High Power Input Couplers and HOM Couplers for Superconducting Cavities

Eiji KAKO (KEK, Japan)

Part-I ; INTRODUCTION

Part-II ; INPUT COUPLERS

Part-III ; HOM COUPLERS

Part - I

INTRODUCTION

References (1)

1. SRF2011 at Chicago;
   Tutorial by W.-D. Moeller (DESY),
   "Design and Fabrication Issues of High Power- and Higher Order Modes- Couplers for SC Cavities"

2. SRF2009 at Berlin;
   Tutorial by S. Noguchi (KEK),
   "Design and Fabrication Issues of High Power and Higher Order Modes Couplers for SC Cavities"

References (2)

3. Textbook;

"RF Superconductivity for Accelerators",
by H. Padamsee, J. Knobloch and T. Hays

18. Input Power Couplers and Windows

16. Higher Order Mode Couplers

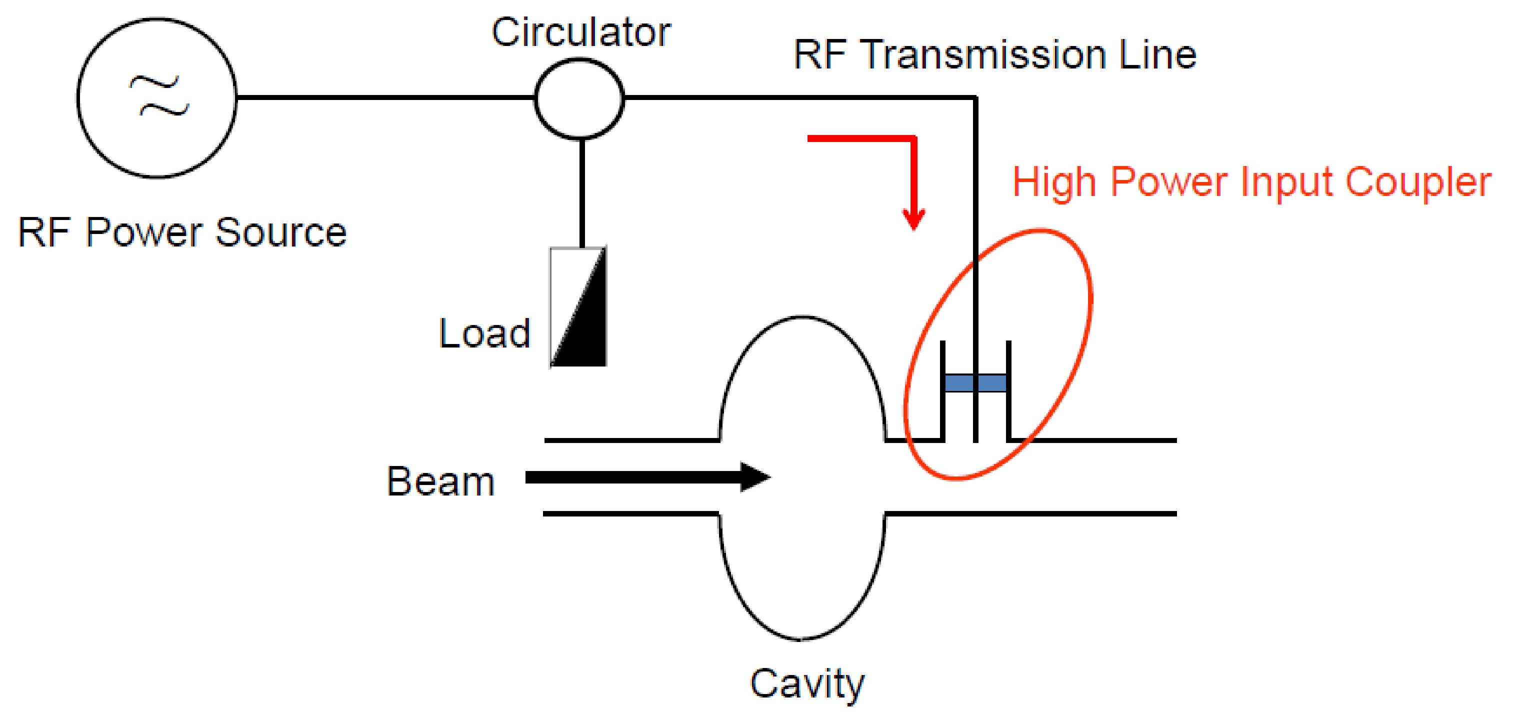
4. TTC CW-SRF Workshop 2013' at Cornell;

http://www.lepp.cornell.edu/Events/TTCWorkshop/

. CW Power Couplers

. HOM Absorber

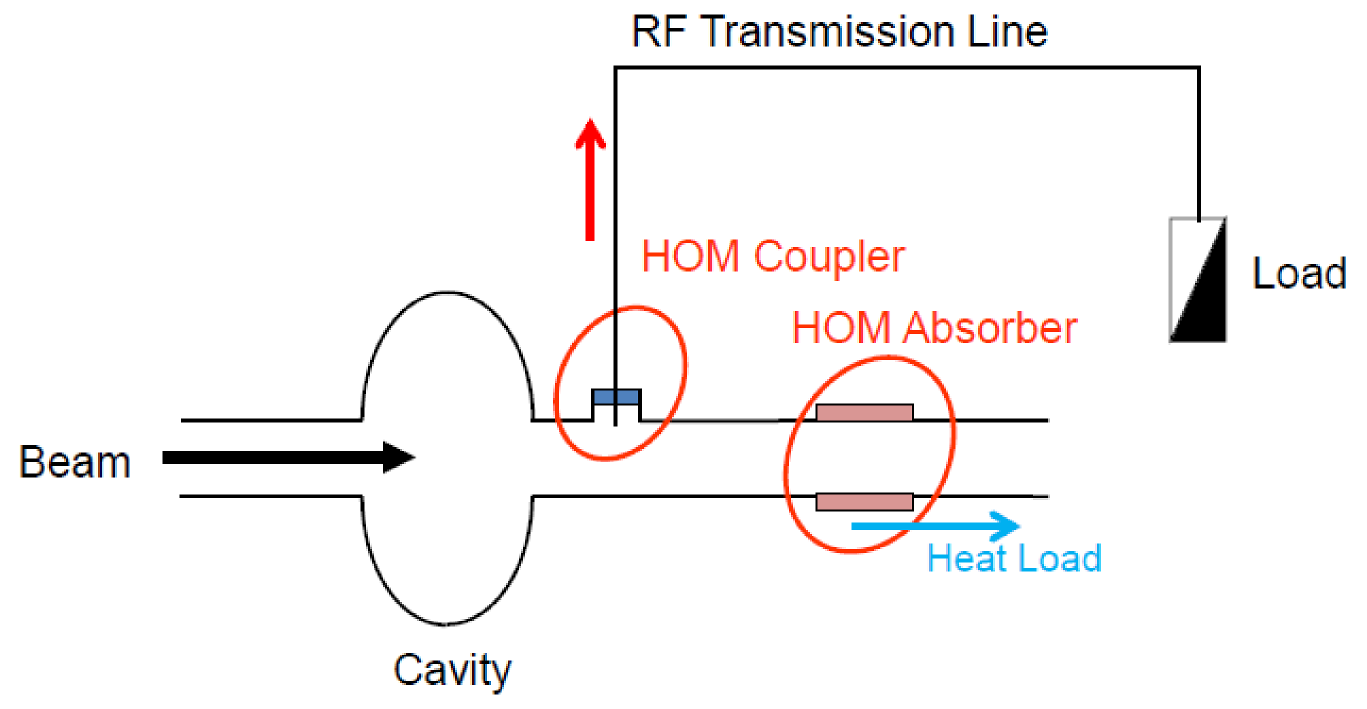
Introduction (1)



The primary role of the input coupler:

to transfer RF power from the generator to the cavity and to the beam.

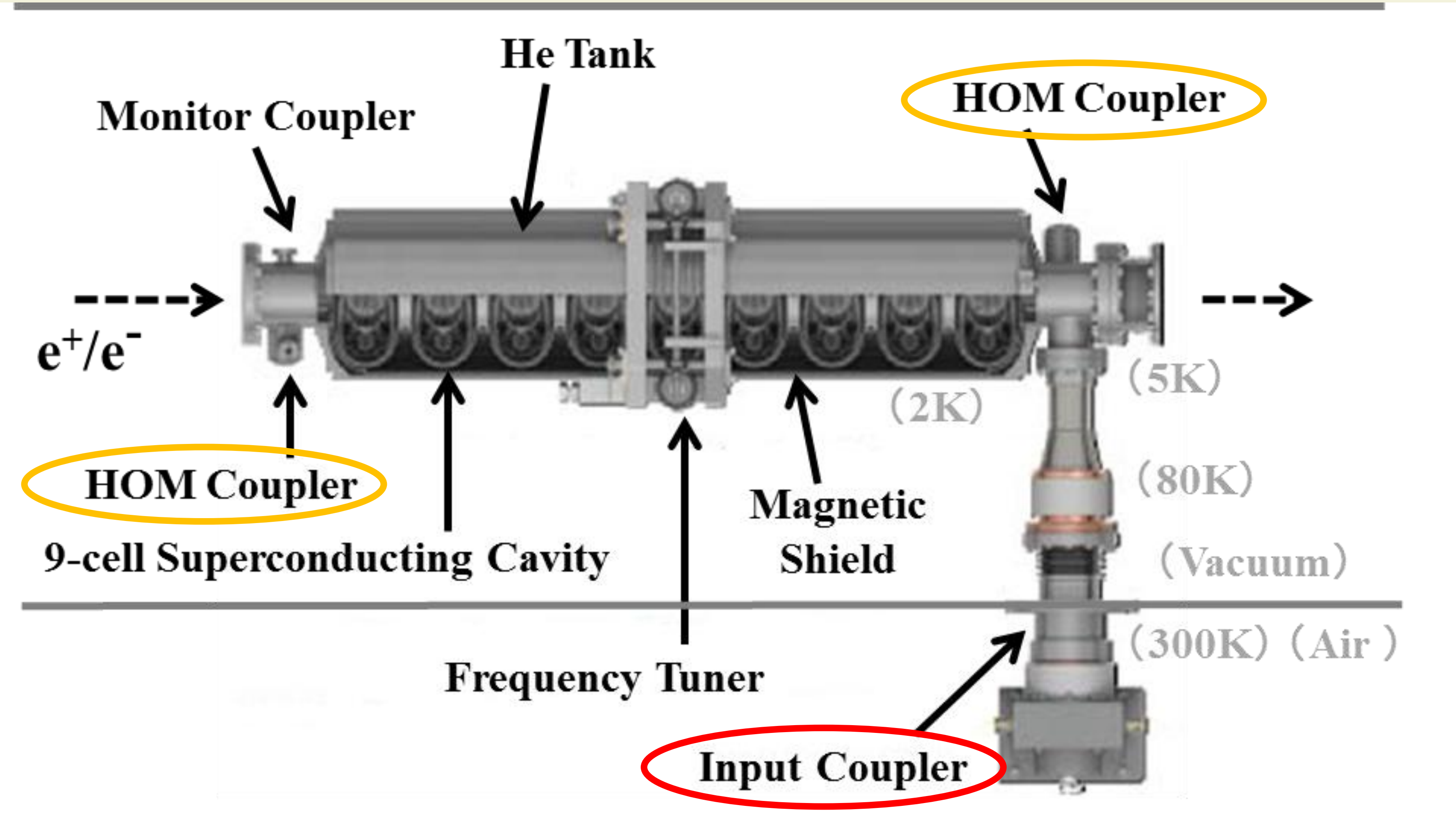
Introduction (2)



The primary role of the HOM coupler:

to remove beam induced power from the cavity in order to avoid resonant buildup of beam induced voltage, and in order to avoid beam instabilities.

Introduction (3)



Cavity package of STF 9-cell cavity at KEK for ILC

Introduction (4)

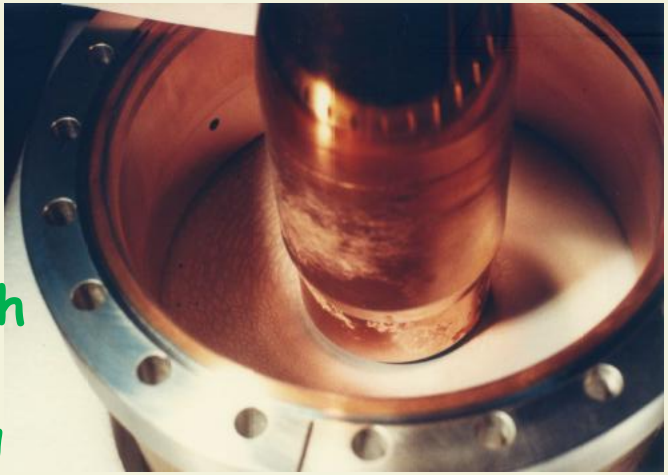
Importance of a Harmonized System Design:

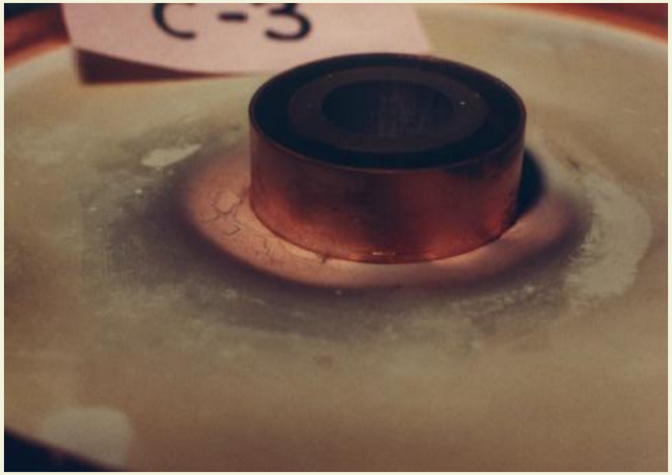
- Only SC cavity is not a special component.
- A harmonized design of a whole cavity package including an input coupler, HOM couplers, a frequency tuner, magnetic shields and a He-tank is a most crucial task for a stable operation in cryomodule with beam.
- Especially, input couplers and HOM couplers are critical components in SC cavity system.

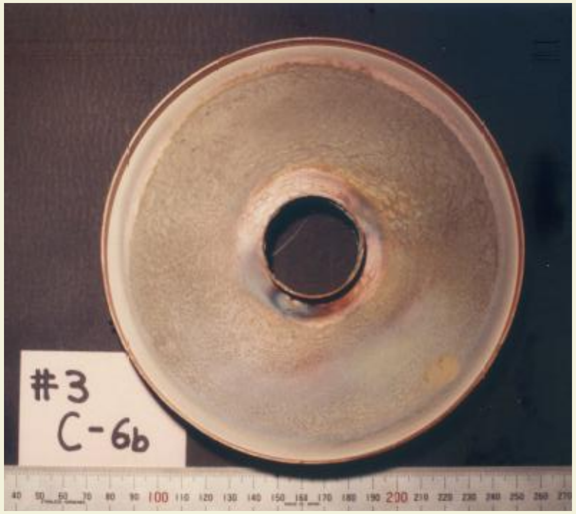
My old experience on Input Coupler

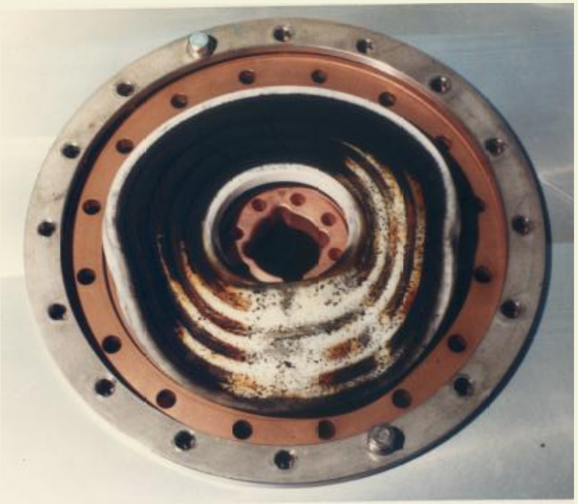
About 25 years ago in TRISTAN at KEK;

508MHz,
CW 50kW
Input coupler with
one warm window
and water cooling









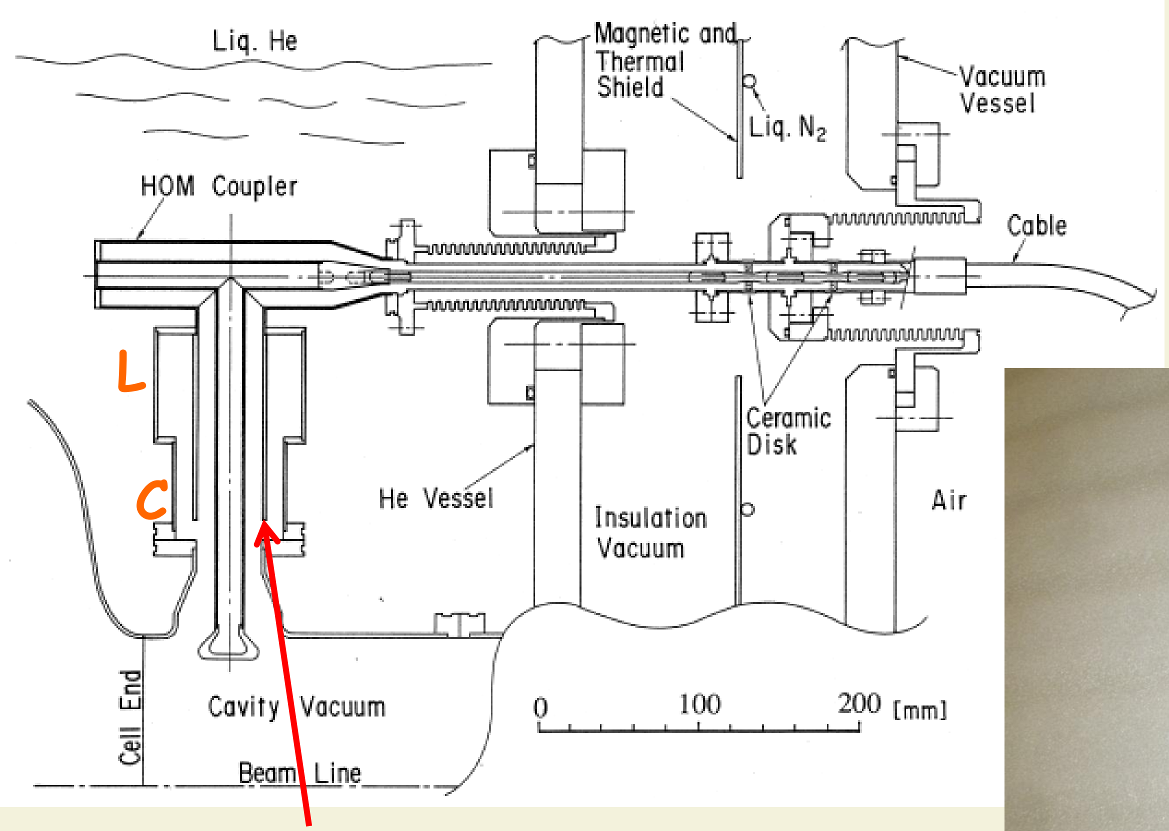
In the initial stage,
no TiN coating
no Arc sensor

⬇

Importance of
TiN coating and
Interlock system

My old experience on HOM Coupler

About 25 years ago in TRISTAN at KEK;



508MHz,
coaxial antenna type,
coupled E-field,
HOM coupler
made of niobium

- heating due to multipacting
- not an efficient cooling
- shift of a rejection frequency

Part - II

High Power Input Couplers

High Power Input Coupler

The input coupler:

1. has to transfer RF power from the generator to the cavity and to the beam.
2. must provide a match between the generator impedance and the combined impedance of the cavity-beam system, so as to minimize the wasted reflect power.
3. may need to be an adjustable coupling.

Contents

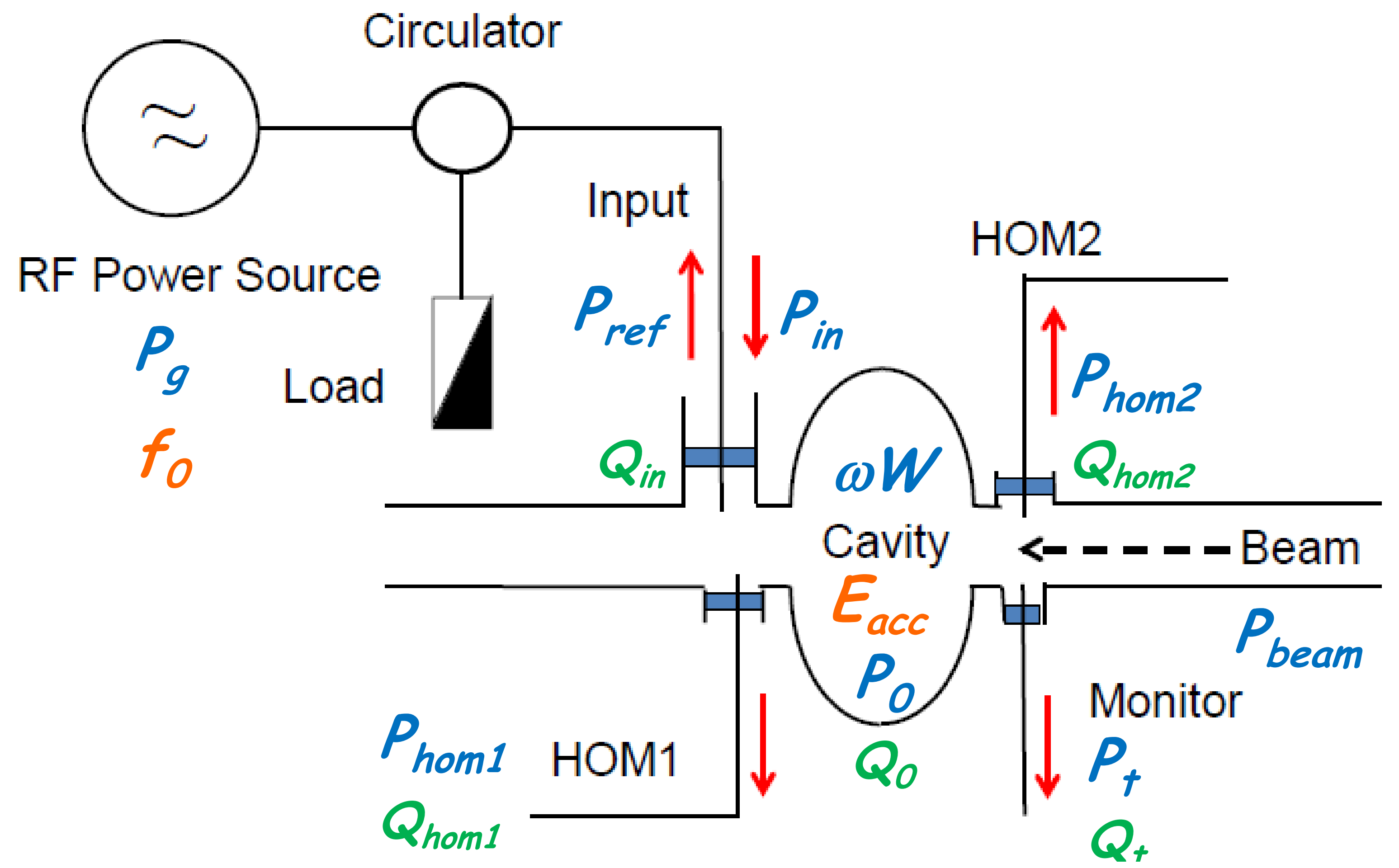
1. Coupling to cavity
2. From design to operation
3. Choice of Coupler Type
4. Design Issues
5. Fabrication Issues
6. RF Conditioning Issues
7. State of the Arts

High Power Input Coupler (1)

Coupling to cavity :

- Circuit for cavity with beam
- Useful equations on coupling
- Optimum coupling with beam
- Calculation of coupling by HFSS
- Measurement of coupling by N.A.

Circuit for cavity with beam



- $P_{in} - P_{ref} = P_0 + P_{beam} + P_t + P_{hom1} + P_{hom2}$
- $Q_{in} \ll Q_0 \ll Q_t, Q_{hom1}, Q_{hom2}$

Useful equations on coupling (1)

Accelerating gradient (E_{acc}) :

$$E_{acc} = \frac{\sqrt{R/Q}}{L_{cavity}} \sqrt{\omega W} = Z_{cavity} \sqrt{P_0 \cdot Q_0}$$

Cavity loss (P_0) :

$$P_0 = \frac{\omega W}{Q_0}$$

Beam power (P_{beam}) :

$$P_{beam} = I_{beam} \cdot V_C \cdot \cos\phi$$
$$= I_{beam} \cdot E_{acc} \cdot L_{cavity} \cdot \cos\phi$$

R/Q : Impedance of accelerating mode
L_{cavity} : Cavity effective length
ωW : Stored energy inside a cavity
Z_{cavity} : Constant parameter
Q_0 : Cavity unloaded Q
V_C : Cavity accelerating voltage
I_{beam} : Beam current
ϕ : Beam phase

Useful equations on coupling (2)

Generator RF power (P_g) :

$$P_g = P_0 + P_{beam}$$

- $P_{ref} \sim 0$ (matching condition)
- $P_g = P_{in}$ (no transmission loss)
- $P_0 + P_{beam} >> P_t , P_{hom1} , P_{hom2}$

Coupling constant (β) :

$$\beta = \frac{P_g}{P_0} = 1 + \frac{P_{beam}}{P_0} \cong \frac{Q_0}{Q_L}$$

$$\frac{1}{Q_L} = \frac{1}{Q_{in}} + \frac{1}{Q_0} + \frac{1}{Q_t} + \frac{1}{Q_{hom1}} + \frac{1}{Q_{hom2}}$$

- $Q_{in} << Q_0 << Q_t , Q_{hom1} , Q_{hom2}$

$$Q_L \cong Q_{in}$$

Loaded Q (Q_L) :

$$Q_L = \frac{Q_0 \cdot P_0}{P_{beam}} \cong \frac{Q_0}{\beta}$$

E_{acc} = 30 MV/m, L_{cavity} = 1.0 m, I_{beam} = 10 mA

P_0 = 100 W, Q_0 = 1.0×10^{10}

→ P_{beam} = 300 kW, Q_{in} = 3.3×10^6, β = 3,000

Useful equations on coupling (3)

Optimum coupling ($Q_L \sim Q_{in} << Q_0$) :

$$Q_{in} \cong \frac{V_c}{(R/Q)\cdot I_{beam}\cdot\cos\phi}$$

Required RF power under matching condition ($P_{ref} \sim 0$) :

$$P_g = \frac{V_c^2}{4\cdot(R/Q)\cdot Q_L}\left[1+\frac{I_{beam}\cdot(R/Q)\cdot Q_L\cdot\cos\phi}{V_c}\right]$$

In case of $I_{beam} \sim 0$;

$$E_{acc} = \frac{\sqrt{R/Q}}{L_{cavity}}\cdot\sqrt{4\cdot P_g\cdot Q_L} = Z_{cavity}\sqrt{P_t\cdot Q_t}$$

Optimum input coupling with beam

$$\text{Optimum coupling ;}\quad \frac{1}{Q_{in}} = \frac{1}{Q_0}\left(1 + \frac{P_{beam}}{P_0}\right) = \frac{1}{Q_0} + \frac{1}{Q_{beam}}$$

$P_{beam} >> P_0$; $Q_{in} = Q_{beam}$, depends on beam current

adjustable coupling may be useful.

$Q_{in} \leq 10^7$ is desireble for better RF control.

