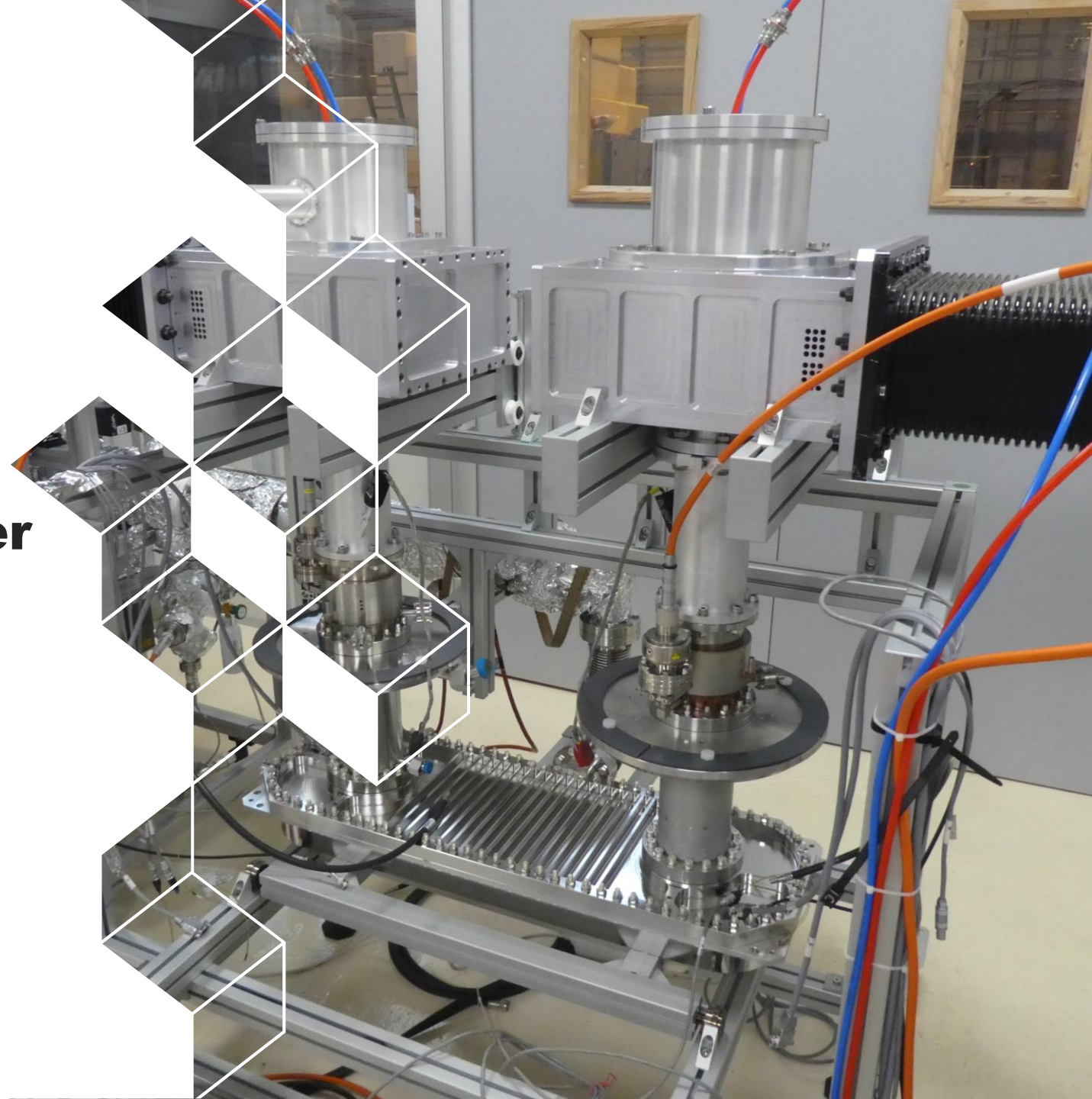
Fundamental Power coupler for ESS, experience from series production and conditioning

Thibault Hamelin



Outline

1. Overview of the ESS coupler
2. Operations before RF conditioning
3. RF conditioning
4. Main technical issues encountered during manufacturing or RF conditioning
5. Conclusions

