Superconducting RF - II
- Basics for SRF Technology -

K.Saito, KEK

10. Cavity Fabrication
11. Performance Limitations and Cures
12. Surface Preparation

10. Niobium Cavity Fabrication

10.1 Deep Drawing

10.2 Trimming of half cell

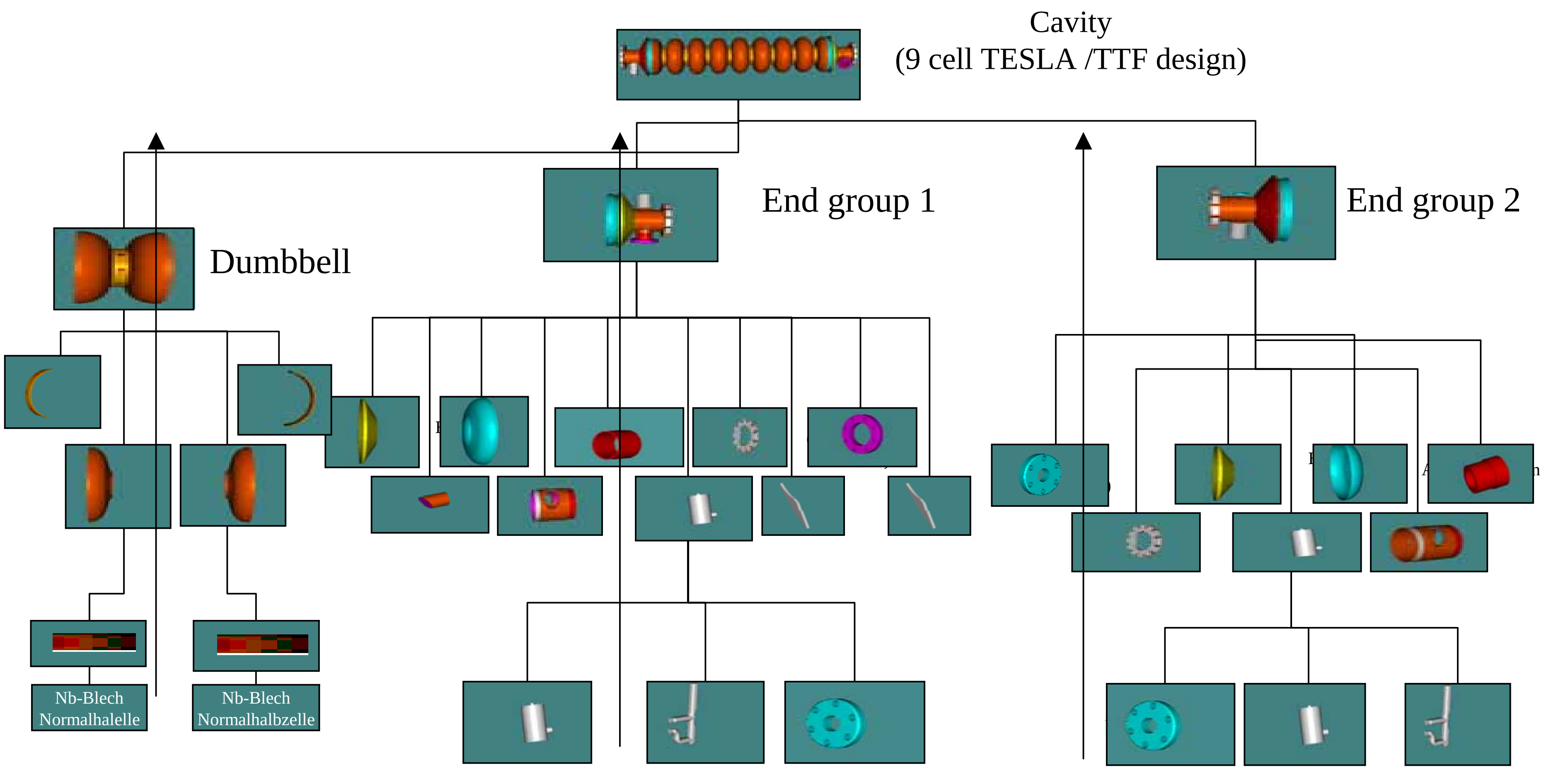
10.3 END group fabrication

10.4 Final EBW assembly

10.5 Nb film coated cavity

Note

Overview on cavity fabrication



Cavity fabrication and preparation sequences
for the TESLA / TTF cavities at DESY

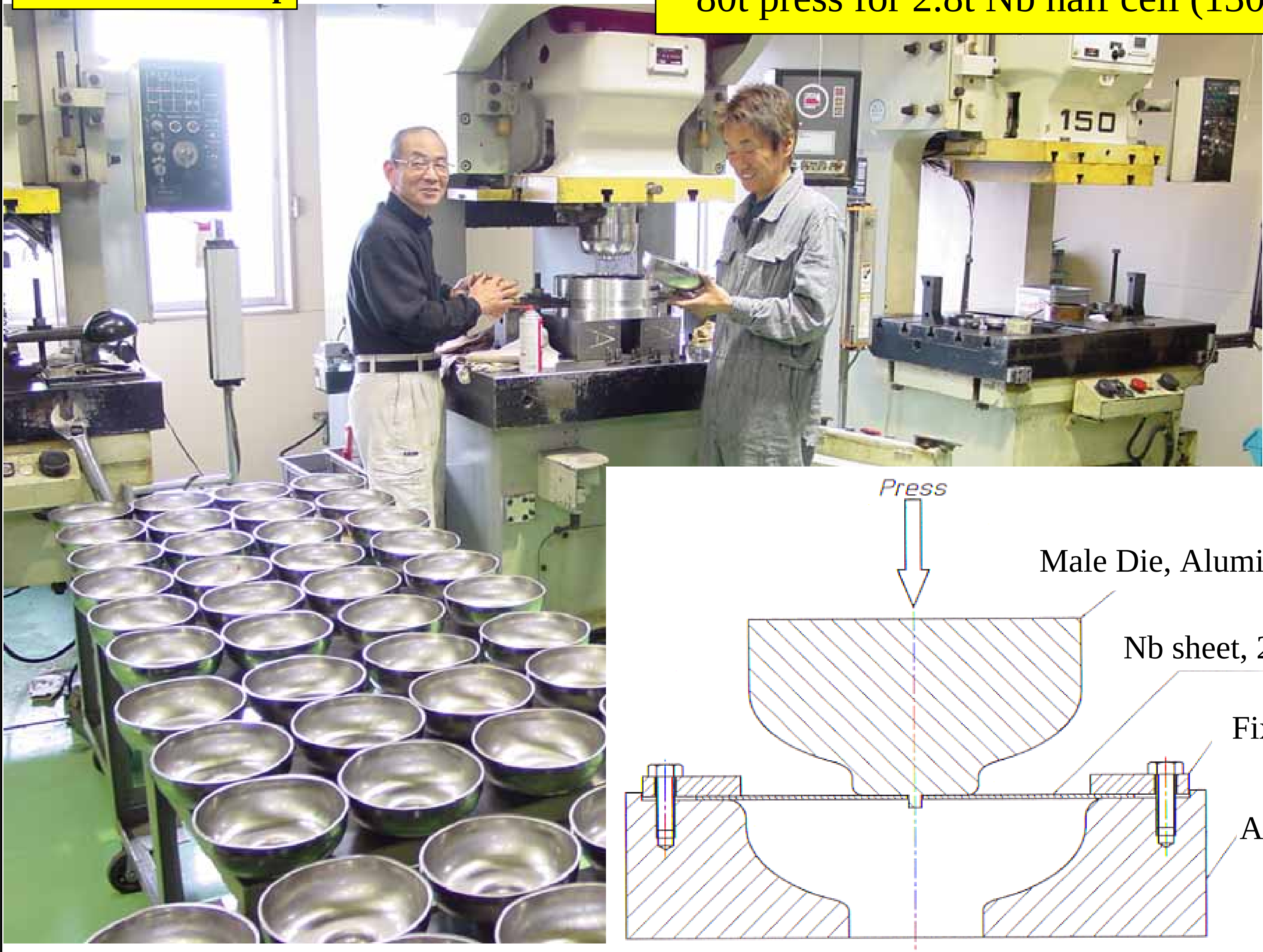
1st ILC workshop at KEK Tsukuba Japan

A.Matheisen
for DESY and the TESLA Collaboration

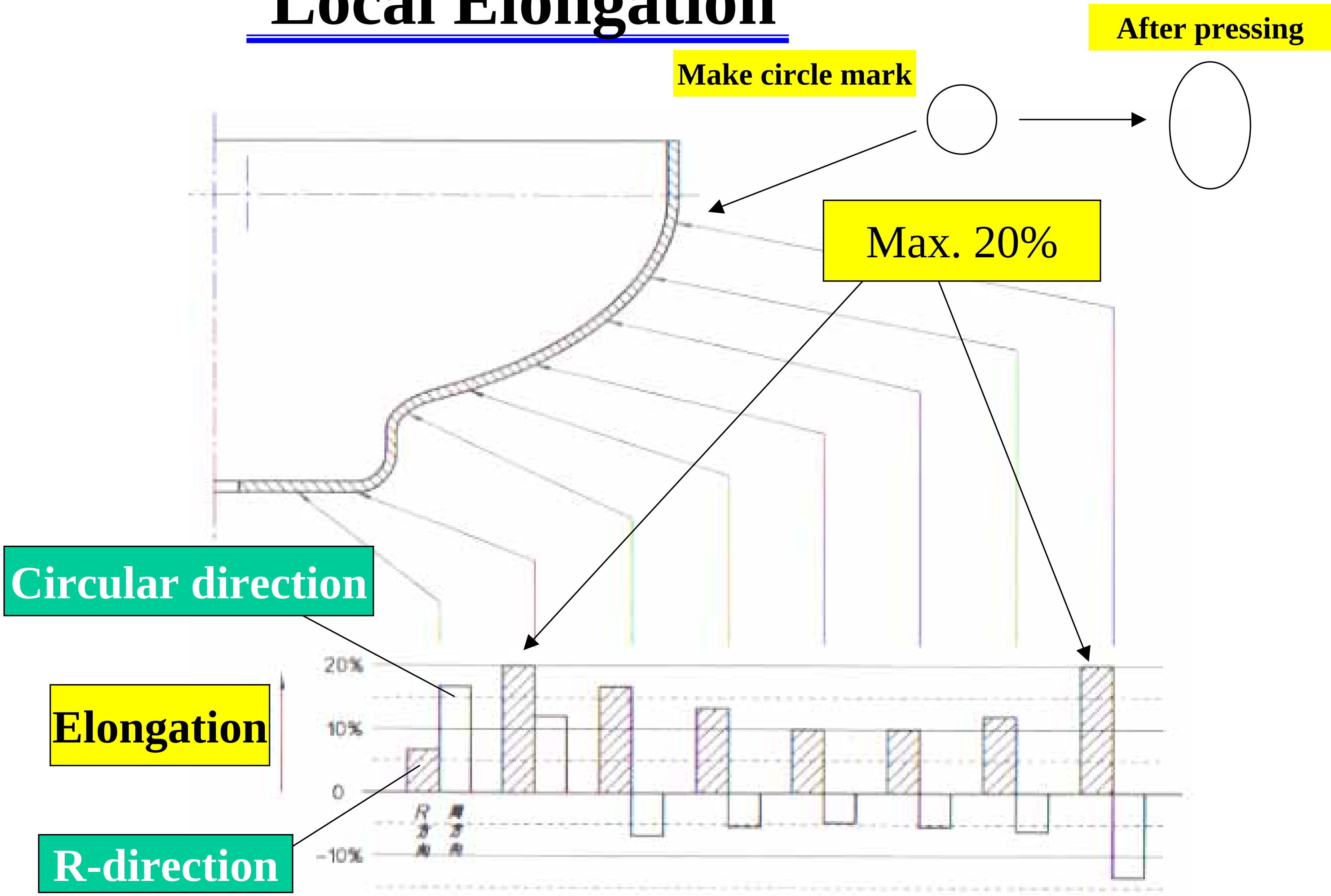
10.1 Deep Drawing

Kikuchi Workshop

80t press for 2.8t Nb half cell (1300MHz)



Local Elongation



10.2 Trimming

Ishizuka Workshop

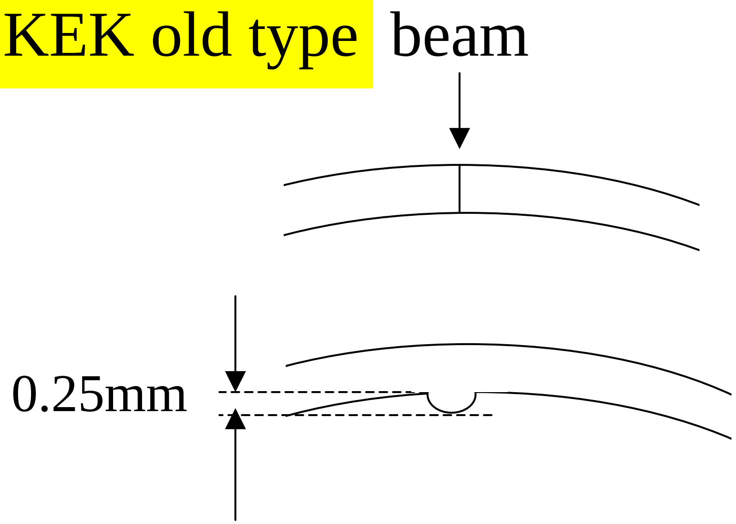
Iris Trimming

Equator Trimming

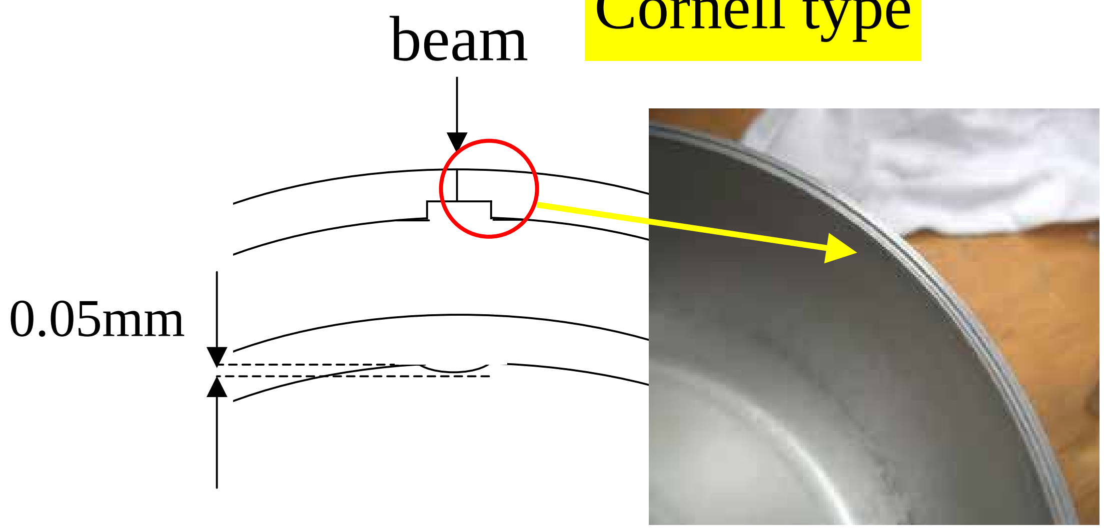
Trimming Configuration at Equator section

So far, KEK has used CBP 100-200μm to make smooth the equator EBW seam. The left trimming shape needs CBP 10 times, and the right trimming configuration needs only CBP twice.

KEK old type



Cornell type

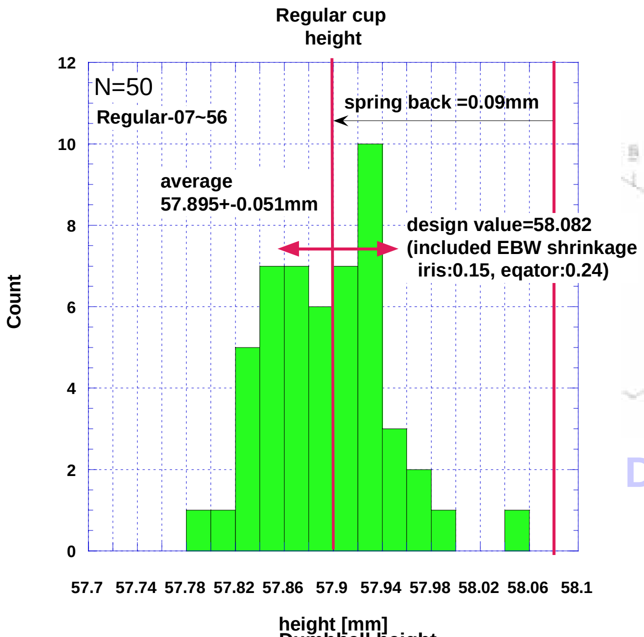


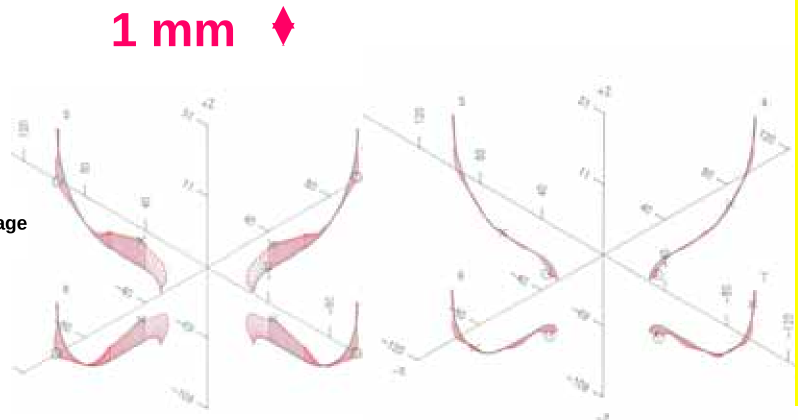
Needed CBP ~10 times

CBP only twice!

Cornell trimming configuration is very useful to smooth the EBW seam by less CBP.

Fabrication Error on half-cell cup

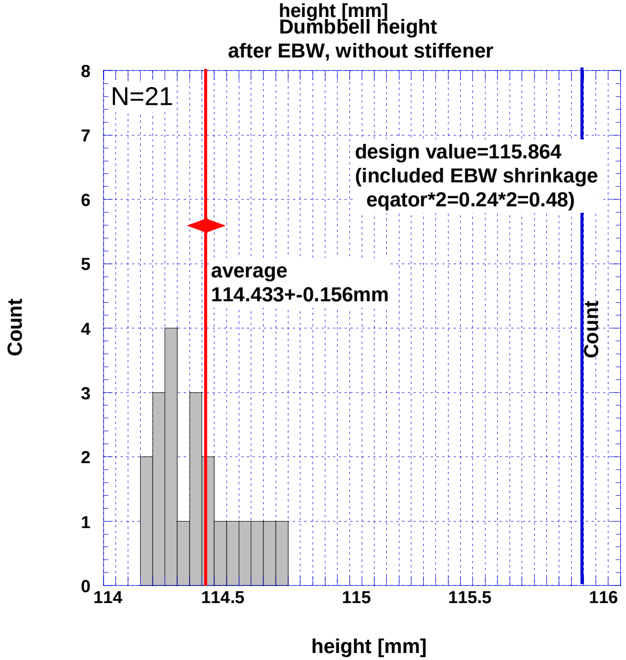


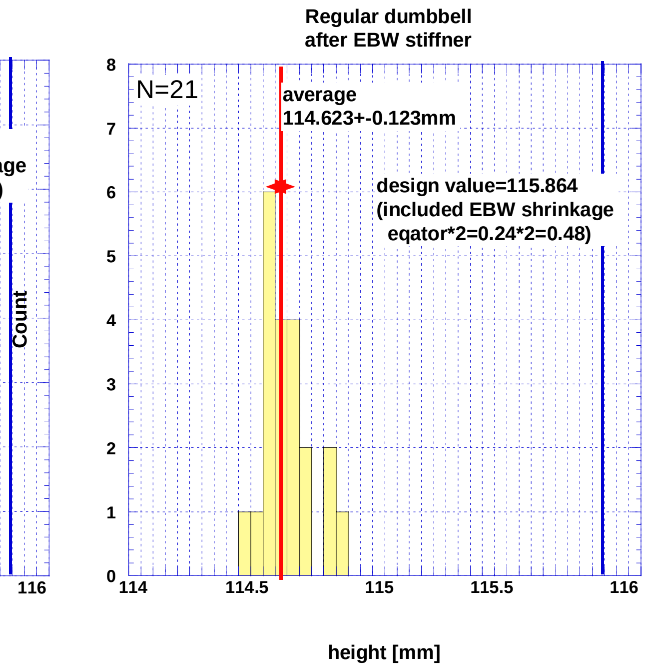


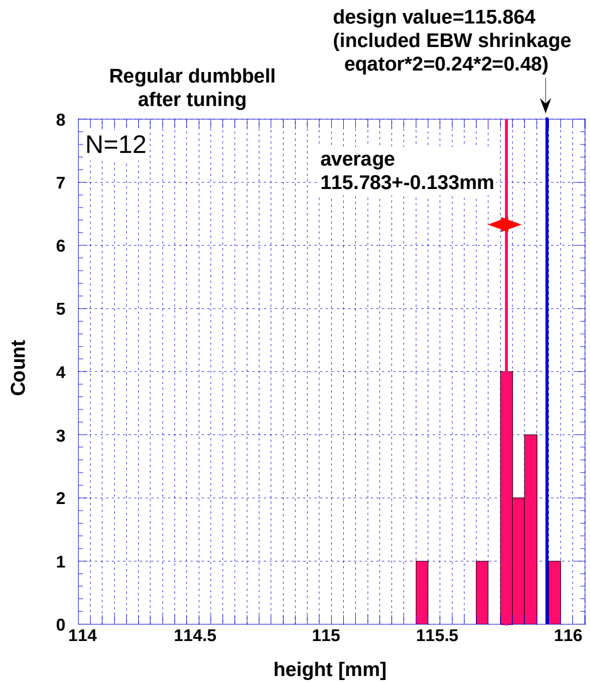
Dumbbell EBW

After stiffener EBW on dumbbell and tuning

Machining error: 50µm
Half cell spring back:90µm
EBW shrinkage
(old trimming configuration)
0.42 ± 0.13mm @ equator
0.15 ± 0.04mm @ iris
Dumbbell fabrication error
~80µm after tuning
9-cell length error:0.7~0.1mm

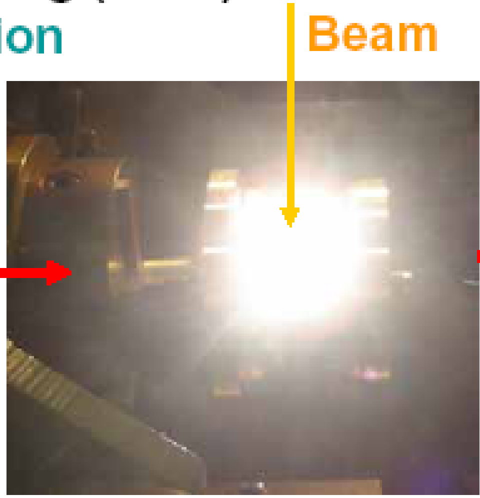




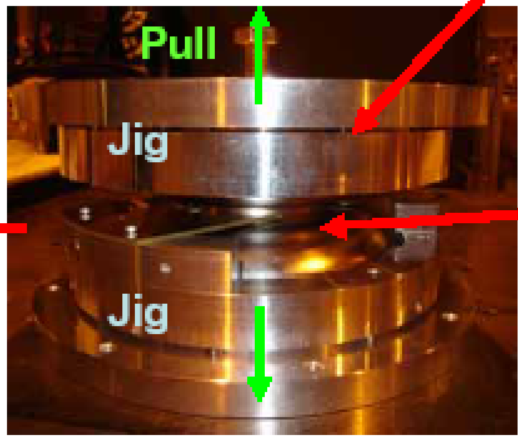


EBW of Dumbbell with stiffener

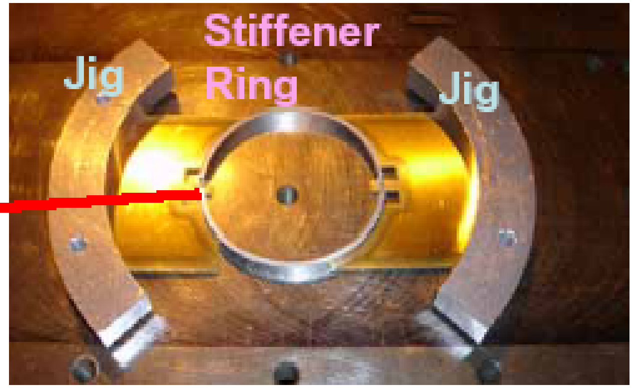
Electron Beam Welding (EBW)
In KUROKI corporation



Dumbbell with stiffener-ring after EBW.



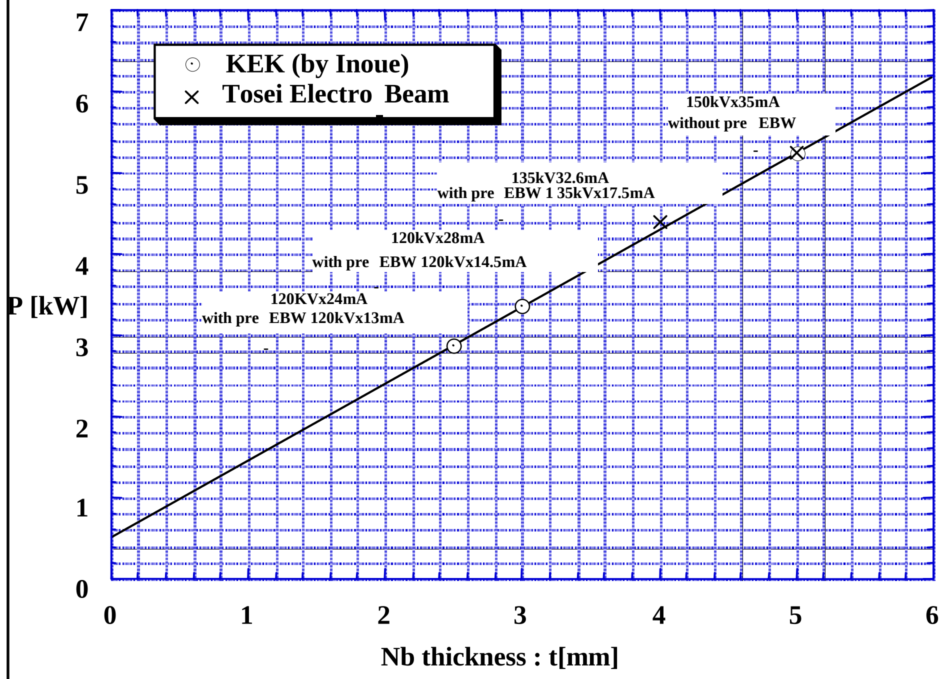
Pull and extend dumbbells to insert stiffener-ring.
=> EBW (dumbbell + ring)

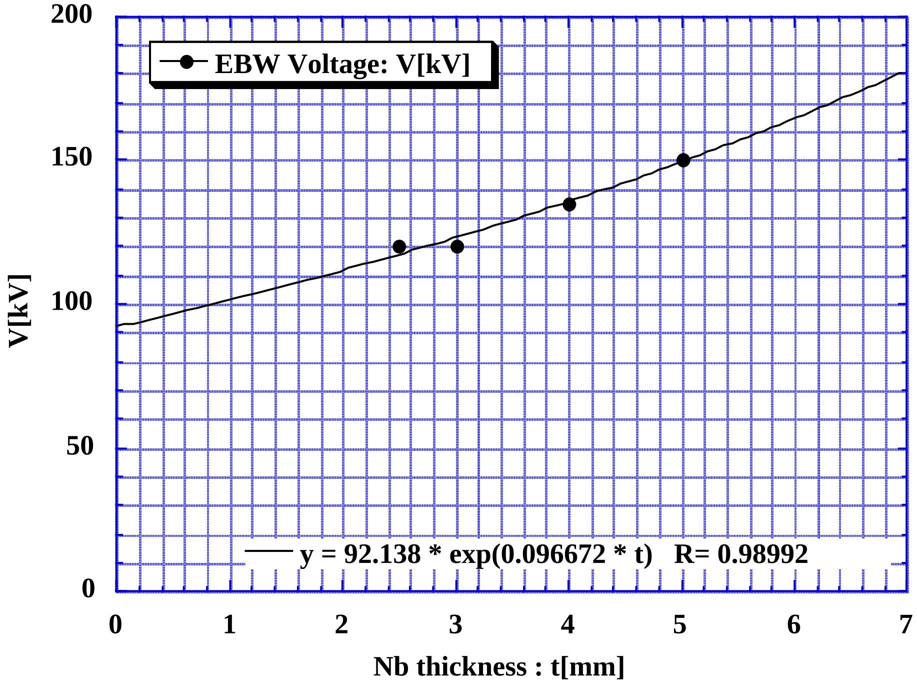


Insert stiffener-ring into the iris part of dumbbell.

EBW Conditions at KEK

KEK Data





Dumbbells and END Cups

PAL

Note

10.3 END Grope fabrication
-Beam Pipe fabrication (thicker Nb tube case)-

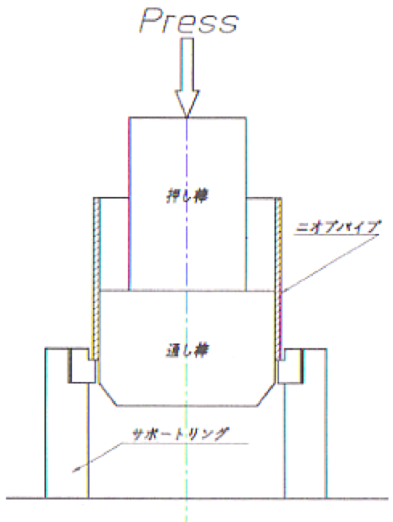
Rounding ends

Bending

Closing

Thickness: 4t ~ 6t

After EBW



Drawing

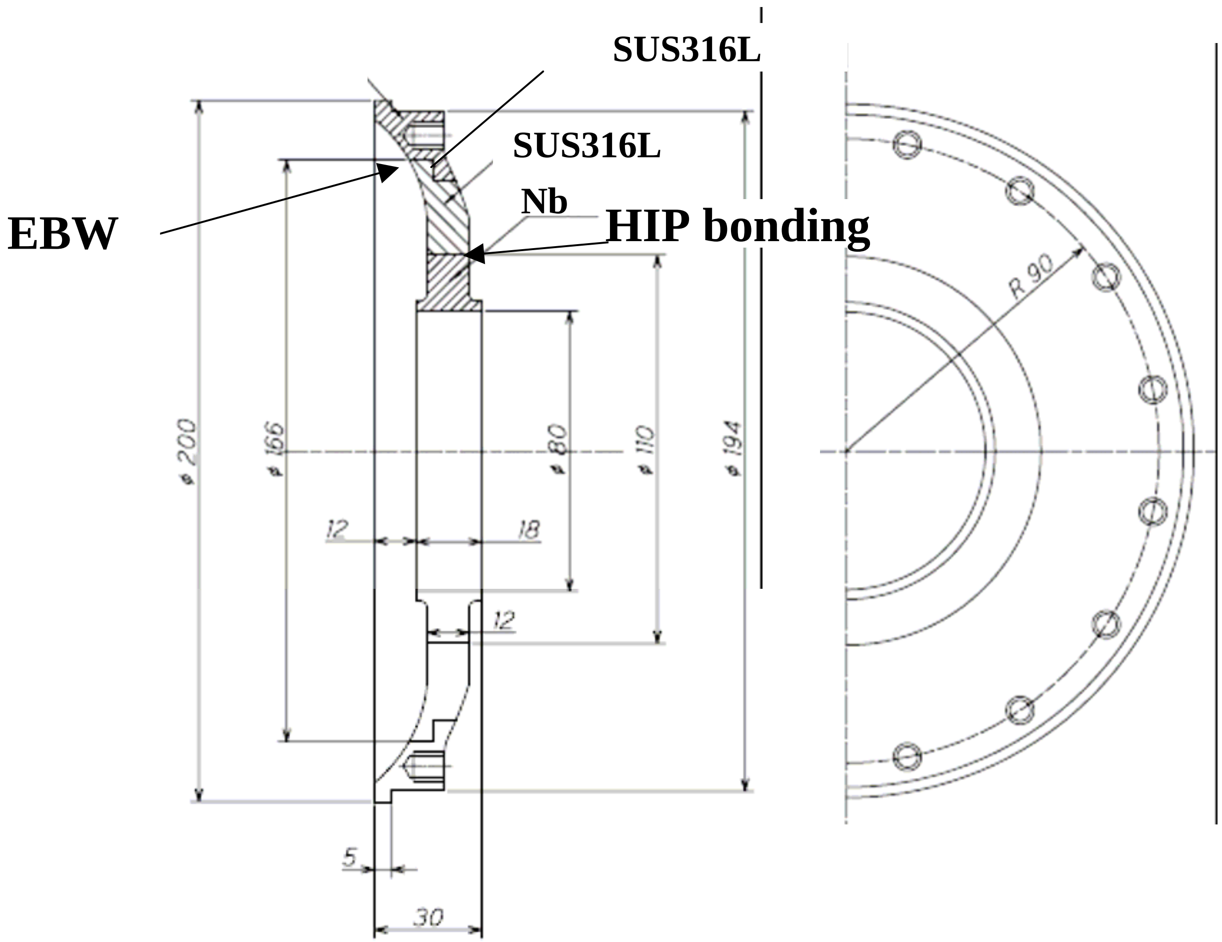
Circular die

Oil pump

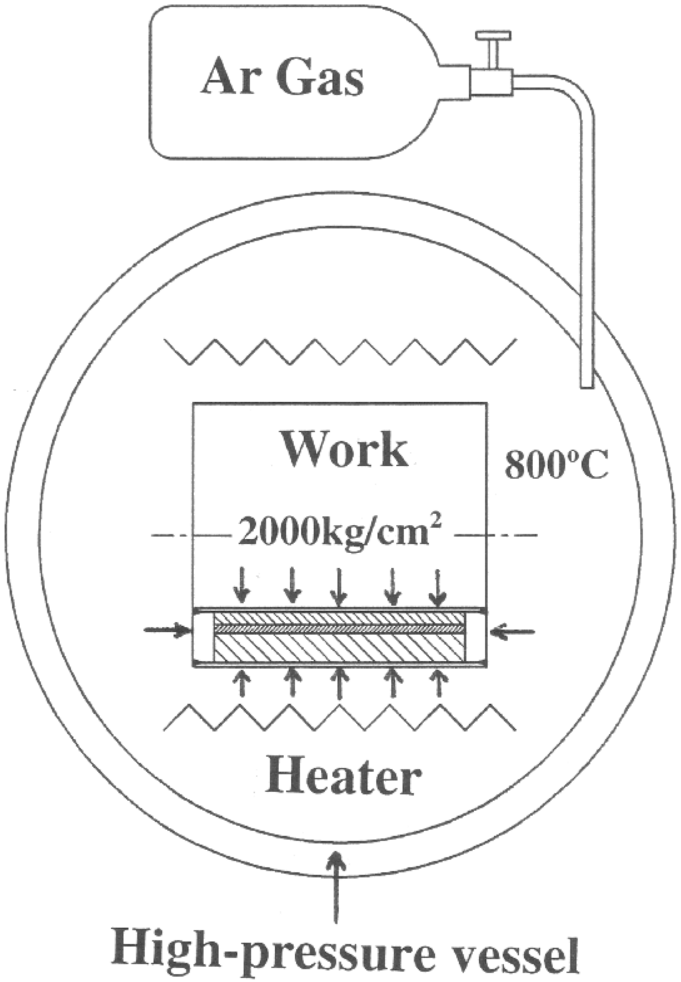
Circular tube

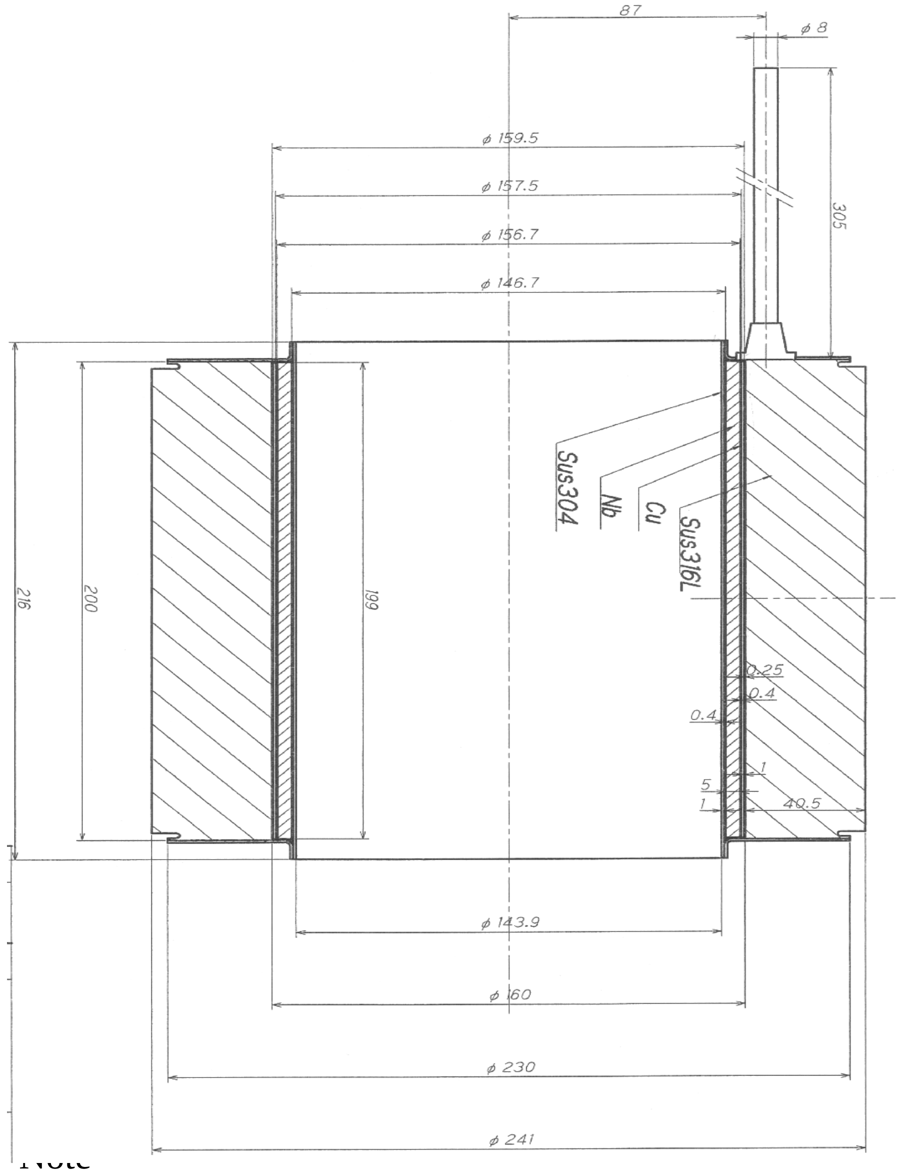
HOM Coupler Parts

END base plate for Helium Vessel



Nb/SUS bonding by HIP

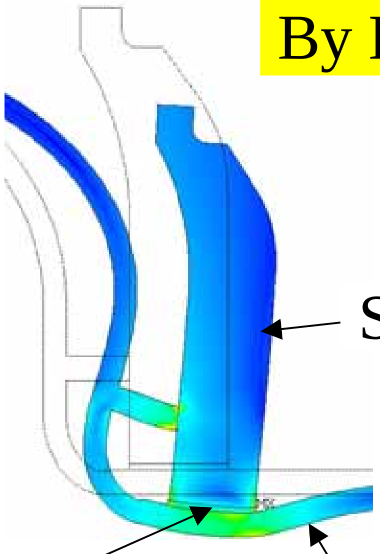




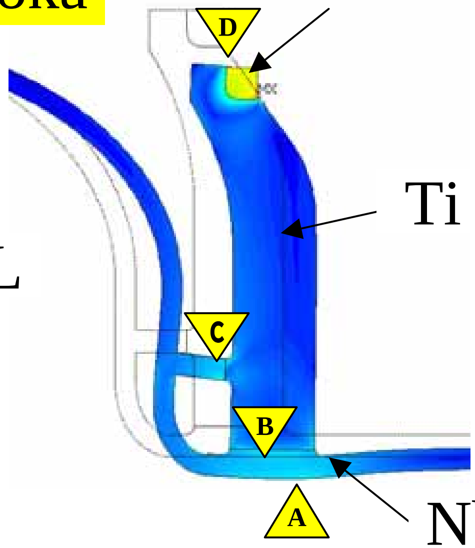
Note

Care for the thermal stress at the base plate

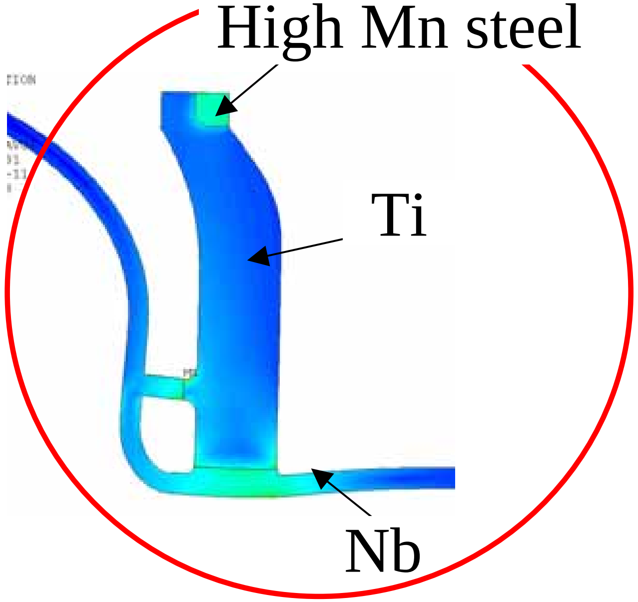
By H.Yamaoka



Nb/Cu/SUS316L



Nb/Ti+SUS316L



Nb/Ti+High Mn steel

Thermal expansion coefficient

	$\alpha = \frac{\int_{77K}^{300K} \alpha(T)dT}{300-77}$ [E-6/K]
SUS316L	16.0
Cu	17.0
High Mn steel	9.8
Ti	8.4
Nb	5.0

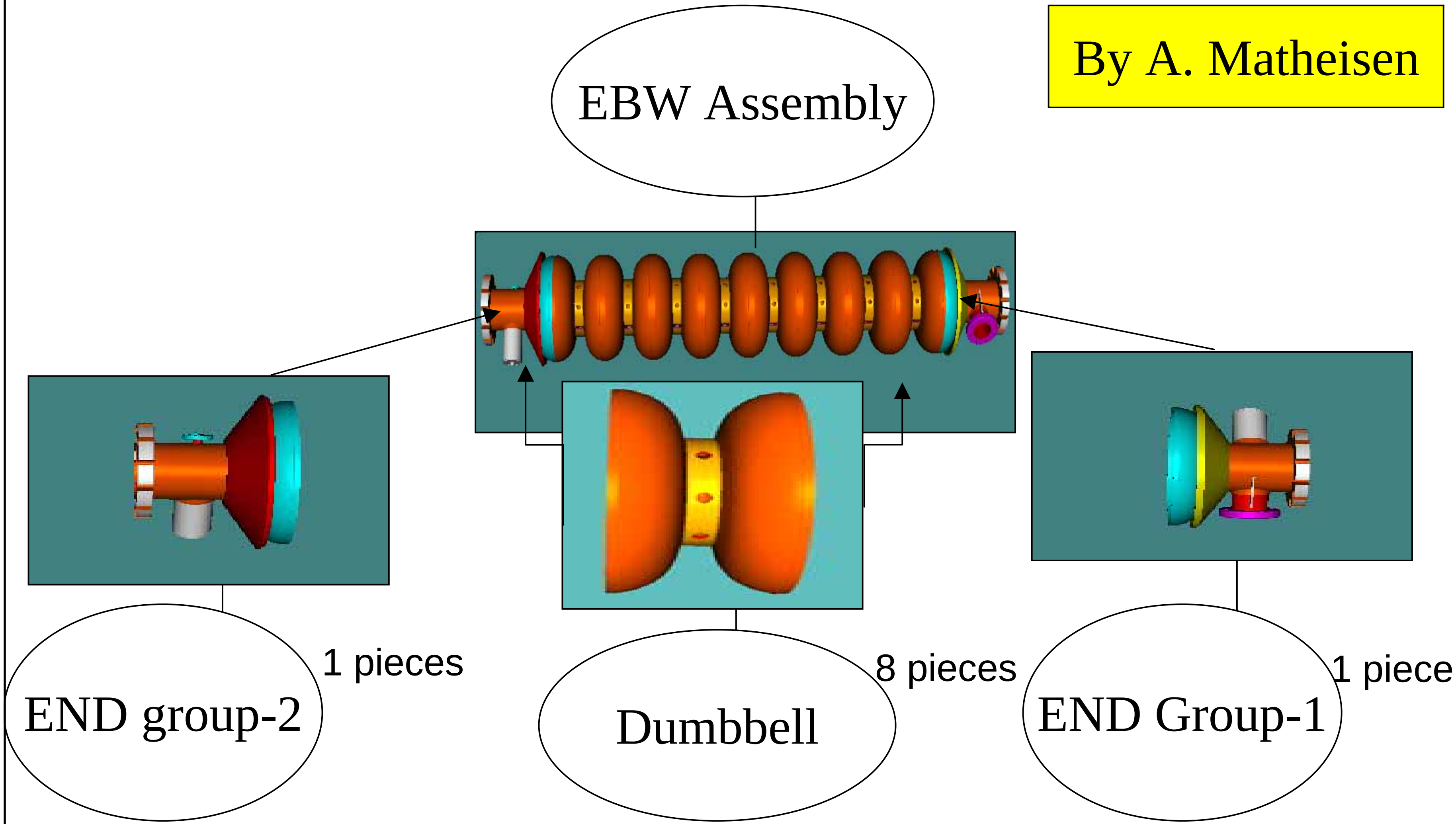
Stress concentration

	A [MPa]	B [MPa]	C [MPa]	D [MPa]
Nb/Cu/SUS316L	250	500	500	
Nb/Ti/SUS316L	100	100	200	470
Nb/Ti/High Mn Steel	100	100	200	80

EBW of END Group

SFC

10.4 Final EBW Assembly

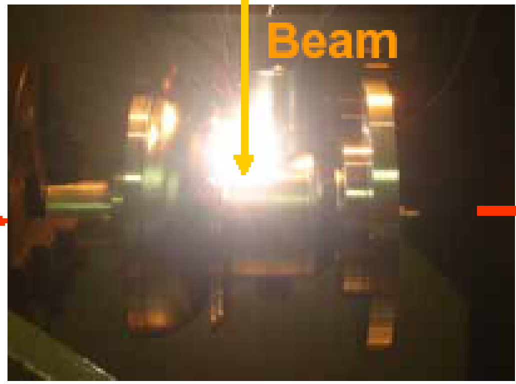


EBW Assembly of Cavity

EBW of dumbbells

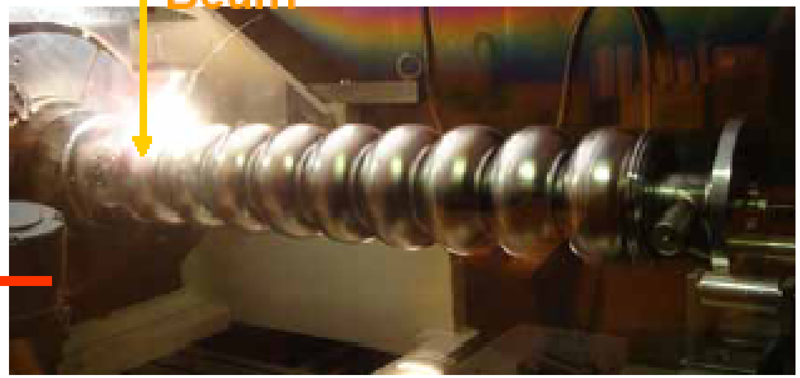
Beam

EBW of end-beam-pipe

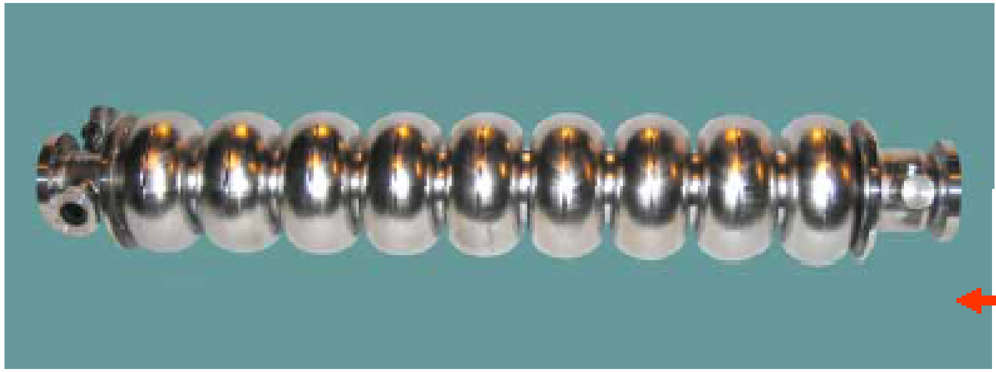


End-beam-pipes with HOM and flanges

Beam



EBW of end-beam-pipes and cell-part



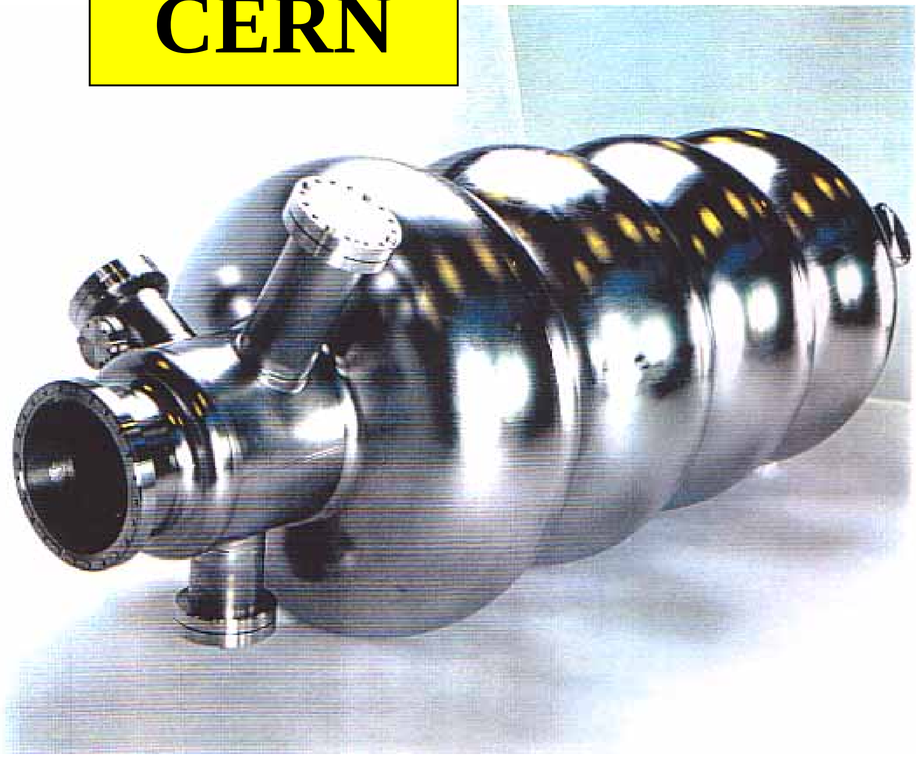
Four 9-cell ICHIRO high-gradient LL Cavities were successfully delivered to KEK ! (4 July 2005)

