

Cavity Gradient R&D

- R&D Current Status
 - **What has been obtained**
 - **What has been standard**
- R&D Plan in TDP
 - **R&D subjects and what will be expected**
 - **Time-line**
 - **Resource**
 - **Global cooperation**
- Reference Information (to be attached)
- NOT:
 - **How to establish the optimum field gradient for ILC**
 - Decision process
 - Time scale
 - **Next talk by A. Yamamoto**

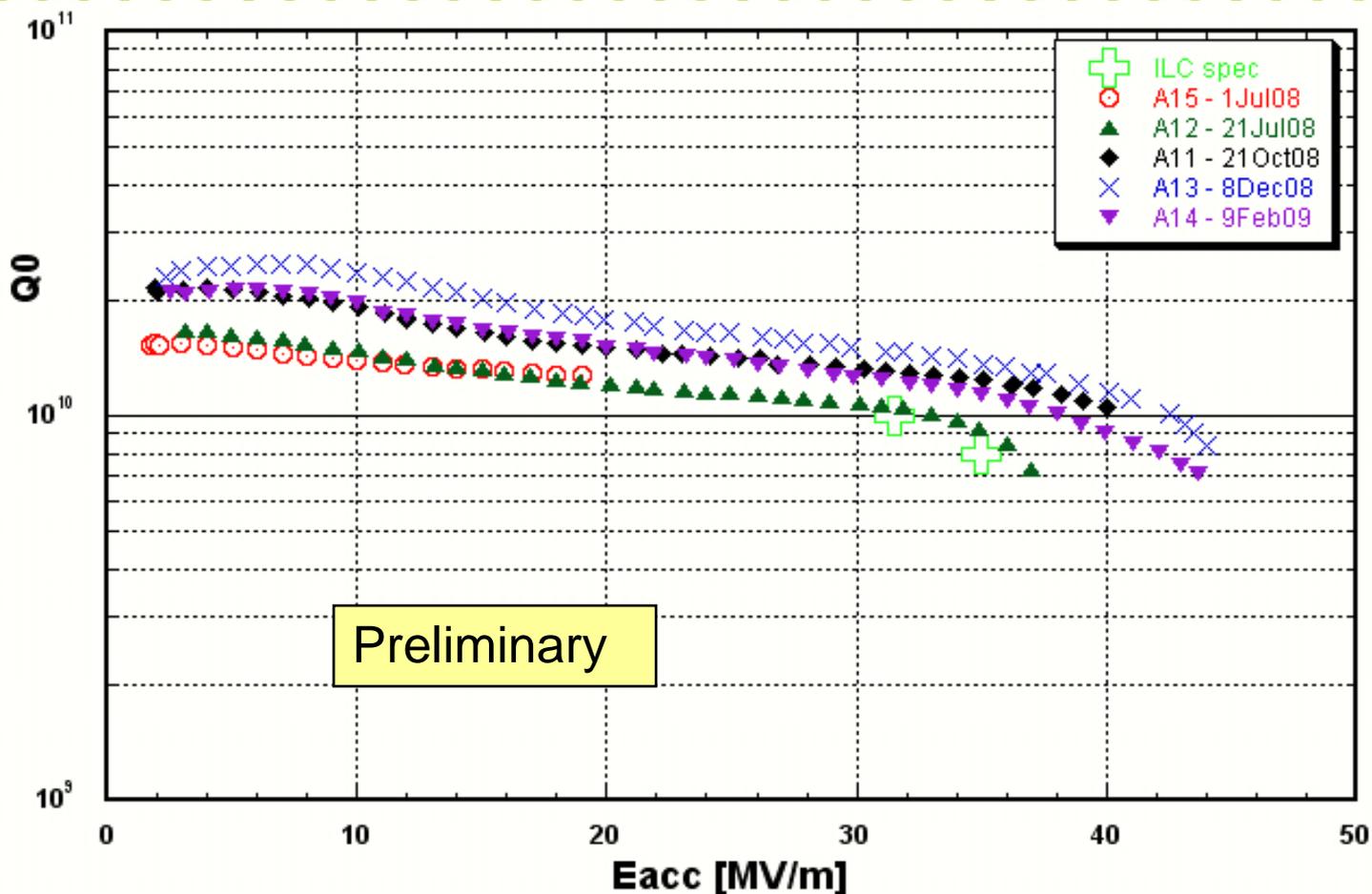


R&D Current Status:

- Americas
 - **Successful preparations at JLab**
 - Most recent production
 - **Startup of the facility at FNAL**
 - **Second sound**
 - **T-map at LANL**
 - **New vendor Qualification**
- Asia
 - **STF**
 - Pulsed tests
 - Vertical Tests online
 - EP online
 - **Vendor qualification**
 - **Optical inspection system development**
 - Guided repair as an option to recover faulty cavities
- Europe
 - **Preparation for mass production**
 - **Development optical inspection**
 - **HiGrade**

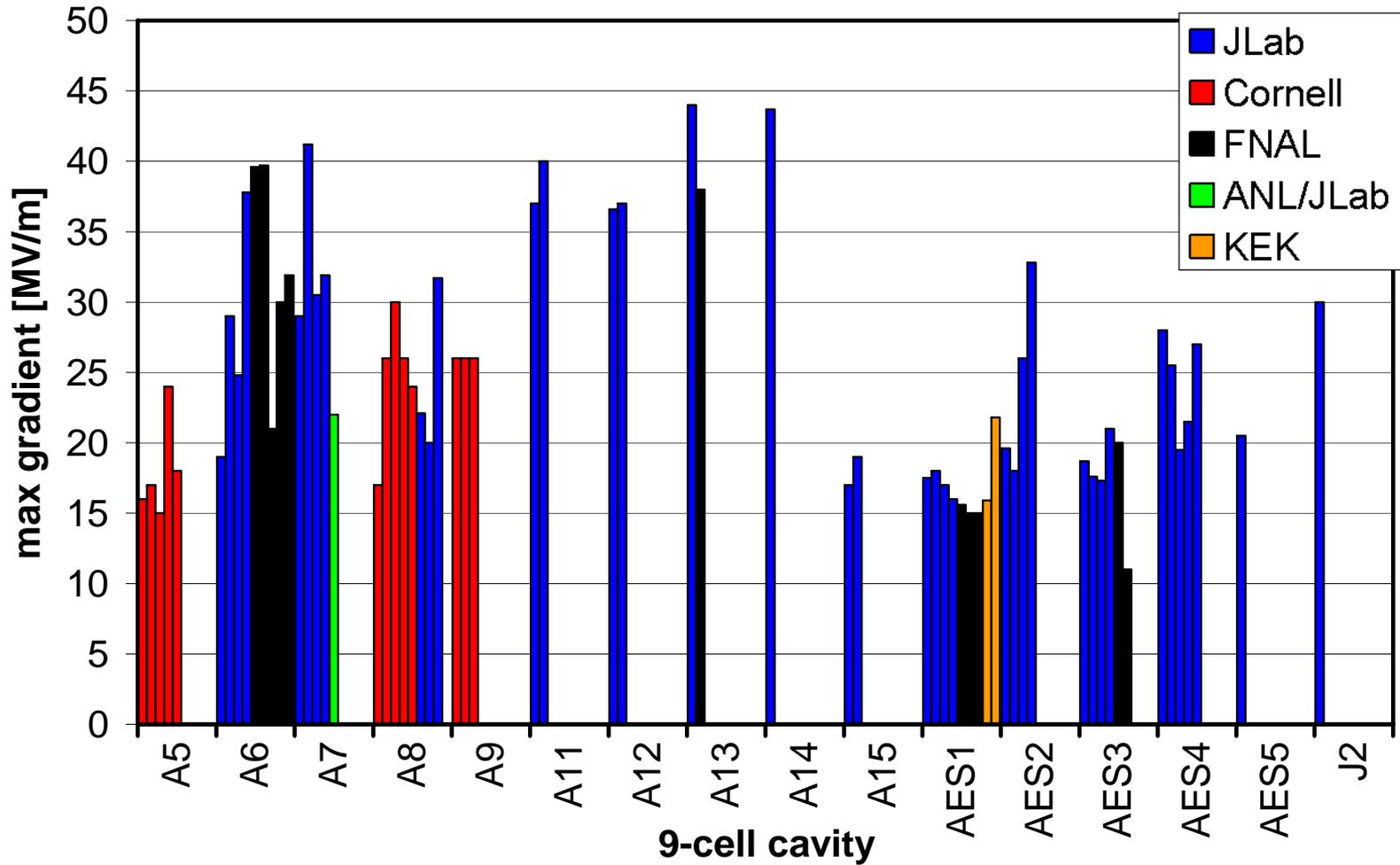
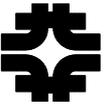


America R&D: Nine-cells new series



- Five 9-cell cavities: built by [ACCEL](#), and processed/tested at [JLab](#).
- All of them processed with one bulk EP followed by one light EP and by ultrasonic pure-water cleaning with detergent (2%).

