Development of the KEK-B Superconducting Crab Cavity

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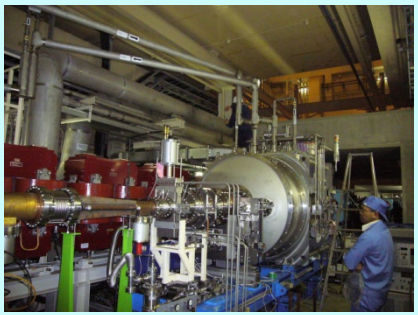
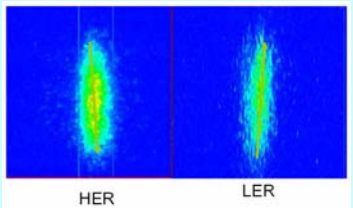
KEK, Tsukuba, Japan
K. Okubo, K. Sennyu, H. Hara, T. Yanagisawa
MHI Kobe Shipyard, Japan



Crab Cavity for HER

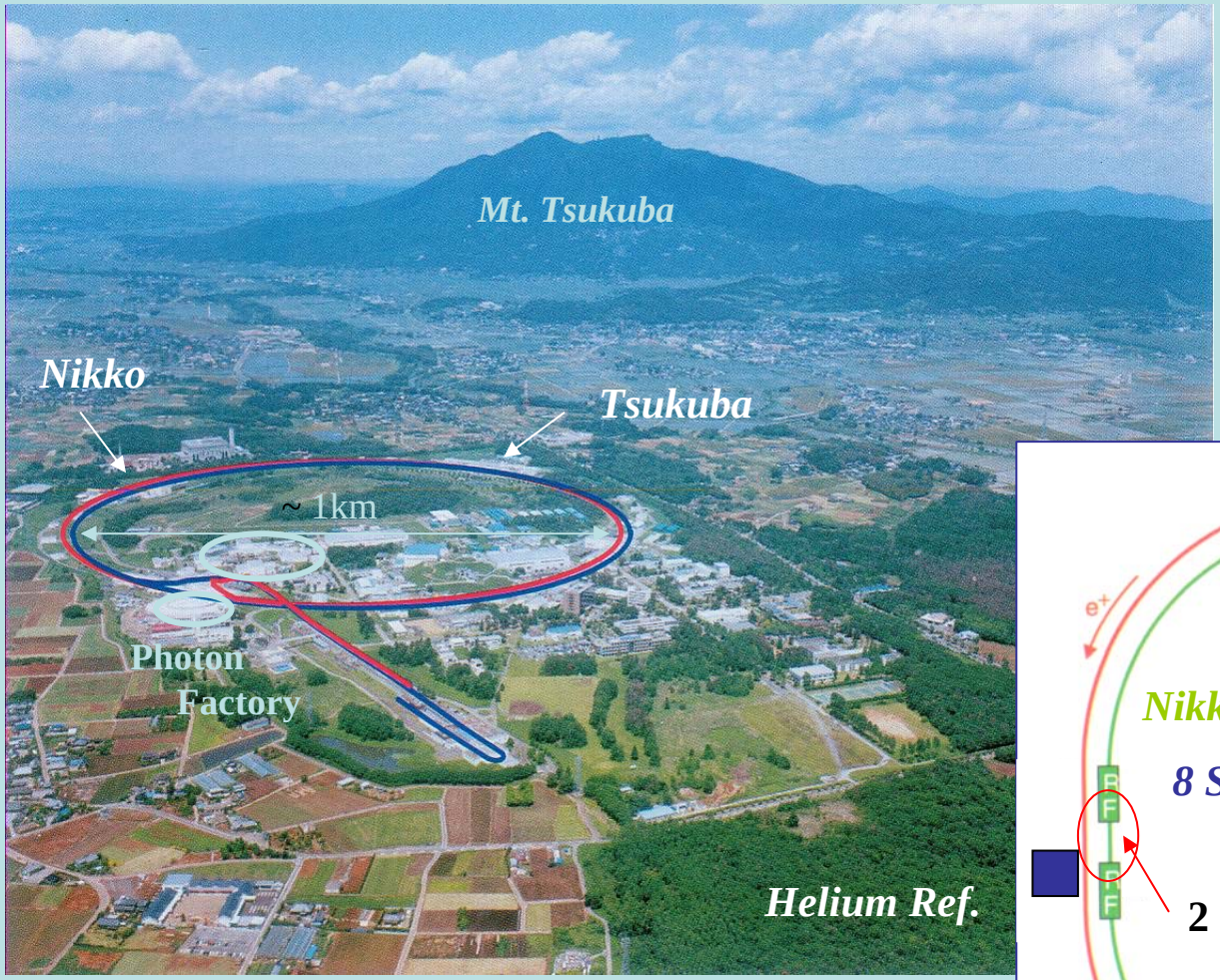


Bunches kicked
by crab cavity

Outline

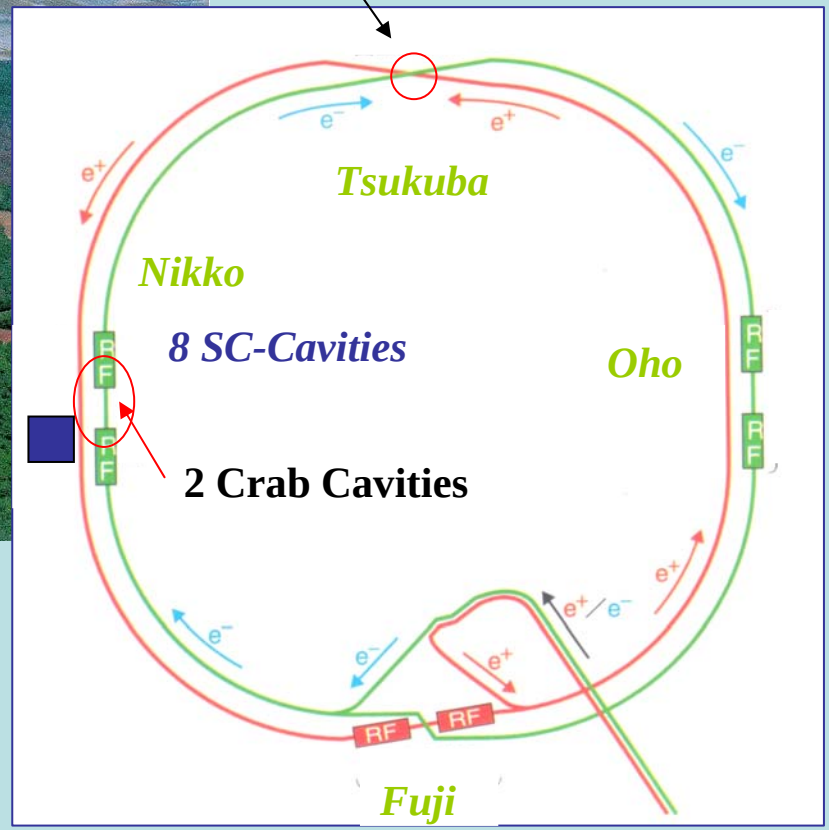
- KEKB and Crab Crossing
- KEKB Crab Cavity Concept and R&D History
- Fabrication of Crab Cavities
- Cold Test in Vertical Cryostat
- Cryostat for Crab Cavities
- Coaxial Coupler
- Frequency Tuning
- Assembling of Crab Cavity into Cryostat
- High Power Test at Test Stand
- Installation & Commissioning of Crab Cavities
- Summary

Crab Cavities for KEKB



KEKB	
LER	3.5 GeV
HER	8.0 GeV
RF freq.	508.9 MHz
Cross. Ang.	2 x 11 m rad.

Collision Point

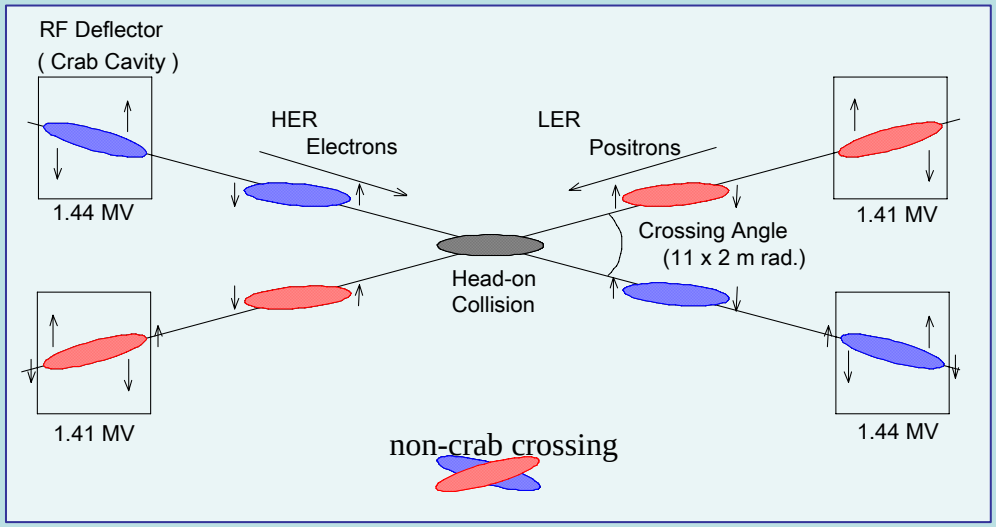


KEKB Crab Crossing

The crab crossing scheme allows a large crossing angle collision without introducing any synchrotron-betatron coupling resonances. [1, 2)]

Original Crab Crossing Scheme

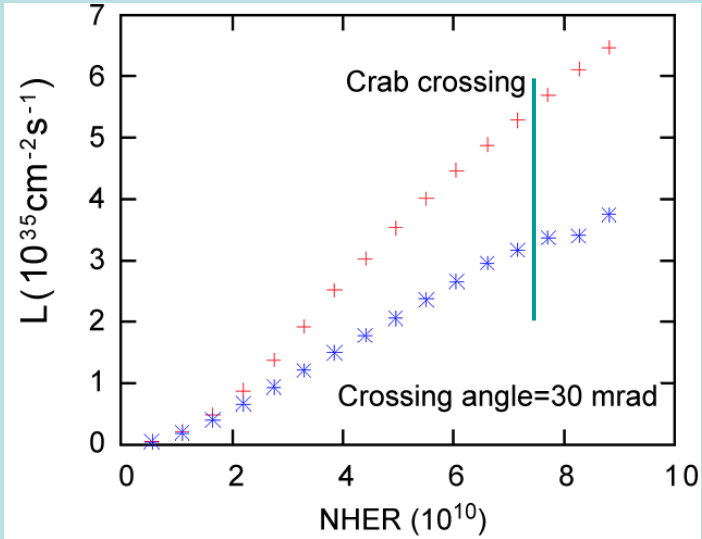
4 Crab cavities scheme Local crab crossing scheme



1) R.B.Palmer, SLAC-PUB-4707,1988
2) K.Oide and K.Yokoya, SLAC-PUB-4832,1989

Effect of Crab Crossing

(Simulation by Ohmi)



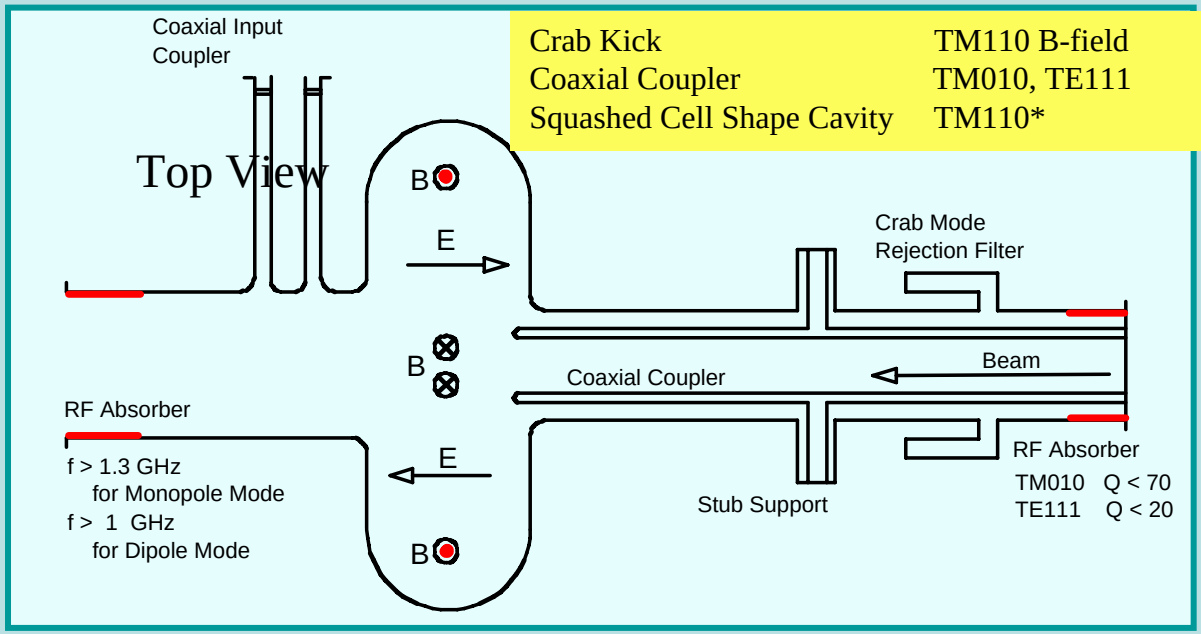
New Crab Crossing Scheme

2 Crab cavities scheme
Global crab crossing scheme

→ Beam-bunch wiggle around the whole ring!

Advantage: We can use existing cryogenic system for Acc. S.C. cavities

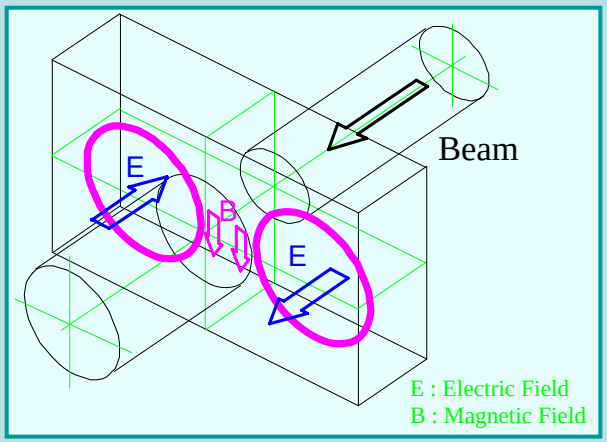
Conceptual Design of KEKB Crab Cavity



Crab Kick	TM110 B-field
Coaxial Coupler	TM010, TE111
Squashed Cell Shape Cavity	TM110*

Characteristics:

- **Squashed Cell Shape**
- **Higher Order / the Lowest Mode Damped Cavity**
  - **Coaxial Coupler to Extract TM010**
  - **Large Beam Pipes for Higher Order**

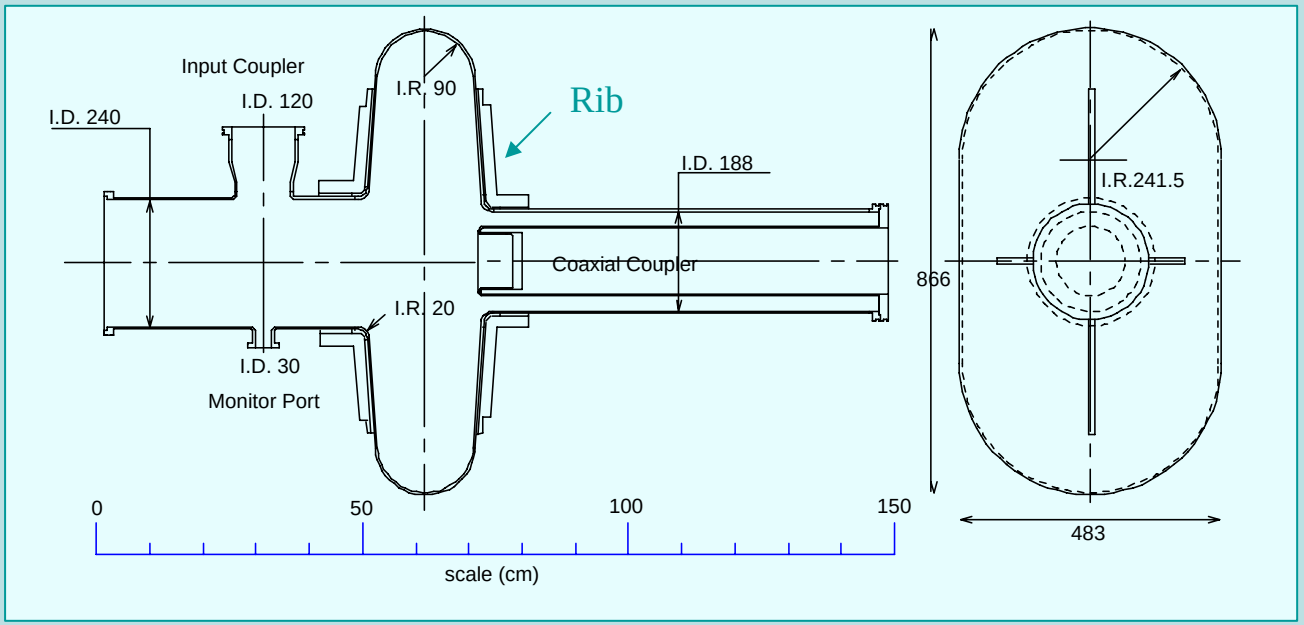


Squashed Cell Shape Cavity Design

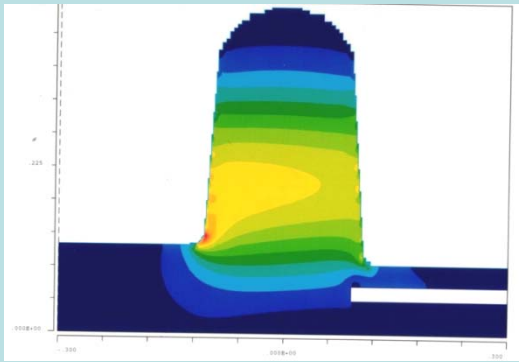
The squashed cell shape cavity scheme was studied by Akai extensively at Cornell in 1991 and 1992 for CESR-B under KEK-Cornell Univ. collaboration.