Completed Ichiro 9-cell Cavity

Kuroki Welding Company

10.5 Nb film coated cavity

CERN



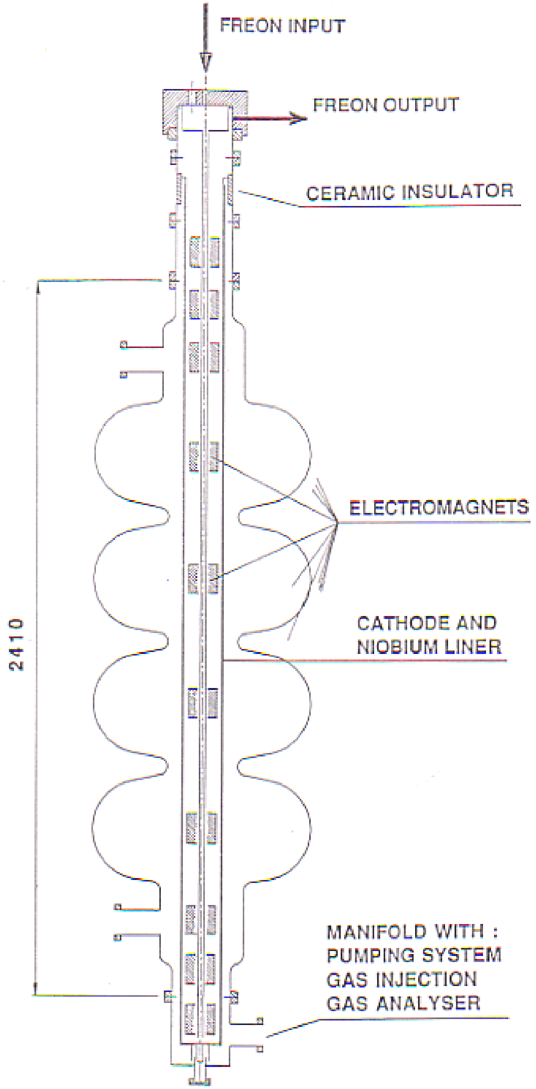
LEP-II 352MHz

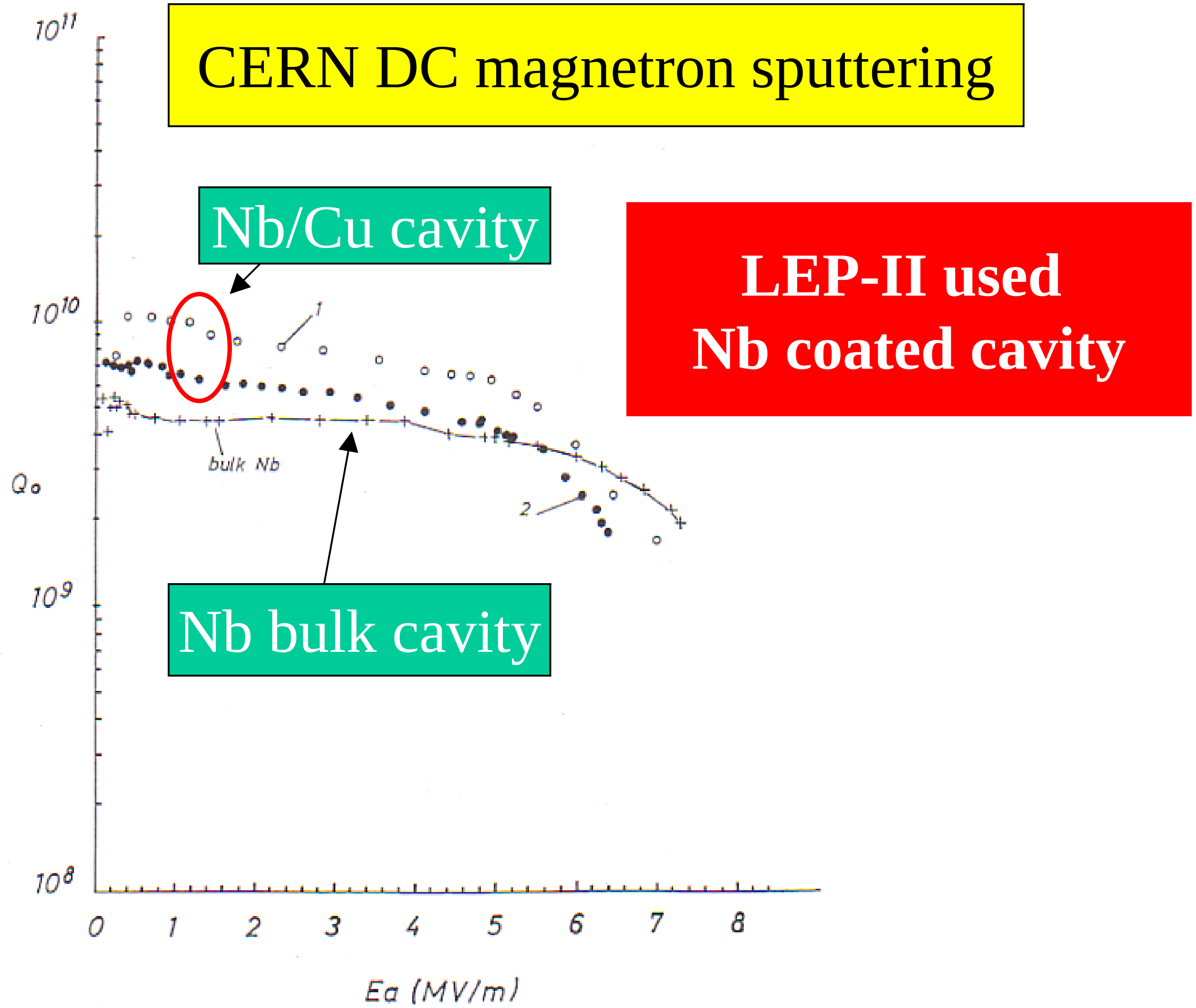
niobium bulk cavity

Copper half cell before Nb coating

(electropolished)

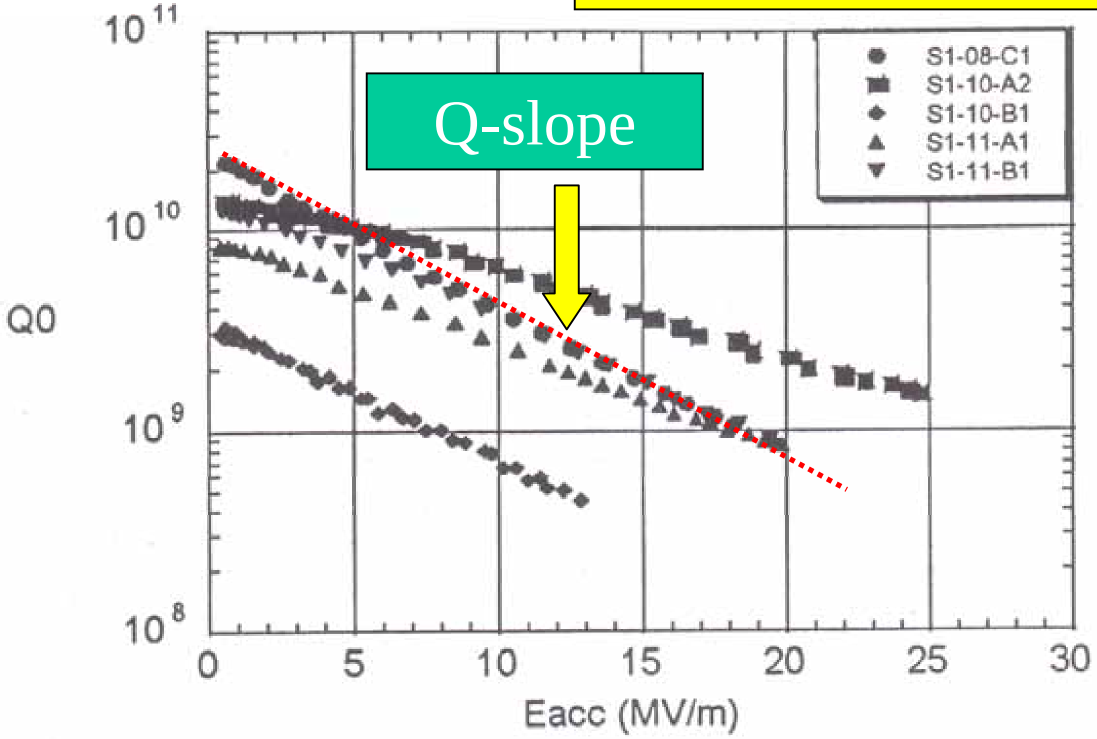
Nb Coating Method at CERN





Q-slope in Nb coated cavities

Saclay 1500MHz



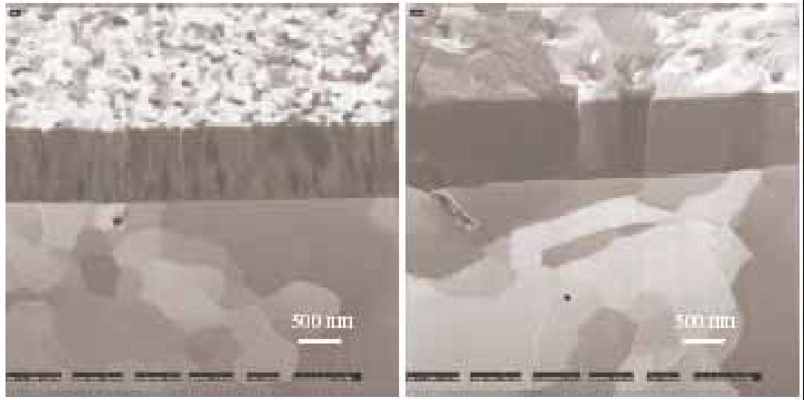
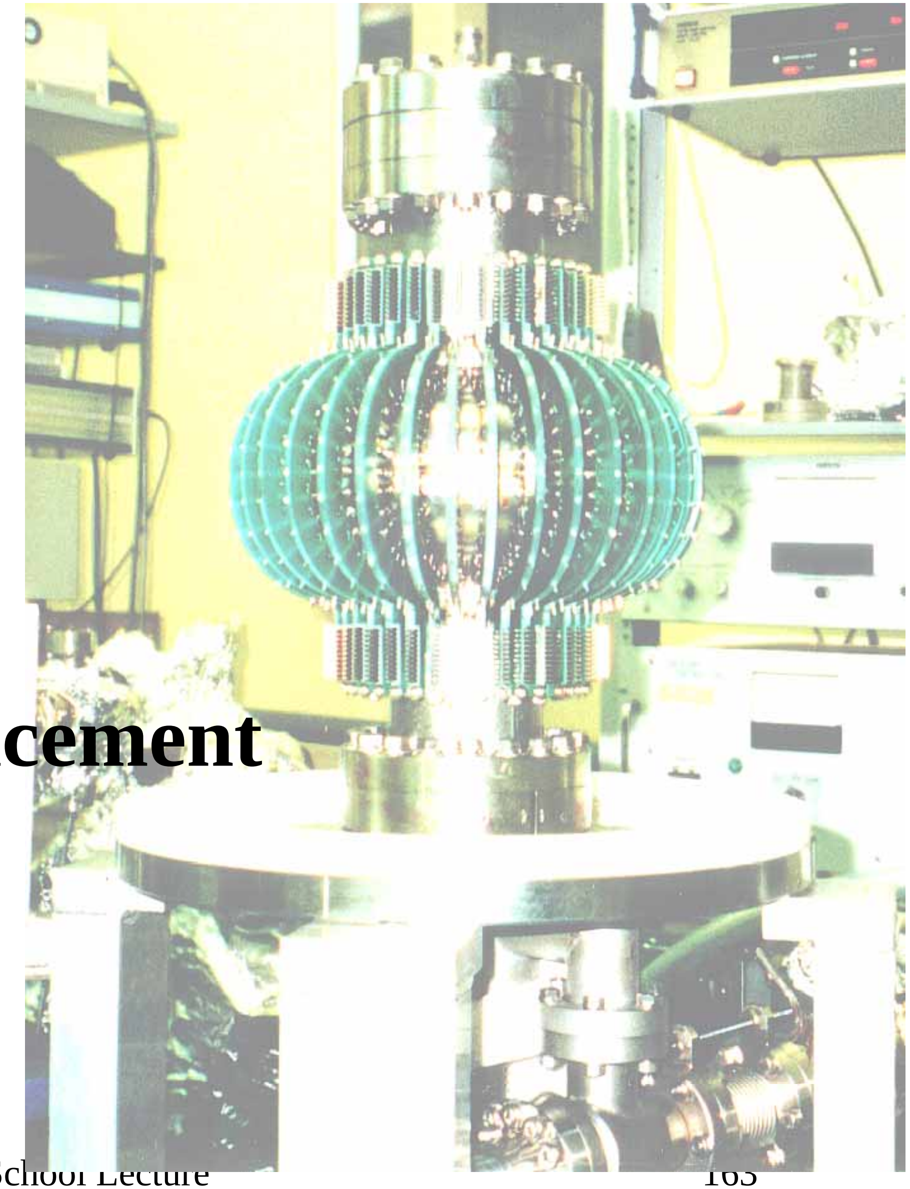


Figure 4: Cross sectional FIB images of niobium films on oxidised (left) and oxide-free (right) copper substrates

Problem: Q-slope
It is no problem at low gradient 5-10MV/m. It brings a serious Q dropping at high gradient. Many studies are under way but so far application of this technology has no hope for ILC.

11. Performance Limitations and Cure



11.1 Field Emission

11.2 Multipacting

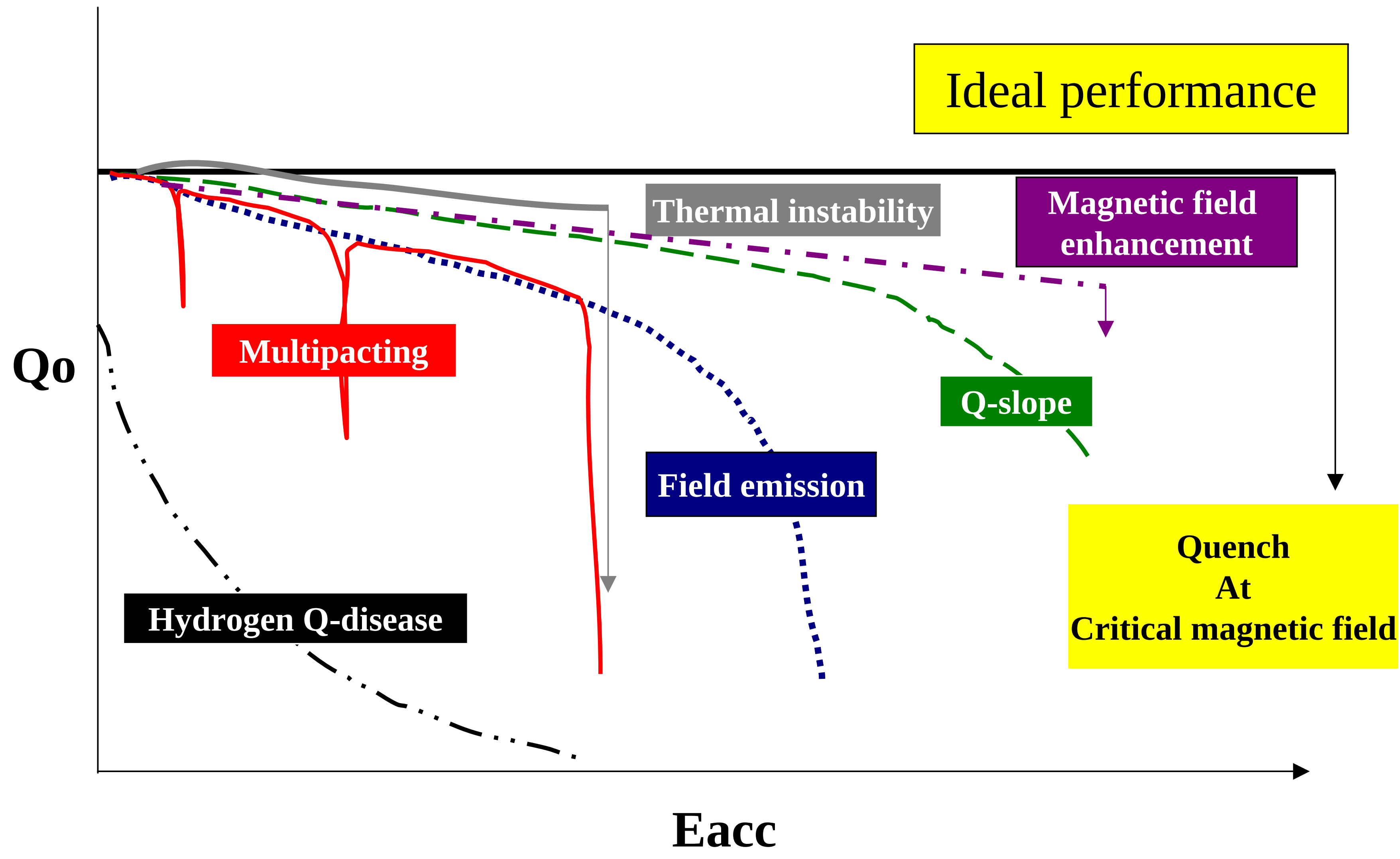
11.3 Thermal Instability

11.4 Hydrogen Q-Disease

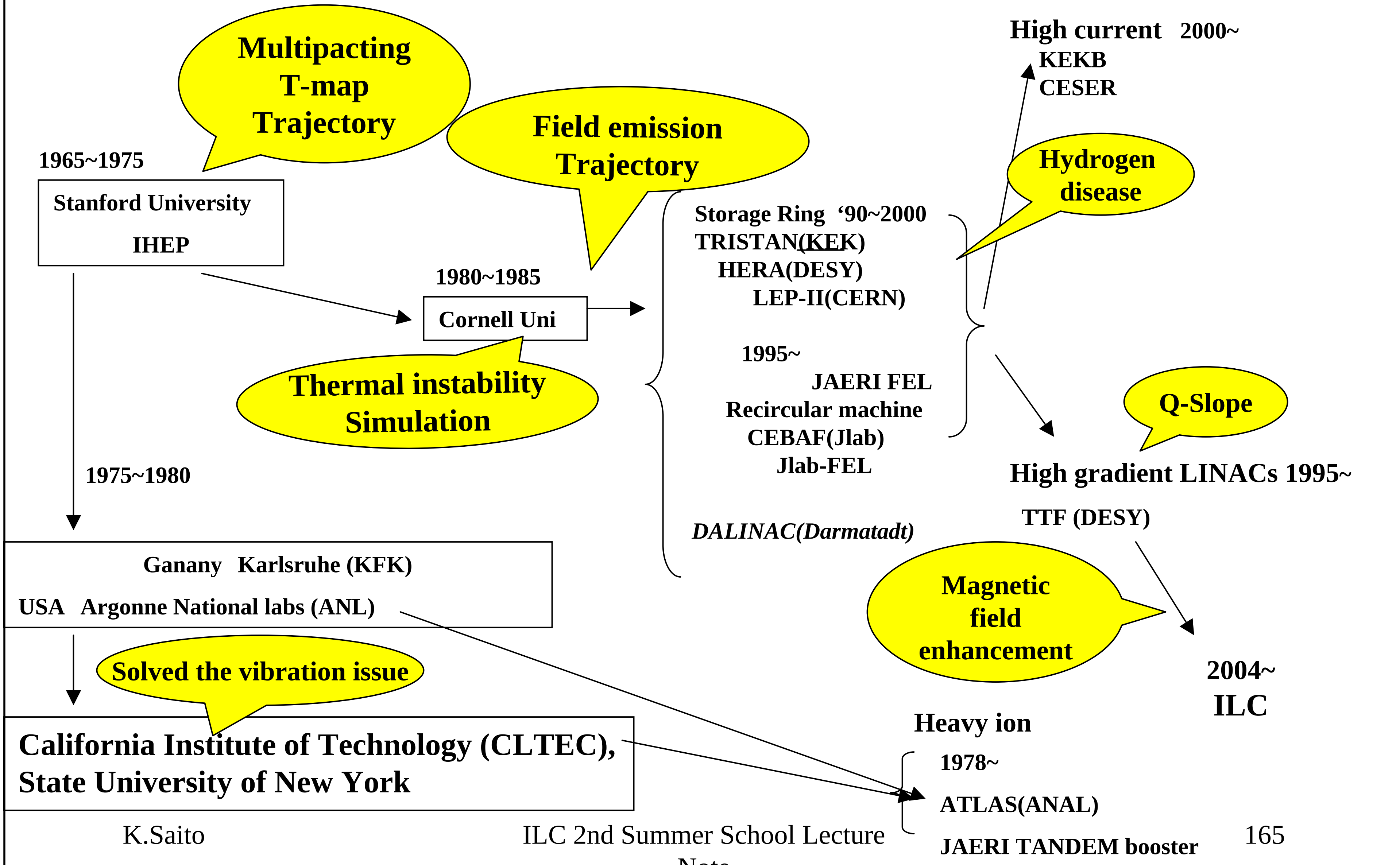
11.5 Q-Slope

11.6 Magnetic Field Enhancement

Various Performance Limitations in SRF Cavity

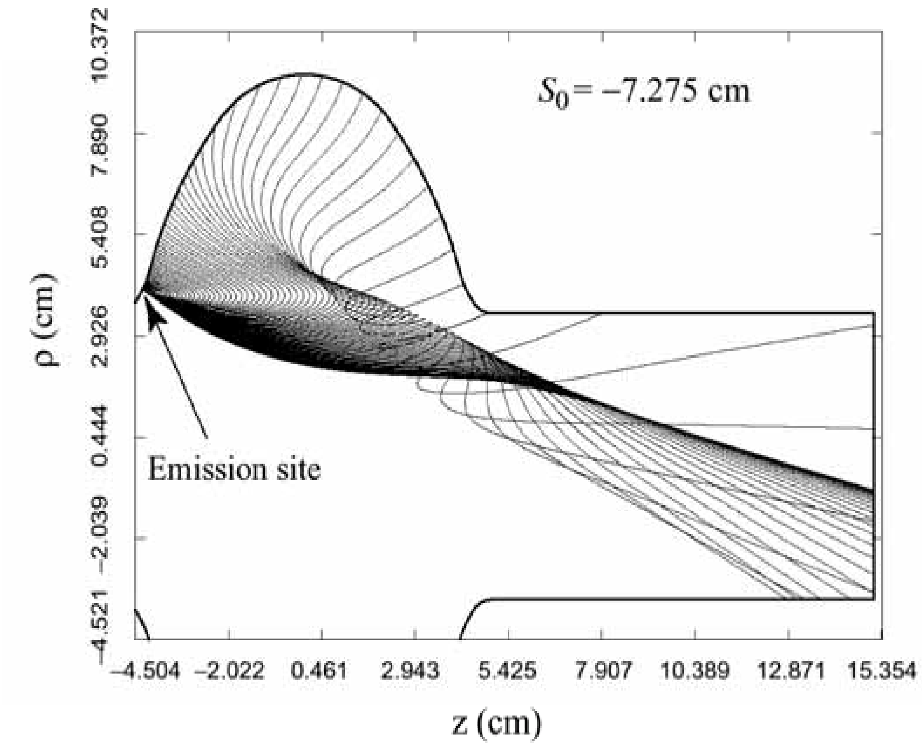


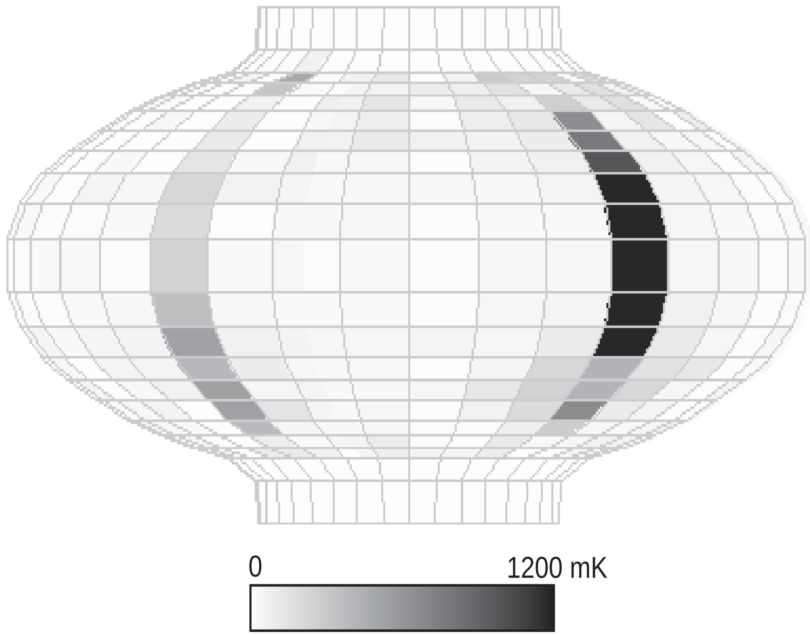
History of the Understanding of limitations



11.1 Field Emission

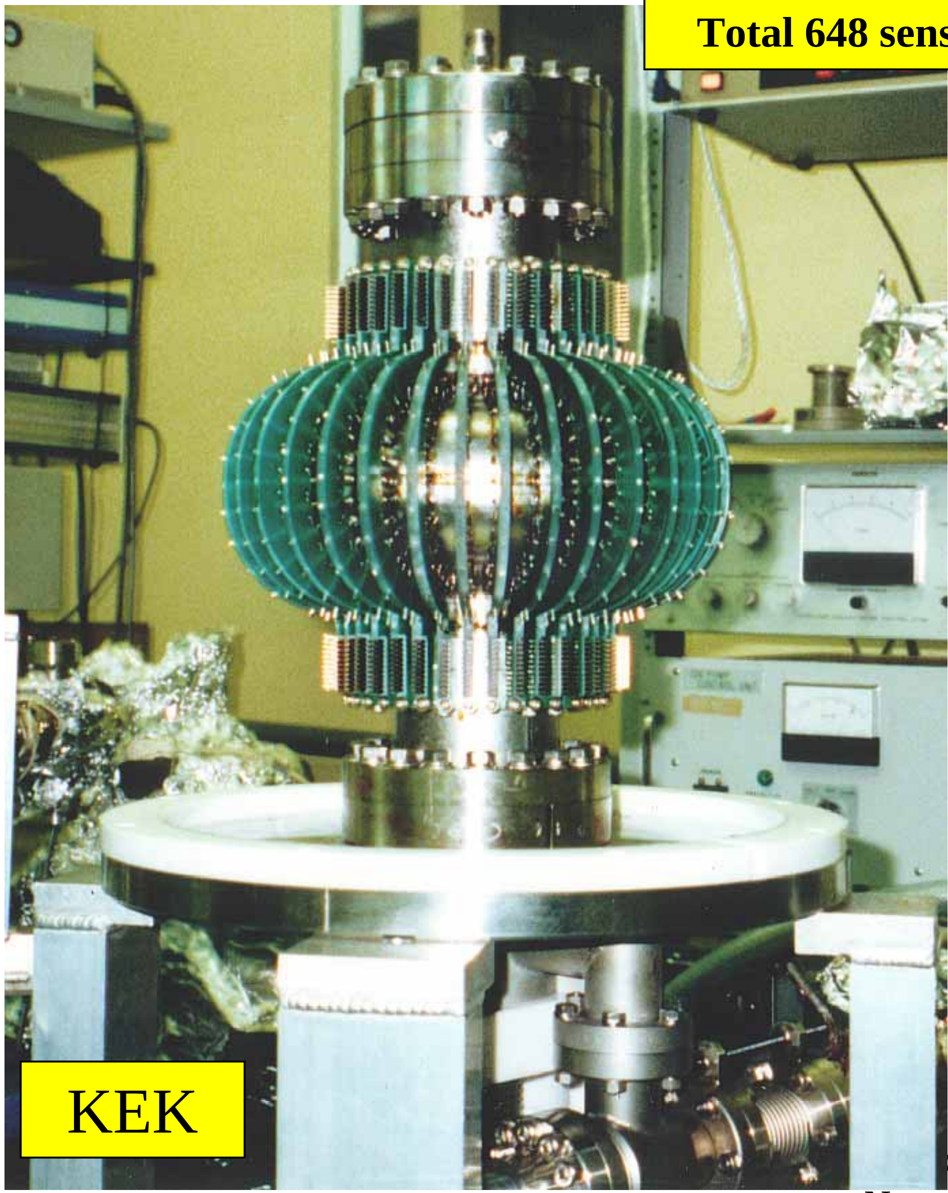
Non-resonant electron loading due to field emitted electrons by tunneling effect

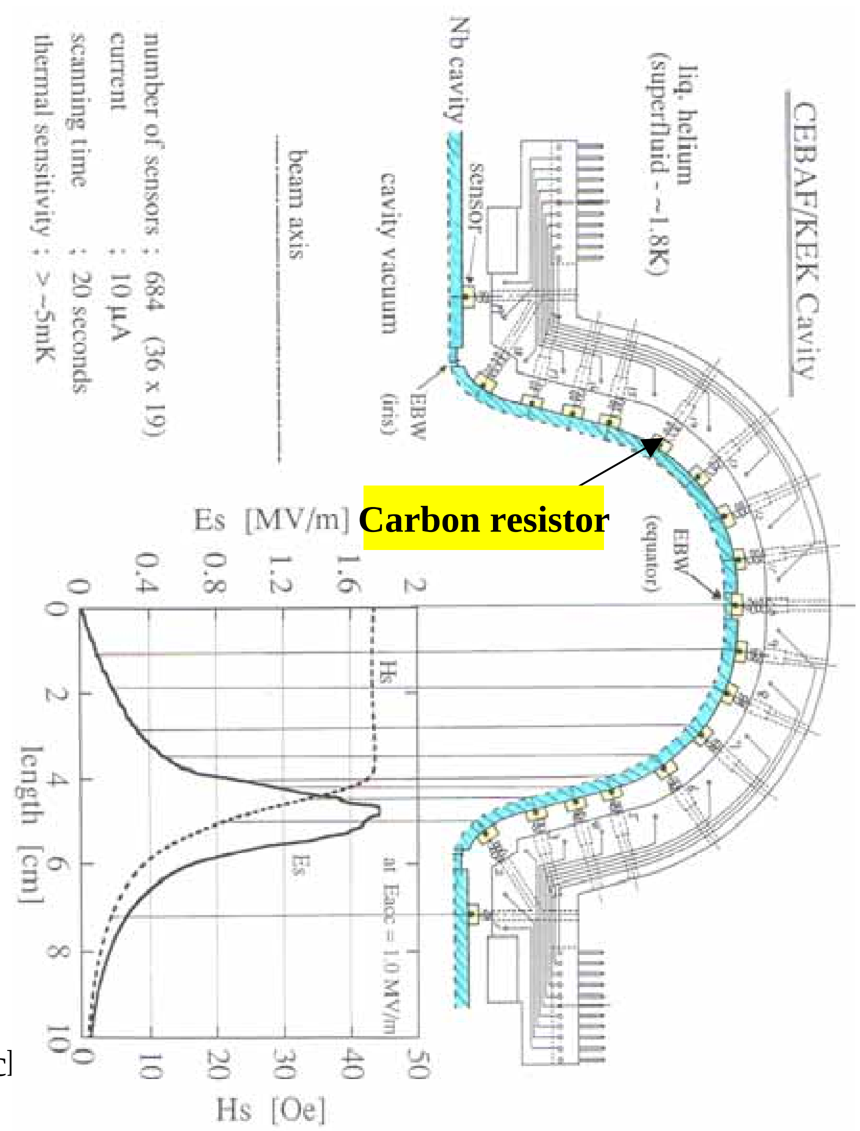




T-mapping System

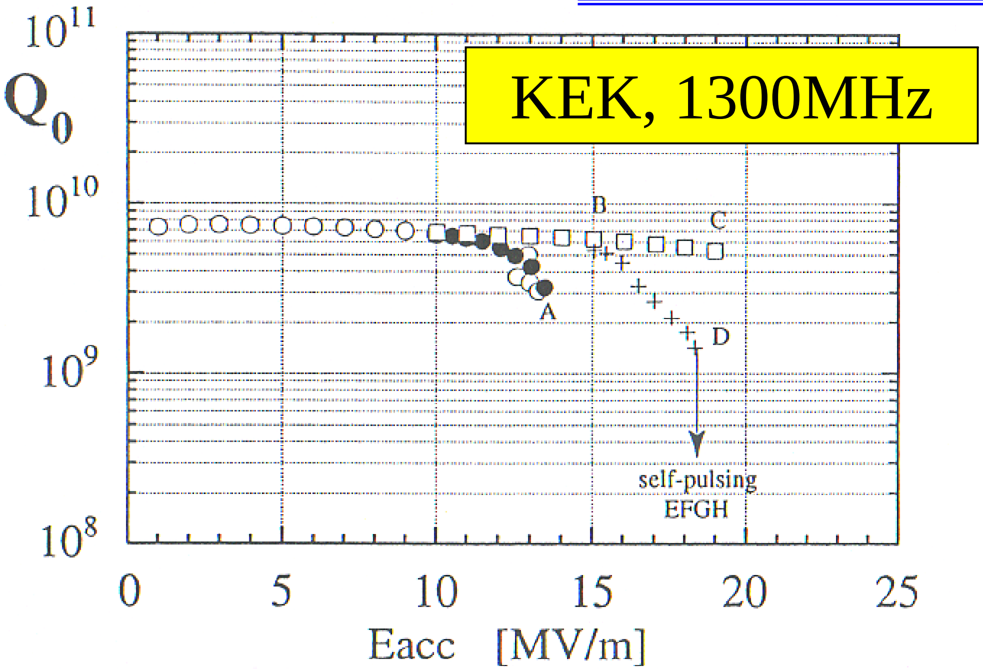
19 sensors at every 10 degree.
Total 648 sensors on outer cavity surface (360x19=684)

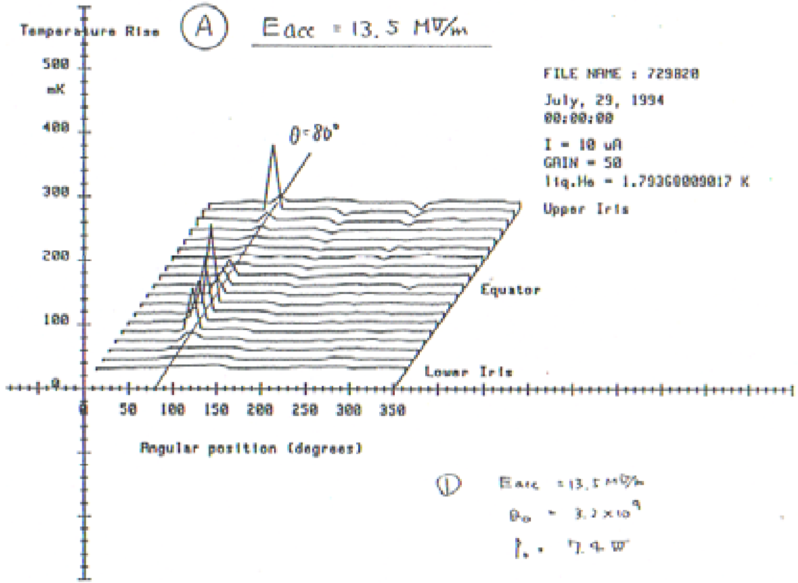


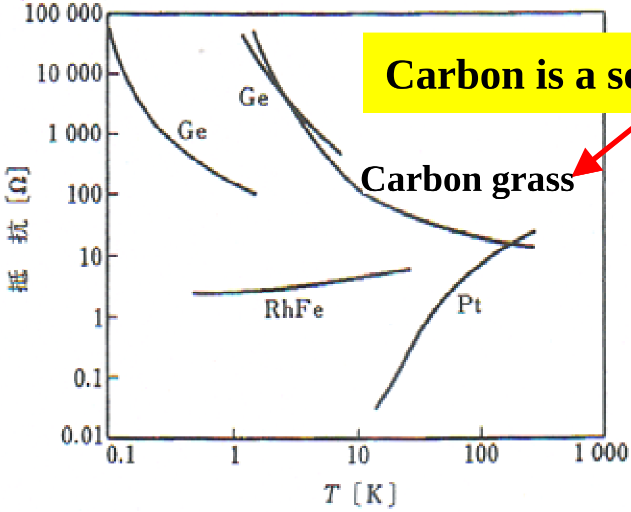


Note

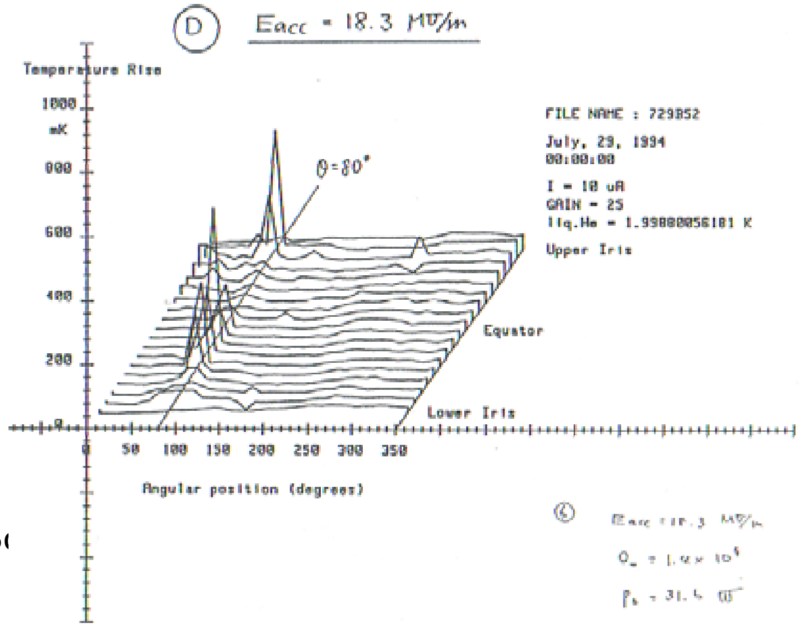
T-mapping KEK



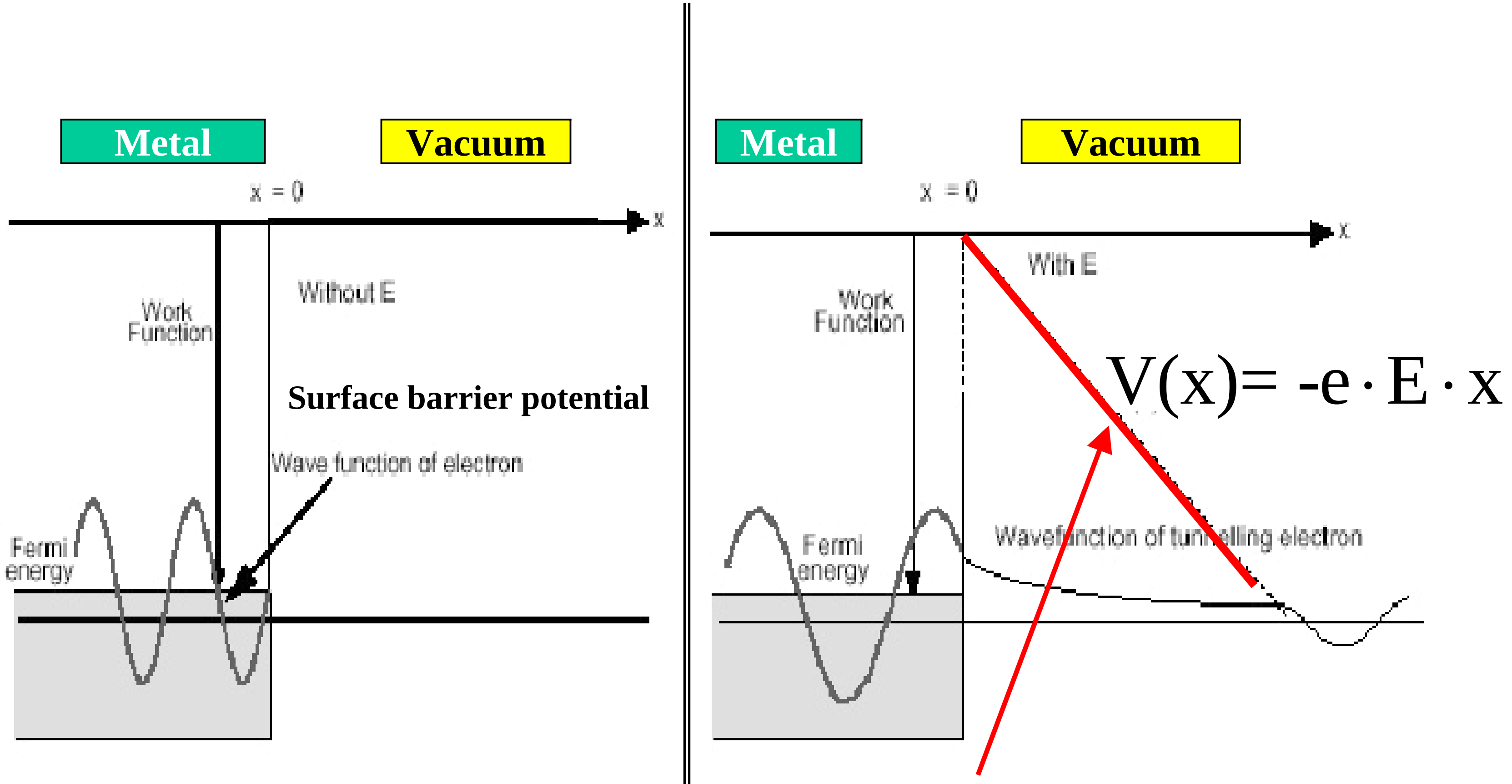




Characteristics of T-sensitivity for various material

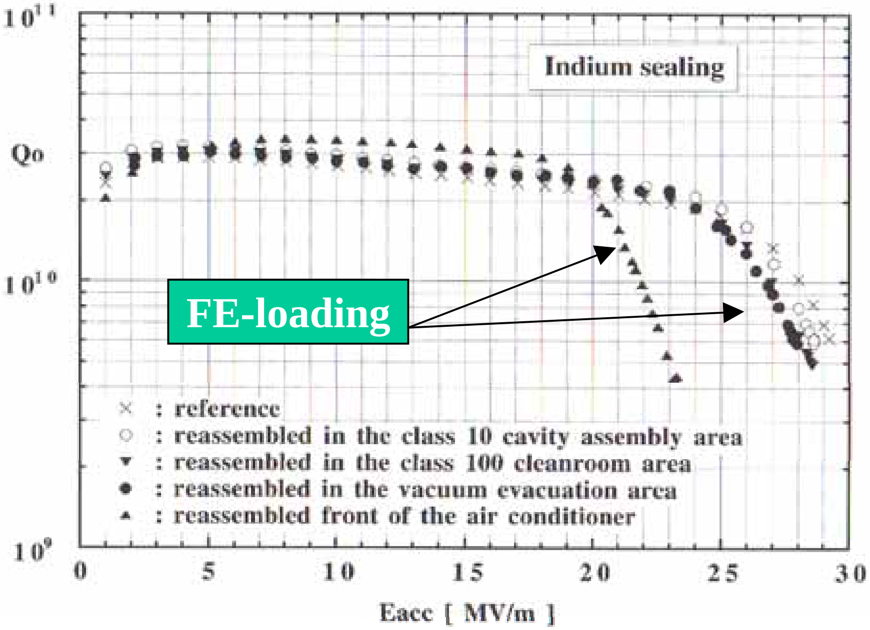


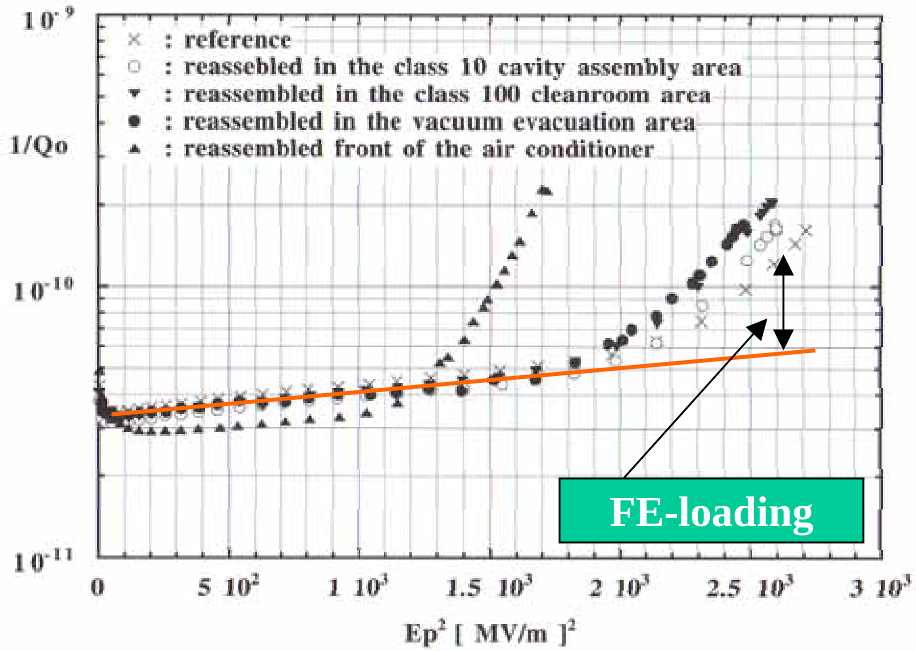
Field Emission Mechanism



A potential: -eEx is added to the surface barrier potential by applying E-field. The surface barrier becomes thinner with the added potential. The number of tunneling electrons is increased exponentially with the thinner barrier potential and lot of electrons are emitted from the surface.

Field Emission Analysis





$$\frac{1}{Q_o} = A + B \cdot E_p[MV/m]^2, \quad \Delta\left(\frac{1}{Q_o}\right) = \frac{1}{Q_o(E_p^2)} - (A + B \cdot E_p[MV/m]^2)$$

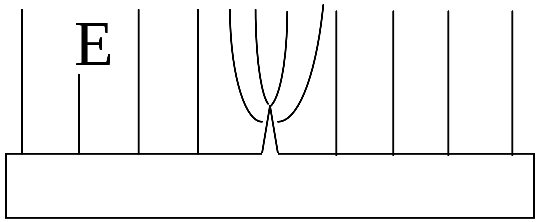
$$\Delta\left(\frac{1}{Q_O}\right) = S \cdot E_p^{1.5} \cdot \exp\left(-\frac{\phi}{\beta \cdot E_P}\right) = S \cdot E_p[MV/m]^{1.5} \cdot \exp\left(-\frac{5.46E+4}{\beta \cdot E_P[MV/m]}\right)$$

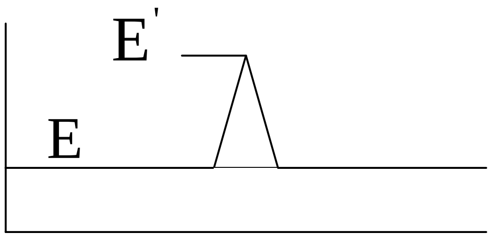
Field Enhancement Factor β

Field enhancement factor ß: 50～1000

Why field enchantment is so large?

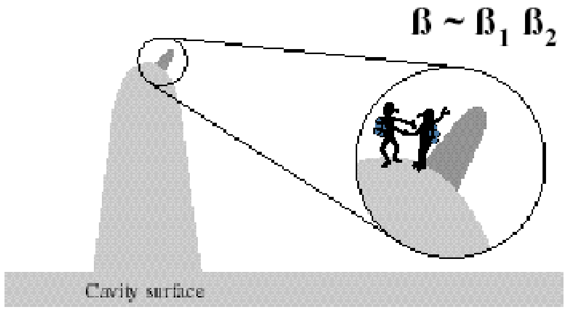
Projection model :

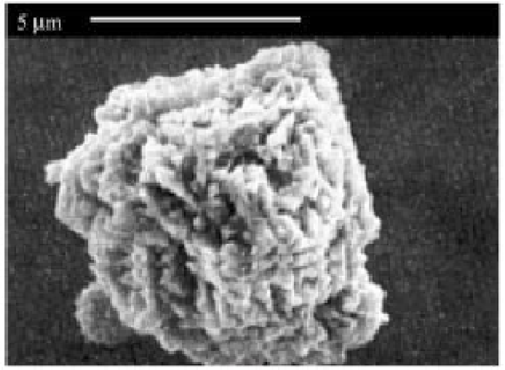


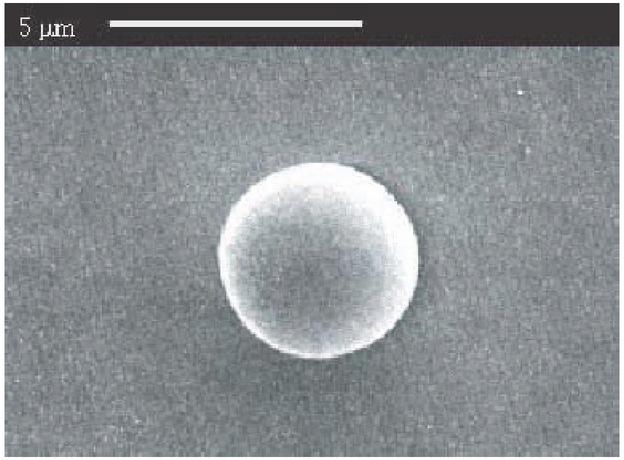


$$\beta = \frac{E'}{E}$$

- *Tip-on-tip* model is one explanation
- Smooth particles don't emit.



