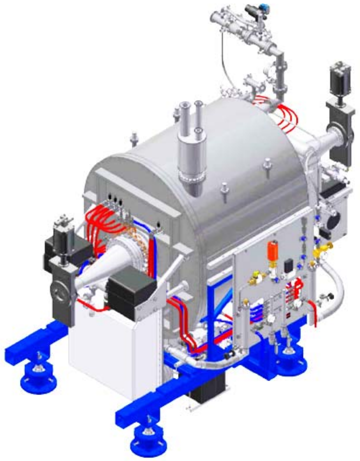
Introduction of PAL and Activities in Superconducting RF

Younguk Sohn



@RREIA, Uppsala University

September 11, 2017

Topics

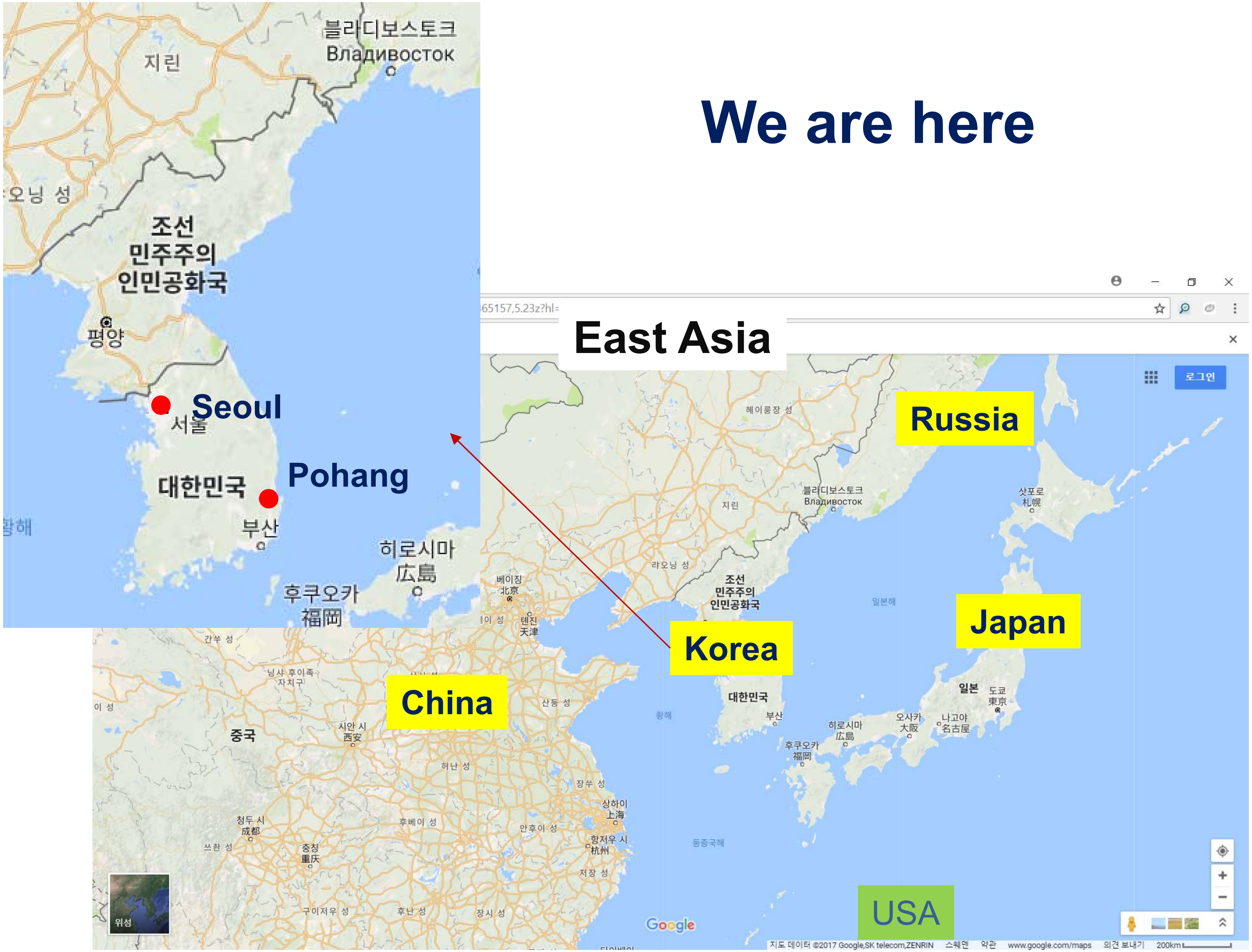
Introduction of PAL

Experience and Activities in SRF

What's PAL ?

- **P**ohang **A**ccelerator **L**aboratory is belonged to POSTECH (Pohang University of Science & Technology). Private Institute supported by Korean government.
- POSTECH, founded by Pohang Steel Company (POSCO) in 1986
- PAL operates
  - PLS-II (3^{rd} generation synchrotron): superconducting RF
  - PAL-XFEL (4^{th} Gen. Syn.): normal conducting RF
- Pohang is one of industrial & Science cities in Korea.

We are here



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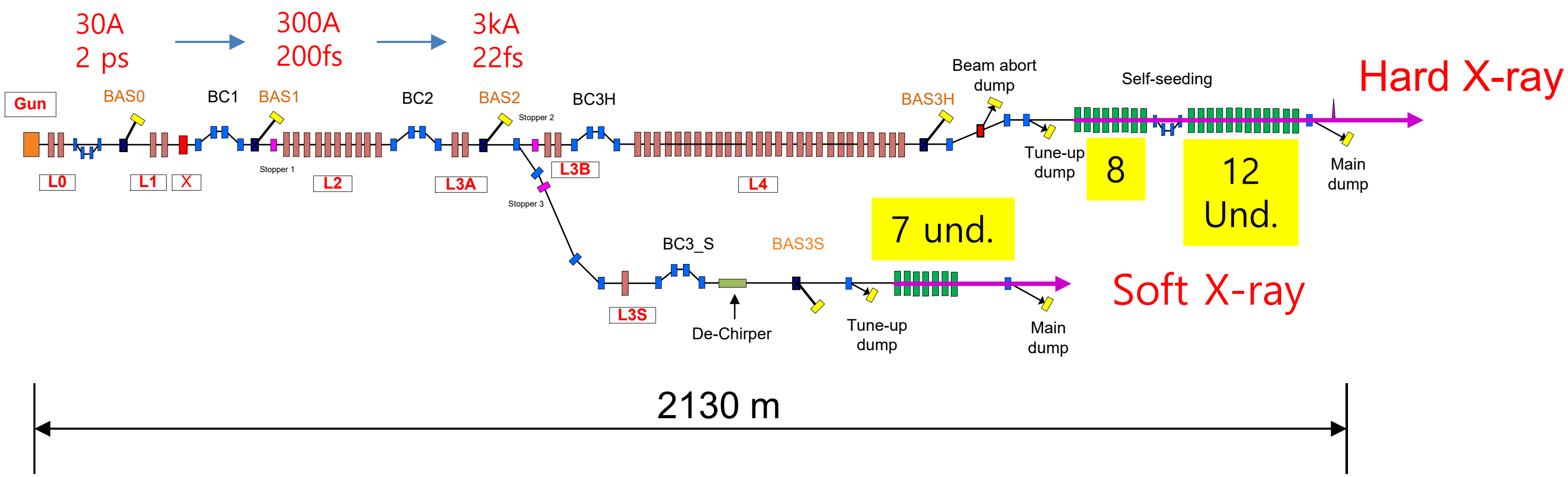
Younguk Sohn

(孫　永旭, 손영욱)

- Nuclear power plant for 2 years
- In accelerator for 26 years
  - Magnet (especially superconducting) design
  - Beamline (synchrotron light) design
  - Superconducting system

Bird View of PAL Site

PAL-XFEL Parameters

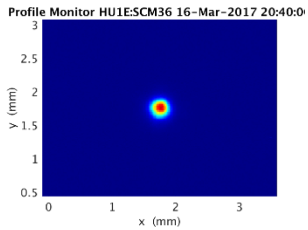


Main parameters	
e^- Energy	10 GeV
e^- Bunch charge	20-200 pC
Slice emittance	0.5 mm mrad
Repetition rate	60 Hz
Pulse duration	10 fs – 100 fs
Peak current	3 kA
SX line switching	DC (Phase-1) Kicker (Phase-2)

