Gradient R&D

Mark Champion

29 April 2009

Outline

- S0 organization
- GDE goals
- Accomplishments
  - New infrastructure
  - Vendor development & cavity procurements
  - Cavity processing and testing
  - Diagnostics development & repair techniques
- Plan for FY2010
- Summary

S0 Organization in the Americas Region

Americas

Organization

- **GDE Project Manager: Akira Yamamoto – KEK**
- **GDE S0 Leader: Rongli Geng – Jefferson Lab**
- **Americas Region Team Leaders**
  - **Mike Harrison – Brookhaven – ART Director**
  - **Mark Champion – Fermilab – ART S0 Coordinator**
  - **Zack Conway (Hoffstaetter, Padamsee) – Cornell**
  - **Rongli Geng – Jefferson Lab**
  - **Mike Kelly – Argonne**

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)**

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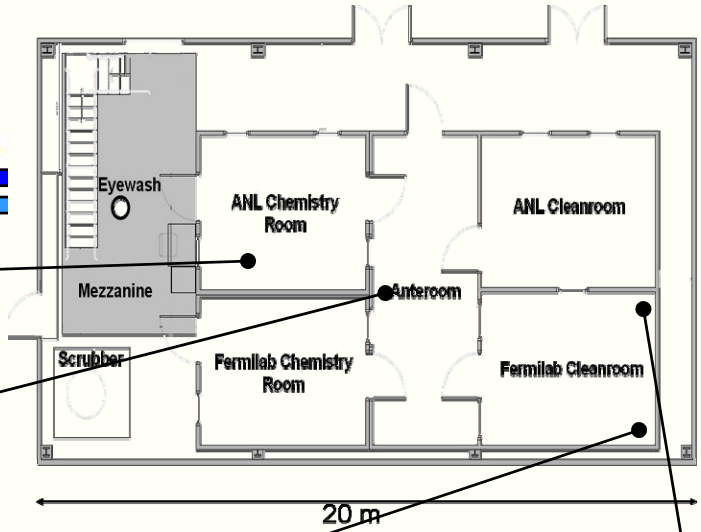
Argonne/Fermilab Cavity Processing Facility is Operational

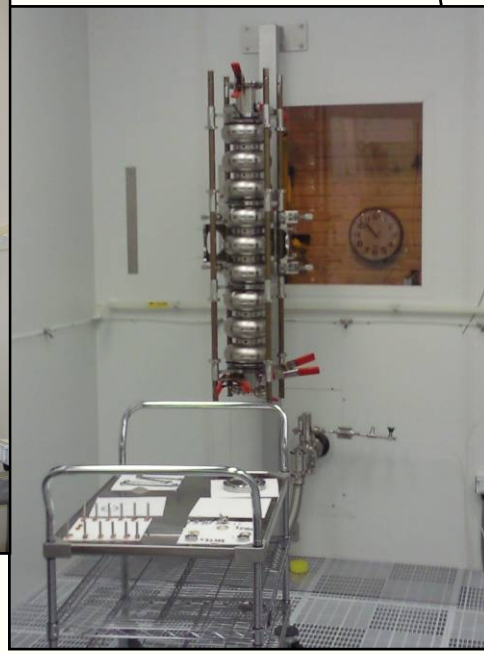
Americas

Electro-Polishing

Ultrasonic Degreasing

High-Pressure Rinsing





Assembly & Vacuum Leak Testing

Custom hoist needed for use with ultrasonic cleaner
400 lb rating → small load, big headache!

First results from Argonne-Fermilab were very encouraging
No field emission and excellent agreement with Cornell data

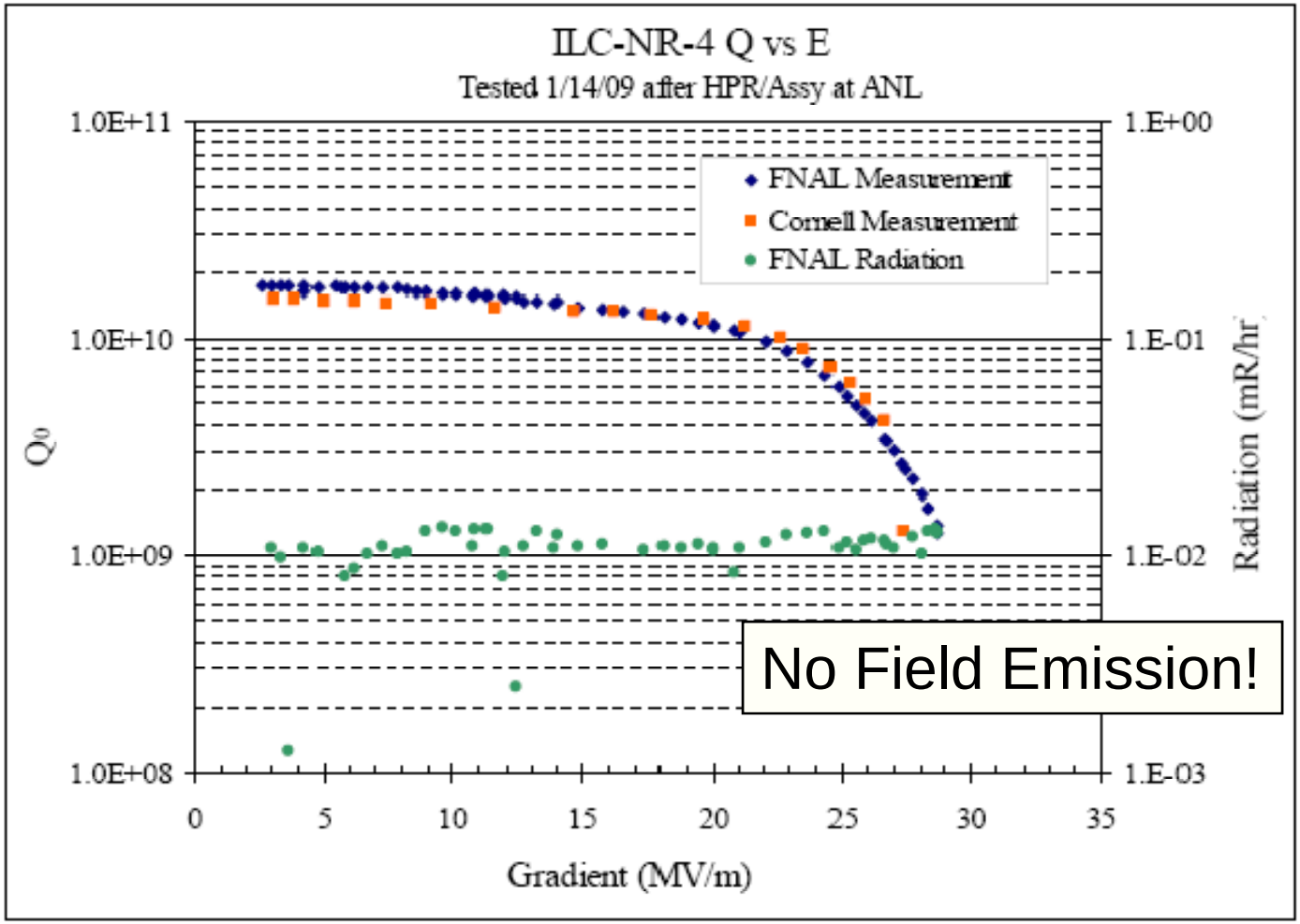
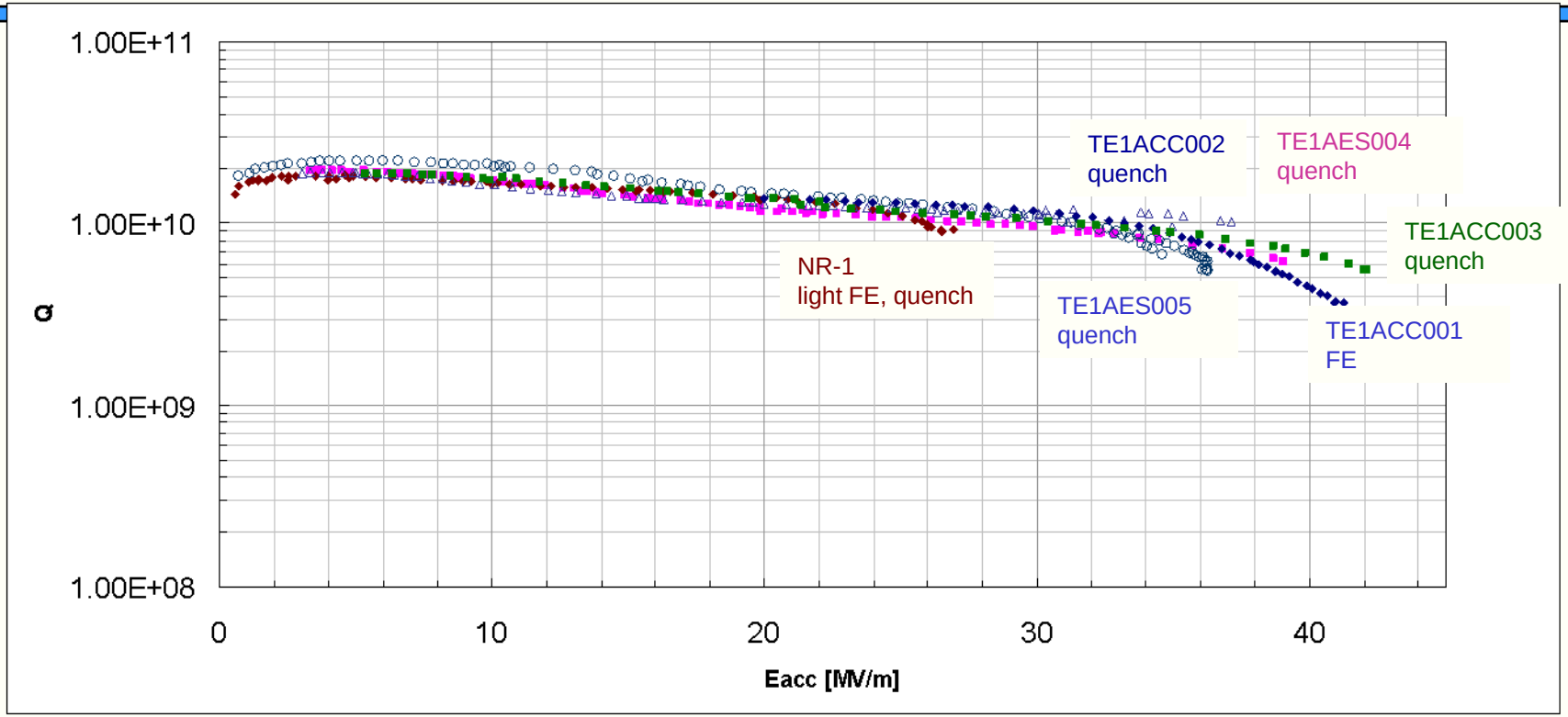


Figure 3.) Final Q_0 vs E run at 2K at FNAL, compared to Cornell data from 2008.

BCP processing at Cornell; no EP so far.

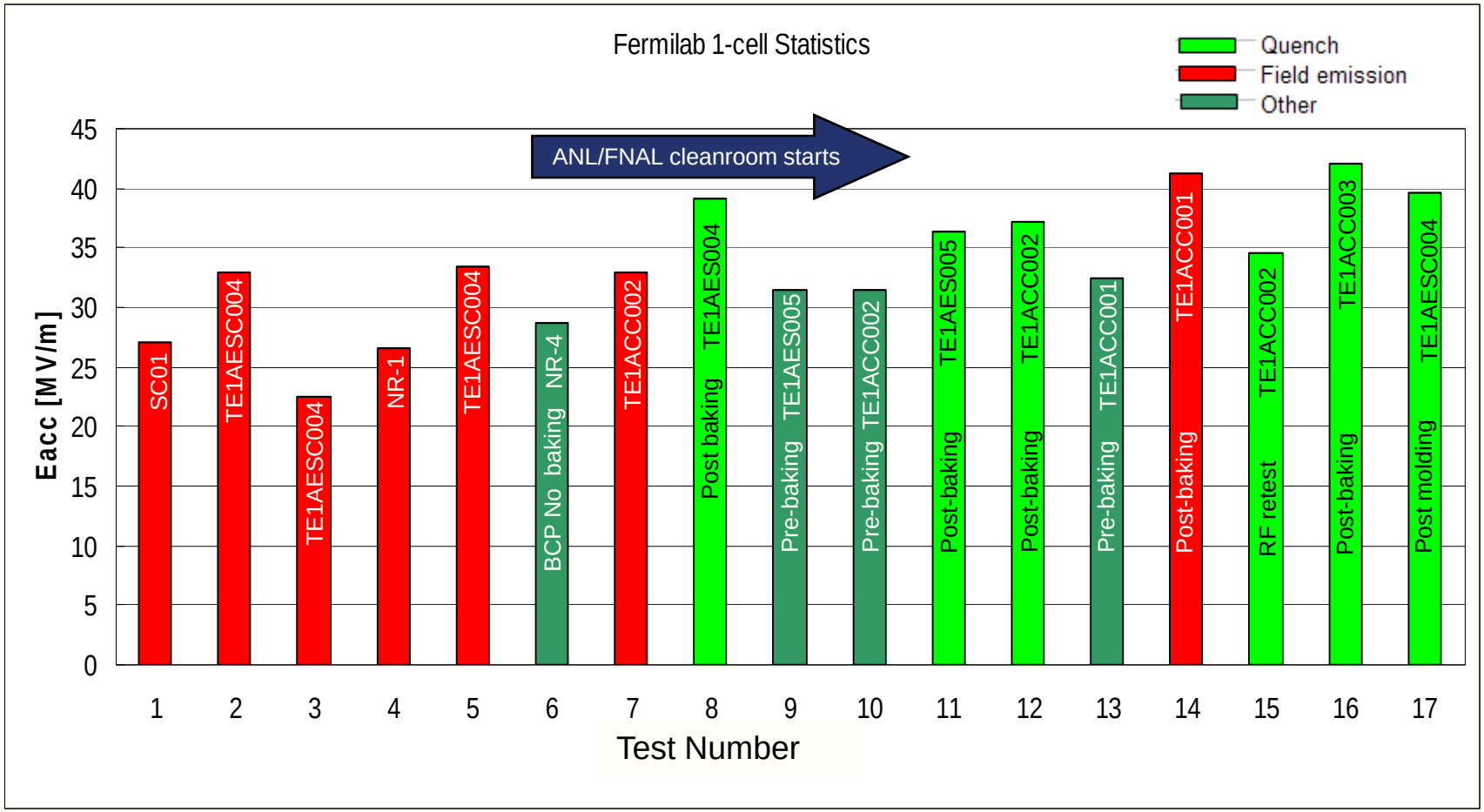
Ultrasonic cleaning and HPR at Argonne; testing at Fermilab.