We adopted this design as “base design”!

KEKB Superconducting Crab Cavity



Frequency	501.7 MHz
R / Q	46.7 Ω
G	220
Esp / Vkick	14.4 MV / m / MV
Hsp / Vkick	415 Oe / MV

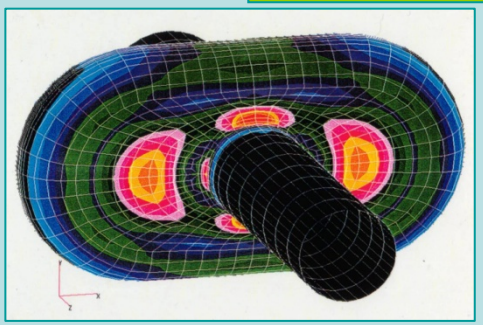


Mechanical and Fabrication Issues

⇨ Non-axial Symmetric Structure
Thickness of 4.5 mm Nb Cavity
Reinforced by Ribs

No Rib

σ_{Max} = 17.6 kgf / mm^2



4 - Rib

σ_{Max} = 7.41 kgf / mm^2

History of KEKB Crab Cavity

0) 1/3 scale model 1.5 GHz 1994
   3 Nb Cavities
   Fabrication & surface treatment of non-axial symmetric cavity

1) Full Scale Prototype Crab Cavity 500MHz 1996

   2 Nb Cavities # 1 & # 2
   Coaxial Coupler
   Prototype Horizontal Cryostat 2003

2) KEKB Crab Cavity 509MHz

   Installation of 2 crab cavities in KEKB was decided 2004

   2 Nb Cavities for LER, HER
   Cold Tested in Vertical Cryostat 2005
   Assembling and High power test 2006
   Installation and Commissioning 2007
   Jan. ~

10 years

3 years

1 year

Construction of KEKB Crab Cavity

collaboration with Industry & build up of infrastructure

1) Fabrication of the crab cavities and coaxial coupler — MHI

2) Surface treatment

Mechanical grinding	Cell equator welding part	KEK/MHI
Barrel polishing		KEK
Electro-Polishing		Nomura Plating
Heat Treatment		Kinzoku Giken
High pressure rinsing		KEK
Clean room for assembling the crab cavity		KEK

3) RF Measurement system at vertical cryostat — KEK

Test Stand in vertical cryostat	1.5 GHz	
	500 MHz	

4) Horizontal cryostat

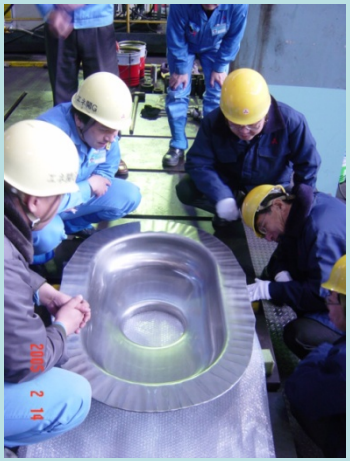
Design and assembling of prototype	KEK/Koike/Hitachi Oxygen
Design and assembling of horizontal cryostat	MHI
Clean Room for Installation of the crab cavity into cryostat	KEK

5) Input coupler and HOM damper — MHI/Kinzoku Giken

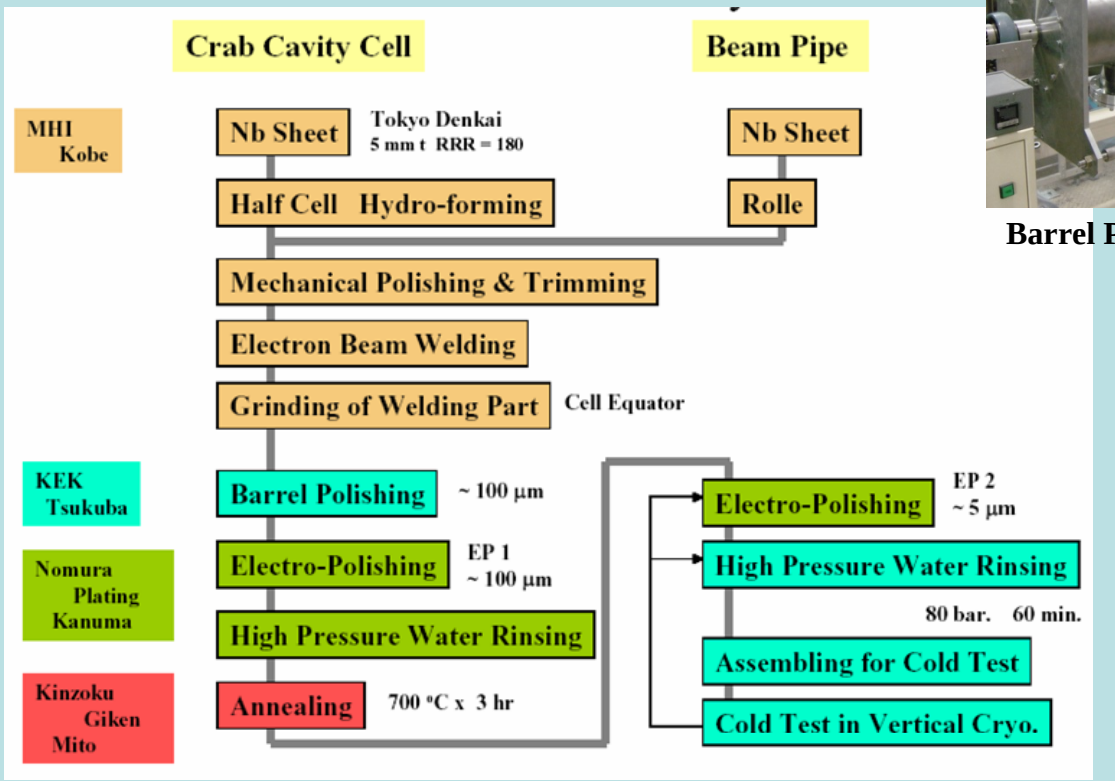
6) Design and construction of cryogenic system — KEK/Hitachi

7) Test Stand for high power RF test — KEK

Fabrication & Surface Treatment



Forming of Half-Cells



Barrel Polishing 312Hr

High Pressure Water Rinsing

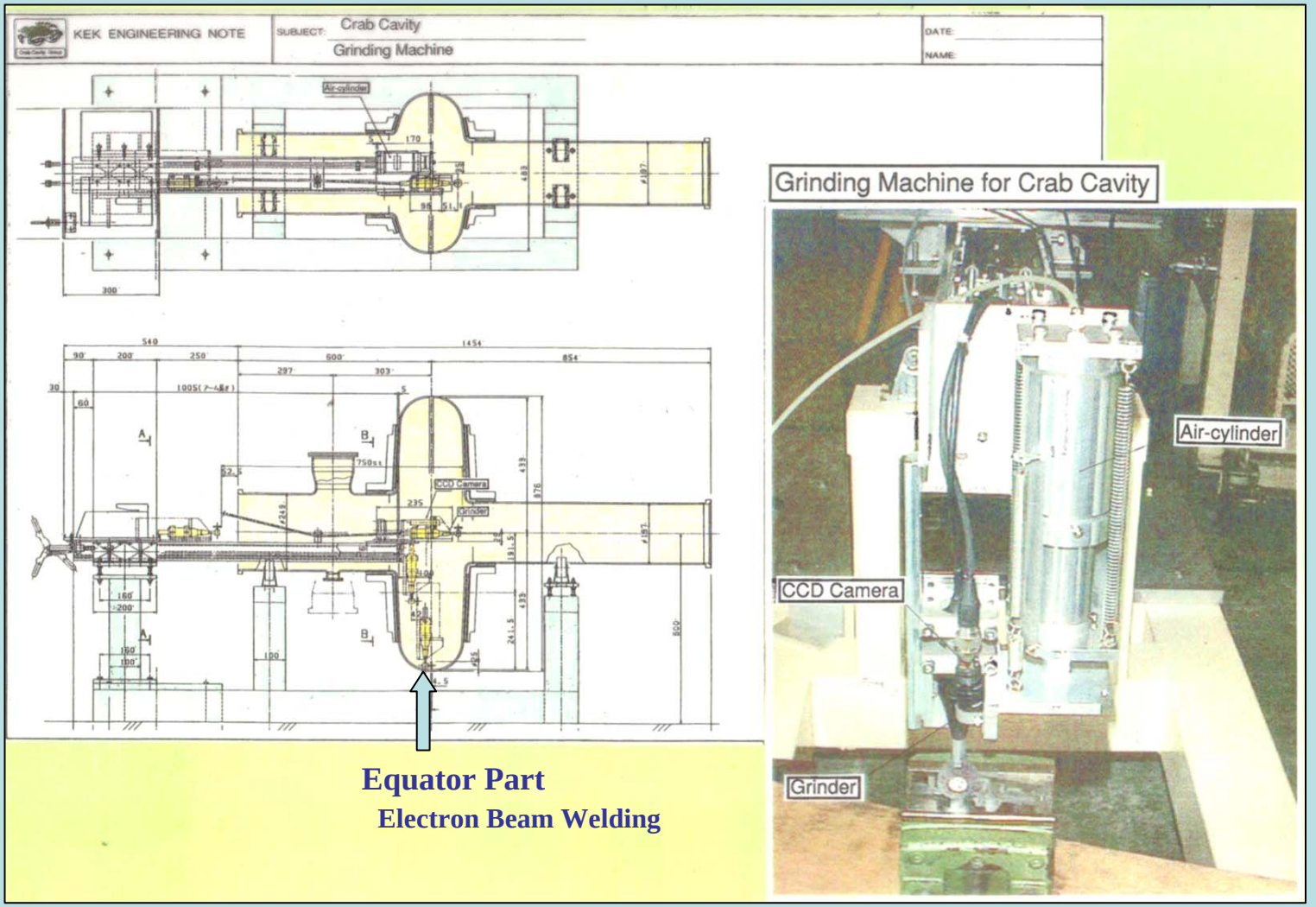
Electro Polishing

Annealing

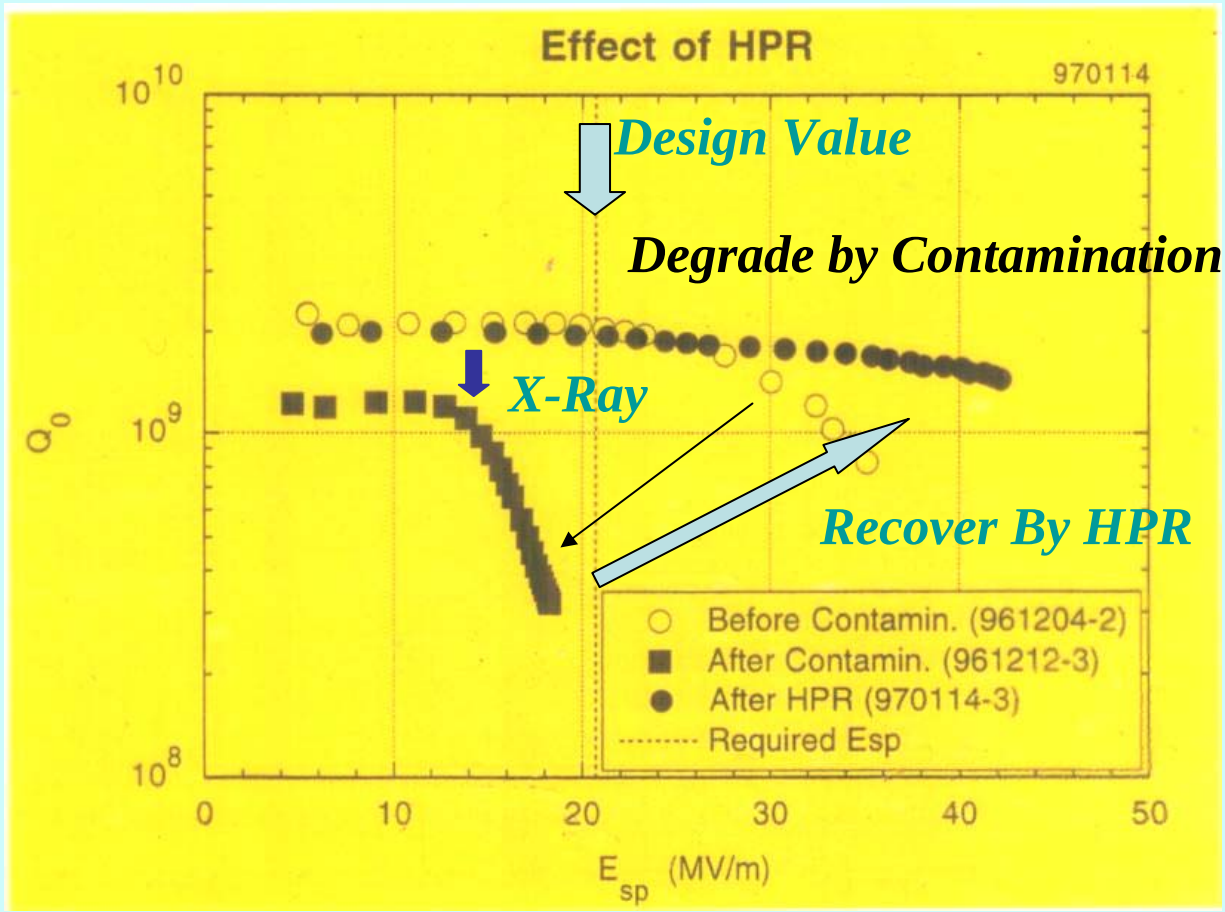
Assembling

Grinding Machine

Crab cavity was assembled; full penetration, defocused electron beam welding.
Inner surface of welding part along the equator of cell has line-like bump
By using grinding machine we must remove it!



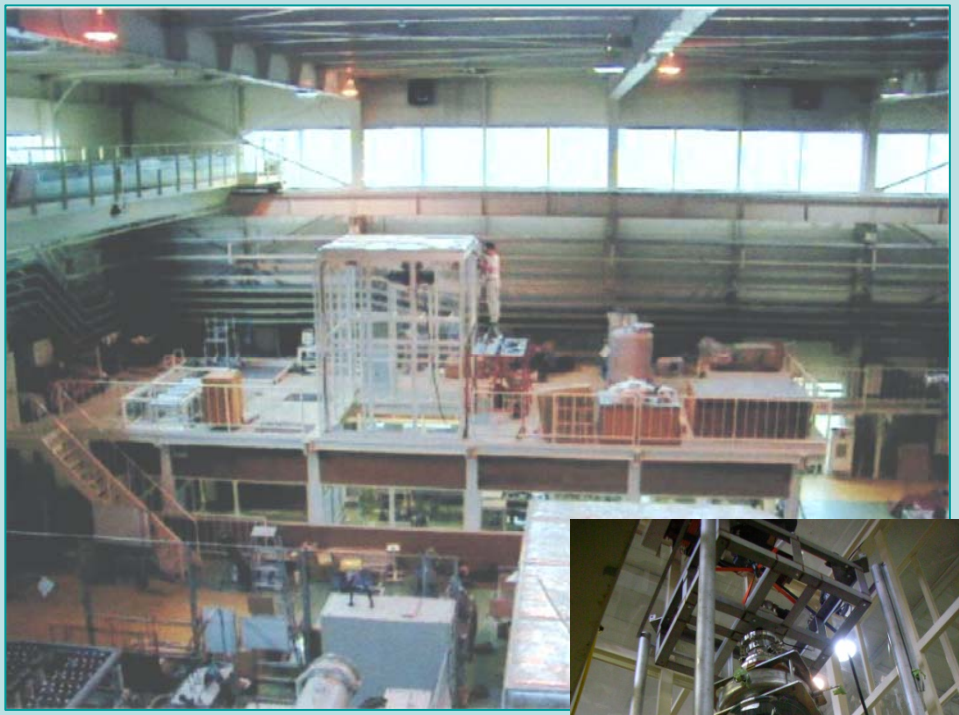
Effect of High Pressure Rinsing



1/3 Scale Model
1.5 GHz

By breaking the vacuum and introducing air into the cavity,
the Q_0 degrade and increase the radiation of X-ray.
High pressure rinsing can recover the performance of the cavity.

