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704 MHZ FPC

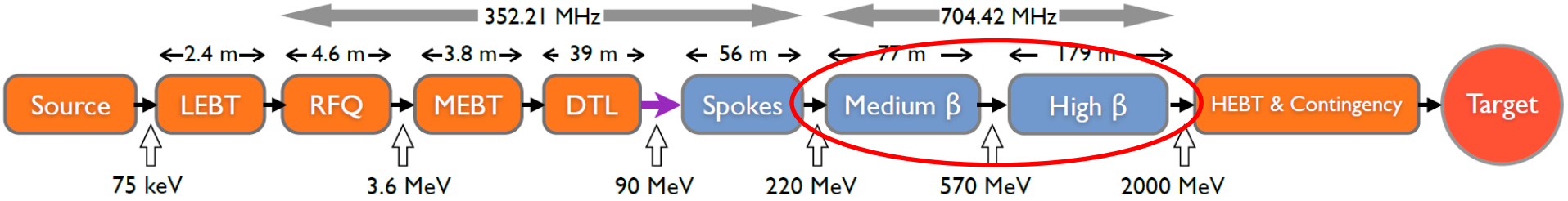
EVOLUTION TOWARDS FPC SERIES FOR ESS

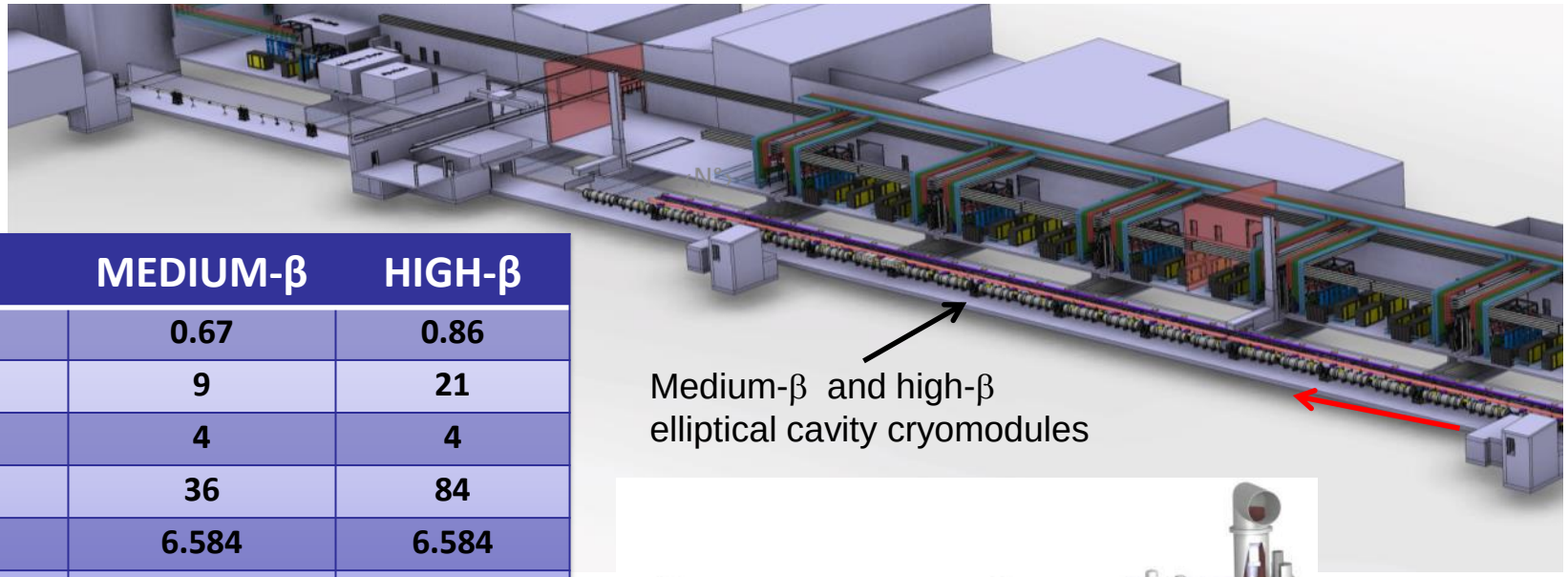
G. Devanz

OUTLINE

- PROTOTYPES
- DESIGN EVOLUTIONS FOR ESS
- PREPARATION FOR SERIES PRODUCTION

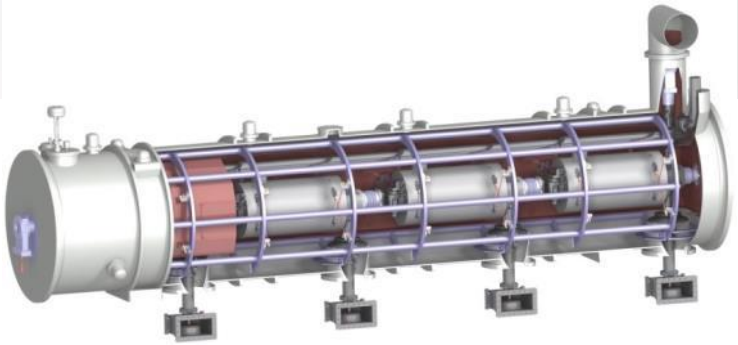
ELLIPTICAL CRYOMODULES FOR THE EUROPEAN SPALLATION SOURCE ESS





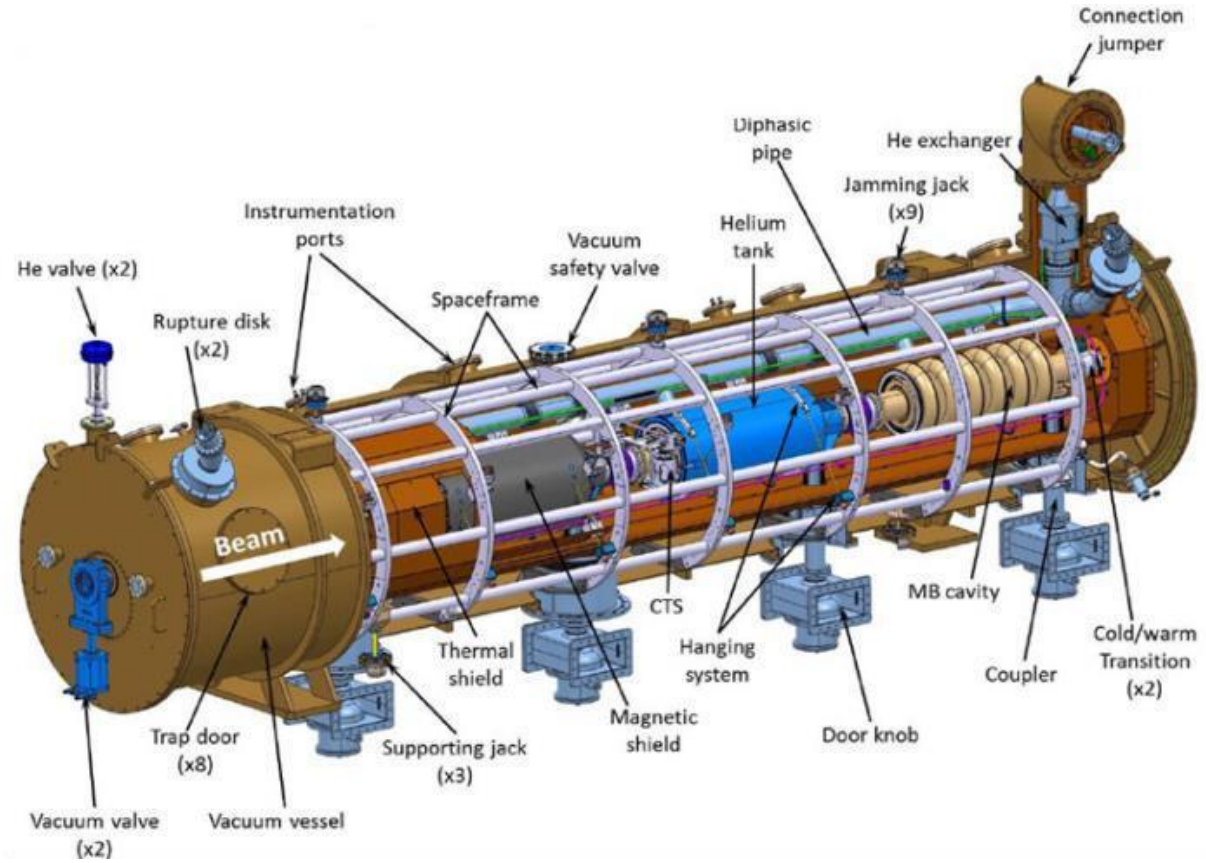
Medium-β and high-β elliptical cavity cryomodules

	MEDIUM-β	HIGH-β
β	0.67	0.86
# CM	9	21
Cav. /CM	4	4
# Cav.	36	84
CM L [m]	6.584	6.584
Sector L [m]	77	179



