Development of "Compact ERL (cERL)" accelerator based on Superconducting cavity technology and its application by using cERL

Hiroshi Sakai

High Energy Accelerator Research Organization (KEK)

(36 pages)

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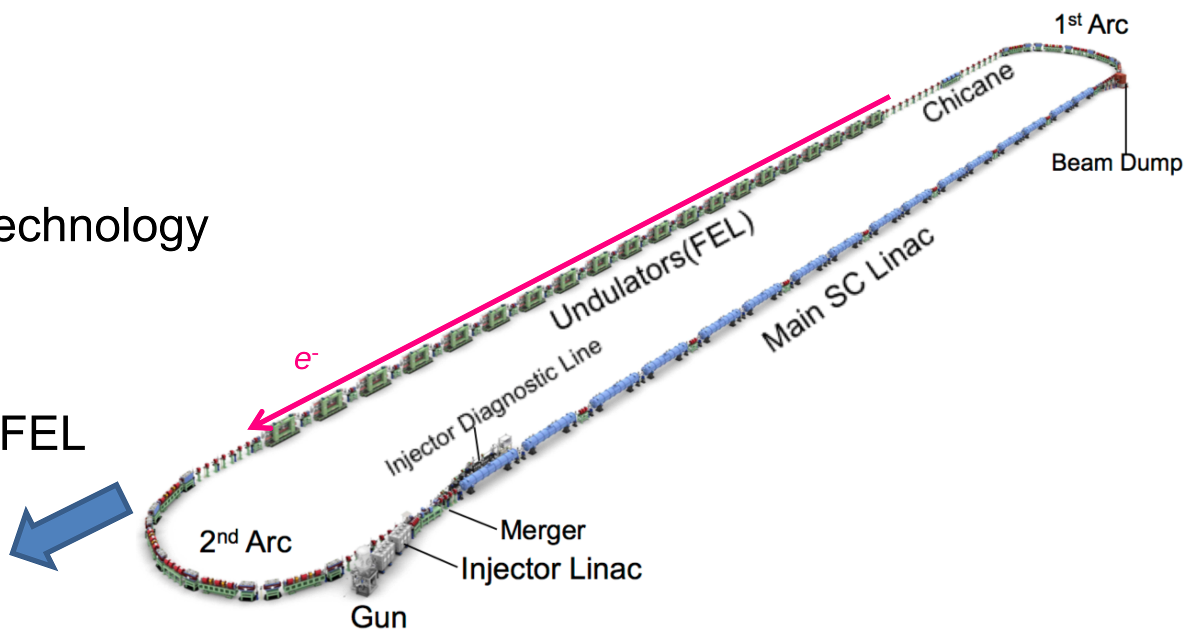
3rd EUV-FEL workshop (Chuo University)(2018.Dec.11)

(A) Introduction for Energy Recovery Linac

- What is Energy Recovery Linac (ERL) ?
- ERL all over the world
- Merit by using Superconducting RF accelerator
- EUV-FEL based on ERL technology

EUV-FEL
Based ERL technology

>10kW EUV-FEL

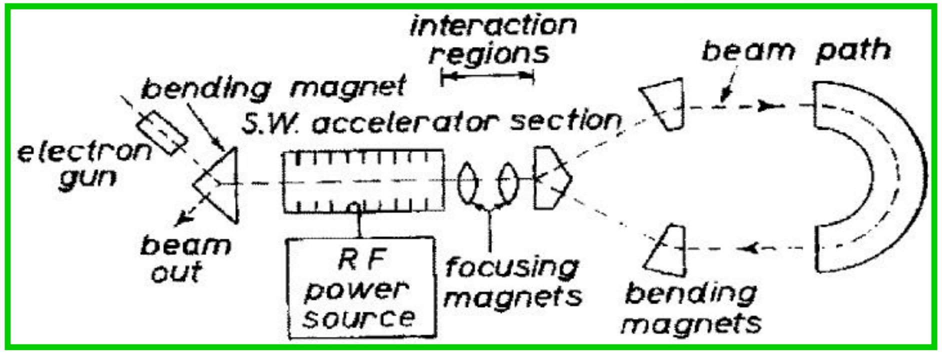


What is Energy Recovery Linac (ERL) ?

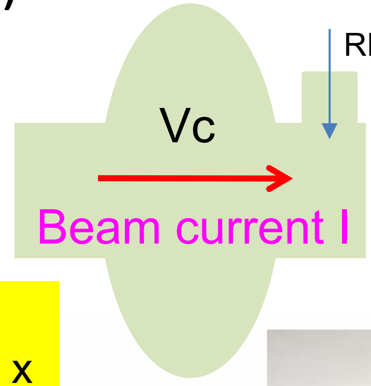
A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER   M.Tigner, Nuovo Cimento 37 , 1228 (1965)

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

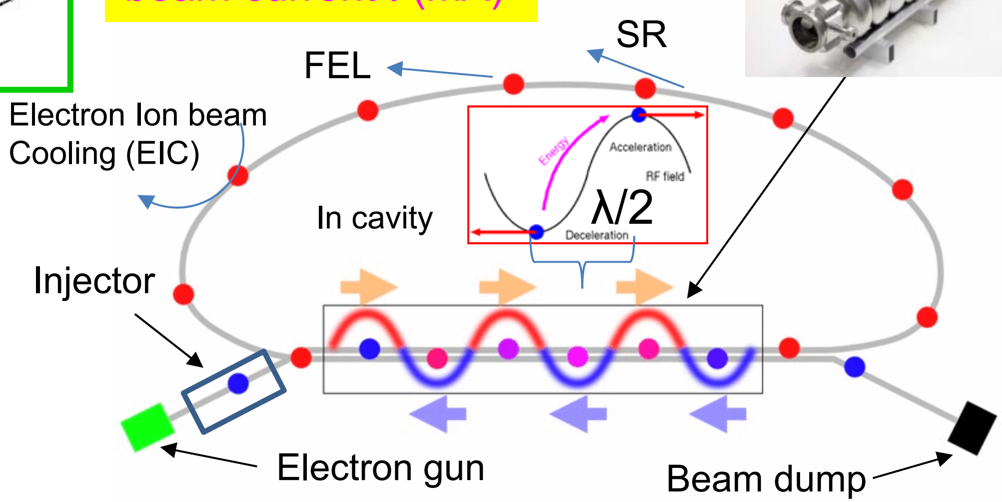


RF acceleration



Main linac

Beam power =
Energy (Vc) (MeV) x
beam current I (mA)



- Without Energy Recovery

Beam power < RF power (high)
800 MeV x 10 mA = 8 MW RF power is needed (EUV-FEL case)

- With Energy Recovery

Beam power >> RF power (very low)

Key technologies for ERL
- High brightness electron gun
- Superconducting RF cavity
- Beam handling of energy recovery beam with high current