Undulator Line	HX1	SX1
Wavelength [nm]	0.1 ~ 0.6	1 ~ 4.5
Beam Energy [GeV]	4 ~ 10	3.15
Wavelength Tuning [nm]	0.6 ~ 0.1 (energy or gap)	4.5 ~ 3 (energy) 3 ~ 1 (gap)
Undulator Type	Planar, out-vac.	Planar
Undulator Period / Gap [mm]	26 / 8.3	35 / 8.3

Milestone PAL-XFEL

2002 ~	Studying and persuading government
Apr. 2011	PAL-XFEL project started
Jun. 2012	Ground-breaking
Apr. 2016	**Commissioning started**
Jun. 2017	**User-service started**



- **14 Jun. 2016 First SASE lasing at 0.5 nm**
- 28 Oct. 2016 Lasing at 0.15 nm
- 27 Nov. 2016 Saturation of 0.15 nm
- **16 Mar. 2017 Saturation of 0.1 nm: Goal**

Klystron Gallery - PAL-XFEL

Linac Tunnel - PAL-XFEL

Undulator Hall - PAL-XFEL

Storage Ring, PLS-II

Parameters	Values
Energy [GeV]	3
Current [mA]	400
Emittance [nm-rad]	5.9
Harmonic number	470
No. of Insertion Devices	20
Electron energy loss / turn [KeV]	1242
RF frequency [MHz]	499.973
Number of RF cavity	3
Accelerating Voltage [MV]	4.5
RF Voltage per cavity [MV]	1.5 (5 MV/m)
Klystron amplifier [kW/each]	300
Cryogenic Cooling Capacity @4.5 K [w]	700

※ PLS-II has 32 beamlines (16 ID and 16 BM)

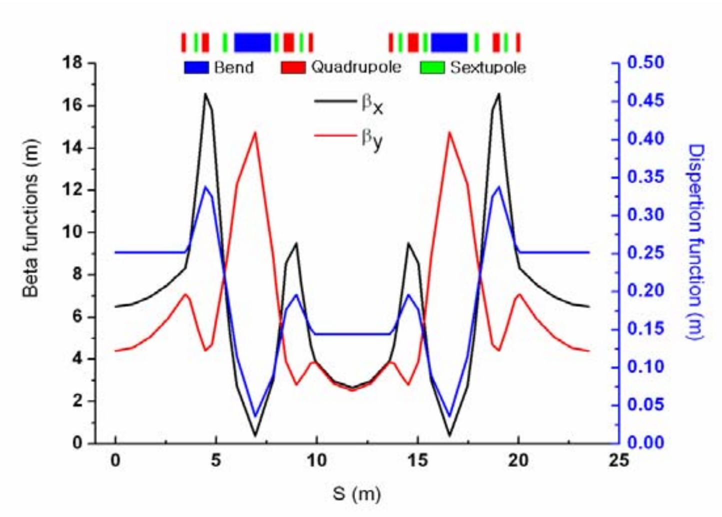
LINAC (3 GeV) as Injector

- Thermionic Electron Gun
- 16 Pulse Modulators (200MW, 7.5μs)
- 16 Klystrons (80 MW, 4μs)
- 15 Energy Doublers (gain=1.5)
- 46 Accelerating Sections

Injector LINAC

- Length = 170m
- 3.0 GeV, full energy injection
- 2,856 MHz (S-band)
- 10Hz, 1.5 ns, 1Å pulsed beam
- Norm. emmittance : 150μmrad

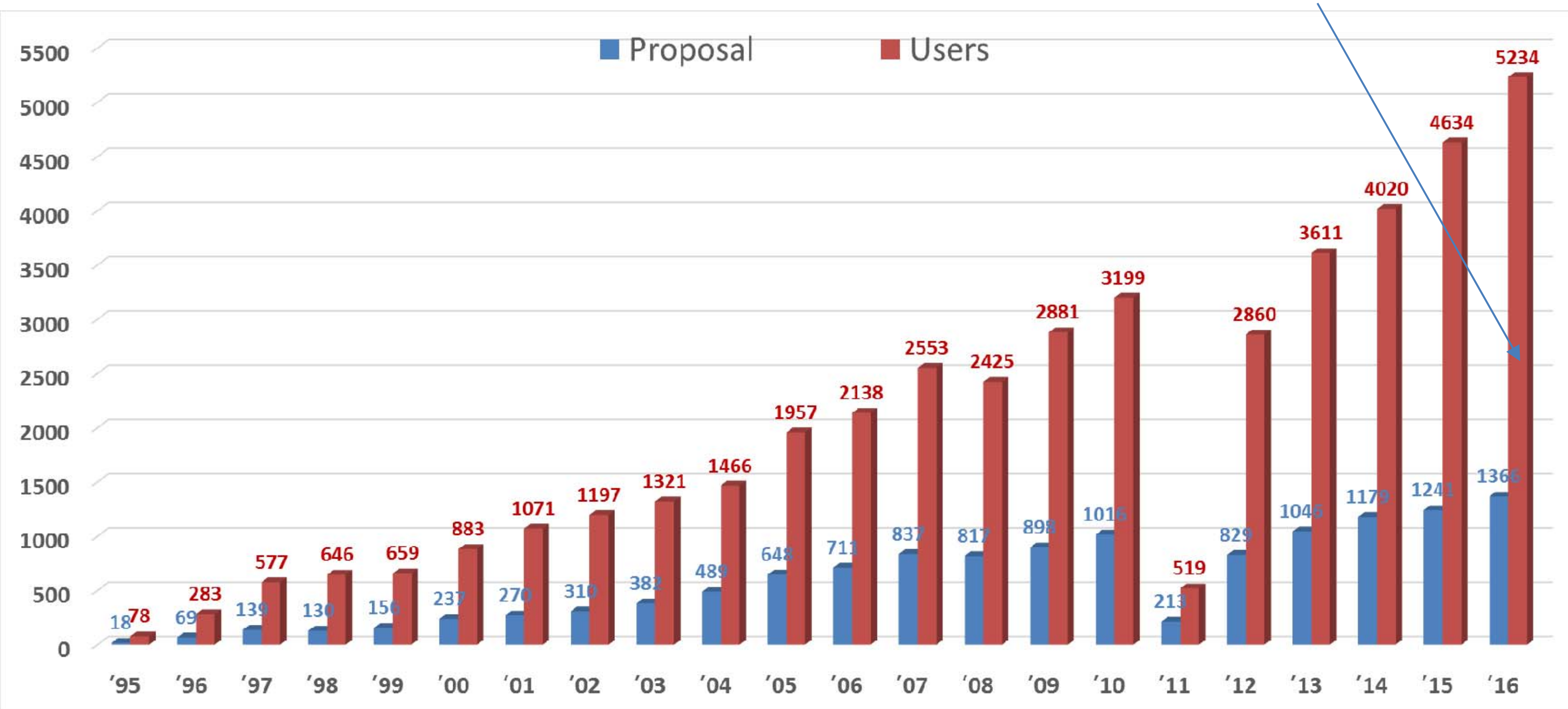
PLS-II Storage Ring



- Beam Energy 3.0GeV
- Beam Current 400mA
- Lattice DBA
- Superperiods 12
- Emittance 5.8 nm·rad
- Tune 15.37 / 9.15
- RF Frequency 499.97 MHz
- Circumference 281 m