ESS ELLIPTICAL CRYOMODULES

Designed by CEA-Saclay/IRFU and CNRS/IPNO



Medium and high beta differ only by the cavity length and number of cells

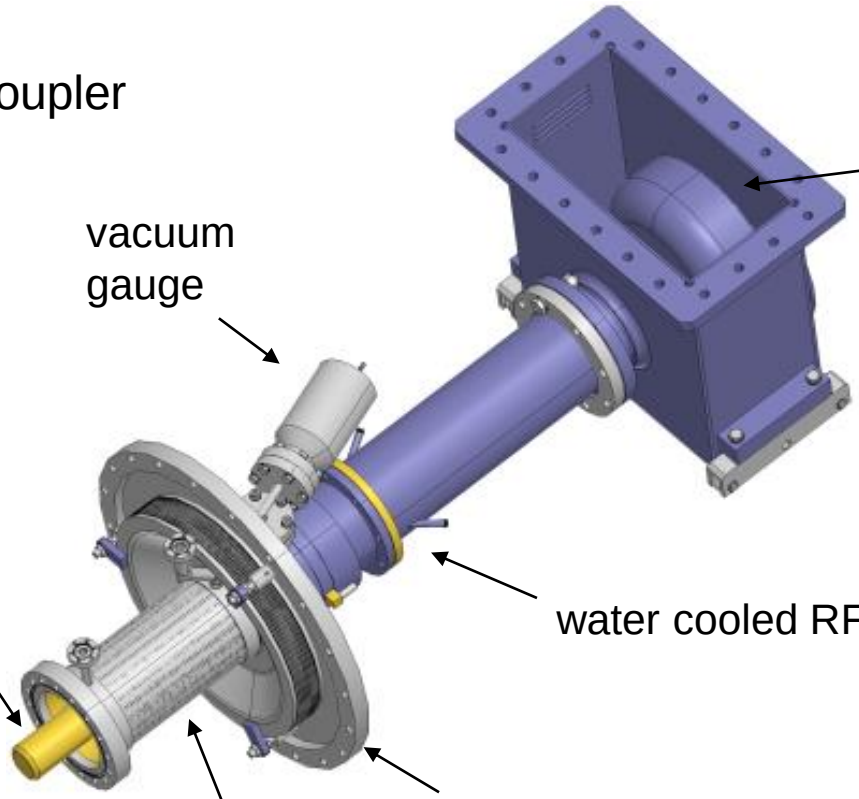
REQUIREMENTS FOR ESS ELLIPTICAL FPCS

- Freq = 704.42 MHz
- Pmax = 1.1 MW, RF pulses at 14 Hz
- Beam pulses duration = 2.86 ms,
- minimum required RF pulse length = 3.1 ms

EU PROGRAMME CARE-HIPPI

The developpement of the 1MW 704 MHz FPC started with EU R&D programme CARE directed towards high power pulsed proton accelerators with 10% duty cycle

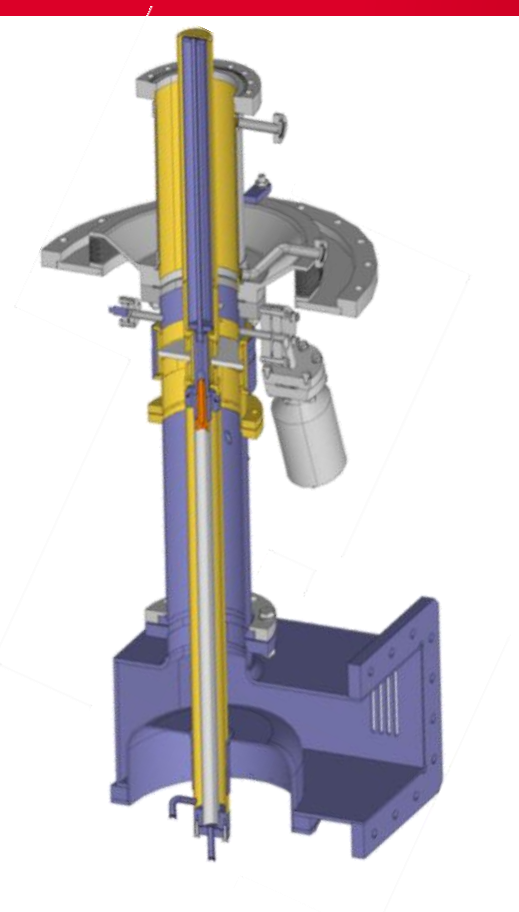
KEK-B, SNS type coupler



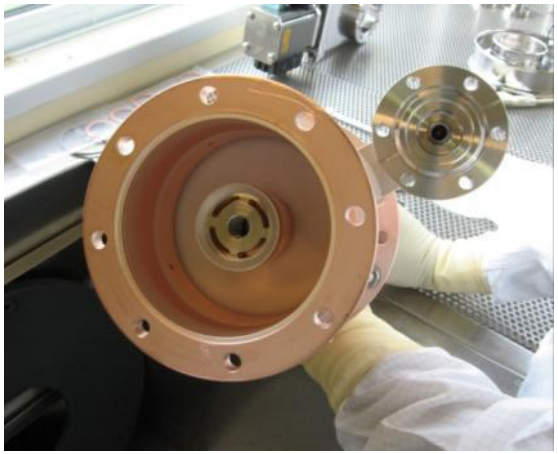
Coaxial coupler

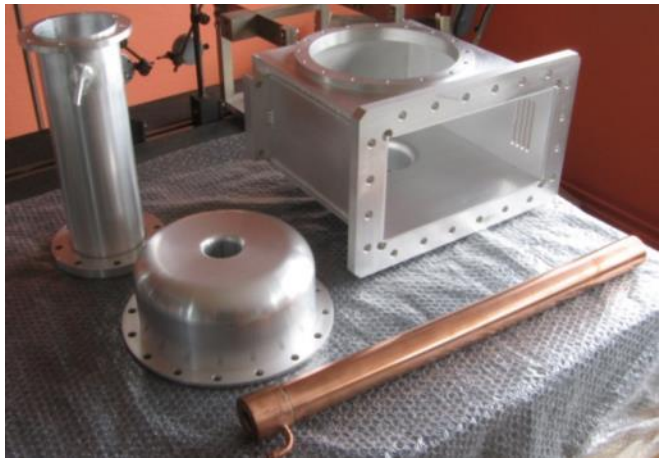
- 100 mm diameter
- 50 Ω

CARE-HIPPI FPC PROTOTYPES



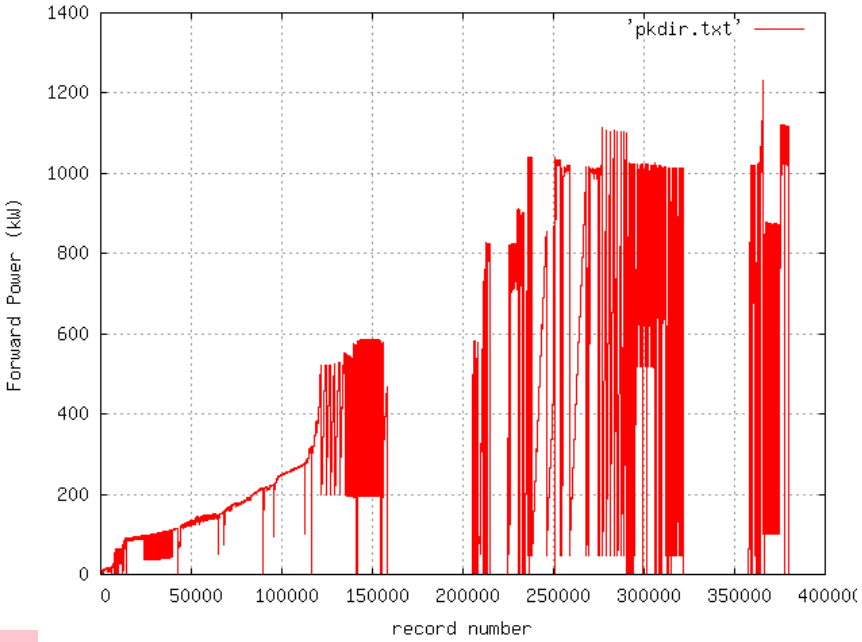
Built one pair of FPC
in industry (one for each of the 3 main compenents), except Cu film done by CERN





