Summary and issue of SC-cavity

IWLC2010 WG3-WG4 joint session

H. Hayano, KEK

SC Cavity issue

There are many issue. I just pick up the followings, in this session.

(1) Yield of High Gradient
Gradient scatter (defect, field emission, contamination)

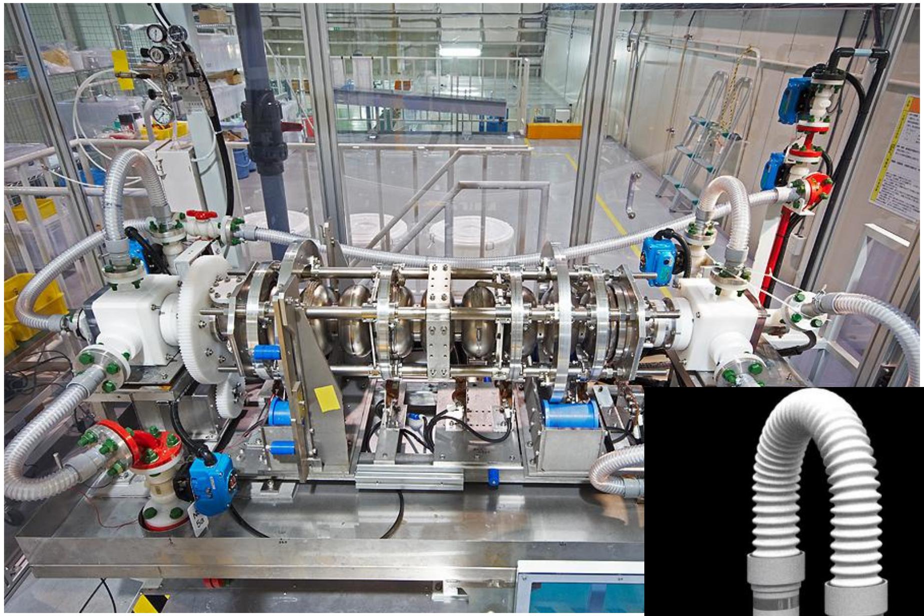
(2) LLRF vector-sum control (need to align cavity performance)

(3) Alignment in the cryomodule
hard to fix the cavity alignment at 2K

(4) Cost reduction
Fabrication cost reduction (cavity cost, coupler cost, etc)
Operation cost saving (RF power, cryo-power saving)

** I do not talk about (4), this time.

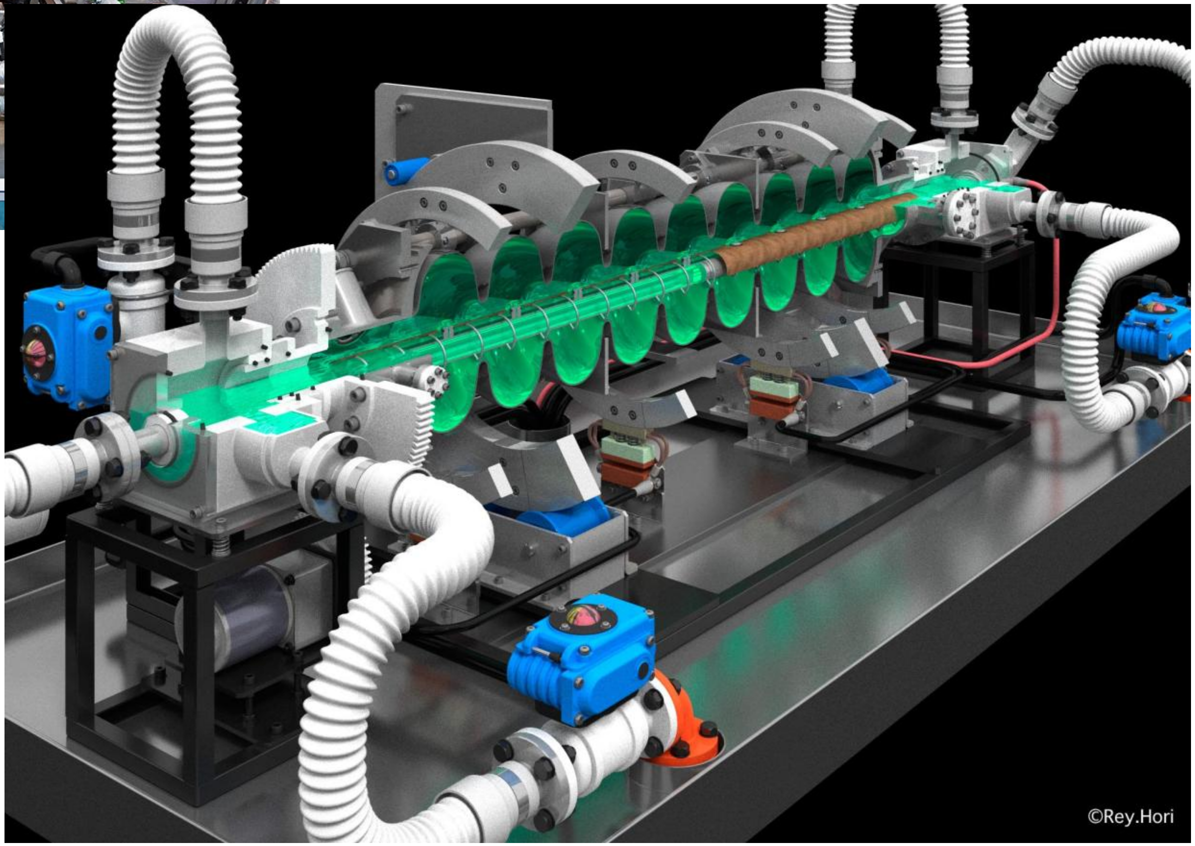
Cavity Surface Treatment

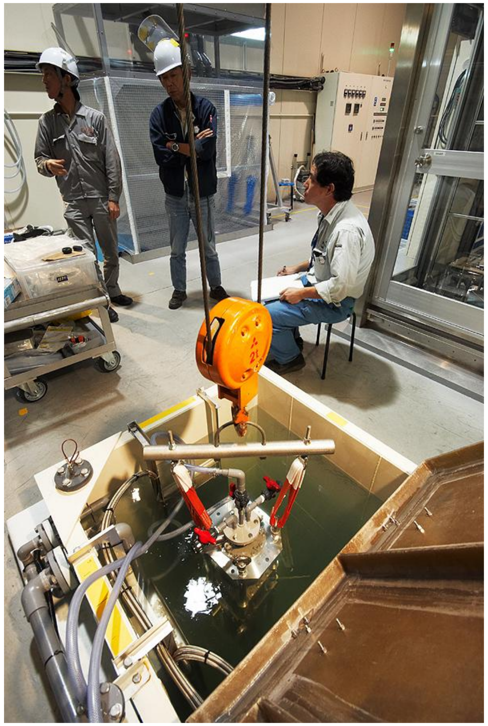


Electro-Chemical Polish

Use Sulfuric acid + HF mixture
Apply voltage
between center Al electrode and Nb cavity
Optimize parameter for smooth surface
without sulfur residual particle
voltage and temperature are key parameter
Successive rinsing is another key technology

KEK STF EP as an example

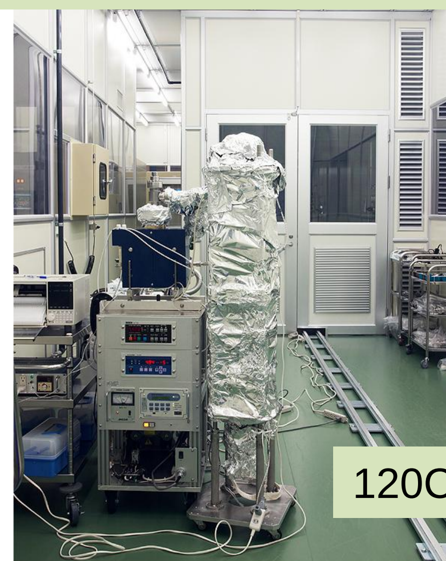




ultra-sonic rinsing
with degreaser

High Pressure water Rinsing

Antenna, pump-port, flanges assembly
in class-10 clean room

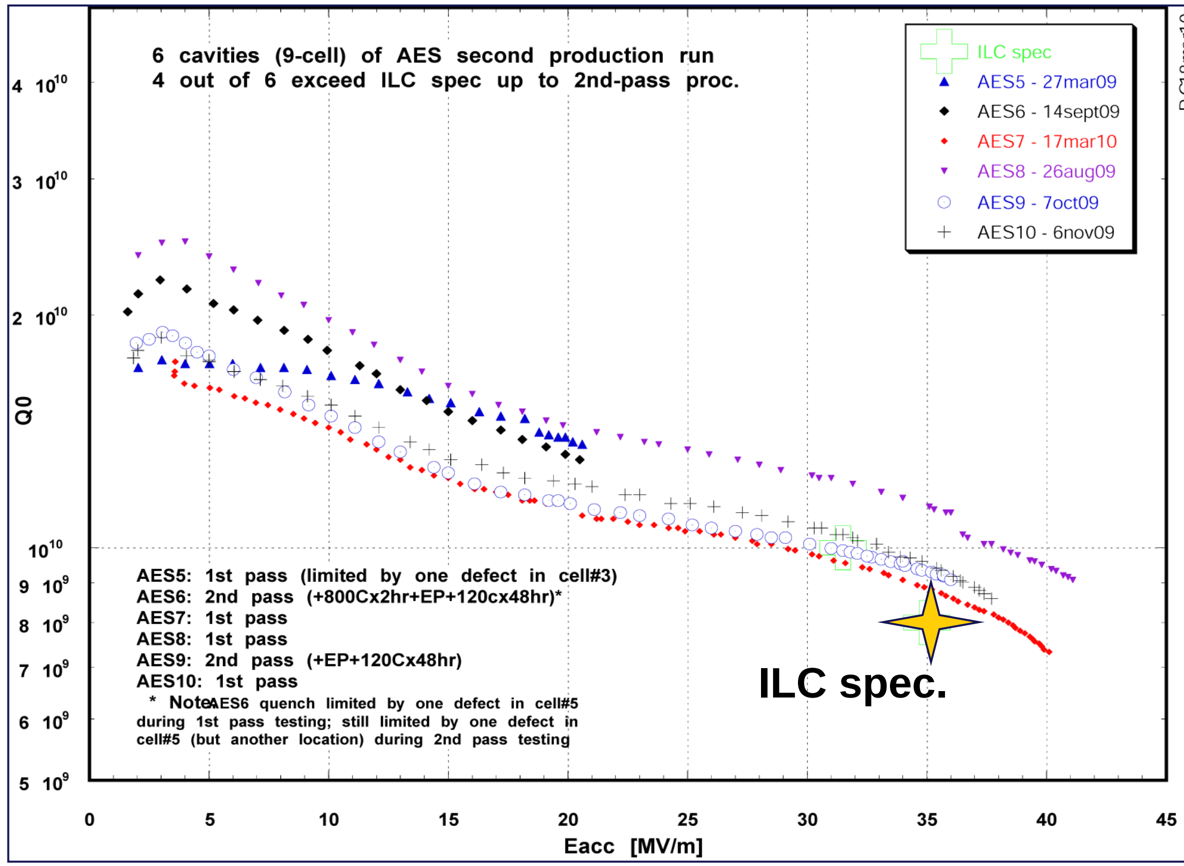


120C baking

Cavity Testing before Cryomodule Installation

Vertical Dewar test
for gradient performance check.
(KEK-STF as an example)

JLAB: AES cavity results March 09 – March 10

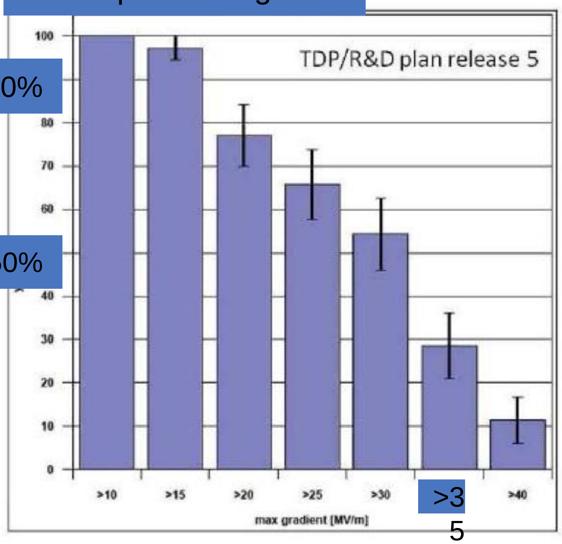


Successive 4 cavities are beyond 35MV/m

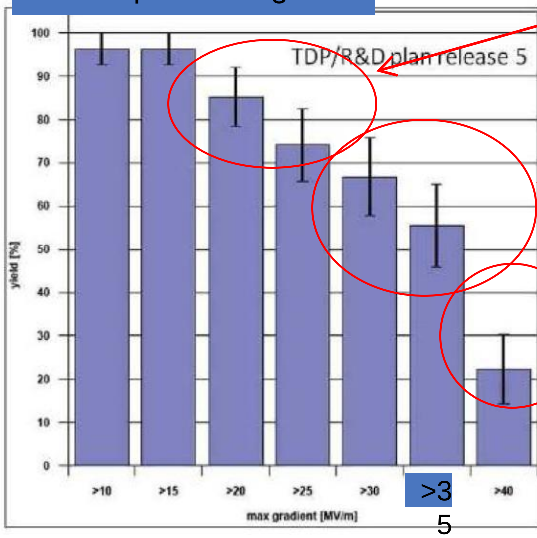
SCRF High-Gradient R&D

Slide from A. Yamamoto

1st EP processing



2nd EP processing



By defect

By field emission

Close to H_c limit

Recent Results from JLab indicate separation of mechanical defects from surface preparation

Production* cavities achieving specified gradient

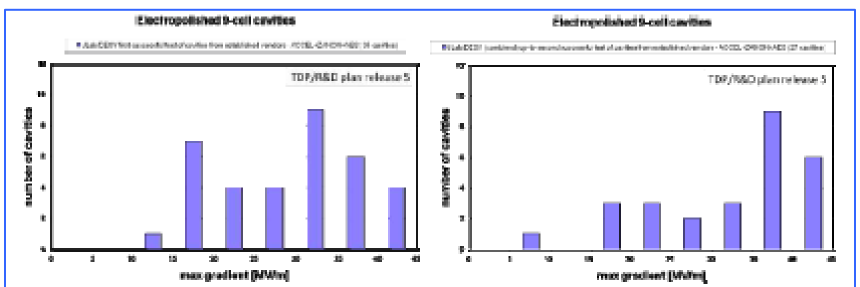
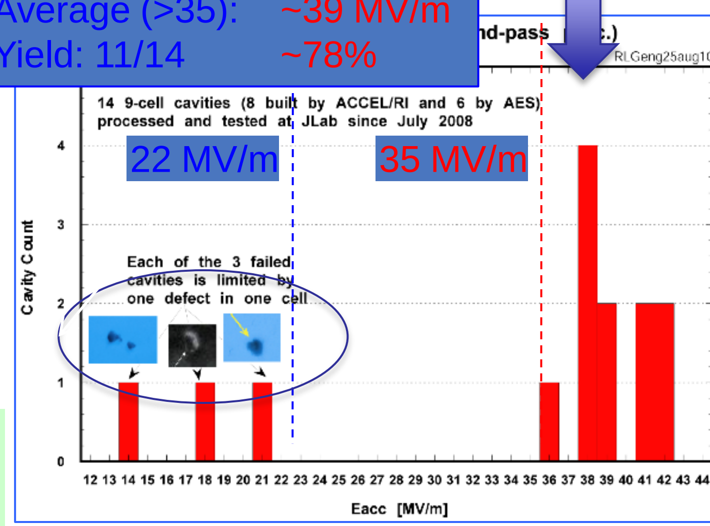
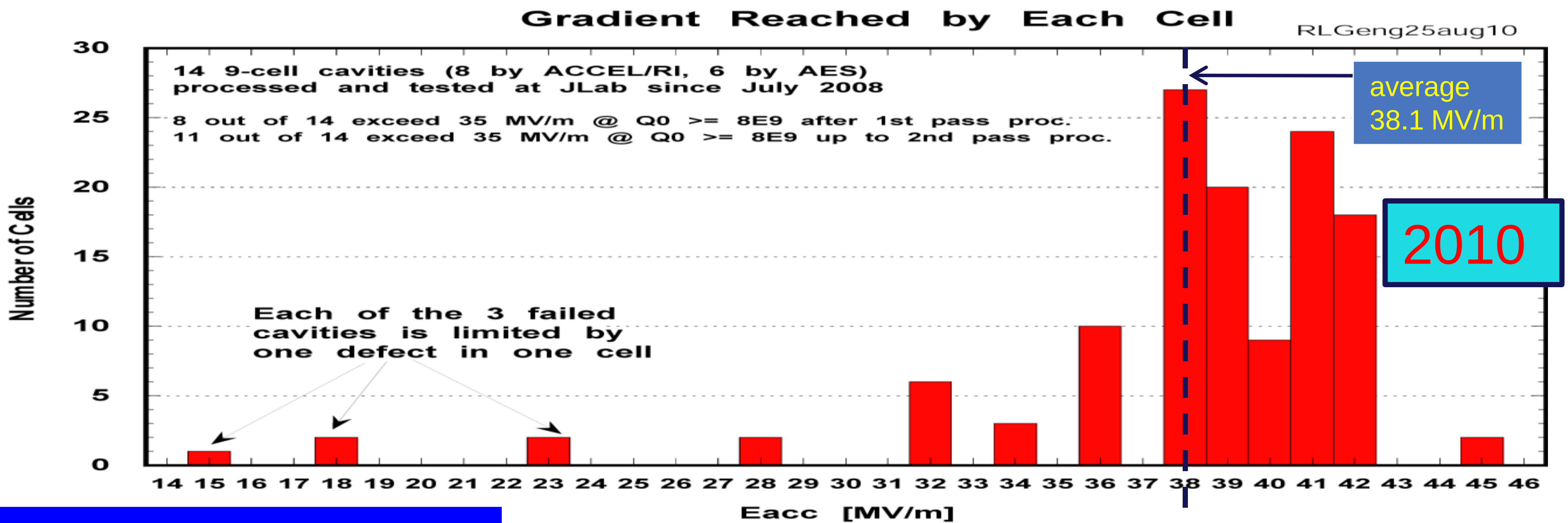


Figure 4.2: Number of cavities as a function of maximum gradient, for first-pass (left) and second-pass (right) data samples. [updated data by June 30.]

