Update on the KEK ERL test facility (cERL)

Hiroshi KAWATA (KEK)

on behalf of cERL Develepment Grp.

Contents

- History of ERL project in KEK
- Compact ERL
- Results of the commissioning
- Updated results
- Summary

cERL Team

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, R. Kato, H. Kawata, Y. Kobayashi, Y. Kojima, Y. Kondou, T. Konomi, A. Kosuge, T. Kubo, 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 [on leave], S. Nozawa, T. Obina, T. Ozaki, F. Qiu,H. Sagehashi, H. Sakai, S. Sakanaka,S. Sasaki, K. Satoh, M. Satoh, Y. Seimiya, 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, N. Yamamoto, Y. Yamamoto, Y. Yano, M. Yoshida

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

Hiroshima University
M. Kuriki

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

3

History of ERL project in KEK (1)

Fiscal Year

2005 Institute of Materials Structure Science in KEK decided to start the R&D of 5GeV ERL light source as a future light source to replace the Photon Factory.
http://pfwww.kek.jp/outline/pf_future/jikikogen.pdf (Japanese)

2006 Establishment of ERL Project Office in KEK

2007 The CDR on Compact ERL (cERL) was published

2008 The construction of the infra structure and equipment; such as update of the building, cryogenic cooling systems, RF sources and electric power supply systems started.

2009 The above construction was completed.

2010 The construction of the accelerator components for cERL started according to the report of the review committee.
http://pfwww.kek.jp/ERLoffice/suishin/hyoka/ERL_hyouka_Report_100427_v2.pdf (Japanese)

History of ERL project (2)

2011 ERL2011 was organized. Radiation shielding was completed.

2012 Cryo-mojules of injector and main linac, and DC electron gun, which was developed in the collaboration JAEA, were installed at the site. The CDR on 3GeV-ERL was published and International Advisory Committee for 3GeV-ERL project was organized.
http://pfwww.kek.jp/ERLoffice/erl_IAC.html

2013 The commissioning of the injector linac started from the spring. The installation of the recirculation loop components was completed between summer and fall. From the winter, commissioning of the ERL operation (recirculation loop) started. (0.01 mA)

2014 Further Commissioning of the cERL（0.1mA) and the construction of the laser Compton scattering beamline.

(Previous ERL15 presentation by Dr. S. Sakanaka)

2015 Further Commissioning of the cERL (1mA), bunch compression and high bunch charge operation (7.7pC/ bunch).

History of ERL project (3)

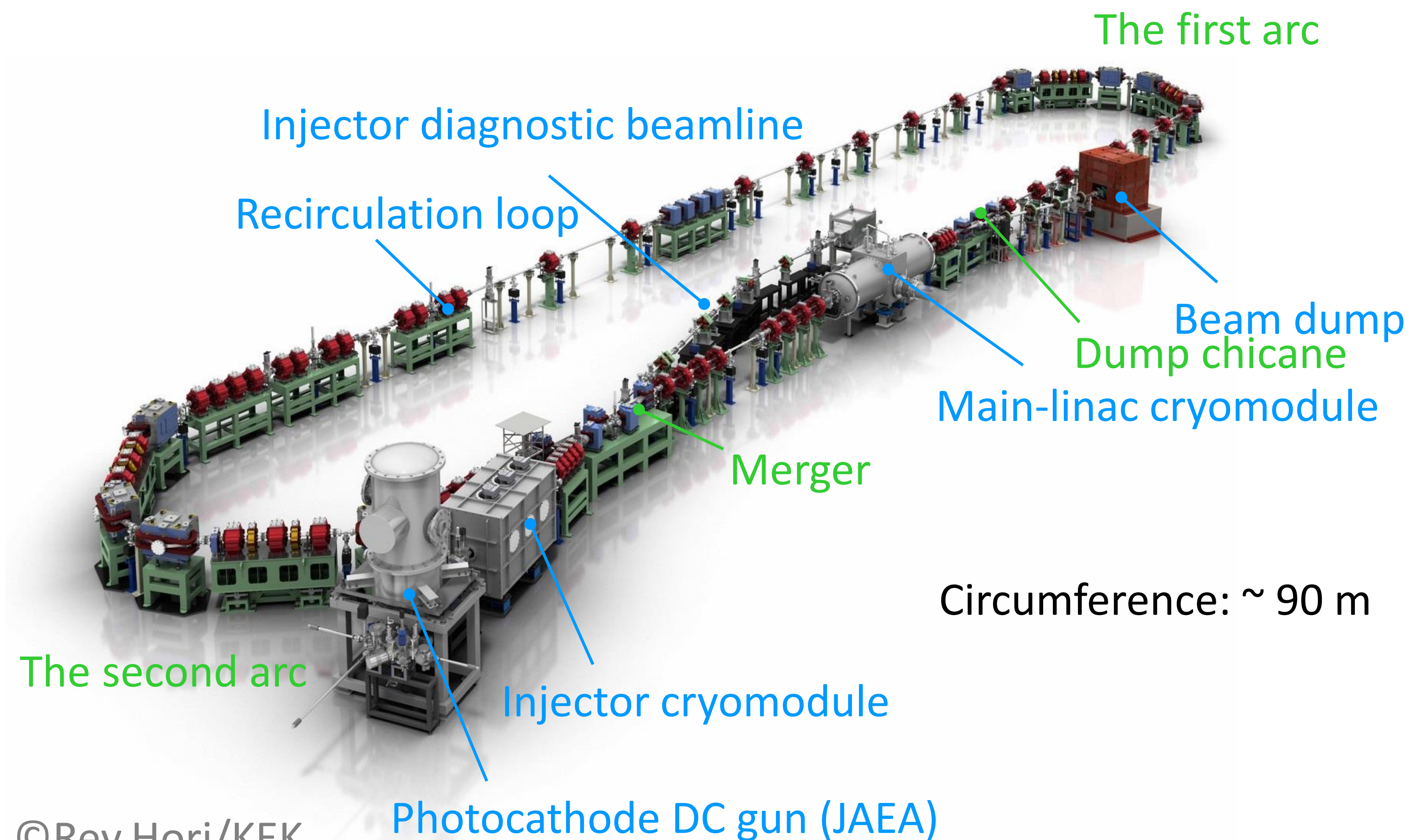
2016　The future light source was shifted to the high-performance ring accelerator, so that there is no back ground to continue the ERL R&D.　On the other hand, KEK directorates kept the importance of the R&D for industrial application based on ERL technologies*). High bunch charge test operation was approved at the end of the fiscal year 2016.

2017　ERL project Office was closed in KEK and "Utilization Promotion Team based on Superconductive Accelerator" was kept in Department of future Accelerator and detector technologies in KEK.

