PHY905 Section 4
Ion Accelerator Technology
Lecture 18
- Performance degradation-free coldmass assembly and advanced cavity fabrication technologies for cost reduction -

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Fundamental Technical R&D for SRF @ KEK

Basic R&D for High Gradient SC Niobium Cavity in KEK L-band Group

High Gradient SC Cavity Eacc ~ 40MV/m

1) High pure niobium material RRR~200
2) Electropolishing (EP)
3) High Pressure Water Rinsing (HPR)
4) Baking (70~140°C)

√

Degradation-free Final Cavity Assembly

Coldmass assembly

1) Opening vacuum with Argon Gas
2) Simple Aluminum Vacuum Sealing

Cost-Effective Cavity Production Method

1) Nb/Cu Clad Seamless Cavity
2) Simplified Surface Treatment

High Gradient & Highly Reliable & Cost-effective SC Cavity

18 Outline

- 18.1 Coldmass Assembly
- 18.2 Cost-effective cavity fabrication method
- 18.2.1 Large Grain Cavity
- 18.2.2 Seamless Cavity Fabrication
    - Nb spun cavities
    - Hydroforming
    - Nb/Cu clad seamless cavities

18.1 Degradation-free Coldmass Assembly
Homework from TRISTAN

- Cavity Performance Degradation after Cryomodule Assembly in the TRISTAN SRF
- Indium Contamination
- Particle Contamination
- Oxidation by Air Vacuum Break
- Vacuum Break by Nitrogen Exposure

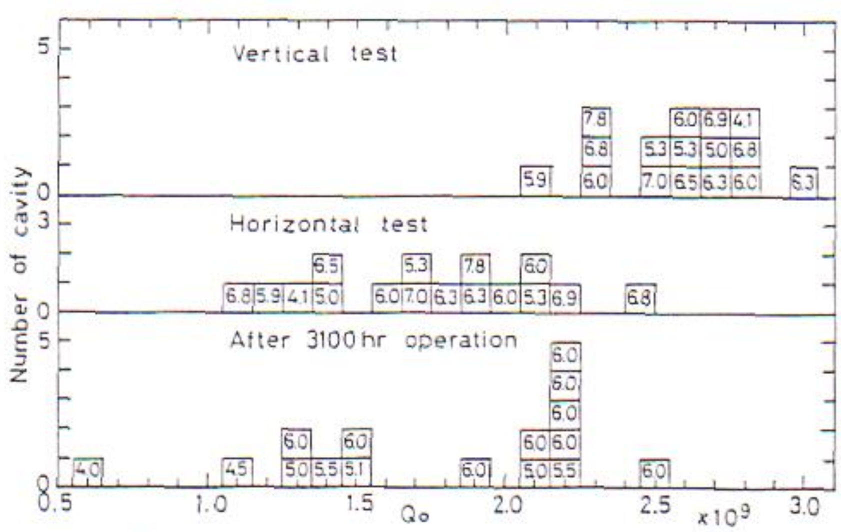
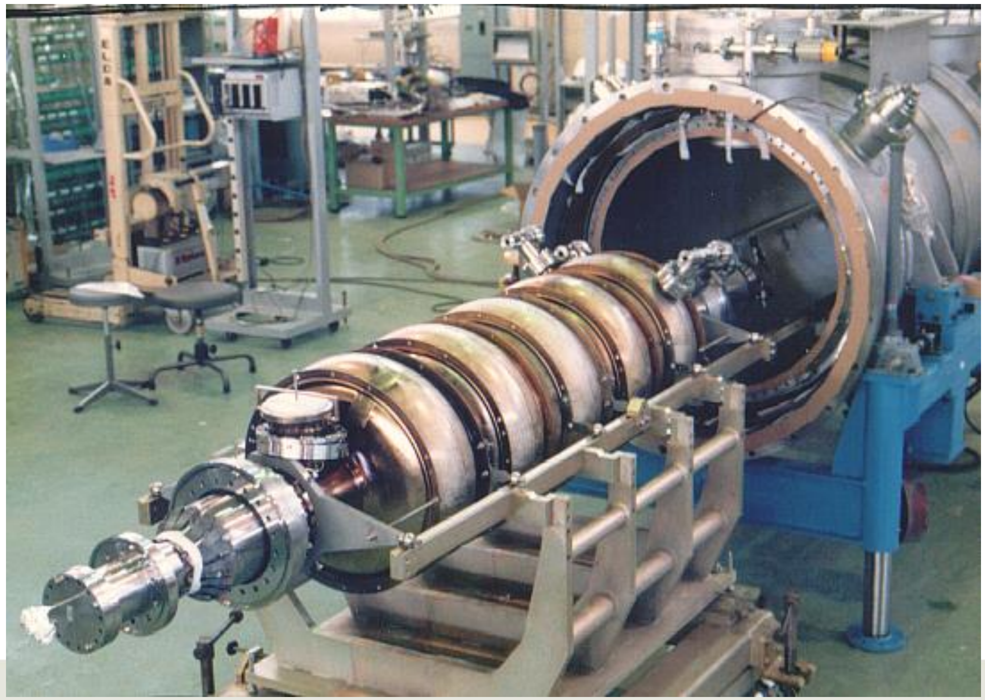


Fig.69

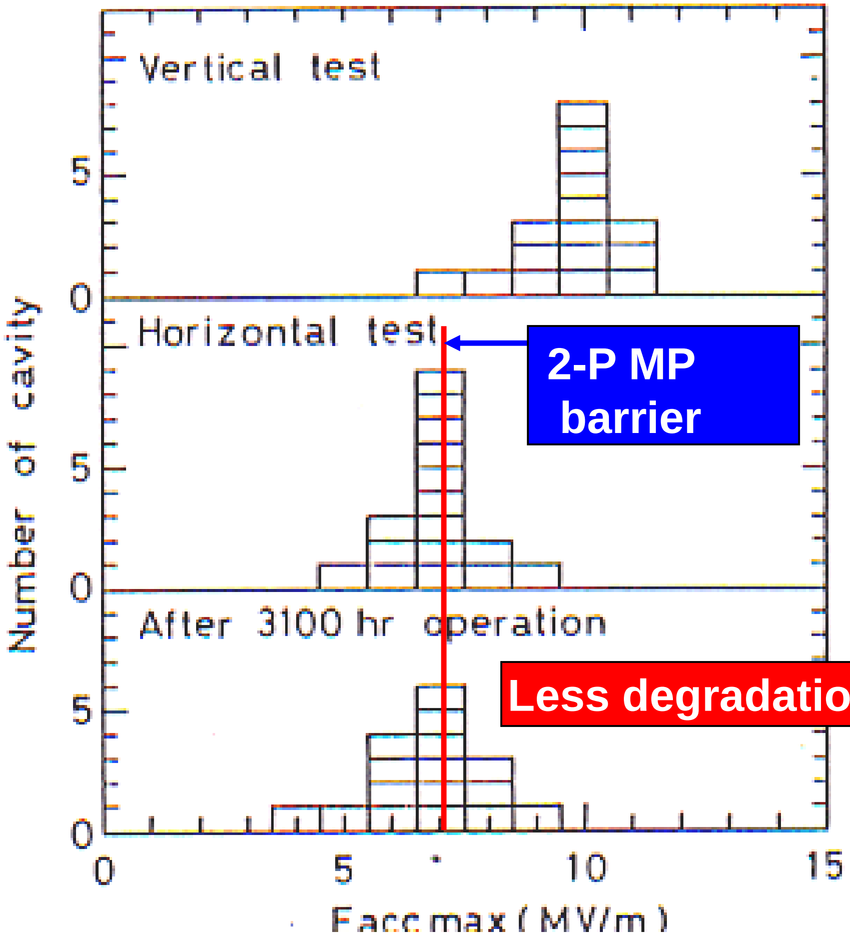
TRISTAN Coldmass Assembly

1) Break vacuum by pure N_2 gas after Vertical test
2) Remove input coupler (Indium seal) and Put blank flange
3) Remove blank flange (Indium seal) and put HOM couplers
4) Join two cavities at the center by Indium seal

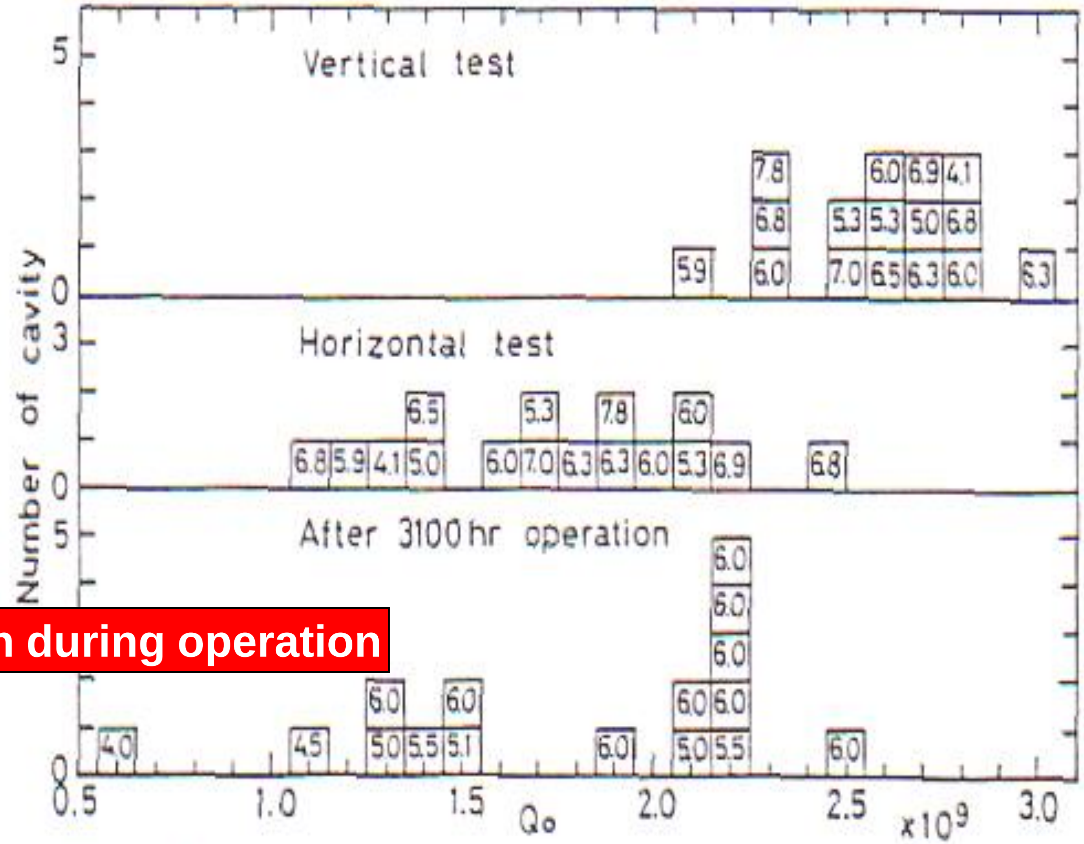
Cryomodule assembly keeping N_2 gas in the
the cavities
1)Insert the paired cavity into cryostat
2)Input coupler on the cavity in the local cleanroom



Performance Degradation After Cryomodule Assembly in TRISTAN SRF



Degradation of the gradient



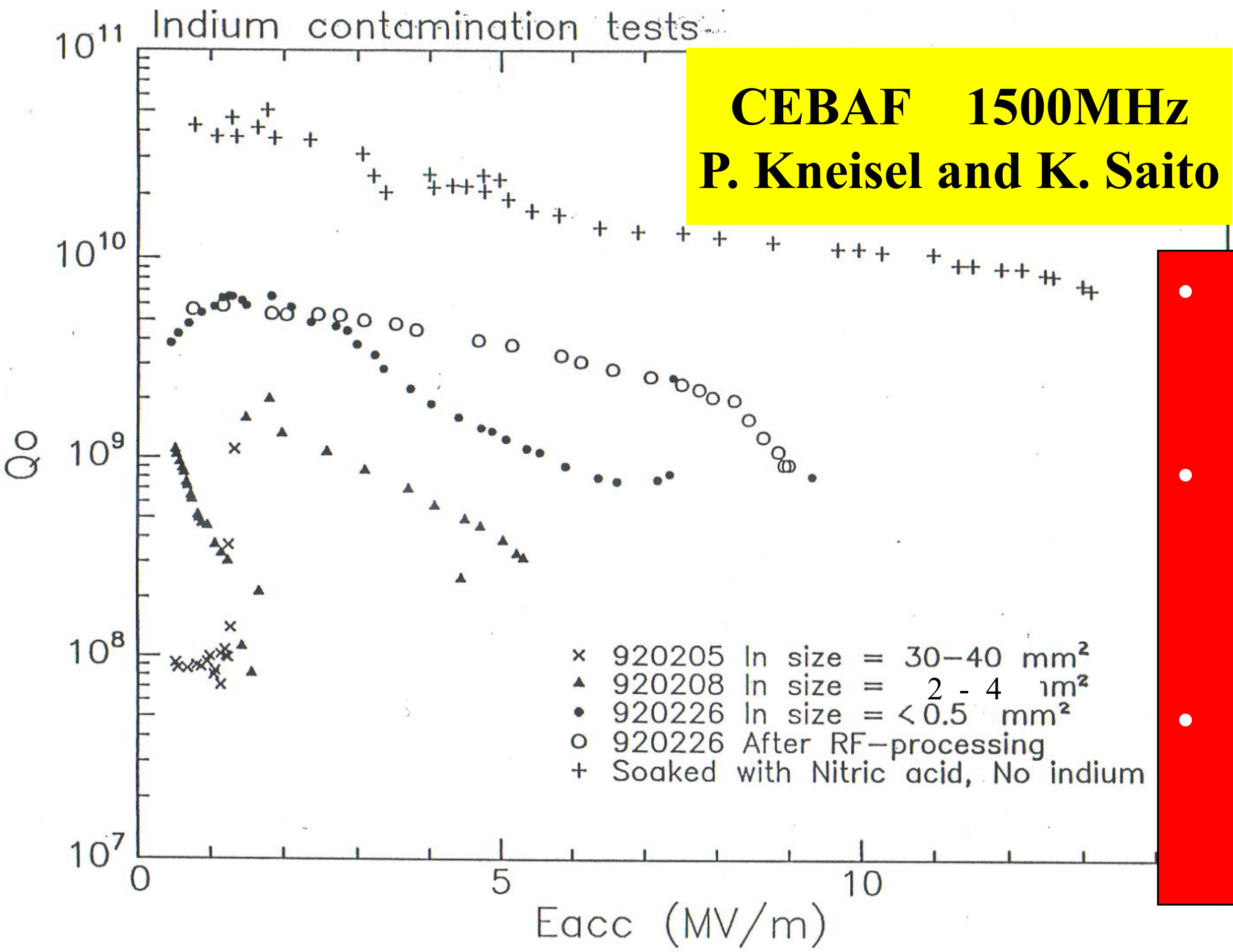
Degradation of the Qo, very much scattered after cryomodule assemble

Homework in the TRISTAN: What is(are) cause(s) of the degradation ?

Potential Causes

- Indium contamination
- Particle contamination during vacuum break by pure N_2 gas
- Cavity surface oxidation
- Nitrogen – Nb reaction
- Others

Internal Indium Contamination



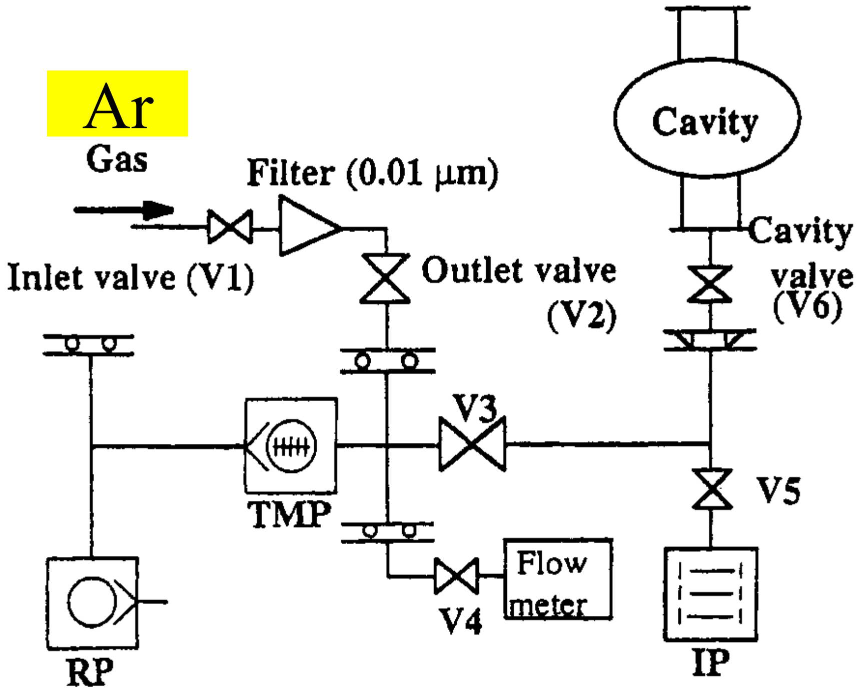
CEBAF 1500MHz
P. Kneisel and K. Saito

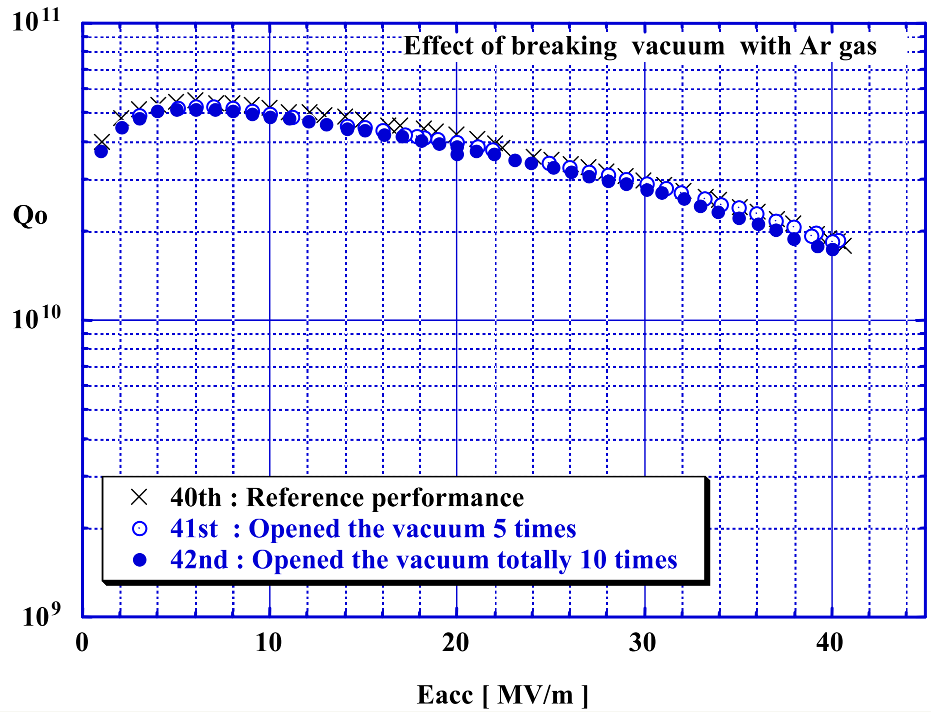
$$\Delta\left(\frac{1}{Q_o}\right) = \frac{1}{Q_{In}} - \frac{1}{Q_o} = \frac{1}{2} R_s^{In}(\Omega) \cdot S_{In}(m^2)$$
$$= 3.09 \cdot 10^{-2} \cdot R_s^{In}(\Omega) \cdot S_{In}(m^2)$$

- Indium Contamination produces a big degradation.
- Maybe too large to explain the TRISTAN Experience
- Recently, many of SRF Institutes stop to use Indium sealing

Gas Exposure System for Vacuum Break

- Gas exposure system was developed to investigate the vacuum break
  - The system was tested to be clean using Ar gas
  - Vacuum break with Ar gas was repeated 5 times then cold tested (no HPR after the Ar exposure), no degradation was observed (Test 41st)
  - After the test 41st, the same procedure was repeated 10 times and cold tested (no HPR after the Ar exposure) , no degradation observed (Test 42nd)



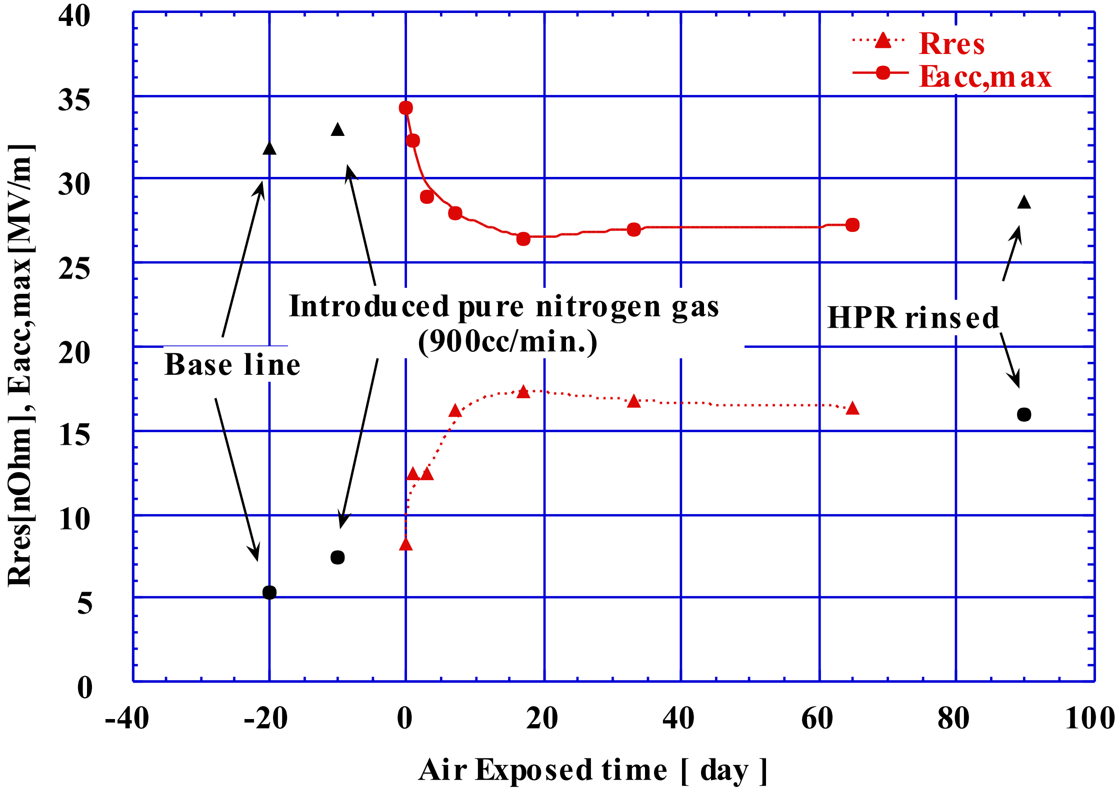


Air Exposure

Air exposure test procedure

1) Baseline test
2) Nitrogen gas exposure for 10 days) and evacuation, and cold tested
3) Oxygen exposure 1 day to 85 days (totally), no HPR
4) HPR before the final test (85 days exposure))

- Qo and gradient both degraded within 10 days exposure
- Degradation was saturated after 10 days exposure
- HPR never recover the performance, which suggest the degradation does not related to particle contamination.