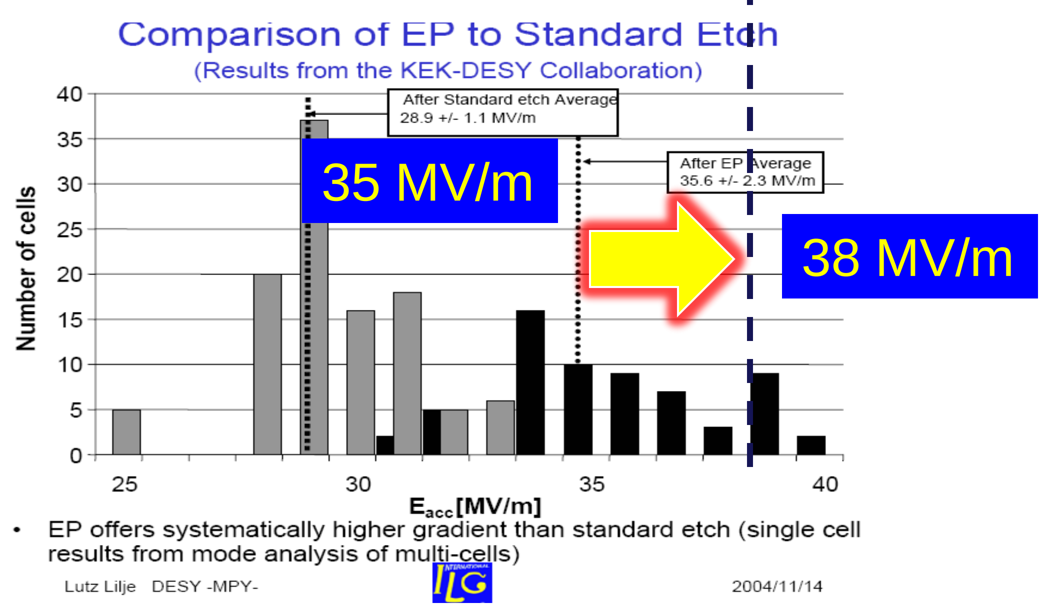
Average (>35): ~39 MV/m
Yield: 11/14 ~78%



Production*: cavities having followed baseline ILC production process, as defined by specific cuts specified by the **GDE International Database Team**



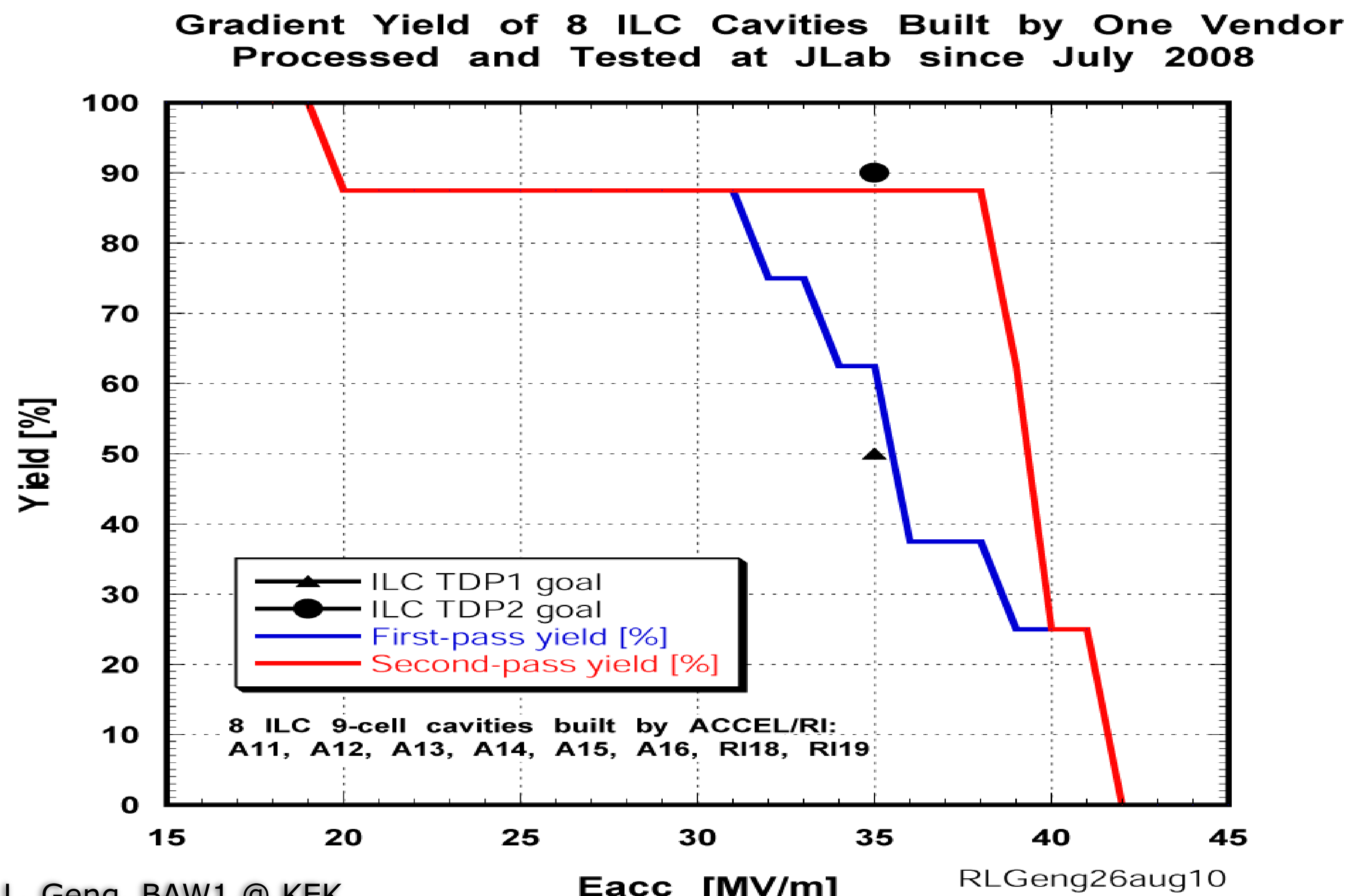
Gradient State-of-the-art then and now



2004

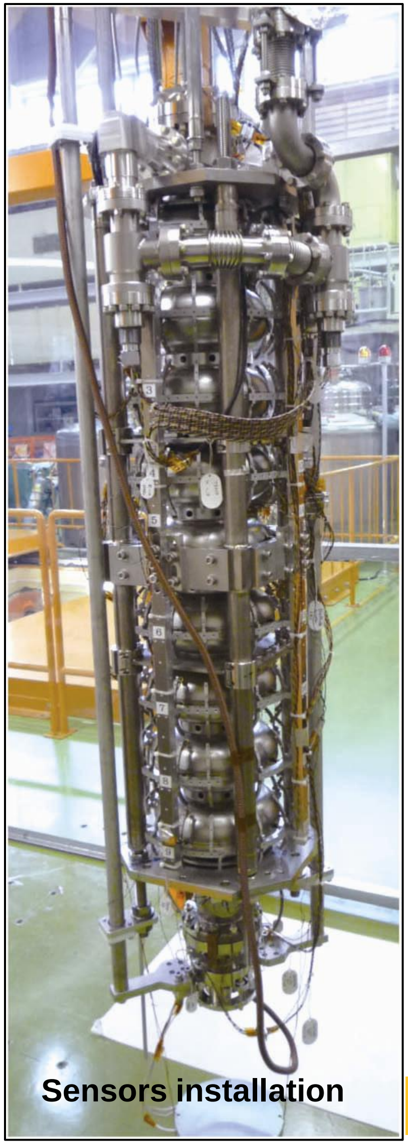
2004 DESY EP 9-cell cavities
Gradient distribution in cells from
pass-band measurements (~ 8 cavities)

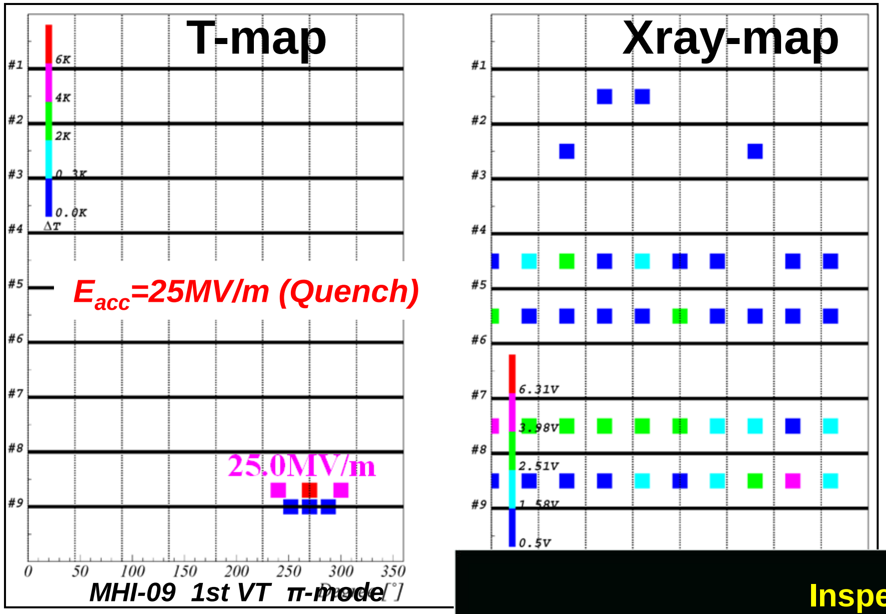
An Example of 88% Yield up to 38 MV/m with 8 Cavities from One Vendor



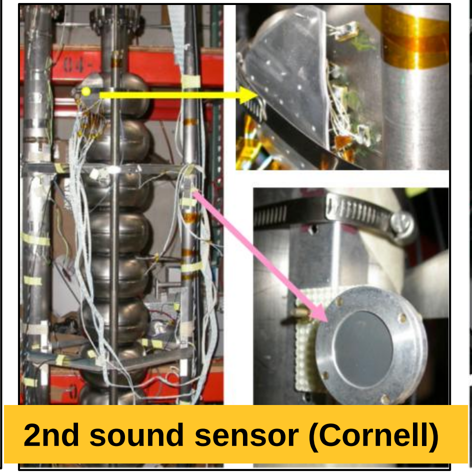
R.L. Geng, BAW1 @ KEK
September 9, 2010

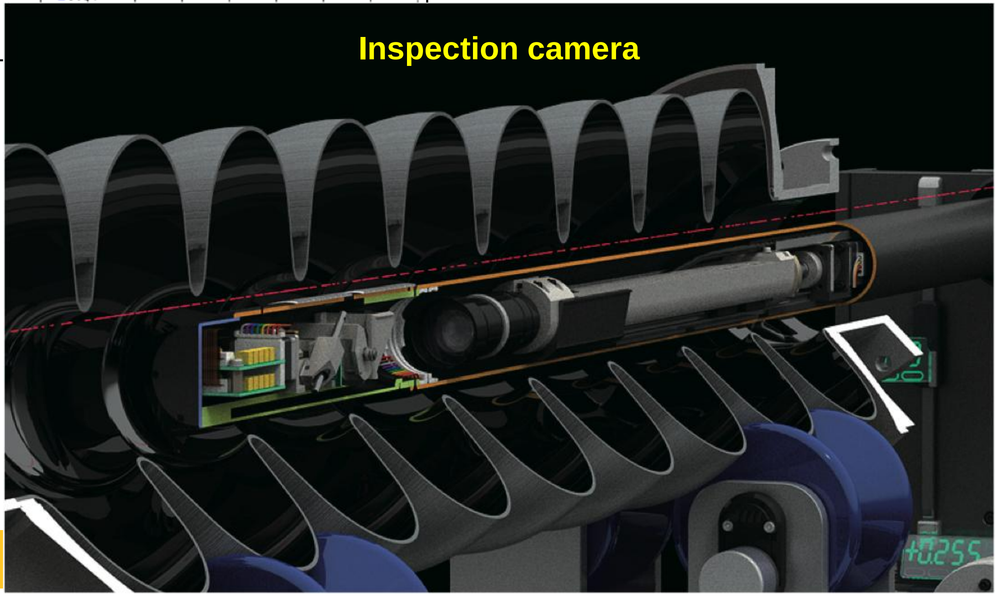
Diagnostics Instruments for quench location identification


Sensors installation

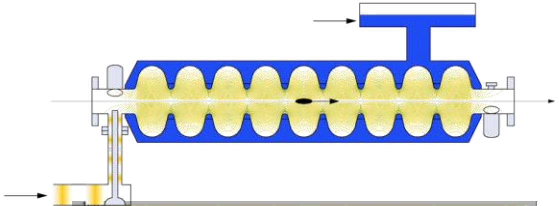


T-map & X-ray-map, 2nd sound sensor together with pass-band mode measurement, location of quench is identified.
Inspection camera visualize what's happen inside.

