PHY905 Section 4
Ion Accelerator Technology
Lecture 19
- Cavity Ancillaries -

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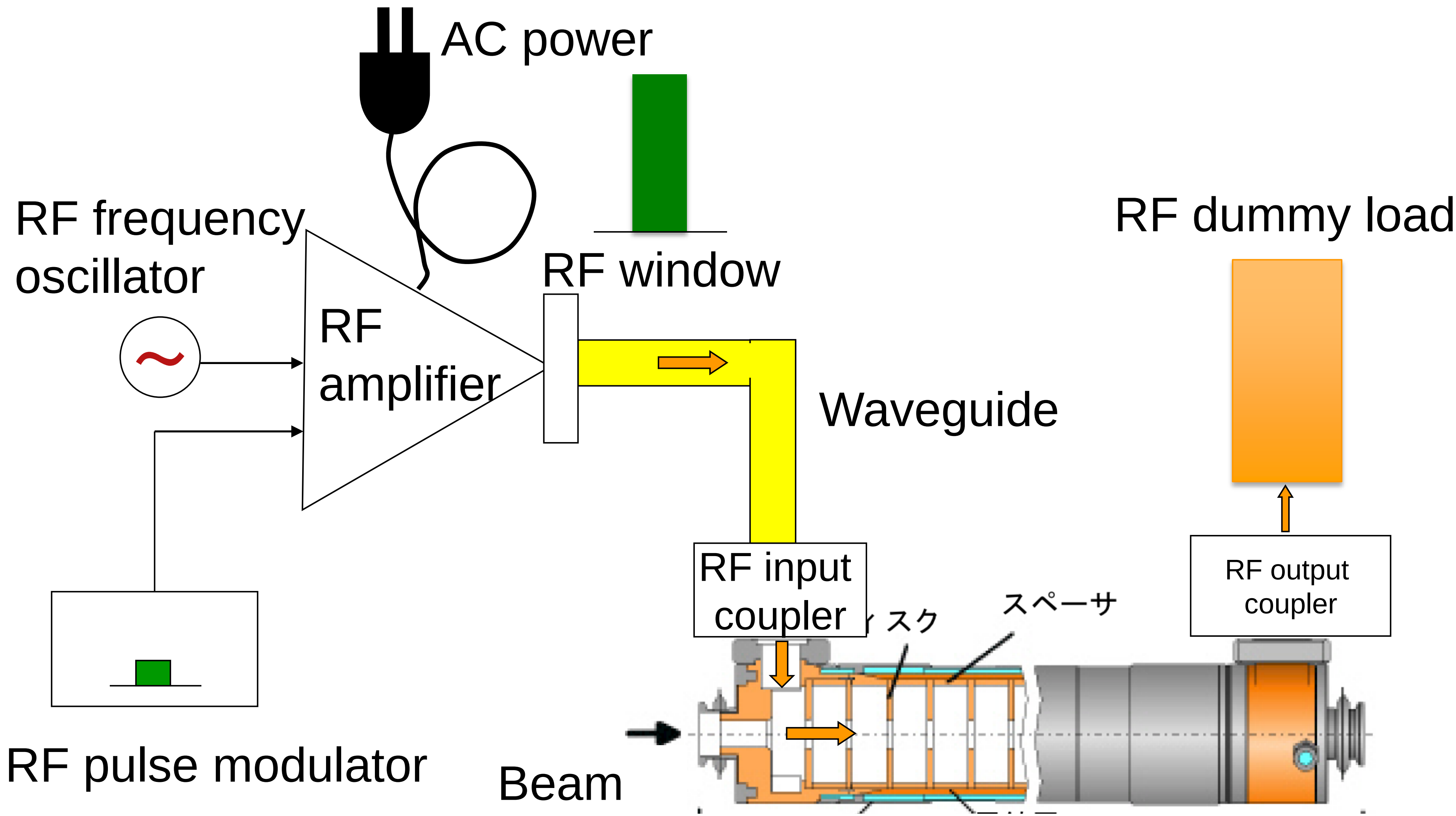
19 Cavity Ancillaries

19.1 Fundamental power coupler

19.2 Higher Order Mode(HOM) coupler

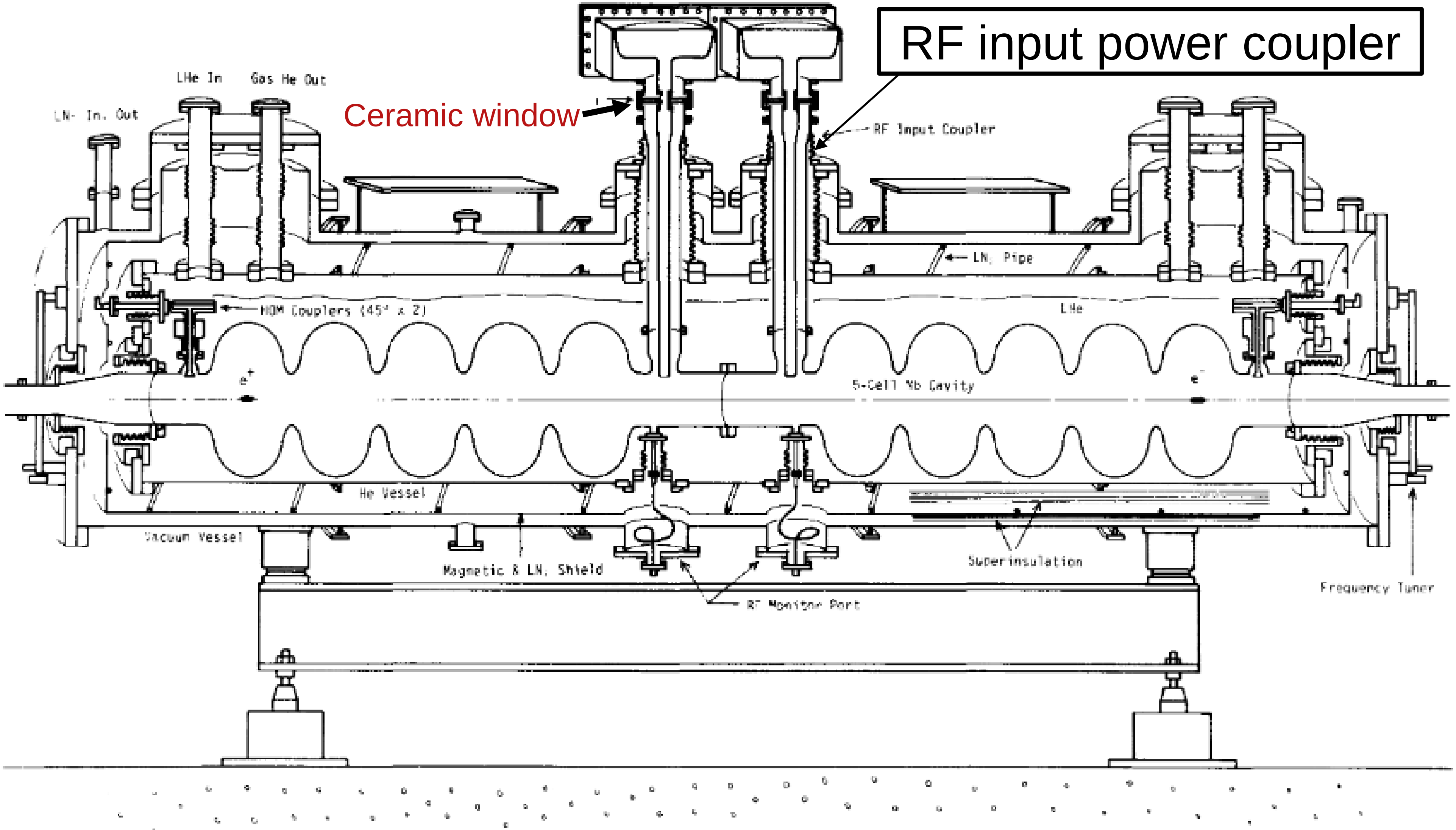
19.3 Tuner

19.1 Fundamental power coupler
Accelerator system (normal conducting case)



SRF Cryomodule

KEK TRISTAN Cryomodule (4.5 K operation)



Function of RF Fundamental Power Coupler (FPC)

- Has to transfer the RF power to the beam and to the cavity field at high power levels in pulsed or CW operation.
- Has to match the impedance of the RF source (klystron or semiconductor RF amp.) to the beam loaded cavity.
- Possibly allow changes to match different beam conditions.
- Bridge the gap between room and cryogenic-temperature.
- Provide a vacuum barrier for the beam vacuum.
- Not contaminate the cavity
  - easy cleaning
  - Clean assembly

KEK TRISTAN SRF FPC

RF amplifier ⇨ Waveguide

⇩

Doorknob
Mode transformer
Square waveguide to coaxial waveguide

⇩

Atmosphere

- - - - - - - - - - - - - - - - - - - -

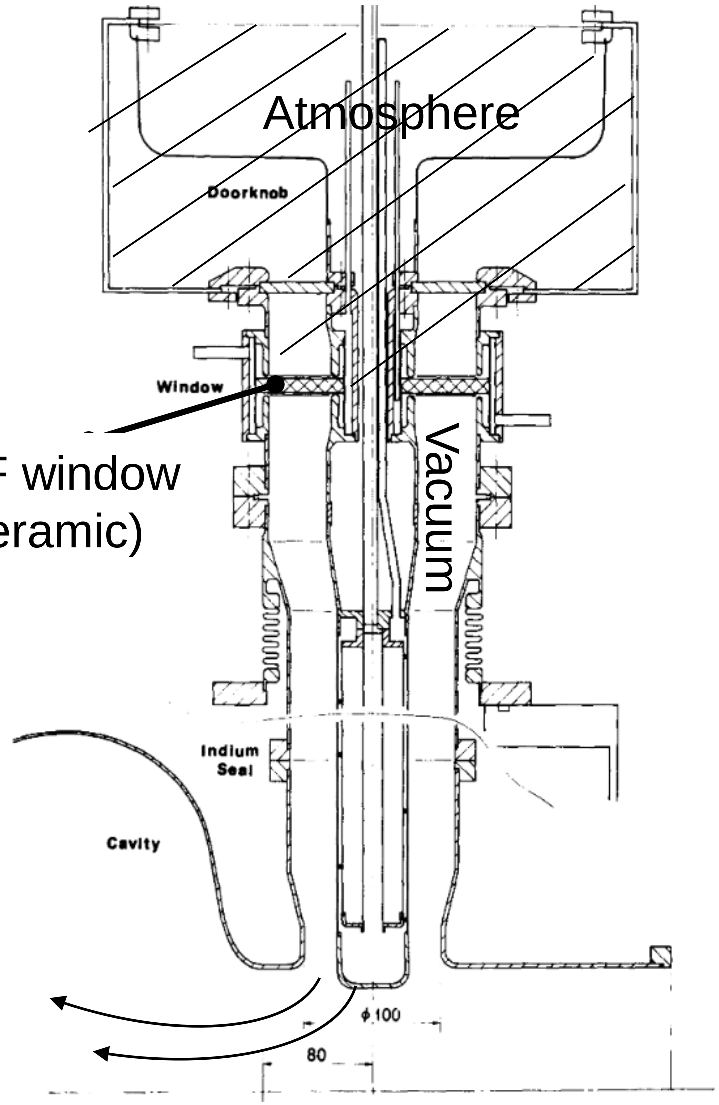
Vacuum

Input coupler

⇩

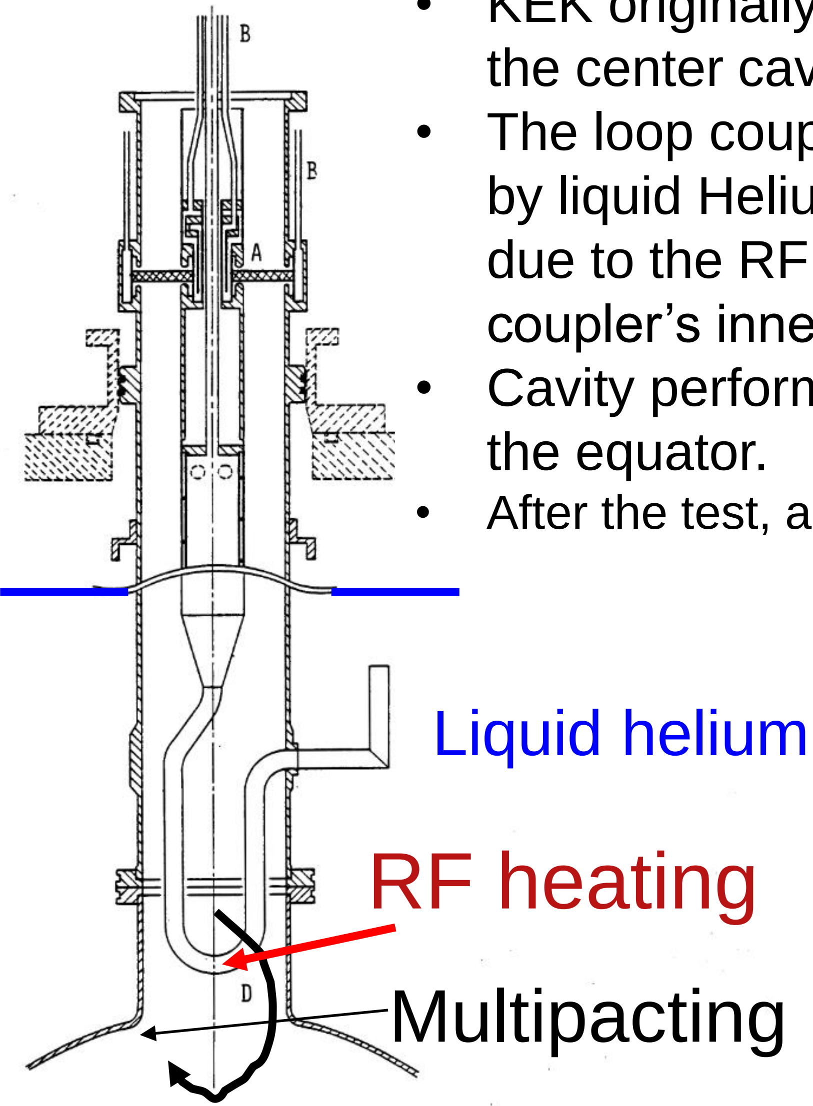
Cavity

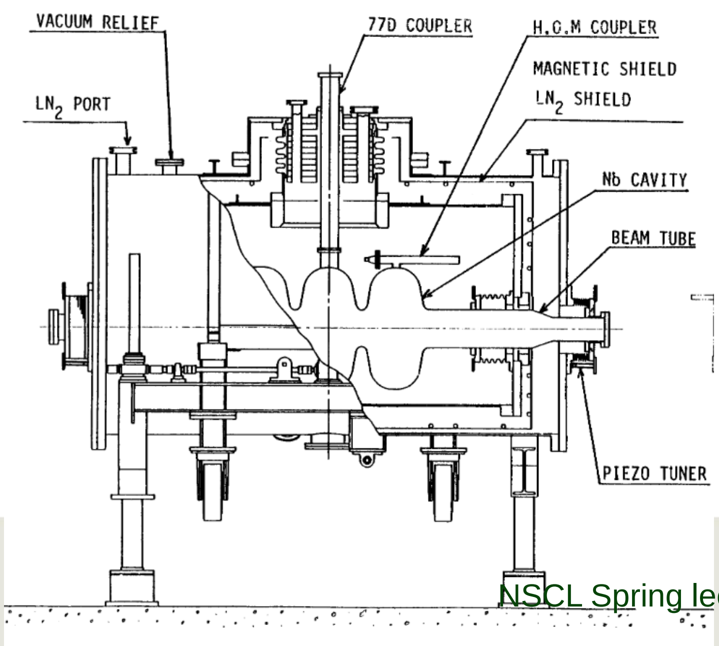
RF window (ceramic)



Why FPC Puts on the Beam Pipe ?

- KEK originally designed the loop couple FPC on the equator of the center cavity and tested the FPC with beam.
- The loop coupler (copper plated on stainless pipe) was cooled by liquid Helium, which was easily boiled off and evaporated due to the RF heating, then the bottom melted. Cooling of loop coupler's inner conductor is very difficult.
- Cavity performance was limited by multipacting on the port on the equator.
- After the test, antenna type FPC on the beam pipe was developed.





FPC: One of the Most Critical Parts of A SRF Cavity System

Wolf-Dietrich Möller

- Vacuum failure (cracked window)–bad contamination of the very delicate SC cavity surface–recovery is time consuming and expensive
- Power limitation (arcing, window heating, multipacting)–limits the SC cavity performance–may damage the coupler over time and makes it inoperable

Destruction by excessive power rises with deactivated interlock!!

Design Criteria of FPCs

- Simpler structure
- Don't let RF window (ceramic) face to the beam
- Good matching to prevent standing waves (increased voltage)
- Prevent multipcating at operating power level
- Prevent field emission and breakdowns
- Fast processing time
- Safe operation
- Interlock system to secure coupler & cavity

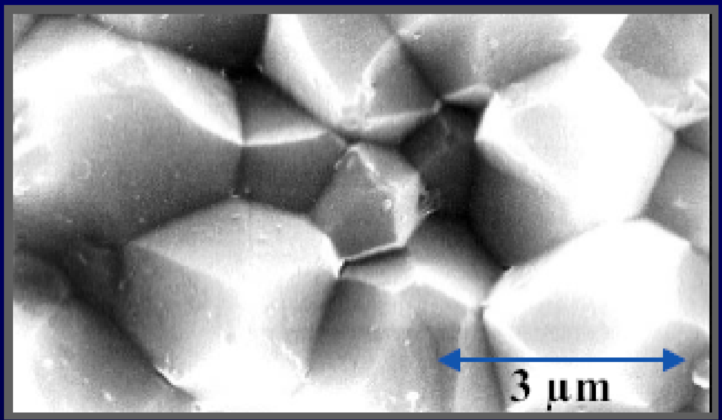
Two Types for RF FPCs
Waveguide and Coaxial

- Wave guide coupler:
  - Lower surface electric field
  - No easy tuning for the match
  - High thermal radiation
  - Machining of rectangular parts is more expensive
- Coaxial coupler:
  - More compact
  - Easy tuning of match, change penetration of antenna
  - Circular parts are easy to machine, assemble, seal
  - Asymmetric fields cause kicking off the beam
- Key technologies for FPC fabrication:
  - Ceramic quality
  - Anti-MP coating on ceramic window (vacuum side)
  - Brazing between Ceramic window and Stainless IC/OC
  - Copper Plating

High Purity Alumina and Diamond-like Carbon Coating

- TiN or Diamond-like carbon coating on RF window (vacuum side) to suppress field emission

Major characteristics of HA-997 (NTK)
- Alumina contents (%): 99.7
- Specific gravity: 3.95
- Dielectric constant (ε): 9.8~9.9 (8-GHz)
- Temperature coefficient of ε (ppm/°C): +90~+110
- Dielectric loss tangent (Tan δ): 3×10^{-5} (@8-GHz)

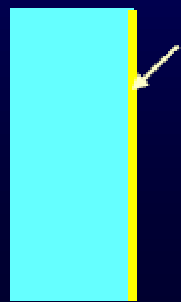


Advantages:
- almost uniform grain size.
- no large voids found between grain boundaries.

Super hard diamond-like carbon coating using Gas Cluster Ion Beam Assisted Deposition (GCIB). Nomura Plating Co.,Ltd.

	GCIB	CVD
Hardness [GPa]:	>50	20~30
Young's modulus:	270	140
Component:	Carbon	Carbon+H_2
Diamond content:	Rich	Weak
Density:	High	Low
Heat resistant: (at air)	500°C	<400°C
Flatness (Ra, nm):	<0.5	0.5

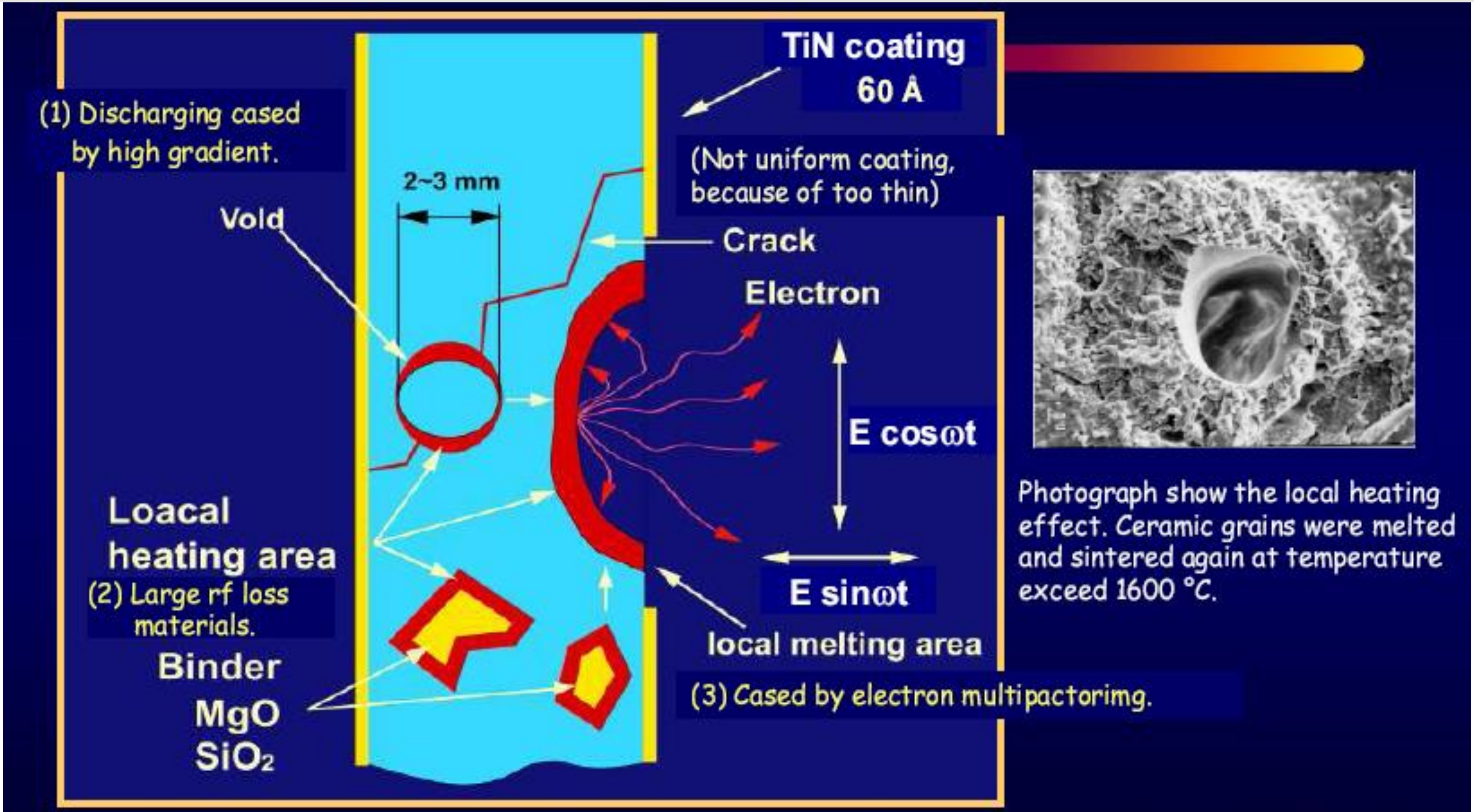
Al_2O_3 (99.7%)



Diamond-like carbon with 100-nm of coating thickness will provide good uniformity.

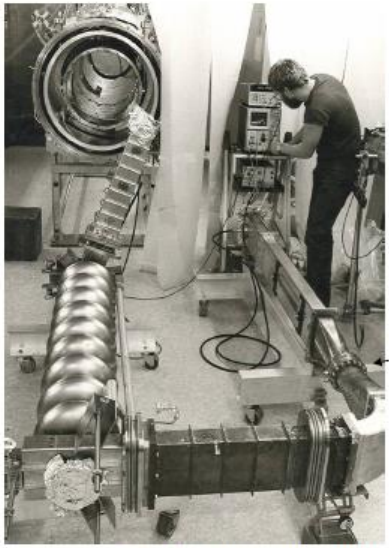
NOTE: need investigate rf characteristics at high power.

Typical Breakdown Mechanism of Ceramic

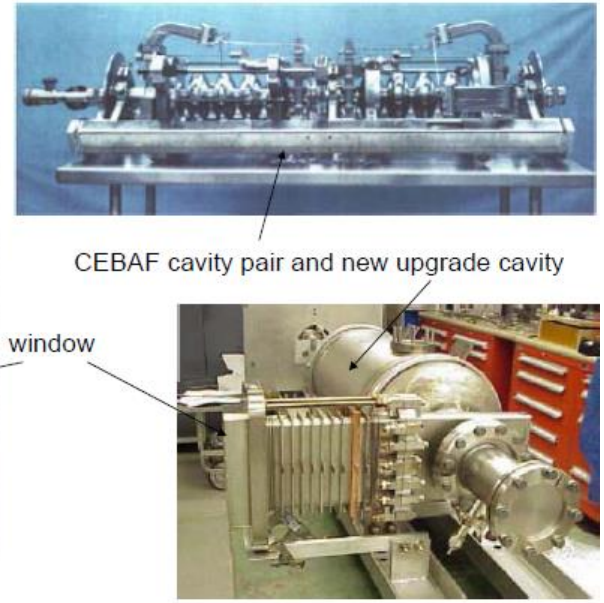


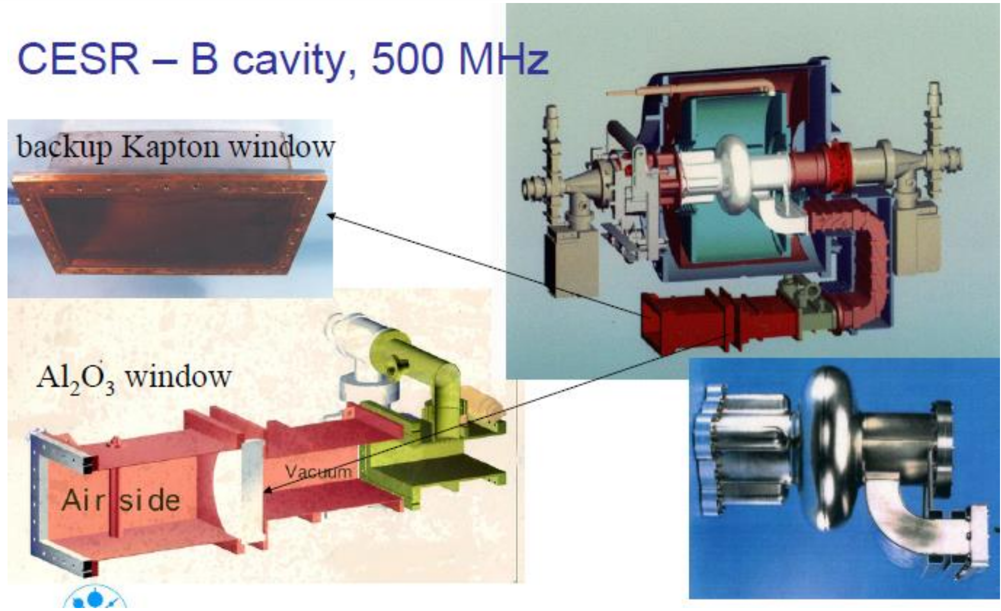
If the binder fraction is made smaller, the sintering temperature has to be increased up to 1600 °C, and increase the porosity (void population). Thus, reduction of binder and reduction of porosity are incompatible.

