Cavity Gradient Progress

RDR to R&D Plan Release 5


ILC Research and Development Plan for the Technical Design Phase

Release 5

August 2010

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto

Rong-Li Geng

Jefferson Lab & GDE

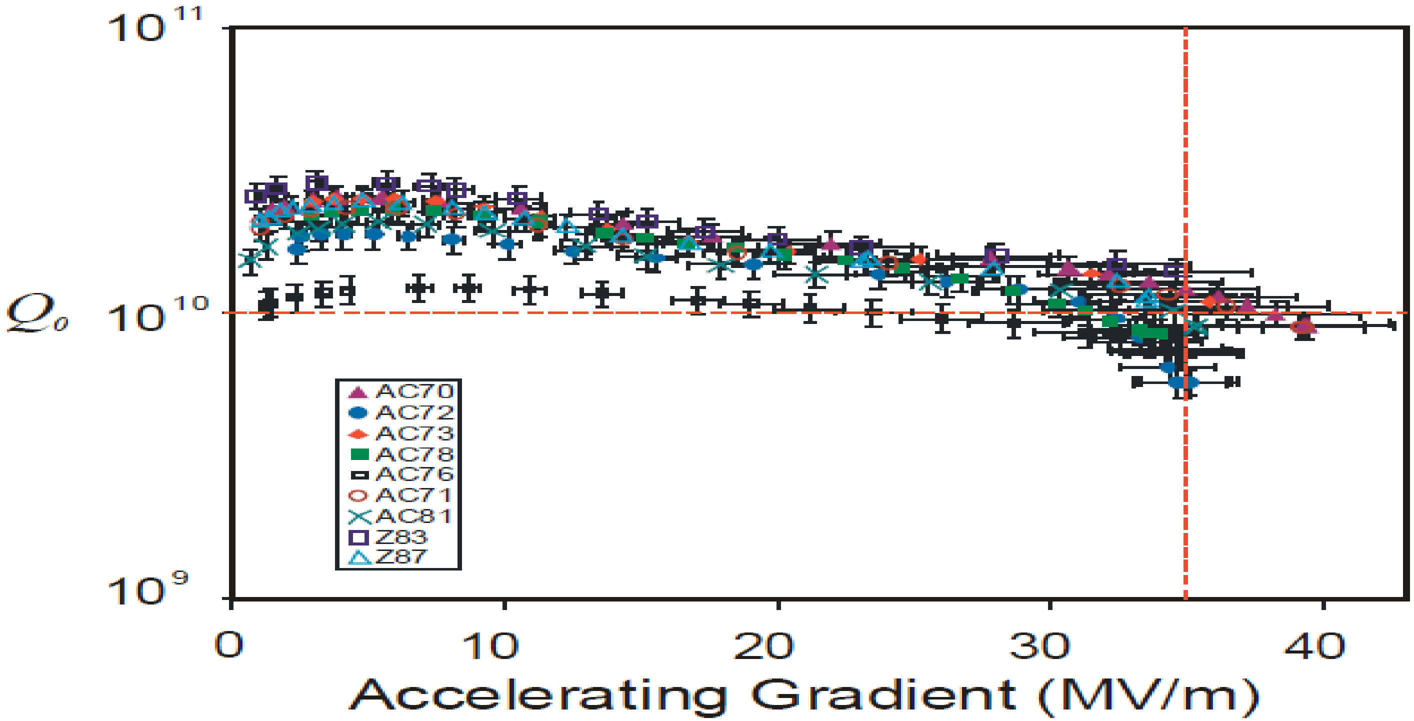
1st Baseline Assessment Workshop, KEK, September 7-10, 2010

Outline

- RDR goal
- S0 program with highlights
- S0 success in field emission reduction
- Gradient yield definition
- Delivery of TDP-1 yield goal of 50%
- TDP-2 gradient R&D priority & plan
- Summary & an example of ~90% yield

RDR Gradient and Yield Goal

The ILC community has set an aggressive goal of routinely achieving[4] 35 MV/m in nine-cell cavities, with a minimum production yield of 80%. Several cavities have already achieved these and higher gradients (see Figure 1.2-3), demonstrating proof of principle. Records of over 50 MV/m have been achieved in single-cell cavities at KEK and Cornell[7]. However, it is still a challenge to achieve the desired production yield for nine-cell cavities at the mass-production levels (~17,000 cavities) required.



RDR Gradient R&D Priority and S0 Task Force/Program

The best cavities have been achieved using electropolishing, a common industry practice which was first developed for use with superconducting cavities by CERN and KEK. Over the last few years, research at Cornell, DESY, KEK and Jefferson Lab has led to an agreed standard procedure for cavity preparation, depicted in Figure 1.2-5. The focus of the R&D is now to optimize the process to guarantee the required yield. The ILC SCRF community has developed an internationally agreed-upon plan to address the priority issues.

The 'S' R&D Task Forces

S0
High-Gradient Cavities

S1
High-Gradient Cryomodule

S2
Test Linac

S3
Damping Ring

S4
Beam Delivery

S5…Sn

- Addresses current 'poor' yield for EP cavities
- Primary goal: establish parameters for routinely producing 35 MV/m EP'd cavities
  - **required ≥ 80% yield**

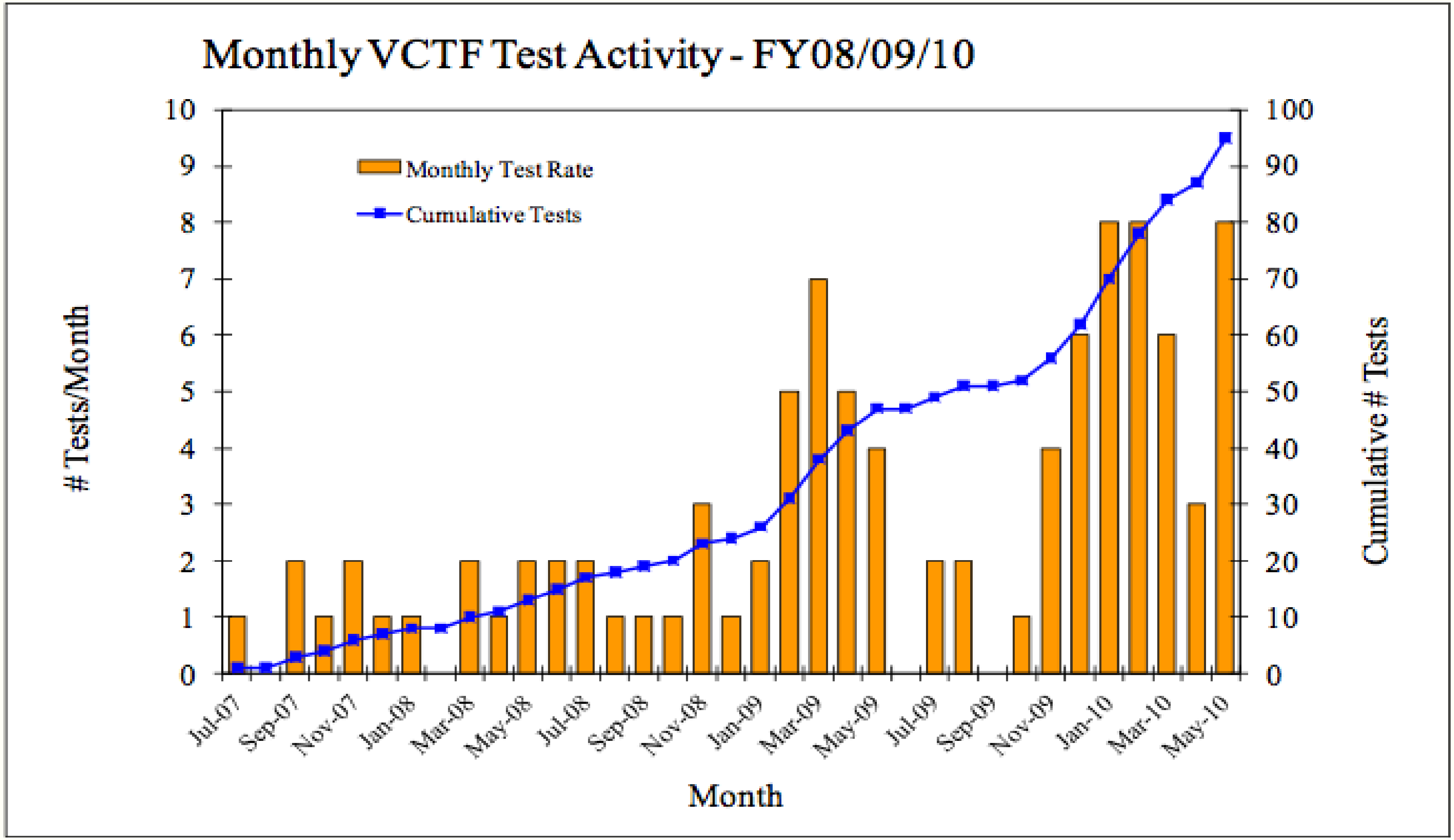
H. Hayano, T. Higo, L. Lilje, J. Mammosser, H. Padamsee, M. Ross, K. Saito

ILC Valencia 7th November 2006 **Global Design Effort** 55

Recent Global Gradient R&D (S0) Highlights

- Americas
  - **AES is "ILC certified" cavity vendor; Niowave-Roark delivered first 2x9-cell cavities.**
  - **FNAL/ANL joint facility improved throughput and quality of 9-cell proc. and testing.**
  - **Cornell increased throughput and quality of 9-cell tumbling and vertical EP.**
  - **JLab set an example of 88% yield at 35 MV/m with 8 cavities from one vendor.**
- Asia
  - **KEK STF facility improved quality of 9-cell proc. and testing. Pilot plant soon.**
  - **Successful 9-cell gradient improvement with guided local grinding.**
  - **New vendors: 1st Hitachi 9-cell cavity 35 MV/m.**
  - **1st 9-cell full cavity in China by PKU 28 MV/m; 1st 9-cell LL cavity by IHEP tested.**
  - **KEK 9-cell cavity Ichiro7 S0 studies in collaboration with JLab.**
- Europe
  - **XFEL/HiGrade cavity order placed – more than 300 will be proc. with "ILC recipe".**
  - **DESY optical inspection tool automation for "optical control"**
  - **DESY large-grain 9-cell proc. and testing; seamless 9-cell in collaboration w/ Jlab.**
- T-mapping/optical inspection in routine use globally.

Increasing throughput at Fermilab vertical test facility



Courtesy of J. Ozelis, M. Champion

Progress at the Argonne/Fermilab Superconducting Cavity Surface Processing Facility (SCSPF)

2010 Summary Data

- 24 cavity test preparations completed January-May 2010
  - 10 one-cell preps
  - 9 nine-cell vertical preps
  - 5 horizontal test preps
- 6 bulk EP
- 11 light EP
- 68 HPR cycles