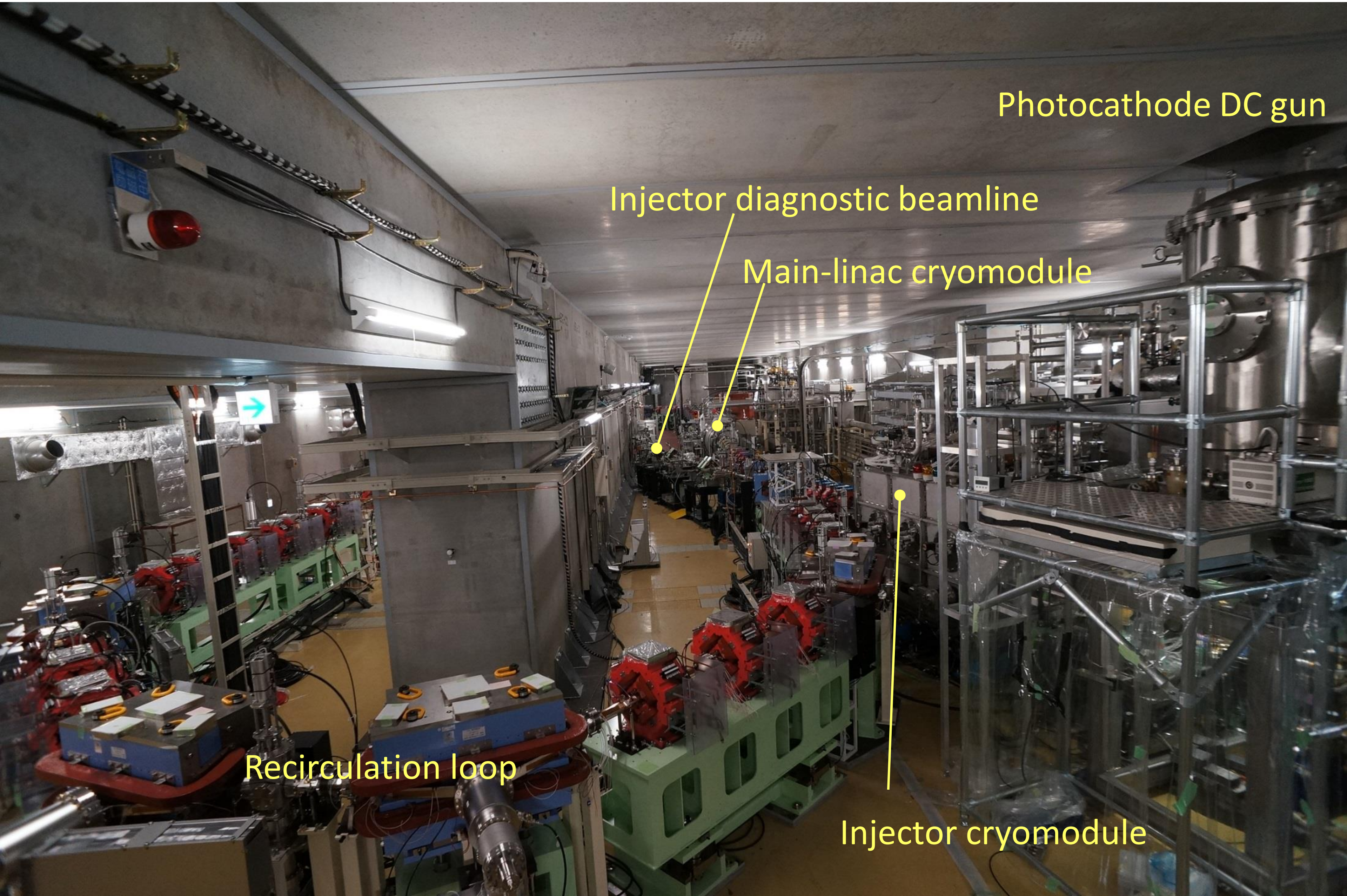
*Reference) KEK Project Implementation Plan (KEK-PIP)
http://www.kek.jp/ja/NewsRoom/Release/20160802141100/
3-2. Other research projects carried out using general funds of KEK
The following projects have up to now been conducted mainly using general funds of KEK. They will be continued on the condition that greater efforts are made to obtain external funding.
・Simulation studies with the existing supercomputer (only up to summer of 2017)
・Industrial application of ERL technology
・

The Compact ERL (cERL)

The cERL contains all important technologies.

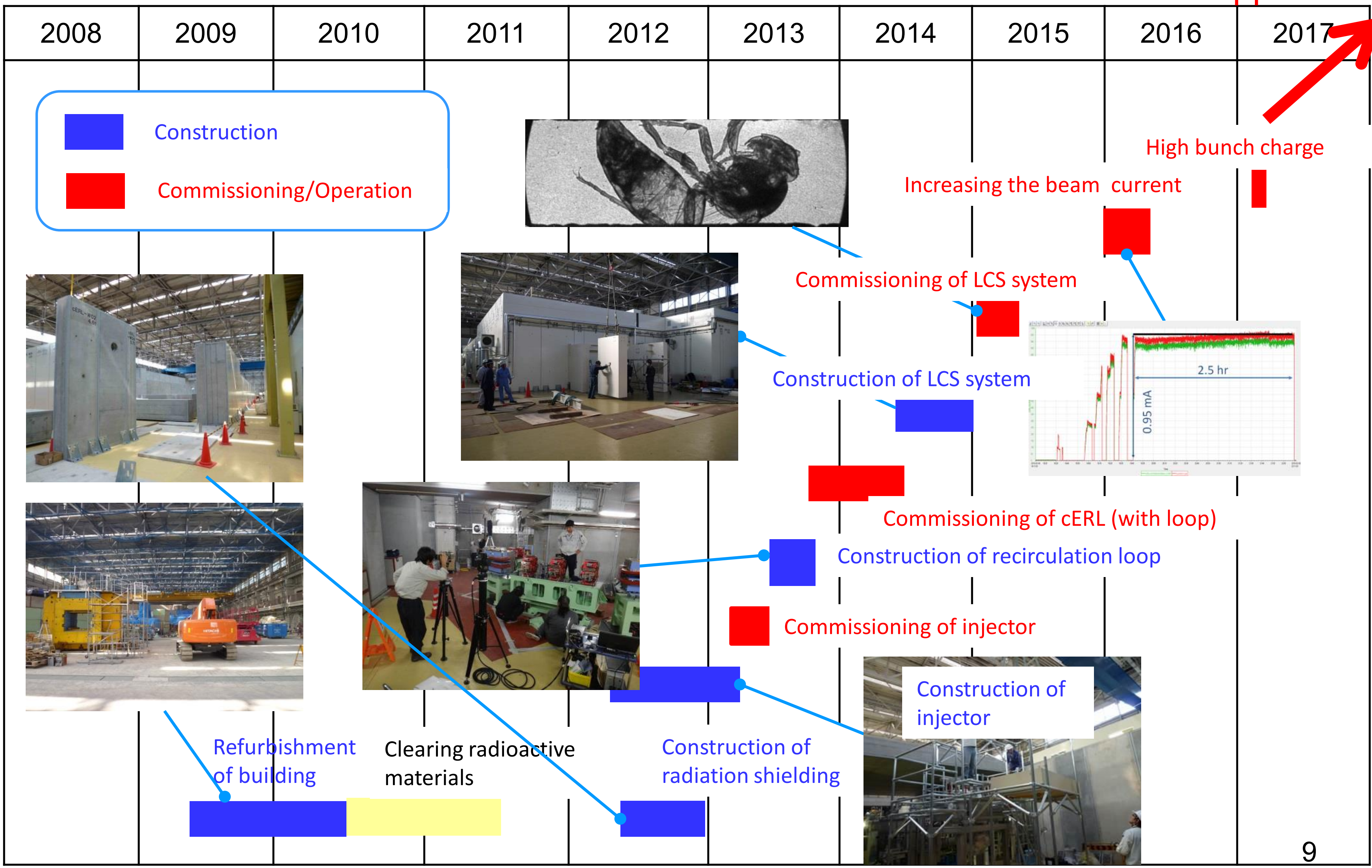


Picture of the cERL



Construction and Commissioning of cERL

R&D for Industrial application



Result of the commissioning at Injector part

(@the end of March/2017)

