CERN-SPL PROPOSED RF POWER COUPLERS

ALBA, BARCELONA, SPAIN

CWRF2010

4th – 7th May

Workshop on High Power RF

BE (Beams department)
RF (RF group)
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  - HIPPI window
  - SPS window
  - LHC window
  - ESRF/SOLEIL couplers upgrade
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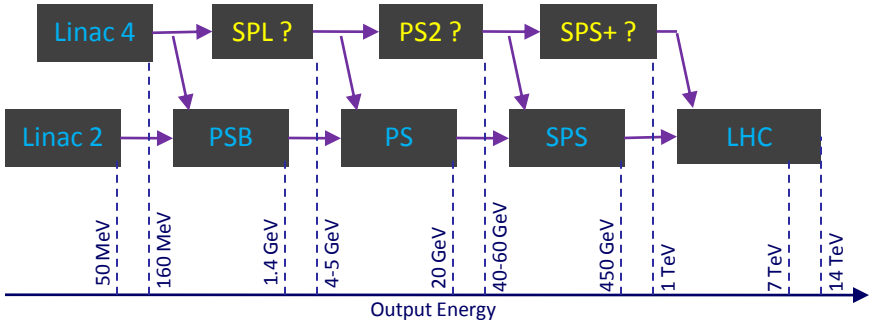
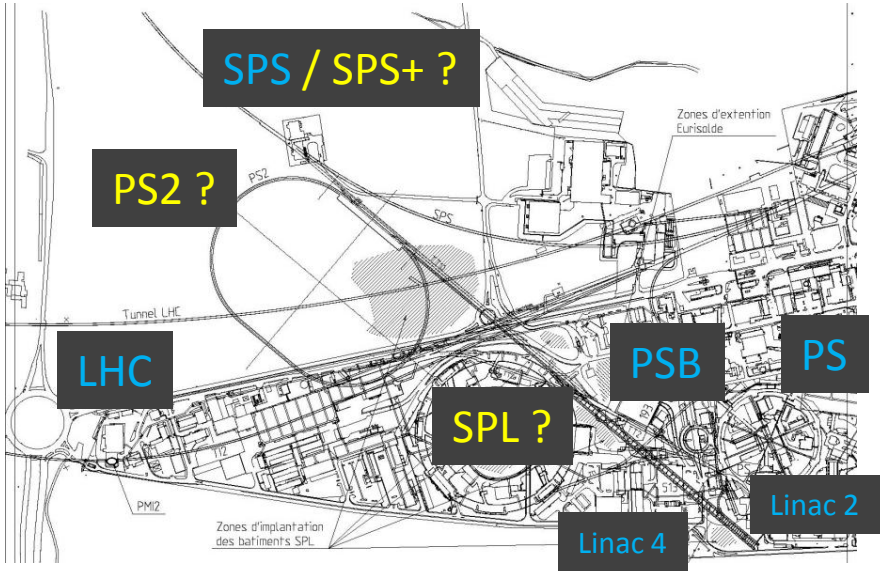
SPL PROJECT

- The existing complex of accelerators at CERN is capable to provide the Large Hadron Collider (LHC) with the beam required to reach its nominal characteristics
- Higher performance injectors will however be necessary to exceed this limit and maximize the physics reach of the LHC
- As a first step, the construction of a new 160 MeV H- linac (Linac4) has started
- A 4-5 GeV high beam power Superconducting Proton Linac (SPL) operating at 704MHz has been under study at CERN for some time
- We are seeking approval for a first stage of prototyping of a general high intensity proton driver based on SPL parameters.

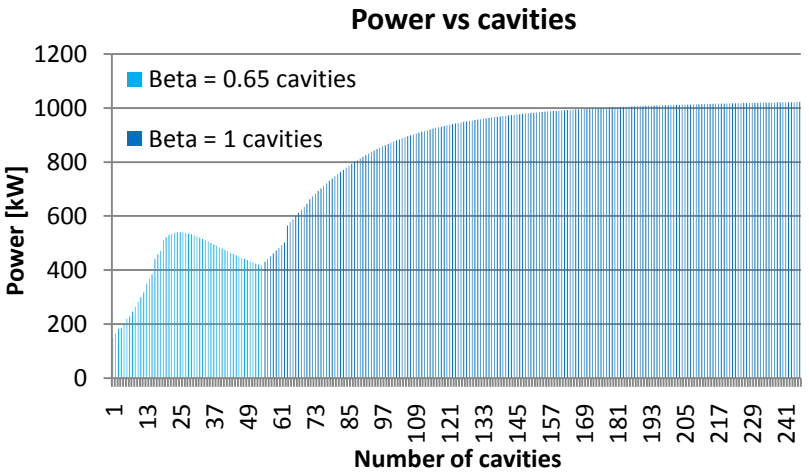




PRELIMINARY REMARKS

- The first goal of this study program is to build an horizontal test cryostat with four cavities and four couplers to prove that contiguous 704MHz cavities can reliably operate at 25MV/m accelerating gradient
- It is foreseen to test cavities in this cryostat at high RF power during the first half of 2013
- From the coupler point of view, this is a tight schedule (we should deliver 4 conditioned couplers for mid 2012)
- We have NO time for a new ceramic window design
- We also have to keep in mind, it could be followed with the production of up to 246 cavities with their own individual couplers, i.e. 275 couplers

f_0	704.4 MHz
High Power SPL	1000 kW pulsed 0.4 + 1.2 + 0.4 = 2.0 ms 50 Hz (20 ms) 100 kW average
Cavity design gradient	25 MV/m
Q_{ext} of input coupler	1.25 x 10^6
Input line Ø	100 / 43.5 mm = 50 Ω



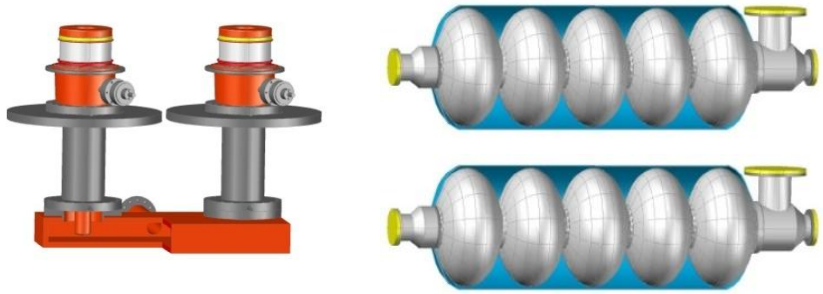
MARCH 2010 COUPLER REVIEW

- In November 2009, we proposed three main ideas:
  - ➢ To use the CEA SACLAY HIPPI coupler and to modify it to fulfill the SPL requirements
  - ➢ To build a new coupler with a similar window as the SPS power load
  - ➢ To build a new coupler with an LHC window
- In March 2010, we had a coupler design review where the two new proposed designs were thought reasonably feasible

Coupler parameters definition
A single window coupler (long history at CERN with single window couplers, LEP I, LEP II, LHC, SPS)
A fixed coupler
With a Double Walled Tube
Mounted on the cavity in clean room with its double walled tube horizontally in only one operation
With its final position vertically below the cavity (HOM cooling requirements)
With a HV DC biasing capacitor
Air cooled

CRYOMODULE INTEGRATION

- The RF conditioning of the couplers will be done prior to joining to the cavity
- A pair of couplers will be brought into the clean room with two cavities
- The couplers will be mounted onto the cavity horizontally with its double walled tube (at the time as HOM, antenna, …) to not pollute the cavity: XFEL "cold window" process



