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Recent Progress and Operational Status of the Compact ERL at KEK

Shogo Sakanaka (KEK), cERL team (see next page)

IPAC'15, Richmond, VA, USA, May 3-8, 2015.

Authors

High Energy Accelerator Research Organization (KEK)
M. Adachi, S. Adachi, T. Akagi, M. Akemoto, D. Arakawa, S. Araki, S. Asaoka, K. Enami,K. Endo, S. Fukuda, T. Furuya, K. Haga, K. Hara, K. Harada, T. Honda, Y. Honda, H. Honma, T. Honma, K. Hosoyama, K. Hozumi, A. Ishii, X. Jin, E. Kako, Y. Kamiya, H. Katagiri, H. Kawata, Y. Kobayashi, Y. Kojima, Y. Kondou, A. Kosuge, T. Kume, T. Matsumoto, H. Matsumura, H. Matsushita, S. Michizono, T. Miura,T. Miyajima, H. Miyauchi, S. Nagahashi, H. Nakai, H. Nakajima, N. Nakamura, K. Nakanishi, K. Nakao, K. Nigorikawa, T. Nogami, S. Noguchi, S. Nozawa, T. Obina, T. Ozaki, F. Qiu, H. Sagehashi, H. Sakai, S. Sakanaka,S. Sasaki, K. Satoh, M. Satoh, T. Shidara, M. Shimada, K. Shinoe, T. Shioya, T. Shishido,M. Tadano, T. Tahara, T. Takahashi, R. Takai, H. Takaki, O. Tanaka, T. Takenaka, Y. Tanimoto, N. Terunuma, M. Tobiyama, K. Tsuchiya,T. Uchiyama, A. Ueda, K. Umemori, J. Urakawa, K. Watanabe, M. Yamamoto, Y. Yamamoto, Y. Yano, M. Yoshida

Japan Atomic Energy Agency (JAEA)
R. Hajima, S. Matsuba, M. Mori, R. Nagai, N. Nishimori, M. Sawamura, T. Shizuma

Hiroshima University
M. Kuriki, Y. Seimiya [on leave]

The Graduate University for Advanced Studies (Sokendai)
E. Cenni [on leave]

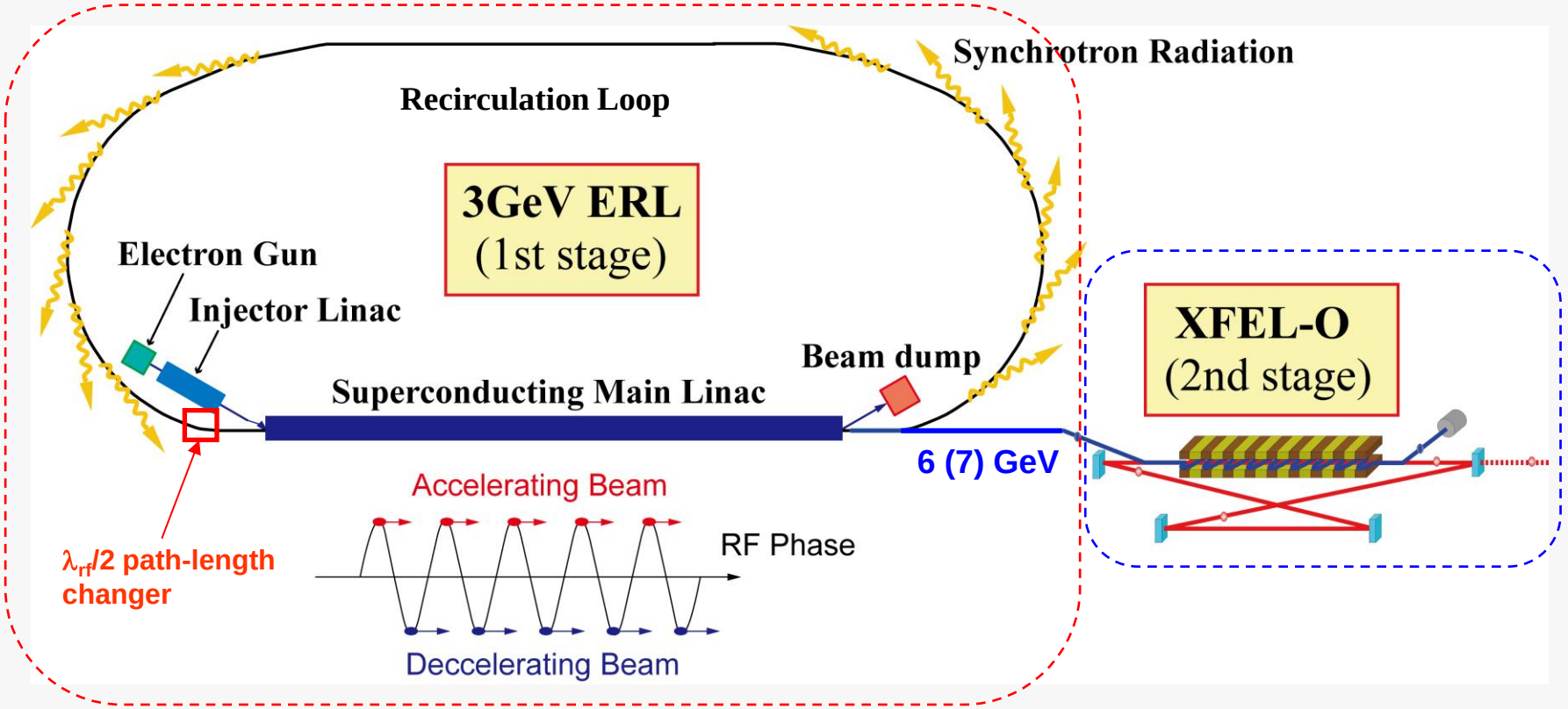
Future Plan: ERL Light Source Project at KEK

Staged plan:

① 3-GeV ERL as synchrotron light source

② 6-7 GeV XFEL Oscillator (XFEL-O)

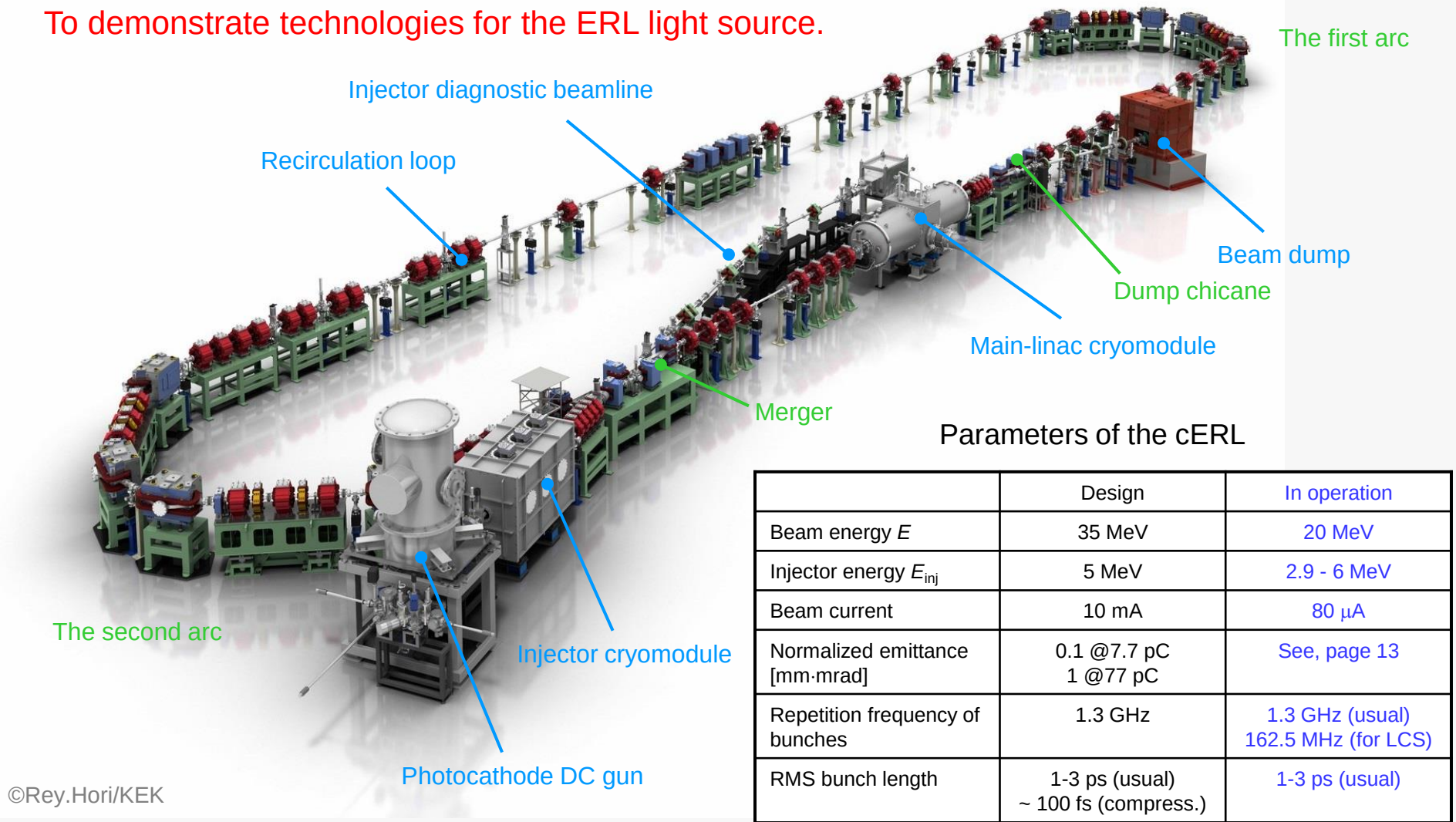
RF frequency: 1.3 GHz
Beam current : 10-100 mA
Bunch charge: 7.7-77 pC
Normalized emittance: 0.1-1 mm·mrad