Clean Room for Assembling Cavity and Cryostat



Clean Room (Class 100)
for Cavity Assembling

High Pressure Pure Water Rinsing

Clean Room
for Cryostat Assembling

HPS : Coaxial coupler

HPS : Jacketed crab cavity

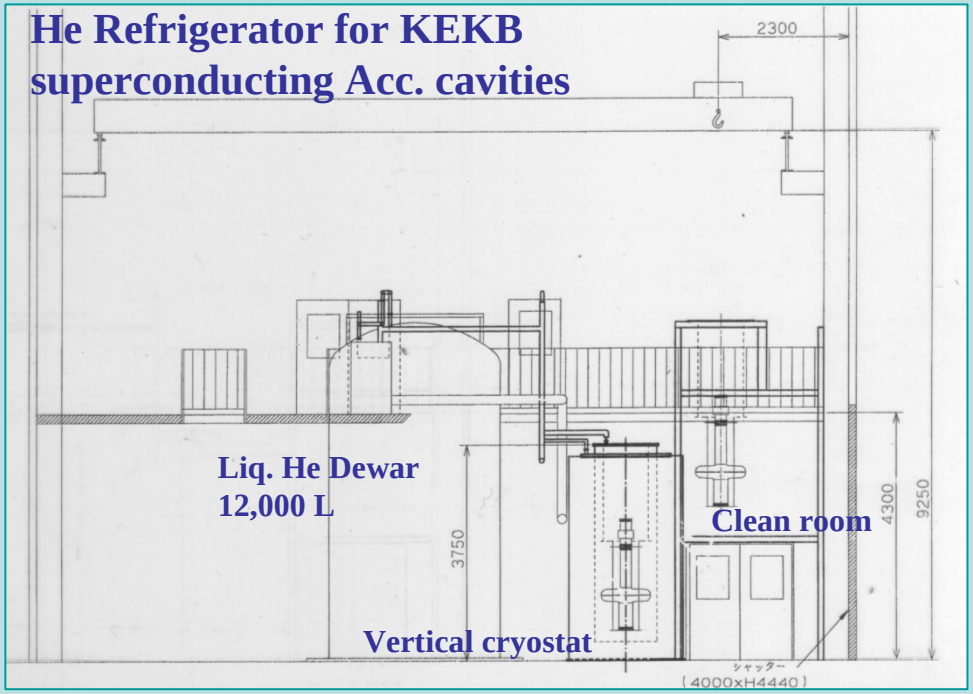
High Pressure Rinsing and Assembling for RF Cold Test

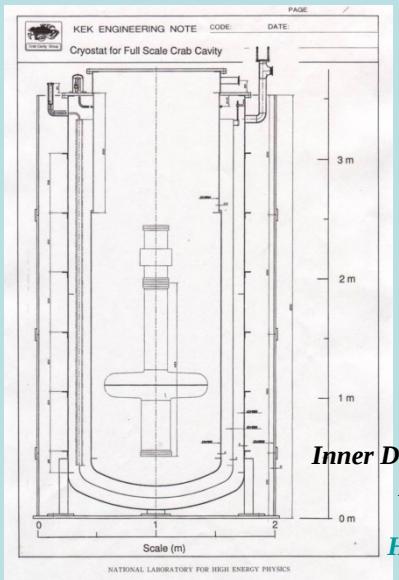
Set Flanges of Beam Pipes and Ports
in Class 100 Clean Room

High Pressure Water Rinsing
by 80 bar Ultra-Pure water

Rotation & Up-Down Motion

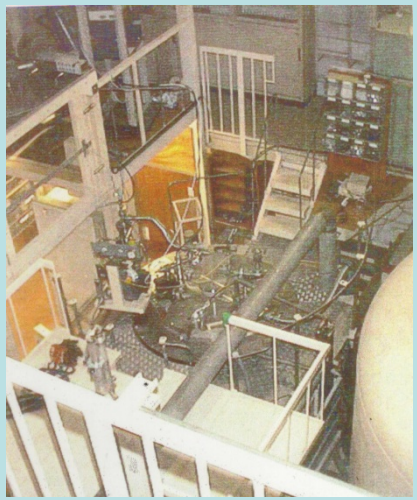
Cold Test Stand for KEKB Crab Cavity





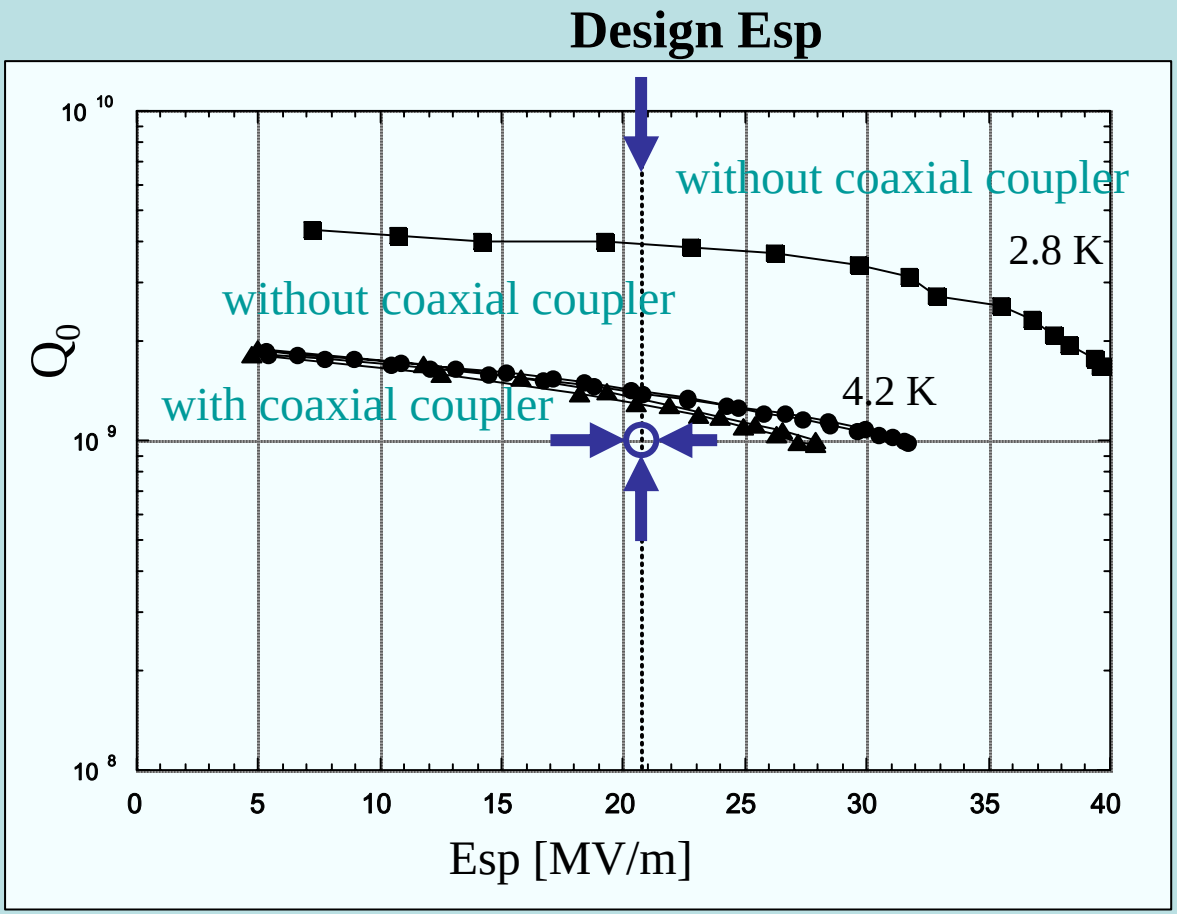
Inner Dia. 1100 x 0.8 t
Depth 3500

Heat Loss ~ 3W



The crab cavity is taken out from clean room to install into the vertical cryostat.

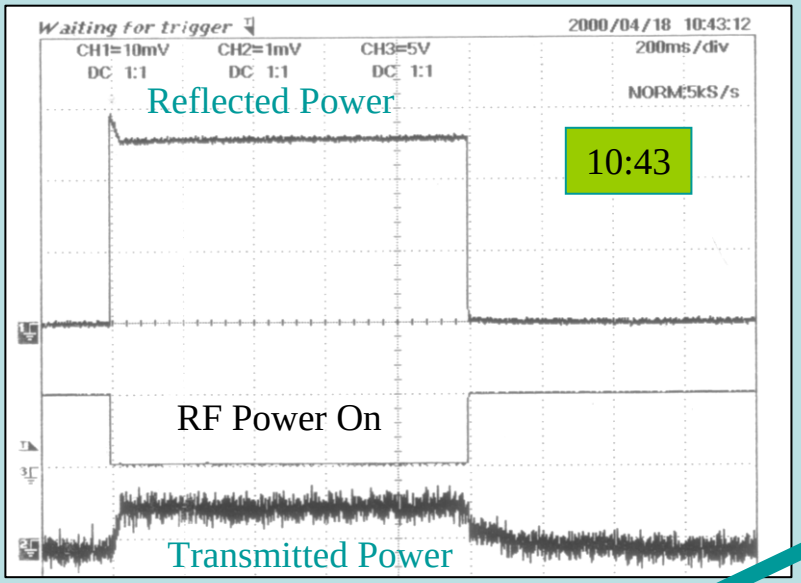
Test Result of KEKB Crab Cavity Prototype #1

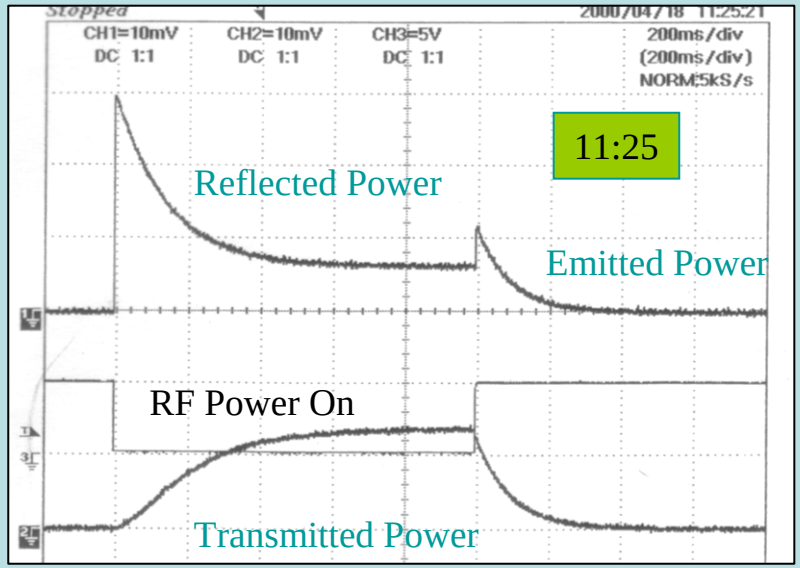


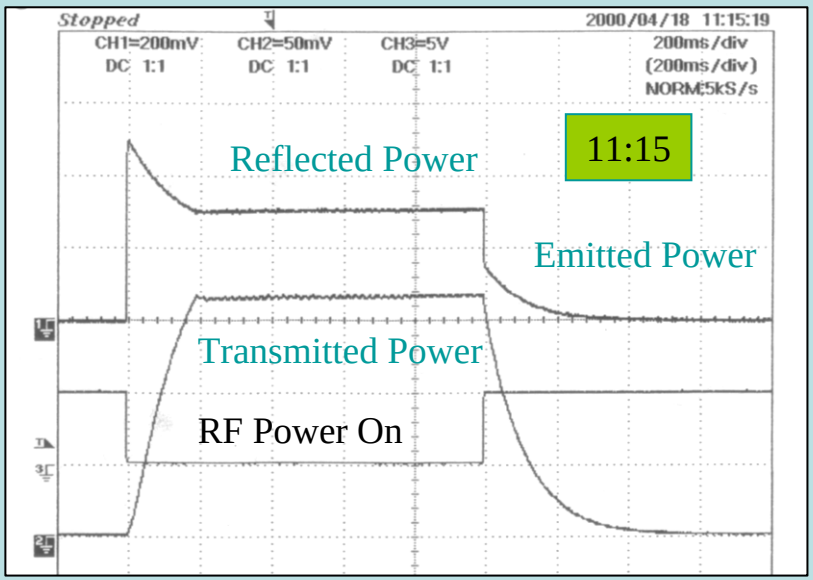
Crab Cavity #2
Same Performance!

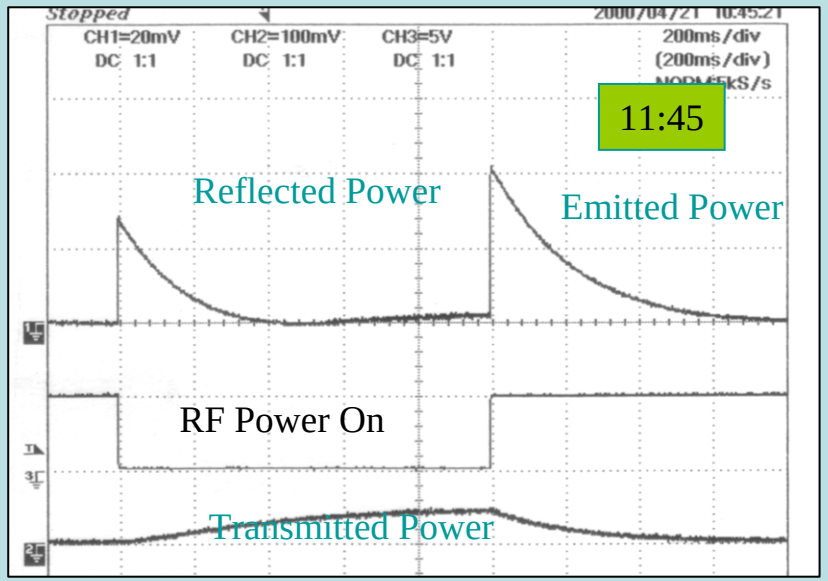
⇨ Fabrication and Surface Treatment
RF Performance Test with a Coaxial Coupler Good!
Multipacting could be overcome by RF process.

Multipactoring in Crab Cavity with Coaxial Coupler

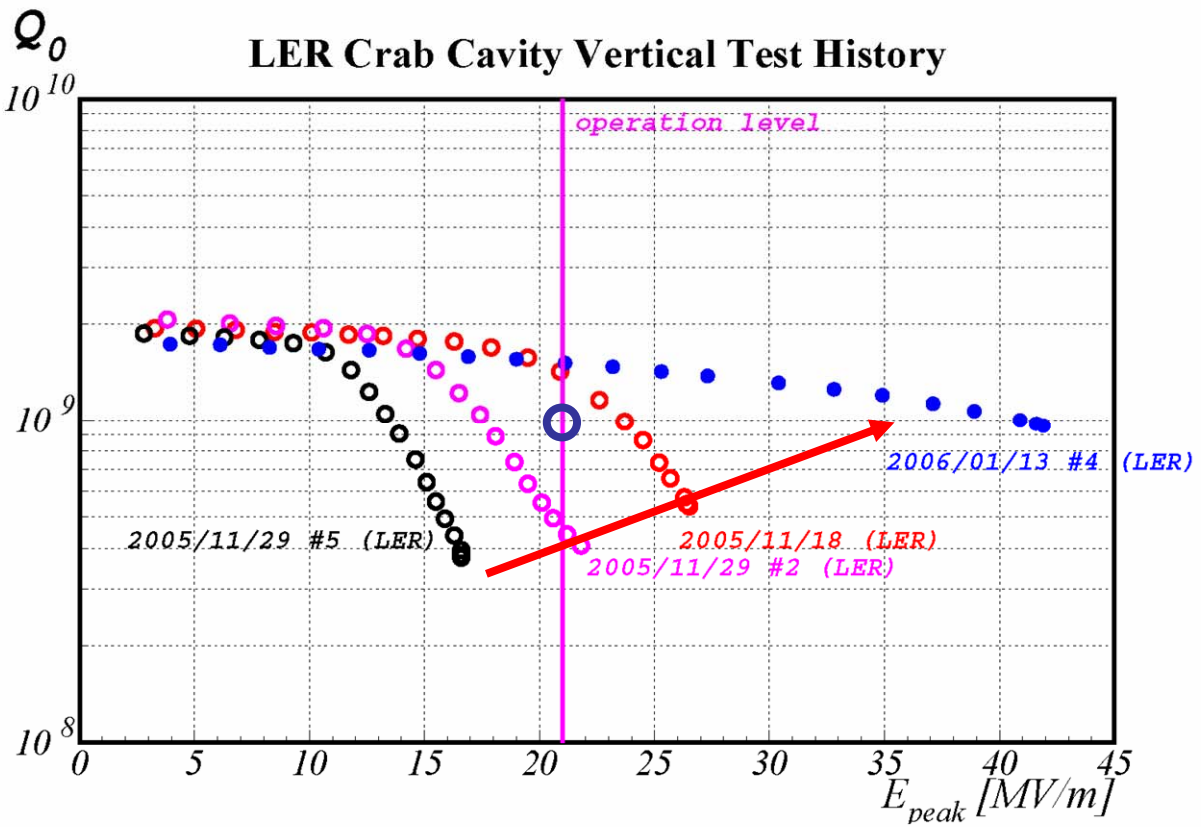




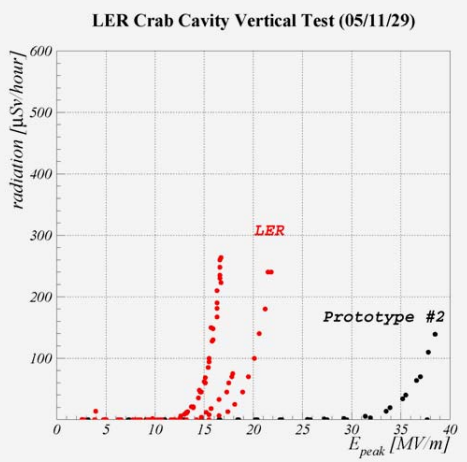




Test Result of KEKB Crab Cavity for LER



X-Ray



Nov. 18 1st Test

↓

H.P.R.

