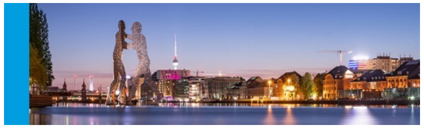
Degradation and Recovery of Cavity Performance in compact-ERL Injector Cryomodule at KEK

Eiji Kako (KEK, Japan)

at HZB

2019, September 19th



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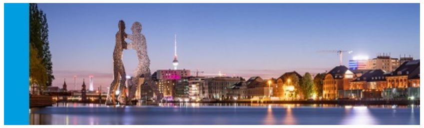
2. Long Term Operational Experience
3. Degradation of Cavity Performance
4. Performance Recovery by Pulsed Processing
5. Future Prospect and Summary



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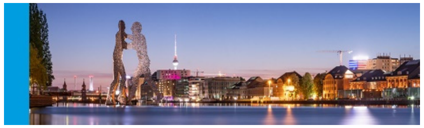
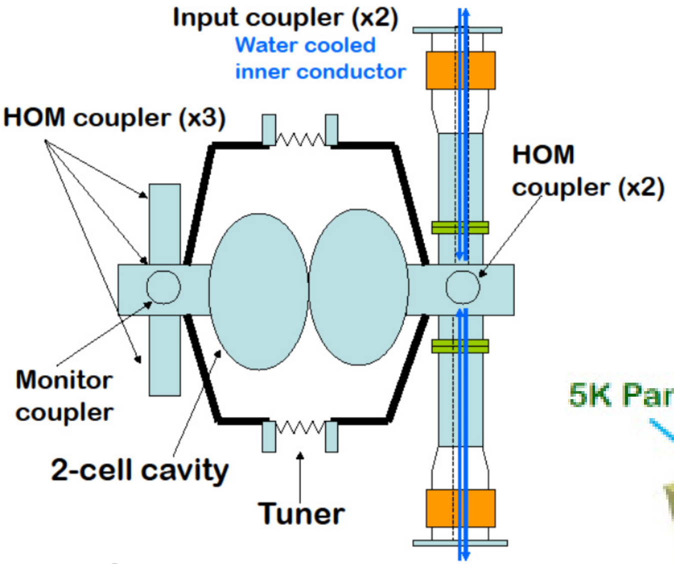
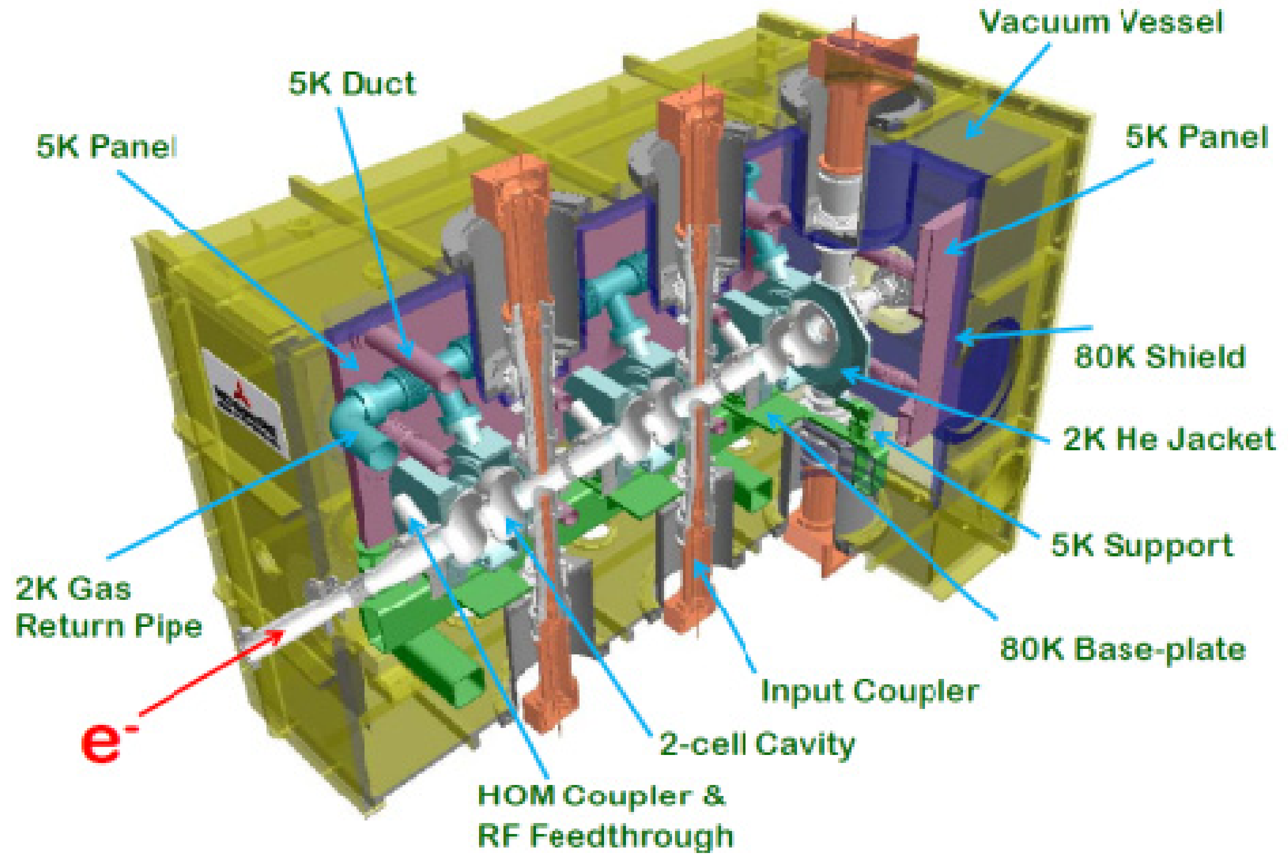


Injector Cryomodule in compact-ERL at KEK



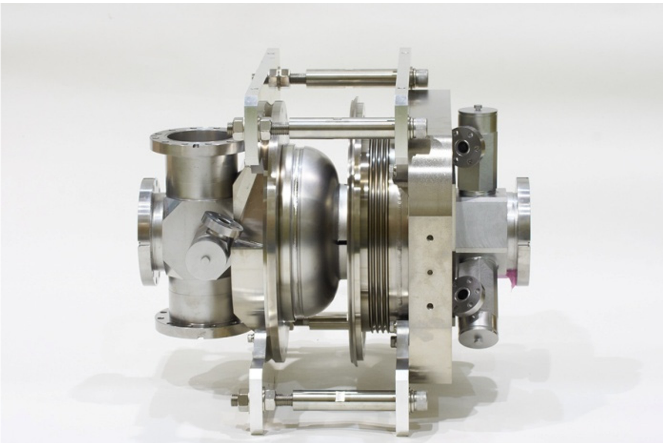


Initial Design Target
10 MeV, 100 mA CW
(300 kW Klystron, CW)
(150 kW/coupler, CW)

⇩

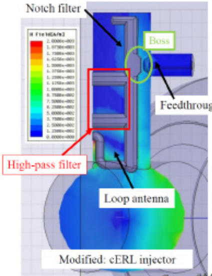
Actual Specification
CW 10mA, 5 MeV
(10 kW/coupler)

Main components of Injector Cryomodule

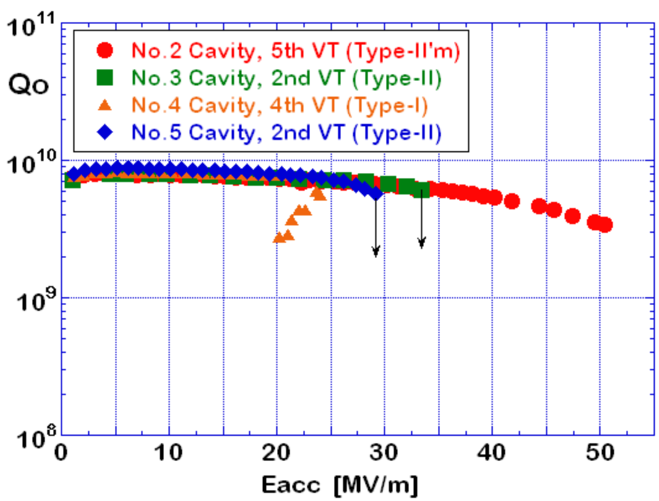


1.3 GHz 2-cell Cavity

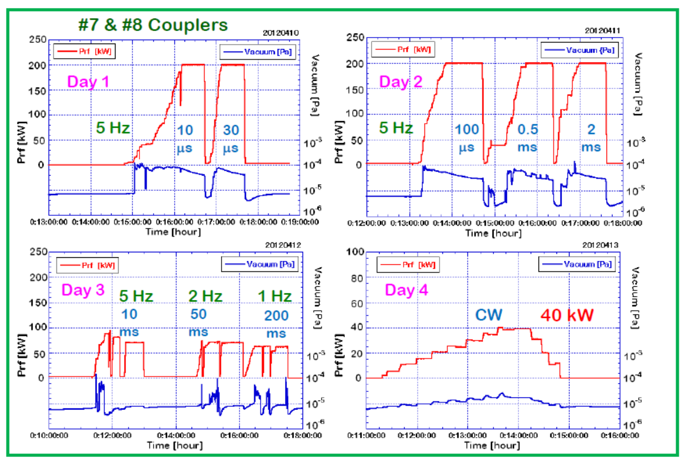
CW Input Couplers



Loop-antenna type HOM Couplers

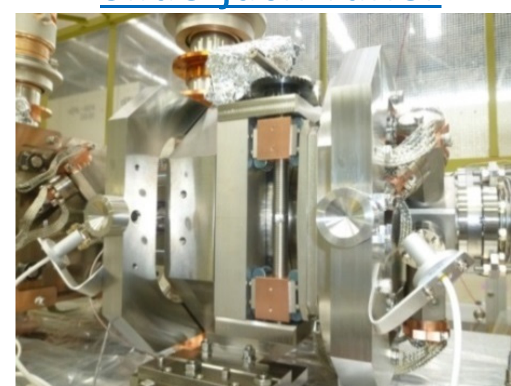


Eacc > 20 MV/m in 3 Cavities

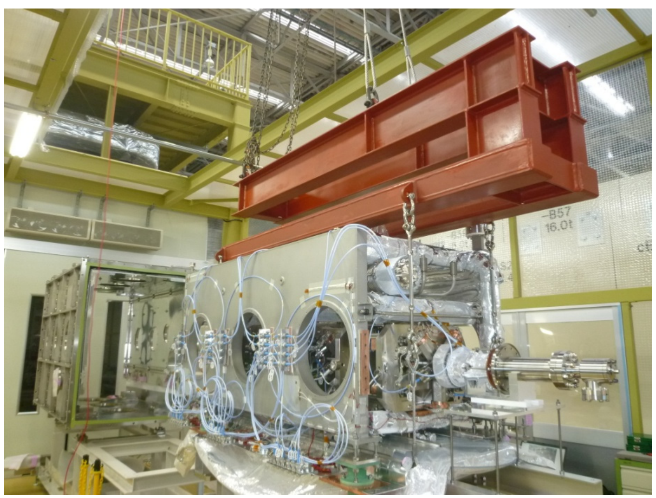


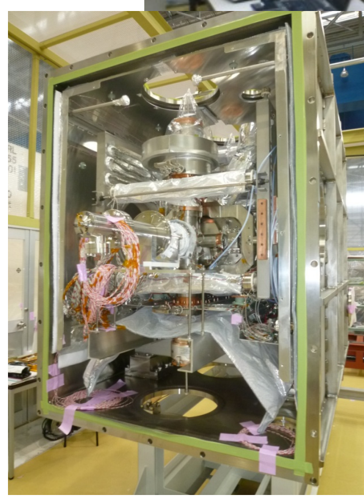
CW 40 kW (short pulse, 200 kW)

