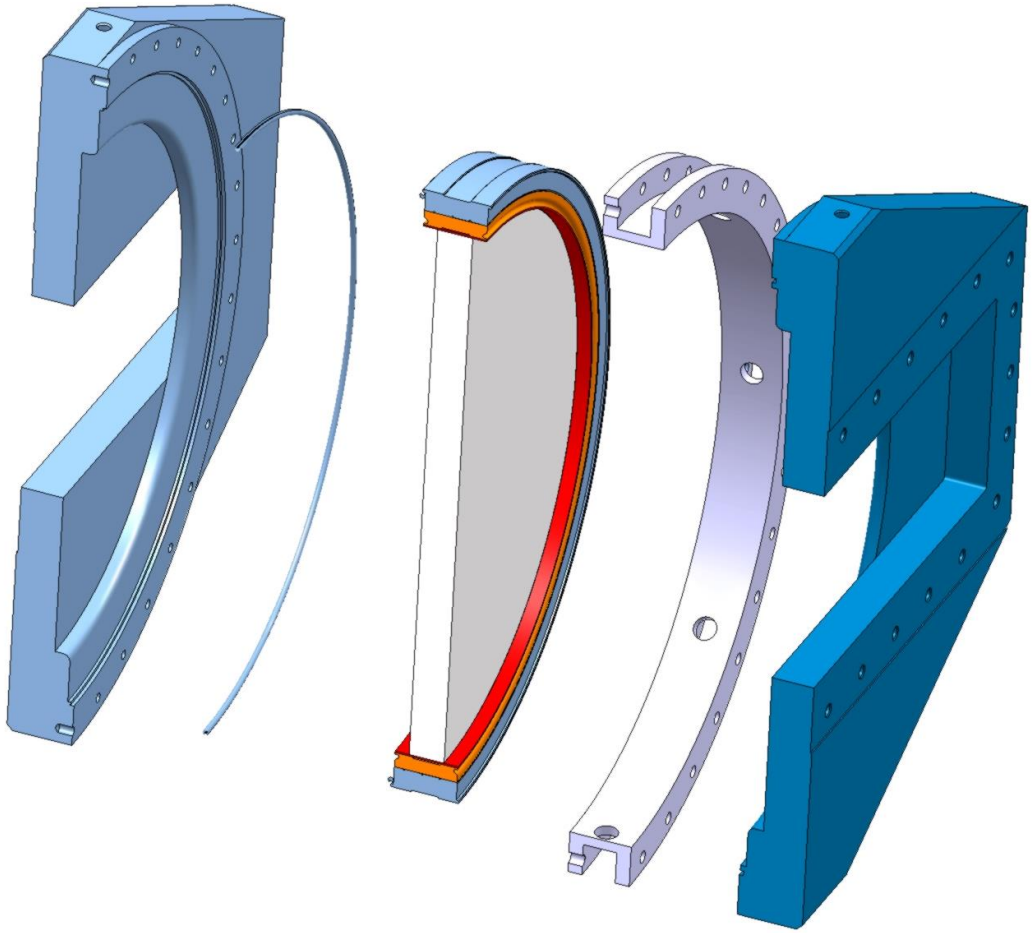
We unsuccessfully tried Cr2O3 paint

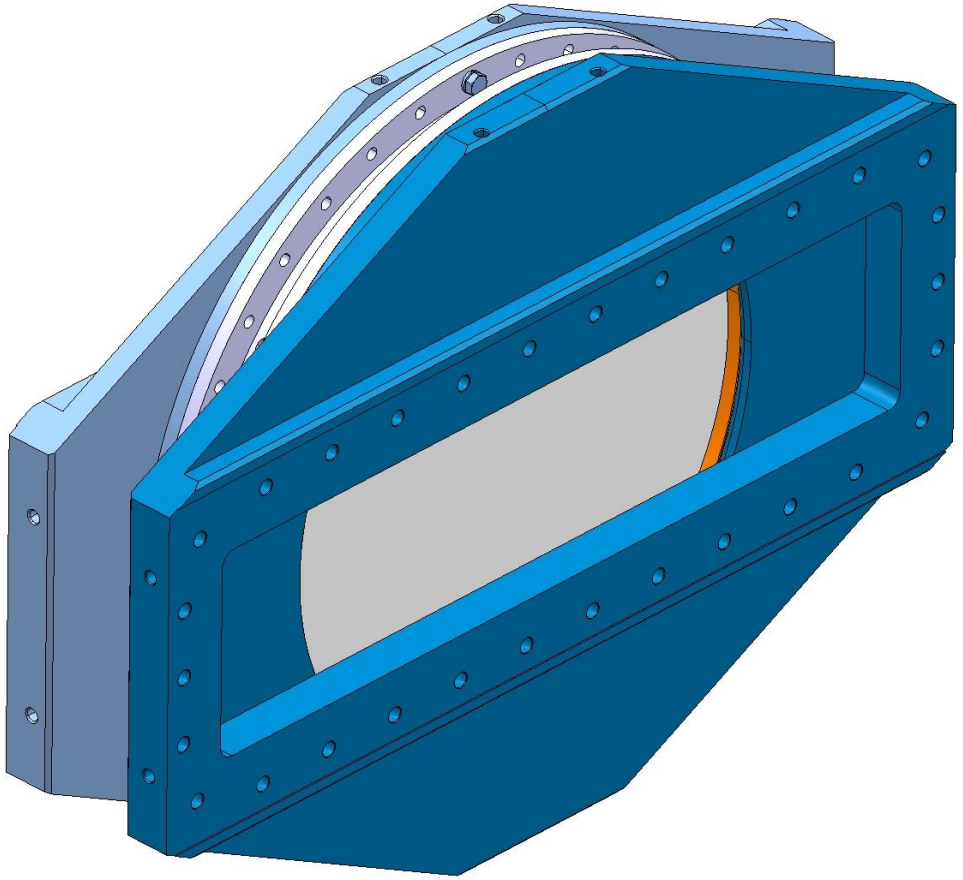
- No proof of better result
- No proof of worse result
- No time to investigate further more
- Any information is welcomed

No sputtering at all

- I heard about some FPC with NO sputtering being successful
- Any information is welcomed

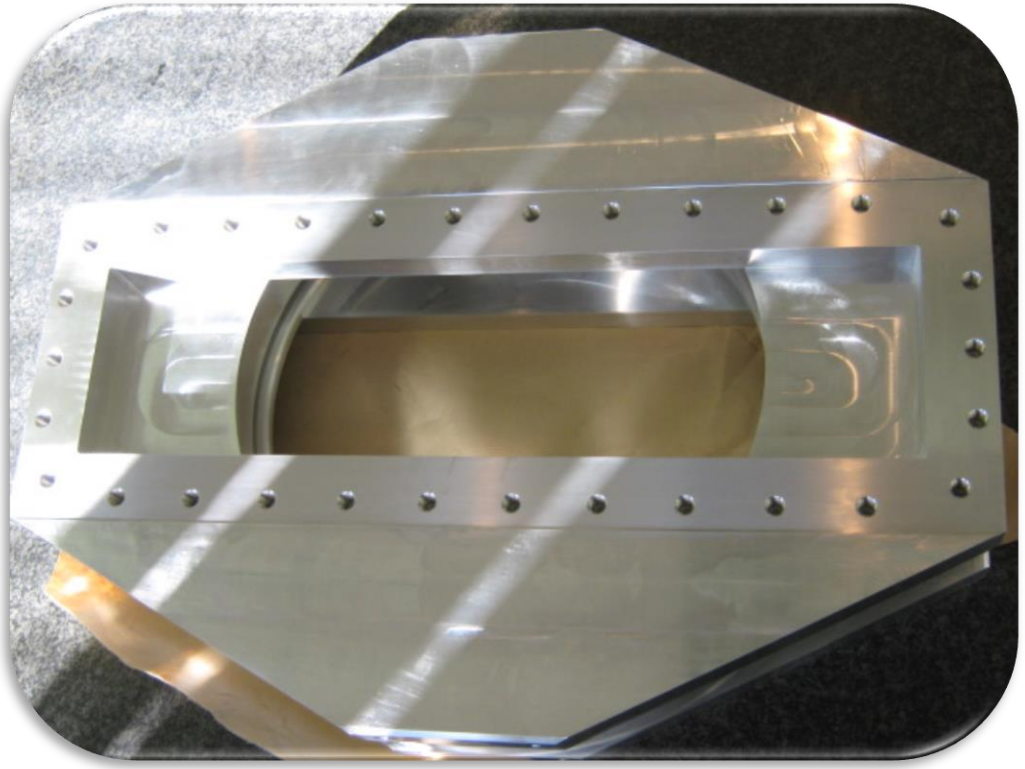
Linac4 windows waveguide flanges



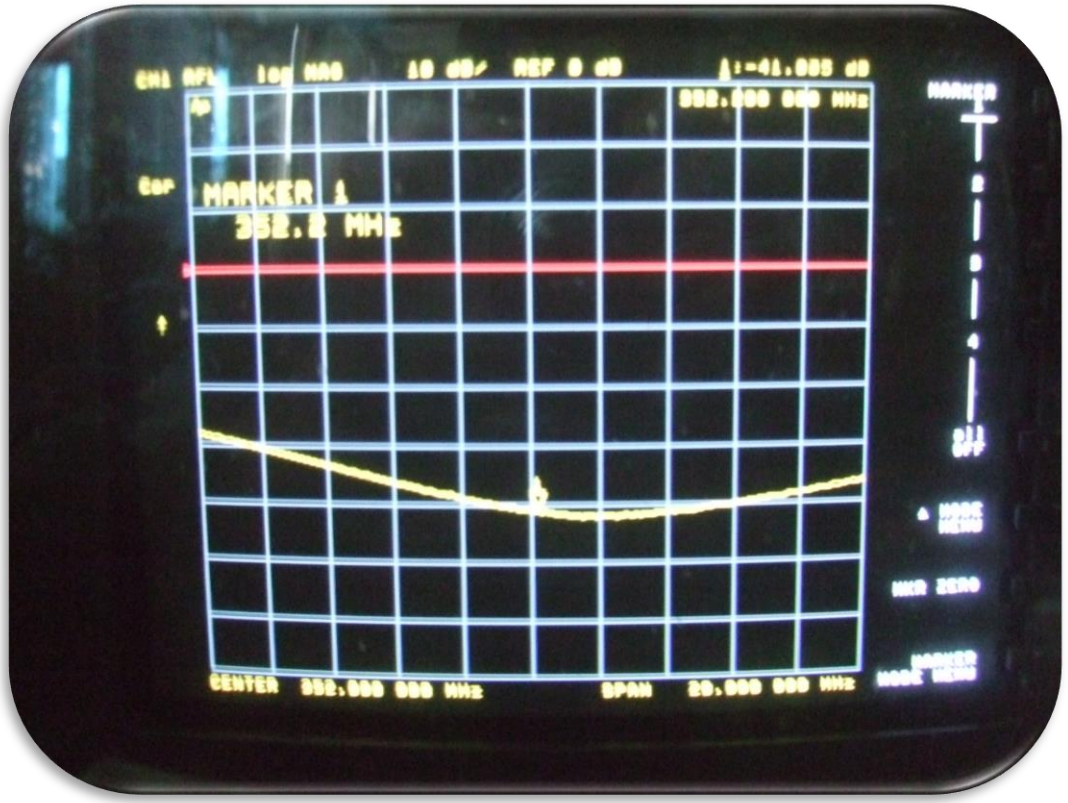


Linac4 windows waveguide flanges

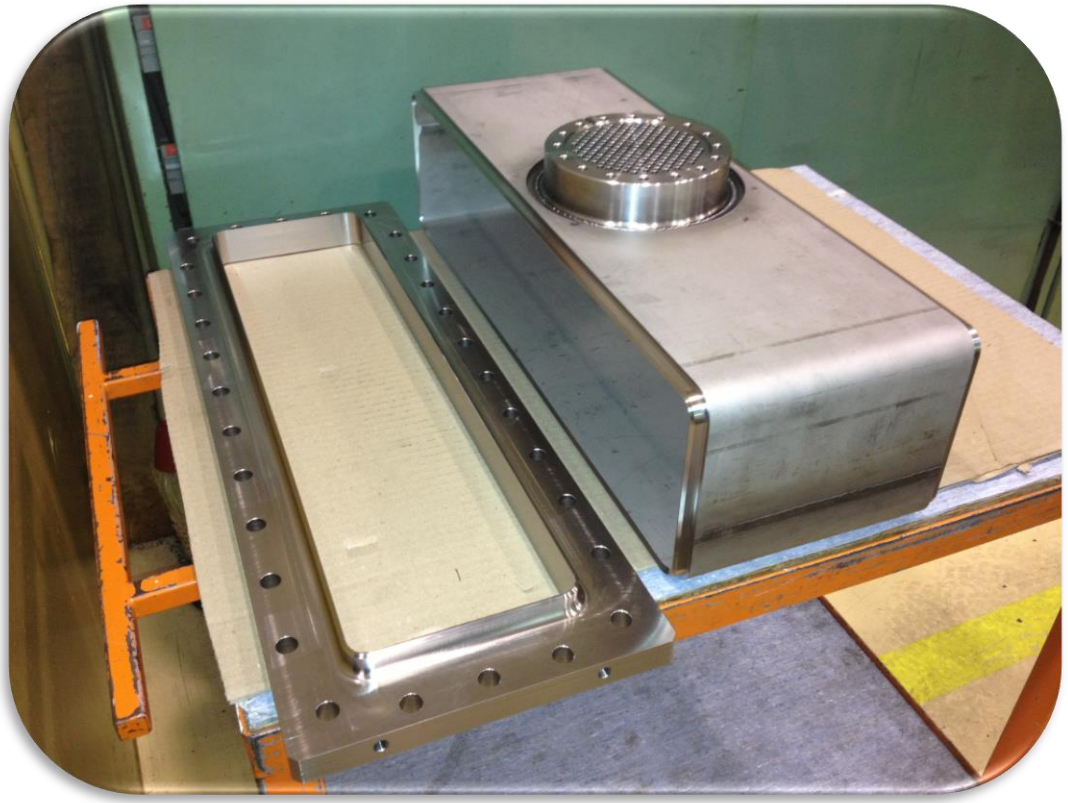
Linac4 windows waveguide flanges



Linac4 windows



Test box



Linac4 windows

Charles is completing the RF processing program

By the end of July 2016, we should deliver the last 4 windows

Main difficulties

Helicoflex faces on the WG flanges have been very difficult to prepare

We had to work them several times before being ok

Rectangular to circular flanges have made a ‘banana’ effect, and a very careful assembly process had to be applied

SPL FPC

RF Characteristics	
f_0	704.4 MHz
Power levels	**1000 kW pulsed** 0.4 + 1.2 + 0.4 = 2.0 ms 50 Hz (20 ms) 100 kW average
Cavity design gradient	19-25 MV/m
Q_{ext} of input coupler	1.2×10^6
Input line Ø	100 / 43.5 mm = 50 Ω (from the cavity design)
Waveguides	WR 1150

Technical Choices
Single window coupler
Fixed coupler
With a Double Walled Tube
Mounted in clean room with its double walled tube
Vertically below the cavity and will be a support for the cavity (first time worldwide)
With a HV DC biasing capacitor
Air cooled

Please refer to SLHiPP#4 workshop : CERN SPL Fundamental Power Coupler Progress report
https://indico.esss.lu.se/event/139/session/5/contribution/19

SPL FPC

2008/2009
- First SPL Collaboration meeting
- Proposal of four possible designs

2010
- Design review with world wide coupler experts, Two designs validated
- ANL-APS: Ali Nassiri
- DESY: Wolf-dietrich Moeller
- Fermilab: Mark Champion & Sergey Kazakov
- Jlab: Mircea Stirbet

2011
- 3D printing & Construction

2012
- First tests & first difficulties
- Copper peeling on Double walled Tube (DT)

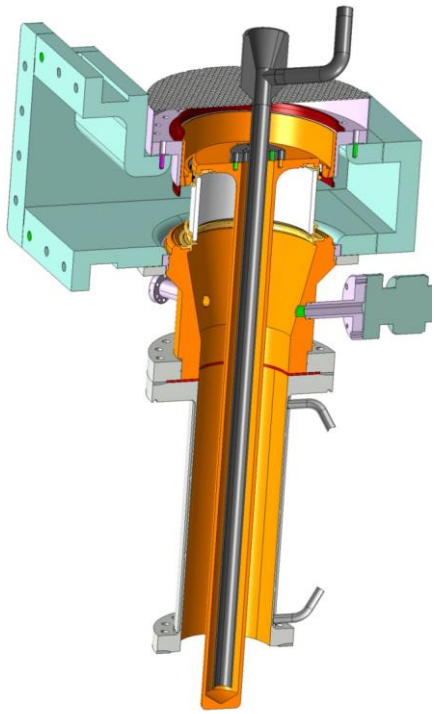
2013
- High peak power difficulties in SW tests
- Arcing regarding some reflected power phases
- Not found with simulations
- New test program
- First pair of Disk couplers ok

2014
- Bolts/nuts & vacuum gasket difficulties
- Still not ok with cylindrical windows
- May: Second pair of Disk couplers ok

2015
- SPL 3.0 & SPL 3.1 Design (CW 1.5 MW TW + SW)
- Launch SPL 3.1 Construction