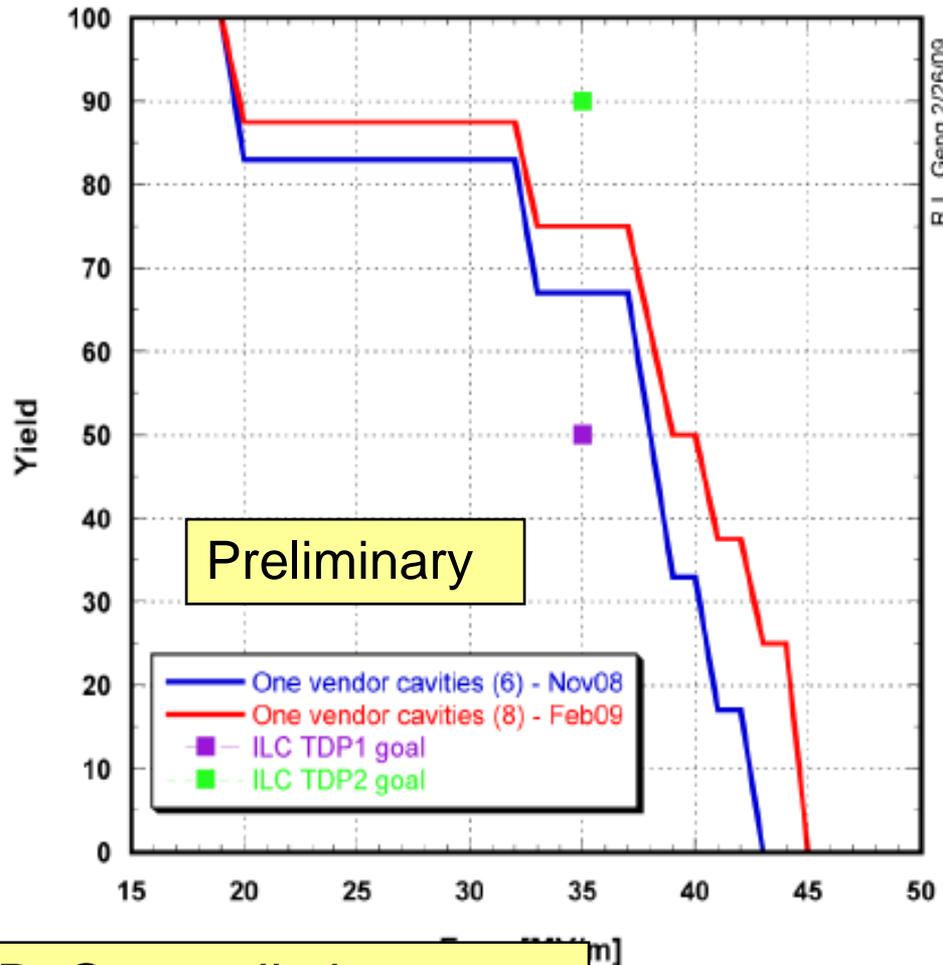
Americas 9-cell Cavity Update



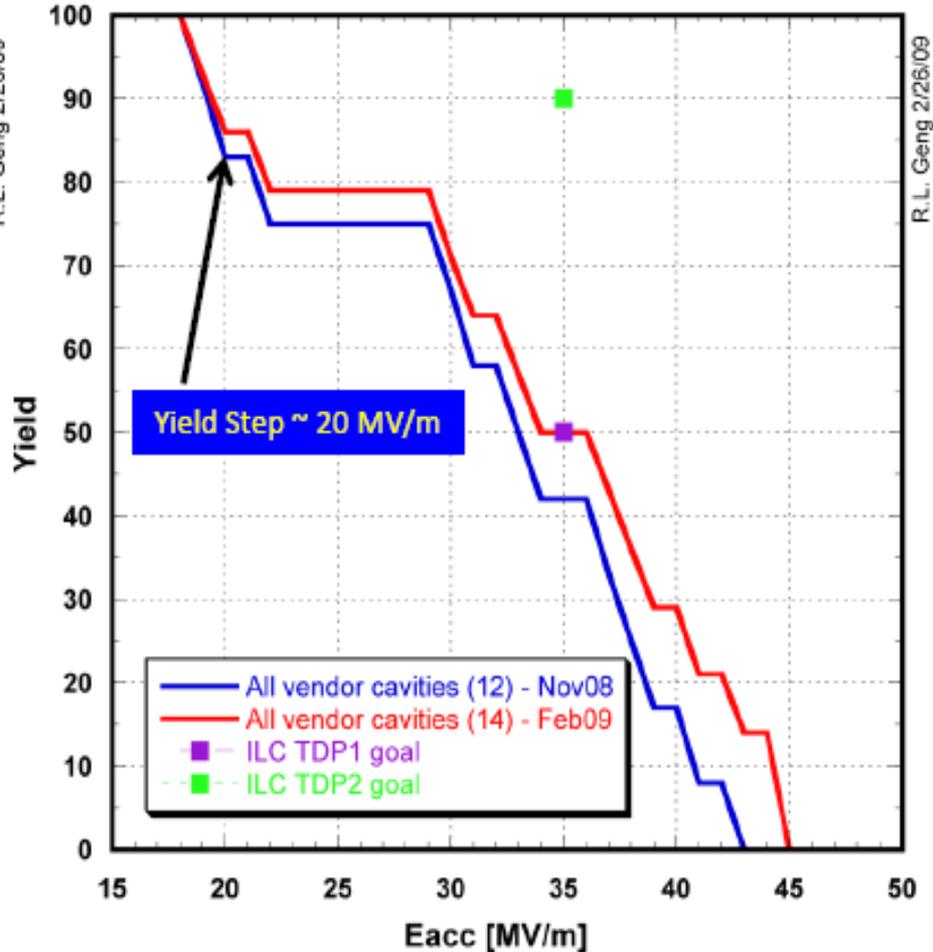
Yield Curve – as of Feb 09

14 9-cell Cavities Processed & Tested at JLab

Best Gradient Yield Feb 09 vs Oct 08
One Vendor Cavities



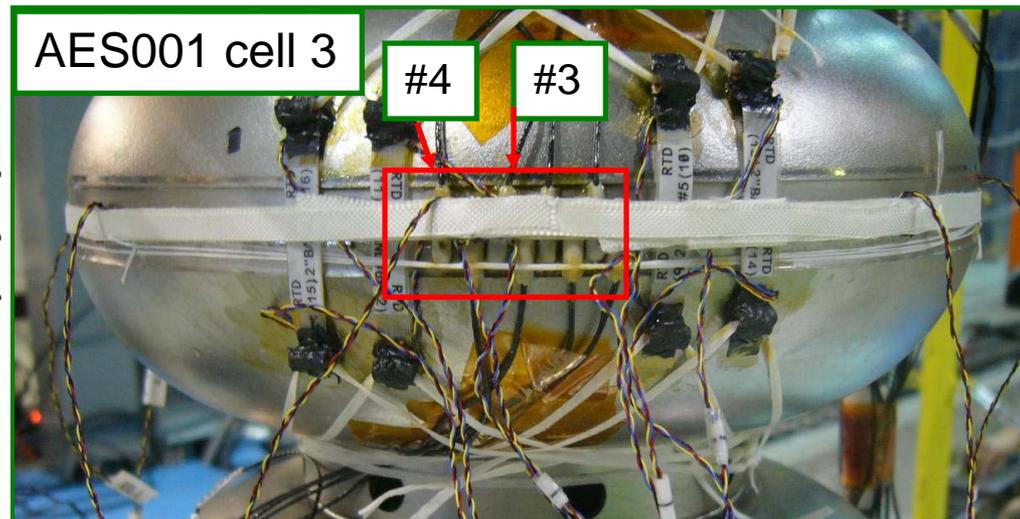
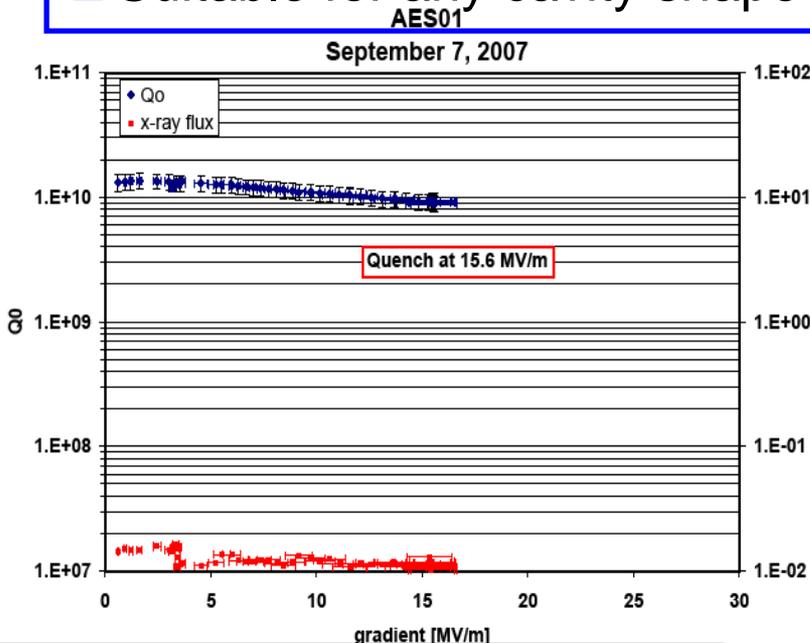
Best Gradient Yield Feb 09 vs Oct 08
All Vendor Cavities



Quench Location with Fast Thermometry



- Example of cavity which quenched at 16 MV/m without field emission
 - Temp rise ~ 0.1 K over ~ 2 sec in sensors #3 & #4 before quench seen on all sensors
- Cernox RTD sensors (precise calibration, expensive) with fast readout (10 kHz)
- Flexible placement of sensors, attached to cavity surface with grease and band; slow installation
- Suitable for any cavity shape and highly portable





America R&D: FNAL Infrastructure

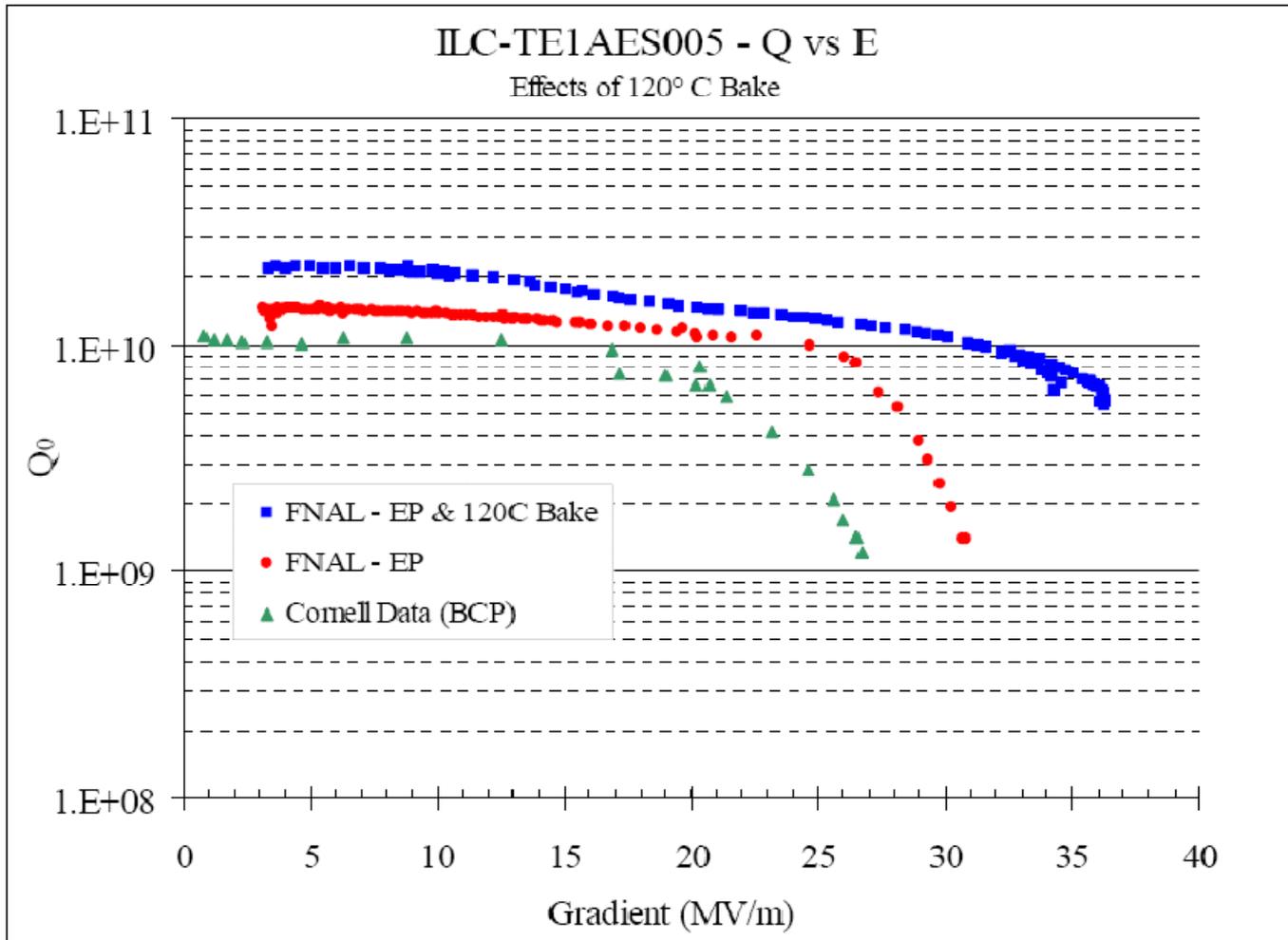


Figure 2.) Q_0 vs E run at 2K. Data from the previous Fermilab and Cornell tests are shown for comparison.