Overview of the ESS coupler

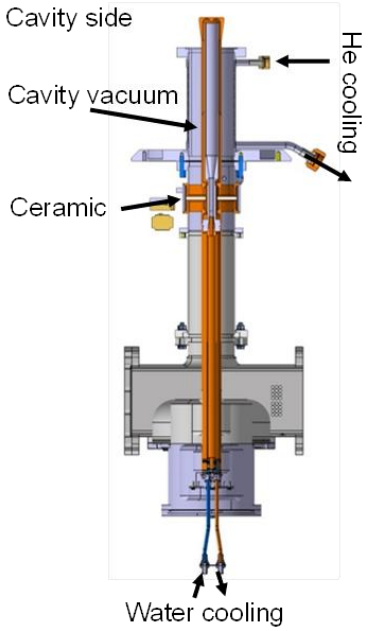
- **ESS supply requirements:**
  - 120 couplers to equip the 30 cryomodules
  - 36 Medium Beta couplers including 6 pre-series units to validate the process
  - 84 High Beta couplers
- **Coupler components:**
  - 1 window-antenna with TiN coating on ceramic
  - 1 double-wall tube with copper coating
  - 1 doorknob transition

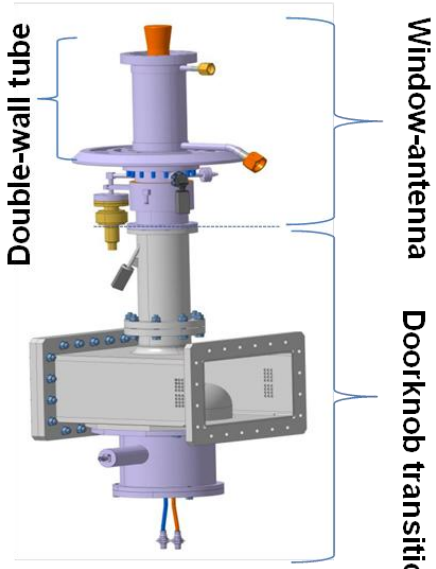
  Same components for HB and MB, except for the tube, which is slightly longer for HB
- **Cooling circuits:**
  - Inner conductor: water cooling
  - Ceramic of the window: natural air convection
  - Double-wall tube: Helium cooling

Spare : 6 windows, 4 MB tubes, 4 HB tubes, 4 doorknobs

Technical specifications

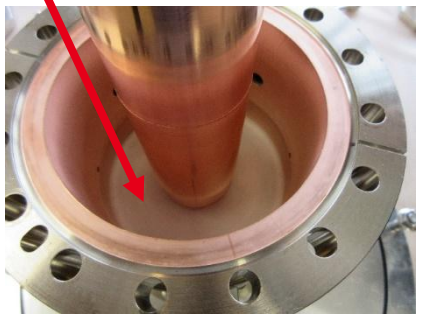
RF frequency	704.42MHz
Repetition frequency	14 Hz
Incident RF power	1.1 MW (peak)
RF pulse width in full reflection (all phases)	500 µs
RF pulse width in travelling waves	3.6 ms
Voltage withstand (voltage between internal conductor and external conductor)	±10 kV





TiN coating (10nm)

Window



Double-wall tube

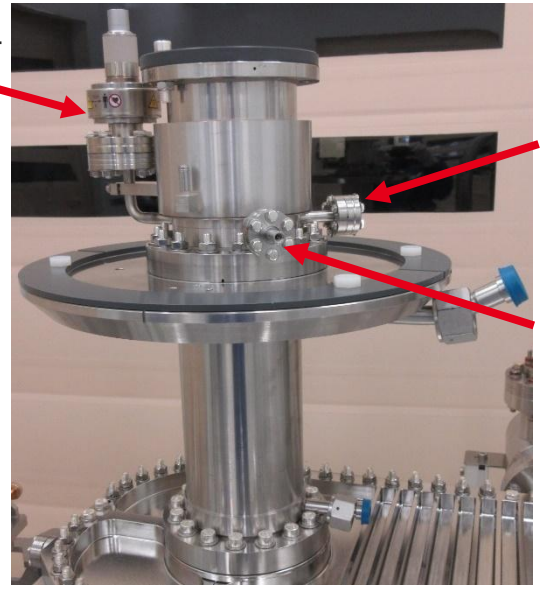
Copper coating (10µm)