(boarder bandwidth)

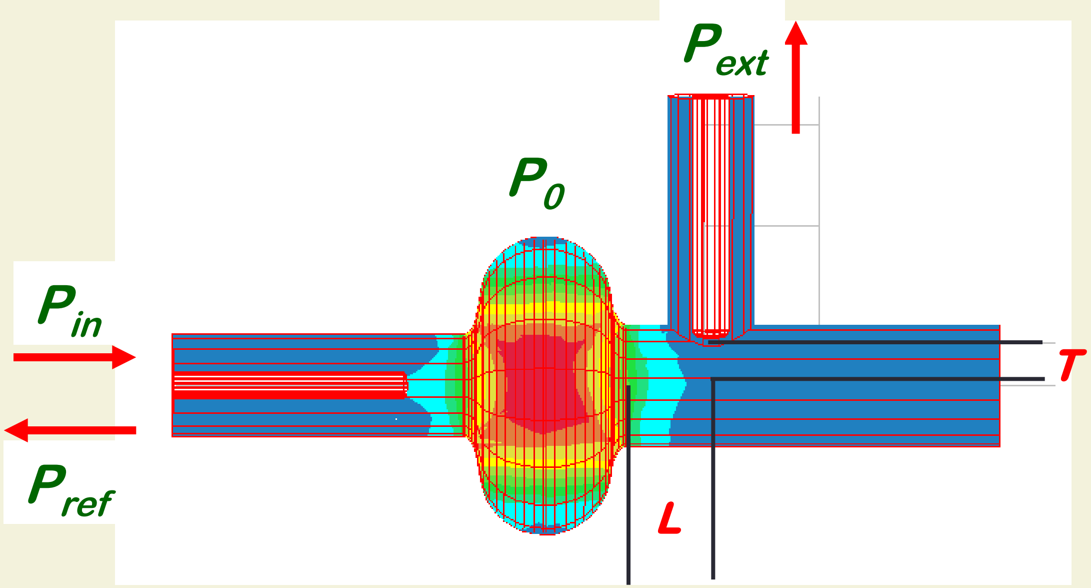
$$\Delta f = \frac{f}{2Q_{in}}$$

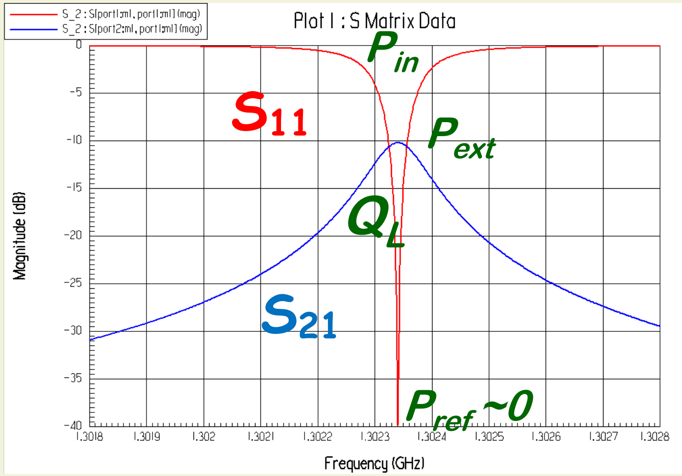
f = 1.3 GHz

Q_{in} = 3 × 10^7

Δf = 22 Hz

Calculation of Coupling by HFSS





$$P_o = P_{in} - P_{ref} - P_{ext}$$

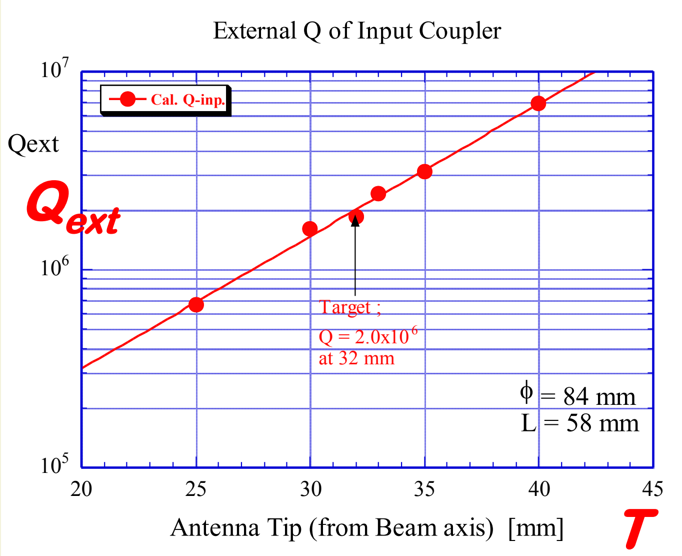
$$\beta^* = \frac{1 \pm \sqrt{P_{ref}/P_{in}}}{1 \mp \sqrt{P_{ref}/P_{in}}}$$

$$\beta_{in} = \beta^* \cdot (1 + \beta_{ext})$$

$$\beta_{ext} = P_{ext}/P_o$$

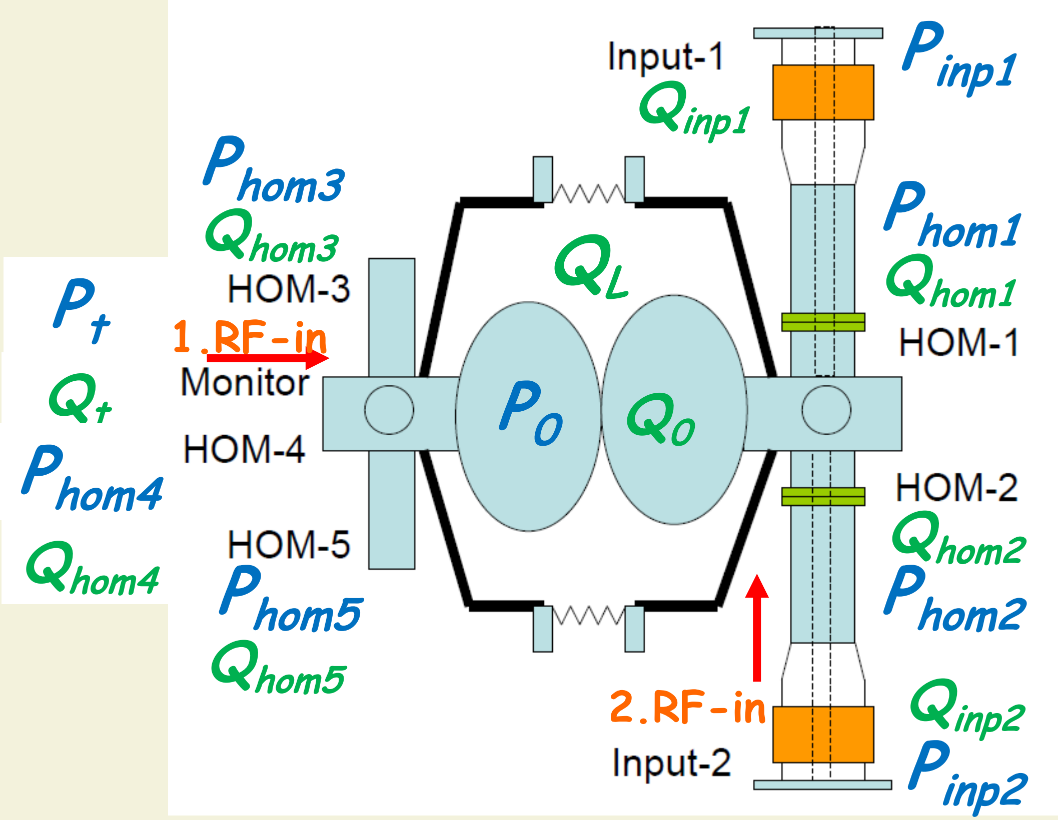
$$Q_o = Q_L \cdot (1 + \beta_{in} + \beta_{ext})$$

$$\boxed{Q_{ext}} = P_o \cdot Q_o / P_{ext}$$



Measurement of Coupling (Q_{ext}) by N.A.

2-cell cavity with 2 input and 5 HOM couplers



$$\frac{1}{Q_L} = \frac{1}{Q_{inp1}} + \frac{1}{Q_{inp2}} + \frac{1}{Q_0} + \frac{1}{Q_t} + \frac{1}{Q_{hom1}} + \frac{1}{Q_{hom2}} + \frac{1}{Q_{hom3}} + \frac{1}{Q_{hom4}} + \frac{1}{Q_{hom5}}$$

$Q_{inp1}, Q_{inp2} << Q_0, Q_t, Q_{hom1}, Q_{hom2}, , ,$

$$\frac{1}{Q_L} \approx \frac{1}{Q_{inp\_1}} + \frac{1}{Q_{inp\_2}}$$

1. RF-in through Monitor;

Q_L, P_{inp1}, P_{inp2}, P_{hom1}, P_{hom2}, ,

$Q_{inp1} \times P_{inp1} = Q_{inp2} \times P_{inp2}$

$$Q_{inp\_1} \approx Q_L \cdot \left(\frac{P_{inp\_2}}{P_{inp\_1}} + 1\right)$$

$$Q_{inp\_2} \approx Q_L \cdot \left(\frac{P_{inp\_1}}{P_{inp\_2}} + 1\right)$$

2. RF-in through Input-2;

Q_L, P_{inp1}, P_t, P_{hom1}, P_{hom2} , , ,

$Q_{inp1} \times P_{inp1} = Q_t \times P_t$

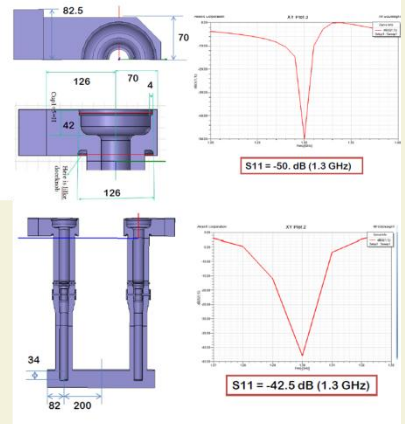
$$\boxed{Q_t} = \frac{Q_{inp\_1} \cdot P_{inp\_1}}{P_t}$$

$$Q_{hom\_1} = \frac{Q_t \cdot P_t}{P_{hom\_1}}$$

Calibration of Eacc

High Power Input Coupler (2)

from coupler design to stable beam operation



Design/Calculation

Fabrication

RF measurement

Cleaning/Assembly
Pumping/Baking

Conditioning at test stand

Cavity string assembly

Conditioning at RT in cryomodule

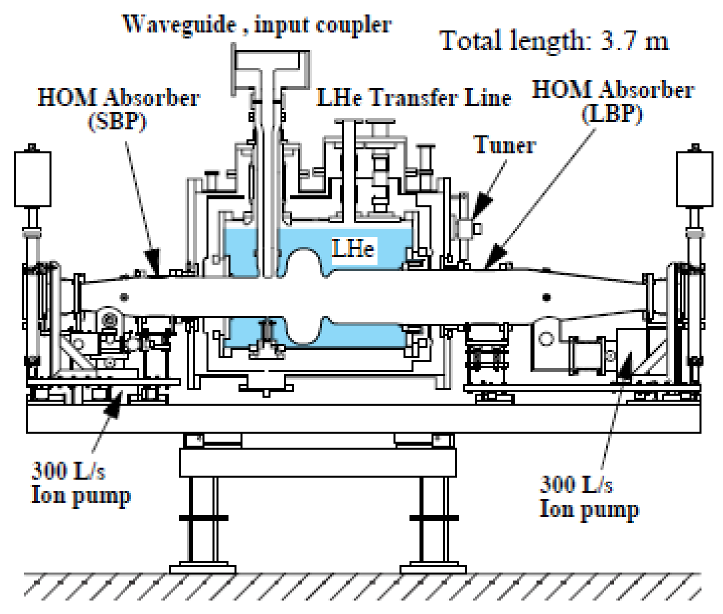
High power operation with beam

High Power Input Coupler (3)

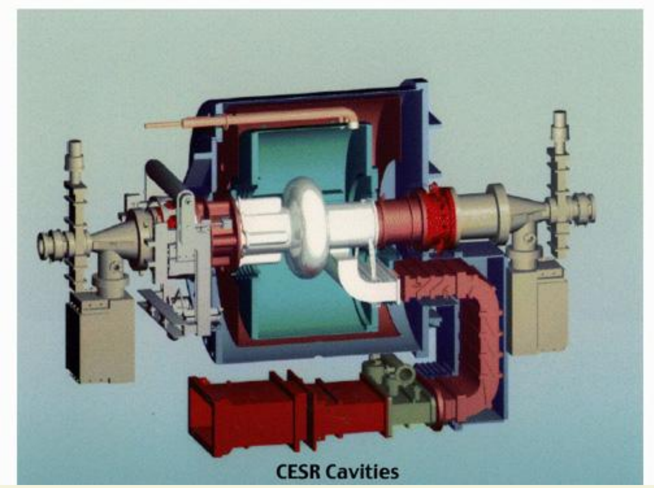
Choice of Coupler Type :

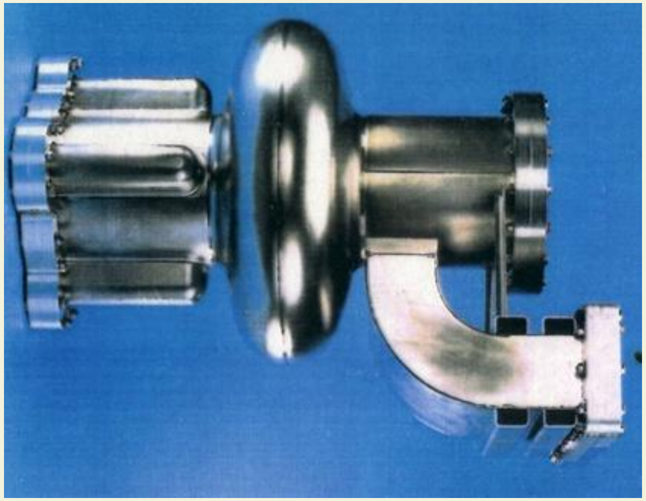
- Coaxial or Waveguide
- Disk or Cylindrical Window
- Single or Double Windows
- Fixed or Variable Coupling
- CW or Pulsed operation
- Double Feed Couplers

Coaxial or Waveguide



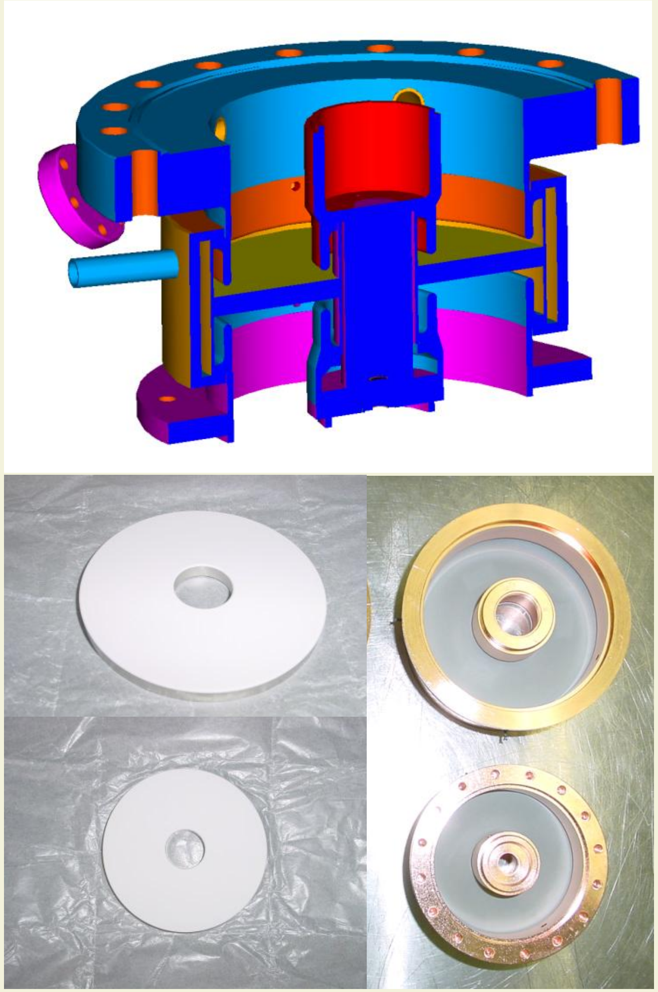
KEK-B Cavity (508MHz) with a coaxial coupler



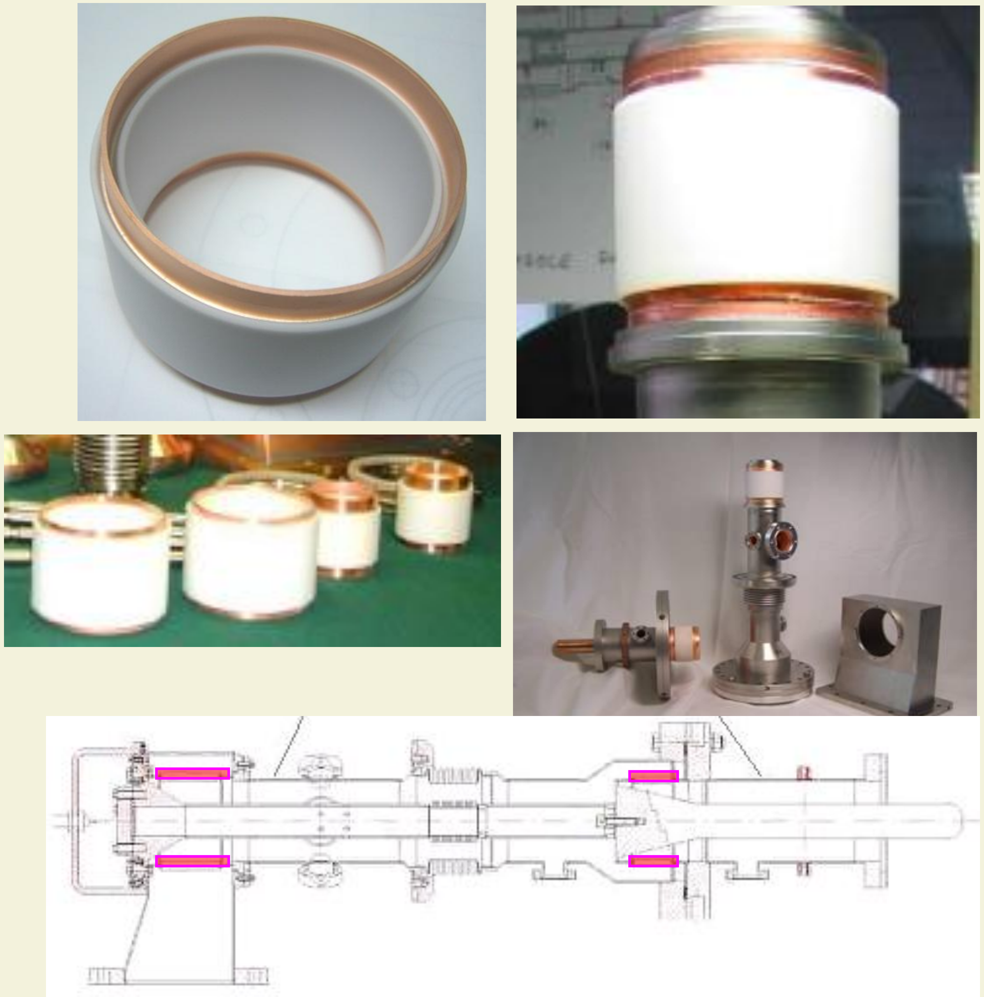


CESR-B Cavity (500MHz) with a waveguide coupler

Disk or Cylindrical Window



Tristan-type coaxial disk ceramics
RF window with choke structure

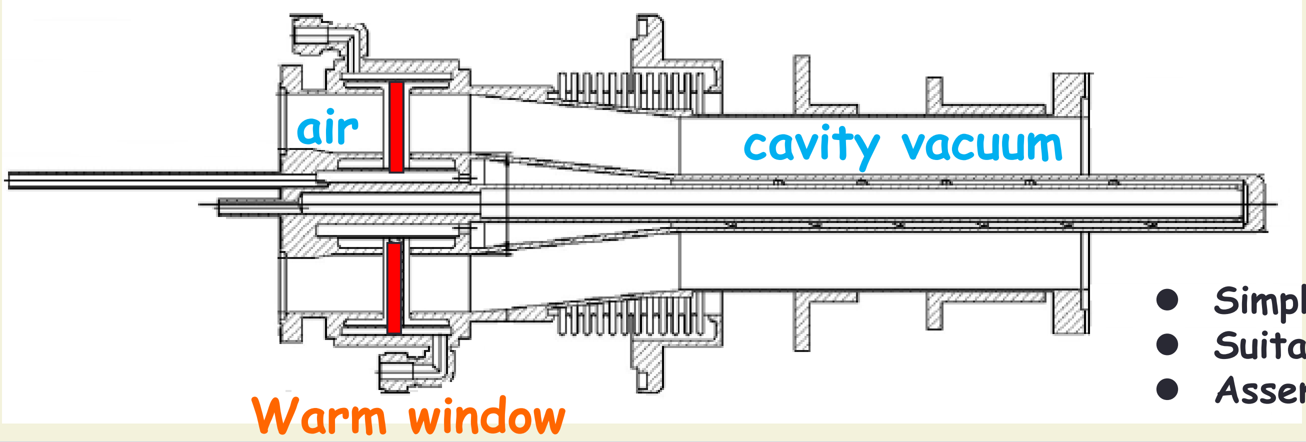


TTF-V input coupler for ILC
with cylindrical ceramic windows

Single or Double Windows

CW Input Coupler for cERL Injector

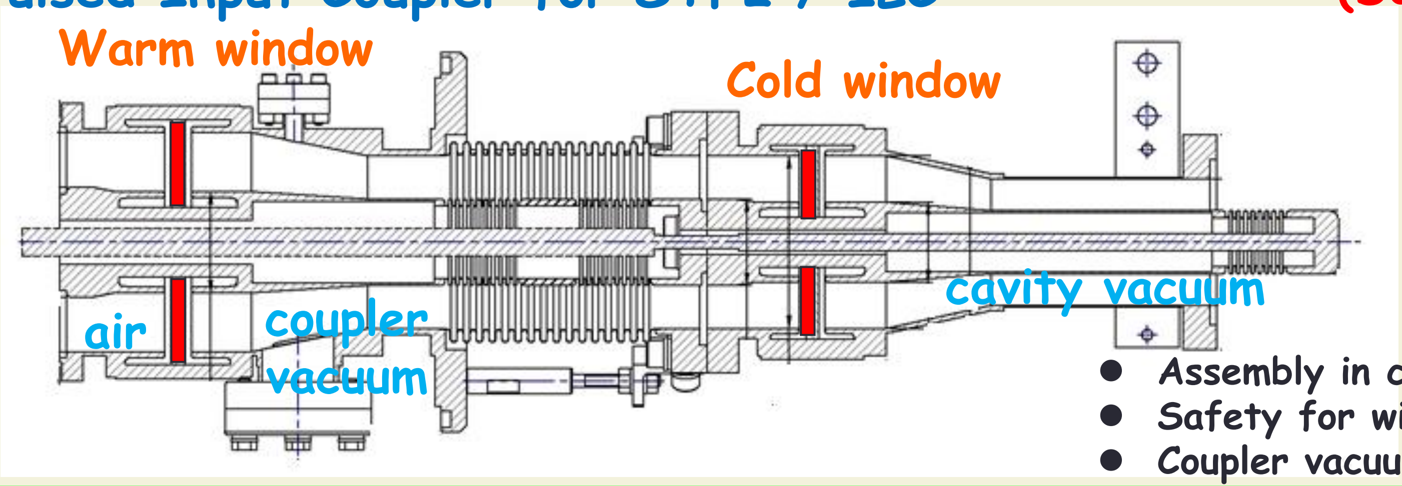
(Single Warm Window)



- Simple structure
- Suitable for cooling
- Assembly with cryomodule

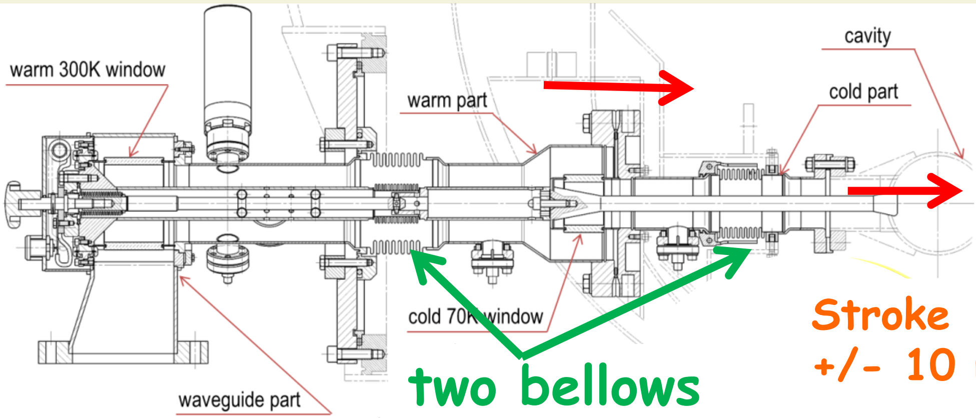
Pulsed Input Coupler for STF2 / ILC

(Double Windows)



- Assembly in clean room
- Safety for window failure
- Coupler vacuum for cold window

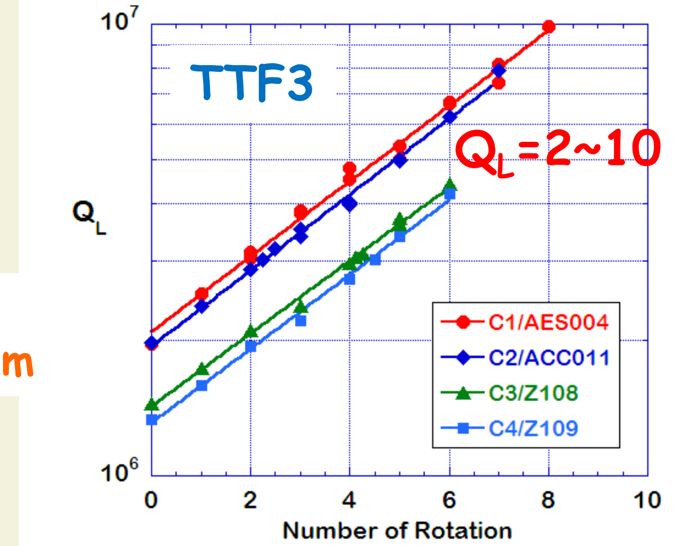
Fixed or Variable Coupling



two bellows
(outer conductor)

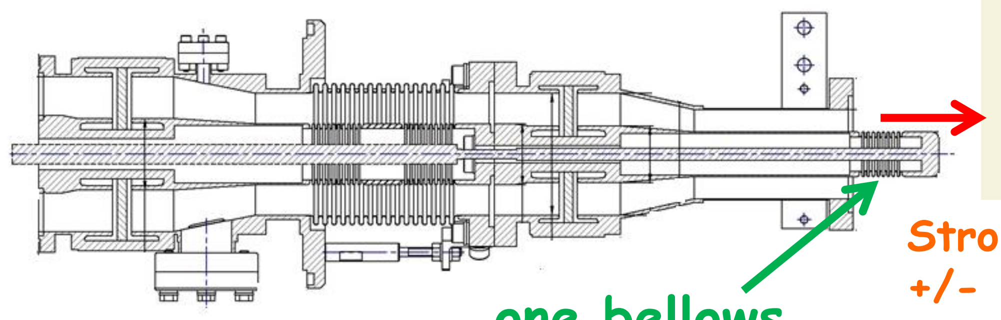
Stroke
+/- 10 mm

TTF3 Input Coupler for XFEL



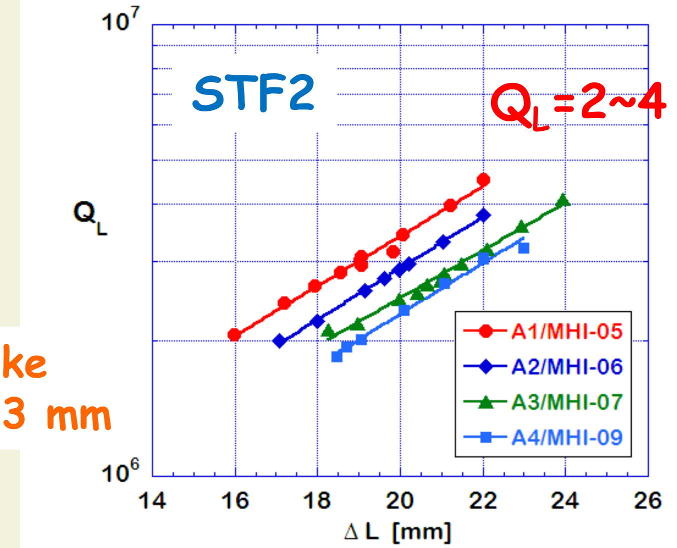
$Q_L = 2 \sim 10 \times 10^6$

STF2 Input Coupler for ILC



one bellows
(inner conductor)