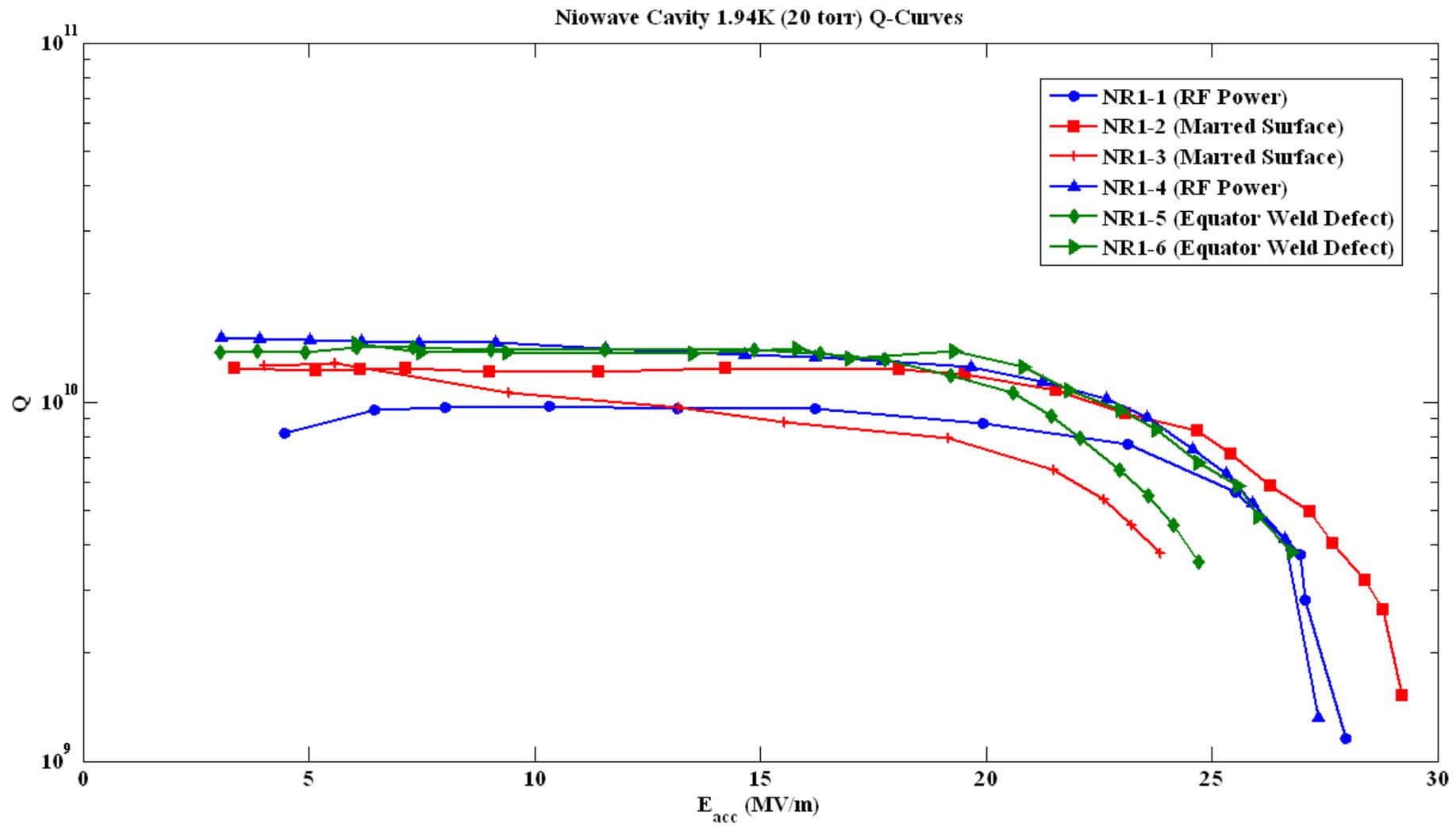


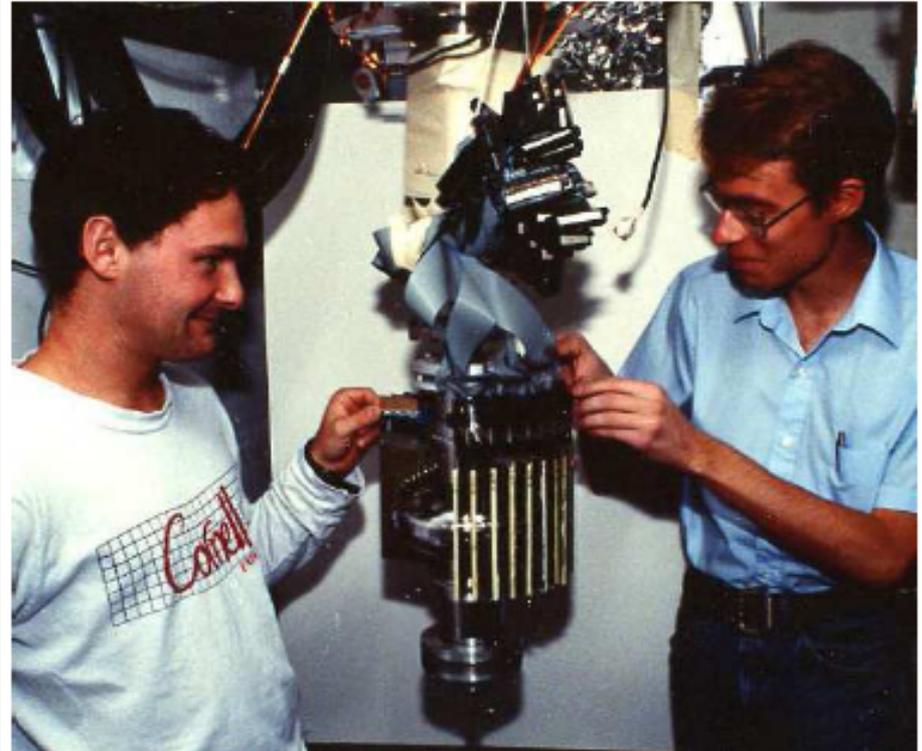
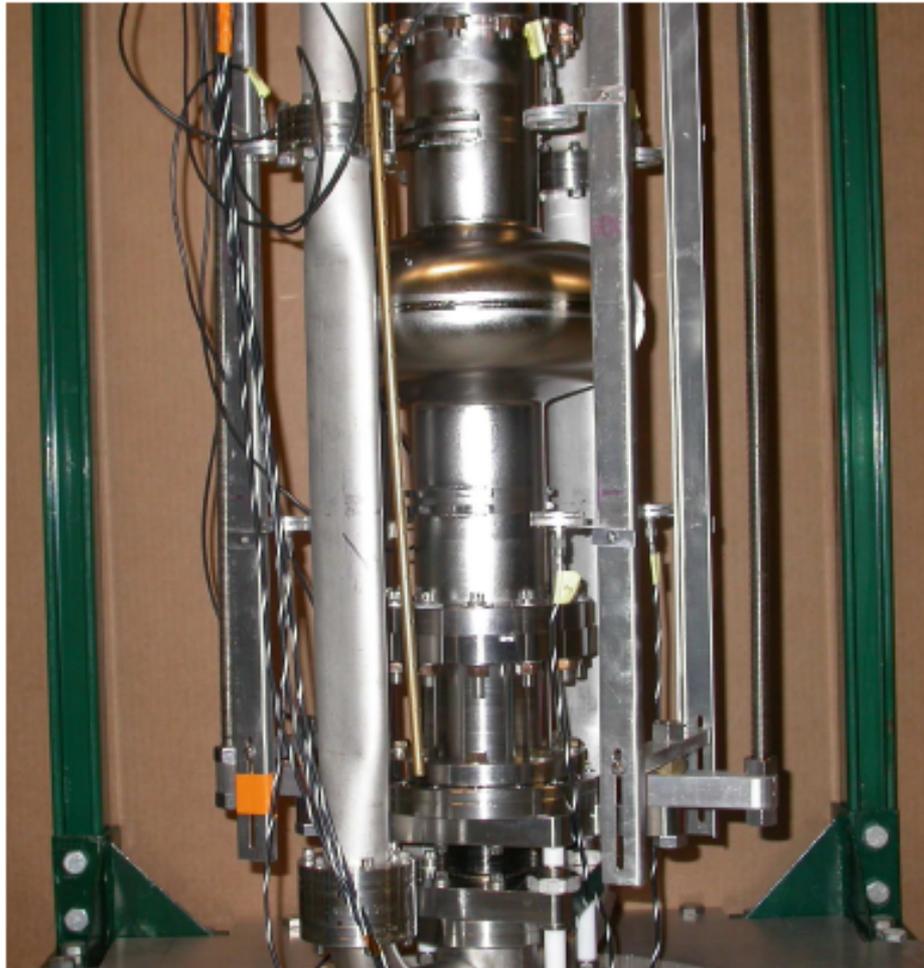
Niowave Single-Cell BCP Cavity Performance

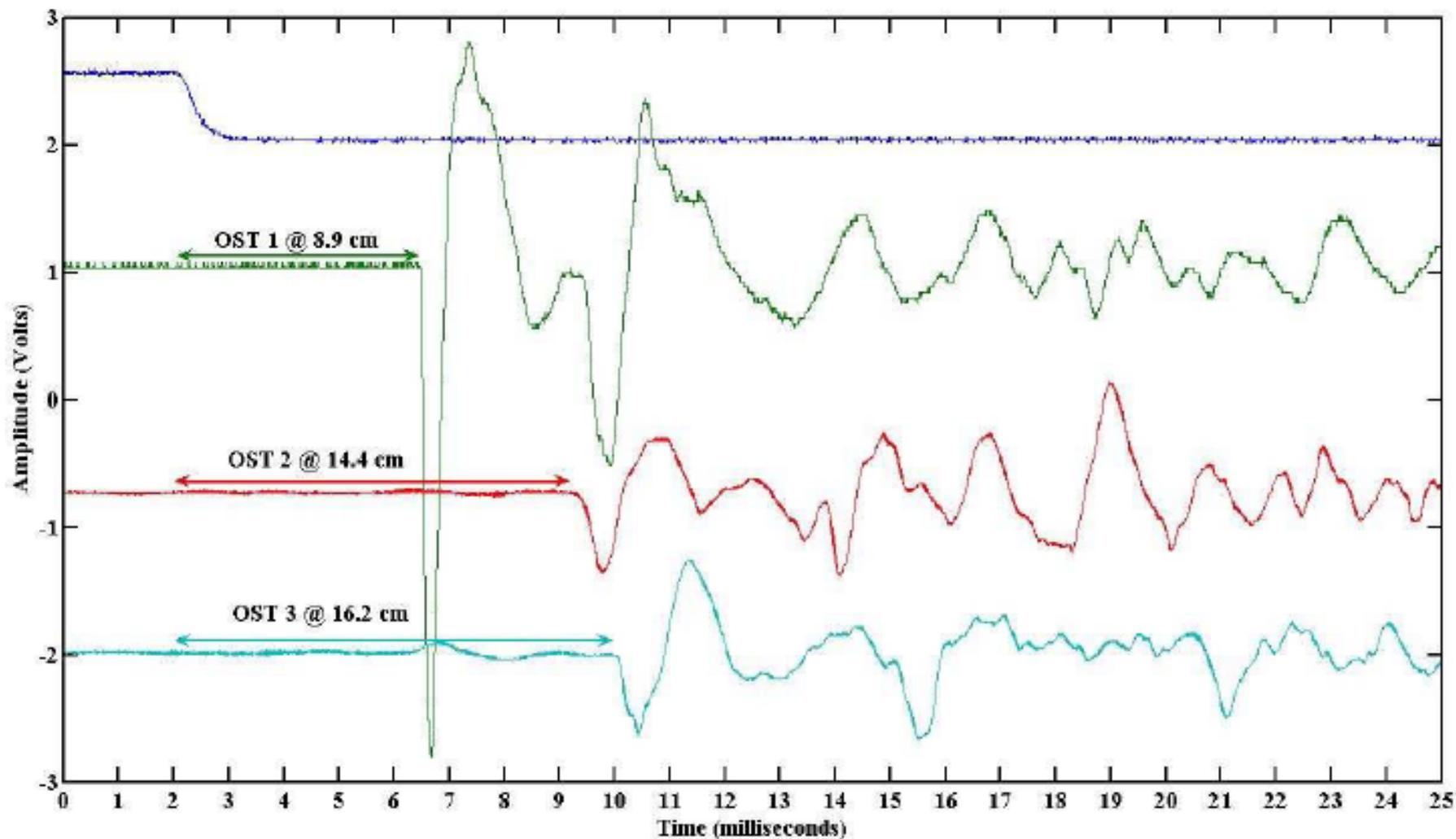
Niowave Cavity	BCP (1:1:2) Etch	Q_0 (1.94 K)	Peak E_{acc}	Q at Peak E_{acc}	Field Limit
NR1-1	85 μm	8.2 e 9	27.9 MV/m	1.2 e 9	RF Power
NR1-2	113 μm	1.2 e 10	29.2 MV/m	1.5 e 9	Marred Surface
NR1-3	60 μm	1.3 e 10	23.8 MV/m	3.8 e 9	Marred Surface
NR1-4	254 μm	1.5 e 10	27.4 MV/m	1.3 e 9	RF Power
NR1-5	184 μm	1.4 e 10	24.7 MV/m	3.6 e 9	Equator Weld Defect
NR1-6	205 μm	1.5 e 10	26.8 MV/m	3.8 e 9	Equator Weld Defect



Niowave Single-Cell BCP Cavity Performance





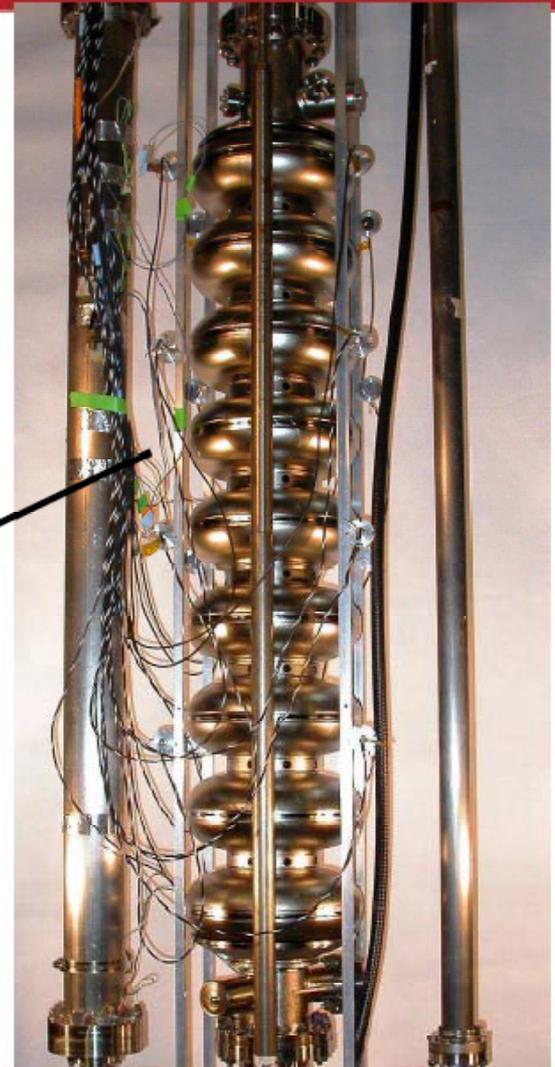
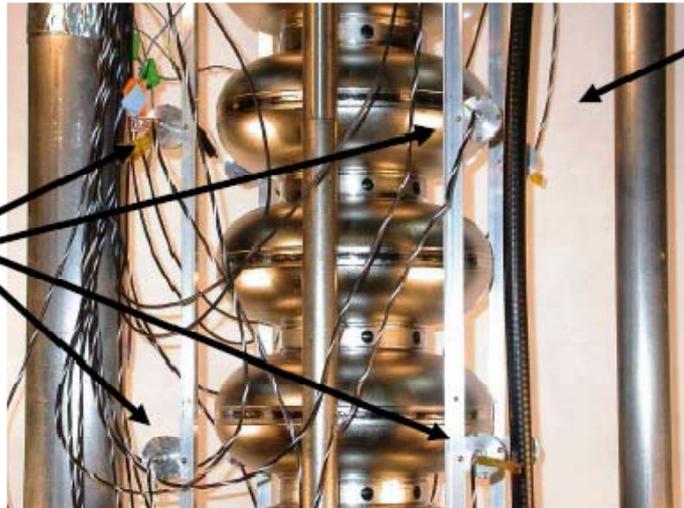


