LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

17th International Conference on RF Superconductivity

Overview of Recent Advances in Coupler Design, Technology, Fabrication and Conditioning

Whistler, September 17th 2015

SRF 2015 WHISTLER

Walid KAABI- LAL/Orsay

Introduction:

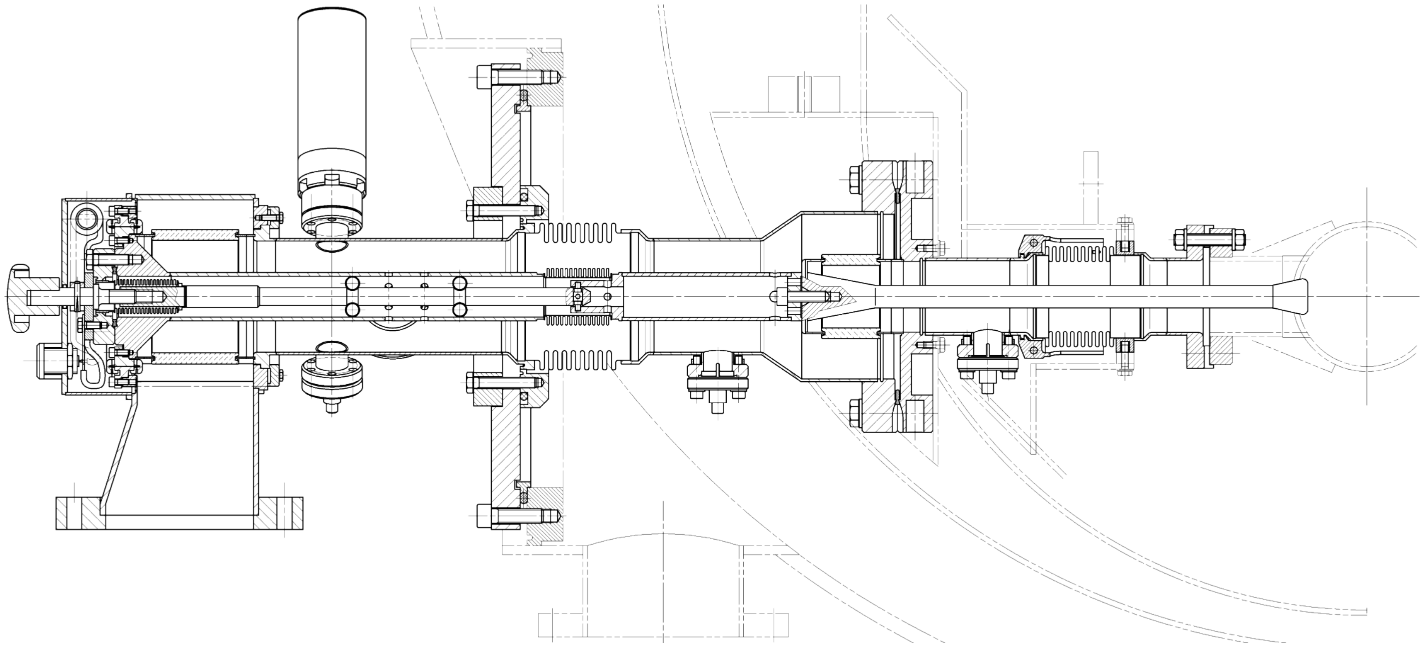
Advances in power coupler development are often driven by project specific requirements and performances to achieve. We will focus in this talk on studies, design improvement and production of power couplers in the framework of projects currently running at different advancement state.

Some new technology and fabrication process at the R&D steep will also be presented.

Outlines:

- Introduction
- Recent advances in coupler development
  - LCLS-II couplers
  - ESS couplers
  - XFEL couplers
- R&D on new technologies & fabrication processes
- Summary

LCLS-II Couplers



THPB005, THPB077, THPB085, THPB086, THPB090

LCLS-II coupler:

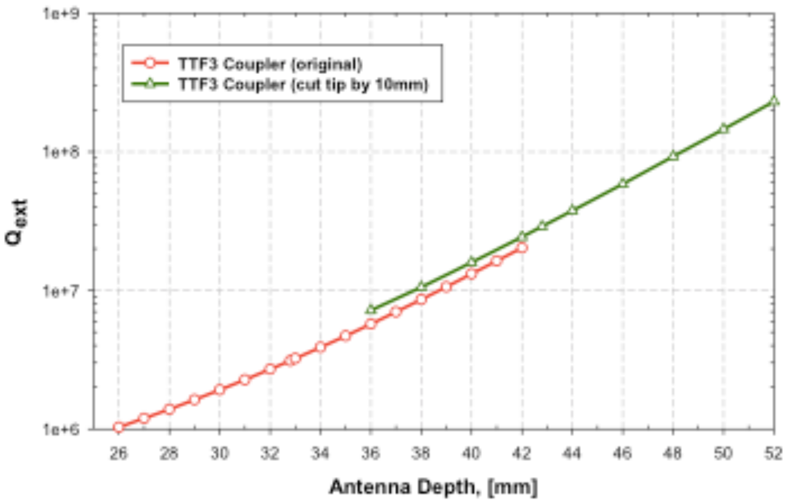
A total need of 280, **1.3 GHz variable couplers** with maximum input power at **7kW CW**.

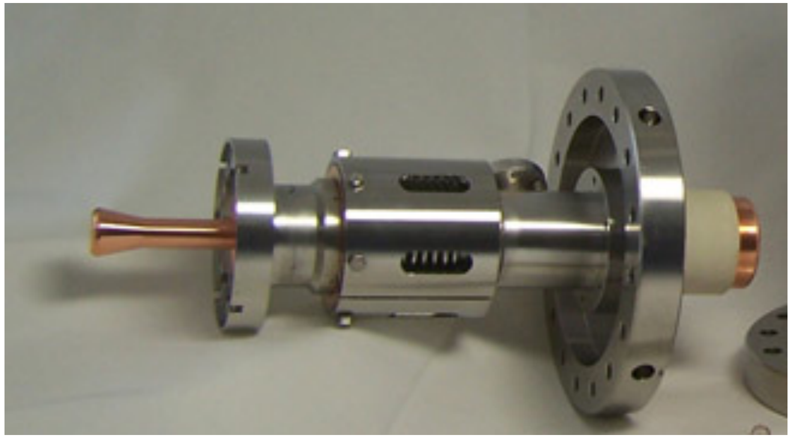
The XFEL design was adopted with some modifications to meet the following requirements:

- Shift Q_{ext} range higher
- Improve cooling of warm section so can run at 7 kW with full reflection
- Modify waveguide assembly (use flex ring and aluminum WG box) and retain the TTF3 manual knob antenna positioner design

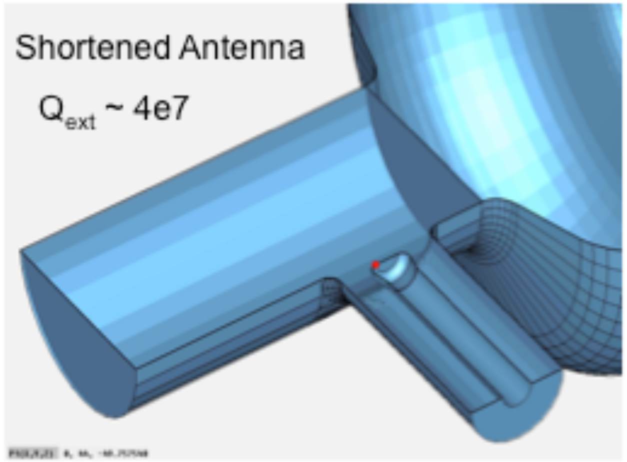
LCLS-II coupler:

Modification to shift the Q_{ext} range higher: Antenna tip cut by 10mm





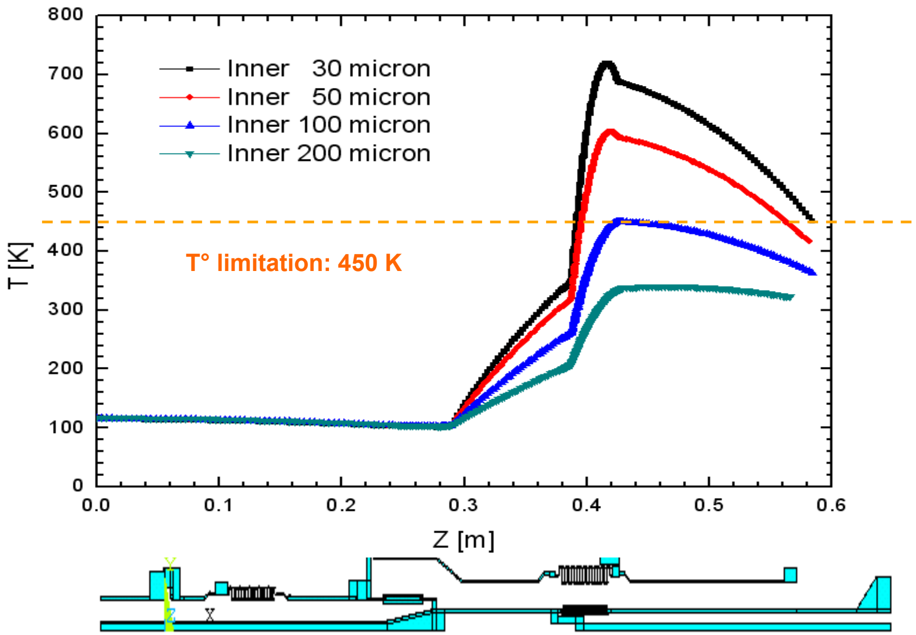
	Q_{min}	Q_{mid}	Q_{max}
Original coupler*	1E6	4.0E6	2.0E7
Tip cut by 10 mm	8E6	4.0E7	2.0E8
Tip cut by 8.5 mm	6E6	2.5E7	1.4E8



LCLS-II coupler:

Study of coupler heating:

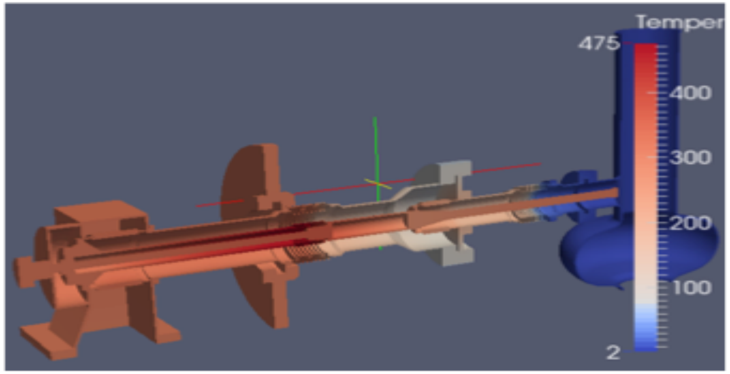
15 kW TW operation for various thicknesses of the Warm Inner Conductor (WIC) copper plating