Various Waveguide Couplers



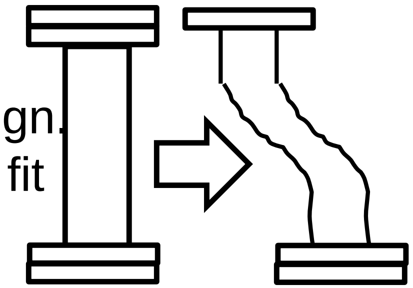
1 GHz Petra test cavity

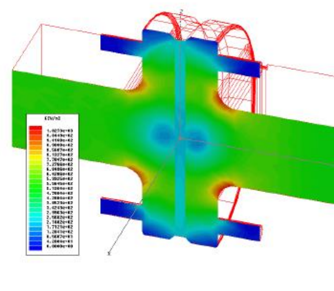




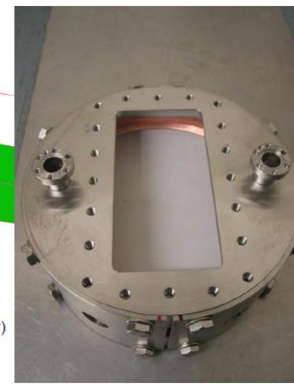
Lessons learned from CEBAF experience

- RF window (ceramic) faces the beam at close to the beam pipe in the original design.
- Errant electrons or field emitted electrons fit the RF window and made holes, vacuum leak happened
- They modified the RF window location: S-shaped waveguide

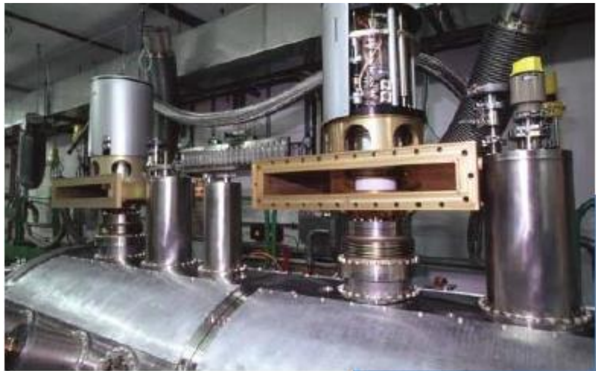




window with diagnostic ports (TTF2 coupler)



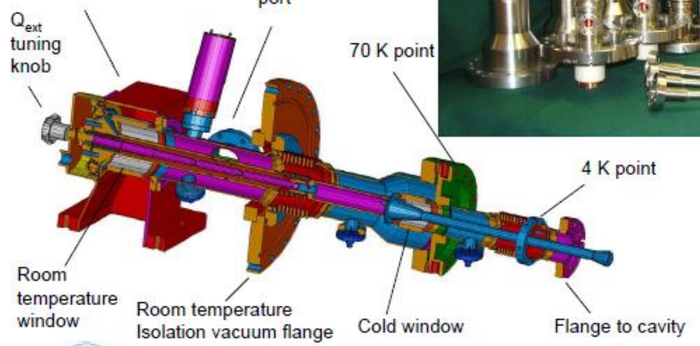
Coaxial Couplers

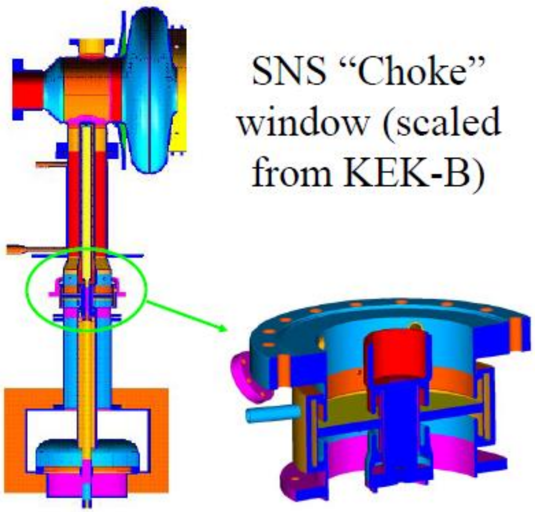


LEP coax to wave guide transition

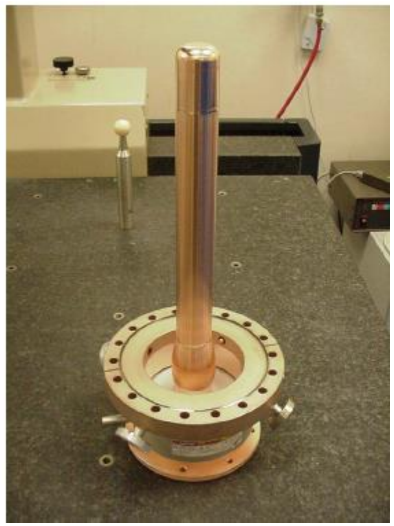
LEP (HERA)

TESLA Coupler





SNS "Choke" window (scaled from KEK-B)



SNS coupler based on KEKB design

My Experience R&D of FPC:
Demand of high power coupler for ILC upgrade (45MV/m)

- limited the site length available in Japan, our first goal will be to realize a 45 MV/m accelerating gradient with a 9-cell super-structure.
- system cost minimum between 40 and 45 MV/m.
- need enough performance margin, if even operate at 35 MV/m.
- increase R/Q at 45 MV/m cavity (LL).

$(R/Q)_{LL@KEK}/(R/Q)_{TESLA} = 1.17$

Acc Gradient [MV/m]	Structure length [km]	
	500 GeV	1 TeV
45	11.1 ☺	22.2 ☺
40	12.5 ☺	25.0 😐
35	16.7 ☺	33.3 ☹

too long

Figure 5.3.2.1

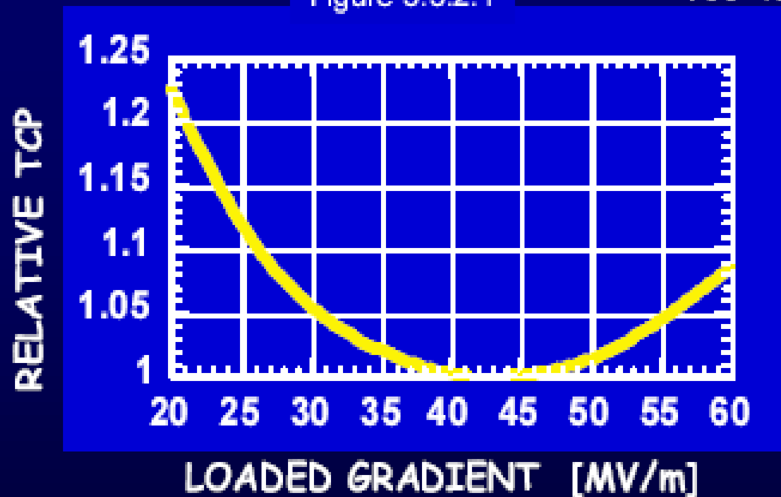


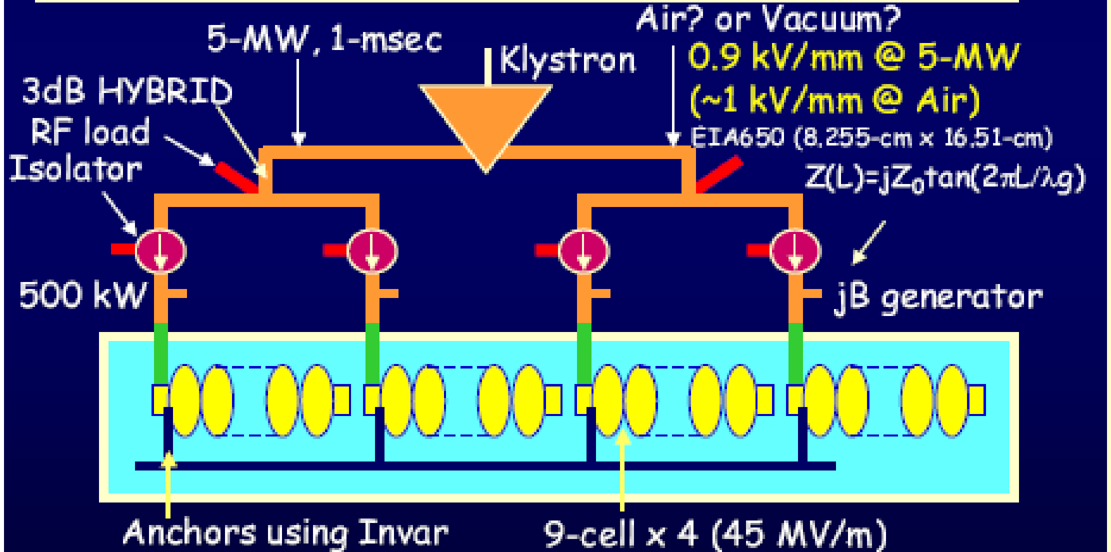
Figure 5.3.2.1: The estimated total cost of 500 GeV c.m. linear colliders, built according to the U.S. cold and warm reference designs, as a function of the main linac cold loaded and warm unloaded gradients. The cost includes both that of the main linac components and power sources, and that of fully outfitted tunnel housings of the appropriate length sufficient to achieve 500 GeV c.m.; it does not include the cost of portions of unoccupied tunnel needed for the 1 TeV upgrade. The vertical scale is normalized to the costs at the minimum of the curve for each option. The curves are plotted without taking into account technology limitations.

refer with "USLCSG Technology Options Study, Page: 259, Spring 2004"

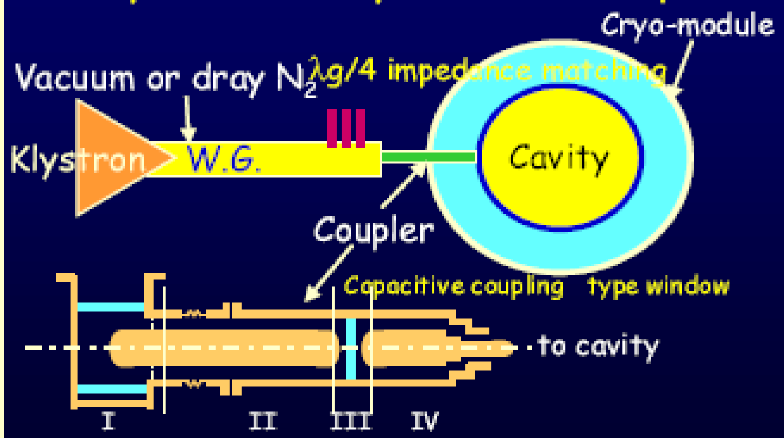
Strategies for ILC Update (45MV/m)

Basic Technologies:
- low electric field gradient at air side → < 1 kV/mm
- high purity ceramic → >99.7%
- use new brazing material Ag:Cu → Au:Cu (:Ti, option)
- surface coating → TiN, and or diamond-like carbon

USE NEW RF FEED SYSTEM.
- Capacitive coupling type rf window at cold temperature.
  - → reduce the thermal energy flow.
- Modular structure.
  - → improve reliability.
  - → system simple.
  - → reduce cost.
- Conventional fabrication method as klystron.
  - → keep reliability.
  - → improve mass productabolity



* Electric field gradient in the waveguide (kV/mm) @ 5-MW
L-band (8.255-cm x 16.51-cm): 0.9 -> seems to be not enough margin in air
S-band (3.404-cm x 7.21-cm) : 2.2 -> no good in air,
good in SF6 (but no good at 10-MW)

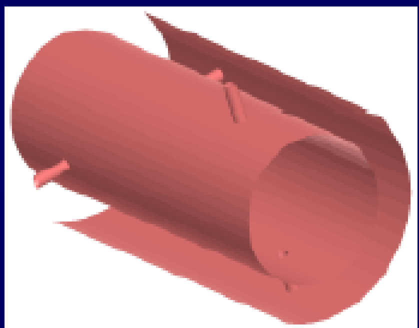


Coupler comprises of four individual modules.

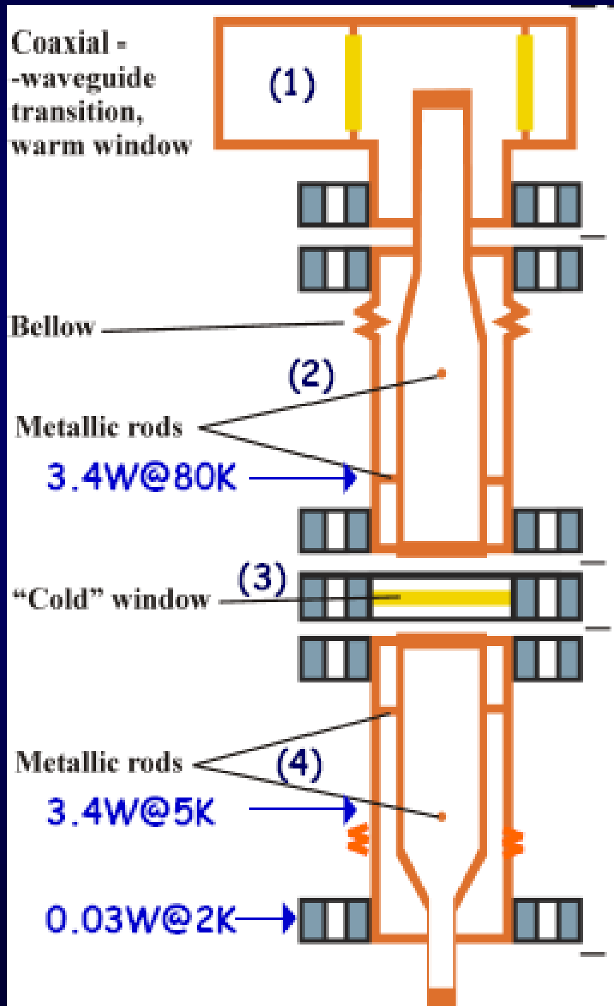
Industrialization with Modular Structure

Input coupler comprises of four modules:

1) coaxial transformer
2) coaxial line
3) rf window
4) antenna at cold side



Each pair of rods is mounted in the gap between the inner- and outer-conductors, and are rotated 90 degrees from each other.



[1] [2] [3] [4] The complete input coupler can be divided into four relatively simple parts to **ease fabrication and assembly**. If we assume that the inner conductors are not attached rigidly to the waveguide, we **need only two bellows to absorb the movement of the coaxial line** due to thermal contaction and expansion between cool down and warm up.

The fabrication of each module **technical requirements dose not overlap for each parts.**

Average power: 3.25-kW (500-kW, 1.5-msec, 5-pps) RRR: 3.5 (measured data for copper plated layer)

Capacitive Coupling Coaxial Line for Input Coupler

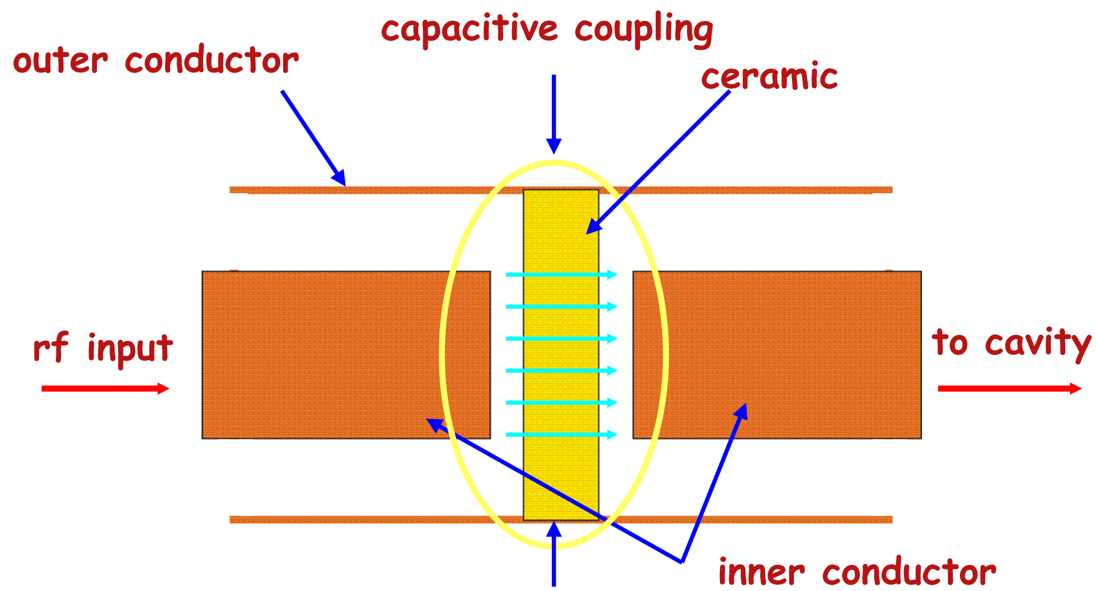
By H.Matsumoto and S.Kazakov

Capacitive coupling coaxial line should have advantages;

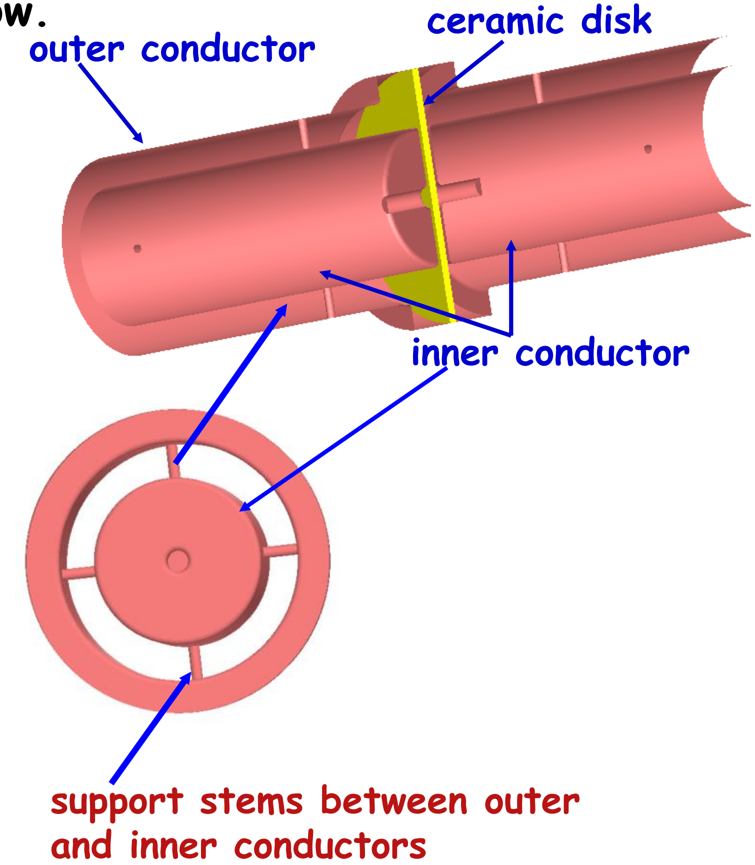
1) Good thermal insulation ability between the warm and the cold sides.

2) Reduce the brazing difficulty for the ceramic window.

Concept of capacitive coupling coaxial line



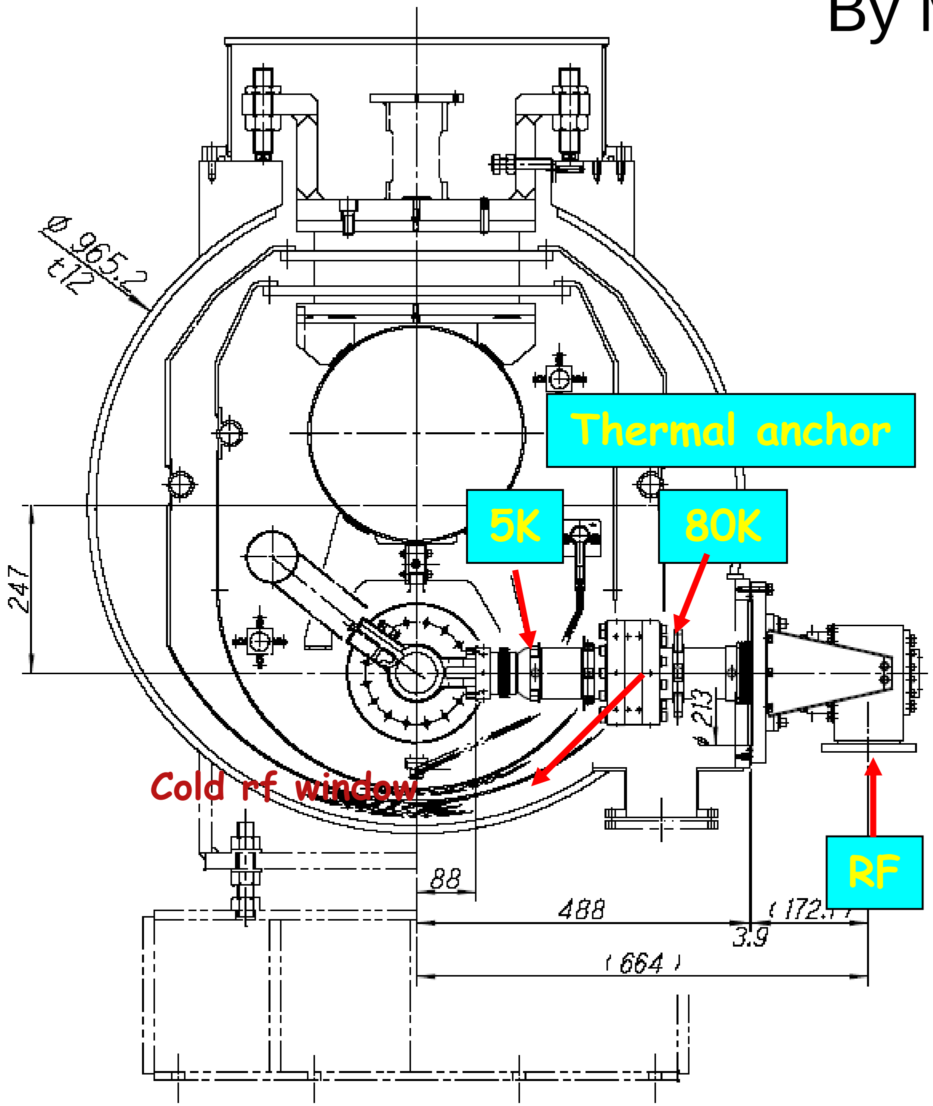
Easy to braze between cooper and ceramic disk.



Well established in warm technology(Normal conducting cavities).

Heat load Specification for ILC

By Matsumoto and Kazakov @ KEK



Major Parameters

Input rf power: 500 kW
Pulse width: 1.3 msec
Repetition rate: 5 Hz
Average rf power: 3.25 kW

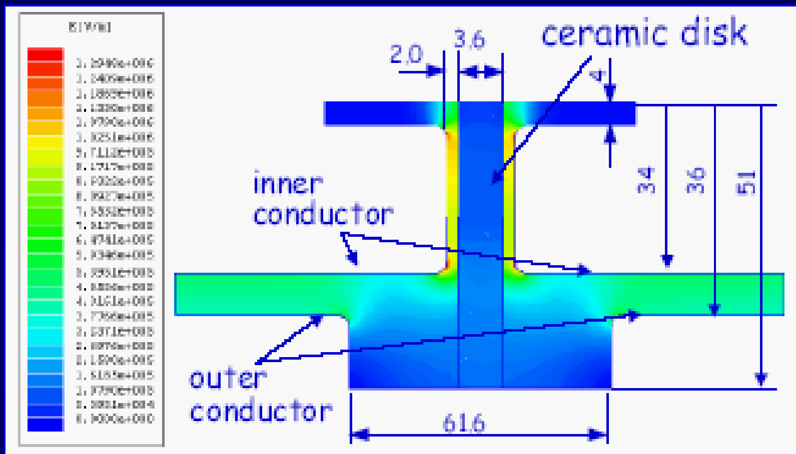
Thermal loss [W]

	80K	5K	2K
Static:	1.24	0.54	2.6x1e-4
Dynamic:	2.14	2.88	0.25
Total:	3.38	3.42	~0.25

RRR: 3.5 (measured data)

Typical Simulation for CC FPC

Simulation result of an electric field gradient patterns around the ceramic disk.