[1] "Energy Recovery Linac Conceptual Design Report", KEK Report 2012-4 (Oct. 2012); http://ccdb5fs.kek.jp/tiff/2012/1224/1224004.pdf

The Compact ERL (cERL)

To demonstrate technologies for the ERL light source.

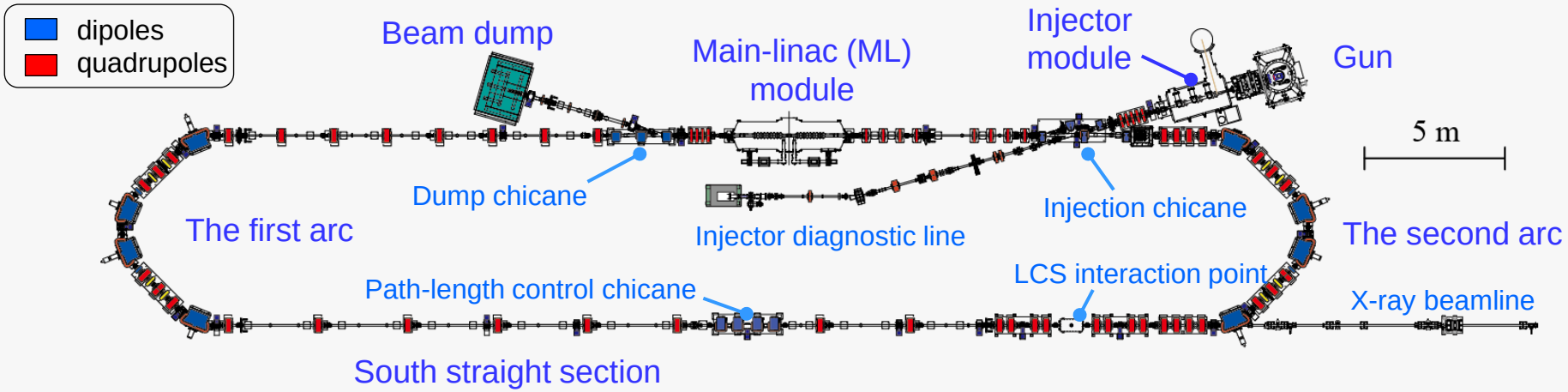


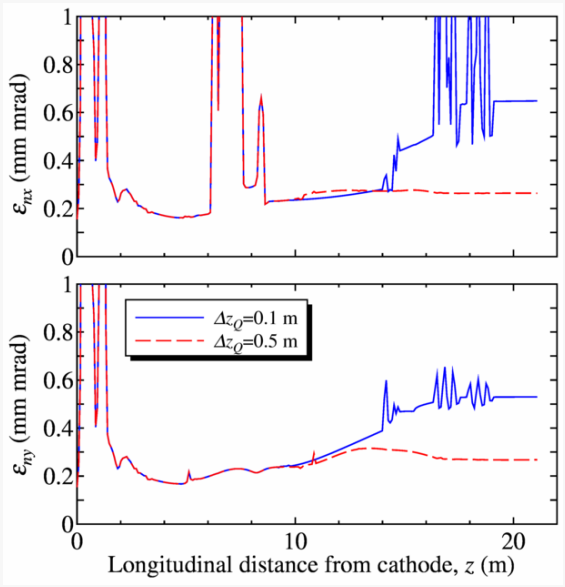
Circumference: ~ 90 m

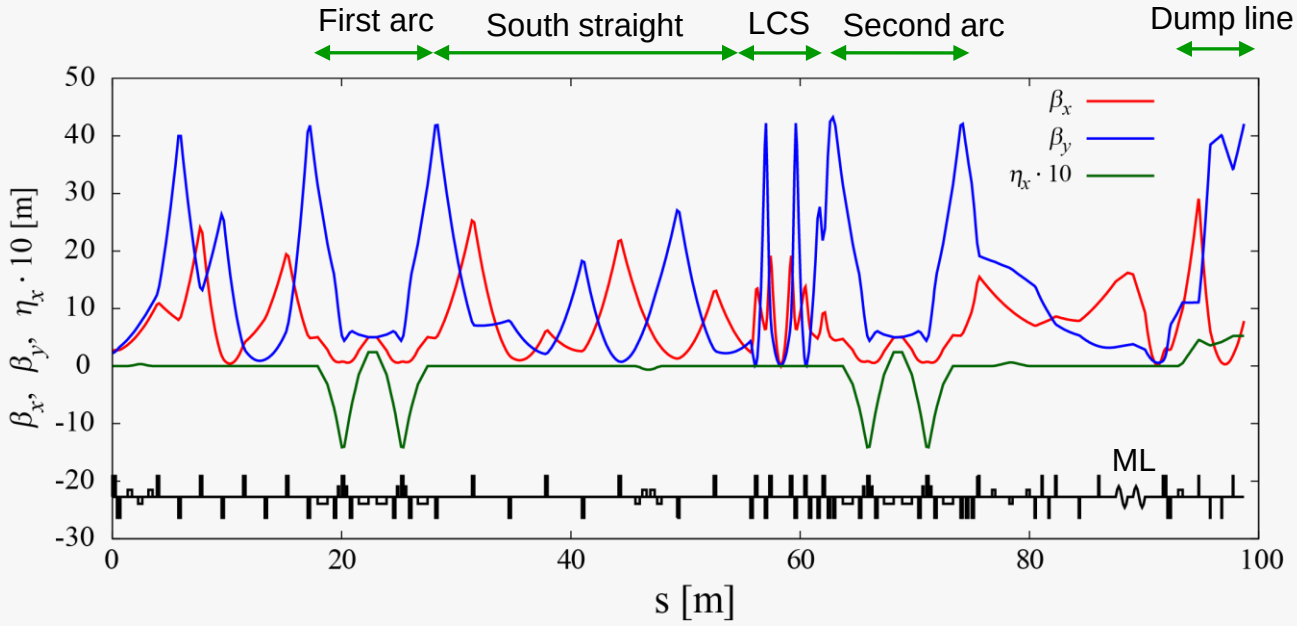
Parameters of the cERL

	Design	In operation
Beam energy E	35 MeV	20 MeV
Injector energy E_{inj}	5 MeV	2.9 - 6 MeV
Beam current	10 mA	80 μA
Normalized emittance [mm·mrad]	0.1 @7.7 pC 1 @77 pC	See, page 13
Repetition frequency of bunches	1.3 GHz	1.3 GHz (usual) 162.5 MHz (for LCS)
RMS bunch length	1-3 ps (usual) ~ 100 fs (compress.)	1-3 ps (usual)
E_{acc} in main linac	15 MV/m	8.2 MV/m
Gun high voltage	500 kV	390 kV
Max. heat load at 2K	80 W	100 - 80 W

Beam Optics of cERL





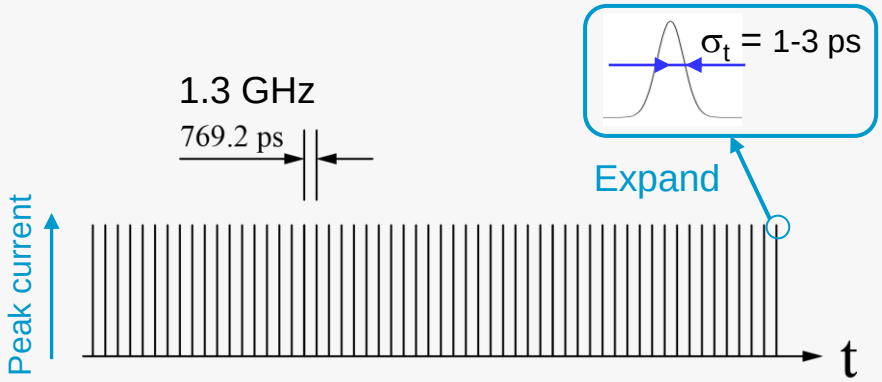


Injector (gun → exit of main linac).
Using GPT.

