Gradient R&D
(a.k.a. S0)

Mark Champion

30 June 2008

Americas

Outline

- S0 organization
- GDE goals
- Accomplishments
  - New infrastructure
  - Vendor development & Cavity procurements
  - Cavity processing and testing
  - Diagnostics development
- Plan for FY08 – FY09
- Relation to Project X
- Summary

S0 Organization and Planning in the Americas

Organization

- **GDE Project Manager: Akira Yamamoto**
- **GDE leadership from Lutz Lilje**
- **Americas Region Team Leaders**
  - **Mark Champion – Fermilab – ART S0 Coordinator**
  - **Mike Harrison – Brookhaven – ART Director**
  - **Mike Kelly – Argonne**
  - **Hasan Padamsee – Cornell**
  - **Bob Rimmer – Jefferson Lab (with strong support from Rongli Geng)**

FY08 activities are funding limited

- **Approximately $1M remained as of mid April**

FY09 proposed budget is $3.276M

New FY08-09 plan presented at April 21st SCRF meeting at Fermilab

ILC GDE SRF Program Goals

TDP1: technical feasibility by 2010

- Gradient (S0) to reach 35 MV/m with 50% yield
- One cryomodule (S1) to achieve average gradient of 31.5 MV/m
- Proof-of-Principle and System Engineering
- Cryomodule design with plug-compatible components

TDP2: technical credibility by 2012

- Gradient (S0) to reach 35 MV/m with 90 % yield
- One-RF unit (three cryomodules) operating with beam (S2)

The Americas Region FY08-09 plan supports these goals

  - it is part of a global program and needs to be well-coordinated with respect to the European and Asian work plans

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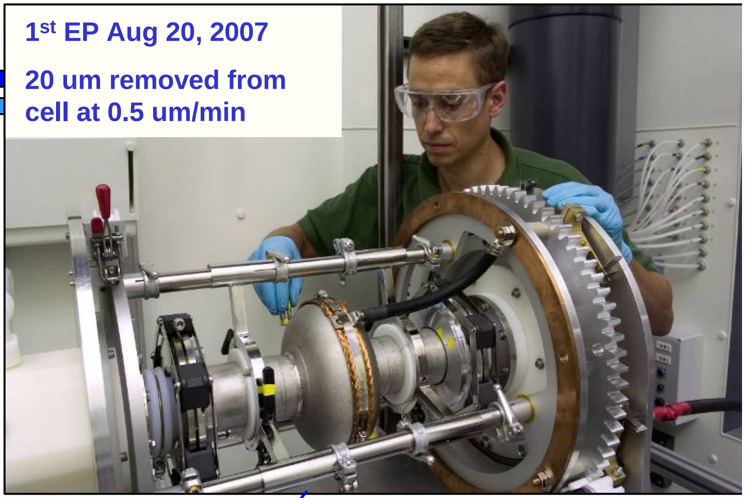
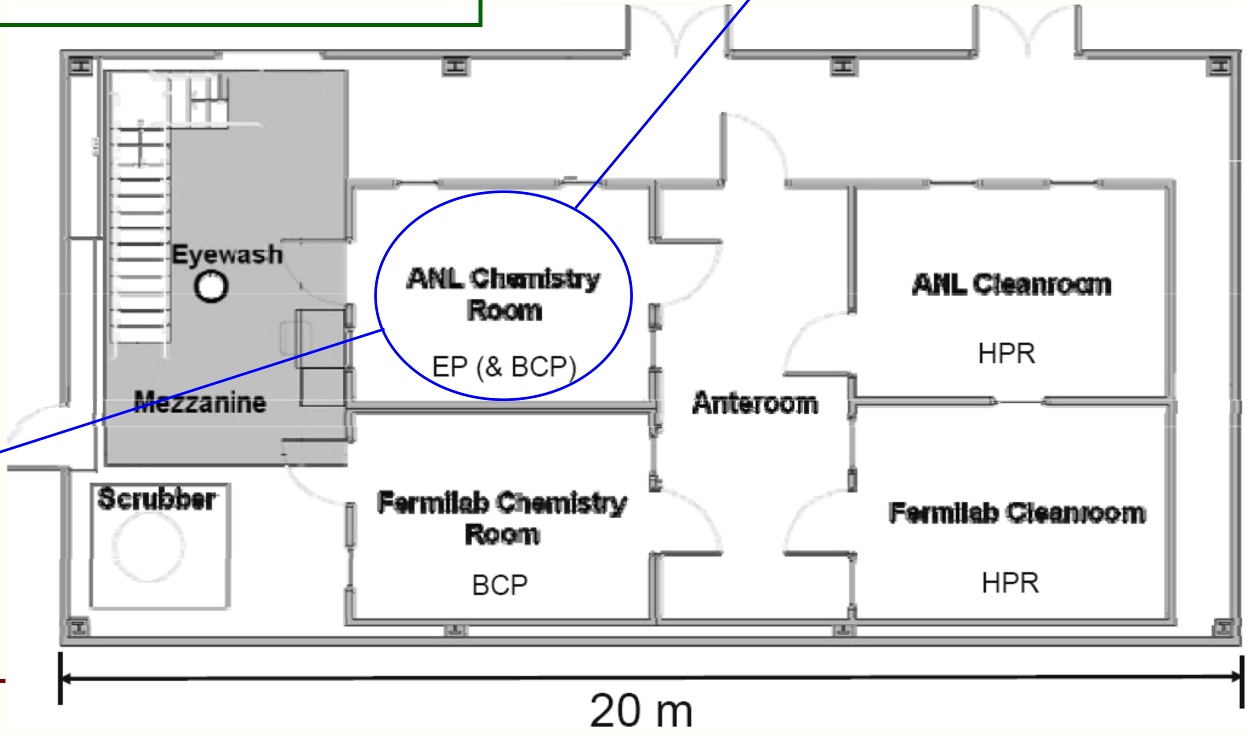
Joint ANL-FNAL ILC SRF Activities

- **ANL processing facility capabilities:**
  - **Electro-polishing, including "flash EP"**
  - **Ultrasonic cleaning**
  - **High-pressure rinsing**
  - **Drying**
  - **Assembly and vacuum leak testing**
  - **BCP (for 3.9 GHz and 325 MHz at present)**



1st EP Aug 20, 2007

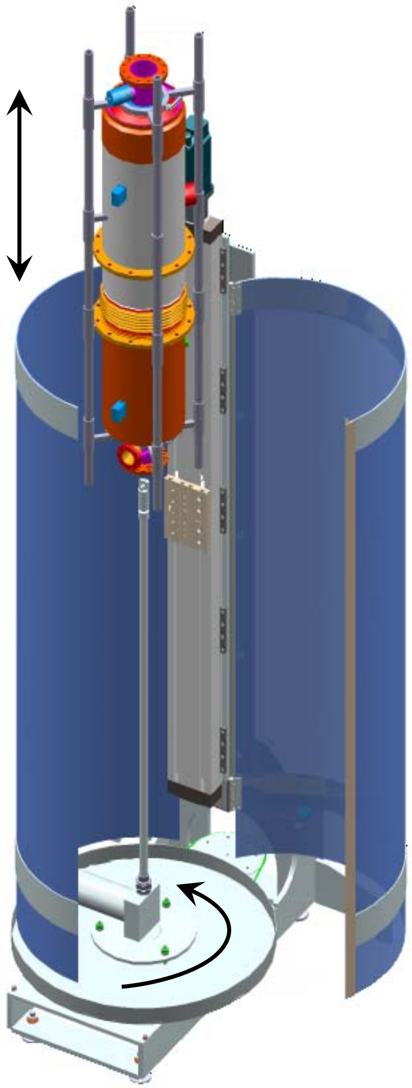
20 um removed from cell at 0.5 um/min



First nine-cell electro-polishing performed at Argonne May 12

- **Accel cavity A7 electro-polished; <removal> ~27 microns.**
- **Upon completion of low-pressure rinsing, cavity was filled with ultra-pure water and shipped to Jefferson Lab.**
- **Ultrasonic cleaning, high-pressure rinsing, and assembly completed at JLab.**
- **Test performed June 4th.**

FNAL High Pressure Rinsing System

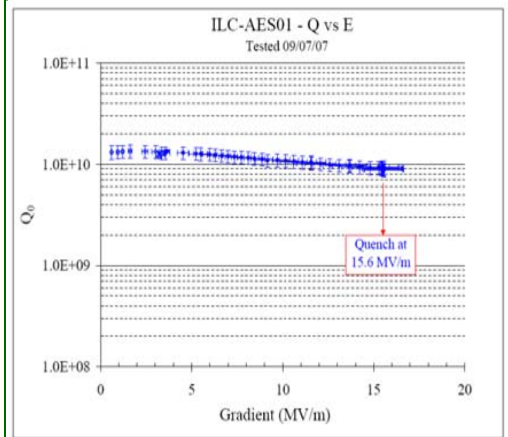


- Design concept based on Cornell HPR system
- Will be installed and operated at ANL processing facility
- Cavity moves vertically
  - Bosch-Rexroth slide with class 100 certification
- Wand rotates
  - 0.02micron filtration after swivel joint
- 1500psi / 100bar
  - LEWA diaphragm pump
- Status
  - Installation in progress at ANL
- Plan to perform first complete processing cycle at ANL in autumn 2008

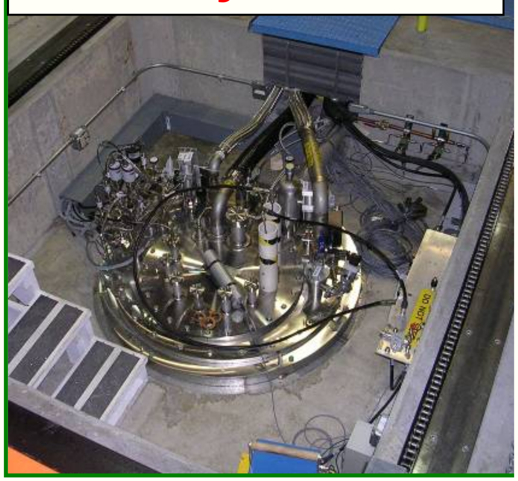
Americas

Vertical test stand at FNAL commissioned summer 2007

- **Recently commissioned (IB1)**
  - **Existing 125W@ 1.8 K Cryogenic plant**
  - **RF system in collaboration with Jlab**
  - **Capable of testing ~50 Cavities/yr**
  - **Evolutionary upgrades:**
    - **Thermometry for 9-cells, 2 cavities at a time, 2 top plates, Cryo upgrades**
    - **Plan for two additional VTS cryostats**
  - **Ultimate capacity ~ 264 cavity tests/yr**

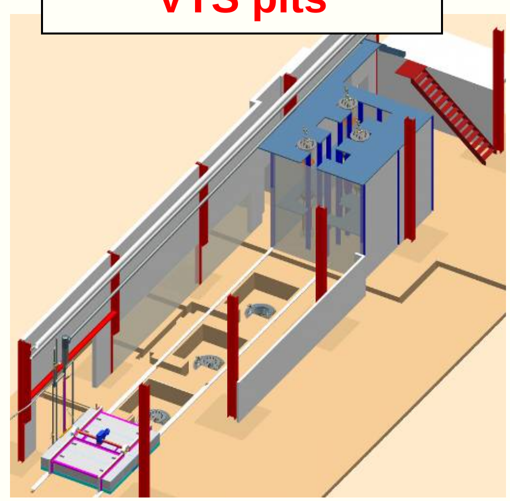


VTS Cryostat:IB1



New RF & Control Room

Plan for 2 more VTS pits



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AES completed 4 nine-cell and 6 single-cell cavities in 2007

- AES delivered 4 nine-cell and 6 single-cell cavities in 2007 (test results to be shown later).
- Another 6 nine-cell cavities presently in production at AES.
- Next cavities will be welded at AES using new electron-beam welder (in photograph).
  - Welding formerly performed by subcontractor under AES supervision

ilc Americas

First Niowave/Roark single-cell cavities received June 2008

Fabrication of Six 1.3 GHz Single-Cell SRF Niobium Cavities for FNAL

Final Report

Niowave, Inc.
&
Roark Welding and Engineering Co., Inc.

