Current Status of SCRF Cavity Development

Jim Kerby, Fermilab
for Rongli Geng and the S0 Cavity Team

23 May 2010

S0 Performance Goal

At the time of the RDR:

- Gradient and Q0 are fundamental length and power drivers for the ILC
- 35 MV/m in vertical test includes 10% technical margin for operating gradient of 31.5 MV/m in the machine
- ILC VT goal the multicell state of the art (at the time)

ILC Research and Development Plan for the Technical Design Phase

Release 4

July 2009

ILC Global Design Effort

Director: Barry Barish

Prepared by the Technical Design Phase Project Management

Project Managers: Marc Ross, Nick Walker, Akira Yamamoto

Table 3-1: Milestones for the SCRF R&D Program.

High-gradient cavity performance at 35 MV/m according to the specified chemical process with a process yield of 50% in TDP1, and with a production yield of 90% in TDP2 (S0, see section 3.1.3 for definition of process yield)	2010 2012

Towards Realization

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)

	Standard Cavity Recipe
Fabrication	Nb-sheet (Fine Grain)
	Component preparation
	Cavity assembly w/ EBW
Process	BCP+ 1st (Bulk) Electro-polishing (>120um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	2nd Electro-polishing (~20um)
	Ultrasonic degreasing or ethanol rinse
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Vertical Test	Performance Test with temperature and mode measurement →inspection, reprocessing, other remediation

The Challenges

- 35 MV/m gradient in vertical test
  - Q0 > 1e10 at 31.5MV/m, 8e9 at 35MV/m
  - Process Yield > 50% in 2010
  - Production Yield (up to 2 passes) > 90% in 2012
- Increase vendor capabilities across regions
  - Technical
  - Quantity
- Standardize (and improve) processing across laboratories
  - Push processing toward industries
- Improve diagnostic capabilities
  - Push towards earlier in the manufacturing cycle
- Improve communication of findings around the globe
- Work within prescribed funding limits

Cavity Yield Database

To improve reporting, consistency, and communication:

ILC Database is now fully functional

- http://tesla-new.desy.de/cavity_database/

- As of 26 March, ILC Database currently contains data from all three regions, from the last few years [92 cavities]
  - KEK [5 cavities]: [MHI005:MHI009]
  - JLab, Cornell, Fermilab [22 cavities]: [A5: A9], [TB9ACC010:TB9ACC017], [AES001:AES004], [TB9AES005:TB9AES010], JLAB-2
  - DESY [65 cavities]: [Z82:Z110], [AC112:AC129], [Z130:Z135,Z137:Z145], [AC147,AC149,AC150]
  - (Production 4,5,6,7)

C. Ginsburg (FNAL), R. Geng (JLab), Y. Yamamoto (KEK), Z. Conway (Cornell), S. Aderhold, D. Gall, V. Gubarev, S. Yasar (DESY) LCWS 2010

Production Yield Plot: First Pass Definition

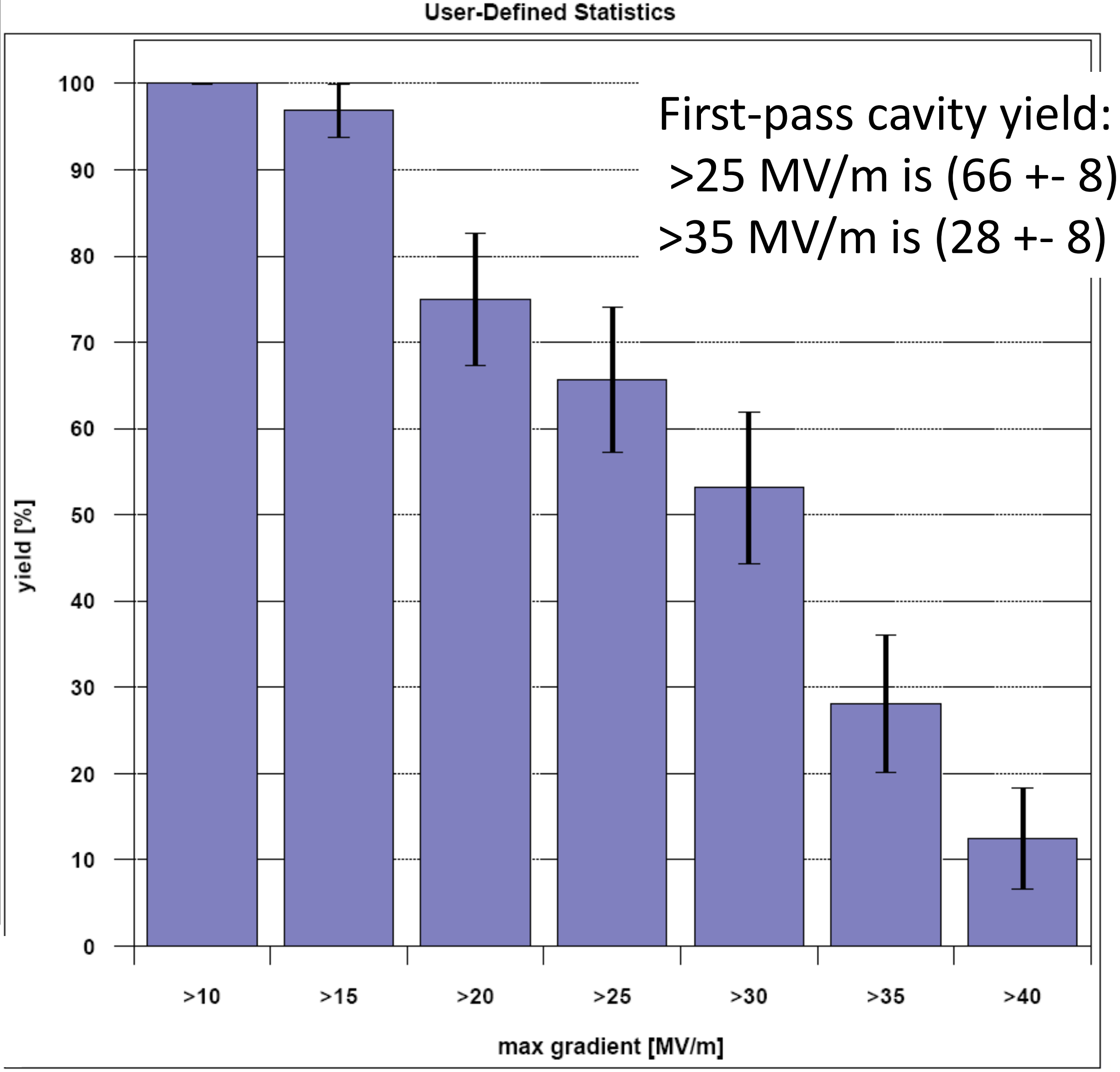
- Cuts
  - Cavity from vendor= ACCEL or ZANON or AES SN>=5
  - Fine-grain cavity
  - Use the first successful (= no system problem/limitation) test
  - Standard EP processing: no BCP, no experimental processes
    - Defined as JLab#1, DESY#2 (weld tank before test), DESY #4 (weld tank after test)
    - Ethanol rinse and 120C bake required for DESY cavities
  - (Ignore test limitation)
- Include binomial errors