Recirculation loop (exit of main linac → beam dump).
Optics for LCS experiment is shown. Using elegant.

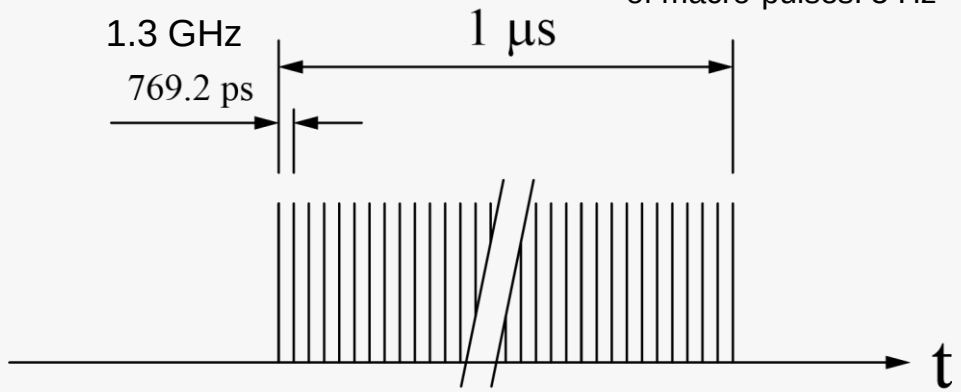
Time Structure of Beams

CW beam (for high currents)



Burst beam (for beam tuning)

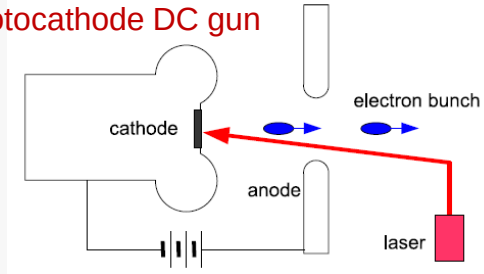
Typical repetition rate of macro-pulses: 5 Hz



Bunch charge: 7.7 pC → average current: 10 mA

Initial conditions are determined by the gun-drive laser.

Photocathode DC gun



Construction and Commissioning

2008	2009	2010	2011	2012	2013	2014	2015

Refurbishment of building

Clearing radioactive materials

Construction of radiation shielding

Construction of injector

Commissioning of injector

Construction of recirculation loop

Commissioning of cERL (with loop)