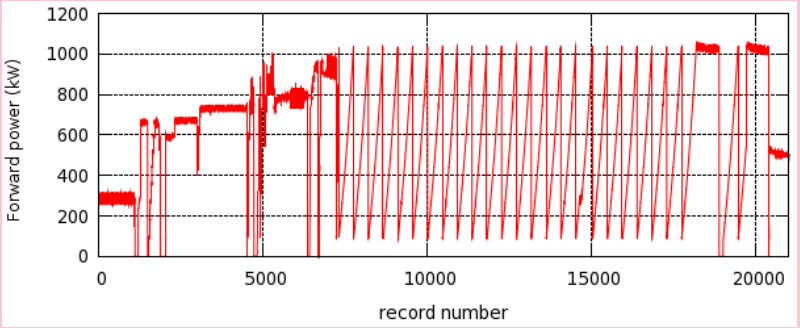
HIPPI PERFORMANCE ON TEST STANDS AND HORIZONTAL TEST CRYOMODULE

TW on conditioning test stand



1 pair tested up to 1.2 MW, 10% duty factor

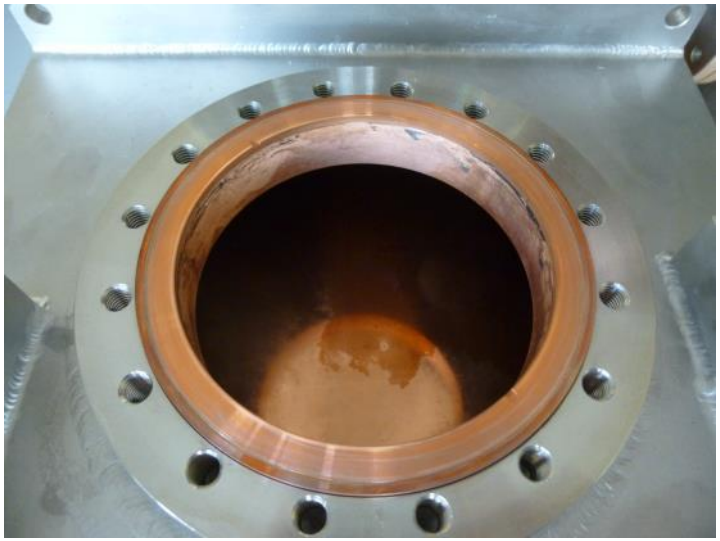
Test of the HIPPI power coupler on the HIPPI cavity at 1.8 K, full reflection

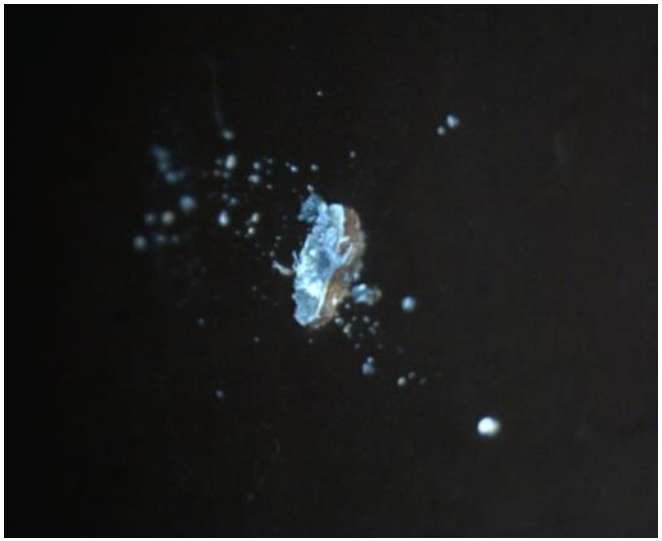


HIPPI conclusion (from WWFPC-2015)

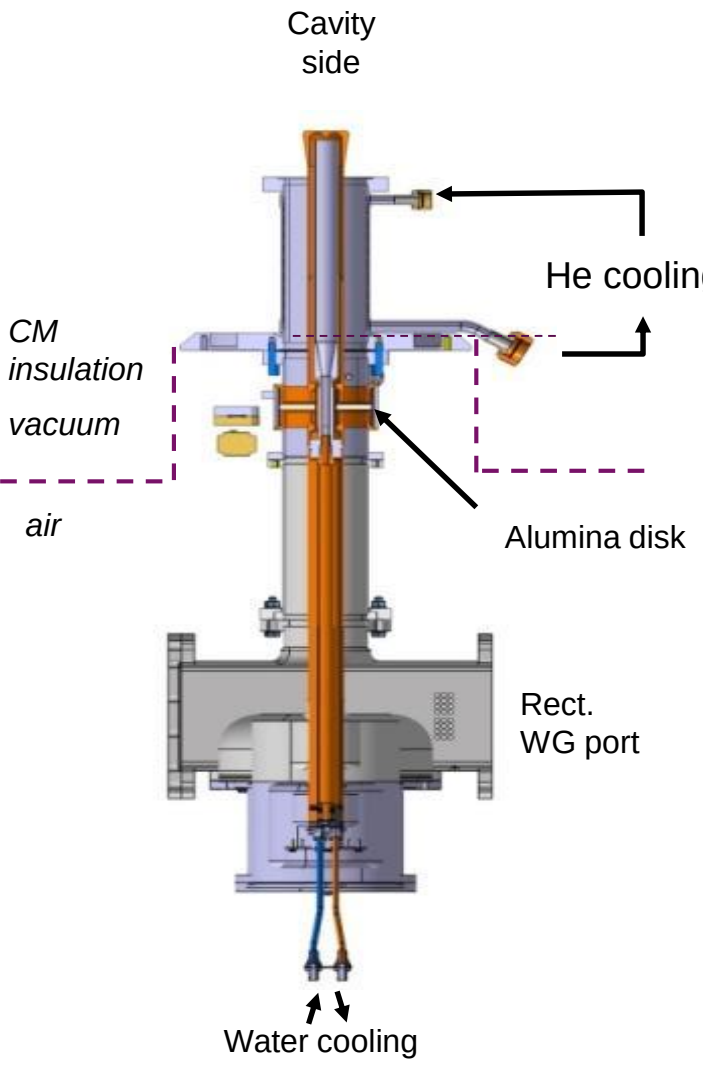
What we tested that generally cause worries :

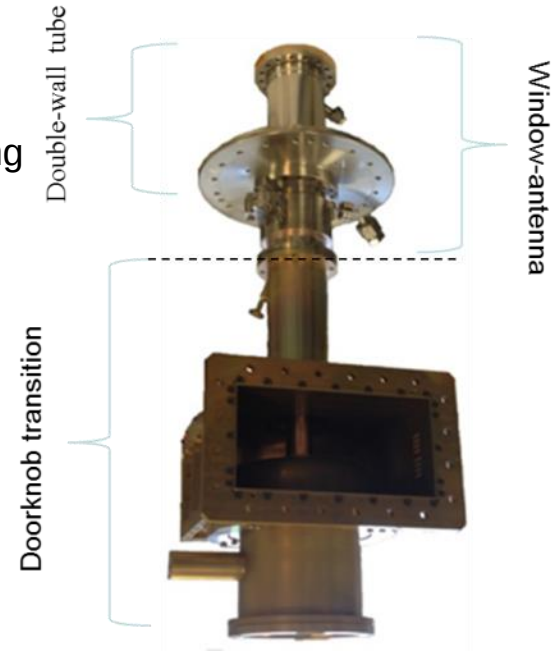
- Assembly on the cavity from the top in the clean room. No particle counting was performed in the 2009 assemblies but FE was not enhanced on the two test SRF cavities
- Massive antenna resting for years in horizontal position: no deflection observed
- More recently a new clean room test assembly of 1 HIPPI coupler was carried out in the new ISO5 clean room succesfully with particle counting
- The coupling waveguide aspect indicates it may have been the most difficult part to condition (Cu particulates were present inside)





