R&D Activities for ILC

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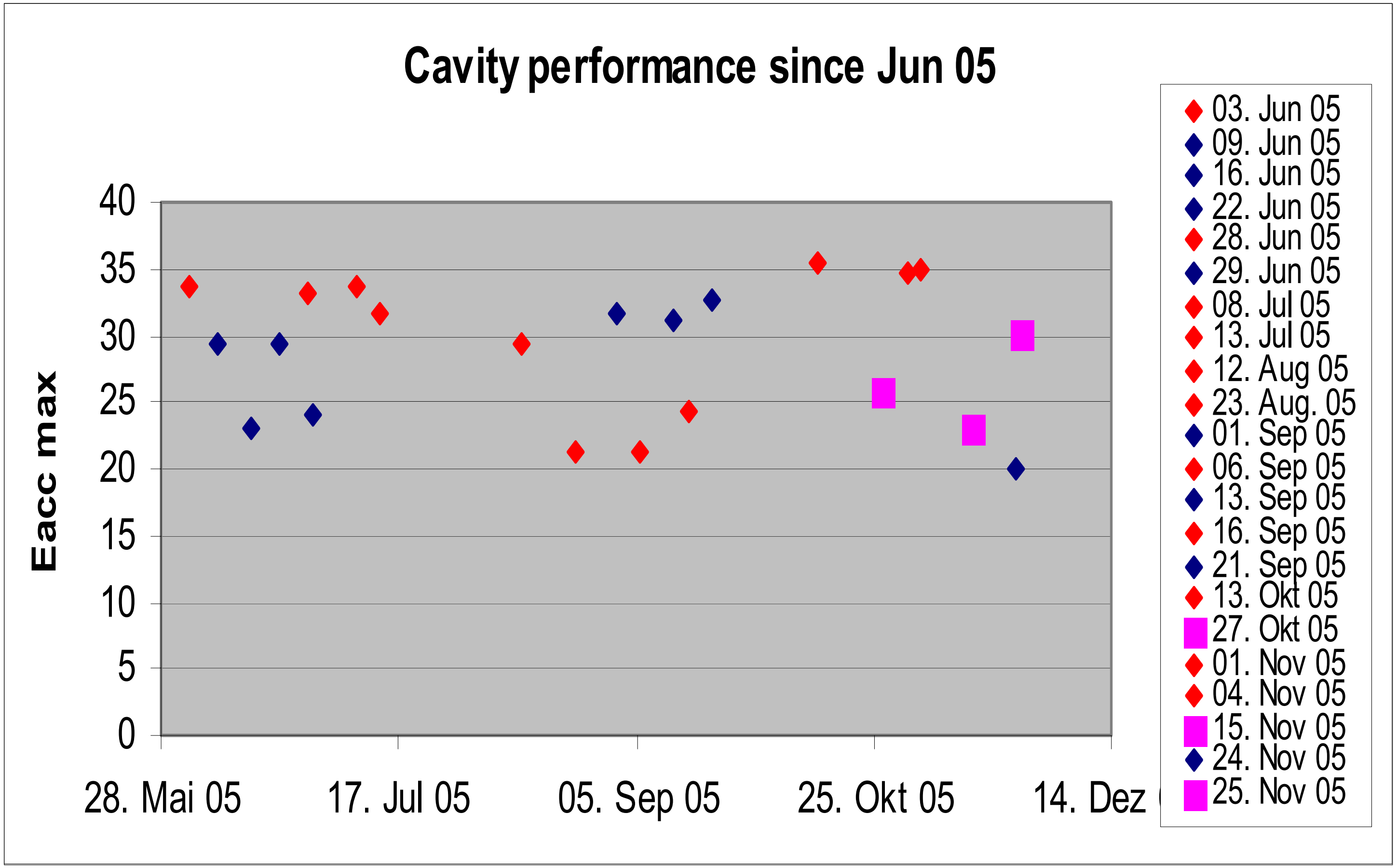
Jefferson Lab

Issues[1]

- Design goals for ILC are a gradient of $E_{acc} = (35 \pm 1.7)$ MV/m, $Q = 1 \times 10^{10}$ at 2K
- Presently such performance levels in gradient have been achieved only at DESY in 9-cell cavities, however the spread is much larger both in gradient ($\pm$ 6 MV/m) and Q-value: $Q = (0.8 \pm 0.3) \times 10^{10}$
- Cavity performance spread is affected by variations in material , surface treatment (EP, BCP) and reproducibility in assembly procedures (contamination)

A. Matheisen, DESY ; TTC meeting, Frascati, Dec. 5-7, 2005



Note: Red diamonds = Eacc after 120 C baking
Pink square = Q disease ! Result after fast cool down

Issues[2]

- Limitations are:
  - Field Emission → Contamination Control

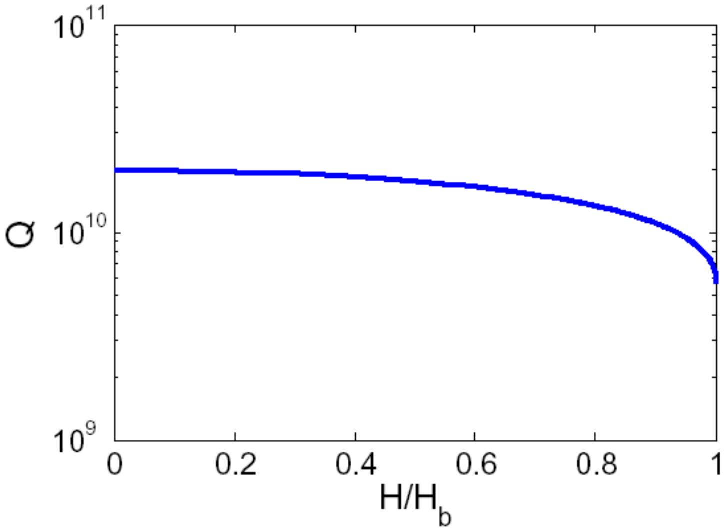
    Remedies: High pressure ultrapure water rinsing, clean room assembly
  - Magnetic Break-down → Material QC

