Design and Development of Power Coupler for MEXT-ATD

Ryo Katayama (KEK, Accelerator laboratory, iCASA)

Members and acknowledgement

Team “Power coupler”

R. Katayama, Y. Yamamoto, H. Sakai, T. Dohmae, M. Omet, T. Yamada (KEK)

S. Kazakov (FNAL)

RF simulation done under the US-Japan science and technology cooperation

Acknowledgement:

A. Yamamoto (CERN/KEK)

S. Belomestnykh (FNAL)

H. Weise, D. Kostin (DESY)

W. Kaabi, A. Miyazaki (IJCLAB)

Thank you very much for the global effort!

License agreement updated by DESY-KEK including IJCLAB

This work was supported by

【MEXT Development of key element technologies to improve the performance of future accelerators Program】

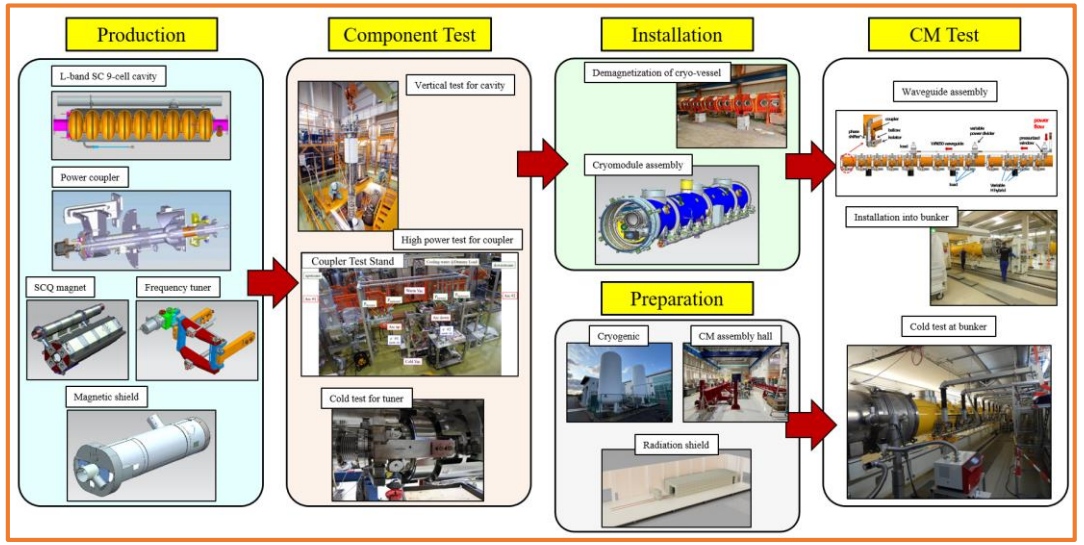
Japan Grant Number JPMXP1423812204.

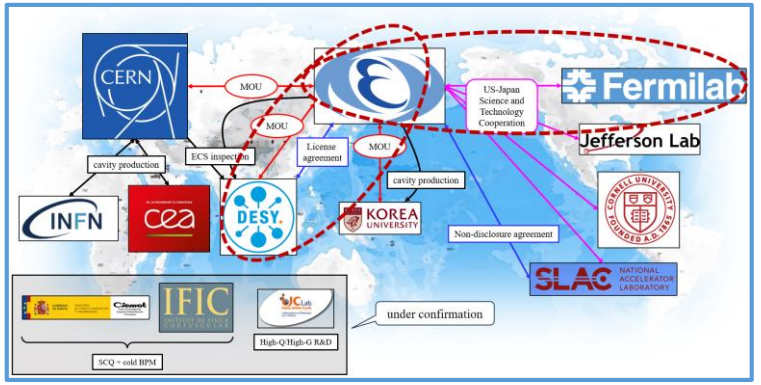
Contents

- Introduction and MEXT-ATD program
- Specifications on power coupler
- Basic design and change requests for power coupler production
- RF design of power coupler by CST
- Quality control/assurance before production
- Production/Test schedule of power coupler
- Summary

Introduction and MEXT-ATD program

- We got the budget for the MEXT-ATD program (related to ITN) from FY2023 to 2027.
  - Production and test of one CM in bunker without beam
    - Eight cavities satisfying the ILC spec
    - Eight frequency tuners
    - Eight fundamental mode power couplers
    - Eight magnetic shields
    - One SCQ magnet
  - Construction of necessary infrastructures
    - Cryogenic system
    - Test bunker
    - High-level RF system.
- Global collaboration related to ITN
  - KEK-DESY contracted the updated license agreement related to E-XFEL.
  - US-Japan science and technology cooperation





Specification on power coupler

In TDR, TTF-3 coupler was recommended as a baseline design.
For construction of E-XFEL, E-XFEL power coupler was designed as modified TTF-3.

Parameter	Specifications	Unit
Frequency	1.3	GHz
Operation pulse width	1.65	msec
Operation Repetition rate	5 (usual)/10 (low energy)	Hz
Required RF power in operation	~400	kW
Range of external Q	(1.0 ~ 10.0) x 10^6	
RF power in CM	> 1.2 MW for ≦ 400 μsec > 500 kW for > 400 μsec	
RF power in test stand	> 600 kW for 1.6 msec	
Number of windows	2	
Bias voltage capability	Required	

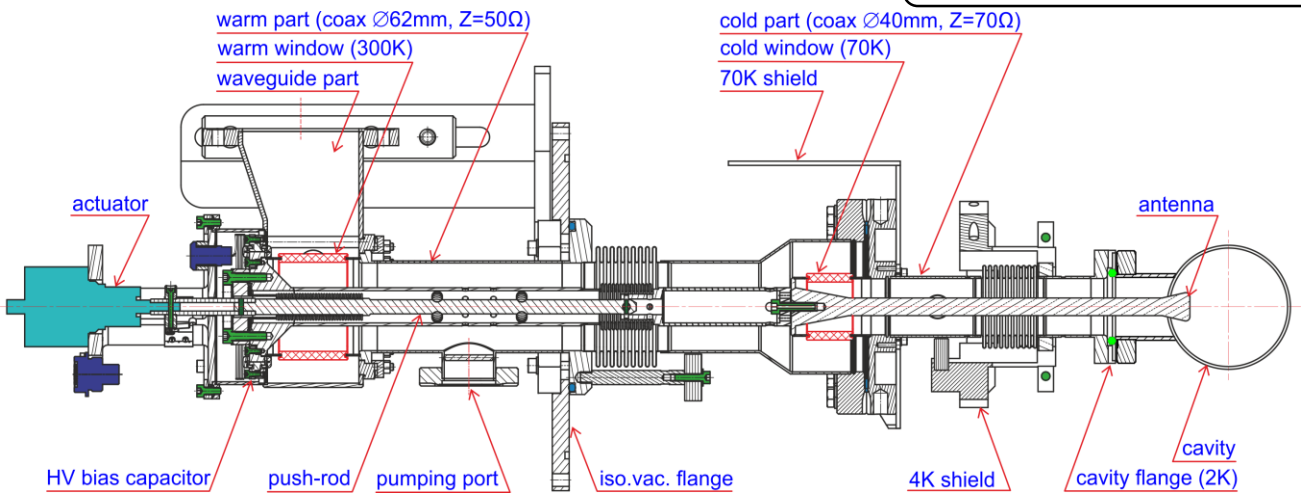
※TDR, Vol. 3: Accelerator Baseline Design

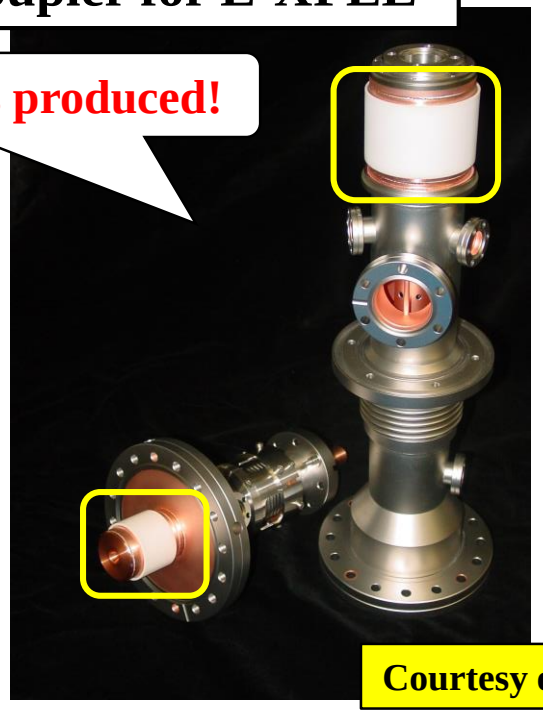
E-XFEL power coupler as basic design, and change requests

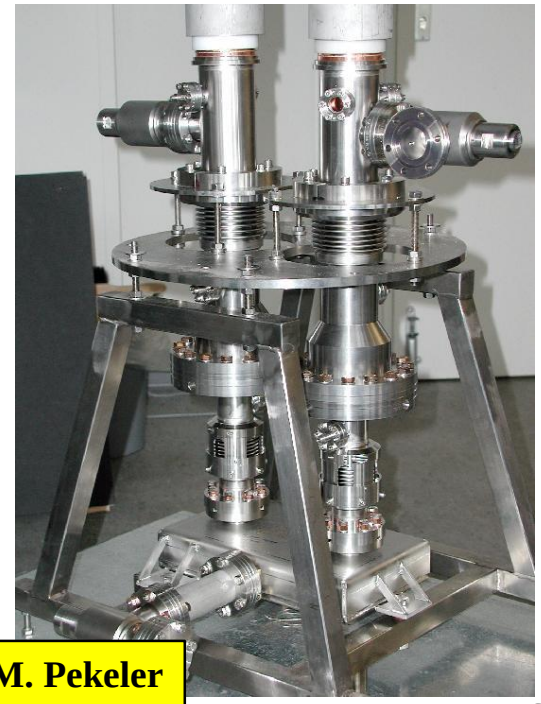
We adopted the E-XFEL power coupler as basic design (described in ILC/TDR) and changed the following items.

- **Ceramic material** (see next page)
- **Bellows in push-rod**
  - 18 waves to avoid RF leakage (→ see backup)
- **Material change for waveguide** (copper to aluminum)
- **No actuator** (manual tuning)

Fundamental mode Power Coupler for E-XFEL







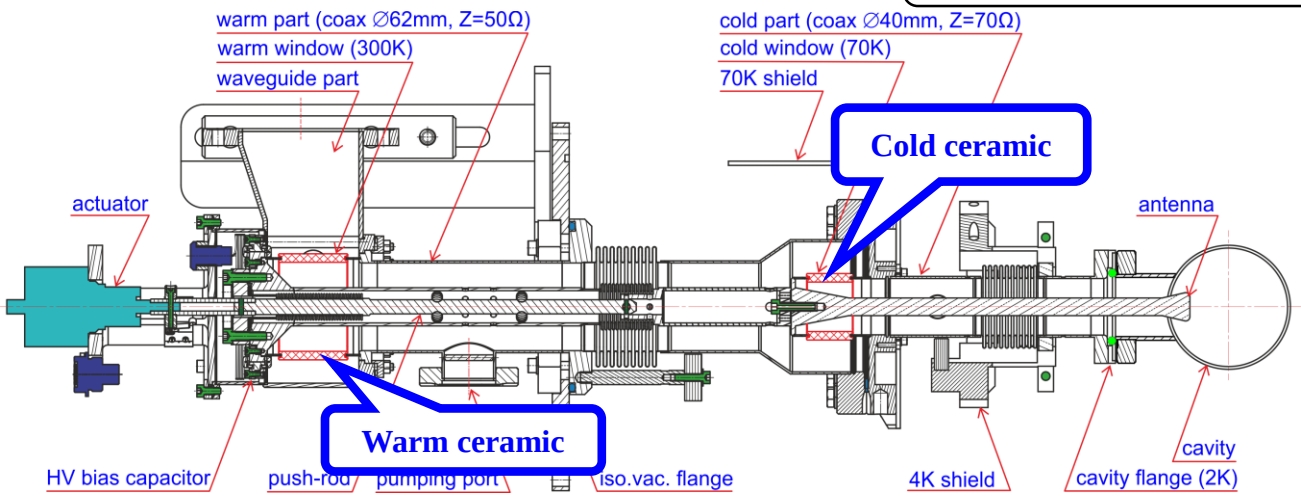
Courtesy of M. Pekeler

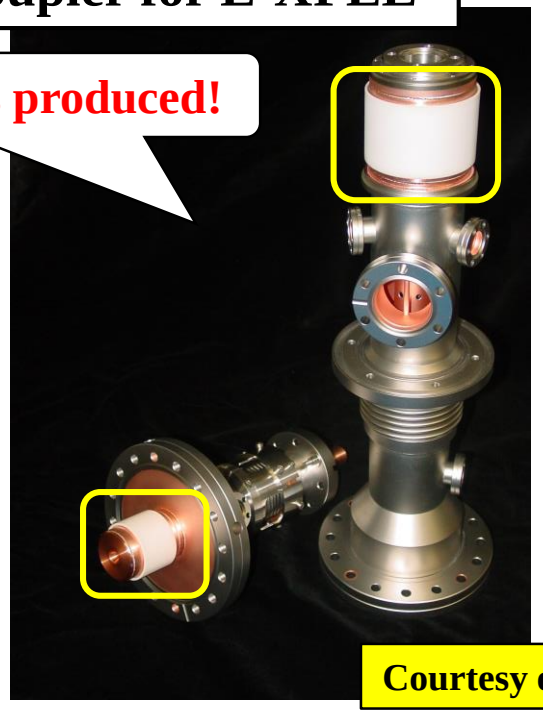
E-XFEL power coupler as basic design, and change requests

