UPDATE ON R&D ACTIVITIES IN THE AMERICAS -A SELECTION-

Peter Kneisel

Jefferson Lab

Instrumentation/Diagnostics

Material Studies

Cavity Developments

Newer Test Results

T-Mapping/Quench Detection

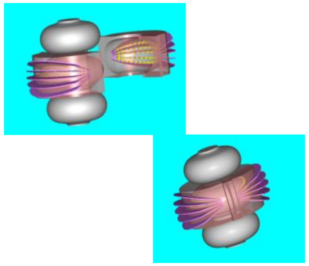
- 9-cell T-mapping systems are being developed/implemented at FNAL and LANL
- A two cell T-mapping system has been implemented and used at Jlab
- T-mapping systems for single and multi-cells are implemented at FNAL

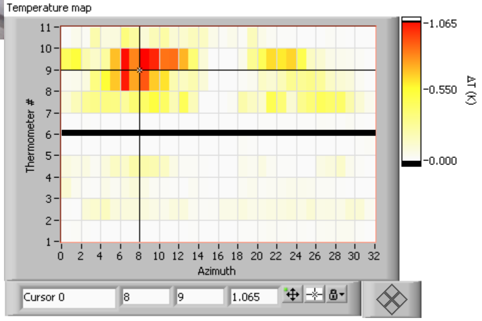
LANL :4608 C-Resistors

T.Tajima et al, EPAC2008

JLab: 2-cells, 160 AB

G.Ciovati, private communication



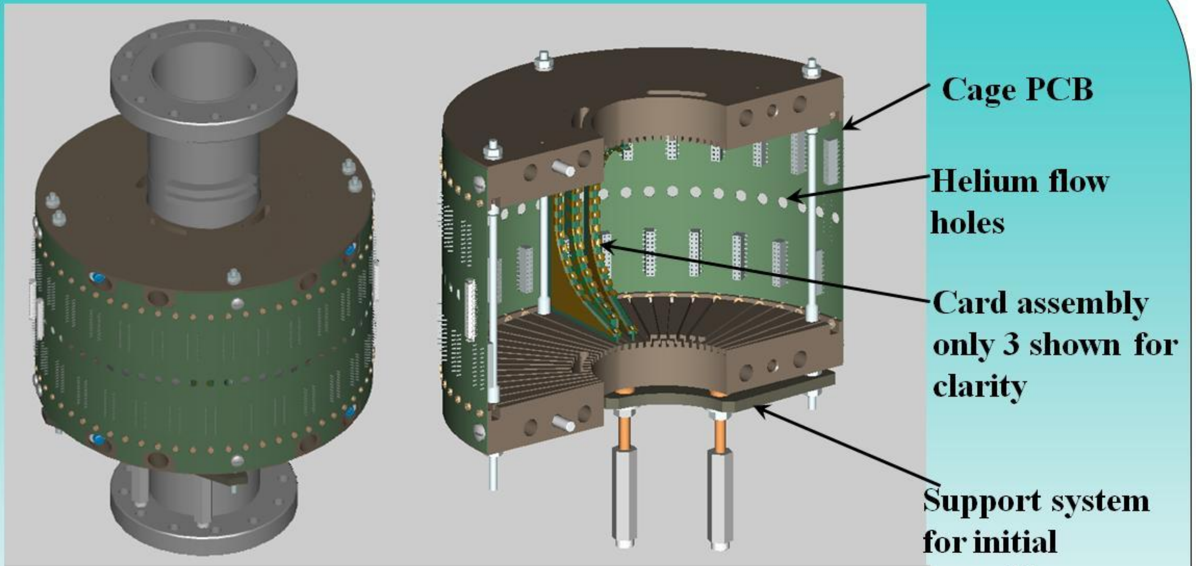


G.Slack

Eacc =36 MV/m

FNAL T-Mapping System[http://ilc.fnal.gov/new/dhanaraj.ppt]

Diagnostics- Thermometry



Prototype for single cell cavity

- Fermilab is developing a new thermometry system using silicon diode sensors to detect quench locations and hot spots
- The diodes are ~ 1mm^2 and 17 of them are mounted on a card and 60 such cards are mounted on each cell, i.e. ~1000 sensors/cell
- The main advantage of this system is multiplexing which drastically reduces the number of cables required

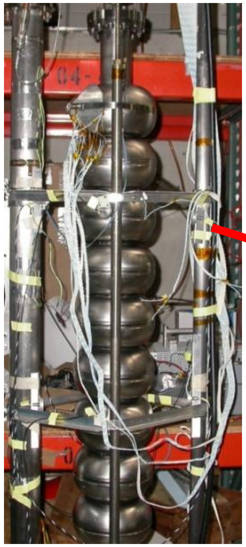
Second Sound for Quench Detection

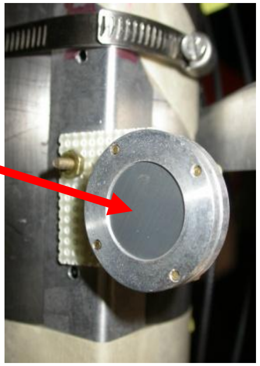
(Z.Conway et al.;LINAC 2008,THP036)

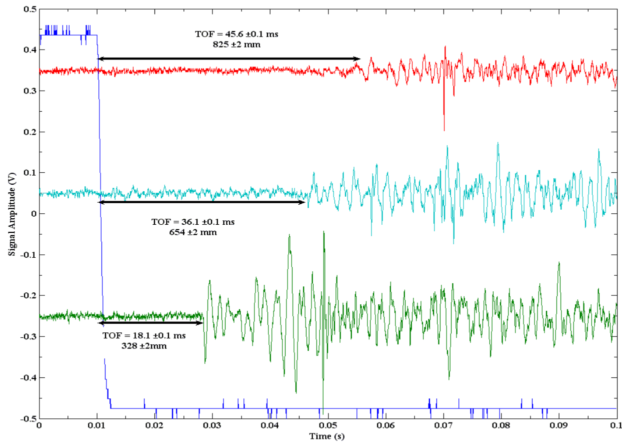
- A second sound temperature wave moves with a known velocity in He II

• Superfluid leak detectors placed at different places on a cavity assembly can detect the time difference of the arrival of the sound wave;from this the location of the break-down spot can be constructed with high accurac

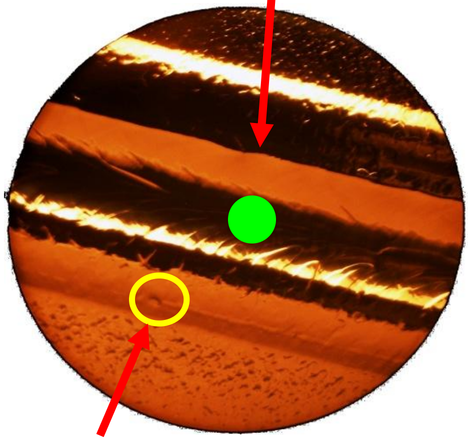
An elaborate T-mapping assembly is replaced with a few sensors







2nd sound



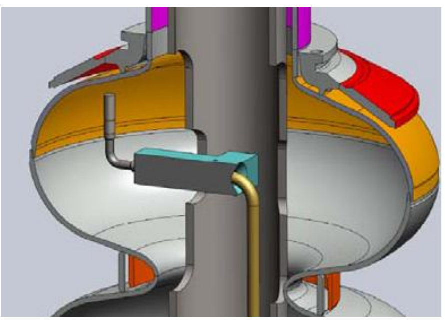
Defect

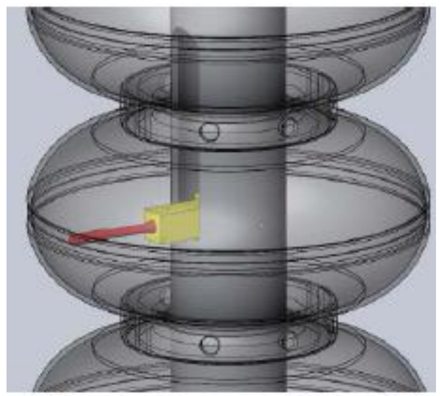
Optical Inspection Tools

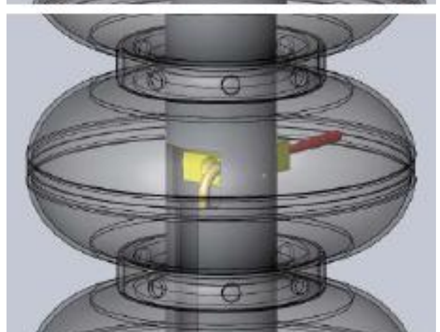
• After the introduction of the Kyoto University/KEK optical inspection system at the previous TTC meeting, inspection systems have been developed at