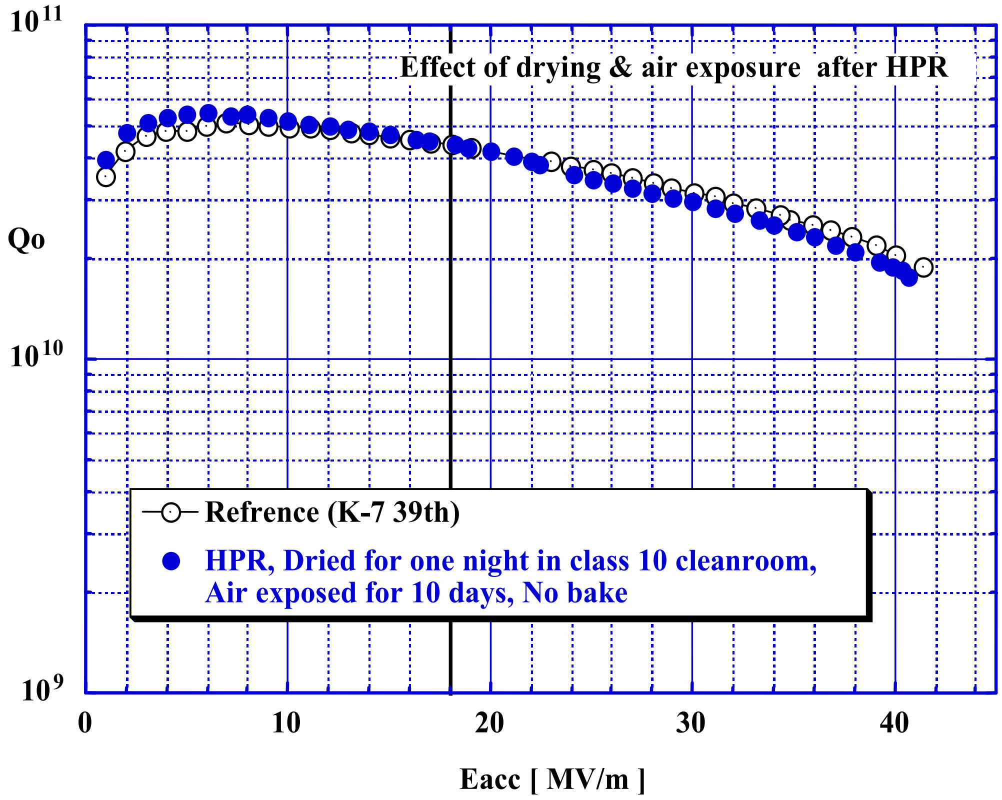


Air Exposure Followed by HPR

Air exposure followed by HPR test

1) Baseline test (baked 120^{O}C)
2) Vacuum break by Air and Disassemble in the class 10 cleanroom
3) HPR and dried and exposed in air for 10 days in the class 10 cleanroom
4) Evacuation (no bake) and cold test

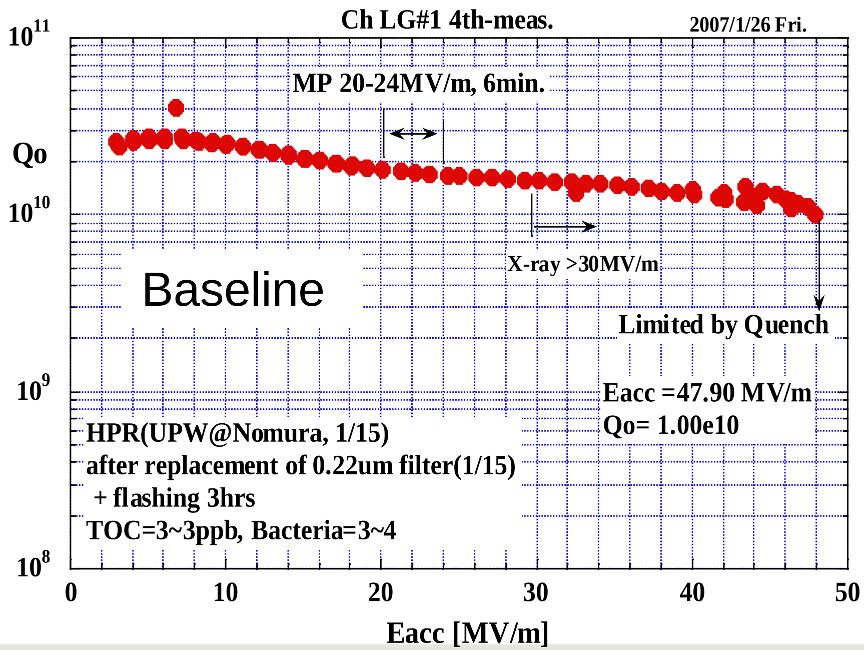
- The result shows no degradation even 10 days air exposure.
- This air exposure impact is different from previous slide, of which reason is not yet understood.
- Bake effect (120^{O}C) is remained by HPR.

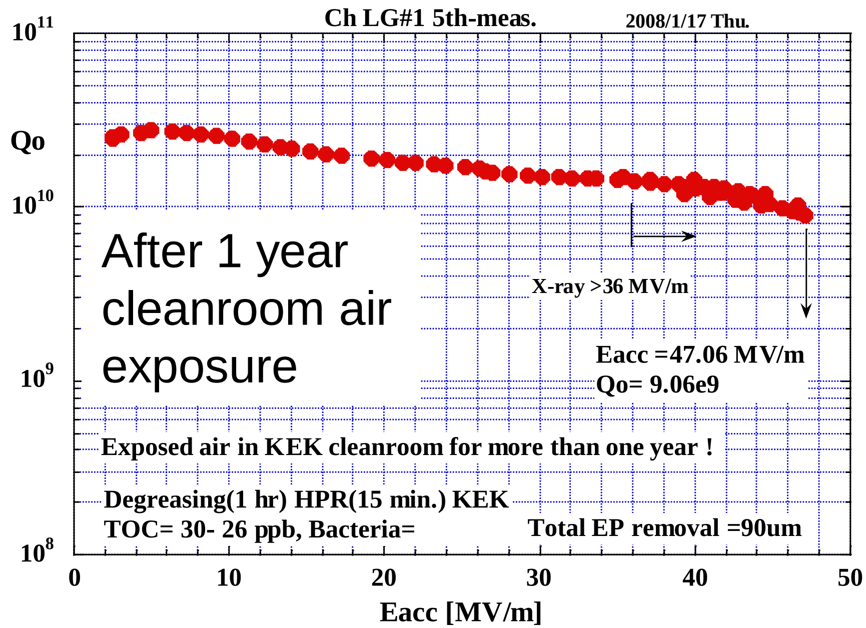


Air Exposure Effect in Long Term with Large Grain Cavity

CH LG#1 cavity was re-tested, which was fabricated at KEK in 2006 used Ningxia large grain niobium material. The cavity was tested once and after disassembly it was left in KEK class 10 cleanroom for one year. Prior to the re-measurement, the cavity was degreased and made HPR. No degradation was observed against such a long term air exposure.

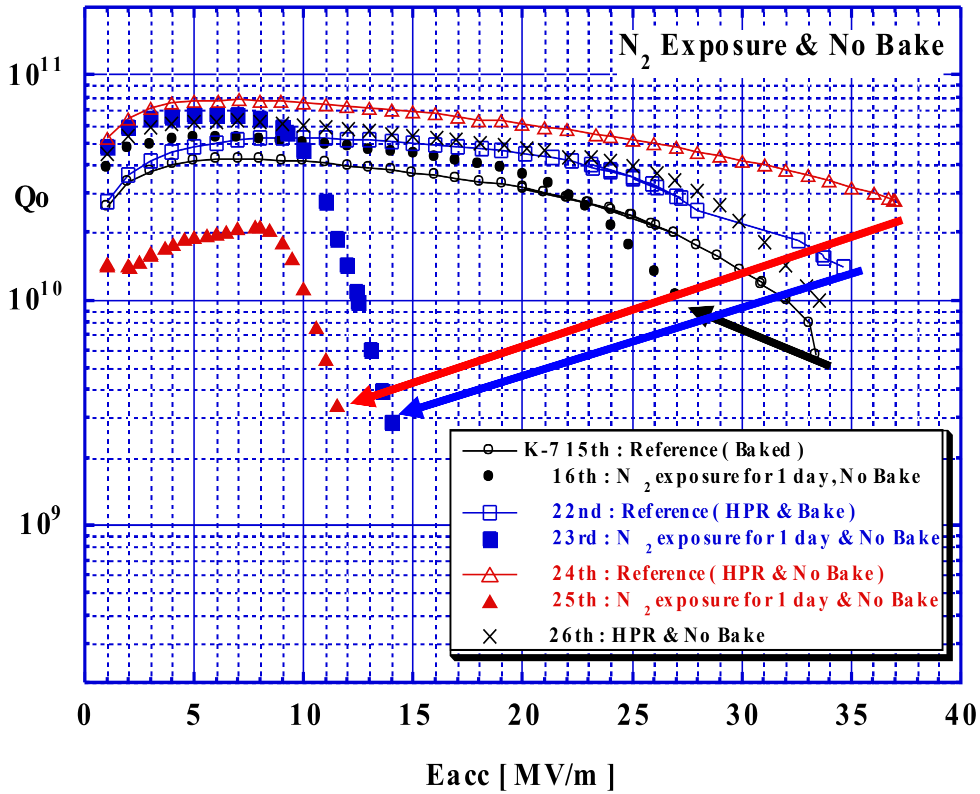
Niobium SRF surface is very stable!
No degradation was found after one year cleanroom air exposure.

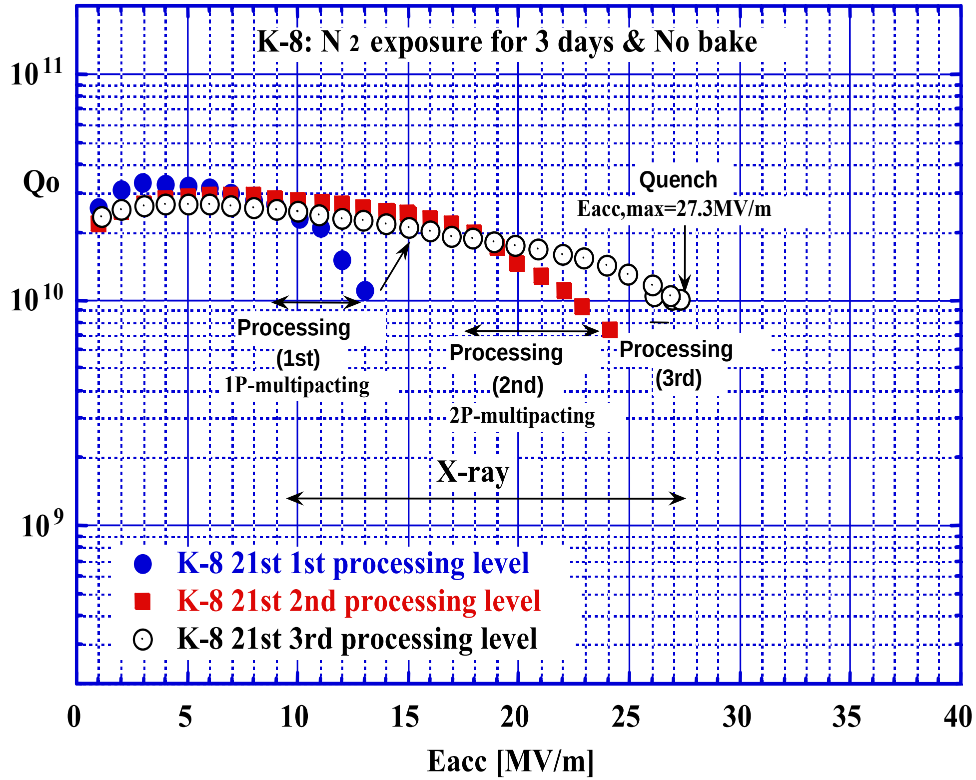




Pure Nitrogen Gas Exposure

N_2 exposure and no bake





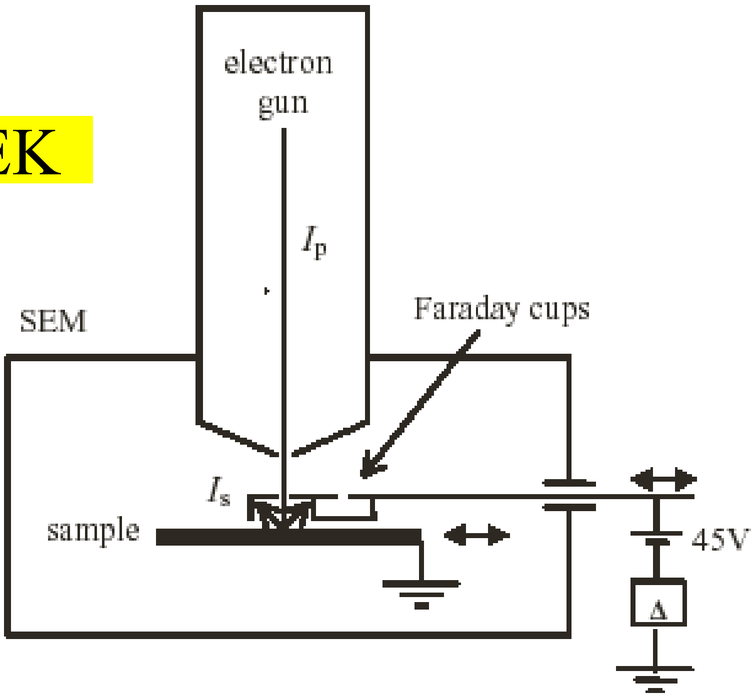
- **Pure nitrogen gas exposure produces a rather big degradation both Qo and gradient.**
- **These degradations are the level explainable the degradation in TRISTAN SRF cavities after cryomodule assembly.**

Secondary Coefficient Measurement

Secondary emission coefficient measurement

Confirmed that N_2 exposure enhances the secondary emission coefficient.

KEK



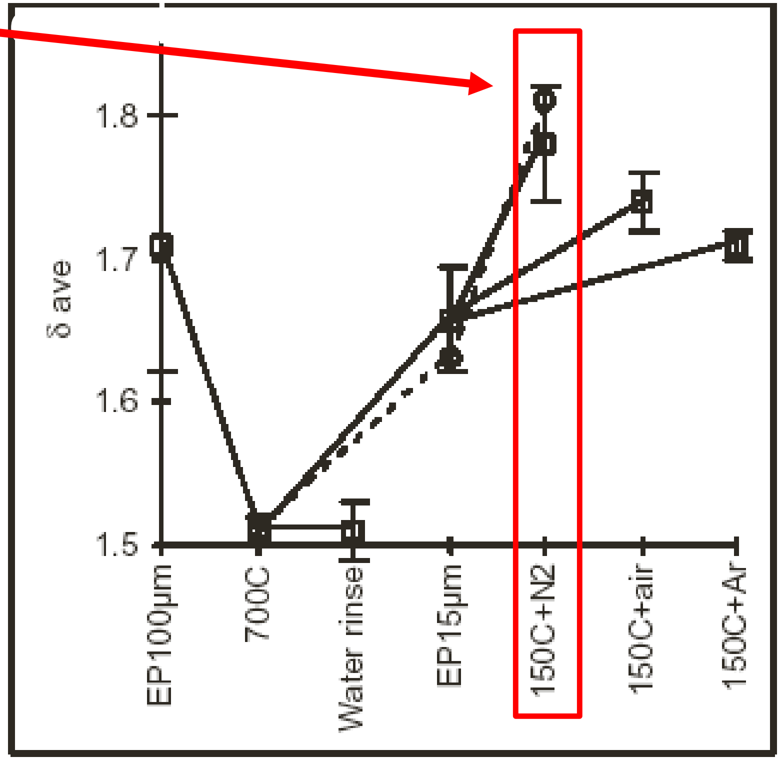
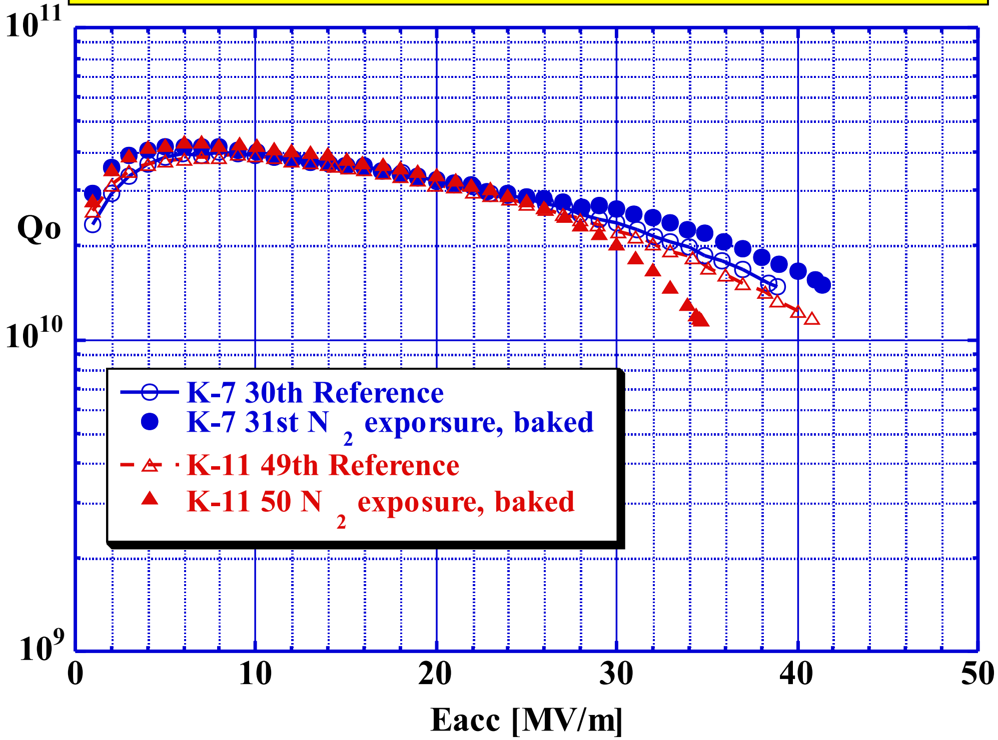


Figure 4: Average δ at 1keV as a function of sample treatments. To the right of the 700C point, dashed (solid) lines connects points made on samples rinsed with ozonized (ordinary) water after the final EP.

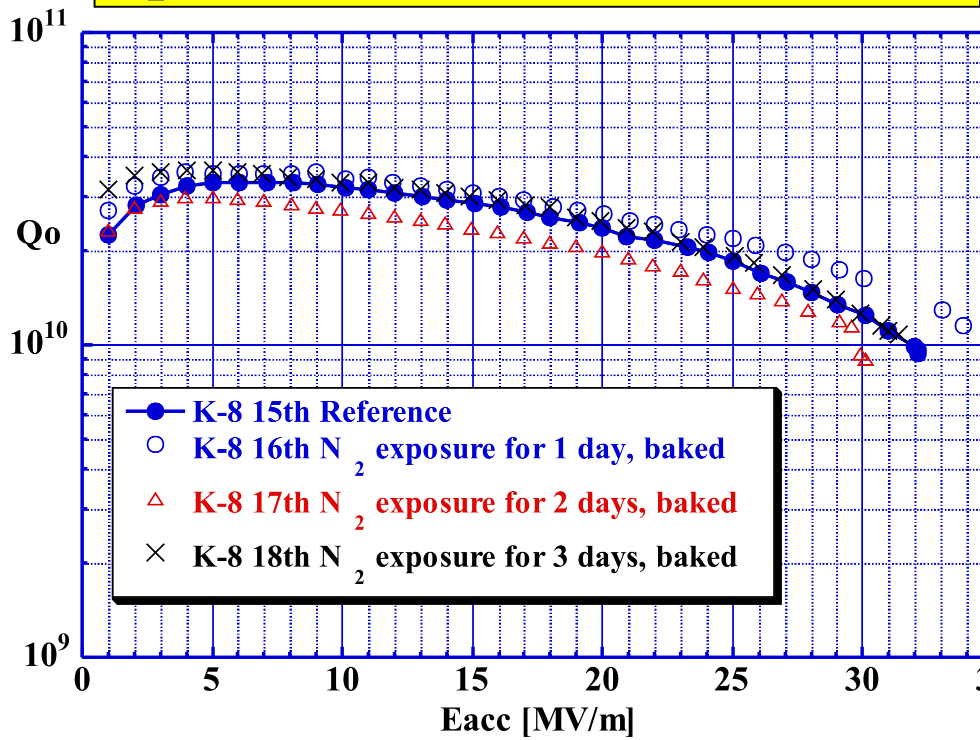
Low Temperature Bake Mitigates the N_2 Exposure Degradation

- Low temperature baking after N_2 exposure mitigates the degradation, while the mechanism is not yet understood.
- Even for long term N_2 exposure, low temperature bake mitigates the N_2 exposure degradation

N_2 exposure (one day)+110^{O}C bake

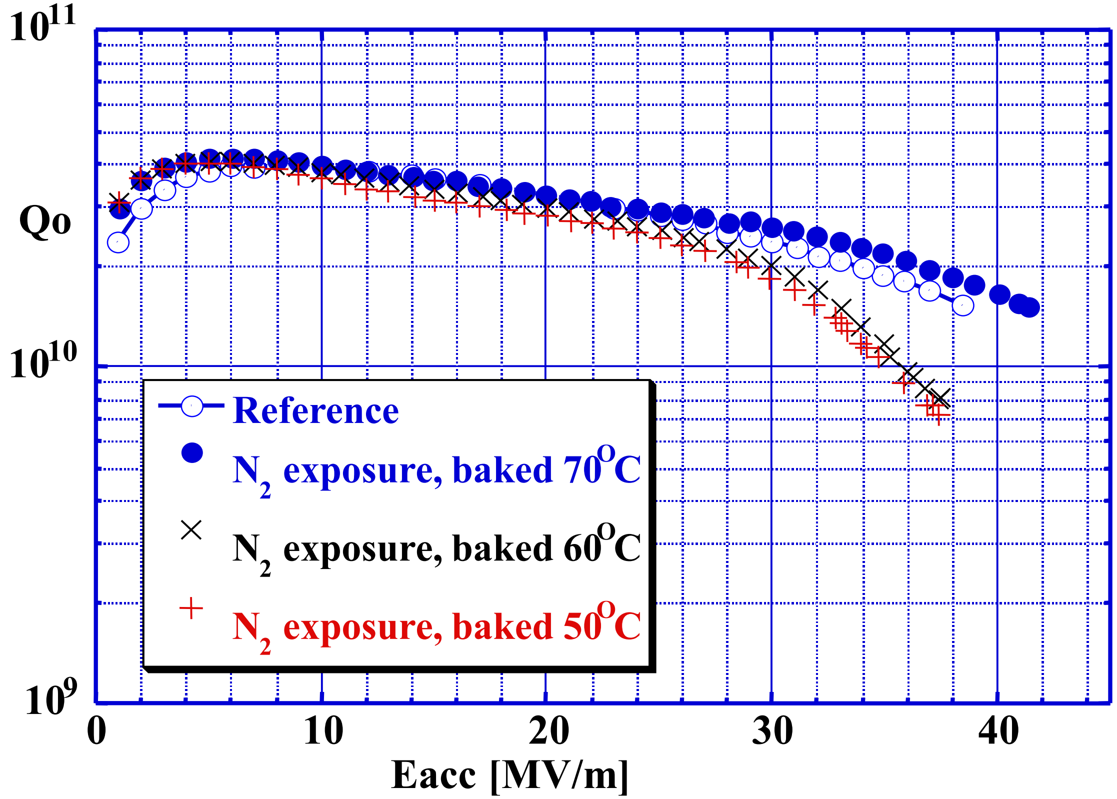


N_2 exposure (1-3 days)+110^{O}C bake



Effective Bake Temperature

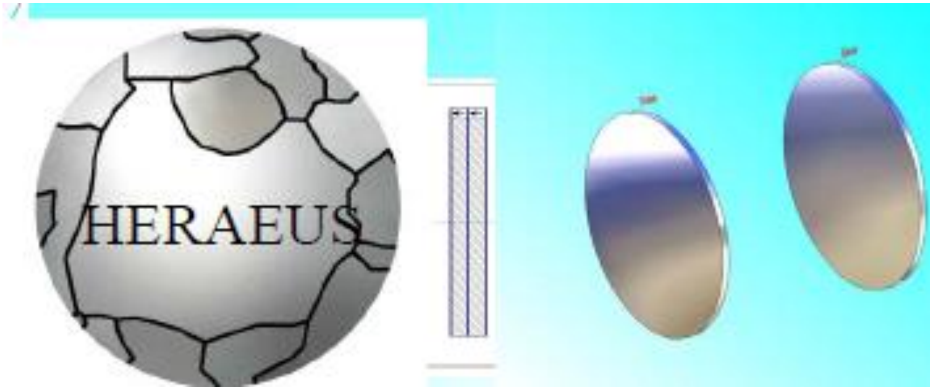
- Effective bake temperature is T > 70^{O}C
- No low temperature bake after cryomodule assembly in the TRISTAN
- The degradation after cryomodule assembly in TRISTAN can be explained by N_2 exposure and no bake.