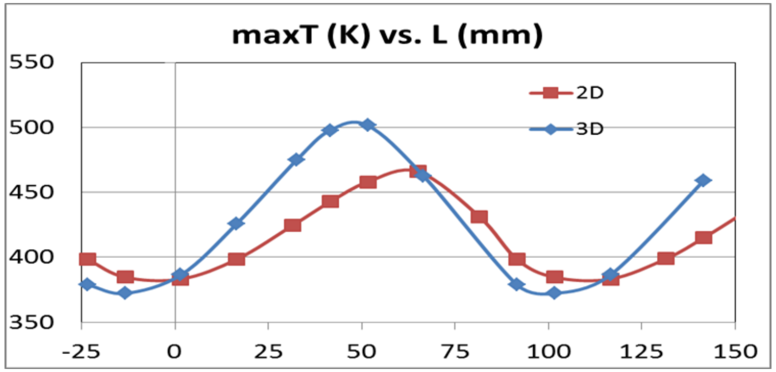


Copper plating thickness increase from 30 to 150 µm in the WIC

7 kW full reflection simulations:

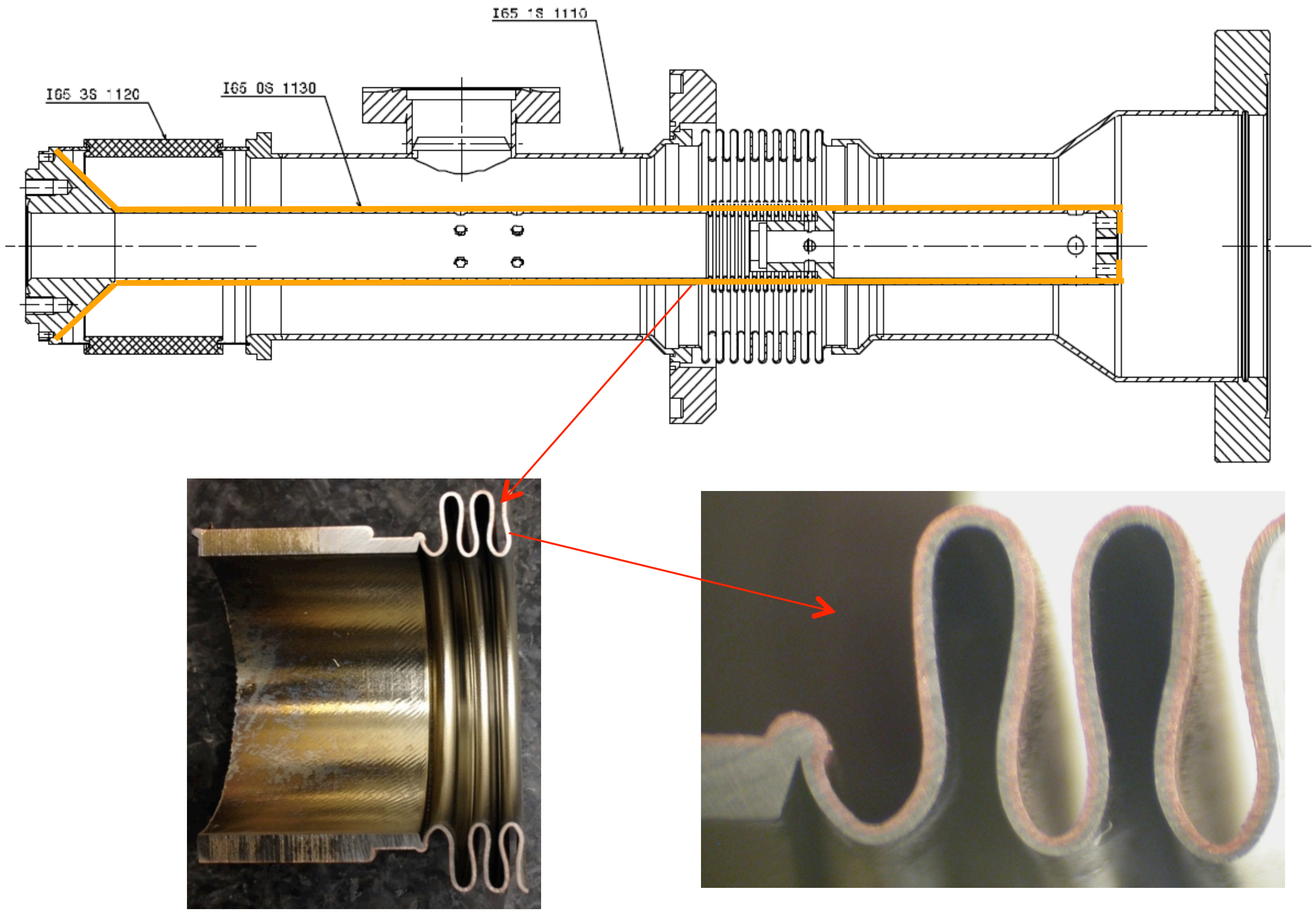
Assumption: 100 µm WIC plating and no resistivity increase with plating roughness. 3D case includes heating in the warm window and assume CF100 flange held at 70 K





Location of a rf short (mm): simulate reflection from cavity for various frequency detuning

LCLS-II coupler:

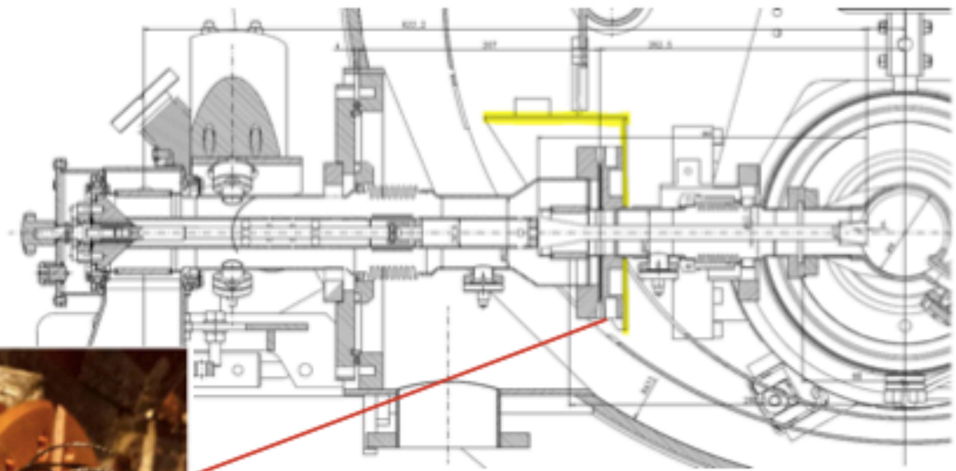


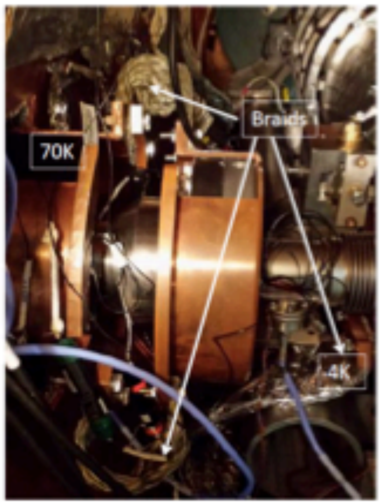
WIC cross section: measurement shown a copper plating distribution in the tolerance range (150 µm ± 30%).

LCLS-II coupler:

First 6 kW CW Operation at FNAL HTS

- Used shorter antenna and warm section with 150 um plating
- Found coupler temp higher than expected due to poor thermal tie-down





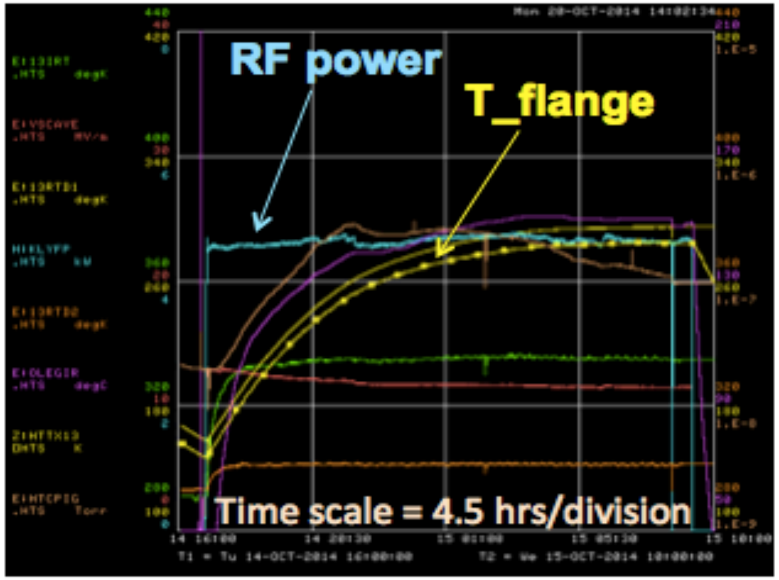
- Will add a SS split-ring washer (a la XFEL) to make the thermal contract between the copper plate and 70 K flange better - also increase the number of braids

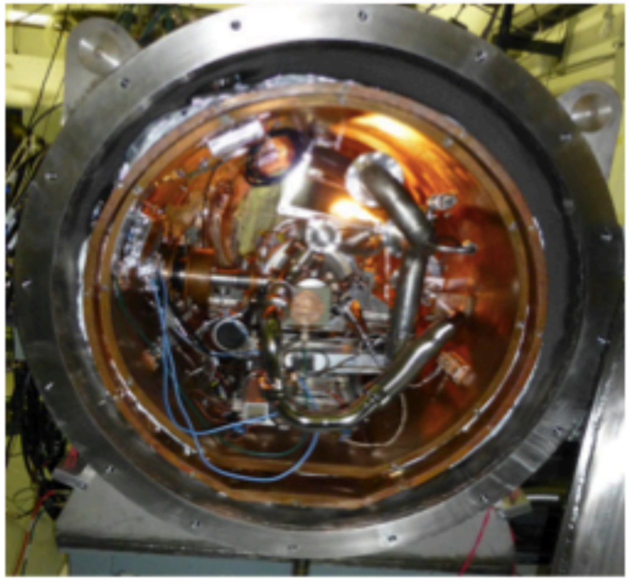
Andy Hocker

LCLS-II coupler:

First Test (cont)

Coupler +JLAB modified HOM feedthroughs assembled on RI026 cavity (good cavity tested for CM3) –DV program