• Jlab, using a questar telescope (described later during the meeting)

• LANL, using an internal videoscope (T.Tajima et al.; EPAC 2008)







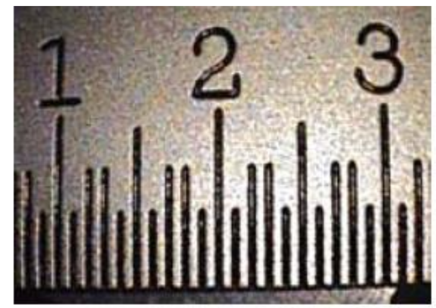
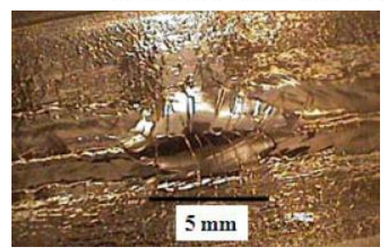


Figure 4: An image of a scale using a 5 mm videoscope. The smallest increment between lines is 254 microns.

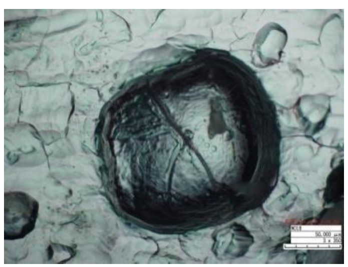


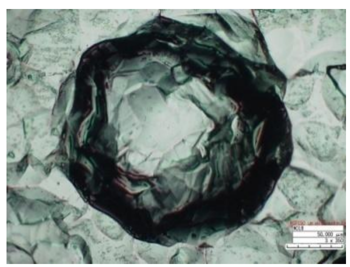
Material Studies(1)[R.Geng,H.Tian, Jlab; T.Saeki, KEK]

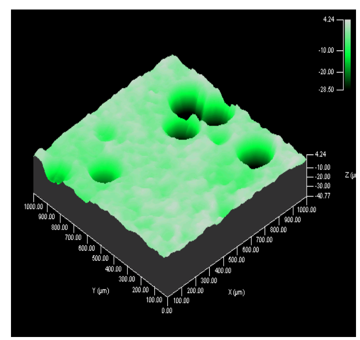
- Optical inspections have revealed that e.g.“pits” in the heat effected zone can cause quenches
- These “pits” cannot be removed by addional BCP or EP, still leaving sharp edges behind
- Developments are underway at Jlab to use external EBW to eliminate these quench location

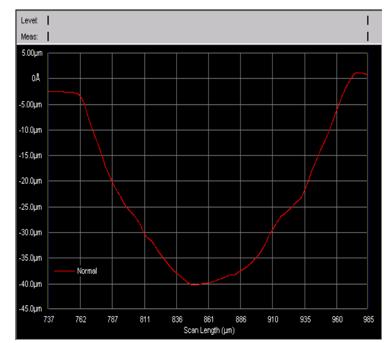
20 micron bcp

150 micron bcp, slope angle 26 - 47^0





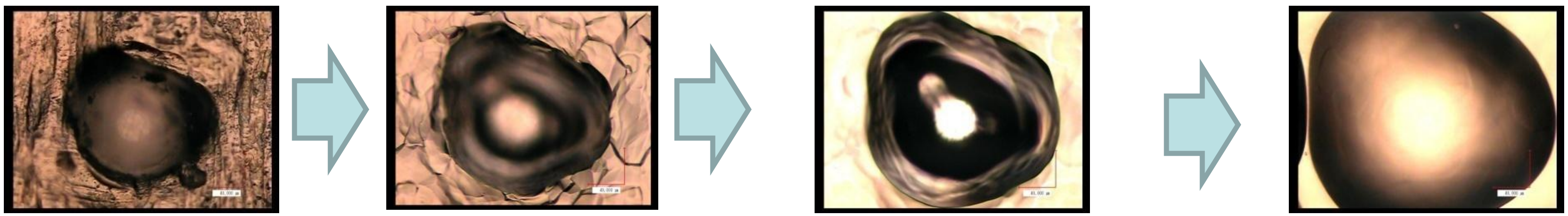




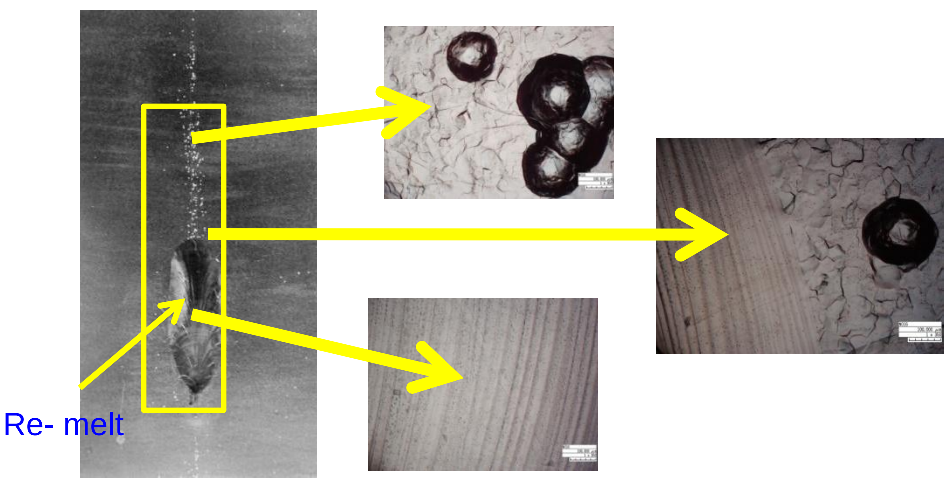
Material Studies (2)

- BCP + EP

As received | 30 μm bcp | bcp(30 μm)+EP(30 μm) | bcp(30 μm)+EP(30 μm)



- Re -Melting

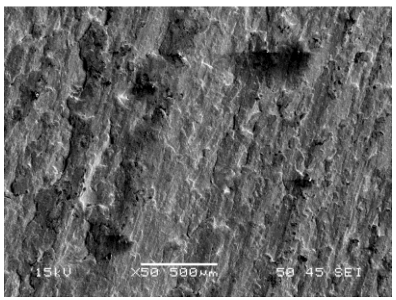


- Preliminary experiments show a pit cannot be removed by BCP or EP, even after heavy (~150μm)material removal.
- Preliminary profiling of pits show geometric features that could cause local magnetic field enhancement of ~ X2.
- Preliminary experiments show encouraging results of removing localized pits by using the E-beam re-melting method.
- Further studies under way to characterize relationship between pit features and quench behavior.

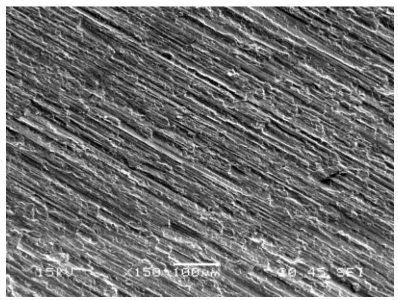
Material Studies (3) [C. Cooper et al.;ASC 2008, LX2]

- Different cutting methods were studied with respect to surface finish, deformation, contamination, cleaning, using electron microscopy, SIMS and energy dispersive X-ray spectroscopy: H - and O-concentration
- Milling, Diamond Saw, Band Saw ,Shearing, Water Jet (Garnet) EDM Wire