Stroke
+/- 3 mm

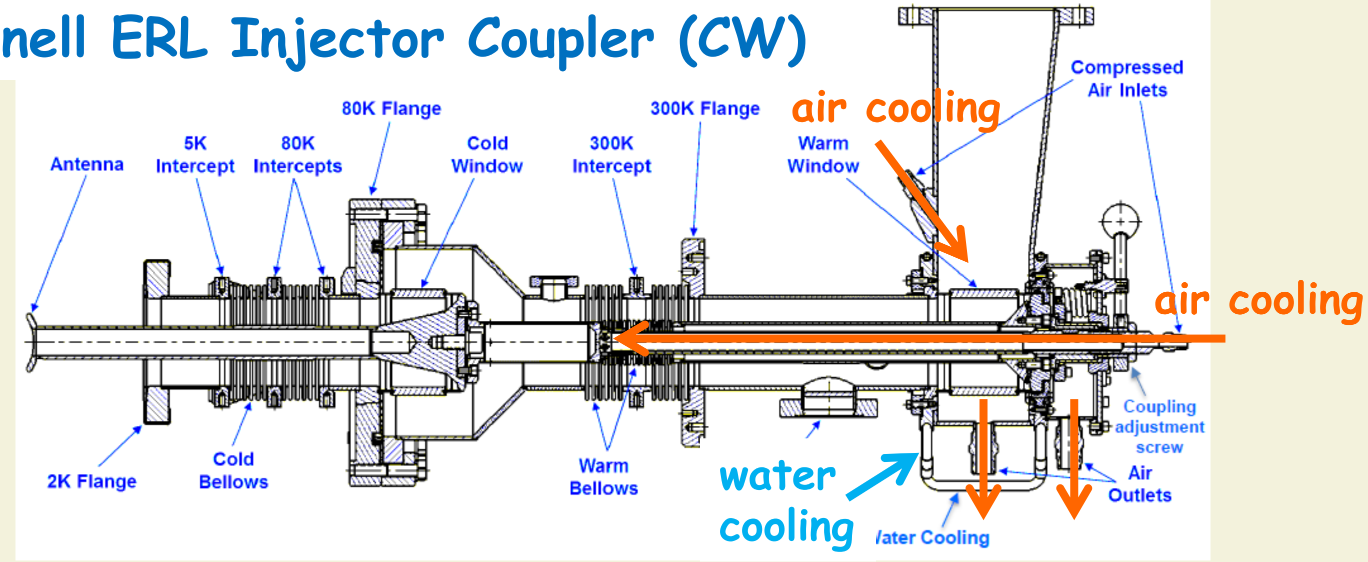


$Q_L = 2 \sim 4 \times 10^6$

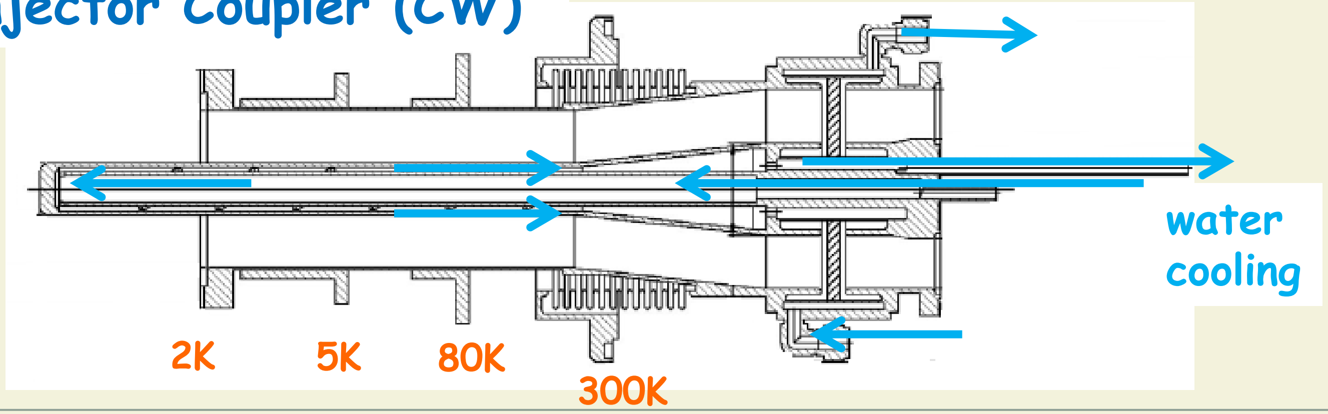
CW or Pulsed Operation

Cooling of inner conductor is necessary in ave. P_{RF} > 3 kW.

Cornell ERL Injector Coupler (CW)



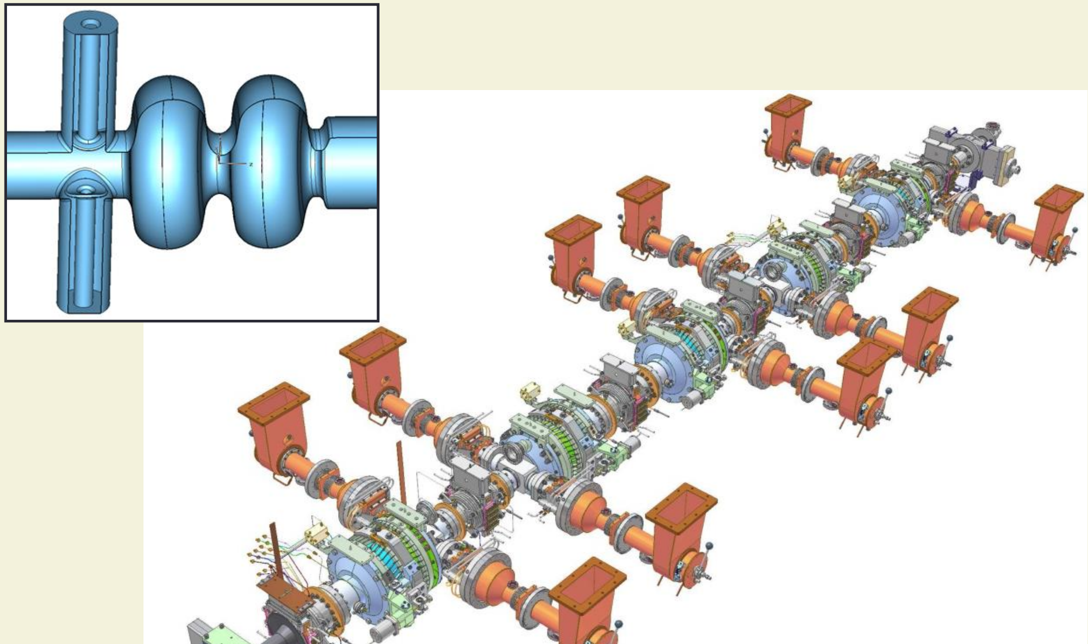
KEK cERL Injector Coupler (CW)

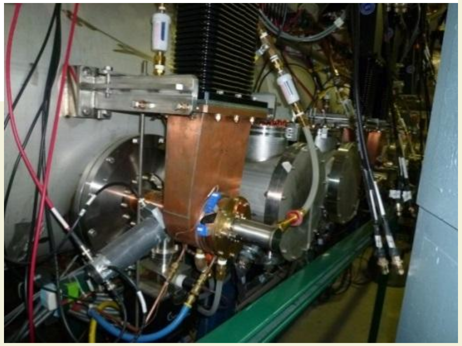


Double Feed Couplers

Vertical-type double feed couplers for cERL Injector (KEK)

Horizontal-type double feed couplers for ERL Injector (Cornell)





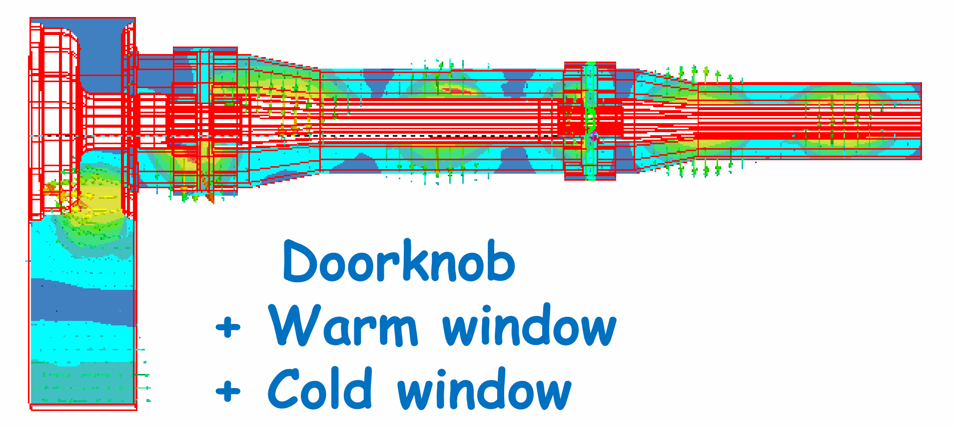
- Power handling capability (1/2)
- Suppression of coupler kick by symmetry structure
- Choice of vertical or horizontal

High Power Input Coupler (4)

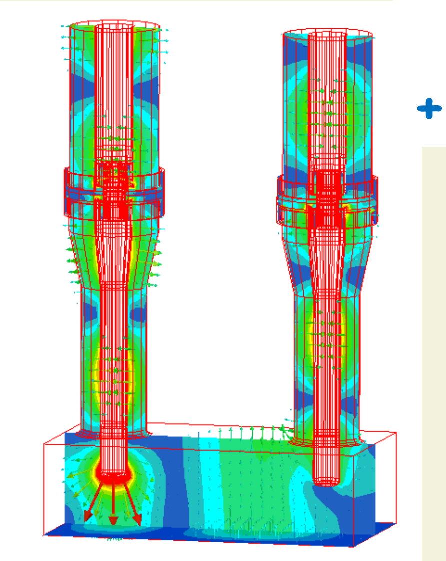
Design issues :

- RF Design
- RF Power Dissipation
- Thermal Calculation
- Mechanical Analysis
- Multipactor Simulation

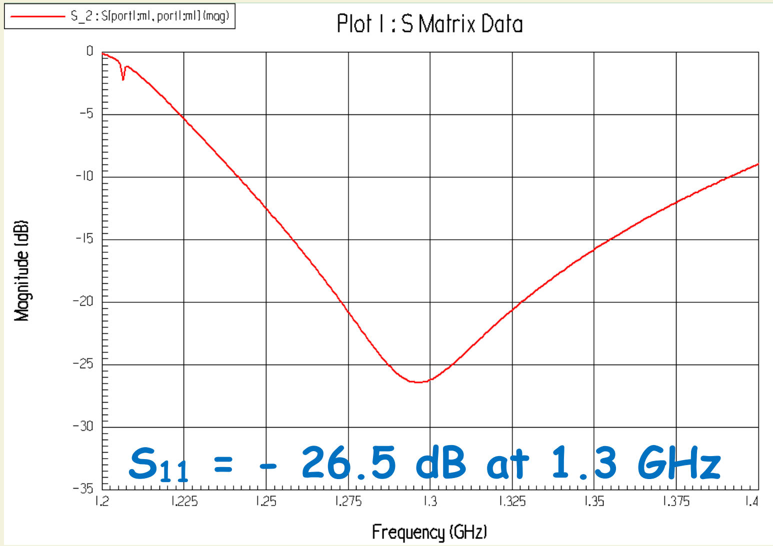
RF Design (HFSS) (1)



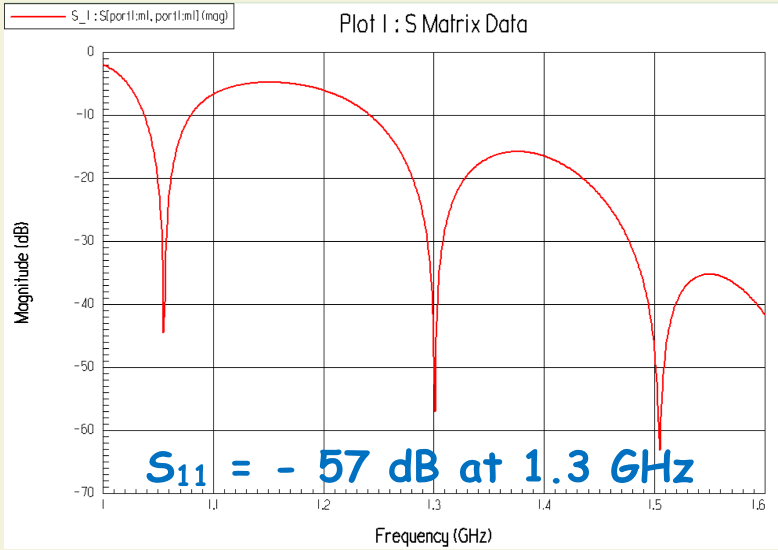
Doorknob
+ Warm window
+ Cold window



Coupling W.G.
+ Cold window

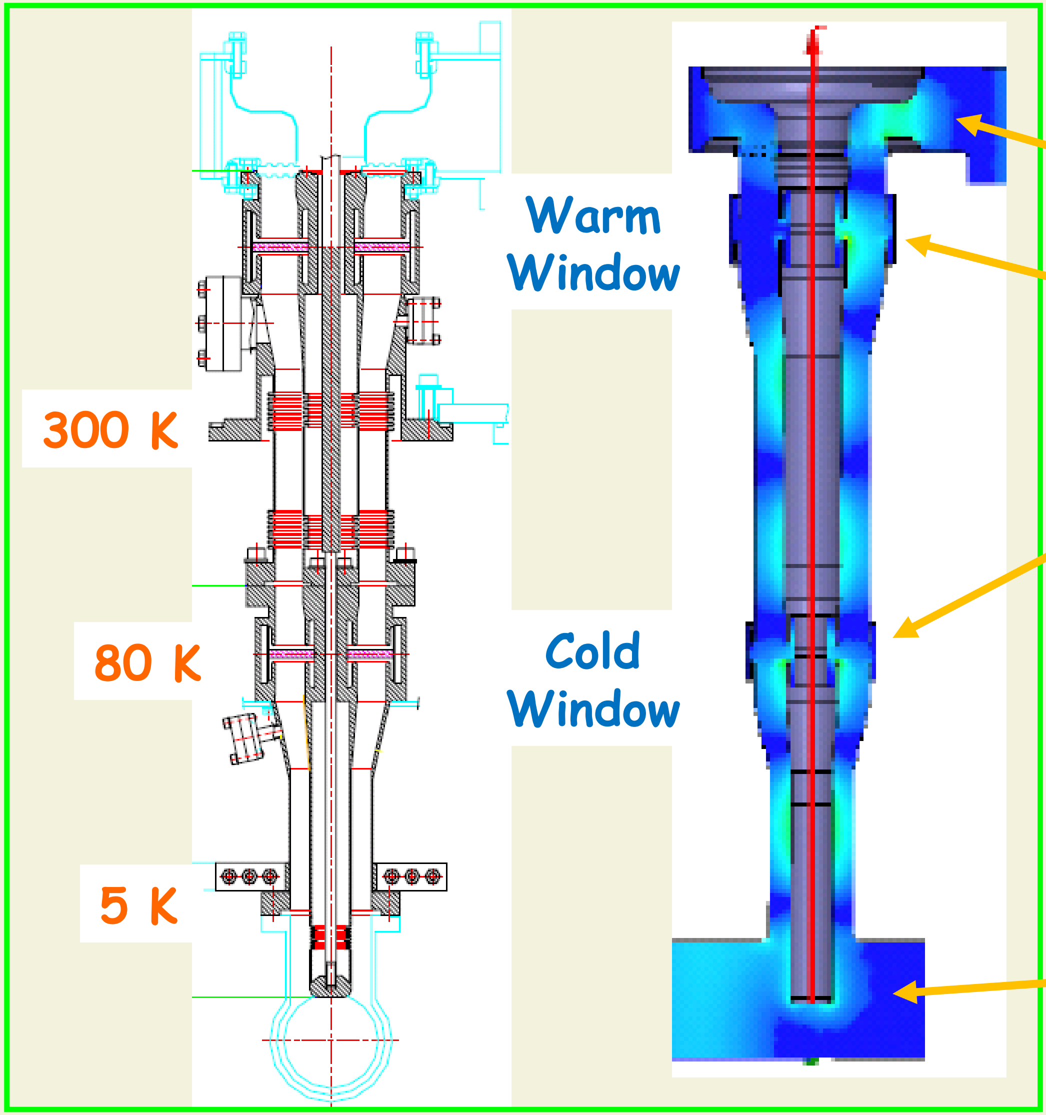


S_{11} = - 26.5 dB at 1.3 GHz

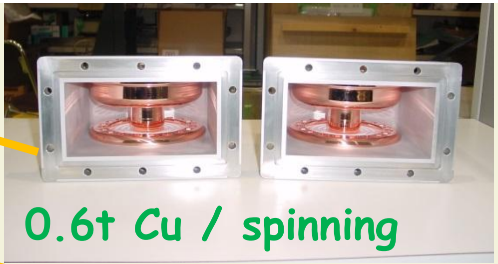


S_{11} = - 57 dB at 1.3 GHz

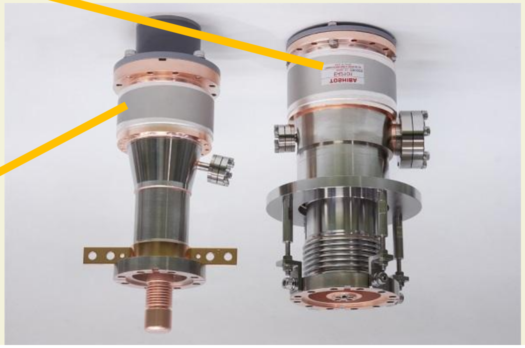
RF Design (HFSS) (2)



Doorknob Coax/WG transition

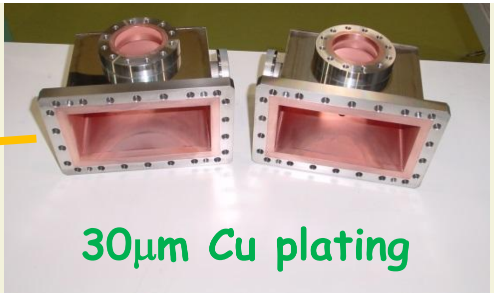


0.6t Cu / spinning



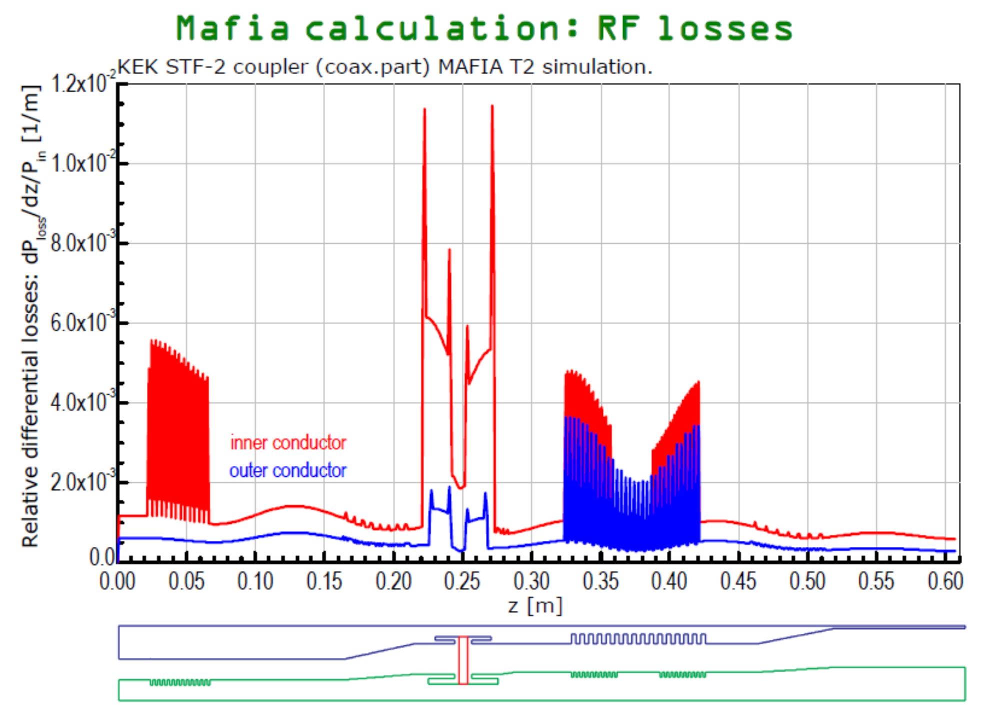
Cold and warm windows

Coupling Waveguide

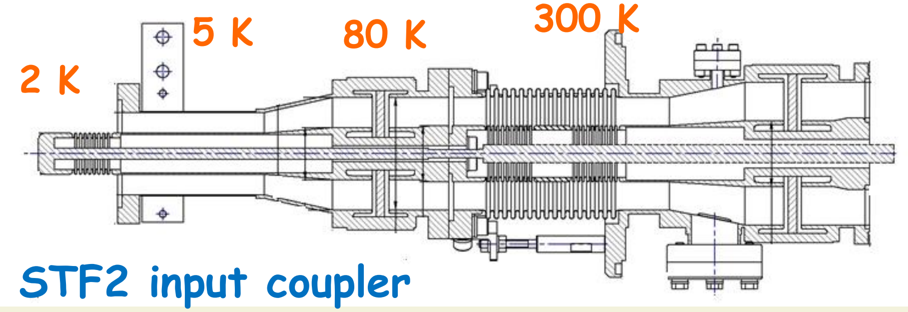


30μm Cu plating

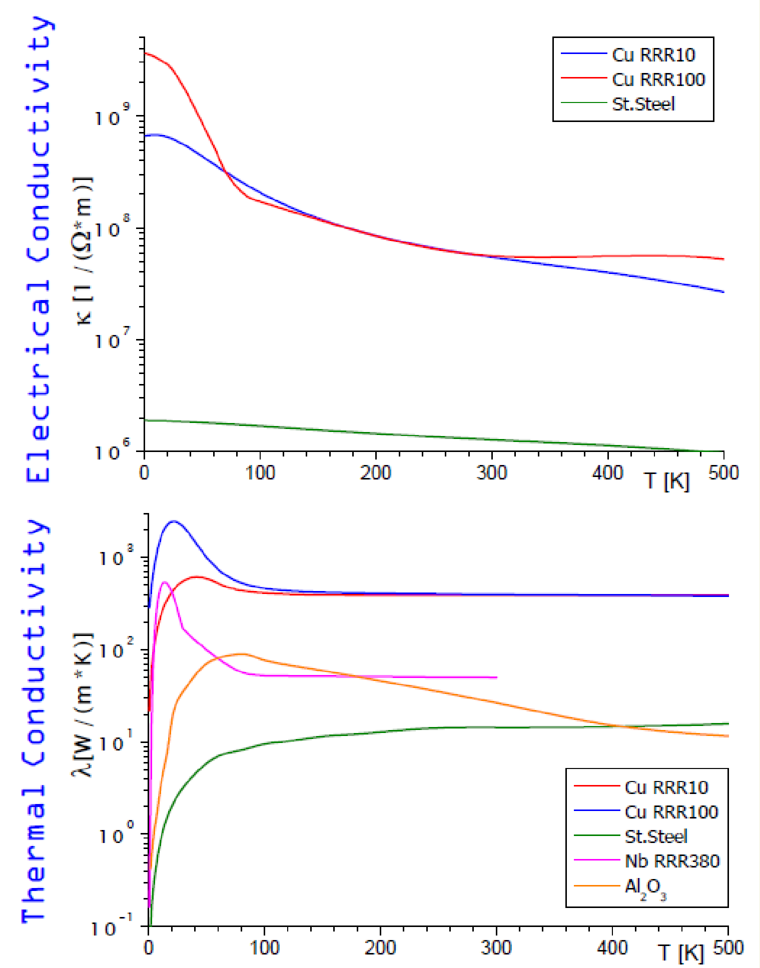
RF Power Dissipation (MAFIA-T2)



Material: Cu, $\kappa_0=5.8\times10^7$ 1/(Ω×m) (300 K)
Power Losses in the 70K ceramic window
($\varepsilon=9.2$, $tg\delta=10^{-4}$): $P_{loss.win}/P_{in} = 1.39\times10^{-4}$

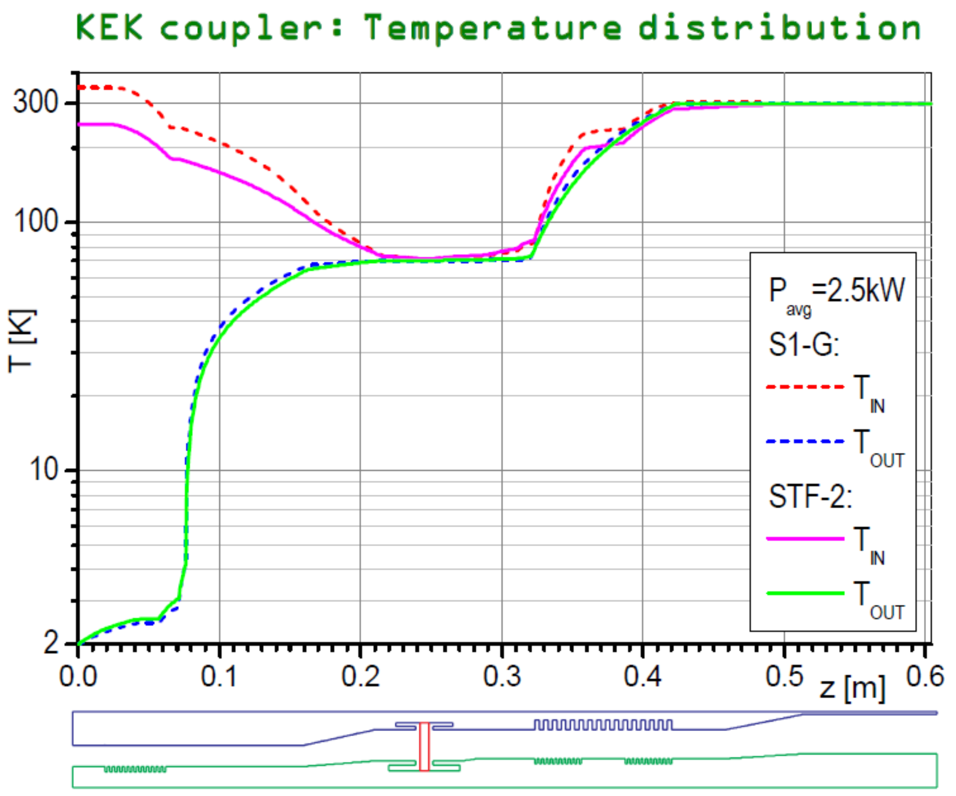


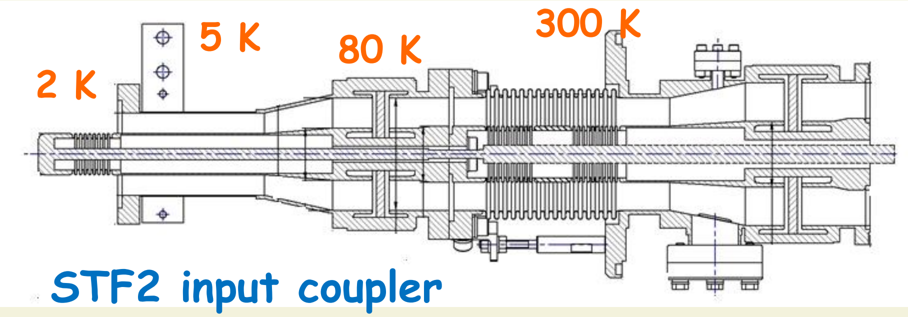
STF2 input coupler



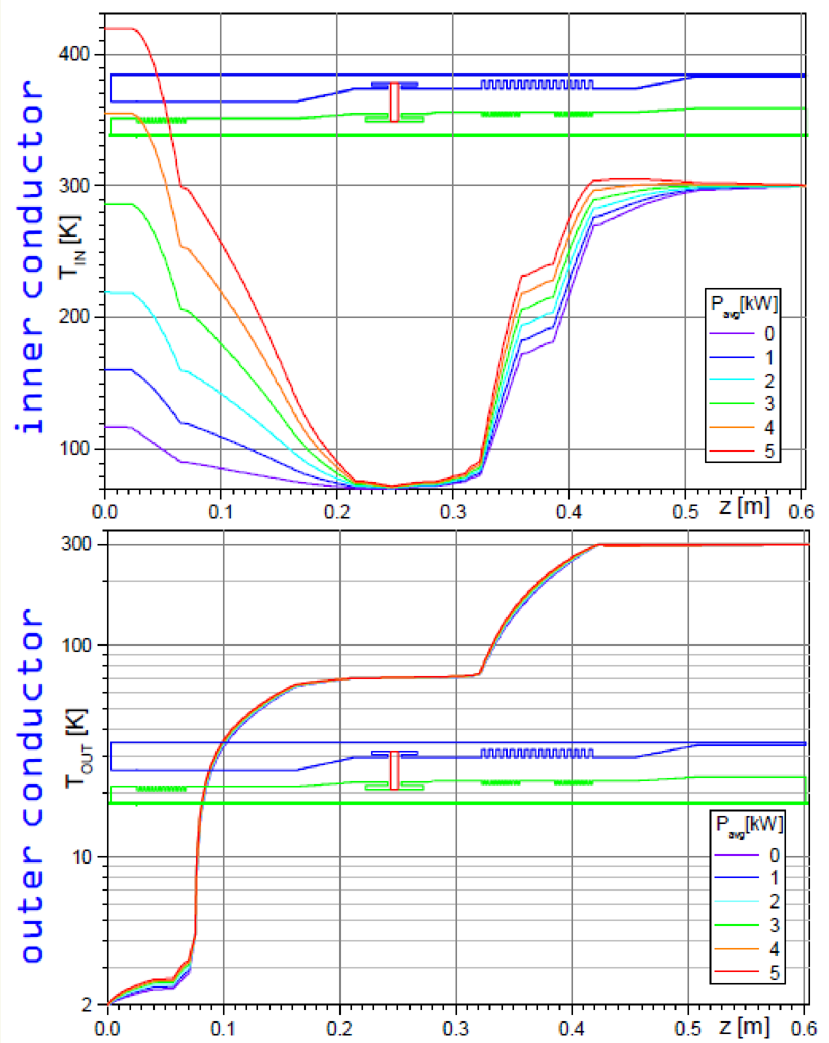
by D. Kostin (DESY)