OVERVIEW OF THE ESS FPC





Technical specifications

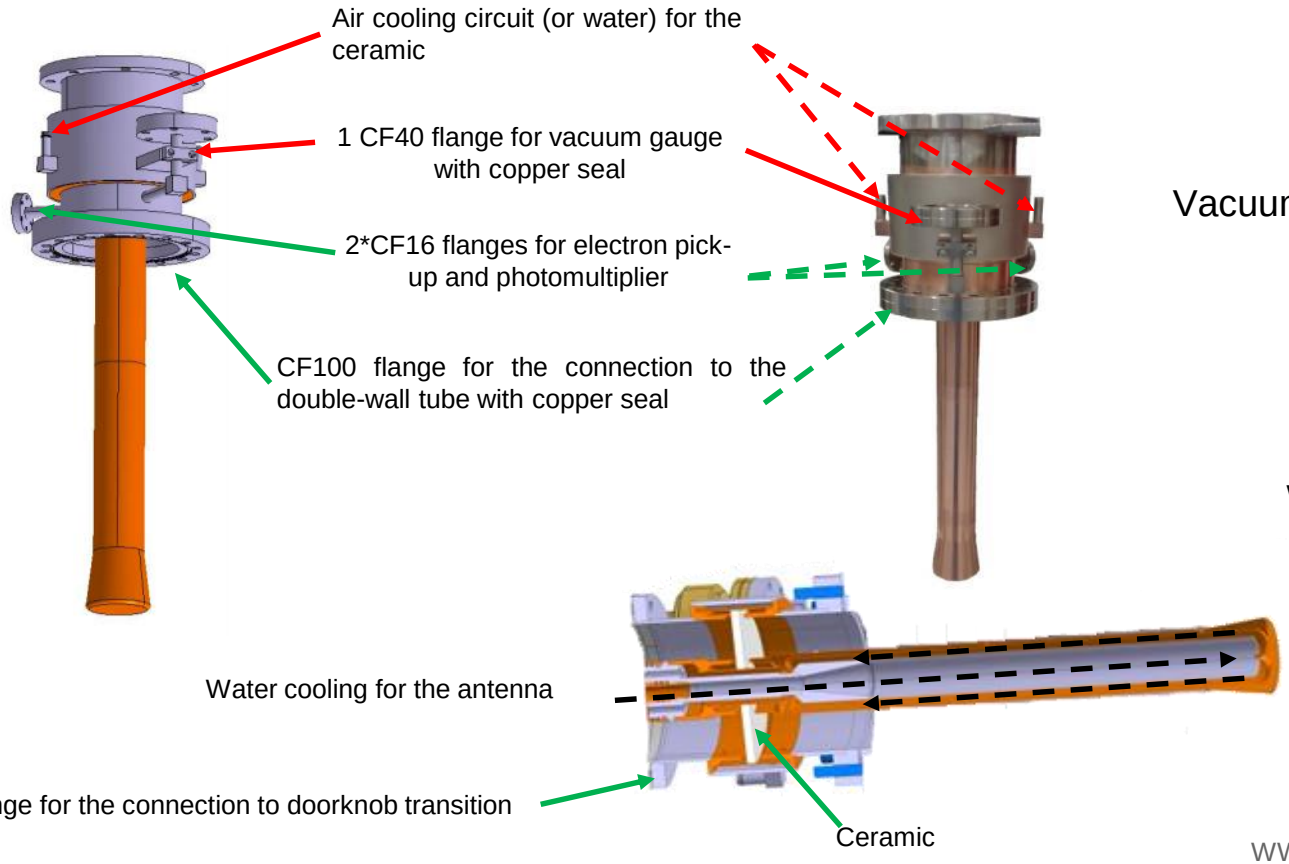
RF frequency	704.42MHz
Repetition frequency	14 Hz
Incident RF power	1.1 MW
RF pulse width in full reflection (all phases)	500 µs
RF pulse width in travelling waves	3.6 ms
Bias Voltage limits	±10 kV

Condition of use

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

RF WINDOW AND ANTENNA

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

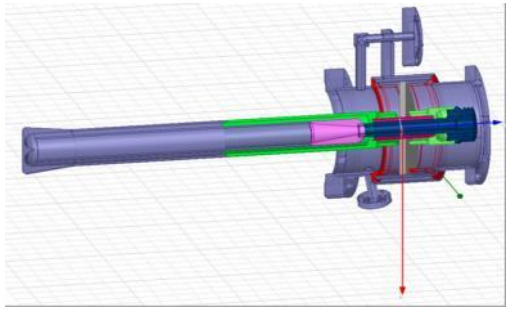


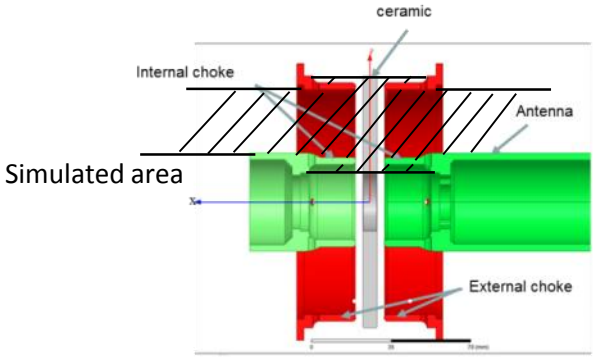
Electron pick-up

Vacuum gauge (Pfeiffer IKR070)

Window for photomultiplier

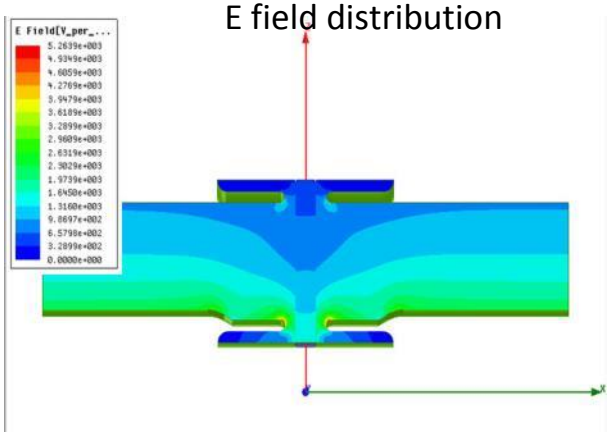
PEAK FIELD AROUND THE CERAMIC WINDOW AND RF MATCHING

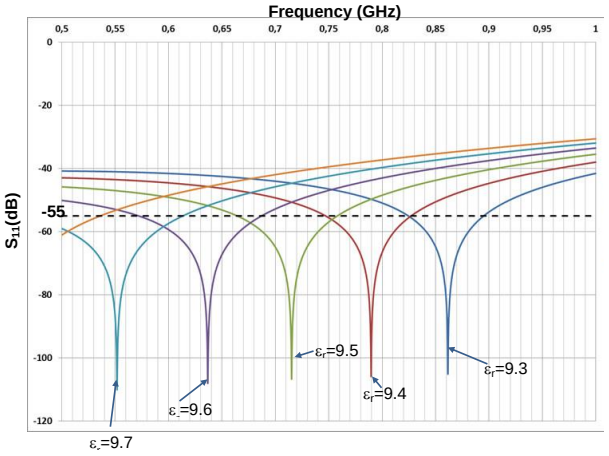


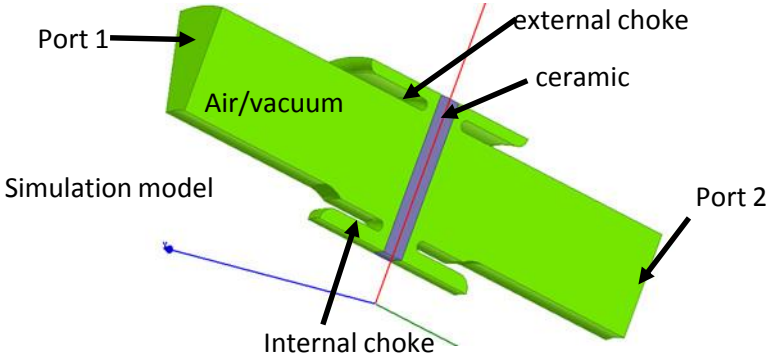


Parameters	Nominal window
Matching frequency (ε_r nominal)	710.2 MHz
Bandwidth at -55dB	94 MHz (753-659)
Frequency shift for a permittivity shift =0.1	+ 75 MHz ($\Delta\varepsilon_r$=-0.1) -78 MHz ($\Delta\varepsilon_r$=+0.1)
Electric field max on surface of internal choke (full transmission)	1.56 MV/m
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



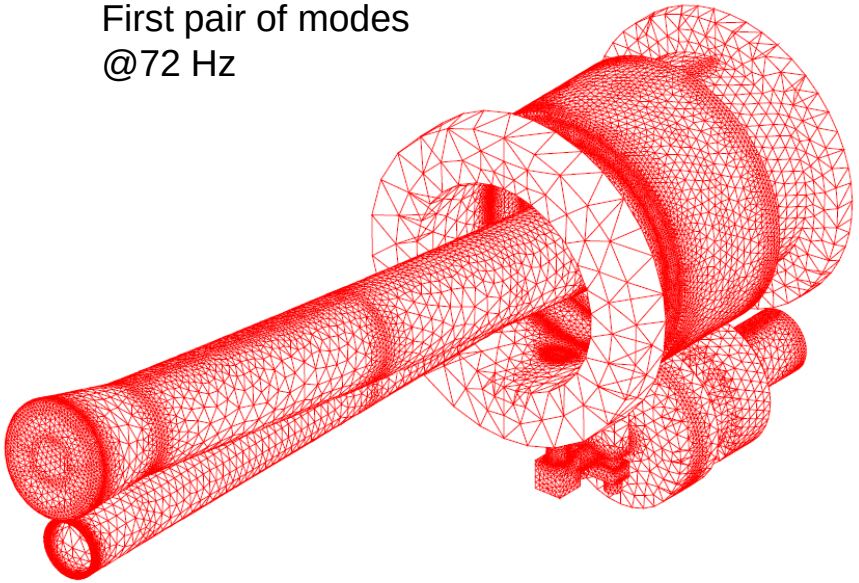




MECHANICAL MODES

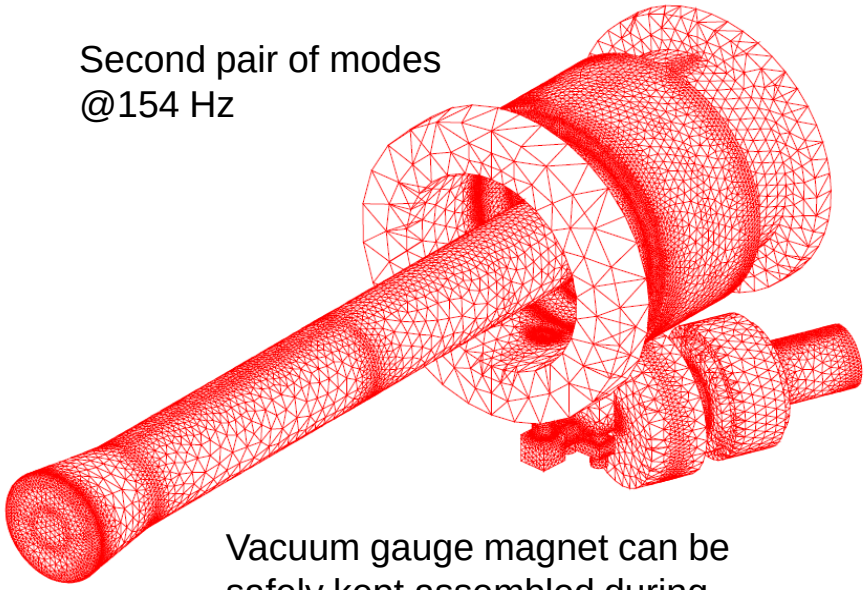
- Antenna is made from solid copper, much heavier than SS/Cu deposition
- Assembled CMs will be shipped by truck from Saclay to Lund
  - Doorknob transitions will be shipped separately
  - The CM will be attached to a damped frame on the lorry
  - Vibration modes with Freq<20Hz which would be a concern for road transport: none