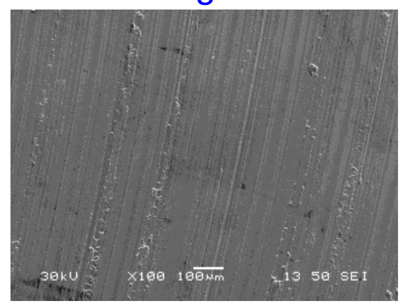
Band Saw



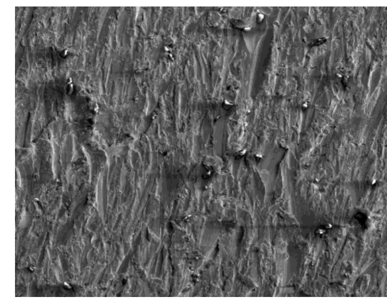
Diamond Saw



Milling



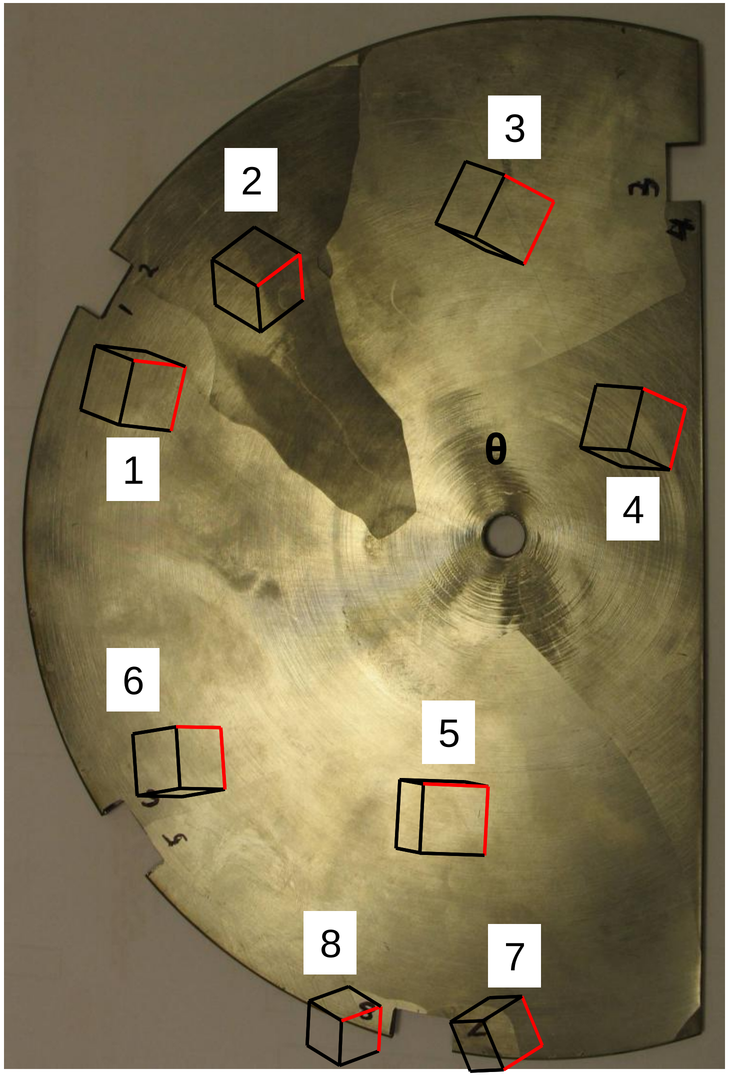
Garnet Water Jet



- Cutting contaminates the surface and changes the surface morphology.
- EDM wire cutting has the best application for Nb: smooth surface, little contamination, easy to remove by light bcp.
- Shear – inroduces bad deformation.
- Garnet water jet cutting badly deforms and contaminates the surfaces with garnet which is comprised of Si, Al, and Fe. 20 μm of BCP is still insufficient to remove contamination from the garnet water jet

Characterizing Large Grain Ingots

- MSU has started a collaborative effort to characterize the material properties of as-received large grain niobium ingots.



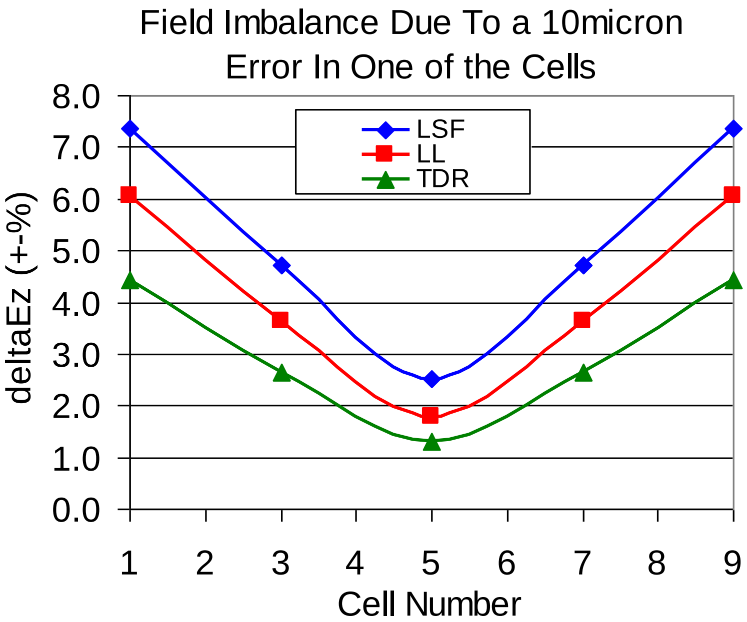
- Goals:
  - to measure how microstructure differs from ingot to ingot, vendor to vendor.
  - Characterize grain orientations, grain misorientations, dislocation density, vacancy density, hydrogen content, and thermal conductivity, RRR.
  - Are there any other properties of interest?

Example showing grain orientation measurements on an ingot slice

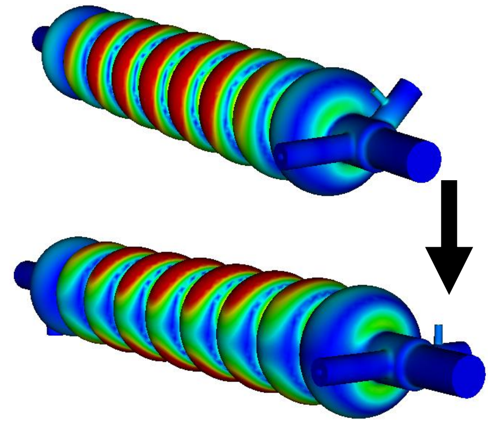
Cavity Shape: LSF, TDR and LL Comparison(Z.Li et al)

The Low Surface Field (LSF) Design

- 15% higher R/Q than TDR
- 11% lower Bs/Ea → 20% lower cryogenic heating
- 15% lower Es/Ea than LL design, same as TDR
- Field flatness 20% more sensitive to cell error than LL

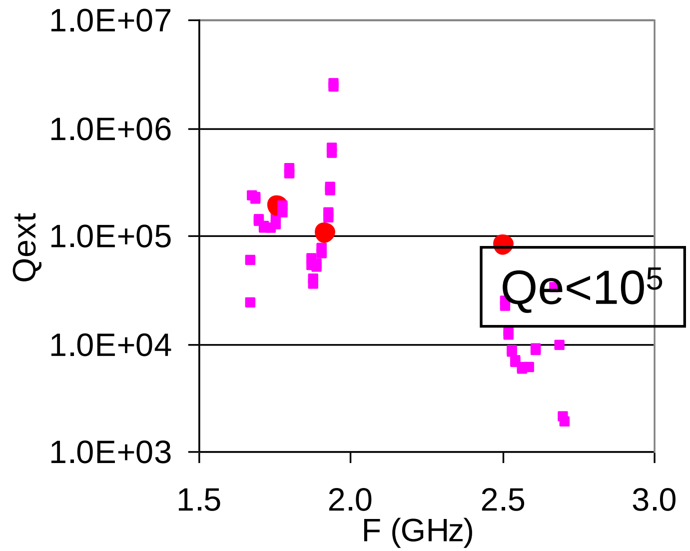


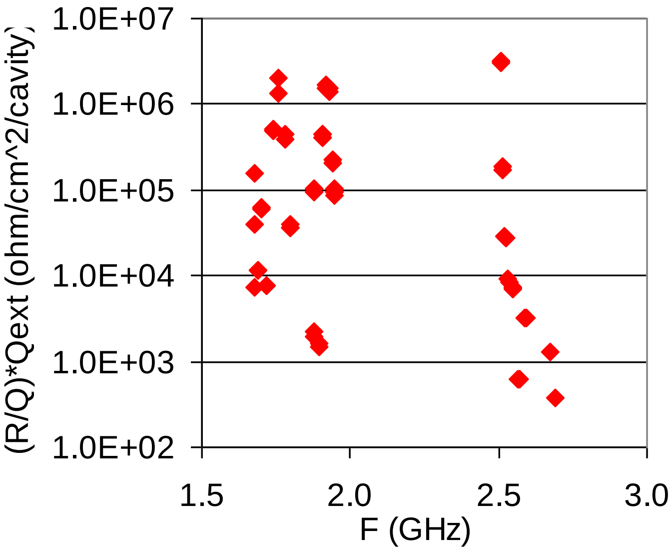
LSF Cavity:HOM Coupler Optimization(cont'd)



