Near Term ILC Gradient R&D

R&D Specification and Standardization

Gradient

Gradient Yield/Scatter

Unloaded Quality Factor

Field Emission Induced Radiation

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Jefferson Lab & GDE

The 1st Baseline Assessment Workshop

September 7-10, 2010, KEK

Outline

- SB2009 and R&D plan release 5
- Gradient
- Gradient yield & scatter
- Unloaded quality factor
- Field emission induced radiation
- Summary & comments

Gradient Re-evaluation in SB2009 and R&D Plan Release 5

SB2009 Proposal Document

Release 1.1

December 2009

ILC Global Design Effort

Prepared by the Technical Design Phase Project Managers and the Accelerator Design and Integration Team Leaders

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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

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SB2009

Gradient, Q and Gradient Spread

2.2.1 Main linac – SCRF: choice of operational accelerating gradient (WA1)

The most highly leveraged R&D that has the greatest potential return in terms of performance and cost is the development of cavity gradient. The cost impact is seen primarily in the linac length required to achieve 500 GeV in the centre of mass. In 2005, a goal of an operational accelerating gradient of 31.5 MV/m per cavity with $Q_0 \geq 0.8 \times 10^9$ in pulsed operation was adopted for the Reference Design, with a cavity production specification of ≥35 MV/m with $Q_0 \geq 10^{10}$ in a low-power, CW vertical acceptance test. These parameters were adopted within the paradigm of developing a forward-looking design, and assumed a worldwide R&D effort to routinely establish these parameters. This R&D is currently on going and represents the largest fraction of the global ILC R&D resources.

For the current SB2009 proposal – and in lieu of expected developments in the SCRF R&D – these specifications for the accelerating gradient and Q_0 are left unchanged. Thus the global CFS requirements (linac length, cryogenic requirements) are left as per the RDR. This is primarily to allow the CFS groups to continue with their design and cost plans. It is noted that any subsequent changes in accelerating gradient, arising from review of the R&D status will (to the first-order) result in a scaling of the main linac which is relatively straight-forward, and will not require major re-evaluation of the design [Over3].

Gradient

Q_0

In contrast to the RDR baseline, however, we propose the HLRF systems support a spread of operational gradients from cavity to cavity. This will allow lower performance cavities to be utilised, assuming that high-performing ones maintain the average. The approach has impact on both the definition and accounting of cavity production yield (together with acceptance criteria), as well as required operational overhead in the accelerator (RF power and gradient). The global R&D groups are currently evaluating these issues. As of this writing every indication is that support of a spread of cavity gradients will provide a better cost optimised solution, albeit at the expense of a more complex HLRF distribution system and lower overall RF-to-beam power efficiency.

Gradient spread

R&D Plan Release 5

Radiation Emitted from Cavity (due to Field Emission)

The most important baseline changes under study are:

- Accepting a *spread* of low-power test cavity gradients during production, and a subsequent spread in cryomodule operational cavity gradients, while maintaining the required average accelerating gradient.
  - The 2007 Reference Design baseline assumed that 80% of the manufactured cavities achieved a gradient ≥35 MV/m during the low-power vertical test, and that all cavities installed in the linacs operate at the same nominal gradient.
  - Supporting a distribution (spread) of accelerating gradients in the main linac is seen as cost effective as the choice of *average* accelerating gradient is the primary cost driver for the machine.
  - The benefit (cost effectiveness) of accepting cavity performance lower than 35 MV/m must be balanced against the need for high-performing cavities to maintain the average, and the increased cost and complexity of the RF power overhead, distribution system and LLRF controls, as well as the potential impact on operational gradient margin.
  - The specification of the cost-effective acceptable gradient spread is a TD Phase 2 deliverable.

Gradient spread further justified

participating labs. Key low-power test results are the maximum (limited) accelerating gradient, the intrinsic Q factor (Q_0) and the radiation emitted from the cavity. For emitted radiation, measurement techniques are not yet mature and no suitable calibrated monitor exists. This is an important goal for TD Phase 2.

Field emission induced radiation

Cavity Gradient and Q Goals in R&D Plan Release 5

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

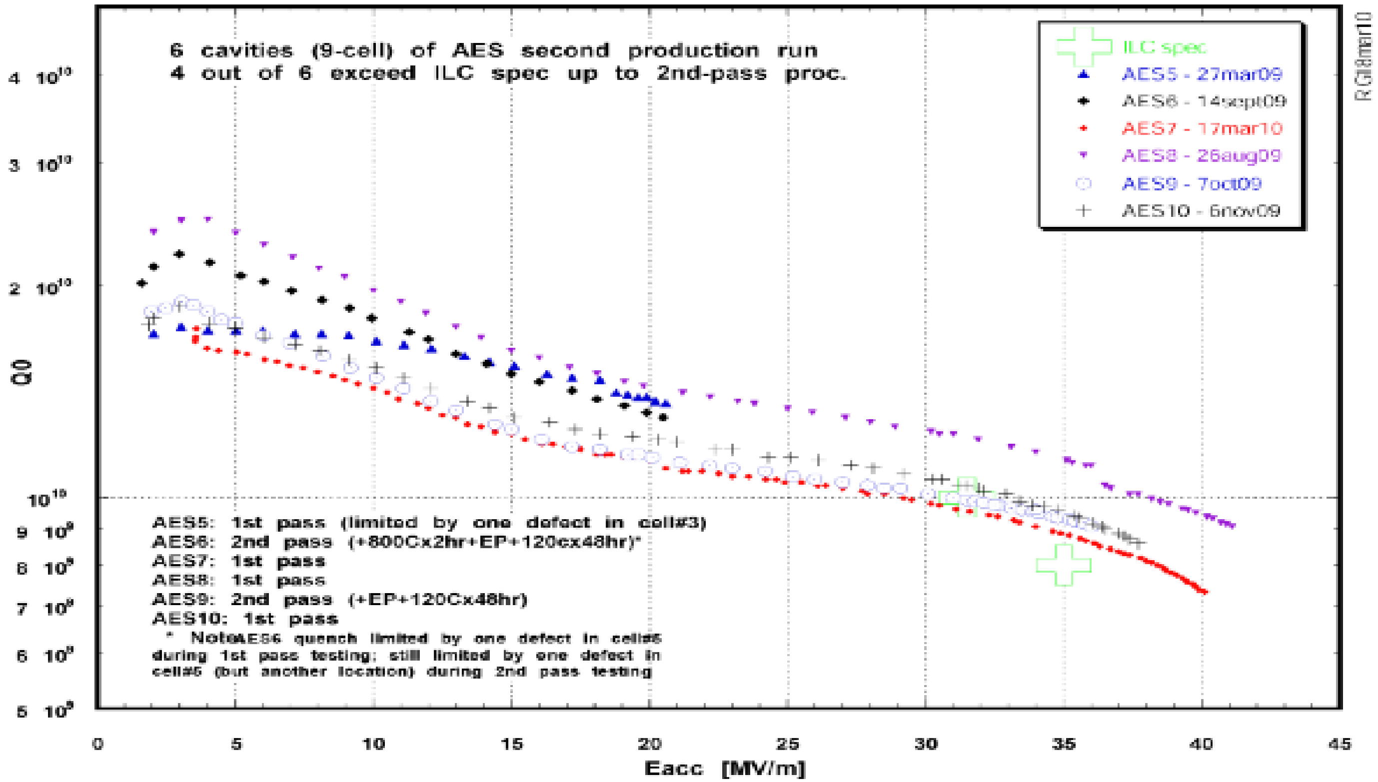
Stage	Subjects	Milestones to be achieved	Year
S0	9-cell cavity	35 MV/m, max., at $Q_0 \geq 8\times10^9$, with a production yield of 50% in TD PHASE 1, and 90% in TD PHASE 2 1), 2)	2010/ 2012
S1	Cavity-string	31.5 MV/m, on average, at $Q_0 \geq 10^{10}$, in one cryomodule, including a global effort	2010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