    Remedies: high purity niobium, eddy current scanning (see talk of A. Gurevich)
  - Q vs E_{acc} → " Q – drop"

    Remedies: electropolishing, "in-situ" baking

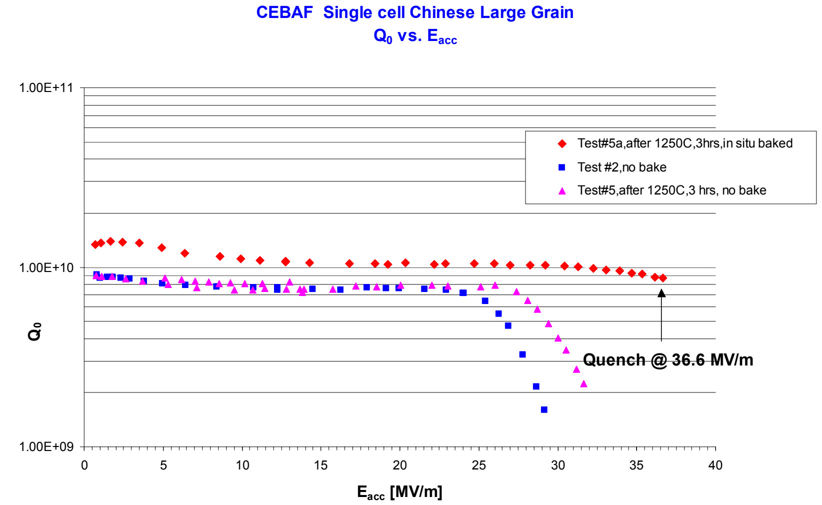
"Q - drop"

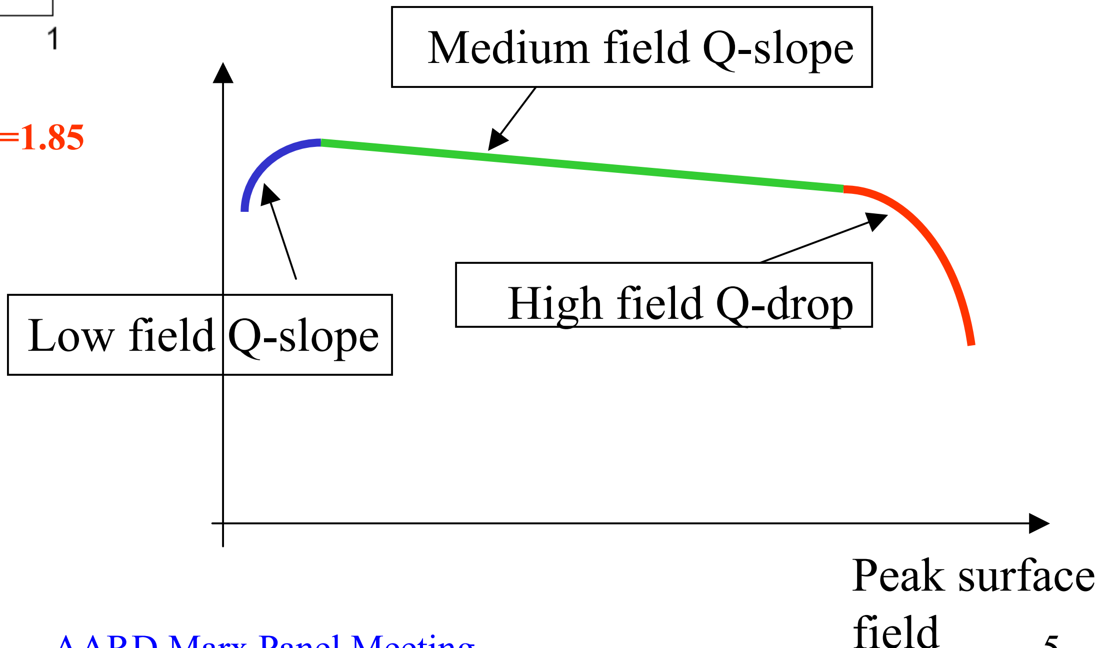
Theoretical Dependence[A. Gurevich]



Linear BCS Resistance,T=2.2K,Δ/kT_C=1.85

Experimental

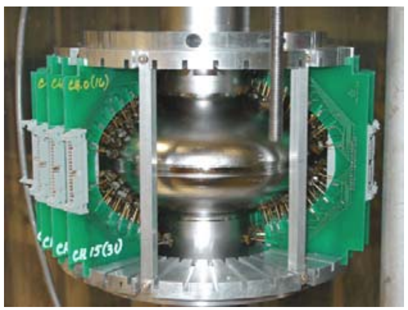




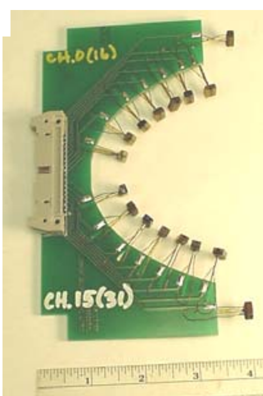
"Q - drop"

Investigation of high field behaviour of Nb cavities

for this purpose a high speed temperature mapping system with ~ 600 thermometers was implemented at Jlab,which can localize "hot spots" on a sc surface at 2K(G. Ciovati, Jlab)



a)