Construction of LCS system

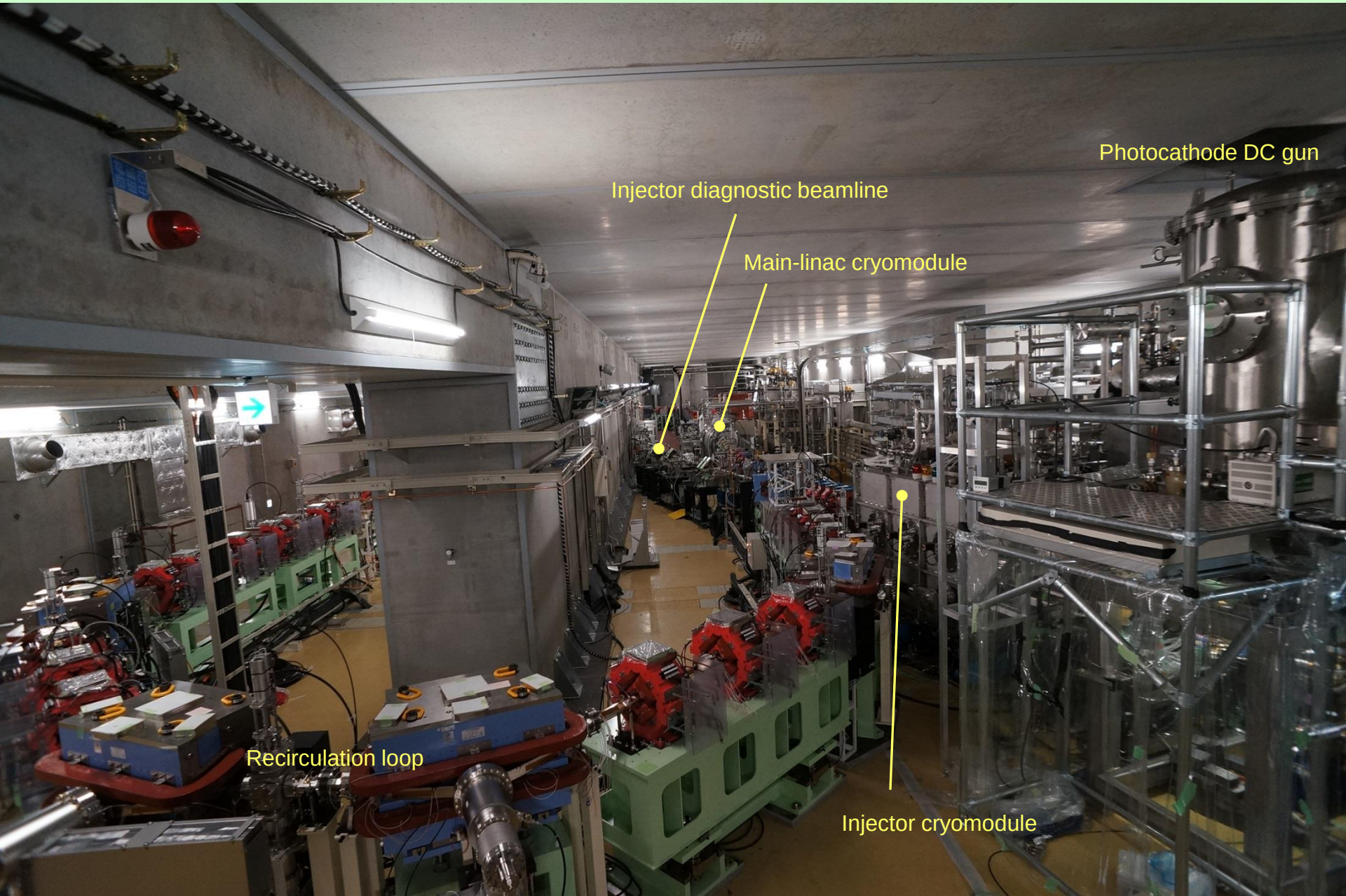
Commissioning of LCS system

Construction

Commissioning/Operation

May, 2015

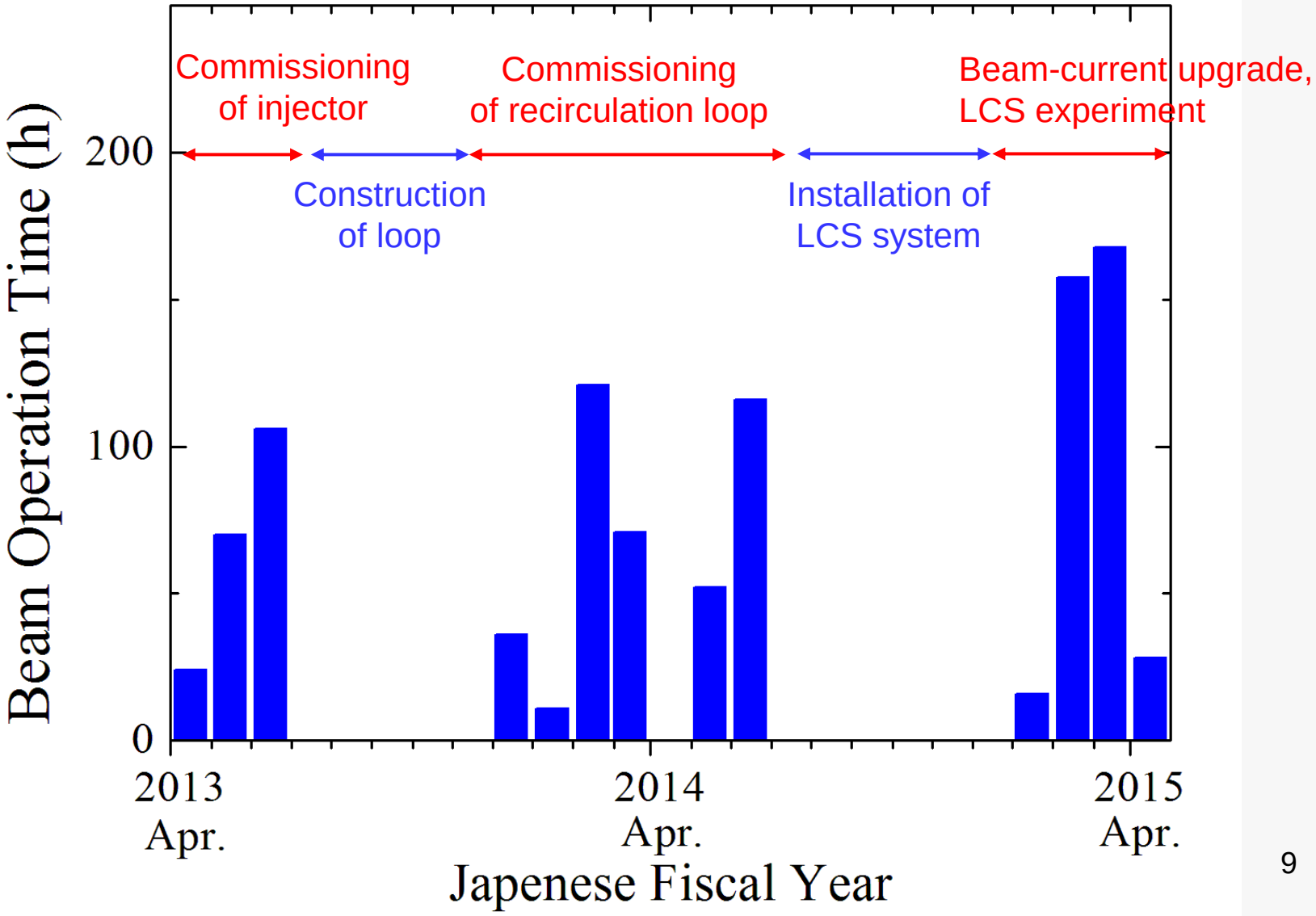
Picture of the cERL



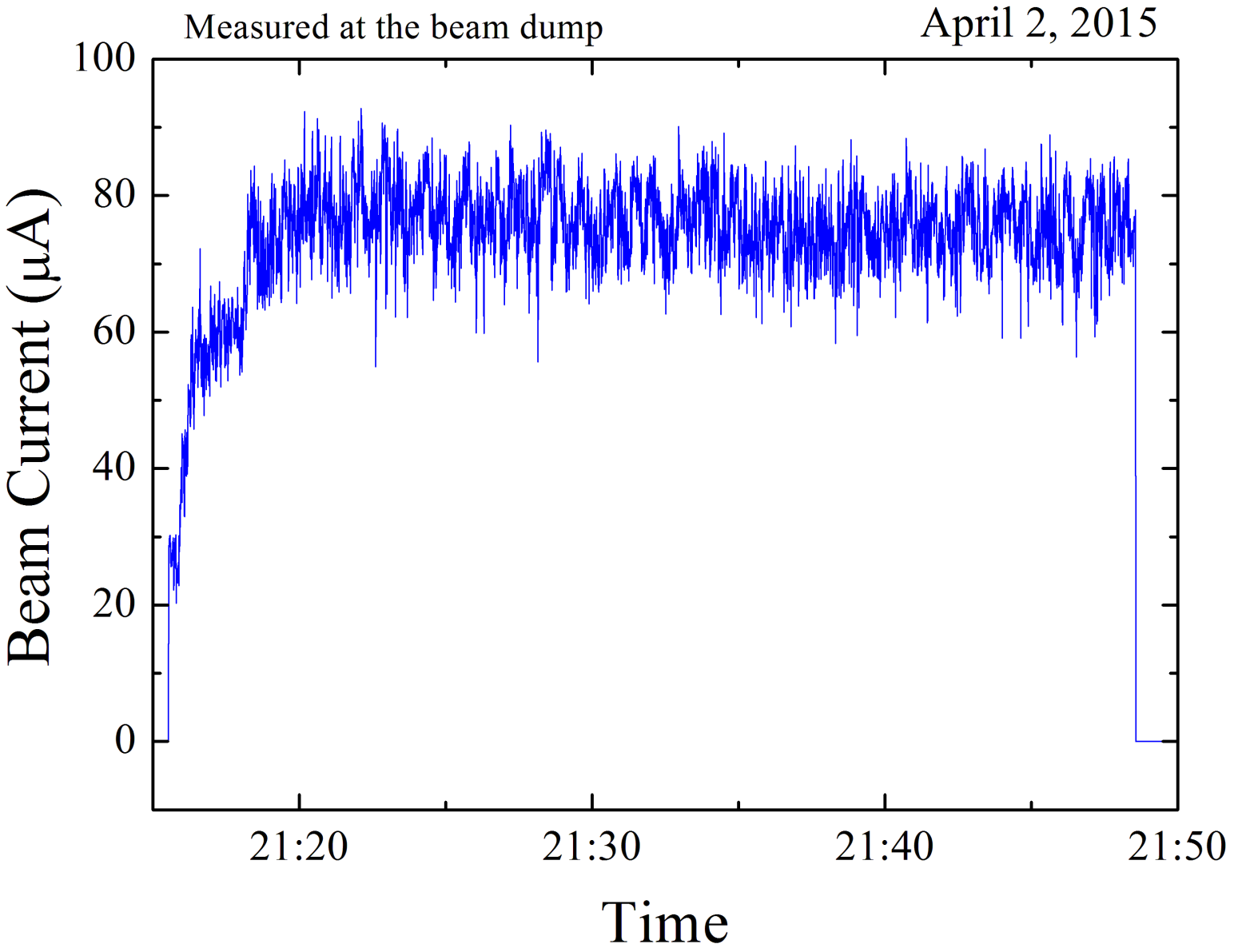
Beam Operation Time

The time while the beam was ON.