NB: No explicit Q0 cut, but all ILC Eacc-qualified cavities pass Q0>8E9

- Despite these cuts, some variability in fab and proc remains
  - Some variability facility specific
- Large number of cavities required to reduce statistical error

First Pass Yield

No.	Cavity	Test Date	Max. Eacc [MV/m]
1	TB9ACC013	01.Dec.08	41.80
2	TB9ACC014	09.Feb.09	41.50
3	TB9AES008	26.Aug.09	41.10
4	TB9AES007	16.Mar.10	41.00
5	AC122	26.Aug.08	38.88
6	AC115	11.Dec.07	38.60
7	TB9AES010	06.Nov.09	37.70
8	TB9ACC011	21.Aug.08	37.00
9	TB9ACC012	07.Jul.08	35.10
10	Z134	13.Nov.09	34.94
11	AC125	15.Jun.08	34.59
12	AC150	30.Jan.09	34.33
13	TB9AES009	18.Aug.09	33.40
14	Z143	09.Oct.08	32.57
15	Z106	21.Feb.07	31.70
16	AC127	13.Feb.09	31.25
17	TB9ACC016	14.Dec.09	31.20
18	ACCEL7	05.Sep.06	29.00
19	AC149	28.Jan.09	26.51
20	AC124	05.Feb.09	26.01
21	Z137	24.Feb.09	25.23
22	Z139	12.Sep.08	24.93
23	Z142	01.Jul.09	20.58
24	TB9AES005	27.Mar.09	20.50
25	ACCEL6	12.Dec.06	19.00
26	Z141	16.Apr.08	18.29
27	TB9ACC015	02.Jul.08	18.00
28	Z130	01.Sep.08	17.30
29	Z131	20.Aug.08	17.17
30	Z132	19.Aug.08	16.83
31	AC126	05.Sep.08	16.37
32	TB9AES006	09.Apr.09	14.10



First-pass cavity yield:
>25 MV/m is (66 +- 8) %
>35 MV/m is (28 +- 8) %

32 cavities, DESY/Jlab processing

LCWS 2010

Production Yield Plot Up-to-2nd-Pass: Definition

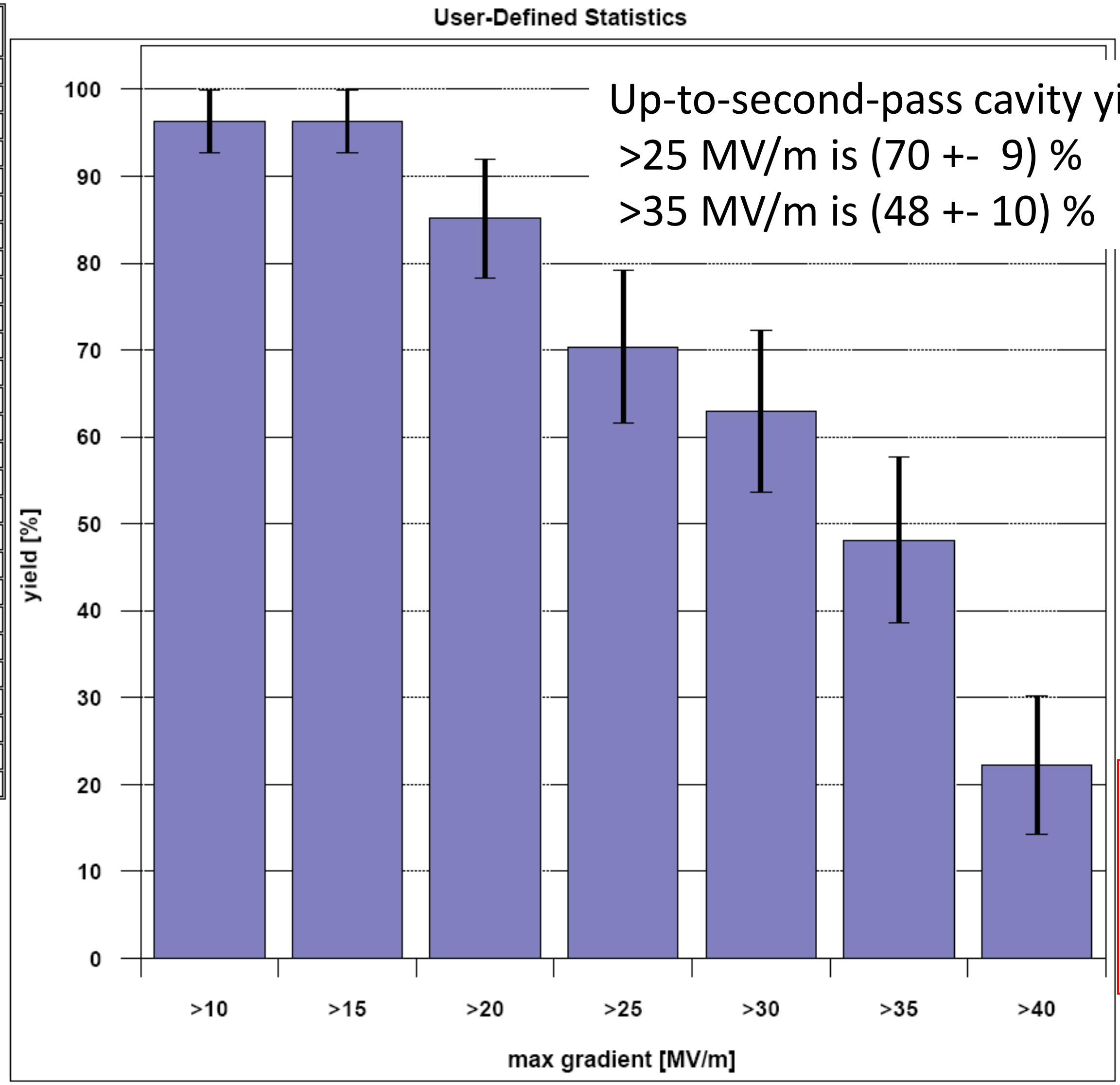
- Cuts
  - First pass
  - Second pass
    - if (Eacc(1st successful test)<35 MV/m) then
      - if (2nd successful test exists) then
        - » plot 2nd test gradient
      - else
        - » plot nothing [assume 2nd test didn't happen yet]
      - endif
    - else
      - plot 1st successful test gradient
    - endif
- Include binomial errors