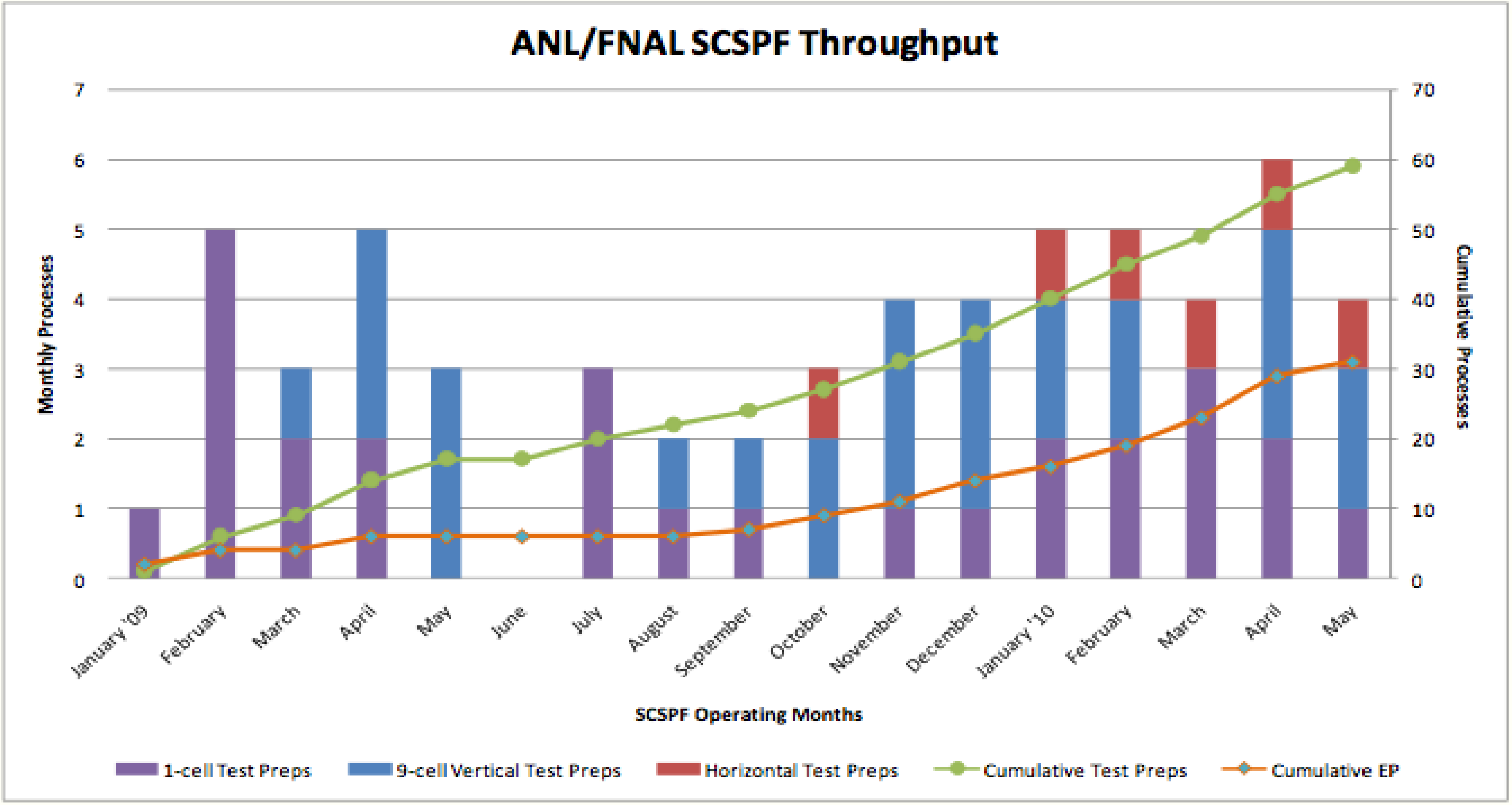
Resultant Test Highlights

- Highest Gradient 9-cell (rinsed and assembled only): TB9AES007 41.8 MV/m (processed/tested at JLab – test results in agreement)
- Highest Gradient w-ANL EP and w/o FE: TB9RI029 34.6 MV/m
- Latest Horizontal test TB9AES009 was FE-free at 35 MV/m
- 20+ single-cell processes FE-free in a row—up to 42 MV/m
- Multiple 30+MV/m 9-cell processed through SCSPF

June 09, 2010 ILC ART Review at Fermilab

Courtesy of A. Rowe, M. Champion

Throughput at the Argonne/Fermilab Superconducting Cavity Surface Processing Facility (SCSPF)



June 09, 2010 ILC ART Review at Fermilab

Courtesy of A. Rowe, M. Champion

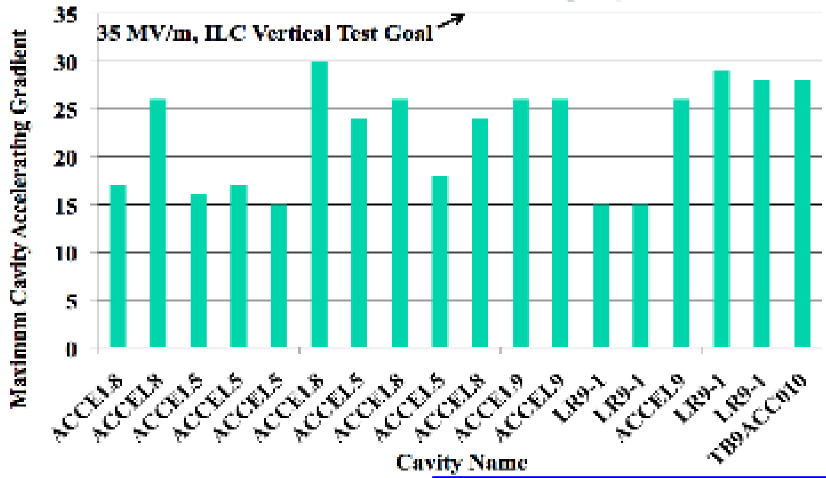
Vertical Electropolish

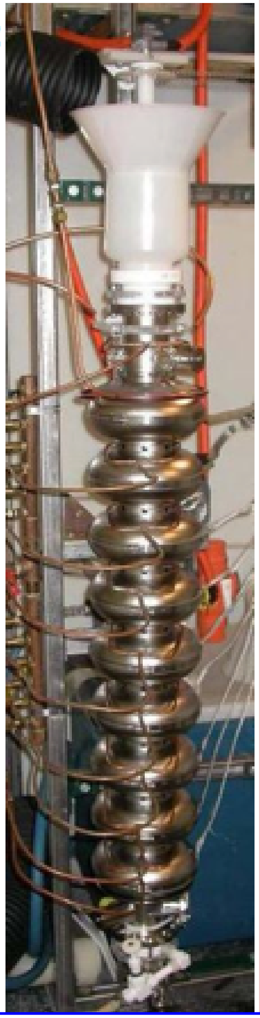
Vertical Electropolish (VEP) has many advantages over the standard EP procedure:

1) Eliminates rotary acid seals
2) Eliminates sliding electrical contacts
3) Eliminates the cavity vertical/horizontal position control fixturing
4) Simplifies the acid plumbing, containment, and cooling
5) Potential for better temperature control than in a partially filled cavity
6) One time use of acid, no pumping back into the cavity of used acid
7) Better cavity stability, usable for cavities without stiffening rings
8) Higher etch rates compared to partially filled cavities in horizontal EP.
9) Lower capital equipment costs
10) Fewer parts reduces the risk of contaminants building-up

We VEP-ed several 9-cell cavities during recent years:

Potential for cheaper Installations at the many cavity vendors needed for ILC Cavity production.





Georg.Hoffstaetter@Cornell.edu

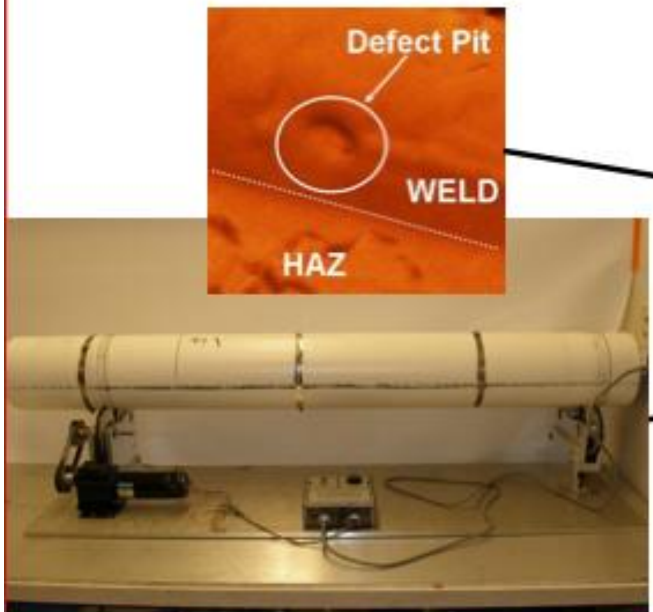
Courtesy of G. Holffstaetter, M. Champion

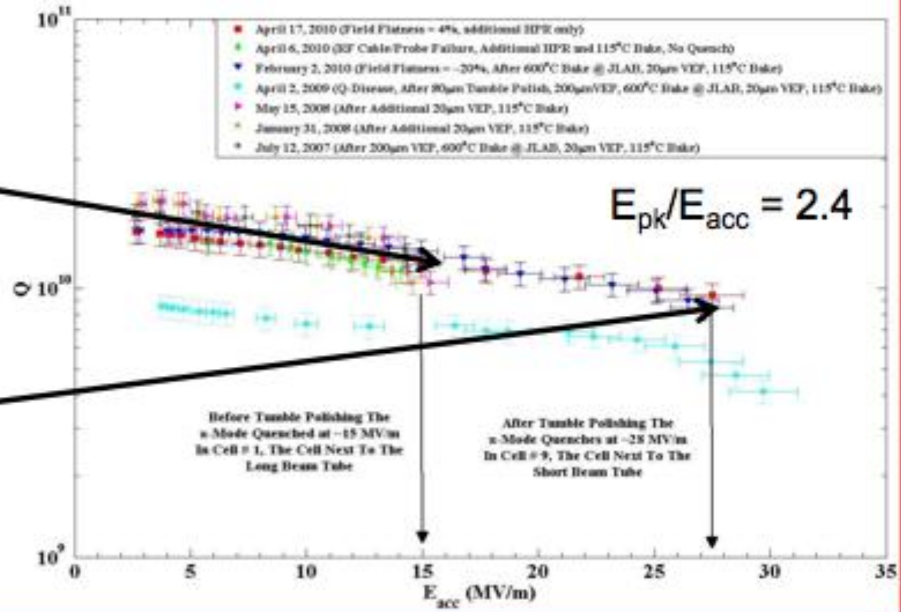
Cavity repair by tumbling

1) AES fabricated 9-Cell Cavity originally quenched at E_{acc} = 15 MV/m, after tumbling and reprocessing E_{acc} > 30MV/m in the repaired cell.
2) When excited in the 5p/9-mode, E_{acc} = 37 MV/m in the center cell.
3) Initially reduced Q was repaired by 2h, 800C baking.

Conclusion:

1) Tumbling is an effective option to repair weld defects, e.g. pits.
2) Individual cells in cavities processed with VEP can reach fields exceeding 35 MV/m for satisfactory Q values.