Thermal Calculation (MAFIA-T2)


KEK coupler: Temperature distribution

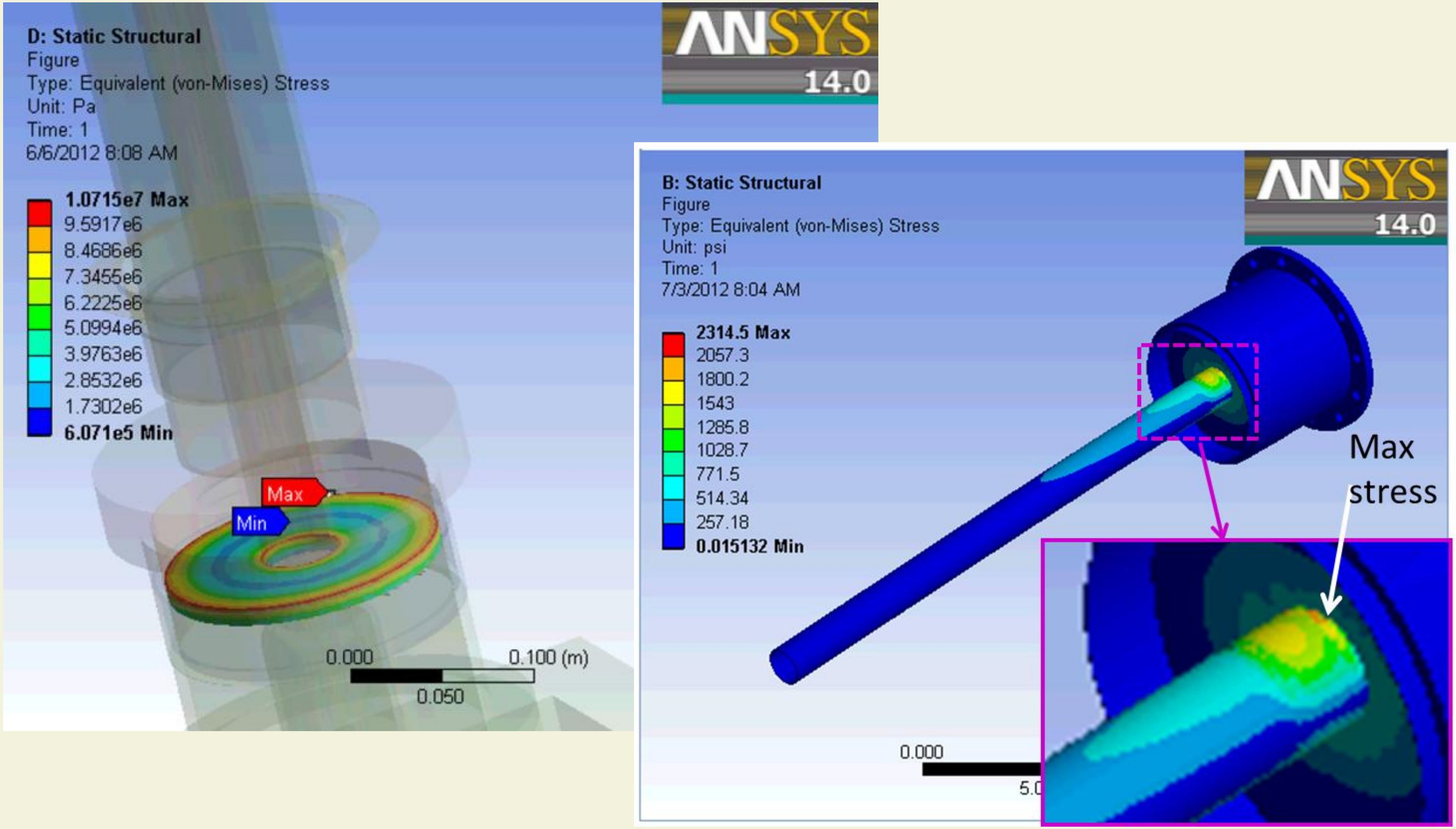


STF2 input coupler



by D. Kostin (DESY)

Mechanical Analysis (ANSYS)

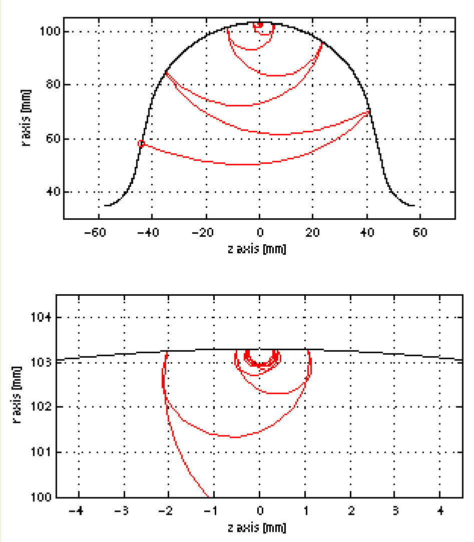


D: Static Structural
Figure
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
6/6/2012 8:08 AM

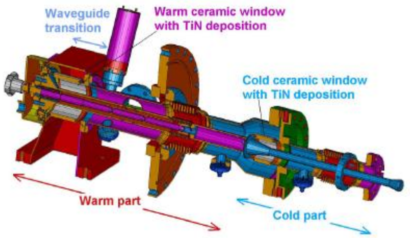
B: Static Structural
Figure
Type: Equivalent (von-Mises) Stress
Unit: psi
Time: 1
7/3/2012 8:04 AM

IFMIF Coupler (CEA-Saclay / CPI Beverly) by H. Jenhani

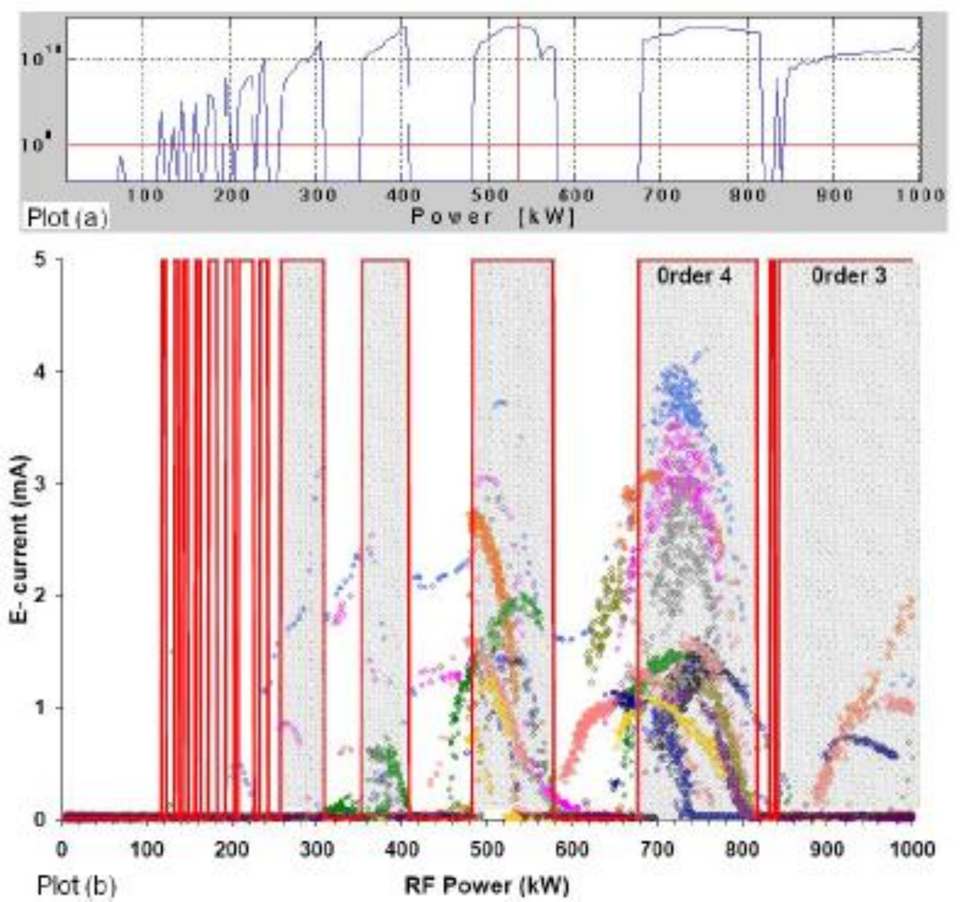
Multipacting Simulation

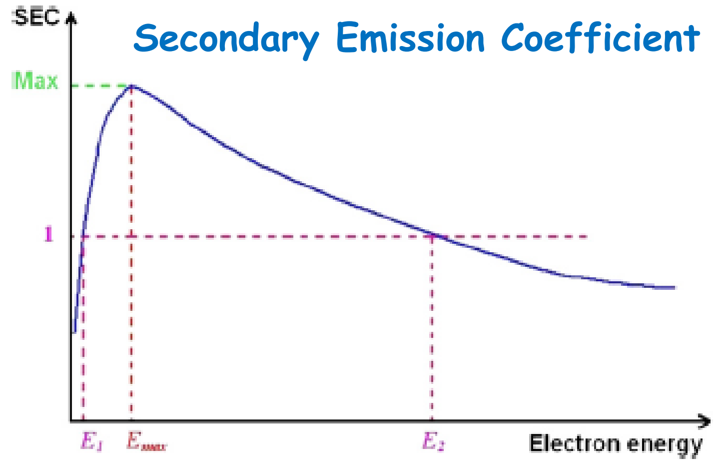


Resonant process of electrons in RF structure



Comparison between MP simulation and e- current measurement in TTF3 coupler





~100eV

~1000eV

by H. Jenhani (LAL-Orsay)

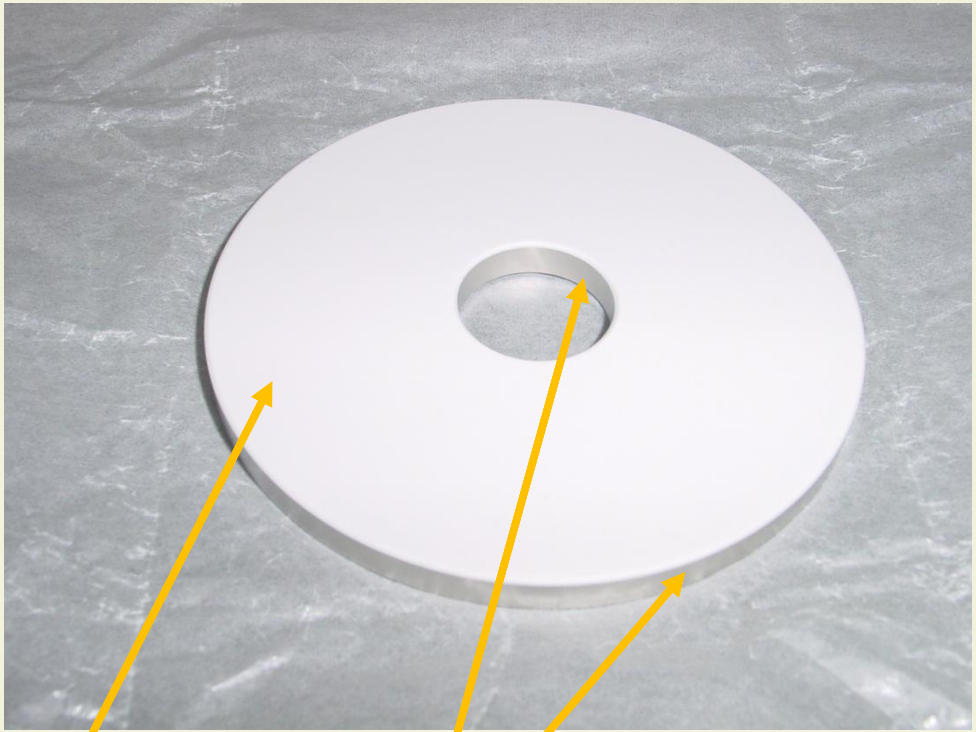
High Power Input Coupler (5)

Fabrication issues :

- Ceramics Window
- Metalizing
- Brazing
- Copper Plating
- Bellows
- TiN Coating

These are essential technologies for coupler fabrication.
But, the details are usually not opened
by fabrication companies.

Ceramics Window



Al_2O_3 ceramics
Purity;
HA95 ~95%
HA99 ~99%
$\varepsilon^* \sim 9.0$

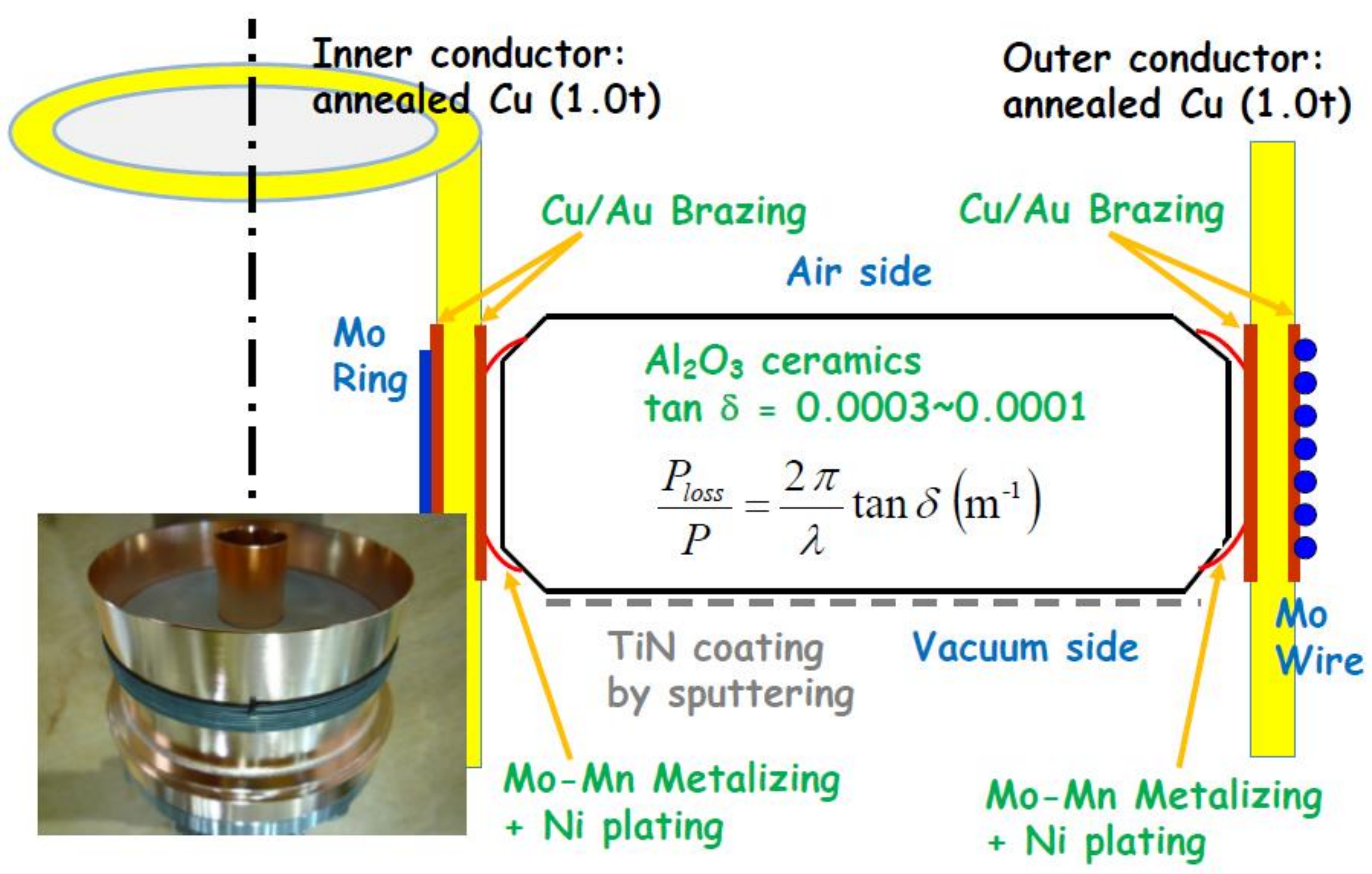
Metalizing by sintering of Mo-Mn paste

Thermal cycle test by liquid N_2 of ceramic-disks & thin Cu-plating.

Brazing

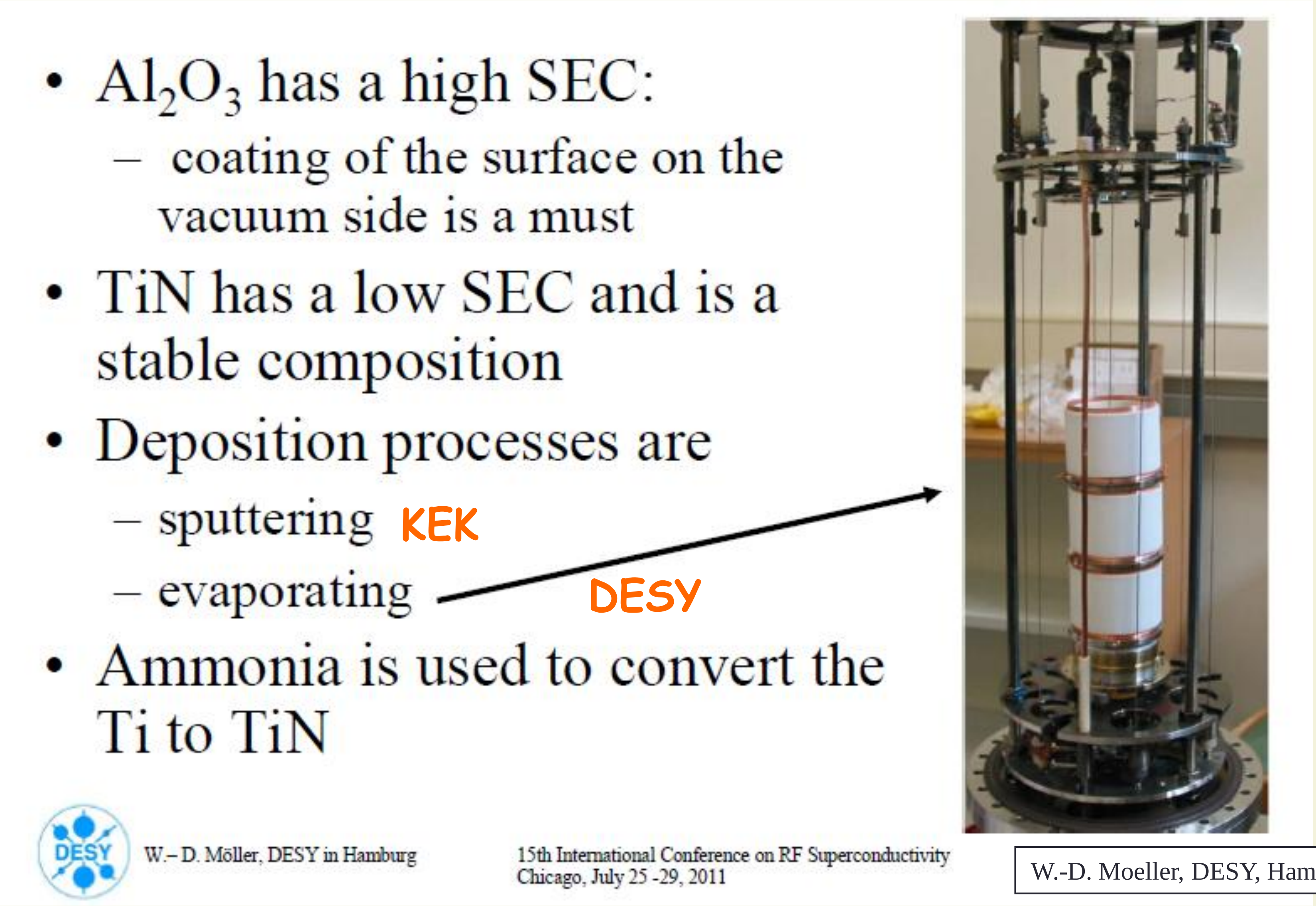
Two steps of Brazing ; 1st brazing by Cu/Au-composition at ~1000°C
2nd brazing by Cu/Ag-composition at ~800°C

Vacuum Furnace or Hydrogen Furnace



$$\frac{P_{loss}}{P} = \frac{2\pi}{\lambda} \tan\delta \left(\mathrm{m}^{-1}\right)$$

TiN Coating



- Al_2O_3 has a high SEC:
  - coating of the surface on the vacuum side is a must
- TiN has a low SEC and is a stable composition
- Deposition processes are
  - sputtering **KEK**
  - evaporating → **DESY**
- Ammonia is used to convert the Ti to TiN

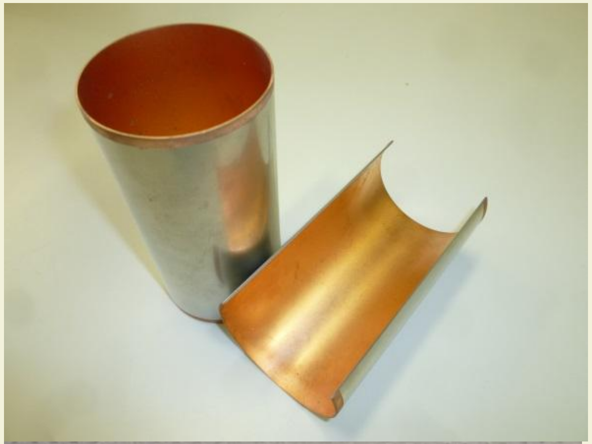
W.–D. Möller, DESY in Hamburg

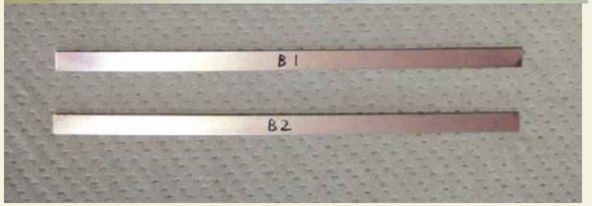
15th International Conference on RF Superconductivity
Chicago, July 25 -29, 2011

W.-D. Moeller, DESY, Hamburg

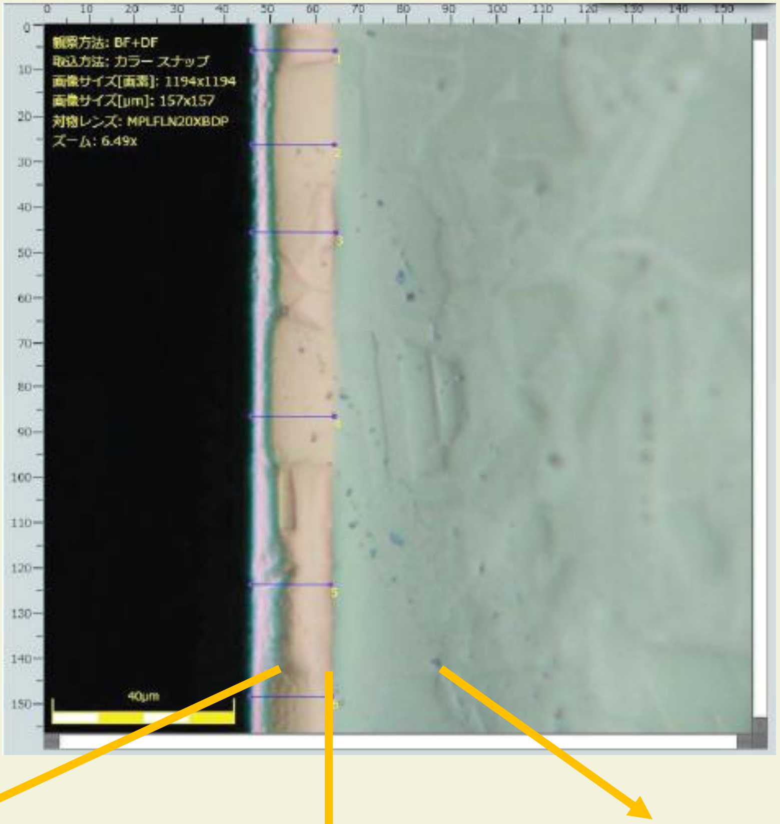
Copper Plating

Cu-plating
Samples :
SUS 1.0t
Ni-strike
0.2 μm
Cu 5 μm





after anneal
at 800 °C
in hydrogen
furnace



観察方法: BF+DF
取込方法: カラー スナップ
画像サイズ[画素]: 1194x1194
画像サイズ[μm]: 157x157
対物レンズ: MPLFLN20XBDP
ズーム: 6.49x

18μm Cu Plating

- $Cu_2P_2O_7$
- CuCN
- $CuSO_4$

0.2μm
Ni or Au
Strike-plating

SUS316L
1.0t,
annealed

High Power Input Coupler (6)

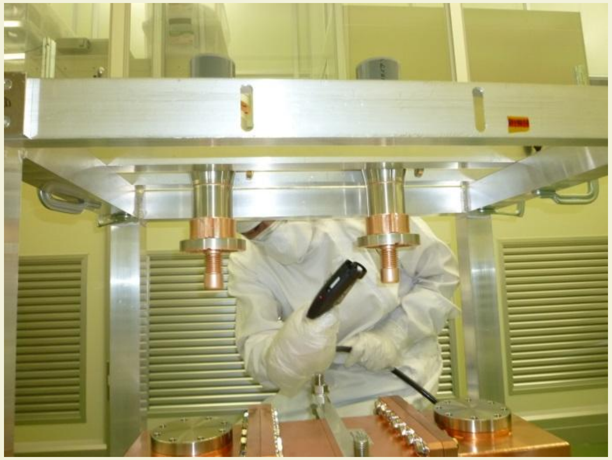
RF Conditioning issues :

- Cleaning Procedure and Assembly
- High Power Test Stand
- Diagnostics and Interlocks
- Conditioning Time at Test Stand
- Cryomodule Assembly
- Conditioning Time in Cryomodule
- Dynamic Heat Loads

Cleaning Procedure and Assembly

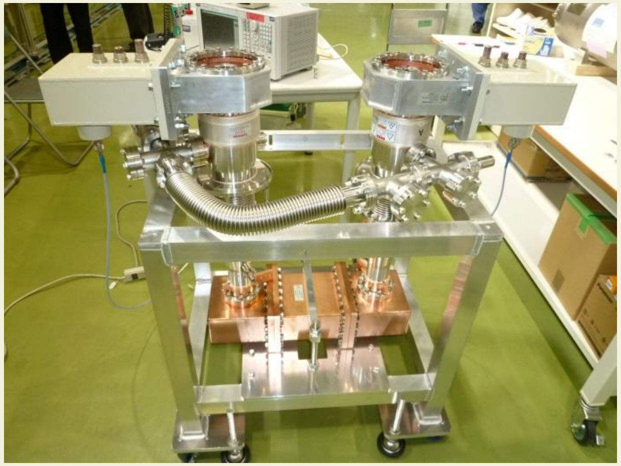

Ultra-pure water rinsing with ultra-sonic agitation


Low pressure water rinsing with ultra-pure water


Drying by ionized air gun

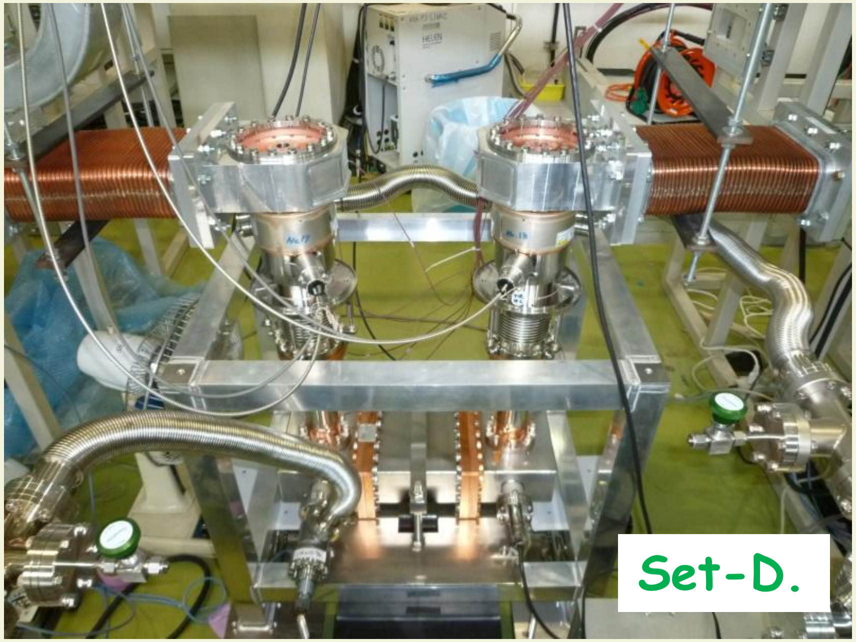

Installation of cold parts


Pumping and leak-check

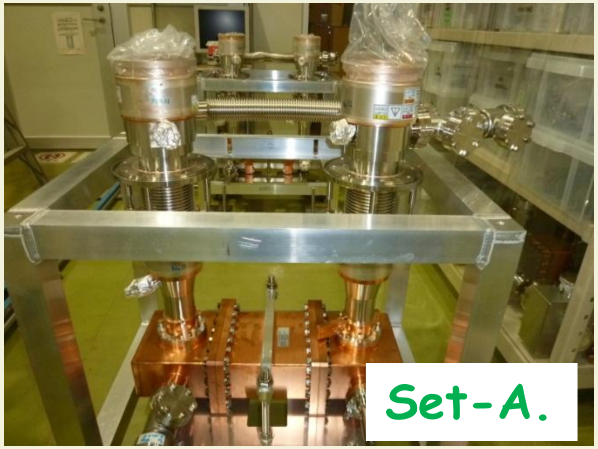

RF measurements

High Power Test Stand

8 pairs of STF2 input couplers



Set-D.