NB:
1.No explicit Q0 cut, but all ILC Eacc-qualified cavities pass Q0>8E9
2.HPR-only is a valid 2nd pass process

Up-to-Second Pass Yield

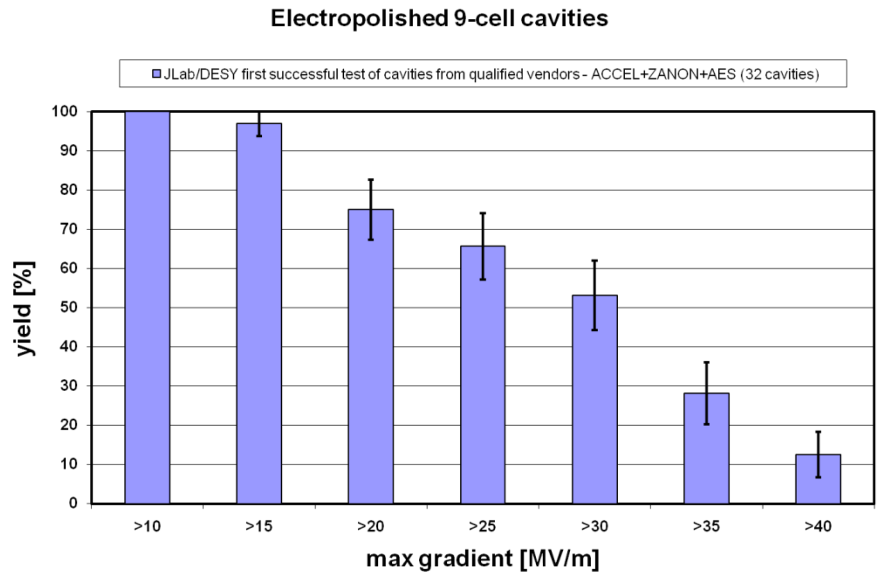
No.	Cavity	Test Date	Max. Eacc [MV/m]
1	TB9ACC013	01.Dec.08	41.80
2	TB9ACC014	09.Feb.09	41.50
3	ACCEL7	18.Jan.07	41.20
4	TB9AES008	26.Aug.09	41.10
5	Z143	12.Nov.08	41.00
6	TB9AES007	16.Mar.10	41.00
7	TB9ACC016	11.Feb.10	39.30
8	AC122	26.Aug.08	38.88
9	AC115	11.Dec.07	38.60
10	TB9AES010	06.Nov.09	37.70
11	TB9ACC011	21.Aug.08	37.00
12	TB9AES009	07.Oct.09	36.00
13	TB9ACC012	07.Jul.08	35.10
14	AC150	08.May.09	33.23
15	Z139	20.Oct.08	32.75
16	Z106	27.Feb.07	31.50
17	AC124	19.May.09	30.93
18	ACCEL6	23.Jan.07	29.00
19	AC127	11.Jun.09	27.85
20	AC149	05.May.09	23.27
21	TB9AES006	11.Sep.09	22.20
22	Z141	14.May.08	20.70
23	TB9AES005	09.Apr.09	20.50
24	TB9ACC015	14.Jul.08	19.00
25	Z131	25.Nov.08	17.96
26	Z130	15.Oct.08	16.60
27	AC126	21.Oct.08	6.14

