2017.7

Activities of Cavity Fabrication Facility at KEK

Mechanical Engineering Center, KEK
Masashi YAMANAKA

Purpose of fabrication of cavities on the KEK site

Development of a mass production techinology in order to fabricate more than 16000 cavities within 3 to 5 years for ILC

- Improvement of yield ratio = Stable quality
- Reduce the cost drastically
- Development of mass production technologies

Development on the KEK site

Speed up the R&D

Realization of ILC

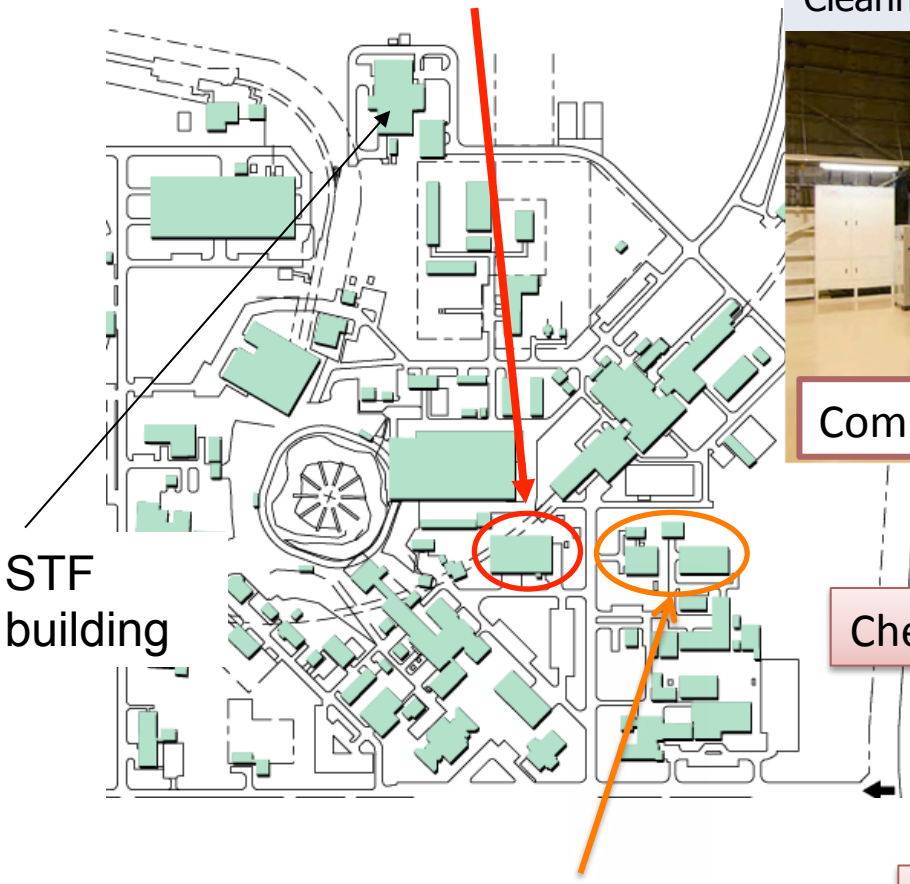
Cooperation with STF

Establish the Cavity Fabrication Facility

Collaboration with many companies

Introduction of Cavity Fabrication Facility (CFF)

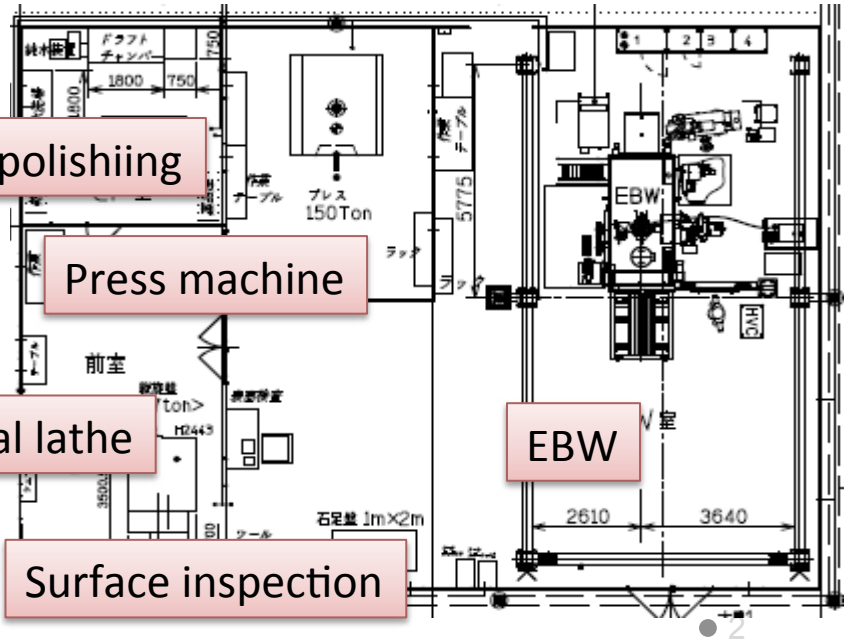
Cavity Fabrication Facility



Map of KEK

Clean room 19m x 14m x 5m (Height)
Cleanness ISO 5

Completed in July 2011



Main equipments in CFF

EB welding machine
（SST, Germany）
Max. beam voltage: 150 kV

Servo press machine
(AMADA, Japan)
Max. applying force:
1500 kN

Chemical polishiing

CNC vertival lathe
(Moriseiki, Japan)

Microscope
(Surface inspection)

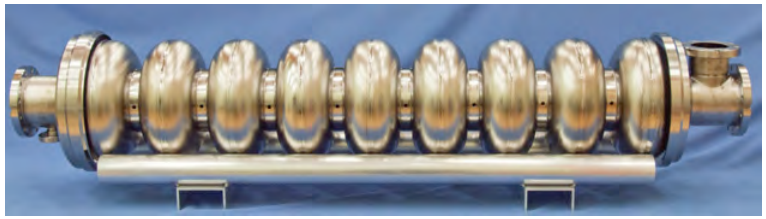
A cavity can be manufactured in KEK site combined with machine tools at MEC

Present status of production

July 2011 Construction of Cavity Fabrication Facility (CFF) is finished.
Feb. 2012 The first cavity named KEK-0 was fabricated in CFF, and its acceleration gradient attained 29 MV/m.
Mar. 2014 The second cavity named KEK-1 was finished, and its acceleration gradient attained **36** MV/m.
April 2014 5 R&D cavities (1-cell & 3-cell) were fabricated to June 2015
Feb. 2016 The third cavity named KEK-2 was finished. (VT is ongoing)
April 2016 Fabrication of new R&D cavity is ongoing.

Opening of CFF

KEK-0



KEK-1

KEK-2

List of manufactured cavities

Three **9**-cell cavities for acquiring experience of ILC cavity
Three **3**-cell cavity and ten **1**-cell cavities for R&D

Code	No. of cells	Purpose	E_{acc} (MV/m)	Note
0	9	First trial of 9-cell cavity fabrication	29	Without HOM coupler EBW for cells were performed at the jobshop outside KEK
1	9	Complete fabrication of 9-cell cavity at CFF Qualify ILC spec. (E_{acc} > 35 MV/m)	36	With HOM coupler Equator part was welded in vertical set up (Gun is horizontal)
2	9	Trial of LG niobium for 9-cell cavity	38	Without HOM coupler Beam tubes are a little longer than std.
R1	1	Prototype using LG niobium material	43	End cell shape
R2	1	Standard cavity using FG niobium	37	Shape is same to R1 For reference
R3	3	Trial of some new manufacturing technique Omit the correction process after EBW in dumbbell Improve EBW conditions	36	Center cell shape Cells were manufactured by the collaborating company
R4	1	Evaluation newly developed niobium material	41	Center cell shape
R5	1	Prototype low RRR and LG niobium material	31	Shape is same to R1
R6	1	Fabrication training by the collaborating company	31	Shape is same to R1