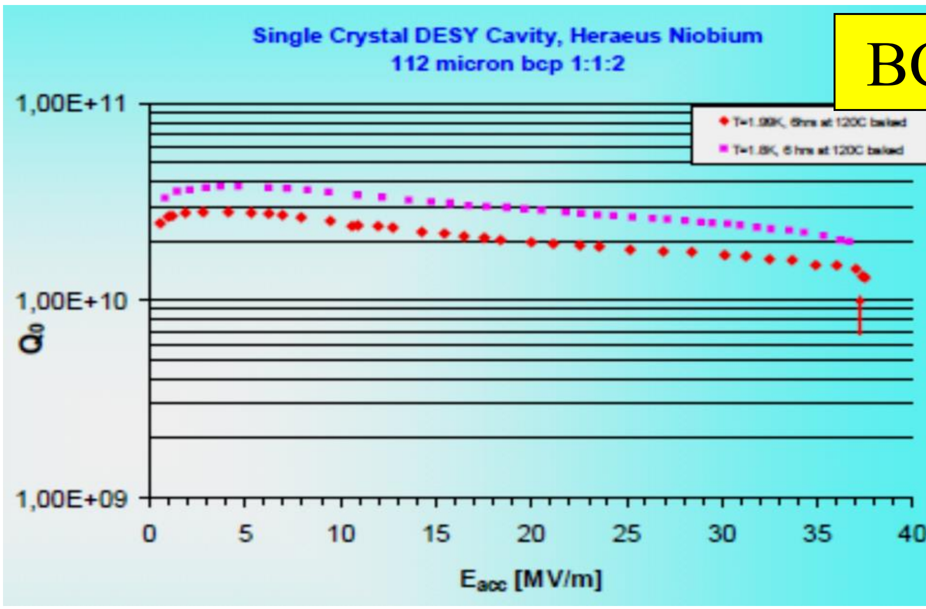
18.2 Cost-effective Cavity Fabrication Method

Large Grain/Single Crystal Nb Cavity (1.3GHz single cell cavity) @ DESY

By W. Singer



Measured at JLAB by P. Kneisel



BCP+HPR+Bake

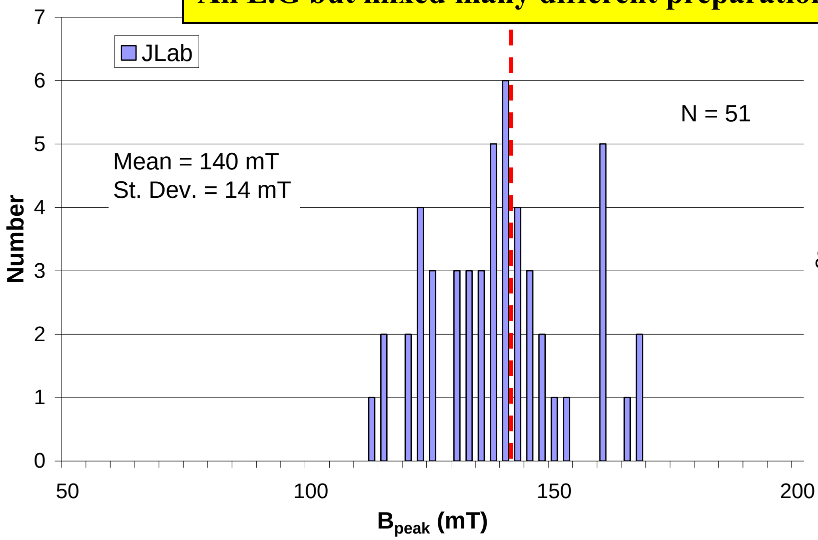
Reached the ILC Goal by BCP

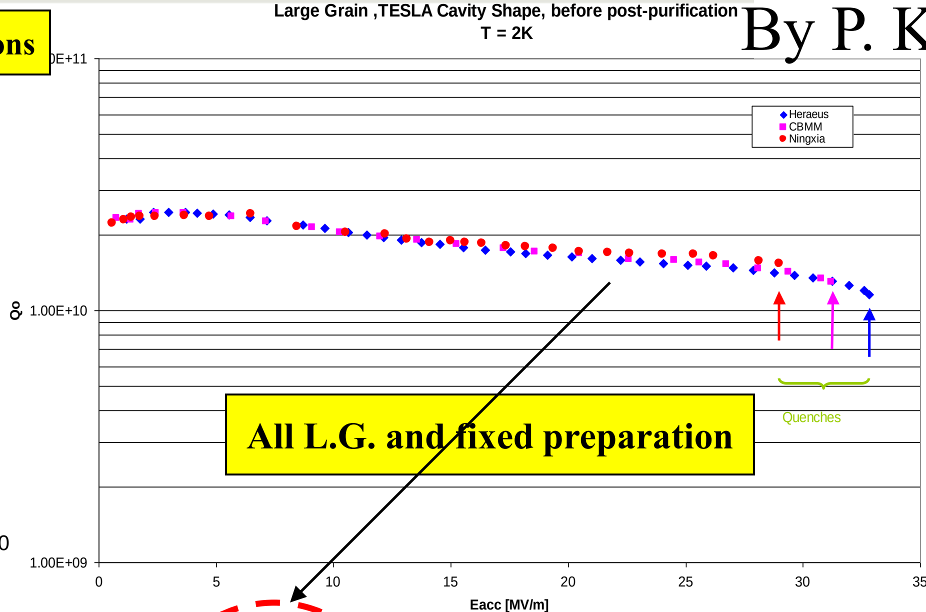
11-13/May/2011
K.Saito

Trend of Small Performance Scatter (5%) with Large Grain Nb Cavities Even by BCP

By P. Kneisel

All L.G but mixed many different preparations





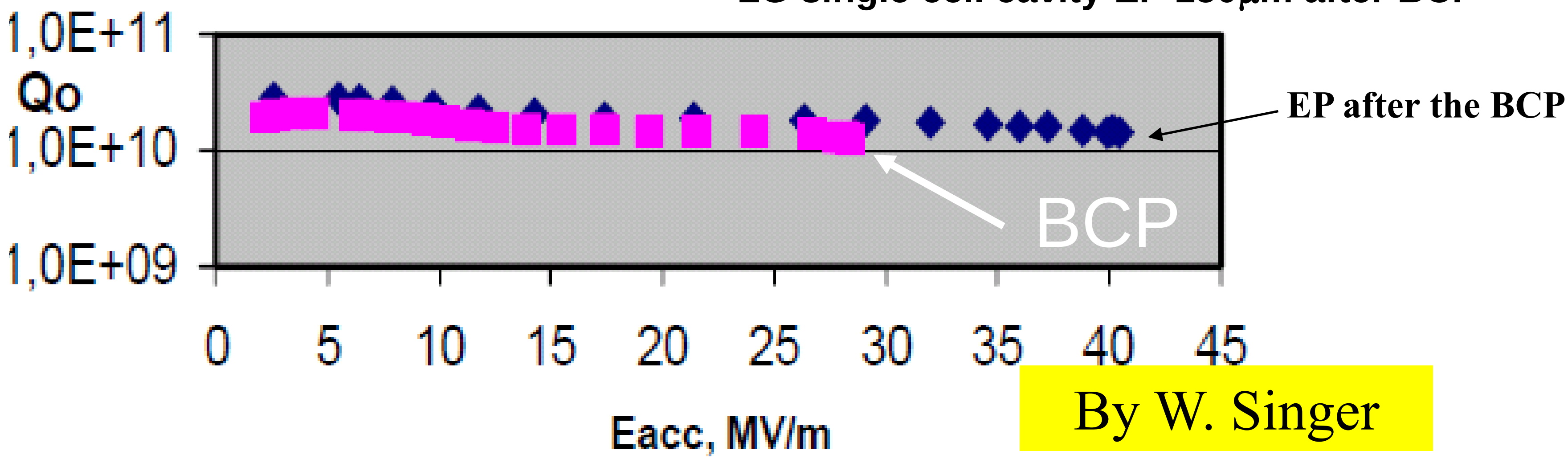
All L.G. and fixed preparation

After post purification

Supplier	Cavity Type	Ta - contents	RRR	Test ½ H_{max} [mT]	Test ½ Q_0 at H_{max}	Test ¾ H_{max} [mT]	Test ¾ Q_0 at H_{max}
W.C.Heraueus	TESLA	<500 ppm	500	140	1.15×10^{10}	146	1.05×10^{10}
Ningxia	TESLA	~ 100 ppm	330	123	1.5×10^{10}	142	1.14×10^{10}
CBMM	TESLA	~ 800 ppm	280	133	1.3×10^{10}	131	1.04×10^{10}
CBMM	Proton Driver	~ 800 ppm	280	139	7.5×10^{9}	148	6.9×10^{9}
CBMM	Proton Driver	~ 800 ppm	280	133	4.4×10^{9}	135	1×10^{10}

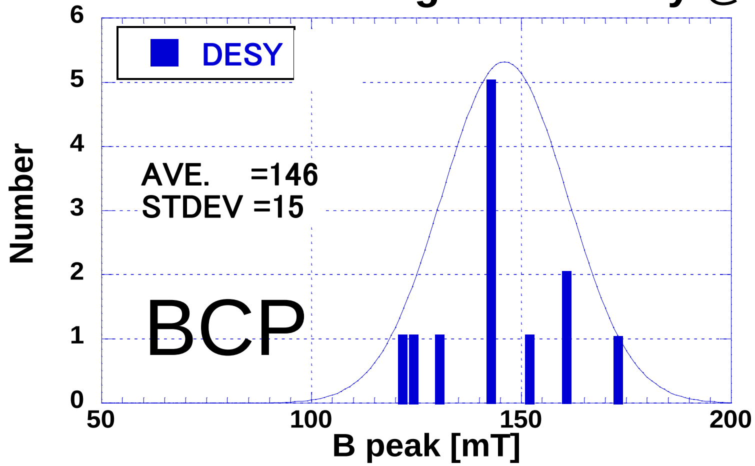
EP Superiority with High Gradient in Large Grain Nb Cavities

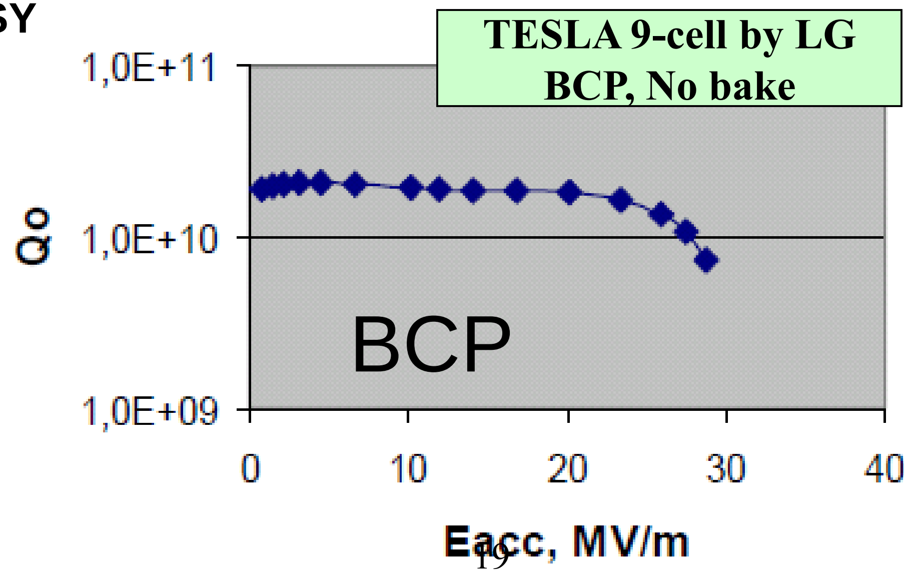
LG single cell cavity EP 150μm after BCP



By W. Singer

Statistics of LG with single cell cavity @ DESY





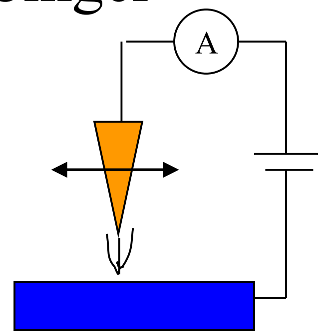
Eacc ave=34.3±3.5MV/m(10.3%)

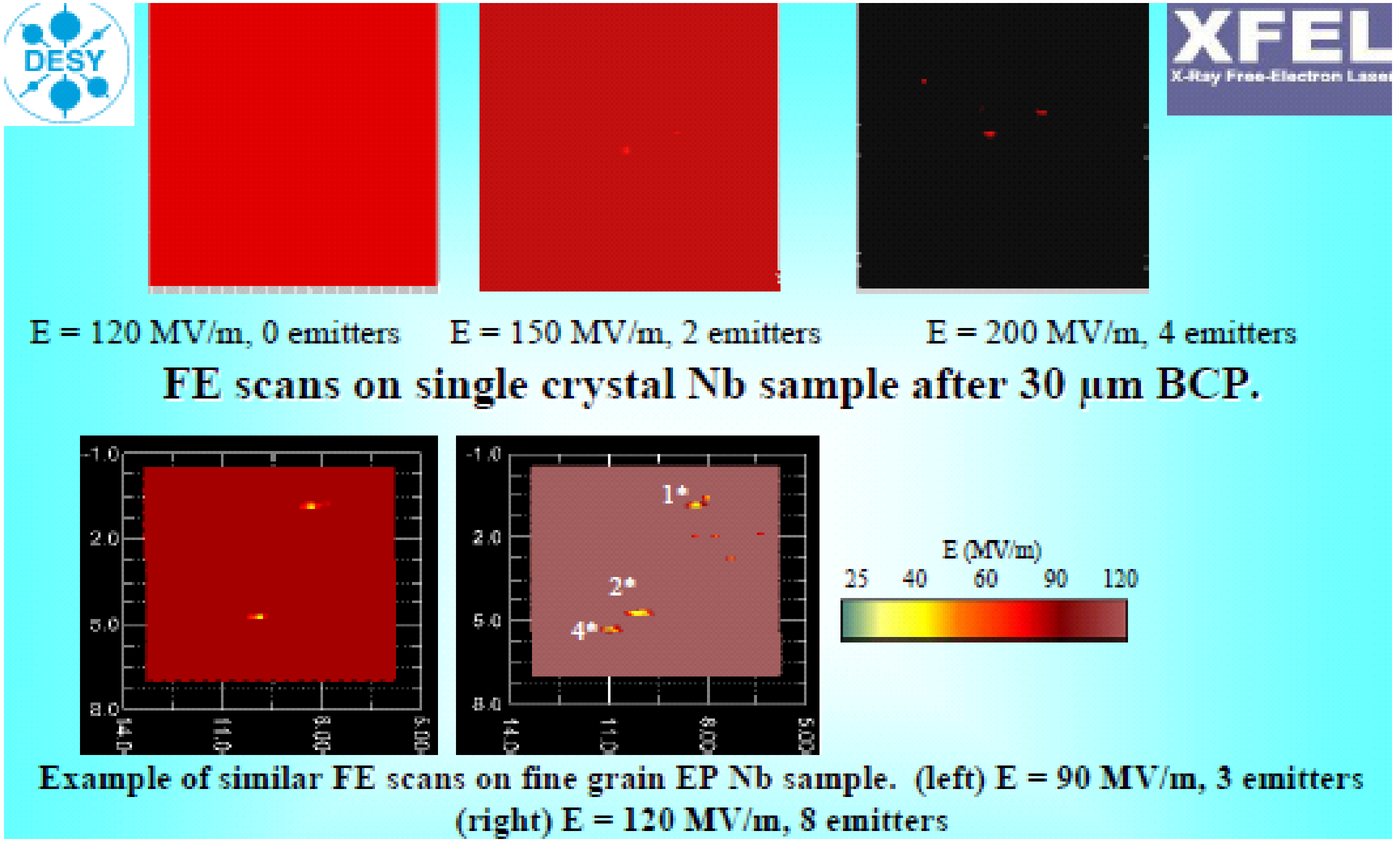
FE. Onset Field on Single Crystal Niobium

Single crystal has higher FE. Onset Field

- FE. Onset field is much higher with single crystal compared to fine grain

By W.Singer





FE scans on single crystal Nb sample after 30 µm BCP.

Example of similar FE scans on fine grain EP Nb sample. (left) E = 90 MV/m, 3 emitters (right) E = 120 MV/m, 8 emitters

Ep=120MV/m ⇨ Eacc = 50MV/m with ICHIRO cavity

Benefits/Disadvantages of LG Nb

▪ Benefits

1) Cost reduction
   - Opinions are distributed 10-50% reductions
   - Development of the ingot slice method is a key.

2) Narrow performance scatter

3) Less field emission

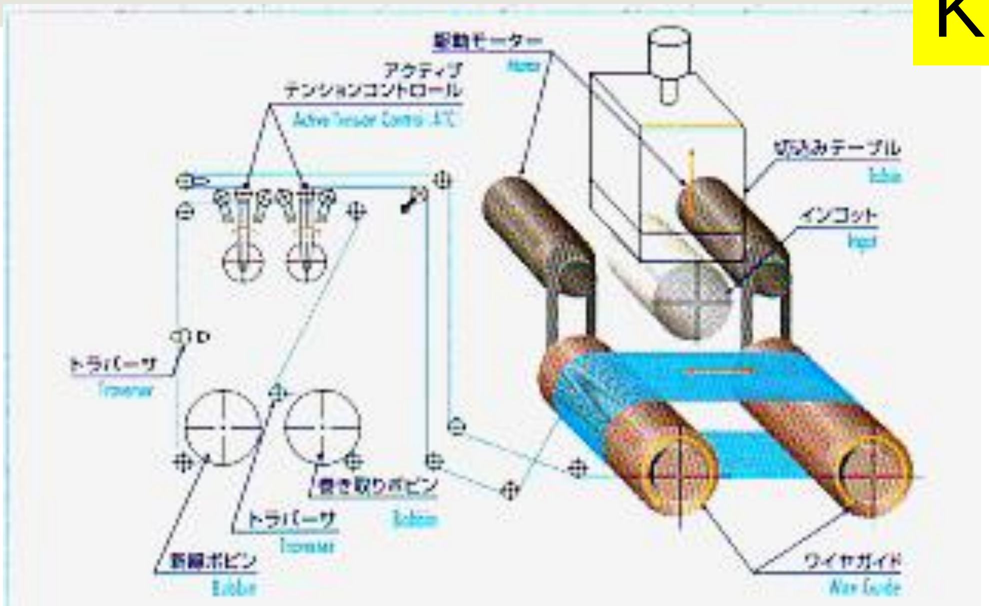
▪ Disadvantages

1) Machining error

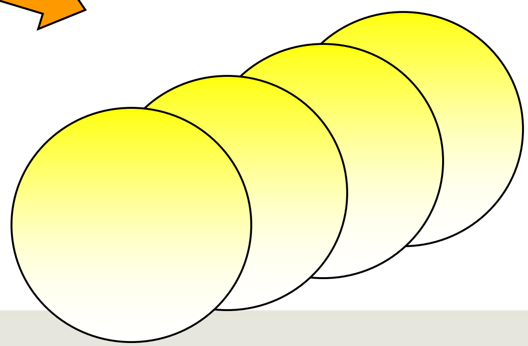
2) Stiffness

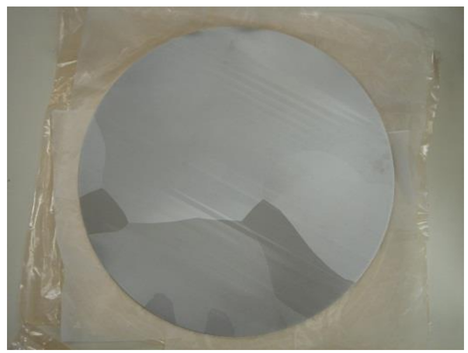
Idea for Cost-effective Nb sheet production