Improved coupling for high R/Q modes

New coupler orientation



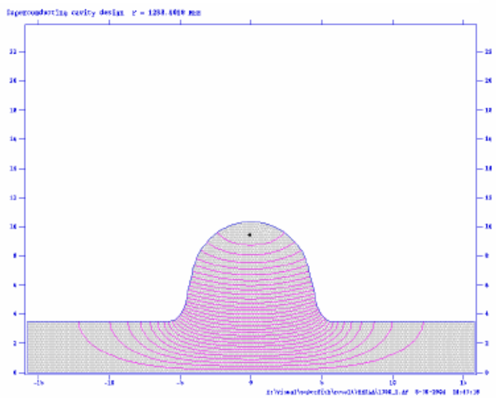


Cavity to investigate Magnetic Field Effect

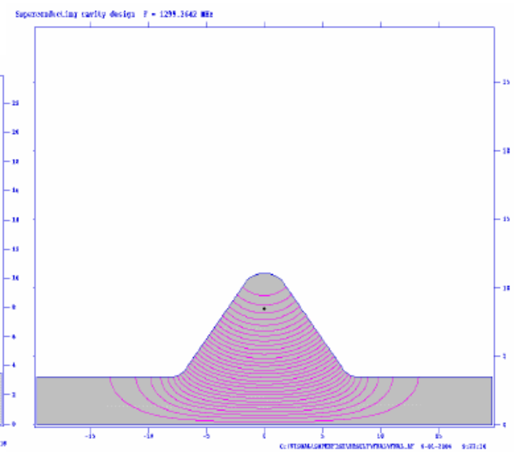
- Motivation: design a cavity with large Bp/Ep to avoid interference by FE
- Cavity quenches before FE starts

M.Ge et al;

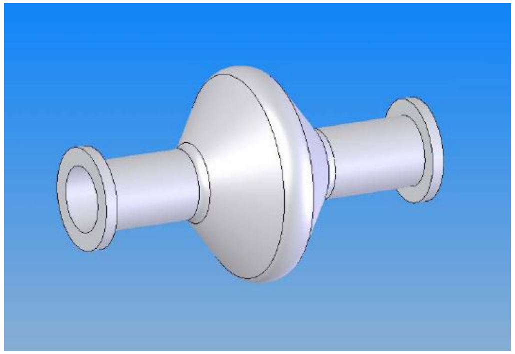
http://conferences.jlab.org/tfsrf

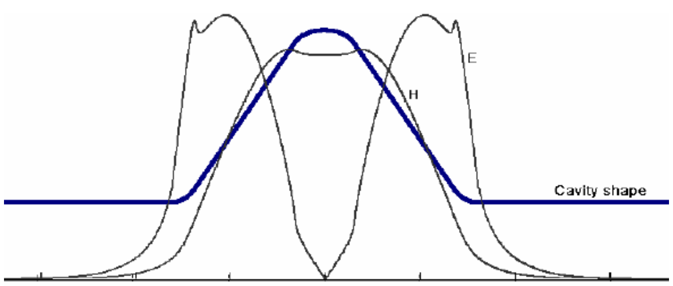


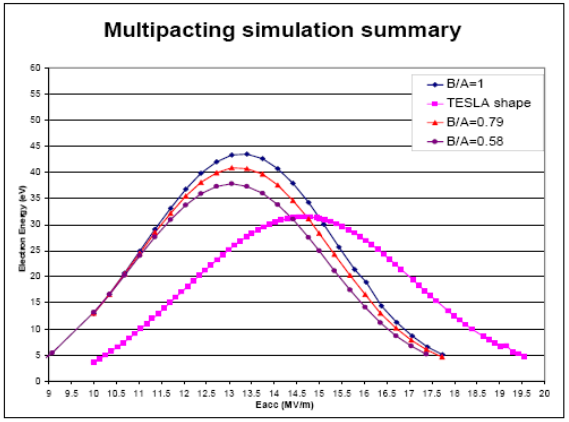
TESLA shape
α =13.3 deg
Hp/Ep=23 (Oe/(MV/m))



Shape for quench study
α =39.2 deg
Hp/Ep=45 (Oe/(MV/m))







The electron energy should be controlled within 40 eV.

Tool: Fishpact code

Other Test Cavity Designs

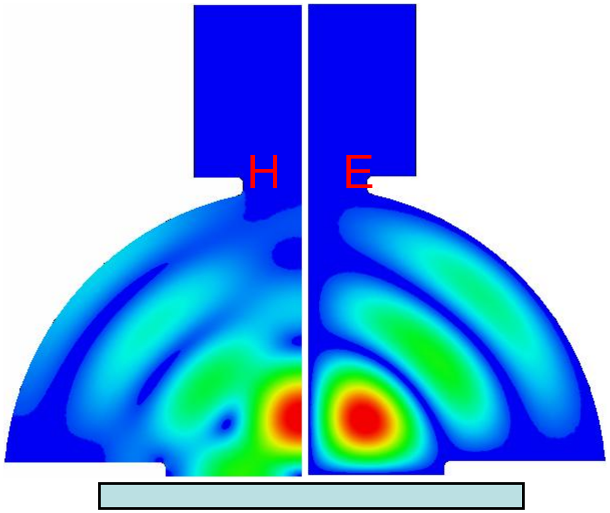
- SLAC/LANL: Hcrit measurements of various superconductors
- Texas A&M : TE011 with dielectric concentrator:Material studies

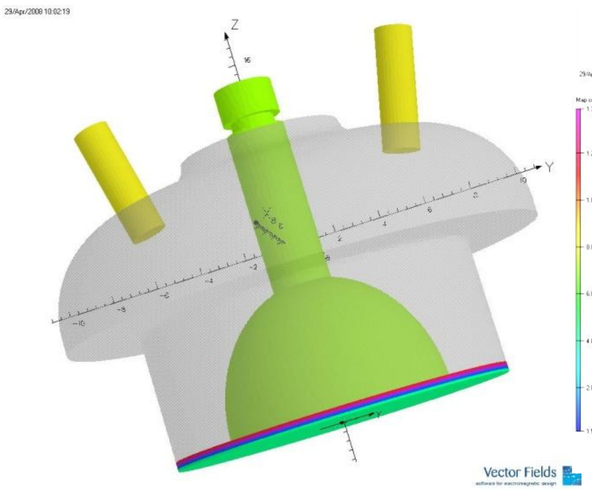
SLAC (C.Nantista,S.Tantawi)

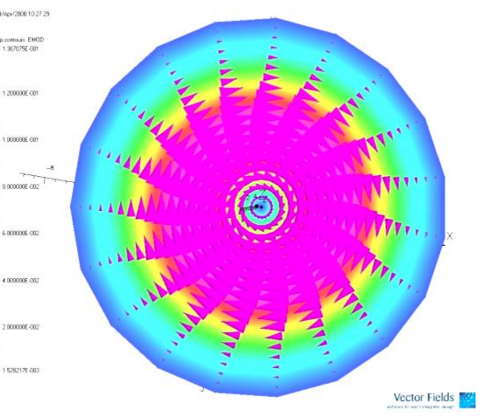
Compared to earlier version, magnetic
Field more concentrated on sample
Improved sensitivity

TEXAS A&M (N. Pogue et al.ASC2008)

TE_{011} mode – at wafer surface field purely azimuthal – no joint problem
Ultra-low-loss sapphire hemisphere has flat face just above sample