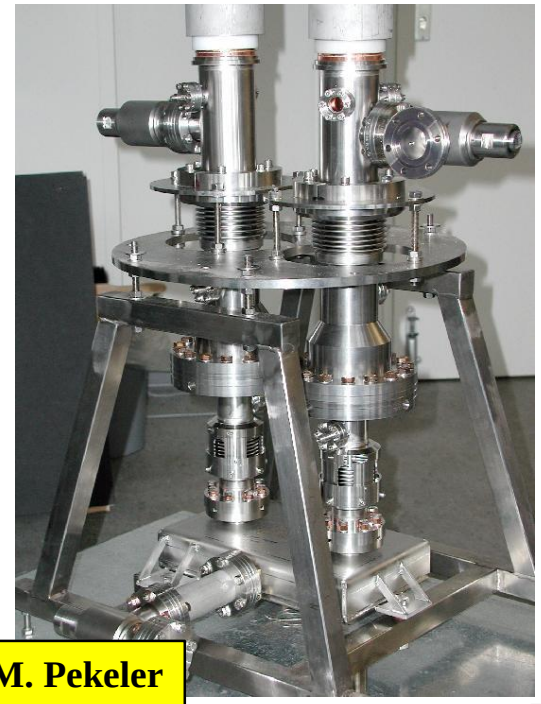
We adopted the E-XFEL power coupler as basic design (described in ILC/TDR) and changed the following items.

- **Ceramic material** (see next page)
- **Bellows in push-rod**
  - 18 waves to avoid RF leakage (→ see backup)
- **Material change for waveguide** (copper to aluminum)
- **No actuator** (manual tuning)

Fundamental mode Power Coupler for E-XFEL







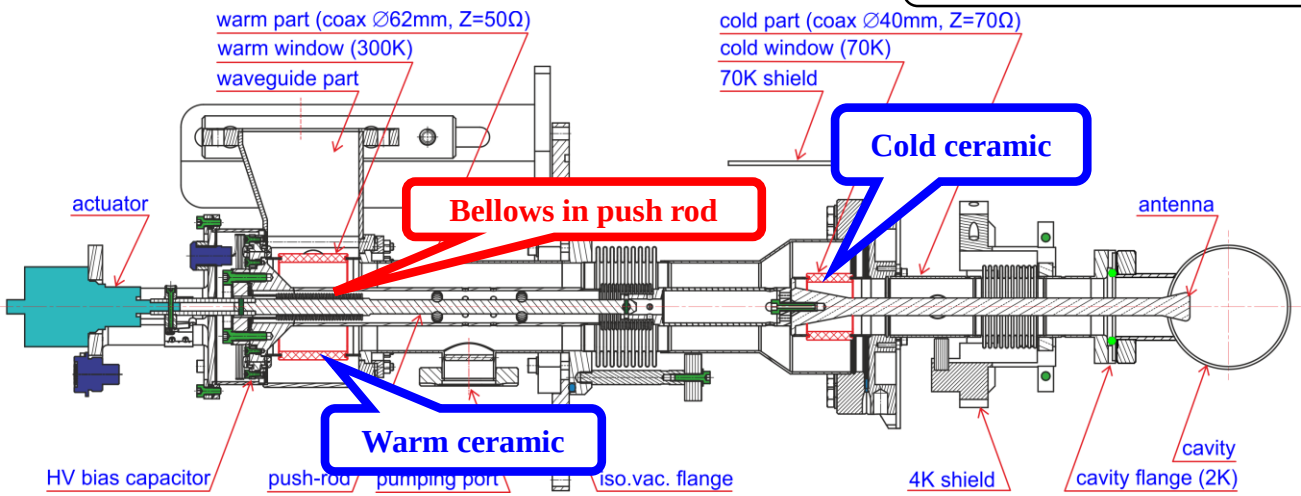
Courtesy of M. Pekeler

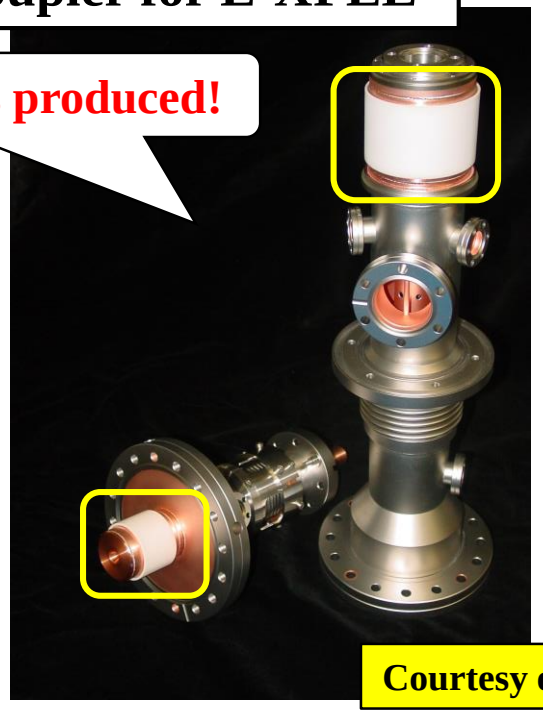
E-XFEL power coupler as basic design, and change requests

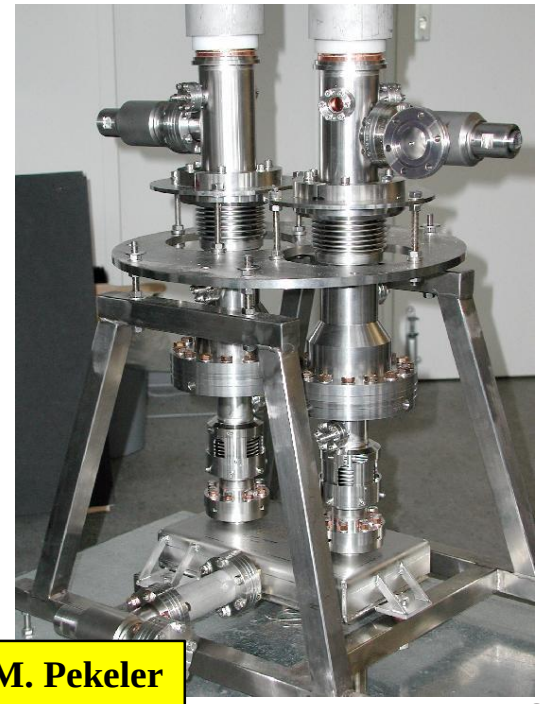
We adopted the E-XFEL power coupler as basic design (described in ILC/TDR) and changed the following items.

- **Ceramic material** (see next page)
- **Bellows in push-rod**
  - 18 waves to avoid RF leakage (→ see backup)
- **Material change for waveguide** (copper to aluminum)
- **No actuator** (manual tuning)

Fundamental mode Power Coupler for E-XFEL







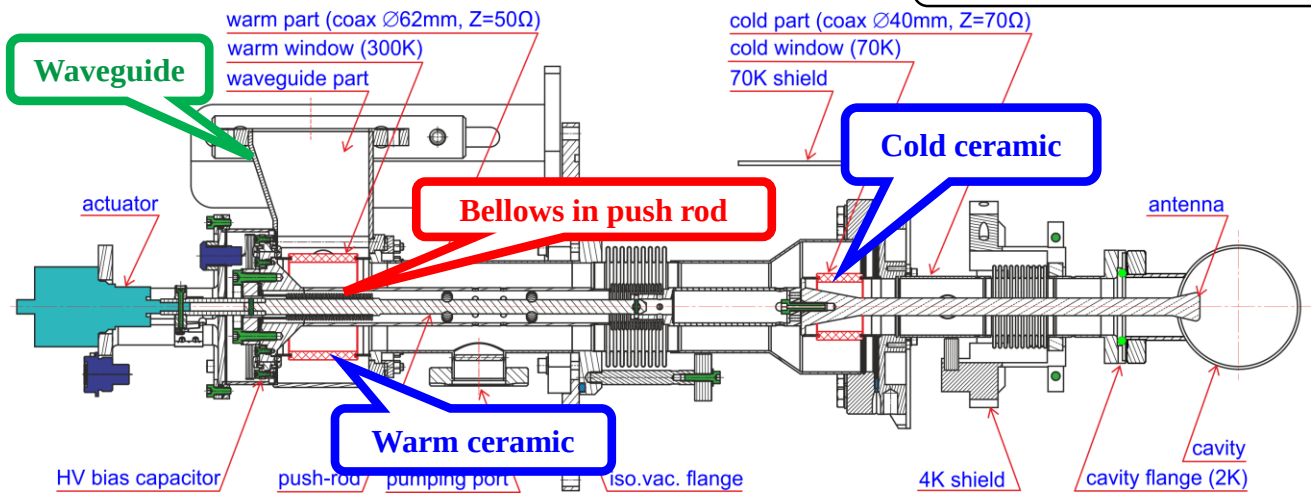
Courtesy of M. Pekeler

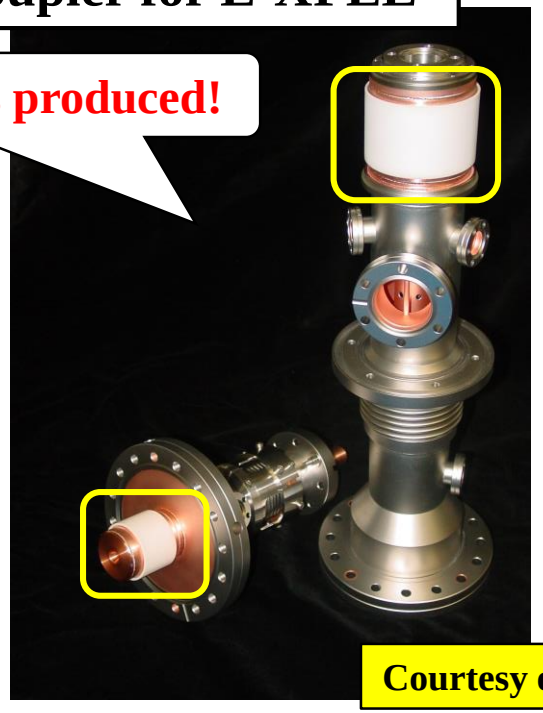
E-XFEL power coupler as basic design, and change requests

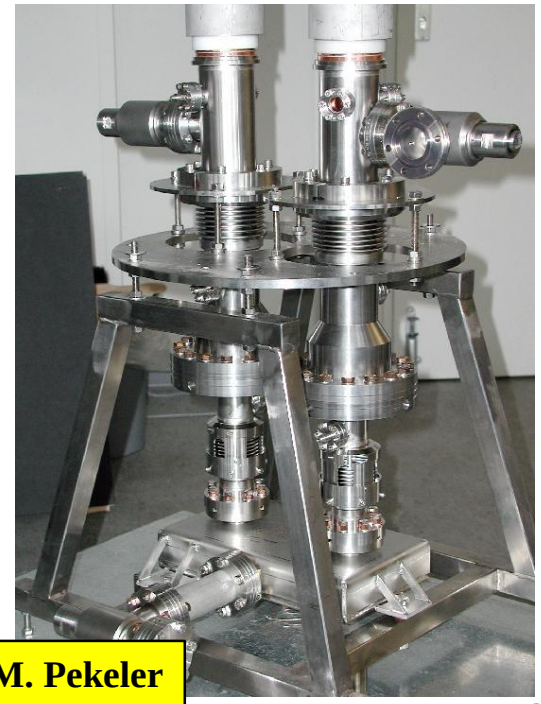
We adopted the E-XFEL power coupler as basic design (described in ILC/TDR) and changed the following items.