Commissioning of the Argonne/Fermilab CPF
Single-cell cavity processing & testing results



	BCP	EP	Ethanol	Eacc [MV/m]	Notes
NR-1	150	93		26.5	Oxidation by acid residual
TE1AES004	107	65		39.2	Equator large pit present
TE1AES005	104	100	Yes	36.3	Oxidation by HPR water
TE1ACC002		112	Yes on second	37.1	
TE1ACC001		99		41.3	FE appeared after 120°C baking
TE1ACC003		119		42.1	Pit present

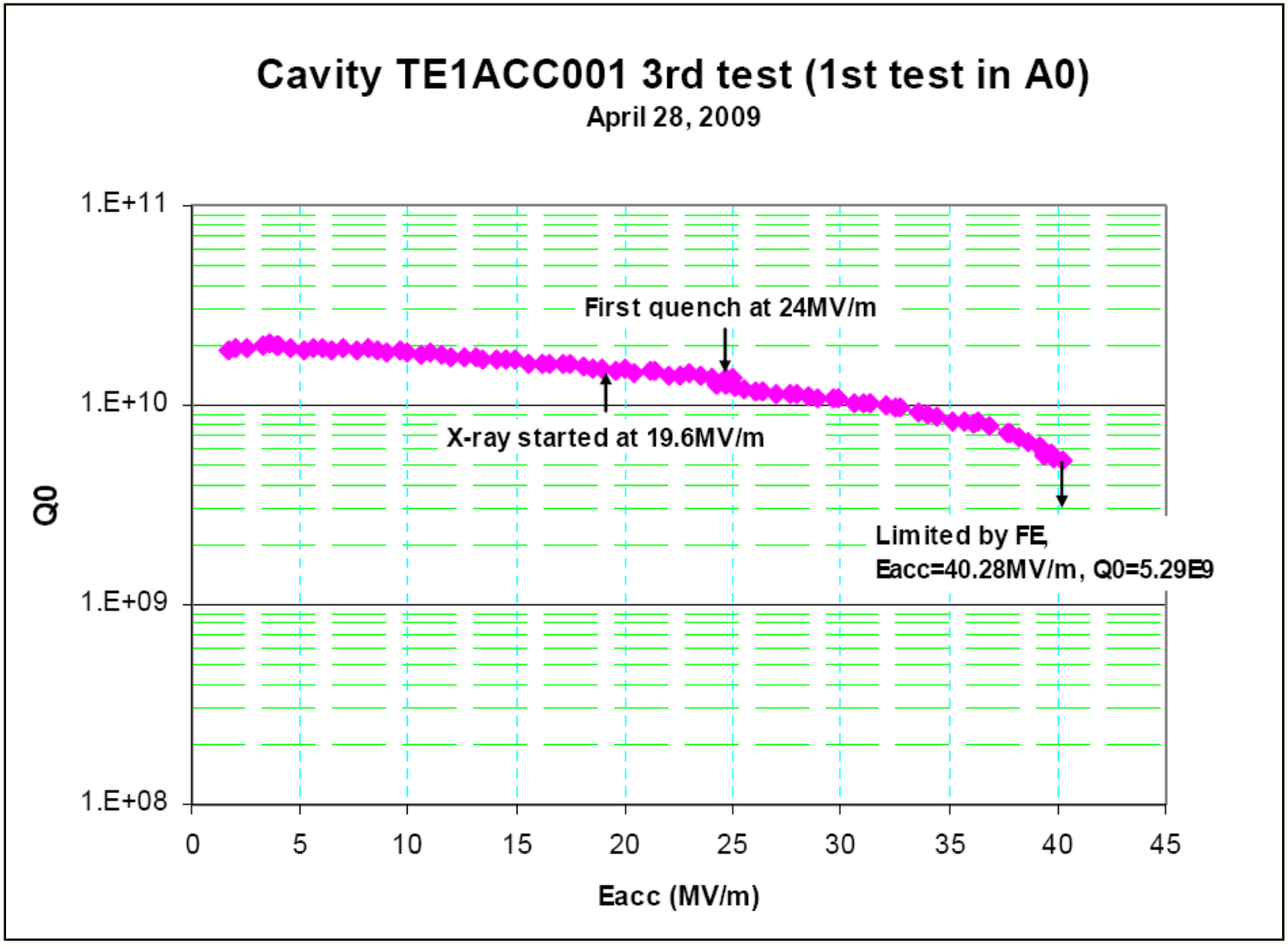
Commissioning of the Argonne/Fermilab CPF Single-cell cavity processing & testing results



Little or no field emission in recent tests
→Commissioning with single-cell cavities is complete

First test of a 1.3 GHz single-cell cavity in the A0 VTS

This system has been used for 3.9 GHz cavity testing, and has been modified for 1.3 GHz single-cell cavities over the last year.



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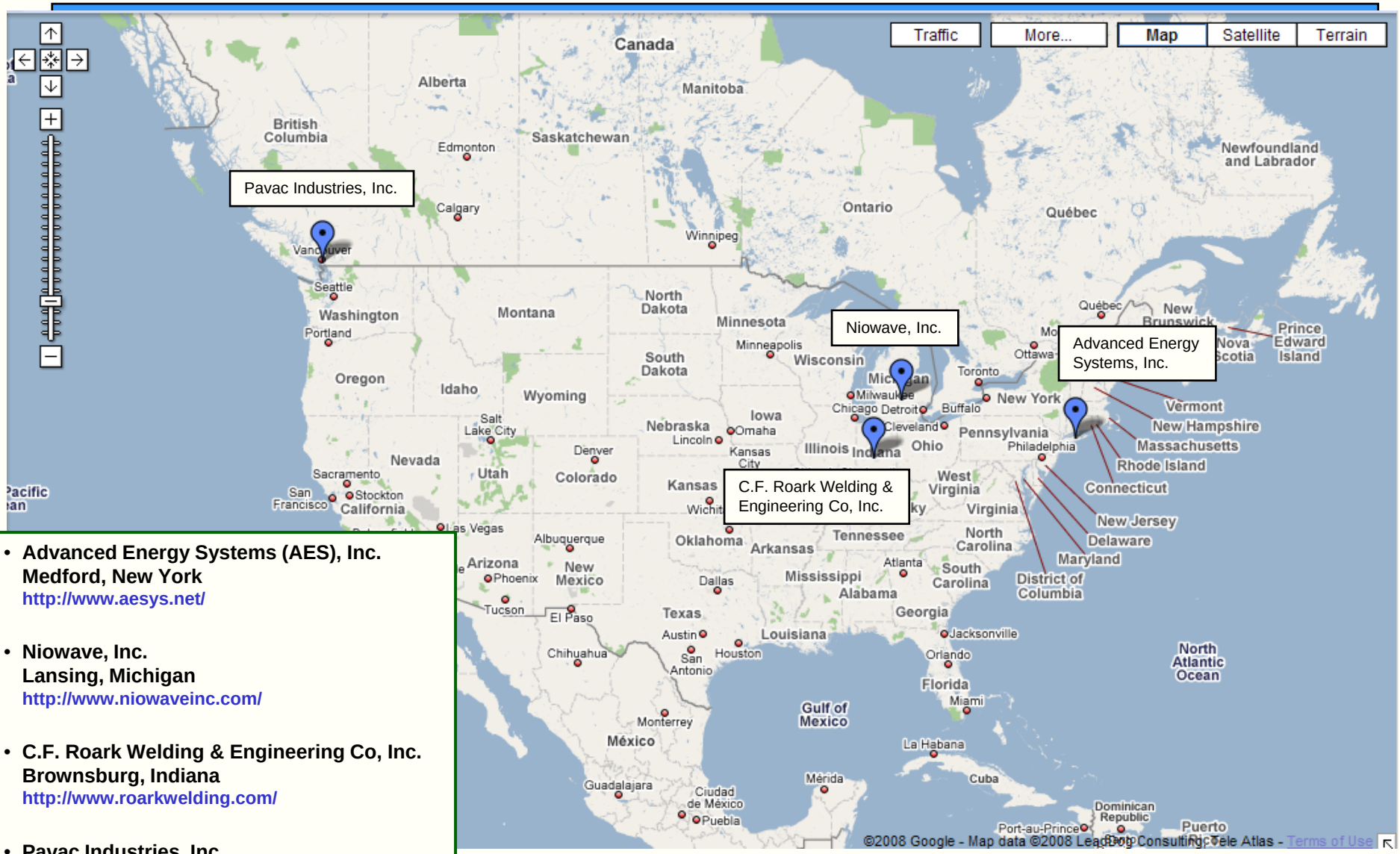
Americas Region Cavity Vendors

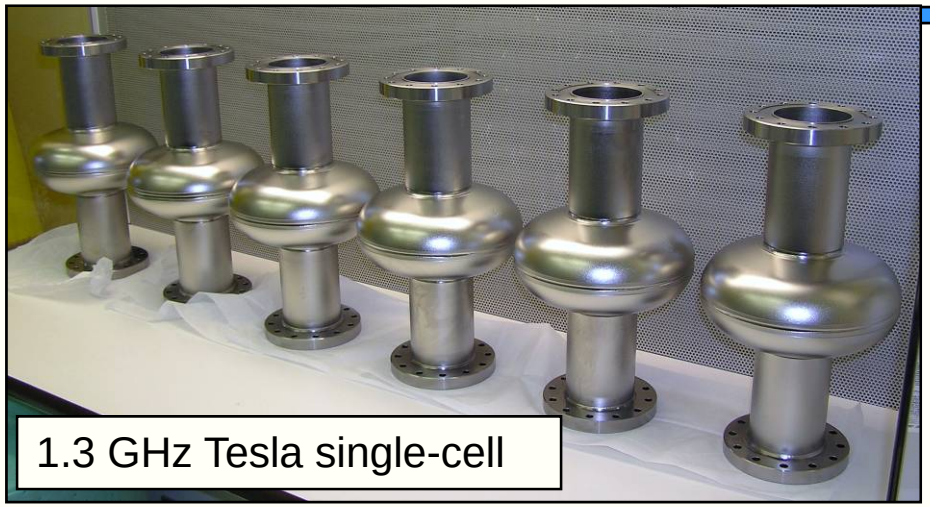
Americas



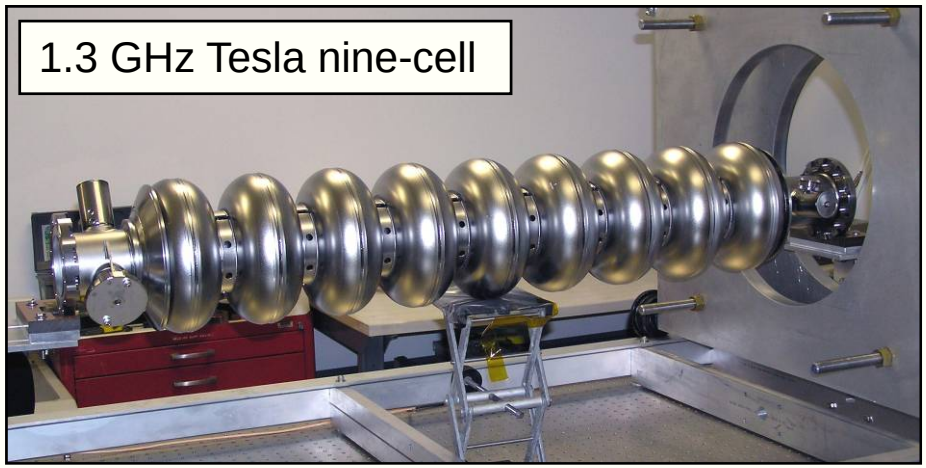
- **Advanced Energy Systems (AES), Inc.**
  Medford, New York
  http://www.aesys.net/
- **Niowave, Inc.**
  Lansing, Michigan
  http://www.niowaveinc.com/
- **C.F. Roark Welding & Engineering Co, Inc.**
  Brownsburg, Indiana
  http://www.roarkwelding.com/
- **Pavac Industries, Inc.**
  Richmond, British Columbia
  http://www.pavac.com

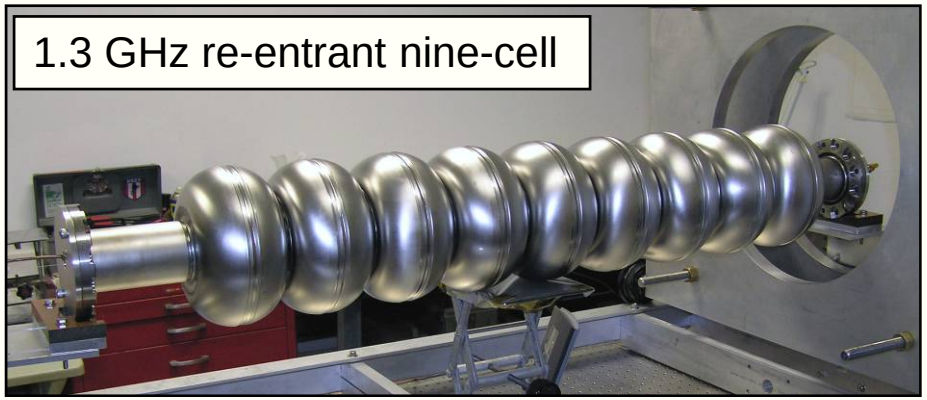
AES has complete production capability on-site
10 nine-cell Tesla cavities delivered to date; 6 more in production

Americas


1.3 GHz Tesla single-cell

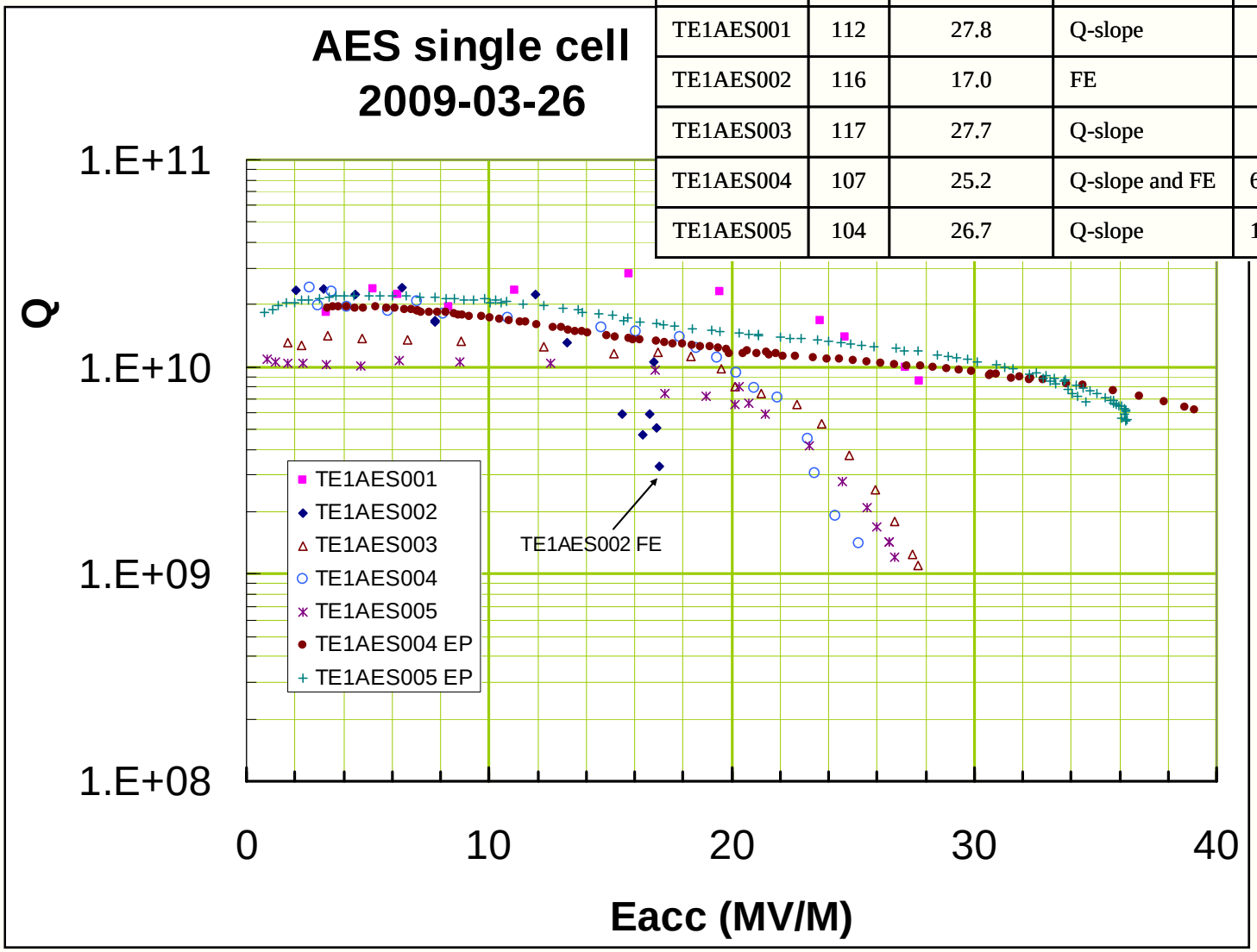
Electron-beam welding facility


1.3 GHz Tesla nine-cell


1.3 GHz re-entrant nine-cell

Performance of AES single-cell cavities
BCP results at Cornell / EP results at Argonne-Fermilab

Cavity	BCP (μm)	Max Gradient (MV/m)	Limitation	EP (μm)	Max Gradient (MV/m)	Limitation
TE1AES001	112	27.8	Q-slope		-	-
TE1AES002	116	17.0	FE		-	-
TE1AES003	117	27.7	Q-slope		-	-
TE1AES004	107	25.2	Q-slope and FE	65	39.2	Quench
TE1AES005	104	26.7	Q-slope	100	36.3	Quench



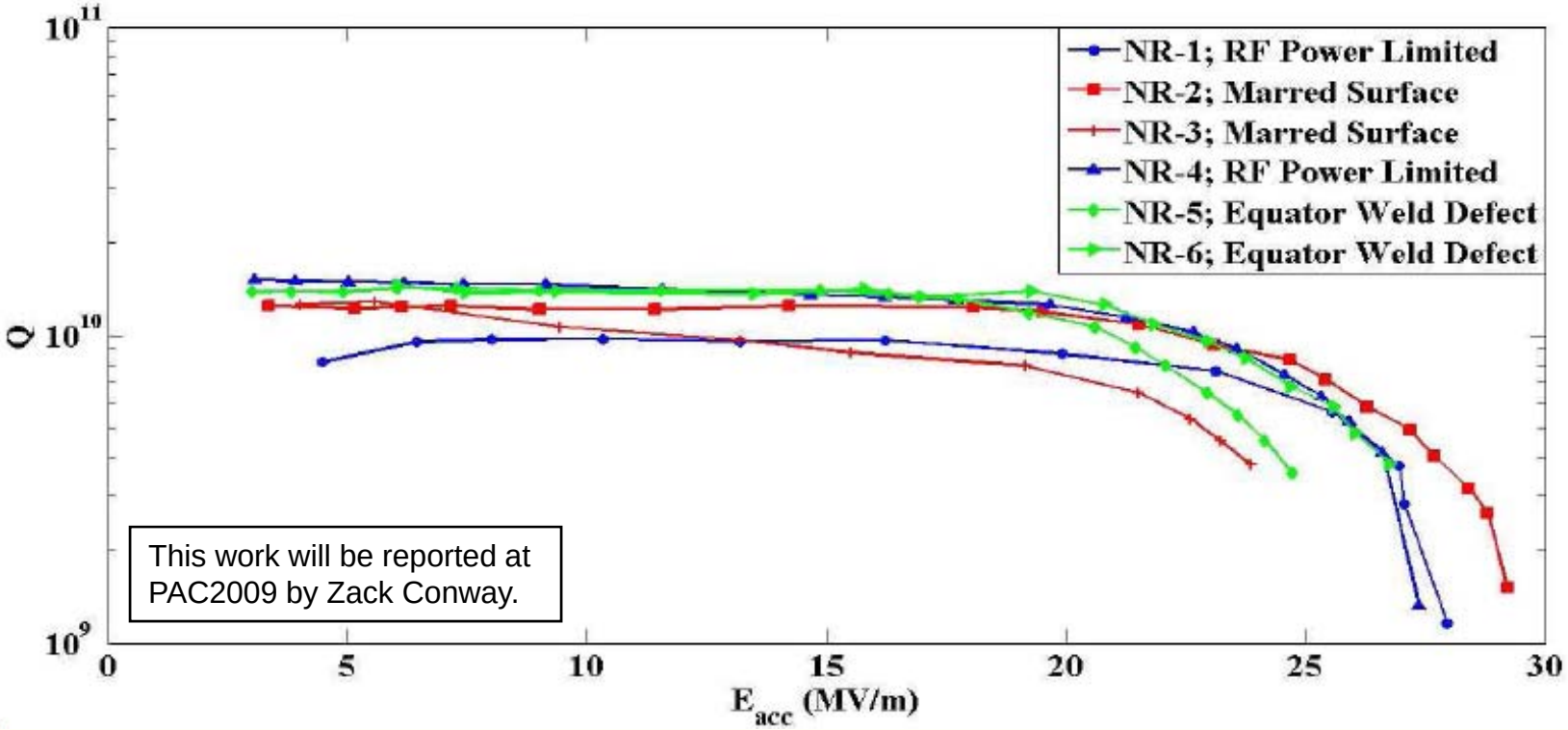
Niowave & Roark collaborate on 1.3 GHz cavities
Roark is working independently on low-beta structures

- Niowave-Roark Tesla single-cell cavities
  - Delivered June 2008
- Six nine-cell cavities currently in production

- Roark 325 MHz beta=0.22 single-spoke cavity
- Delivered Summer 2008

Pre-Qualified Niowave/Roark Cavities

- **Quick pre-qualification of 6 Niowave/Roark 1-cell cavities in 13 cold tests.**
  - **BCP (~150 μm), Ultrasonic Degreasing, HPR, and Clean Assembly.**
- **2 cavities did not quench and showed the expected Q-slope limit due to BCP.** (NR-1, NR-4)
- **2 cavities quenched due to "surface bump" from a defect on the manufacturing die.** (NR-2, NR-3)
- **2 cavities quenched due to pits on equator weld.** (NR-5, NR-6)
- **All quench locations were located by 2nd sound detection and inspected with a Questar long distance microscope.**

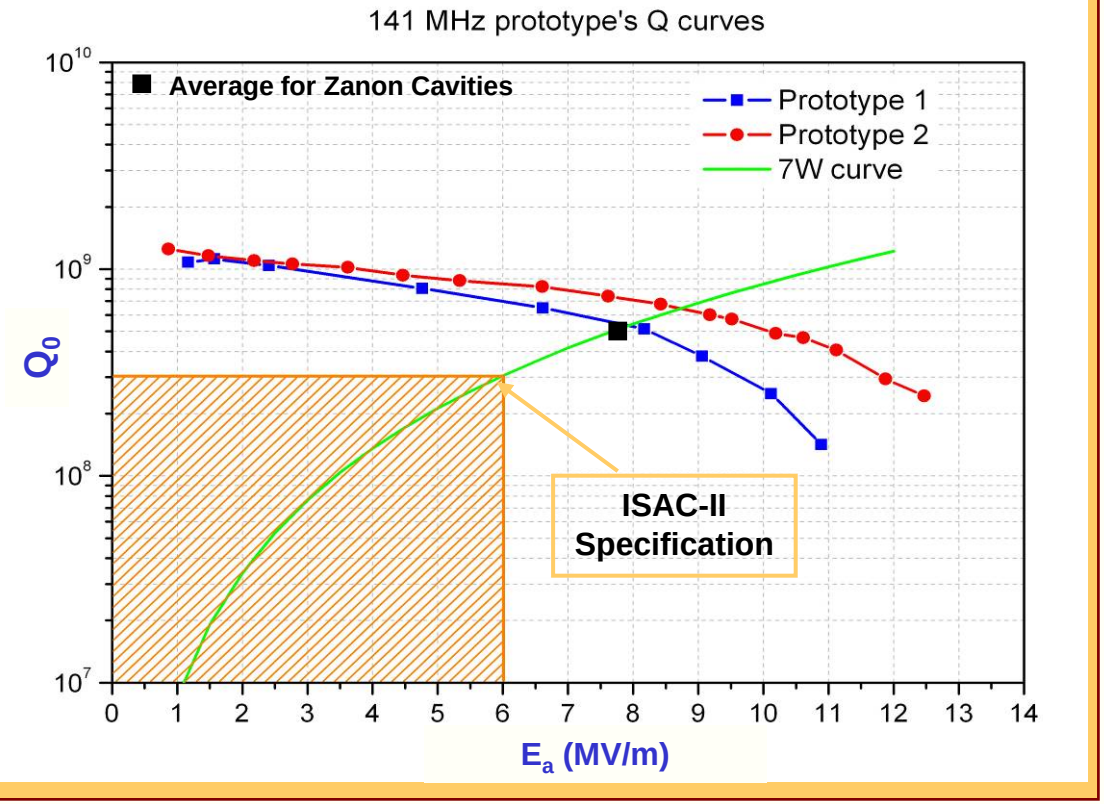


This work will be reported at PAC2009 by Zack Conway.

Pavac is producing 20 coaxial resonators in collaboration with Triumf for the ISAC-II Phase-II extension

Americas

- Two prototypes manufactured and tested; production under way.
- Both prototypes perform significantly above ISAC-II specifications; average values of E_a=8.2MV/m, Ep=40MV/m cw (specification 6MV/m)
- Pavac is preparing to produce Tesla 1.3 GHz cavities in collaboration with Triumf and Fermilab (6 single-cell and 2 nine-cell cavities)



Fermilab Meeting with North American Cavity Vendors held in March 2009

Americas

Objectives

Fermilab

- **Present the latest results from world-wide cavity gradient R&D**
  - a series of presentations describing experimental results, theoretical studies, and practical experience
- **Engage the vendors in discussion of the fabrication, performance and yield issues**
- **Reiterate our interest in increasing North American industrial expertise and capacity for the production of niobium RF cavities**
  - We seek multiple vendors of high-gradient high-yield TESLA-shape nine-cell cavities for Project X at Fermilab and for the ILC project
  - Project X also requires a number of other types of niobium cavities, including beta=0.81 elliptical cavities at 1.3 GHz and an assortment of single-spoke and triple spoke low-beta cavities at 325 MHz

March 6, 2009 Fermilab Cavity Vendor Meeting

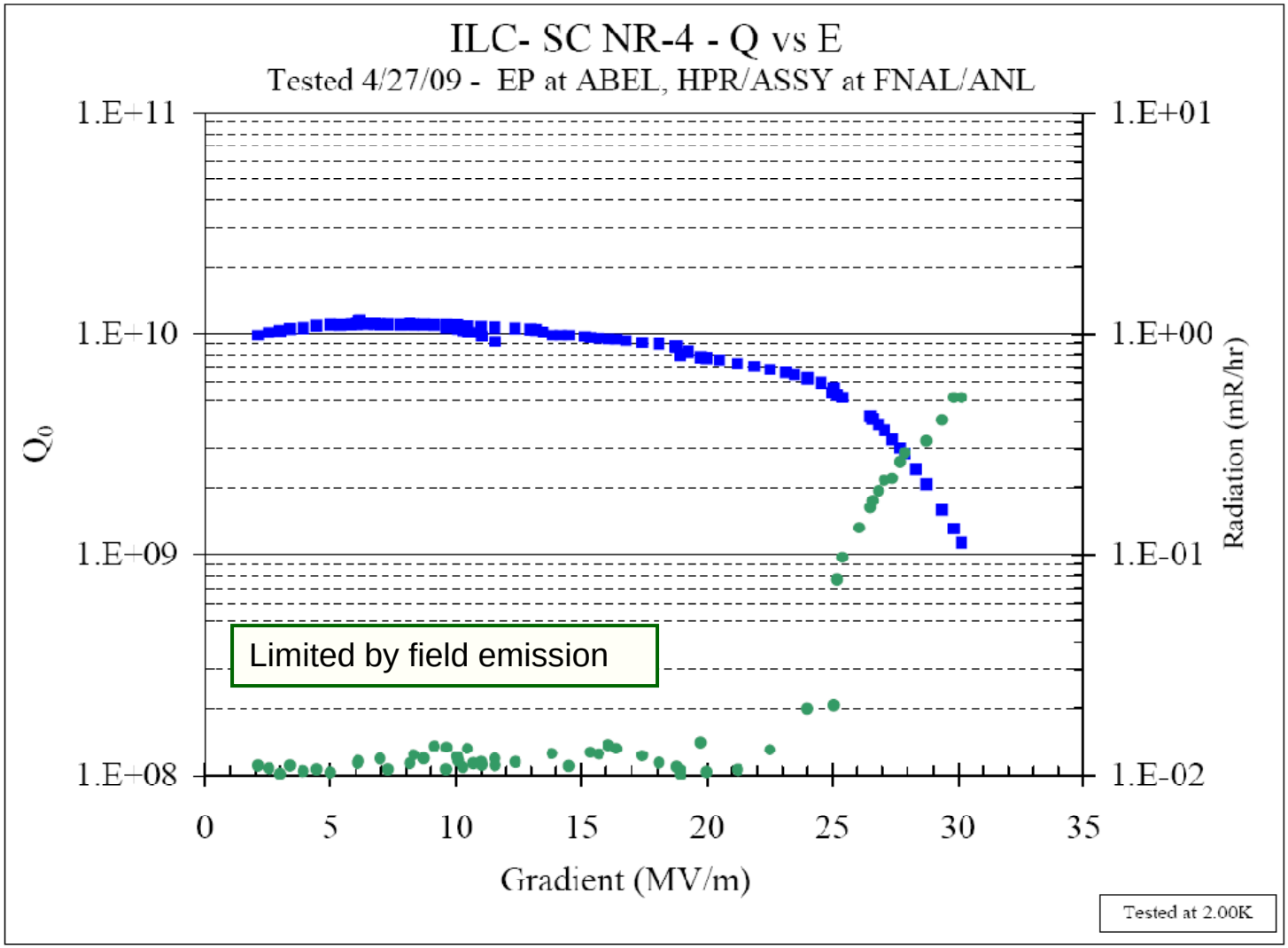
One significant outcome was that we should have a similar meeting with the niobium vendors!

Start Times	Duration	Description	Speaker	Affiliation
8:30	10	Introduction	Mark Champion	Fermilab
8:40	30	Overview of nine-cell cavity progress	Camille Ginsburg	Fermilab
9:10	30	Observations at Fermilab	Genfa Wu	Fermilab
9:40	30	Observations at Cornell	Zack Conway	Cornell
10:10	20	Break	all	
10:30	30	Observations at Jefferson Lab	Rongli Geng	Jefferson Lab
11:00	30	Fundamental studies and issues	Lance Cooley	Fermilab
11:30	15	Material studies	Chris Compton	MSU
11:45	15	Fermilab plans for Cavity Development in Industry	Bob Kephart	Fermilab
12:00	60	Lunch	all	
1:00	120	Discussion	all	
3:00		Close	all	

Cavity Inventory

Tesla-shape nine-cell cavities		
Description	**No. Cavities**	**Status**
AES 1-4	4	tested
AES 5-10	6	received; testing in progress
AES 11-16	6	due Oct 2009
Accel 6-9	4	tested
Accel 10-17	8	received Mar 2008; testing in progress
Accel 18-29	12	due May 2009
Jlab fine-grain 1-2	2	fabrication complete; testing in progress
Niowave-Roark 1-6	6	due Oct 2009
Stimulus Procurement	xx	still in the planning stages; assume first cavities ~April 2010
Total	**48**	
Already Received	24	
Tesla-shape single-cell cavities		
Description	**No. Cavities**	**Status**
AES 1-6	6	tested at Cornell; further testing in progress
Accel 1-6	6	received Dec 2008; testing in progress
Niowave-Roark 1-6	6	received Jun 2008; testing in progress
PAVAC	4	requisition in progress
Total	**22**	
Already Received	18	

First test of a single-cell cavity electro-polished by industry using full-immersion proprietary technique shows promise



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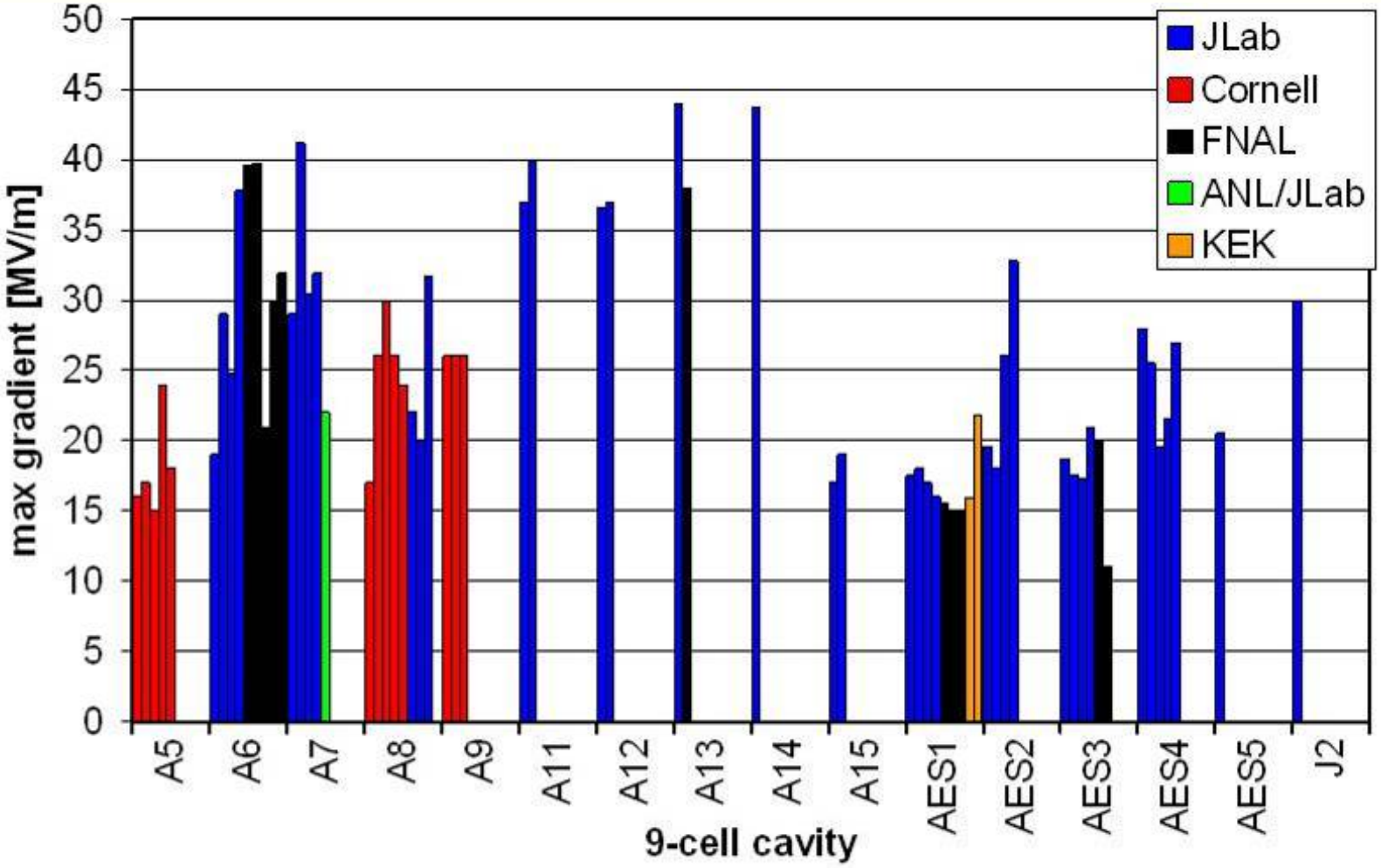
Summary of cavity performance

Americas

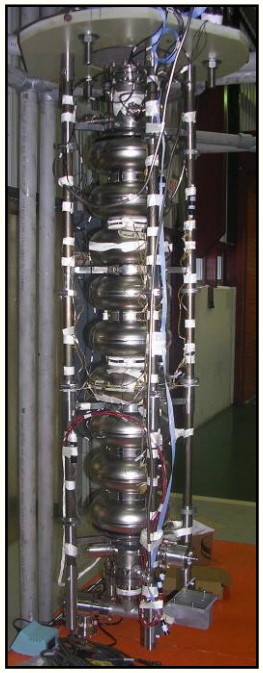


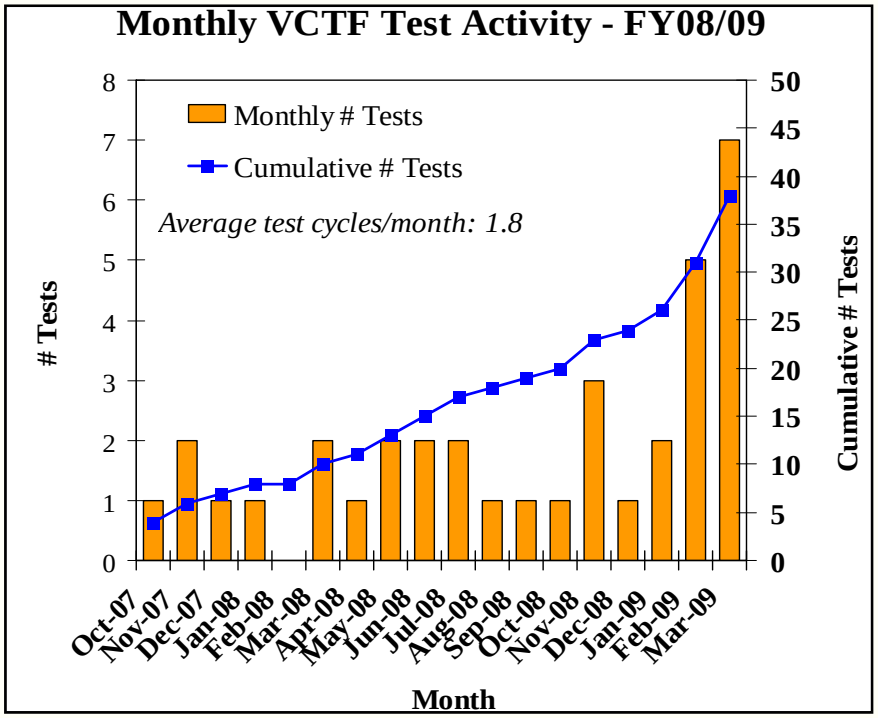
C.M. Ginsburg 7.Apr.2009

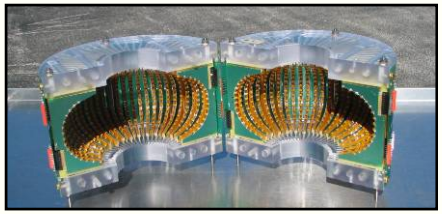
Test rate is increasing at the Fermilab Vertical Cavity Test Facility

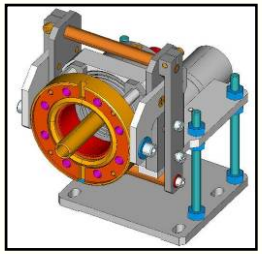
35 cavity tests in FY08/FY09, where “test” = cryogenic thermal cycle

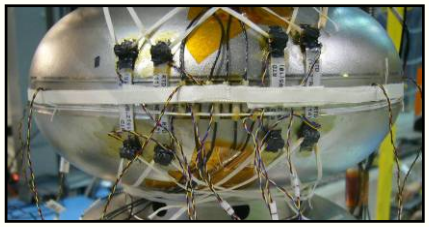
- 9-cell & single-cell 1.3 GHz elliptical cavities and 325 MHz HINS single-spoke resonators
- instrumentation development, variable coupler, thermometry, cavity vacuum pump system, cavity vendor development
- Many cavity tests dedicated to ANL/FNAL CPF commissioning





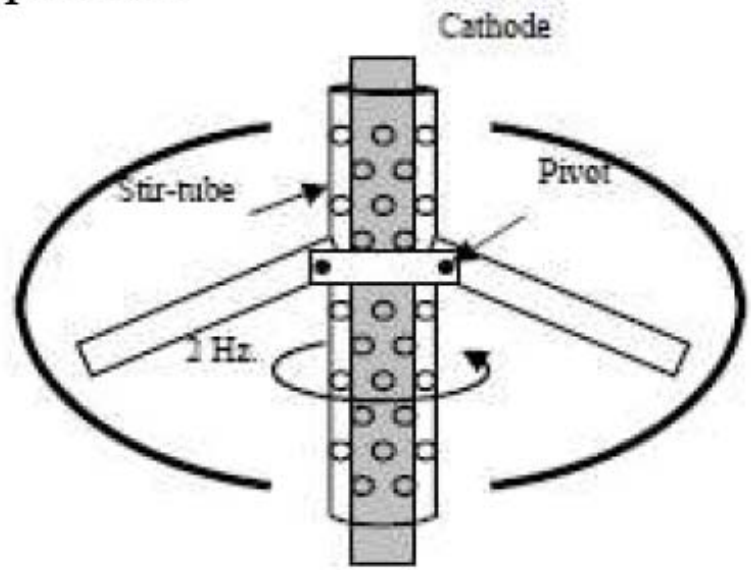




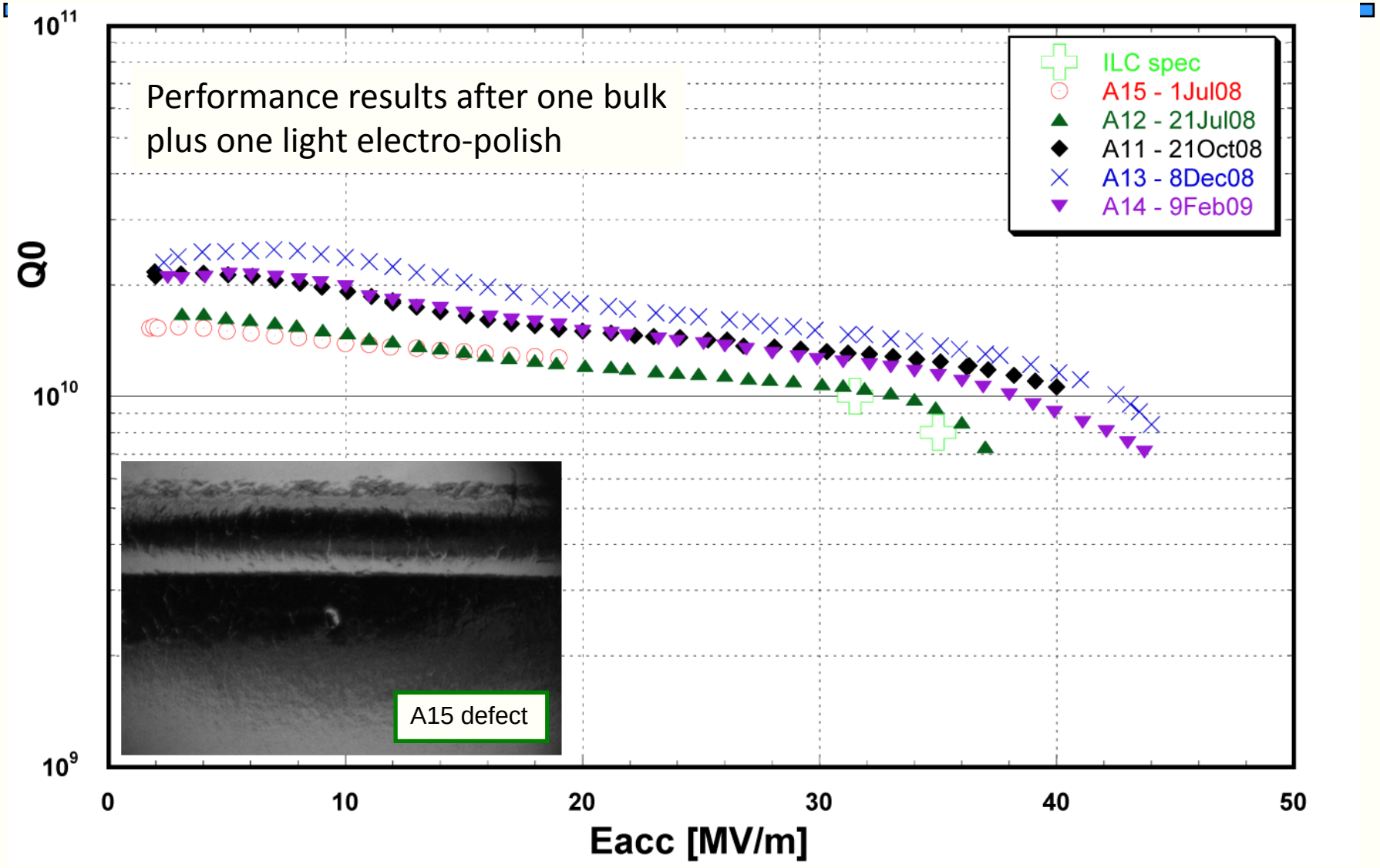


Vertical Electropolish Proven Effective

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



Excellent recent results at Jefferson Lab in processing and testing of Accel nine-cell cavities

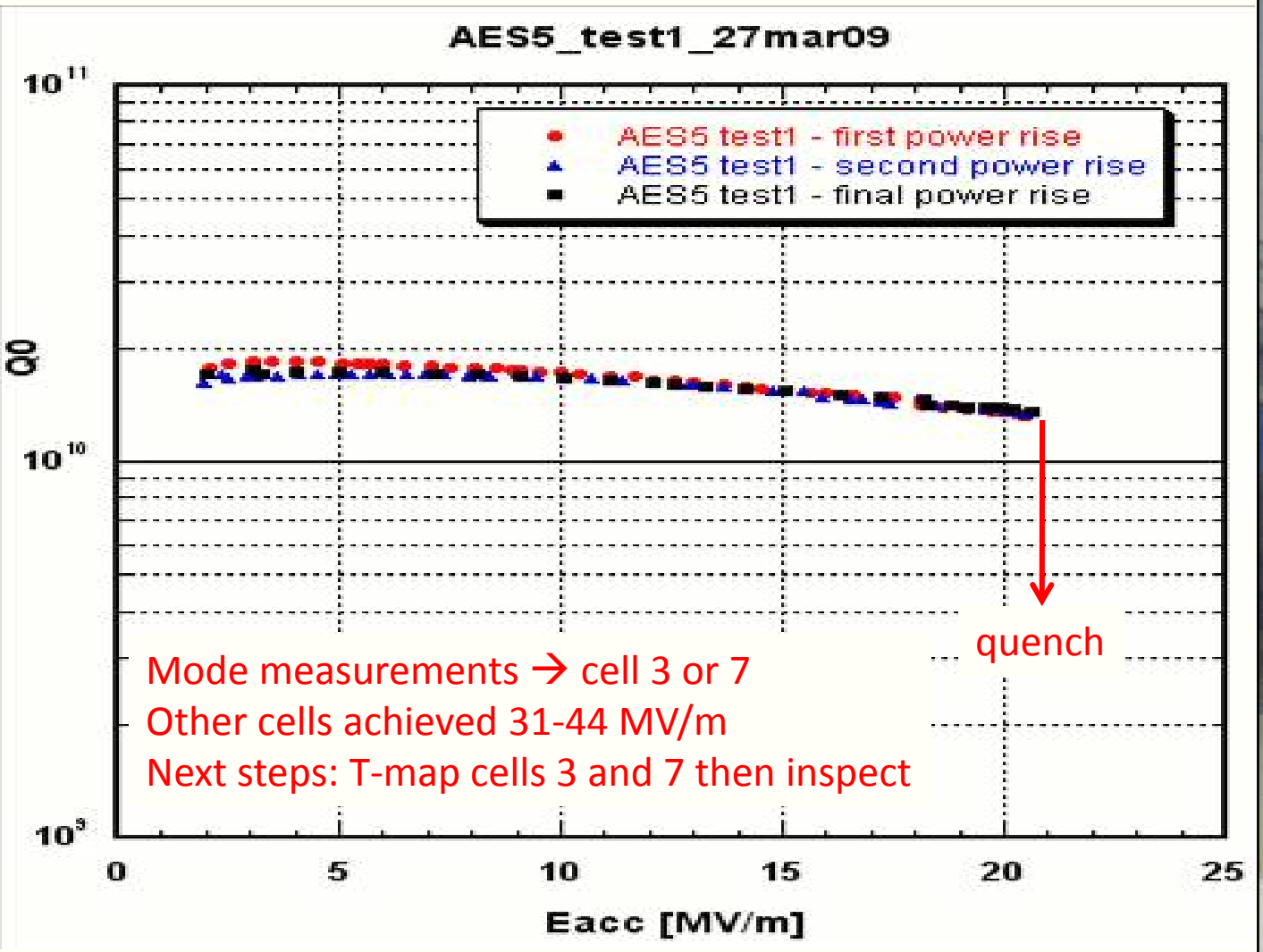


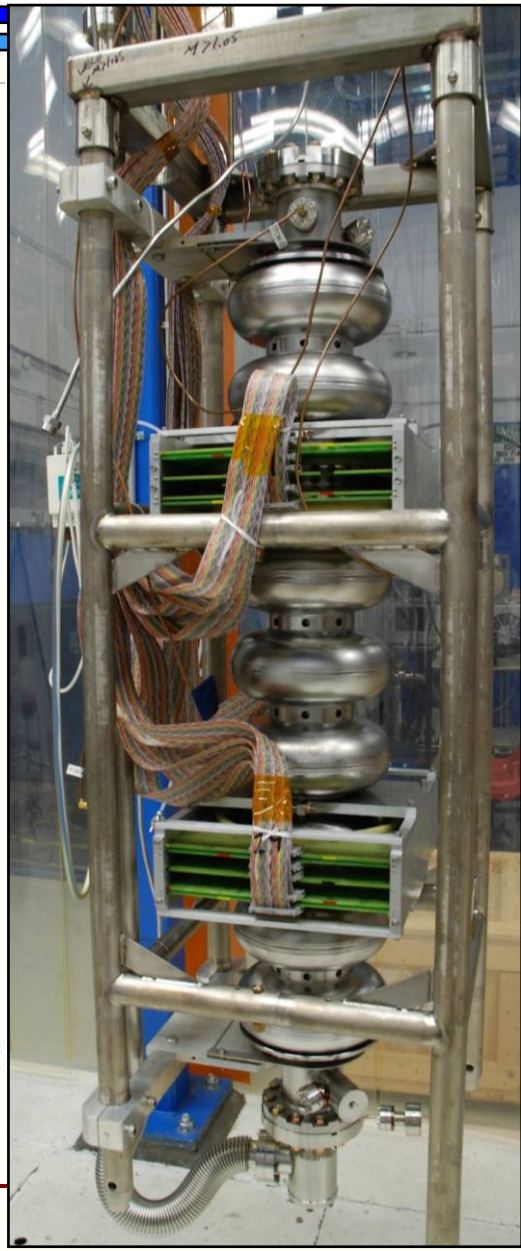
Jefferson Lab

- **For FY09, 16 EP cycles and 16 vertical test cycles are completed so far. We are on track to delivered 30 EP/VT cycles for FY09. This EP/VT rate is consistent with that demonstrated in FY07 (FY08 number was reduced due to funding limit)**

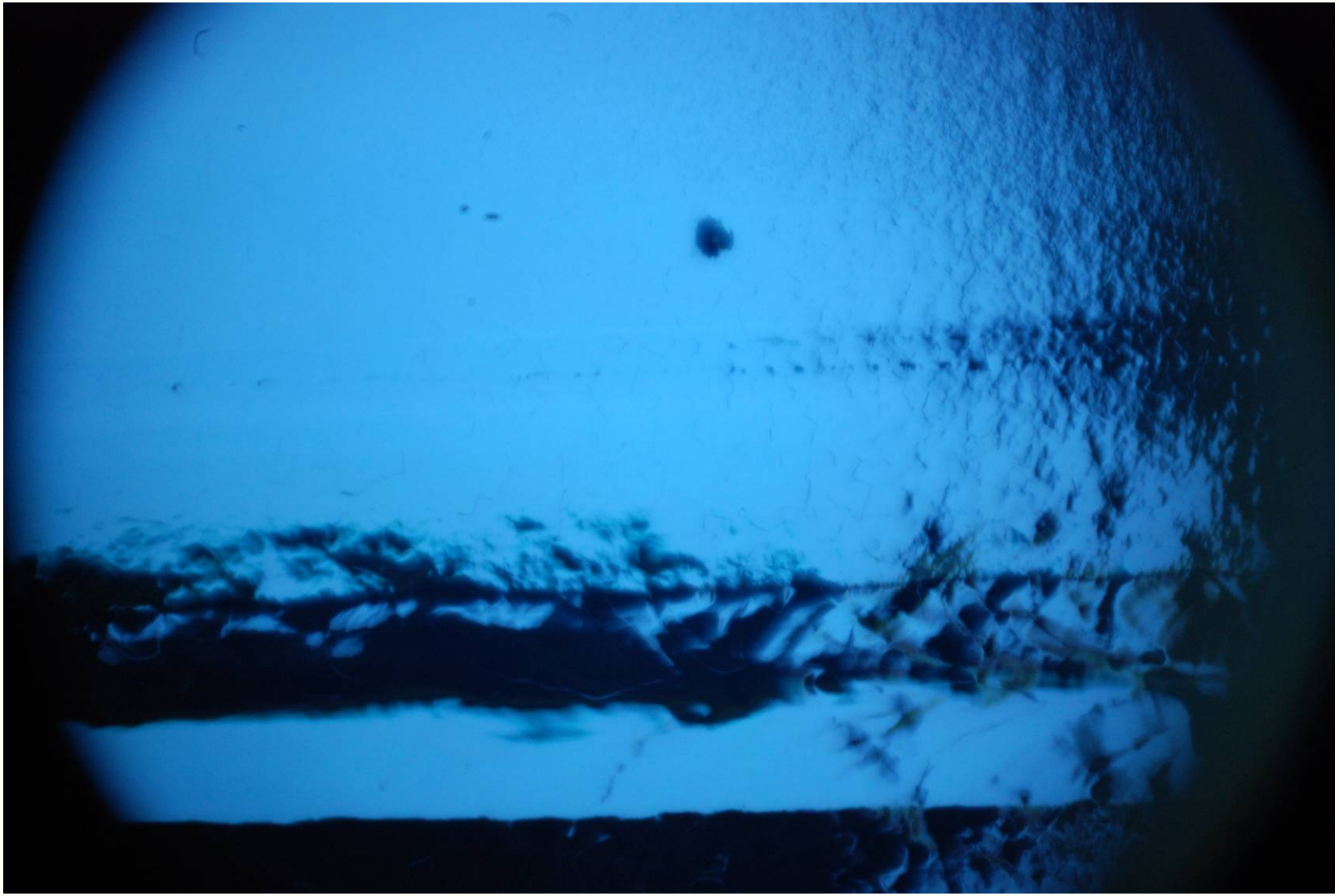
Two fine-grain cavities completed at Jefferson Lab in July 2008

First test result on AES5 at Jefferson Lab (2nd AES production of nine-cell cavities)



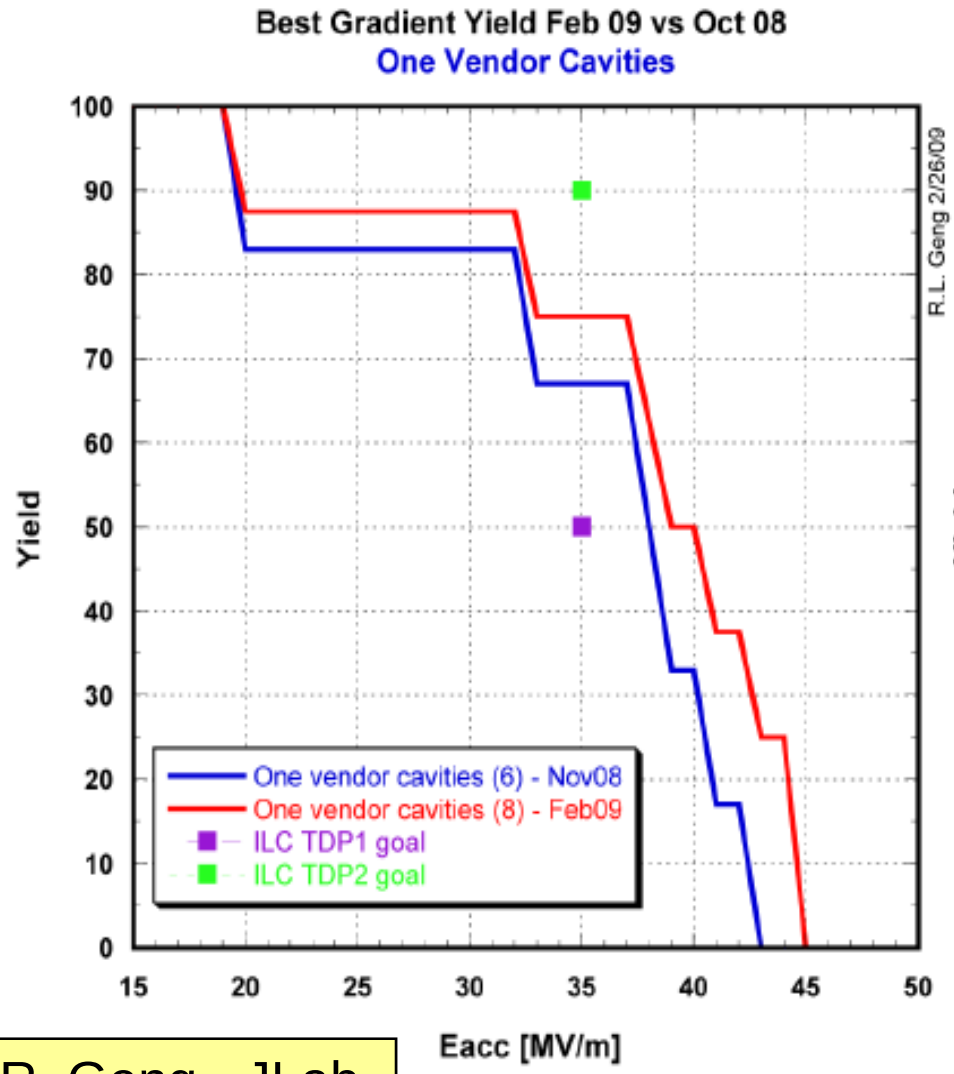


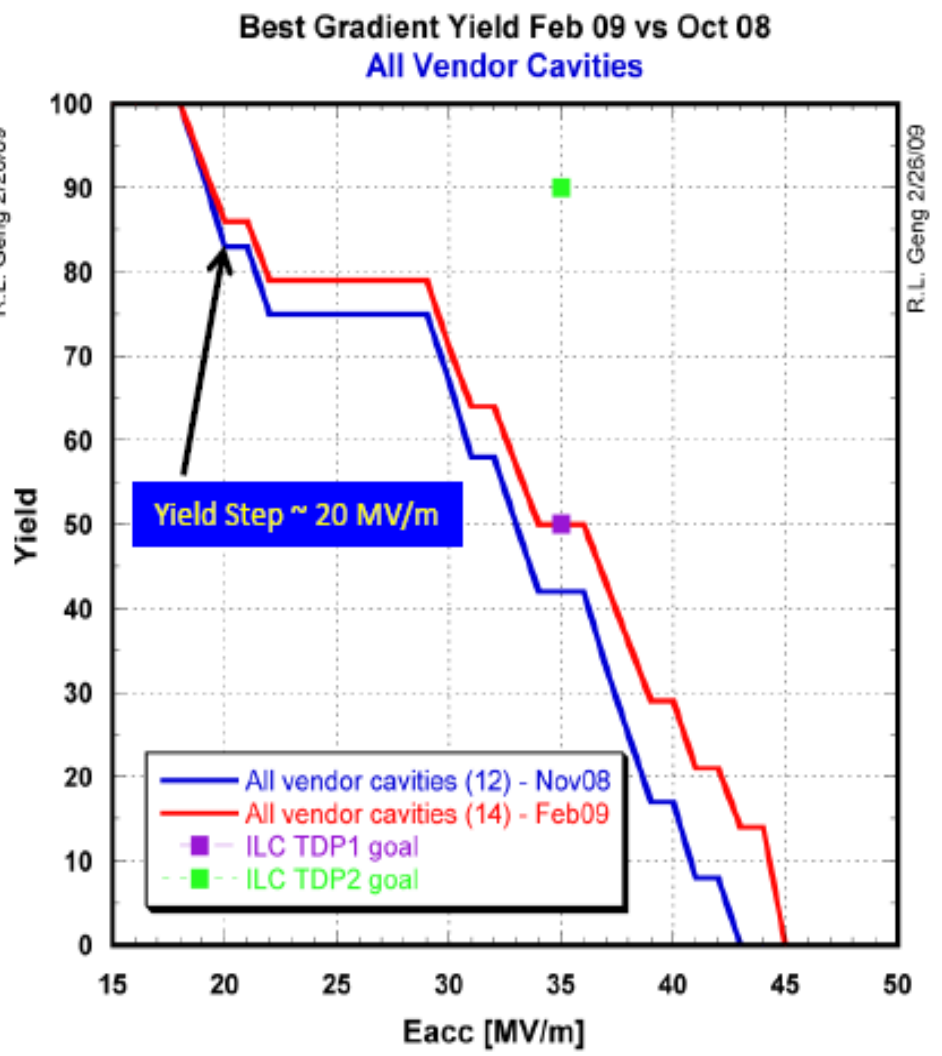
AES5 Defect Photo
Cell 3, ~700 um diameter, 8 mm from weld seam



Yield Curve – as of Feb 09

14 9-cell Cavities Processed & Tested at JLab

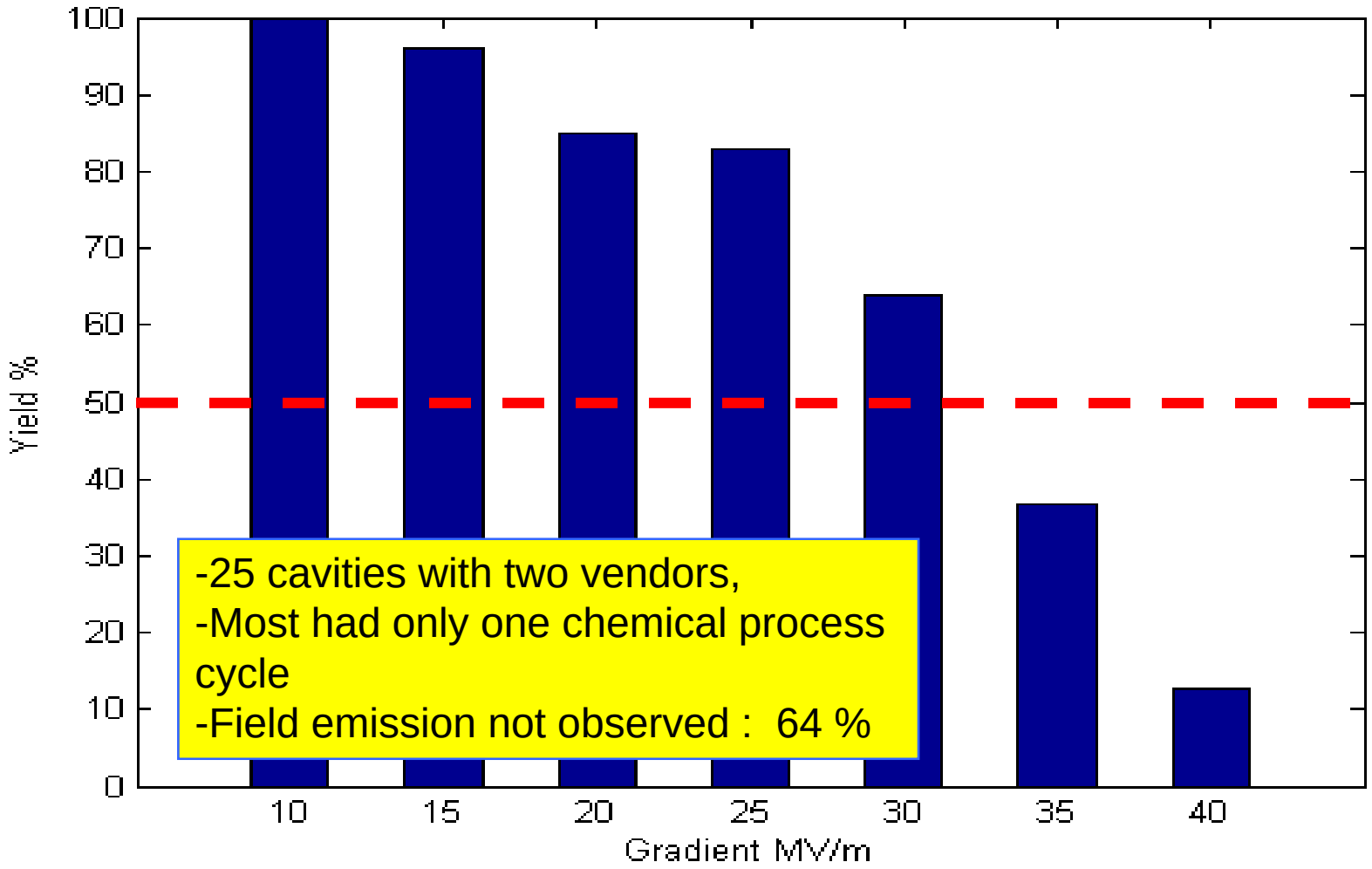




R. Geng - JLab

Recent Progress in Yield at DESY

Data provided by D. Reschke



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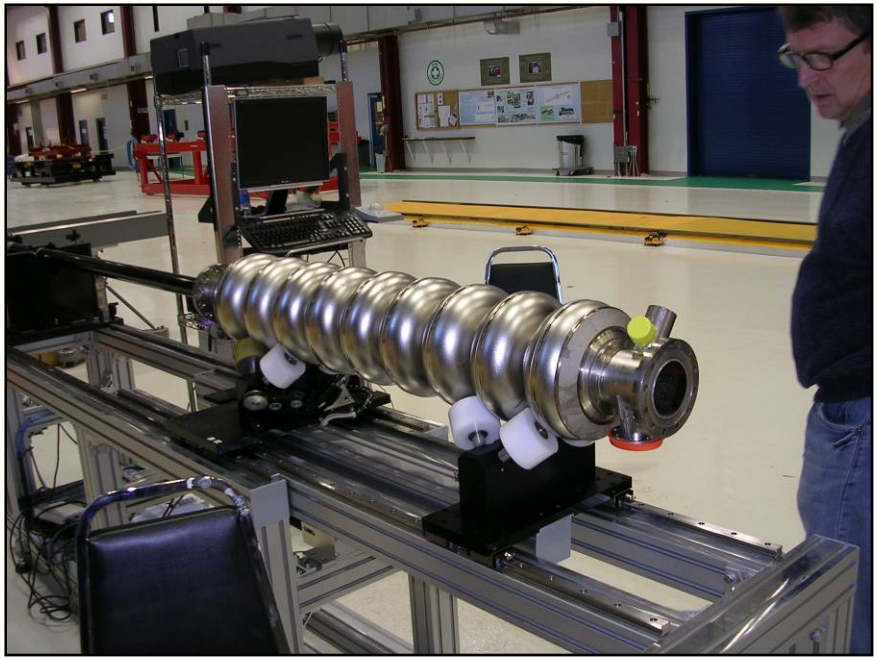
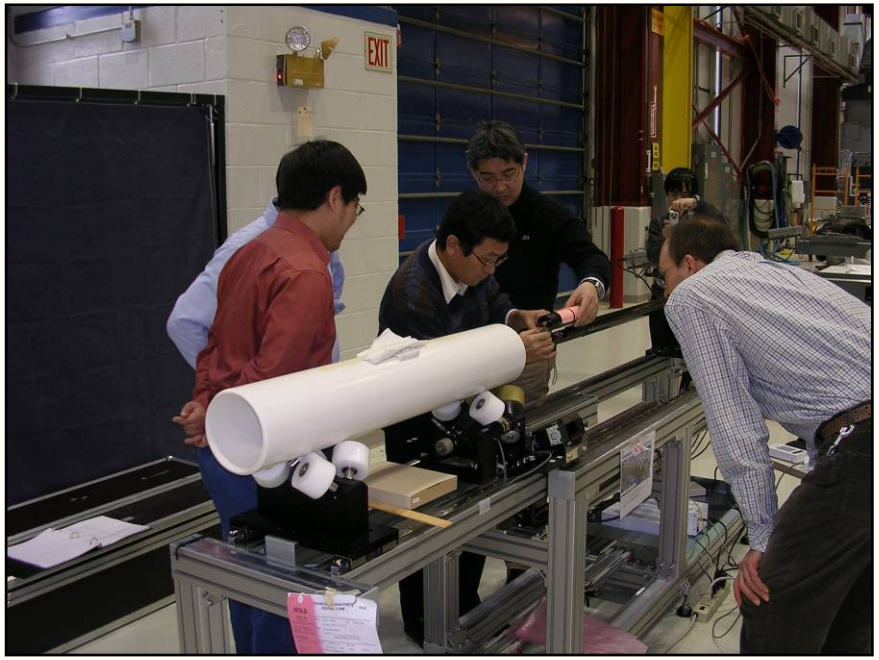
The KEK/Kyoto optical inspection system is operational at Fermilab

- KEK/Kyoto inspection system delivered, installed, commissioned early in 2009
- Expert assistance to optimize system in March 2009
- In routine use; software development underway



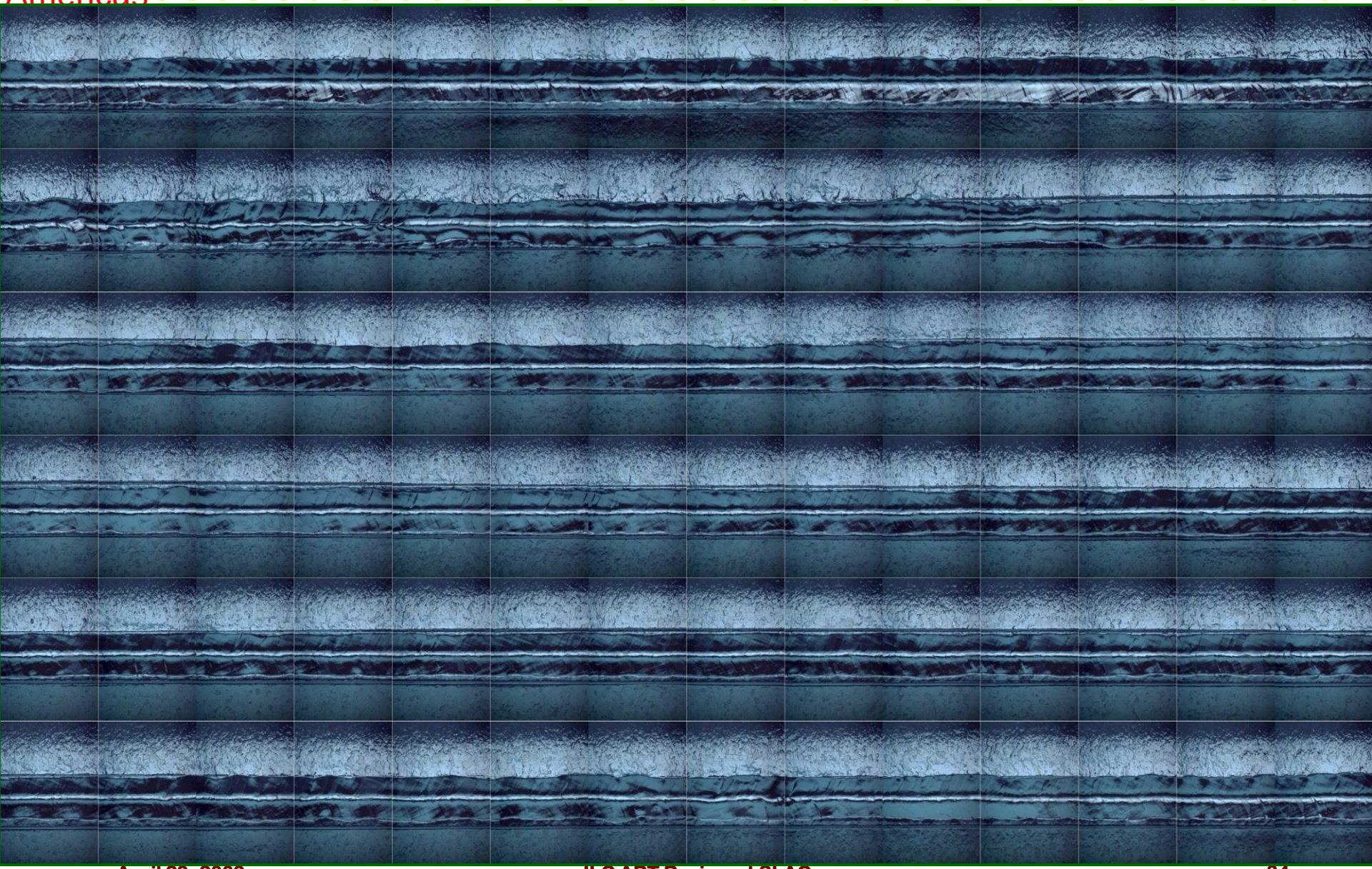
Accel7 on the optical inspection stand



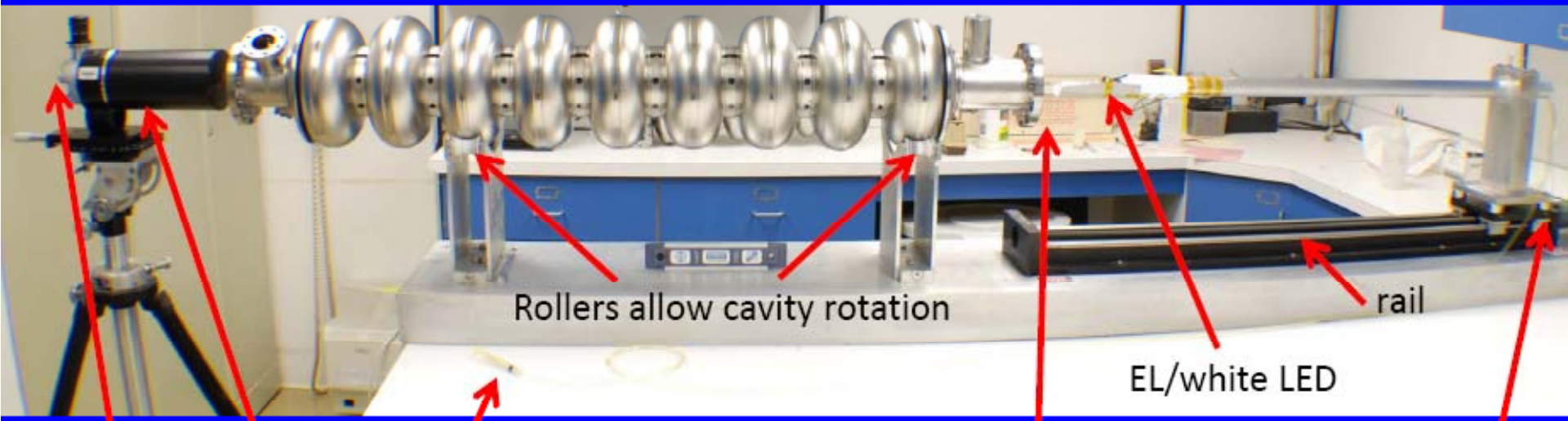
Optical inspection optimization

Collage of a typical equator weld at KEK
The same system is now in use at KEK, DESY and Fermilab

Americas



JLab High Resolution Cavity Inspection Apparatus



Mirror tilter

Mirror

Questar QM1
- Working Range: 22 – 66 inchs
- Resolution: better than 3 microns at 22 inches

Step motor

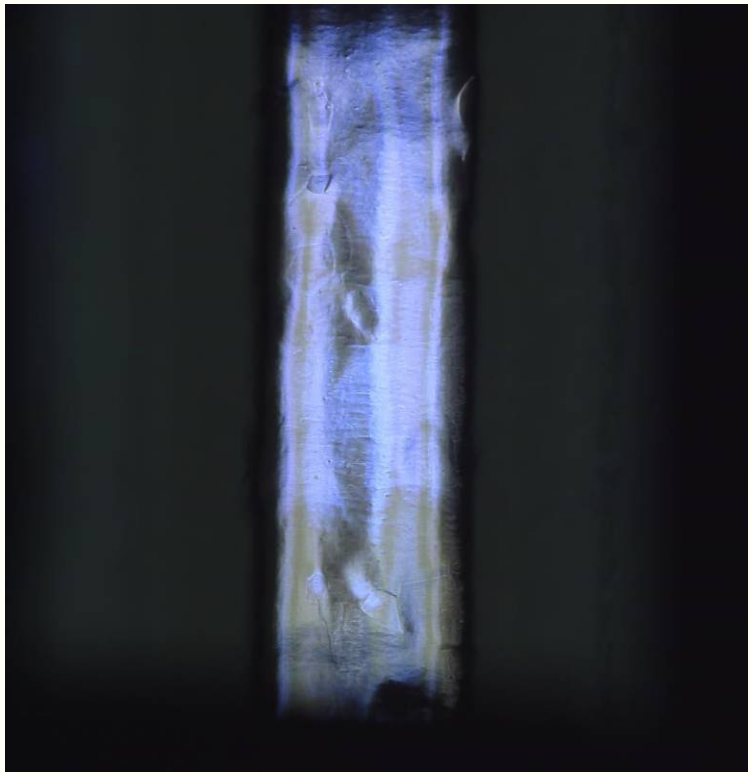
Nikon digital camera
Pixelink CCD camera

New step motor controller added for mirror insertion/retrieval
New cavity rotation actuator is under preparation

Questar-based system also in use at Cornell

Optical inspection of nine-cell cavity Accel6 at Fermilab

Iris between cells 1-2



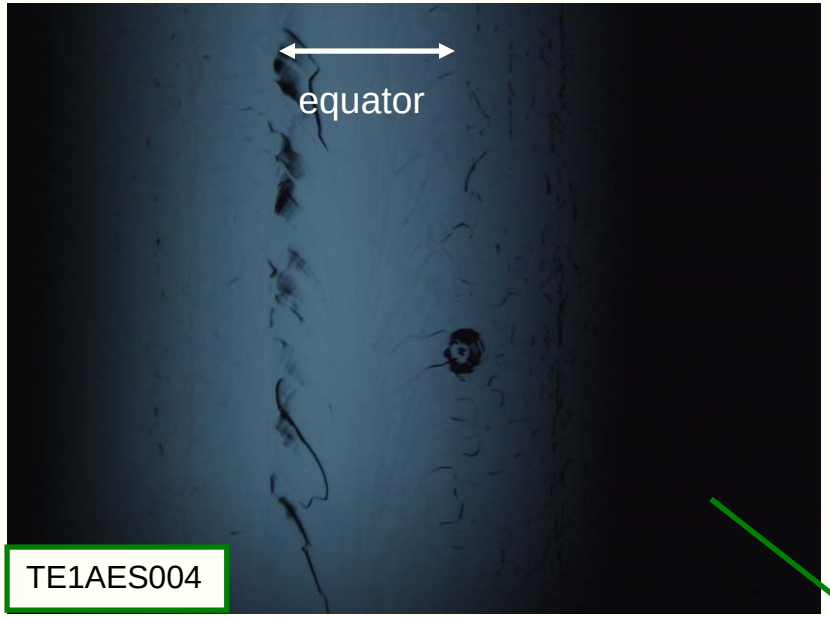
Iris between cells 7-8

- Irises near input coupler end appear rough with many small point-like features
- Irises appear smoother at other end
- Cavity presently limited by persistent field emission → plan to do light electro-polish

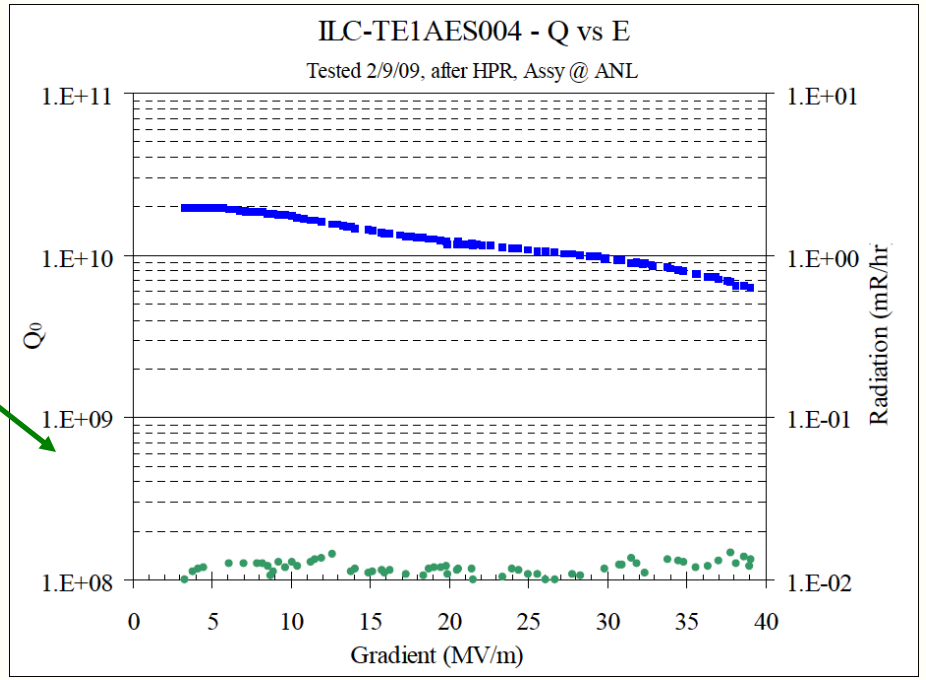
Example of a pit that has minimal effect on performance

Americas

- **TE1AES004 has huge pit at edge of weld seam, size ~1mm**
- **Nevertheless, 39 MV/m**

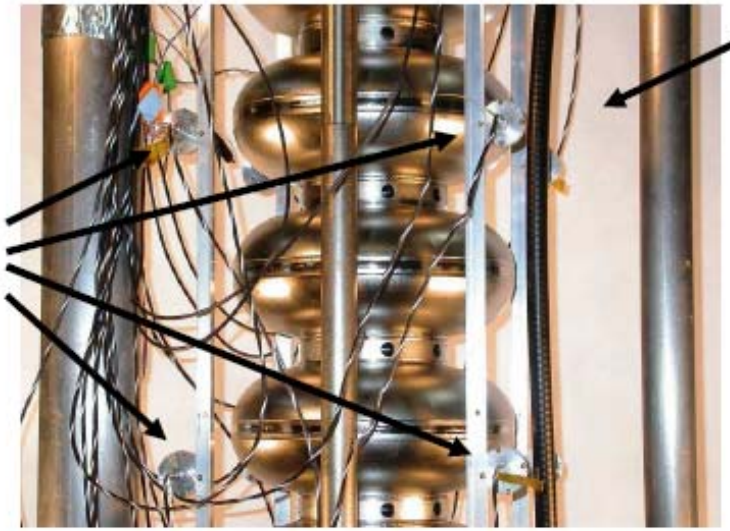


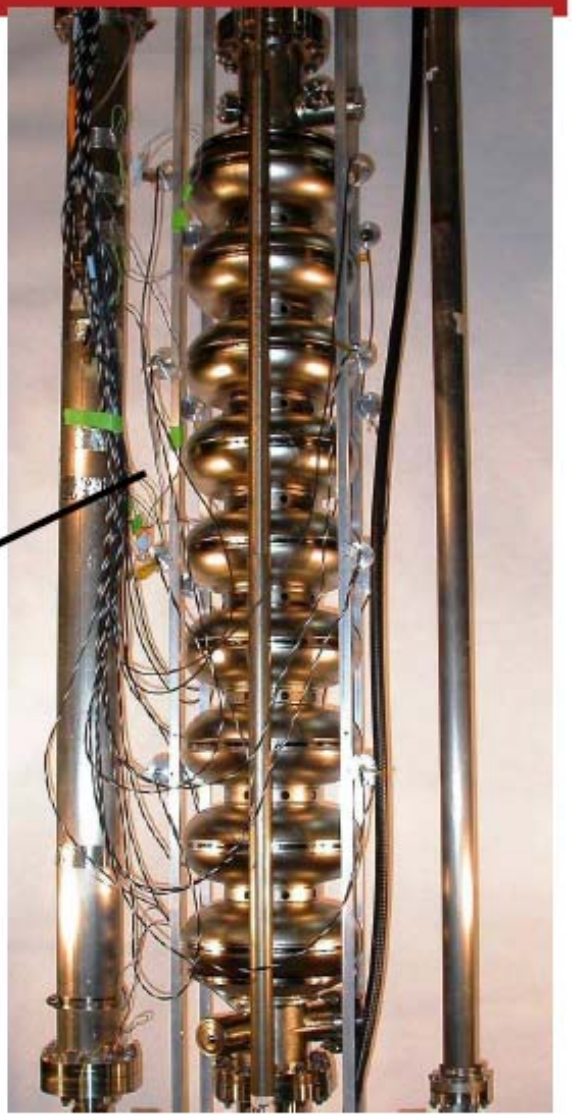
HPR and reassembly only



2nd Sound Quench Detection

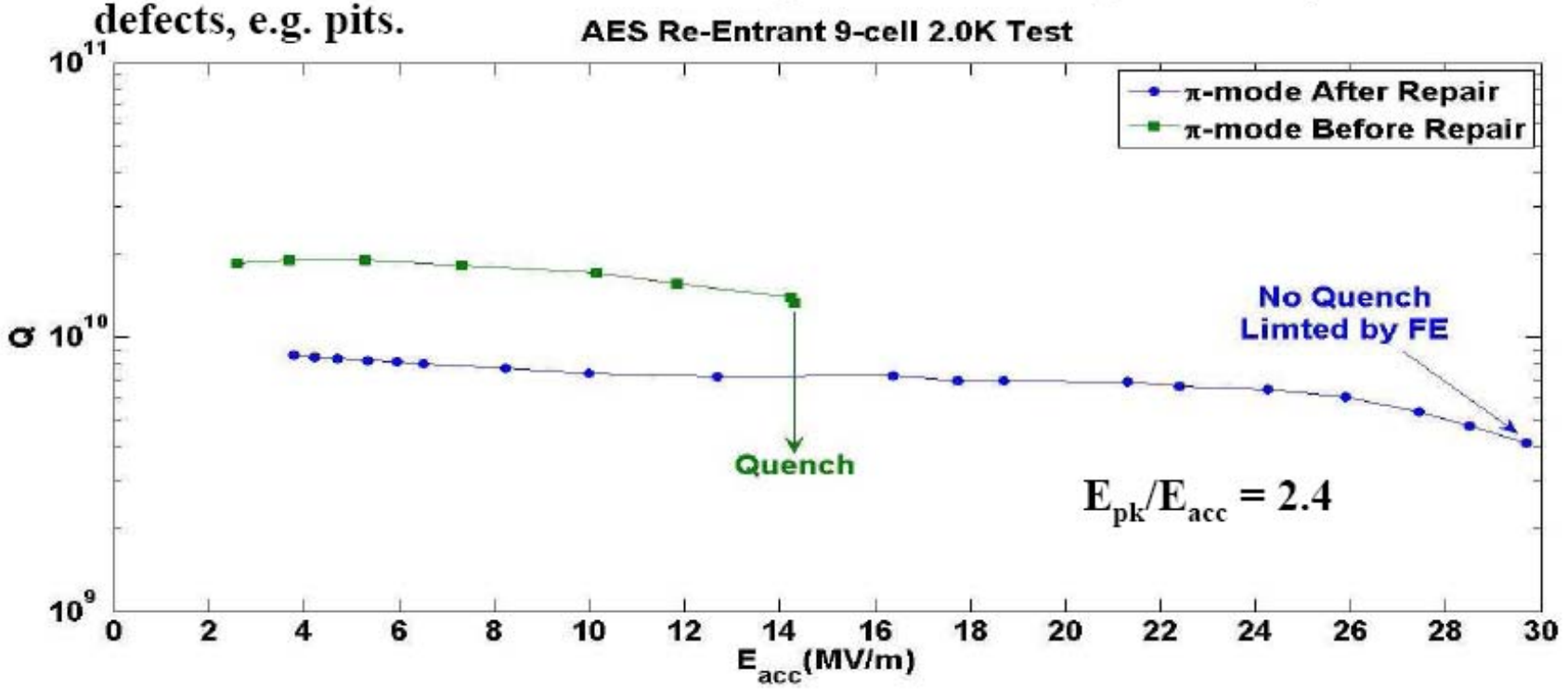
- We have demonstrated that 2nd sound detection can locate multiple quench locations in a single 9-cell cavity cold test
- By exciting different TM_{010} pass-band modes of a 9-cell cavity different cells can be driven to quench.
- This technique is simple, low cost, and quick to implement.