Parameter	Achieved performance	Target values	Remark
Beam energy T	5.6 MeV (typ.), 5.9 MeV (max.)	5 MeV (typical)	OK
DC voltage for DC gun V_{gun}	450 kV in operation (500kV achieved)	500 kV	OK
Acceleration Energy E_{acc}	7 MV/m (typ.)		OK
Normalized Emittance (Very low bunch charge)	≈ 0.07 μm·rad (@~10 fC/bunch, T=390 keV)	0.1 μm·rad	OK
Normalized Emittance (Low bunch charge)	≈ 0.17 μm·rad (@0.02 pC/bunch, T=5.6 MeV)	0.1 μm·rad	OK
Normalized Emittance (Medium bunch charge)	≈ 0.8 μm·rad (@7.7 pC/bunch, T=5.6 MeV)	≤ 1 μm·rad (at the beginning) 0.1 μm·rad (aggressive)	OK Still
Normalized Emittance (High bunch charge)	1.5~3 (@40 pC/bunch)	1 μm·rad	still
Momentum spread $(\sigma_p/p)_{rms}$	$< 10^{-3}$ (< 1 pC/bunch) $(1.5 - 2.5)\times10^{-3}$ (@7.7 pC/bunch)	$\leq 10^{-4}$ (3 GeV ERL)	Should be OK

Result of the commissioning at recirculation loop (RL)

(@the end of March/2017)

Parameter	Achieved performance	Target Value	Remark
Energy of the electron beam E	19.9 MeV	35 MeV	Still
Energy of Injector E_{inj}	2.9 MeV	5 MeV	Still
Average Current I_0	6.5 μA（steady state）、 1mA (steady state)	10 μA 10 mA	OK Should be OK
Field gradient of main linac E_{acc}	8.2 MV/m	15 MV/m	Still
Normalized Emittance at RL (Very low bunch charge）	≈ 0.13 μm·rad (@~0.05pC/bunch)	0.1 μm·rad	OK
Normalized Emittance at RL (Low bunch charge）	0.3 μm·rad (@0.5 pC/bunch)	0.1 μm·rad	Not bud
Normalized Emittance at RL (Medium bunch charge）	～ 1.0-1.6μm·rad (@7.7 pC/bunch, E=19.9 MeV)	≤ 1 μm·rad （Beginning） 0.1 μm·rad （aggressive）	Should be OK Still
Normalized Emittance at RL (High bunch charge）	2-10 μm·rad (preliminary) (@40 pC/bunch)	1 μm·rad (@77 pC/bunch)	Still we need an adjustment time
Momemtun Spread $(\sigma_p/p)_{rms}$	1.2 x 10^{-4}	≤ 10^{-4} (3 GeV ERL）	OK
Jitter of Momemtum $(\Delta p/p)_{rms}$	6 x 10^{-5}	≤ 10^{-4} (3 GeV ERL）	OK
Bunch compression (σ_t)	0.25ps @ 2pC/bunch	0.1ps	Not bad

To realize 1mA stable operation (1)

S.Sakanaka et. al.;
PASJ2016 (WEOM15)

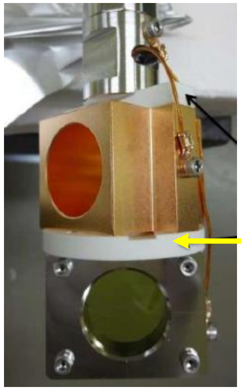
- Up grade of the accelerator components
  1. Replacement of the Al evaporated mirror for laser input to metal mirror to be antistatic.
  2. Metal shielding at the ceramic material at the Faraday-cup to be antistatic.
  3. Increasing the number of beam loss monitoring systems
  4. Additional radiation shielding

1. Replacement of the Al evaporated mirror to metal mirror.

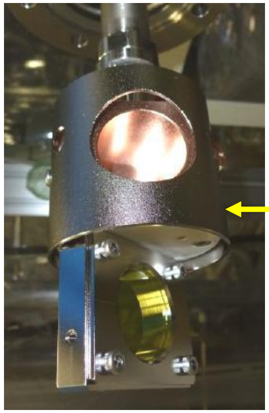
Al evaporated
Glass mirror

Metal Mirror

2. Metal shielding at the ceramic material at the Faraday-cup.



Ceramic
material



Metal
shielding

To realize 1mA stable operation (2)

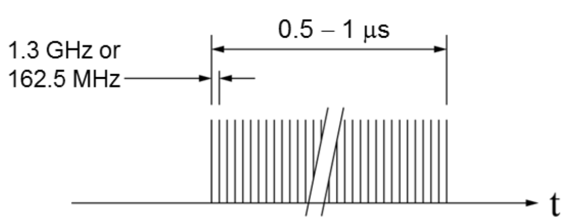
2. Beam handling system

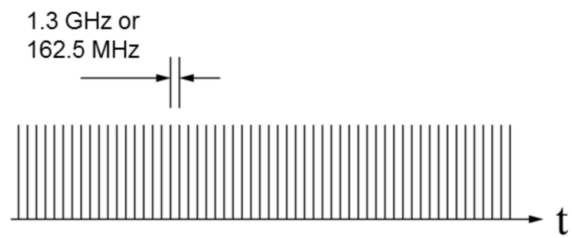
S. Sakanaka et. al.;
IPAC'16 (TUPOW038)

- Careful optics matching and orbital optimization
- Beam development with the burst-mode operation