Summary

Niowave and Roark have fabricated six 1.3 GHz single-cell SRF niobium cavities for FNAL, in order to quality both vendors for ILC nine-cell SRF cavity work. Duration of project was eight months, from late September 2007 to early June 2008. Completed intermediate steps include CAD modeling, eddy current scanning, tooling and die design and fabrication, half cell and end tube fabrication, CMM analysis, electron beam welding, and frequency measuring. Six fully welded cavities have been frequency and QA tested to ensure all specifications were met. Two additional cavities were completed and may be purchased by FNAL for additional testing. Once the cavities undergo final cleaning and chemical processing, they will be tested for high field RF performance at FNAL.

NIOWAVE/ROARK 1.3 GHz Progress Report 1 of 10

Niowave/Roark

- Cavities presently undergoing QC checks at FNAL
- Will be processed and tested to qualify vendor procedures

PAVAC/TRIUMF

- TRIUMF is developing capabilities at local vendor: PAVAC.
- Plan to build two single-cell cavities initially.
- FNAL is providing a single-cell cavity to TRIUMF for use in commissioning their processing and testing facilities.

ILC Cavity Inventory

Americas

	A	B	C	D
1	**ILC Tesla-shape nine-cell cavities**			
2	**Description**	**No. Cavities**	**Status**	**Location**
3	AES 1-4	4	tested	AES1 at KEK; AES3 at LANL AES2,4 at Jlab
4	AES 5-10	6	due Sep 2008	
5	Accel 5-9	5	tested	Acc7,8 at Jlab; Acc6 at FNAL; Acc5,9 at Cornell
6	Accel 10-17	8	received Mar 2008	Acc11,12,15 at Jlab; Acc14 at ANL; remainder at FNAL
7	Accel 18-29	12	due Sep 2008	
8	Jlab fine-grain prototype	1	tested	at Jlab
9	Jlab large-grain 1-2	2	tested	at Jlab
10	Jlab fine-grain 1-2	2	fabrication in progress	at Jlab
11	TBD - 10 cavity FY09 order	10	will order in FY09	
12				
13	Total	50		
14	Already Received	20		
15				
16				
17				
18				
19	**ILC Tesla-shape single-cell cavities**			
20	**Description**	**No. Cavities**	**Status**	**Location**
21	AES 1-6	6	tested at Cornell	one at Jlab, one at ANL, two at FNAL, two at Cornell
22	Accel 1-6	6	due Sep 2008	
23	Roark 1-3	3	received Jun 2008	at FNAL
24	Niowave 1-3	3	received Jun 2008	at FNAL
25				
26	Total	18		
27	Already Received	12		

Americas

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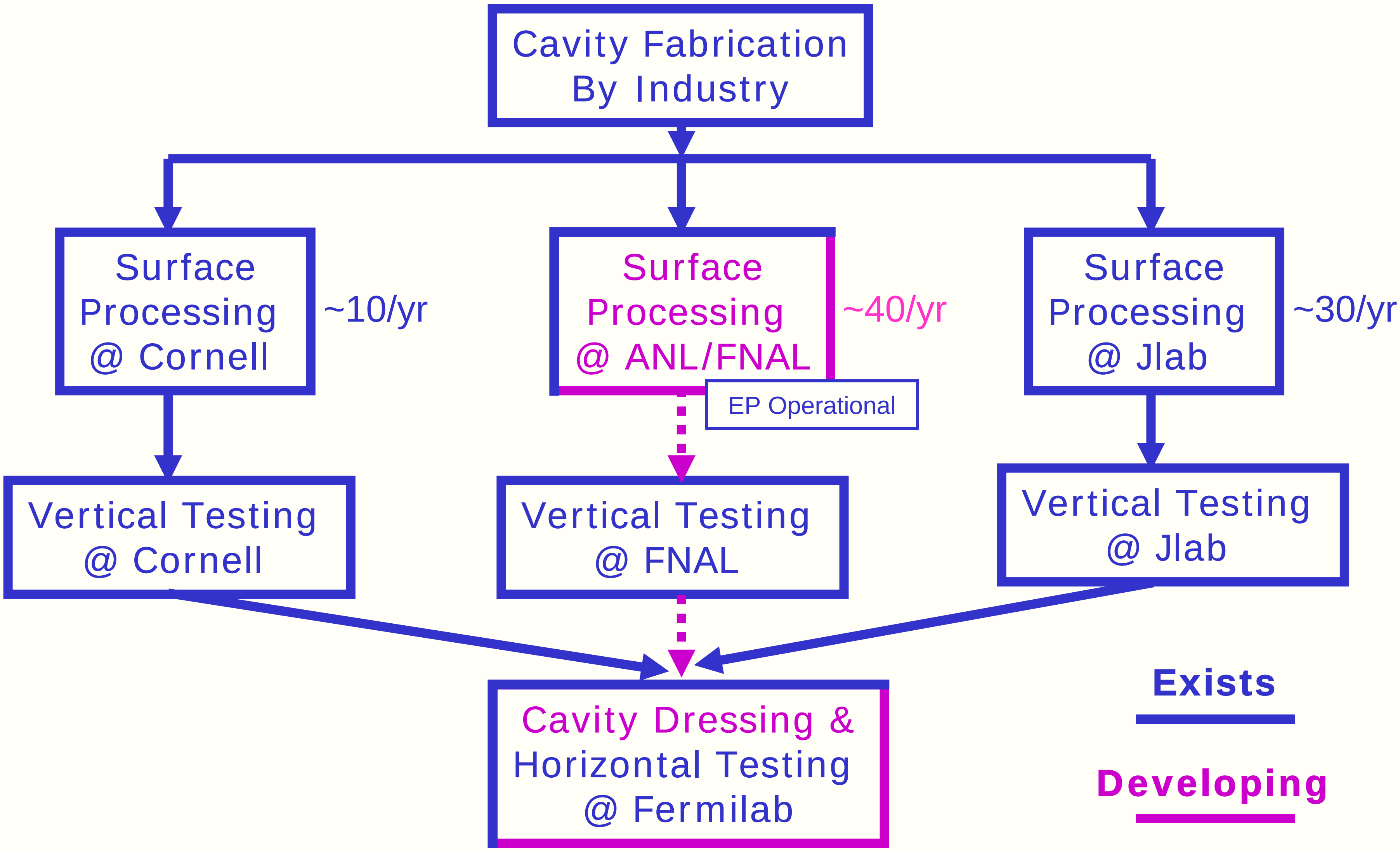
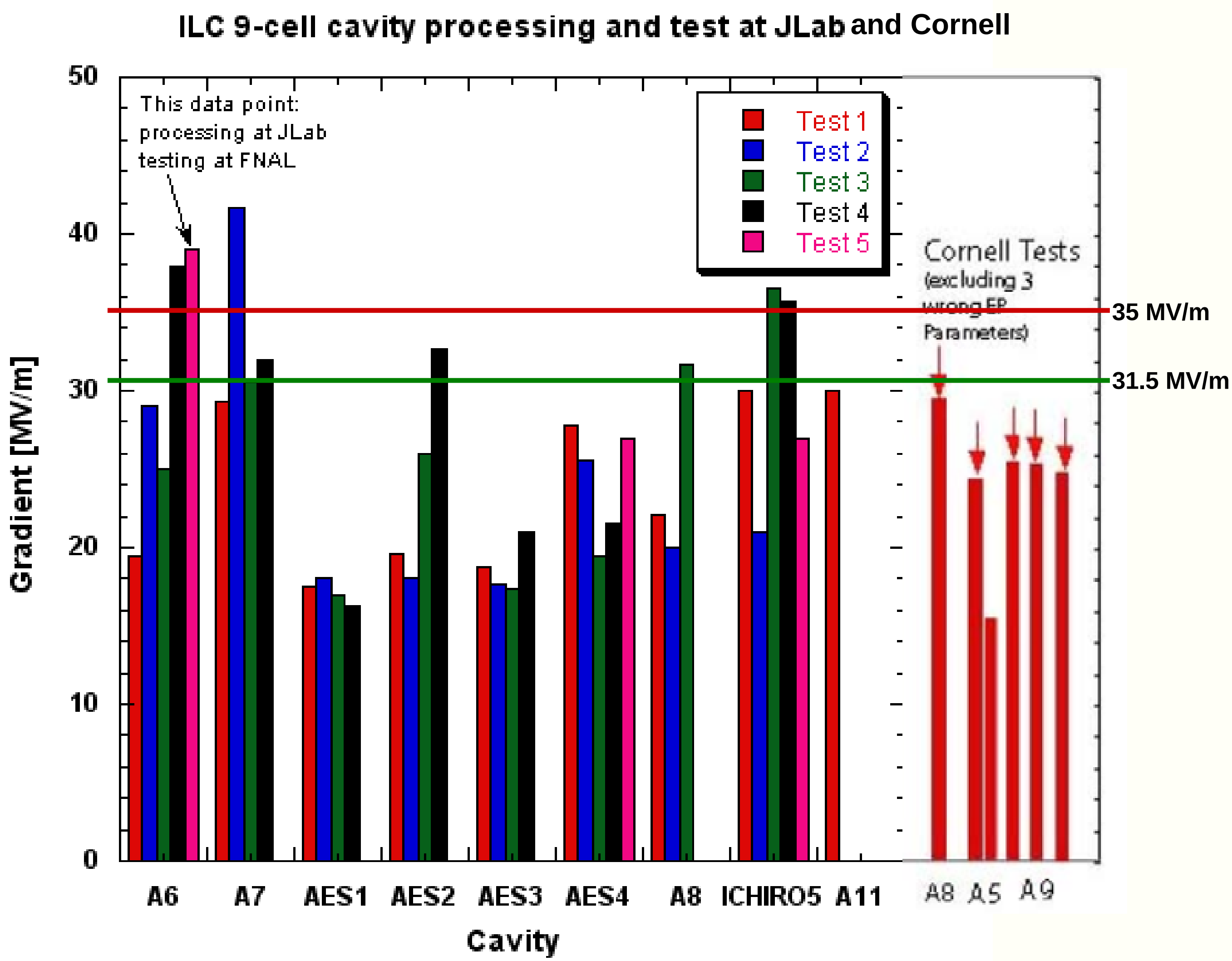
U.S. Cavity Processing & Testing



Summary of cavity performance in testing at JLab and Cornell

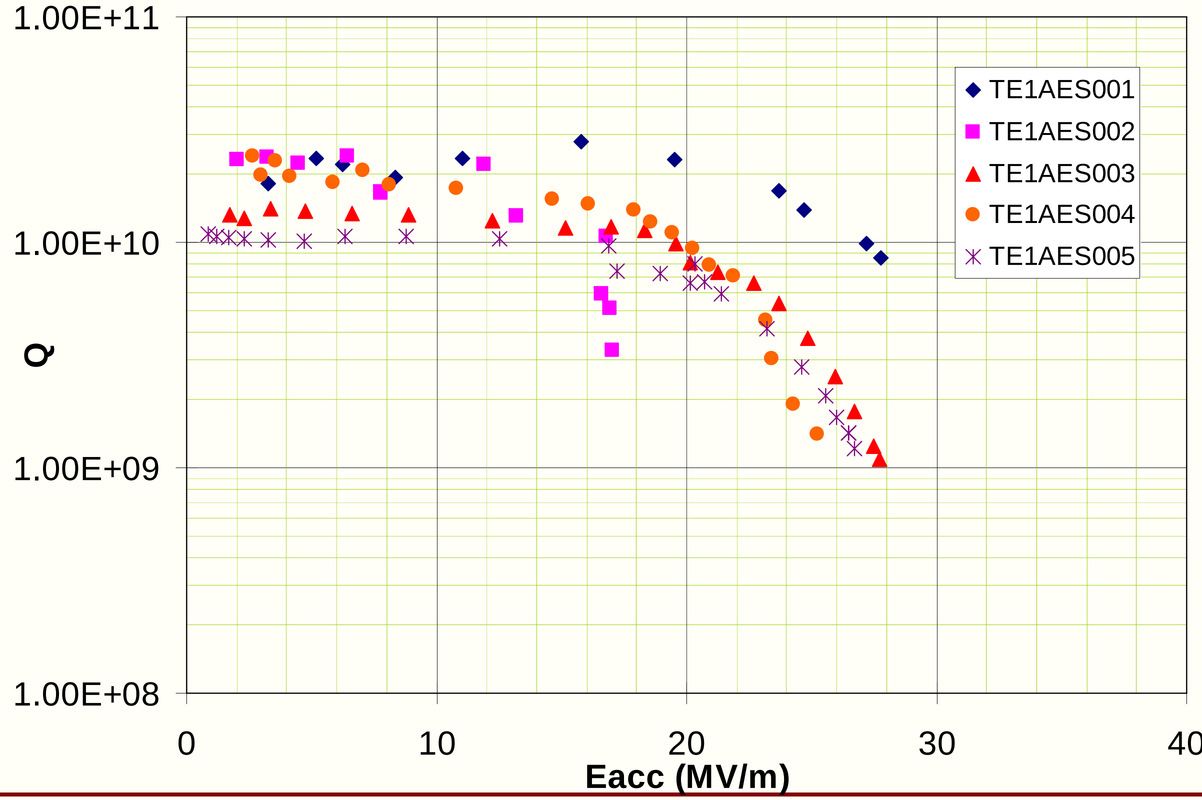


Americas

Test results on first batch of AES 1.3 GHz single-cell cavities

- Six single-cells cavities procured from AES for vendor qualification
- Five cavities tested so-far at Cornell (Bulk BCP~110 µm + HPR ~2 hrs) in late 2007
- 4 of 5 cavities reached 25 MV/m without quench
- 1 of 5 cavities reached 17 MV/m limited by field emission

