Recent Fundamental RF Power Coupler developments at CERN

CWRF2012 Workshop
BNL, Port Jefferson, May 7th – 11th

Contents

Tricks and tips with various couplers over last years

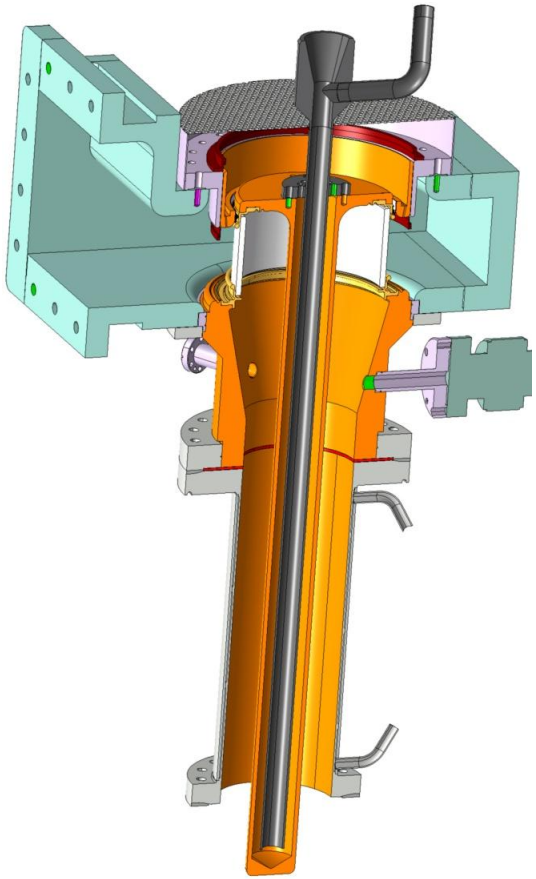
- SPL
- ESRF
- APS
- Linac 4
- 3D printing

SPL coupler(s)

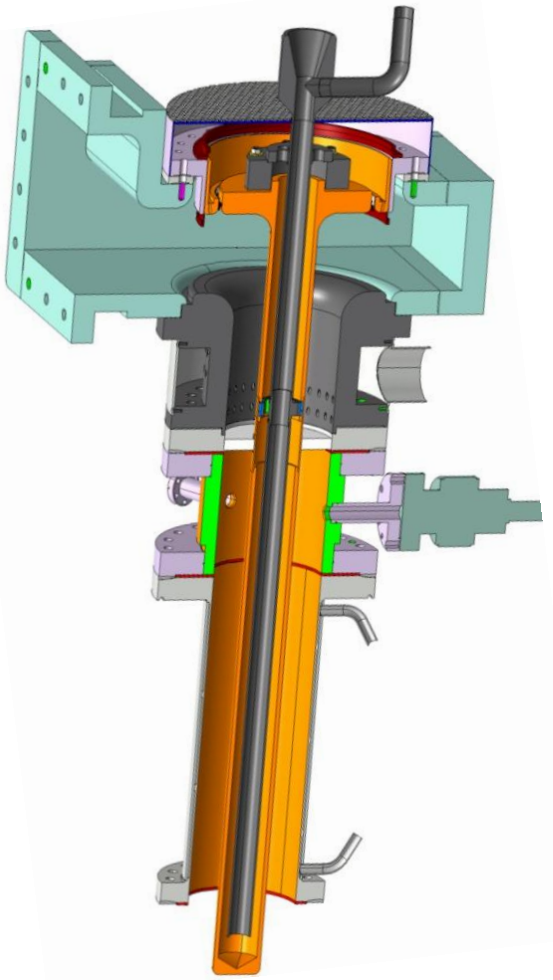
Technical Choices
Single window coupler
Fixed coupler
With a Double Walled Tube
Vertically below the cavity and will be a support for the cavity (first time worldwide)
With a HV DC biasing capacitor
Air cooled