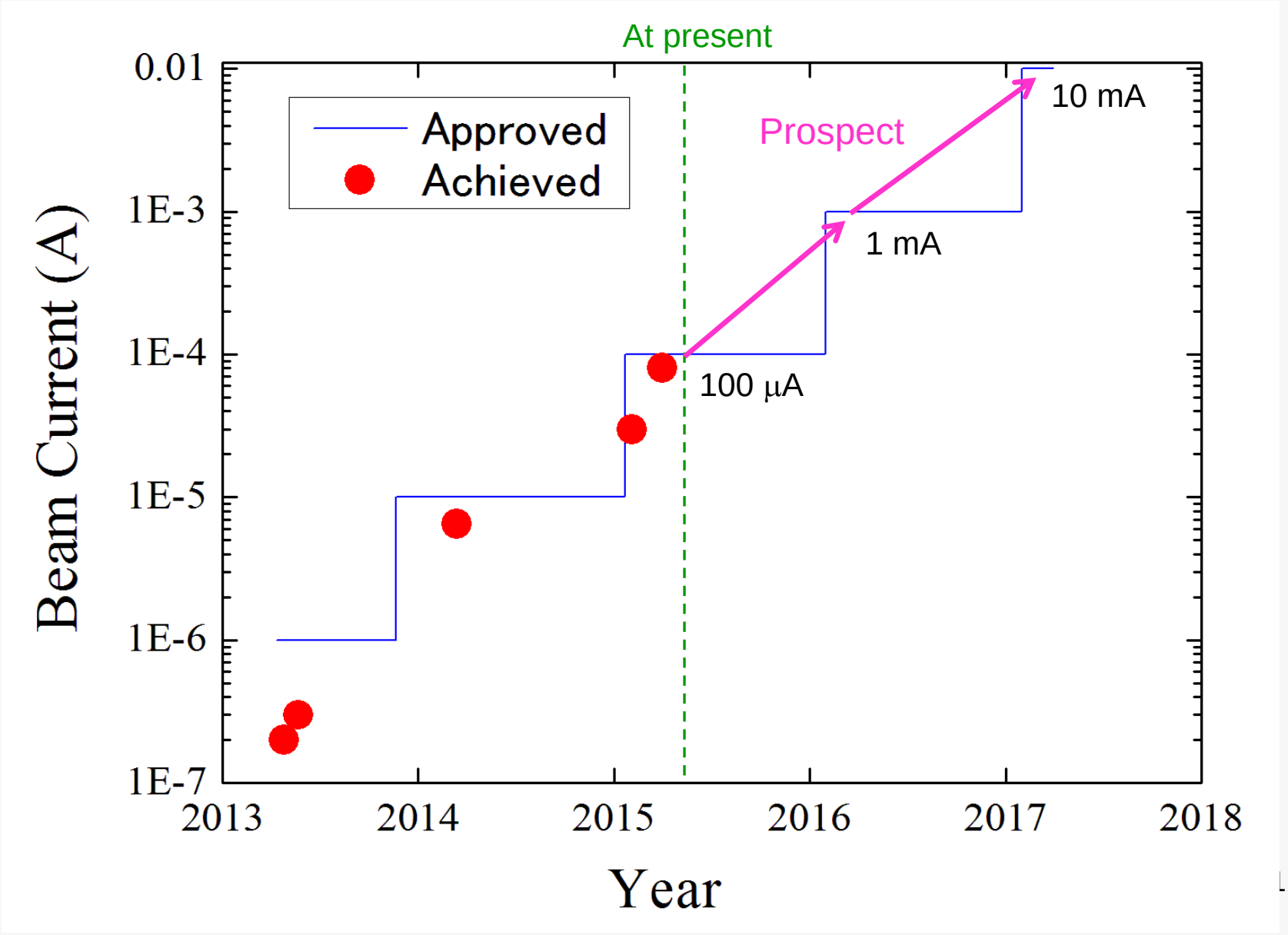
Japanese fiscal year: April - March
LCS: Laser Compton Scattering



Beam Current of 80 μA (CW) was Recirculated



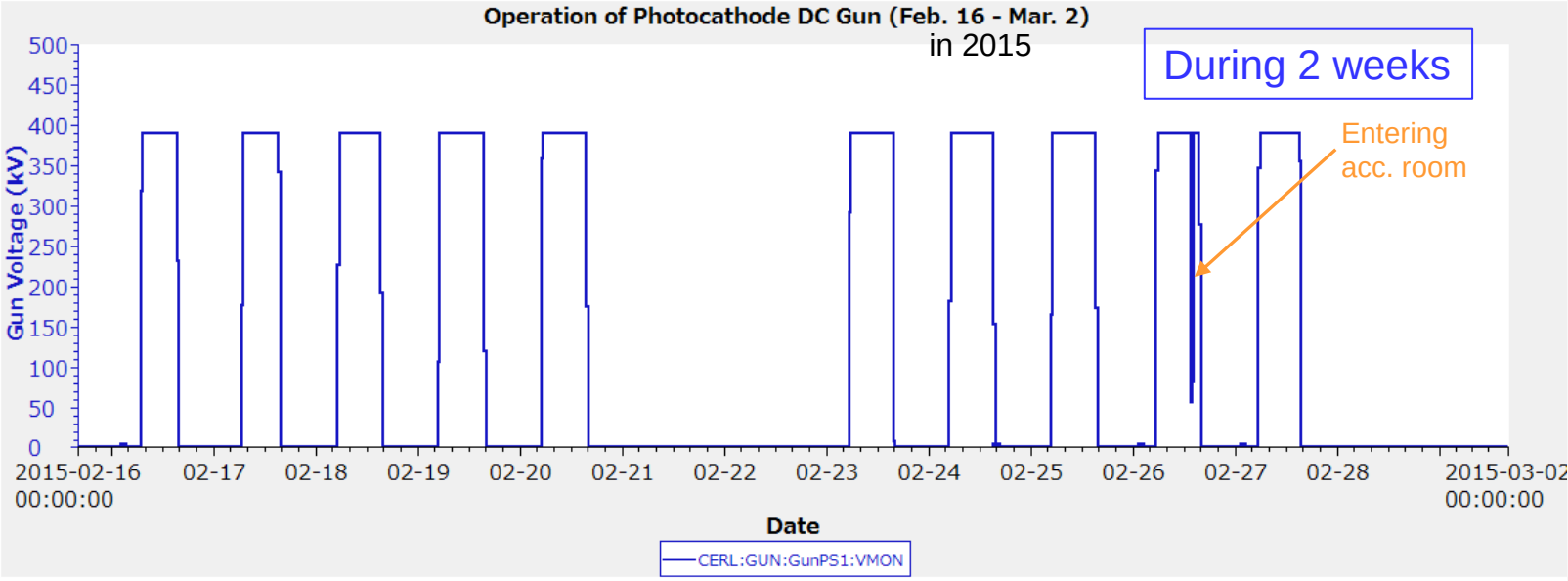
Beam Currents: Achievement and Prospect



Gun and SC Cavities worked very stably

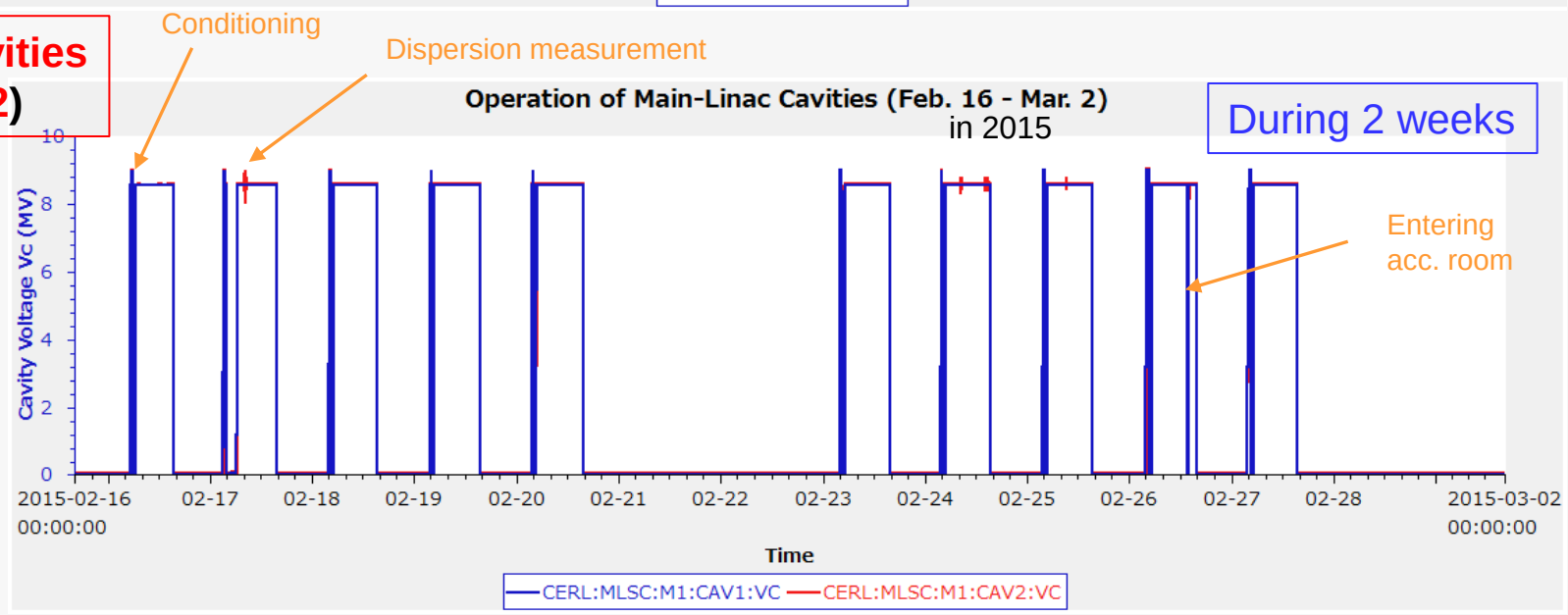
Gun voltage

0 - 500 kV



Main-linac Cavities
(ML-1, ML-2)