K. Saito



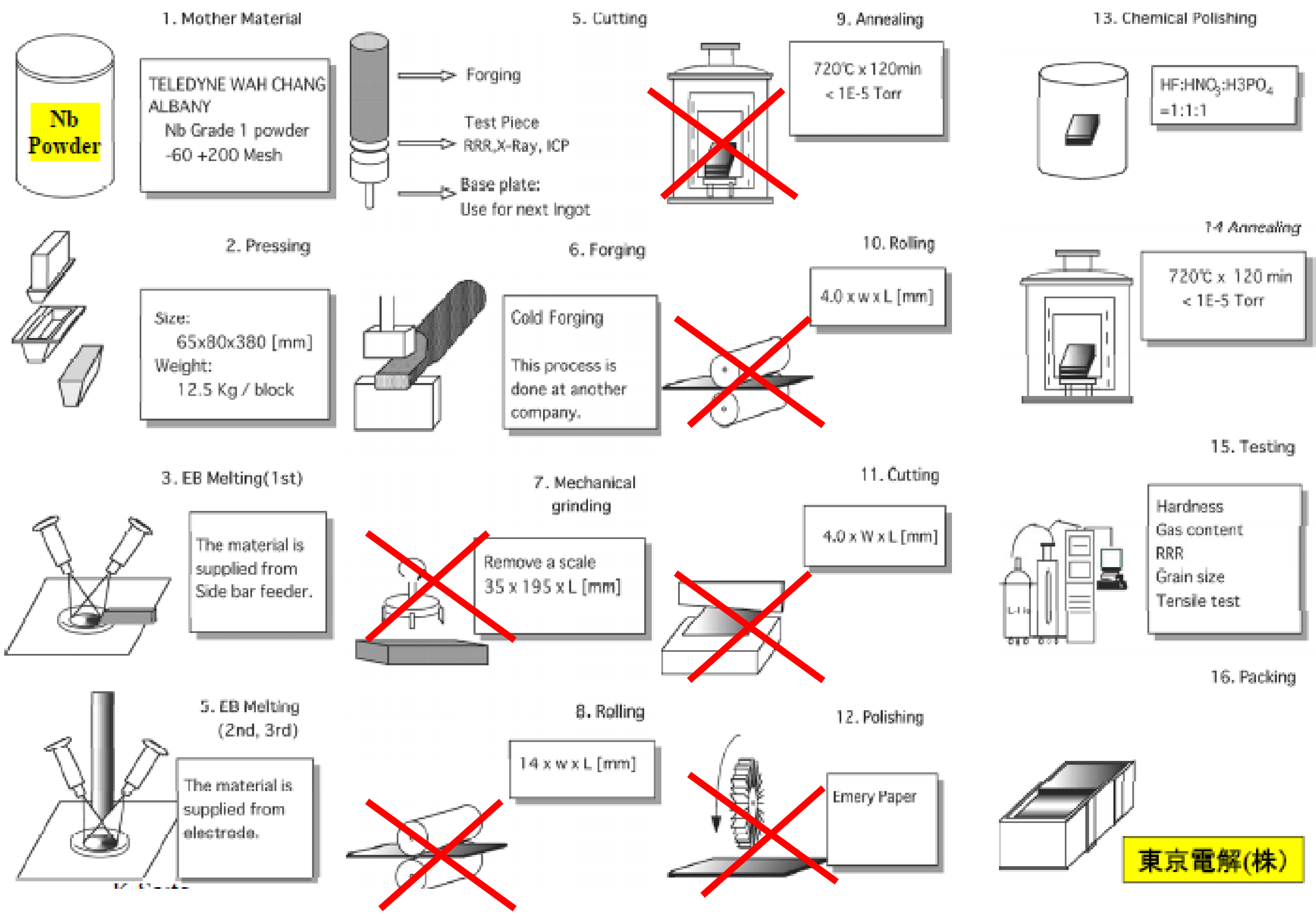
Ingot slice



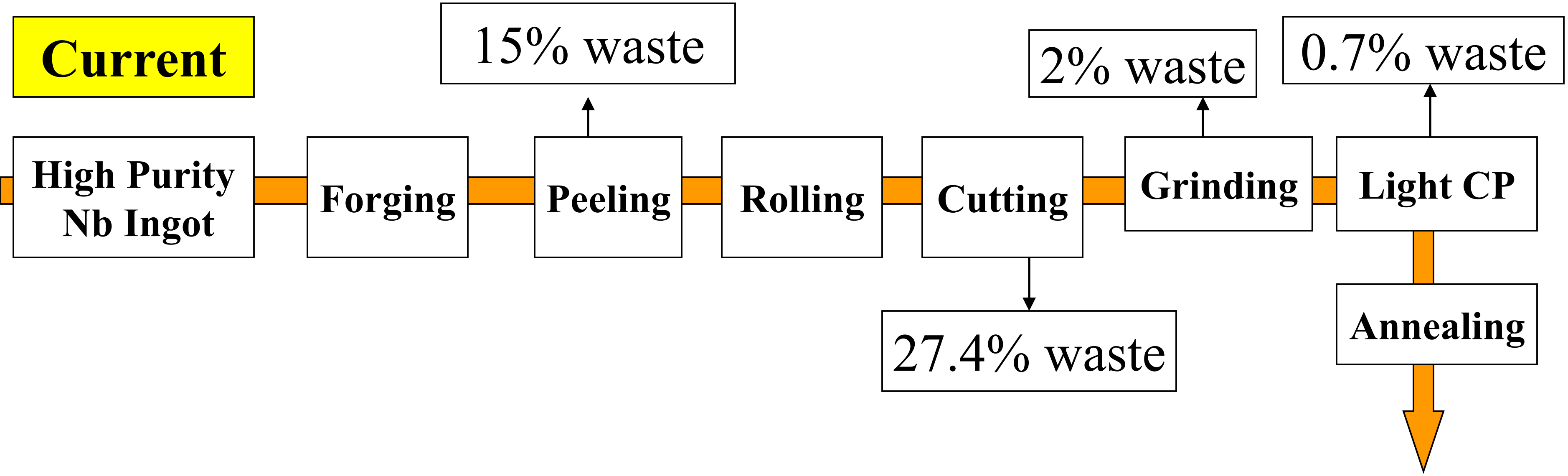


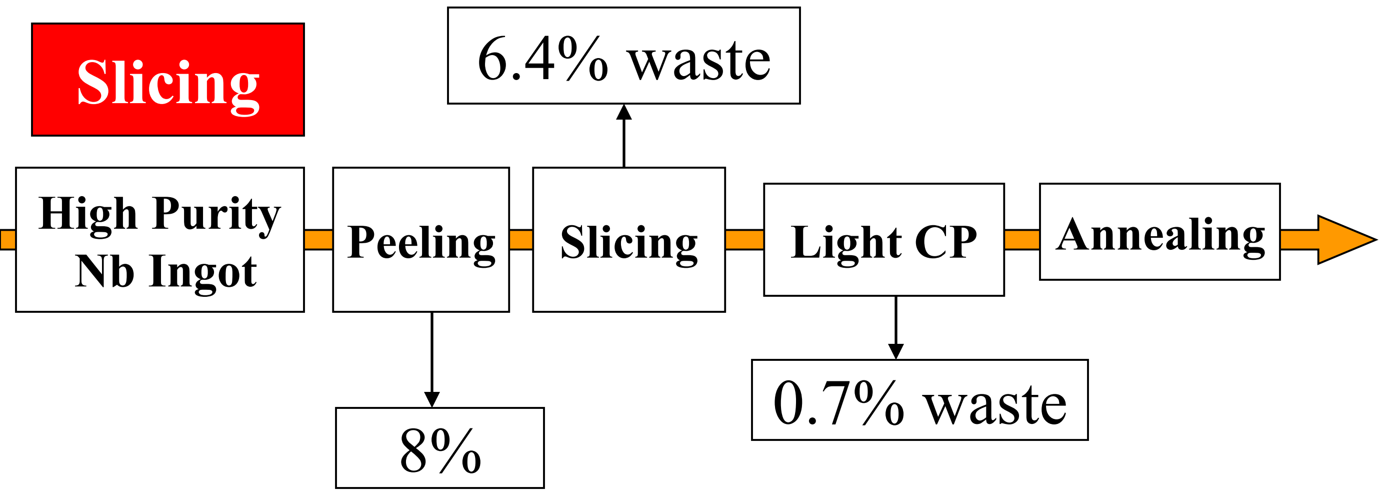
How Simplified the Sheet Nb Production by Ingot Slicing

By H. Umezawa



Estimated Nb Waste in Nb Sheet Production

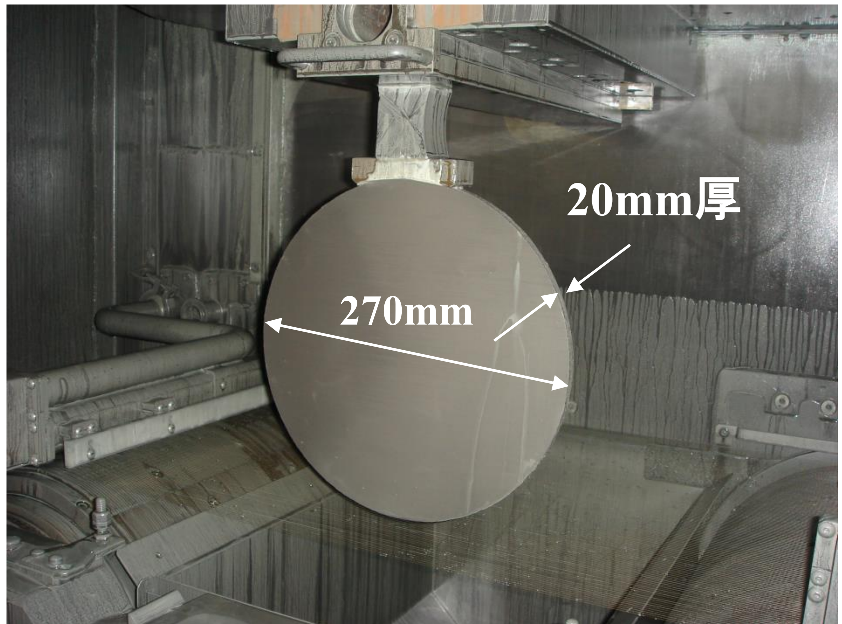




	Waste ratio [%]
Current	**45.1**
Slicing	**15.1**

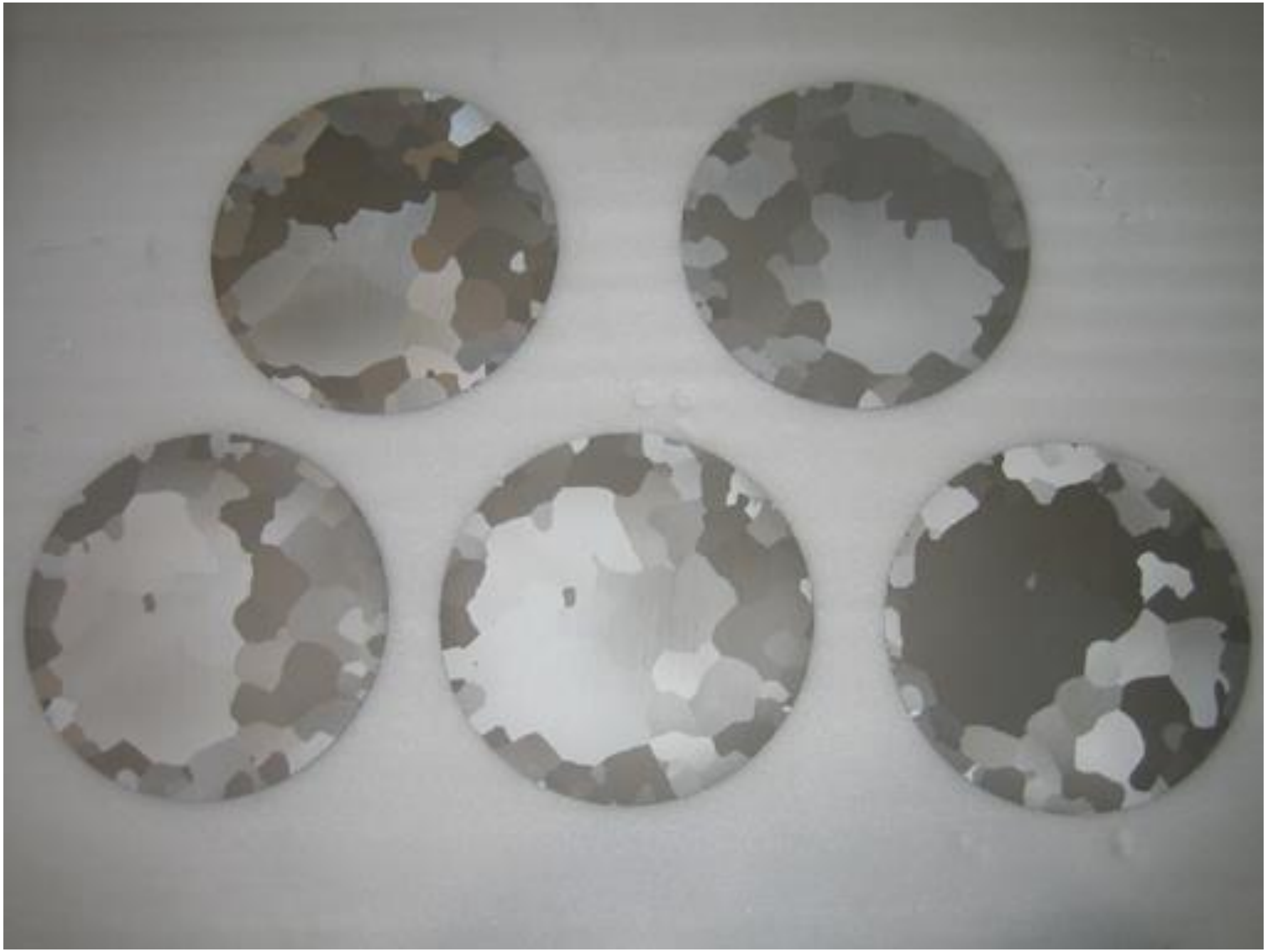
Successfully Developed Wire Sawing Method for Nb Ingot

KEK/Tokyodenkai/Izumi-tech



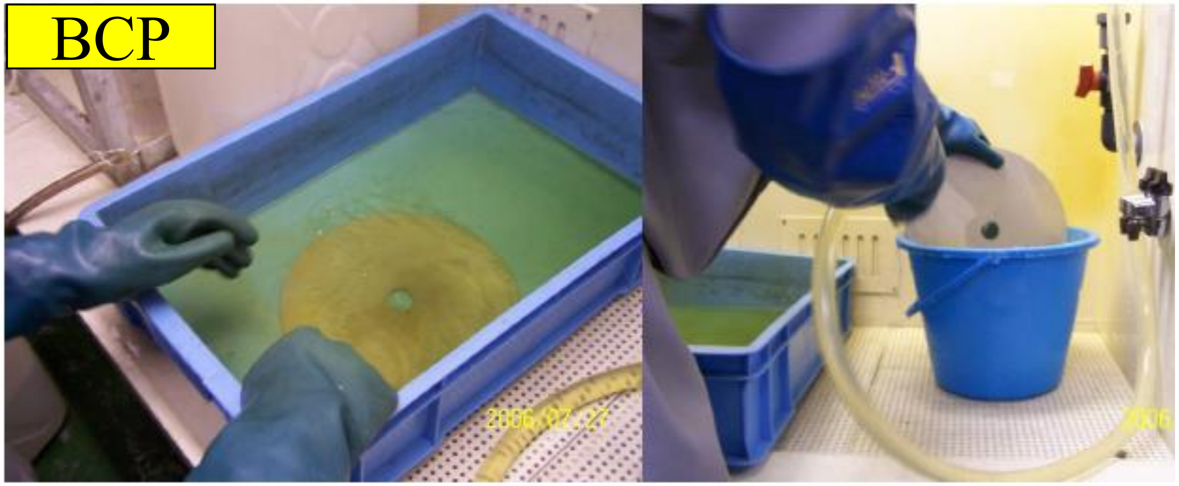
Duration：39hr

LG Nb Ingot Wire Sawed Sheet Samples



Material cleaning @ KEK

BCP



Ultrasonic rinsing

HF, HNO3 and H3PO4 in the ratio 1:1:1; about one minute per piece.

Annealing @ 750^{O}C

Ti box

Deep Drawing on CBMM Material

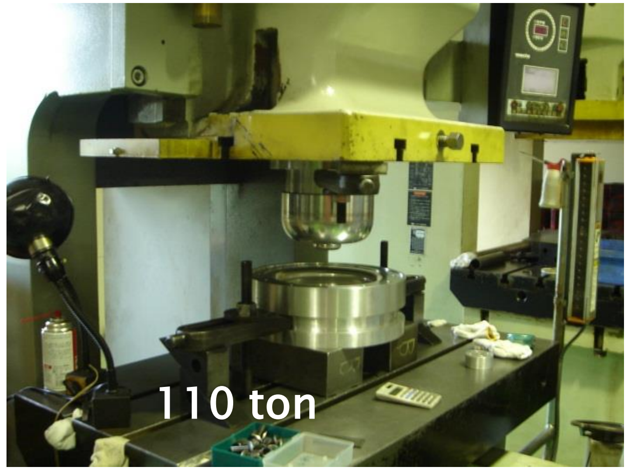
Thickness

Before Deep Drawing

Large Grain from CBMM

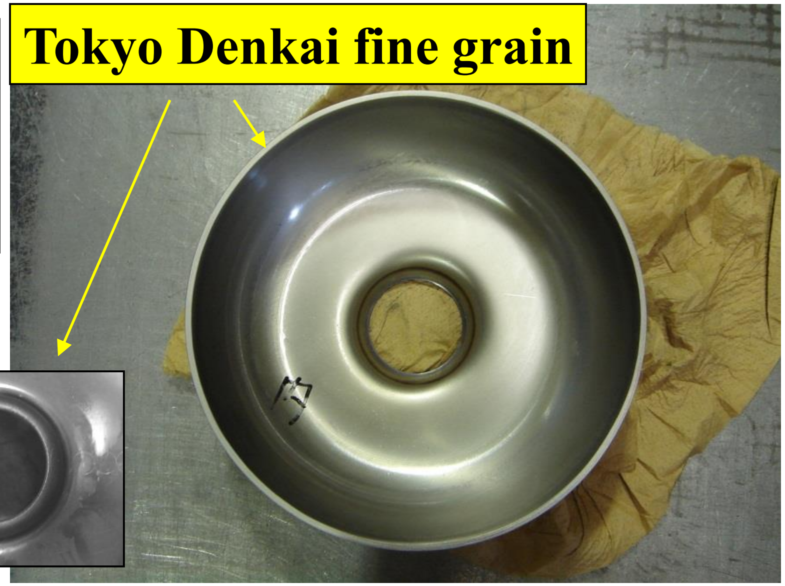
: 2.75, 2.80 mm

Fine Grain : 2.80 mm



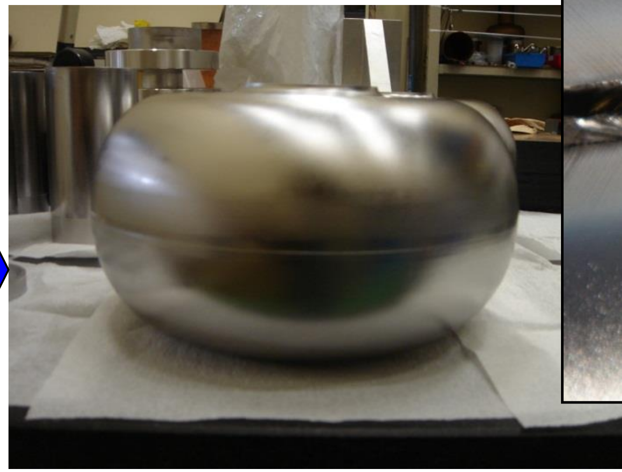
CBMM large grain

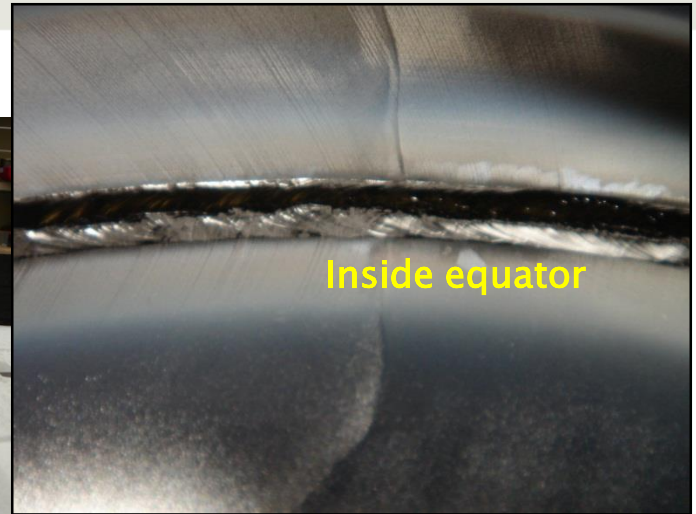
Tokyo Denkai fine grain



Deep Drawing for LG Nb Sheets (Ningxia Material)

EBW @ KEK Machine Shop



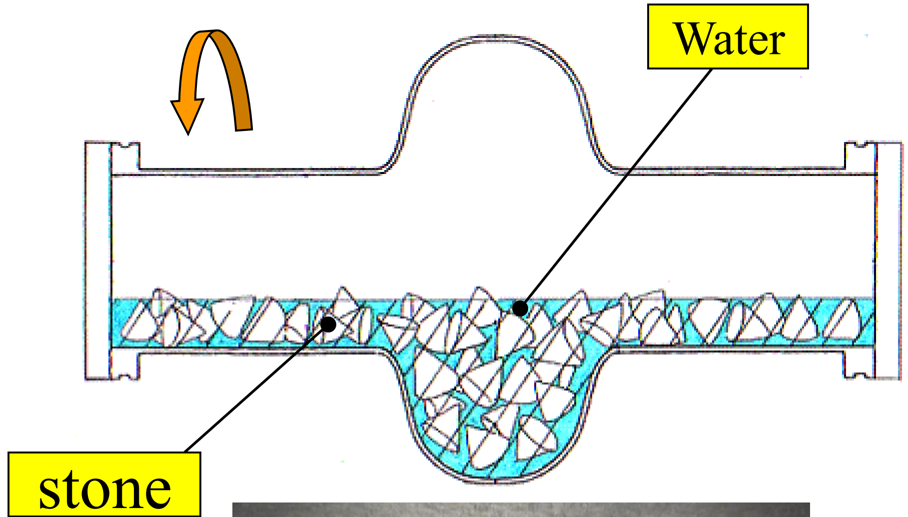


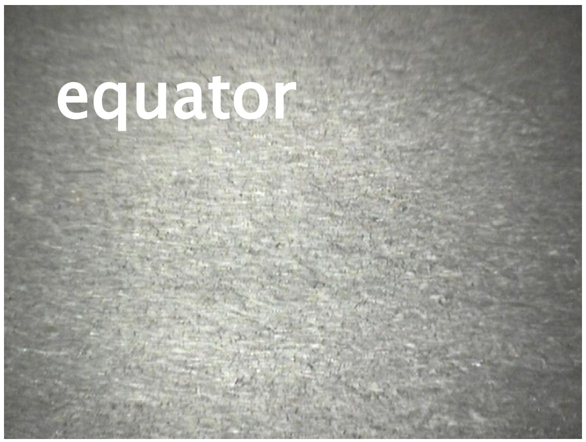
CBP(Centrifugal Barrel Polishing) at KEK

Rotated ~100rpm on a oppositely rotating table

CBMM cavity

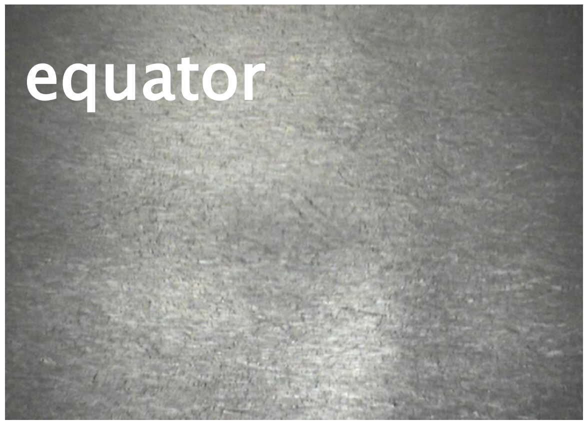
Rough stone : 5 times
Green stone : Once
Brown stone : Once
White stone : Once
Totally ~ 200 **μm removed @ equator**





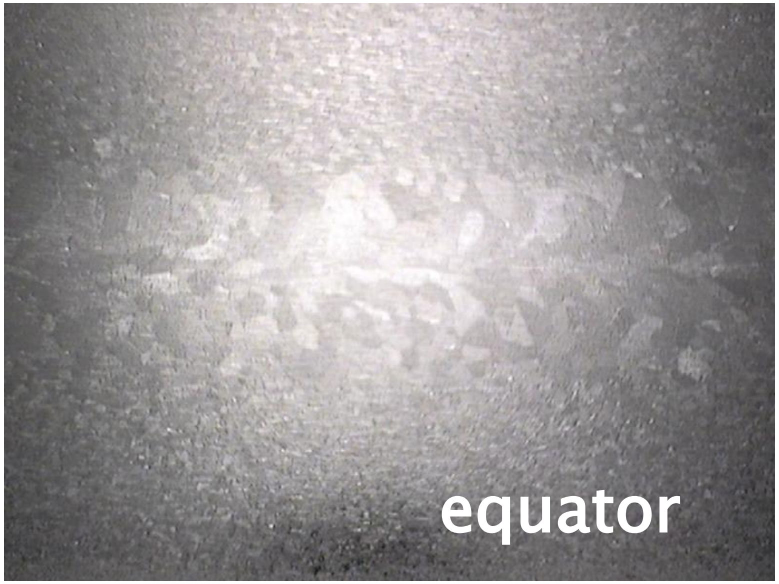
Fine grain cavity after CBP

Remove
large defects!



