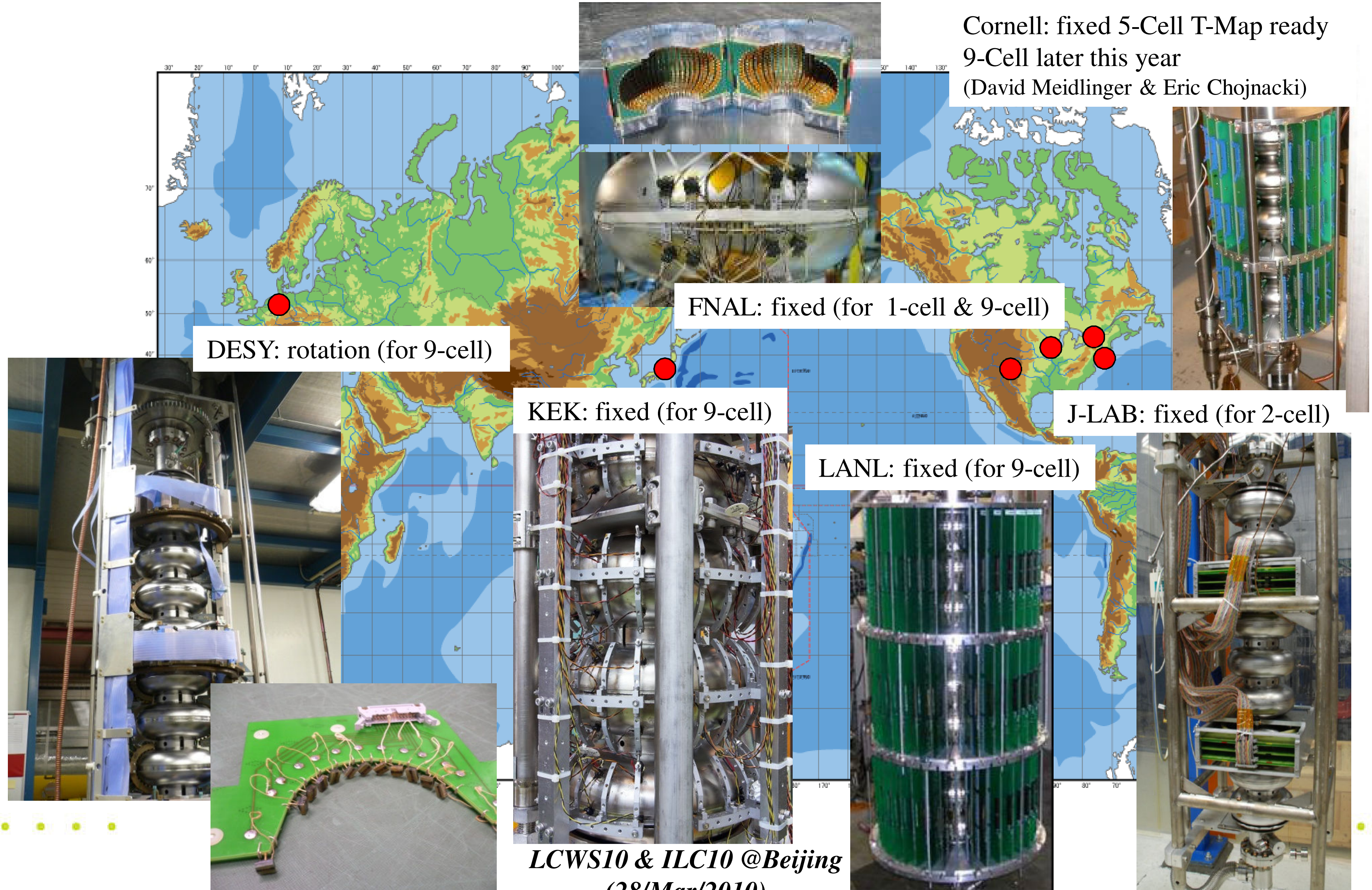
Summary of understanding of quench limit in 9-cell cavities using T-mapping and optical inspection

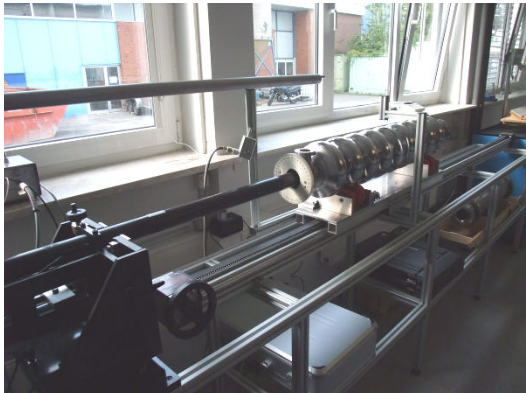
Contents

Sebastian & Kirk

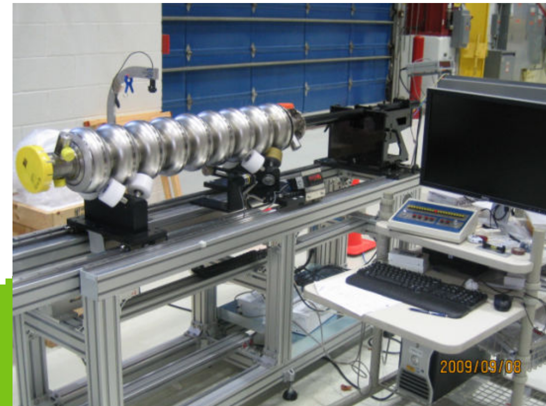
T-mapping system in the world



Optical inspection in the world



DESY : Kyoto Camera



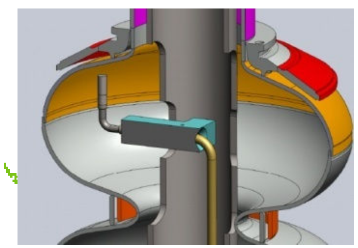
FNAL : Kyoto Camera,
Questar long-distance microscope

Defect Location @ Cornell

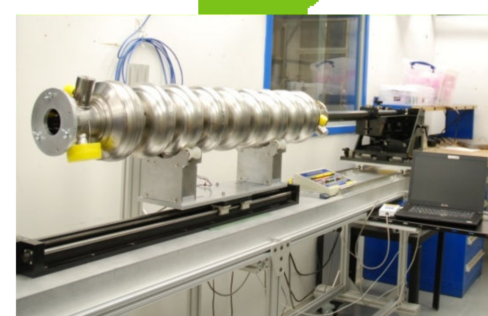
Cornell : Inspection system

KEK (STF) : Kyoto

LosAlamos: Karl Storz videoscope



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

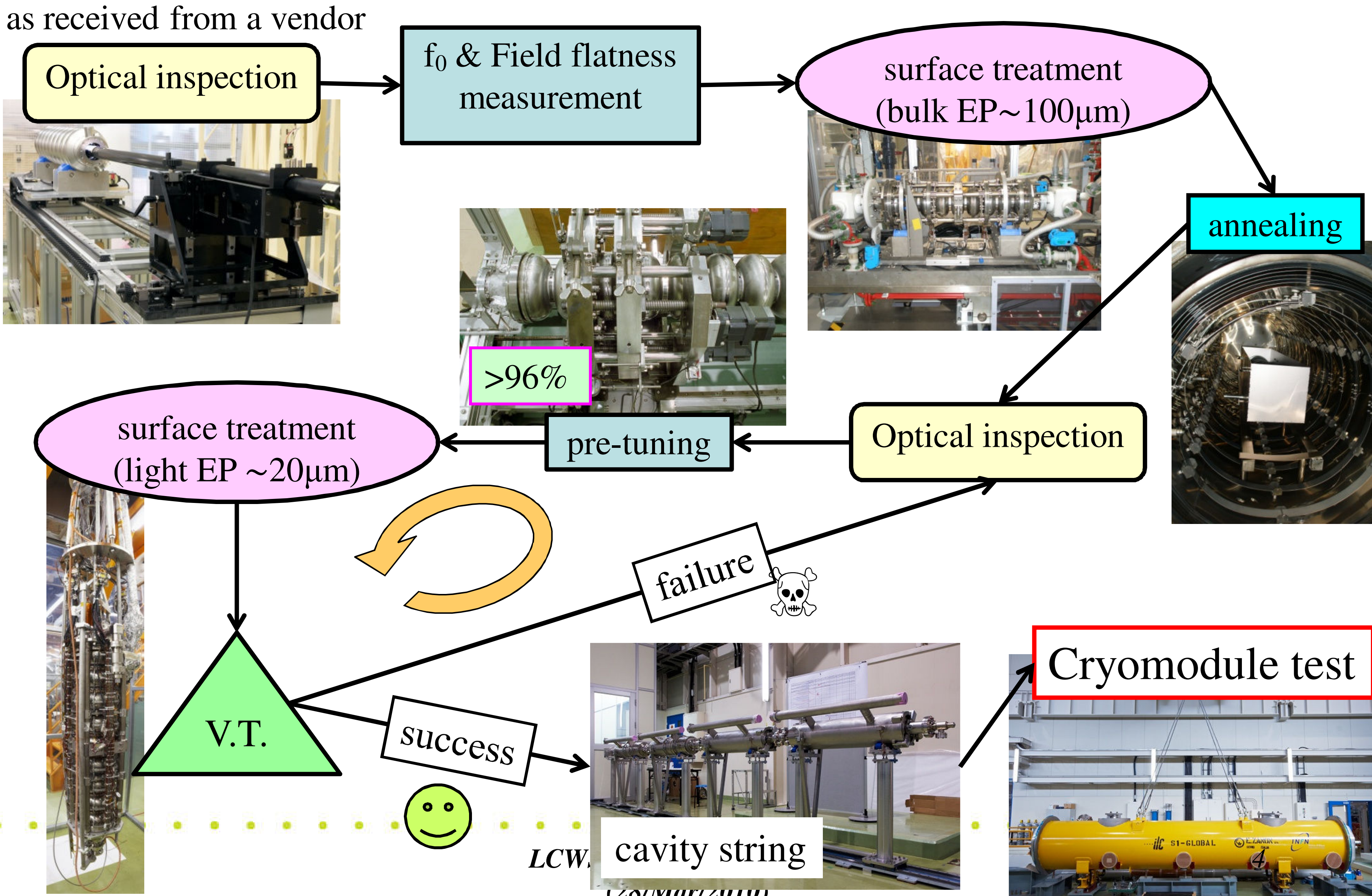


High resolution camera system is generally used at many labs around the world for 1.3 GHz 9-cell cavities to understand the field limitation.

LCWS10 & ILC10 @Beijing (28/Mar/2010)

K. Watanabe, Sept. 22 2009, SRF2009 in Belrin

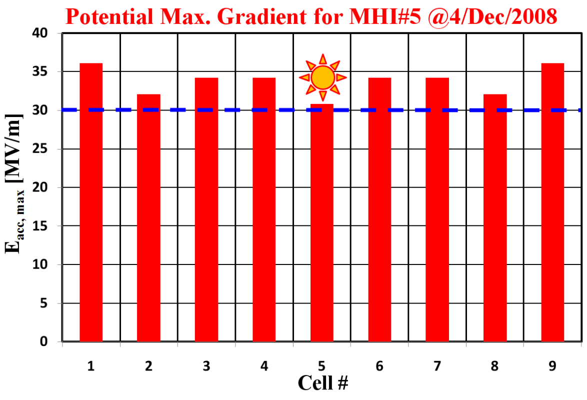
General working process at KEK-STF



T-mapping, optical inspection and pass-band measurement ①

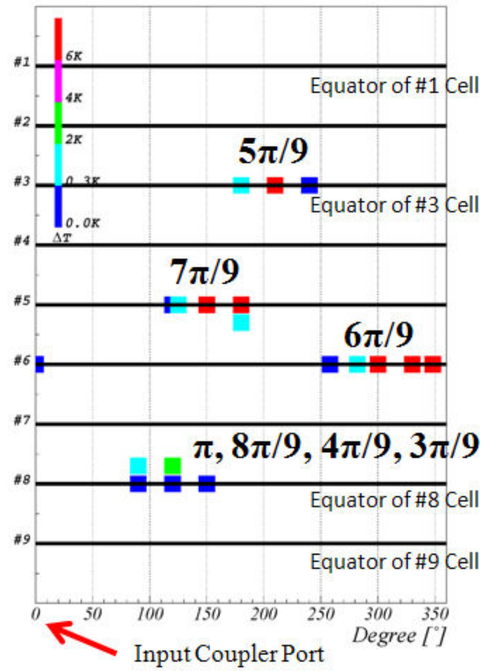
Pass-band measurement

9 pass-band modes
(π, 8π/9, 7π/9, 6π/9, 5π/9, 4π/9, 3π/9, 2π/9, π/9)



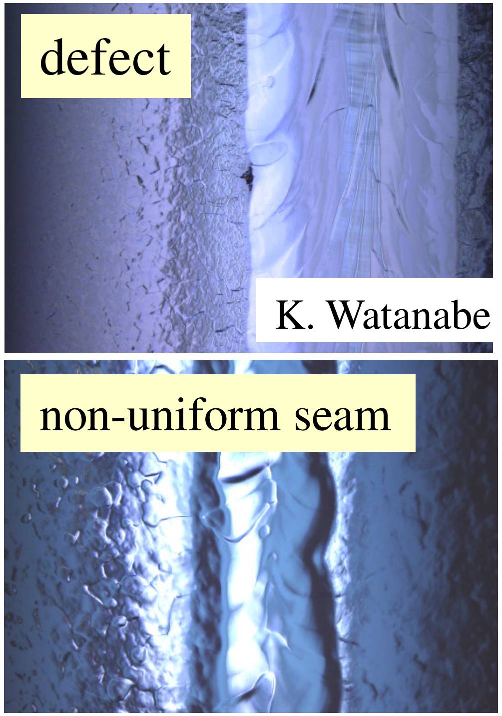
Achievable gradient at each cell

T-mapping



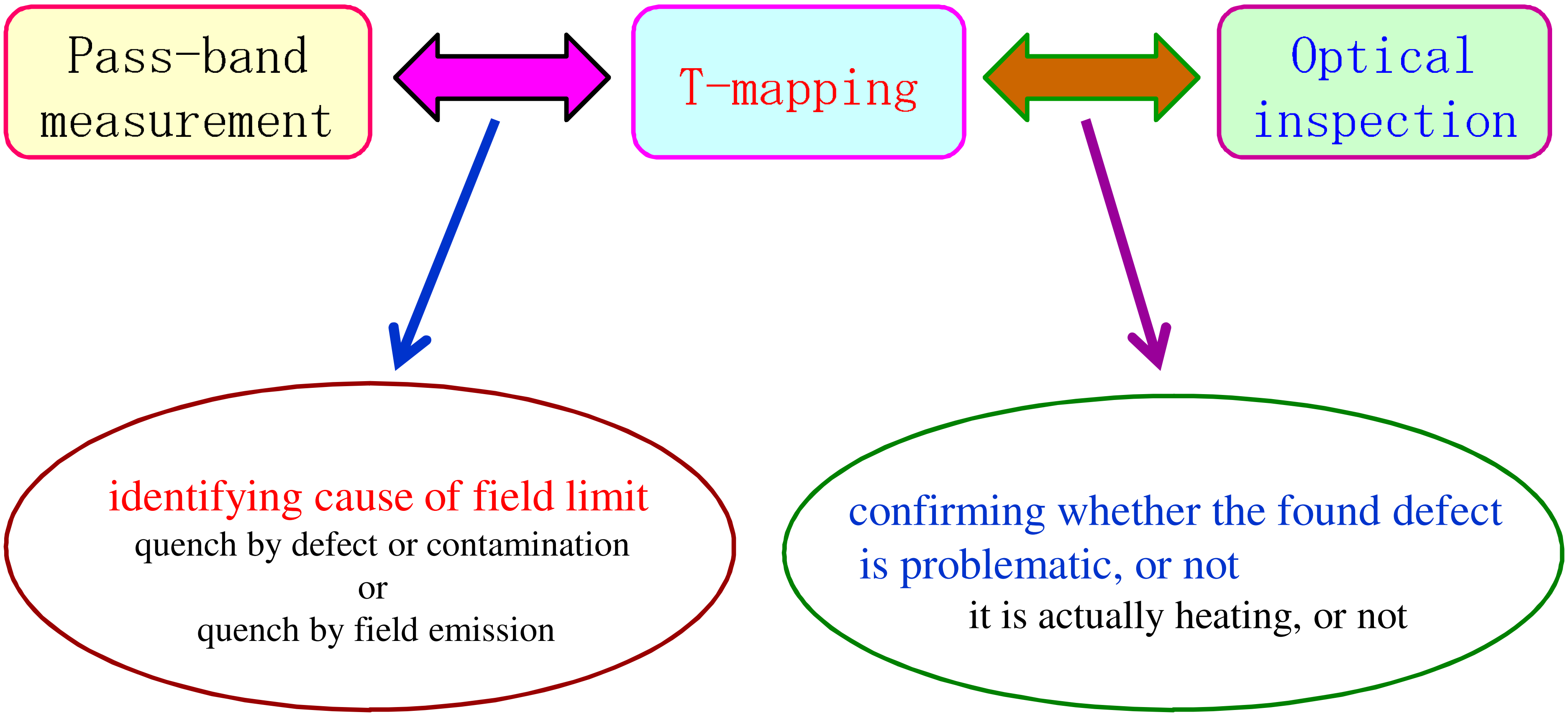
Heating location at thermal quench for each pass-band measurement

Optical inspection

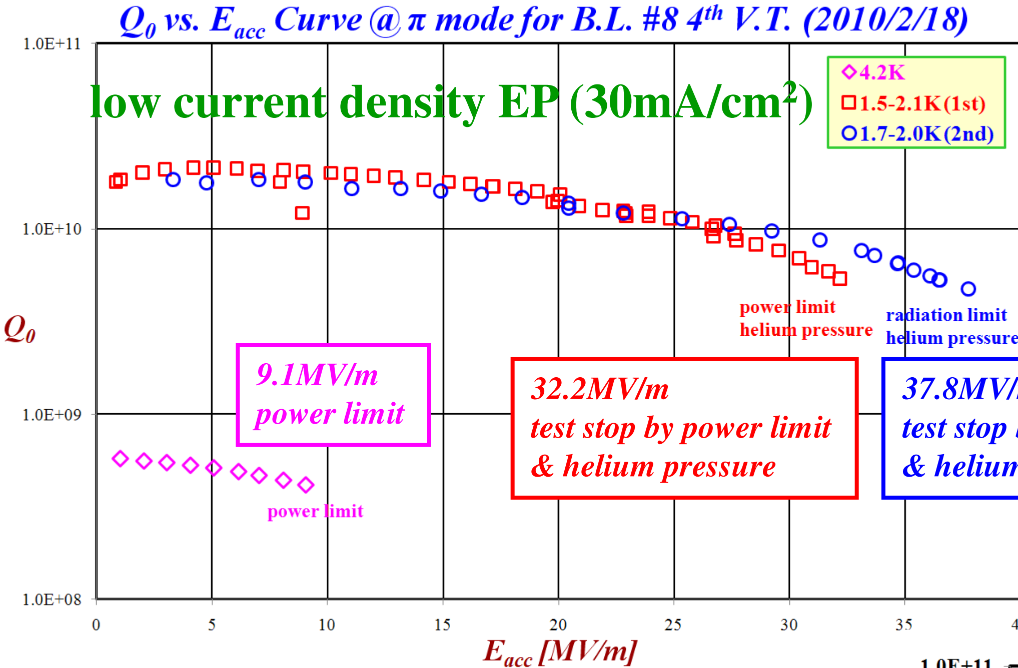


Suspicious spot
Quality of EBW seam

T-mapping, optical inspection and pass-band measurement ②

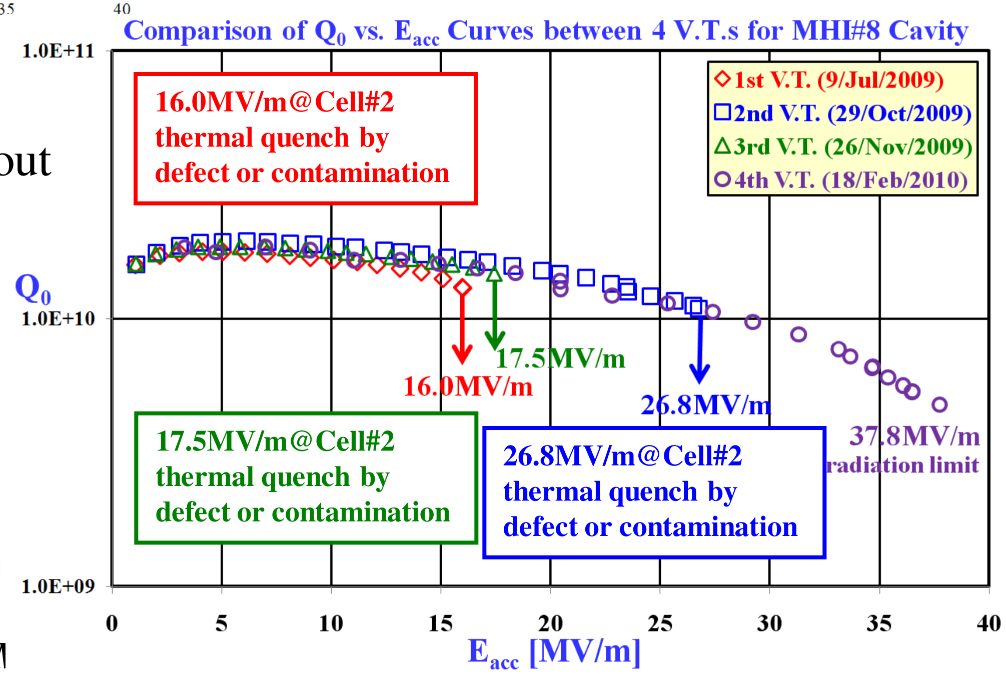


V.T. Results of MHI#8

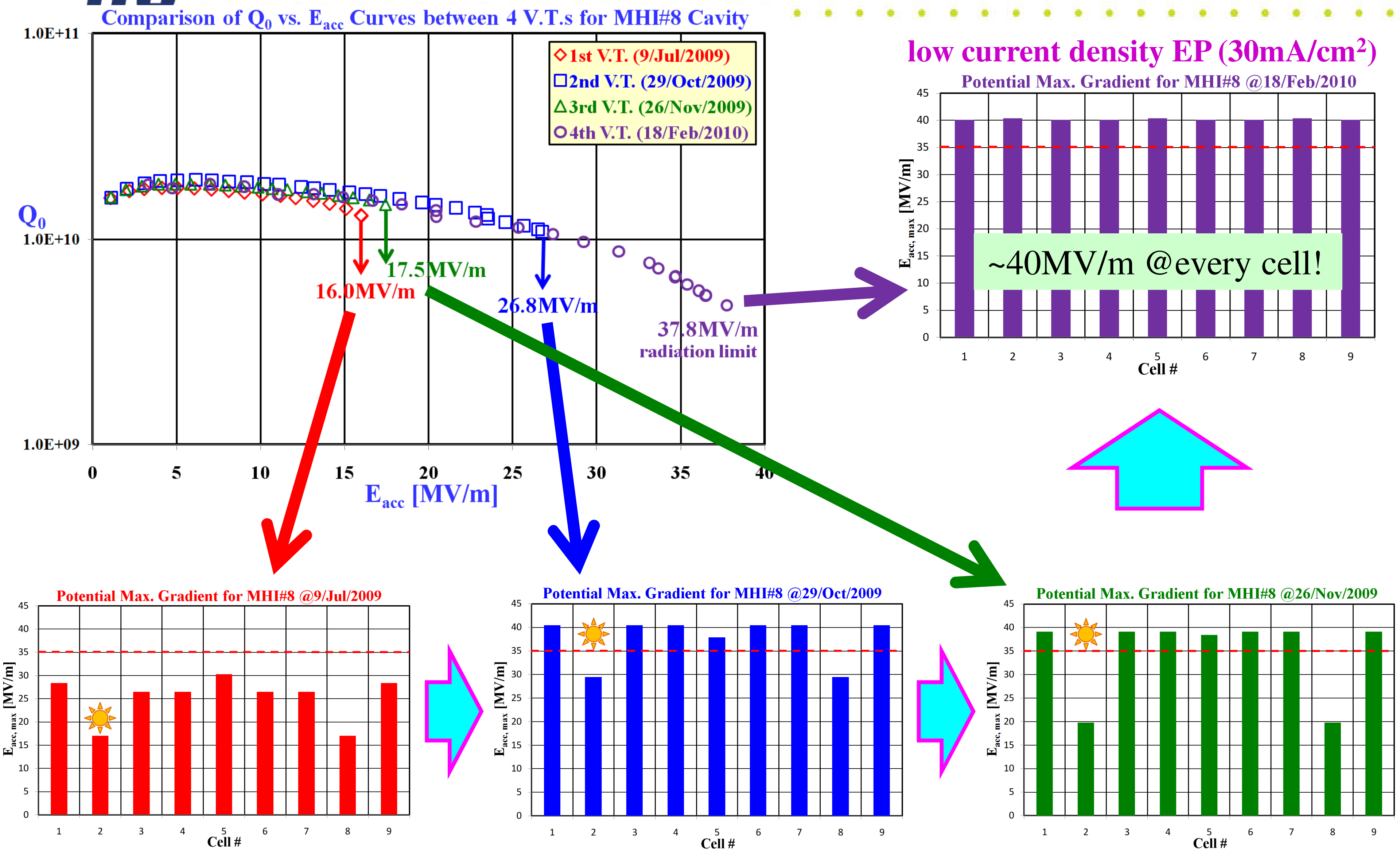


MHI#8 did not have any quench in pi-mode at 2K in 4th V.T.
Limitation of RF test was the radiation level and helium pressure.

After the first V.T., local grinding was carried out and the pit at heating location was removed.
After the second V.T., no grinding was done.

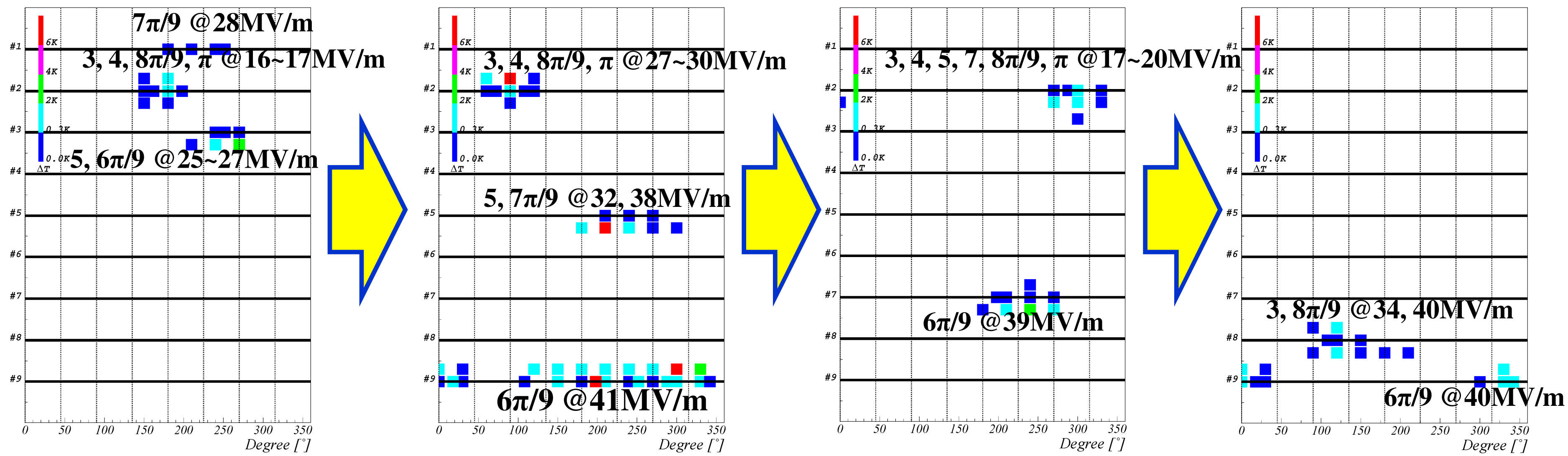


Result of pass-band measurement for MHI#8



Result of T-mapping for MHI#8

1st V.T. @9/Jul/2009 | 2nd V.T. @29/Oct/2009 | 3rd V.T. @26/Nov/2009 | 4th V.T. @18/Feb/2010



1st V.T.

pre-EP : 5μm
EP1 : 100μm
EP2 : 20μm

Ethanol+HWR+HPR

2nd V.T.

EP2 : 30+20μm

Degreasing(FM-20)
+HWR+HPR

3rd V.T.

EP2 : 20μm

Degreasing(FM-20)
+HWR+HPR

4th V.T.

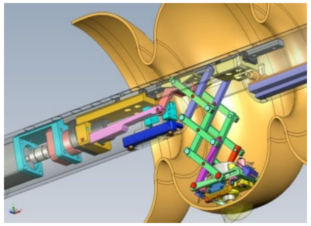
EP2 : 20μm
(low current density)

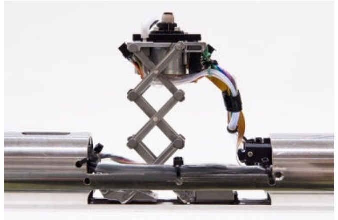
Degreasing(FM-20)
+HWR+HPR

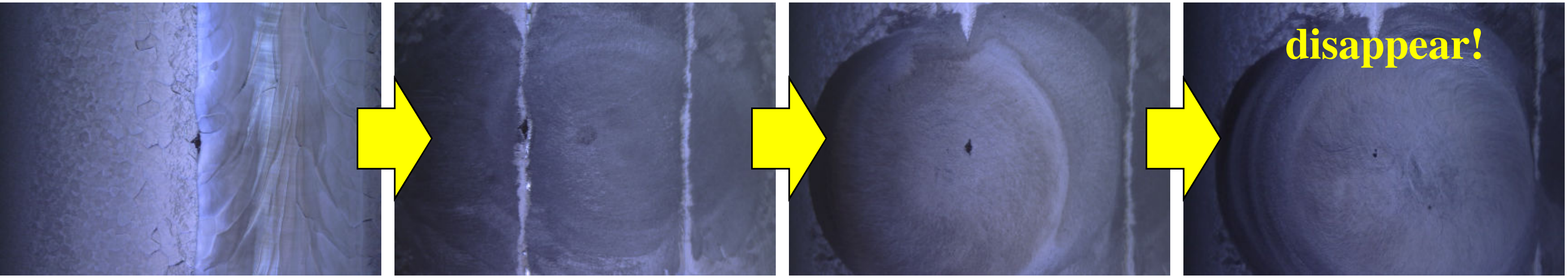
Result of optical inspection for MHI#8

cell #2, 172°@16.0MV/m (triangle pit)

Local grinding was performed to remove it!
(Ken will talk about it in detail.)

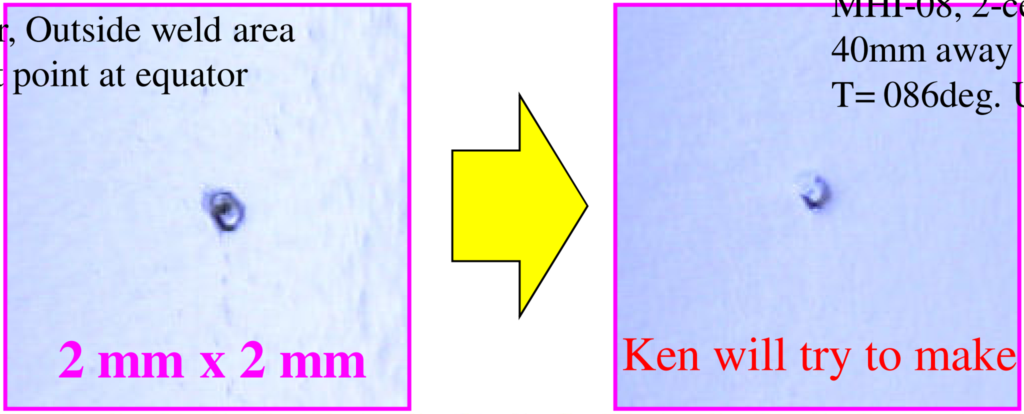






cell #2, 86°@26.8MV/m (ellipse bump)

After 2nd V.T.   195 um removed
MHI-08, 2-cell equator, Outside weld area
40mm away from joint point at equator
T= 086deg. Upstream



After 4th V.T.   235 um removed
MHI-08, 2-cell equator, Outside weld area
40mm away from joint point at equator
T= 086deg. Upstream

Ken will try to make the replica of this bump!

Analyzed cavities (problematic defect)

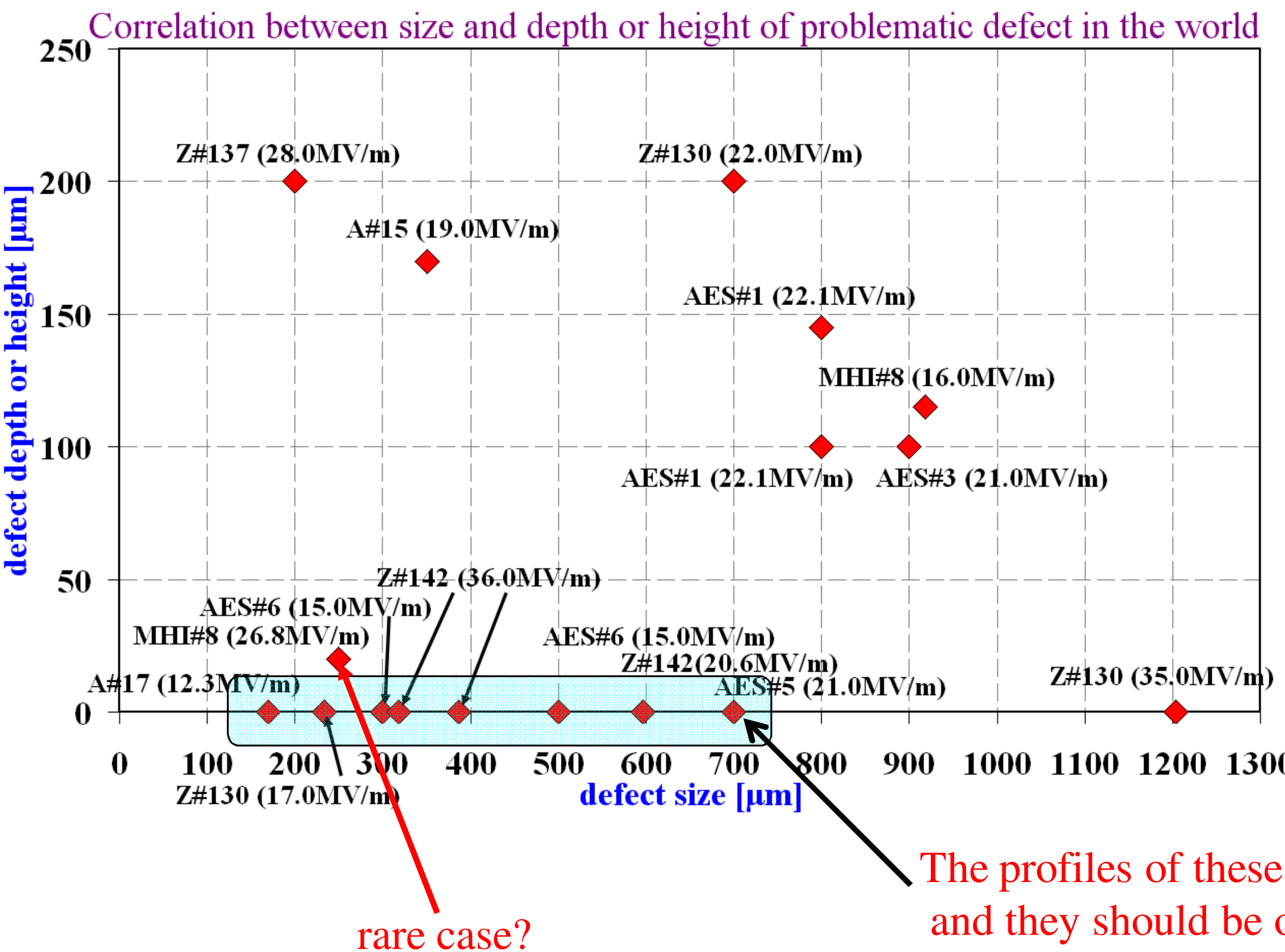
- Totally, we have 14 results for this case for now.
- The achievable gradient at the heating cell is typically around 20MV/m.
- The typical size of the problematic defect is several hundred microns.
- The bump found in MHI#8 is smallest in these defects. Therefore, higher quench field?

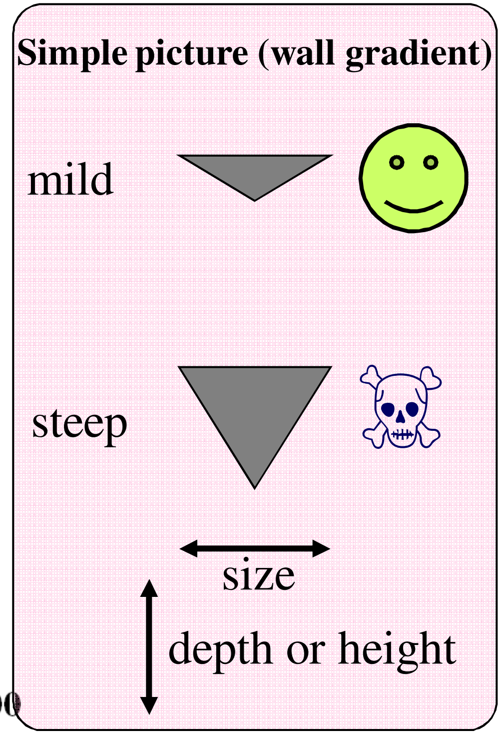
Vendor	EP	V.T.	Optical inspection	defect shape	defect size [μm]	Gradient [MV/m] @heating cell in a pass-band
MHI#8	KEK	KEK	KEK	triangle (pit)	450 x 800 x 115	16.0MV/m @cell #2 in π
MHI#8	KEK	KEK	KEK	ellipse (bump)	150 x 200 x 20	26.8MV/m @cell #2 in π
AES#1	KEK	KEK	KEK	two circles (bumps)	800x145, 800x100	22.1MV/m @cell #3 in π
AES#3	J-Lab	J-Lab	KEK	circle (bump)	900 x >100	21MV/m @cell #4 in π
AES#5	J-Lab	J-Lab	J-Lab	circle (?)	700 x ?	21MV/m @cell #3 in π
AES#6	J-Lab	J-Lab	J-Lab	two circles (?)	300 x ?, 500 x ?	15MV/m @cell #5 in π
A15	J-Lab	J-Lab	J-Lab	circle (pit)	350 x 170	19MV/m @cell #3 in π
A17	FNAL/ANL	FNAL	FNAL	circle (pit)	170 x ?	12.3MV/m @cell #4 in 4π/9
Z130	DESY	DESY	DESY	ellipse (bump)	210 x 100 x ?	17MV/m @cell #1 in π
Z130	DESY	DESY	DESY	ellipse (bump)	1200 x 100 x ?	35MV/m @cell #2 in 2π/9
Z130	DESY	DESY	DESY	circle (pit)	700 x 200	22MV/m @cell #5 in 3π/9
Z137	DESY	DESY	DESY	circle (pit)	200 x 200	28MV/m @cell #5 in 5π/9
Z142	DESY	DESY	DESY	ellipse (pit)	310 x 510 x ?	21MV/m @cell #6 in π
Z142	DESY	DESY	DESY	ellipse (bumps?)	220 x 230 x ?, 310 x 230 x ?	36MV/m @cell #9 in 8π/9

"?" means unknown data.

Analyzed cavities (problematic defect)

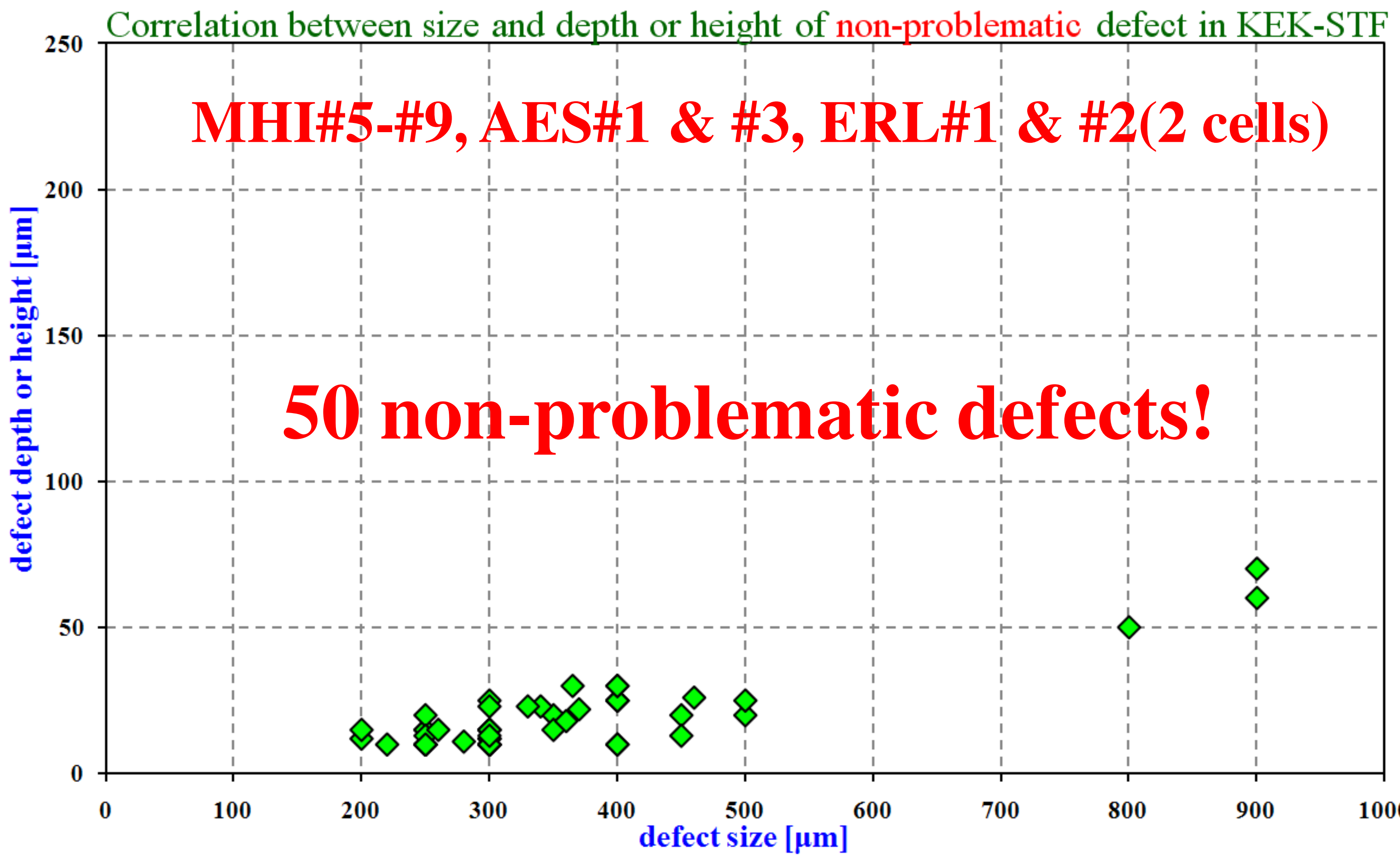
This graph shows the correlation between the size and the depth or height of problematic defects.





Analyzed cavities (non-problematic defect)

This graph shows the correlation between the size and the depth or height of non-problematic defects.



Generally, a smaller-size-and-depth defect is not problematic for heating. And, this is the common case for a defect in STF (at least)!

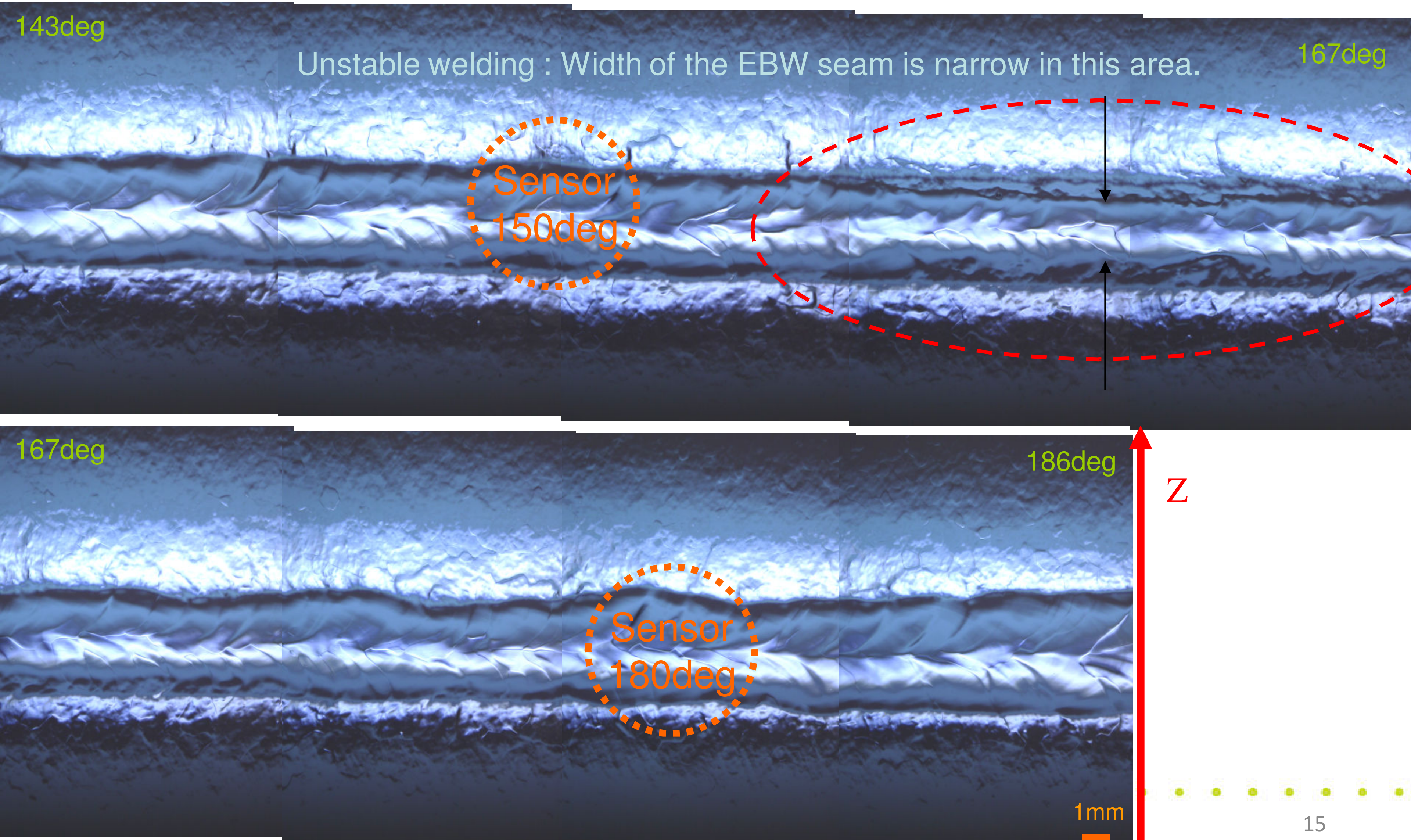
Analyzed cavities (problematic EBW seam)

- Totally, we have 7 results for this case for now.
- The achievable gradient at the heating cell ranges over 14-35MV/m.
- The feature of the problematic EBW seam is various and not common.

Vendor	EP	V.T.	Optical inspection	Gradient [MV/m] @cell #	Comments
MHI#5	KEK	KEK	KEK	27.1MV/m @cell #5 in π	no visible defect, non-uniform EBW seam, this heating didn't disappear even after a few EP's
MHI#5	KEK	KEK	KEK	31.2MV/m @cell #6 in 6π/9	no visible defect, non-uniform EBW seam, this heating didn't disappear even after a few EP's
MHI#6	KEK	KEK	KEK	34.6MV/m @cell #5 in 5π/9	no visible defect, non-uniform EBW seam, this heating didn't disappear even after a few EP's
LG1	J-Lab	J-Lab	J-Lab / KEK	30MV/m @cell #5 in π	weld repaired by EBW during fabrication
Z110	DESY	DESY	KEK	14.2MV/m @cell #8 in π	a group of spots exist
Z111	DESY	DESY	KEK	16.0MV/m @cell #6 in π	Holes with sharp edges along grain boundaries (using SEM)
Z137	DESY	DESY	DESY	25.2MV/m @cell #1 in π	rough and steep edges at grain boundaries, not removed by light BCP (5μm)

MHI-05 2nd V.T., #5 cell equator, 29.2MV/m @ 7/9

Heating area #5 cell equator : 120°~ 180° : Sensor 120°⊿T=1 K, 150° ⊿T=10 K, 180° ⊿T=5 K



K. Watanabe

(28/Mar/2010)

Analyzed cavities (unknown, but not F.E.)

Vendor	EP	V.T.	Optical inspection	Gradient [MV/m] @cell #
MHI#5	KEK	KEK	KEK	19.7MV/m @cell #8 in π
MHI#6	KEK	KEK	KEK	19.6MV/m @cell #9 in π
MHI#6	KEK	KEK	KEK	35.5MV/m @cell #7 in $6\pi/9$
MHI#7	KEK	KEK	KEK	33.6MV/m @cell #9 in π
MHI#7	KEK	KEK	KEK	33.6MV/m @cell #9 in π
MHI#7	KEK	KEK	KEK	42.6MV/m @cell #5 in $5\pi/9$
MHI#8	KEK	KEK	KEK	28.4MV/m @cell #1 in $7\pi/9$
MHI#8	KEK	KEK	KEK	26.5MV/m @cell #3 in $6\pi/9$
MHI#8	KEK	KEK	KEK	37.9MV/m @cell #5 in $5\pi/9$
MHI#8	KEK	KEK	KEK	17.5MV/m @cell #2 in π
MHI#8	KEK	KEK	KEK	39.1MV/m @cell #7 in $6\pi/9$
MHI#8	KEK	KEK	KEK	40.1MV/m @cell #9 in $6\pi/9$
MHI#8	KEK	KEK	KEK	40.4MV/m @cell #8 in $3\pi/9$
MHI#9	KEK	KEK	KEK	38.8MV/m @cell #5 in $5\pi/9$
MHI#9	KEK	KEK	KEK	27.9MV/m @cell #2 in $4\pi/9$
MHI#9	KEK	KEK	KEK	15.9MV/m @cell #2 in π
MHI#9	KEK	KEK	KEK	27.0MV/m @cell #2 in π
A12	J-Lab	J-Lab	J-Lab	32MV/m @cell #7 in π
Z134	DESY	DESY	DESY	35MV/m @cell #1 in π
Z134	DESY	DESY	DESY	37MV/m @cell #5 in $7\pi/9$
Z134	DESY	DESY	DESY	45MV/m @cell #6 in $4\pi/9$
Z134	DESY	DESY	DESY	36MV/m @cell #2 in $3\pi/9$

Around these heating locations, there were no obvious defects!

In STF (at least), this is the most common case.

The quenching gradient ranges over from 16 to 45MV/m.

The cause is the chemical residual or theoretical limit or any others?

We have to solve out this case as the top priority!

Summary

- ✓ T-mapping and optical inspection are crucial technique for understanding of correlation between heating location and defect.
- ✓ Generally, the problematic defects have the size of several hundred microns and the achievable gradient around 20MV/m.
- ✓ Generally, the smaller-size-and-depth defect is not problematic for heating.
- ✓ For the case of the problematic EBW seam, there are various causes.
- ✓ Generally, there is no obvious defect around many heating locations.
- ✓ These defect data should be recorded on the cavity database.

Kirk's suggestion

- ✓ Before and after every V.T., every equator and iris region (at least) should be inspected by the optical inspection.
- ✓ If a defect is found there, the profile of the defect should be measured.
- ✓ Every heating location should be identified using T-mapping for several pass-bands.
- ✓ When the quench limit is the field emission, the X-ray-mapping is sometimes effective for confirming the correlation between the heating location and the x-ray emission.

Thank you for your attention!

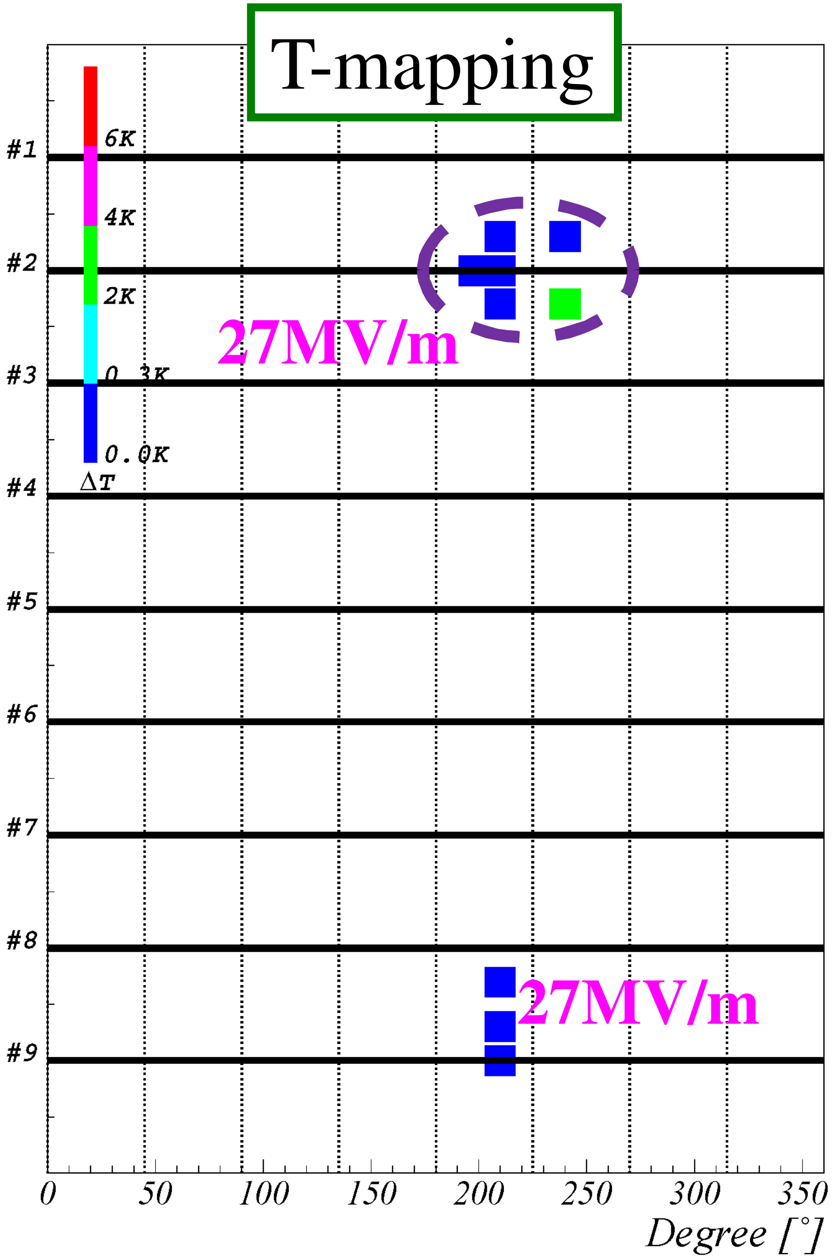
Special thanks to…

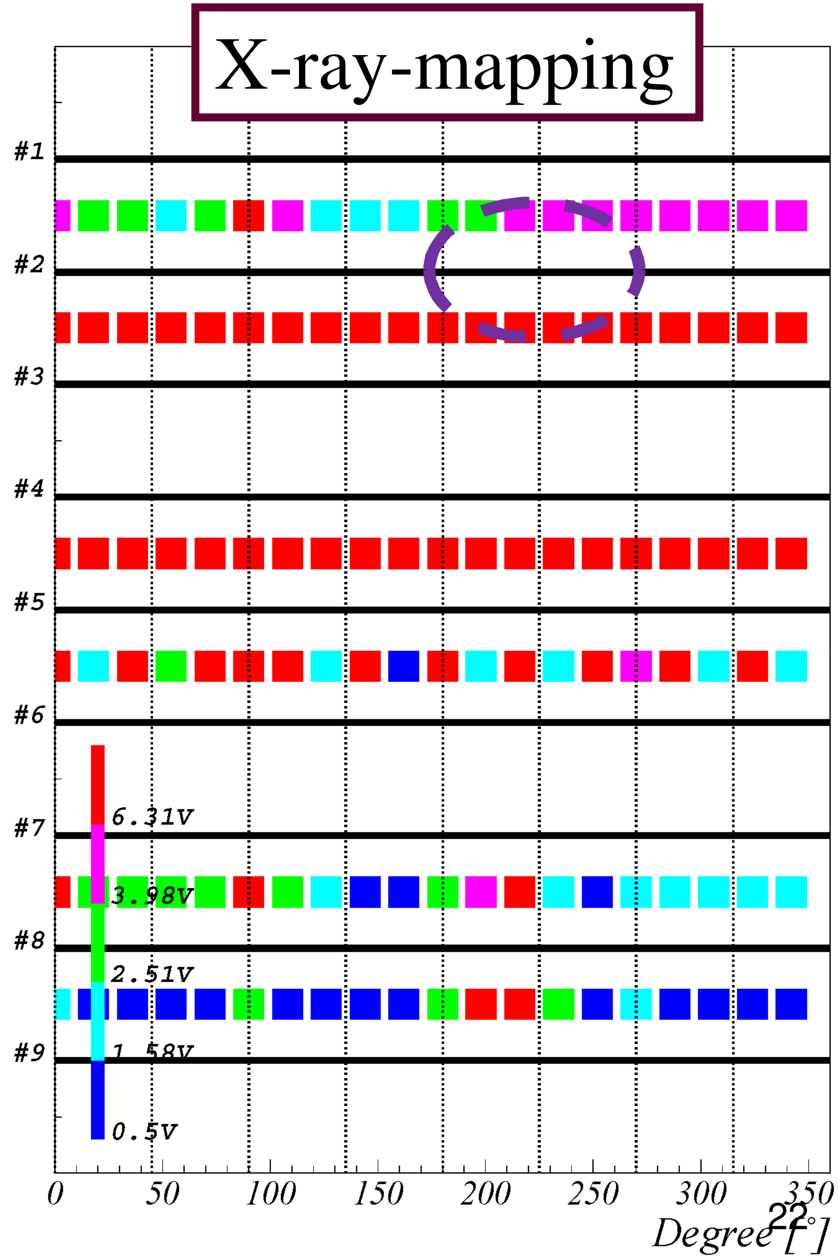
Rong-Li Geng (J-Lab), Camille Ginsburg (FNAL), Sebastian Aderhold (DESY), Zachary Conway (Cornell)

Back-up slides

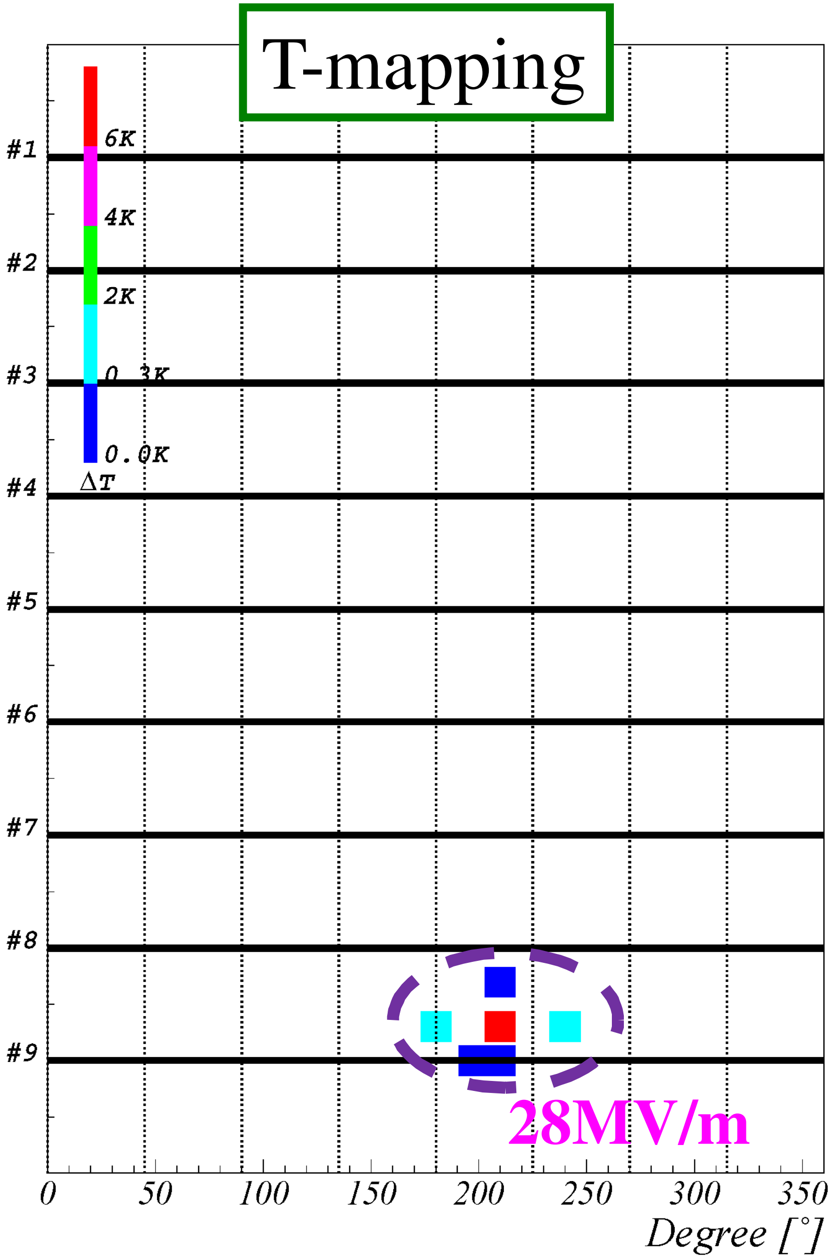
Correlation between T-mapping and X-ray-mapping at 3rd V.T. of MHI#9

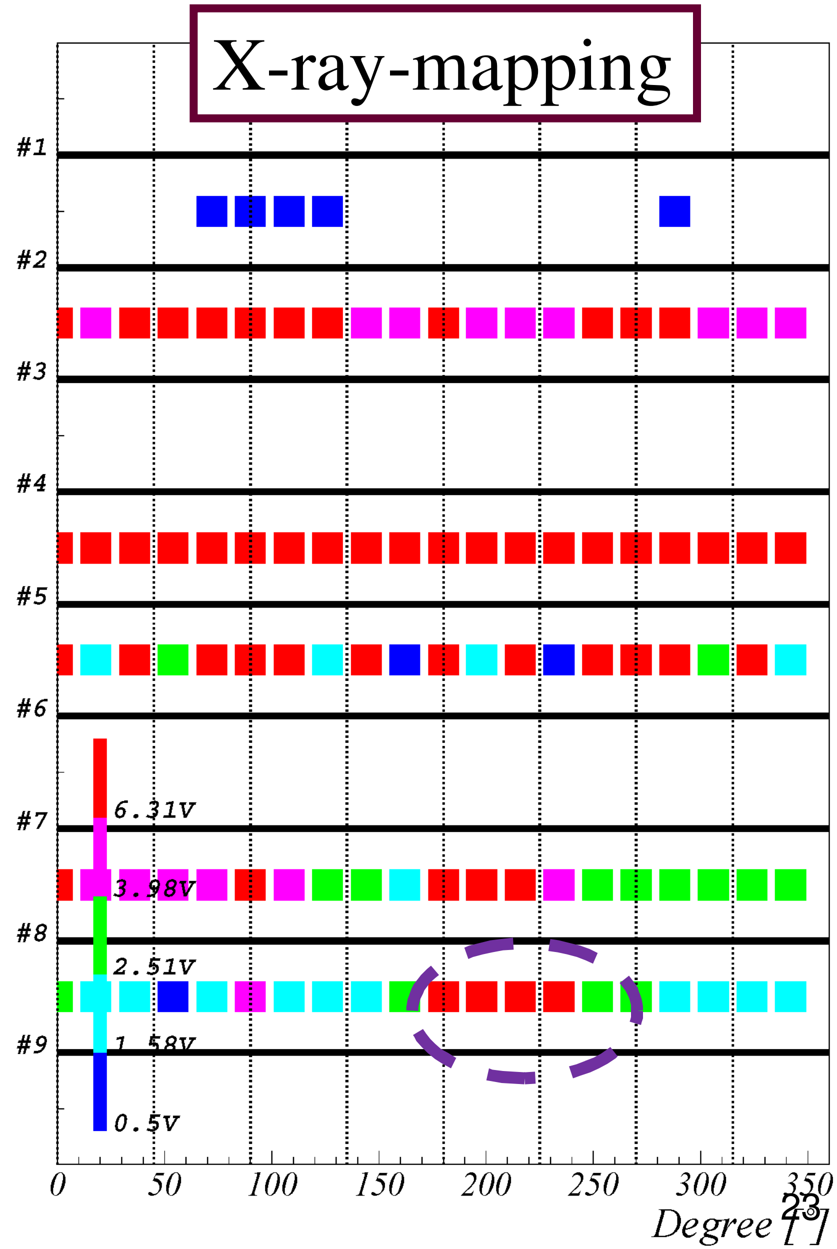
Comparison between T-mapping and X-ray mapping @2nd π



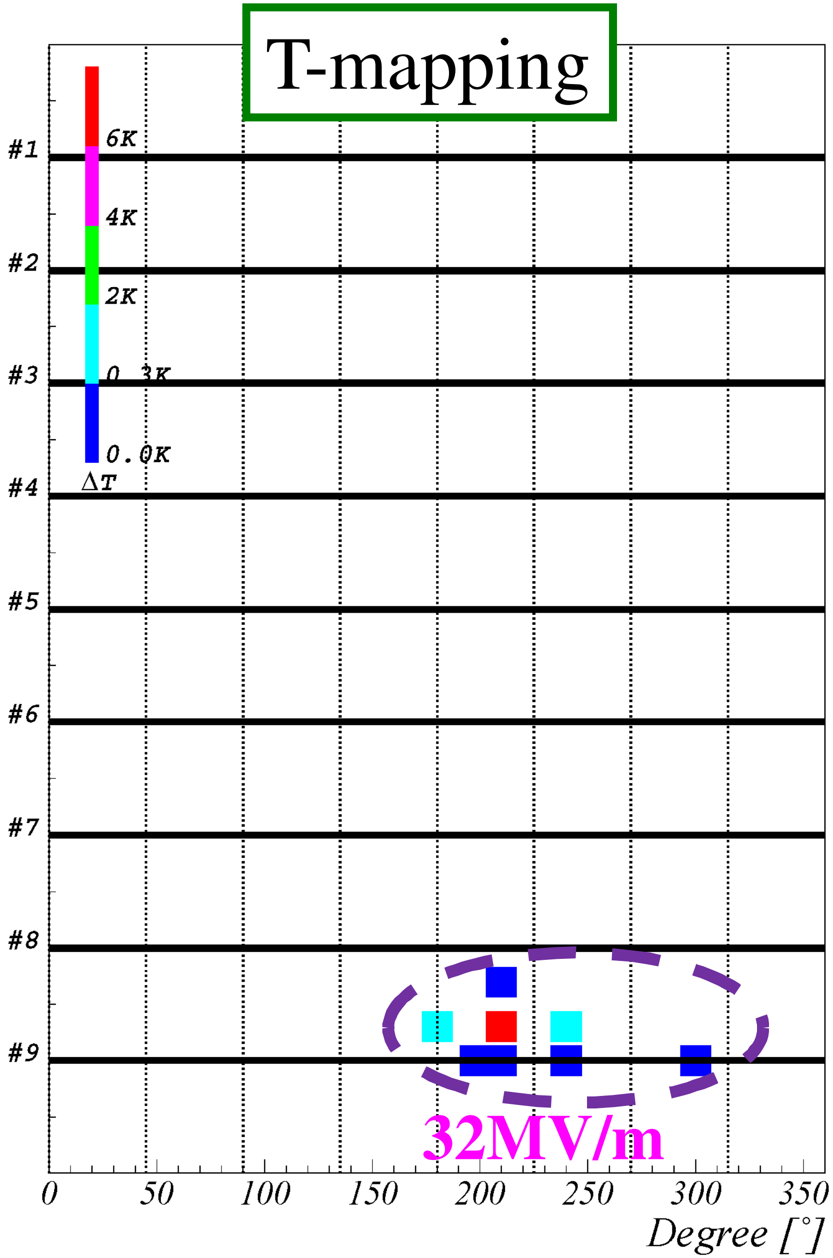


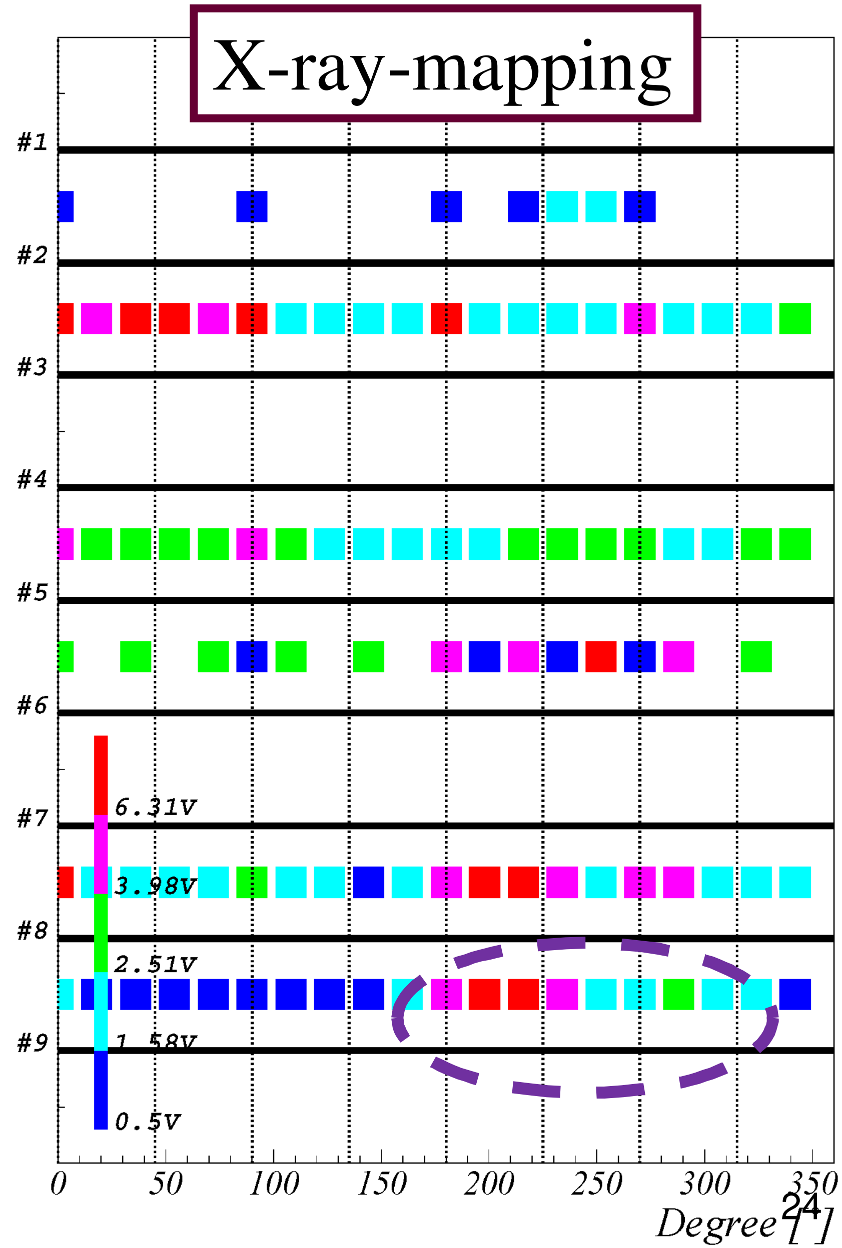
Comparison between T-mapping and X-ray mapping @8π/9



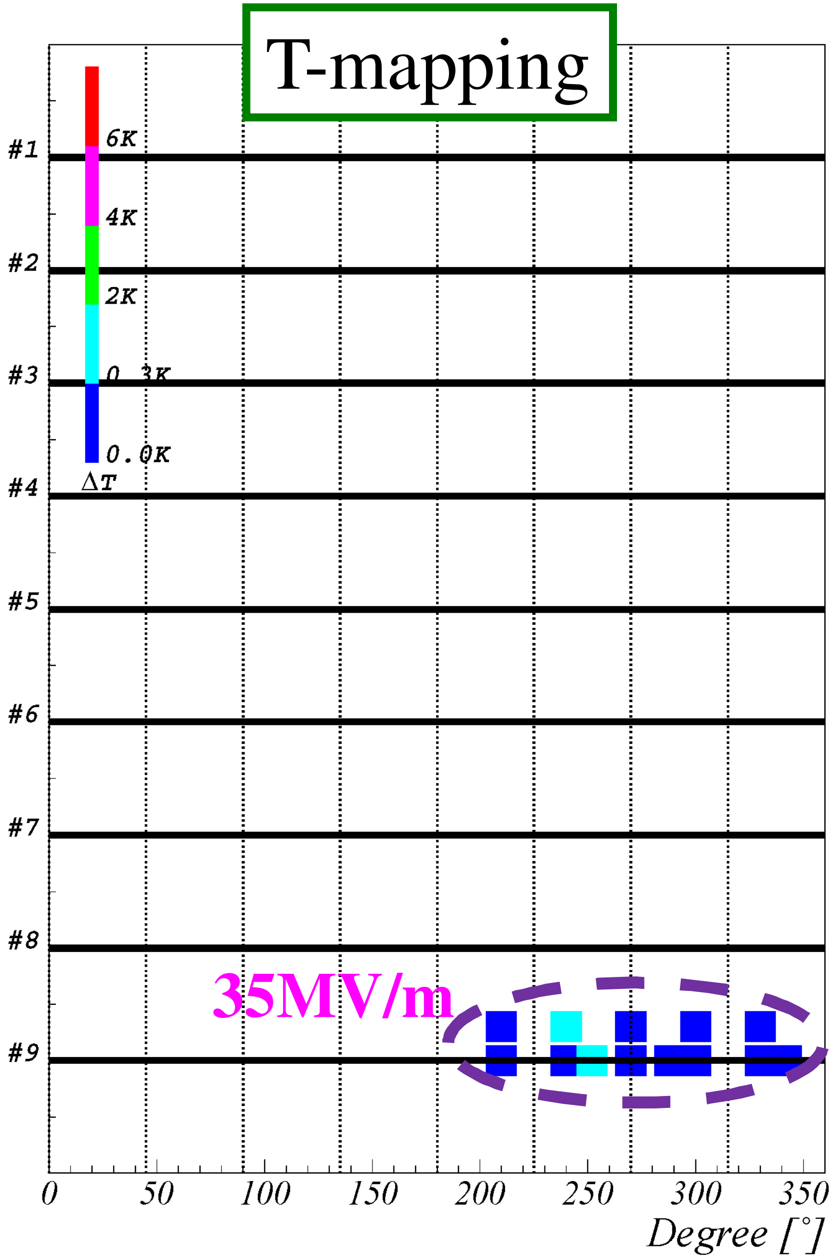


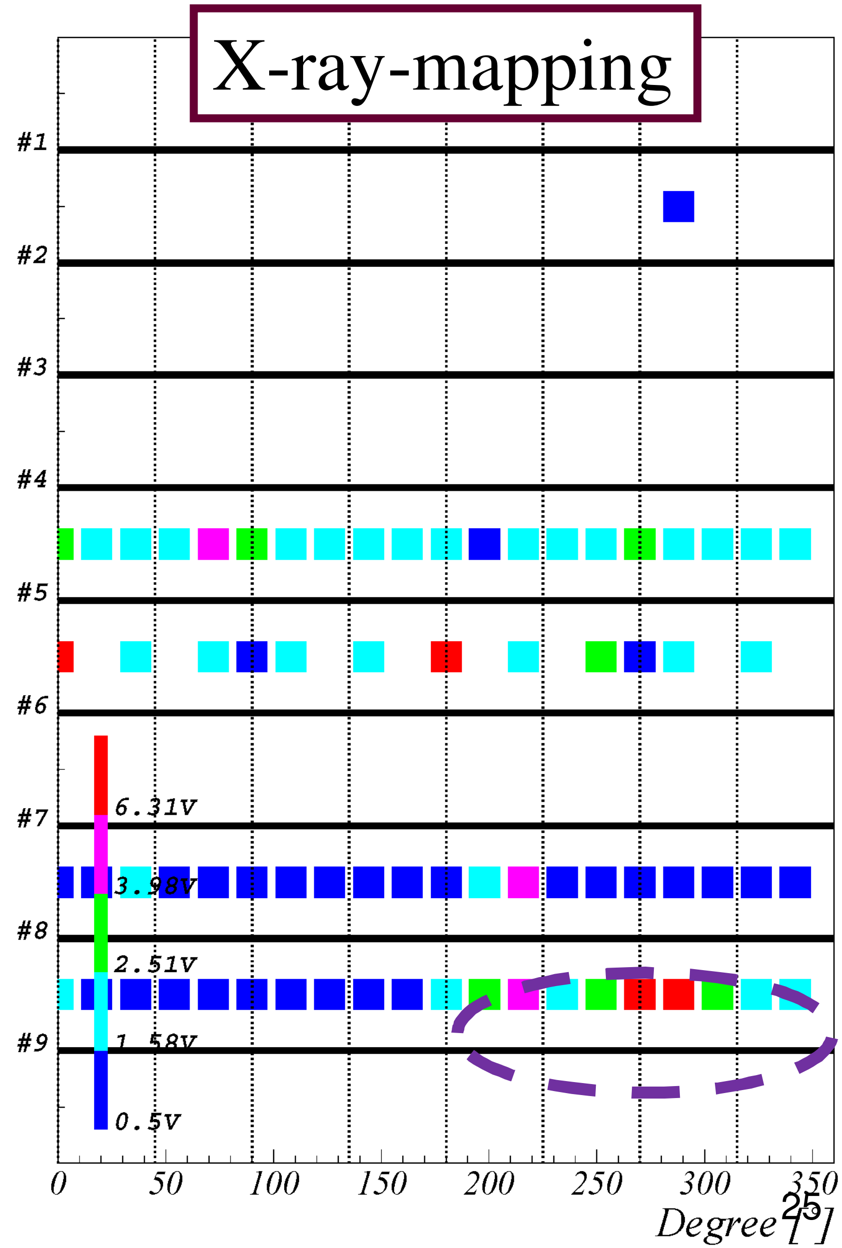
Comparison between T-mapping and X-ray mapping @7π/9



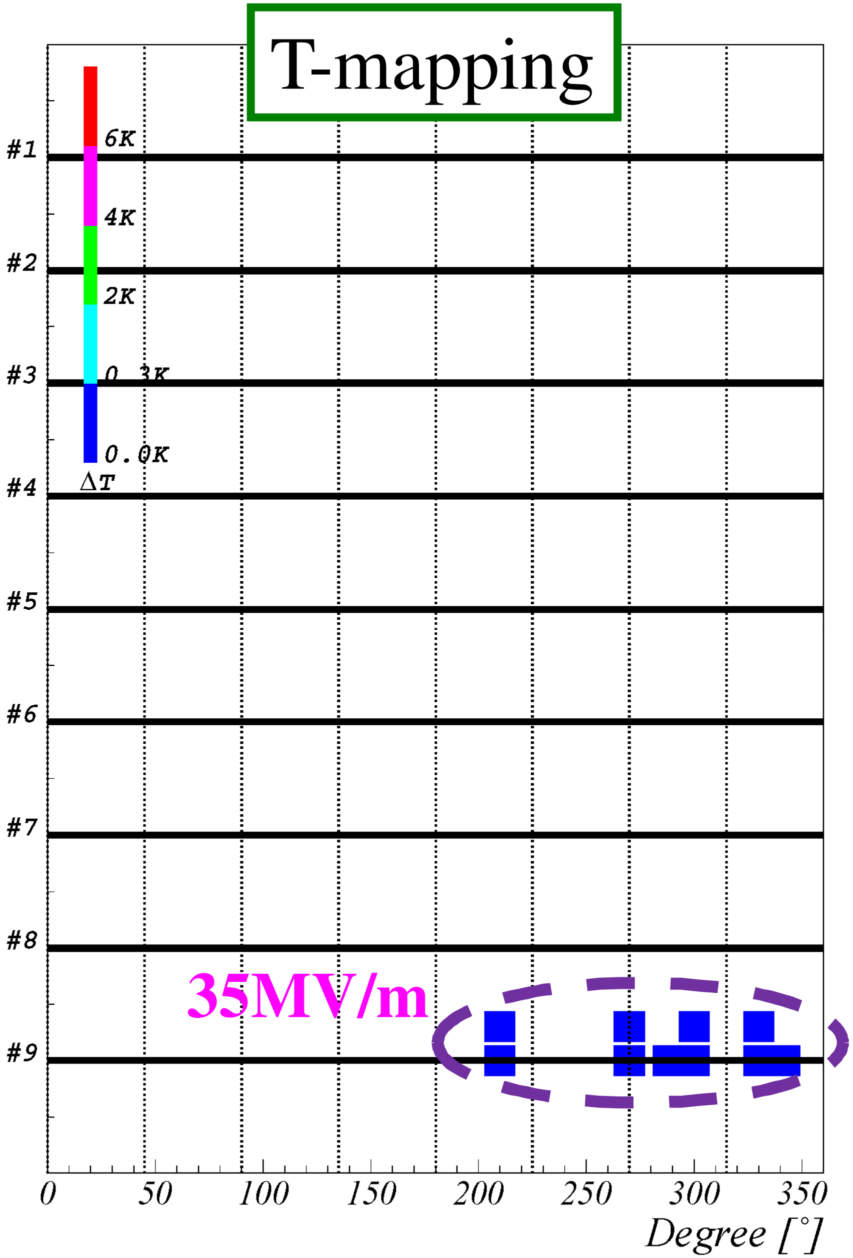


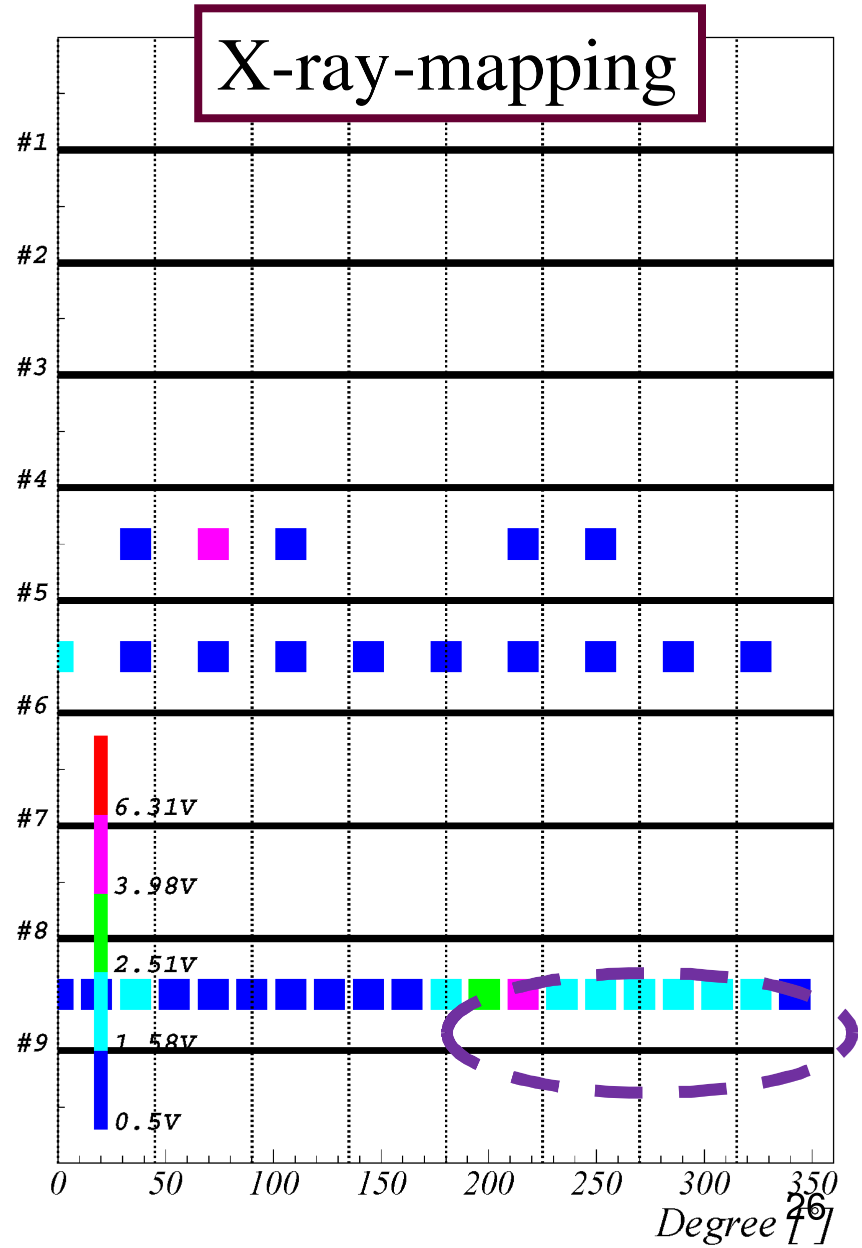
Comparison between T-mapping and X-ray mapping @6π/9



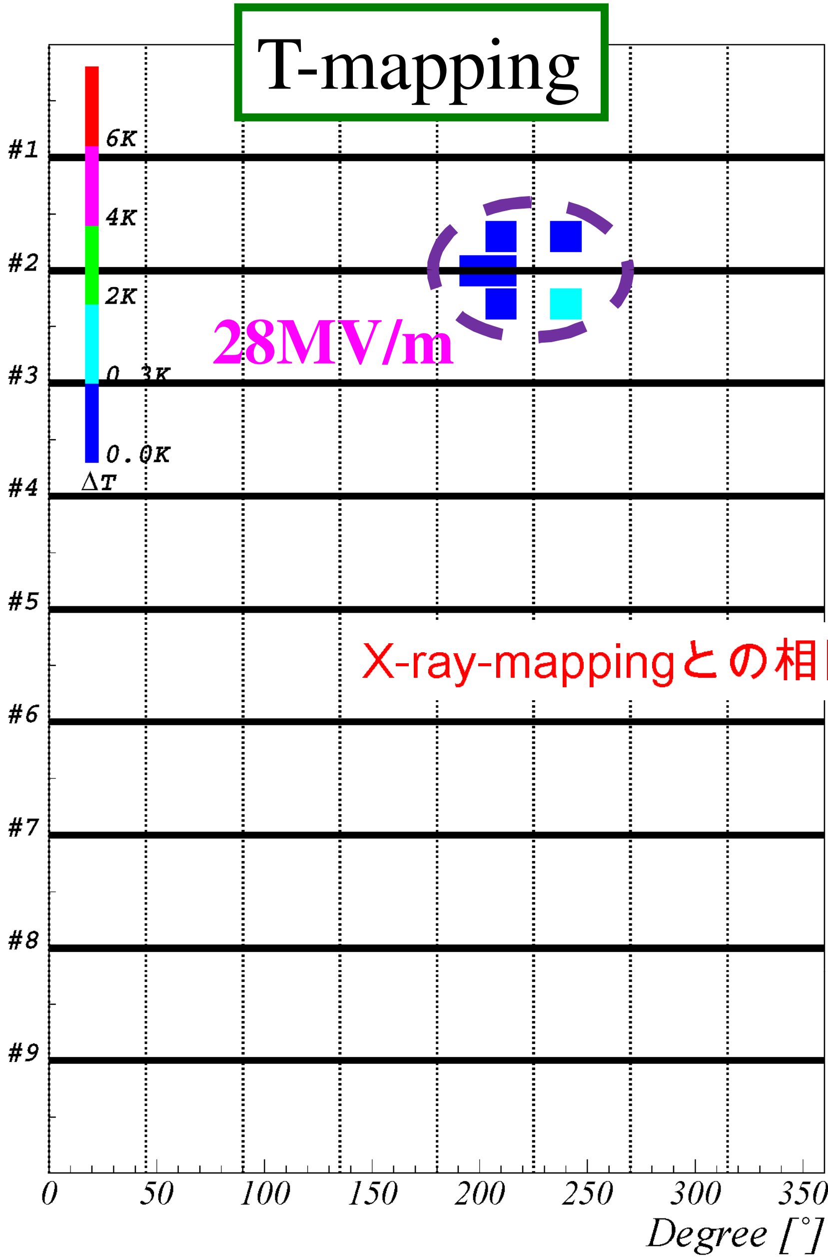


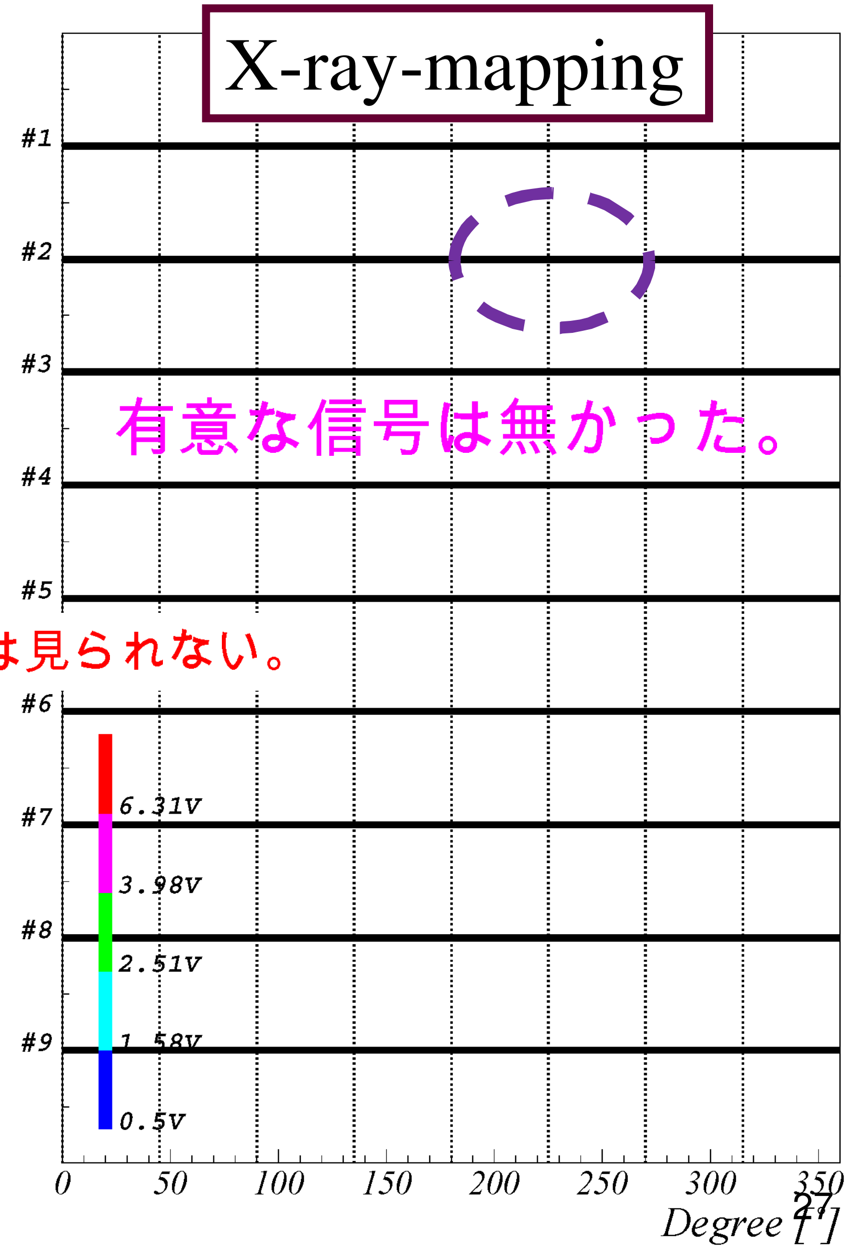
Comparison between T-mapping and X-ray mapping @5π/9





Comparison between T-mapping and X-ray mapping @4π/9

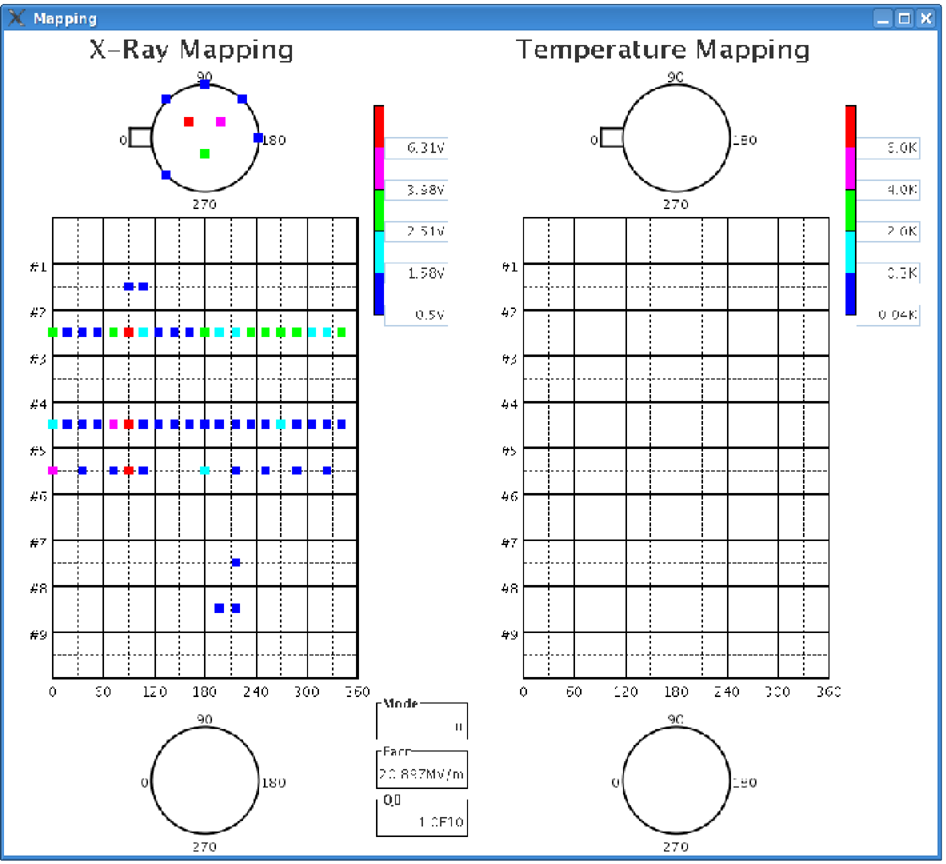


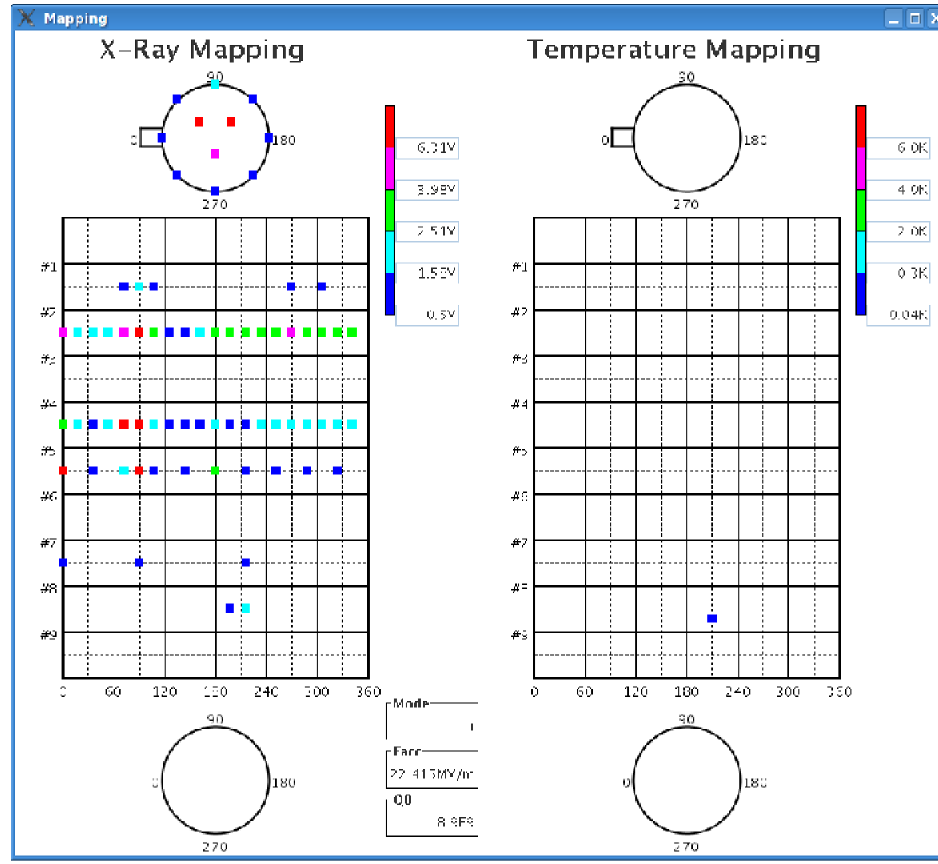


X-ray-mappingとの相関は見られない。

Online monitorの状況⑪

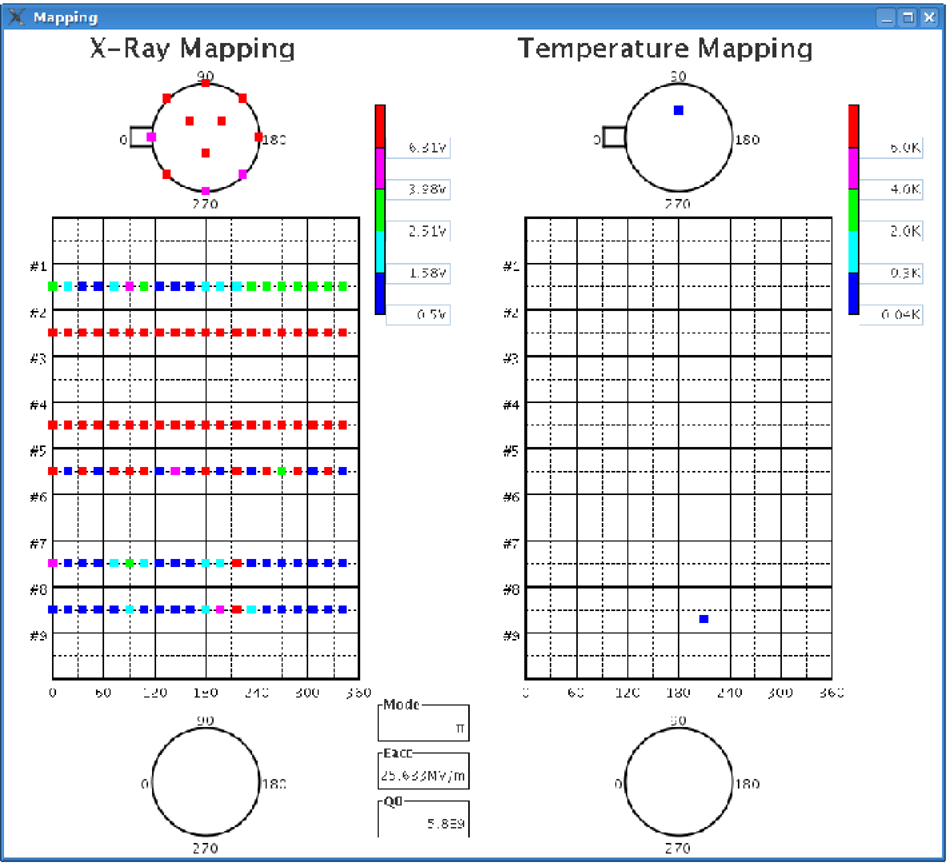
2nd πモード時の様子

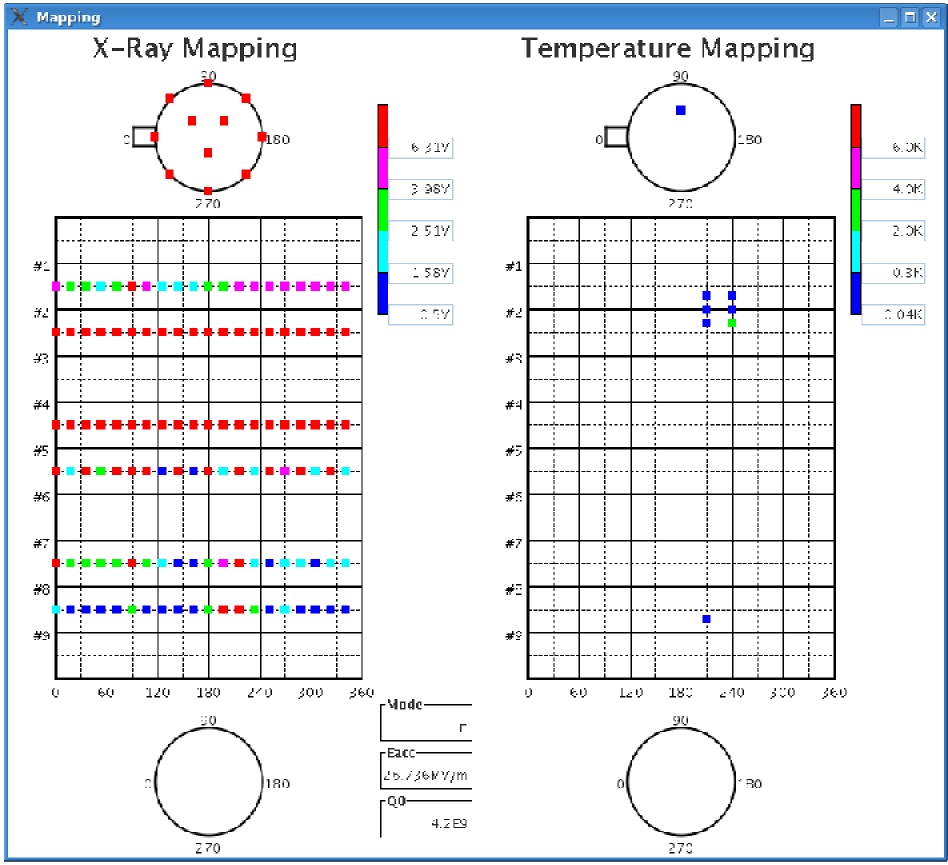




Online monitorの状況⑫

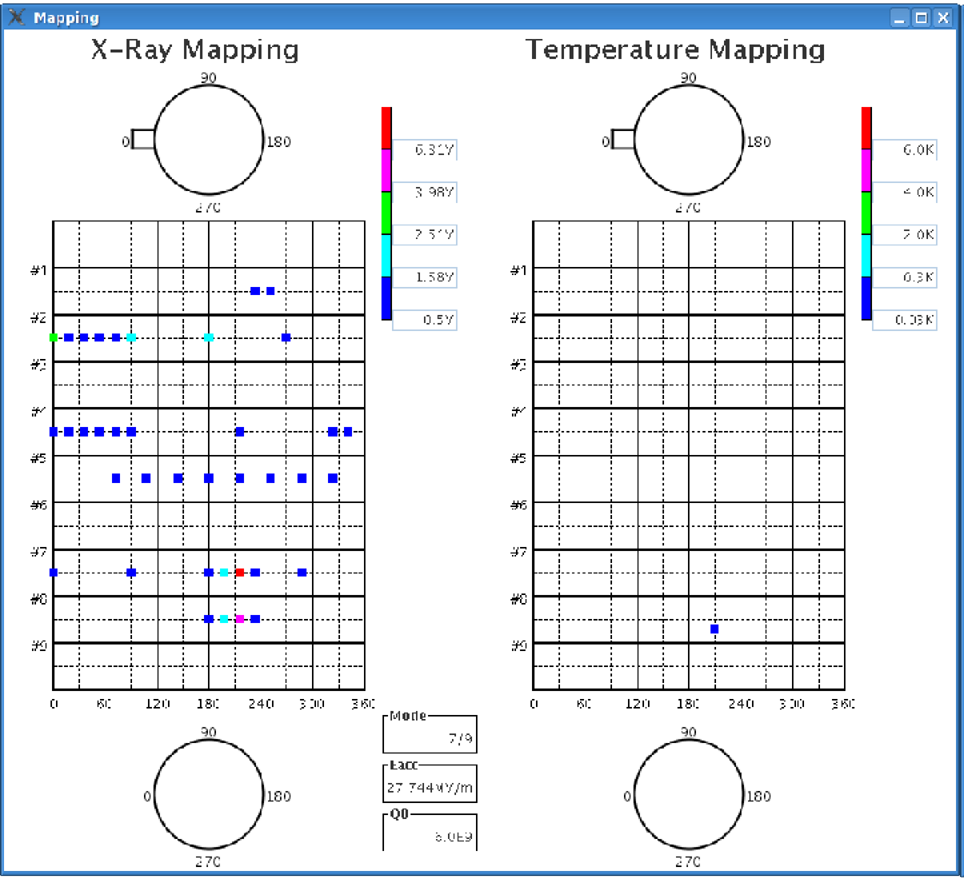
2nd πモード時の様子

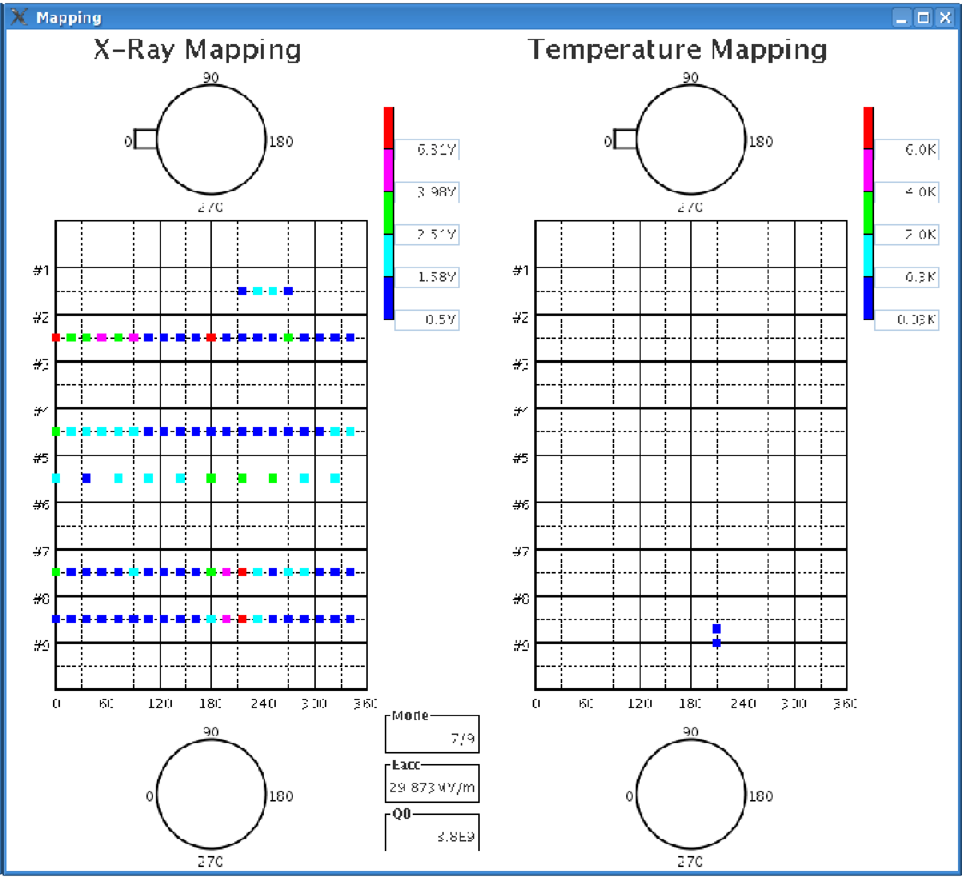




Online monitorの状況⑥

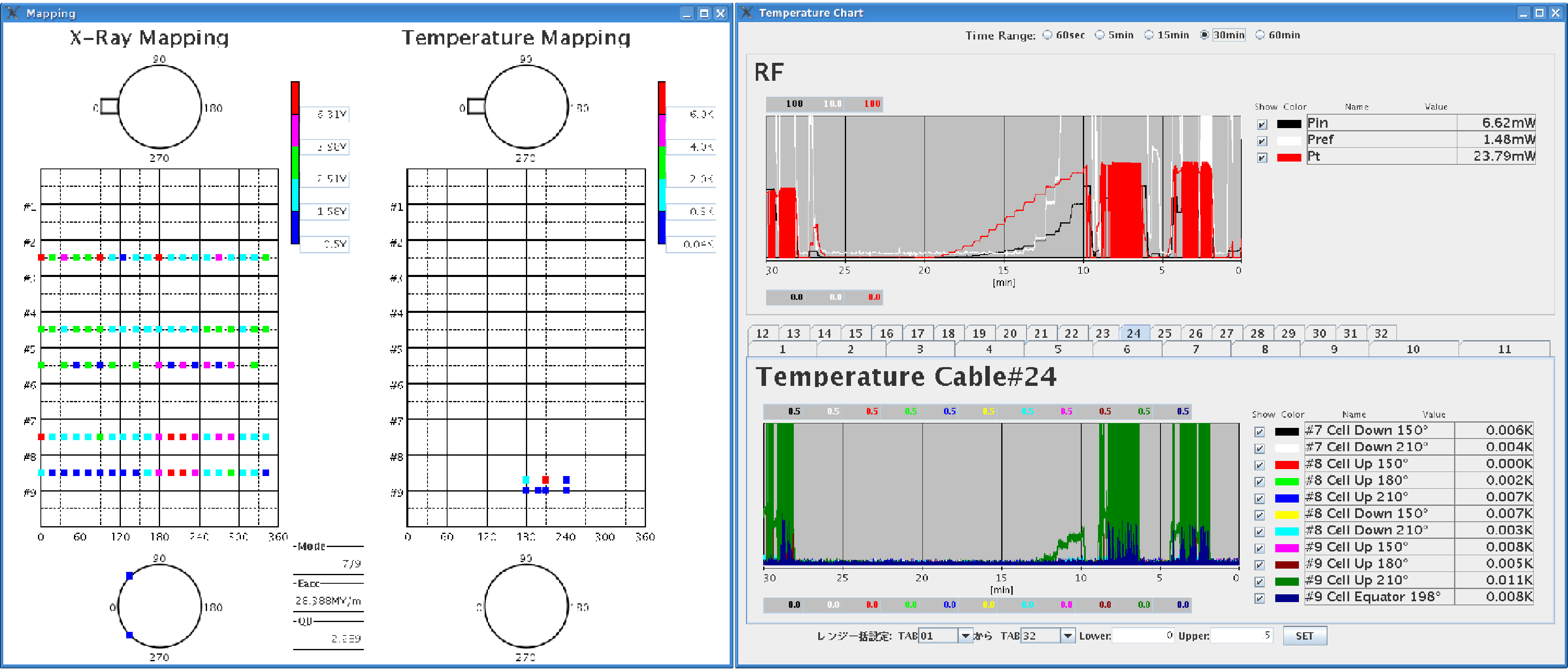
7π/9モード時の様子



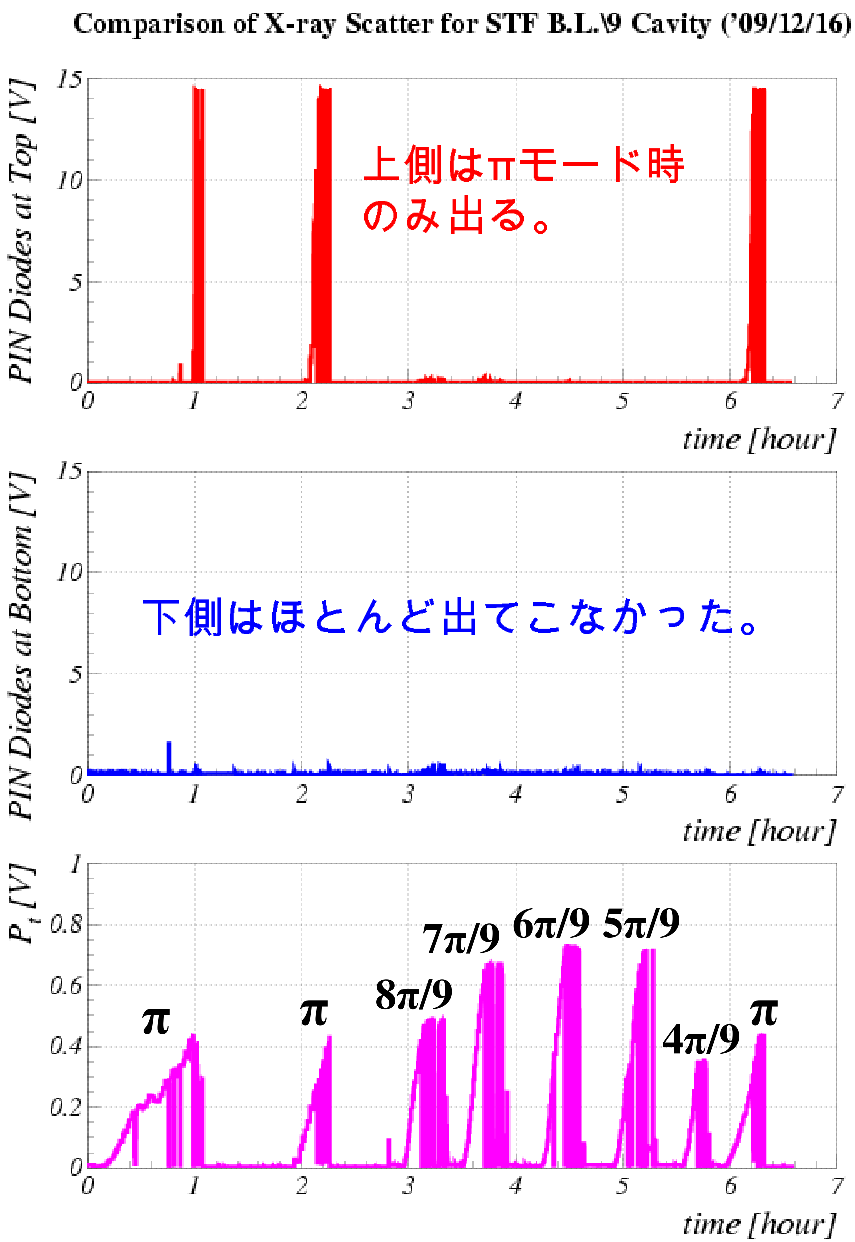


Online monitorの状況⑦

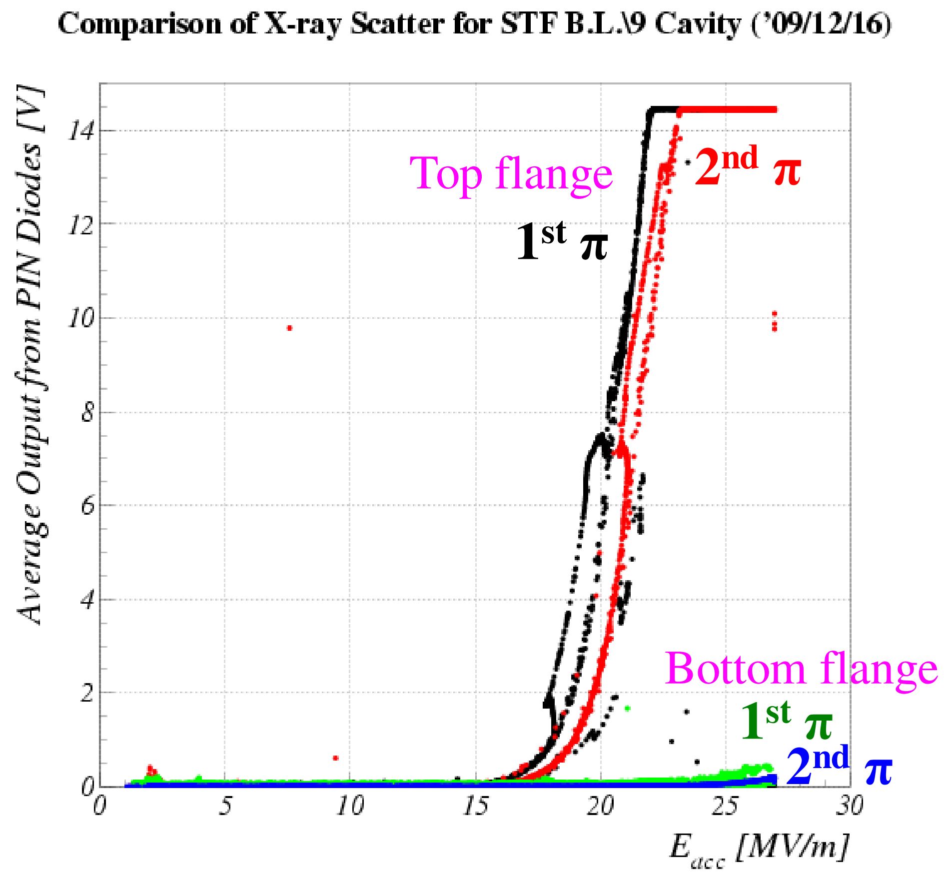
7π/9モード時の様子



X線の振る舞い (上下の軸上の比較)①

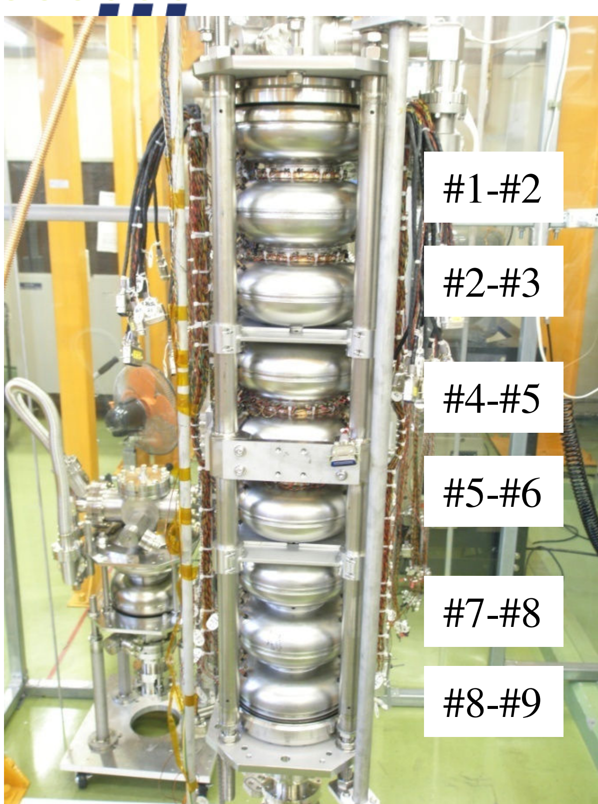


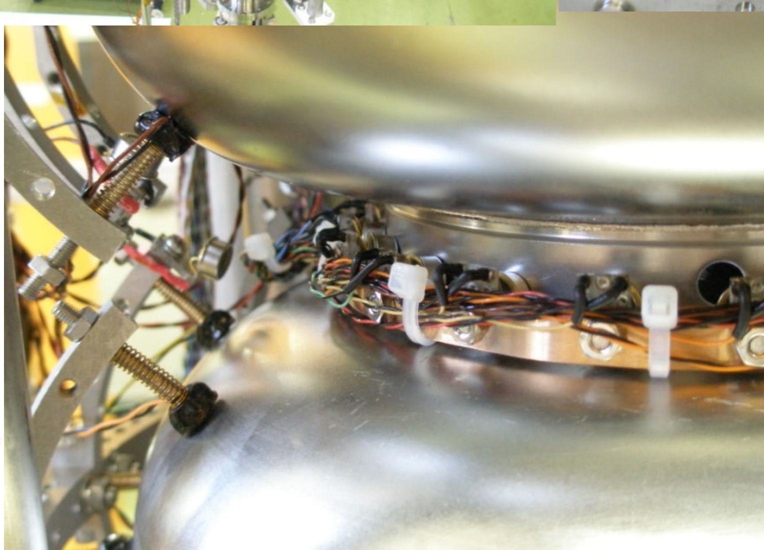
1st power riseの途中から放射線量が
急激に増加した。
放射線モニターとも相関がある。



π modeのみフィールドに焼き直してある。

PIN diodes at each iris





各アイリスで20個ずつセットされている。

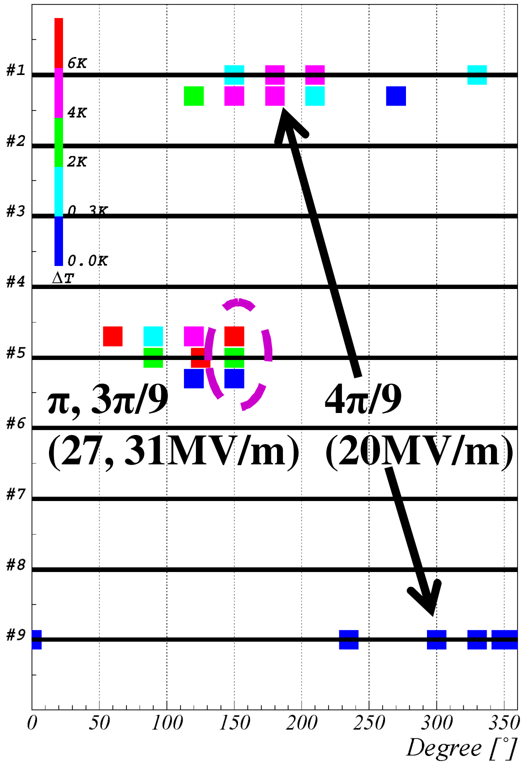
Summary of heating location in Vertical Tests for S1-Global

- Result of MHI#5
- Result of MHI#6
- Result of MHI#7
- Result of MHI#8
- Result of MHI#9
- Summary of heating location in T-mapping
- Summary of cause of quenching at each mode

Last Update : 2010/3/24 (Mon)

Transition of heating location for MHI#5

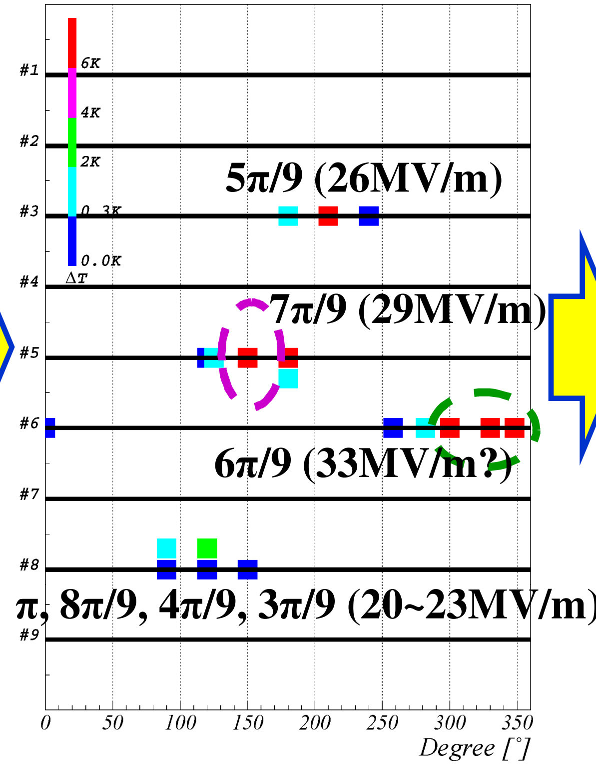
1st V.T. @4/Dec/2008



pre-EP : 5μm
EP1 : 100+20μm
EP2 : 50μm

H_2O_2+HWR+HPR

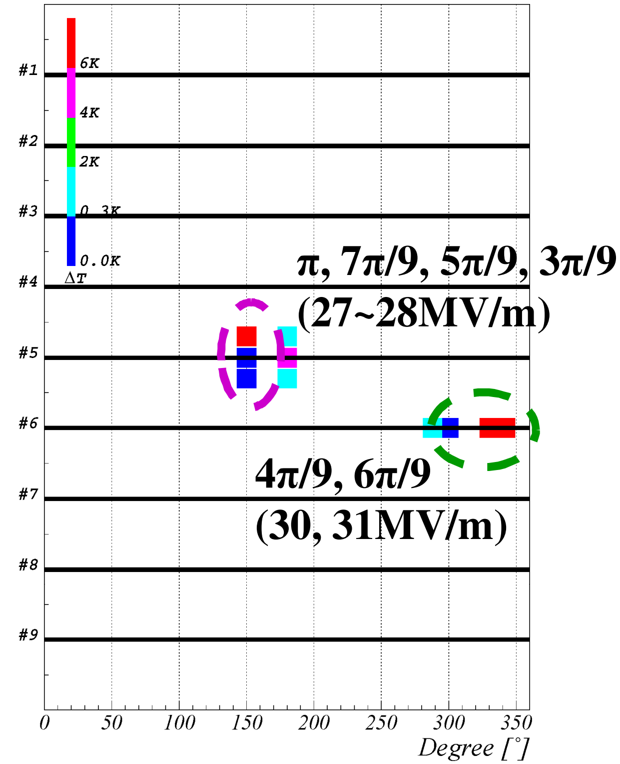
2nd V.T. @26/Feb/2009



EP2 : 50μm

H_2O_2+HWR+HPR

3rd V.T. @16/Apr/2009



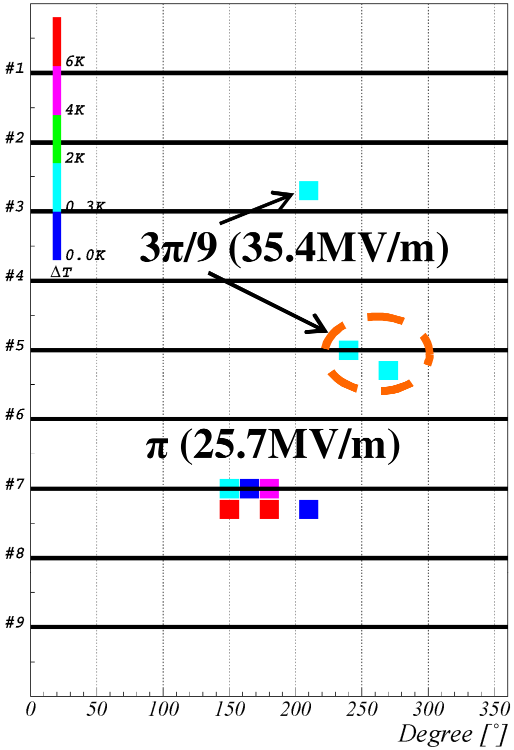
EP2 : 20μm

Ethanol+HWR+HPR

Hot Water Rinsing with Ultrasonic

Transition of heating location for MHI#6

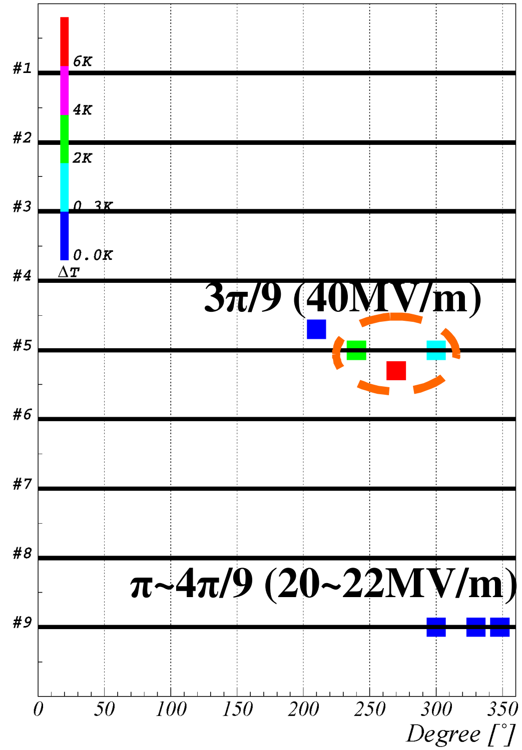
1st V.T. @18/Dec/2008



pre-EP : 5µm
EP1 : 100+20µm
EP2 : 50µm

H_2O_2+HWR+HPR

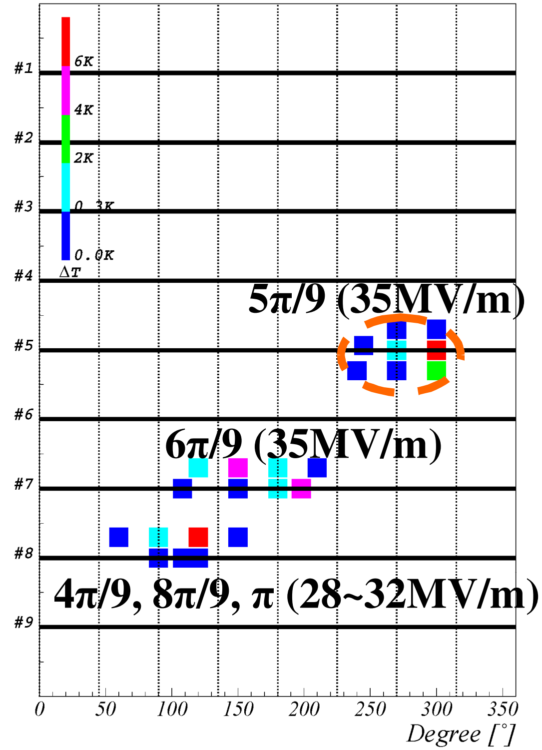
4th V.T. @12/Mar/2009



EP2 : 50µm

H_2O_2+HWR+HPR

6th V.T. @16/Sep/2009



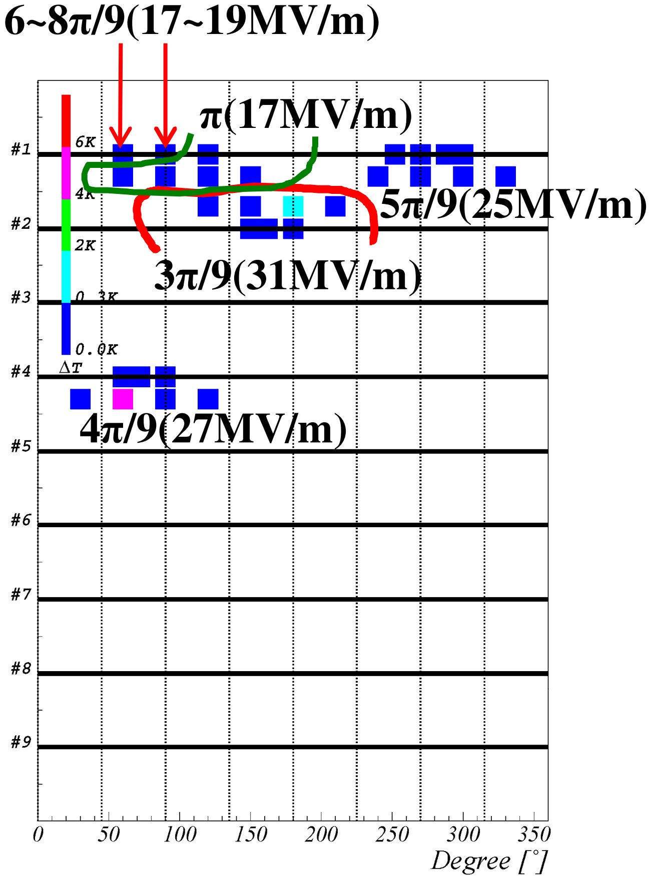
EP2 : 20µm

Ethanol+HWR+HPR

EP2 : 20µm
Ethanol+HWR+HPR
(before 5th V.T.)

Transition of heating location for MHI#7

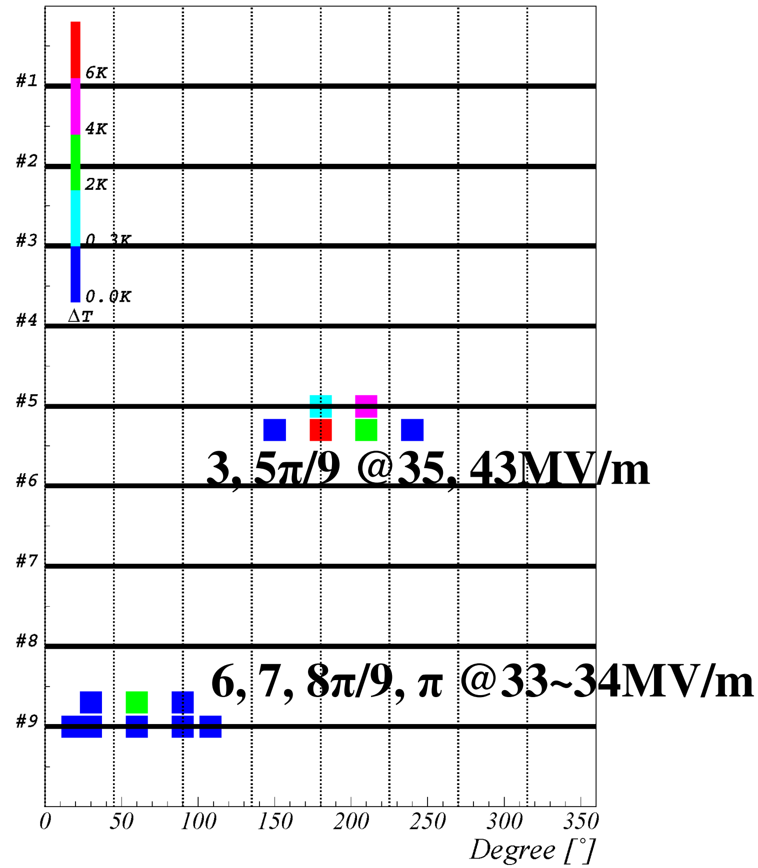
1st V.T. @25/Jun/2009



pre-EP : 5μm
EP1 : 100μm
EP2 : 20μm

Ethanol+HWR+HPR

2nd V.T. @15/Sep/2009

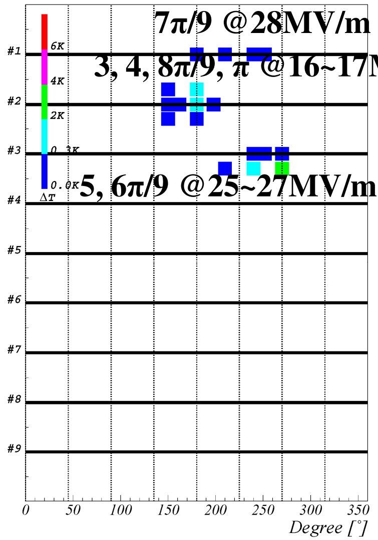


EP2 : 20μm

Degreasing(FM-20)
+HWR+HPR

Transition of heating location for MHI#8

1st V.T. @9/Jul/2009

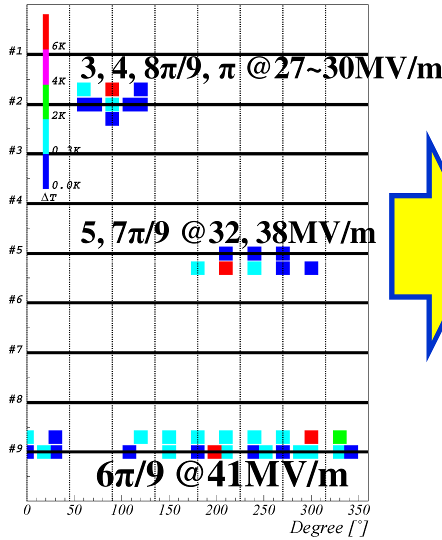


pre-EP : 5μm
EP1 : 100μm
EP2 : 20μm

Ethanol+HWR+HPR


cell #2, 172°

2nd V.T. @29/Oct/2009

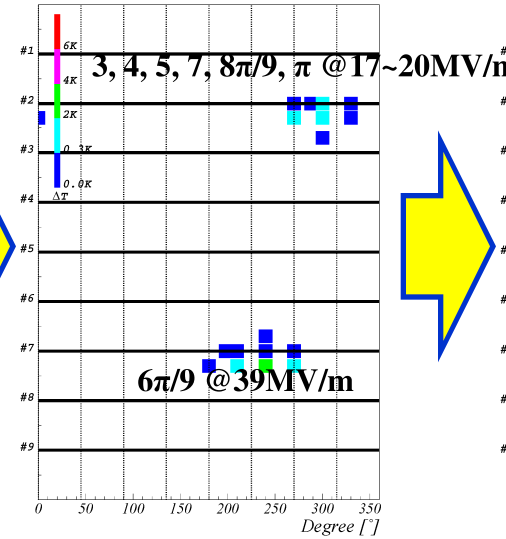


EP2 : 30+20+20μm

Degreasing(FM-20)
+HWR+HPR


cell #2, 86°

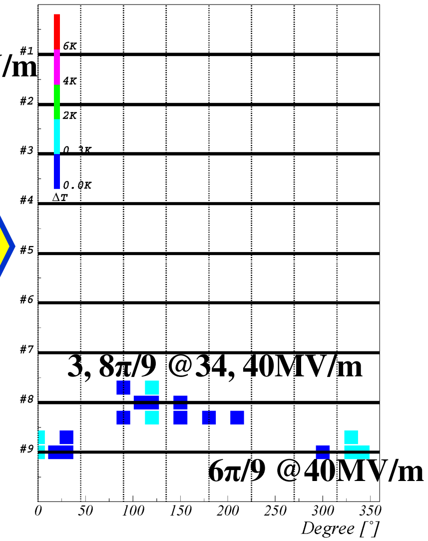
3rd V.T. @26/Nov/2009



EP2 : 20μm

Degreasing(FM-20)
+HWR+HPR

4th V.T. @18/Feb/2010

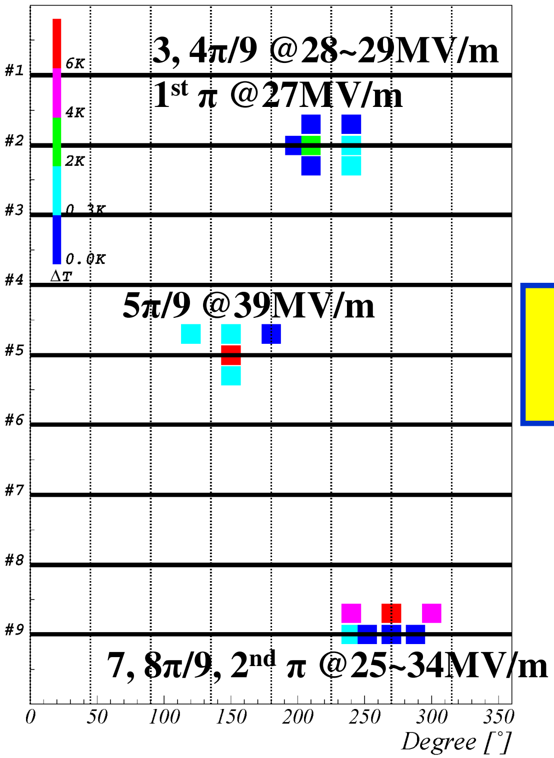


EP2 : 20μm
(low current density)

Degreasing(FM-20)
+HWR+HPR

Transition of heating location for MHI#9

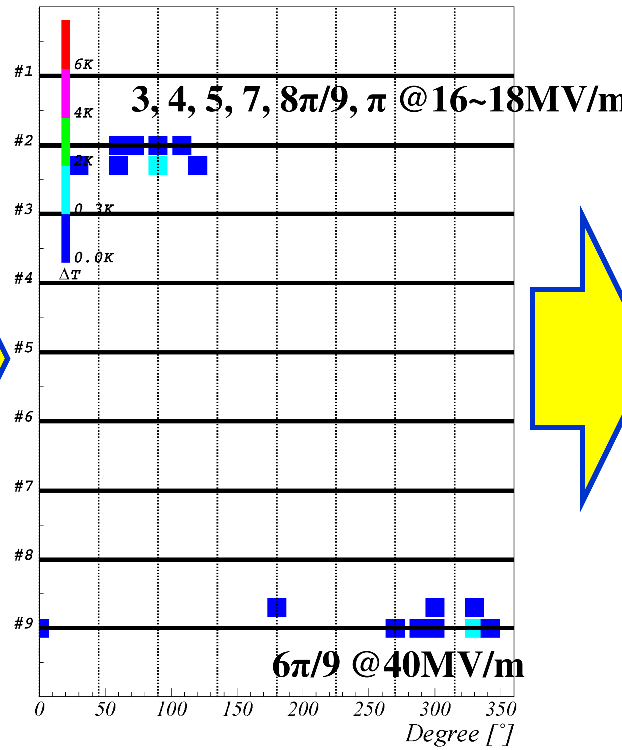
1st V.T. @3/Sep/2009



pre-EP : 5µm
EP1 : 100µm
EP2 : 20µm

Ethanol+HWR+HPR

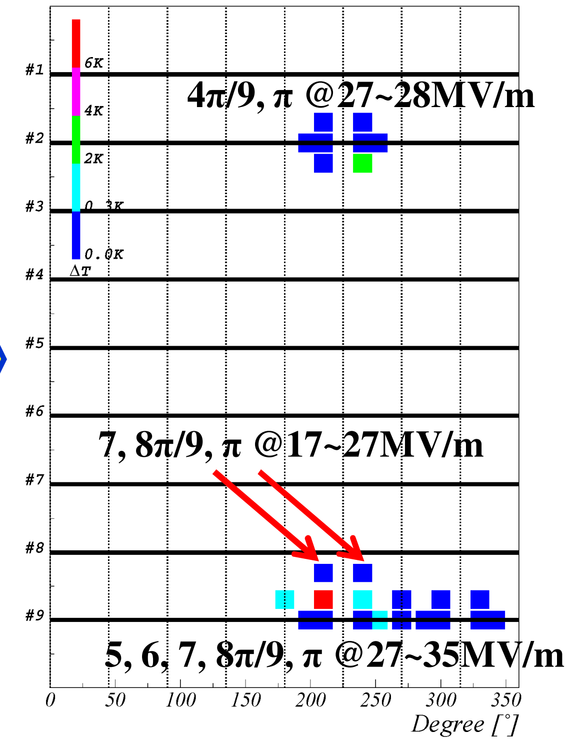
2nd V.T. @12/Nov/2009



EP2 : 20µm

Degreasing(FM-20)
+HWR+HPR

3rd V.T. @16/Dec/2009



EP2 : 20µm

Degreasing(FM-20)
+HWR+HPR

Quenchの原因は如何にして識別されるか？

- Pass-band測定の結果
  - **T-mappingと相関があるとdefect or contaminationによるクエンチと判断される**
  - **T-mappingと相関が無いとfield emissionによるクエンチと判断される**
- T-mappingの結果
  - **Pass-band測定と相補的関係にあり、クエンチの原因はこれら２つの測定から大部分が識別できる**
- X-ray-mappingの結果(ここ数回のみ使用されている)
  - **πモード以外の場合は発熱箇所周辺での放射線量の多寡でfield emissionか否かを判断する場合もある**
- 放射線モニターの結果
  - **状況によっては天板で測定している放射線モニターの結果も用いることがある**

Summary of heating location in T-mapping

cavity	# of V.T.	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5	Cell #6	Cell #7	Cell #8	Cell #9
MHI#5	1st					60~150 (27, 31)				
MHI#5	2nd			180~240 (26)		120~180 (29)	252~360 (33?)		90~150 (20~23)	
MHI#5	3rd					150~180 (27~28)	288~342 (30, 31)			
MHI#6	1st					240~270 (35)		150~210 (26)		
MHI#6	4th					210~300 (40)				300~342 (20~22)
MHI#6	6th					240~300 (35)		108~210 (36)	60~150 (28~32)	
MHI#7	1st	60~150 (17~19) 240~330 (25)	120~210 (31)		30~120 (27)					
MHI#7	2nd					150~240 (35, 43)				18~108 (33~34)
MHI#8	1st	180~252 (28)	150~198 (16~17)	210~270 (25, 27)						
MHI#8	2nd		60~120 (27~30)			180~300 (32, 38)				108~30 (41)
MHI#8	3rd		270~360 (17~20)					180~270 (39)		
MHI#8	4th								90~210 (40)	300~30 (40)
MHI#9	1st		198~240 (27~29)			120~180 (39)				240~300 (25~34)
MHI#9	2nd		30~120 (16~18)							270~360 (40)
MHI#9	3rd		198~240 (27~28)						210 (17~27)	180~342 (27~35)

赤字はdefect or contaminationによる発熱
青字はfield emissionによる発熱
黒字はunknownによる発熱

表中の数値は角度、()内は発熱している際のフィールド[MV/m]を表す。

Summary of cause of quenching at each pass-band

cavity	# of V.T.	1st π	2nd π	8π/9	7π/9	6π/9	5π/9	4π/9	3π/9
MHI#5	**1st**	test stop 27	Cell #5 27, N.Q.	test stop	test stop	test stop	test stop	test stop	Cell #5 31, N.Q.
MHI#5	**2nd**	Cell #8 20, N.Q.	Cell #8 20, N.Q.	Cell #8 23, N.Q.	Cell #5 29, N.Q.	Cell #6 33(?), N.Q.	Cell #3 26, F.E.	Cell #8 21, N.Q.	Cell #8 22, N.Q.
MHI#5	**3rd**	Cell #5 27, N.Q.	Cell #5 27, I.S.	I.S. (N.H.)	Cell #5 28, N.Q.	Cell #6 31, N.Q.	Cell #5 27, N.Q.	Cell #6 30, N.Q.	Cell #5 28, N.Q.
MHI#6	**1st**	test stop	Cell #7 26, F.E.	test stop	test stop	test stop	test stop	test stop	Cell #5 35, N.Q.
MHI#6	**4th**	Cell #9 20, N.Q.	Cell #9 20, N.Q.	Cell #9 21, N.Q.	Cell #9 21, N.Q.	Cell #9 22, N.Q.	Cell #9 21, N.Q.	Cell #9 21, N.Q.	Cell #5 40, N.Q.
MHI#6	**6th**	Cell #8 29, F.E.	Cell #8 28, F.E.	Cell #8 30, F.E.	power limit	Cell #7 36, N.Q.	Cell #5 35, F.E.	Cell #8 32, F.E.	skip
MHI#7	**1st**	Cell #1 15, F.E.	Cell #1 17, F.E.	Cell #1 17, F.E.	Cell #1 18, F.E.	Cell #1 19, F.E.	Cell #1 25, F.E.	Cell #4 27, F.E.	Cell #2 31, U.K.
MHI#7	**2nd**	Cell #9 34, N.Q.	Cell #9 34, N.Q.	Cell #9 33, N.Q.	Cell #9 34, N.Q.	Cell #9 34, N.Q.	Cell #5 43, N.Q.	power limit	Cell #5 35, N.Q.
MHI#8	**1st**	Cell #2 16, N.Q.	Cell #2 16, N.Q.	Cell #2 17, N.Q.	Cell #1 28, N.Q.	Cell #3 27, N.Q.	Cell #3 25, N.Q.	Cell #2 16, N.Q.	Cell #2 17, N.Q.
MHI#8	**2nd**	Cell #2 27, N.Q.	Cell #2 27, N.Q.	Cell #2 30, N.Q.	Cell #5 32, N.Q.	Cell #9 41, U.K.	Cell #5 38, N.Q.	Cell #2 28, N.Q.	Cell #2 29, N.Q.
MHI#8	**3rd**	Cell #2 20, N.Q.	Cell #2 17, N.Q.	Cell #2 19, N.Q.	Cell #2 19, N.Q.	Cell #7 39, N.Q.	Cell #2 20, N.Q.	Cell #2 18, N.Q.	Cell #2 19, N.Q.
MHI#8	**4th**	test stop	test stop (radiation)	Cell #8 34, N.Q.	skip	Cell #9 40, N.Q.	skip	skip	Cell #8 40, N.Q.
MHI#9	**1st**	Cell #2 27, N.Q.	Cell #9 25, F.E.	Cell #9 28, F.E.	Cell #9 34, F.E.	power limit >36	Cell #5 39, N.Q.	Cell #2 28, N.Q.	Cell #2 29, N.Q.
MHI#9	**2nd**	Cell #2 16, N.Q.	Cell #2 16, N.Q.	Cell #2 18, N.Q.	Cell #2 17, N.Q.	Cell #9 40, U.K.	Cell #2 18, N.Q.	Cell #2 17, N.Q.	Cell #2 17, N.Q.
MHI#9	**3rd**	Cell #2 26, N.Q.	Cell #2 27, N.Q.	Cell #8, 9 28, F.E.	Cell #8, 9 32, F.E.	Cell #9 35, F.E.	Cell #9 35, F.E.	Cell #2 28, N.Q.	skip

表中の用語解説①

- N.Q. (Normal Quench)
  - Defect or contaminationによる発熱が原因のクエンチ
  - X-ray-mappingとの相関は無い
- F.E. (Field Emission)
  - Field emission起源の電子衝突による発熱が原因のクエンチ
  - X-ray-mappingと相関がある
- U.K. (Unknown)
  - 原因はよくわからないが発熱を伴うクエンチが起こっているもの
  - クエンチの際の発熱箇所があちこちに移動しているもの
- I.S. (Intermediate State)
  - 中間状態に陥ってよくわからなかったもの
  - 入力ケーブルの不具合が疑わしい
- N.H. (No Heating)
  - 中間状態に陥った後、発熱がどの抵抗にも観測されなかったもの
  - 入力ケーブルの不具合が疑わしい

表中の用語解説②

- Power limit
  - 入力パワーが250W近くになるとそれ以上入らないようになる
- Skip
  - 時間（ヘリウム）が無くてそのモードをスキップした
- Test stop
  - そのモードの測定を途中終了した
  - クエンチで終了していないため、発熱箇所は不明である