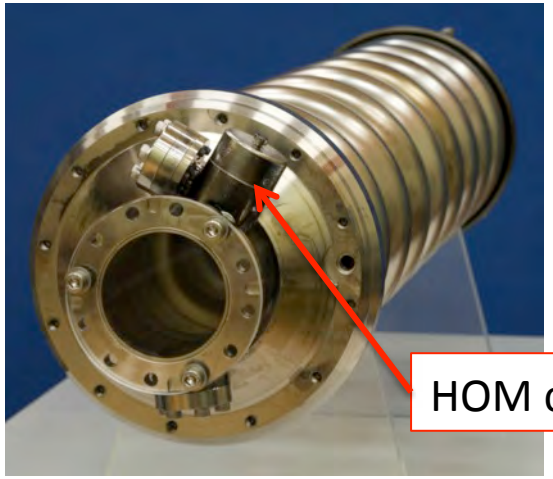
All cell shapes are TESLA-like

List of manufactured cavities 2

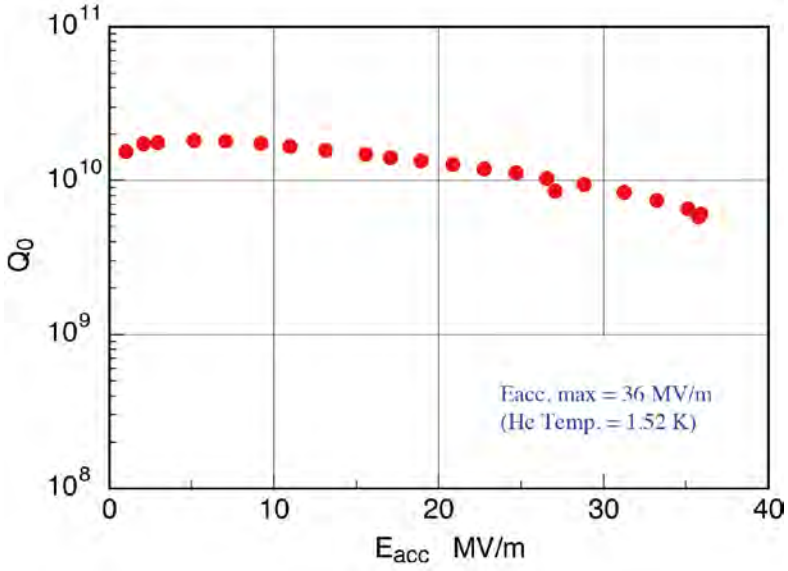
Code	No. of cells	Purpose	E_{acc} (MV/m)	Note
R7/ 7b	3	Test cavity for low cost niobium	30/36	Shape is different from R3
R8/ 8b/8c	1	Test cavity for High-G/Q study (trial of N-dope/infusion)		Shape is same to R1
R9/ 9b	1	Test cavity for High-G/Q study (trial of N-dope/infusion)		Shape is same to R1 EBW was performed by the collaborating company

All cell shapes are TESLA-like

Finish of KEK-1



Member of fabrication



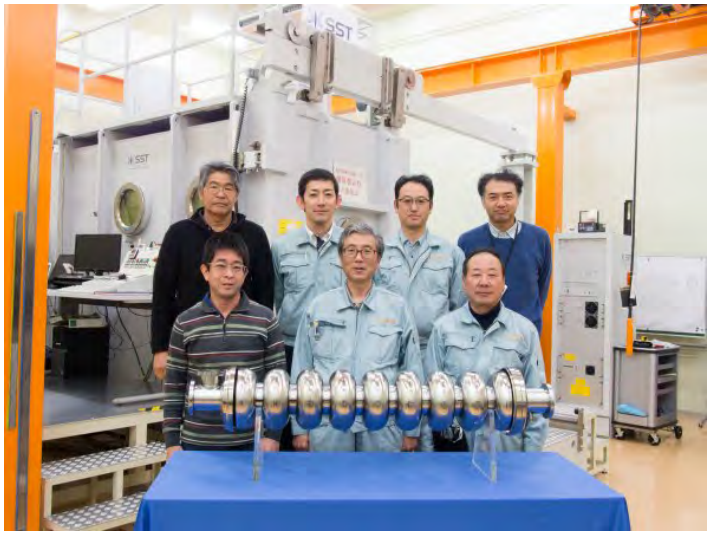
Result of vertical test
⇒Qualify the ILC spec.（35 MV/m）

Finish of KEK-2

Using LG niobium expecting high Q value and cost reduction.
We got good performance.

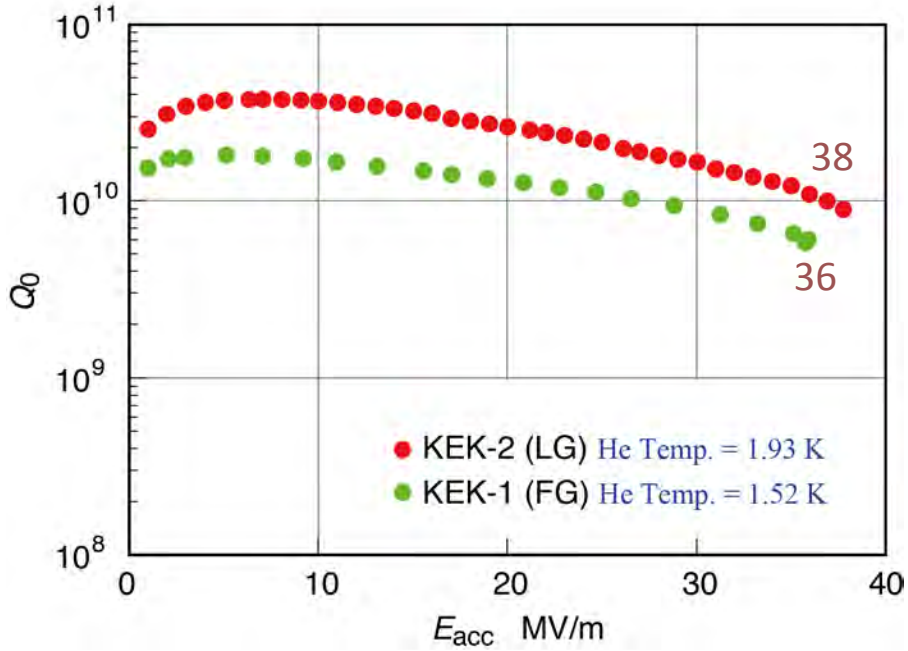
1.3 GHz TESLA-like SRF cavity for ILC (Length: 1.3 m)

Ingot sliced Niobium (Tokyo Denkai)
(Dia : 260 mm)



Member of fabrication (part)

少数精鋭



Result of vertical test
⇒Qualify the ILC spec.（35 MV/m）

Example of R&D cavity

Motivation

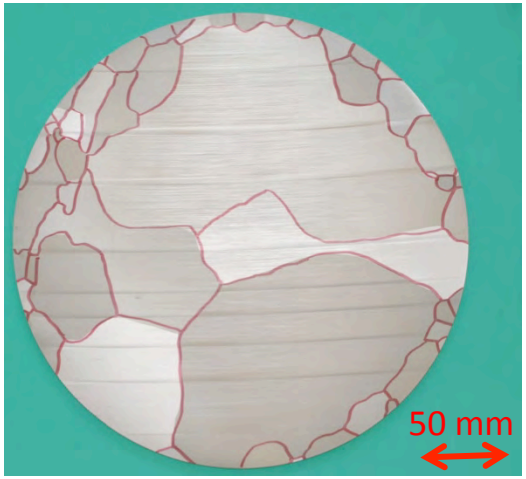
Reduce the niobium material cost

Approach

- Use low RRR cheap niobium
- Use sliced ingot sheet

Objectives

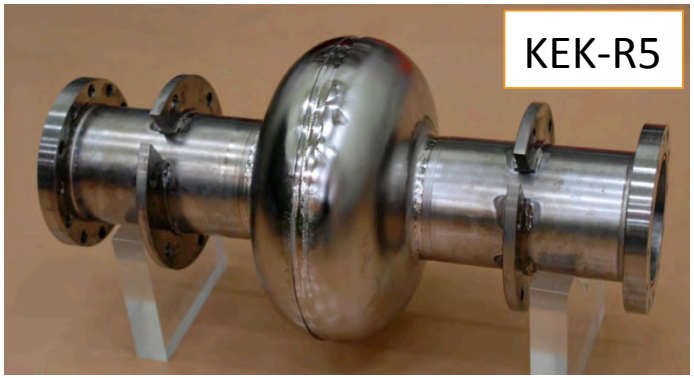
- Manufacture a single cell cavity
- Evaluate the performance



