

# "Crab Cavity Processing Challenges & Higher Gradients".

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LHC- CC08 at BNL  
February 25-26, 2008

- SRF Technology Issues
- Major Applications
- State of the Art
- ANL Crab Cavity Results
- Challenges

# SRF Technology

At the 2007 SRF workshop in Beijing several tutorials about SRF technology were given:

- J. Knobloch,"Basics of RF Superconductivity"
- J. Sekutowicz," SC High Beta Cavities"
- D. Reschke," Limits in Cavity Performance"
- A. Matheisen," Cavity Preparation"
- W. Singer, “ SC Cavities;Materials, Fabrication and QA”

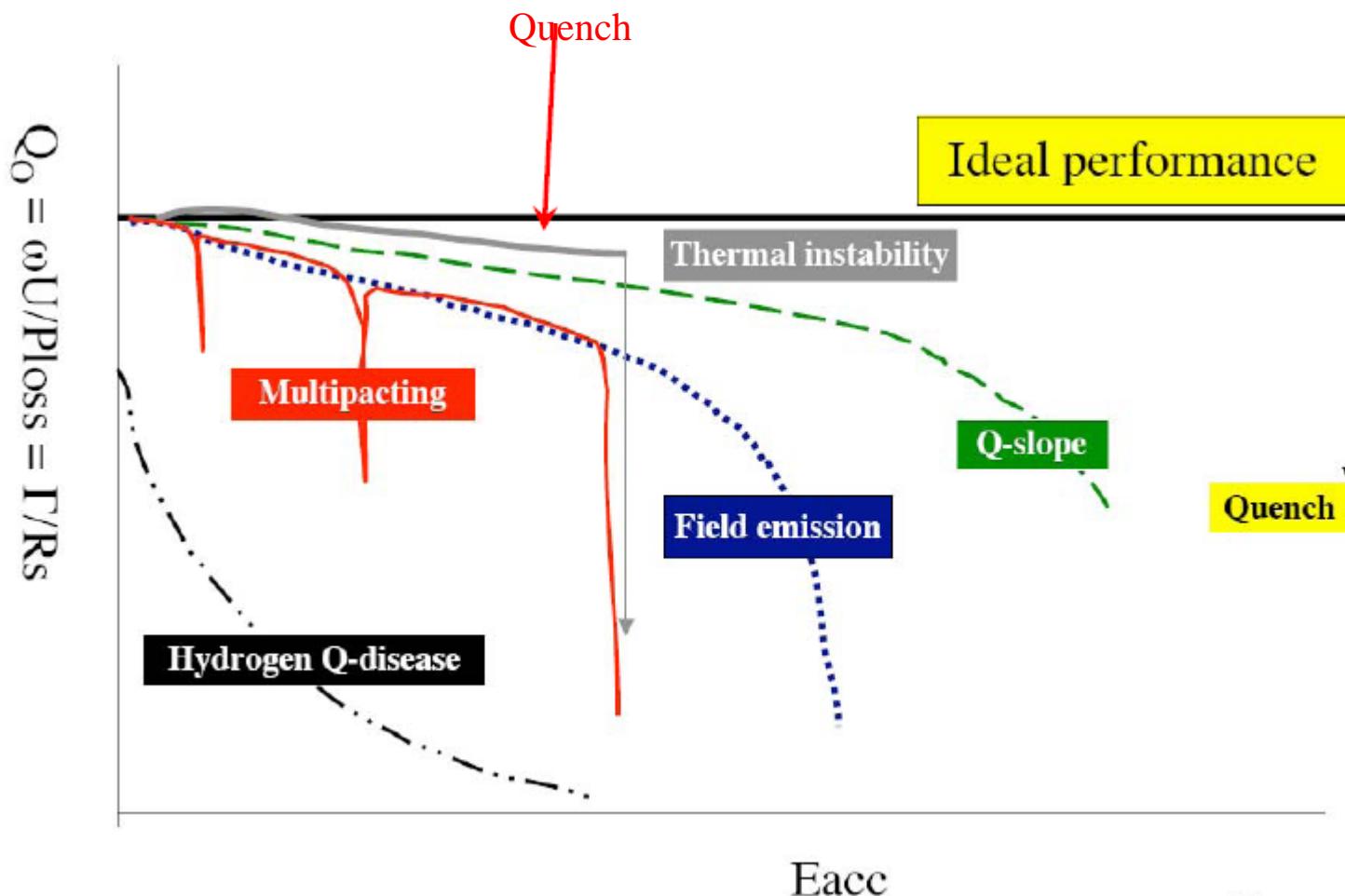
<http://www.pku.edu.cn/academic/srf2007/program.html#tutorial>

# Superconducting Cavity Limitations(1)

- Quench (transition from sc state to nc state)
- Q –drop ( degradation of Q-value at  $H \geq 100$  mT)
- Medium field Q-slope ( heat transfer to He bath...)
- Field emission ( surface contamination, intrinsic FE?)
- Multipacting ( cavity shape, surface cleanliness)
- Hydrogen Q – disease ( remedy: degassing, fast cooldown)
- Residual resistance

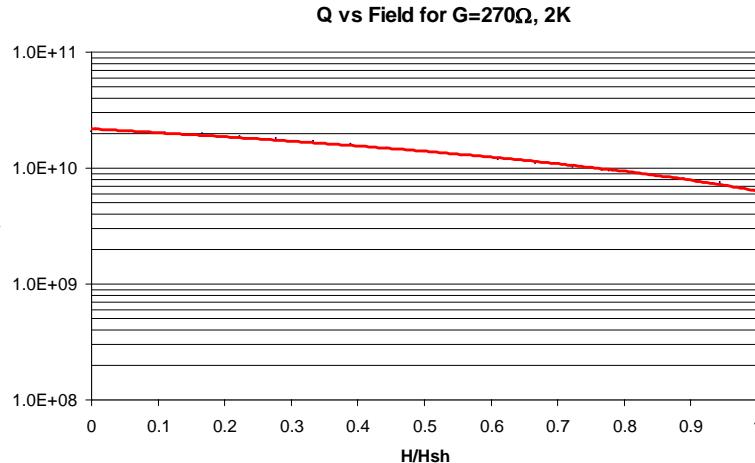
# Superconducting Cavity Limitations(2)

- D. Reschke, Tutorial SRF2007

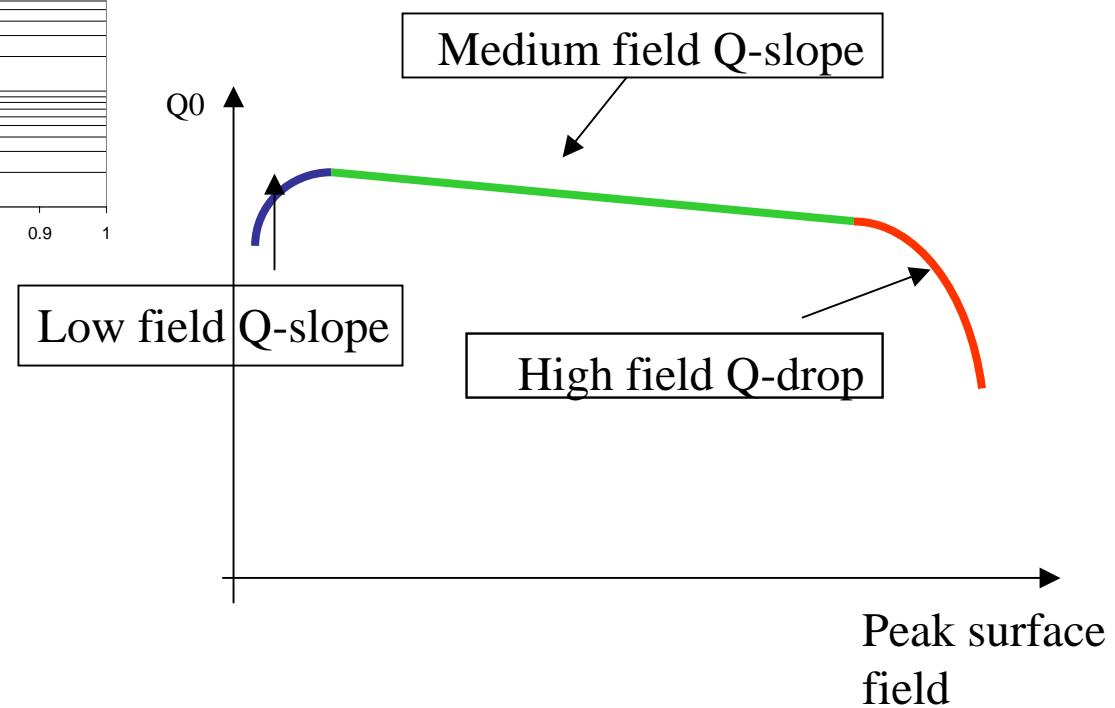


# Obstacles to “Ideal” Performance

Even if the low field Q is high (residual resistance low), there is typically a field dependence of the Q-value

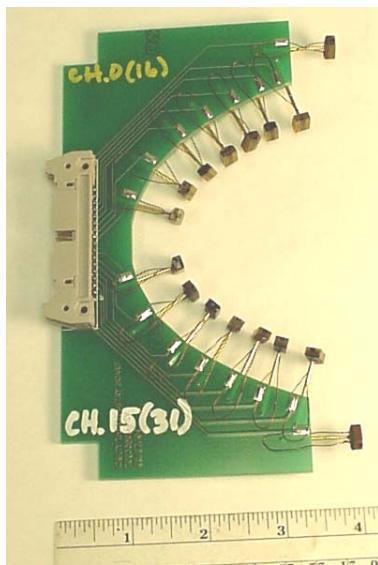
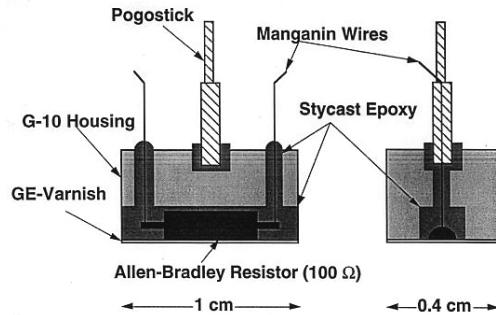