Slide-jack Tuner



Assembly of cERL Injector Cryomodule



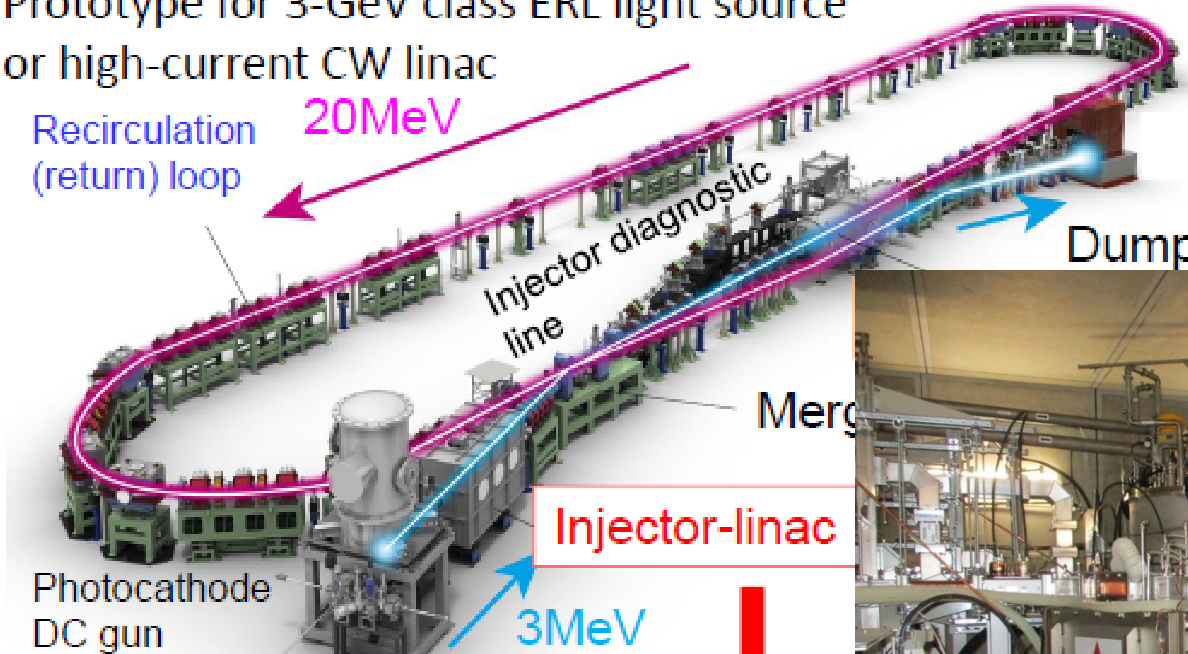


cERL injector cryomodule completed and installed in June 2012.

Injector-Linac section of compact-ERL

Compact ERL

Prototype for 3-GeV class ERL light source
or high-current CW linac



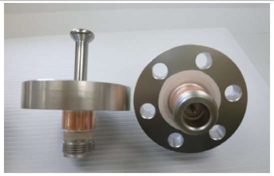
Beam operation at 5 MeV
in cERL Injector-Linac section
was started in April 2013.

Injector Cryomodule

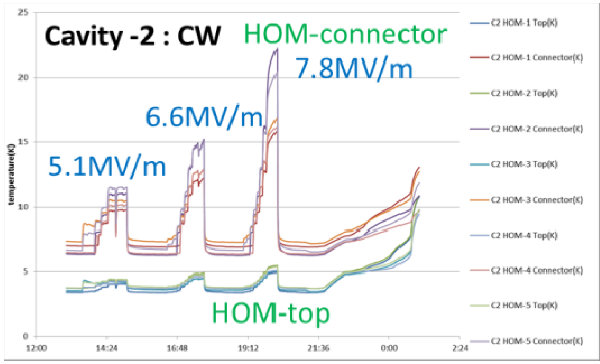
Cryogenic power : 90 W at 2K

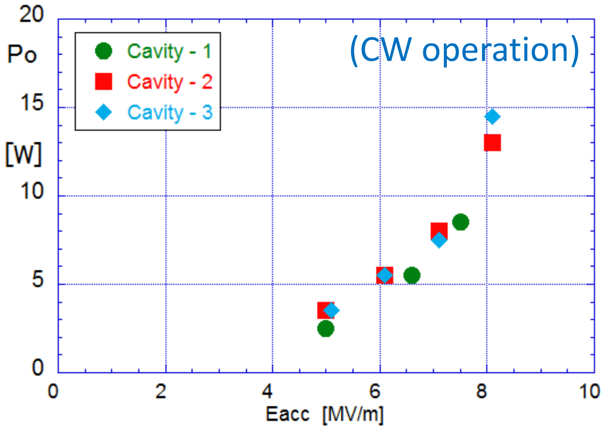
Summary of design values and obtained results

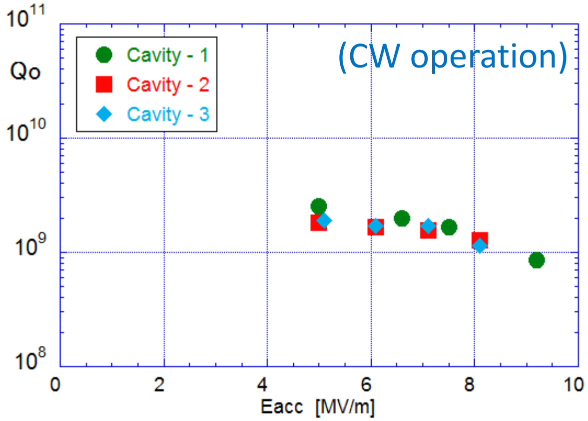
Injector Cryomodule	Design	Result
Static heat load at 4.2 K	33 W	36 W
Static heat load at 2 K	11 W	14 W
Dynamic heat load at 2 K, (7 MV/m)	< 1.0 W	8.5 W
Q_0 at 2 K, (7 MV/m)	> 1.0×10^{10}	1.8×10^{9}
Operating total Vc	5 MV	5 MV
Conditioning RF power at RT	---	CW 40 kW
Operating RF power at 2 K	---	CW 10 kW
Tuner stroke	> 500 kHz	600 kHz
Piezo stroke	> 1 kHz	2 kHz

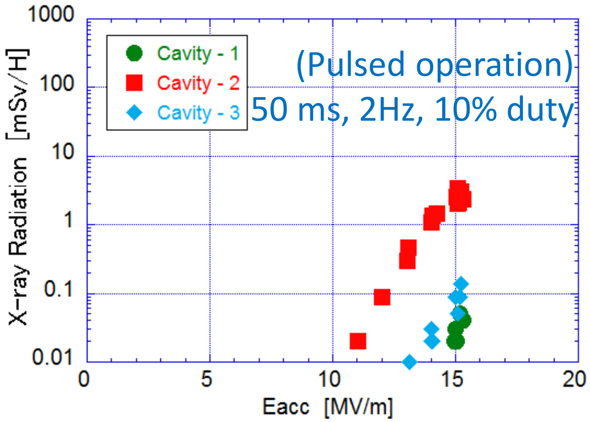


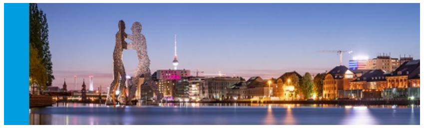
Due to heating-up of HOM pick-up antenna