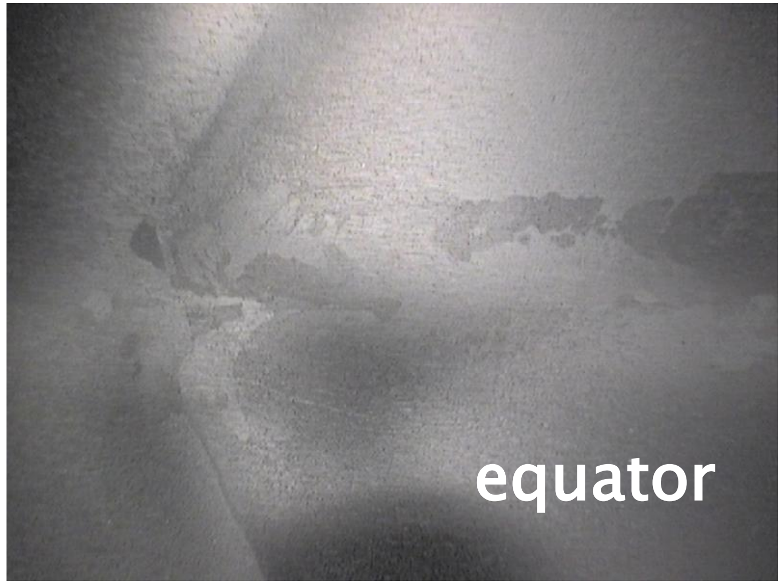
Large grain cavity after CBP

Surface Cleaning by BCP(~10μm) after CBP



10 μm each

Fine Grain Cavity after BCP and Annealing



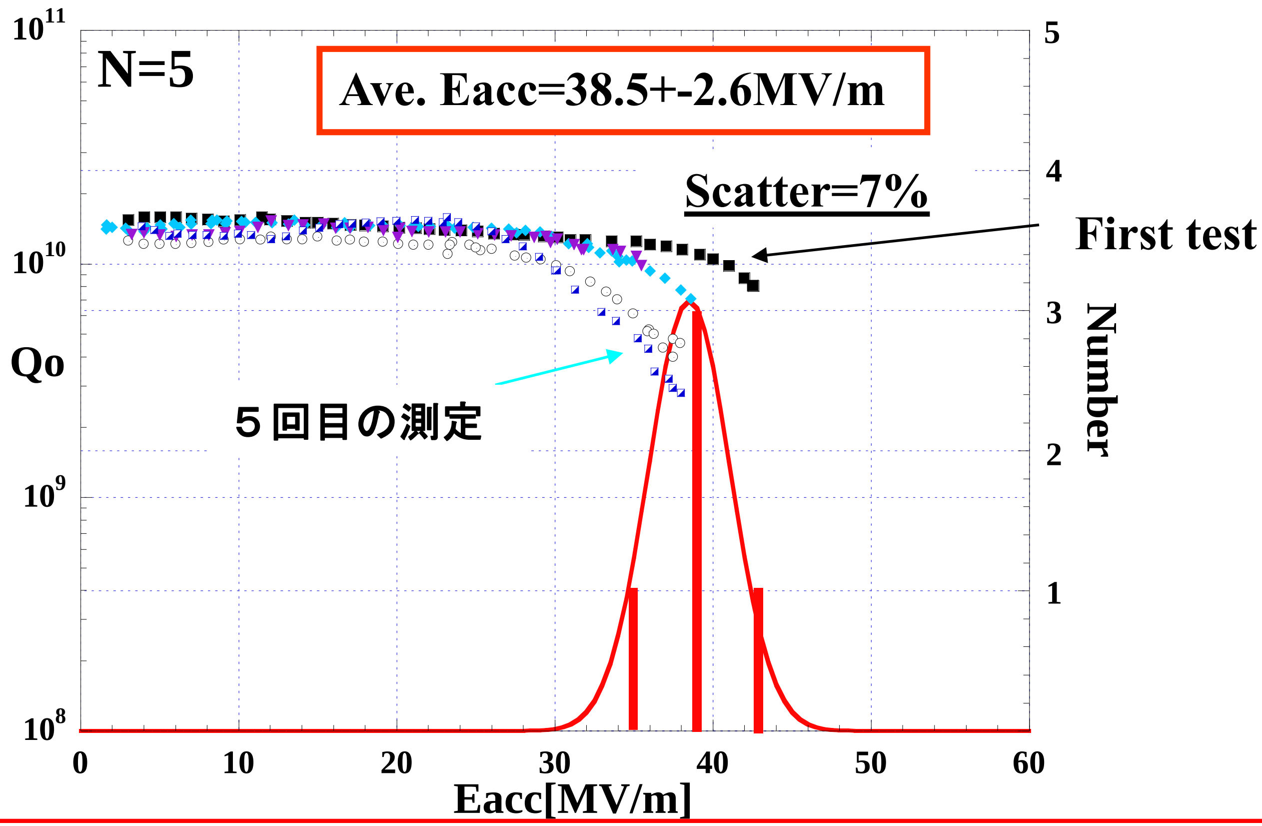
Large Grain Cavity after BCP and Annealing

Cavity Performance of LG Nb Cavity (Ichiro shape) with BCP

Baseline: CBP+AN+BCP(170μm)

+CP(30μm) +Wiping +HPR (15min)+Baking(120^{O}C, 48hrs)+Vertical test

Tight Loop Test



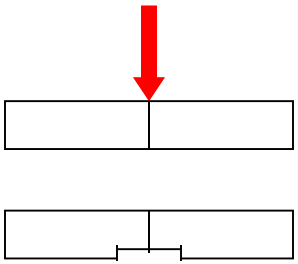
High Q-slope appeared with increased BCP

Grain steps becomes steeper by the increased BCP　　Magnetic field enhancement ?

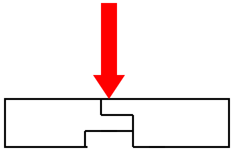
LG 9-Cell Cavity Fabrication

Development of trimming shape at equator section to smooth EBW seam

Cell assembly is not easy due to the deformation.
Fitting trim structure mitigates this issue.

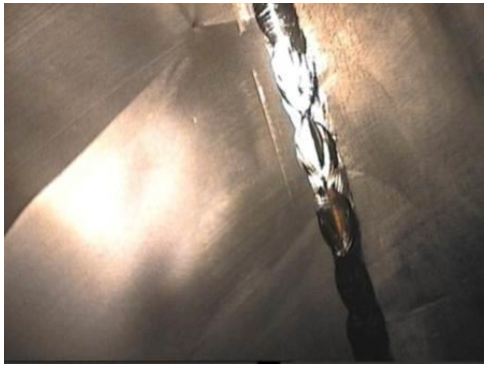


Development 1



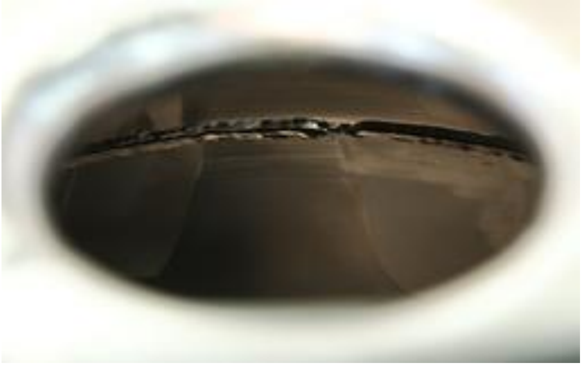
More easy assembly

Fitting



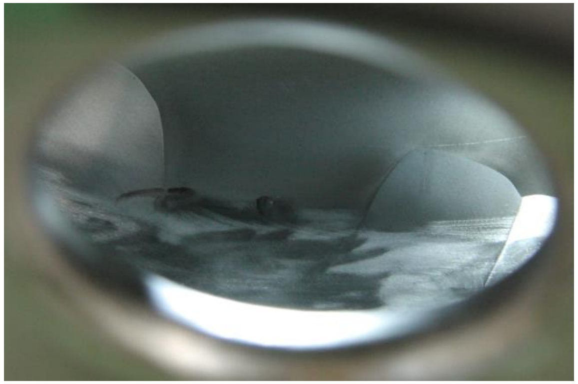
Trim shape and the resultant inside EBW seam at quarter section

EBW trouble during EBW assemble and removing the EBW defect by local mechanical grinding



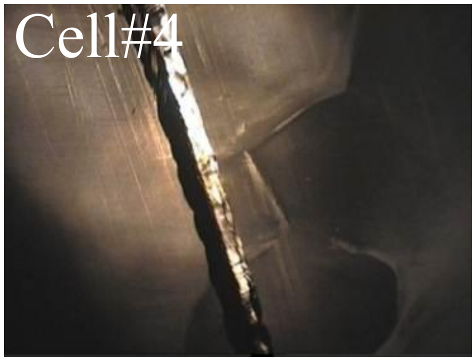
Defect on the EBW seam

Mechanical grinding by small handy grinder

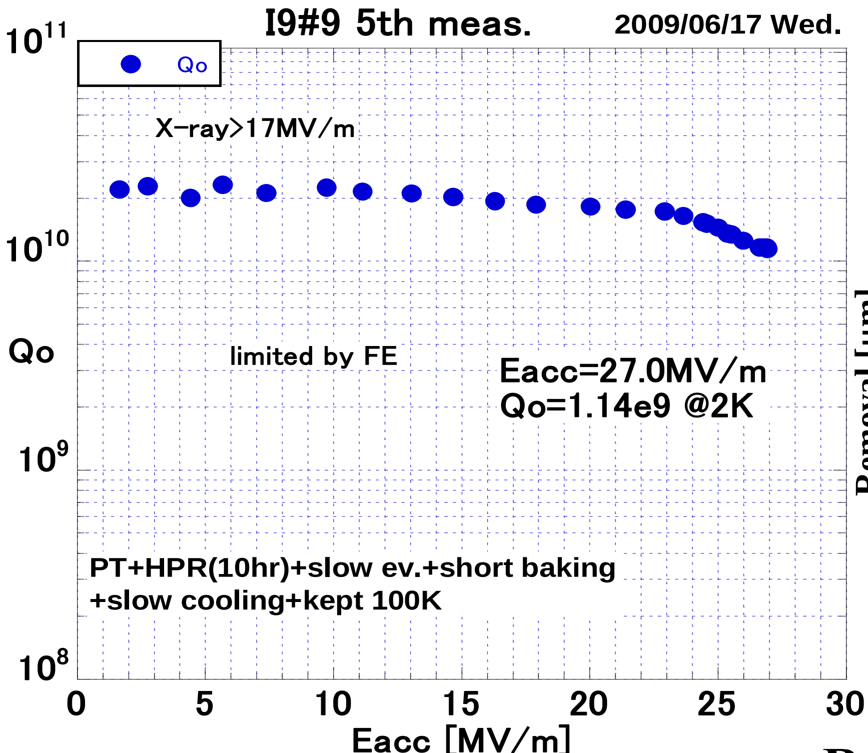


After the mechanical grinding

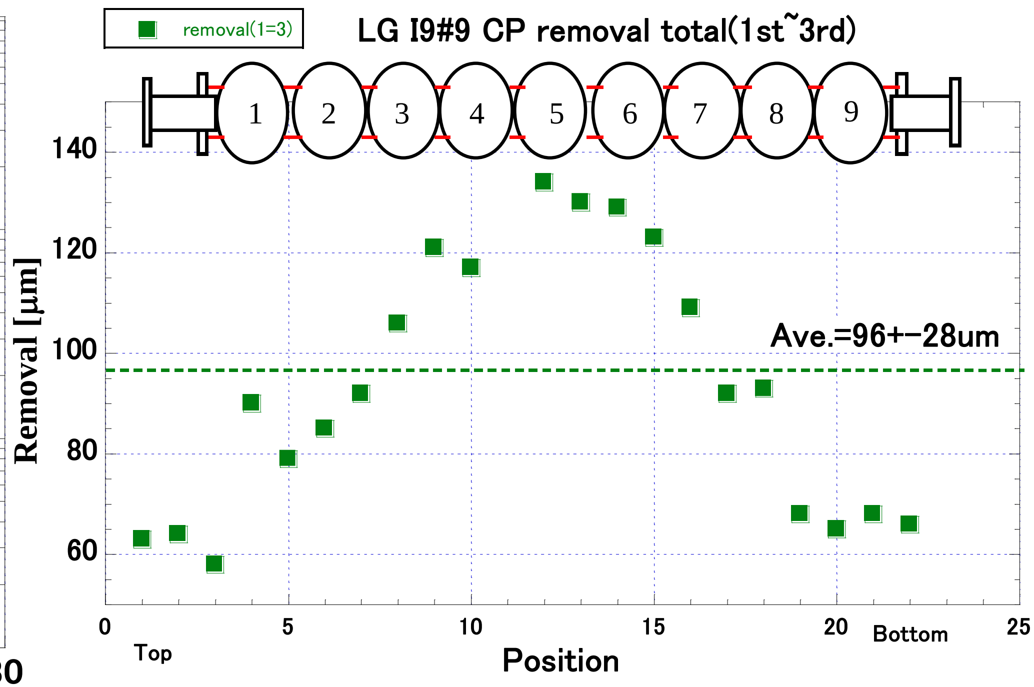
CBP for the LG Cavity and the Visual Inspection on the Equator EBW Seams



Ichiro#9 LG 9-Cell Cavity Performance with BCP



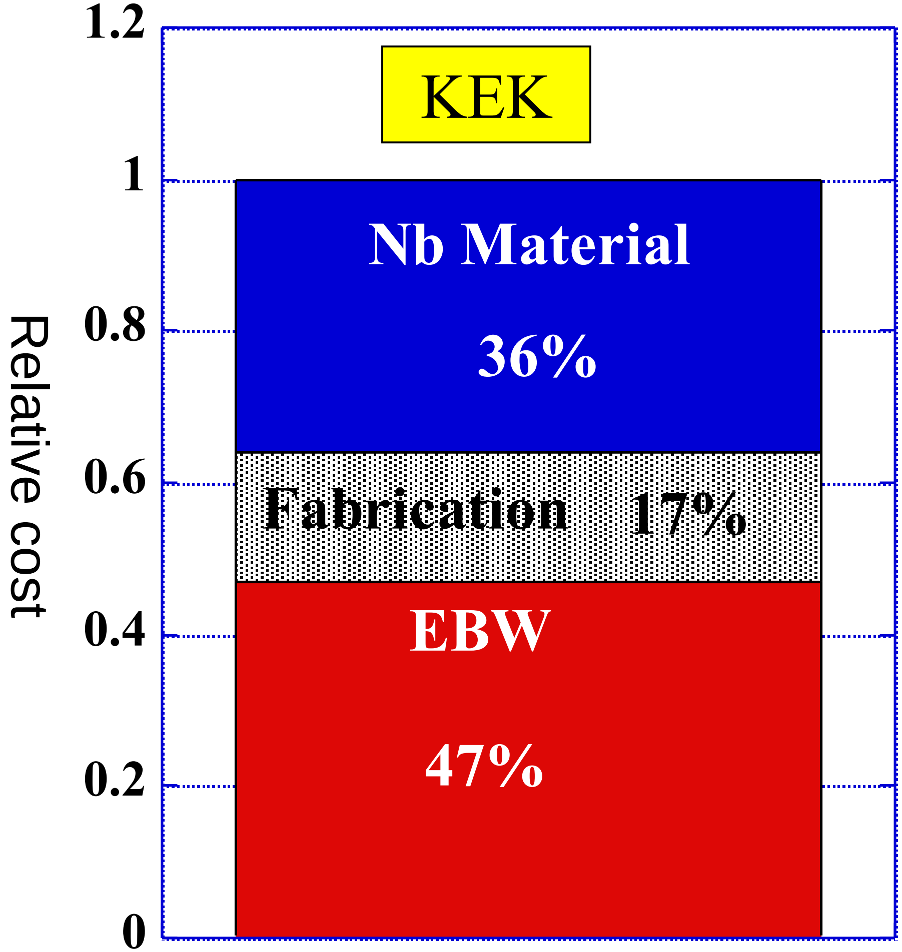
96μm in average BCP



Removal material distribution with horizontal BCP

Need to modify the BCP method to remove uniformly for each cell

18.2.2 Seamless Cavity Fabrication



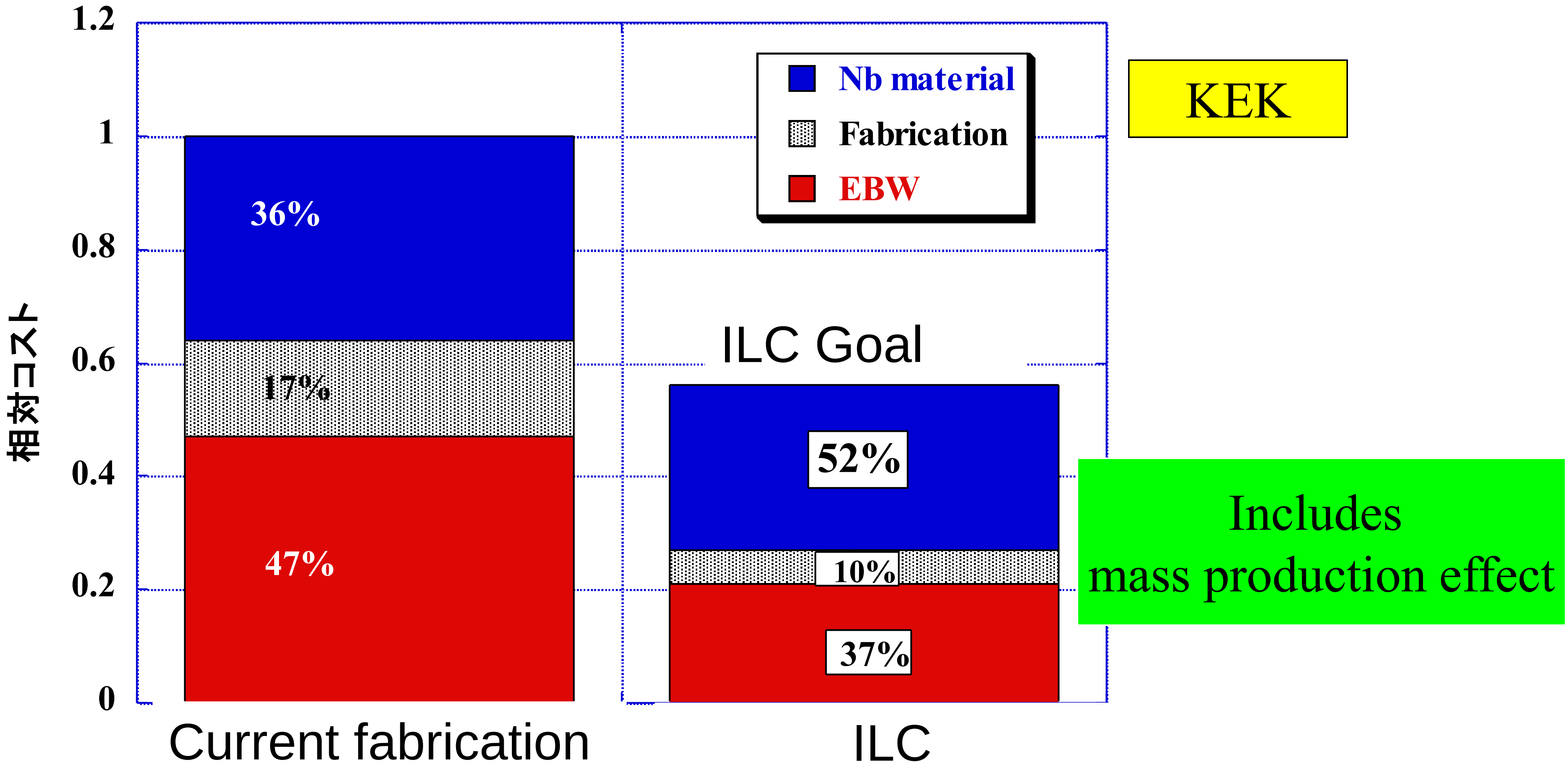
Cost break in the current cavity fabrication

- Cost break under current cavity fabrication (EBW assembly based)
- Need to reduce the cost in Nb material and EBW

Europe (INFN-LNL, DESY) : Development of Nb bulk seamless cavity

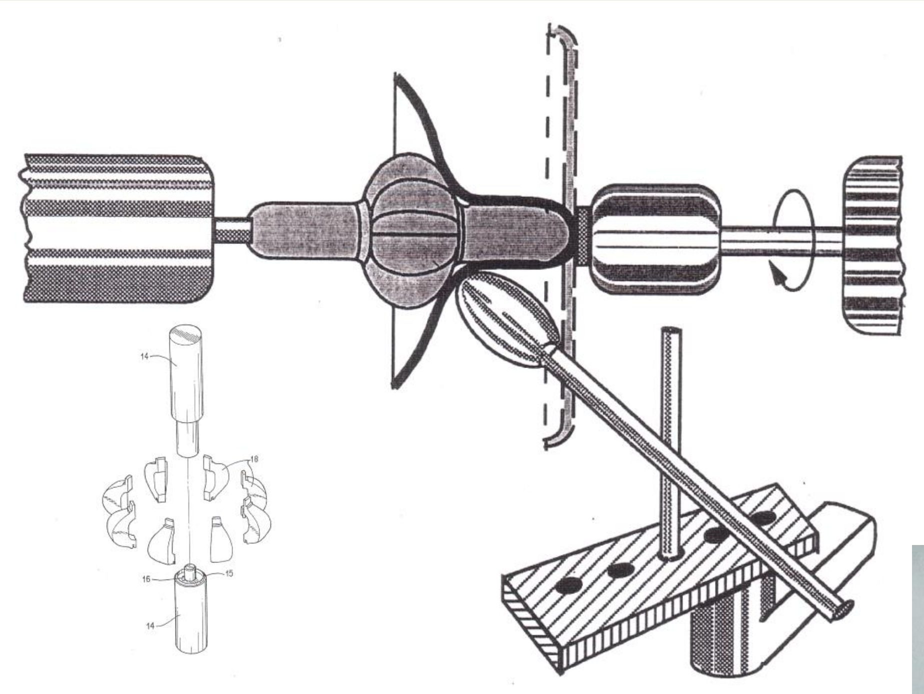
KEK:
Development of Nb/Cu clad cavity

Estimated ILC Cavity Fabrication Cost: Mass-production Effect



- The cavity cost is still high by just mass production effect with the current fabrication method.
- Need to develop more cost-effective fabrication method

Spun Cavity in Italy (INFN-LNL)



Cavity fabrication by spinning technology from one sheet, Italy

By V.Palmieri

Spun Multi-cell Cavity Fabrication

Succeeded fabrication of 9-cell LIC cavities by spinning

Seamless Pipe Fabrication Technology in Italy

Deep drawing

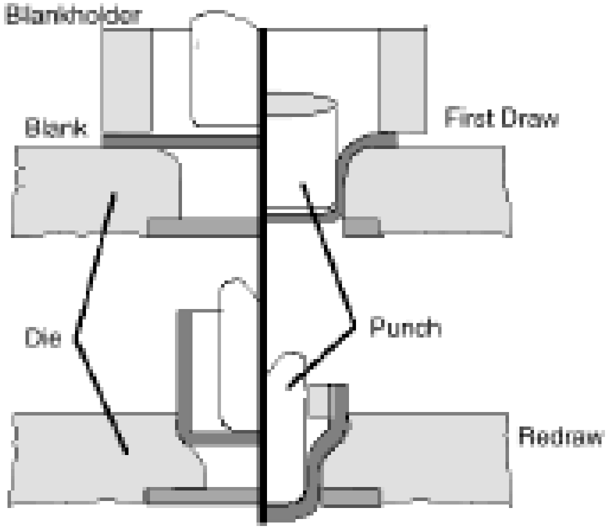


Fig. 4 – Direct Deep-Drawing of seamless tubes from circular blanks. Top picture: First drawing of a blank. Bottom picture: Redrawing of the cup into a taller one with a smaller diameter. On the left is displayed the configuration before drawing, while that on the right is during the operation.