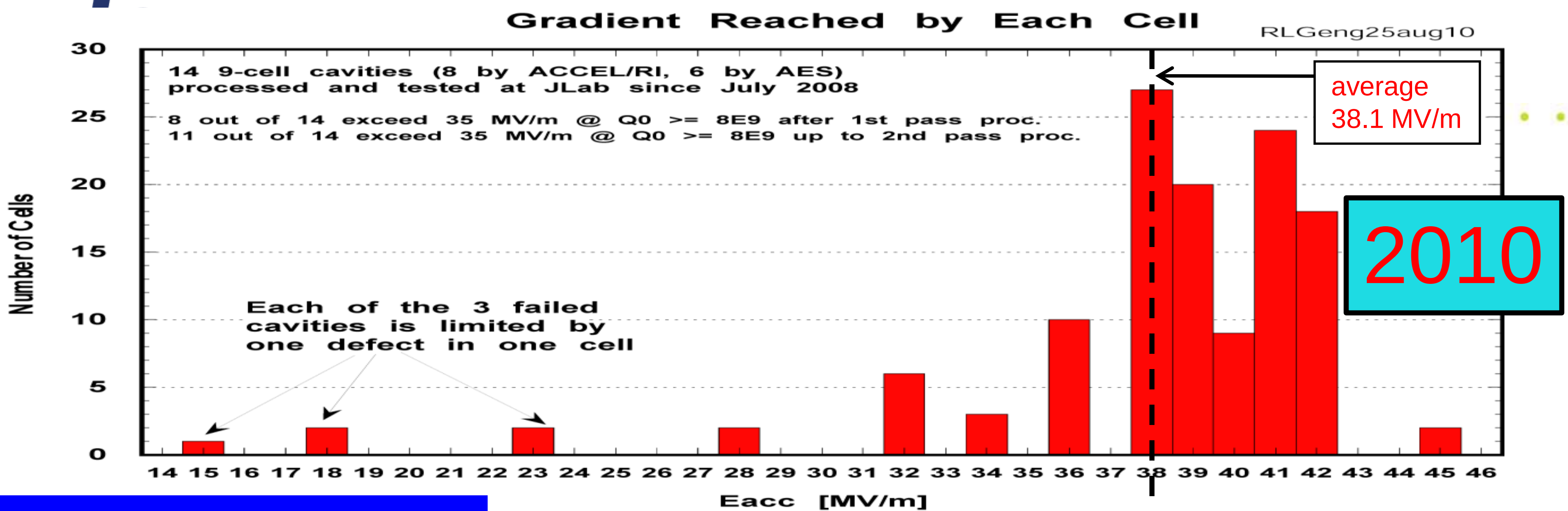
Gradient

Site-Independent Demonstration of > 35 MV/m in 9-Cell Cavities by "New" vendor

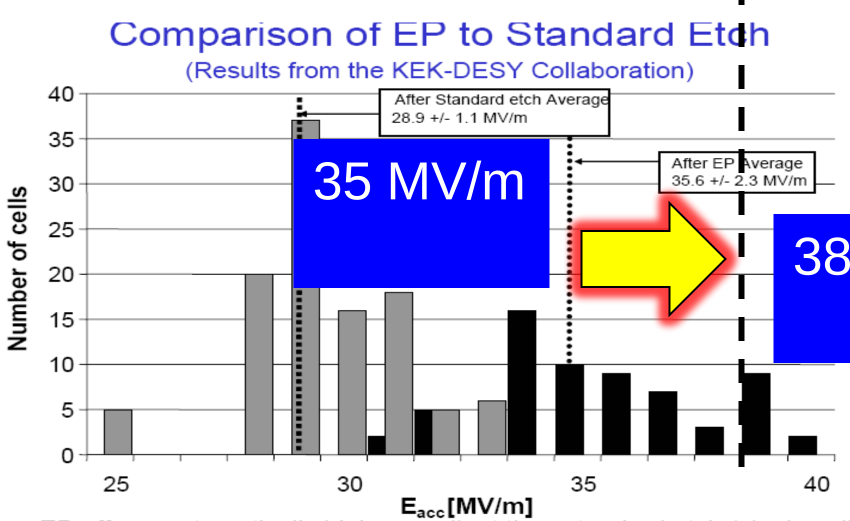
Performance of AES 2nd Production Cavities Processed and Tested at JLab



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



Gradient State-of-the-art then and now



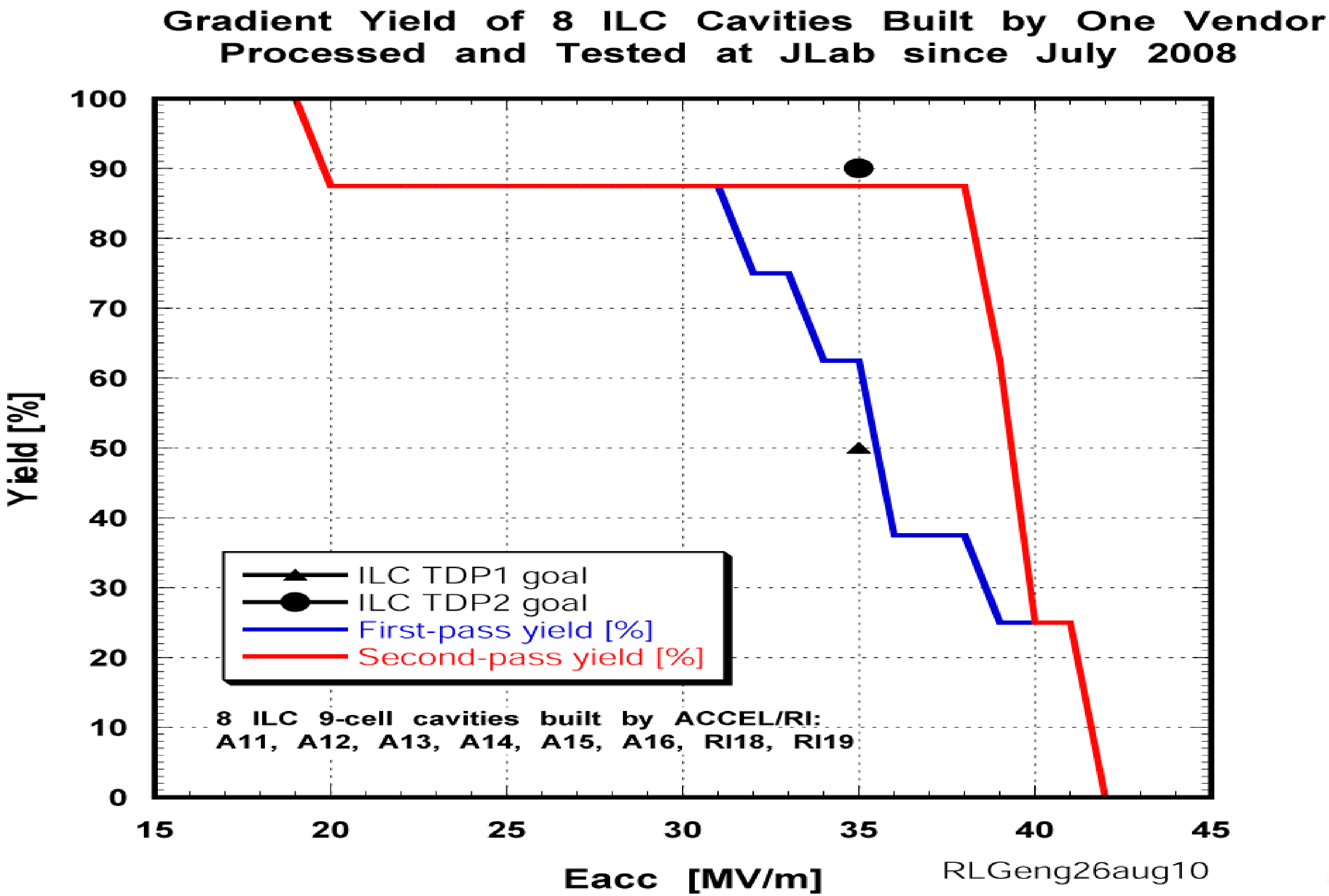
- EP offers systematically higher gradient than standard etch (single cell results from mode analysis of multi-cells)