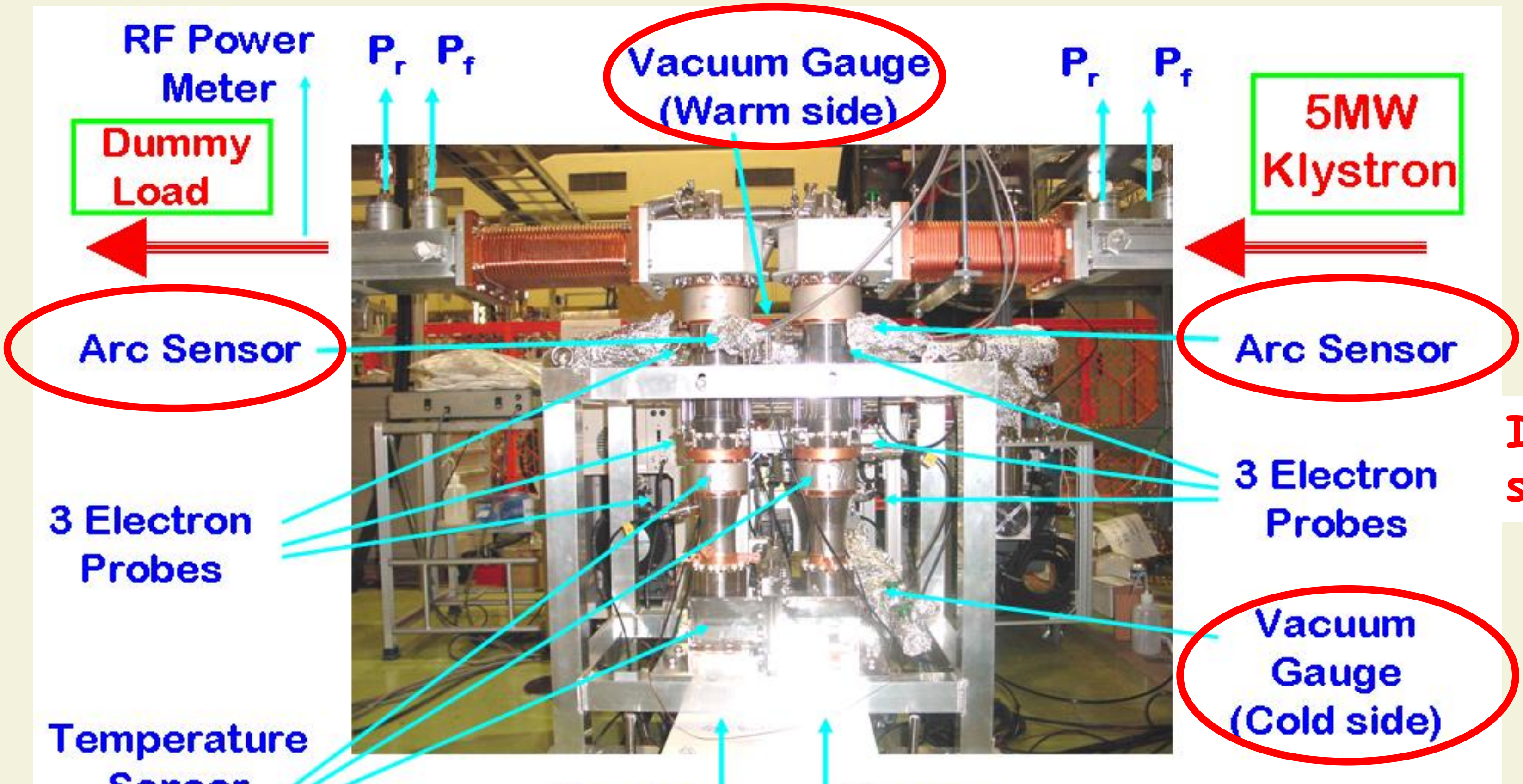


Set-A.

Set-B.

Set-C.

Diagnostics and Interlocks



RF Power Meter

P_r P_f

Vacuum Gauge (Warm side)

P_r P_f

5MW Klystron

Dummy Load

Arc Sensor

Arc Sensor

3 Electron Probes

3 Electron Probes

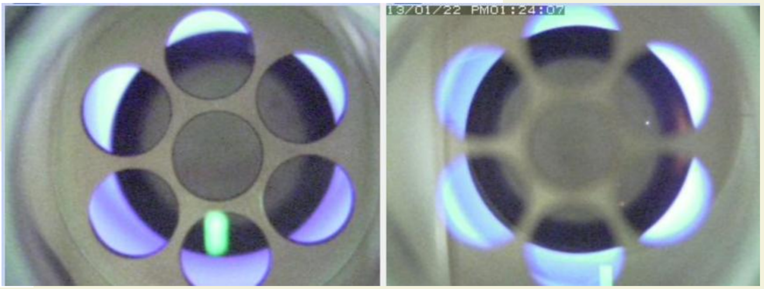
Vacuum Gauge (Cold side)

Temperature Sensor

Monitor Camera

Monitor Camera

Interlock system

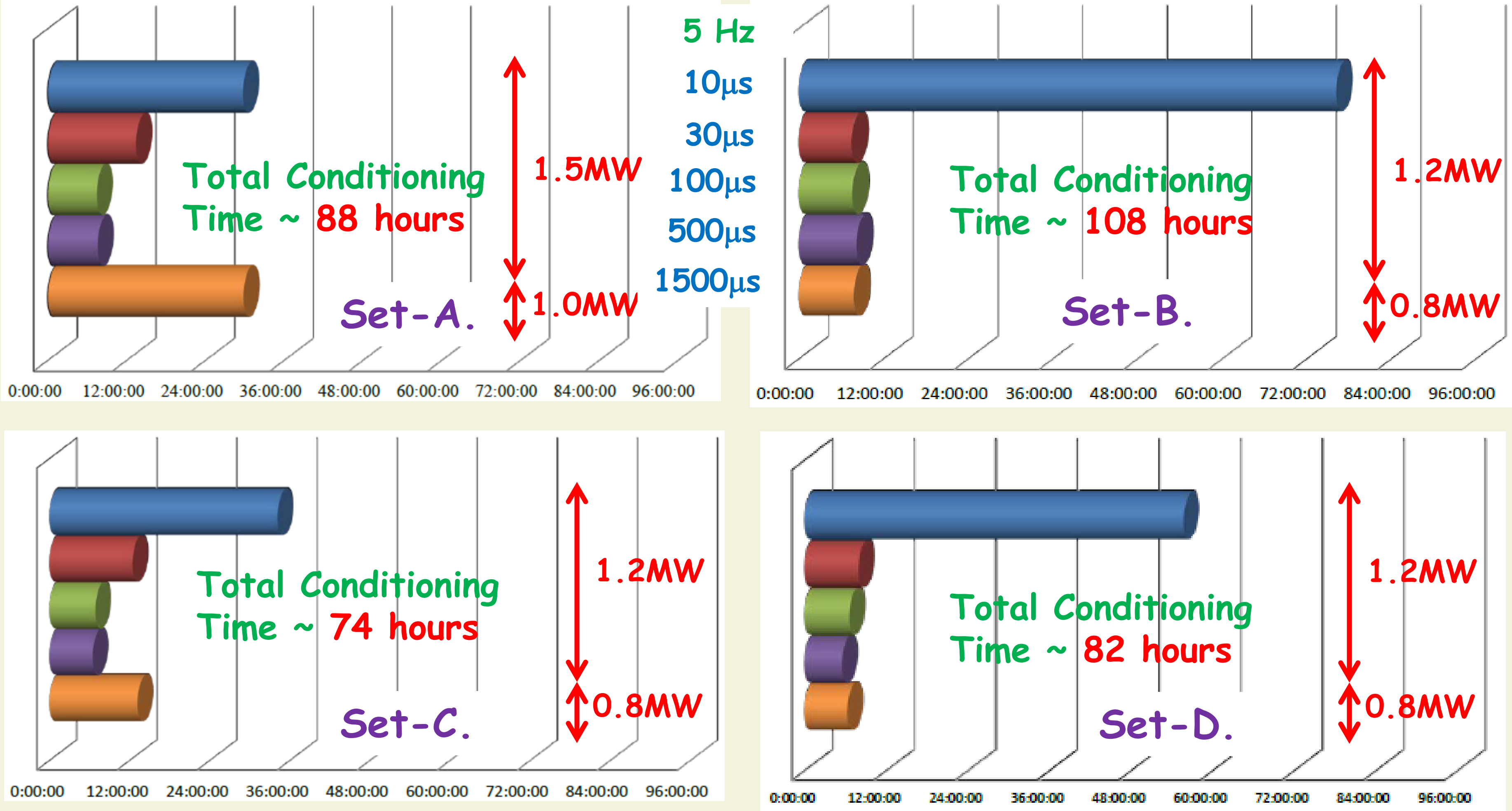


Observation of multipacting

Conditioning Time at Test Stand

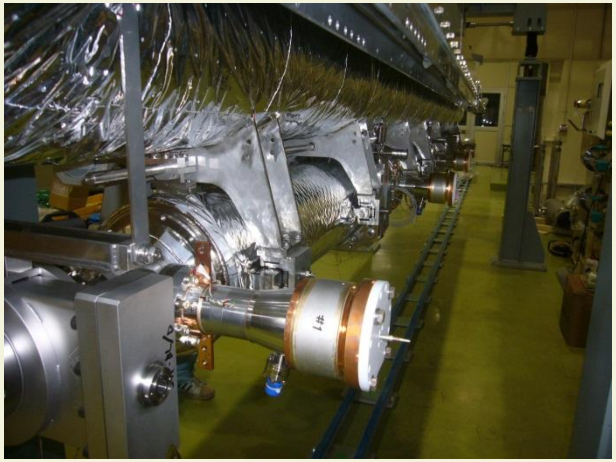
8 pairs of STF2 input couplers

2013' Jan. ~ May

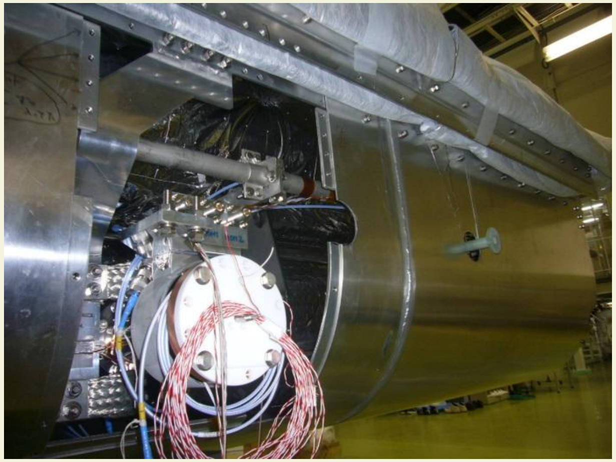


S1-G Cryomodule Assembly (STF2 coupler)

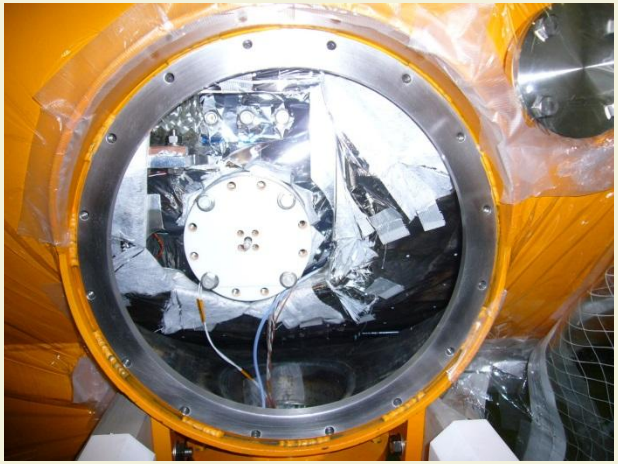
Cavity string assembly



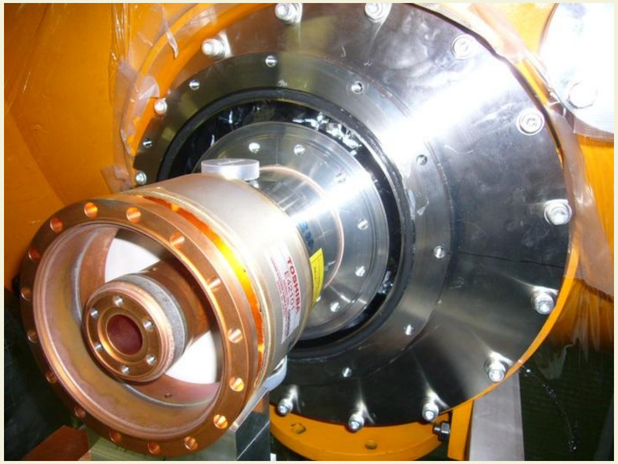
Hanging under He-GRP



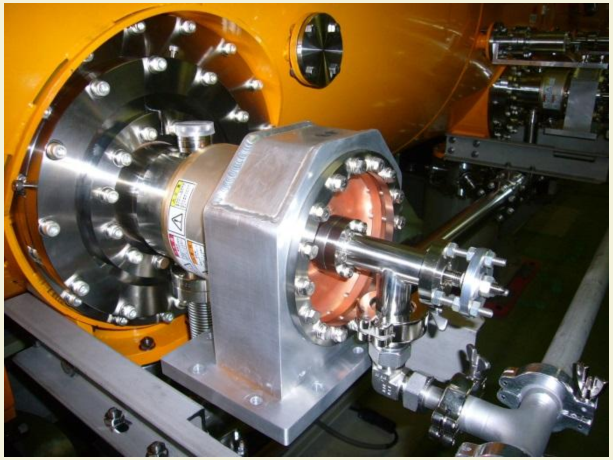
5K, 80K thermal anchor



Installation into vacuum vessel



Warm coupler assembly

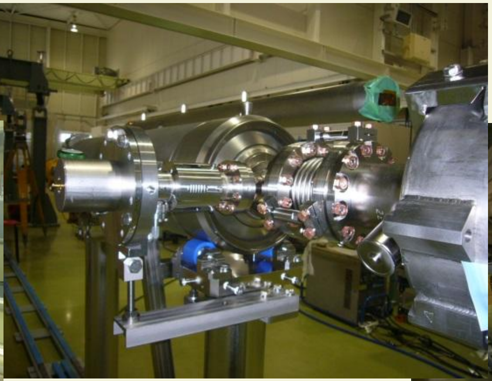


Attachment of doorknob WG

S1-G Cryomodule Assembly (TTF3 coupler)

Transportation with coupler

Cavity string assembly

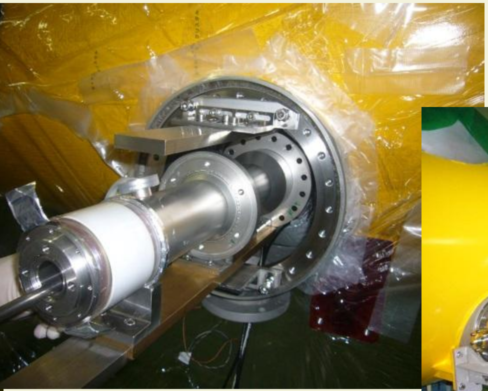


Welding of 2K-He pipe

Hanging under He-GRP

5K and 80K thermal anchor

Installation in vacuum vessel

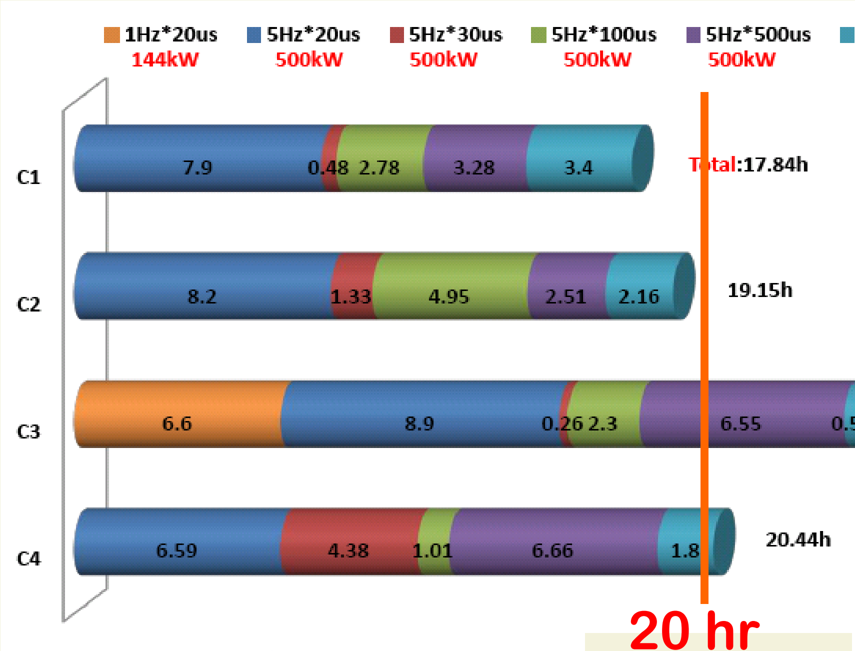


Warm coupler assembly

Waveguide assembly

Conditioning Time in S1-G Cryomodule

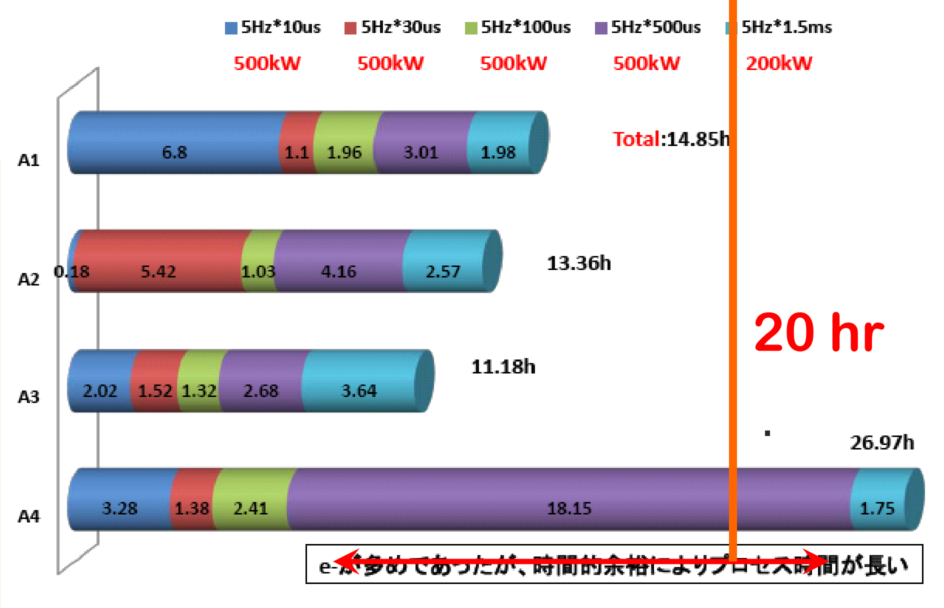
at Room Temperature;
0.5 ms, 5 Hz, 500 kW
1.5 ms, 5 Hz, 200 kW



Cryomodule-C
(four TTF3 couplers)
ave. processing time
~ 21 hours

Vacuum I/L ; 2.x10^{-4} Pa

Cryomodule-A
(four STF2 couplers)
ave. processing time
~ 13 hours



Dynamic Heat Loads (1)

Dynamic loss measurements in S1-G Cryomodule (2010')

	TTF3		STF2			TTF3	STF2				
	C-4	C-1	A-3	A-2	A-2	4 C Cavities	4 A Cavities	4 C Cavities	4 A Cavities	7 Cavities	7 Cavities
Date	Nov. 17	Nov. 19	Nov. 23	Nov. 24	Nov. 25	Nov. 26	Nov. 30	Dec. 2	Dec. 3	Dec. 9	Dec. 10
Gradient	28 MV/m	25.2 MV/m	32.3 MV/m	38 MV/m	32 MV/m	32 MV/m Detune	32 MV/m Detune	20 .0 MV/m	26.9 MV/m	25.4 MV/m	20.4 MV/m
Dynamic Loss	0.84 W	1.44 W	2.8 W	4.8 W	2.6 W			2.7 W	6.9 W	9.6 W	4.8 W
Detuned Loss	0.09 W	0.18 W	0.7 W	1.8 W	1.2 W	0.5 W	4.6 W	0.2 W	2.5 W	2.6 W	1.6 W
Dynamic Loss at Cavity	0.75W	1.26 W	2.0 W	2.9 W	1.3 W			2.5 W	4.4 W	7.0 W	3.2 W
Q_0	8.8E9	4.3E9	4.3E9	4.2E9	6.5E9						
								C1=22.2 C2=18.9 C3=14.9 C4=24.3	A1=15.8 A2=37.6 A3=32.9 A4=21.4	C1=25.2 C2=NA C3=17.6 C4=28.8 A1=15.3 A2=37.4 A3=32.4 A4=20.9	C1=20.1 C2=NA C3=14.1 C4=23.0 A1=12.3 A2=30.4 A3=26.0 A4=16.7

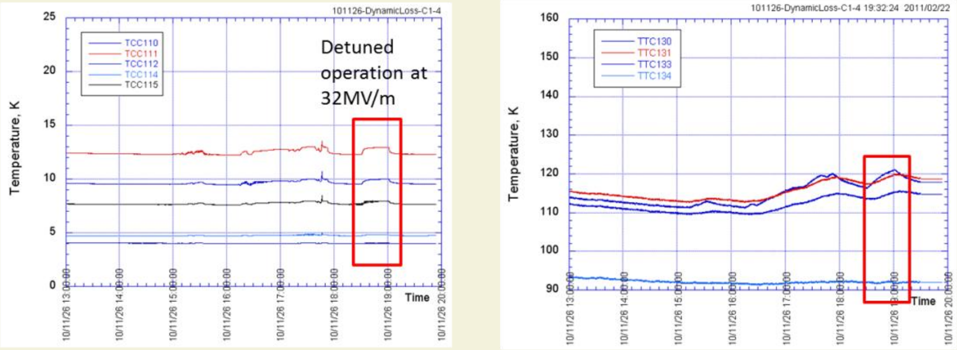
Dynamic losses of KEK couplers was 9 times larger than those of TTF3 couplers.