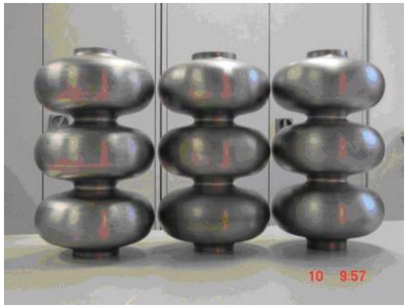


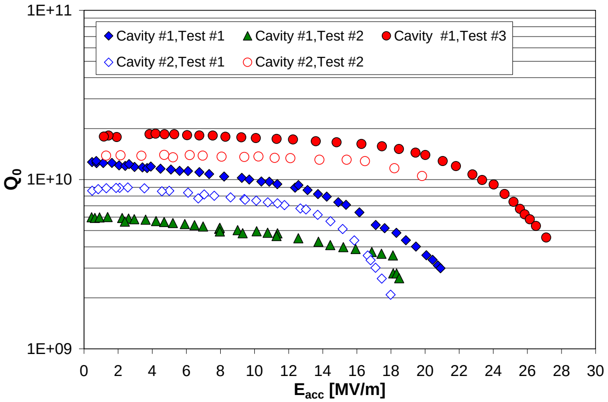


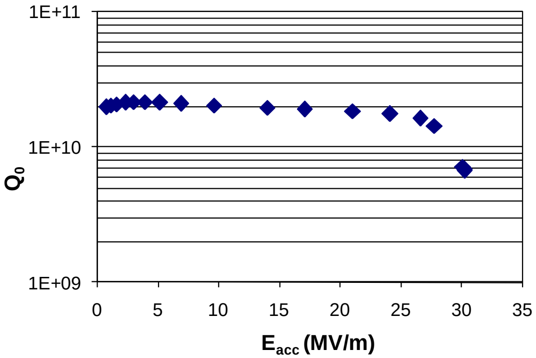


Seamless Cavities

- Technology has been developed at INFN(spinning) and DESY (Hydroforming) within the CARE program over several years
- 3-cell units were fabricated at DESY; three units combined to 9-cell cavity at DESY
- Two units completed, surface treated and tested at Jlab
- The 9-cell and the two 3-cell units performed well, indicating a sound technolgy; quench limits not yet reached because of Q-drop







W.Singer et al,LINAC2008,THP043

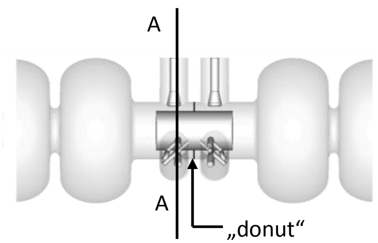
3-cells,tested at Jlab

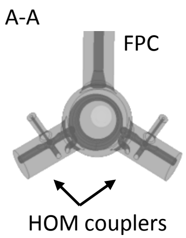
9-cell,tested at DESY

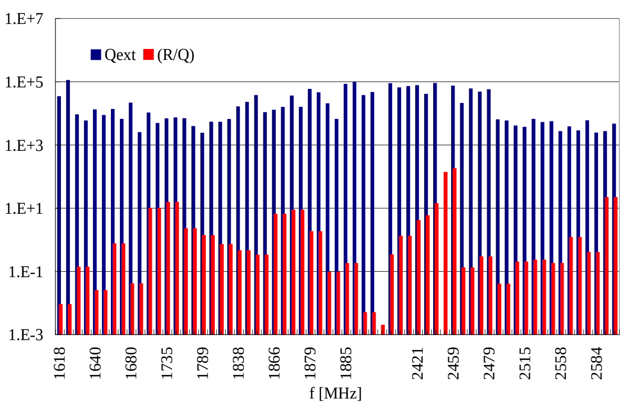
Coaxial Coupler for ILC-type Cavities

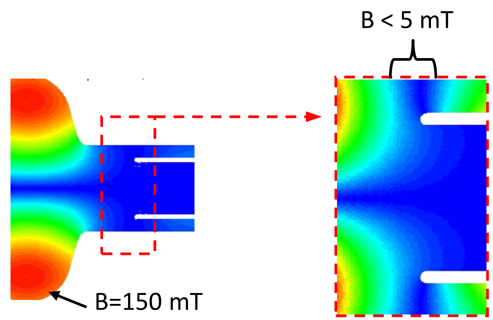
Advantages [J.Sekutowicz et al.; LINAC 2008, THP044]

- Field asymmetries and kicks from all couplers are minimized
- Shorter distance between cavities (9 cm for ILC), cavities remain cylindrical symmetric ⇨ hydroforming, seamless
- Independent cleaning of the coupling assembly

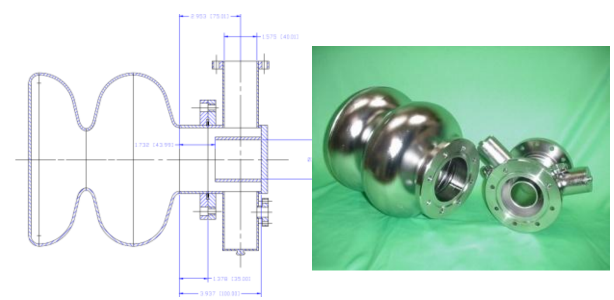








Field Distribution



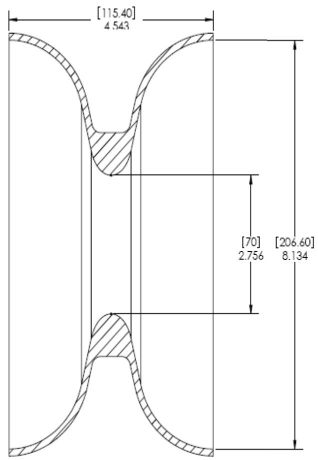
Test Cavity

Niowave Ingot Forming (T. Grimm)

- Use industrial metal forming processes to fabricate SRF cavity assemblies directly from large grain ingots

Nb

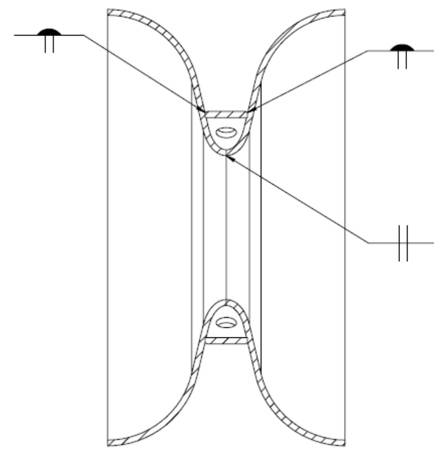
Ingot



Single piece

No welds

No stiffeners

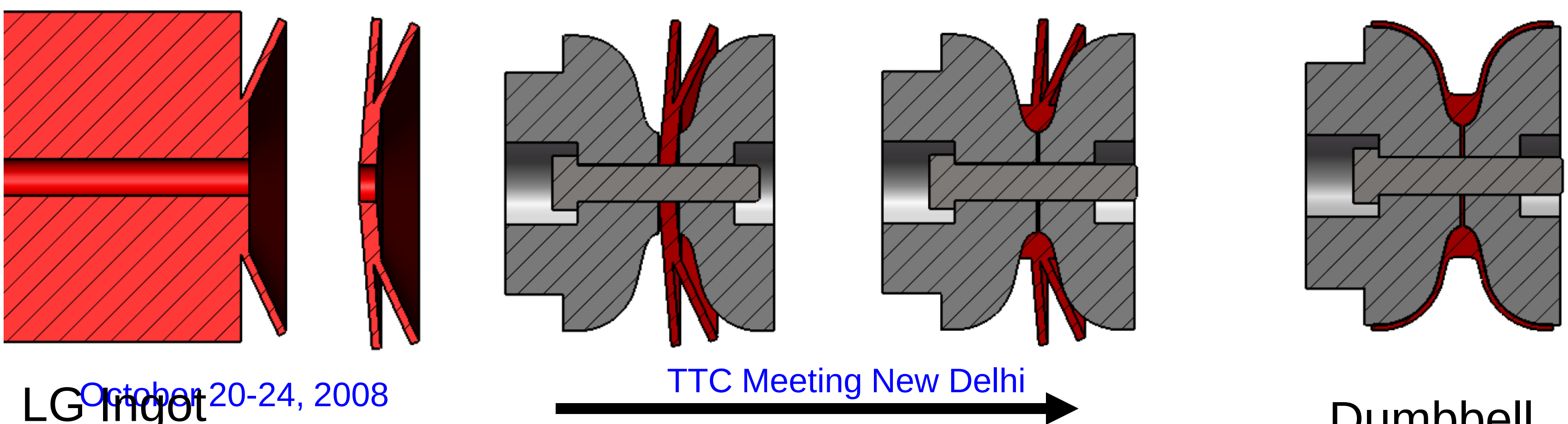


Multiple sheets

Multiple EBW

Stiffeners

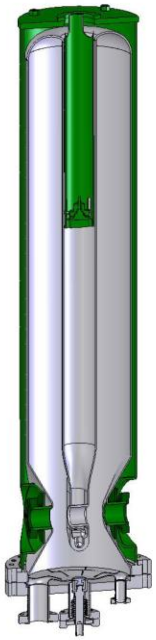
Multiple fixtures



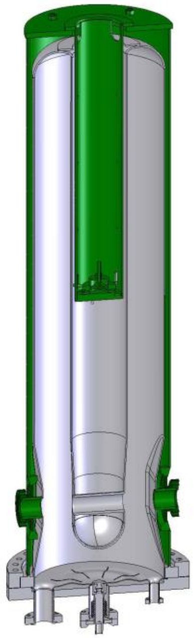
LG Ingot

Dumbbell

Cavity Development for Re-Acc [MSU]