Lutz Lilje DESY -MPY- ILC 2004/11/14

2004

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

An Example of 88% Yield up to 38 MV/m with 8 Cavities from One Vendor

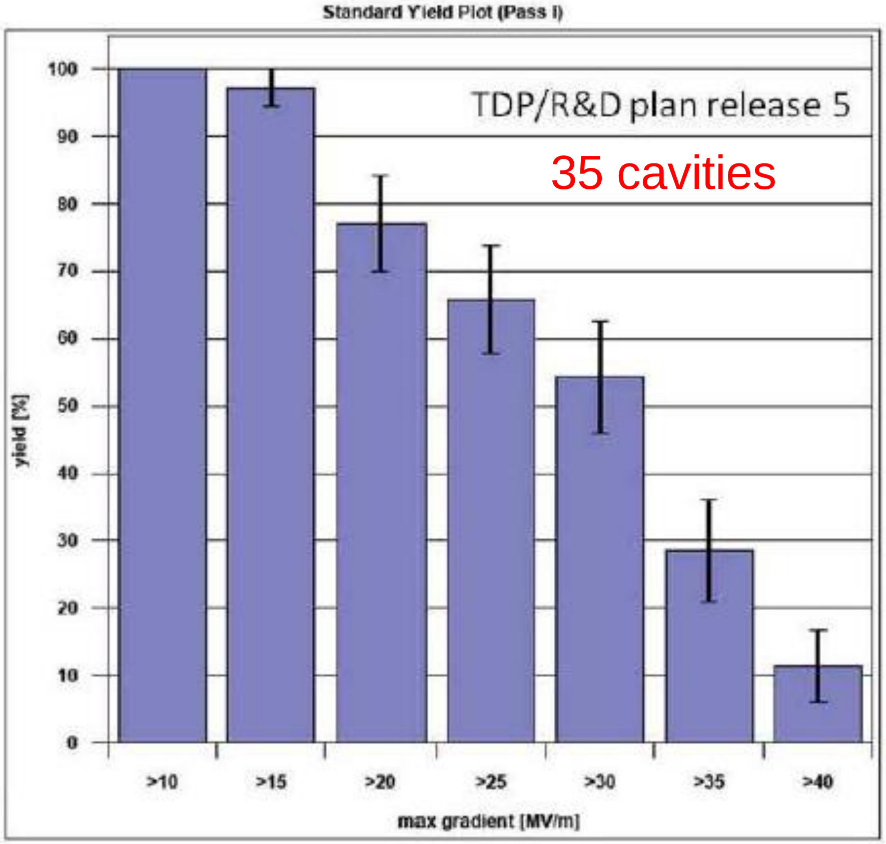


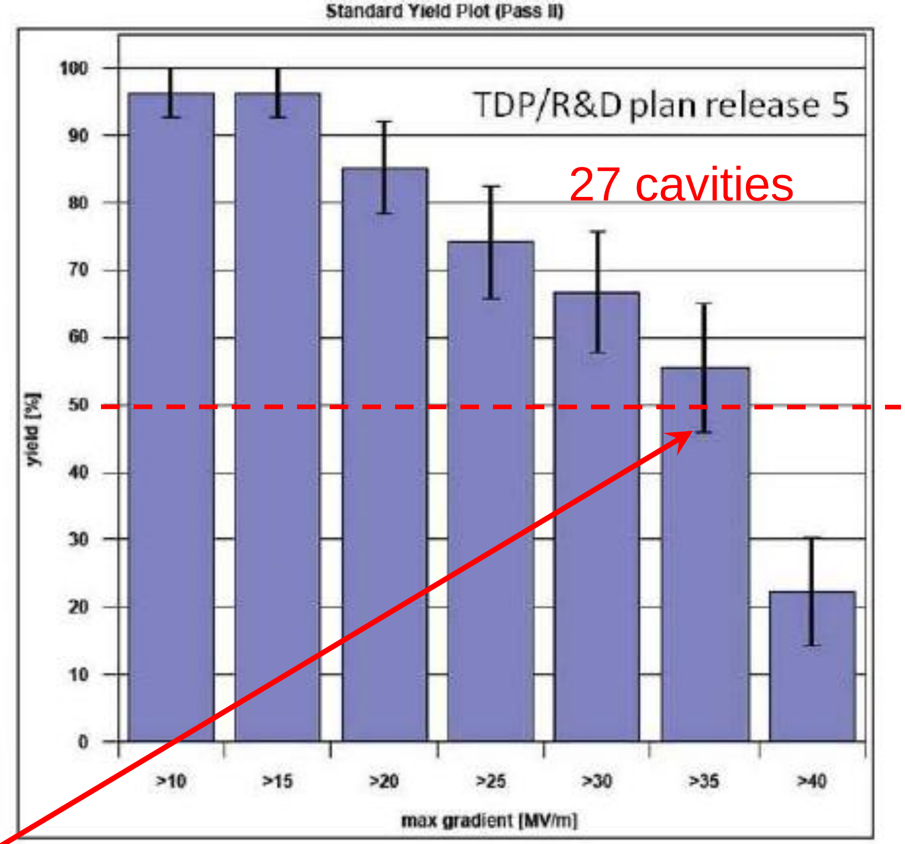
Gradient Specification

- 35 MV/m for cavity vertical acceptance was chosen in RDR
  - **based on the then state-of-the-art from DESY with 9-cell cavities built by European vendors.**
- Globally coordinated gradient R&D since publication of RDR resulted in progress
  - **site-independent demonstration of > 35 MV/m in 9-cell cavities built by a US vendor.**
  - **State-of-the-art gradient results from most recent 9-cell processing and testing show that average gradient for vertical test is 38 MV/m.**
- Conclusion: 35 MV/m is a technically sound choice.
- Recommendation: increase gradient specification for cavity vertical test to 38 MV/m.

Gradient Yield & Scatter

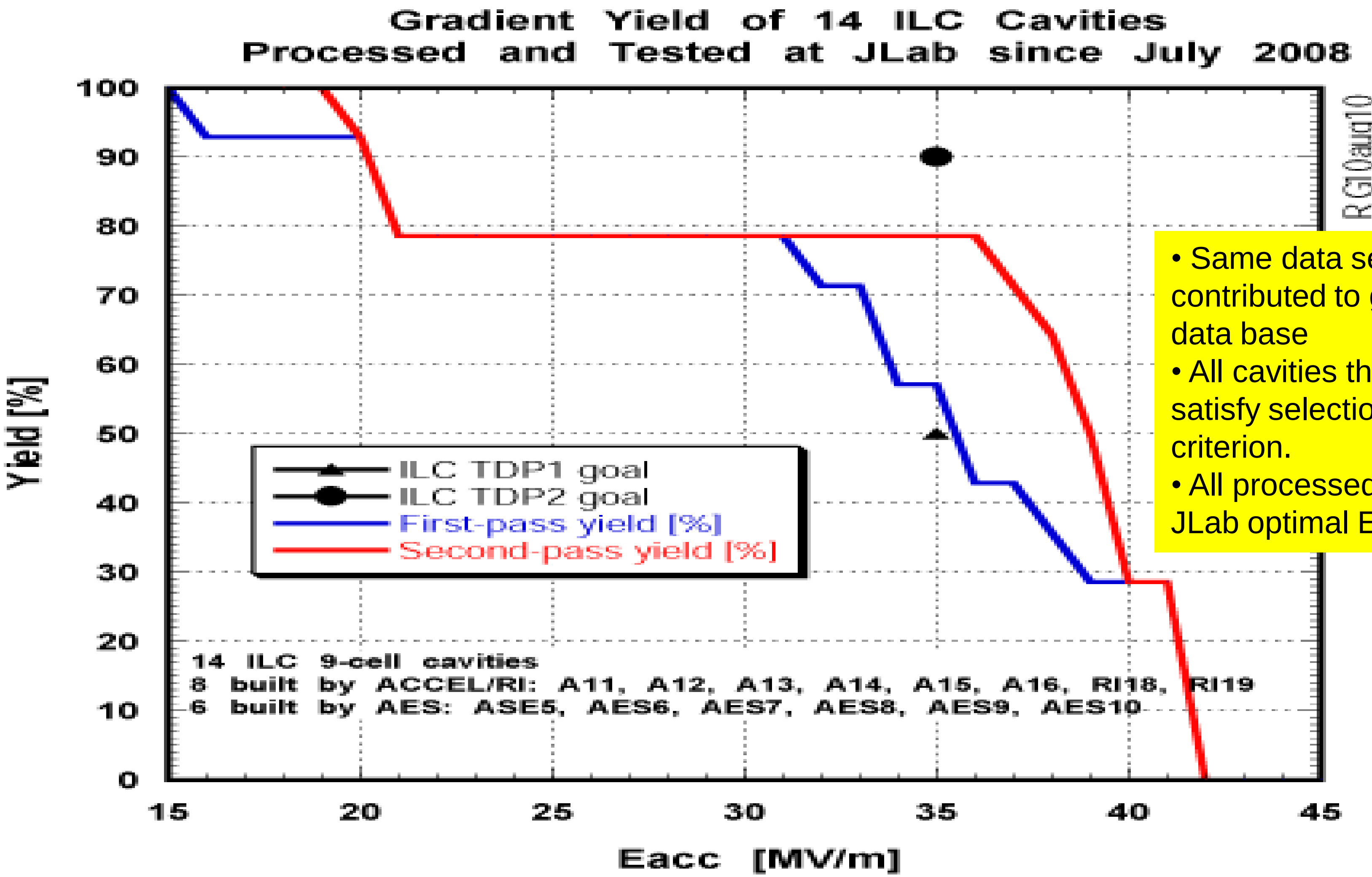
"Global" Gradient Yield as Published in R&D Plan Release 5