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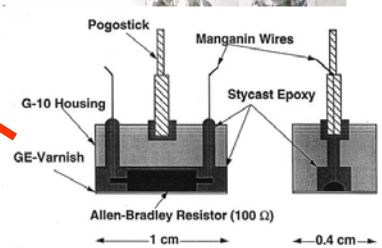
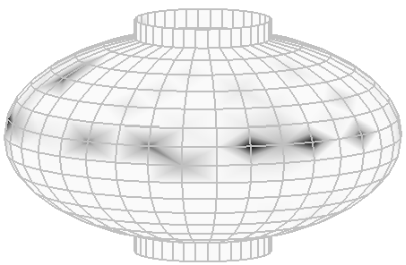
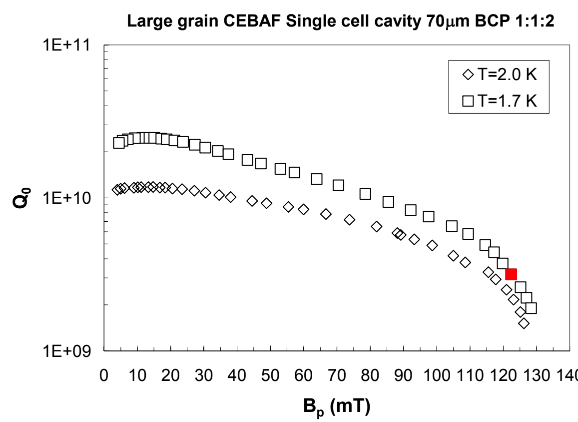






Issues[3]

- Cost Reduction
  - Alternative Material

    large grain/single crystal vs polycrystalline

    "streamlining" of procedures
  - Improvement in effectivity of cavity shape

    TESLA shape vs Low Loss, Re-entrant shapes

    reaching the magnetic field limit of niobium
  - Increasing the real estate gradient

    superstructure

    reduction in length, reduction in # of components

Talk by K.Saito in JLAB on Oct. 2003

Electropolishing of Niobium

Current oscillation control: innovated by H.Diepers et al. in 1971

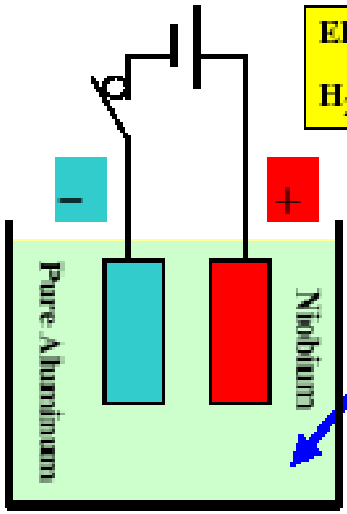
$2Nb + 10HF \rightarrow 2H_2NbOF_5 + 5H_2 \uparrow$

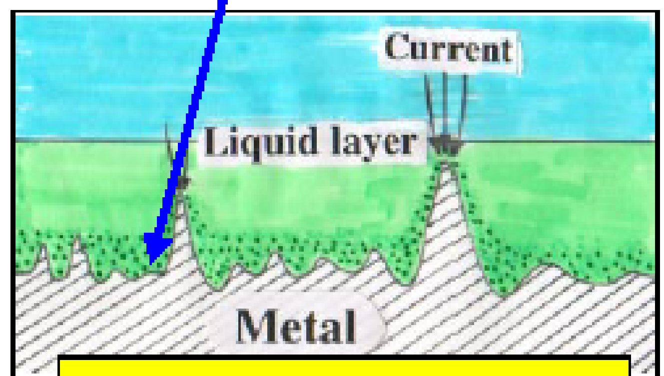
Metal complex salt

EP acid

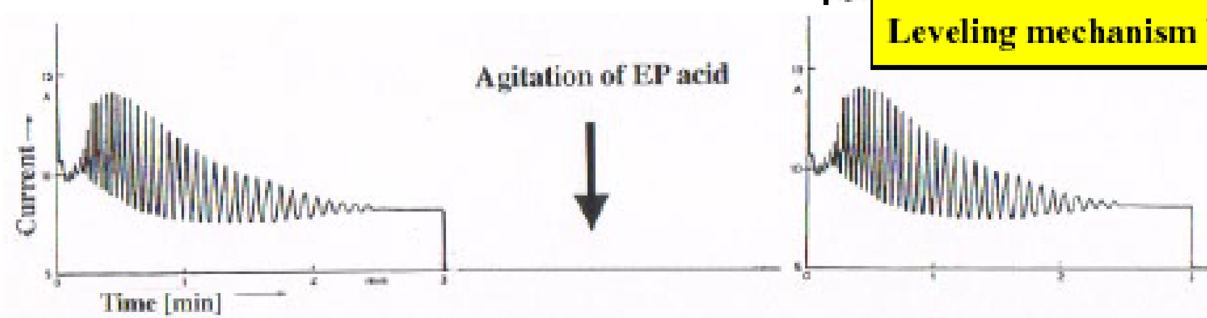
H_2SO_4(>95%) : HF(46%) = 10 : 1 V/V

Very hazardous Acid



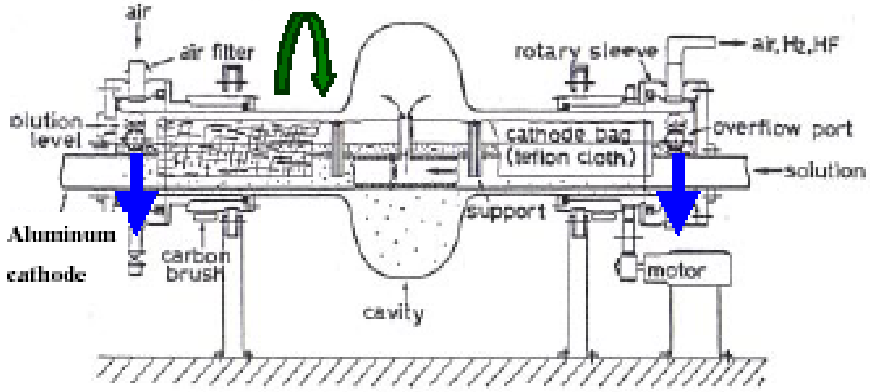


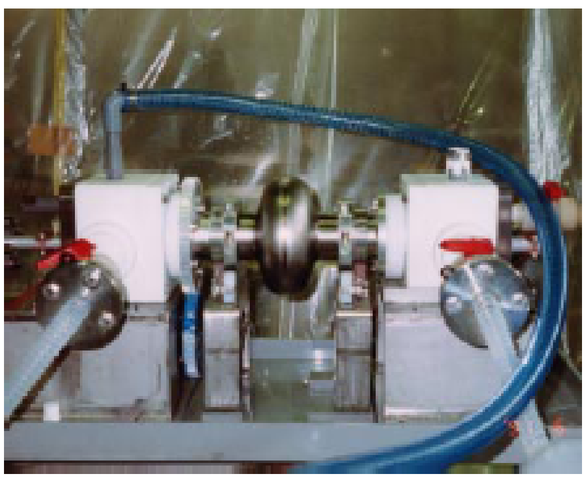
Leveling mechanism by P.A.Jaquet



Talk by K.Saito in JLAB on Oct. 2003

Horizontally Rotated Continuous EP (HRC-EP)