- **Ceramic material** (see next page)
- **Bellows in push-rod**
  - 18 waves to avoid RF leakage (→ see backup)
- **Material change for waveguide** (copper to aluminum)
- **No actuator** (manual tuning)

Fundamental mode Power Coupler for E-XFEL







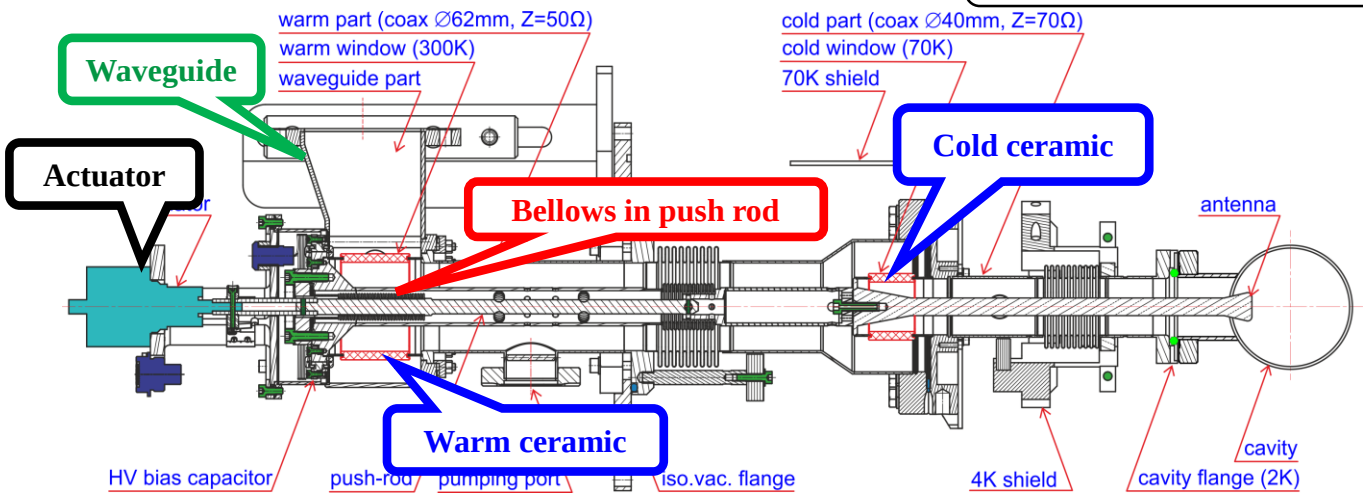
Courtesy of M. Pekeler

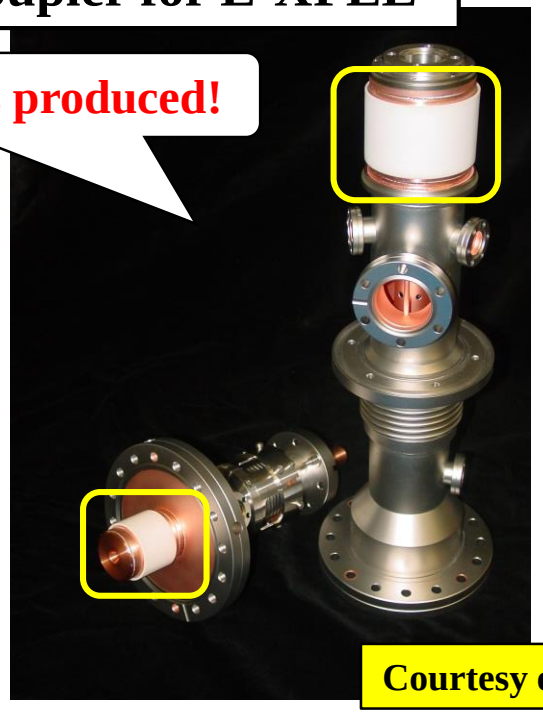
E-XFEL power coupler as basic design, and change requests

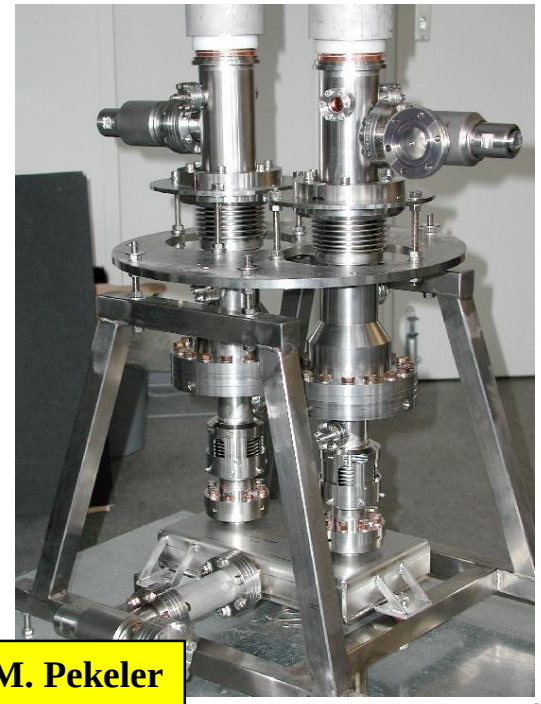
We adopted the E-XFEL power coupler as basic design (described in ILC/TDR) and changed the following items.

- **Ceramic material** (see next page)
- **Bellows in push-rod**
  - 18 waves to avoid RF leakage (→ see backup)
- **Material change for waveguide** (copper film on aluminum)
- **No actuator** (manual tuning)

Fundamental mode Power Coupler for E-XFEL





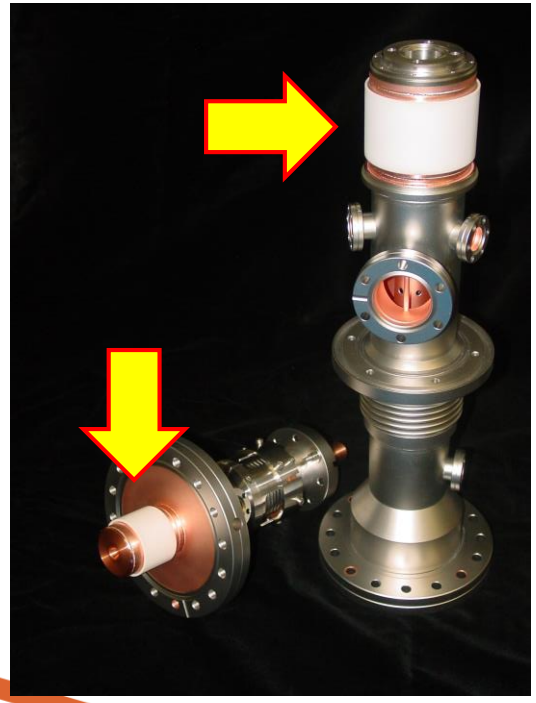


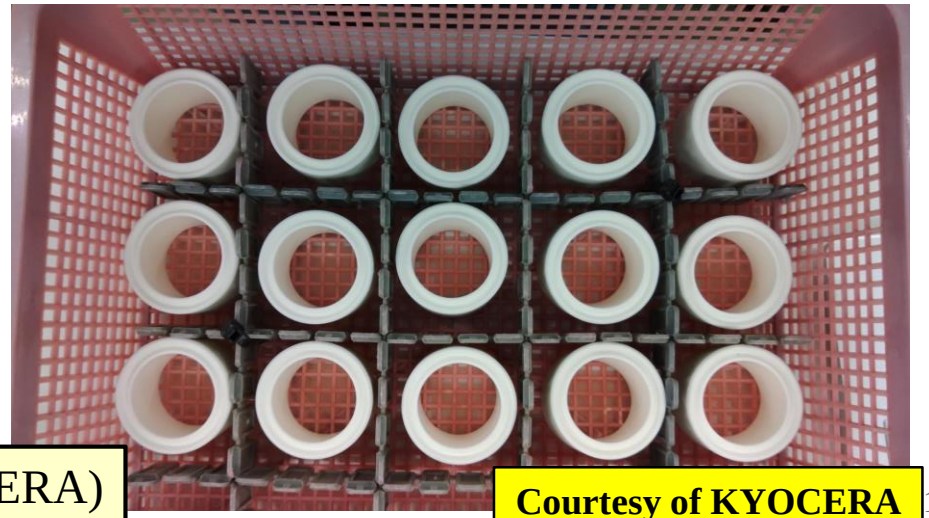
Courtesy of M. Pekeler

Change of ceramic material

KEK and KYOCERA have evaluated new type ceramic for power coupler in past several years.
We will use this ceramic (A479U) for our project, because of high reliability and availability in Japan.
But this ceramic has different specification from E-XFEL, then we needed to check by RF simulation.
And, also, KEK has never experienced the use of TTF-3 power coupler with cylindrical ceramic.
Then, we need to check quality of brazing, TiN coating, thermal cycle test, etc. (see later).

	ε	tanδ	Thickness
European XFEL	9.3 (@1.0GHz)	2.6×10^{-4} (@1.0GHz)	6.0 mm
MEXT-ATD/ITN	9.7 (@1.3GHz)	3.6×10^{-5} (@1.3GHz)	5.7 mm





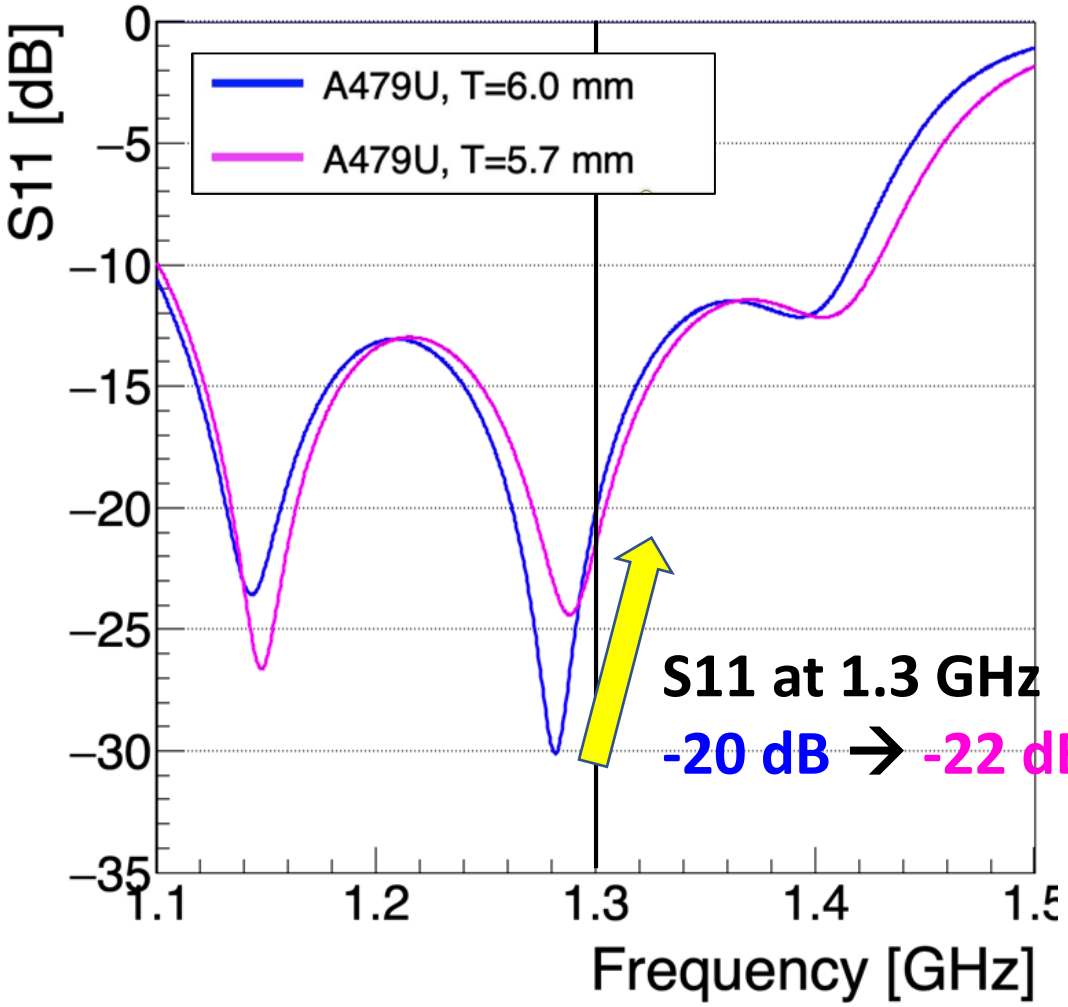
A479U (KYOCERA)

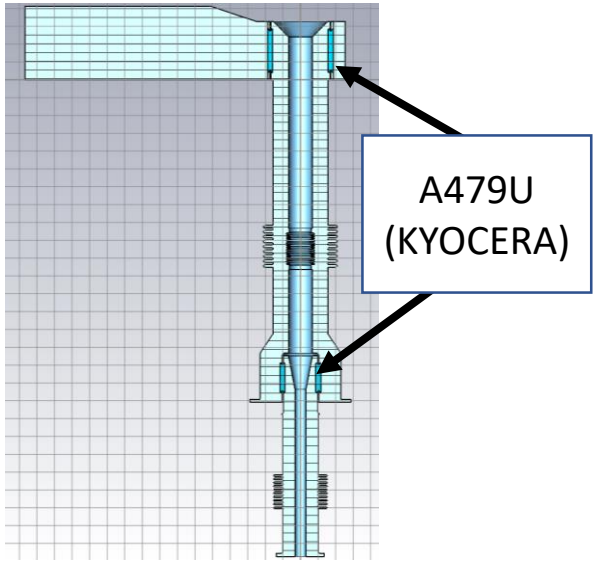
Courtesy of KYOCERA

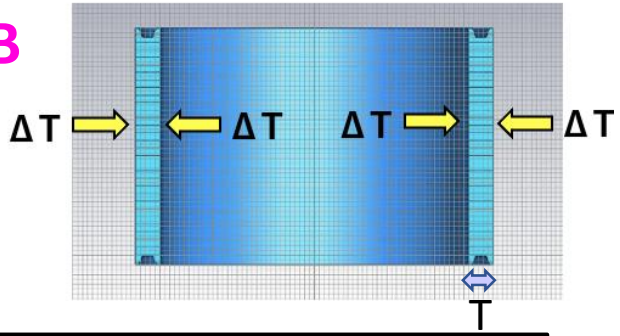
Check of different ceramic material by CST

KEK

The RF simulation has been done by FNAL and KEK under the US-Japan science and technology cooperation.



