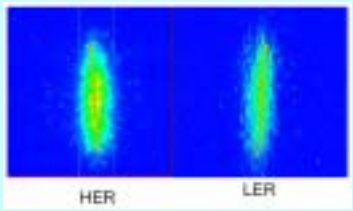
Crab Cavities Fabrication Challenges

K. Hosoyama

Crab Cavity for HER



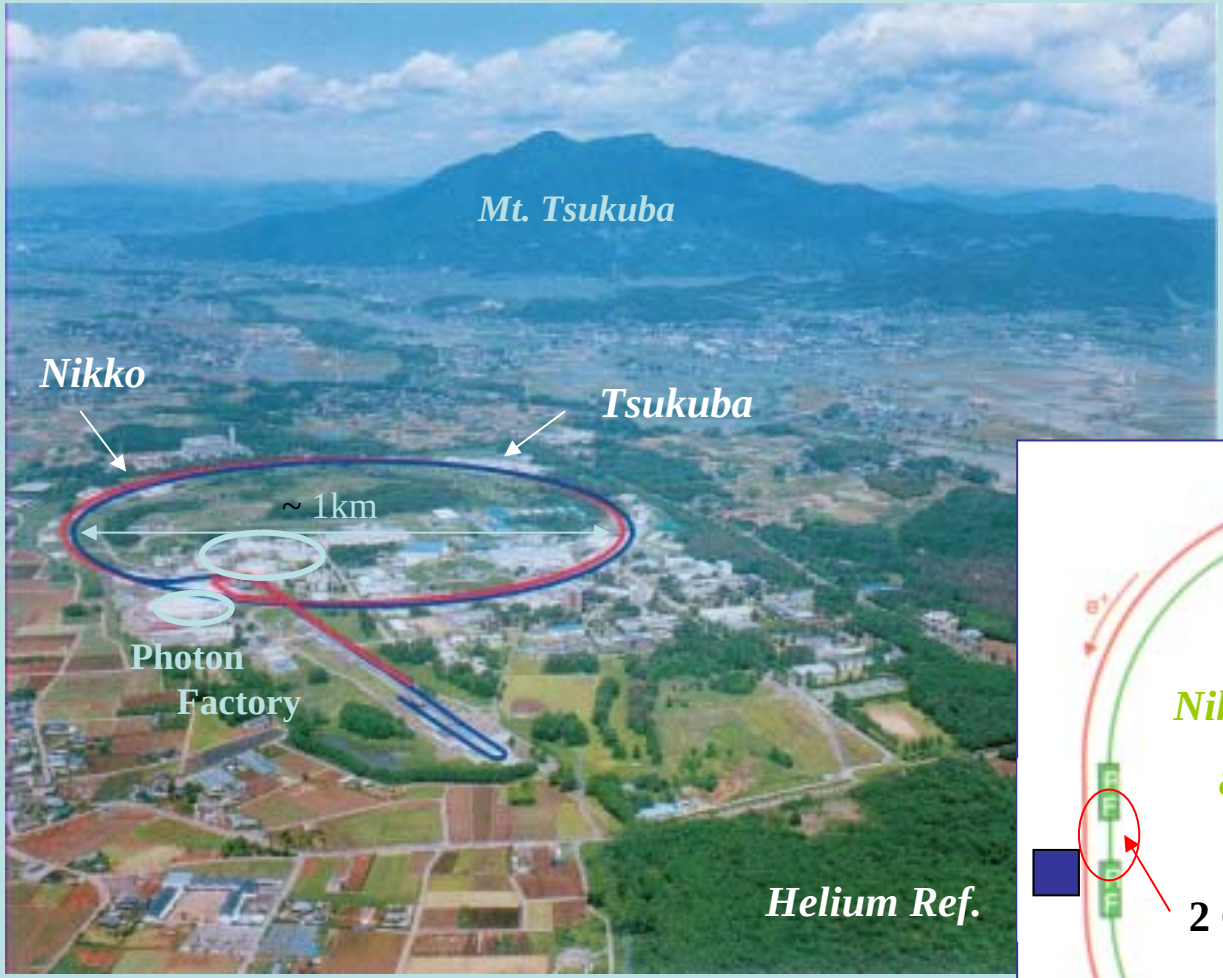
Bunches kicked
by crab cavity

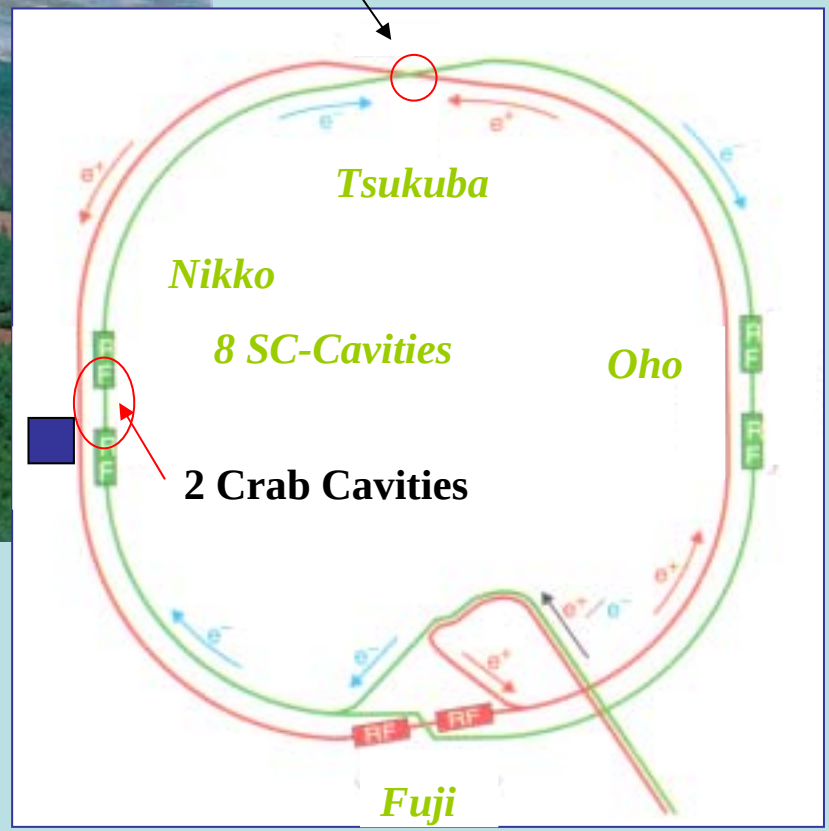
Contents

- KEKB and Crab Crossing
- KEKB Crab Cavity
- Fabrication of Crab Cavities
- Cold Test in Vertical Cryostat Test Results
- 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
- Problems - Tuner issue -

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.



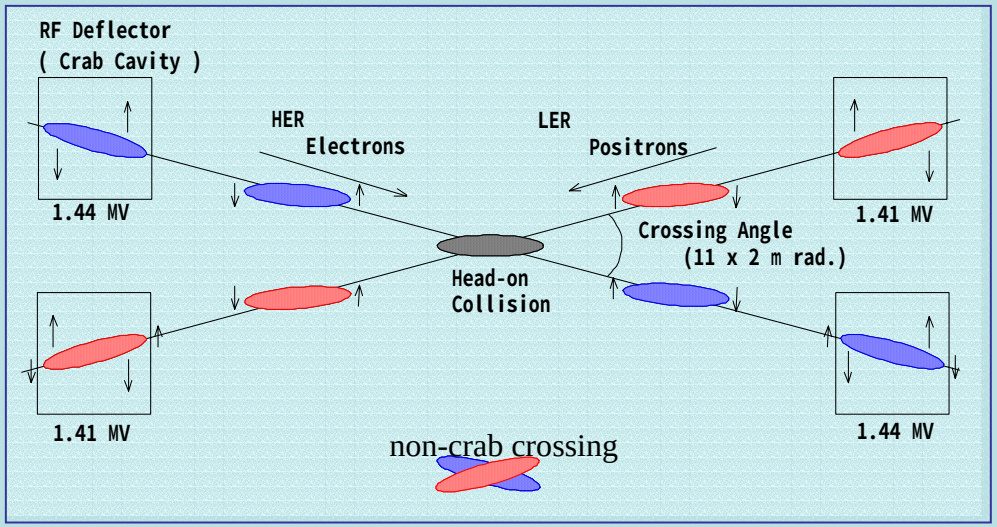


KEKB Crab Crossing

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

Original Crab Crossing Scheme

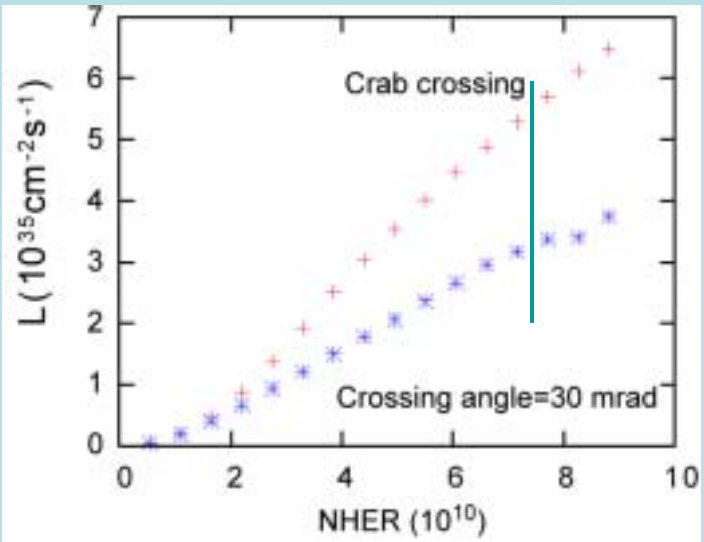
4 Crab Cavities at Colliding Section



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)

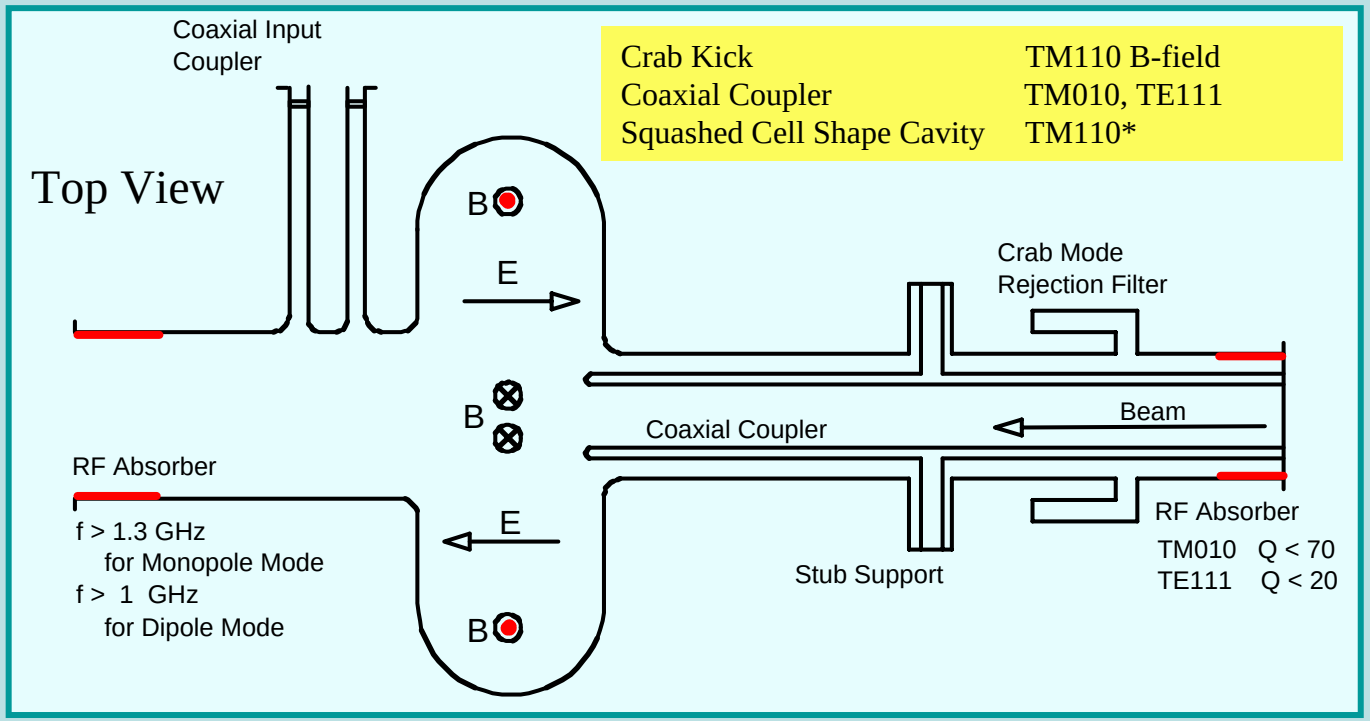


New Crab Crossing Scheme

2 Crab Cavities at "Nikko" → Beam-bunch wiggle around the whole ring!

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

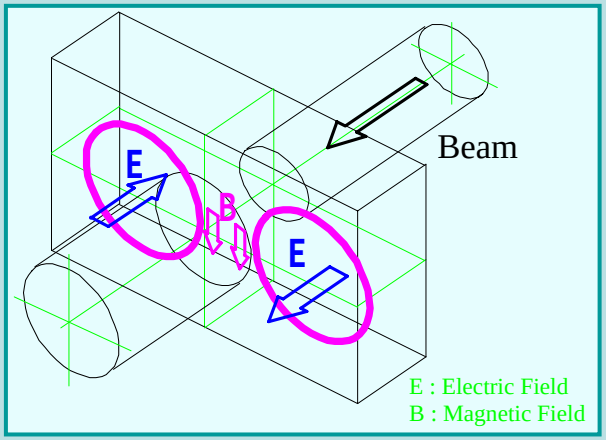
Conceptual Design of KEKB Crab Cavity



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

We adopted this design as "base design"!