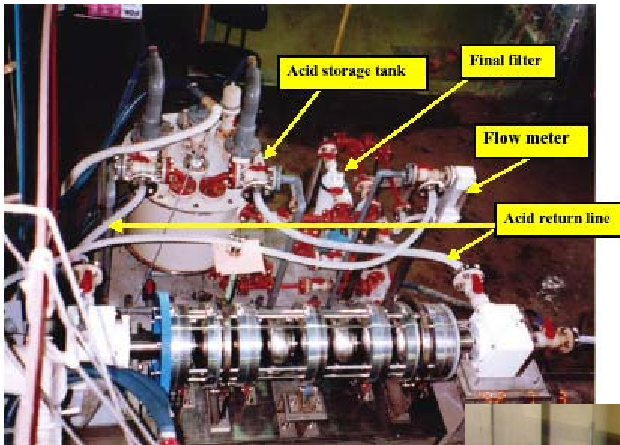
Advantages

1) Larger Cathode Surface Area ⇨ Smooth surface in the whole area
2) Easy Hydrogen exhaustion ⇨ Elimination of the hydrogen problem
3) Inside EP ⇨ Prolongation of the EP acid life
4) Closed system ⇨ Safe System against the hazardous EP acid
5) Easy control

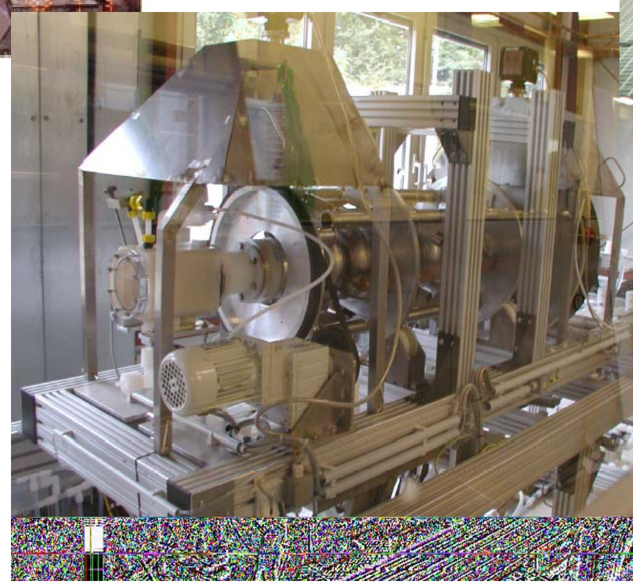
" Very Suitable System for Mass Production"

EP- Systems

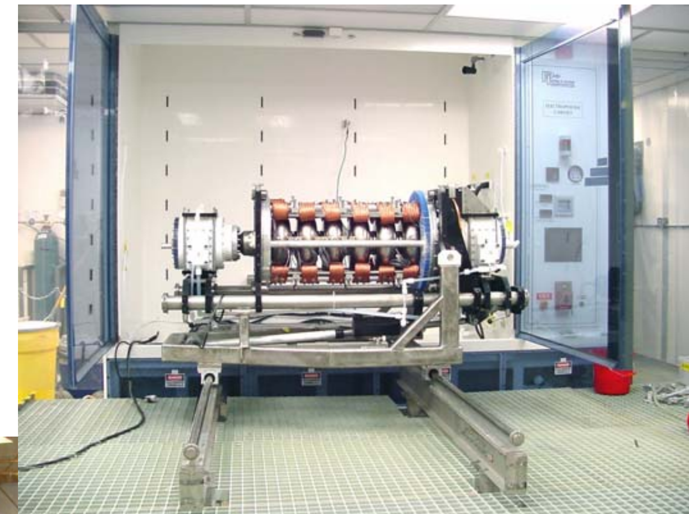
KEK/Nomura Plating



DESY

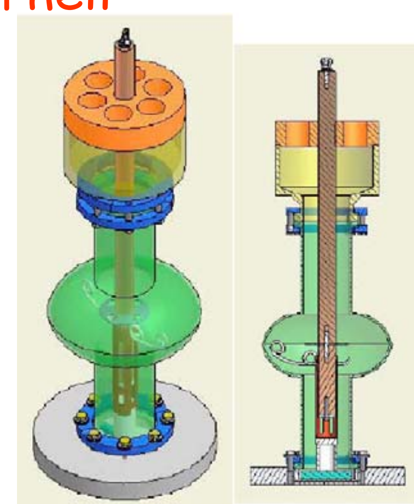


JLab



INFN

Cornell



Electropolishing- Issues

Even though EP of niobium cavities is being done for several decades there are still gaps in understanding its application for large systems:

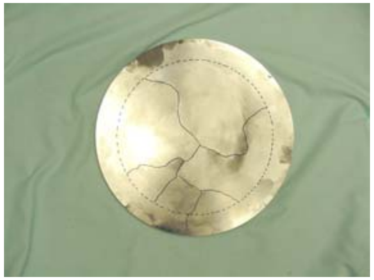
- Proper rinsing after ep to avoid field emission (sulfur contamination)
- EP geometry and procedures to avoid pick-up of hydrogen, which leads to Q-disease
- Computer modeling of the process with variables such as cathode geometry,acid flow rate, temperature distribution, current distribution..
- "On – line " data acquisition and data logging of polarization curves, HF concentration..