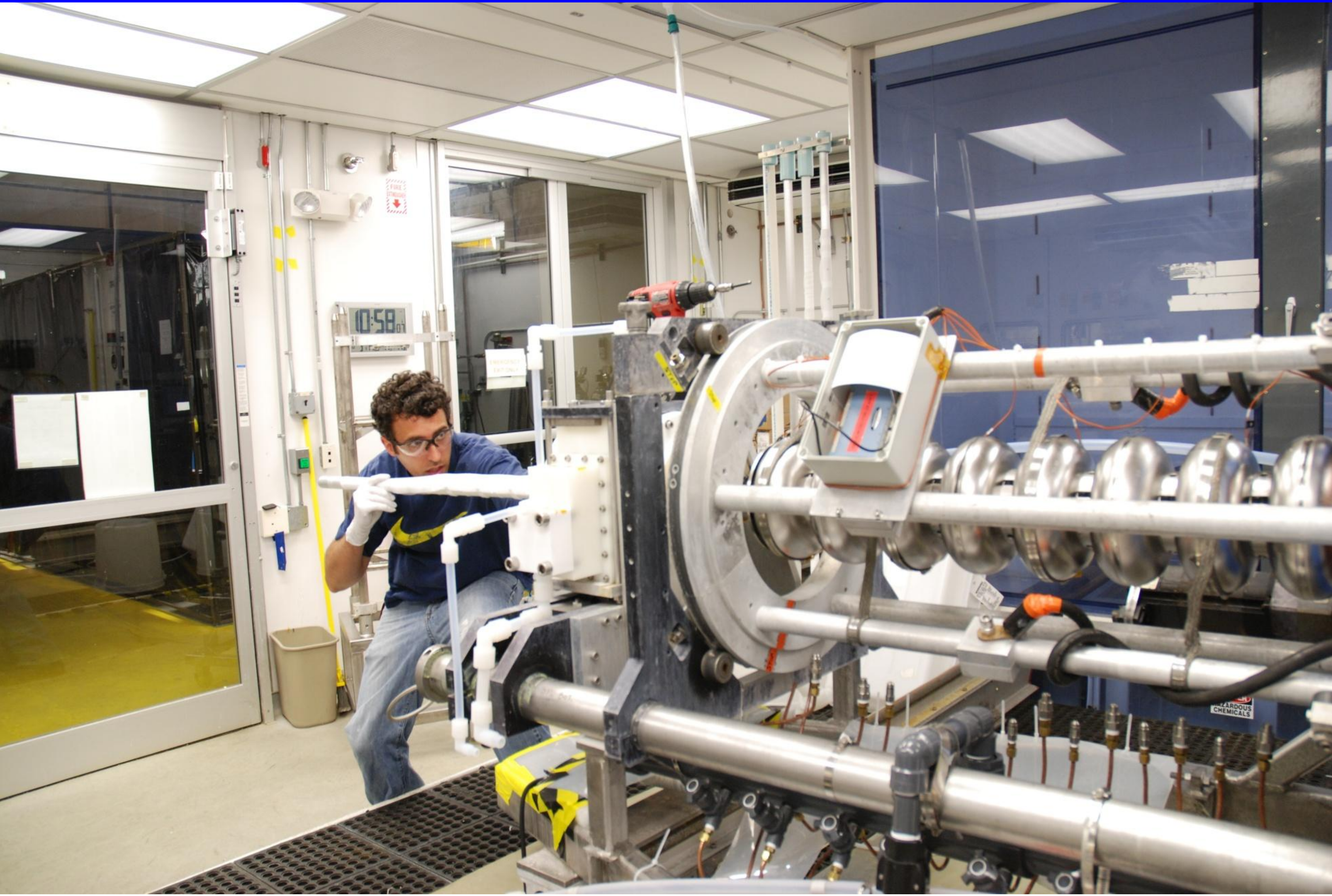




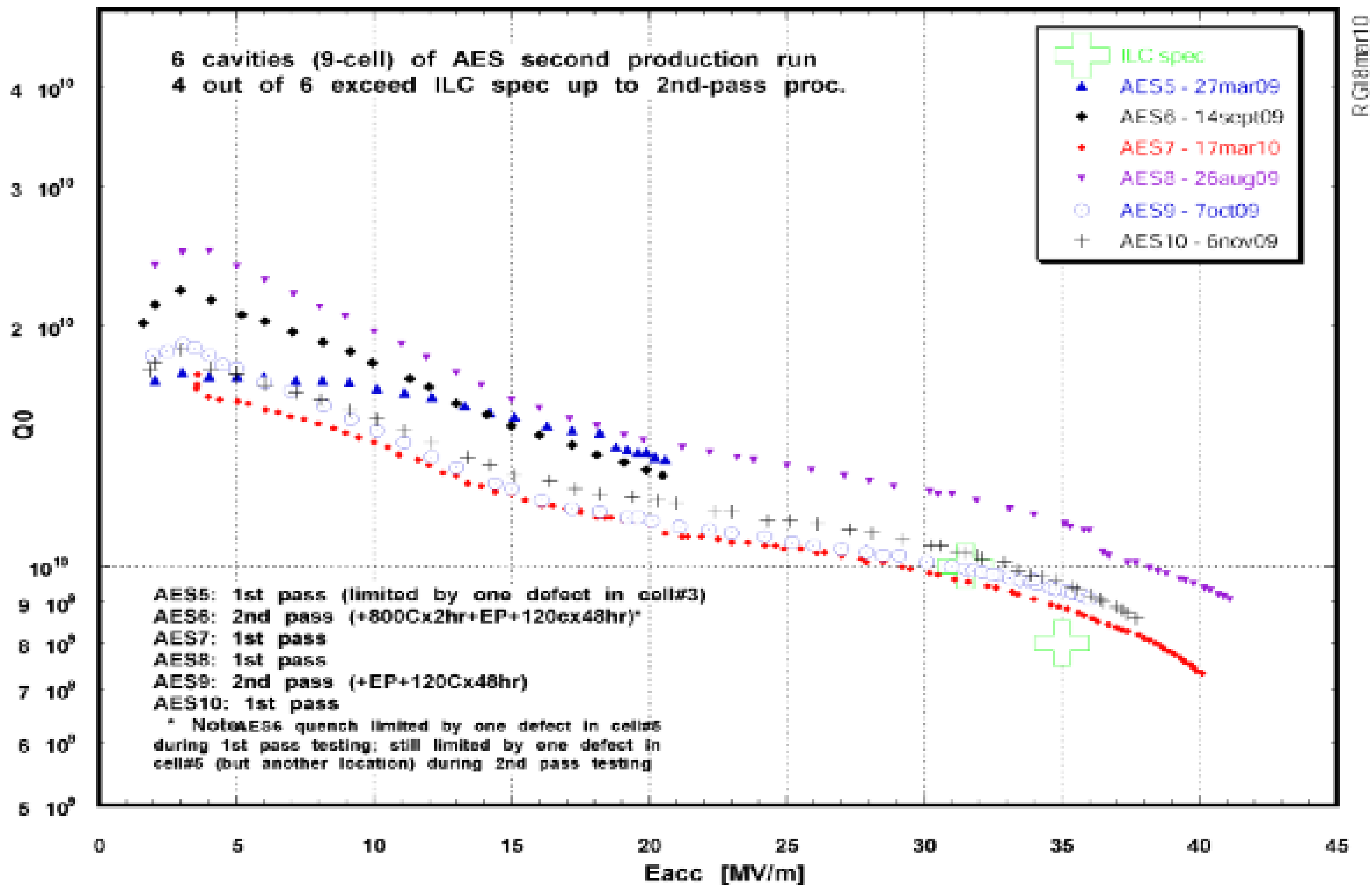
Georg.Hoffstaetter@Cornell.edu

Courtesy of G. Holffstaetter, M. Champion

JLab technician inserts a cathode into a 9-cell ILC cavity for optimal EP.
Three technicians were qualified in past year to run optimal EP at JLab.

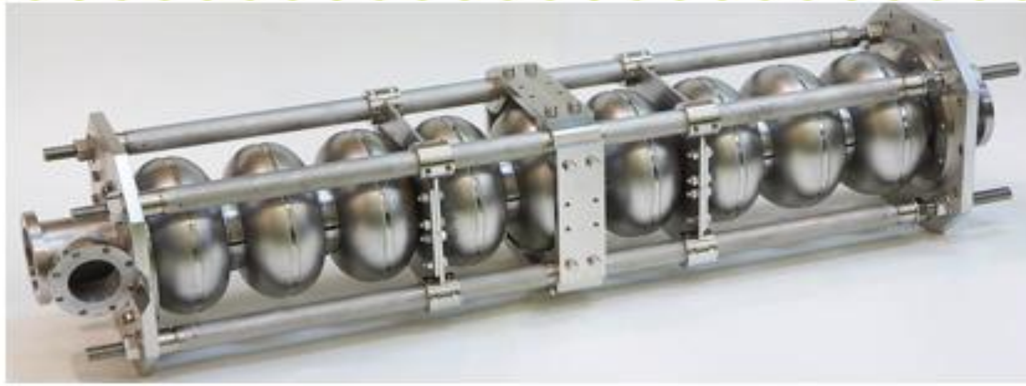


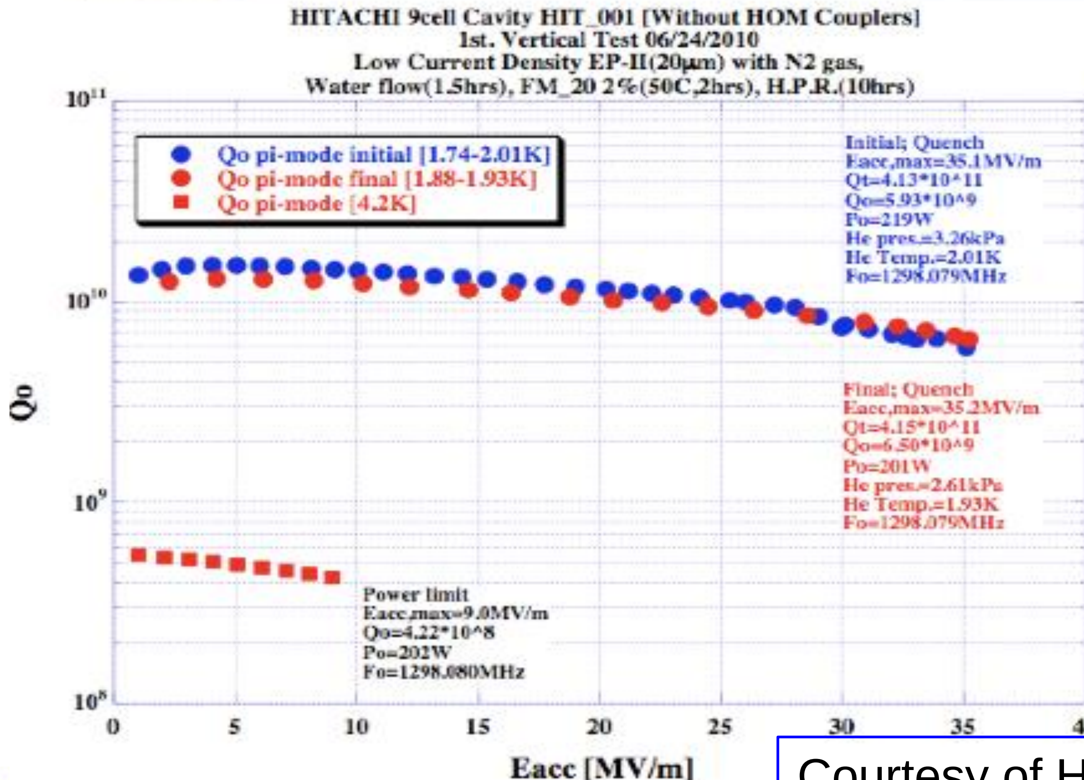
Performance of AES 2nd Production Cavities Processed and Tested at JLab