Squashed Cell Shape Cavity



Characteristics of KEKB Crab Cavity

RF Issues

Higher Operation Field Esp = 21 MV/m
Squashed Cell Shape TM_{110} for Crab Mode
Higher Order / the Lowest Mode Damped Cavity
Large Beam Pipes for Higher Order
Coaxial Coupler to Extract TM_{010}
Multipactoring at Coaxial Coupler

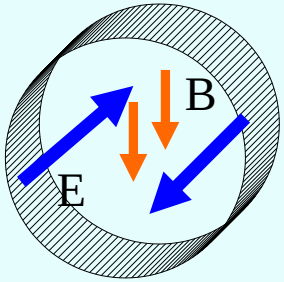
Mechanical and Fabrication Issues

Non-axial Symmetric
Large Size and Weak Structure
Thickness of 4.5 mm Nb Cavity
Reinforcement by Ribs

Why squashed cell shape cavity?

TM110

500MHz

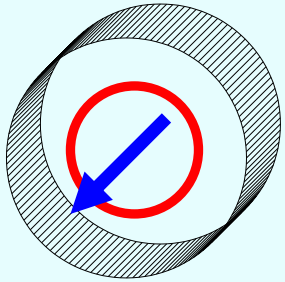


Crab Mode

Unwanted Modes

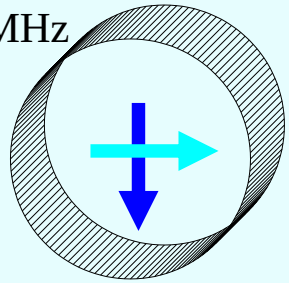
TM010

324MHz



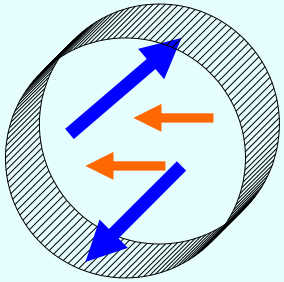
TE111

720MHz



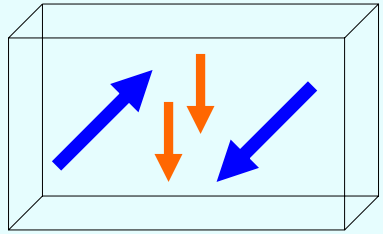
TM110

500MHz



TM110 - like Mode

500MHz

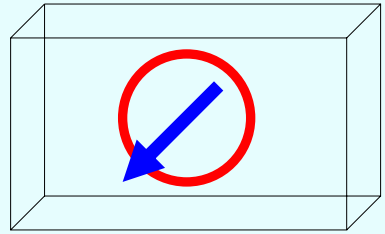


Crab Mode

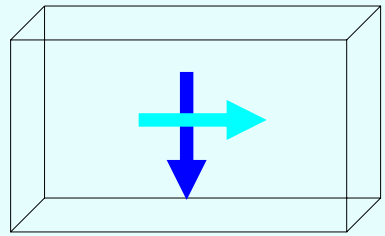
Unwanted Modes

TM010 - like Mode

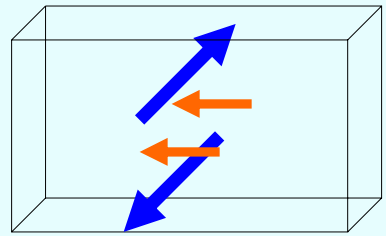
413.3MHz



650.5 MHz / 677.6MHz

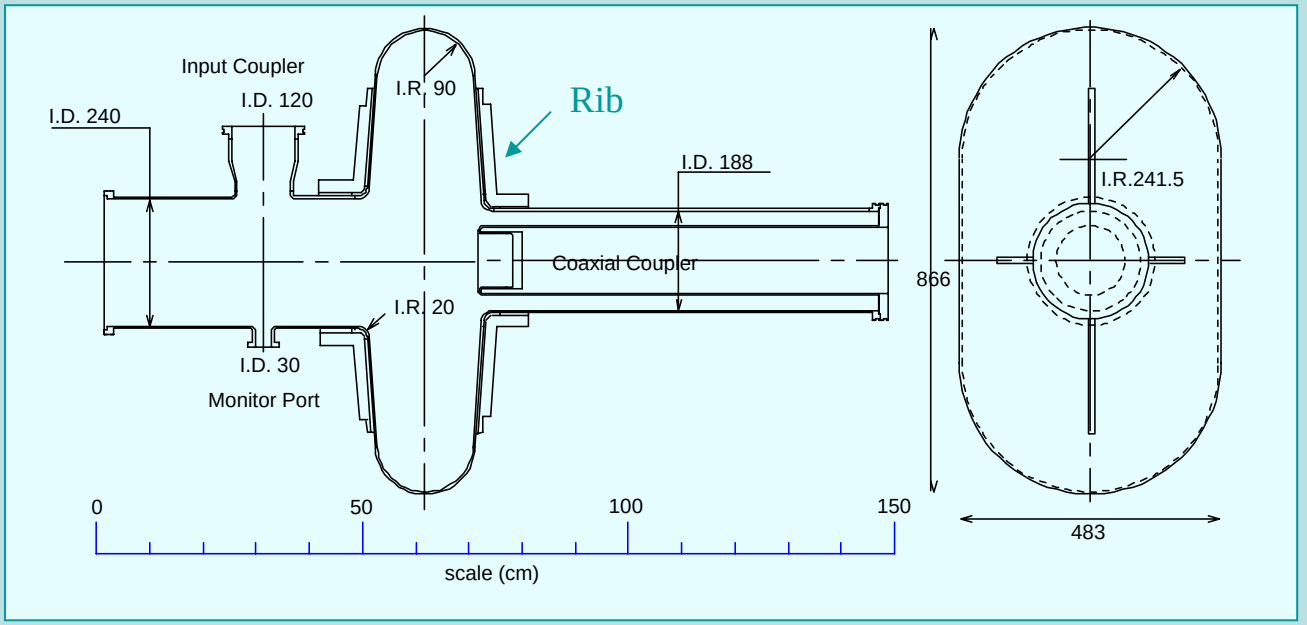


700MHz



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

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

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

Simplified Nb Coaxial Coupler

Milestone of KEKB Crab Cavities

0) 1/3 scale model 1.5 GHz 1994

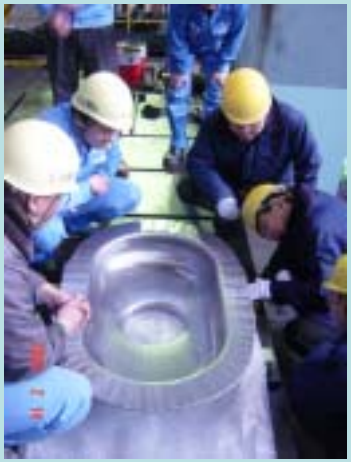
1) Full Scale Prototype Crab Cavity 500MHz 1996

2 Nb Cavities # 1 & # 2 2003
Coaxial Coupler
Prototype Horizontal Cryostat
(# 2 was Installed
into Prototype Horizontal Cryostat for Cool down Test)

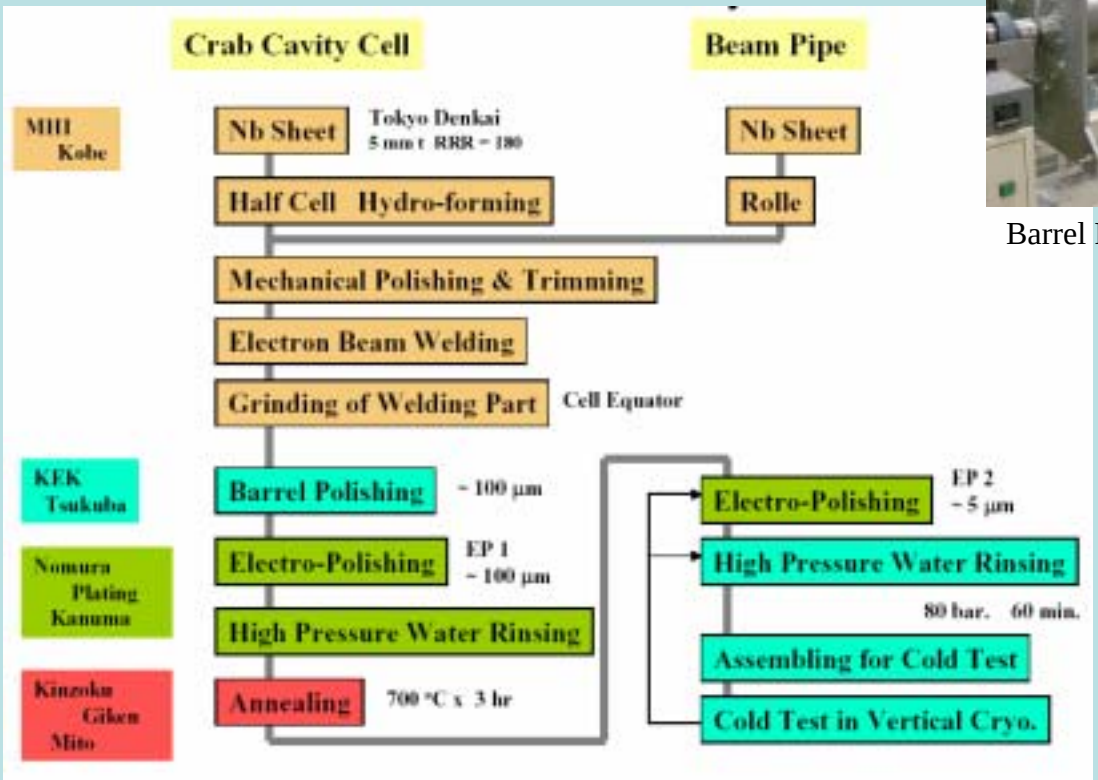
Installation of 2 crab cavities in KEKB was decided 2004

2) KEKB Crab Cavity 509MHz
2 Nb Cavities for LER, HER
Cold Tested in Vertical Cryostat 2005
Assembling and High power test 2006
Installation and Commissioning 2007
Jan. ~ Jun.
Sept.~