Possible parameters of capacitive rf window

Ceramic diameter: 110 ~ 120 mm

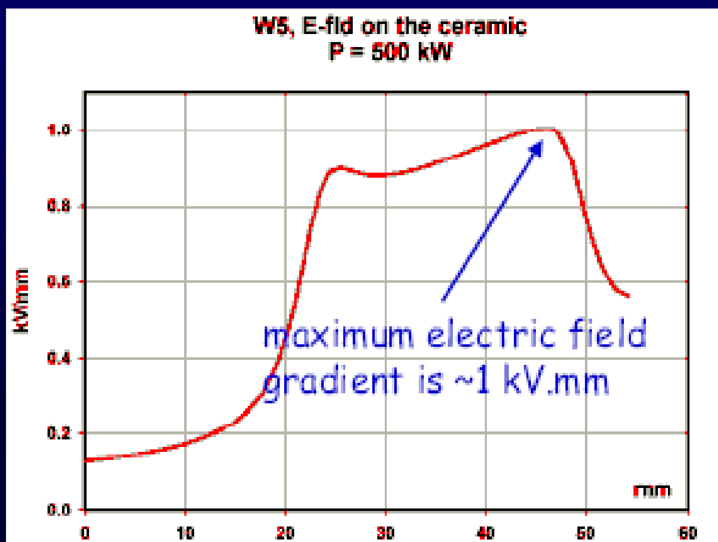
Ceramic thickness: 3 ~ 9 mm

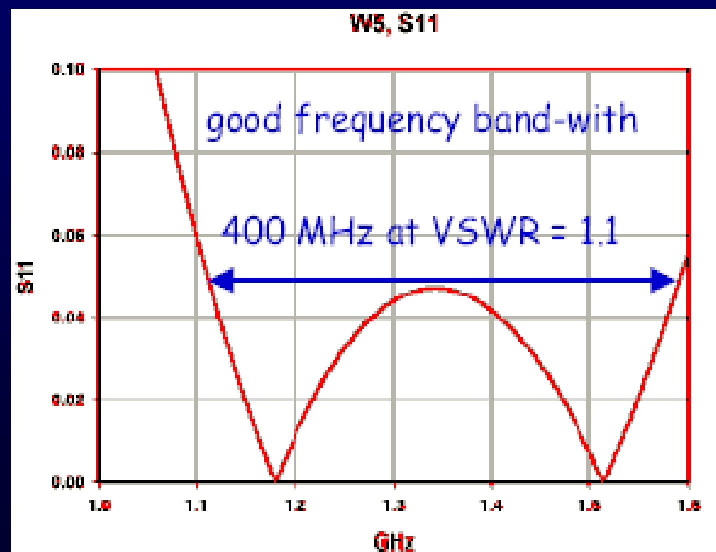
Inner conductor diameter: Ø55 ~ Ø68 mm

Outer conductor diameter: Ø63 ~ Ø82

Max. electric field on ceramic surface: ~ 1 kV/mm

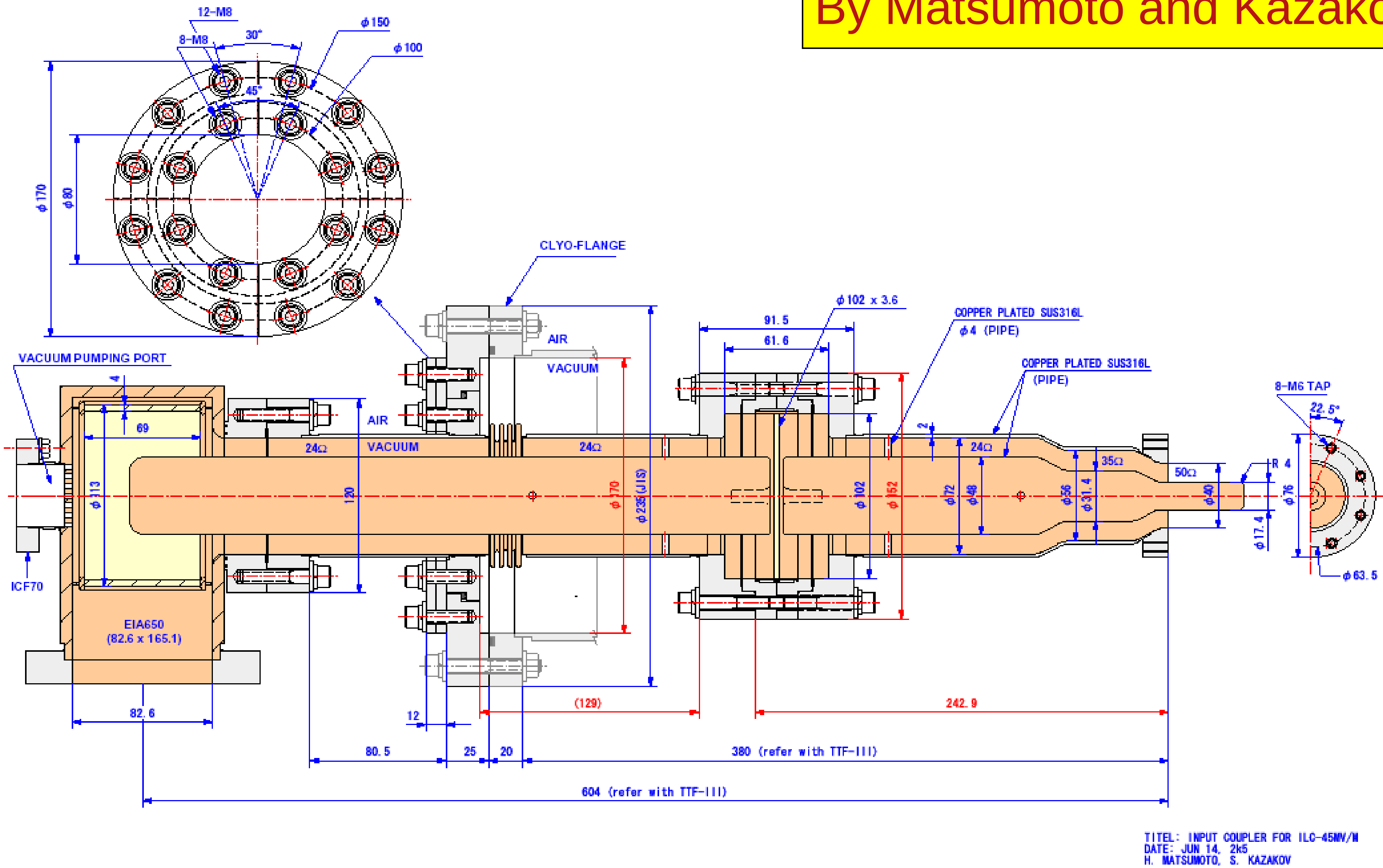
Frequency band-width: ~ 400 MHz at VSWR=1.1





Design of CC Coupler

By Matsumoto and Kazakov



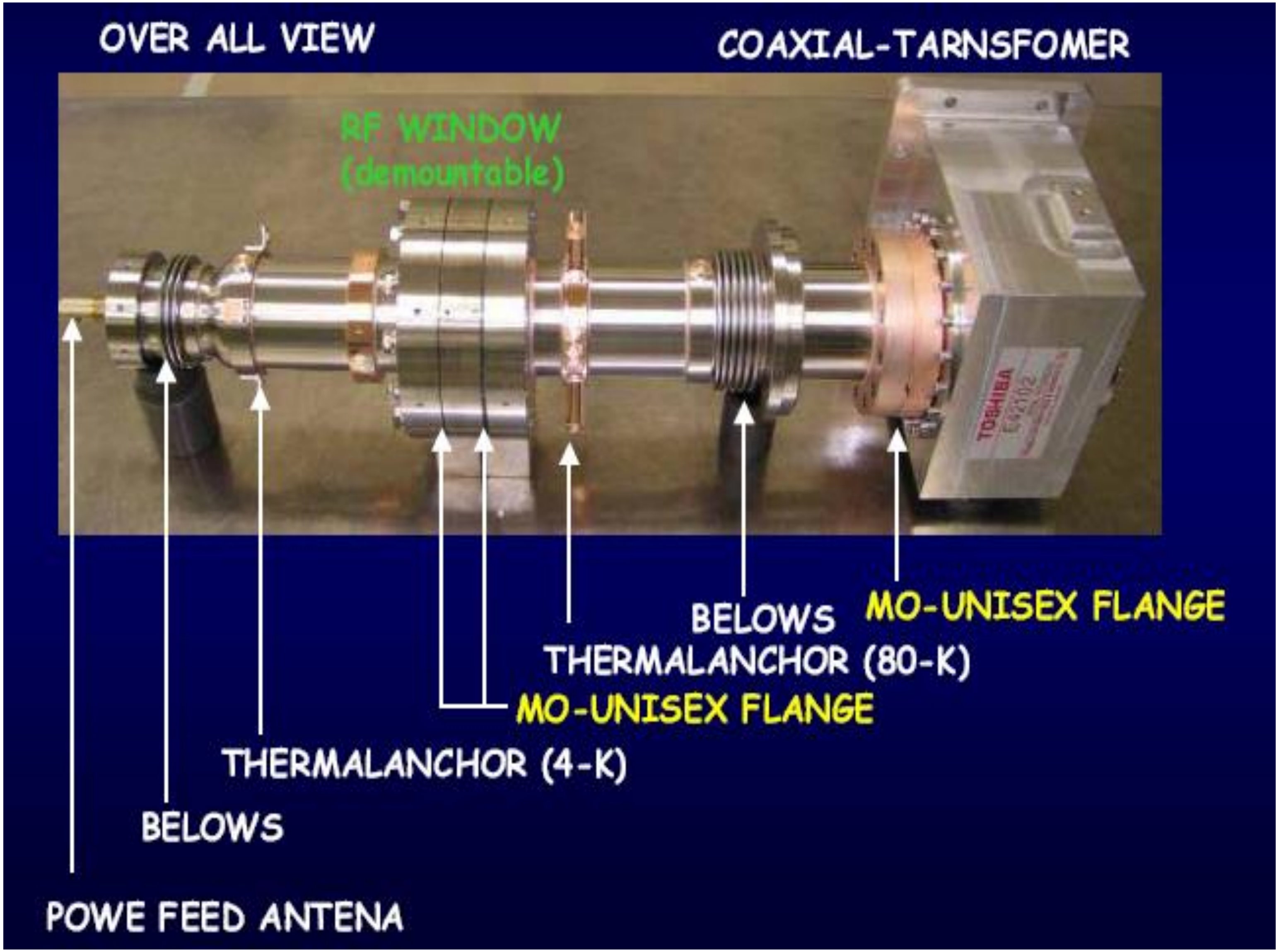
Photos of Parts for CC FPC

Warm bellow

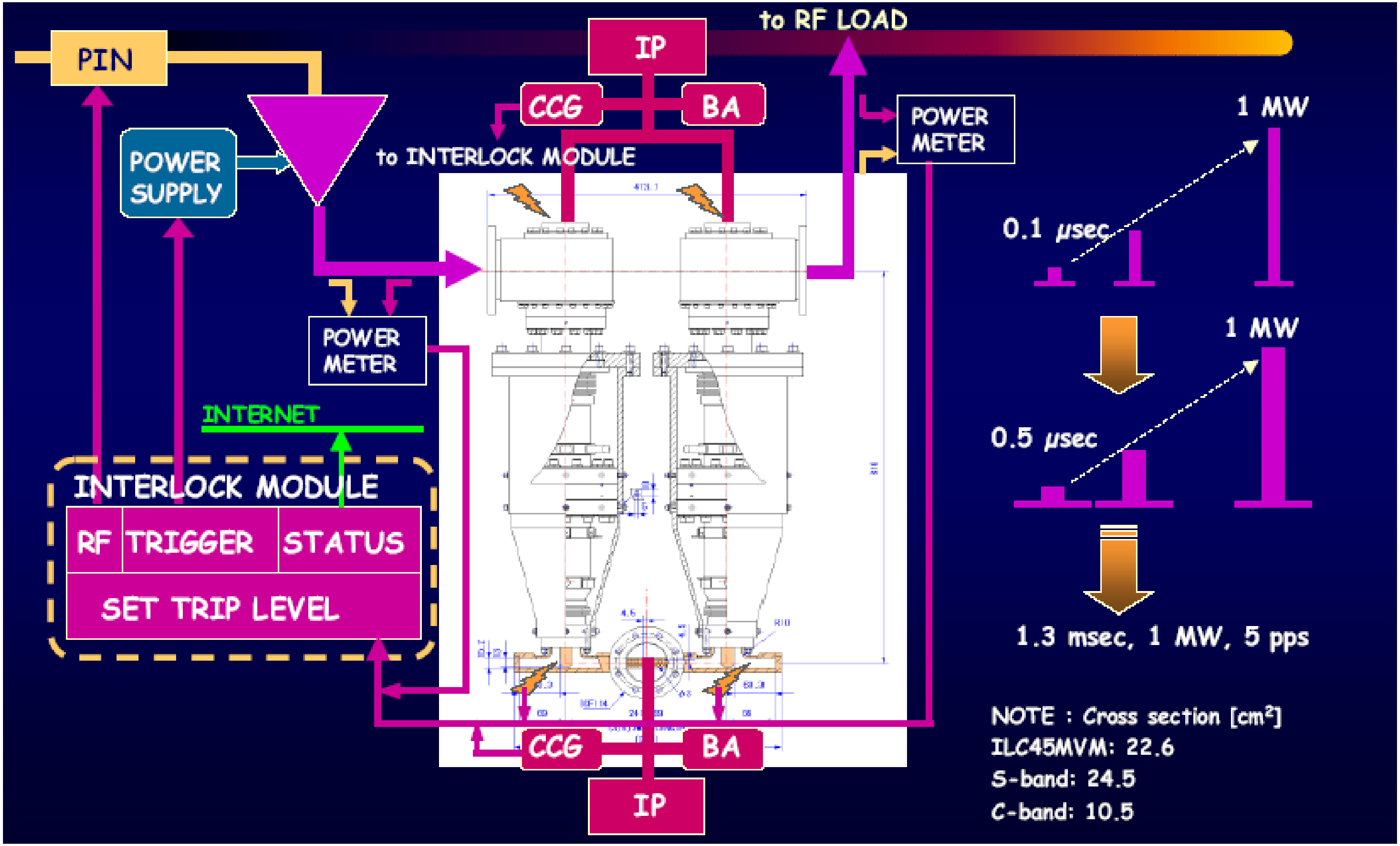
Cold bellow

Inner conductor at warm side

Assembled CC FPC



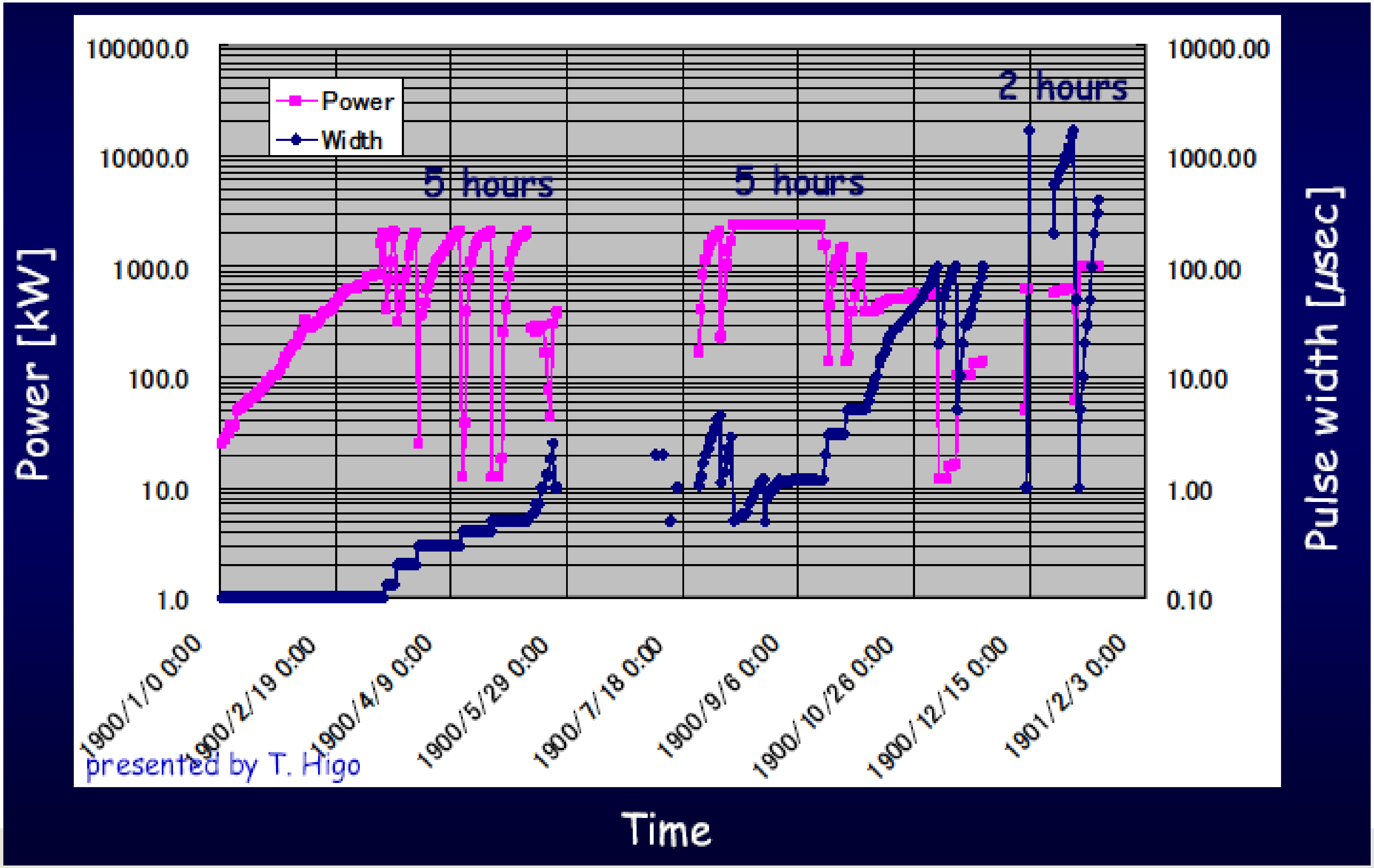
RF Conditioning System of CC FPCs at KEK



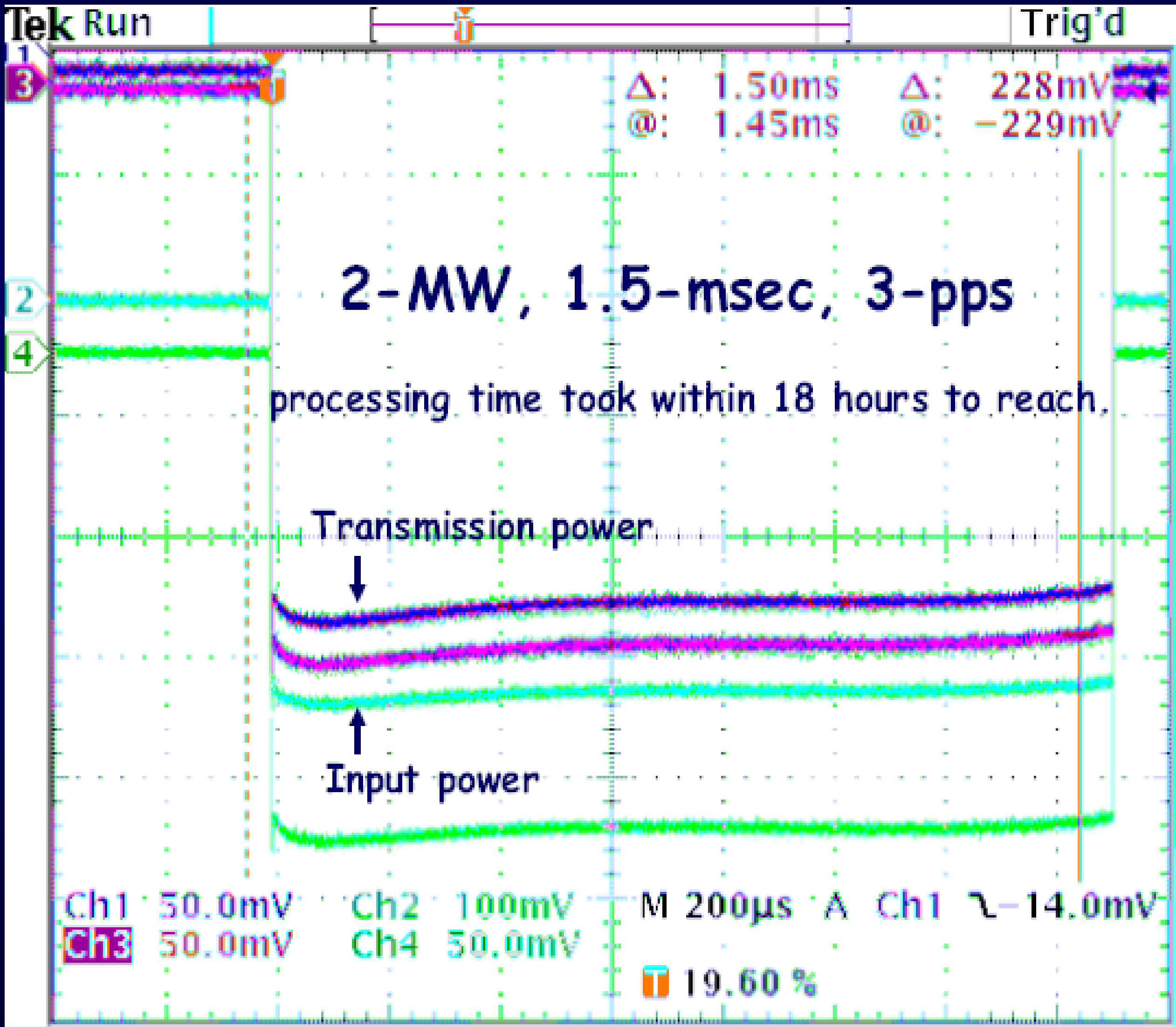
500kW CC FPC High Power Test Stand @ STF

Power and Pulse Width vs. Processing Time

- Degassing from RF window through RF power



High Power Test Result



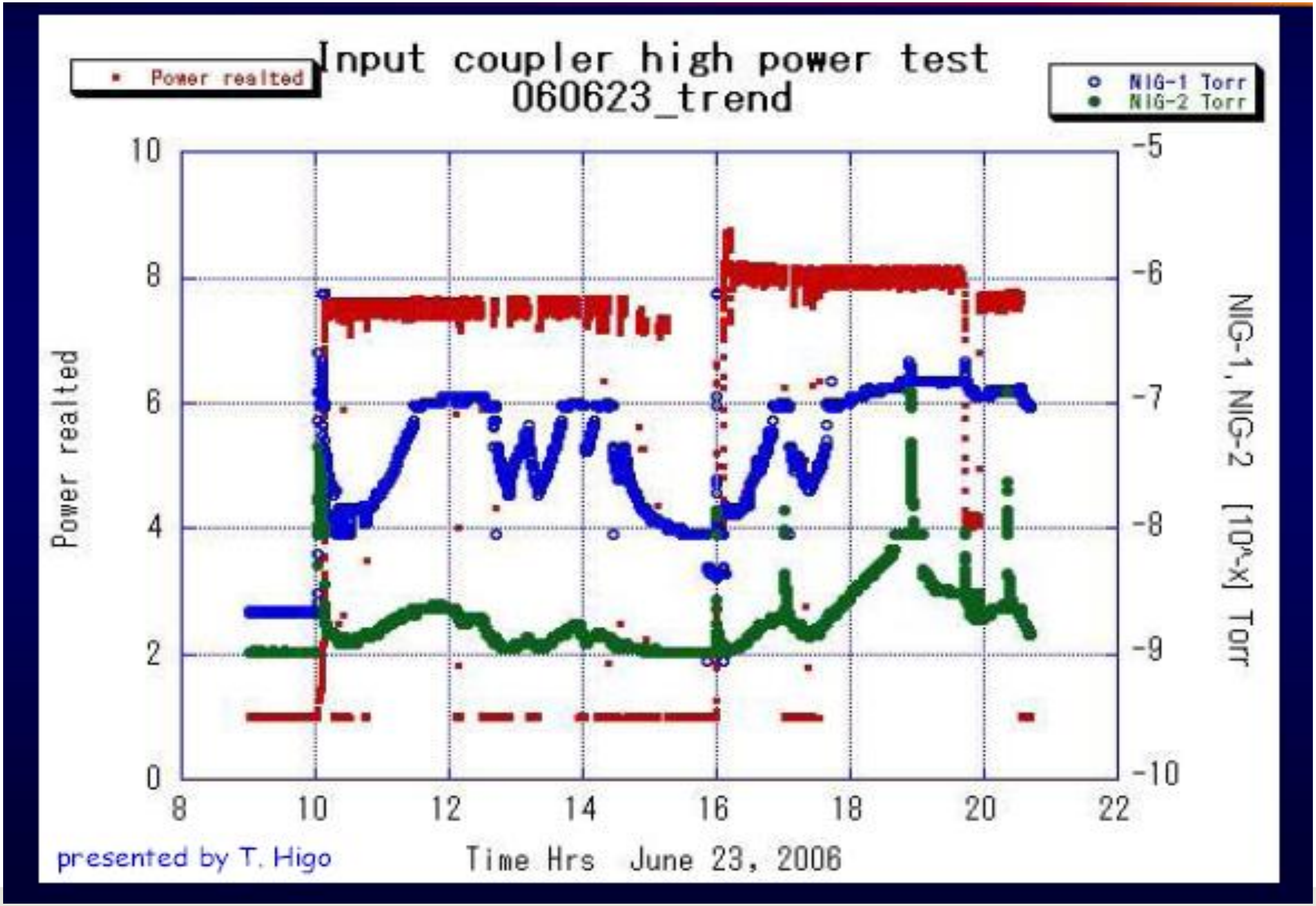
Other tested power:

500-kW and 1-MW with 1.5-msec, 5-pps for each 20 hours.