RF Characteristics	
f_o	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

Two proposed designs



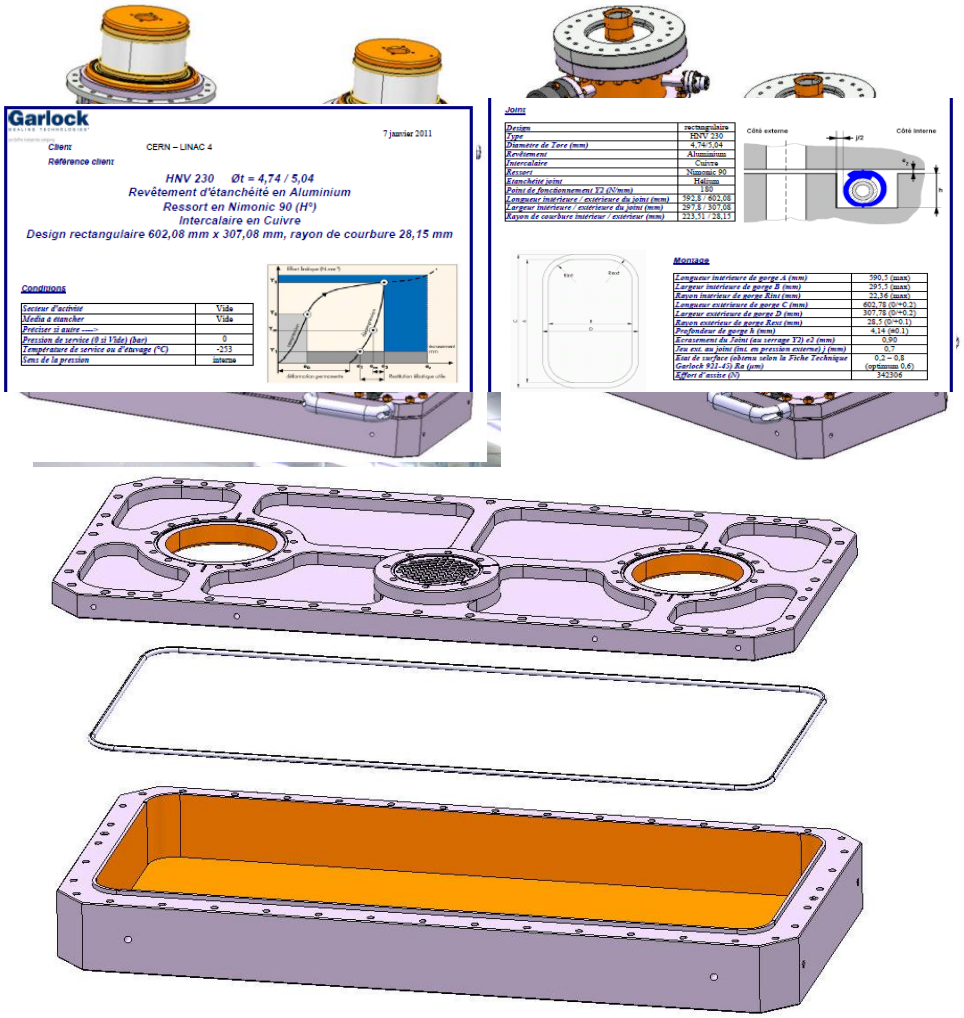
Based on a LHC ceramic



Coaxial planar disk

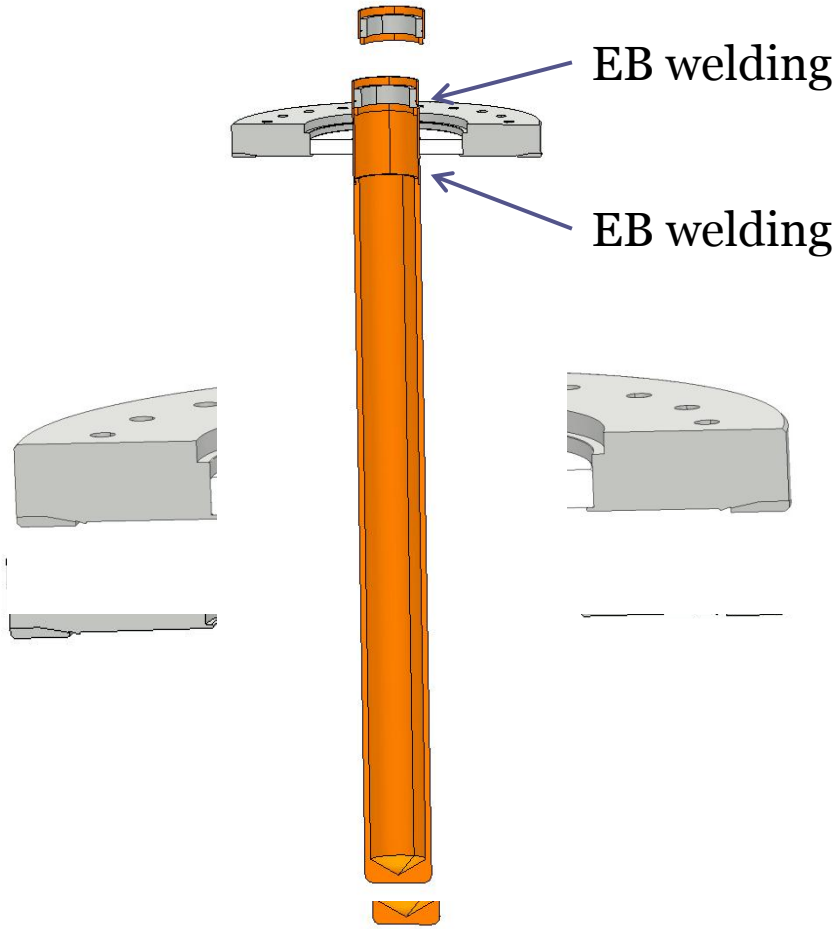
Test box

- Test box is made with only two parts with a helicoflex seal :
  - Upper cover with included machined vacuum knife flanges
  - Two Stainless Steel covers with copper plated inner
  - Helicoflex is not a rectangle but has rounded angles, i.e. RF design has to be compatible
- Advantages :
  - Easier (not easy) to copper plate
  - Easily cleanable regarding clean room requirements for high gradient field cavity
  - Can be used for several sets of couplers (if large series : SPL, …)
- Drawbacks :
  - Helicoflex faces have to be very well prepared
  - Self-supporting structure : heavy weight



Coaxial planar disk coupler

- Make it as simple as possible
- Titanium external flange to ease the brazing
- As we wanted the coupler to be air cooled to avoid any water leak we had to find a specific trick to ensure inner RF contact :
  - Inner line on top of the ceramic
  - Springs are compressed
  - Air cane inside the inner line
  - Screw to the inner ceramic
  - Release springs to ensure RF contacts
  - Absolutely no stress to the ceramic



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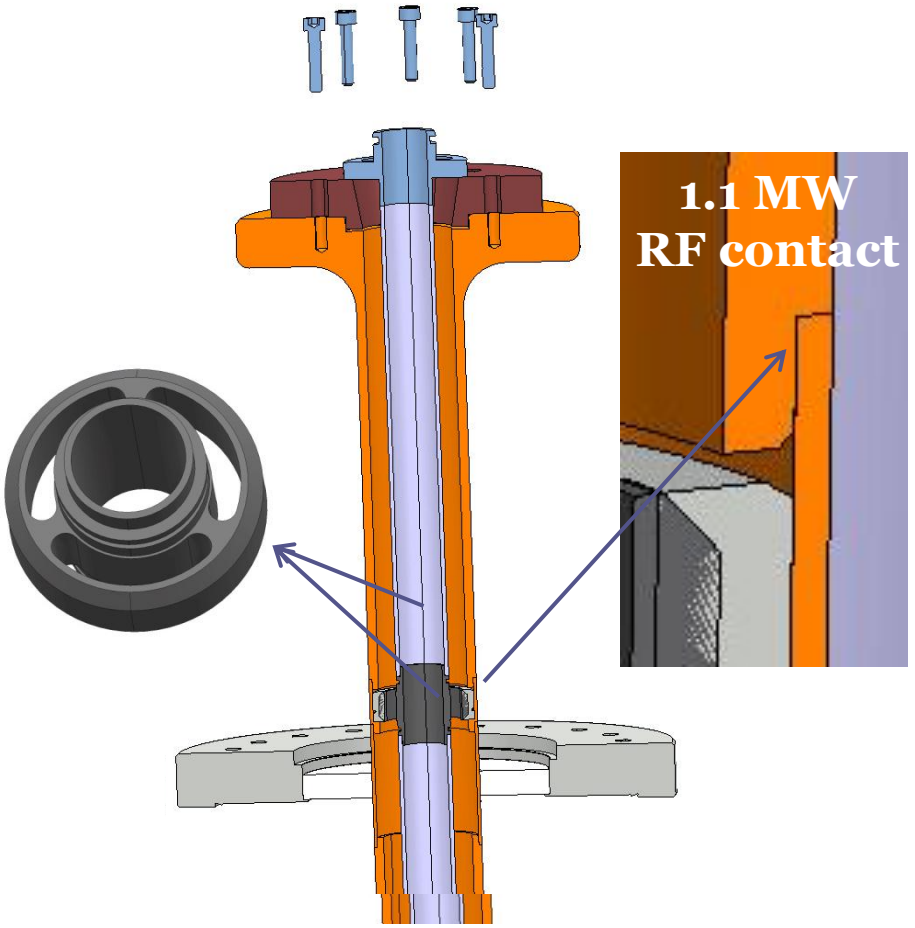
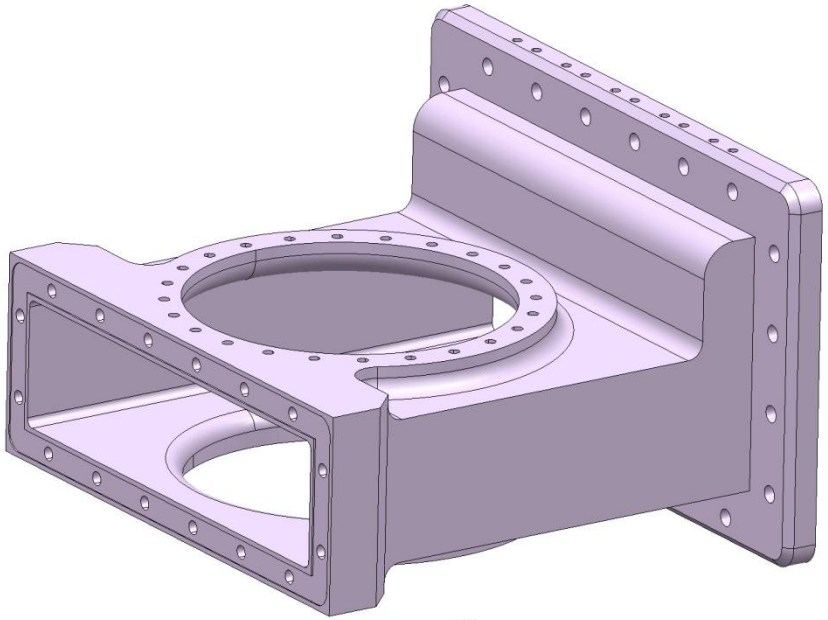
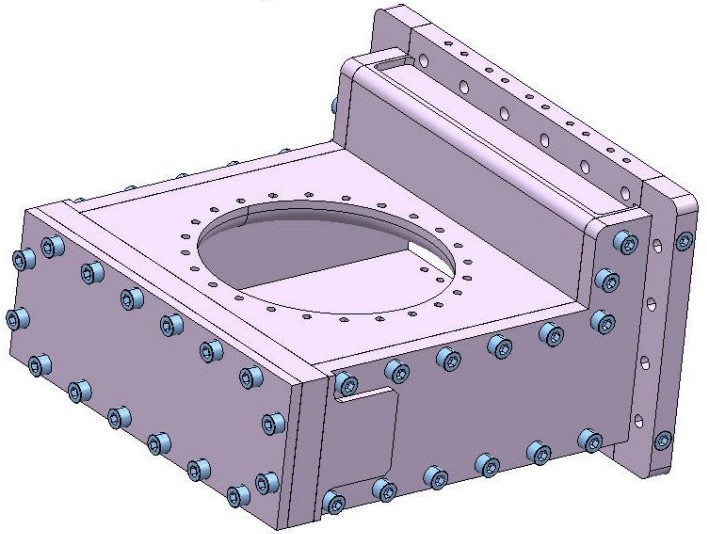


