

Lecture B: Superconductive RF

Cavity Fabrication

T. Saeki (KEK)

LC school 2015

27 Oct. - 6 Nov. 2015, Whistler, Canada



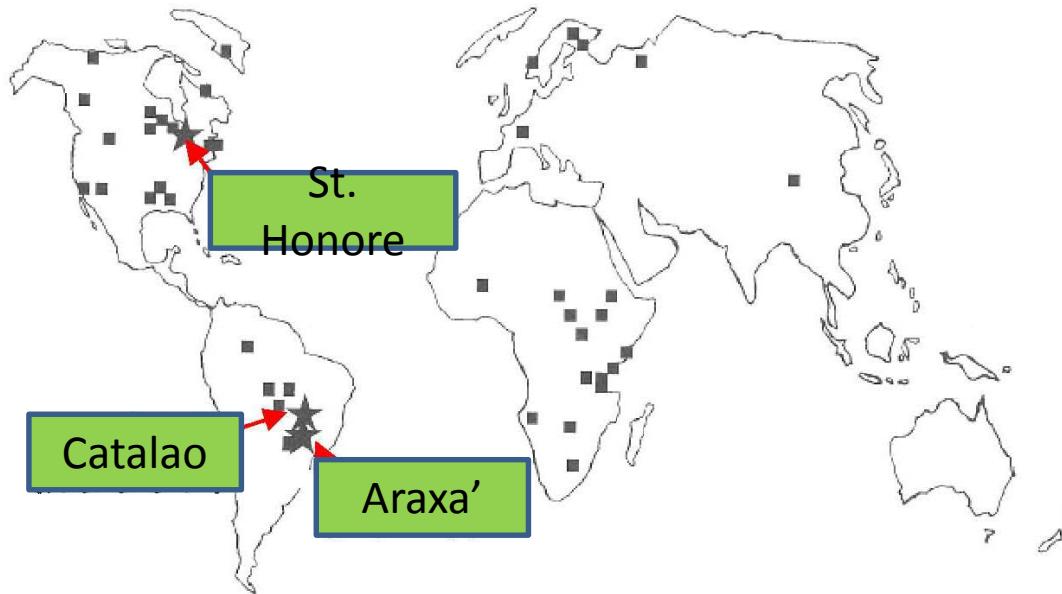
1.3 GHz elliptical 9-cell cavity



**TESLA 9-cell Cavity
(Iris 70 mm)**



Nb Mines in the world



■ Nb deposits
★ Nb Mines

金屬 Vol.72 (2002) No.3

Ore of Nb:
Carbonite

Three largest mines in
the world:
Araxa'
Catalao
St. Honore

Niobium is the 33rd abundant/rich metal
in the all existing metals in the earth.

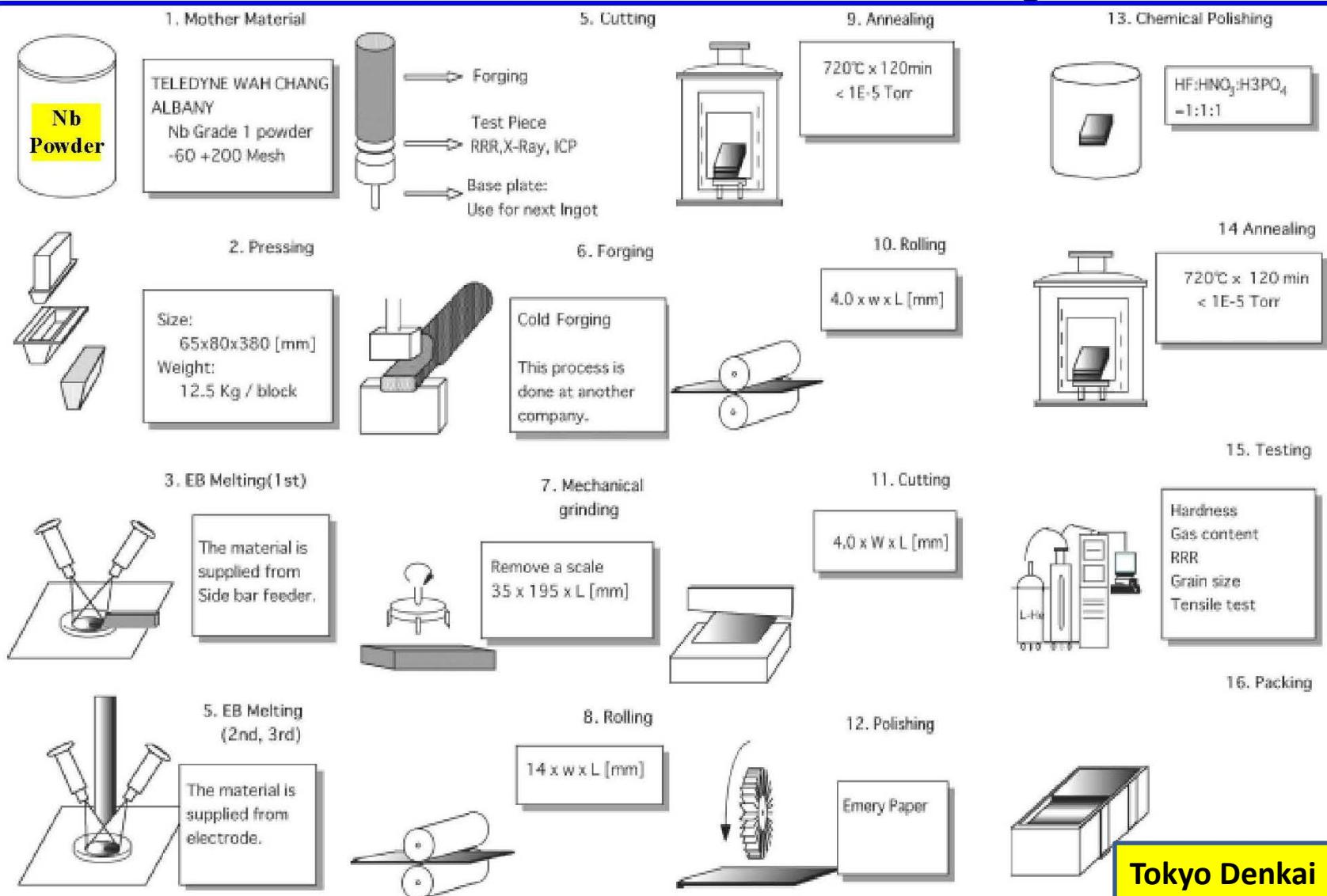
Nb Mine



Brasil CBMM, Araxa



Process flow of the industrial Nb production



Tokyo Denkai



Electron Beam Melting (EBM) Furnace and Nb Ingots



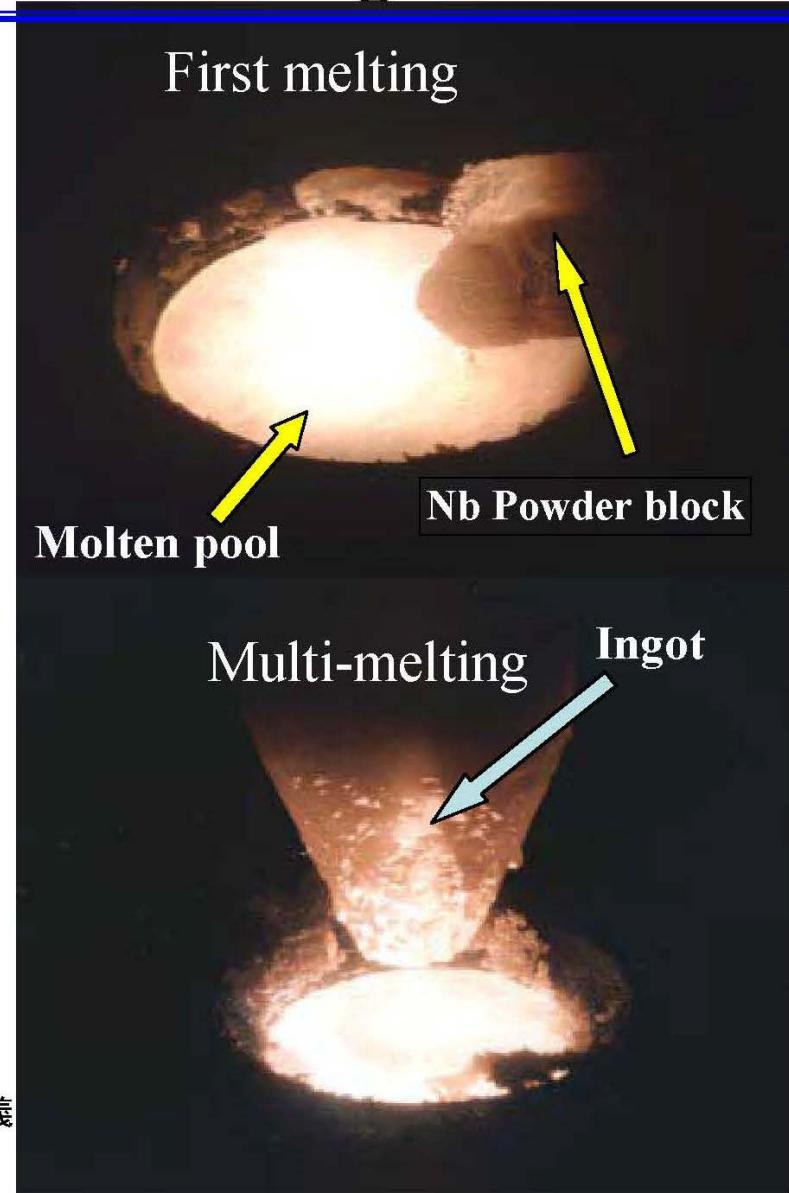
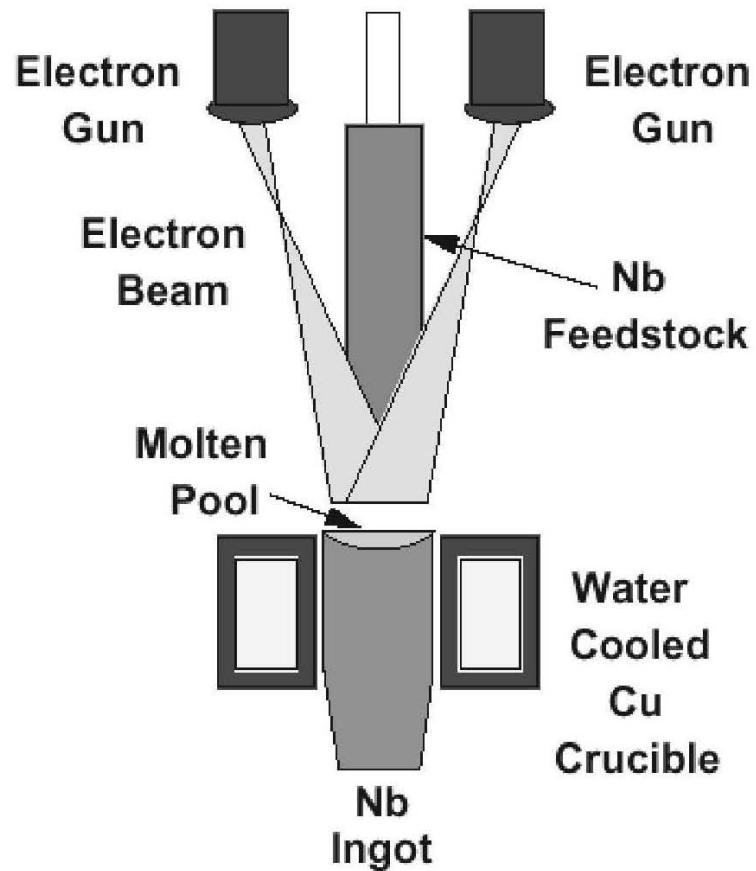
Tokyo Denkai



150 kg

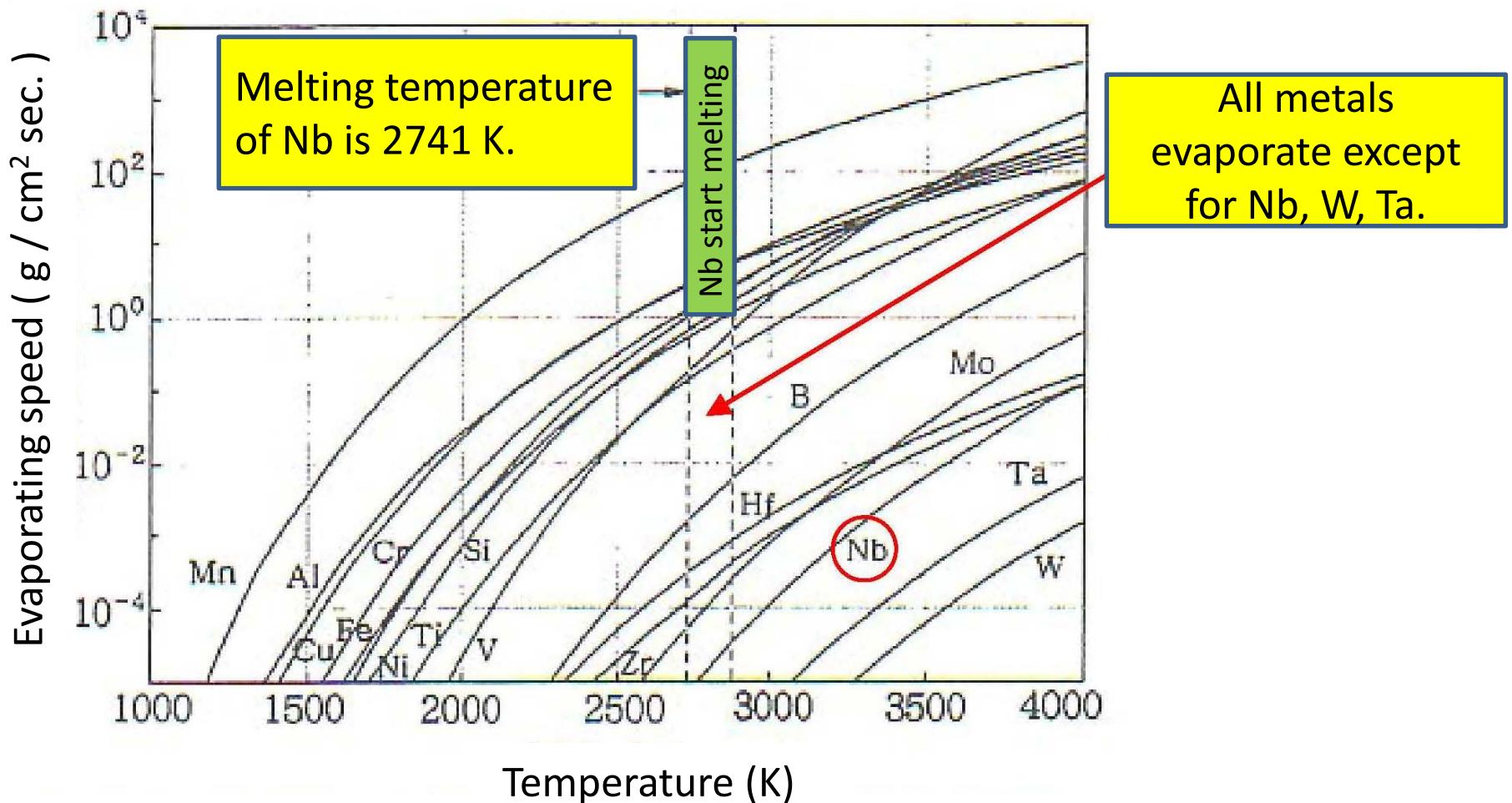


Electron Beam Melting





Evaporation Pressure of Various Metals



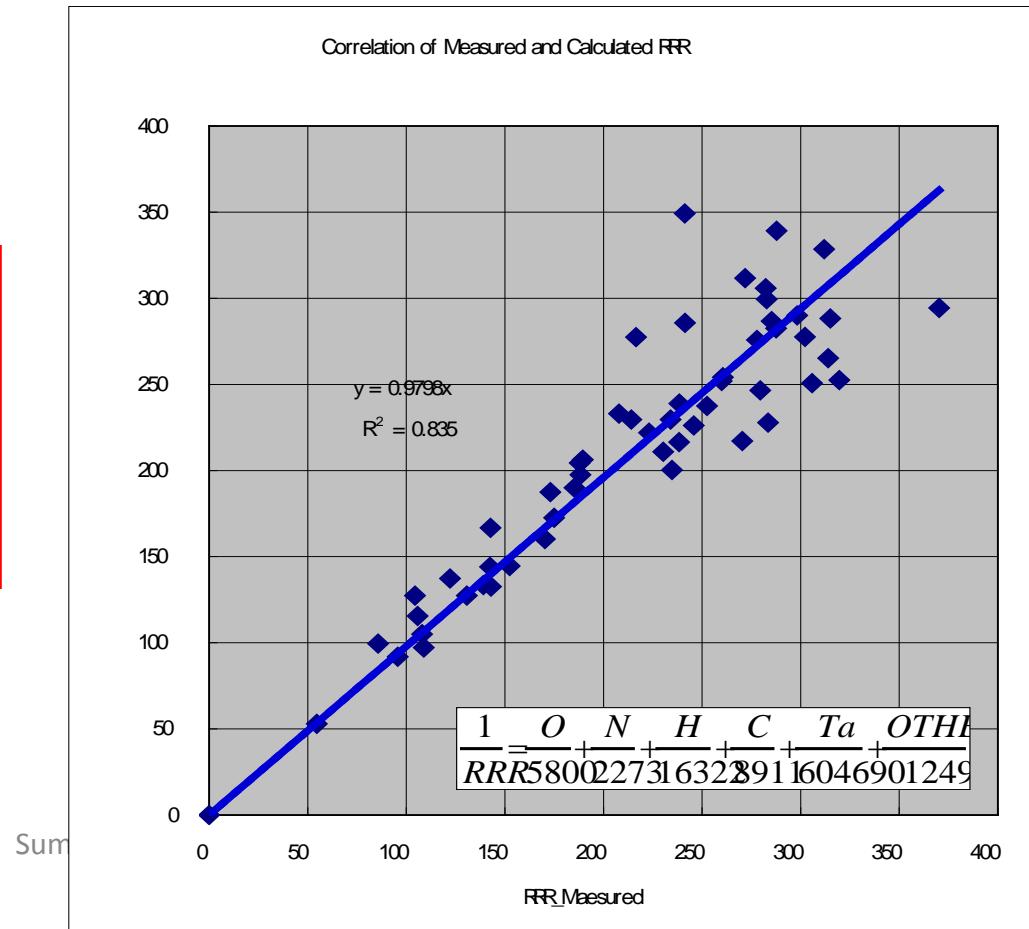
Relation between impurity in NB and RRR

Umezawa's calculation.



$$\frac{1}{RRR} = \frac{O}{5800} + \frac{N}{2273} + \frac{H}{16322} + \frac{C}{8911} + \frac{Ta}{604690} + \frac{1}{1249}$$

$$RRR \equiv \frac{R(300K)}{R(9.5K)}$$

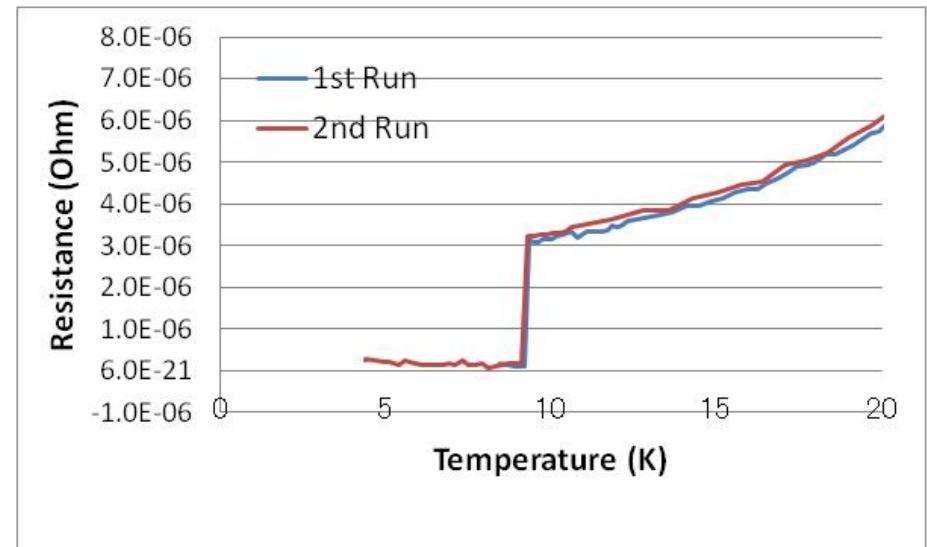
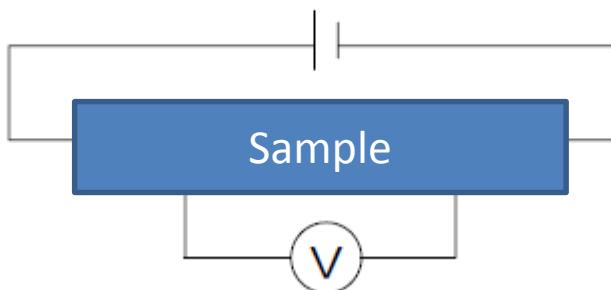




RRR Measurement

$$RRR \equiv \frac{R(300K)}{R(9.5K)}$$

4-terminal method



Rolling of Nb plates

Tokyo Denkai

Intermediate rolling



Clean room

Final rolling



It is very important to avoid any contamination when rolling Nb plates.