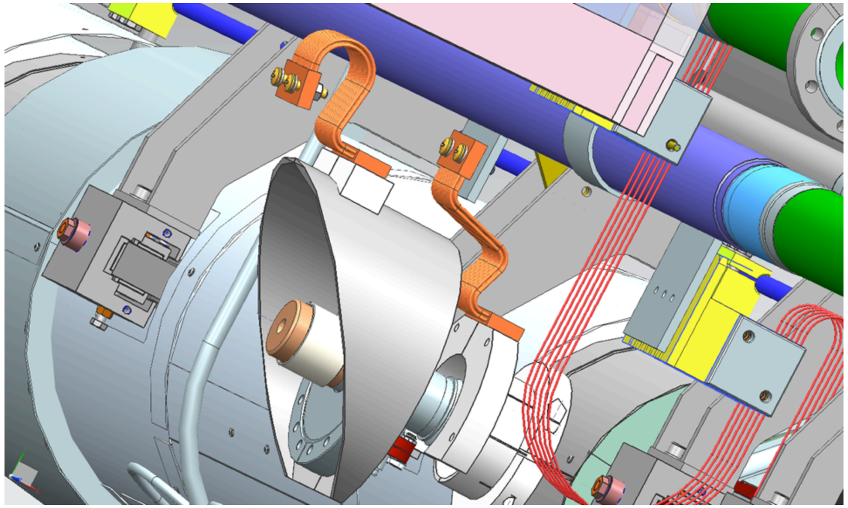


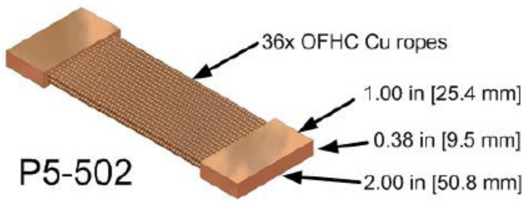
RF processing (max 6kW cw): RT; cold-cavity OFF-resonance; cold, cavity ON-resonance

- Smooth processing, no sparks or breakdowns, no MP. Vacuum interlock.
- No effect on Q_0 from FPC (Cornell test, HTC)
- Thermal time constant ~10 hrs

Nikolay Solyak

LCLS-II coupler:





P5-502

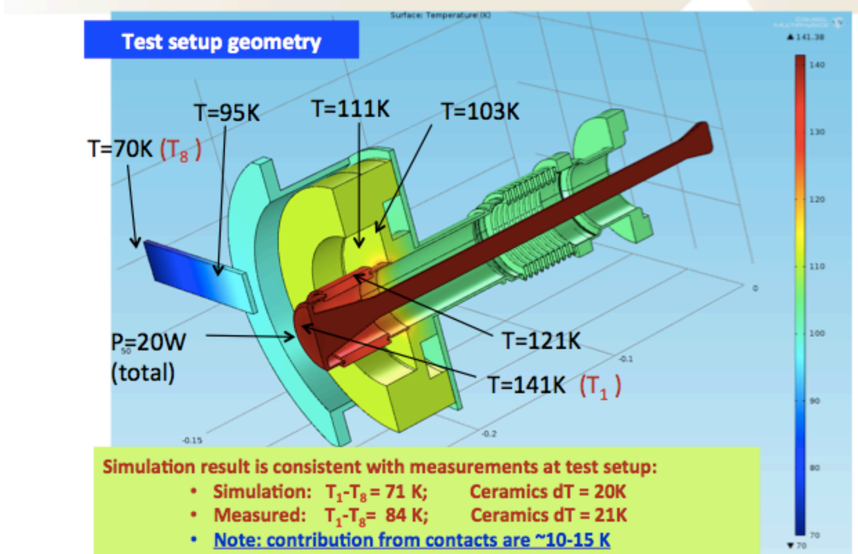
The P5-502 is our largest off-the-shelf CuTS option available to date. This unit is our most thermally conductive and fairly flexible, even with the additional 2nd layer (stiffness is only a slight issue at braid lengths of under 6-7 cm).

Braid length is customizable at no additional charge (up to 25 cm). Bolt holes are optional.

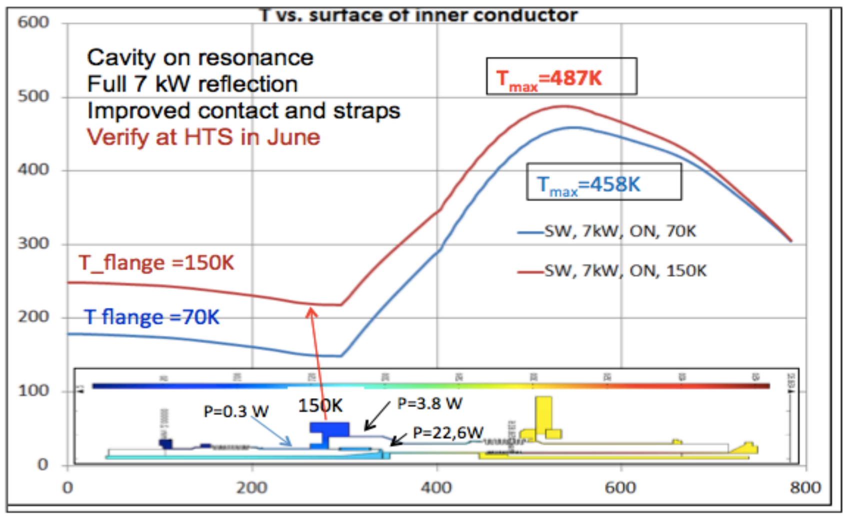
Performance Data & Mass
(at braid length = 10 cm):

Conductance *(at 300K)*: 0.43 W/K
Projected Conductance (at 8K): 1.0 W/K
Projected Conductance (at 40K): 1.14 W/K
Approximate Weight: 271 g

Technology Applications, Inc., 5710 Flatiron Parkway, Suite A, Boulder CO. 80301 www.techapps.com

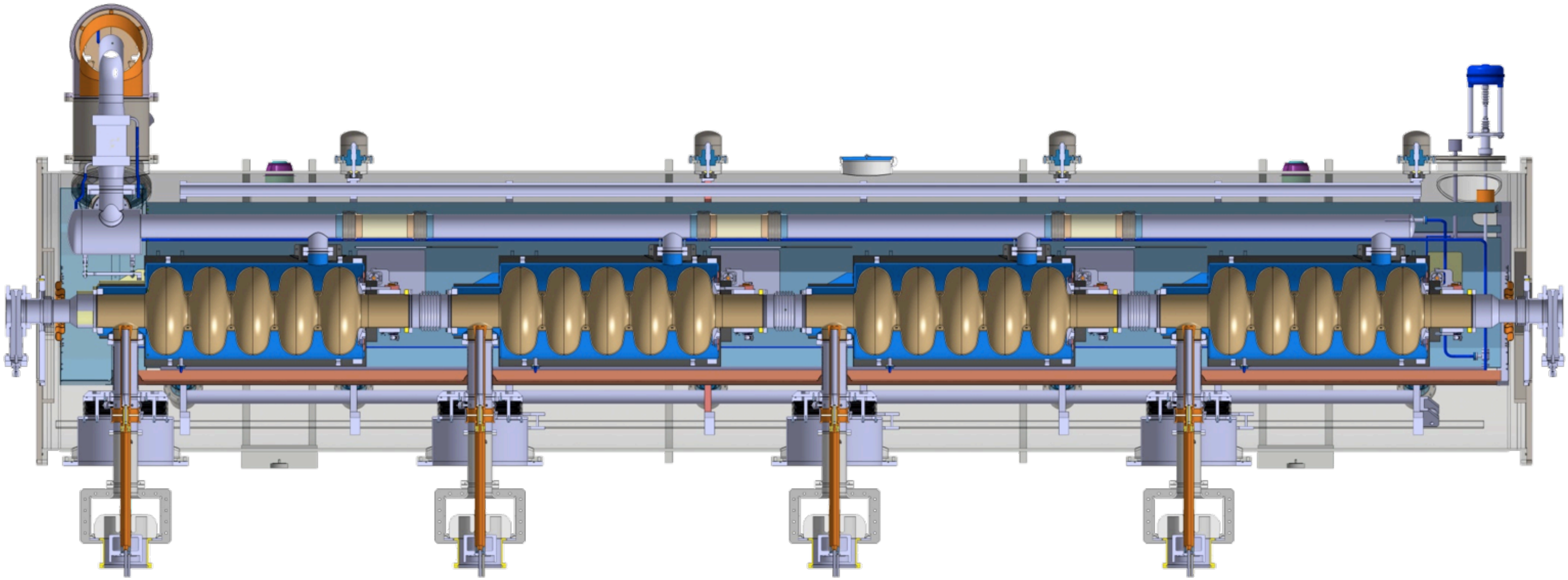


N Solyak, I Gonin



N Solyak, I Gonin

ESS Couplers

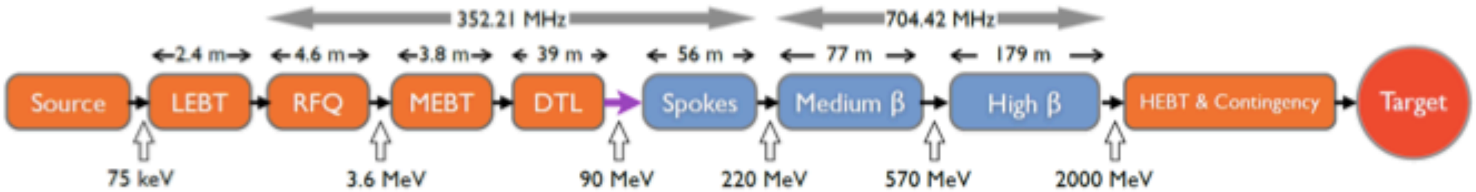


THPB078

ESS Couplers:

The European Spallation Source linac

Beam power (MW)	5
beam current (mA)	62.5
Linac energy (GeV)	2
Beam pulse length (ms)	2.86
Repetition rate (Hz)	14



Segmented, superconducting proton linac, with RT focusing elements

	Num. of CMs	Num. of cavities
Spoke	13	26
6-cell medium β	9	36
5-cell high β	21	84

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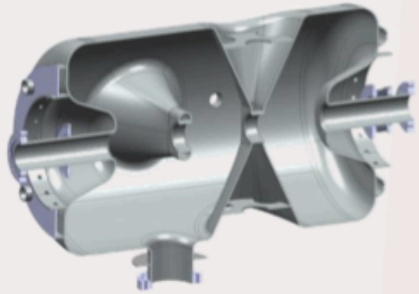
ESS Couplers:

Status of Spoke and Elliptical cryomodules

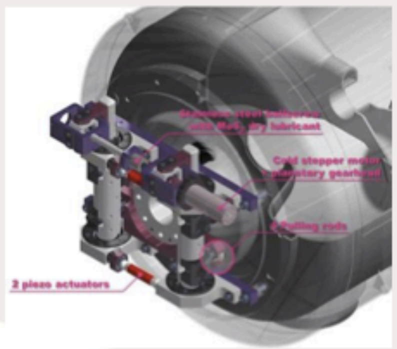
Spoke Cryomodule components

Double Spoke SRF Cavities

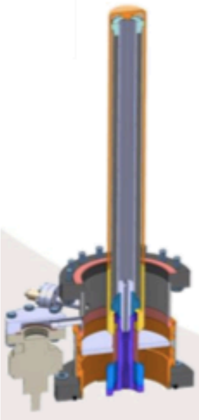


- Double spoke cavity (3-gaps), 352.2 MHz, β=0.50
- Goal: Eacc = 9 MV/m *[Bp= 62 mT ; Ep = 39 MV/m]*
- 4.2 mm (nominal) Niobium thickness
- Titanium Helium tank and stiffeners
- Lorentz detuning coeff. : ~-5.5 Hz/(MV/m)^2
- Tuning sentivity $\Delta f/\Delta z$ = 130 kHz/mm