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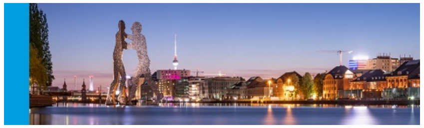
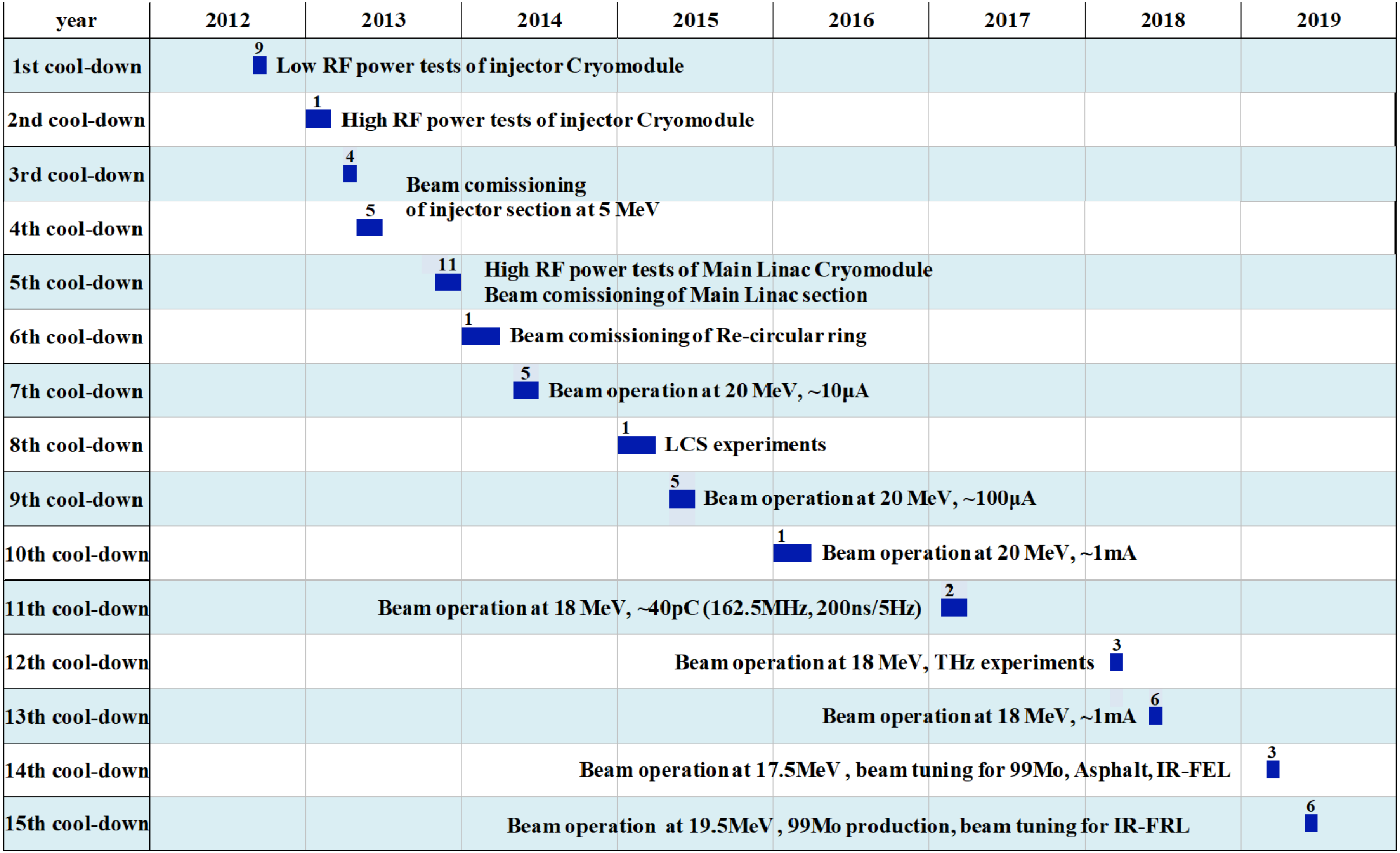
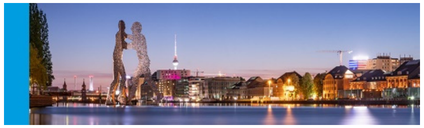


History of cool-down cycles in injector cryomodule





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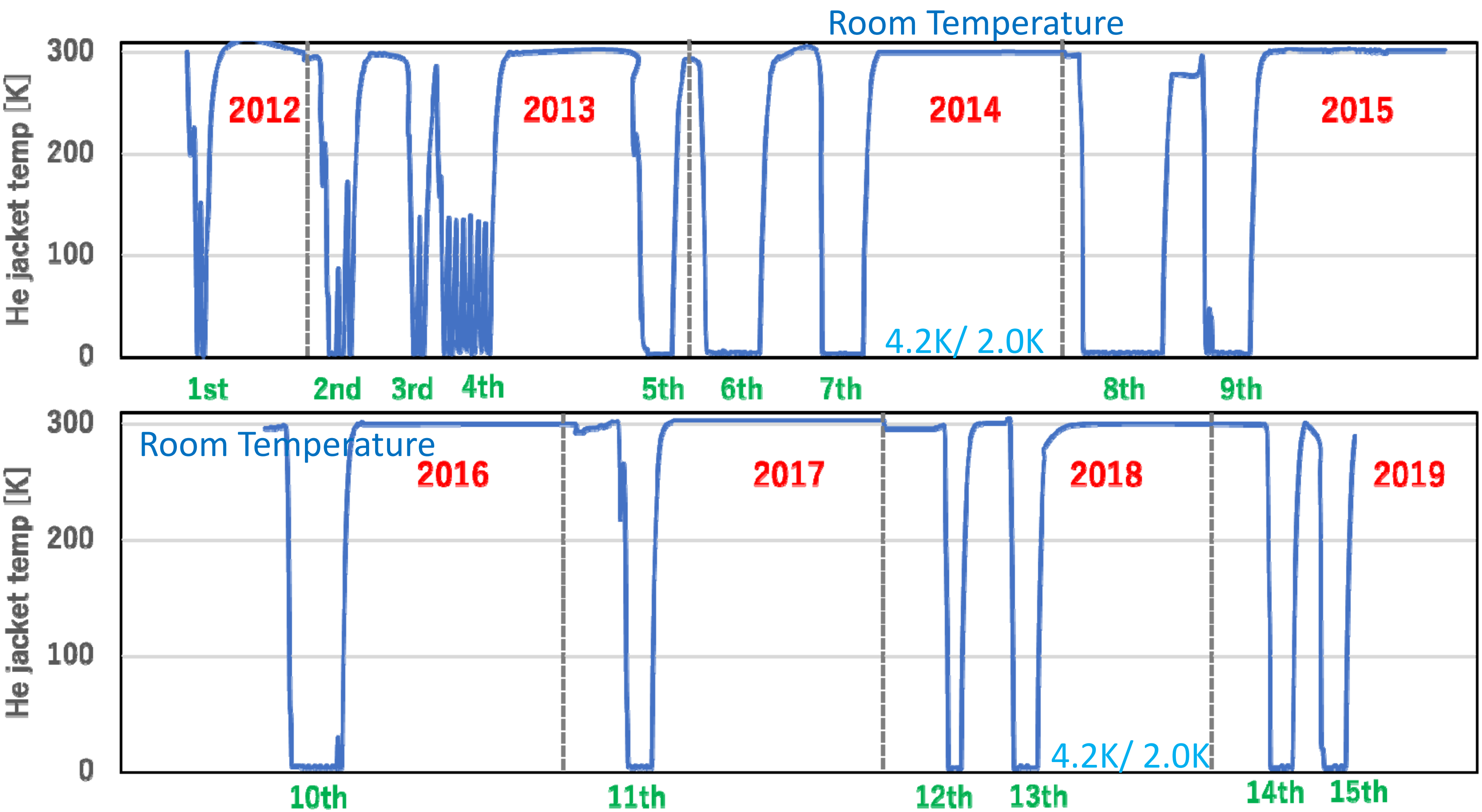
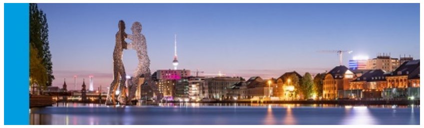
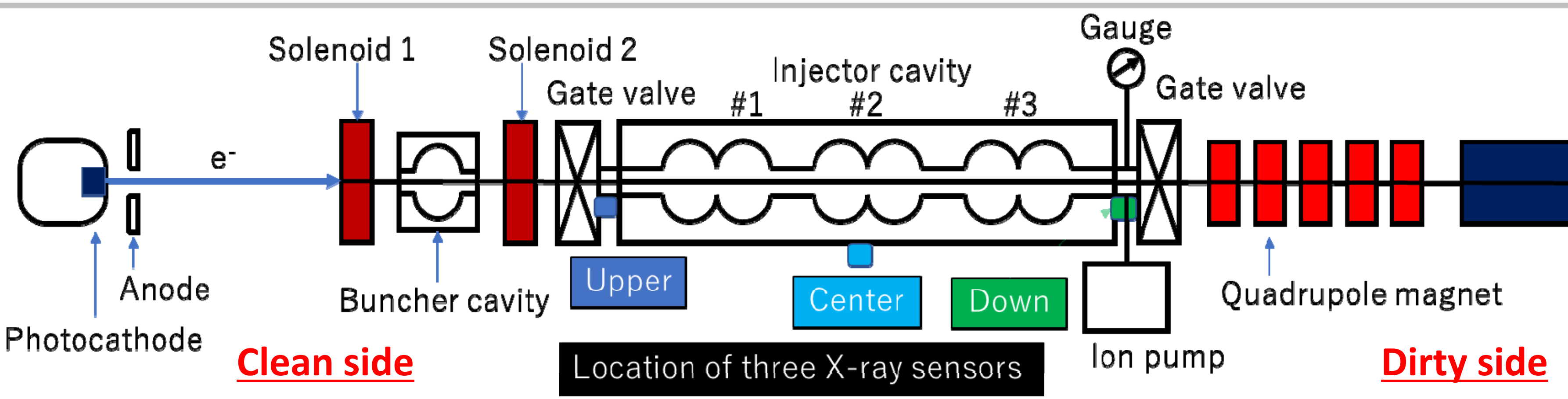
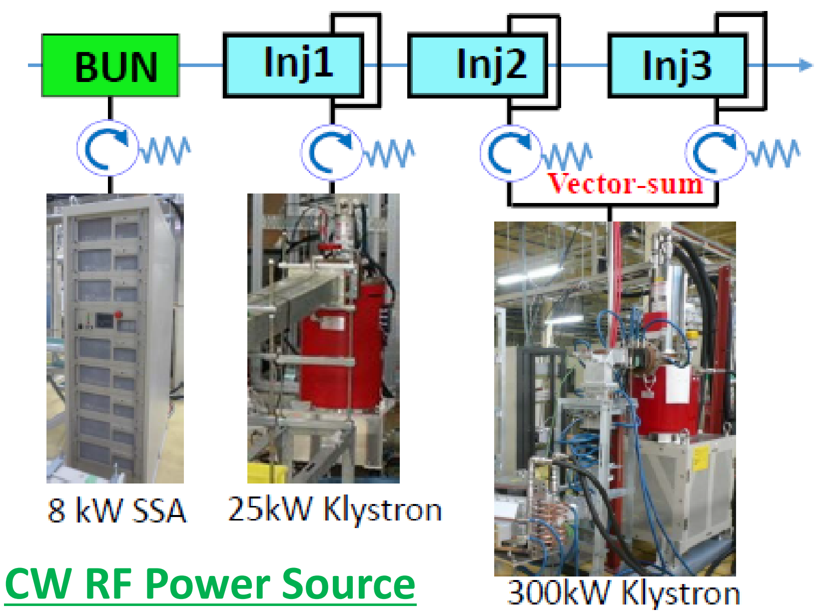