First pair of modes
@72 Hz



Other modes (incl. antenna cooling channel) above 200 Hz

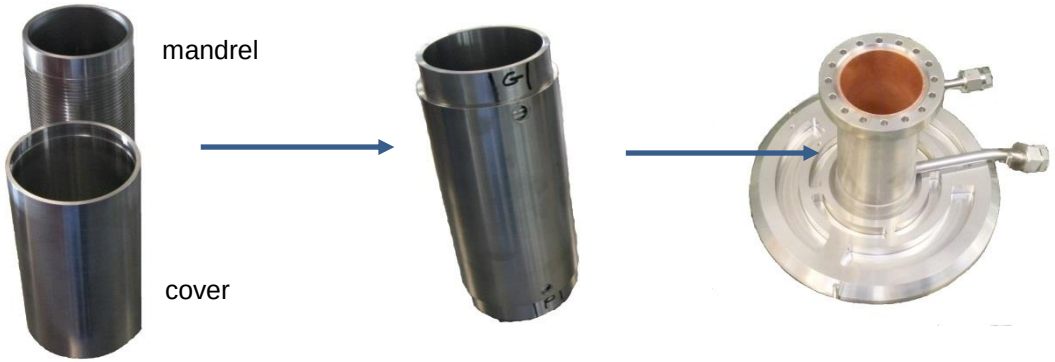
Second pair of modes
@154 Hz

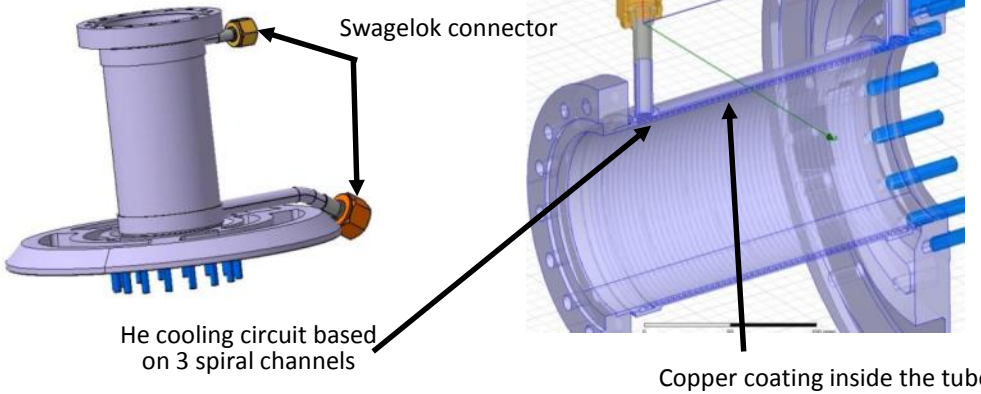


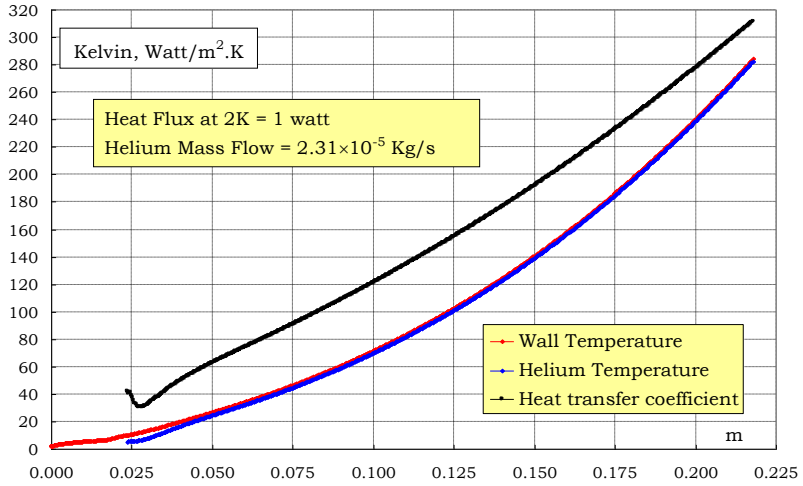
Vacuum gauge magnet can be safely kept assembled during shipping

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)