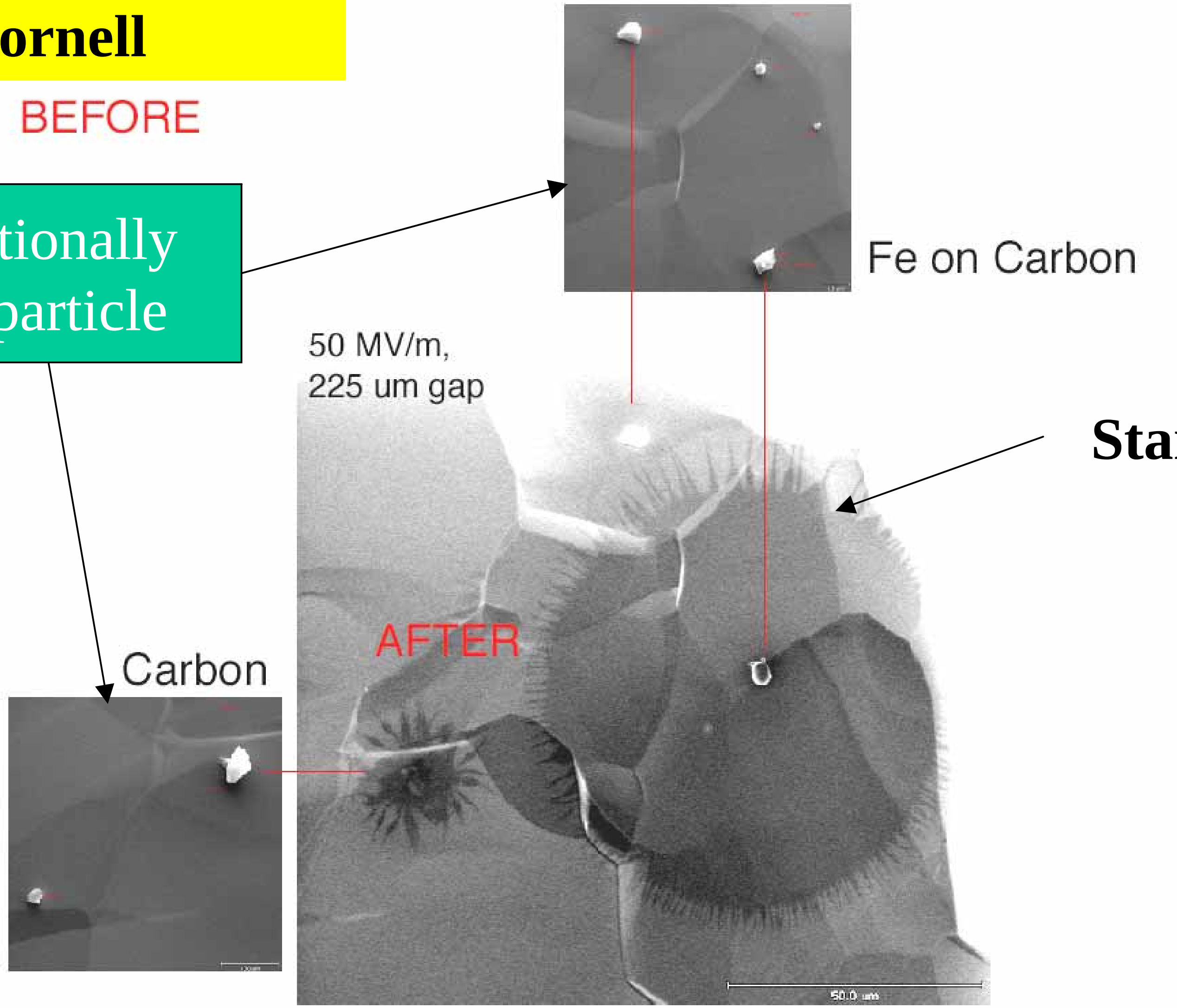




Particle Contamination produces field emission

DC Field emission study in Cornell

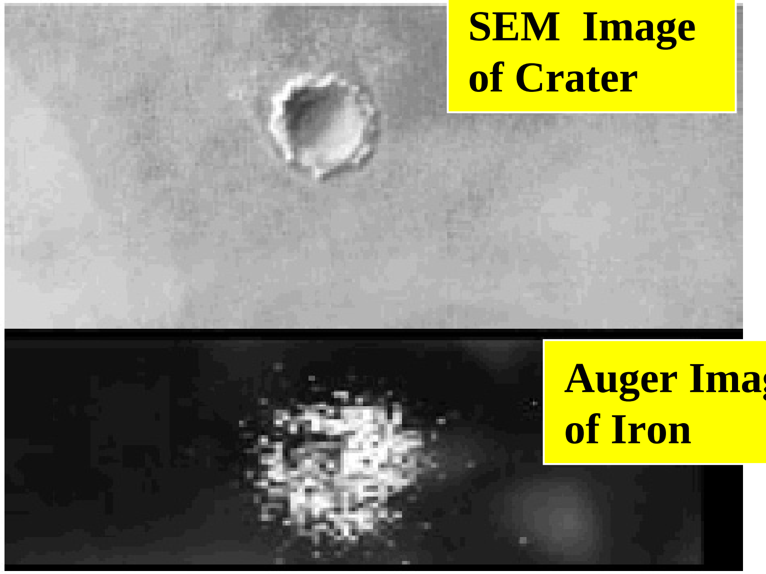
Intentionally put particle



Star burst

Particle is a seed of field emission.

Foreign Elements

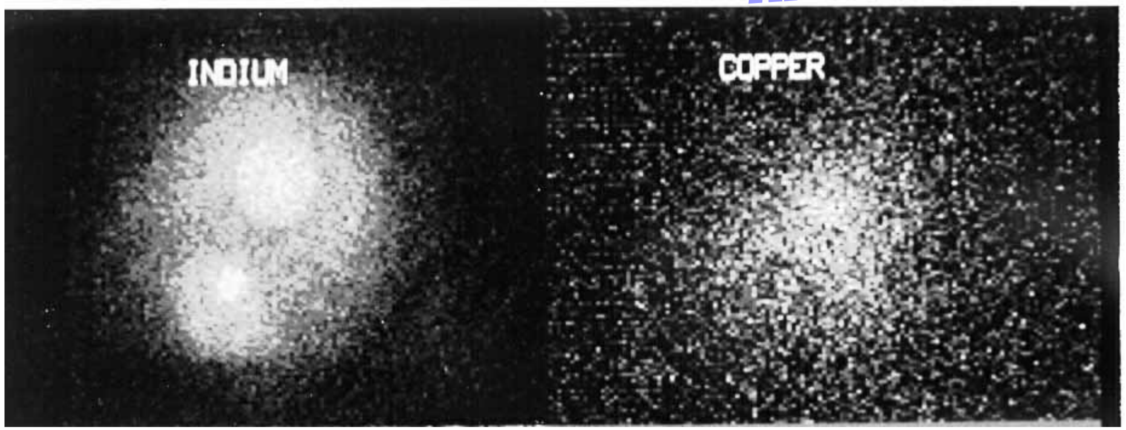


SEM Image of Crater

Auger Image of Iron

Nothing with EDX

But - With Auger Analysis
Almost all craters show foreign material



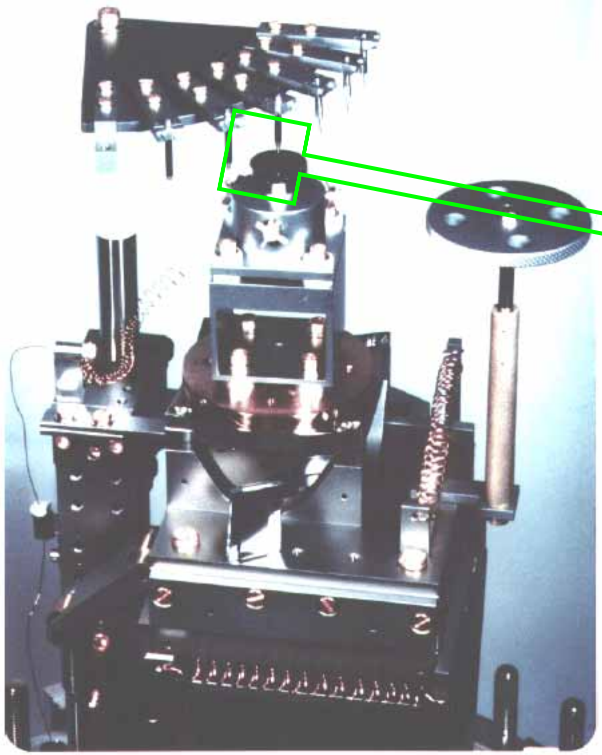
Auger Images of Craters

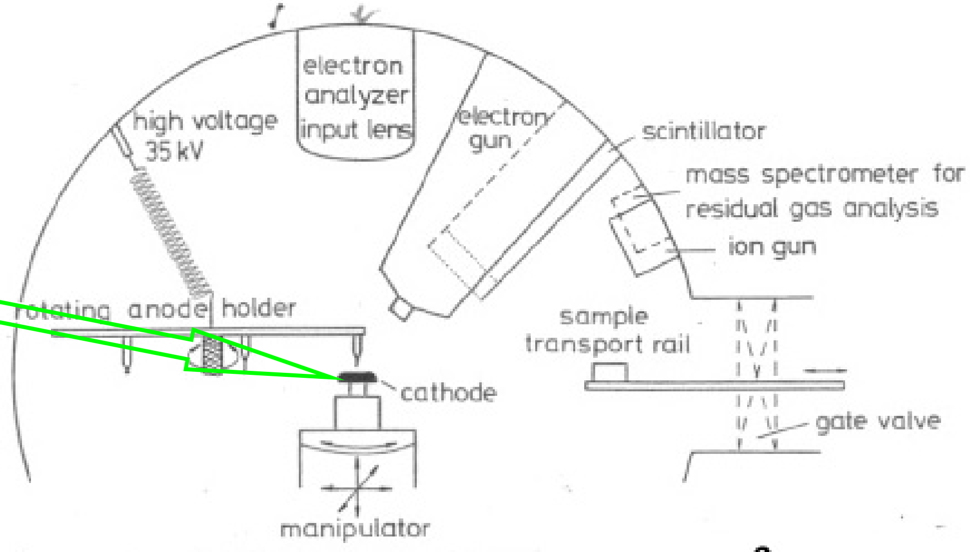
K.Saito

CORNELL UNIVERSITY

Foreign material is another seed of the filed emission.

DC Field Emission Study in Geneva Uni. and Wuppertal Uni.

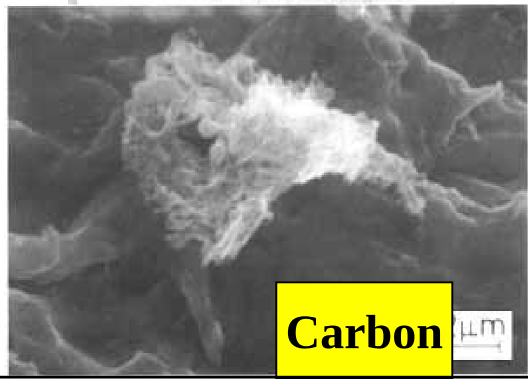


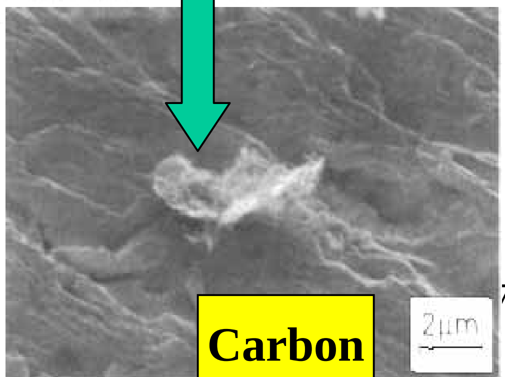


non-annealed

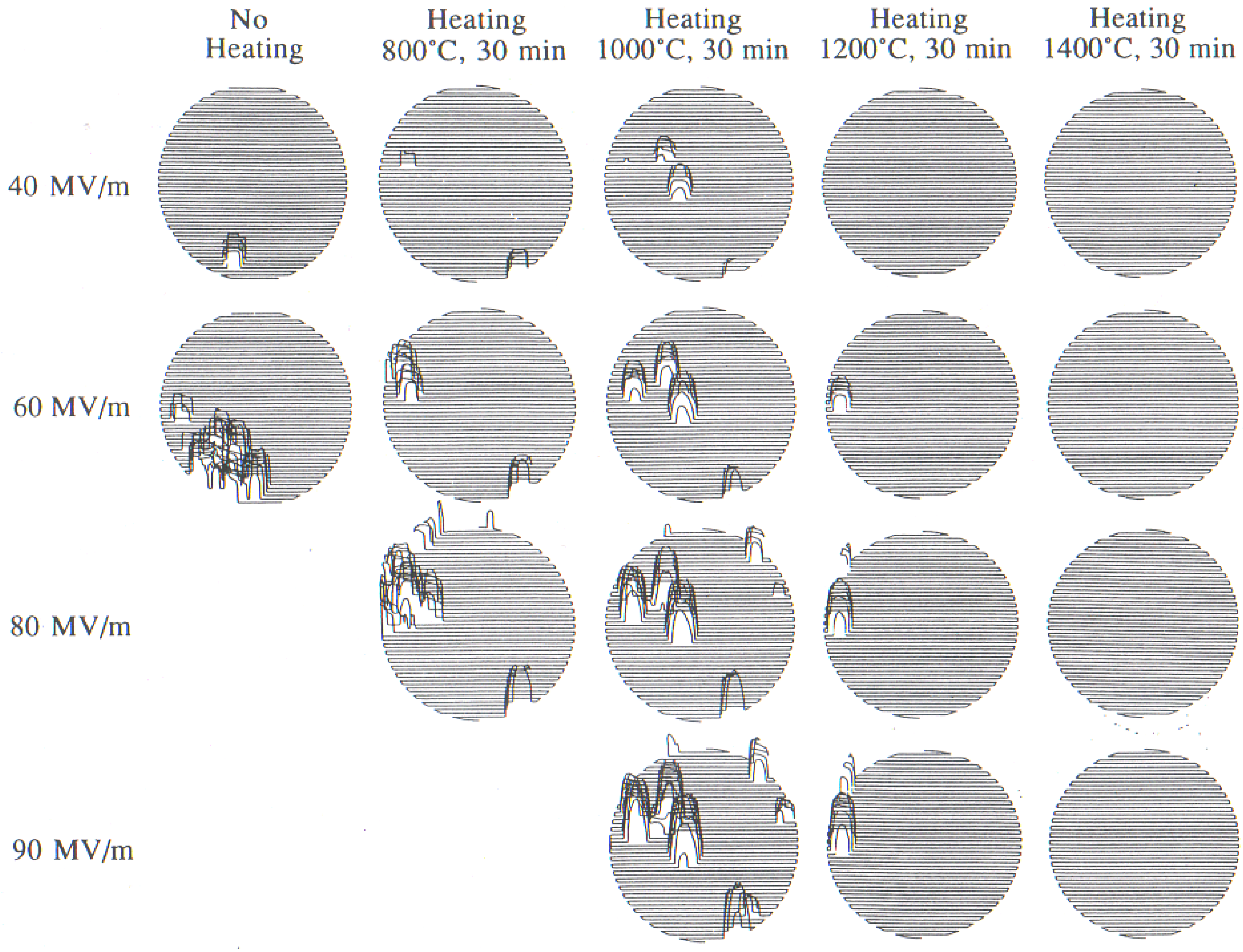
1 cm^2 sample

Emission Current



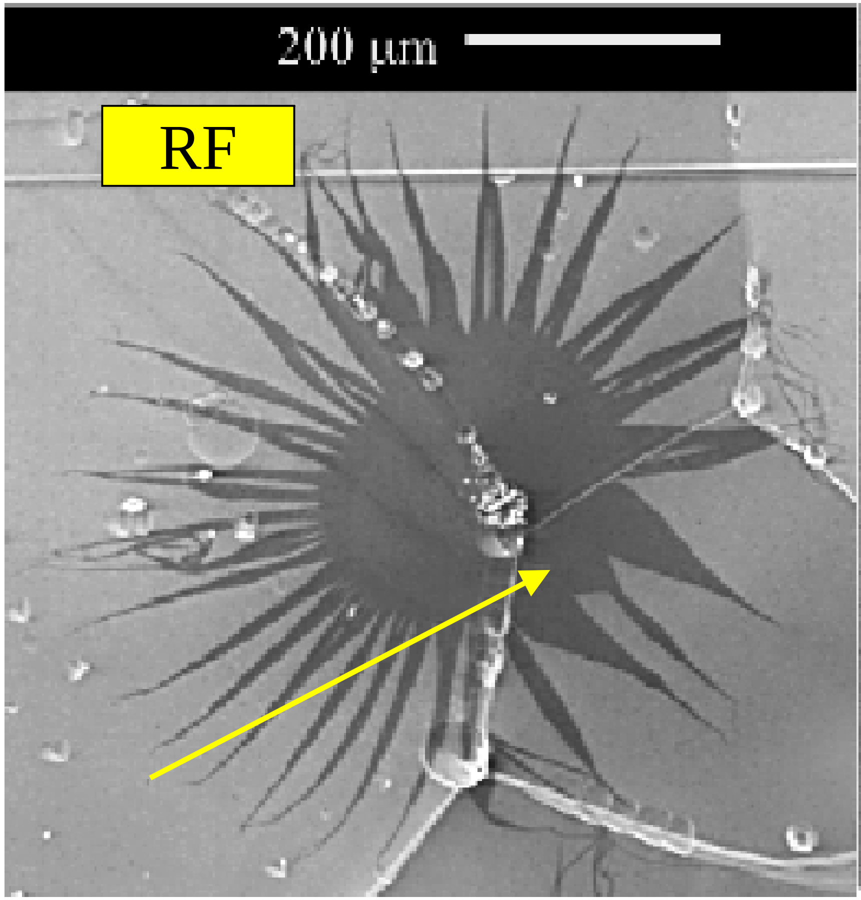


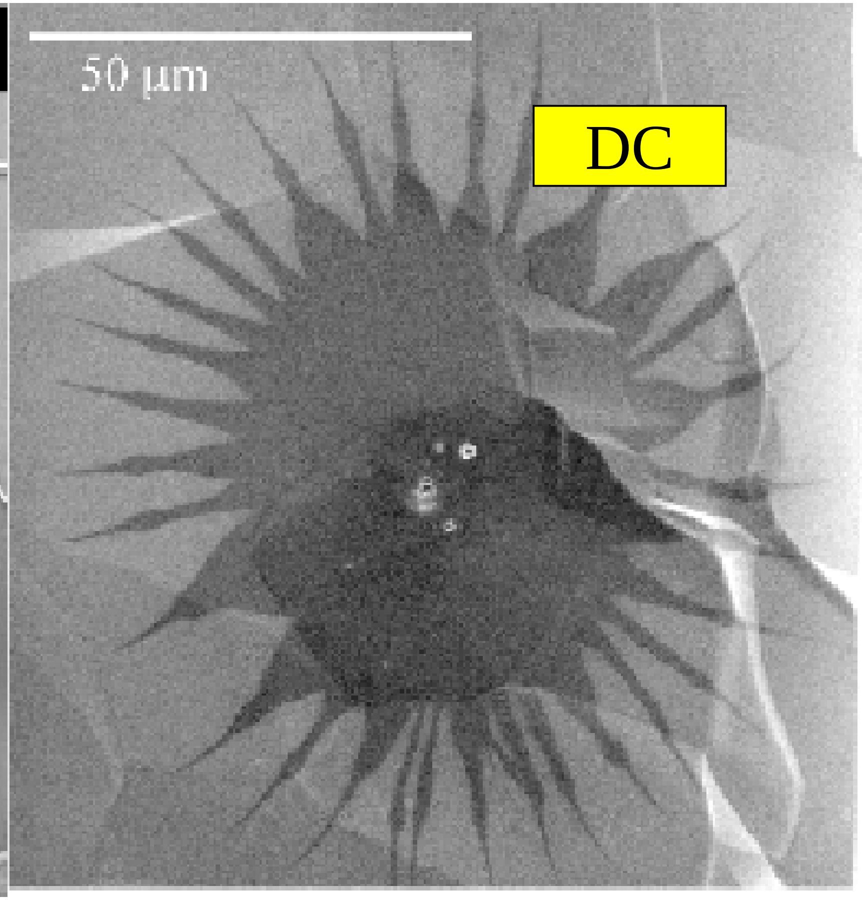
Wuppertal Result



High Temp. Annealing evaporates or diffuses FE emitters.

Difference between DC and RF





Starburst in a 1.5GHz Nb cavity

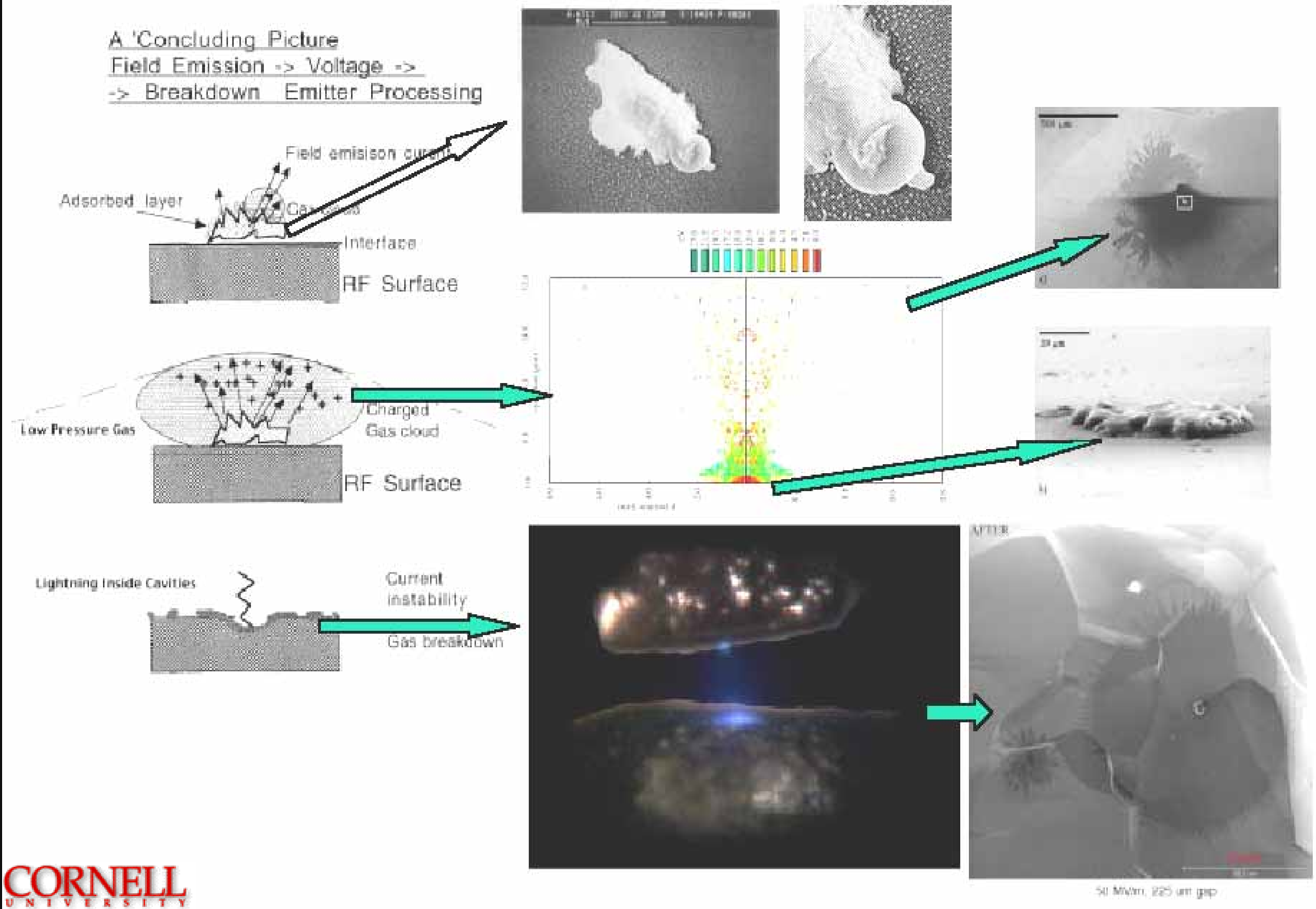
Starburst on a DC cathode (Nb)

Emitter sites are observed on grain boundary in RF case,
that suggests magnetic field enhancement there:
the enhanced Joule heating promotes evaporating gas and results in star burst.

CORNELL UNIVERSITY

Note

Cornell Model for FE



CORNELL
UNIVERSITY

Cures against Field Emission

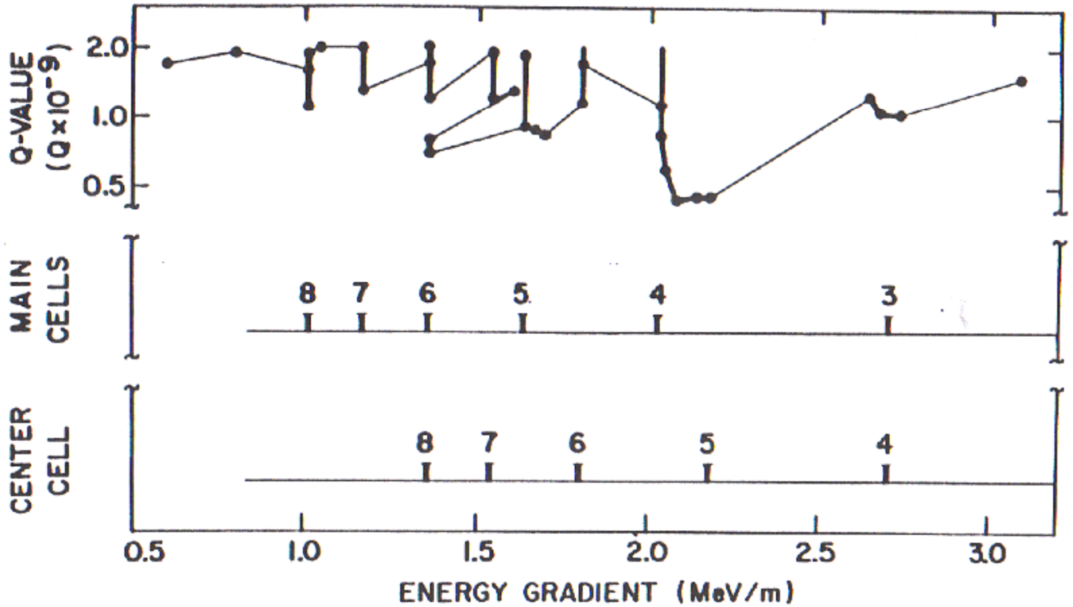
1) Make dust free clean surface
   - Use ultra-pure water in the rising process
   - High Pressure water Rinsing to remove particle contamination on the SRF surface
   - Use clean-room in the cavity assembly
2) Make smooth surface
   - Electropolishing
3) Cavity design
   - Lower Ep/Eacc

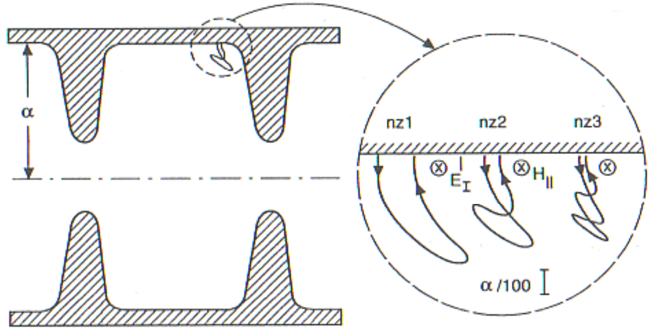
11.2 Multipacting

Multipacting ： Resonant electron loading due to secondary electrons
(synchronized electron motion with RF)

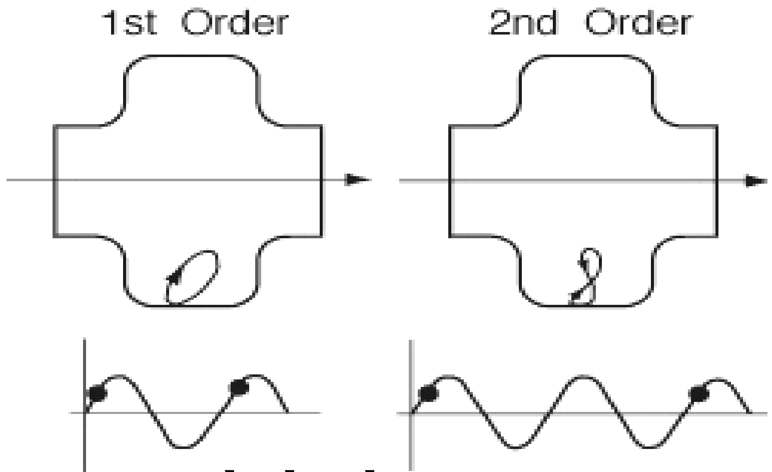
Seriously Limited by 1PM or 2PM

One point multipacting





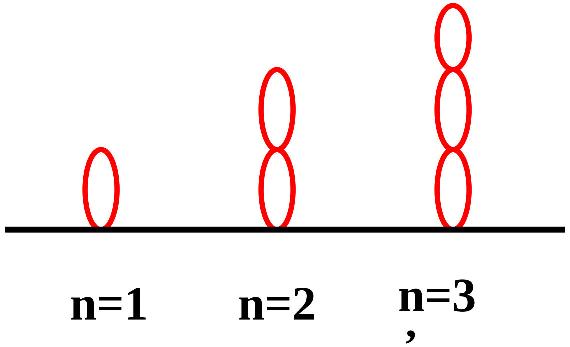
1 point MP



Characteristic: Q-drop at some discrete field levels, X-ray at the levels,
Diagnostics: Temperature mapping & X-ray mapping

Onset Field of One-point MP

Scale law on RF frequency with the maltipacting levels



Cyclotron frequency : $\omega = \dfrac{e \cdot H}{c \cdot m}$

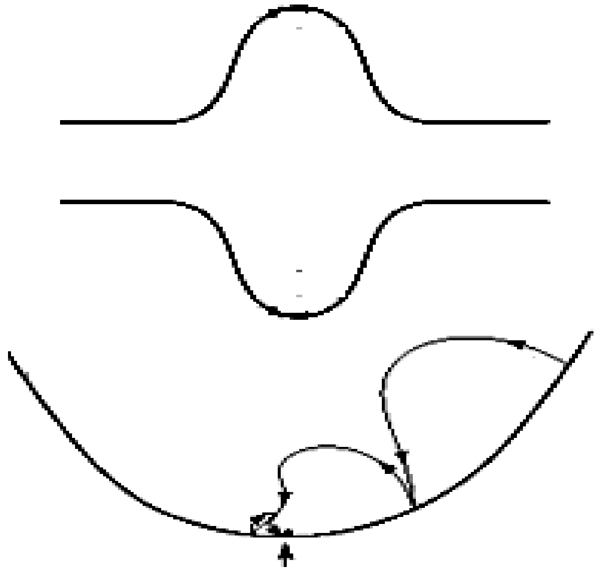
$$2\pi \cdot f(1P-nth) = \frac{e \cdot H(1P-nth)}{c \cdot m}$$

$$T(1P-nth) = \frac{1}{f(1P-nth)} = \frac{2\pi \cdot c \cdot m}{e \cdot H(1P-nth)} = n \cdot T_{RF} = \frac{n}{f_{RF}}$$

$$\frac{H(1P-nth)}{f_{RF}} = \frac{constant}{n}, \quad \text{n=1, 2, 3} \cdots \quad \text{[Oe/Hz]}$$

Experiment : Onset field $\dfrac{H(1P-nth,[Oe])}{f_{RF}[MHz]} = \dfrac{0.3}{n}$ **[Oe/MHz]**

Spherical shape suppresses the one point multipcting.

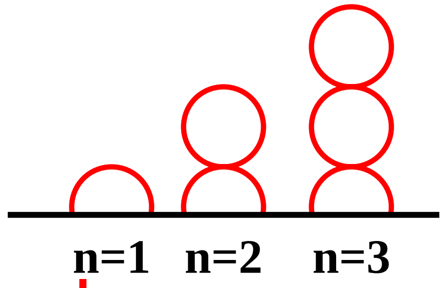


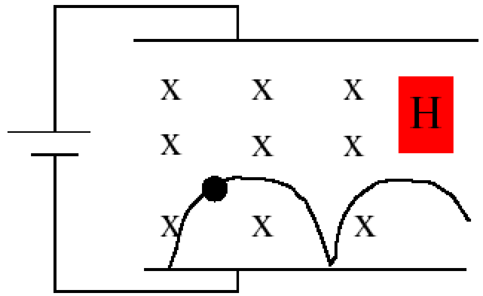
Example ;
1300MHz, Hp/Eacc = 43.8 [Oe/(MV/m)]
1P-1st order・・・H_{RF}(1P-1st) =0.3 x 1300 = 390 Oe
Eacc(1P-1st) = 390/43.8=8.9 MV/m
1P-2nd order・・・Eacc(1P-2nd) = 4.5 MV/m

Two-point MP

Two-point multipacting

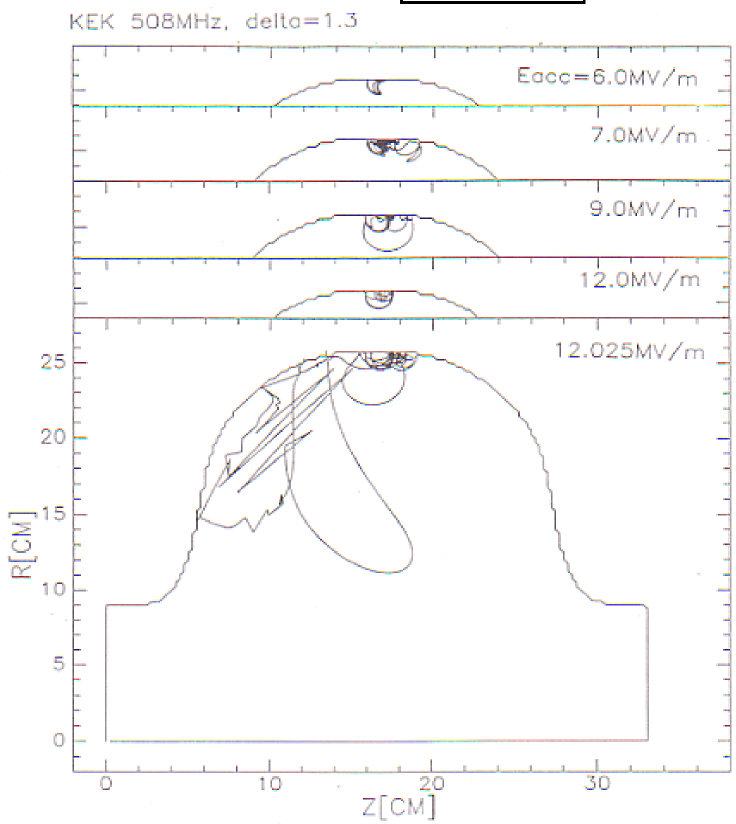
$$T(2P-nth) = (2n-1)T_{RF}$$





$$\frac{H(2P-nth)}{f_{RF}} = \frac{constant}{2n-1}$$ **, n=1, 2, 3 ･･･ [Oe/Hz]**

Experiment :Onset field $$\frac{H(2P-nth,[Oe])}{f_{RF}[MHz]} = \frac{0.6}{2n-1}$$



Examples ;

508MHz , Hp/Eacc=40.6 [Oe/(MV/m)]

2P-1st order Hp(2p-1st) = 0.6 x 508 = 304.8 Oe

Eacc(2P-1st) = 304.8/40.6 = 7.5 MV/m

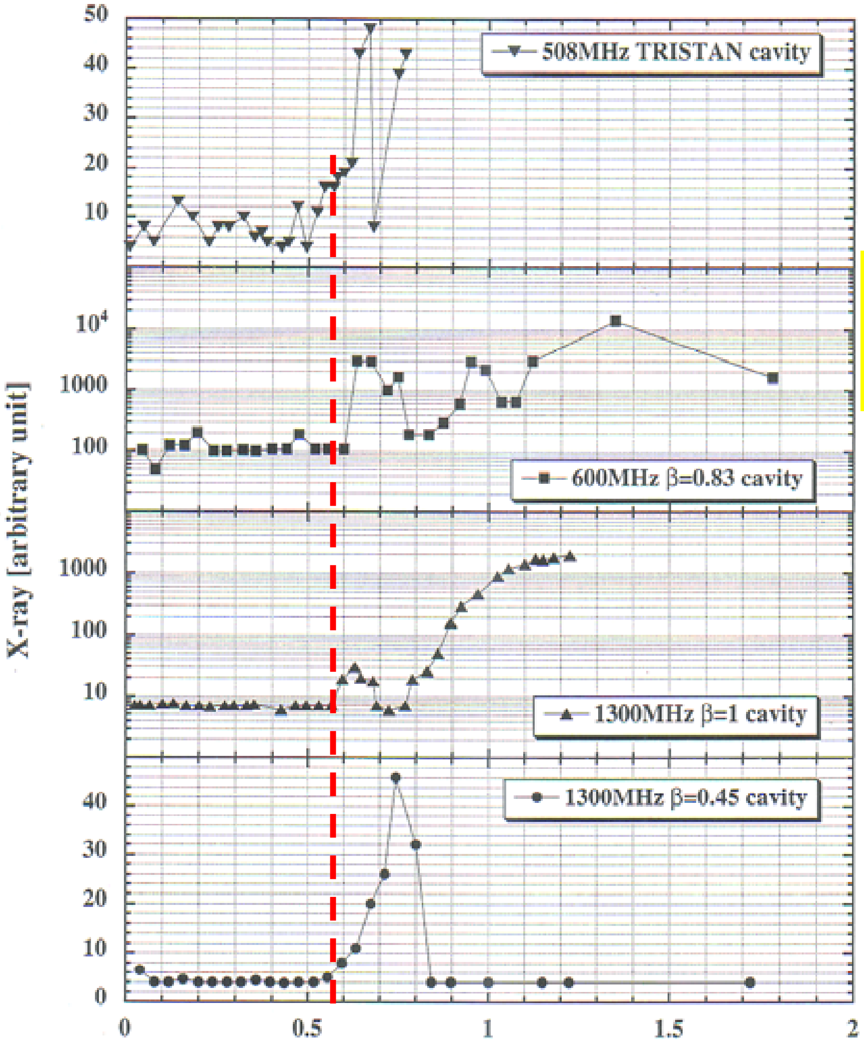
1300MHz, Hp/Eacc=43.8 [Oe/(MV/m)]

2P-1st order Hp(2p-1st) = 0.6 x 1300 = 780 Oe

Eacc(2P-1st) = 780/43.8 = 17.8 MV/m

2P-2nd order Eacc(2P-2nd) = 17.8/3 = 5.9 MV/m

Onset Field of Two-point MP

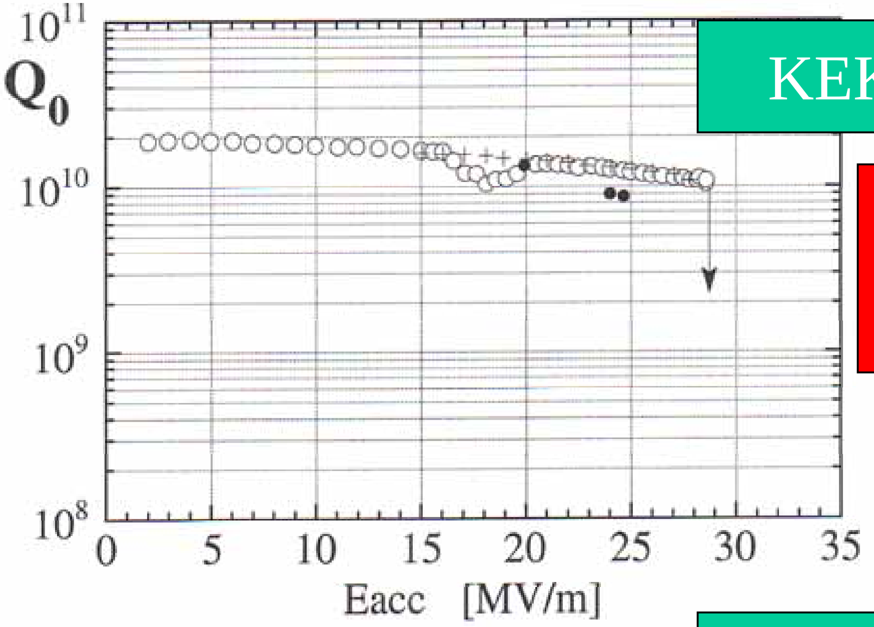


Hp [Gauss] / f [MHz]

$$2P - onset = \frac{Hp[Gauss]}{f\,[MHz]} \approx \frac{0.6}{2n-1}$$

Multipacting keeps RF processing memory effect up to 200K warm up.

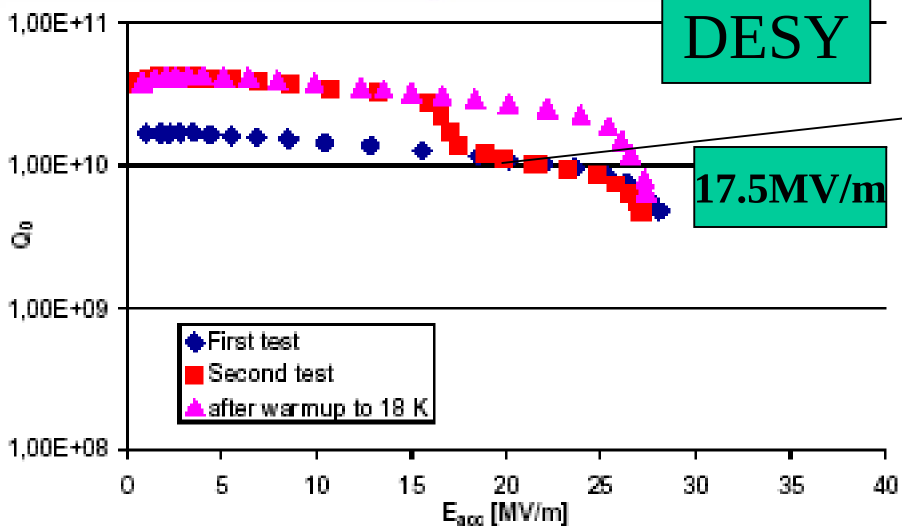
T-mapping of Tow-point MP



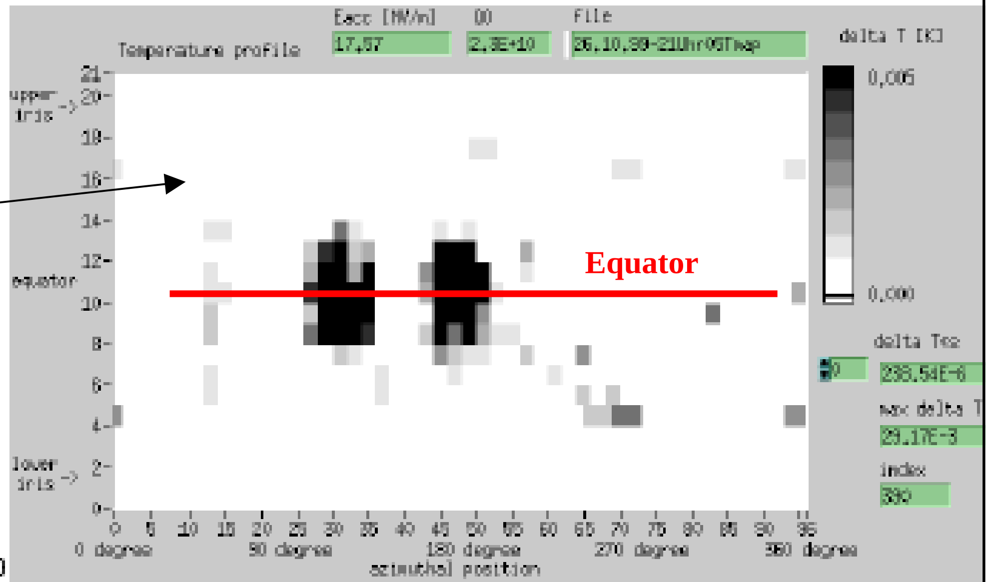
MP → Frozen flux trapping → Warm-up T >Tc