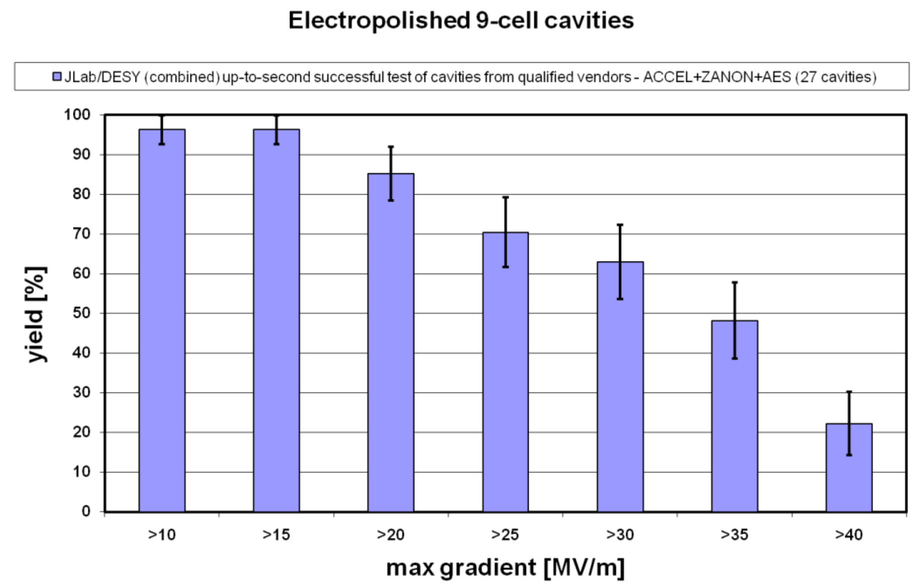
27 cavities, DESY/Jlab processing

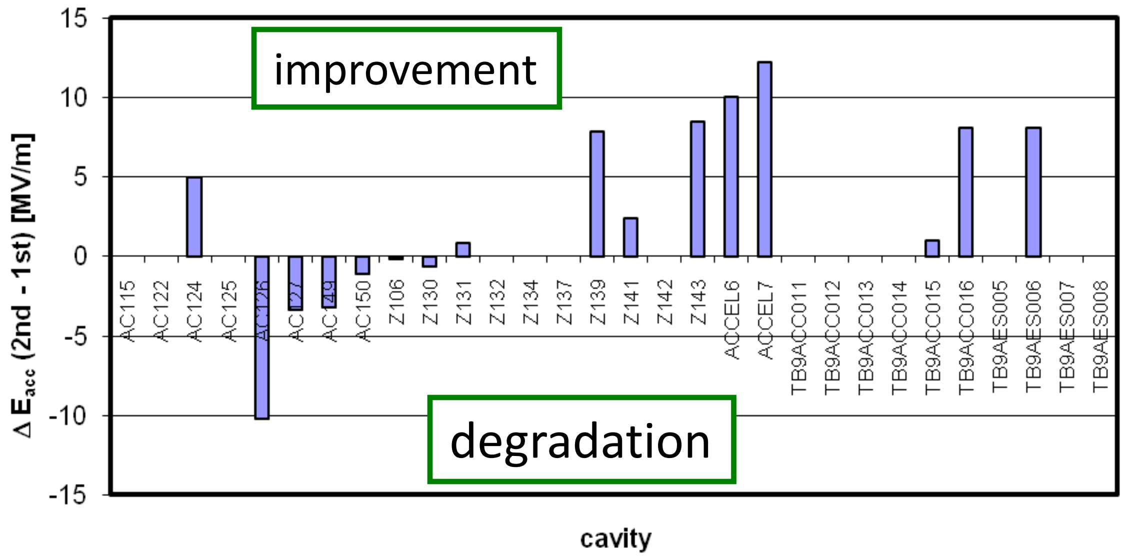


LCWS 2010

1^{st} and 2^{nd} pass yield comparison







LCWS 2010

Current Status

Given the statistics it is difficult to generalize, but—

- Using production yield, the 2010 goal of 50% is met
- One more vendor/laboratory combination is now included in production plots
  - Another vendor and two laboratories on the verge
  - Five more vendors manufacturing cavities
  - Vendors taking on greater role in processing after EBW
  - Processing / Testing rate in Americas greatly increased

Diagnostics improved, quench results better understood

- <~25MV/m (typ) a defect can be seen in a single cell
  - Repeated processing does not cure this→in fact can make it worse
- >~25MV/m (typ) reprocessing can improve performance

Towards 2012

Success depends on

- Overcoming quench limit for Eacc <20MV/m
  - Need to prevent defects in material / manufacturing
- Increasing use of diagnostics earlier in the process
- Increased understanding and earlier remediation
- Faster feedback

	Standard Cavity Recipe
Fabrication	Nb-sheet (Fine Grain)
	Component preparation
	Cavity assembly w/ EBW
Process	BCP + 1st (Bulk) Electro-polishing (>120um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	2nd Electro-polishing (~20um)
	Ultrasonic degreasing or ethanol rinse
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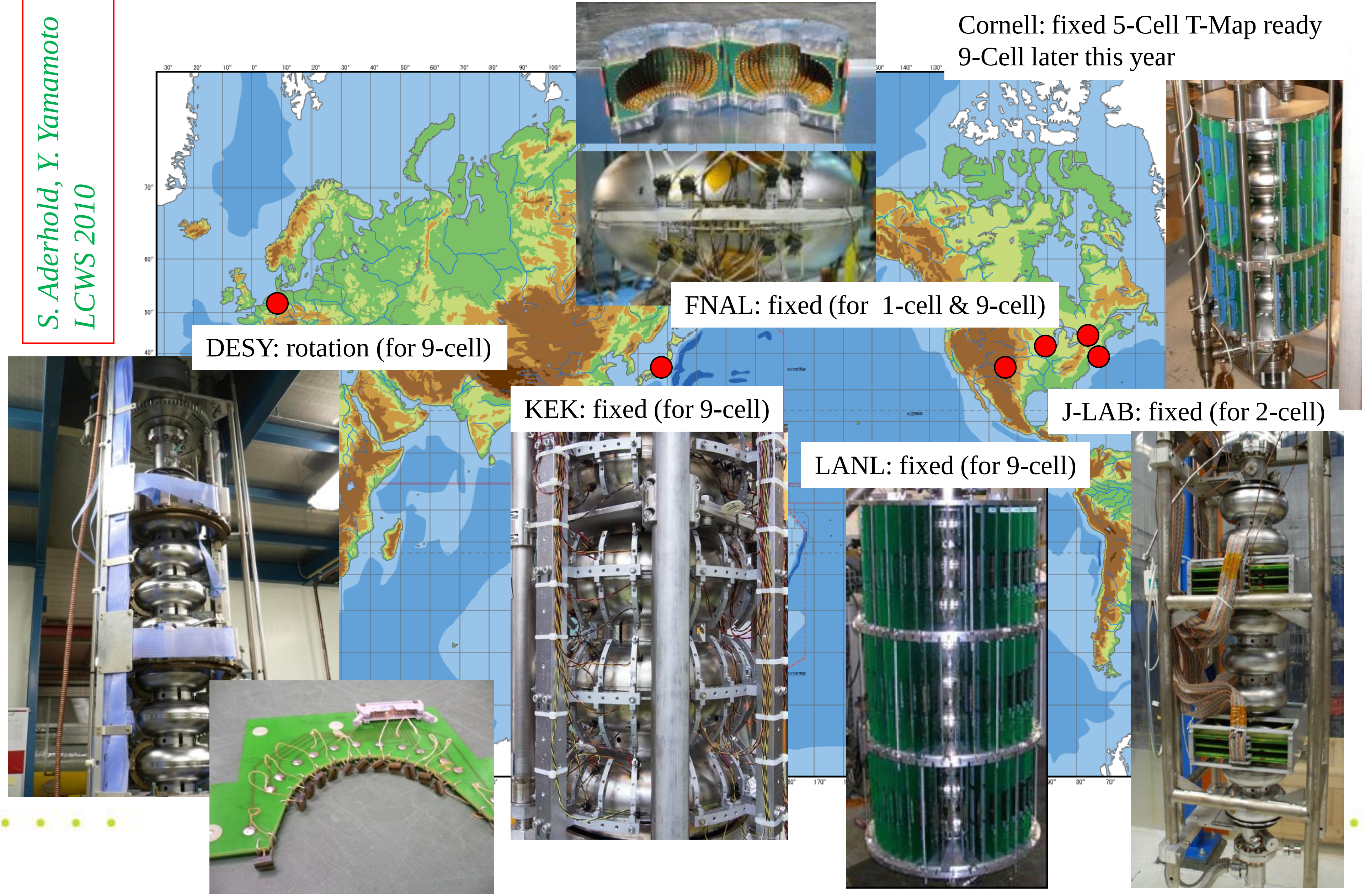
	Antenna Assembly
	Baking at 120 C
Vertical Test	Performance Test with temperature and mode measurement →inspection, reprocessing, other remediation