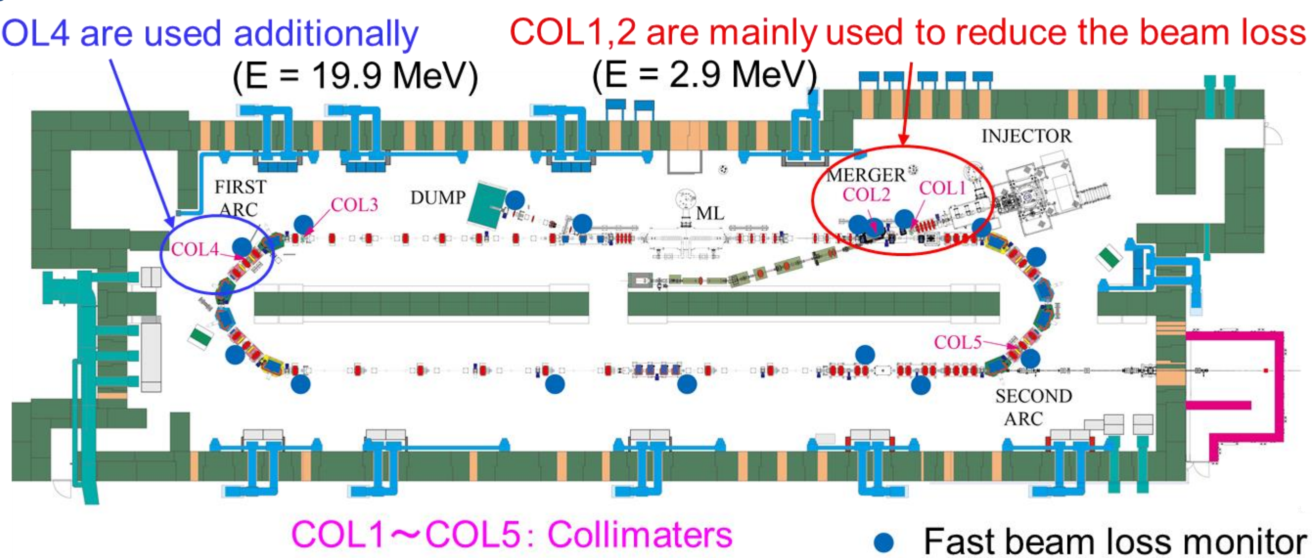
burst-mode operation → CW operation

Beam development, reduction of beam loss

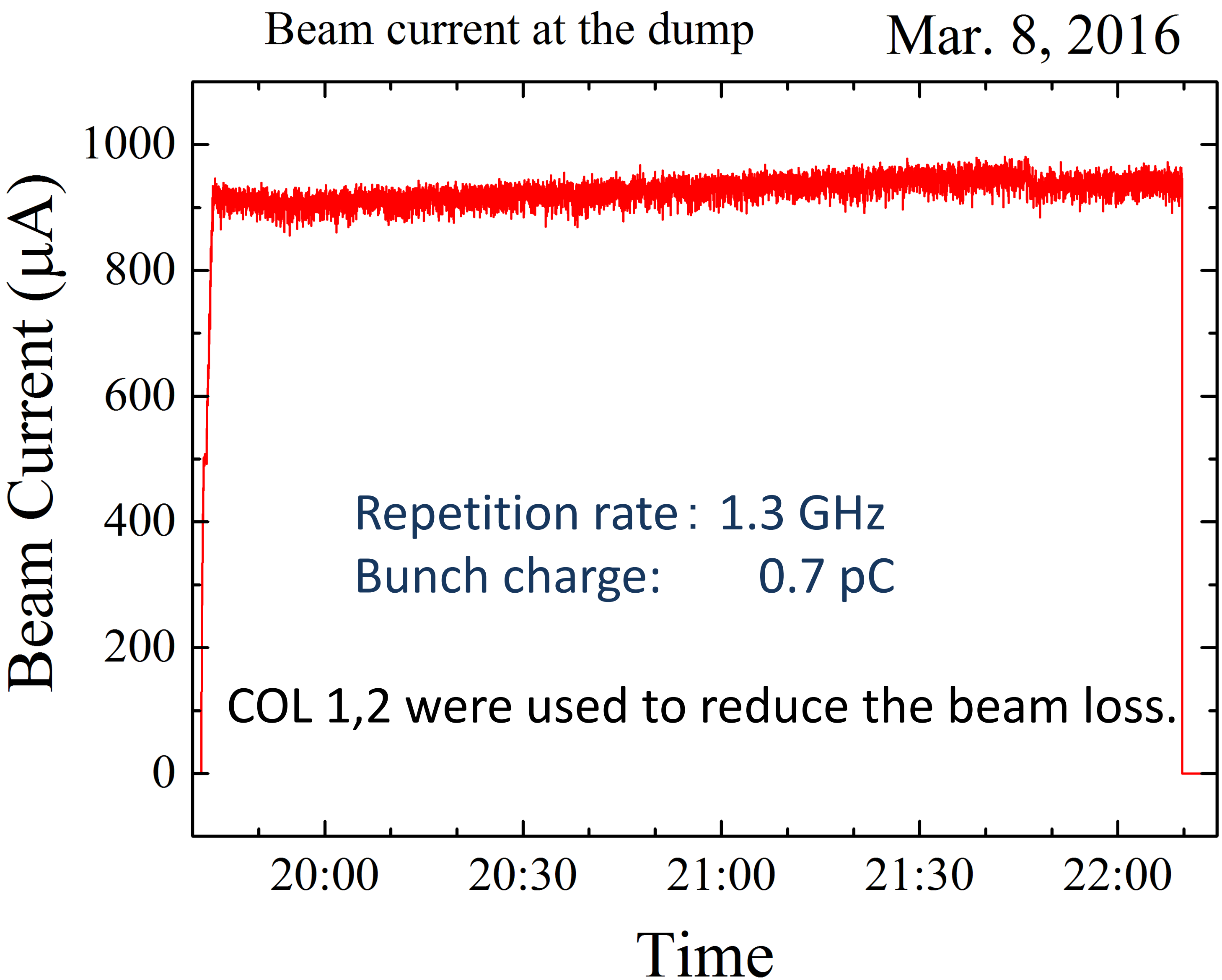




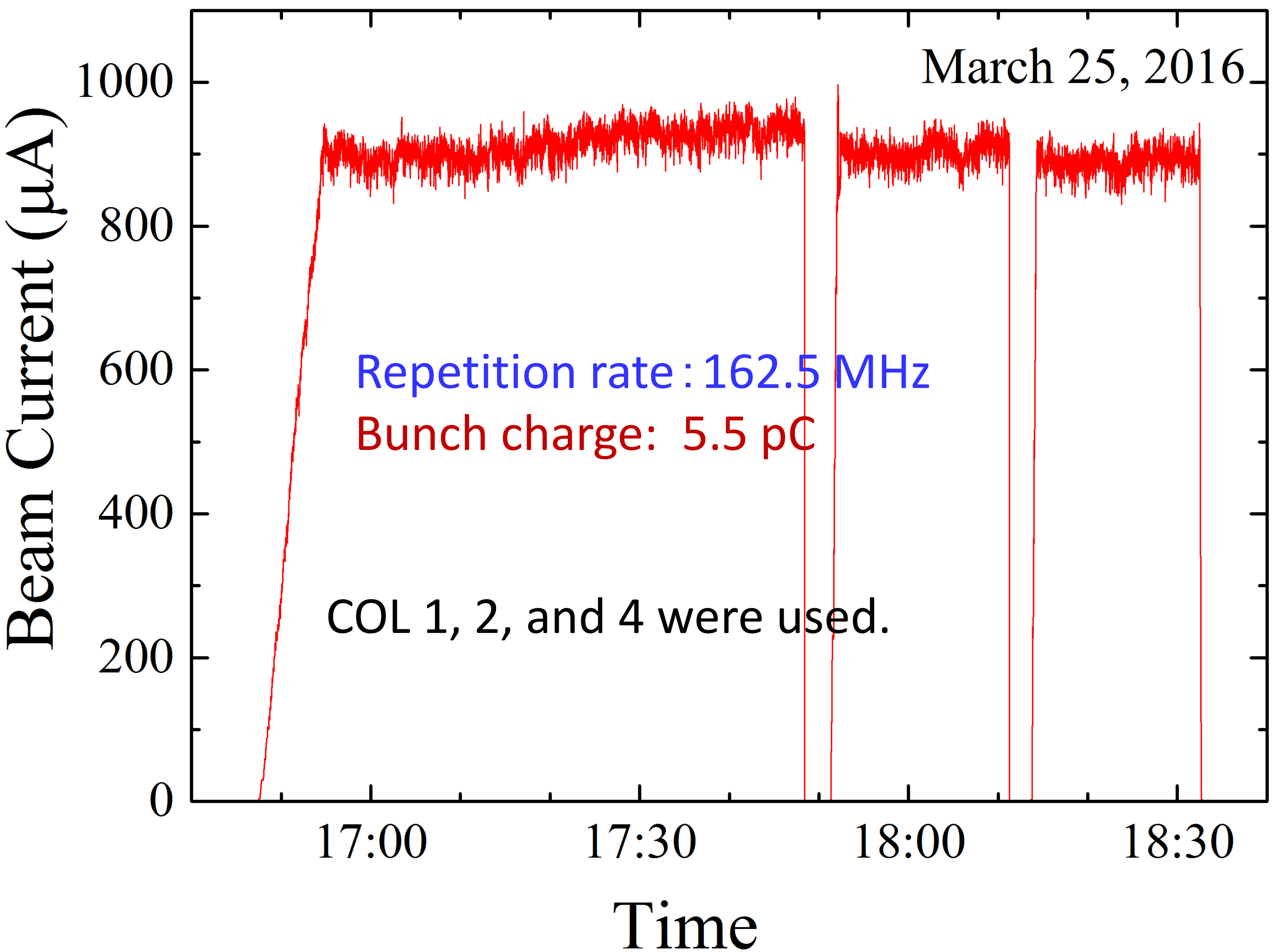
- Adjustment of the beam collimator to avoid beam loss



Success of the 0.9 mA CW operation with 1.3 GHz



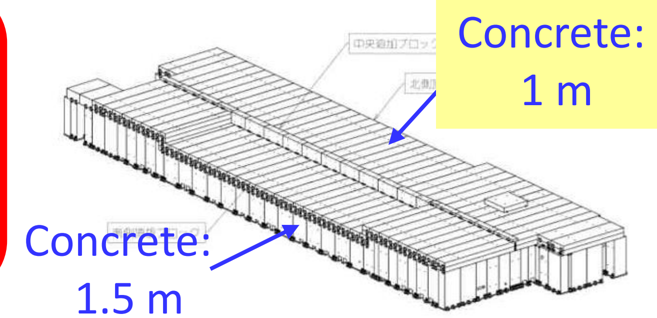
Success of the 0.9 mA CW operation with 162.5 MHz