↓

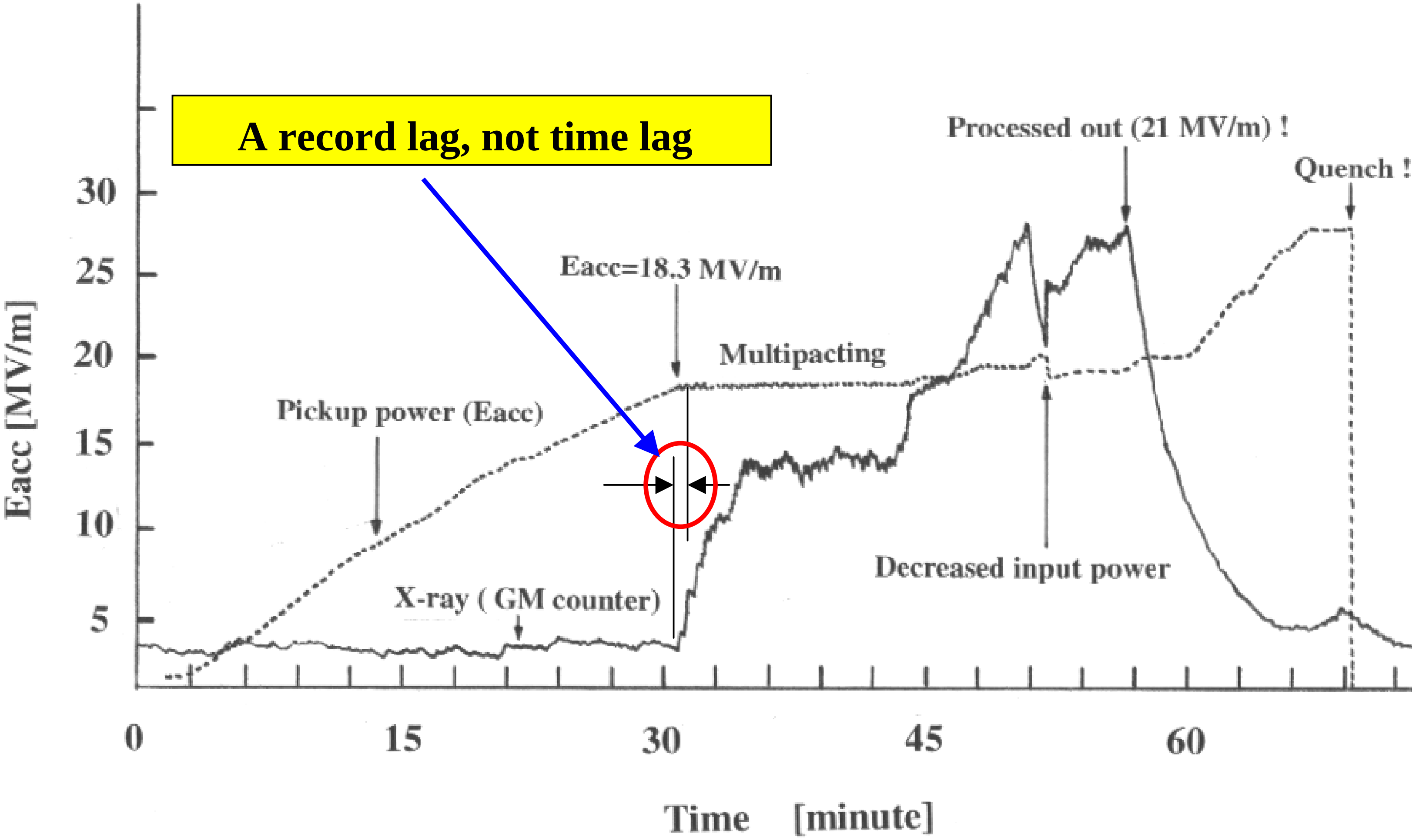
Disappear of the heating spots



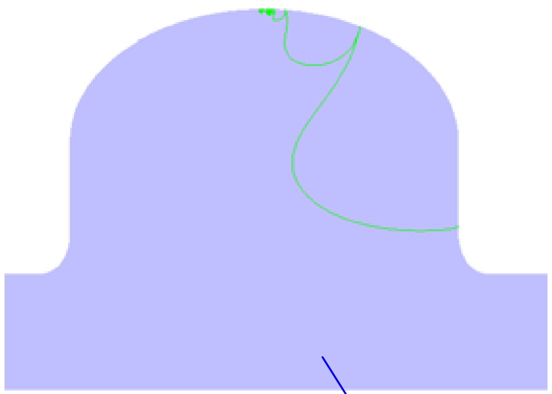
T-mapping at 17.5MV/m

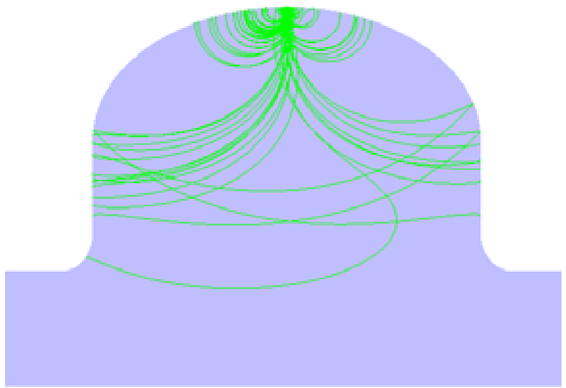


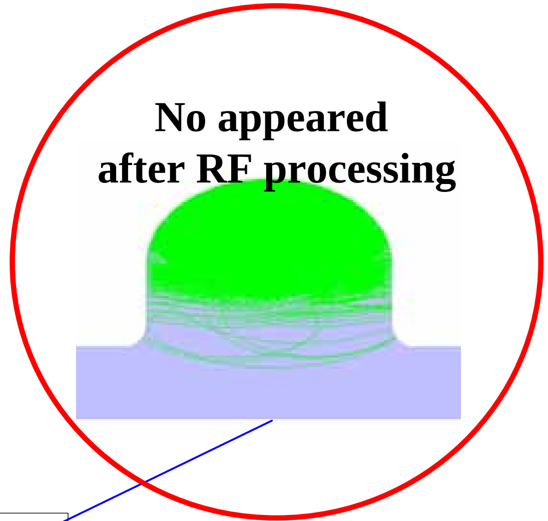
Processing of Two-point MP



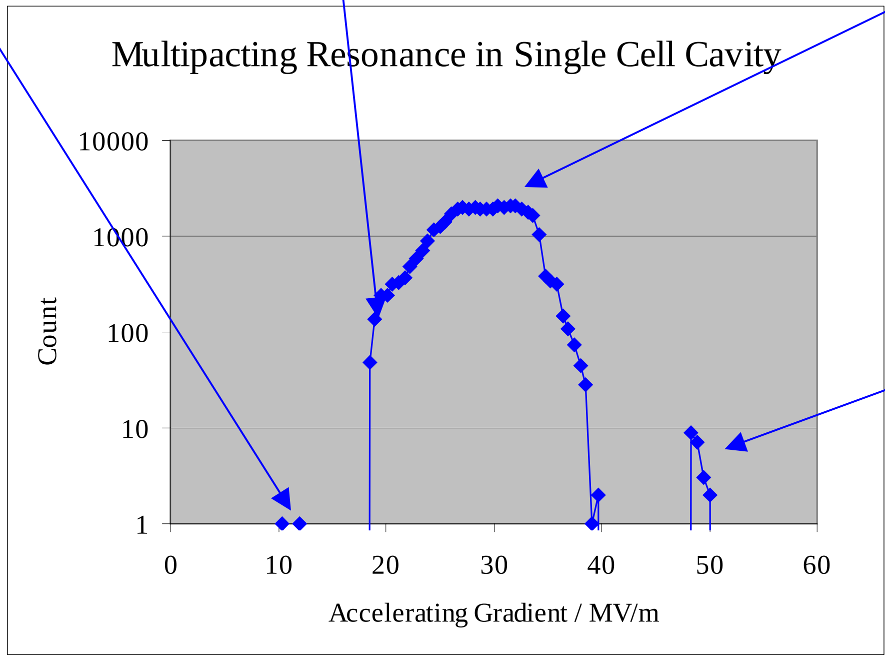
Multipacting in LL shape cavity

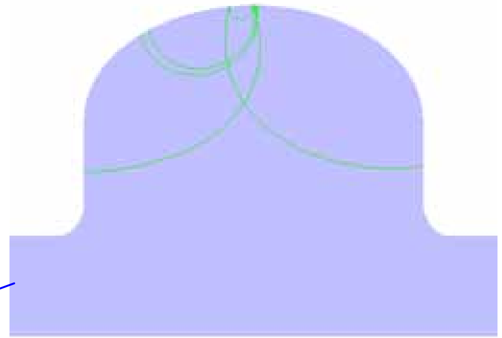




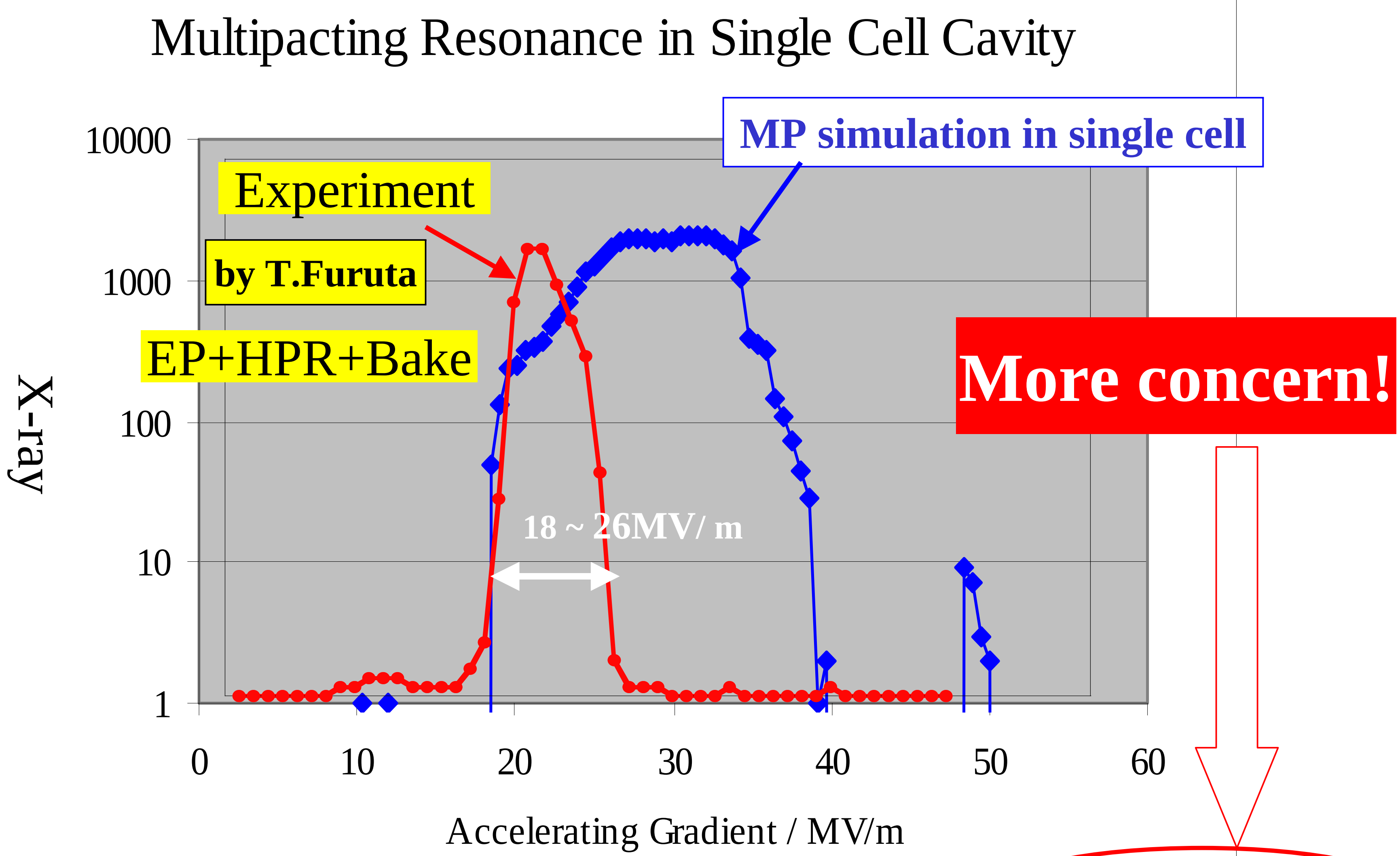


by Morozumi





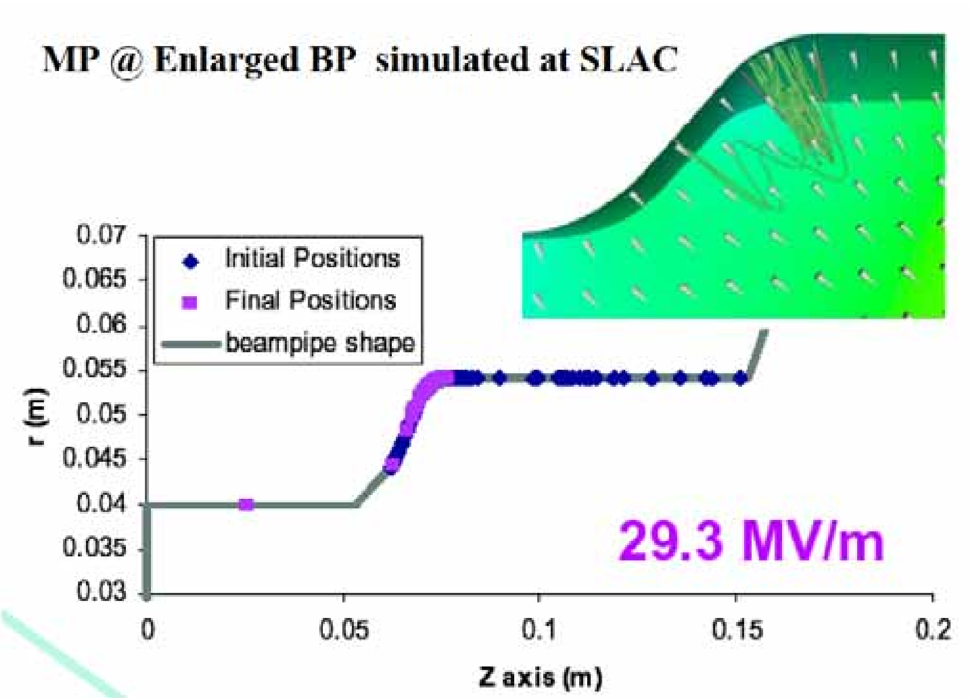
Comparison with Experiment

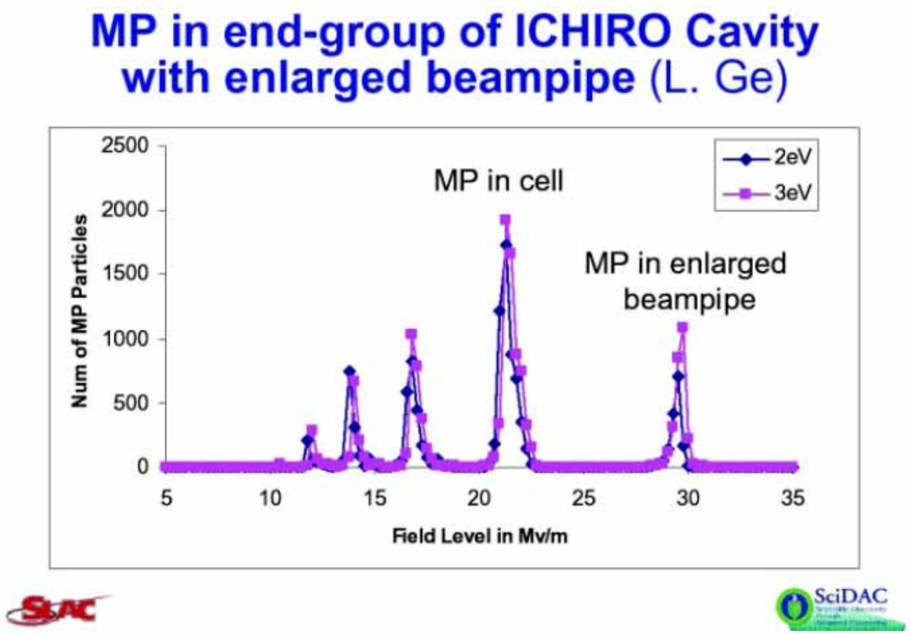


	V.T.	MP process out	No-MP	Couldn't process (FE)
Total times	69	53	2	14 (20%)

K.S

Multipacting @ Beam pipe

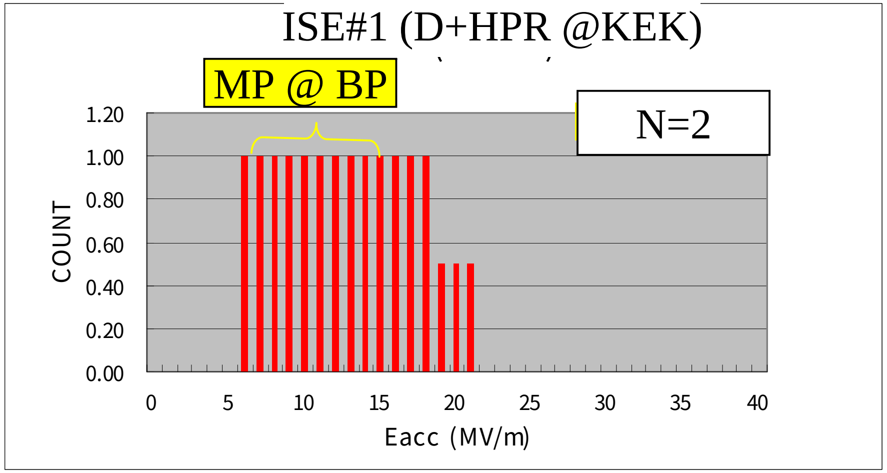




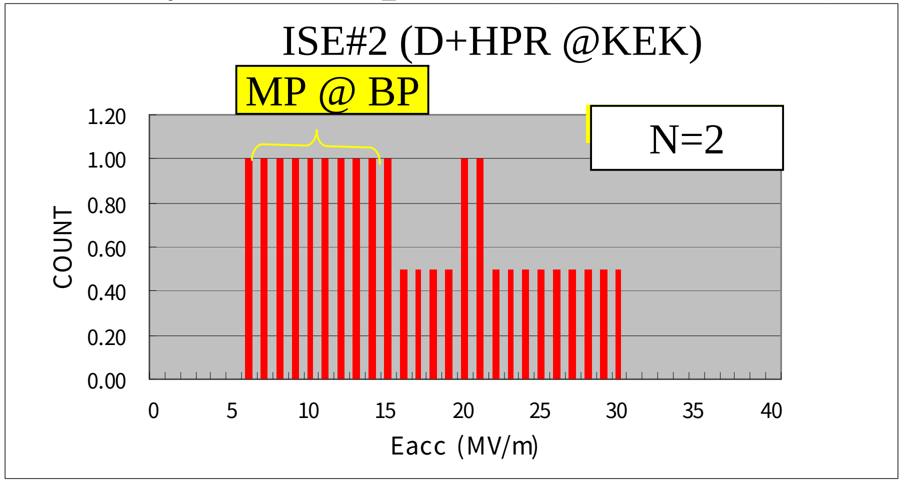
MP @ BP could be overcome by EP+Degreasing+HPR.

Multipacting in the large BP

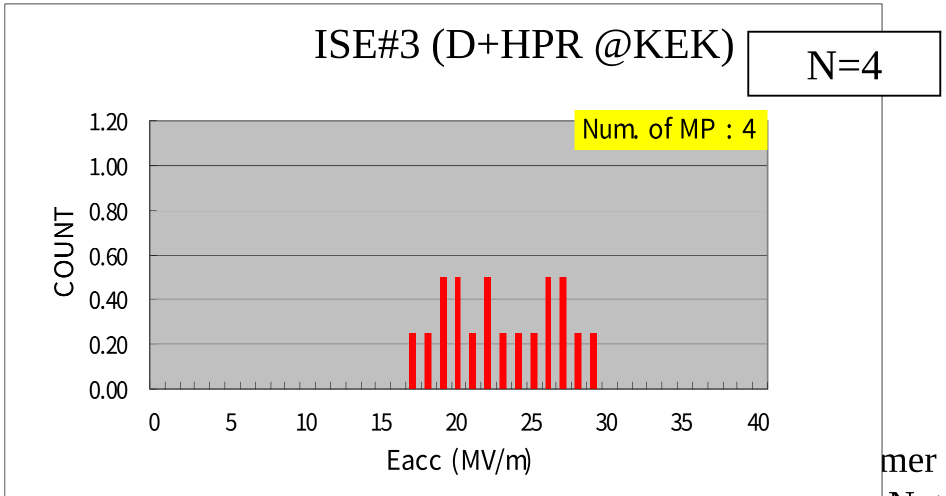
108ϕ BP, Straight



108ϕ BP, Tapered (Old Ichiro)



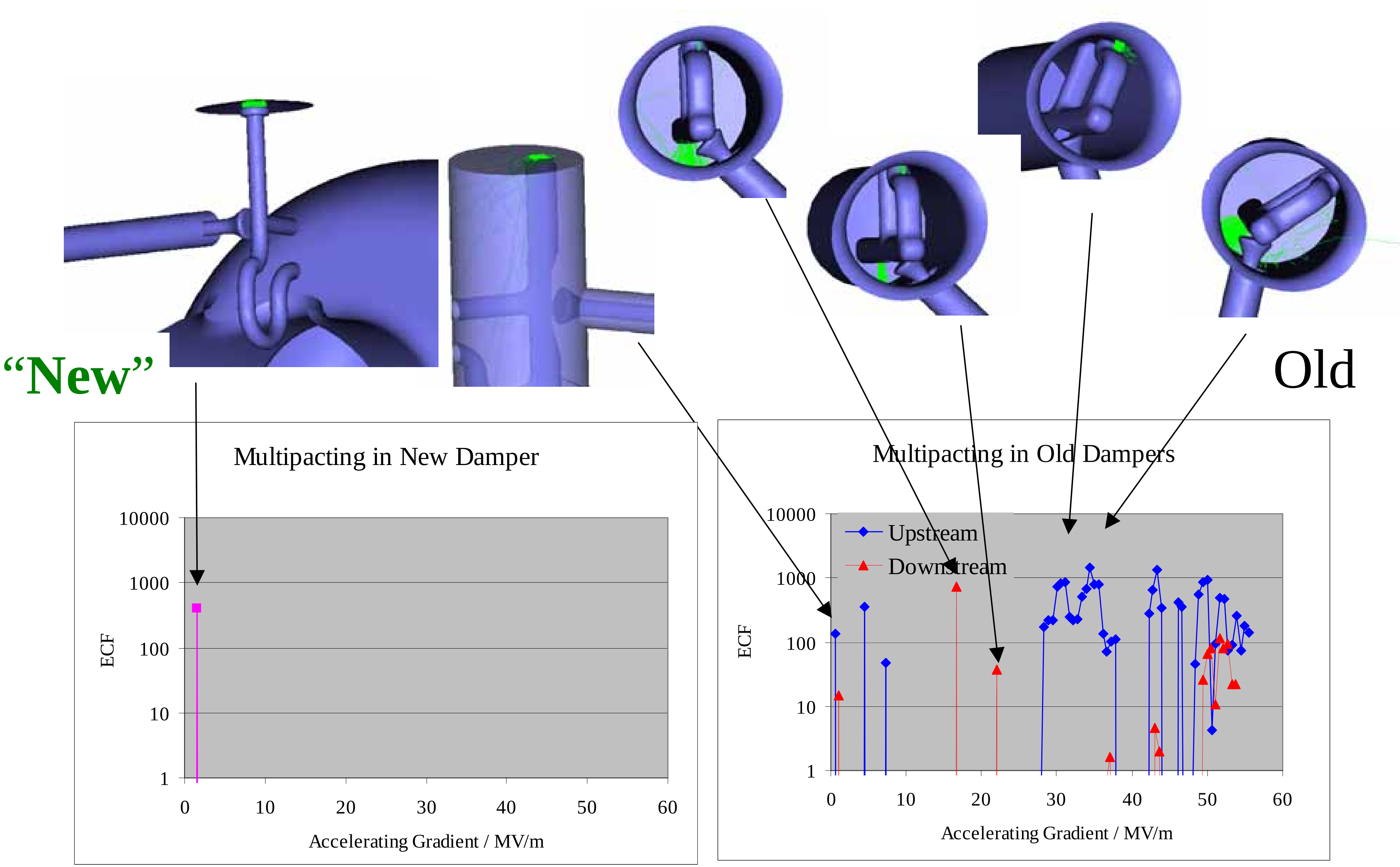
80ϕ BP, Straight (New Ichiro)



End cell cavity with Large BP:
ϕ108 mm diameter has multipacting at BP for both cases: Straight and Tapered BP.

When changed to ϕ80mm diameter BP,
No multipacting happens at BP.

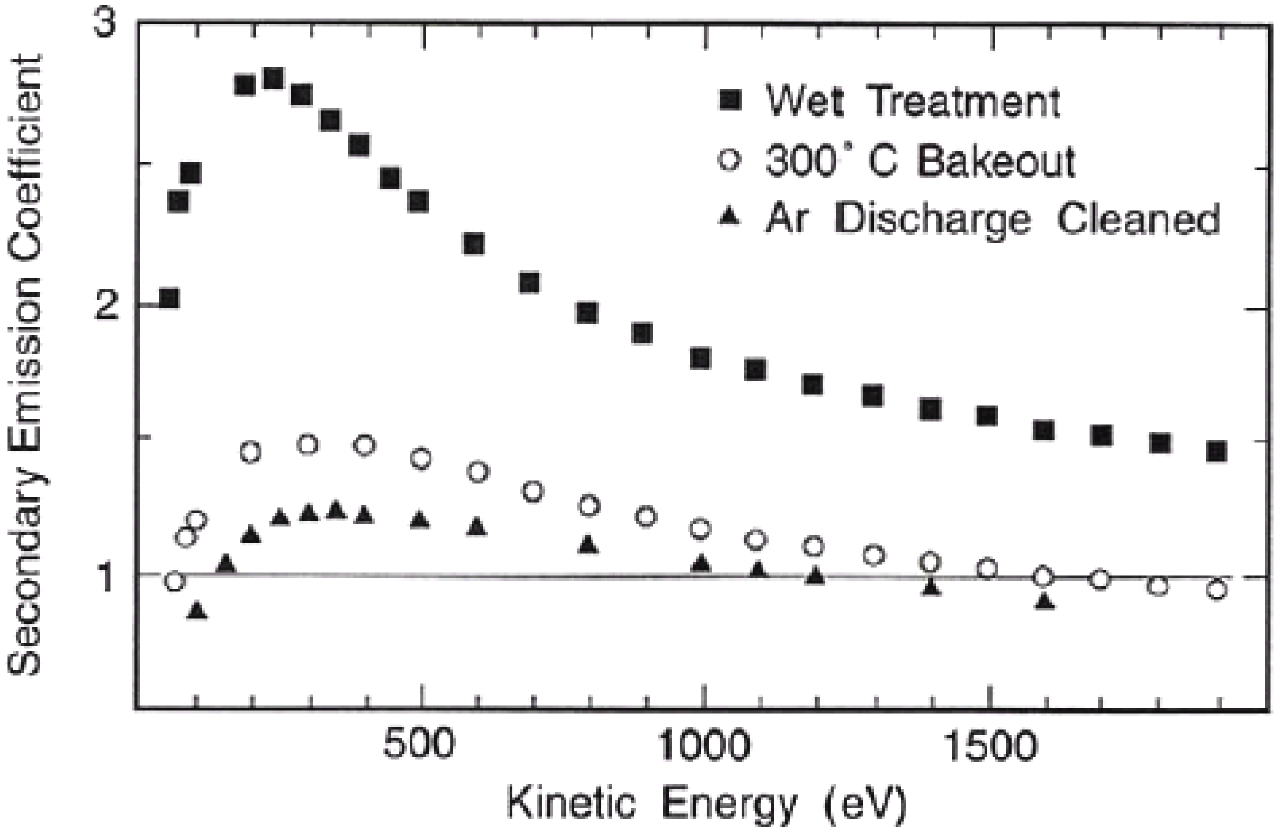
Multipacting in HOM Cylinder (Simulation)



Cures against MP

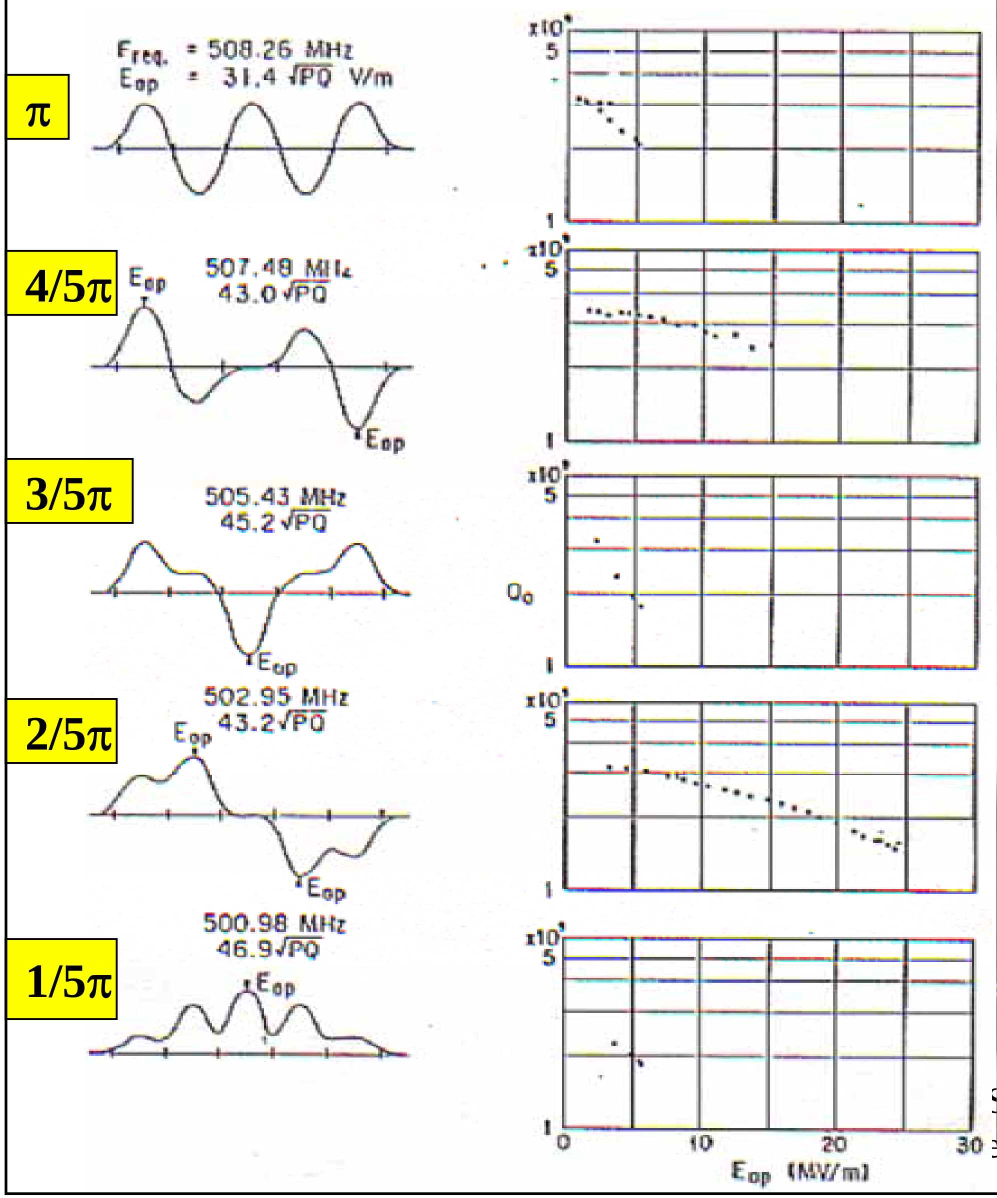
1) Cavity shape ⟶ Spherical or Elliptical shape
(effective for one point multipacting)

2) $\delta < 1$: Clean surface ⟶ Surface preparation
High pressure water rinsing
Degreasing
Argon gas or Helium gas discharge cleaning



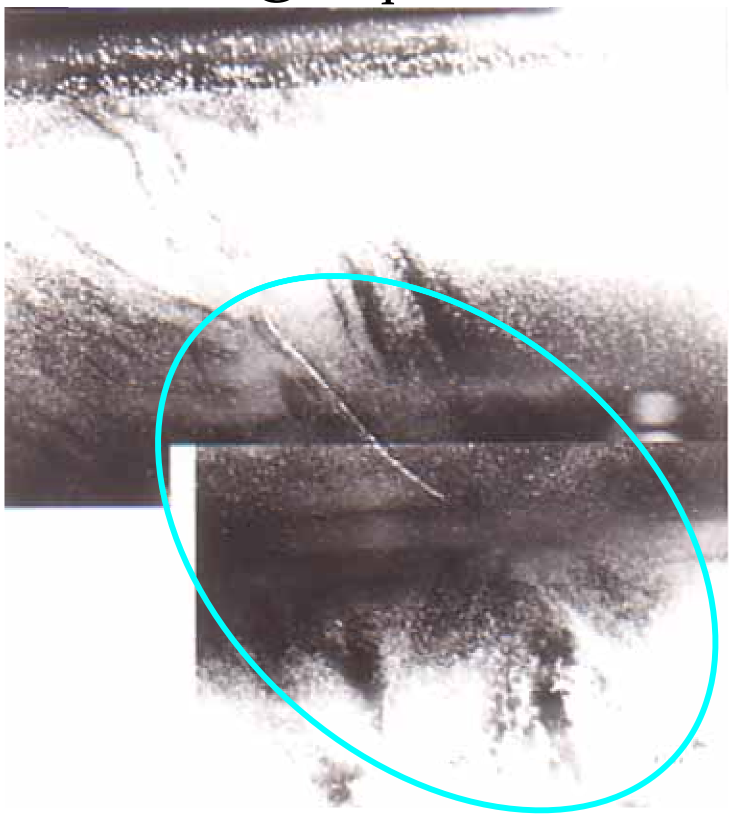
11.3 Thermal Instability

- An Example in A TRISTAN SC Cavity -

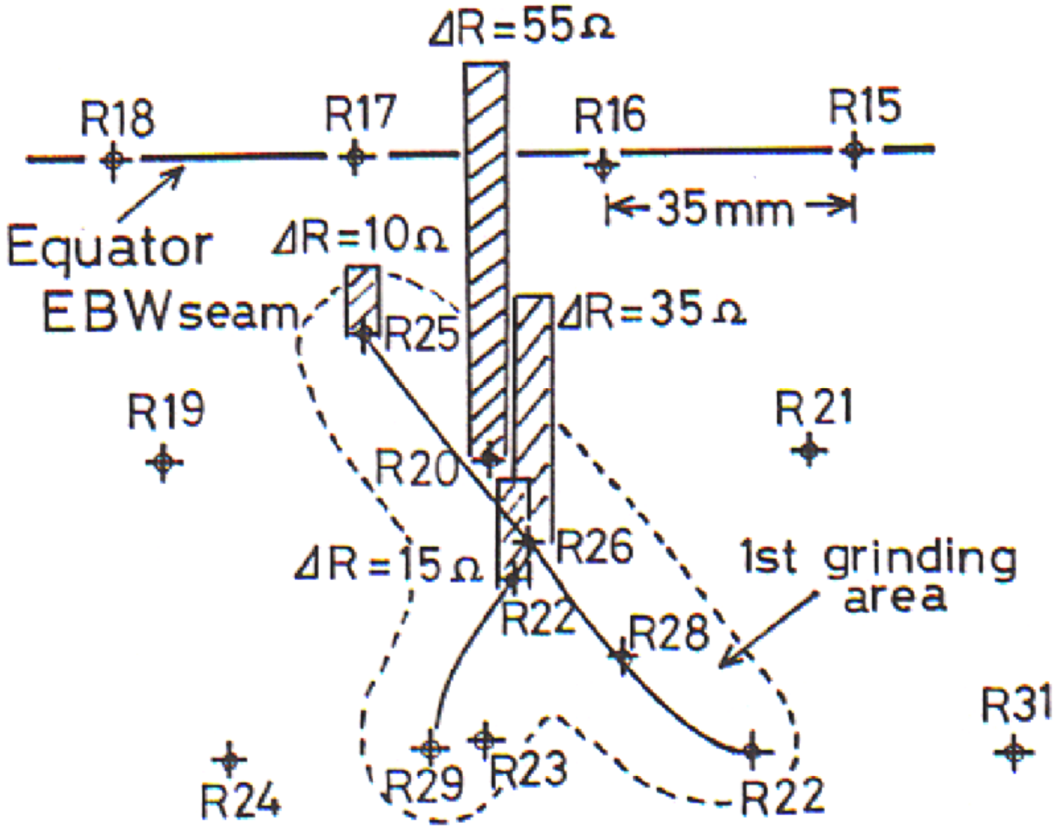


Surface Defect of the quench location

EBW @ Equator

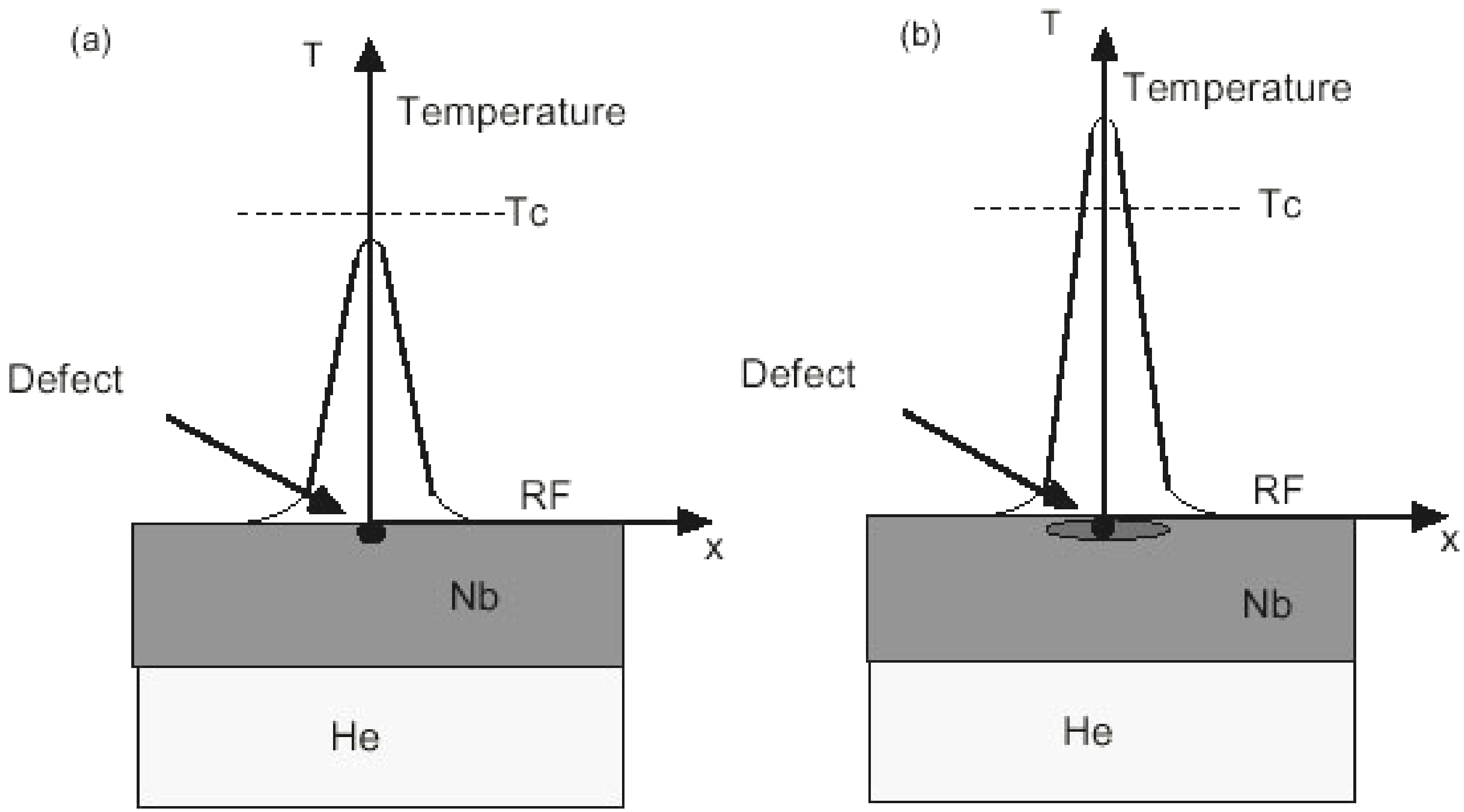


Picture of the defect area



T-mapping on the defect

Mechanism of Thermal Instability

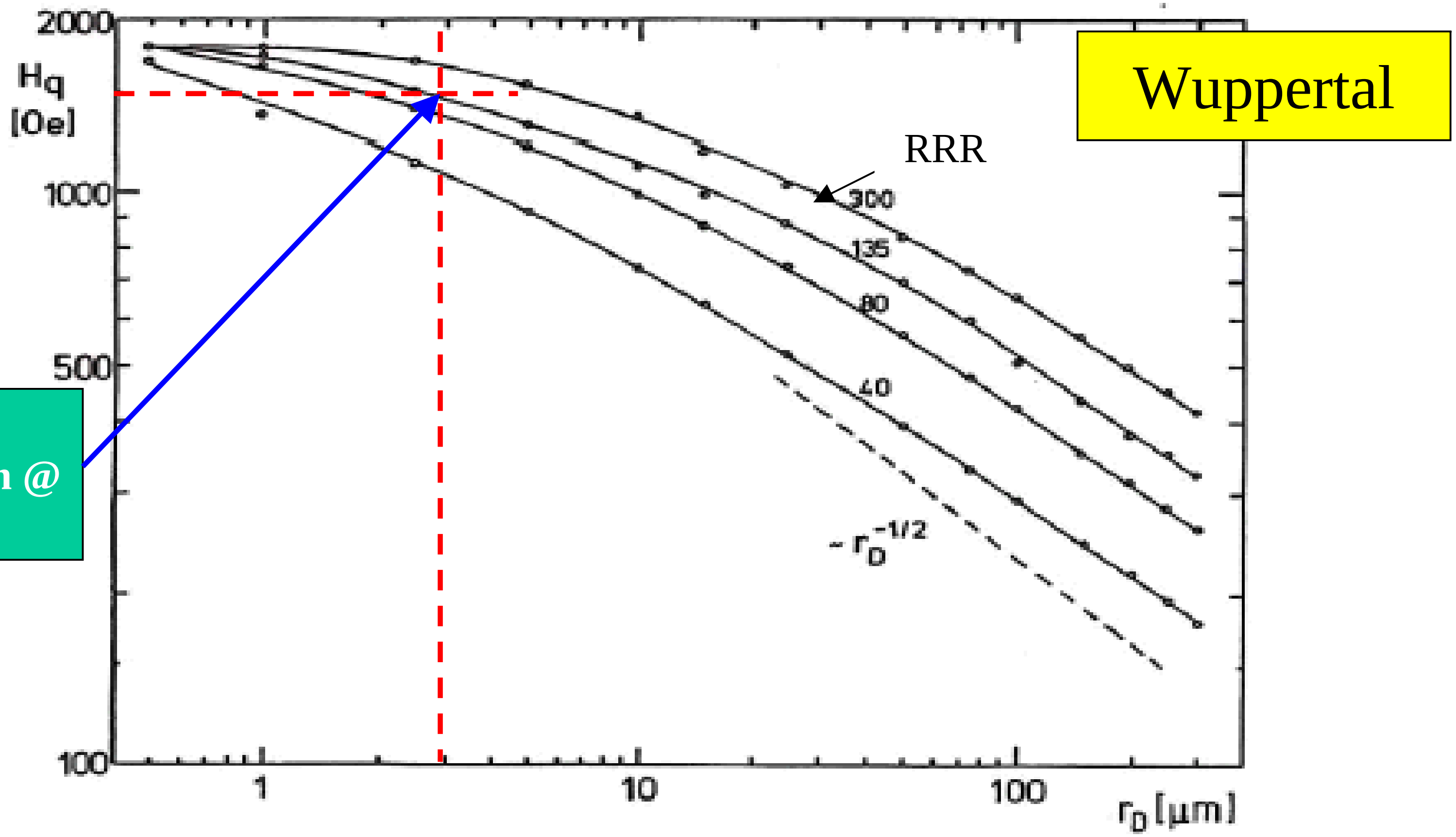


Thermal conductivity of the niobium material is concerned
In order to suppress the thermal instability.

Thermal conductivity has linear relationship with RRR.
RRR is used instead of the thermal conductivity.

RRR Dependence of Quench Field

$$\textbf{Quench Field : } Hq = \sqrt{\frac{4\kappa(Tc - Tb)}{r_D \cdot R_s(Tb)}} \propto RRR^{\frac{3}{4}} \cdot \sqrt{\frac{(Tc - Tb)}{r_D \cdot Rs(300K)}}$$



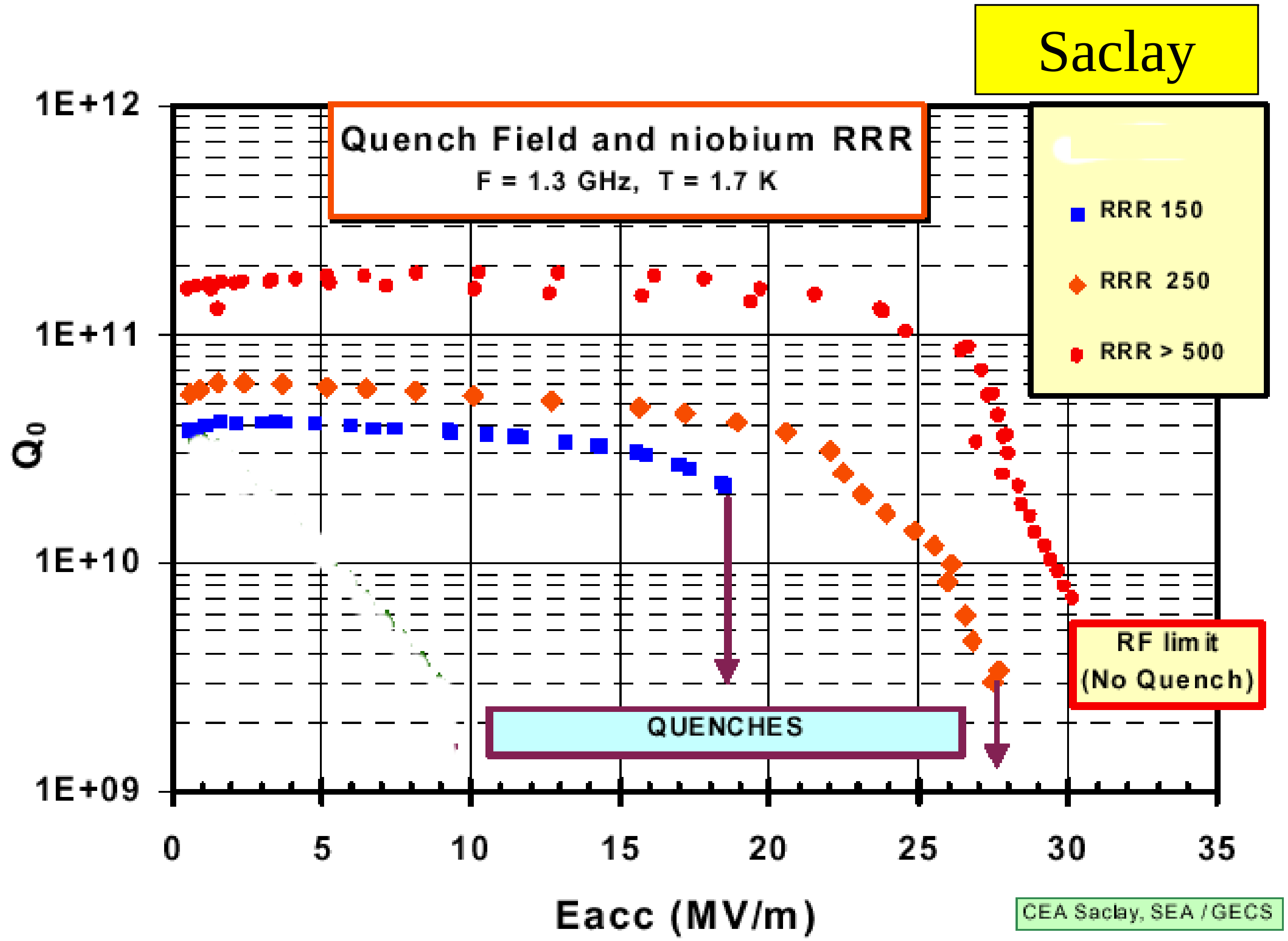
Hq~1500Oe, Eacc,max ~34MV/m @ RRR=135, r_D=3μm

Defect radius

K

Need to remove 1μm size defects. Use high purity niobium with RRR>200.