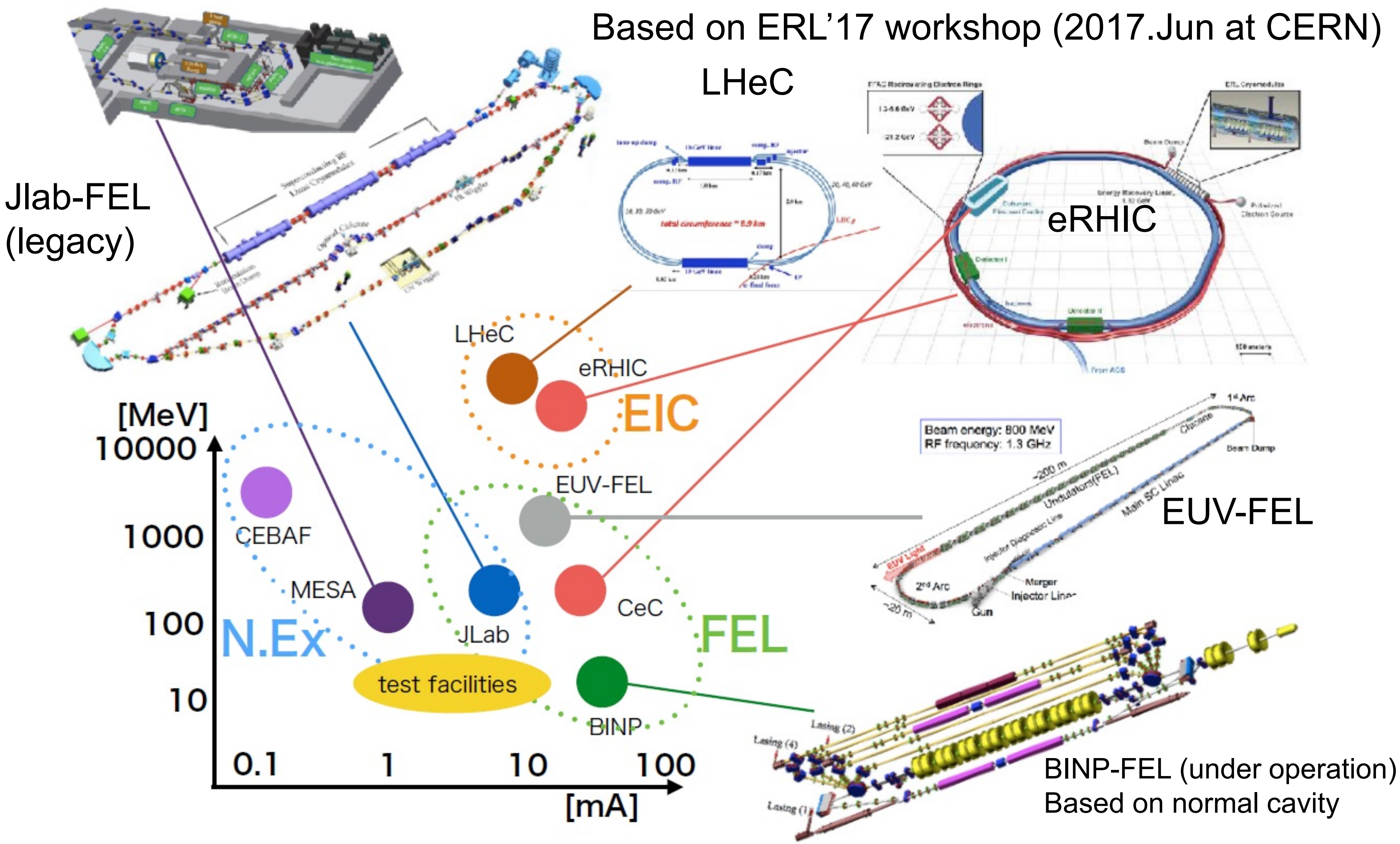
Development of ERL technologies are carried out all over the world.

Figure of Merit of ERL
- **Linac beam with high current beam**
- Low emittance beam (High quality beam)
  → more bright beam than 3rd generation SR ight source
- Short bunch (~< 100 fs) with high current beam (> 10 mA)
- Large disturbance during beam recirculating is acceptable (like FEL interaction and/or ion cooling for high energy collider)
- → it is difficult to fulfill these condition by using storage ring.

MESA (under construction)

The ERL based project

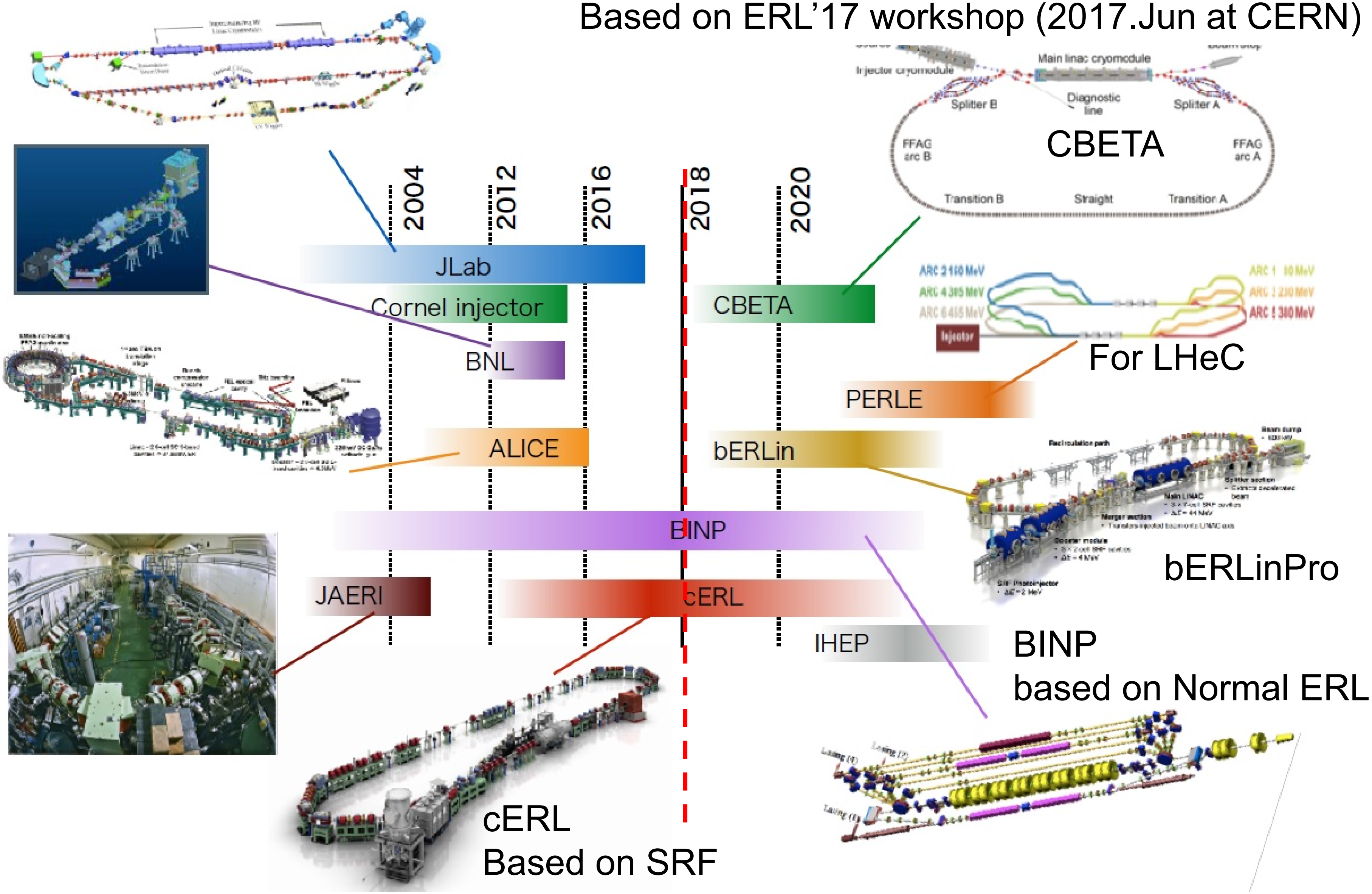
Based on ERL’17 workshop (2017.Jun at CERN)



ERL based accelerator will be planed to use EIC (Electron ion cooling) for High energy physics, Nuclear physics experiment and high power FEL project. Especially, EIC and high power FEL need ERL technology.

The latest ERL test facilities all over the world

Based on ERL'17 workshop (2017.Jun at CERN)



Operating superconducting RF based ERL is only <u>cERL</u> at present.
Next coming ERL based on SRF is under construction.

Why SRF cavity is essential for ERL?

(Figure of merit by using SRF cavity)

Cavity wall loss — Accelerating voltage

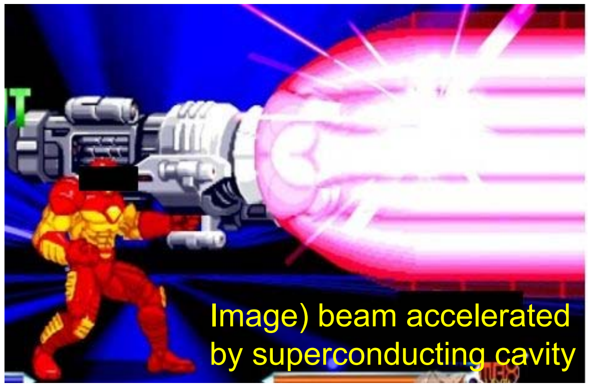
$$P_c = \frac{V_c^2}{R/Q * Q_o}$$

R/Q: decided by geometry only

1m cavity

Cu: 9mΩ(@300K) (Q0~10^4))
10MV/m → 10MW loss
½ power was dissipated on wall

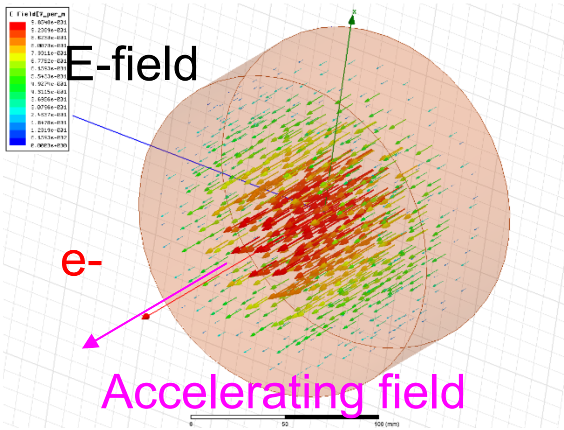
Nb: a few10nΩ(@2K) (SRF) (Q0~10^10)
10MV/m → 10W low loss. << Beam power (Important for ERL)
(loss was 1/100000 times reduced from normal cavity)