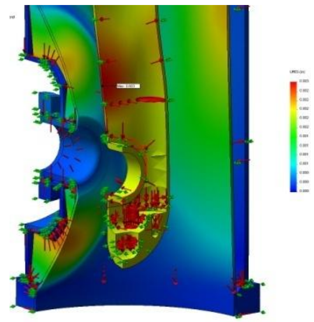
β_{opt}=0.041



β_{opt}=0.085

Type	λ/4	λ/4
Optimum β	0.041	0.085
Frequency	80.5 MHz	80.5 MHz
Epeak	16.5 MV/m	20.0 MV/m
Vacc	0.46 MV	1.18 MV
Eacc	4.84 MV/m	5.62 MV/m
Bpeak	28.2 mT	46.5 mT
Temperature	4.5 K	4.5 K
Length	0.095 m	0.21 m
Aperture	30 mm	30 mm

Cavity Production for ReA3 Project



df/dp modeling and cavity stiffening

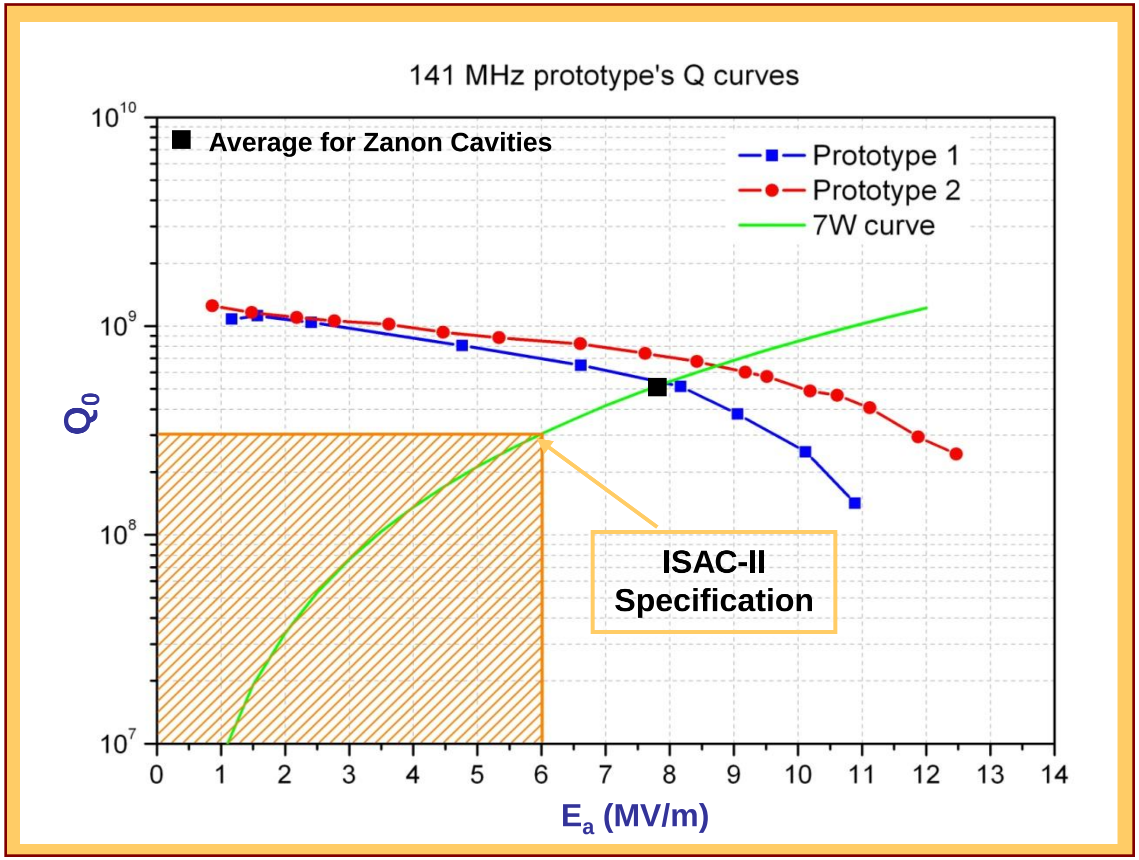
Optimizing tuner for RF requirements

Design, fabrication, and conditioning of production power couplers

Processing and Testing of Production cavities

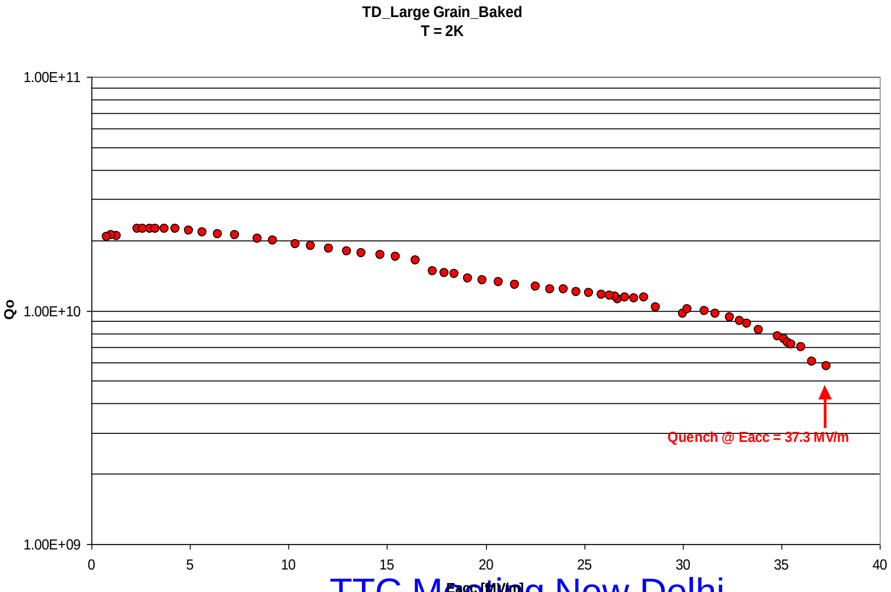
Triumf : Cavity Prototyping for ISAC II[R.Laxdal]

- Two prototypes manufactured at PAVAC
- Both prototypes perform significantly above ISAC-II specifications; average values of E_a=8.2MV/m, Ep=40MV/m cw (specification 6MV/m)



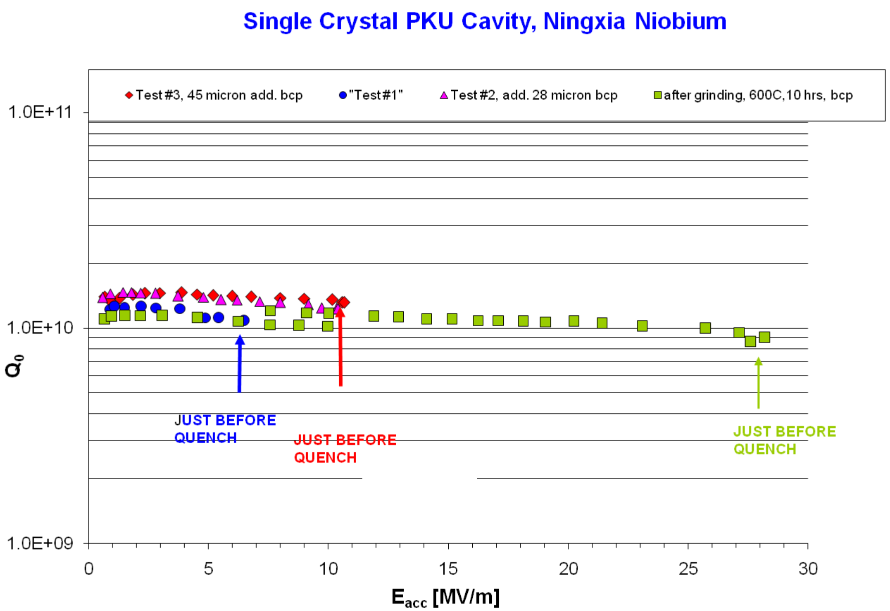
Large Grain (1)