Fabrication of KEKB Crab Cavity



Forming of Half-Cells



Barrel Polishing 312Hr

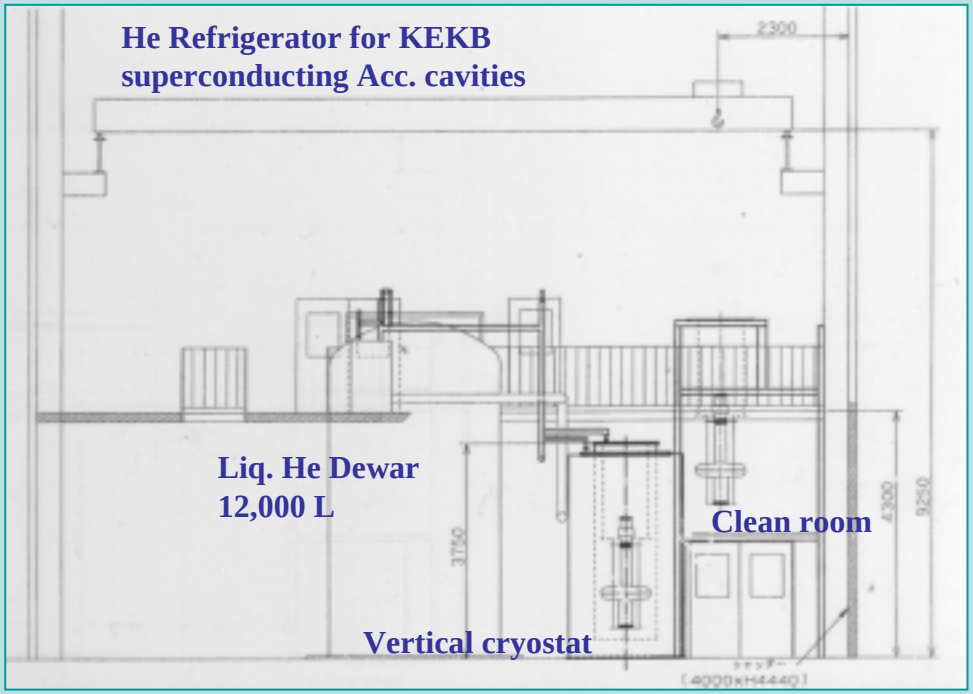
High Pressure Water Rinsing

Electro Polishing

Annealing

Assembling

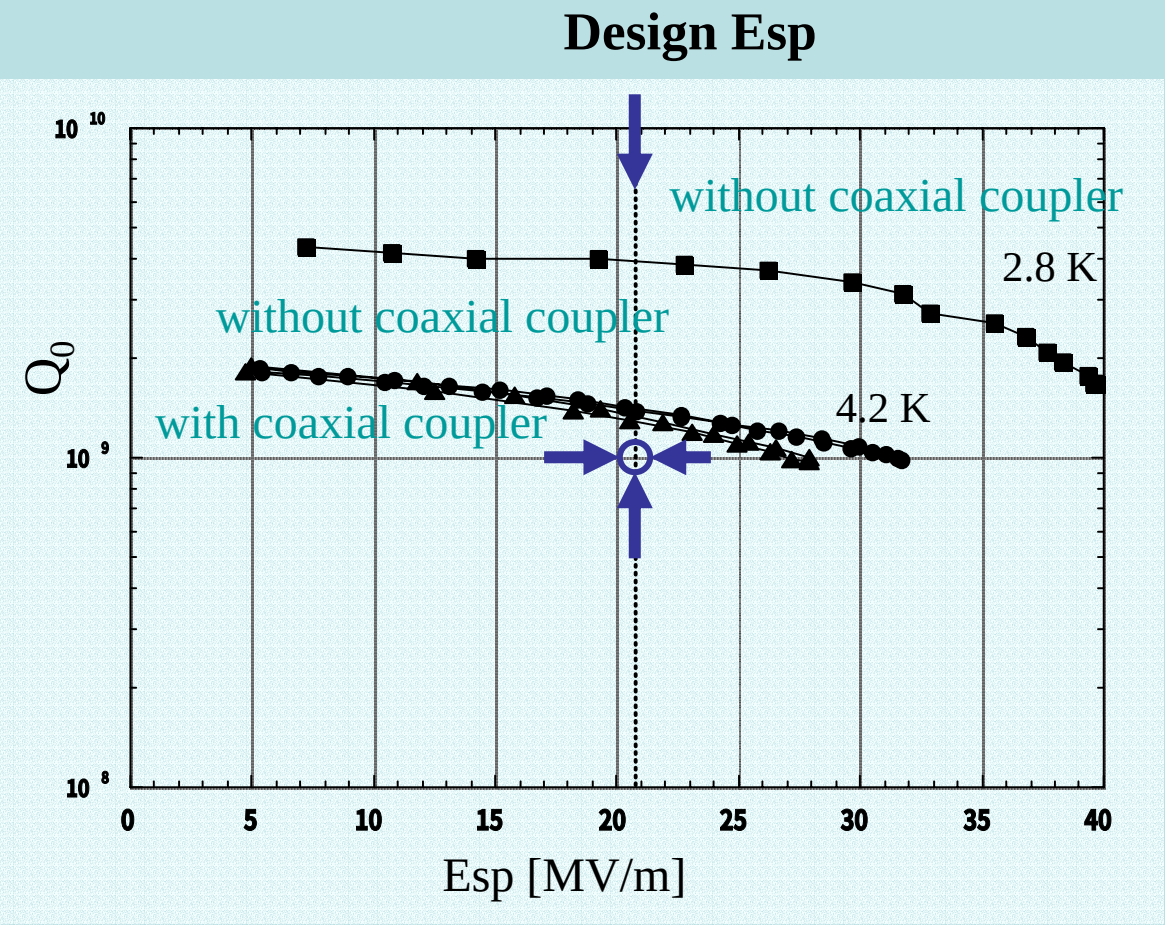
Cold Test Stand for KEKB Crab Cavity



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

The crab cavity is set in the vertical cryostat

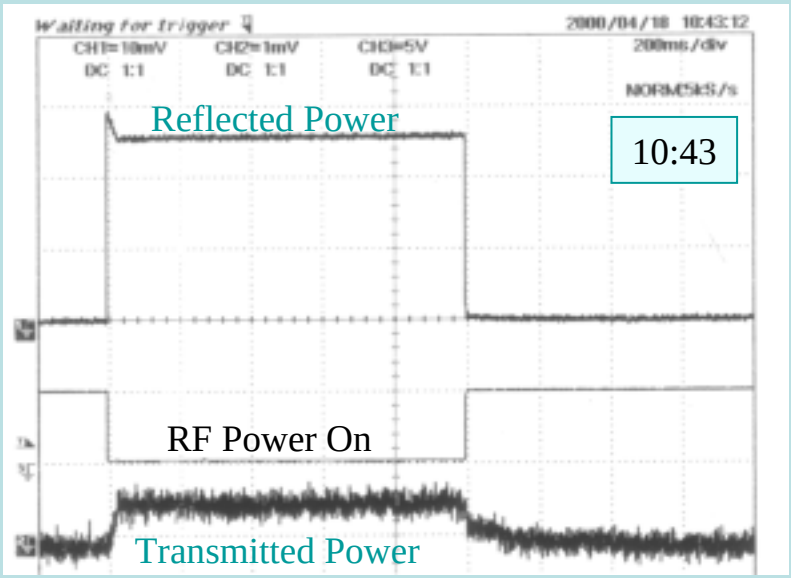
Test Result of Prototype #1 Crab Cavity

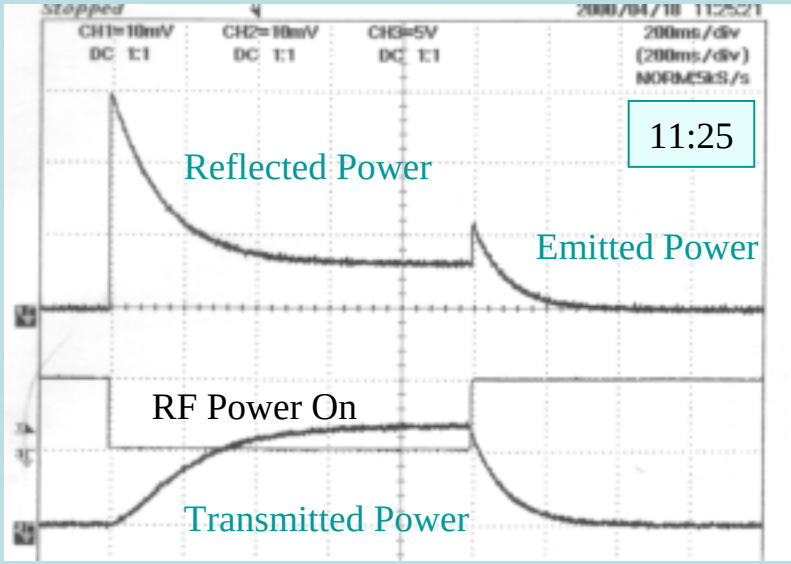


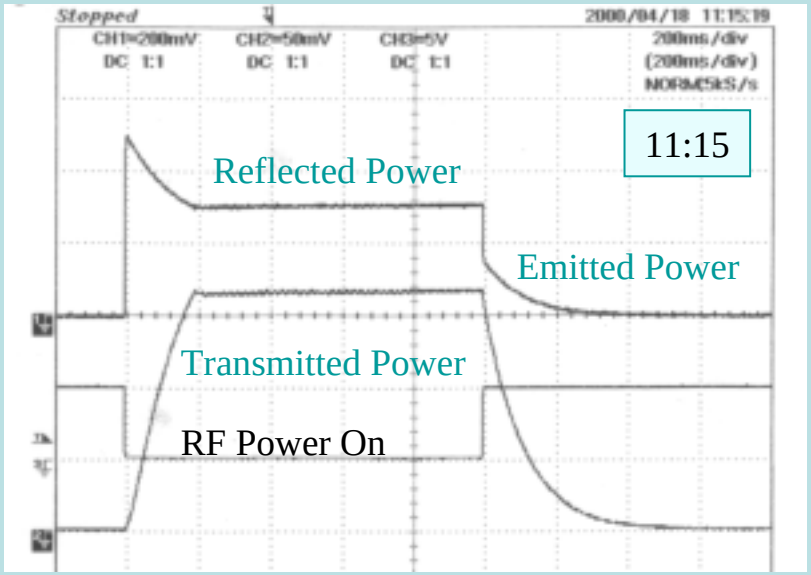
Crab Cavity #2
Same Performance!

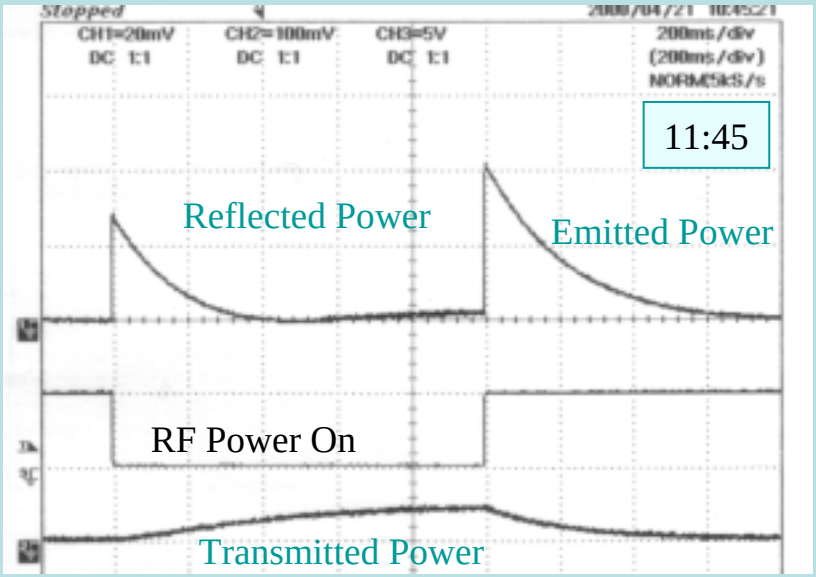
⇨ Fabrication and Surface Treatment OK!
RF Performance Test with a Coaxial Coupler
Multipacting could be overcome by RF process.

Multipactoring in Crab Cavity with Coaxial Coupler

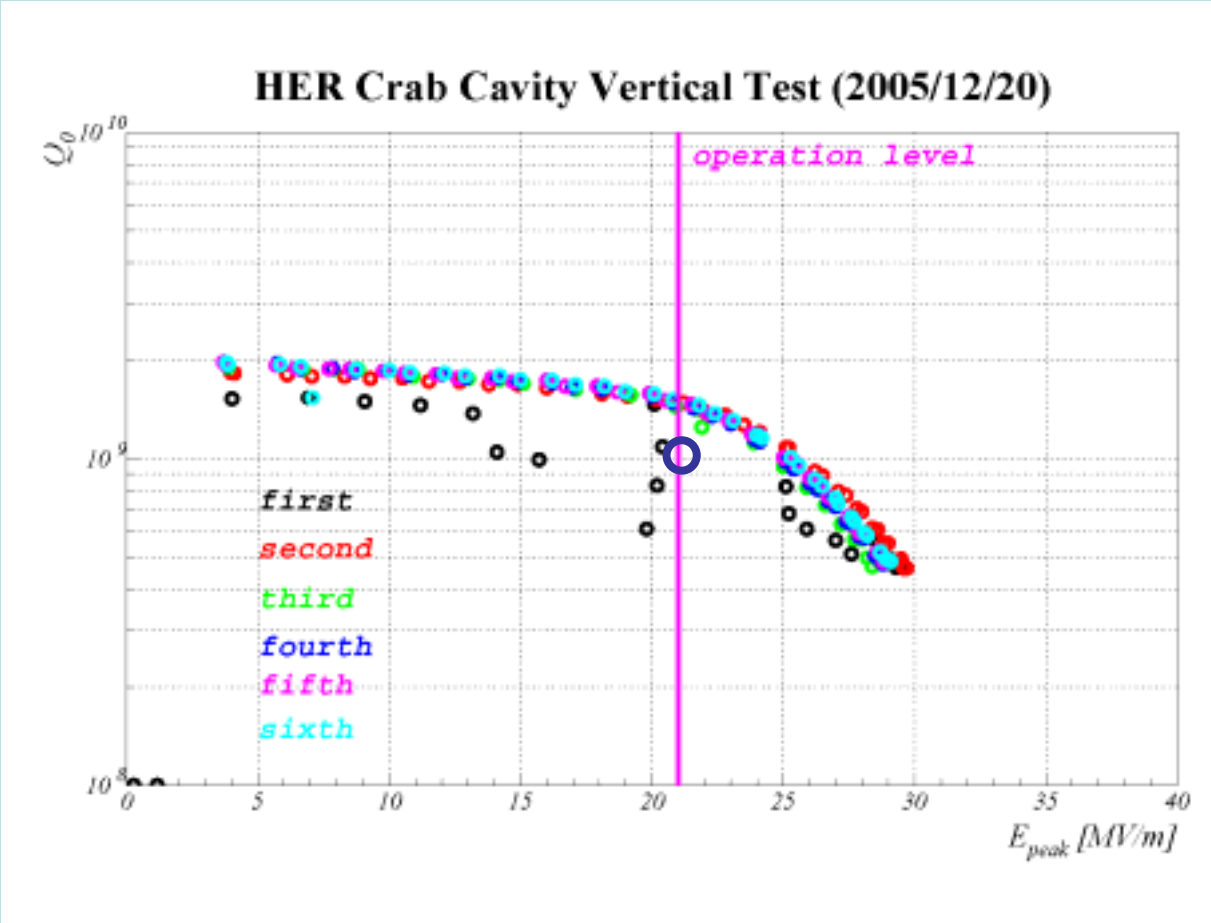


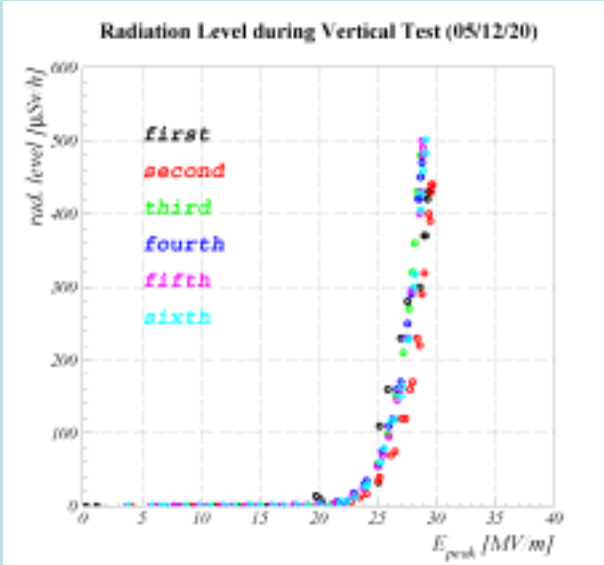






Test Result Crab Cavity for HER

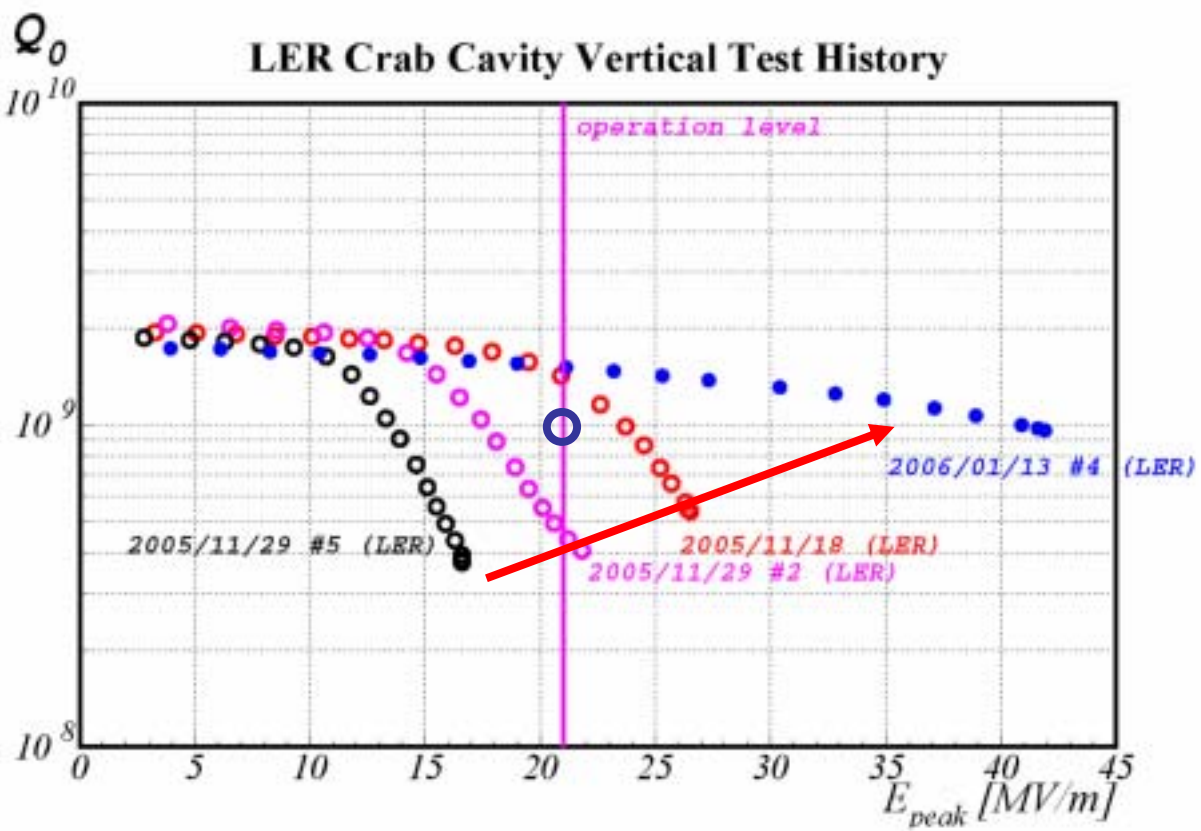




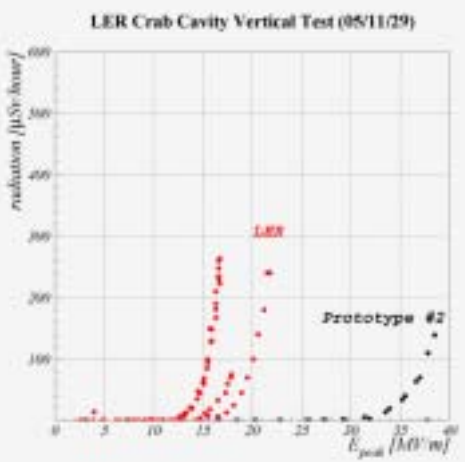
Test result satisfied the design value!