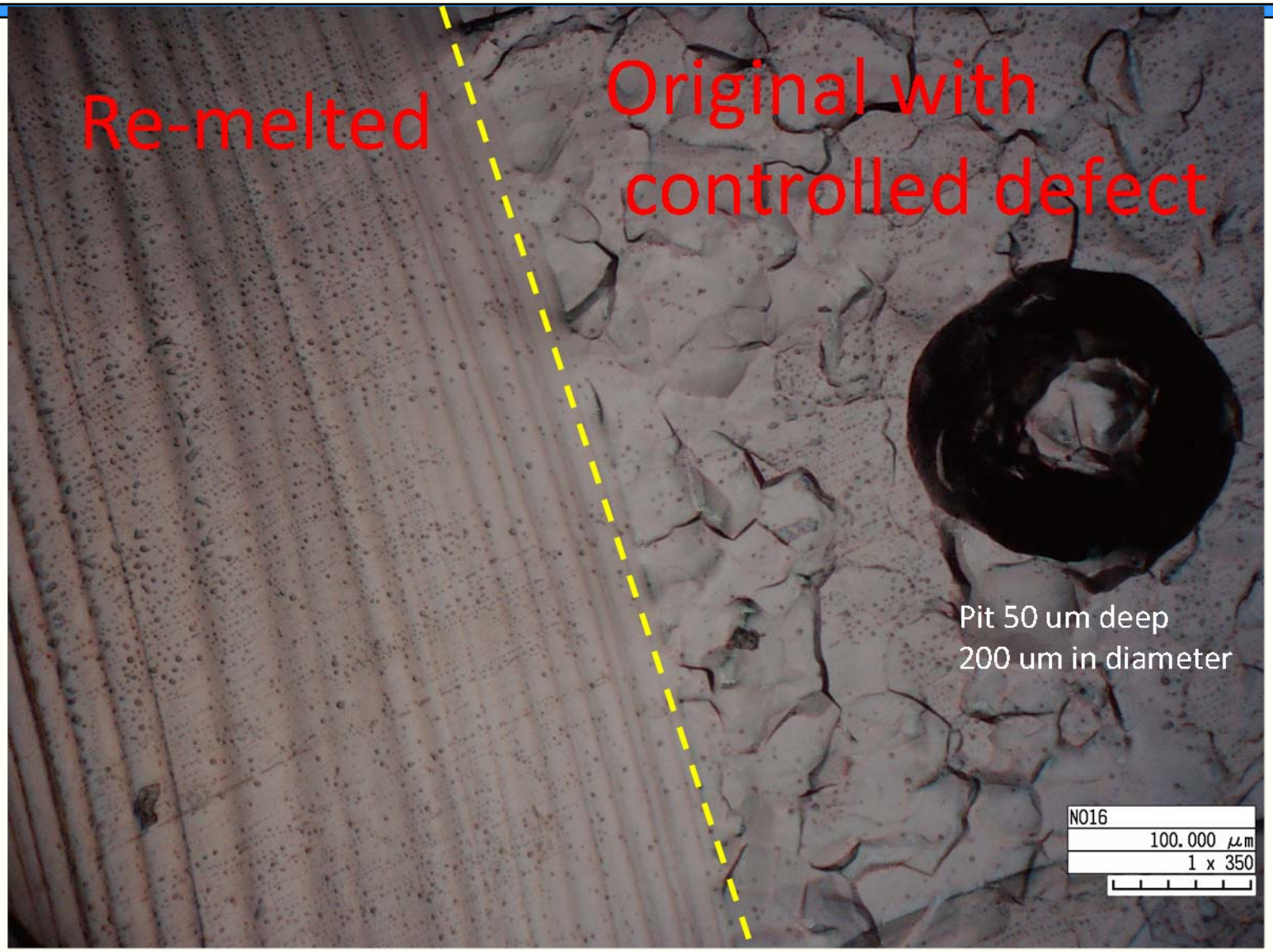


AES Fabricated 9-Cell Cavity Weld Pits Repaired

- 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} > 30MV/m.(100 um tumbling, 200+25 um EP)
- When excited in the 5π/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.



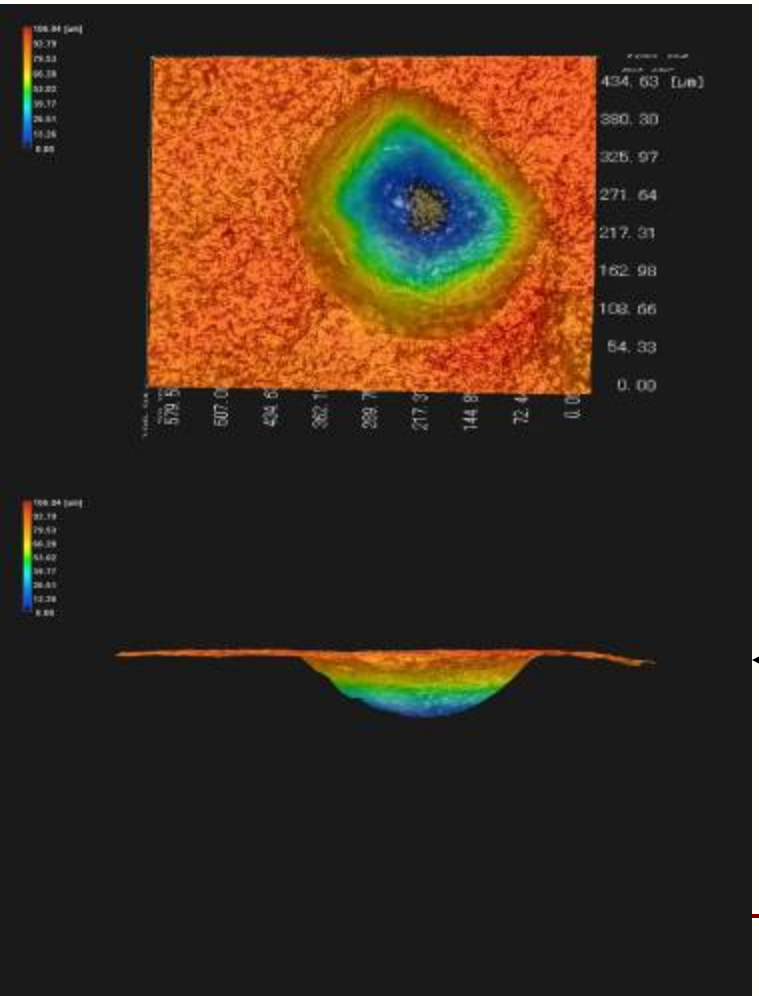
Electron beam melting may be a viable way to eliminate defects
Example from Jefferson Lab



Laser melting shows potential for defect repair at Fermilab

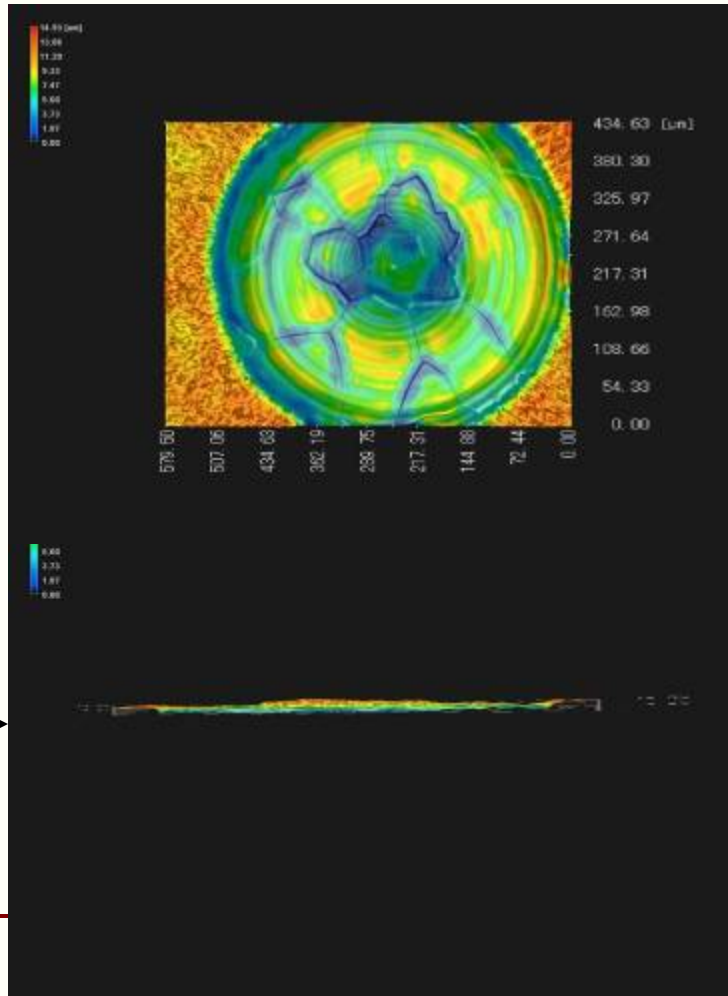
Americas

- A pit cannot be removed by BCP or EP, even after ~150 um removal, in recent investigations
- Laser melting experiments at Fermilab show potential for repair of pits:
  - Irregular pit with depth ~100 um melted to form shallow circular pit of depth ~14 um
  - Investigations ongoing; plan to test repair method using single-cell cavity



100 µm

14 µm



Outline

- S0 organization
- GDE goals
- Accomplishments
  - New infrastructure
  - Vendor development & cavity procurements
  - Cavity processing and testing
  - Diagnostics development & repair techniques
- **Plan for FY2010**
- Summary

Planning for FY2010

- **Assumptions**
  - **Funding will be the same as FY09**
  - **New nine-cell cavities:**
    - **12 from Accel beginning May 2009**
    - **6 from Niowave/Roark by Oct 2009**
    - **6 from AES by Oct 2009**
    - **~10 from US vendors in summer 2010**
  - **Resources approximately constant**
- **Goals**
  - **Process and test available nine-cell cavities**
    - **Utilize optical inspection, mode-measurements, and T-mapping to understand performance limitations**
    - **Attempt repairs via local grinding, tumbling, and e-beam or laser melting**
    - **Provide cavities for cryomodule construction**
  - **Increase throughput at Argonne/Fermilab**
  - **Improve infrastructure at JLab**
  - **Further validate vertical electro-polishing at Cornell; assist with deployment of vertical EP at AES.**

Starting point for FY2010 budget

Americas

Argonne	# cycles	cost k$	FY09
9-cell EP	23.0	345.0	
Single-cell EP	10.0	60.0	
Processing facility maintenance		46.0	
Total		**451.0**	**451.0**
Fermilab			
9-cell test cycles	20.0	300.0	
Single-cell test cycles	10.0	150.0	
Total		**450.0**	**450.0**
Cornell			
9-cell T-Mapping studies	5.0	153.3	
9-cell cavity repair	5.0	150.0	
2nd sound detection on dressed cavities	2.0	80.0	
Single-cell process & test	8.0	70.4	
Vertical EP development		146.3	
Management & travel		50.0	
Total		**650.0**	**650.0**
Jefferson Lab			
9-cell process and test cycles			
fine grain EP + maintenance	30.0	1000.0	
Management & travel		75.0	
Total		**1075.0**	**1725.0**
Remainder		**650.0**	
Grand Total		**3276.0**	**3276.0**

- **Assume same budget as last year**
- **Start with same distribution**
- **Need detailed proposal from Jefferson Lab**
- **Work together to finalize plan for next year**

Adequacy of funding and labor resources

- **Labor resources tight but marginally adequate**
  - **One-year assignment of Fermilab technician to JLab will conclude in October; no replacement planned**
  - **Plan to add 4 technicians to Argonne/Fermilab facility**
    - **Supported by Fermilab SRF funding, not ART**
- **Funding is adequate but not stand-alone**
  - **Additional funds from Fermilab SRF budget are planned and essential**
  - **Fermilab purchase orders have augmented funding at Argonne, Cornell and Jefferson Lab in FY09**
  - **Need to work out the details for FY10**

Summary

- There has been significant technical progress in the last year despite the financial difficulties of FY08 and the FY09 continuing resolution
  - Continued processing and testing at Cornell and JLab
  - Completion of Argonne/Fermilab cavity processing facility
  - Increased testing rate at Fermilab
  - Continued cavity orders and vendor development
- There have been changes in the S0 leadership
  - Zack Conway at Cornell
  - Rongli Geng at JLab
- Planning for FY10 is underway with funding and resources expected to be unchanged from FY09
- GDE TDP1 goal of 35 MV/m at 50% yield is already achieved in JLab data set

Bonus:
The Fermilab 3.9 GHz cryomodule has been delivered to DESY!

- Arrived at DESY Tuesday afternoon, April 28
- Beamline vacuum okay
- Shipping was uneventful - instrumentation revealed minimal dynamic loading during transport