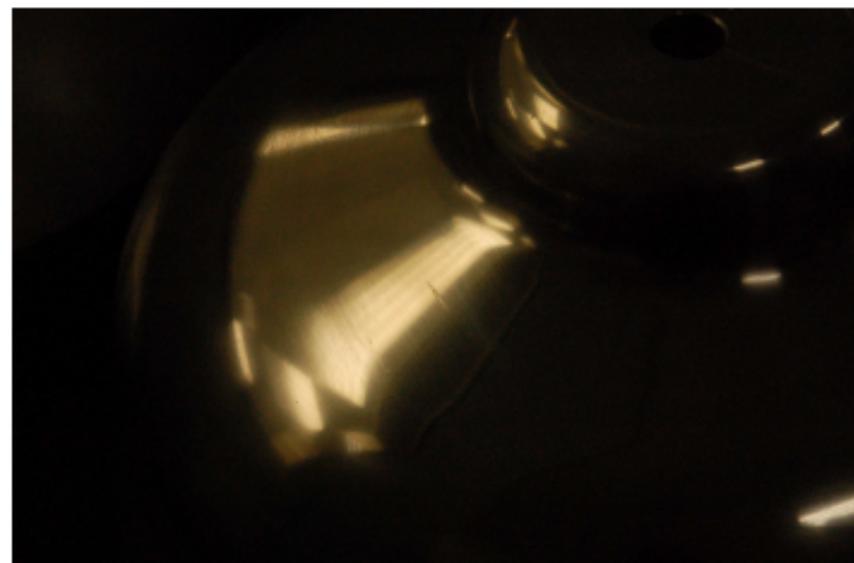
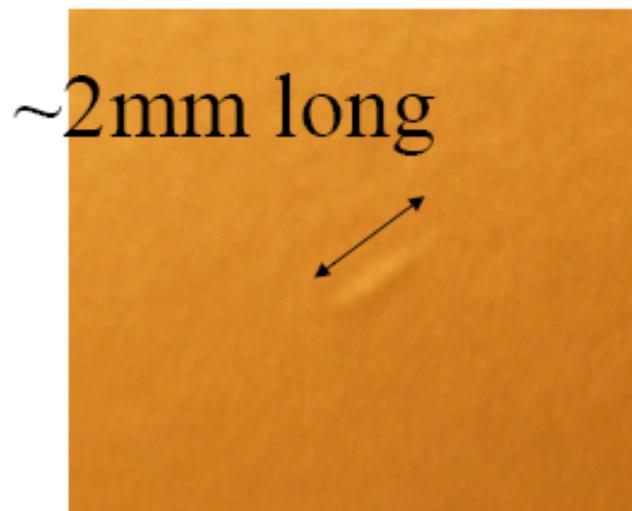


2nd Sound Quench Detection

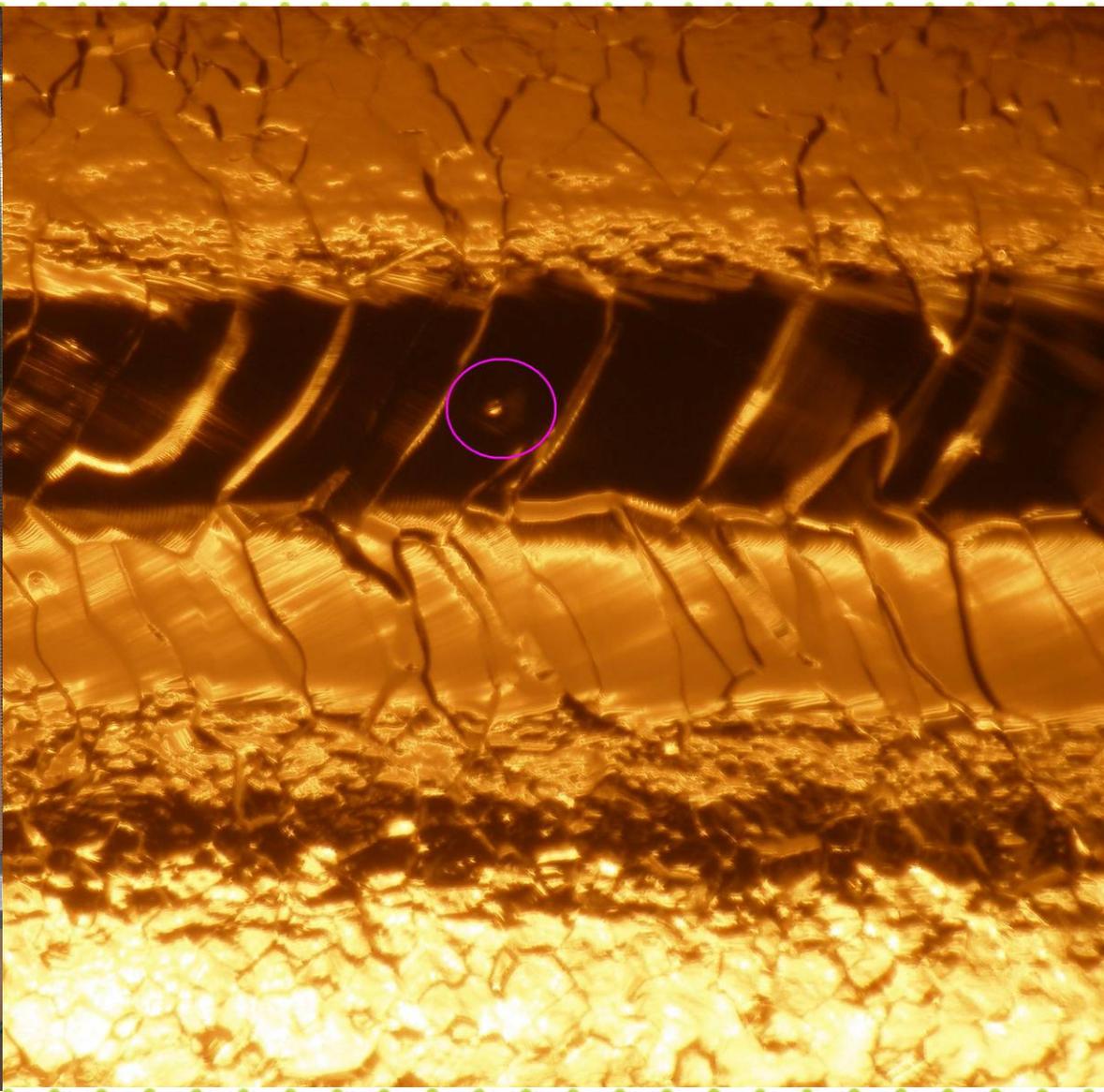
- We have demonstrated that 2nd sound detection can locate multiple quench locations in a single 9-cell cavity cold test
- By exciting different TM_{010} pass-band modes of a 9-cell cavity different cells can be driven to quench.
- This technique is simple, low cost, and quick to implement. In the test pictured here we found 3 distinct defects: 1st cell (from top), 4th cell, and 5th cell.

Four Of The
Transducers





Right-hand picture courtesy of Charles Reece (JLAB)
and Genfa Wu (FNAL)

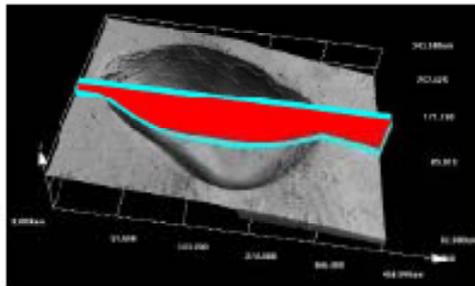
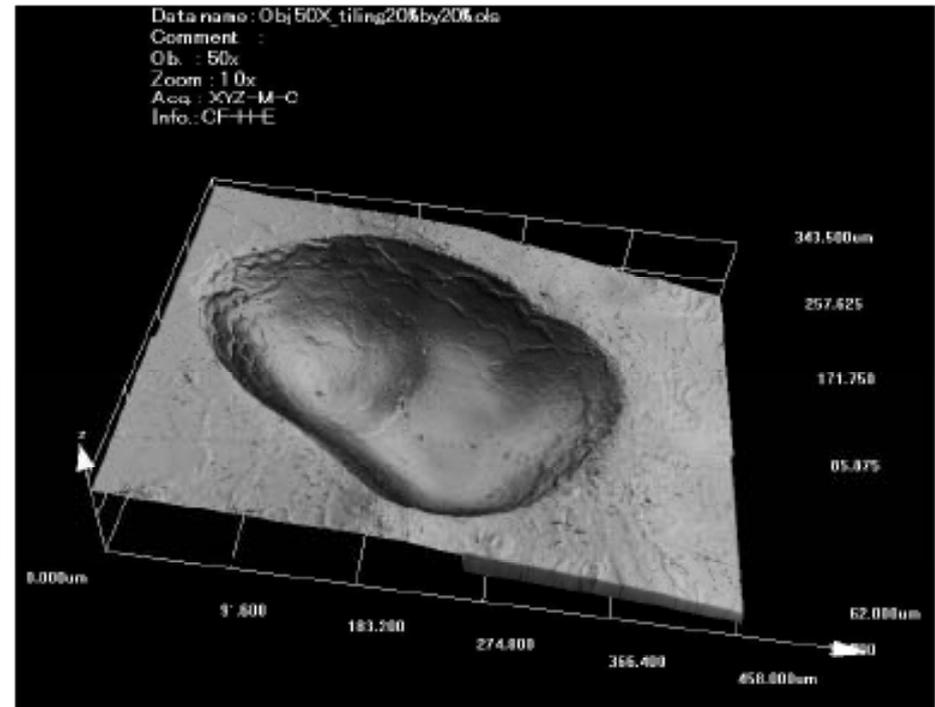


Pit 1

ASC/NHMFL/FSU
Imaged using Olympus Laser
Scanning Confocal 3D
Microscopy (LSCM-LEXT)

Obj 50X – 2 by 2 tiling image

Courtesy Zu-Hawn Sung and
Peter Lee, FSU



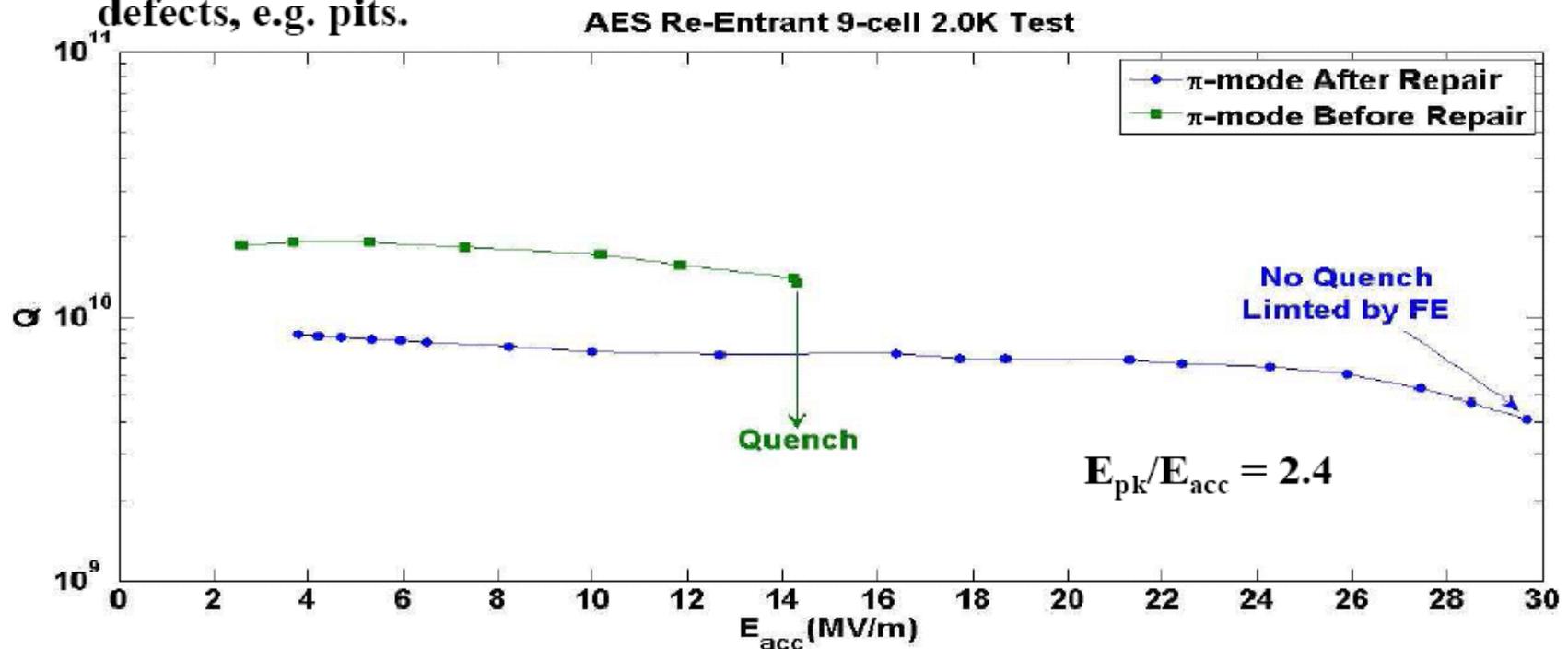
Profile is across the red line on the left 3D surface image





AES Fabricated 9-Cell Cavity Weld Pits Repaired

- We have successfully repaired an AES 9-cell cavity with tumbling and VEP.
- This cavity originally quenched at $E_{acc} = 15$ MV/m at a weld pit in the first cell, after tumbling and reprocessing $E_{acc} > 30$ MV/m.
- When excited in the $5\pi/9$ -mode a peak fields of 89 MV/m and 1400 Oe were reached in the center cell. This corresponds to $E_{acc} > 37$ MV/m.
- This test demonstrates that tumbling is an effective option to repair weld defects, e.g. pits.