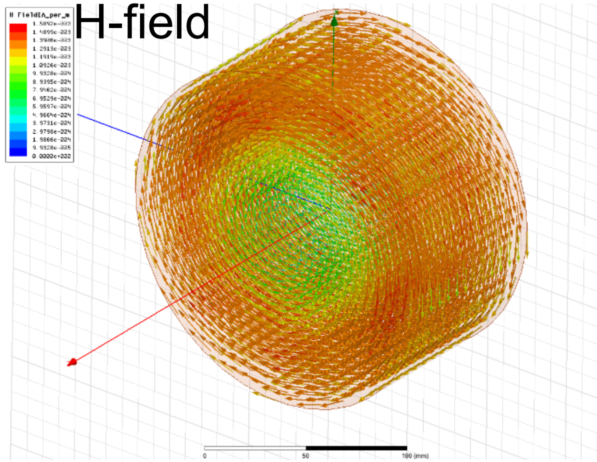


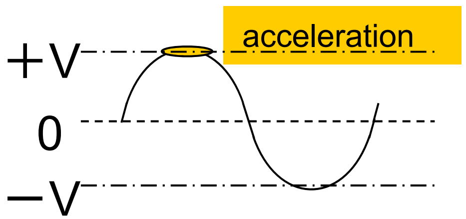
Normal conducting cavity made by Cu
→ Low field (<1MV/m CW)

If surface resistance reach→0 ohm by Superconducting cavity,
CW beam accelerated with very high gradient

e-





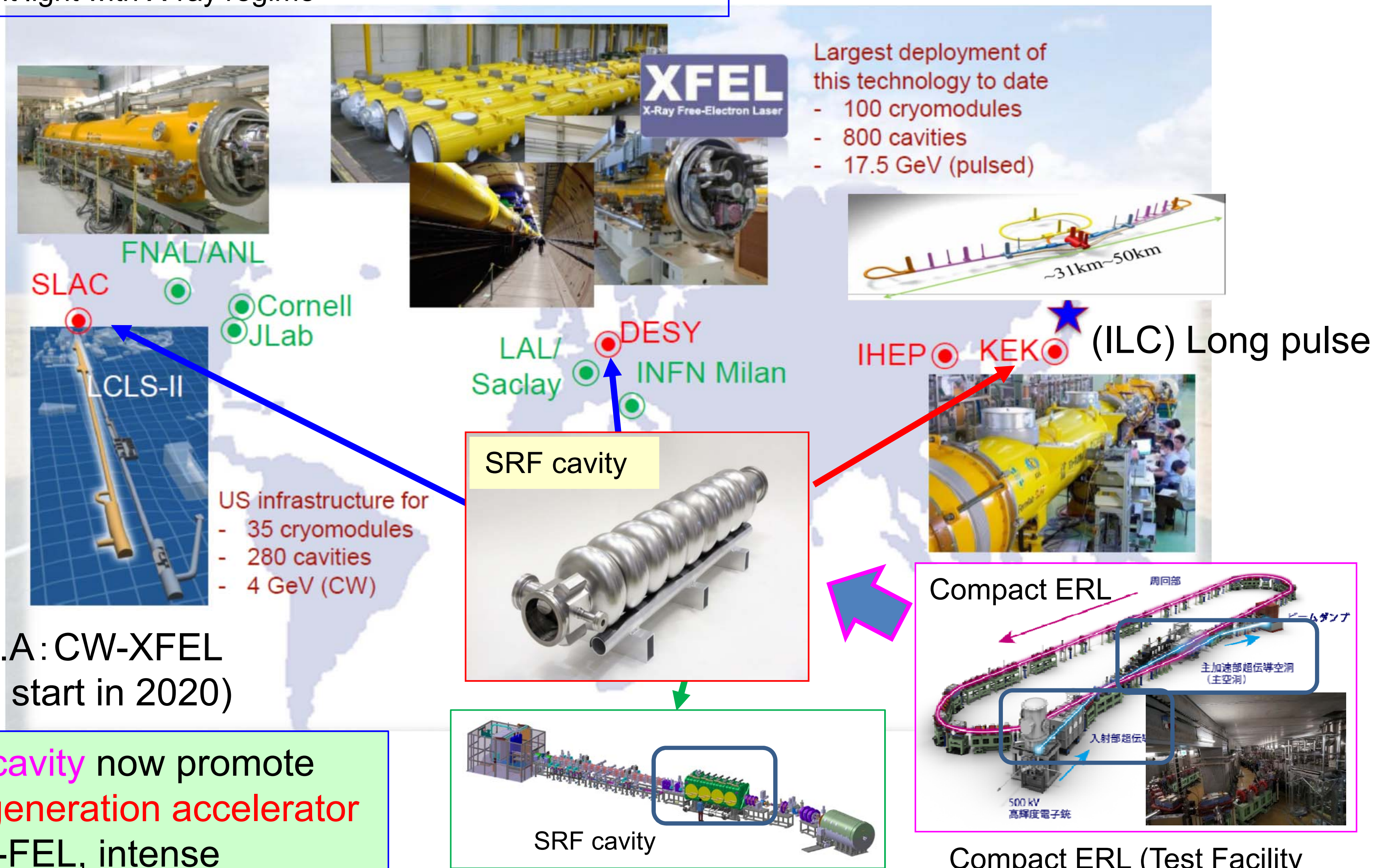


Heating was occurred by surface H-field (current). Pc (wall loss) was created.

Large scale SRF facility (XFEL & ILC and more)

XFEL (X-ray Free Electron Laser):
Next generation light source makes high peak intense coherent light with X-ray regime

Europe: Germany (DESY): (start in 2017) Long pulse -XFEL



U.S.A: CW-XFEL (will start in 2020)

SRF cavity now promote new generation accelerator like X-FEL, intense proton/ion beam and ILC.

IFMIF accelerator (for material test of nuclear fusion) in Aomori (2019)

Compact ERL (Test Facility of ERL in KEK) In 2013 we achieved Energy Recovery.

FEL (Free electron Laser)

Breakthrough for EUV light by using FEL (with ERL)

- FEL power

FEL parameter Average beam current

$$\langle P_{FEL} \rangle = \rho \langle P_{beam} \rangle = \rho E \times \langle I_{beam} \rangle$$

- FEL (Pierce) parameter ρ

Peak beam current Depend on undulator

$$\rho = \frac{1}{\gamma} \left\{ \frac{1}{64\pi^2} \frac{I_P}{I_A} \frac{K^2 \lambda_u^2 [JJ]^2}{\sigma_x \sigma_y} \right\}^{\frac{1}{3}}$$

Beam energy Beam sizes

$$[JJ] = J_0(\xi) - J_1(\xi)$$

$$\xi = \frac{(K/2)^2}{2\left(1 + (K/2)^2\right)}$$

$$\sigma = \sqrt{\beta \varepsilon}$$

ε: emittance

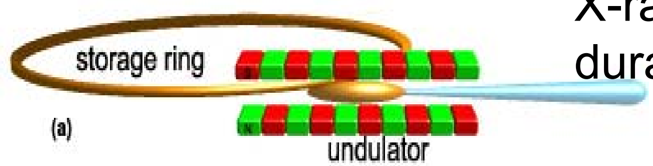
- FEL wavelength

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

- High average current,
- high peak current (< 100 fs),
- low emittance beam

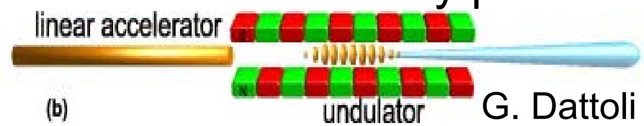
is required to obtain high average output power.