Field Improvement by High RRR Material



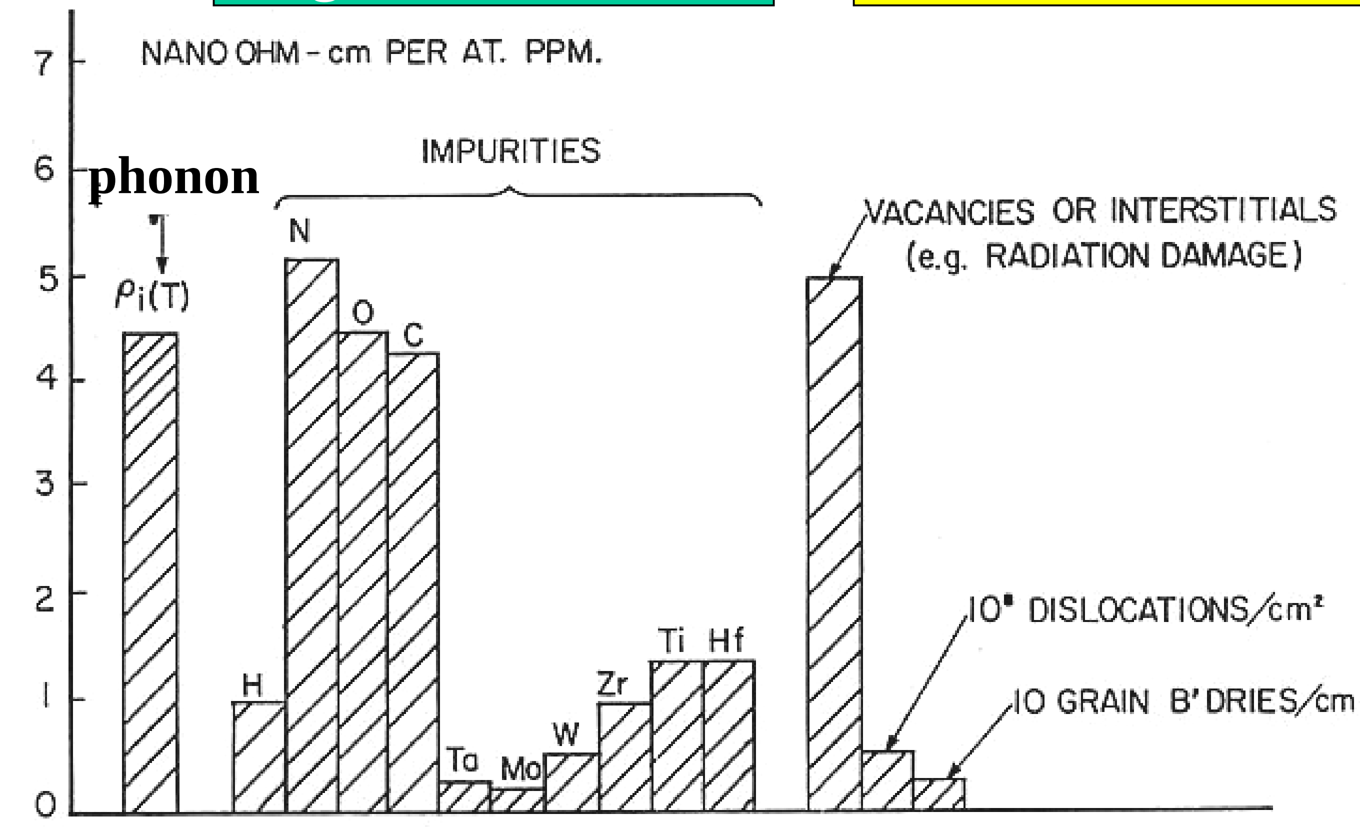
Effect of Various Scattering Mechanisms on Electric Resistivity

High purity + **Homogeneity**

High RRR material

Vacuum annealing

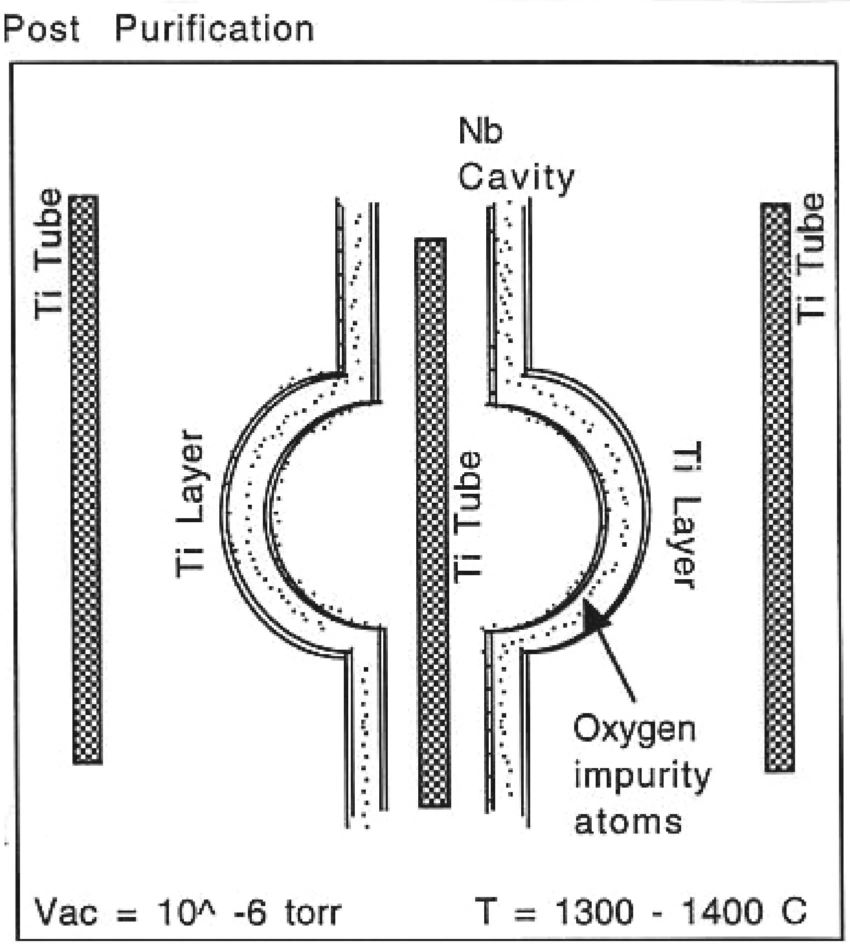
Nb



E-Resistivity = $\sum$(mechanism)$_i$

= e-phonon scat. + e-imprity scat. + e-inhomogenety scat.+ $\cdots$

Cure : Post Purifying of Niobium



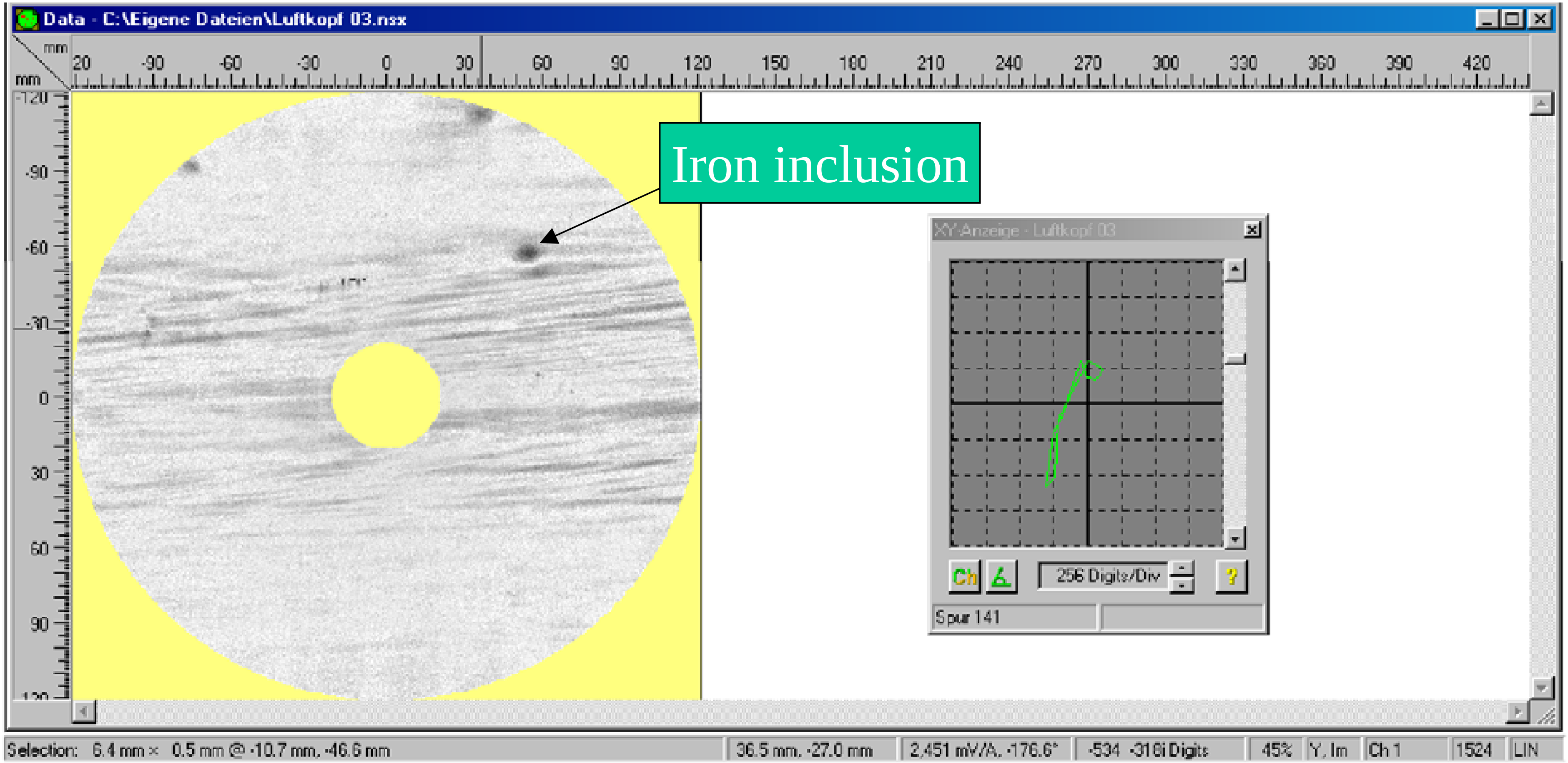
After cavity or half-cell is produced

- **Heat in vacuum furnace to ~ 1350 C**
- **Evaporate Ti on cavity surface**
- **Use titanium as getter to capture impurities**
- **Later etch away the titanium**
- **Doubles the purity**
- **(RRR ~ 600 if originally RRR = 300)**

Cure : Inspection of Nb Sheet and Cavity Surface

Defect free material : Quality control

Result of eddy current scanning a Nb disc, dia. 265 mm at DESY



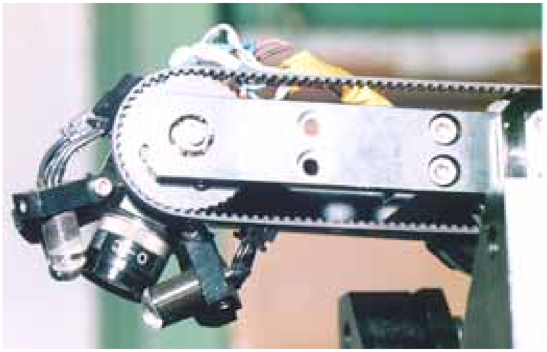
Global view, rolling marks and defect areas can be seen

Real and imaginary part of conductivity at defect, typical Fe signal

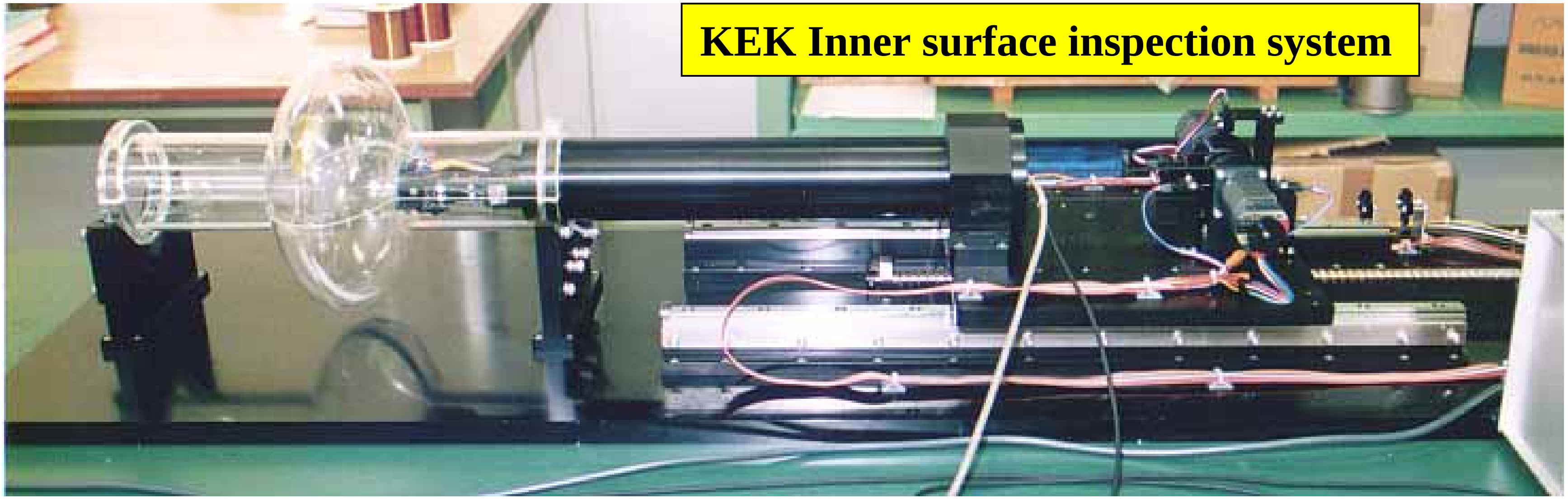
Eddy current scanning system DESY

Cavity Inner Surface Inspection System : KEK

Small CCD camera



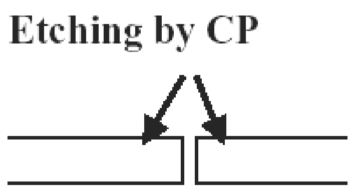
CRT monitor
Magnification ~13

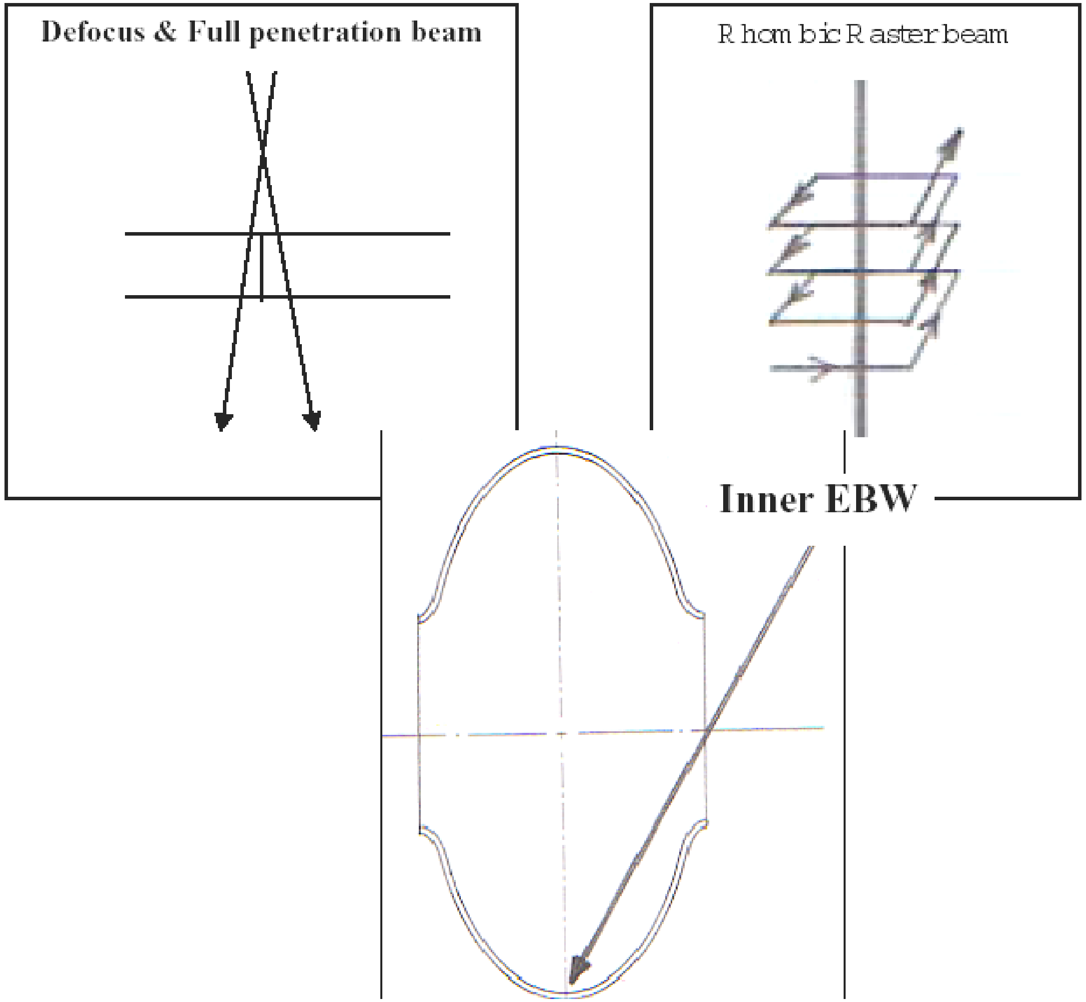


KEK Inner surface inspection system

Cure : High Quality EB-welding

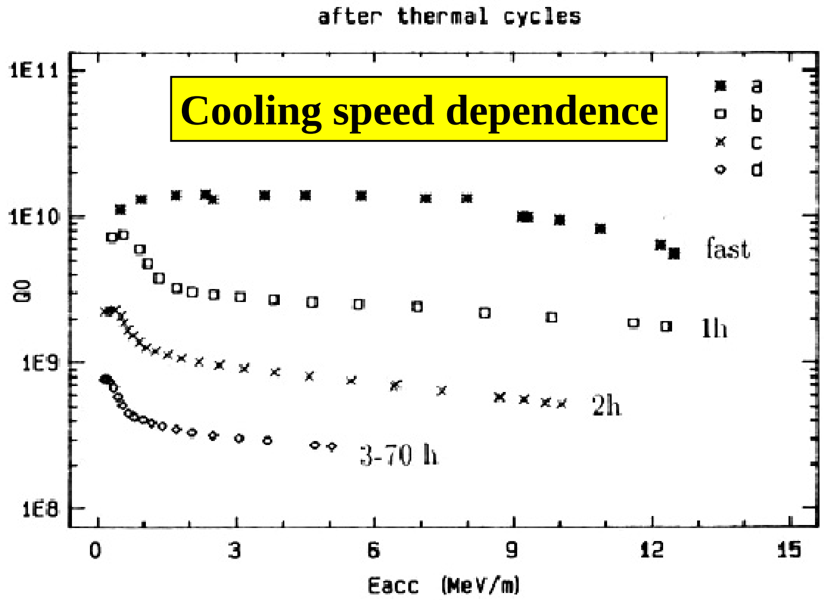
Better EBW

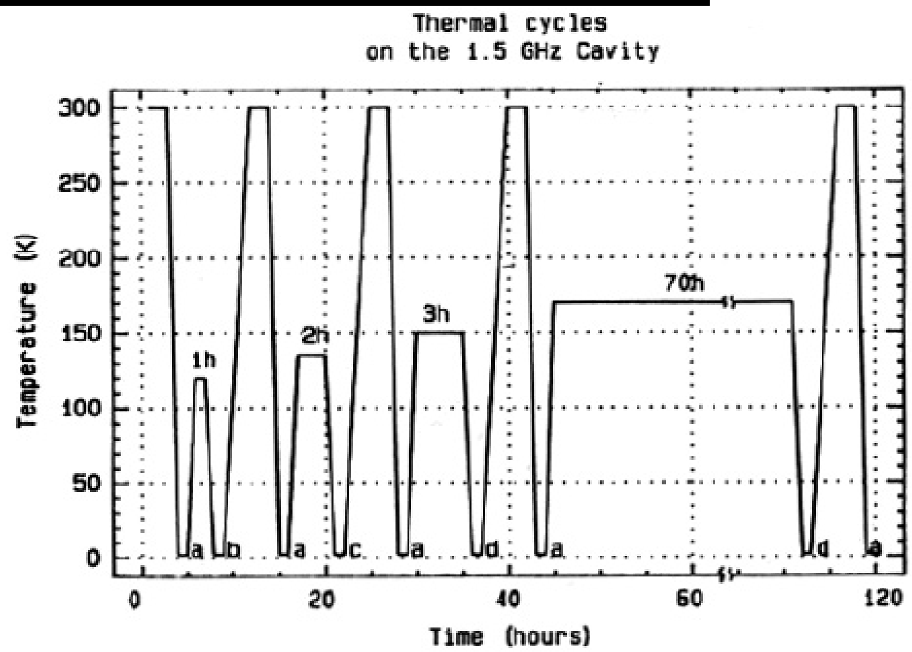




11.4 Hydrogen Q-Disease

Q_o-value strongly depends on cooling down speed.

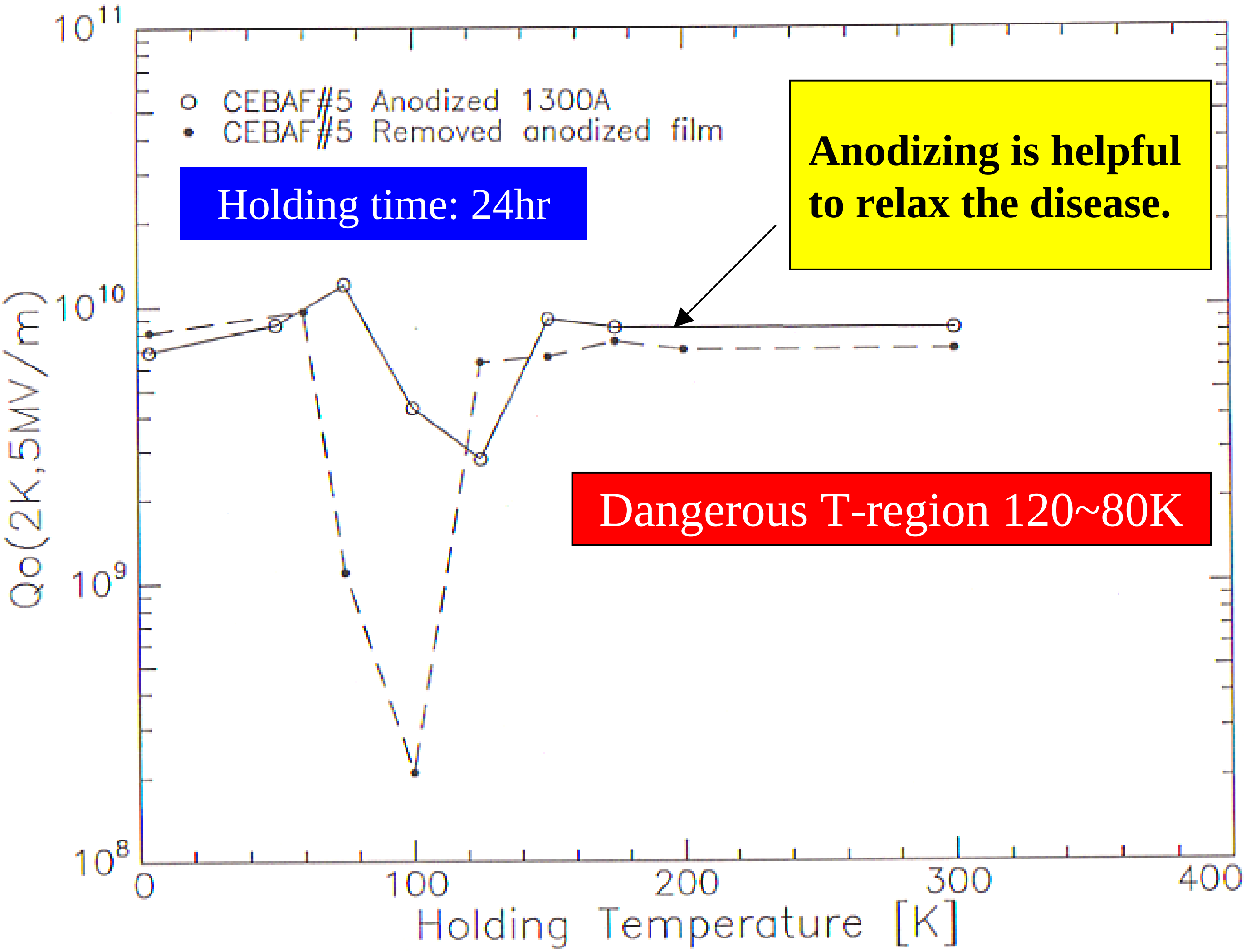




In 1990, Discovered
with chemically polished niobium cavity

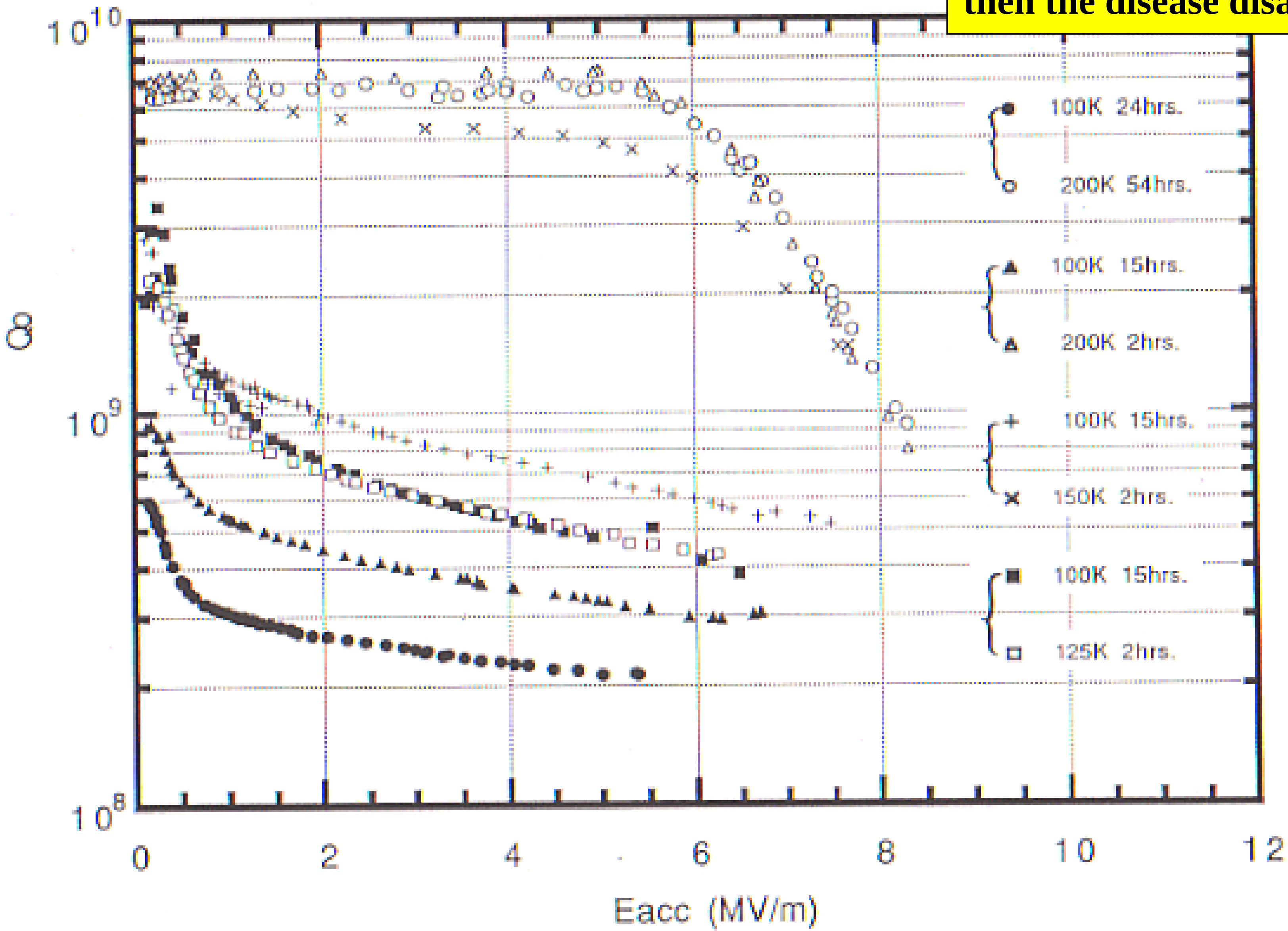
At those days, all labs in Europe and US have been used chemical polishing, because it is simple and no needs hydrogen degassing annealing.

Dangerous Temperature



Recovery of Hydrogen Q-Disease

Warm up to 200K,
then the disease disappears.



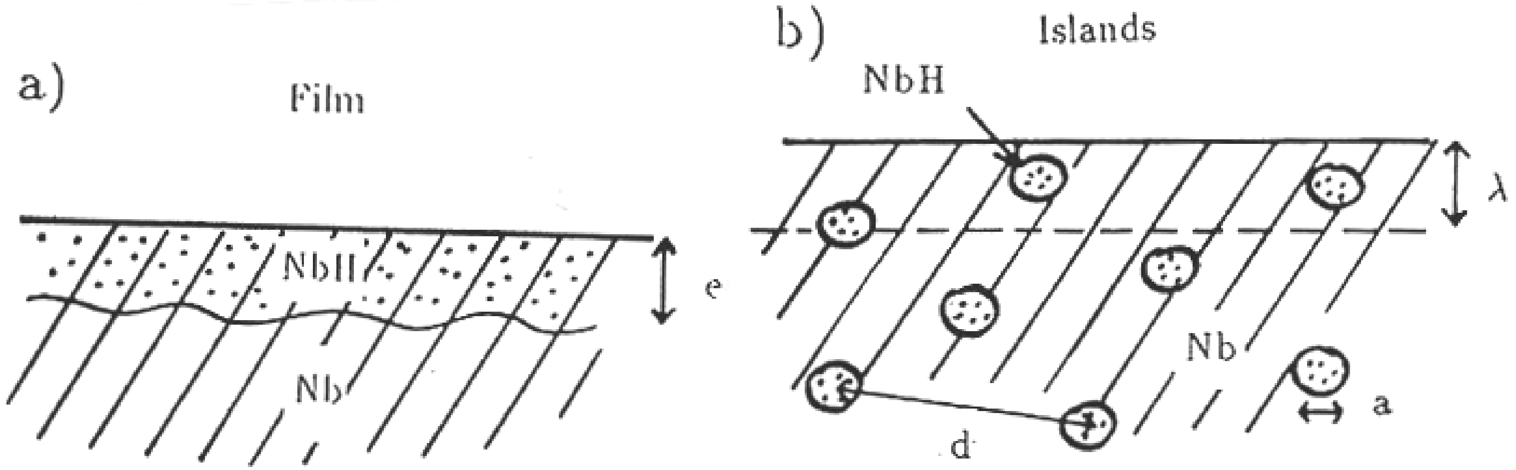
Mechanism of Hydrogen Q-disease

Mechanism
and Explanation of Symptons

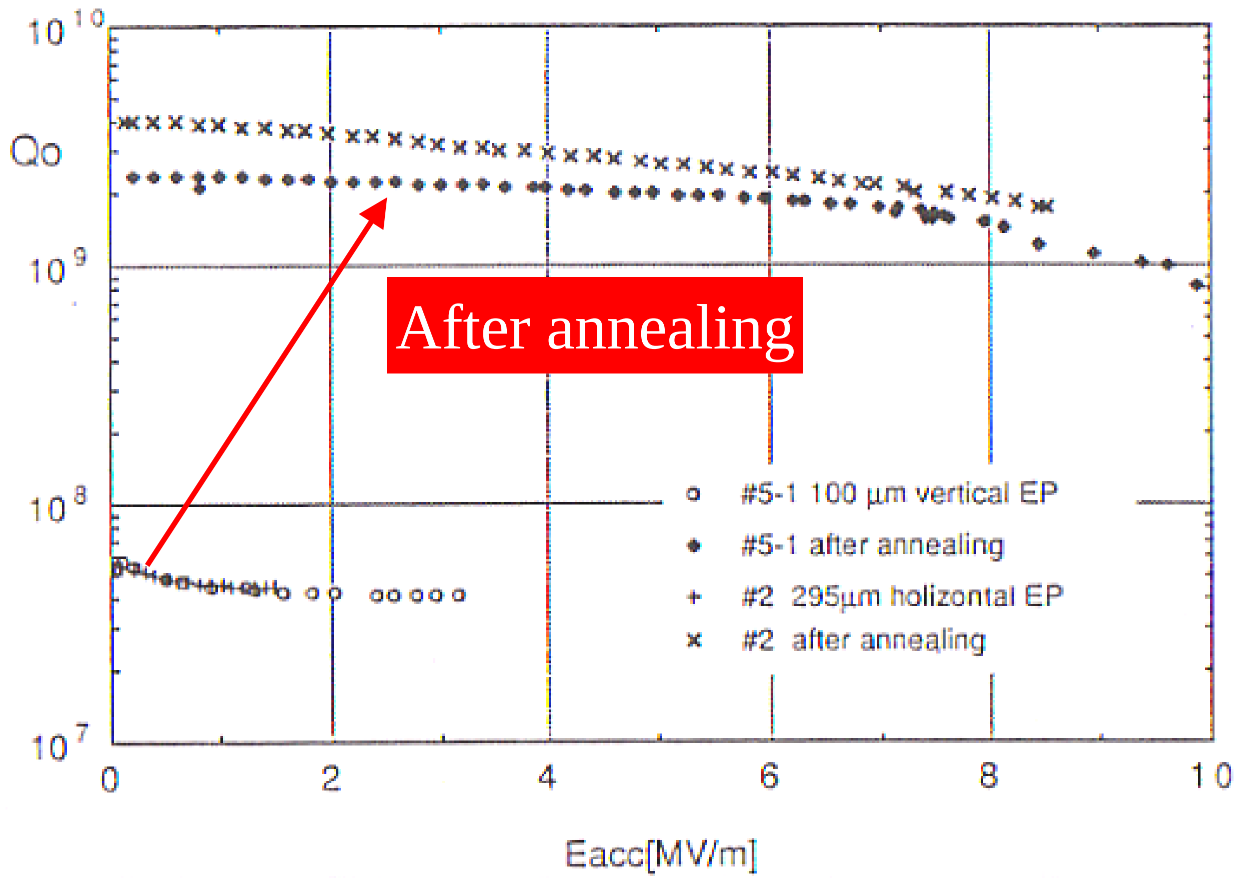
At room temperature H moves freely,
there is some evidence of surface enrichment

When a cavity is cooled the dissolved hydrogen
precipitates as a hydride phase that has high rf loss
Tc of hydride = 2.8 K, Hc = 60 Oersted

This explains shape of Q vs E curves
of Q-disease cavities

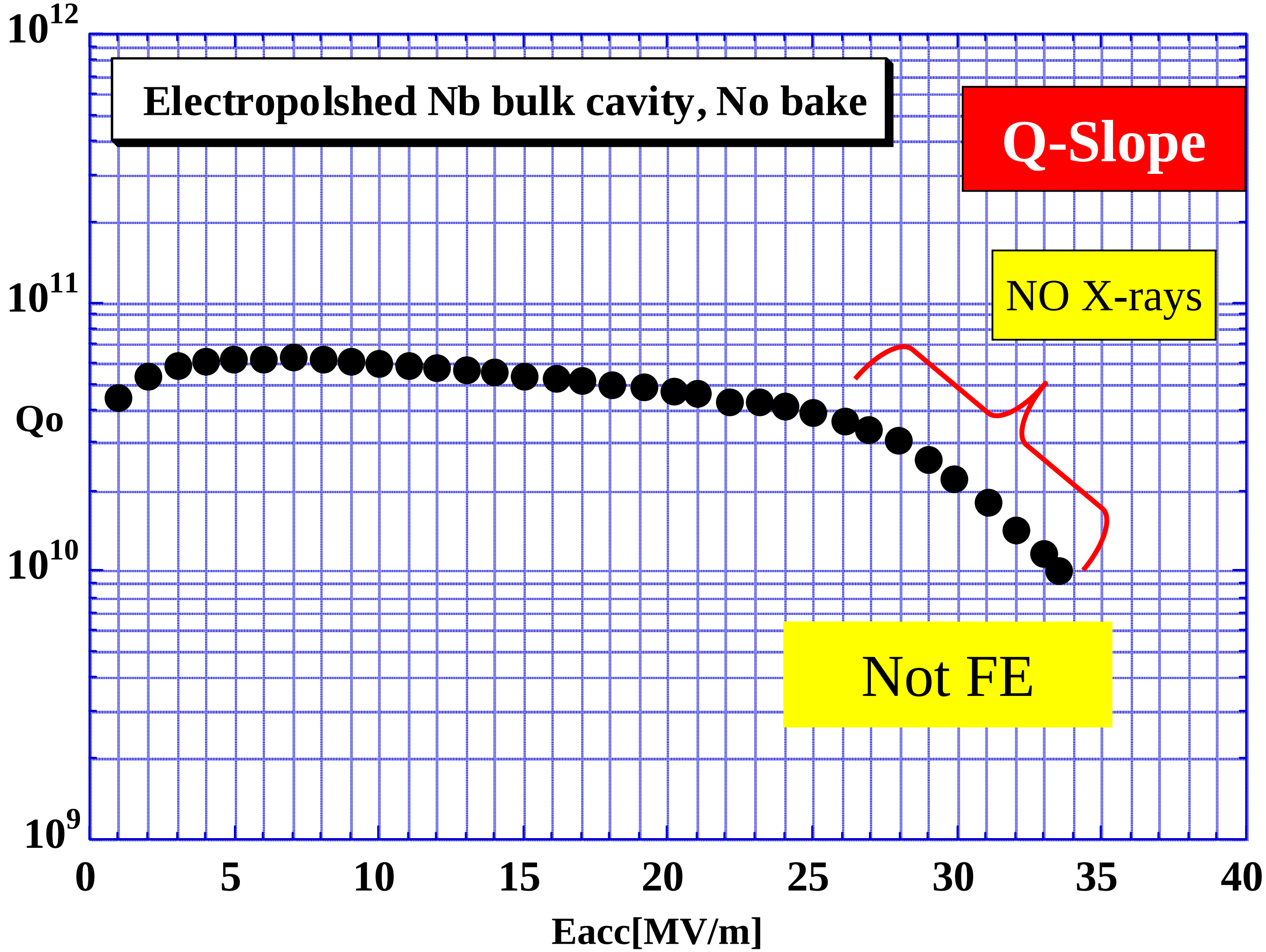


Hydrogen Q-disease in electropolished cavity



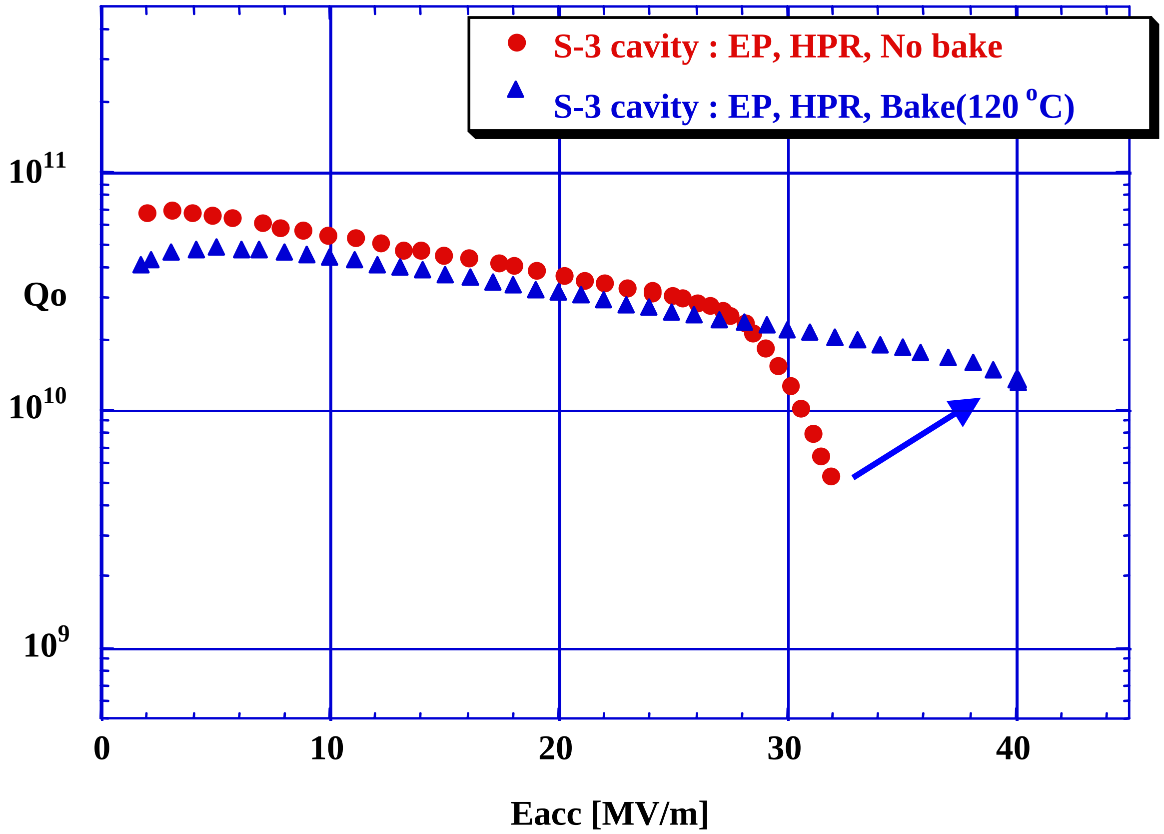
Hydrogen Q-disease is much serious on electropolished cavity.
Hydrogen degassing has been routinely done by annealing.
In those days, pre-cooling with liquid nitrogen had been used and nobody knew the disease depends on cooling down speed.

11.5 Q-Slope



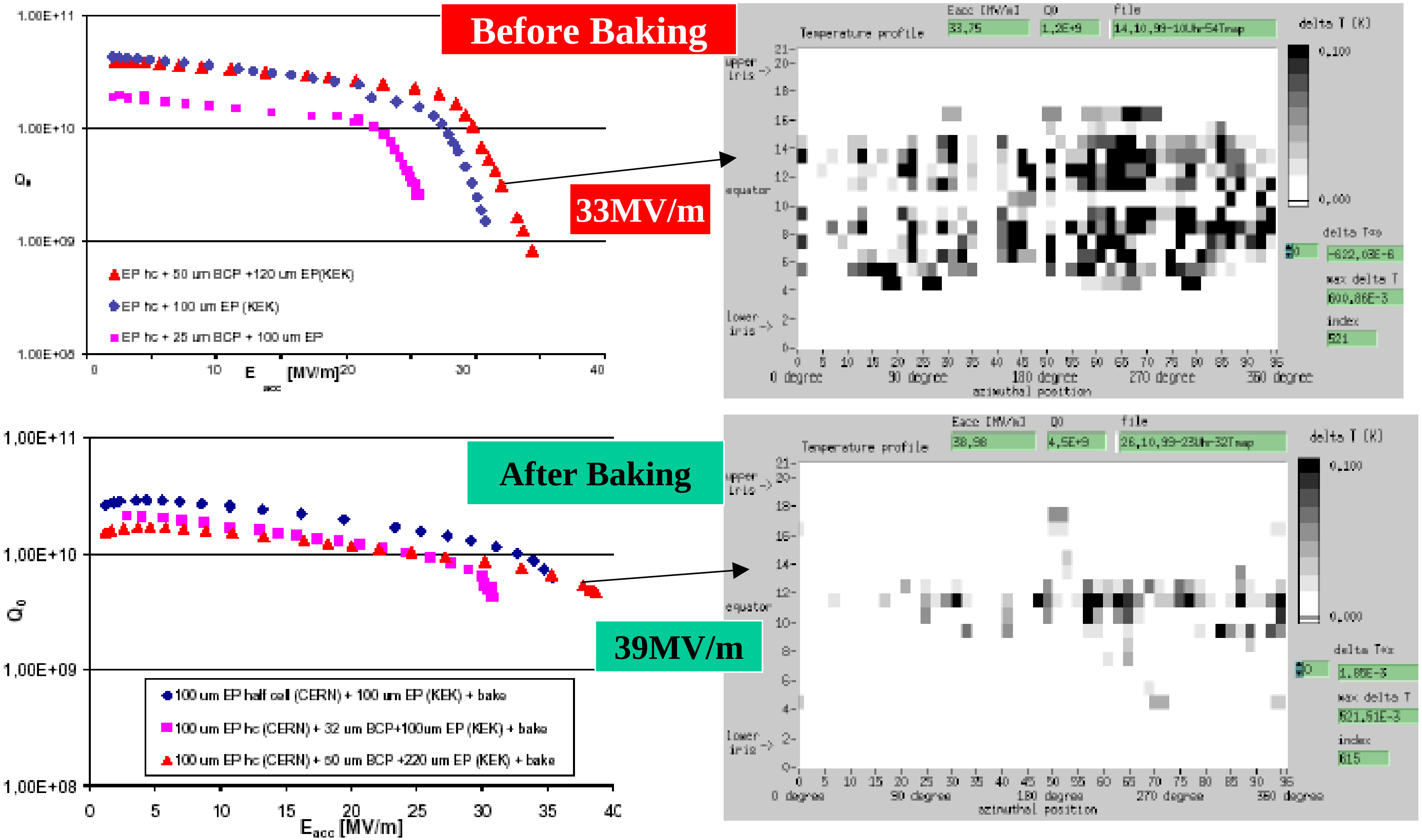
Discovered in 1998

Crucial Baking Effect on EP Cavity

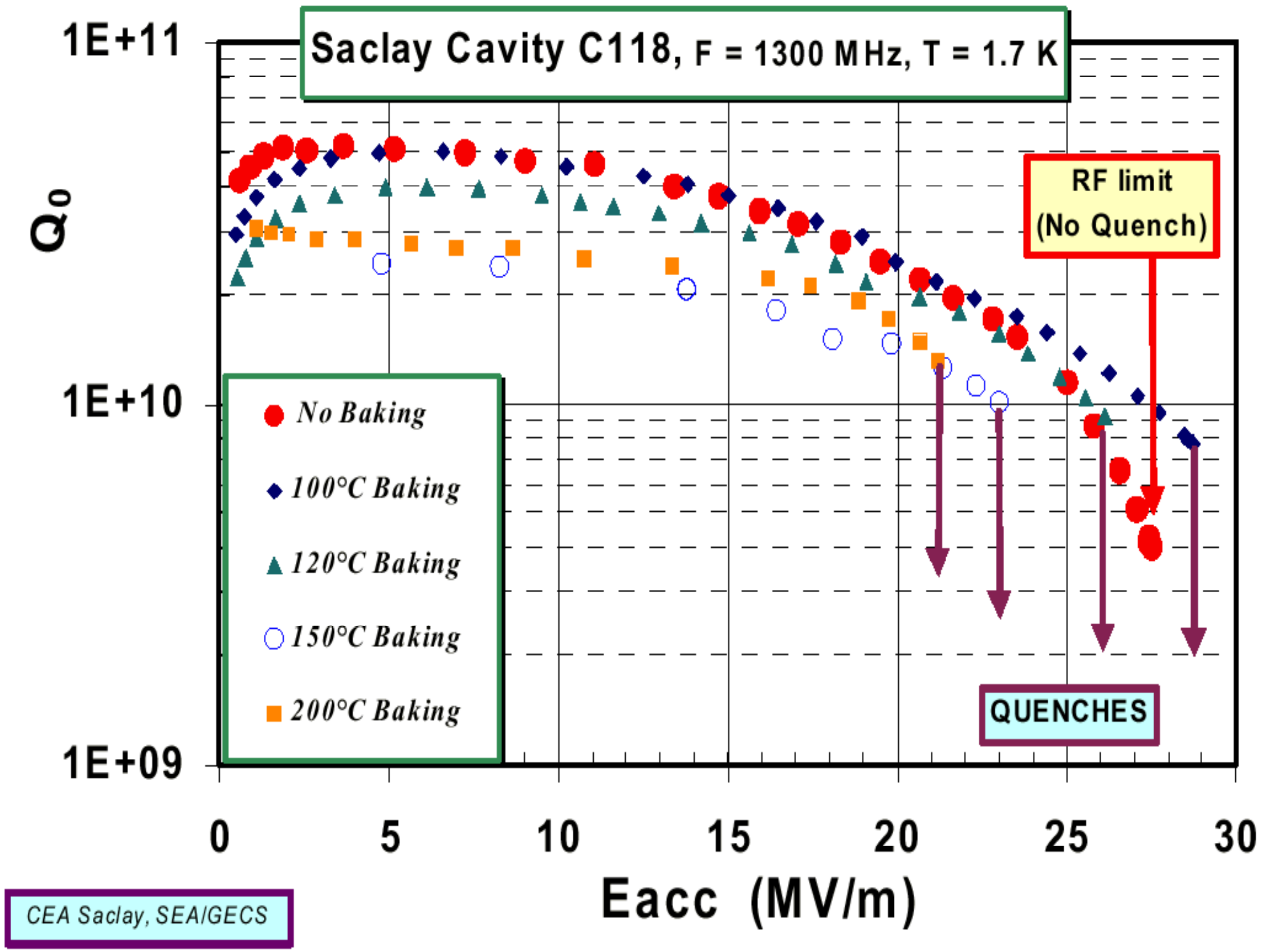


When took baking, Q-slope disappears in case of electropolished cavity. KEK has been used baking and thought that it gets better vacuum. They did not notice the Q-slope.

Disappeared Heating Spots by Baking on EP Cavity

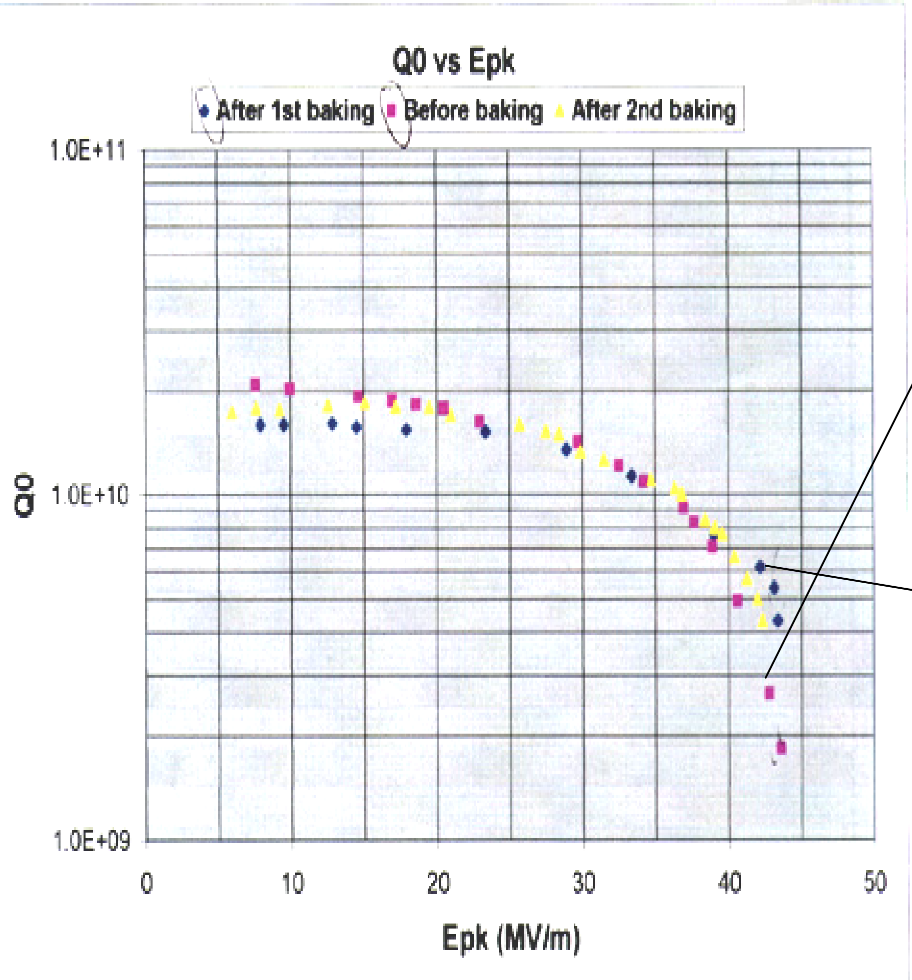


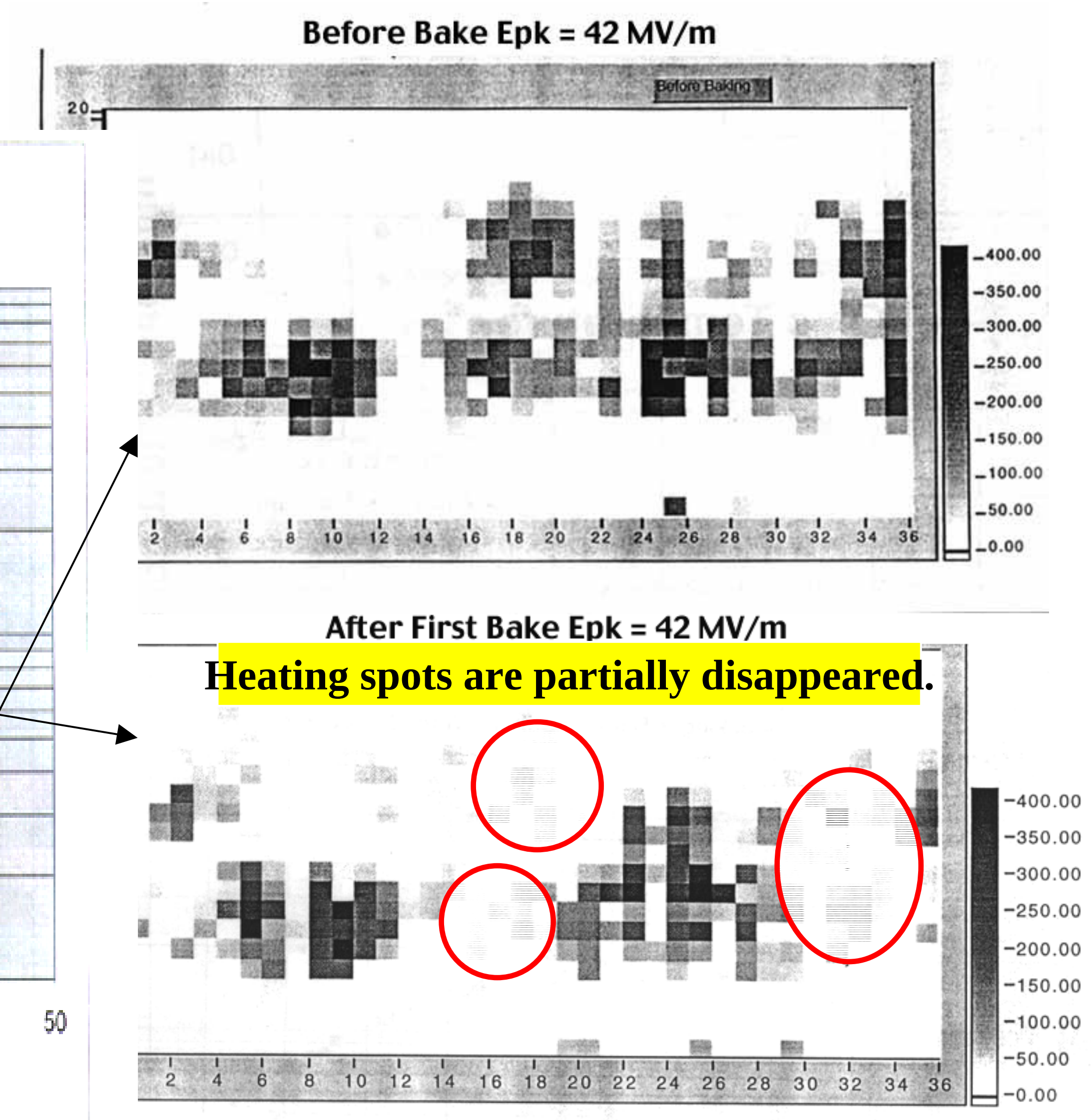
Small Baking Effect on CP Cavities (polycrystalline)



Baking effect on the Q-slope looks small on chemically polished polycrystalline cavity.