Cold Tuning System



- Slow tuning (stepper motor):
  Max stroke: ~ 1.3 mm
  Tuning range: ~ 170 kHz
  Tuning resolution: 1.1 Hz
- Fast tuning (piezo-actuator):
  Applied voltage up to +/- 120V
  Tuning range at 2K: 675 Hz (min)



Power Coupler

- Ceramic disk, 100 mm diameter
- 400 kW peak power (335 kW nominal)
- Antenna & window water cooling
- Outer conductor cooled with SHe
- Doorknob transition from coaxial to ½ height WR2300 waveguide

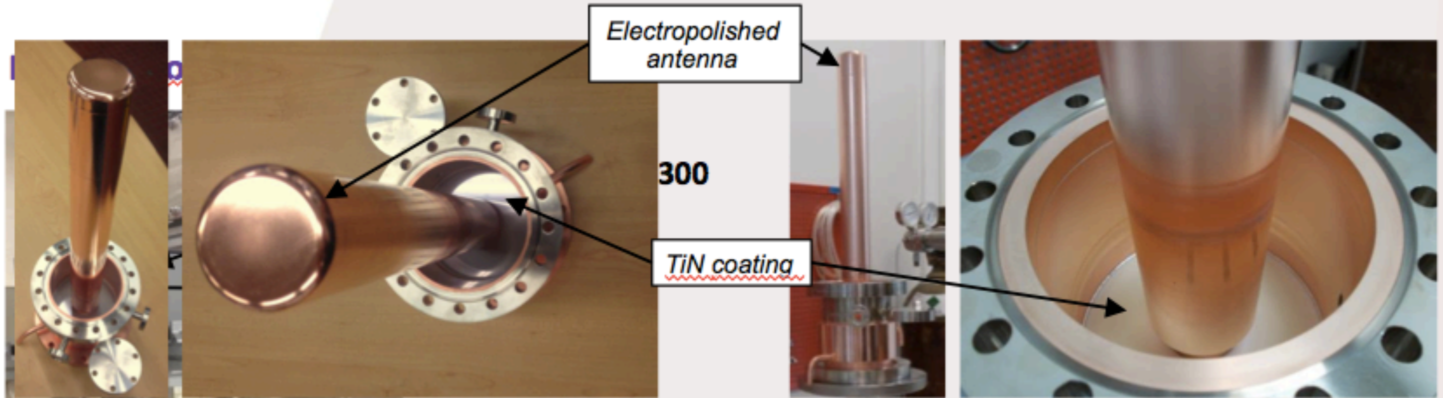
1

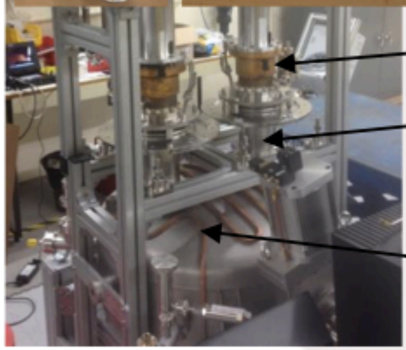
ESS Couplers:

Status of Spoke and Elliptical cryomodules

RF couplers

RF Power Couplers: 4 prototypes built by two french companies (SCT & PMB) and delivered





- Tuning of the coupling cavity
- Assembly in ISO4 clean room
- Baking (24h@155°C)

Baking stand

- Ramp-up to 155°C in 24 h
- 155°C is kept for 24h
- 10^{-9} mbar pressure level is reached

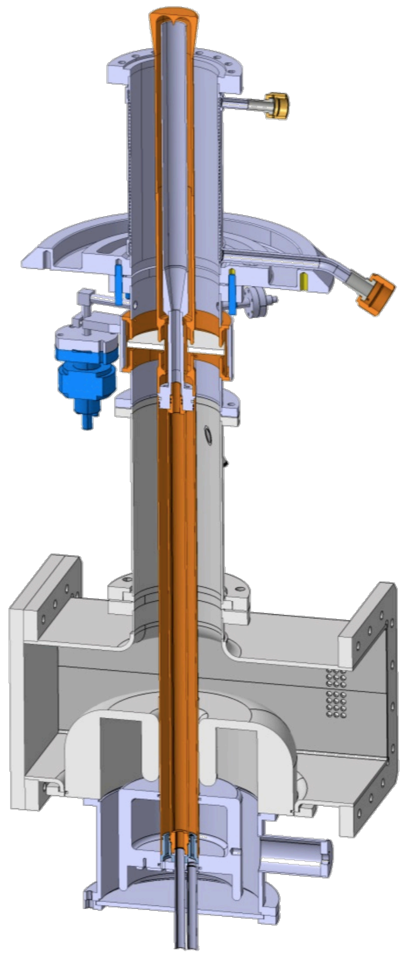
2

ESS Couplers:

Couplers needed for medium beta and high beta cavities have the same design. They are composed of 3 main parts:

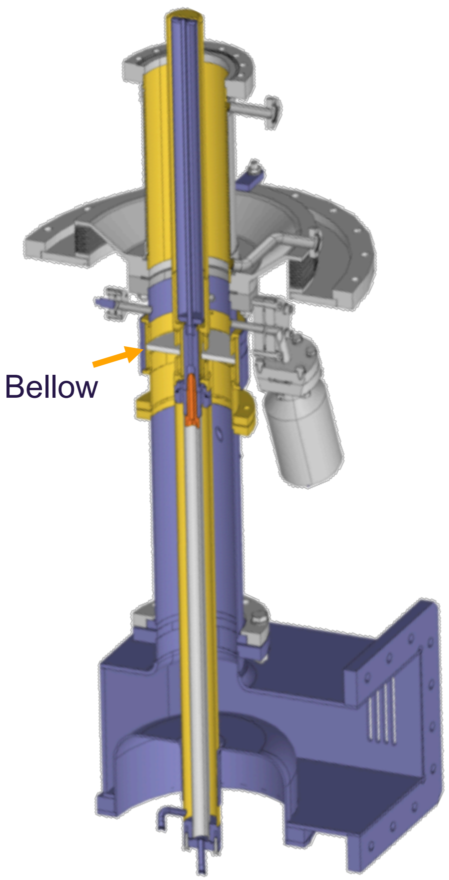
- Alumina disk window with its antenna: ensure RF power coupling and vacuum barrier
- A cooled double wall tube: allow thermal transition between ambient and cryogenic cavity temperature
- A doorknob transition: allow RF matching between the coupler and the RF power source

Only the length of the double wall tube changes to obtain a different antenna penetration and assures the required external quality factor for each kind of cavity.



ESS Couplers:

The ESS coupler is based on the design of the HIPPI coupler with some modifications:

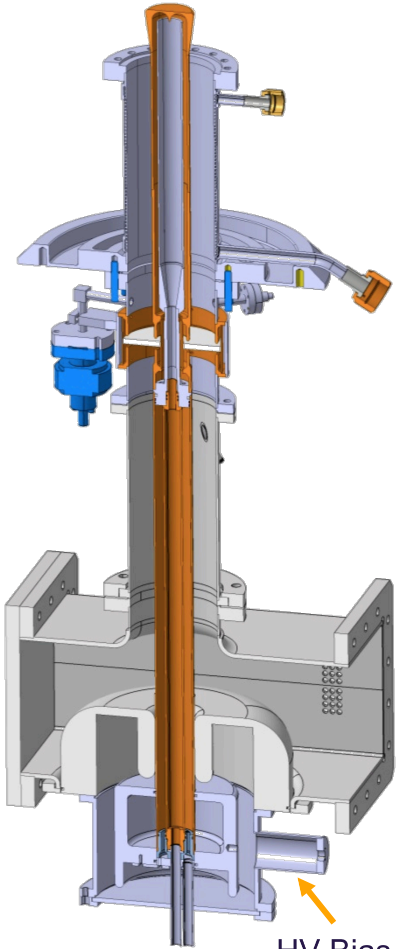


HIPPI coupler

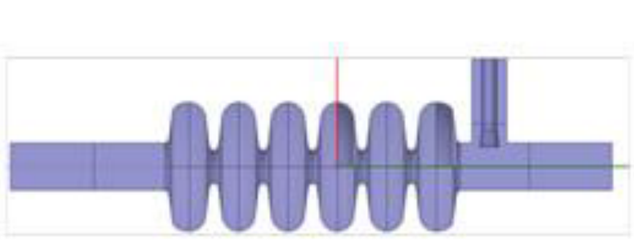
- Bellow removed from the double wall tube and become part of the ESS cryomodule (vacuum vessel)
- Change on diagnostic port distribution
- Adding a HV bias with RF trap
- Inner conductor: conical tip for stronger coupling
- improved water cooling channel.

RF pulse features

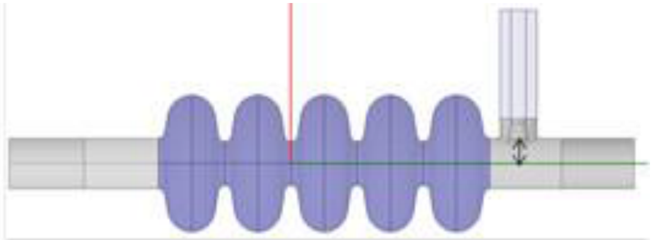
Nominal frequency	704.42MHz
Maximum peak power	1.1MW
RF length pulse	2.86ms
Repetition rate	14Hz
External Quality factor	
Medium β couplers	$Q_{ext} \in [5.9\times105; 8\times105]$
High β couplers	$Q_{ext} \in [5.6\times105;7.6\times105]$



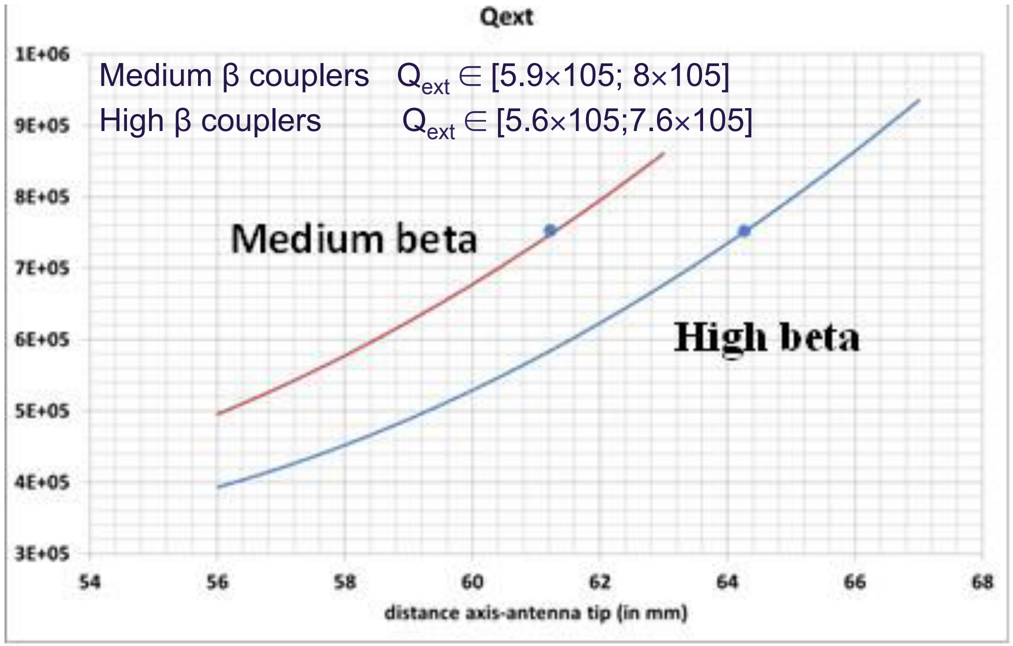
ESS Couplers:



Medium β cavity with coupler

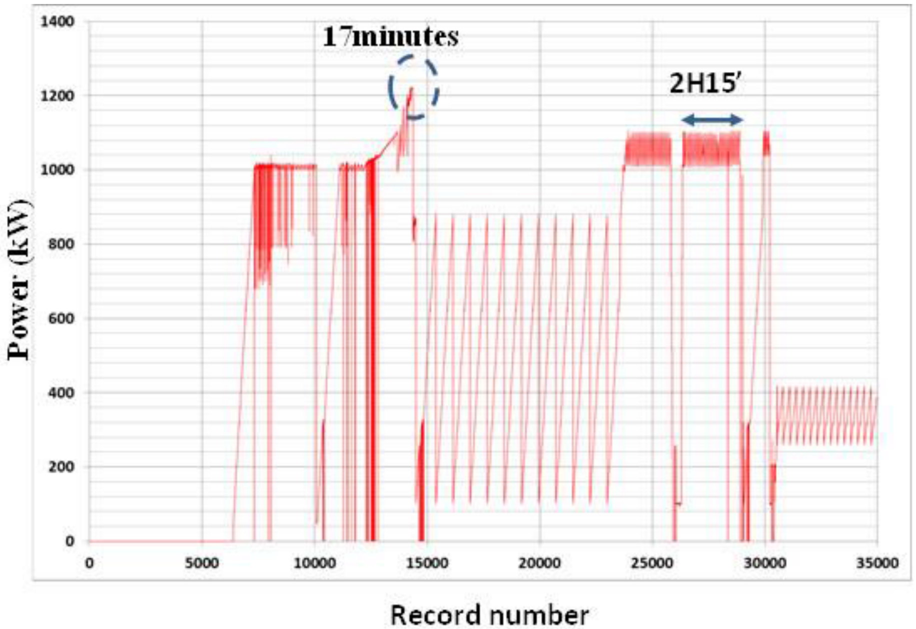


High β cavity with coupler

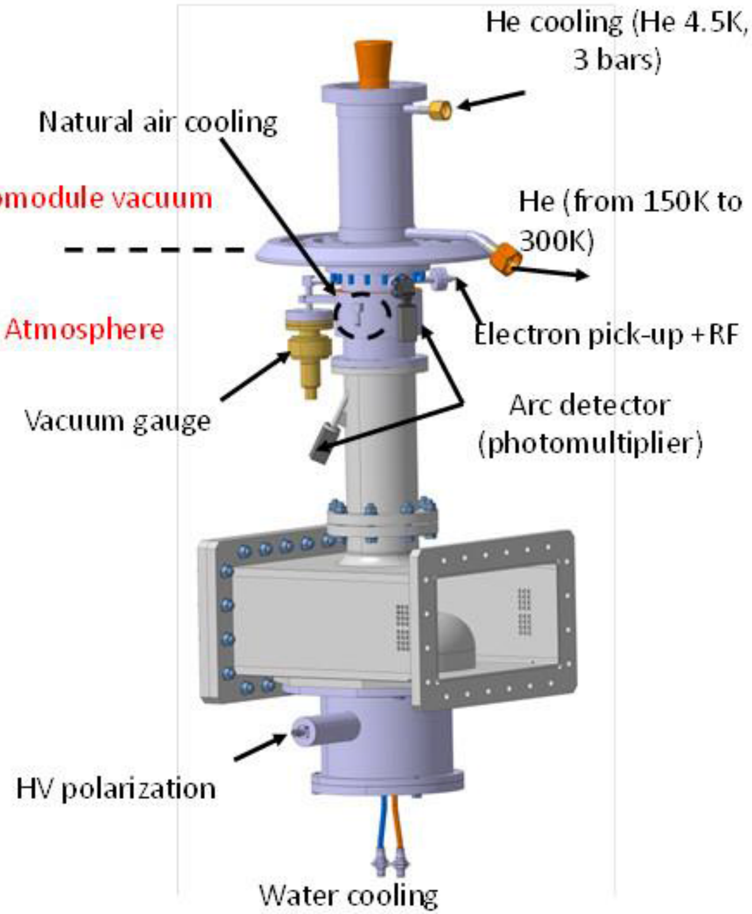


The 3 mm penetration difference will be obtained by changing the double wall tube length between medium and high beta couplers.

ESS Couplers:



HIPPI coupler was tested until 1.2MW for some minutes and 1.1 MW for several hours, duty cycle 10%. This last power value is the one retained in ESS requirements.



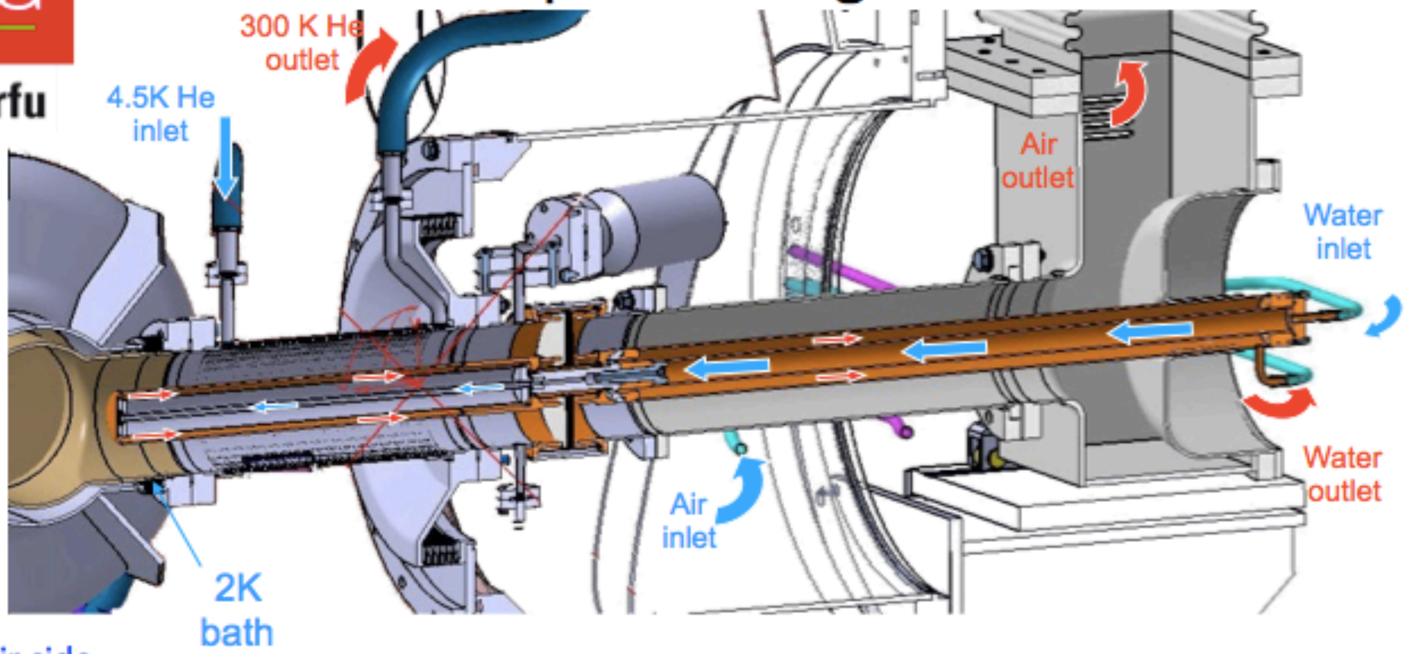
For the maximum power (1.1MW, 5% duty cycle), the power dissipation was estimated by simulation:

- In the ceramic: 33W (SW) and 9.3W (TW), assuming 3 10^4 for loss tangent
- The inner conductor: 58W (TW)

→ 3 different cooling circuit are needed to dissipate these power.

ESS Couplers:

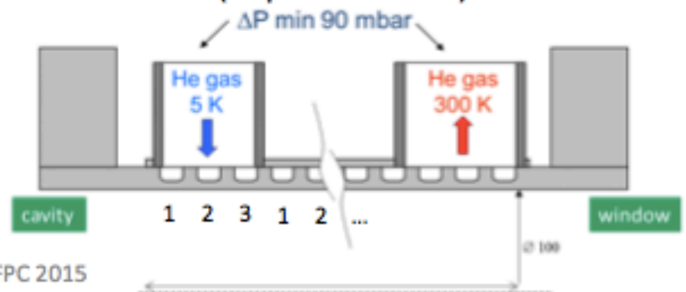
Coupler cooling



Air side
- blown air on the ceramic
- Internal conductor (IC) water cooled

Vacuum side
- Outer conductor (OC) He cooled
- IC water cooled
- ceramic outer water cooling channel

He cooling channel capable of up to 100 W extraction (3 spiral channels)



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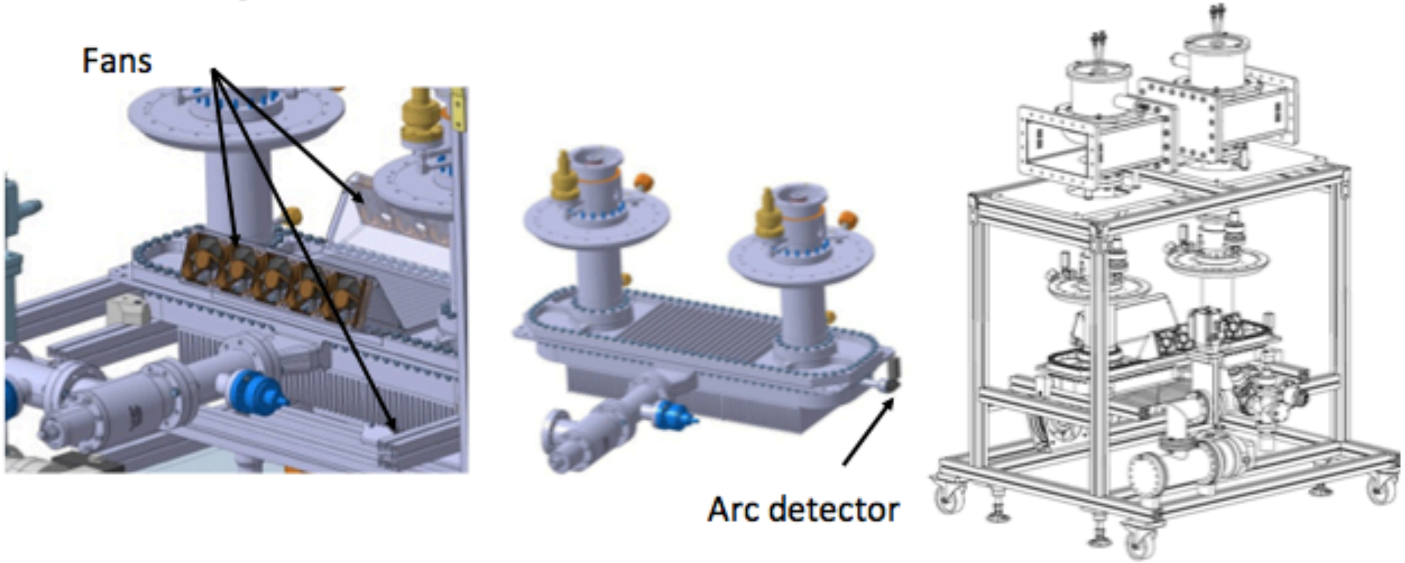
Conditioning waveguide

- Full stainless steel designed (no copper coating). Dismountable (as Eric's 700 MHz test box). Top cover can be Cu deposited if first tests prove it is necessary
- Air cooling designed accordingly ;
  - heat sinks + fans on bottom plate
  - Channeled air flow with push-pull fans on the top
- Arc detector added in order to have the opportunity to distinguish between window arcs and waveguide arcs.