R.L. Geng, JLAB   2010 ART Annual Review   36

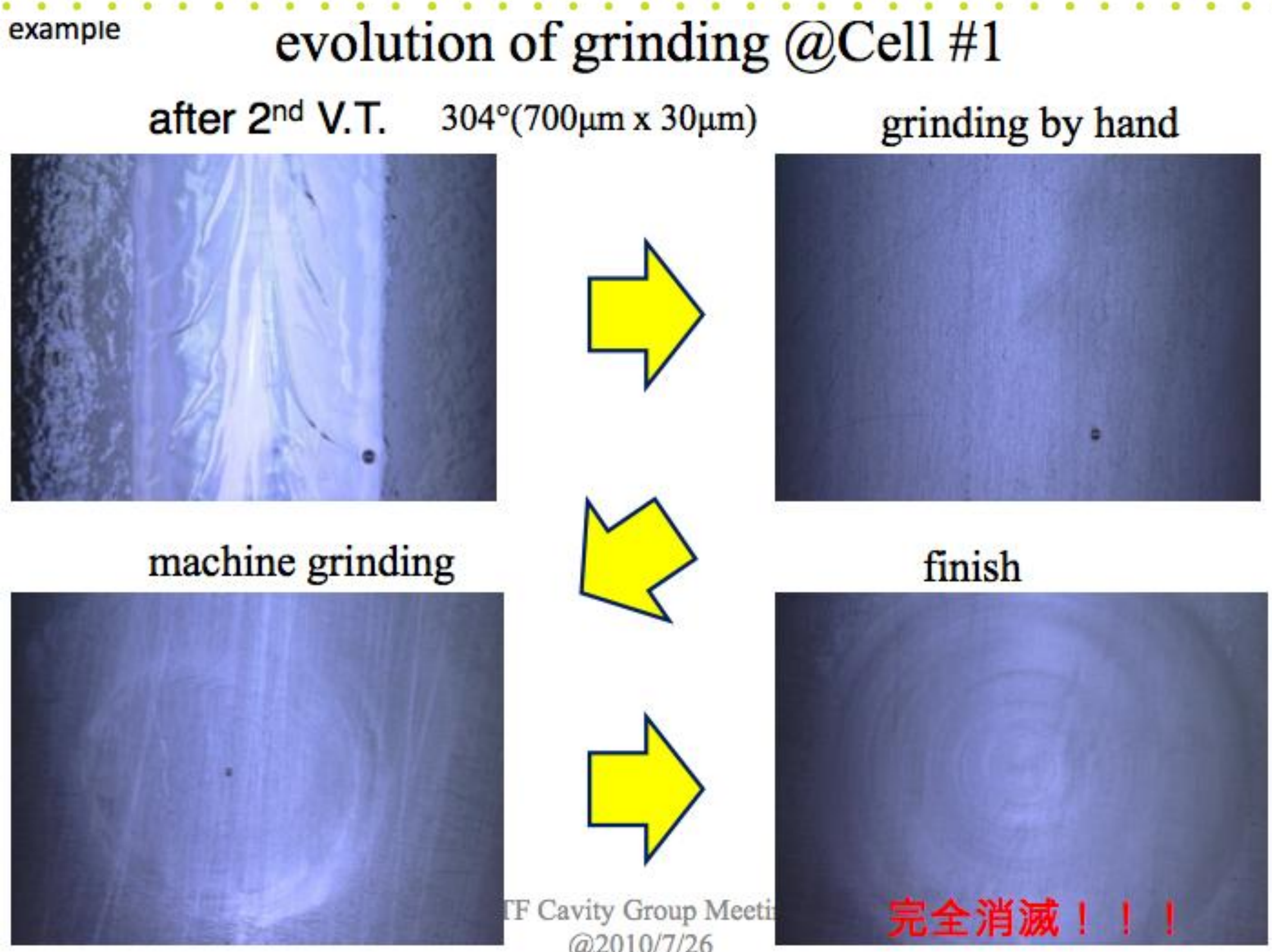
1st Hitachi Built 9-Cell Cavity 35 MV/m





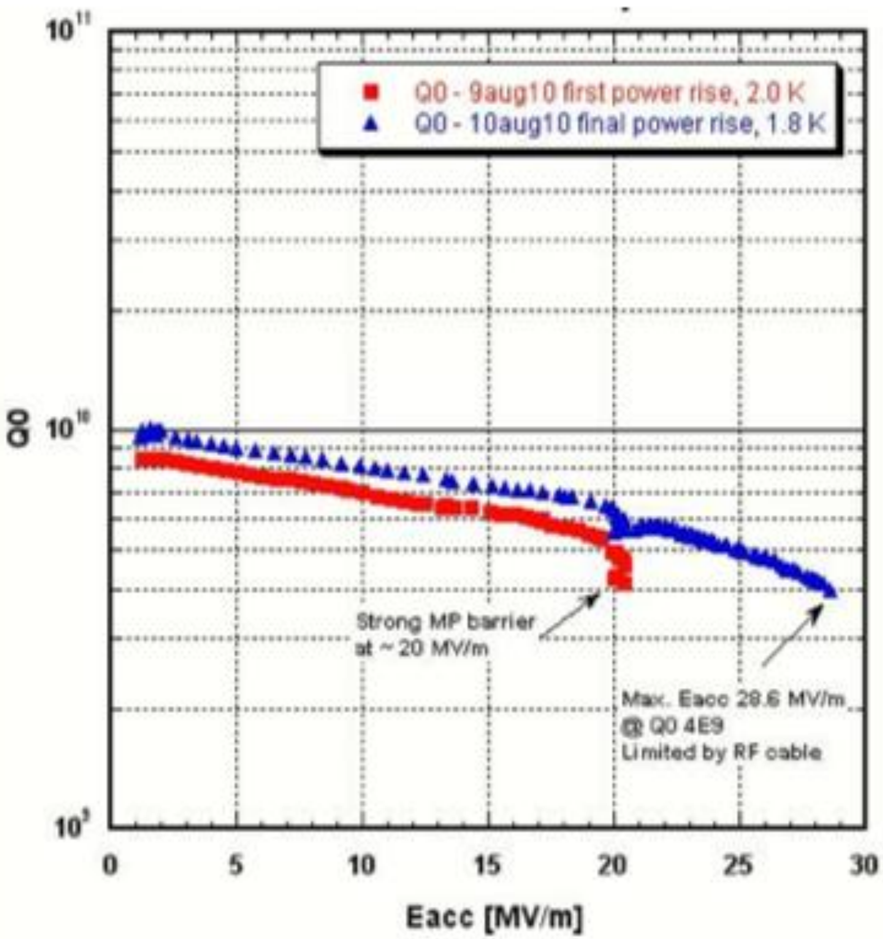
Courtesy of H. Hayano

KEK Local Grinding for Defect Removal



Courtesy of H. Hayano

Peking University 9-cell Cavity w/ End Group PKU3 After Standard ILC Processing at JLab



PKU3 is the 3rd 9-cell cavity built by Peking University SRF Group since 2008

ICHIRO 9-Cell Cavities

Old shape

Ichiro#1 **Done**
bare cavity

Ichiro#2 **STF0.5**
#3 **Tuner test**
#4

New
Ichiro#5
#6 (PAL)
bare cavities

Ichiro#7 **Shipped JLAB**
#8

Ichiro#9(L.G)
bare cavity
June 16-19th 2009

Courtesy of K. Saito

Cavity order for XFEL

- 300 cavities have been ordered at RI and Zanon each
  - Divided into 280 series cavities, 8 prototypes and 12 HiGrade-cavities
  - HiGrade cavities will be delivered without He-vessel
- No performance guarantee will be given by the companies, cavities are built to specification
- Option for 40 or 80 additional cavities part of both contracts, based on production success

24.08.2010 ILC Cavity Group - WebEx meeting Global Design Effort 1

Courtesy of S. Aderhold

Cavity order for XFEL (2)

RI

- Final surface treatment is EP
- He-vessels and semi-finished products (Nb and Nb-Ti) are not part of the contract and will be supplied by DESY, only He-vessel welding is part of the contract

Zanon

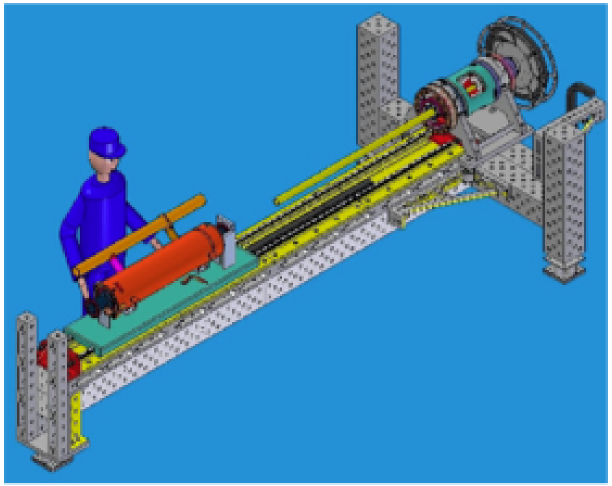
- Final surface treatment is
  BCP-flash (=10 um BCP after 140 um main EP)
- He-vessels are part of the contract, semi-finished products will also be supplied by DESY

24.08.2010 ILC Cavity Group - WebEx meeting Global Design Effort 2

Courtesy of S. Aderhold

Optical inspection at DESY

- Kyoto/KEK-camera system in use since August 2008
- More than 25 cavities inspected
- Correlation between hotspot in Tmap-measurement and defect found by optical inspection in several cases
  - See talk by Y.Yamamoto and S. Aderhold for examples
- Automated inspection set-up under development
  - Reproducibility, speed, robustness
  - Suitable for application in cavity mass production



Eckhard Elsen, Sebastian Aderhold, Detlef Reschke | Activities for ILC at DESY | Page 5

Courtesy of S. Aderhold

The World Map of the Inspection Camera

superconducting rf test facility

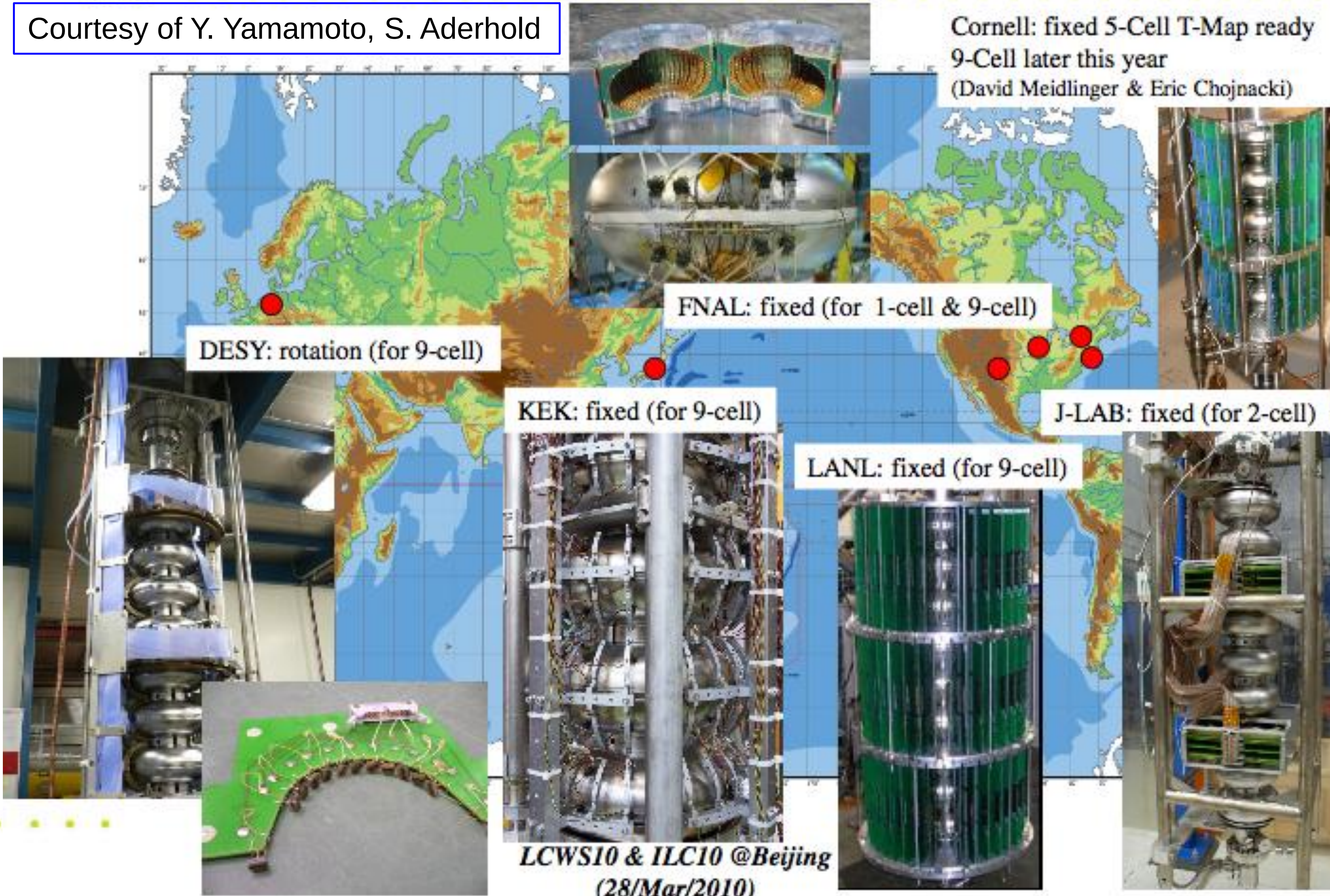
stf

High resolution camera system is adopted at labs around the world for 1.3 GHz 9-cell cavities to understand field limitation.

Courtesy of K. Watanabe

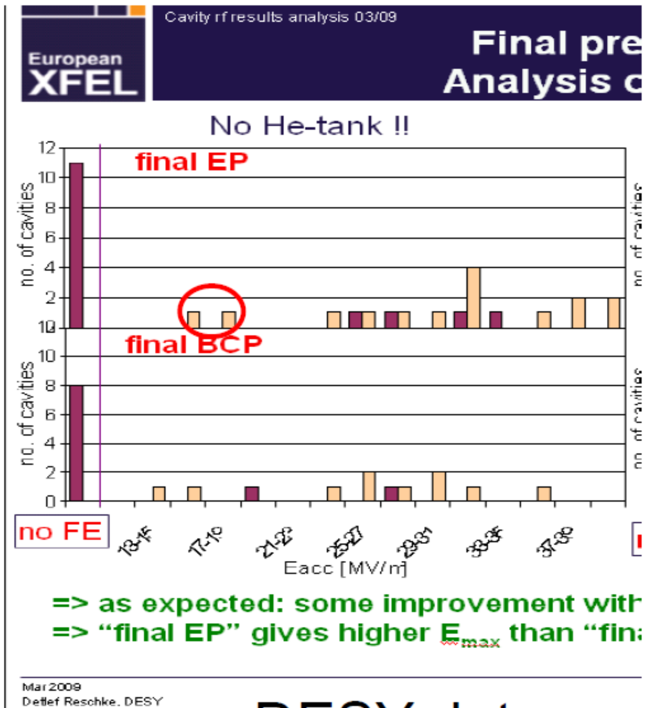
T-mapping system in the world

Courtesy of Y. Yamamoto, S. Aderhold

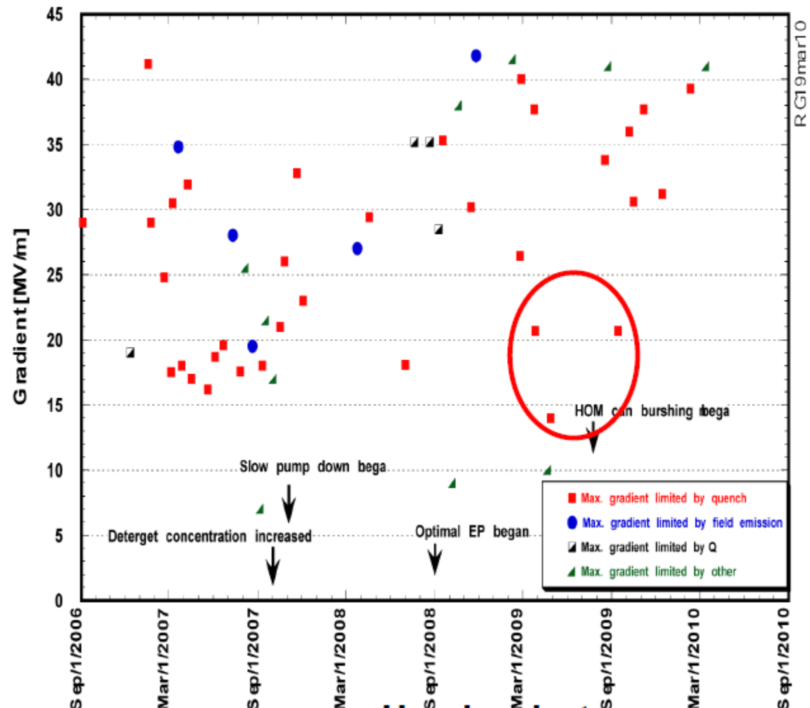


Progress since 2006

- FE limit much reduced (Post-EP rinsing, assembly, optimal EP)
- Scatter remains - due to quench (more later)