User Statistics

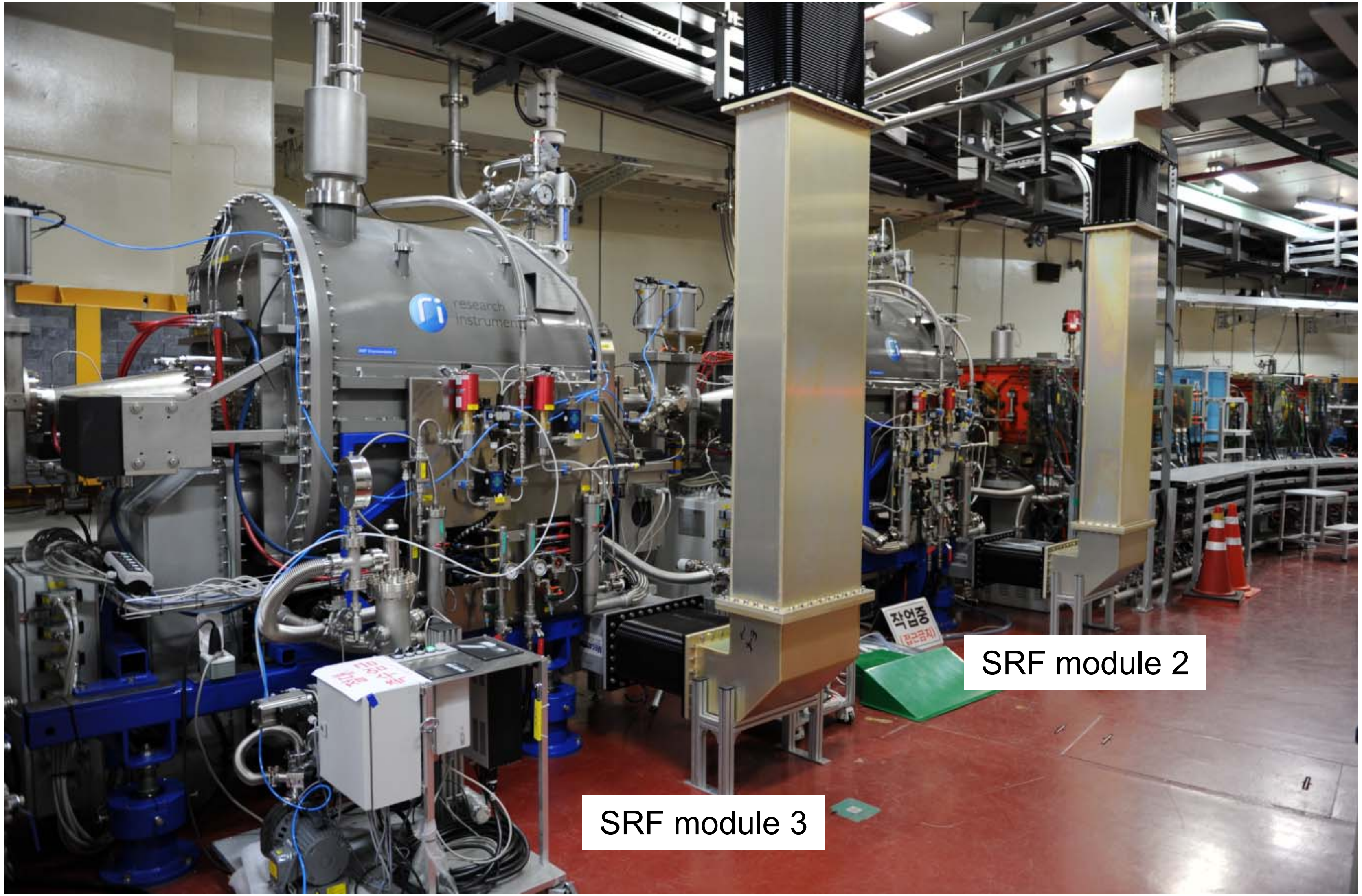
1366 experiments
5234 by users

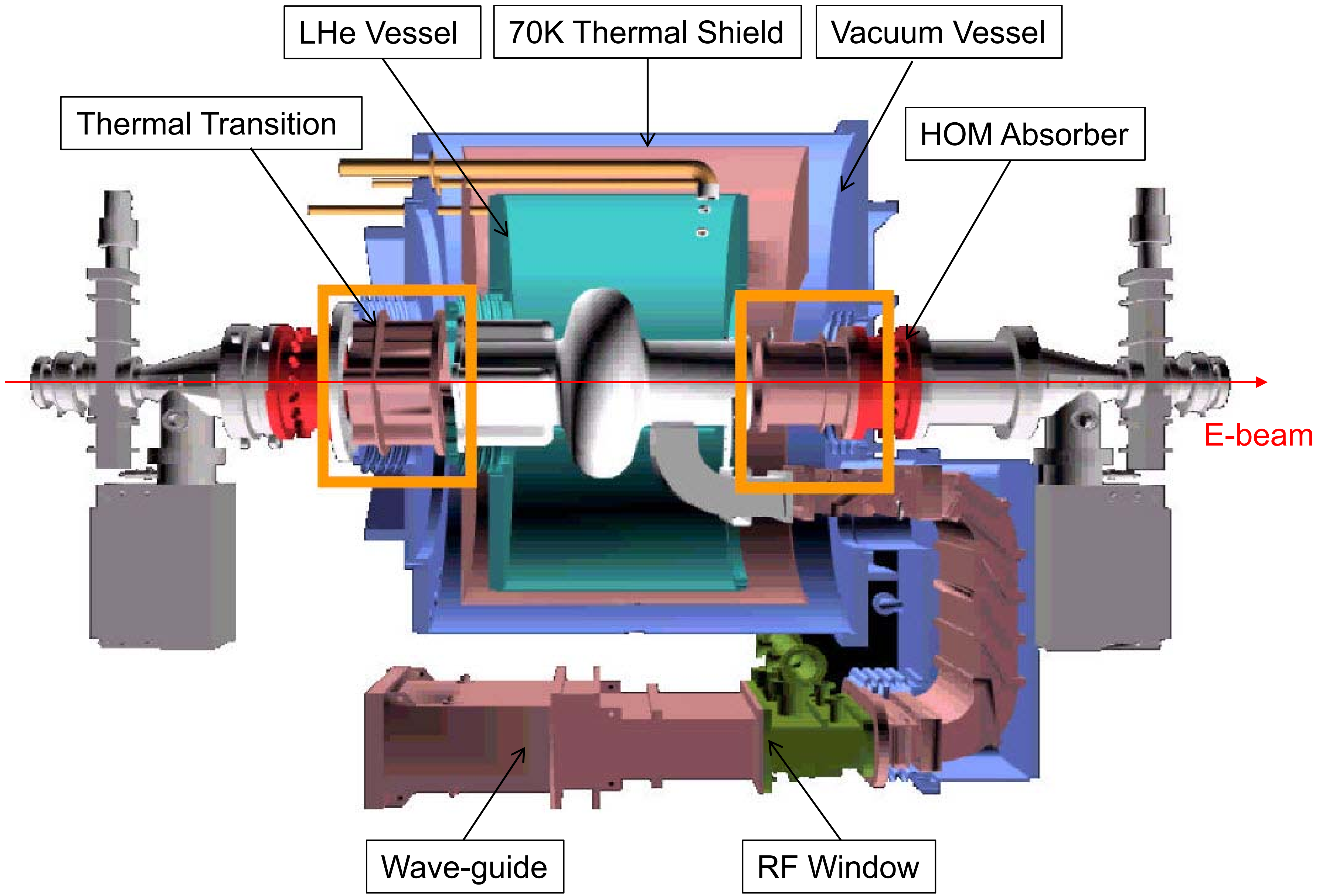


Introduction

Superconducting RF System in PLS-II

3 SRF Modules @Tunnel





CESR-3 Cryomodule, Designed by Cornell University

PLS-II, SRF 500 MHz Cavities

- Orbit stability @ high beam current to 400 mA
- High beam power W/ 20 insertion devices

→ Higher synchrotron radiation brightness, order of 2 (100 times) compared to PLS

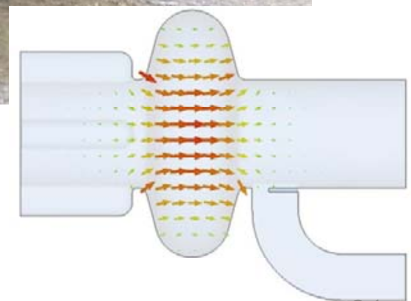
PLS-II operated with 380mA topup mode,
But, **nominal is 400 mA.**