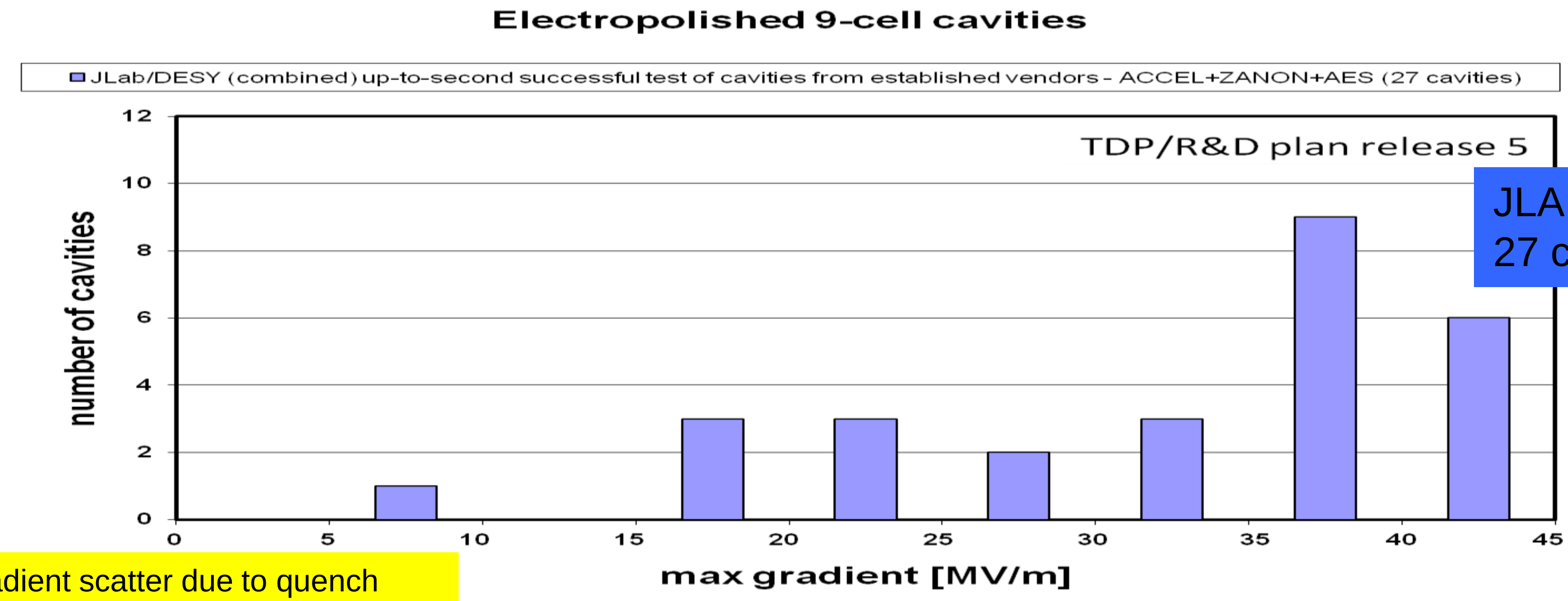
Accomplishment of 50% yield (up to 2nd pass proc.) at 35 MV/m
TDP-1 cavity gradient milestone

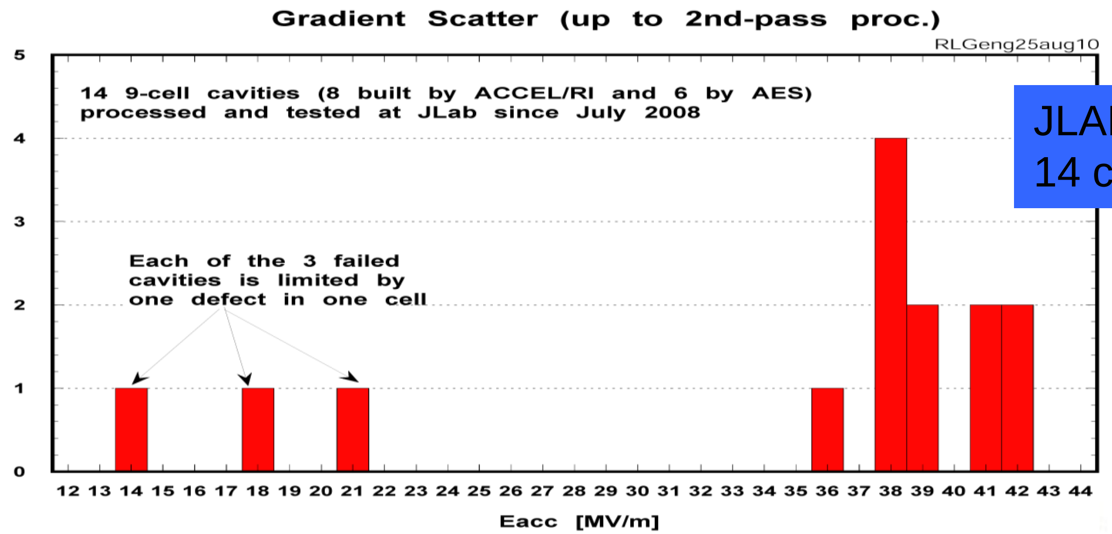
Gradient Yield based on 2008-2010 JLab Results as of August 2010



- Same data set as contributed to global data base
- All cavities that satisfy selection criterion.
- All processed using JLab optimal EP.

Gradient Scatter



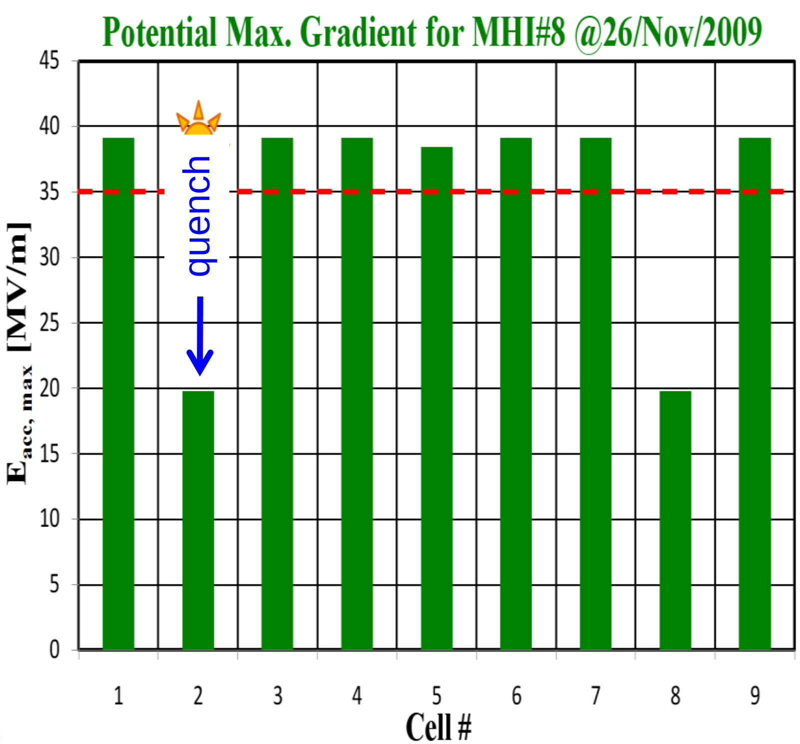


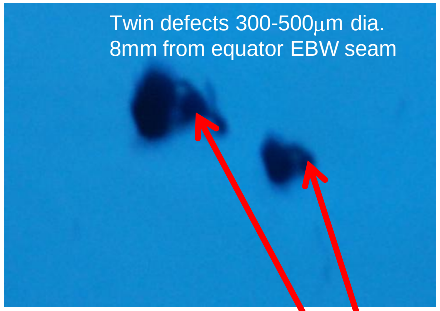
- Gradient scatter due to quench caused by highly localized defect.
- Often limited by only one sub-mm sized defect in one cell near equator EBW while other superior cells already reaching surface field capability of equivalent gradient of > 30 MV/m.
- Quench limit < 25 MV/m due to geometrical defect and in-sensitive to re-EP.
- Quench limit > 25 MV/m due to probably compositional defect and often can be raised by re-EP.