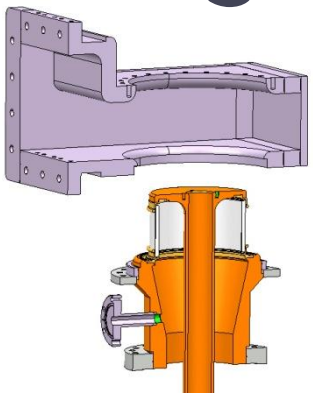
Waveguides

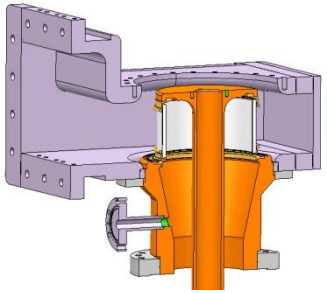
- Six parts waveguide
- No doorknob, the whole waveguide path is part of the matching system
- Easily exchangeable shims for matching if needed
- Knife contacts all along to suppress any gap at intersections in order to avoid any arcing
- For the 'series' production (6), we already ordered a mono-bloc waveguide :
  - Much lighter
  - Less expensive than screwed version
  - Surprisingly it is even less expensive than a welded waveguide

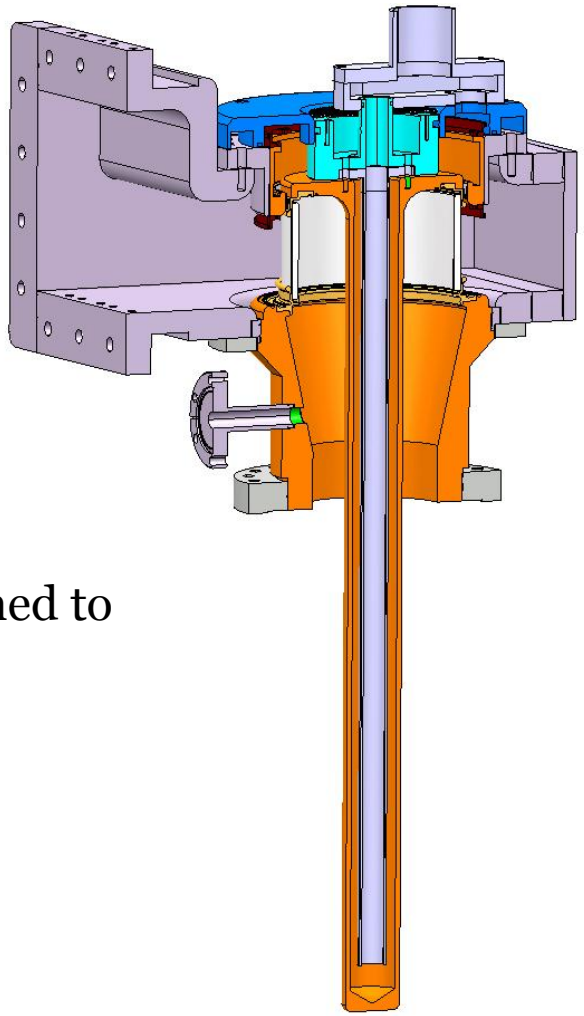




Waveguides

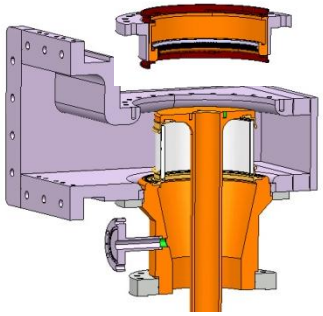


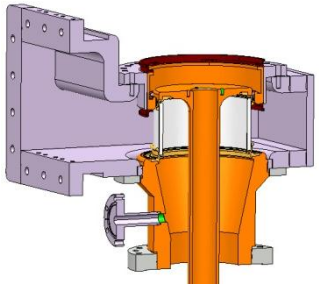




No mechanical stress given to the ceramic, fixed point onto the body only

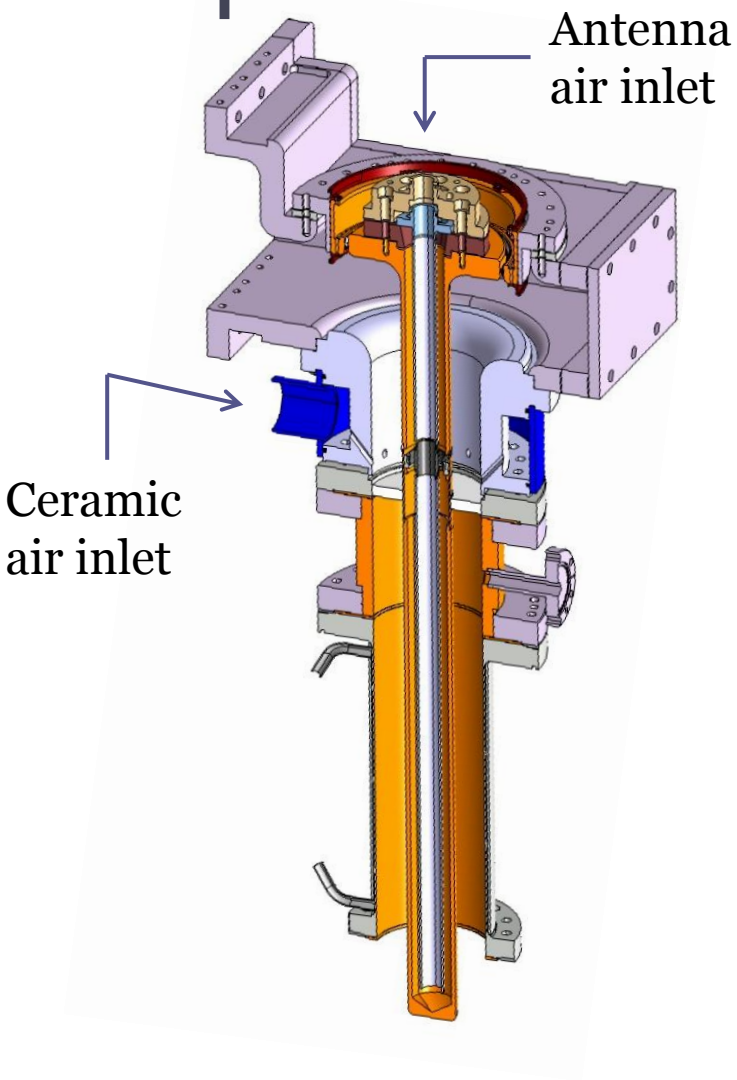
Capacitor self centered around the ceramic and designed to symmetrically air cool the ceramic



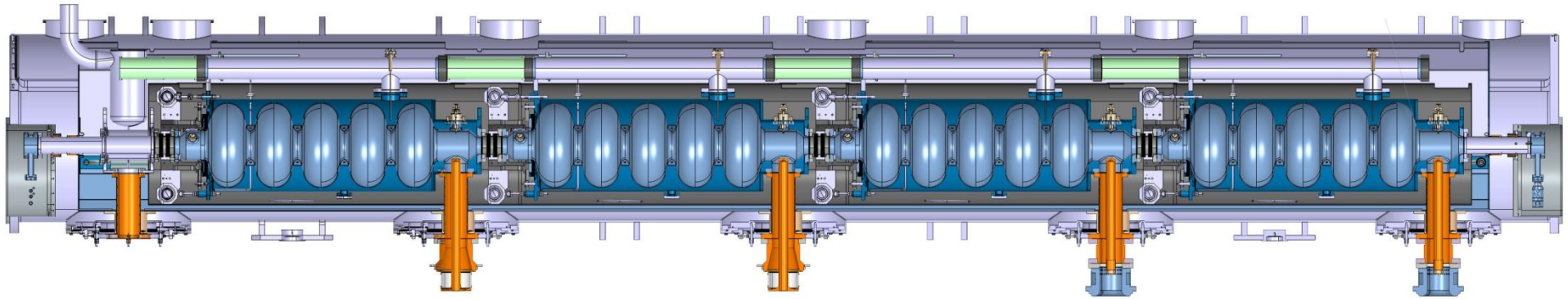


Coaxial planar disk coupler

- No doorknob
- Outer lines and waveguide are the matching path
- Only air cooled coupler
  - Specific air cooling directed to the ceramic
- Tested up to
  - 1.1 MW 2 ms 25 Hz
  - Limited because of the DT

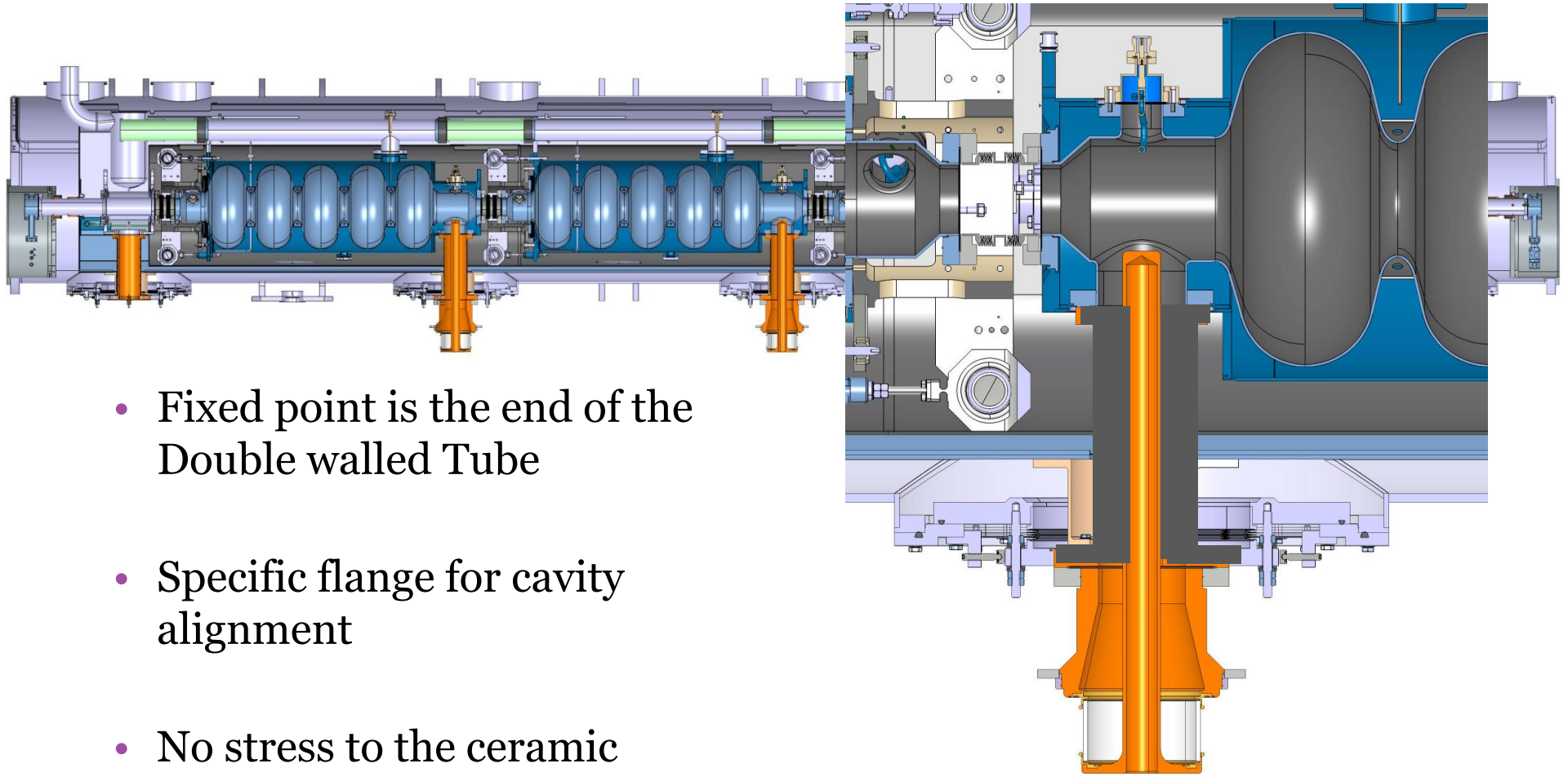


Coupler as a support for the cavity



- Fixed point is the end of the Double walled Tube
- Specific flange for cavity alignment
- No stress to the ceramic

Double Walled Tube ~~Coupler~~ as a support for the cavity

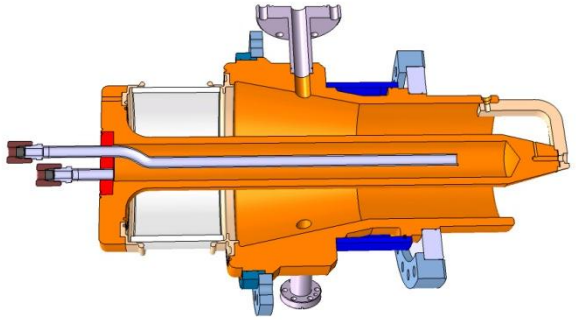


- Fixed point is the end of the Double walled Tube
- Specific flange for cavity alignment
- No stress to the ceramic

ESRF/SOLEIL/APS couplers

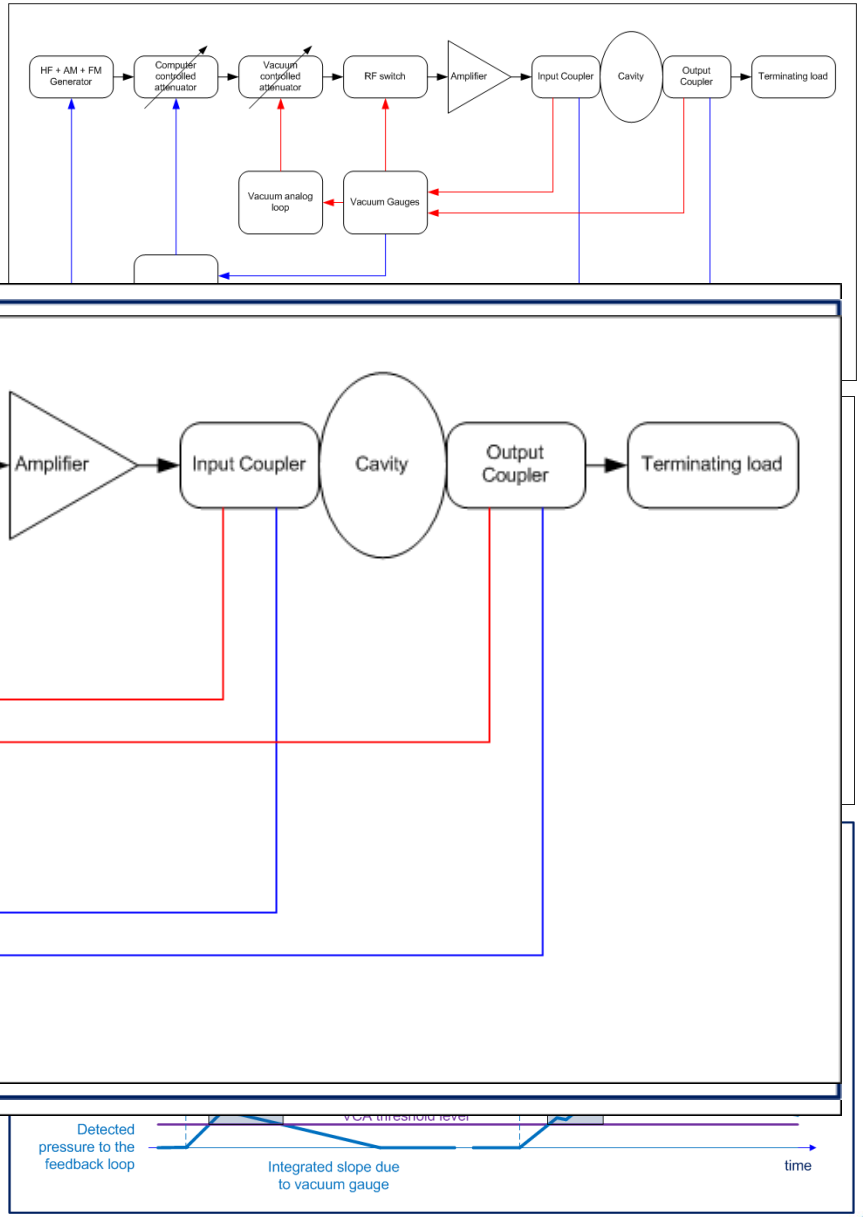
RF Characteristics	
fo	352.2 MHz
Power levels	200 kW cw
Technical choices	Single window, fixed coupler
Waveguides	WR 2300 half height
Mechanical constraints	Must match with previous design without any infrastructure modification

ESRF coupler



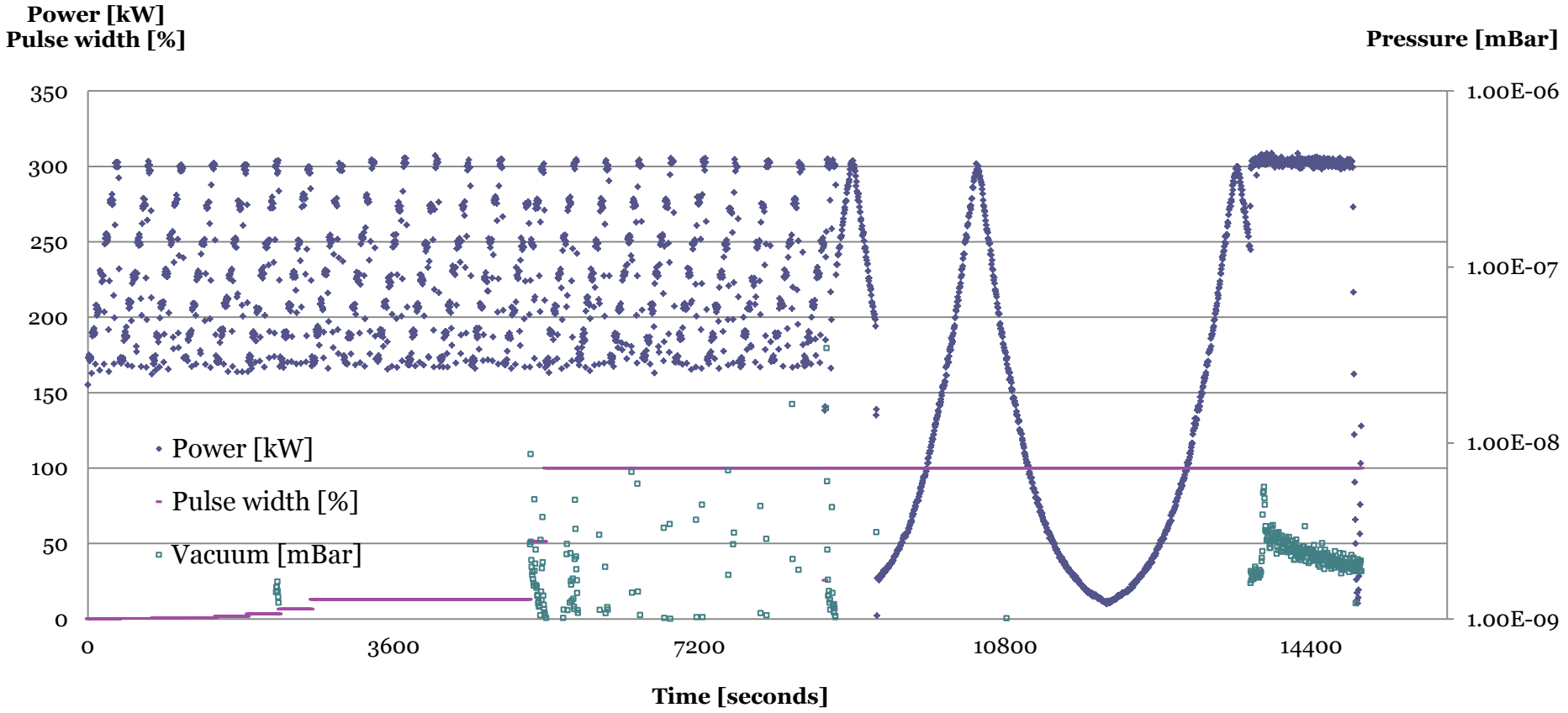
- LEP I style coupler became ESRF trouble maker (five unexplained vacuum leaks in 2008)
- Proposal of a new coupler to fit into existing premises with NO (or minor) infrastructure modifications
- Coupling loop :
  - Water cooled to be sure there will be no mechanical stress given to the ceramic
- Same waveguide ‘principle’ as for SPL:
  - No doorknob
  - Matching included
  - Six panels screwed

Conditioning



gauge acquisition delay

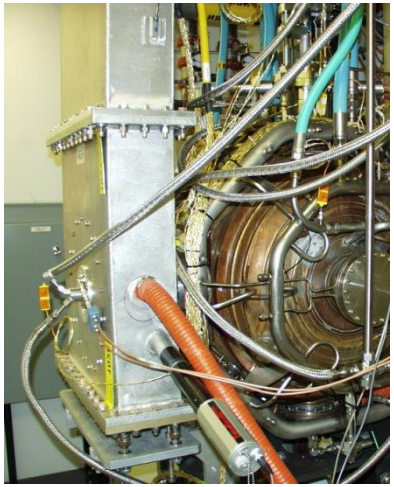
ESRF coupler conditioning

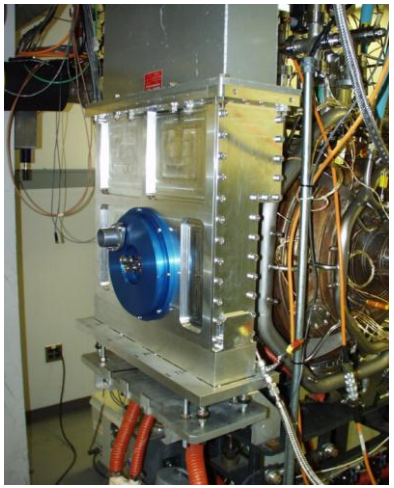


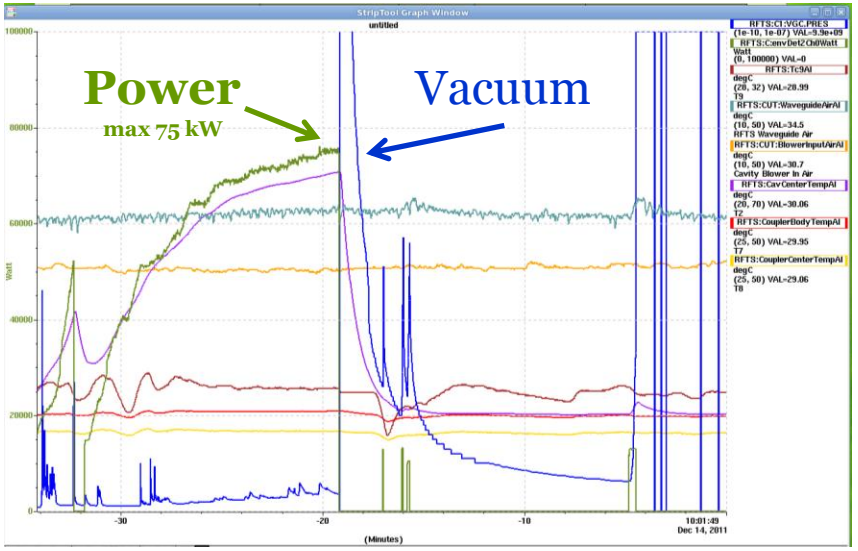
Conditioning was very efficient, and we were able to reach 300 kW CW

APS coupler

- Collaboration agreed following CWRF2010 workshop in Barcelona
- Design similar to ESRF:
  - LHC ceramic
  - Coupling loop differs
  - Proposal of a new coupler to fit into existing premises with NO (or minor) infrastructure modifications
- No pulse mode conditioning loop
- Conditioning in cw mode with a very low pressure:
  - 1 x 10-8 Torr maximum
  - interlock at 5 x 10-8 Torr
- 25 kW cw after two days
- We destroyed the ceramic after few days !

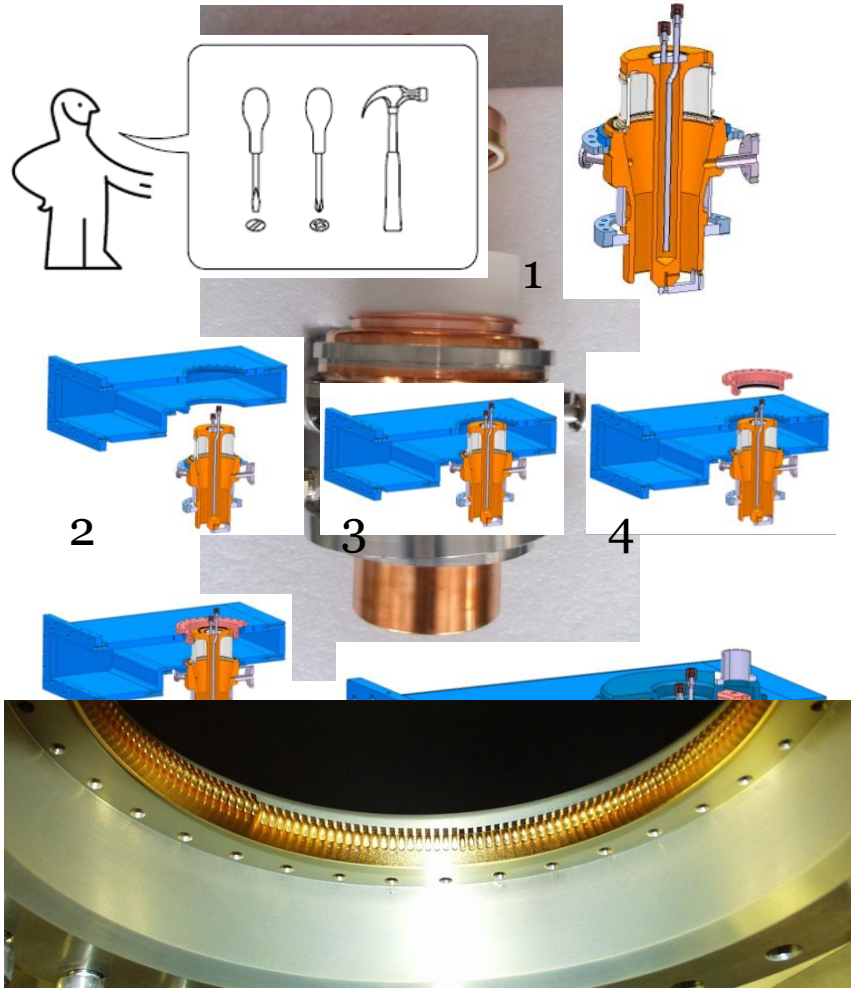






Broken ceramic

- We have forgotten to send the assembly notice
- The waveguide and its contact ring were pre-assembled for transportation, but **NOT** aligned
- We believe the default is explainable as follow :
  - While mounting the waveguide, as the contact ring was not centered, stress was given to the ceramic

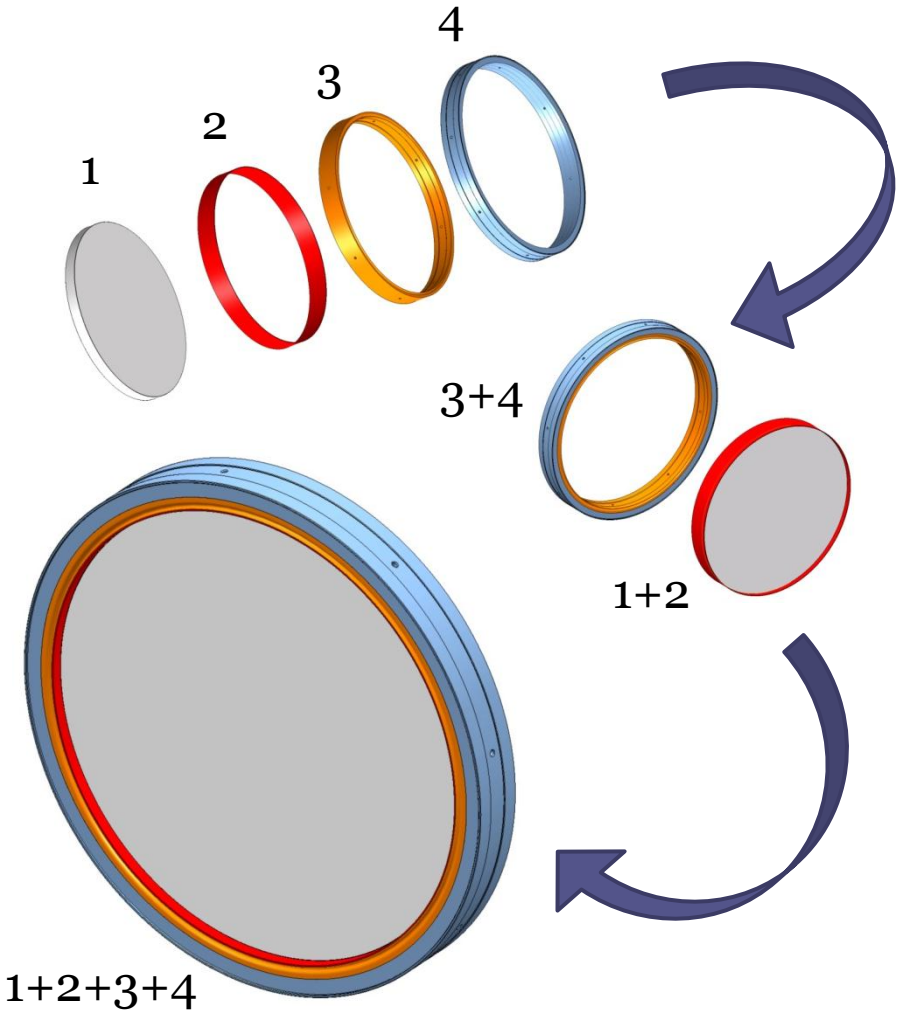


Linac 4 window

RF Characteristics	
fo	352.2 MHz
Power levels	1250 kW pulsed 0.4 ms /2 Hz (Linac 4 cycle) 1250 kW pulsed 2 ms / 50 Hz (SPL cycle)
Waveguides	WR 2300
Mechanical constraints	As short as possible

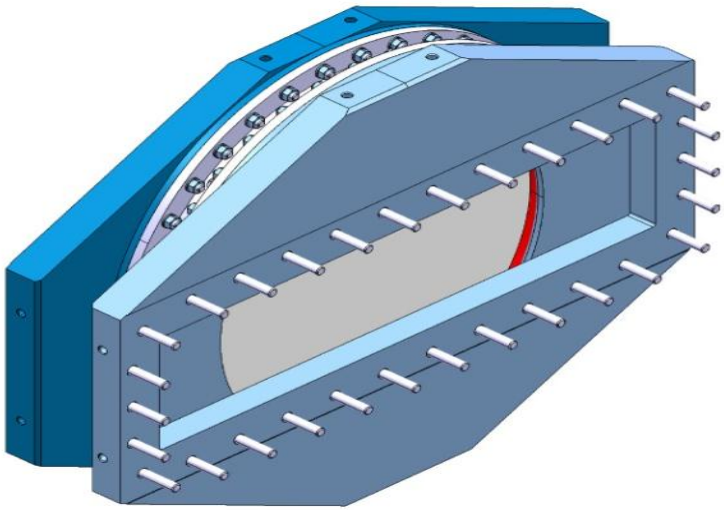
Ceramic assembly

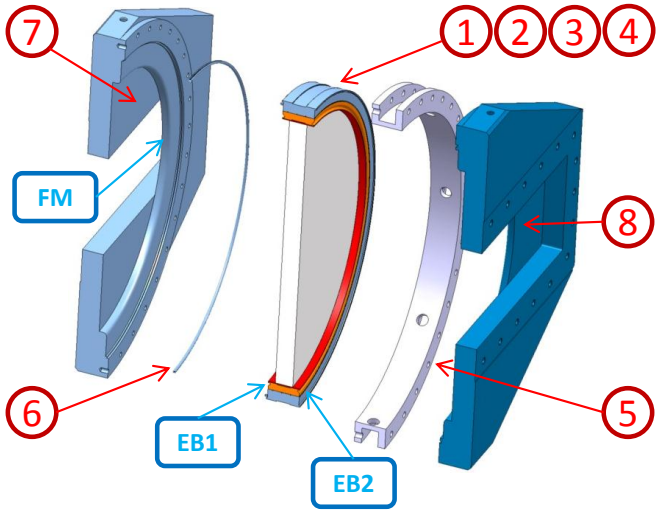
- As simple as possible :
  - 1 : Ceramic Ø 400 mm x 25 mm
  - 2 : Inner copper ring Ø 400 mm x 1.25 mm
  - 3: Outer copper ring
  - 4 : Stainless steel ring for Helicoflex
- Two first individually brazed sub-assemblies:
  - Brazed ceramic = ceramic + inner copper ring
  - Outer ring for Vacuum seal = outer copper ring + stainless steel ring
- Main ceramic = EB welding of two parts
- Ti sputtering of the vacuum side



LINAC 4 window

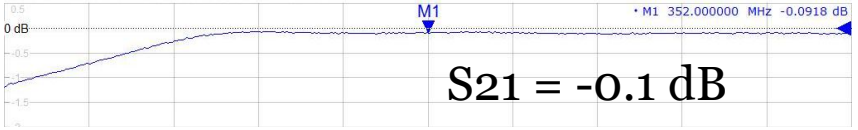
- As simple as possible
  - 1-2-3-4 : Ceramic assembly
  - 5 : spacer
  - 6 : Helicoflex seal (or EB welding)
  - 7-8 : Stainless Steel flanges
- Massive flanges
  - Not copper plated
  - Air cooling path included into the copper/stainless steel ring
  - FM = Final Machining for tuning if needed
- More difficult design than it look likes because of the two shapes : cylindrical and rectangular, including screws



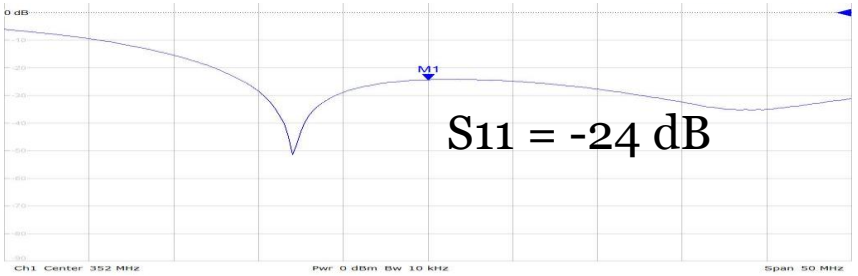


LINAC 4 window next step

- Two First prototypes :
  - Individual leak tests ok
  - Low Level RF tests ok
- Tests of two prototypes face to face onto a vacuum waveguide line :
  - 1.25 MW 2 ms 1 Hz
  - 60 kw CW
  - Define the best design (Helicoflex/EBW)
- Series construction of 30 windows
  - Ceramics already ordered



Two WG/N transition + two windows + Vacuum WG measurements



3D Printing

- To make some Mechanical tests we recently used 3D printing
- It has helped us to check several key components
- We decided to try to make it available also for RF tests
  - We first tried copper paint, but it was not successful
  - After several trials we found a specific silver conductive paint

3D Printing

S21 = 0.01 dB
S11 = -40 dB

S21 = 0.03 dB
S11 = -25 dB

Electrolube Silver Conductive Paint (SCP)	
Consistency	Creamy
Surface Resistance 0.6 to 2g/100cm²	0.01 to 0.03 Ohms/sq
Electrical Rating	0.1 to 1 W/cm²
Drying time @ 20°C	10 minutes
3 Grams SCP03B	12 $
50 Grams SCP50G	150 $

Machined Printed	Delay [days]	Cost [$]
Simple	4	271
Line	2	231
Complex	9	4500
	3	2000

Future coupler developments

- ESRF
  - Produce 2 'series' couplers
- APS
  - Repair the faulty coupler (quite finished)
  - Preparing a pulse mode conditioning system
- SOLEIL
  - Design and produce 2 'series' couplers
- LIU-SPS 200 MHz
  - New concept with coaxial plain disk and capacitive coupling
  - 900 kW pulsed 50 % (ms)
  - 450 kW average power
- SPS 800 MHz consolidation
  - Scaling of Linac 4 to 800 MHz
  - Minimum 150 kW cw
- Crab Cavities coupler

Acknowledgements

- SPL coupler review committee :
  - Ali Nassiri, Wolf Dietrich Moeller, Mark Champion, Sergey Kazakov, Mircea Stirbet, Amos Dexter, Rama Calaga, Miguel Jimenez, Sergio Calatroni, Ofelia Capatina, Vittorio Parma
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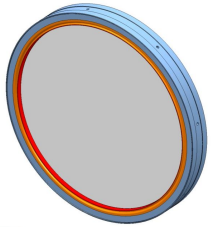
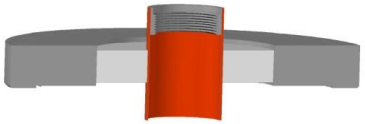
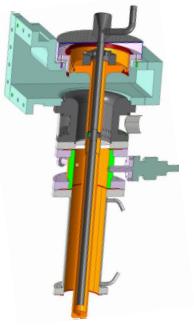
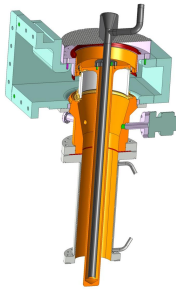
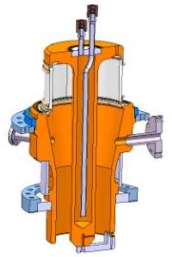
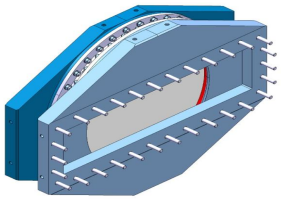
- CEA :
  - Stephane Chel, Guillaume Devanz, Michel Desmond, Abdallah Hamdi, and team
- ESRF :
  - Jorn Jacob, Vincent Serriere, Jean-Maurice Mercier, Didier Boilot, and team
- APS :
  - Ali Nassiri, Doug Horan, Gian Tenko, Dave Brubenker, and team
- CERN :
  - Mechanical & Material Engineering group :
    - Ramon Folch, Francesco Bertinelli, Serge Mathot, Agostino Vacca, Thierry Tardy, Thierry Calamand, Thierry Renaglia, Ofelia Capatina, Marc Polini, Laurent Deparis, Philippe Frichot, Jean-Marie Geisser, Jean-Marc Malzacker, Pierre Moyret, Alain Stadler, and team
  - Vacuum, Surface & Coating group :
    - Miguel Jimenez, Sergio Calatroni, Wilhelmus Vollenberg, Marina Malabaila, Nicolas Zelko, and team
  - Magnets, Superconductors & Cryostats group:
    - Vittorio Parma, Arnaud Van de Craene, and team
  - RF group :
    - Antoine Boucherie, Sebastien Calvo, Charles Julie, all FSU-AB03 team members

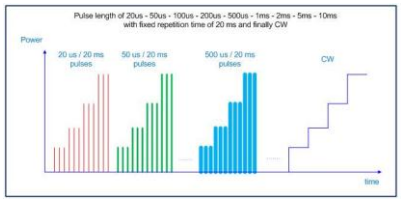
Summary

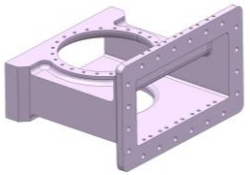


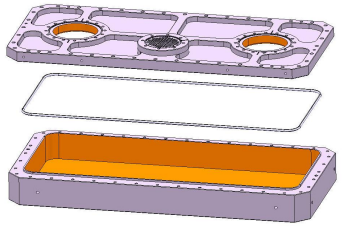
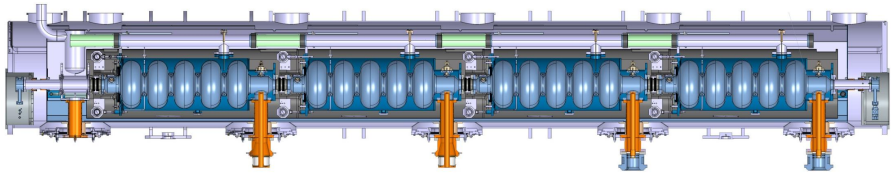






We now have a team specialized in design of
Fundamental Power Coupler
in the range of MHz

Open to collaborate
with other laboratories





Thank you very much for your attention

Certains hommes parlent pendant leur sommeil. Il n'y a guère que les conférenciers pour parler pendant le sommeil des autres

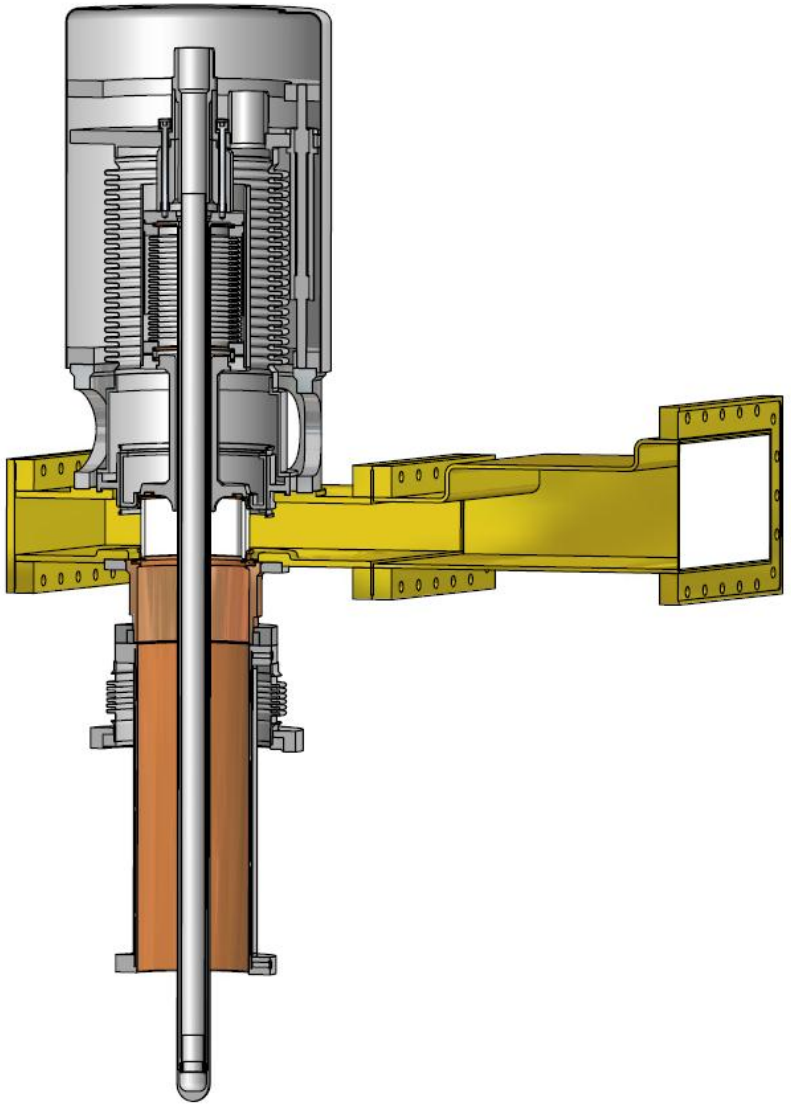
Some people talk during their sleep, there are only lecturers to talk during others sleep

Alfred Capus (1858-1922)

LHC coupler

Technical Choices
Single window coupler
Variable coupler
With a Double Walled Tube
Vertically above the cavity
With a HV DC biasing capacitor
Air cooled

RF Characteristics	
f_o	400 MHz
Power levels	330 kW fwd + 650 kW rev 250 kW average
Q_{ext}	2×10^5 to 3.4×10^6
Input line Ø	145 mm / 41 mm = 75 Ω
Waveguides	WR 2300 half heigth

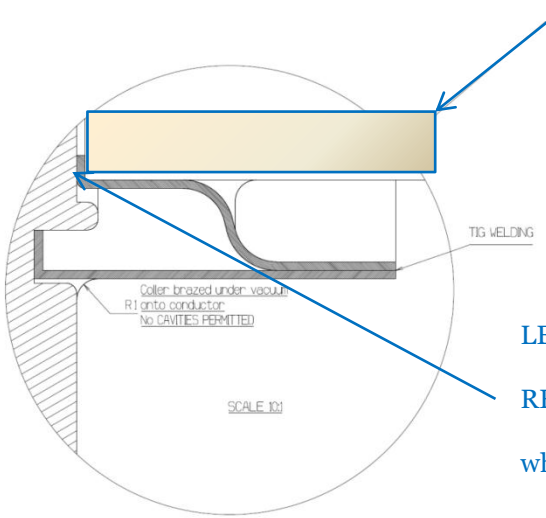


Kovar vs copper window

- LEP Kovar® brazed window :
  - Kovar ® rings on both ends
  - Body and Antenna with Stainless Steel rings brazed onto copper
  - TIG welding under mechanical pressure ensuring RF contact
  - Easy Kovar ® brazing process
  - Weakness of the design : RF contact
  - High field between two Kovar ® 'antennas', arcing

- LHC copper brazed window :
  - Massive copper ring for high power
  - No RF contact, fully continuous RF path
  - Spherical ends of copper rings for no arcing
  - Very difficult brazing process (6 years to be finalized)
  - Advantage of the design: extremely powerful

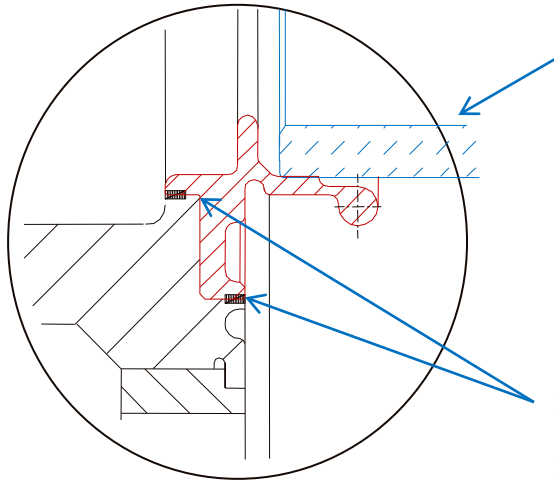
- Ceramic characteristics (CERN Tech Spec 96-05 RF):
  - Aluminum Oxide contents >97.6%
  - Dielectric constant /1GHz/25C = 9.00
  - Dissipation factor at 1 GHZ at 25C = 0.00030



LEP kovar collar

RF contact via compression

while TIG welding



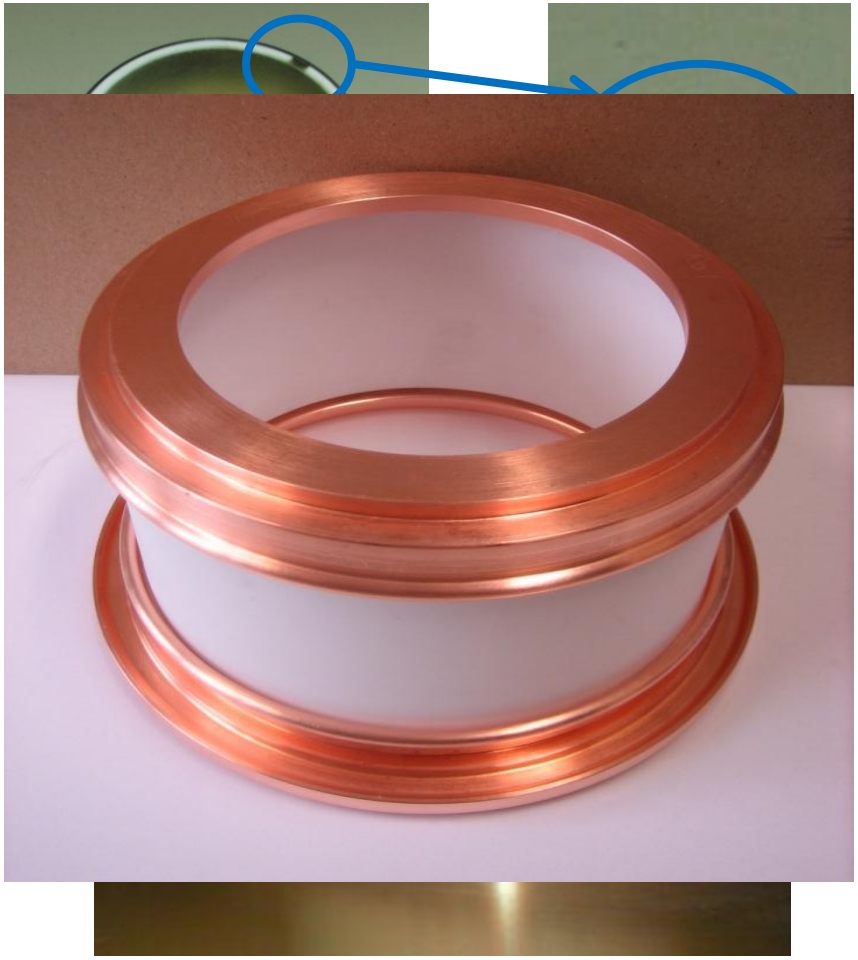
LHC copper collars

EB welded

Metallic continuity

Kovar vs copper window

- APS coupler with kovar/copper misalignment :
  - RF contact lost
  - kovar has metalized ceramic (grey)
  - Thermal losses
  - Vacuum leak
- CERN Kovar vs CERN copper with a LHC test :
  - kovar RF losses
  - Thermal overheating
  - Burnt kapton and peek (> 250 C)
- Copper ceramic window is not only a simple upgrade, it is a very new design really stronger than kovar window ceramic
- 16 windows are in use in LHC couplers since 2007 and have accumulated 30'000 hours of operation each.



Thank you very much for your attention

Certains hommes parlent pendant leur sommeil. Il n'y a guère que les conférenciers pour parler pendant le sommeil des autres

Some people talk during their sleep, there are only lecturers to talk during others sleep

Alfred Capus