Move to installation into the cryostat.

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

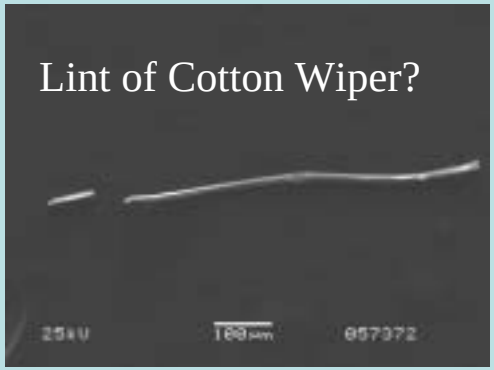
↓

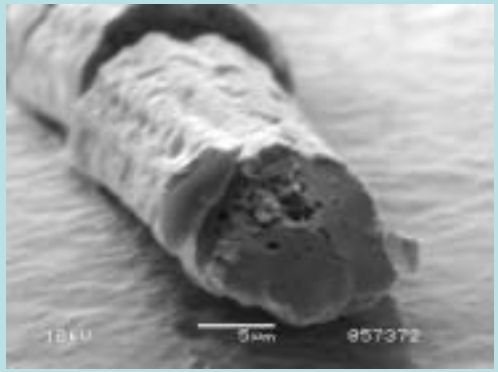
Jan. 13 Test

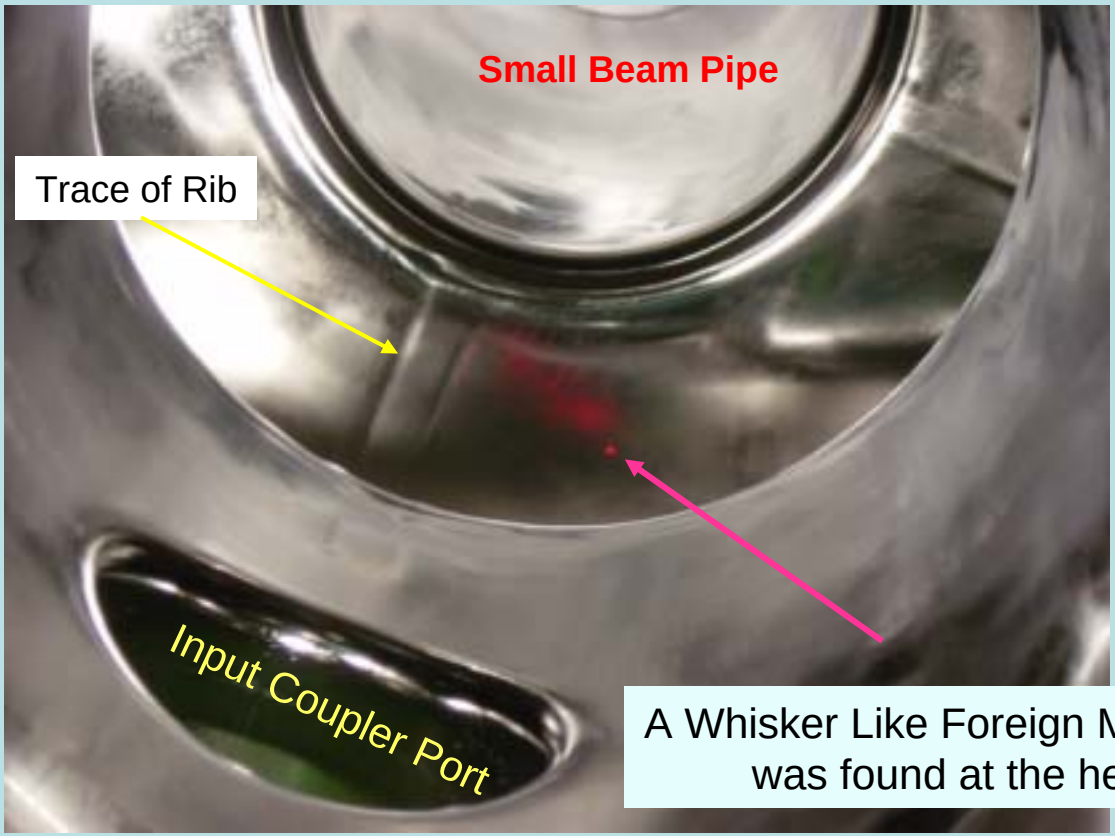
Recovered !

Test result could not satisfy the design value!
Back to EP II processing.

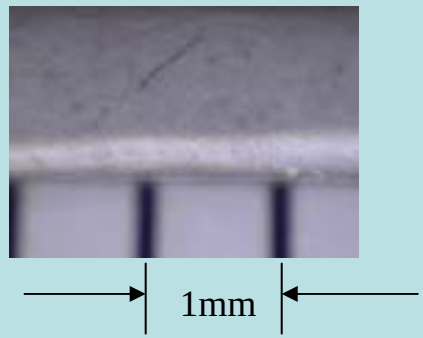
Inspection in the cavity







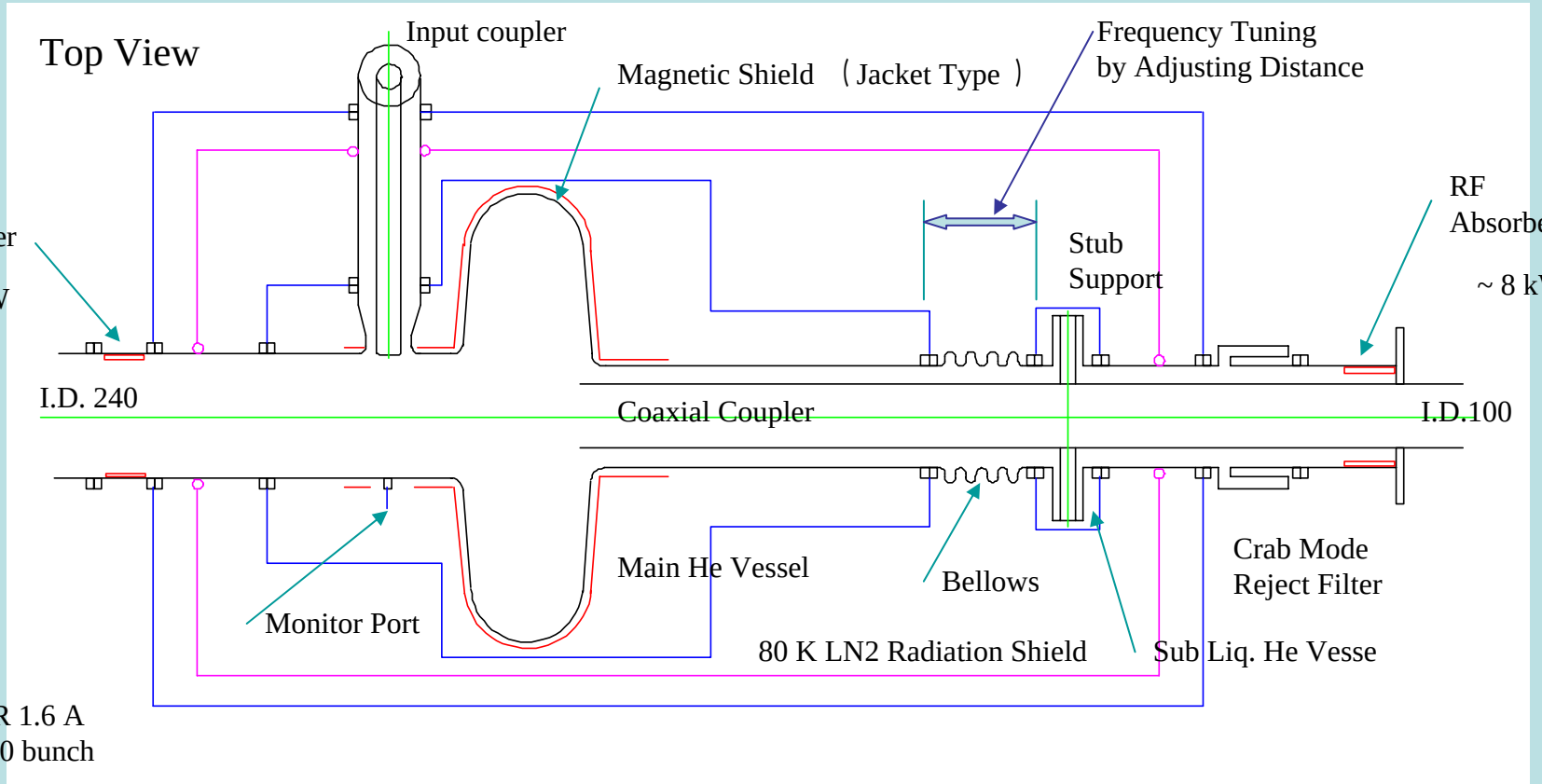
A Whisker Like Foreign Material
was found at the heating spot !



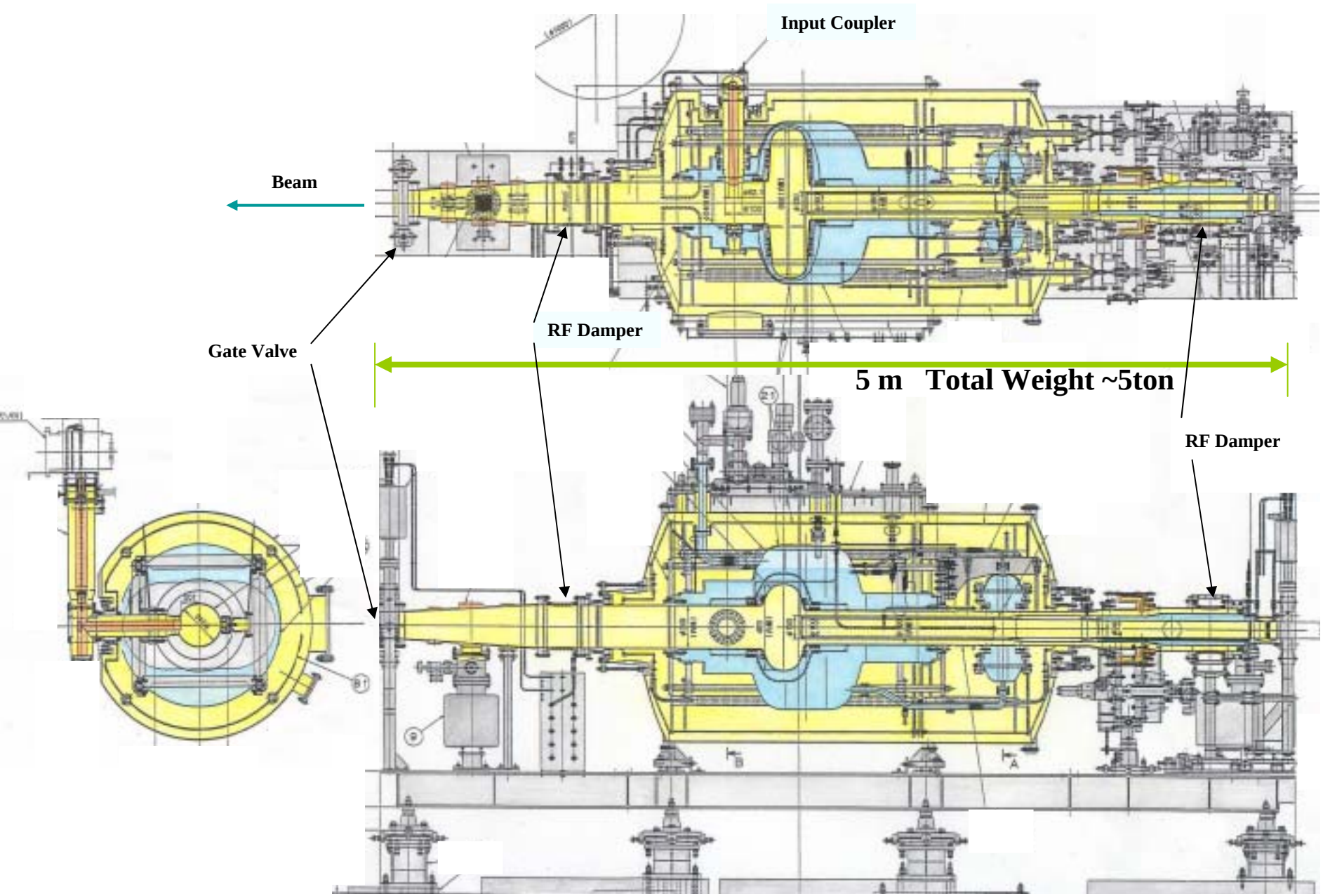
Conceptual Design of Cryostat for KEKB Crab Cavity