Examples of Quench Limited Cavities

MHI#8

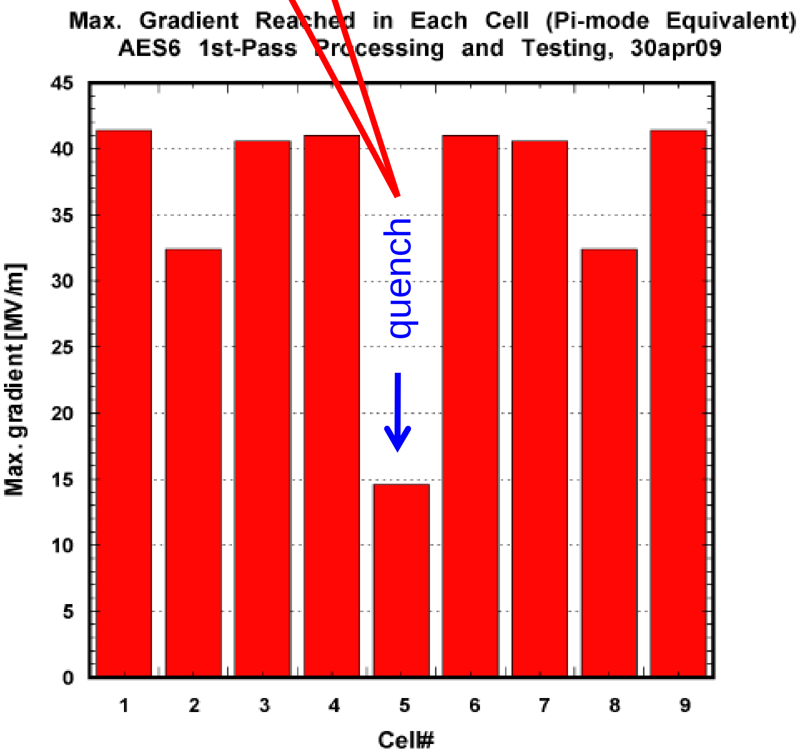
- No geometrical defects (down to ~10μm) observed at quench location
- Re-EP effectively raises cavity gradient: 18 MV/m >>> 38 MV/m





AES6

Twin defect in center cell limit cavity gradient to 15 MV/m; while all other cells capable of 32-41 MV/m; re-EP has little effect.



Gradient Spread Specification

- Gradient spread mainly due to two types of local defects within 20 mm from seam of equator EBW.
  - **Geometrical**
  - **Compositional (further R&D needed to confirm)**
- Low performing cavities < 25 MV/m often limited by geometrical defect; insensitive to re-EP.
- Quench limit > 25 MV/m can be raised to 30-40 MV/m by a second EP.
- Conclusion: global data set is still relatively small and a confident choice of gradient spread has to wait; and gradient scatter seems to be site dependent suggesting variability in cavity fabrication and processing.
- Recommendation: choose a starting value of 25 MV/m as lower bound of acceptable gradients spread.

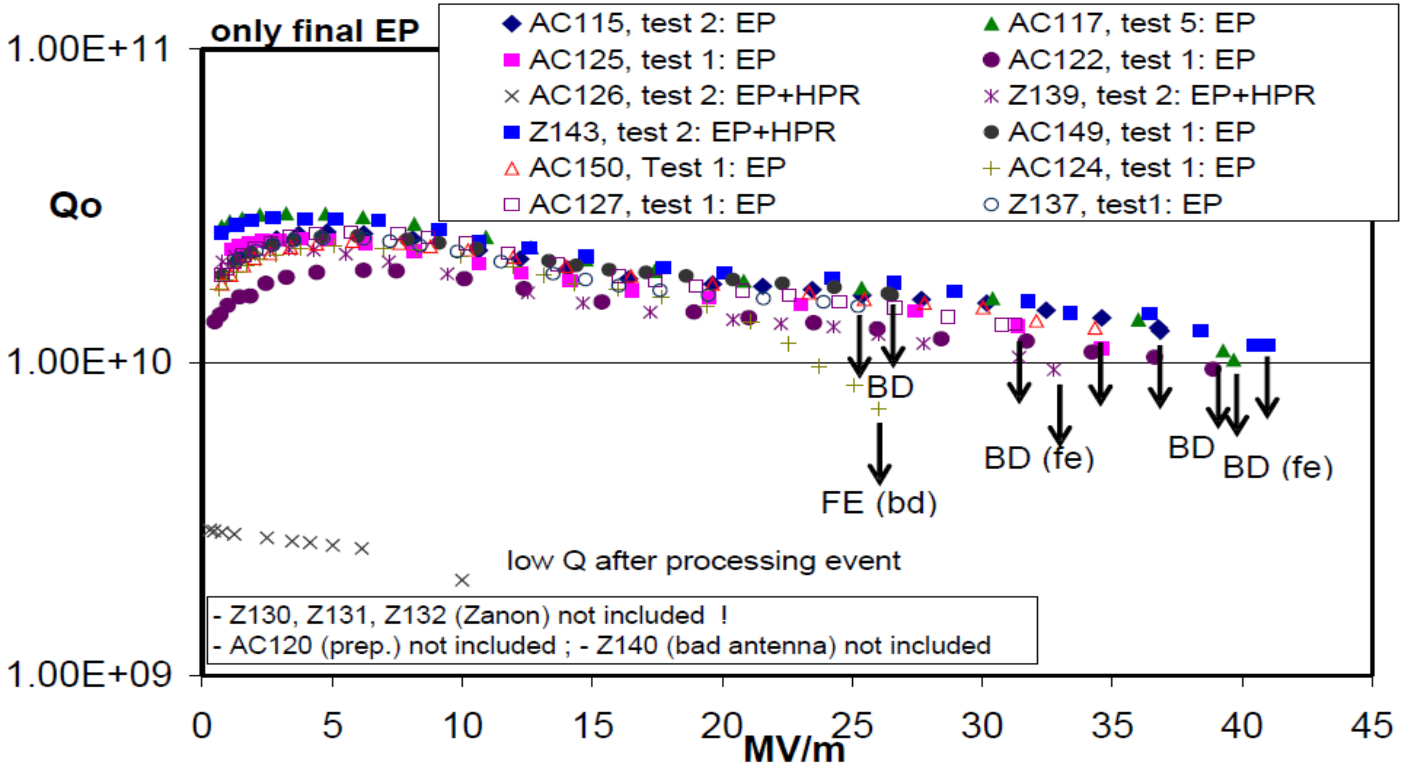
Cavity Gradient Yield Specification

- Reliable gradient yield prediction on a global basis requires controlled variability in cavity Material, Fabrication & Processing and sufficient number of cavities.
- Significant variability in M, F, & P the cause of vendor- and lab- dependency in gradient yield.
- Effort in fabrication improvement will increase first-pass yield at 15 - 25 MV/m; effort in processing improvement will increase second-pass yield at 25 – 40 MV/m.
- First-pass yield at 25 MV/m 66% (2xLab,3xVendor) to 78% (1xLab, 2xVendor); second-pass yield at 35/38 MV/m 56% (2xLab, 3xVendor) to 88% (1xLab, 1xVendor).
- Recommendation: First-pass yield at 25 MV/m 80%; second-pass yield at 38 MV/m 80%.