Theoretical Dependence



# T-Mapping (1)

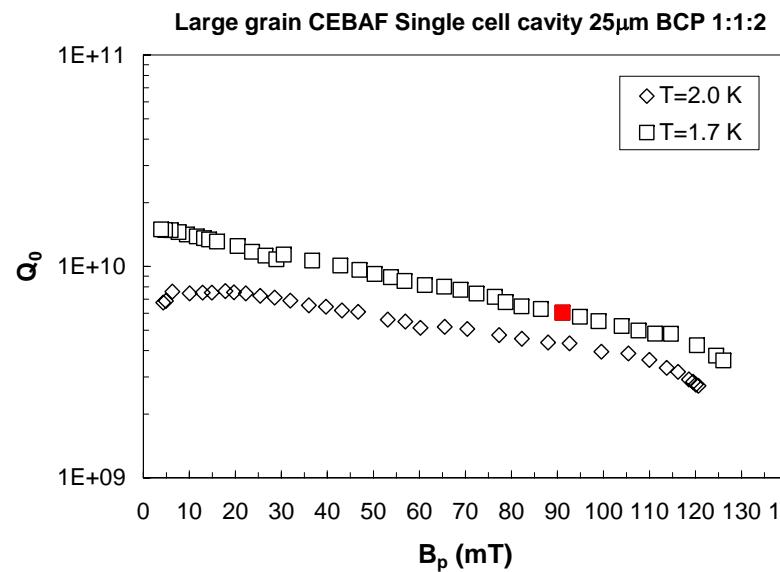
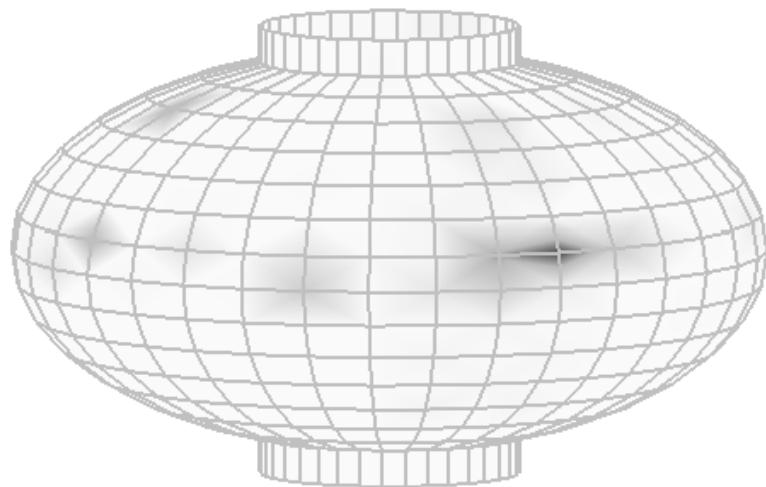
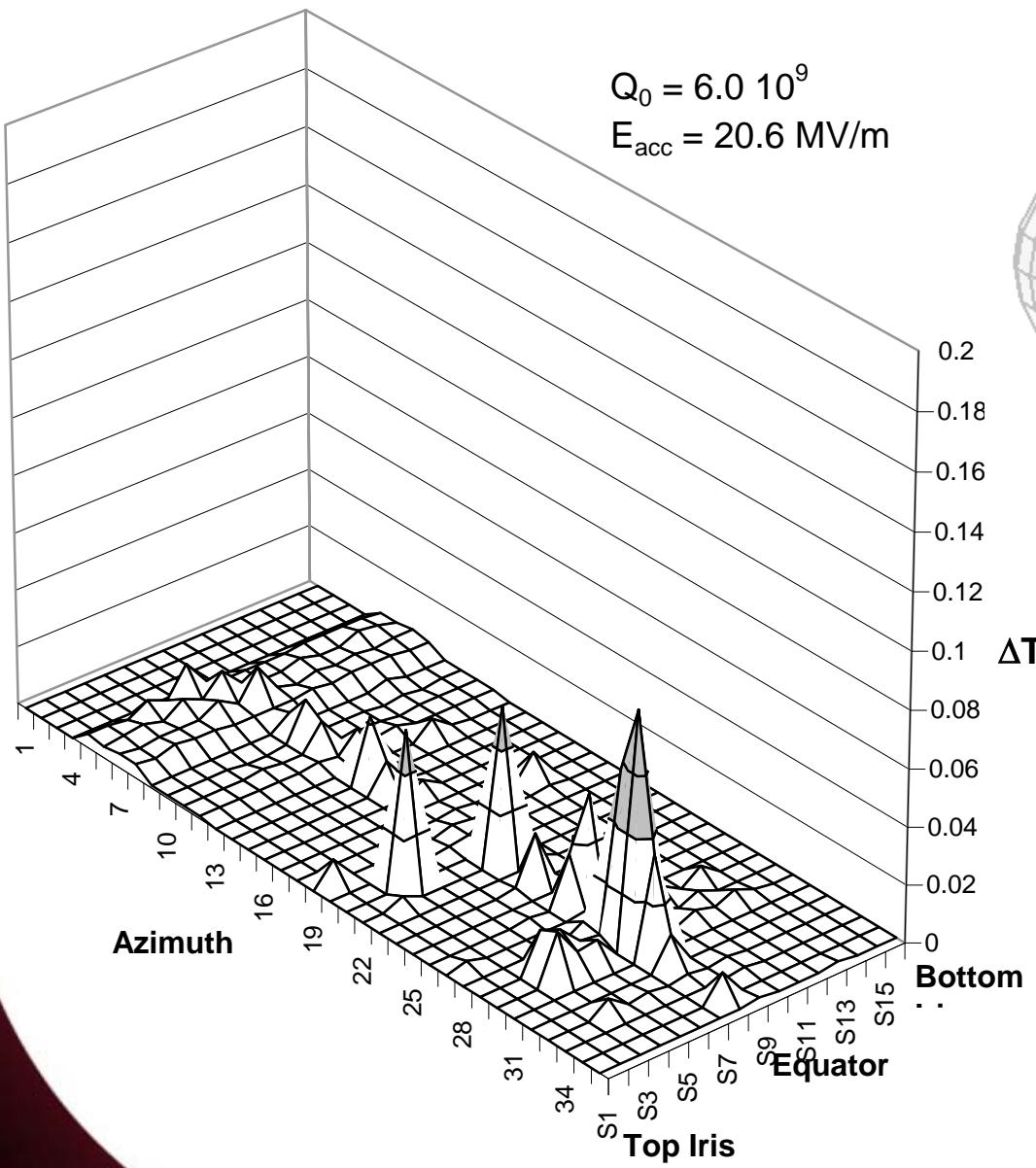
T-mapping system: ~600 Allen-Bradley C-resistors



a)



b  
)



# Applications

Presently there are 2 major applications for sc cavities:

- Pulsed machines: ILC, XFEL, SNS upgrade

ILC design goal:  $E_{acc} \geq 35 \text{ MV/m}$ ,  $Q_0 \sim 1 \times 10^{10}$  ( $H_{peak} \sim 150 \text{ mT}$ )

$$E_{acc} = 31.5 \text{ MV/m}$$

X-FEL design goal:  $E_{acc} \geq 28 \text{ MV/m}$ ,  $Q_0 \sim 1 \times 10^{10}$

$$E_{acc} \sim 23.5 \text{ MV/m}$$

- CW application (ERL's, FEL's, CEBAF Upgrade...)

Design goals:  $E_{acc} \sim 20 \text{ MV/m}$ , very high Q

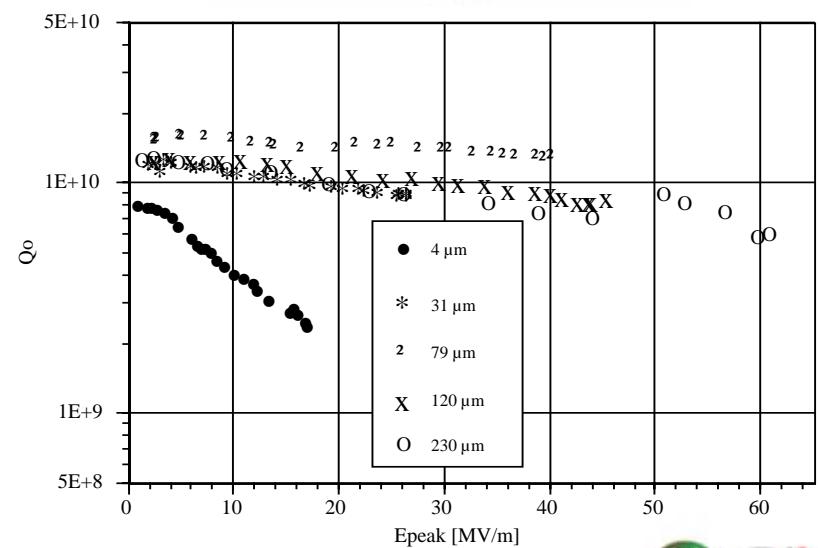
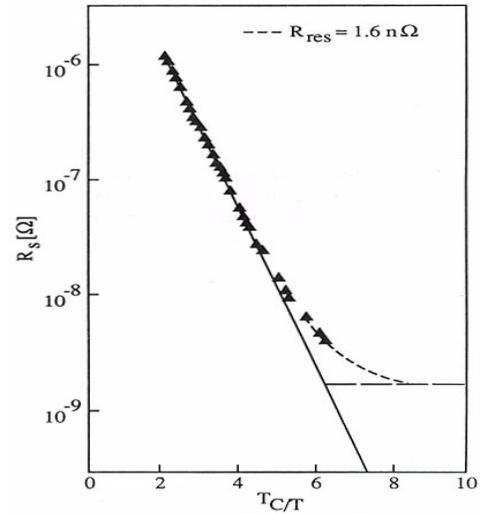
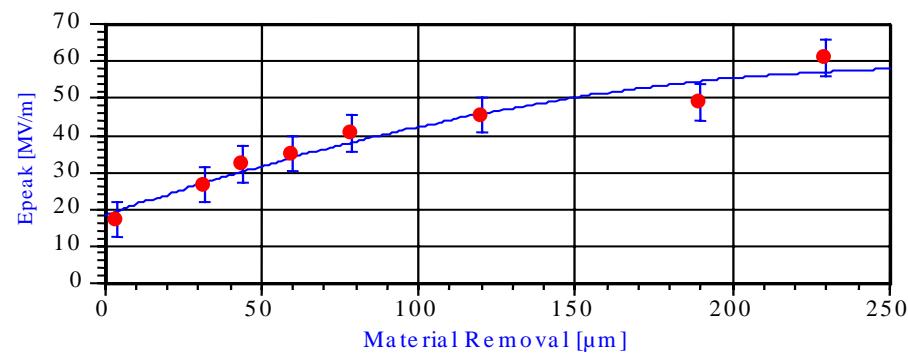
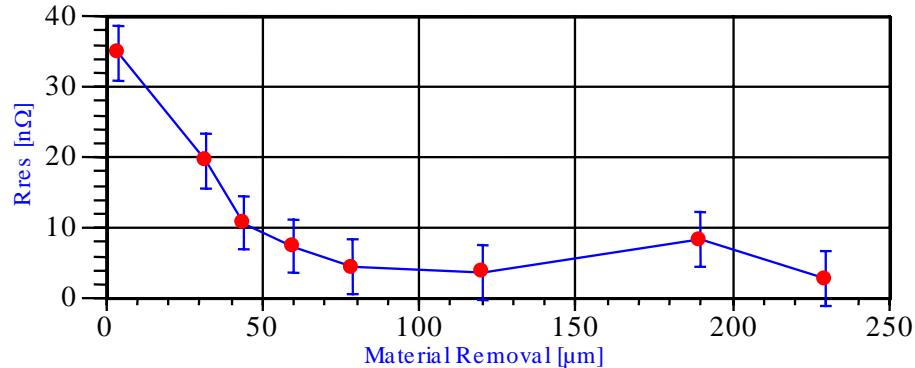
These application “struggle” with different limitations

# “State of the Art”

- Material of choice: bulk niobium, RRR $\geq$  300, polycrystalline or large grain/single crystal
- Surface treatment: removal of damage layer, 100 to 200 micron, by EP or BCP
- High Temperature Heat Treatment (600C to 1400C for Hydrogen degassing, Post Purification)
- Extensive high pressure ultrapure water rinsing (> 10 hrs)
- Drying and assembly in class 10 clean room
- “in situ” baking at ~ 120 C for up to 48 hrs ( removes Q-drop)
- Meticulous cleaning of auxiliary parts such as flanges, couplers, pump-out ports....