Specifications of SRF System

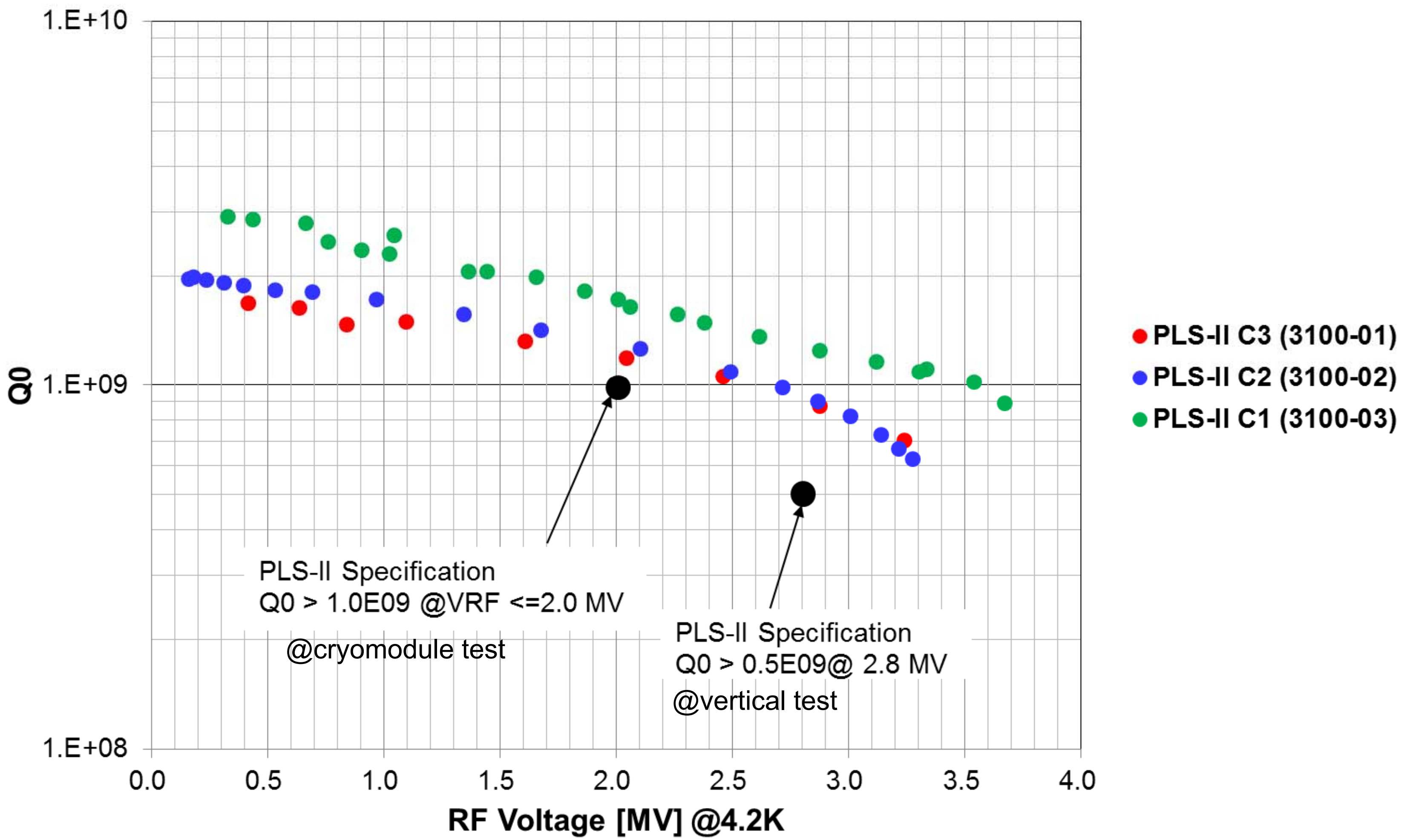
Specification	
Resonant frequency [MHz]	**499.973**
R/Q [Ω]	**89**
Q_0	**>1×10^9 @ Vacc ≤ 2.0 MV (~7 MV/m)**
Q_e	1.37E5 +/- 0.2E5
Frequency tuning range (step-motor)	±150 kHz with resolution of 10 Hz
Operating Temperature [K]	**4.4**
Accelerating Voltage / Cavity [MV]	1.3 – 2.5 (4.5 – 8.5 MV/m)
Max. RF Power(CW) / Cavity [kW]	**300 (operation < 200 kW)**
HOM Removal	Ferrite Absorber
Input power coupler	Waveguide
Window	• 300 kW in TW cw • 150 kW SW cw at full reflection

Superconducting 500 MHz RF Cavities

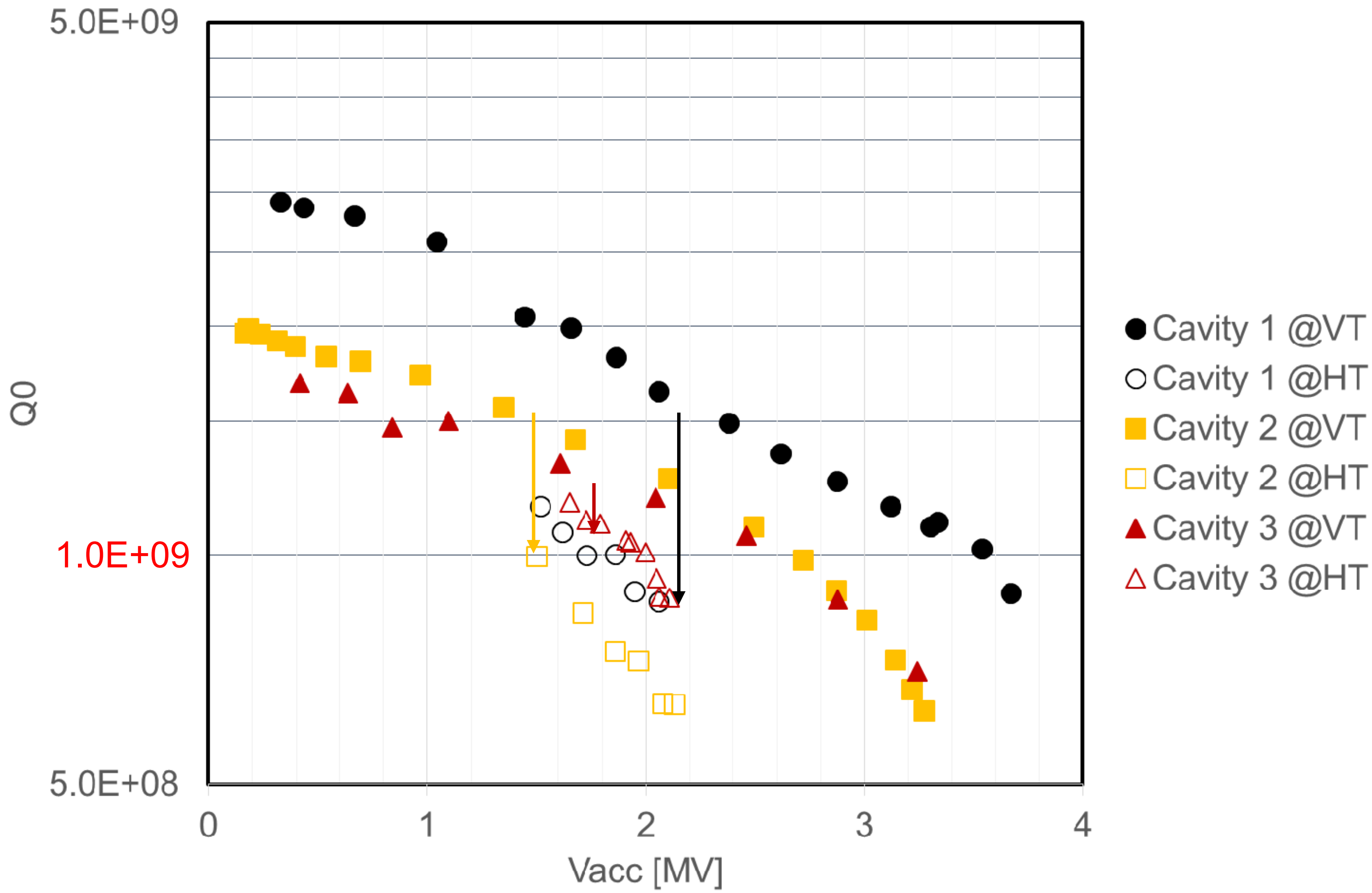
CESR Type



Accelerating Voltages @ Bare Cavity

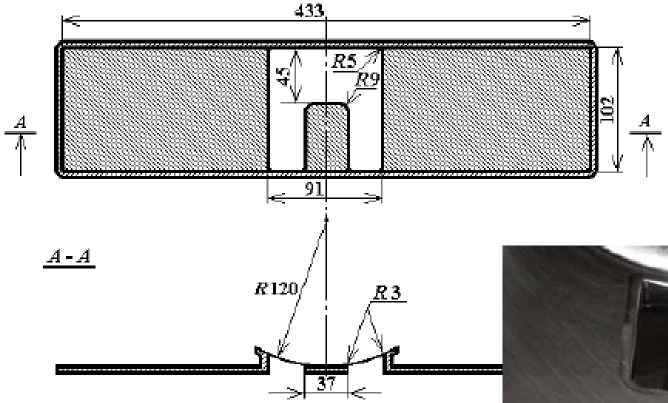


Q0 Degradation, VT *vs* HT (SAT)