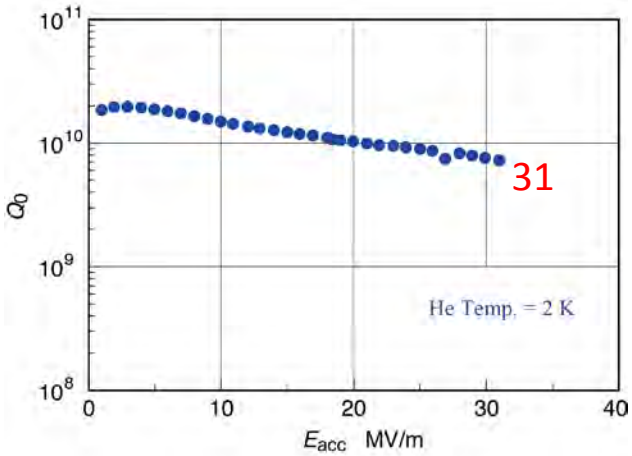
Sliced ingot niobium（ϕ260）
Boundary was traced by felt pen
Material was manufactured by CBMM

Chemical compositions (unit: ppm) and RRR

H	C	O	N	Fe	Si	Ta	RRR
< 10	< 30	< 30	10	3	20	1034	**100**



1.3 GHz single cell cavity manufacture by CFF at KEK
Cell shape: TESLA-like (end cell)

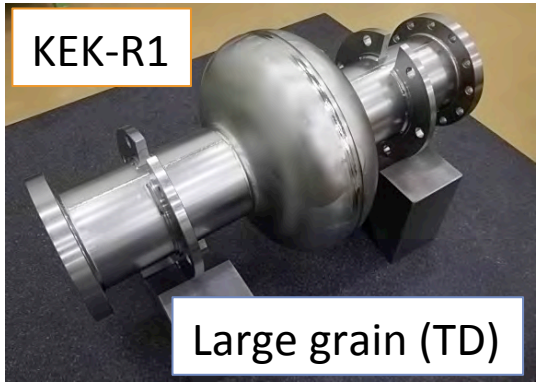


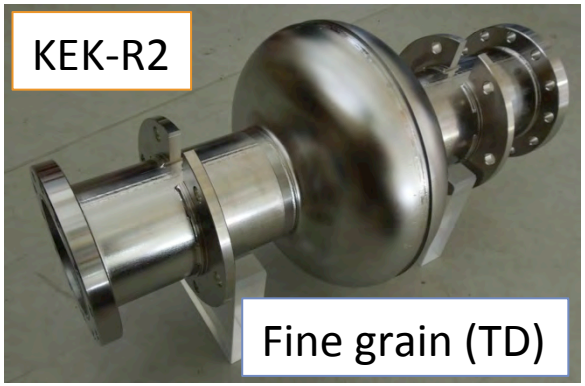
Result of vertical test

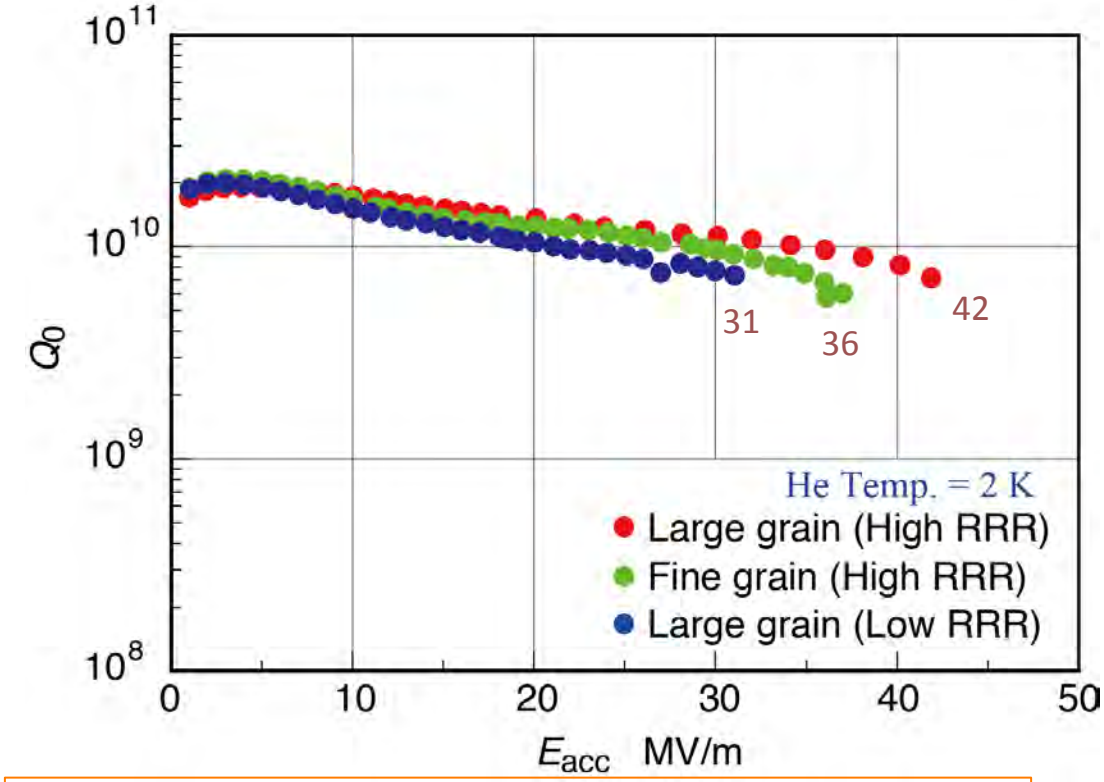
Example of R&D cavity 2

	H	C	O	N	Fe	Si	Ta	RRR
LG (TD)	< 5	< 10	< 10	< 10	< 10	< 10	80	390*
FG (TD)	< 10	40	100	40	20	20	700	258**
LG (CBMM)	< 10	< 30	< 30	10	3	20	1034	100*