Dynamic Heat Loads (2)

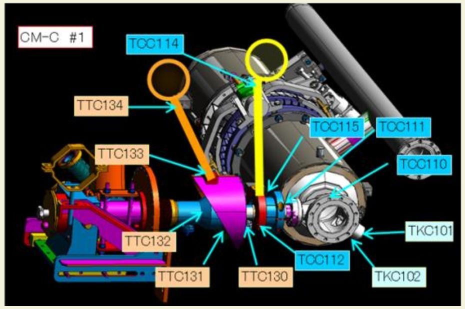
Dynamic loss measurements in S1-G Cryomodule (2010')

TTF3 Input Coupler

Temperature change during detuned 32MV/m
Module-C



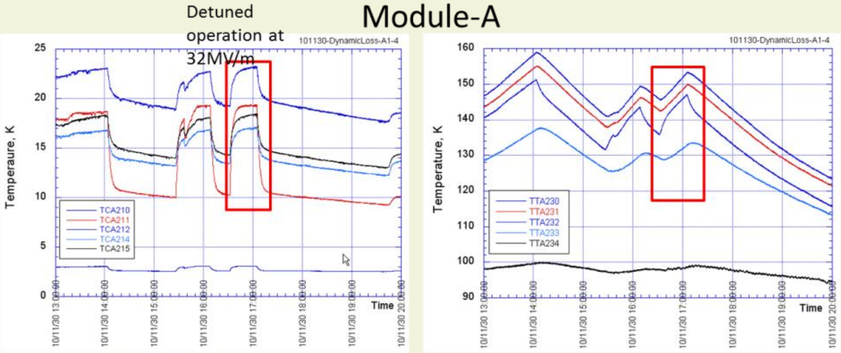
Cavity-C1



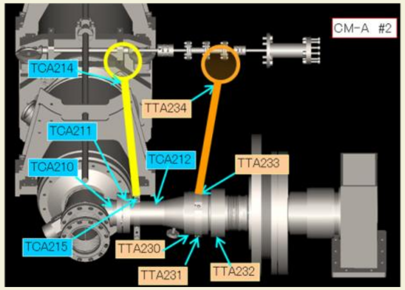
For 30 min. operation,
$\Delta T_{@TCC111}$=0.7K (12.3K->13.0K)
$\Delta T_{@TTC130}$=5K (116K->121K)

STF2 Input Coupler

Temperature change during detuned 32MV/m
Module-A



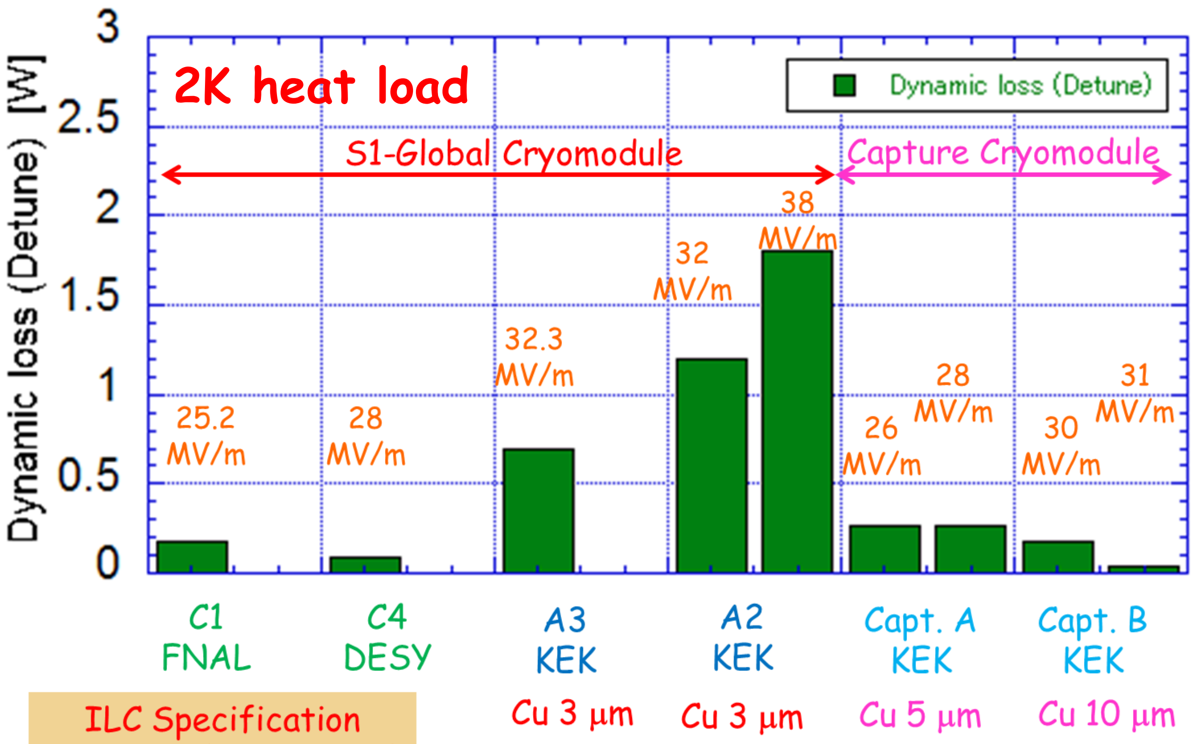
Cavity-A2



For 30 min. operation,
$\Delta T_{@TCA211}$=9K (10.3K->19.3K)
$\Delta T_{@TTA230}$=10K (137K->147K)

Much higher temperature rises were observed in KEK-STF2 coupler.

Dynamic Heat Loads (3)

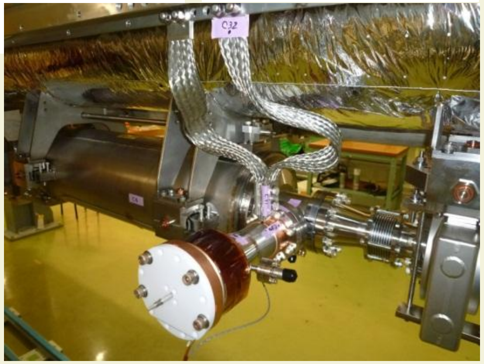


ILC Specification
< 0.02 W (2K dynamic)

STF-2' (A) input coupler
SUS 0.8t + Cu 5 μm
Capture Cryo. - MHI-12

STF-2' (B) input coupler
SUS 0.8t + Cu 10 μm
Capture Cryo. - MHI-13

5K anchor



80K anchor

Thermal anchors with efficient cooling are also important to reduce heat loads.

High Power Input Coupler (7)

State of the Arts :

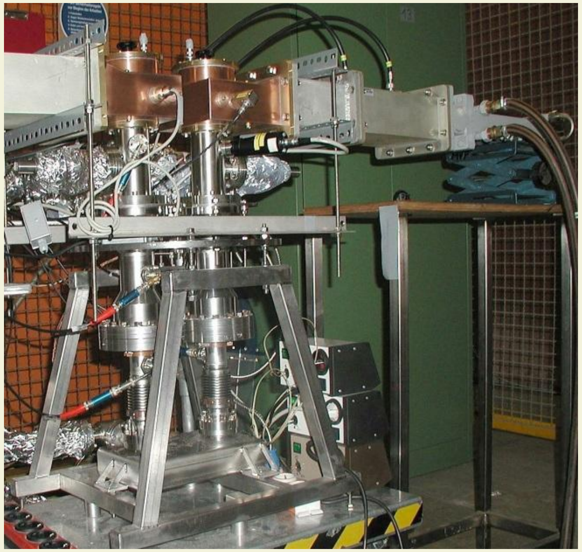
- Pulsed coupler for XEFL/ILC
- CW coupler for ERL
- CW/HD coupler for Proton Linac
- CW coupler for Low-β structure
- CW waveguide input coupler
- High power performance

Pulsed coupler for XEFL/ILC (1.3GHz)

2 windows, no cooling

STF2 Coupler (KEK)

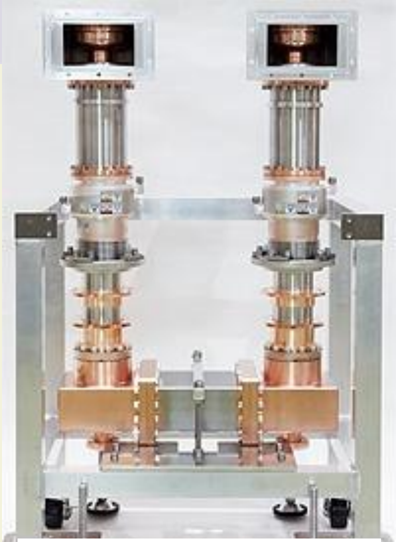
TTF3 Coupler (DESY)



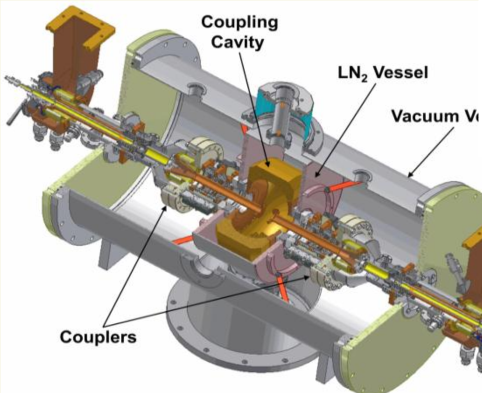
TTF-V Coupler (LAL)

CW coupler for ERL (1.3GHz)

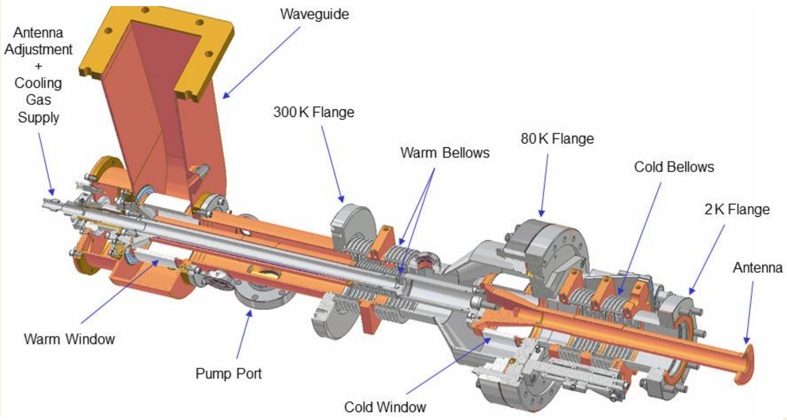
cERL Injector Coupler (KEK)



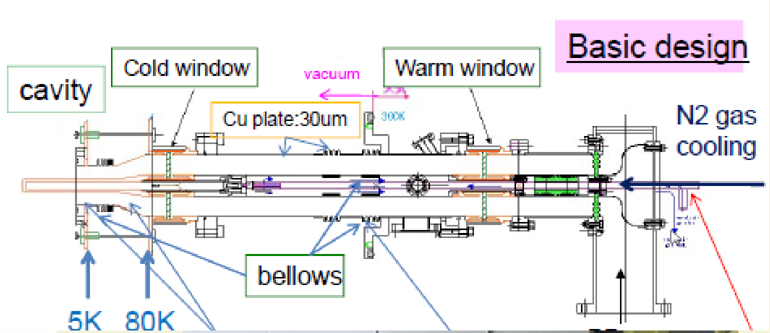
1 window, water cooling

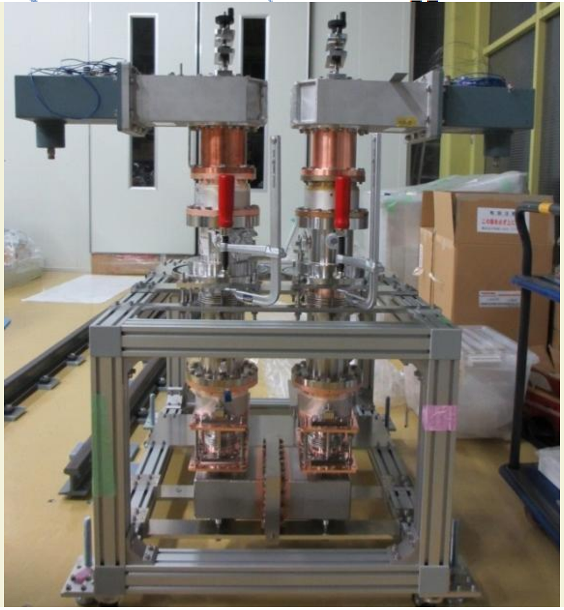


ERL Injector Coupler (Cornell)



2 windows, air cooling



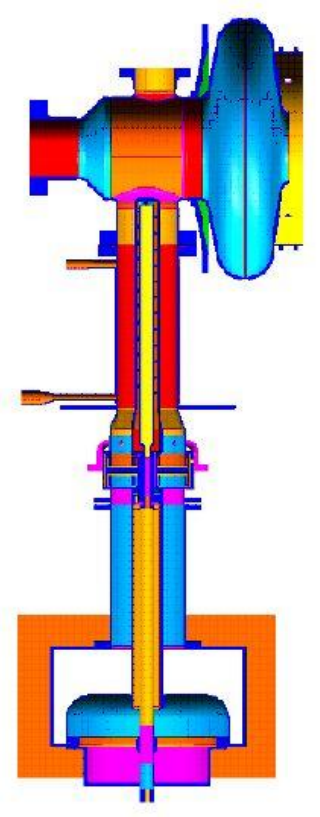


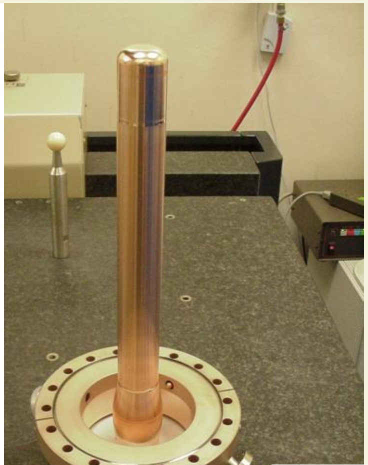
cERL ML Coupler (KEK)

2 windows, N_2 gas cooling

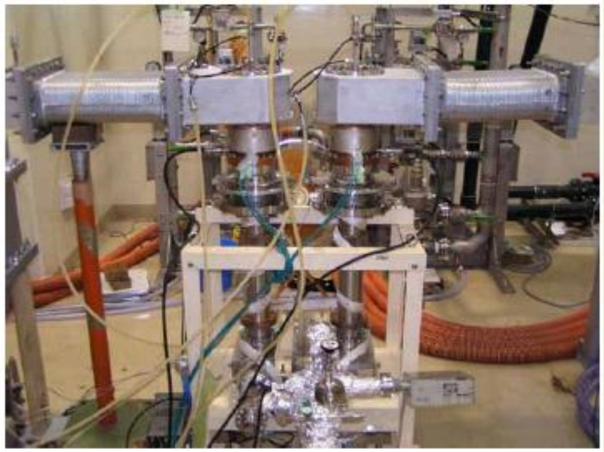
CW/high-duty coupler for Proton Linac

SNS Coupler (ORNL)
805MHz

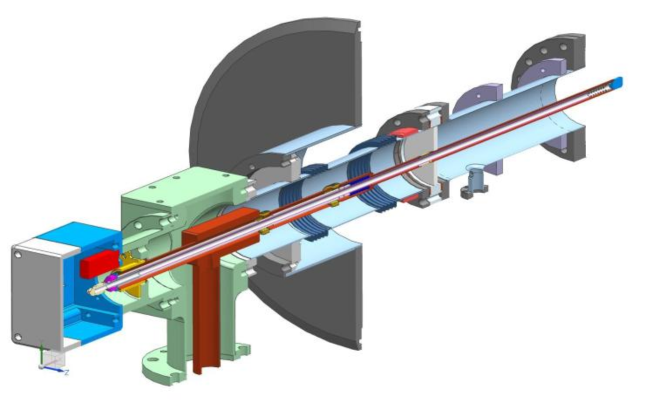




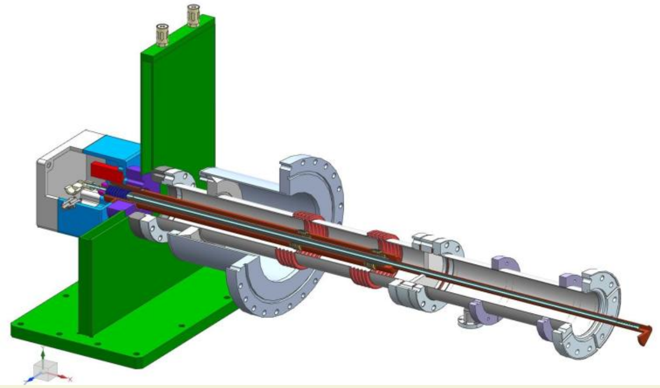
ADS Coupler (KEK)
972MHz



Project-X Coupler
(FNAL) 325MHz

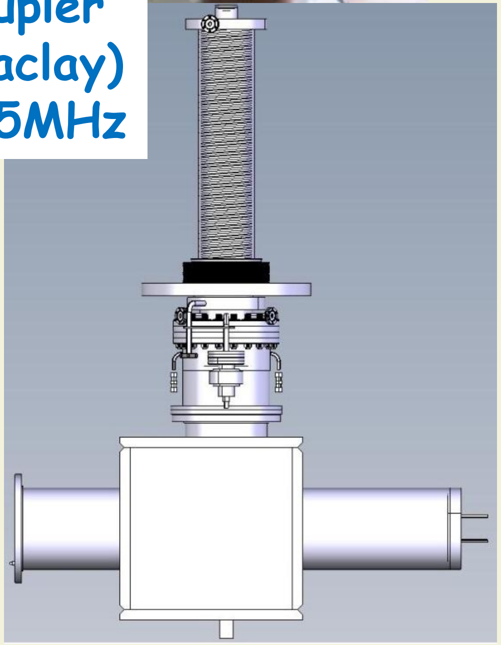


Project-X Coupler
(FNAL) 650MHz

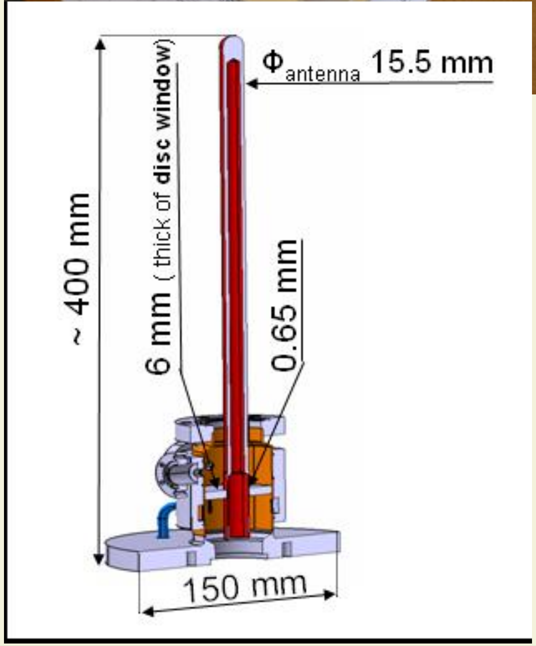


CW coupler for Low-β structure

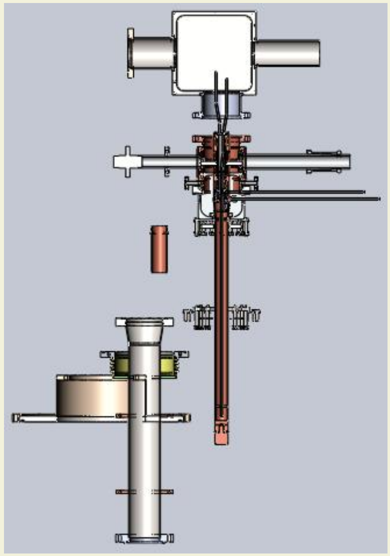
IFMIF Coupler (Saclay) 175MHz



SPIRAL-2 Coupler (LPSC grenoble) 88MHz



Spoke Cavity Coupler for CADS (IHEP) 325MHz

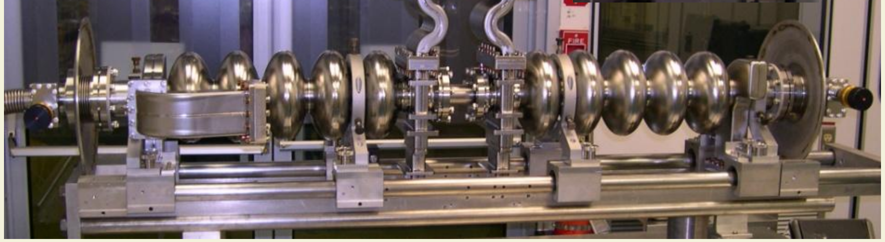


CW Waveguide Input Coupler

Original CEBAF 5-cell cavity (JLab) 1.5GHz

1.5GHz, 2.5kW rectangular WG RF window (TiO_2 ceramics)

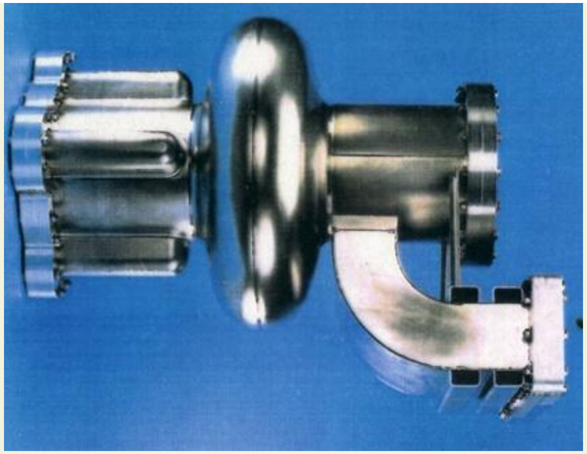
Dogleg waveguide



CEBAF upgrade 7-cell cavity (JLab) 1.5GHz

High current cavity for ERL/FEL (JLab) 1.5GHz

CESR-B cavity (Cornell) 500MHz



High power performance of single-window couplers

Facility	Frequency	Coupler type	RF window	Qext	Max. power
TRISTAN /KEK	508 MHz	Coaxial, Fixed	Coaxial disk	1×10^5	test 200kW, CW oper. 70kW, CW
KEK-B /KEK	508 MHz	Coaxial, Fixed	Coaxial disk	7×10^4	test 800kW, CW oper. 380kW, CW
ADS /KEK	972 MHz	Coaxial, Fixed	Coaxial disk	5×10^5	test 2.0MW pulse oper. 350kW pulse
SNS /ORNL	805 MHz	Coaxial, Fixed	Coaxial disk	-	test 2.0MW pulse oper. 350kW pulse
SPL/Saclay	704 MHz	Coax Fix	Coax. disk	-	test 1.2MW pulse
cERL-Inj. /KEK	1300 MHz	Coaxial, Fixed	Coaxial disk	1×10^6	test 40kW, CW oper. 10kW, CW
SPIRAL-2	88 MHz	Coaxial, Fixed	Coaxial disk	5×10^5 And 1×10^6	test 20kW, CW oper. 12kW, CW
IFMIF	175 MHz	Coax Fix	Coax. disk	6×10^4	spec. 200kW, CW
BERLinPro	1300 MHz	Coax Fix	Coax. disk	1×10^5	spec. 130kW, CW

High power performance of double-window couplers

Facility	Frequency	Coupler type	RF window	Qext	Max. power
TTF3 /DESY	1300 MHz	Coaxial, Variable	Cylindr.	0.1-2x10^7	test 1.0MW pulse oper. 350kW pulse
TTF-V /LAL	1300 MHz	Coaxial, Fixed	Cylindr.	3x10^6	test 2.0MW pulse oper. - pulse
STF2 /KEK	1300 MHz	Coaxial, Variable	Coaxial disk	2-4x10^6	test 1.5MW pulse oper. 450kW pulse
ERL Inj. /Cornell	1300 MHz	Coaxial, Variable	Cylindr.	0.9-8x10^5	test 60kW, CW oper. 40kW, CW
cERL-ML /KEK	1300 MHz	Coaxial, Variable	Coaxial disk	1-4x10^7	test 40kW, CW oper. 15kW, CW
TT3-CW /HZB	1300 MHz	Coaxial, Variable	Cylindr.	3.6x10^6	test 8kW, CW spec. 10kW, CW

Summary

- High power input couplers are one of the most critical components of a superconducting RF cavity system.
- High power input coupler includes varieties of key technologies in design, fabrication, conditioning and operation.

Part - III

Higher Order Mode Couplers

Higher Order Modes Coupler (1)

1. A charge passing through a cavity can excite modes.
2. The mode excited by bunches can seriously affect subsequent charges passing through the cavity.
3. If not sufficiently damped, they can lead to beam instabilities and beam loss.
4. Even without beam break-up, HOMs can degrade the beam quality, leading to loss of luminosity or loss of brightness.

Higher Order Modes Coupler (2)

5. HOMs increase the cryogenic losses due to the additional power dissipation in the cavity wall.

The HOM coupler/damper:

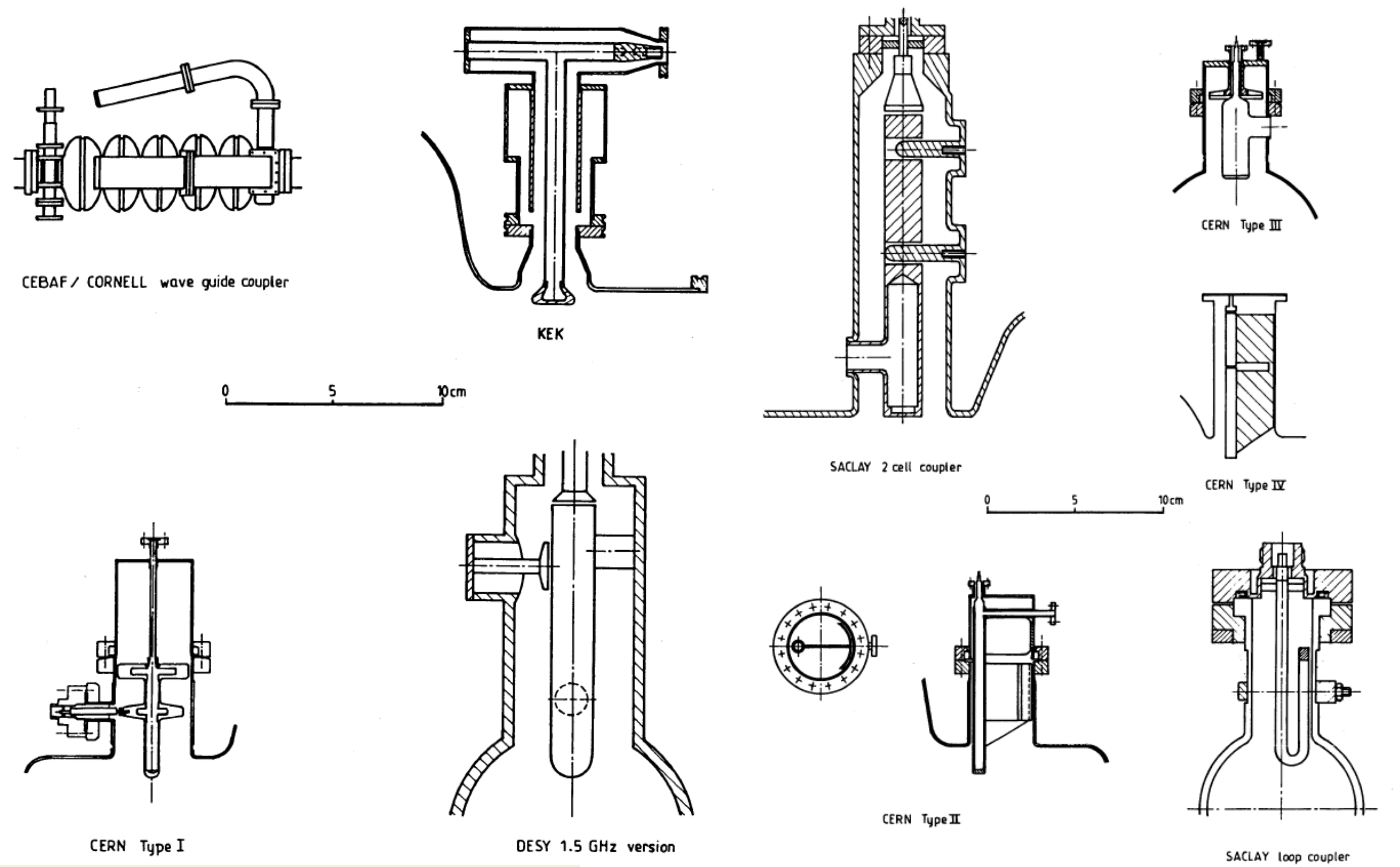
- must remove beam induced power from the cavity in order to avoid resonant buildup of beam induced voltage, and in order to avoid beam instabilities.
- Three types of HOM coupler/damper;

  1. waveguide, 2. coaxial, 3. beam tube.

Contents

1. Design Considerations
2. Waveguide HOM Coupler
3. Coaxial HOM Coupler
4. Beam-tube HOM Damper
5. RF Feedthrough

Design Considerations (1)



SRF1989, by A. Mosnier (CEA-Saclay)

Design Considerations (2)

Requirements for a HOM coupler:

- Damping of all dangerous higher order modes.
- Very small coupling with the fundamental mode.
- Precise tuning of the filter; Qext >10^{11}.
- Effective cooling of superconducting parts to avoid excessive heating.
- Simple design for easy cleaning to remove dusts.
- Cost reduction.