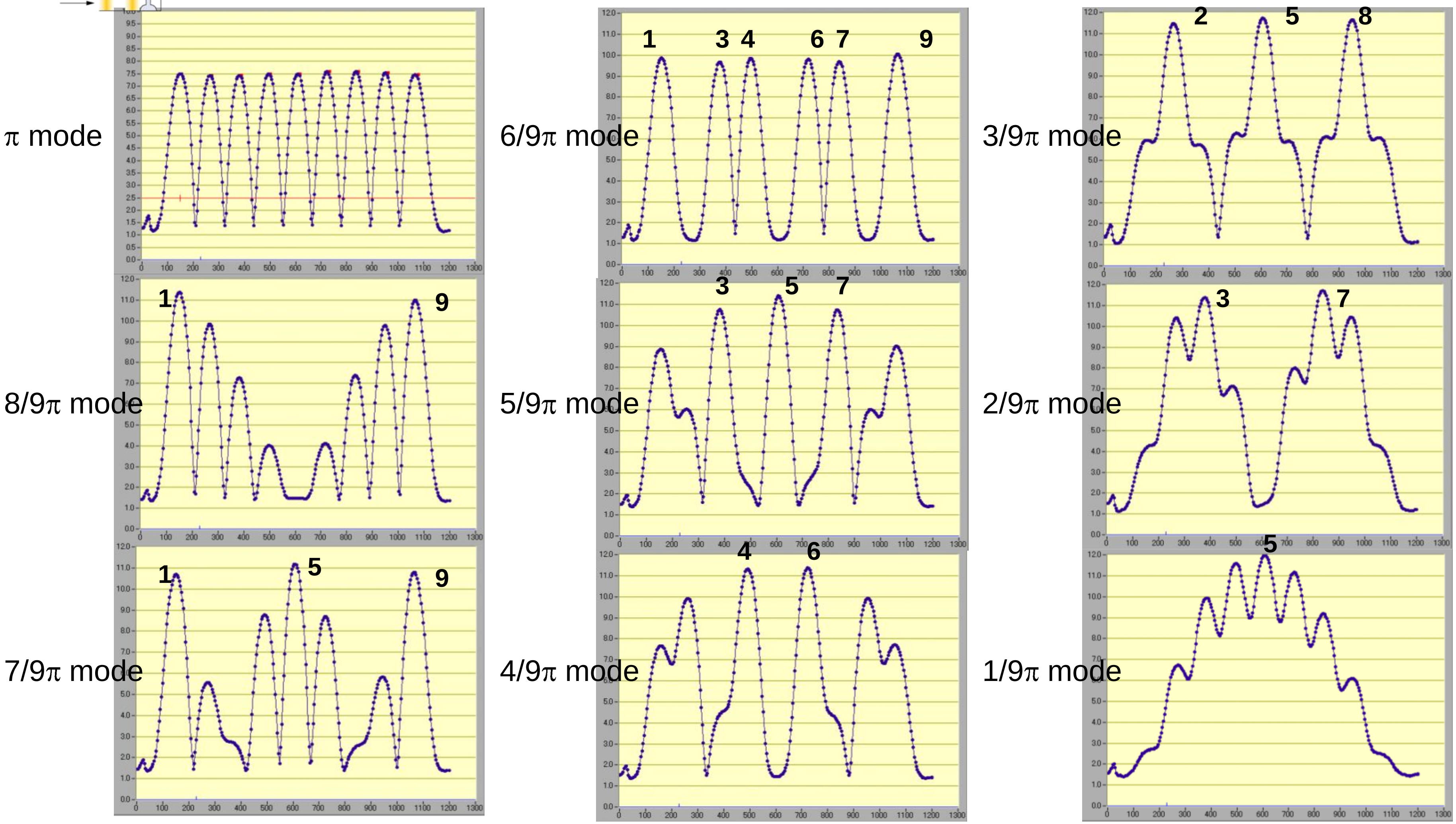

2nd sound sensor (Cornell)


Inspection camera

Each cell performance by Pass-band mode excitation



9-cell cavity has 9 modes in the pass-band

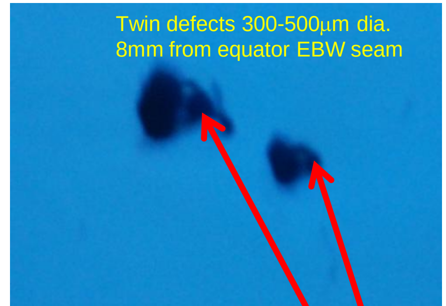


Field distribution on axis

Examples of Quench Limited Cavities

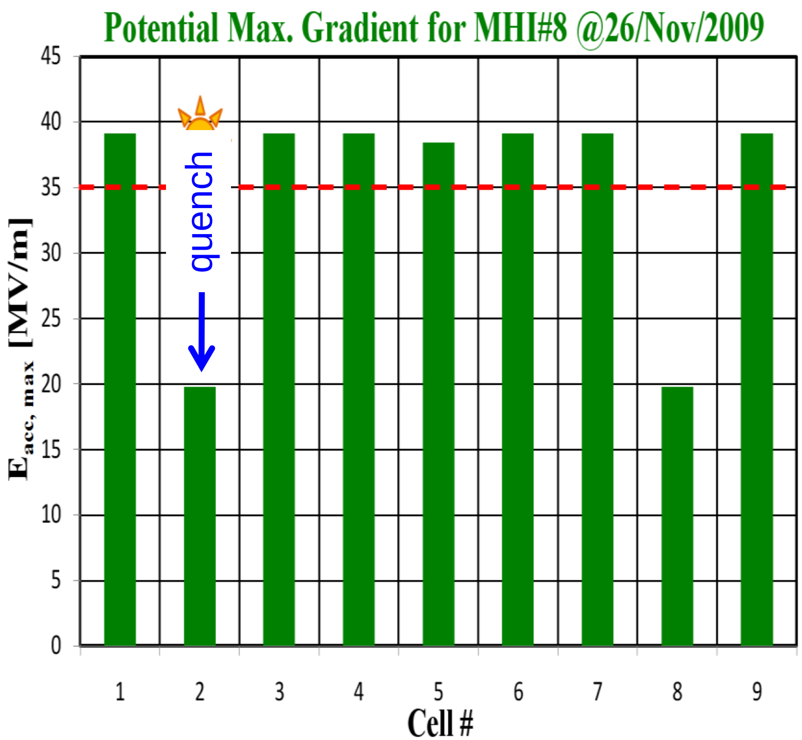
MHI#8

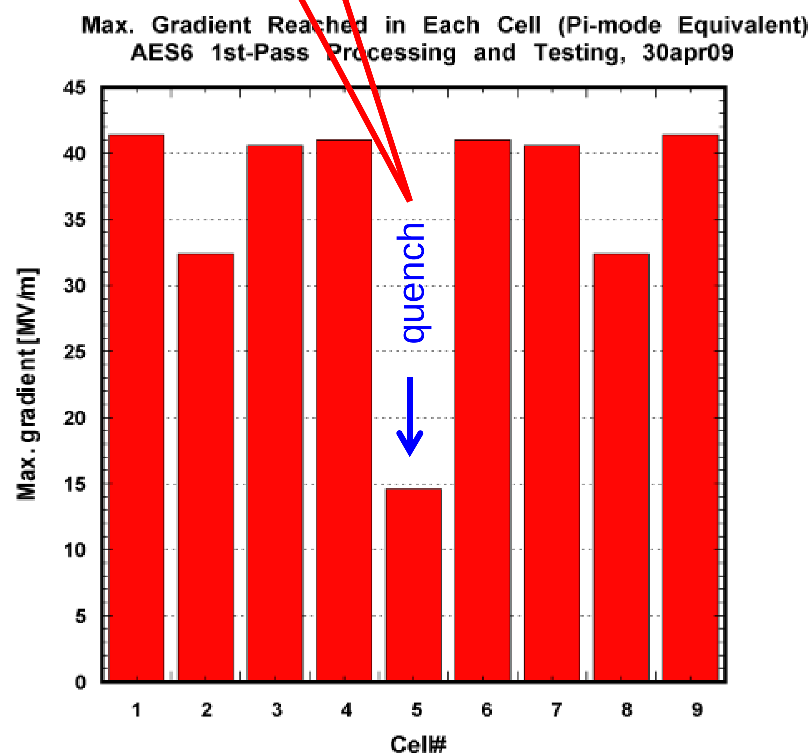
- No geometrical defects (down to ~10μm) observed at quench location
- Re-EP effectively raises cavity gradient: 18 MV/m >>> 38 MV/m



AES6

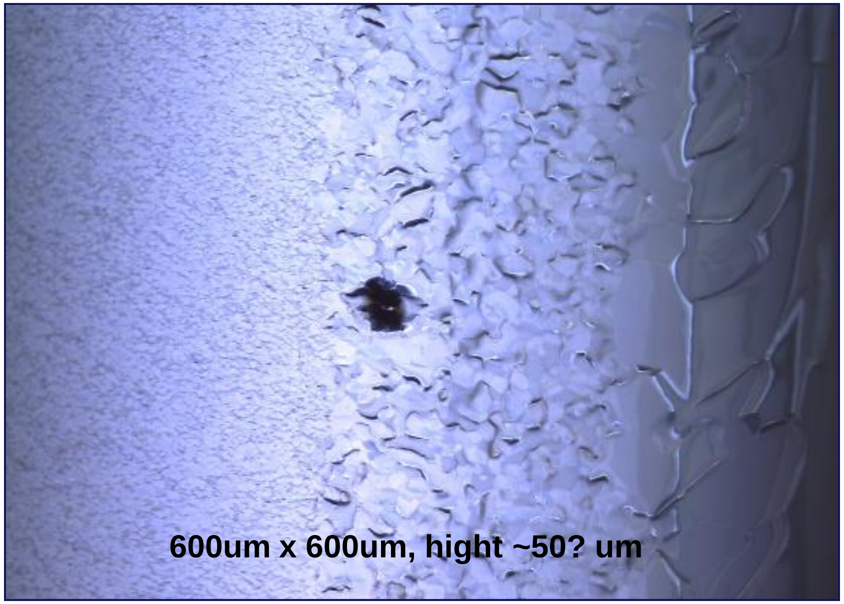
Twin defect in center cell limit cavity gradient to 15 MV/m; while all other cells capable of 32-41 MV/m; re-EP has little effect.





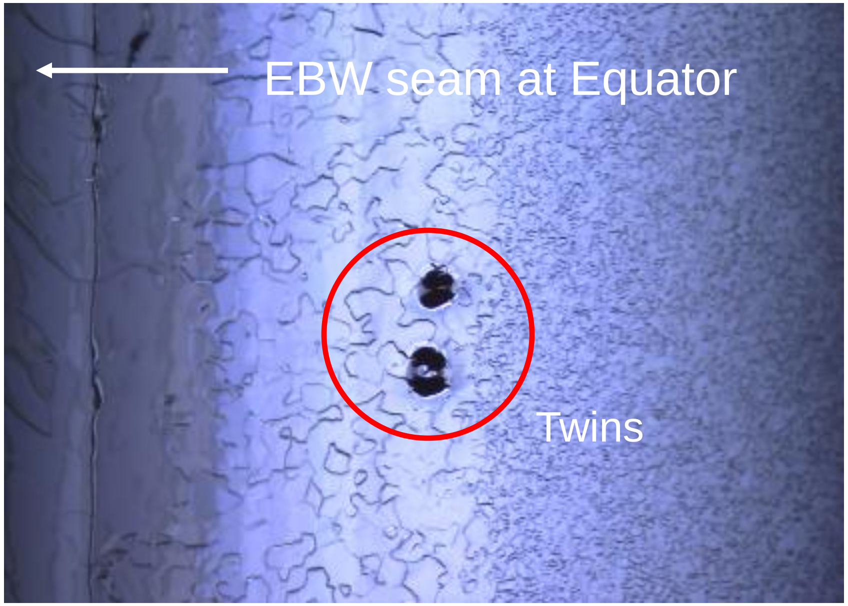
What's inside at quench location

AES003 4-cell equator, t=306 degree



Quench at 20MV/m

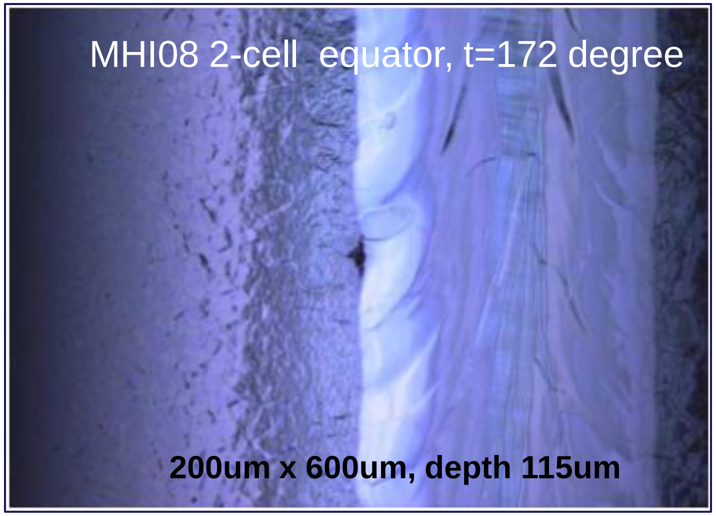
AES-001: 3-cell equator, t = 169 deg. Bump type