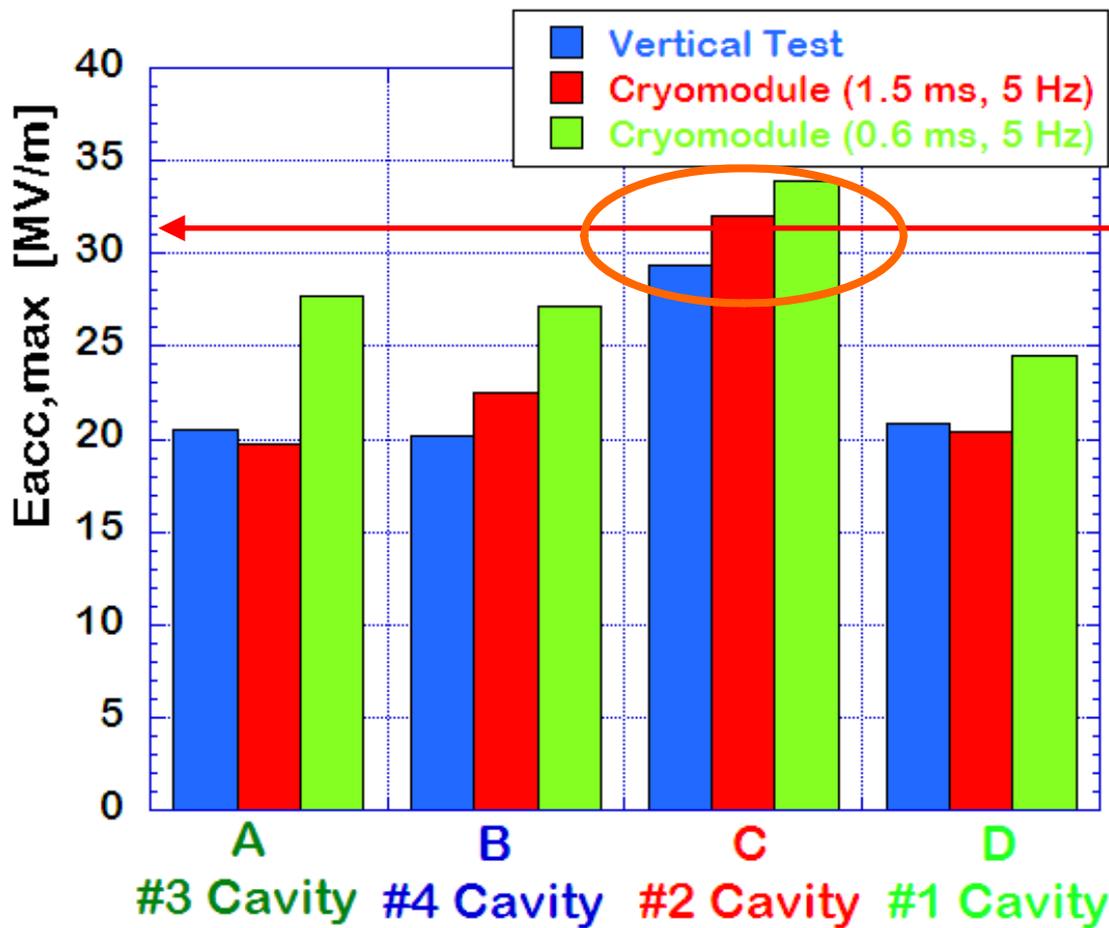


- First pulsed measurements at high gradients
 - **STF operation**
 - **Demonstrated upto 32 MV/m with standard puls length**
- Kyoto Camera Upgrade
 - **Improve resolution**
- Manufacturer Training



Comparison of achieved Eacc,max between Vertical Tests and Cryomodule Tests

November, 2008



RF Feedback / ON

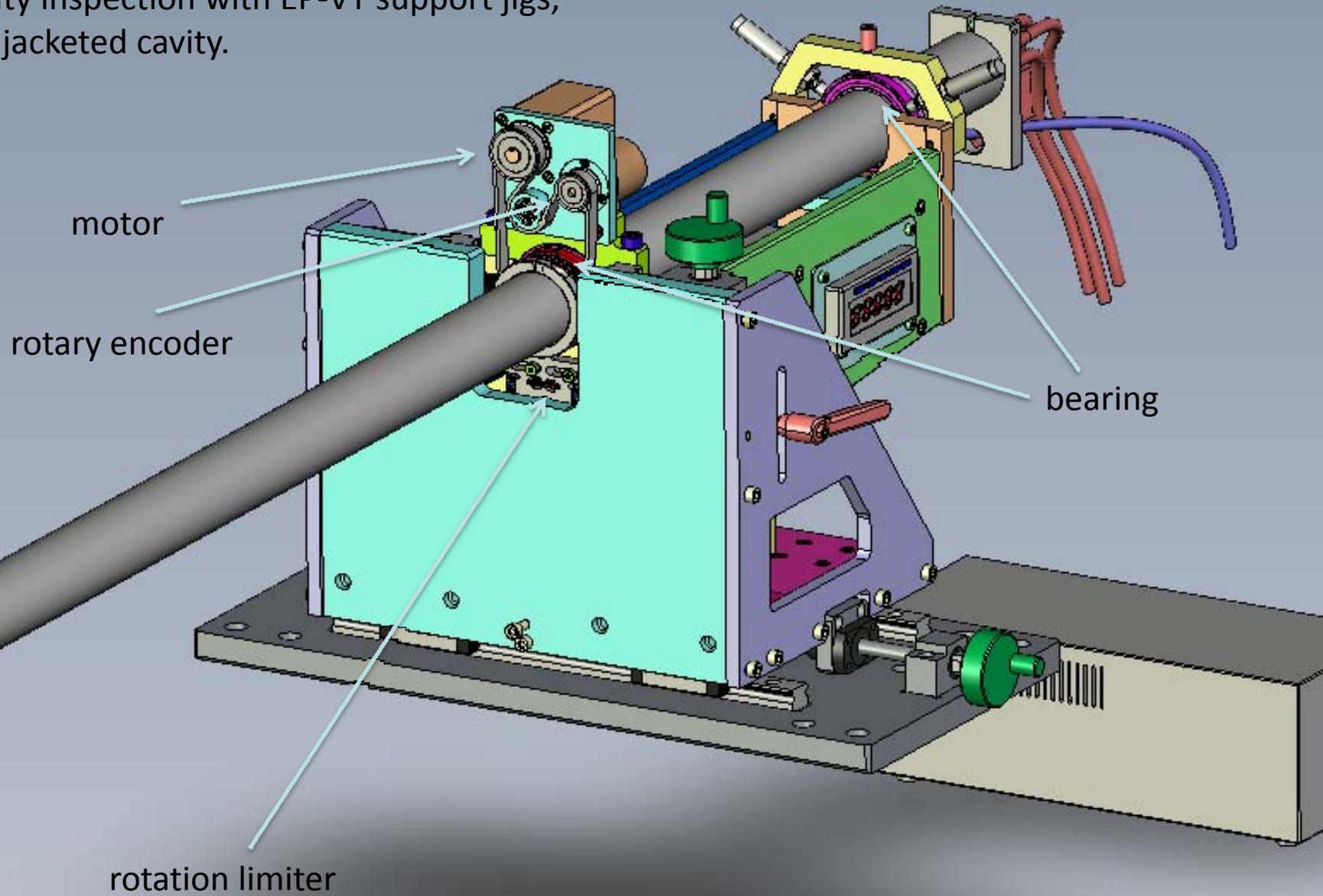
Operational Gradient at 31.5 MV/m for ILC

Ave. Eacc,max (V.T)
= 22.7 MV/m

Ave. Eacc,max (Cryo.)
= 23.7 MV/m

No degradation was observed in the cryomodule tests.

Introduction of camera-cylinder rotation mechanism
for cavity inspection with EP-VT support jigs,
and for jacketed cavity.



H. Hayano, Y. Iwashita,
K. Watanabe, Y. Kikuchi



Kyoto Camera Upgrade

(1) CCD camera upgrade

from $5\mu\text{m}$ CCD pixel to $2.2\mu\text{m}$ CCD pixel camera.

(2) Lens upgrade

more magnification with more larger aperture.

(3) illumination upgrade

EL panel has limited life with more high voltage
(for more brightness).

-> LED + light guide with scattered surface (twice more light).

$\sim 7\mu\text{m}/\text{pixel}$ \rightarrow targeting $3.5\mu\text{m}/\text{pixel}$

H. Hayano, Y. Iwashita,
K. Watanabe, Y. Kikuchi



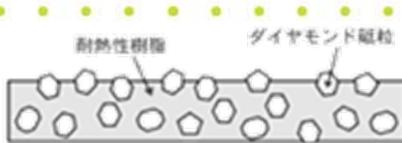
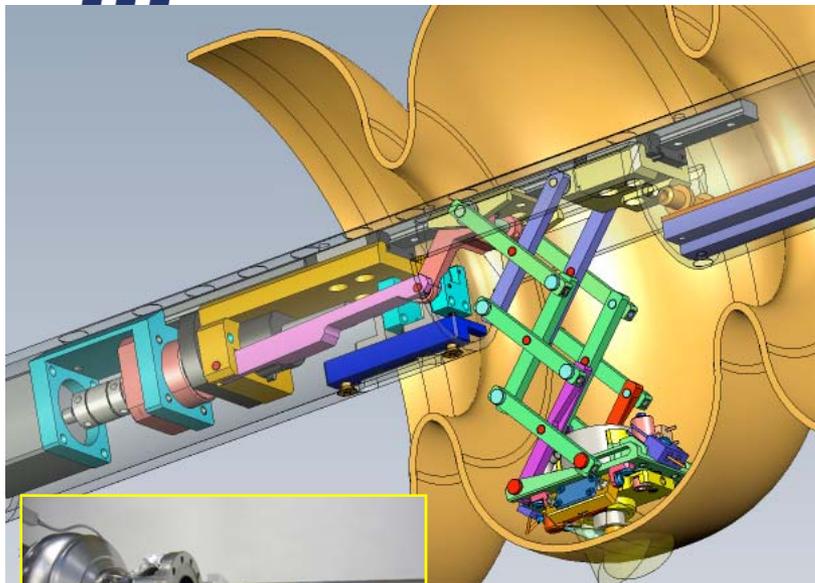
Kyoto Camera Upgrade: Image Capture Automation

- (1) control of cavity position
being done by VB application.
- (2) Image capture and automated file-save
already done by VB application.
(speed is enough fast, but must wait for vibration damping)
(automated focus is the next concern)
- (3) defect pattern matching
the software already fabricated in 2007 was tested
using recent high quality pictures.
-> no good results, so far.
(match to every bright traces, not suspected defects only)

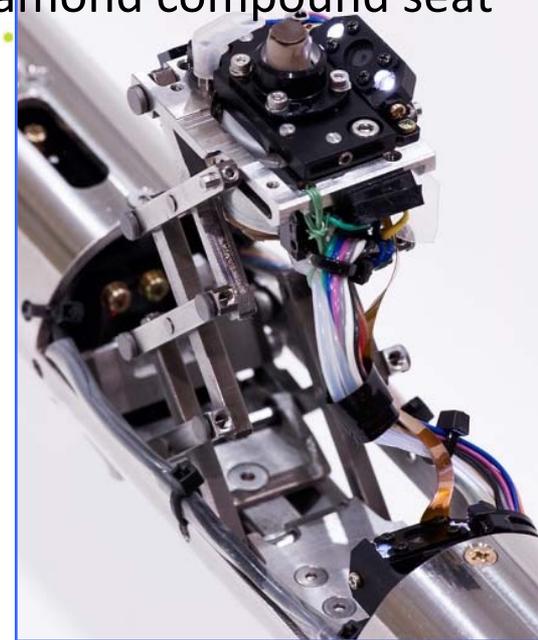


Grinding Effort at KEK

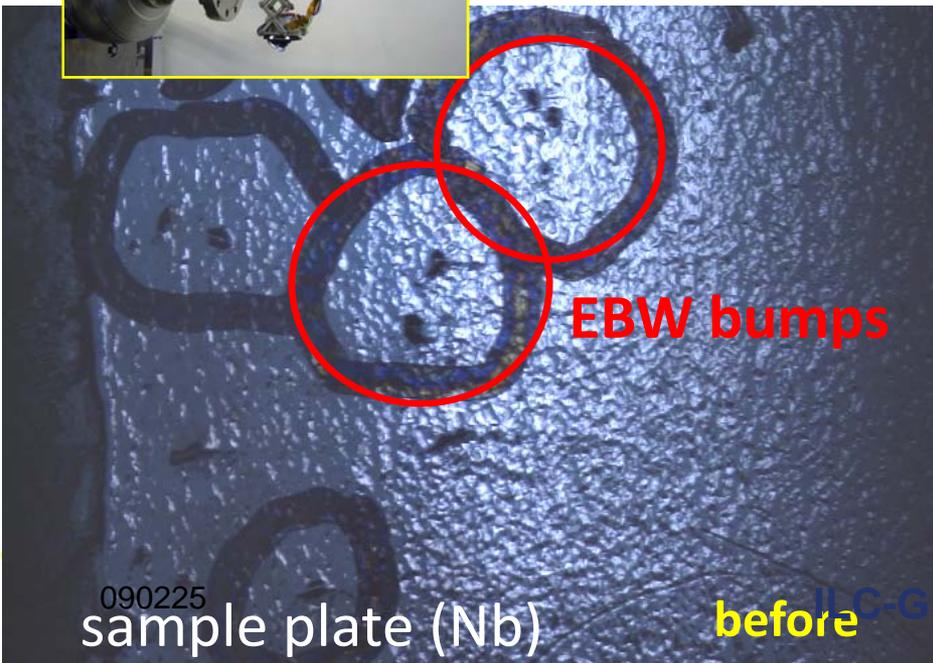
Grinder Head with
Diamond compound seat



Diamond compound seat
#400 (size = 40 ~ 60 um)
as for 1st test



Grinding machine was delivered in last week.