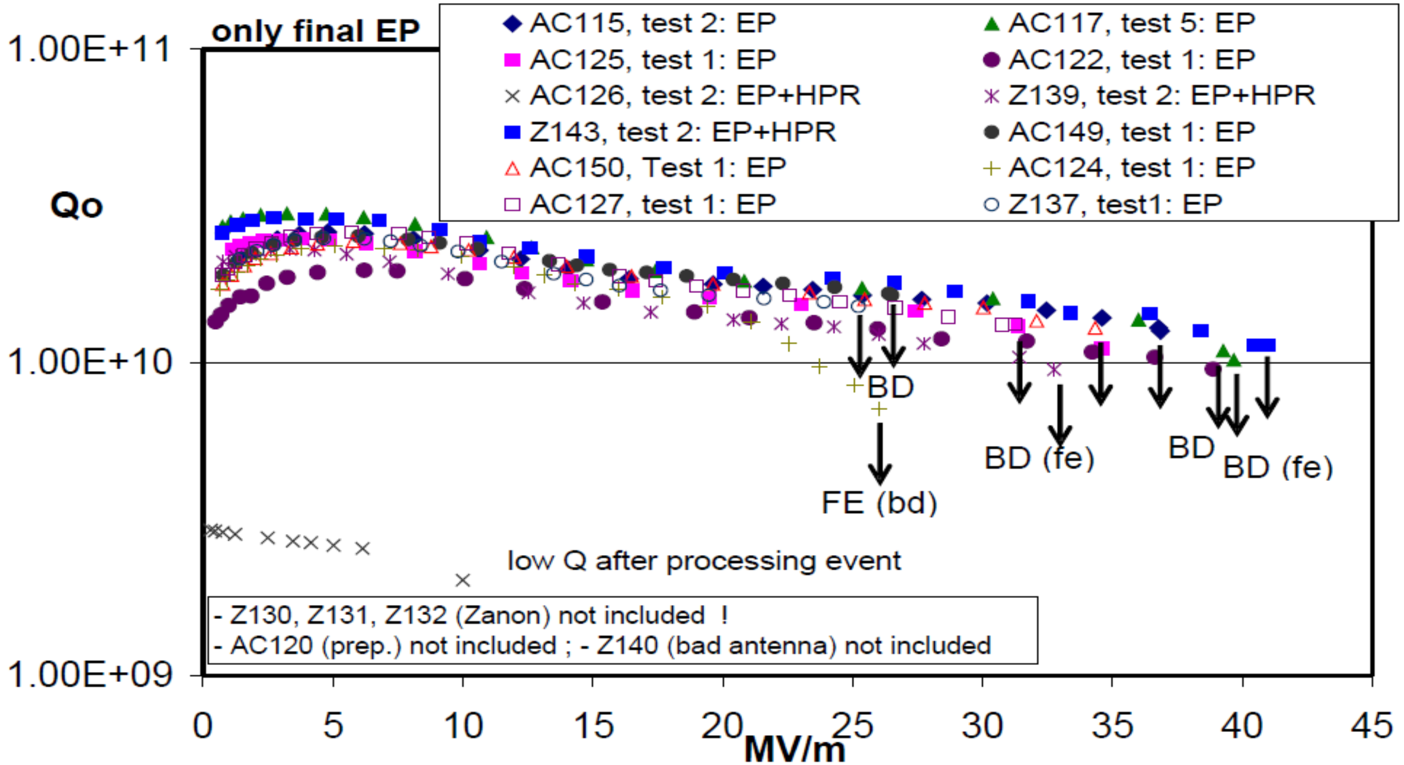
DESY data



JLab data

Courtesy of D. Reschke

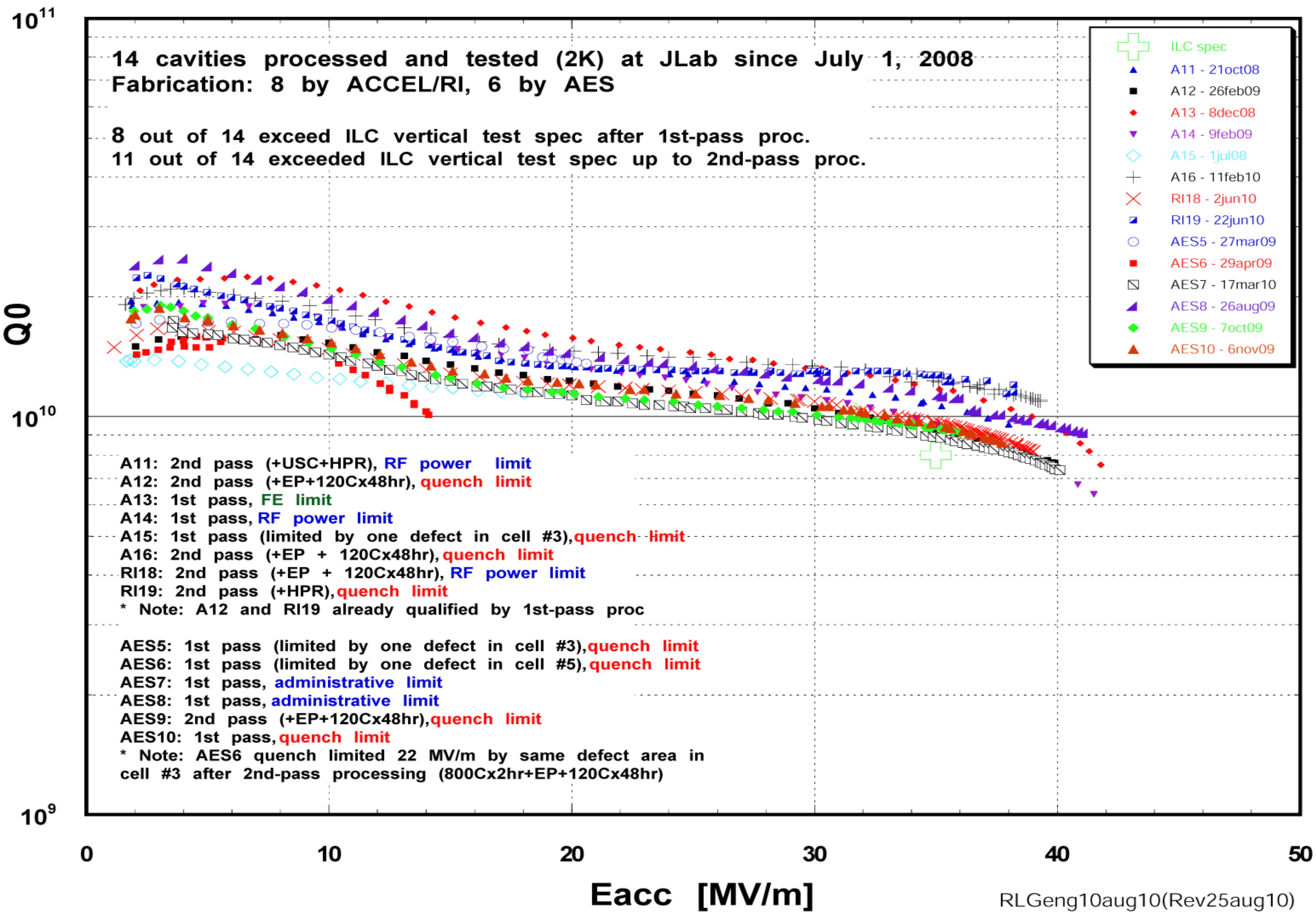
6th production: Q(E) of final EP-cavities



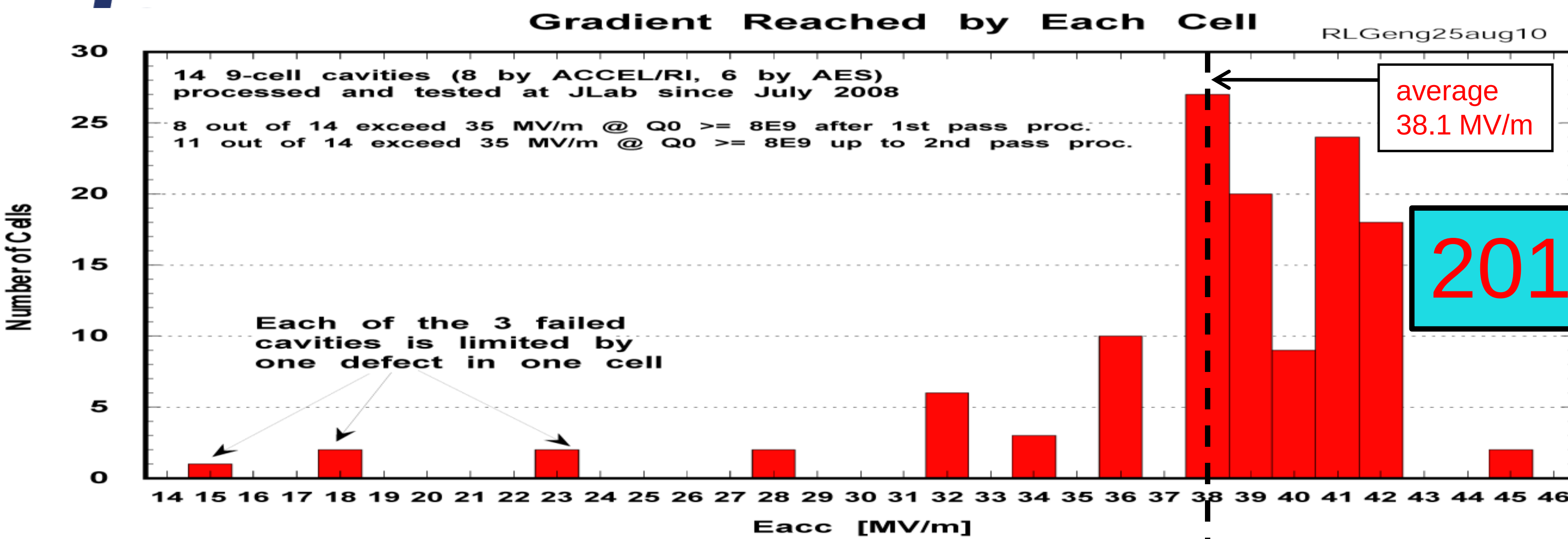
=> high gradients at high Q; low gradient Z-cavities after EP; sometimes field emission (with and w/o He-tank)