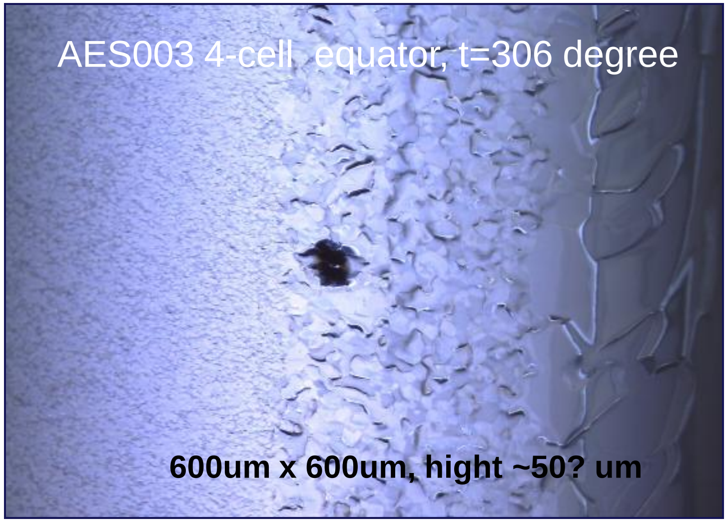


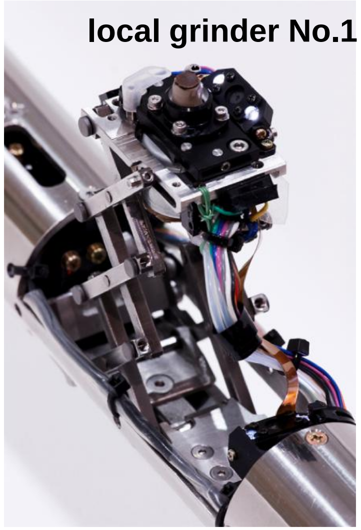
Quench at 22MV/m

Try to grind inner surface

for example







Pit; appeared after bulk EP, limit to 16MV/m

↓ local grinding & EP

27MV/m

↓ additional EP

38MV/m

Bump at heat affecting zone, limit to 20MV/m

↓ local grinding & EP

30MV/m

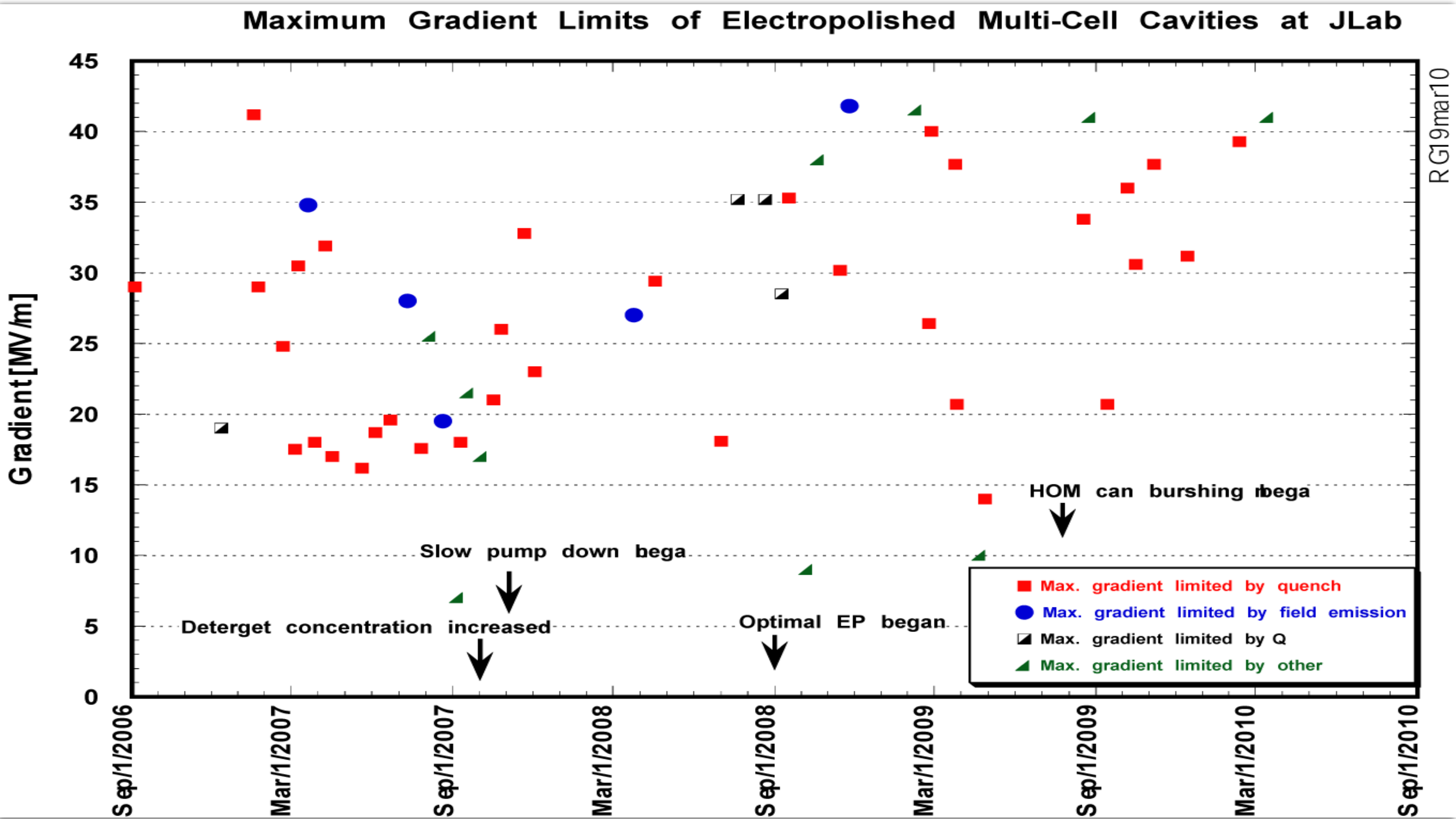
↓ additional HPR and bake

34MV/m

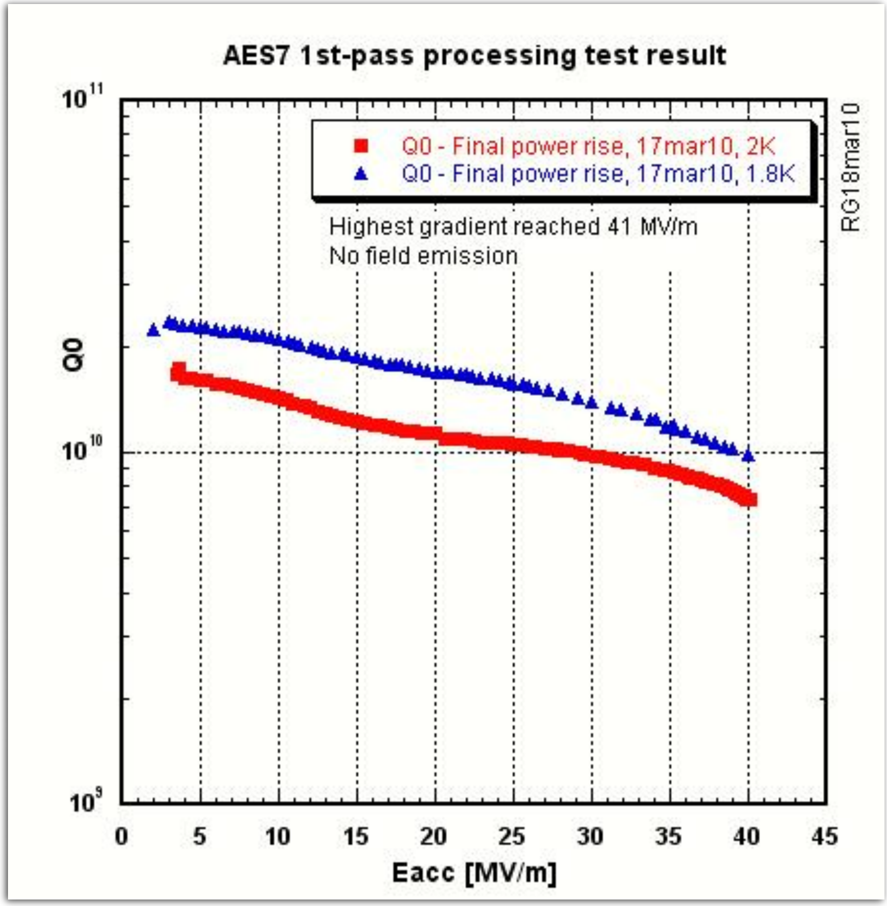
local grinder No.3

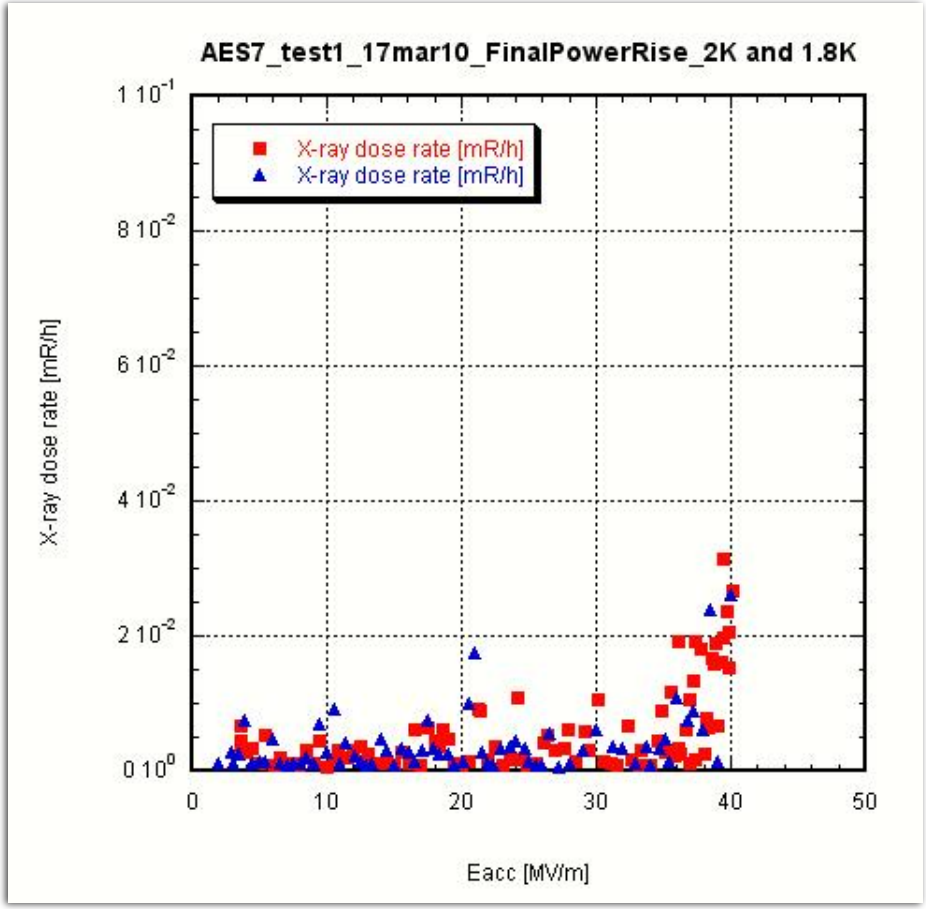
Gradient were improved by grinding repair

Maximum Gradient in EP Multi-Cell Cavities



Latest EP 9-Cell Result w/o FE at 40 MV/m

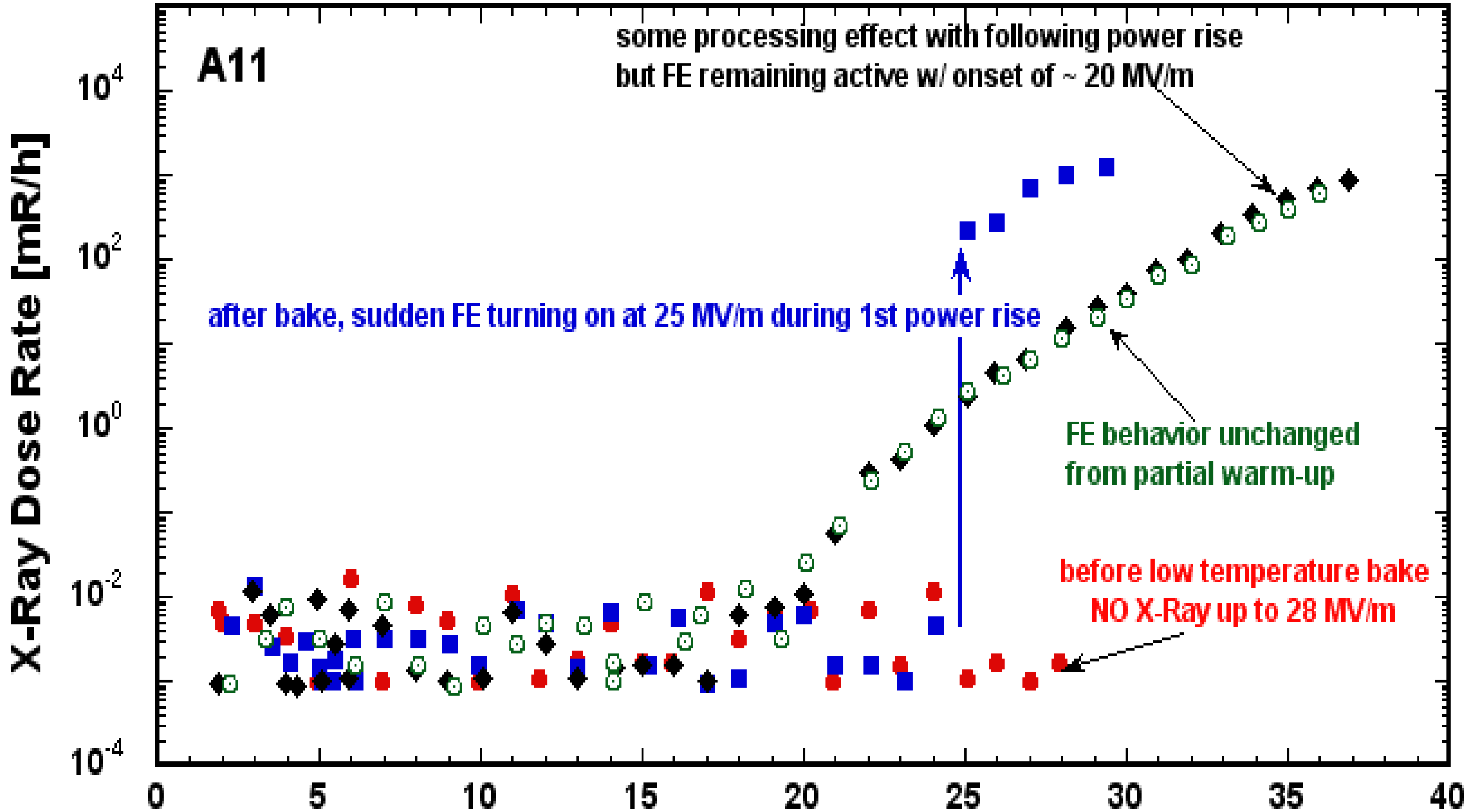




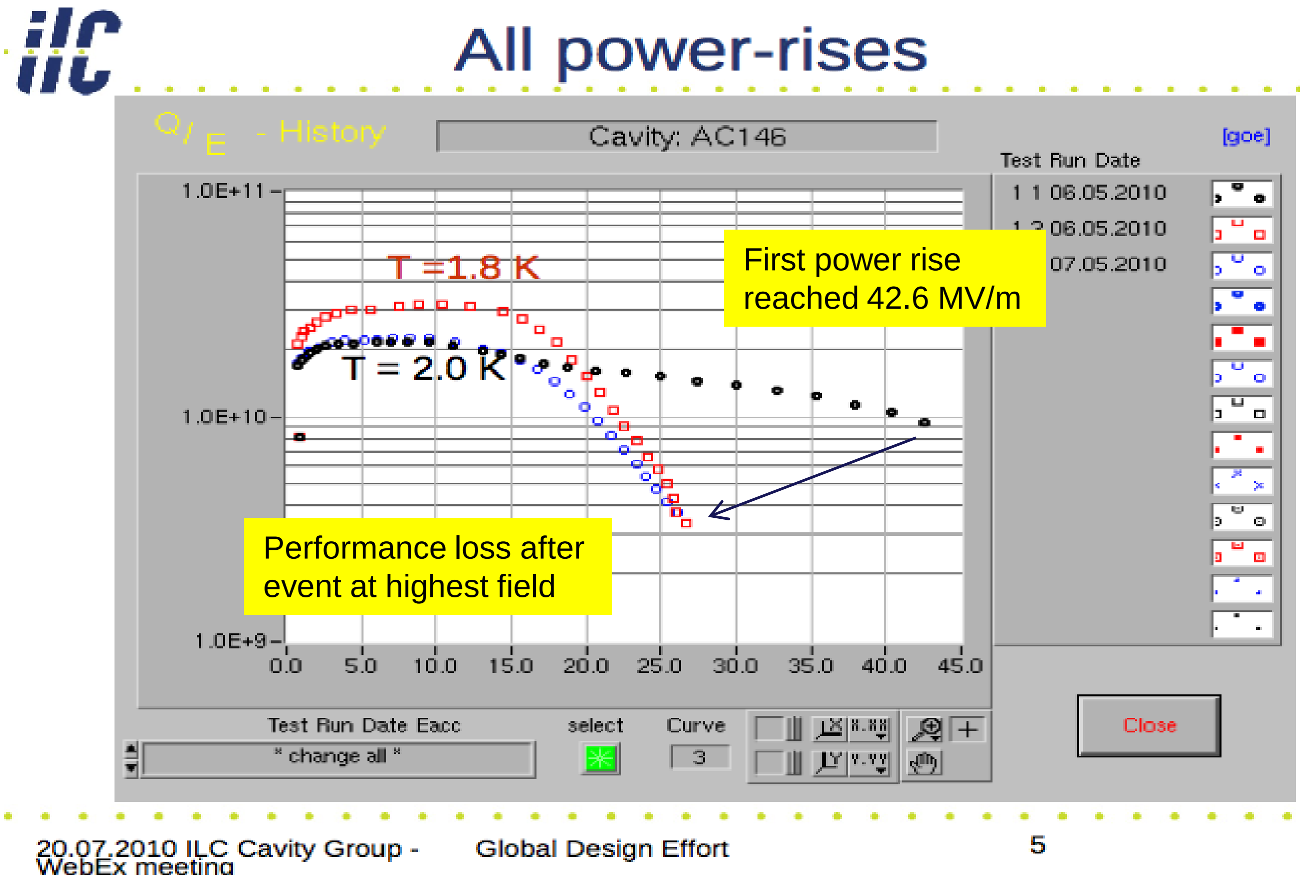
41 MV/m reached during initial power rise, at which gradient precursor FE started
Later power rise limited to 40 MV/m to prevent explosive emitter activation

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.



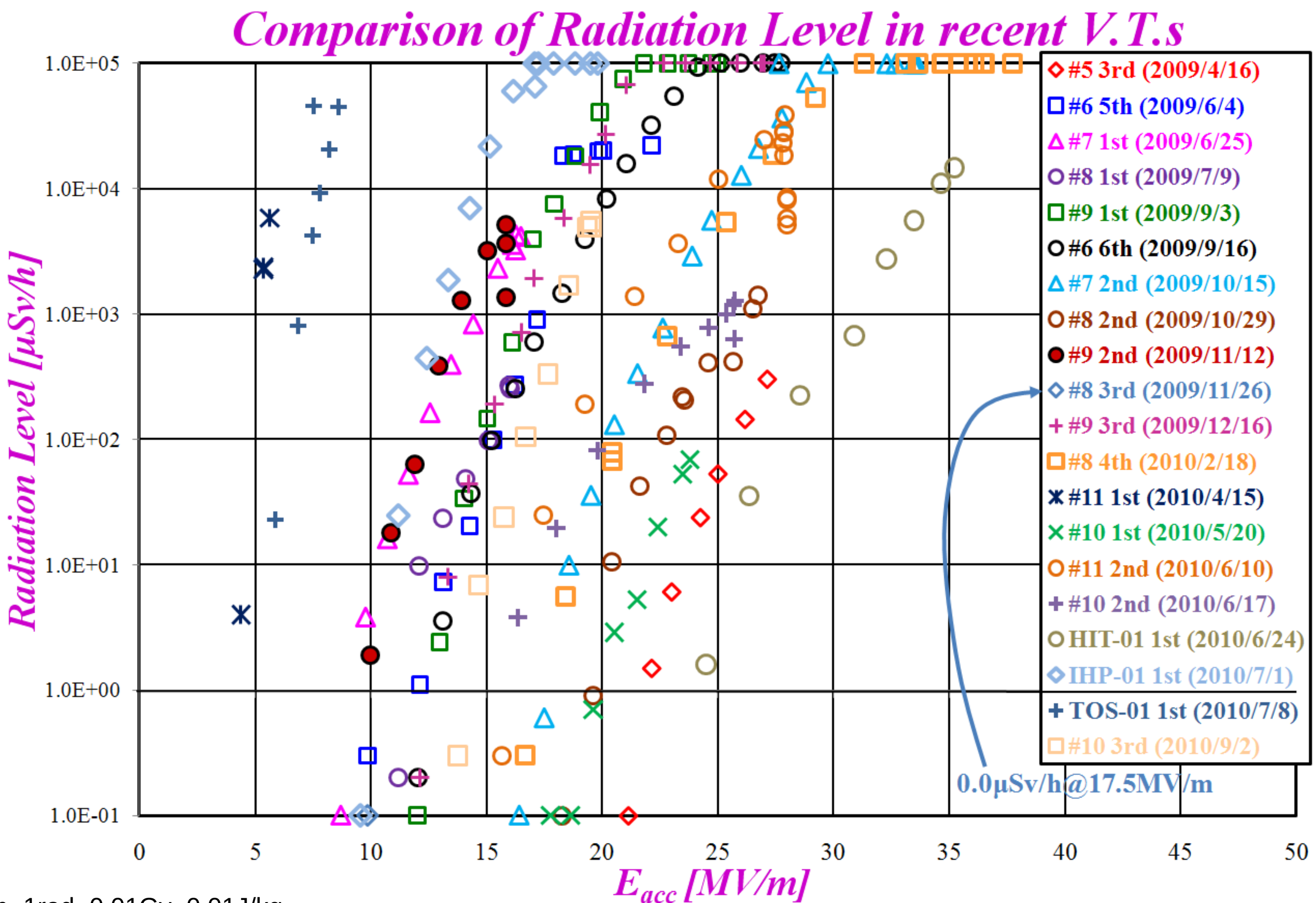
Another example of Field Emission turned ON



- 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.