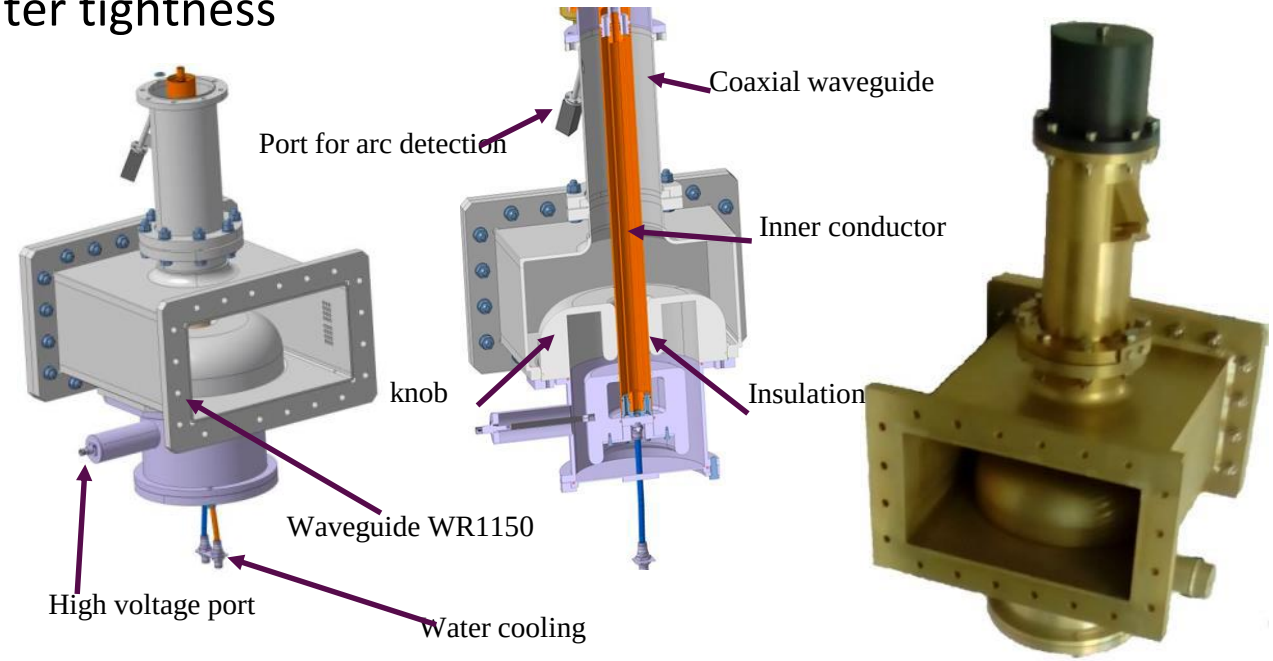




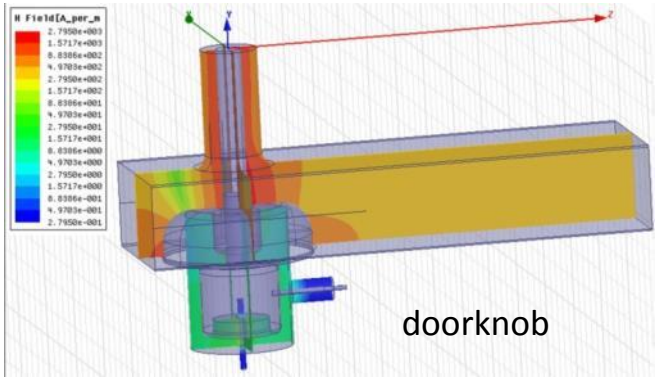
Design temperature profile

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



- 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

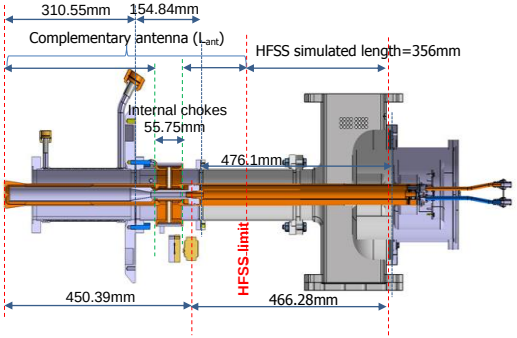
in standing wave 94W

-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

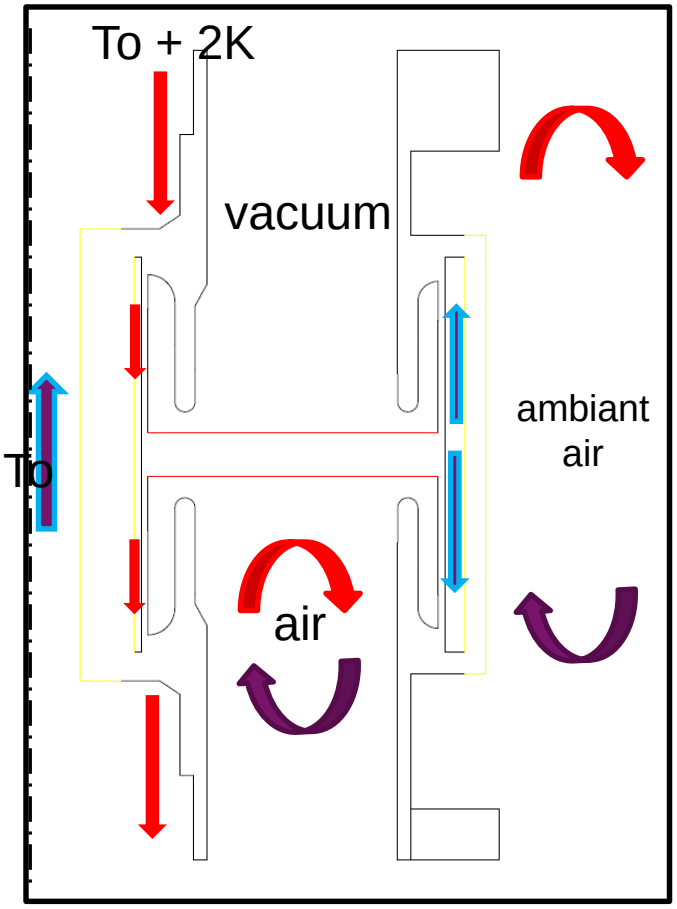
T water input=25.6°C

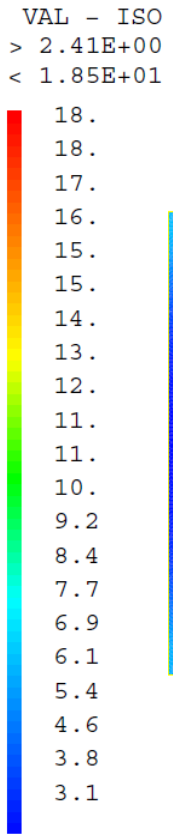
T water output=26.2°C

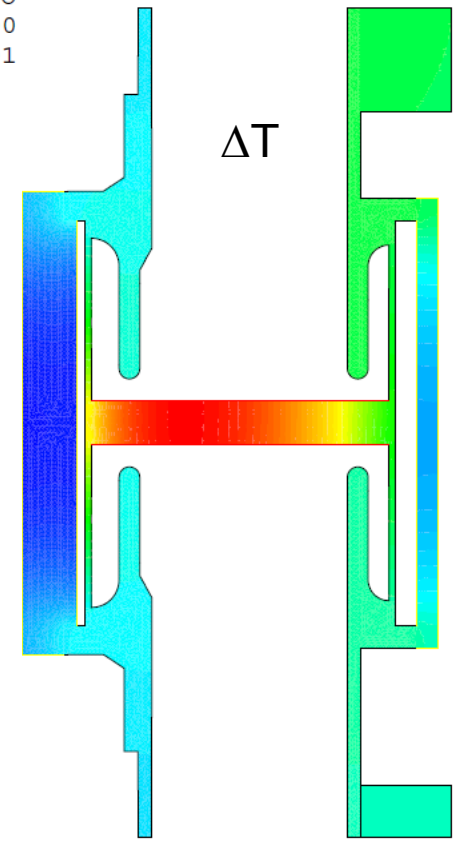
THERMO-MECHANICAL SIMULATIONS

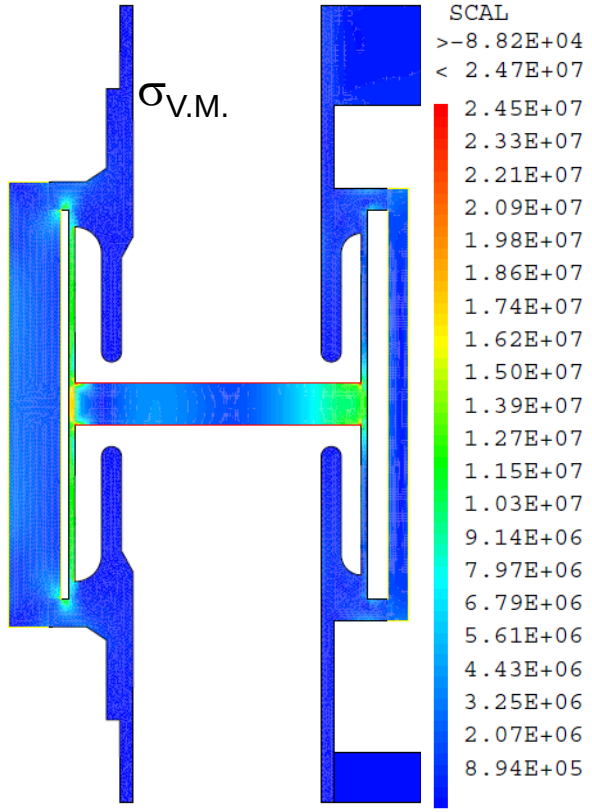
- Steady state in TW 120kW avg power (HIPPI test case)
  - 2.5 x the ESS average RF power
  - pressure, convection for air and water are modeled
  - RF dissipations

HIPPI test case	
RF PEAK POWER (MW)	1.2
Duty cycle (%)	10
Regime	TW



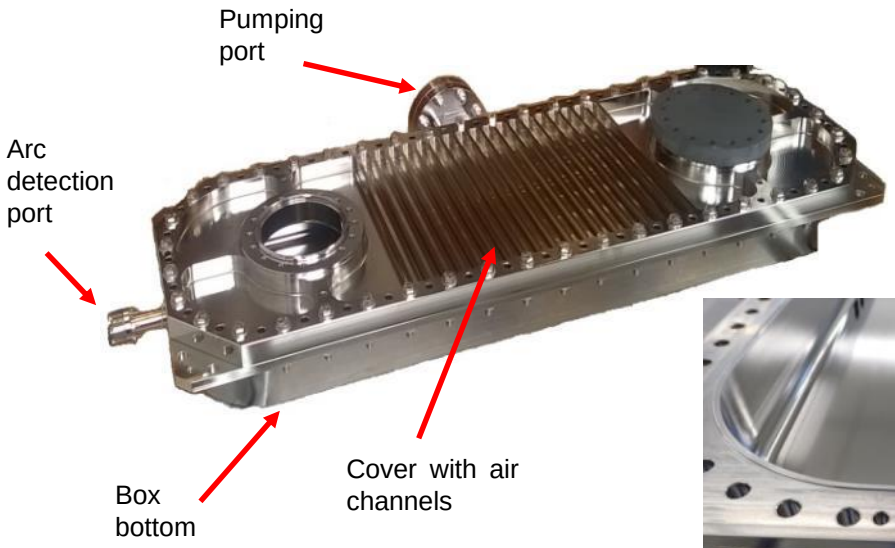


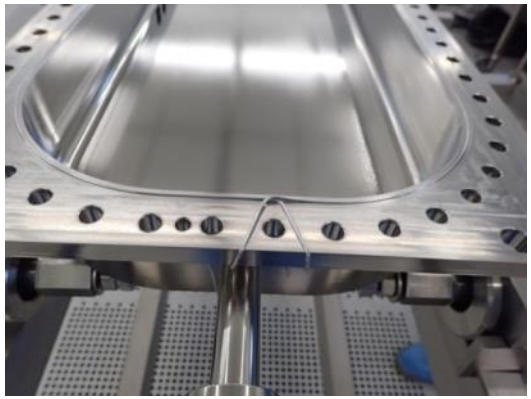


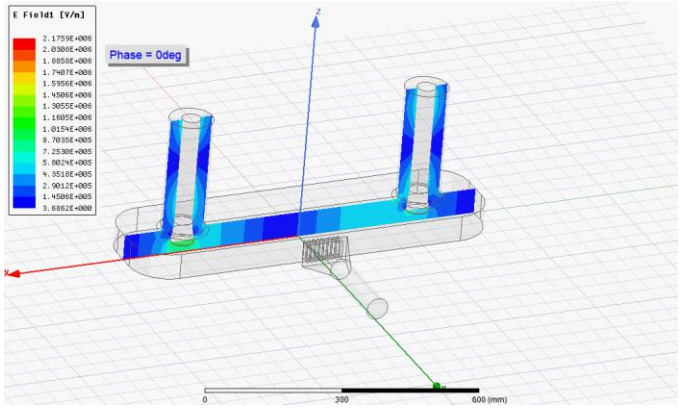


CONDITIONING CAVITY

- Lesson learned from HIPPI previous design (copper coated welded SS cavity) and Eric's dismountable cavity, we tried to simplify a step further by not having any copper.
- Thermal design with margins showed fin heat exchangers and fan system were required.
- In use, the box was operated with good thermal stability with only air circulation on the cover plate (air channels)
- Pumping port and port for arc detection
- Aluminum wire used as seal between cover and bottom for vacuum tightness