Measurement RRR: * by KEK, ** by TD

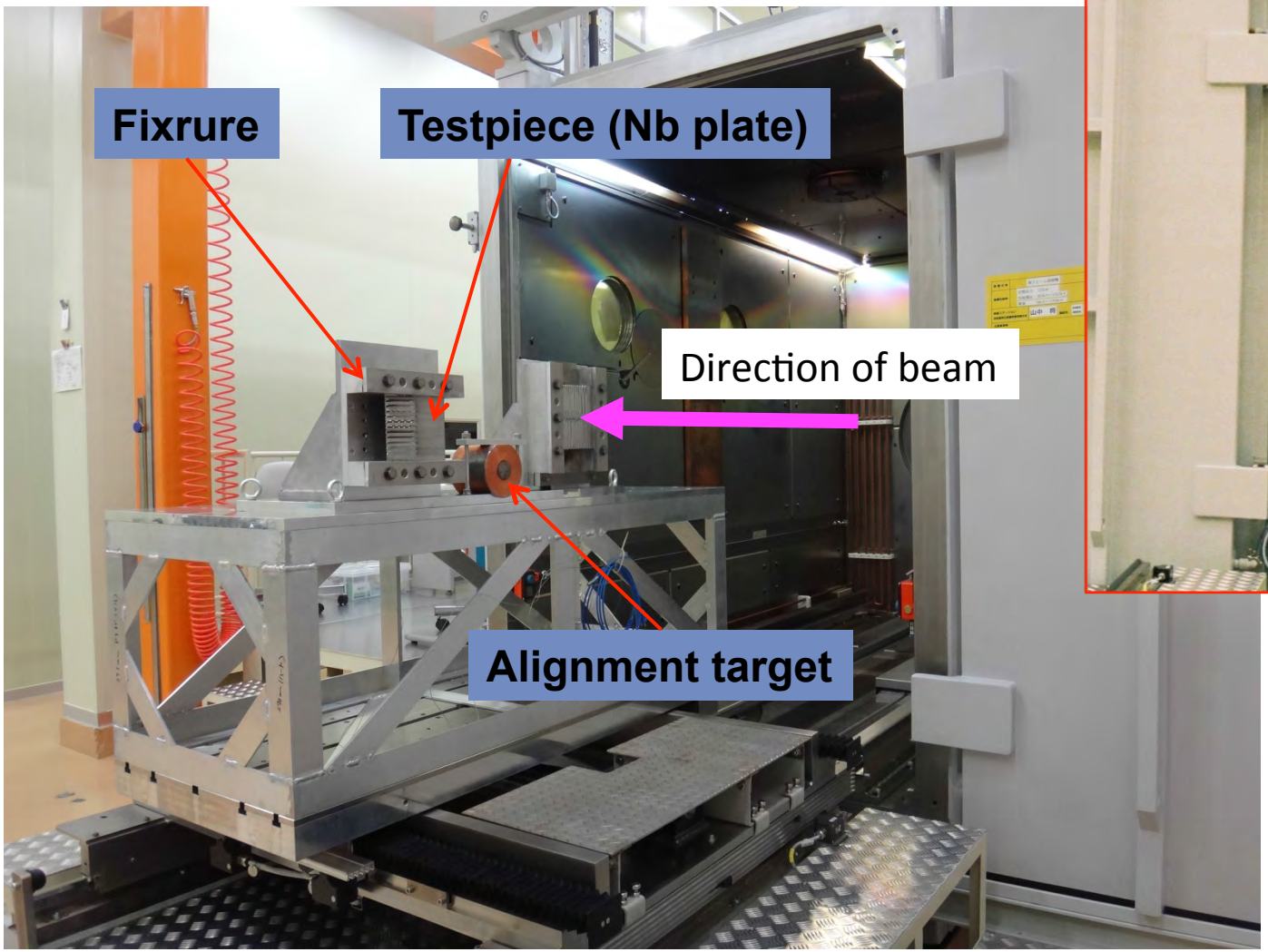


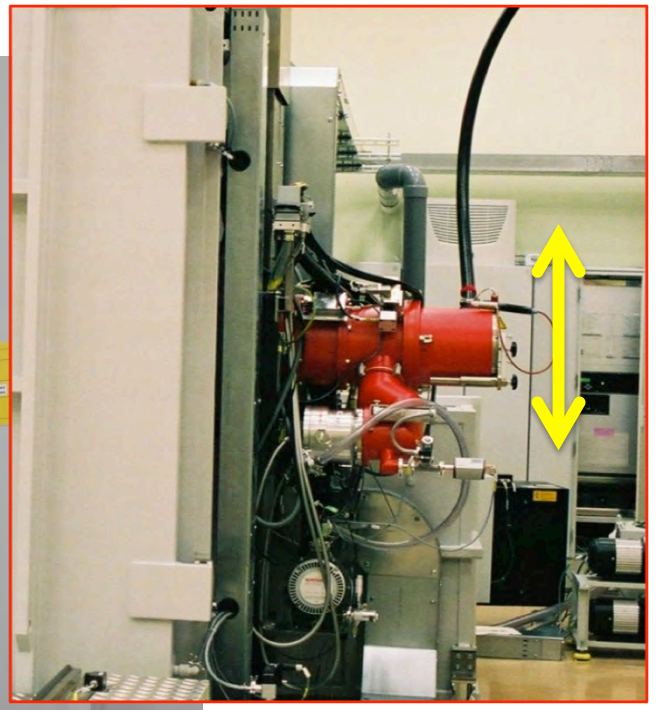




The effect of low RRR and high Ta is not separated here.