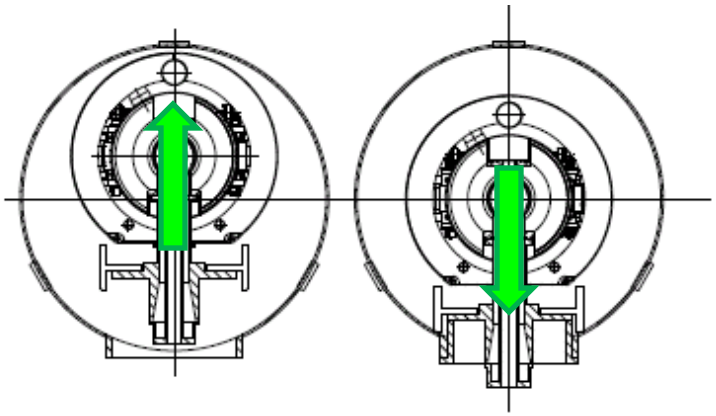
CRYOMODULE INTEGRATION

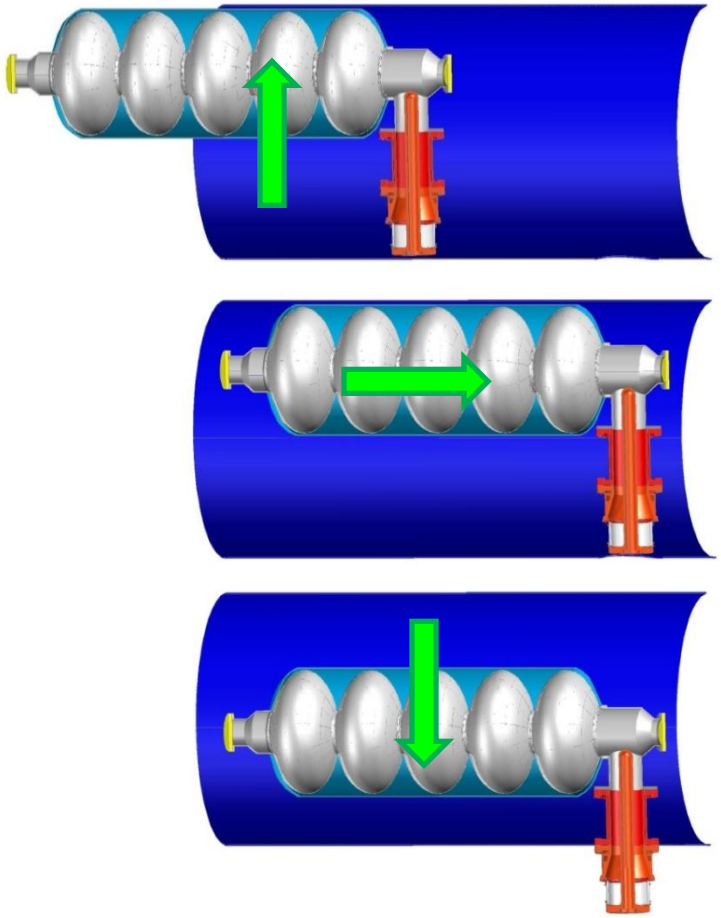
- Very important decision for the design of the coupler

→ imposes a short distance from the ceramic to the beam axis …

... because this defines minimum diameter of “pipeline” type vessel:

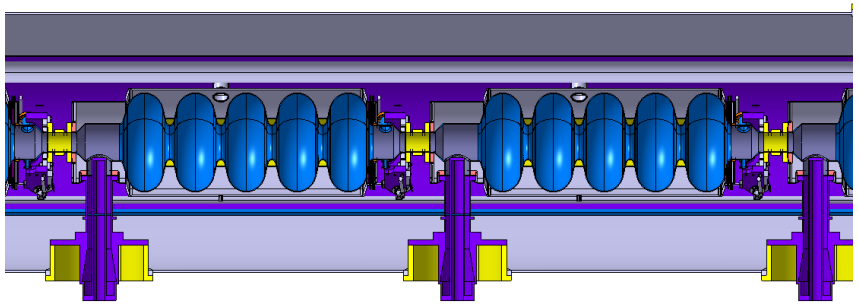
- Lenght of double-walled tube
- Integration of thermal shield

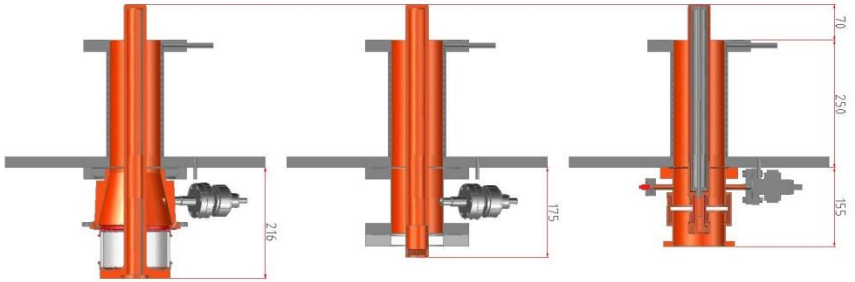




CRYOMODULE INTEGRATION

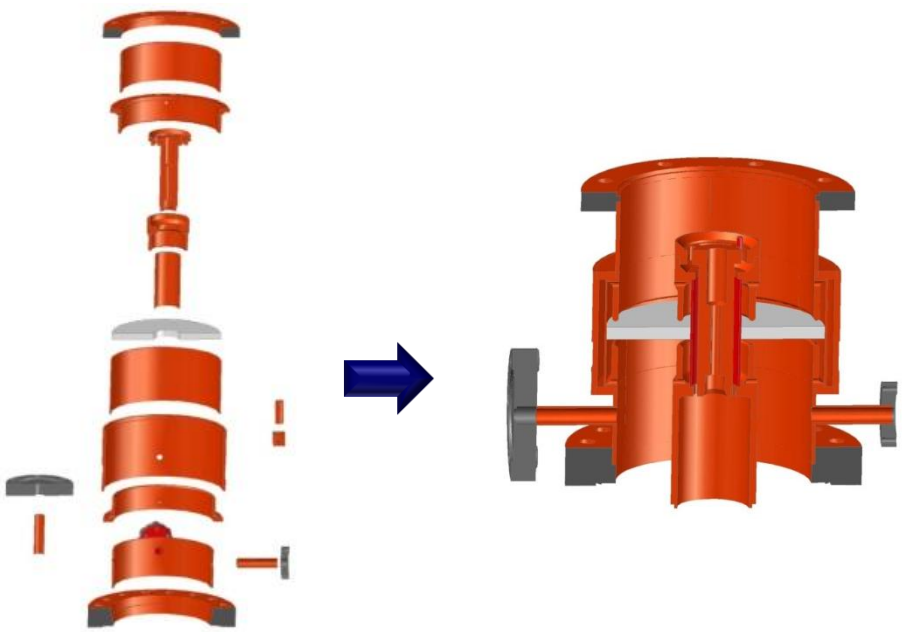
- Even if the cryomodule is not yet fully defined, all the proposed designs should fit into the same cryomodule
- We are trying to design them to be not different from the cryomodule point of view
- They will be connected to the cavity with exactly the same double walled tube





FIRST DESIGN:
COAXIAL DISK WATER COOLED WINDOW

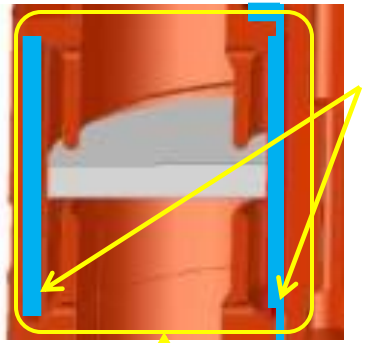
- The first approach was to use the CEA SACLAY HIPPI coupler and to modify it to fit the SPL requirements
- Design based on a coaxial disk ceramic window as in operation at KEKB and SNS, modified for 704 MHz
- Advantages:
  - Commercially produced window
  - High power capability, tested with HIPPI configuration (slightly different coupling value than for SPL) up to 1MW with 2ms / 50Hz on warm test cavity and on cold cavity



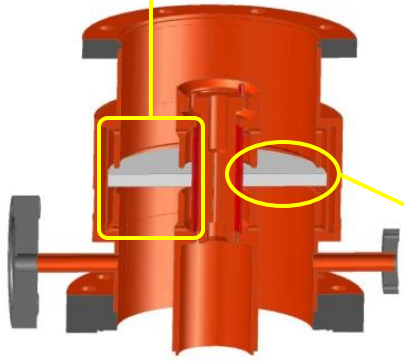
Not original drawings, but HIPPI window as we could build it

FIRST DESIGN DRAWBACKS

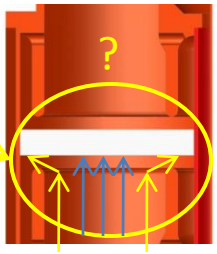
- Quite complex brazing process (compare to the next two one proposed)
- Window outer and inner are water cooled:
  - Not following CERN vacuum group recommendations
  - More difficult to integrate a DC HV biasing (need insulating pipes)
- TI coating process ?:
  - One coating after brazing
  - What about the part of ceramic masked by the chokes ?