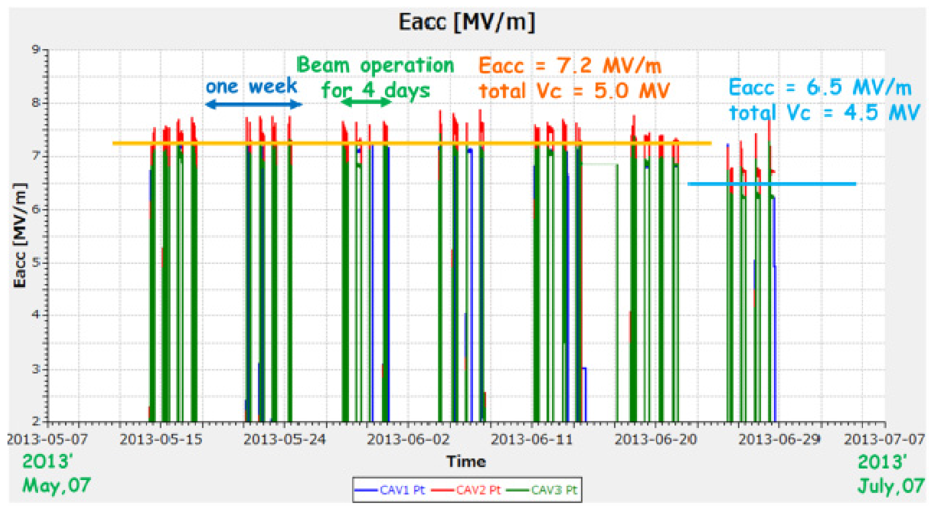
Injector-Linac section of compact-ERL



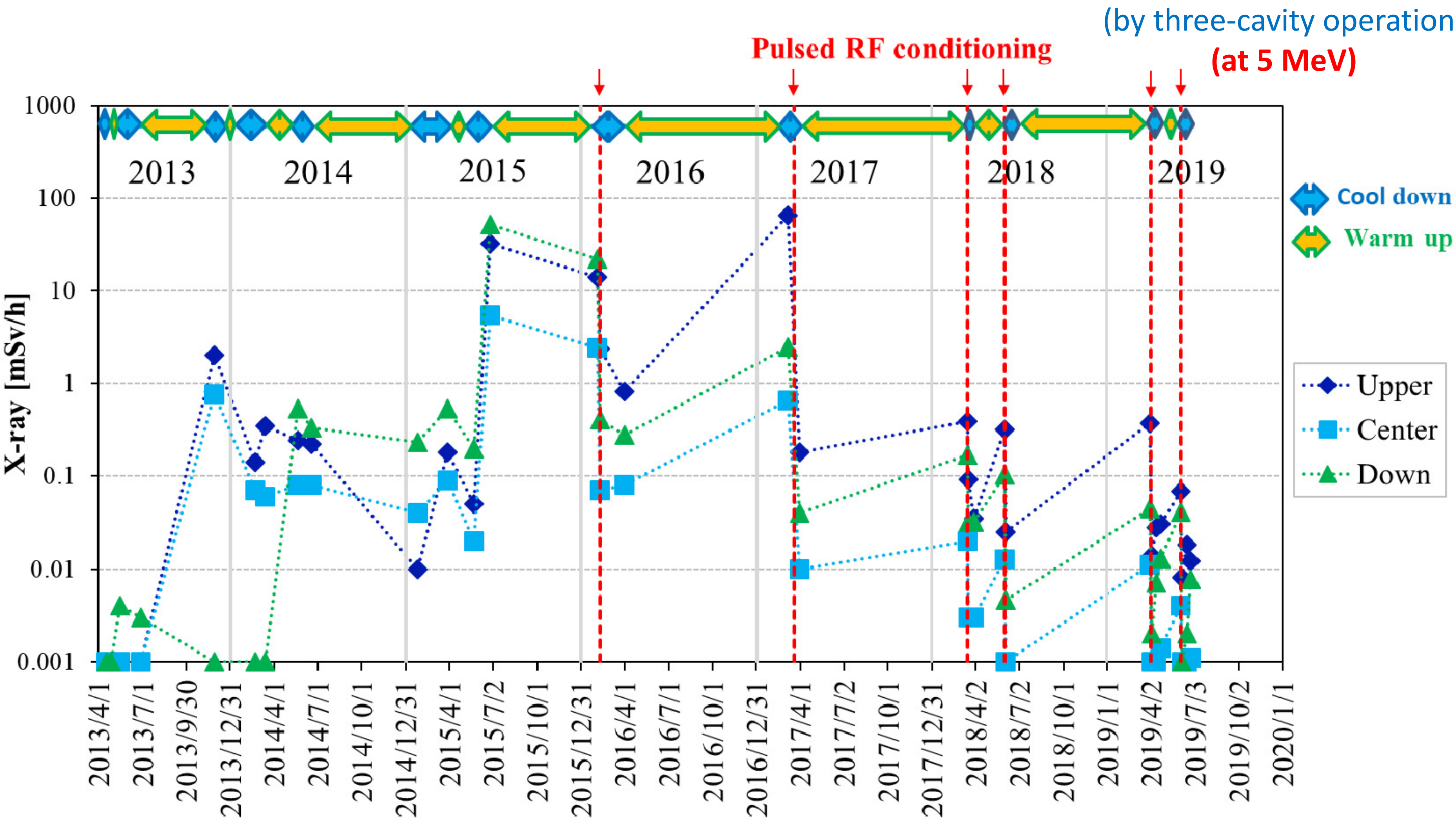


CW RF Power Source

Operation of Injector-Linac section at 5 MeV (7 weeks)



Change of x-ray radiation levels in 2013' – 2019'

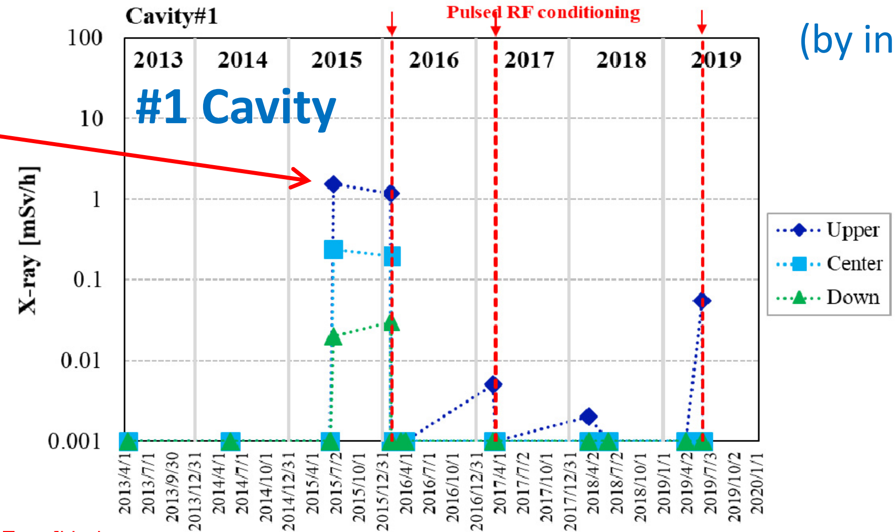


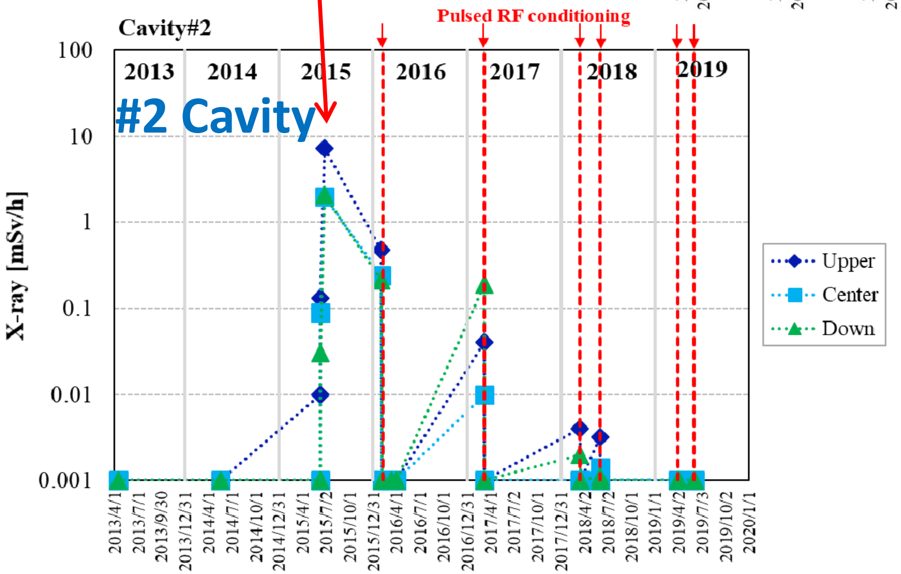
Change of x-ray radiation levels in 2013' – 2019'

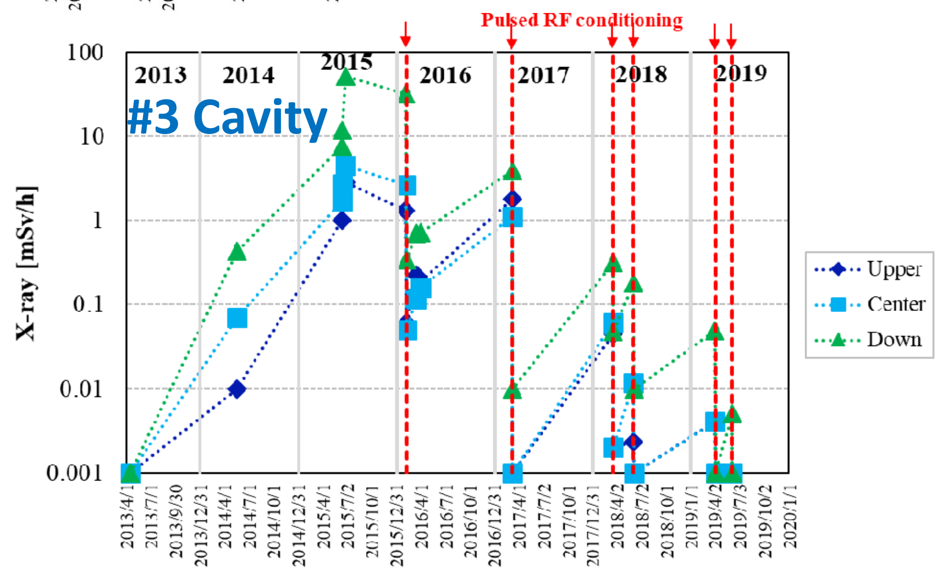
Sudden increase of x-ray radiation

(by individual cavity operation)

(at 7 MV/m)







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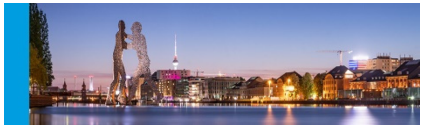