2016
- SPL 3.1 under construction

SPL 1.0 & SPL 2.0



Cylindrical window
Coupler

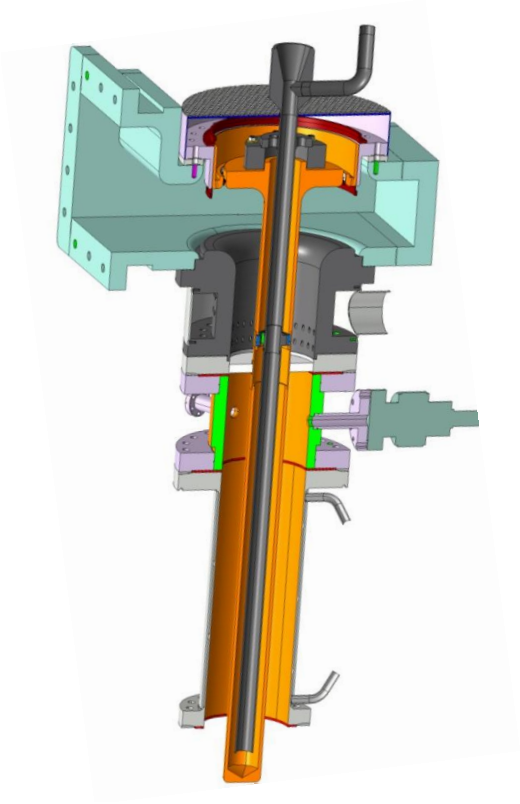
Both designs
will have the same

Double walled tube

Matching waveguide
without doorknob

Contacts ring including
DC capacitor

Interface to
cryomodule flange &
RF + vacuum gasket



Disk window
Coupler

SPL 1.0 Power limitations

Tested at CEA Saclay

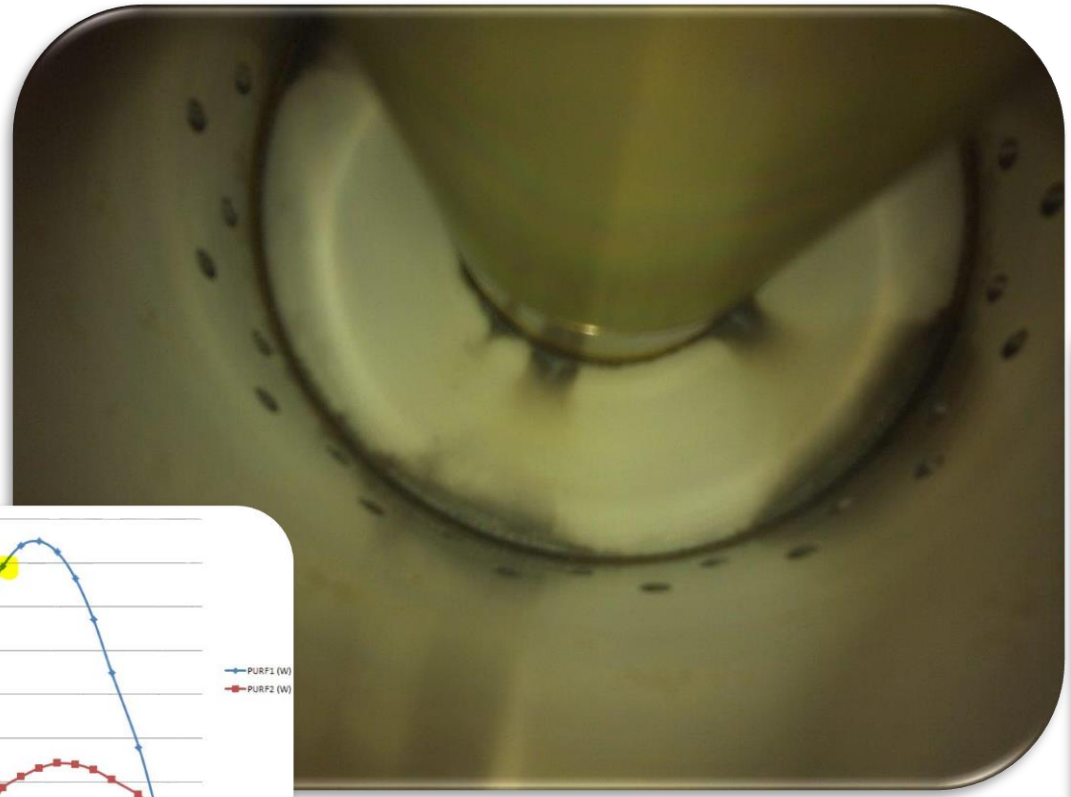
(thanks again for the fruitful collaboration)

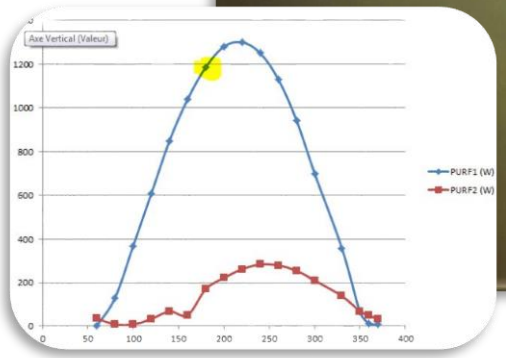
1 MW TW ok

Emax limitations with SW to 650 kW

Arcing between the two copper rings

SPL 2.0 power limitations

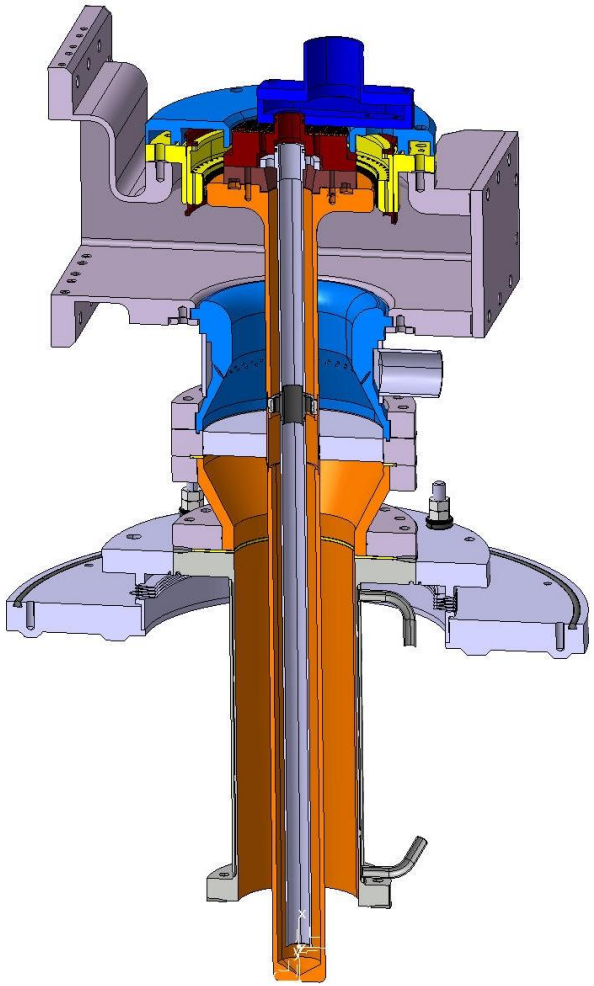


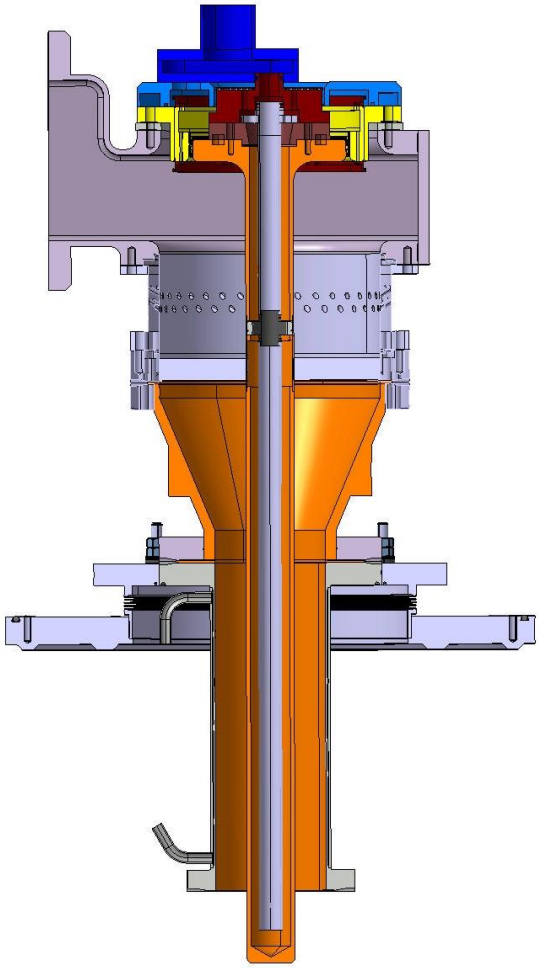


We had arcing in the air side when reaching 1 MW full reflection with few SW phases

With a piece of paper in the waveguide, we were able to localize the phenomena as initiated close to the ceramic window

SPL 3.0 & SPL 3.1





All devices have been produced, we are now in the construction process

Tests will be performed at CERN with a resonant ring

Crab Cavities

100 kW CW @ 400 MHz

2 DQW + 2 RFD by end of May 2016

1 DQW + 1 RFD by end 2016

Please refer to HL-LHC WP4 (Crab Cavities) : SPS Cryo-module Engineering Review

https://indico.cern.ch/event/435319/contributions/1081895/

Test box by October 2016

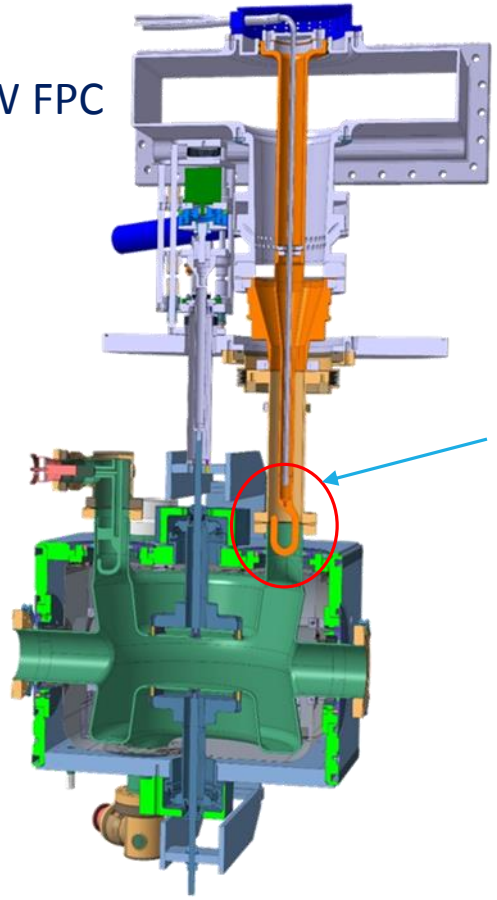
Assembly in clean room by end 2016

Start RF processing beginning 2017

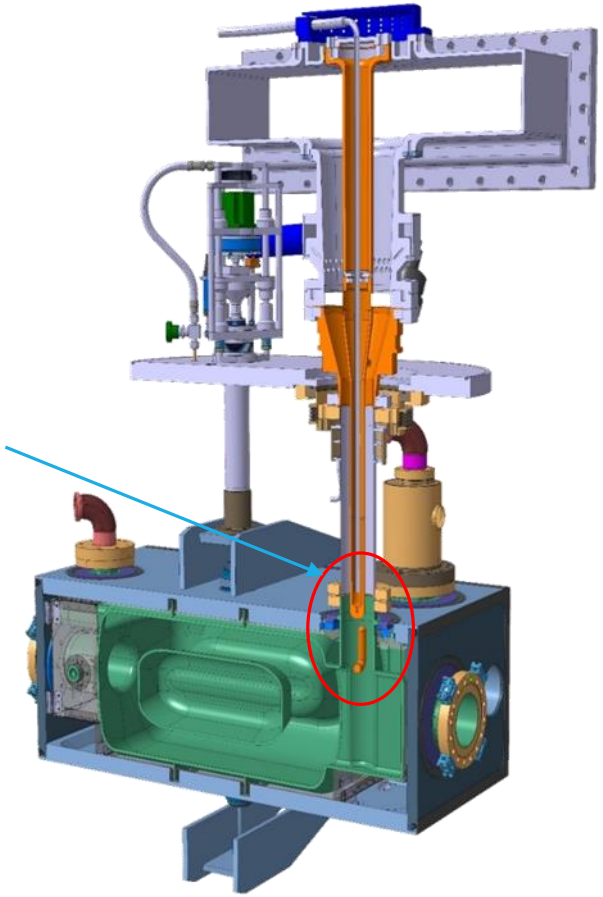
Two first couplers ready by April 2017

Crab Cavities

DQW FPC

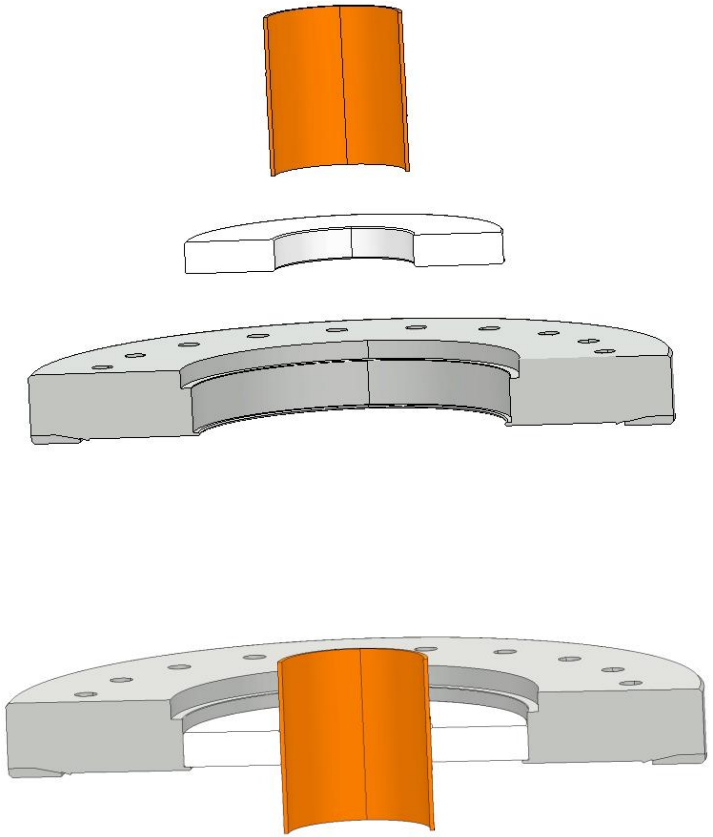


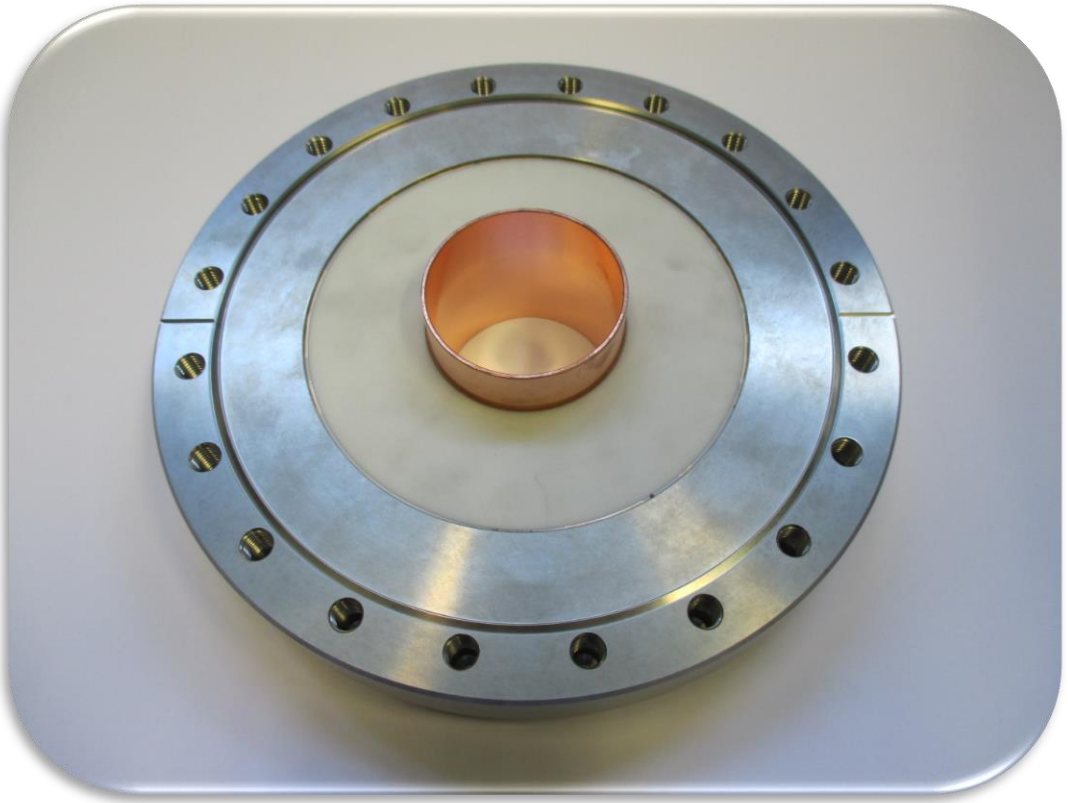
Regarding FPC the difference is only the length of the antenna and the shape of the hook