EBW bumps

090225
sample plate (Nb)

before

IL C-GDE SCRF



after



EU Status: Cavity Summary

– Processes streamlined for mass production

- processes yield similar results as before
- tank welding at an early state poses no problem

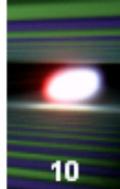
– Electropolishing is still superior

- Data is problematic as it mixes different vendors

– Scatter is large

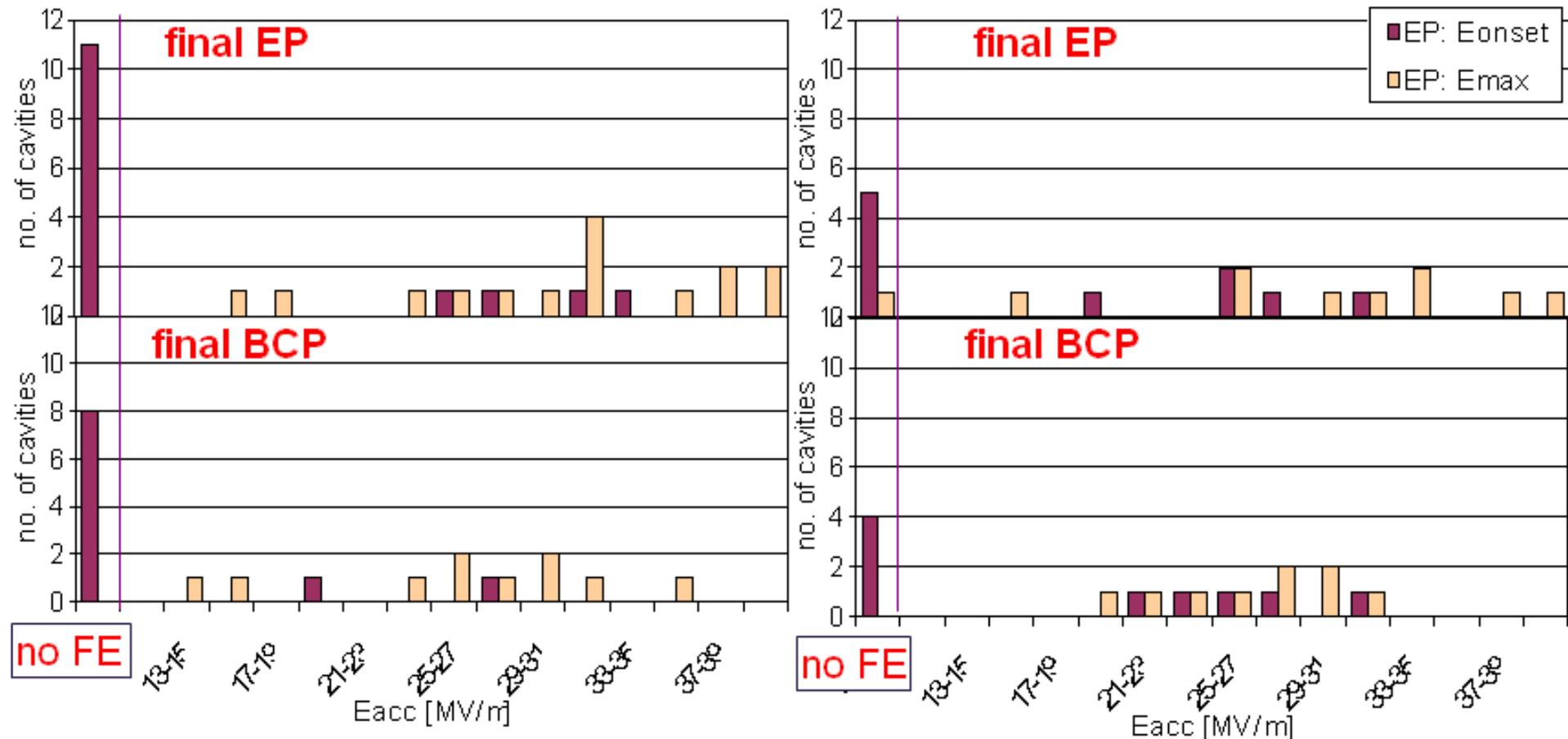
- Can be traced to mechanical fabrication
- Defects have been identified
 - Need to improve QC at companies

Final preparation: Analysis of final test



No He-tank !!

With He-tank !!



=> as expected: some improvement with respect to field emission

=> "final EP" gives higher E_{max} than "final BCP"



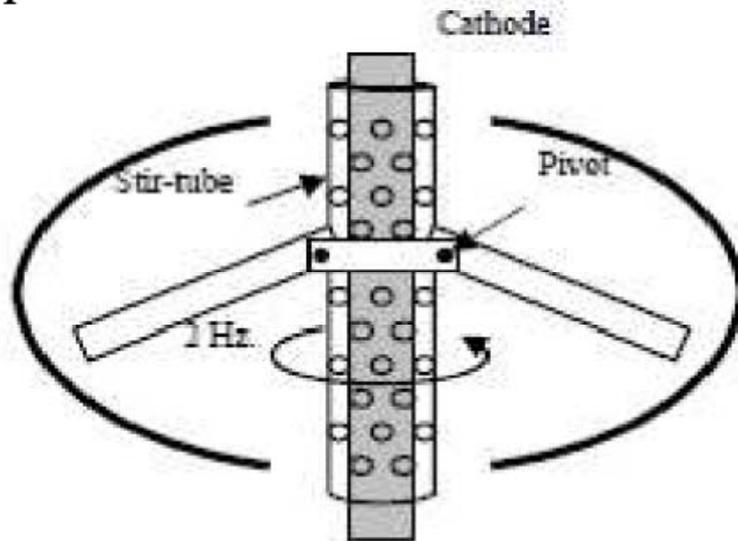
Alternative Developments for ILC

- Cost reduction is a strong driving force for ILC
 - **~16000 cavities**
- New processes
 - **Vertical EP**
- New Material
 - **Large-grain niobium Material**
 - **Less fabrication steps than standard material**
- New Shapes
 - **‘Low-loss’ and ‘Re-entrant’**
 - **Could reduce power dissipation at cryogenic temperatures**



Vertical Electropolish Proven Effective

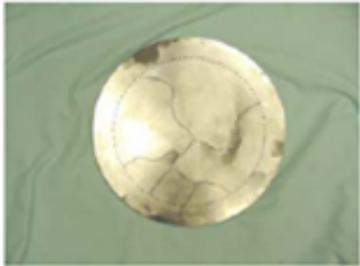
- We have demonstrated gradients >35 MV/m in individual cells of two 9-cell cavities processed with vertical EP.
- In each test the π -mode was limited by quench/FE.



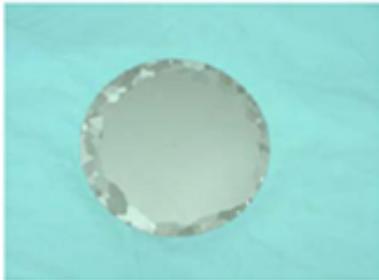


Large Grain Material (JLab)