Unloaded Quality Factor

DESY Data
2K $Q_0 > 1\times10^{10}$ for 25-41 MV/m

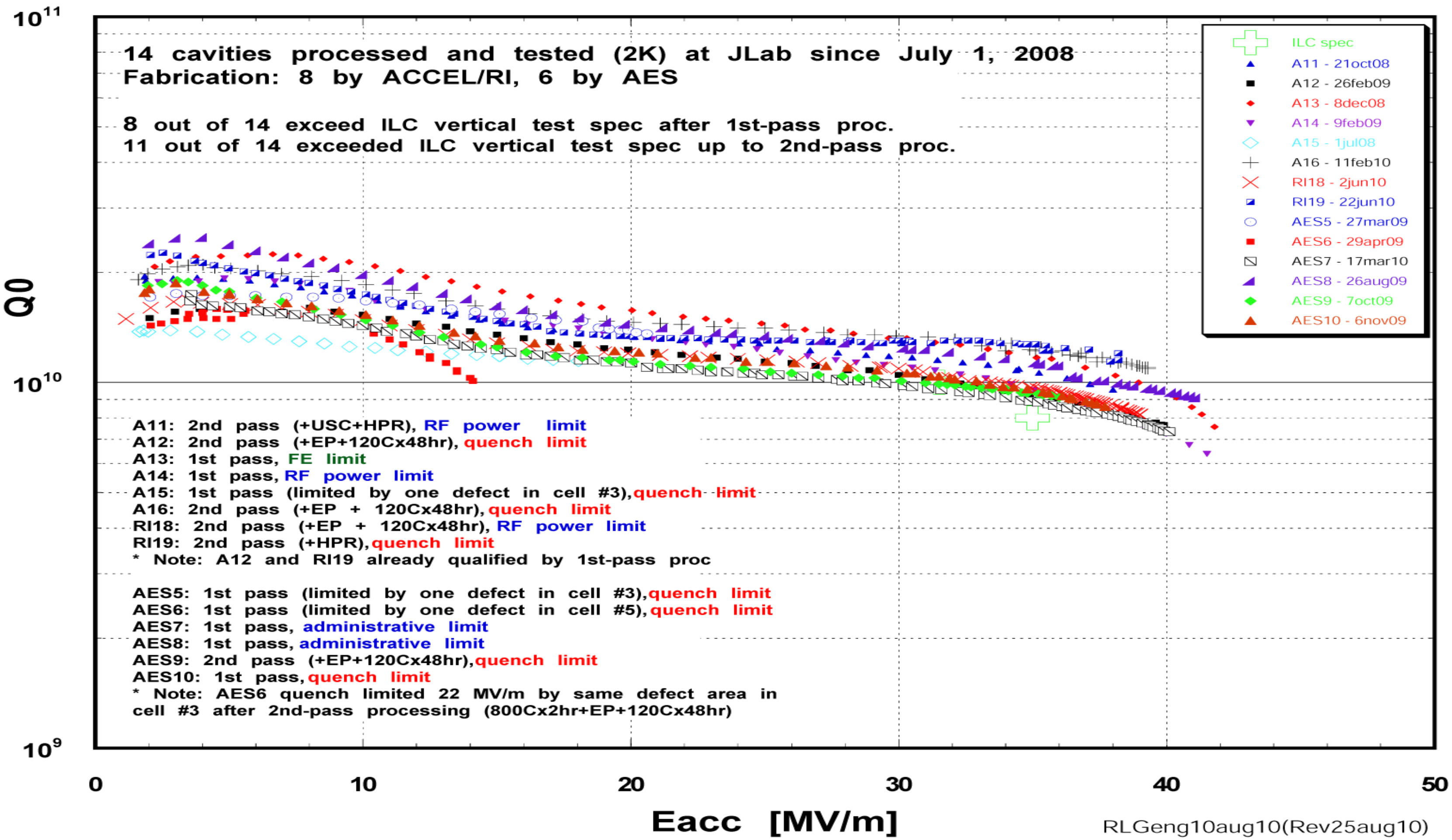
6th production: Q(E) of final EP-cavities



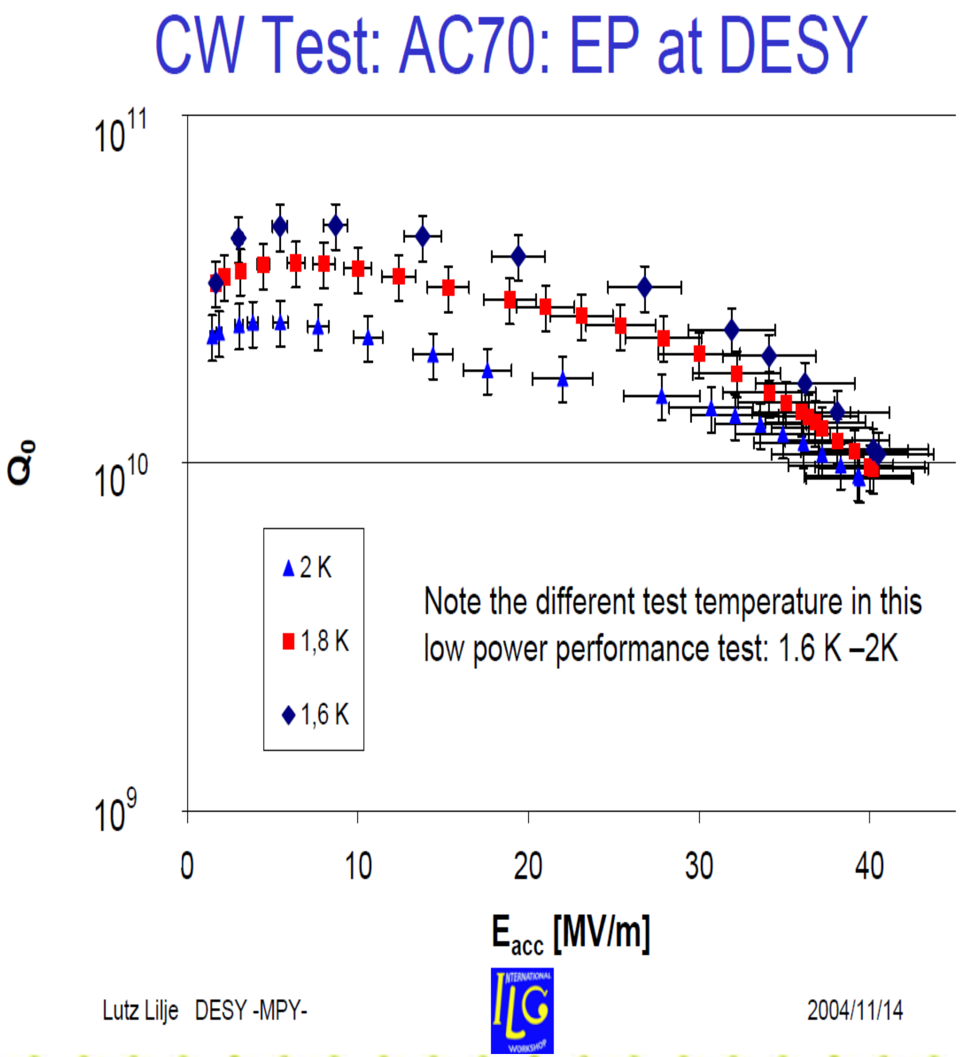
=> high gradients at high Q; low gradient Z-cavities after EP; sometimes field emission (with and w/o He-tank)

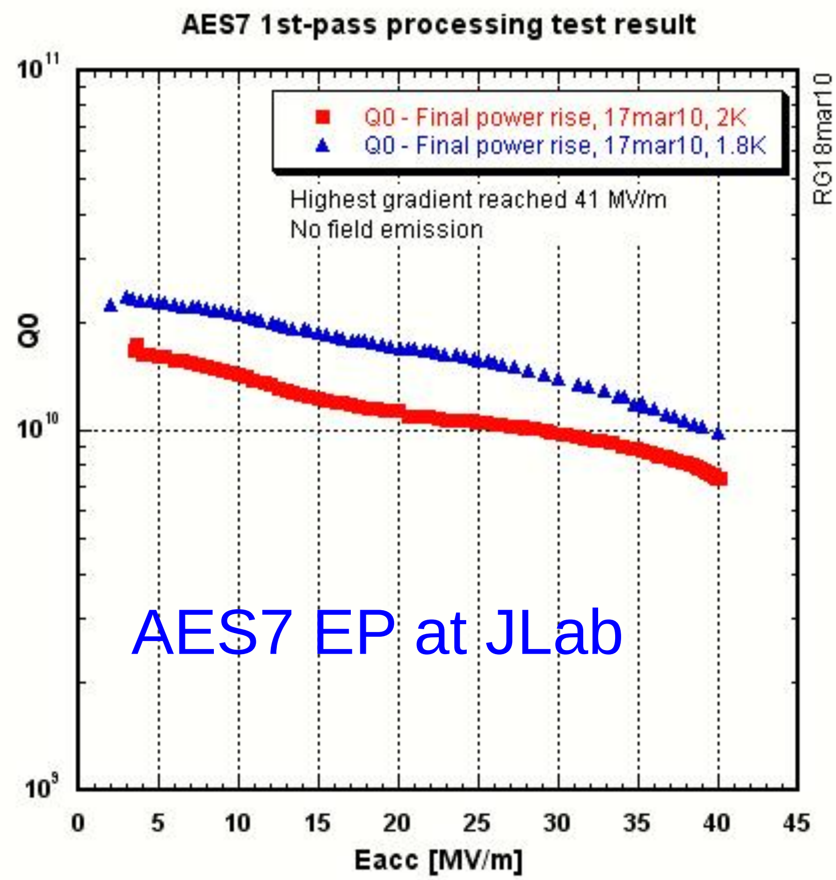
16.06.2009 S. Aderhold EU regional report TTC Meeting @ LAL Orsay 19

JLab Data
2K $Q_0 > 8\times10^9$ for 25-38 MV/m
$Q_0 > 6\times10^9$ up to 42 MV/m



Higher Q_0 at Lower Temperatures
1×10^{10} at 40 MV/m





Unloaded Quality Factor Specification

- Consistent Q_0 values above 8×10^9 are obtained up to 38 MV/m; scatter in unloaded quality factors is about +/-20% around the mean values.
- These values are obtained usually with measureable field emission induced radiation (although examples exist where no measurable radiation up to 40 MV/m).
- Perspective of higher unloaded quality factor at lower temperature can be expected. There are experimental examples of Q_0 1×10^{10} at 1.8K at 40 MV/m
- Conclusion: RDR choice of unloaded quality factor is sound; perspective of higher Q0 at lower temperature should be examined in context of ILC operation cost.
- Recommendation: unloaded quality factor 8×10^9 at 38 MV/m and 1×10^{10} at 31.5 MV/m.