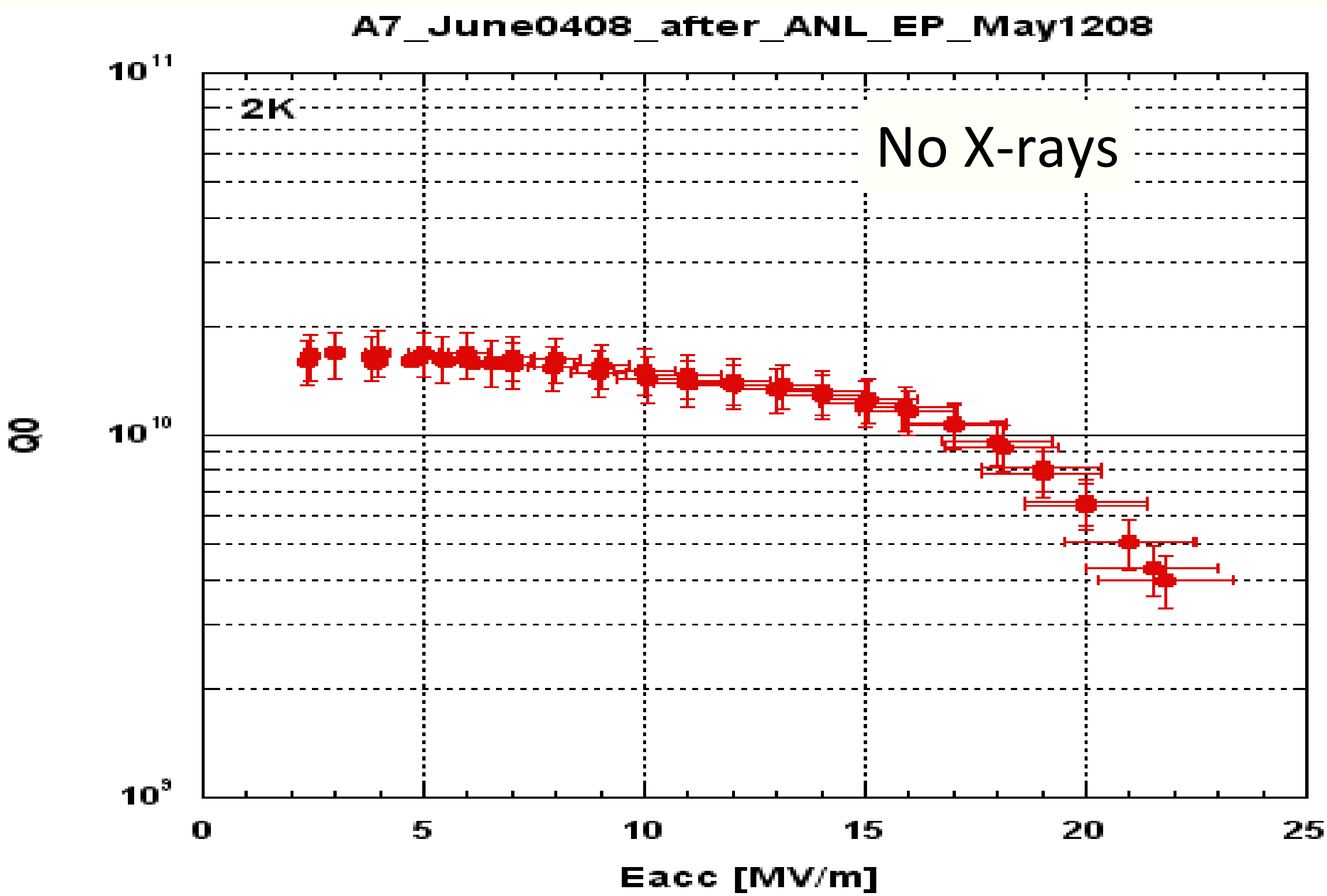
Conclusion: AES exhibits competency in the fabrication of single-cell cavities



Accel7: Q_o vs Gradient measurement at JLab June 4

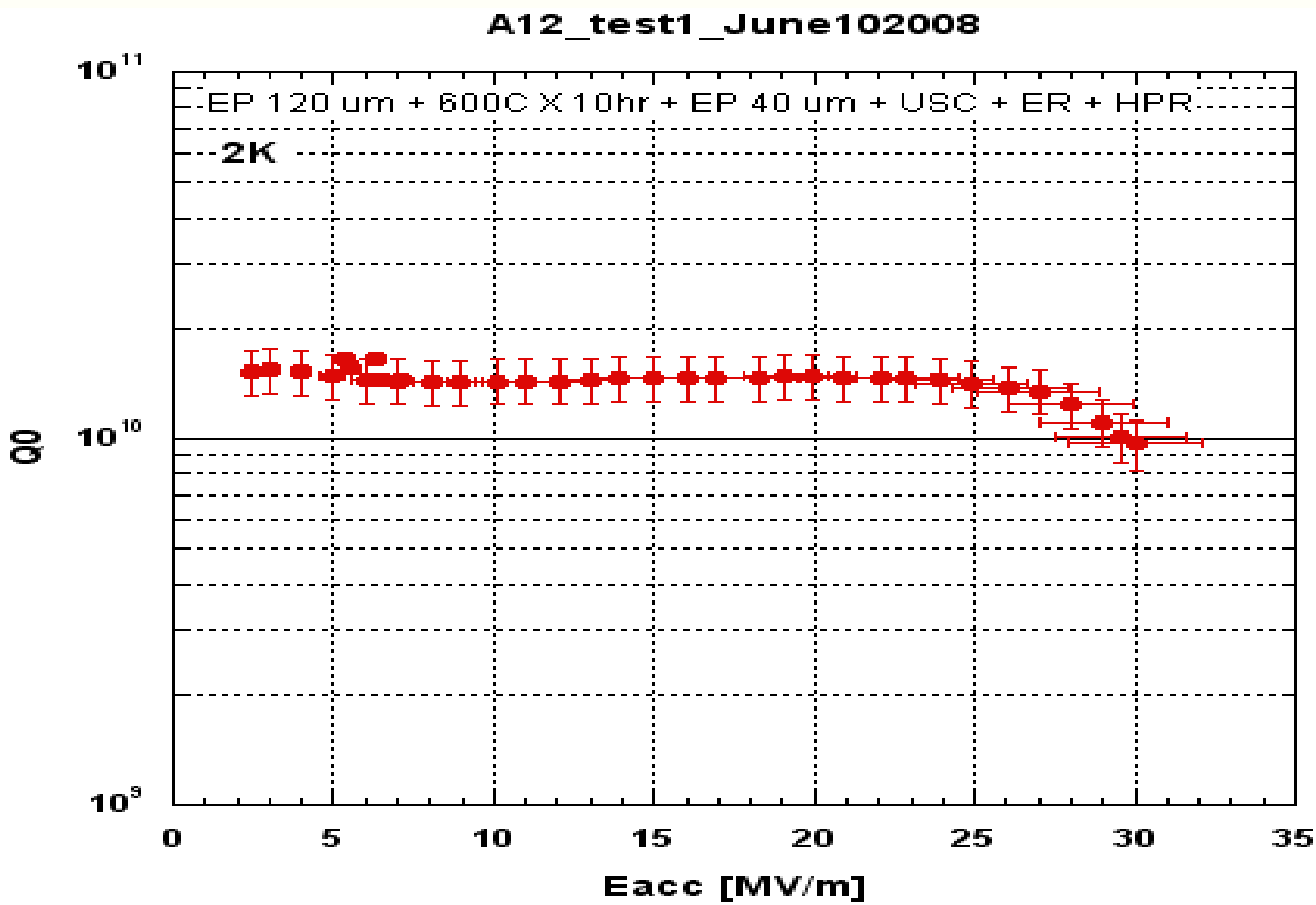
First nine-cell cavity electro-polished at Argonne

Previously achieved ~32 MV/m at JLab → EP process at ANL needs optimization!



Accel12: Q_o vs Gradient measurement at JLab June 10

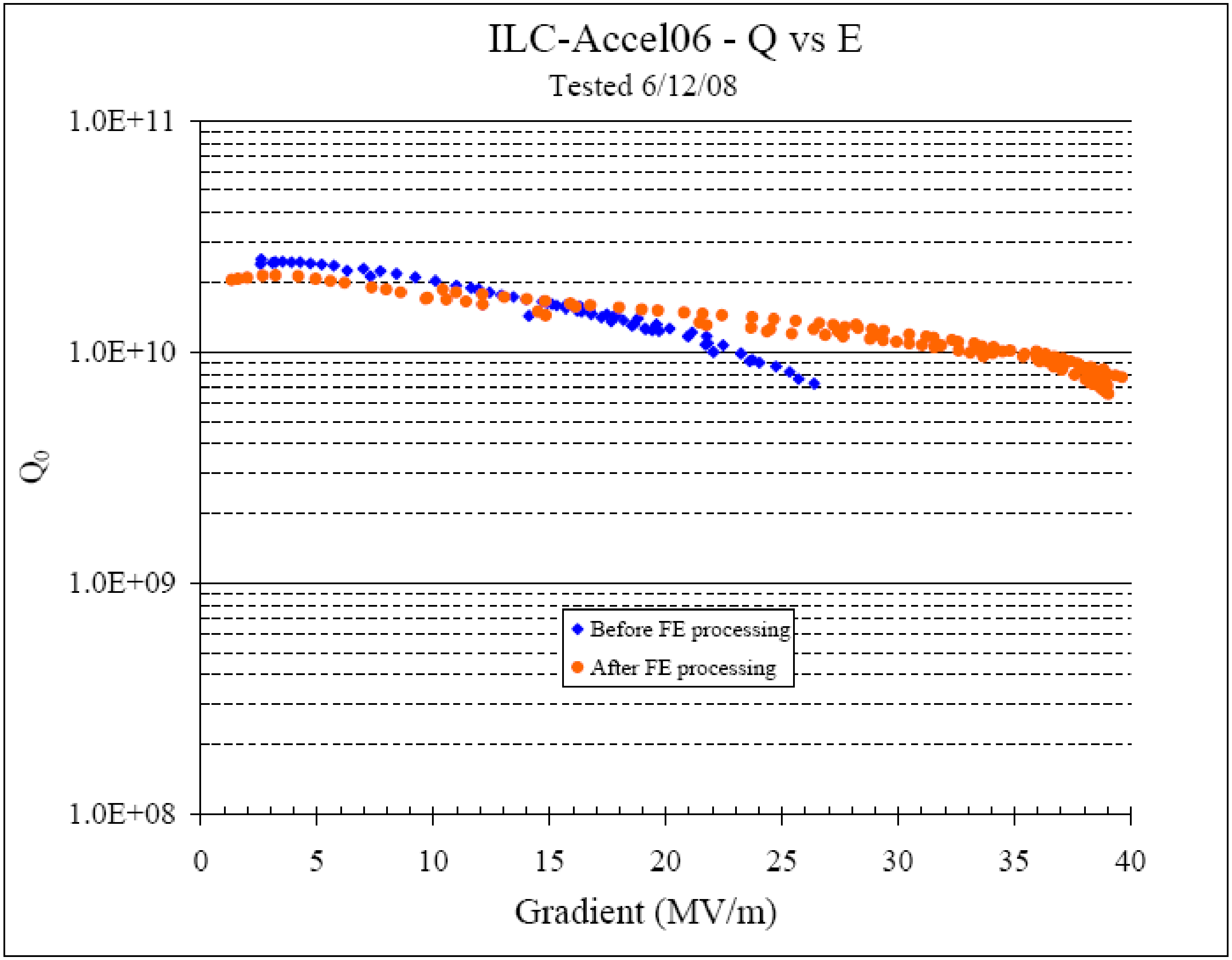
First measurement on batch of 8 Accel cavities received March 2008