# Why Surface Treatment?

Damage layer influences cavity Performance



# High Pressure Rinse Systems



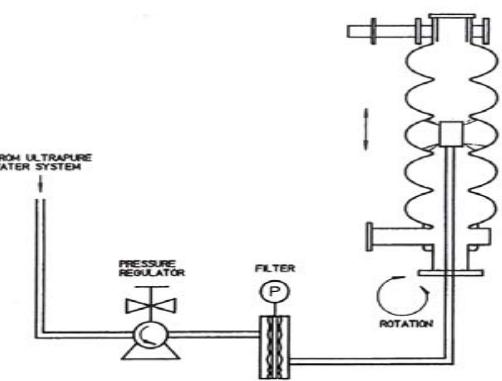
DESY-System



Jlab HPR Cabinet

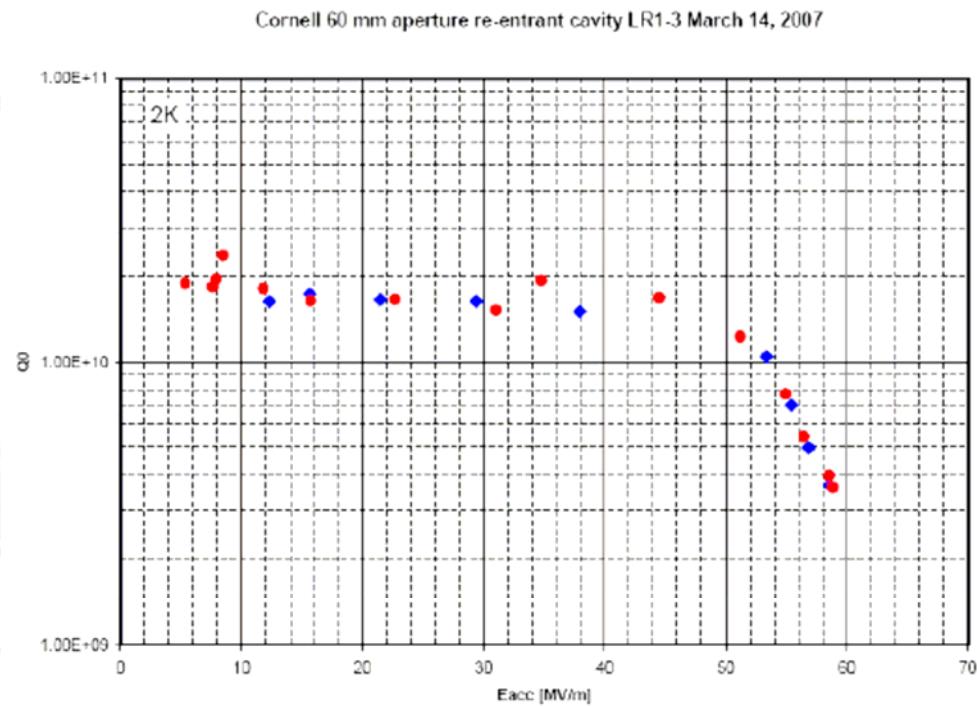


KEK-System



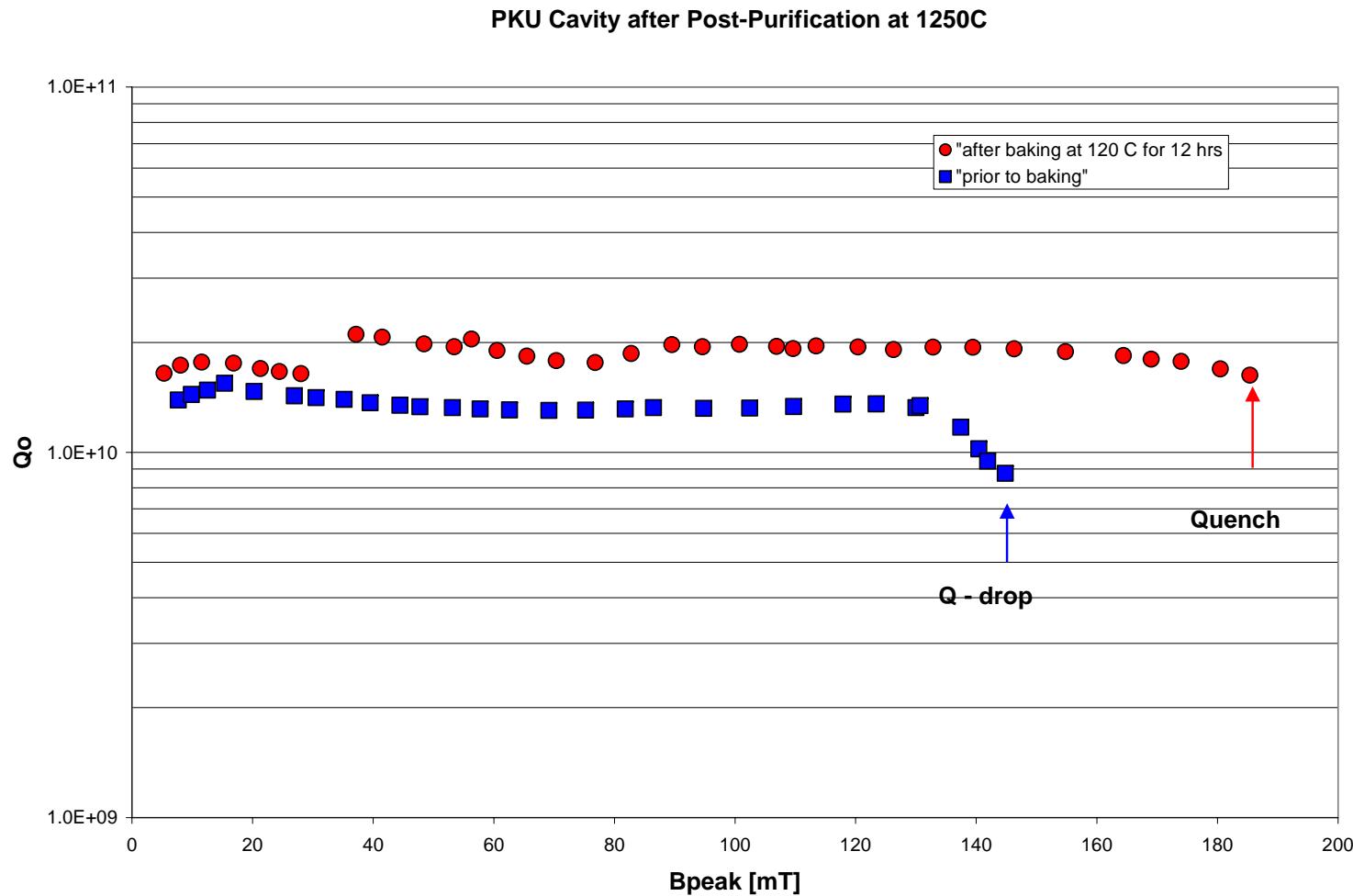
- H.Padamsee, TTC Meeting Apr. 23-26,2008, FNAL