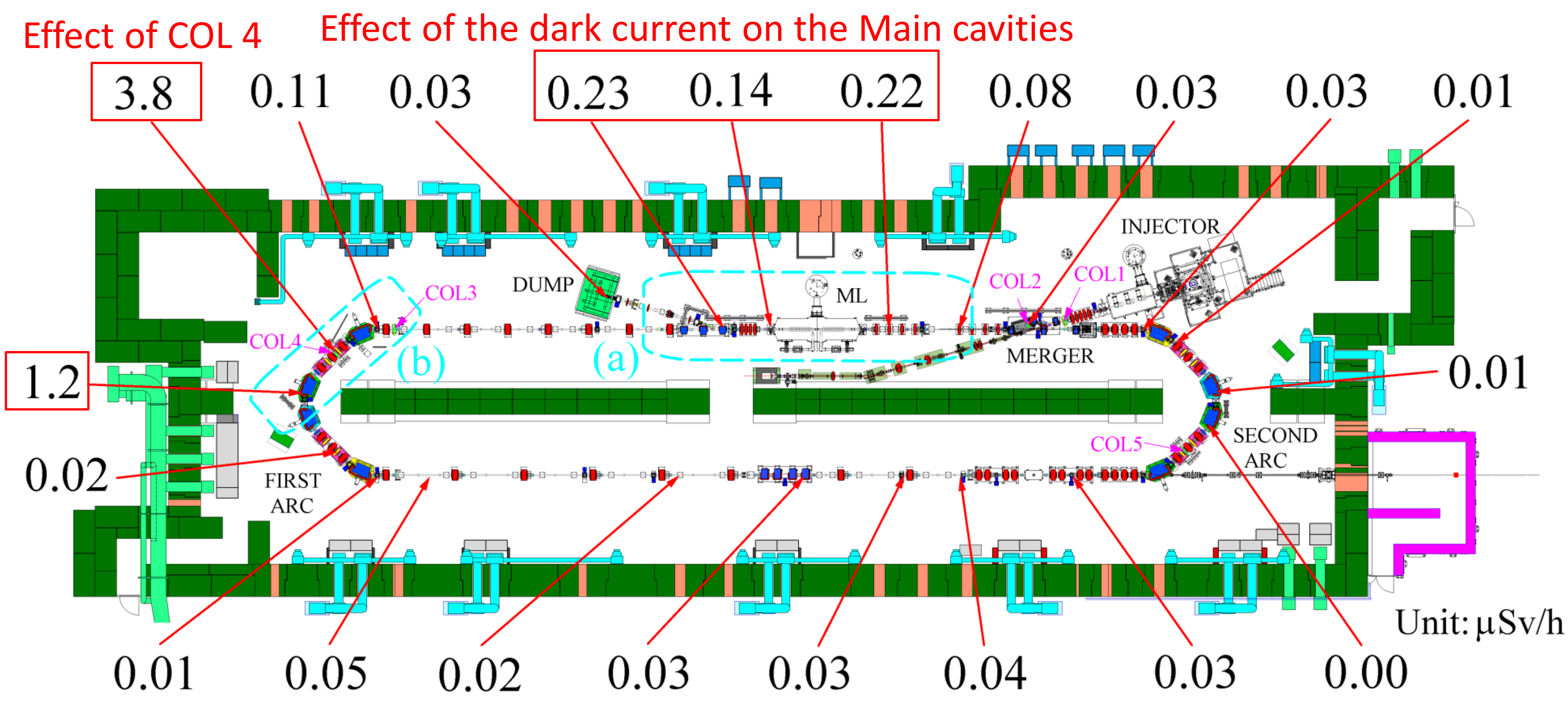


Radiation dose rate at the roof of the radiation shielding at (900μA, 162.5 MHz)

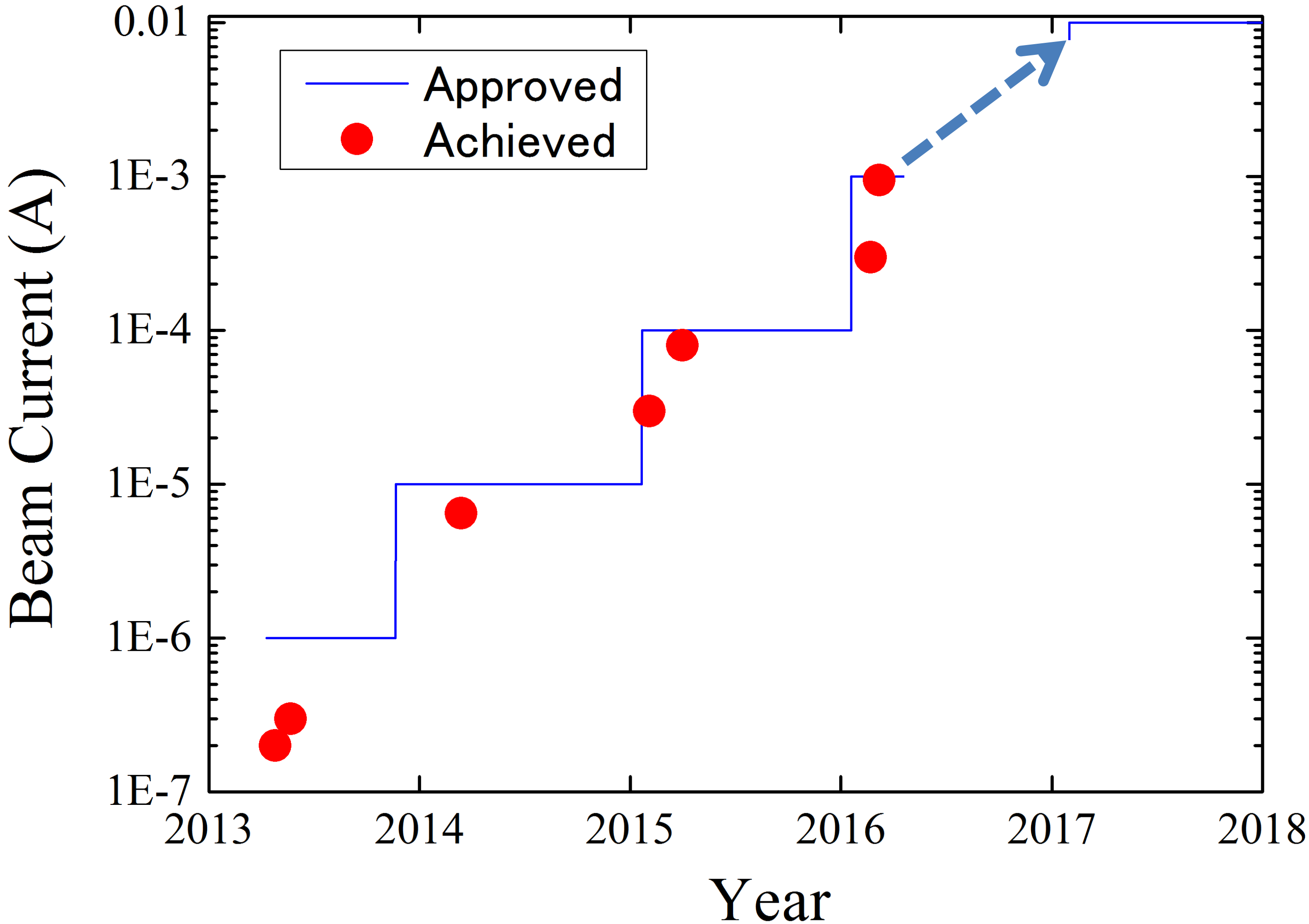
S. Sakanaka et. al.; IPAC'16 (TUPOW038)

- The obtained dose rate is sufficiently low, so that it will be acceptable to operate 10 mA CW operation.