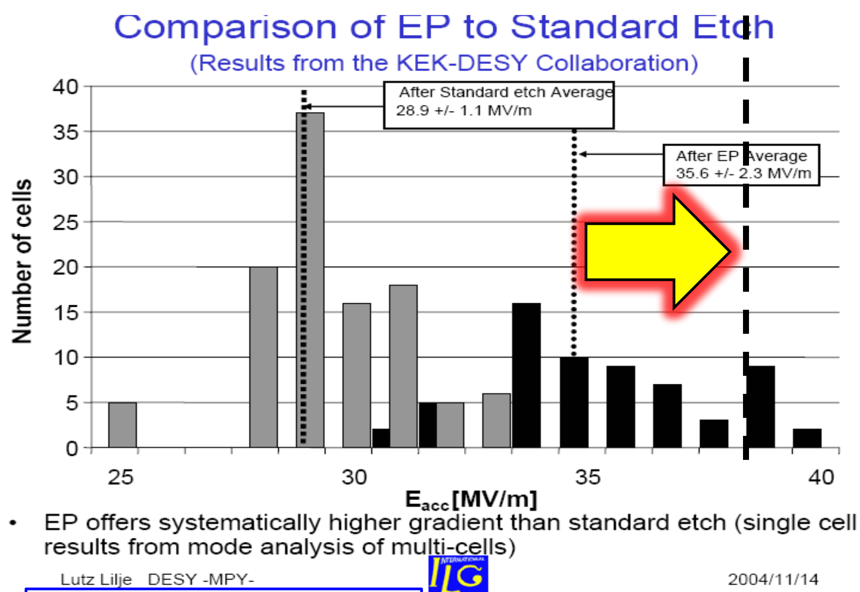
16.06.2009 S. Aderhold EU regional report TTC Meeting @ LAL Orsay 19

Courtesy of D. Reschke, S. Aderhold



14 cavities processed and tested (2K) at JLab since July 1, 2008
Fabrication: 8 by ACCEL/RI, 6 by AES
8 out of 14 exceed ILC vertical test spec after 1st-pass proc.
11 out of 14 exceeded ILC vertical test spec up to 2nd-pass proc.
ILC spec
A11 - 21oct08
A12 - 26feb09
A13 - 8dec08
A14 - 9feb09
A15 - 1jul08
A16 - 11feb10
RI18 - 2jun10
RI19 - 22jun10
AES5 - 27mar09
AES6 - 29apr09
AES7 - 17mar10
AES8 - 26aug09
AES9 - 7oct09
AES10 - 6nov09
A11: 2nd pass (+USC+HPR), RF power limit
A12: 2nd pass (+EP+120Cx48hr), quench limit
A13: 1st pass, FE limit
A14: 1st pass, RF power limit
A15: 1st pass (limited by one defect in cell #3), quench limit
A16: 2nd pass (+EP + 120Cx48hr), quench limit
RI18: 2nd pass (+EP + 120Cx48hr), RF power limit
RI19: 2nd pass (+HPR), quench limit
* Note: A12 and RI19 already qualified by 1st-pass proc
AES5: 1st pass (limited by one defect in cell #3), quench limit
AES6: 1st pass (limited by one defect in cell #5), quench limit
AES7: 1st pass, administrative limit
AES8: 1st pass, administrative limit
AES9: 2nd pass (+EP+120Cx48hr), quench limit
AES10: 1st pass, quench limit
* Note: AES6 quench limited 22 MV/m by same defect area in cell #3 after 2nd-pass processing (800Cx2hr+EP+120Cx48hr)
Q0
10^{11}
10^{10}
10^{9}
0
10
20
30
40
50
Eacc [MV/m]
RLGeng10aug10(Rev25aug10)



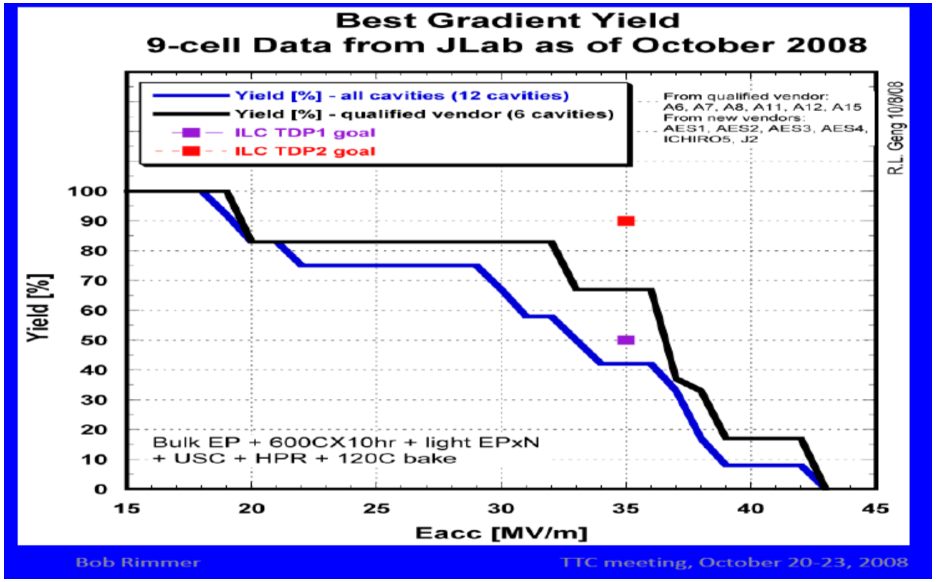


2004 DESY EP 9-cell cavities
Gradient distribution in cells from
pass-band measurements (~ 8 cavities)

2004

Courtesy of L. Lijie

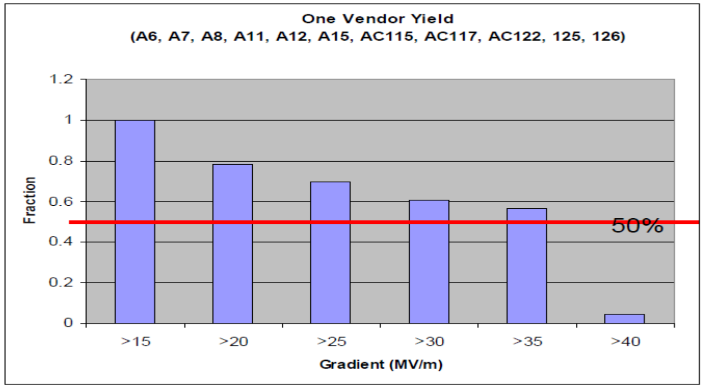
In Pursuit of Gradient Yield (Definition)



- First attempt for ILC 9-cell cavity gradient yield curve in 2008
  - **First JLab gradient yield curve reported at TTC meeting in New Delhi (Oct. 2008).**
  - **First yield curve based on “global” data (DESY and JLab processed cavities) reported by H. Padamsee at LCWS in Chicago (Nov. 2008).**

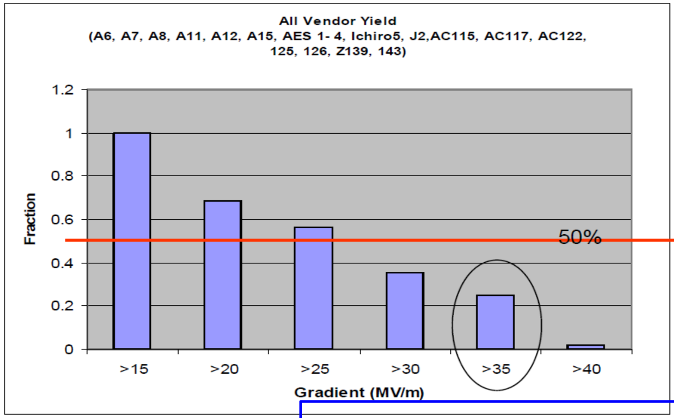
Combined Yield of Jlab and DESY Tests
Reported at TTC Delhi Meeting (October 2008)
For One Vendor

23 tests, 11 cavities



Multiple Vendor Yield

48 Tests, 19 cavities, including ACCEL, AES, Zanon, Ichiro, Jlab



Clearly there are many more variables to bring under control when dealing with many vendors.

Courtesy of H. Padamsee

In Pursuit of Gradient Yield (Definition)

Tight loop → Feedback loop

Processing yield → Production yield

1st pass and 2nd pass yield proposed at AD&I Meeting at DESY, May 28-29, 2010

Gradient Yield

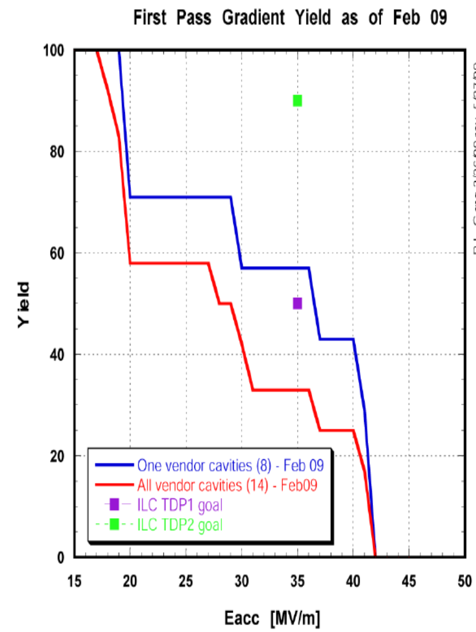
- Processing yield vs. production yield
  - Lessons learned
    - Yield can be pessimistically lowered by repeated EP processing of candidate cavity (example next slide)
    - For various reasons: physical defect from mat/fab not effectively removed by EP; facility failure/human error (process complexity & many critical steps)
  - What counts is production yield
    - Particularly the first-pass production yield
    - It has been shown cavities from some vendor have (significant) advantage
    - The first-pass production yield of cavities from "qualified" vendor should serve the purpose of the "best possible" yield
    - A small (cavities processed at JLab & DESY) data set is now available; more statistics expected in view of new cavity orders (for example FNAL's order of >=12 cavities)
  - Second-pass production yield
    - Given the cost for cavity construction, first-pass result is a decision point
    - Re-work or reject?
    - Re-working may take different path (data driven): re-HPR; re-EP, repair & re-process
    - In the current R&D phase, we may need to develop a re-work strategy

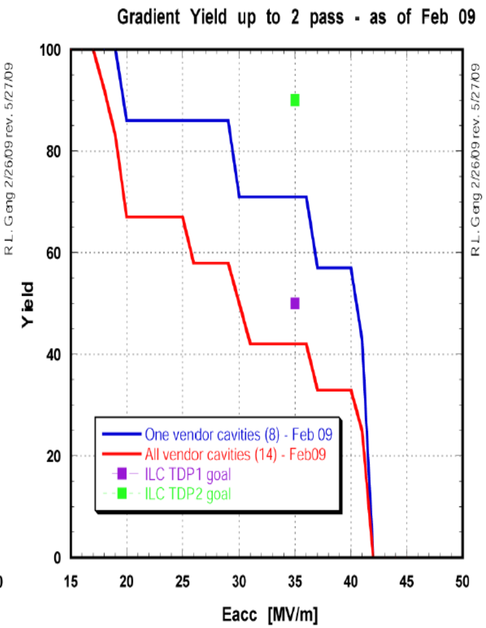
R.L. Geng ILC AD&I, DESY, may 28-29, 2009 6

A Proposed Method for Gradient Yield

First-pass result decides path forward:
- Move on for S1 if spec met
- Re-process (Re-HPR; Re-EP; Local repair) if spec not met

Sample data from JLab





R.L. Geng ILC AD&I, DESY, may 28-29, 2009 8

ILC Cavity Global Database (June 2009)

Creation of a Global Database for Better Understanding of "Production Yield" in TDP-2

- Global Data Base Team formed:
  - Camille Ginsburg (Fermilab)
    - Team Leader & Data Coordination
  - Rongli Geng (JLab)
    - GDE-SCRF Cavity TA Group Leader
  - **Zack Conway (Cornell University)**
  - **Sebastian Aderhold (DESY)**
  - **Yasuchika Yamamoto (KEK)**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Around the World

News from China on ILC collaboration

Vacuum vessel fabrication in factory

The effort towards realising the International Linear Collider is being carried out by global collaboration. Such efforts focus mainly on the technology development, but other aspects such as training the younger generation, are also important to ILC community. From 7 to 18 September China hosted the Fourth International Accelerator School for Linear Colliders in Beijing at Huairou. Among 69 students from 21 countries, there were 29 students from Asia, including 15 Chinese students. Since 2005, Chinese PhD students majoring in ILC-related topics are increasing

Feature Story

One sheet to plot them all

DESY database becomes standard tool for cavity research

The new worldwide ILC cavity database features only nine-cell, no single-cell cavities like the one held by Camille Ginsburg in this picture. Image: Fermilab.