Change of x-ray radiation levels in three cavities

DC-Gun side

(clean environment)

Photo cathode of Gun
Faraday Cup
Gate Valve
Stopped at

Acceleration of F.E. electrons by Cavity-1

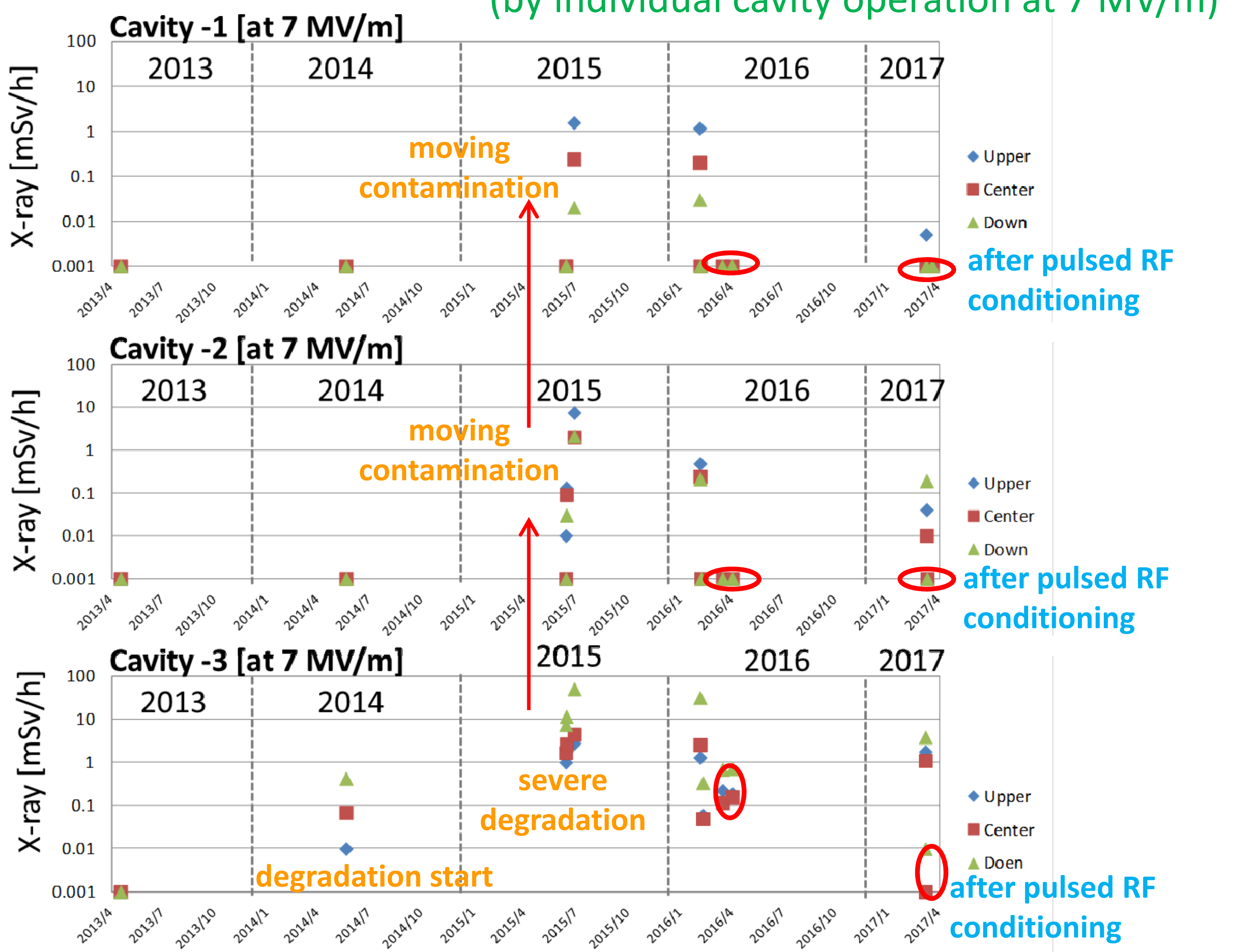
Acceleration of F.E. electrons by Cavity-2

Main sources of field emission locates in Cavity-3

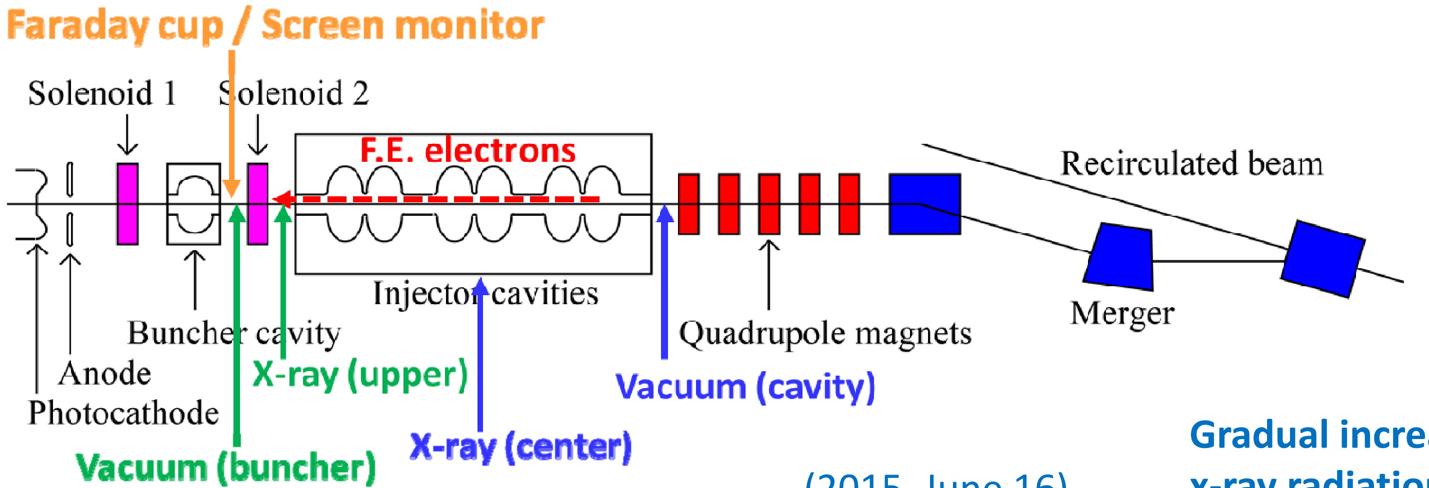
(dirty environment)

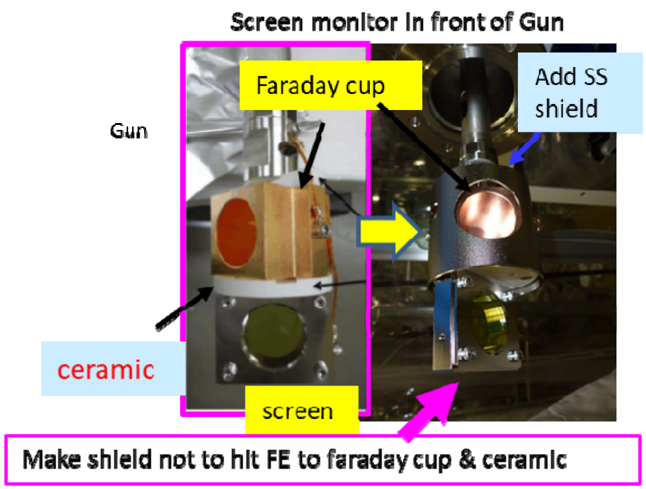
Merger side

(by individual cavity operation at 7 MV/m)



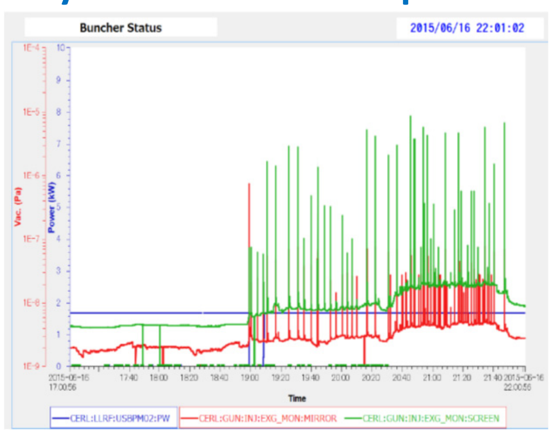
Unexpected vacuum discharge phenomenon (1)



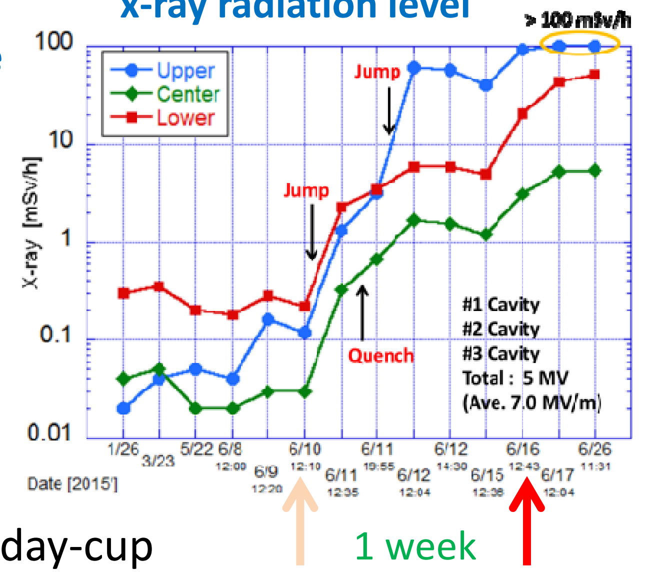


(2015, June 16)

Many bursts of vacuum pressure

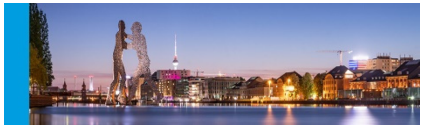


Gradual increase of x-ray radiation level

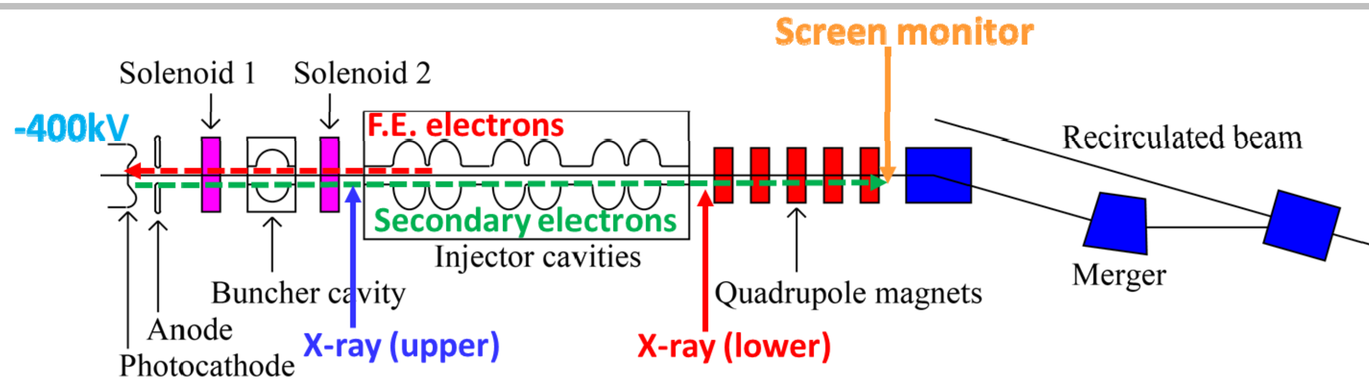


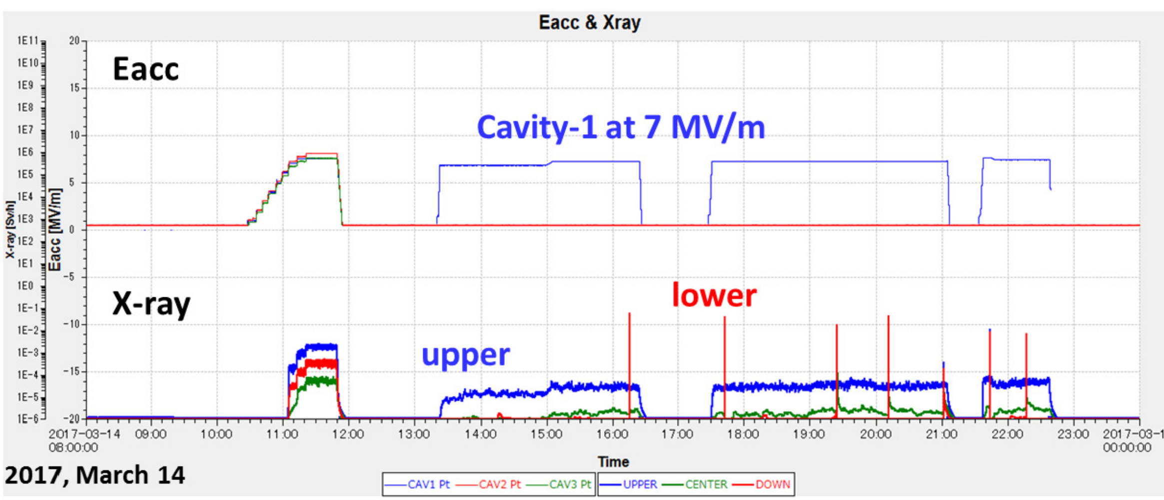
(2015, June 16)

Vacuum discharge caused by charging-up of Faraday-cup due to field emitted electrons come from injector cavities.

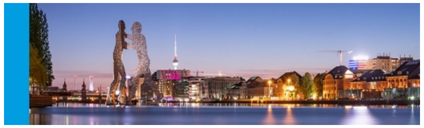


Unexpected vacuum discharge phenomenon (2)





Field emitted electrons from Cavity-1 hit the photocathode. Then, secondary electrons extracted by applied DC voltage of 400 kV, and furtherly accelerated by injector cavity. Finally, high energy electrons collided with a screen monitor and radiate x-rays.



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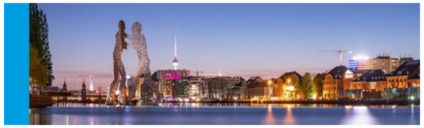
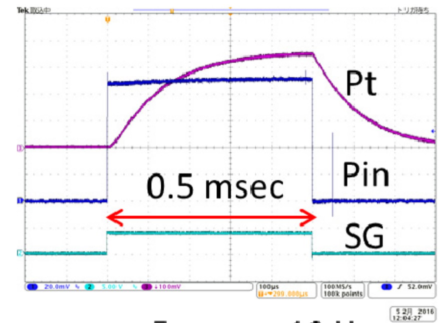


High RF power pulsed conditioning

	No.1 Cavity	No.2 Cavity	No.3 Cavity
Q_L	1.2×10^6	5.3×10^5	5.4×10^5
Required RF power at 15 MV/m	12 kW	27 kW	27 kW
Required RF power at 20 MV/m	21 kW	47 kW	47 kW

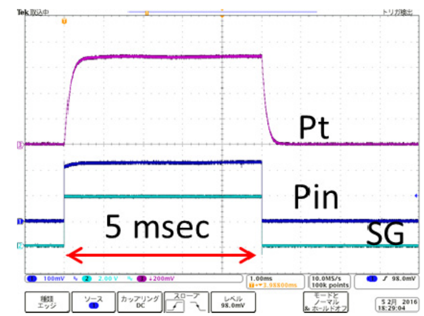
CW 25 kW Kly. CW 300 kW Klystron

0.5 msec x 10 Hz



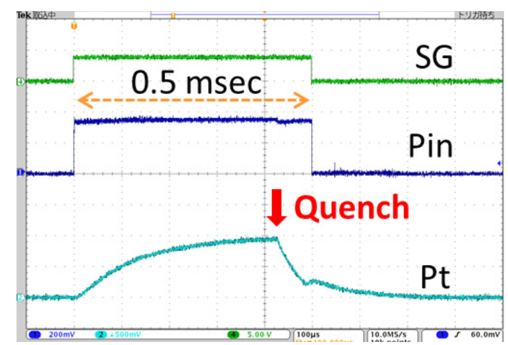
Duty: 0.5 %

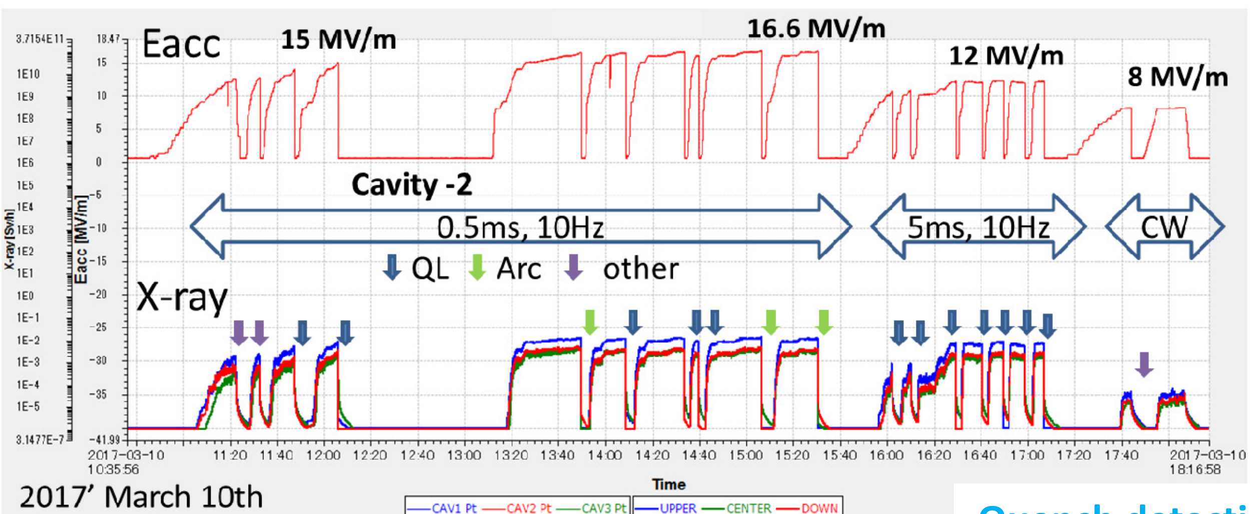
5 msec x 10 Hz



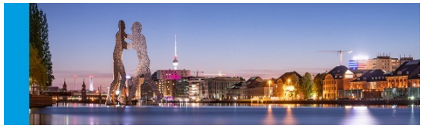
Duty: 5 %

CW

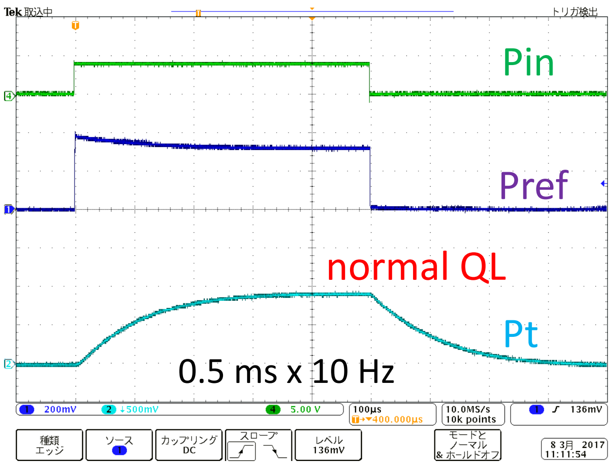




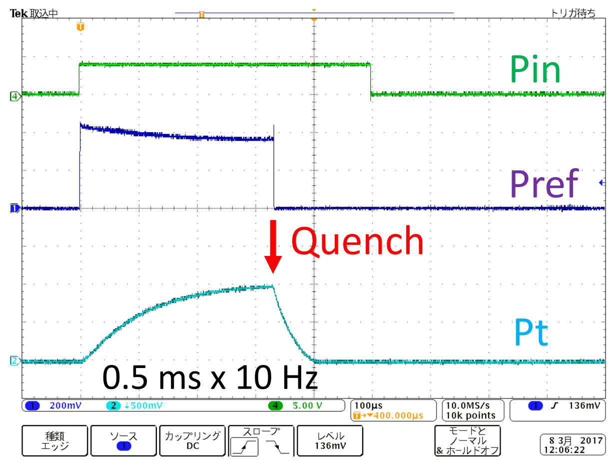
Quench detection : Q_L-interlock < 0.8 x Q_L (normal)



Quench events during high RF power pulsed conditioning



#3 Cavity (2017, March 8)



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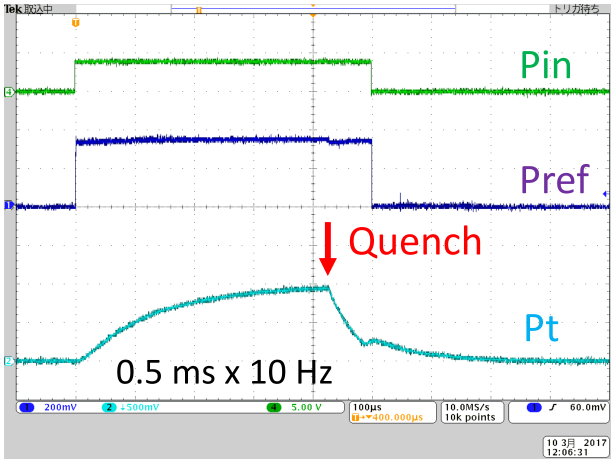
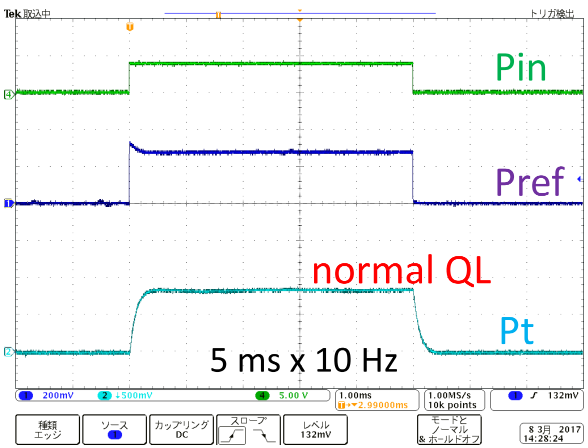


#2 Cavity (2017, May 10)



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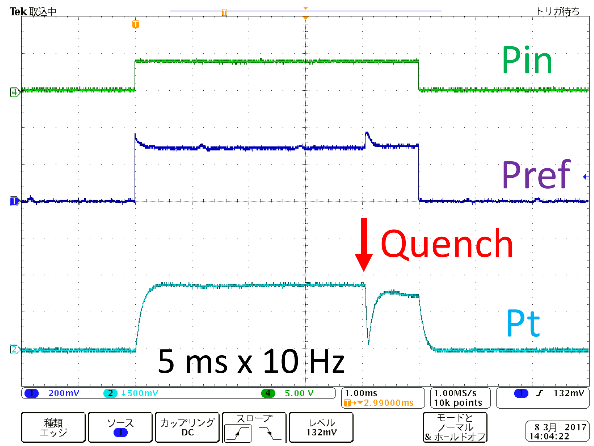

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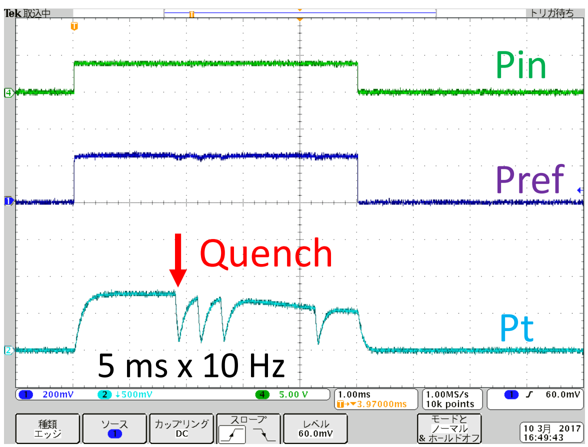

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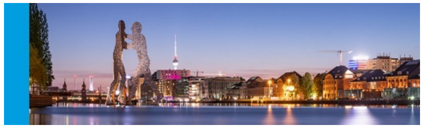
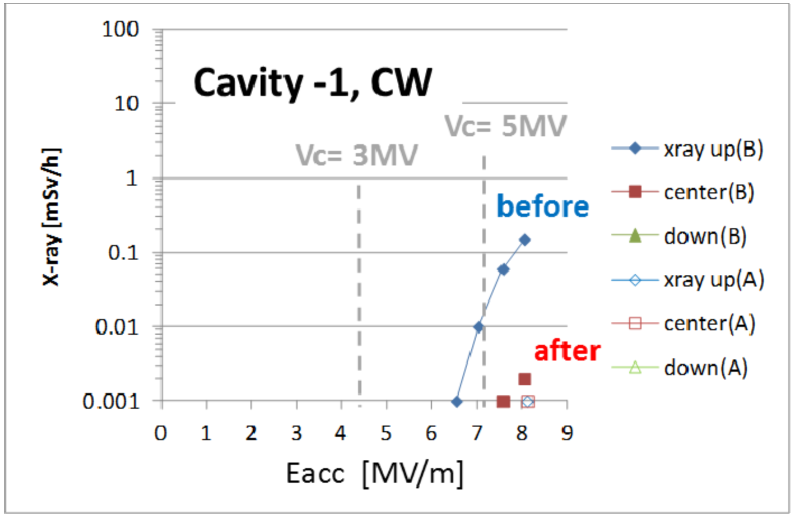
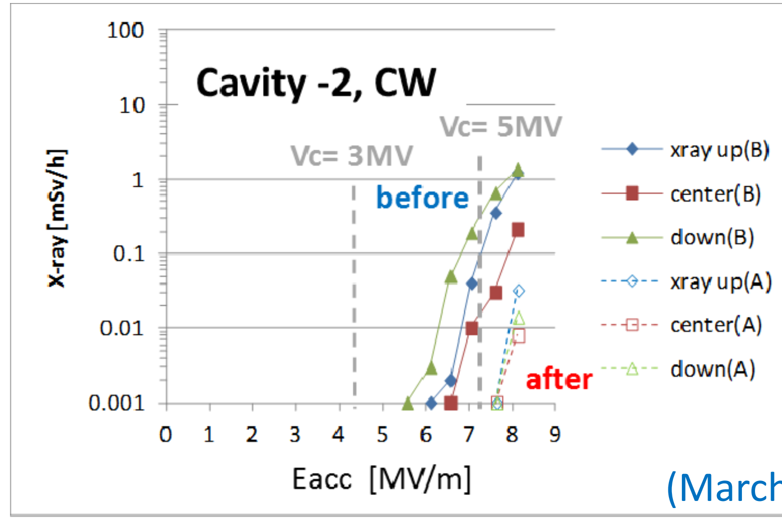
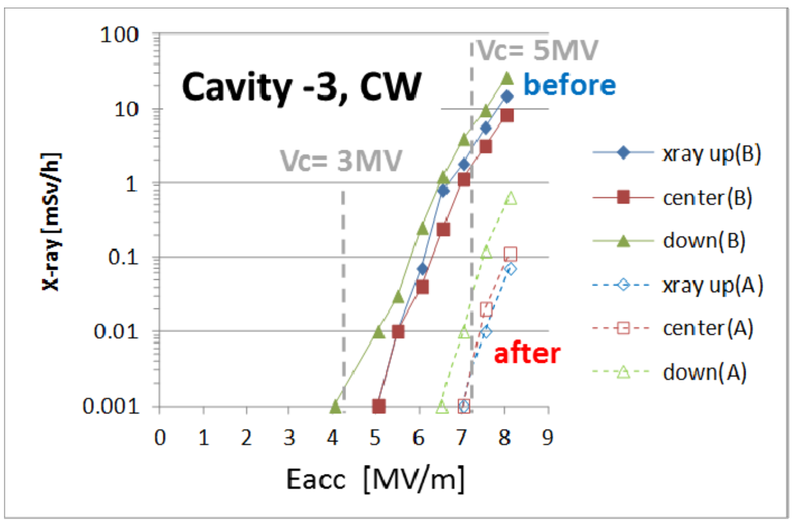


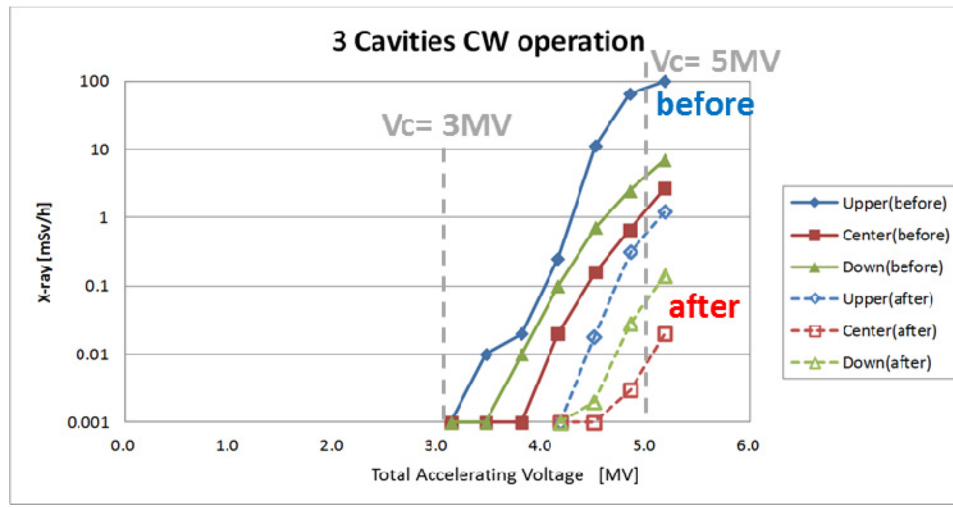
Performance recovery by pulsed RF conditioning (2017')



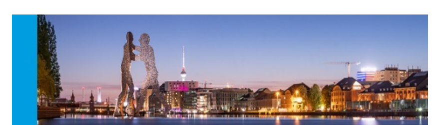


(March, 2017)



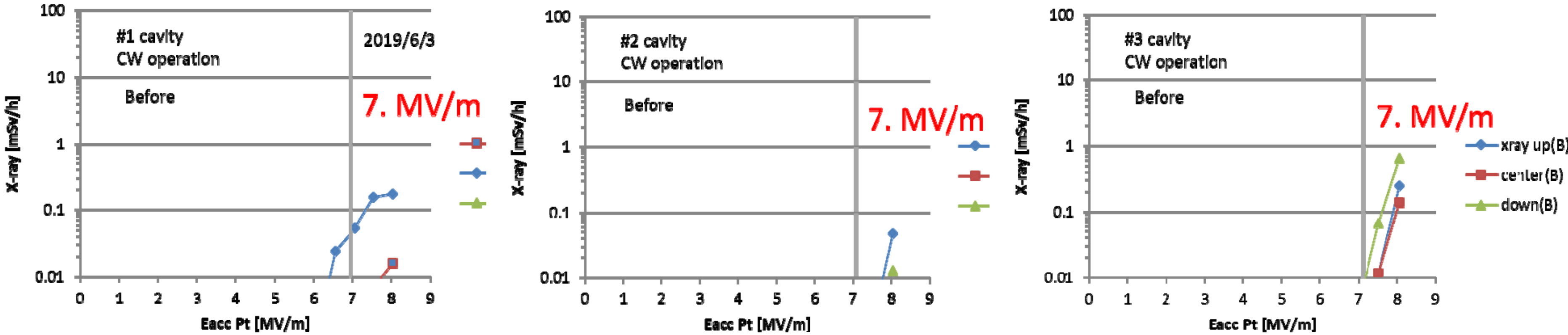


Heat load at 2 K was dramatically reduced at 5 MV.



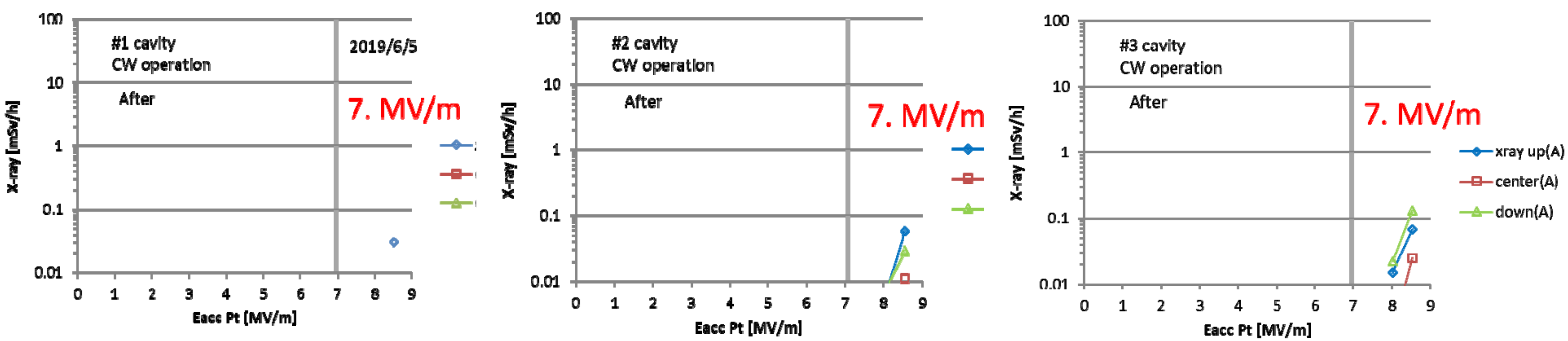
Performance recovery by pulsed RF conditioning (2019')

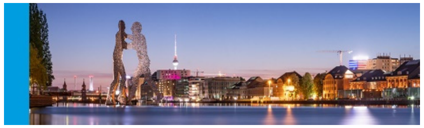
Initial measurement (2019, June 03)



After pulsed conditioning (2019, June 05)

Pulsed RF conditioning has been routinely carried out before beam operation after every cool-down cycles.





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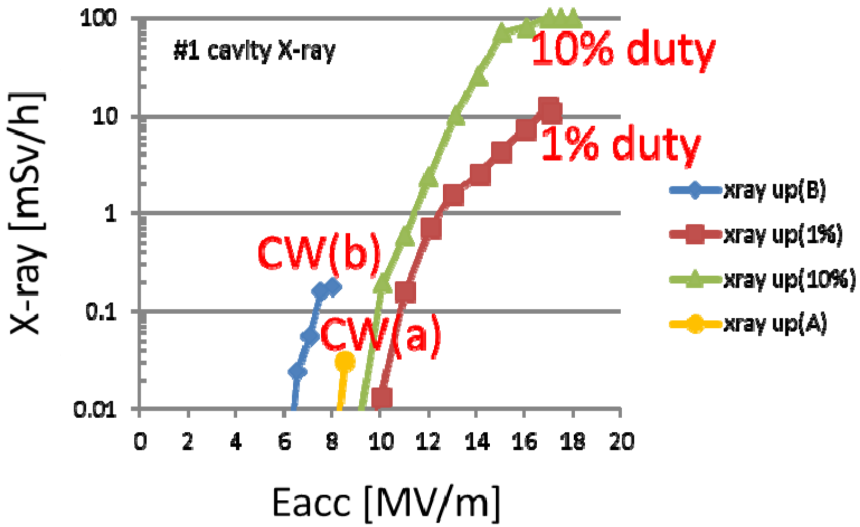
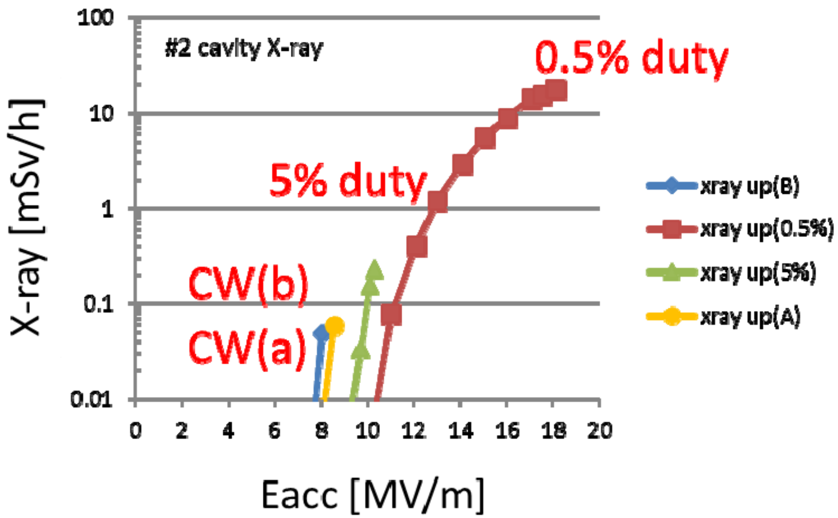


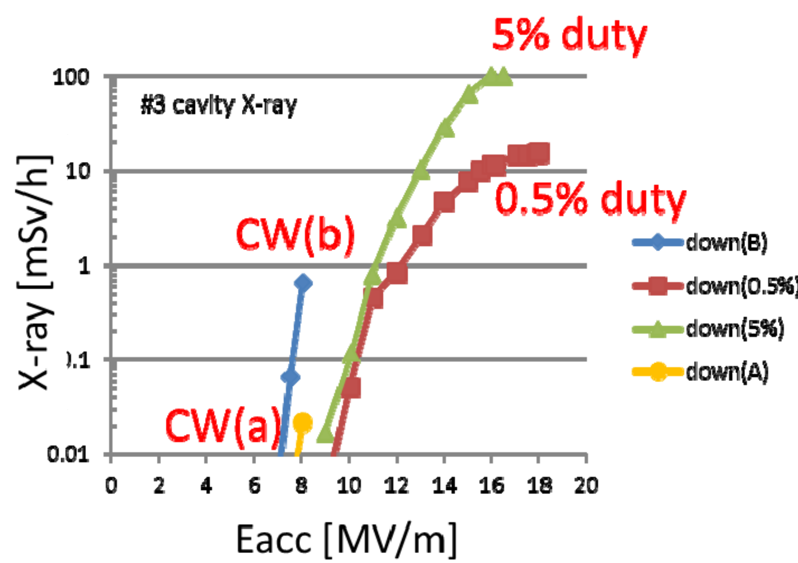
1: CW(b) ; before conditioning

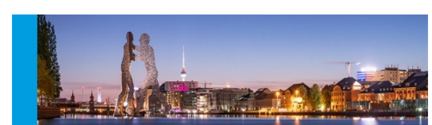
2: 0.5% duty ; pulsed conditioning

3: 5% duty ; pulsed conditioning

4: CW(a) ; after conditioning

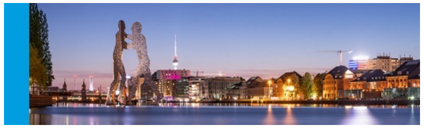






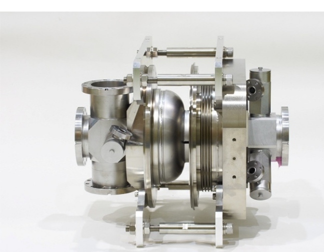
OUTLINE

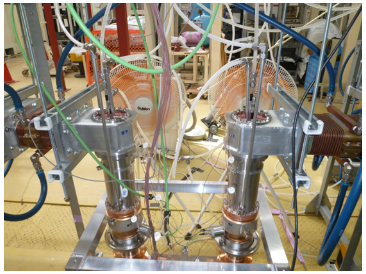
1. Introduction of cERL Injector Cryomodule
2. Long Term Operational Experience
3. Degradation of Cavity Performance
4. Performance Recovery by Pulsed Processing
5. Future Prospect and Summary

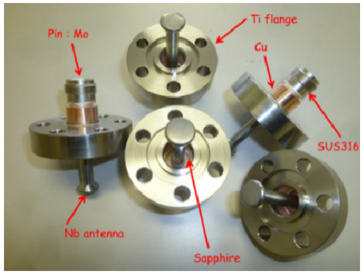


Future Prospect

Components	Current status	for the next step
Cavity	○ (stable, < 7 MV/m)	Toward higher operational Eacc > 14 MV/m
Field emission (x-ray)	× → △ (pulsed conditioning)	R&D for clean assembly techniques and cure method for performance recovery
Tuner	○ (stable)	
Input coupler	○ (stable, < 10 kW)	Higher power test of >80 kW at test-stand
HOM coupler	○ (stable)	
HOM RF connector	×	RF feedthroughs with efficient cooling
Static heat load	△	Improvement for lower heat load
Dynamic heat load	△	Improvement for lower heat load
Q_{HOM}, HOM power	△	Observation at higher current > 10 mA
Beam operation	○ (stable, 1 mA)	Demonstration at higher current > 10 mA

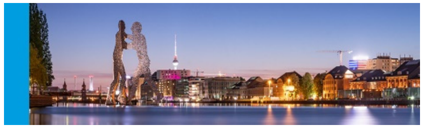




SUMMARY

- After completion of the cERL injector cryomodule in 2012, 15 thermal cycles (300K-4.2K/2K-300K) have been performed for 7 years without any severe troubles.
- Observation of x-ray radiation levels around the injector cryomodule showed gradual increases during long term beam operation. The cavity performances were seriously degraded due to heavy field emission during beam operation at 5 MeV in 2015.
- The degraded cavity performances were successfully recovered by high power pulsed RF conditioning with duty cycles of 0.5% and 5% in 2016-2017.
- Almost no trip during the present beam operation has been observed, and very stable beam operation has been continued in 2018-2019.



Thank you for your attention.