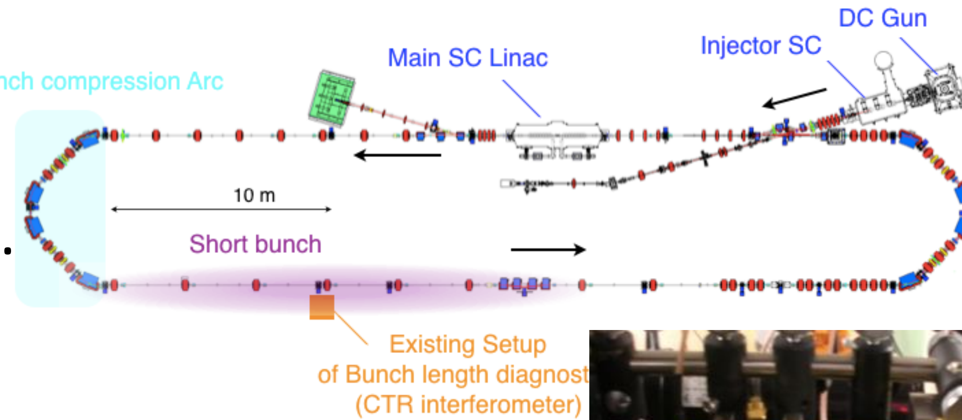
Beam Currents: Achievement and Prospect

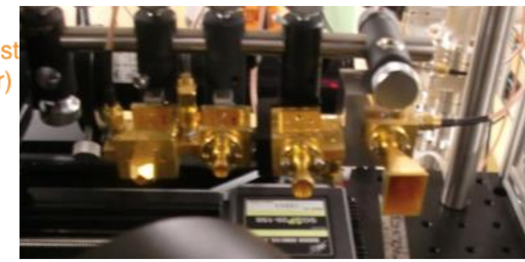


By achieving low beam loss operation and high charge low emittance beam generation, 10mA operation is within target.

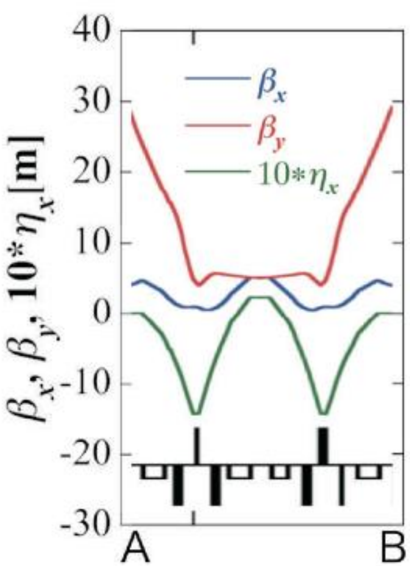
Bunch compression tuning

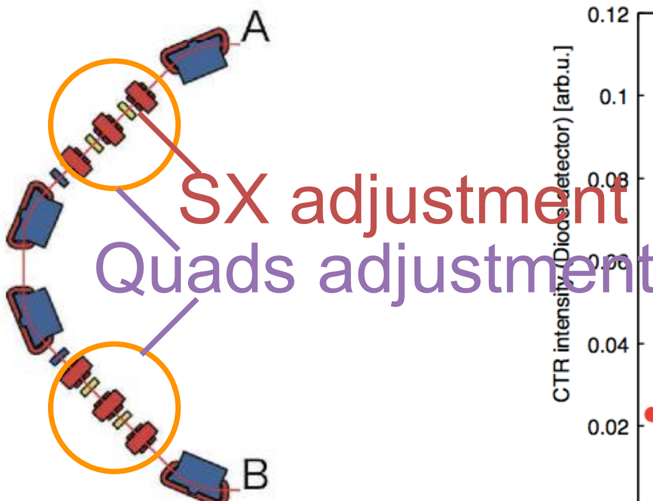
Courtesy of Y. Honda

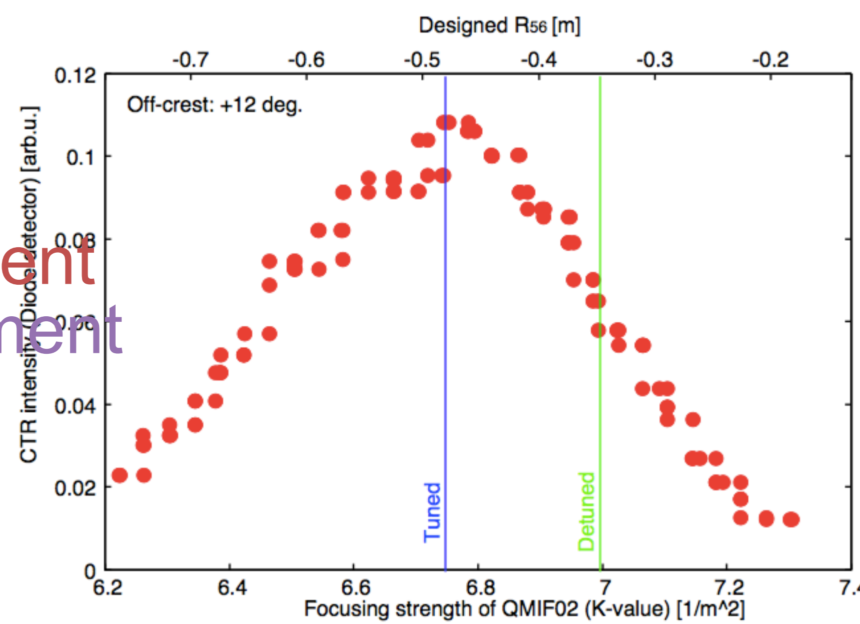




- Beam tuning procedure
  - Set Main linac Off-crest acc.
  - Scan the arc optics
    - R56 by Q combination
    - SX
  - Referring CTR intensity