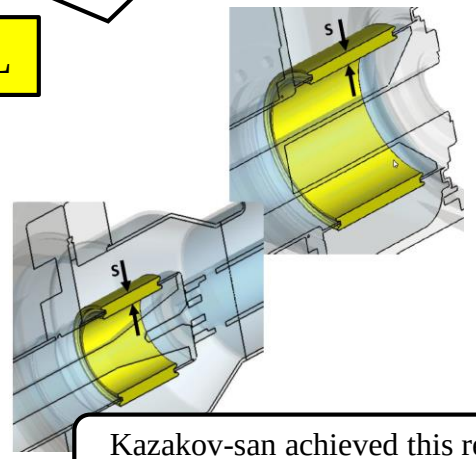




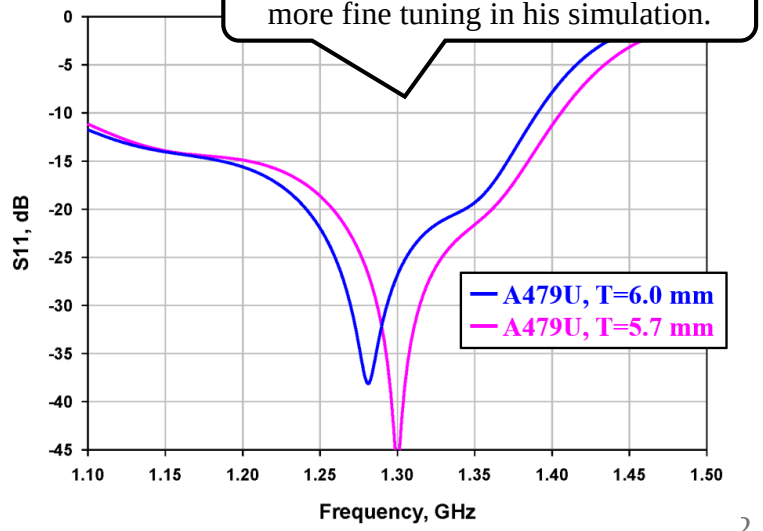
S_{11} is improved by thinner ceramic!

Kazakov-san suggested thinner ceramic!

FNAL

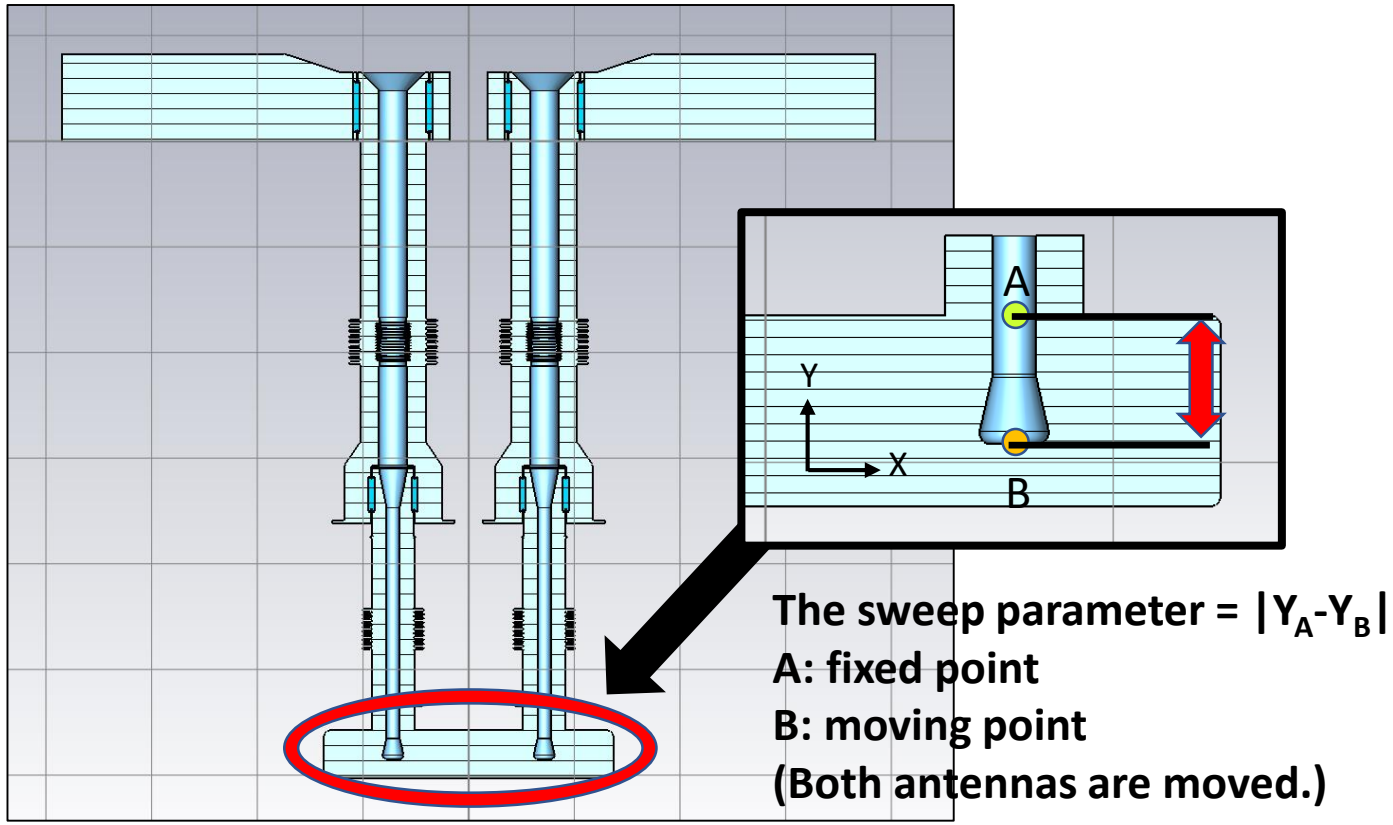


Kazakov-san achieved this result by more fine tuning in his simulation.

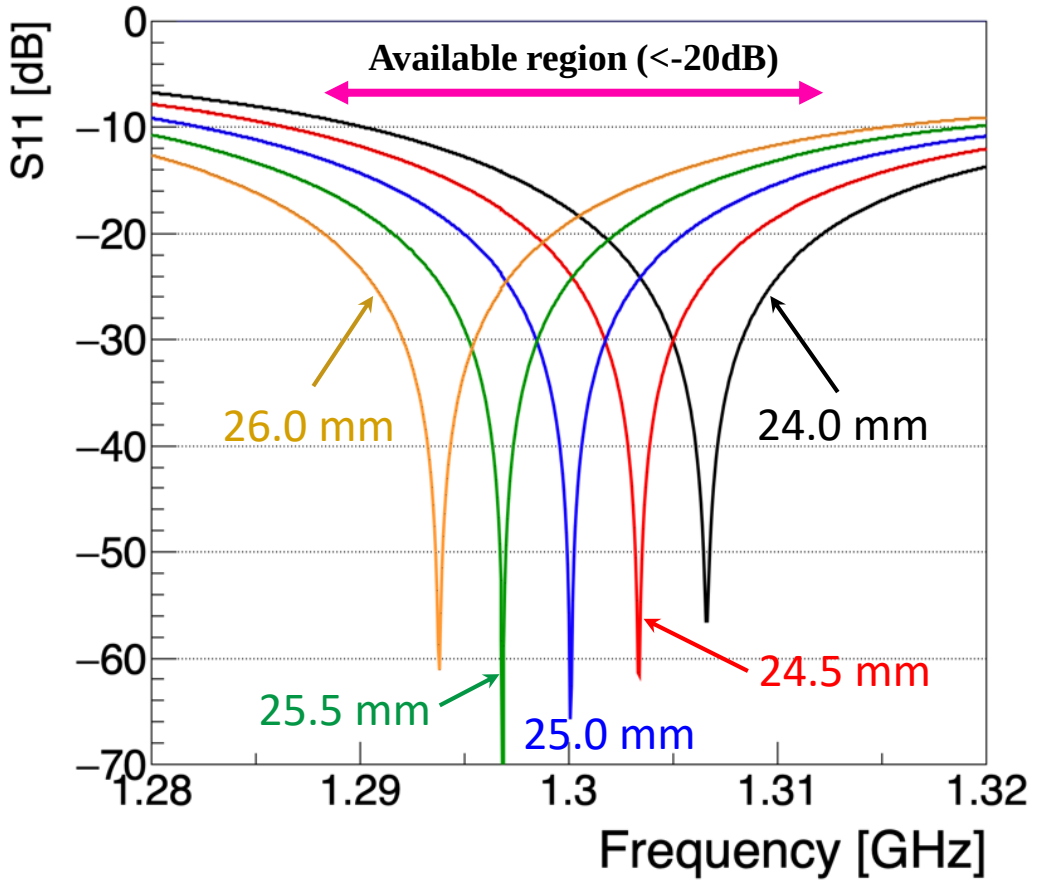


Check of high power test stand by CST

We performed the CST simulation the test stand model as below.



The sweep parameter = $|Y_A - Y_B|$
A: fixed point
B: moving point
(Both antennas are moved.)



- S11 value was better than -20 dB at 1.3 GHz in the case that the parameter is 24.5 – 25.5 mm.
- The amount that we can move Bellows is +-10 mm → ok.

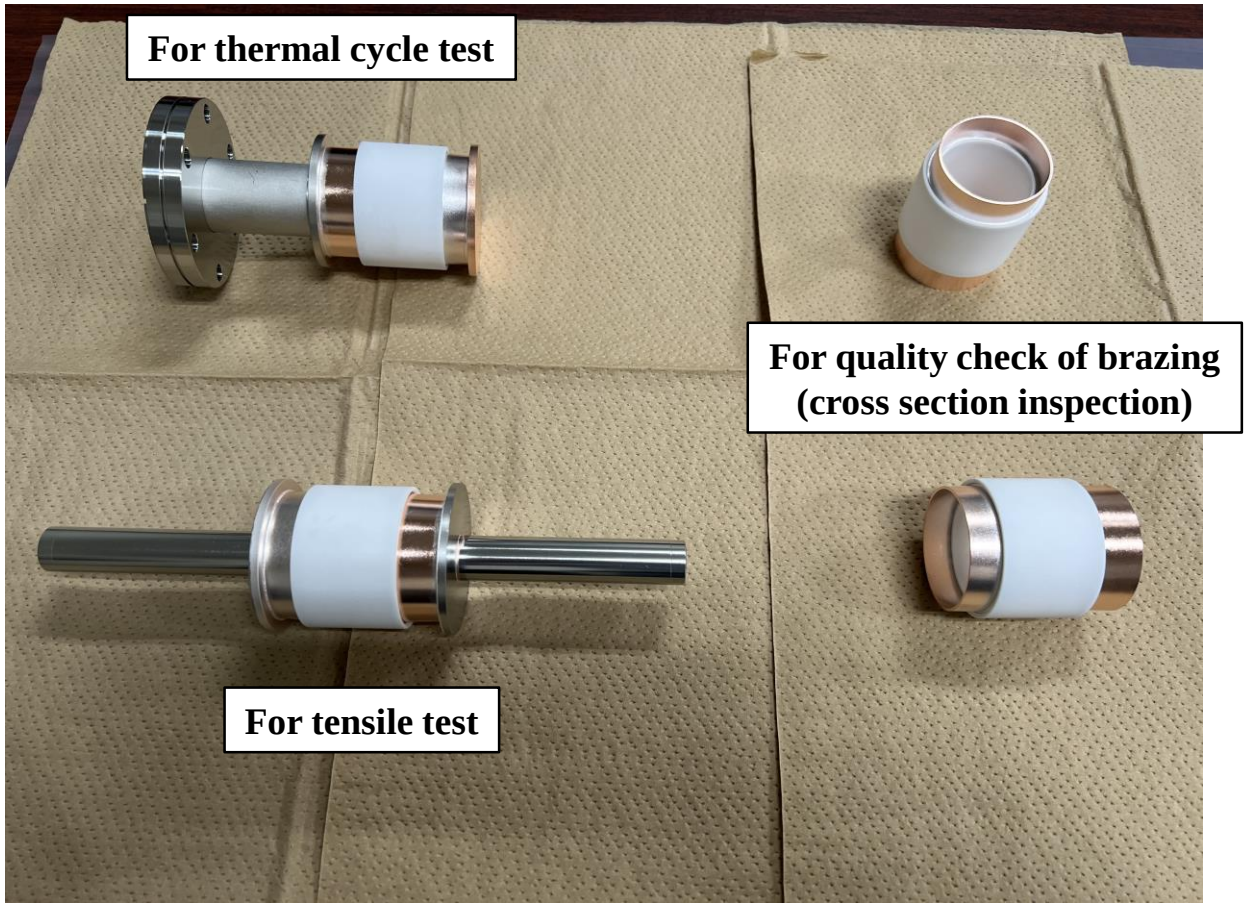
Quality control/assurance of each process/item

We are thinking of the following tests as quality control/assurance before production of power coupler.