Accel6: Q_o vs Gradient measurement at Fermilab June 12

Previous test at JLab: 38 MV/m (one year ago)

Preparation for this test: ultrasonic degreasing + high-pressure rinsing (no EP)



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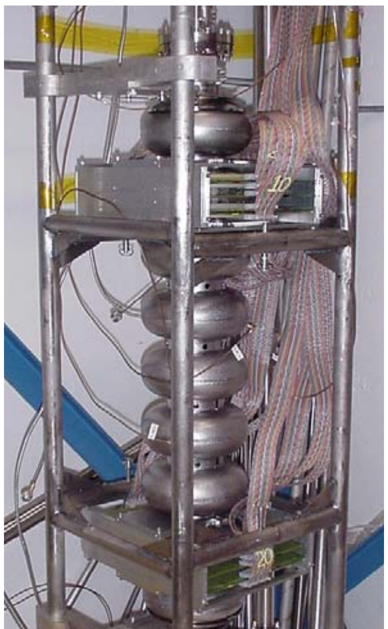
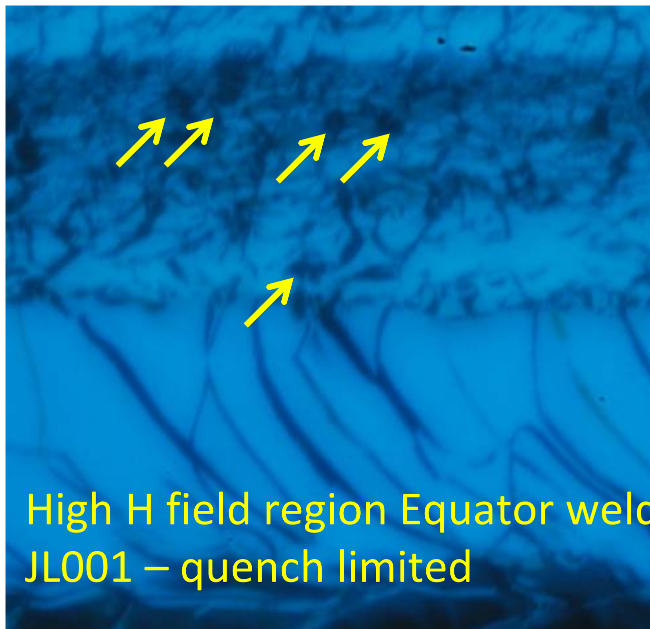
New Jefferson Lab Diagnostics: T-mapping and optical inspection

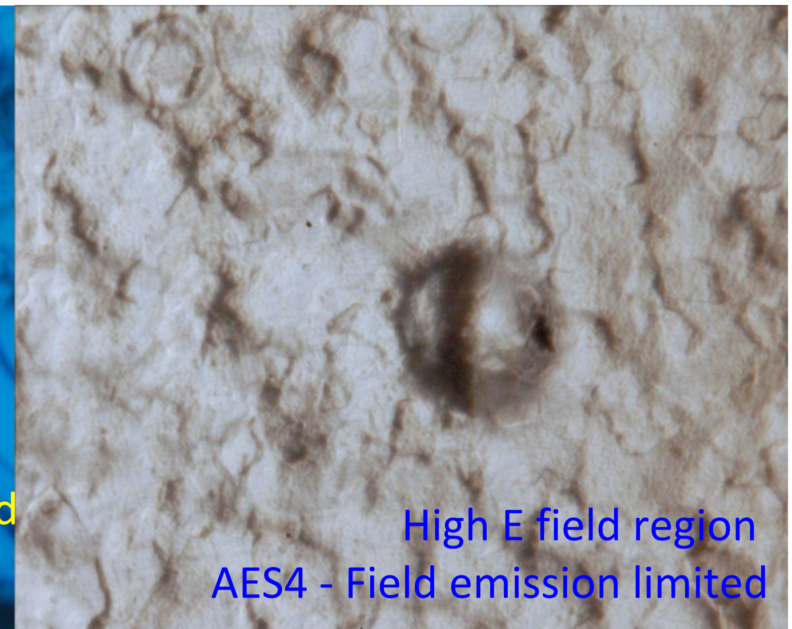
Goal: Improve Gradient Yield by understanding quench limit in 9-cell cavities

2 of 9 thermometry near Equator locates hot spots

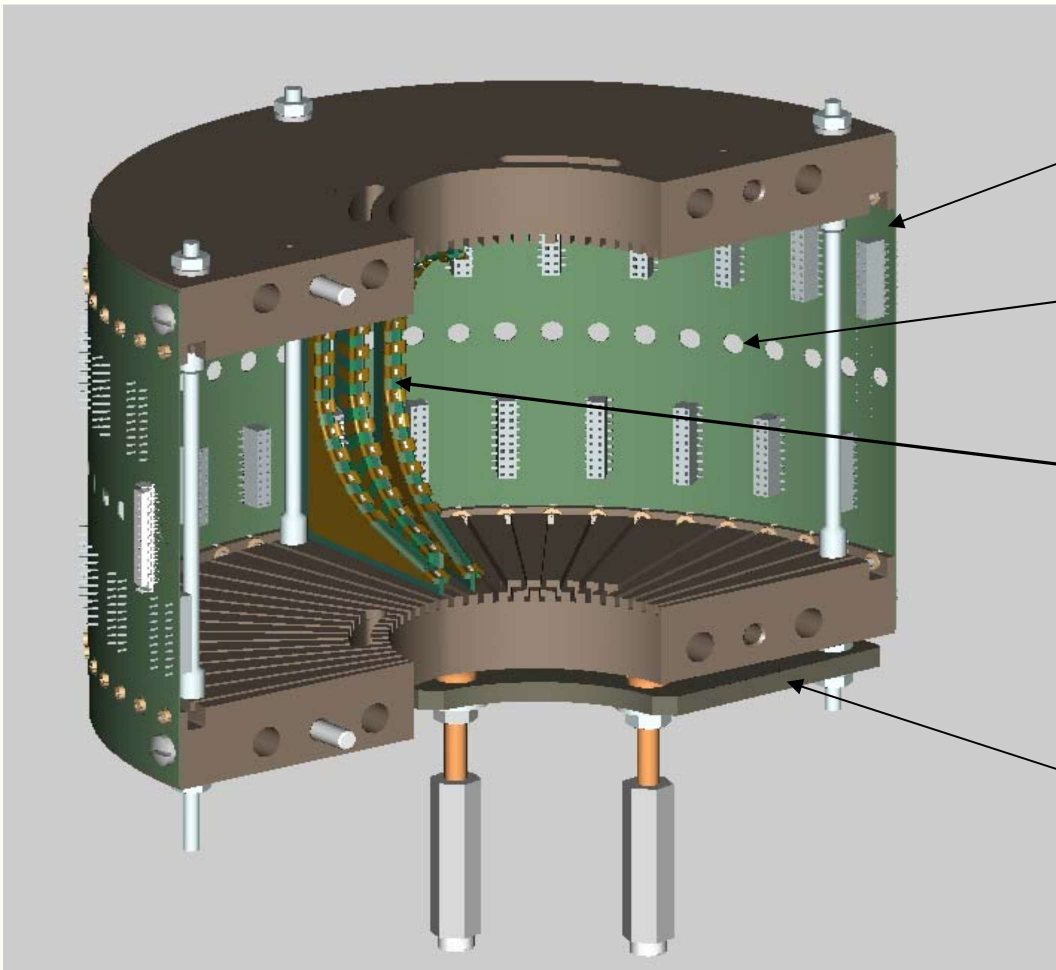
Long-distance microscope direct 9-cell cavity complete RF surface inspection for defects







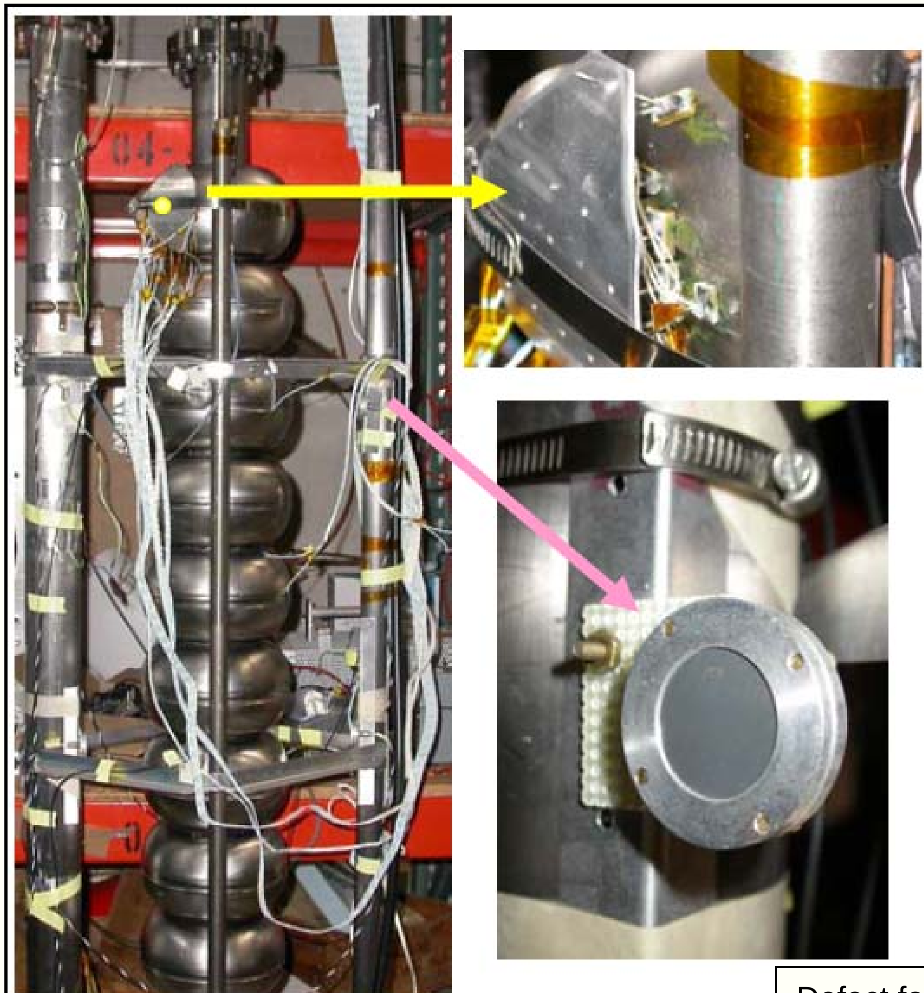
T-Mapping for single-cell and nine-cell cavities under development at FNAL (Mukherjee)