Brazing directly making insulation between water channel and beam vacuum



How to ensure the TI coating behind the chokes ?

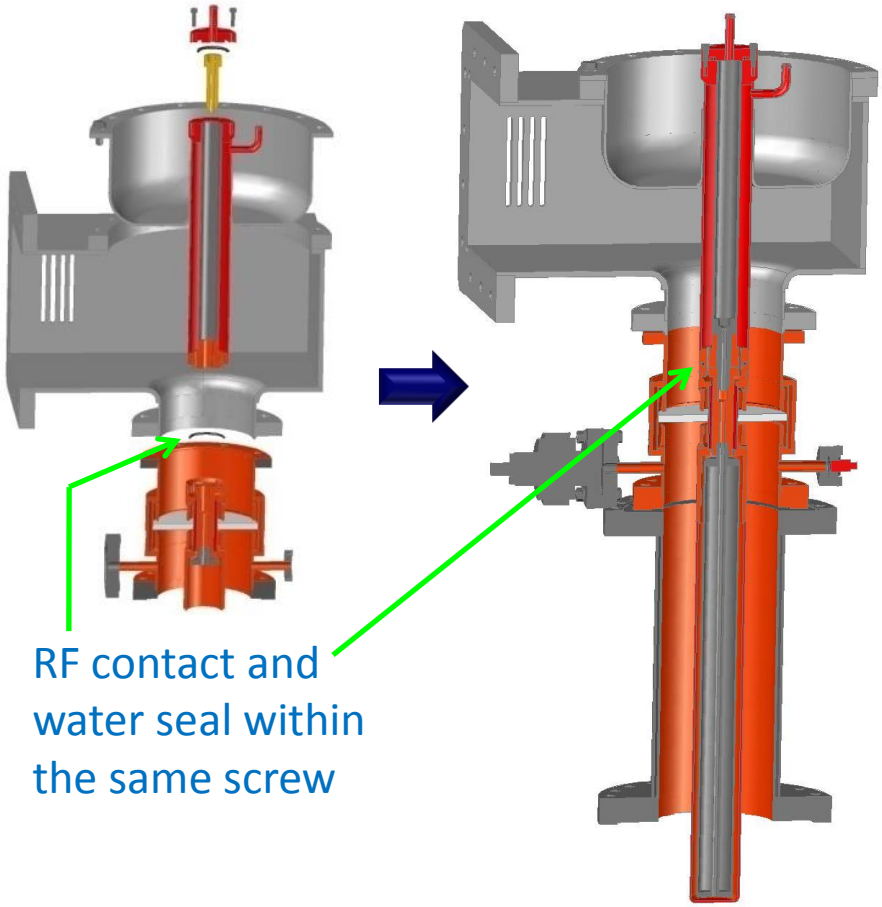


FIRST DESIGN DRAWBACKS

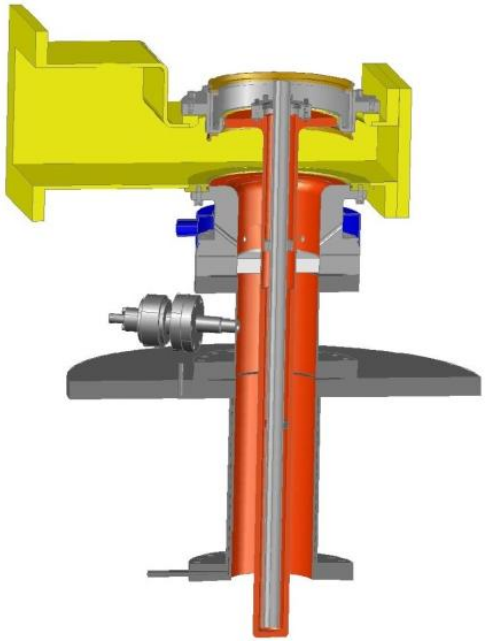
- Careful assembly process:
  - Possible stress to the ceramic
  - RF contact depends on tolerances
  - Possible water leak if misalignment (already happened)

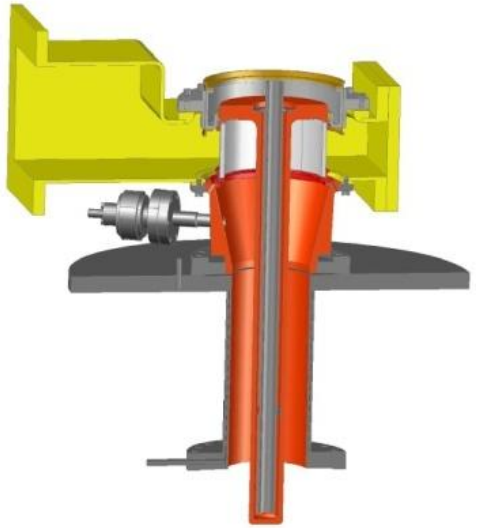
- Window price : 45 k€

  (with its inner vacuum side antenna)
  (quoted March 2010)



TWO NEW PROPOSED DESIGNS





The main goal is to check if we are able to build a coupler following our requirements and being:

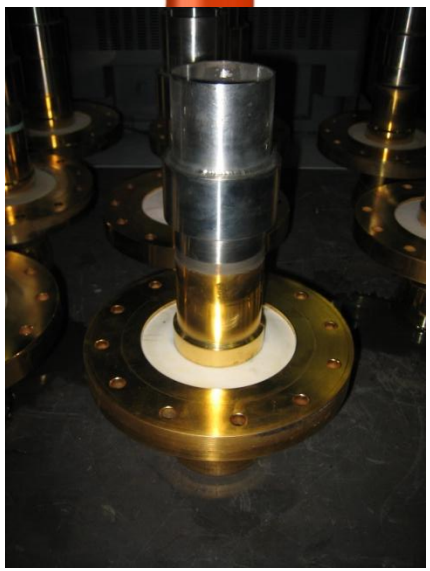
- Cheap
- Reliable
- Easy for mass production

SECOND DESIGN: COAXIAL DISK AIR COOLED WINDOW

- Design based on a coaxial disk ceramic window similar as the one in operation on the CERN SPS TWC 200MHz power load

- Advantages
  - Very simple and well mastered brazing of ceramic onto a titanium flange
  - High power capability (500 kw cw)
  - Simple to cool down with air cooling
  - Least expensive of the three couplers !

SPS Window: very simple brazing process

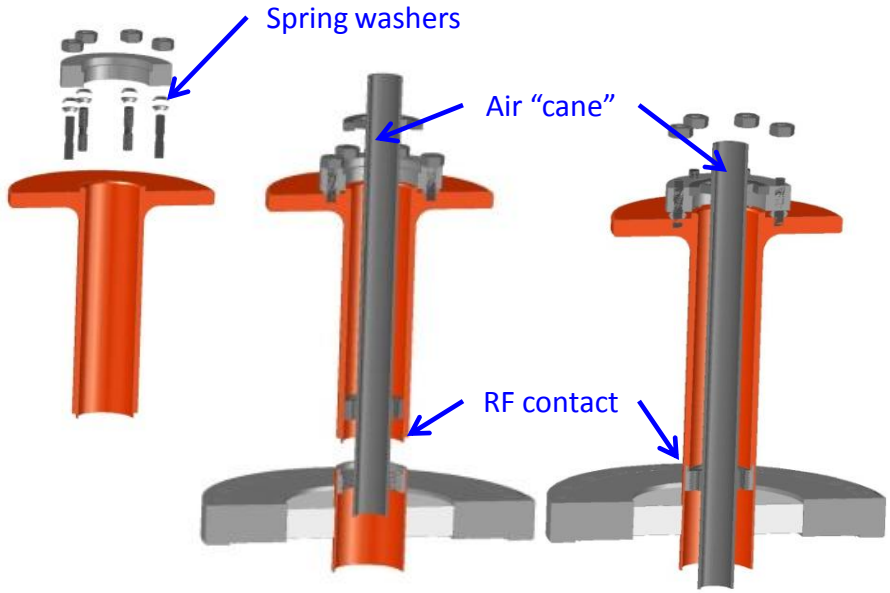


RF CONTACT

- Antenna inner upper part has been designed:
  - With spring washers for a good RF contact
  - Without any stress to the ceramic
  - Allowing a correct air flow

