DE LA RECHERCHE À L'INDUSTRIE

CEA - Saclay

www.cea.fr

# CRITICAL DESIGN REVIEW #1 FOR MEDIUM BETA CAVITY CRYOMODULES

3-4 APRIL 2017

-

## COUPLERS

-

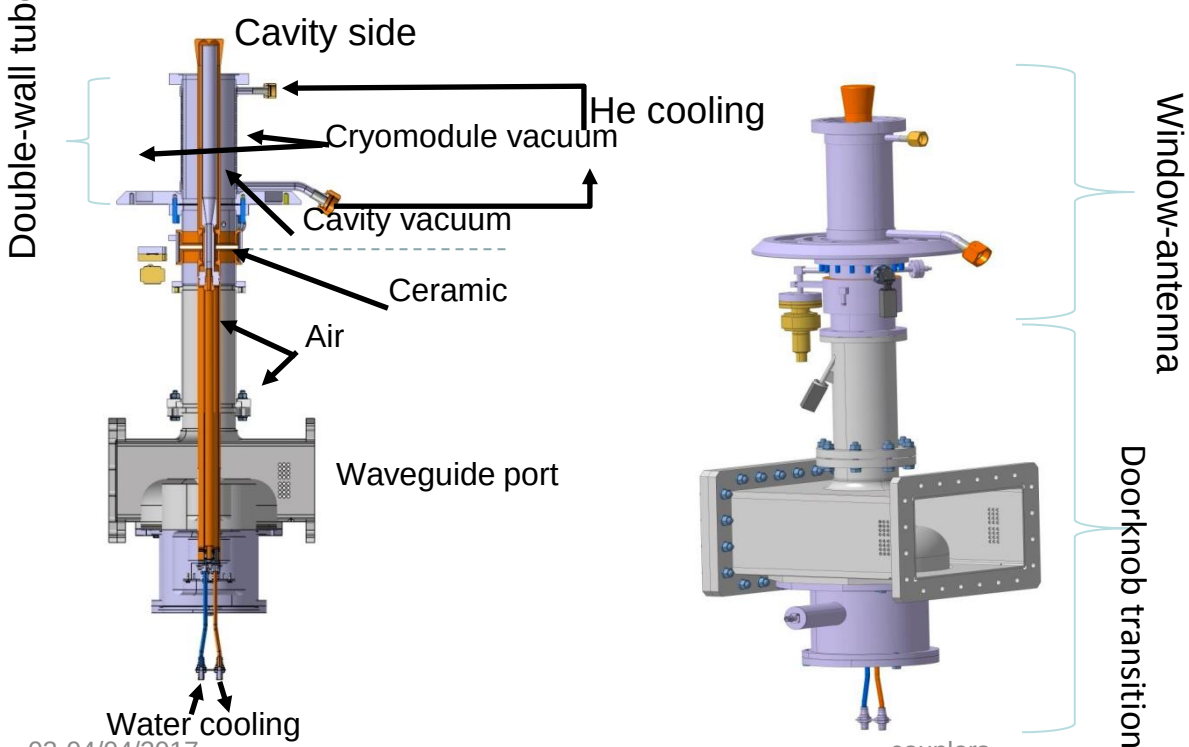
**CHRISTIAN ARCAMBAL**

# OUTLINE

- Overview of the couplers
  - Window-antenna
  - Double-wall tube
  - Doorknob transition
  - Conditioning box
- Controls and checks during manufacturing of the prototypes
- RF characterization of each part
- Conditioning of the 2 first pairs of couplers

# OVERVIEW OF THE COUPLER

- Three main parts: window-antenna, double wall tube, doorknob transition
- Window-antenna and doorknob transitions common to medium and high beta cavities
- Double-wall tube slightly different between the 2 kinds of cavities: only the tube length is modified




| | |
|---|---|
| **RF frequency** | 704.42MHz |
| **Repetition frequency** | 14 Hz |
| **Incident RF power** | 1.2 MW |
| **RF pulse width in full reflection (all phases)** | 500 µs |
| **RF pulse width in travelling waves** | 3.6 ms |
| **Voltage withstand (voltage between internal conductor and external conductor)** | ±10 kV |

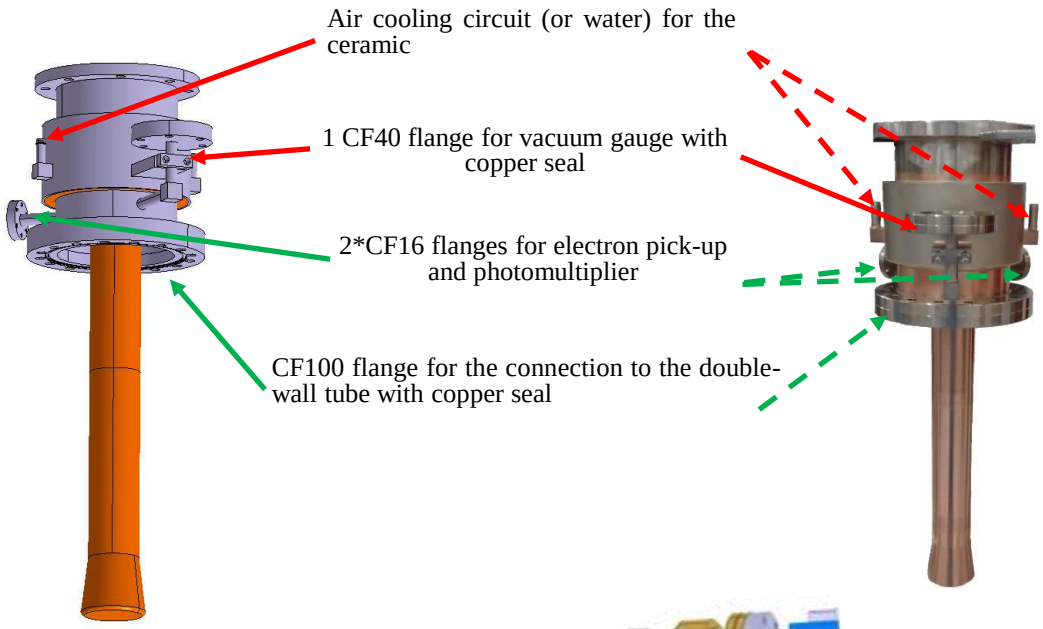
**Technical specifications**

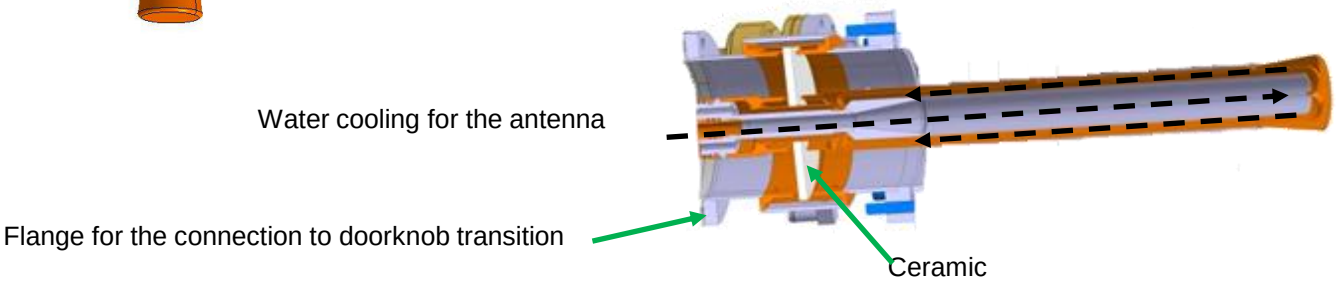
| | |
|---|---|
| **Nominal temperature** | 20°C |
| **Temperature during baking** | Max : 200°C for 100h |
| **Water pressure in cooling circuit** | 3 bars |
| **Water flow in cooling circuit** | 3 l/min |
| **Water temperature in the antenna** | from 20 to 25°C |

**Use conditions**

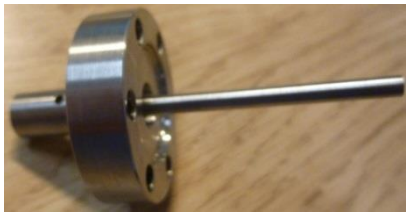
# WINDOW ANTENNA

- Vacuum tightness obtained with the brazing of ceramic
- Design of chokes to improve the impedance matching
- TiN coating for multipactor effect (vacuum side)




Electron pick-up



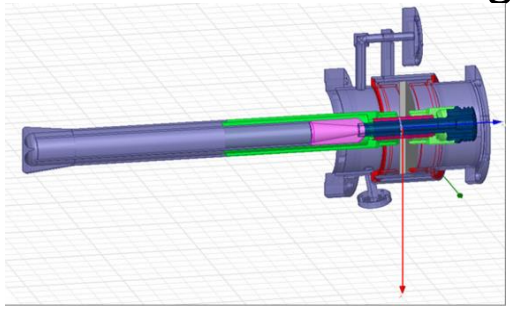
Technical note “Estimation de la longueur du pick-up électron »

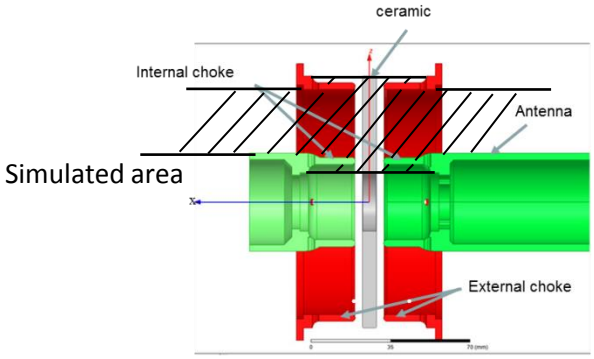
Vacuum gauge (IKR070 from Pfeiffer)