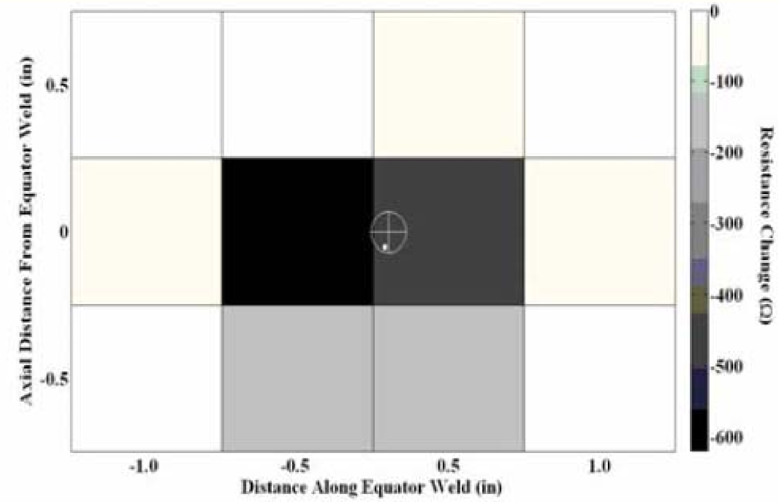


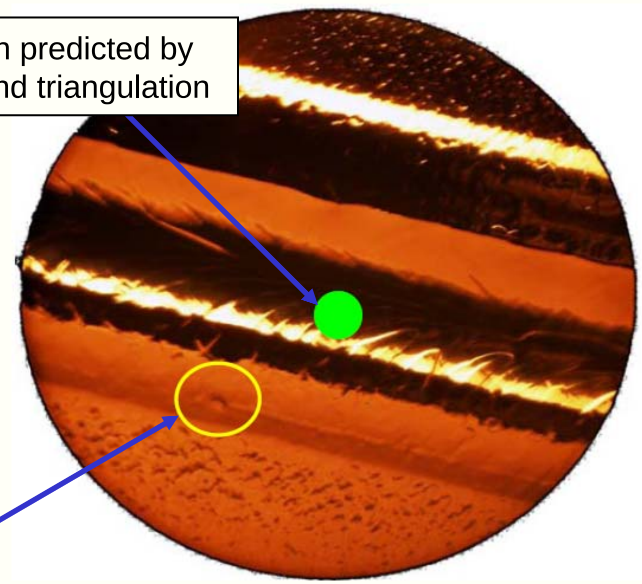
Second-sound defect location demonstrated at Cornell

http://flash.desy.de/sites/site_vuvfel/content/e403/e1644/e2271/e2272/infoboxContent2355/TTC-Report2008-06.pdf

Americas

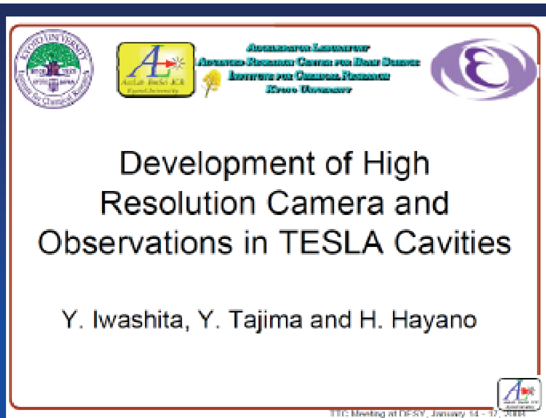


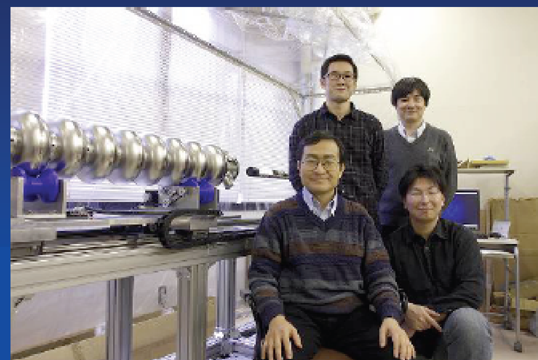




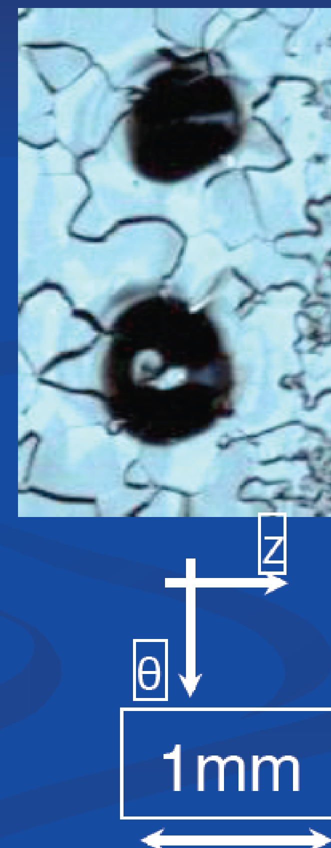
Americas

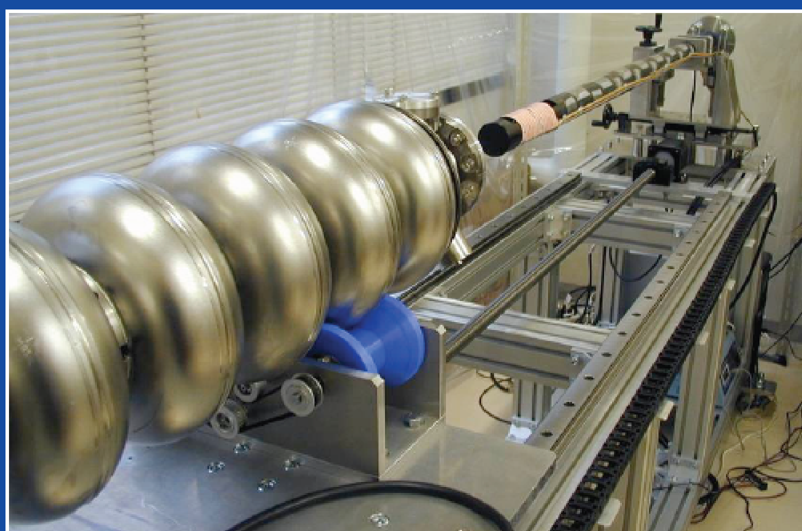
New Kyoto/KEK inspection tool has been useful in understanding quench limits



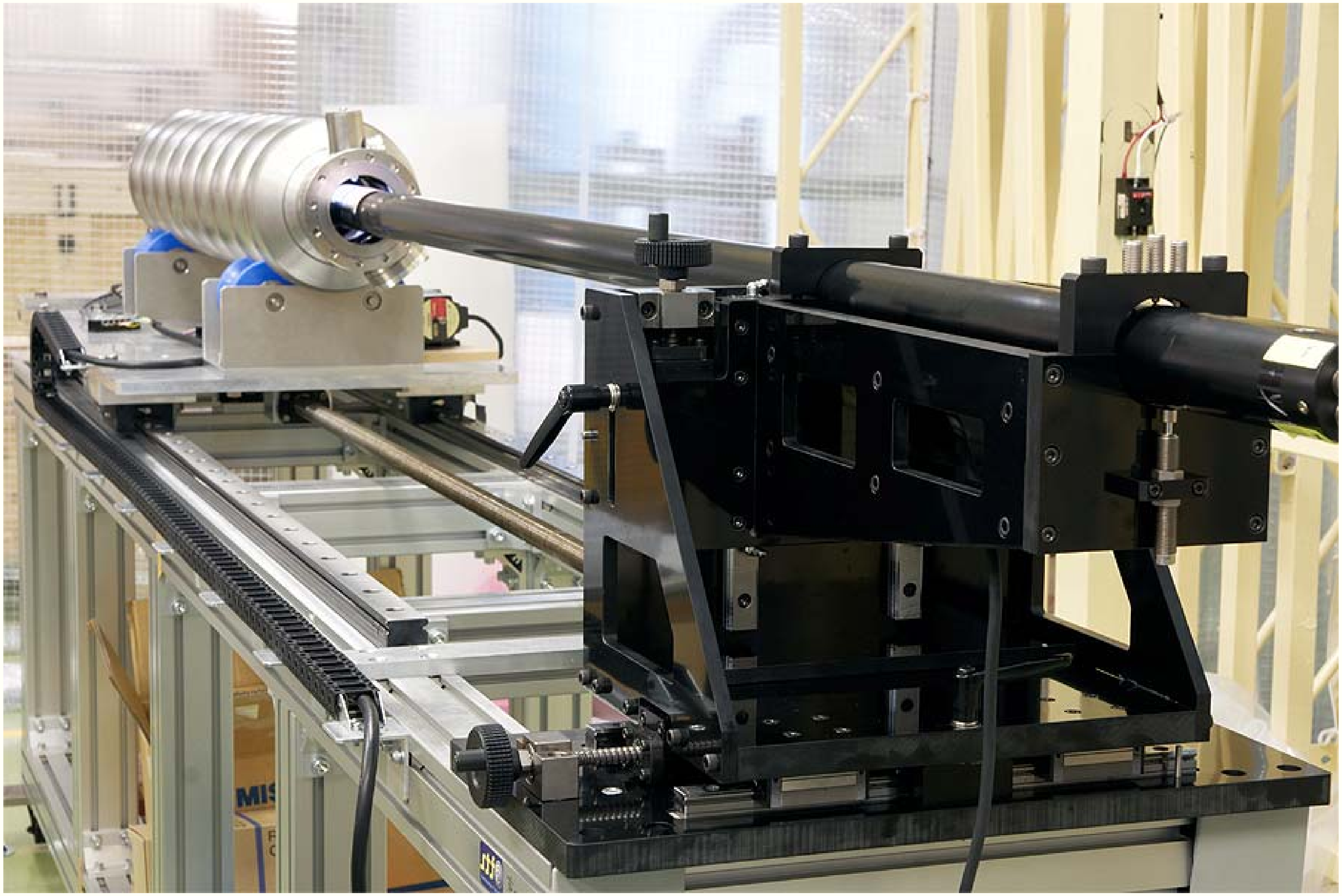


AES001 #3 cell 169°
Edge of heat-affected zone





First industrially-produced Kyoto-KEK inspection system
Plan to acquire 2-3 systems for use in Americas Region



T-Mapping system under development at Los Alamos (Tajima)

- AES3 on loan to LANL for commissioning of system.
- Work supported by non-ILC funds.

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Work Plan for FY08-09 presented at April SCRF meeting at FNAL
Final version released June 2nd

Americas Region FY08-09 Work Plan for ILC GDE Cavity Gradient Program (S0)

Introduction

The purpose of this document is to detail the Americas Region work plan for FY08-09 in support of the S0 gradient goals. The participants in this work plan include Argonne National Laboratory, Cornell University, Fermilab, and Jefferson Laboratory. The team leaders are listed below.

GDE S0	Lutz Lilje, DESY
Americas Region	Mike Harrison, BNL
Argonne	Mike Kelly
Cornell	Hasan Padamsee
Fermilab	Mark Champion[1]
Jefferson Lab	Bob Rimmer

The Americas Region is committed to supporting the ILC Global Design Effort (GDE) in achieving the goals of Technical Design Phases 1 & 2, which are reiterated here:

TDP1: technical feasibility by 2010
- Gradient (S0) to reach 35 MV/m with 50% yield
- One cryomodule (S1) to achieve average gradient of 31.5 MV/m
- Proof-of-Principle and System Engineering
- Cryomodule design with plug-compatible components

TDP2: technical credibility by 2012
- Gradient (S0) to reach 35 MV/m with 90 % yield
- One-RF unit (three cryomodules) operating with beam (S2)

The general scheme is to divide up the work according to fiscal year and institution. Fermilab and Argonne will work together with the cavity processing being performed at Argonne and the cavity testing being performed at Fermilab. It is expected that all four institutions will assist each other as necessary and will work together closely in the quest for high gradient performance. The work plan will be a consensus plan to the extent possible. The plan will be modified as necessary due to experimental results and changes in the financial situation. In case of disagreement, the Americas Region leader, Mike Harrison, will be called upon to arbitrate.