Reverse Deep Drawing Technology in Italy

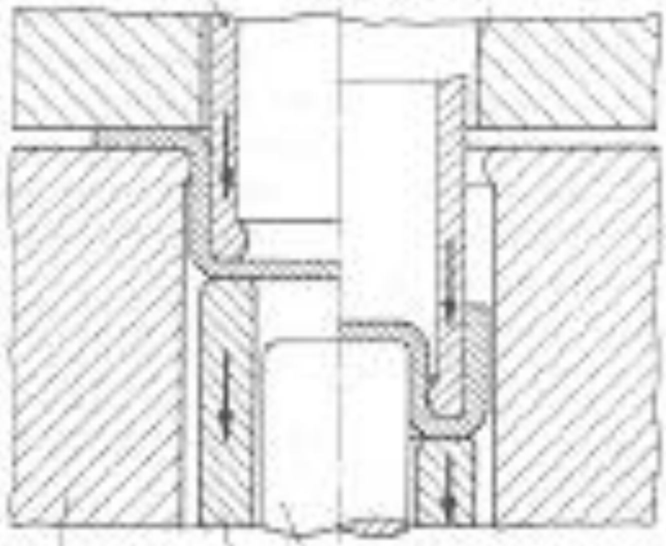
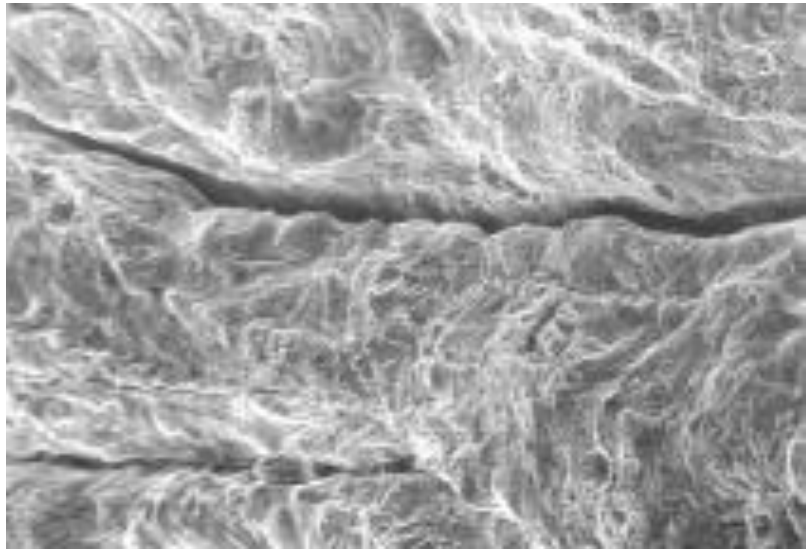


Fig. 7 – Reverse deep-drawing of seamless tubes. During each redrawing, the external surface of the cup to be drawn becomes the internal of the drawn part.

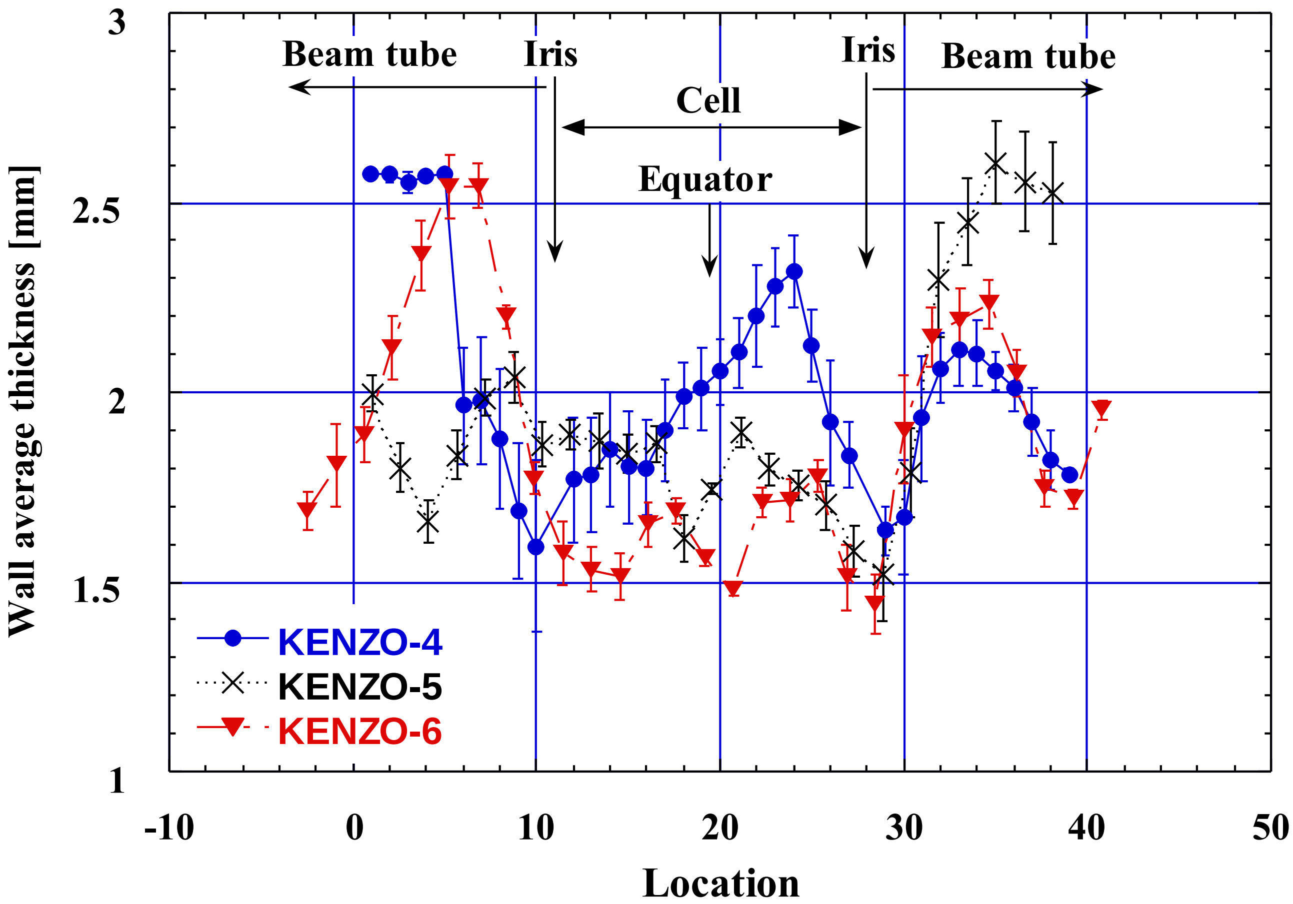
Cracking Problem of Spun Cavity Technology in the Early State

In the early cavity, now improved to be better



None Uniform Wall Thickness (Single cell cavities)

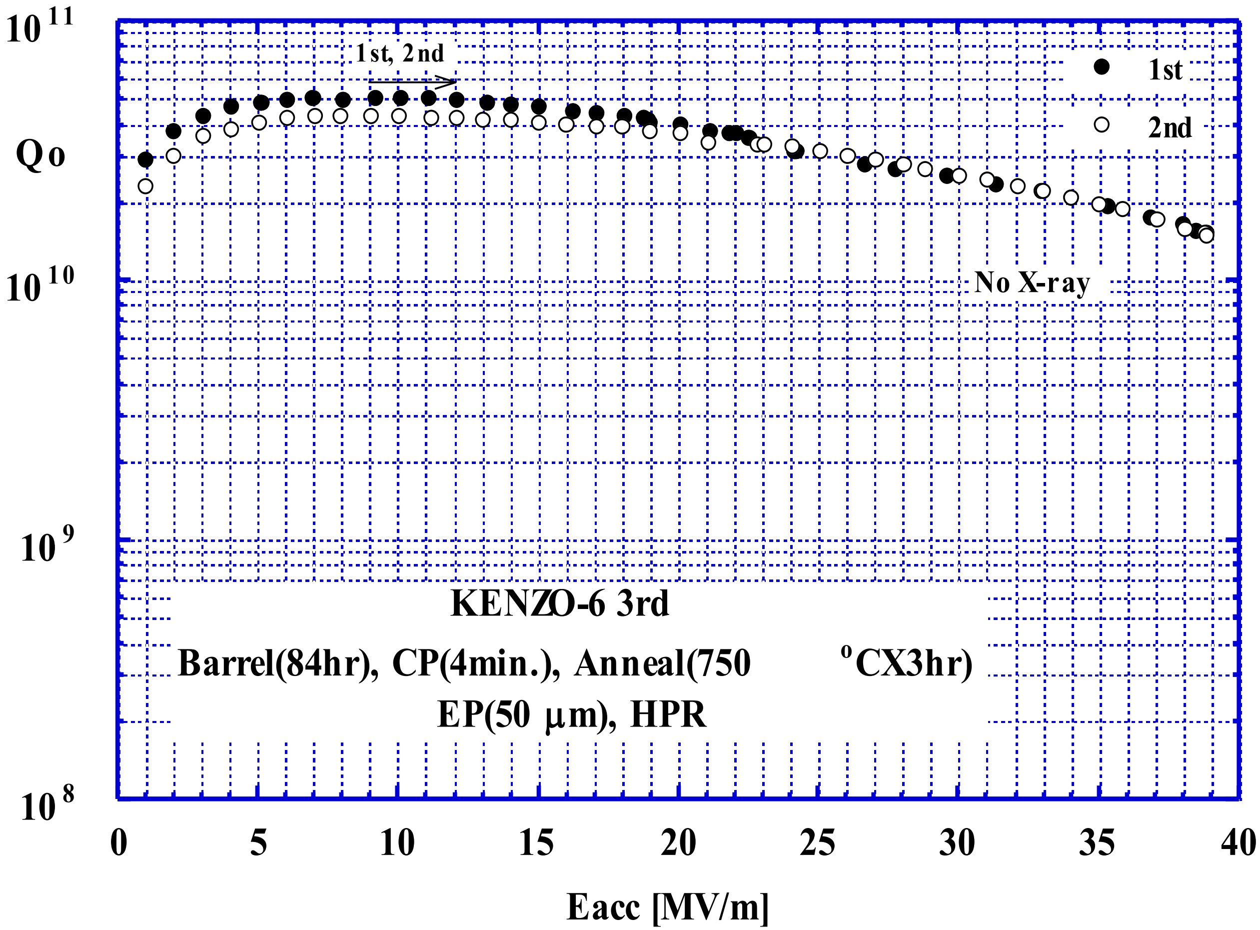
- Scattered the cavity wall thickness.
- Problem in tuning



This issue was rather improved later.

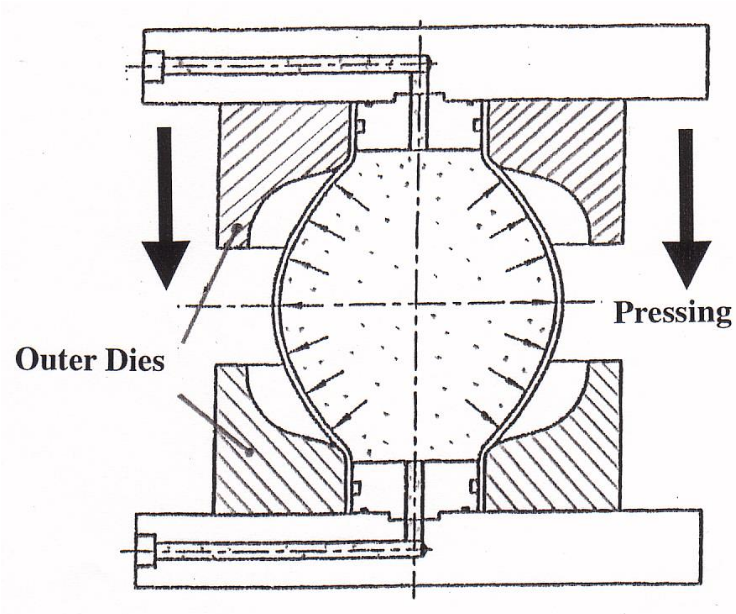
Cavity Performance Electropolised Spun Single Cell Cavity with ILC Shape

KEK/INFN-LNL



Excellent cavity performance !!

Hydroforming of Nb Bulk Seamless Cavity in DESY

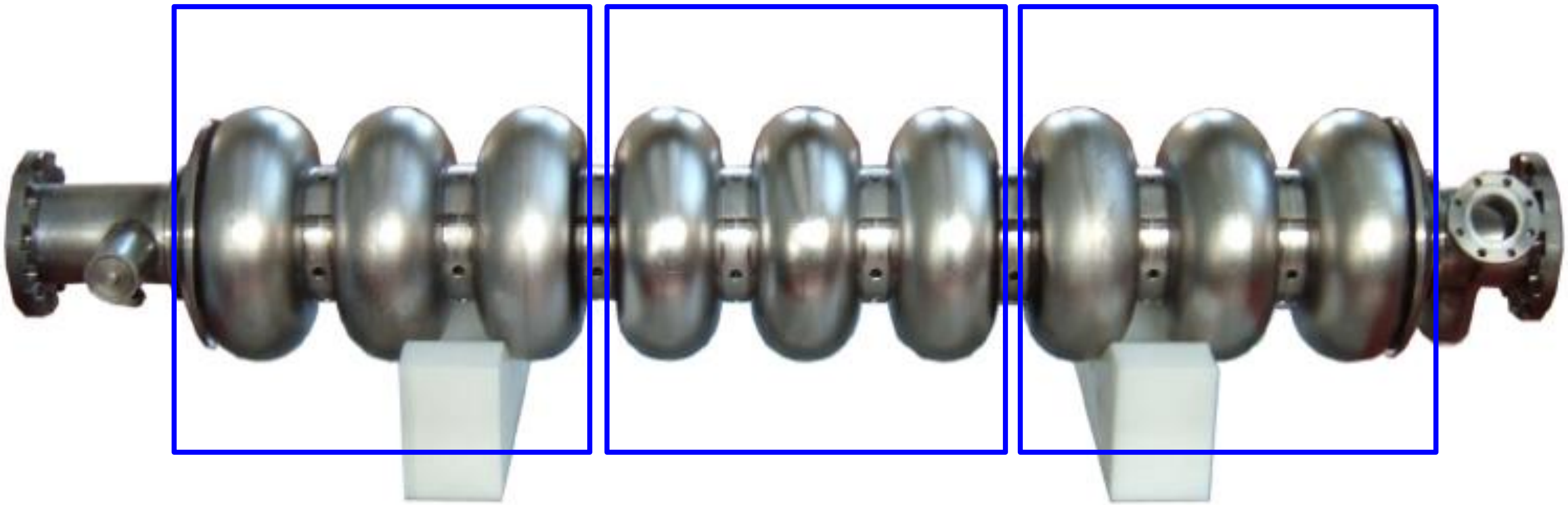


DESY Hydro-formed Cavities

Nb bulk seamless cavity by hydroforming DESY

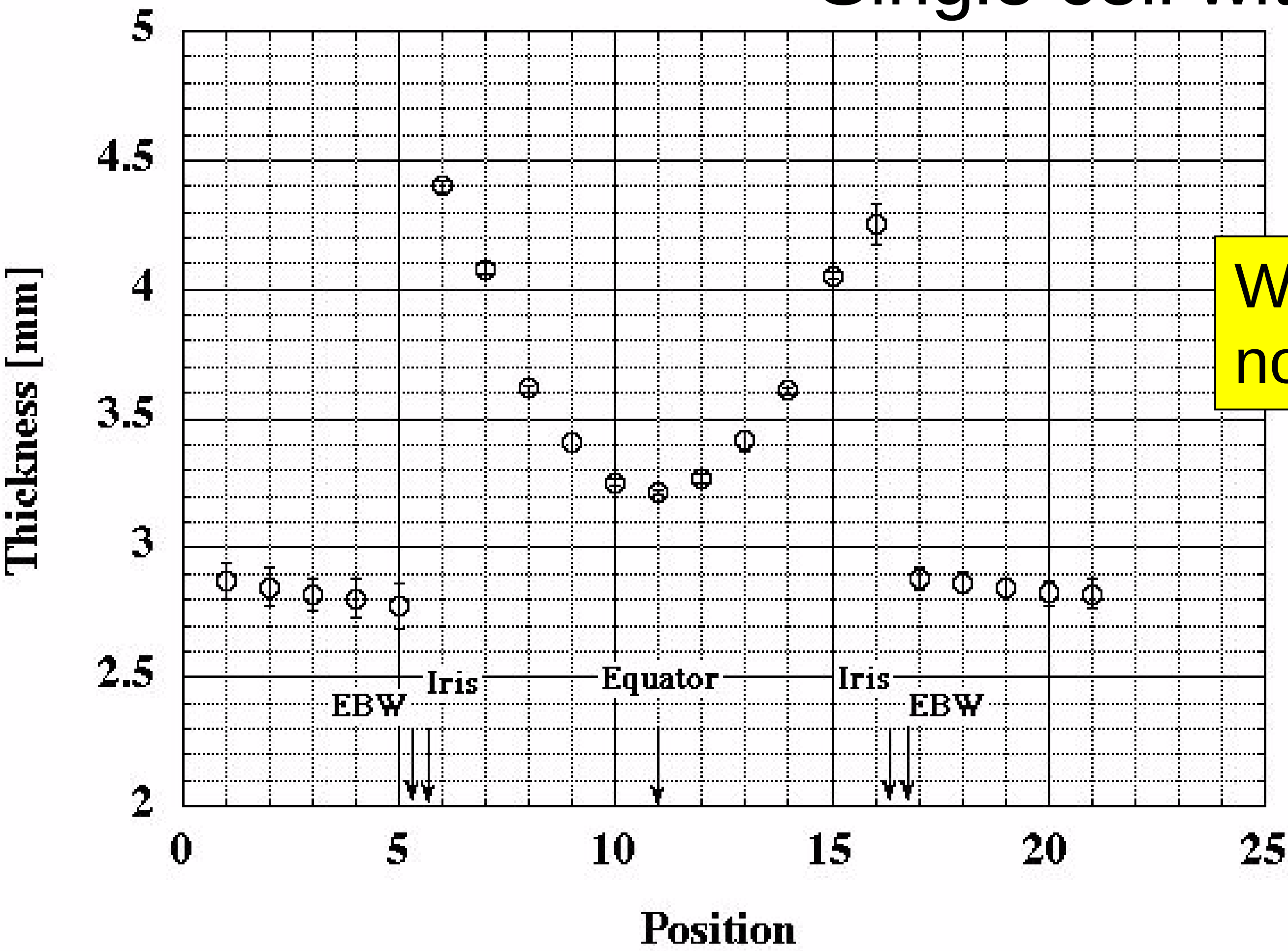
KEK/DESY collaboration (Nb/Cu clad cavities)