Window for photomultiplier

# PEAK FIELD AROUND THE CERAMIC WINDOW AND RF MATCHING

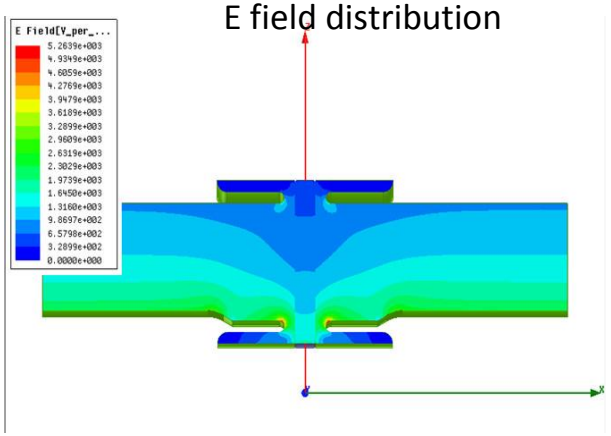
- RF simulations using HFSS

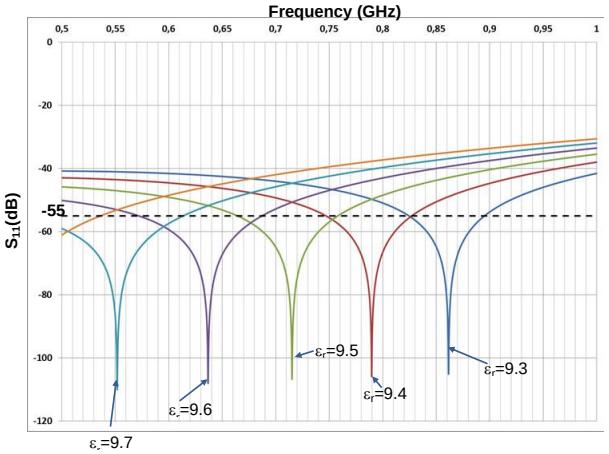


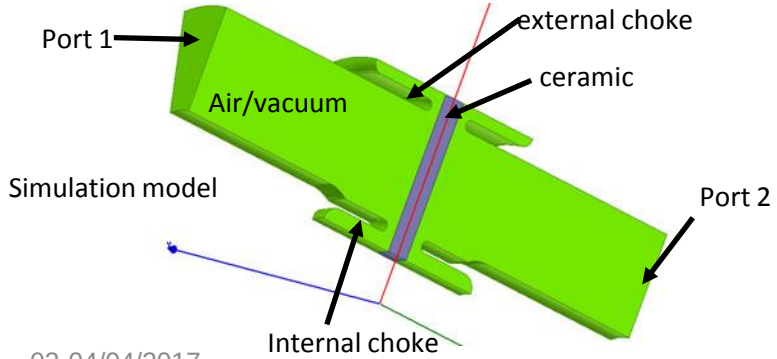



| Parameters | Nominal window |
|---|---|
| Matching frequency ($\varepsilon_r$ nominal) | 710.2 MHz |
| Bandwidth at -55dB | 94 MHz (753-659) |
| Frequency shift for a permittivity shift =0.1 | + 75 MHz ($\Delta\varepsilon_r$=-0.1)<br>-78 MHz ($\Delta\varepsilon_r$=+0.1) |
| Electric field max on surface of internal choke (full transmission) | 1.56 MV/m |
| Electric field max on surface of internal choke (full reflection) | 3.12 MV/m |
| Dielectric losses (travelling wave) | 10 W |
| Dielectric losses (full reflection) | 29.4 W |
| RF losses for external choke (travelling wave) | 1.2 W |
| RF losses for external choke (full reflection) | 1.4 W |
| RF losses for internal choke (travelling wave) | 6.1 W |
| RF losses for internal choke (full reflection) | 6.8 W |

E field distribution



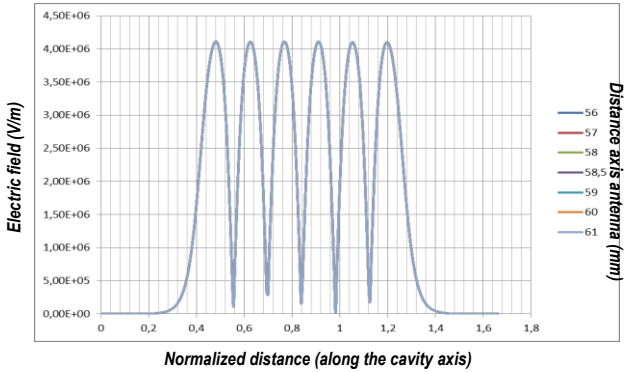


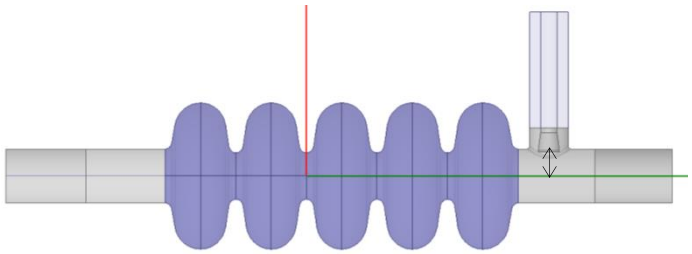




**Technical note "Etude de la sensibilité des cotes de la fenêtre du coupleurs (pour linac à protons) sur les performances RF"**

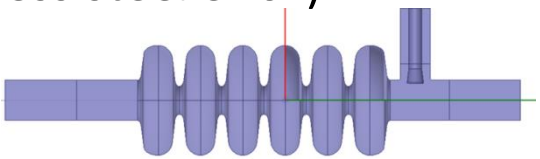
# LENGTH OF THE ANTENNA

- Procedure to evaluate the antenna length
  - HFSS simulation to determine the distance cavity axis –antenna tip + curve interpolation : dist=61.26mm for the medium β cavity, dist= 64.41mm for the high β cavity
  - Taking into account the seals (compression) and thermal expansion of the double wall tube (stainless steel 316L)

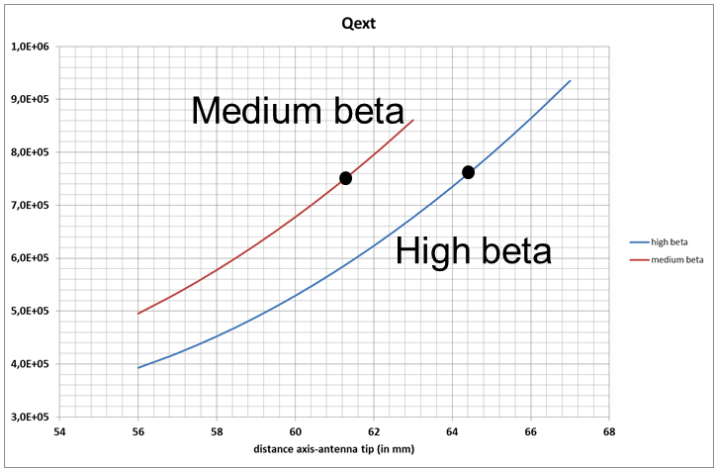


HFSS model of the high β cavity and the coupler



HFSS model of the medium β cavity and coupler

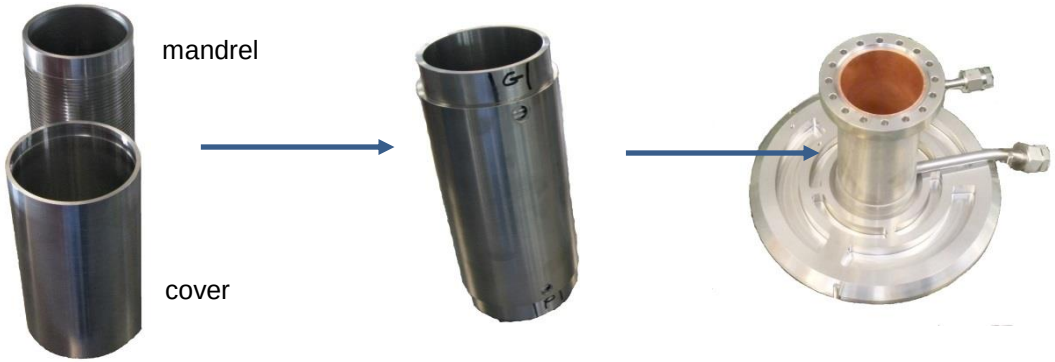


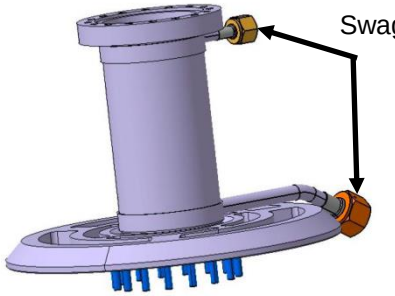

Technical note “Calculation of the coupler antenna length (medium beta cavity)»

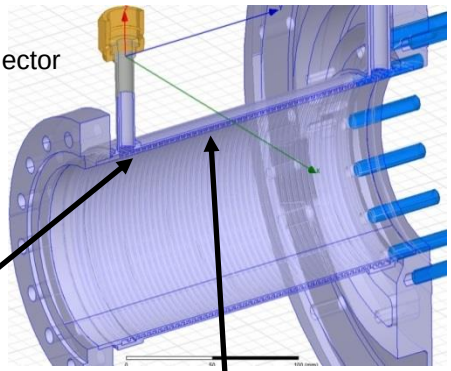
Technical note “Estimation de la longueur du pick-up électron (medium beta cavity) for drawing»

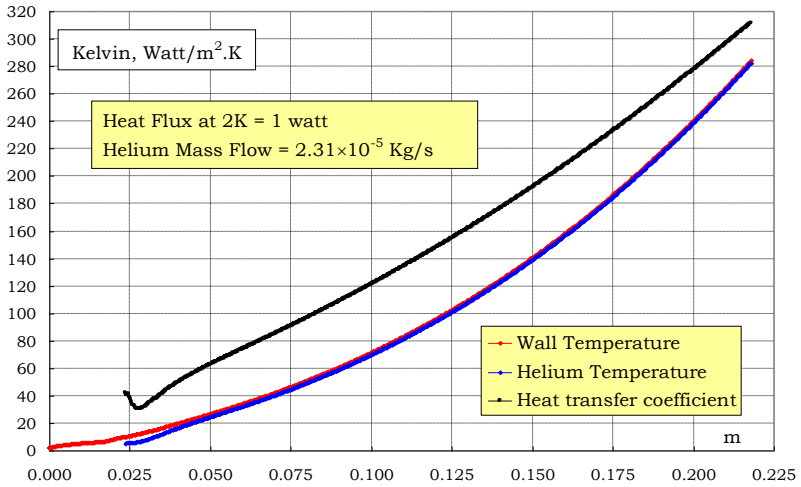
# DOUBLE-WALL TUBE

- Stainless steel 316L
- Cooling circuit manufactured with the shrink-fitting method
- Copper coating with 10µm(-3/+2µm) thickness and RRR∈ [20;40] (threshold between RF and thermal aspects)