- Qualification of Tokyo-Denkai large grain material with single cell TESLA shape
- Collaboration with PKU: single crystal cavity fabricated at PKU, treated and tested at Jlab; significant improvement after weld repair
- Single crystal cavity : sheets prepared at DESY, cavity fabricated and tested at JLab
- Two 9-cell cavities fabricated and tested – funded by FNAL – with moderate results; one cavity send to KEK for barrel polishing, but started to leak after 100 micron material removal at stiffening ring. Try to fix and re-test after X-raying

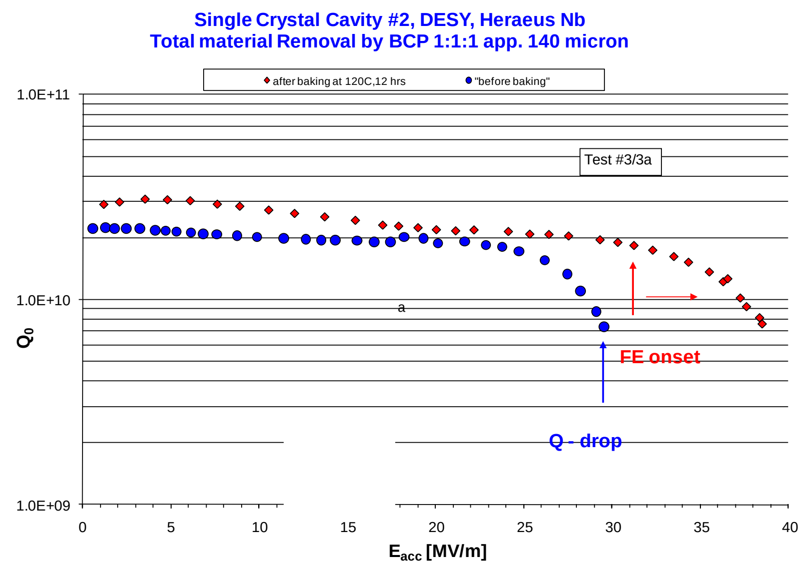


Large Grain (2)

PKU – Single Crystal



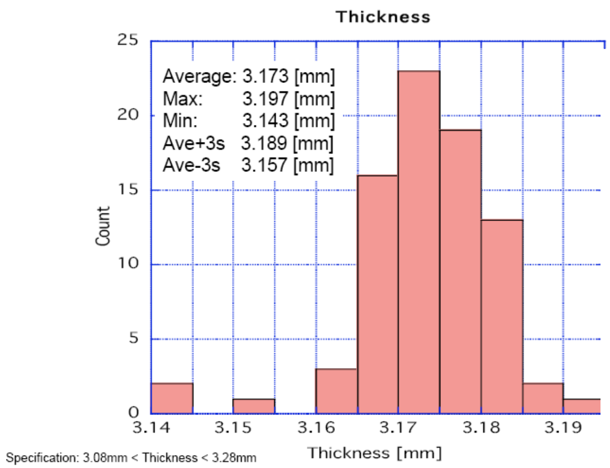
DESY/Jlab Single Crystal



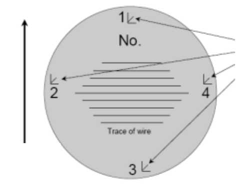
Large Grain (3)

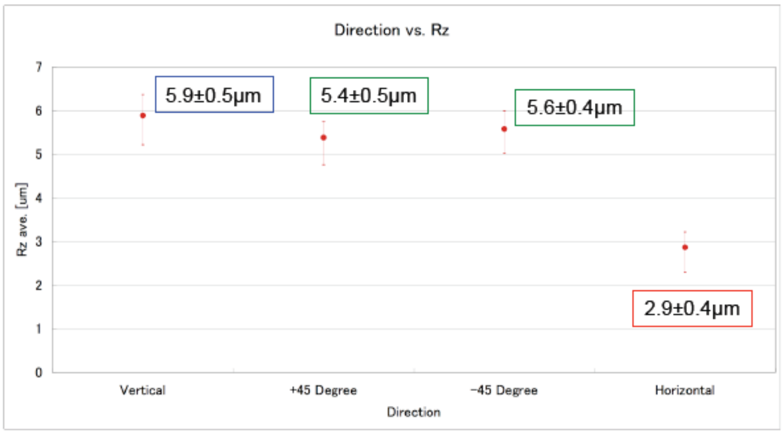
- Five single cell cavities from Tokyo-Denkai material are in fabrication and will be tested for reproducibility
- For two 9-cell Ichiro-type cavities fabrication has started; CBMM material and TD will be used
- The 20 sheets of TD material were sliced simultaneously by multi-wires – development done by K.Saito with Japanese Industry – with very good tolerances and surface quality.

Histogram of Thickness



Surface Roughness

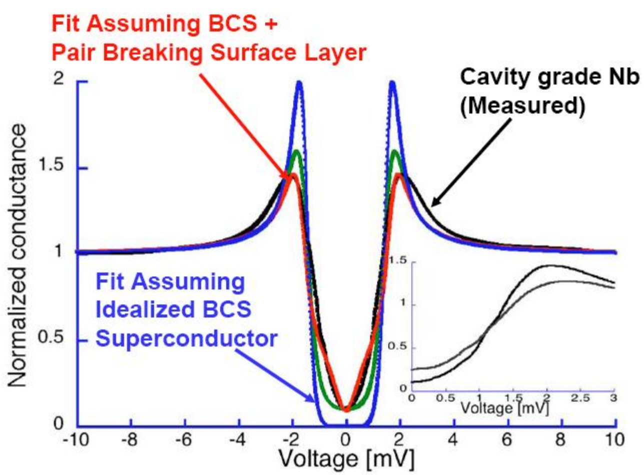




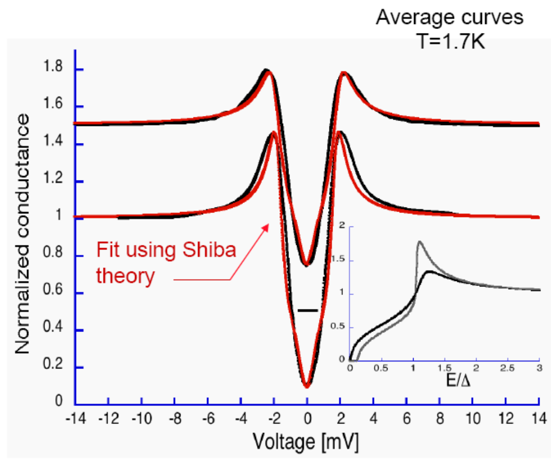
Atomic Layer Deposition [M. Pellin et al, 3rd Thin Film Workshop]

- Niobium has a complex surface: Nb-suboxides, Nb_2O_{5-x}, interstitially dissolved impurities such as H,N,O,C; H-precipitates(Q-disease)
- Point contact tunneling on “cavity grade” Nb samples revealed the presence magnetic impurities (pair breaking)most likely oxygen vacancies in the (Nb_2O_{5-x}) layer
- Mild baking reduces magnetic scattering

unbaked



baked at 120C for 24 hrs



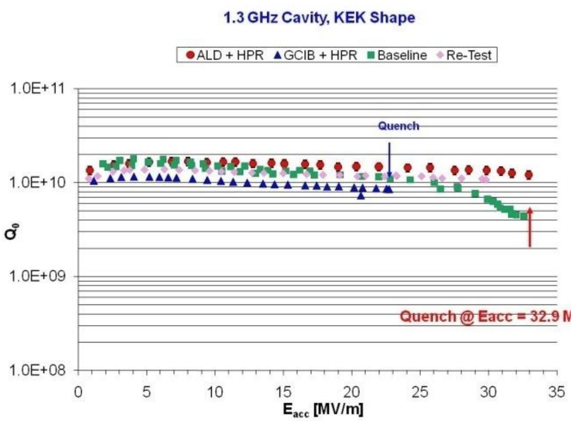
Unbaked: Δ=1.55 meV, α = 0.17, ε=0.6
Baked: Δ=1.55 meV, α = 0.32, ε=0.6

Atomic Layer Deposition (2)