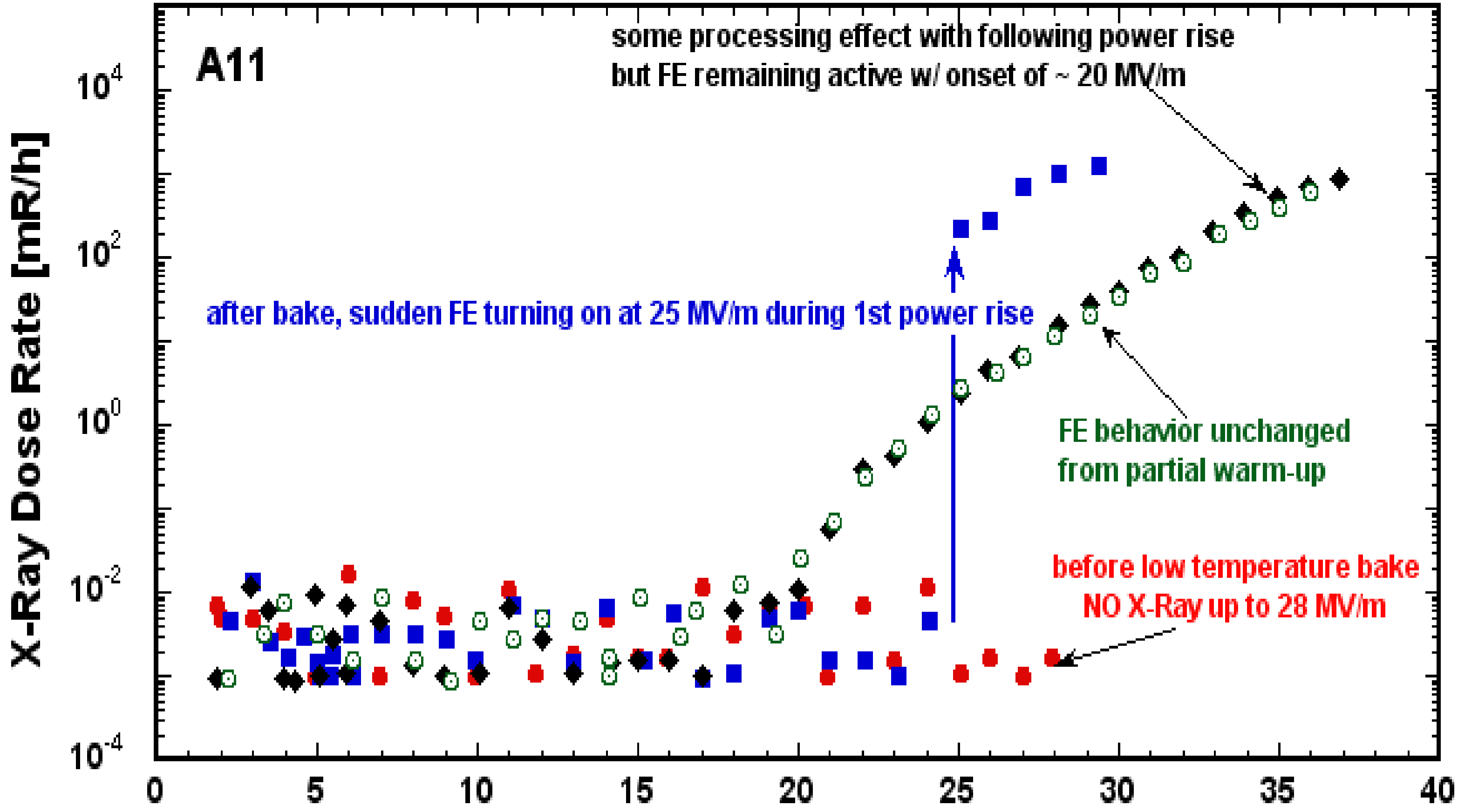
Field Emission Induced Radiation

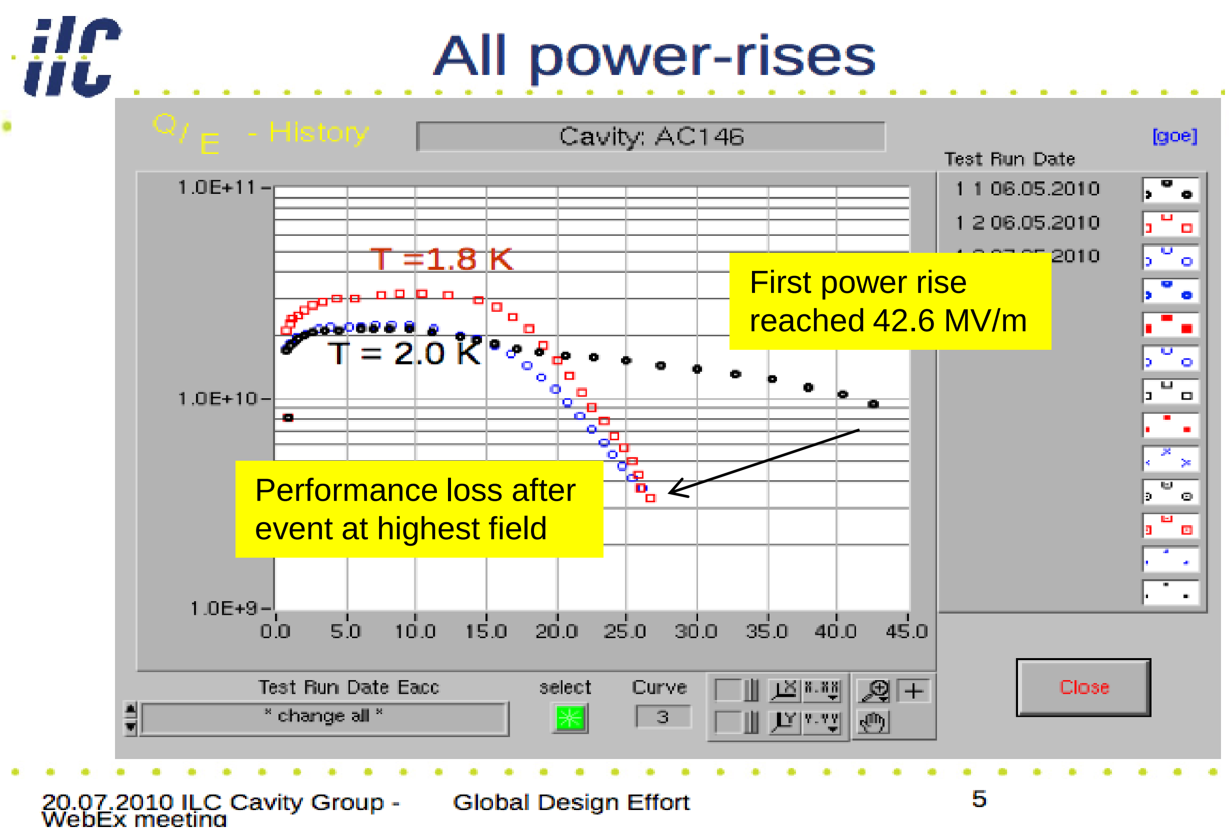
Some Remarks

- As reported earlier in the gradient progress overview talk, field emission is much reduced due to S0 effort.
- There are several examples of 9-cell test up to 40 MV/m without measureable field emission induced radiation.
- It is also fairly established that re-HPR can be used as an effective 2nd-pass processing technique for reducing radiation induced by field emission.
- However, measureable field emission induced radiation still present despite in most cases negligible impact to cavity quality factor.
- Two main field emission related phenomena:
  - **Baking induced field emission**
  - **Explosive field emission turn on, followed by performance loss**

Baking Induced Field Emission

• There is evidence to show this phenomenon has to do with sulfur migration/segregation due to in-situ 120 Celsius bake.
• “Hidden spaces” in end groups such as HOM coupler cans are involved.
• Wiping and brushing HOM cans seems useful.