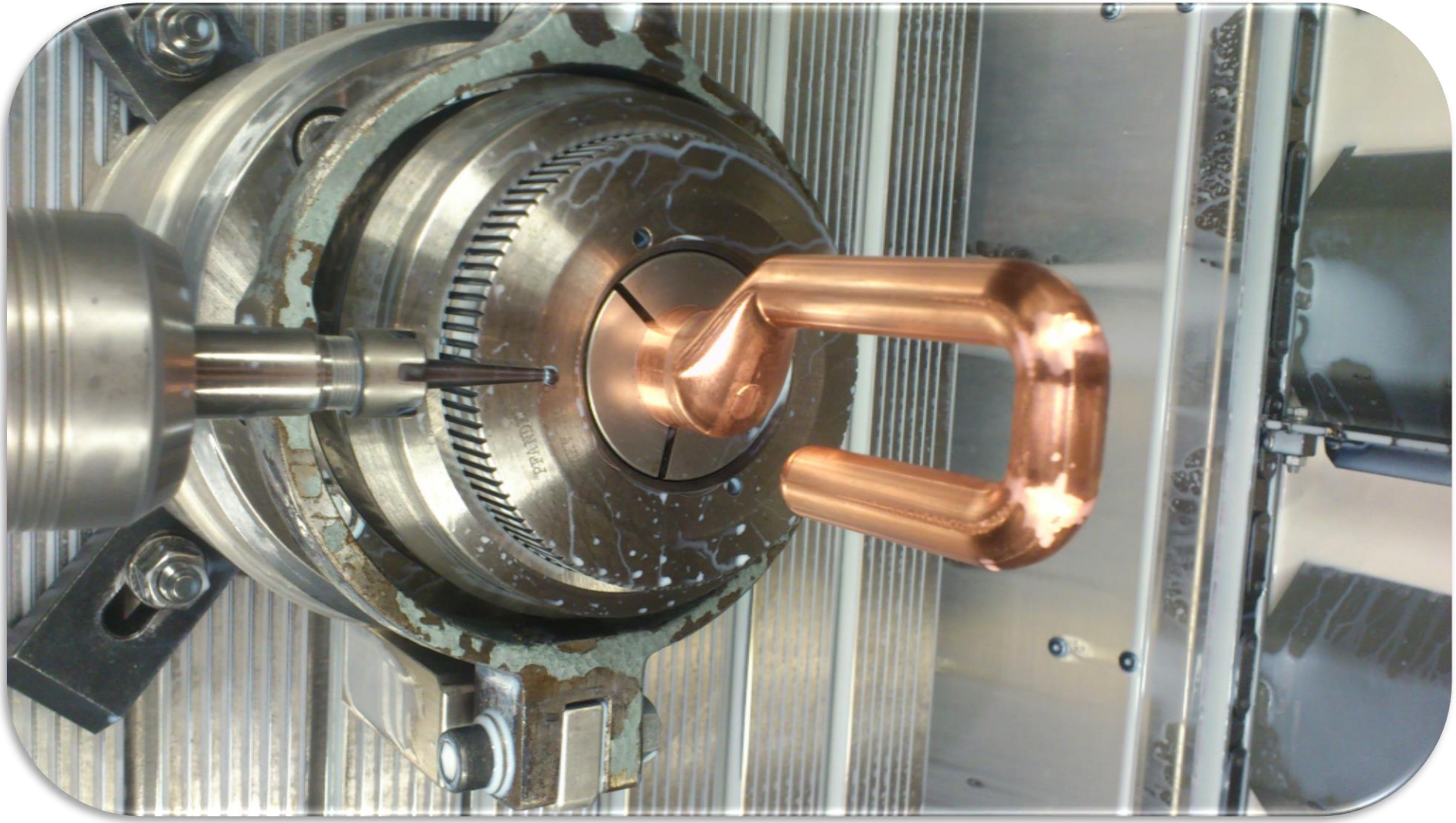
RFD FPC

Crab Cavities FPC windows



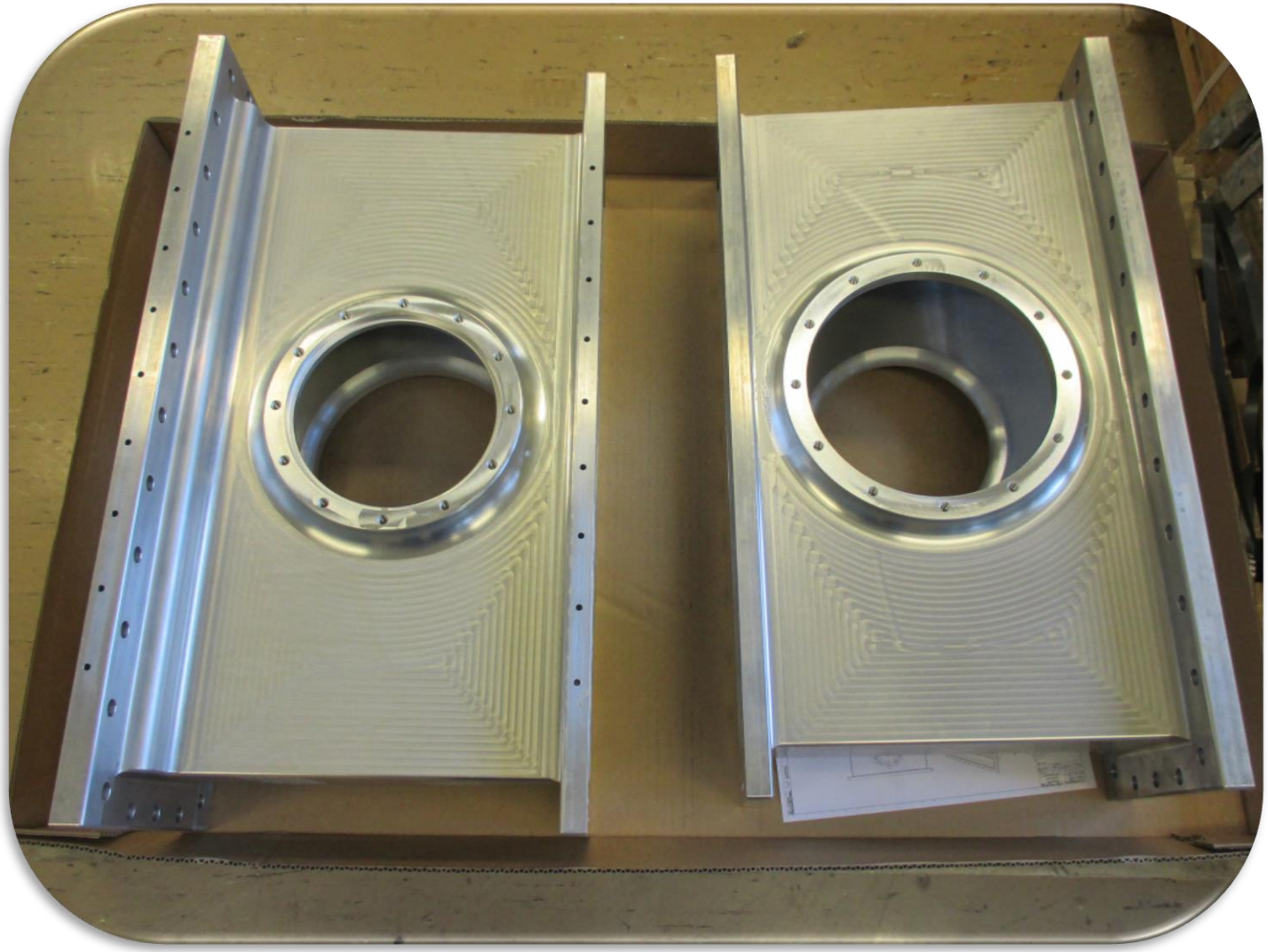


Crab Cavities FPC Hooks



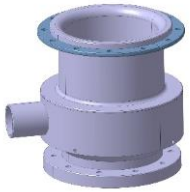
Crab Cavities FPC Antennas

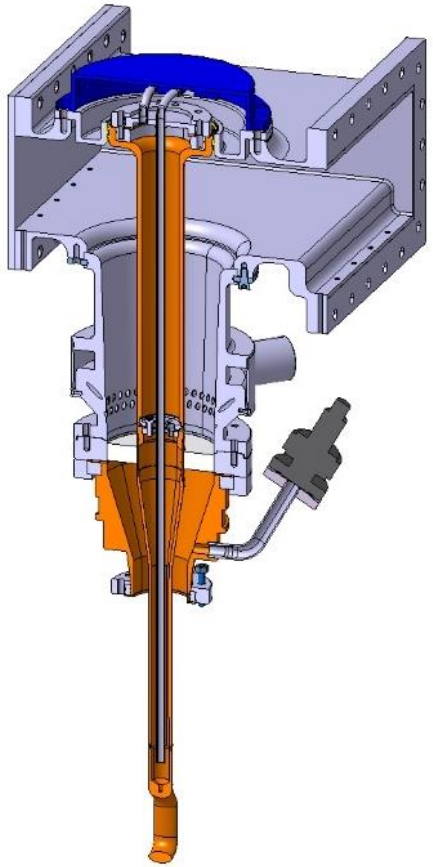
Crab Cavities FPC WG from a single block



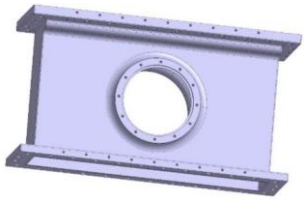
Crab Cavities FPC status

2 needed, 3 done

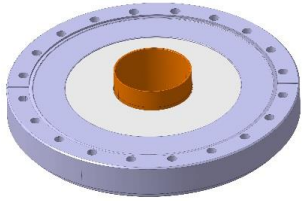




2 needed, 2 done

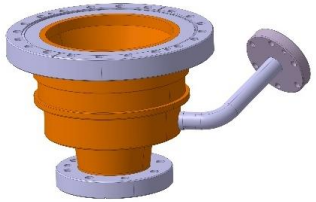


4 needed, 4 done, 2 additional to come



2 needed, 4 done

4 needed, 8 done



2 needed, 4 done

2 needed, 4 done

Crab Cavities FPC Status

Since end of June 2016

- Two DQW FPC ready for RF
- Two RFD FPC ready for RF

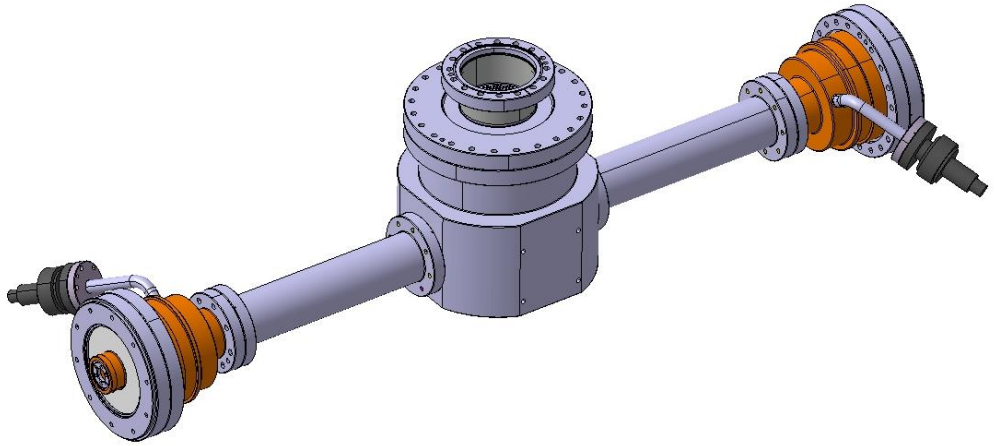
Crab Cavities Test box

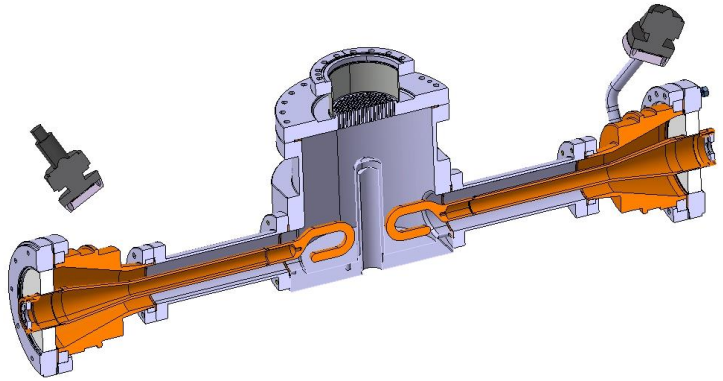
Started simulations with a PhD we got sick end of last year

New PhD started this Spring

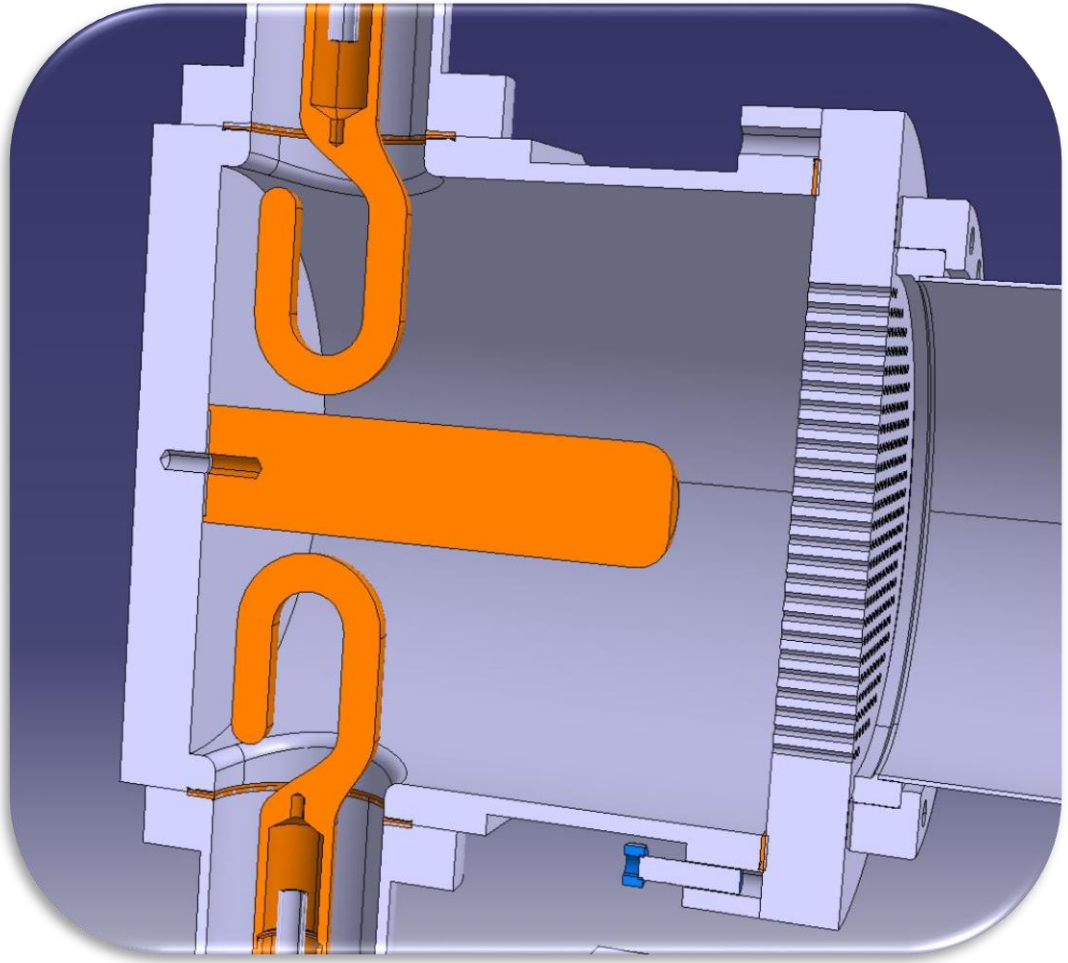
- Same Test box for both couplers
- Outer coaxial line with different lengths

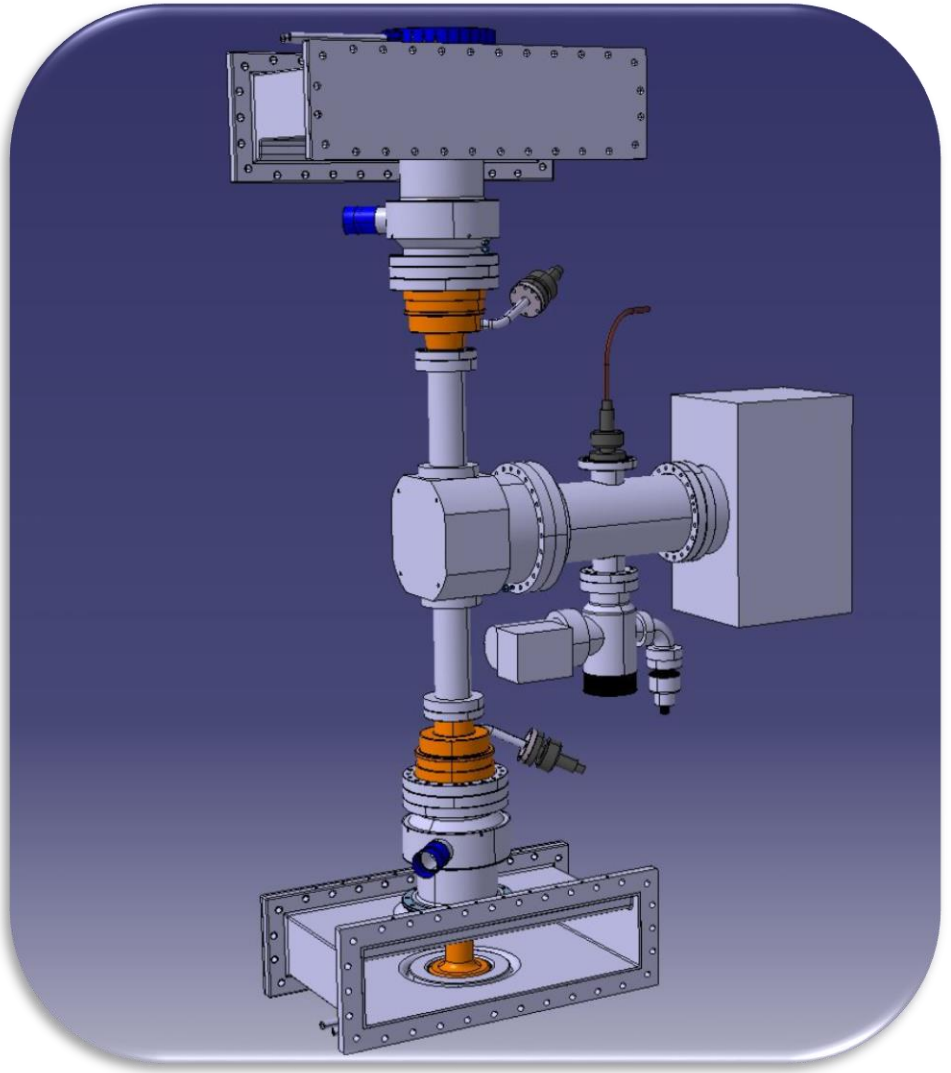
As delivery delay of Stainless steal is incredibly long (6 months), we will also try a test box in Aluminium (comment, advice?)