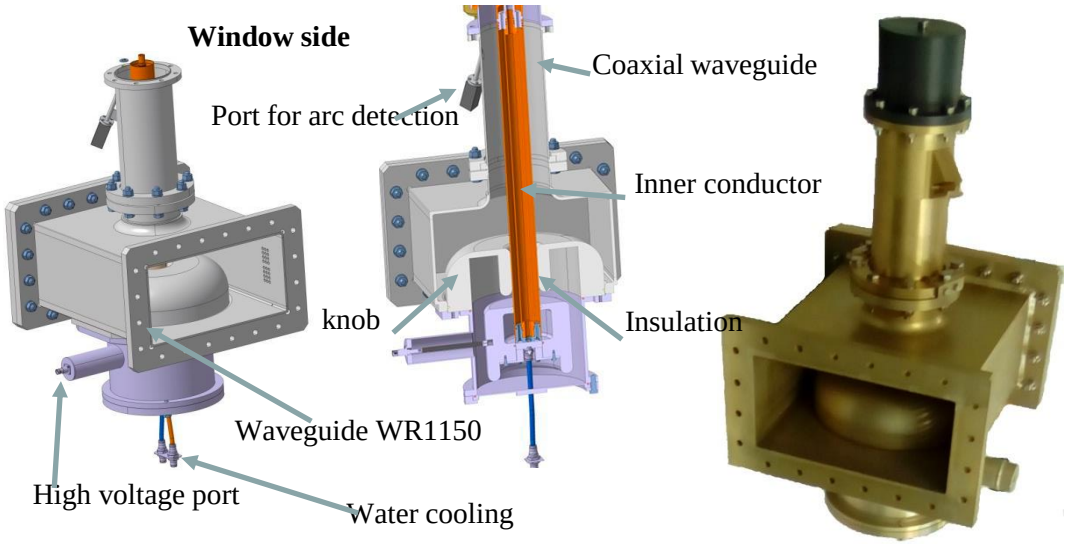




**Technical note "RF Coupler double walled tube cooling", ref. ESS-0003981**

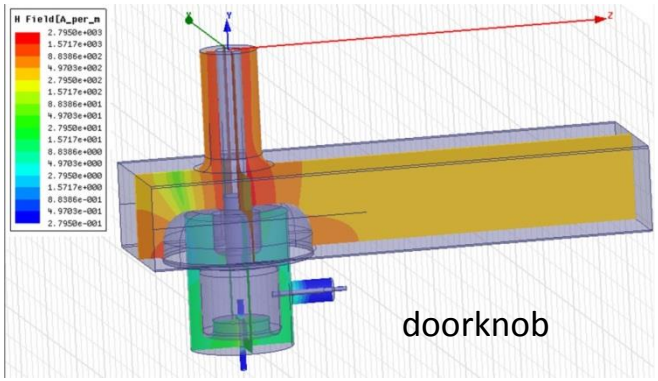
# DOORKNOB TRANSITION

- Insulation obtained with a material with a dielectric constant =3.3 (+/- 10%) able to provide 10kV insulation (breakdown voltage ≥18kV). Use of PEEK
- Insulation cylinder obtained from solid material and machining.
- Protective coating for aluminum parts: alodine 1200
- Water tightness



# COOLING CIRCUITS

- Estimation of the power dissipated by the coupler (simulation and analytical calculation)




Magnetic field distribution

For 1.1 MW peak, duty cycle 5%

-RF power dissipation of the antenna:

in travelling wave 58W

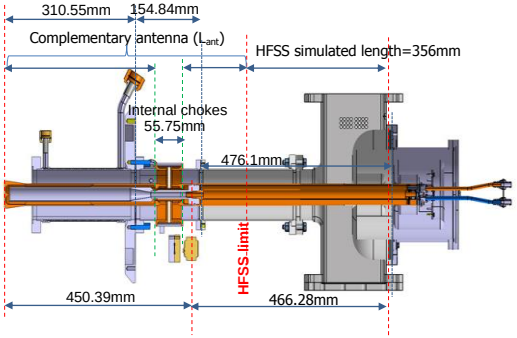
in standing wave 94W

-RF power dissipation of the ceramic (tan $\delta=3\times10^{-4}$)

in travelling wave 9.3W

in standing wave 40W (worst case)

- Cooling of the antenna




Estimation of the water flow

| Φ | ΔT |
|---|---|
| 2 l/min | 0.97° |
| 2.5 l/min | 0.78° |
| 3 l/min | 0.65° |

During the conditioning: for Φ=2.4l/min

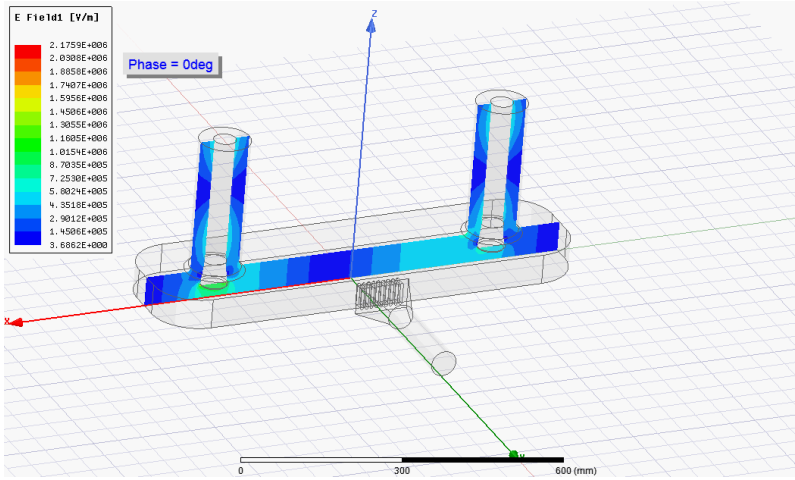
T water input=25.6°C

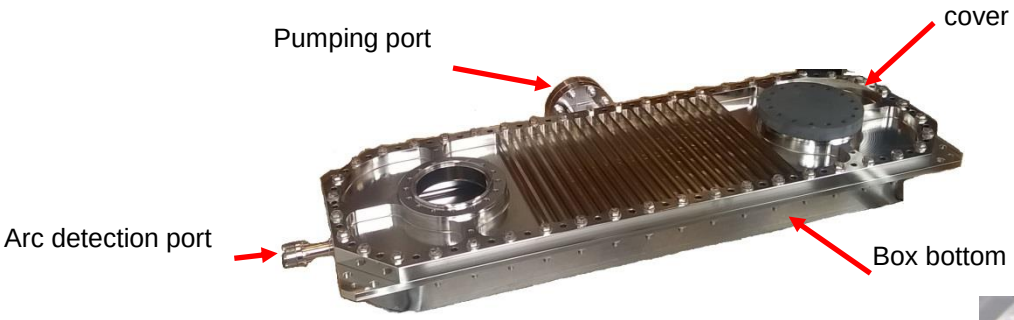
T water output=26.2°C

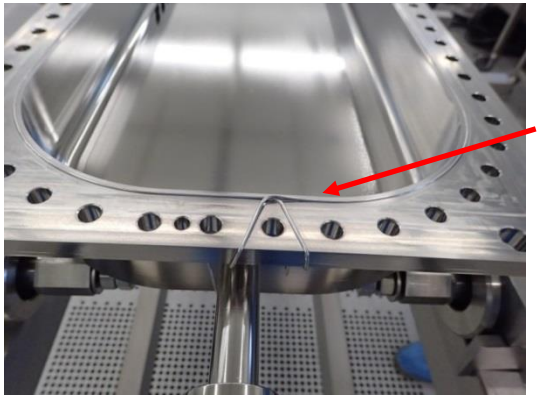
**Technical note "Definition of the water characteristics for the cooling system of the elliptical cavity coupler" (ref. CEA-ESS-CMD-NT-0003 A)**

# CONDITIONING BOX

- Pumping port and port for arc detection
- Aluminum wire used as seal between cover and bottom for vacuum tightness
- Dimensions of the box defined to have the box common to medium and high beta couplers



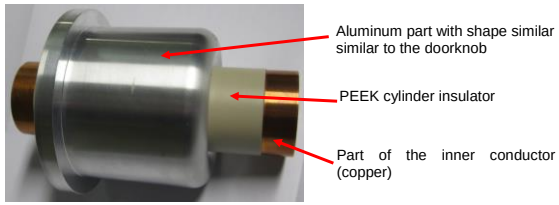



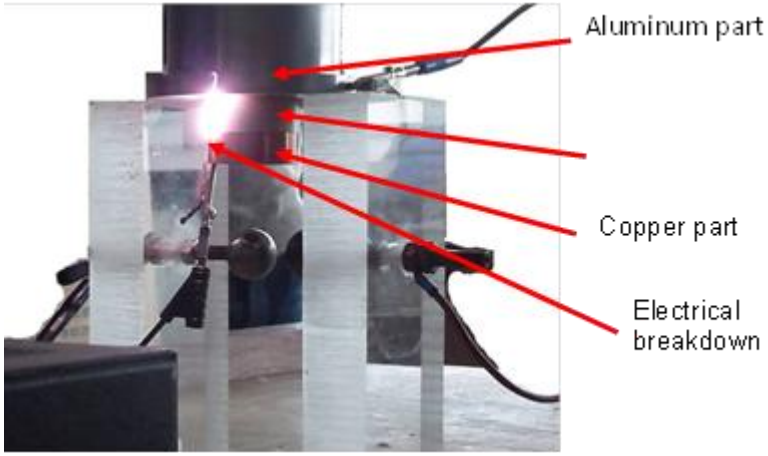




**Technical note "Test box for the power couplers of the elliptical cavities – Mechanical, thermal and RF study" (ref. ESS-0015806)**

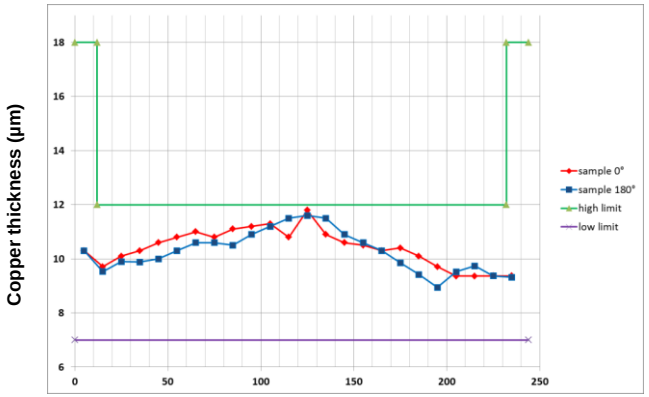
# CONTROLS AND CHECKS DURING MANUFACTURING

- Window, tube, electron pick-up: check of vacuum tightness
- Window and doorknob: check of the water tightness
- Doorknob: check of the insulation