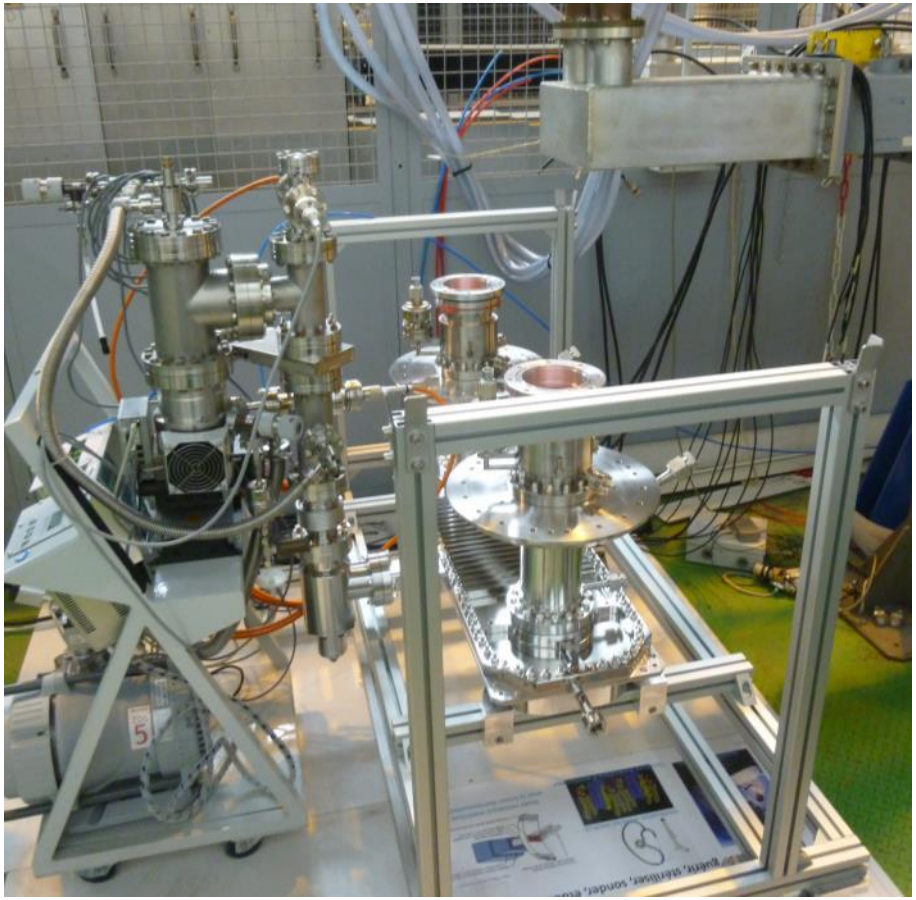
VACUUM SYSTEM EVOLUTION

For prototypes
Vacuum system includes:
Slow N2 venting systems
Safety gate valve between primary and turbo pump (pneumatic actuator)

For production, vacuum sytems will derive from systems used for X-fel assembly with higher pumping speed, automated slow venting system

Vacuum gauges IKR070, no electronics in the tunnel, used at CERN exclusively (still the case?)

Pre-conditioning baking parameters:



- Experience of IFMIF prototype FPC primarily baked at 150°C, not efficient (2014)
- T=170 °C chosen, within reach of tape heaters, baking is effective with a 3 days duration
- Copper parts of the window (air side) need protection from oxydation

This was the plan 3 years ago…

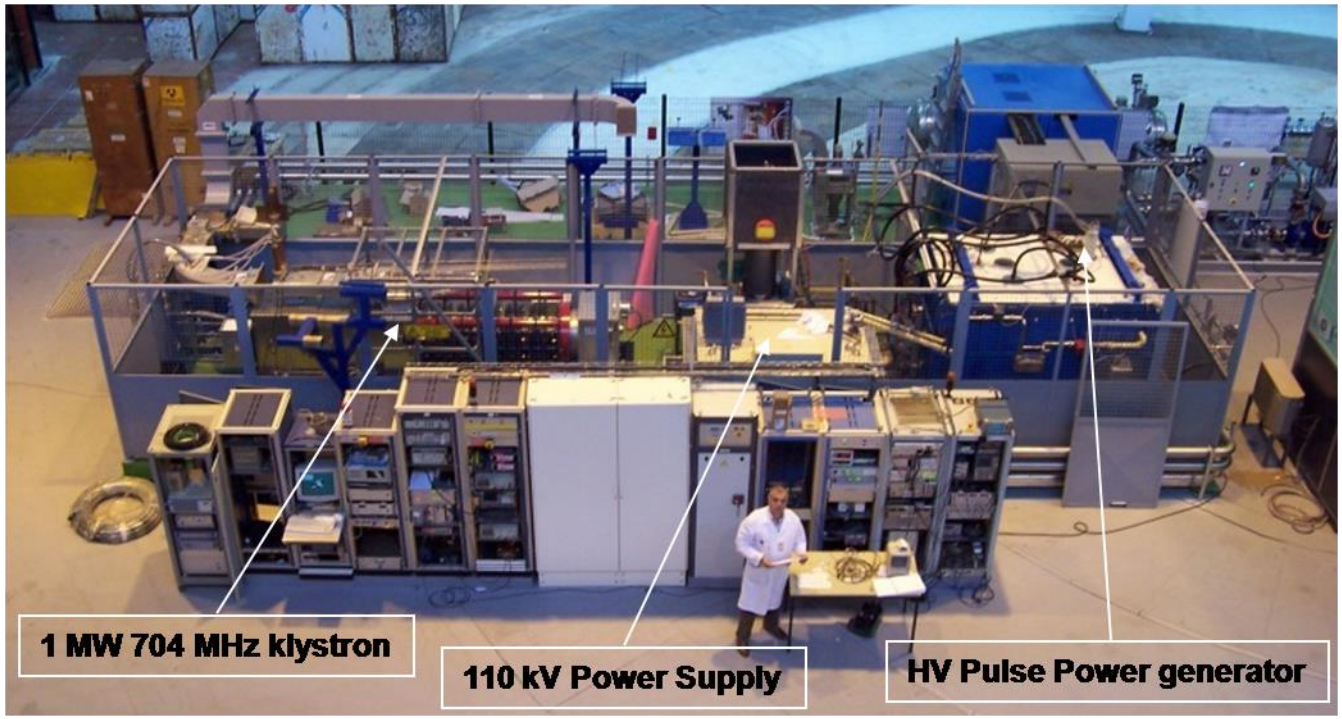
Running since 2008:

Nominal parameters :

- Peak power : 1MW (1.2 MW for a short period)
- Repetition rate : 50 Hz
- RF pulse length : 2 ms

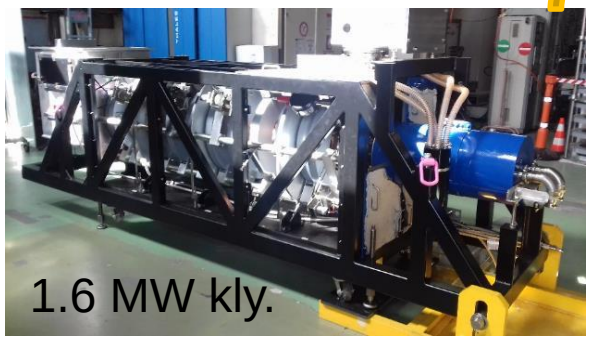
Update for ESS tests :