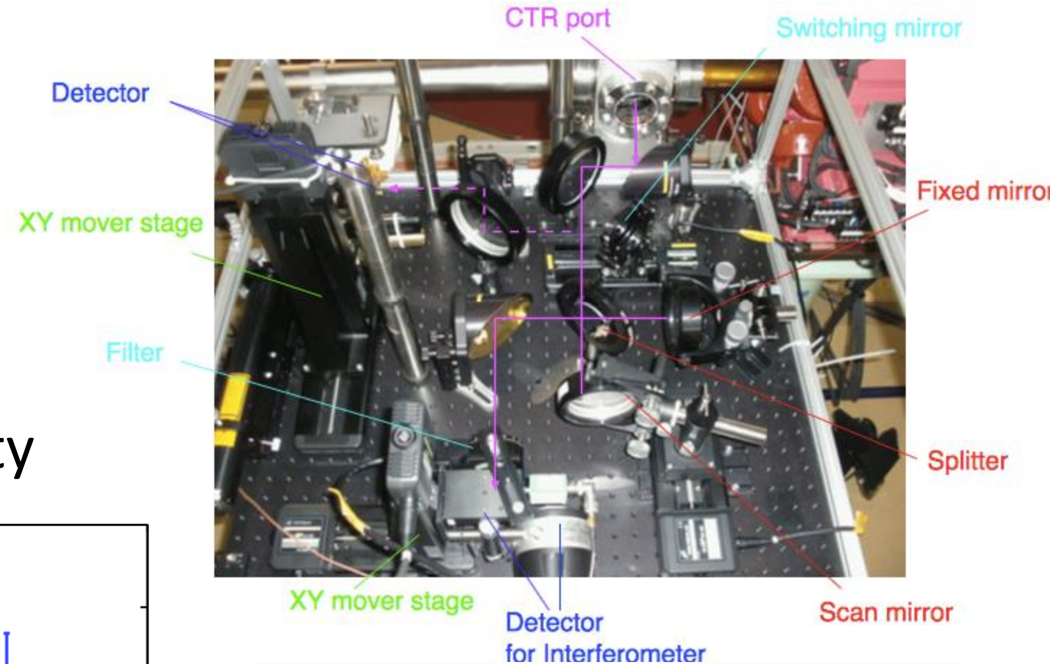


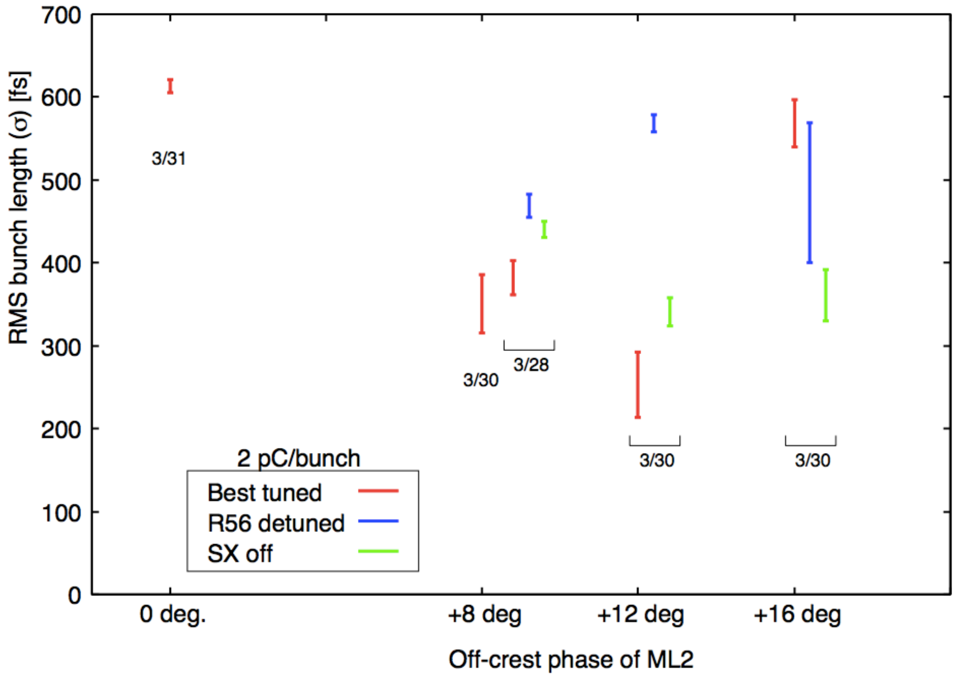


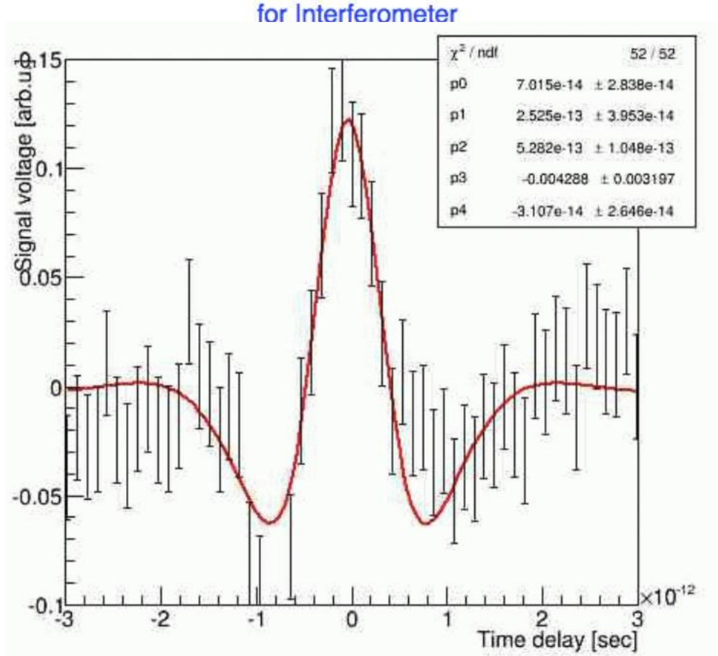
Bunch length and THz measurement

Courtesy of Y. Honda

- Michelson interferometer at CTR port.
- Spectrum reaching ~1THz
- Bunch length 250fs (RMS) is realized in good reproducibility





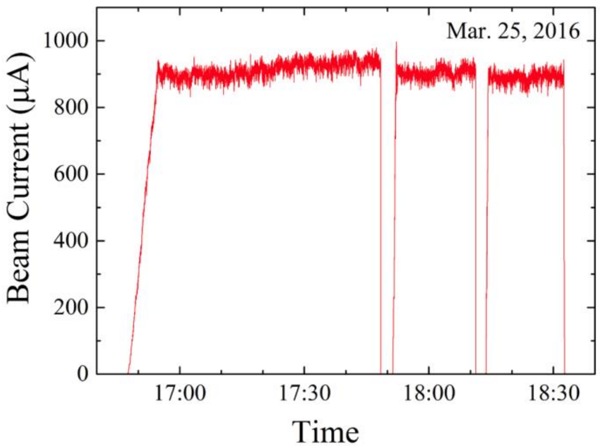


High bunch charge operation for Industrial application

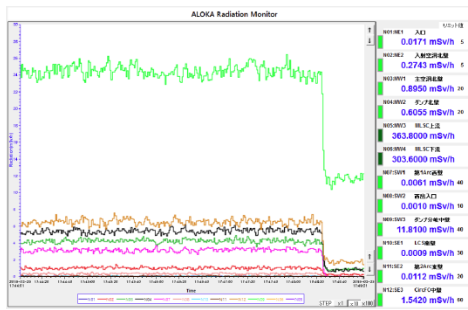
T. Miyajima: This workshop

Beam operation of the cERL from 2013 to 2016

We achieved CW 0.9 mA operation with 5.5 pC bunch charge and very low beam loss.



Radiation level (17:44-17:49)



As the next step, we planed high bunch charge operation for EUV-FEL driver.

60 pC operation (13 Mar. – 31 Mar. 2017)

To demonstrate generation, acceleration and transportation of the bunch charge of 60 pC

- Bunch charge: 60 pC (Target for EUV-FEL)
- Injector total energy: 2.9 MeV for energy recovery ⇒ 5.1 MeV (without energy recovery) to reduce space charge effect

Generation of Higher Bunch Charge

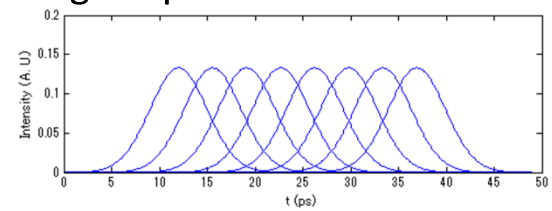
Quantum efficiency (QE): 3 %

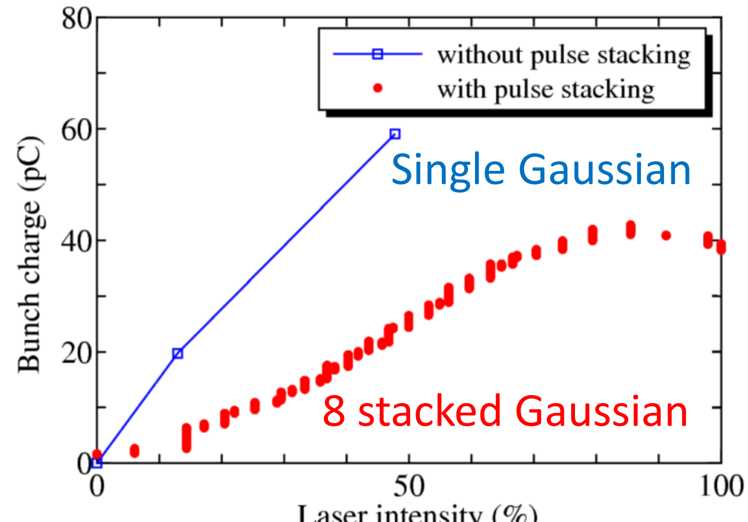
Laser pulse: single Gaussian 3 ps RMS

- We achieved the generation of 60 pC bunch charge.