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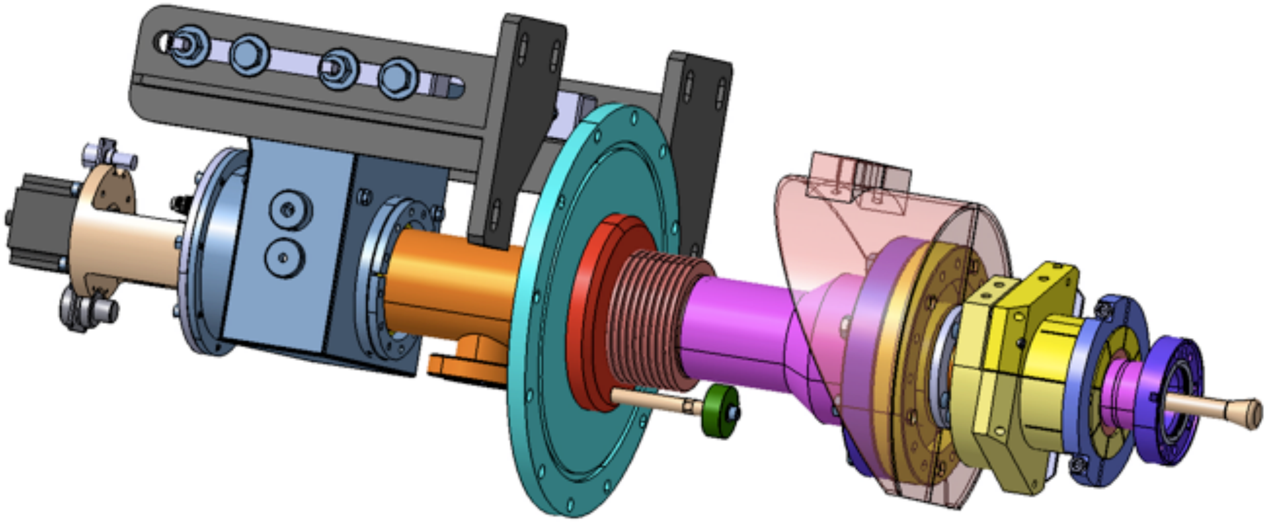
XFEL Couplers



THPB094, THPB095, THPB096, THPB102

XFEL Couplers:

800 power couplers 1.3 GHz are needed to equip **100 XFEL cryomodules**.

XFEL couplers are produced by 2 suppliers at 3 production sites:

- **Consortium Thales-RI** (Thonon les bains-France and Koln-Germany): **670** units.
- **CPI** (Beverly-Massachusetts-USA): **150** units.

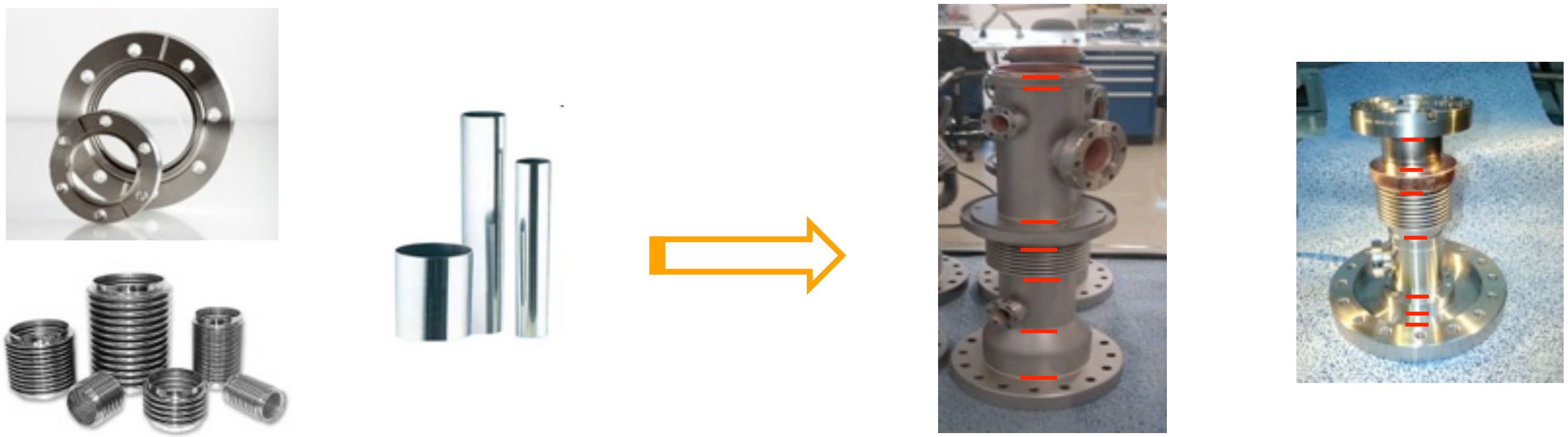
Supported by DESY, LAL-Orsay has in charge:

- The **production monitoring** and the **quality control** at Thales-RI sites.
- The **RF conditioning** of all the couplers at Orsay and the weekly **delivery of 8 couplers/ week** to IRFU-CEA.

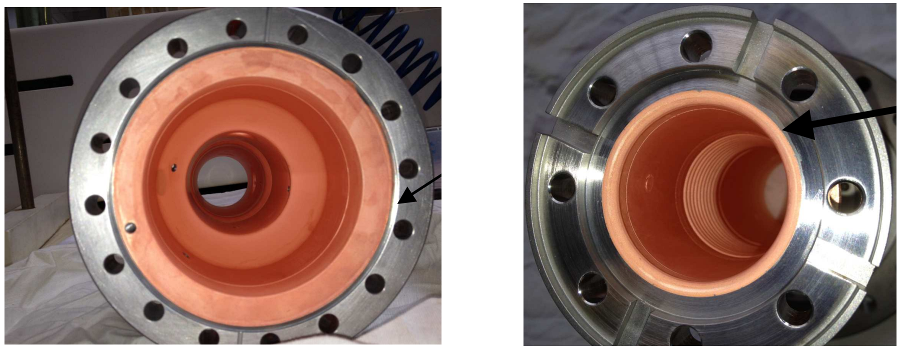
XFEL Couplers:

At Thales site:

- 1st step: parts assemblies by brazing:



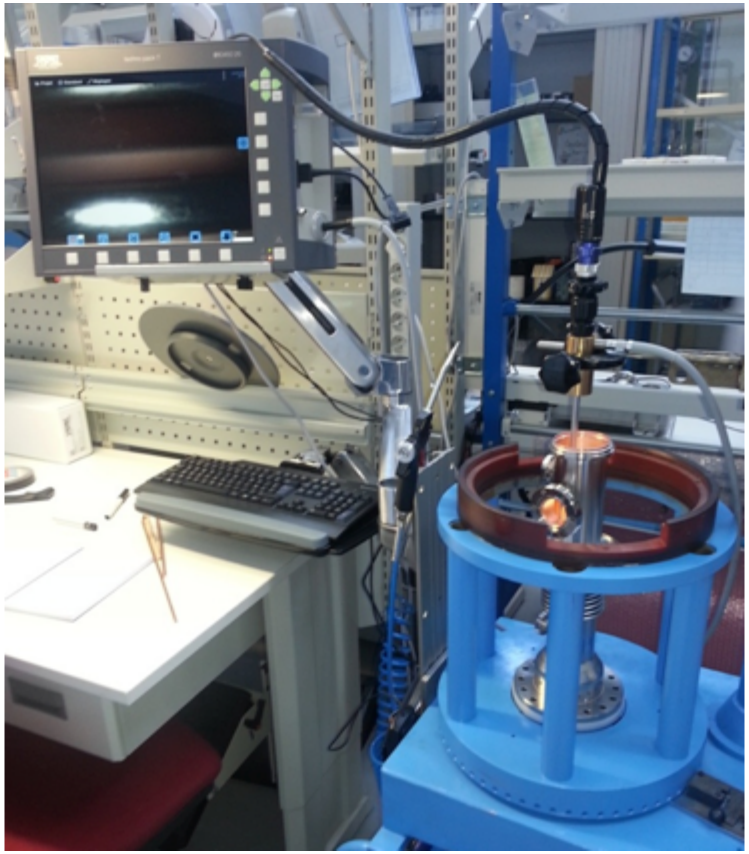
- 2nd step: RF Surfaces copper plating of the assembled parts:

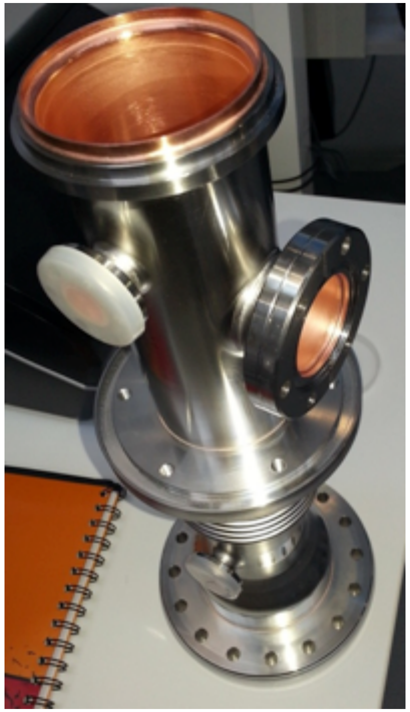


XFEL Couplers:

Weekly inspection at Thales-Thonon to control parts copper plating quality

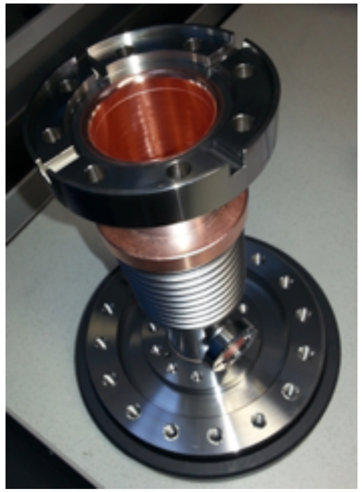
Double check at RI-Koln with the same shared control criteria