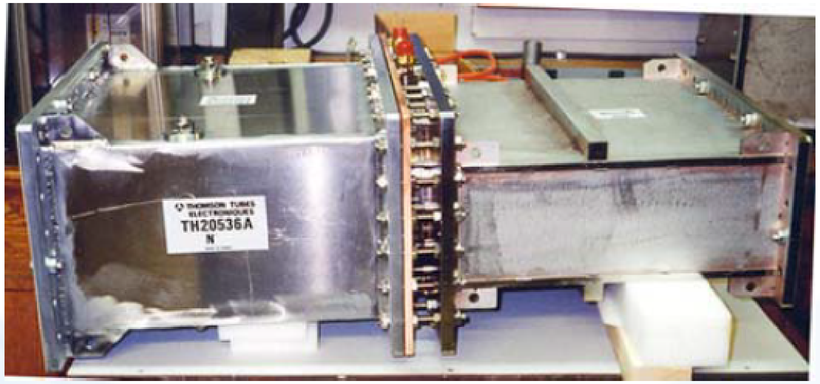


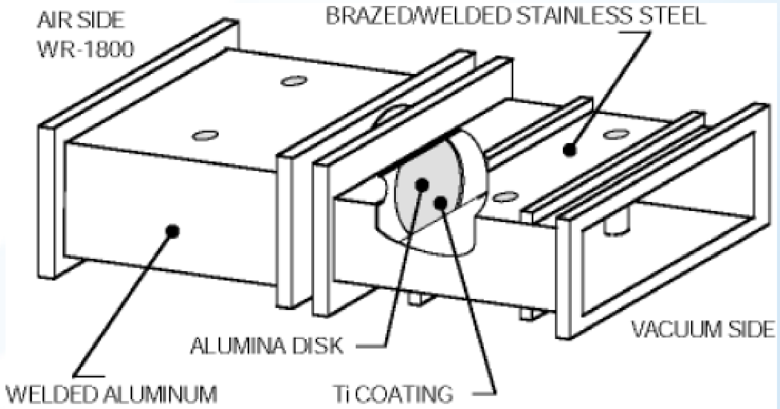
※ Cavity 2 was less Q0 than spec. 1.0E9 @2 MV/m

Input coupler and RF window



- Waveguide transfer line coupled via a coupling slot.
- Fixed coupling.
- Solenoid winding for magnetic field biasing to mitigate miltipacting (MP).
- Waveguide disk ceramic window.
- Each window tested to 400 kW (CW if possible, otherwise pulsed, average power is usually limited by available RF load) in traveling wave (TW) and >125 kW in SW.
- Coupling adjustability is provided by an external to the cryomodule 3-stub waveguide transformer.
- Depending on the CESR operating mode, Q_{ext} is set to 1.5×10^5, 2×10^5, or 4×10^5.





Window Conditioning & Test

- 9 days (~10 hours/day) for conditioning and test of RF window at Test Stand @warm temperature
- Travelling Wave Mode; Spec.
  - 8 hours @300 kW CW
  - Max △T=29 C (<60 C)
  - Vacuum pressure: 2.9~4.9E-9 mbar, no trip (<1E-7)
- Standing Wave Mode; Spec.
  - 4 hours @150 kW CW
  - Max △T=47 C (#24), 56.5C (#25)
  - Vacuum pressure: 1.2E-8 ~ 5.9E-9 mbar, no trip

Site Acceptance Test (SAT) @PLS-II

Leak Check: Cavity from atmosphere and He vessel

- Spec. (@warm & cold temp.) < 2e-10 mbar l/s

Window & cavity conditioning

- On-resonance and off-resonance
- Pulse conditioning: 1, 2, 5, 10, 20, 50 msec and CW mode
- Repetition rate: primarily 10 Hz with 1, 2, 5 Hz

RF Voltage (Vacc) and Q0 Measurement

- Long term operation: 2.03 MV, Q0=6.8e8 (Spec: >5.0e8)
- Maximum Vacc: 2.5 MV (8.5 MV/m), Q0=6.4e8