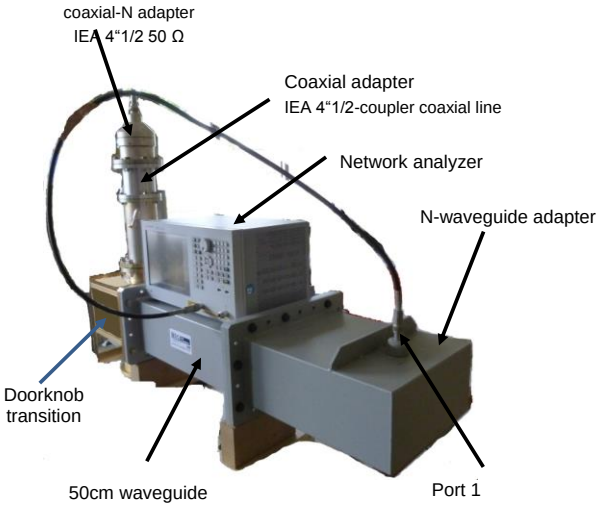



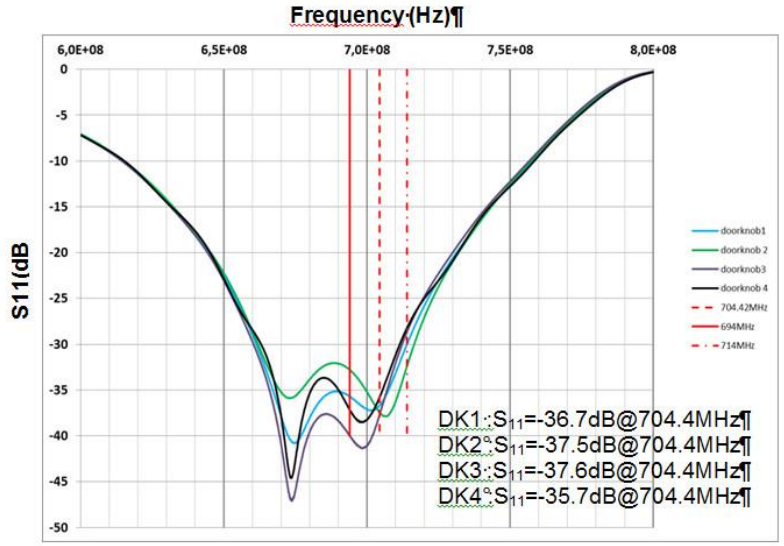

Check of the copper coating thickness



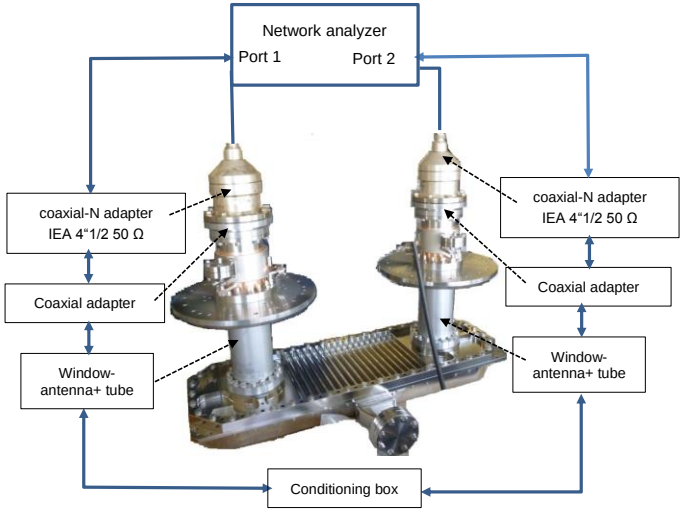
# RF CHARACTERIZATION

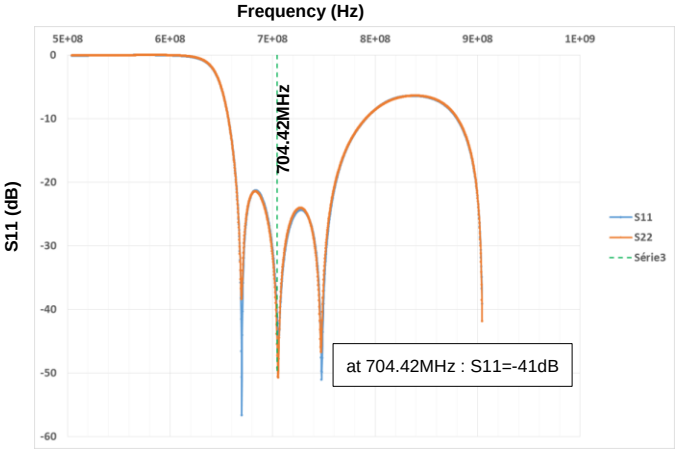
- Doorknob




- Couplers on the conditioning box



# PREPARATION-CLEANING & ASSEMBLY

- Double-wall tubes cleaned in an ultrasonic bath with Tickopur R33
- Cleaning of the window-antenna with cleanroom wiper, use of alcohol and RBS T310
- Assembly in a ISO 4 cleanroom

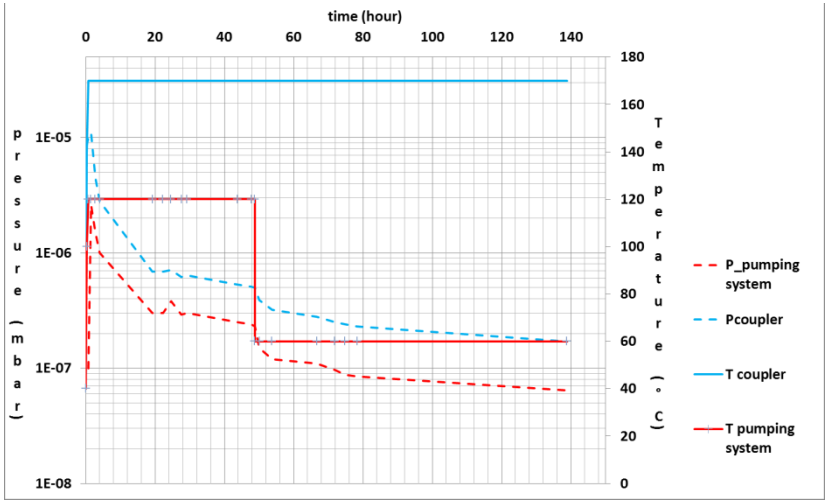
Double-wall tube

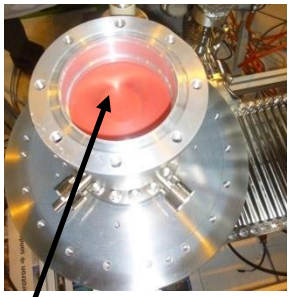
Cleaning of the antenna with alcohol and RBS T310 if oxidation marks

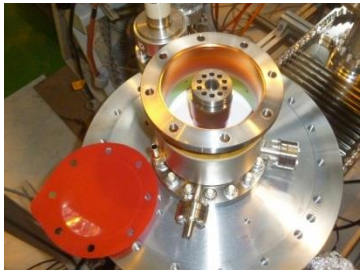
***Procedure "Procédure de montage des coupleurs en salle blanche" in progress***

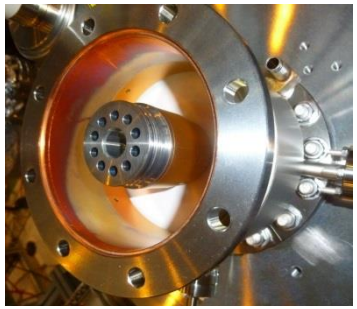
# BAKING OF PROTOTYPE COUPLERS

- Baking of the couplers mounted on a test box: 170°C for 110H,
- Baking of the pumping system at 120°C for 48H then 60°C for 62H



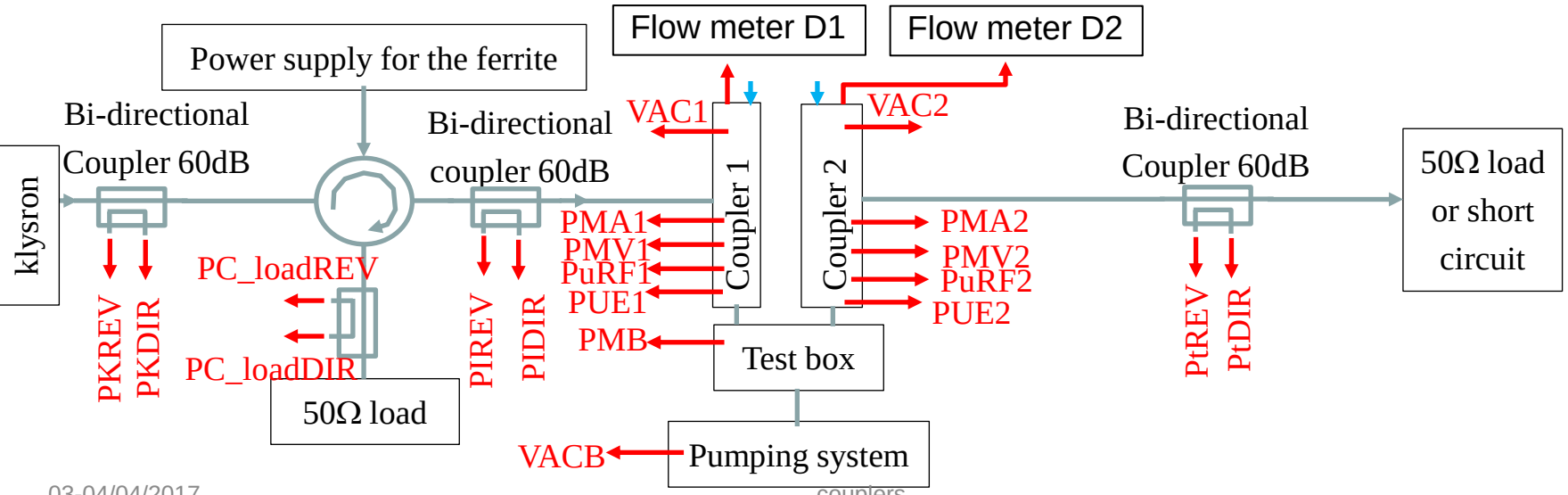


Silicone seal to cover the air part

Air part of the window antenna is under nitrogen to avoid oxidation of the copper parts

# MEASURED SIGNALS DURING HIGH POWER RF CONDITIONNING

- 5 Photomultipliers (HAMAMATSU H10721-110):
  - Coupler1: 1PM vacuum side (PMV1) , 1PM air side (PMA1)
  - Coupler 2: 1PM vacuum side (PMV2) , 1PM air side (PMA2)
  - Box: 1PM (PMB)
- 2 electron pick-up / RF (coupler 1+coupler 2)
  - Coupling 80dB (10.4dBm for 1.1MW in TW, 16.4dBm in SW with Emax in front of pick-up antenna)
- 3 vacuum gauges:IKR070 with TPG300 controller from Pfeiffer (Coupler 1 (VAC1) & 2 (VAC2) + pumping system (VACB))
- 5 temperature probes (PT100): 2 for water cooling,1 for each coupler (set up on the window close to the ceramic), 1 for the test box
- 8 RF signals: Reverse and forward powers for each bidirectional coupler
- Security signals: 3 vacuum signals from the controllers, 2 water signals from flow meters (relays)

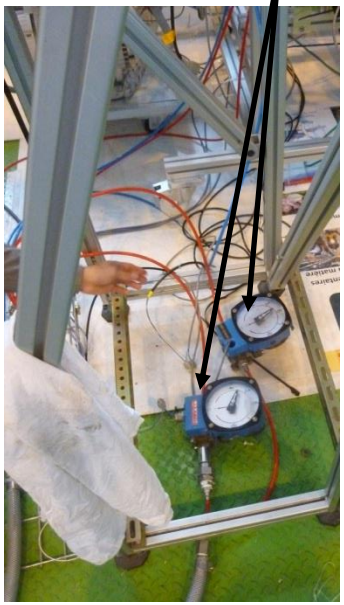


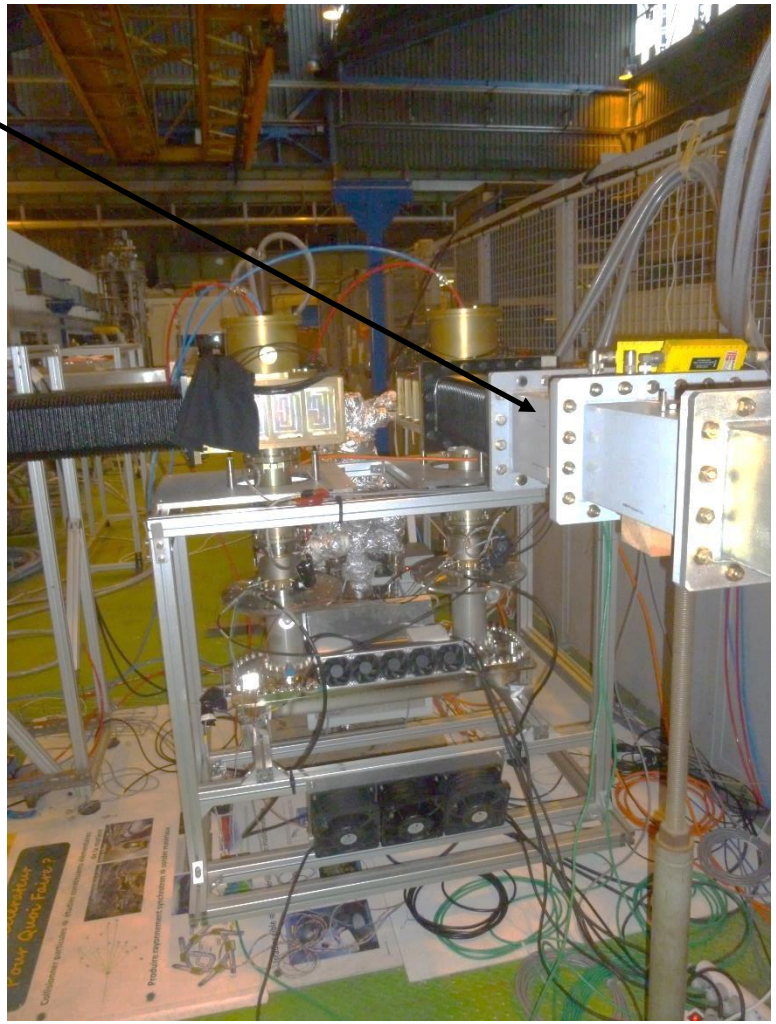
# OVERVIEW OF THE CONDITIONING BENCH (1/2)

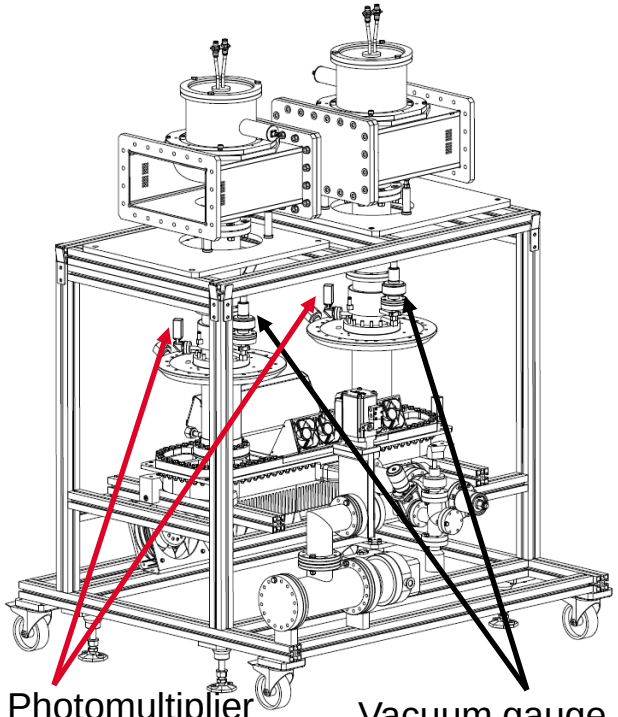
- Position of each diagnosis components

Bidirectional coupler (input Power :incident & reflected power)

Flow meter (ouptut water) &
Temperature probes (water)

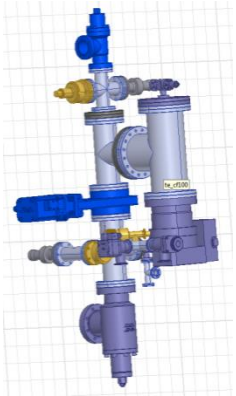






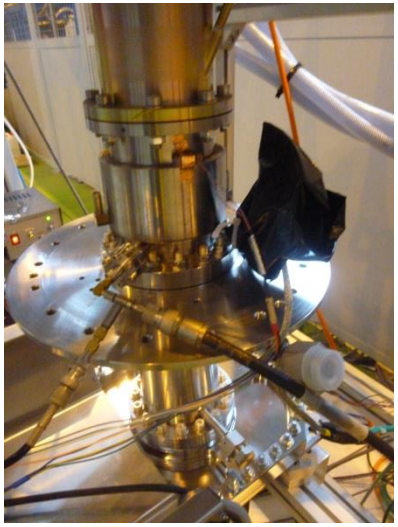
Photomultiplier (vacuum side)

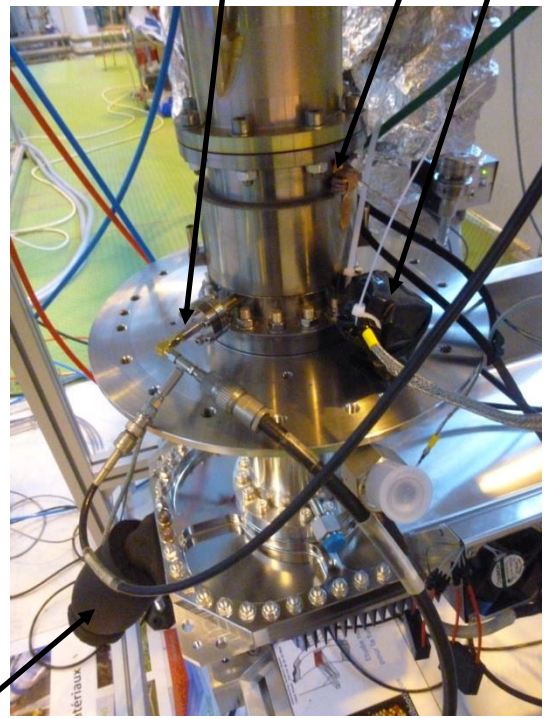
Vacuum gauge



Pumping system

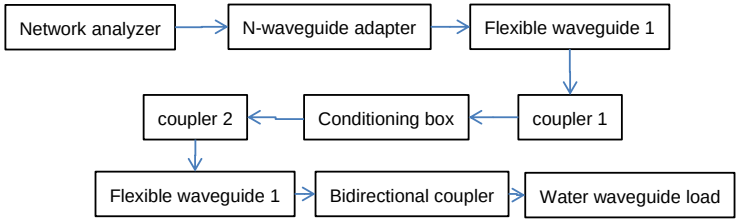
# OVERVIEW OF THE CONDITIONING BENCH (2/2)

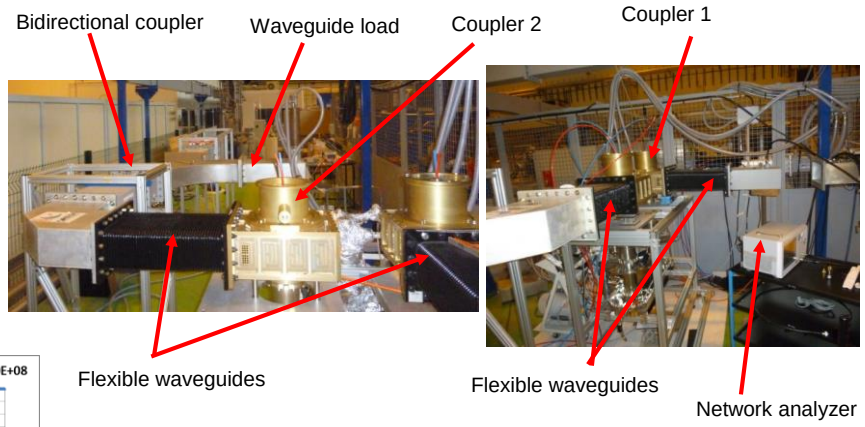


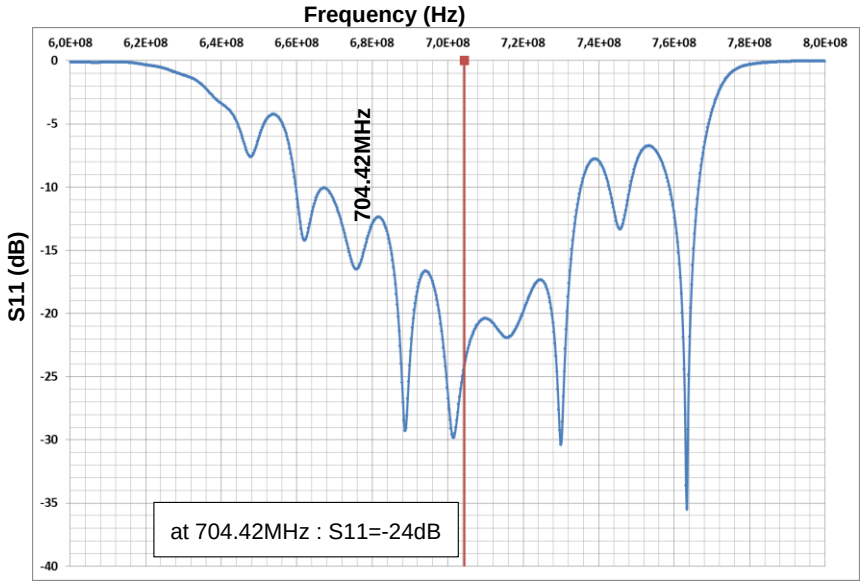


# RF CHARACTERIZATION ON THE TEST STAND

- Measurement of the reflection coefficient of the pair of couplers with all the waveguide components (load 50Ω)



# CONDITIONING SEQUENCE

- Sequence for travelling wave

| Step | Pulse width [ms] | Repetition frequency [Hz] | Duty cycle | Power[kW] |
|---|---|---|---|---|
| TW-L01 | 0.03 | 1 | 0.003% | 15 - 1200 |
| TW-L02 | 0.1 | 1 | 0.01% | 15 - 1200 |
| TW-L03 | 0.2 | 1 | 0.02% | 15 - 1200 |
| TW-L04 | 0.4 | 1 | 0.04% | 15 - 1200 |
| TW-L05 | 0.8 | 1 | 0.08% | 15 - 1200 |
| TW-L06 | 1.2 | 1 | 0.12% | 15 - 1200 |
| TW-L07 | 1.6 | 1 | 0.16% | 15 - 1200 |
| TW-L08 | 2 | 1 | 0.2% | 15 - 1200 |
| TW-L09 | 2.5 | 1 | 0.25% | 15 - 1200 |
| TW-L10 | 3 | 1 | 0.3% | 15 - 1200 |
| TW-L11 | 3.6 | 1 | 0.36% | 15 - 1200 |
| | | | | |
| TW-H01 | 0.2 | 14 | 0.28% | 15 - 1200 |
| TW-H02 | 0.4 | 14 | 0.56% | 15 - 1200 |
| TW-H03 | 0.8 | 14 | 1.12% | 15 - 1200 |
| TW-H04 | 1.2 | 14 | 1.68% | 15 - 1200 |
| TW-H05 | 1.6 | 14 | 2.24% | 15 - 1200 |
| TW-H06 | 2 | 14 | 2.8% | 15 - 1200 |
| TW-H07 | 2.5 | 14 | 3.5% | 15 - 1200 |
| TW-H08 | 3.0 | 14 | 4.2% | 15 - 1200 |
| TW-H09 | 3.6 | 14 | 5.04% | 15 - 1200 |
| TW-H10 | 3.6 | 14 | 5.04% | 1200 for 1h |

- From L01 to H10: RF Time ≤120 hours
- H09 & H10: P ≤$2\times10^{-8}$mbar

- Sequence for standing wave (2 positions of the short circuit)

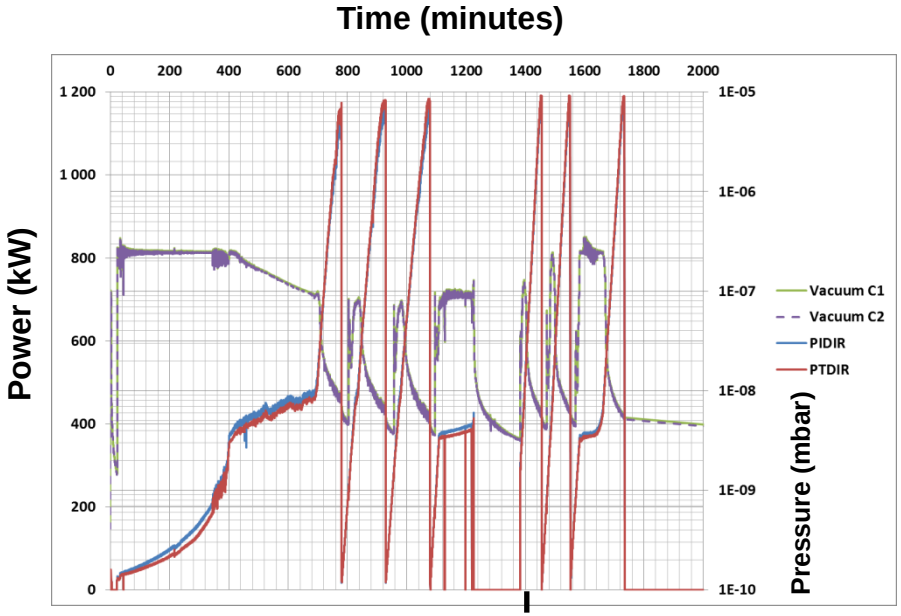
| Step | Pulse width [ms] | Repetition frequency [Hz] | Duty cycle | Power[kW] |
|---|---|---|---|---|
| SW-S01 | 0.05 | 1 | 0.005% | 15 - 1200 |
| SW-S02 | 0.1 | 1 | 0.01% | 15 - 1200 |
| SW-S03 | 0.2 | 1 | 0.02% | 15 - 1200 |
| SW-S04 | 0.3 | 1 | 0.03% | 15 - 1200 |
| SW-S05 | 0.4 | 1 | 0.04% | 15 - 1200 |
| SW-S06 | 0.5 | 1 | 0.05% | 15 - 1200 |
| SW-S07 | 0.5 | 2 | 0.1% | 15 - 1200 |
| SW-S08 | 0.5 | 4 | 0.2% | 15 - 1200 |
| SW-S09 | 0.5 | 8 | 0.4% | 15 - 1200 |
| SW-S10 | 0.5 | 14 | 0.7% | 15 - 1200 |
| | | | | |
| SW-L01 | 0.8 | 14 | 1.12% | 15 - 300 |
| SW-L02 | 1.5 | 14 | 2.1% | 15 - 300 |
| SW-L03 | 2.5 | 14 | 3.5% | 15 - 300 |
| SW-L04 | 3 | 14 | 4.2% | 15 - 300 |
| SW-L05 | 3.6 | 14 | 5.04% | 15 - 300 |

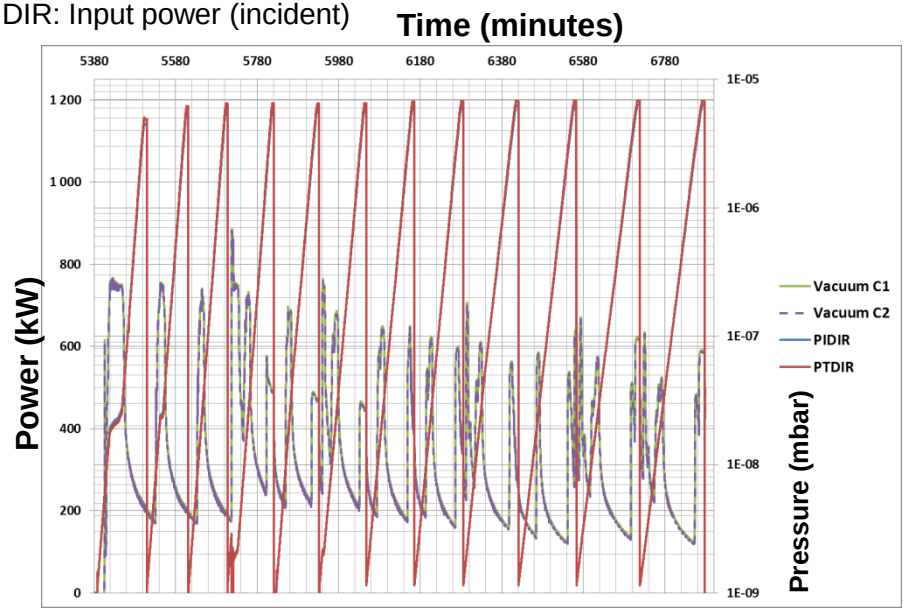
- S10 & L05: P ≤$2\times10^{-8}$mbar

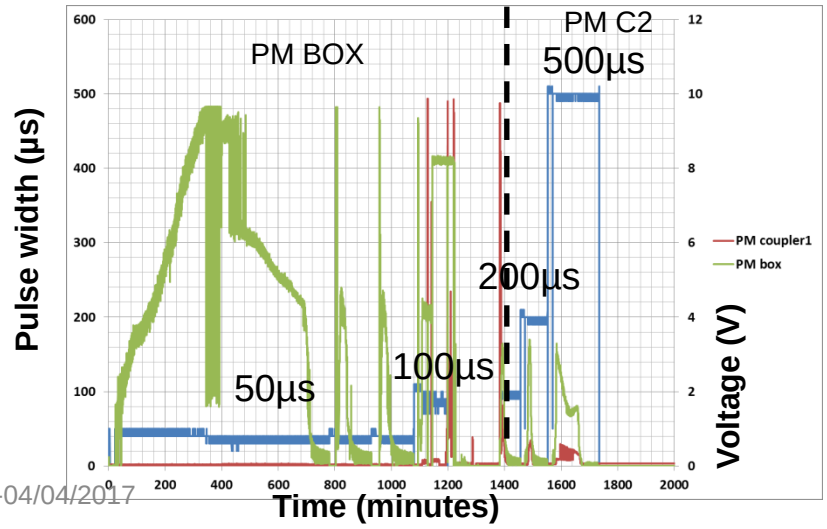
# CONDITIONING-TRAVELLING WAVE (1/2)

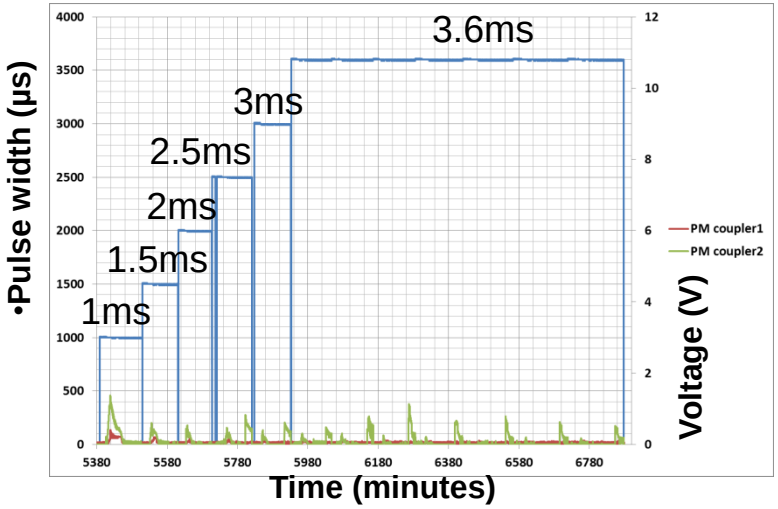
- Results for repetition period=1.2second

PTDIR: Output power (incident)
PIDIR: Input power (incident)



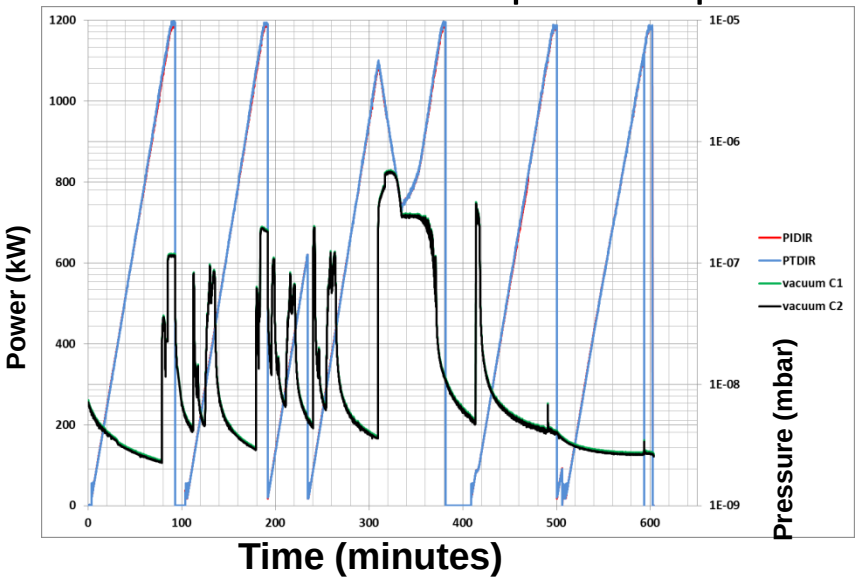



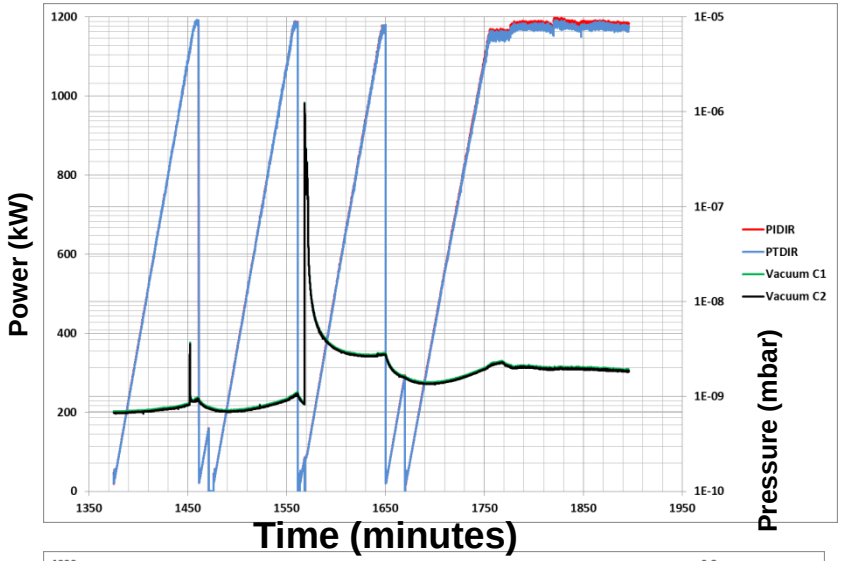



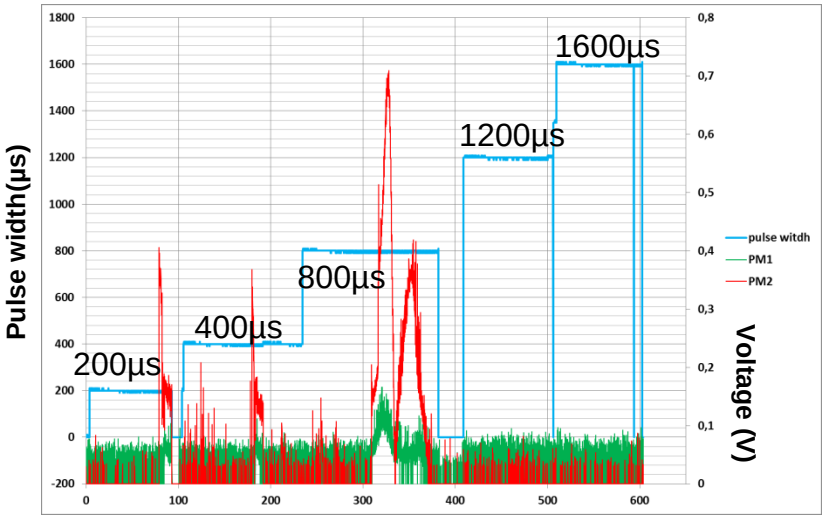
# CONDITIONING-TRAVELLING WAVE (2/2)

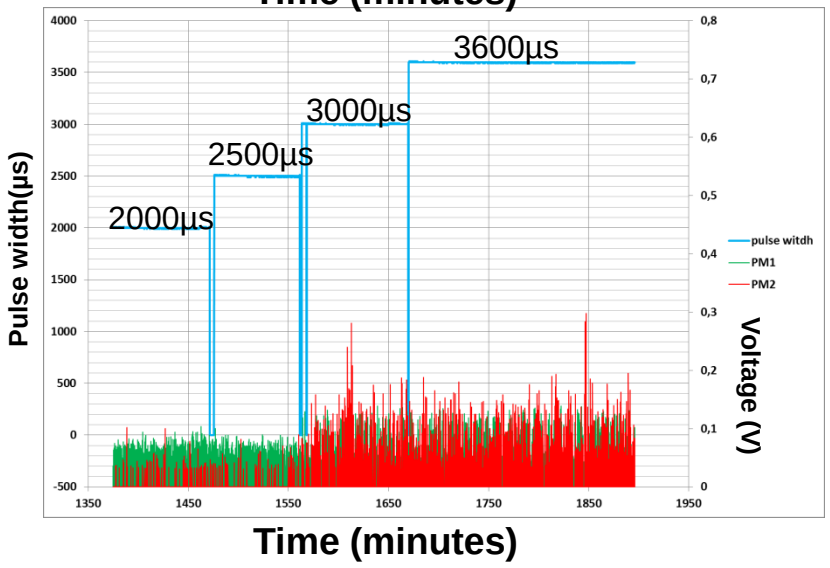
– Results for repetition period=72 ms



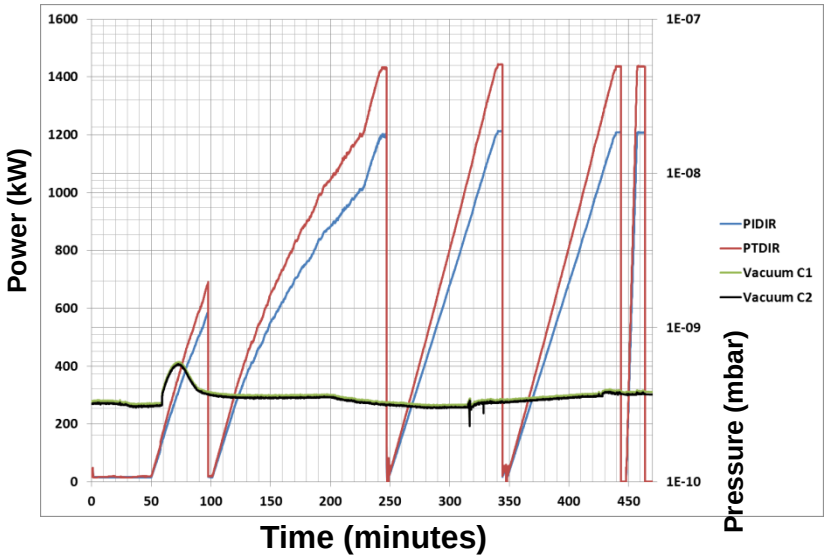

PTDIR: Output power (incident)
PIDIR: Input power (incident)

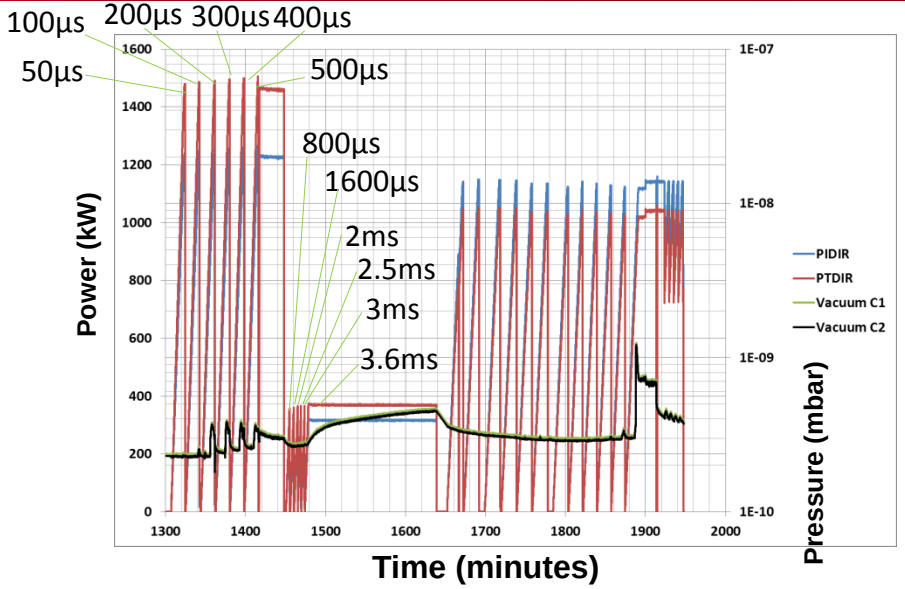


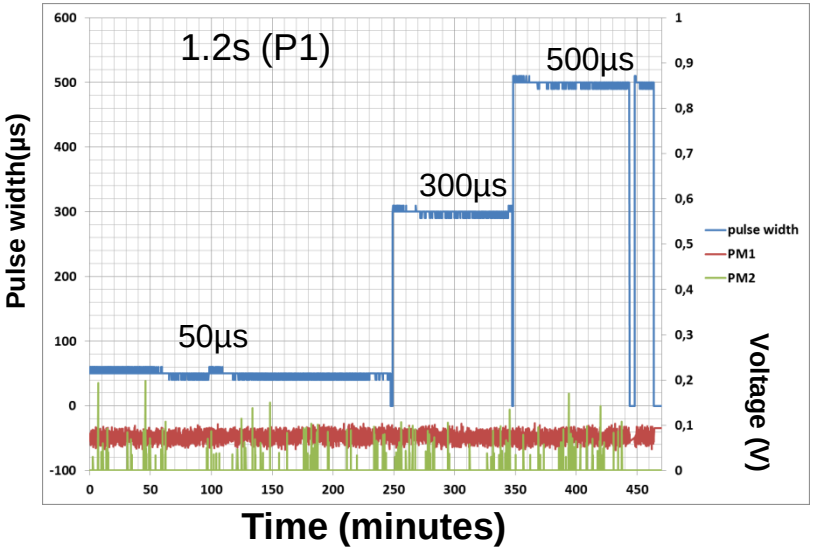



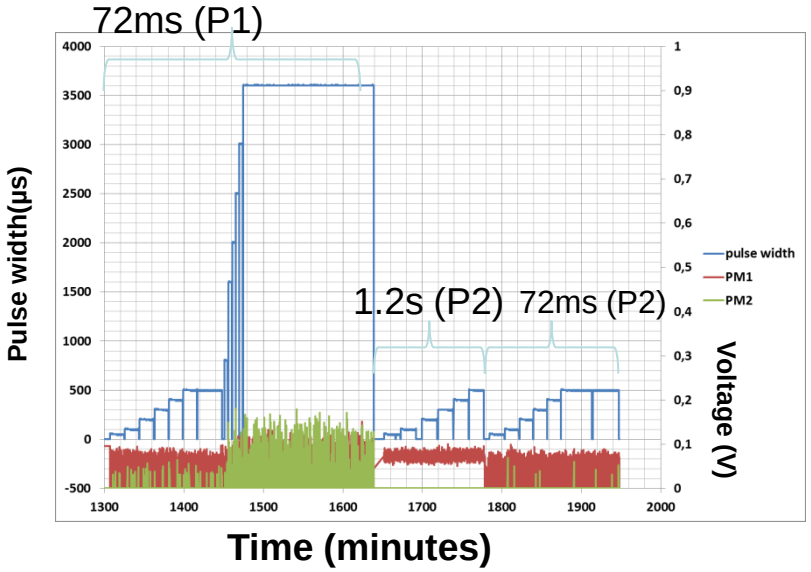



# CONDITIONING-STANDING WAVE



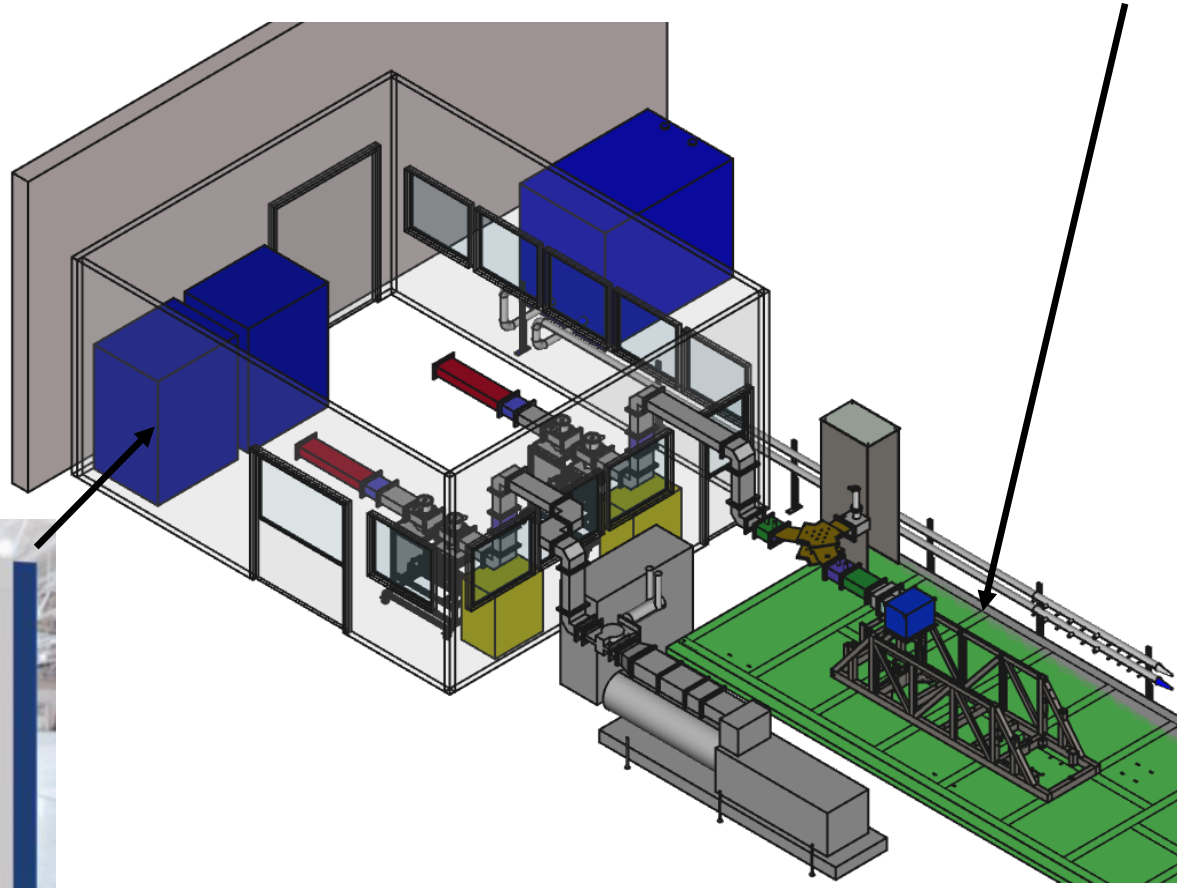



# BAKING AND RF CONDITIONNING TEST STAND FOR THE SERIES POWER COUPLERS

- New baking system (furnace)
- Use of two 704 MHz klystrons in parallel (new klystron ordered)



# CONCLUSION

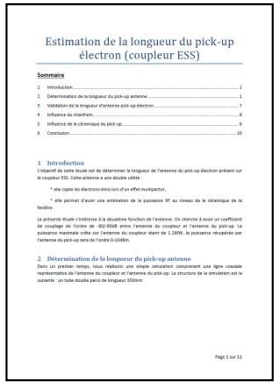
- Overview of the manufacturing for prototypes:
  - 6 medium beta double-wall tubes
  - 10 windows
  - 8 doorknob transitions
  - In progress, manufacturing of 6 high beta double-wall tubes (delivery in June 2017)
- Conditioning of 2 pairs of couplers with success (these couplers are assembled in cavities)

- Conditioning of the third pair of couplers in progress
- Conditioning of the first pair of high beta couplers foreseen in June 2017

# TECHNICAL NOTES

- List of the technical notes written in the framework of the coupler development

Electron pick-up


Estimation de la longueur du pick-up électron (coupleur ESS)

Sommaire

1 Introduction
2 Détermination de la longueur du pick-up antenne
3 Validation de la longueur d'antenne pick-up électron
4 Influence du chanfrein
5 Influence de la céramique du pick-up
6 Conclusion

1 Introduction

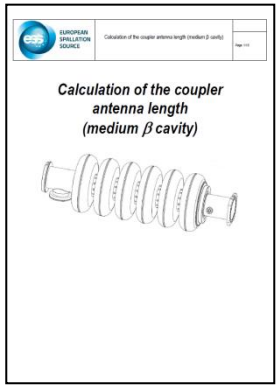
2 Détermination de la longueur du pick-up antenne

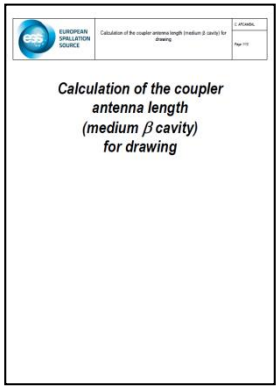
RF Design of the window


Note technique

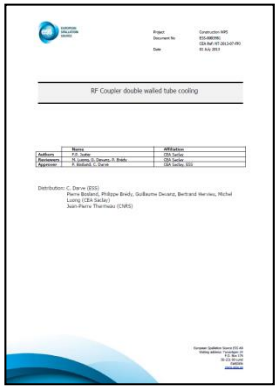
ETUDE DE LA SENSIBILITE DES COTES DE LA FENETRE DU COUPLEUR (POUR LINAC A PROTONS) SUR LES PERFORMANCES RF

Antenna length

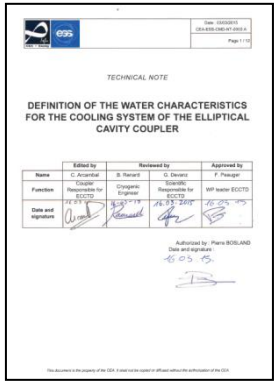

Calculation of the coupler antenna length (medium β cavity)


Calculation of the coupler antenna length (medium β cavity) for drawing

Cooling of the tube

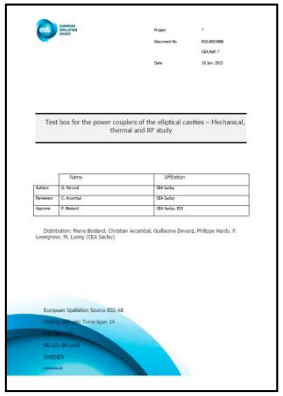

RF Coupler double walled tube cooling

Water for cooling

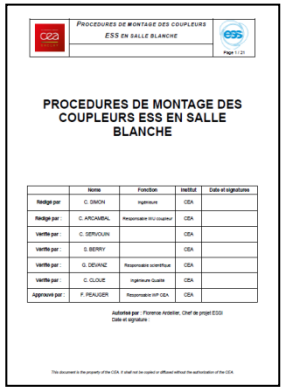

TECHNICAL NOTE

DEFINITION OF THE WATER CHARACTERISTICS FOR THE COOLING SYSTEM OF THE ELLIPTICAL CAVITY COUPLER

Test box characterization


Test box for the power couplers of the elliptical cavities – Mechanical, thermal and RF study

Procedure of coupler assembly in cleanroom


PROCEDURES DE MONTAGE DES COUPLEURS ESS EN SALLE BLANCHE

# Thank you

•Commissariat à l'énergie atomique et aux énergies alternatives
•Centre de Saclay ¦ 91191 Gif-sur-Yvette Cedex
•T. +33 (0)1 69 08 76 11 ¦ F. +33 (0)1 69 08 30 24
•Etablissement public à caractère industriel et commercial ¦ RCS Paris B 775 685 019