- Similar phenomenon observed in high gradient (35-42 MV/m) 9-cell cavity vertical test at JLab.
    - ✧ Explosive field emission turn on, followed by “permanent” performance loss.
- Another similar case was reported in a high gradient 9-cell cavity horizontal test at FNAL. Until 37 MV/m, no field emission, then sudden turn on followed by “permanent” performance loss.

FE Induced Radiation Specification

- Examples exist of 41 MV/m 9-cell without measurable radiation.
- Further effort in FE suppression is necessary as some cavities have to be operated at very high gradient to compensate lower performance cavities – due to acceptance of gradient spread.
- Present day radiation monitoring varies from lab to lab. Calibrated radiation monitoring is a TDP-2 goal.
- Conclusion: Very high gradient (> 40 MV/m) operation requires increased FE suppression due to exponential nature of the process. Calibrated radiation monitoring requires coordinated effort due to importance of the matter and limited resources.
- Recommendation: Establish site-independent radiation monitoring; choose 40 MV/m as the upper bound of acceptable gradient spread.

Cavity Specification Summary

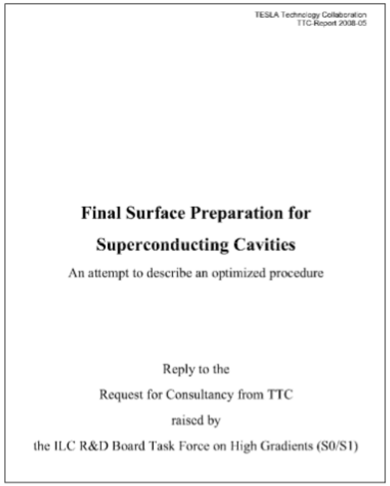
	Specification	Unit	Note
Gradient	38	MV/m	
Gradient Spread	25 - 40	MV/m	
Gradient Yield	80%(1st-pass) 80%(2nd-pass)	- -	at 25 MV/m at 38 MV/m
Unloaded Quality Factor	$\geq 8\times10^{9}$ $\geq 1\times10^{10}$	- -	at 38 MV/m at 31.5 MV/m
Field Emission Induced Radiation	TBD		TDP-2 goal

Comments

- Cavity specification recommendation based on most recent R&D status.
- SRF technology gradient confidence has increased since publication of RDR due to global effort in gradient R&D.
  - **Following DESY success, FNAL, JLAB, and KEK demonstrated 9-cell cavity processing and testing of ≥ 35 MV/m.**
  - **Following ACCEL and Zanon success, AES and MHI demonstrated 9-cell cavity fabrication of > 35 MV/m.**
  - **Hitachi (35 MV/m w/o end groups) and PKU (> 28 MV/m w/ end groups) fabrication 9-cell cavities encouraging initial results.**
  - **More coming: Niowave-Roark, Toshiba, IHEP, PAVAC.**
- State-of-the-art average gradient is now 38 MV/m; practical gradient limit in 9-cell cavity is pushed to 41-42 MV/m.

Comments (cont.)

- Cavity specification must be backed by a detailed specification of technology including
  - **Material requirements**
  - **Fabrication requirements**
  - **Processing requirements**



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)

Comparison of EP parameters between Jlab and KEK looks very successfull.

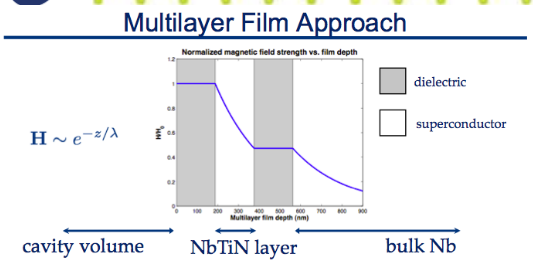
TTC-Report 2008-05 :
Detailed comparison of surface processes among laboratories.
But this is going to be obsolete in some part.

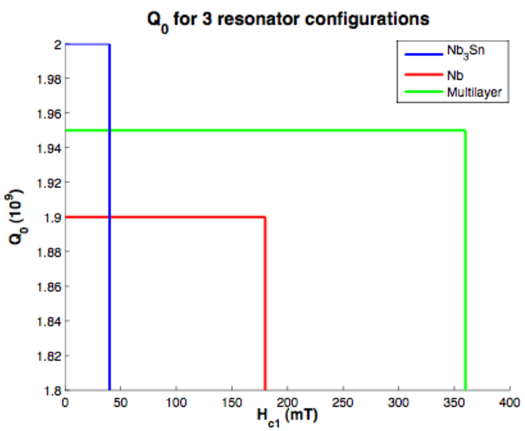
Natural question:
Should we update the comparison table step by step?

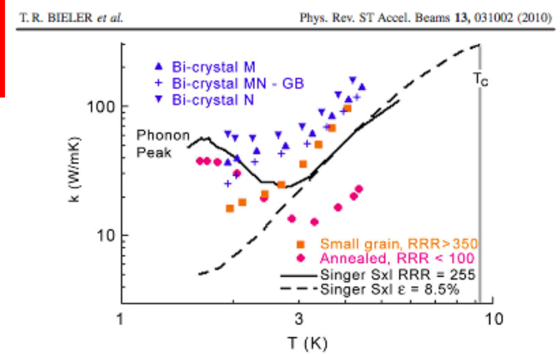
Camille Ginzburg proposed me to visit ANL during the TTC meeting (FNAL, April 2010) to compare the EP parameters among KEK, Jlab and ANL.
I agreed with this proposal.

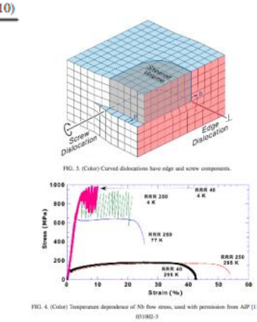
- Recent effort of EP parameter comparison in reference to TTC report 2008-05 by T. Saeki of KEK is a good start toward cavity processing EP technology specification.
- Intensified analysis, exchange and communication of material, fabrication and processing measurements important.

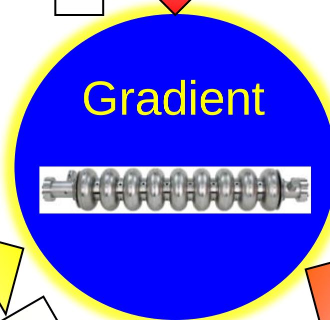
Material

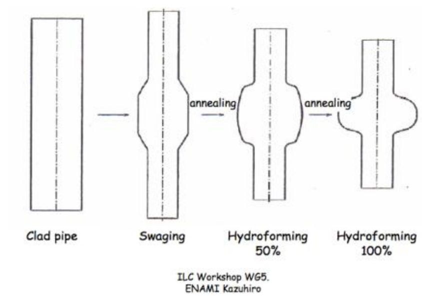












Processing

Fabrication

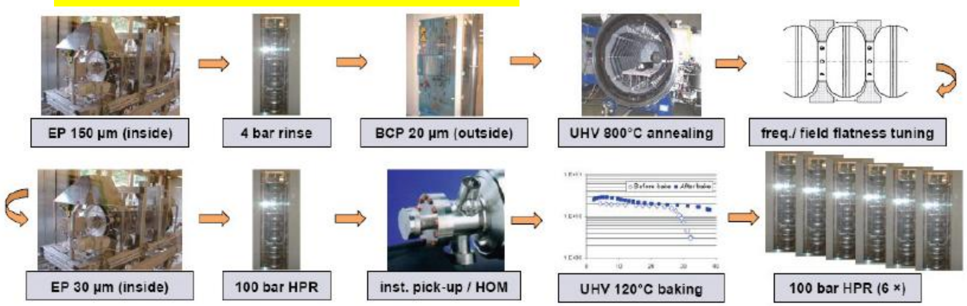


FIGURE 1.2-5. Birth of a nine-cell cavity: basic steps in surface treatment needed to achieve high-performance superconducting cavities. (EP = electropolishing; HPR = high-pressure rinsing.)

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