An R&D plan has been recently developed in the context of the TTC, relying heavily on single cell testing and it needs to be carried out.

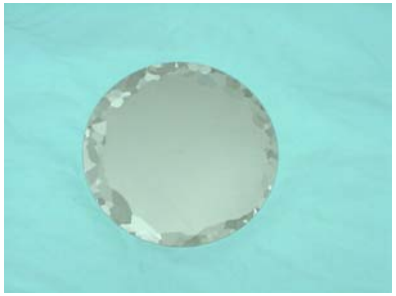
Large Grain/Single Crystal Niobium[1]

CBMM

Ingot "D",800 ppm Ta

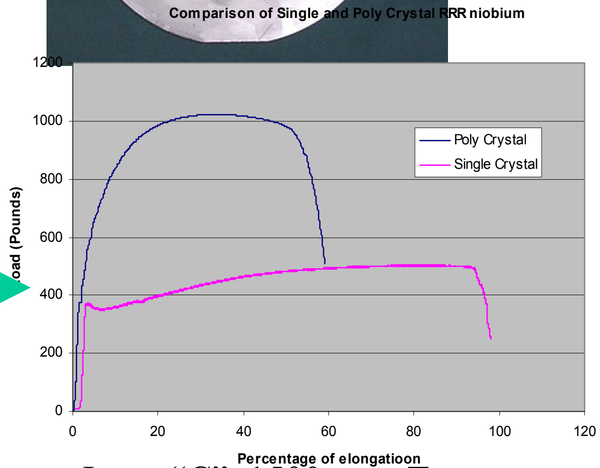


Ingot "A", 800 ppm Ta



Ingot "B", 800 ppm Ta

Ninxia

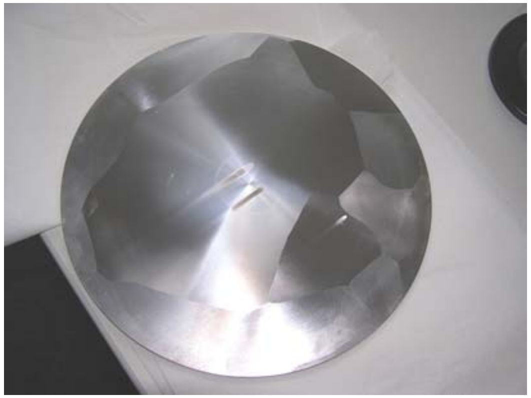


Ingot "C", 1500 ppm Ta

Wah Chang

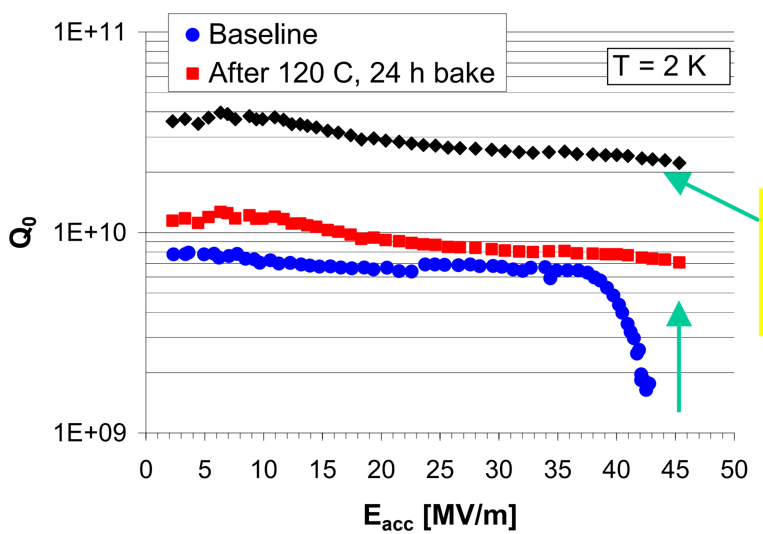
G.R.Myneni,Jlab

Heraeus



Large Grain/single crystal Niobium[2]

Nb Discs



Scaled to 1300 MHz

1:1:2 BCP only

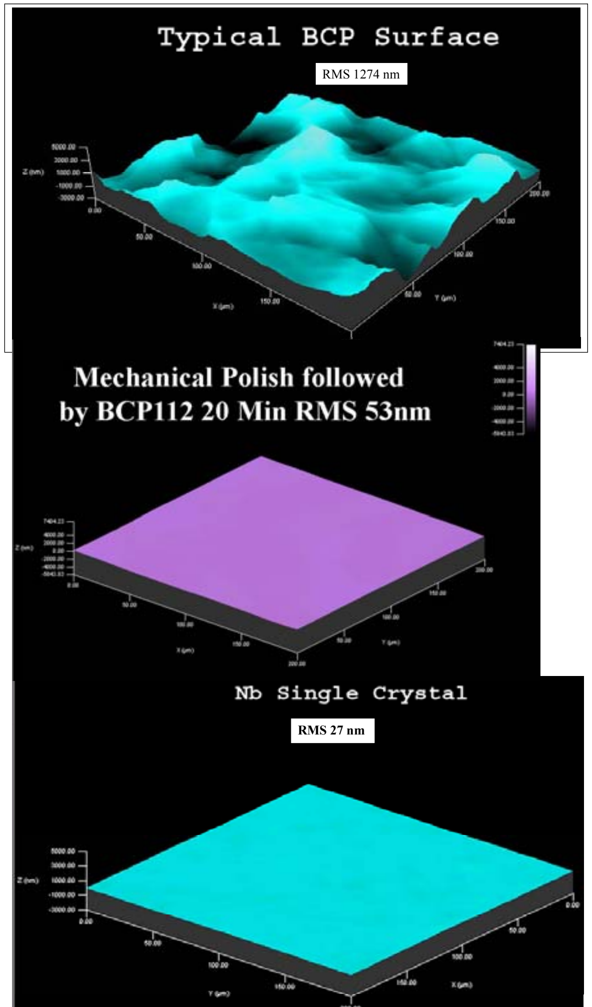
LL cavity 2.3GHz

$E_{peak}/E_{acc} = 2.072$

$H_{peak}/E_{acc} = 3.56$ mT/MV/m

Surface Roughness (1)

BCP provides very smooth surfaces as measured by A.Wu, Jlab



RMS: 1274 nm fine grain bcp

53 nm after ~ 35 micron, single Crys

27 nm after ~ 80 micron,single Crys

251 nm fine grain ep

app.100 micron removed by 1:1:2 bcp

Large Grain/single crystal Niobium[3]

What are the potential advantages of large grain/single crystal niobium?