Industry

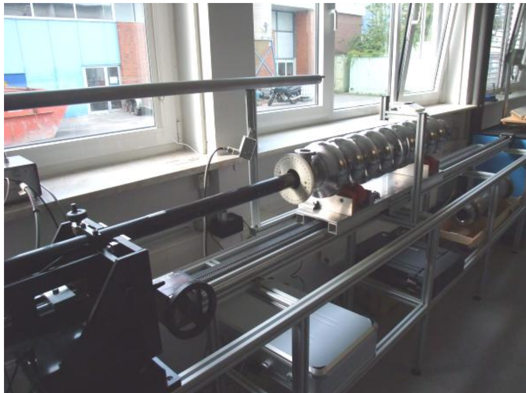
Inspection & remediation

T-mapping systems

S. Aderhold, Y. Yamamoto
LCWS 2010



Optical inspection in the world



DESY：Kyoto Camera

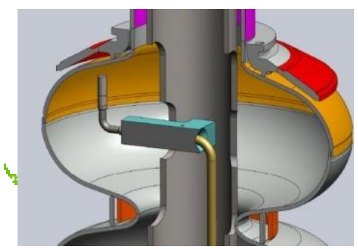
FNAL：Kyoto Camera, Questar long-distance microscope

Defect Location @ Cornell

Cornell：Inspection system

KEK (STF)：Kyoto

LosAlamos: Karl Storz videoscope



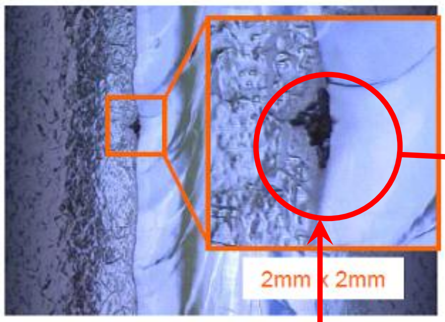
J-Lab：Lab cavity inspection tool based on long-distance microscope, Kyoto Camera

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

K. Watanabe, SRF2009

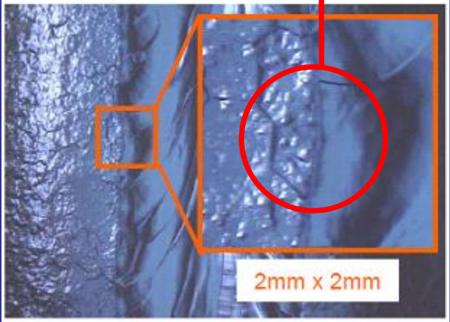
MHI-08 : The location of target for Grinding

Cell#2 equator, t=172 deg. Pit



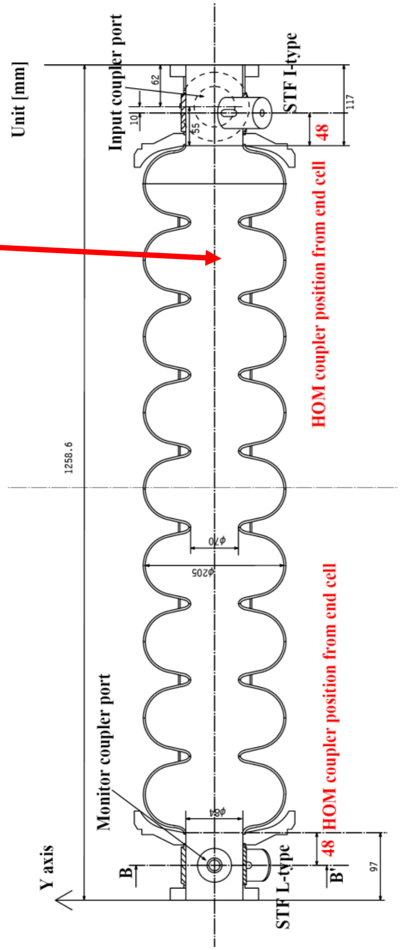
After V.T.