Summary of high power tests:

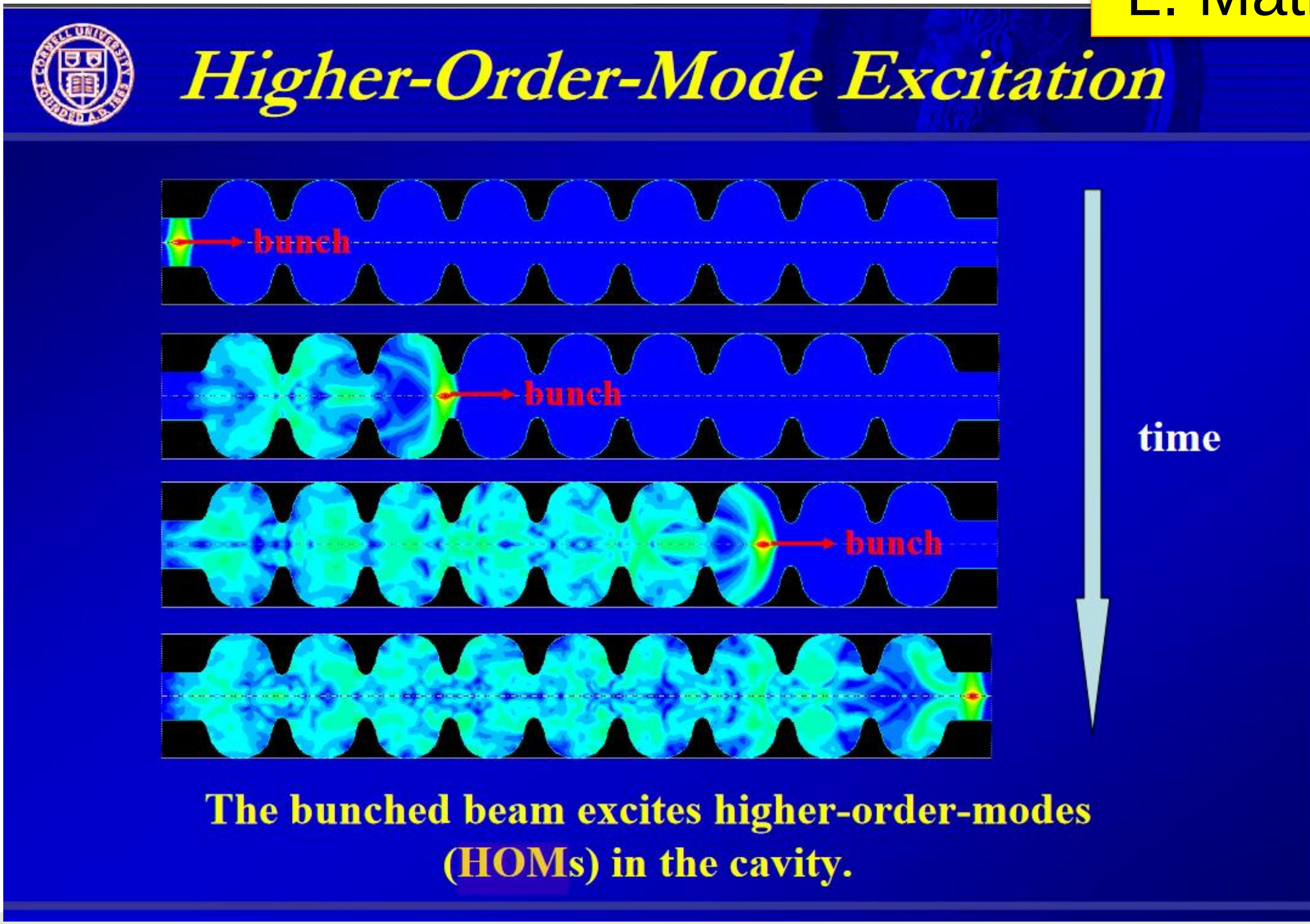
1) a prototype input coupler reached a first goal for power capability for ILC 45 MV/m scheme.
2) modular structure provide good maintainability, if even repair the broken parts, such as warm side rf window, which happened in #1 coupler.
3) MO type rf flange provided the good performance.

Temperatures at Various Locations and Vacuum during Long Run Operation



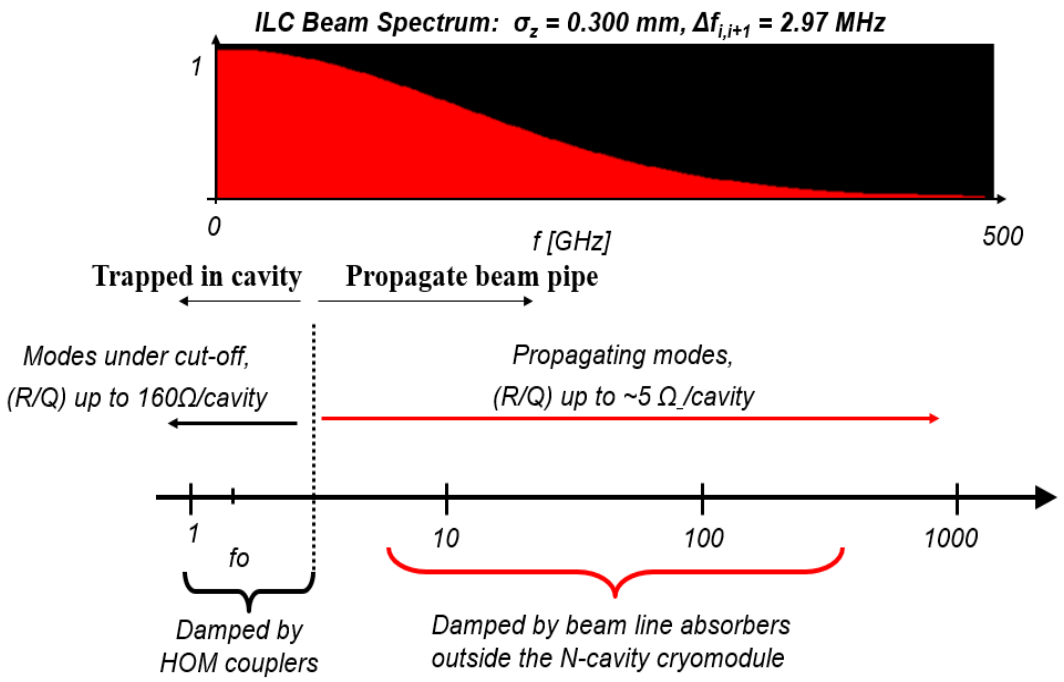
19.2 HOM Couplers/Dampers

L. Matheus



Higher Order Mode(HOM) Couplers

- Trapped HOMs (high power case, ~ 100W order)
  - KEK type HOM filter
  - DESY loop antenna type
  - CEBAF absorber
- Trapped HOMs (extremely high power ~ kW order):
  High current machine : high luminosity frontier or high bright light source
  - KEK or CESER Ferrite absorber
  - Damper close to cavity
- Traveling HOMs
  - Absorber on beam line



Various HOM Coupler Designs

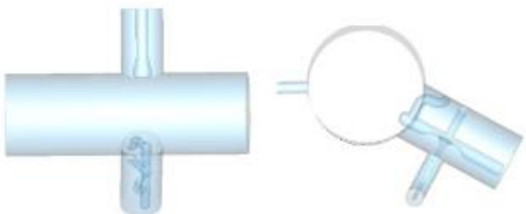
Coaxial Couplers
(Loop coupling)

Waveguide Couplers
(use cutoff frequency)

Beam Line Absorbers

JLAB

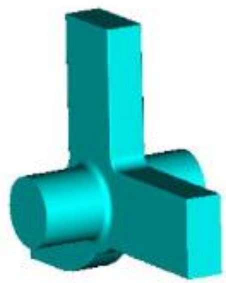
TESLA/ILC



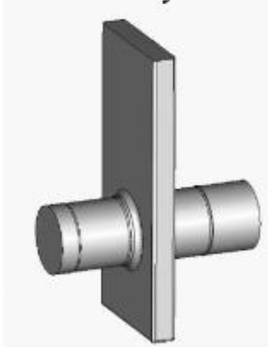
DESY/JLAB

JLAB High Current

JLAB CEBAF

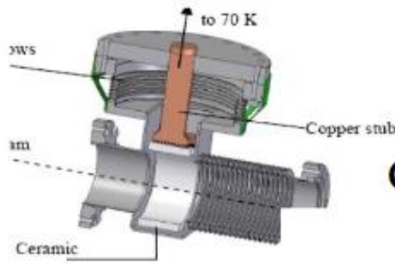


JLAB CEBAF

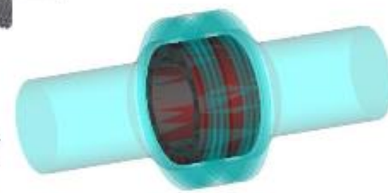


KEK

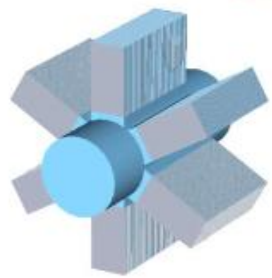
DESY FLASH/X-FEL

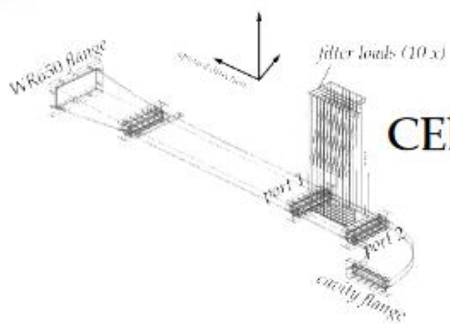


Cornell ERL



DESY

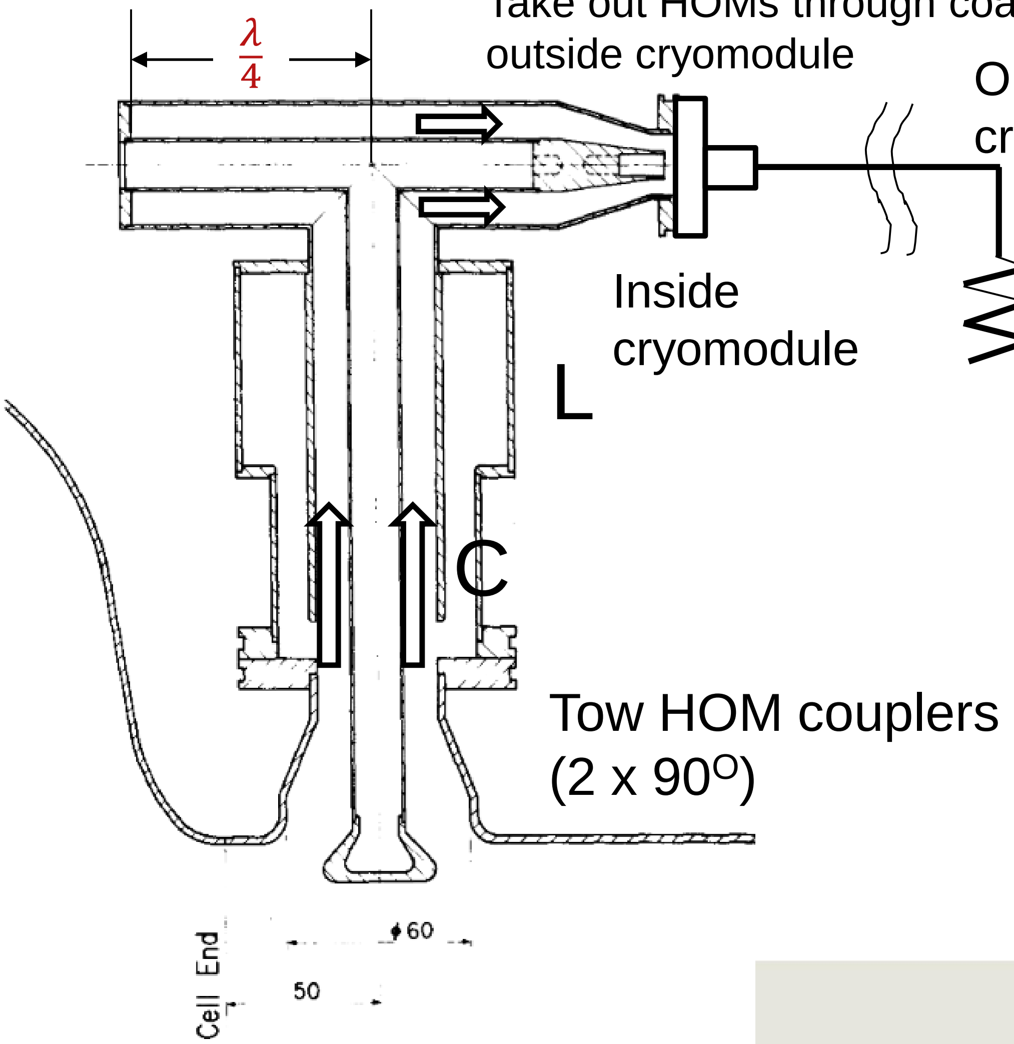




CEBAF filter

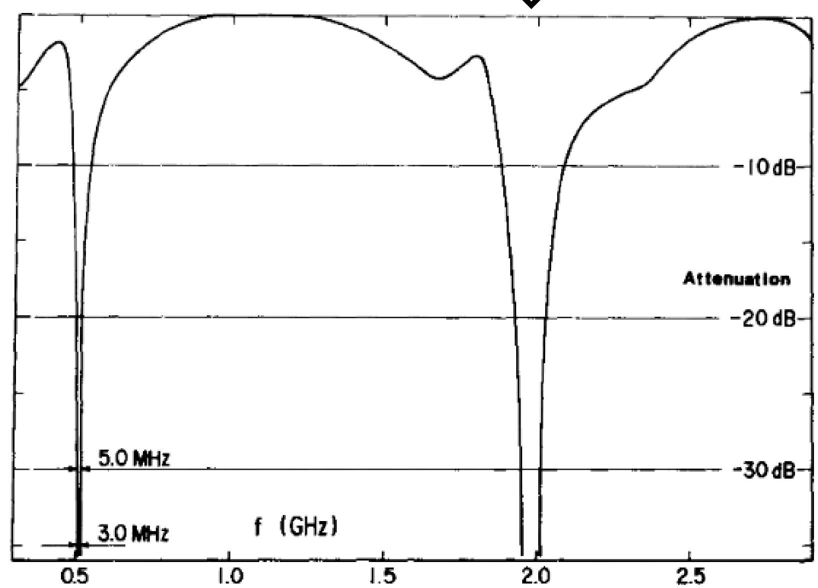
Chock Filter Type HOM Coupler (KEK)

- Coaxial waveguide has no cutoff frequency, any frequency can travel through
- Filter out HOMs while keeping the fundamental mode using choke structure($\lambda/4$)
- Needs two HOM couplers with different reject band



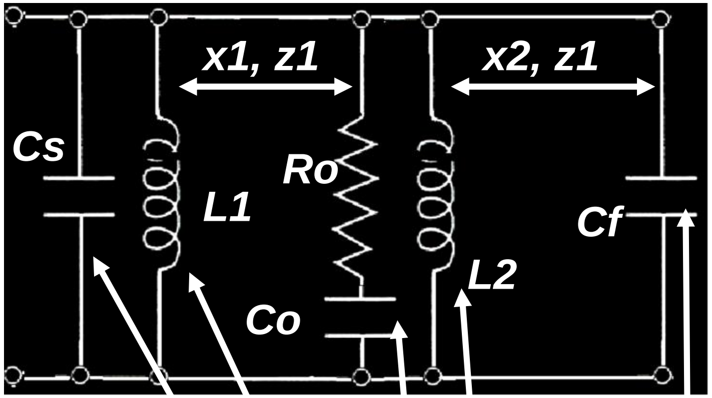
Use two HOM couplers with different rejection band

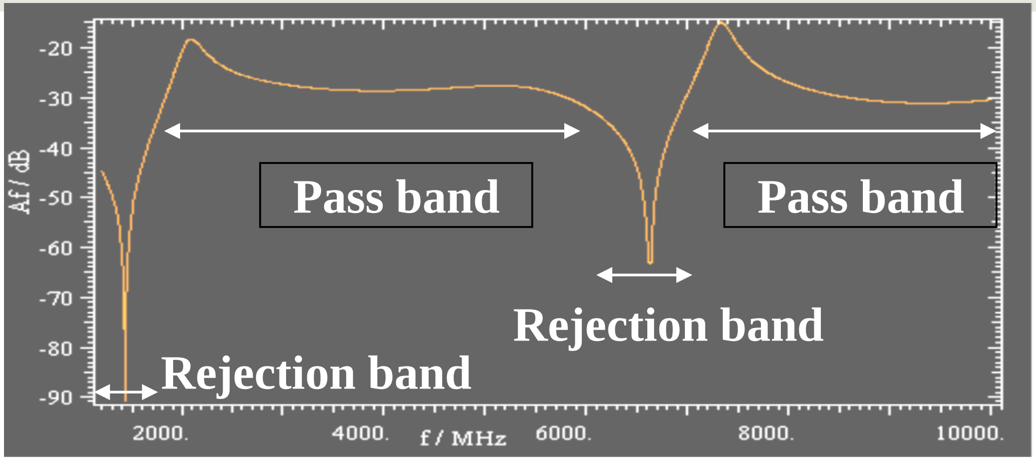
Reject band

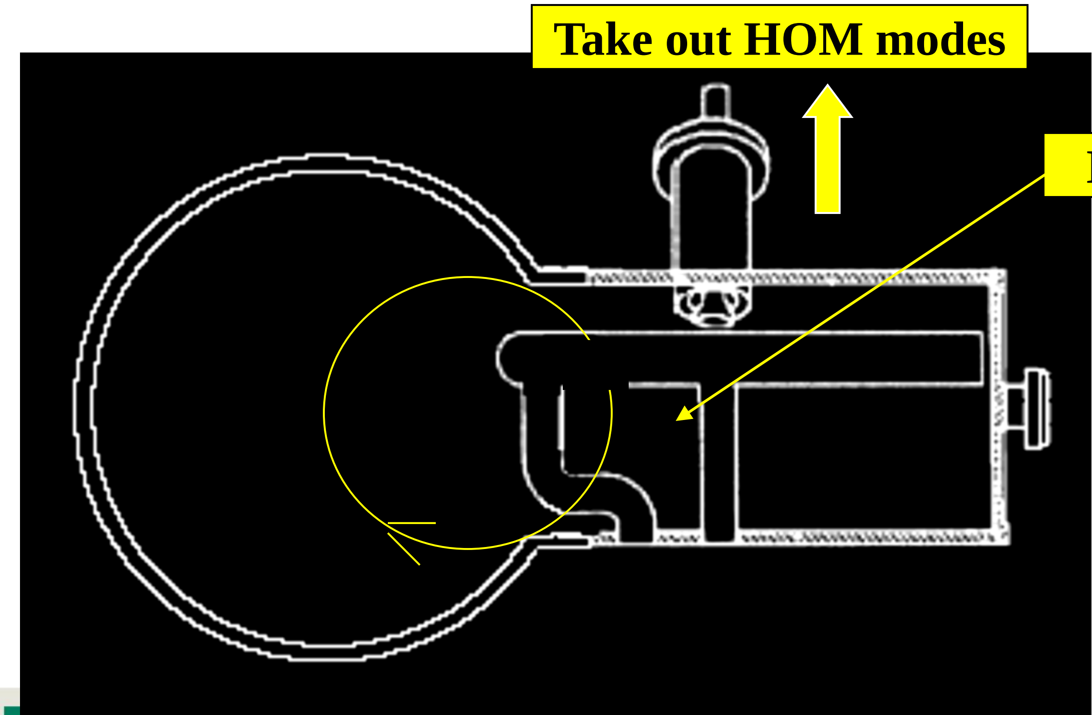


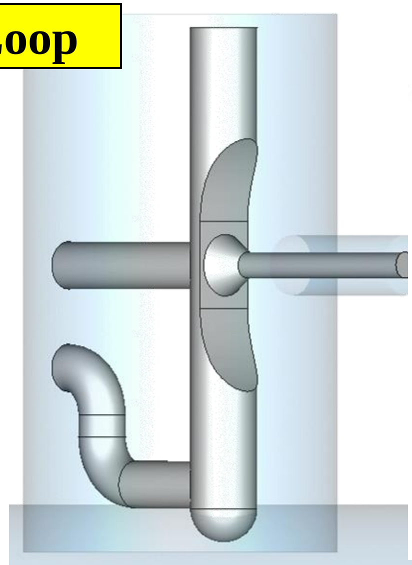
DESY Loop Coupling HOM Coupler

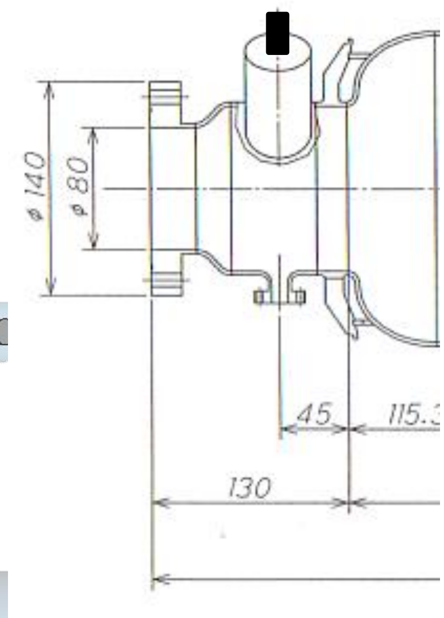
The TESLA –like HOM couplers are nowadays designed in frequency range: 0.8-3.9 GHz





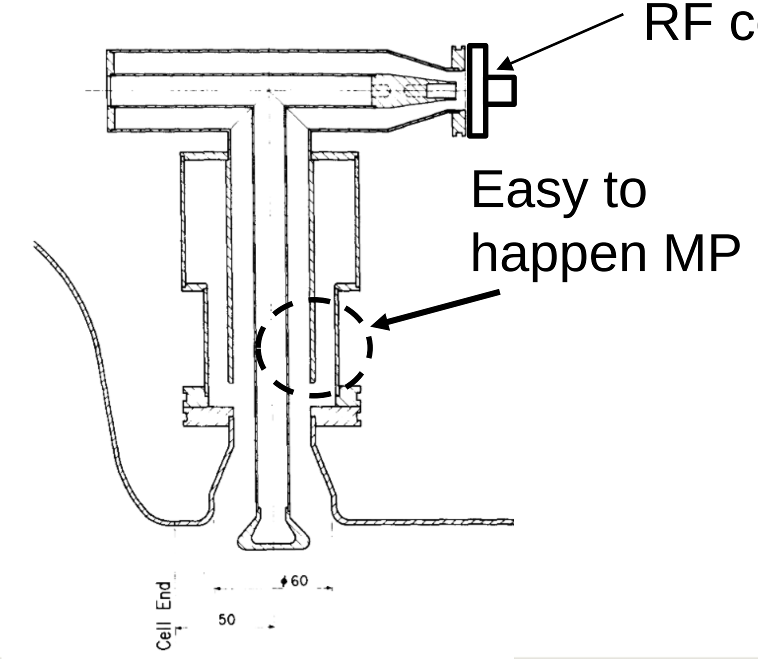


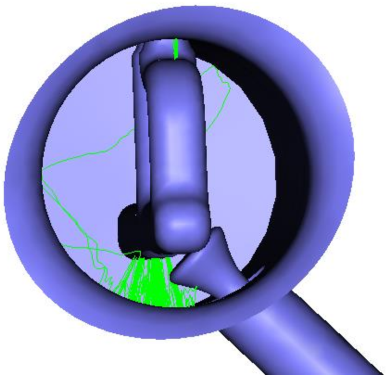


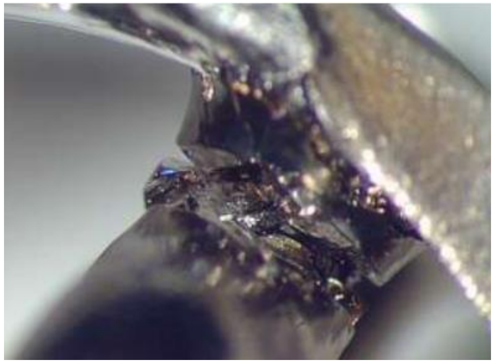


Common Issue for Both HOM Couplers

- Complex structure
- Cleaning is not easy
- Multipcating easy to happen
- Made of all niobium material and expensive
- Easily burn out at the RF connecter head by when MP happened
  - Needs enough RF contact and efficient cooling



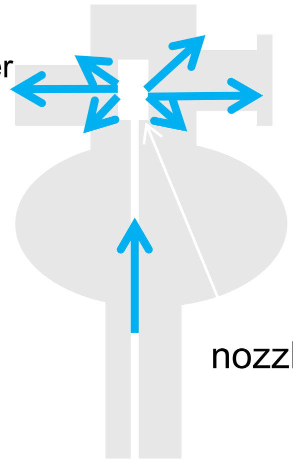


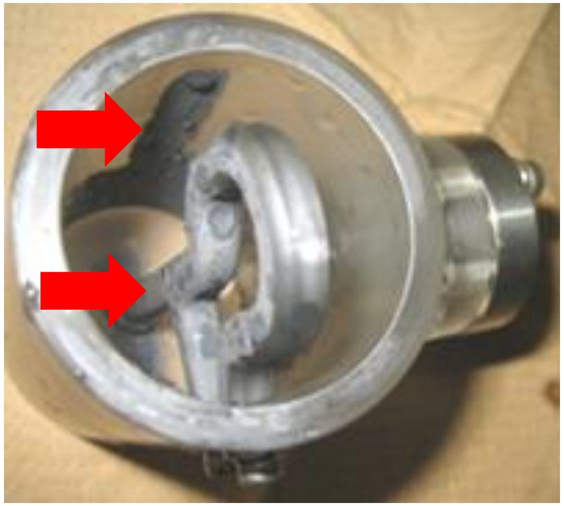


Difficulty in Cleaning of HOM Interiors

- The weak point of loop coupler is complex structure and cleaning of the inside is not easy.
- In order to check the washing effect of HPR and ultrasonic, It was examined using the acrylics model cavity. The molybdenum coat spray interior of the coupler and HPR and then ultrasonic rinsed, however, contamination still exist in the loop coupler.

After HPR(15min)





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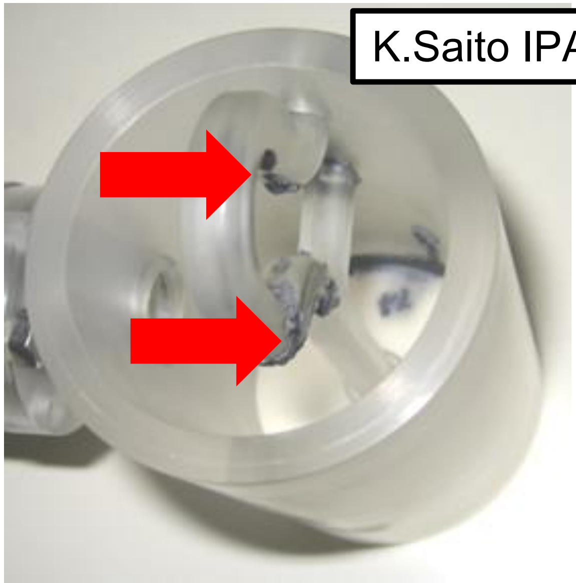
After Ultrasonic(30min)

K.Saito IPAC'10



It was found that dust inside and behind the antenna is not removed by HPR.