- We were advised by the Coupler Review Committee to reduce the ceramic thickness to increase the bandwidth and reduce the reflection coefficient

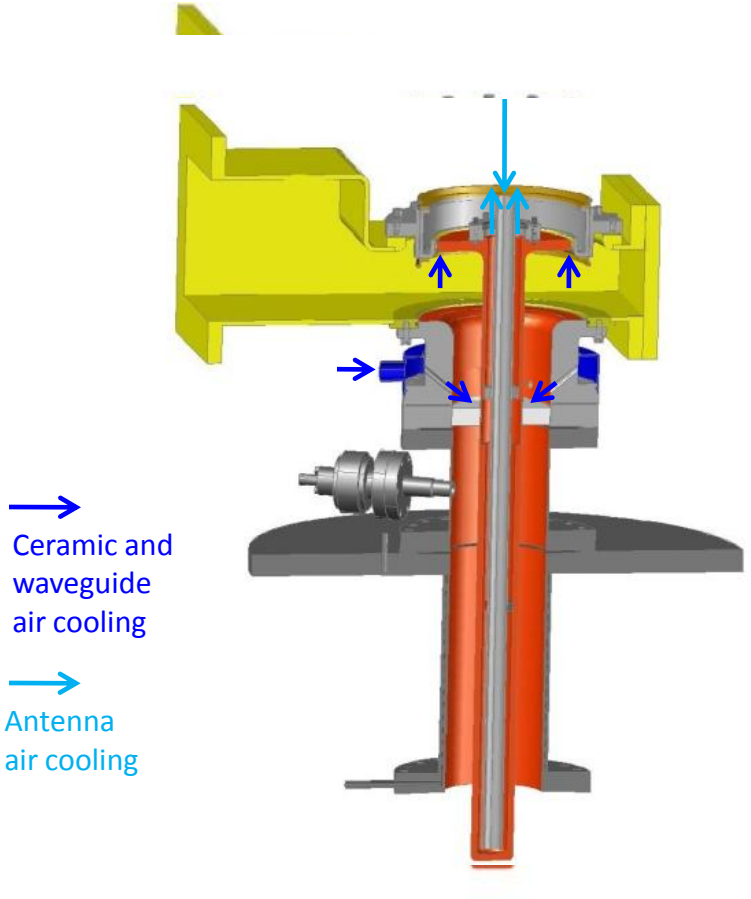
- As it will be a single window coupler, we do not want to go to a too small ceramic, and we would like to keep a minimum mechanical robustness so we reduce the thickness from 18mm to 10mm



RF contact without stress to the ceramic
by compression of the outer line through the air “cane”

"PLUG AND PLAY" WAVEGUIDE

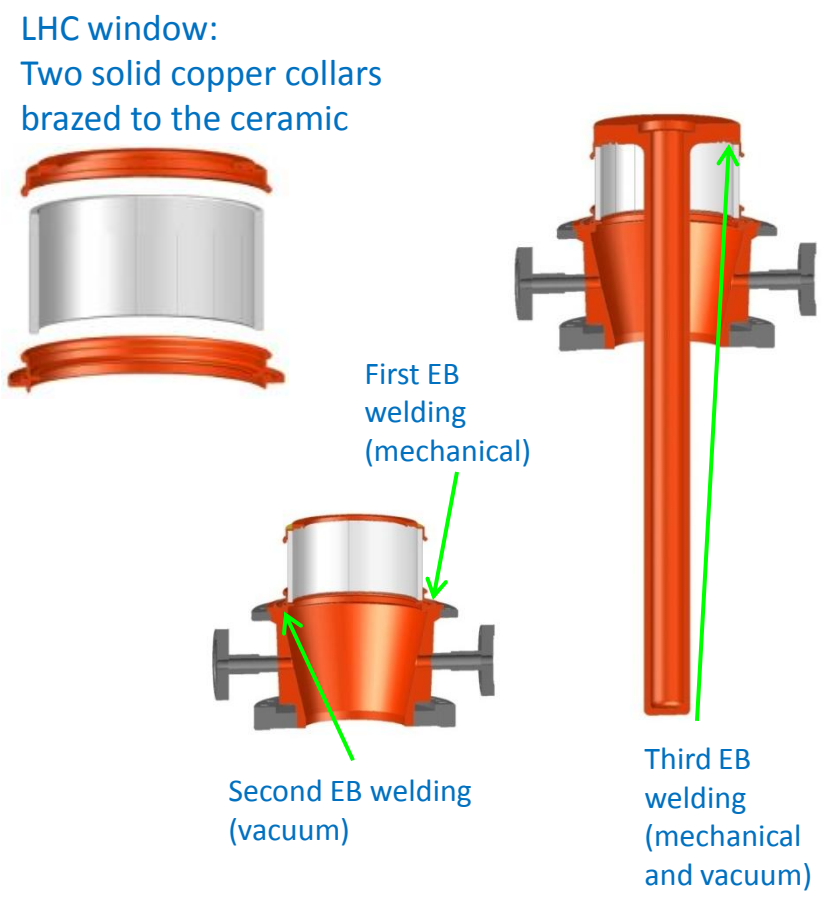
- Need additional 50 Ω outer lines:
  - Vacuum side for monitoring vacuum, electron, light, …
  - Air side for RF matching and for air cooling of the ceramic
- There is a finger contact all around the capacitor to avoid stress on the ceramic:
  - dimensions have been calculated to avoid circumferential resonances
- This waveguide mounting method has already been used successfully for the LHC couplers



THIRD DESIGN: CYLINDRICAL AIR COOLED WINDOW

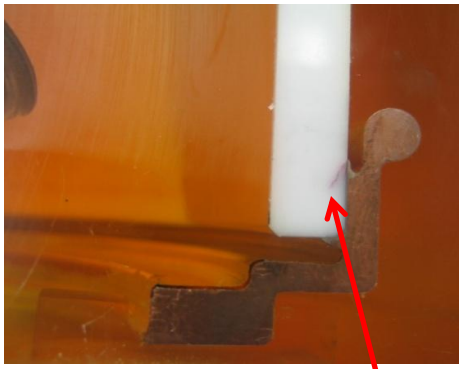
- With the aim of sharing the same ceramic with several projects (LHC/ESRF/SOLEIL/SPL) we also designed an SPL coupler with exactly the same ceramic as the LHC one

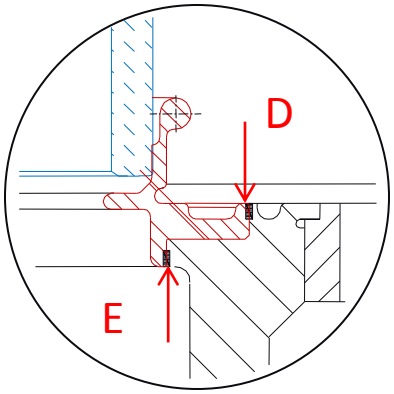
- Advantages
  - High power capability window, LHC proven
  - Simple to cool down with air cooling
  - Simple version to assemble !