This work plan is part of a larger global effort supporting the ILC GDE. Lutz Lilje is the GDE leader for the S0 program and will guide the global program. The team leaders at the participating institutions will be called upon to support Lutz in this effort and to communicate directly with each other as needed.

[1] Americas Region S0 coordinator

June 02, 2008 Page 1 of 8

FY08 Details

The primary goals for the remainder of FY08 are to:

- **Process and test 8 new Accel cavities received in March 2008.**
- **Complete and commission the Argonne cavity processing facility.**
- **Acquire Kyoto/KEK-style optical inspection systems at Fermilab and Jefferson Lab (depends on support from US-Japan funds).**

Argonne/Fermilab

- **Complete and commission the Argonne cavity processing facility.**
- **Electro-polish Accel-7 to qualify nine-cell EP process.**
- **Process and test 2-3 new nine-cell cavities.**
- **Process and test a few single-cell cavities.**
- **Acquire industrialized Kyoto/KEK optical inspection system.**
- **Commission the single-cell T-mapping system.**

Cornell

- **Carry out final EP and test for 2-3 new nine-cell cavities with bulk EP, hydrogen degassing and tuning done at Argonne/Fermilab.**

Jefferson Lab

- **Test Accel-7 following EP at Argonne.**
- **Process and test 3-4 new nine-cell cavities.**
- **Utilize "2 of 9" temperature mapping system and optical inspection system to localize defects.**
- **Acquire industrialized Kyoto/KEK optical inspection system.**
- **Complete the fabrication of two nine-cell fine-grain cavities.**

FY09 Plan – Cavities and Goals

- At the beginning of FY09, all existing nine-cell cavity orders will be fulfilled
  - 20 new cavities from Accel
    - 8 of the 20 Accel cavities were received in March 2008
  - 6 new cavities from AES
  - 2 new cavities from Jefferson Lab
- The primary goals for FY09 are to:
  - Process and test 20 new Accel, AES and Jefferson Lab cavities.
  - Improve the understanding of gradient limits in nine-cell cavities through the application of temperature-mapping and optical inspection.
  - Improve the understanding of gradient limits via a single-cell R&D program.

Elements of FY09 Plan

- Reduce emphasis on “tight-loop” processing of nine-cell cavities
- Increase emphasis on understanding high-gradient (>25 MV/m) limitations
- Improve understanding of thermal breakdown
  - Utilize temperature (T) mapping and optical inspection
  - Complete nine-cell Fermilab and Cornell T-mapping systems
  - Utilize recently completed “2 of 9” Jefferson Lab T-mapping system
- Improve understanding of the role of sulfur
  - Compare ethanol rinse and ultrasonic rinsing
  - Perform “Flash EP” on nine-cell and single-cell cavities
- Improve understanding of large-grain cavity performance and possible cost advantages
- Investigate advantages of tumbling for bulk removal and/or elimination of defects
  - For example, repair of AES1&3, in collaboration with KEK
- Process and test all new Accel, AES and Jefferson Lab nine-cell cavities
- Procure 10 new nine-cell cavities from industry (funded from SRF, not ILC)

FY09 Plan Details

Argonne/Fermilab

- Process and test 5 new nine-cell cavities.
- Perform bulk EP, hydrogen degassing, and tuning on 3 new nine-cell cavities in collaboration with JLab.
- Perform single-cell processing and testing.
- Complete and commission the nine-cell temperature-mapping system.

Cornell

- Process and test 3 new nine-cell cavities (bulk EP, hydrogen degassing and tuning at Argonne/Fermilab).
- Test effect of Flash-EP on gradient spread for 9-cells in collaboration with JLab.
- Design, fabricate and commission 9-cell temperature-mapping system.
- Perform single-cell processing and testing.
- Utilize 2nd-sound and make improvements to system.

Jefferson Lab

- Process and test 12 new nine-cell cavities.
- Test Flash-EP cavities from Cornell and JLab large-grain nine-cell cavities (4+4).
- Perform single-cell processing and testing.
- Perform flat-sample studies.
- Perform cooling upgrade on EP system.
- And a few more items detailed on next slide.

FY09 Budget Details

Argonne	# cycles	cost/cycle k$	cost k$	Notes
9-cell EP	20.0	15.0	300.0	5 new cavities, 3-4 cycles each
Bulk EP for Cornell	3.0	15.0	45.0	3 new cavities, 1 cycle each
Single-cell EP	10.0	6.0	60.0	
Processing facility maintenance			46.0	
Total			**451.0**	
Fermilab				
9-cell test cycles	15.0	15.0	225.0	5 new cavities, 2-3 cycles each
Single-cell test cycles	10.0	15.0	150.0	
Complete 9-cell T-Map			75.0	
Total			**450.0**	
Cornell				
9-cell process and test cycles (new cavities)	9.0		384.0	3 new cavities, 2-3 cycles each
Single-cell process & test	15.0		93.6	
Flash-EP cycles (no test)	4.0	10.0	36.0	
Design, Fab & Commission 9-cell T-Map			57.6	
2nd-sound development			28.8	
management & travel			50.0	
Total			**650.0**	
Jefferson Lab				
9-cell process and test cycles				
fine grain EP + maintenance	30.0	30.0	1000.0	12 new cavities, 2-3 cycles each
Cornell Micro-EP & Jlab large-grain tests	8.0		50.0	($6.25k/cycle)
Single-cell fab, process & test	25.0		150.0	
EP Cooling upgrade			50.0	
Flat sample studies			215.0	
Nine-cell large-grain cavities			95.0	
Cryomodule & component value engineering			50.0	
Integrated cavity processing studies			50.0	
Management & travel			65.0	
Total			**1725.0**	
Grand Total			**3276.0**	

Relation to Project X

- Gradient R&D directly supports Project X
  - Provides cavities for cryomodules → supports S1 & S2 goals
    - S1: cryomodule that achieves average gradient of 31.5 MV/m
    - S2: RF unit (three cryomodules) operating with beam
    - More on cryomodules from Harry Carter
  - Develops processes needed to reliably produce high-gradient cryomodules for Project X linac
    - Project X gradient requirement: 23.6 – 31.5 MV/m (XFEL – ILC)

Summary

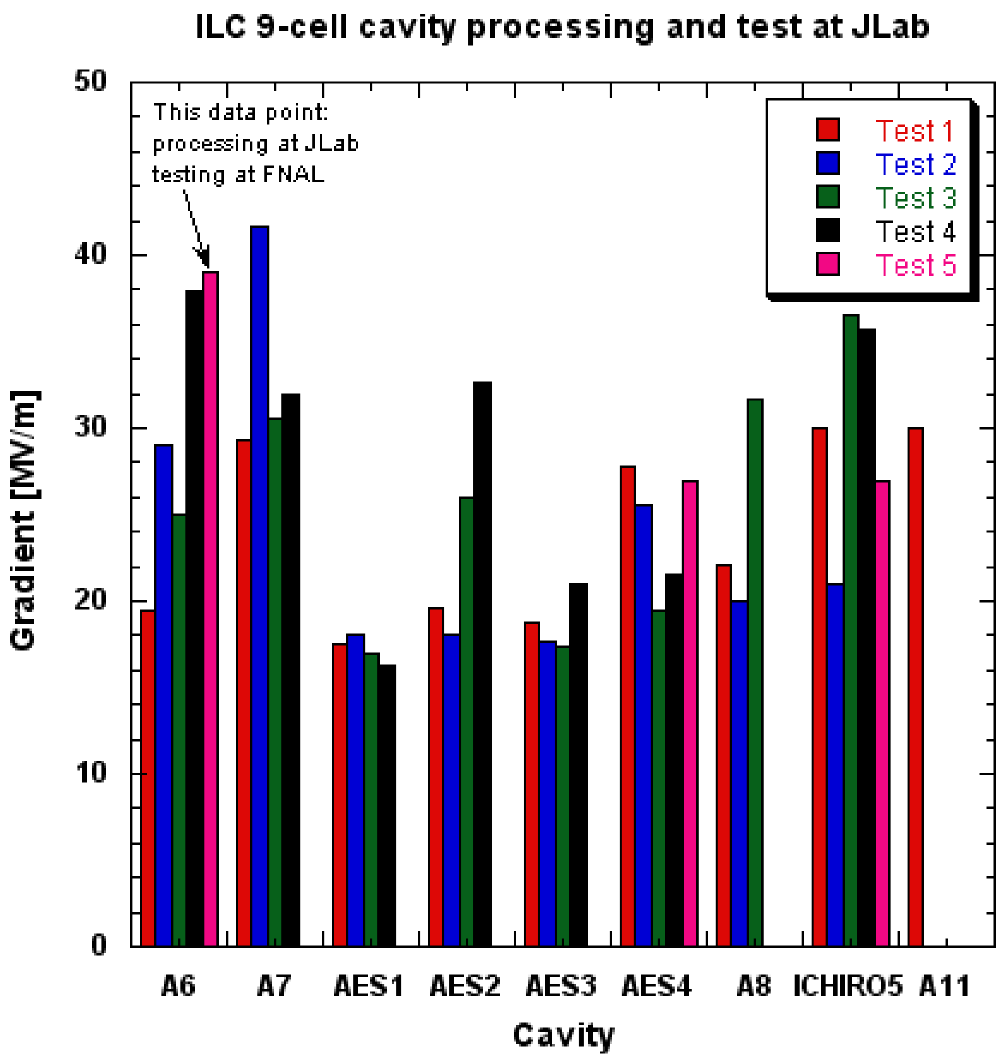
- Significant progress on new infrastructure
  - Argonne/Fermilab facility to come online ~ Oct 2008
- Developing new cavity vendors
  - AES, Niowave/Roark, PAVAC
- Completed many process and test cycles on existing cavities
  - Low performance cavities have equator-based quench limits
  - High performance cavities exhibit significant spread in performance
- Developing diagnostic tools to better understand performance limits
  - T-mapping
  - 2nd sound
  - Optical inspection
  - Witness samples
- Plan for FY08-09
  - Process and test all new cavities
  - Utilize diagnostics to increase understanding of performance limits
- Supports Project X
  - Provides cavities and develops needed processes

Extra Slides

Support for processing studies and cavity fabrication

- **Barrel-polishing machine received and acceptance-tested at Fermilab**
- **3.9 GHz electro-polishing system installed at ABLE Electropolishing in Chicago. First process planned for this summer.**
- **Tensile strength measurements in progress on samples at Fermilab in support of 3.9 GHz cryomodule safety documentation**
  - **RRR300 material: as received, welded, formed, 800 C heat treatment**
- **All Nb for next cavity production eddy-current scanned at Fermilab**