It was found that dust on base and edge of the antenna is not removed by ultrasonic.

To achieve a high gradient, it is necessary to use another method ➡ Brushing
Or, It is necessary to reconstruct an easy washing structure. ➡Demountable

HOM Damper Used Waveguide Cutoff Frequency (CEBAF)

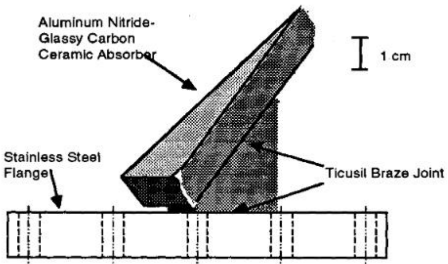
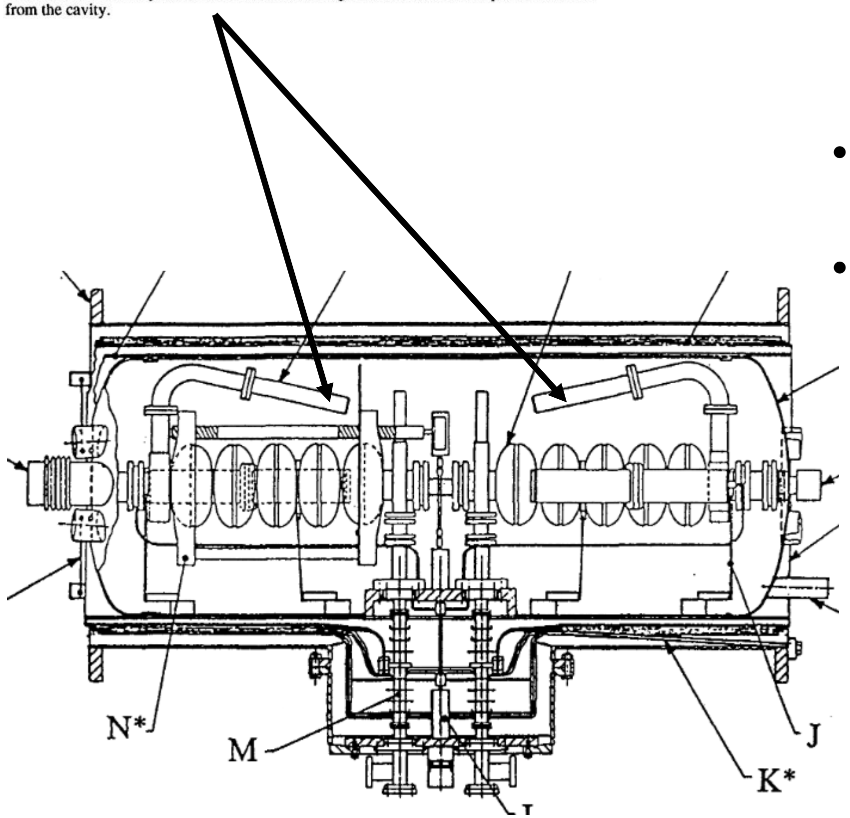


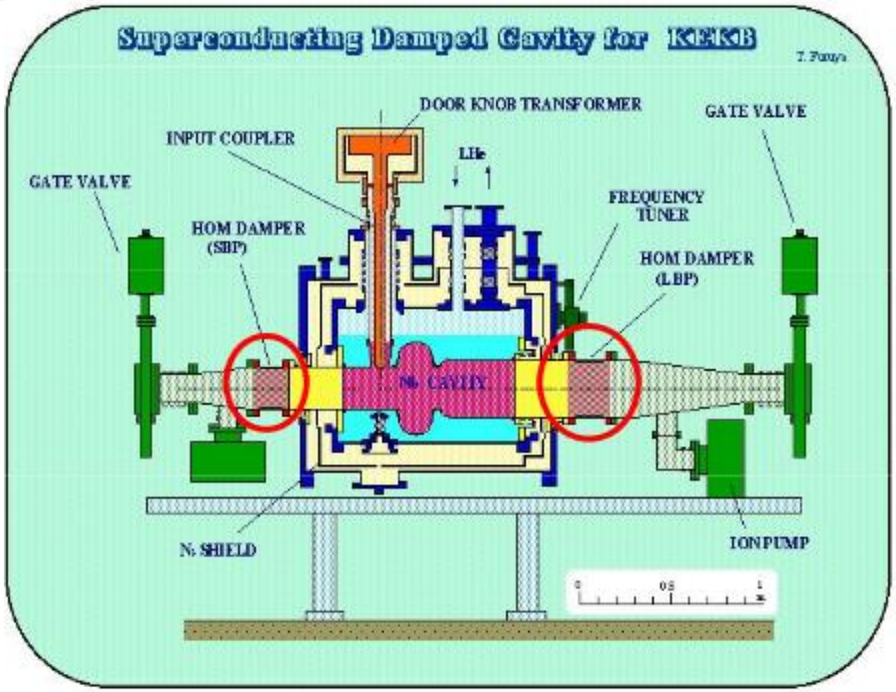
Figure 1: CEBAF's HOM load comprises the absorber (an Aluminum Nitride-Glassy Carbon ceramic composite) and a blank-off flange which must seal superfluid helium from the cavity.

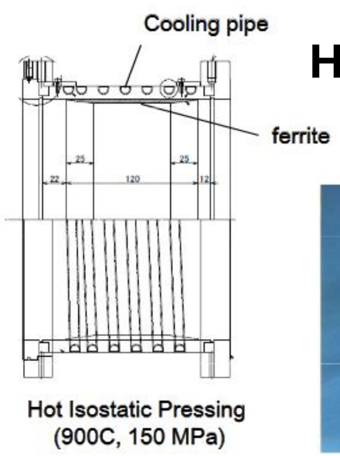


HOM damper

- Waveguide has a cutoff frequency.
- Lower frequency RF can not penetrate the waveguide enough.
- Fundamental RF has a lower frequency than the cutoff frequency and can not come to the absorber location.
- While other high frequency HOMs come to the absorber and are consumed as heat.
- The RF HOM heating becomes the cryogenic loss in the CEBAF cryomodule design.

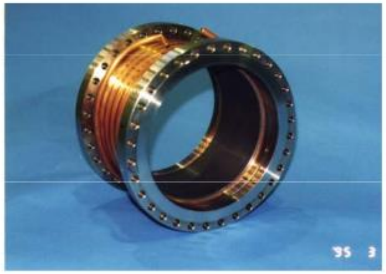
KEKB SRF Cryomodule
(Extremely high current machine)





Hot Isostatic Pressing (900C, 150 MPa)

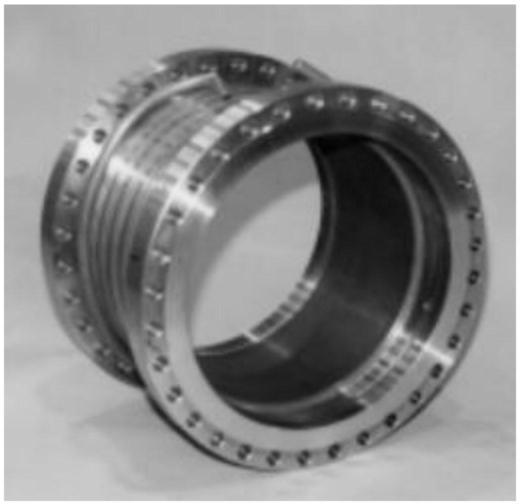
HOM damper at Beam pipe



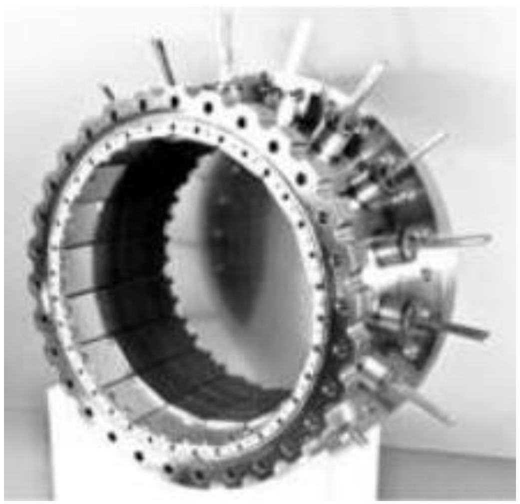
	design		achieved			superKEKB	
	LER	HER	LER	HER		LER	HER
Beam energy (GeV)	3.5	8	3.5	8		4	7
Beam intensity (A)	2.6	1.1	2	1.4	→	3.6	2.62
Peak luminosity ($cm^{-2}s^{-1}$)	1E+34		2.1E+34			80E+34	
Bunch charge (nC)	5	2	12	10	2010 -2013	14	10
Bunch length (mm)	4	4	6	6		6	5

High Power HOM Damper of KEKB/Cornell CESER b

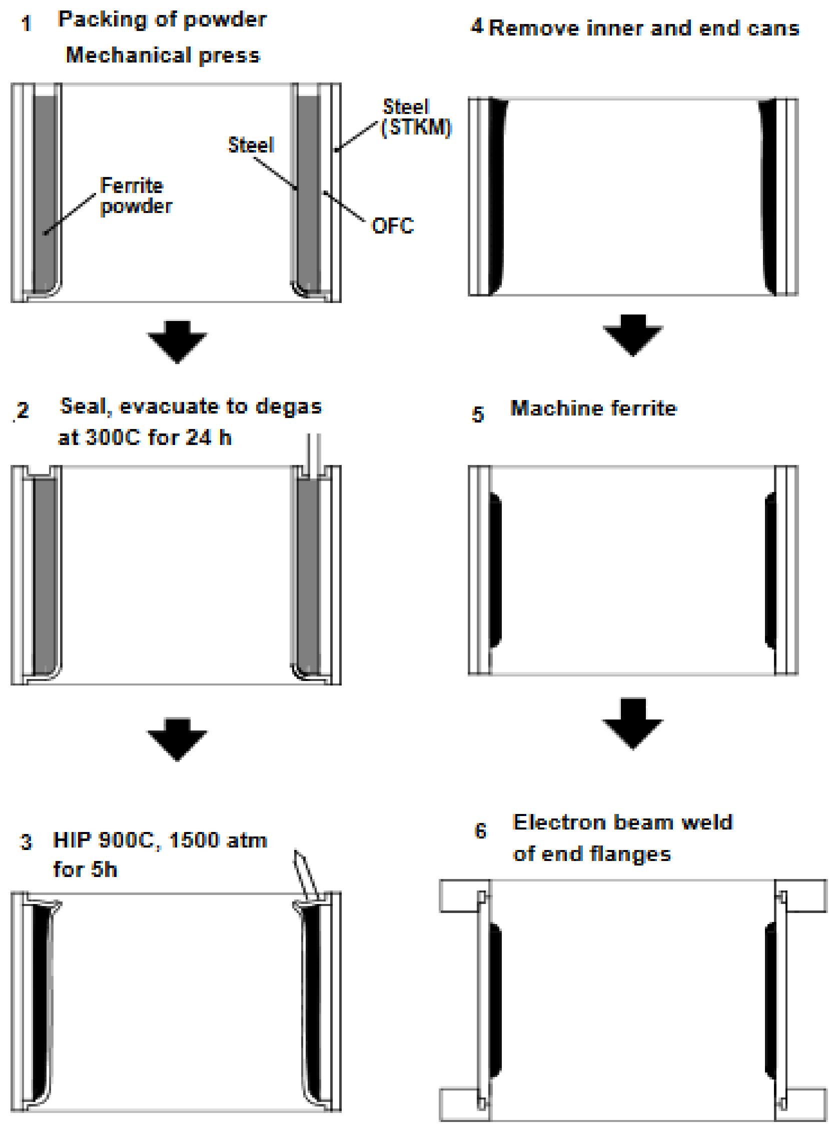
- KEKB HOM damper
  - Used Hot Isostatic Pressure(HIP) technology to rescue voids in Ferrite
  - Directly bonded the Ferrite on the Oxygen Free Copper (OFC) tube
- CESER b HOM damper
  - Brazing Ferrite plates on the oxygen free copper (OFC) tube



KEKB HOM damper



CESER b HOM damper



Beam Line Absorber

- Beam line absorber
  - Higher frequency than cutoff frequency travels beam line and goes to other cavities.
  - Lossy materials are put on the beam line and absorb the HOMs.
  - In ILC case, the beam line is in the cryomodule and all the heat has been taken out of the 70K shield, otherwise the heat goes to cryogenic 2K heat load.

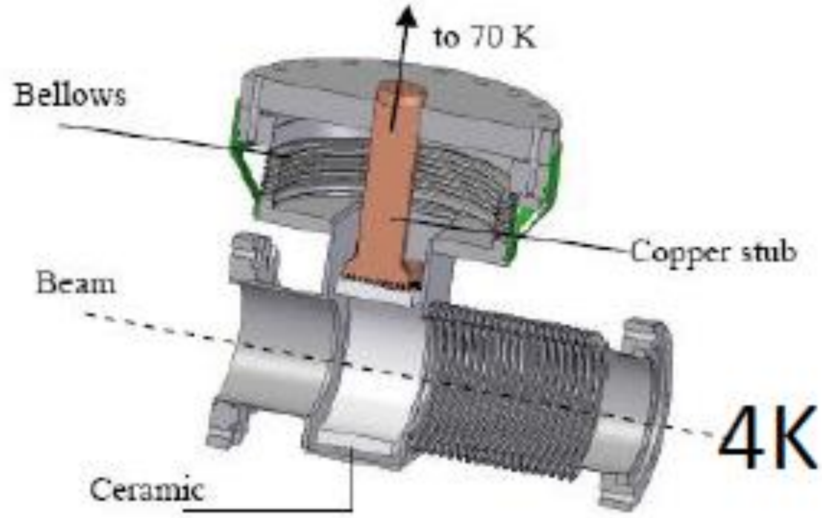
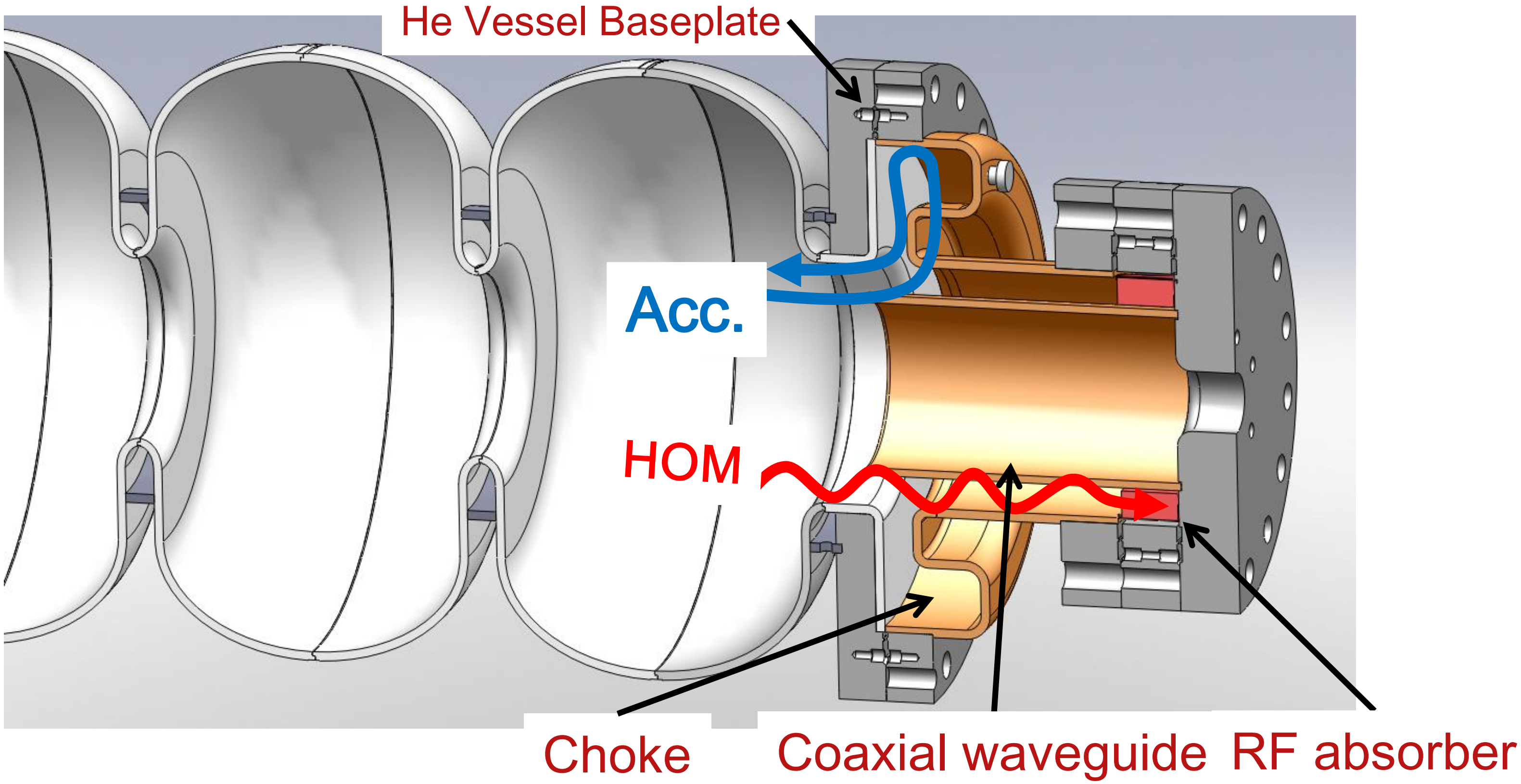


Figure 2: Layout of the beam line absorber.

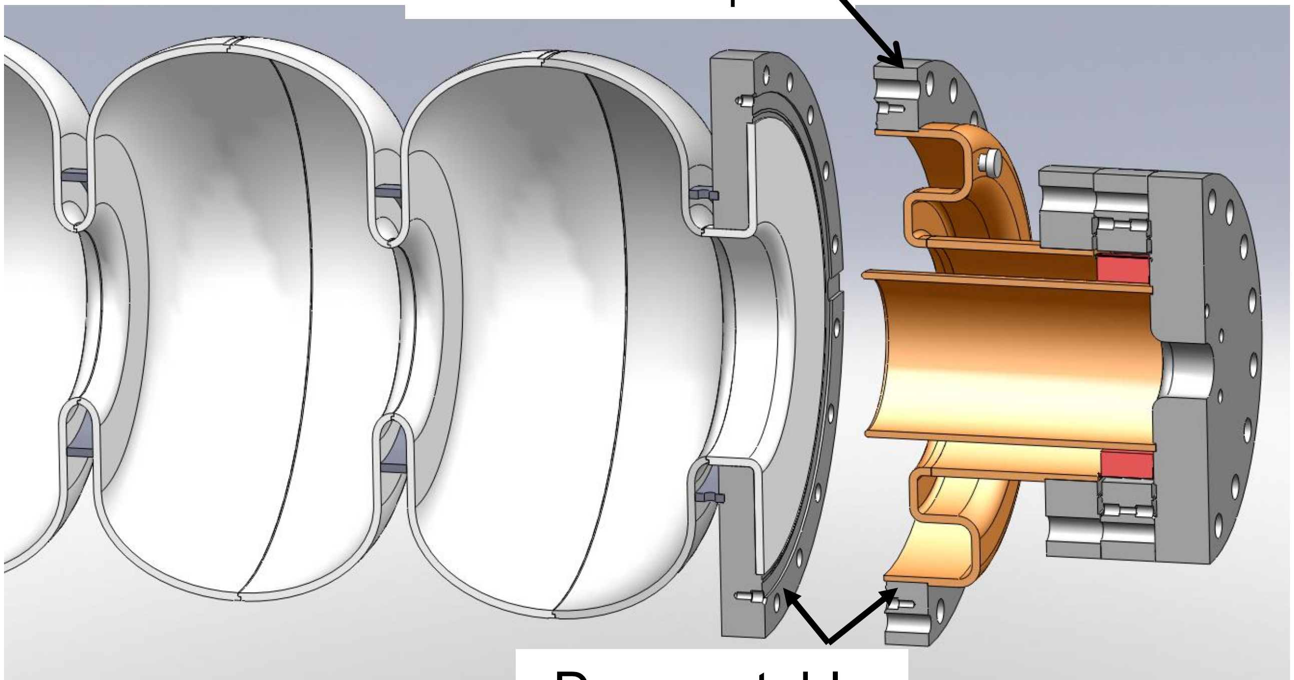
My R&D Experience for HOM
Concept of Demountable Damped Cavity (DDC)



Accelerating Mode is reflected by choke filter.
HOM is damped at RF absorber through the coaxial waveguide.

Concept 1. DDC is the axial symmetry structure by using coaxial choke filter.

Demountable Structure for Easy Cleaning



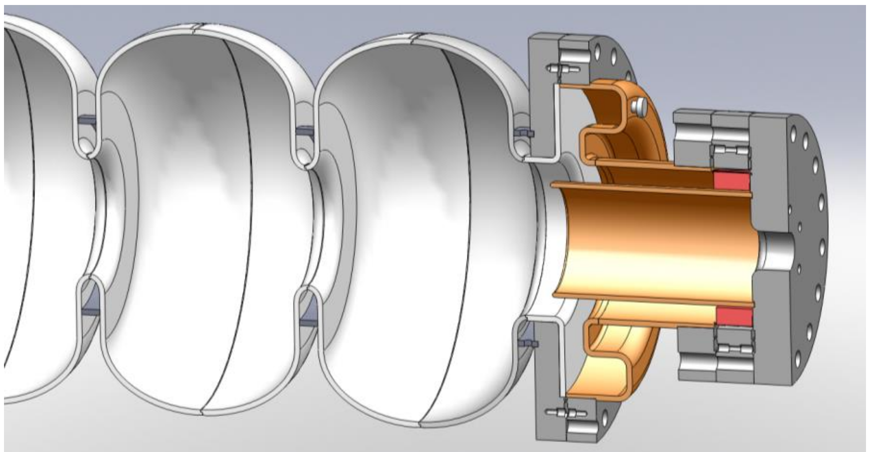
Helium vessel base plate is used as the part of choke filter in order to reduce the space factor.

Concept 1. DDC is the axial symmetry structure using coaxial choke filter.
Concept 2. DDC is demountable structure.
DDC can be separated to choke, inner conductor and RF absorber

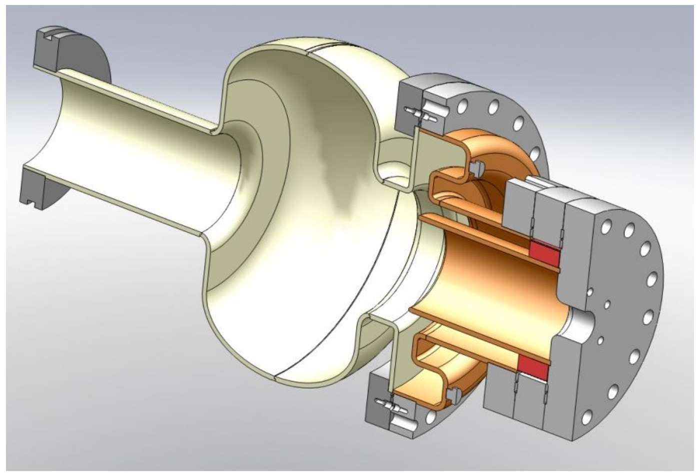
Design of DDC

- Important points in our design.
  - Choke refection frequency can be match to cavity resonant frequency?
  - Serious multipcating occurs in Choke filter?
  - Enough damping efficiency can be got at small space?
  - How to remove the heat occurred at RF absorber?
  - Inner conductor and choke are out of helium vessel, and can be cool down by only heat transfer.
  - Quench occurs by the demountable flange?

In this research, simulation and experiment was done by using a single cell cavity.



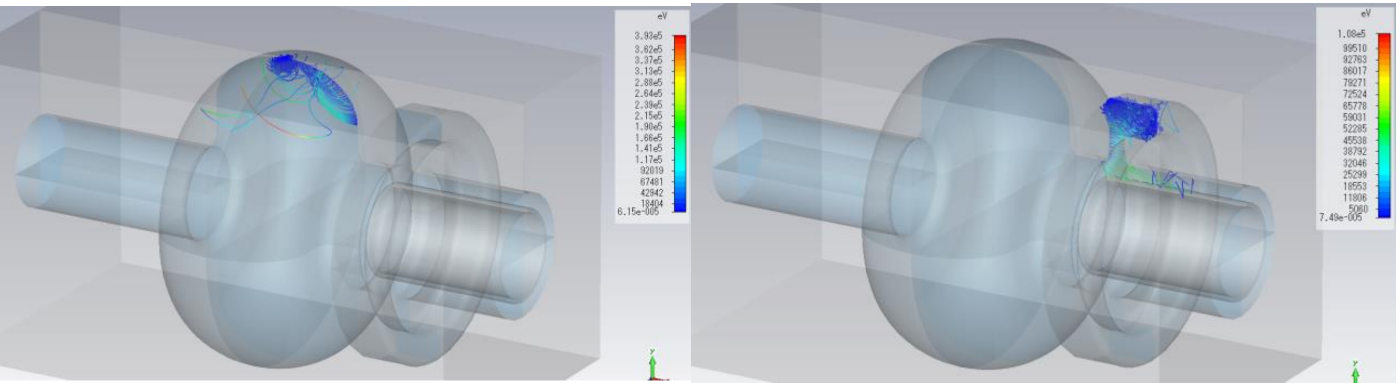
Single cell cavity



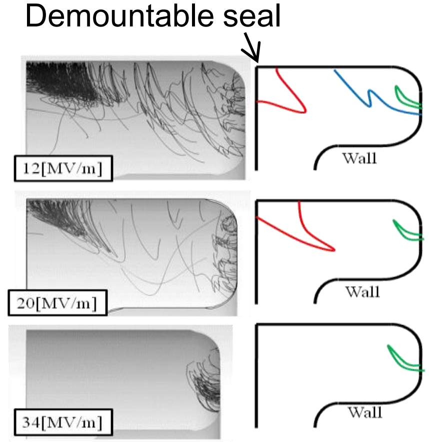
Multipcating Simulation

T. Konomi

First we worried about choke filter because it is the parallel electrode.
We simulated the strength of the multipcating by CST studio.