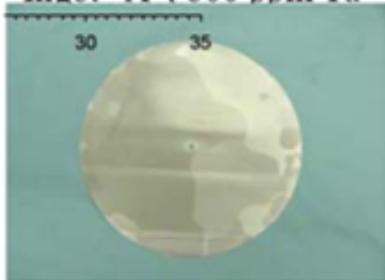
CBMM



Ingot "D", 800 ppm Ta



Ingot "A", 800 ppm Ta



Ninxia



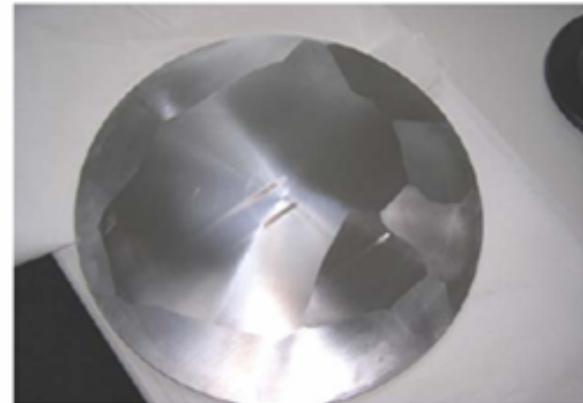
Wah Chang

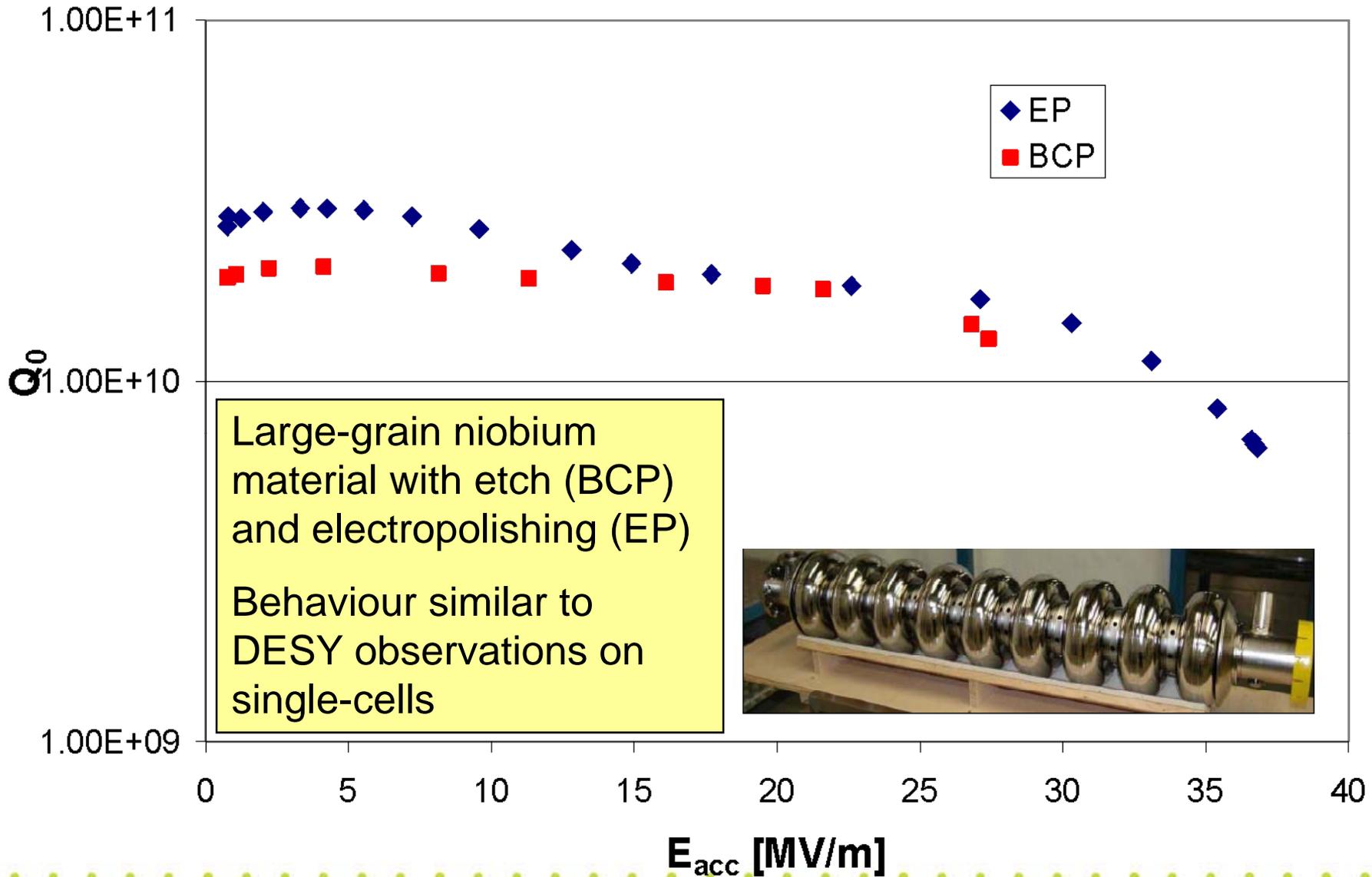


Heraeus



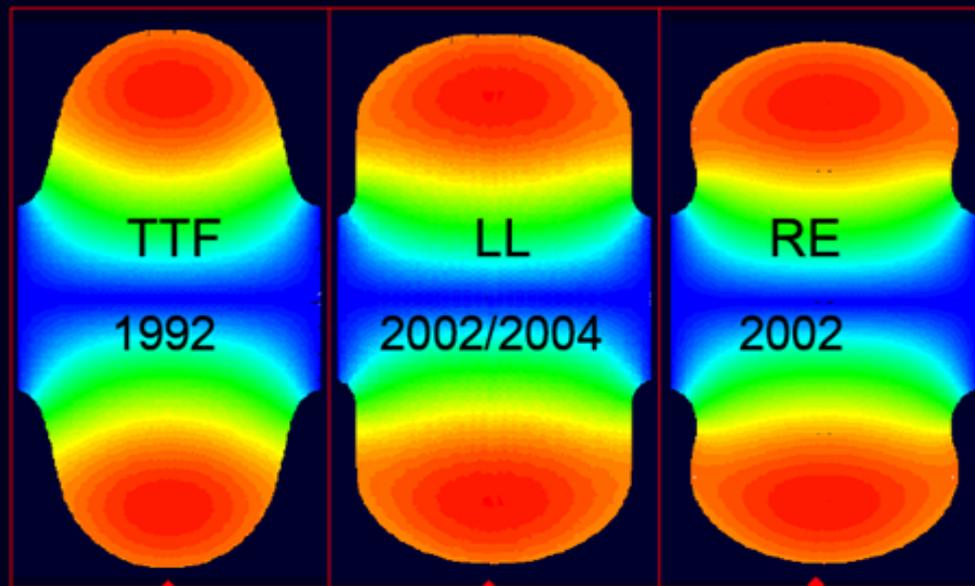
Ingot "C", 1500 ppm Ta





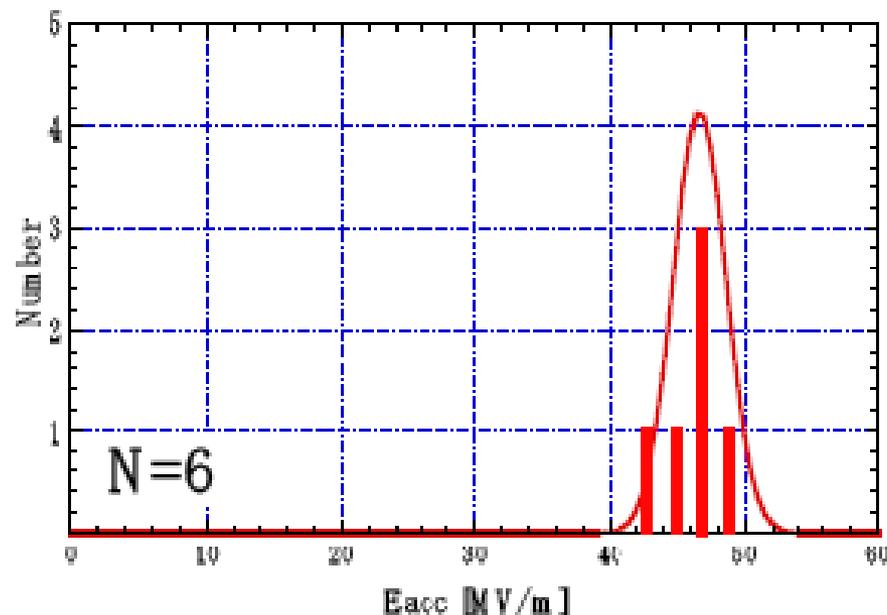
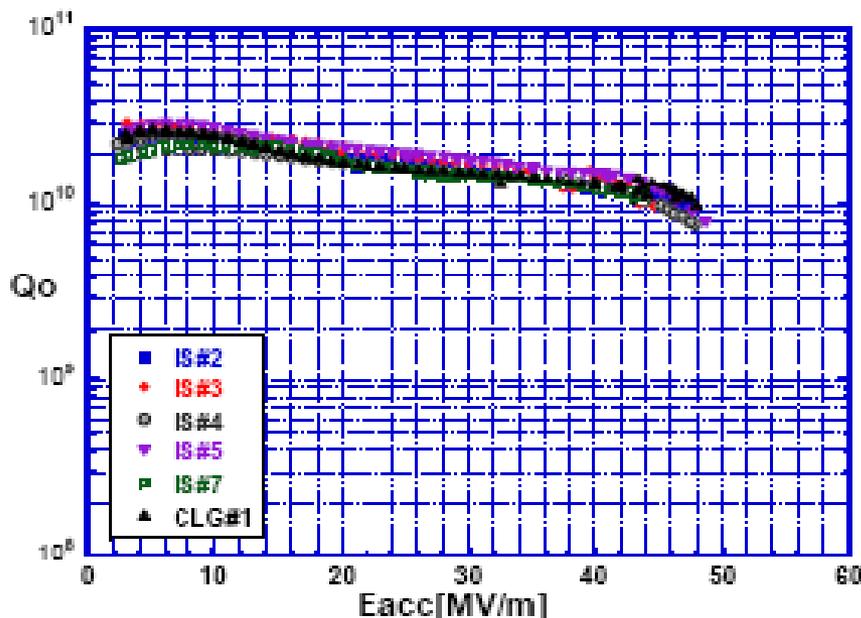
Alternative Cavity Shapes

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
$E_{\text{peak}}/E_{\text{acc}}$	-	1.98	2.36	2.21	max gradient (E limit)
$B_{\text{peak}}/E_{\text{acc}}$	[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^2]	30840	37970	35123	dissipation (Cryo limit)

(D) +EP(20 μ m)+EP(3 μ m, fresh, closed) +HF*
 +HPR+Baking (120C*48hrs)



Ave. Eacc=46.7+1.9MV/m

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

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



60mm-Aperture Re-Entrant Cavity

Best Eacc = 59 MV/m

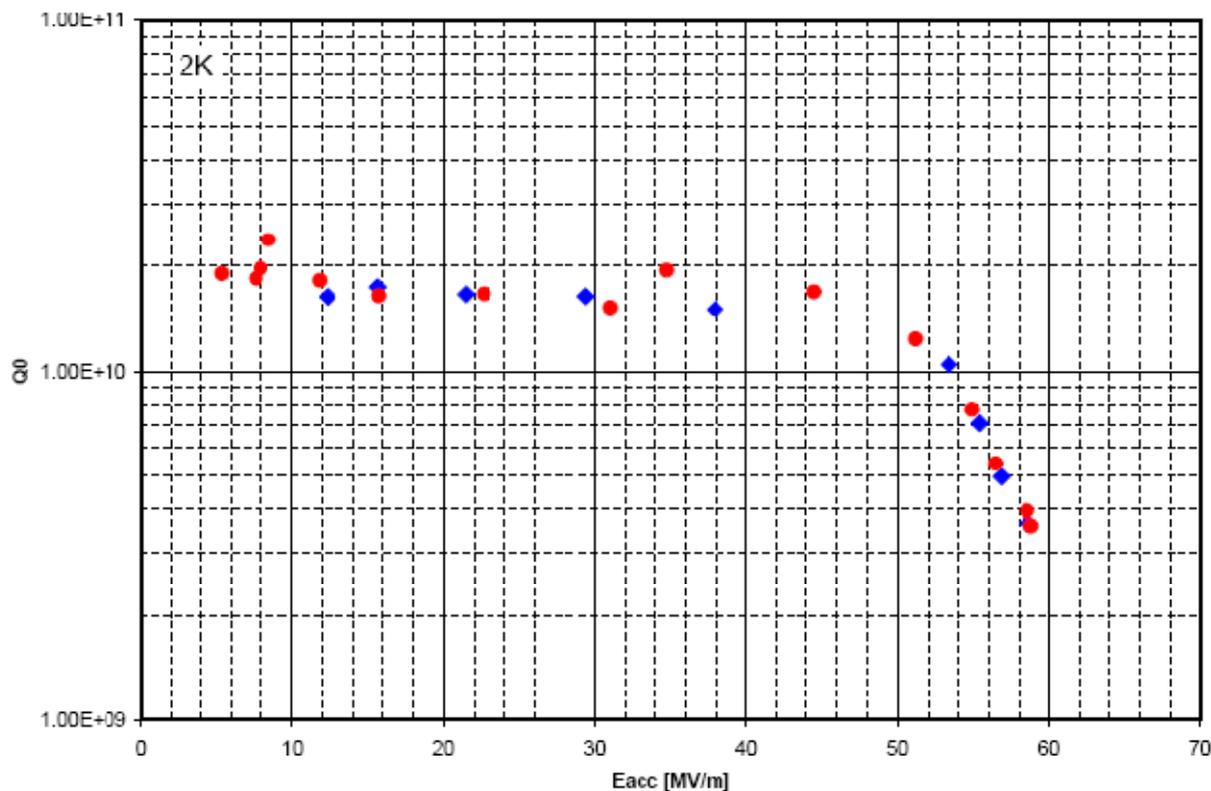
Cornell-KEK Collaboration

H. Padamsee et al.
WEPMS009



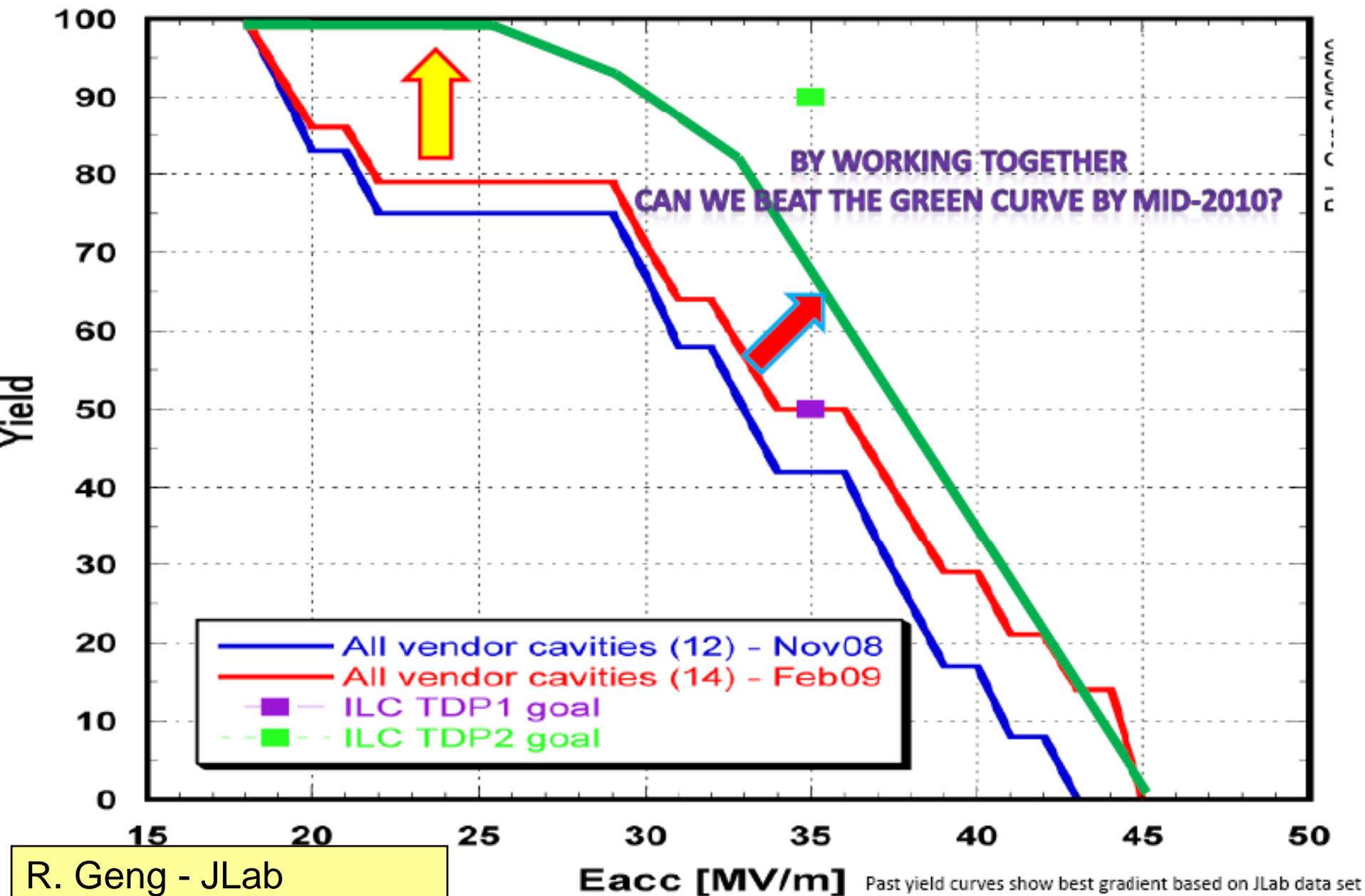
RE-LR1-3

Cornell 60 mm aperture re-entrant cavity LR1-3 March 14, 2007



- EU
 - **Preparation of the call for tender for XFEL cavities**
 - Focus at DESY will be
 - resolution of mass production problems
 - improvements to QC process
 - **HiGrade**
 - Serves as a tool to implement the ILC process
 - **Series of 8 Large-Grain Cavities waiting for test**
- US
 - **Project X**
 - **Vendor development**
 - **Coupon studies**
- KEK
 - **S1-Global**
 - **Inspection methods**
 - **Local repair**

Two Big Pushes Ahead...

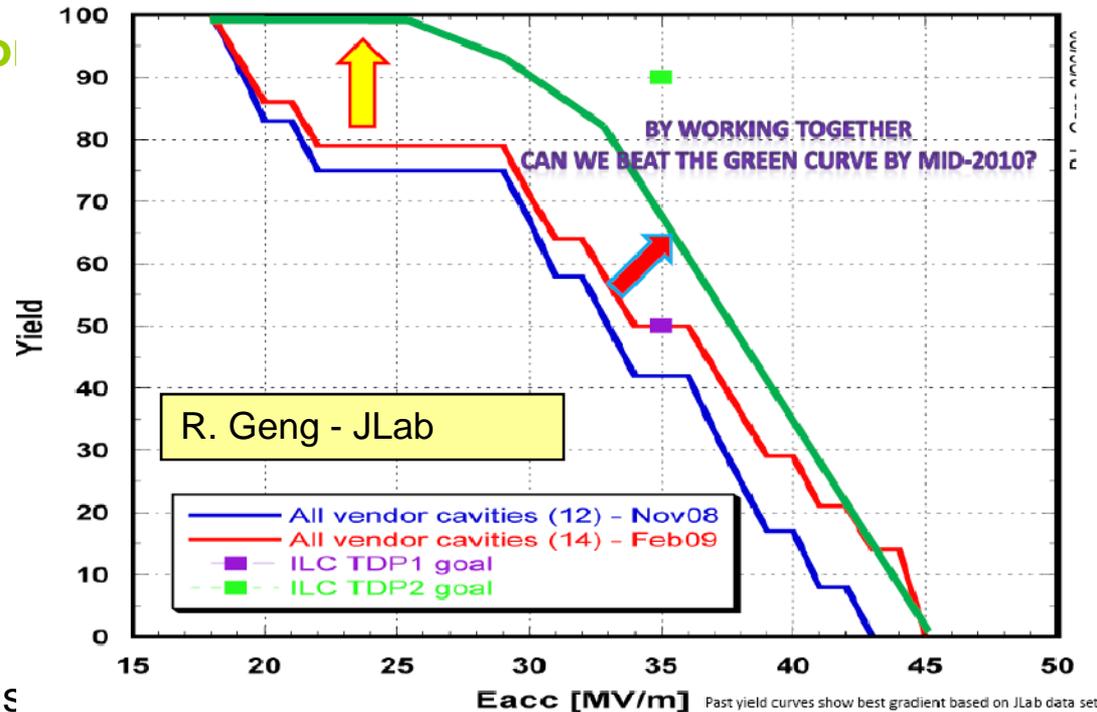




Strategy to Improve Performance

- The lower gradient part
 - Vendor qualification
 - Improvement of fabrication and weld quality
 - Typically larger defects, 'easily' detectable
- The higher gradient part
 - More systematic studies needed
- Tools are available
 - Surface Mapping
 - T-Map
 - Second Sound
 - Optical inspection
 - Common data evaluation is the way
- In addition:
 - Study repair options
 - Local grinding
 - Tumbling

Two Big Pushes Ahead...