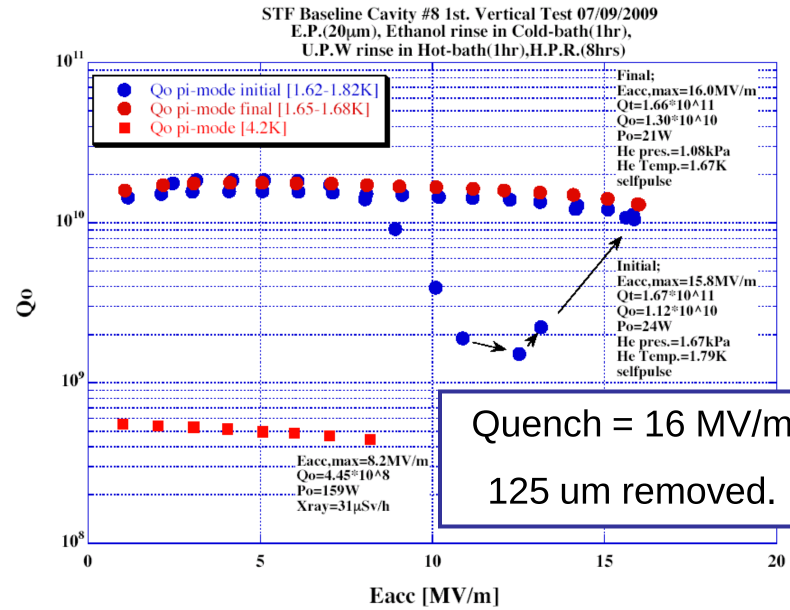
(Removed material = 125 μm)



Before V.T.

(Removed material = 105 μm)

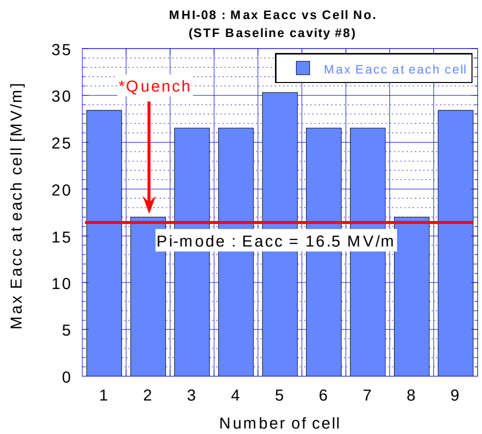


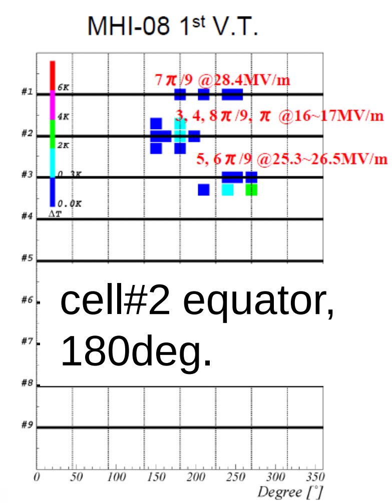


Quench = 16 MV/m

125 um removed.

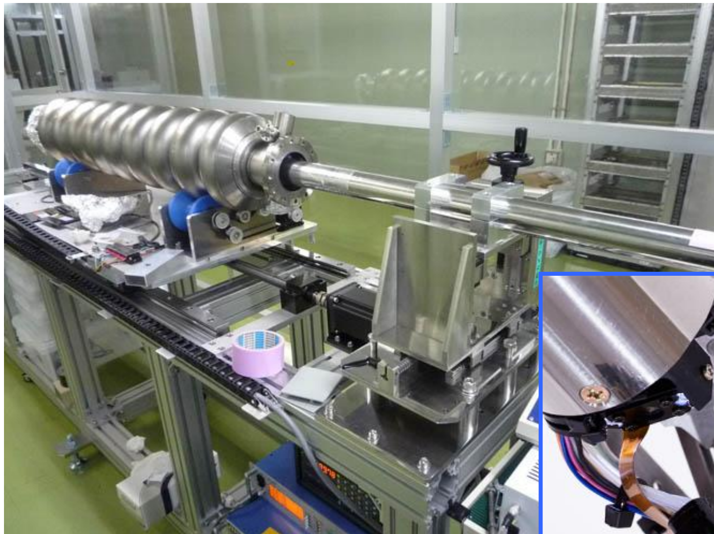
H. Hayano, TTC, April 2010

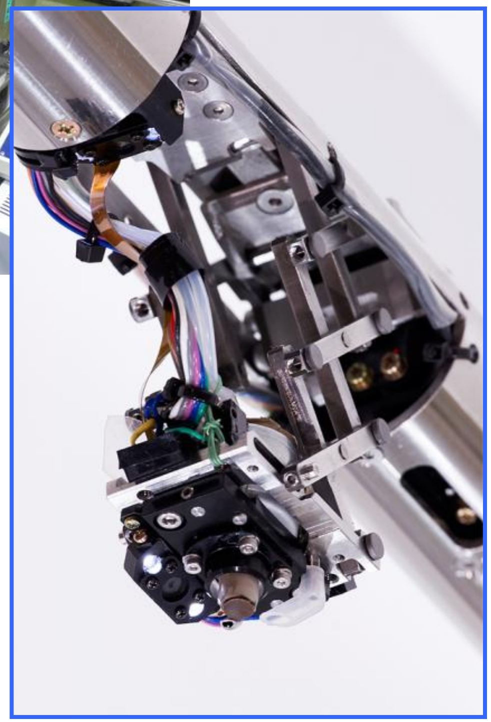




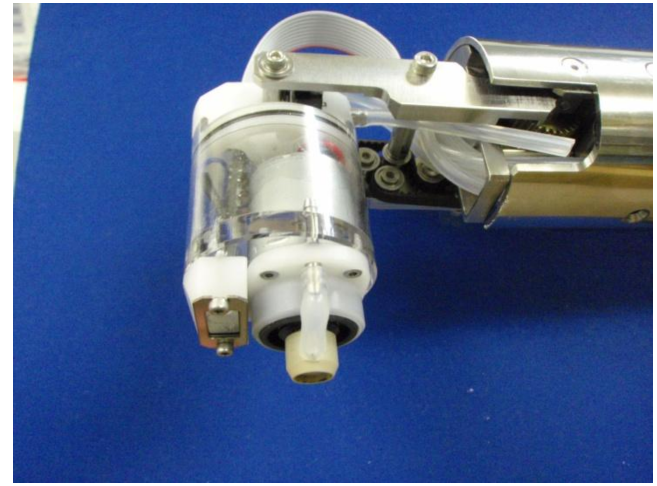
The cavity quenched at 16 MV/m on the cell #2 equator. The defect was made after EP-2 process.