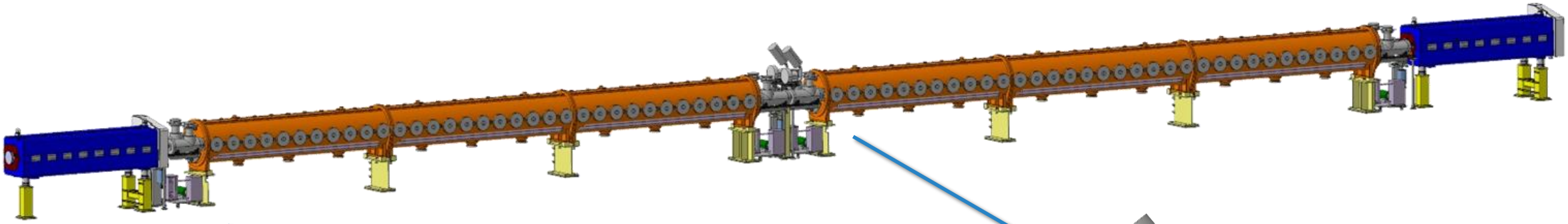


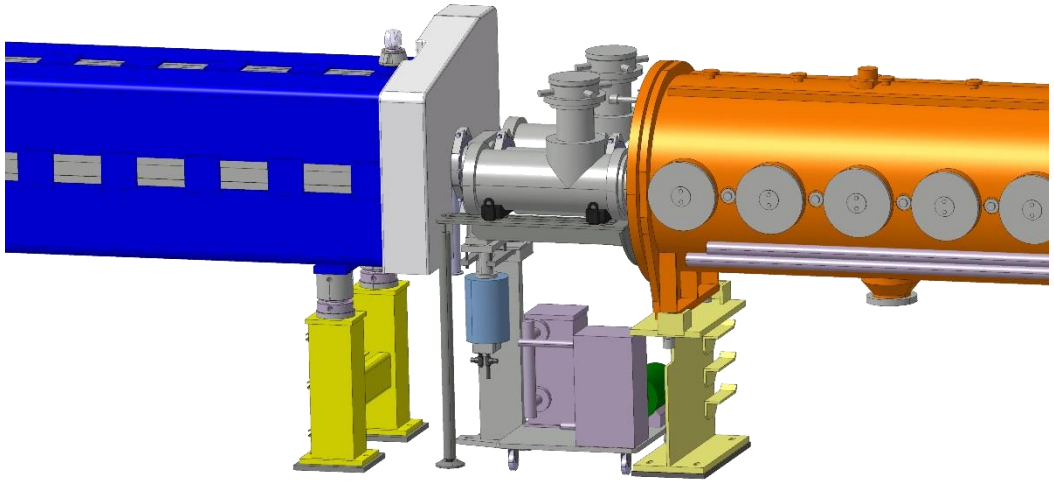
Crab Cavities Test box

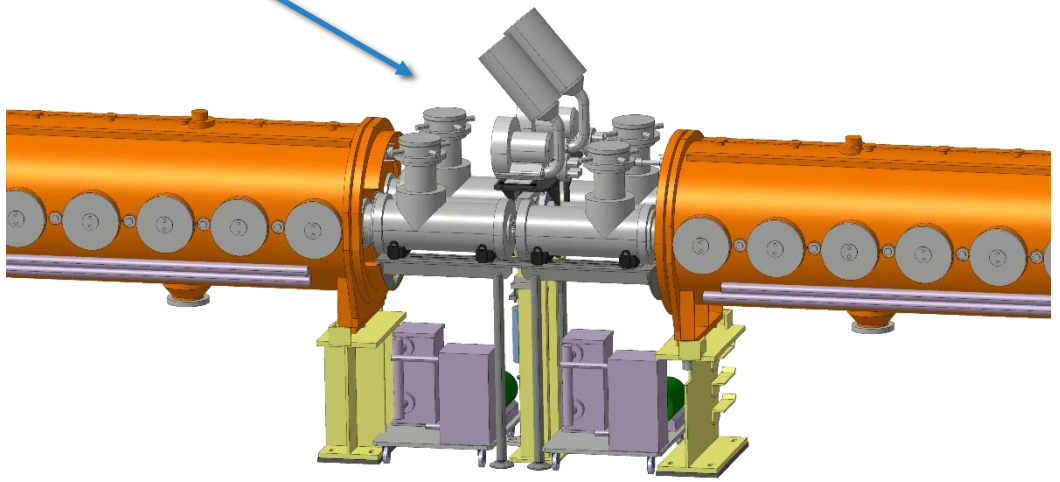




LIU SPS 200

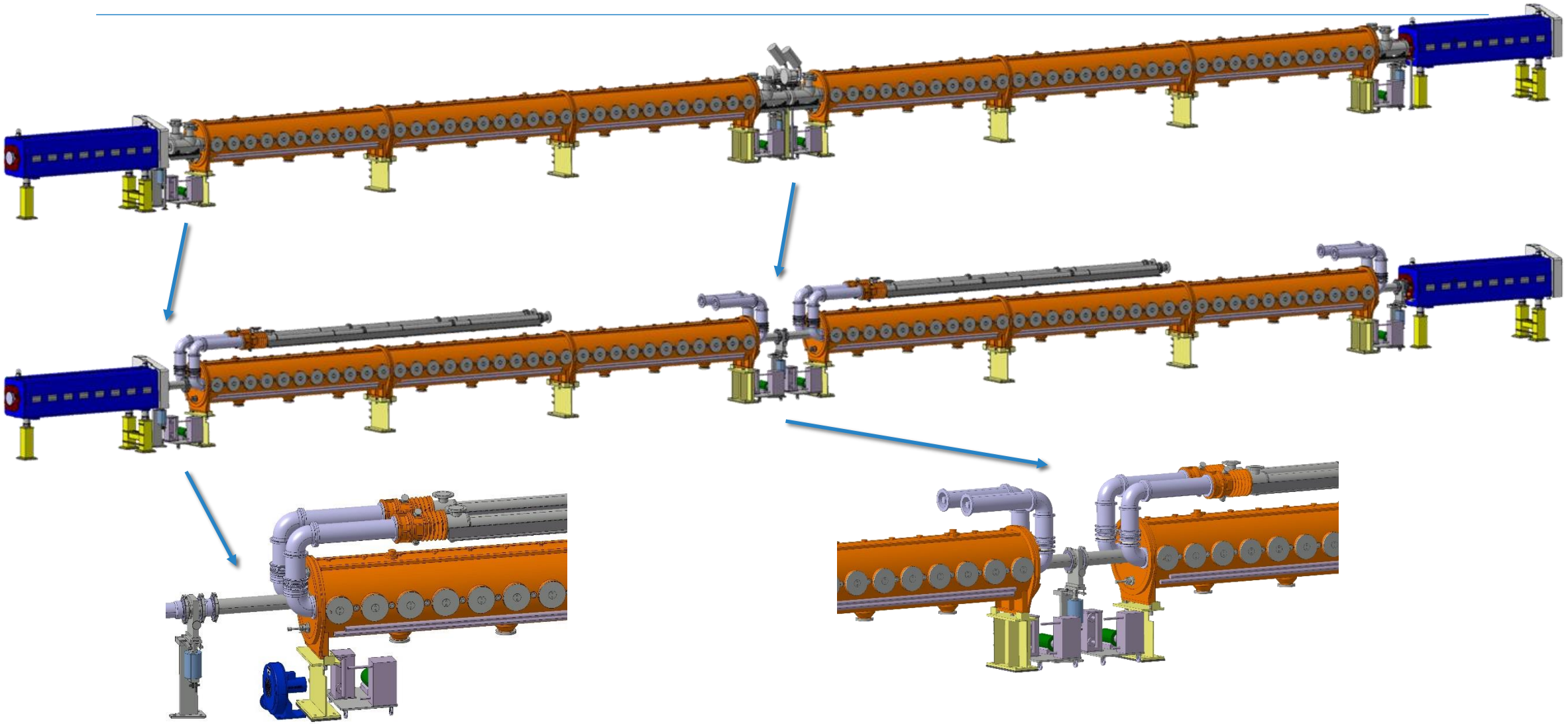




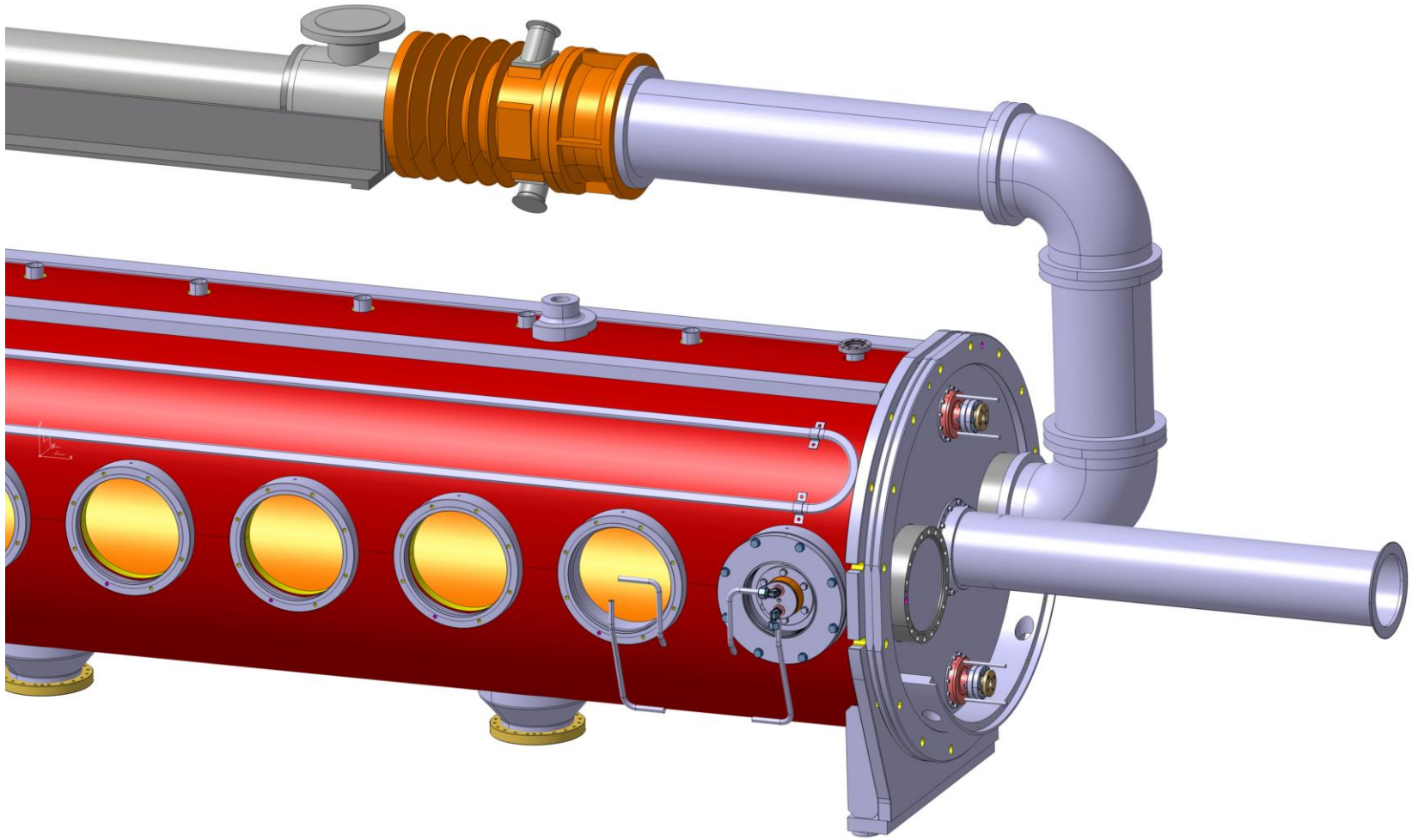


With present FPC design two three sections cavities do not fit in-between two quadrupoles !

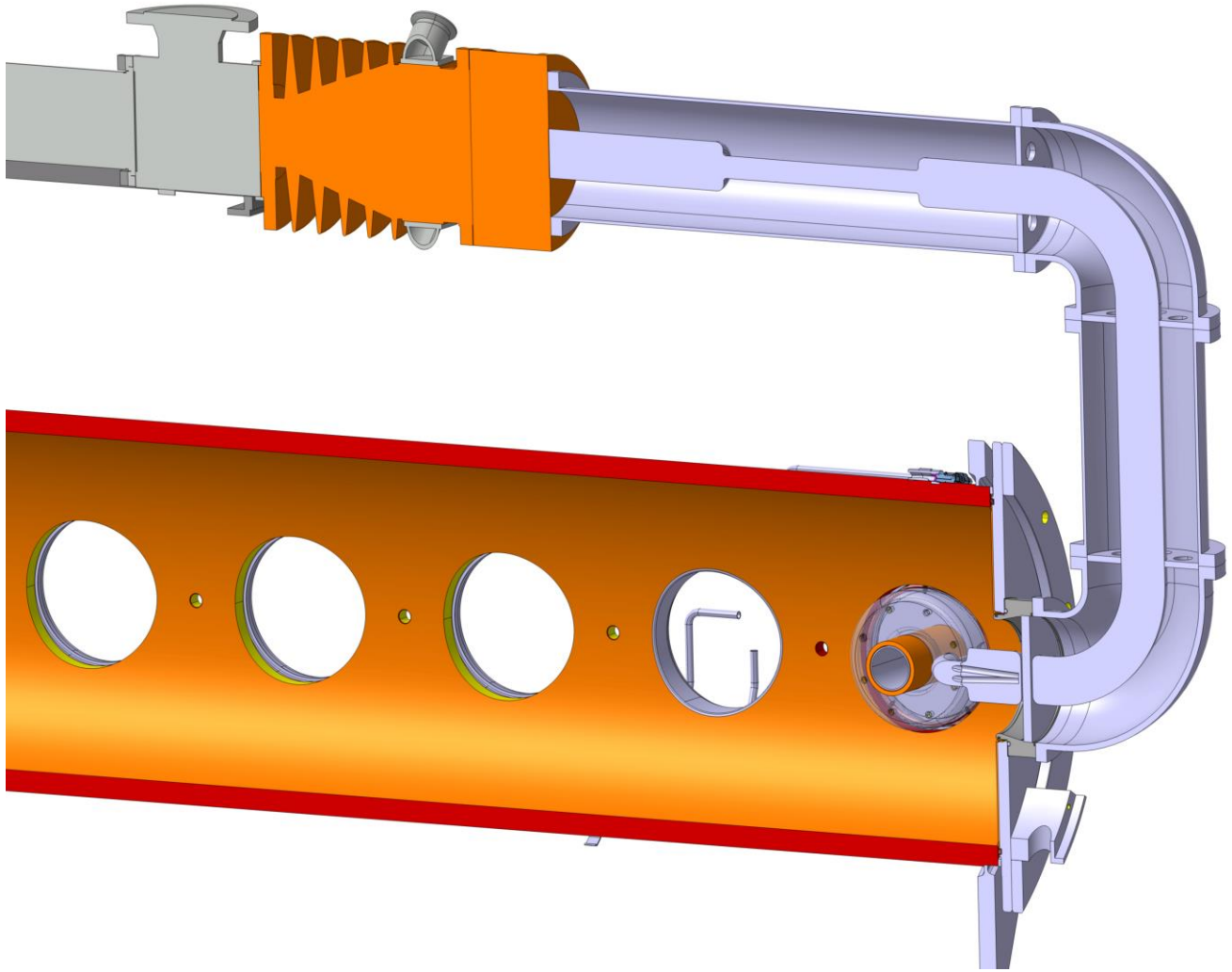
LIU SPS 200



LIU SPS 200



LIU SPS 200

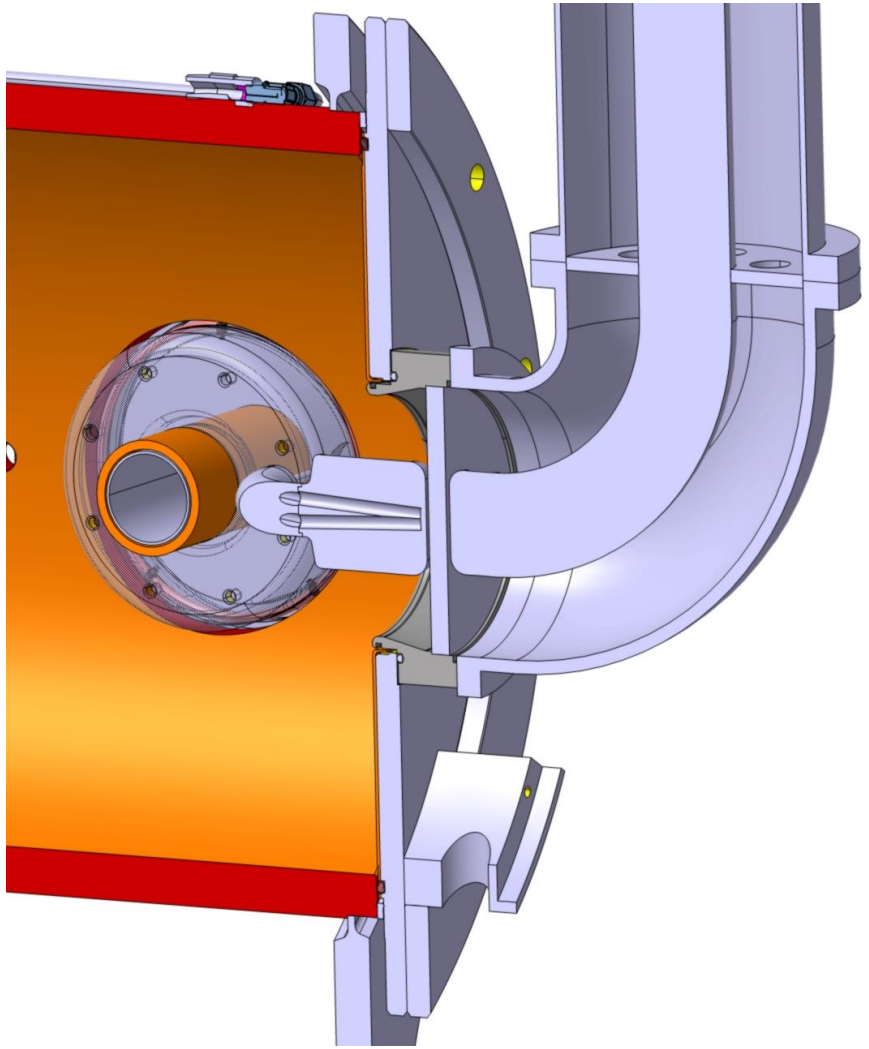


LIU SPS 200

Four ceramics have been delivered

We are building a simple transmission line to test that the principle is ok

I would like to try ‘Kyocera’ ceramic in order to skip the TiOx sputtering process