X-ray pulse duration ~ 50 ps



Micro-bunching -> SASE lasing → high peak power

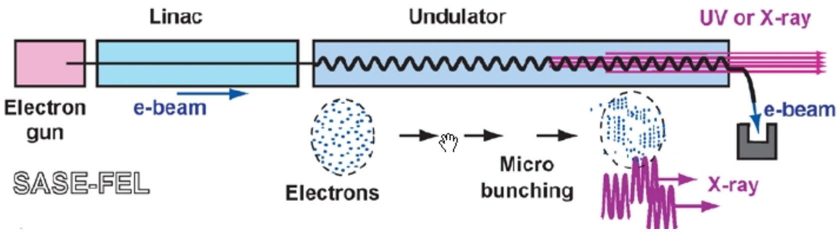
X-ray pulse duration ~ 10 fs



G. Dattoli et al., NIM-A (2001)

LCLS-II (CW-XFEL) (2020 start)

Normal 120Hz(LCLS), 60Hz(SACLA)
→ MHz repetition (LCLS-II) by using SRF cavity

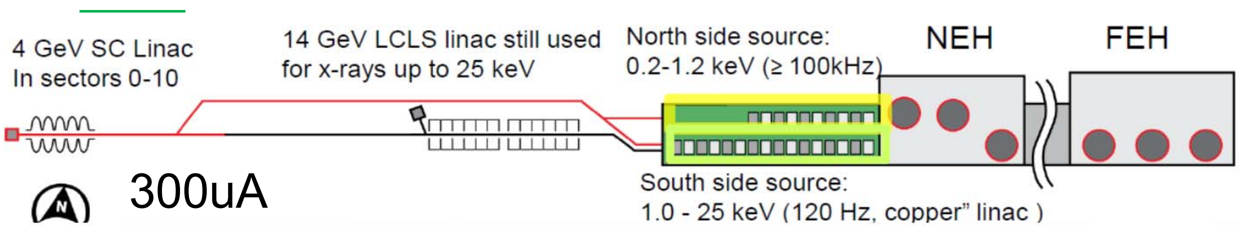


A New LCLS-II Project Redesigned in Response to BESAC

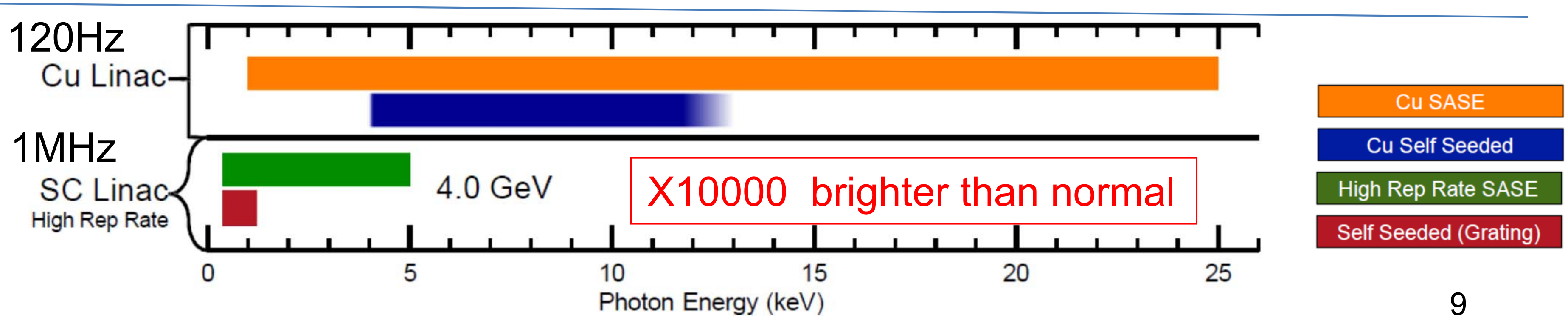
Accelerator	**Superconducting linac**: 4 GeV
Undulators in existing LCLS-I Tunnel	New variable gap (north) New variable gap (south), replaces existing fixed-gap und.
Instruments	Re-purpose existing instruments (instrument and detector upgrades needed to fully exploit)

Fermilab · Jefferson Lab · Berkeley Lab · Argonne National Laboratory · Cornell University

requirement: 16MV/m : Q0 > 2.7x10^10 (High-Q technology)



By M.Ross



300uA x 4 GeV = 1.2 MW beam power is needed. → need RF power & beam dump

Merit of ERL based FEL

Low power → High power

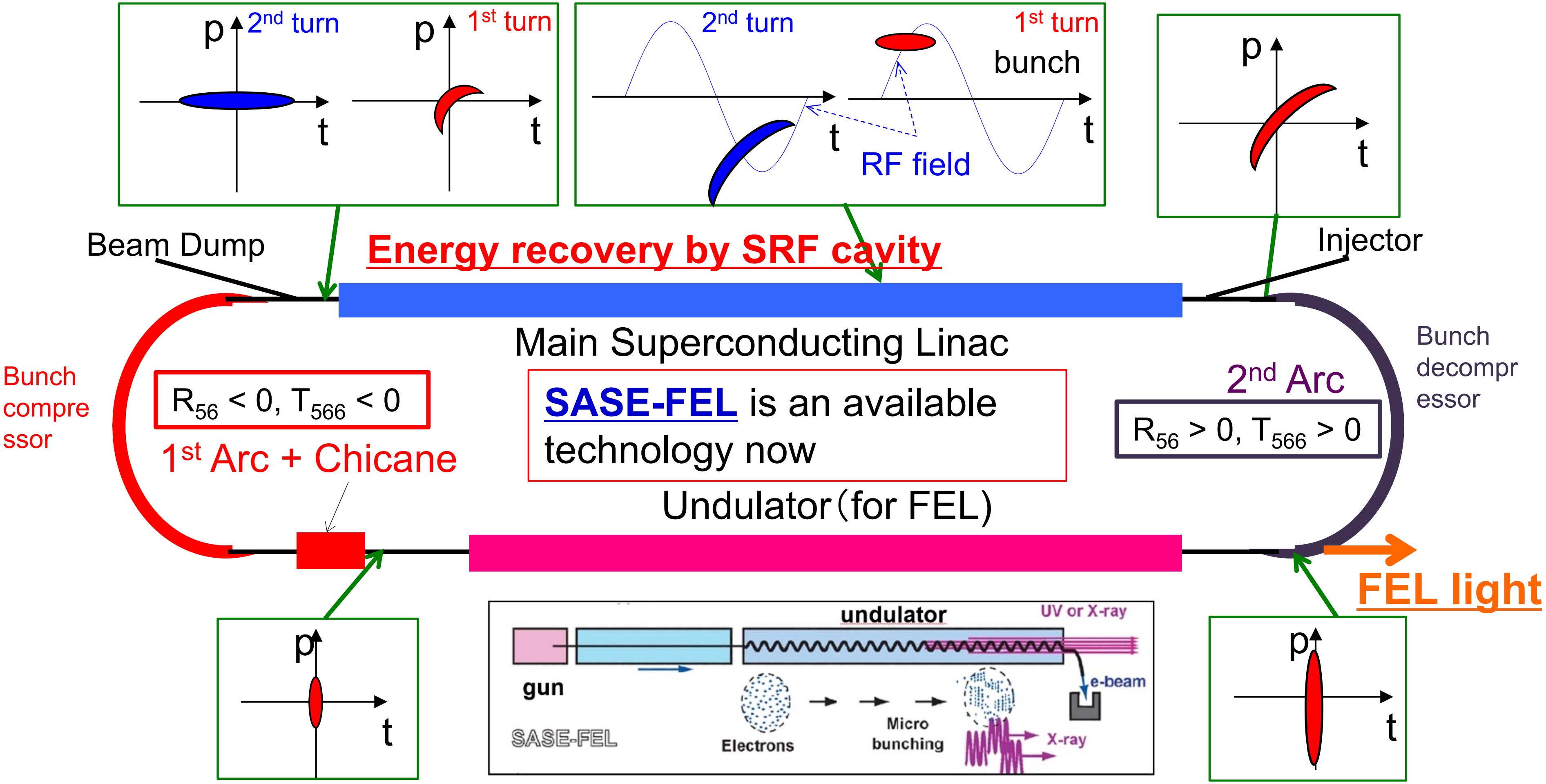
	LCLS	SACLA	FLASH	Euro-XFEL	LCLSII	EUV-FEL
Type of linac	Normal conducting		**Super conducting**			
Operation mode	Pulse		Long pulse		**CW**	
Country	US	Japan	Germany	Germany	US	-------
ERL scheme	No	No	No	No	No	**Yes**
Repetition rate	120	30～60	<5000	<27000	1M	**162.5M**
Beam energy (MeV)	14300	6000～8000	1250	17500	4000	**800**
Wavelength(nm)	0.15	0.08	4.2-52	0.05	~0.3	13.5
Pulse energy(mJ)	~10	~10	<0.5	~10	~1	~0.1
Average Power (W)	~1	~1	<0.6	~100	~1000	**>10000**
Beam dump power (W)	~1.5k	~0.5k	~6k	~0.5M	~1M	**< 0.1M**
Status	Operation 2009	Operation 2011	Operation 2004	Operation 2017	Construction 2020	Planning

ERL helps to make high power CW FEL and reduce the beam dump power (important in future)