Partially Disappeared Heating Spots by Baking on CP Cavity

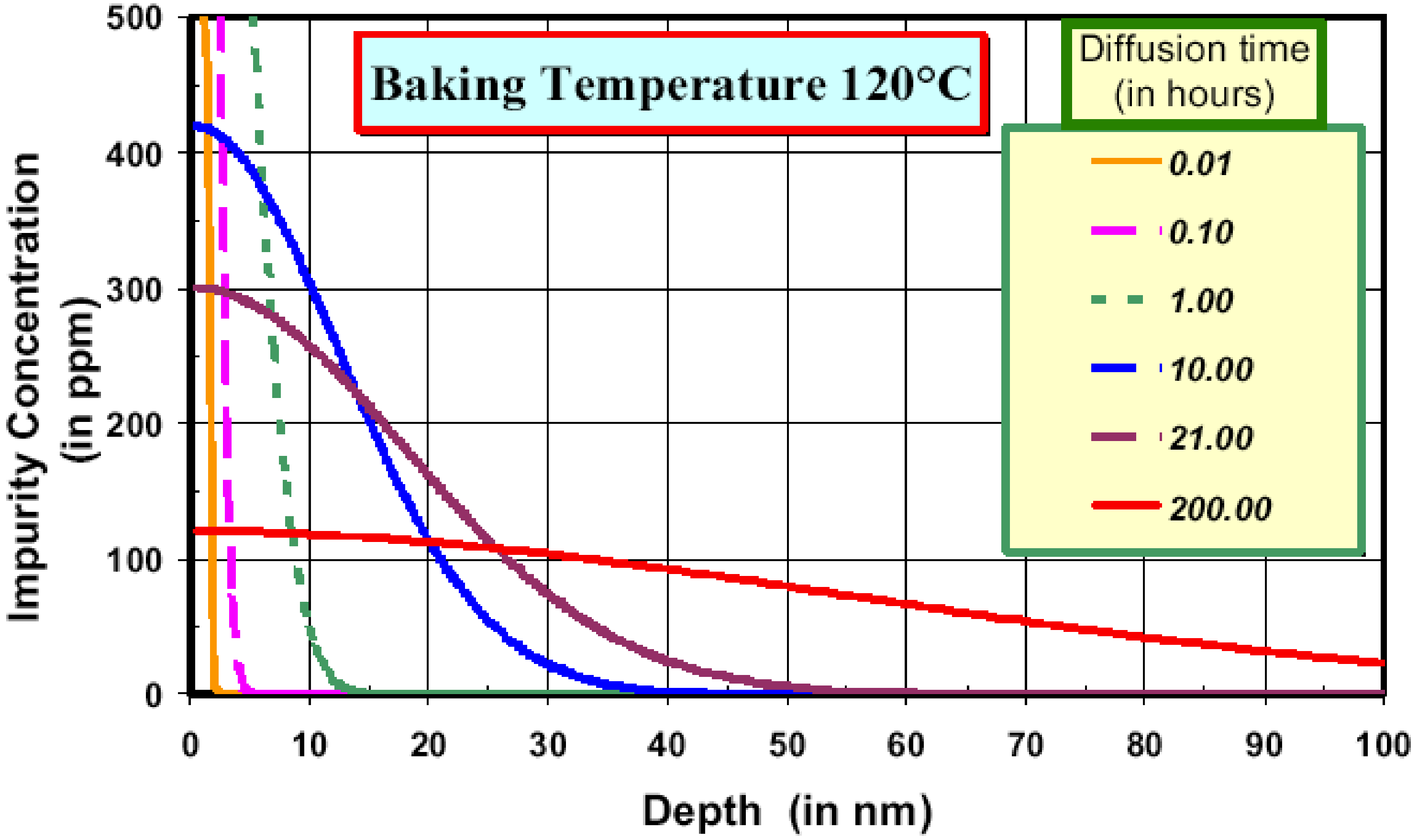




Heating spots are partially disappeared.

CORNELL UNIVERSITY

Oxygen Diffusion



Baking could defuse the oxygen contamination on the top into the bulk and the niobium RF penetration surface could be become clean.

Loss Mechanism

Interface Tunnel Exchange(ITE Model)
By J.Halbritter

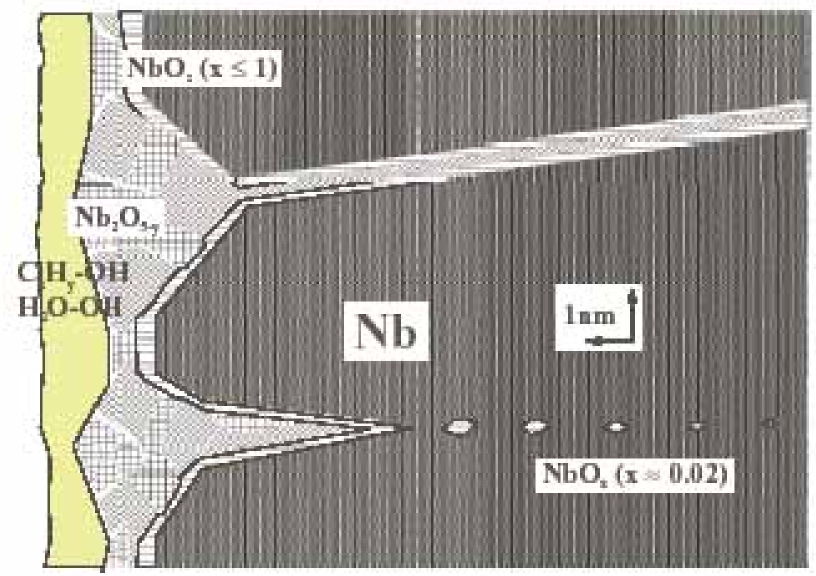


Fig. 1: Nb surface with crack corrosion by oxidation by Nb_2O_5 volume expansion (factor 3). Nb_2O_{5-y}-NbO_x weak links/segregates (y, x < 1) extend up to depths between 0.01 – 1/ 1-10 μm for good – bad Nb quality and weak - strong oxidation [8]. Embedded in the adsorbate layer of H_2O/C_xH_yOH (≥ 2 nm) being chemisorbed by hydrogen bonds to $NbO_x(OH)_y$, adsorbate covered dust is found. This dust yields enhanced field emission (EFE [7]) summarized in Sect. 3.1.

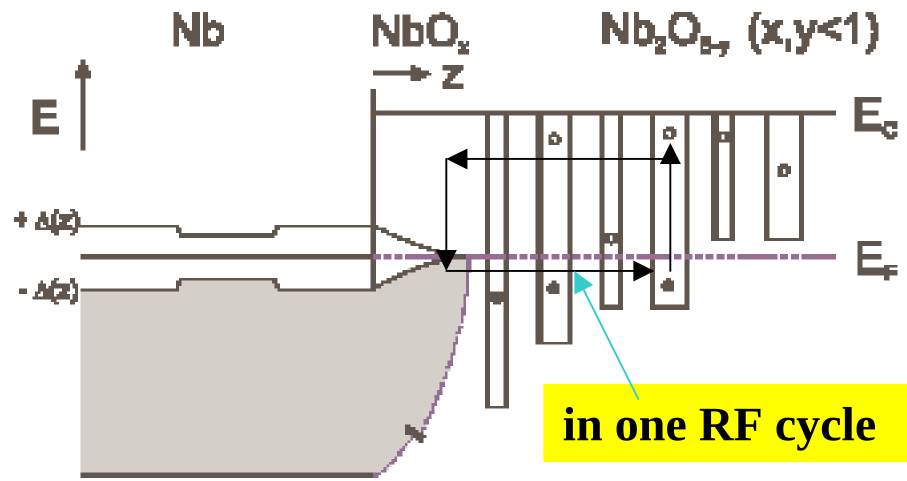
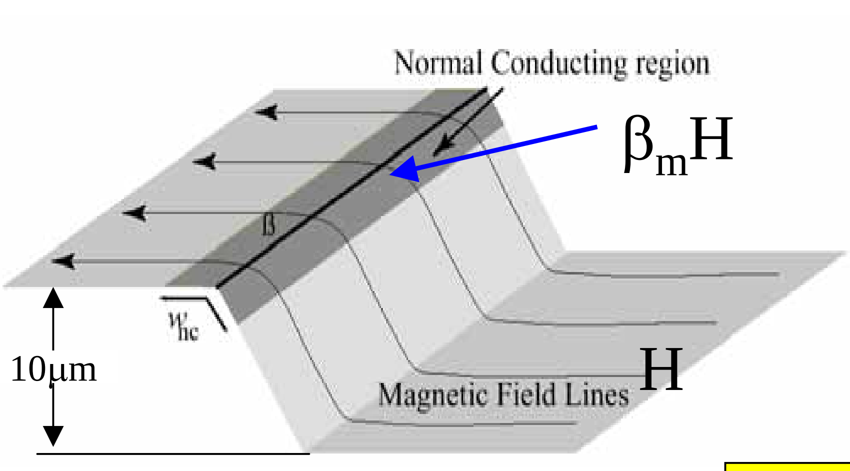
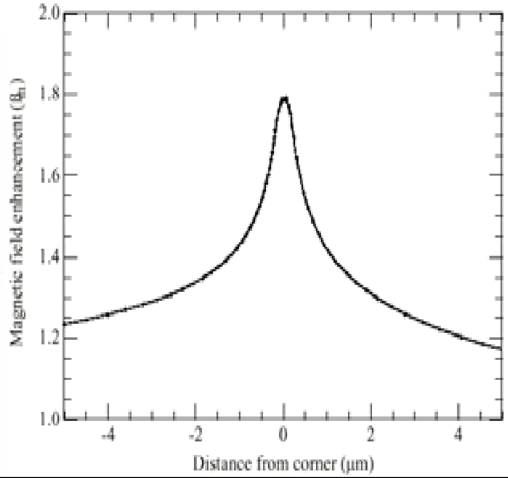
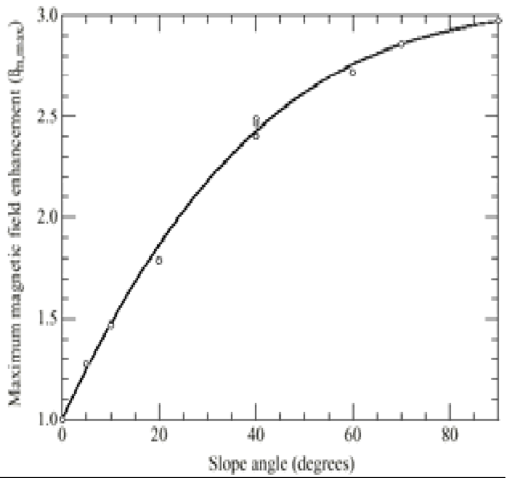


Fig. 3: Band structure at Nb-NbO_x-Nb_2O_{5-y} interfaces with E_c-E_F = $\phi \approx 0.1 - 1$ eV as barrier heights for tunneling along crystallographic shear planes (~ 0.1 eV) or of Nb_2O_{5-y} crystallites (~ 1 eV). Added is the superconducting energy gap $\Delta^*(z) < \Delta_o$ being reduced in NbO_x clusters or interfaces and being normal conducting Δ^* ($z_L \geq 0.5$ nm) in localized states of Nb_2O_{5-y}. By their volume expansion those clusters locally enhance T* and Δ^* > Δ_o in adjacent Nb by the uniaxal strain yielding a smeared BCS DOS.

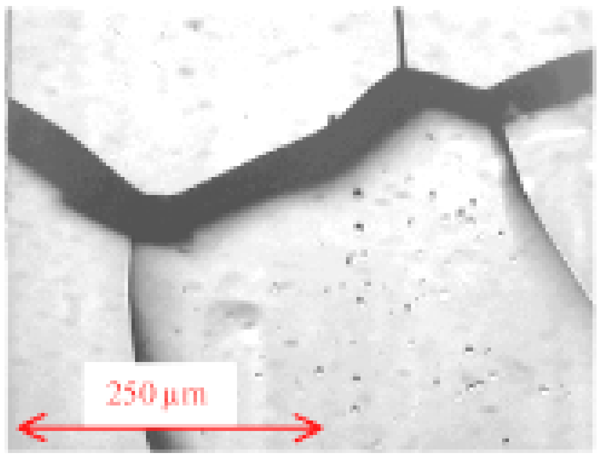
11.6 Magnetic Field Enhancement on Sharp Edges



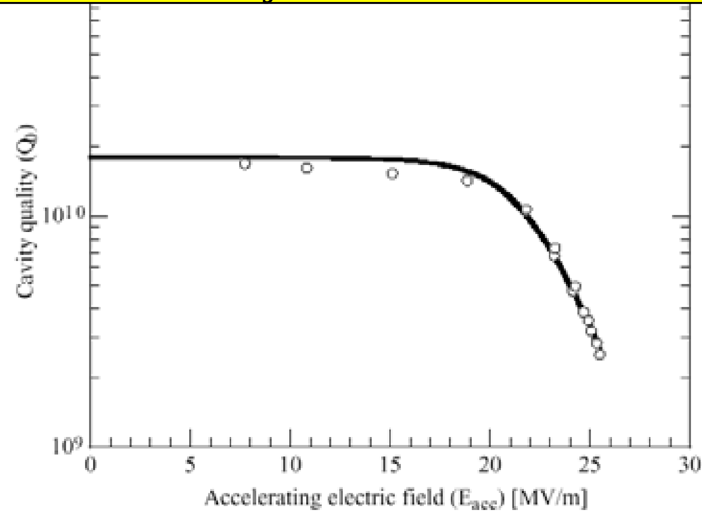




Standard BCP Chemistry on niobium :
Sharp boundary edges are clearly visible



Why the gradient can not be improved after baking in chemically polished cavity ?



$$\beta_m \cdot H_{RF} \geq H_C = \frac{\sqrt{2} \cdot H_C(0)}{\kappa(0)} \cdot (1 - t^4)$$

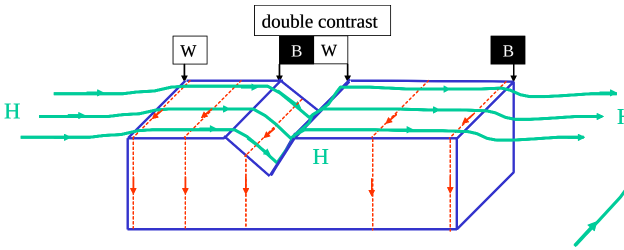
Figure 19: Comparison of the measured cavity quality (Test C) with that calculated by (25) using $H_{crit} = 1875$ Oe.

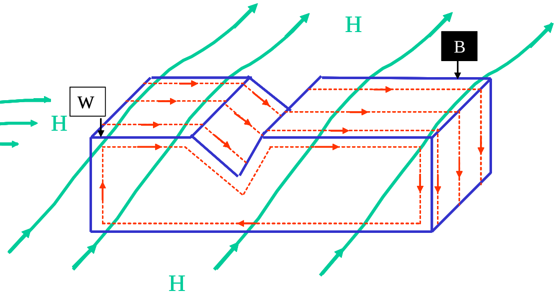
Monograph effect on Magnetic field

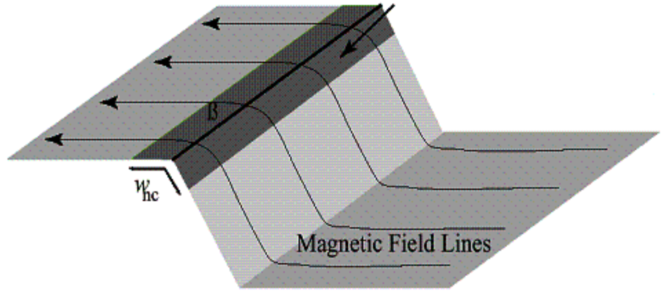
By C.Antone

CBP is right way to eliminate the monograph effect !!

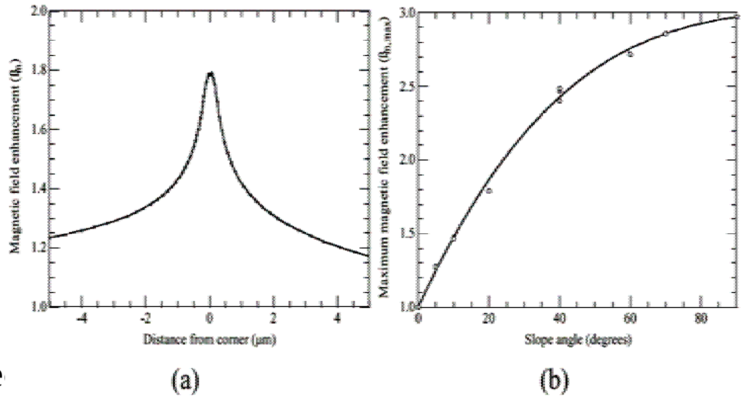
J.Knobloch



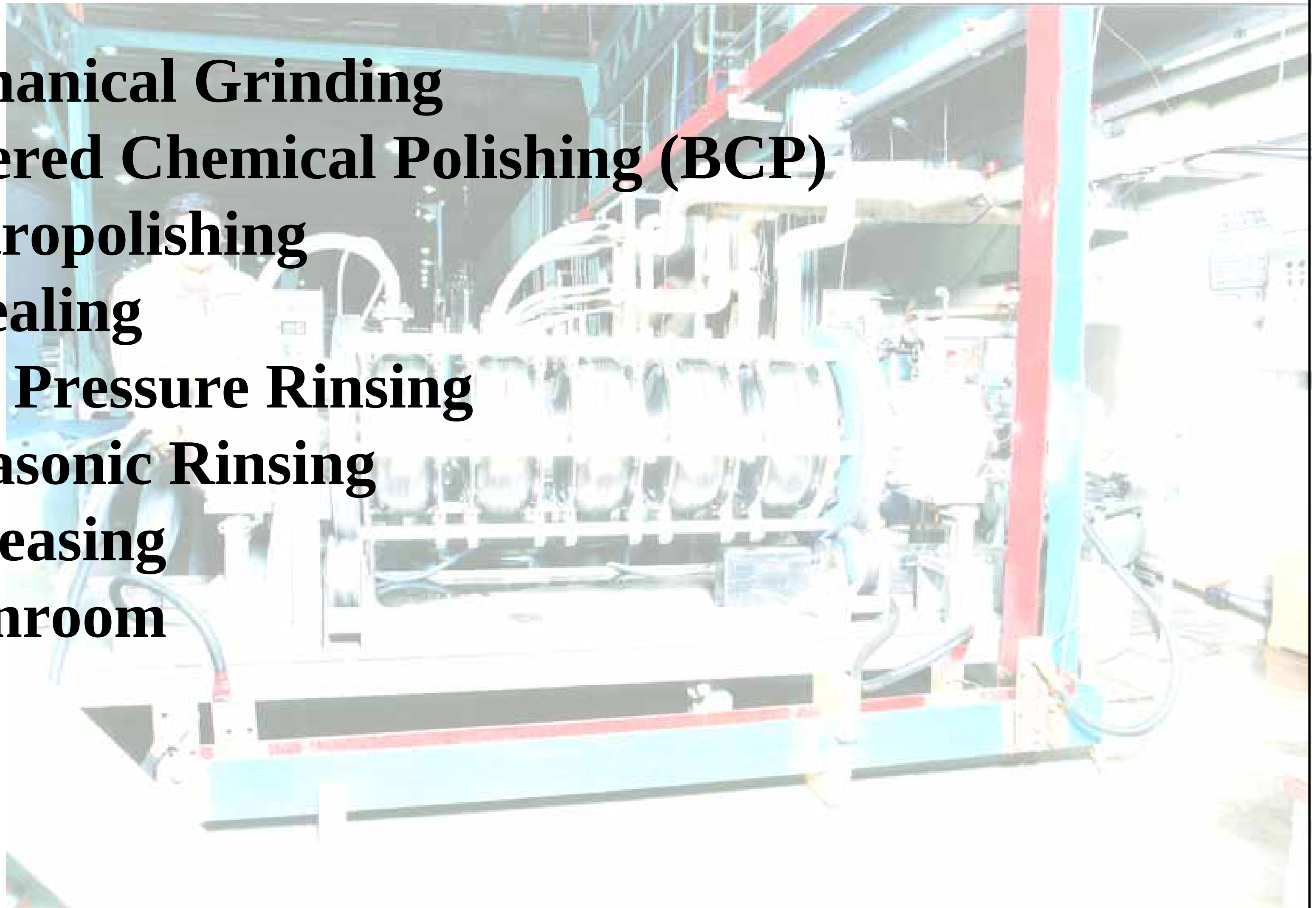




Flux trapping happens on the
steps perpendicular to the magnetic flux !

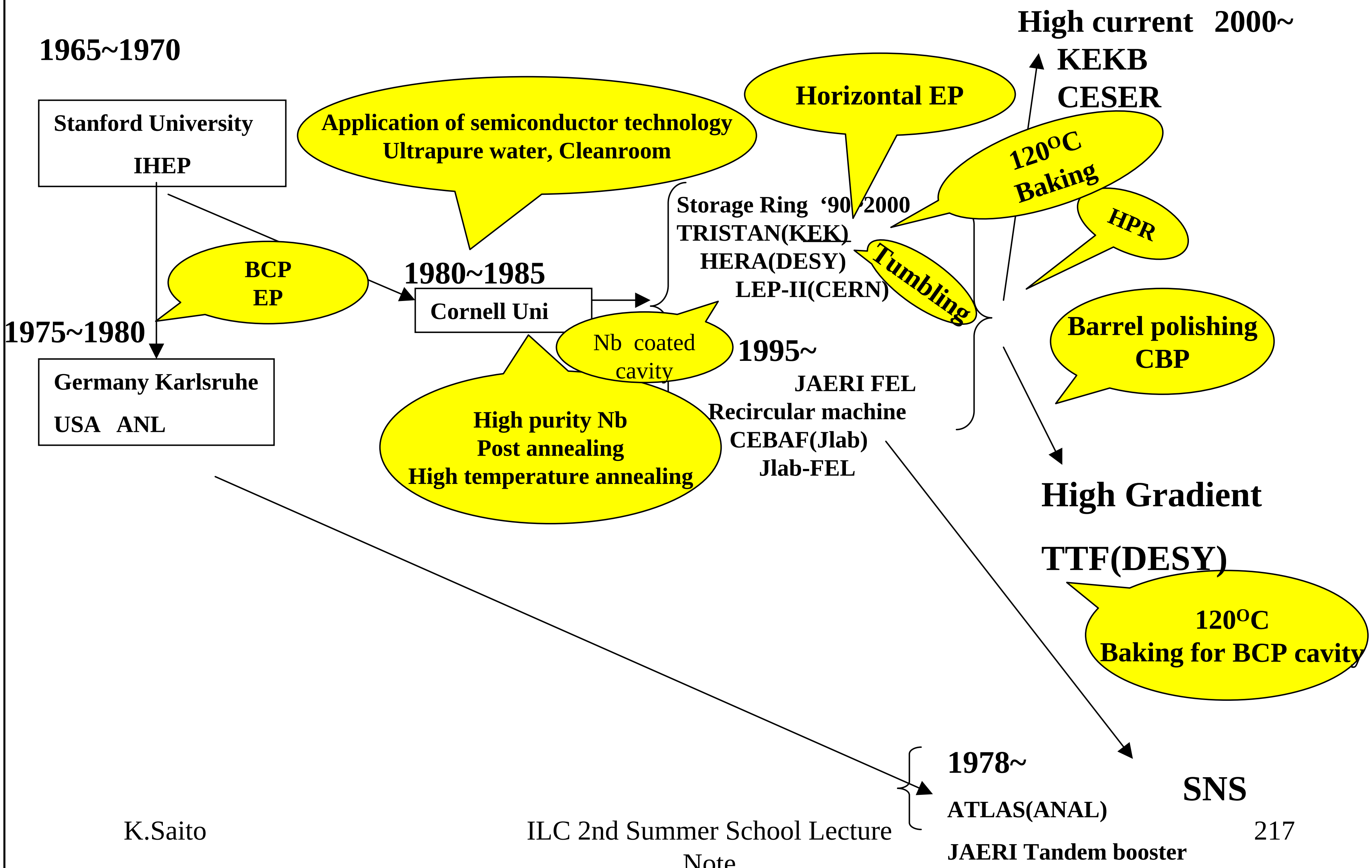


12. Surface Preparation Techniques

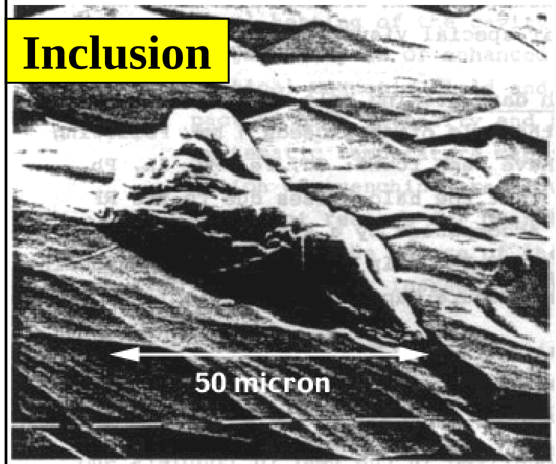


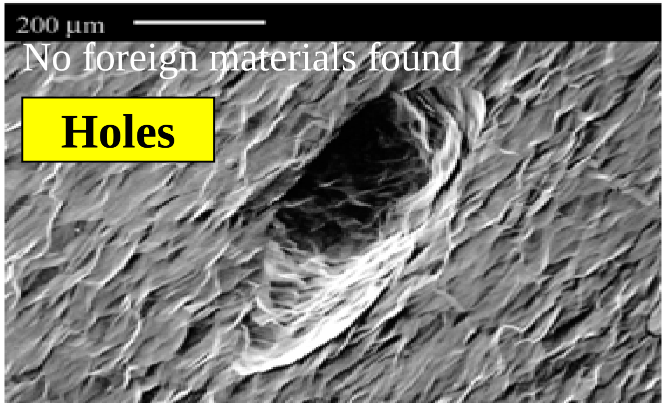
12.1 Mechanical Grinding
12.2 Buffered Chemical Polishing (BCP)
12.3 Electropolishing
12.4 Annealing
12.5 High Pressure Rinsing
12.6 Megasonic Rinsing
12.7 Degreasing
12.8 Cleanroom

History of Preparation Technologies

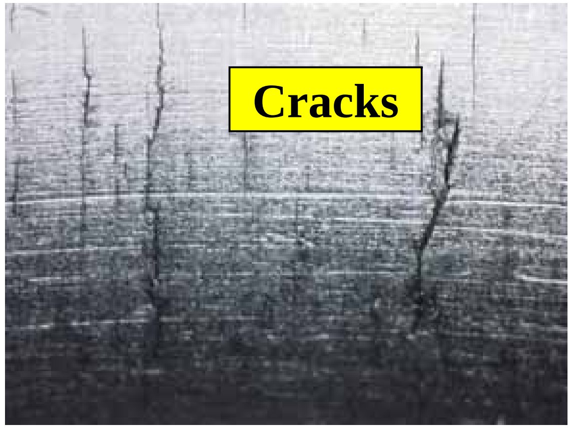


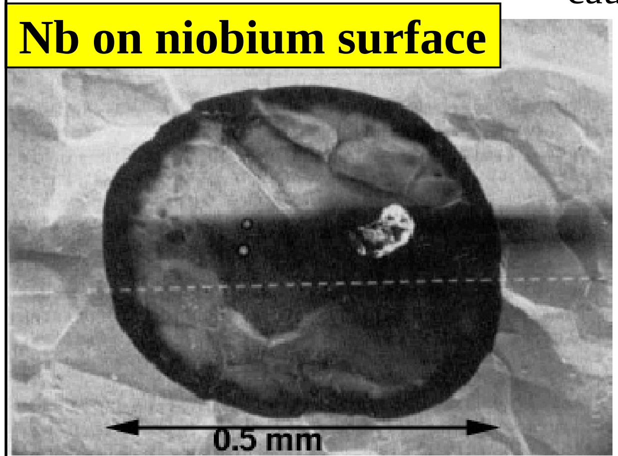
Various Surface Defects

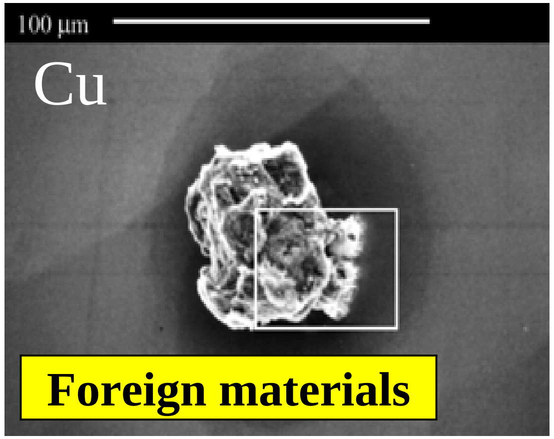


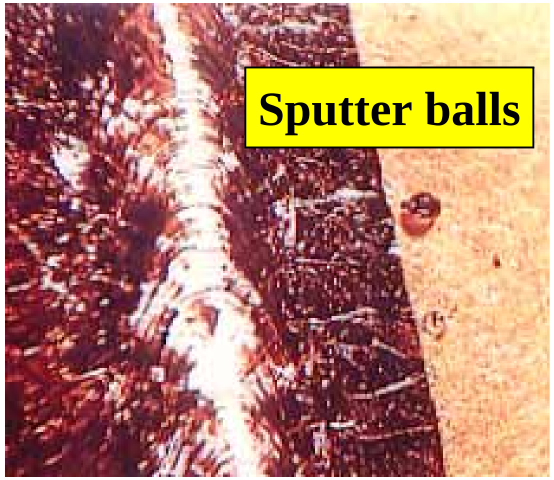


Surface defects, holes can also cause TB









Mechanical grinding is a powerful tool to remove large surface defects.

12.1 Mechanical Grinding

MG is very powerful to remove surface defects but remains Contamination on the ground surface.
It is usually used as pre-treatment before chemical preparation.

Buffing

Buffing TRISTAN 320 half cups.

- **Very powerful**
- **High reliable**
- **Well controlled the surface roughness**

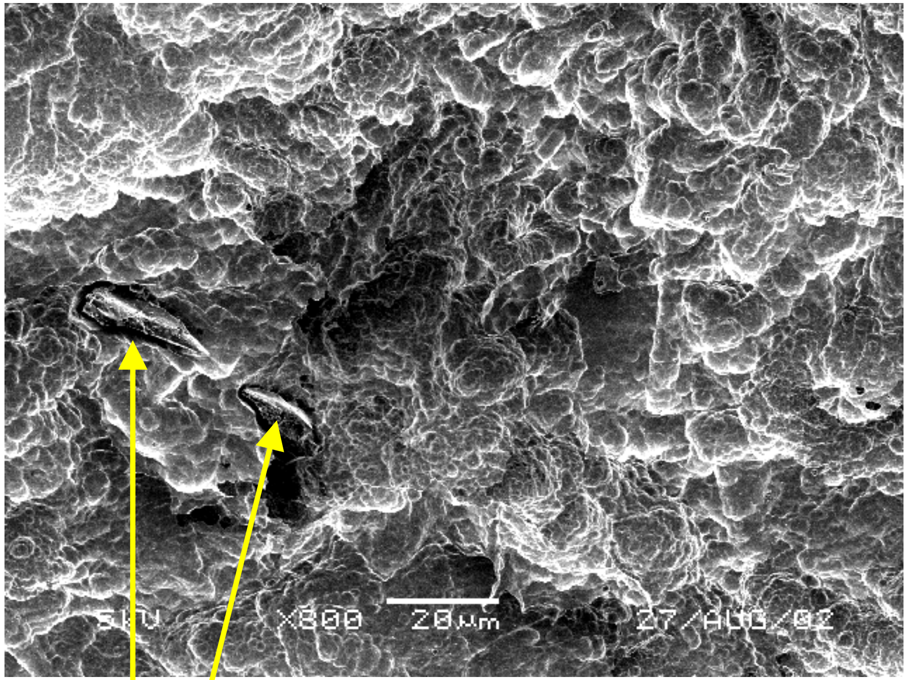
Used in the TRISTAN @ KEK

- **All half-cup were buffed.**
- **Other mechanical grinding for welding seams.**

Problem with buffing

1) High cost
2) Impossible to completed structure

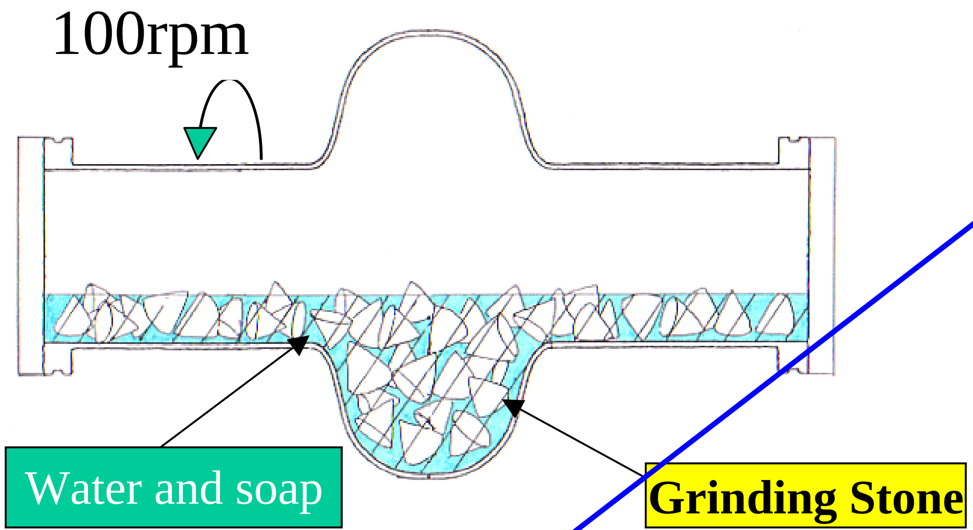
Contamination by mechanical grinding

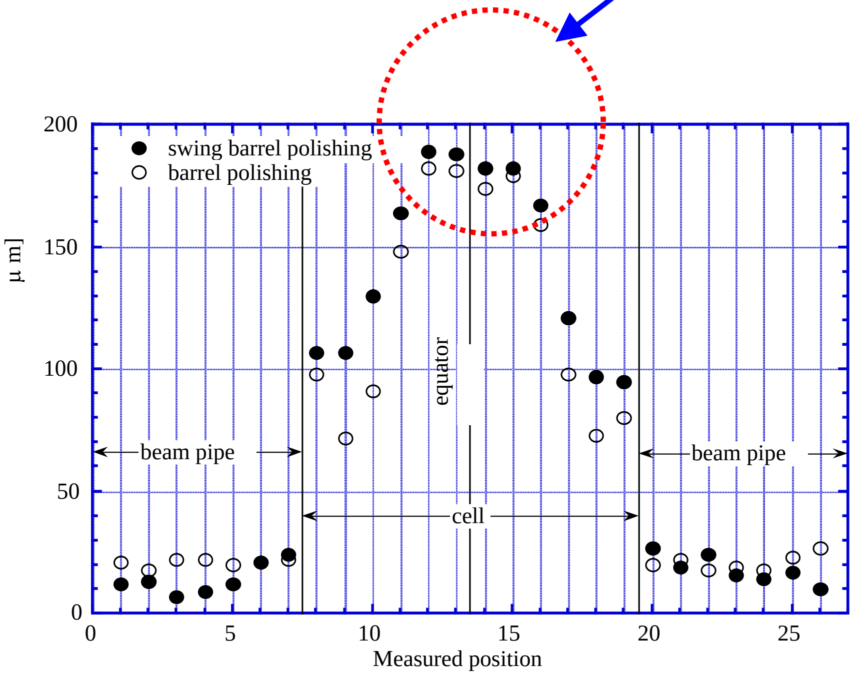


Remained grains of grinding material
(Barrel polishing)

Need to make a chemical preparation in order to remove these contamination.

Tumbling or Barrel Polishing(BP)





- Simple
- Possible to a competed structure
- Low cost

Problem in BP

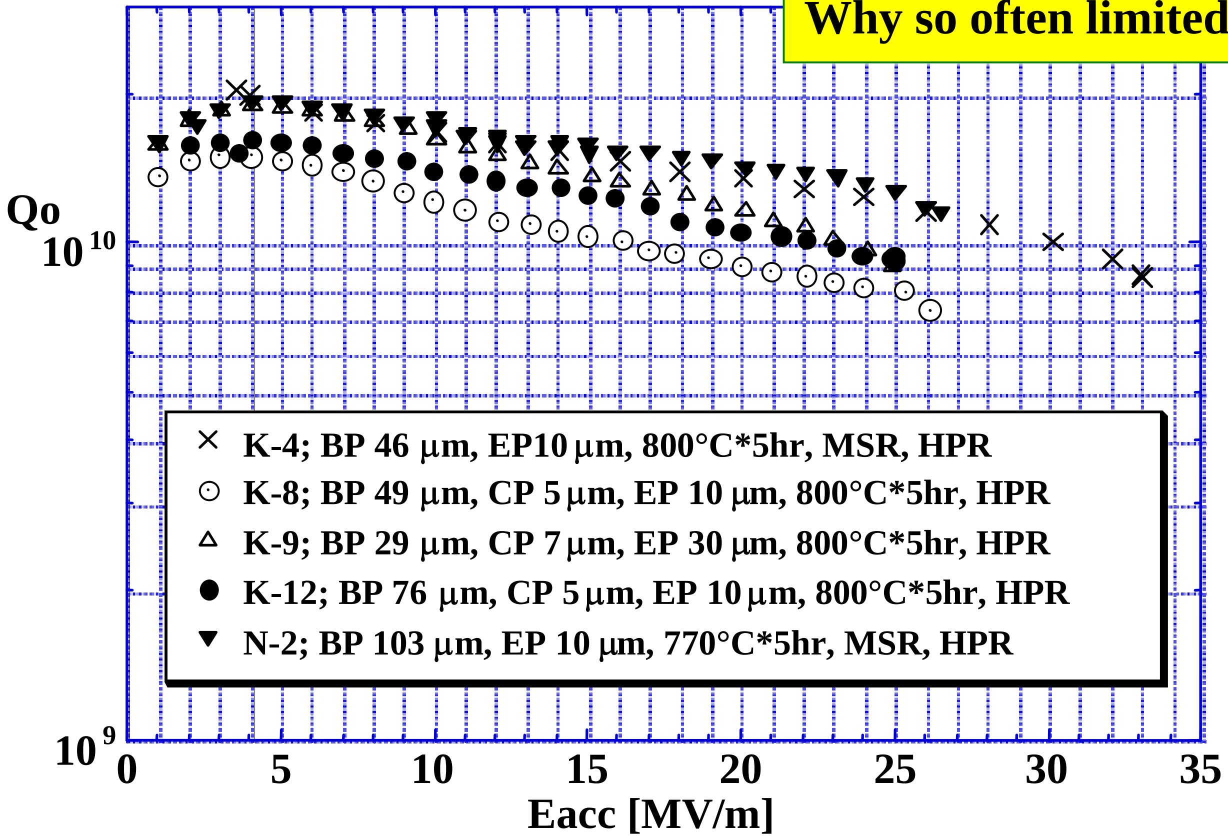
Slow material removal speed 3μm/day

Takes "one week" to remove 30μm.

Dopes hydrogen in the Nb material

Confirmation of the BP effectiveness as pre-treatment prior to EP

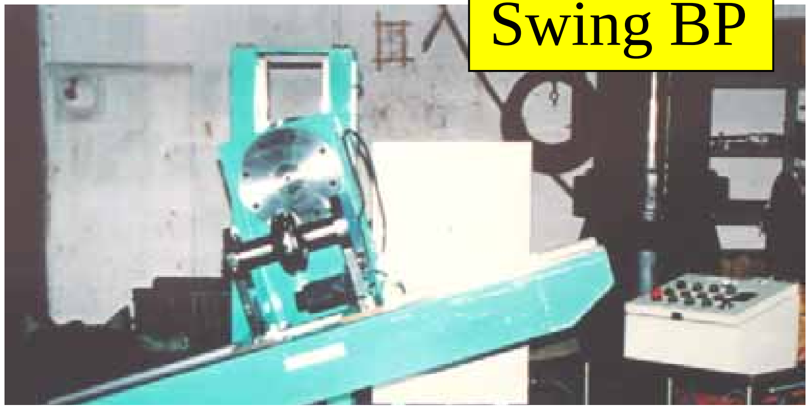
Cavity was annealed after BP.
Why so often limited at 25MV/m?



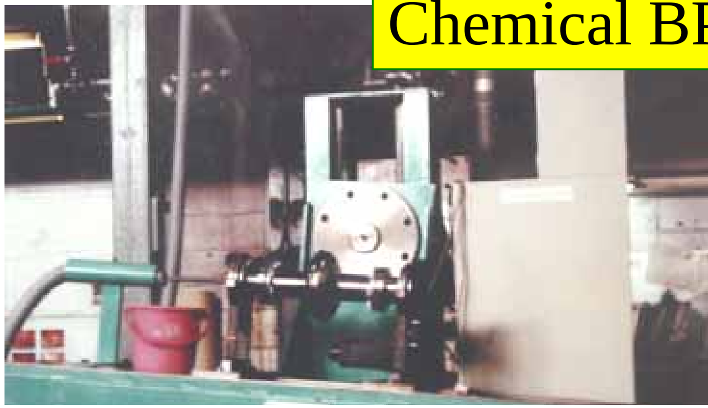
Confirmed 25MV/m by combination BP+Annealing + EP,
25MV/m was enough high gradient in those days (1995).

Some trials to improve the material removal speed of BP

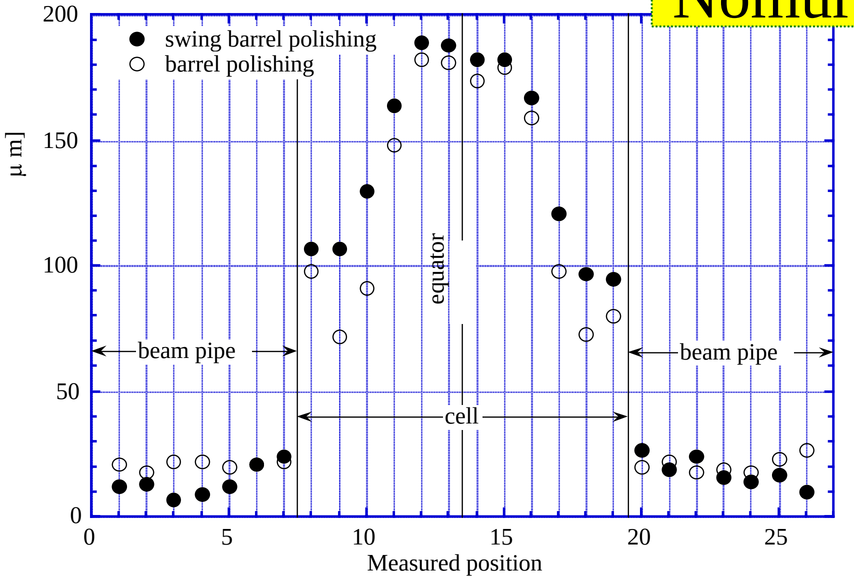
Swing BP

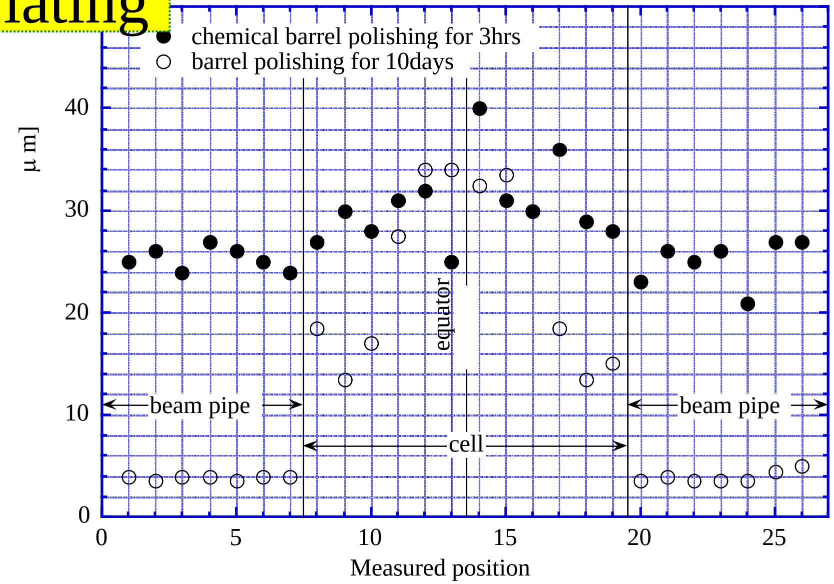


Chemical BP



Nomura Plating





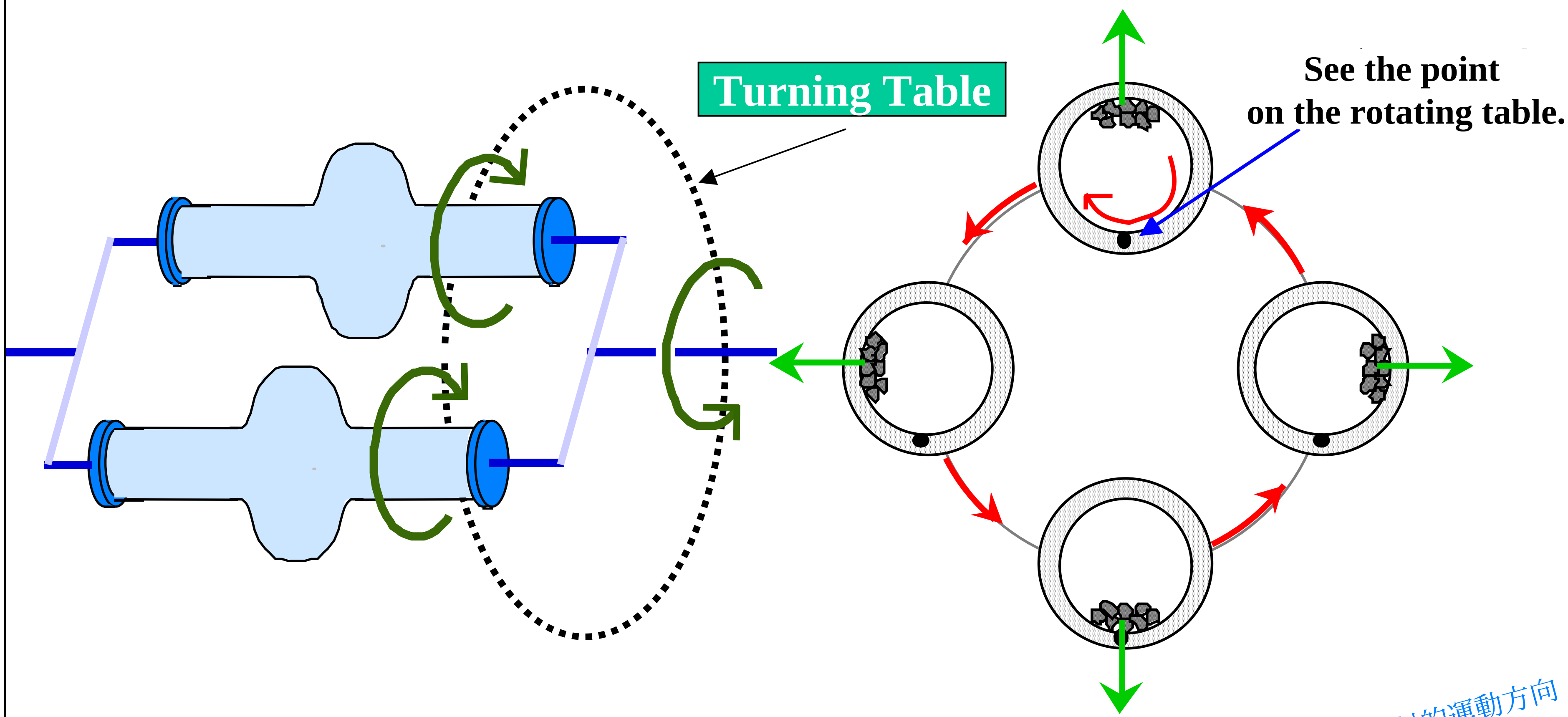
No improvement on the removal speed

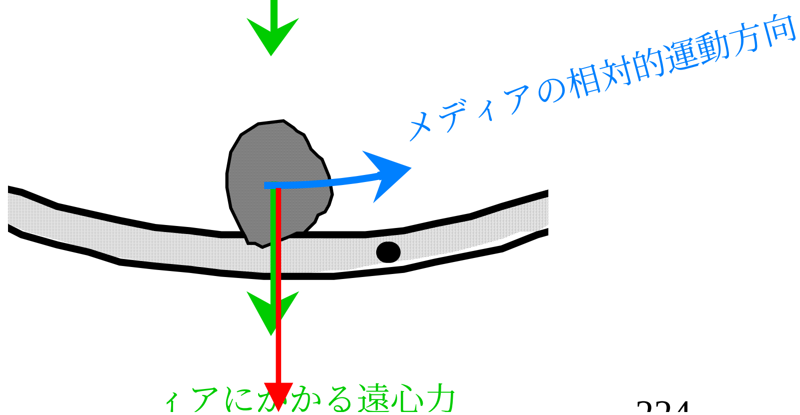
mmer

Not

Large removal speed
but could not good cavity performance

Innovation Centrifugal BP (CBP)





- Rotate cavity on a “rotating table”
- Rotation directions are opposite each other

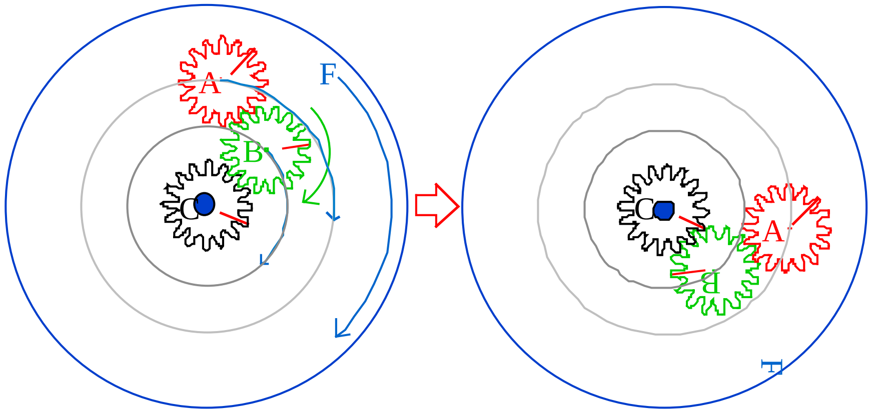
Two centrifugal forces are added on the grinding stones

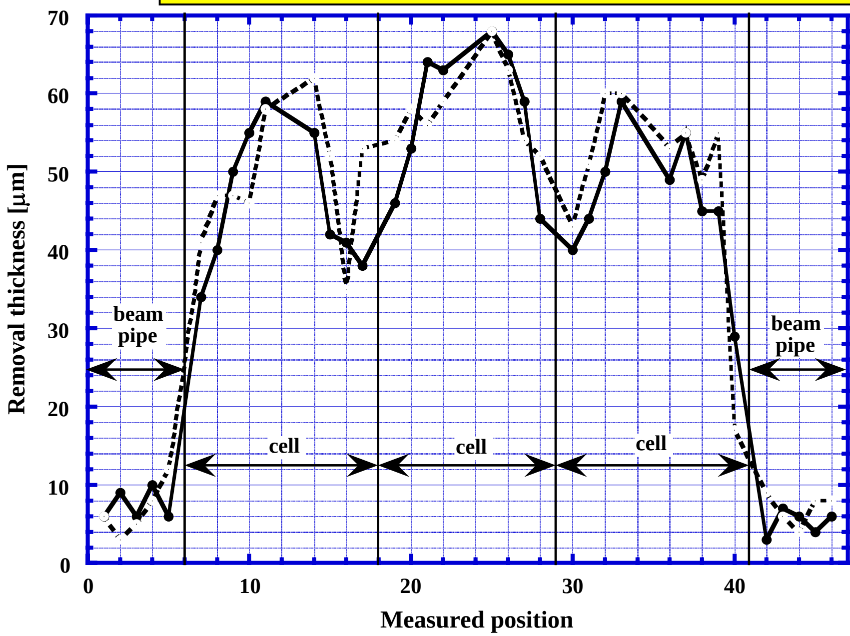
Developed CBP Machine

KEK

Front surface

Three cell CBP (1300MHz)





Rotation mechanism：

Cavity rotating/table rotation

CBP Finishing Surface

Large Grain cavity case

Rough stone (rough) : 5 times (4 hour each)
Green stone (medium) : Once
Brown stone (medium): Once
White stone (for final fine finish) : Once
Totally ~ 200 **μm removed @ equator**

Very fast removal speed!