## 60mm-Aperture Re-Entrant Cavity, 58 MV/m! KEK/Cornell Collaboration



RE-LR1-3

# PKU:TESLA Shape, Ningxia Nb



October 15-19, 2007

Jefferson Lab

SRF 2007

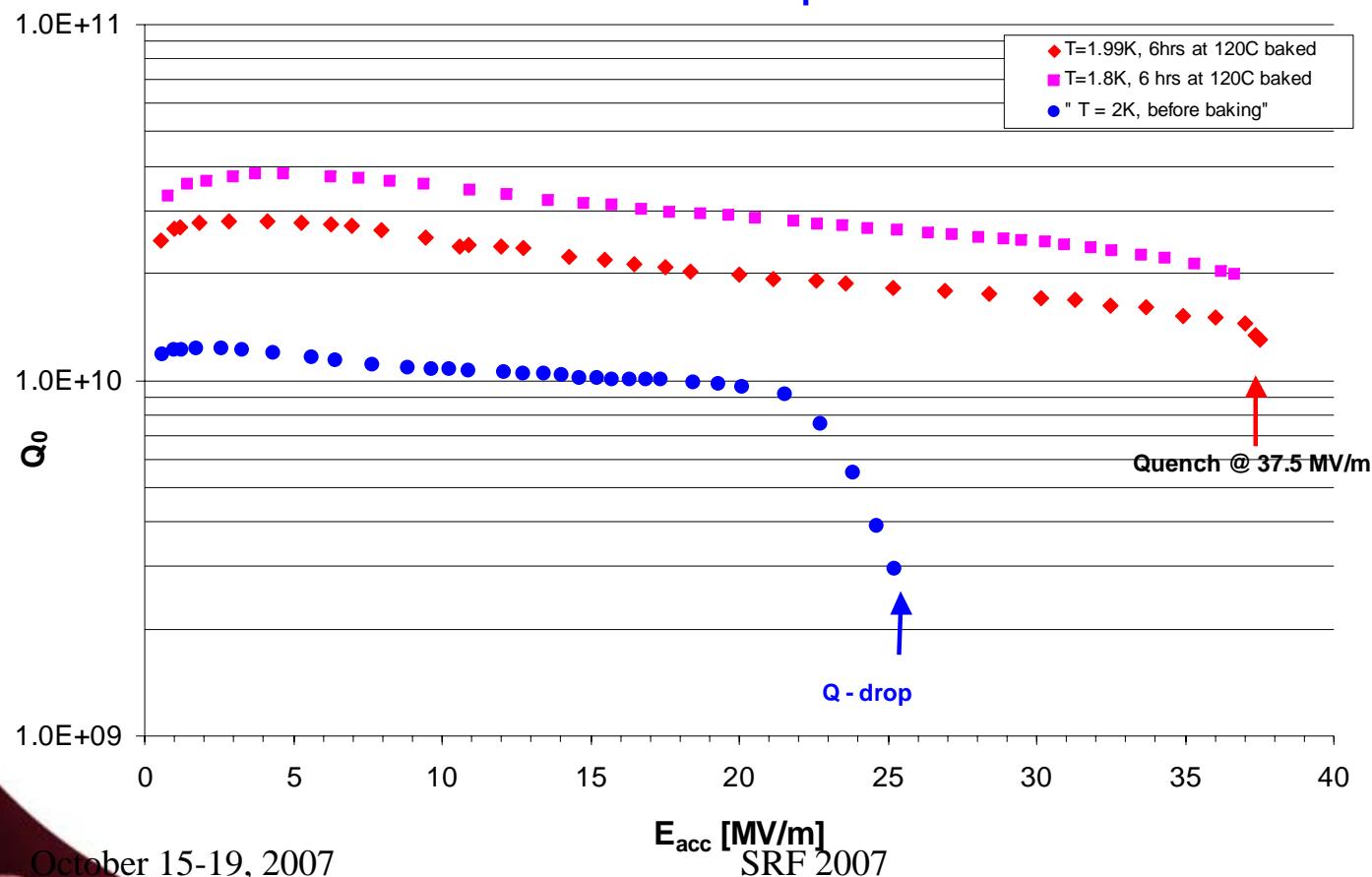
14  
JSA

# Test #6, cont'd

- The cavity was baked at 120C for 6 hrs

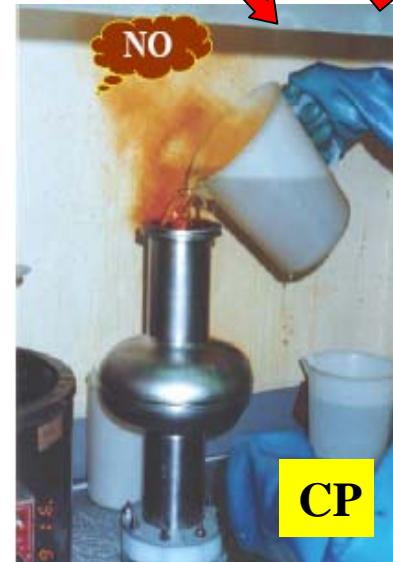
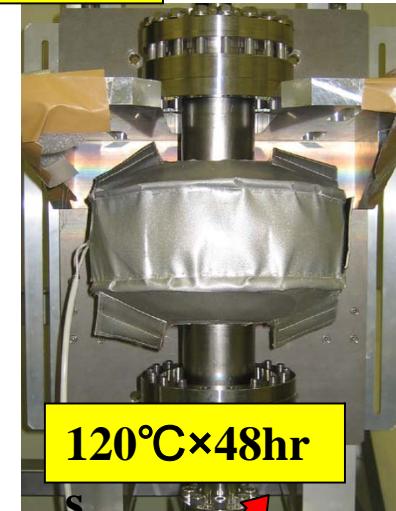
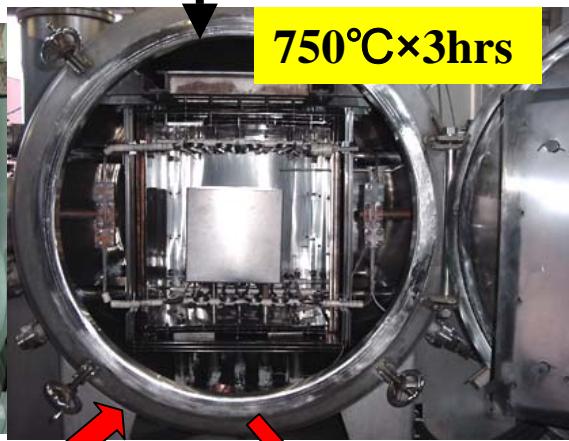
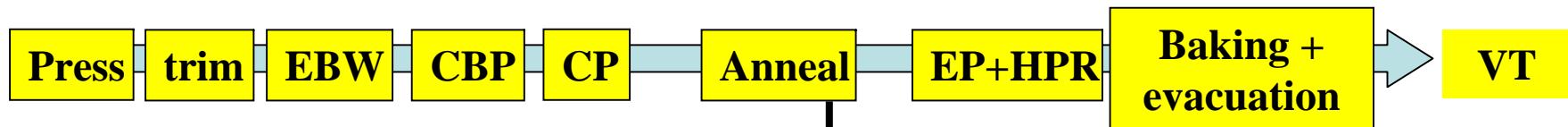


Single Crystal DESY Cavity, Heraeus Niobium  
112 micron bcp 1:1:2



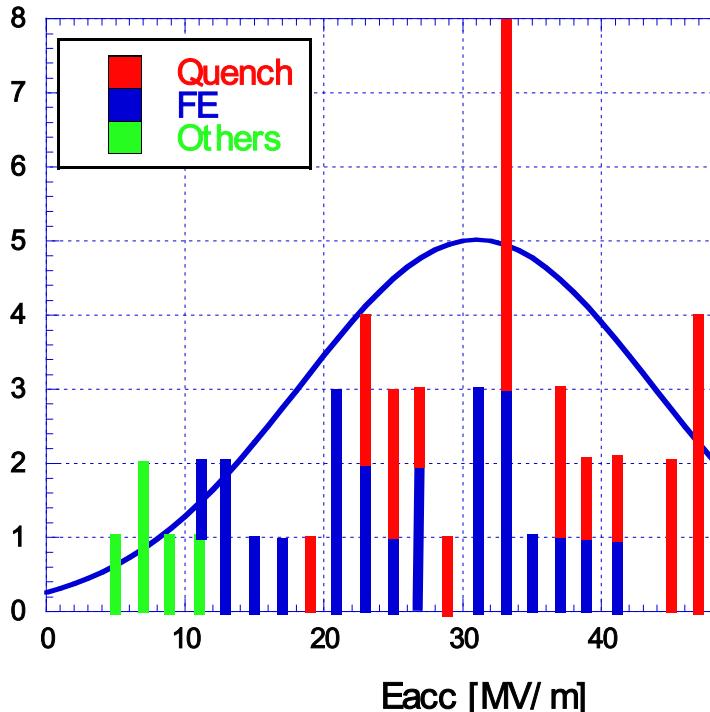
October 15-19, 2007

# Cavity fabrication~ surface treatment at KEK

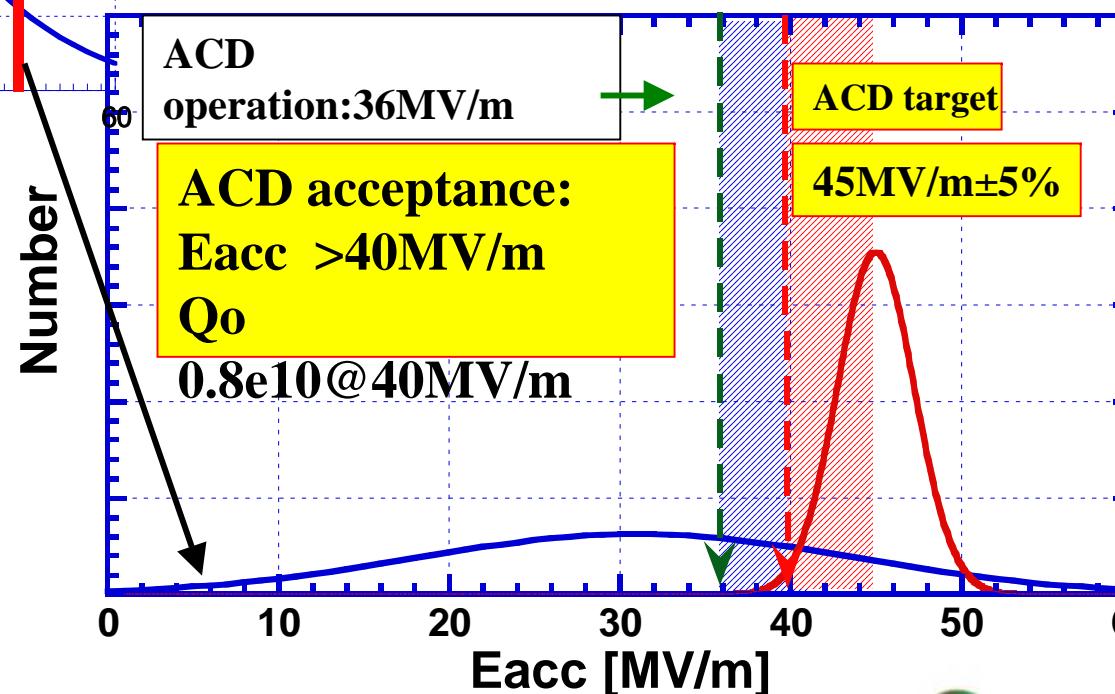
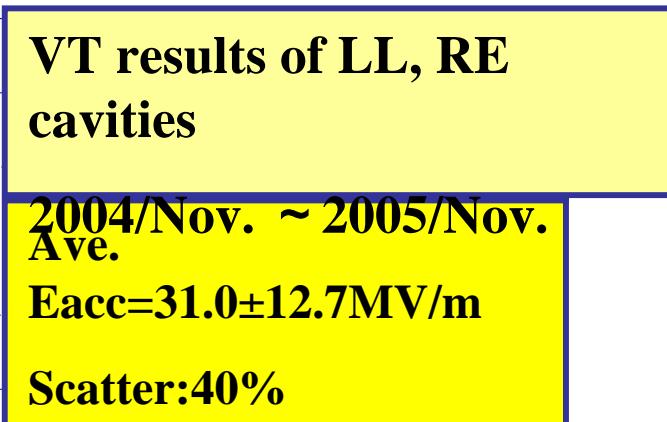


\*photo : LL-  
cavity

# Scattering of VT results at KEK :2004/Nov.~ 2005/Nov.

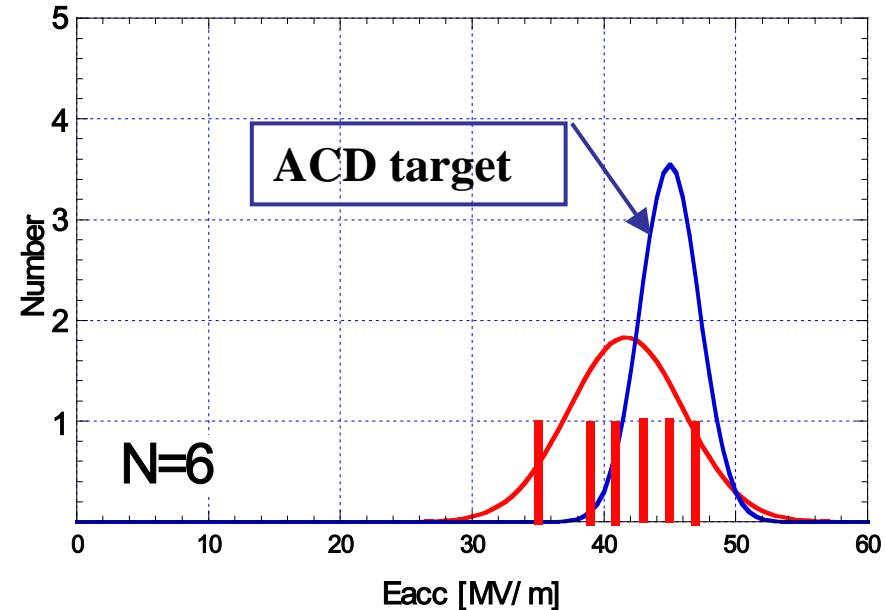
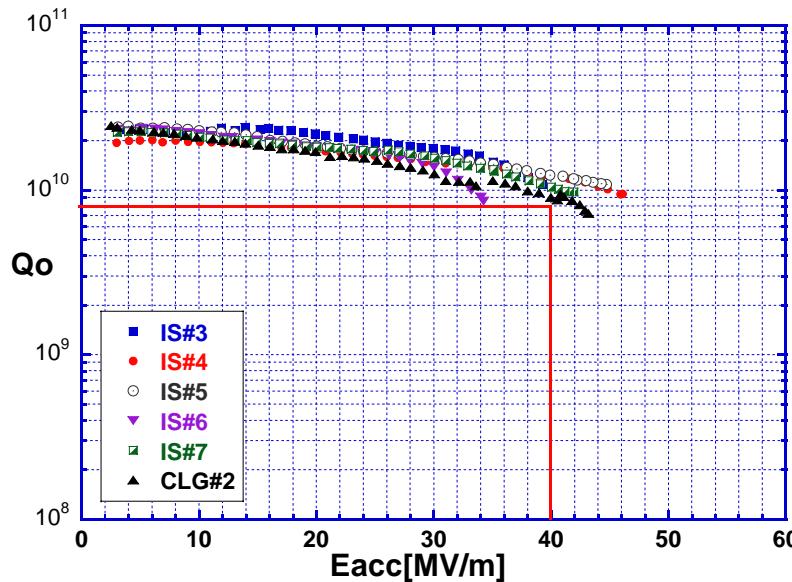