Accelerating voltage/cavity (MV)



Beam Emittance (under study)

See poster:
T. Miyajima et al., TUPWA067

At an injector energy of E = 6.1 MeV Normalized emittance: ε_n [mm·mrad] = $\beta\gamma\varepsilon$

Bunch charge	At injector
0.02 pC	0.17 mm·mrad
0.77 pC	≈ 0.3 mm·mrad
7.7 pC	0.5 - 0.8 mm·mrad

Measurement location
(slit-scan method)

Measurement location
(Q-scan method)

At an injector energy of E = 2.9 MeV ($\varepsilon_{n,x}$ / $\varepsilon_{n,y}$)

Bunch charge	At injector (E=2.9 MeV)	At recirculation loop (E=19.9 MeV)
0.02 pC	-	0.14 / 0.14
0.5 pC	-	0.32 / 0.28
7.7 pC	2.5 / 2.9	5.8 / 4.6

For LCS experiment

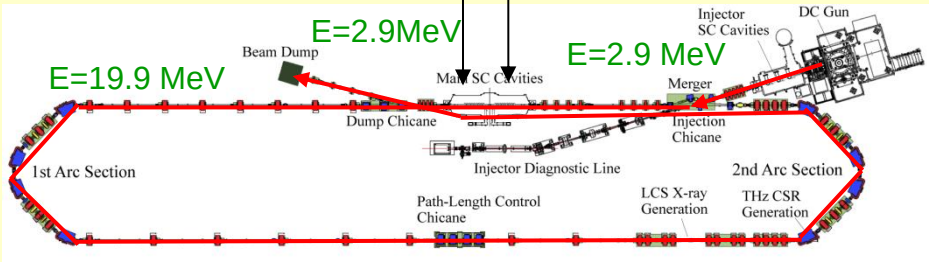
Very preliminary

Study to reduce the beam emittance is in progress.

Demonstration of Energy Recovery (I_0 = 30 μA)

ERL operation

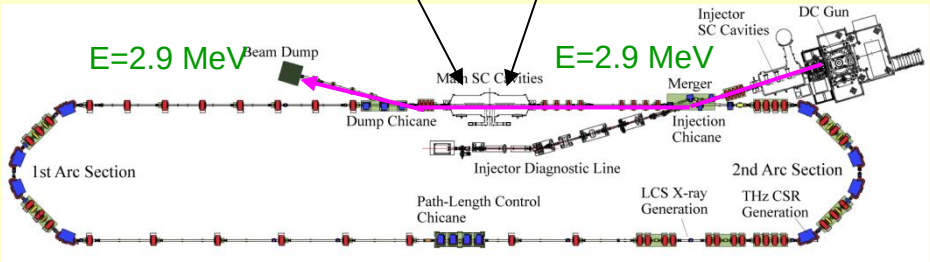
Cavities 1 and 2: acceleration (1st pass) and deceleration (2st pass)



Non-ERL operation

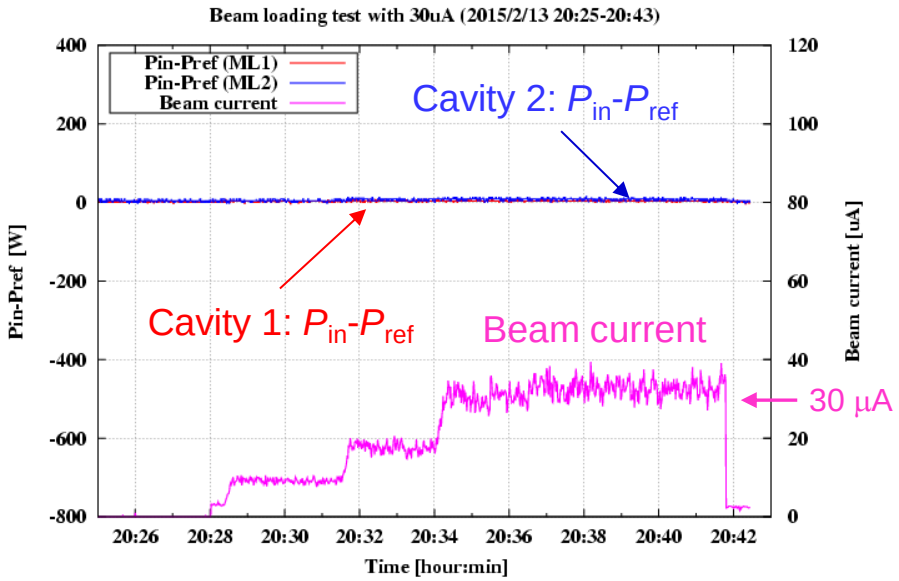
Cavity 2: deceleration (Vc=8.57 MV/cavity)

Cavity 1: acceleration (Vc=8.57 MV/cavity)



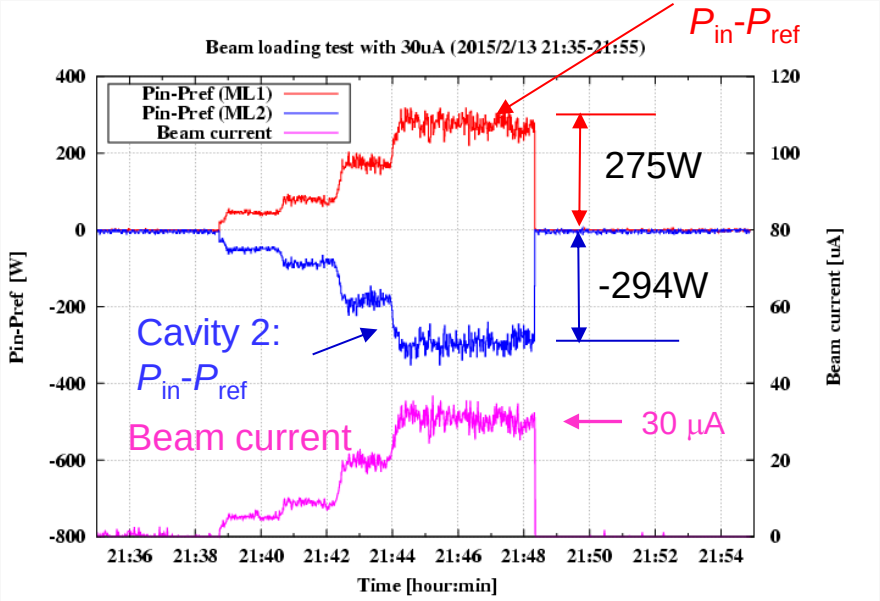
No beam loading

Energy recovery: 100-98.6%
(within accuracy of the measurement)



Beam loading (+ and -)

Cavity 1: P_{in}-P_{ref}



(Power lost in cavity) = (P_{in} : input power to cavity) - (P_{ref} : reflected power from cavity)

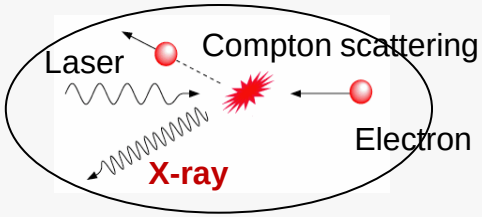
Laser Compton Scattering (LCS)