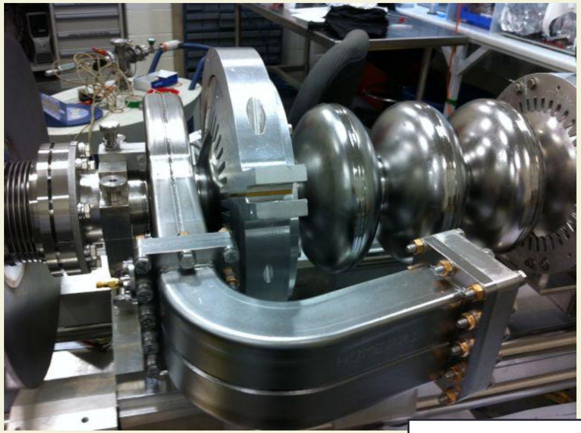
Design Considerations (3)

Requirements for a HOM damper:

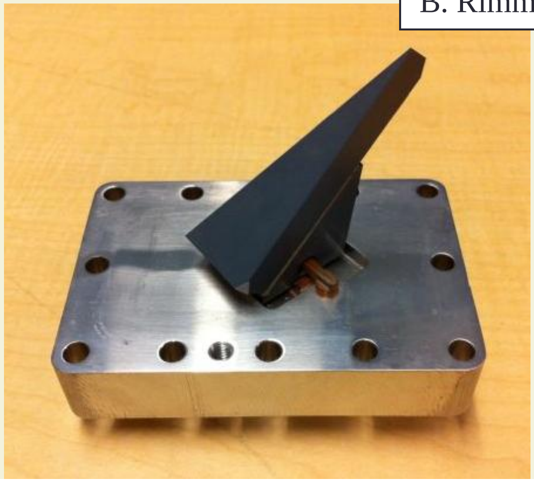
- Damping of all dangerous higher order modes.
- Choice of broad-band absorbing material;
  Ferrite, SiC, AlN, Glassy carbon, etc...
- Preferable operating temperature for cooling.
- Efficient cooling method.
- Low outgassing property in vacuum.
- Reliable cleaning procedure for dust free.
- Cost reduction.

Waveguide HOM Coupler

Original CEBAF waveguide HOM couplers at 2K (JLab)



B. Rimmer, JLab



Glassy-carbon ceramic

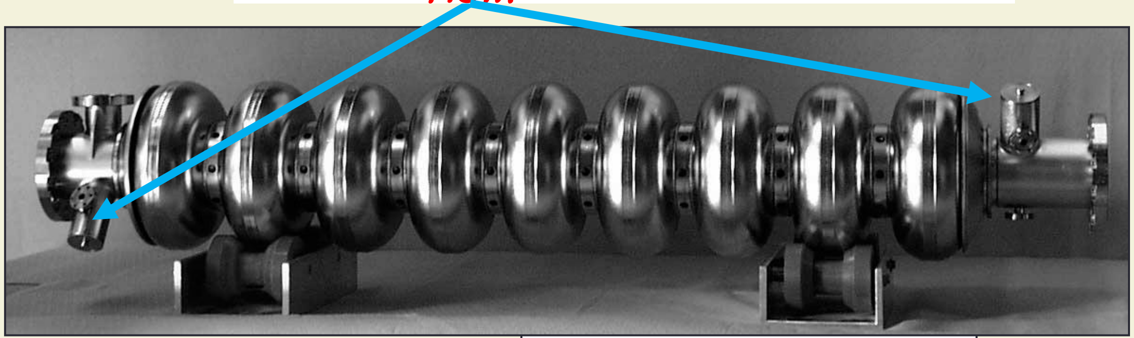
AlN-based composites

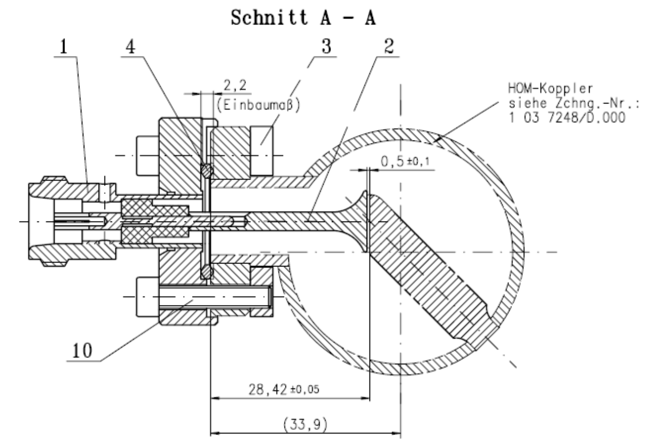
- Cut-off frequency of WG; no tuning in the high pass filter.
- WG flange to be far enough from beam tube.
- Matching stub on beam tube in opposite side.

Coaxial HOM Coupler (1)

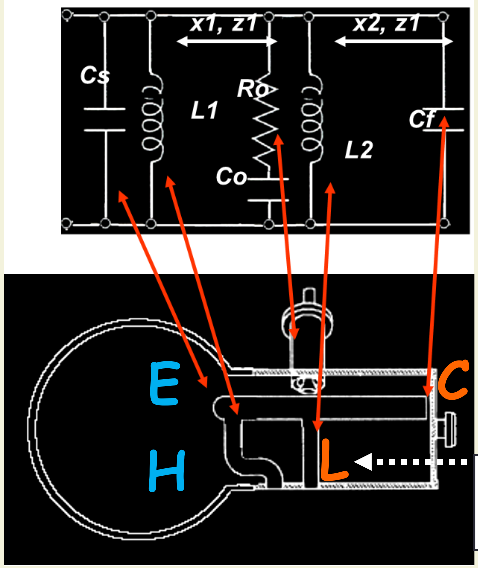
HOM Couplers for 1.3GHz TESLA 9-cell Cavity (DESY)

2 HOM couplers (welded)
$\langle P_{HOM} \rangle$ ~ few watts

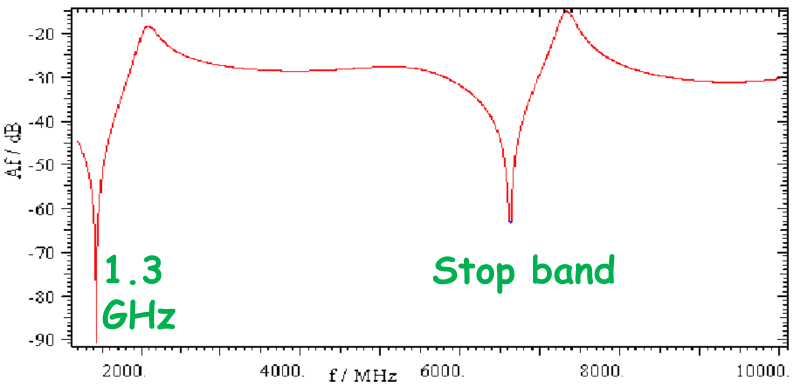




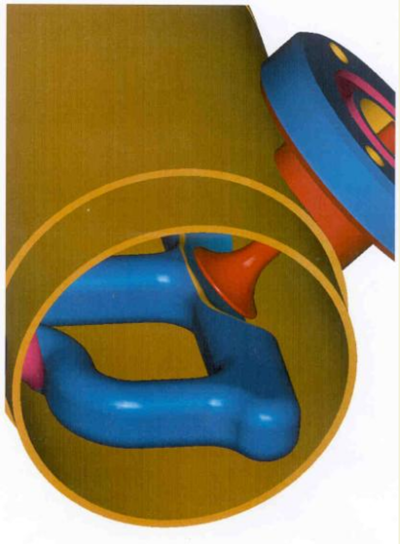
J. Sekutowicz, DESY, Hamburg



FM rejection filter



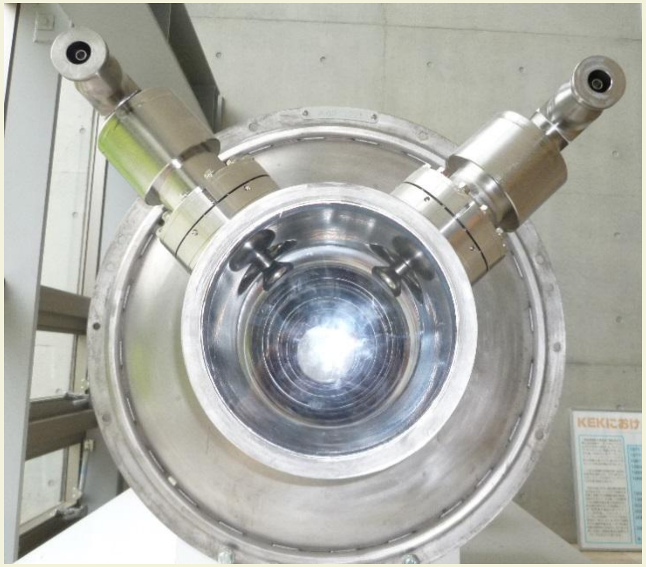
$$f_{rej.} = 1/2\pi\,(LC)^{\wedge}0.5$$

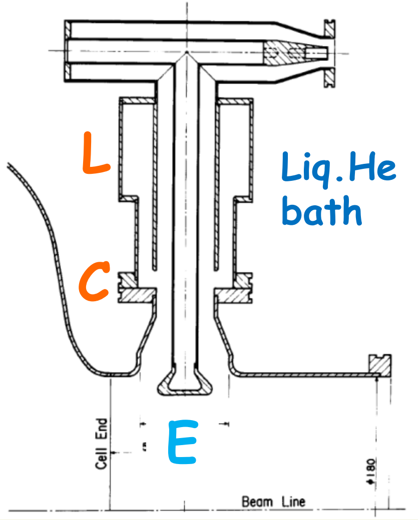


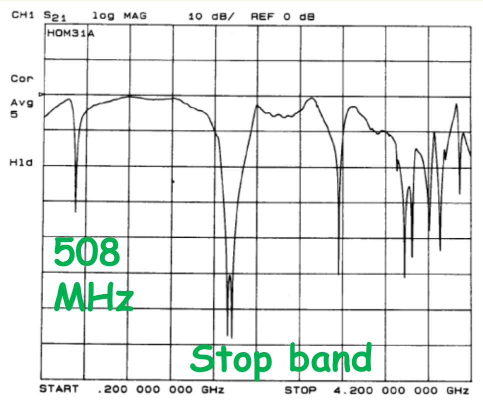
Coaxial HOM Coupler (2)

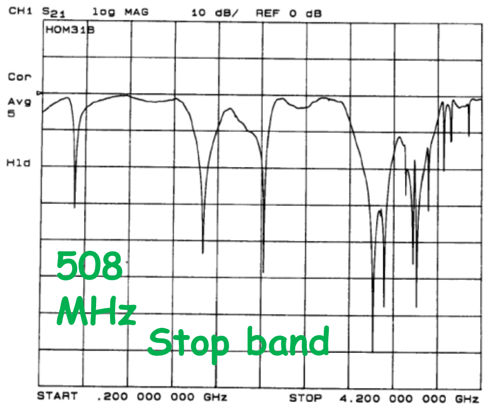
HOM Couplers for 508MHz TRISTAN 5-cell Cavity (KEK)

2 HOM couplers (demountable)





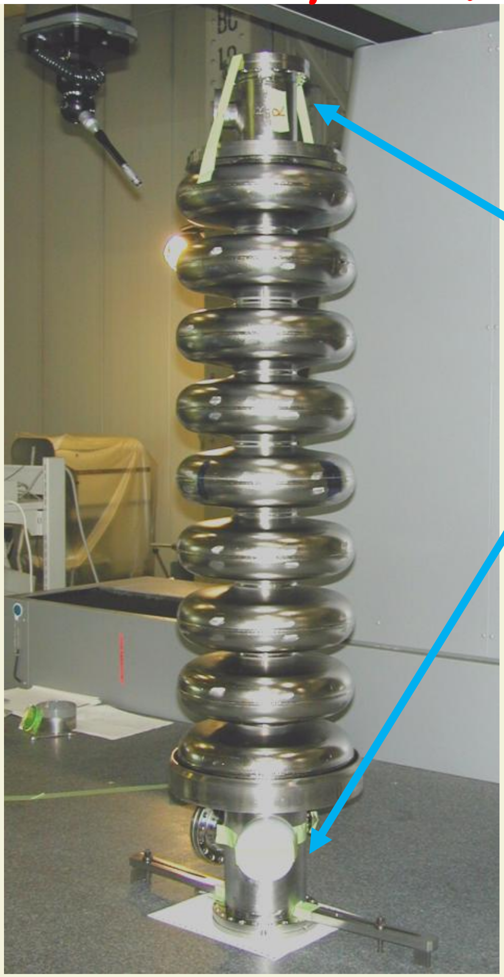


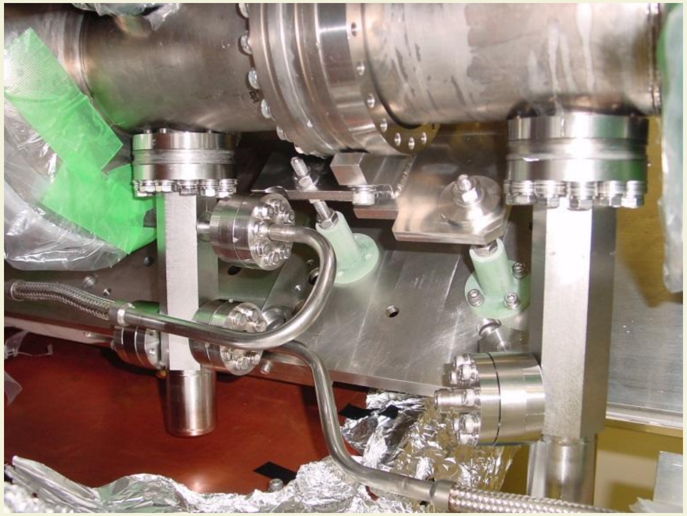


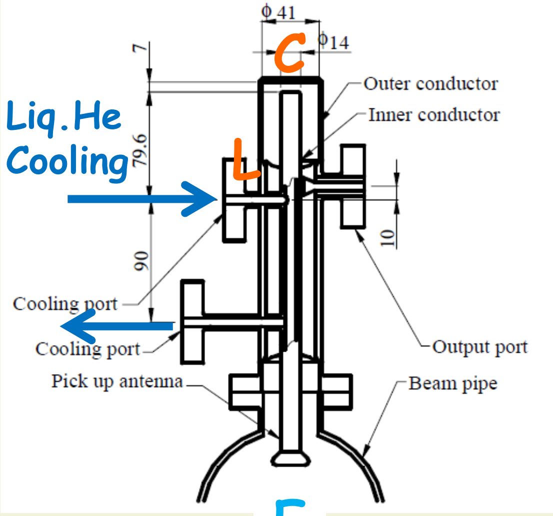
Coaxial HOM Coupler (3)

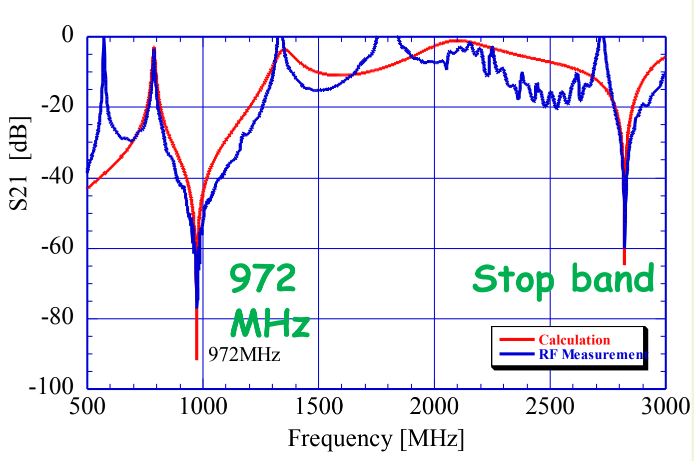
HOM Couplers for 972MHz ADS 9-cell Cavity (KEK)

2 HOM couplers (demountable)







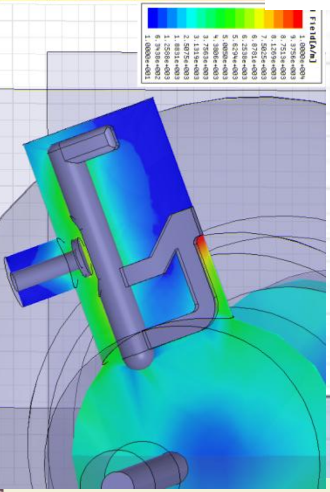


Coaxial HOM Coupler (4)

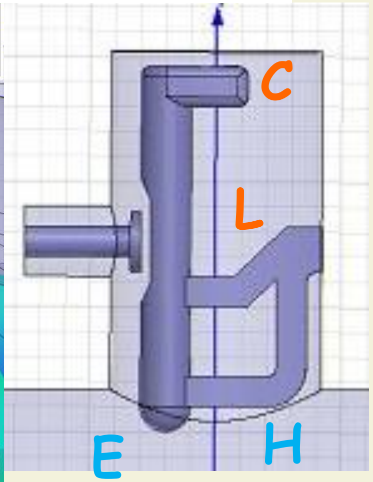
HOM Couplers for 1.3GHz STF 9-cell Cavity (KEK)

2 HOM couplers (welded)

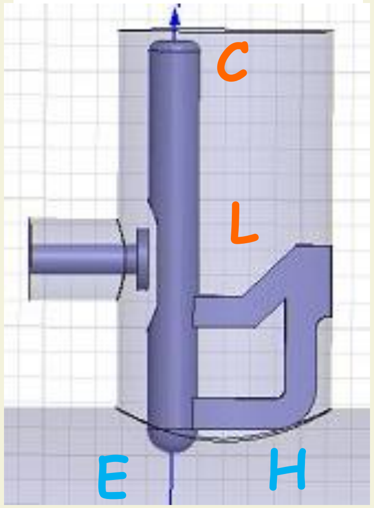
Two types of HOM couplers

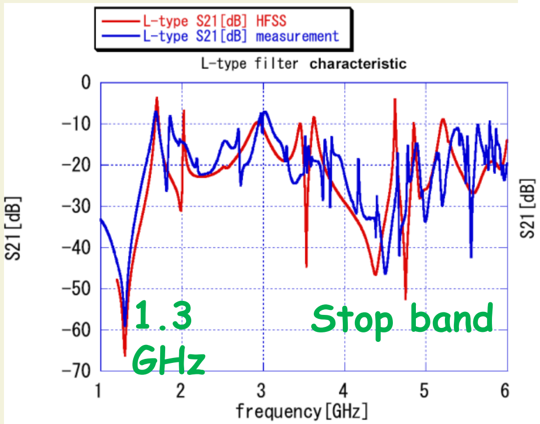


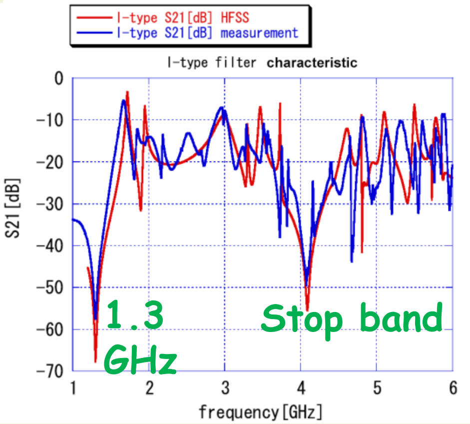
HOM L-type



HOM I-type



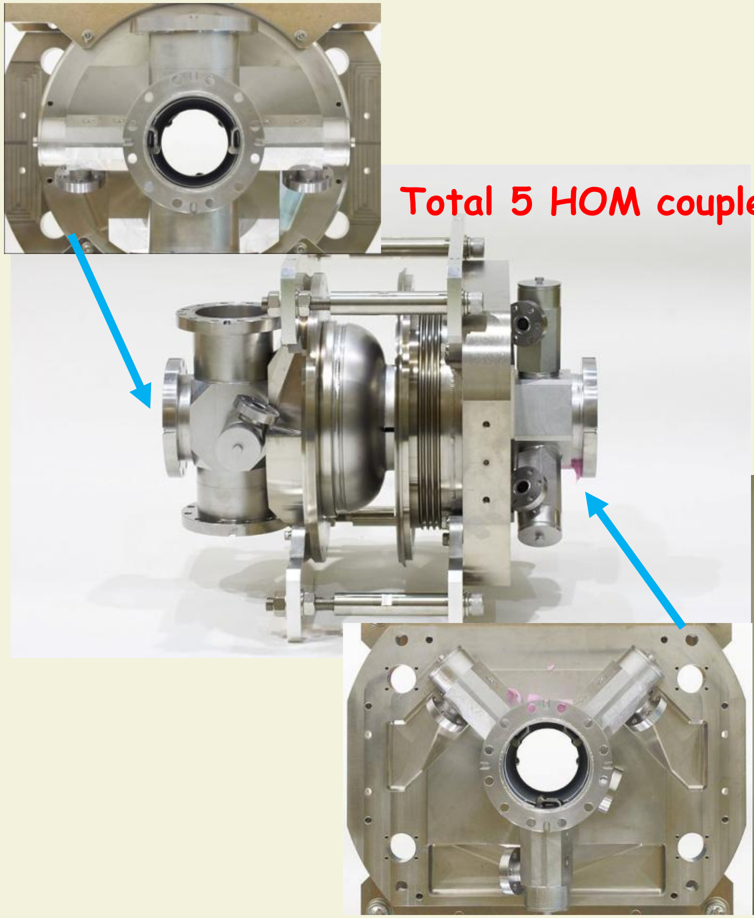




Coaxial HOM Coupler (5)

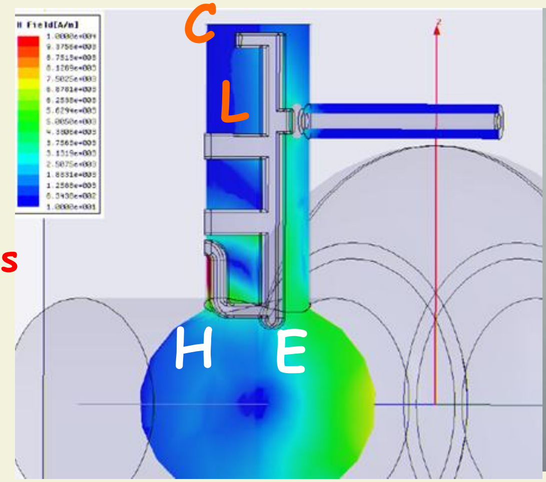
HOM Couplers for 1.3GHz cERL 2-cell Cavity (KEK)

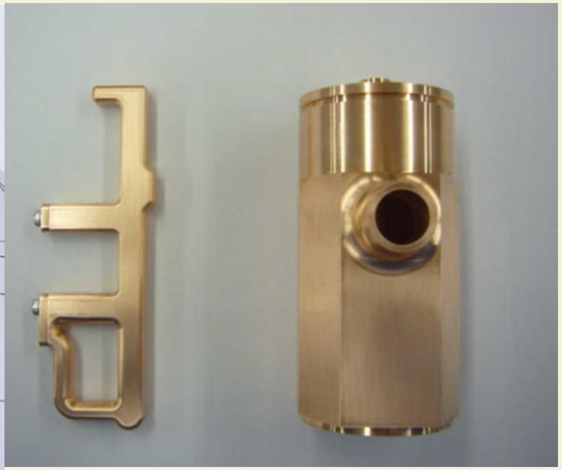
2 HOM & 2 Input couplers

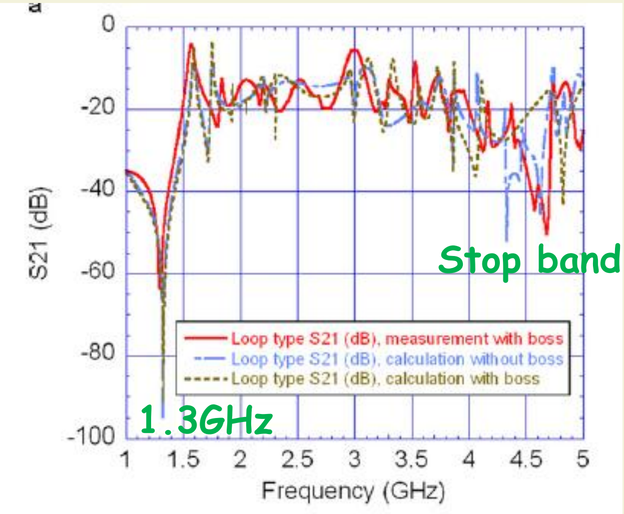


Total 5 HOM couplers

3 HOM couplers

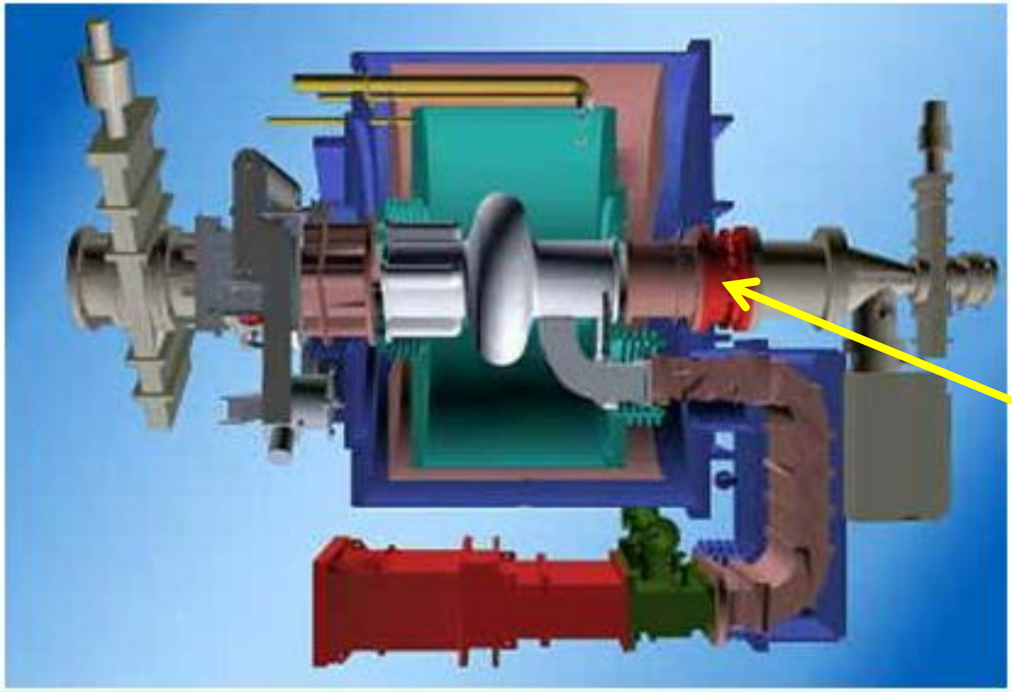






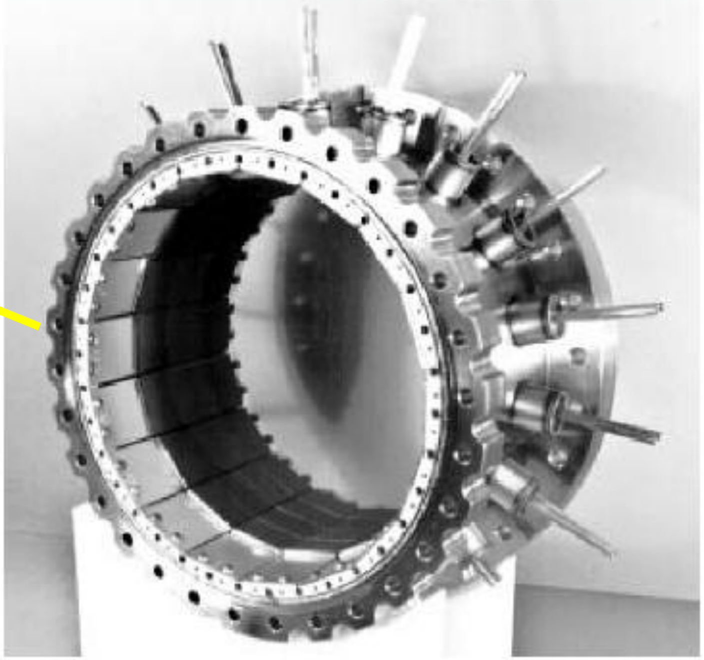
Beam Tube HOM Damper (1)

HOM Damper for 500MHz CESR-B Cavity (Cornell)



S. Belomestnykh, Cornell

Cornell CESR HOM Load

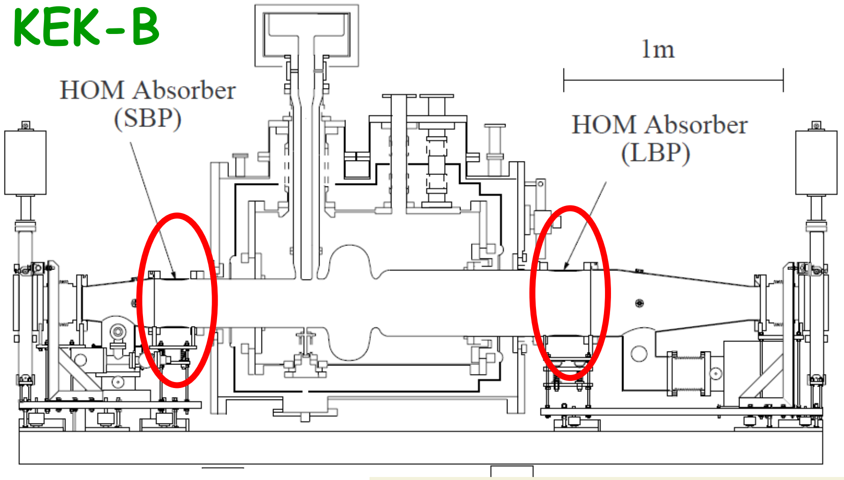


- Ferrite absorber tiles
- Water cooled

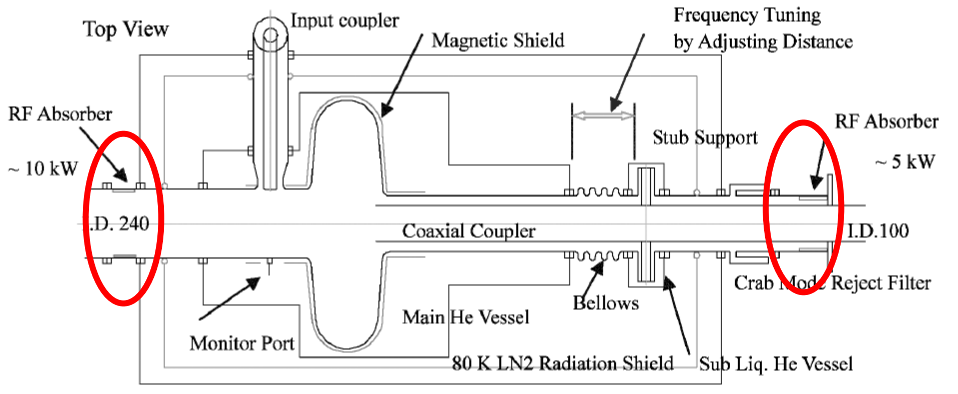
Beam Tube HOM Damper (2)

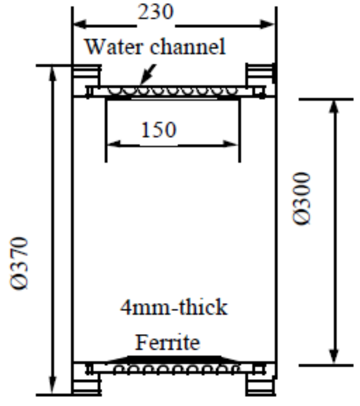
HOM Damper for 508MHz KEK-B and Crab Cavity (KEK)

KEK-B



Crab Cavity

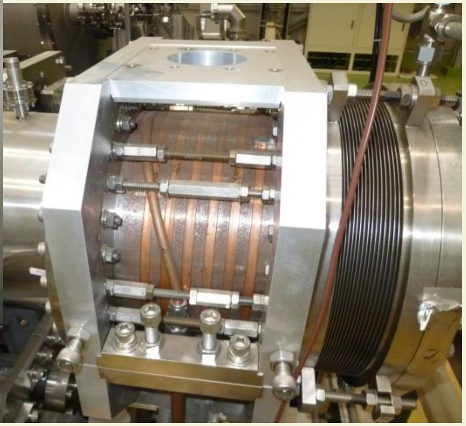




Absorber (L)

T.Tajima, KEK

- HIP Ferrite absorber
- Water cooled



H. Nakai, KEK

Beam Tube HOM Damper (3)

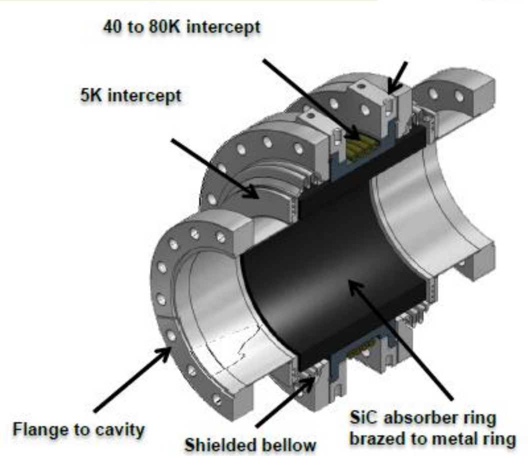
HOM Damper for 1.3GHz ERL Injector and ML Cavity (Cornell)

Cornell ERL injector HOM Load

- 3 types of absorber tiles
- One was charging up ☹
- Operated at 80 K
- Complicated to mount

- Ferrite tile absorber
- Cooled at 80K

Main Linac HOM Absorbers



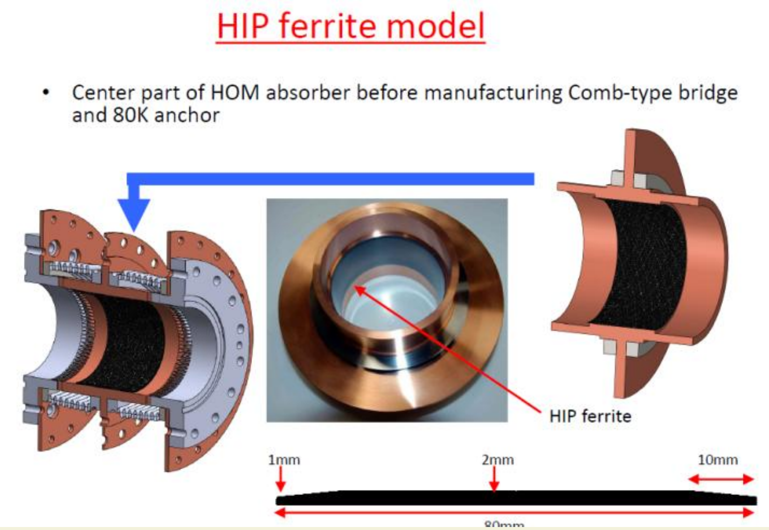
- SiC ring absorber
- Cooled at 40-80K

- Full-circumference heat sink to allow >500W dissipation @ 80K
- Broadband SiC absorber ring
- Includes bellow sections
- Flanges allow easy cleaning
- Zero-impedance beamline flanges

R. Eichhom, Cornell

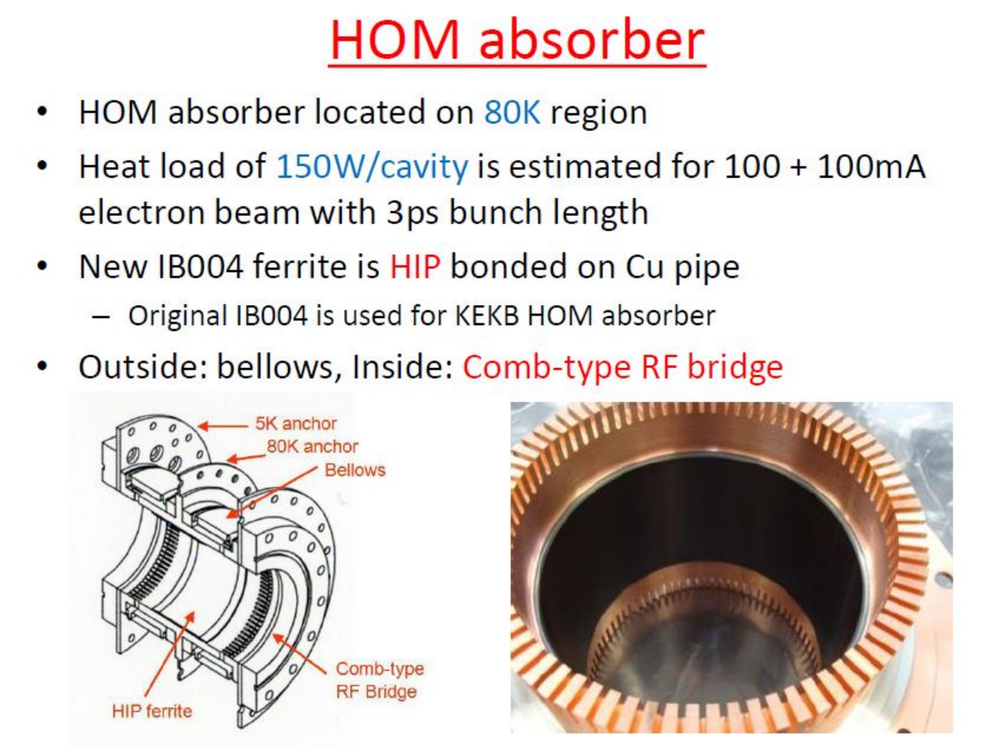
Beam Tube HOM Damper (4)

HOM Damper for 1.3GHz cERL ML 9-cell Cavity (KEK)



HIP ferrite model

- Center part of HOM absorber before manufacturing Comb-type bridge and 80K anchor



HOM absorber

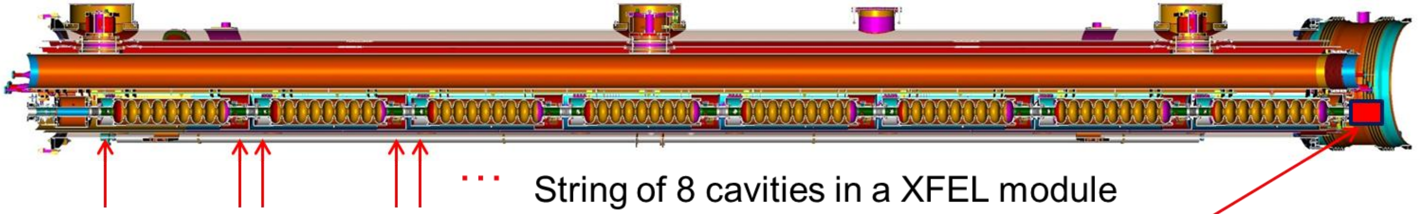
- HOM absorber located on 80K region
- Heat load of 150W/cavity is estimated for 100 + 100mA electron beam with 3ps bunch length
- New IB004 ferrite is HIP bonded on Cu pipe
  - Original IB004 is used for KEKB HOM absorber
- Outside: bellows, Inside: Comb-type RF bridge

K. Umemori, KEK

- **HIP Ferrite absorber**
- **Cooled by nitrogen, 80K**
- **Very slow cool-down speed**

Beam Tube HOM Damper (5)

HOM Damper for 1.3GHz XFEL 9-cell Cavity (DESY)



String of 8 cavities in a XFEL module

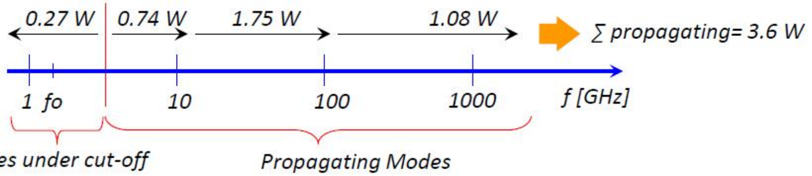
2 HOM couplers on cavities

One HOM absorber per string

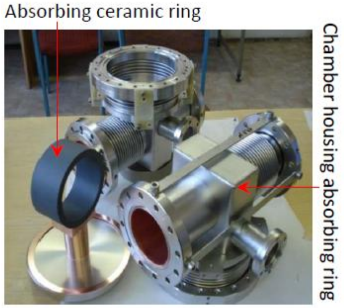
J. Sekutowicz, DESY, Hamburg

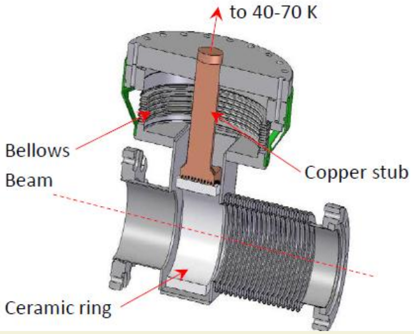
Beam Line Absorber Concept:

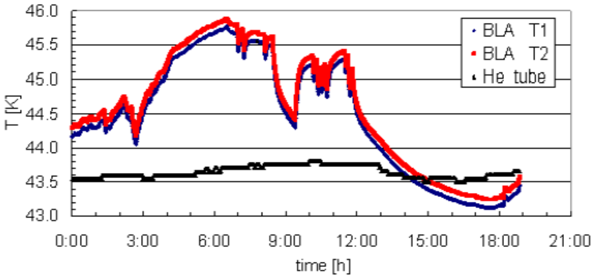
Nominal beam with 27000 short bunches will generate HOM power of 3.9 W/CM

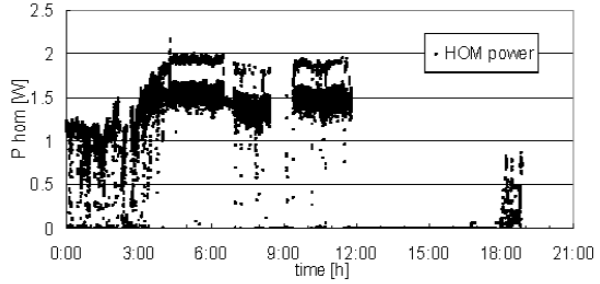


The XFEL beam line absorbers suppressing propagating modes have capacity of 100 W, which makes them suitable for large DF operations .





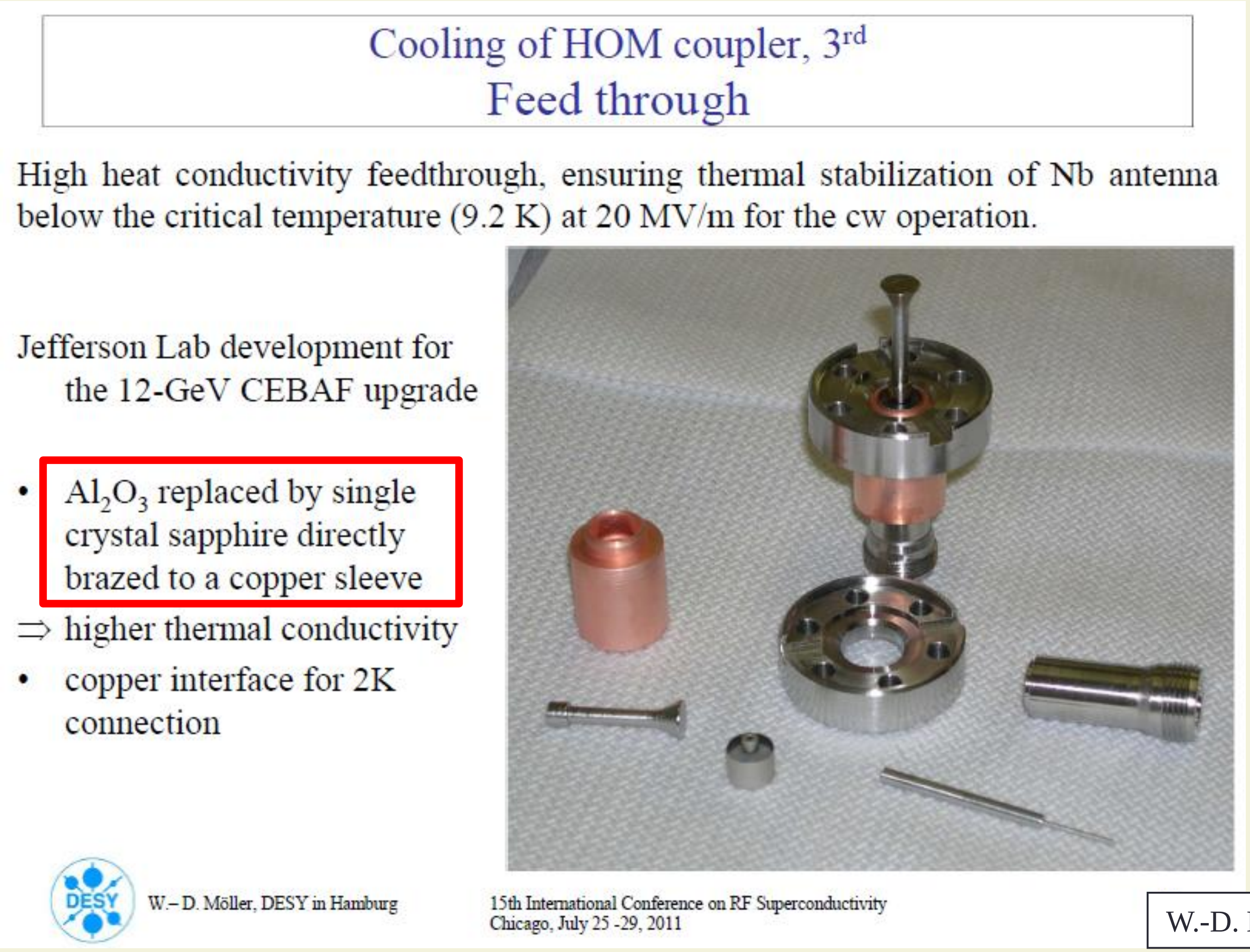




- **Special ceramic ring absorber**
- **Cooled to 40-70K**

RF Feedthrough (1)

RF Feedthrough for 1.5GHz CEBAF-Upgrade 7-cell Cavity (JLab)



Cooling of HOM coupler, 3^{rd}
Feed through

High heat conductivity feedthrough, ensuring thermal stabilization of Nb antenna below the critical temperature (9.2 K) at 20 MV/m for the cw operation.

Jefferson Lab development for the 12-GeV CEBAF upgrade

- Al_2O_3 replaced by single crystal sapphire directly brazed to a copper sleeve

⇒ higher thermal conductivity

- copper interface for 2K connection

W.– D. Möller, DESY in Hamburg

15th International Conference on RF Superconductivity
Chicago, July 25 -29, 2011

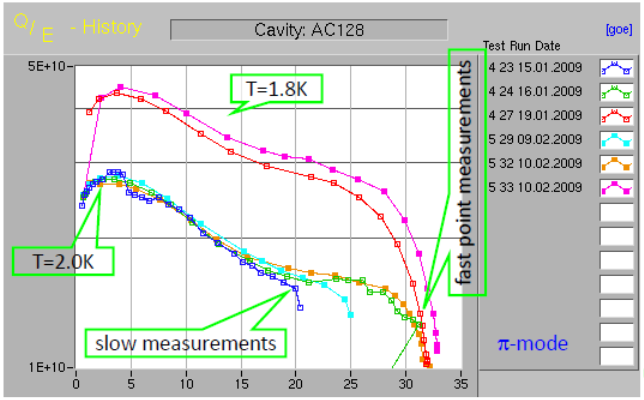
W.-D. Moeller, DESY, Hamburg

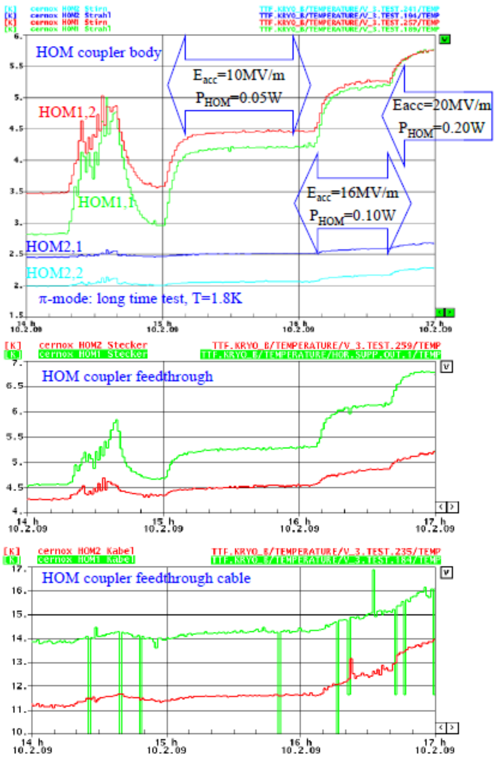
RF Feedthrough (2)

RF Feedthrough for 1.3GHz XFEL 9-cell Cavity (DESY)

HISTORY:

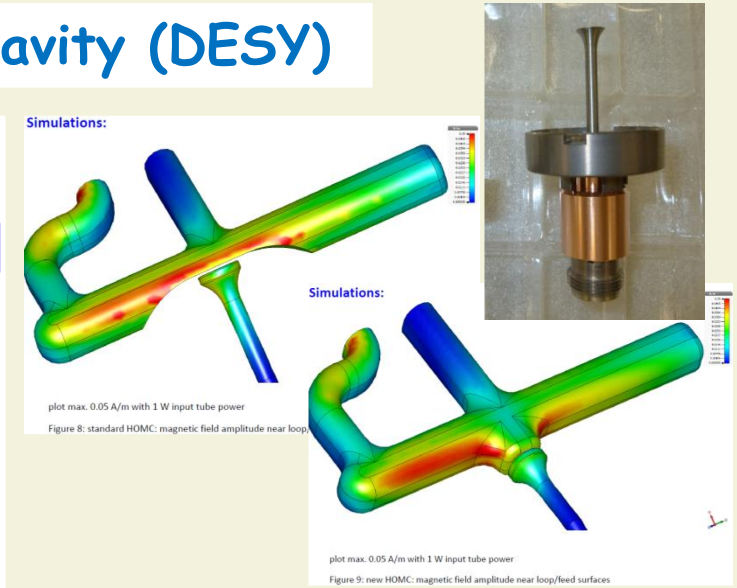
CW test on cavity AC128 in the horizontal cryostat





Heat load from HOM couplers / HOM couplers temperature increase

D.Kostin, at.al, **TESLA Type 9-Cell Cavities Continuous Wave Tests**, SRF2009


Simulations:

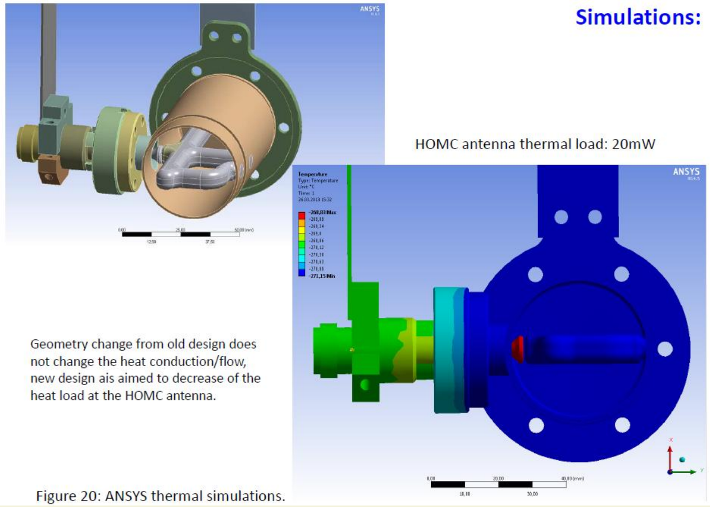
plot max. 0.05 A/m with 1 W input tube power

Figure 8: standard HOMC: magnetic field amplitude near loop

Simulations:

plot max. 0.05 A/m with 1 W input tube power

Figure 9: new HOMC: magnetic field amplitude near loop/feed surfaces


Simulations:

HOMC antenna thermal load: 20mW

Geometry change from old design does not change the heat conduction/flow, new design ais aimed to decrease of the heat load at the HOMC antenna.

Figure 20: ANSYS thermal simulations.

D. Kostin, DESY, Hamburg

RF Feedthrough (3)

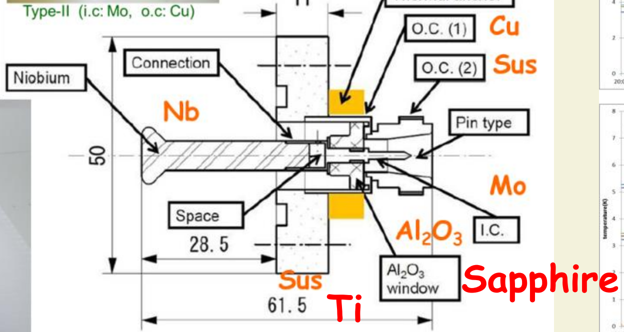
RF Feedthrough for 1.3GHz cERL 2-cell Cavity (KEK)

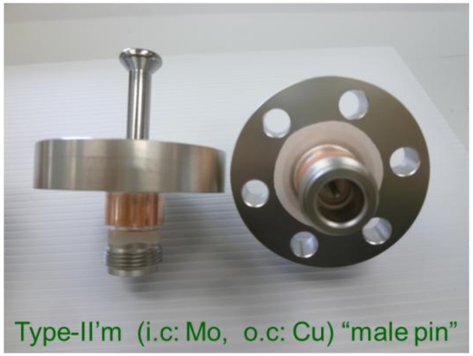

Type-0 (i.c: Kovar, o.c: Kovar)

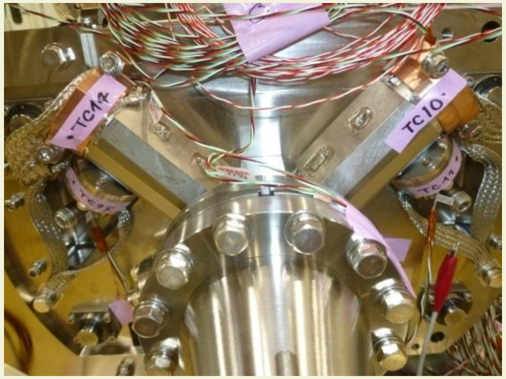

Type-I (i.c: Mo, o.c: Kovar)

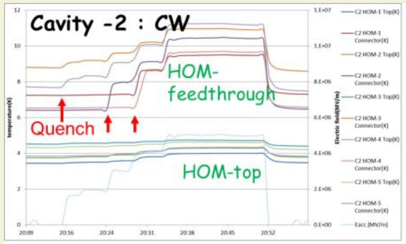

Type-II (i.c: Mo, o.c: Cu)

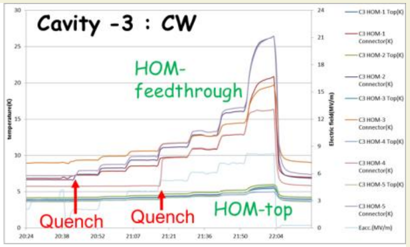
By K. Watanabe

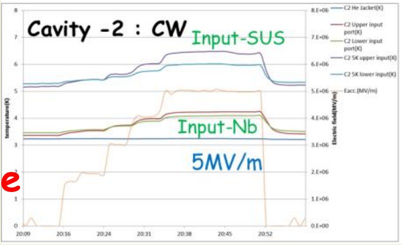


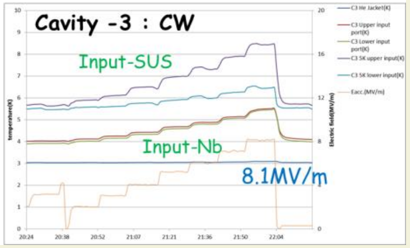

Type-II'm (i.c: Mo, o.c: Cu) "male pin"

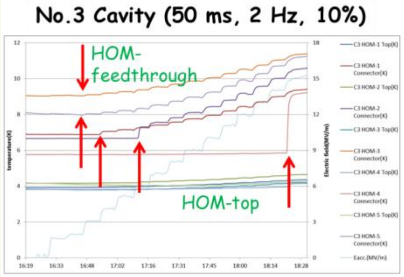


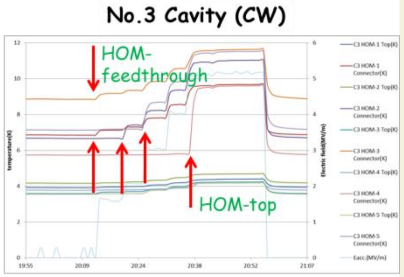












Eacc at antenna quench

	No.3 Cavity (10% Duty)	No.3 Cavity (CW)
HOM-1:	4 MV/m	1.7 MV/m
HOM-2:	6 MV/m	2 MV/m
HOM-3:	3 MV/m	1.7 MV/m
HOM-4:	15 MV/m	5 MV/m
HOM-5:	3 MV/m	3 MV/m

Summary

- Higher order modes couplers are one of the critical components of a superconducting RF cavity system.

- Higher order modes coupler includes varieties of key technologies in design, fabrication, conditioning and operation.

I would like to acknowledge to all colleagues, who have contributed to this talk.

END

Thank you for your attention.