- Reduced costs
- Comparable performance
- Very smooth surfaces with BCP, no EP necessary
- Possibly elimination of "in situ" baking because of "Q-drop" onset at higher gradients
- Possibly very low residual resistances (high Q's), favoring lower operation temperature (B.Petersen,ERL 2005)
- Good or better mechanical performance than fine grain material (e.g.predictable spring back..)
- Less material QA (eddy current/squid scanning)

Large Grain/single crystal Niobium[4]

- It is desirable to develop the technology for growing ingots of single crystal niobium
- A workshop on this topic is being organized for November 2006 by Jlab and it will be hosted by CBMM
- The hope is to energize niobium suppliers to develop this technology; however, this most likely will not happen without "incentives"

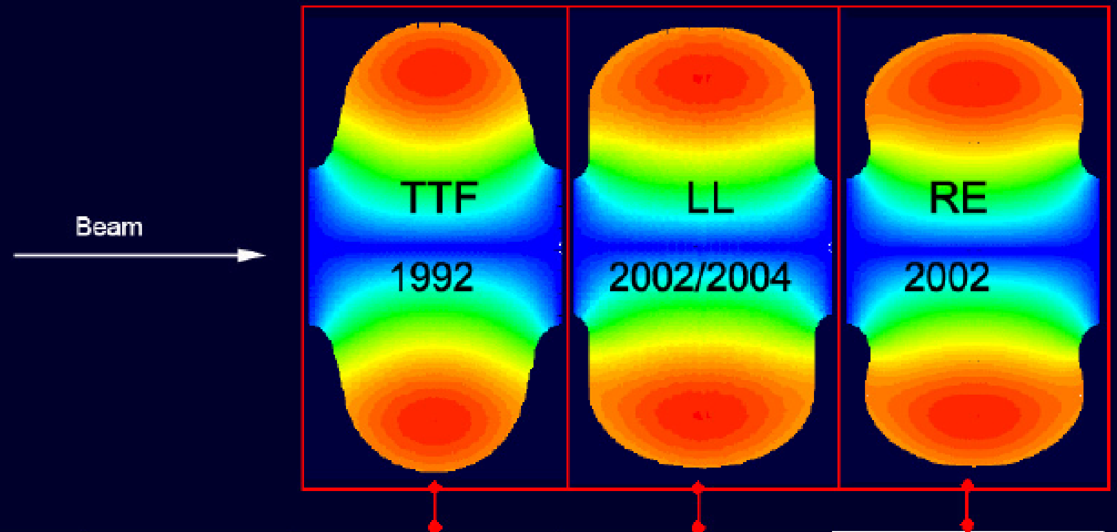
Cavity Shape- Increasing the Effectivity of a structure[1]

- The ratios of E_{peak}/E_{acc} and B_{peak}/E_{acc} are determined by the cavity shape
- The limitations in a sc cavity are given by field emission loading $\Rightarrow$ (E_{peak}) or by "quench" $\Rightarrow$ (H_{peak})
- The new shapes ("Low Loss" and "Re-entrant") reduce B_{peak}/E_{acc} ,thus increasing the accelerating gradient for a given "quench" field (for Nb ~ 190 mT),
- Unfortunately, at the same time is the surface electric field increasing, demanding even better control of contamination

Cavity Shape- Increasing the Effectivity of a structure[2]