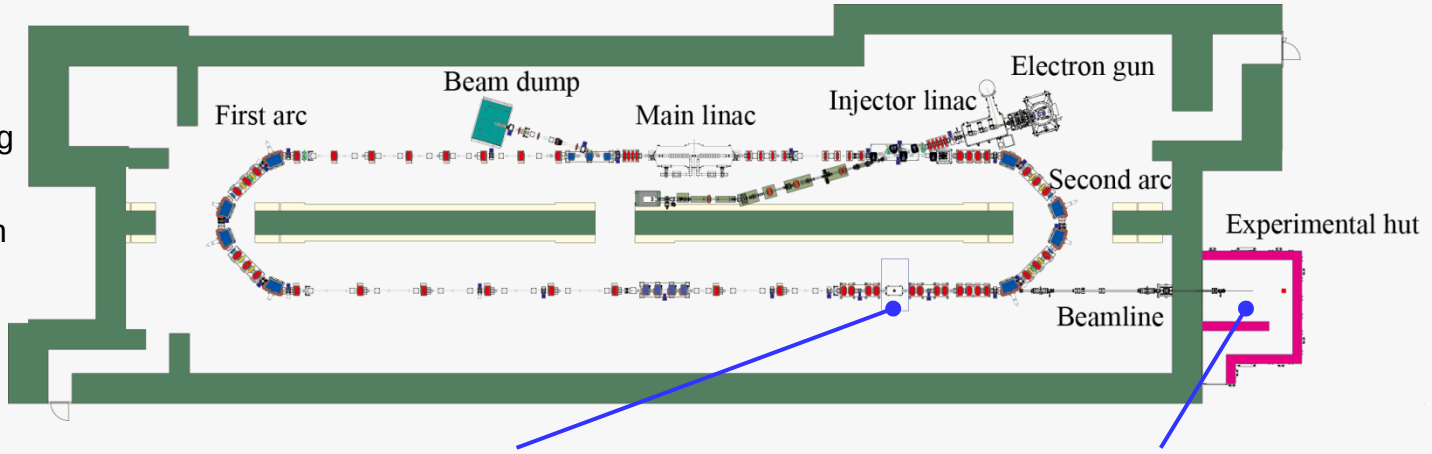
IPAC'15

R. Nagai et al., Demonstration of High-flux Photon Generation from an ERL-based Laser Compton Photon Source, TUPJE002

A. Kosuge et al., Development of a High Average Power Laser for High Brightness X-ray Source and Imaging at cERL, TUPWA066

Work is supported by:
A government (MEXT) subsidy for strengthening nuclear security (R. Hajima, JAEA), and
Photon and Quantum Basic Research Coordinated Development Program from the MEXT (N. Terunuma, KEK)

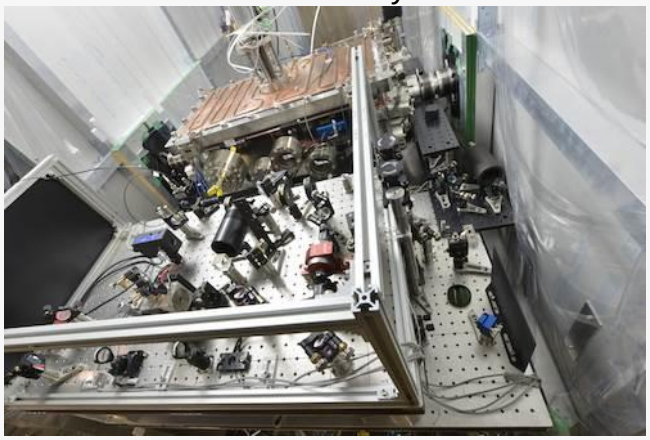




The principal parameters

Electron beams:	
Energy	20 MeV
Repetition rate	162.5 MHz
Max. current	80 μA
Laser:	
Wavelength	1064 nm
Repetition rate	162.5 MHz
Produced X-ray	
Photon energy	6.9 keV

Laser enhancement cavity and 45W laser



Experimental hut

Beam Optics for the LCS

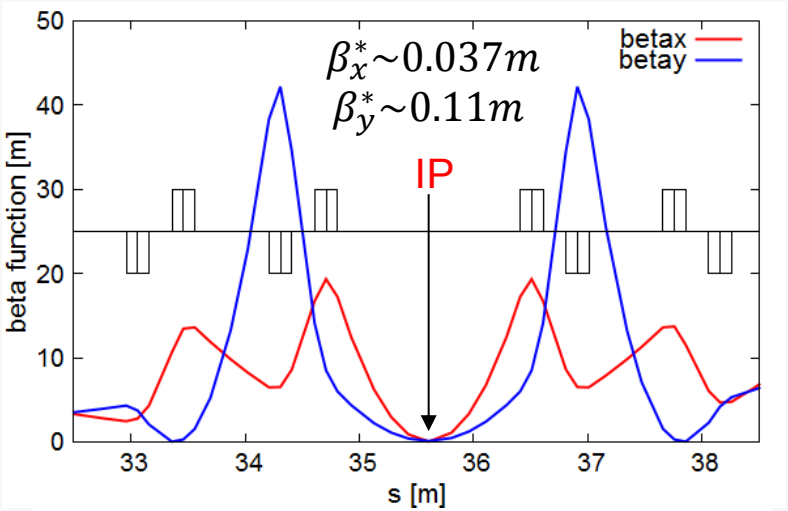
- Low-beta insertion for small beam sizes at IP
- Transport beams to the dump with small beam losses

Beam optics was established

IP: interaction point

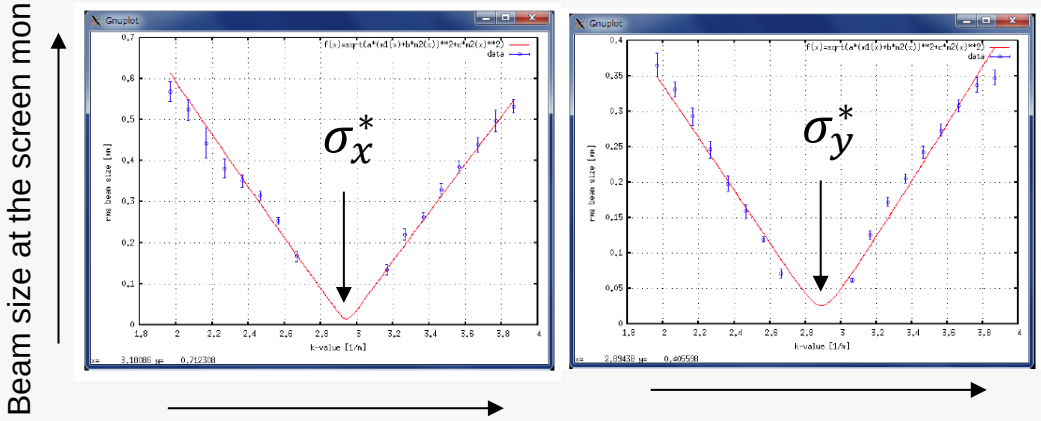
Design optics (example: “70% middle” optics)

σ_x^* = 21 μm, σ_y^* = 33 μm at IP



Beam sizes at IP were estimated from Q-scan data

σ_x^* ~ 13 μm, σ_y^* ~ 25 μm (example)



σ_x^*, σ_y^* < (resolution of the screen monitor)

Bunch charge: 0.5 pC/bunch,
Normalized emittances : $(\varepsilon_{nx},\varepsilon_{ny})$=(0.47, 0.39) mm·mrad

X-ray was Successfully Produced by LCS

See posters for detail:
R. Nagai et al., TUPJE002
A. Kosuge et al., TUPWA066

Parameters of electron beams:

Energy [MeV]	20
Bunch charge [pC]	0.36
Bunch length [ps, rms]	2
Spot size [μm, rms]	30
Emittance [mm mrad, rms]	0.4
Repetition Rate [MHz]	162.5
Beam current [μA]	58

Parameters of laser (enhanced by cavity):

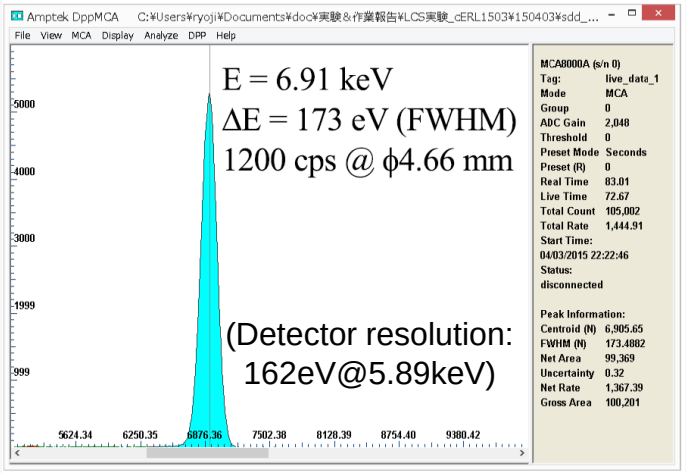
Center wavelength [nm]	1064
Pulse energy [μJ]	64
Pulse length [ps, rms]	5.65
Spot size [μm, rms]	30
Collision angle [deg]	18
Repetition rate [MHz]	162.5

Results:

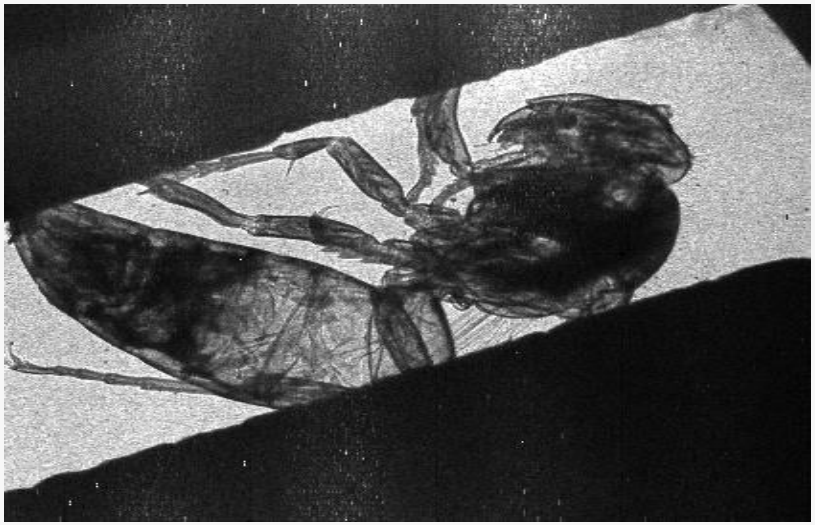
Photon energy = 6.9 keV
Detector count rate = 1200 cps @ϕ4.66mm
Source flux = 4.3 x 10^7 ph/s (*)

(*) calculated by CAIN/EGS simulations

Demonstration of high-quality and stable electron beam.



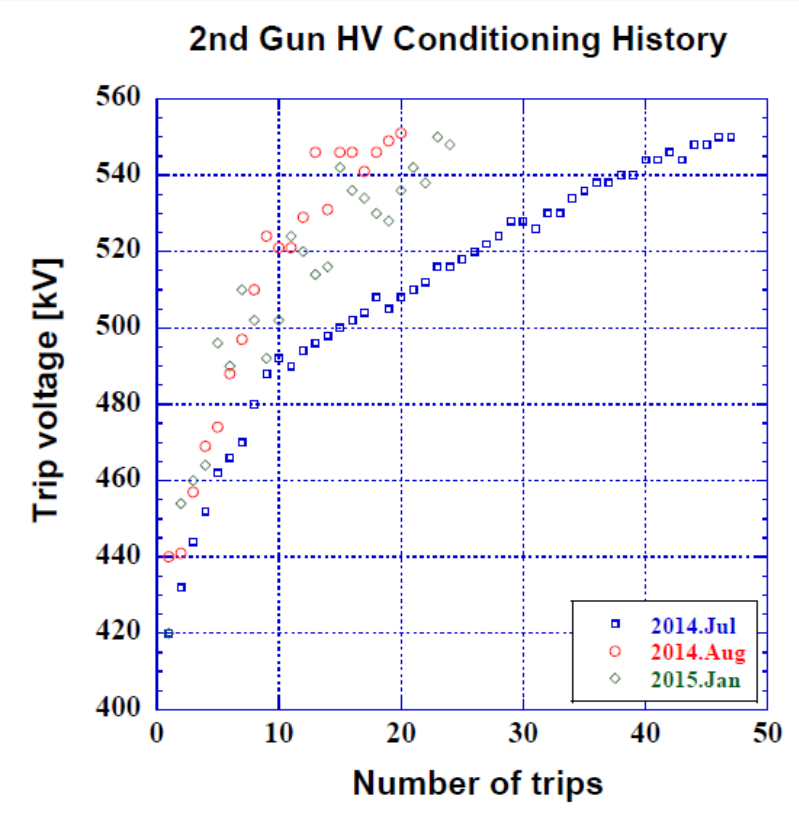
Measured spectrum of produced X-ray

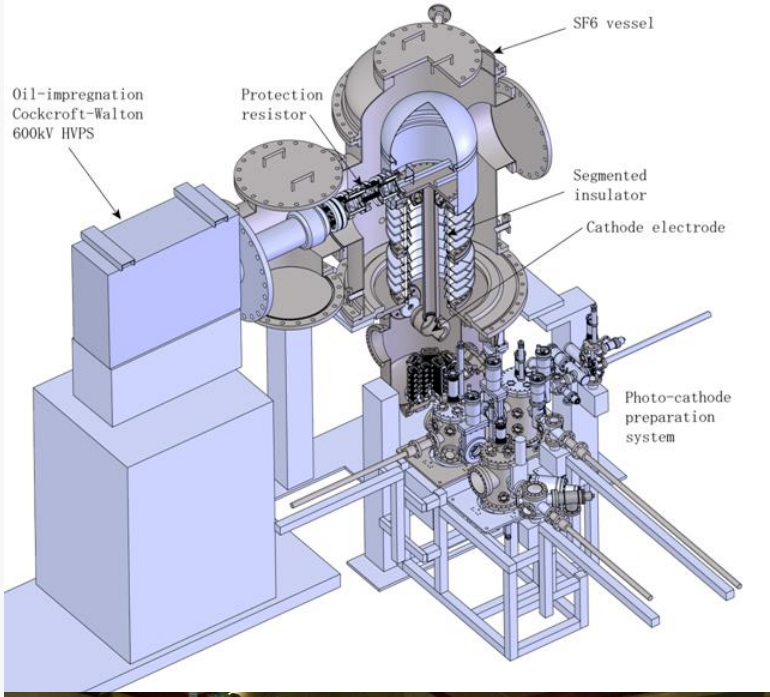


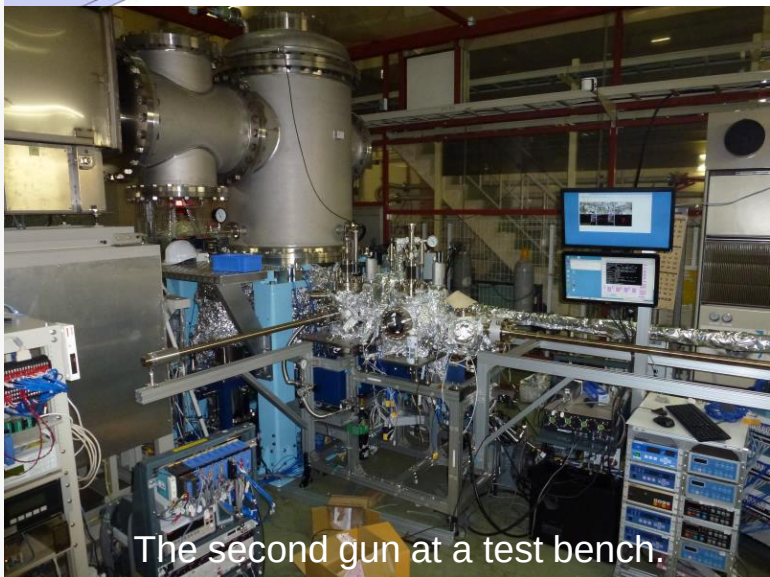
An X-ray image of a hornet which was taken using LCS-produced X-ray. Detector: HyPix-3000 from RIGAKU. Detector was apart from the sample by approx. 2.5 m.

The Second Photocathode DC Gun

M. Yamamoto, to be presented at ERL2015.







The second gun at a test bench.

- Vacuum pressure: 4×10^{-10} Pa
- Conditioned up to 550 kV
- 500 kV was hold for 50 h without any trips
- Ready for beam-extraction test

Summary and Outlook

- The Compact ERL was commissioned and is in stable operation.
- Learned many lessons from the commissioning.
- The photocathode DC gun and both (injector and ML) SC cavities are operating very stably.
- Achieved beam current of 80 μA.
- X-ray of 7 keV was successfully produced from laser Compton scattering.
- We have established many important technologies for the ERL light source. We continue to conduct R&D effort on remaining issues such as:
  - Improved cavity-assembly technique for higher accelerating gradient
  - Mass-production technique for main-linac cavities

Subjects in FY2015

- Lower emittance at high buhch-charges ($q_b \geq 7.7$ pC)
- Beam current: 1 mA
- Bunch compression ($\sigma_t \sim 100$ fs)
- Higher X-ray flux in LCS experiment

Acknowledgment

We would like to thank the people of ERL community, especially, the members of the Jefferson Lab. and the Cornell University, for useful information and discussions.