↓

Nov. 29 2nd Test

Field Emission

↓

EP2

↓ Re-processing

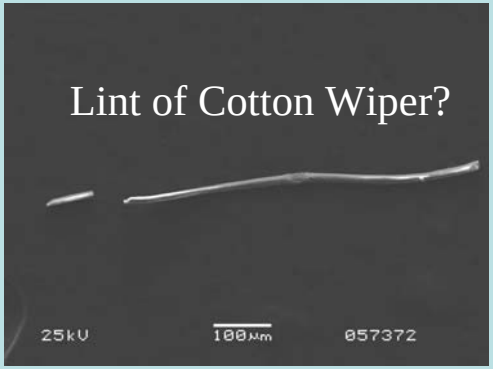
Jan. 13 Test

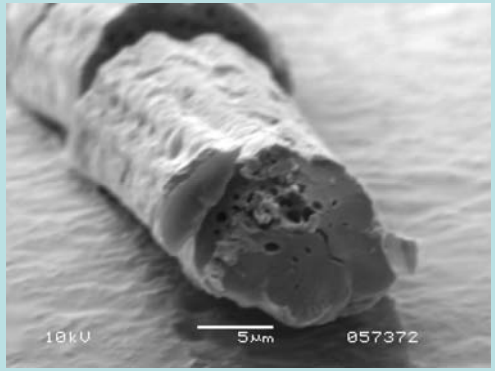
Recovered !

Test result could not satisfy the design value!

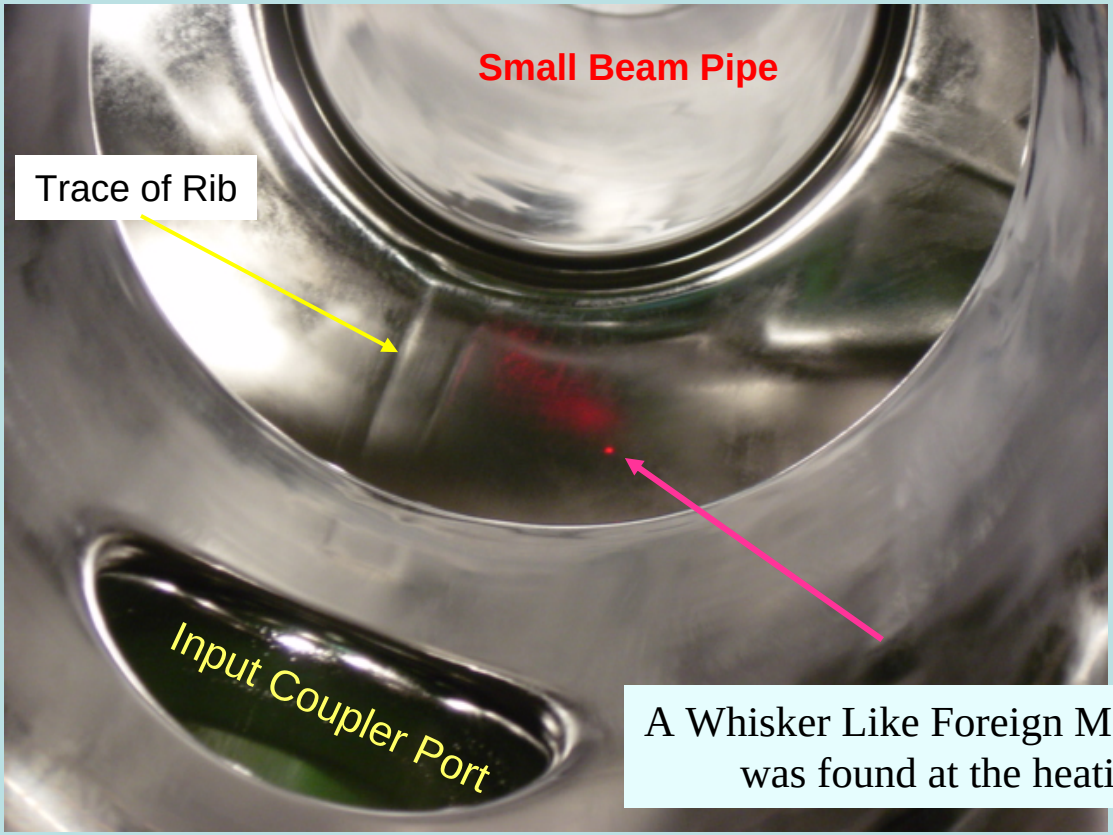
Back to EP II processing.

Inspection in the cavity

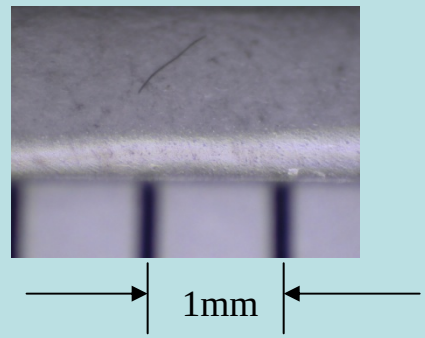




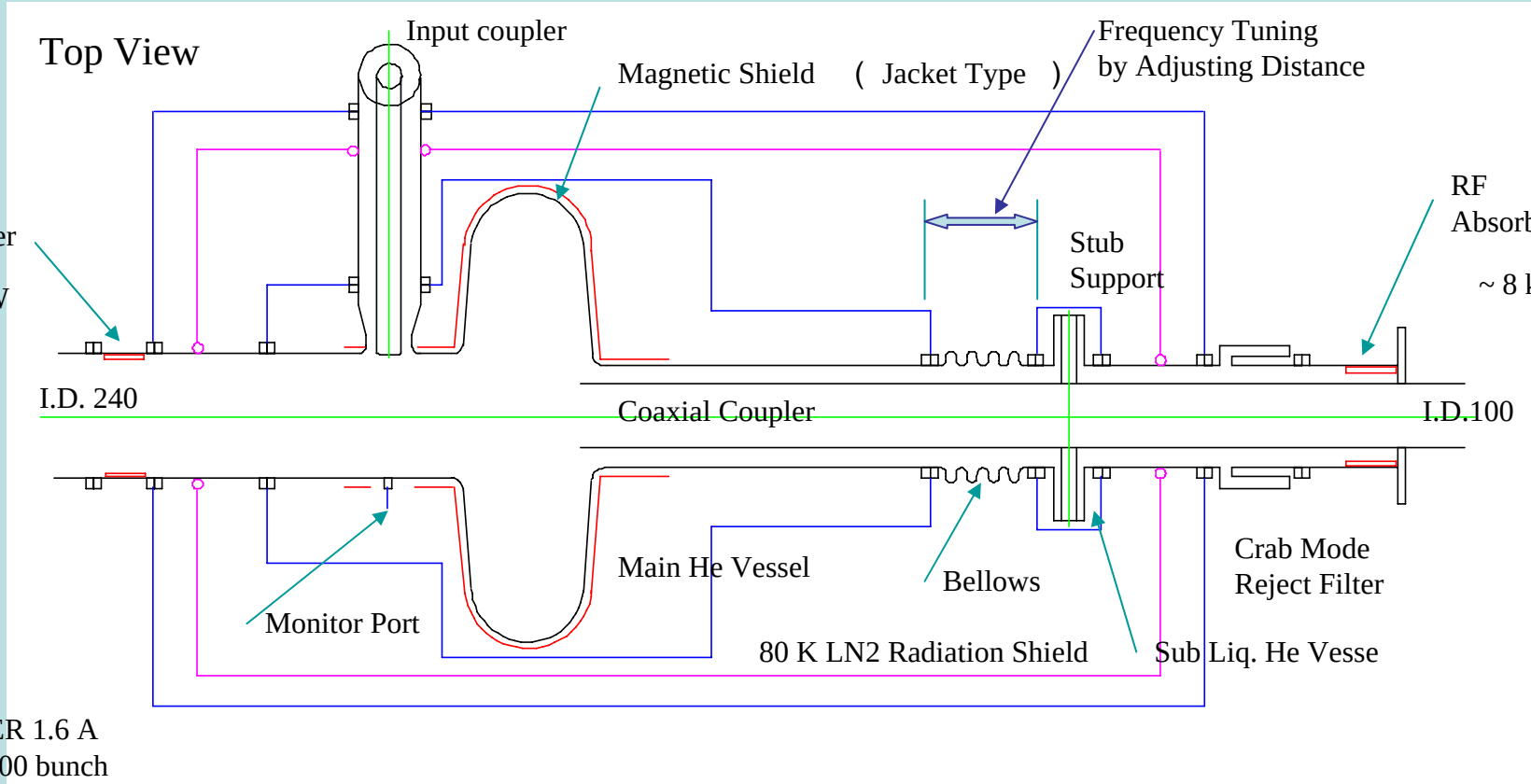
Picture of electron microscope



A Whisker Like Foreign Material
was found at the heating spot !



Conceptual Cryostat Design for KEKB Crab Cavity



Characteristics

- *Frequency Tuning Coaxial Coupler ~30 kHz / mm*
- *Stub-Support -- Mechanical Support & Cooling of Coaxial Coupler*
- *Jacket-type Helium Vessel (Main He Vessel and Sub He Vessel)*
- *Jacket-type Magnetic Shield*

Design and Fabrication of KEKB Crab Cavity Cryostat

- No design and construction examples
- Easy to assemble and disassemble under clean condition
- Compact and light weight for transportation
- Leak tight for long period operation stress free at In seal

Frequency tuning by coaxial coupler

Jacket type helium vessel

Main-Helium Vessel for Crab Cavity

Sub-Helium Vessel for Coaxial Coupler

- Complex structure and challenging design

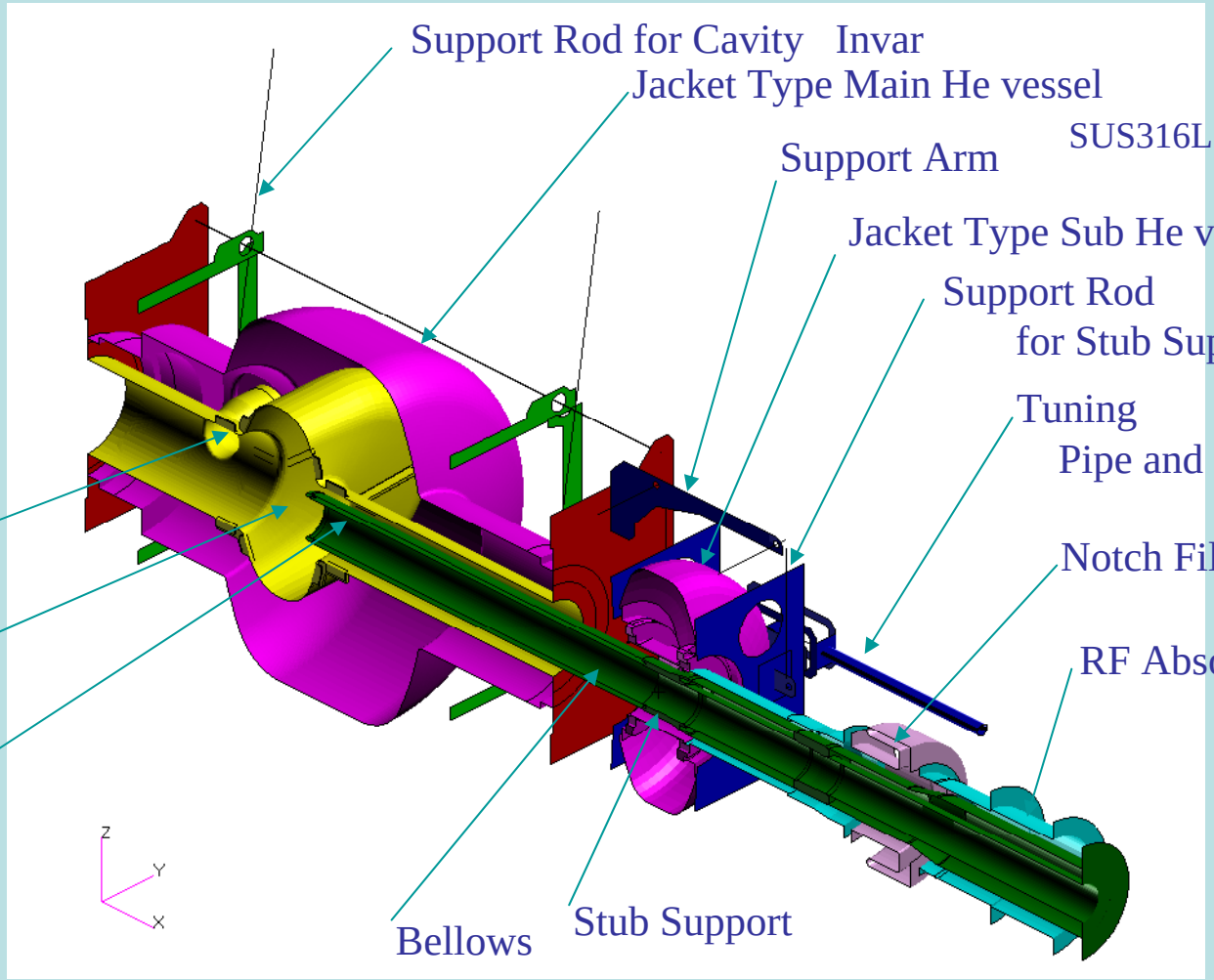
A prototype cryostat was designed, constructed and cold tested at KEK.

R&D efforts for important components

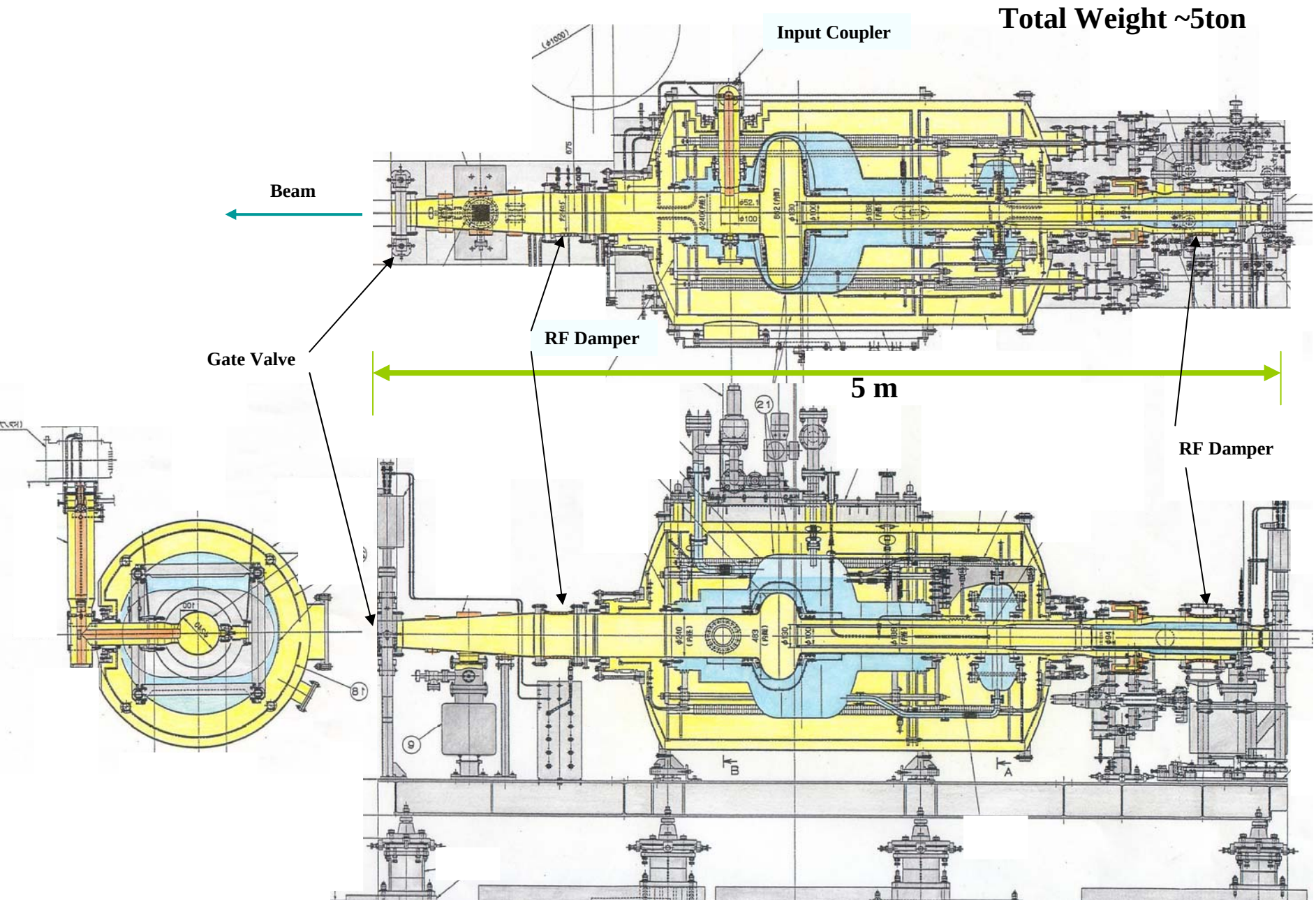
Bellows, End cell, Input coupler, HOM damper

Crab Cavity & Coaxial Coupler in Cryo-module

1) **Crab Cavity is hanged by 4 invar support rods.**
2) **Coaxial coupler is hanged by 4 stainless rods which are supported by 2 support arms.**
3) **Head position of the coaxial coupler is controlled by 2 tuning rods.**
4) **Head of coaxial coupler is cooled by liq. helium supplied from stub support.**



Cryostat for KEKB Crab Cavity

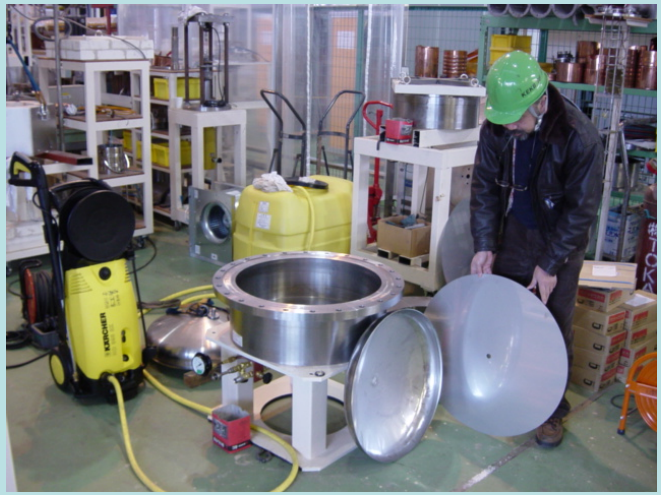


Forming of Helium Vessel End Shell

Main Helium Vessel	ϕ 920	2t
Sub Helium Vessel	ϕ 600	1.5t
Cryostat Vacuum Vessel	ϕ 1200	2t

ϕ 920 x 2 t

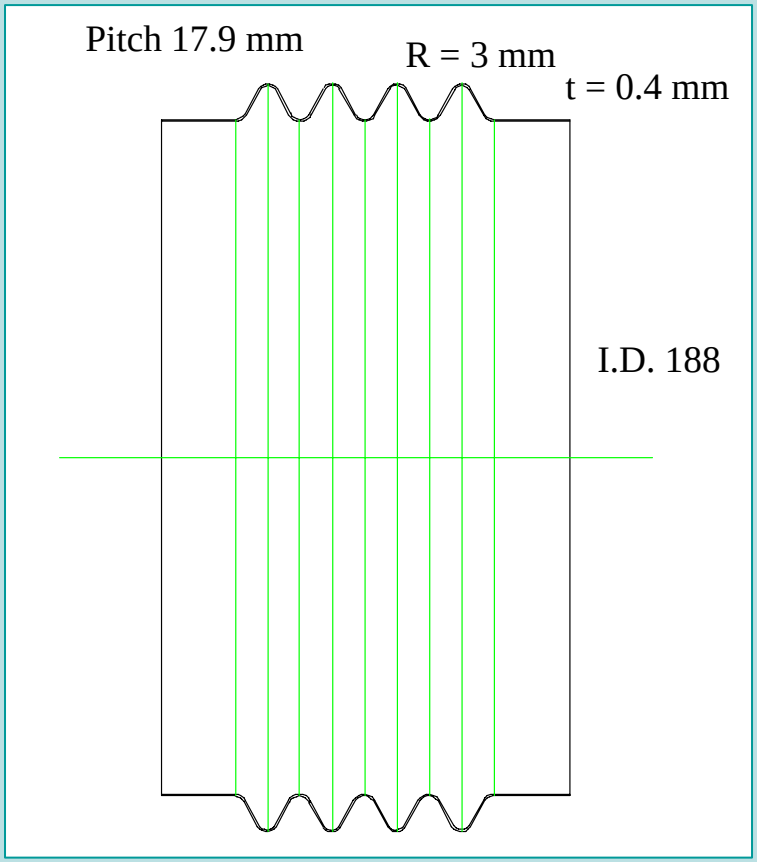
Main helium vessel end shell



ϕ 600 x 1.5 t

Sub helium vessel end shell

Bellows



Press Unit
and
Pressure Water Pump

Female Die
and Outer Guide Pipe

To Increase the tuning range
change to stainless steel with copper plating bellows!

Thickness t = 0.3 mm

Assemble & Cold Test of Prototype Cryostat

1) Jacket Type Helium Vessel to Check the Leak Tight

2) Input Coupler to Check Thermal Contraction

3) Without Coaxial Structure

Design and assembled in KEK

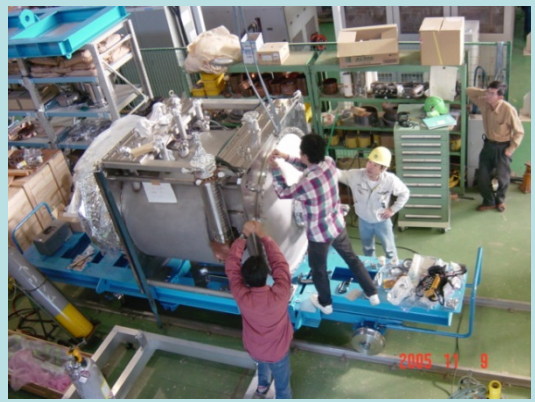
Leak at In-Seal of Beam Pipe Flange!
Nov. 29, 2005

⇩

Disassemble and Reassemble

⇩

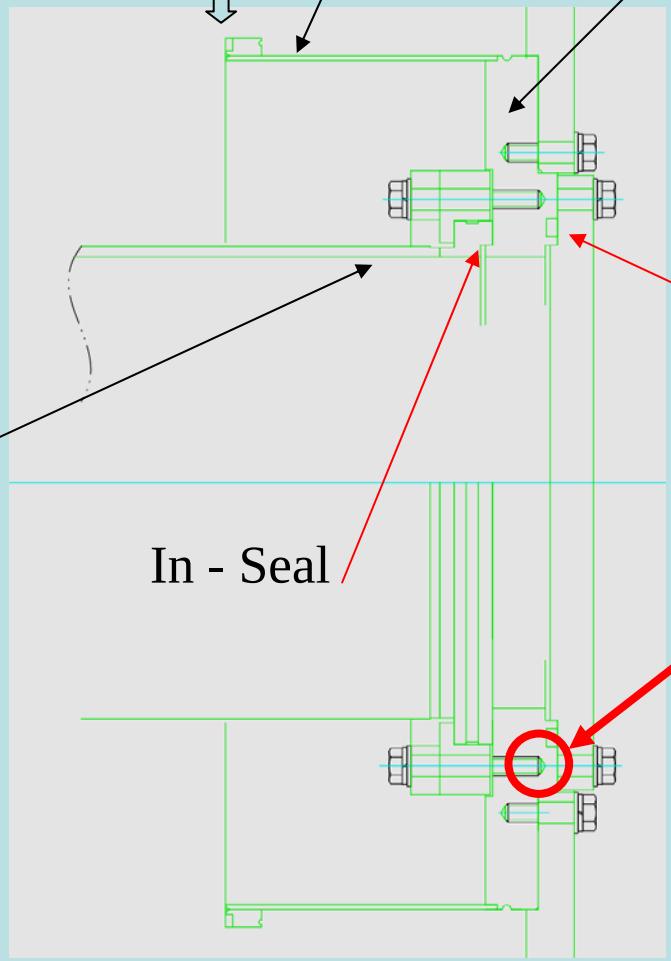
Cool Down Test OK !
Feb. 6-10, 2006



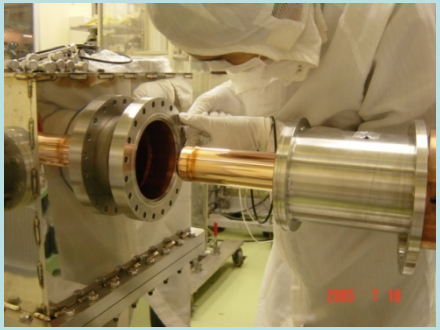
What cause the Leakage?

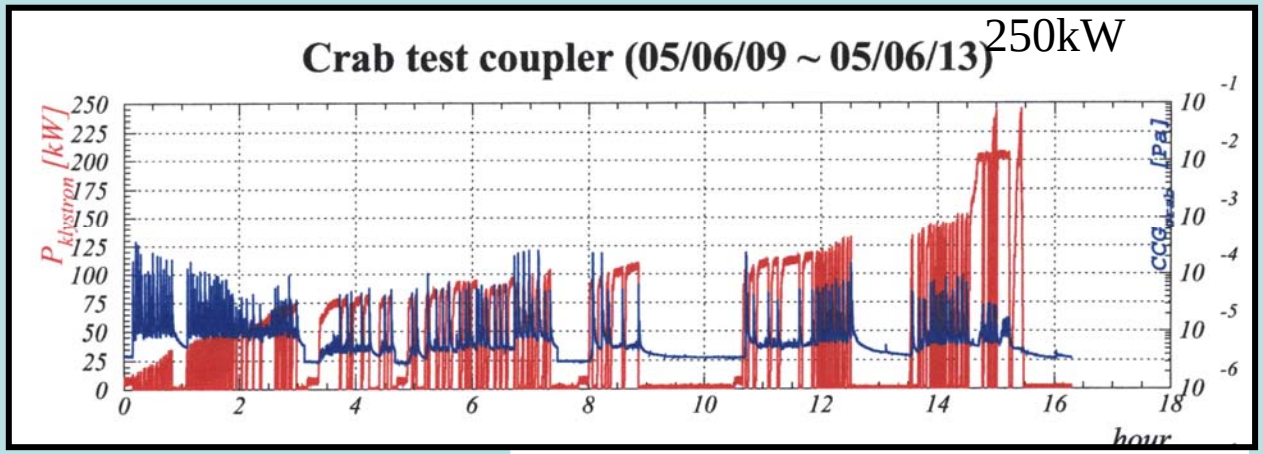
Transition Flange

Niobium – SUS
by Indium Seal

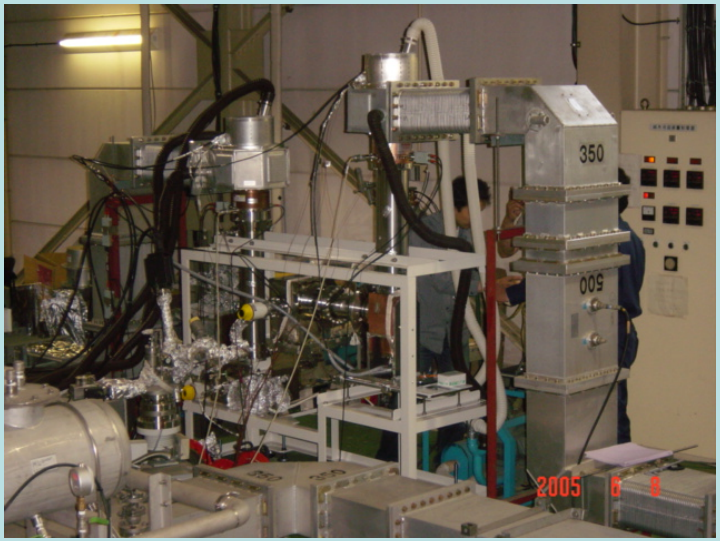


Input Coupler for KEKB Crab Cavity

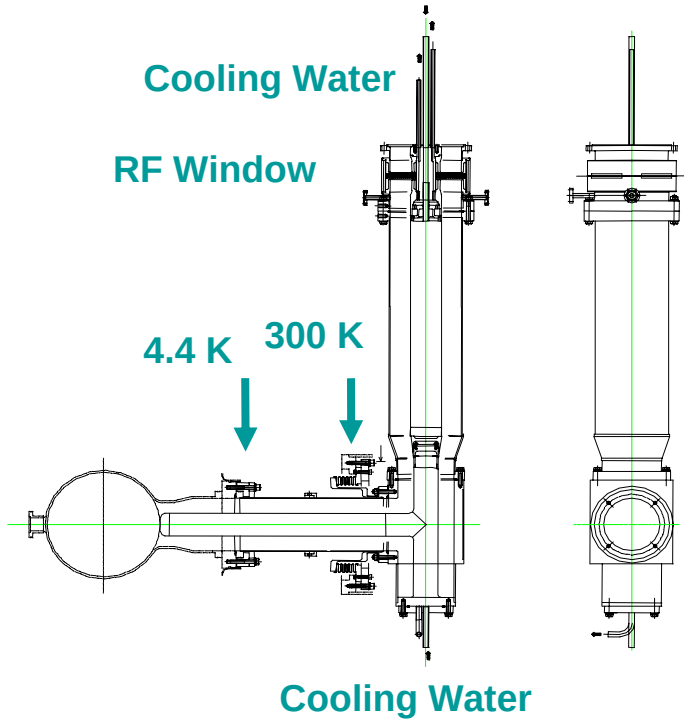




TW: 200kW
SW: 100kW



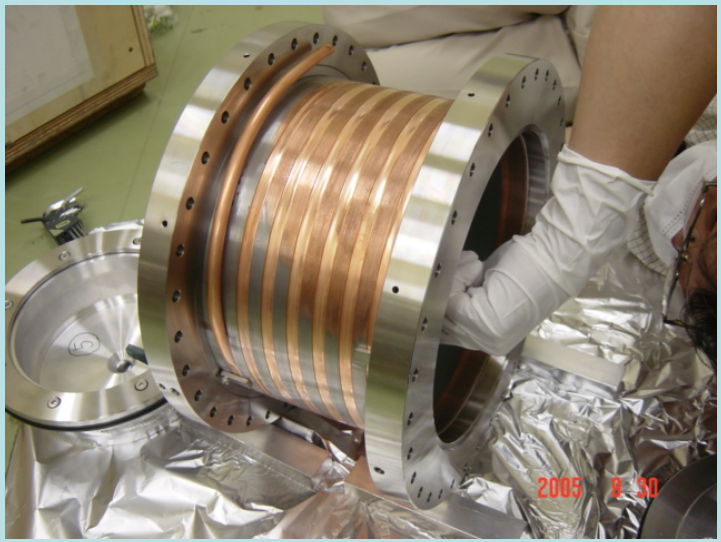
High Power Test Stand

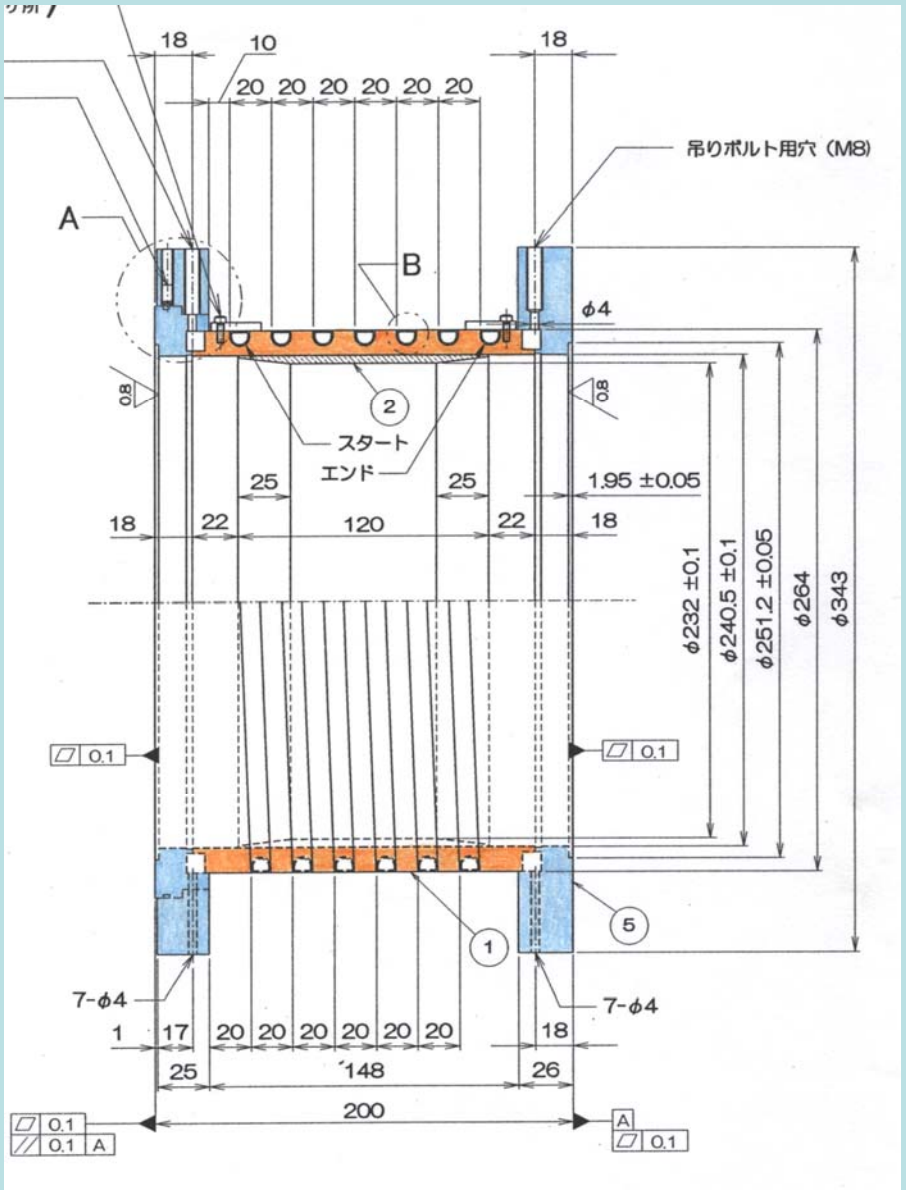


HOM Damper Ferrite RF Absorber

Same design used in KEKB Acc. SC cavity

Cavity 0.7 V/pC
Taper 0.04 V/pC
Damper 0.3 V/pC
Total: 1.04 V/pC
HOM power: 20.5 kW
(1.6 A, 1300-bunch)

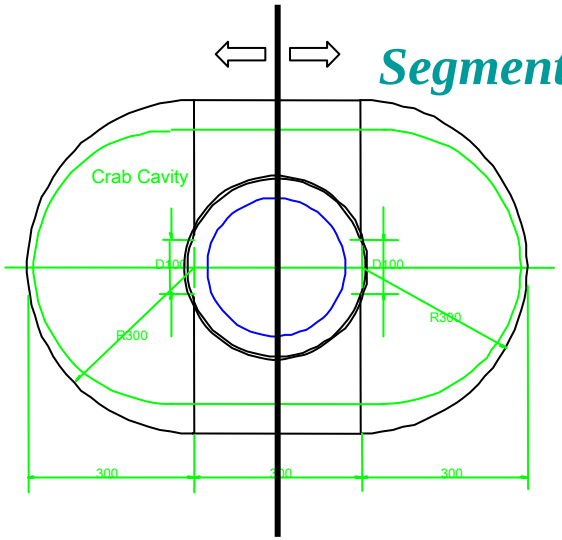


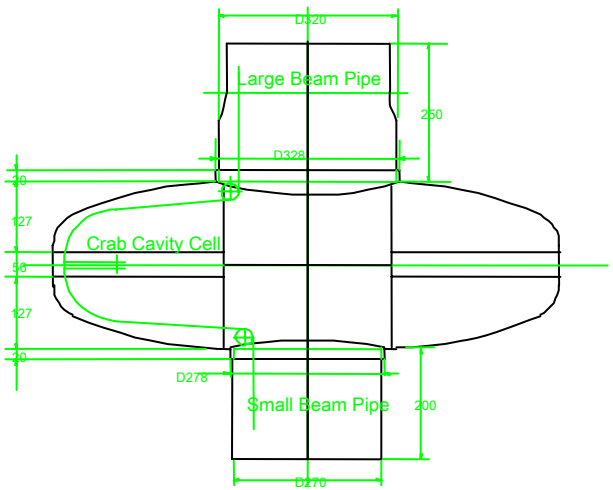


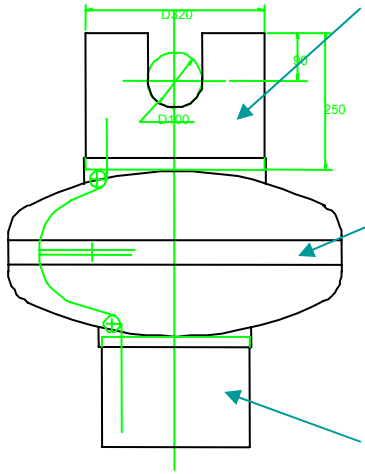
Magnetic Shield (Jacket Type)

Permalloy 3t

Segmentation





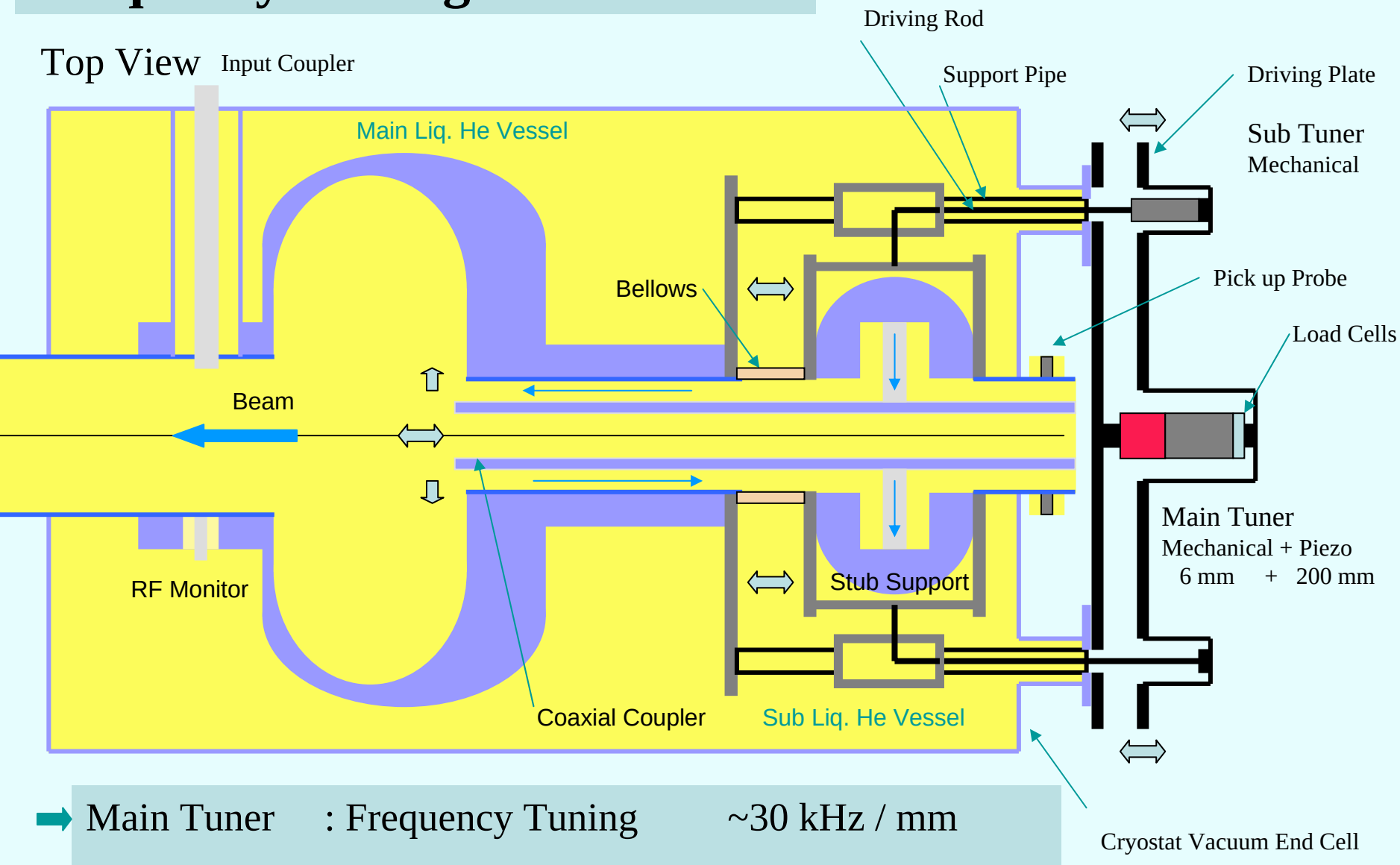


Large Beam Part

Cell Part

Small Beam Part

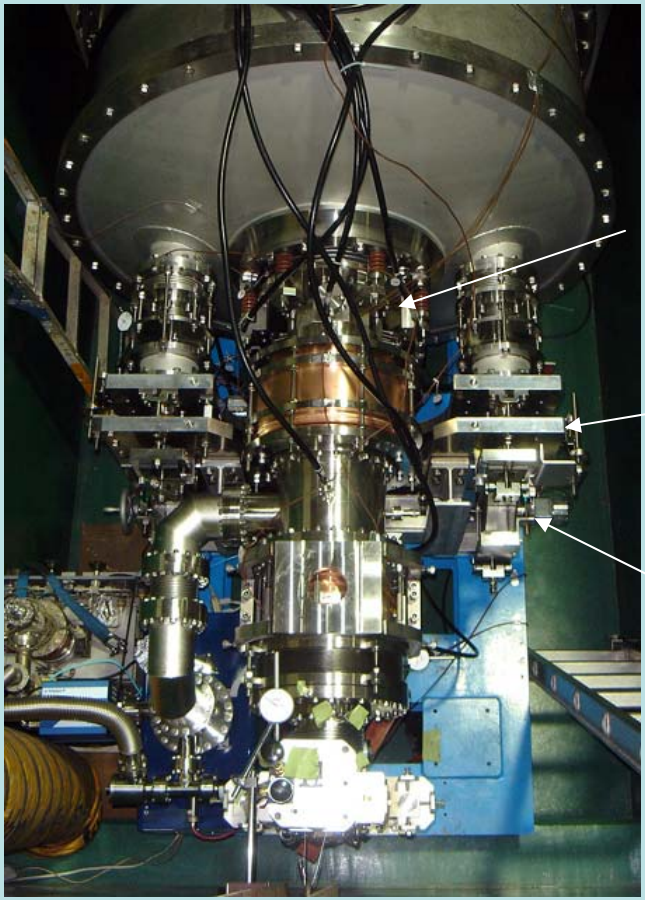
Frequency Tuning Mechanism



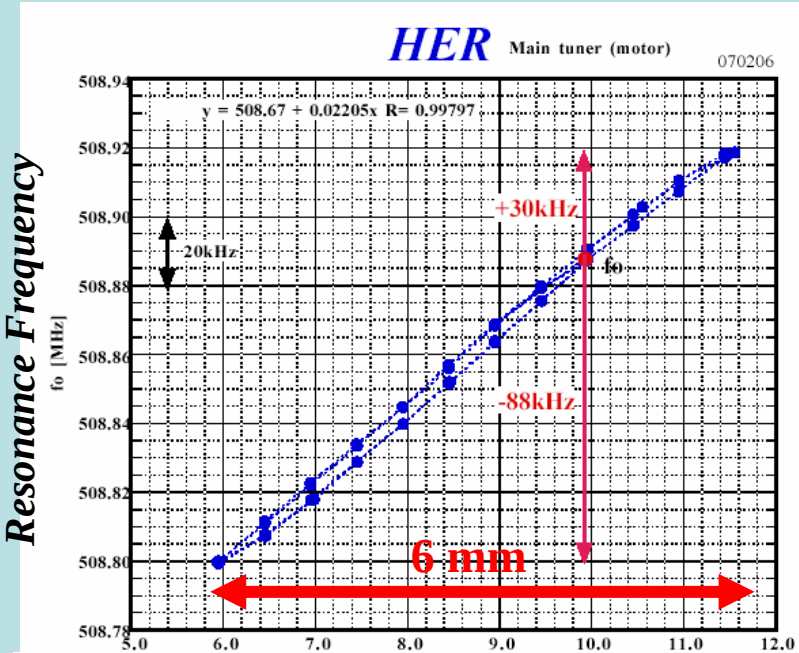
- Main Tuner : Frequency Tuning ~30 kHz / mm
- Sub Tuner : Adjust Position of Coaxial Coupler

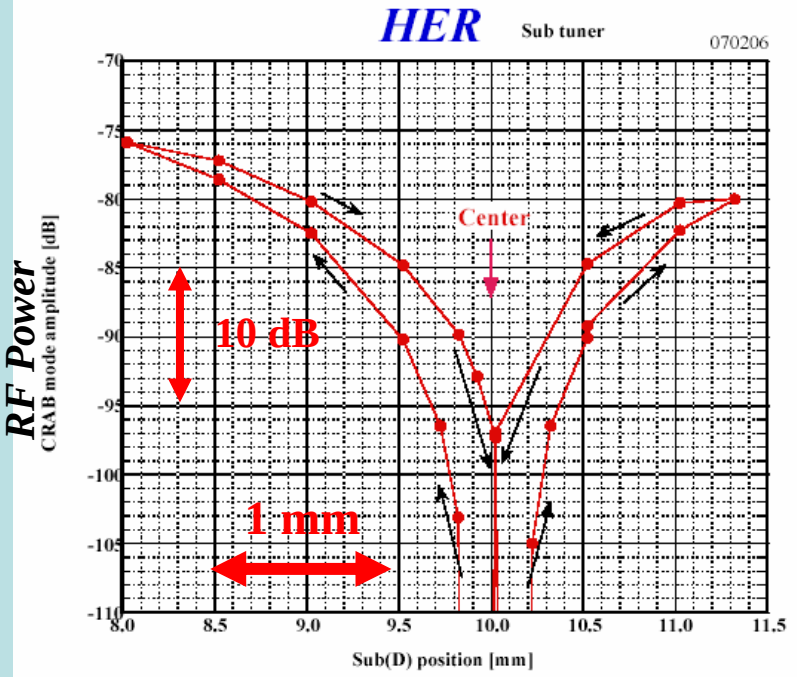
Frequency Tuner

- Resonance frequency can be controlled by main tuner.
- Coaxial coupler position can be controlled by sub-tuner.