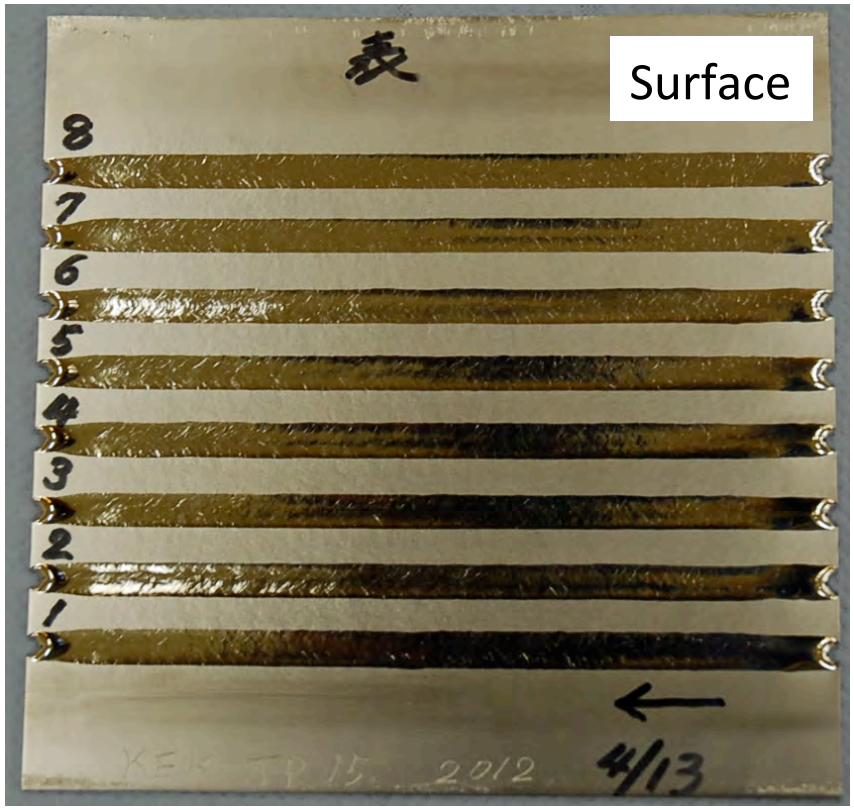
Setup of EBW test

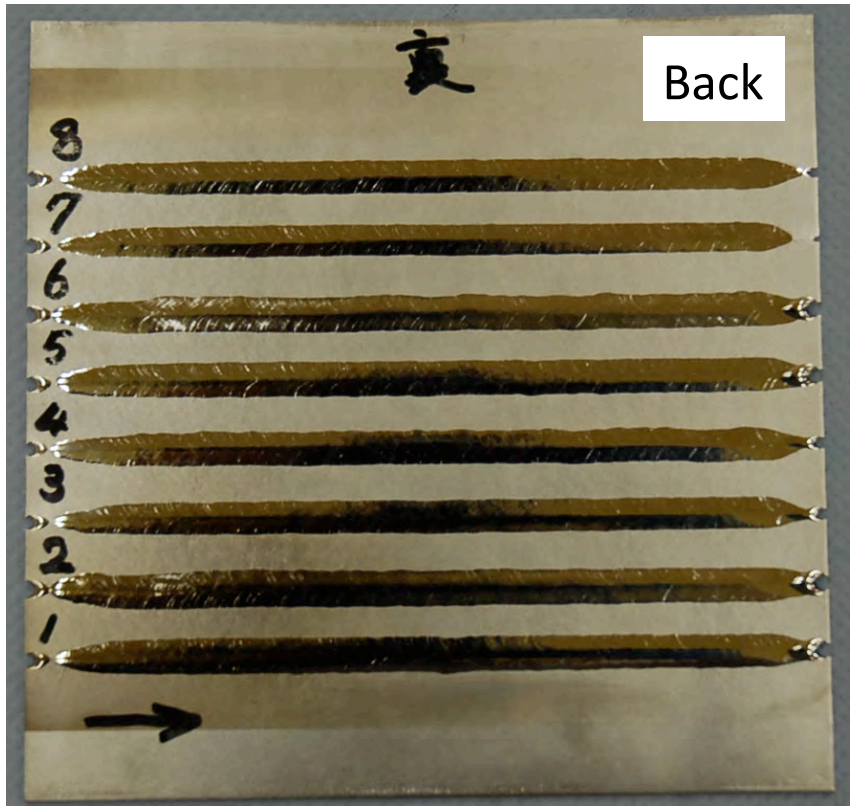




Gun in horizontal

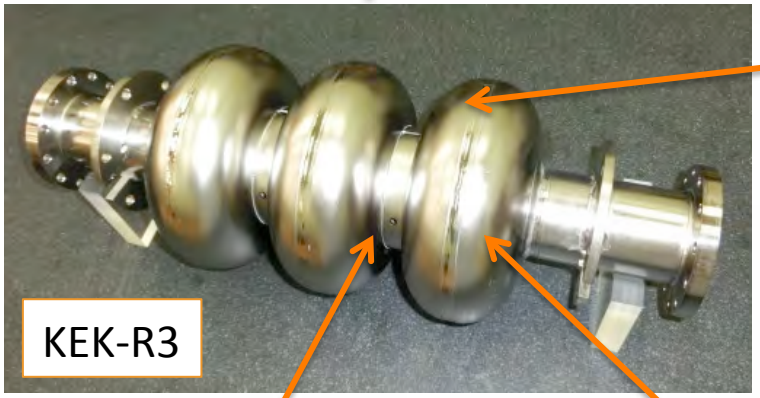
Example of EBW test result using plate



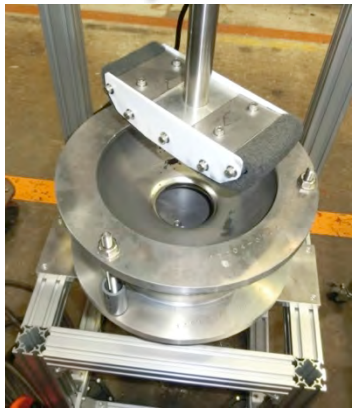


・Getting　penetrated bead from surface
・Serach for good parameters of welding
(volatege, current, speed, focus, etc)

Development manufacturing techniques

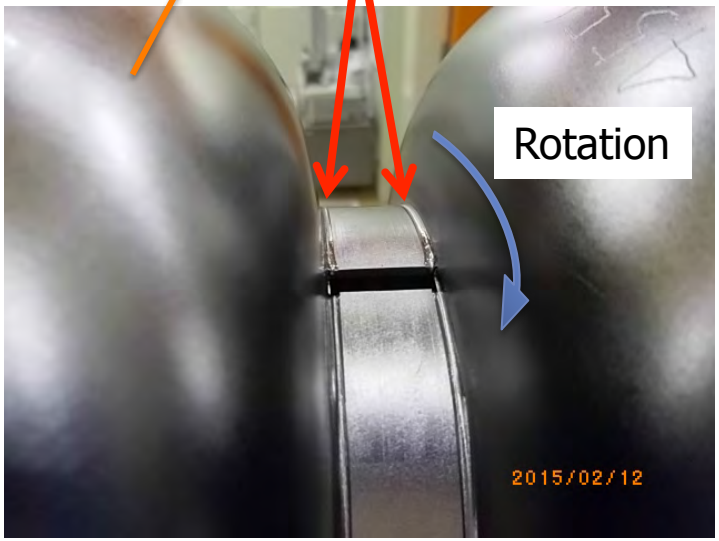


No height correction for dumbbell
（optimum width of stiffener）

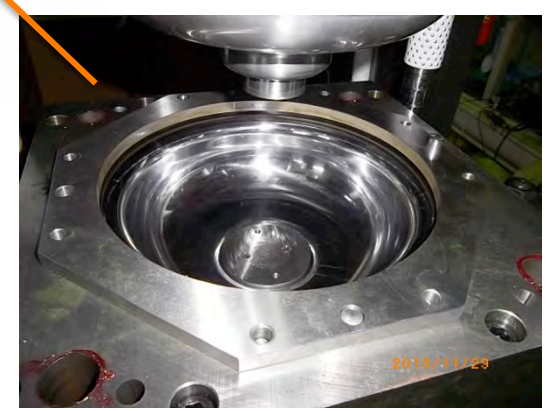


Automatic polishing
for inside cells

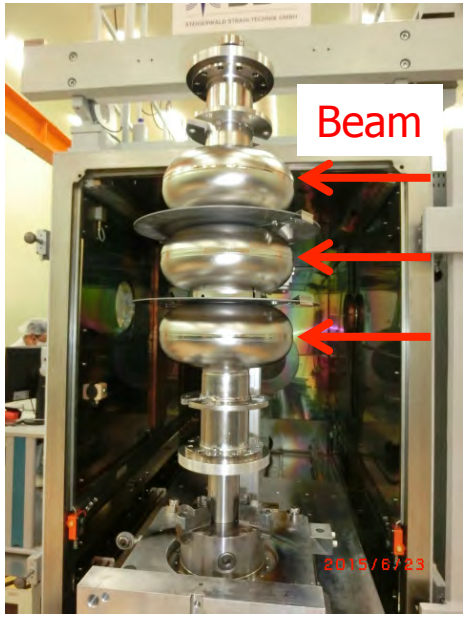
Beam (deflection)



2-beam welding for stiffener ring
Both sides are welded simultaneously



Press forming and machining
for cells are held at company
(Technical transfer)

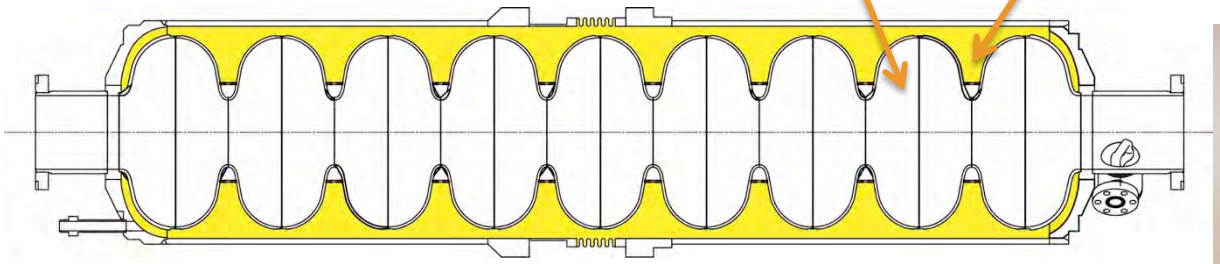


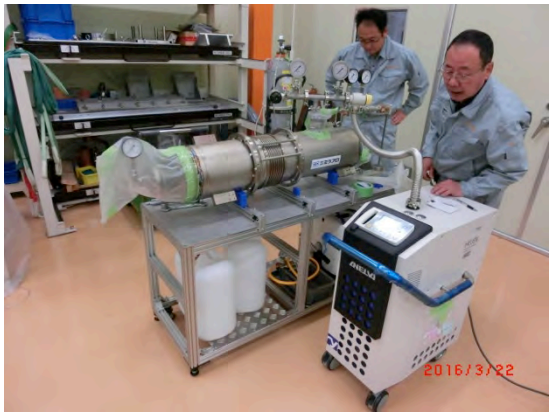
Continuous welding
for equator

Manufacturing He tank and TIG welding

Cavity is placed inside He tank made by Ti

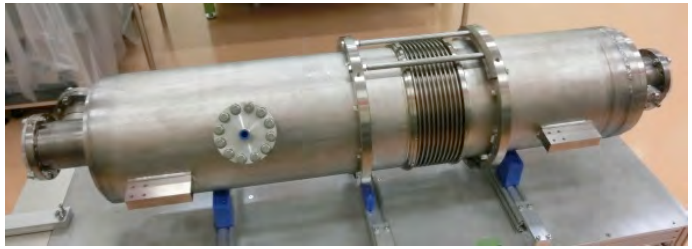
Filled with LHe





Leak check

TIG welding He tank with cavity



Finished

Collaboration with company 1

Objective: Cost reduction of HOM Coupler
Approach : Improve plastic forming techinique