Diagnostic components

- **On the ESS couplers:**
  - Vacuum gauge (IKR070 from Pfeiffer)
  - Photomultiplier (model H10721-110 from HAMAMATSU) (ceramic on the vacuum side)
  - Photomultiplier on the doorknob transition (ceramic on the air side)
  - Electron pick-up (for electron activity measurement and RF measurement)
- **On the RF conditioning test stand:**
  - Photomultiplier on the coupling box
  - Vacuum gauges on the pumping system

Electron pick-up

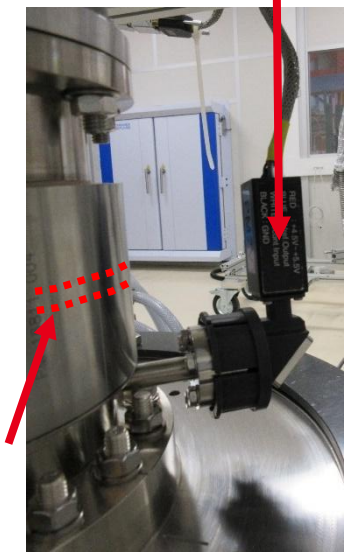
Vacuum gauge



Window for photomultiplier

Electron pick-up

Photomultiplier (vacuum side)

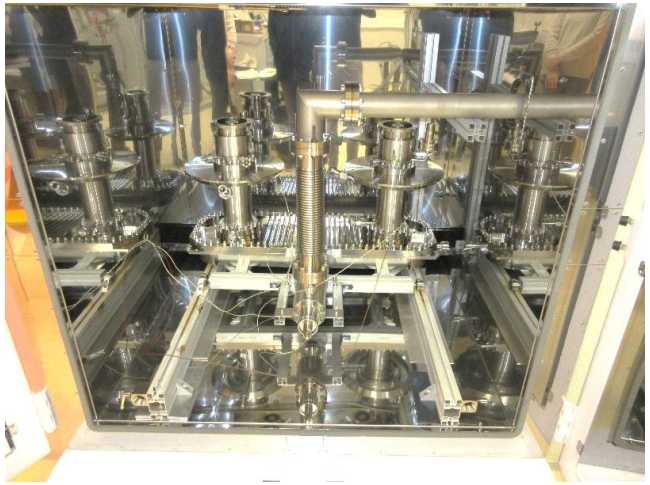


Position of the ceramic disk

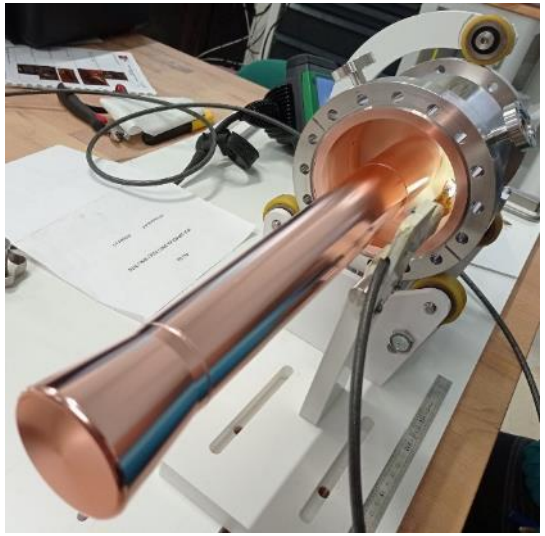
Photomultiplier (air side)

Operations before RF conditioning

- Inspection of the components:
  - Verification of RF surfaces (in particular copper plating, antenna, chokes), sealing surfaces, etc
- Cleaning of the components:
  - Ultrasonic bath for double-wall tubes (Tickopur R33 detergent)
  - Manual cleaning for window (absolute ethanol, antenna cleaned with RBS T310)
- Assembly in a ISO5 cleanroom
- Baking in an oven (couplers 170°C for 4 to 5 days, pumping system 120°C then 60°C)
  - Outgas the surfaces and remove any remaining contaminants