Need more reliable recipe



# Recipe : CBP+CP+Anneal+EP(80 $\mu$ m)

+EP(3 $\mu$ m, fresh, closed)+HPR+Baking

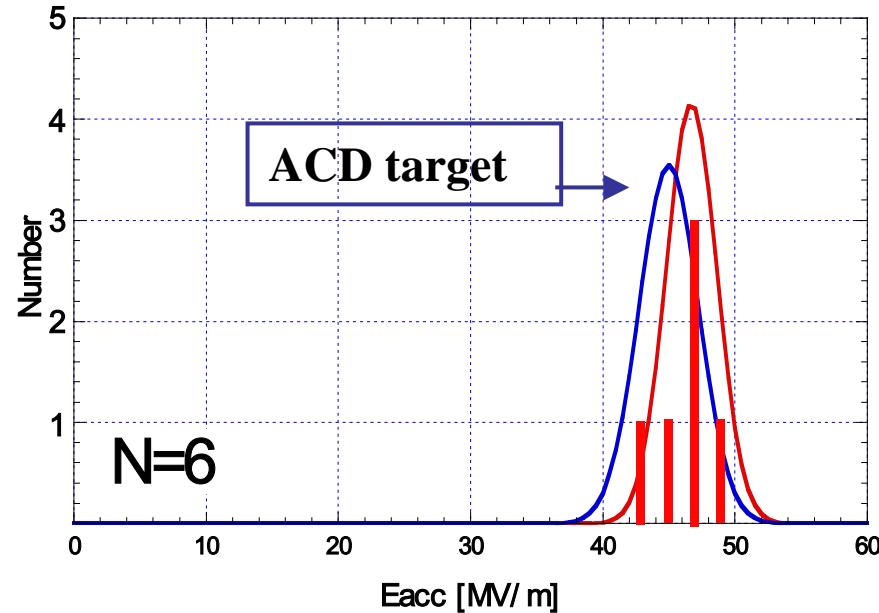
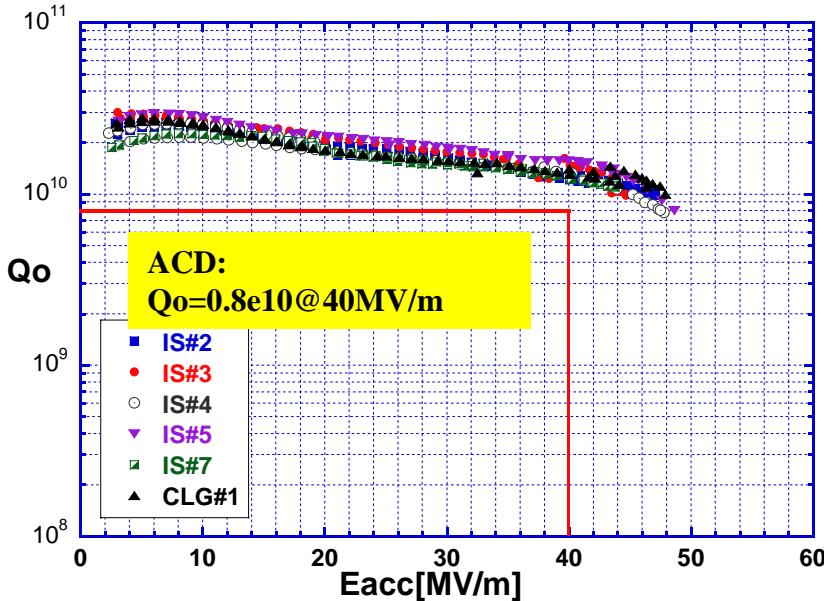


Ave.  $E_{acc}=41.7 \pm 4.4$  MV/m,

Scattering: 11%, Acceptability@40MV/m(ACD): 67%

|                 |      | IS#3   | IS#4   | IS#5    | IS#6   | IS#7    | CLG#2  |
|-----------------|------|--------|--------|---------|--------|---------|--------|
| EP(80+3)<br>+HF | Eacc | 42.00  | 46.10  | 44.70   | 34.25  | 39.30   | 43.80  |
|                 | Qo   | 9.72e9 | 9.47e9 | 1.08e10 | 8.56e9 | 1.03e10 | 3.46e9 |

# Recipe : +EP(20 $\mu$ m)+EP(3 $\mu$ m, fresh, closed) +HPR+Baking

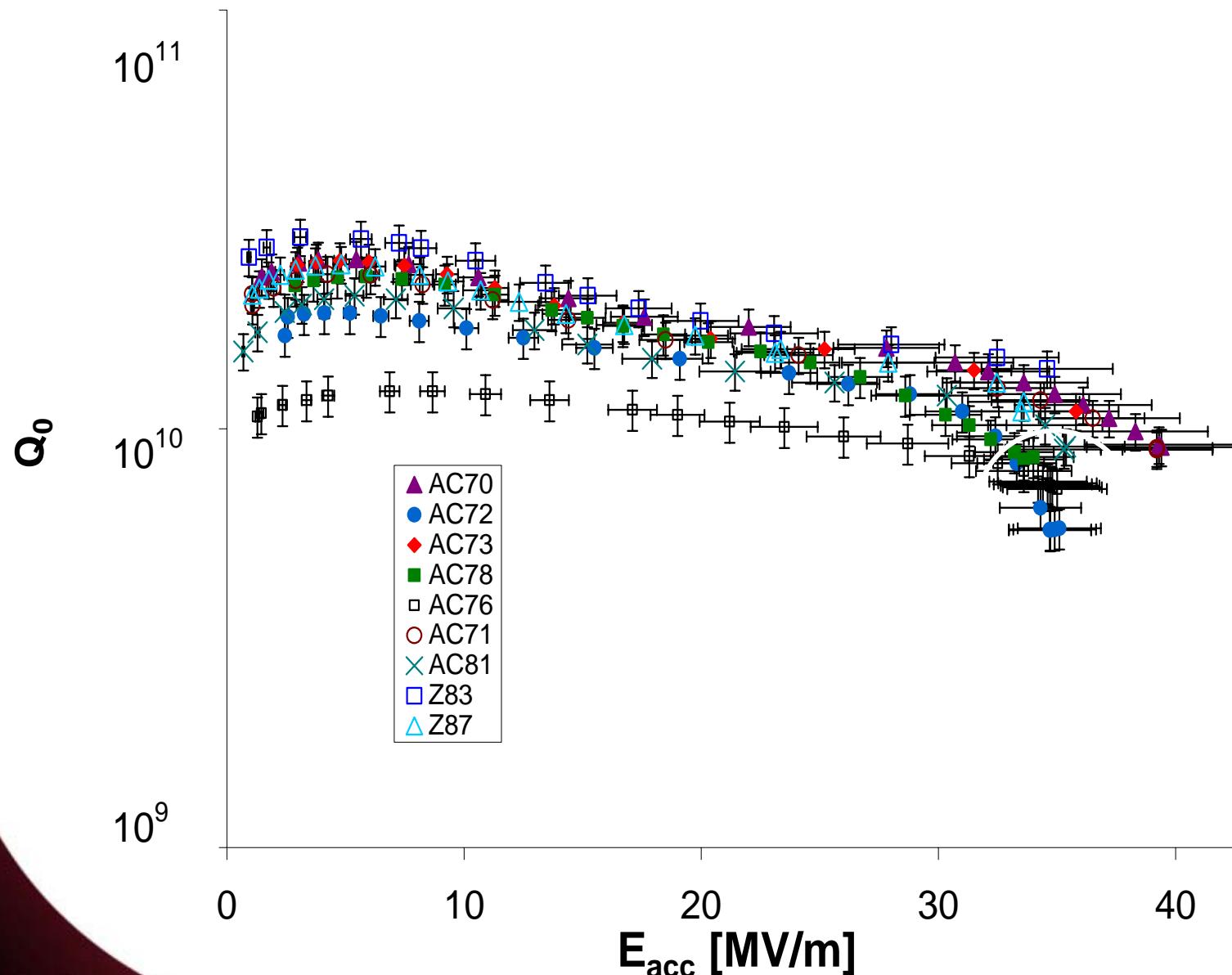


**Ave.  $E_{acc}=46.7 \pm 1.9\text{MV/m}$**

**Scattering:4%, Acceptability@40MV/m(ACD):100%**

|                   |      | IS#2    | IS#3    | IS#4    | IS#6    | IS#7    | CLG#1  |
|-------------------|------|---------|---------|---------|---------|---------|--------|
| +EP(20+3)<br>+HF* | Eacc | 47.07   | 44.67*  | 47.82   | 48.60*  | 43.93*  | 47.90* |
|                   | Qo   | 1.06e10 | 0.98e10 | 0.78e10 | 0.80e10 | 1.17e10 | 1.0e10 |

# Principle Potential of EP + Bake Process



# XFEL

- L.Lilje, SRF2007, paper MO102
- D.Kostin et al, SRF2007, paper WEP05

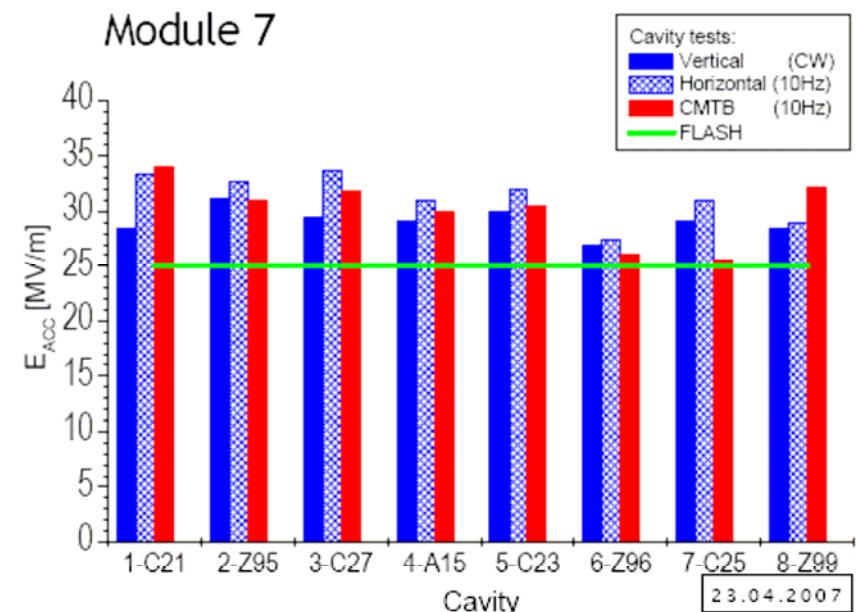
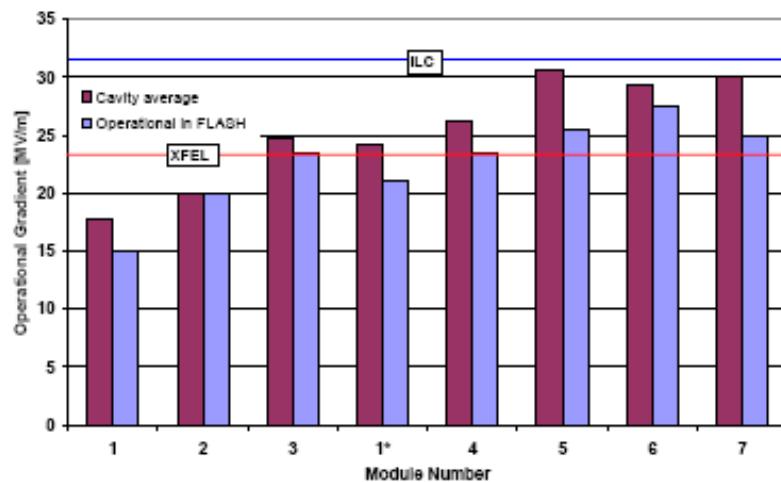
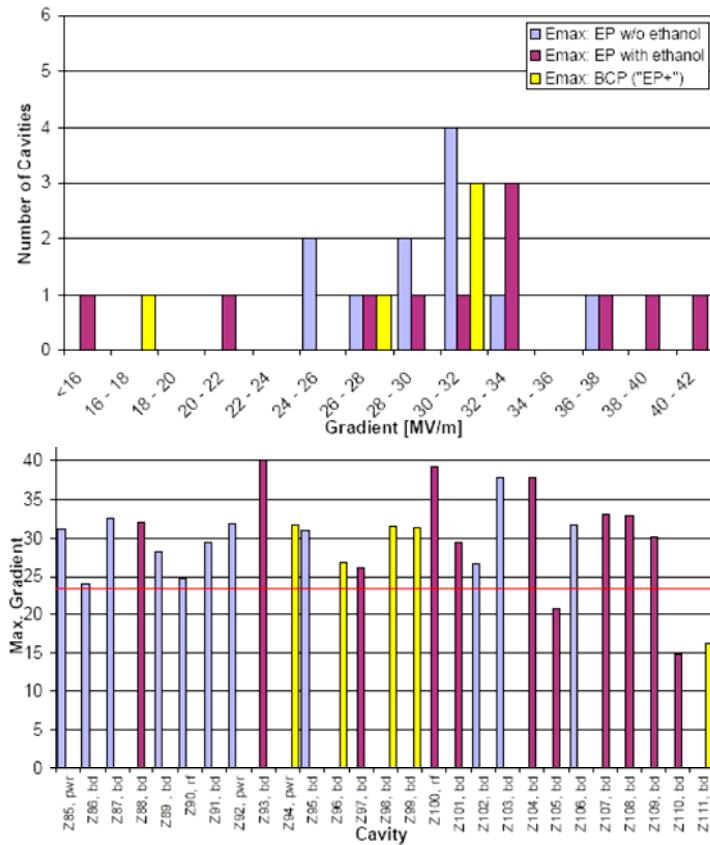


Figure 5: New FLASH SRF module 7 gradients.