- R&D subjects and what will be expected
 - **Improve the yield of the preparation process**
 - Vertical test yield not yet sufficient
 - Subsets of certain vendors do pass
 - Module integration (cavity assembly) will be investigated
 - **Improve weld quality**
 - PMs have visited the various cavity manufacturers
 - Training for manufacturers is important
 - **Alternatives not to be forgotten**
 - Large-grain
 - Low-loss shape
- Time-line
 - **Beginning 2010**
 - Revise choice of the gradient if necessary
- Resources
 - **Ongoing cavity fabrication in the three regions**
 - ~60 tests targeted at ILC in TDP1
 - parallel startup of XFEL with 800 cavities on order

Thanks!

- Several people were very supportive in providing data and slides
- C. Ginsburg, R. Geng, Z. Conway, L. Cooley, D. Reschke, W. Singer, J. Sekutowicz, H. Hayano, E. Kako, K. Saito

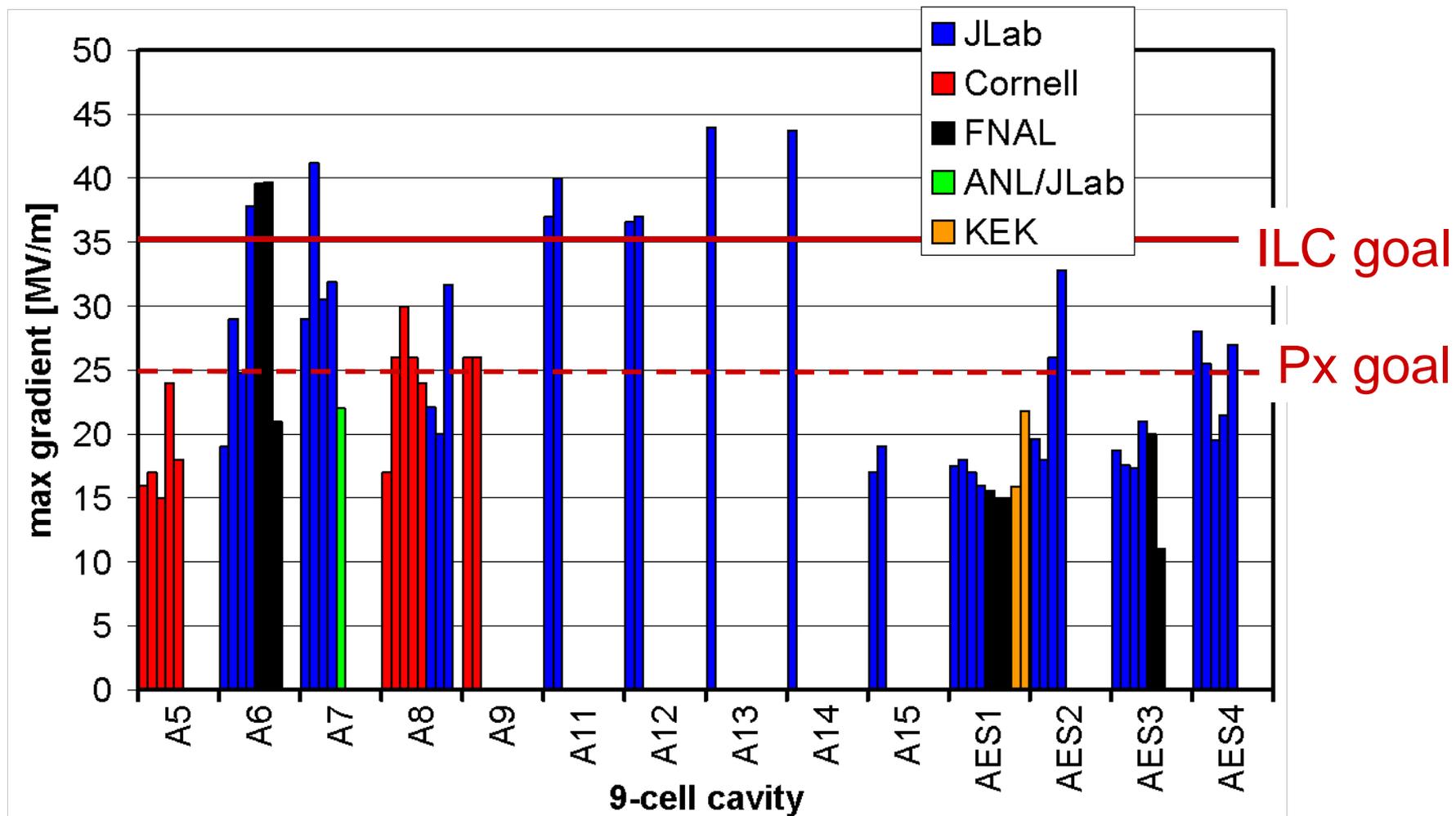


Backup Slides

Americas 9-cell Vertical Tests



Of 14 cavities, 6 cavities meet ILC VT spec & 10 meet Project X VT spec
NB: These are the tests which individual Labs choose to publish...



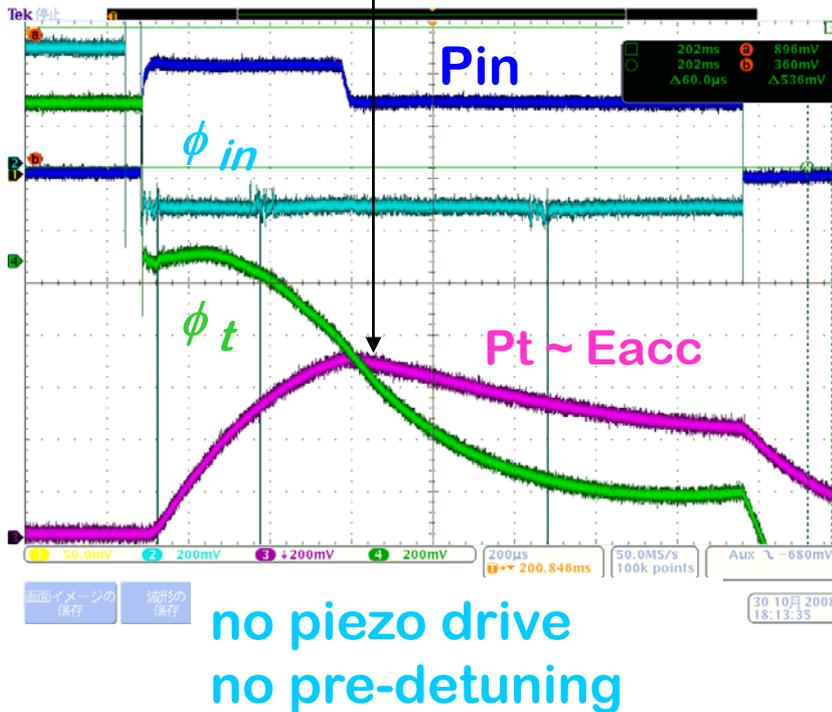
Stable Pulsed Operation ; STF Phase-1.0

Best Result ; obtained Eacc,max in #2 Cavity

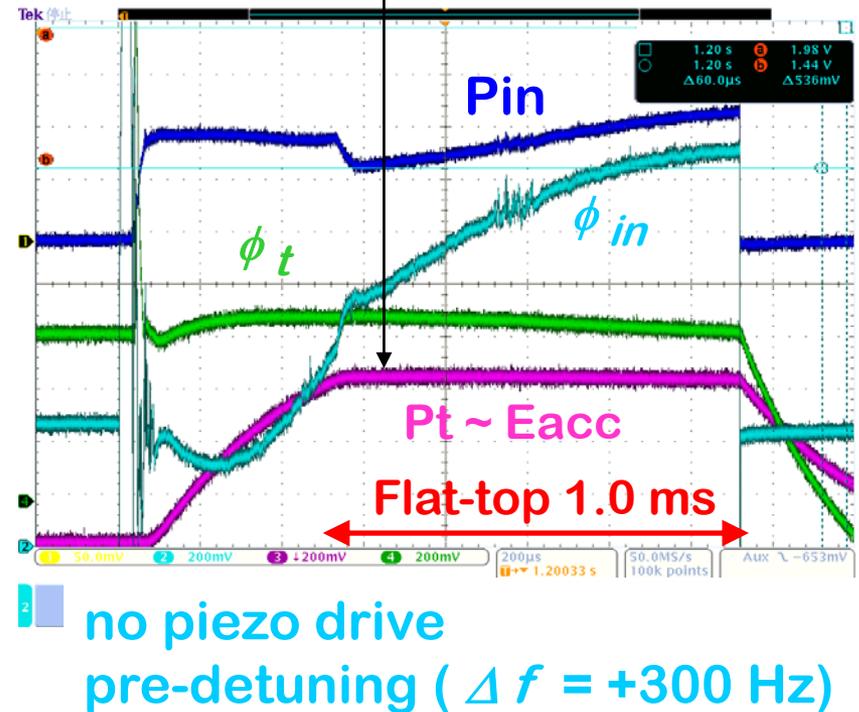
1.5 msec, 5 Hz operation

November, 2008'

RF Feedback / OFF
32.7 MV/m



RF Feedback / ON
32.0 MV/m



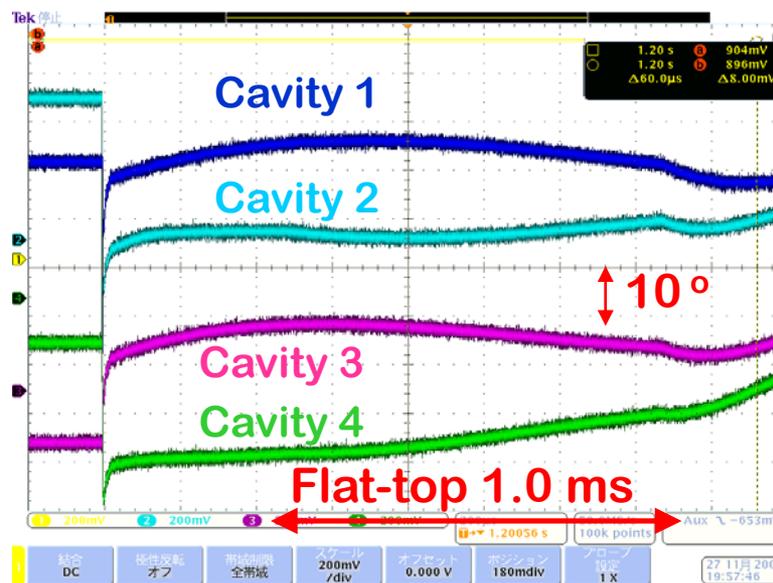
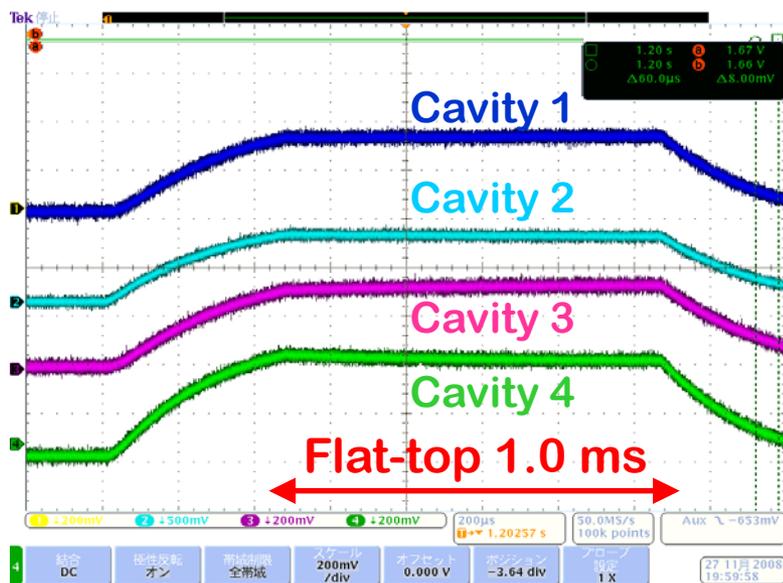
Four-Cavity Operation with Vector-Sum Control

November, 2008

1.5 msec, 5 Hz operation

Accelerating Gradient (E_{acc})

Cavity Phase (ϕ_t)



Cavity 1 ; $E_{acc} = 17.6 \text{ MV/m}$
Cavity 2 ; $E_{acc} = 18.0 \text{ MV/m}$
Cavity 3 ; $E_{acc} = 17.9 \text{ MV/m}$
Cavity 4 ; $E_{acc} = 15.2 \text{ MV/m}$

Total Acceleration Voltage
70 MV with $\phi_t < +/- 5^\circ$