Process	Item to be checked	Content
Brazing	Brazing test (cold/warm)	Brazing between A479U and copper sleeve at 1000℃ w/ H_2 gas Cut model to be made for visual inspection
	Thermal cycle test (only cold)	Brazed ceramic-copper sample to be cyclically tested from RT to 80 K
	Tensile test (cold/warm)	Mechanical stiffness to be checked by pulling grippers
TiN coating	TiN coating test (cold/warm)	• Thickness measurement • SEY to be checked after TiN coating @KEK (some ceramic samples to be installed) • Before/after heat treatment @800℃ • Depth profile of Titanium and Nitrogen by XPS (?)
Copper plating	RRR measurement at various thickness	Copper plating condition to be established by RRR measurement (@KEK) and EBSD/EPMA before/after heat treatment @800℃
	Mechanical property check	• Adherence test after HT • Bending test after HT • Ultrasonic rinsing after HT
Bellows	Lifetime test	• Expansion-shrink cycle test (several thousand times)

Cold ceramic samples produced for quality check

- We will perform some quality check using ceramic samples.
- Warm ceramic samples are under production (delivery in Aug).
- TiN coating test is under preparation.

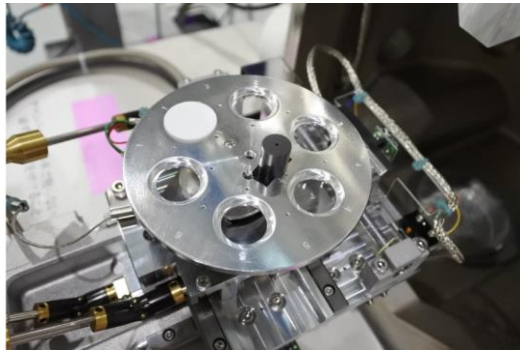


Courtesy of CETD

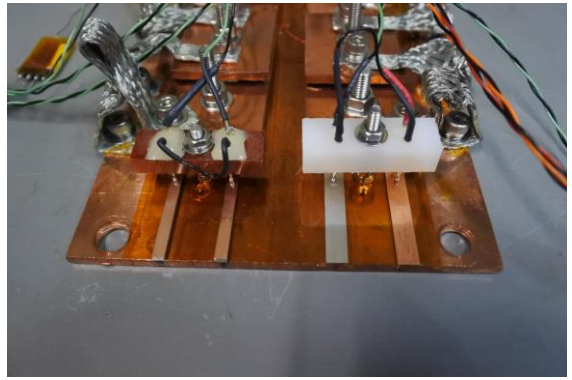
Plan of Quality Check in FY2024

We are planning the following tests as quality control/assurance before production of power coupler .

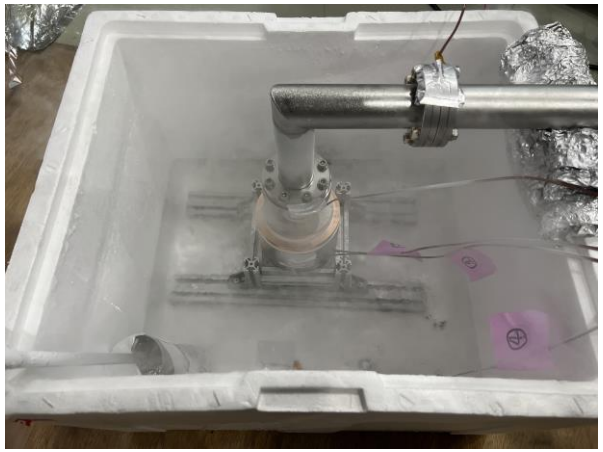
SEY measurement to check TiN coating



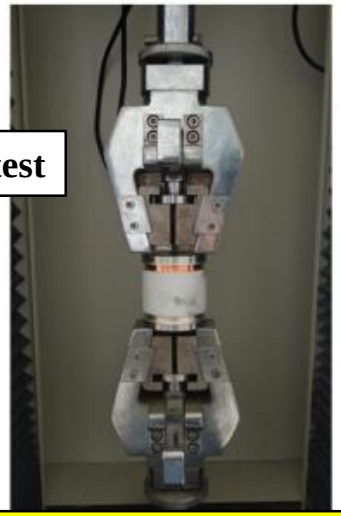
RRR measurement to check copper plating



Thermal cycle test

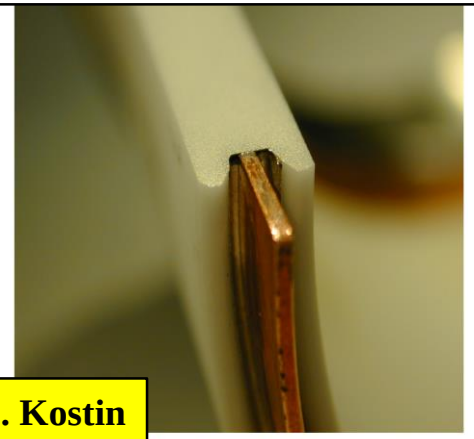


Tensile test



Z-Y, Ma, et al., PRAB 25, 113501 (2022)

Cutting mock-up for check of brazing



Courtesy of D. Kostin

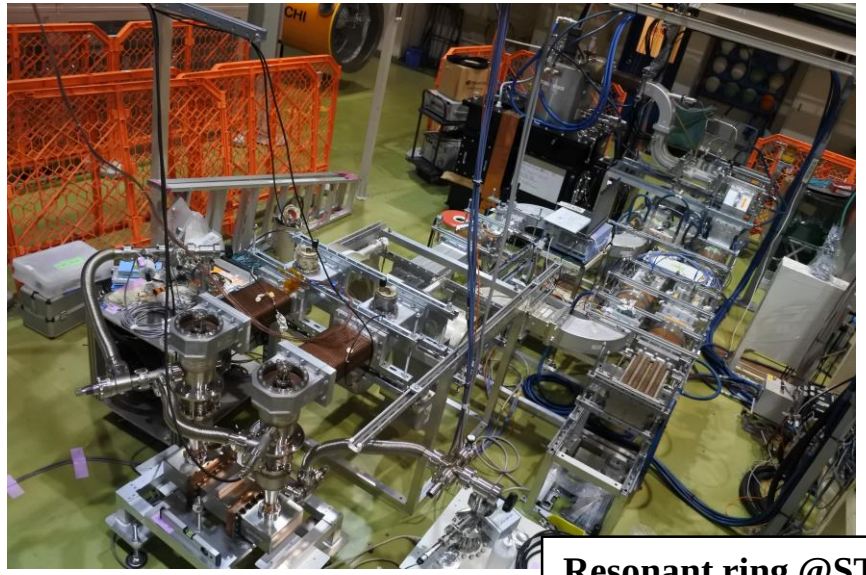
cut-view of the ceramics to copper collar brazing: braze is very regular.

Production/Test schedule of power coupler

We will produce and test eight power couplers in these three years.
If you are interested, please join us (global collaboration is always welcome)!

	FY2024	FY2025	FY2026	FY2027
Production	4 pieces	4 pieces		
Test at resonant ring		4 pieces	4 pieces	
Installation			cold assembly	Warm assembly
Cold test				First cooldown

Large clean room @COI



Resonant ring @STF

Summary

- KEK started the MEXT-ATD program from FY2023.
- Production of one Cryomodule and test in bunker in FY2027.
- We will produce eight power couplers as the E-XFEL type.
- KEK and FNAL have done the RF simulation for this production.
- KEK and DESY have updated the license agreement.
- We have completed the detailed drawings and the specification document.
- KEK is performing the quality check related to power coupler.
- We will start high power test in STF from FY2025.

Thank you very much for your attention

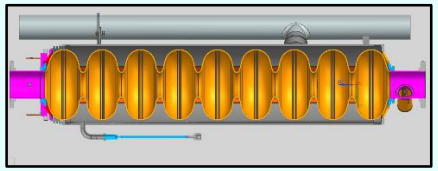
Thank you very much for global collaboration

Backup slides

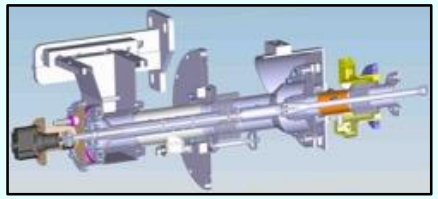
Each Step of MEXT-ATD program (JFY2023-2027)