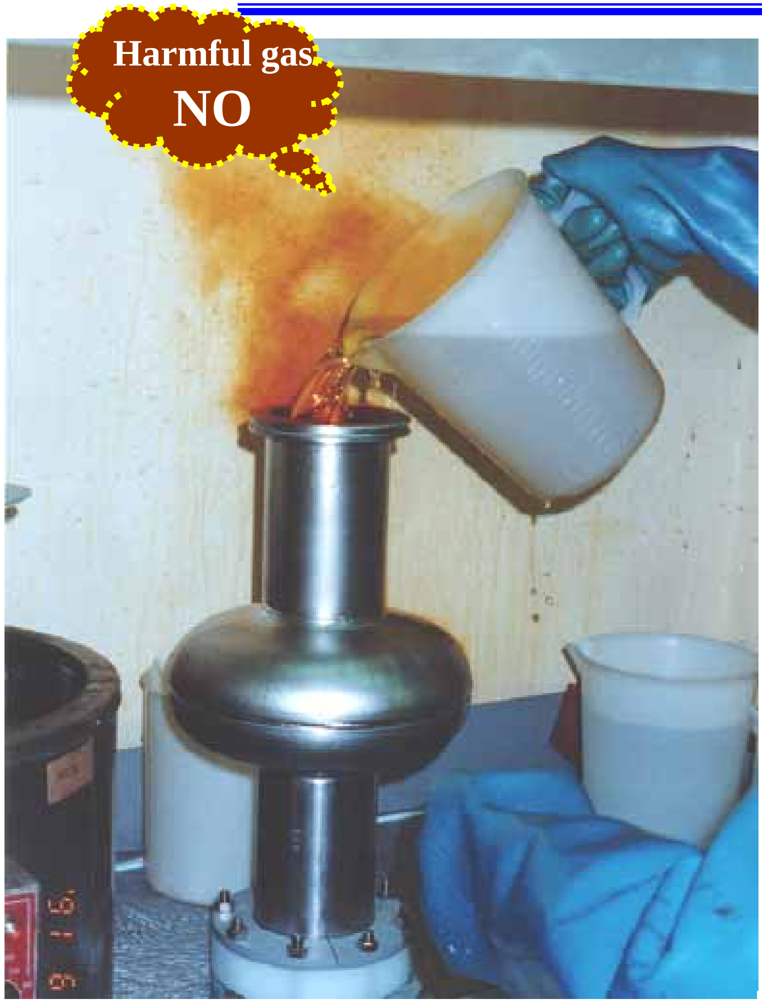
Material removal speed: "one week"(BP) → 4hr (CBP)

Before CBP (equator EBW seam)

After CBP

After light CP(10μm)

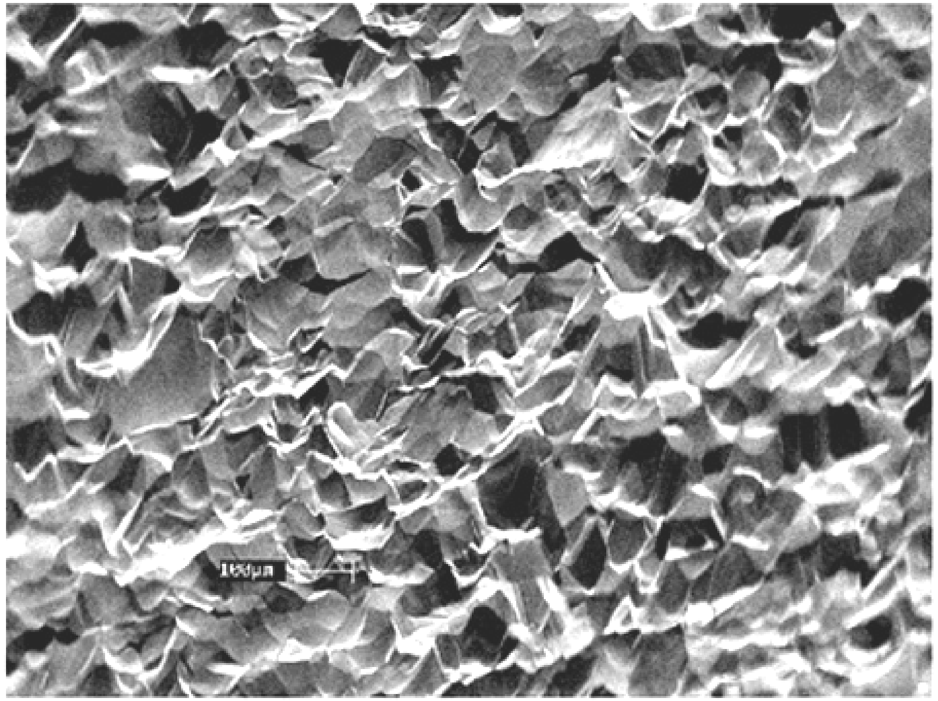
12.2 Buffered Chemical Polishing (BCP)



HF(46%):HNO$_3$(60%):H$_3$PO$_4$
1:1:1 (V/V)

No reaction with Nb, Mild the reaction,
Increase viscosity of the acid.

d



- **Simple and A large material removal speed (10μm/min @ R.T.)**

Problem of BCP: Surface is not so smooth.

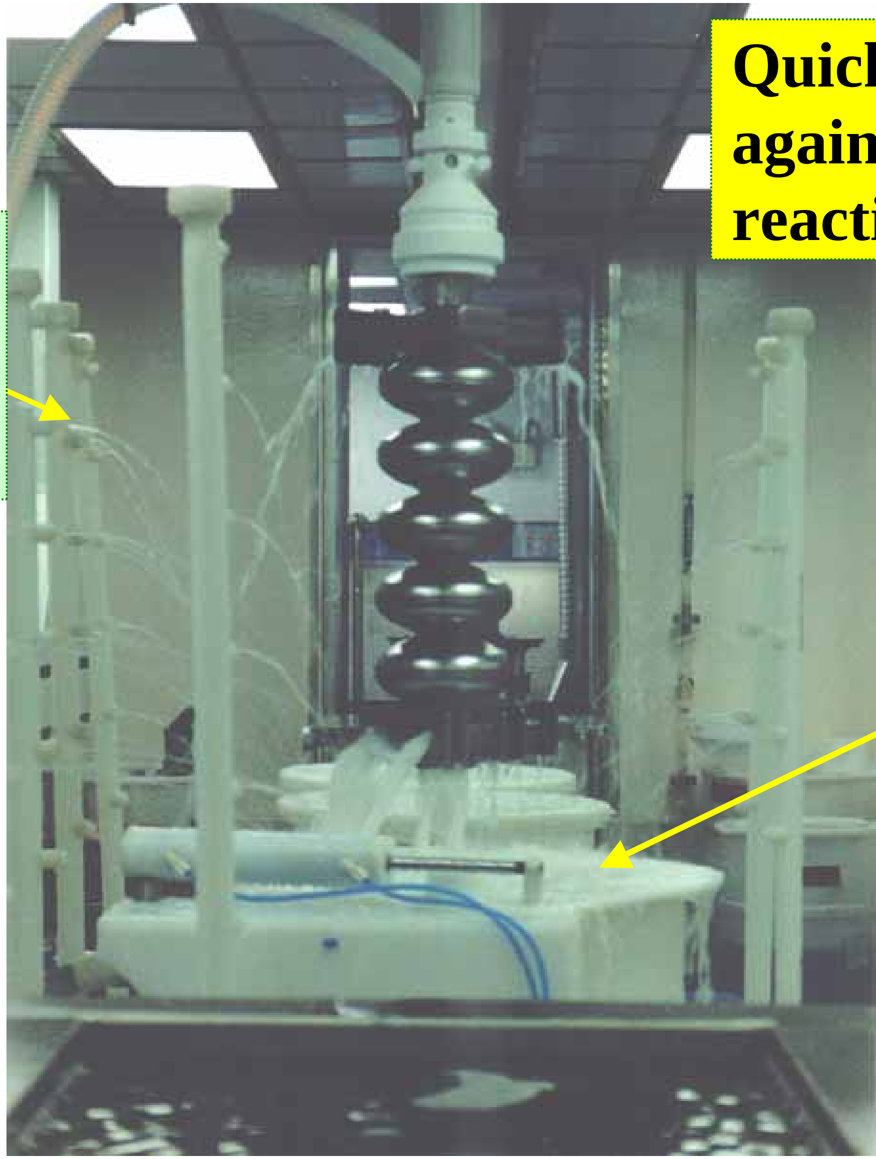
Chemical reaction:

$6Nb+10HNO_3 \rightarrow 3Nb_2O_5+10NO\uparrow+5H_2O$

$Nb_2O_5+10HF \rightarrow 2NbF_5+5H_2O$

$6Nb+10HNO_3+30HF \rightarrow 6NbF_5+10NO\uparrow+20H_2O$

CEBAF CP & Rinsing

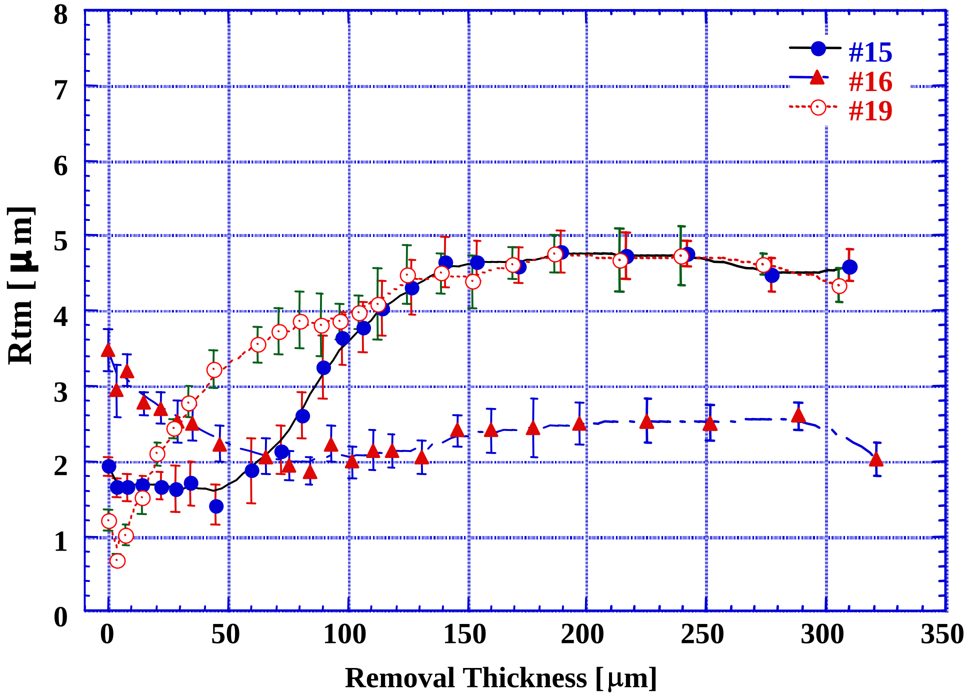


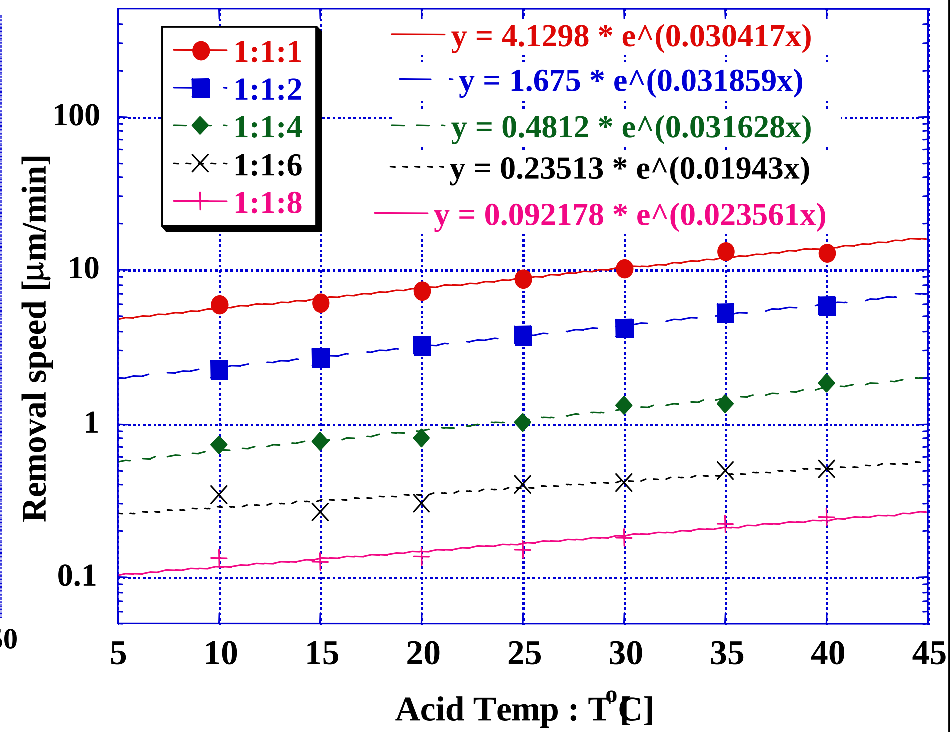
Quick rinsing against the runaway reaction

Shower for Rinsing the outer cavity surface

CP acid tank
Cavity is immersed in the BCP acid.

Characteristics of BCP



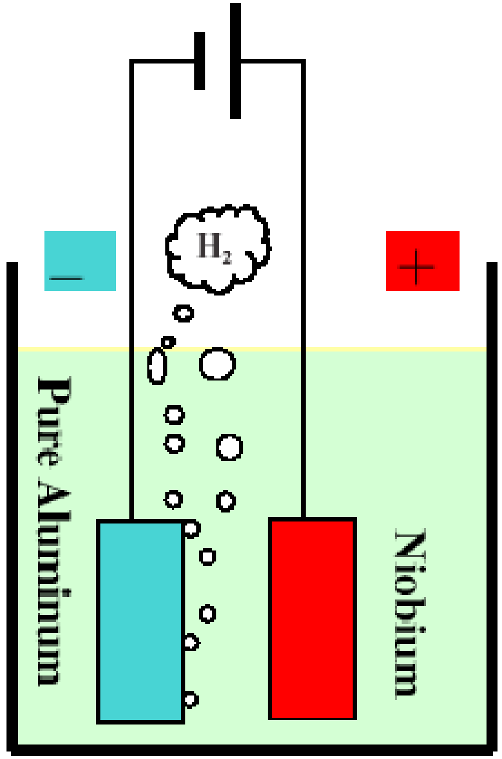


Typical surface roughness = 2 ~ 5 μm after 100μm CP,
Material removal speed ~ 10μm/min at the room temperature with CP acid 1:1:1

CP is faster in material removal speed than EP.

The finished surface roughness strongly depends on the grain size of the Nb material.

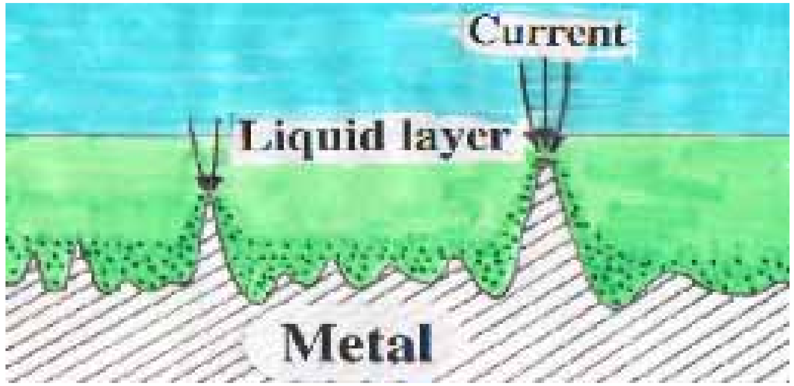
12.3 Electropolishing

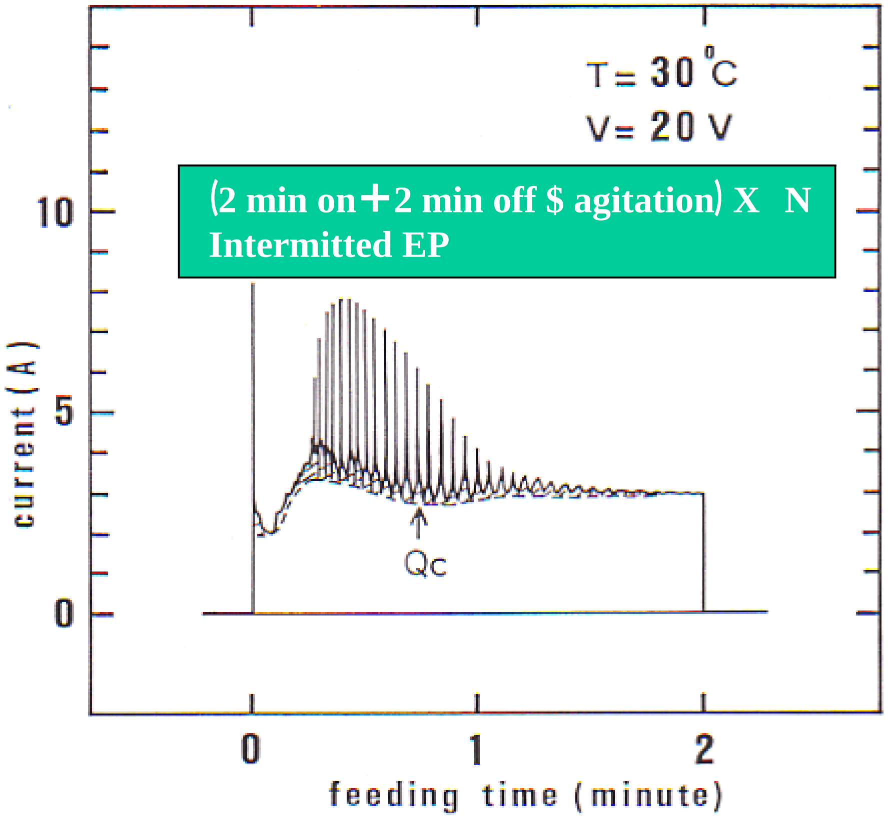


Acid:
H_2SO_4 (>93%): HF(46%)=10:1 V/V

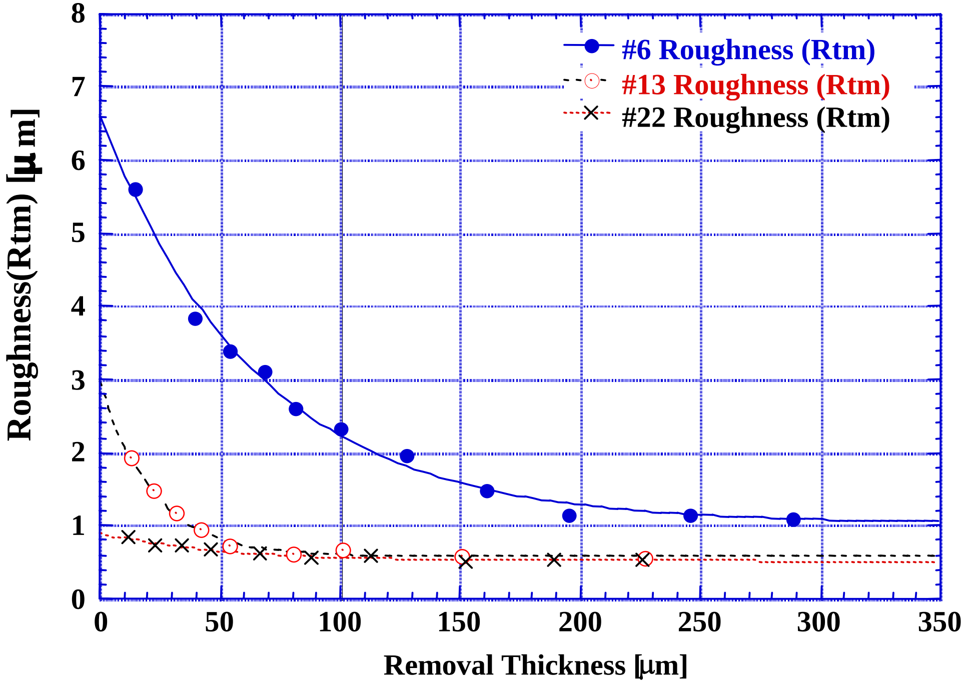
Chemical reaction:
$2Nb + 10HF + 2H_2O \rightarrow 2H_2NbOF_5 + 5H_2\uparrow$

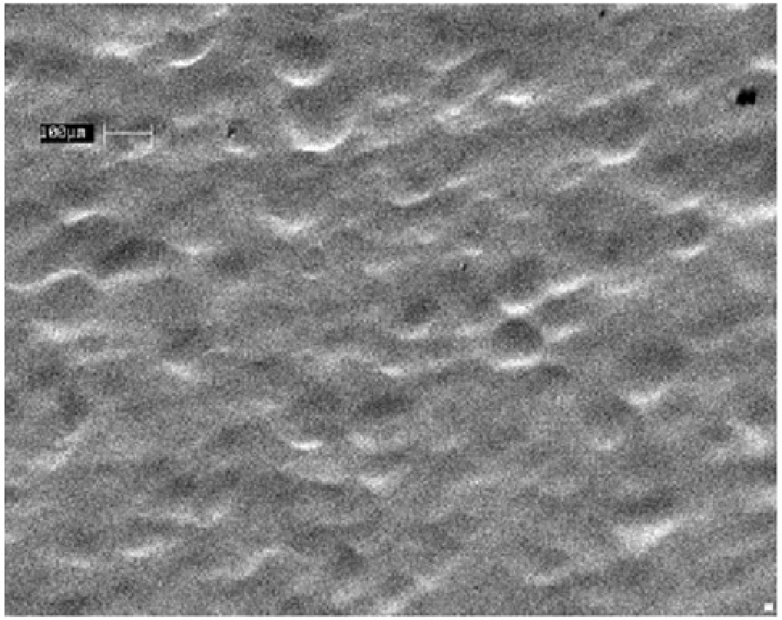
H_2SO_4 does not react with Nb, which make viscosity in the acid.





EP Finished Surface

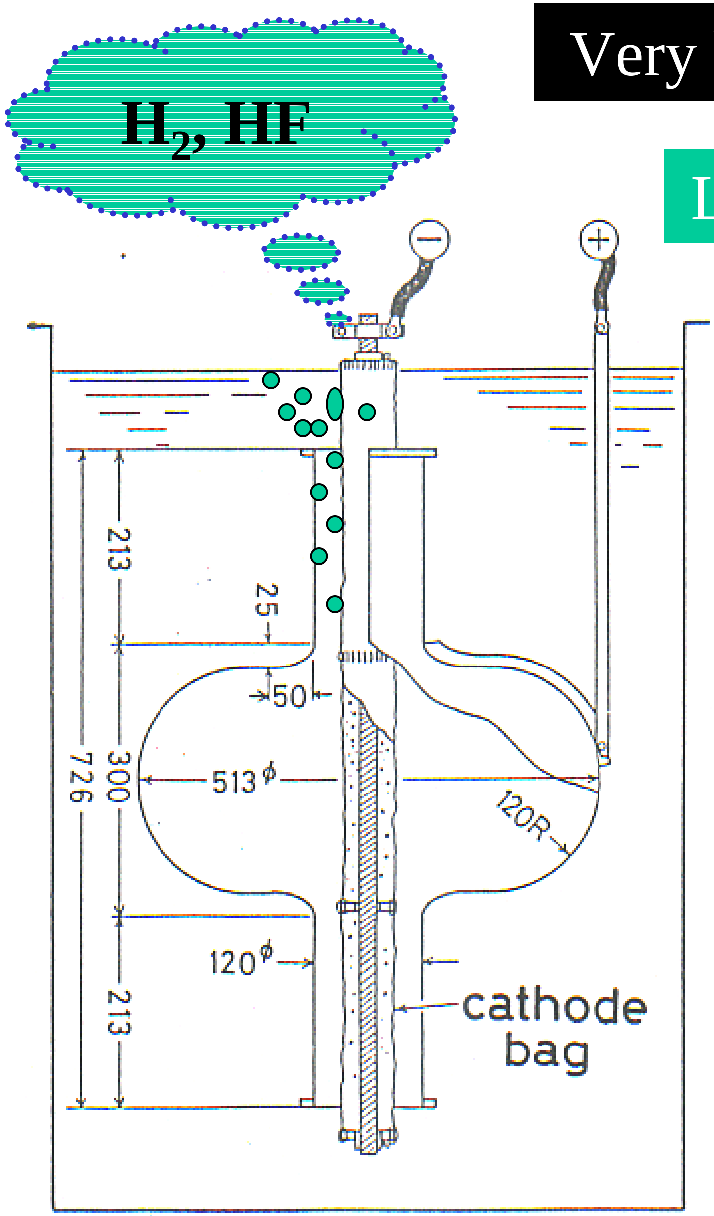




1) The finishing surface roughness depends on that of the initial surface.
2) The finishing roughness becomes smooth exotically with the material removal.
3) Grain boundary is not sharp edge as that of BCP case.
4) Easy control of surface roughness.

KEK Early EP (Vertical EP)

Very hazardous working environment



Light hydrogen Q-disease

Hydrogen Q-disease

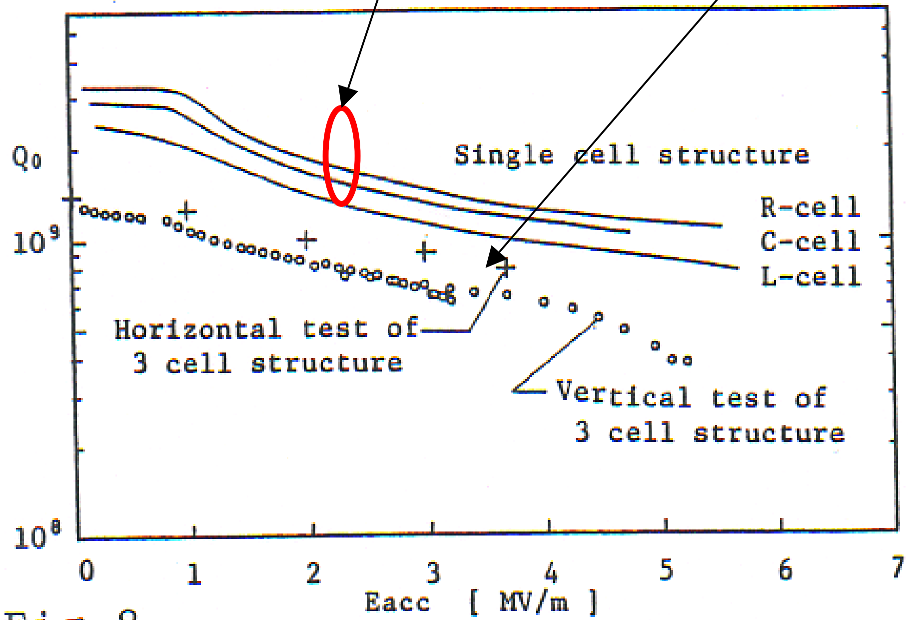
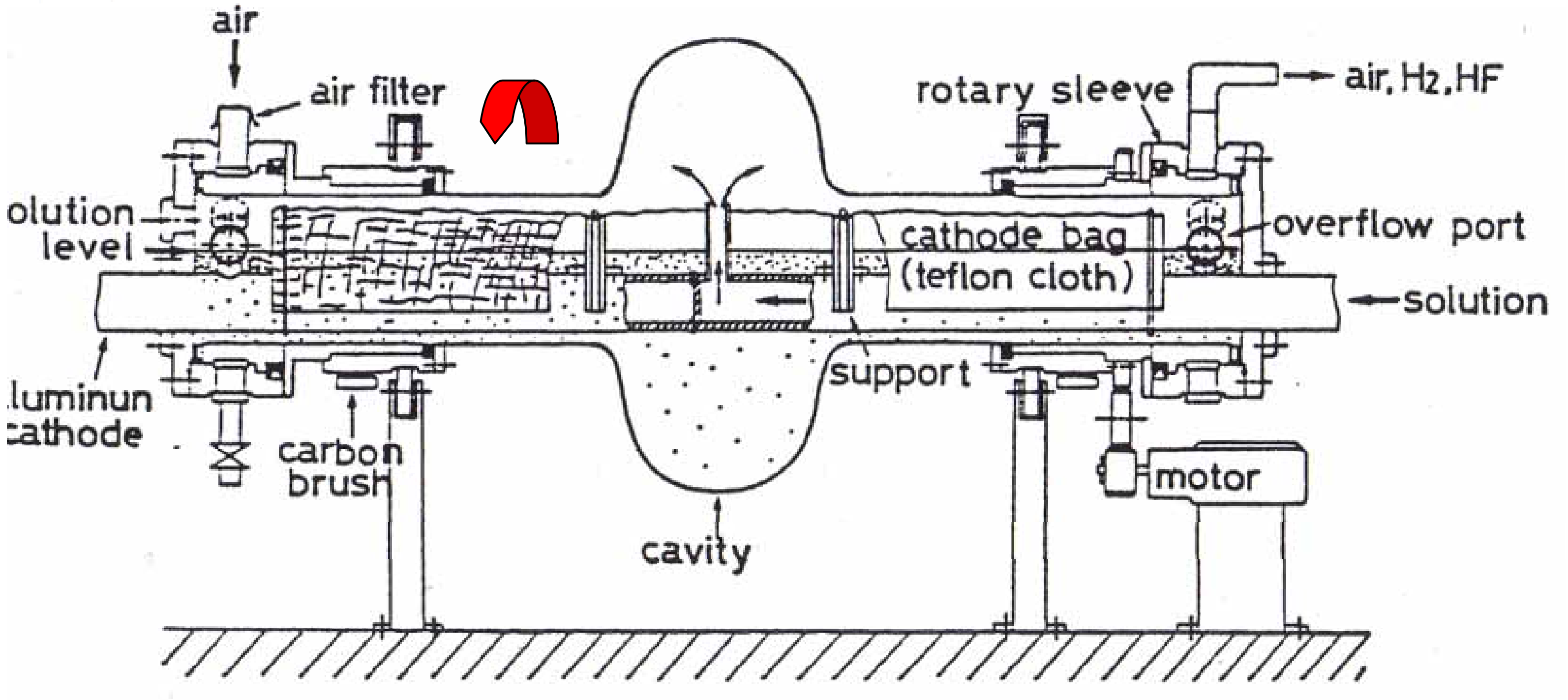


Fig.8
Qo-Eacc curves of a three-cell cavity electropolished using the vertical EP method. R,C,L-cell are single cell cavities before completing the three cell cavity.

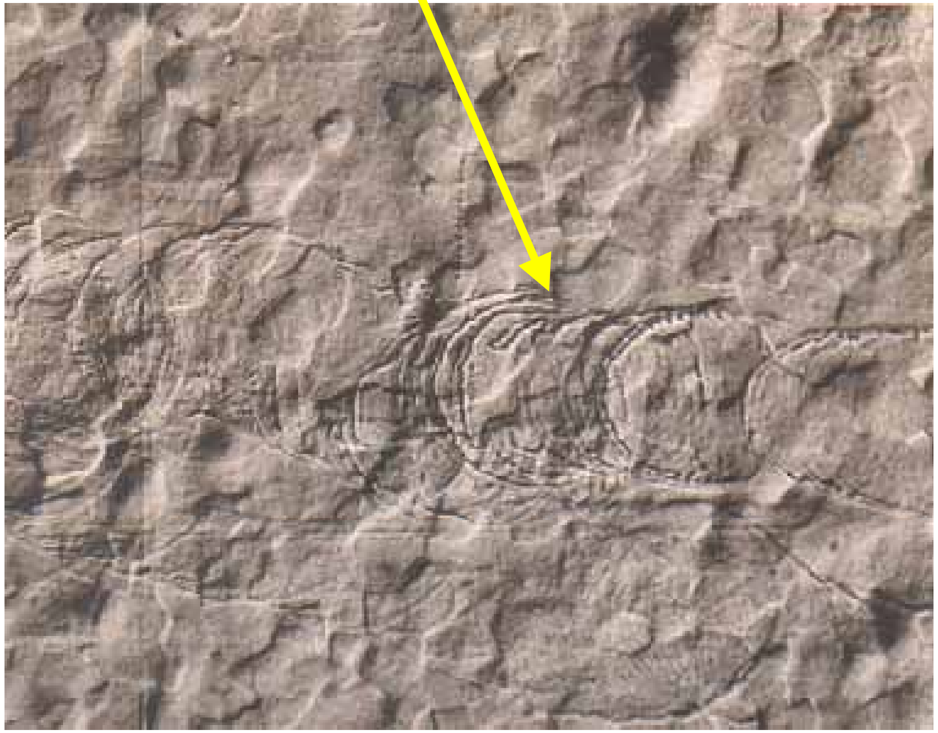
Innovation of the Horizontal EP

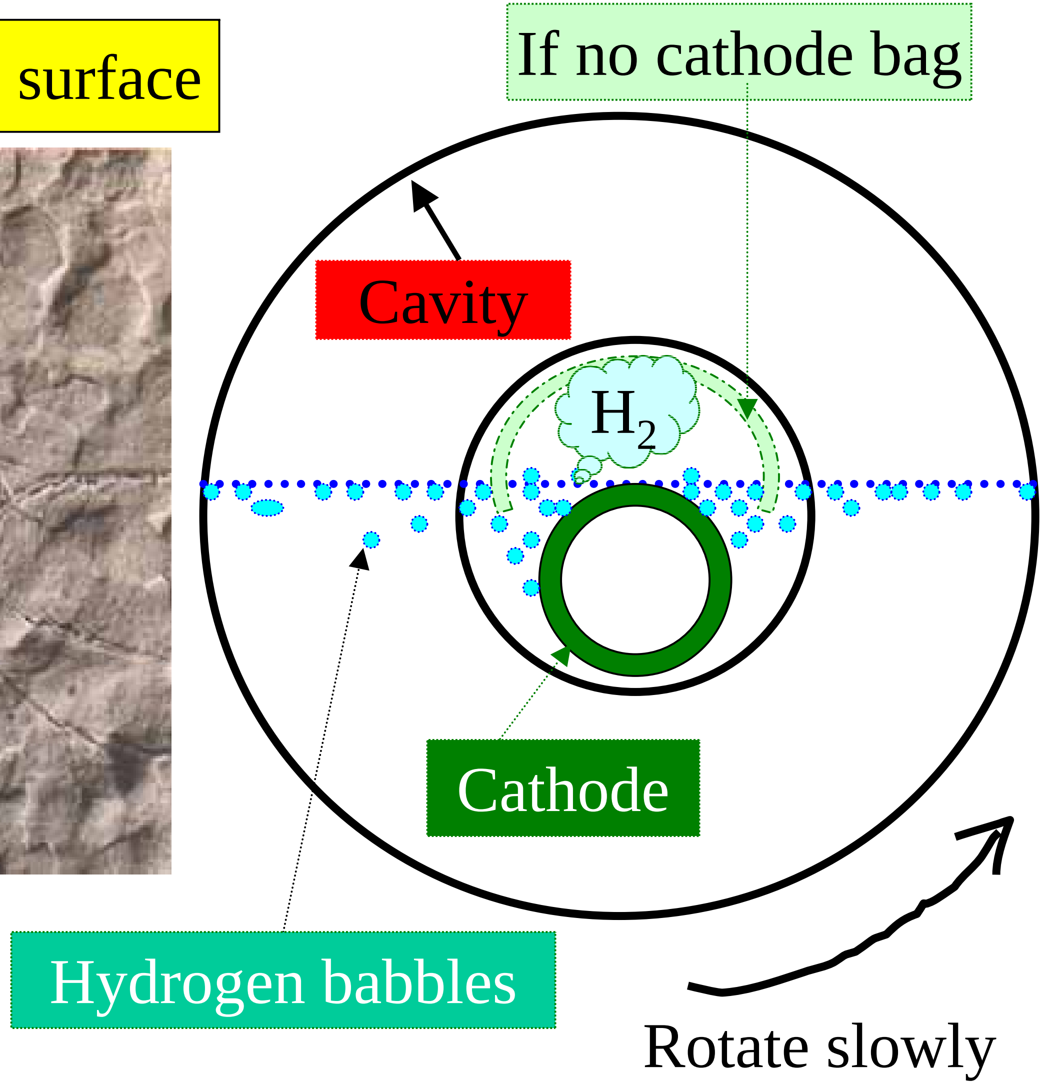


1) Close the EP acid in the EP system to improve the working environment.
2) Easy H_2 gas evacuation even for multi-cell cavity.
3) Uniform material removal in each cell for multi-cell cavity.
4) Simple control.

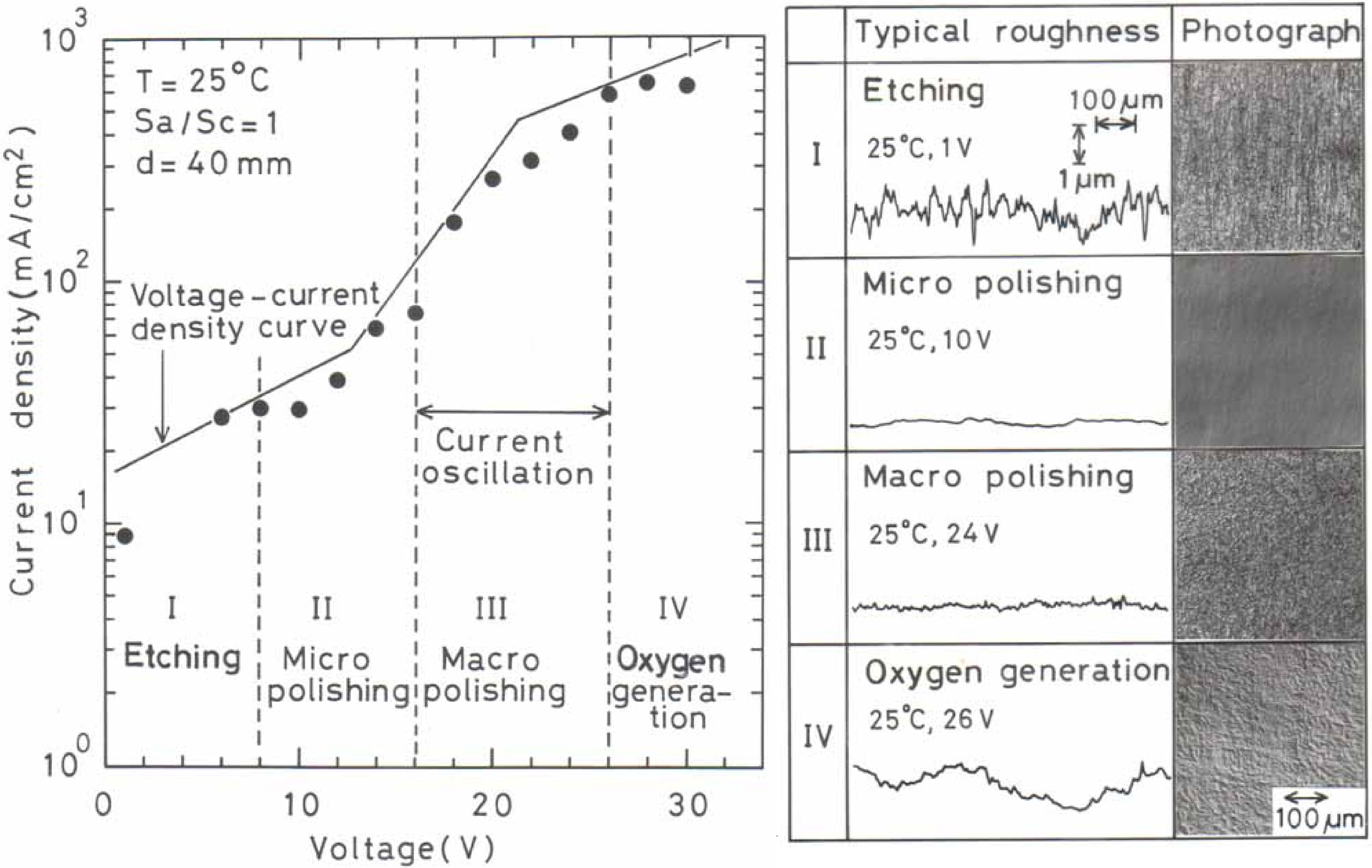
Cathode Bag

Hydrogen babble trace on Nb surface





Electrolishing Characteristics with Nb

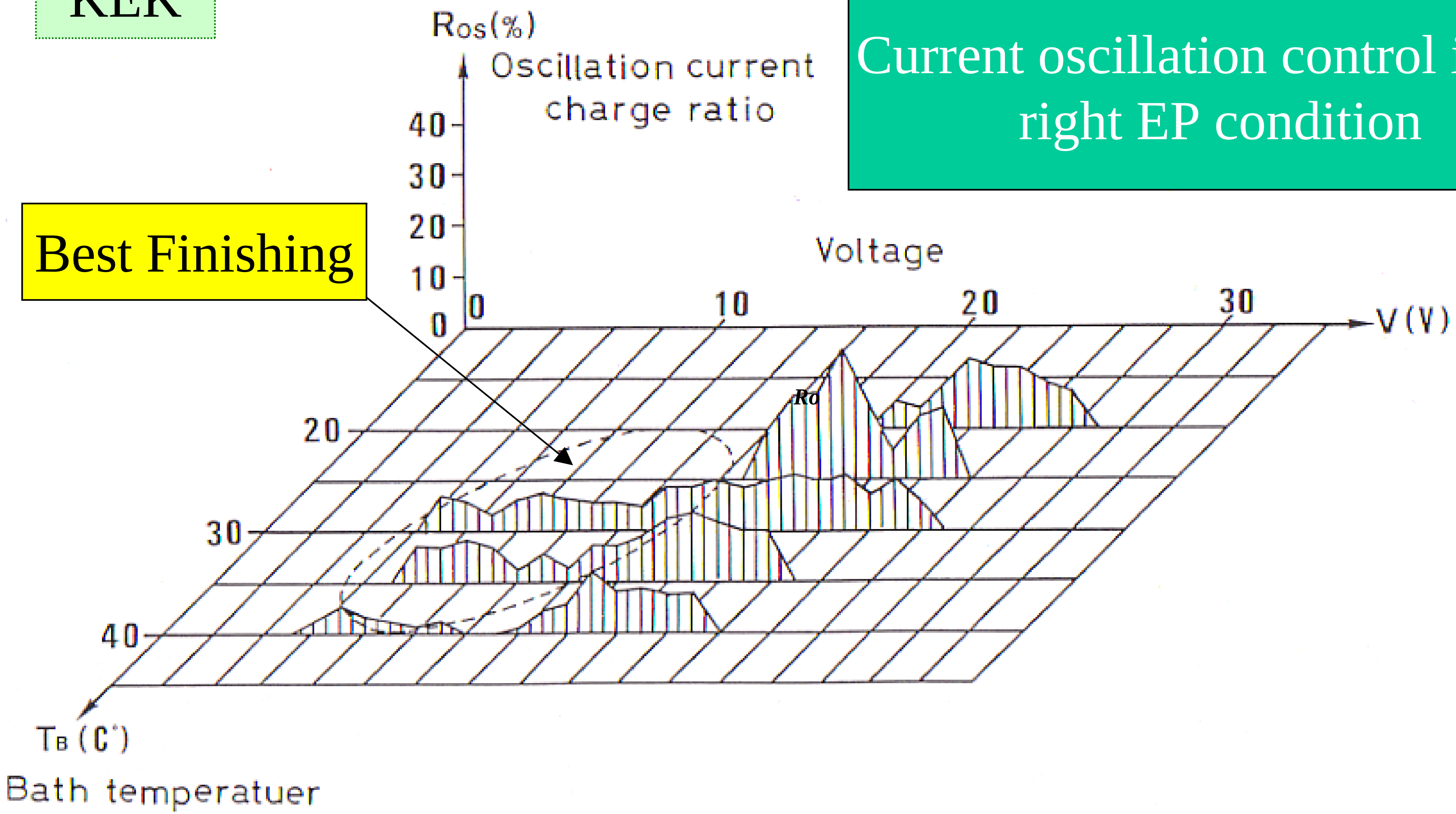


Reconsideration of the Current Oscillation

KEK

Current oscillation control is not right EP condition

Best Finishing



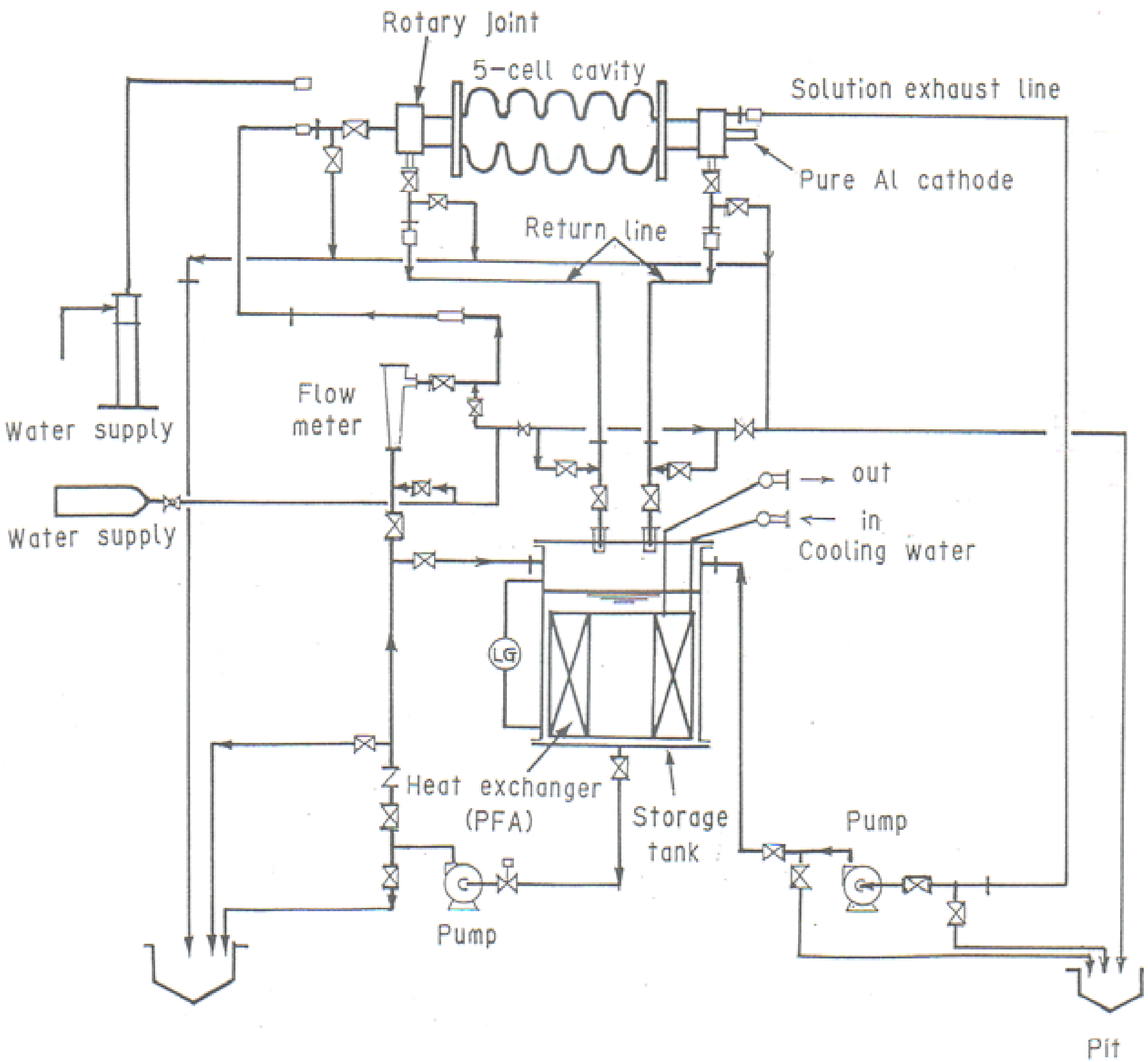
Successfully developed Horizontal EP system

TRISTAN SRF cavity

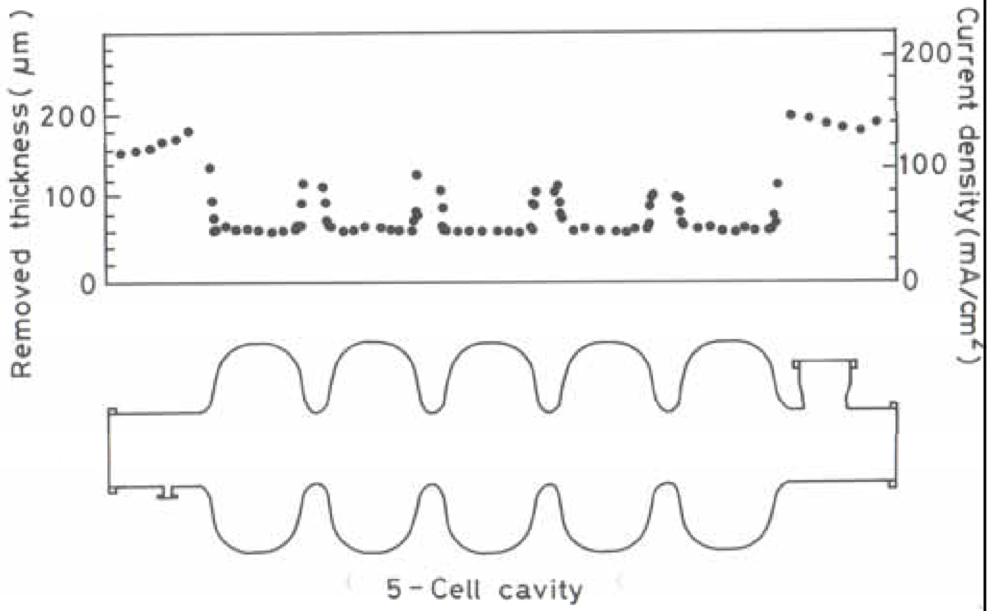
KEK/Nomura Plating

1300MHz single cell cavity

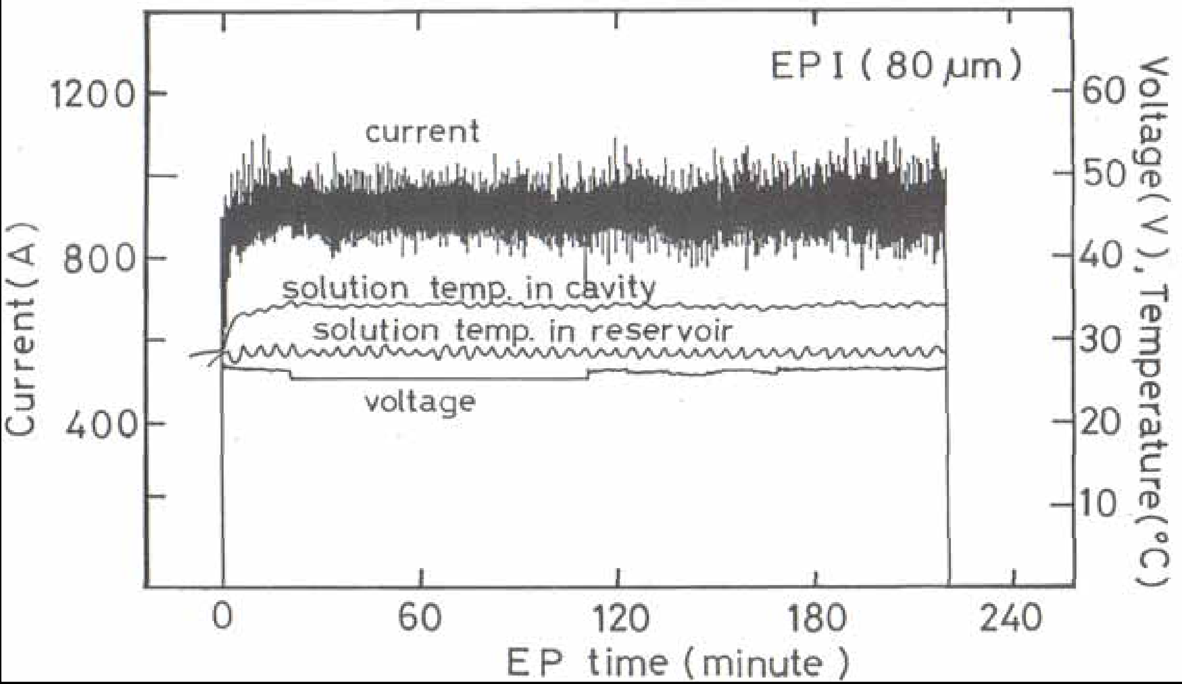
EP System Flow



EP Control



TRISTAN 508MHz 5-cell cavity, Continuously EP



Uniform removal in each cell

re

Cathode extraction after EP：TRISTAN

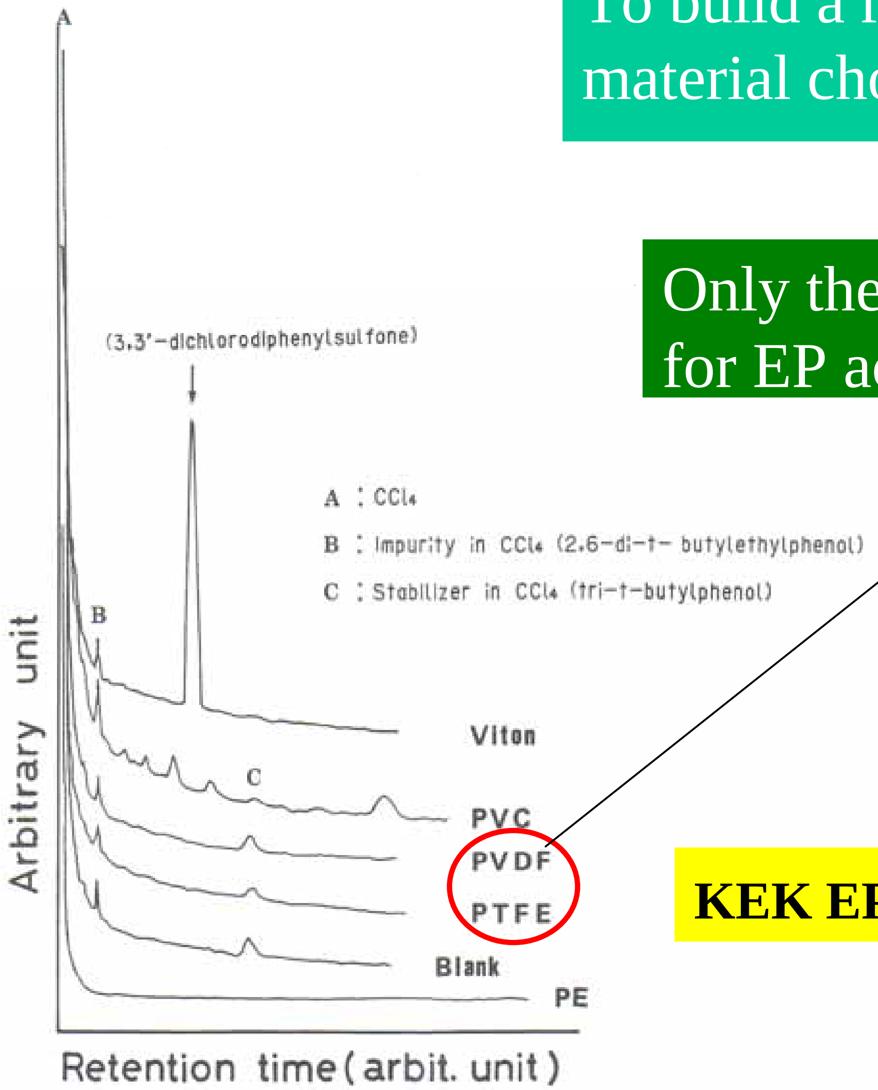
Nomura Plating

Note

Material Choice for the Reliable EP System

To build a reliable EP,
material chose in the EP acid line is curtail.