- Activity Plan/Schedule
  - **July 2009:**
    - Determine DESY-DB to be viable option,
  - **Sept., 2009: (ALCPG/GDE)**
    - Dataset, web-based, support by FNAL-TD or DESY
    - Some well-checked, easily explainable, and near-final plots, available,
  - **Nov.- Dec., 2009:**
    - Finalize DB tool, web I/F, standard plots, with longer-term plans

A, Yamamoto, 09-11--02 **ILC-PAC: SCRF Report**

Courtesy of A. Yamamoto

More later on Global database by Camille Ginsburg

Gradient Yield (June 2010)

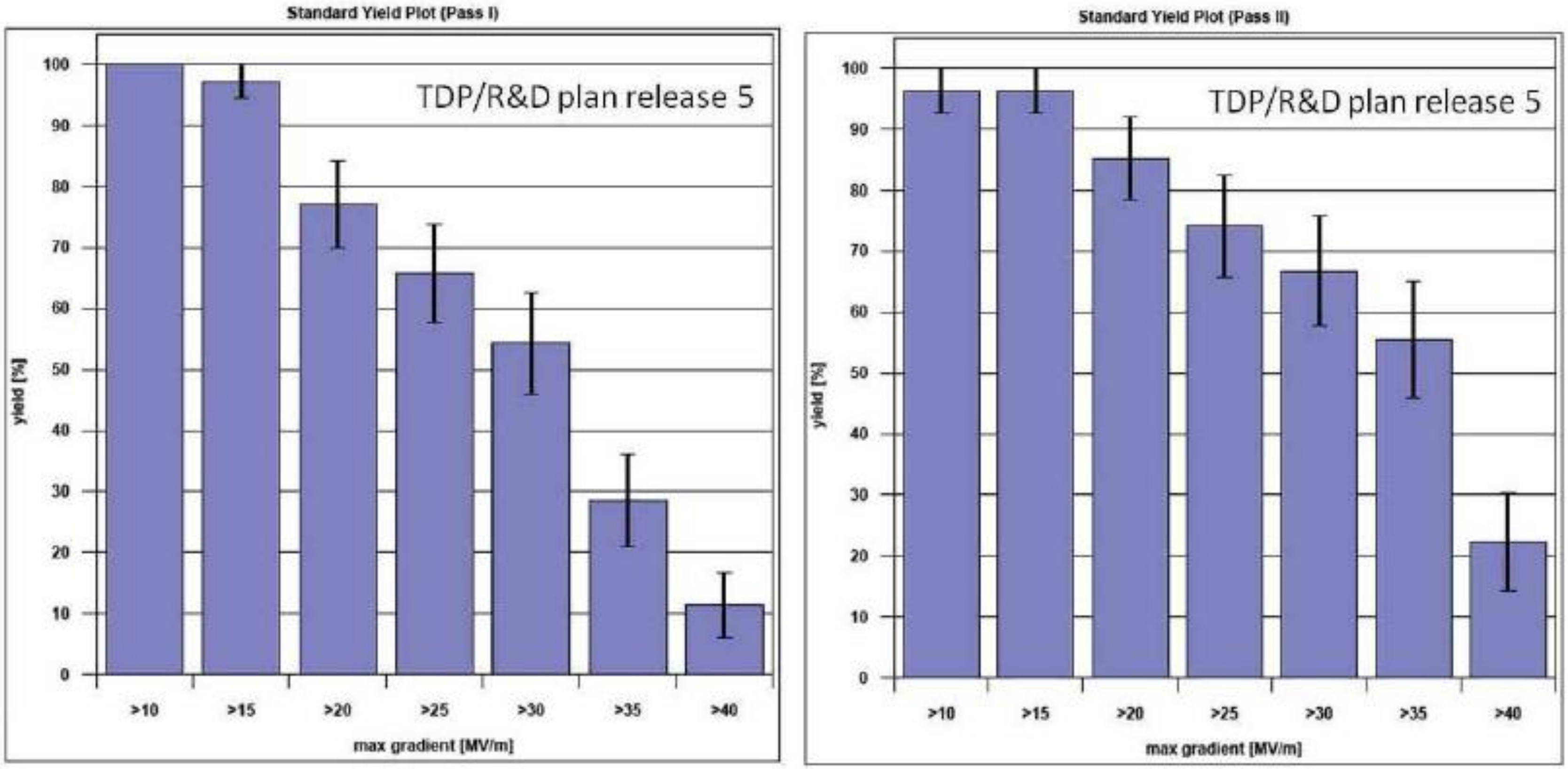


Figure 4.1: First-pass (left) and second-pass (right) yields as a function of maximum gradient. [updated data by June 30.]

Courtesy of C. Ginsburg

ILC R&D Plan for TDP (release 5)

ILC Research and Development Plan for the Technical Design Phase

Release 5

August 2010

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross
Nick Walker
Akira Yamamoto

Table 4-1: Milestones for the SCRF R&D Programme

Stage	Subjects	Milestones to be achieved	Year
S0	9-cell cavity	35 MV/m, max., at $Q_0 \geq 8\times10^9$, with a production yield of 50% in TD PHASE 1, and 90% in TD PHASE 2 [1), 2)]	2010/ 2012
S1	Cavity-string	31.5 MV/m, on average, at $Q_0 \geq 10^{10}$, in one cryomodule, including a global effort	2010
S2	Cryomodule-string	31.5 MV/m, on average, with full-beam loading and acceleration	2012

1. The process yield of 50 % in TDP-1, in the R&D Plan (release 2), has been revised to be the production yield of 50 % in the TDP-1.
2. A quantitative evaluation of radiation emission is to be included in the milestone list in near future.

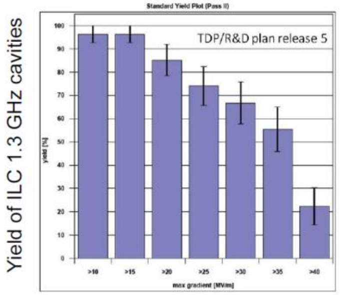
Gradient Progress Reported by Barry at ICHEP2010 Well Received by Community

Now the challenge is 90% yield by 2012

1. Beam Power Challenge

- Many critical technologies
  - Targets, collimators and dumps, materials, MPS, SCRF, …

Barry Barish, Saturday session



- LHC beam will be ~350 MJ
  - Beam collimation challenge!

Metallic collimator to reduce $Z_{\perp}$

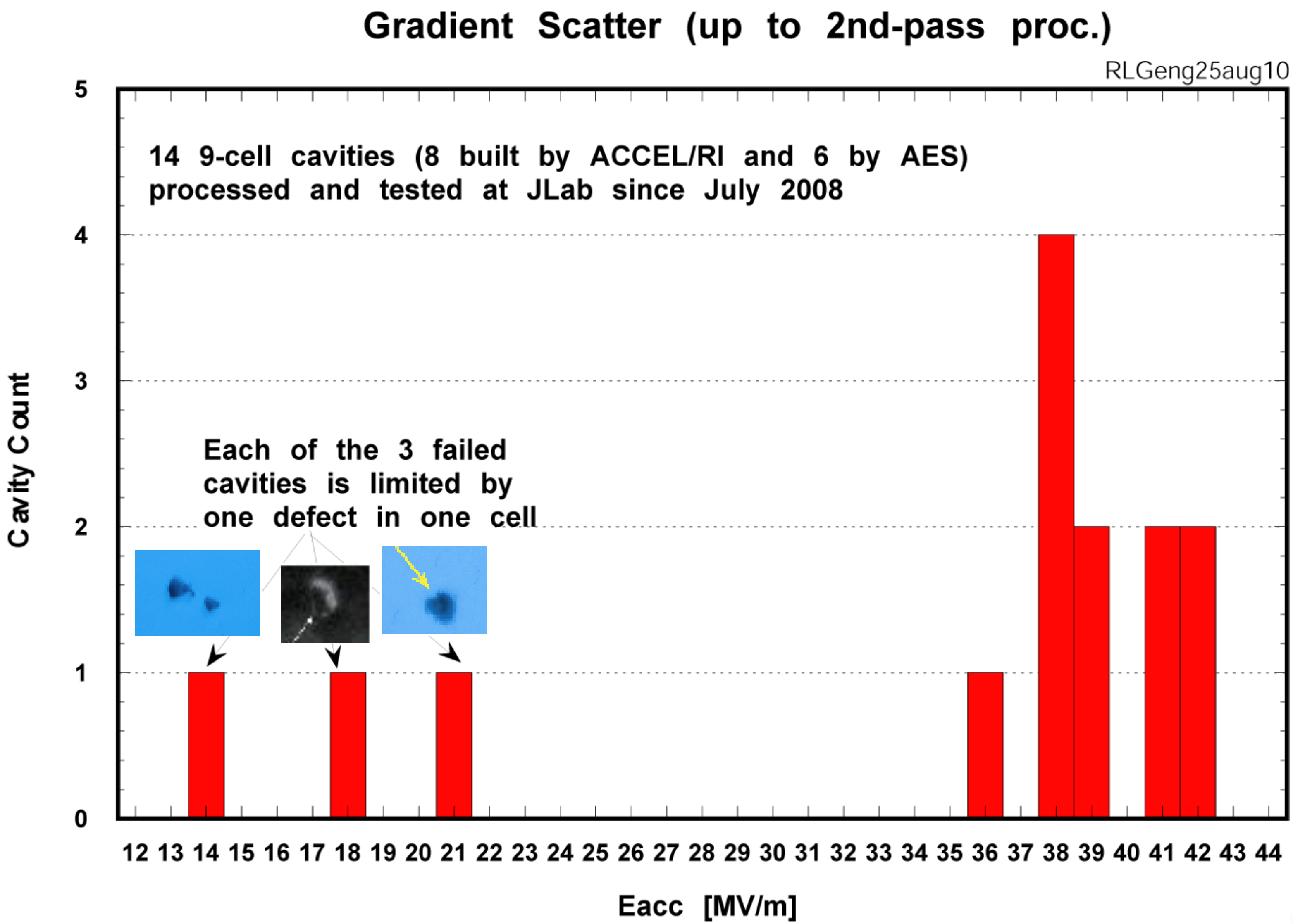
- SCRF → high power proton beams for a number of new applications:
  - Neutrino beams
  - Neutrino factory & Muon Collider
  - Accelerator Driven Systems (sub-critical reactors) and transmutation of waste

Tor Raubenheimer, ICHEP2010

Successful ILC Super Conducting RF developments in global collaboration

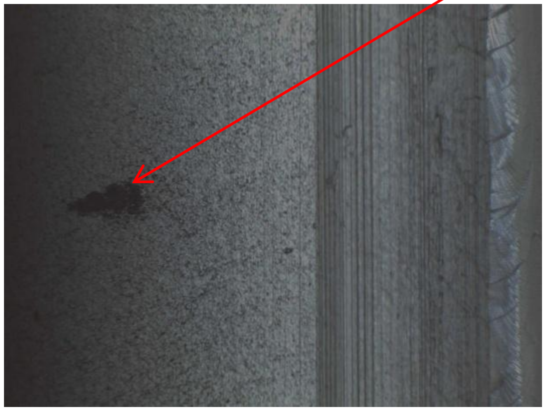
J.P.Delahaye, ICHEP2010

Gradient Limit Understanding



Gradient Limit Understanding (cont.)

- Low performance (<25 MV/m) cavity limited by "genetic" defect.
- Known facts about these defects
  - Sub-mm sized geometrical irregularity, within 20 mm from equator EBW.
  - Insensitive to re-EP.
  - Local removal (by grinding, laser or e-beam) results in gradient improvement.
- Another class of subtle defects (again local, but not geometrical) responsible for quench > 25 MV/m; re-EP usually effective in improving gradient limit.