Conditioning processes

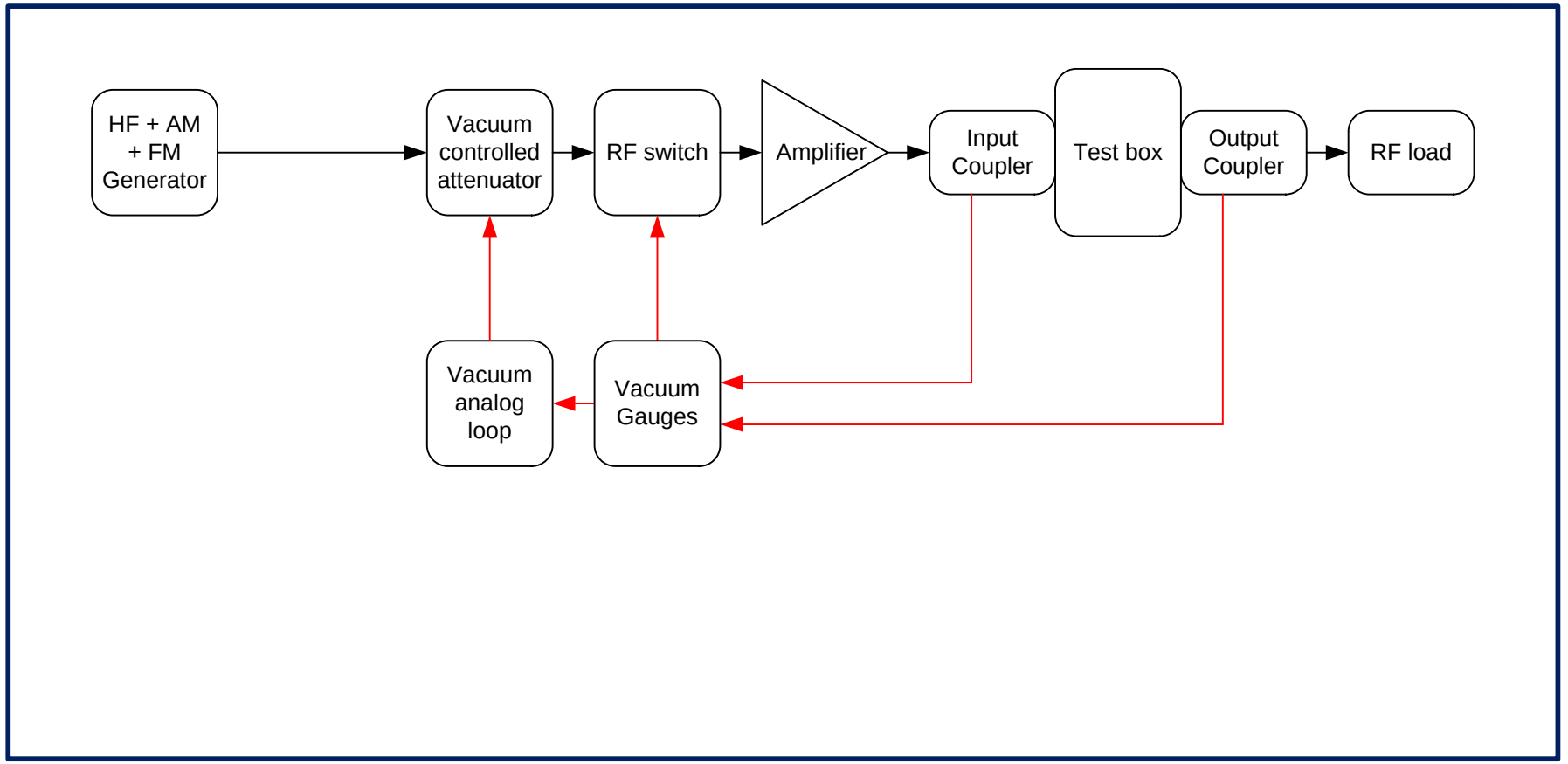
Please refer to SLHiPP#6 workshop : Coupler conditioning at CERN

https://indico.esss.lu.se/event/528/session/2/contribution/15

Conditioning processes

Vacuum gauges reading used for

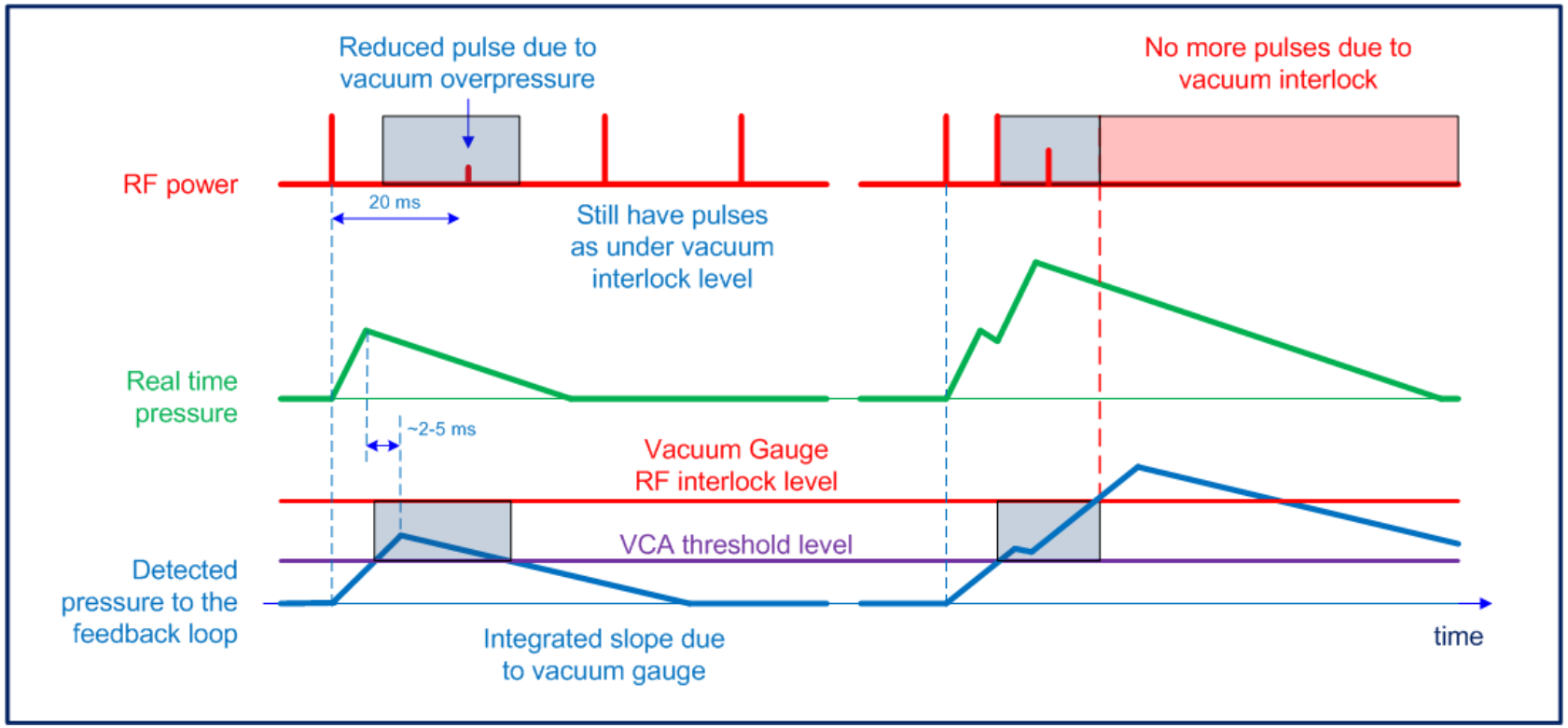
- Interlocking the RF switch if vacuum pressure value exceeds maximum ratings
- (5 x 10^{-7} mbar based on experience)
- Vacuum analog loop to reduce the RF drive in case of vacuum outgassing



Conditioning processes

It is important to keep the repetition rate low enough to allow enough time to the vacuum gauge to detect the pressure rise

This allows not to stop the system, only few pulses are missed



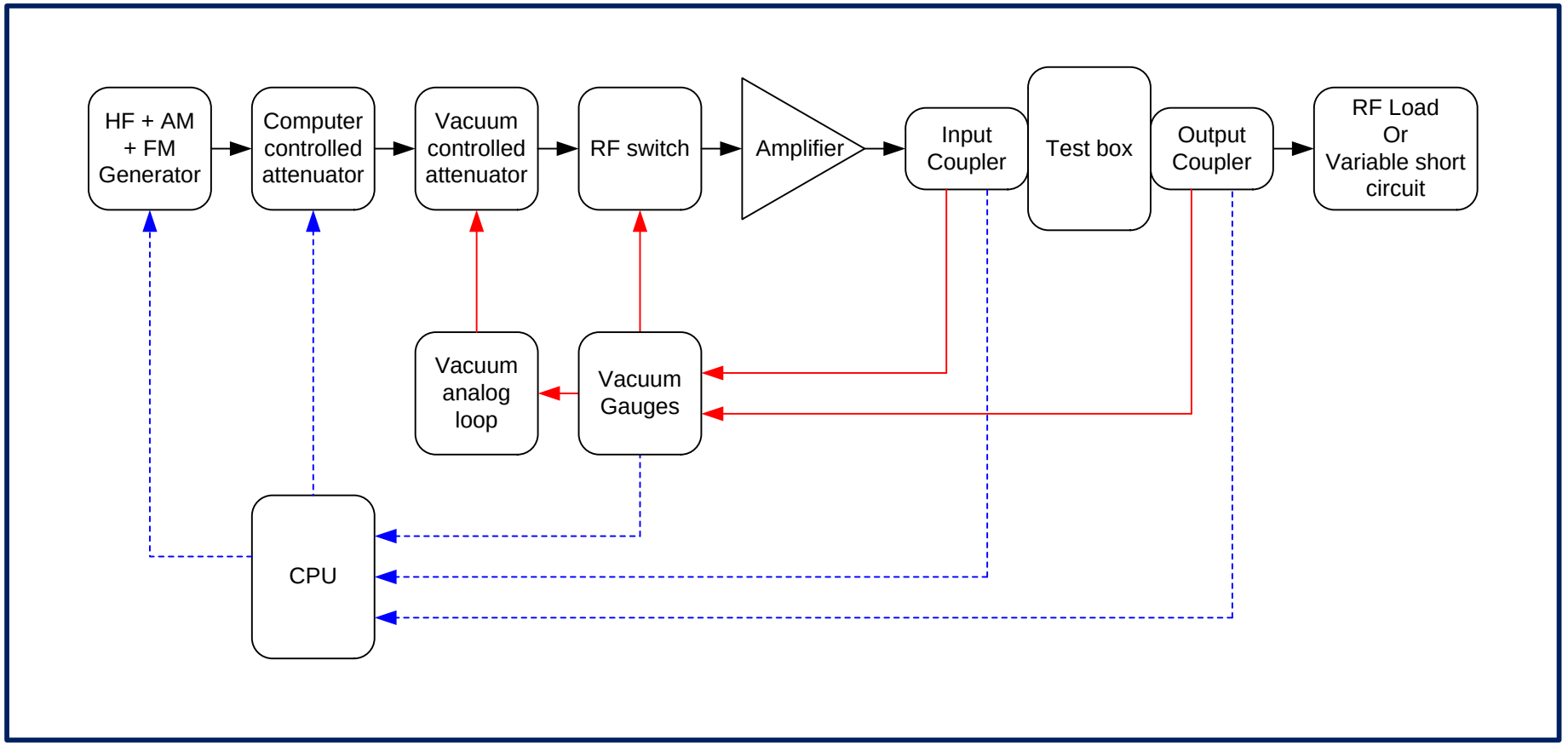
Conditioning processes

In order to speed-up the process, we automated it

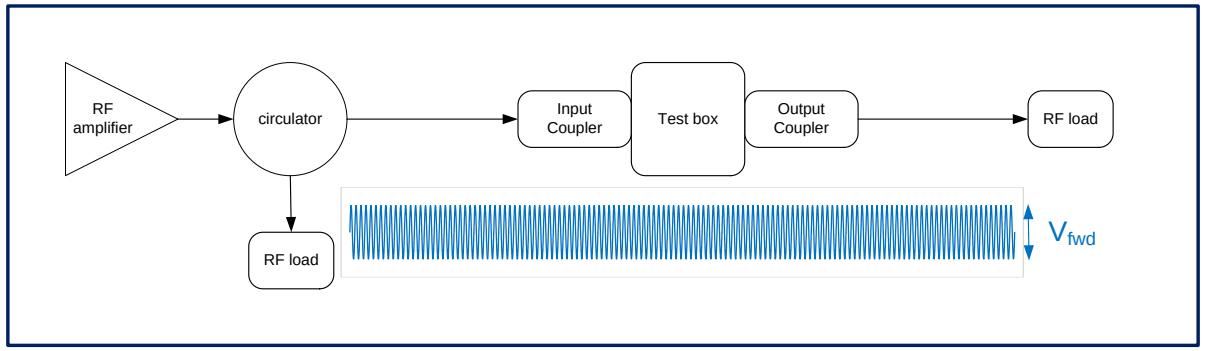
A second loop, computer controlled, was added

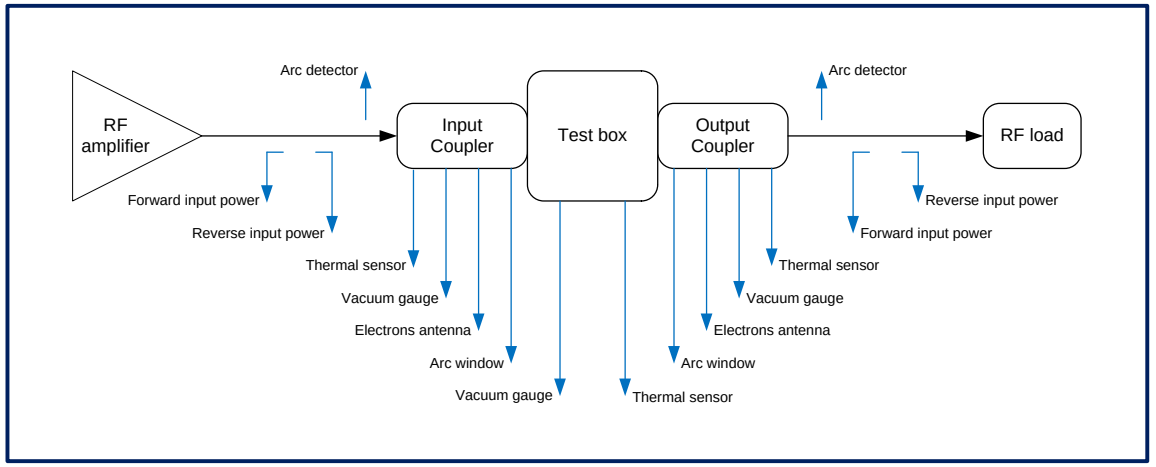
The CPU is also monitoring the vacuum pressure, and also acts in case of outgassing

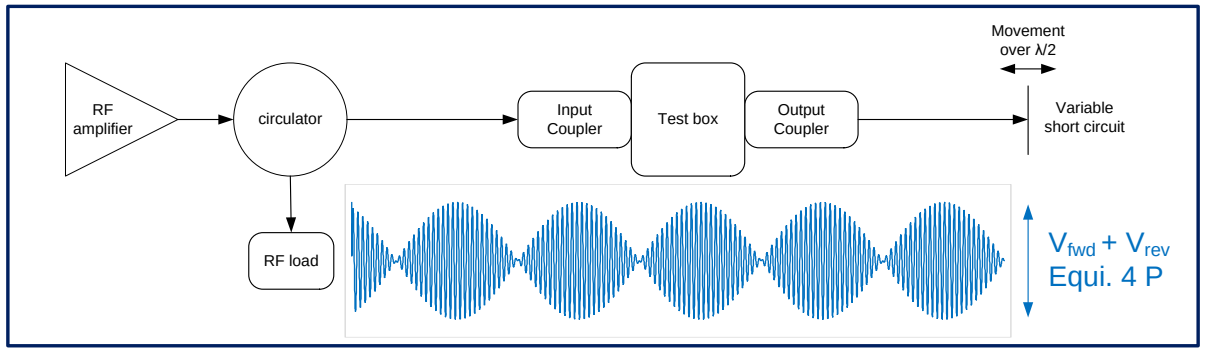
Its main task is to safely increase as quick as possible the RF power level