Oven



Endoscopic inspection

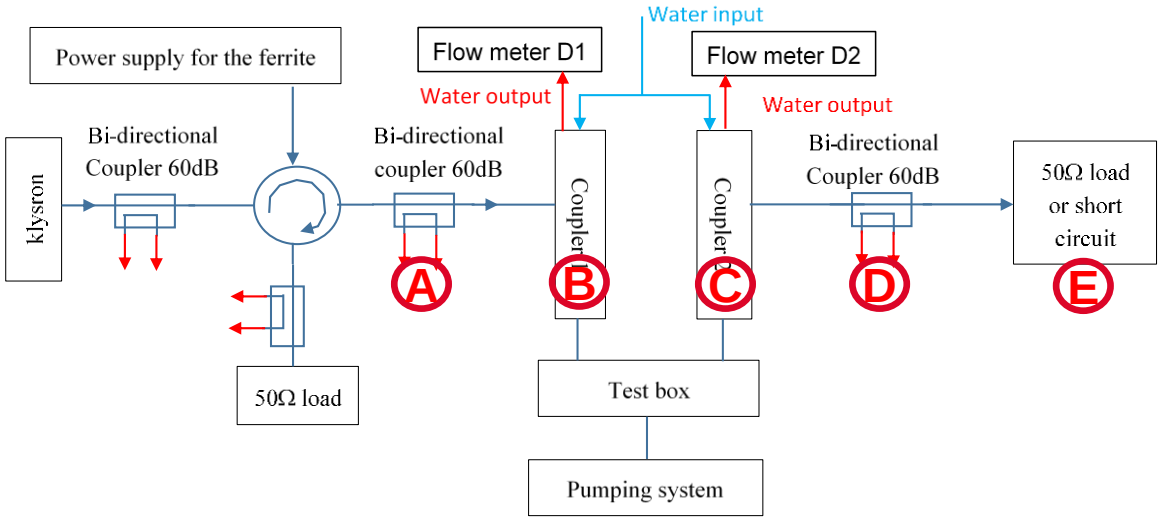
Double-wall cleaning

Window assembly on the tube

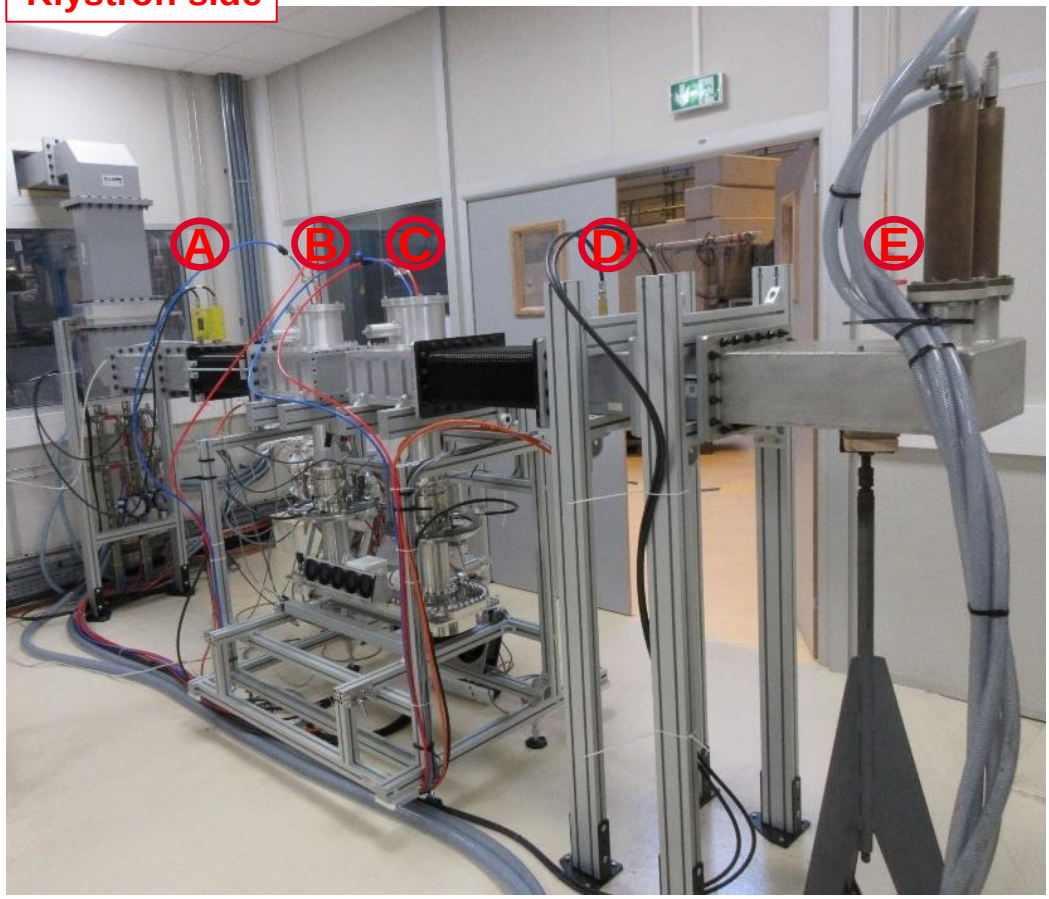
Coupler assembly on the coupling box

Conditioning test stand: monitoring and measurements systems

- **Coupler and coupling box diagnostics :** Vacuum, Photomultiplier, electron pick up
- **RF power (forward & reflected)**: klystron output, input and output of the couplers, on each coupler with the electron pick-up
- **Water cooling**: flowmeters and input/output temperature sensors for each coupler
- **Temperature**: on the window, the tube and the coupling box



ESS coupler conditioning test stand



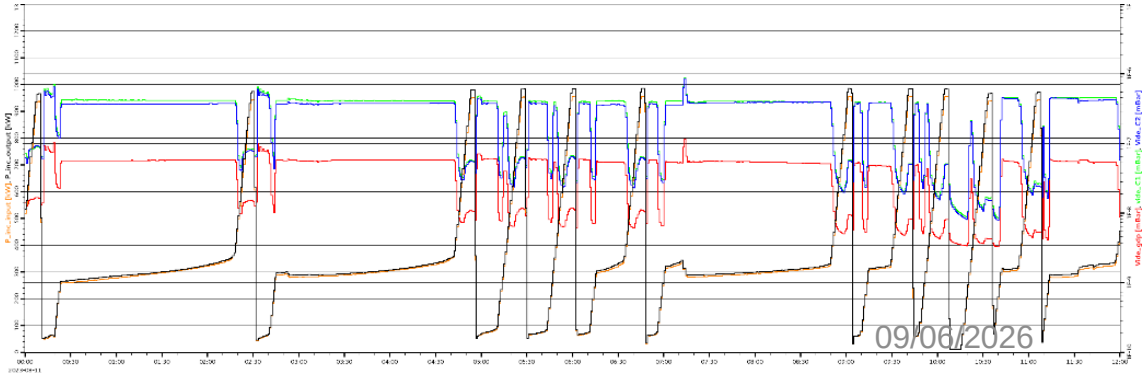
RF Conditioning sequences

- Gradually ramping up the RF power from 10 kW to 1.1 MW (pulse width from 50µs to 3.6ms) (frequency rate from 1Hz to 14Hz)
  - Increase the power step by step (usually 1 kW per second)