DESY 9-Cell Cavity by EB Welded 3-Cell Seamless Cavities



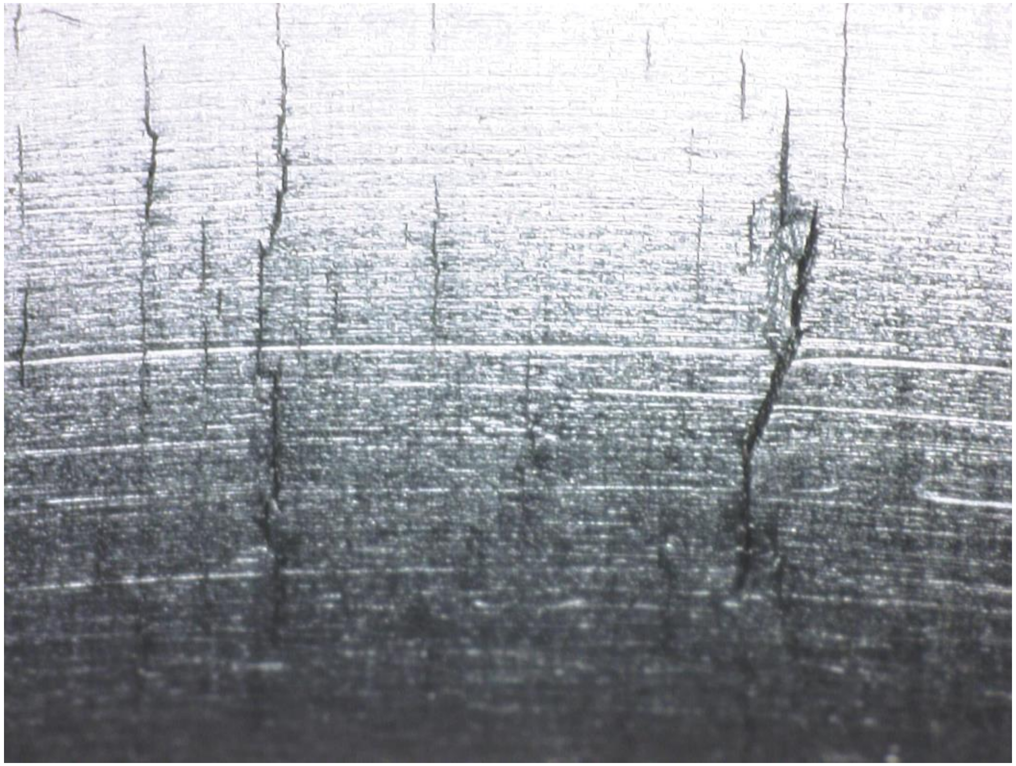
Wall Thickness Distribution with Hydroforming

Single cell with beam pipes



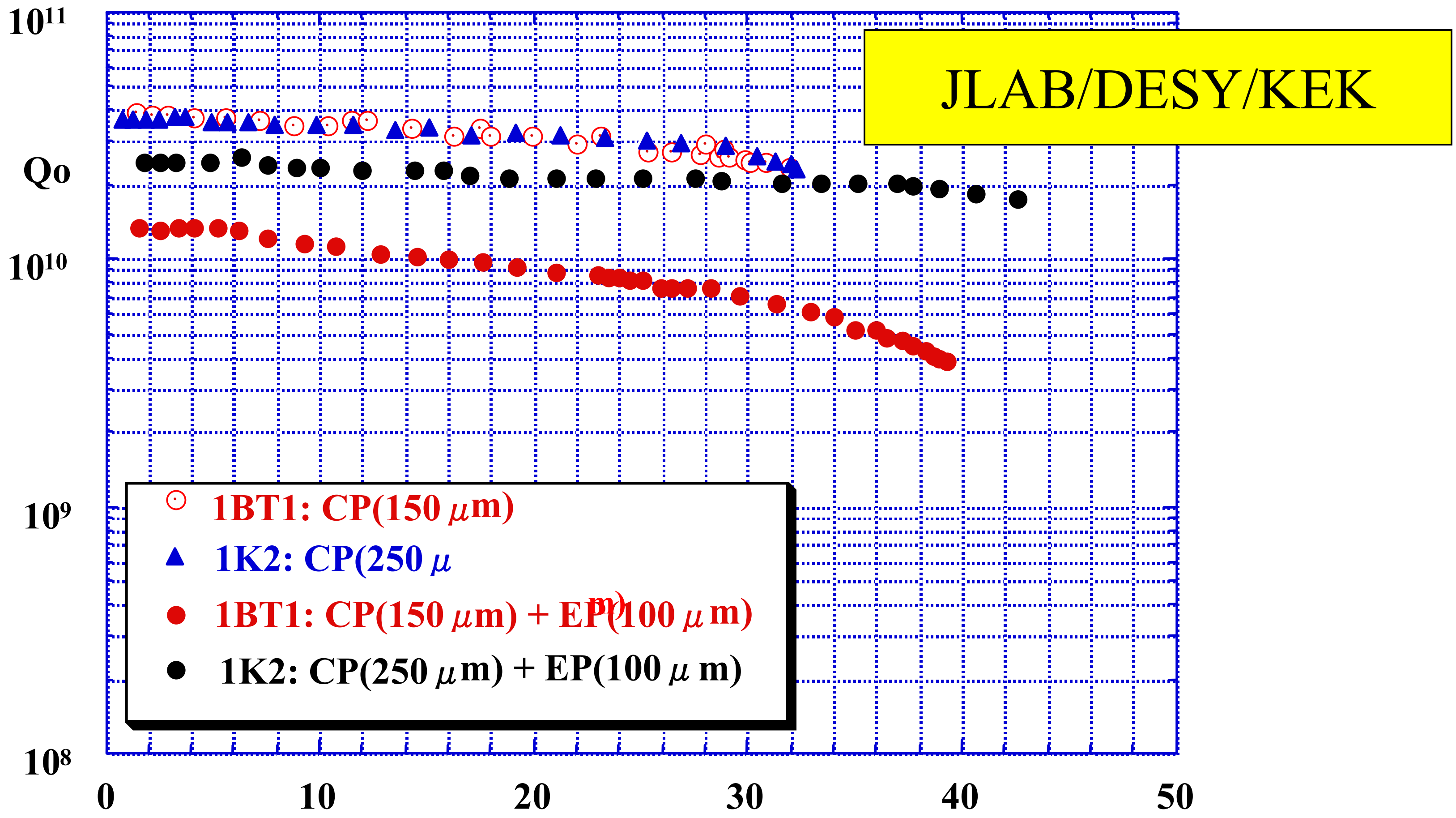
Wall thickness seems to not scatter cell by cell

Cracking in Nb Bulk Seamless Cavity in DESY



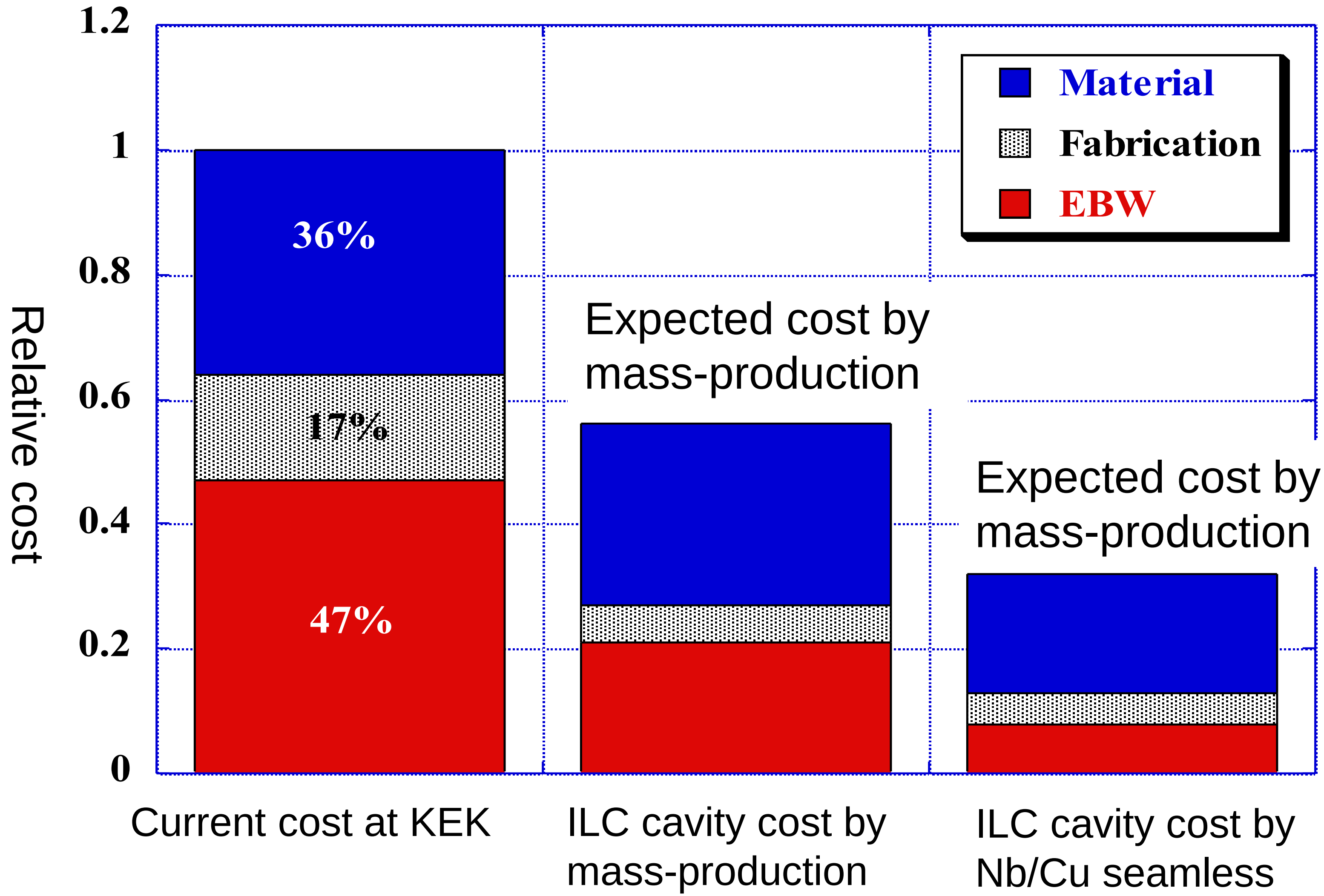
- Many crakes are observed on inner surface of received cavities
- The crake direction is longitudinal, so not so big impact for cavity performance.

Electropolised Hydroformed Cavity Performance (ILC Shape)



- BCP (CP) limited the gradient at 32 MV/m.
- Additional EP produced excellent cavity performance even crakes remain on the SRF surface !!

Nb/Cu Clad Cavity for More Cost-effective Fabrication



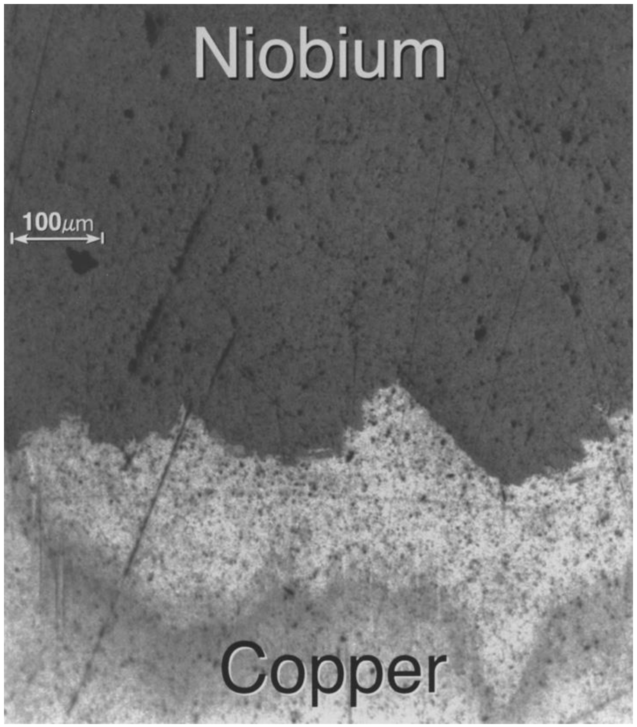
Nb/Cu Clad Seamless Cavity, KEK

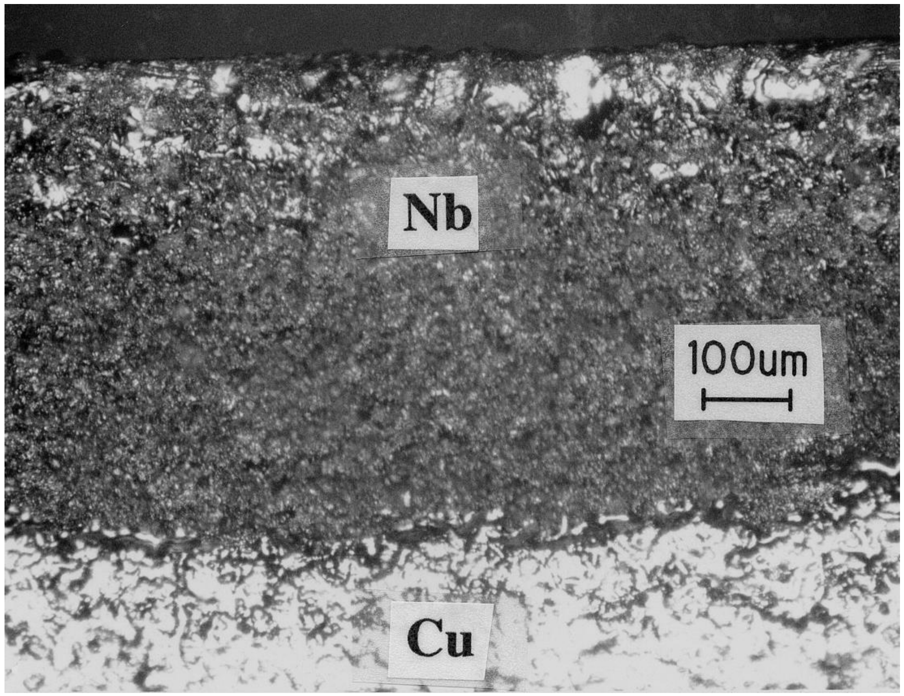
Issues to be resolved for cost reduction
1) Reduce EBW
2) Reduce Nb material
3) Guarantee cavity performance

Applicable to EP

Keep Nb bulk property

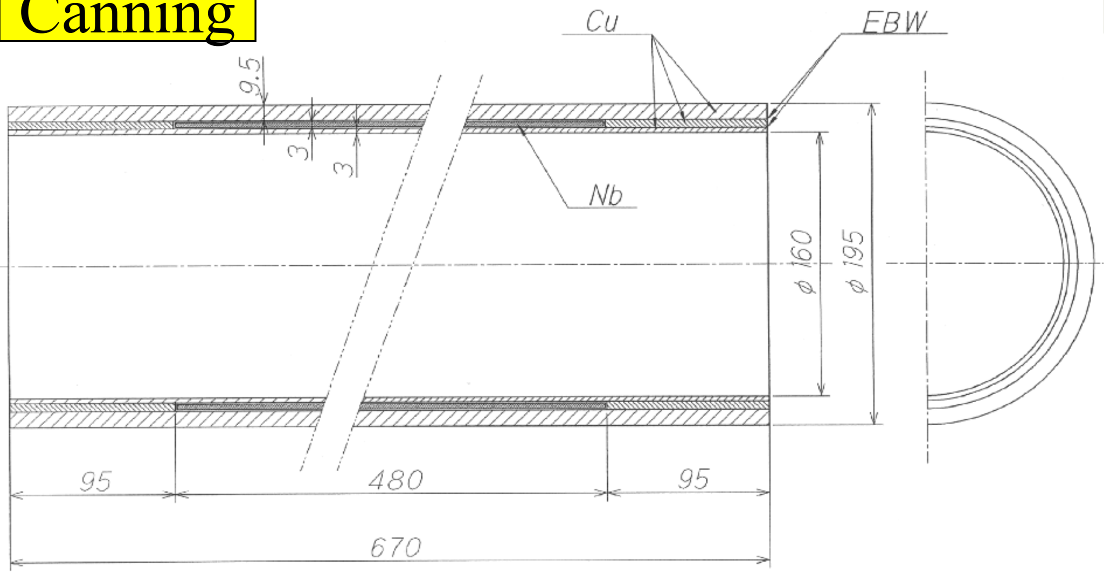
- Bond thinner Nb pipe in the thicker copper pipe
- Make seamless cavity by hydroforming



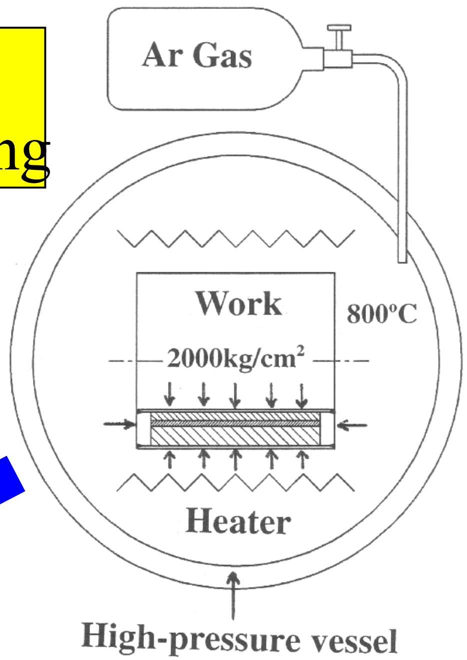


Idea of KEK

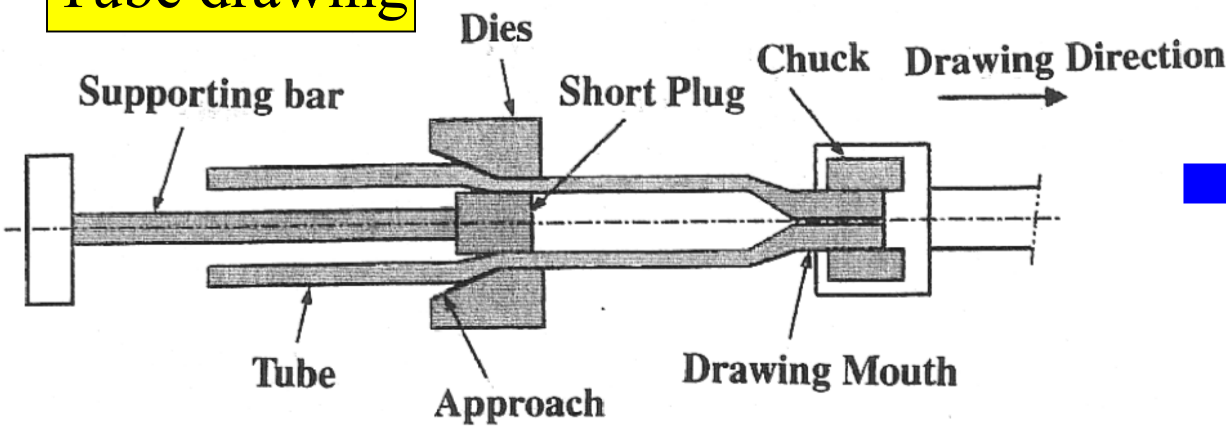
Canning



HIP Bonding

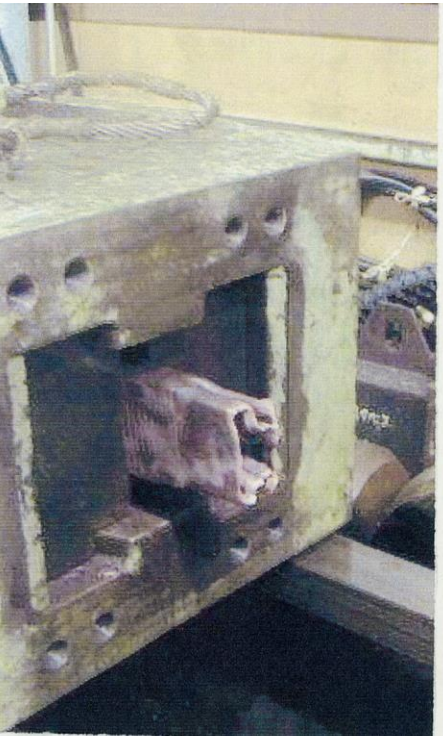


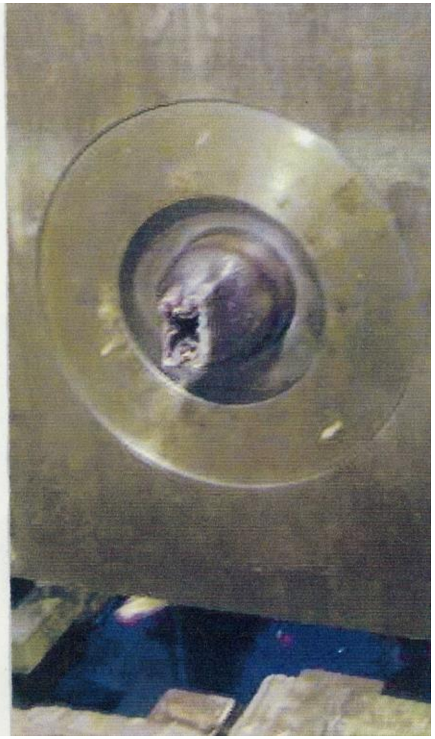
Tube drawing



Clad pipe

Tube Drawing



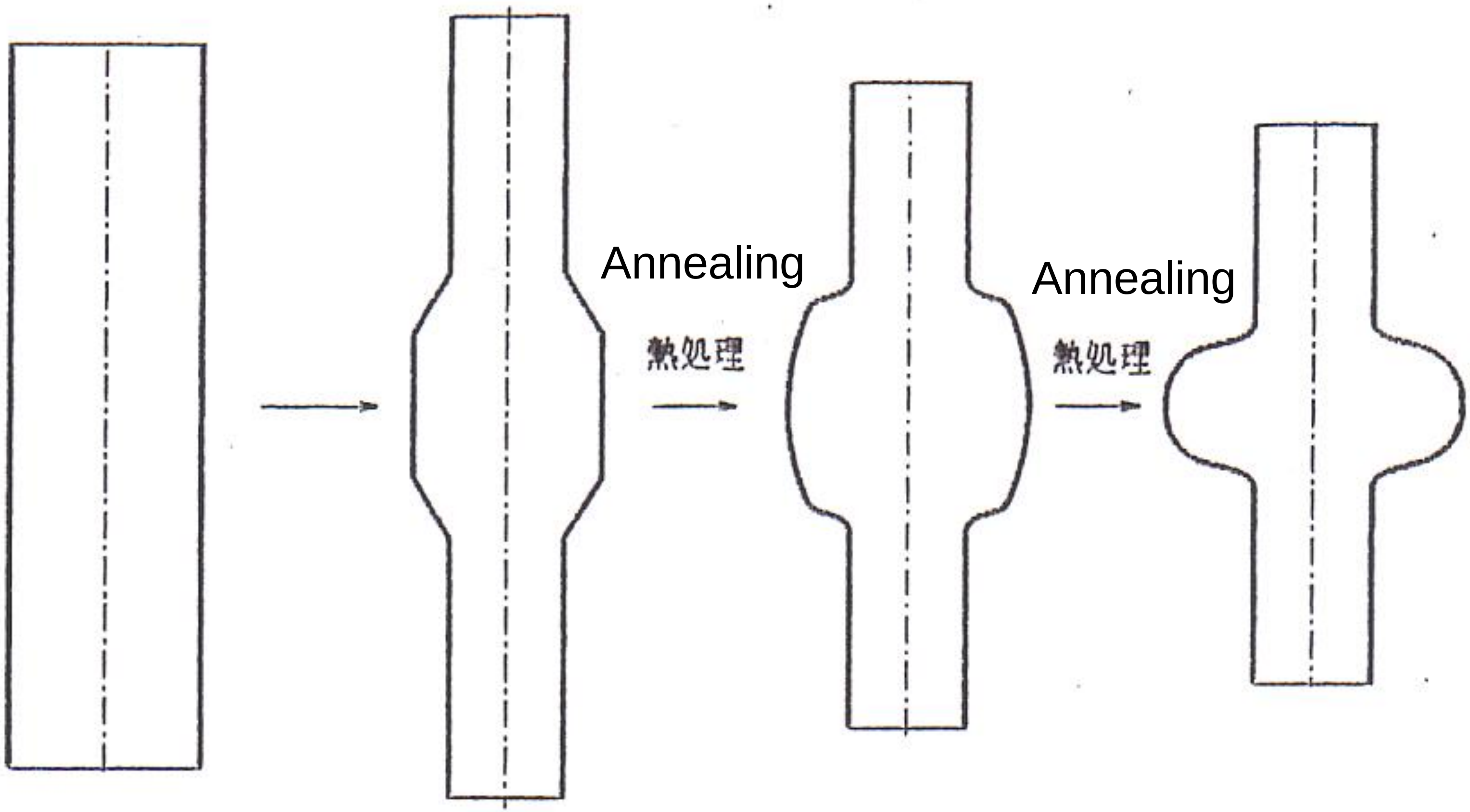


KEK/Hitachi Cable/
Okuno Metal

Drawn Nb/Cu Clad Tubes and Cutting

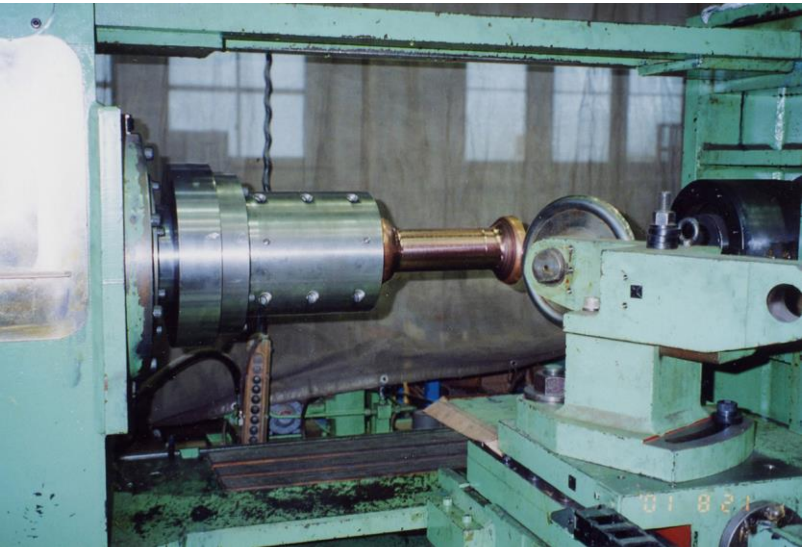
Nippon Steel/KEK
(Tubing from hot rolled sheet)