J.Sekutowicz

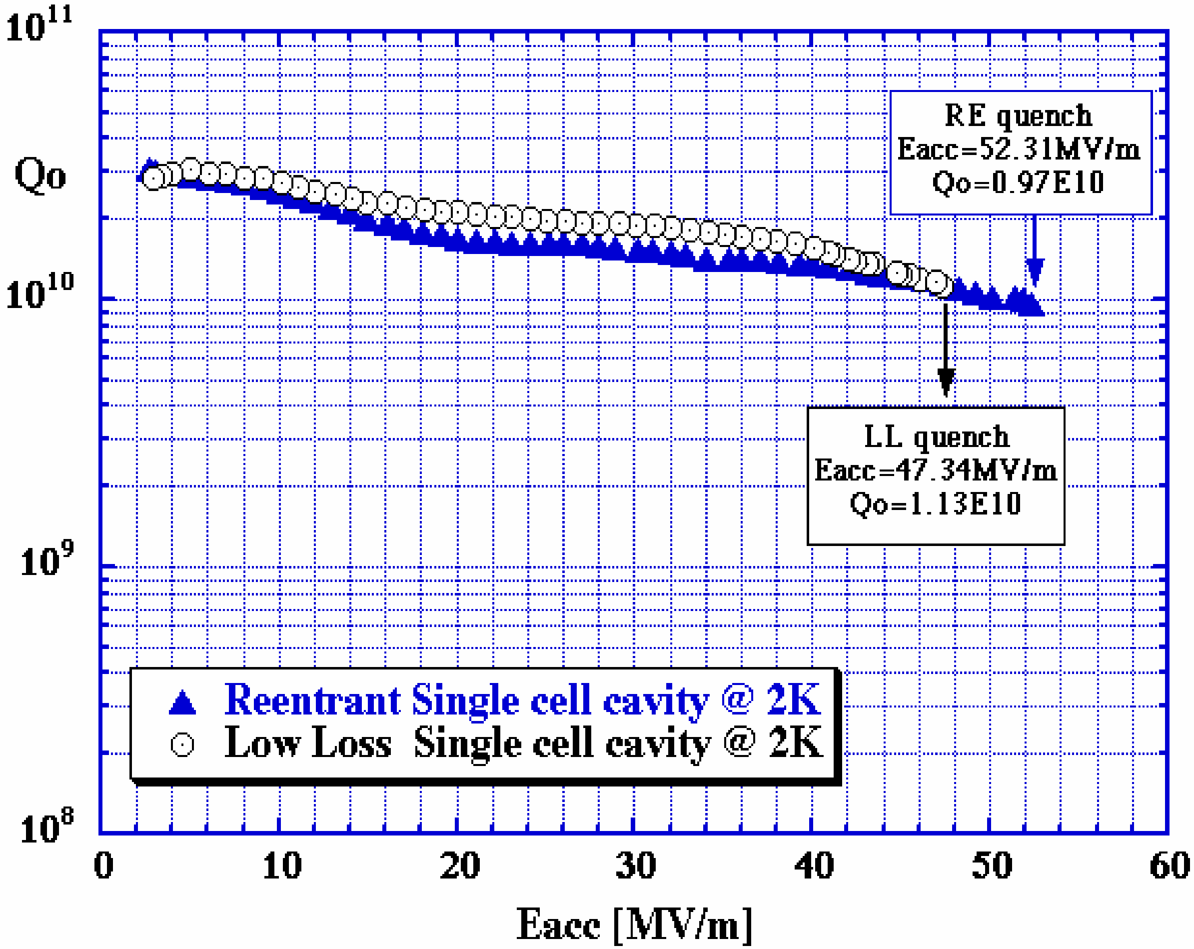
Example: 1.3 GHz inner cells for TESLA and ILC



r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

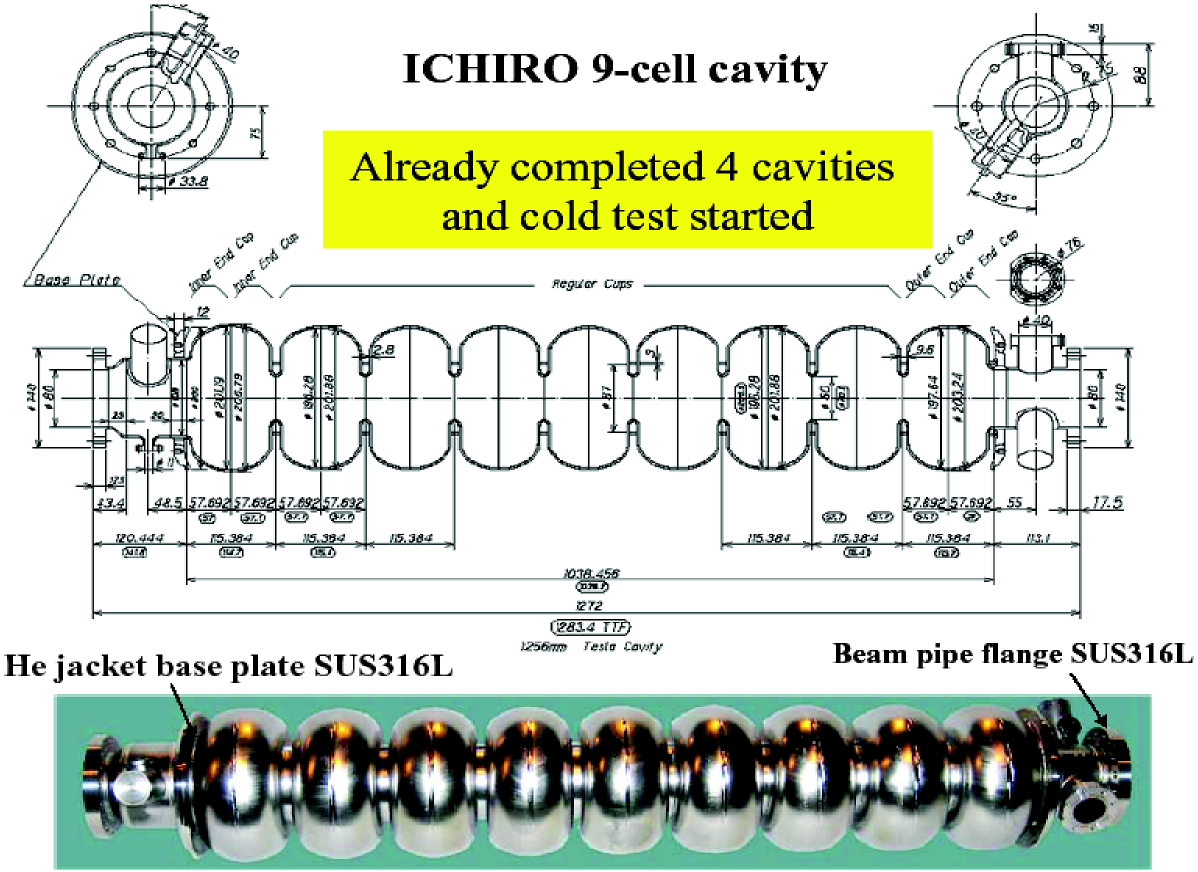
Cavity Shape- Increasing the Effectivity of a structure[3]

K. Saito,KEK



Cavity Shape- Increasing the Effectivity of a structure[4]

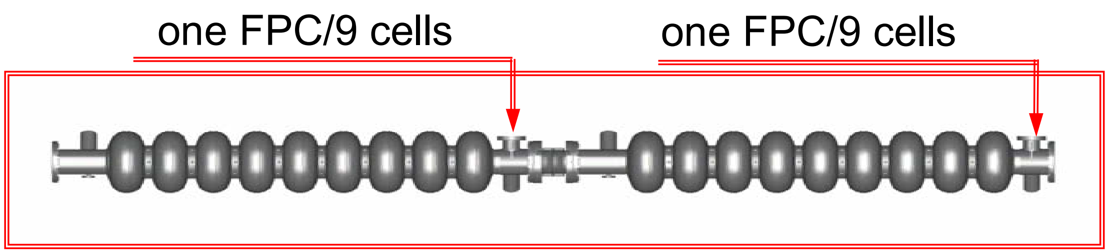
K. Saito, KEK



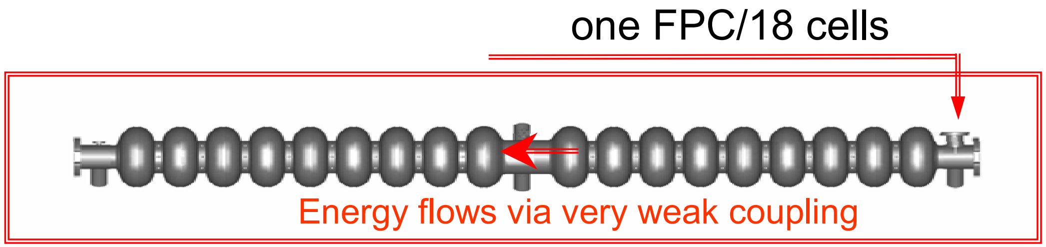
Super-Structure[1]

A Super-Structure combines two multi-cell cavities through a weakly coupling beam pipe into one unit

Standard layout: 9-cell structures separated by 286 mm long tube



SST layout: two 9-cell structures coupled by λ/2 long tube



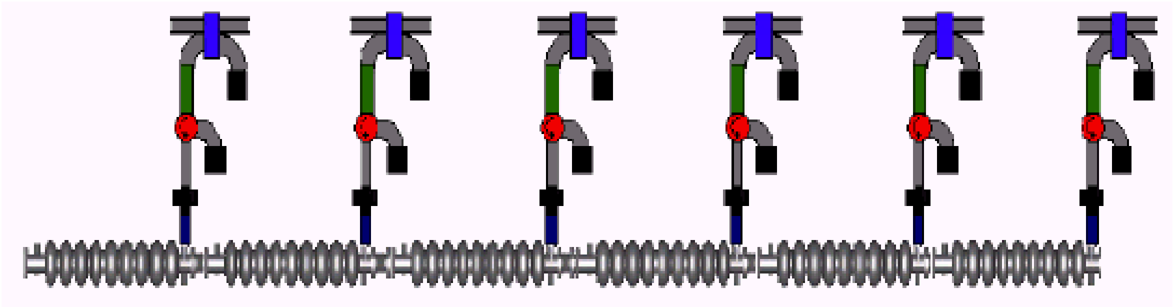
24/01/2006 J. Sekutowicz

J. Sekutowicz

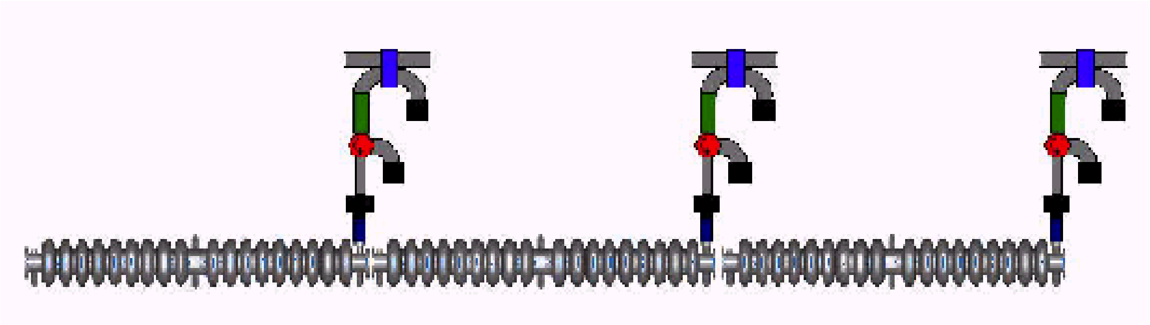
Super-Structure[2]

- **RF-distribution system and Real Estate Gradient (cont'd)**

Standard layout:



SST layout **saves thousands** of these components



Super-Structure[3]

I. Significantly lower cost of the RF-system (40-50% less components).

II. 40-50% less Input Couplers, therefore cleaning/assembly/processing time and cost reduced

III. Tunnel shorter by 5-6%, because of shorter inter-cavity connection

IV. Less openings in cryostat (40-50%), simplified assembly and design.

V. Less time for assembly of cryostats in the linac.

VI. Less LLRF units.

VII. Remedy to synchronic excitation of dangerous HOMs.

Cons: No much experience with beam (Proof of Principle at TTF is the only test).

More difficult production and cleaning, unless we will have sc-joint.

1.8-2 x higher power capability of Input Couplers (fortunately it is ~ $\varnothing^4$).

Cold tuner on He vessel (like the blade tuner), more experience needed.

Super-Structure[4]

Estimate of cost reduction **(Couplers only)**

- Present coupler costs are ~ $ 30000
- Goal is $ 10000
- Actual costs maybe in between~ $ 20000
- Coupler Processing: estimated cost/coupler: $ 3000

Table III. Potential savings

FPC price	**$ 30000**	**$20000**	**$ 10000**
Savings	**$ $398 \cdot 10^6$**	**$ $292 \cdot 10^6$**	**$ $189 \cdot 10^6$**

Summary

- More effort has to go into development of procedures to achieve reproducibly high performance cavities with small spread in performance
- This means one has to gain a better understanding of the EP process, improve the QA procedures for control of contamination and of material variations
- Control of the costs of a large machine such as the ILC can possibly achieved by implementation of large grain/single crystal high purity niobium and of a super-structure configuration for the accelerator
- **In view of a potential combined cost savings of up to half a billion dollars for the ILC, we believe that it would be a justifiable and a clever decision to invest a few percent of the potential cost savings in these developments.**