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*

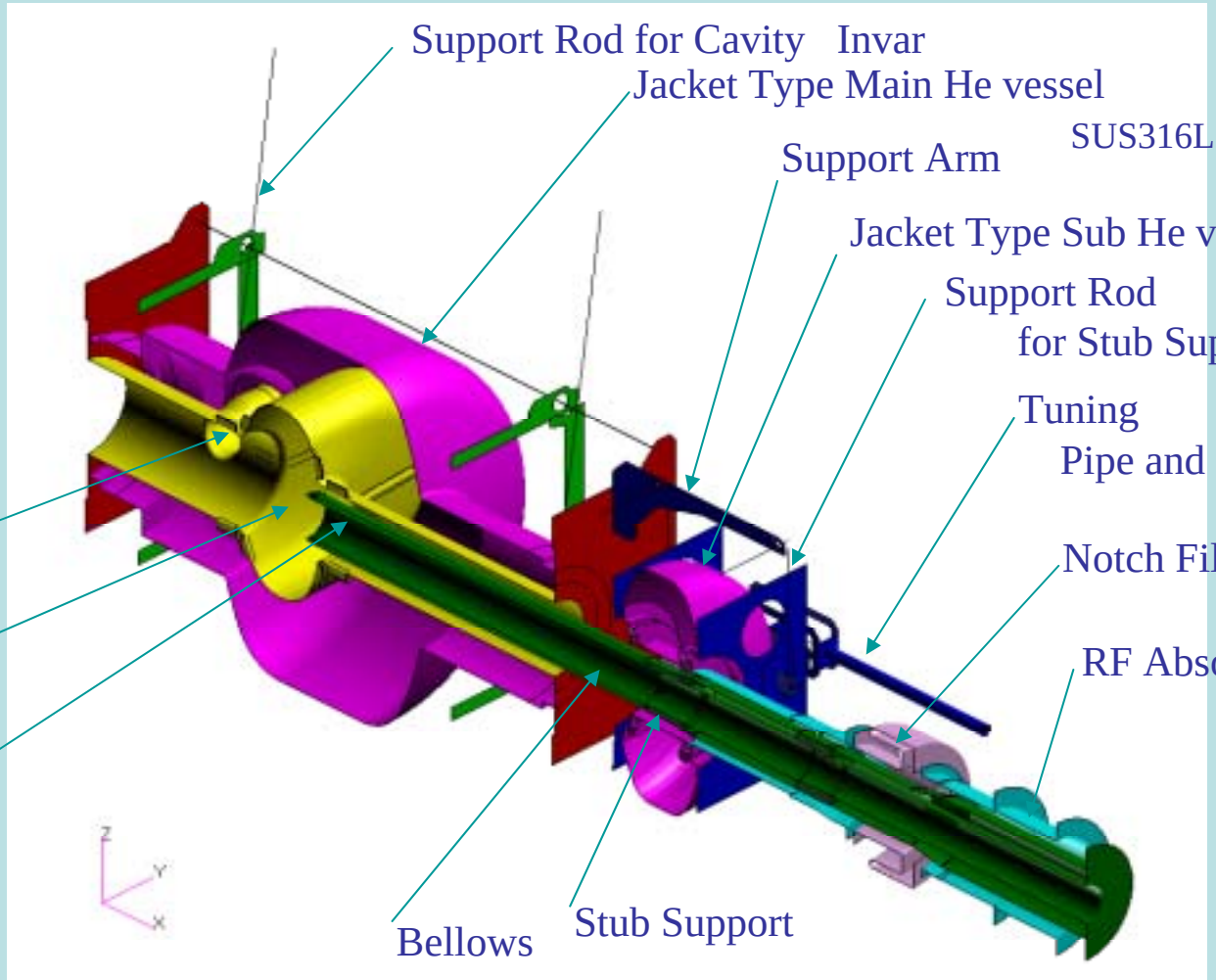


Cryostat for KEKB Crab Cavity

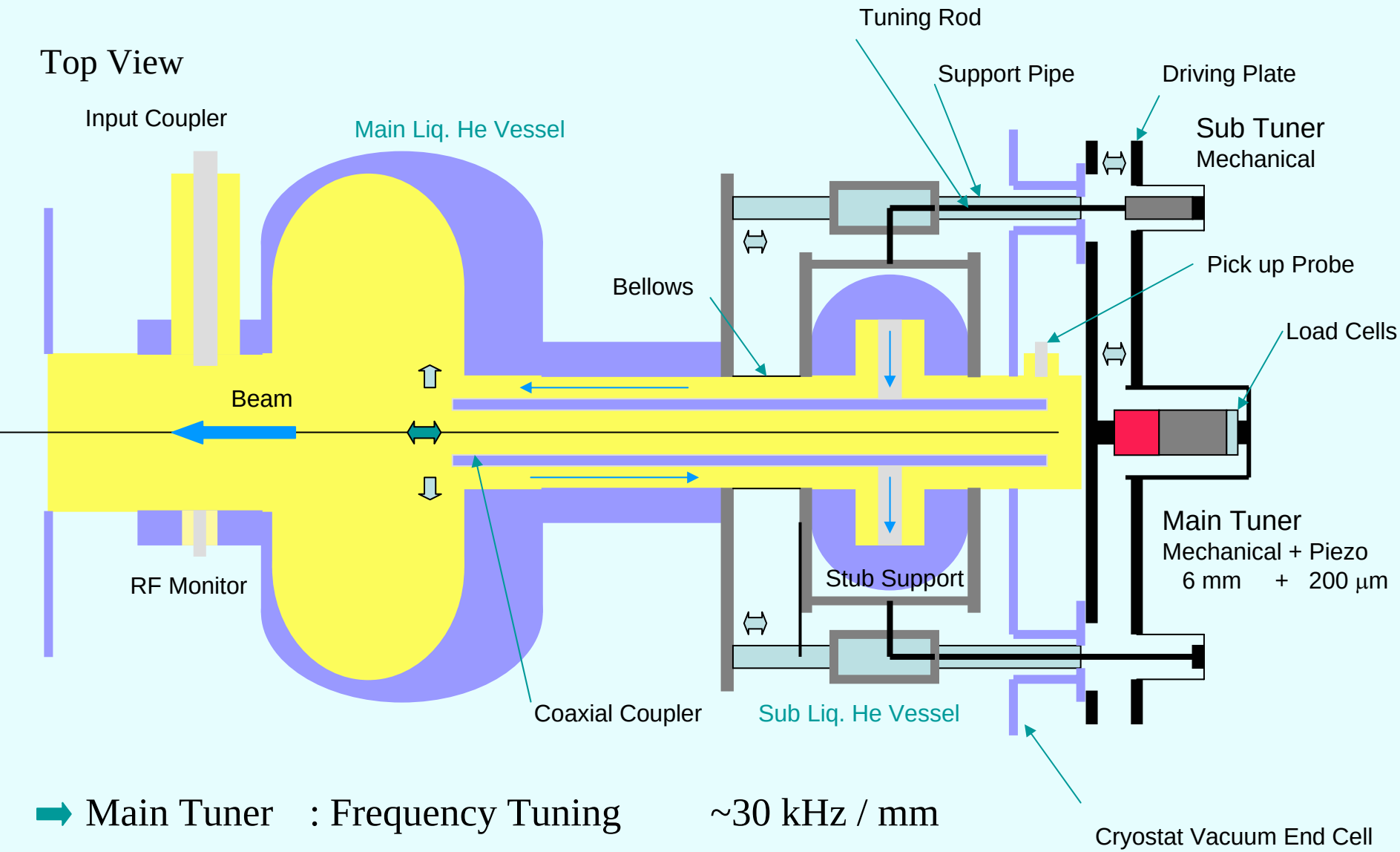


Crab Cavity & Coaxial Coupler in Cryo-module

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.**



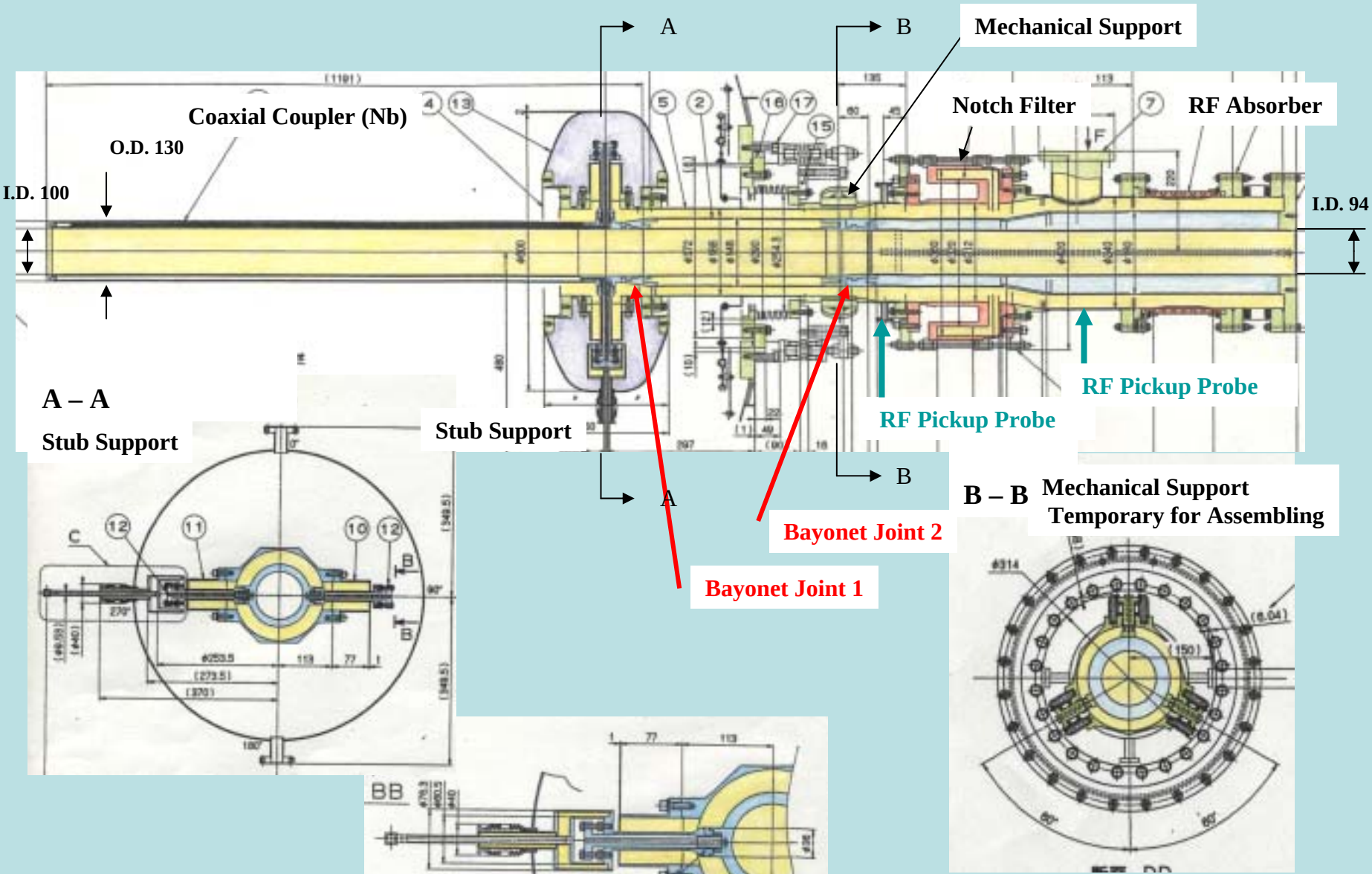
Frequency Tuning Mechanism



➡ Main Tuner : Frequency Tuning ~30 kHz / mm

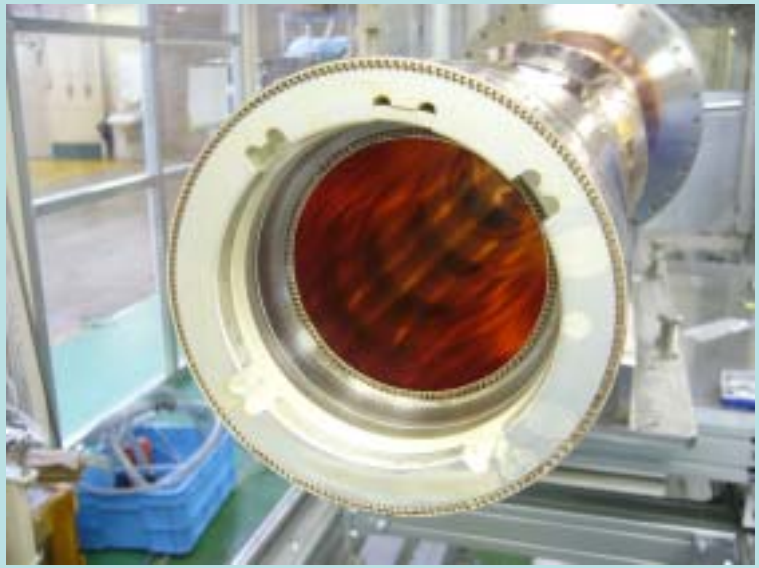
⇨ Sub Tuner : Adjust Position of Coaxial Coupler

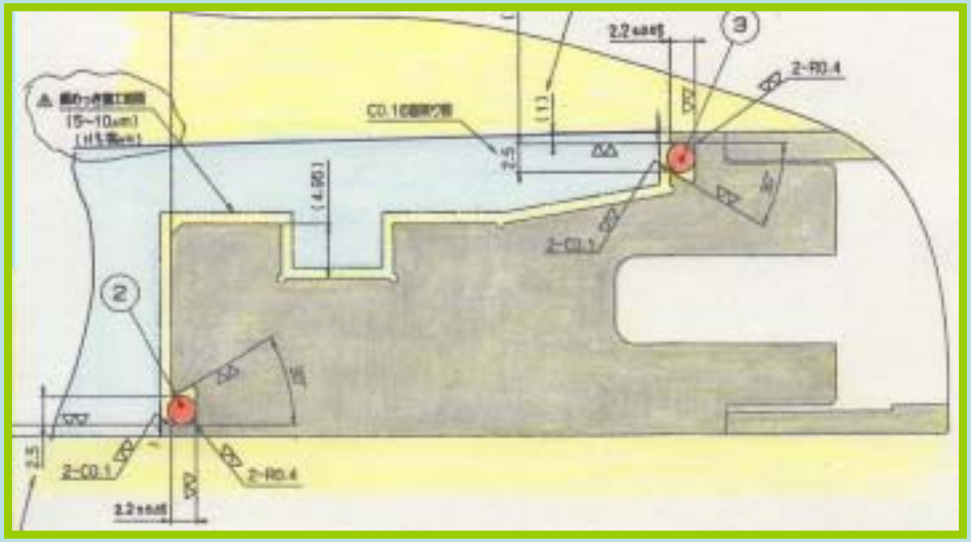
Coaxial Structure Detail



RF Contact

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

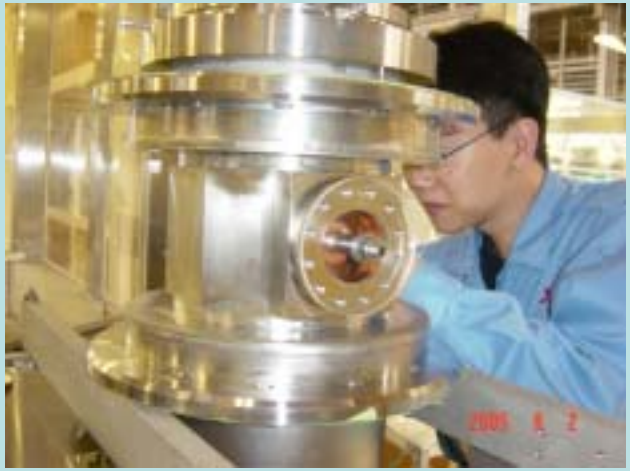




Assembling the Coaxial Coupler

Nb Inner Conductor of Coaxial Coupler

Inner Conductor
of Stub Support



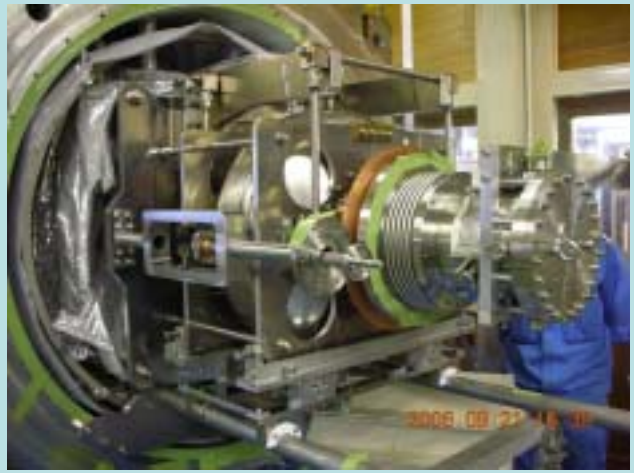
Stub Support

Leak Check of Assembled Coaxial Coupler

Assembling Coaxial Structure to Crab Cavity

High Pressure Rinsing

Coaxial coupler was ready to install

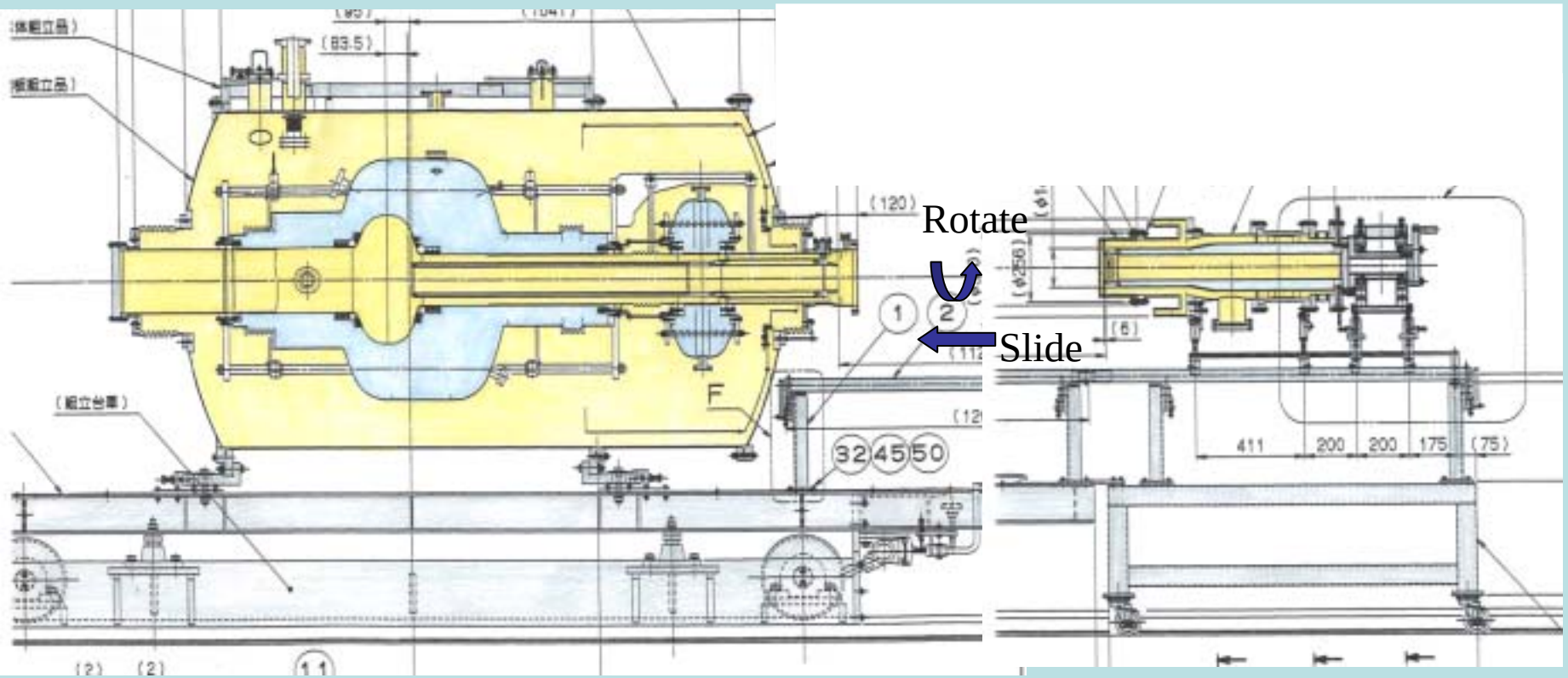


Tuning Structure

- 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.

Setup for Connection of Coaxial Structure

- **Assembling the coaxial coupler to the cryostat was very “tough job”.**
- **We could not connect the bayonet type joint of coaxial coupler.**



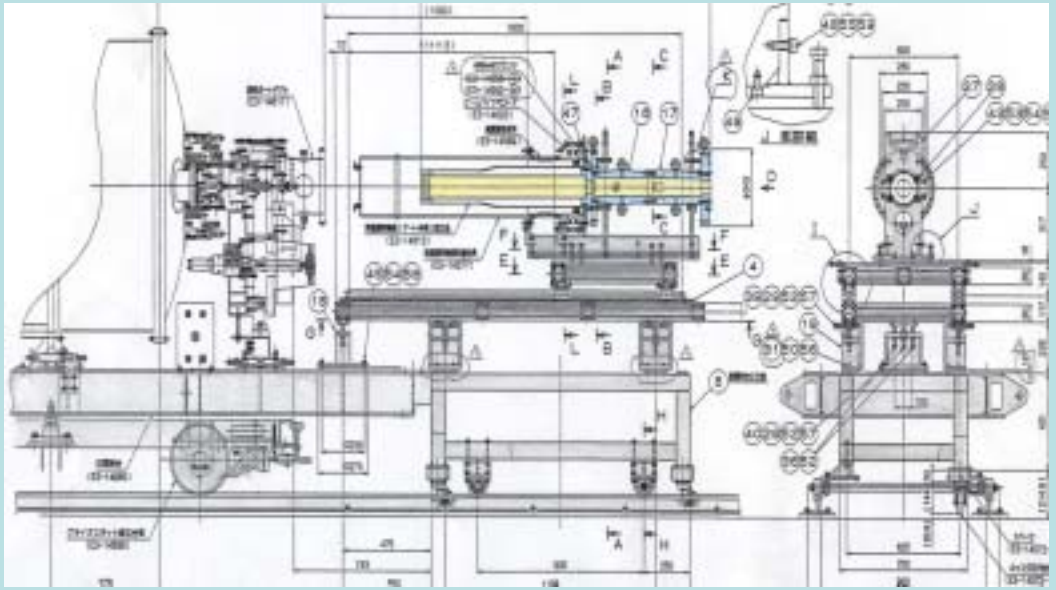
Need Modification

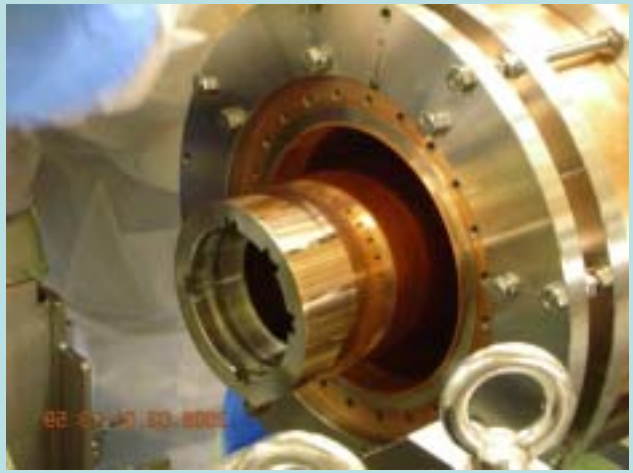
Precise Alignment
- Position of Axis
- Direction Axis

Insertion Tool
- Rigid Support Structure
- Precise Adjustment Knob

New Insertion Setup

We could assemble it by using improved Insertion tool!



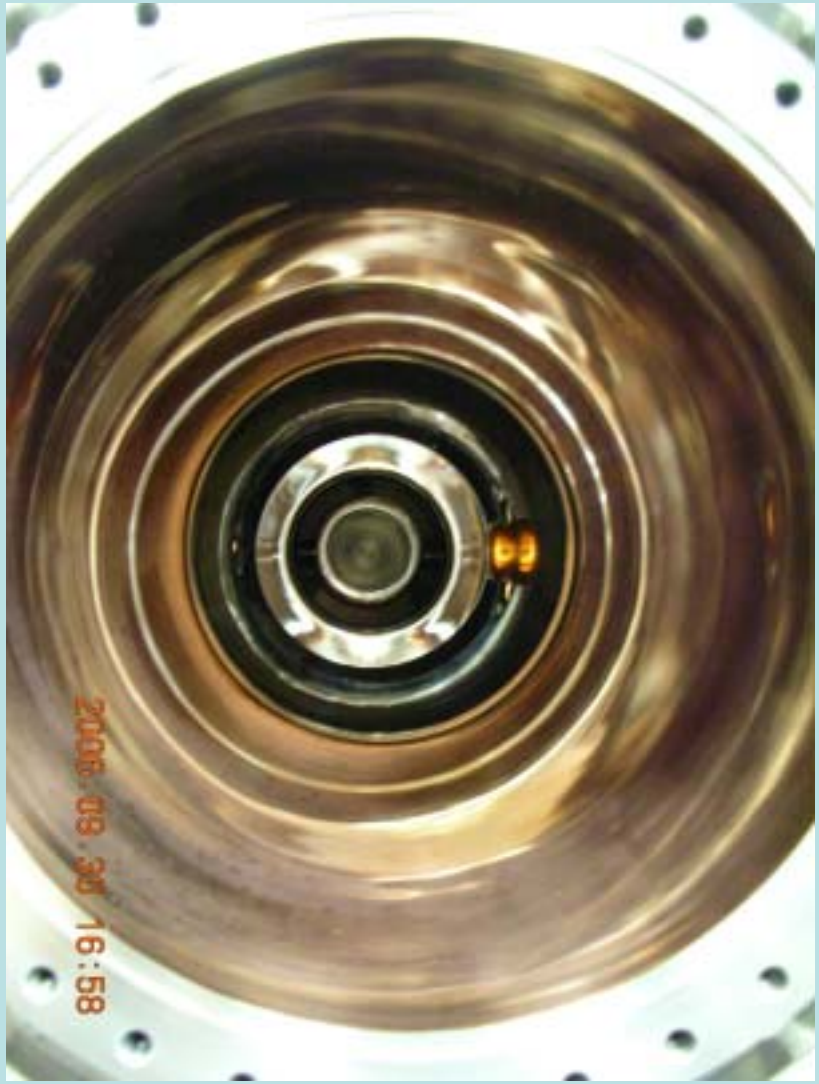


Crab Cavity (Cryostat) Side

Notch Filter Side

Assembling Large Beam Pipe

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

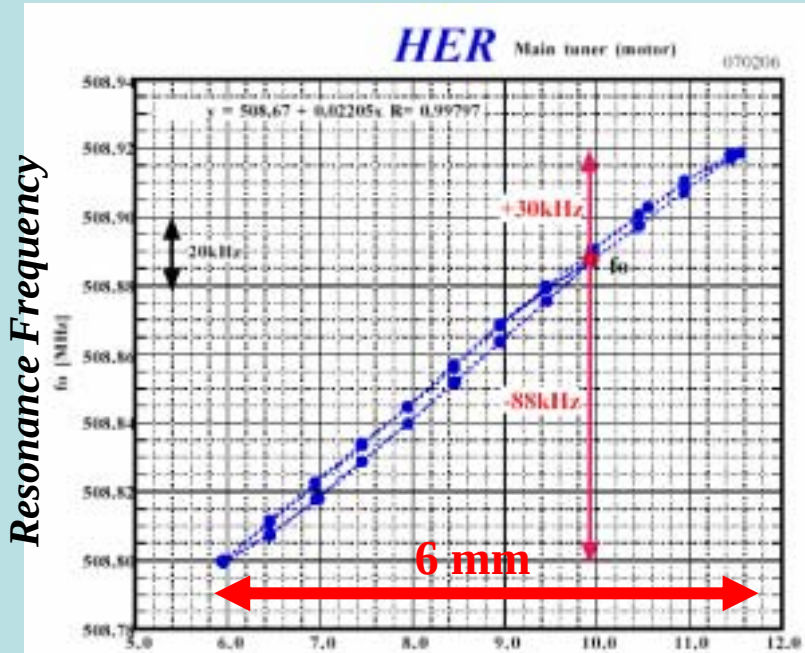


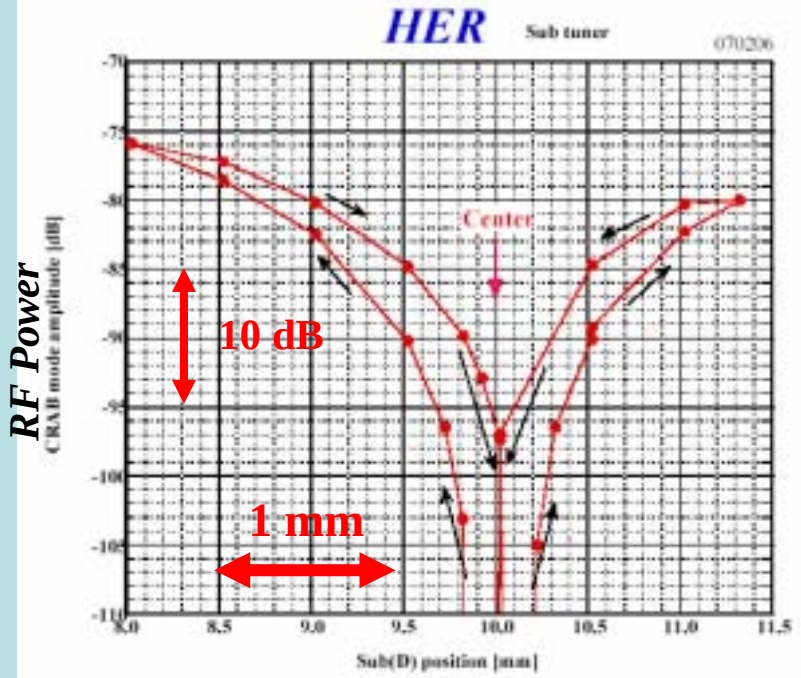
Inside crab cavity
Coaxial coupler
Iris of crab cavity
Input coupler
Tapered copper pine

Frequency Tuner Test

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

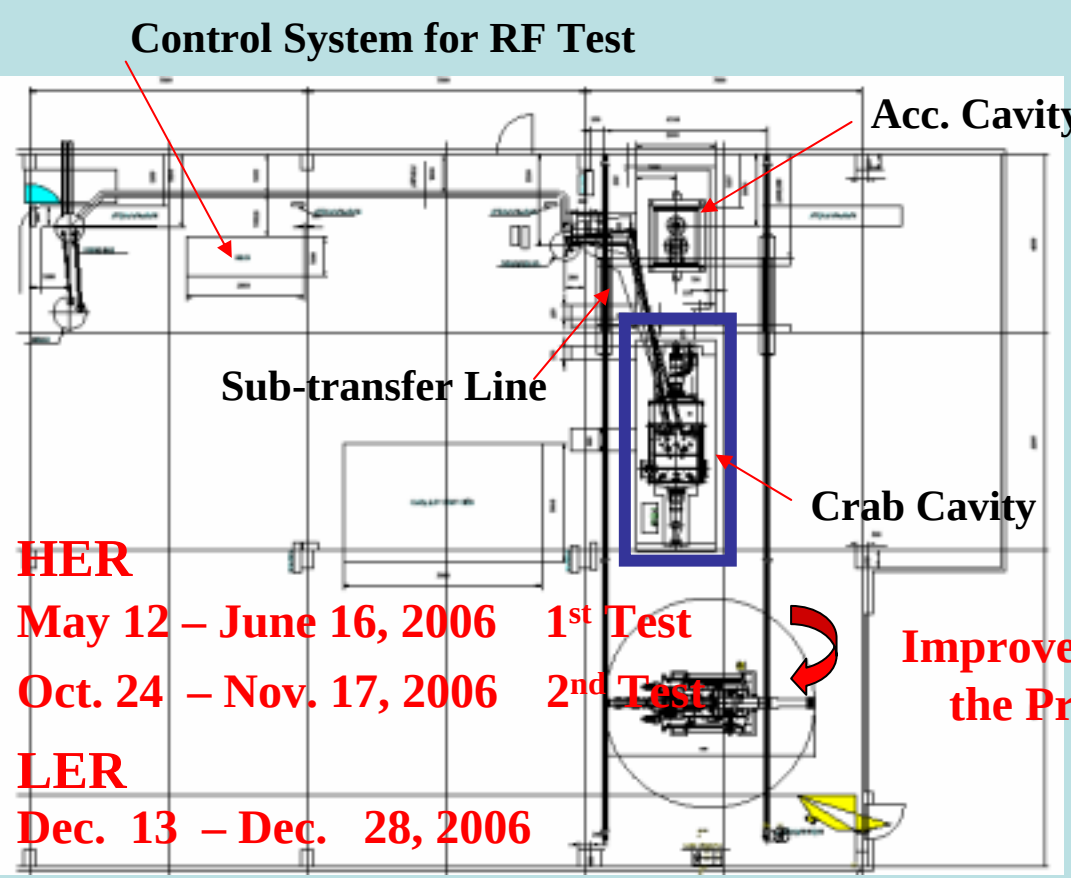
Frequency Tuner Crab Cavity for HER





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

Test Stand for Crab Cavity at D10 Station



HER

May 12 – June 16, 2006 1st Test

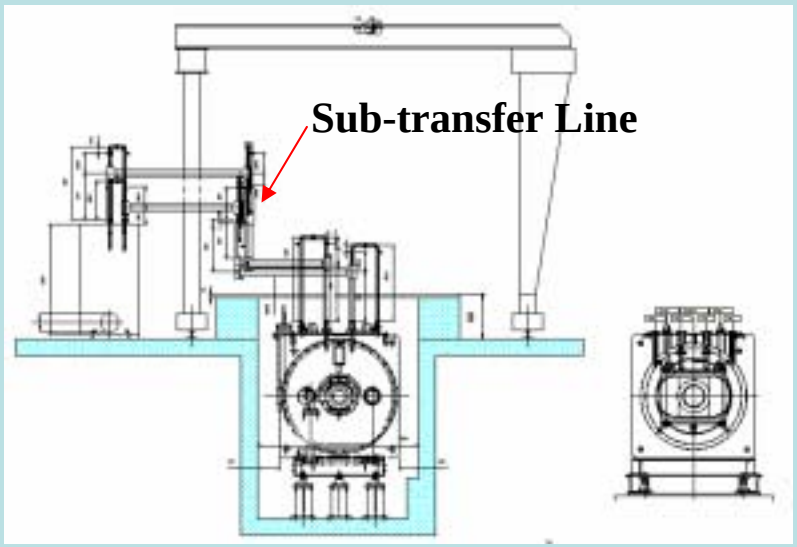
Oct. 24 – Nov. 17, 2006 2nd Test

Improved the Problems

LER

Dec. 13 – Dec. 28, 2006

High Power Test



1st High Power Test for Crab Cavity HER

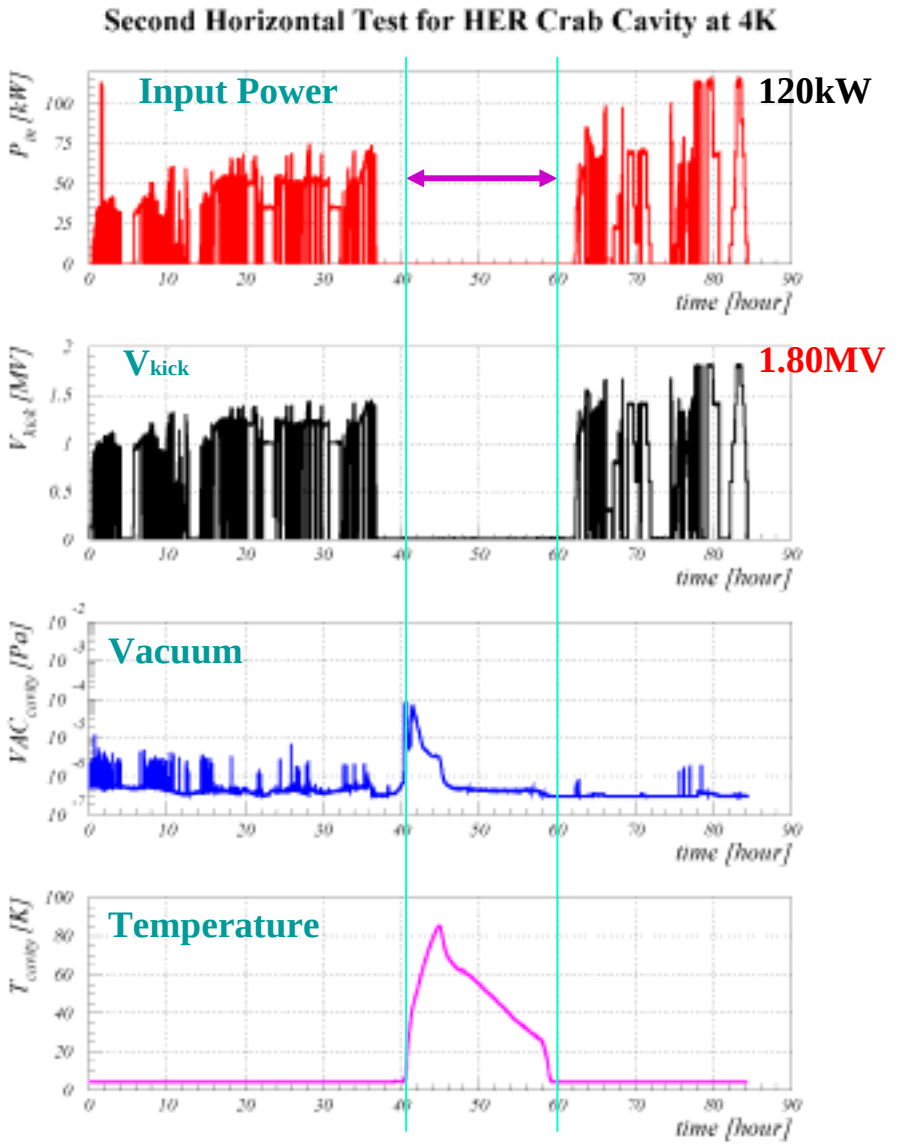
- Crab cavity for HER was cooled down without leakage.
- V_{kick} = 1.67 MV, exceed the design value of 1.44 MV.
- Cavity and coaxial coupler was cooled stably during the high power test. Cryogenic system worked very well.

Problems & Improvements (Disassemble & Re-assemble)

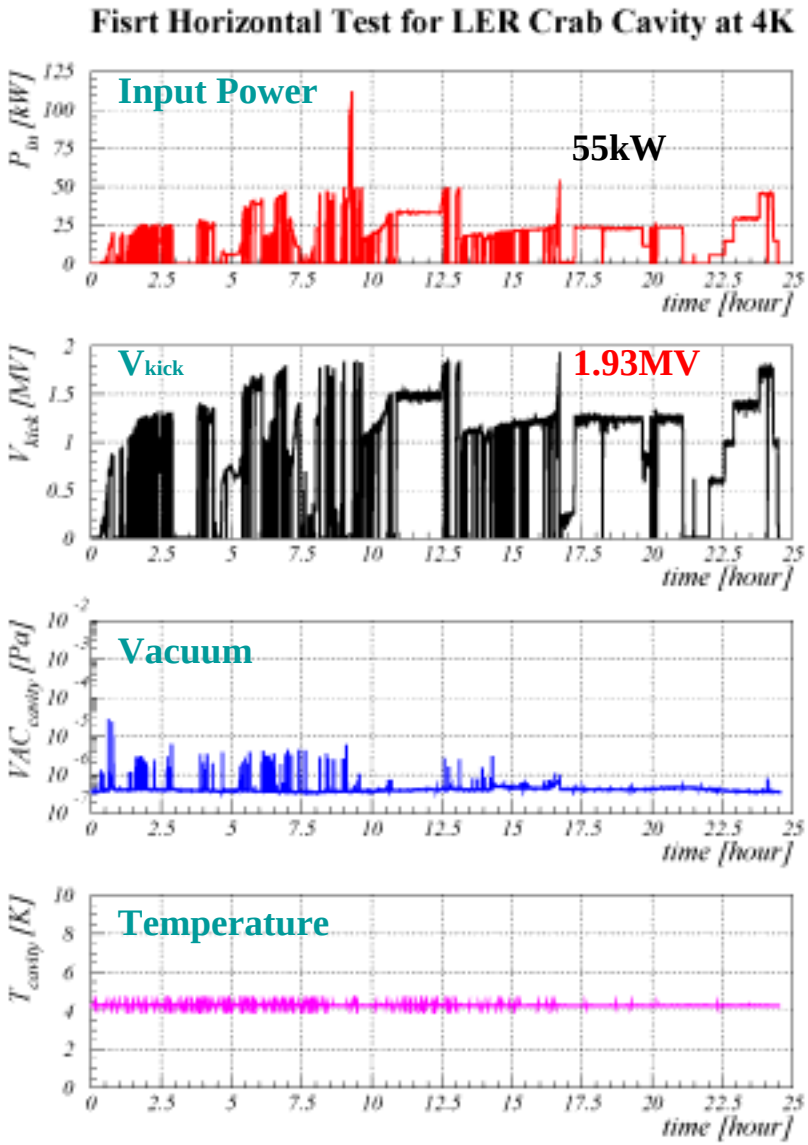
- Resonant frequency was lower than design value (~300kHz)
  → After cool down, the cavity was pre-tuned
- Narrow tuning range
  Main tuner & Sub tuner
  → Change to thin stainless bellows with copper plating
- Tuner feedback stability is not good
  → Reinforce the tuning structure
- RF contact at the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