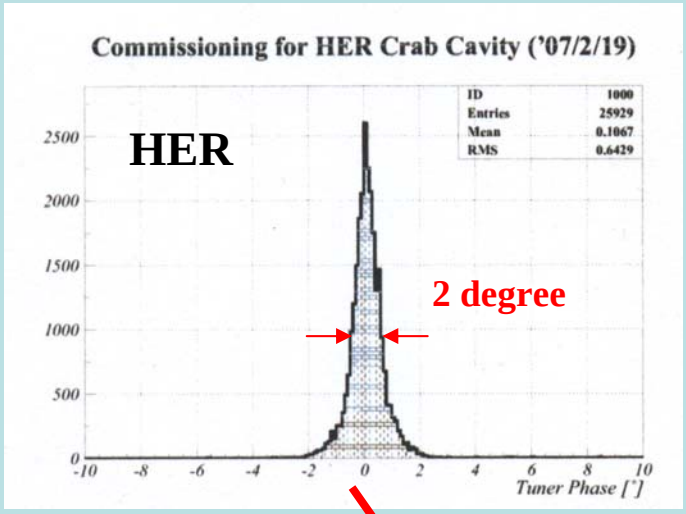
Frequency Tuner Crab Cavity for HER

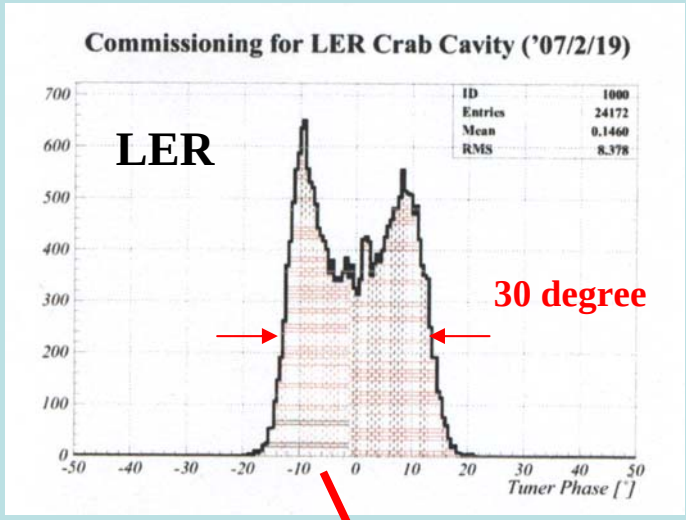




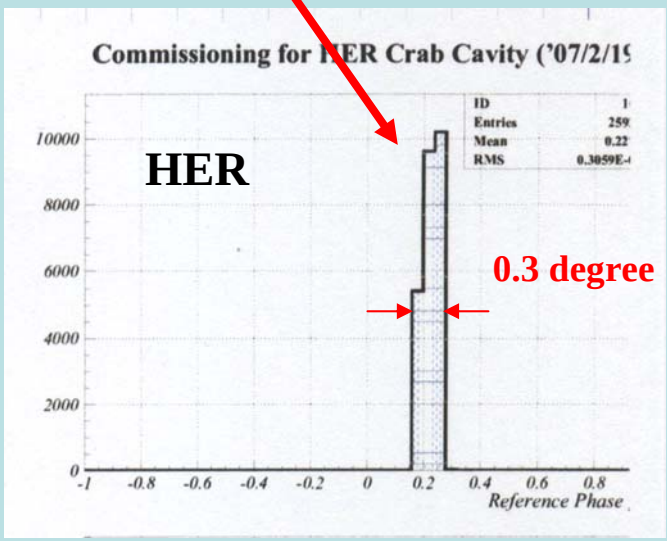
Phase stability

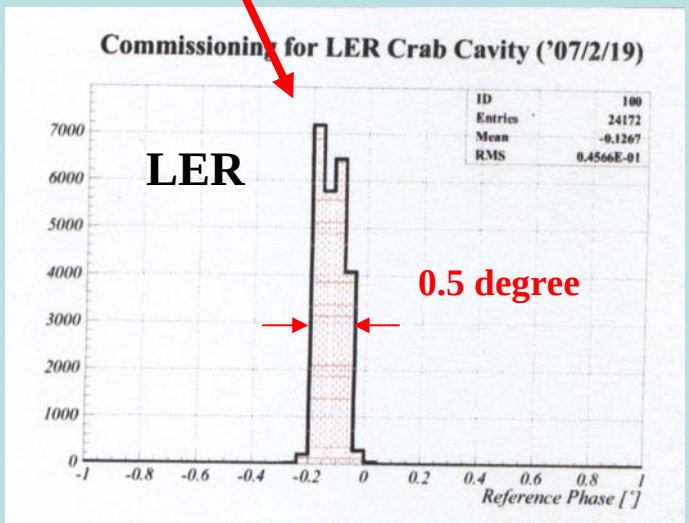
Phase Stability by Mechanical Tuner



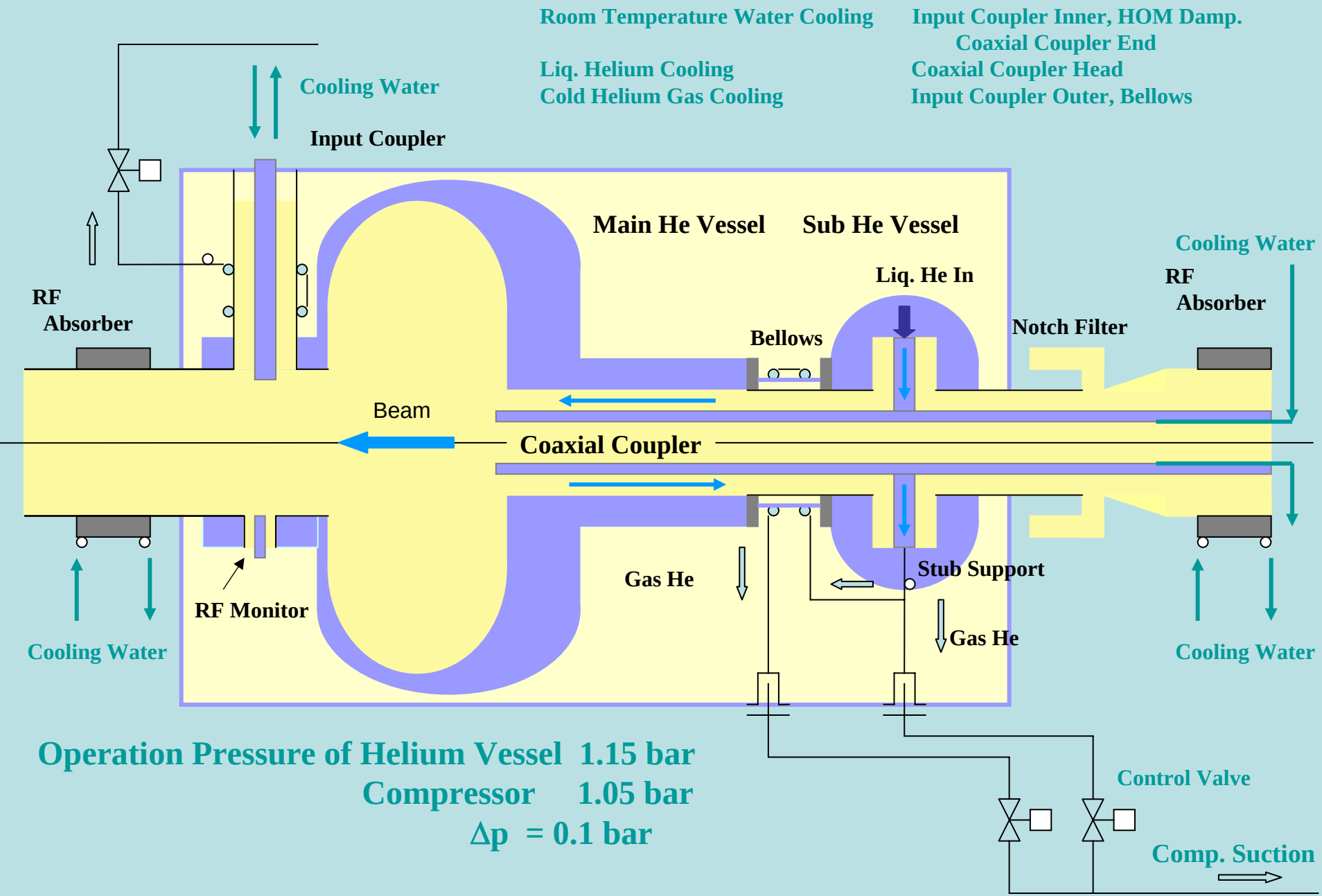


Phase Stability is improved by RF Feedback



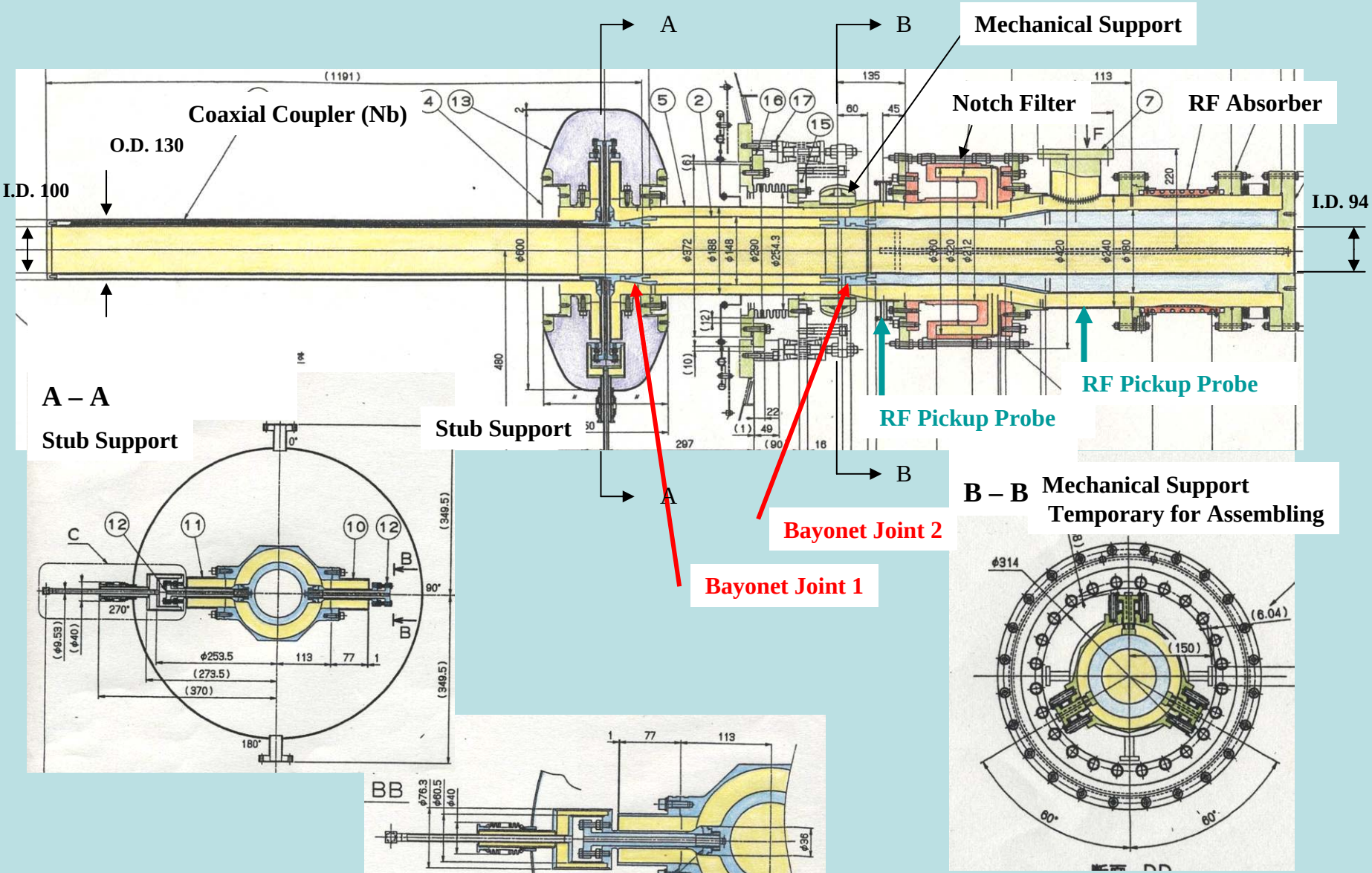


Cooling System for KEKB Crab Cavity



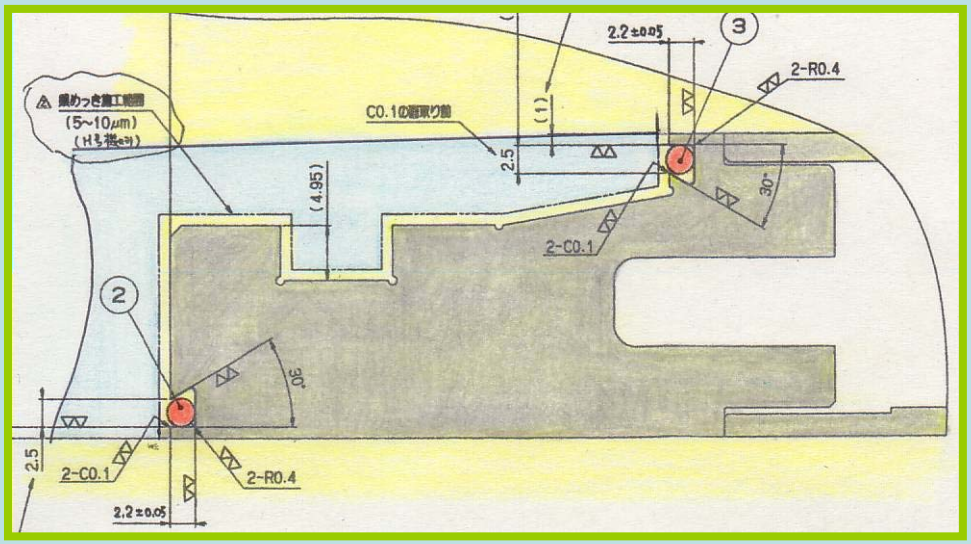
Operation Pressure of Helium Vessel 1.15 bar
Compressor 1.05 bar
Δp = 0.1 bar

Coaxial Structure Detail



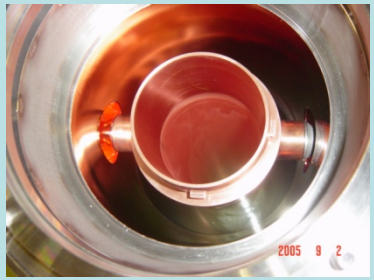
RF Contact

Type： Spiral
Material： BeCu
Spring Constant： 14kg/φ94mm（0.5kg/cm）

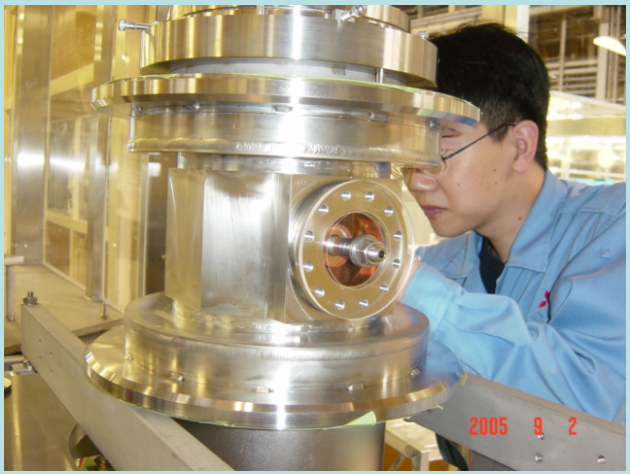


Assembling the Coaxial Coupler

Nb Inner Conductor of Coaxial Coupler



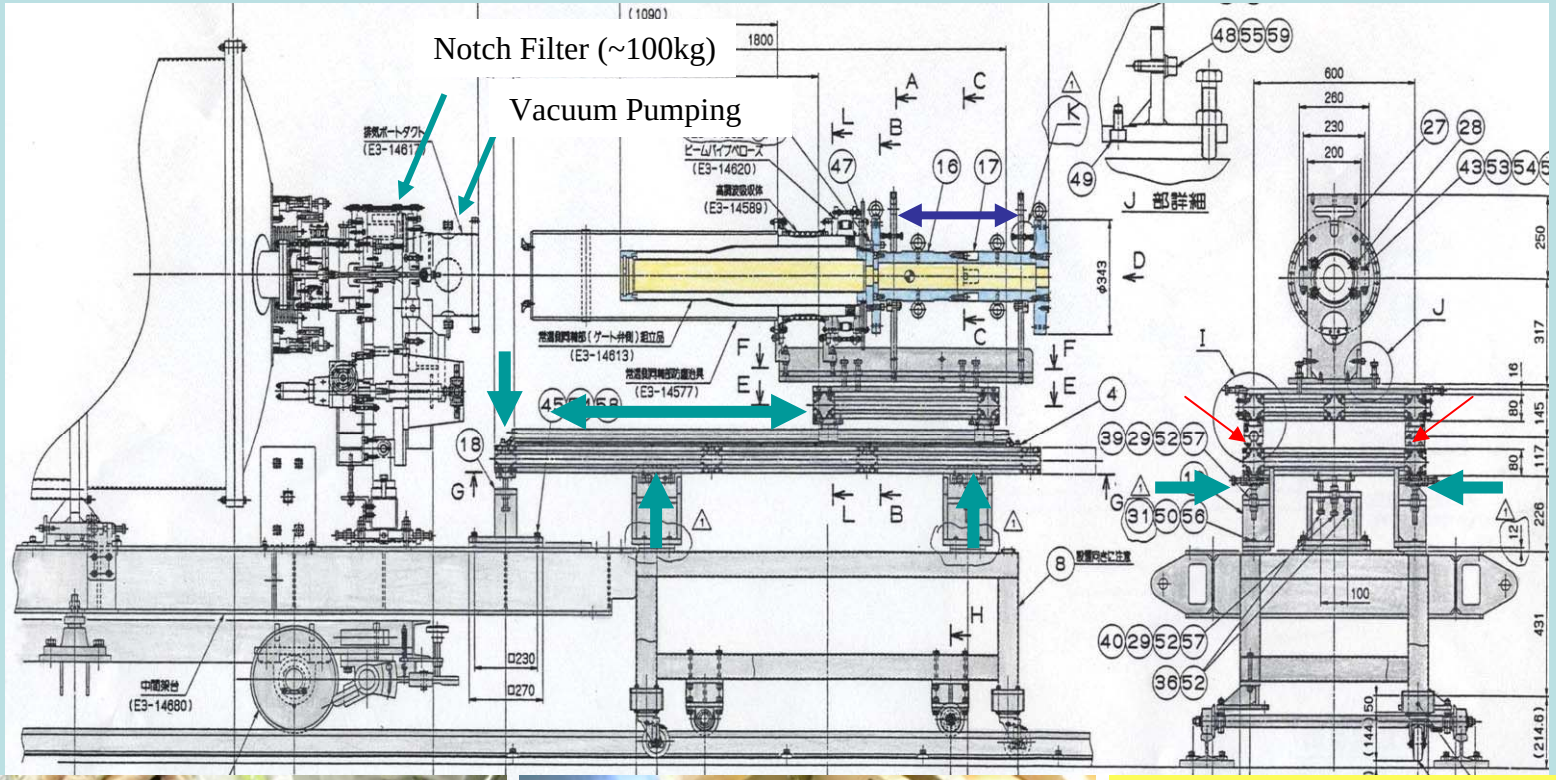
Inner Conductor
of Stub Support



Stub Support

Leak Check of Assembled Coaxial Coupler

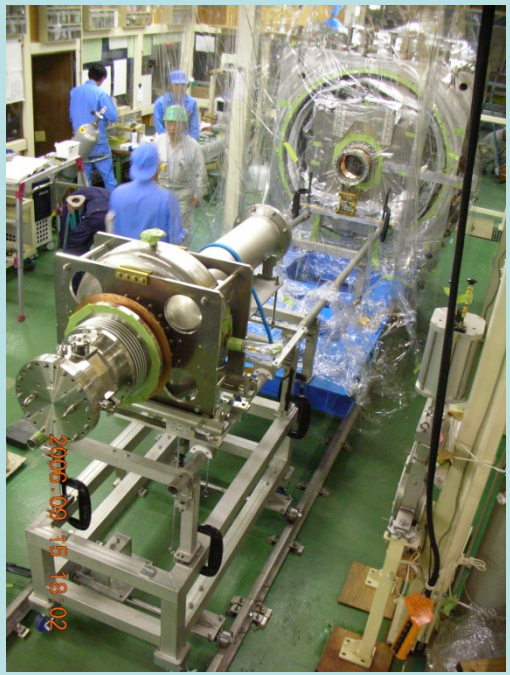
Insertion Setup for Coaxial Coupler



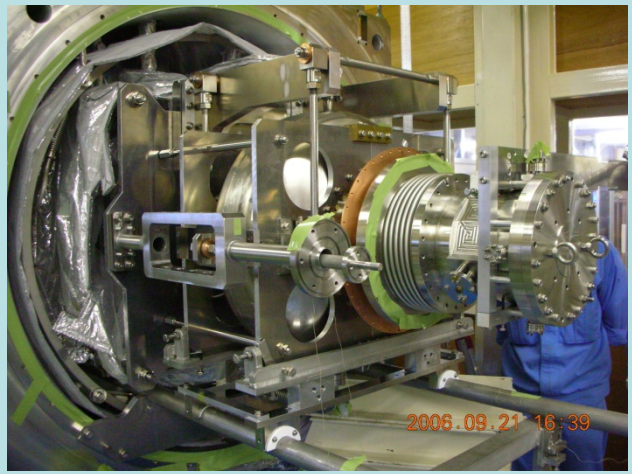
Connect of inner conductor
Step 1 Insert
Step 2 Rotate Clockwise 30 degree

Assembling Coaxial Structure to Crab Cavity

High Pressure Rinsing



Coaxial coupler was ready to install



Tuning Structure

- Inner conductor of the assembled coaxial coupler was high pressure rinsed.
- Head part of the coaxial coupler was installed in to the cavity and assembled.
- Coaxial coupler was hanged by 4 rods which were connected to 2 support arms.