Production

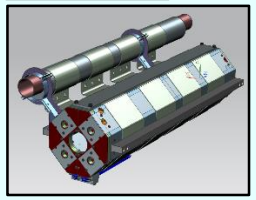
L-band SC 9-cell cavity



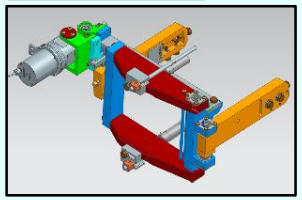
Power coupler



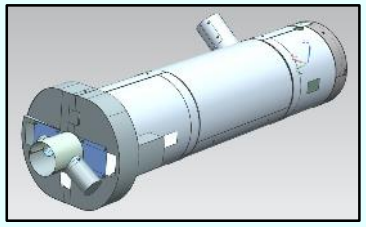
SCQ magnet



Frequency tuner



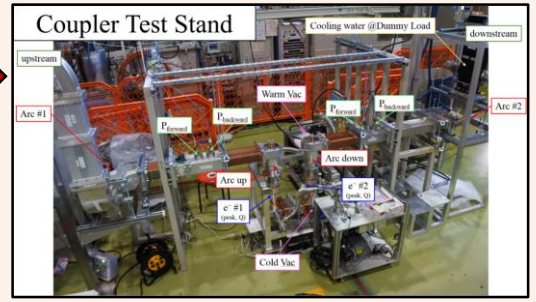
Magnetic shield



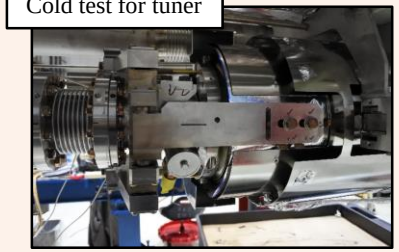
Component Test

Vertical test for cavity

High power test for coupler



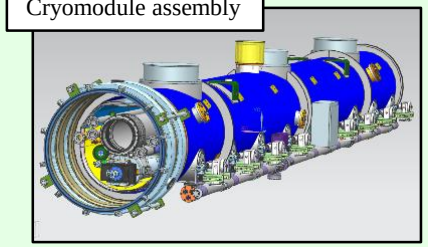
Cold test for tuner



Installation

Demagnetization of cryo-vessel

Cryomodule assembly

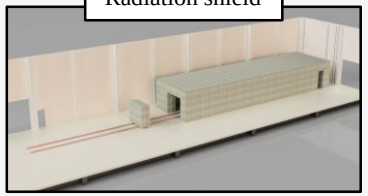


Preparation

Cryogenic

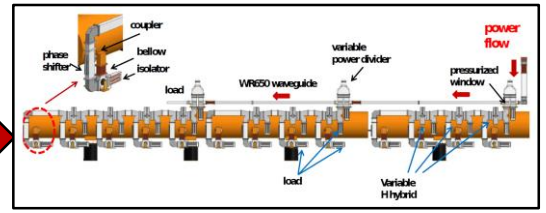
CM assembly hall

Radiation shield

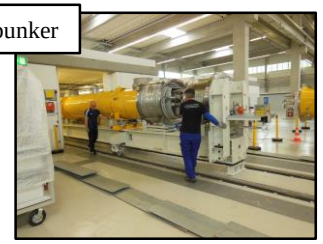


CM Test

Waveguide assembly

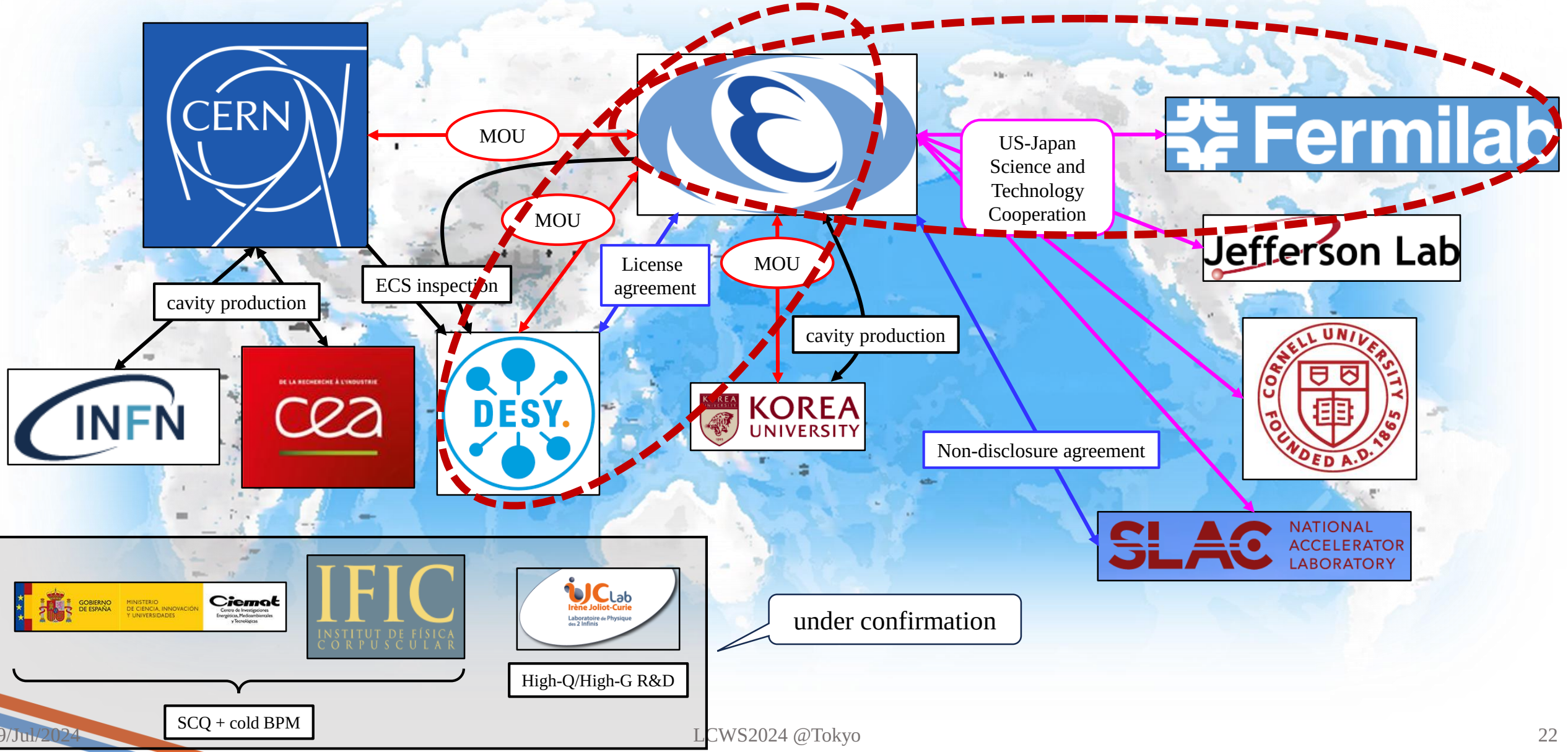


Installation into bunker



Cold test at bunker

Global collaboration on SRF for MEXT-ATD/ITN



Progress of License Agreement (LA) and NDA updates for ITN

(based on the License Agreement between DESY and KEK, and NDA between SLAC and KEK)

License agreement between DESY and KEK

Legal process

Licensed

Sub-Licensed
b/w labs
legally established

DESY
(for Cavity/coupler)

LA updated
(Feb. 2024)

DOE / SLAC
(for CM)

NDA Addendum
in progress

KEK

Required for ITN program

ITN
(virtual organization)

Lab-Lab agreements enabled

EU

CERN
DESY
CEA
INFN
IJCLab

AMs

DOE
(SLAC,
FNAL,
JLab,
Cornell)

AS

KEK
Korea U.
PAL

Written Oath

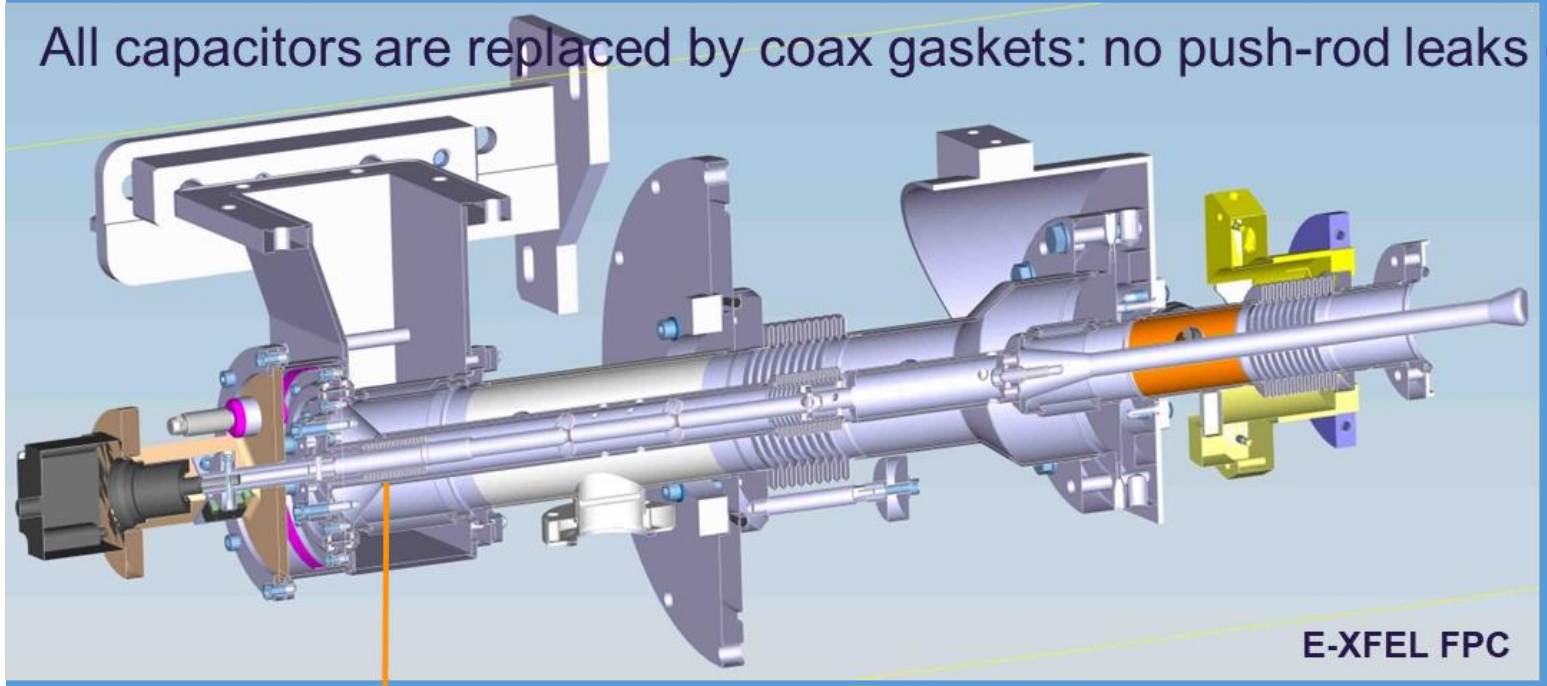
submitted from
Third-Parties:
(contractors)

Sub-license agreement is under progress
for CERN-KEK and KU-KEK.

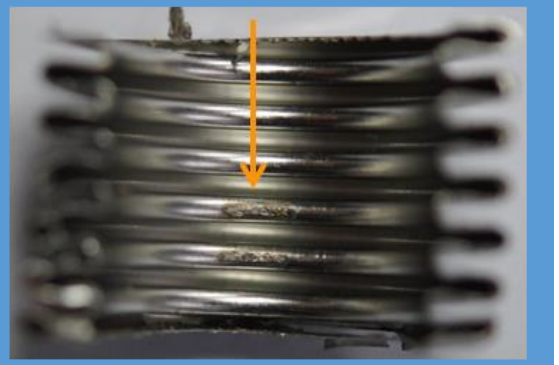
E-XFEL FPC: Coax Gaskets

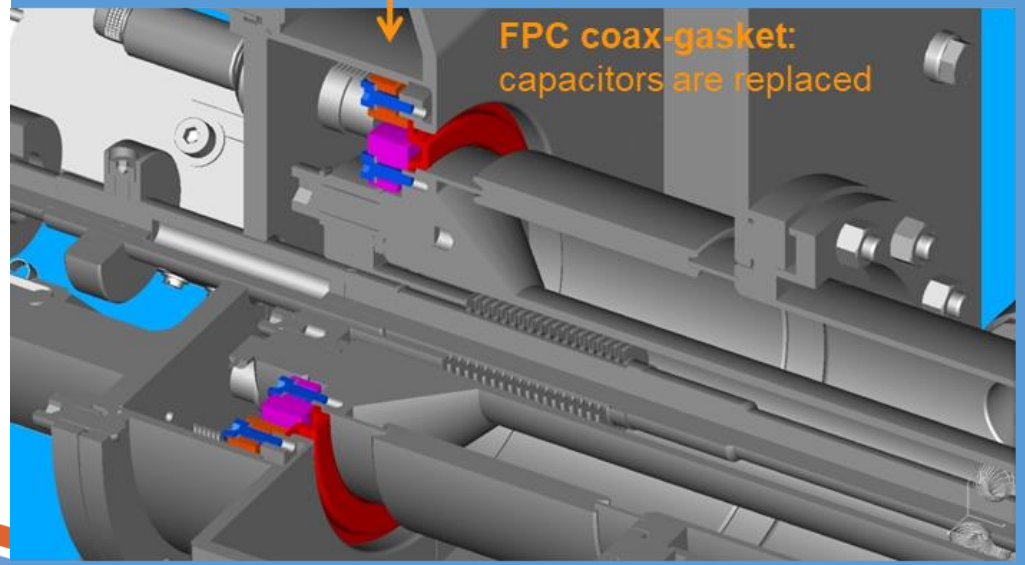
All capacitors are replaced by coax gaskets: no push-rod leaks (RF is ON) since then