  - Increase or decrease the power according to the outgassing
  - We perform the conditioning in travelling-wave mode and at two positions in standing-wave mode, corresponding to the minimum and maximum electromagnetic field on the ceramic

- RF power turned off when :
  - Outgassing resulting in a vacuum level exceeding the hardware threshold of $1x10^{-6}$ mbar
  - Electrical arcs with an intensity greater than approximately 3 lux (detected by the photomultiplier)
  - Electron activity with an intensity greater than 8 mA (detected by the electron pick-up)
  - Window temperature above 45°C

- All conditioning sequences, interlocks and data logging are automatically controlled by EPICS

- Coupler acceptance criteria:
  - Outgassing below 2×10^{-8} mbar
  - No arc and no electron activities



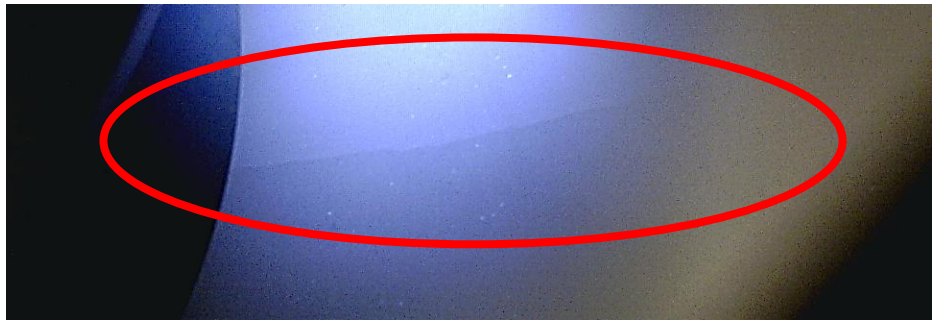
Main technical issues encountered during manufacturing or RF conditioning