Warm part

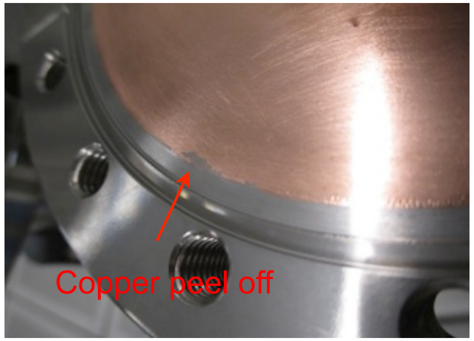
Cold part

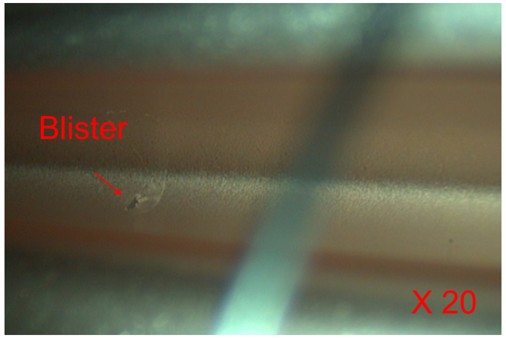


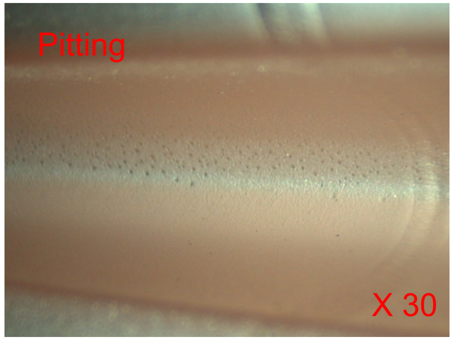
XFEL Couplers:

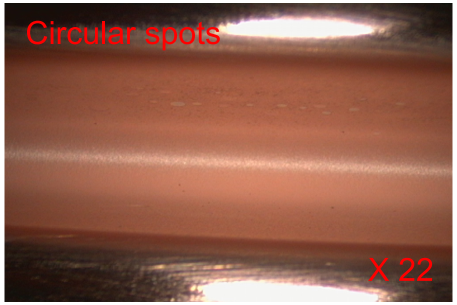
Main reasons of coupler rejection at the final inspection:

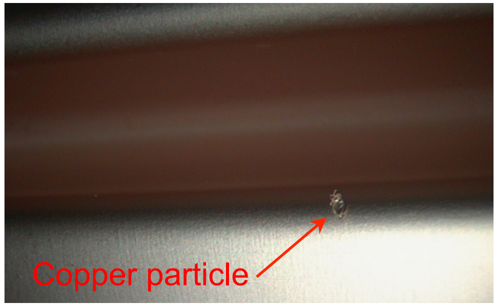
- **Copper plating defects** (mainly during ramp up phase and before production stabilization):







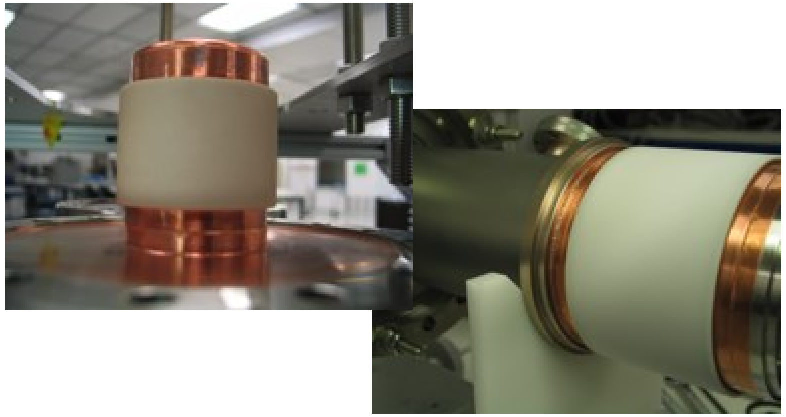




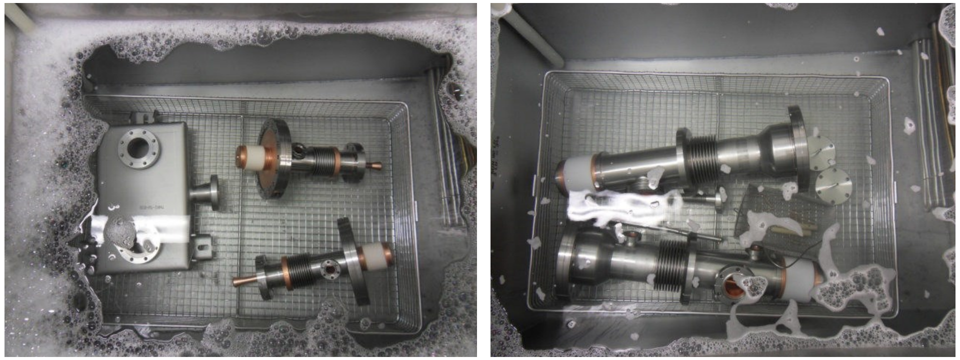
→ Solved: process improvement, setting acceptance criteria (defects classification by types, dimensions and number. Agreement in corrective actions and tests.

XFEL Couplers:

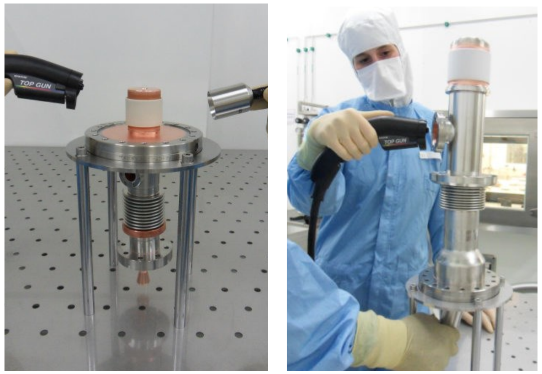
At RI site:



- TiN coating on ceramics
- ceramics EB welding of cold & warm parts



US degreasing of parts

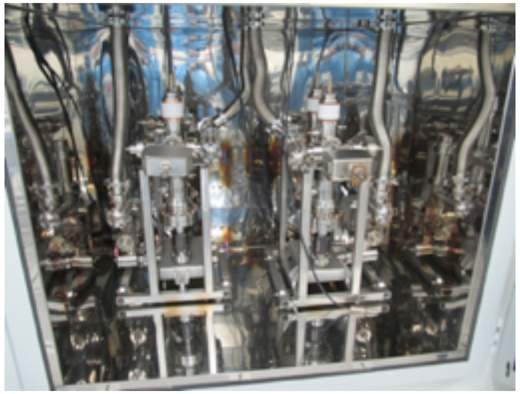


particle counting

coupler pair clean room assembly,
leak and actuator displacement test

XFEL Couplers:

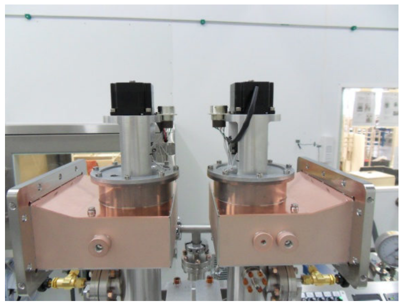
Leak test after reception



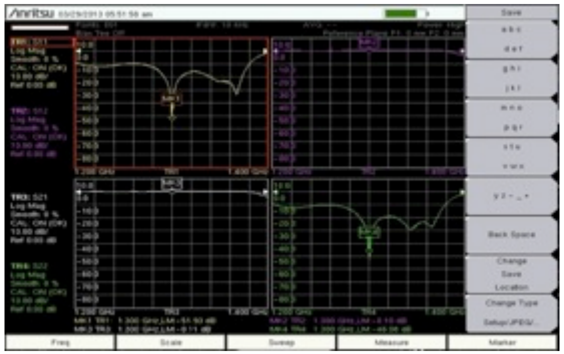
75h baking cycle at 150°C

WGBs assembly

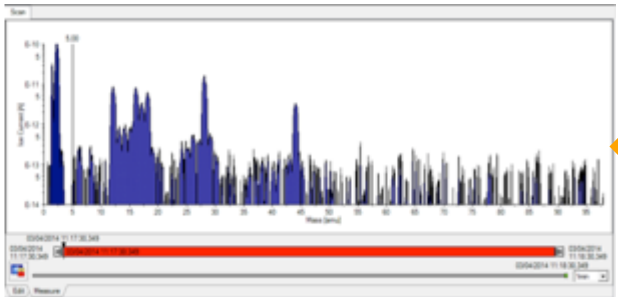
Capacitors assembly



Actuators assembly

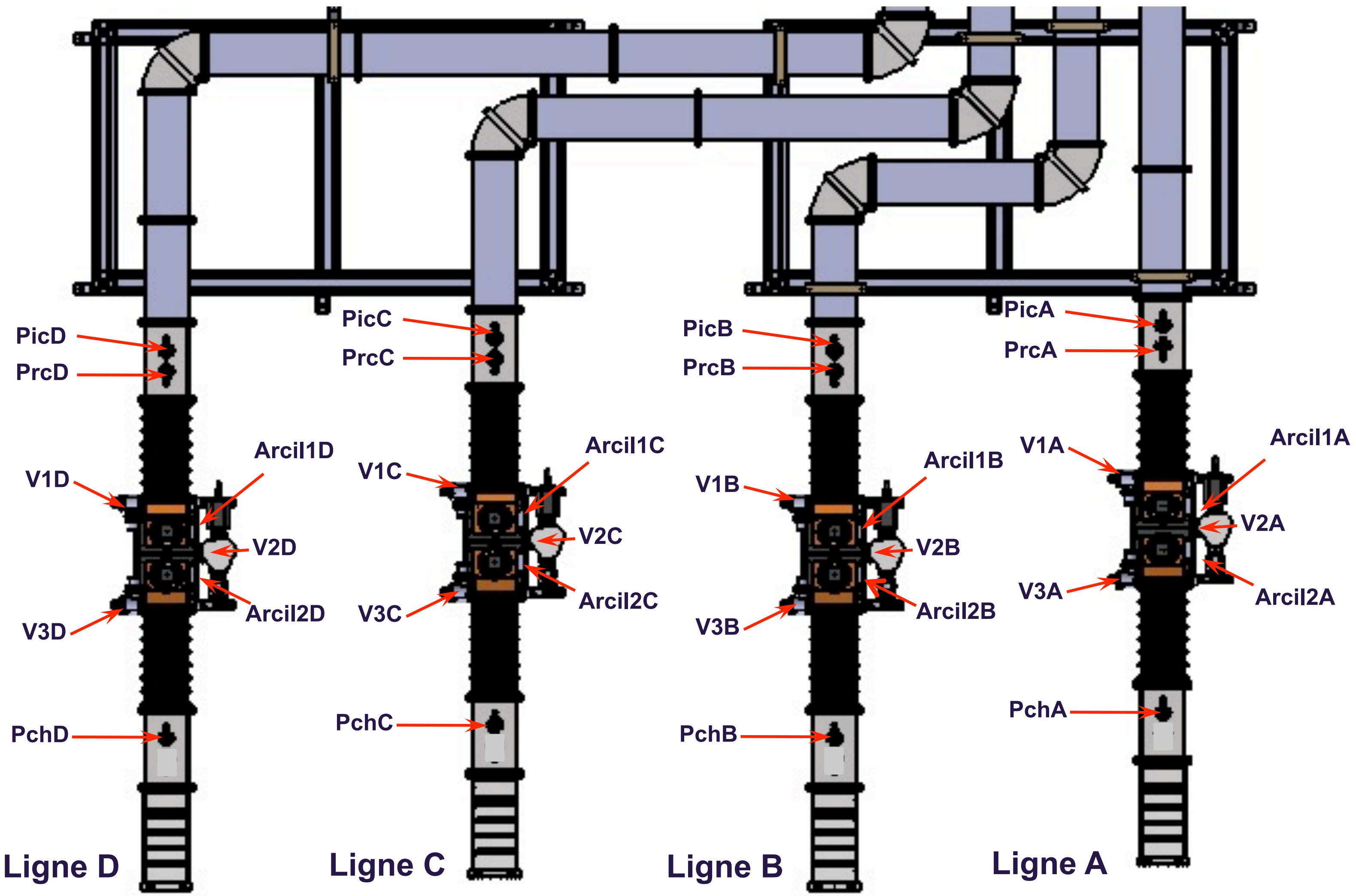


Antenna tuning



RGA spectrum recording

XFEL Couplers:



XFEL Couplers:

Optimized RF process, equipment, tools and man-power at LAL allow to process up to 14 couplers/week.