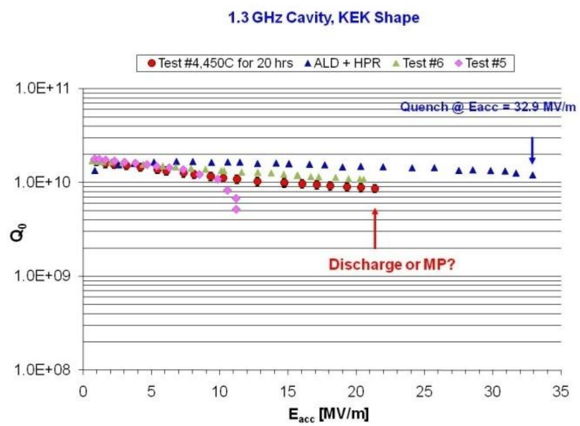
Solution:

- Use ALD to synthesize a dielectric diffusion barrier on the Nb surface
- Bake to “dissolve” the O associated with the Nb layer into the bulk
- Coat cavity with 10 nm’s Al_2O_3, 3 nm Nb_2O_5
- 3 cavities (fine grain+EP; large grain+ bcp; fine grain+ bcp) were coated
- Cavities #1 and #2 showed MP; cavity #3 ok, with Q-drop as in baseline

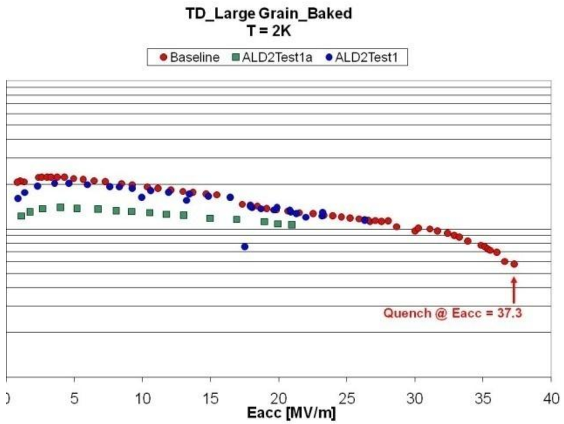
unbaked



baked @450C, 20 hrs



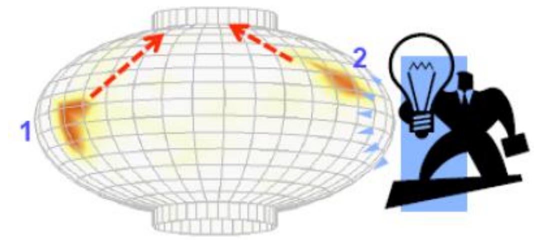
unbaked



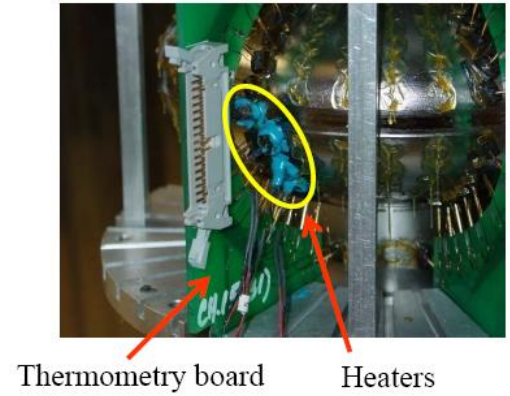
Another Q-drop Mechanism:Trapped Vortices(1)

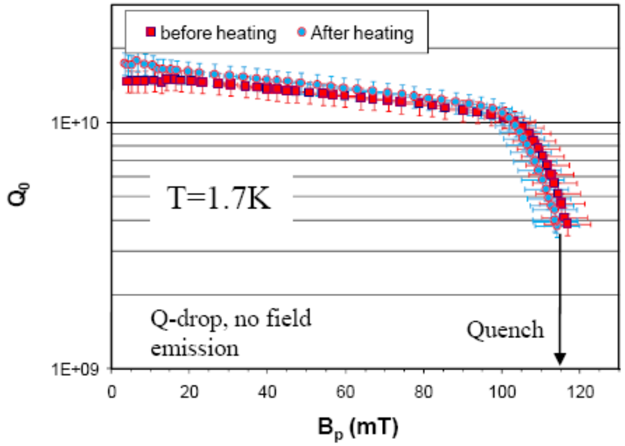
- A. Gurevich proposed at the SRF2007 the trapping of vortices as a possible mechanism responsible for the Q-drop [www.pku.edu.cn/academic/srf2007/program.html]
- “Hot Spots” caused by trapped vortices can be “cooled” by untrapping the vortices.
- This can be accomplished by generating a temperature gradient of a few Kelvin at the cavity surface
- Experimental verification has been provided by G.Ciovati, Jlab [G.Ciovati, A.Gurevich; http://conferences.jlab.org/tfsrf/Tuesday/Tu2_3-Trapped_vortices_Ciovati.pdf] by using a T-mapping system on single cell niobium cavities and calibrated heaters

Another Q-drop Mechanism:Trapped Vortices(2)

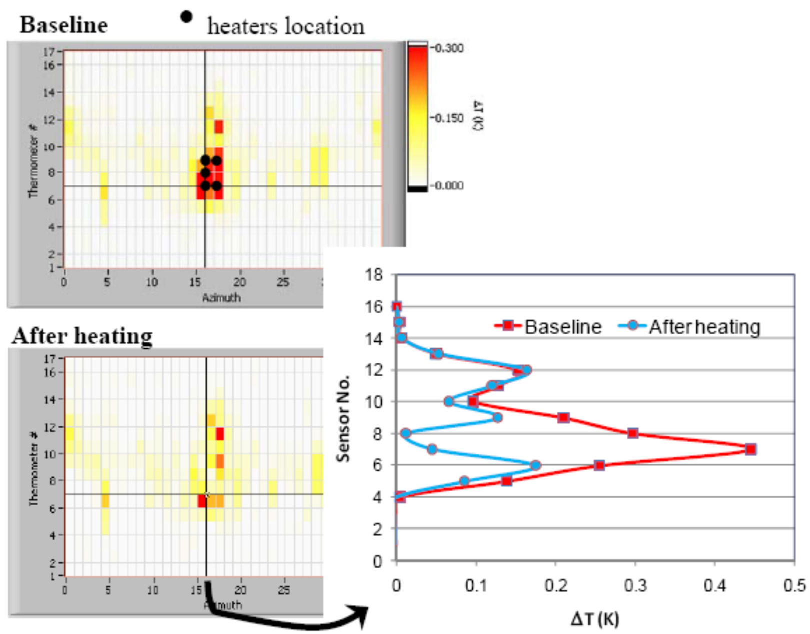


Pushing hotspots toward the orifice by external heaters





R_{res} ~ 13 nΩ, decreasing ~ 15% after heating



Thermal and Statistical Models for Quench in Superconducting Cavities

- Joshua Wiener, Hasan Padamsee, Laboratory for Elementary Particle Physics, Cornell University, Ithaca, New York, 14853, USA

  Future TESLA Report

- Authors used thermal model calculations and statistical analysis to analyse data sets from DESY (EP,HPR,Baking) and Jlab (BCP,HPR)
- Conclusions
  - Average quench fields improved from 25 MV/m to 31 MV/m
  - Improvement corresponds to a shift in the peak of defect size distribution from 10 micron to 2 micron (DESY data)
  - CEBAF refurbished cavities show nearly 50% lower quench fields (older material? Scanning?)
  - Cavity performance (field) is more influenced by defect size and RRR
  - than by He bath temperature and phonon mean free path
  - Film boiling and Kapitza resistance can significantly influence cavity performance depending on defect size

More information about R&D activities in the Americas can be found at

- Proceedings of EPAC 2008
  http://accelconf.web.cern.ch/accelconf/e08/html/class.htm
- Proceedings of 3rd International Thin Film Workshop
  http://conferences.jlab.org/tfsrf/
- Proceedings of Applied Superconductivity conference
- Proceedings of LINAC2008
- SRF Material Workshop, MSU, Oct. 29-31, 2008

Acknowledgement

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9-cell Cavity performance(Jlab)

- Two 9-cell cavities (LG#1,LG#2) were fabricated at Jlab from large grain CBMM niobium (ingot"D"); several holes during EBW in both cavities
- Standard processing:pre-tuning, 100 micron bcp,hydrogen degassing at 600C for 10 hrs,final tuning, final bcp
- LG #1 received only ~ 40 micron, LG#2 ~ 57 micron bcp in final bcp
- LG#1: quench at Eacc = 23 MV/m,
- LG#2: quench at Eacc = 20 MV/m