Design Concept for high repetition high current EUV-FEL

EUV Source (ERL)

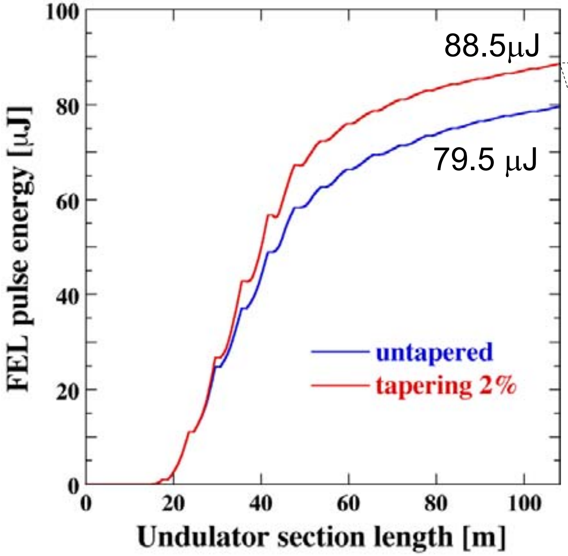
- Target : 10kW power @ 13.5 nm, (800 MeV, 10mA)
- Use available technology (based on SASE-FEL) without too much development
- Make ERL scheme by cERL designs, technologies and operational experiences

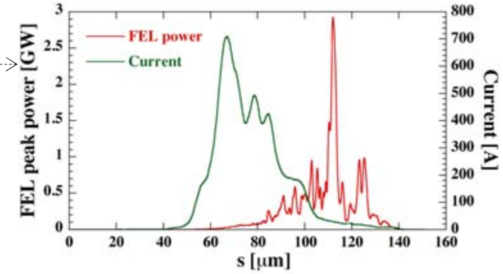


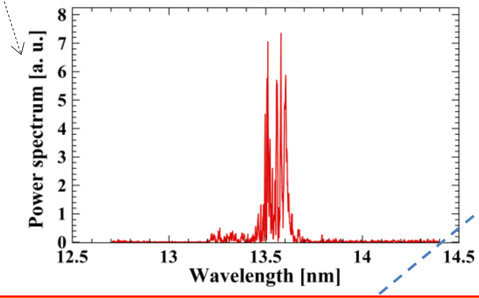
Energy recovery is needed for accelerating more than 10 mA to reduce beam dump and save RF power.
This operational experience with high current is studied in Compact ERL (cERL) at KEK

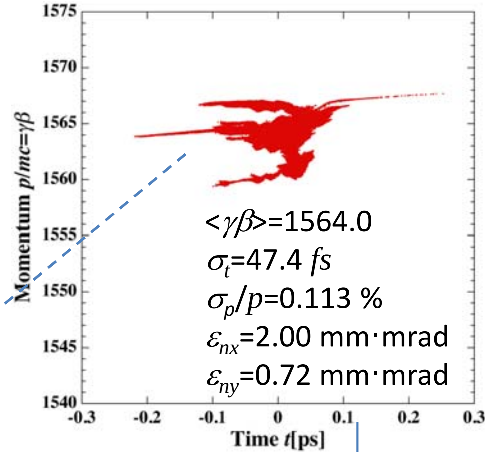
FEL Performance

BY N. Nakamura: 2nd EUV-FEL workshop





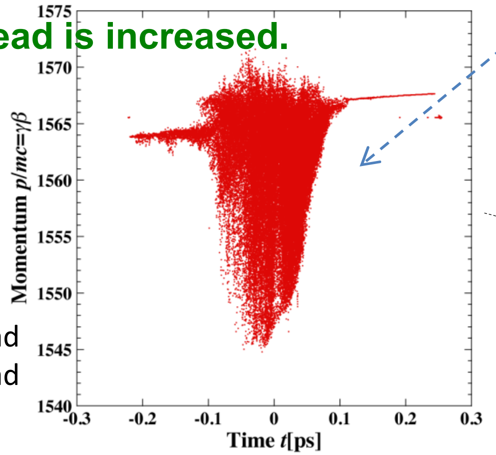




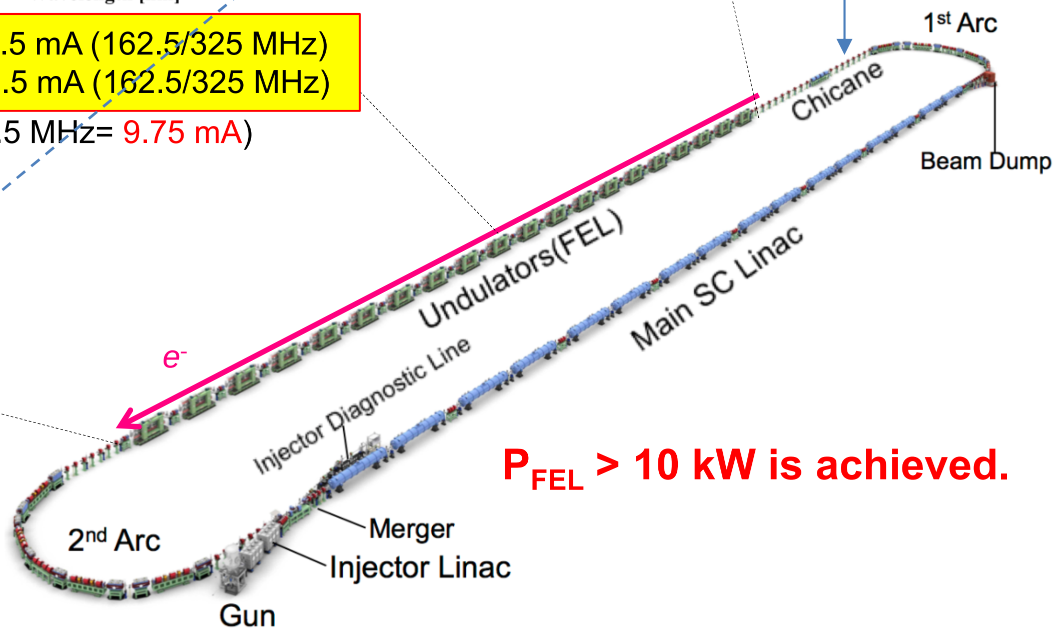
FEL power without tapering: 12.9/25.8 kW @ 9.75/19.5 mA (162.5/325 MHz)
FEL power with 2% tapering: 14.4/28.8 kW @ 9.75/19.5 mA (162.5/325 MHz)

(P_{FEL}=88.5 μJ x 162.5 MHz =14.4 kW, I_{av}=60pC x 162.5 MHz= 9.75 mA)

Energy spread is increased.



$<\gamma\beta>$=1561.1
σ_t=48.5 *fs*
σ_p/p=0.299 %
ε_{nx}=1.98 mm·mrad
ε_{ny}=0.71 mm·mrad

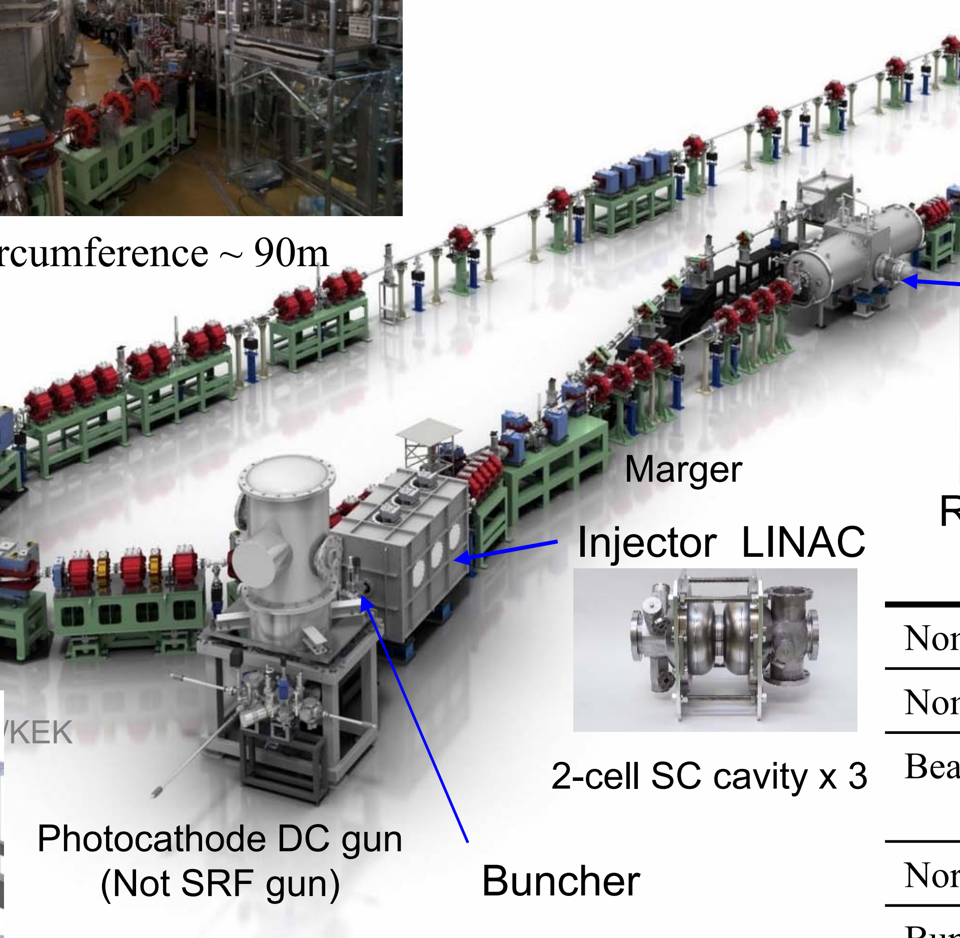


P_{FEL} > 10 kW is achieved.