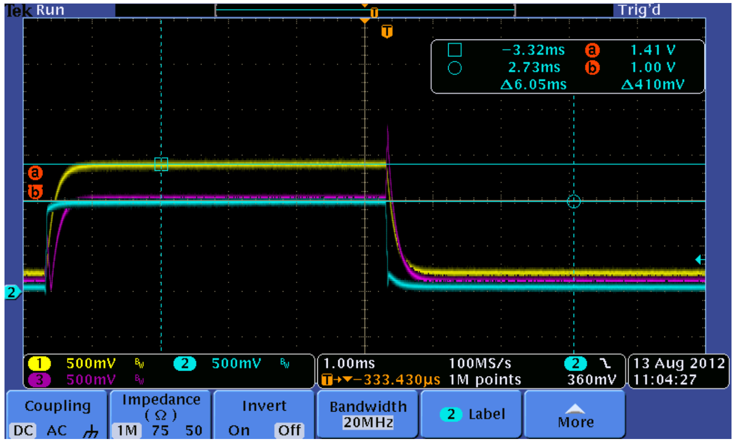
Q external: 1.65E5

Tuner performance test: stroke > +/- 150 kHz, resolution <10Hz

Site Acceptance Test

Test-pit With radiation shield

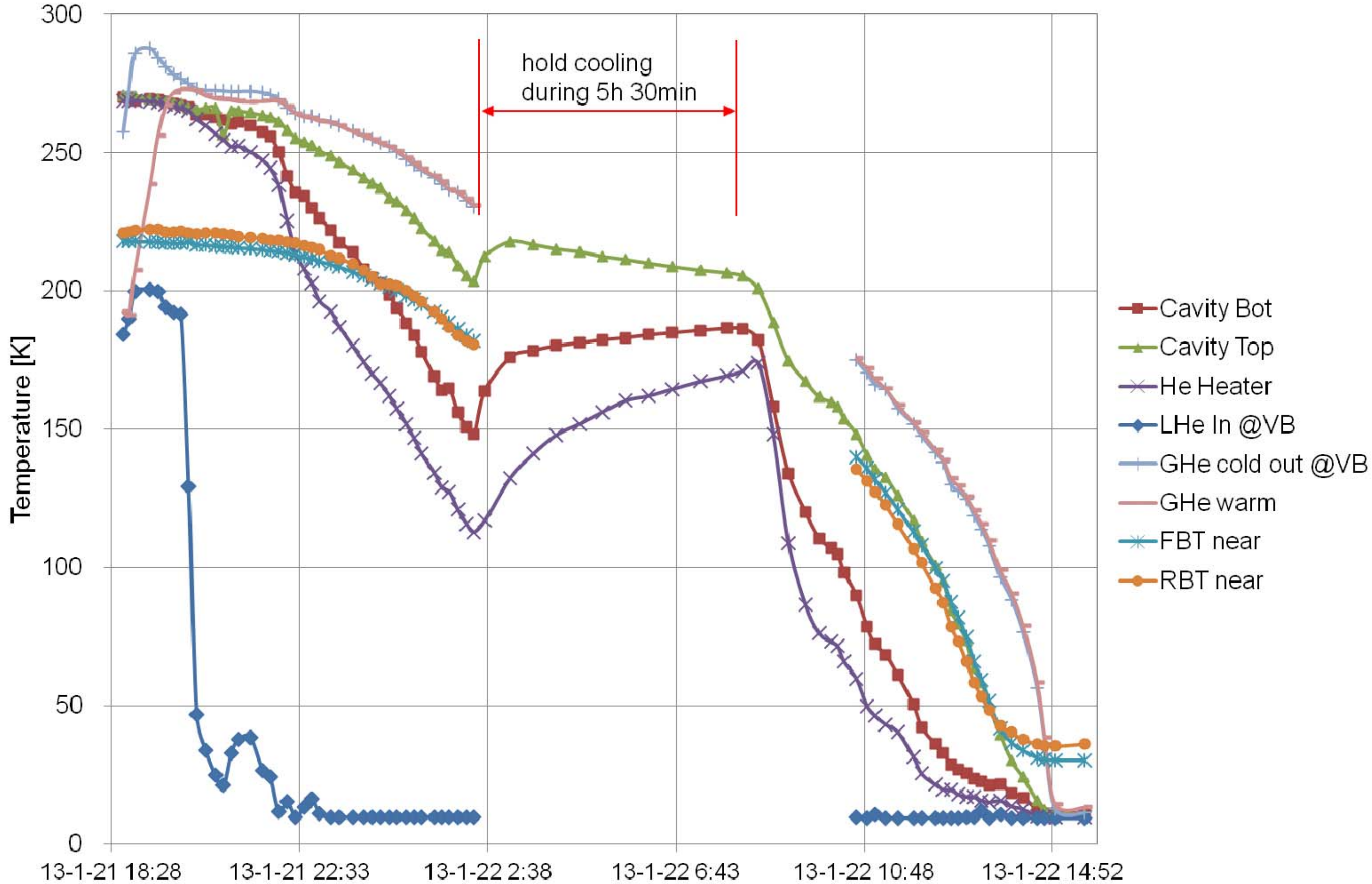
Pulse-1,2,5,10,20,50 &100 msec



Cryomodule control system

Cooling with Liquid He

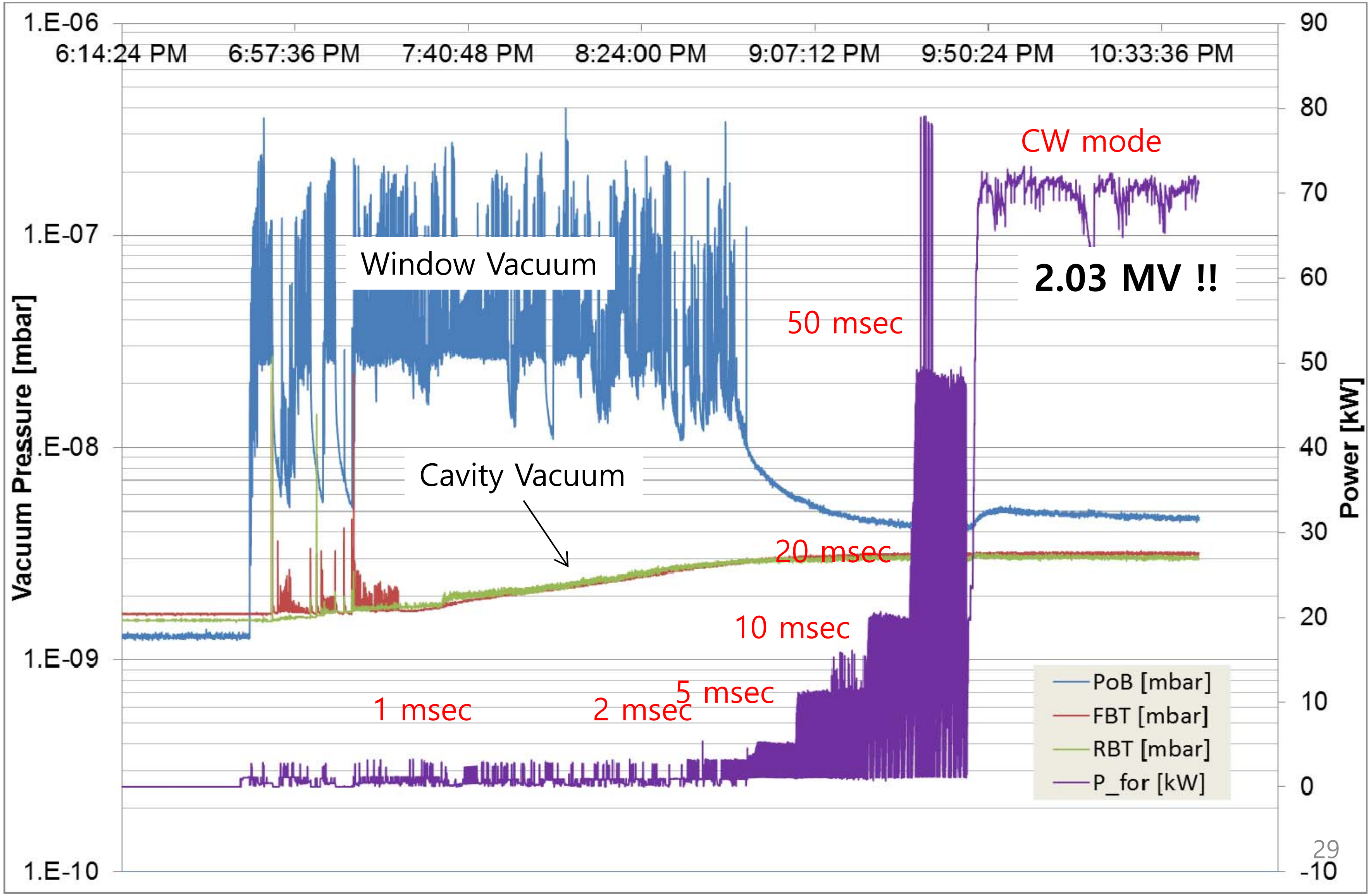
~15 hours: room temp. to 4.4 k