Vacuum Annealing Furnace



Tokyo Denki

1400°C Max,

$\sim 1 \times 10^{-6}$ Torr

Effective working zone

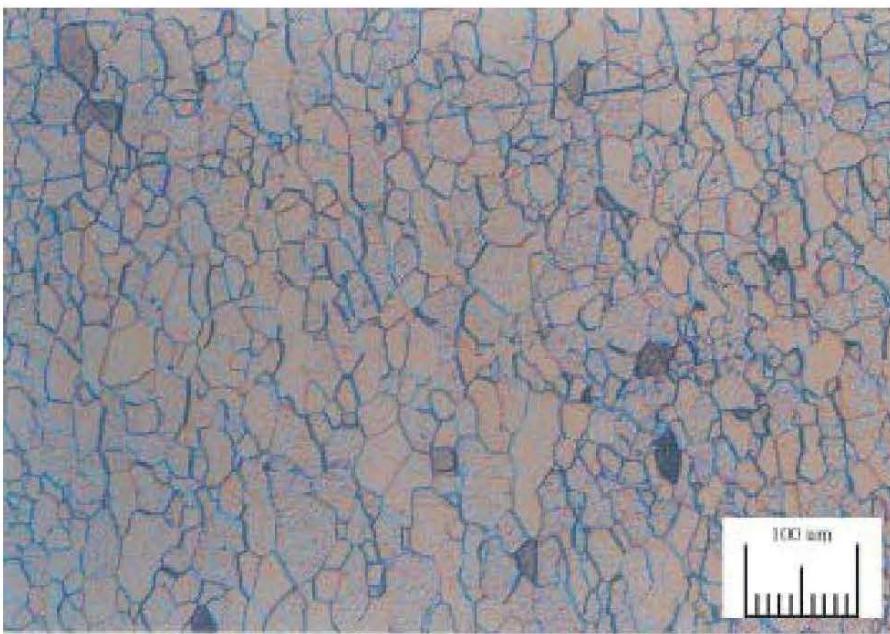
1000 x 1800L

Ta heater

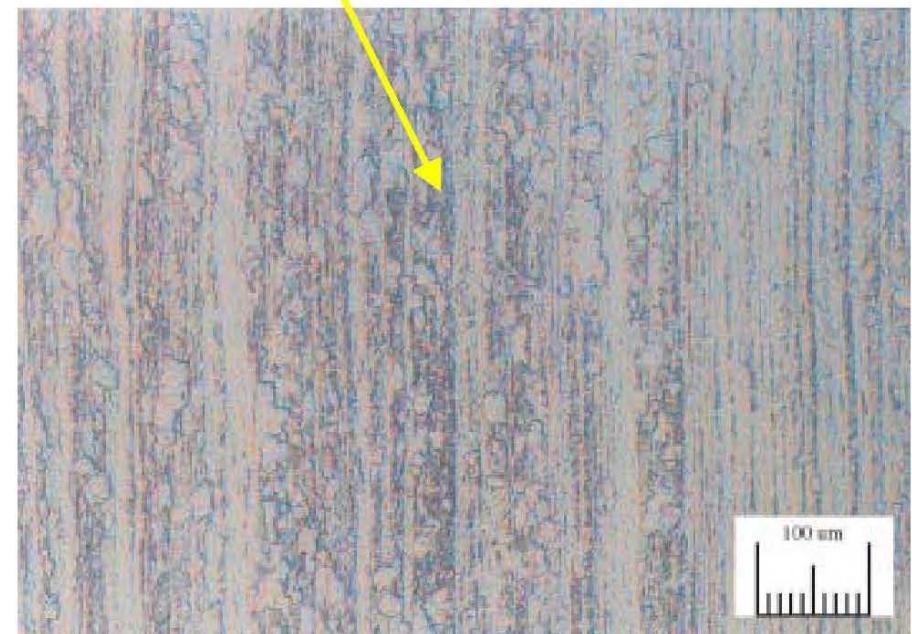


Nb metal structure

Layer structure caused by rolling



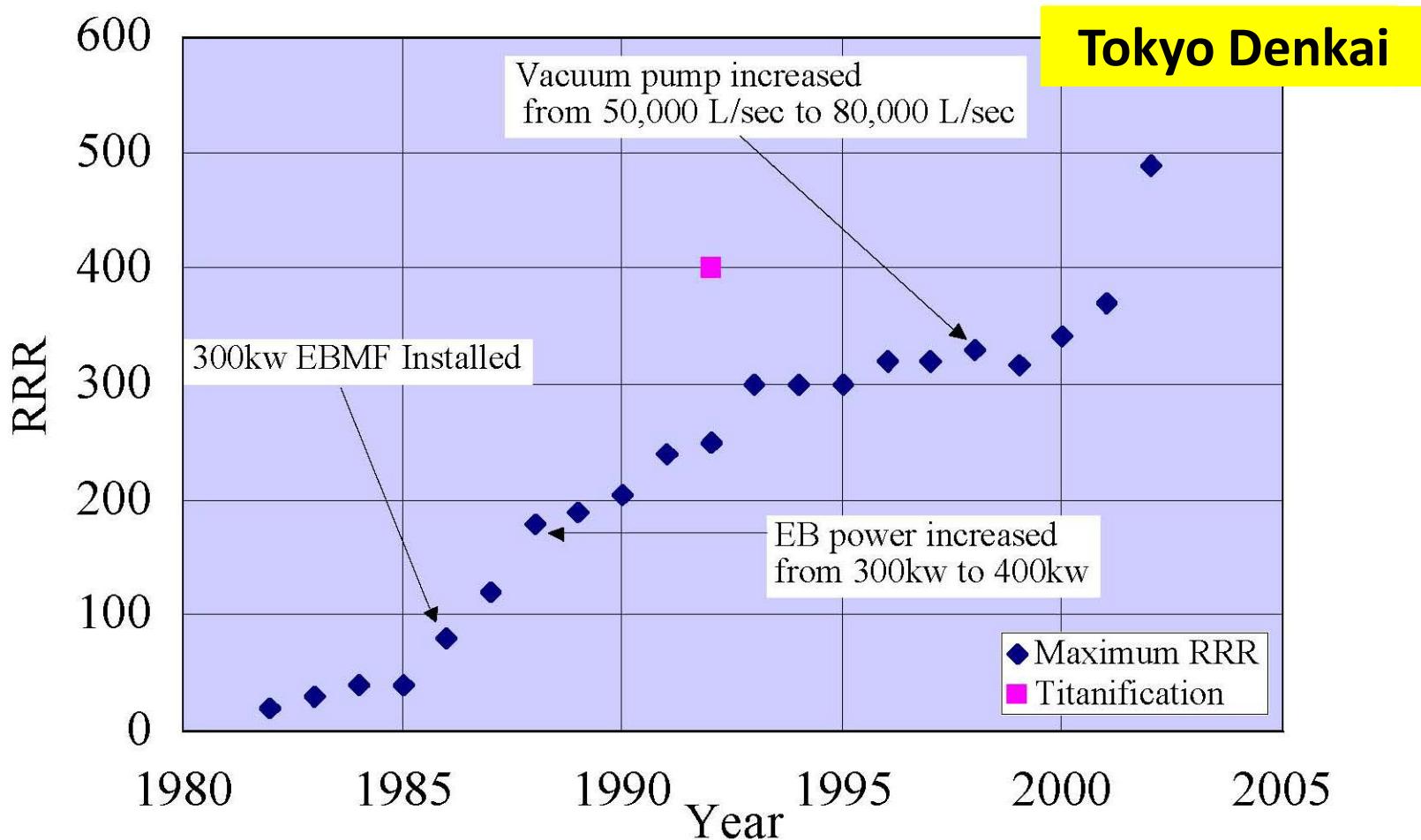
After annealing process



Before annealing process

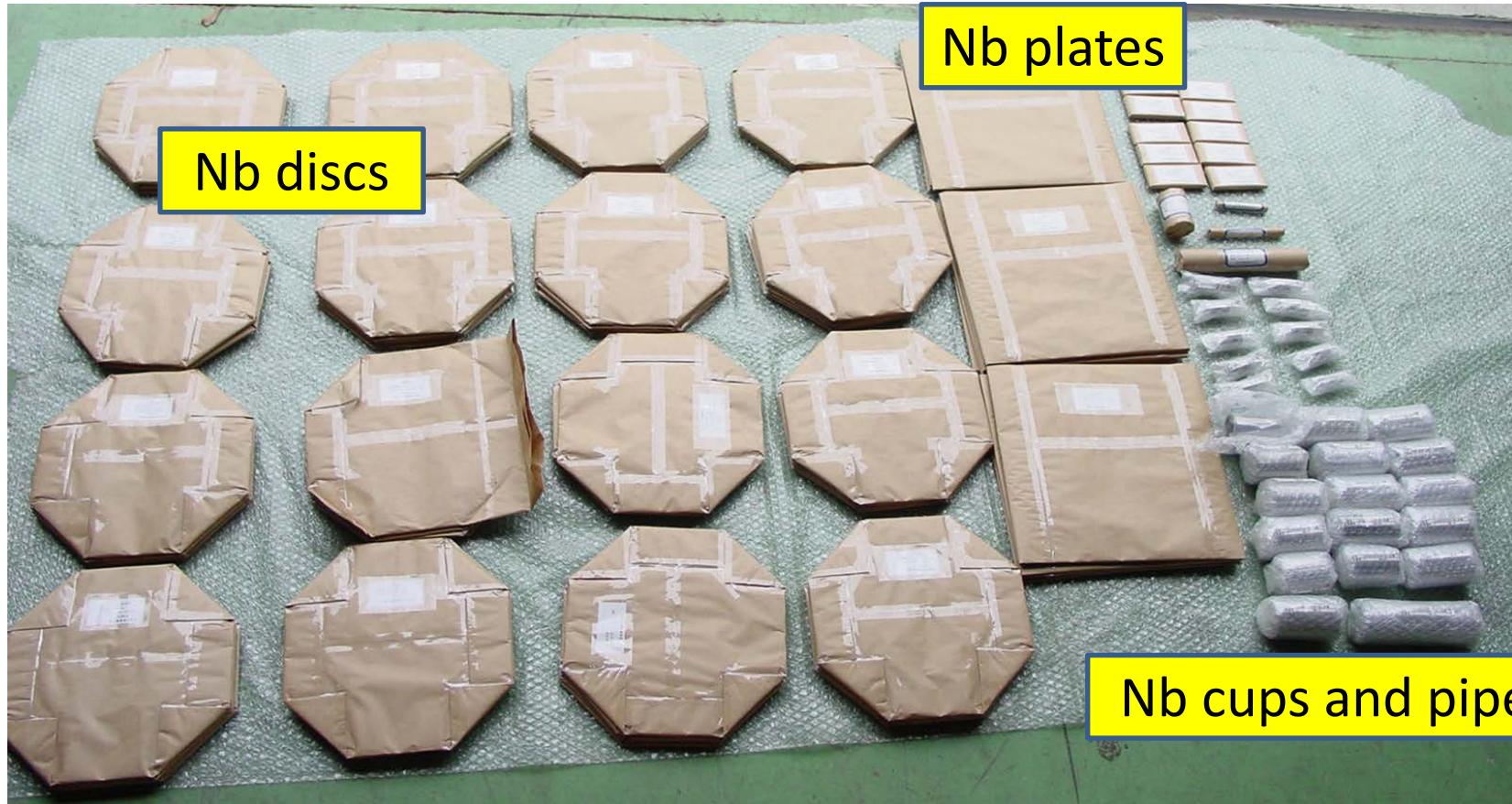


History of improvement with RRR





Nb materials for 9-cell cavity



Material for four 9-cell cavities



Nb materials for 9-cell cavity

Nb plate for beam-pipe

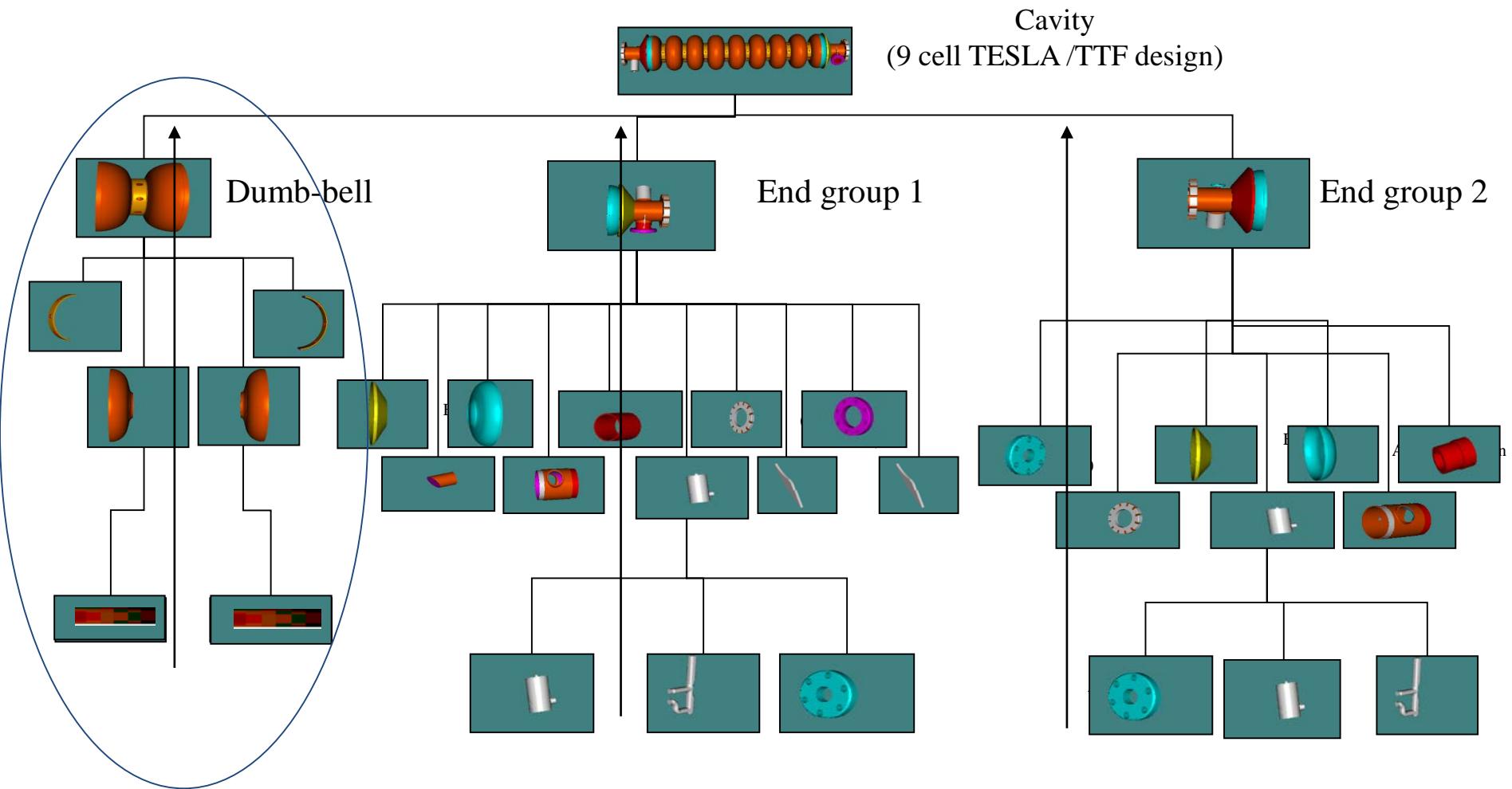
HOM antenna and so on



Nb disc for half-cell cup

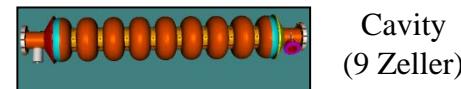
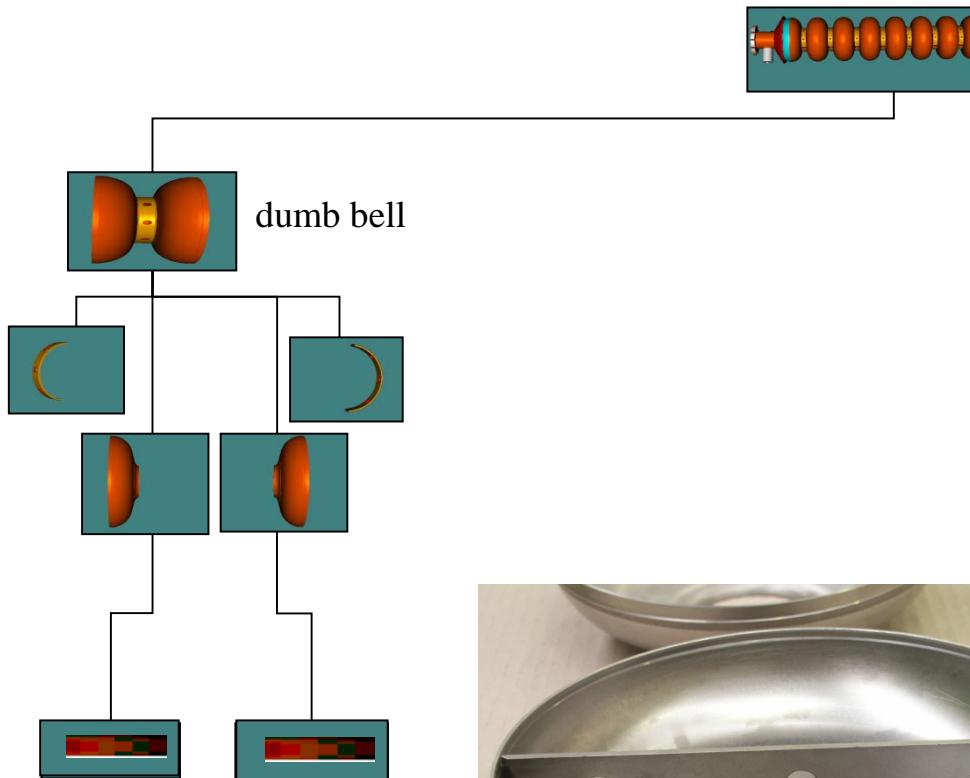


Overview over Fabrication of 9-cell cavity





Overview over Fabrication of 9-cell cavity



Cavity
(9 Zeller)



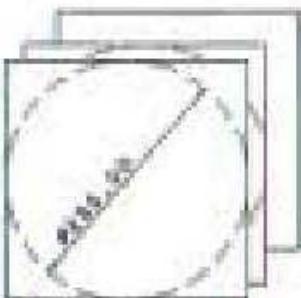
Fabrication Processes of half-cell



MATERIALS (INOBUMI)



IN FLANGED
PLATE TYPE NO. 100
100-00

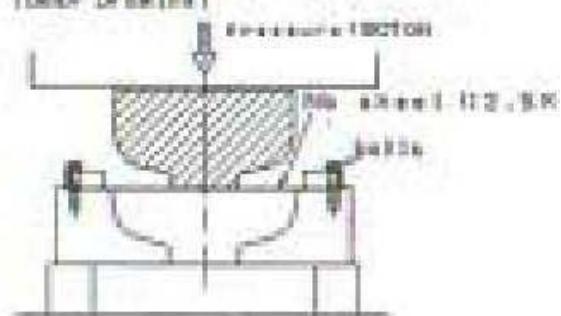


IN SHEETS
10 PLATES NO. 100
100-100

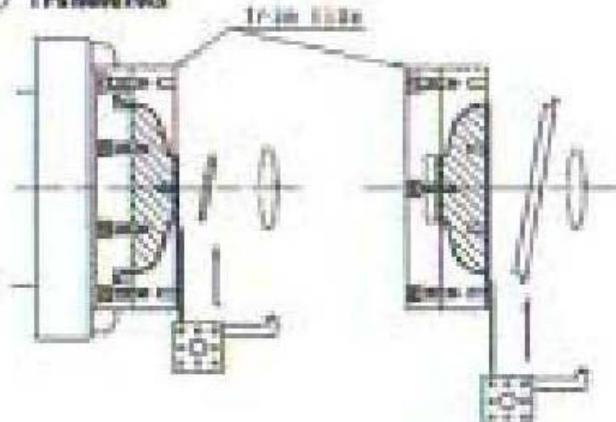
supplied by Tokyu Denki, Ltd.

HALF-CELL FABRICATION

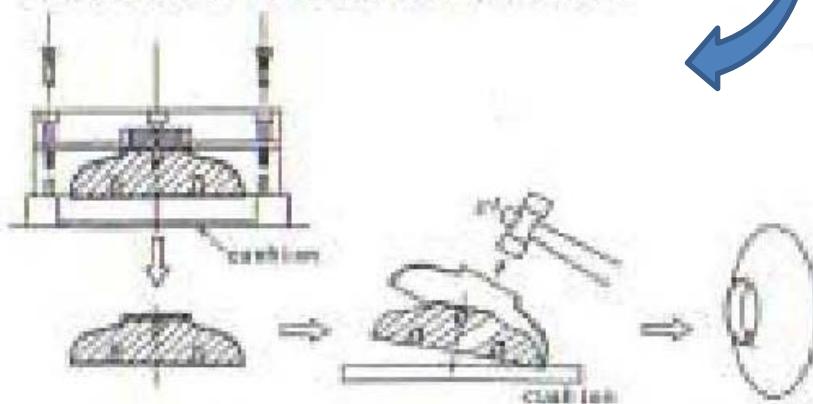
① FORMING OF HALF-CELL (Deep Drawing)



② TRIMMING



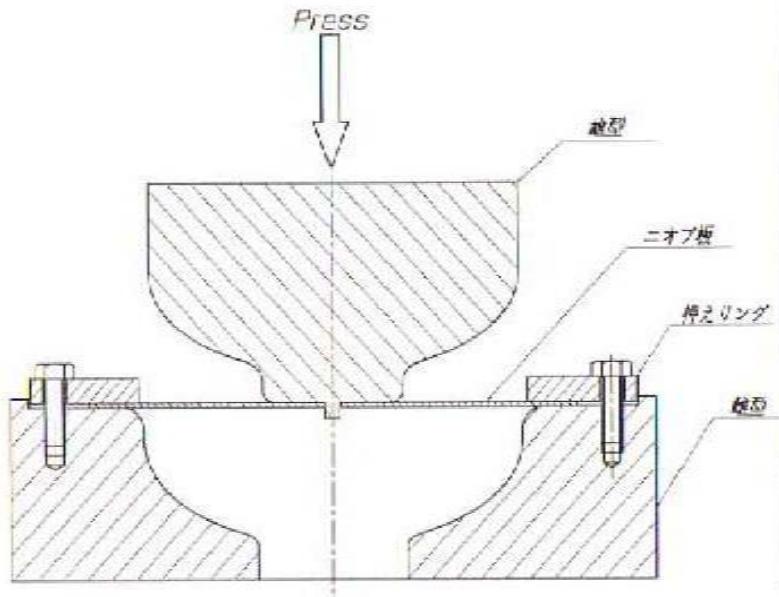
③ DISASSEMBLE FROM THE TRIM JIGS





Deep-drawing of half-cell cups

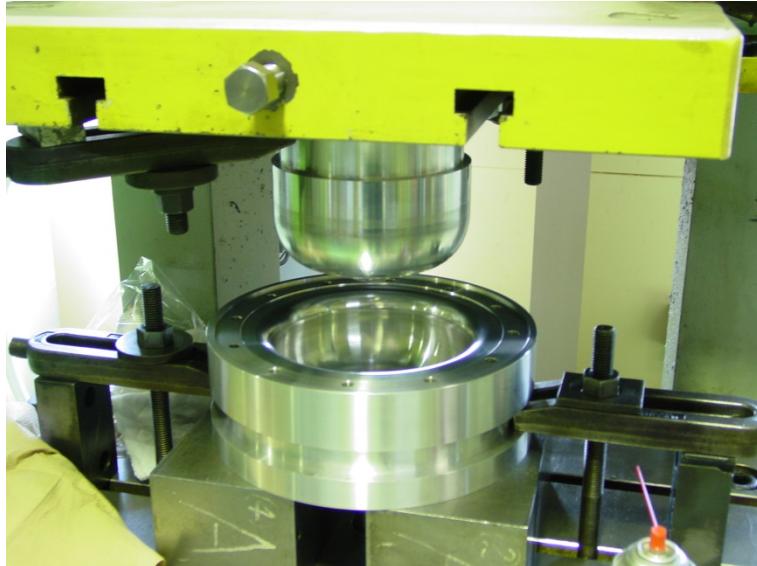
Deep-drawing of Nb half-cell at 2.5 ton
by a press-machine (80 ton).



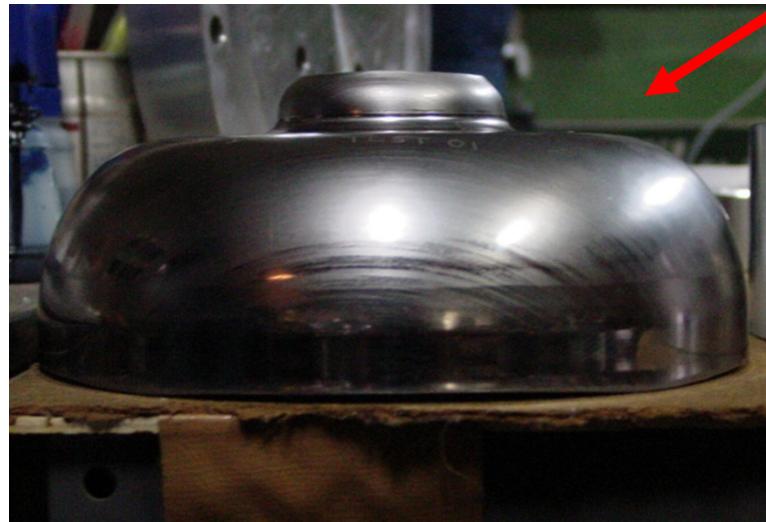
Fabrication of LL Cavity at KEK



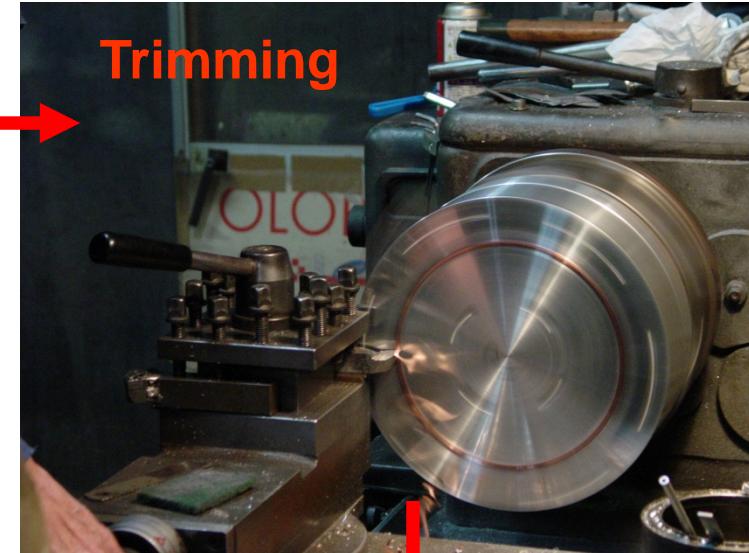
Pressing Nb plate



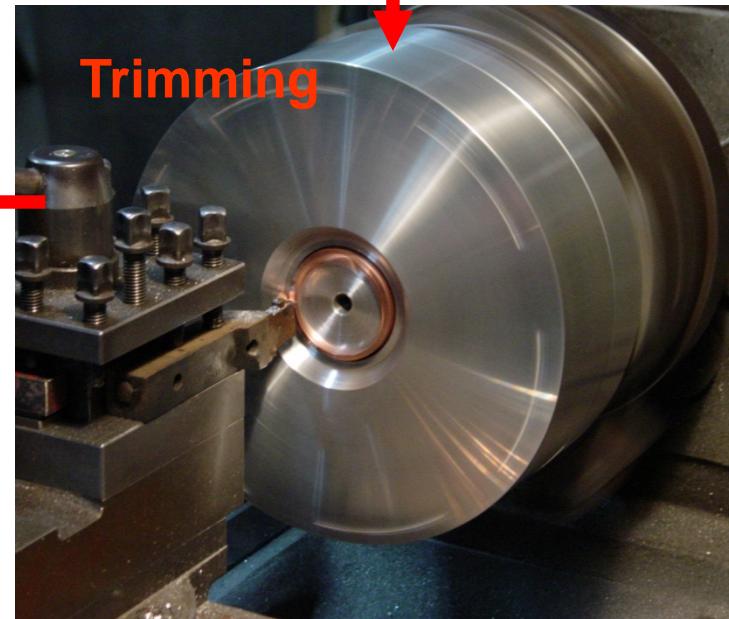
56 half-cells were pressed in a few hours



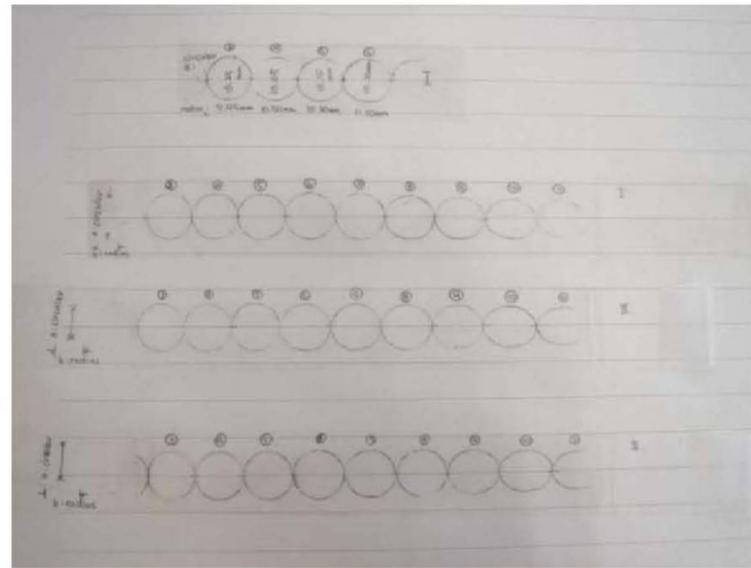
Fabrication of LL Cavity at KEK



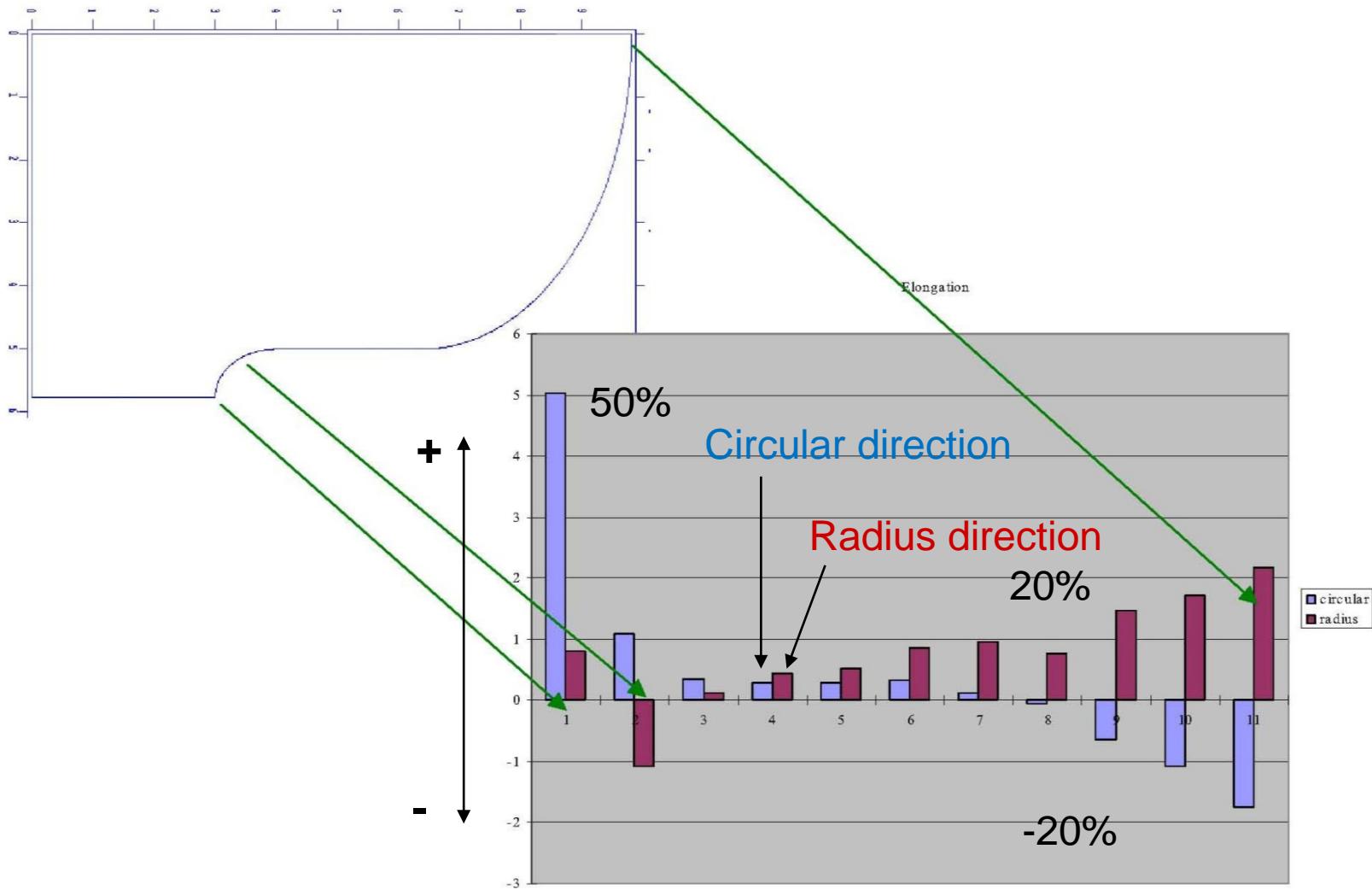
After trimming



Elongation Measurement

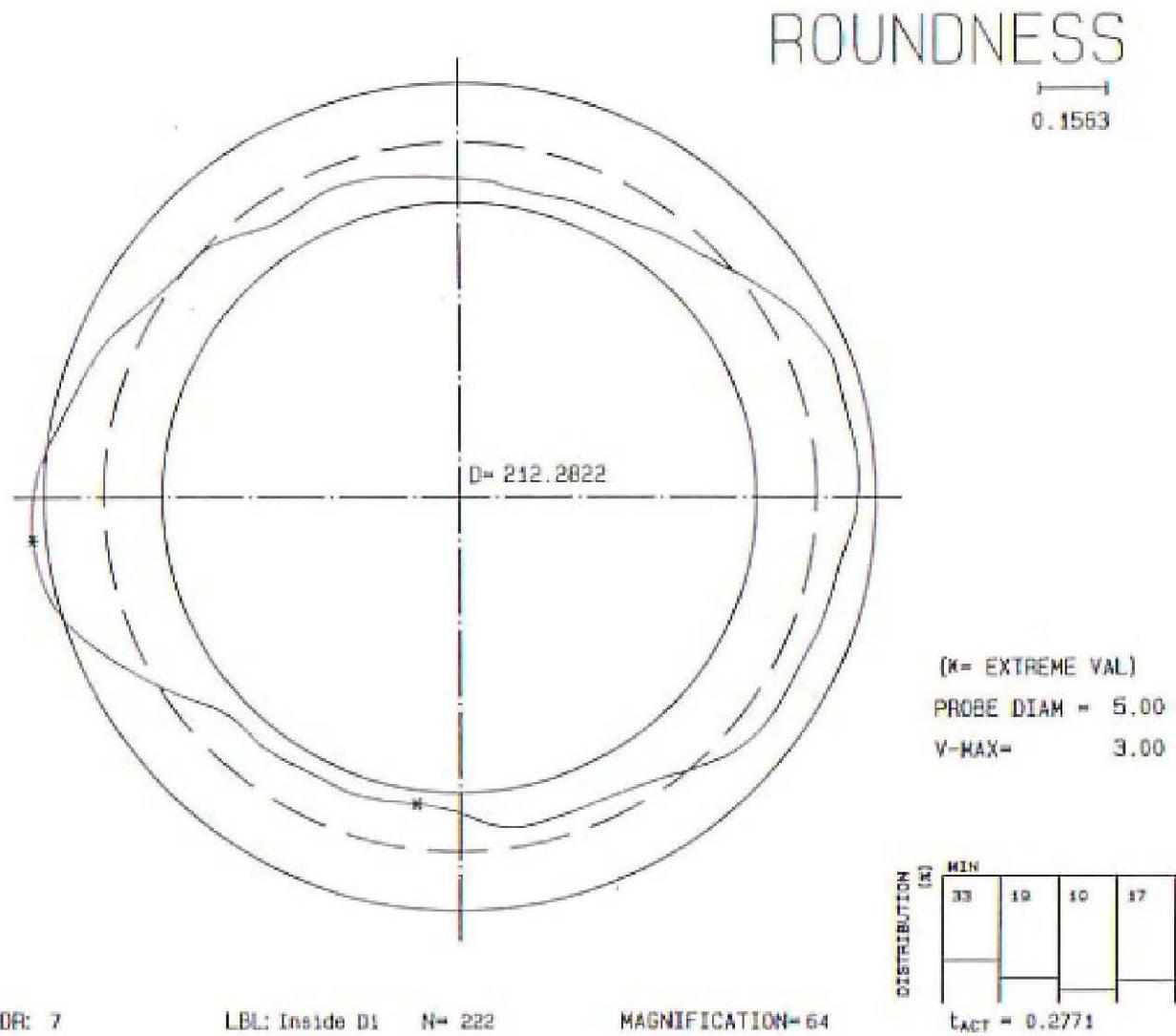


Elongation



Roundness of half-cell cup

Stn. Dev. ~ 80um





Production procedure of 9-cell cavity for ILC

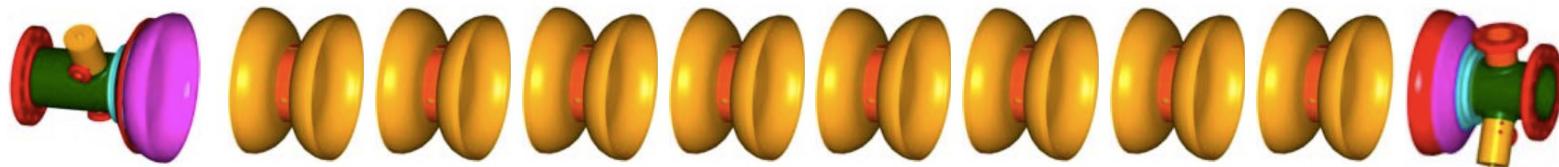
Dumbbell = EBW of two cups:



Dumbbell

EBW assembly of all parts:

8 dumbbells are needed for one cavity



Welding of He tank:



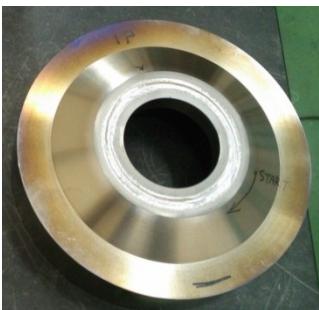


Fabrication of 9-cell Cavity

HOM coupler (Nb)



End-Plate (Ti) + Nb ring



End-cells (Nb)



End-Plate (Ti) + Nb ring



Flanges (Nb-Ti alloy)



Beam-pipe (Nb)



Beam-pipe (Nb)

Input-port pipe (Nb)



Center cells (Nb)



Dumb-bells (Nb)



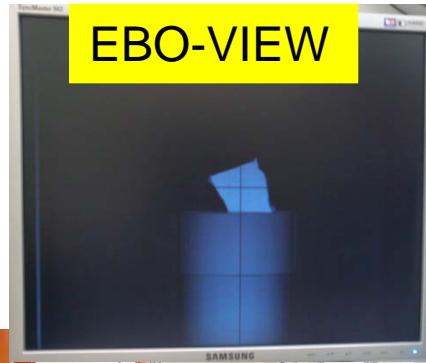
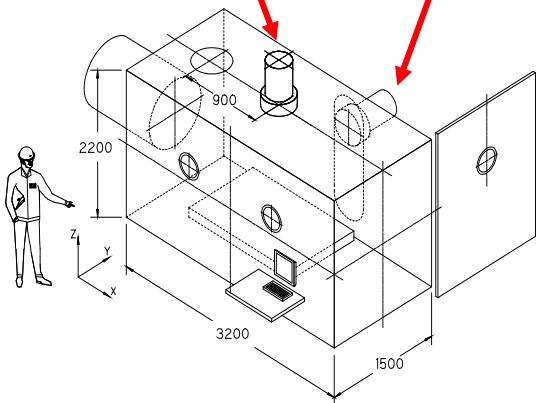
Electron Beam Welding (EBW) machine / KEK



Gun in
vertical
position



Gun in horizontal
position



EBO-VIEW



Pressure : below 1×10^{-2} Pa within 20 min.
Inside material:SUS316L, Volume:10.56 m³

Steigerwald Strahl Technik
EBW machine : 150 kV, 15kW

Electron Beam Welding (EBW) Machine



Assembly of all Nb parts are done by EBW machine. This is because contamination of O₂, N₂, CO₂, etc. degrade the SC performance of cavity.



The chamber inside is pumped down to exclude the air before the EBW assembly.



Electron Beam Welding (EBW) Machine

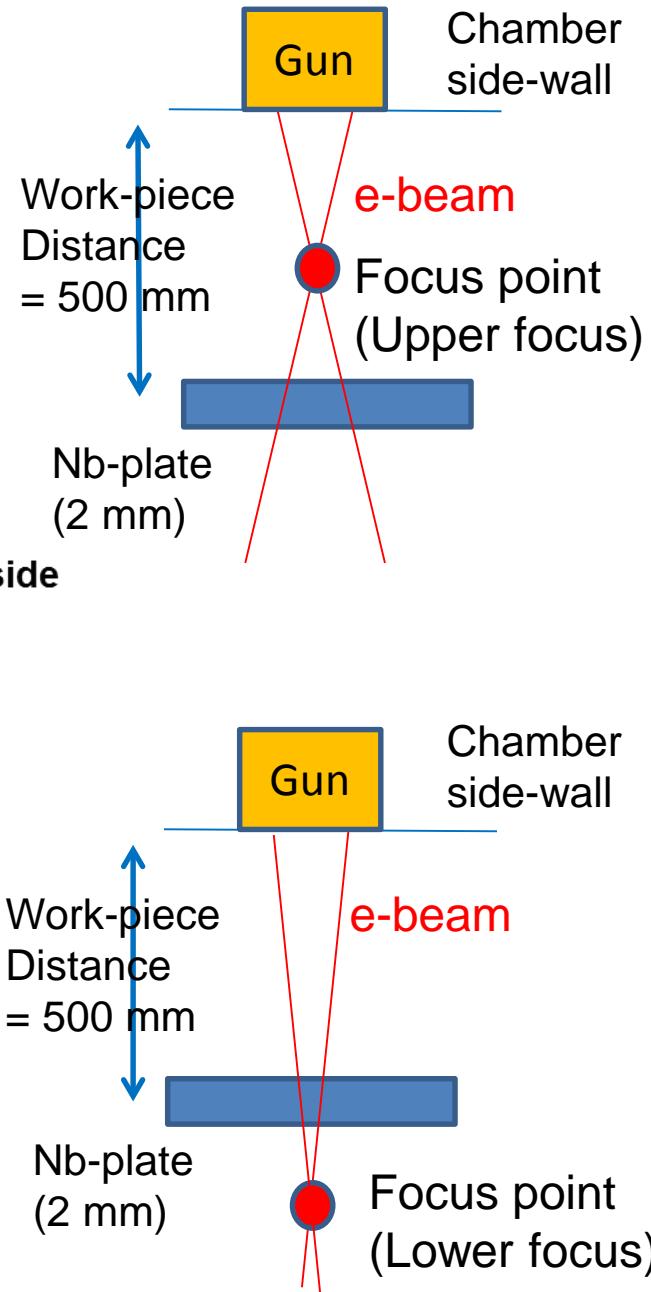
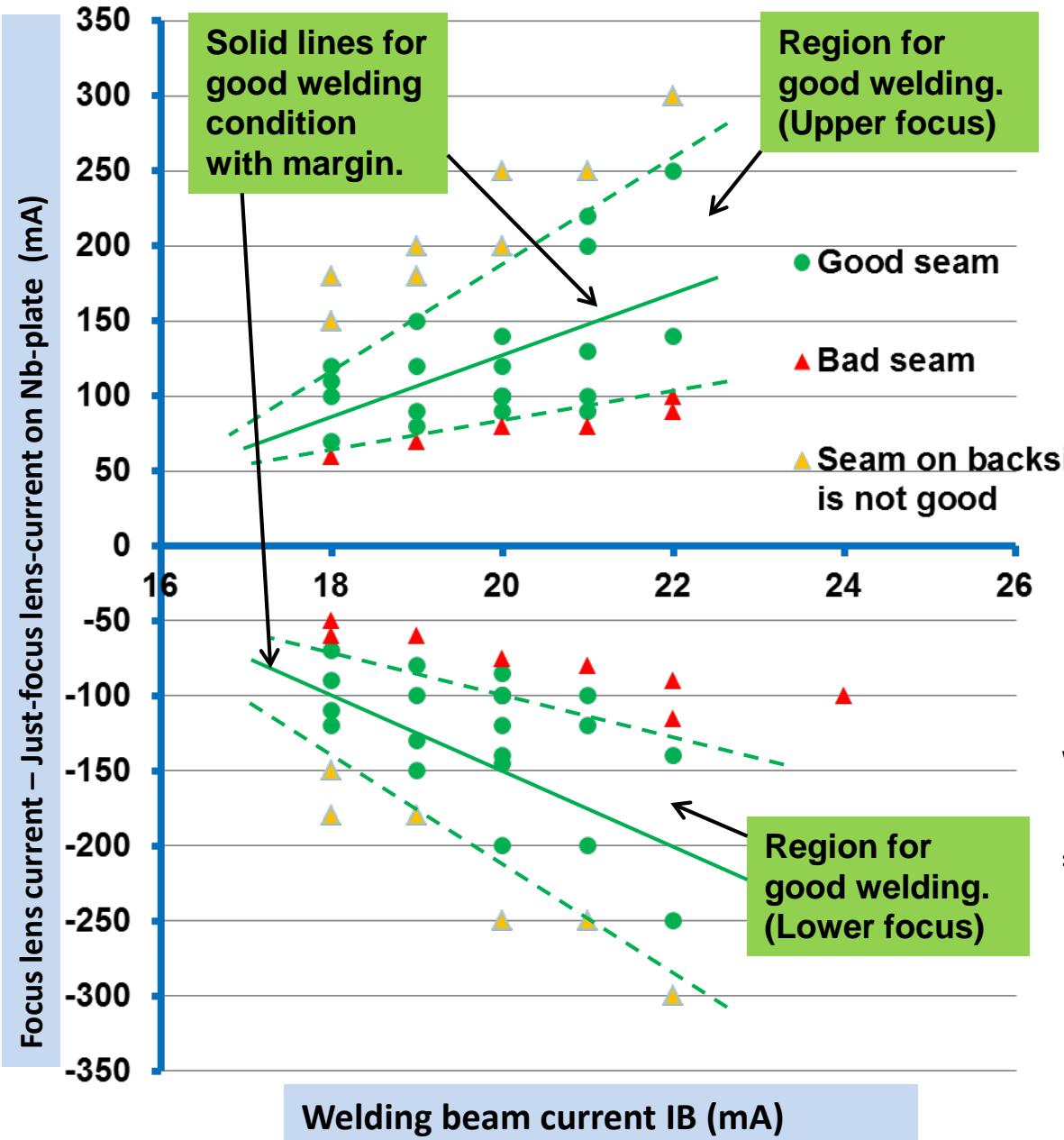


Electron Gun

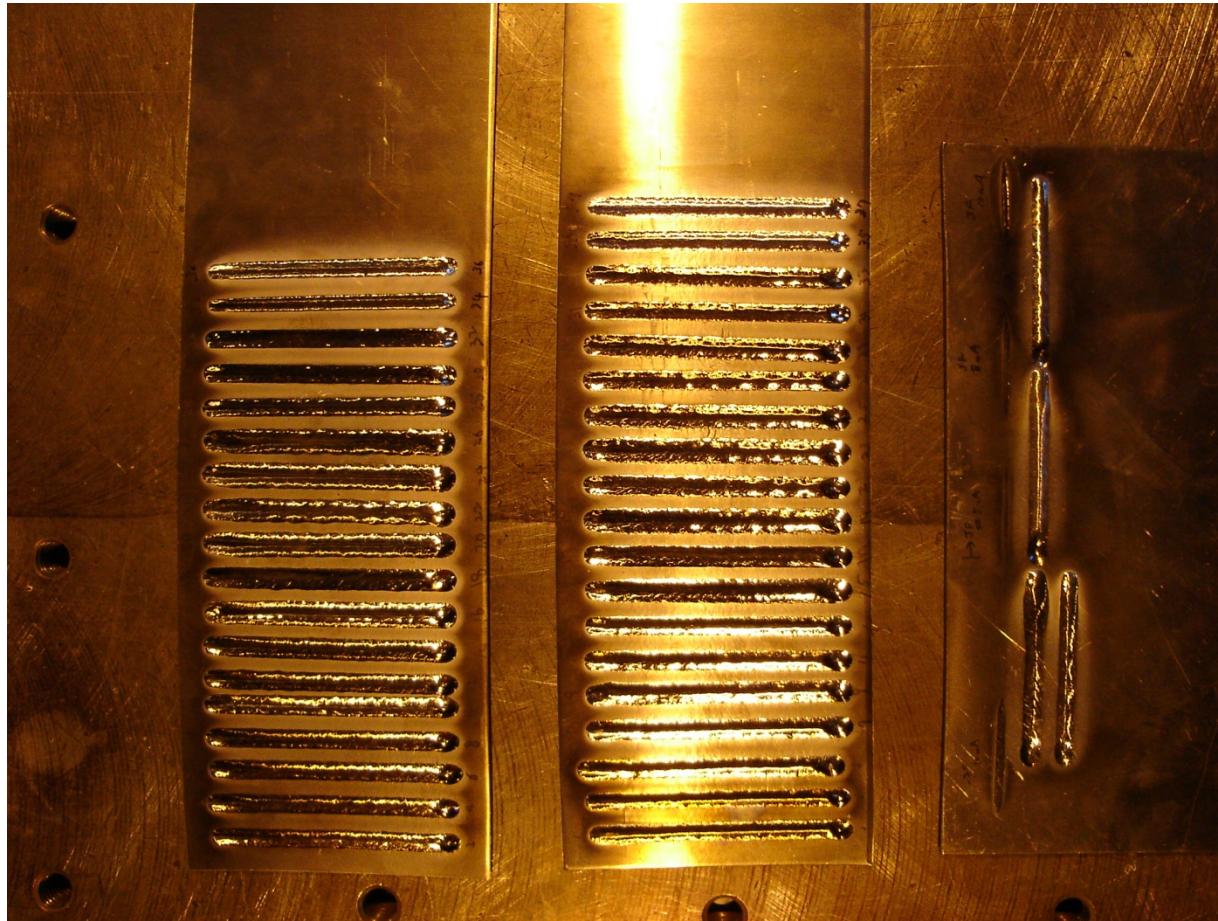


Operator

Voltage = 120 kV, Moving speed = 5 mm/sec., Work-piece distance (W.D.) = 500 mm, Nb-plate thickness = 2.0 mm



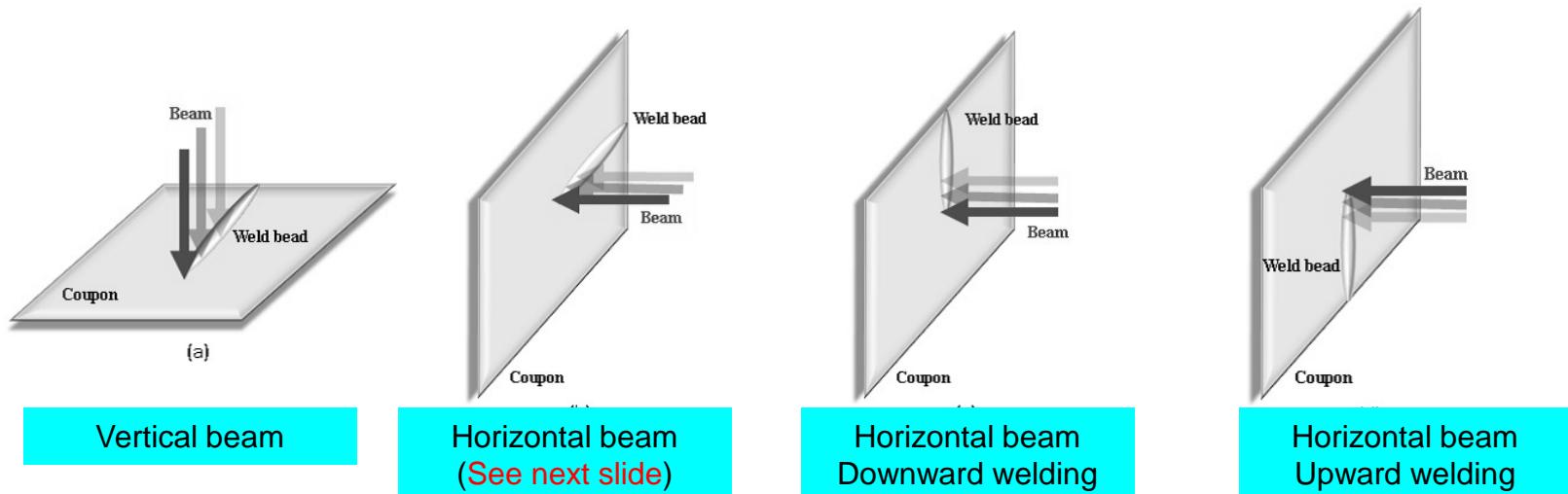
Electron Beam Welding (EBW) parameter search



**Beam-parameter search with Nb test-pieces.
Oscillation of beam was applied.**

Studies on EBW parameter

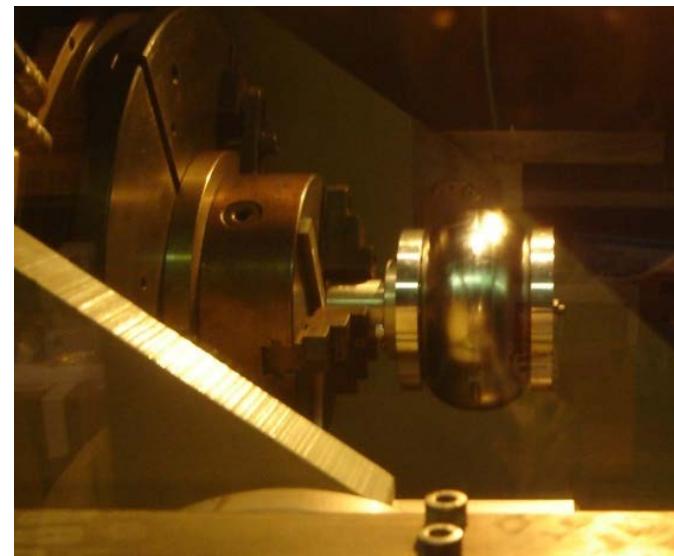
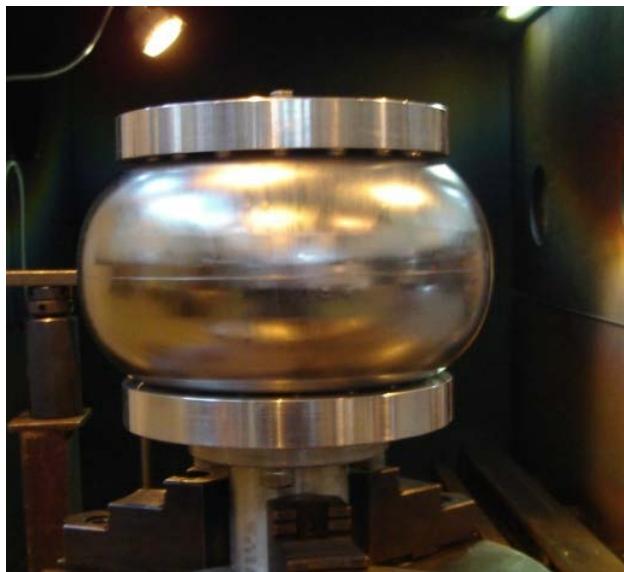
Search for good EBW parameter was done by changing the welding beam-voltage, beam-current, focus-current, working-piece distance from gun, working-piece moving speed, Nb-plate thickness, and **the gun and working-piece configuration**.



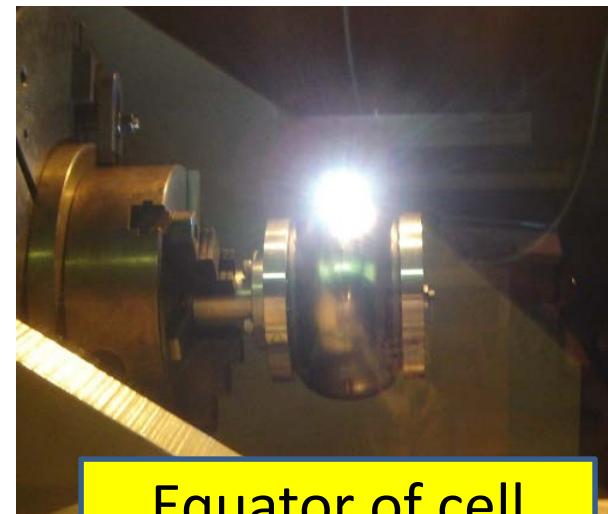
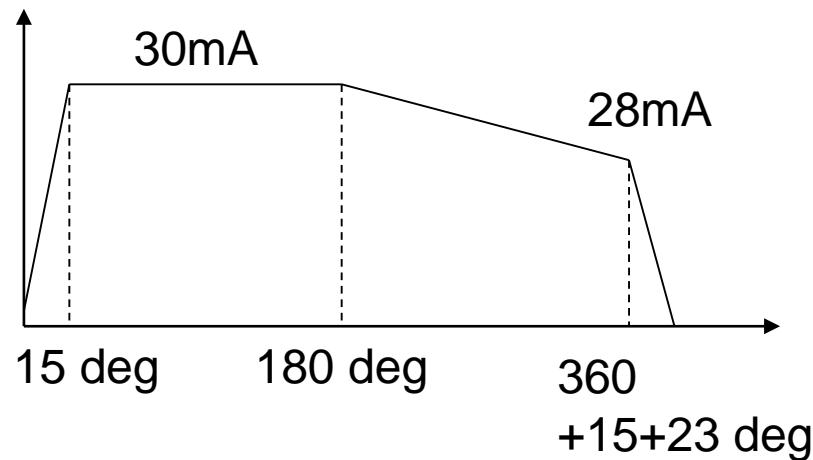
In particular, the gun and working-piece configuration affects the results of welding seam.

For more details of studies on EBW parameters , see following presentation.
ID: 3364 - WEPWO015 / 2013 15th May (Wed.), IPAC2013 by T. Kubo (KEK):
Title: Electron Beam Welding Parameters for High Gradient Superconducting Cavity

Electron Beam Welding (EBW) parameter search

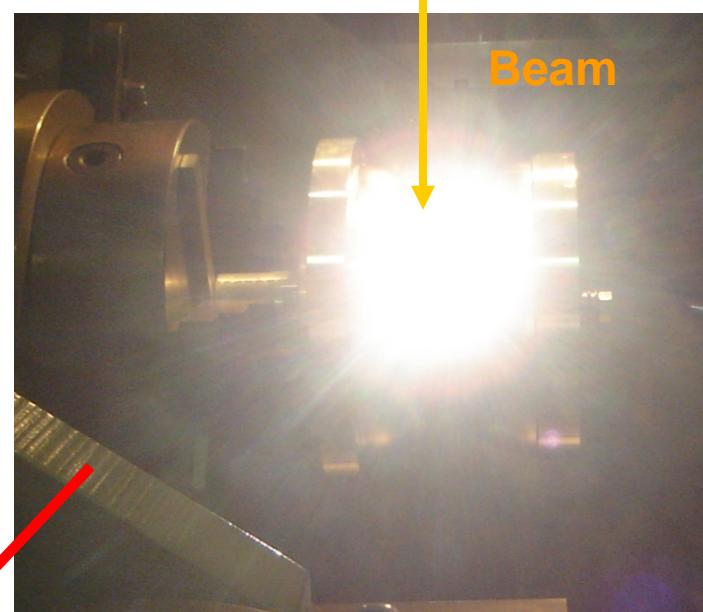
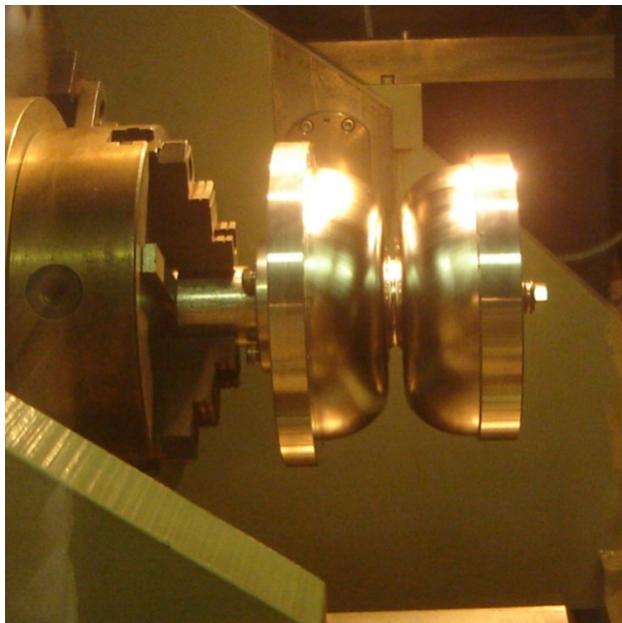


150 kV, 30 mA, 10 mm/s



Equator of cell

EBW of Dumbbell

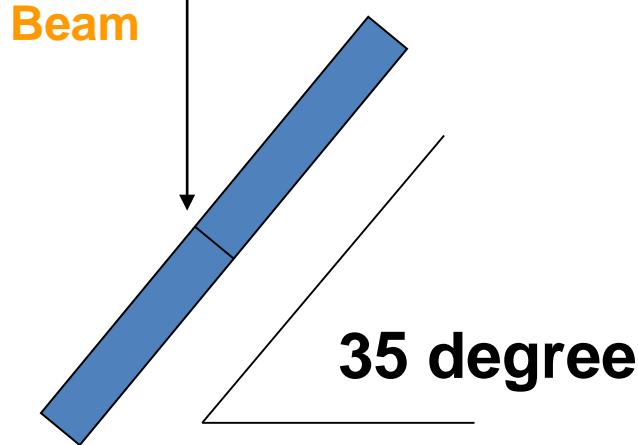


Outside, EBW depth = 70%
150kV, 18 mA, 10 mm/s



High electric field at iris.
The inner surface of iris should be smooth to avoid field-emission.

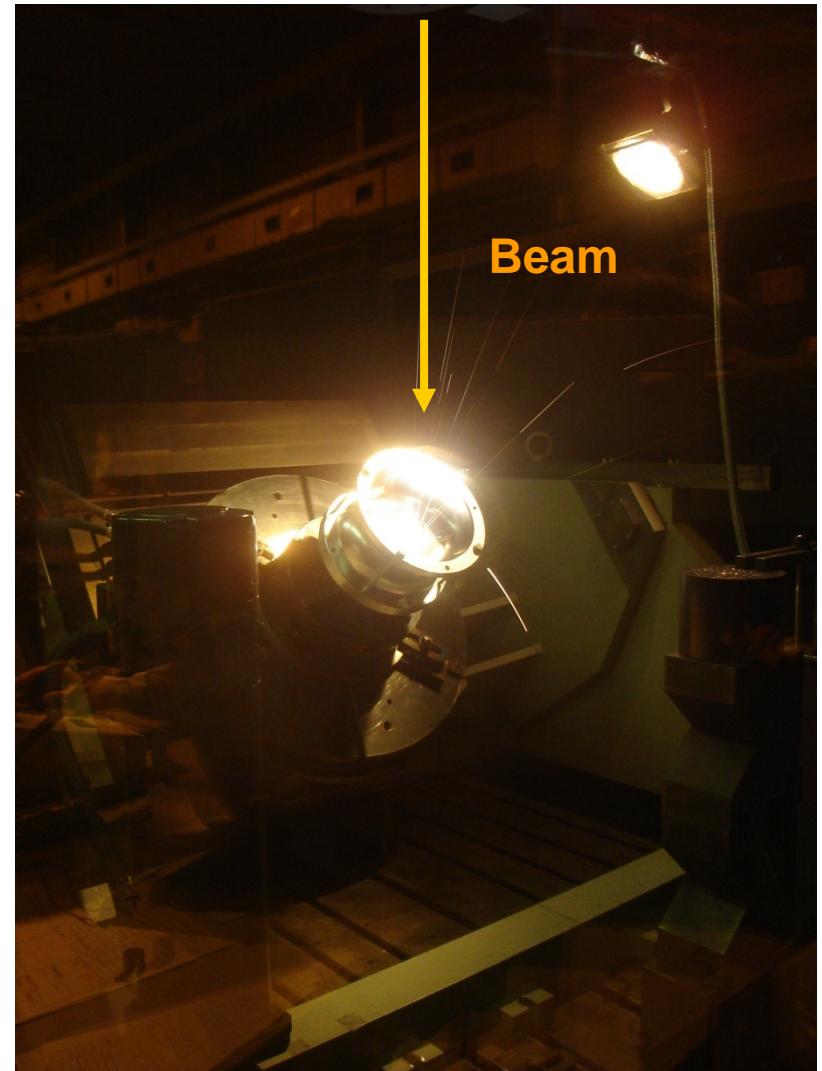
Electron Beam Welding (EBW)



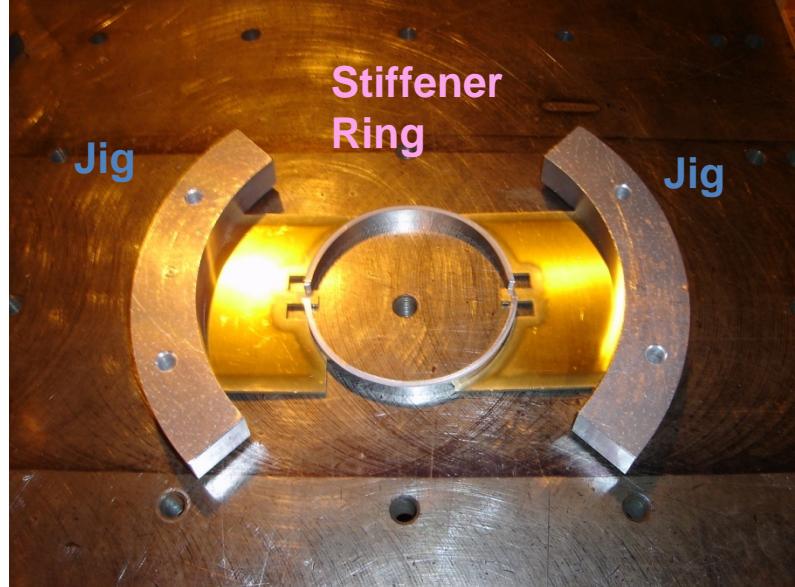
**Inside, EBW depth = 40%
(10% overlap)**

150kV, 10mA, 10 mm/s

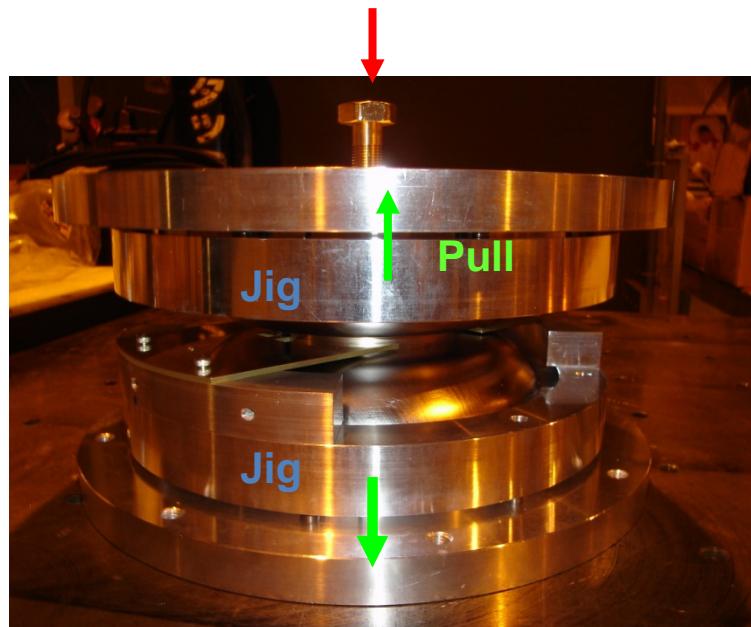
Cooling 5 min. => 45 C



Stiffener-ring



Dumbbell with
stiffener-ring
after EBW.

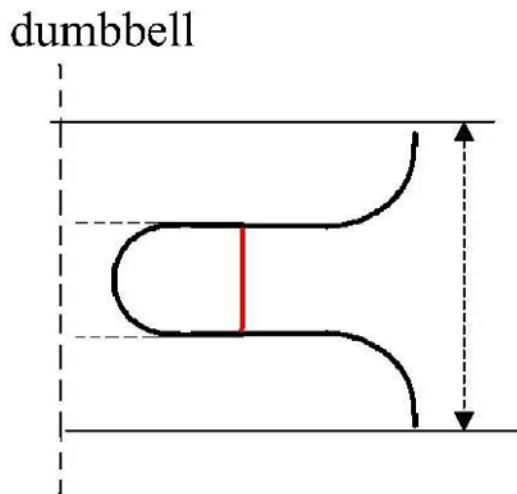
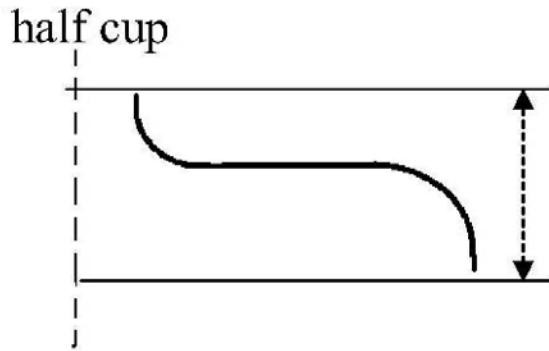


3-Dimensional Measurement

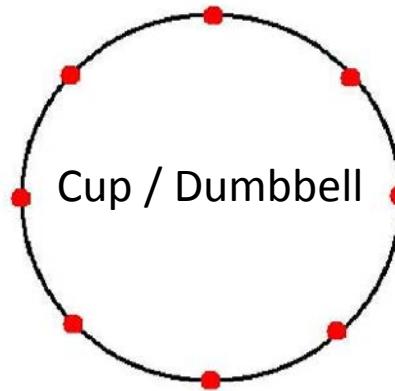


3-Dimensional Measurements of cup and dumbbell

Height measurement

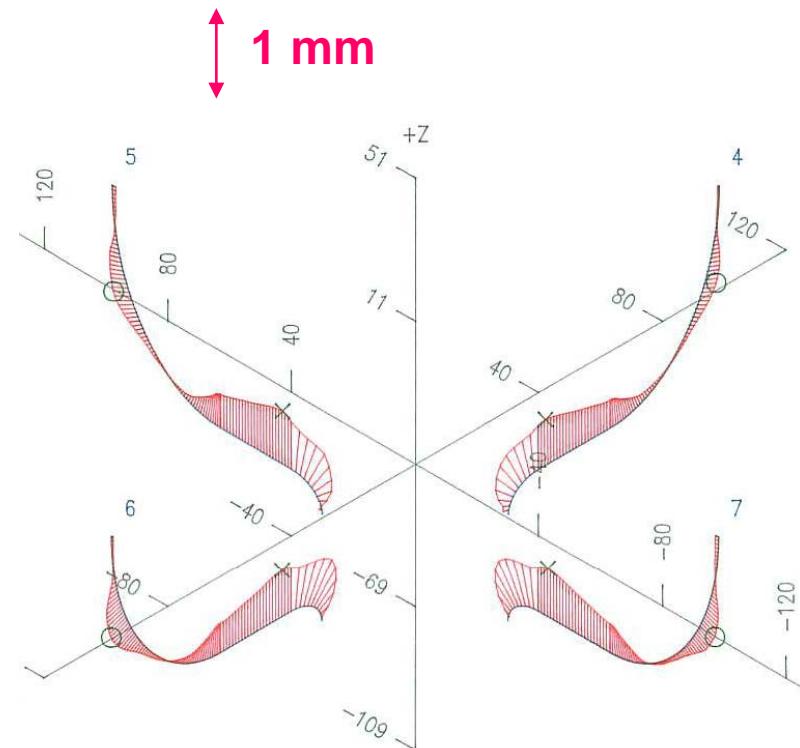
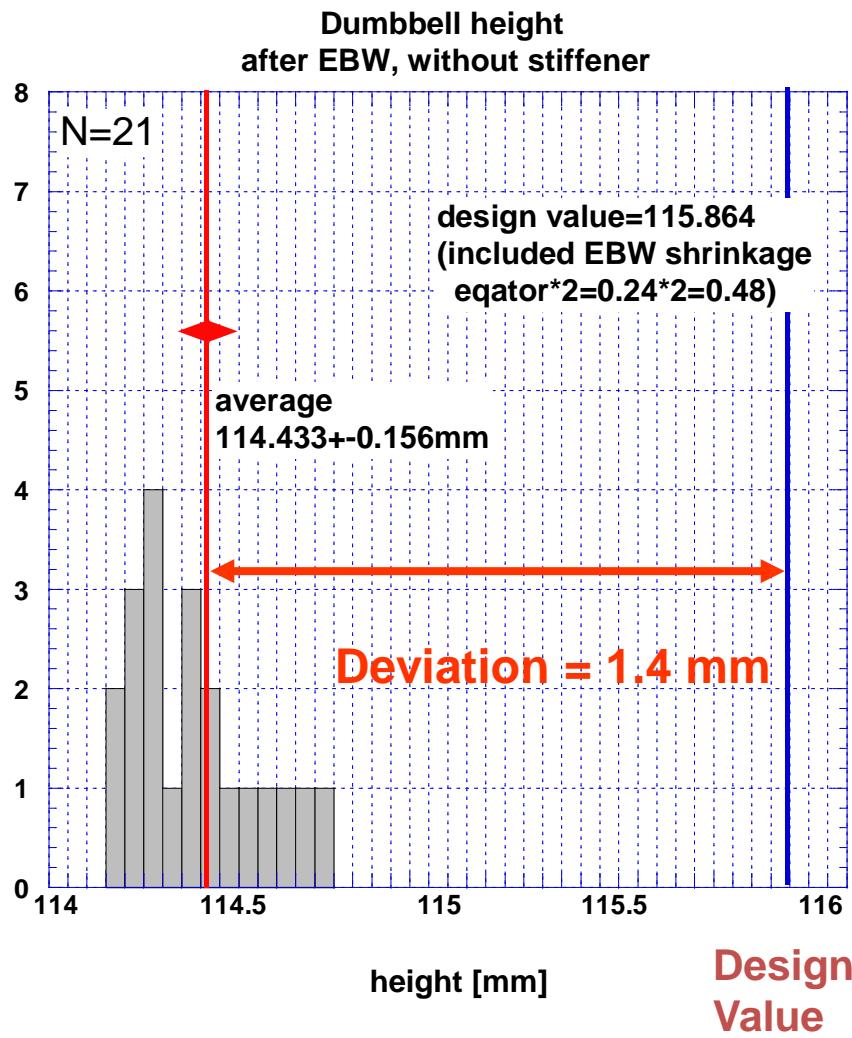


measured by 8 points



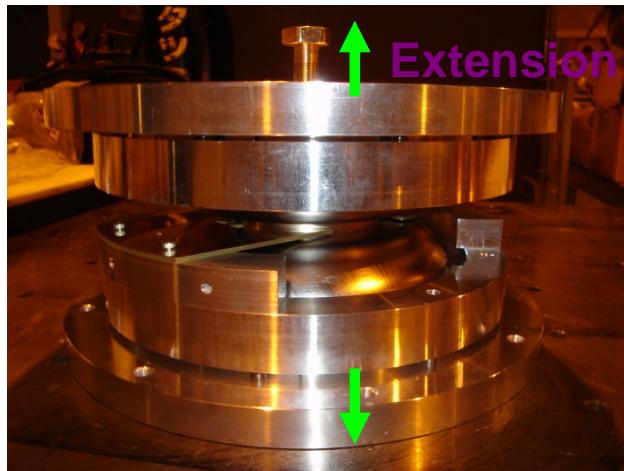
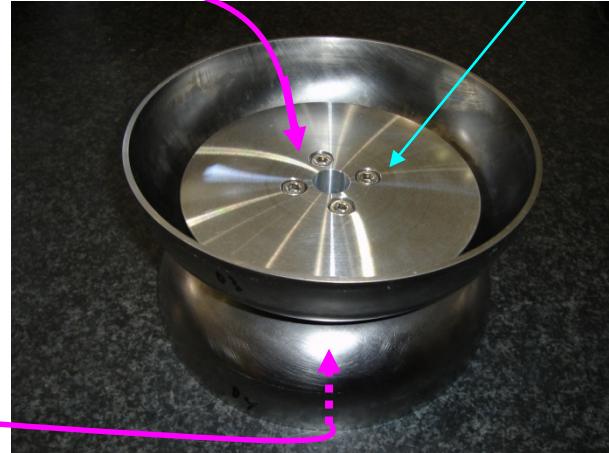
measured by KEK Mechanical Engineering Center

Dumbbell-height measurement and tuning

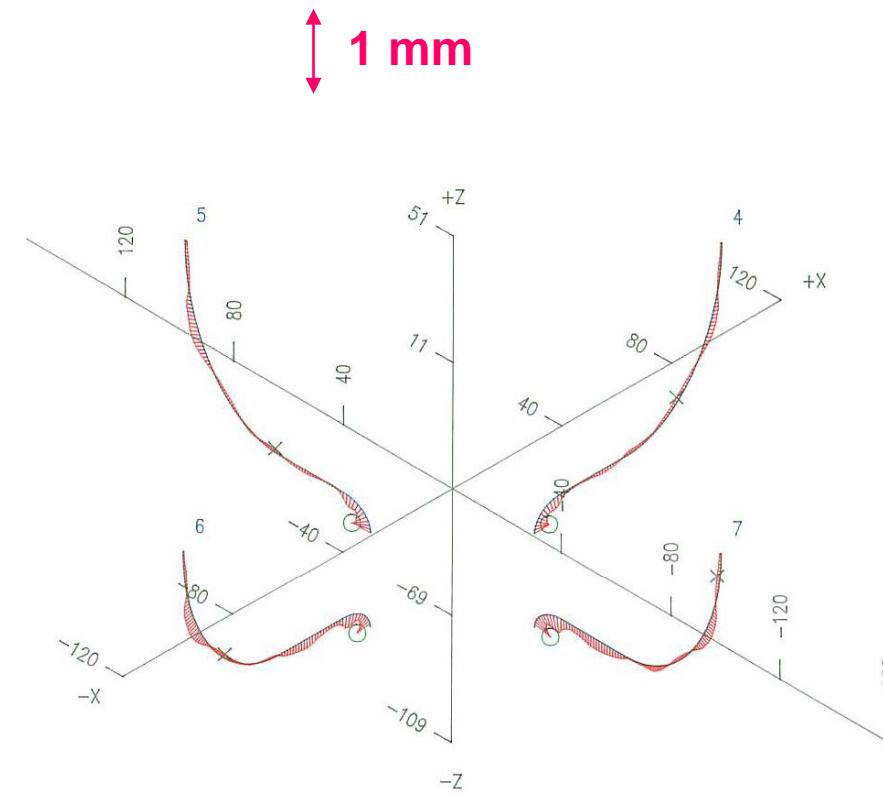
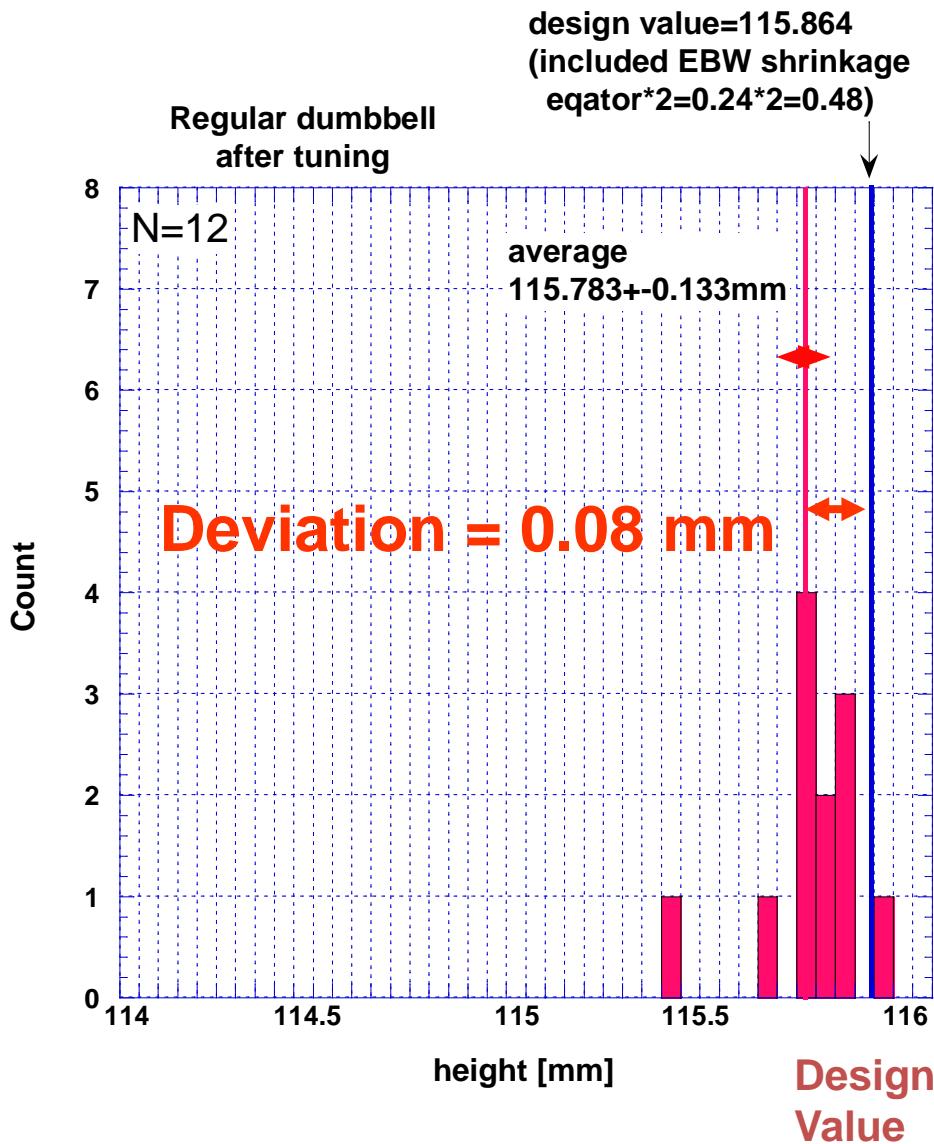


3-D measurement of
dumbbell before tuning

Tried to extend each dumbbells by ~1 mm.



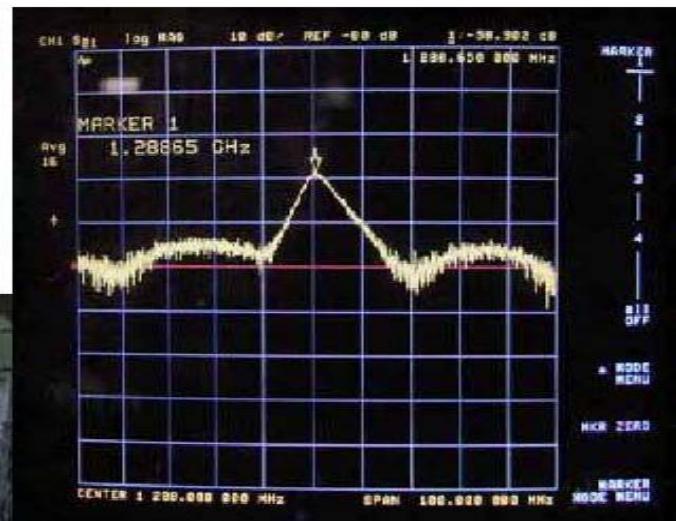
Dumbbell-height measurement and tuning



3-D measurement of
dumbbell after tuning

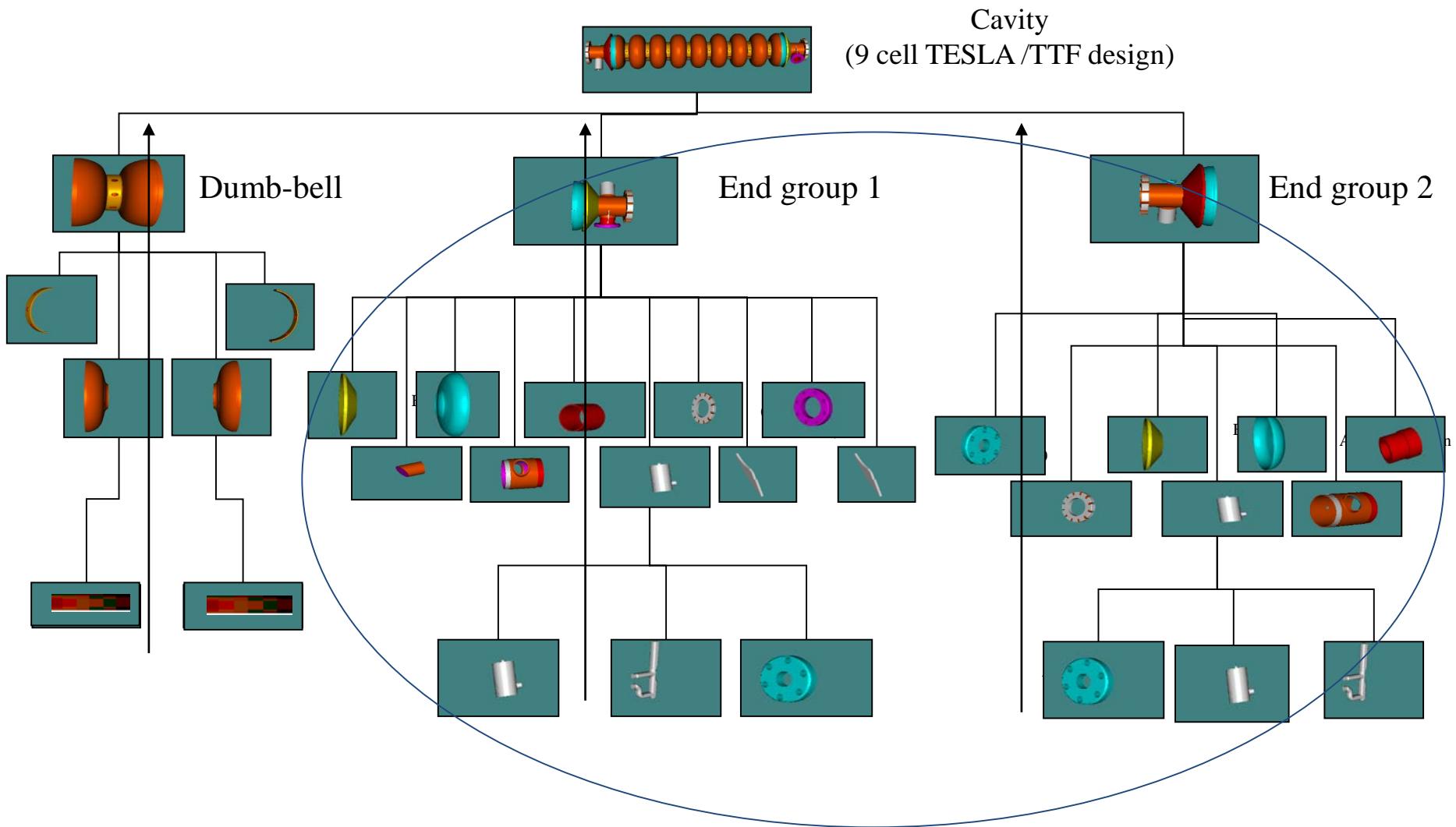
Frequency measurement of cup / dumbbell

Frequency measurement





Overview over Fabrication of 9-cell cavity

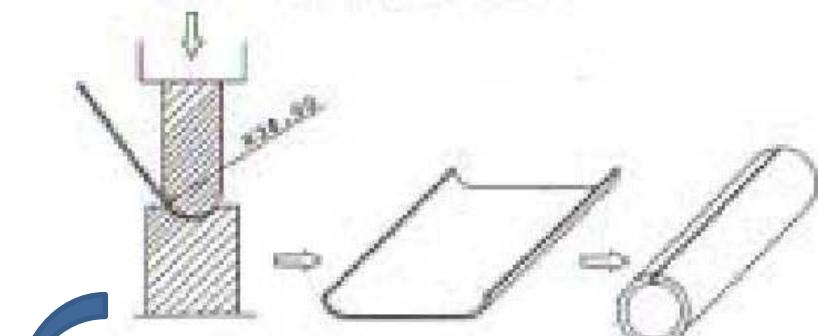


Fabrication Processes of beam-pipe

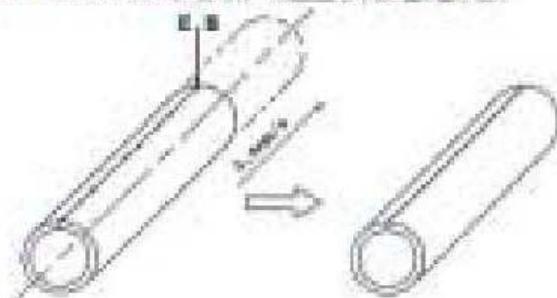


BEAM TUBE FABRICATION

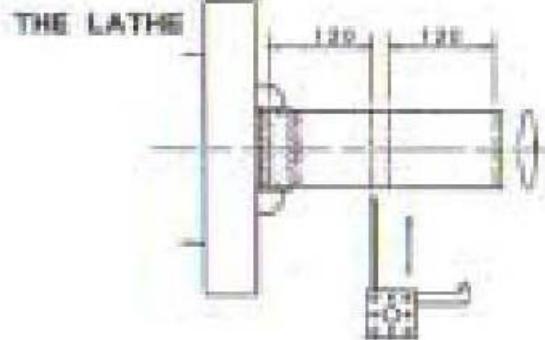
① ROLLING OF BEAM TUBE



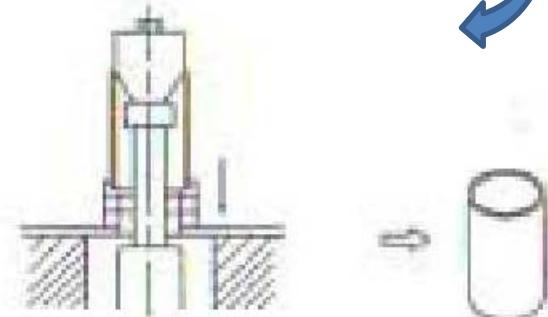
② ELECTRON BEAM WELDING(E.B.W)



③ CUTTING



④ FORMING OF REAL CIRCLE



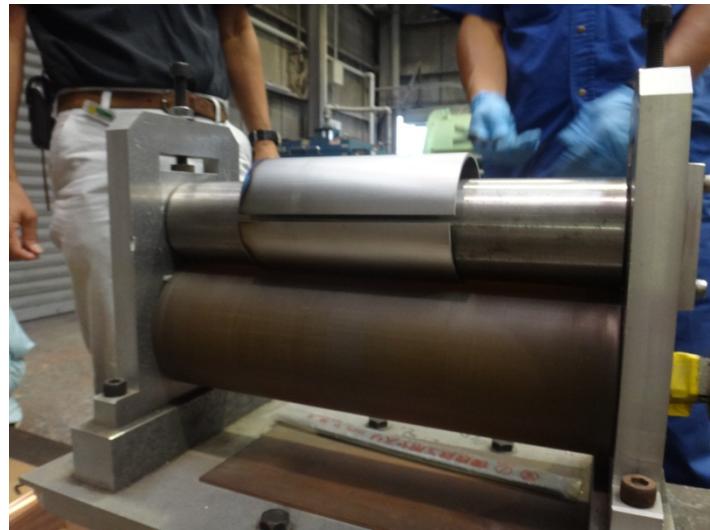


Rounding of Beam Pipe from Nb plate





Rounding of Beam Pipe from Nb plate



Final rounding



After rounding



Fixture for EBW

EBW of Beam Pipe



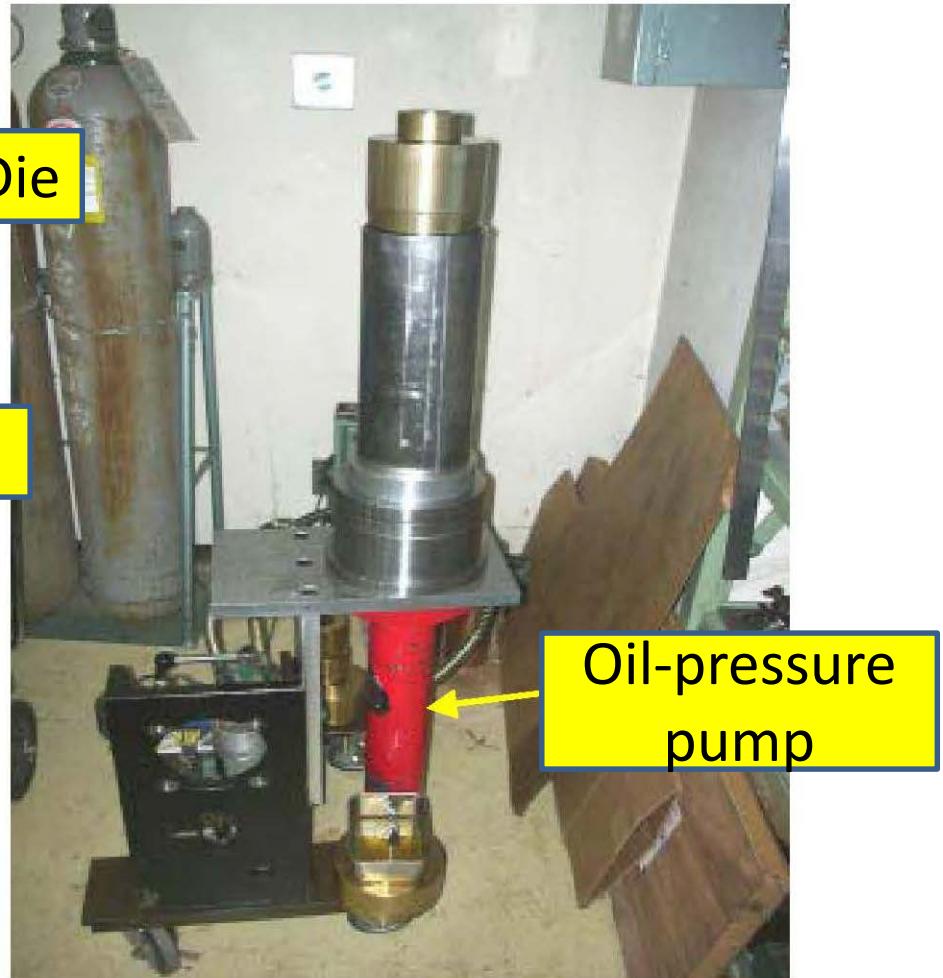
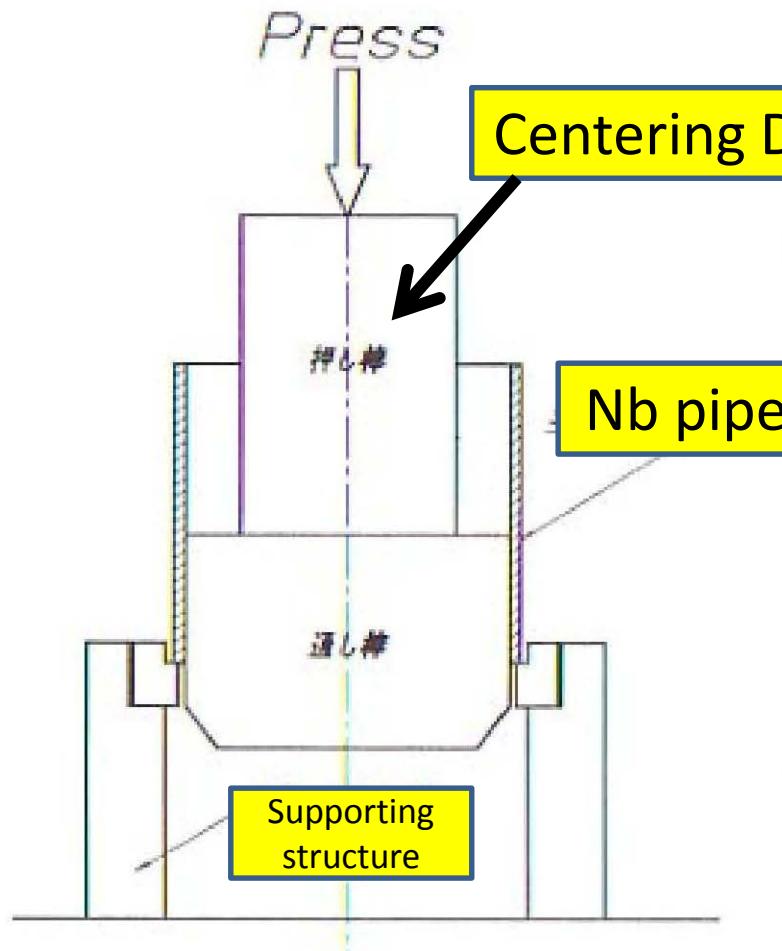
Point EBW



After EBW



Centering of Beam Pipe



Fabrication Processes of beam-pipe



- The fabrication methods of beam-pipe are depending on the industries.
- Deep-drawing from a Nb plate to a pipe: For this process, several deep-drawing processes with different dies are needed with annealing process inbetween deep-drawing processes.
- Back-extrusion from a shaped Nb ingot to a pipe: Fabrication of Nb plate is skipped in this process, but you need a large press machine.



Beam Pipe

80 phi Nb Beam-pipe (input-coupler)

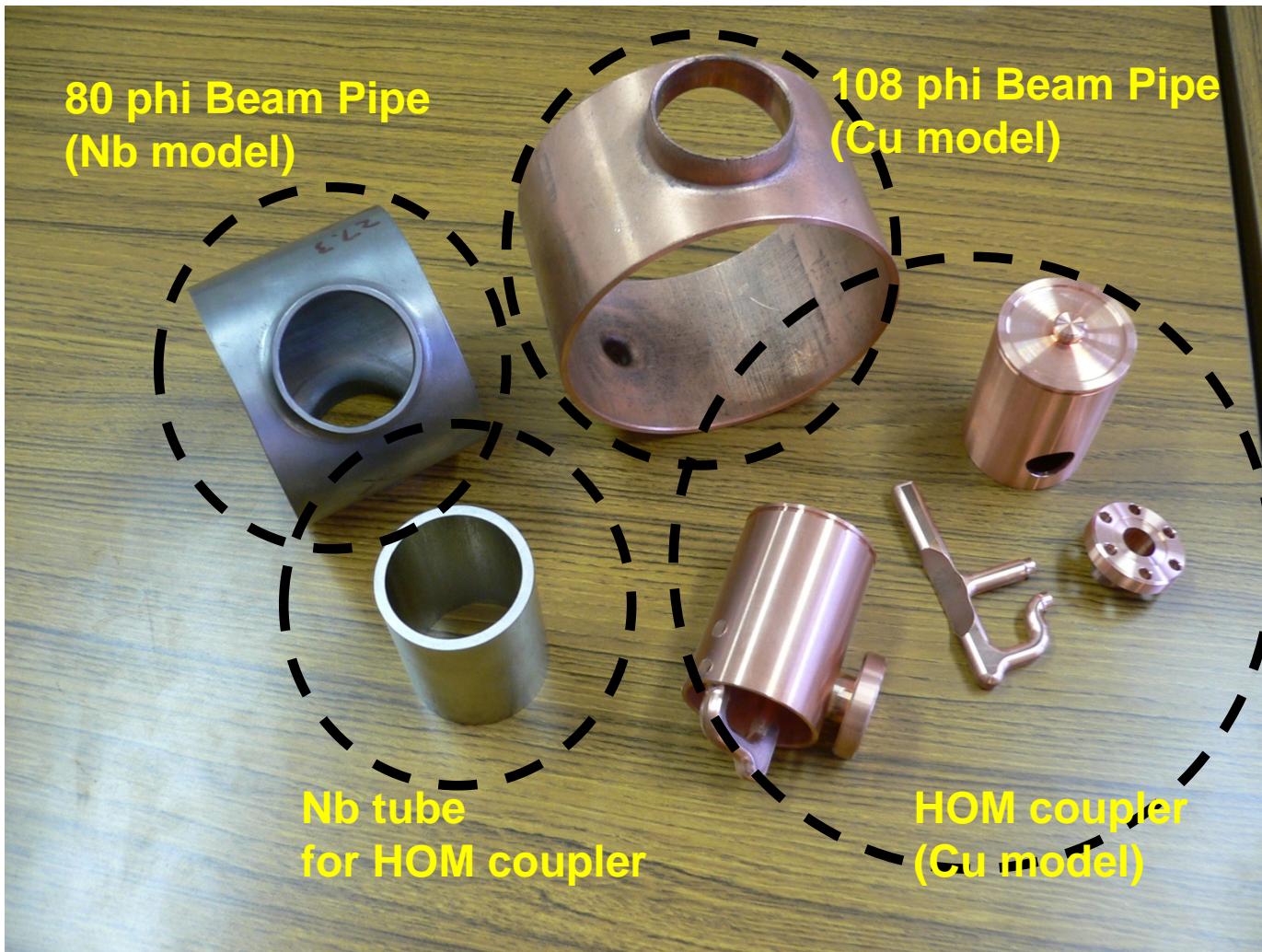


108 phi Nb Beam-pipe (pickup)





End-group





End-group

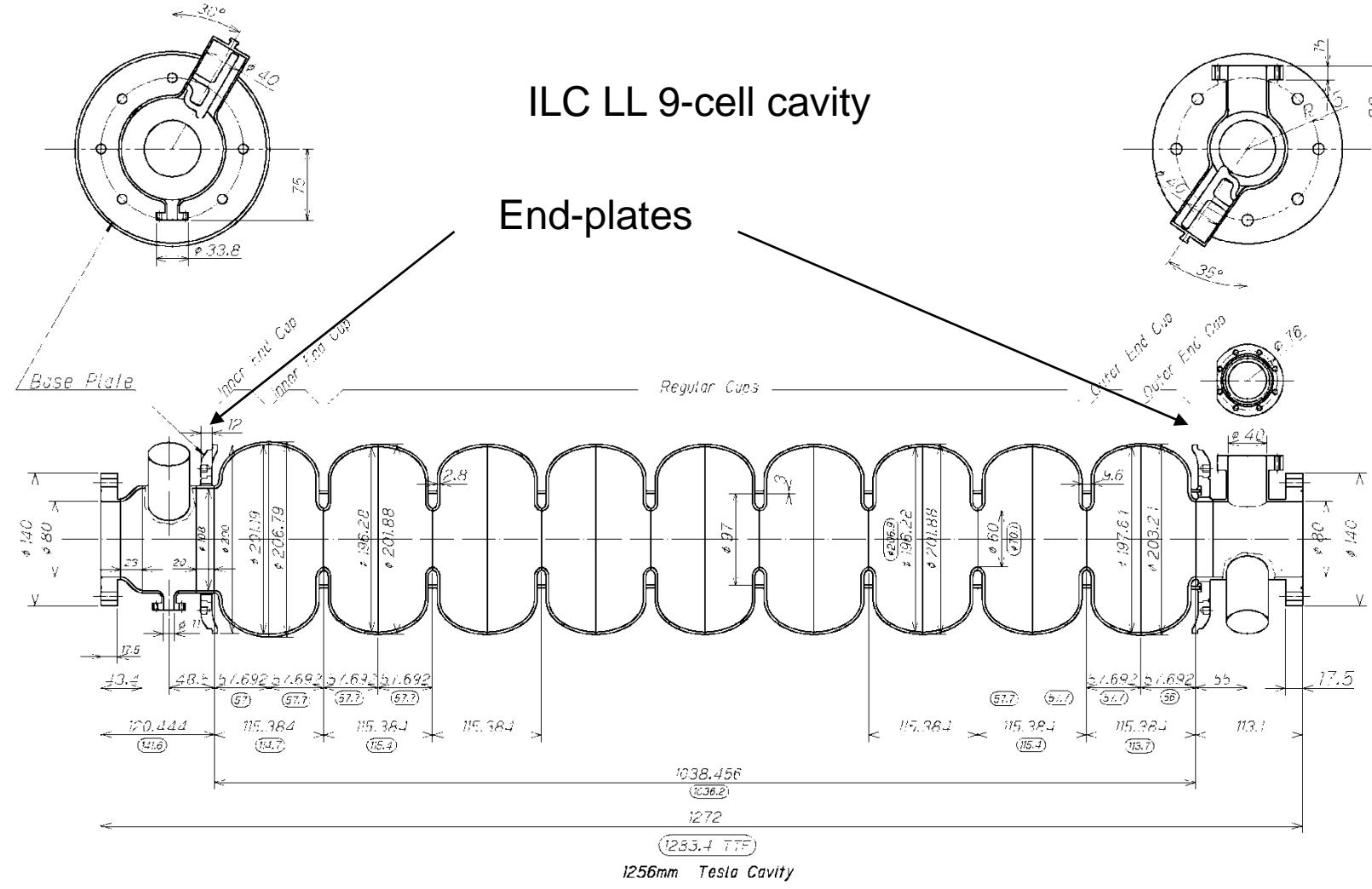


End-plates / joint to He jacket



ILC LL 9-cell cavity

End-plates



Dimensions in Units of mm at Operation Temperature (2K)

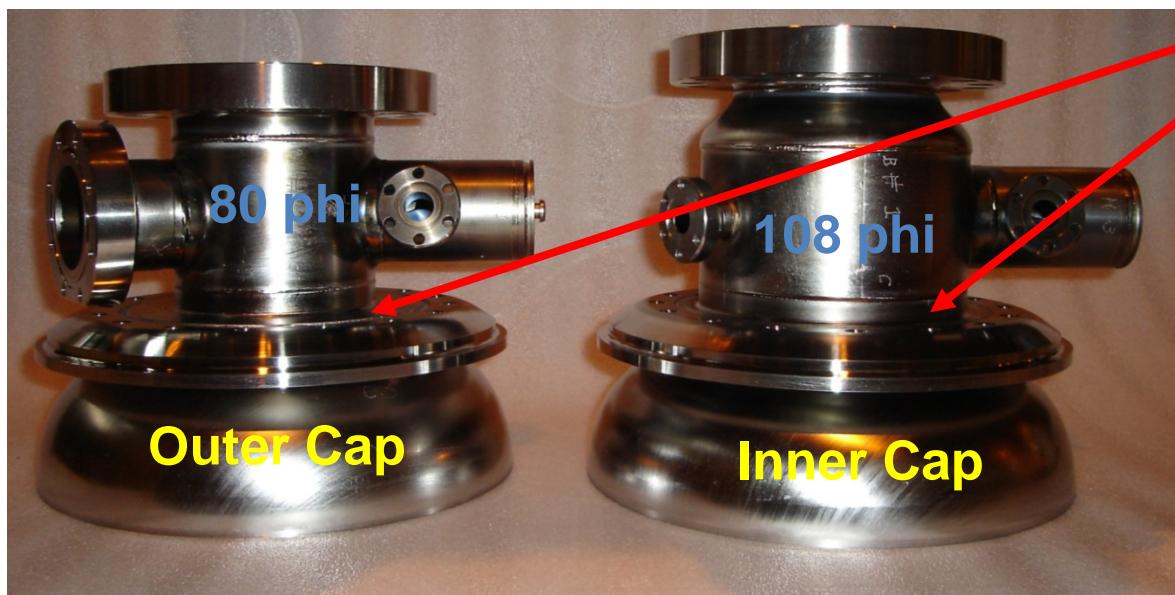
注. #付さ方法はTESLAの方法 (0362)

2005-4-12
2005-4-17
2005-4-31
2005-3-31
2004-12-17
2004-12-15
2004-12-8

End-plates / joint to He jacket



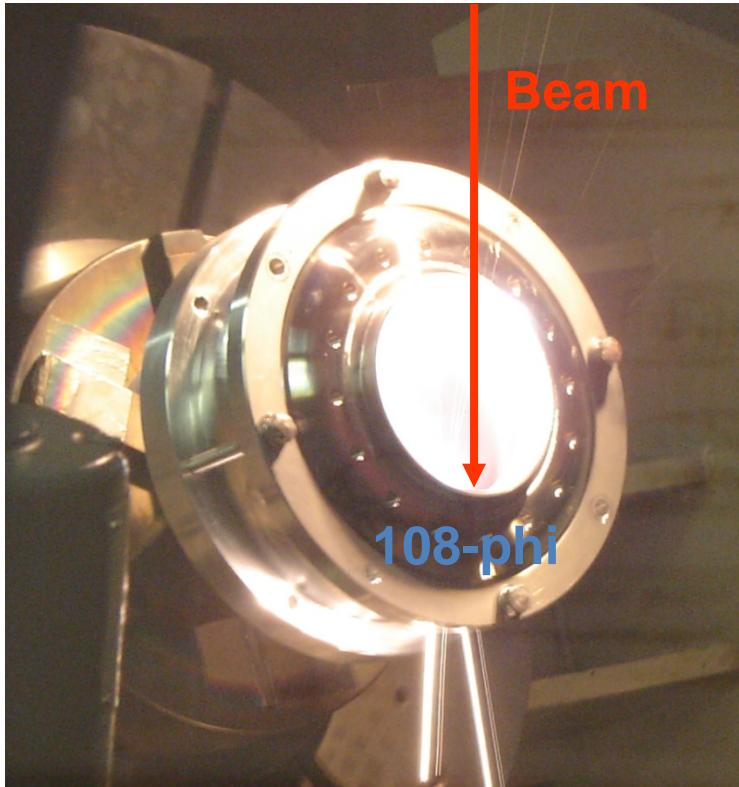
SUS Base-plate



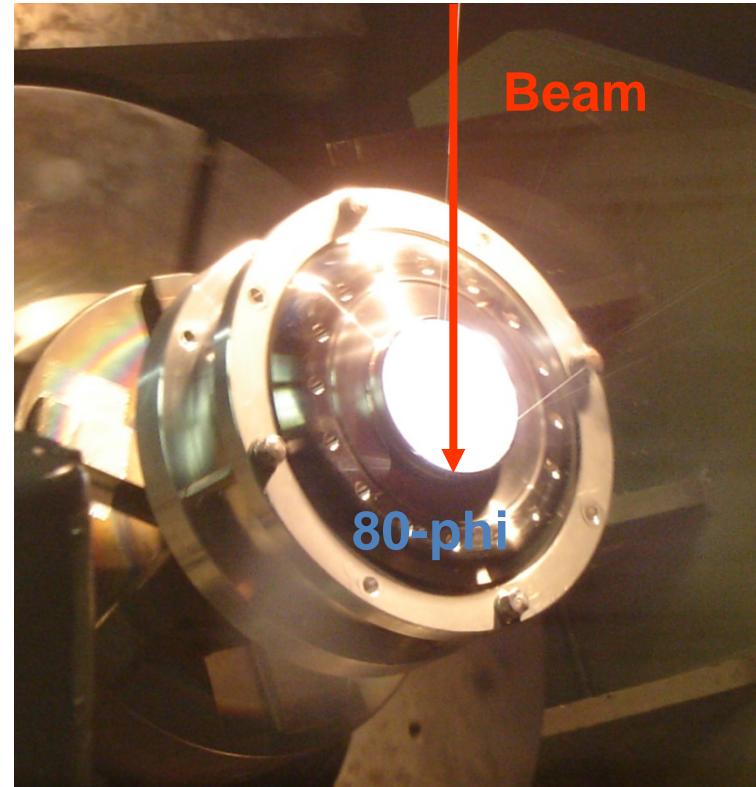
HIP bonding



End-group EBW



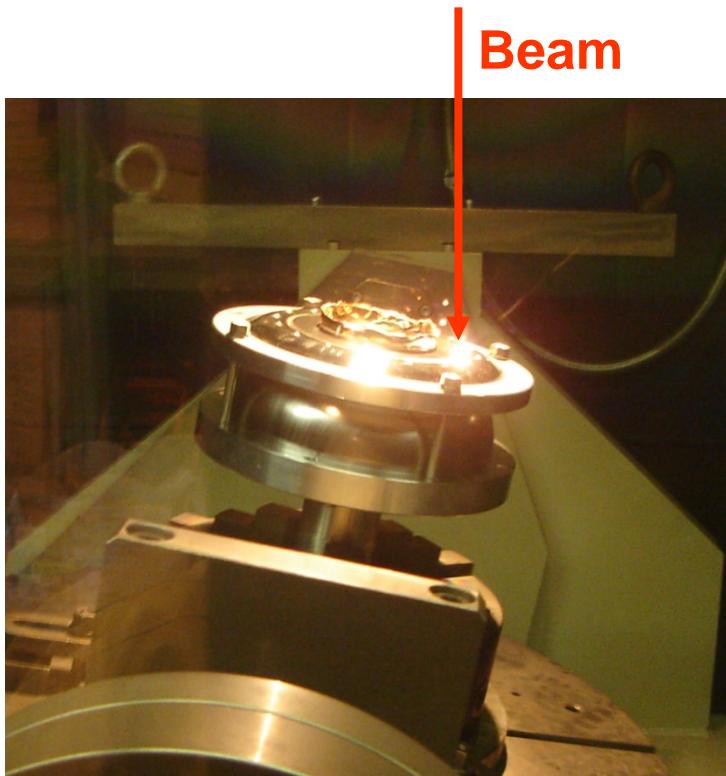
Base-plate 108-phi beam-pipe
+ Inner End-Cap



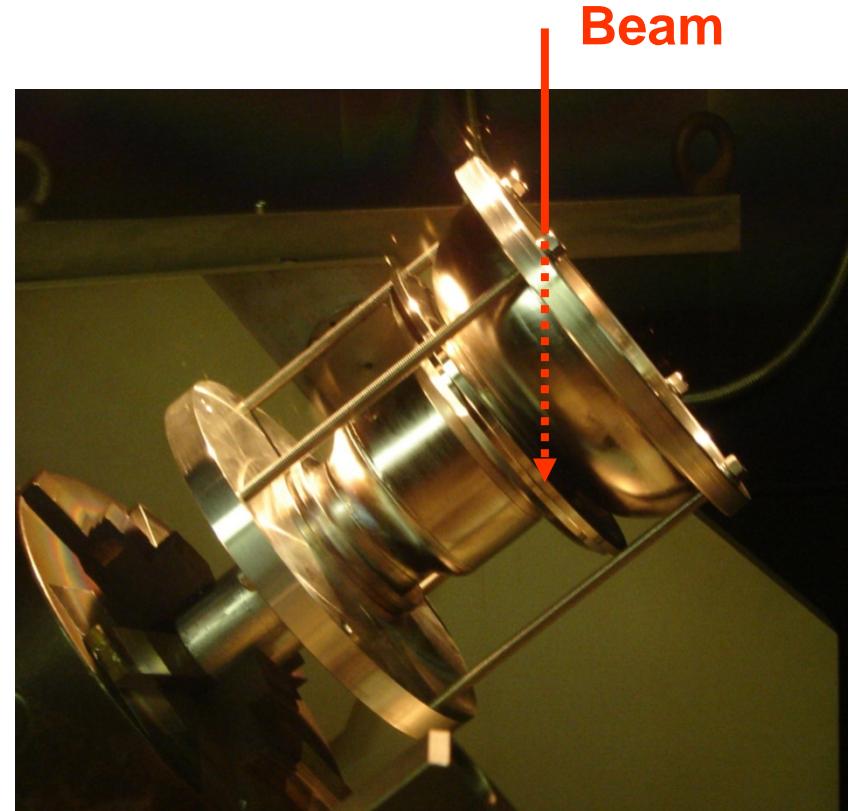
Base-plate 80-phi beam-pipe
+ Outer End-Cap



End-group EBW



EBW of SUS Base-plate



EBW of 108-phi beam-pipe

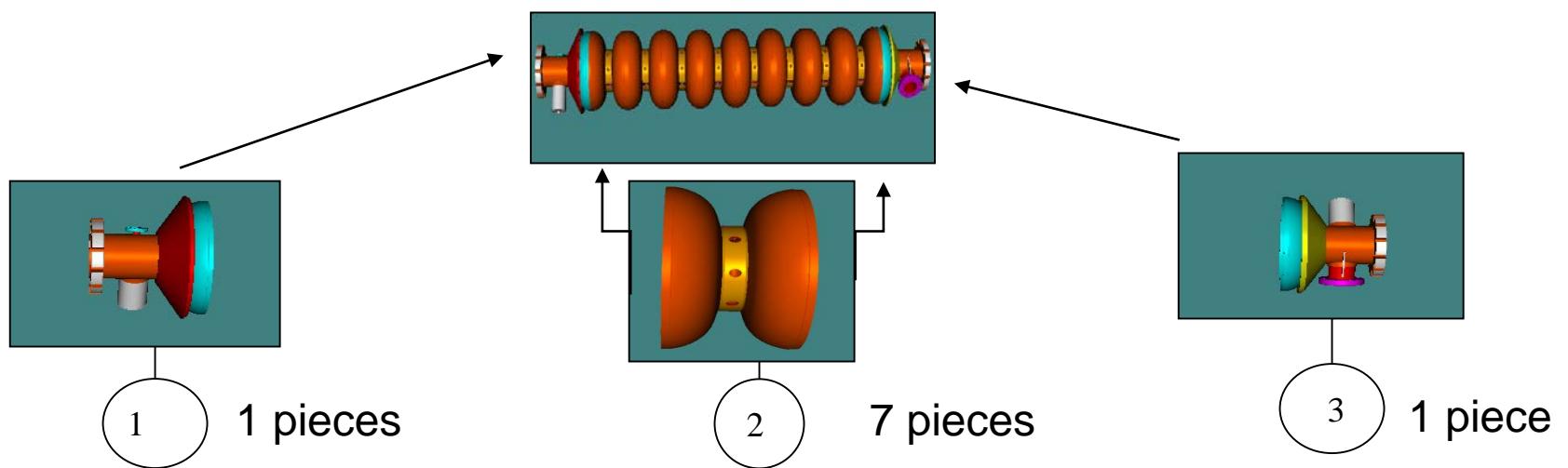


End-group assembled by EBW

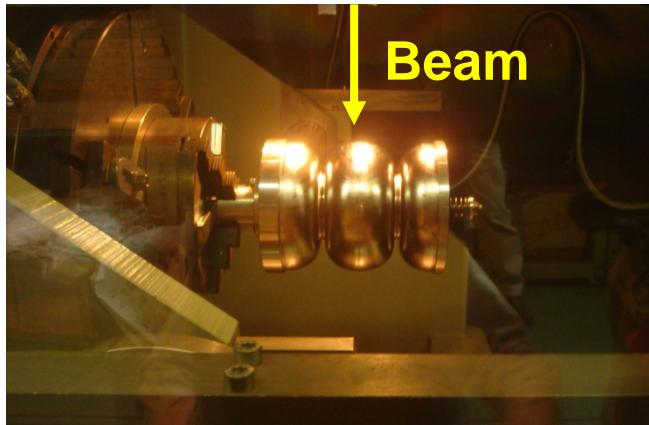




EBW assembly of end-group + dummbells



EBW of two dumbbells

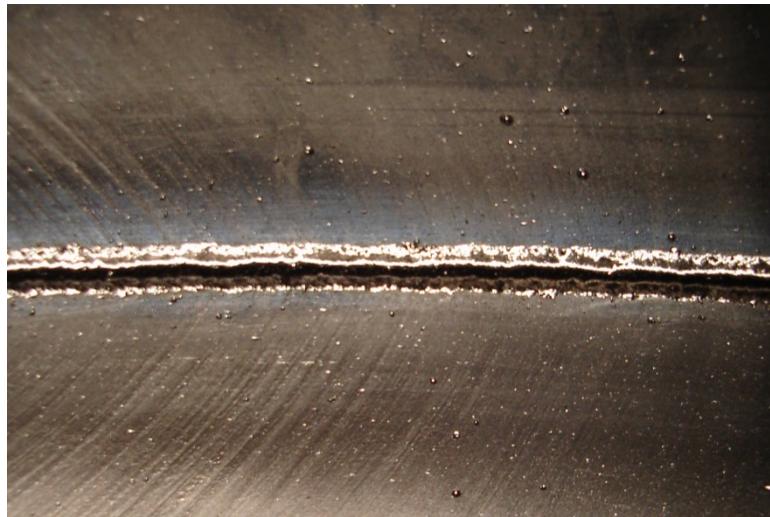


High magnetic field at equator.
The inner surface of equator should be defect-free.



Good inner surface
(EBW with beam oscillation)

EBW of four dumbbells



Bad EBW example

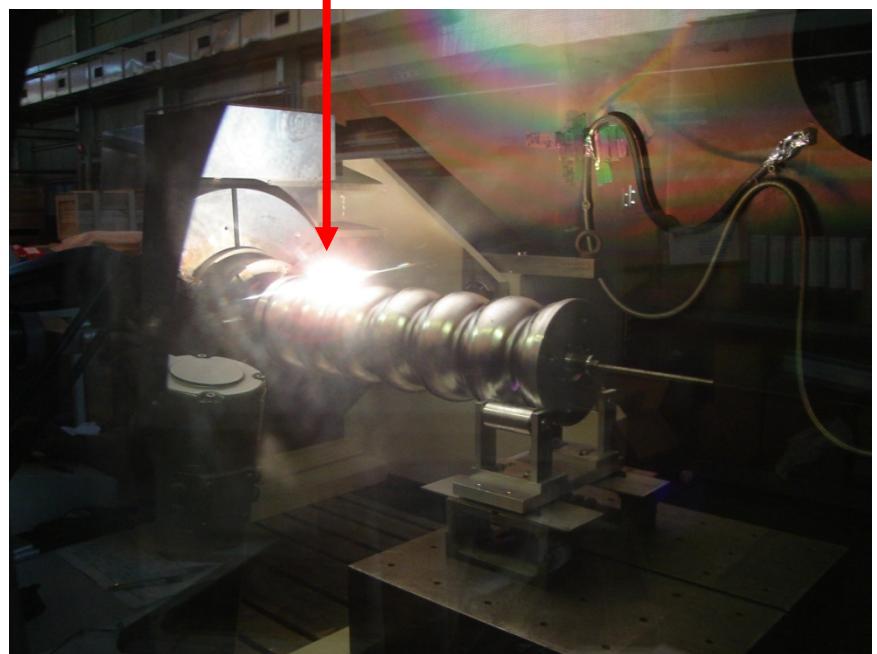


EBW of six dumbbells

Six dumbbells

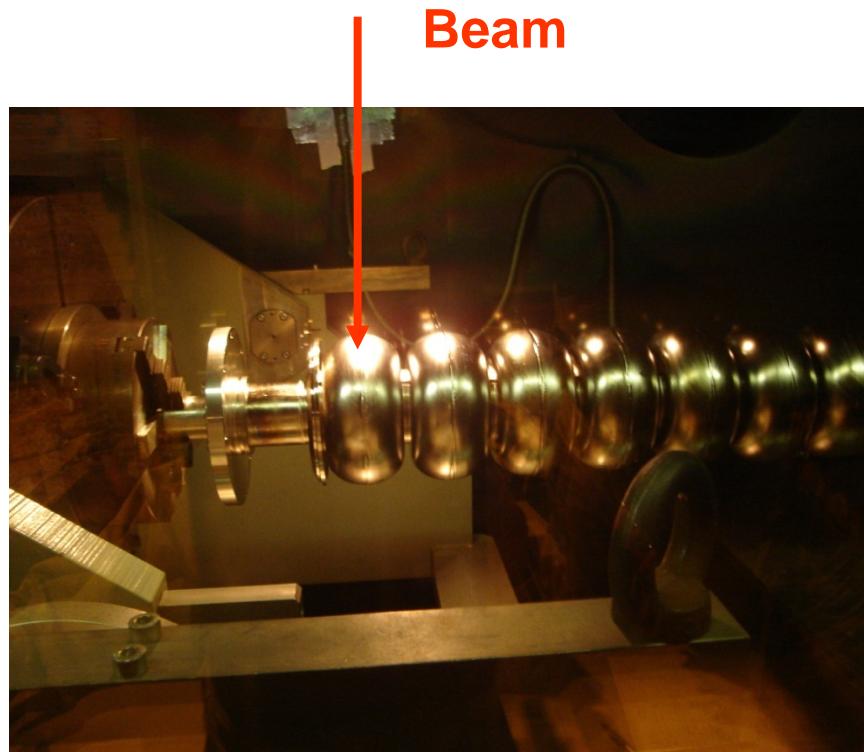


Beam





EBW of Center-cells + End-group



EBW of End-group + Center-cells



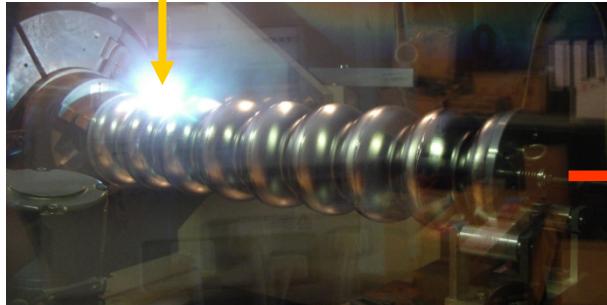
EBW completed

Fabrication of LL Cavity at KEK



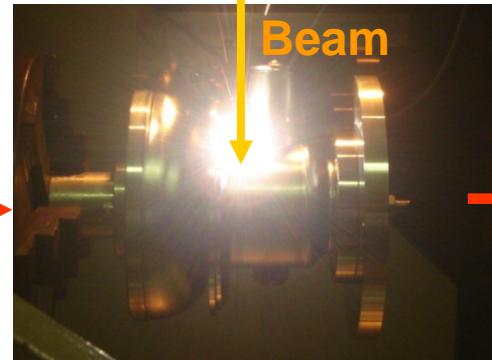
EBW of dumbbells

Beam

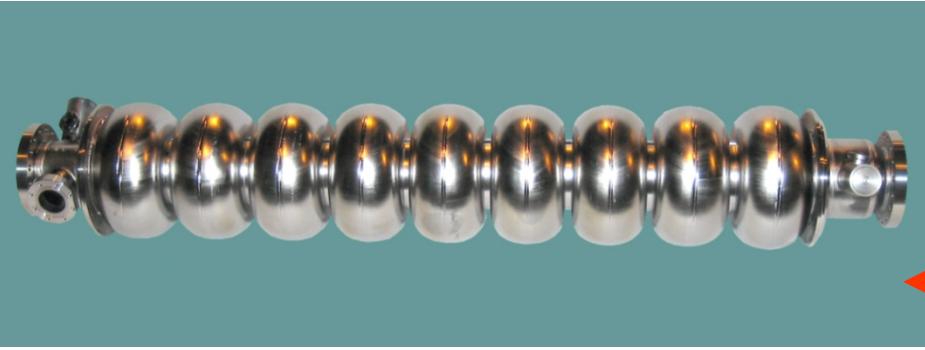


EBW of end-beam-pipe

Beam



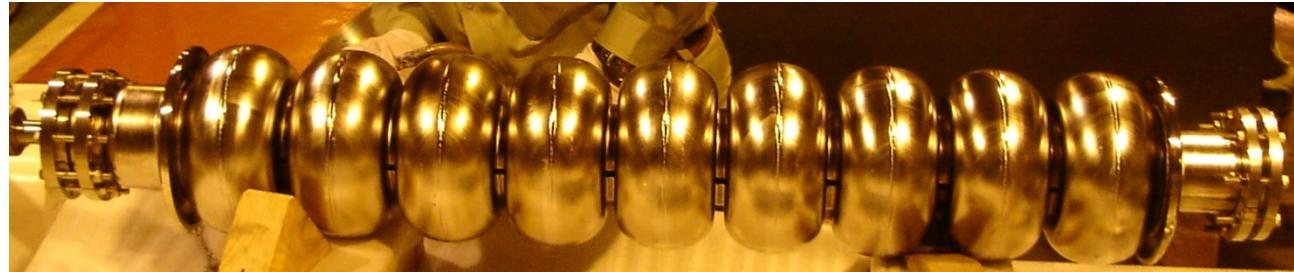
End-beam-pipes with
HOM and flanges



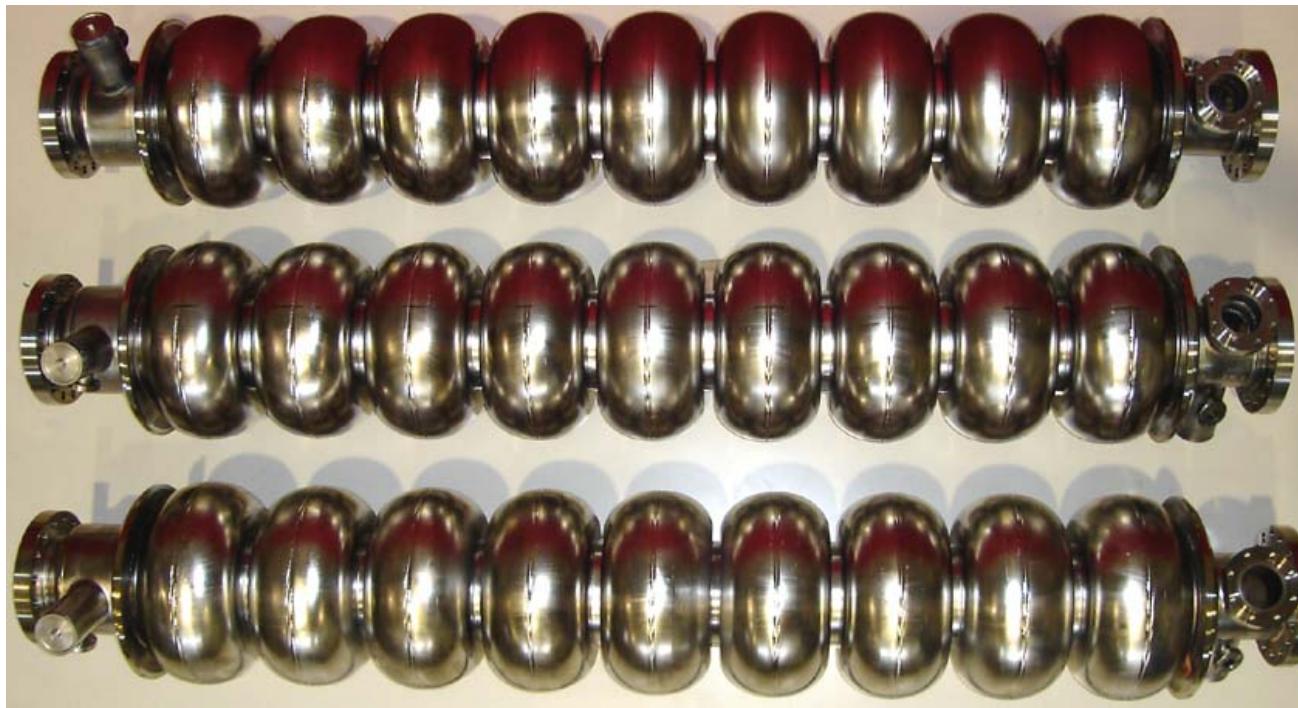
Delivery of 9-cell LL Cavities

EBW of end-beam-pipes
and cell-part

1st, 2nd, 3rd, 4th LL 9-cell cavities



**without
HOM coupler**

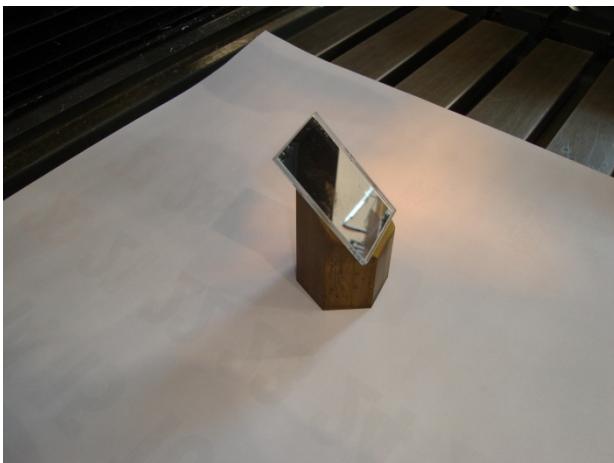
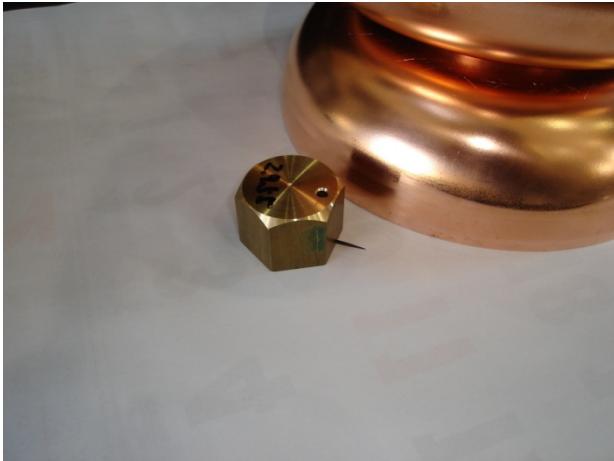


**with
HOM coupler**

**with
HOM coupler**

**with
HOM coupler**

Shrinkage by EBW



	EBW shrinkage
iris	0.148+-0.044 mm
equator	0.424+-0.125 mm

Dimensional measurements



Length of the cavities were measured by 3D-measurement machine.



Dimensional deviation of length (only 9-cell part: 1038.5 mm)

- 10 mm (1st 9-cell ICHIRO cavity)
- 0.7 mm (2nd 9-cell ICHIRO cavity)
- 0.1 mm (3rd 9-cell ICHIRO cavity)
- 0.1 mm (4th 9-cell ICHIRO cavity)

Without dumbbell tuning

With dumbbell tuning

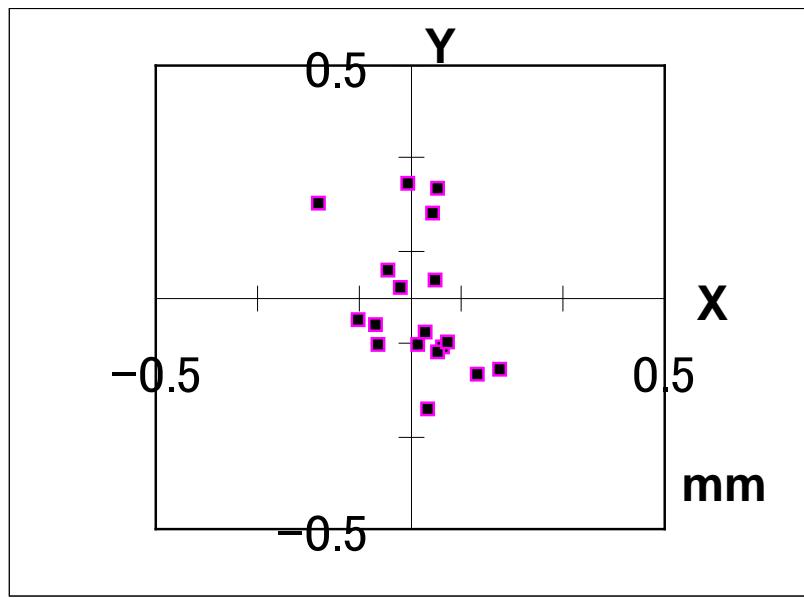
Operator learned how to tune the dumbbells and fabrication error became less than 0.1 mm !

Straightness



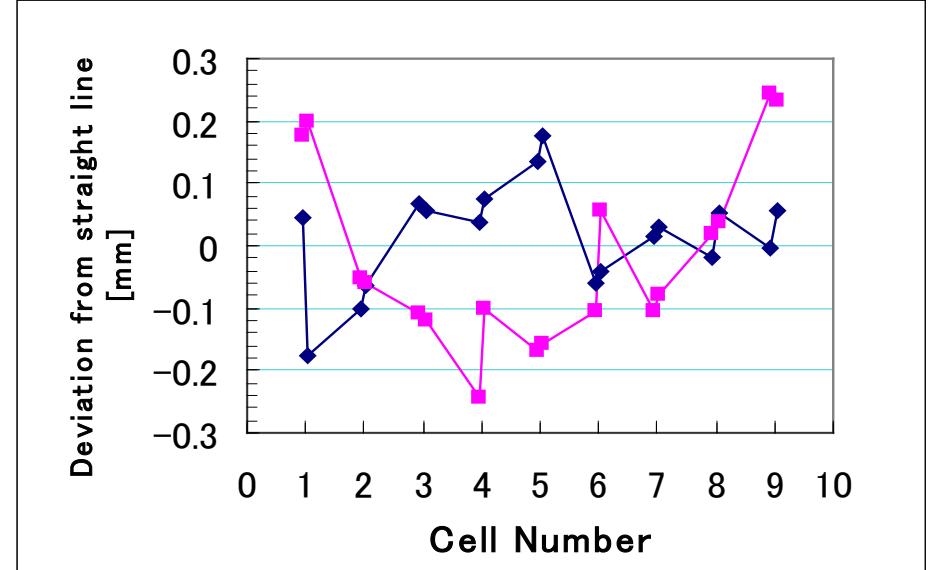
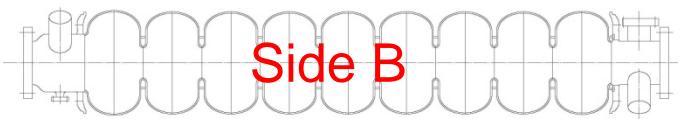
3-D measurements of straightness of cavity

Cross-section view



Cell
No, 1

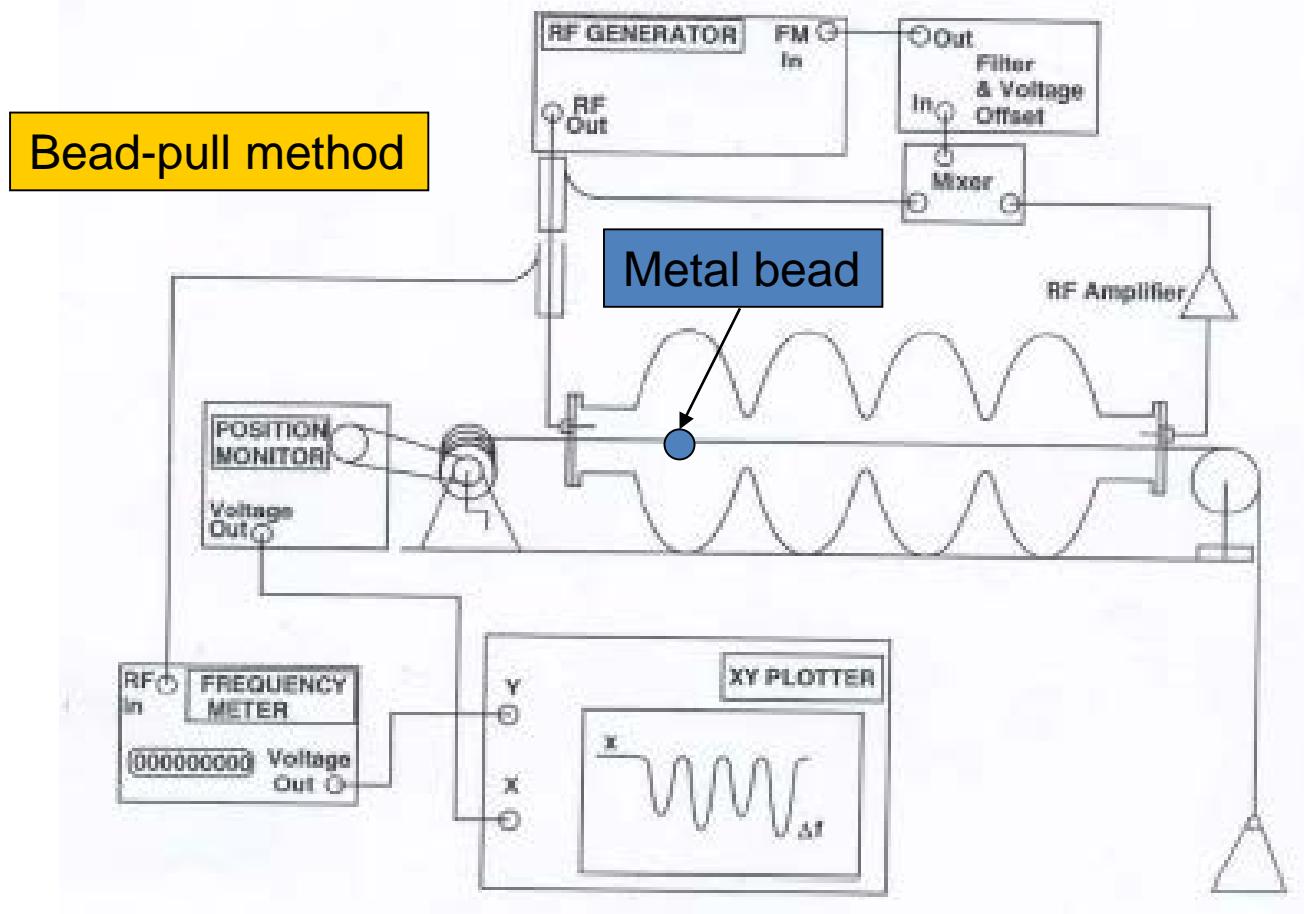
Cell
No, 9



Pre-tuning for field flatness



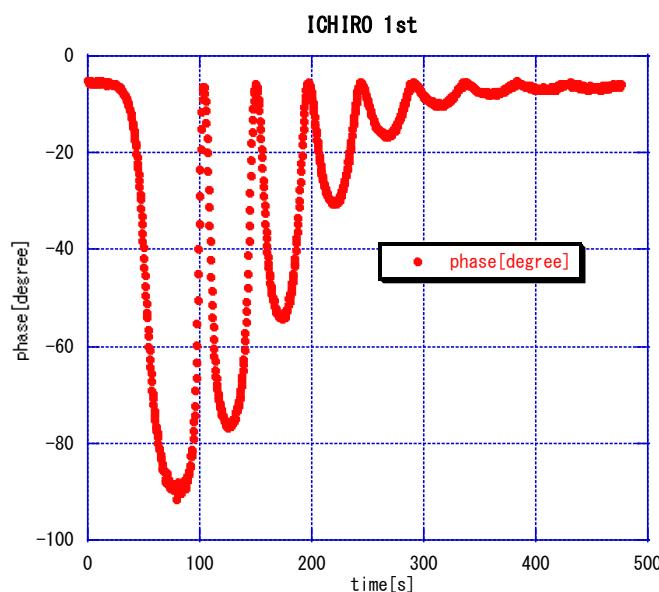
Set-up for field profile measurements: a metallic needle is perturbing the rf fields while it is pulled through the cavity along its axis; the stored energy in each cell is recorded.



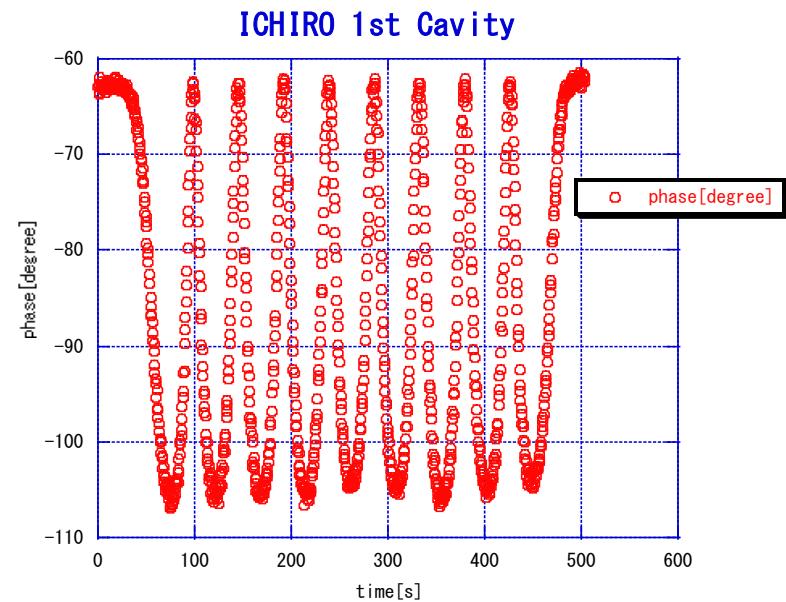


Filed flatness before/after pre-tuning

π mode frequency 1298.774 MHz



π mode frequency 1298.547 MHz

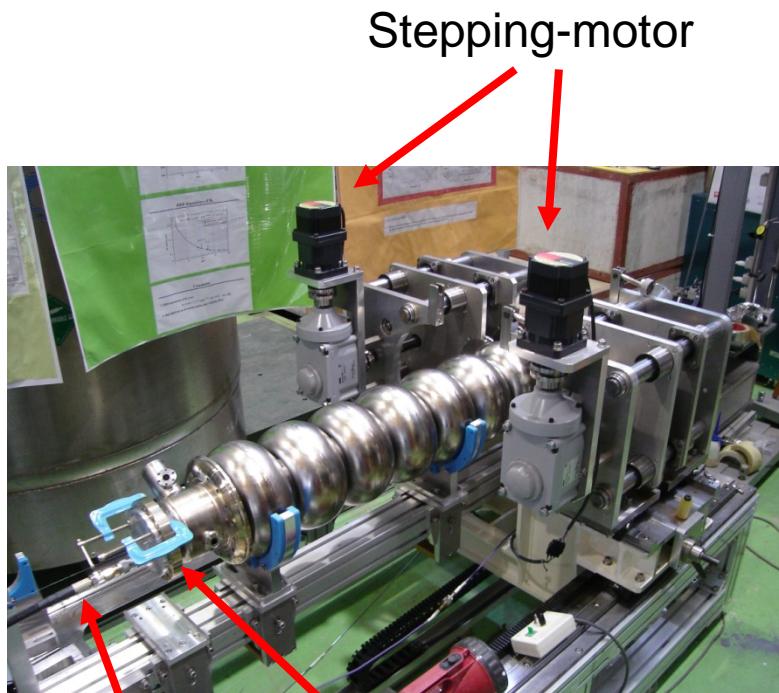


Field flatness = 0.1 %
(as delivered to KEK)

Field flatness = 98 %
(after pre-tuning)



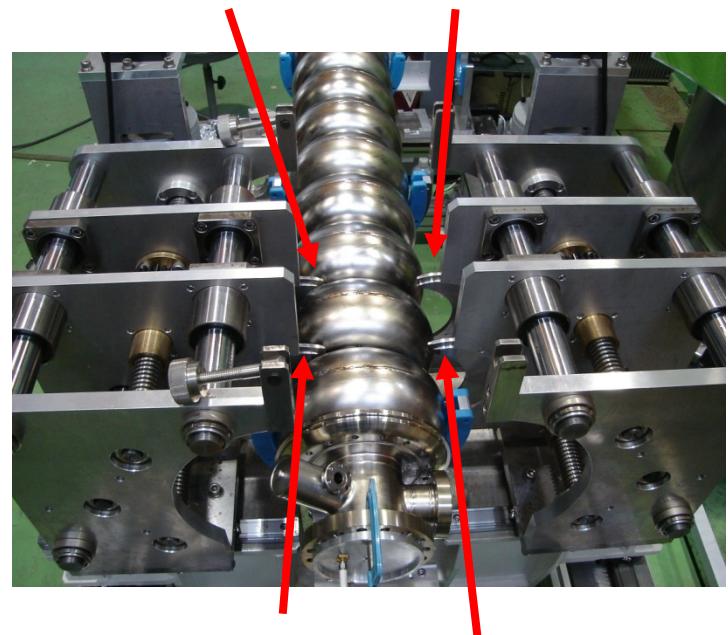
Pre-tuning



Stepping-motor

Flange with antenna
Line with metal bead

Blades are inserted into the iris

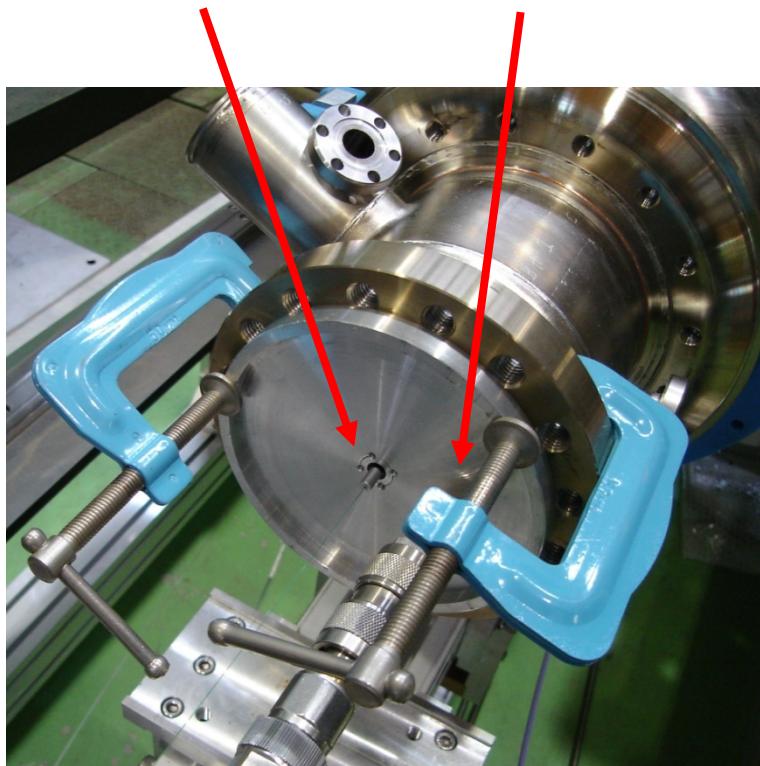


Blades are inserted into the iris



Pre-tuning

Metal bead



Antenna

Pressing the cell by the blades