JLab High-Gradient R&D for ILC
9-cell Cavity EP Processing and Vertical Testing

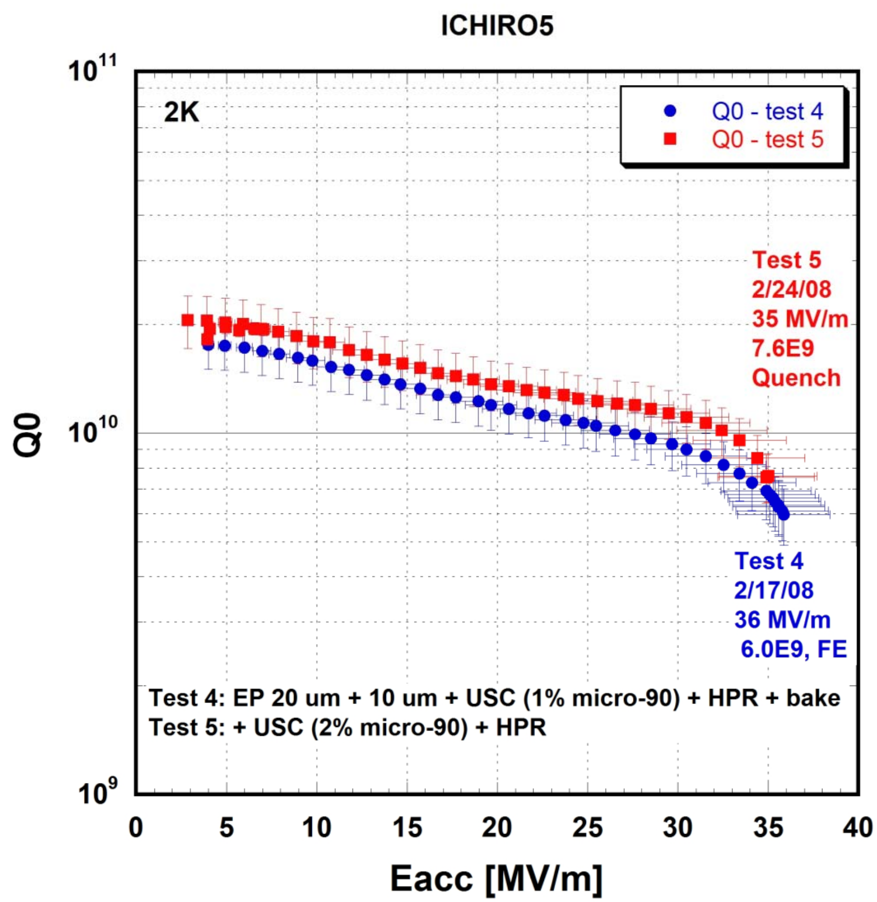


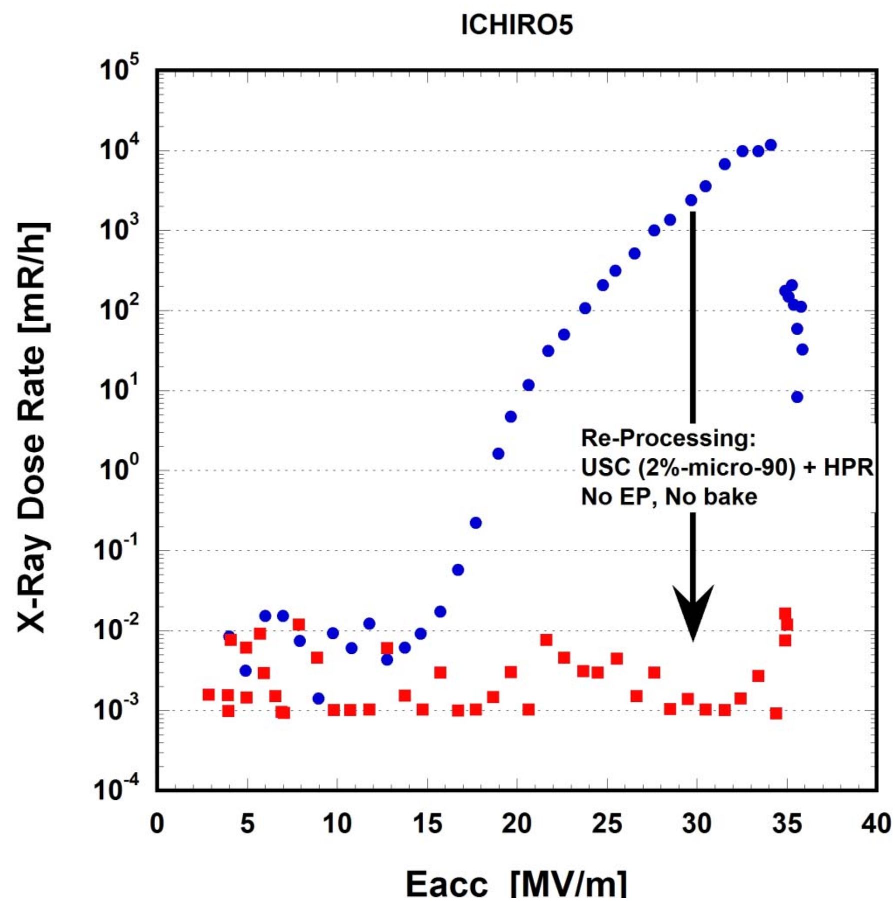
JLab/FNAL/KEK collaboration

- 30 EP/VT cycles FY07
- 16 EP/VT cycles FY08
- 10 cavities 2006-2008
- 3 cavities ≥ 35 MV/m
- 6 cavities ≥ 30 MV/m

ICHIRO5 S0 Studies at JLab

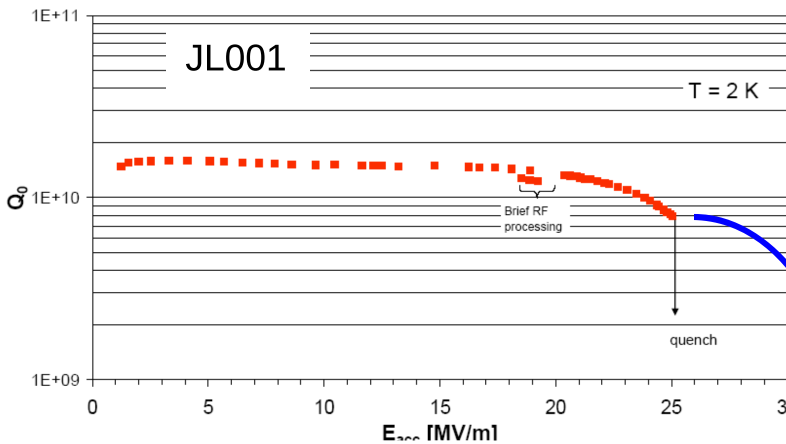
An example of reduced Field Emission by re-processing
(ultrasonic degreasing and high-pressure rinsing – no additional electro-polishing)



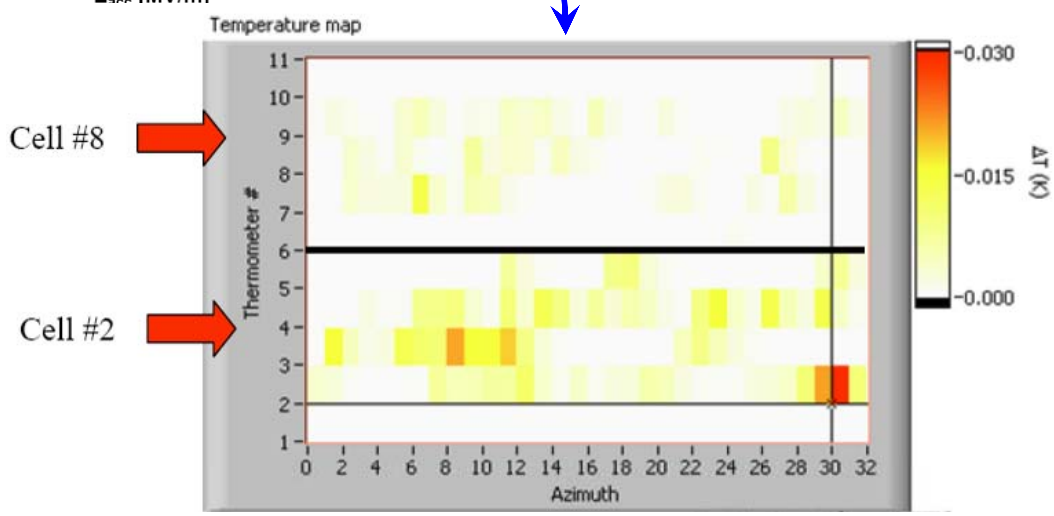


Thermometry in support of ILC

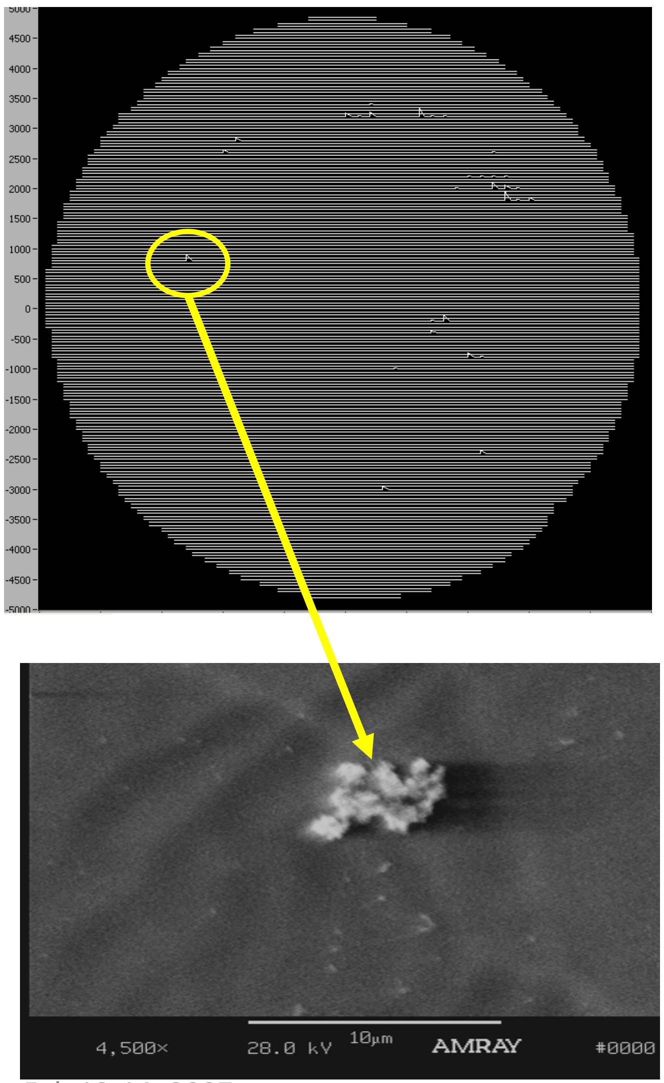
A 2-cell thermometry system for ILC 9-cell cavity was designed, built and commissioned at JLab and will be used routinely in conjunction with optical inspection of hot-spots/defect to improve understanding of thermal breakdown.

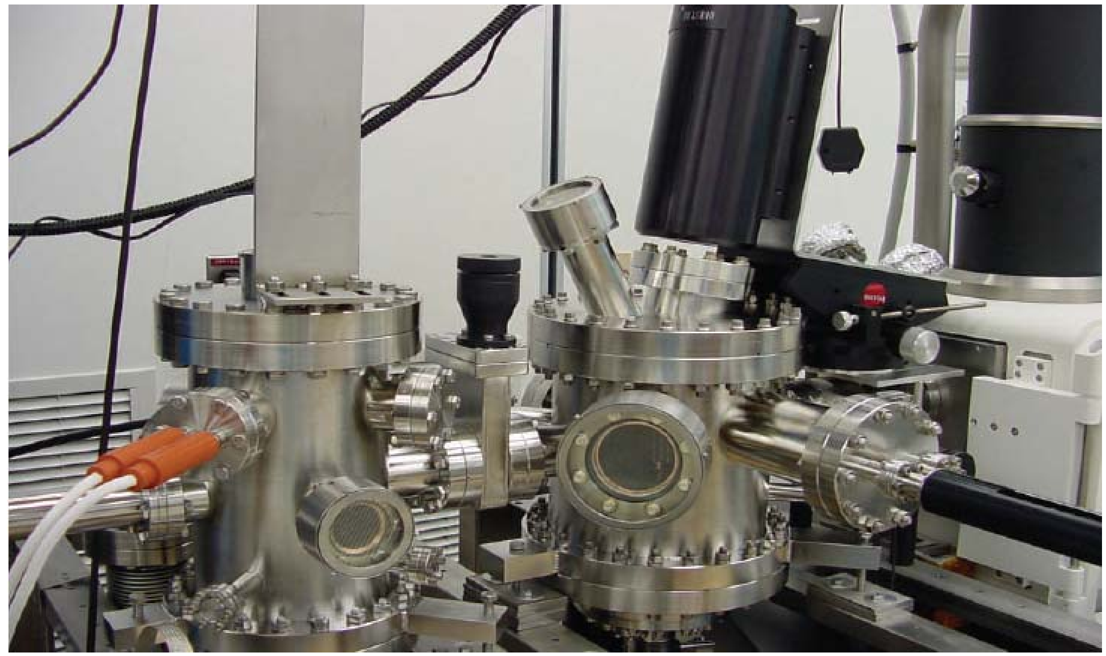


"Hot-spots" were detected near the equator weld of one of the cells, causing the Q-drop



JLab: Reduce Field Emission by understanding contaminants on electro-polished surface





- Nb flat sample EP'ed together with 9-cell cavity
- DC field up to 140 MV/m discloses field emitters
- SEM/DEX diagnose emitter properties
- Many Nb-O emitters found
- On-going studies for removal by post-EP cleaning, including ultrasonic cleaning, oxy-polishing, HPR

Single-Cell R&D Plans

Reproducibility Studies (degreasing vs. ethanol)

- **Select a qualified fine-grain cavity (>25 MV/m with standard BCP processing, >30 MV/m with standard EP processing). If no qualified cavity is available, then cavity qualification becomes part of this experiment.**
- **Perform bulk EP if not already done.**
- **Perform 4 cycles of electro-polishing of ~10-20 microns following the standard recipe of processing and testing (ultrasonic degreasing following electro-polish).**
- **Perform 4 cycles of electro-polishing of ~10-20 microns. Supplement ultrasonic degreasing with ethanol rinsing.**
- **Compare performance and spread.**

Flash-EP Studies (a.k.a. Micro-EP)

- **Select a qualified fine-grain cavity (>25 MV/m with standard BCP processing, >30 MV/m with standard EP processing). If no qualified cavity is available, then cavity qualification becomes part of this experiment.**
- **Perform bulk EP if not already done.**
- **Perform 4 cycles of Flash-EP followed by either standard degreasing and/or ethanol rinse.**
- **Compare performance and spread.**

Note: utilize temperature mapping in all tests if possible.