High Power Test for Crab Cavity HER & LER

Crab Cavity HER

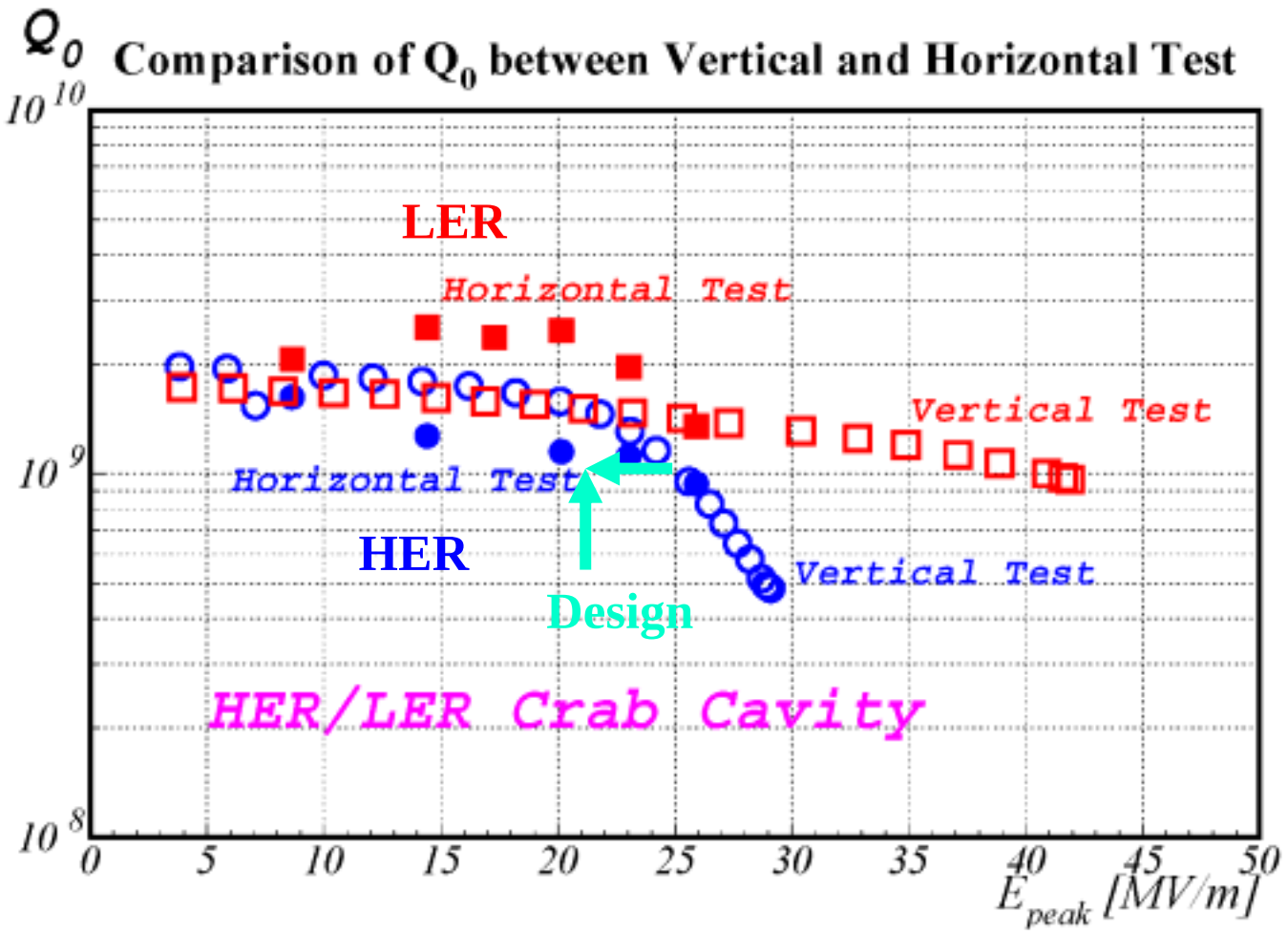


Crab Cavity LER



Q_0-Measurement

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



SUMMRY High Power Test at Test Stand

- Crab cavity for HER and LER were cooled down without leakage.
- Resonant frequency could adjust to operating frequency of 508.9MHz.
- V_{kick} = 1.8 MV and 1.93 MV respectively, exceed the design value of 1.44 MV.
- Qo – values at design kick voltage were higher than $1x10^9$.
- Cavity and coaxial coupler was cooled stably during the high power test. Cryogenic system worked very well!
- Frequency tuner of crab cavity HER work very well.
  Phase stability of crab cavity HER is good.
  Phase stability of crab cavity LER is no good!

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
Beam Operation Start
Feb. 13

Crab Cavity for LER

SUMMARY Commissioning of Crab Cavities (1)

- Kick voltage of crab cavity HER and LER reached

  V_{kick} = 1.6 MV and 1.5 MV respectively,

  exceed the design value of 1.44 MV.
- RF phase tuner of crab cavity LER did not work well.

  By using the RF feed back system, we could control within the design value.

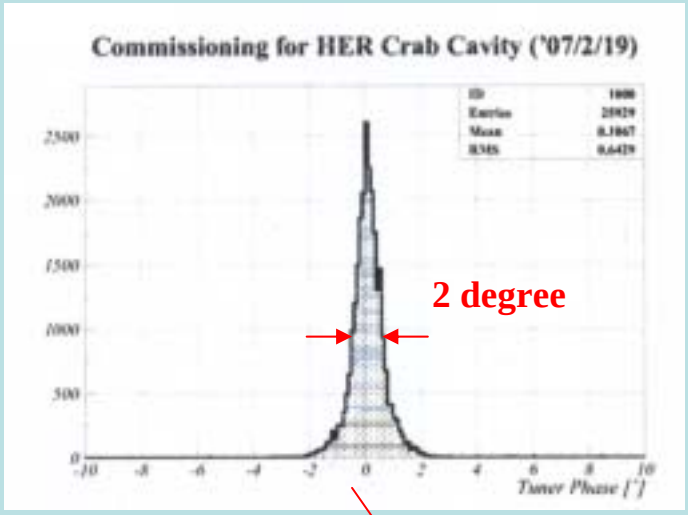
Troubles:

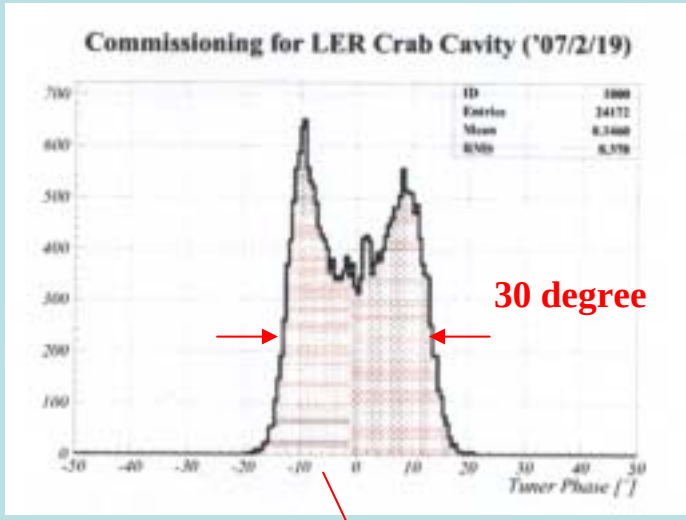
- Cold helium gas leak at connection part of recovery pipe.

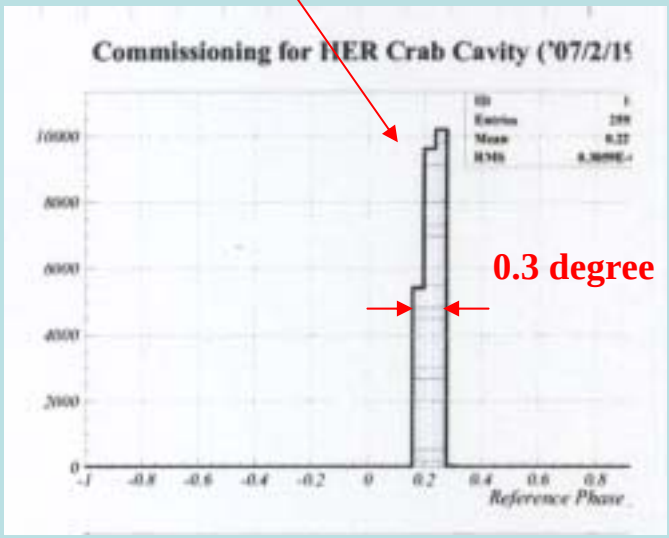
  Tighten the connector and set a heater at connection part.
- Lack of cooling power at coaxial coupler.

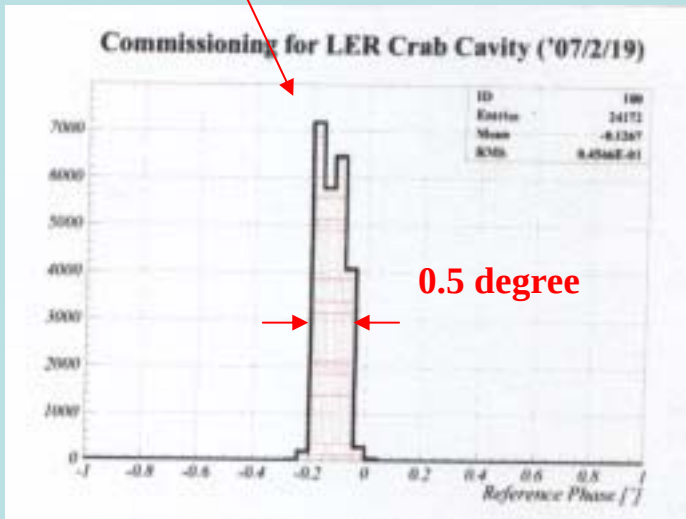
  Add bypass line to increase the gas flow.
- Poor vacuum at coaxial coupler part of crab cavity LER.

Phase stability could be improved by RF feed back system

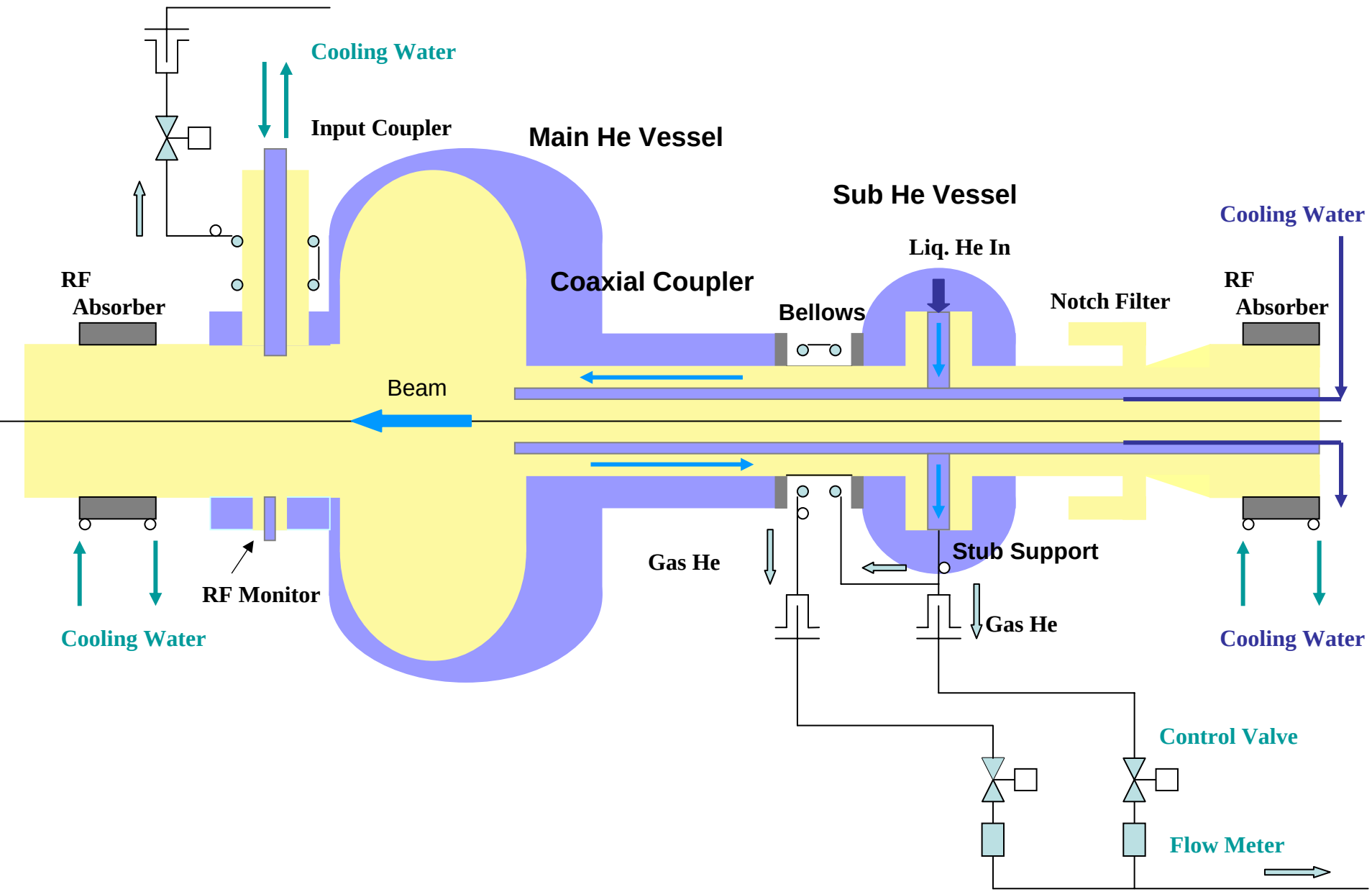








Cooling System for KEKB Crab Cavity



SUMMARY Commissioning of Crab Cavities (2)

- L_{peak} =14.7 x 10^{33} /cm^2/s attained under crab on operation.
- High current beams of 1.7A (LER) and 1.35A (HER) could pass through the crab cavities under RF off operation.
- Crab cavity and coaxial coupler could keep cold under high current beam operation.
- The HOM power of about 10kW could absorb by HOM damper.
- The RF contacts at inner conductor of coaxial coupler worked well under high current operation.
- Trip ratio of crab cavity could decrease by warm up of cavity up to room temperature.

Troubles:

- Kick voltage of crab cavity LER has decreased to V_{kick} = 1.1 MV
- Piezo tuner of crab cavity LER broken

. Crab cavities can operate without Piezo tuner.

- Lack of cooling power at coaxial coupler.

Add bypass line to increase the gas flow.