LHC POWER COUPLER WINDOW HISTORY

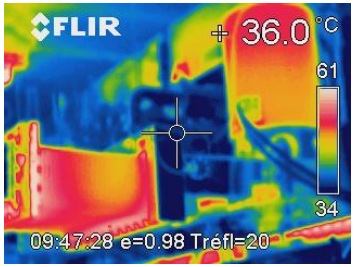
- Long and difficult process to make the ceramic reliable:
  - more than six years studying different ways to braze the solid copper rings to the ceramic
  - we had to fight against semi-cracks developing with time
- Finally, powers up to 575 kW cw full reflection all phases were achieved for some hours (Local peak power: 2.3 MW SW):
  - The tests were stopped because the klystrons failed
  - All our test area was at its limits, the waveguides were heated up to 70 ˚C, but the couplers worked perfectly
  - We do not know the real maximum power limit of the LHC coupler
- Four modules with 16 couplers were installed in the LHC in December 2006 and operate fine since that time (more than 5'000 hours of operation at around 200 KW)





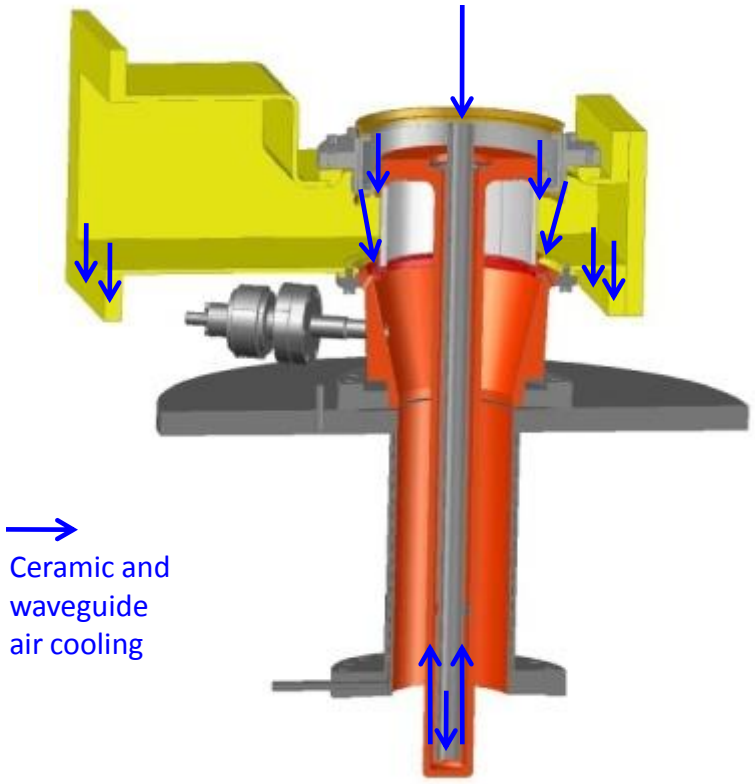
LHC process:

1) Braze a solid copper collar to the metallised ceramic
2) Two EB welding (D+E) for metallic continuity



"PLUG AND PLAY" WAVEGUIDE

- Up to date, multipacting simulations have shown the "conical" outer line not more difficult than a "standard" coaxial line:
  - ➢ Simulations still under way to check the ceramic area
- The same HV DC biasing capacitor as the SPS window and "Plug and play" waveguide
- Very easy air cooling path

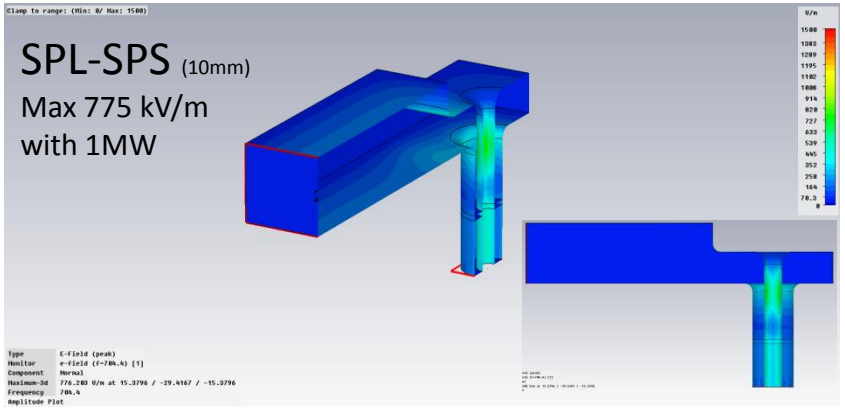


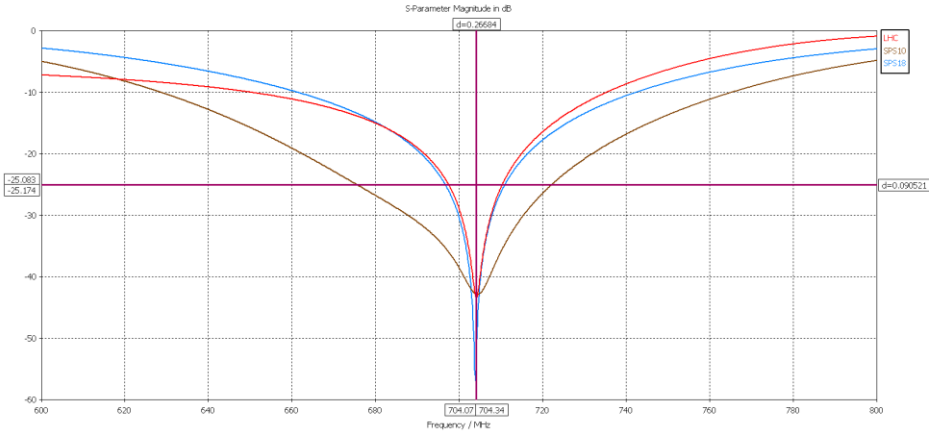
RF SIMULATIONS

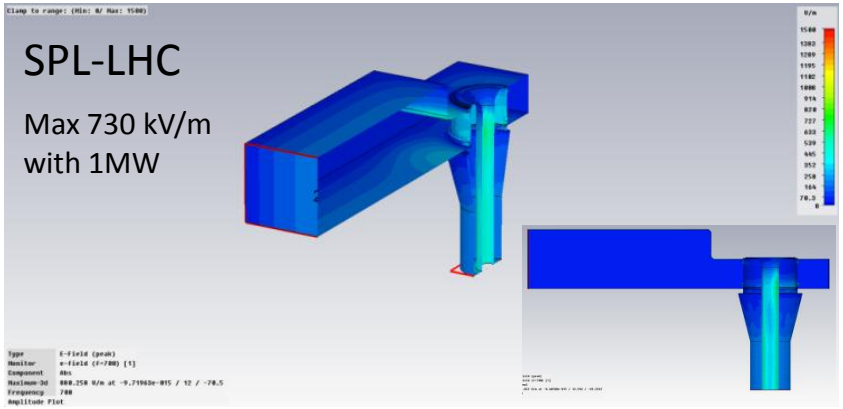
Cavity bandwidth

704 MHz / Qext (1.2×10^6) = 586 Hz

Design	Bandwidth < - 25 dB [MHz]
SPS (18 mm)	14
SPS (10 mm)	36
LHC	12

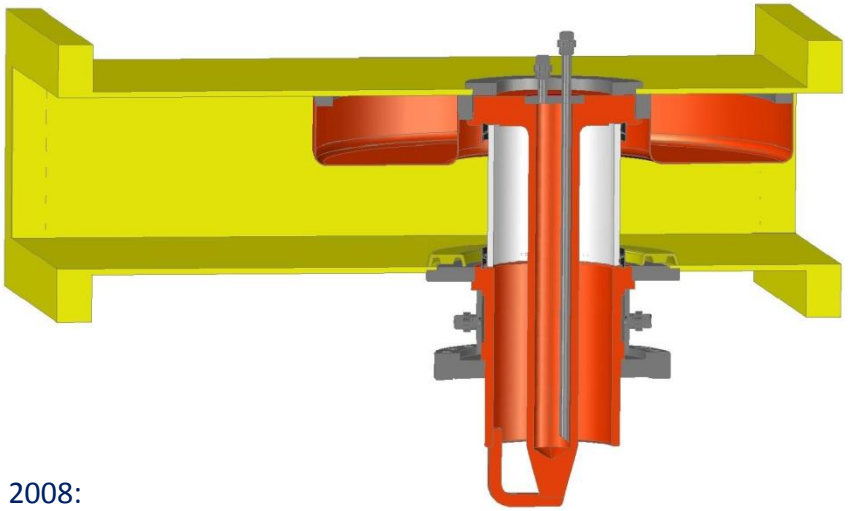






ESRF/SOLEIL – POWER COUPLER UPGRADE

- Project which has started before the SPL project
- LEP I type couplers :
  - 352 MHz
  - Kovar + stainless steel
- 17 years of operation :
  - Early breakage due to bad vacuum
  - Then no more major problems
- 5 damaged couplers beginning 2008:
  - 3 pinhole leaks in the bulk of the ceramics
  - 2 leaks in brazing joint