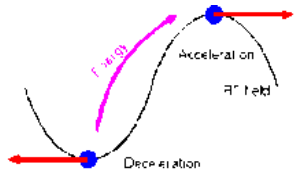
(B) Compact ERL (cERL) status and the latest results

Compact ERL (cERL) in KEK

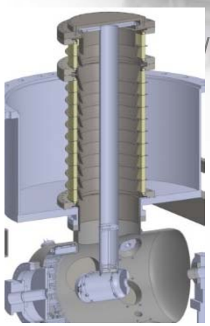
Compact ERL (**cERL**) has been constructed in 2013 at KEK to demonstrate energy recovery with low-emittance, high-current CW beams of more than 10 mA for future multi-GeV ERL.



9-cell SC cavity x 2



2-cell SC cavity x 3



RF frequency= 1.3 GHz

17.7 MeV

Design parameters of the cERL

Nominal beam energy	35 MeV → 20MeV
Nominal Injector energy	5 MeV →2.9MeV
Beam current	10 mA (initial goal) 100mA (final)
Normalized emittance	0.1 – 1 mm·mrad
Bunch length (bunch compressed)	1-3ps (usual) 100fs (short bunch)

Injector & Main linac made by MHI.

History and Change the target from academia to industry of cERL

2013-2015 The beam commissioning started in 2013 for future 3 GeV ERL light source and achieve 1mA under energy recovery operation

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.)

See the detail KEK Project Implementation Plan (KEK-PIP)

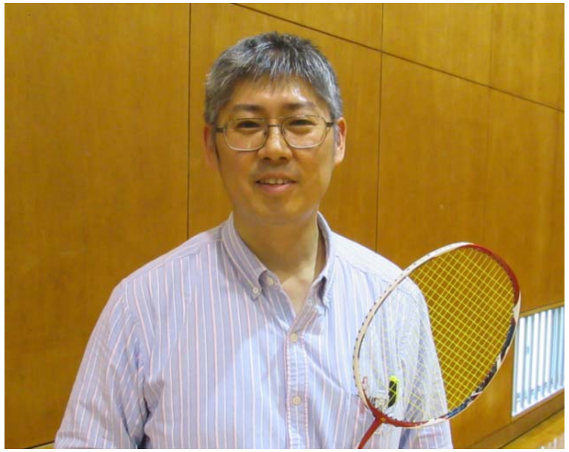
http://www.kek.jp/ja/NewsRoom/Release/20160802141100/

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

2018 Change the team leader of "SRF application team" from Kawata-san to me (Sakai)

Restart the beam operation by using cERL for SRF application. (2018.Mar. & Jun. (1mA))

Hiroshi KAWATA (KEK)



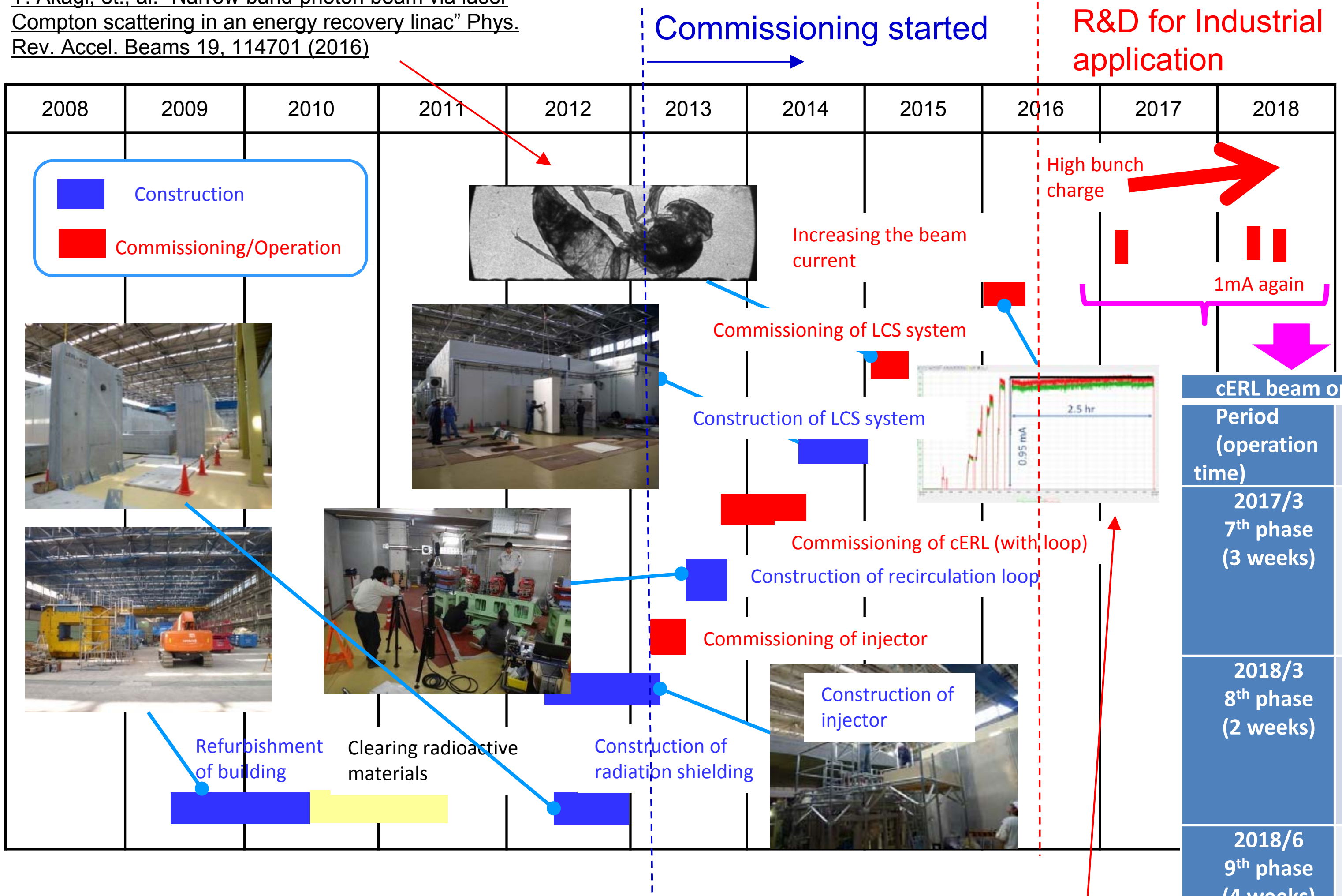
Hiroshi SAKAI (KEK)

Construction and Commissioning of cERL

(Published) M. Akemoto *et al.*, “Construction and commissioning of the compact energy-recovery linac at KEK” Nucl. Instrum. Method A 877 p.197-219 (2018).

Laser Compton scattering experiment in ERL

T. Akagi, et., al. “Narrow-band photon beam via laser Compton scattering in an energy recovery linac” Phys. Rev. Accel. Beams 19, 114701 (2016)



What kind of beam study is on going ?

Beam was stably operated for a long time ?

cERL beam operation from 2017 to 2018		
Period (operation time)	Current [mA]	Comment
2017/3 7th phase (3 weeks)	60 pC/ bunch	High charge for EUV-FEL study. Pulse operation for beam optimization.
2018/3 8th phase (2 weeks)	60 pC/ bunch	High charge Pulse operation for THz radiation experiment (RCDR)
2018/6 9th phase (4 weeks)	60 pC/ bunch & 1 mA (CW)	High charge Pulse operation for beam optimization & THz radiation (RCDR) experiment & CW beam operation

Construction started in 2009 and commissioning start in 2013.