Laser pulse: 8 stacked Gaussian 31 ps FWHM

- The maximum bunch charge was limited to 40 pC.
- The stacked laser power is about 1/3 of the original power.



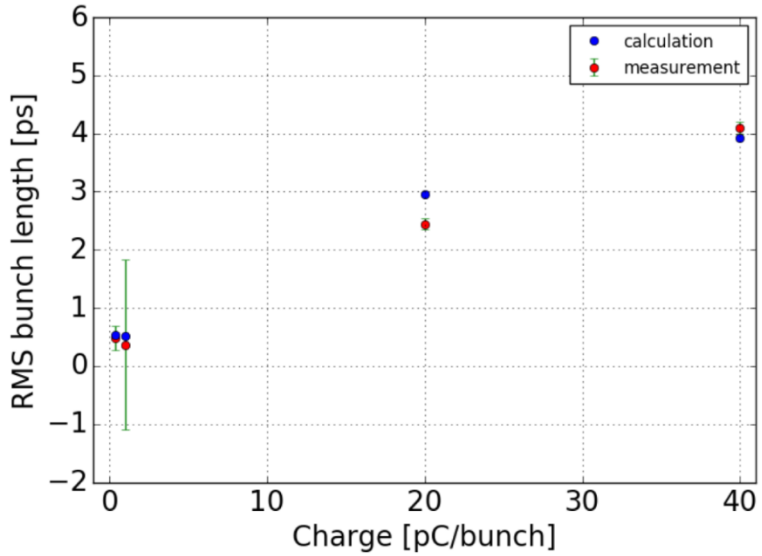


High bunch charge operation for EUV-FEL

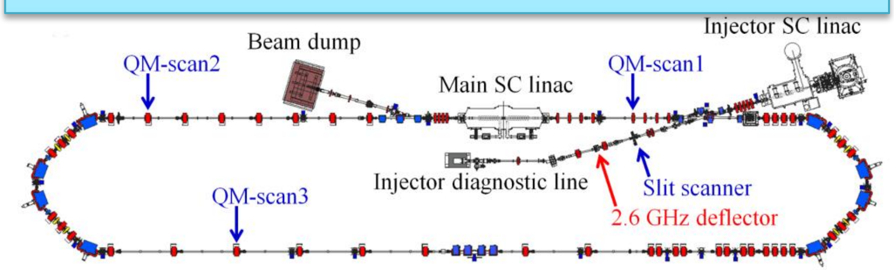
T.Miyajima; This workshop

Bunch length in injector diagnostic line

- The bunch length was measured by a 2.6 GHz deflecting cavity.
- In this operation, we improved phase tuning method for the buncher and the injector.

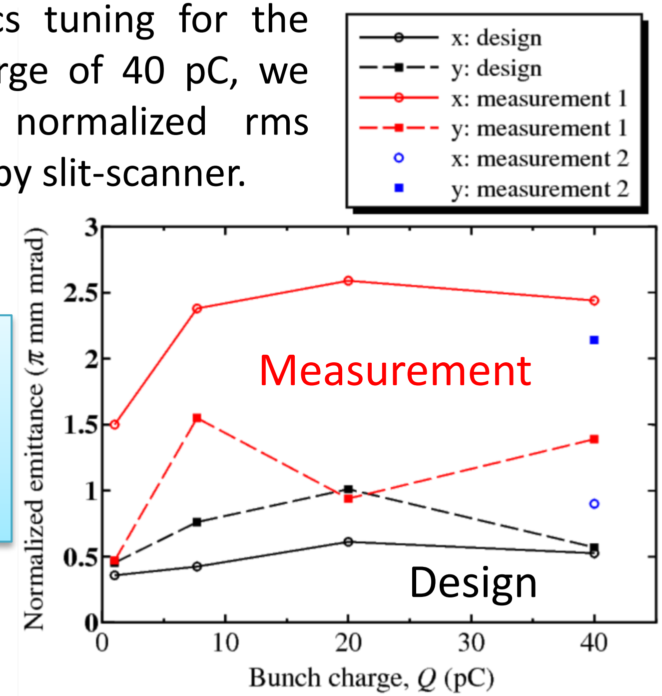


The measured bunch lengths well agreed with the design values.
Now, we can well control longitudinal dynamics.

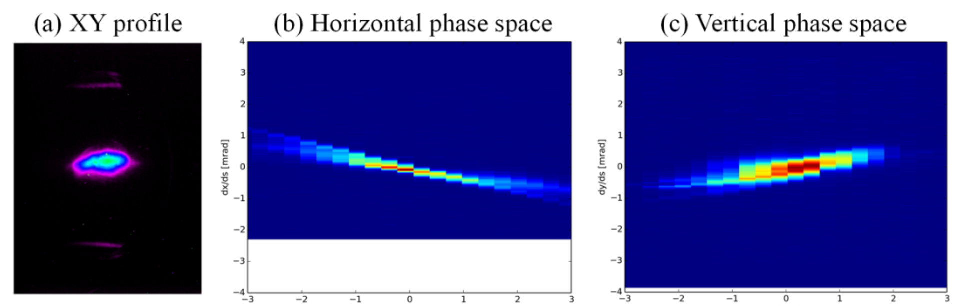


Emittance in injector diagnostic line

- After optics tuning for the bunch charge of 40 pC, we measured normalized rms emittance by slit-scanner.



We observed large emittance growth after the injector.



As the next step, we are planning to re-model the injector cavity including the effect of couplers to reduce the emittance growth.

Summary and Outlook at present ERL17

- 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 1 mA
- Achieved low beam emittance (~1 mm·mrad) at medium bunch charges (< 7.7 pC/bunch).
- X-ray production from Laser Compton Scattering was successfully demonstrated.

Subjects in the near future

- Lower emittance at high buhch-charges ($q_b \geq 7.7$ pC) Achieved
- Beam current: 1 mA ($\rightarrow$ 10 mA) Achieve 1mA operation and also demonstrate the possibility of 10mA operation
- Bunch compression (σ_t ~ 100 fs) and THz production (σ_t ~ 250 fs)

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

Presentations related in cERL at this workshop

<Oral Presentation>

- Development of SRF Gun Applying New Cathode Idea Using a Transparent Superconducting Layer *Taro Konomi*
- Resonant Frequency Control at the Compact ERL in KEK *Takako Miura*
- EUV ERLs for Semiconductor Integrated Circuit Lithography *Norio Nakamura*
- Applications by means of the accelerator technologies based on cERL *Hiroshi Kawata*
- Commission results of the compact ERL high voltage DC gun *Nobuyuki Nishimori*
- Higher bunch charge operation in compact ERL at KEK *Tsukasa Miyajima*
- Beam halo study at the KEK Compact ERL *Olga Tanaka*
- Development of a multialkali photocathode dc gun for high current operation *Nobuyuki Nishimori*

<Poster Presentation>

- Proposal of sharing 6-GeV class CW superconducting linac with ILC and high brilliance X-ray light source *Miho Shimada*
- Resonant Coherent Diffraction Radiation System at KEK-cERL *Youke Honda*

Thank you for your attention!