Choke



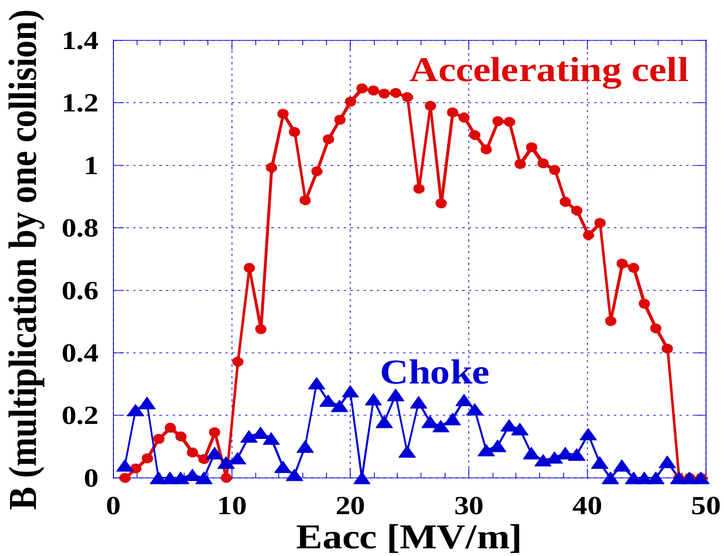
In this simulation strength of the multipacting means the multiplication factor of electrons to collide with the cavity wall every once.

$$Y = A \cdot \exp(B \cdot \frac{f}{2} \cdot t)$$

Multiplication in choke is smaller than in accelerating cell.

Multipacting in Ichiro type accelerating cavity can be process out.

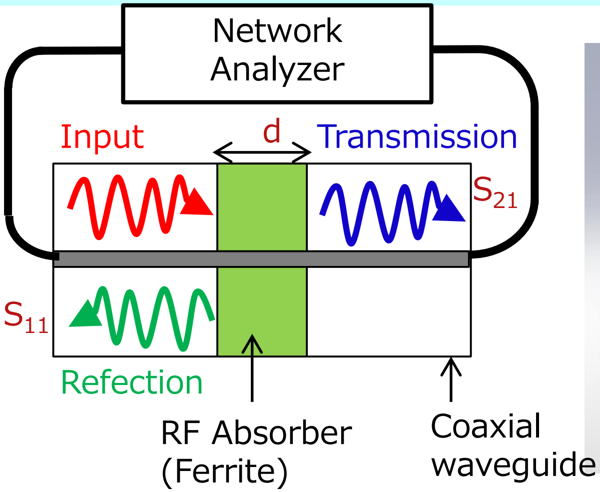
We concluded that multipacting in choke has no problem.

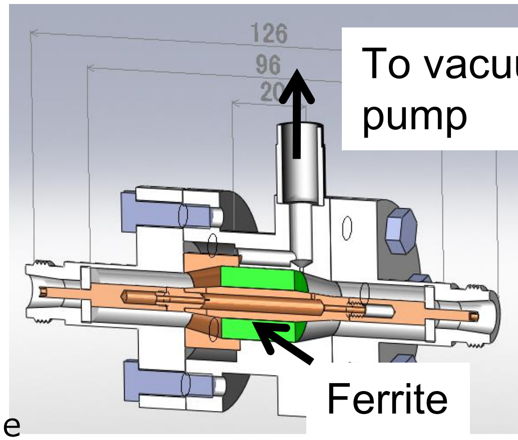


RF Absorber (Ferrite: CMD10)

T. Konomi

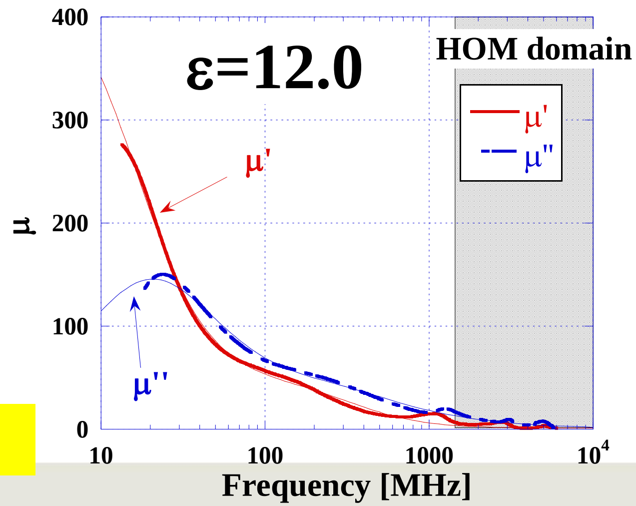
- RF absorber is mounted on 77K thermal anchor.
- We estimated the RF absorber (Ceramic Magnetic Inc.: CMD10) property by using the transmission method at 77K.
- Because it includes brazing to the manufacturing process, this ferrite was annealed at 800 ℃.
- Measurement system is very simple. Sample holder include RF absorber sink to liquid nitrogen.





The permeability and permittivity data which used to design the RF absorber shape was calculated by fitting.

$$
\begin{cases}
\mu' \approx 1 + \dfrac{\mu_{Spin}}{1+(\omega/\omega_{Spin})^2} + \dfrac{\mu_{DomainWall}}{1+(\omega/\omega_{DomainWall})^2} \\
\mu'' \approx \dfrac{\mu_0 \omega/\omega_{Spin}}{1+(\omega/\omega_{Spin})^2} + \dfrac{\mu_0 \omega/\omega_{DomainWall}}{1+(\omega/\omega_{DomainWall})^2}
\end{cases}
$$



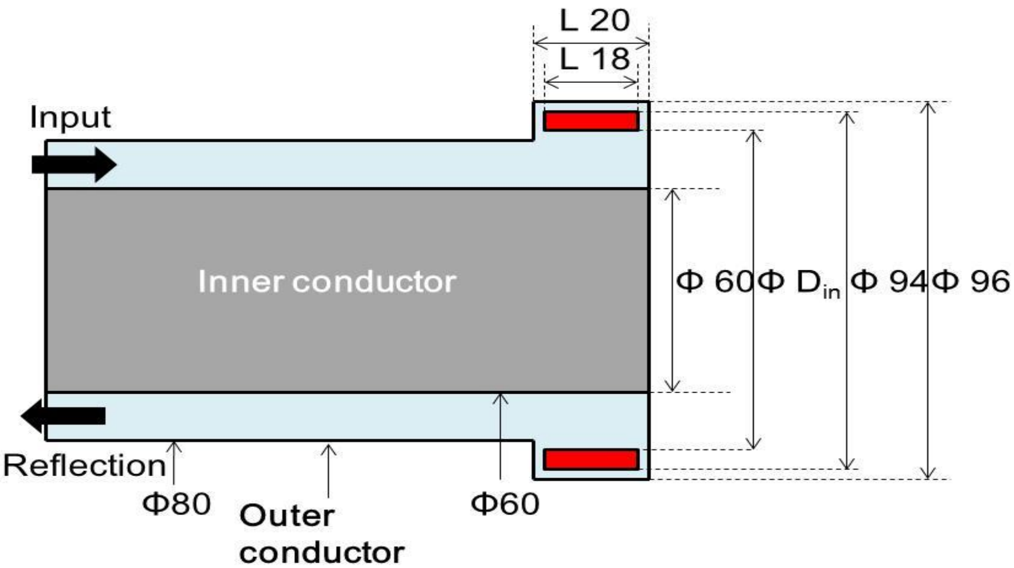
We conclude this ferrite has sufficient absorb ability at 77K.

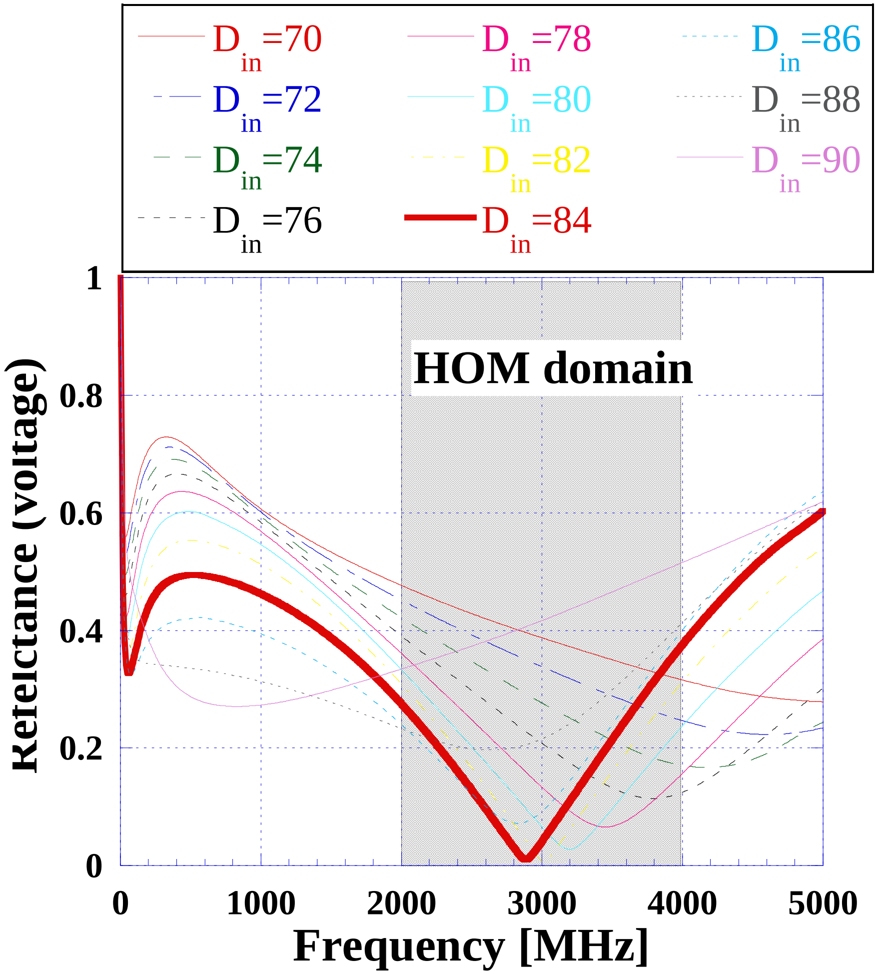
RF Absorber Shape

T. Konomi

Because space is limited, RF is absorbed in the housing space by resonance.

- The optimal shape was designed shape using the coaxial waveguide.
- In order to strongly resonance, the outer diameter of absorber is designed maximum size.
- The frequency of minimum reflection was matched to particularly harmful HOM domain





We looked for the optimal value by changing the inner diameter, and select Φ84mm.

Experiment of Demountable Damped Cavity

- The experiment was carried out separately for each feature of the DDC.
- And hence, the single cell DDC has many attachments.
- How to assemble the cavity in each test items are
  1. Frequency matching.
     - Insert pickup antenna at the end of Inner conductor without RF absorber and check the leak field.
  2. Super-Joint
     - Remove the inner conductor and RF absorber to simplify the problem.
     - At the demountable seal, magnetic field does not change by removing the inner conductor.
  3. Field emission & multipcating
     - Insert the inner conductor, and check occurring of the multipcating?
  4. Q-value of HOMs
     - Q-value of HOMs were compared with or without the absorber.

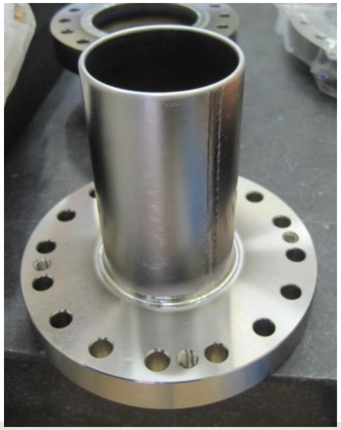
Single cell cavity

+

Choke

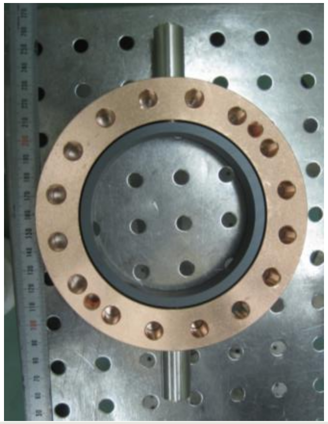
+

Inner conductor



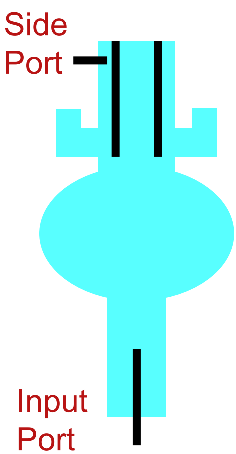
+

RF absorber

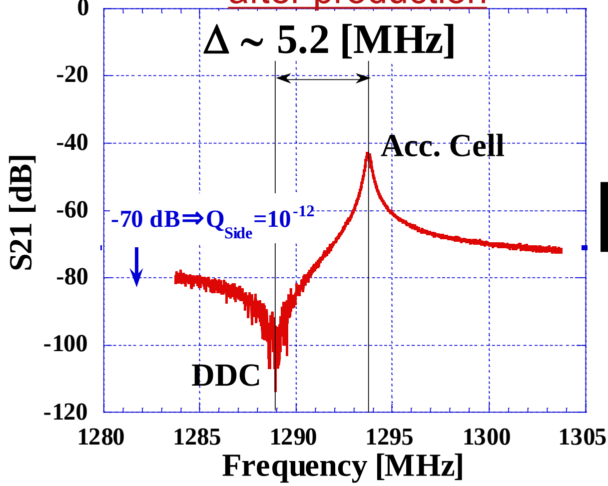


Frequency Matching

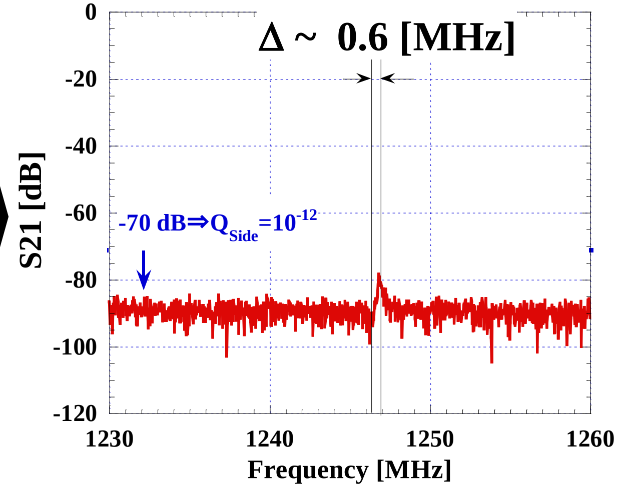
- The frequency of cavity and choke could be adjusted easily at room temperature.
- The question is that this frequency matching is or isn't remained after cooling down to 2K.
- Tuning method is transmission method.
- It has shifted the resonant frequency due to the choke's flange cutting for super-joint test described later.



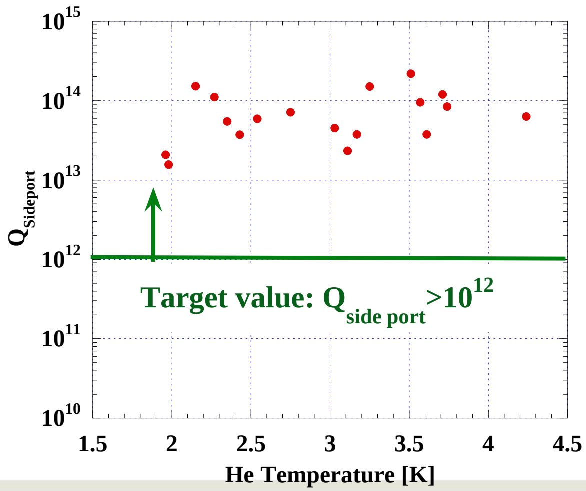
after production



after tuning at room temperature



Cool down to 2K



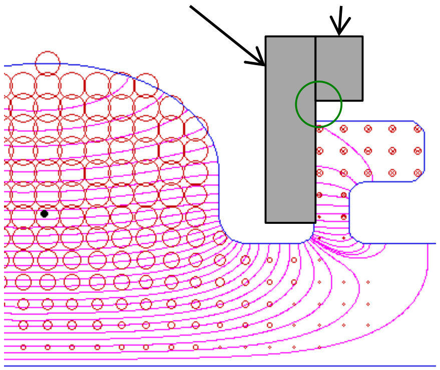
Leak into the port field is suppressed to less than 1% of the cavity loss.

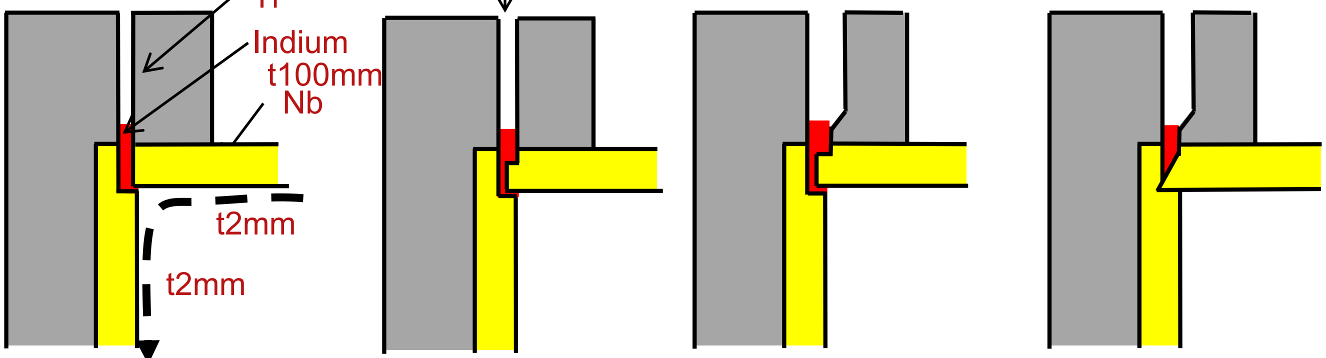
Target value: $Q_{Sideport} > Q_0 \times 0.01 = 10^{12}$

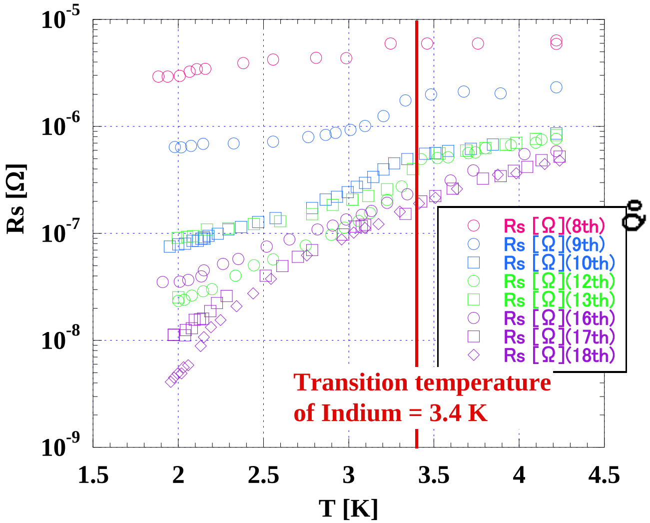
We confirmed there is no problem in the frequency matching

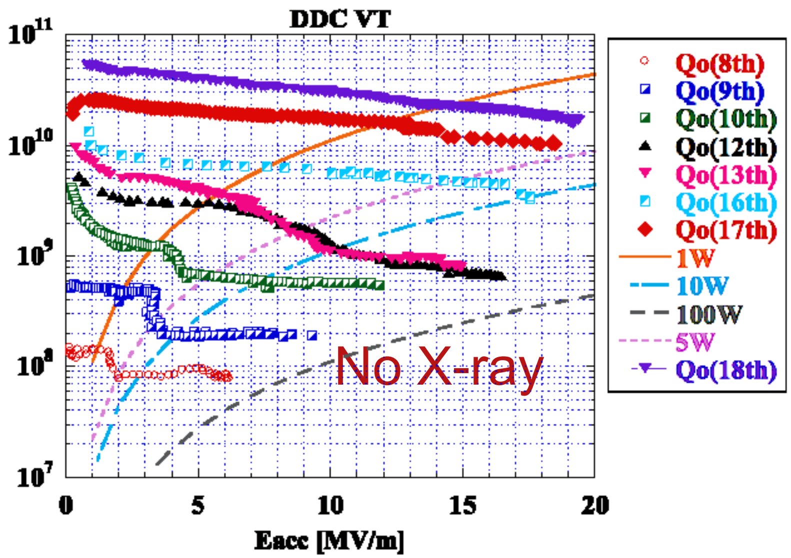
Super-Joint

- The magnetic field at the super-joint is 1/6 of the cavity's maximum field.
- Sealing material is indium. This transition temperature is 3.4K.
- Gradually, we changed the flange edge shape, because shape is not optimized and good performance couldn't be achieved.







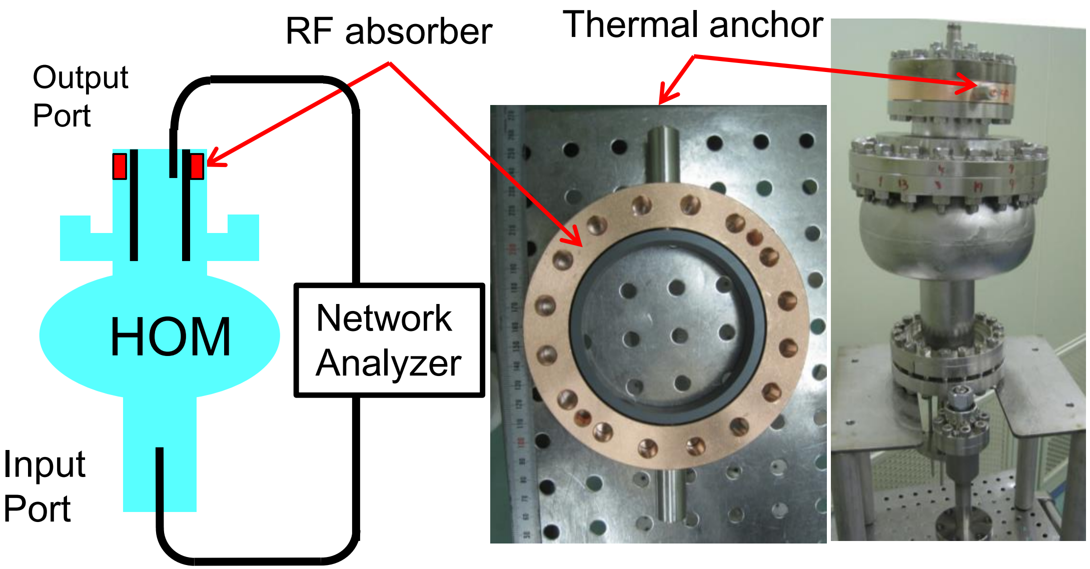


- We had changed into the knife edge shape gradually.
- There are transition temperature at 3.4K in 8th~17thVT. This means indium had been exposed to the RF field.
- But, finally We achieved to 19MV/m @Qo=1.5×10^{10}

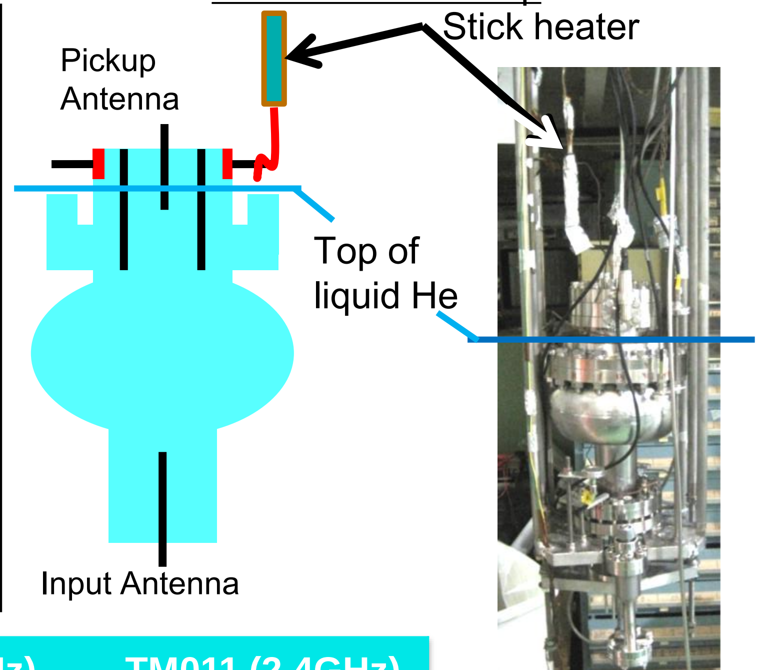
HOM Damping Efficiency

- HOM's Q-value was measured by network analyzer.
- Ferrite was kept at 77K by stick heater.

Measurement method



Measurement setup



	TE111(1.6GHz)	TM110 (1.8GHz)		TM011 (2.4GHz)
		Low	High	
DDC(2K, simulation)	146	435		520
DDC(2K, measurement)	Not Found	620		180
TESLA type HOM Coupler	2×10^4	3.5×10^4	4.7×10^3	1×10^5

TESLA type data from K. Watanabe doctor thesis

- Q-value of HOMs in DDC is lower than TESLA type HOM coupler.
- Separation of HOM is not appeared in DDC.