- **Windows:**
  - TiN coating: After the pre-series phase, the TiN coating became too dissipative. This caused window overheating and ceramic cracking during conditioning
    - ⇒ change the subcontractor and made new coating qualification phase (2019)
    - ⇒ add a new temperature criterion for the window
    - ⇒ add a new deposit resistance measurement (multimeter)
  - Brazing overflows
    - ⇒ rework using abrasive treatment or reject the parts
  - Pieces of ceramic from the brazing spacers trapped in the chokes
    - ⇒ removal of the piece of ceramic

Importance of diagnostics during RF conditioning

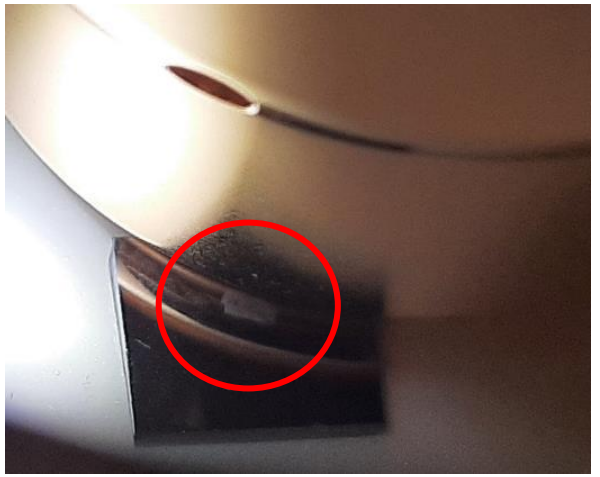
Importance of inspection

Crack in the ceramic



Brazing overflow

Ceramic fragments



Condition of the unconditioned windows

- Main reason is breakdowns:
  - Clearly visible marks
  - Heating area at the brazed joint
  - Deterioration of the copper-plated surfaces
- Reworks using abrasive treatment are then performed. Some windows were successfully conditioned, while others were definitively rejected

Breakdowns marks

Heating area

Main technical issues encountered during manufacturing or RF conditioning

- **Tube:**
  - Copper coating with an RRR close to 100 on the latest tubes instead of being within the [20;40] range

    Measurements were performed on samples requested during the manufacturing process

    In cryomodule testing, no excess helium consumption was observed

    ⇒ waiver to accept this non-conformity

    Importance of samples and measurements during manufacturing

  - Copper coating with stains

    ⇒ stripping the copper plating from the tubes and copper-plated again

    Importance of inspection

Copper coating with stains

Main technical issues encountered during manufacturing or RF conditioning

- **Tube:**
  - Generation of electron activity that may cause tube heating } **Importance of diagnostics during RF conditioning**
    - Verification of copper deposits using samples requested during the manufacturing process : } **Importance of samples and measurements during manufacturing**

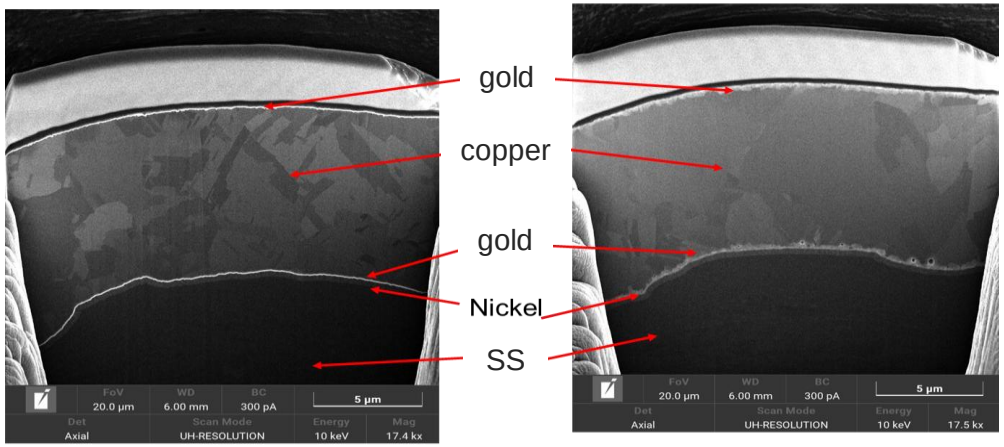
      Drift in the copper plating process. Presence of an unintended gold flash on the surface