Now we continue beam operation.

1mA ERL achieved

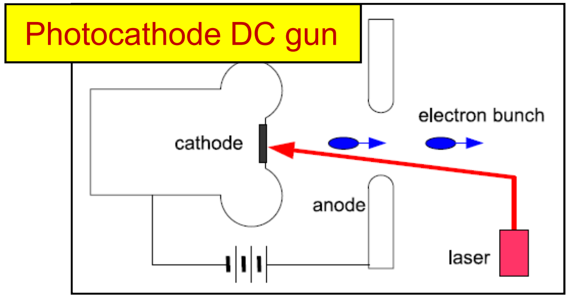
Toward 1mA CW ERL beam operation & its results

- Strategy for reaching beam current higher
  - Sophisticated beam tuning (optics matching) by Burst beam and sometimes use collimator at injector point to reduce halo of beam.
  - After changing CW mode, we increase the beam current by changing laser power under monitoring the beam loss by loss monitor.

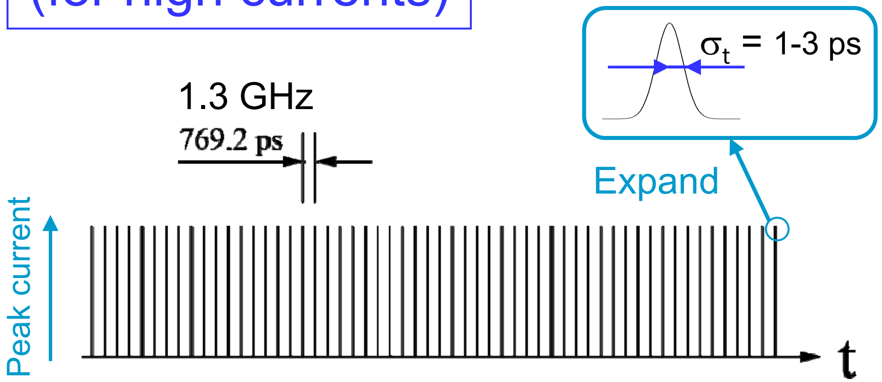
	condition	Parameters
Beam Repetition	Standard	1300 MHz
	LCS	162.5 MHz
Bunch Length	Standard	1 – 3 ps
	Compressed	< 0.2 ps
Total path length	Gun to Dump	120 m

Prepare to submit paper

Initial conditions are determined by the gun-drive laser.

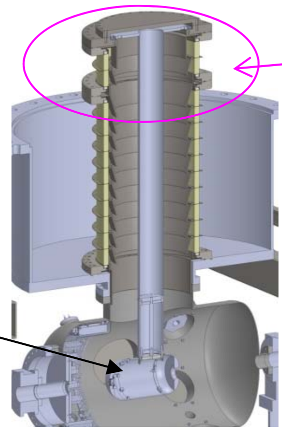


CW beam
(for high currents)

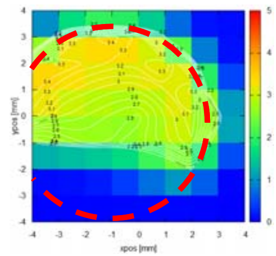


Bunch charge: 7.7 pC → average current: 10 mA

cathod



Two ceramics for DC 500 kV in 2016



Cathode #2 QE after installation

Try two parameters

0.77pC : 1.3 GHz = 1mA
6 pC : 162.5 MHz ~ 1mA

We successfully extract 500 keV electron from gun to dump (previous 390keV)
→ Highest DC field achieved in the world .

For LCS experiment or high charge operation, not 1.3 GHz but 162.5 MHz beam operation was used

To realize 1mA stable operation

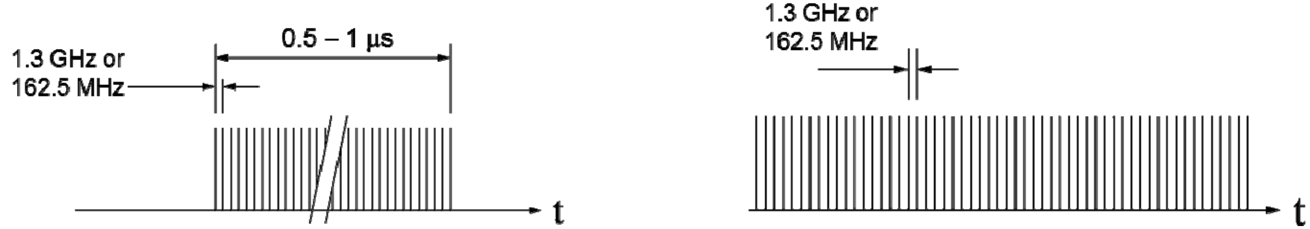
Beam handling system

Courtesy of S. Sakanaka

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

burst-mode operation → **CW operation**

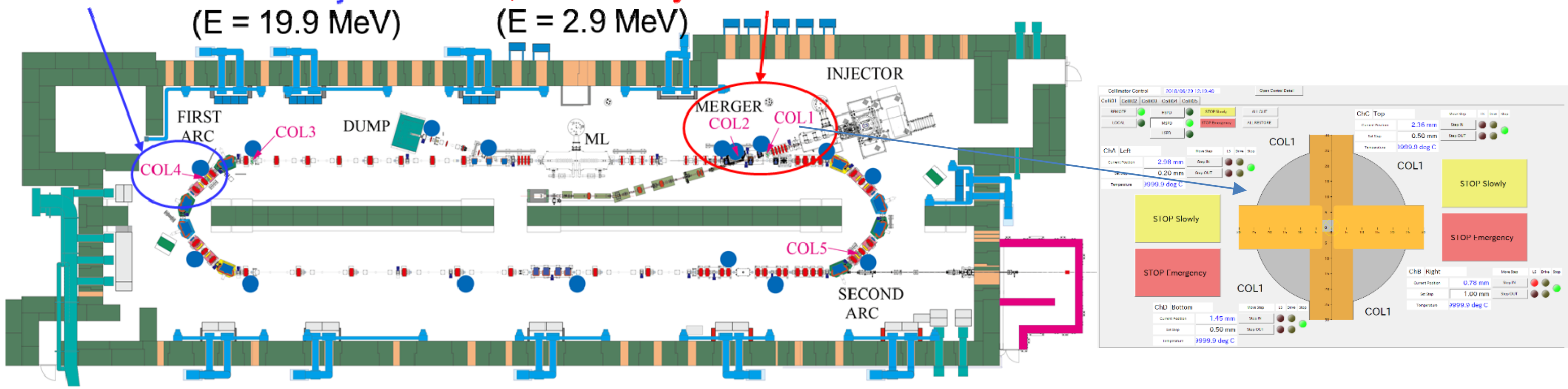
Beam development, reduction of beam loss