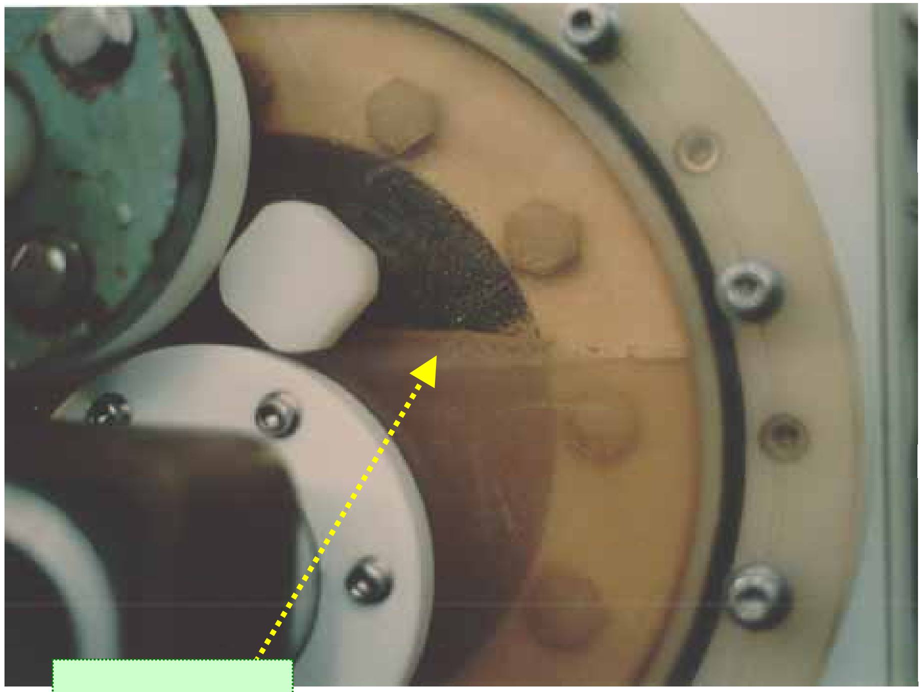
Only the Teflon is the reliable material for EP acid line.



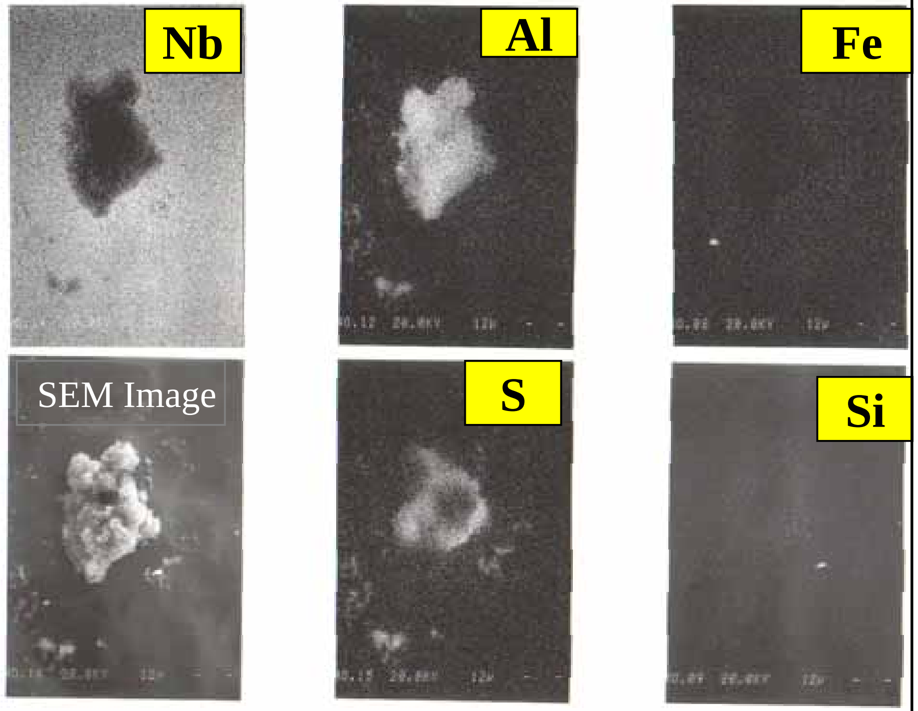
KEK EP system is still working for 20 years.

Dissolved chemicals into EP acid from Plastic Materials

Contamination Problem from Buffing



Sulfur



Al, Si, Fe are originated from buffing (TRISTAN)
S is due to decomposition of H_2SO_4 during EP process.

In the early stage of the TRISTAN mass production, these contamination brought heavy field emission on cavity performance.
The EP system was overhauled once. See next slide.

Sulfur Contamination in EP System

Teflon heat exchanger tube (Brand-new)

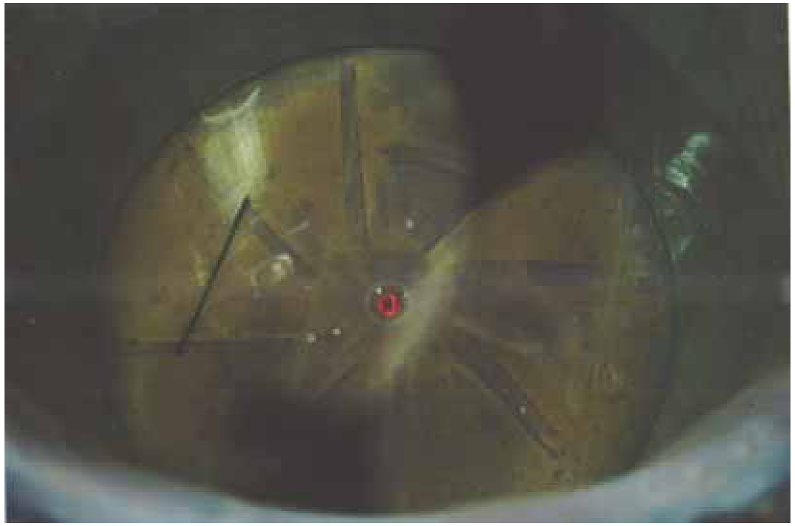
Teflon lining EP acid tank (brand-new)

Reduced H_2SO_4

S precipitated on the contaminants

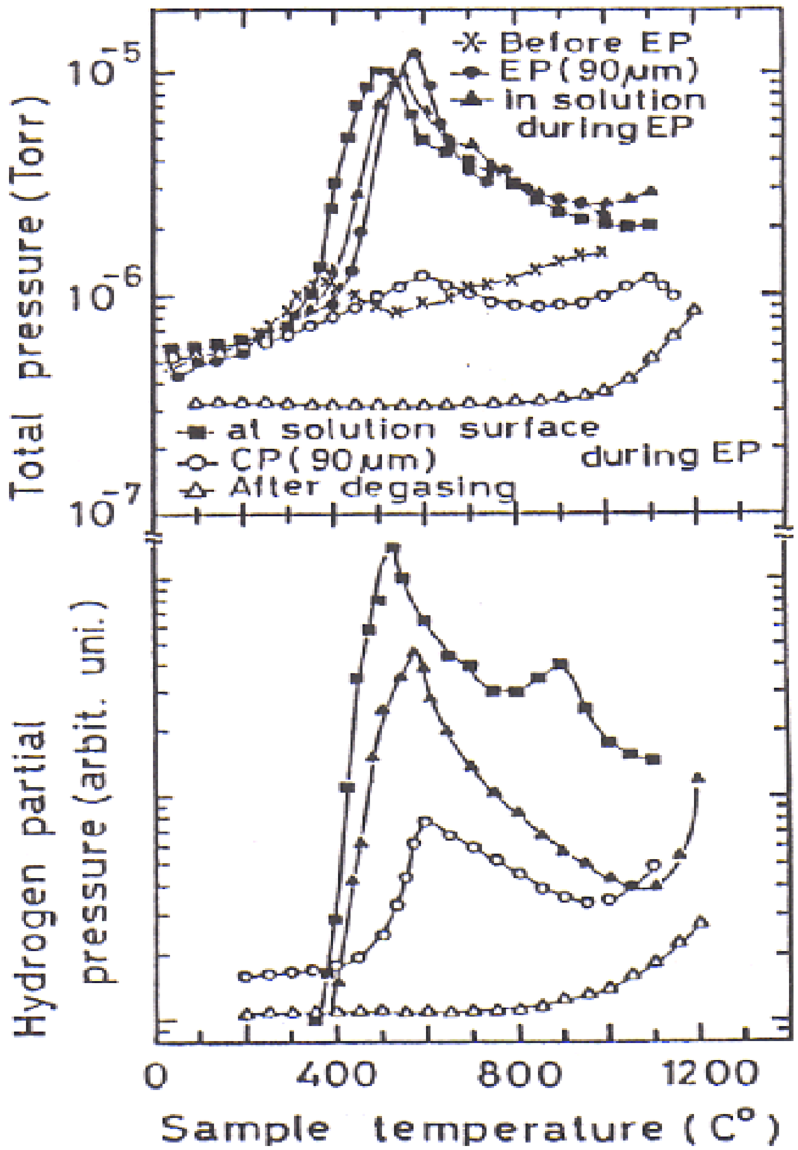
EP system was cleaned up.

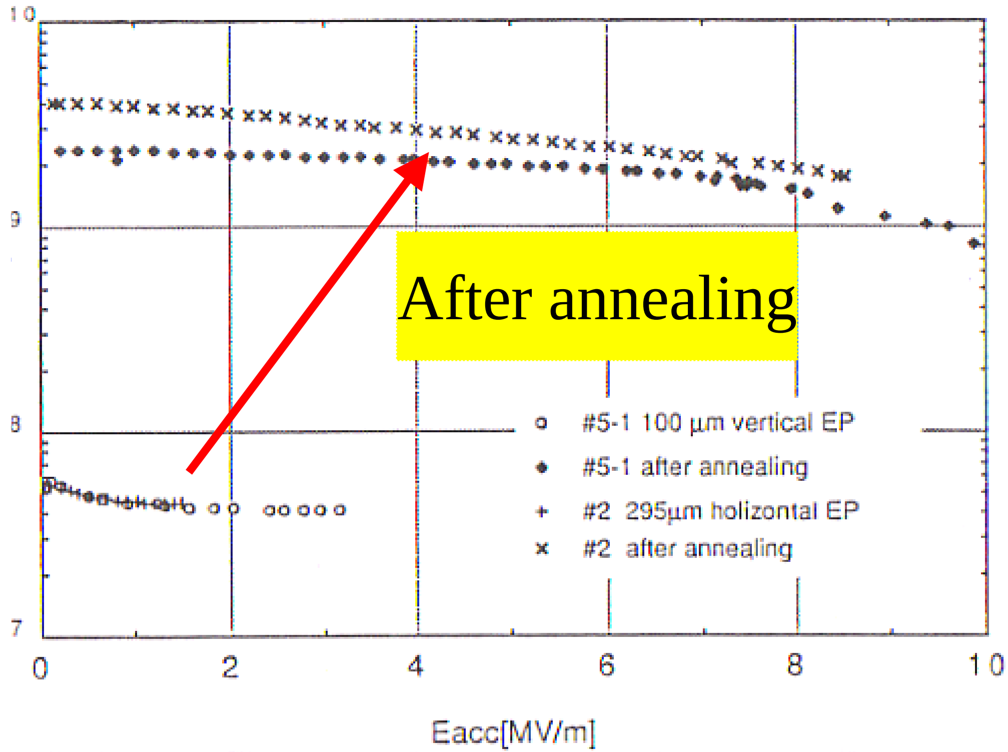
The contaminated heat exchanger



The contaminated EP acid tank

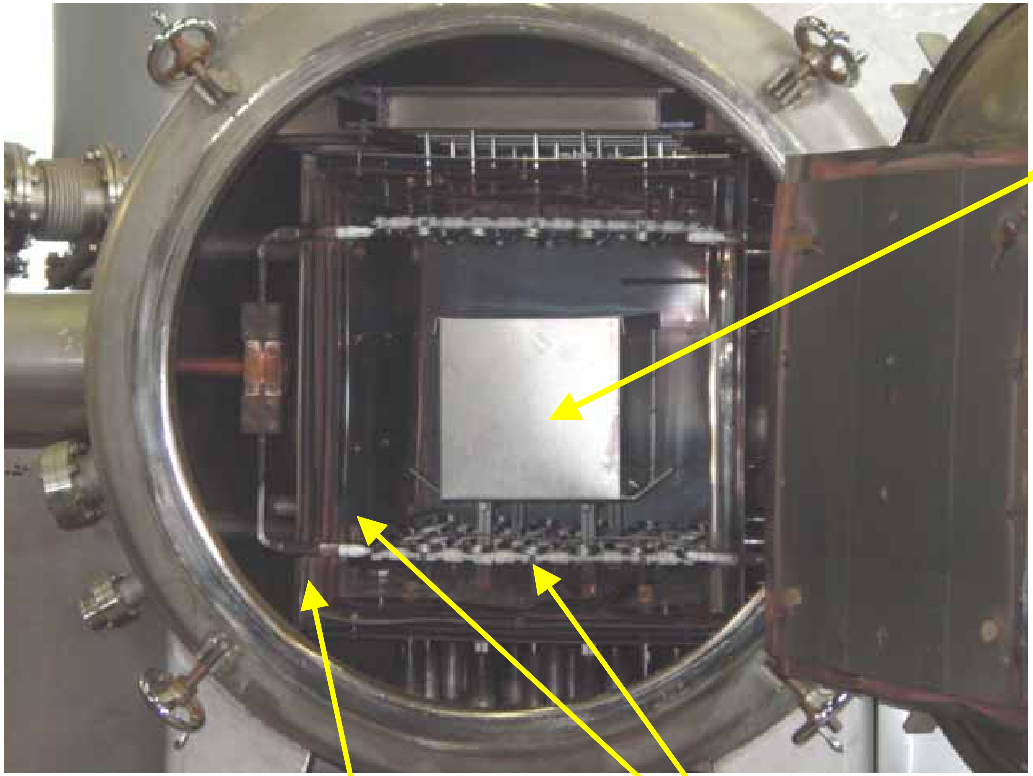
12.4 Annealing





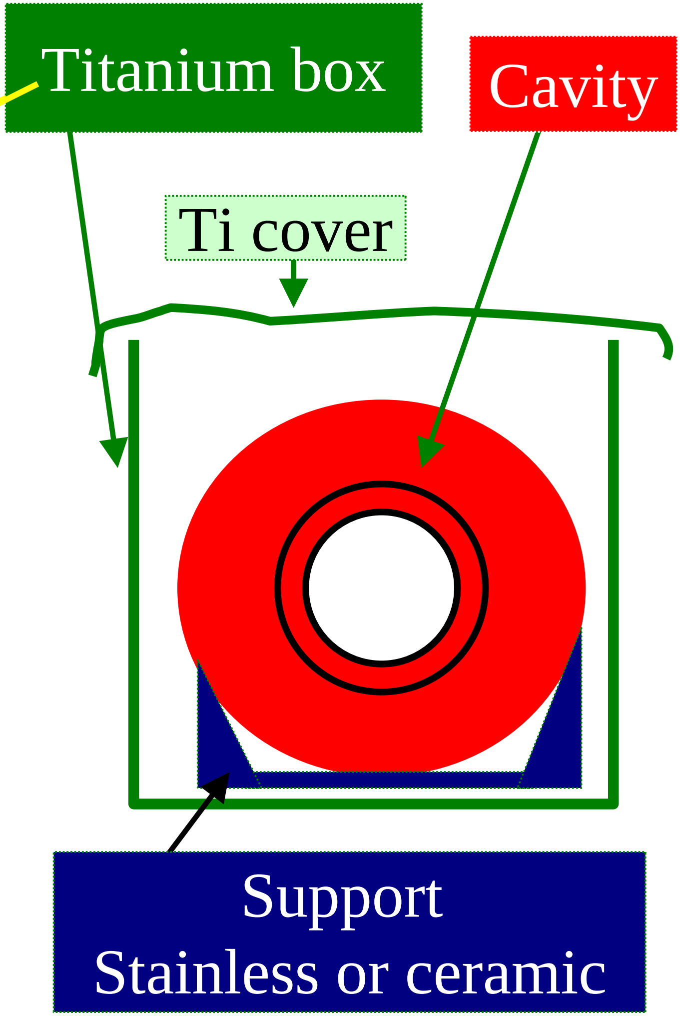
Hydrogen doped in niobium material is easily degassed at 700~800^{O}C.
This temperature dose not soft the niobium material.

Annealing Furnace in KEK Machining Center



KEK Machining Center

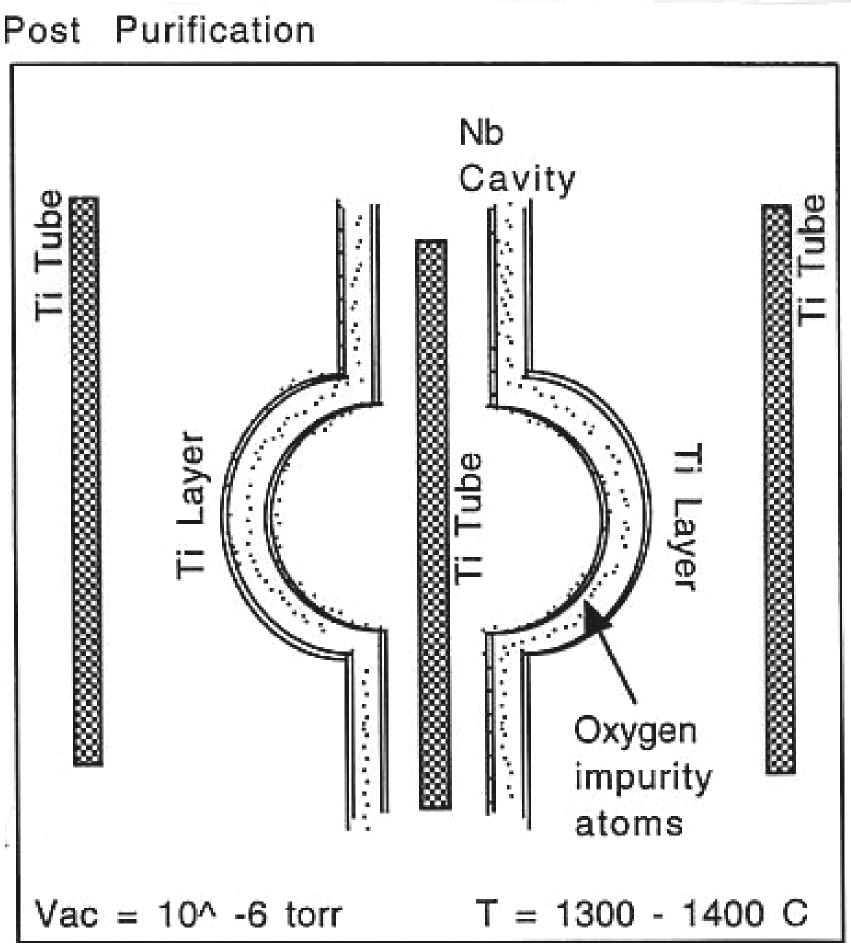
1300^{O}C max, 1X10^{-6} Torr



Large Vacuum furnace for ILC cavity (KEK Machining Center)

Specification：800^{O}C, ~E-6 Torr,
Working zone 500$^{\phi}$x 3000L

Post Purification (Titanization)



1400^{O}C annealing with Ti
@ DESY TTF cavity

Using Titanium getter effect, Oxygen in Nb material can be reduced.

RRR cab be increased by this process.

Problem: Softening of the material

Diffusion Coefficients

$$O: 0.20\exp\left(-\frac{1.354 \cdot 10^{4}}{T}\right)\ cm^{2}/sec$$

$$C: 0.043\exp\left(-\frac{1.670 \cdot 10^{4}}{T}\right)\ cm^{2}/sec$$

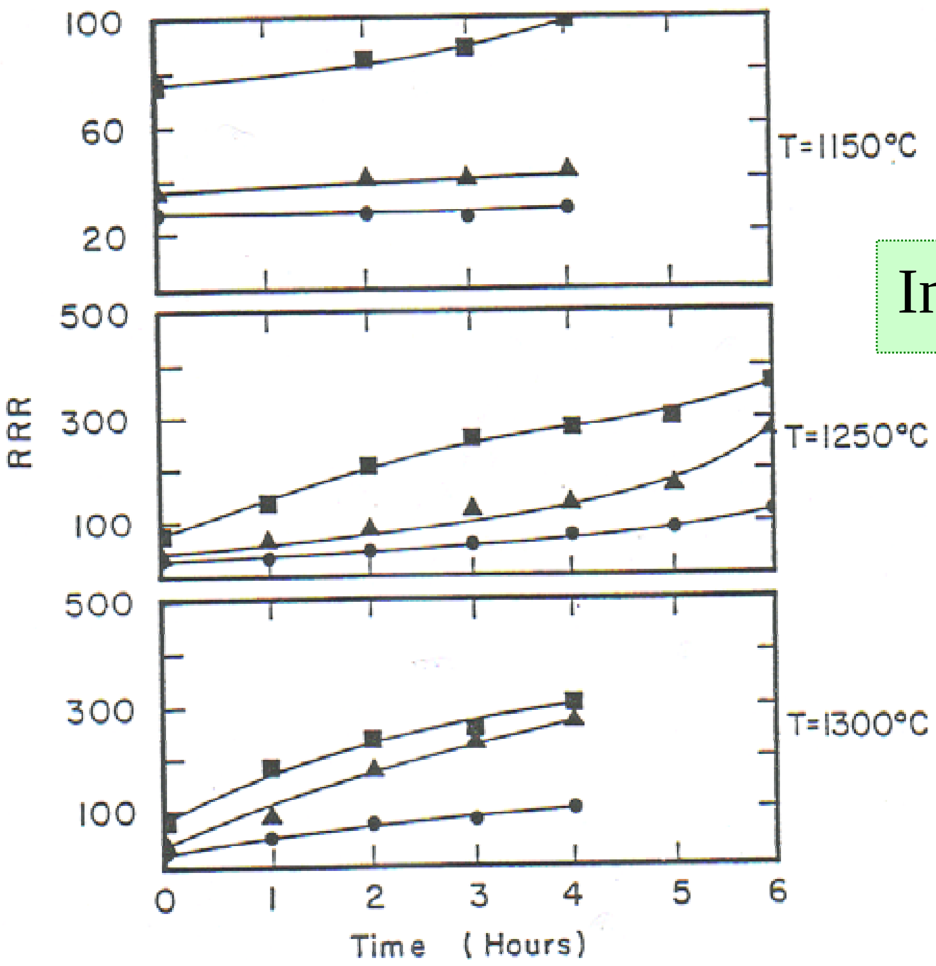
$$N: 0.0085\exp\left(-\frac{1.758 \cdot 10^{4}}{T}\right)\ cm^{2}/sec$$

T (^{o}C)	O (mm / hr)	N (mm / hr)	C (mm / hr)
900	0.4	0.005	0.005
1000	0.6	0.008	0.008
1100	0.9	0.13	0.13
1200	1.2	0.19	0.19
1400	2.0	0.38	0.38

RRR Improvement by Post Purification

P.Kneisel

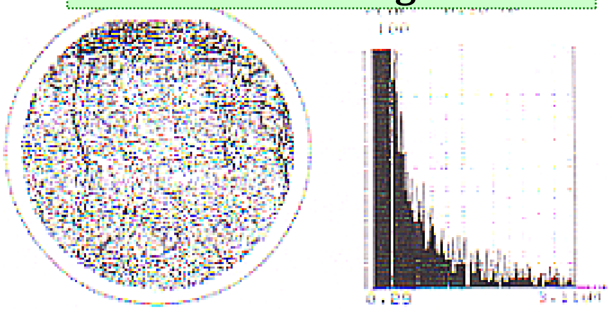
Improved by a factor 3



Dependence of the RRR-value on reaction temperature and reaction time for niobium samples of different purity exposed to titanium vapor (● 1/8" thick, RRR=27; ▲ 1/8" thick, RRR=37; ■ 1/16" thick, RRR=77)

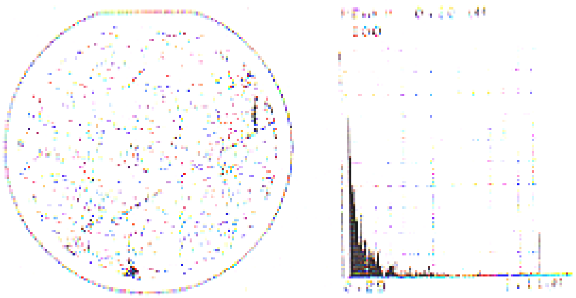
12.5 High Pressure Water Rinsing

TRISTAN rinsing method

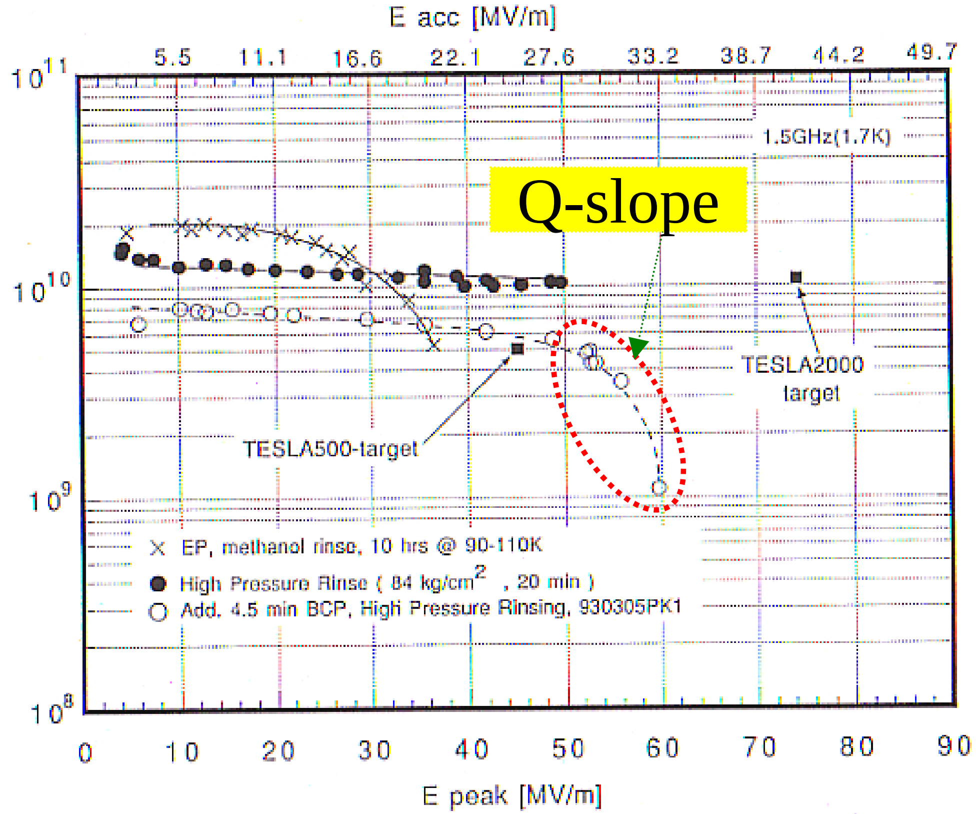


Particle size	Count
0.30-1.20 µm	5825
1.20-2.01 µm	405
2.01-3.00 µm	2720
> 3.00 µm	1069
Total	10019

HPR rinsing

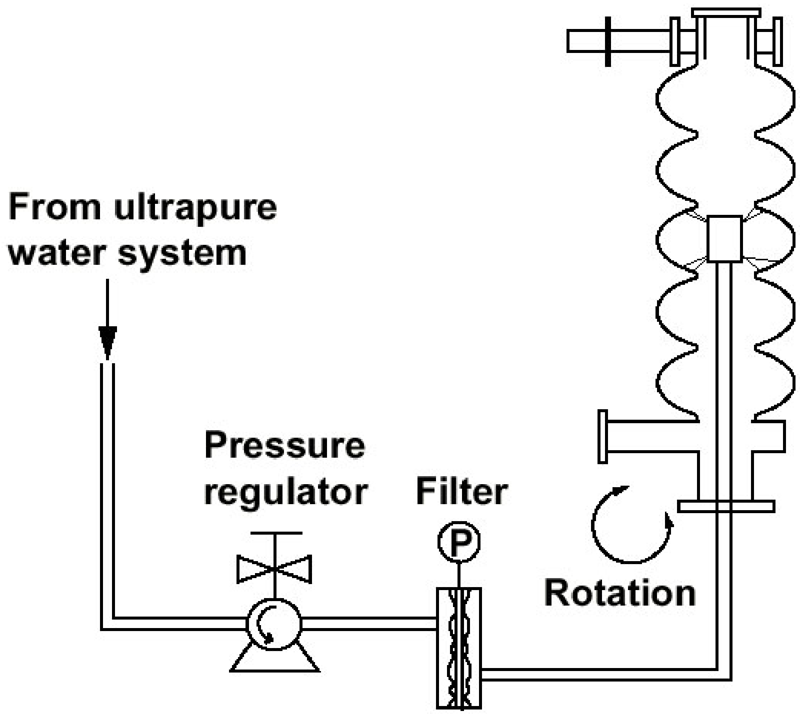


Particle size	Count
0.30-1.20 µm	646
1.20-2.01 µm	52
2.01-3.00 µm	282
> 3.00 µm	37
Total	1017



HPR is a very powerful tool to remove the particle contamination on niobium cavities.

HPR System

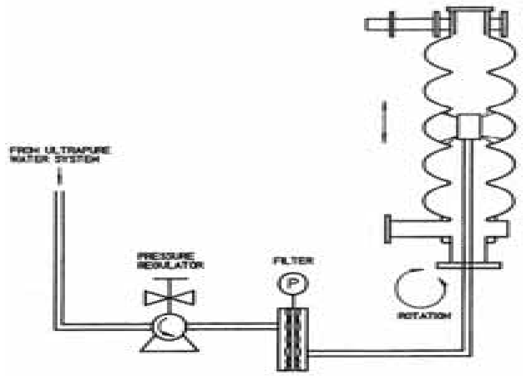


Nomura Plating

HPR Systems at other labs

DESY-System

Jlab HPR Cabinet

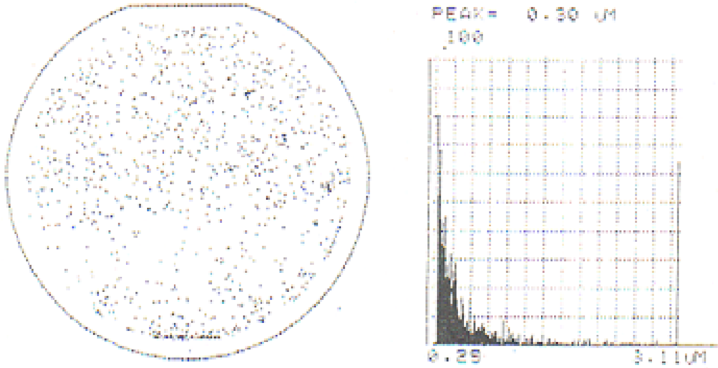


12.6 Megasonic Rinsing

An attractive rinsing method if compact oscillator can be product.

Megasonic Rinsing Effect

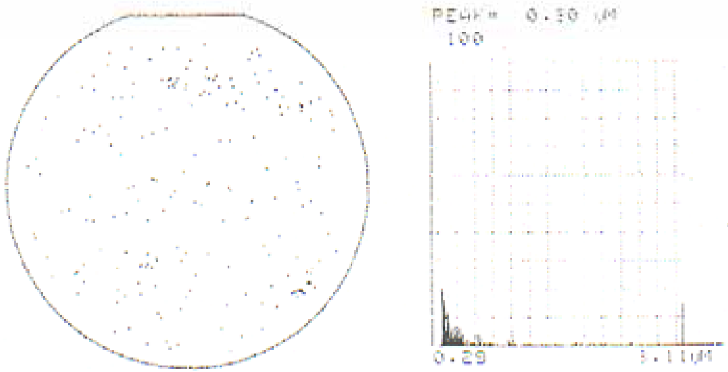
HPR rinsing



Particle size	Count
0.30-1.20 µm	673
1.20-2.01 µm	50
2.01-3.00 µm	305
> 3.00 µm	90
Total	1118

Fig. 11 Residual particles on a wafer surface after HPR; rinsing condition 19 in Table 1

Mega-sonic rinsing



Particle size	Count
0.30-1.20 µm	158
1.20-2.01 µm	5
2.01-3.00 µm	43
> 3.00 µm	18
Total	224

Fig. 12 Residual particles on a wafer surface after megasonic rinsing; rinsing condition 16 in Table 1.

Amount of particle Contamination is reduced to 1/5 of HPR

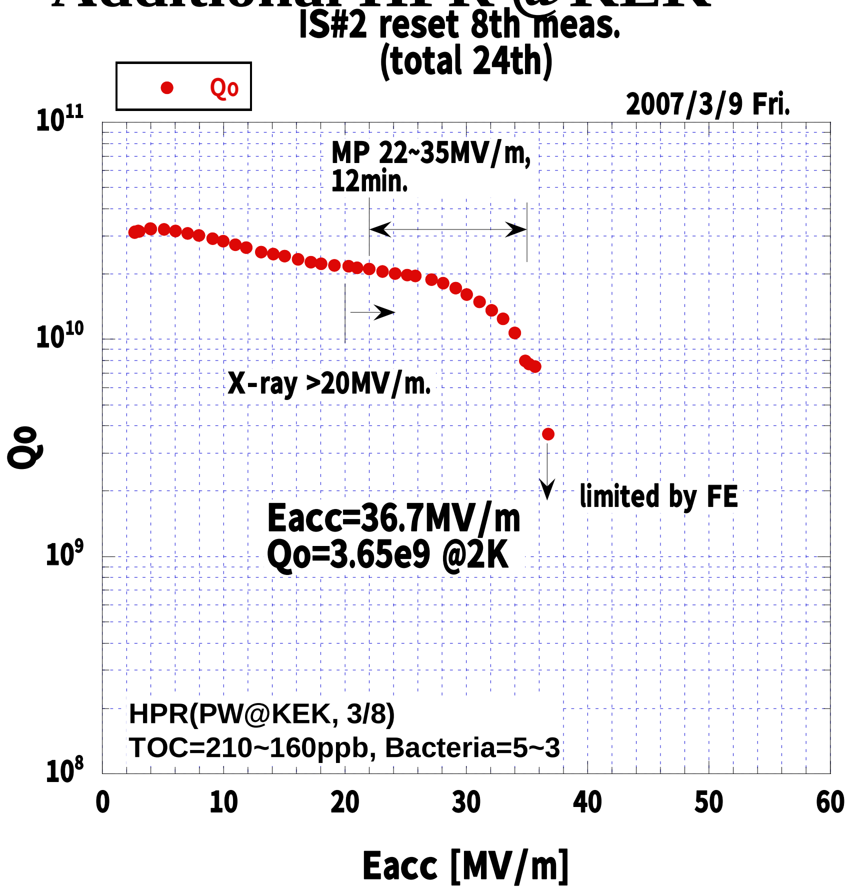
Megasonic rinsing can be an alternative of HPR ?

KEK will start investigation of Megasonic.

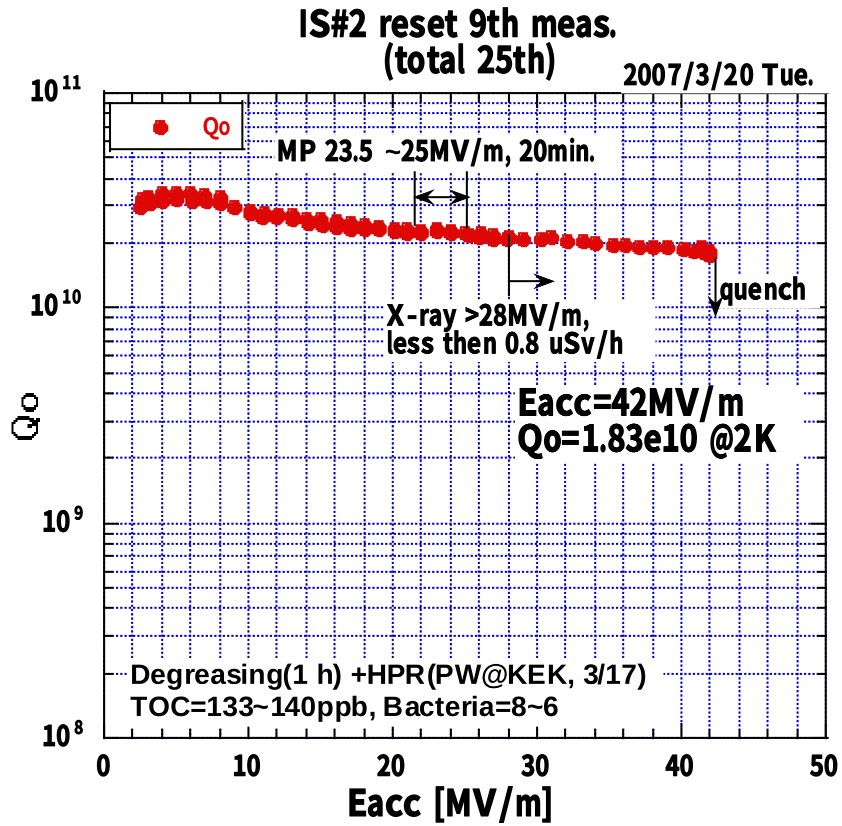
12.7 Degreasing after EP

Developed @ JLAB, J.Mammosser

Additional HPR @KEK



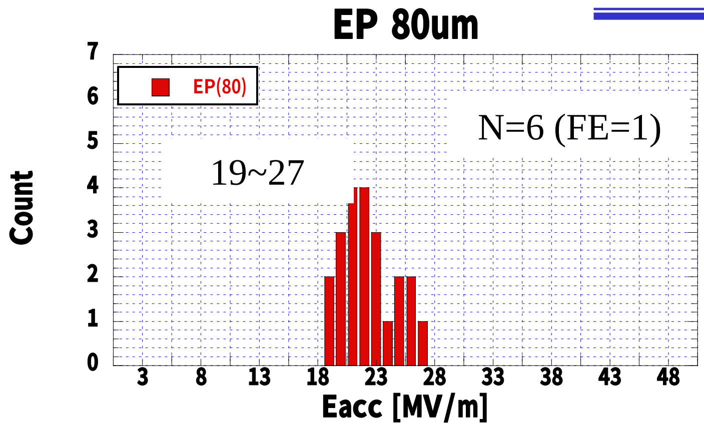
Additional Degreasing + HPR@KEK

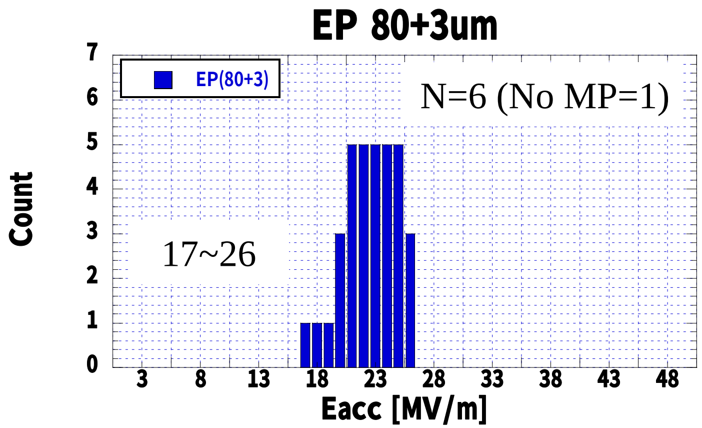


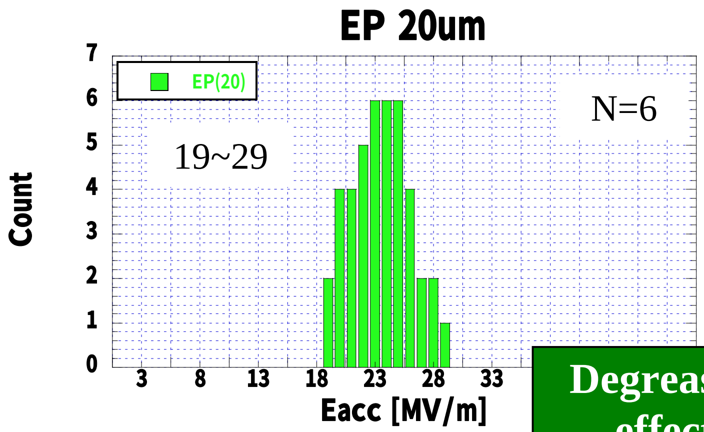
(Use Japanese degreaser)

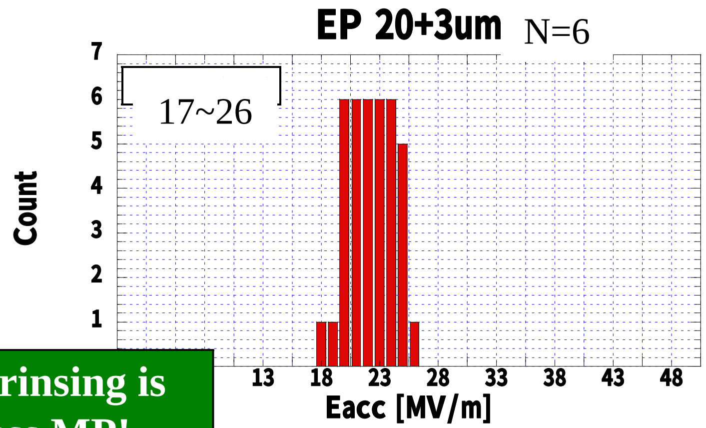
Degreasing is very much effective to eliminate contamination !

Multipacting

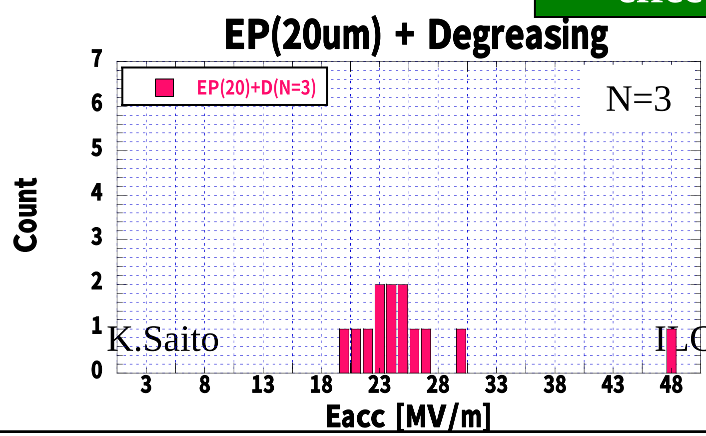


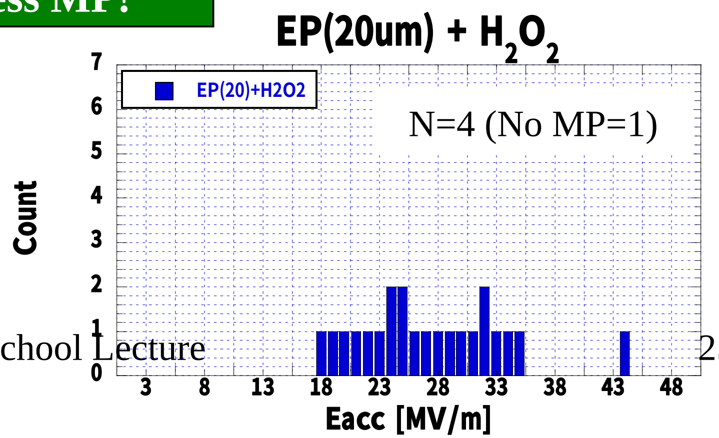






Degreasing or H_2O_2 rinsing is effective to suppress MP!





12.8 Cleanroom Assembly