Single-Cell R&D Plans

Large-Grain and Single-Crystal Studies

- **Fabricate and test large-grain and single-crystal cavities.**
- **Perform BCP processing and test with temperature mapping.**
- **Compare performance to fine-grain EP results.**

Facility and Diagnostics Commissioning

- **Process cavities at Argonne (EP or BCP) followed by testing at Fermilab to qualify facilities. Follow standard recipe.**
- **Commission Fermilab single-cell temperature-mapping system.**
- **Commission Fermilab single-cell VTS (A0 facility).**

Materials Quality Control Studies

- **Fabricate single-cell cavities using niobium sheets deemed "risky" based on eddy-current scanning.**
- **Process and test these cavities using standard recipe and temperature mapping.**
- **Study correlation between defects and performance.**

Alternative Surface Processing Studies

- **Perform studies of the effectiveness of surface processing techniques such as plasma cleaning, dry ice cleaning, oxi-polishing, conformal layers, etc.**

Recipes for Processing, Testing, and Diagnosing

Standard Processing Recipe

1. Incoming cavity quality control checks.
2. Optical inspection of as-received cavity.
3. Bulk electro-polishing of ~150 um.
4. Ultrasonic degreasing.
5. High-pressure rinsing.
6. Hydrogen degassing at 600 deg C.
7. Field-flatness tuning.
8. 20 um electro-polishing.
9. Ultrasonic degreasing.
10. Field-flatness verification and retuning if <95%.
11. High-pressure rinsing.
12. Assembly and vacuum leak testing.
13. 120 deg C bake.
14. Vertical dewar test.

Standard Testing Recipe

1. Hold at ~100 K during cool down to check for Q disease.
2. Q vs. T measurement during cool down.
3. Q vs. E measurement on Pi mode. RF process as needed.
4. Q vs. E measurement on all other modes. RF process as needed.
5. Final Q vs. E measurement on Pi mode.

Notes:

All Q vs. E measurements to include radiation data logging.

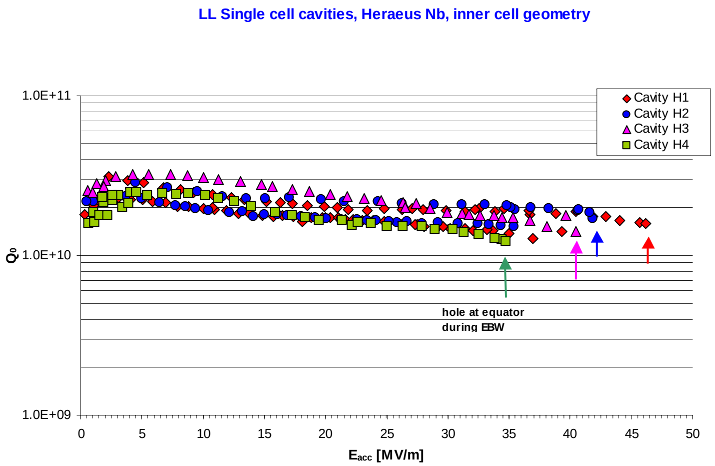
Utilize nine-cell temperature-mapping system if available.

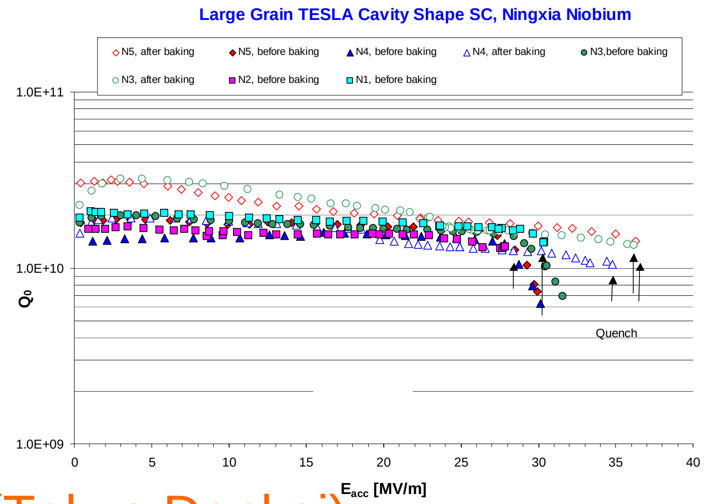
Diagnostic Techniques

1. Determine limiting cells based on mode measurements.
2. If nine-cell temperature-mapping was not employed, apply thermometry to limiting cells and retest.
3. Perform optical inspection of limiting cells.

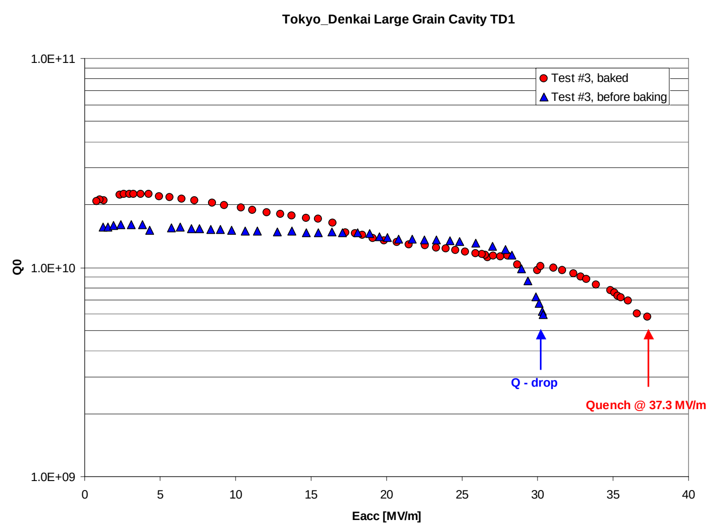
JLab: Large grain/Single Crystal Niobium(1)

- Reproducibility Tests with single cell cavities from large grain niobium of different manufacturers



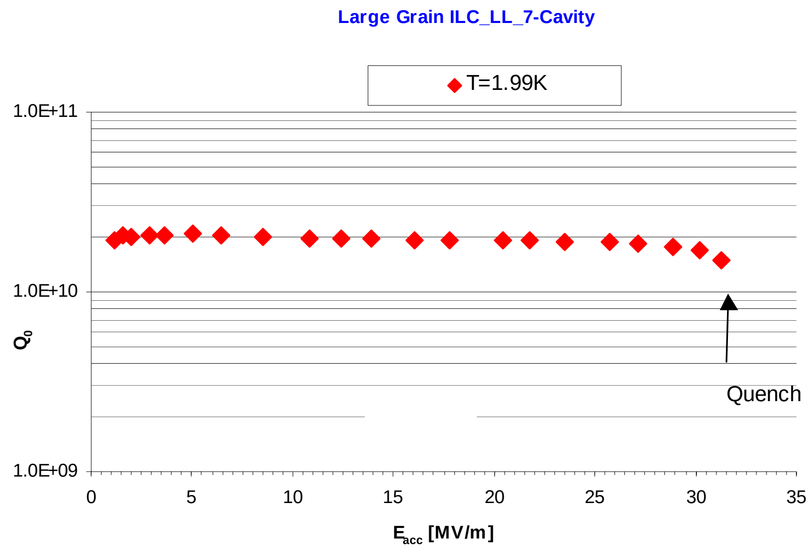


- Qualification of new vendor (Tokyo Denkai)



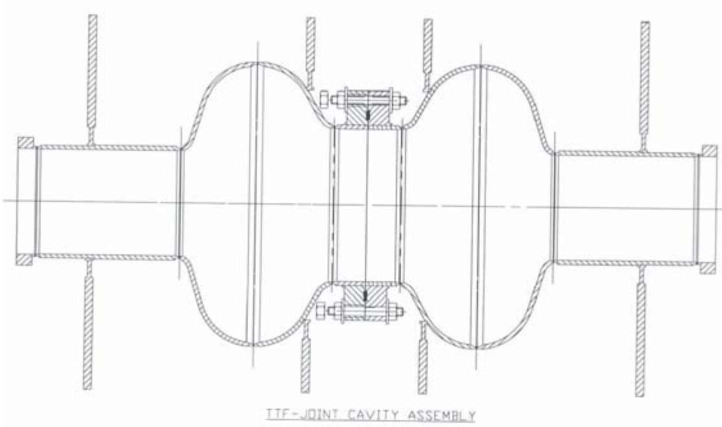
JLAB: Large grain/Single Crystal Niobium (2)

- 2 Jlab 9-cell large grain cavities have not yet qualified – investigating quench sites and considering repair options
- Further evaluation of JLab 7-cell LL prototype cavity performance more successful after re-tuning & more BCP

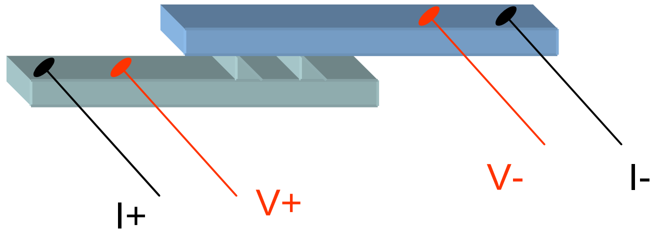


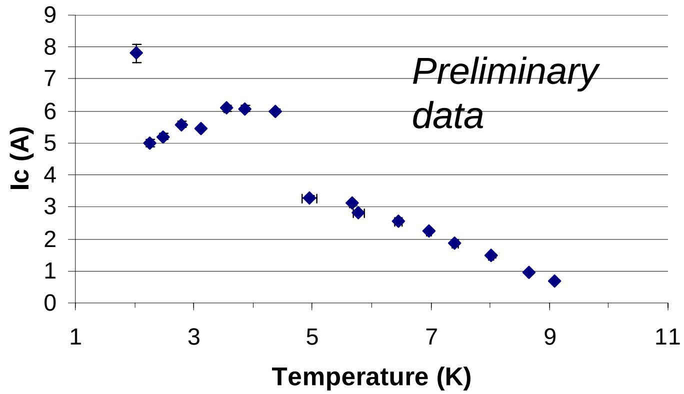
Superconducting joint development

The development of a superconducting joint will allow to shorten the distance between beam pipes, enabling the fabrication of superstructures with large savings on cryomodule and RF components for long accelerators, such as ILC.



A "double single cell cavity" with NbZr conflat flanges has been fabricated to measure the RF performance of the sc joint





Setup to measure the critical current through the NbZr/Nb sc joint

Americas

TTC documents optimized cavity processing

TESLA Technology Collaboration
TTC-Report 2008-05

Final Surface Preparation for

Superconducting Cavities

An attempt to describe an optimized procedure

Reply to the

Request for Consultancy from TTC

raised by

the ILC R&D Board Task Force on High Gradients (S0/S1)