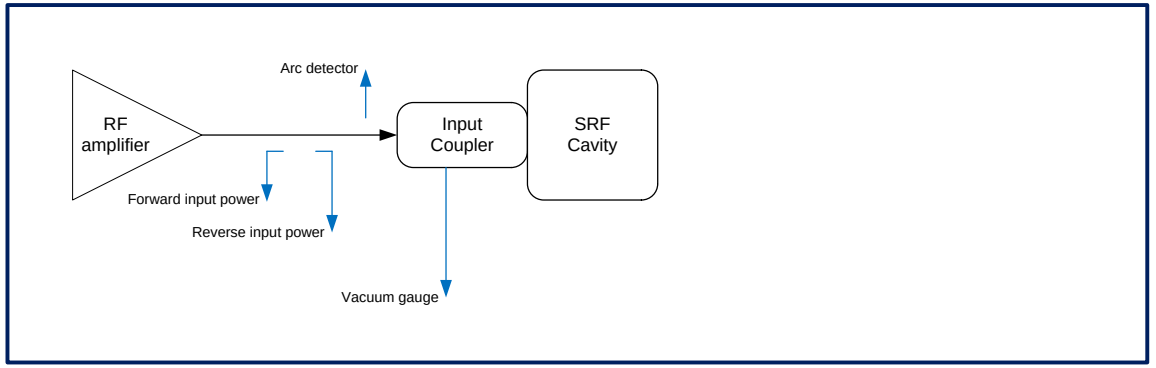


Conditioning processes

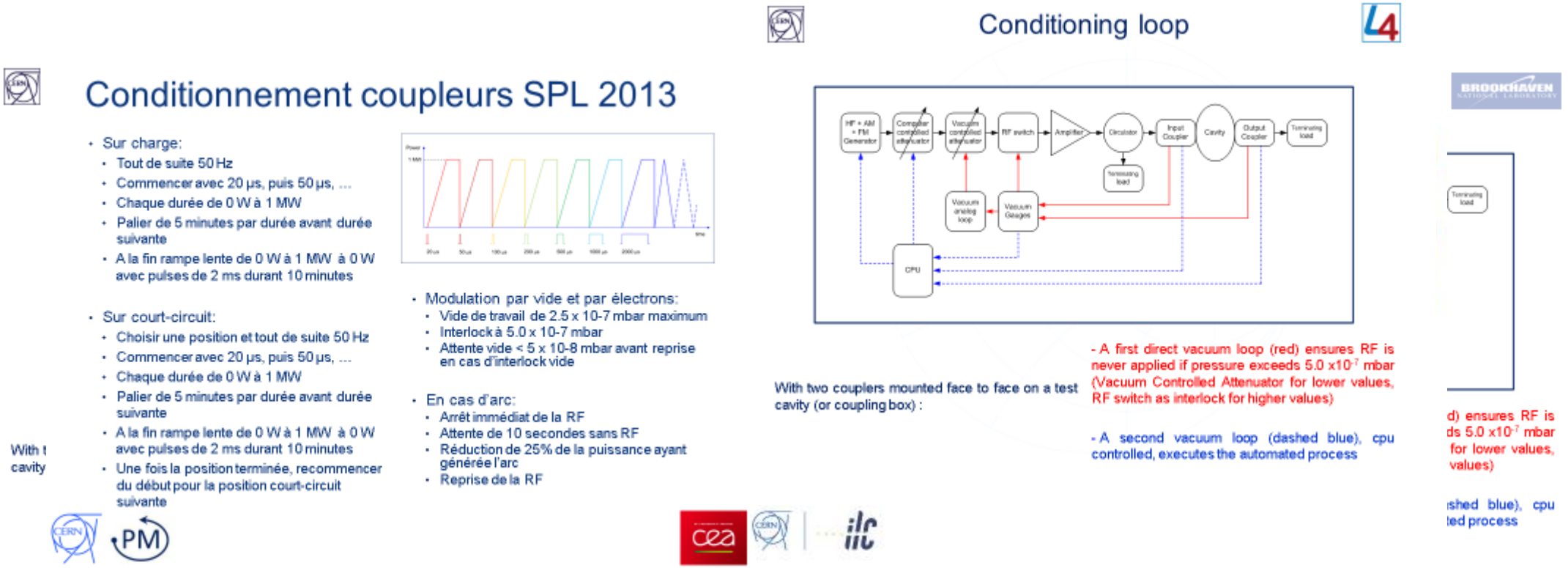






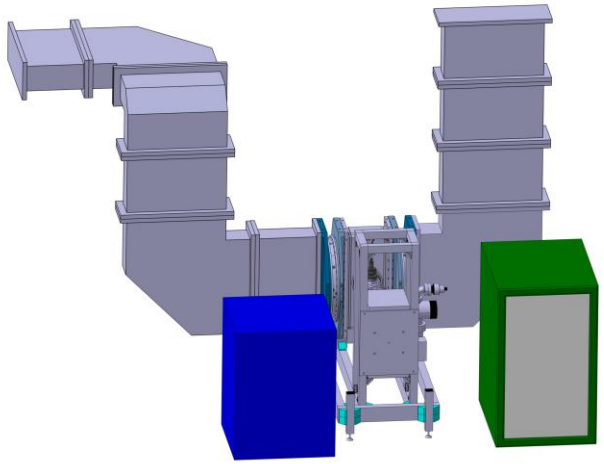


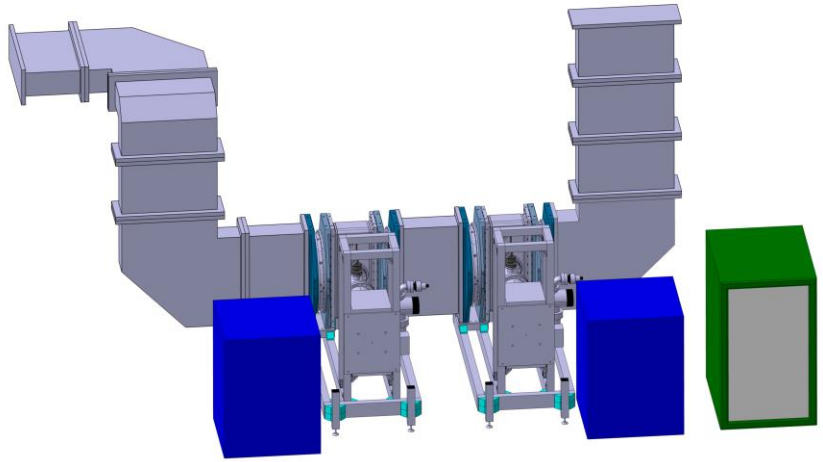
Conditioning processes



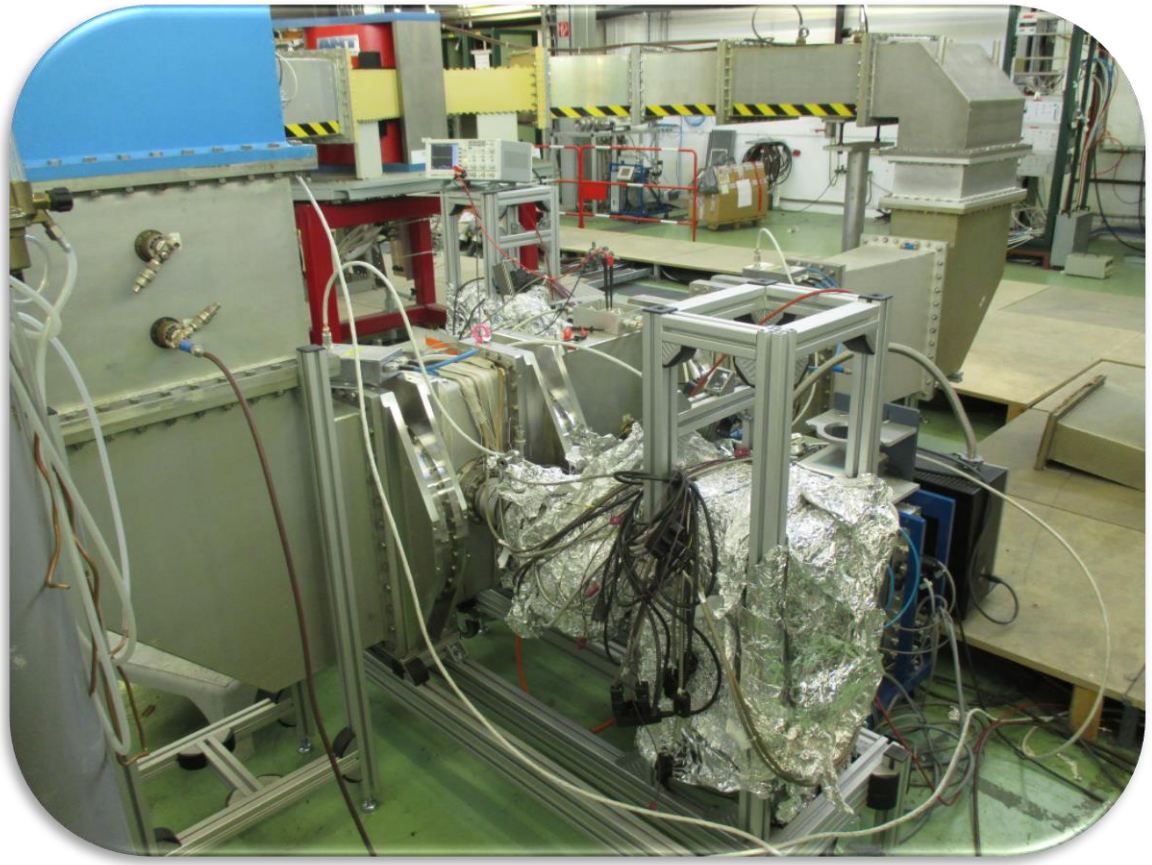
Since we developed it, we provided the system to several places over the world: ESRF, SOLEIL, APS, BNL, LAL, KEK, and of course to all our recent CERN couplers: SPS200, SPS800, LHC, SPL, Linac4
For sure, it is available to whoever would like to have it

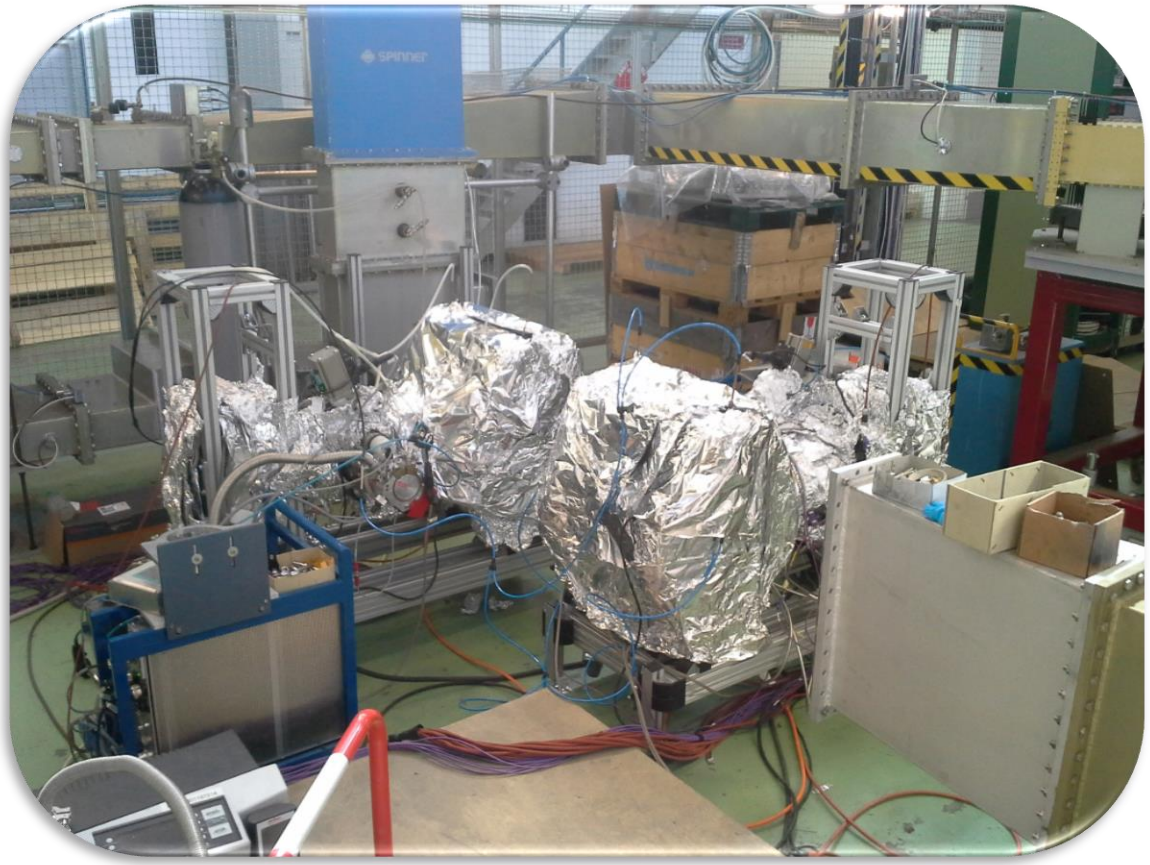
Test bench: one versus two test boxes





Test bench: one versus two test boxes





RF Conditioning

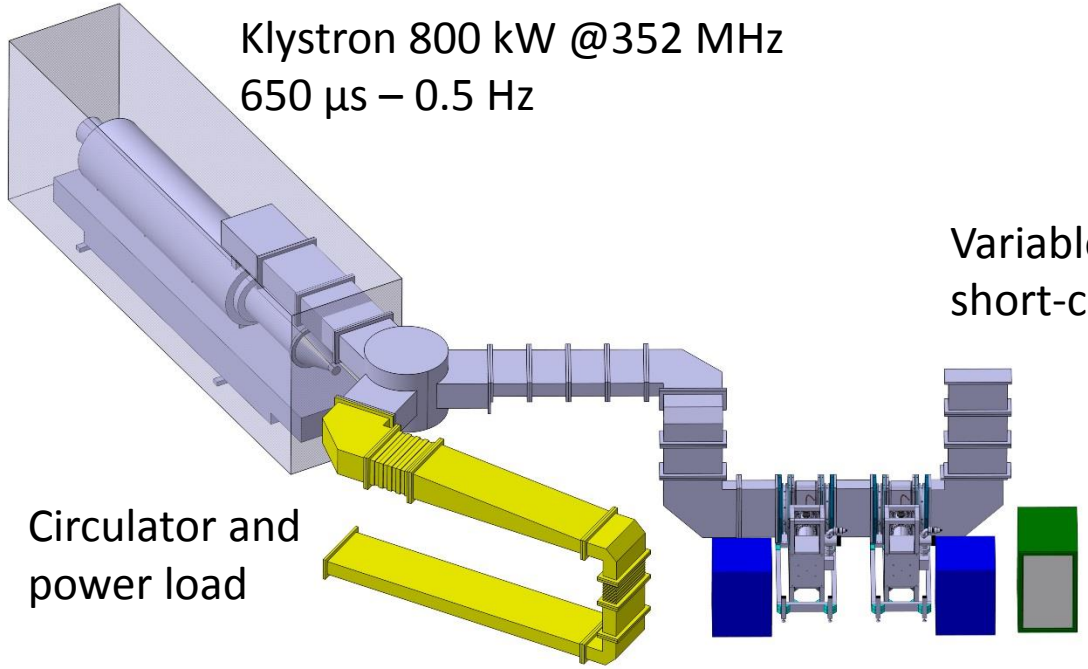
We had to provide 26 windows

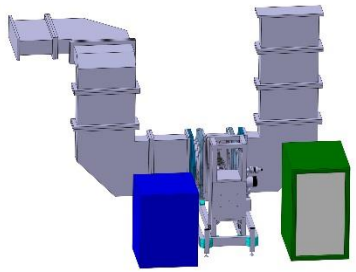
Whilst we were processing a pair of couplers, the next pair was prepared in order to reduce the overall process duration

Later, we decided to test four windows in series (two test boxes)

Some were expecting it not to be quicker as the worst window will slow down the process for both test boxes

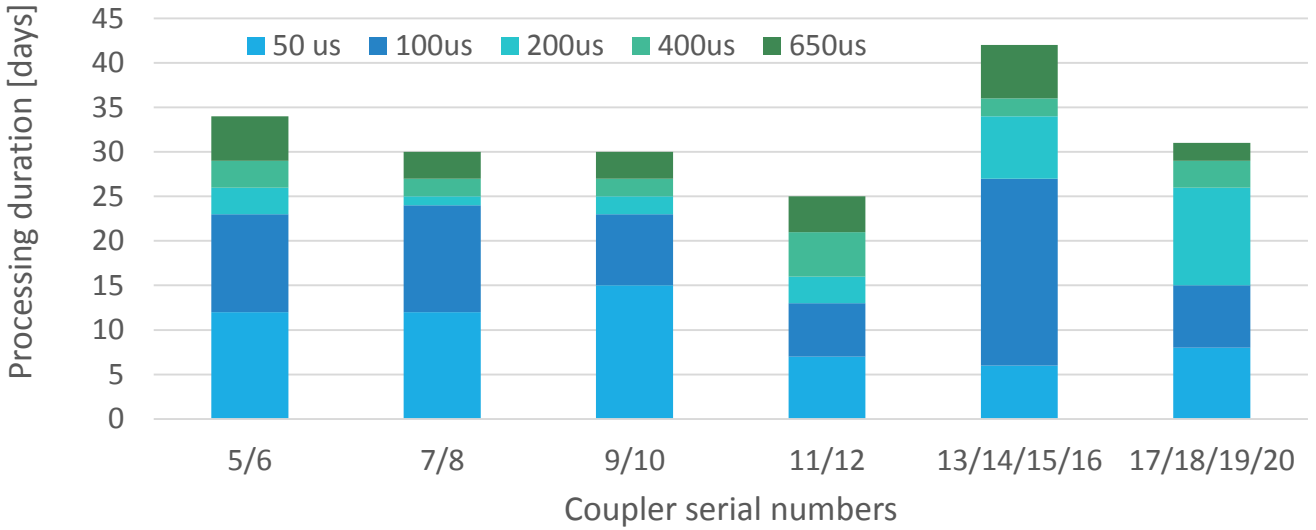
At the end, the process was significantly quicker



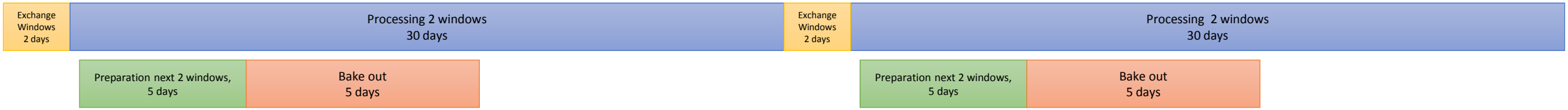


Option with one test box and so one vacuum pump system

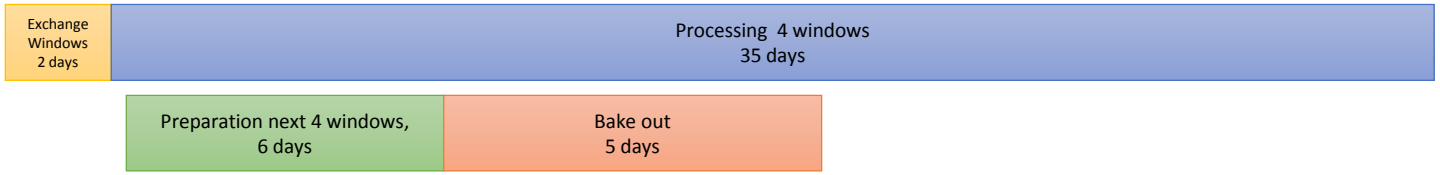
RF Conditioning



Total duration 2 windows + 2 windows = **64 days**



Total duration 4 windows = **37 days**



Four windows in series is much faster than two plus two windows

New FPC area

In addition to SM18 clean room area

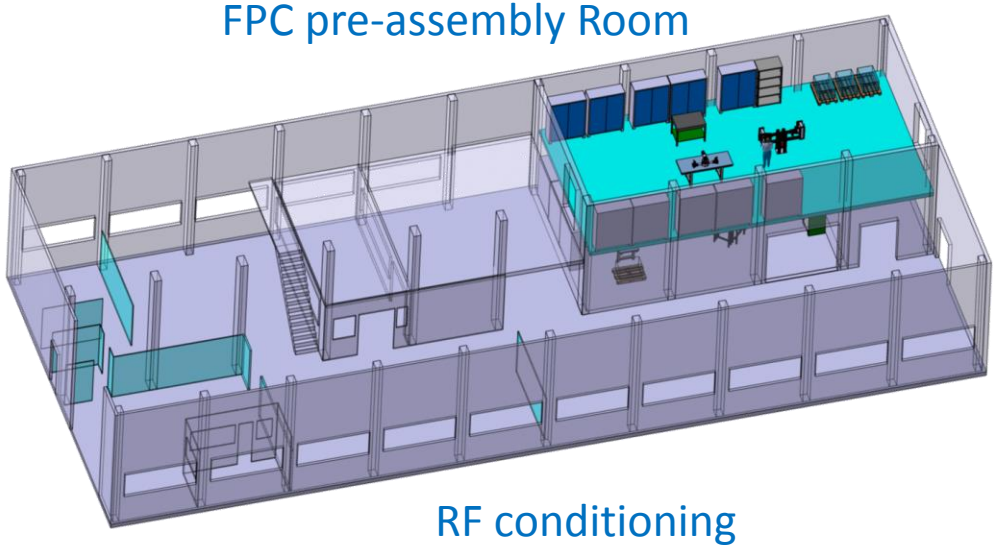
Building 864 FPC zone

65 m2 for pre-assembly (‘grey room’)