Radiation level of Recent STF cavities in VT

Radiation monitor is placed at Top outside of VT cryostat end-plate, inside of radiation shield.



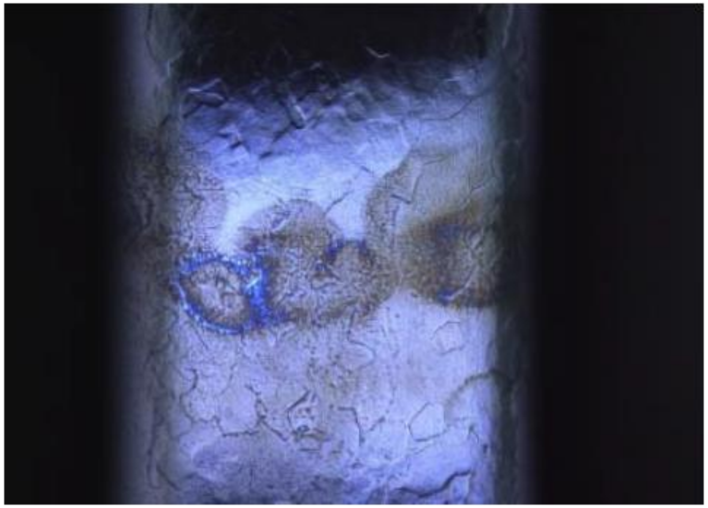
1 Sv=100rem
For X-ray, 1rem=1rad=0.01Gy=0.01J/kg

Cf. KEK Radiation worker area: <20μSv/h

KEK cavities in VT have strong radiation, every time.

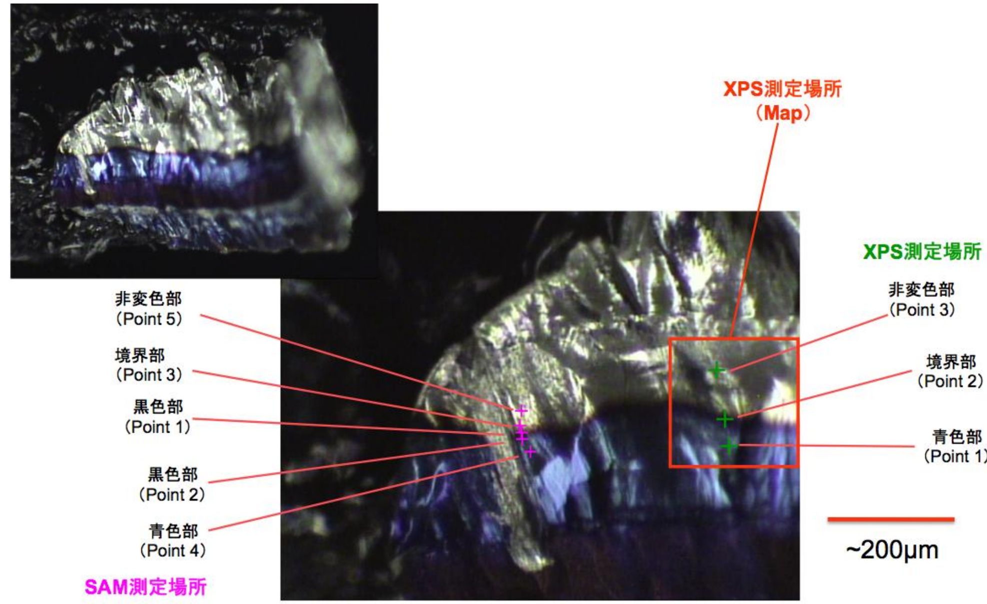
STF EP process evaluation: stain problem

BL#6 #9-BP, t = 241 deg. -2



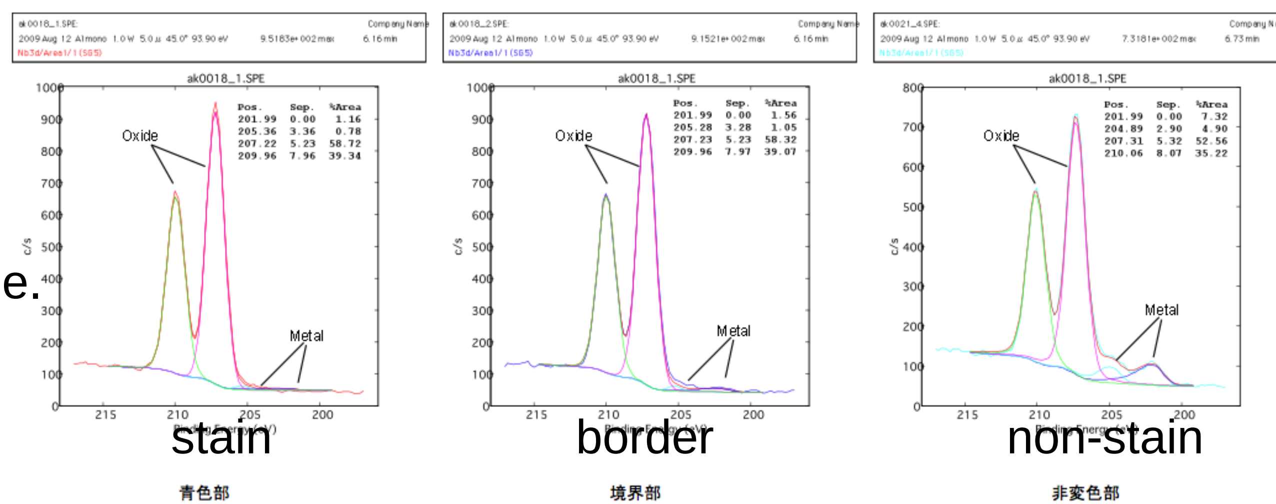
Observed stain in cavity.
may cause field emission??

component analysis of stain region and normal region by microXPS



stain is Niobium-oxcide.

new acid cause stain.

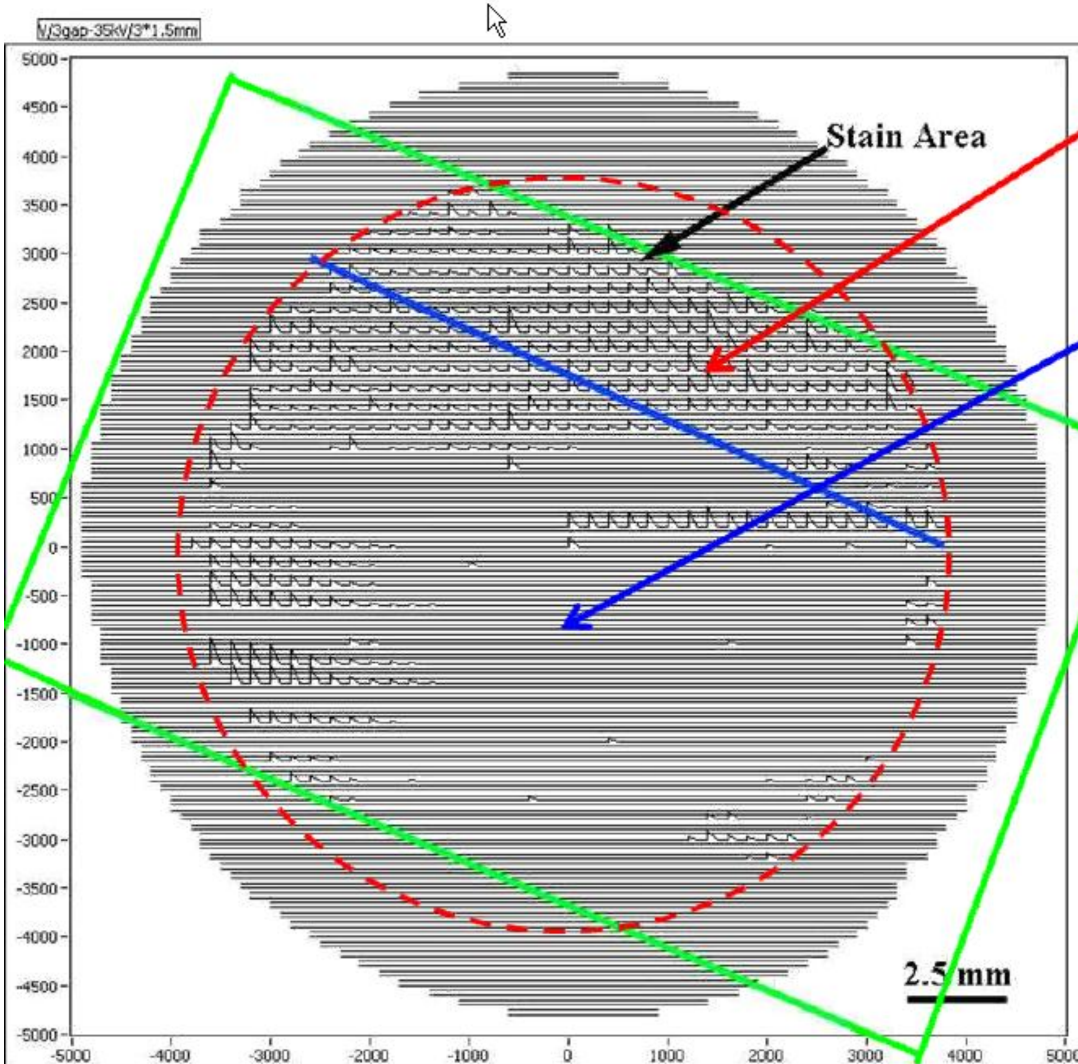


stain border non-stain

Field emitter scan on stain sample : JLAB-KEK collaboration

JLab SFSEM analysis of KEK rectangular shape EP'ed Nb coupon with stain

First data of DC field scan up to 140 MV/m. It seems to confirm stain being source of FE.



High field emitter density in stain area

Much lower field emitter density outside stain area

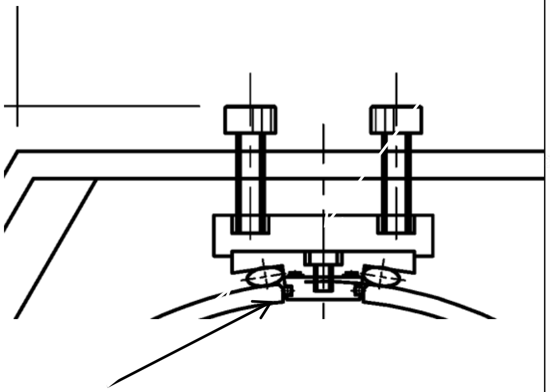
A. Wu

EP'd surface analysis (monitoring) using button samples

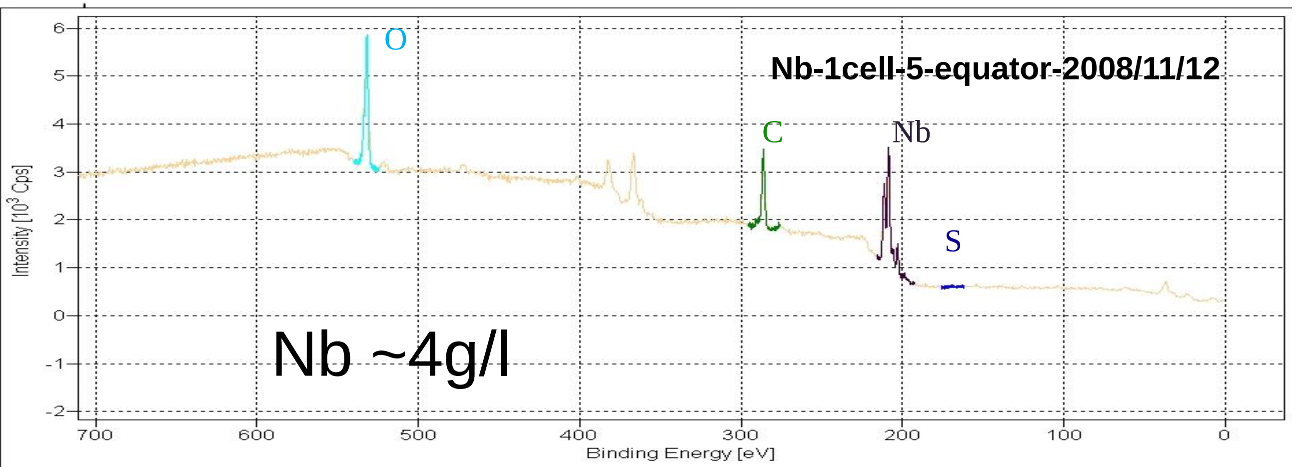
Nb button samples: 8mm dia.

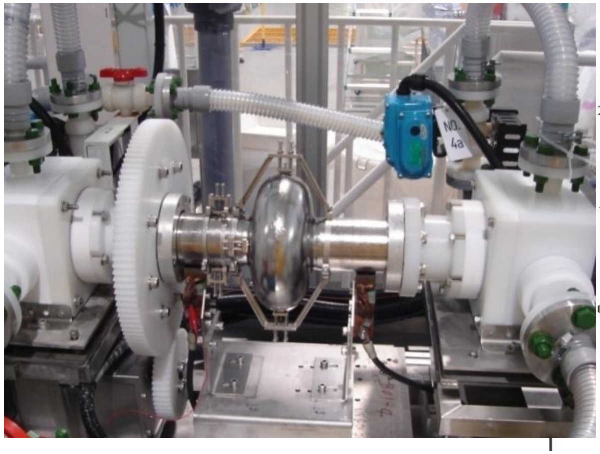
For understanding of Residuals after treatment,

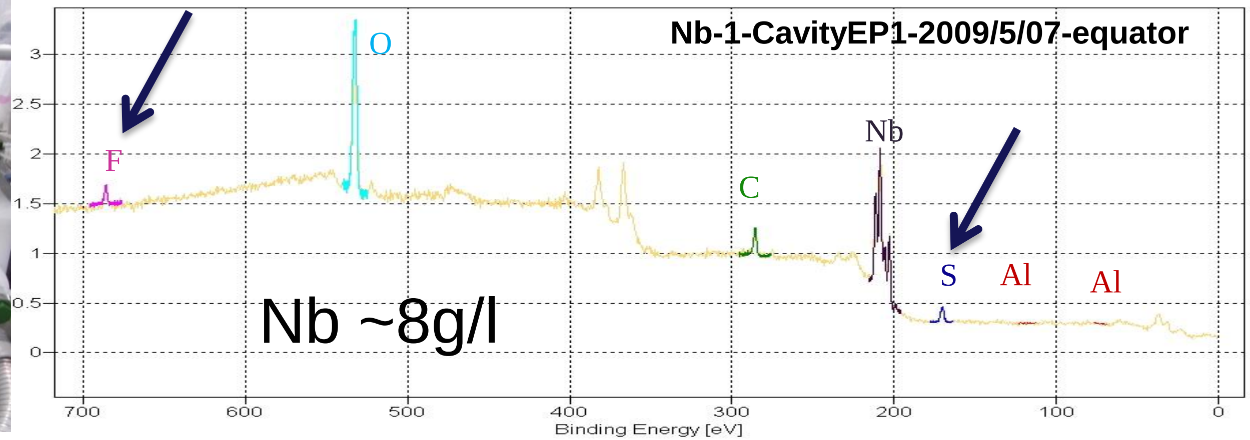
SEM-EDX, XPS, AES, SIMS are the tool of analysis.



button sample



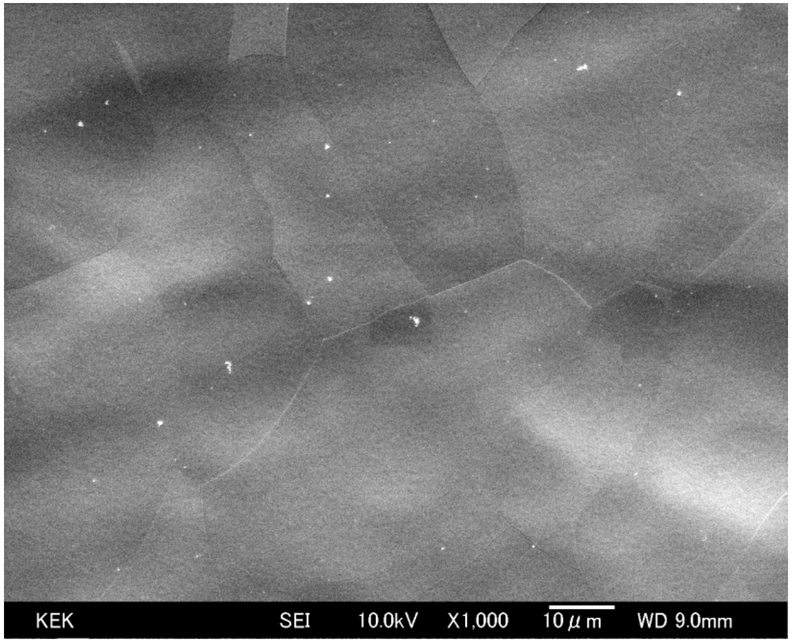




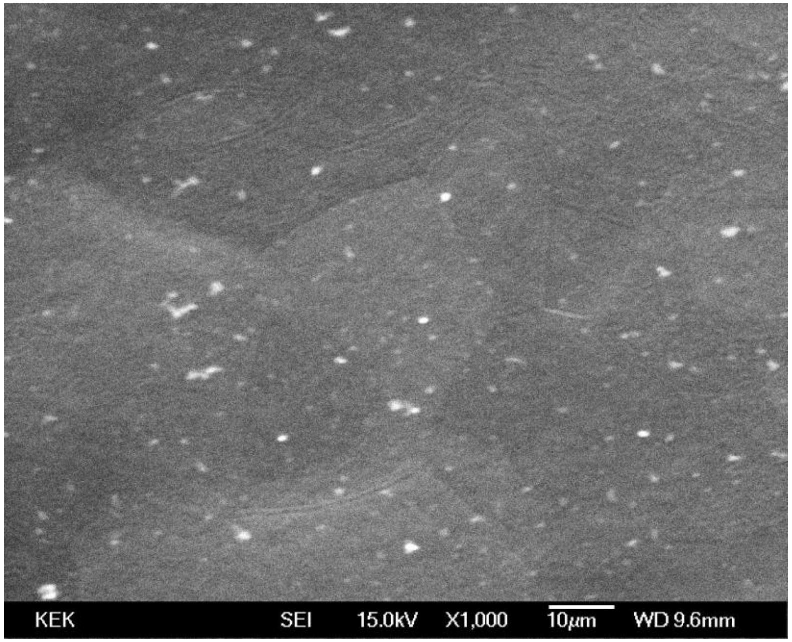
EP'd surface analysis (monitoring) using button samples

SEM analysis example

button sample on beam-pipe



new EP acid



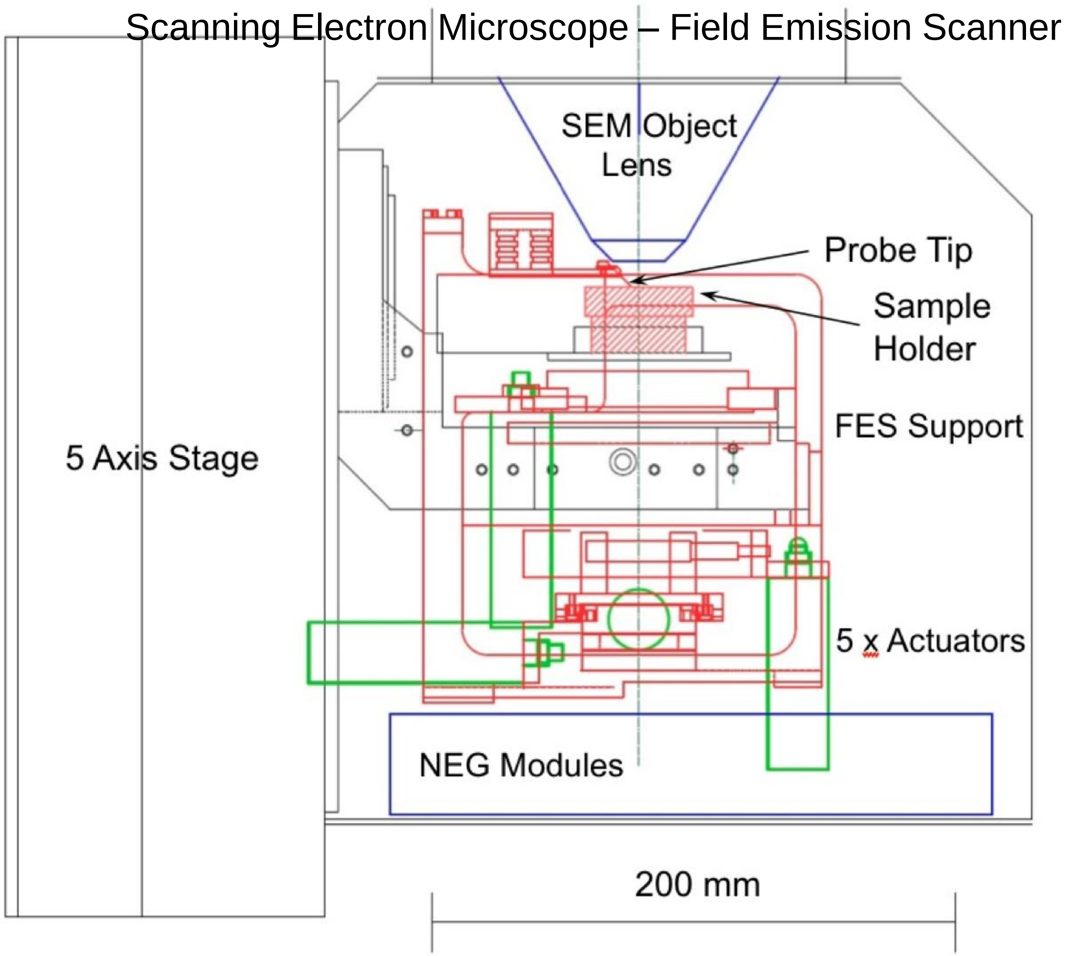
aged EP acid (Nb = 7.9g/l)

(KEK-EDX could not analyze the white spot.)

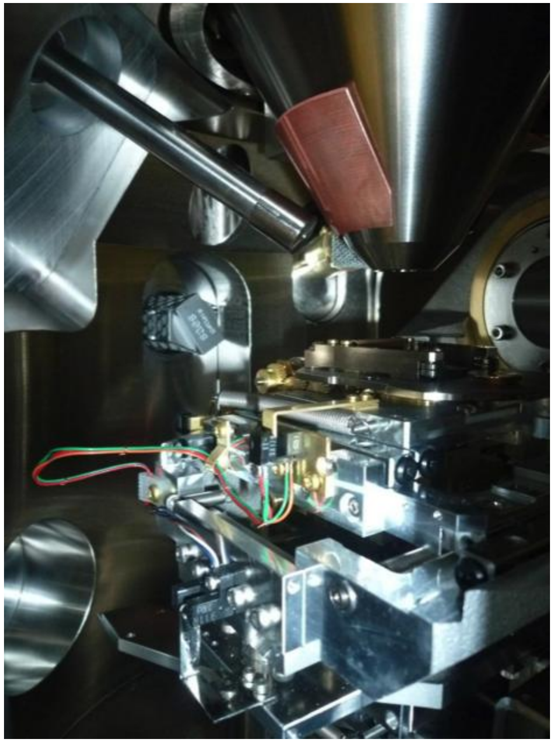
For more systematic study of field emission and stain correlation,

SEM-FES combination device is under development in KEK

Scanning Electron Microscope – Field Emission Scanner



Schematic view of SEM-FES



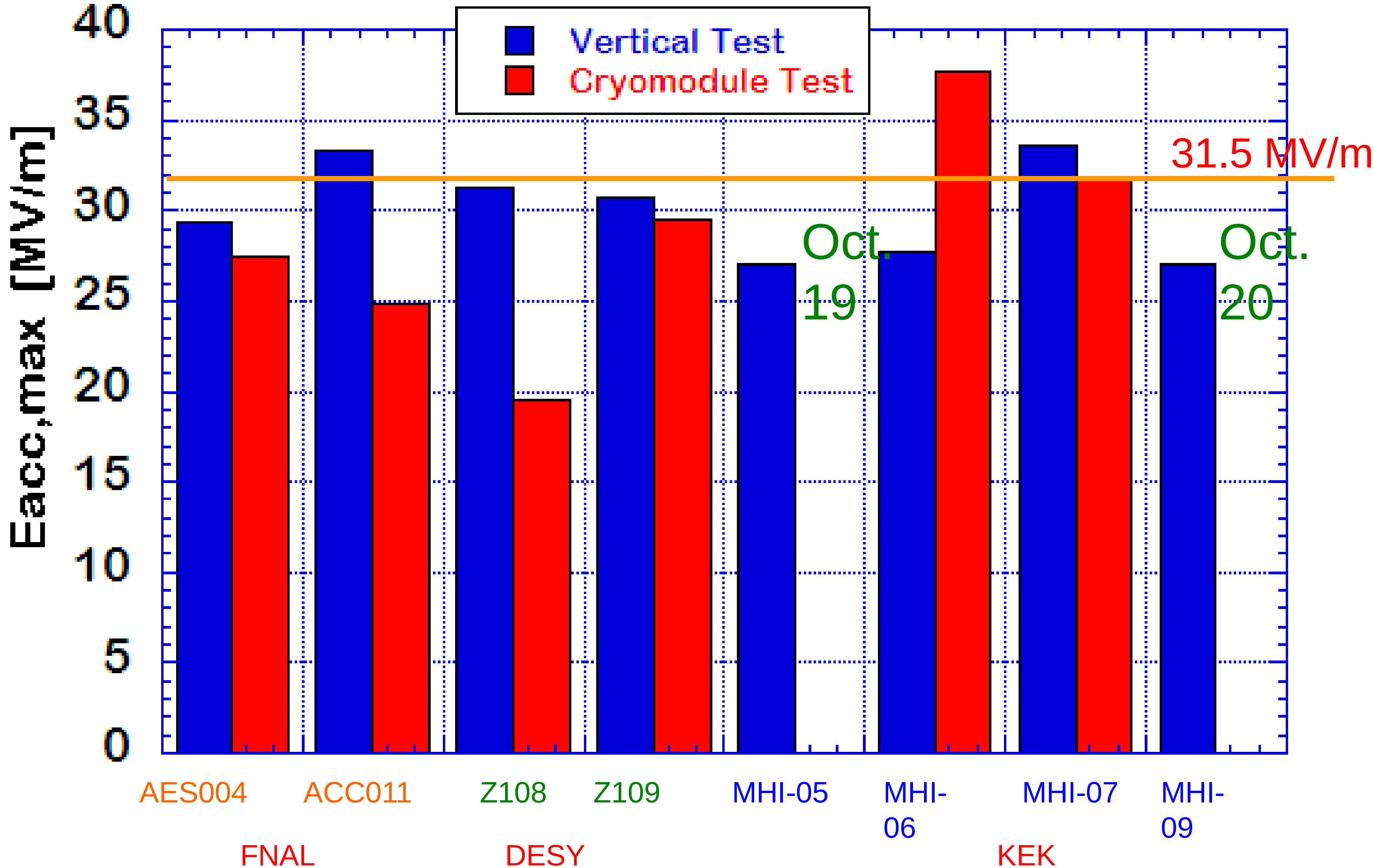
Picture of SEM-FES movable table under developing

<5kV/50μm=100MV/m
Raster Scan over 5mm□
with help of SEM obserbation

Field reduction after cryomodule assembly

S1-Global cryomodule Test at KEK

RF feedback / ON
Flat-top = 1.0 ms, 5 Hz



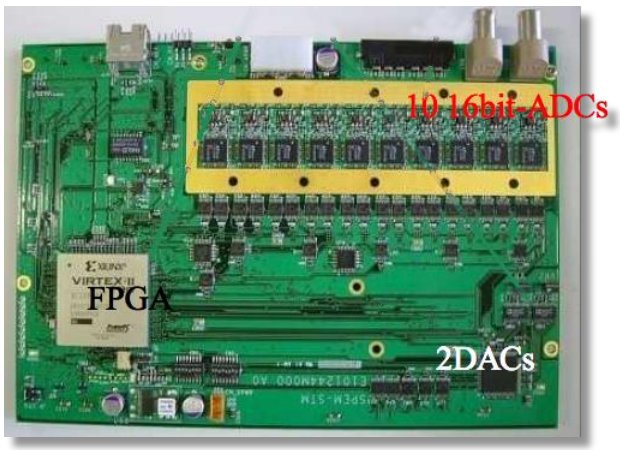
Just a recent example

Field variation in vector-sum control

Precise digital feedback control with feed forward

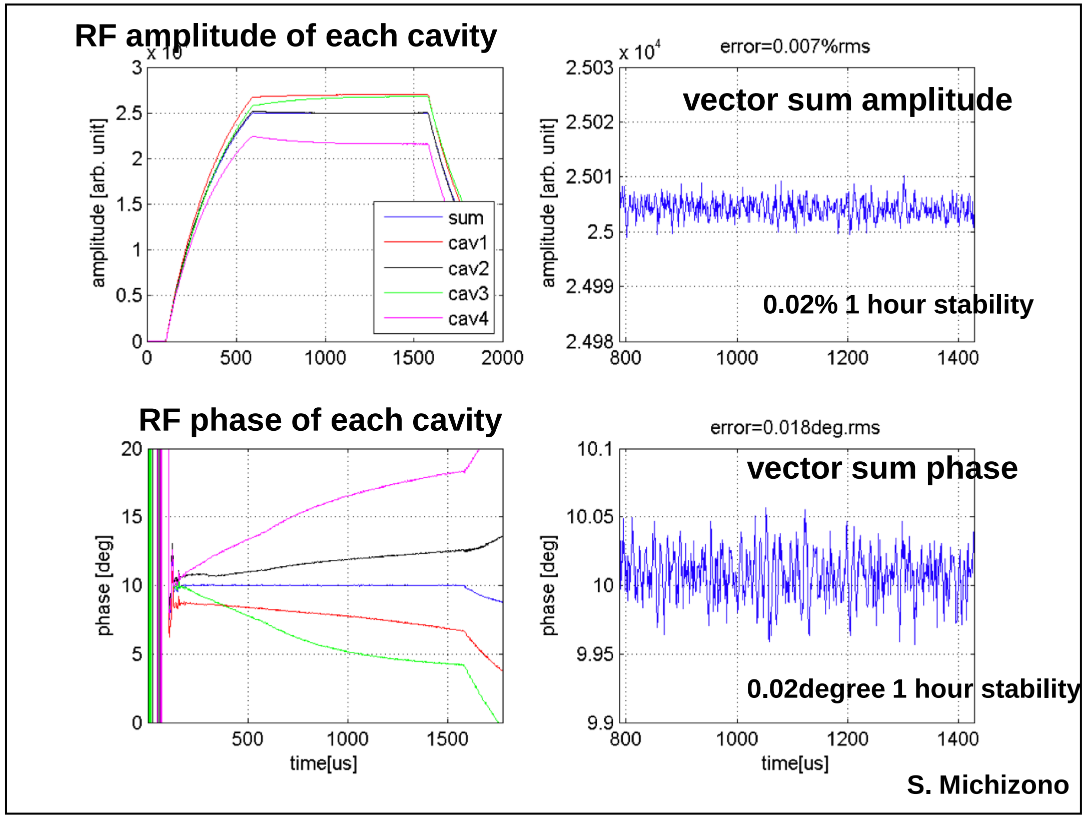
cavity pickup -> Down converter -> AD -> FPGA -> DA -> IQ modulator

By vector sum control



STF FPGA Board

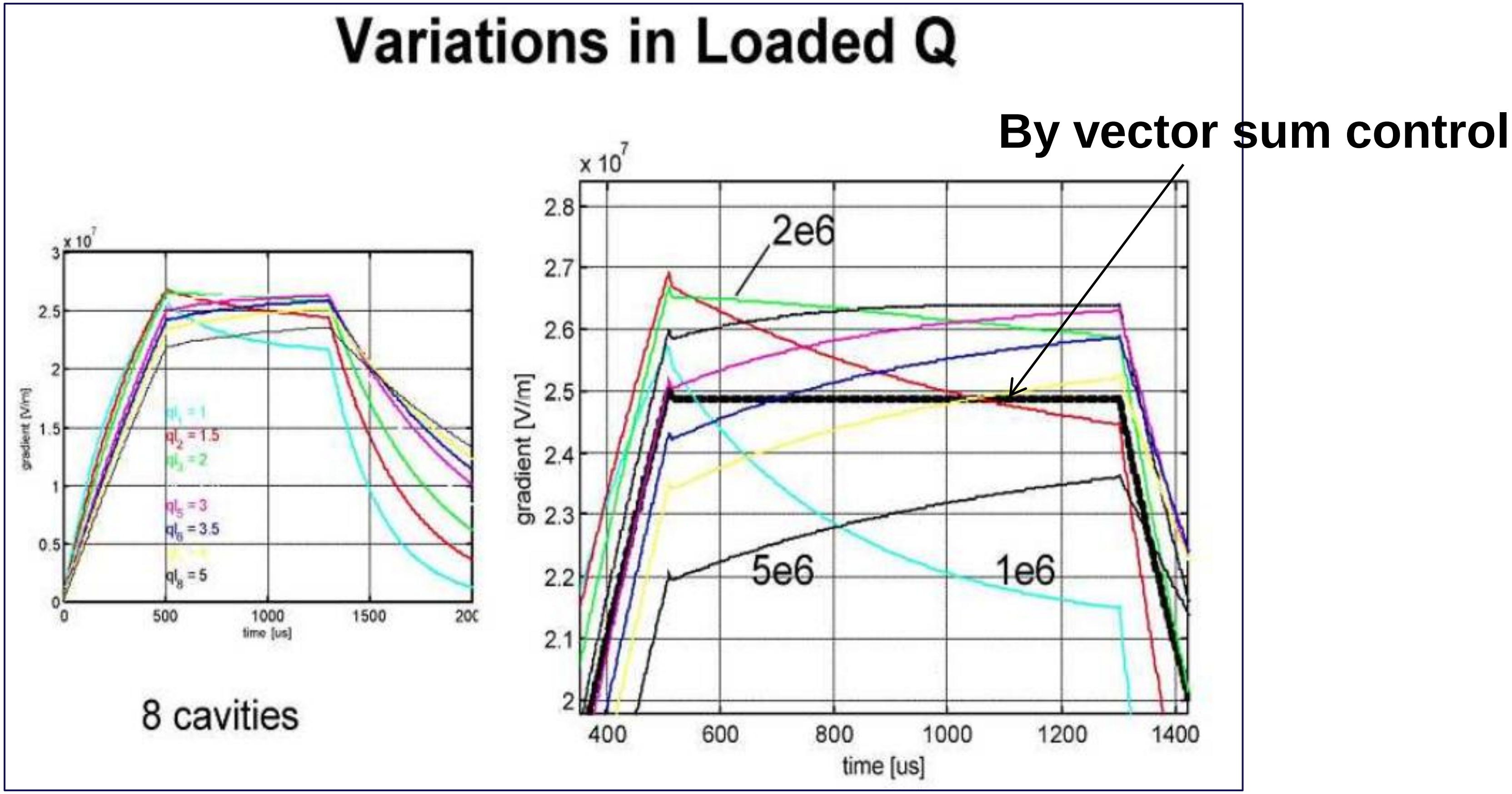
STF DSP Board for online diagnostics



STF feedback boards and its performance as an example

QL tuning in vector-sum feedback control

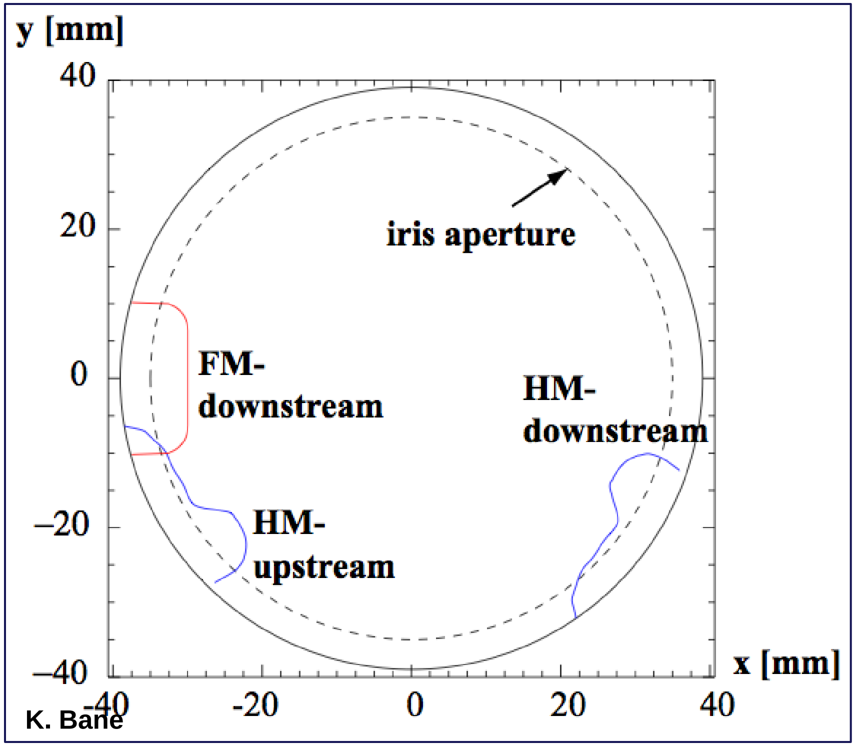
In case of multi-cavities cryomodule powered by single klystron

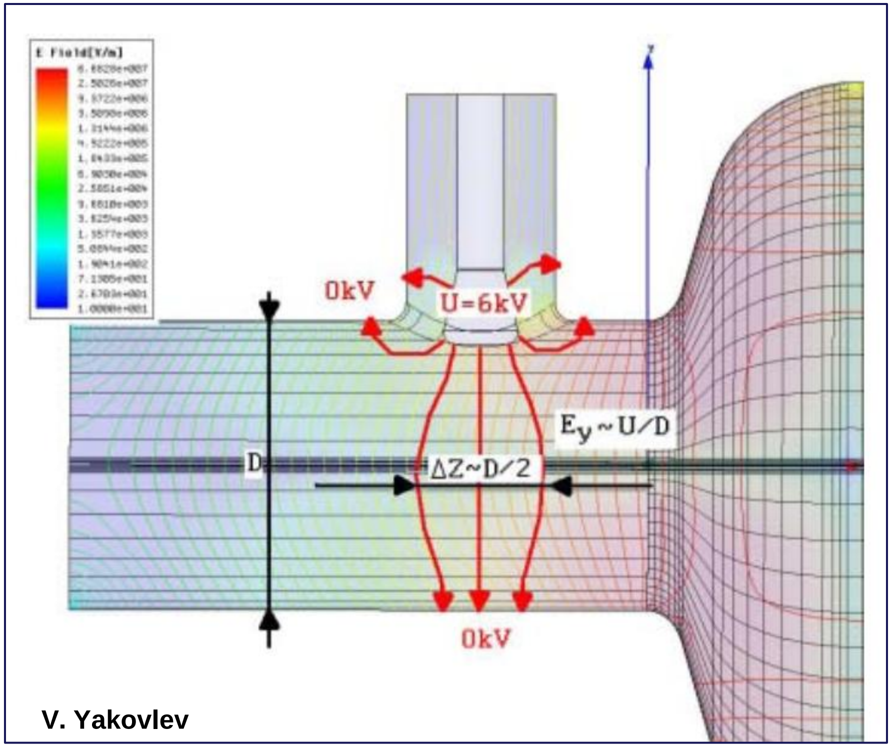


When QL of each cavity are scattered, voltage at flat-top will have slope, and weak cavity tend to reach its quench level.
Even if QL are adjusted for nominal beam loading by tuning of input coupler coupling etc, the voltage will change in case of beam off.

Cavity alignment in cryomodule

Coupler kick issue

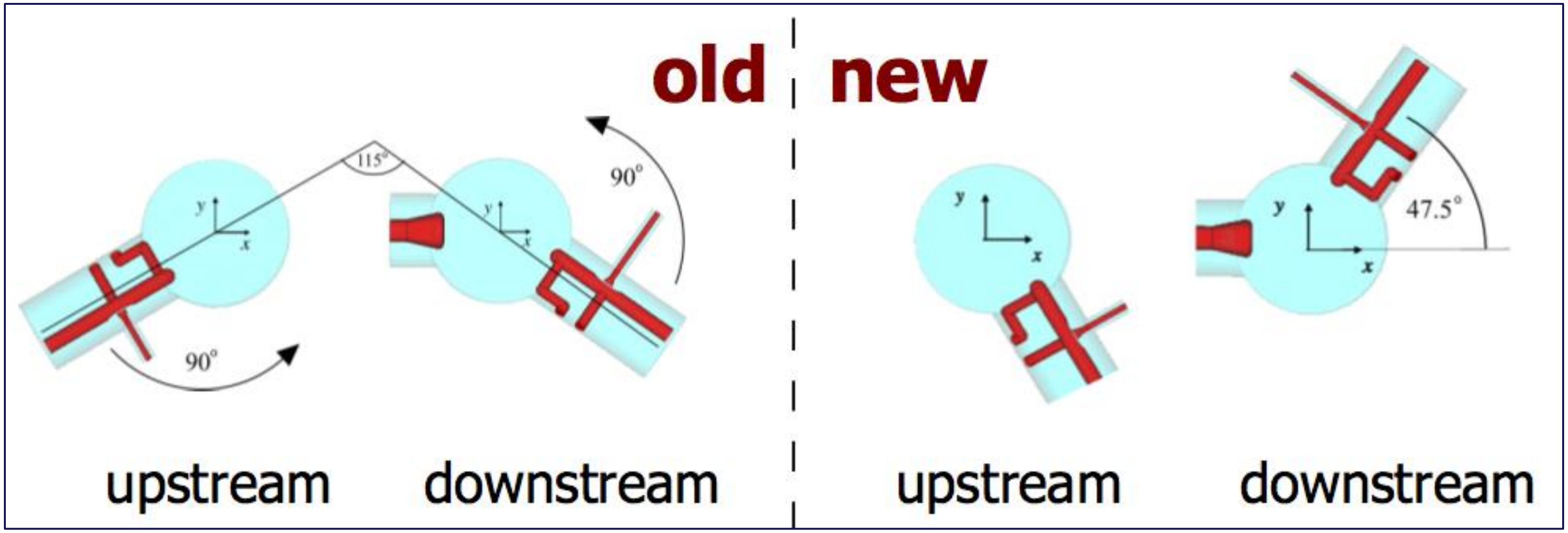




Asymmetric arrangement of couplers introduced discussion on emittance growth in ILC main Linac, in 2006-2008.

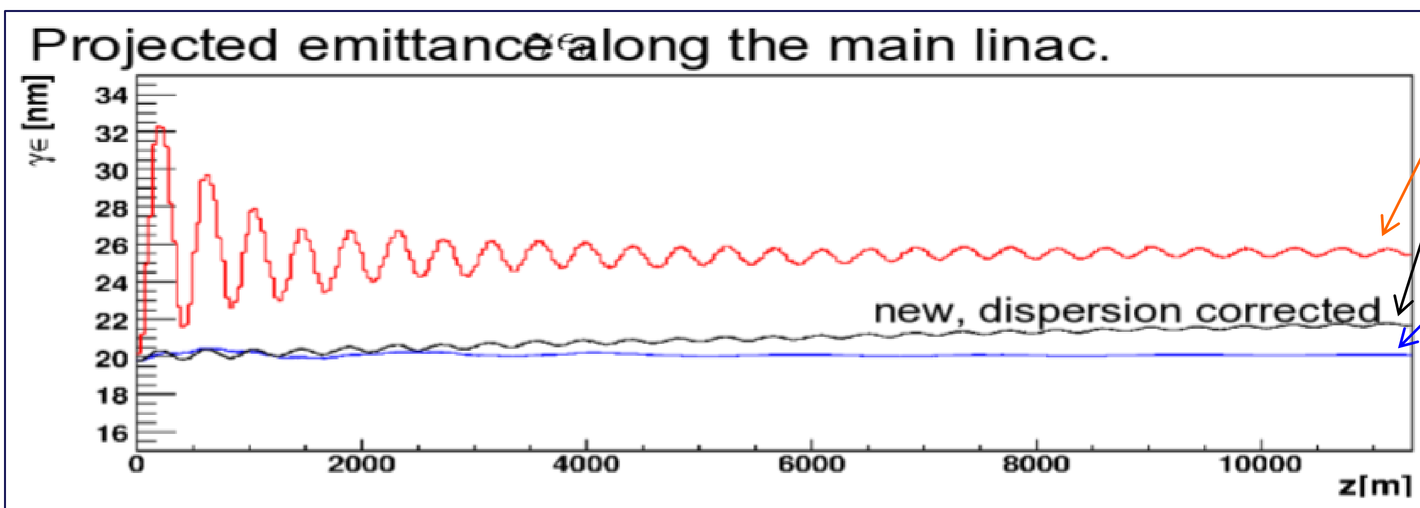
RF field asymmetry by main coupler and HOM antenna is another issue for beam kick.

Coupler kick effect in ILC Linac



reduced wake-field in new design, but it increase RF kicks.
(Dirk Krucker, Chicago GDE-meeting, Nov.2008)

for 20.0nm
(input emittance)



new design
25.1nm
(no correction)
21.8nm
(dispersion corrected)

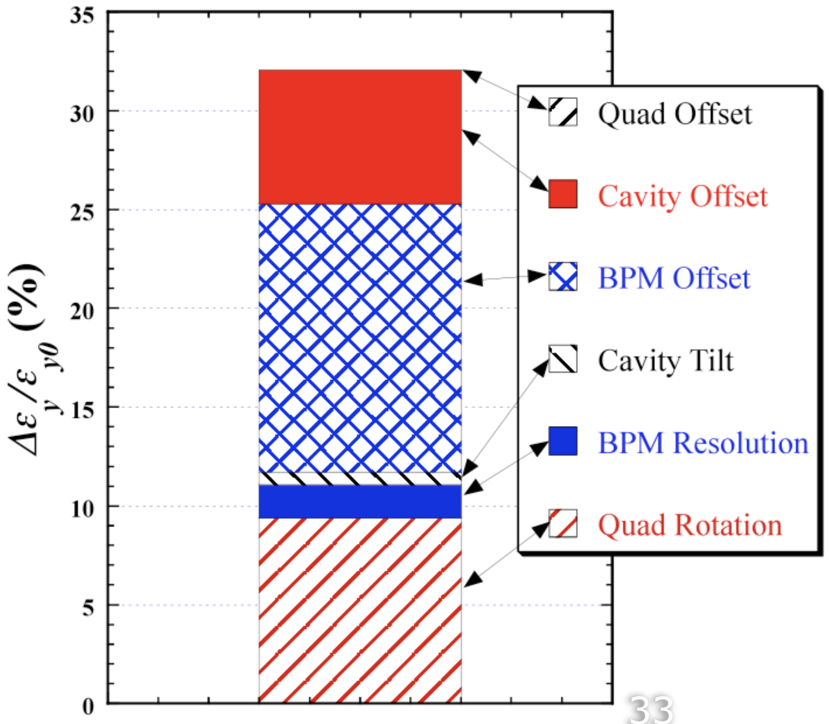
old design
20.3nm
(no correction)
20.3nm
(dispersion corrected)

Alignment Tolerance of ILC Linac

Assume following local misalignment only

	Vertical	Horizontal
Quad Offset (μm)	360	1080
Quad Roll (μrad)	300	
Cavity Offset (μm)	640	1920
Cavity Pitch and Yaw (μrad)	300 (pitch)	900 (yaw)
BPM Offset (μm)	360	1080
BPM Roll (μrad)	0	
BPM resolution (μm)	1	1
BPM scale error	0	0

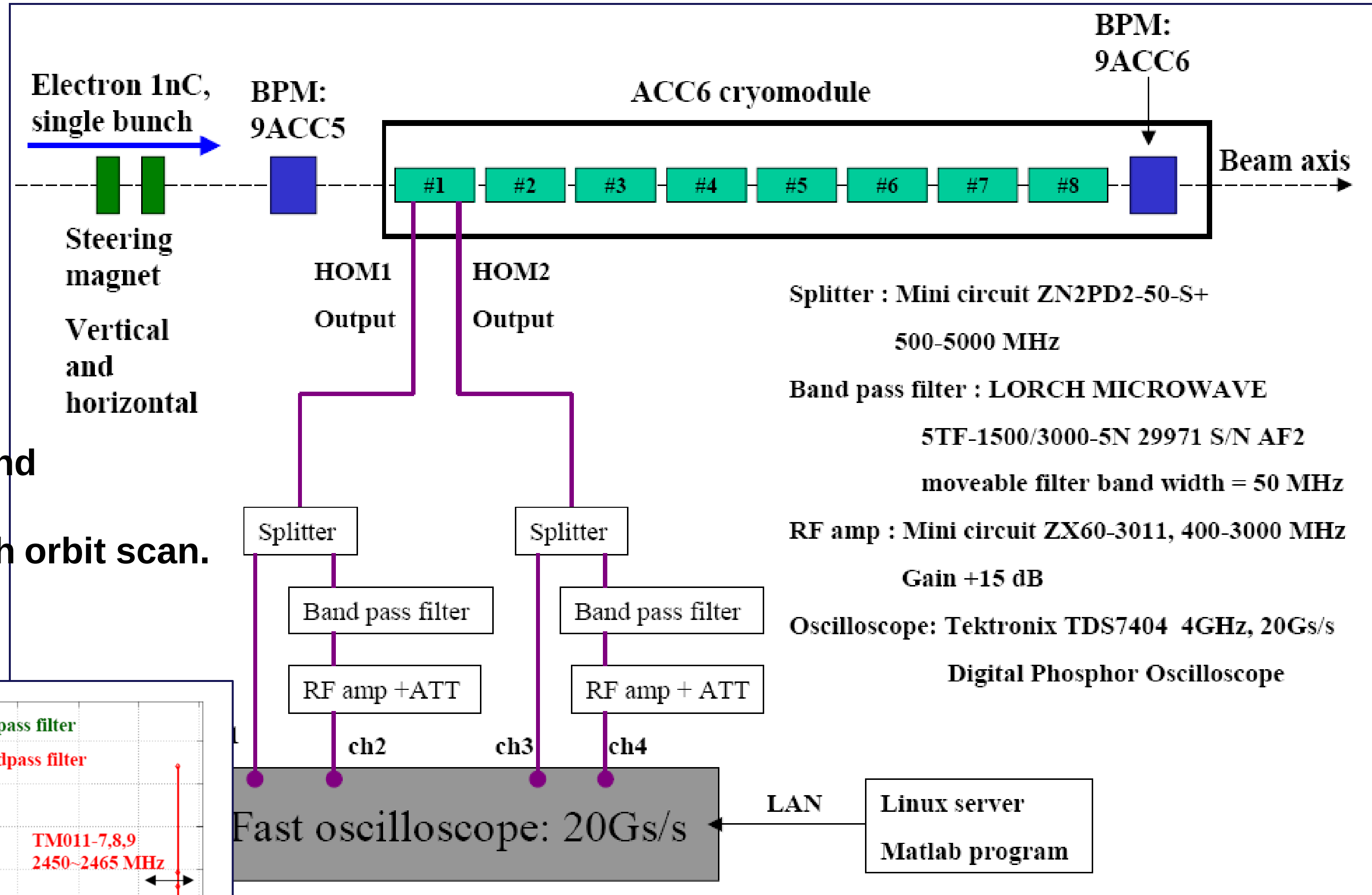
Cavity offset contribution to vertical emittance growth is 7%
Cavity tilt contribution is 1%



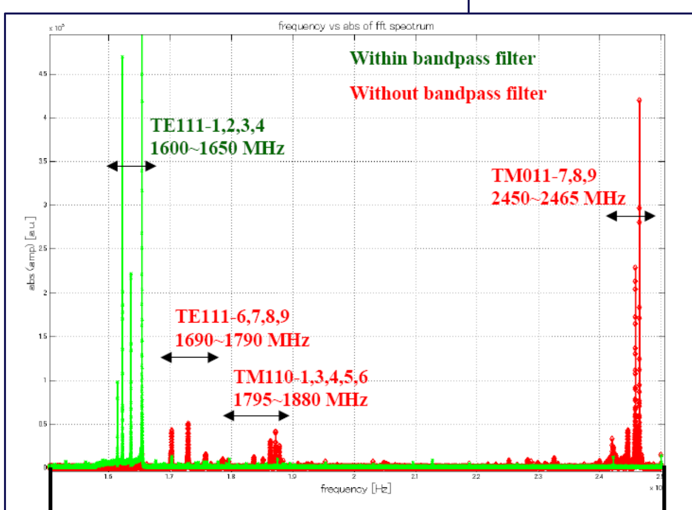
Simulation by code SLEPT,
using DMS (Dispersion Matching Steering),
15GeV -> 250GeV

(K. Kubo, Beijing GDE-meeting, Mar.2010)

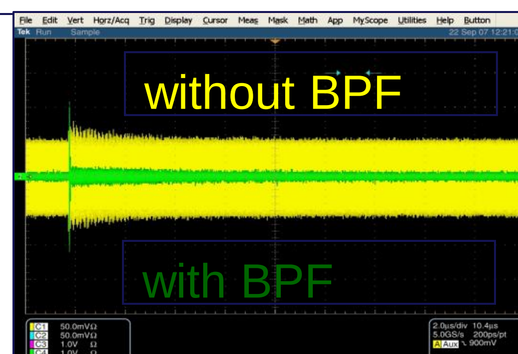
HOM-BPM for Alignment Confirmation



HOM pickup RF signal and BPMs are recorded for many beam passage with orbit scan.



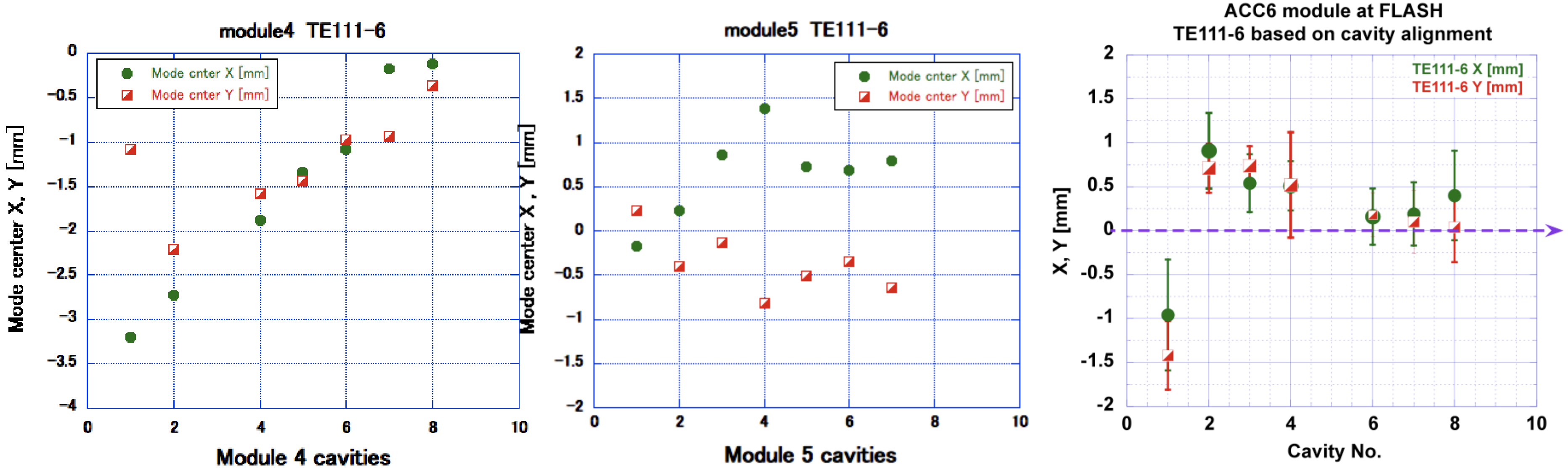
K. Watanabe



Cavity offset in cryomodule by HOM-BPM

FLASH module 4, 5, 6: cavity offset measurement

Recorded HOM signal are analyzed to estimate HOM center and polarization axis.
Cavity offsets are estimated by HOM center, relative to BPMs axis.



S. Pei, EPAC08 S. Pei, EPAC08 K. Watanabe

3 modules average offset: X= -0.21 +/- 1.23 mm
Y= -0.51 +/- 0.78 mm

We can measure each cavity offset by using beam,
however, only average correction is possible after tunnel installation.

Summary

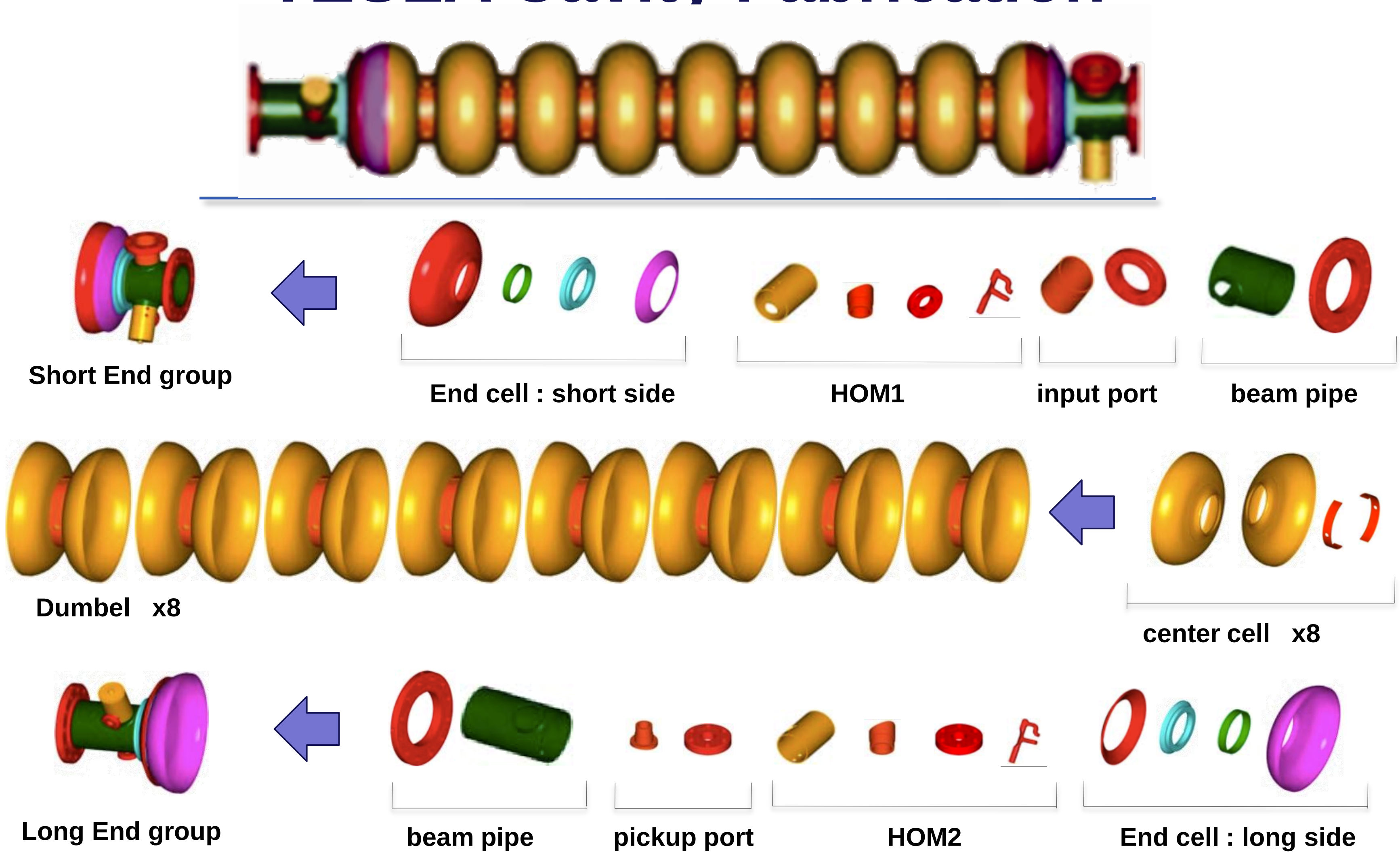
1. TESLA cavity gradient performance is greater than 35MV/m in average by the qualified vender.
   The gradient yield is progressing.
   Yield reduction at around 20MV/m is by defect.
   Yield reduction at around 30MV/m might be field emission turned on.

   Reduce the risk of field emission is required.

2. Spread of gradient performance and QL adjustment error introduce gradient slope in flat-top field in case of multi-cavity vector-sum control.

3. Alignment tolerance for long ILC linac is relatively relaxed.
   HOM-BPM method is useful for alignment confirmation, however,
   Cavity alignment in the cryomodule need to be considered.

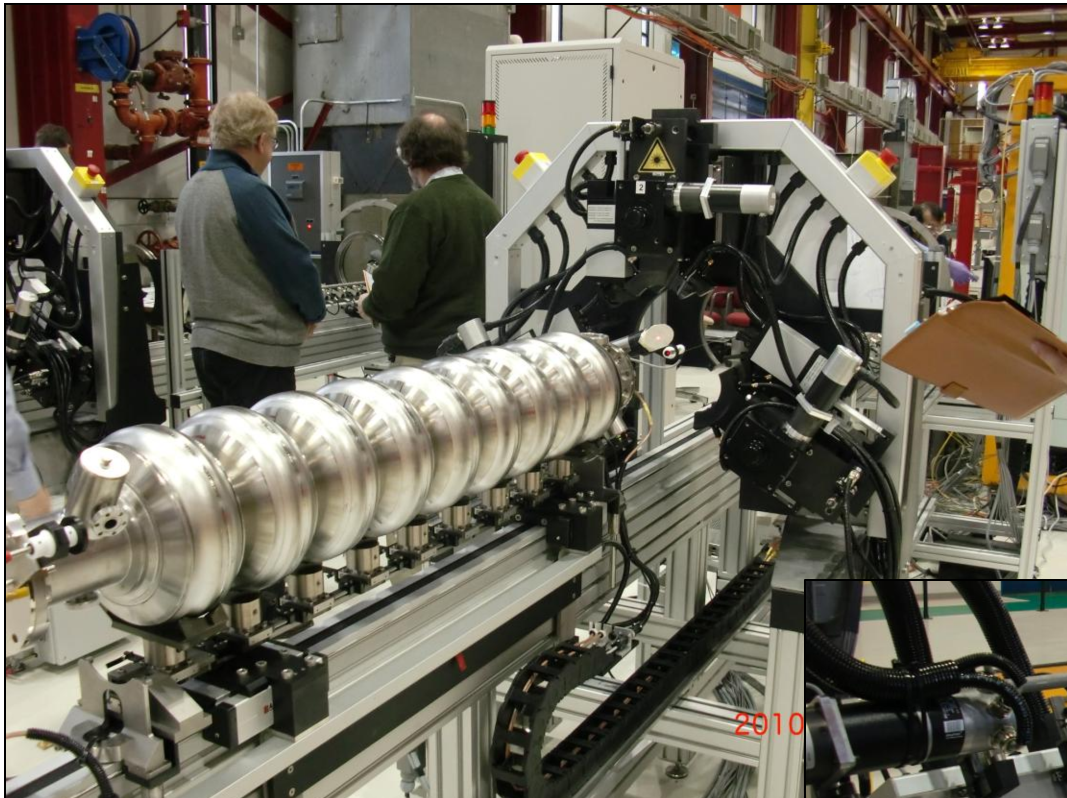
TESLA Cavity Fabrication



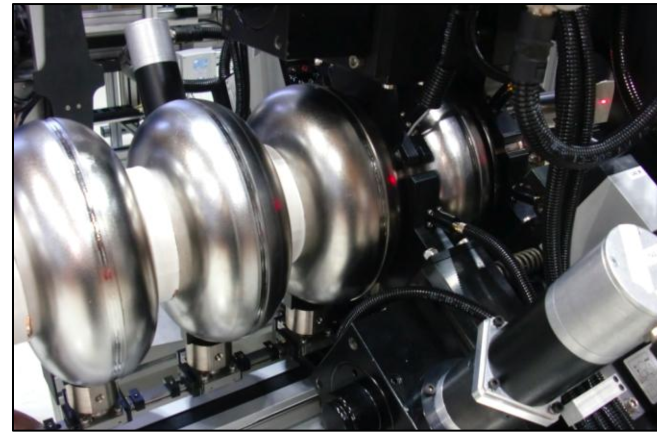
56 parts: Nb (RRR>300)= 46, Nb-Ti = 10, by press, burring, machining
75 Electron Beam Welding (EBW) place

Cavity Frequency & Straightness Tuning

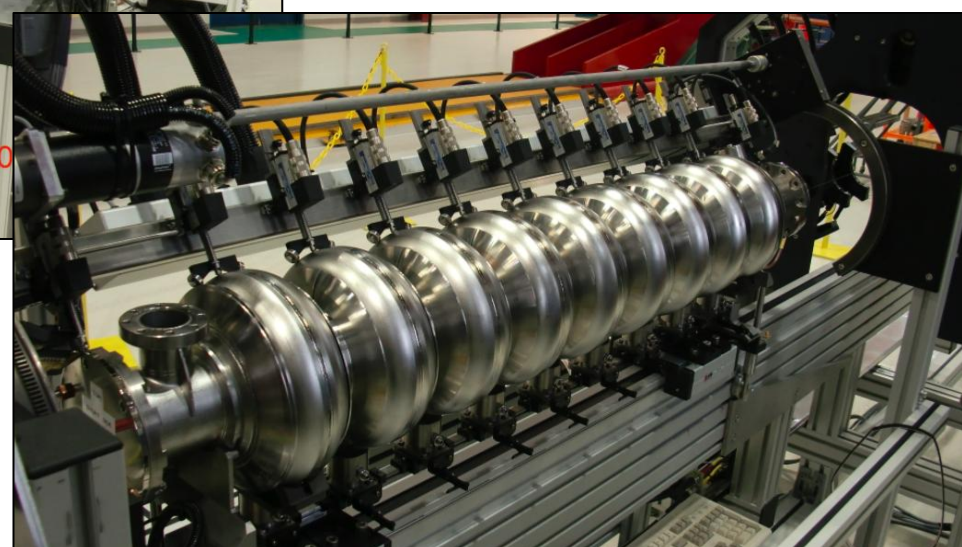
π-mode frequency, field flatness and eccentricity tuning done by 6 jaws.



DESY-FNAL-KEK Pre-tuning machine



Push and Pull freq. tuning by 6 jaws, keeping cavity straightness.



eccentricity measurement for Each cell