Effort for Repairing: Grinding

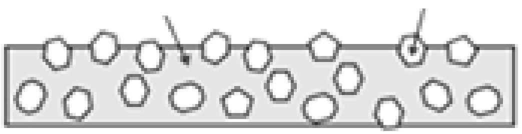




Grinder for equator



Grinder for sloped surfaces



Material for grinding：Diamond seat #400 - #3000

(particle size = 40 ~ 3 um), (POLYMOND)

Polymond+water used for grinding

MHI-08 : Grinding of the defect : cell #2 equator t = 172deg

In this case, the defect type was pit at the boundary between EBW seam and HAZ.

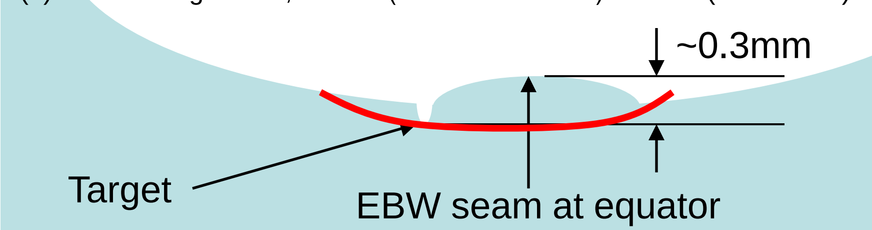
History of the Grinding, (0) before Grinding.

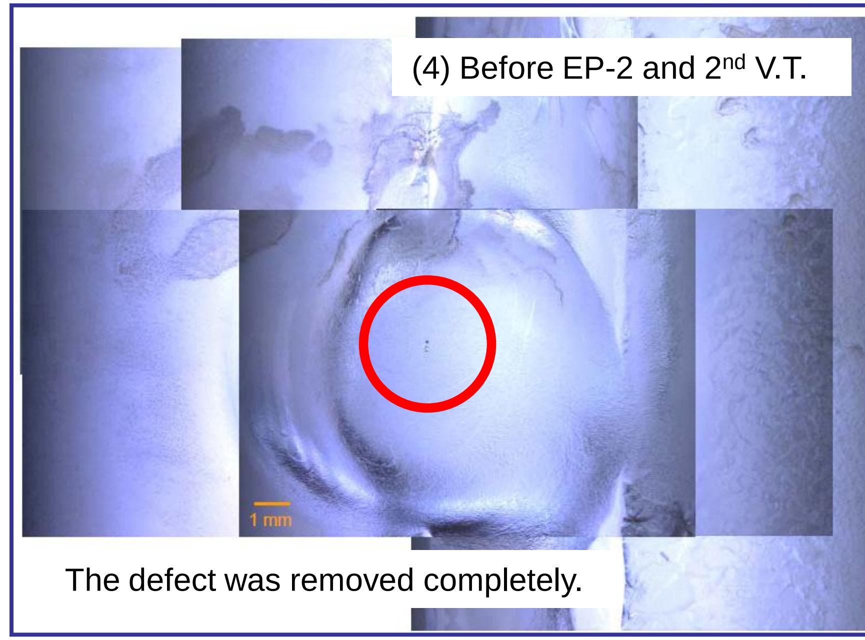
(1) 1st Grinding #400, 58 min

(2) 2nd Grinding #400, 76min (Total 134min)

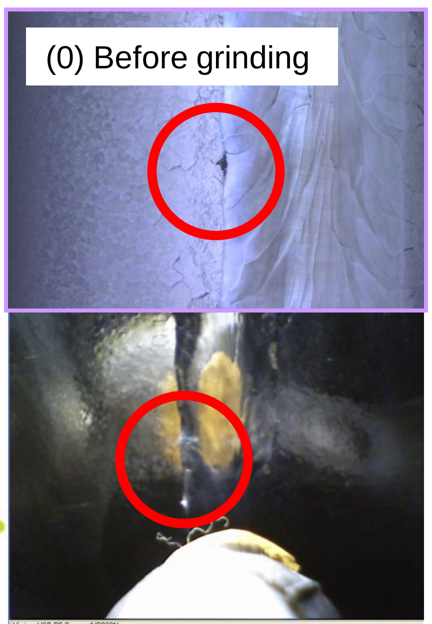
(3) 3rd Grinding #400, 70min (Total 204min)

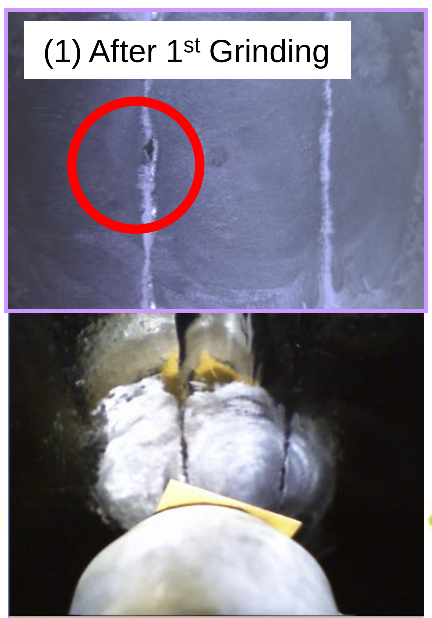
(4) 4th Polishing #1000, 60min (Total : 264min) and EP (20 +30 um)

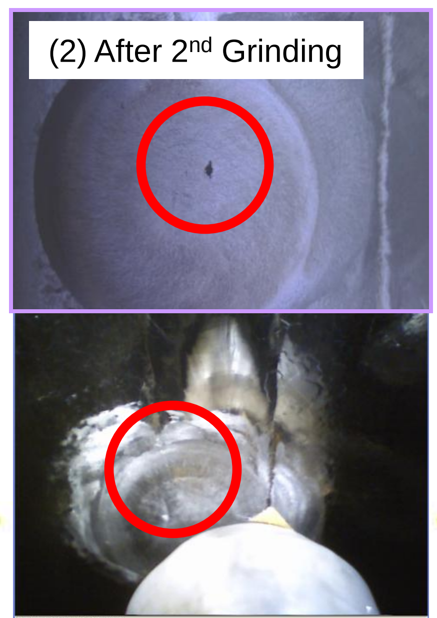




The defect was removed completely.