      Due to operator changes in the coating process

      Because of budget limits, we could not continue the investigation and cannot certify that this heating effect was caused by the gold flash coating

      ⇒ Anyway the electronic activity disappears with RF conditioning but increase the conditioning time

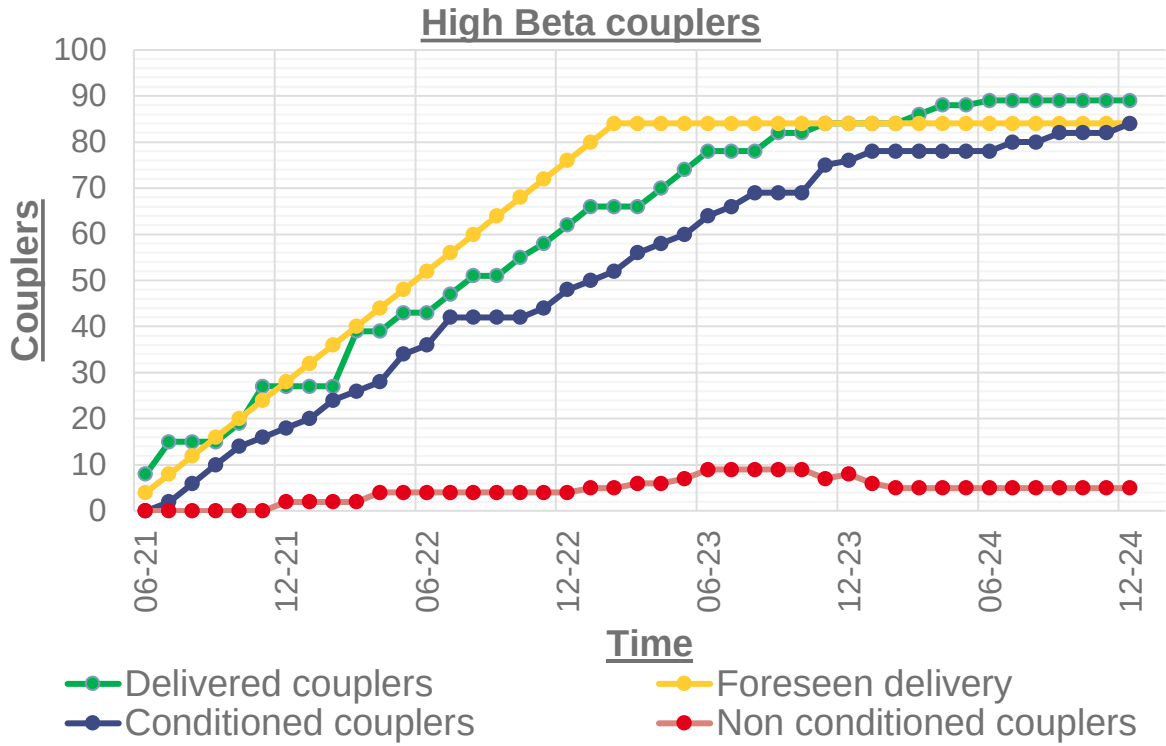
Without heat treatment *With heat treatment*



→ **Or sur couche de Nickel + diffusion des couches d'or**

Conclusions

- The conditioning of the 126 couplers (including spares)
  - The average conditioning time is 2 weeks, 24 hours a day
  - 15 windows were rejected (including a batch of 8 units with a TiN coating issue) (~13% / 126)
  - 0 tubes were rejected
- The main issues were related to the TiN and copper coatings
  - It is important to monitor these steps during the manufacturing process with samples, measurements, inspections…



- Delay in supplying the latest couplers, and mostly the couplers replacing the rejected ones, is significant
  - Mainly due to the supply of new parts in small quantities

Thank you for your attention

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