Future business plan :
Buy HOM parts from this company

HOM coupler

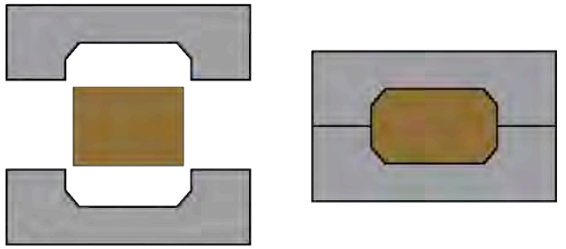
Outer conductor（ϕ48×64）
Manufacturing in plastic forming
to reduce the amount of material
Ordinary : Multiple press forming
New method:
Deep drawing in single forming

Antenna
Ordinary: machining with end mill
New method:
Water jet cutting + press forming

Material after deep drawing
（Height > 70 mm）

- KEK : Drawings of parts
  Provide test niobium material
  Evaluation of performance
- Company : Design of mold & die
  Manufacture mold & die
  Development press forming process
- Regular meeting
- Patent application

Left: Before press, Right: After press



Press forming process

Installed to KEK-1 cavity

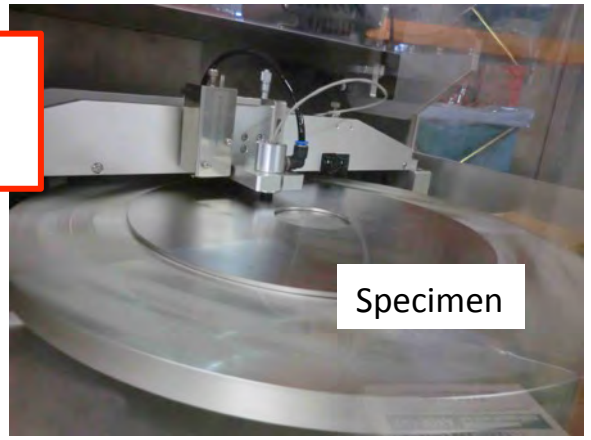
Collaboration with company 2

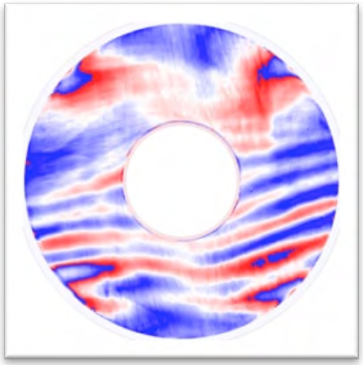
Objective: Bring up new Niobium builder
Approach : To use existence facilities and technology

Future business plan :
Buy niobium from this company

Available to produce niobium ingot (RRR>300)

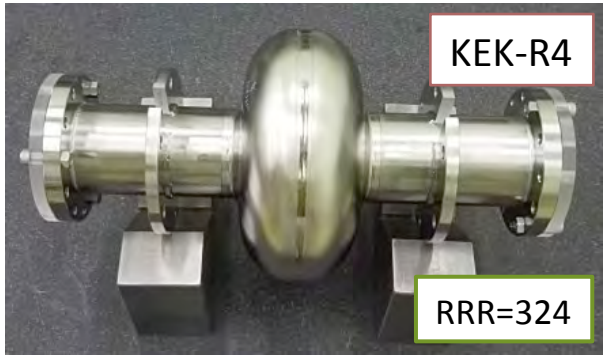
600 kW EB melting furnace（existence facilitiy）



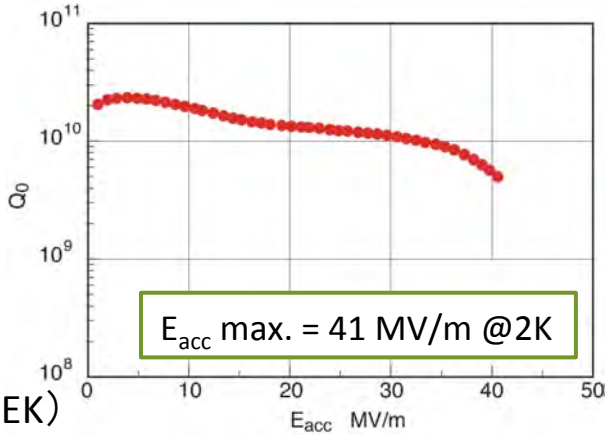


Inspection by eddy current >> No problem

- KEK : Evaluation of performance of niobium material
  Fabrication and evaluation of cavity
- Company : EB melting of niobium
  Evaluation of performance of niobium material
  Production of niobium sheet
- Regular meeting



Fabrication of 1-cell cavity（CFF at KEK）



Result of vertical test（STF at KEK）

Available to use as SRF cavity material

Cost reduction of the Nb material

Principal researcher: M. Yamanaka (KEK)

Motivation

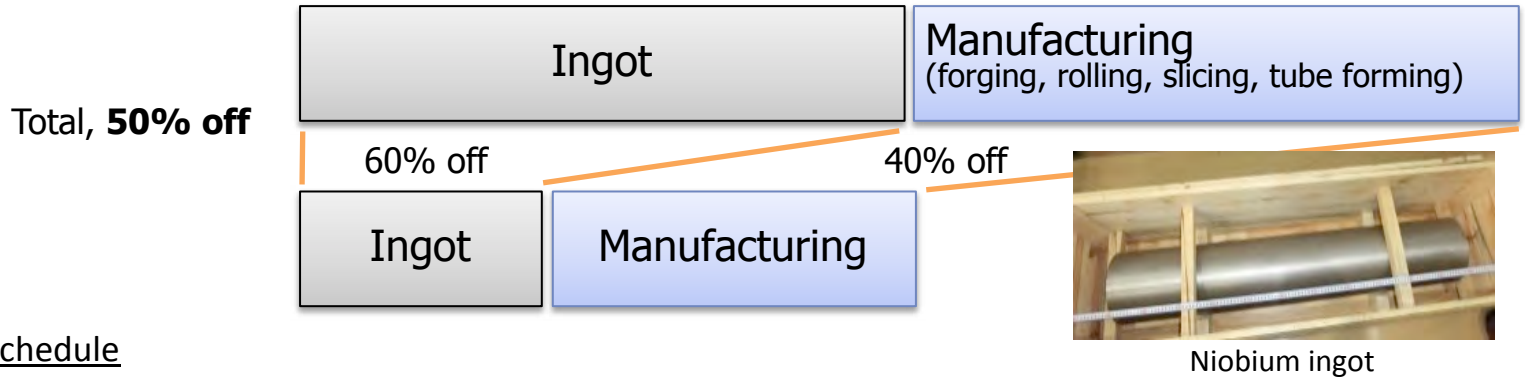
Niobium material cost for fabricating SRF cavity cell and end-groups is relatively high. There are 20 kinds of mechanical parts in 9-cell cavity, which shape and the requirement of performance are different, respectively. If the ingot purity and manufacturing method for each part is optimized precisely as well as satisfying the ILC specification shown in the TDR, the cost will be reduced drastically.