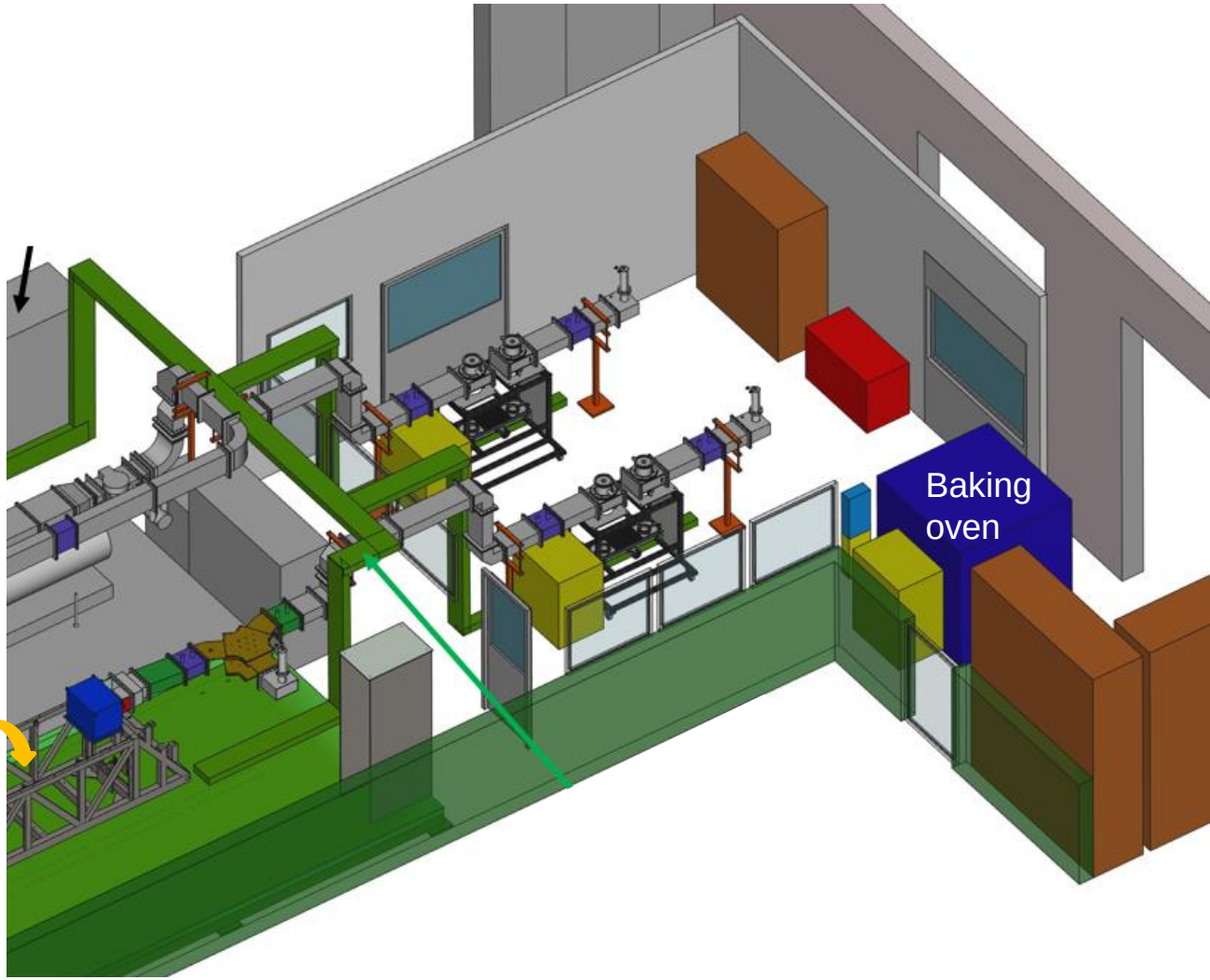
- Peak power : 1MW (1.2 MW for a short period)
- Repetition rate up to : 25 Hz
- RF pulse length : 3 ms



NEW CONDITIONING INFRASTRUCTURE

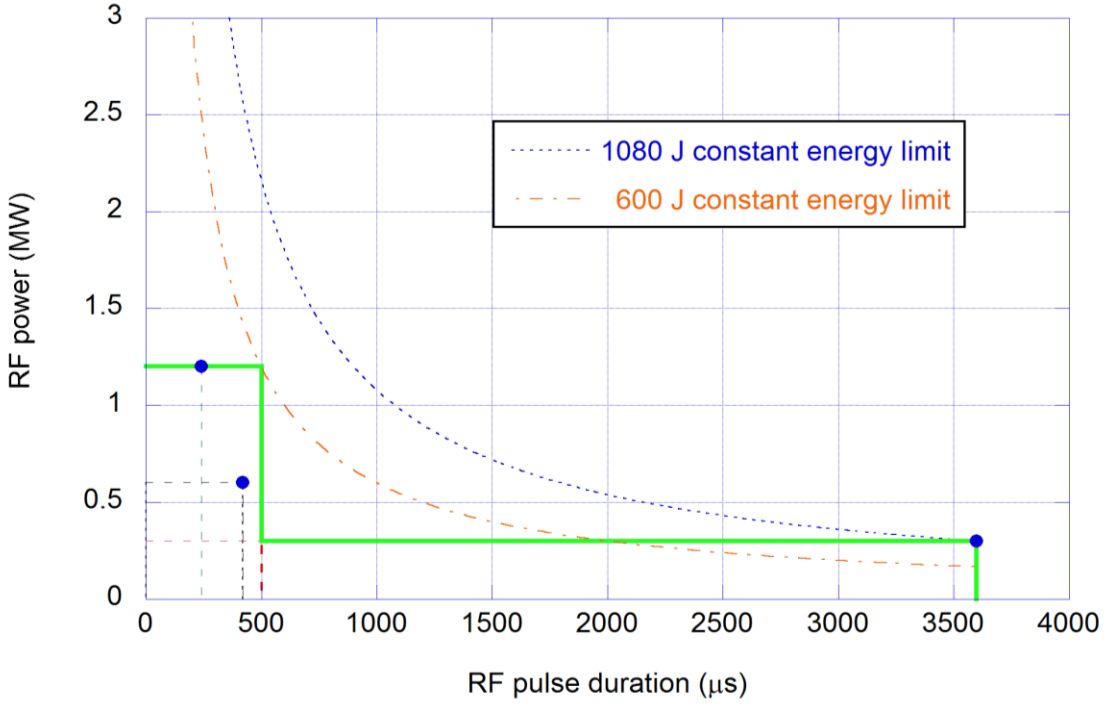
- 2 klystrons
  - existing CPI klystron + cea modulator upgraded to 1.2MW 3.6ms pulses
  - Additional 1.6 MW Thales klystron
- 2 FPC pairs can be conditioned in parallel
- 2 conditioning systems w EPICS control/DAQ/ hardware interlocks
- 2 Baking ovens with N2 atmosphere





EXPECTED RF PERFORMANCE - ACCEPTANCE

- Reach the peak power of 1.2 MW, 3.6 ms pulses at 14 Hz TW *in less than 120 hrs* with applied RF
- Sustained application of max. power for 1 hour
- Full reflection
  - up 1.2 MW for 500μs pulses at 14 Hz
  - Up to 300 kW for 3.6 ms pulses at 14 Hz



- 2 most arcing-prone short-circuit positions
- 4 other short circuit positions
- No time limit

MANUFACTURING PREPARATION

- Prototypes have been fabricated in a different context than the series production (FPC procurements for ECCTDs , ESS CM prototypes)
- Difficult step is to have the manufacturing company endorse the design which is not its own to the point they agree to have the coupler accepted based on high power performance (previous slide conditions)
- It was not required to have them built ESS FPC prototypes beforehand in order to be part of the call for tender for the series
- Having a power test of the prototypes was anyway necessary to prove them the level of risk that the FPC fails is acceptably low and at least that the design (RF,thermo-mechanical) is valid.

MANUFACTURING PREPARATION

- ESS FPC Prototypes (before call for tender):
  - 8 window antenna assemblies from supplier 1
  - 4 double wall tubes from supplier 2, Cu coating subcontracted by supplier 3
  - 4 doorknob transitions from supplier 2
  - 2 complete FPCs inluding doorknob from supplier 3
- RF conditioning passed with success involving windows from 1 and 3

- Being aware of the succesful RF test of 2 pairs , 3 companies presented offers for the series (supplier 1,3 and 4)
- Two major companies involed in FPC manufacturing did not build any protoype, nor RF window:
  - One did not even participate to the first round of the CfT (publicity)
  - The other did

SERIAL MANUFACTURING CONTRACT STRATEGY

After the production readiness review is passed,
manufacturer capability is assessed based on

- Initial Samples of each critical manufacturing step:
  - Cu coating on real size ss tube
  - Window
  - Antenna weld and electropolishing
  - Bias insulator
- a pre-series of 6 couplers : they must pass acceptance test

For each pair acceptance is based on :

- Dimension control
- Leak test, RGA
- Visual inspection
- RF performance

After preseries acceptance, and QC control audit, series production is authorized

Sampling of critical processes is maintained but is set at a different rate

CAVITY STRING WITH PROTOTYPE FPCS

FURTHER TESTING

- Transfer of completed CM in the bunker this week
- Room temperature RF conditioning in the CM test bunker
- Each coupler can be powered individually to the max RF power in sequence
- Cryogenic testing of the CM for performance assessment

Thank you

Commissariat à l'énergie atomique et aux énergies alternatives
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