# XFEL (2)

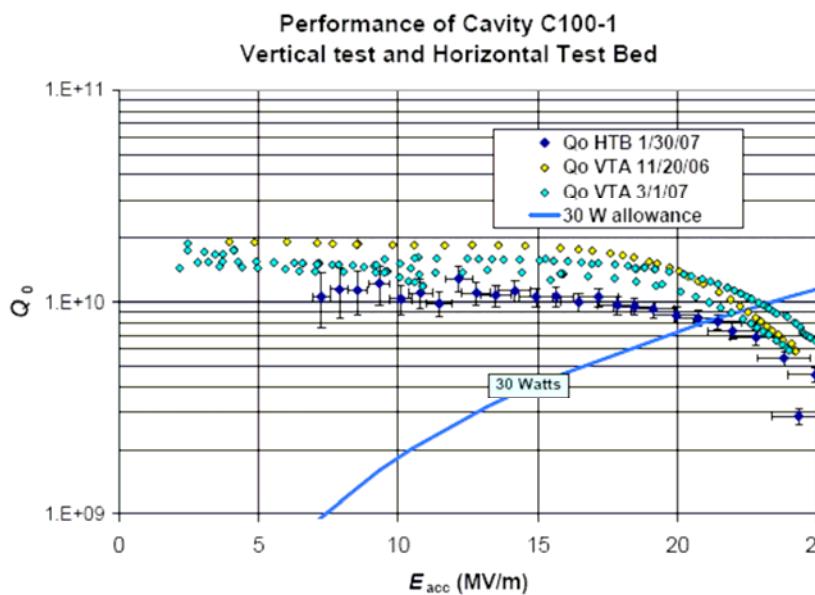
- D. Reschke et al.; SRF2007, paper TUP77
  - Last 9-cell cavity production: 30 cavities, RRR  $\sim 300$
- 150  $\mu\text{m}$  EP, 800C heat treatment, 50  $\mu\text{m}$  EP(ethanol rinse, 10  $\mu\text{m}$  bcp)



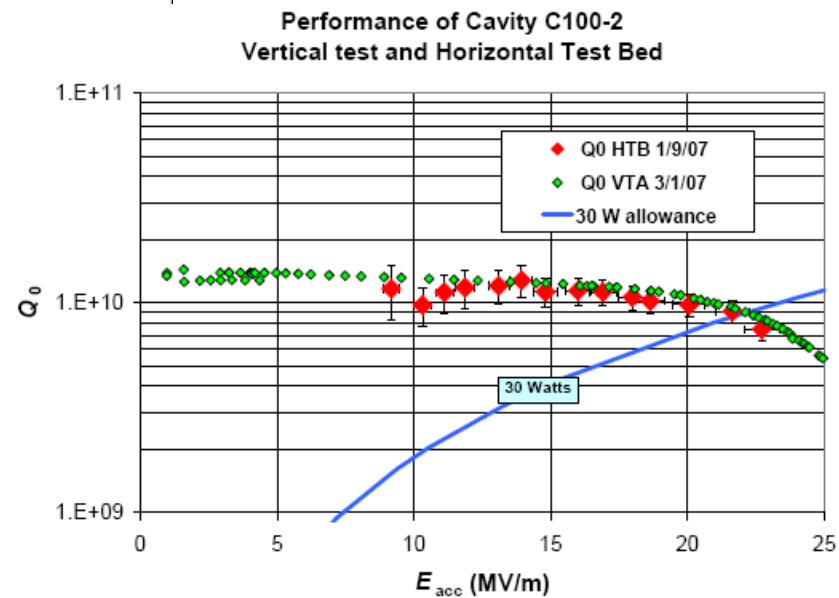
| Preparation:<br><b>First preparation</b>           | $\langle E_{\text{acc,max}} \rangle$<br>[MV/m] | $\langle E_{\text{acc,usable}} \rangle$<br>[MV/m] |
|--|--|---|
| EP without ethanol                                 | $26 \pm 4$                                     | $24 \pm 5$  |
| EP with ethanol rinse<br>(without Z110; see below) | $26 \pm 6$                                     | $23 \pm 6$  |
| Short BCP ("EP+")<br>(without Z111; see below)     | $29 \pm 2$                                     | $27 \pm 4$  |

# CEBAF Upgrade

- C.Reece et al.; SRF 2007, paper WEP31



Low Loss 7-cell cavities



# SNS Cavities: 805 MHz, 6 cells



Figure 1: SNS  $\beta=0.61$  (a) and  $\beta=0.81$  (b) cavities.

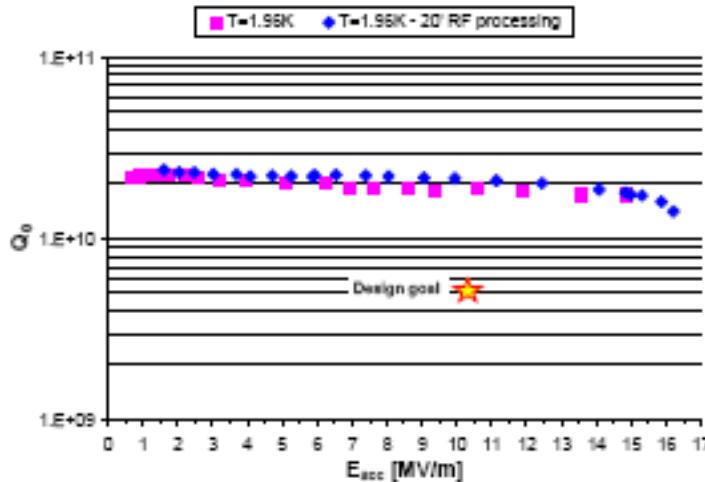


Figure 2: SNS  $\beta=0.61$  vertical test results.

Table 1: SNS cavities' electromagnetic parameters.

| Cavity $\beta$                 | 0.61    | 0.81    |
|--------------------------------|---------|---------|
| Frequency [MHz]                | 805.000 | 805.000 |
| $E_{peak}/E_{acc}$             | 2.71    | 2.19    |
| $B_{peak}/E_{acc}$ [mT/(MV/m)] | 5.72    | 4.72    |
| $R/Q [\Omega]$                 | 279     | 483     |
| $G (=R_iQ_0) [\Omega]$         | 179     | 260     |
| Cell-to-cell $k$ [%]           | 1.53    | 1.52    |
| $K_L$ [Hz/(MV/m) $^2$ ]        | -2.07   | -0.43   |

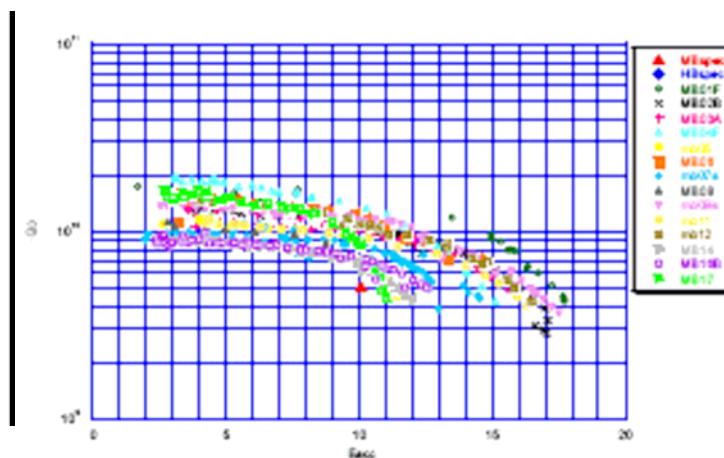


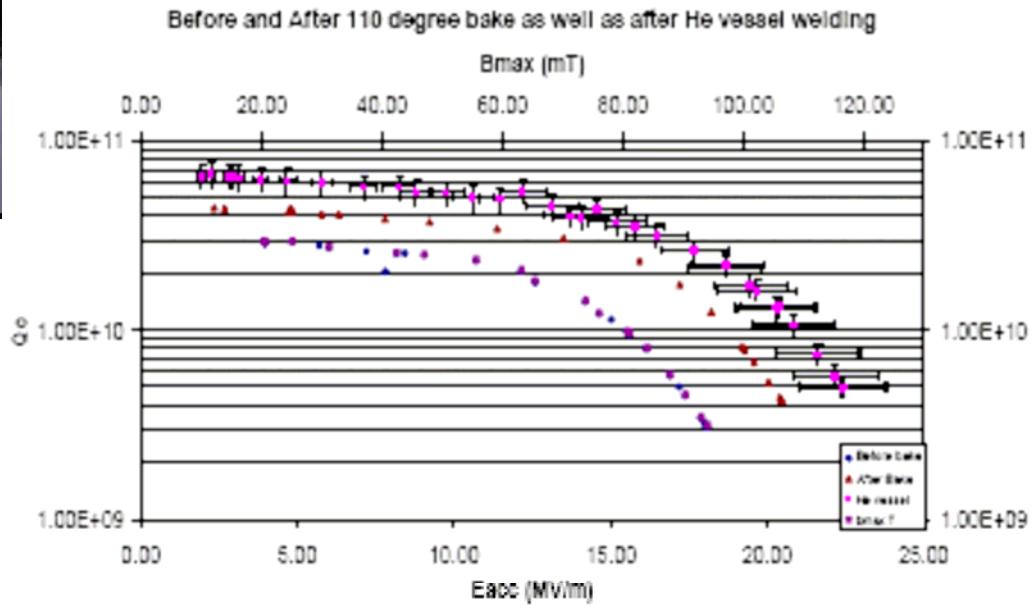
Figure 4.  $Q_0$  vs  $E_{acc}$  for SNS Medium Beta Cavities

# eRHIC 5-cell cavity



Table 1: Cavity Characteristics

| Diameter (cm)         | 17                   | 19                 |
|-----------------------|----------------------|--------------------|
| Freq (MHz)            | 703.75               | 703.75             |
| $G$ ( $\Omega$ )      | 225                  | 200                |
| $R/Q$ ( $\Omega$ )    | 807                  | 710                |
| $Q$ @ 2k              | $4.5 \times 10^{10}$ | $4 \times 10^{10}$ |
| $E_p/E_a$             | 1.97                 | 2.10               |
| $H_p/E_a$ (mT/MV/m)   | 5.78                 | 5.94               |
| cell to cell coupling | 3%                   | 4.8%               |