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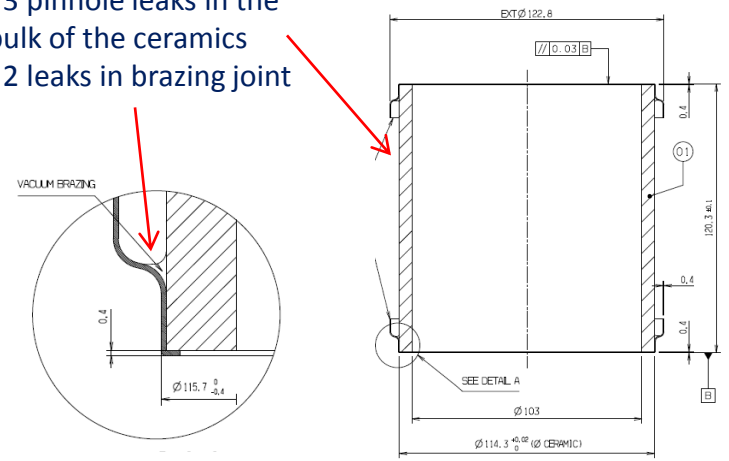
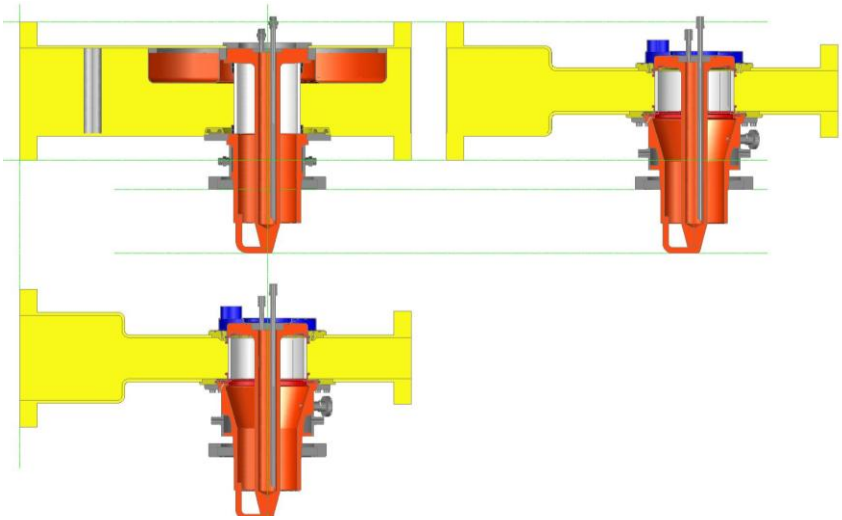
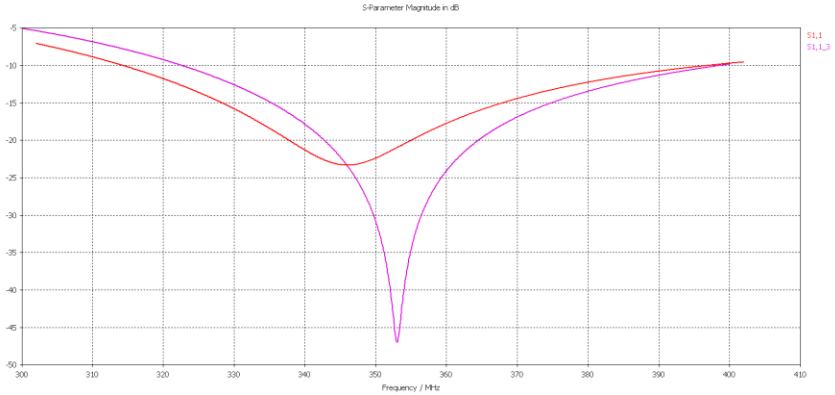


ESRF/SOLEIL – POWER COUPLER UPGRADE

- Design based on the same cylindrical window as used with LHC couplers
- We will have to remove the LEP window coupler and just replace it with the new LHC window coupler
- When the ESRF coupler will be validated (soon), we will launch the construction of SOLEIL coupler with exactly the same ceramic and the same principle

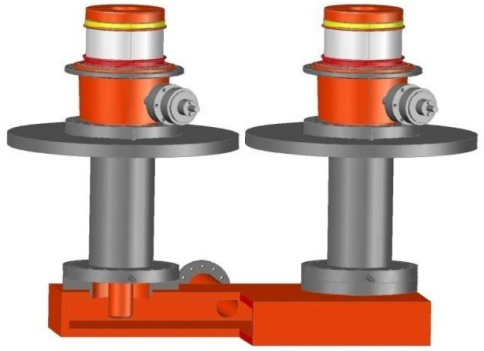
→ share the same ceramic



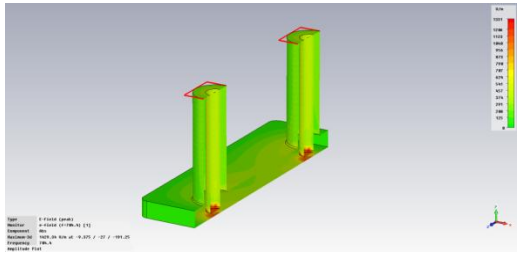


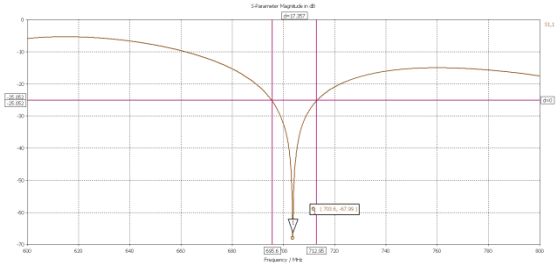
TEST CAVITIES

- Will be used to:
  - Connect two couplers in the vertical position for conditioning
  - Storage and transport chamber with springs to damp shocks
- Solid copper:
  - Low RF losses
  - Strong enough to sustain deformation due to strong pressure effects
- Could be EB soldered or assembled from two parts:
  - Vacuum seal
  - Easy to clean, we want to re-use it for 250 couplers !



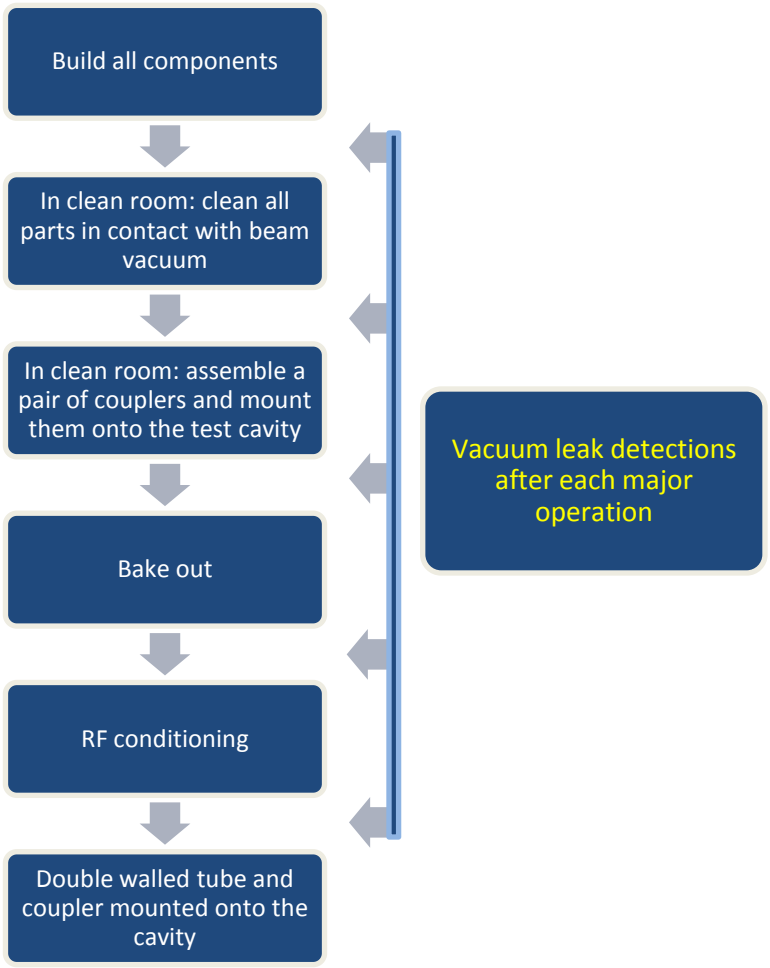
Springs to avoid any shock while transporting