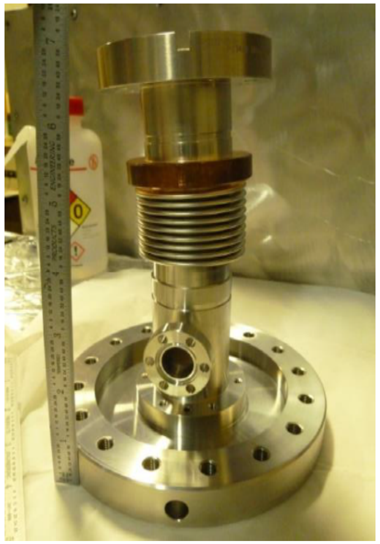
XFEL Couplers:

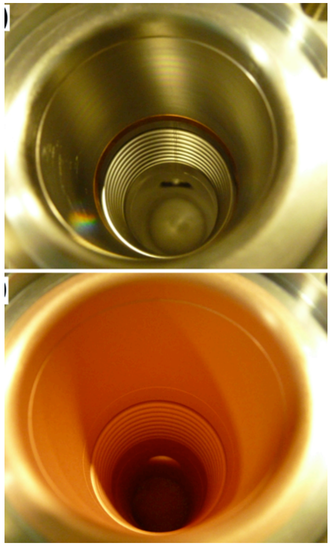
REX from Coupler mass production:

- Mass production may need adjustment in tolerances and specifications (at least during the ramp up phase).
- The copper coating is the critical process: Important to set a common classification of the defects & acceptance criteria.
- Finishing treatment after copper coating (Brushing Vs. glass bead blasting): No problem with Mo wool brushing (Thales production). Investigations with CPI production still running to determine the impact of glass bead blasting treatment on the high outgassing observed during first pairs conditioning.
- The cleaning and assembly process must be carefully controlled. RF conditioning time is highly impacted.
- Increasing the baking temperature by only 20°C (from 130 to 150°C) allow to reduce by nearly 55% the conditioning time (from 63h to 35h).

R&D on new technologies & fabrication processes:

Alternative process to the copper plating is proposed by Alameda Applied Sciences Corporation (AASC) team: Coaxial Energetic Deposition (CED) from a cathodic arc plasma to grow directly the copper films on Stainless Steal coupler parts.





HPR test: Adhesion strength above 1000 psi water rinse and thermal shock of 77K (from RT)

RRR measurement: first test results give RRR around 50

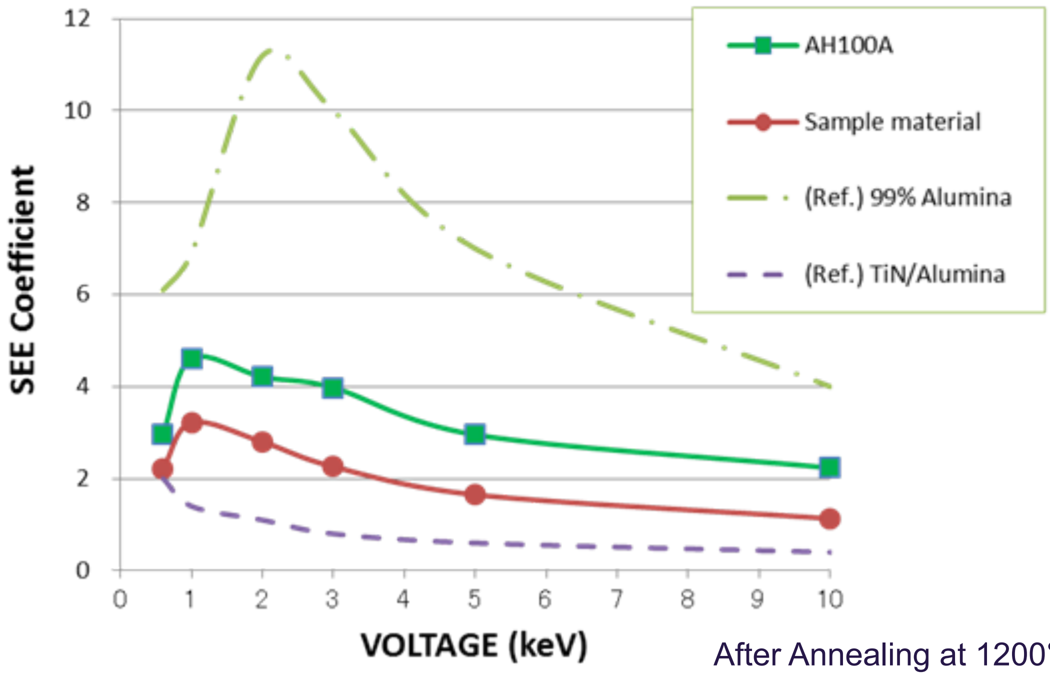
To learn more: THPB083

R&D on new technologies & fabrication processes:

KEK and Kyocera are developing an uncoated ceramic window based on a low SEE coefficient material:

AH100A has 1/2 smaller SEE Coefficient than that of 99% alumina.

Sample material can make SEE coefficient less than AH100A, however still higher than TiN coated alumina surface.



After Annealing at 1200°C

First coupler with the new ceramic material will be tested on 2016 at KEK

Summary:

Status of LCLS 2 coupler production:

- First 16 prototypes will be delivered fall 2015.
- Serial production will start beginning 2016.
- Couplers will be delivered to SLAC cleaned, assembled in clean room and baked at 150°C.
- Most probably, the RF conditioning of couplers will be performed directly in cryomodule.

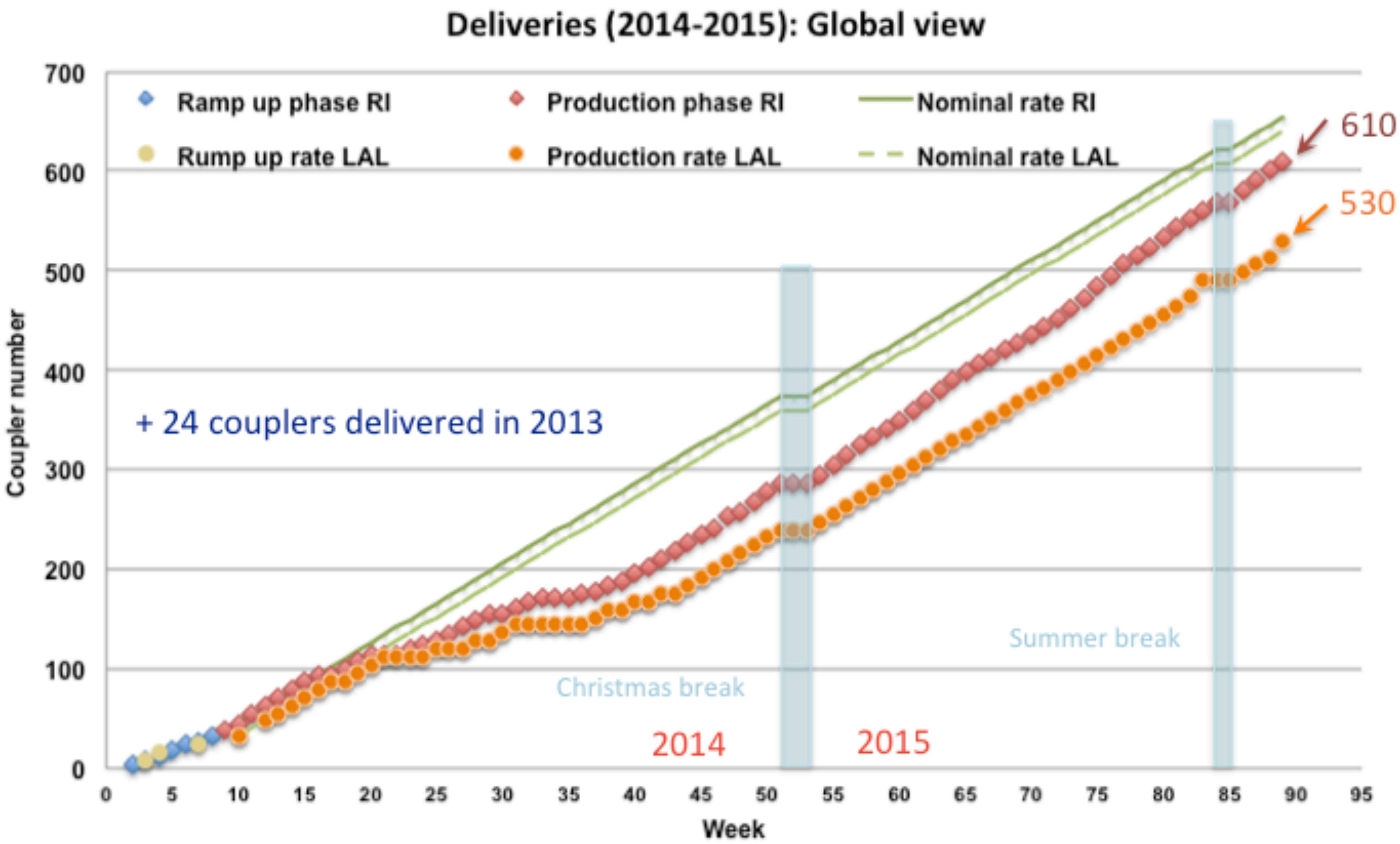
Status of ESS coupler production:

- First 8 prototypes will be delivered on October 2015
- Test boxes will be delivered in January 2016
- Serial production will start after validation of the prototypes.

Couplers will be prepared, assembled (clean room assembly training is done on HIPPI couplers), RF conditioned at CEA (beginning 2016).

Summary:

Status of XFEL coupler production:



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Thank you for your attention