19.3 Tuner

- SRF cavity bandwidth on QL: loaded Q

$$Q_L = \frac{f_C}{2\Delta f}, \quad 2\Delta f = \frac{f_C}{Q_L}, \quad Q_L = \frac{\omega U}{P_{loss} + P_t + P_e + P_b}, \; P_b = I \times V$$

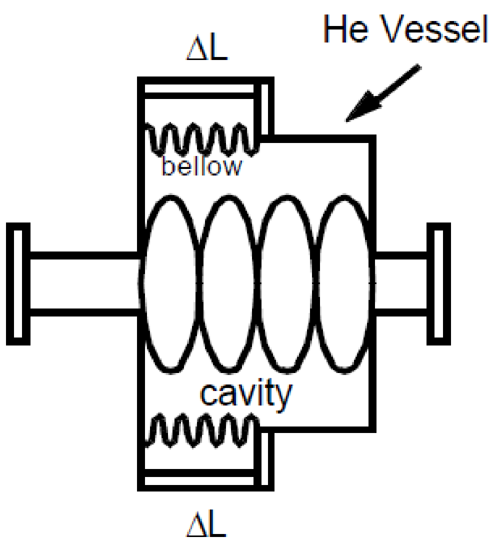
P_{loss} is very small for SRF cavity.

Cavity resonant frequency has to follow the accelerator frequency.

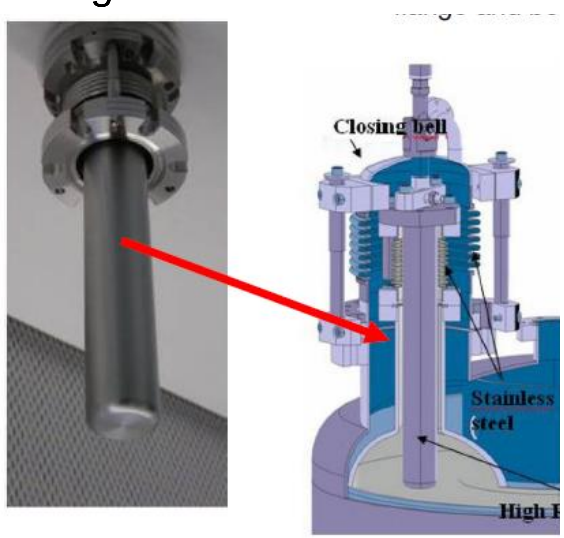
The cavity frequency has to stay within $f_o - f_c < \Delta f$.

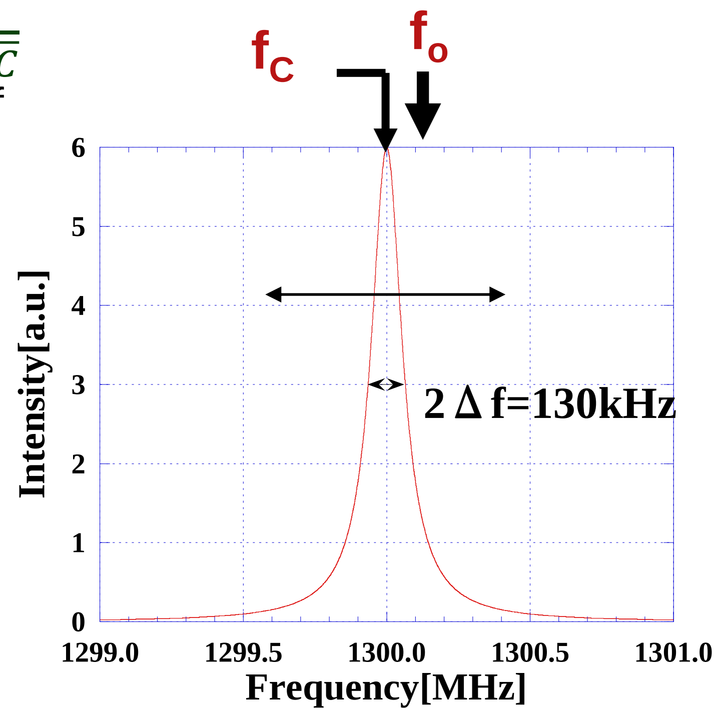
- Cavity frequency is changed by L or C, $f_C = \frac{1}{2\pi\sqrt{LC}}$

Change the iris distance : C



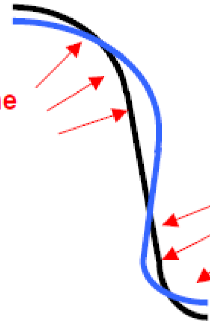
Change the surface areas of high H : L

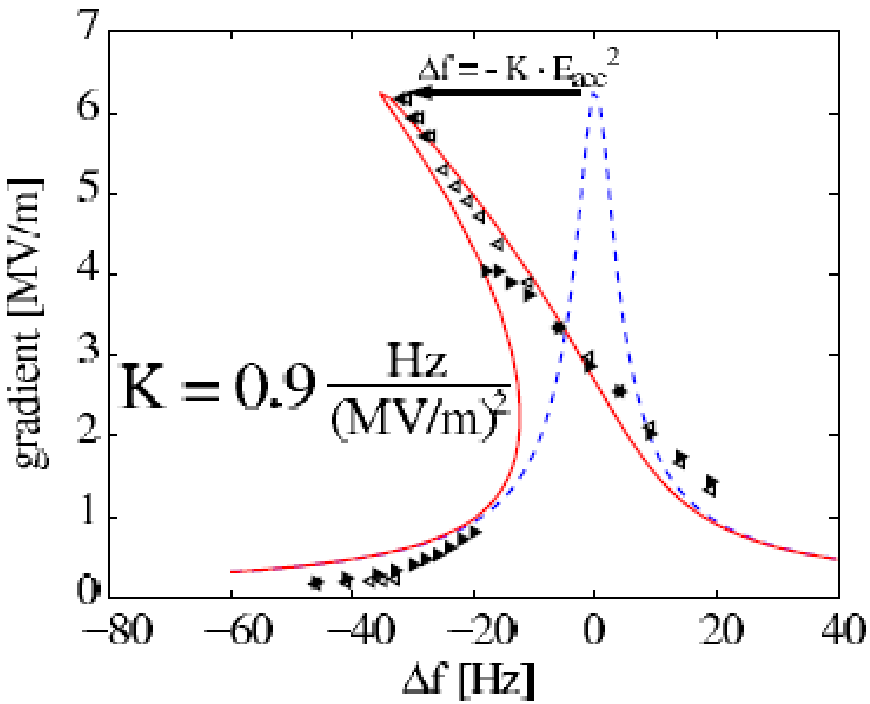




Cavity frequency change by Lorentz detuning

- Maxwell stress changes cavity frequency
  - $\Delta f = - k_L \, Eacc^2$
- Tuner has to compensate the Lorentz detuning





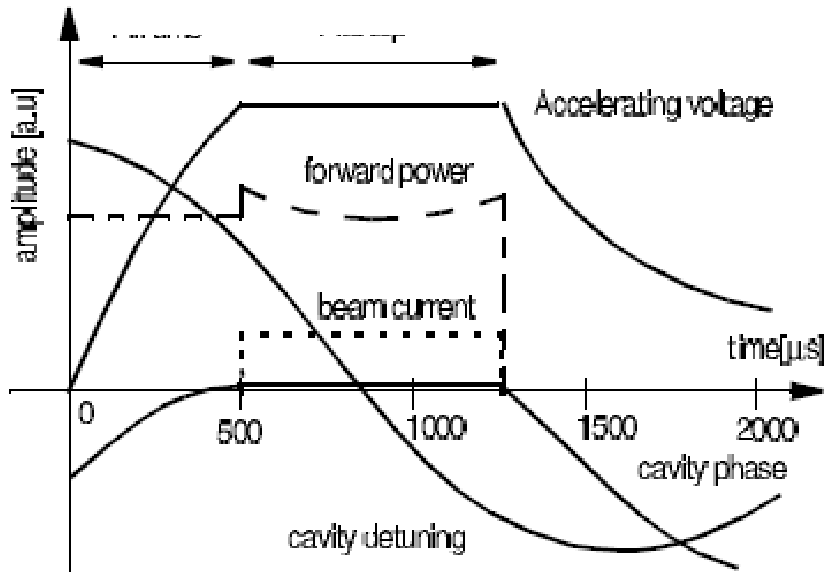
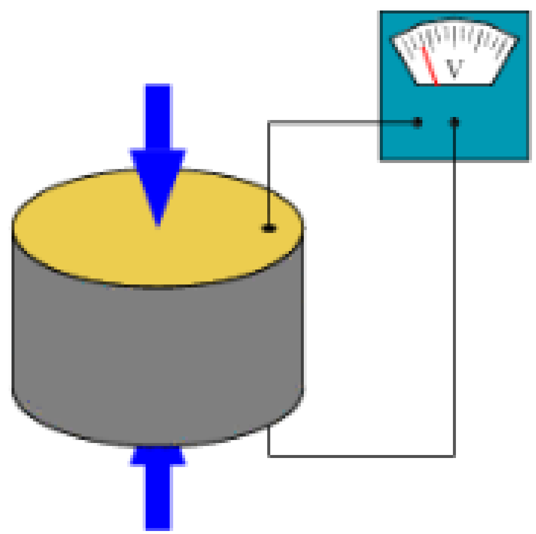


Figure 1: Various parameters related to the pulsed cavity fields in the superconducting cavities of the TESLA Test Facility.

Tuner

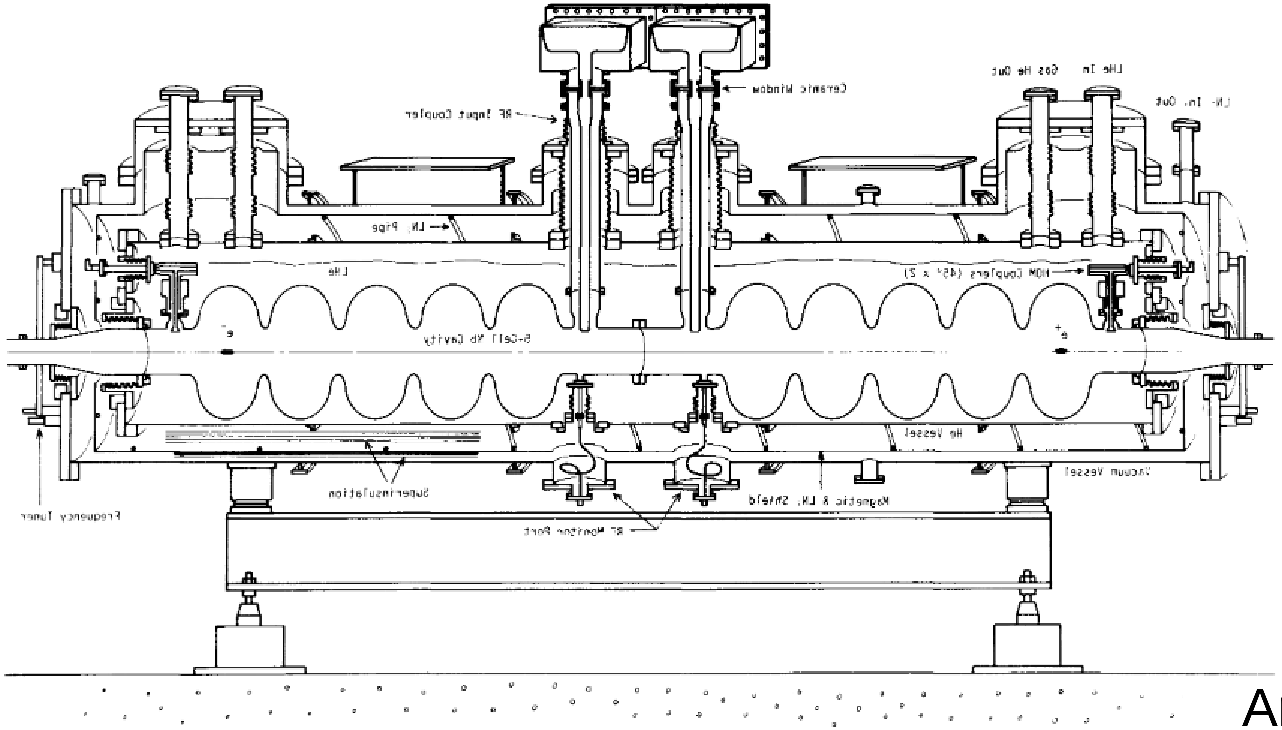
- SRF cavity is vibrating in the cryomodule due to the environment noise
  - Helium pressure
  - Vibration on the base of the cryostat (culture noise: care, train…..); microphonics
  - Lorentz detuning
- The cavity resonant frequency (f_C) has to be the same as accelerator frequency (f_O)
- The combination of slow tuner and PIEZO sensitive tuner(f_O)
  - Mechanical tuner: set the f_C to as same as f_O using motor drive
  - PIEZO tuner: fine frequency control applying voltage PIEZO element
- Piezoelectric effect:
  - Quartz or some ceramics produce a voltage due to electric polarization when applied pressure, or the opposite phenomena happens

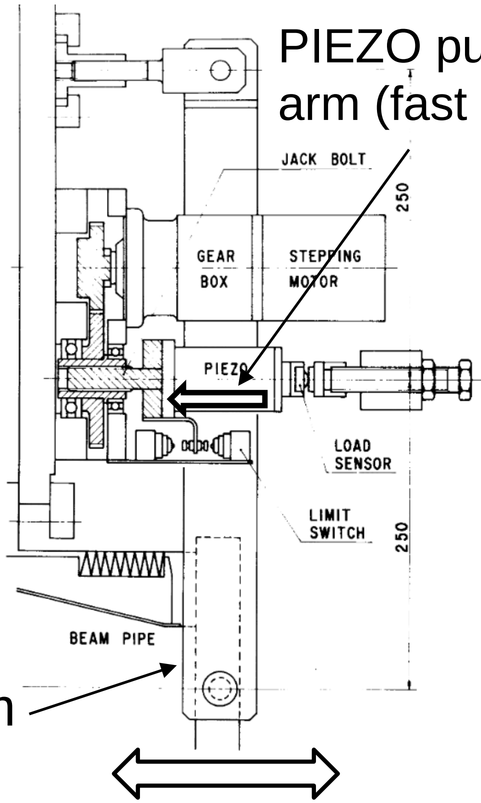


Applying voltage ⇒ Length change in PIEZO element ⇒ Change cavity dimension

Tuner for TRISTAN cryomodule

- Tuning is accessible from outside cryomodule up to two cavities configuration in one cryomodule (TRISTAN).
- Many cavities in one cryomodule is preferred to increase the space efficiency
- In this case, tuning mechanism has to be located in the cryomodule.

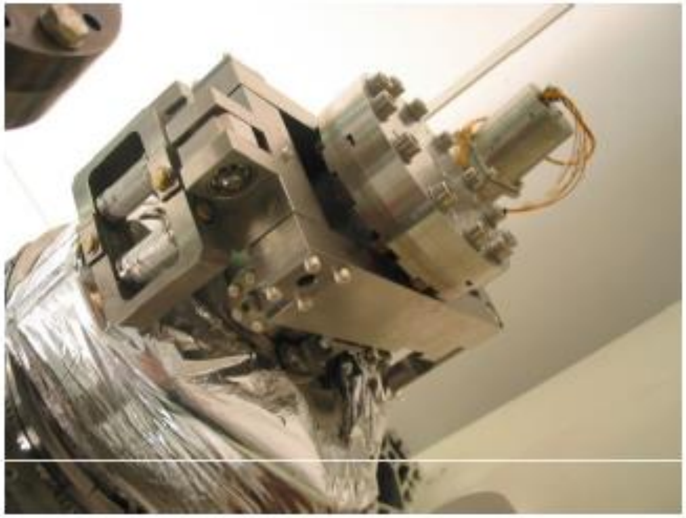


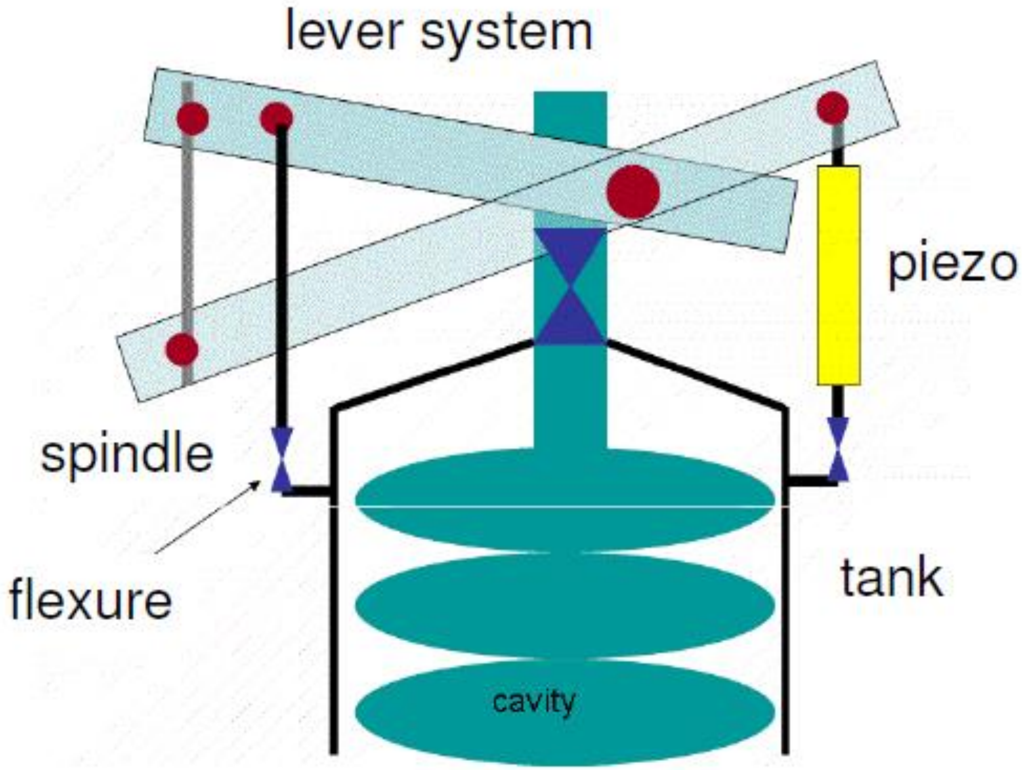


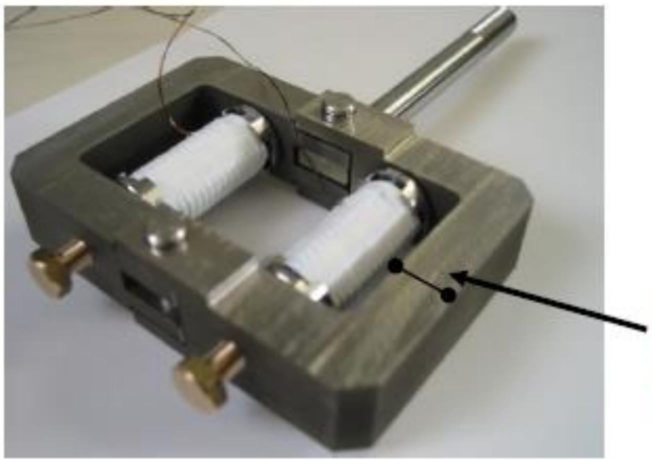
Arm is pushed/pulled the beam pipe by motor drive (slow/wide tuning)

Saclay level tuner for elliptical cavities

Saclay I tuner

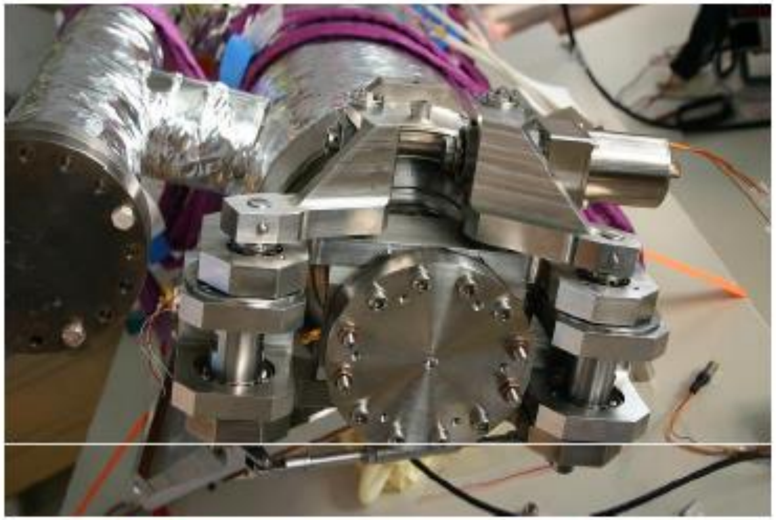


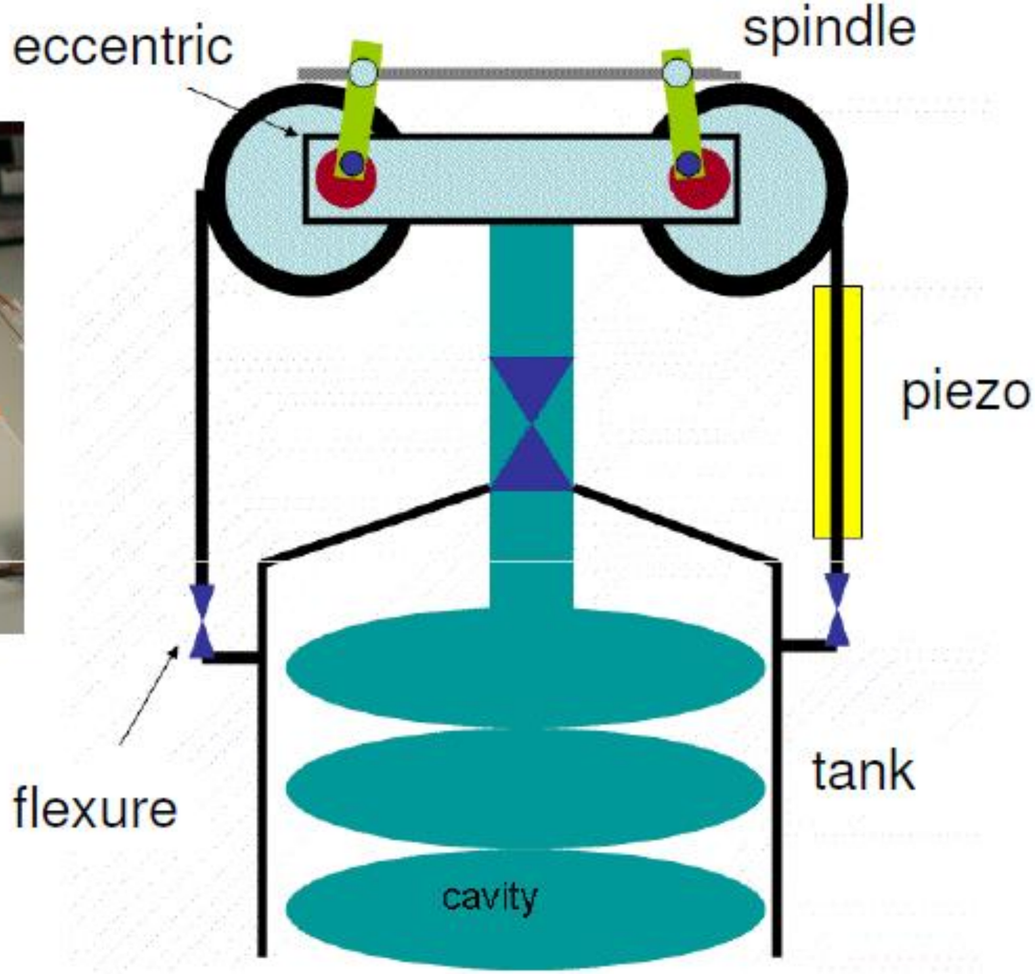




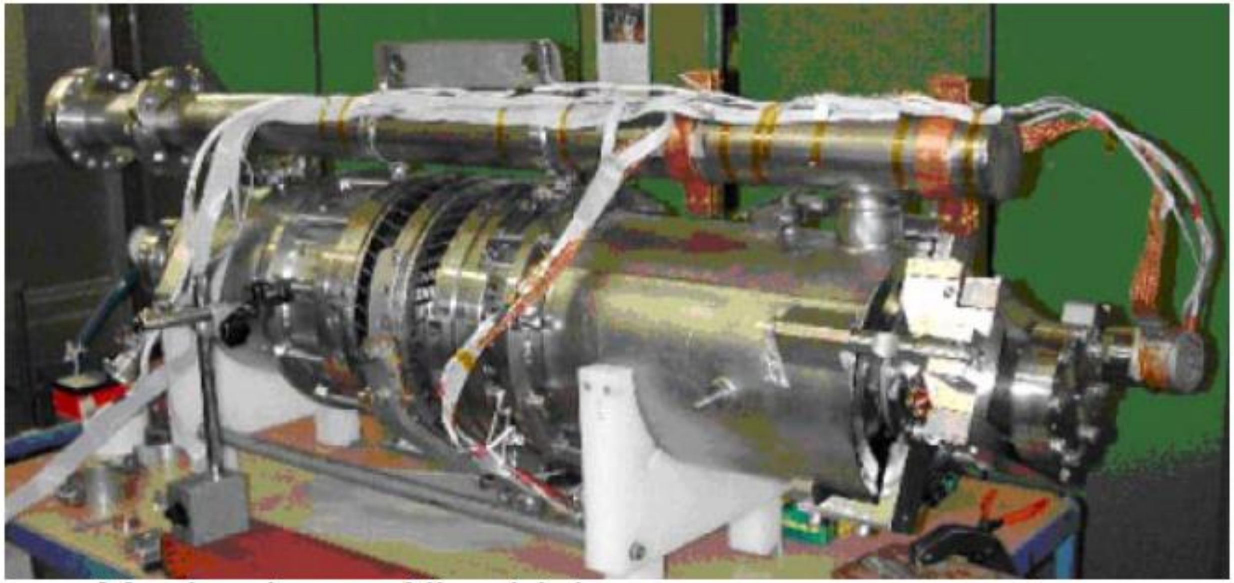
Modified piezo holder frame:
Higher wall thickness