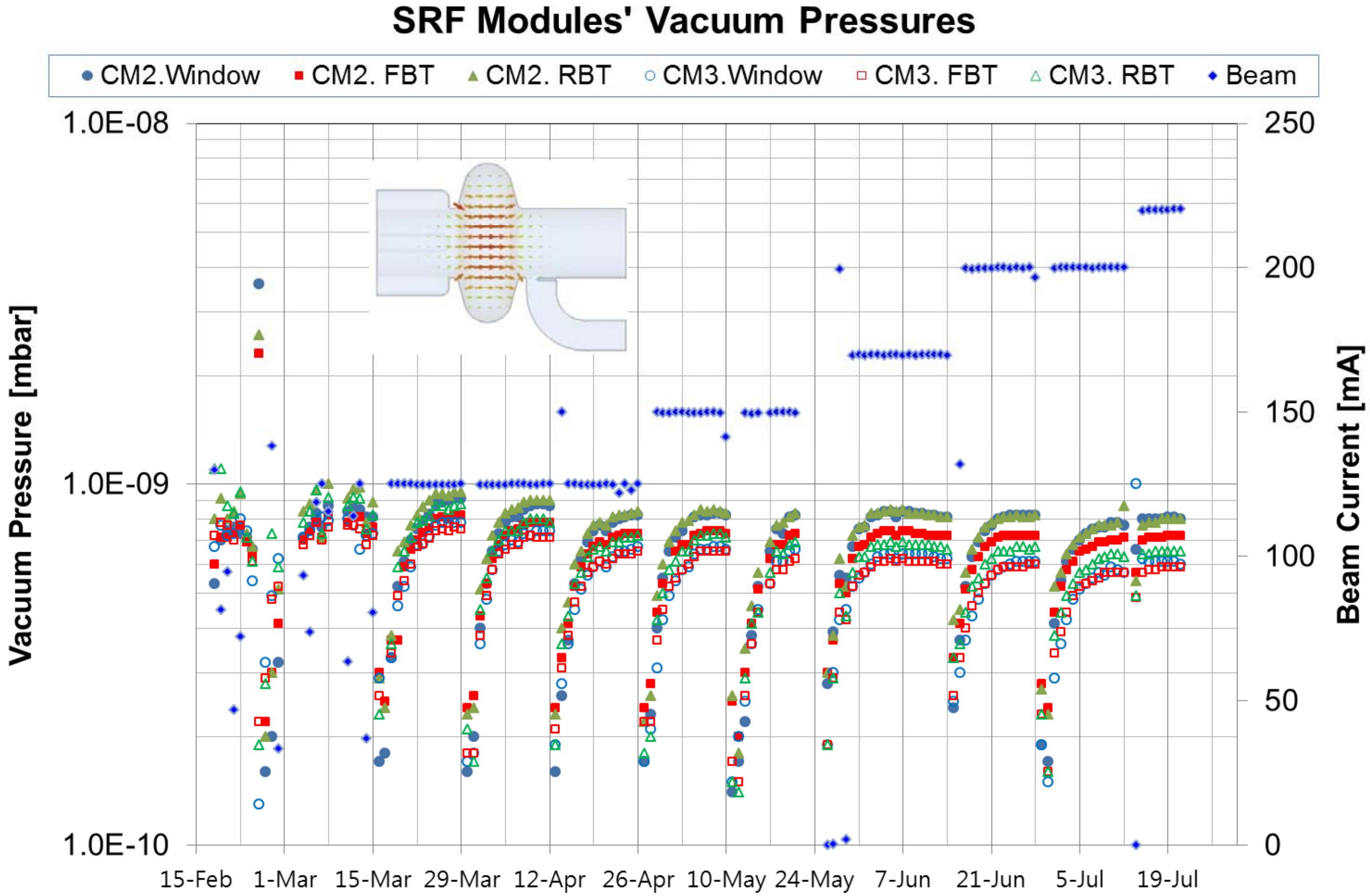
Conditioning Window & Cavity

Last 16 hours

Aug. 14, 2012



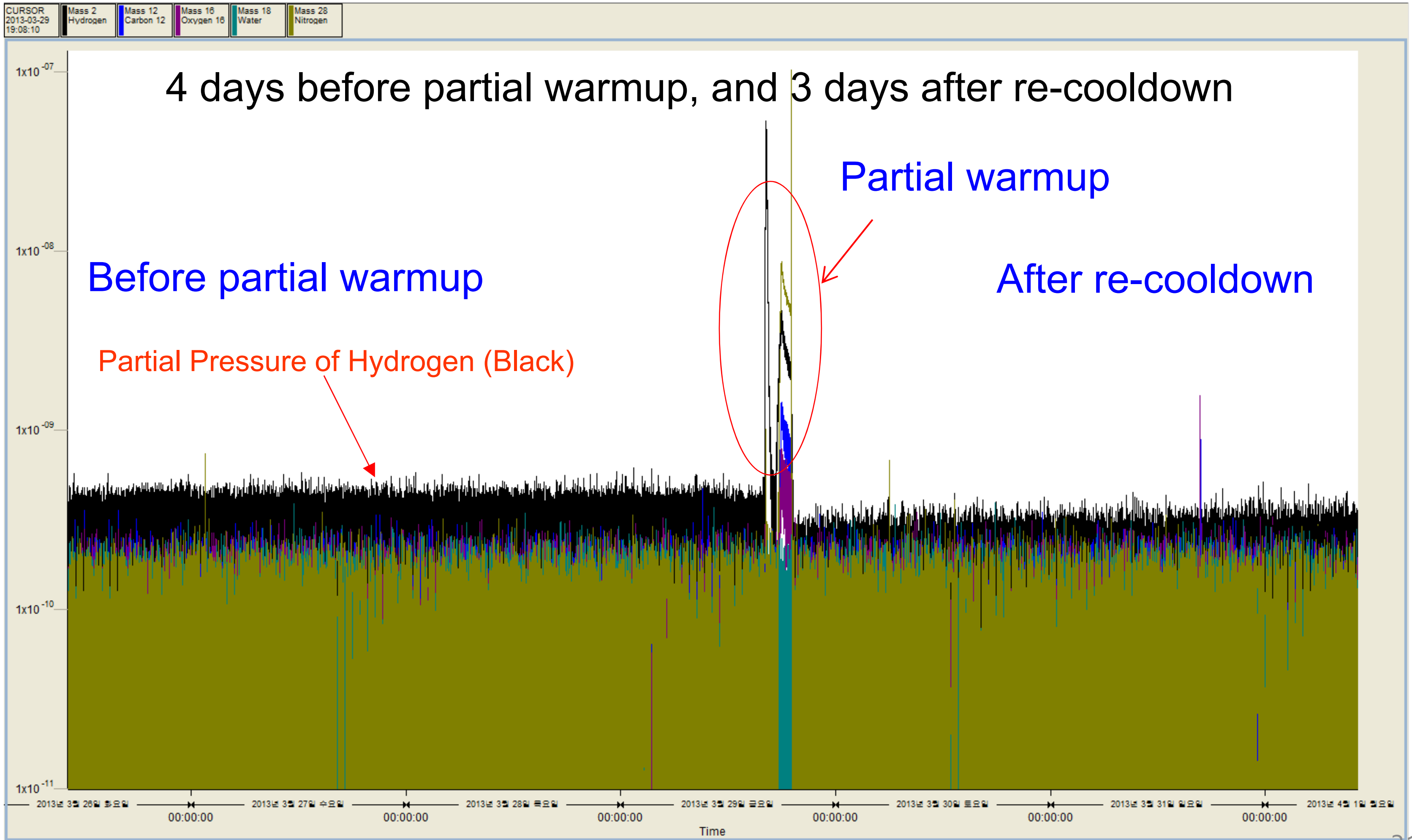
Management, Cavity & Window Vacuum



- Partial warming-up cavity up to 40K
- Threshold pressure vacuum bursts >1 x 10^9 mbar

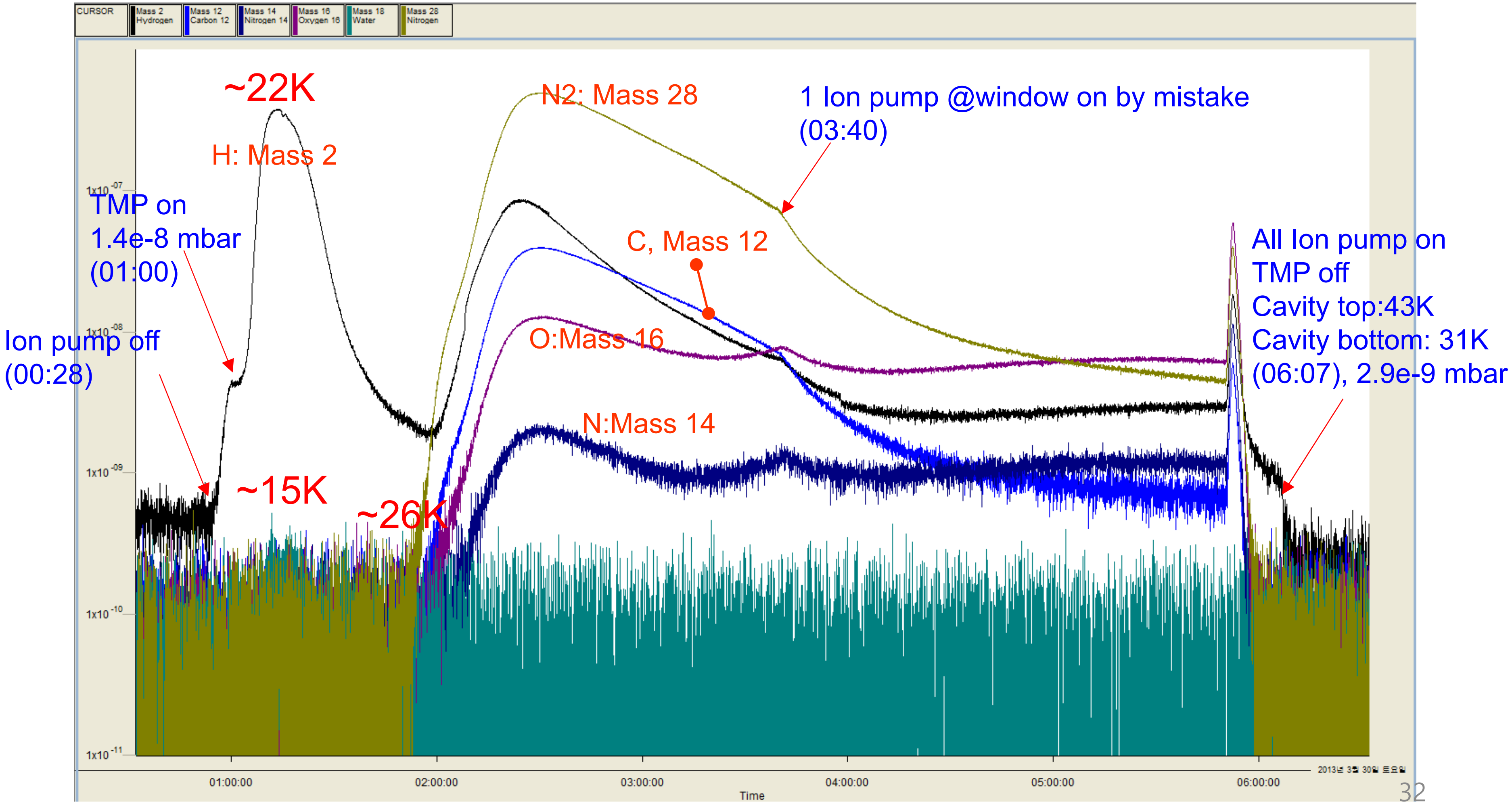
Partial Warmup & Cooldown

Mass-Spectrometer (RGA)



Partial Warmup & Cooldown

During partial warmup & cooldown with TMP operation



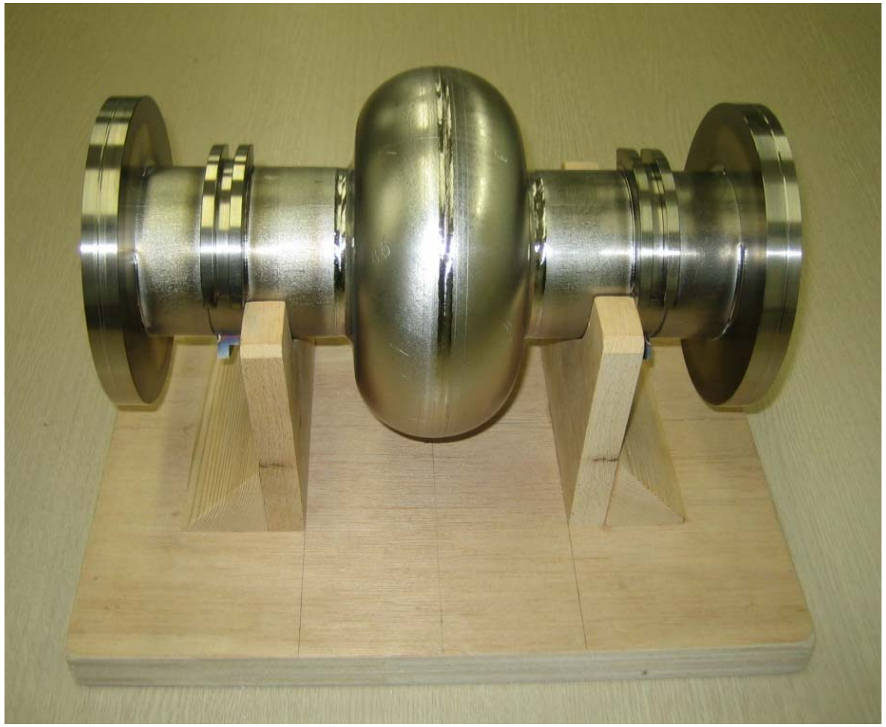
3rd Harmonic Cavity for PLS

(Mar. 2004 – Dec. 2007)

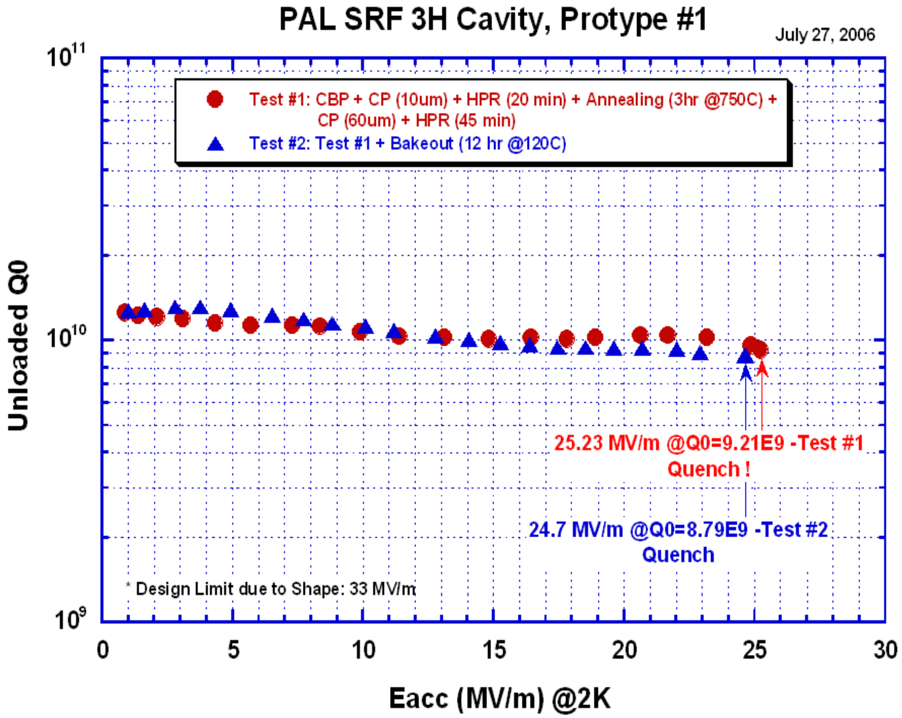
For;

- Increase beam lifetime by lengthening e-beam bunches
- Reduce coupled-bunch instabilities from higher order mode (HOM)

Prototype 3rd Harmonic SRF Cavity for PLS



Prototype 3rd H Cavity



Cavity Performance from vertical test

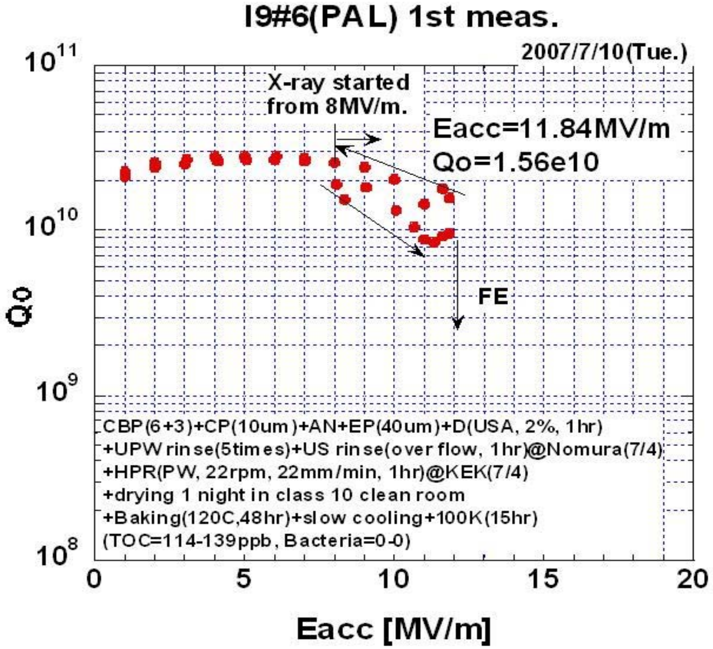
Design/fabrication @ PAL, surface preparation @KEK, vertical test @Jlab.

First SRF Cavity developed in Korea !!

R&D for ILC SRF

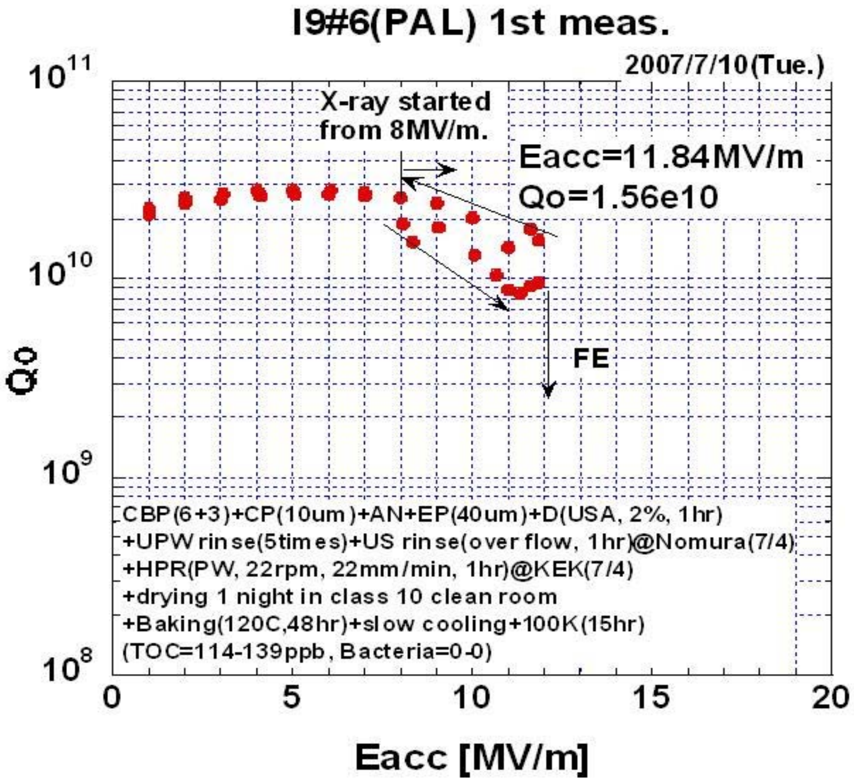
- Cavity (KEK-Low loss) design by K. Saito
- Design/Fabricating dies, jigs & fixtures by PAL
- Fabricating two 9-cell cavities with simple straight beam pipe
- Surface preparation and vertical test at KEK, Japan

Fabrication of 9-cell Cavity - PAL #1 and 2



- 3 Measurements of Eacc
  - Average Eacc = 23.0 MV/m
  - Max. Eacc = 27.2 MV/m

Results of Vertical Test for 9-cell Cavity



- 3 Measurements of Eacc
  - Average Eacc = 23.0 MV/m
  - Max. Eacc = 27.2 MV/m

Tack !

감사합니다 !

(Gam-Sa hap-ni-da !)