CONSTRUCTION PROCESS

- We plan to follow an upgraded LHC coupler construction process, upgraded for 25 MV/m:
  - Build all components:
    - Metrologic controls
    - Mechanical and thermal tests
  - In clean room (class 100 / ISO 5):
    - clean all parts in contact with beam vacuum with pure water or pure alcohol
    - Particle counting to validate the cleaning
    - assemble a pair of couplers and mount them on a test cavity
  - Bake out
  - RF conditioning
  - In clean room (class 100 / ISO 5): mounting of coupler with its double walled tube on SPL cavity

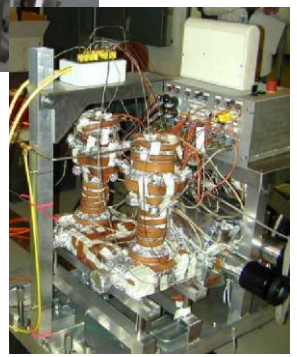


CONSTRUCTION PROCESS

- Even if we have a pretty good idea of what is needed, we are not up to date for high gradient field cavities, so we will assemble our coupler within the SPL collaboration (still under discussion):
  - DESY (Wolf-Dietrich Moeller)
  - Jefferson Lab (Robert Rimmer, Mircea Stirbet)
- Still have to be carefully followed-up:
  - Assembly tooling
  - Optimization the process to minimize the number of handlings
  - Specially designed transport and storage containers to avoid contamination of surfaces by hydrocarbons or by intermediate packing in polymeric sealed bags
- Install one cavity with its two power couplers make a bake out to:
  - help the conditioning
  - make a thermal mechanical test

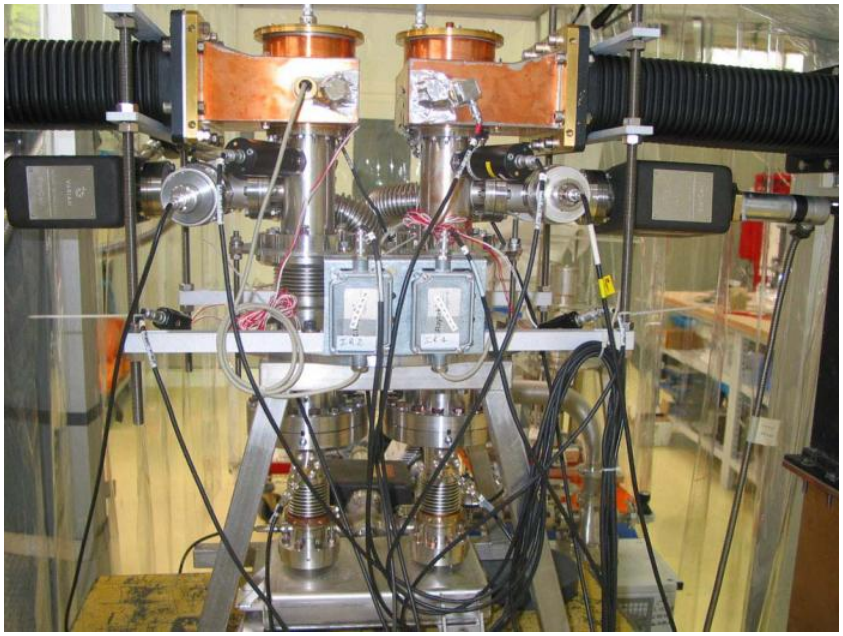






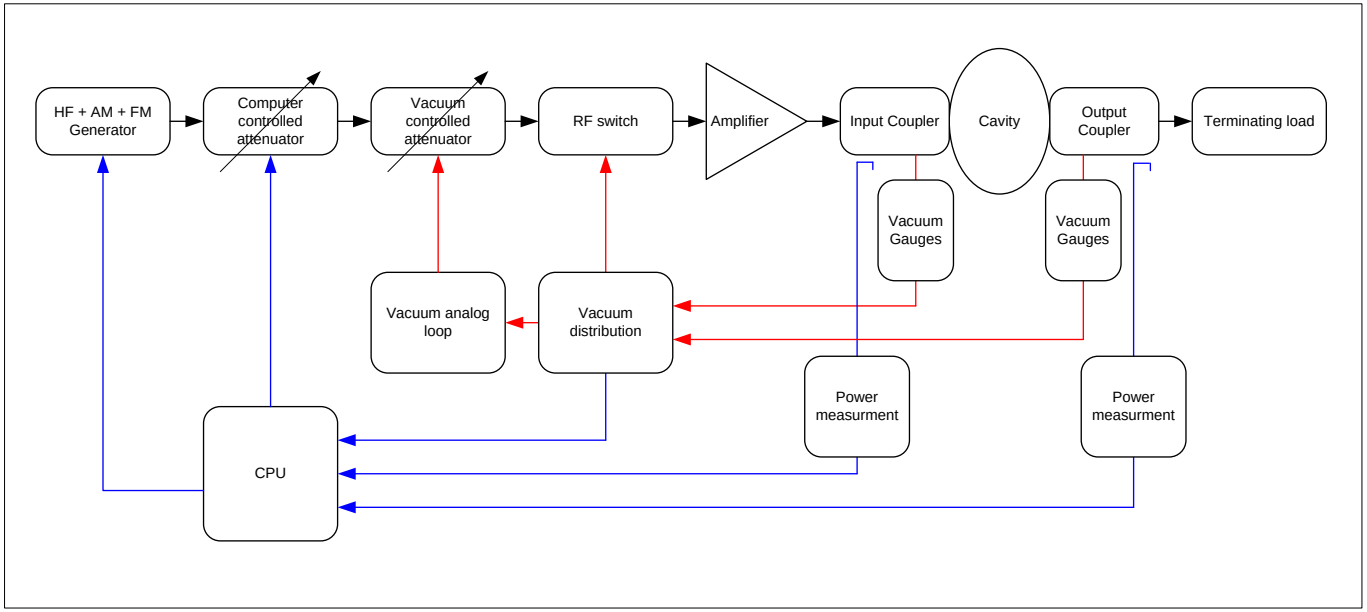
CONSTRUCTION PROCESS

- Then prepare for conditioning, connect interlocks and monitoring:
  - Vacuum gauges
  - Directional couplers
- But also, at least for the prototypes :
  - Light detector
  - Electron monitor
  - Thermal measurements
  - Gas analyzer
  - Air flow meter
  - …
- The tests will be done at CEA Saclay premises (which have already been used to qualify the HIPPI coupler)