A. Burill et al, PAC 2007, paper WEPMS088

ANL Scaled Crab Cavity Tests  
at  
Jefferson Lab

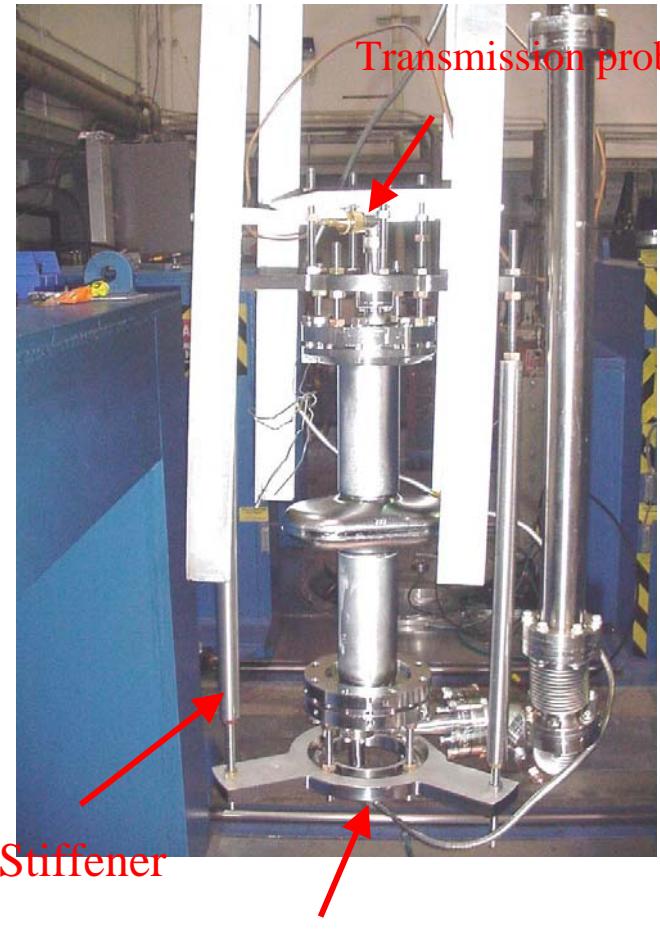
# Cryogenic Test(1)

After Fabrication the cavity was tested 4 times so far

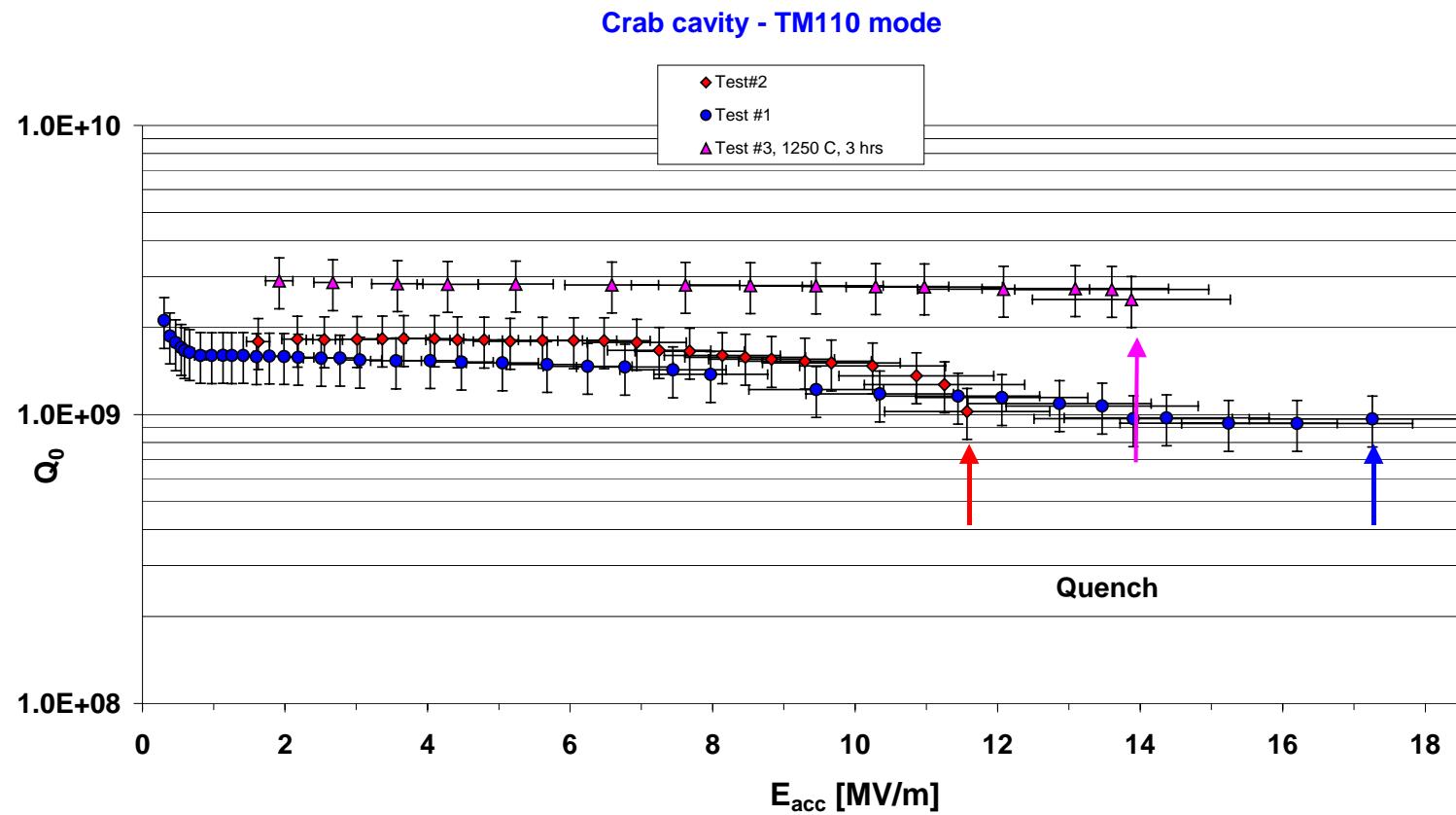
- Test #1: app. 100 micron of bcp (1:1:1) , HPR and assembly in class 10 clean room
- Test #2: add. 25 micron of material removal by bcp (1:1:1), HPR assembly in class 10
- Prior to test # 3 the cavity was post-purified in Ti- box at 1250 C for 3 hrs
- Test #3: app. 40 micron removed by bcp (1:1:1), HPR and clean room assembly
- Test #4: add. 25 micron of material removal by bcp (1:1:1), HPR and clean room assembly; preliminary result:  
 $E_t \geq 18 \text{ MV/m}$ ,  $H_{\text{peak}} \geq 110 \text{ mT}$