65 m2 for RF conditioning

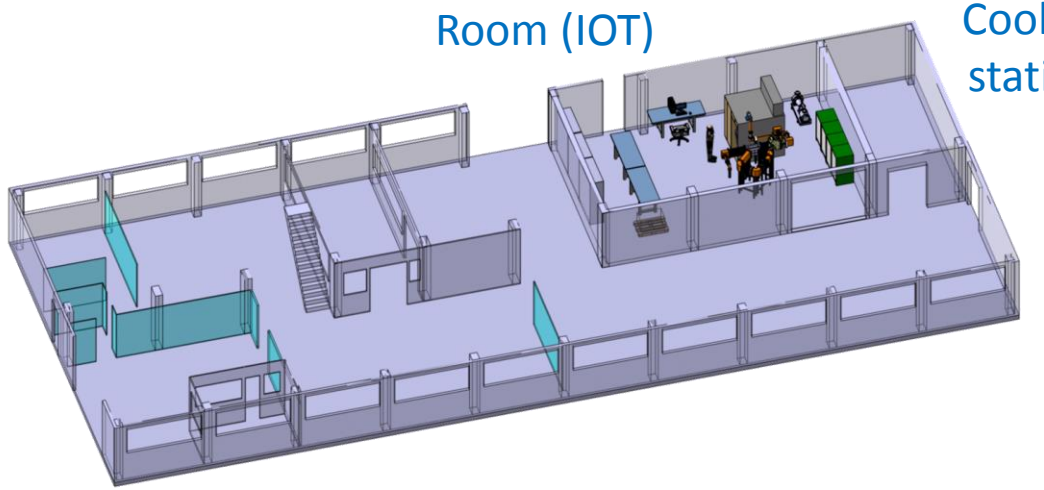
- One IOT
- Solid State Power Amplifiers
- Resonant rings
- Loads
- Variable short circuits

FPC pre-assembly Room



RF conditioning Room (IOT)

Cooling station



Ceramics R&D

Wesgo

Friatec

Kyocera

LEP2 Al2O3 99.6%

MoMn metalized by the ceramic supplier

Silver plated

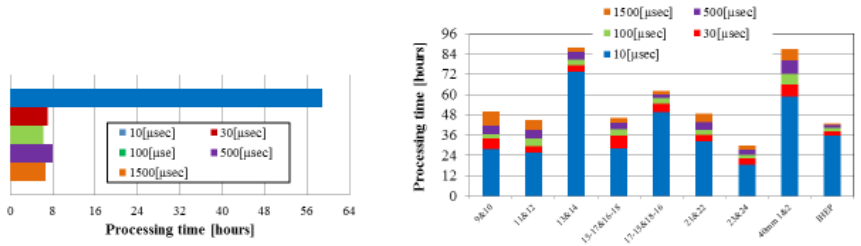
Counter piece (Copper - Titanium - ~~Kovar~~) Ni plated

Wire in molybdenum if needed

TiOx sputtered

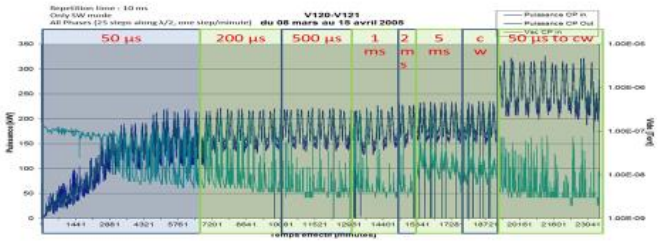
Short pulses R&D

Processing time, short pulses is the most demanding step



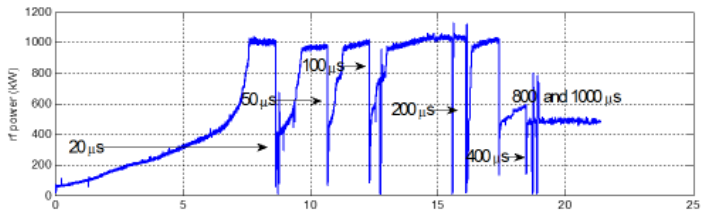
Summary of STF-2 coupler conditioning at test bench
Courtesy of Y. Yamamoto, A. Yamamoto, T. Matsumoto, E. Kako (KEK)

Processing time, short pulses is the most demanding step



Example of LHC coupler conditioning at test bench

Processing time, short pulses is the most demanding step

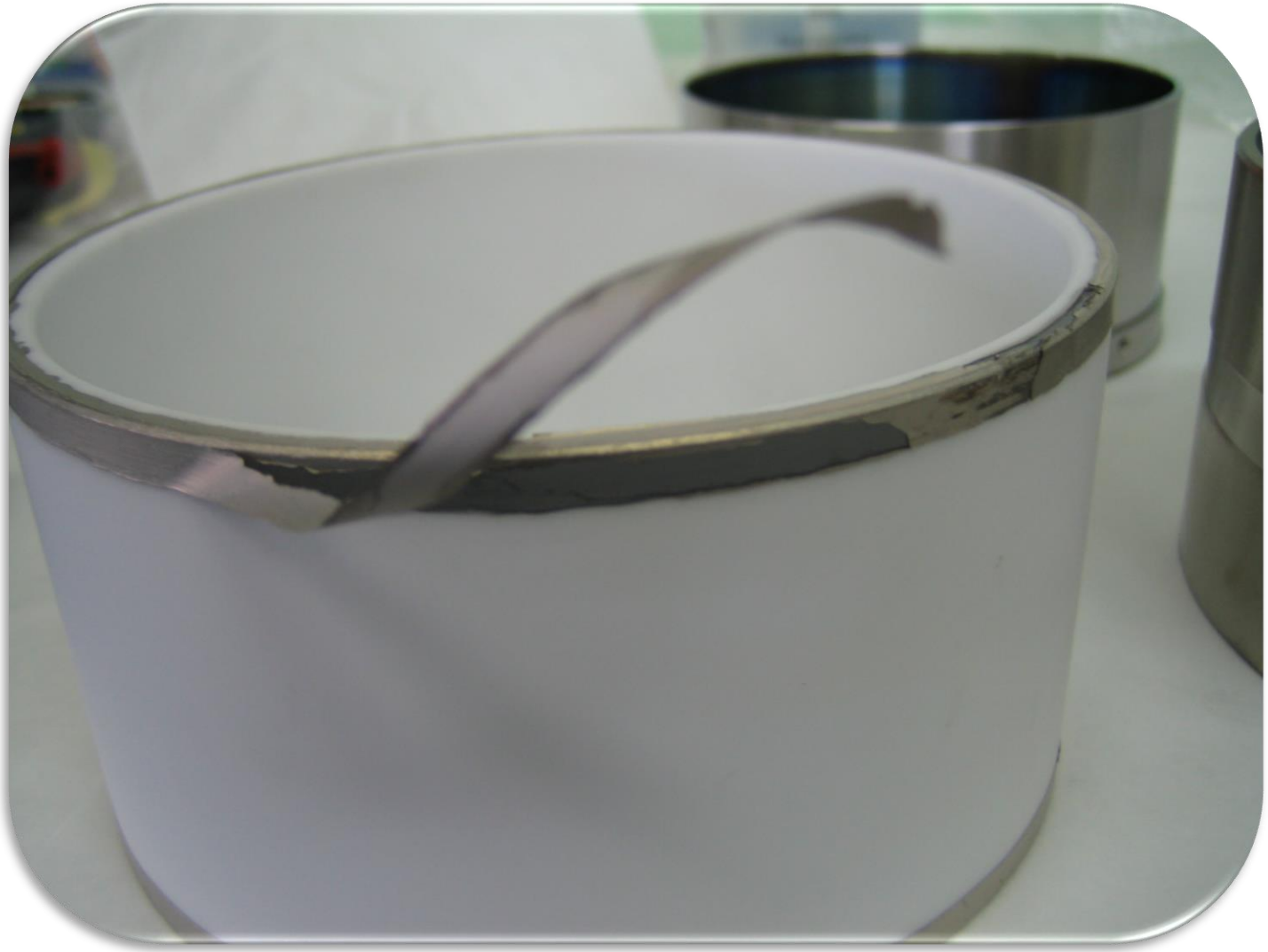


LCLS-II Couplers processing, courtesy of C. Adolphsen (SLAC)

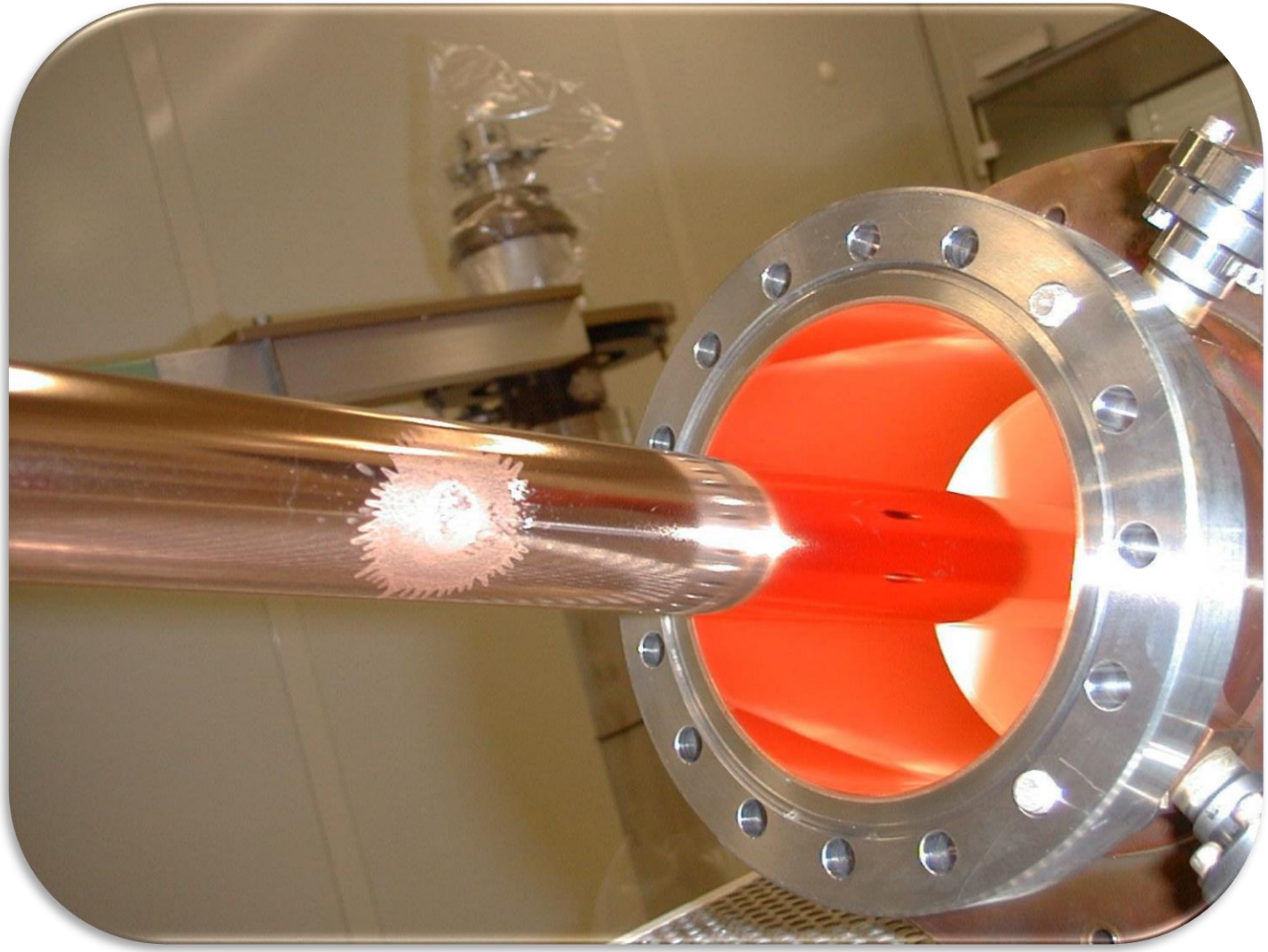
How to improve the first pulse length processing time?

Difficulties encountered in the past years

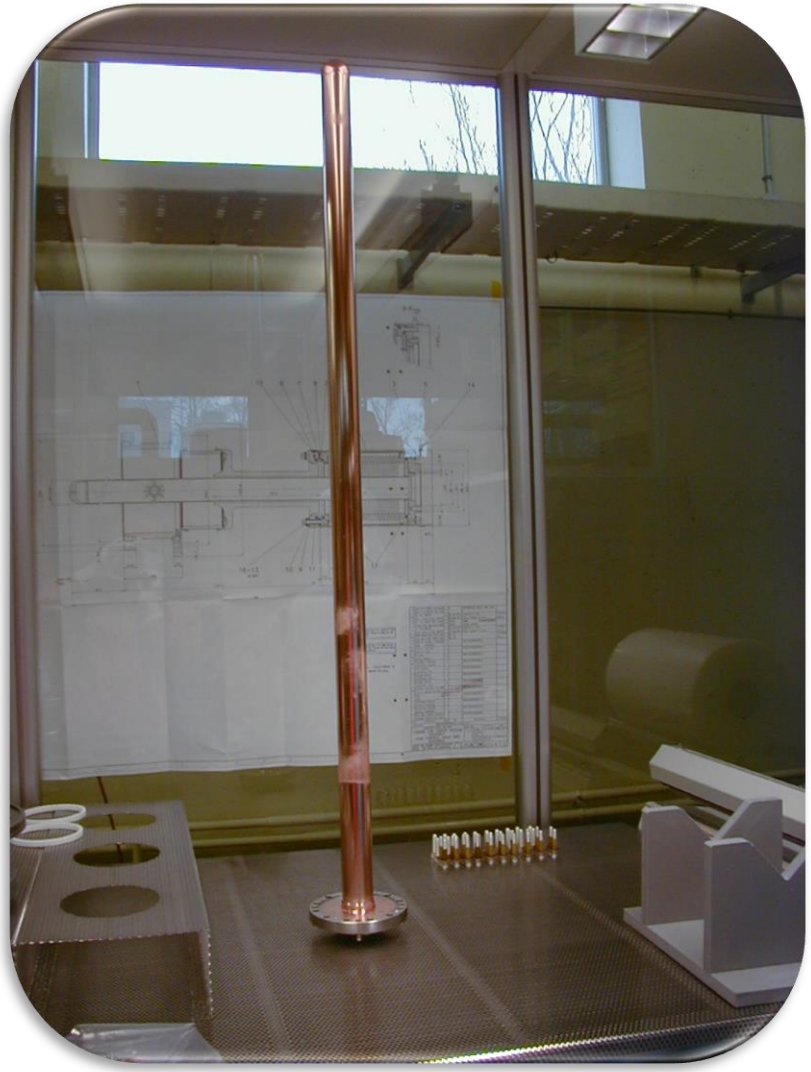
Difficulties encountered in the past years