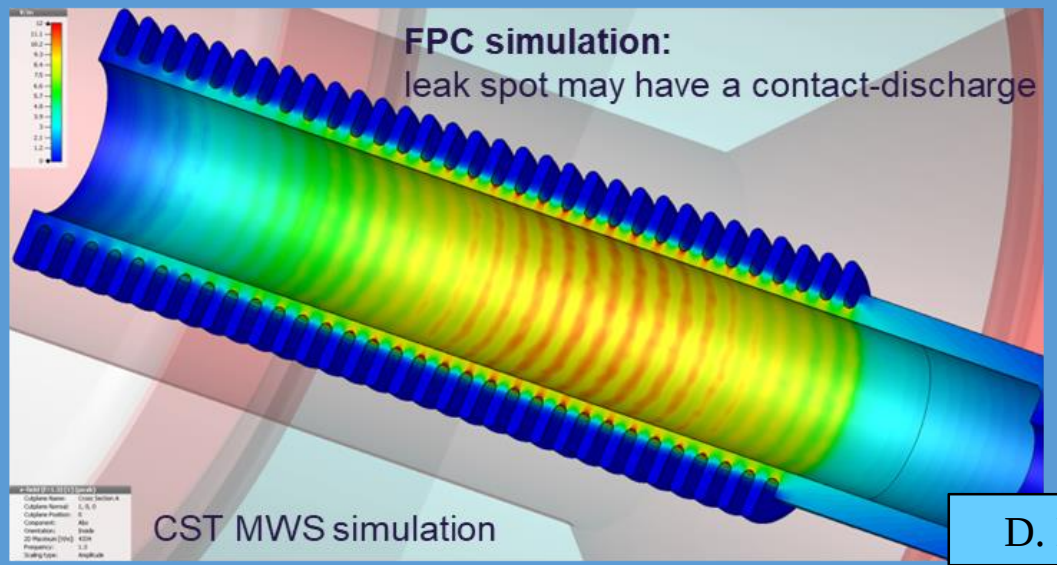
problem solved



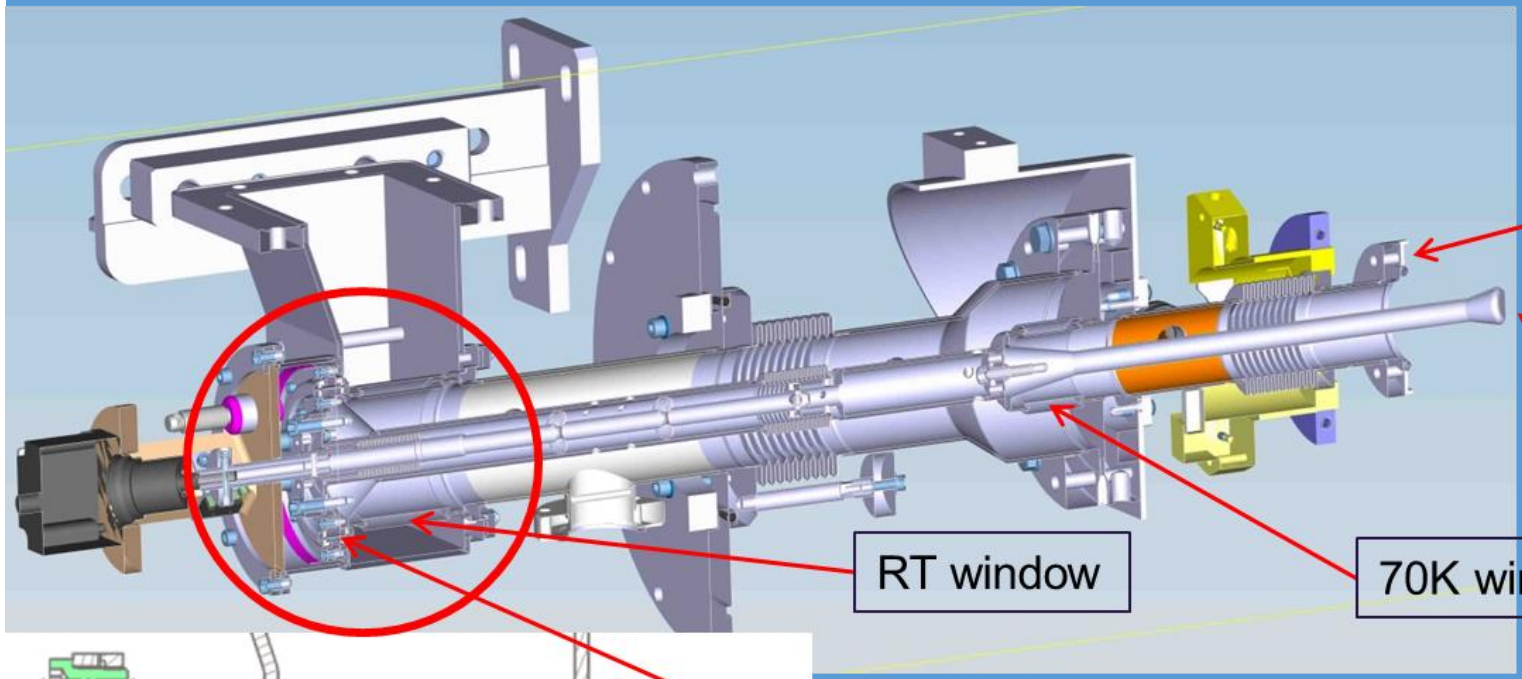
FPC push-rod leak:
leak spot discovered

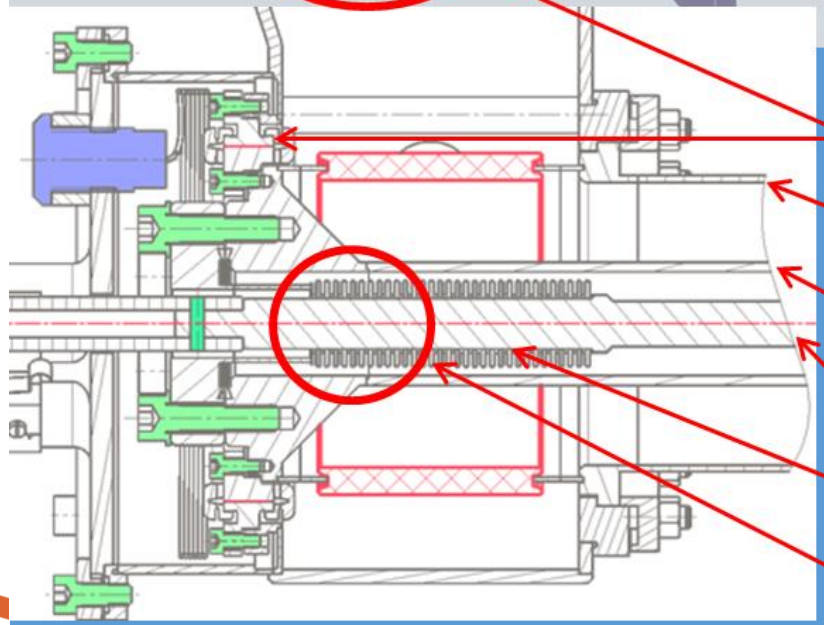


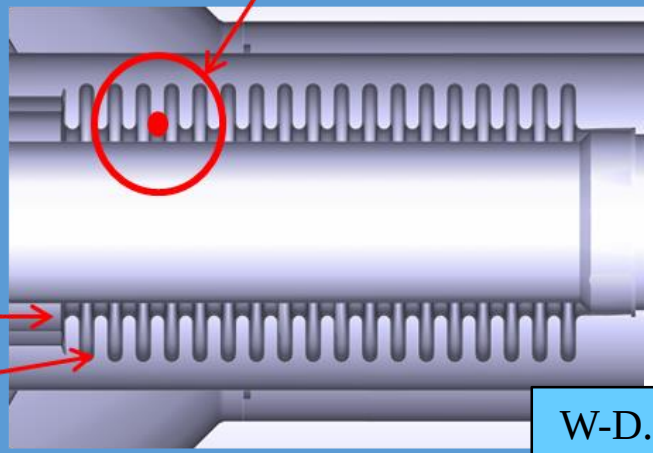




Pushrod leak, location





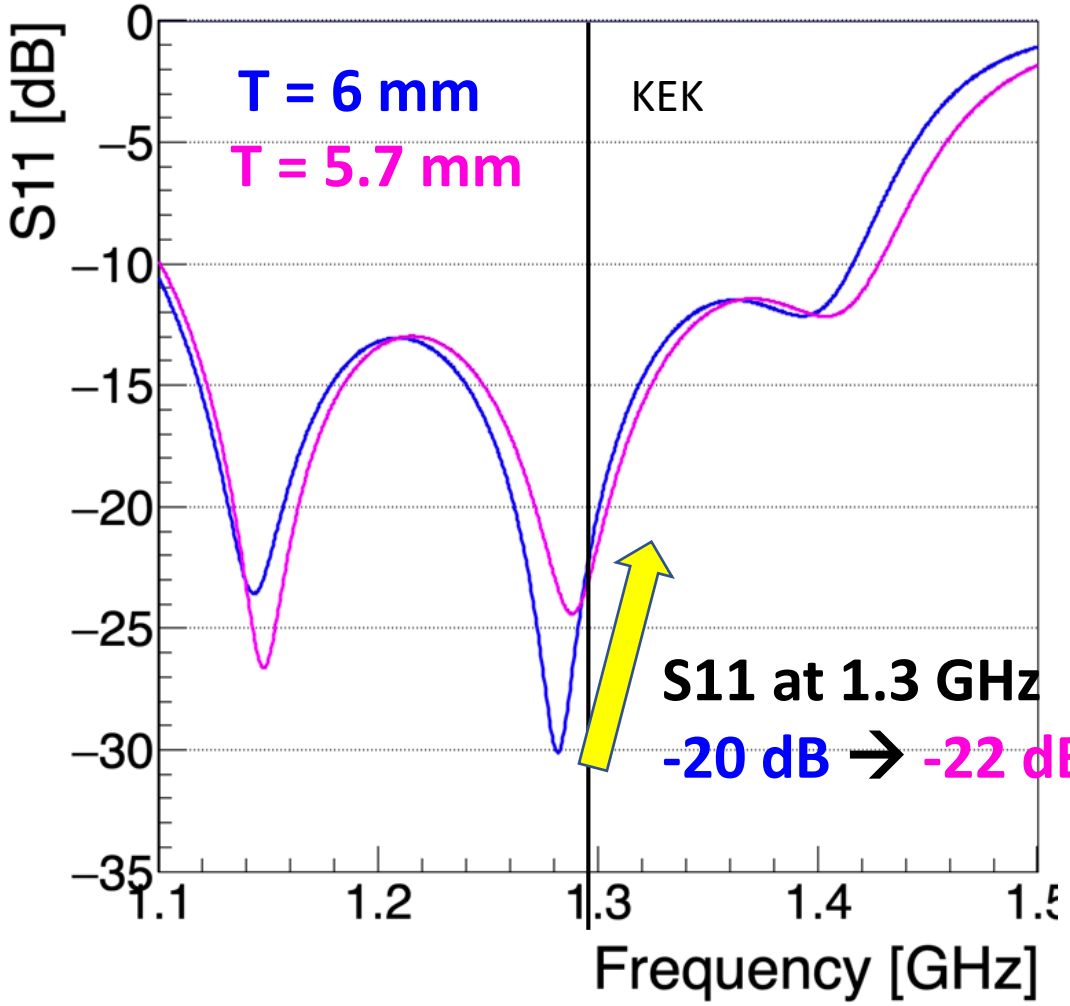


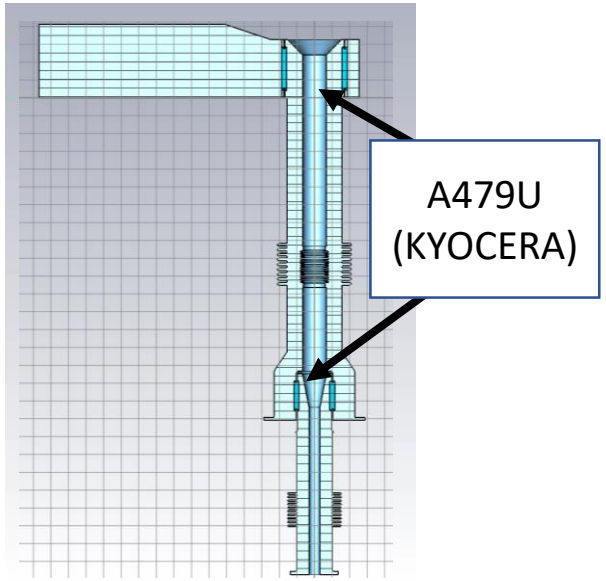
Production/Test schedule of power coupler

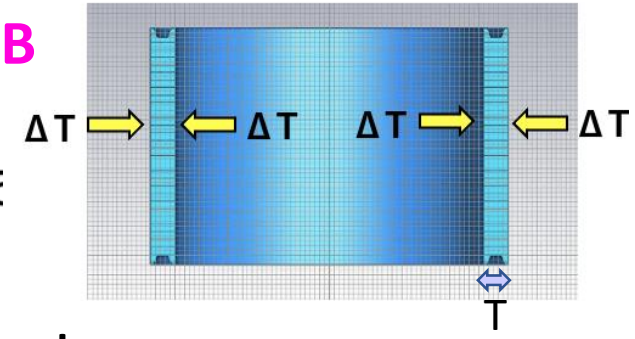
Last update: 17/Jun/2024	FY2024									FY2025													FY2026													FY2027															
	CY2024									CY2025													CY2026													CY2027															CY2028		
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Detailed design consideration Preparation for specification document																																																	
Contract phase as international bidding for 1st batch																																																	
Delivery of all cold/warm ceramic w/ TiN coating																																																	
Real production 1st batch (4 couplers)																																																	
Contract phase as international bidding for 2nd batch																																																	
Real production 2nd batch (4 couplers)																																																	
RF conditioning at resonant ring																																																	
Design, Production of jigs to install into CM																																																	
Cold coupler assembly																																																	
Warm coupler assembly																																																	
High power operation at CM																																																	
Cavity string																																																	
CM production																																																	
CM assembly																																																	
Completion inspection (CM+Cryogenic system)																																																	
1st cooldown test (low power)																																																	
2nd cooldown test (high power)																																																	

Check of different ceramic material by CST

The RF simulation has been done by FNAL and KEK under the US-Japan science and technology cooperation.