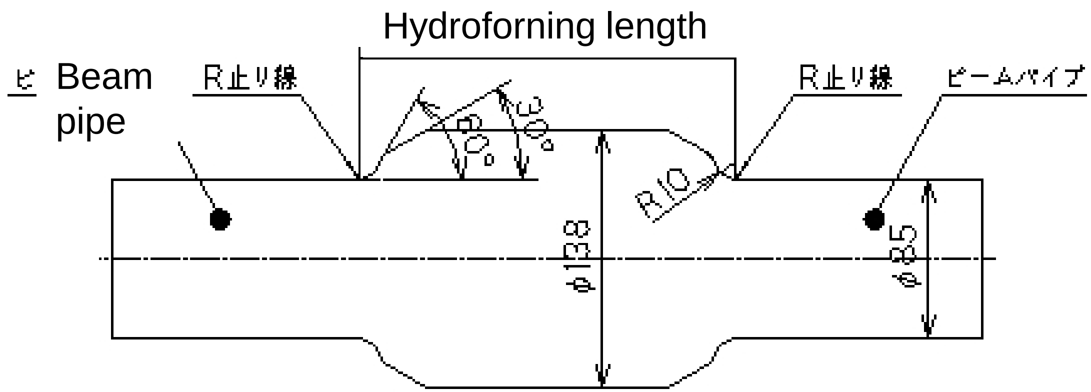
Fabrication Process in KEK for Hydroforming

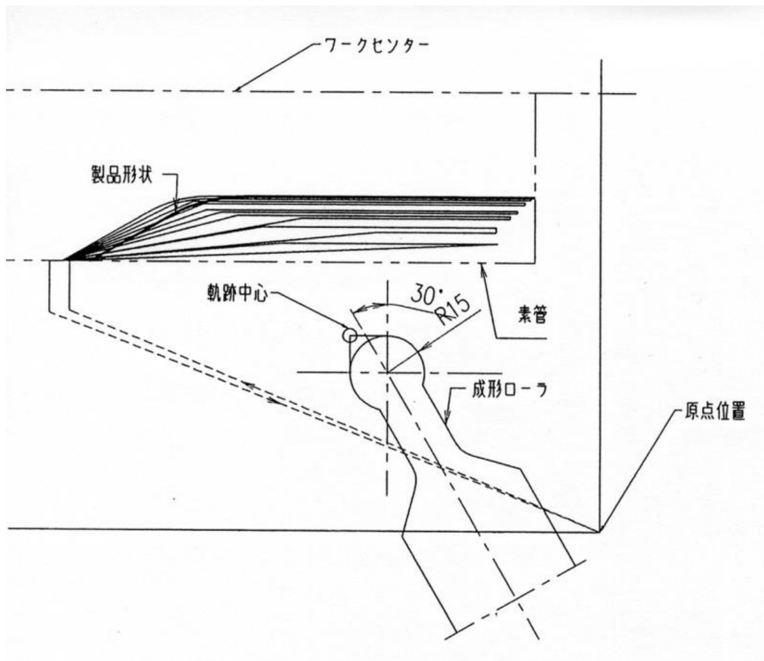


Primary tube
Swaging
Hydroforming (50%)
Hydroforming (100%)

Swaging of Beam Pipe for Single Cell Cavities







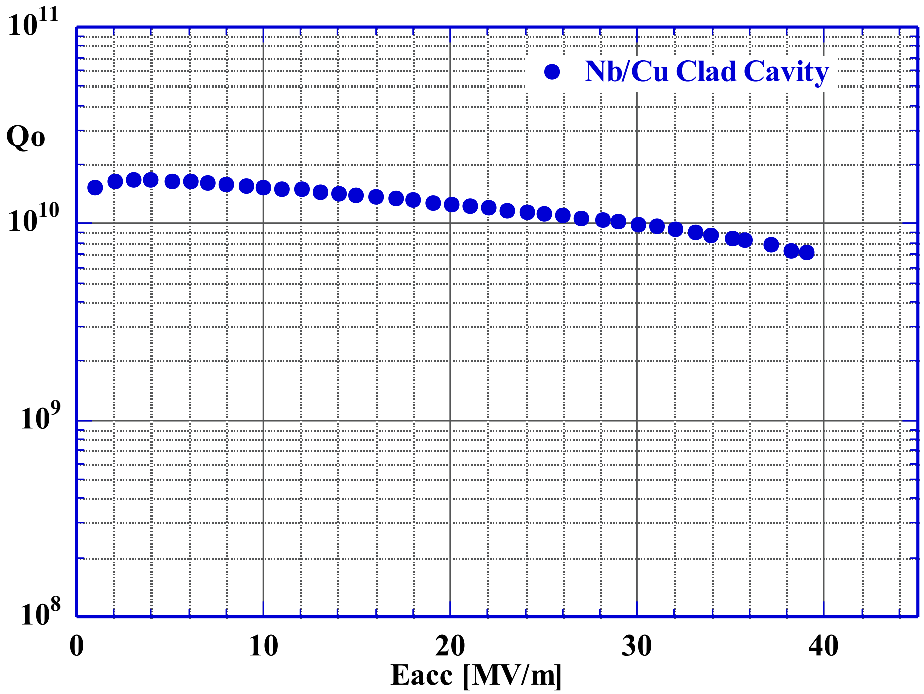
Koshin-Giken
(Japan, Shizuoka prefecture)

Hydroforming of Nb/Cu Clad Cavity in KEK

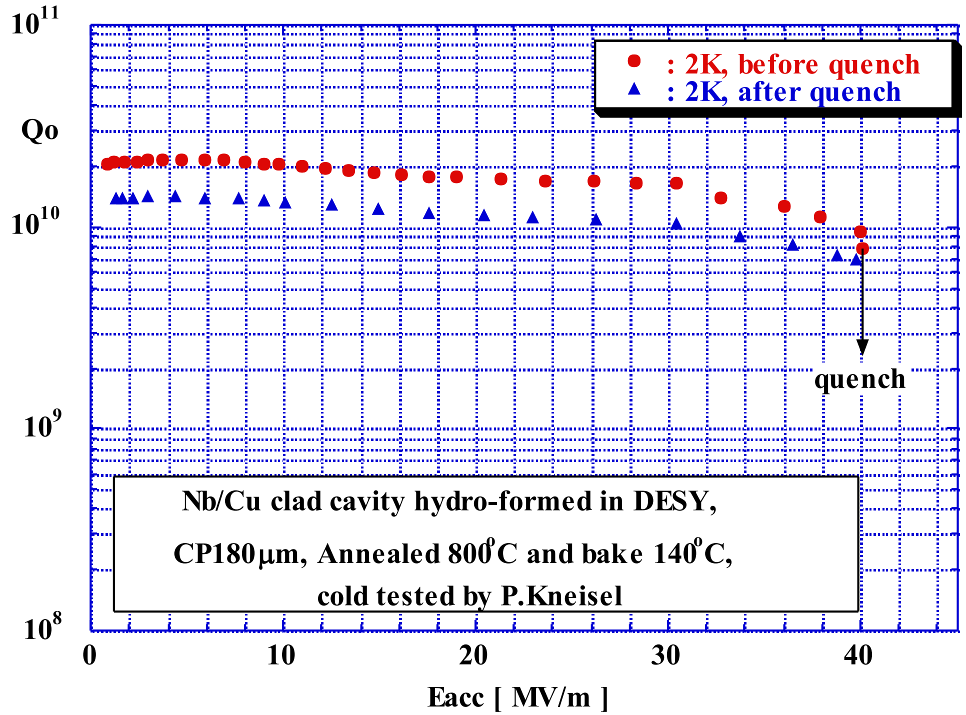
Koshin-Giken
(Japan, Shizuoka prefecture)

Cavity Performance of Nb/Cu Clad Cavities with ILC Shape

KEK/Nippon Steel/DESY

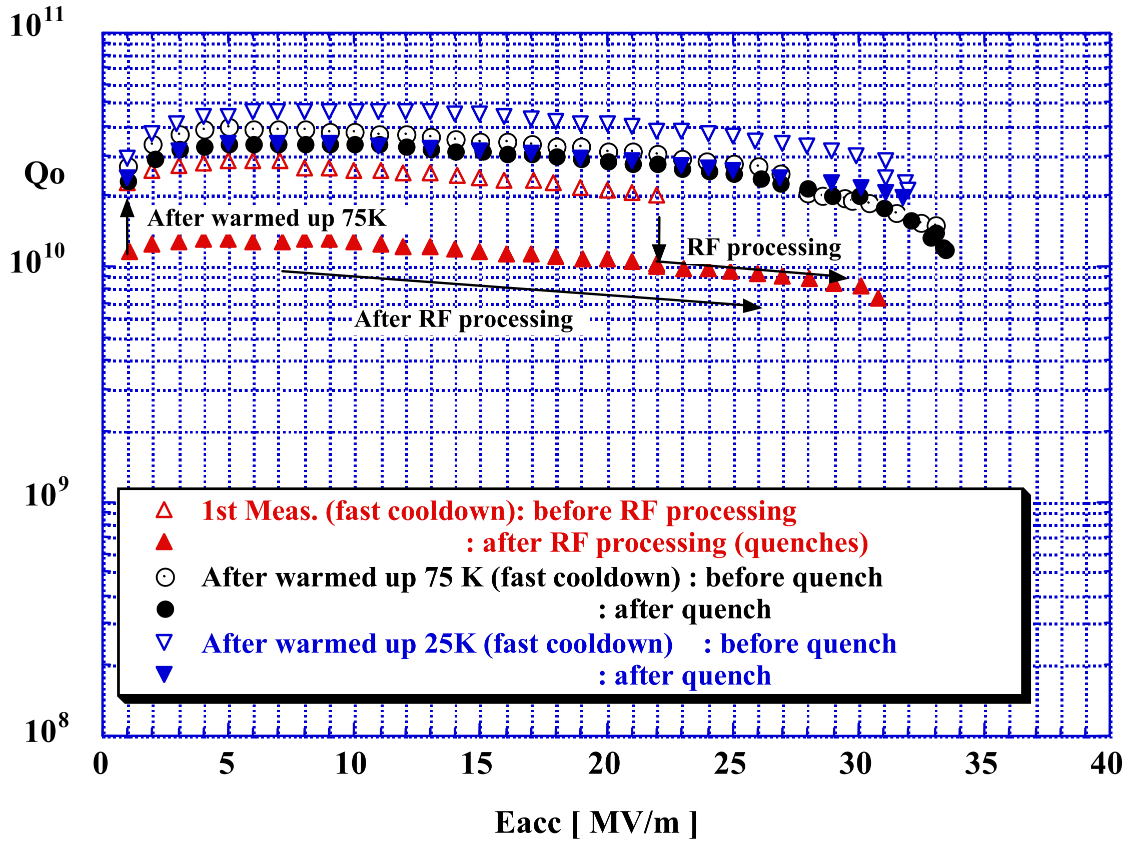


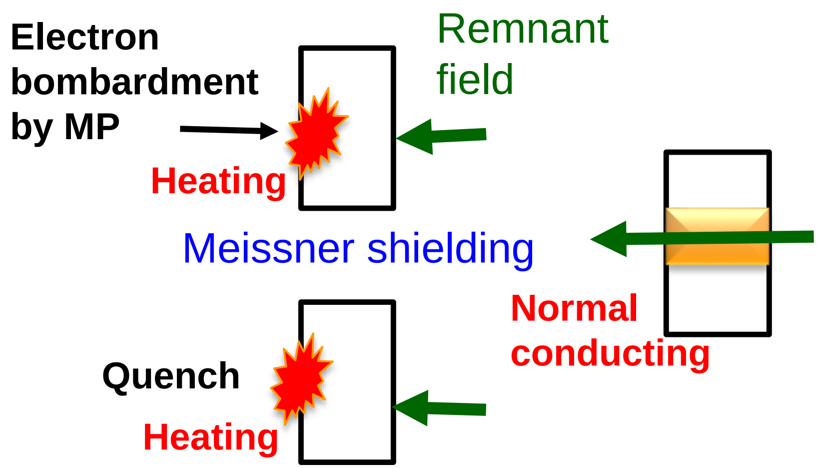
JLAB/DESY/KEK



- Excellent performance !!
- Even BCP(CP) can produce 40MV/m.
- After quench, Q degrades.

Flux Trapping Issue





At first test, Q dropped during RF conditioning of MP

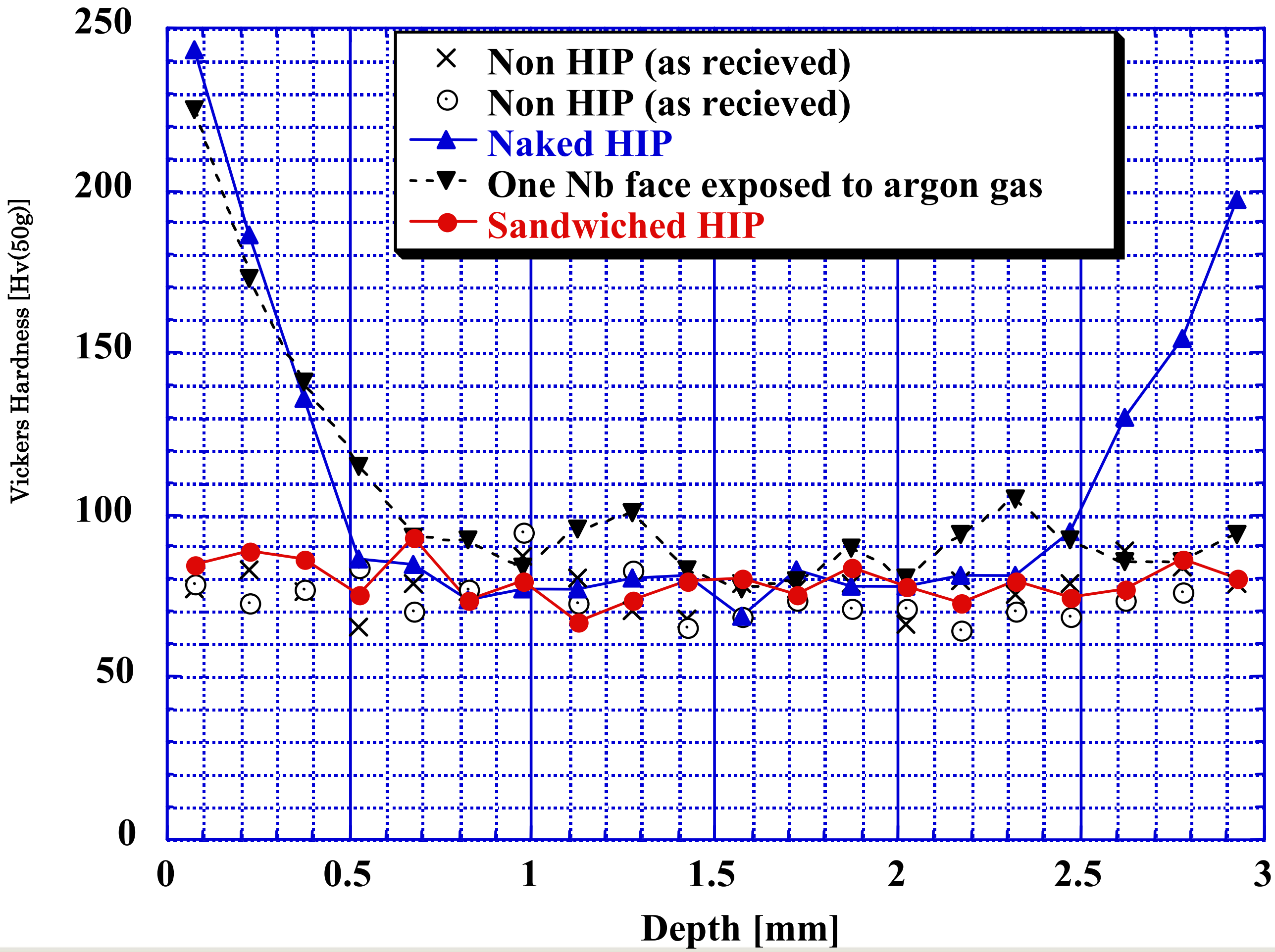
After RF successful conditioning, gradient reached 32MV/m with low Q

After warmed up 75K, gradient reached 33MV/m with high Q.
Even after quench no Q dropped

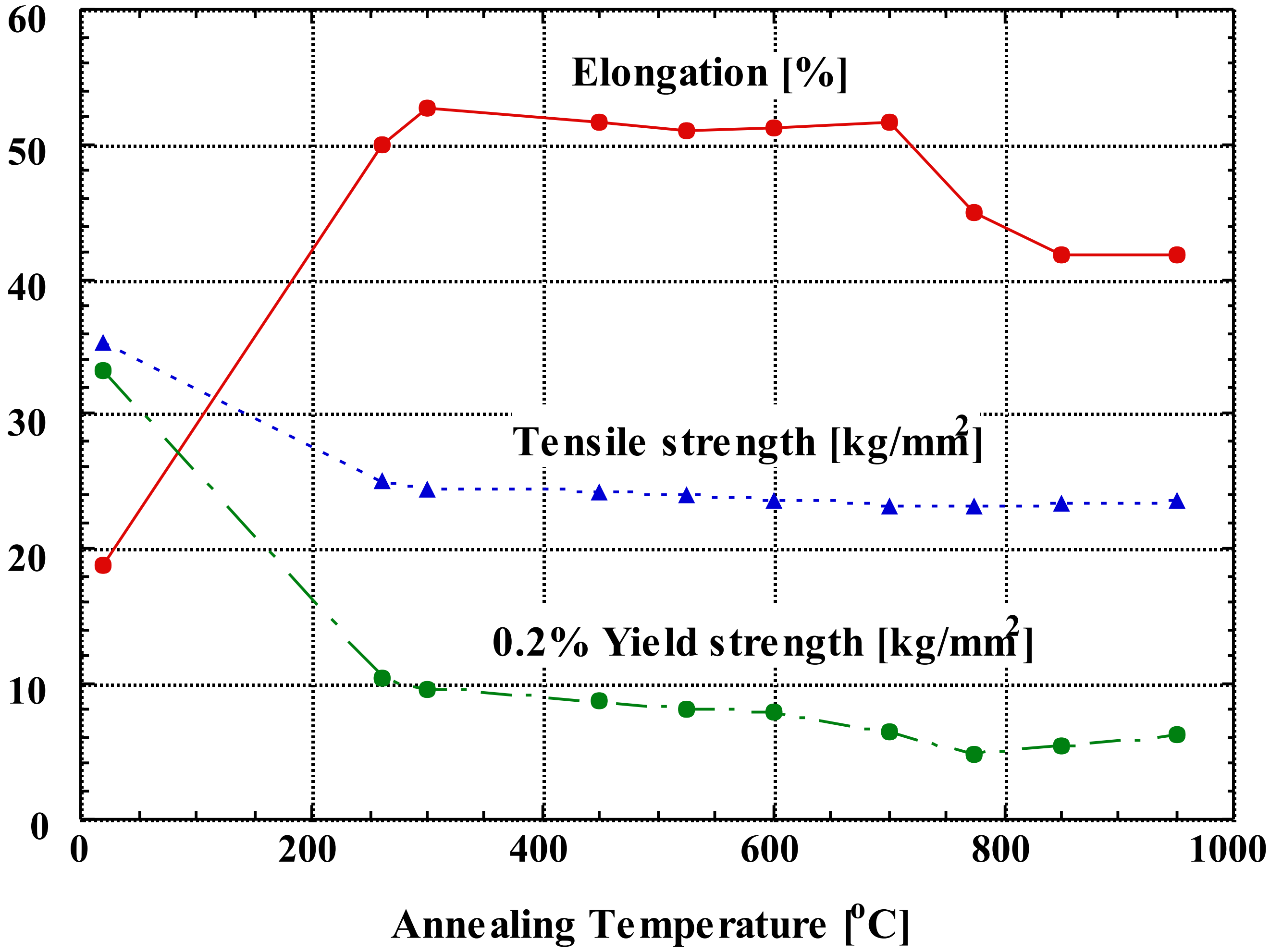
After warmed up 25K, gradient reached 32MV/m with high Q.
After quench, Q dropped

Merits of the Sandwich Structure

No material degradation on Nb by sandwiched structure



Better Formability with Clad Nb/Cu Material



Improved formality of Niobium material

18 Homework

- 18.1 Homework

Low temperature baking after N_2 exposure mitigates the degradation, while the mechanism is not yet been understood.

Describe your idea why the low temperature baking can mitigate the degradation of N_2 exposure.

- 18.2 Homework

Nb/Cu clad seamless technology has a demerit with the flux trapping issue.

Describe your idea about what kind of technical strategy is able to resolve or mitigate this issue.