Assembling Large Beam Pipe

Large beam pipe
(HOM damper & taper chamber)
was assembled to crab cavity.

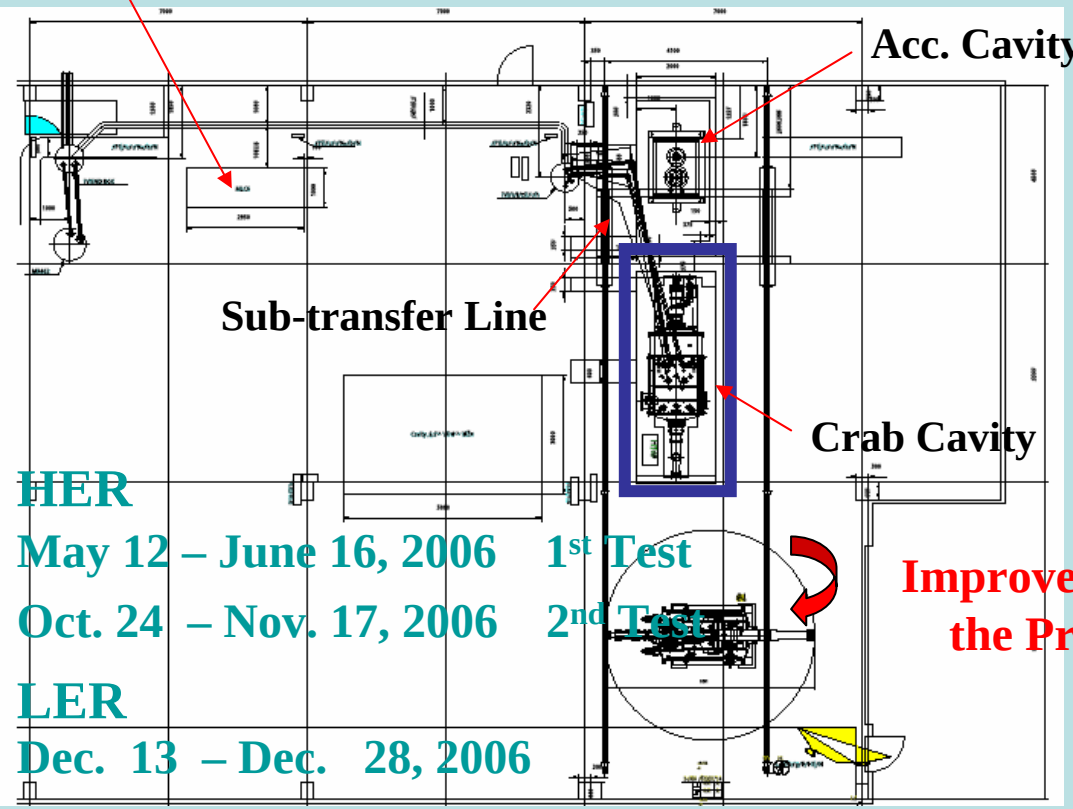
Inside crab cavity
Coaxial coupler
Iris of crab cavity
Input coupler
Tapered copper pine

Move to Test Stand for Cool-down & High Power Test

April 26, 2006 1st

Oct. 16, 2006 2nd

Test Stand for Crab Cavity at D10 Station



- High Power RF Station
- Cryogenic System

HER

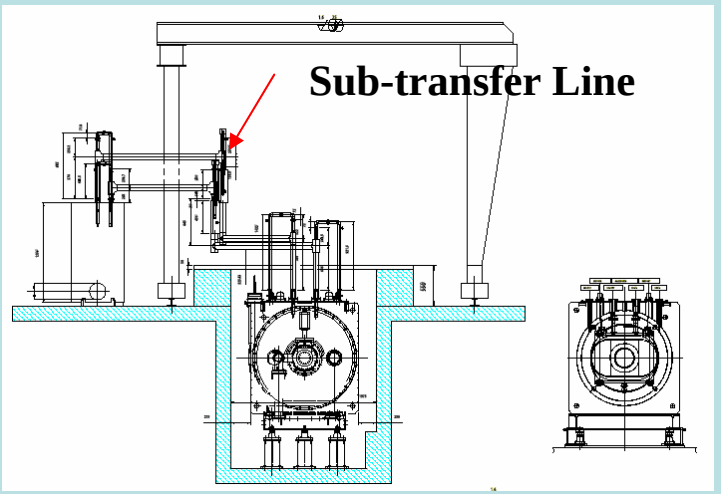
May 12 – June 16, 2006 1st Test

Oct. 24 – Nov. 17, 2006 2nd Test

LER

Dec. 13 – Dec. 28, 2006

Improved the Problems



1st High Power Test for Crab Cavity HER

- Crab cavity for HER was cooled down without leakage.
- V_{kick} = 1.67 MV, exceed the design value of 1.44 MV.
- Cavity and coaxial coupler was cooled stably during the high power test.

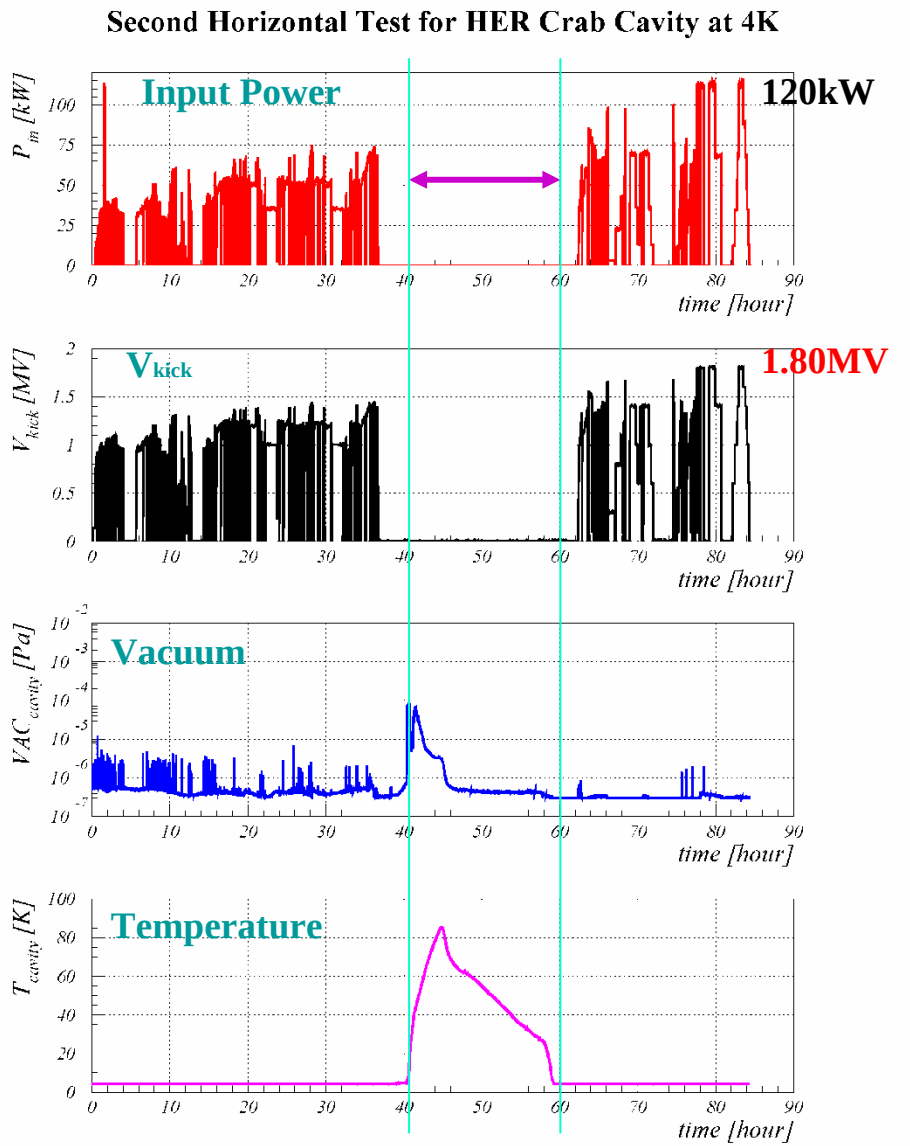
Cryogenic system worked very well.

Problems & Improvements (Disassemble & Re-assemble)

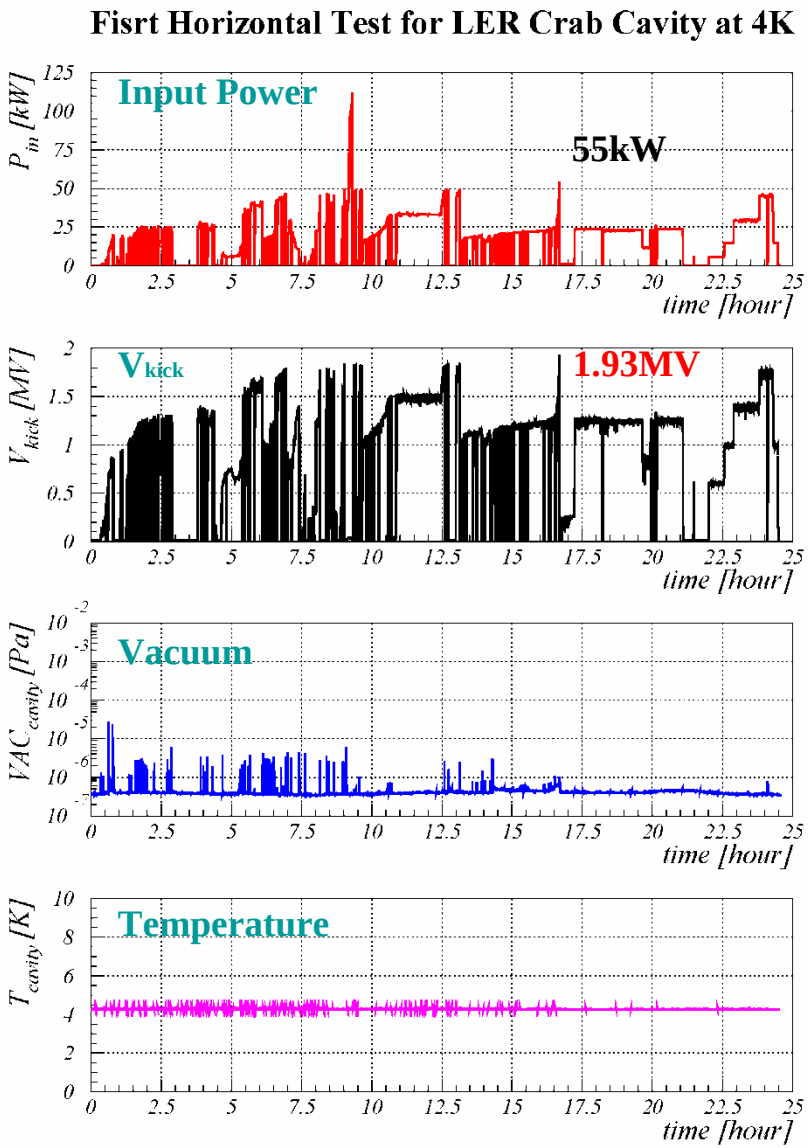
- Resonant frequency was lower than design value (~300kHz)
  → After cool down, the cavity was pre-tuned
- Narrow tuning range
  Main tuner & Sub tuner
  → Change to thin stainless bellows with copper plating
- Tuner feedback stability is not good
  → Reinforce the tuning structure
- RF contact at the joint part of the coaxial coupler: for high current operation

High Power Test for Crab Cavity HER & LER

Crab Cavity HER

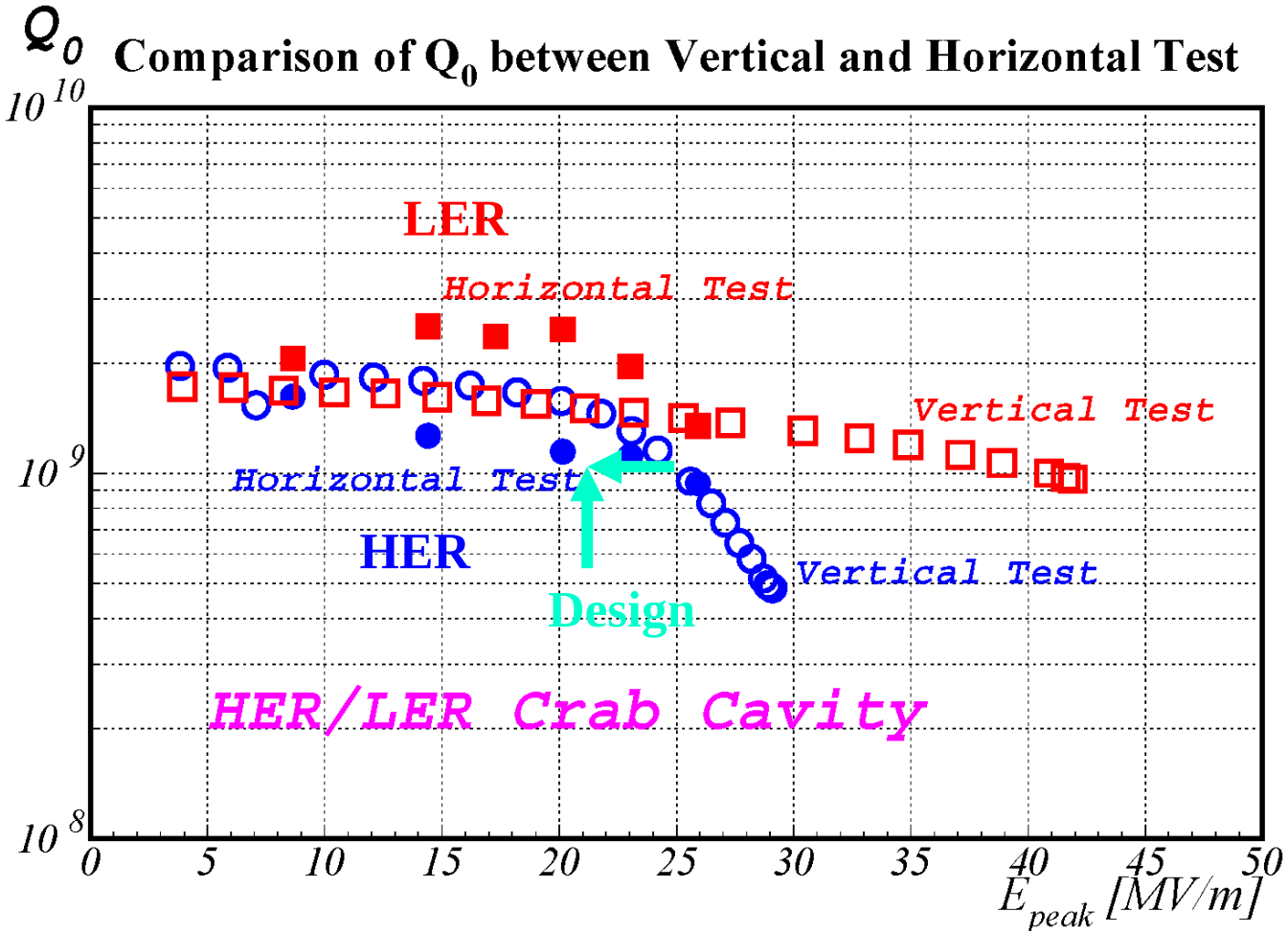


Crab Cavity LER



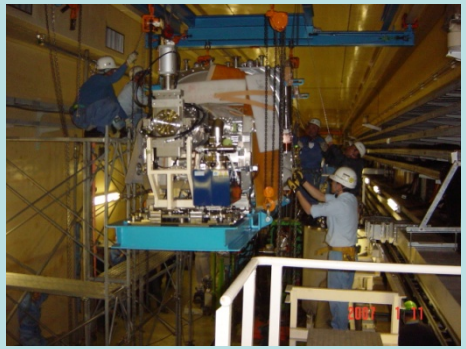
Q_0-Measurement

During high power test at test stand Q_0 were measured by calorimetric method.



Installation & Commissioning of Crab Cavities

Installation of Crab Cavities
for HER Jan. 8, 2007,
for LER Jan. 11, 2007



Carrying the crab cavity using crane track

Crab Cavity for HER

Cool-down of Crab Cavities
Jan. 29 , 2007
Vkick = 1.5 MV for LER
Vkick = 1.6 MV for HER

Beam Operation Start
Feb. 13

Crab Cavity for LER

SUMMARY

- After R&D efforts of 1.5 GHz and 500MHz crab cavities:
  We have constructed facilities
  for assembling of the cavities & cold RF test.
- 2 KEKB crab cavities have been constructed
  and installed in KEKB.
- The crab cavities are operating more than 1 year without serious problems.

  Kick voltage of crab cavity LER has decreased to V_{kick} = 1.1 MV
- L_{peak} =15 x 10^{33} /cm^2/s attained under crab on operation.

- Potential of superconducting crab cavity could be shown!