TTF III power coupler test bench

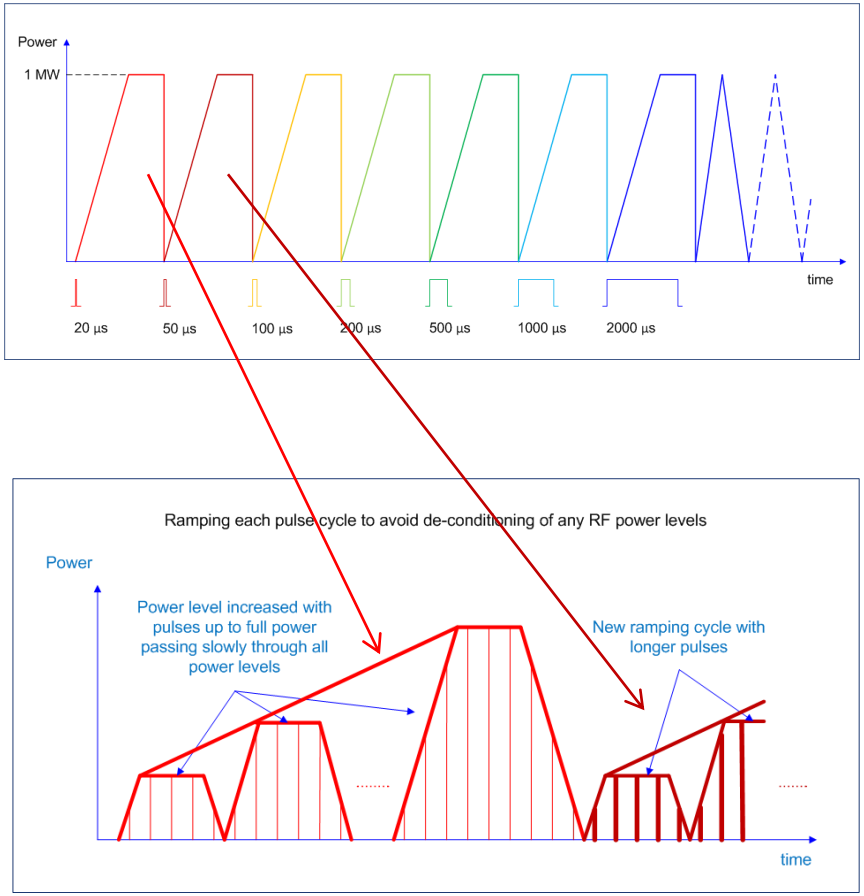
CONDITIONING PROCESS



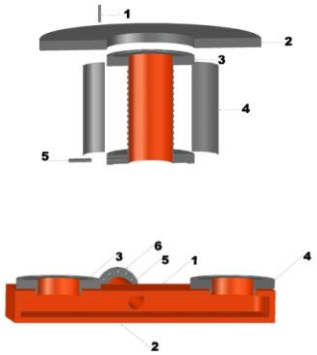
- With two couplers mounted face to face on a test cavity:
  - A first direct vacuum loop (red) ensures RF is never applied if pressure exceeds 5.0 x 10^{-7} mbar
  - This interlock vacuum threshold of 5.0 x 10^{-7} mbar will be chosen, guided by our experience, to protect the couplers, but also to have an as short as possible conditioning time
  - The settings are adjusted to have minimum attenuation under 1.0 x 10^{-8} mbar and maximum attenuation over 2.5 x 10^{-7} mbar (~40 dB dynamic range with the attenuator)
  - A second vacuum loop (blue), cpu controlled, executes the automated process

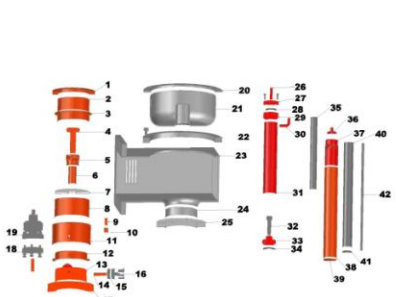
CONDITIONING PROCESS

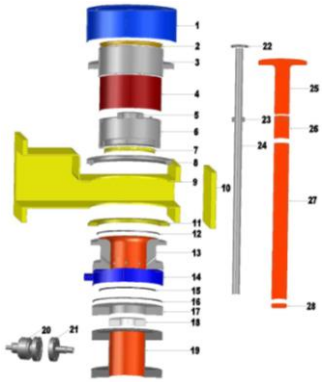
- The conditioning process will be similar to the LHC one:
  - The process always starts, under vacuum control, with very short pulses of 20 µs every 20 ms
  - Power level is increased using short pulses up to full power passing slowly through all power levels to avoid “de-conditioning”
  - Same procedure repeated for initially short then longer and longer pulses up to the maximum length
- Check the DC biasing effectiveness with the short pulses, continue the RF processing without DC biasing
- The conditioning process will be considered finished when the vacuum level decreases below a predefined level (1 x 10^{-8} mbar for example), while ramping the maximum length pulse

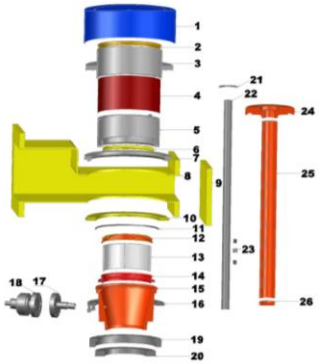


FOUR PROTOTYPES COSTS





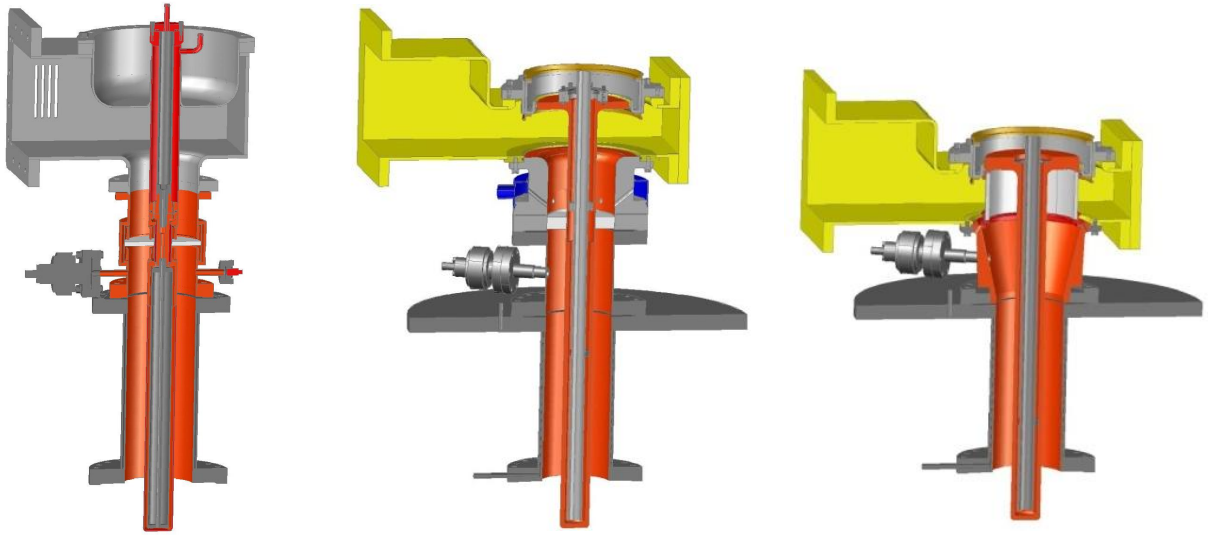




	Qty	Coaxial disk Water cooled	Coaxial disk Air cooled	Cylindrical Air cooled
Main line (window + outer line + antenna)	4	45 k€	13 k€	15 k€
Waveguide + HV capacitor	4	7.5 k€	5 k€	
Double walled tube	4	10 k€		
Test cavities	2	17 k€		
Miscellaneous (clean room, leak detections, bake out, …)	4	10 k€		
Prototype couplers	**4**	**324 k€ / 435 k$**	**186 k€ / 250 k$**	**194 k€ / 260 k$**

MASS PRODUCTION (275 COUPLERS)

No large cost reductions due to high gradient field requirements



	Coaxial disk water cooled	Coaxial disk air cooled	LHC Cylindrical air cooled
Coupler unit price	60 k€ / 80 k$	26 k€ / 33.5 k$	28 k€ / 36 k$
275 couplers (no test cavities, no conditioning process)	**16'500 k€ / 22'100 k$**	**7'000 k€ / 9'600 k$**	**7'700 k€ / 10'300 k$**

CONCLUSION

- Coaxial air cooled and LHC cylindrical air cooled versions will be tried
- Simple to assemble
- Potentially inexpensive for mass production
- Interesting for large machines (and small machines)

- Would like to share the LHC ceramic:
  - ESRF
  - SOLEIL
- If anyone is interested, please let us know
- If someone has a 704 MHz power station over 1MW, we are very interested !!!

MANY THANKS