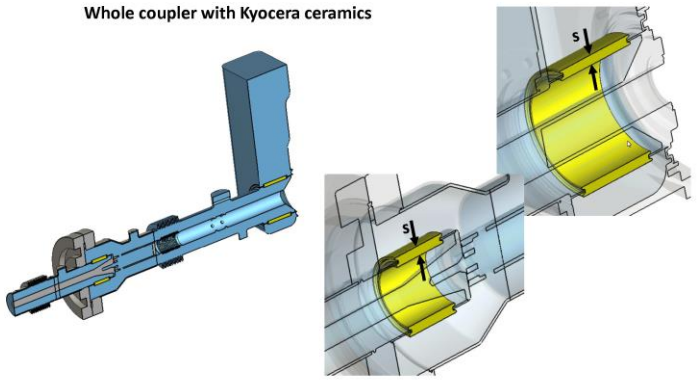


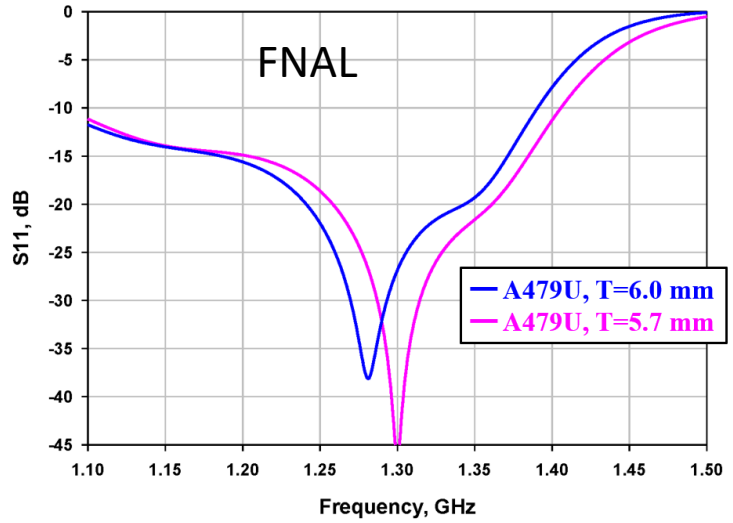




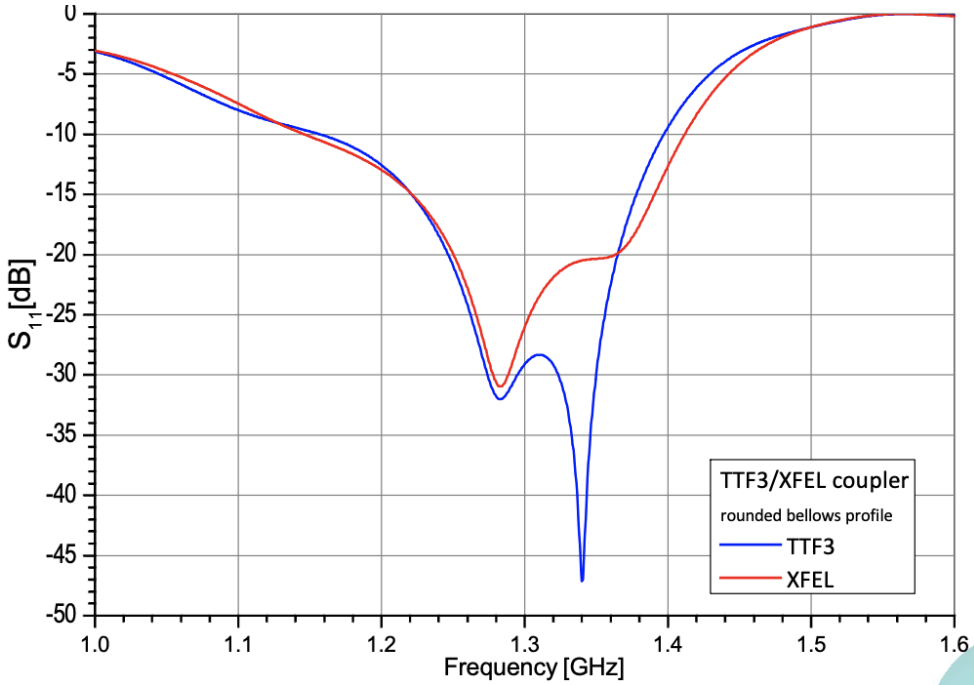
Improved …

Kazakov-san suggested thinner ceramic!



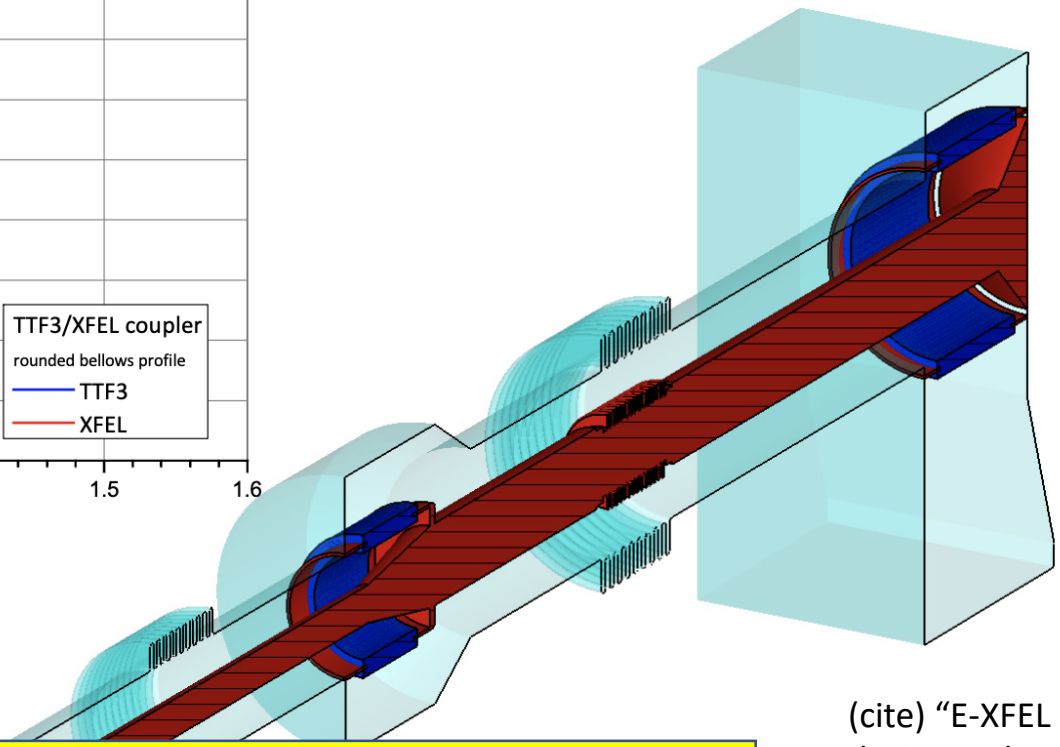


Simulation result of DESY (E-XFEL FPC)



full coupler model simulation yields the S-matrix data and is a final proof of the RF design. RF fields/voltages data are the simulation goal as well.

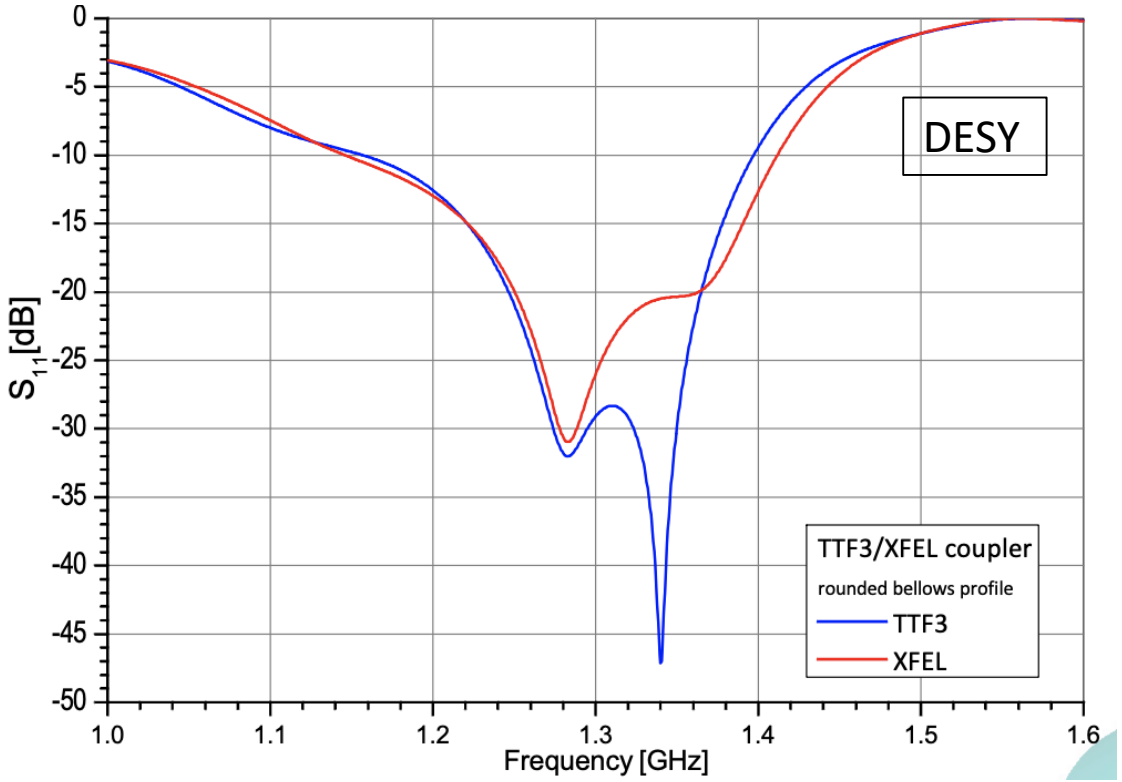
Complete Input Coupler Simulation

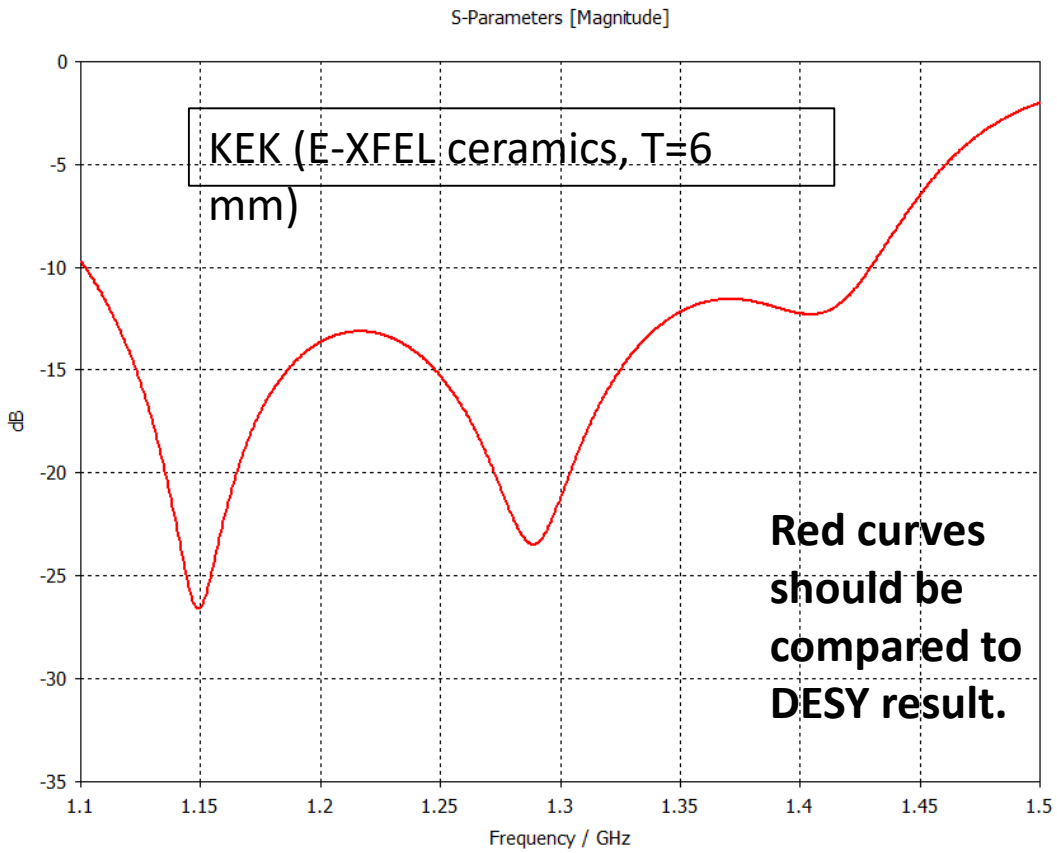


(cite) "E-XFEL input coupler design and simulations", D. Kostin, 21.11.2016

- Frequency at peak value is at 1.29 GHz.
- S11 was -26 dB at 1.3 GHz.
- Two peak does not appear.

Comparison of DESY result to KEK result (E-XFEL ceramics)





(cite) "E-XFEL input coupler design and simulations", D. Kostin, 21.11.2016

- **Frequency at optimum S11 value is exactly same.**
- **Best S11 value of DESY is -31 dB, while that of KEK is -24 dB.**
- **S11 value at 1.3 GHz of DESY (-26 dB) is better than that of KEK (-21 dB).**
- **Two peak appear only in KEK result.**