MHI-08 : 2nd V.T. result

Progress work after 1st V.T. (June 2009):

* Inspection after 1st V.T.
* Make a replica and shape analysis
* Local Grinding (One equator)
* Cleaning by water and wiping before EP process

* EP 20um, 50mA/cm2 (Air) at KEK-STF
  1st water rinsing (Air) 90 min, HPR 2 hour

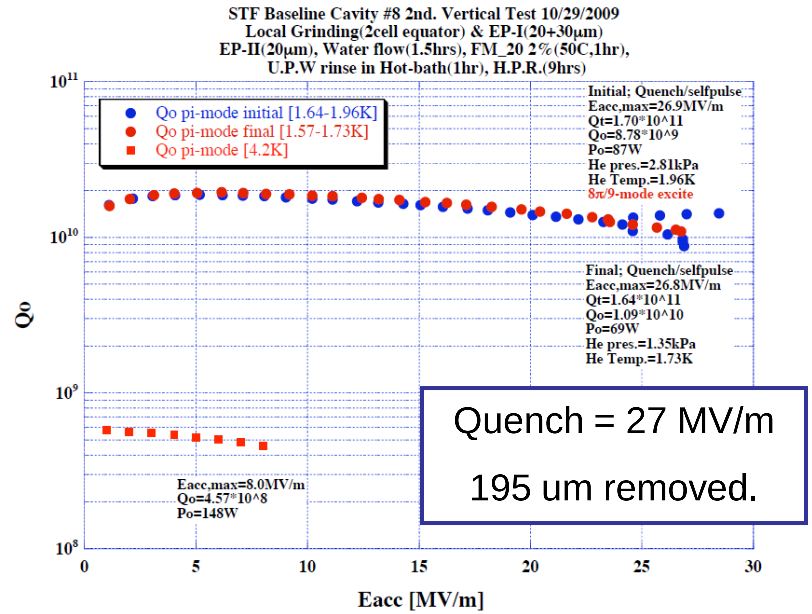
* Inspection after EP 20um
* Local Grinding to obtain narrow edge around circle.

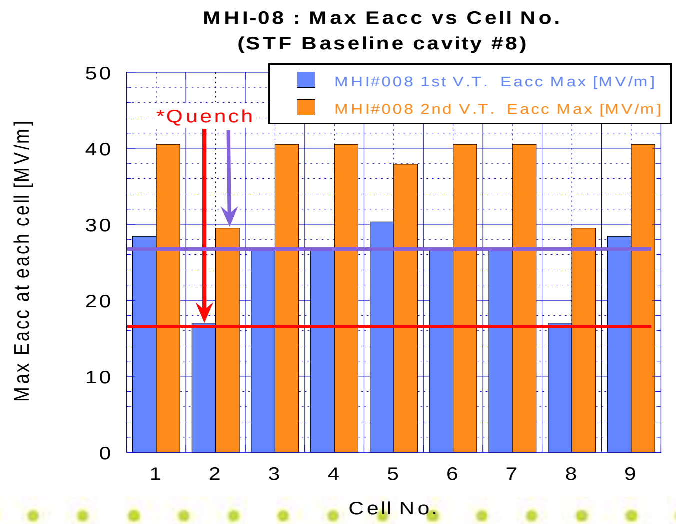
* EP 30um, 50mA/cm2 (Air) at KEK-STF
  1st water rinsing (Air) 90 min, HPR 2 hour

* Inspection after EP 30um, check the grinding location
  Field flatness measurement = keep the flatness.

* EP 20um, 50mA/cm2 (Air) at KEK-STF
  1st water rinsing (Air) 90 min
  FM-20 (2%) 50 C 1hour
  Hot bath 50 C 1hour
  HPR 9 hour, baking 100 C 48 hour

* 2nd Vertical test at KEK-STF. The gradient was raised to 27 MV/m. The quench was occurred at other location.





Inspection and Remediation

T-mapping and optical inspection has proven very powerful in locating geometric defects that explain the majority of lower gradient quenches

- Local grinding has improved performance in 3 cavities so far (4^{th} on the way)
  - Laser / e-beam remelting, barrel polishing / tumbling alternative remediation methods
- Re-EP successful in some cases
  - Also have examples of defects appearing w/ additional EP cycles
- Analysis of defect geometry started
  - Attempt to predict, rather than react
- Root cause of geometric defects still undetermined
  - Location typically, but not always near HAZ of equator weld

Fundamental understanding is increasing, but not yet sufficient. We do not yet have a set of inspection criteria for an as-built cavity.

Remediation / Improvements

- Defect Prevention
- Defect Detection and Repair
- Surface Resetting

For < 25MV/m quenches drive defect recognition / repair / prevention much earlier in the manufacturing cycle

For > 25 MV/ m limits continue efforts to better control and understand process

- Post VT Defect Remediation
- Post VT Re-EP

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Vertical Test	Performance Test with temperature and mode measurement →inspection, reprocessing, other remediation

Summary

Efforts to date have

- Increased number of vendors
- Increased vendor scope of work
- Increased the processing facilities
- Increased the diagnostic tools
- Increased the fundamental understanding of limitations

Leading to the increased production yields seen now

To 2012…..

- We have tens of cavities in the pipeline this year to work with
- We need an understanding of an earlier acceptance criteria
- We need to learn how to prevent pits and bumps
- We need to continue to best mix industry and laboratory skills