Approach

- Optimize the ingot purity with a lower residual resistivity ratio (RRR) with accepting specific residual content.
- Simplify the manufacturing method such as forging, rolling, slicing and tube forming with small loss.
- Collaborate with material companies

Cost reduction fraction

35%(SRF)*16%(material)*50%(reduction) >> 2 ~ 3% (of ILC total cost in the TDR)



Niobium ingot

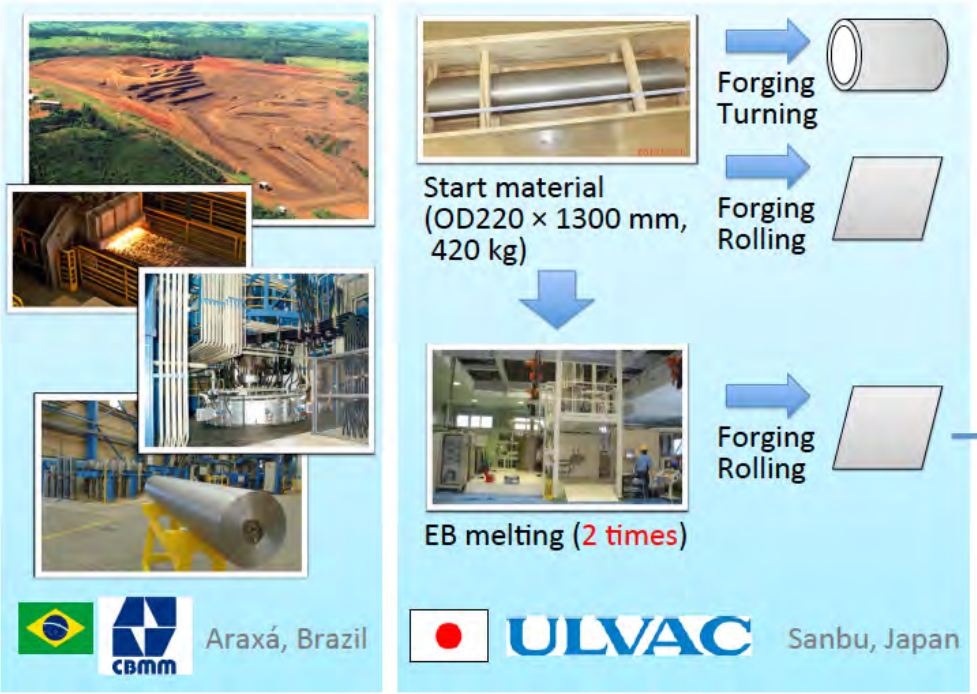
Schedule

	2016-17	2018	2019	2020-
KEK	Feasibility study using 4x3-cell cavities (ongoing)	Preparing materials; Manufacture 8x9-cell cavities	Evaluation (Vertical&Horizontal tests)	Cryomodule test

If the evaluation is succeeded, the test cavities will be assembled in a cryomodule

Cost Reduction of Niobium Material for ILC SRF Cavities

SRF2017: TUPB029

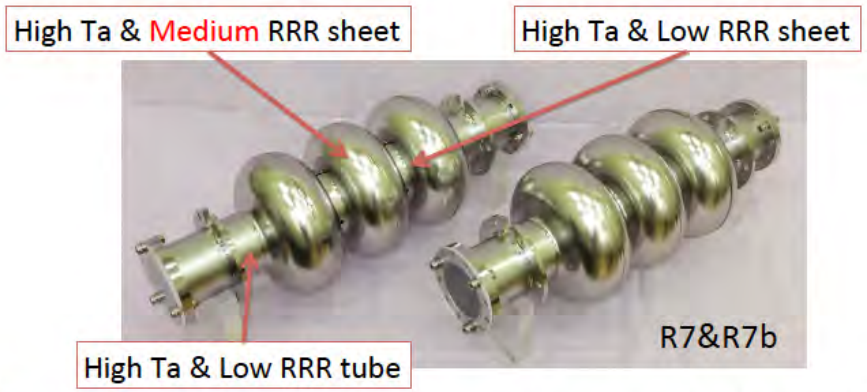


Procedure of material preparation

Chemical compositions and RRR unit: wt ppm except RRR

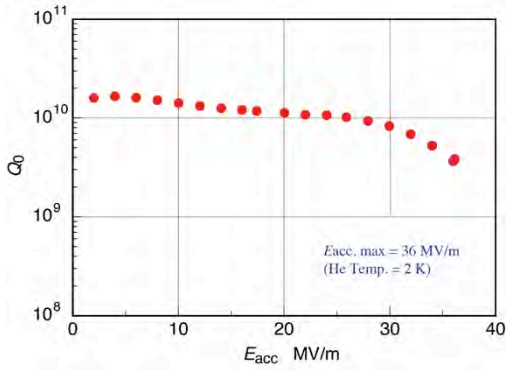
	C	N	O	H	Zr	Ta	Fe	Si	W	Ni	Mo	Hf	Ti	S	RRR*4
Spec. ASTM B391*1	100	100	250	15	200	3000	100	50	500	50	200	200	300	N/A	N/A
Ingot*2	<30	33	26	<2	<1	1194	3	<20	<5	<1	<1	<2	7	<10	60~ 103
Ingot*3	<10	30	<10	1	<10	1210	<10	<10	<10	10	<10		<5		277~ 298

*1 R04210-Type 2, Commercial grade unalloyed niobium
*2 Start material, measured by CBMM
*3 After 2-time EB melting, measured by ULVAC
*4 RRR was measured by KEK



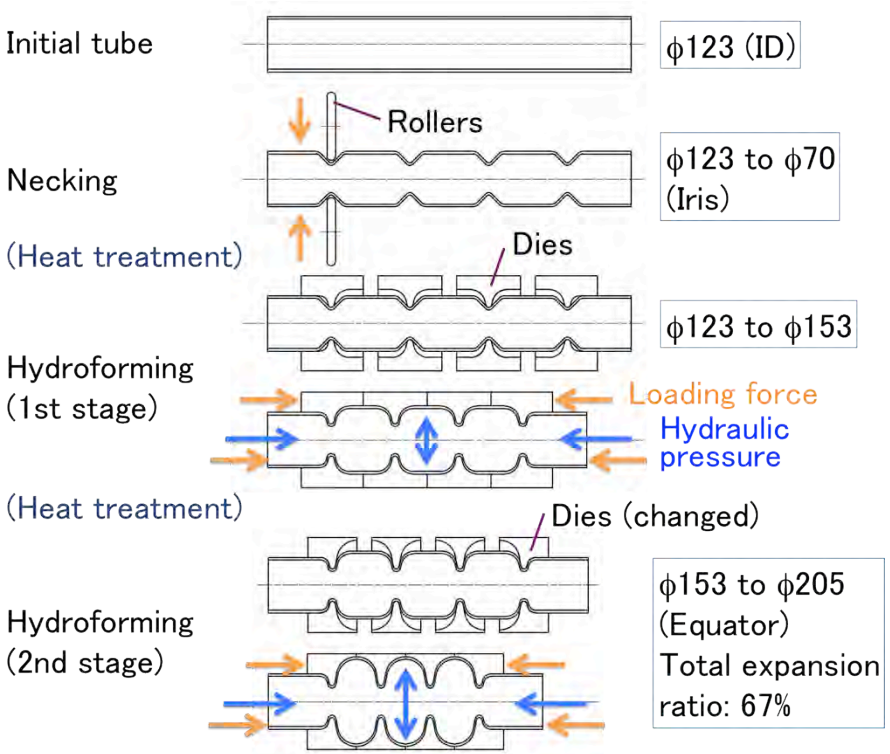
1.3 GHz three-cell cavities manufactured by CFF at KEK
Cell shape: TESLA-like

Waterjet was used in doughnut shape cutting for cells

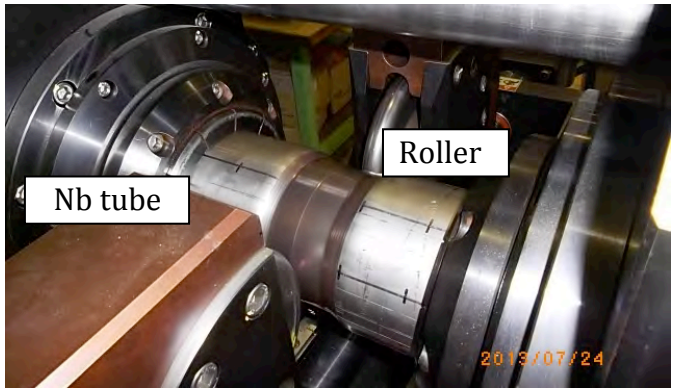


Result of VT (R7b)