## Cryogenic Test(2)

- Cavity on test Stand with Stiffening Rods
- $f \leq 2804$  MHz

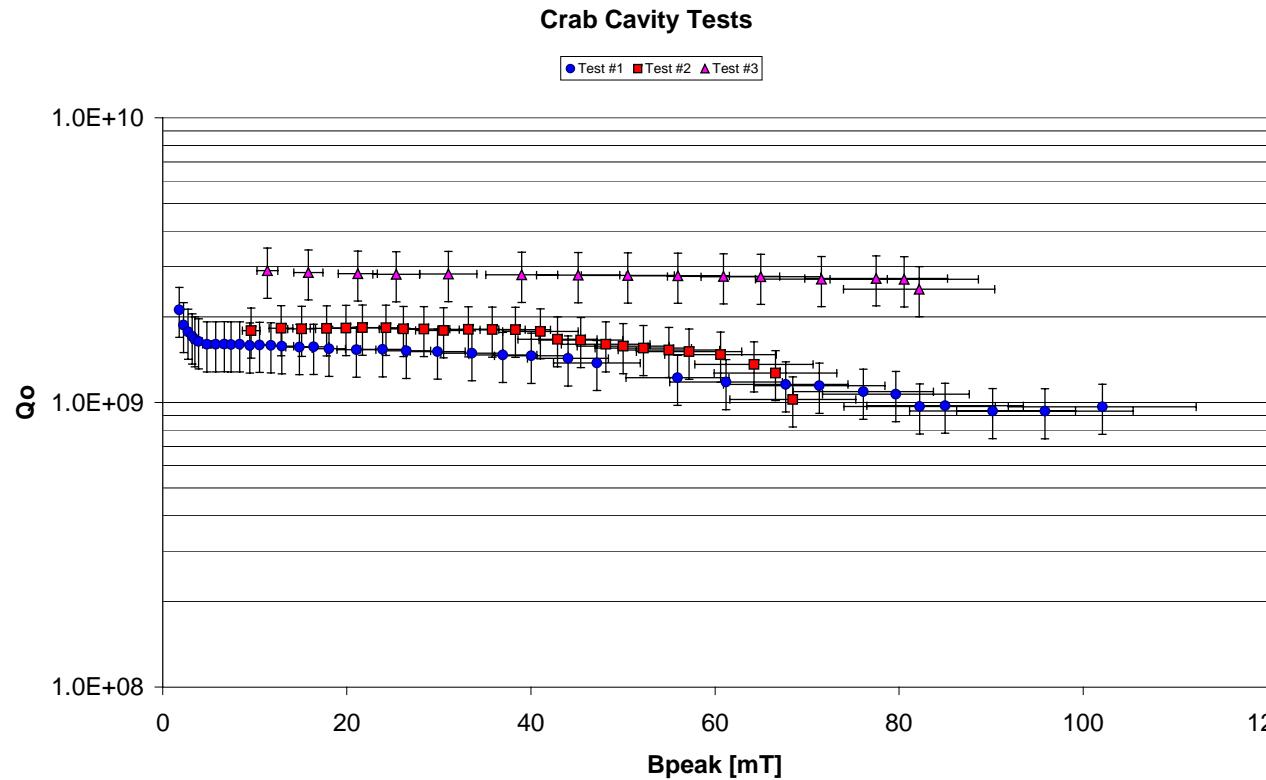


# Cryogenic Test(3)



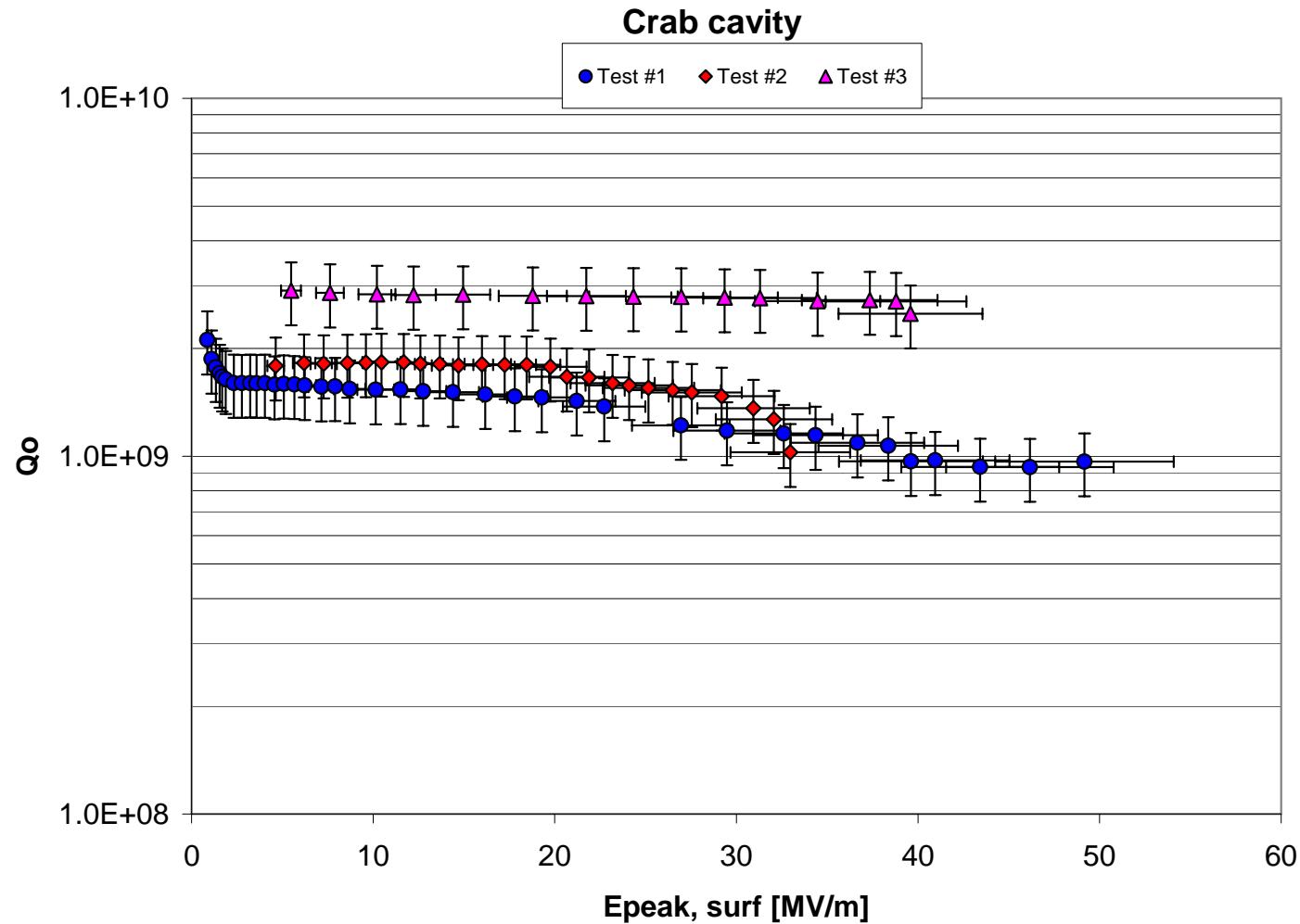
# Cryogenic tests

## Peak magnetic Surface Fields



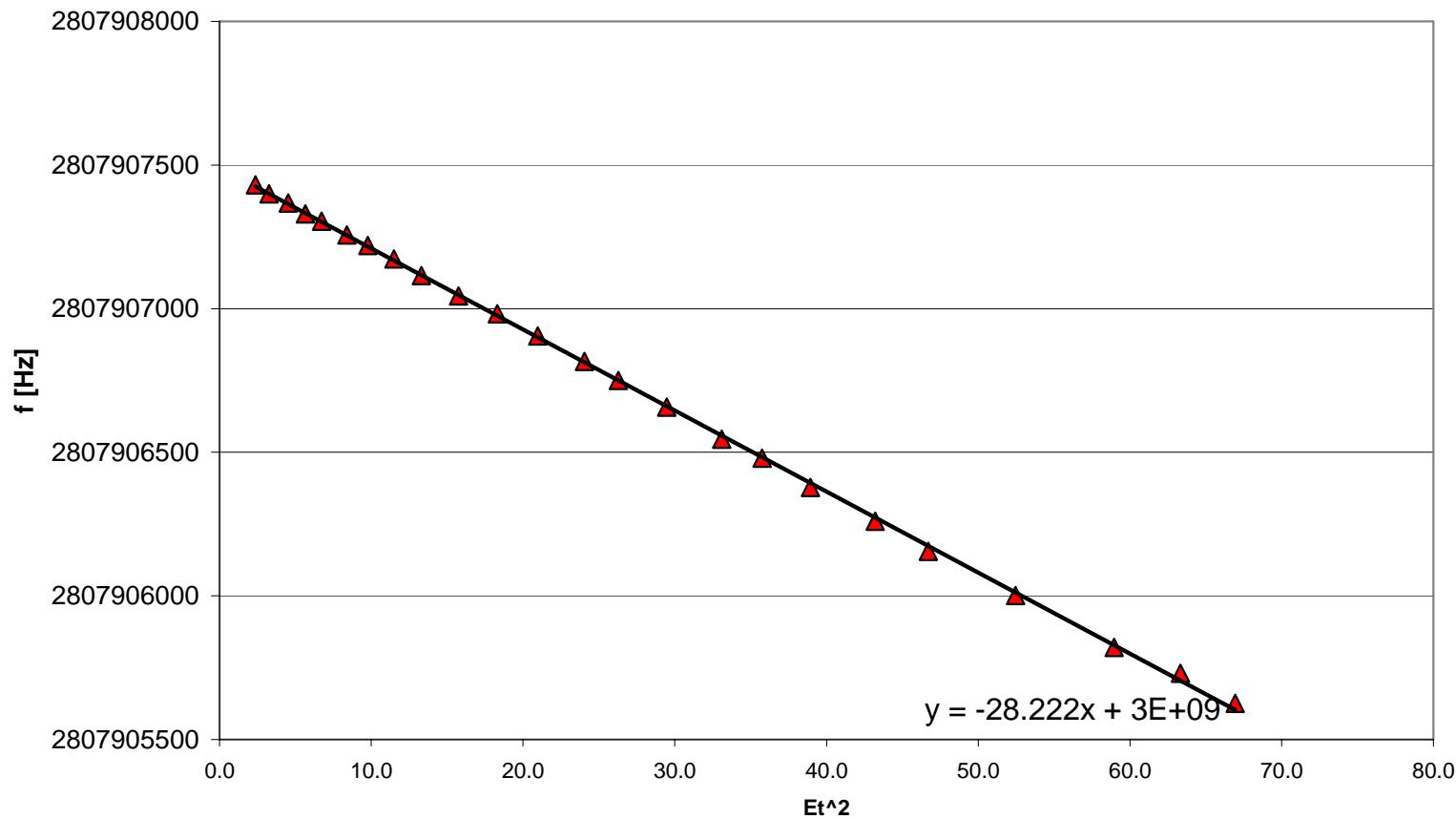
# Cryogenic Test

- Peak Surface Electric Fields



# Lorentz-Force Detuning

**Lorentz Force Detuning  
Test #2**



# KEK Crab Cavity

K. Hosoyama et al.; Proc. 9<sup>th</sup> SRF workshop, p. 540 ( 1997)

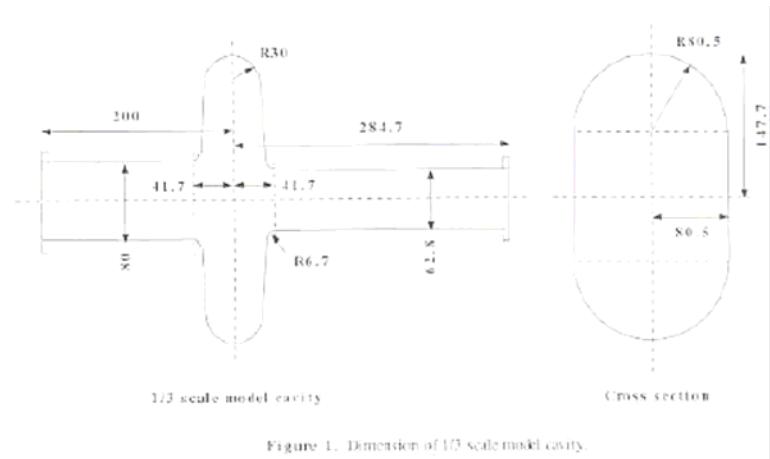


Figure 1. Dimension of 1/3 scale model cavity.

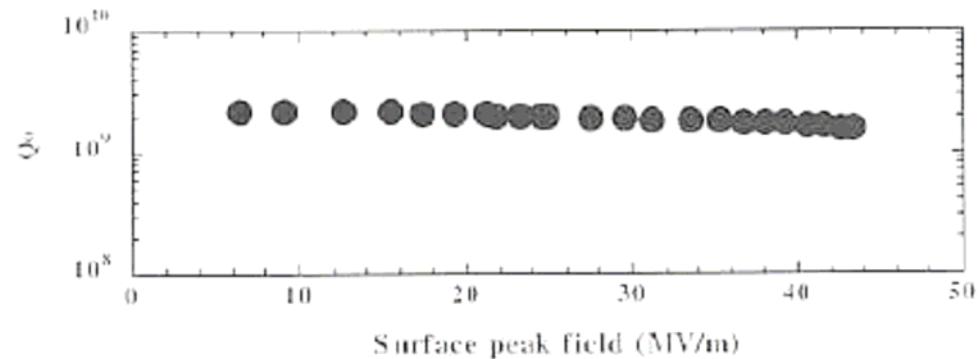


Figure 2.  $Q_c$  vs surface peak field.

# KEKB Crab Cavity

- K.Hosoyama et al, SRF2007, paper MO405

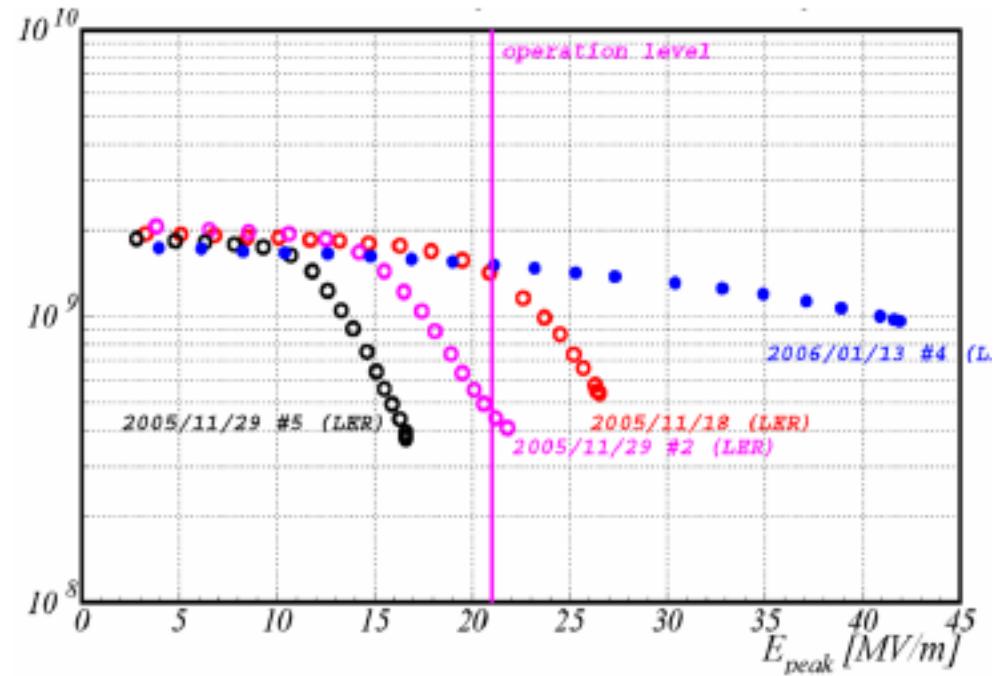


Figure 7: Measured  $Q_0$  of KEKB crab cavity for LER.

# Challenges (1)??

- For once, the specifications for the CRAB cavities are reasonable compared to the status of the technology
- Therefore, the challenges seem to be modest?
- With today's “ simple” technology (bcp, HPR, clean room assembly, possibly large grain niobium) one can “readily” achieve B-fields of  $\geq 100$  mT,  $E_{peak} \geq 40$  MV/m in single cells or even in multi-cells of a moderate number – this is probably true for  $f \geq 700$  MHz nad VTA testing
- Lower frequencies: not sure
- The challenges are to maintain such “VTA” performances in a complicated cryo-module environment with many auxiliary parts attached to the cavity ( multi-cell)

## Challenges (2)??

- The challenges seem to be more of an “engineering nature” such as input coupler design, dampers, tuners – compatible with clean assemblies
- Most dangerous is contamination, causing possibly MP and definitely FE
- Large size ( KEKB) is always a challenge in treatment and assembly