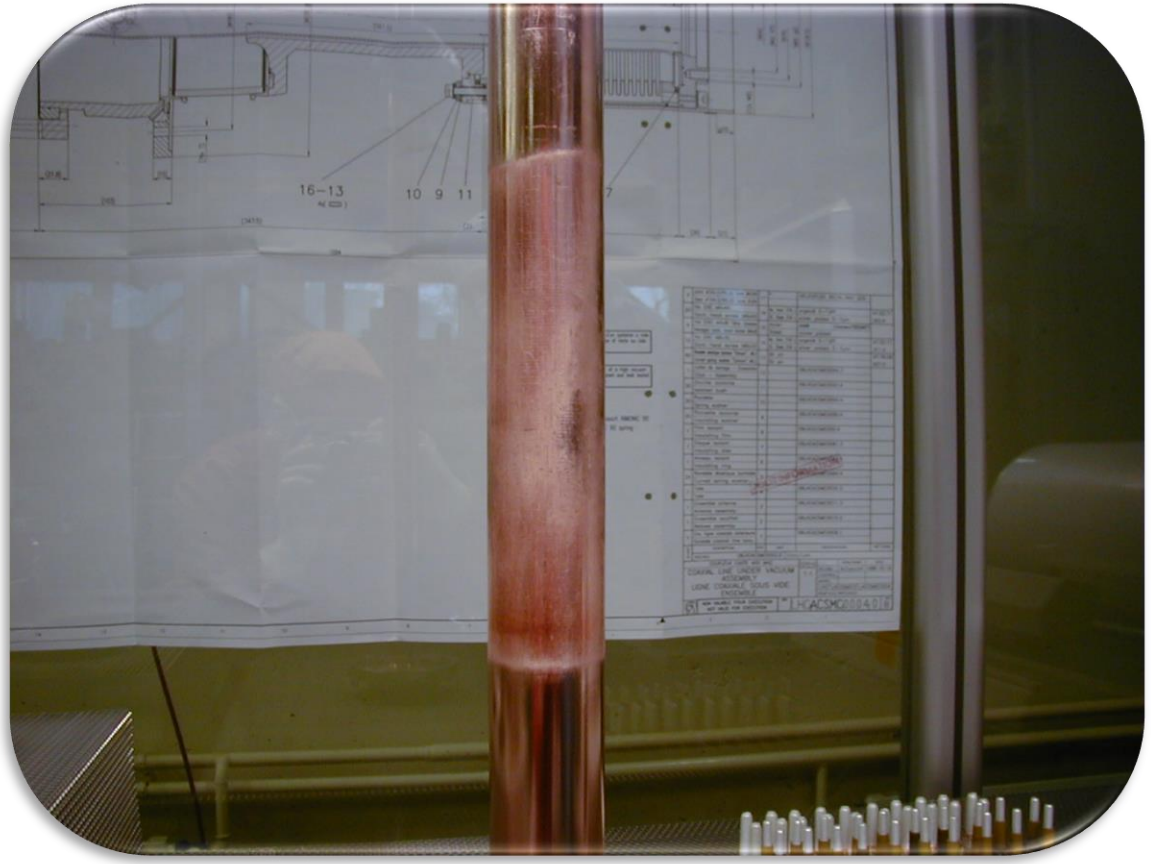


Difficulties encountered in the past years

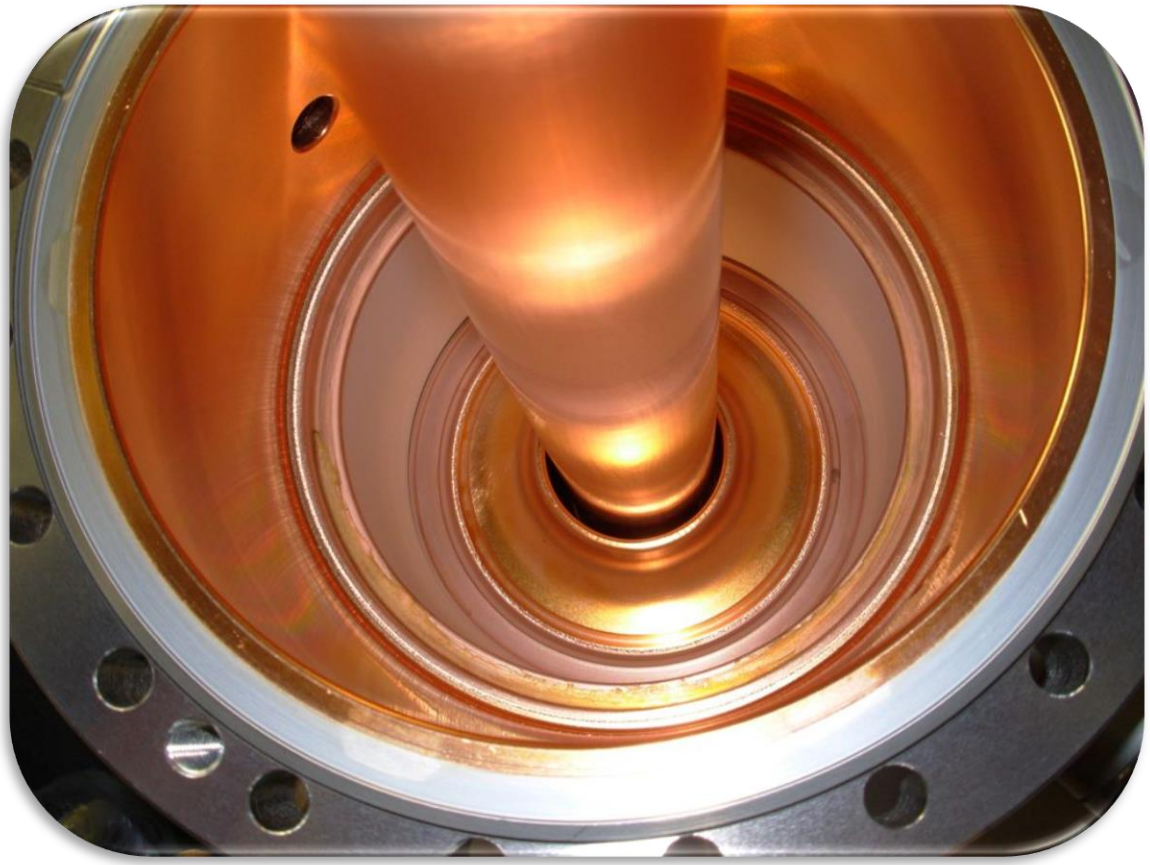


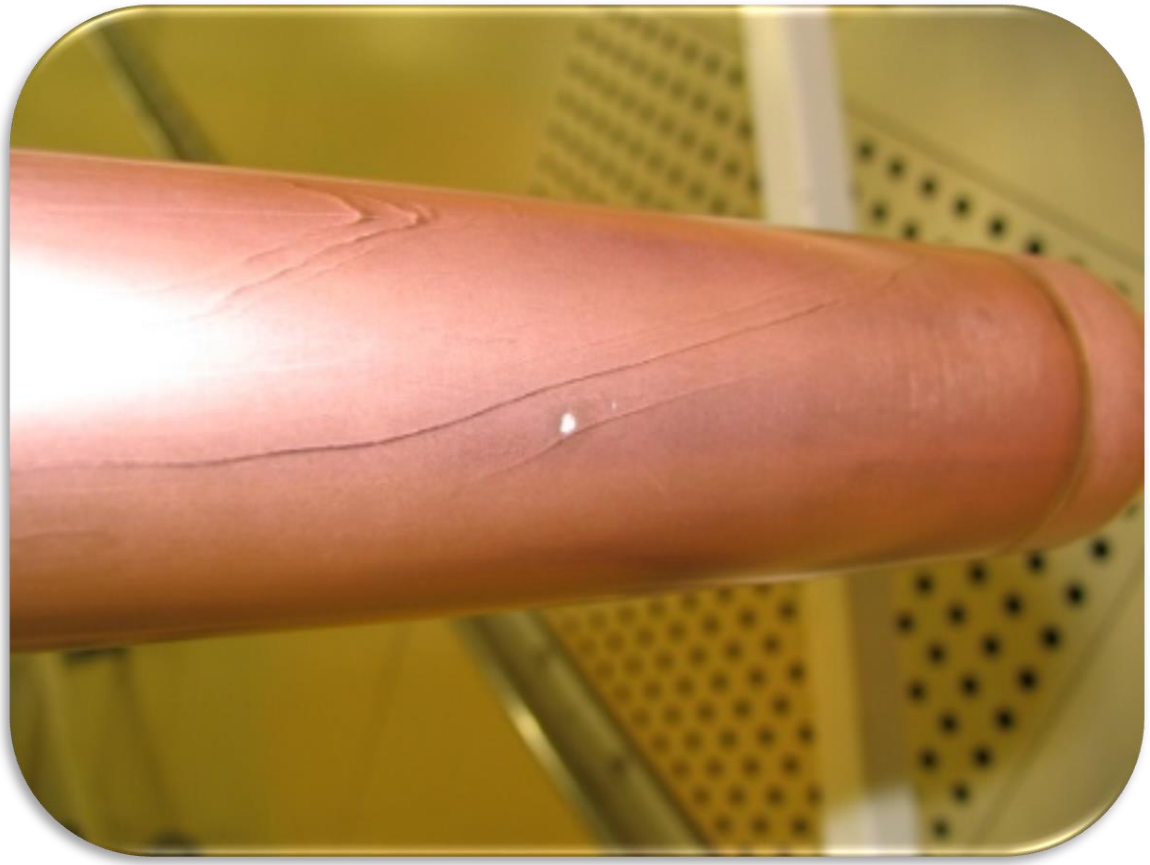
Difficulties encountered in the past years





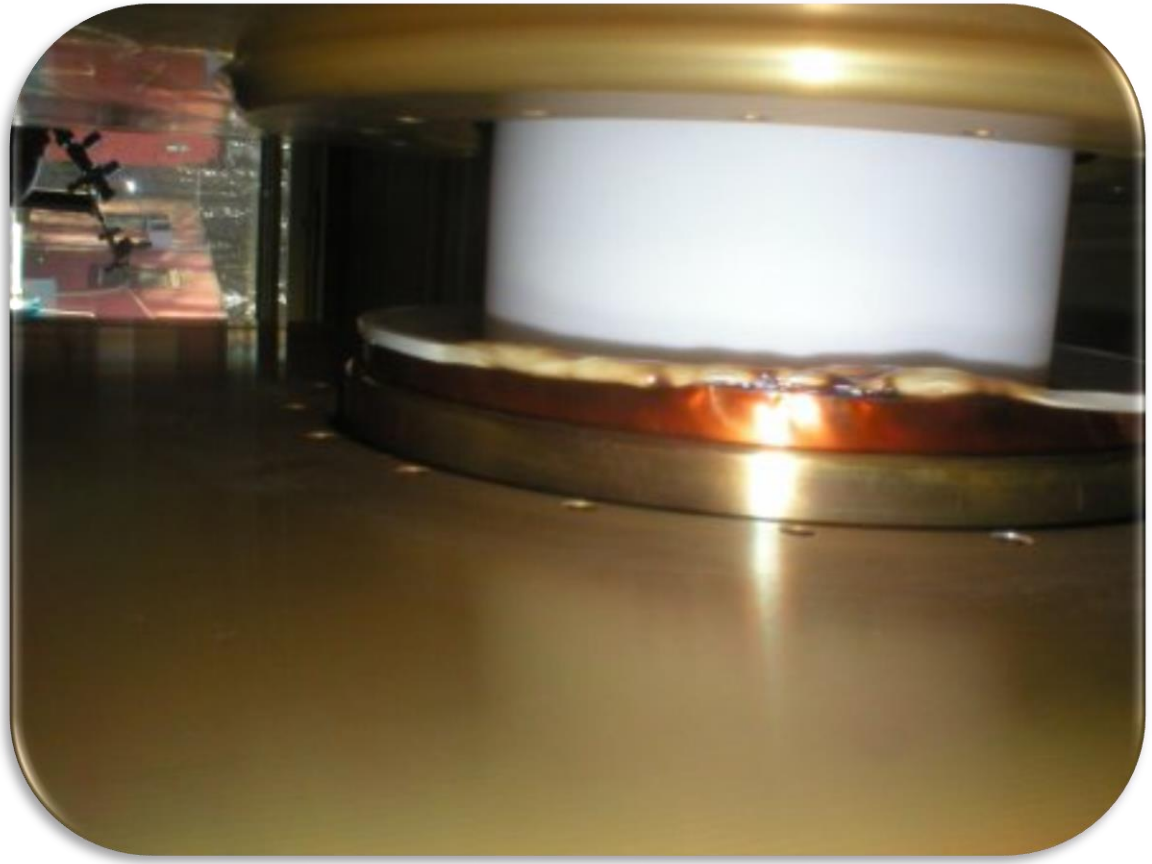
Difficulties encountered in the past years



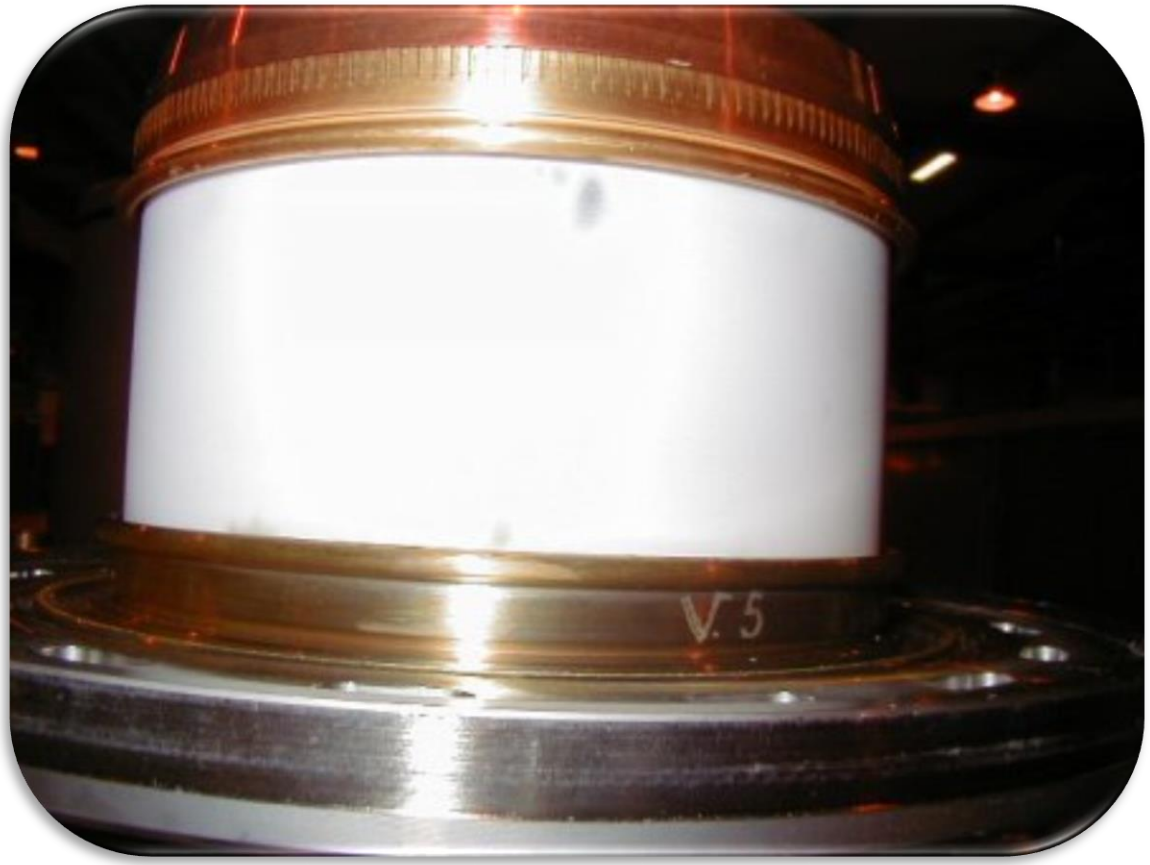


Difficulties encountered in the past years

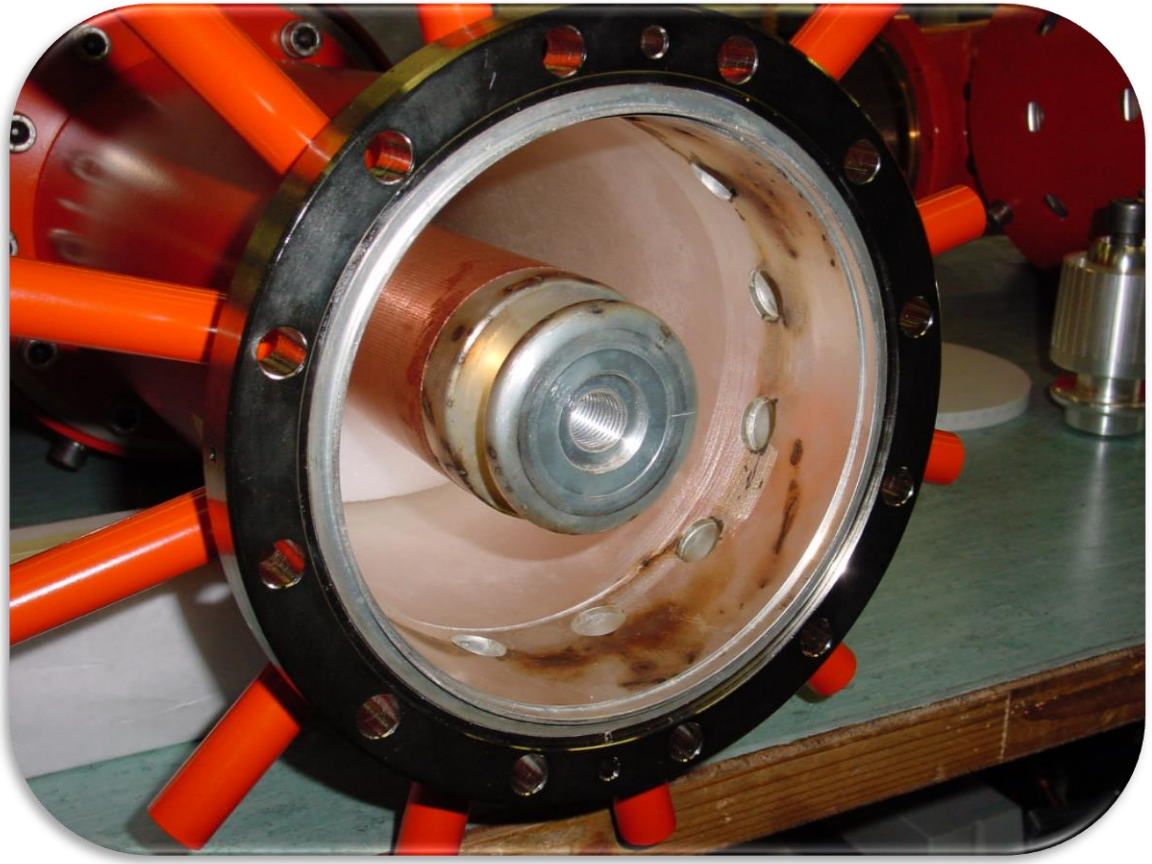
Difficulties encountered in the past years



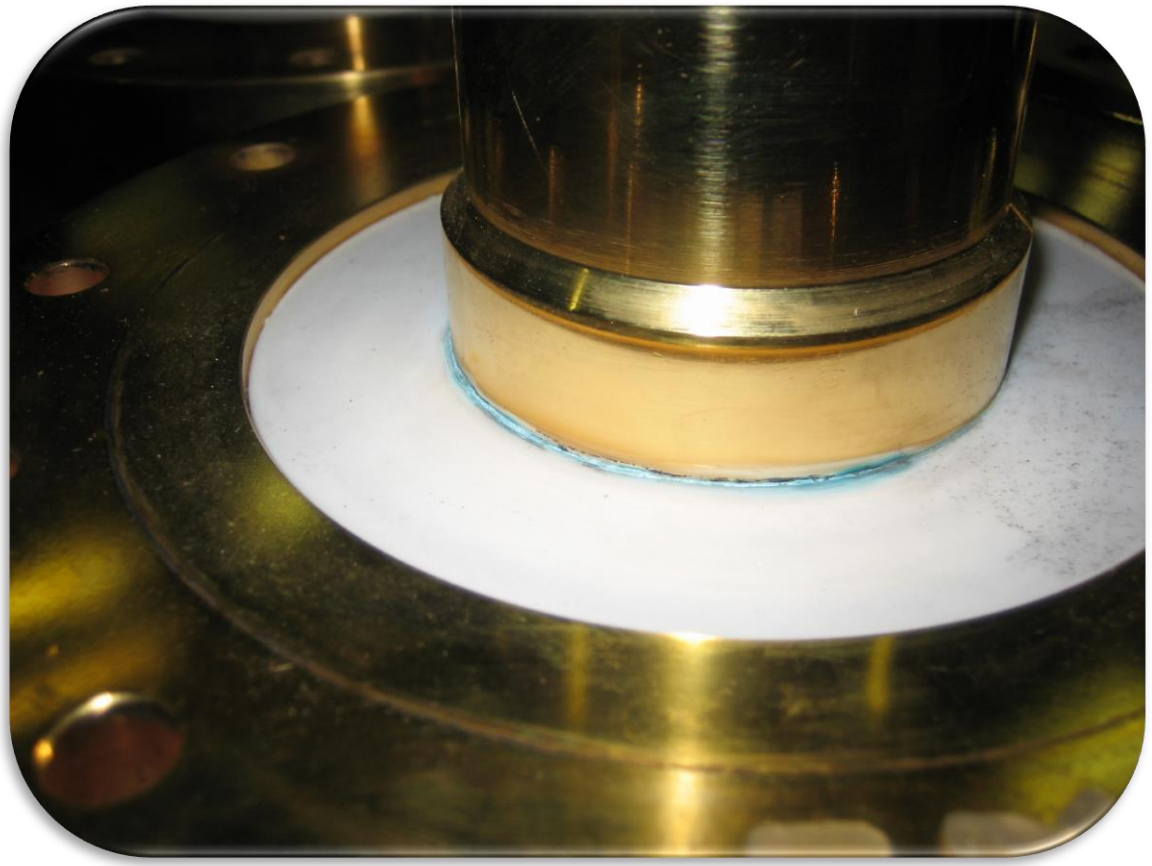
Difficulties encountered in the past years



Difficulties encountered in the past years



Difficulties encountered in the past years



Conclusion

We now have knowledge on

- Design
- Construction (many various processes with various experts that have constructed their experience on many other projects than FPC)
- Clean room tooling and assembly
- Test boxes
- RF Processing
- Integration in labs or machines

Even if we still have a lot to learn, whenever you want to share, please do not hesitate, it will be our pleasure to try to help and to always learn more !