Cavity fabrication by hydroforming



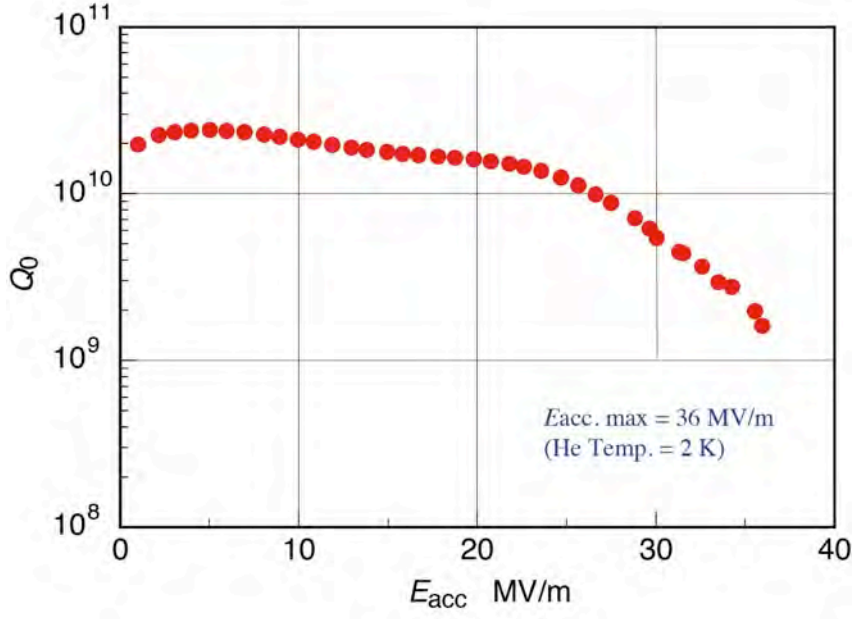
Process of necking and hydroforming



Necking machine

Hydroforming machine
(Final hydraulic pressure: 25 MPa)

1-cell cavity made by hydroforming



ATI Wah Chang
Allegheny Technologies

Nb seamless tube was manufactured by **ATI Wah Chang** and supplied by **FNAL** Fermilab

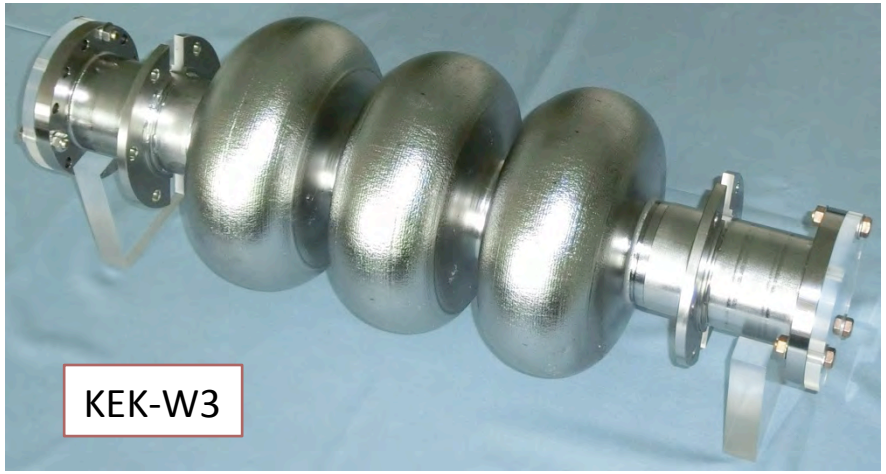
Size: ϕ130-ϕ123 (t3.5) × 450
RRR of ingot Nb: 387 (top)
Hardness: 46 HV

Hydroforming and finishing to cavity were held by **KEK**
Vertical test was also held by **KEK**
Maximum *E*acc: 36 MV/m

Future plan
Hydroforming 9-cell cavity from one long tube

TTC2014@KEK

3-cell cavity made by hydroforming

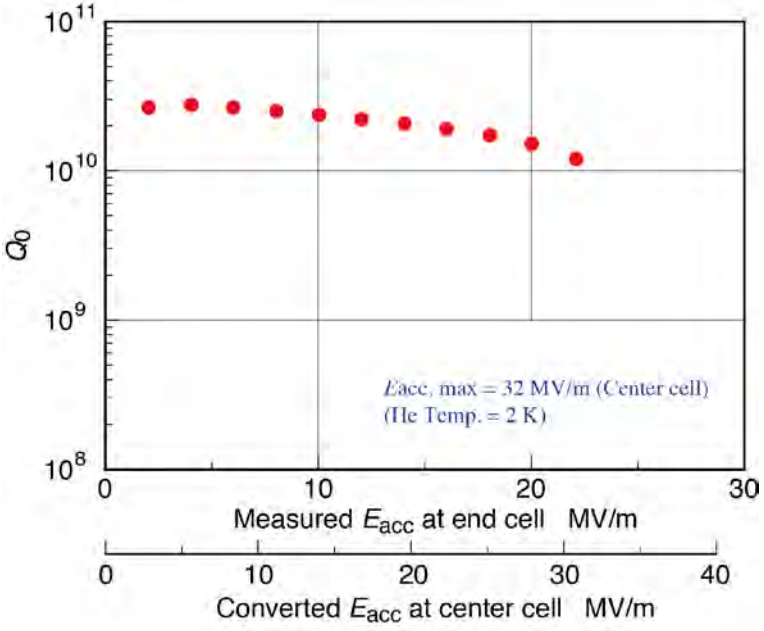


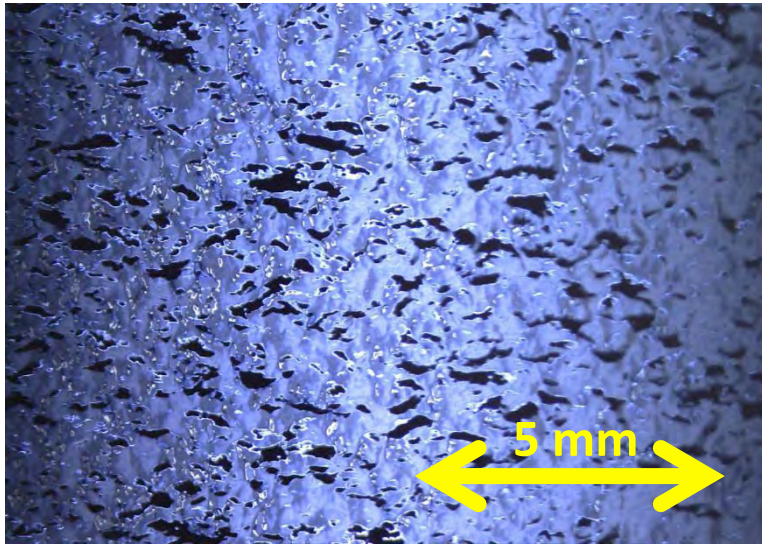
Dimensions of Nb tube

ATI Wah Chang
Allegheny Technologies

Size: ϕ130-ϕ123 (t3.5) × 800
RRR of ingot Nb: 387 (top)
Hardness: 46 HV
Roughness inside: 1 μmRa

IPAC2016@Busan





Inside cavity after EP at equator (Roughness: 9.1 μmRa)
(no welding bead, radial in vertical)

A barrel polishing process was omitted after the hydroforming. The vertical test was carried out with very rough inside surface.

Summary

- Construction of Cavity Fabrication Facility (CFF) was finished in 2011.
- The second cavity named KEK-2 was fabricated in CFF, and its accelerating gradient attained 38 MV/m.
- We totally manufactured three 9-cell cavities and 13 short cavities for R&D.
- Most important porcess to improve productivity is EBW.
- Recent theme is “cost reduction”. Our (CFF’s) viewpoint is low cost niobium material.
- KEK_MEC is carrying out study of seamless cavity.