As built

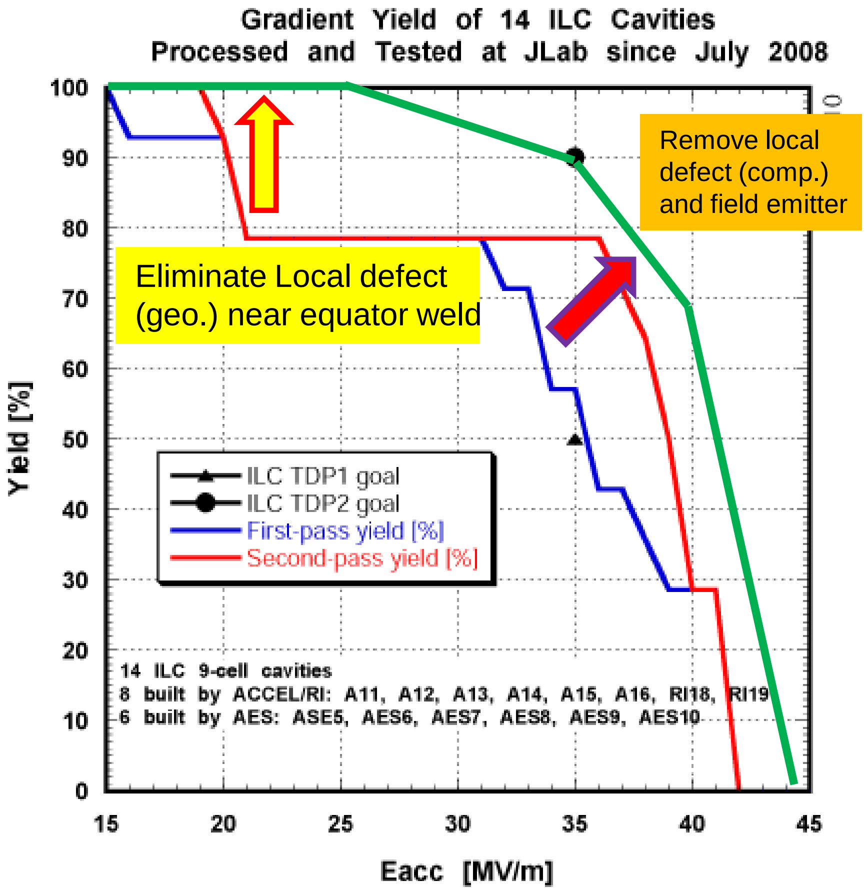
Courtesy of J. Dai

+ USC
+ 10 um BCP

+ 120 um EP
+ 800Cx2hr
+ 25 um EP

Gradient Improvement Plan

Based on Recent Understanding due to Globally Coordinated S0 Program

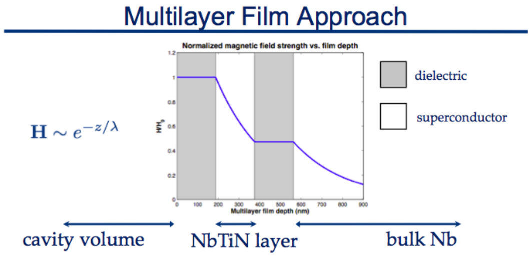


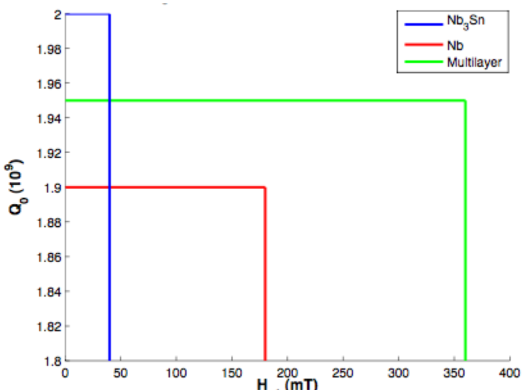
- Highest priority is to push yield up near 20 MV/m – the yield drop due to local (geometrical) defects near equator weld.
  - **Fabrication QA/QC**
  - **Mechanical polish prior to heavy EP**
  - **Post-VT local targeted repair**
  - **Seamless cavity**
  - **Large-grain mat. from ingot slicing**
  - **Fine grain mat. optimization**
- Also high priority is to suppress field emission at high gradient (up to 42 MV/m) – and quantify its effect on cryogenic loss and dark current.

Reliable and reproducible EP essential. Example now exists. Pursuit is continuing in some facilities.

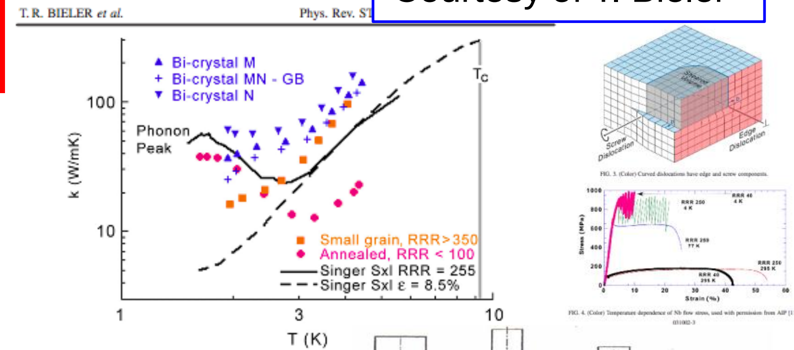
Updated Gradient R&D Issues

Material

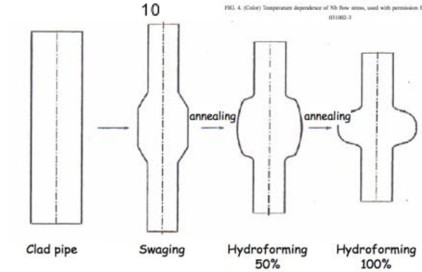




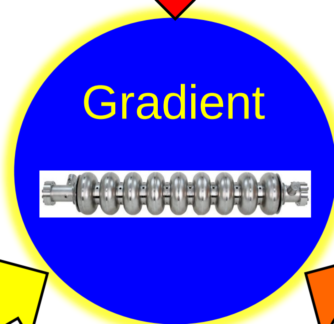
Courtesy of D. Bowring



Courtesy of T. Bieler



Courtesy of K.Enami



Fabrication

Processing

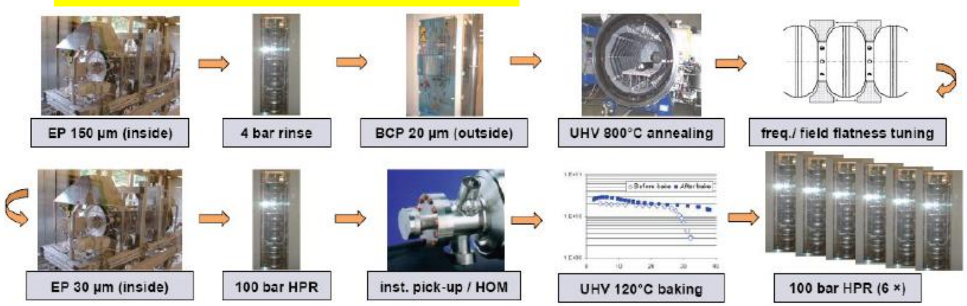
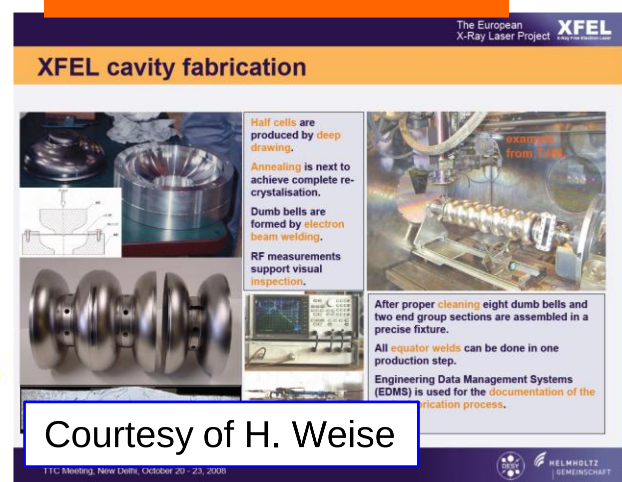


FIGURE 1.2-5. Birth of a nine-cell cavity: basic steps in surface treatment needed to achieve high-performance superconducting cavities. (EP = electropolishing; HPR = high-pressure rinsing.)

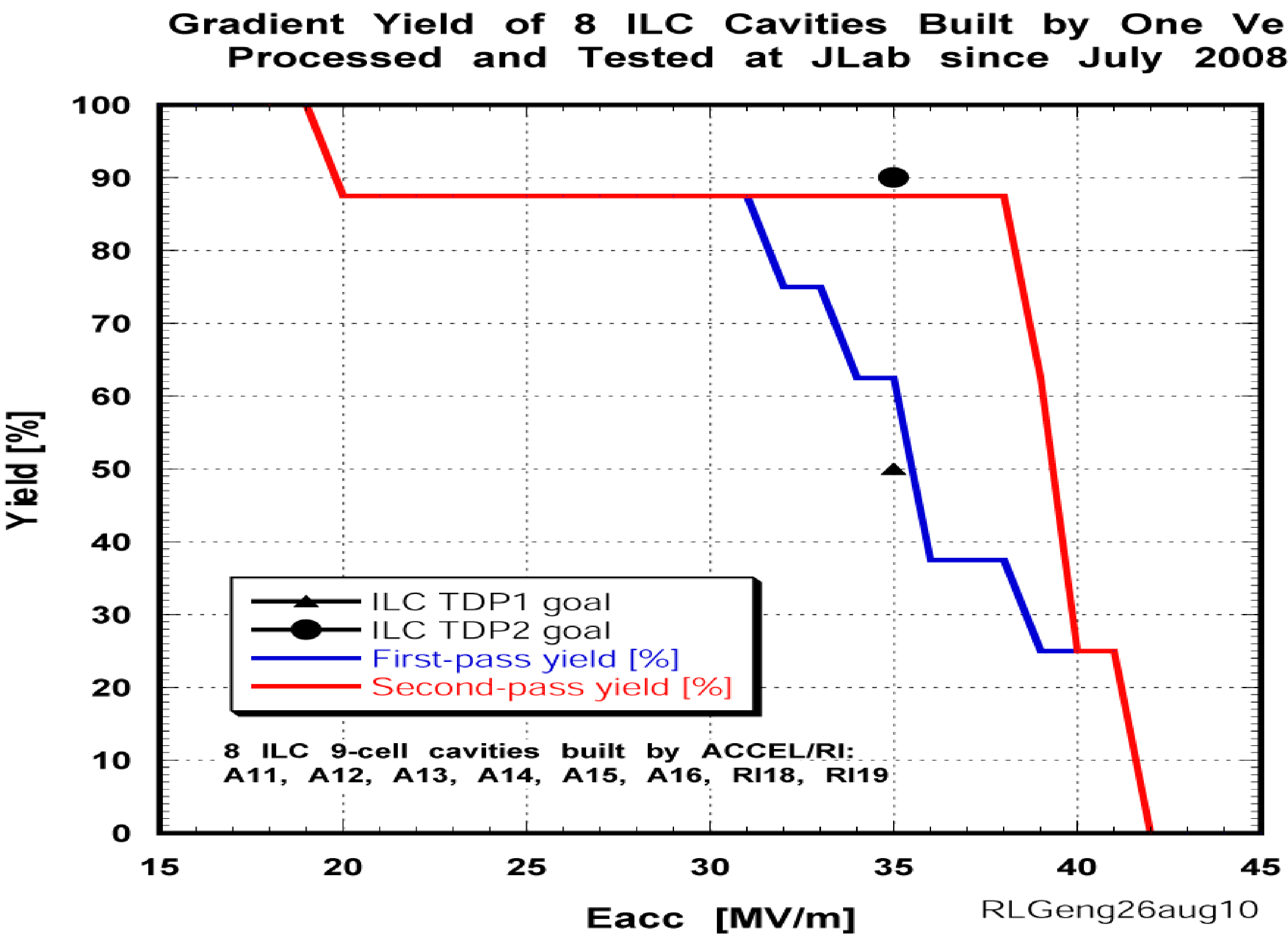


Courtesy of H. Weise

Cavity Gradient R&D Evolution

	RDR	TDP R&D release 5
Vertical test gradient	35 MV/m	35 MV/m
Vertical test Q0	8E9	8E9
Vertical test radiation	Not specified	To be specified
Gradient yield goal	80% at 35 MV/m	90% at 35 MV/m
Gradient yield curve	Not available	Established incl. gradient spread
S0 program theme	Tight loop	Feedback loop
R&D priority	Process optimization and QA/AC	Fabrication & material optimization and QA/QC
ACD topics	ACD shapes, large grain material	Seamless cavity, ACD shapes, large grain material, thin film cavity
9-cell cavity processing/test facility	DESY (total 1)	DESY,FNAL/ANL,KEK,JLAB Cornell (total 5)
9-cell cavity fabrication facility	ACCEL, Zanon, DESY (total 3)	ACCEL/RI, Zanon, AES (qualified vendor) DESY, JLAB, MHI, PKU, Niowave (full cavity) Hitachi, Toshiba, IHEP (cavity w/o HOM) PAVAC, KEK (planed) (total 13)

An Example of ~ 90% Yield at 35 MV/m



90%

ILC Research and Development Plan for the Technical Design Phase

Release 5

August 2010

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto