Main Linac / SCRF R & D

1. Cavity R&D Status and Prospects
2. Cryomodule System Tests

Jim Kerby

with thanks to Rongli Geng, Elvin Harms, Camille Ginsburg, Hitoshi Hayano, Charlie Cooper, Eiji Kako, Lance Cooley, Yuriy Pischalnikov and colleagues in all three regions without whose efforts this would not be possible

Cavity Database Updates

- **Previous update was LCWS11 (Granada) September 2011**
  - 44 cavities for 1st pass, 33 cavities for 2nd pass
- **Updates which affect standard yield plots**
  - KEK
    - MHI018: test#1 E_{acc}=31.0 MV/m added
    - MHI019: test#1 E_{acc}=26.3 MV/m added
    - MHI020: test#1 E_{acc}= 9.0 MV/m added
    - MHI021: test#1 E_{acc}=38.9 MV/m added
  - DESY
    - Z162: test#2 E_{acc}=29.4 MV/m added
    - CAV00001: test#1 E_{acc}=28.4 MV/m added
      test#2 E_{acc}= 8.7 MV/m added
    - CAV00002: test#1 E_{acc}=37.6 MV/m added
    - CAV00004: test#1 E_{acc}=38.1 MV/m added
  - 51 cavities for 1st pass, 35 cavities for 2nd pass

Yield Plot Updates: 1st Pass detail

1st-pass cavity yield at >25 MV/m was (66 +- 7) %

now (69 +- 7) %

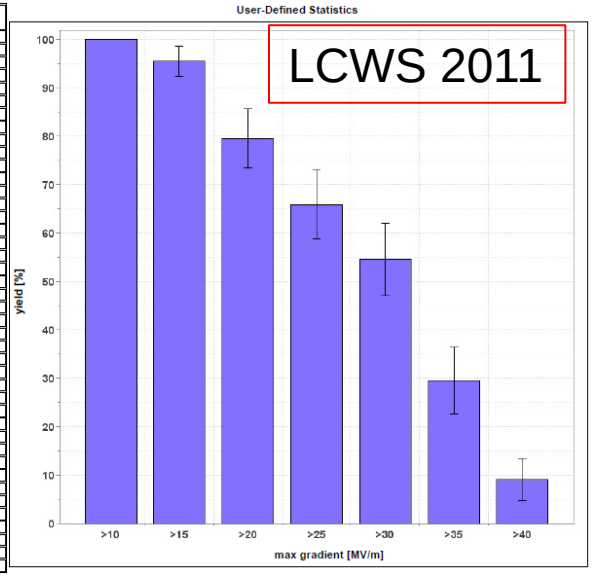
>35 MV/m was (30 +- 7) %

now (31 +- 7) %

>28 MV/m is (58.8 +- 6.9) %

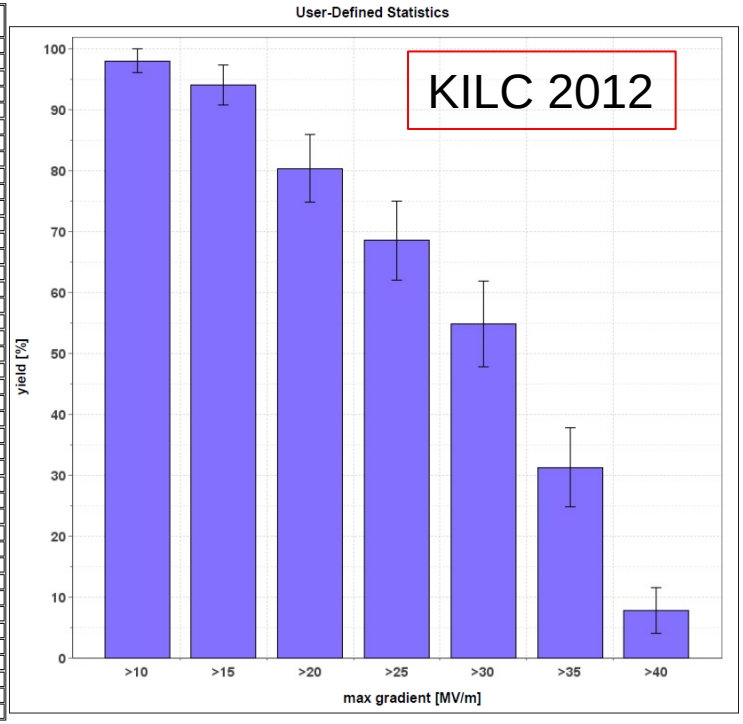
No.	Cavity	Test Date	Max. Eacc [MV/m]
1	TB9ACC013	01.Dec.08	41.80
2	TB9ACC014	09.Feb.09	41.50
3	TB9AES008	26.Aug.09	41.10
4	TB9AES007	16.Mar.10	41.00
5	AC122	26.Aug.08	38.88
6	AC115	11.Dec.07	38.60
7	MHI017	06.Feb.11	38.40
8	TB9RI019	11.Jun.10	38.00
9	TB9AES010	06.Nov.09	37.70
10	MHI012	11.Nov.10	37.50
11	TB9ACC011	21.Aug.08	37.00
12	MHI013	25.Nov.10	36.20
13	TB9ACC012	07.Jul.08	35.10
14	Z134	13.Nov.09	34.94
15	AC125	15.Jul.08	34.59
16	AC150	30.Jan.09	34.33
17	TB9AES009	18.Aug.09	33.40
18	TB9RI018	15.Apr.10	33.10
19	Z143	09.Oct.08	32.57
20	Z106	21.Feb.07	31.70
21	AC127	13.Feb.09	31.25
22	TB9ACC016	14.Dec.09	31.20
23	Z162	24.Mar.11	31.01
24	TB9RI027	09.Sep.10	31.00
25	ACCEL7	05.Sep.06	29.00
26	AC149	28.Jan.09	26.51
27	AC146	06.May.10	26.13
28	AC124	05.Feb.09	26.01
29	Z137	24.Feb.09	25.23
30	Z139	12.Sep.08	24.93
31	MHI015	03.Feb.11	22.50
32	TB9RI028	01.Oct.10	22.00
33	MHI016	19.May.11	20.77
34	Z142	01.Jul.09	20.58
35	TB9AES005	27.Mar.09	20.50
36	ACCEL6	12.Dec.06	19.00
37	Z141	16.Apr.08	18.29
38	TB9ACC015	02.Jul.08	18.00
39	Z130	01.Sep.08	17.30
40	Z131	20.Aug.08	17.17
41	Z132	19.Aug.08	16.83
42	AC126	05.Sep.08	16.37

No.	Cavity	Test Date	Max. Eacc [MV/m]
43	MHI014	20.Jan.11	15.00
44	TB9AES006	30.Apr.09	14.10



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	MHI021	12.Apr.12	38.90
6	AC122	26.Aug.08	38.88
7	AC115	11.Dec.07	38.60
8	MHI017	06.Feb.11	38.40
9	CAV00004	06.Mar.12	38.09
10	TB9RI019	11.Jun.10	38.00
11	TB9AES010	06.Nov.09	37.70
12	CAV00002	09.Mar.12	37.58
13	MHI012	11.Nov.10	37.50
14	TB9ACC011	21.Aug.08	37.00
15	MHI013	25.Nov.10	36.20
16	TB9ACC012	07.Jul.08	35.10
17	Z134	13.Nov.09	34.94
18	AC125	15.Jul.08	34.59
19	AC150	30.Jan.09	34.33
20	TB9AES009	18.Aug.09	33.40
21	TB9RI018	15.Apr.10	33.10
22	Z143	09.Oct.08	32.57
23	Z106	21.Feb.07	31.70
24	AC127	13.Feb.09	31.25
25	TB9ACC016	14.Dec.09	31.20
26	Z162	24.Mar.11	31.01
27	MHI018	16.Feb.12	31.00
28	TB9RI027	09.Sep.10	31.00
29	ACCEL7	05.Sep.06	29.00
30	CAV00001	09.Feb.12	28.42
31	AC149	28.Jan.09	26.51
32	MHI019	01.Mar.12	26.30
33	AC146	06.May.10	26.13
34	AC124	05.Feb.09	26.01
35	Z137	24.Feb.09	25.23
36	Z139	12.Sep.08	24.93
37	MHI015	03.Feb.11	22.50
38	TB9RI028	01.Oct.10	22.00
39	MHI016	19.May.11	20.77
40	Z142	01.Jul.09	20.58
41	TB9AES005	27.Mar.09	20.50
42	ACCEL6	12.Dec.06	19.00

No.	Cavity	Test Date	Max. Eacc [MV/m]
43	Z141	16.Apr.08	18.29
44	TB9ACC015	02.Jul.08	18.00
45	Z130	01.Sep.08	17.30
46	Z131	20.Aug.08	17.17
47	Z132	19.Aug.08	16.83
48	AC126	05.Sep.08	16.37
49	MHI014	20.Jan.11	15.00
50	TB9AES006	30.Apr.09	14.10
51	MHI020	15.Mar.12	9.00



Yield Plot Updates: 2nd Pass Detail

2nd-pass cavity yield at >25 MV/m was (79 +- 7) %

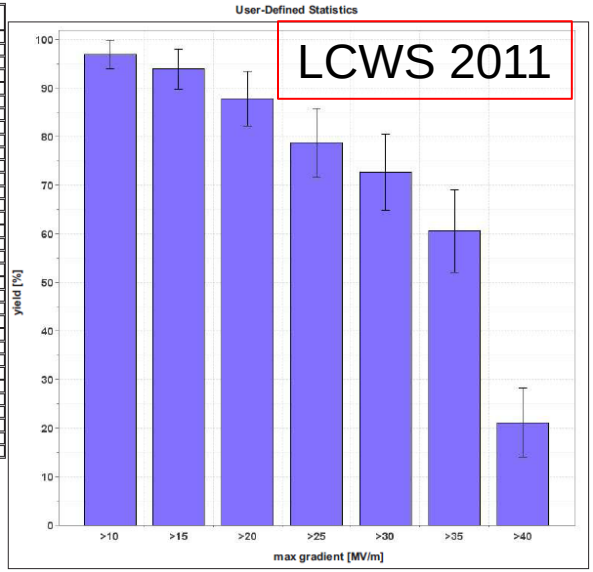
now **(77 +- 7) %**

>35 MV/m was (61 +- 9) %

now **(57 +- 8) %**

>28 MV/m is (74.3 +- 7.4) %

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	TB9AES007	16.Mar.10	41.00
6	Z143	12.Nov.08	41.00
7	AC146	04.Aug.11	40.18
8	TB9ACC016	11.Feb.10	39.30
9	TB9RI018	02.Jun.10	39.00
10	AC122	26.Aug.08	38.88
11	TB9RI028	18.Oct.10	38.80
12	AC115	11.Dec.07	38.60
13	MHI017	06.Feb.11	38.40
14	TB9RI019	11.Jun.10	38.00
15	TB9AES010	06.Nov.09	37.70
16	MHI012	11.Nov.10	37.50
17	TB9ACC011	21.Aug.08	37.00
18	MHI013	25.Nov.10	36.20
19	TB9AES009	07.Oct.09	36.00
20	TB9ACC012	07.Jul.08	35.10
21	TB9RI027	11.Oct.10	34.80
22	AC150	08.May.09	33.23
23	Z139	20.Oct.08	32.75
24	AC124	19.May.09	30.93
25	ACCEL6	23.Jan.07	29.00
26	AC127	11.Jun.09	27.85
27	TB9AES006	11.Sep.09	22.20
28	Z141	14.May.08	20.70
29	TB9AES005	09.Apr.09	20.50
30	Z131	25.Nov.08	17.96
31	Z130	15.Oct.08	16.60
32	MHI014	17.Feb.11	13.00
33	AC126	21.Oct.08	6.14



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16	MHI012	11.Nov.10	37.50
17	TB9ACC011	21.Aug.08	37.00
18	MHI013	25.Nov.10	36.20
19	TB9AES009	07.Oct.09	36.00
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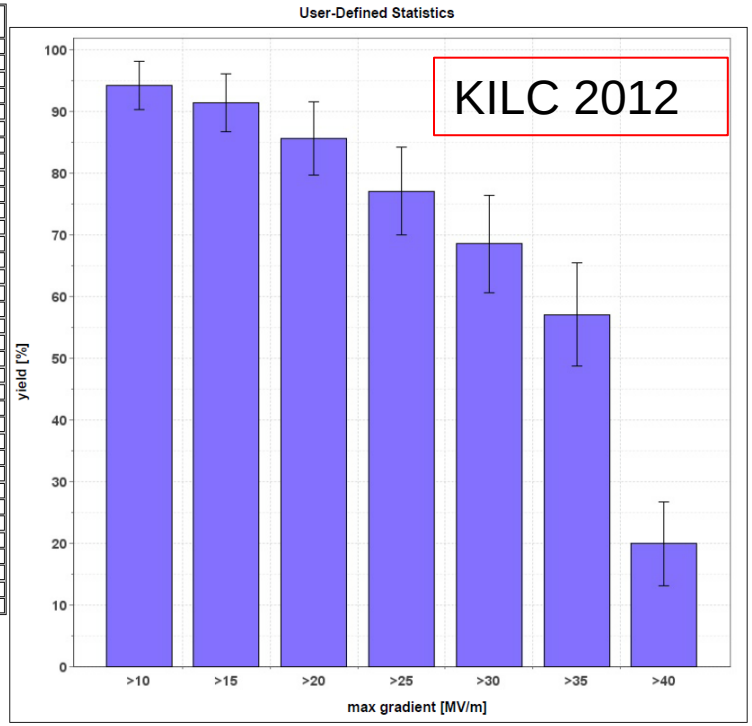
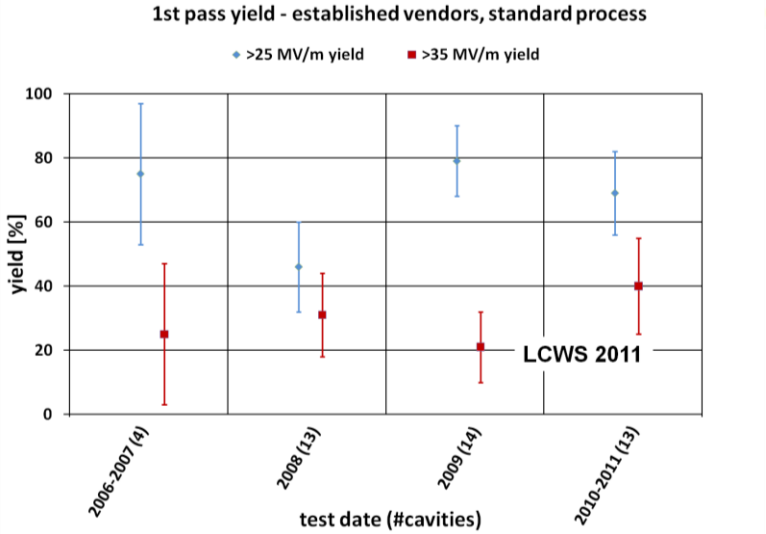
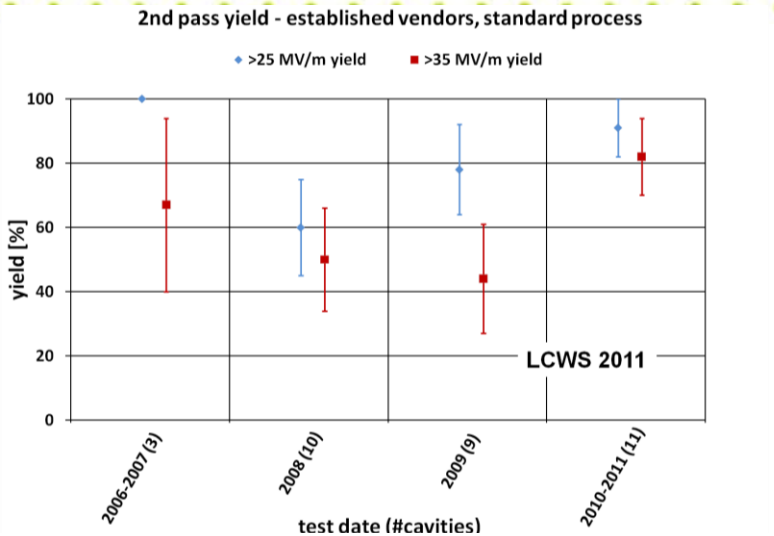
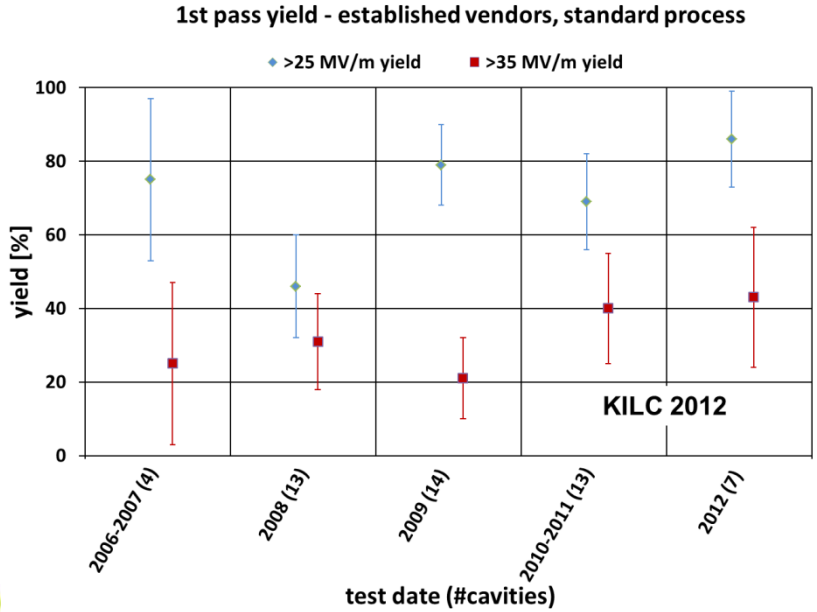
31	Z131	25.Nov.08	17.96
32	Z130	15.Oct.08	16.60
33	MHI014	17.Feb.11	13.00
34	CAV00001	22.Mar.12	8.66
35	AC126	21.Oct.08	6.14

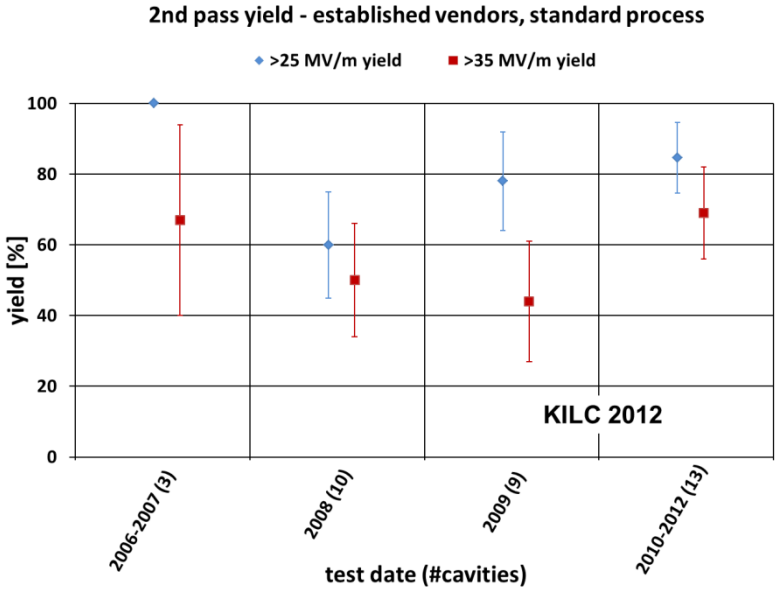


Time Progression by Year





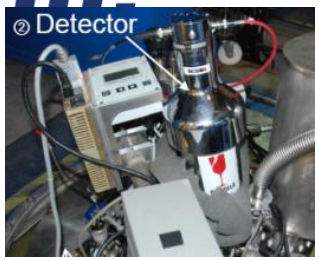




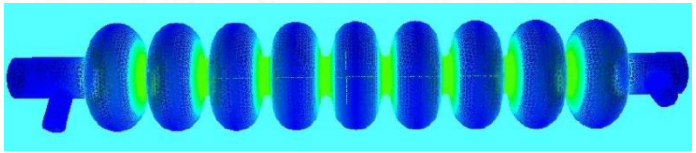
Cavity R&D Status

- **Americas**
  - 3 of 6 9-cell cavities from Niowave-Roark (second vendor in line to be qualified) tested, two cavities reaching 29 MV/m; 4 of 10 9-cell cavities of AES 3rd production passed 35 MV/m
  - 3 9-cell seamless niobium cavities processed and tested at JLab in collaboration with DESY. One achieved 34 MV/m.
  - Localization of active field emitter in 9-cell cavity through combined instrumentation and code modeling achieved at JLab
  - Continued optimization and test of Mechanical Polishing Process (CBP)
  - 9-cell vertical EP demonstrated 39 MV/m at Cornell
- **Asia**
  - First 9-cell cavity with HOM couplers from Hitachi achieved 35 MV/m
  - First “in-house” KEK cavity achieved 29 MV/m
  - A 2-cell 1.3 GHz cavity (for cERL) achieved 50 MV/m
    - Peak surface magnetic field 2127 Oe – new world record!
- **Europe**
  - XFEL reference cavities from both industrial vendors tested at DESY with good results

Active Field Emitter Localization in 9-cell Cavity



NaI (Tl) crystal forX-ray energy

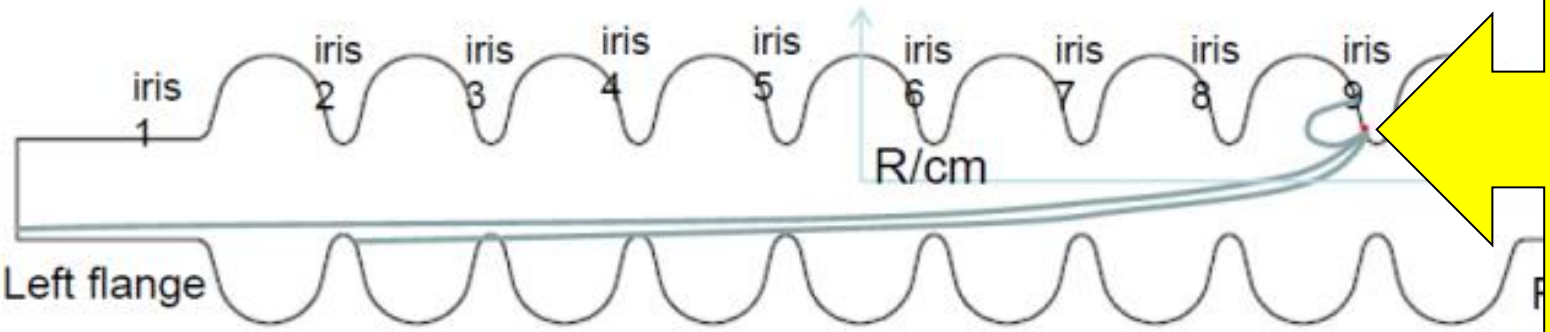


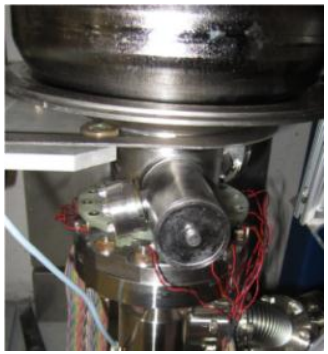
SLAC ACE3P for electron trajectory

Longitudinal Location of field emitter

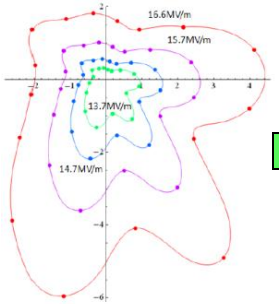
Field emitter location uniquely determined

First successful demonstration at JLab in 9-cell cavity RI23, March 2012





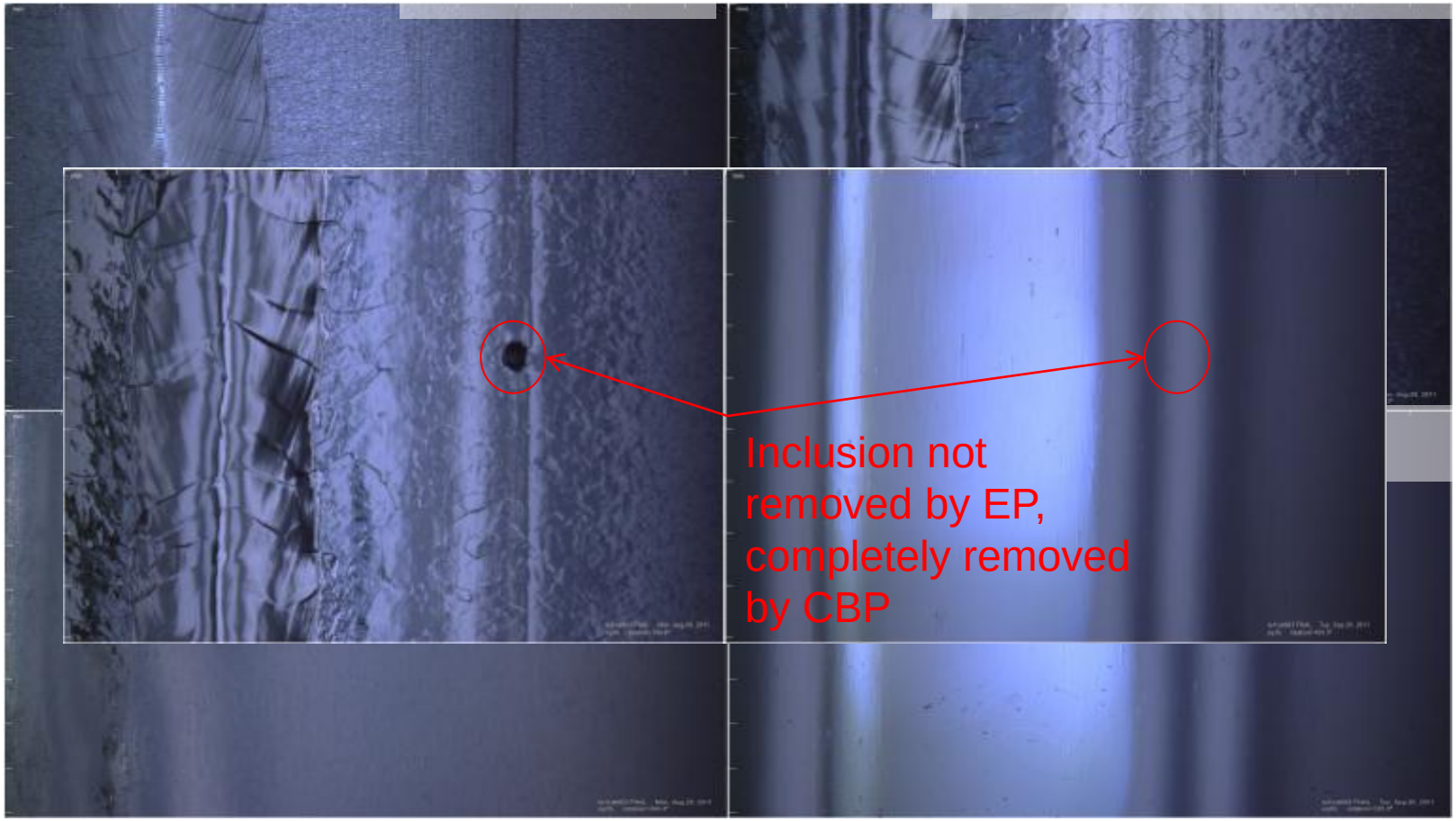
Cryogenic X-ray sensors (diode) at cavity iris for angular location of field emitter



- An advanced field emission diagnostic system under way at JLab including rotating X-ray mapping
- We collaborate with KEK where X-ray mapping systems exist and in operation already at STF and at cERL

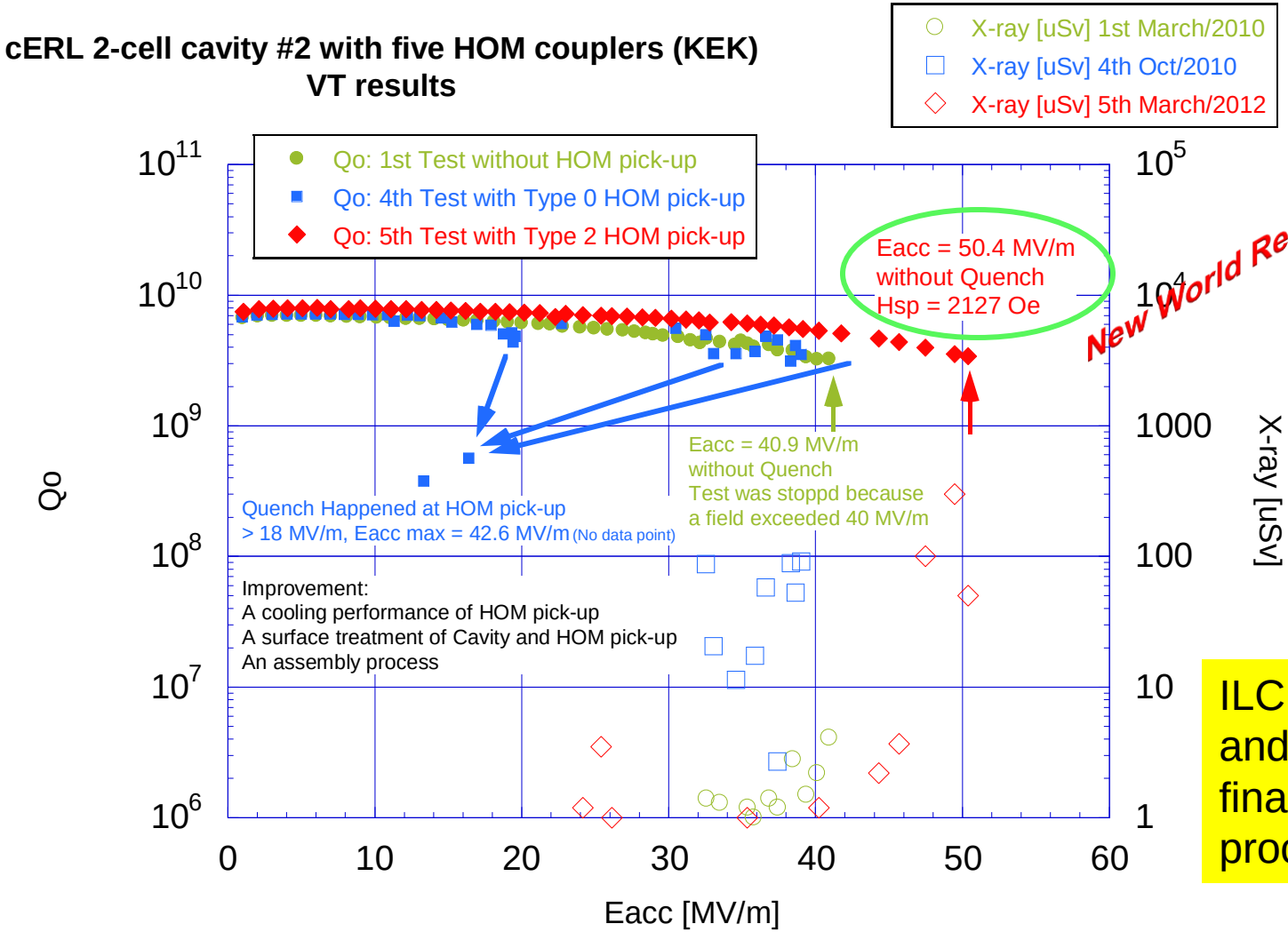
Y.M. Li, A.D. Palczewski, R.L. Geng,

Mirror Finish from CBP on Single Cell Cavity CAT003



- recovery of extremely marginal surfaces can be recovered
- remediation→baseline?…included as alternative in Americas Industrial Study

New World Record Peak Surface Magnetic Field achieved at KEK



Previous record
Eacc=59 MV/m,
Hpk=2065 Oe, 1-cell
1.3 GHz Nb cavity

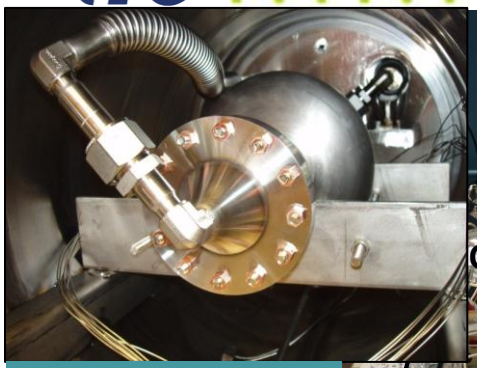
ILC baseline material and fabrication and final surface processing

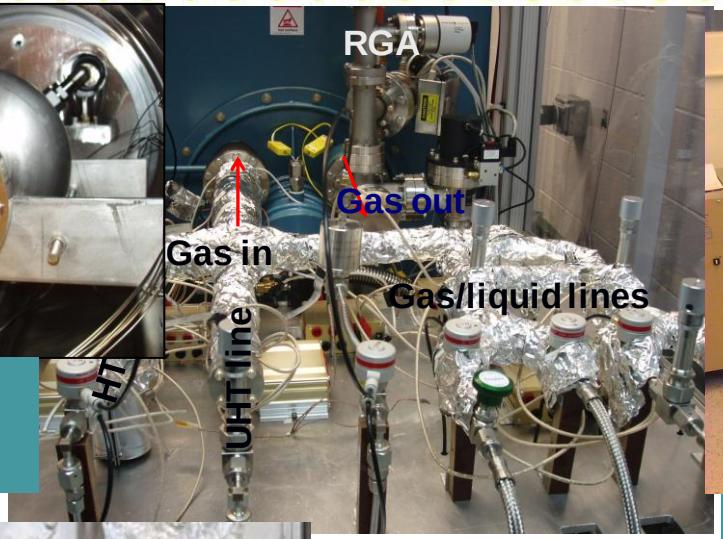
Post-TDR High Gradient SRF R&D

- Higher gradient 45 MV/m and higher Q0 2E10 R&D for 1 TeV upgrade
  - Alternative shape cavity
    - Excellent 1-cell and 2-cell cavity demonstration of Hpk > 2000 Oe in hand
    - >>> ILC 1 TeV SRF cavity goals are reachable
  - Highest priority is to reduce field emission at Epk ~ 100 MV/m
    - Require improved understanding to guide development of counter measures
    - Like we did for quench limit improvement in ILC Technical Design Phase
  - Second priority is to understand the physics of medium-field and high-field Q-slope and develop new treatment for reduced Q-slope
- Lowering cost of SRF technology
  - Evaluate acceptable RRR and Tantalum content
  - Seamless cavity (bulk Nb and Nb-Cu clad material)
  - Large-grain material
  - Mechanical polish
- Organization
  - Requires global coordination for R&D prioritization
  - Seamless forming; CBP efforts support partially from core programs / parallel projects
  - Films and coatings need additional support beyond FY13
    - Work across multiple stakeholders; initial experiments simple but cavities only way to finally prove process

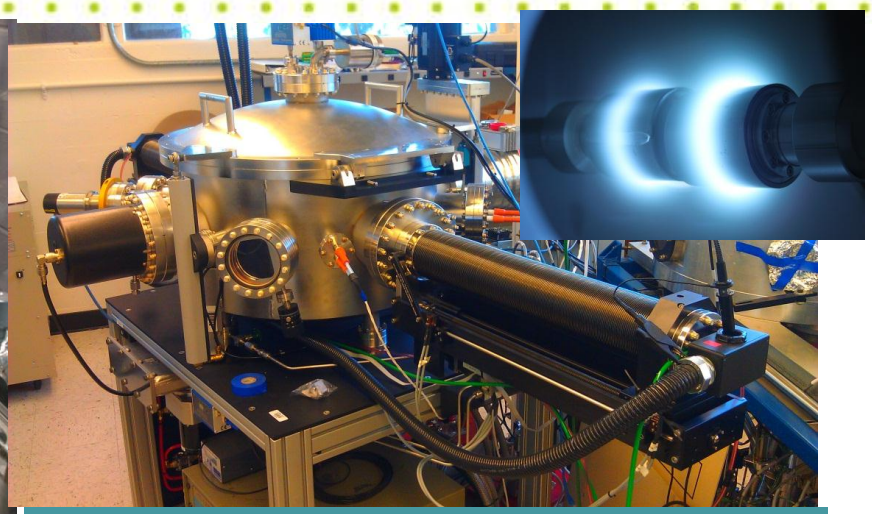
In US, aside from National Labs, includes SBIR; Young Investigator Awards; Universities…

Key components exist across the SRF labs

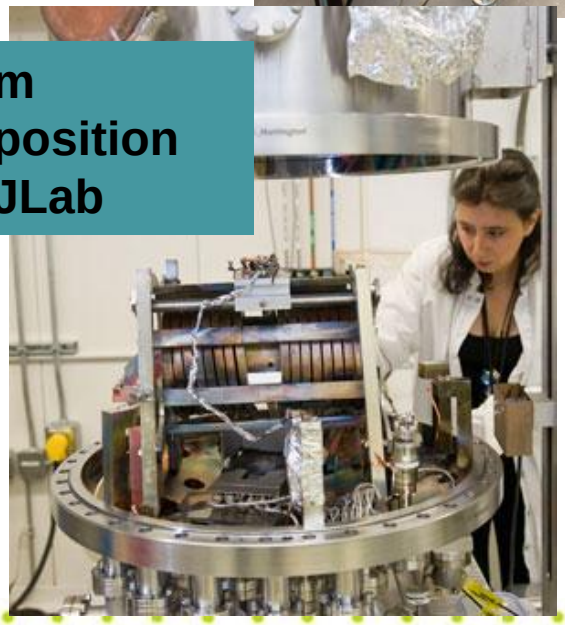




Cavity ALD at ANL



High-impulse deposition at LBNL



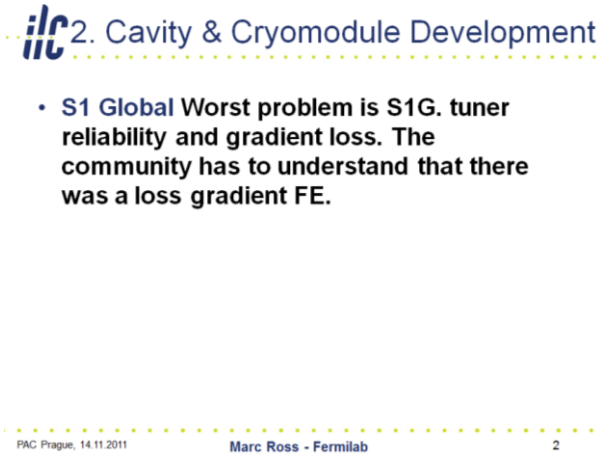
Film deposition at JLab

Mirror smooth polishing at Fermilab

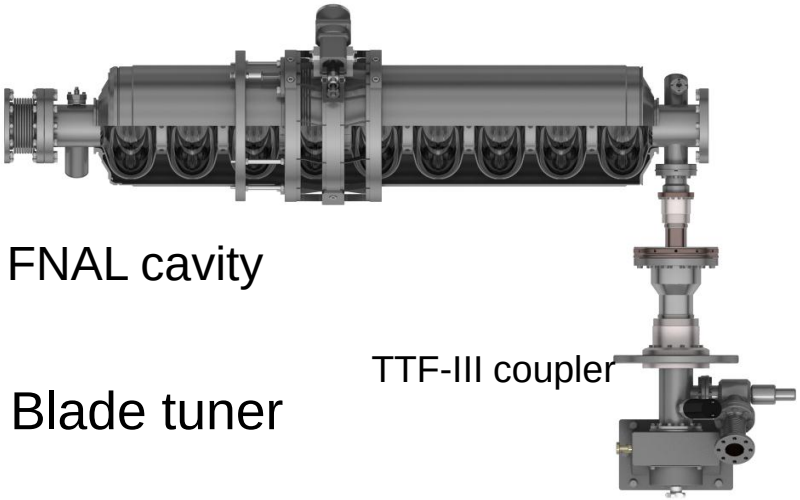
wood blocks w/ colloidal silica; felt blocks w/ colloidal silica

Cryomodule System Tests

- **Asia**
  - S1 Global (complete!)
  - Quantum Beam Experiment
- **Europe**
  - FLASH
  - XFEL Prototypes
- **Americas**
  - CM1 (Complete!)
  - CM2



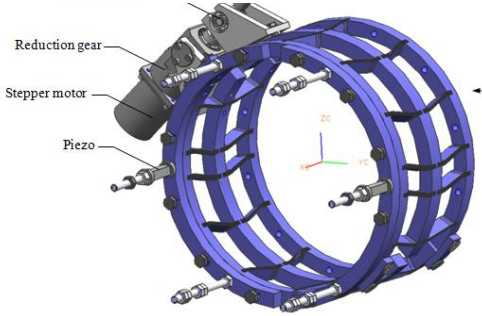
S1 Global Tuners

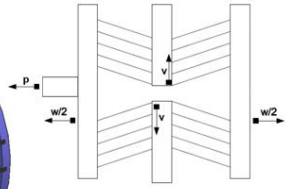


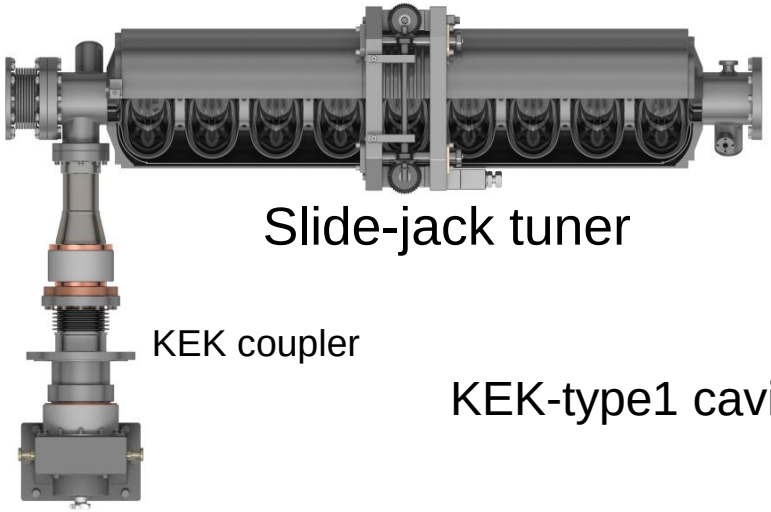
FNAL cavity

TTF-III coupler

Blade tuner



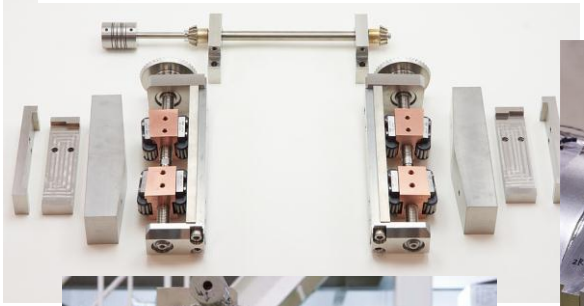


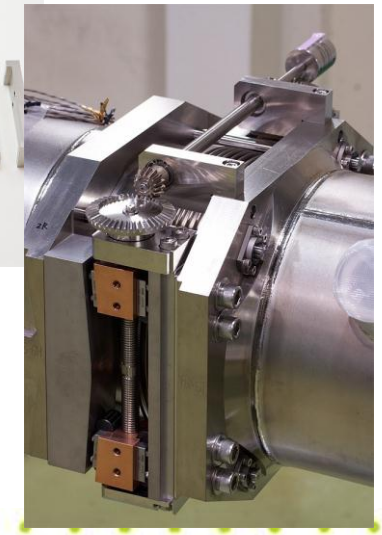


Slide-jack tuner

KEK coupler

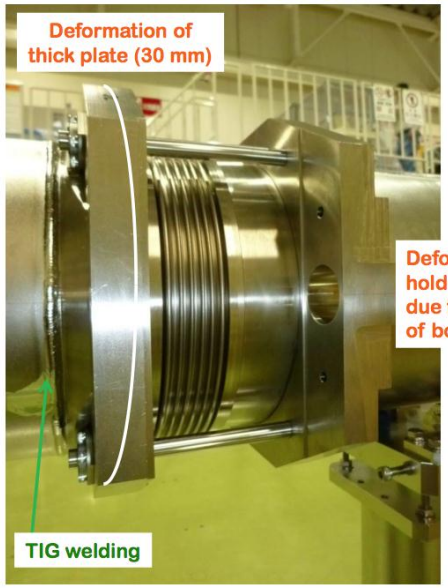
KEK-type1 cavity

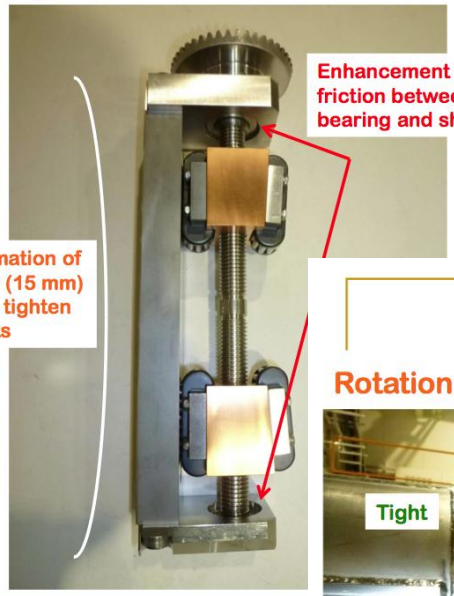




S1 Global – Slide Jack Tuner Ass'y

Check of Slide-jack Tuner





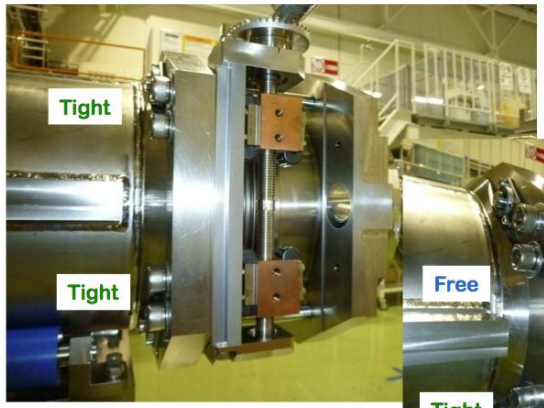
E. Kako (KEK) Webex Meeting in July 19, 2011

Re-assembly of Slide-jack Tuner

Rotation of drive shaft is not easy.

(A4/MHI-09 cavity)

Rotation of drive shaft is smooth !!

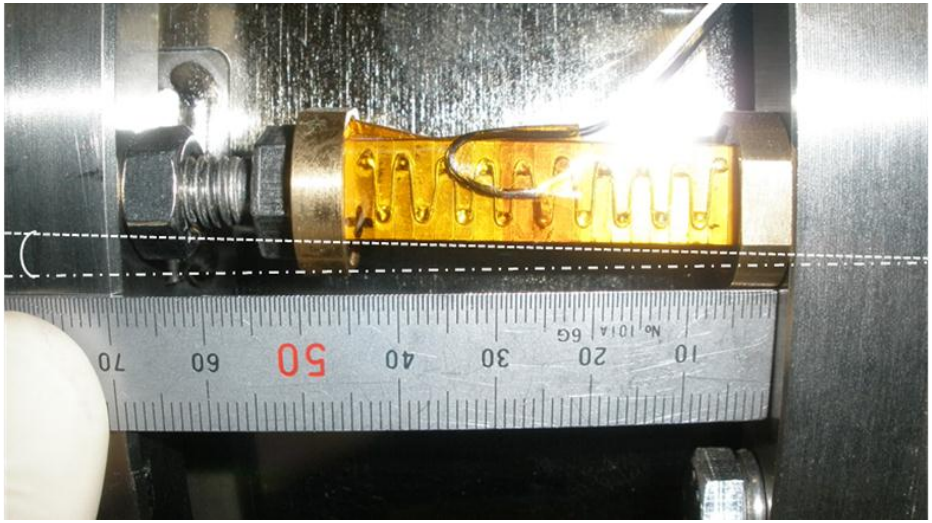


Measurement of thickness gauge

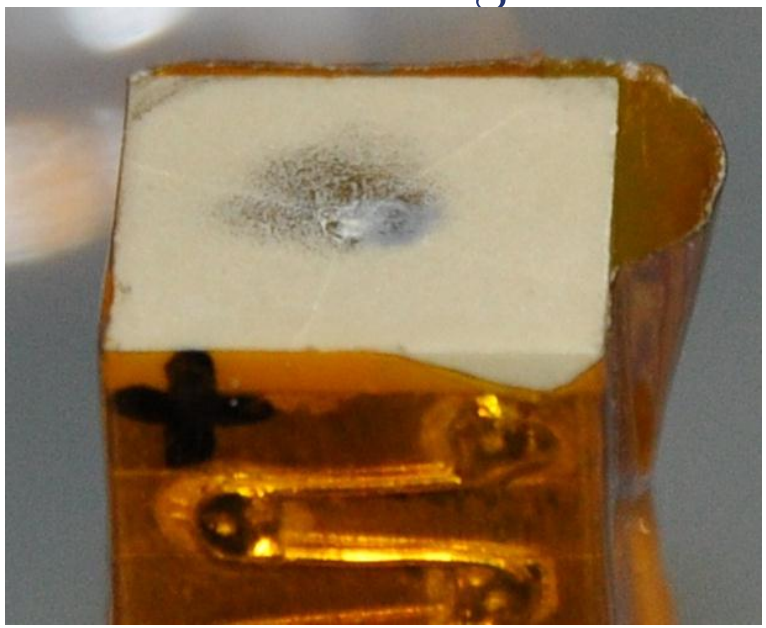
E. Kako (KEK) Webex Meeting in July 19, 2011 8

S1 Global – Slim Blade Tuner

Modification of the Fast Piezo Tuner Design



Offset results in shear forces applied to piezostack

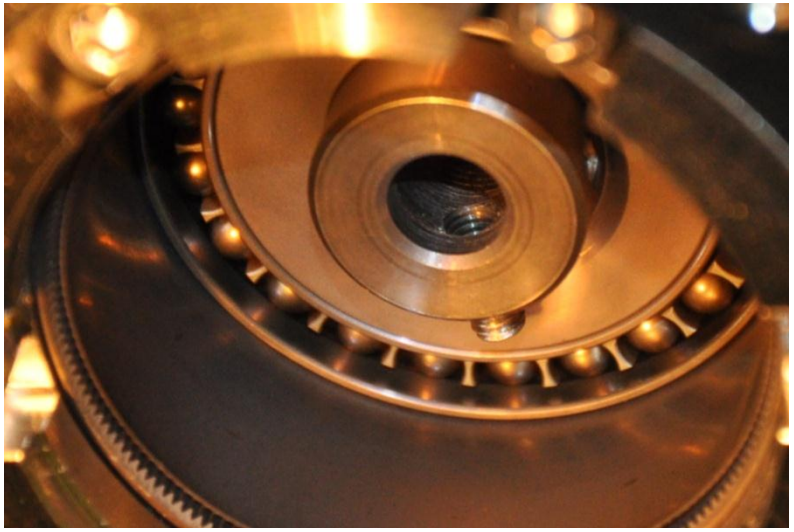


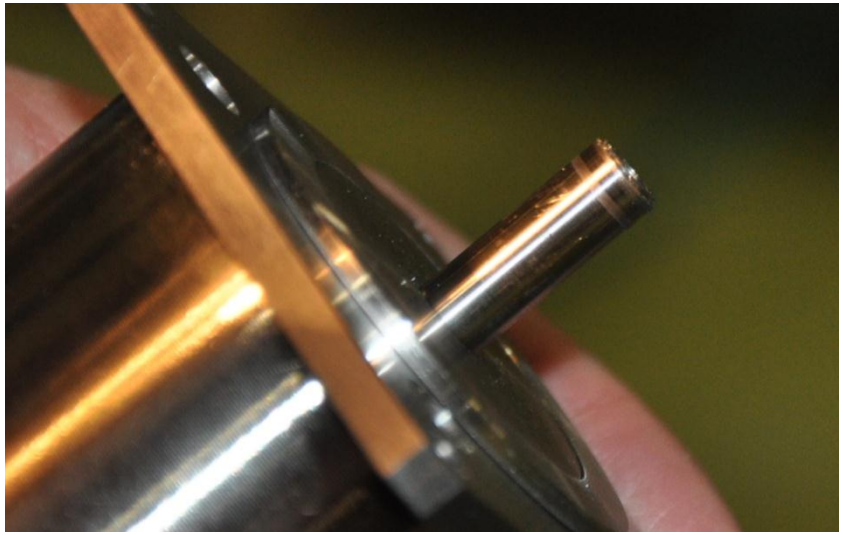
coupler side piezo in C2:
fractures at one edge and cracks passing through electrical layers including possible sputtering of metal→explaining the systematic discharge at lower voltage.
With the impaired integrity of ceramic explains the observed lack of piezo tuning efficiency

S1 Global – Slim Blade Tuner

Modification of the Stepper Motor Design

- Disassembly of C2 stepper motor revealed loss of grip between the motor shaft and the harmonic drive wave generator
  - One of the two screws totally unscrewed due to operational vibrations
  - Remaining screw not sufficient to fix grip and was sliding over the motor shaft

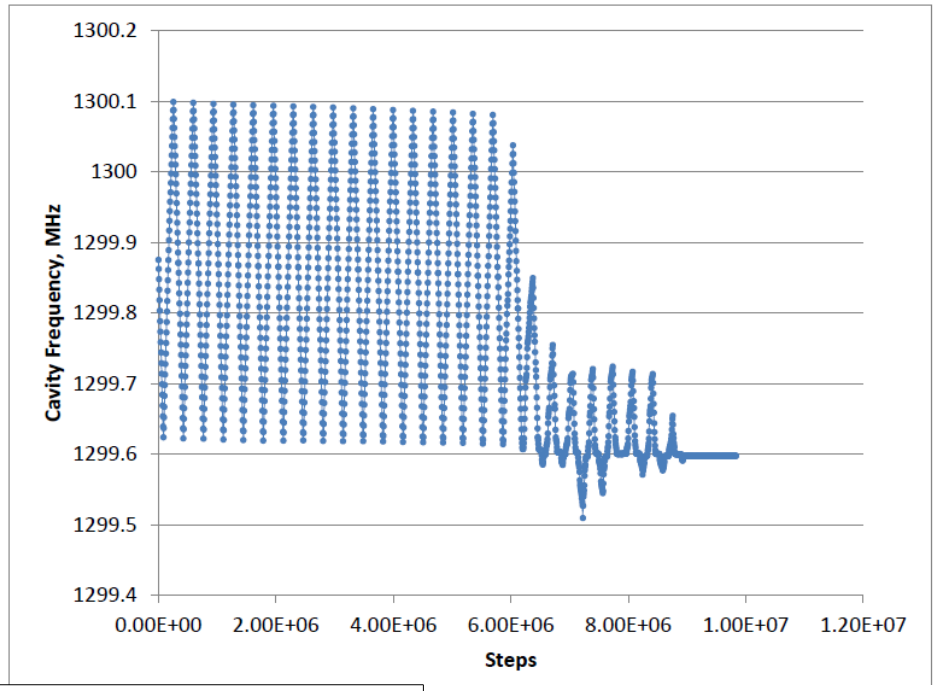




Slim Blade Tuner Lifetime, CM2 Warm Tests

HTS used for cold cycling steps:

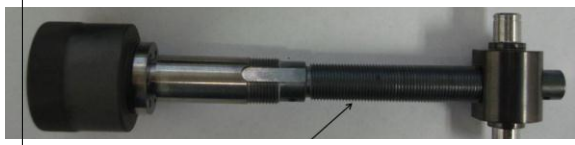
- 50M steps
- extra parts not available at Fermilab; INFN supplied similar shaft/nut for test
- Tuner failed after 6M steps when SS nut seized on shaft



Warm tests on CM2, to 5M steps, also showed problems w/ connection of CuBe shaft to harmonics drive

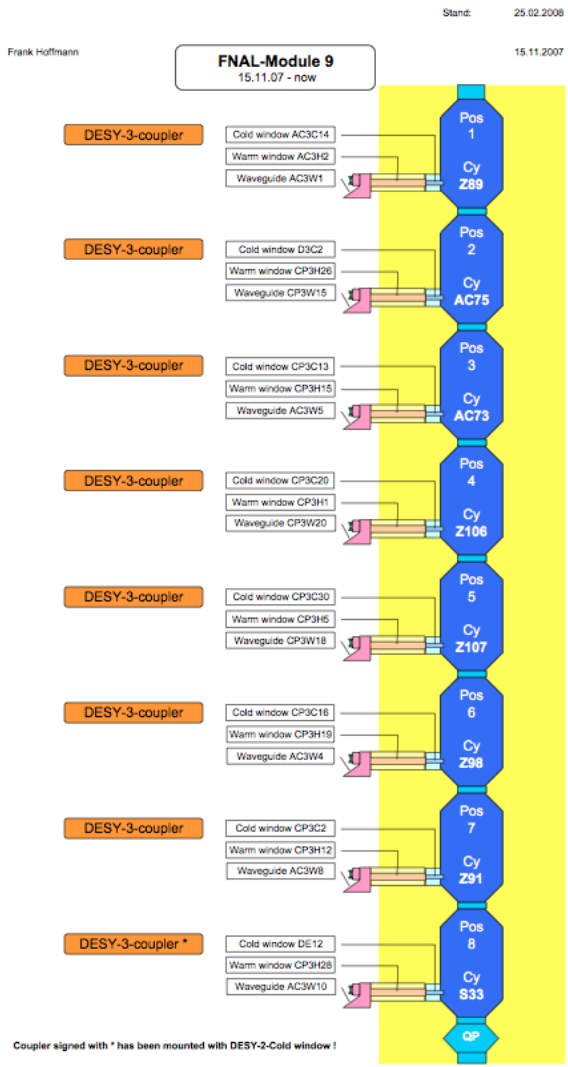
Solution:

- Motor shaft cross drilled; pointed set screw; cryo grade Loctite
- Flex gear to shaft now incl lock washers, cryo grade Loctite
- Stepper motor operation modified to reduce vibrations



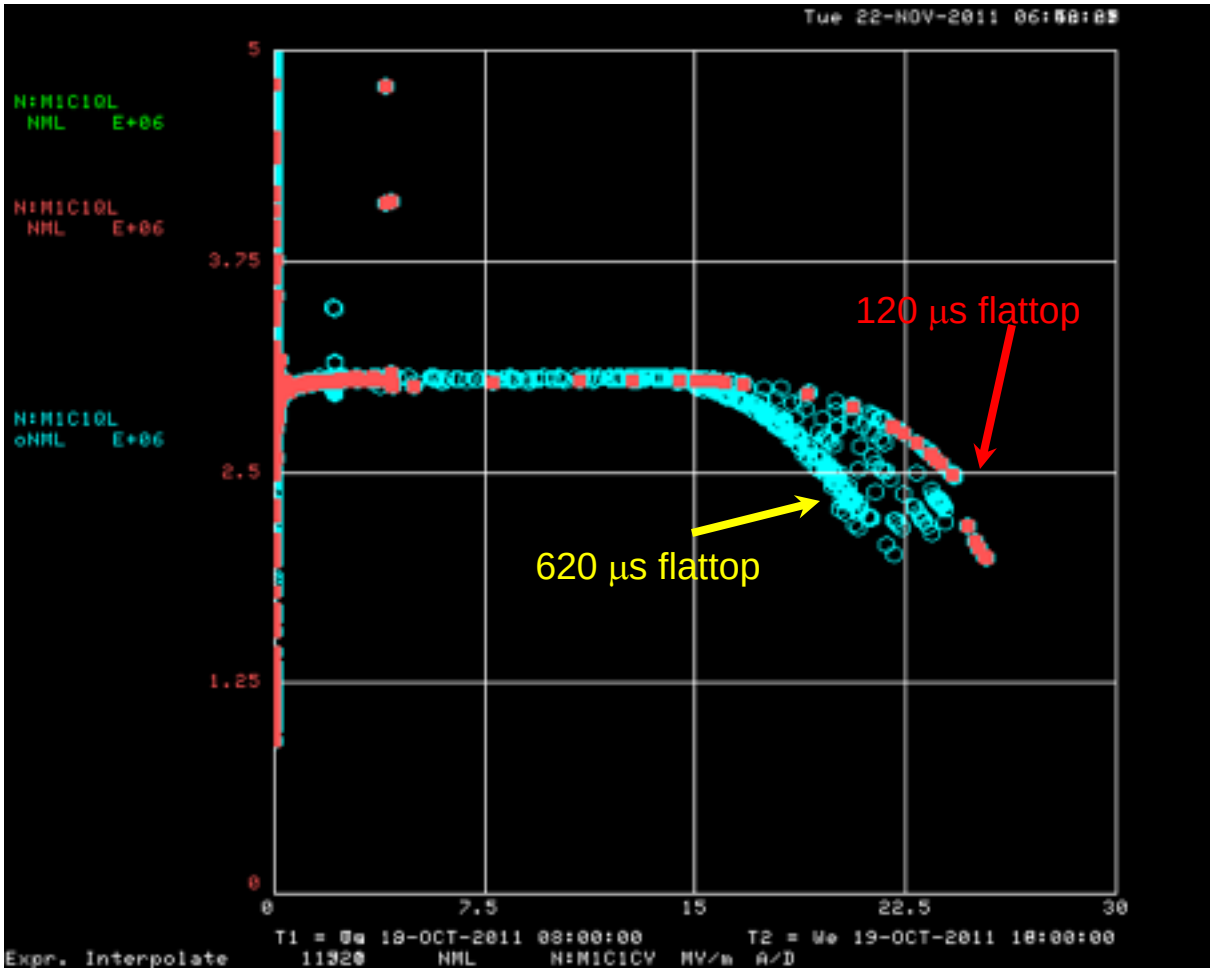
CM1 Cavity Performance Summary

Cavity	Peak E_{acc} (MV/m)	Estimated maximum Q_0 (E09)	Limitation/Comments
1/Z89	20.2	11	‘soft’ quench/heat load
2/AC75	22.5	12	Quench
3/AC73	23.2	0.43	‘soft’ quench/heat load
4/Z106	24*	2.3	*RF-limited
5/Z107	28.2	39	Quench
6/Z98	24.5	5.1	Quench
7/Z91	22.3	4.7	‘soft’ quench/heat load
8/S33	25	18	Resonant frequency at 1300.240 MHz; tuner motor malfunction



‘Soft Quench’ investigation: Vary Flattop Length

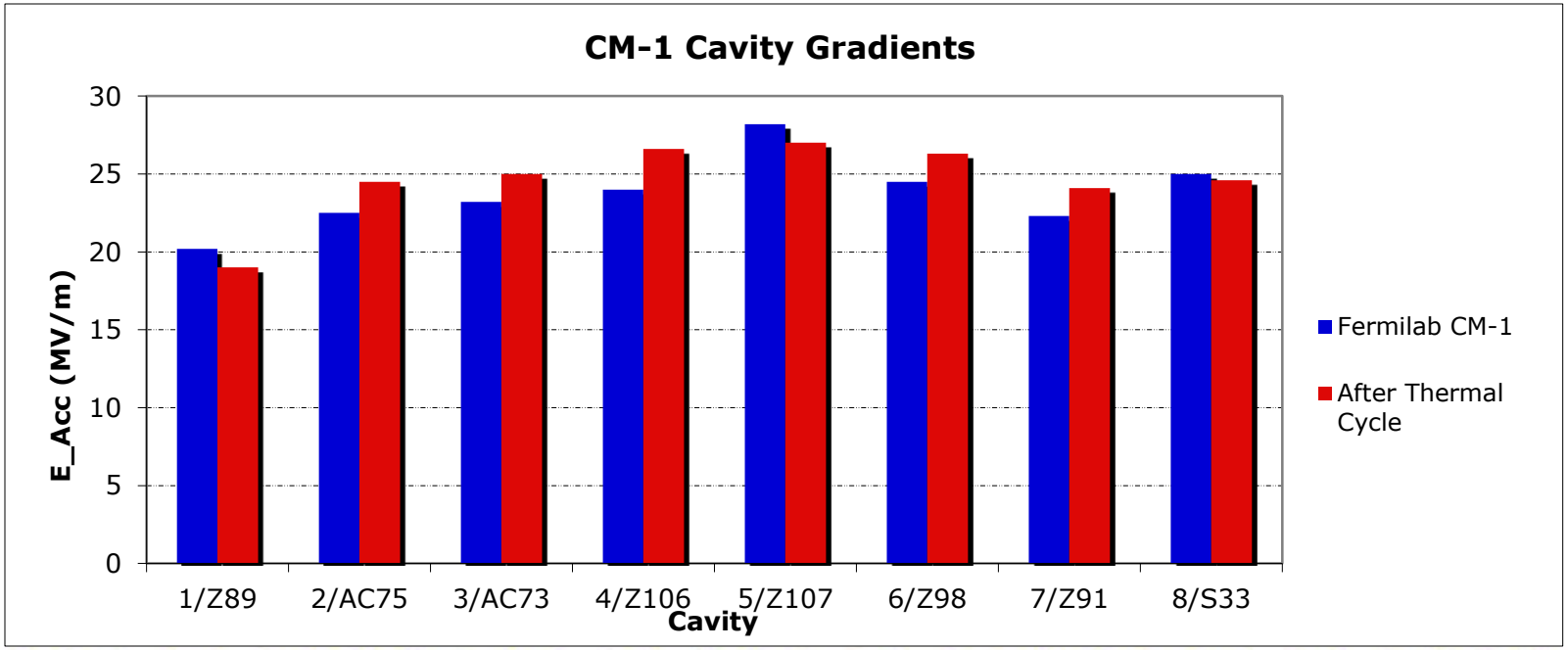
- Variation of Q_L and peak gradient with flattop length
- 100 μs increments in flattop length
- Onset of Q_L drop from 14 - 17 MV/m
- Quench limit inversely proportional to flattop
- No clear indication of increased HOM heating on suspect cavities
- Some cavities limited by available RF power



Cavity #1

CM1 Thermal Cycle

- **Resumption of operation on 8 February**
  - Re-tune cavities to cold resonant frequency (they were de-tuned prior to warm-up)
  - Gently bring up power (thanks, Denis)
    - 100 μs, 500μs, 1.3 ms pulse widths
    - Bring up to full power at each pulse width in 20-30 minutes while observing FEP's, vacuum, etc.
  - Repeat cavity performance measurements - cryo instability, quench limit, FEP, etc. as before and compare
  - Overall modest improvement in performance:



CM1 Post Mortem

- **A partial list of inspections based on CM1 ops:**
  - Cryomodule and ends for helium leak
    - unsuccessful in situ search
  - Cavity #2 & #8 tuners
    - #8 is non functional after ~160k steps, #2 'sticks'
  - Thermal intercepts on Cavities 1, 3, 7, especially HOM cans
  - Piezo on #7 plus possibly others….
  - Cavity #4 coupler – Q_L behavior
  - Test subset of the 'soft quench' cavities at HTS
    - 1/Z89, 3/AC73, 7/Z91
    - a recent cavity under test at HTS, RI021, is exhibiting similar behavior, further investigation is in progress
    - A not infrequent occurrence at DESY, results repeated at Chechia, but no resolution
    - Make π-mode measurements to try to understand offending cells, if any
    - Thermal instrumentation on beam pipe, HOM's?

Current and Future System Tests

DESY, KEK and FNAL cryomodule tests have been extremely useful in diagnosing and debugging system issues

- Tuner issues understood and steps taken to address before next cold tests
- Ongoing post mortem investigations of soft quenches seen at CM1
- Field emission a topic of interest in multiple operational aspects
- Extensive and excellent report at TTC (D. Reschke) on open issues seen at DESY

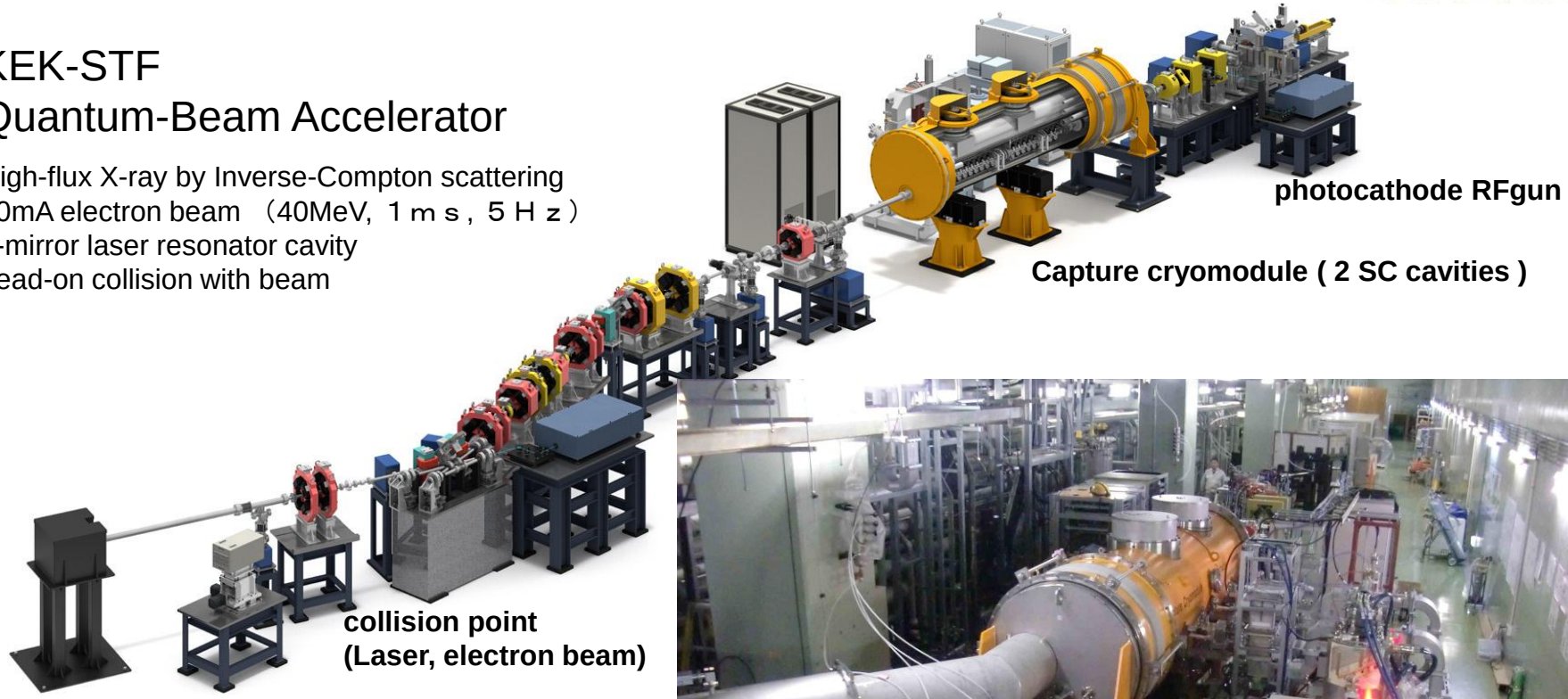
Good progress, but limited tests and typically conducted in a more ‘production’ like environment

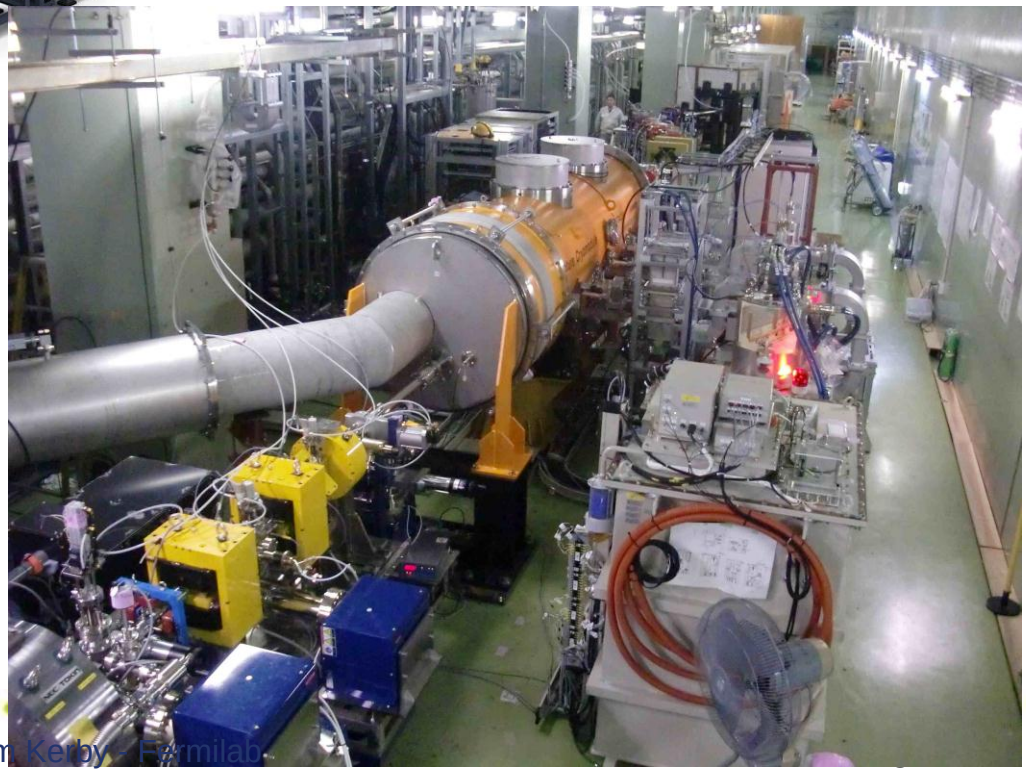
More system tests, open comparison of findings and measurements is critical

STF Quantum-Beam experiment

KEK-STF
Quantum-Beam Accelerator

High-flux X-ray by Inverse-Compton scattering
10mA electron beam （40MeV, １ｍｓ, ５Ｈｚ）
4-mirror laser resonator cavity
head-on collision with beam

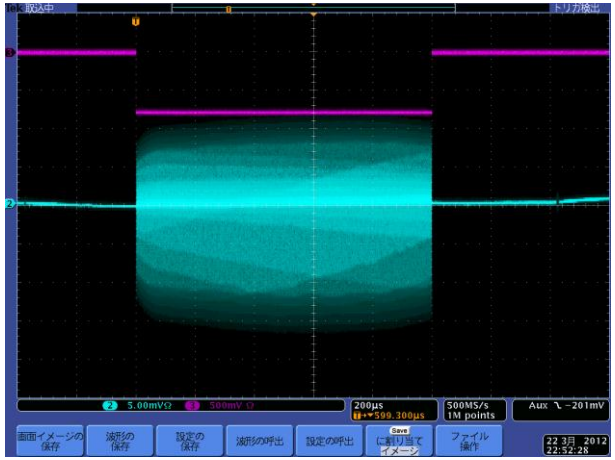




Target: 1.3 x 10^{10} photons/sec 1%bandwidth

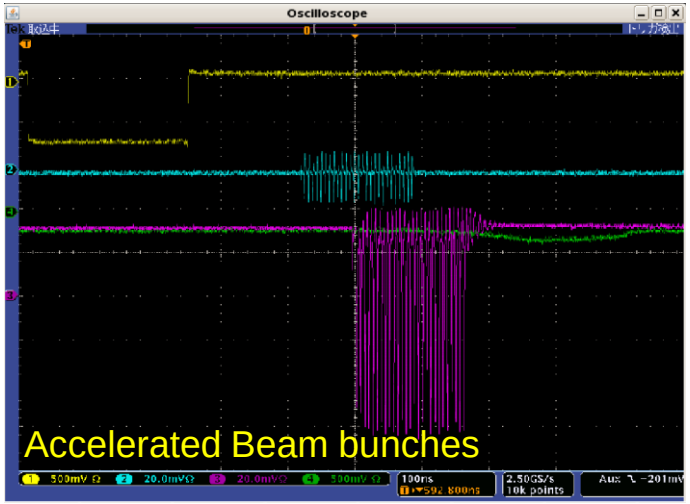
2012. Feb : cool-down started,
April : beam acceleration

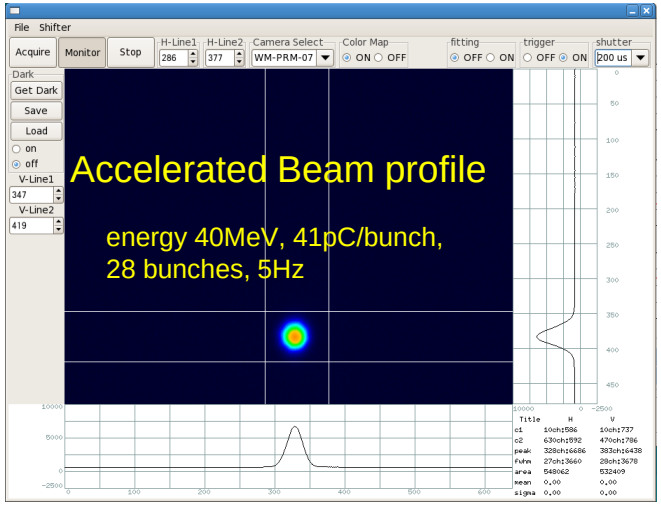
STF QB accelerator commissioning

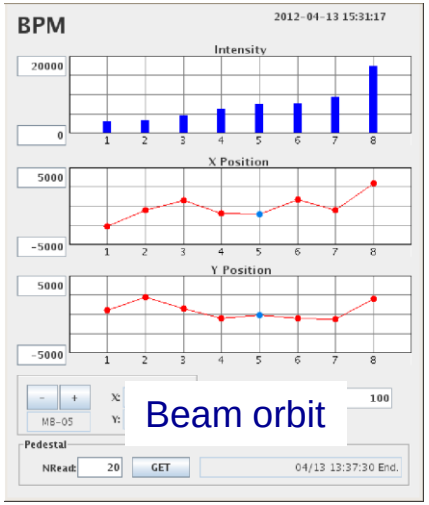


1ms Beam extraction from RF-gun (Mar.22,2012)

Accelerator tuning (April 13,2012)

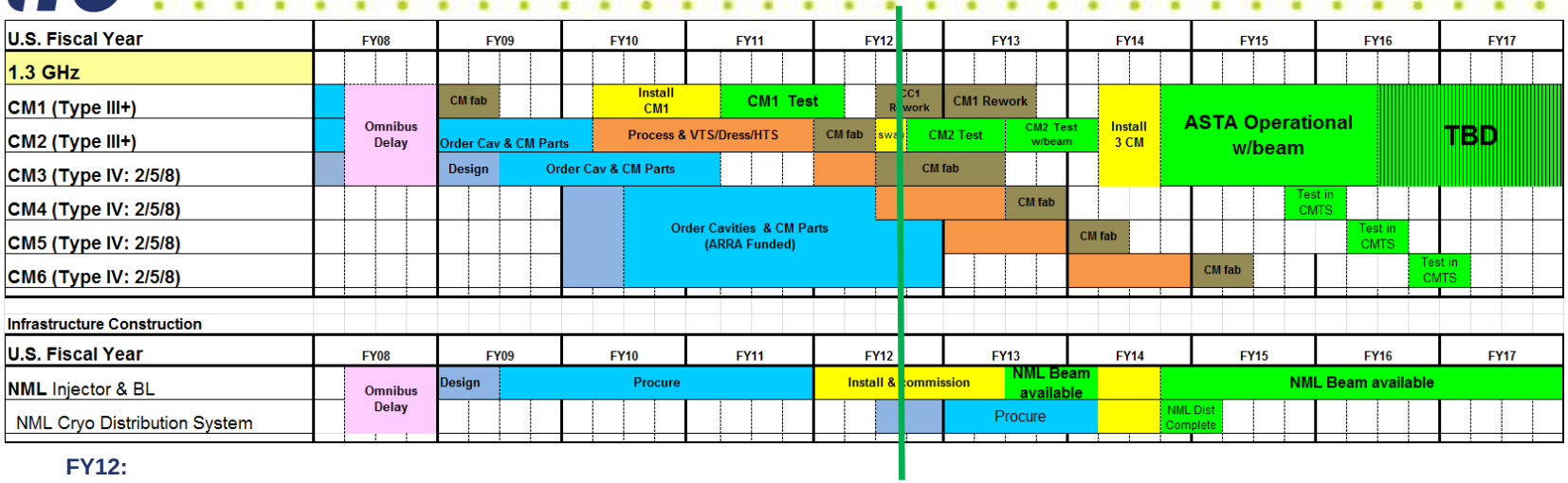






172ns-long Beam bunches were accelerated by superconducting cavities (April 13, 2012)

NML ASTA Long Range Plan



FY12:

- Complete all NML infrastructure – LCW, cryogenics, AC power, HVAC, civil construction
- Replace cryomodule 1 with cryomodule 2 and commission
- Install and commission the laser system, electron gun, and its RF system; establish 5 MeV beam to the Faraday downstream of the electron gun
- Start installation of the 50 MeV injector line

FY13:

- Complete installation and commissioning of the 50 MeV injector beamline (including capture cavity 1) and deliver low intensity beam to the low energy beam dump
- Complete the 1st AARD experiment in the 50 MeV beamline – the high brightness x-ray channeling experiment
- Install and commission the high energy beamlines – deliver low intensity beam through 1 cryomodule to the high energy dump

FY14

- Establish a baseline design for the 50 MeV experimental beamline; install, commission and mount the first AARD experiment there
- Complete the installation of the IOTA experiment and start experiments there
- Install and commission the 2nd and 3rd cryomodules
- Commission CMTF

FY15

- Deliver high energy beam through 3 cryomodules to the high energy dump
- Establish routine, high reliability operations

FY16

- Work towards high (ILC) intensity beam delivery – conduct ILC "string test"
- Establish an AARD review process and start the full AARD experimental program

ML SCRF R&D Summary

Cavity R&D Status and Prospects

- ‘Production’ yield #s constant in past year
  - MHI + DESY preproduction additions; yield numbers used in baseline Americas industrial studies
- R&D to further address yield, gradient, cost planned (in parts already started!)
  - Field Emission, ‘production’ CBP, alt shapes, alt materials

Post TDR effort spans projects, institutes, & agencies → requires continued support and coordination

Cryomodule System Tests

- XFEL, FLASH, S1 Global, CM1 provide good but limited data set
  - Patience required leading up to, during, and after tests
  - Communication of results to feed into following assemblies
  - Flexibility to implement solutions (or new diagnostics) required

Continued communication of data; findings critical given available data