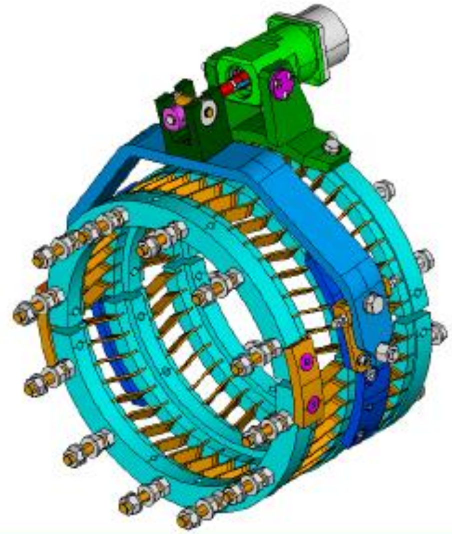
Saclay Updated Tuner for Elliptical Cavities



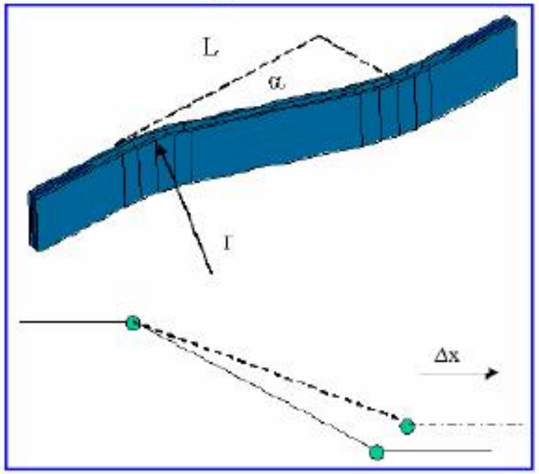


Blade Tuner for ILC Cavities

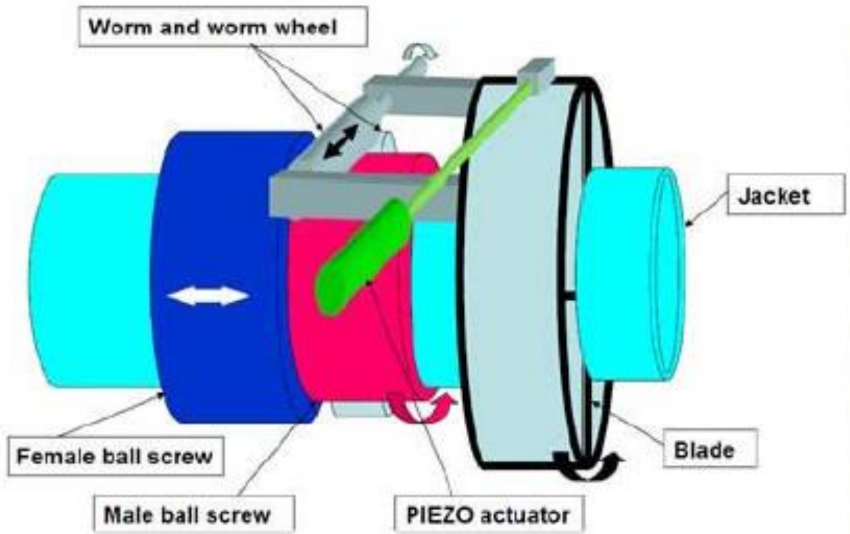


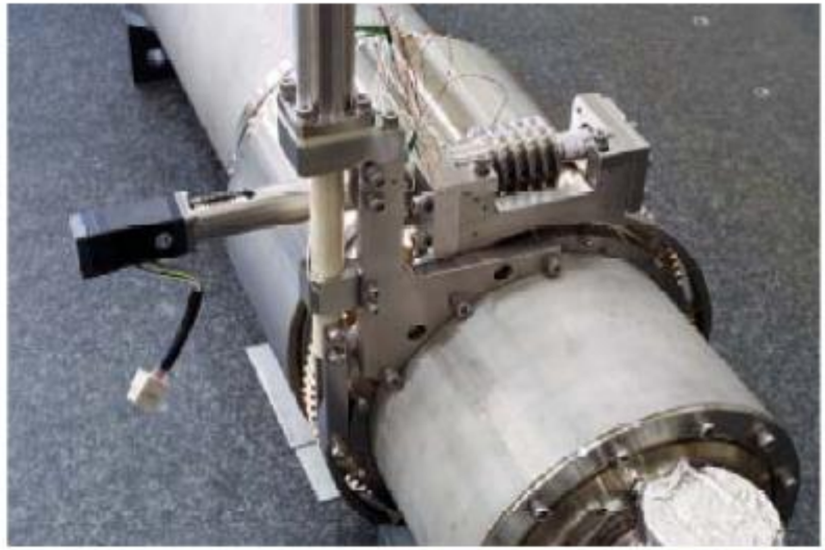


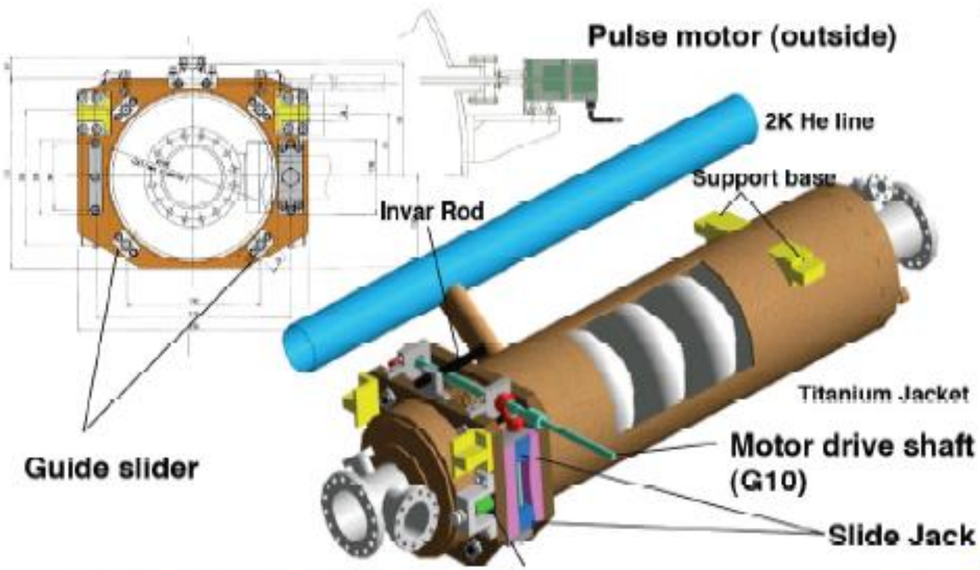
- Mechanism – All cold, in vacuum components
  - Titanium frame
  - Attaches to helium vessel shell
  - Pre-tune using bolts pushing on shell rings
  - Dicronite coating on bearings and drive screw
  - Cavity tuned in tension or compression – blades provide axial deflection



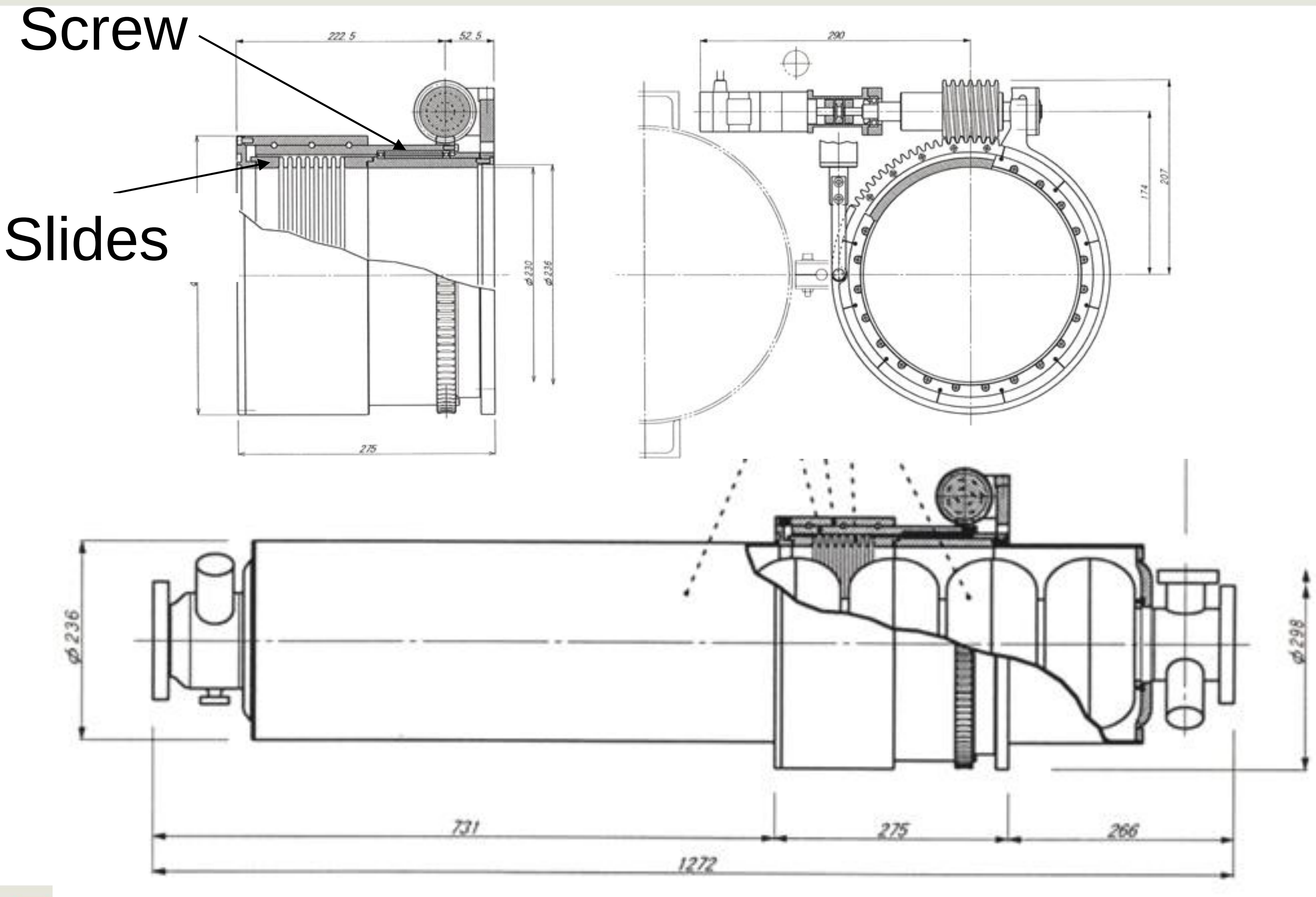
KEK Coaxial Ball Tuner and Jack Tuner



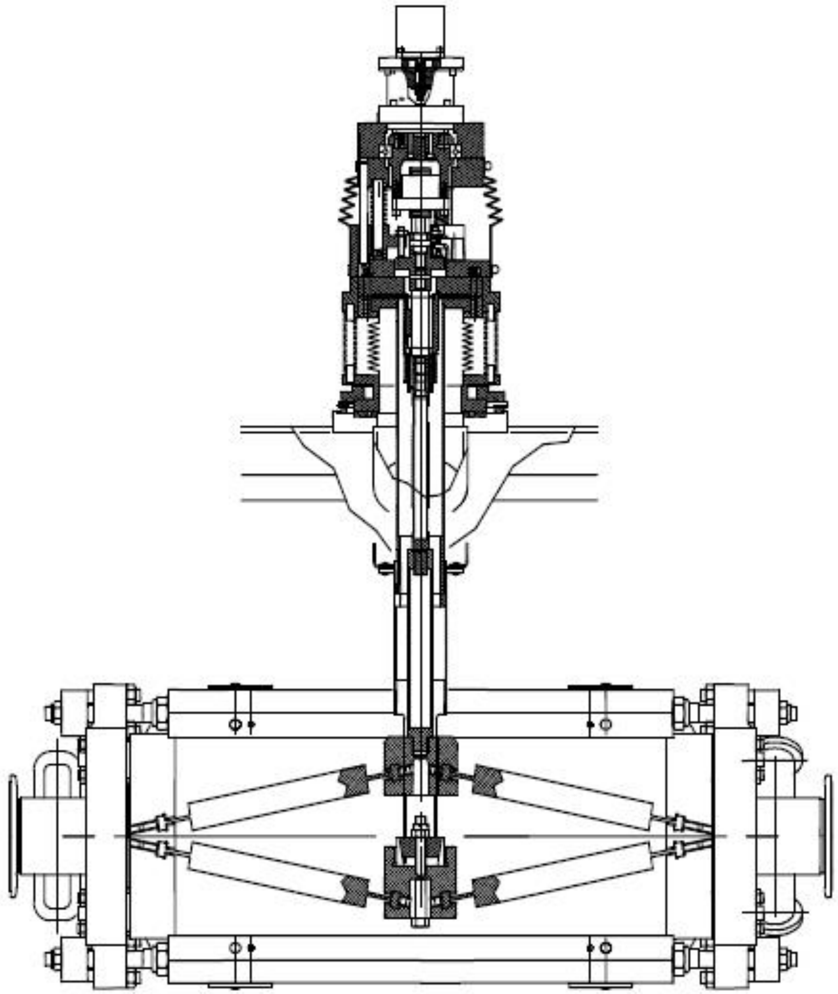




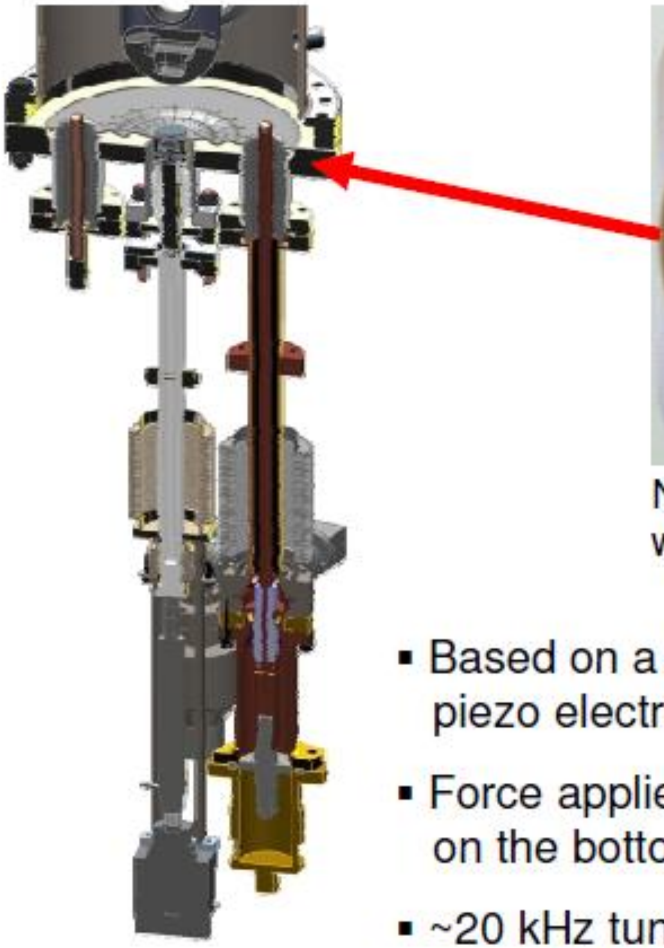
Detail of Coaxial Ball Tuner



Jlab Scissors Tuner



ReA Base Plate Tuner for QWRs

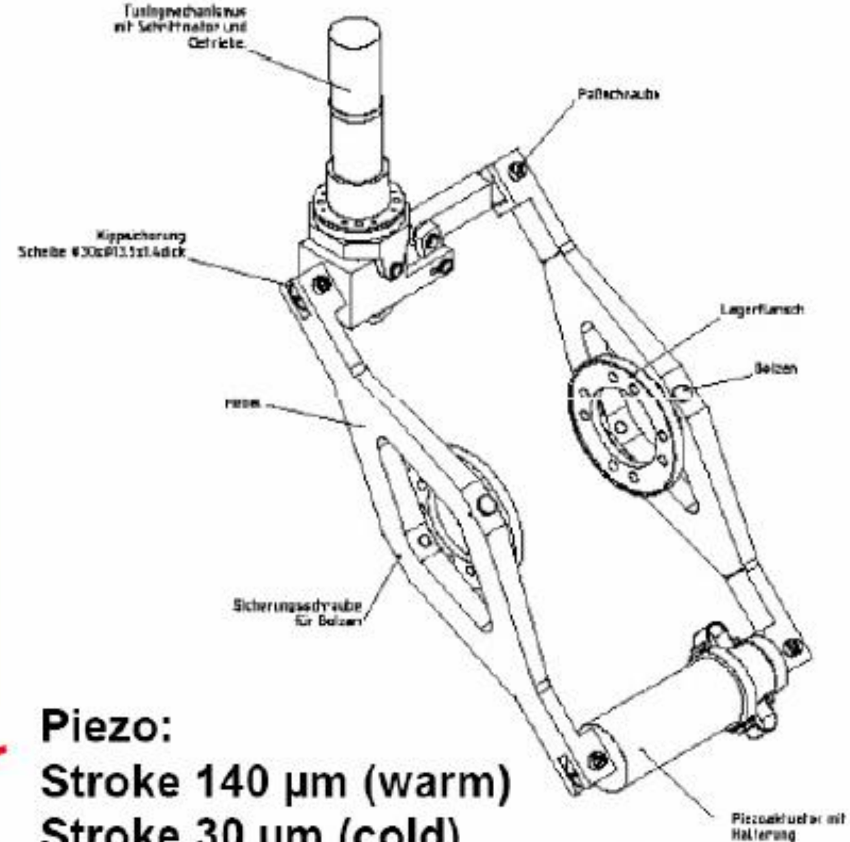


Niobium push-pull tuning plate
with convolutions and cuts

- Based on a warm linear stepper motor plus piezo electric stack
- Force applied through to a tuning rod to a tuning plate on the bottom of the cavity
- ~20 kHz tuning range (+/- 25 mm) using stepper motor 300 Hz full range with piezo

Orsay Mechanical Tuner for QWRs

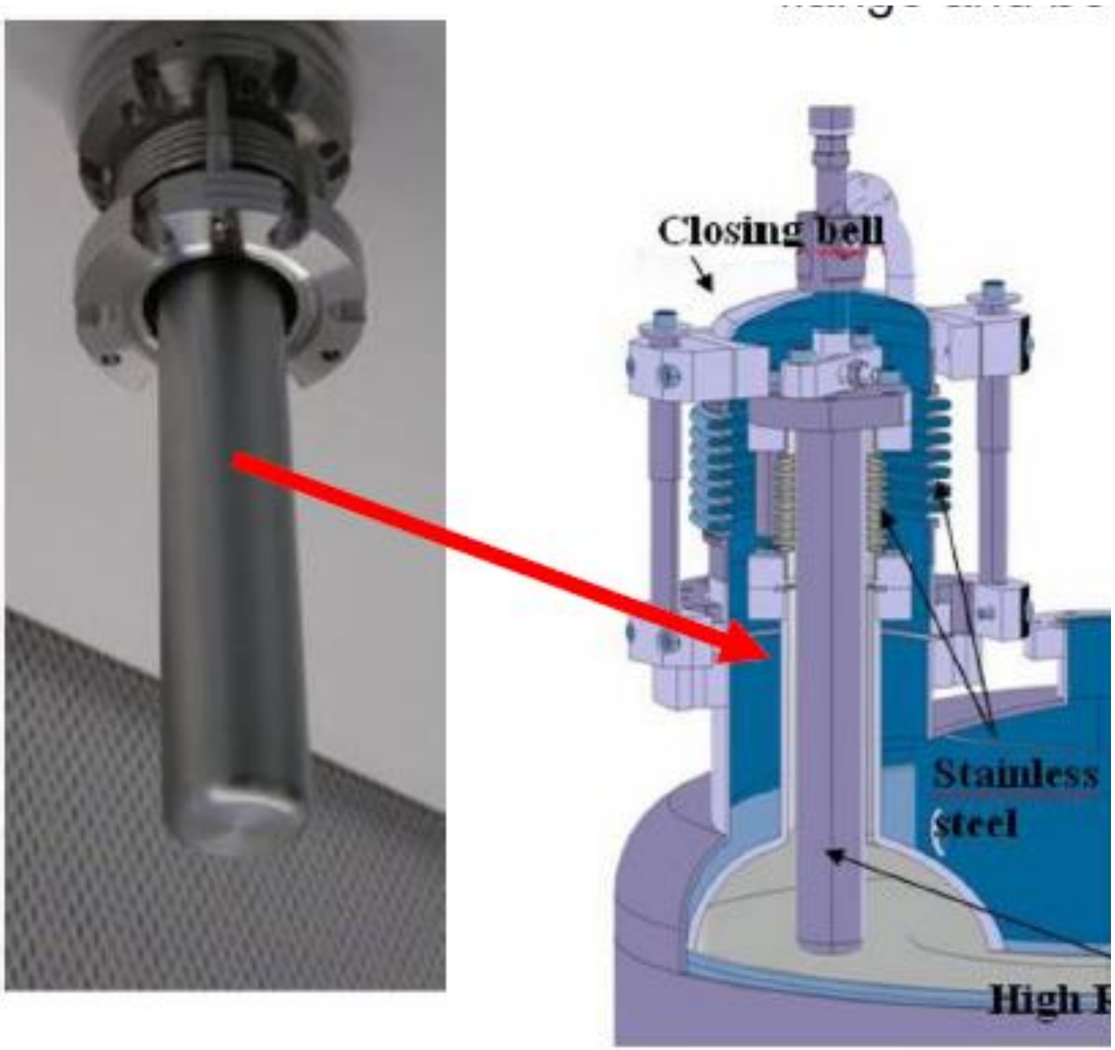
Mechanical: Warm & Cold
Sensitivity: 0.2 Hz/step



Piezo:
Stroke 140 μm (warm)
Stroke 30 μm (cold)
Usable stroke (+/-3 μm)
-> +/- 450 Hz tuning range

Soreq

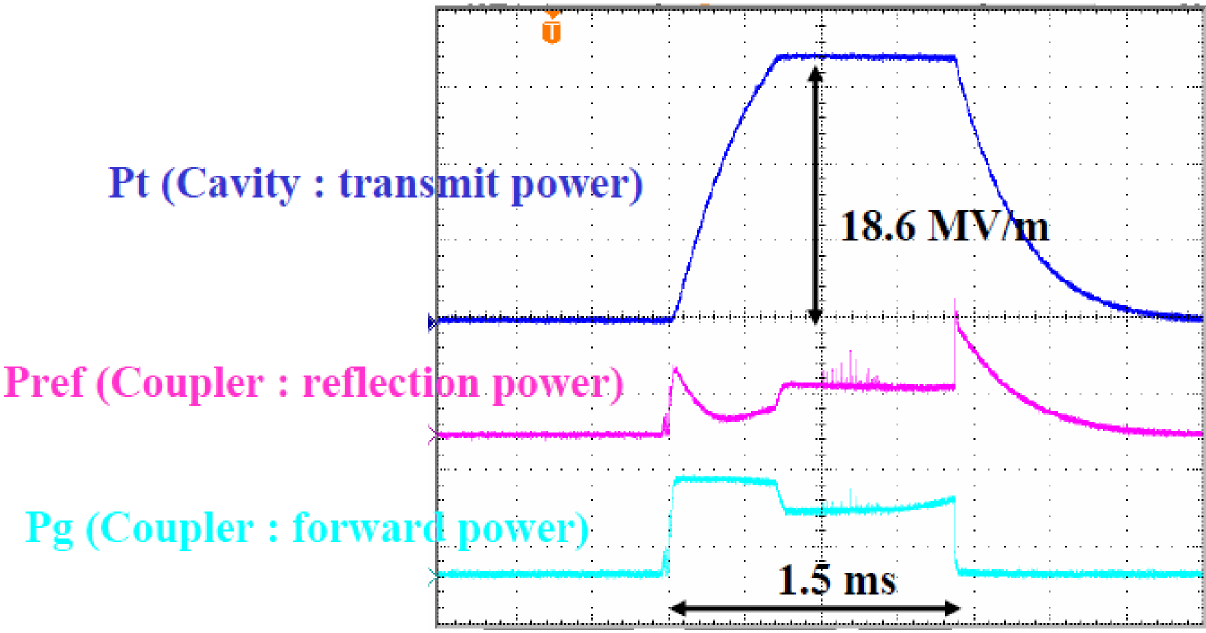
Orsay Plunger Tuner



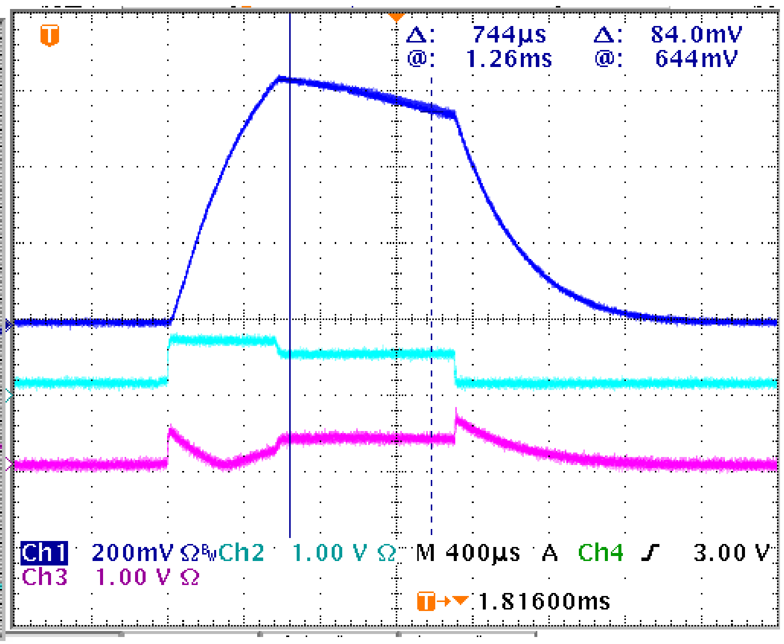
Tuner Operational Experience with Coaxial Ball Tuner at KEK

Stable operation at Eacc=18.6 MV/m

Digital Feed-back On & Piezo On



Piezo off



Homework 19

- Homework 19.1

  Please describe the role of the cavity Ancillaries: Input couplers, HOM couplers, and tuners.

- Homework 19.2

  Please explain the functional principle of these three ancillaries using an example?.