- Adjustment of the beam collimator to avoid beam loss

COL4 are used additionally

COL1,2 are mainly used to reduce the beam loss



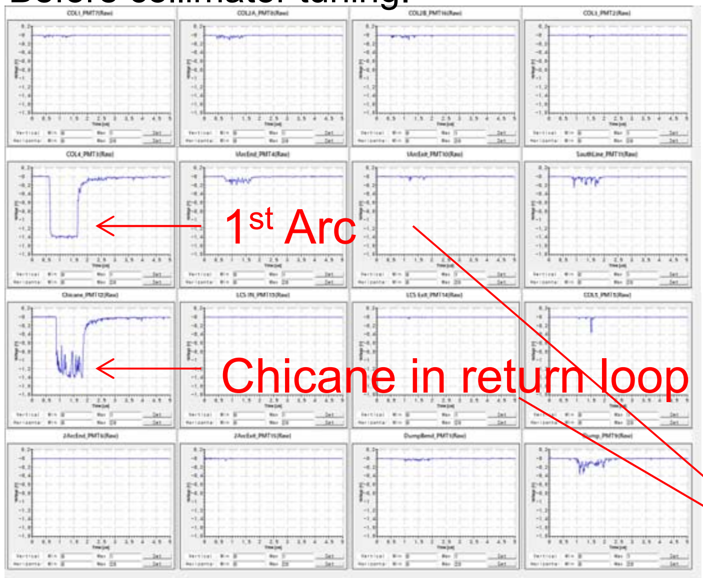
COL1～COL5：Collimaters

● Fast beam loss monitor

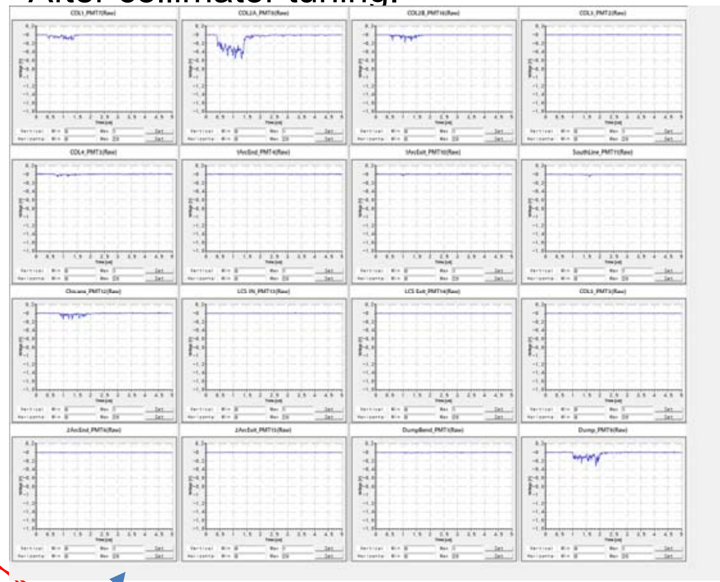
Collimator tuning for CW 1 mA operation

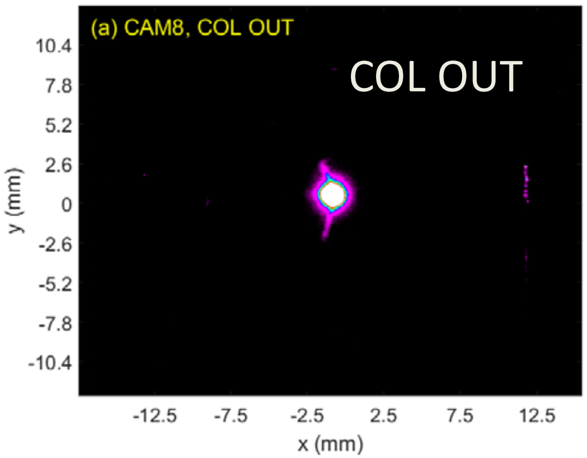
Los monitor signals

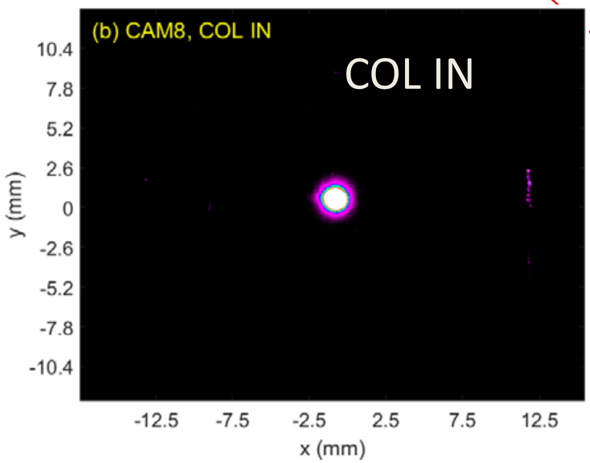
Before collimator tuning.

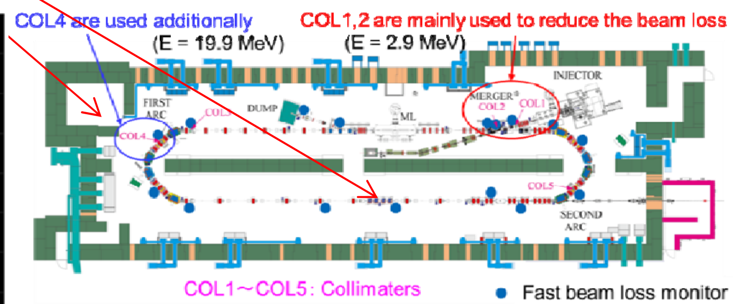


After collimator tuning.







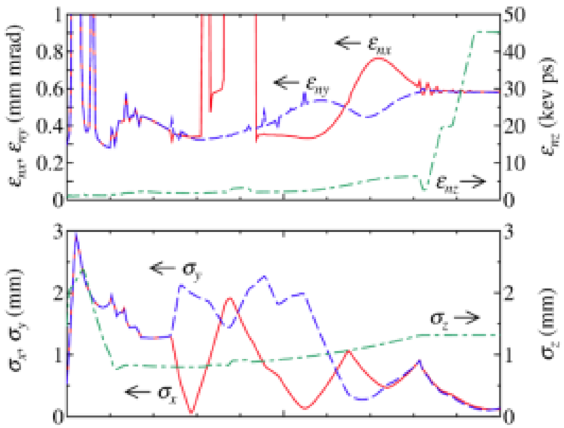


Courtesy of Olga. Tanaka

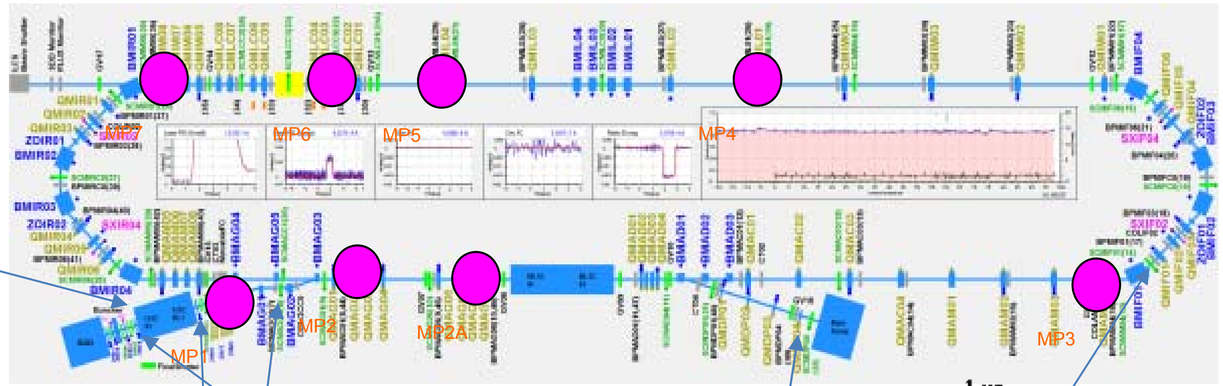
Matching of beam profile and measured emittance with high charge

T. Miyajima, Proc IPAC'15

Calc. of injector parts :
390 keV Gun, 7.7 pC/bunch, laser 3 ps/8 pulse stack



Add new matching point not to make beam loss by using burst mode



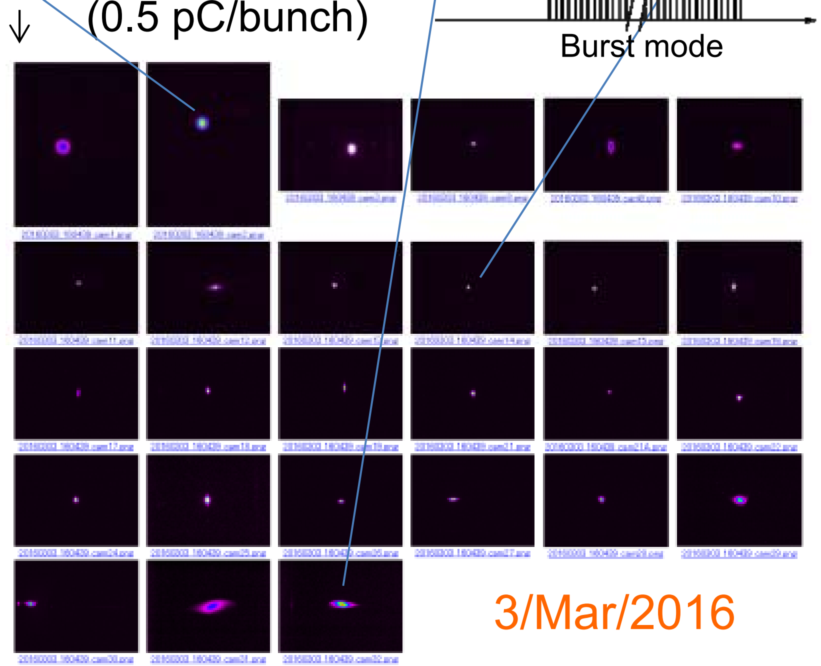
collimator

Burst mode

Measured emittance

Bunch Charge	Normlized Emittance at arc Horiz/Vert [mm.mrad]
0.02 pC	0.14 / 0.14
0.5 pC	0.27 / 0.17
7.7 pC	1.5 / 1.1 (Tentative)

Matching Example (0.5 pC/bunch)



3/Mar/2016

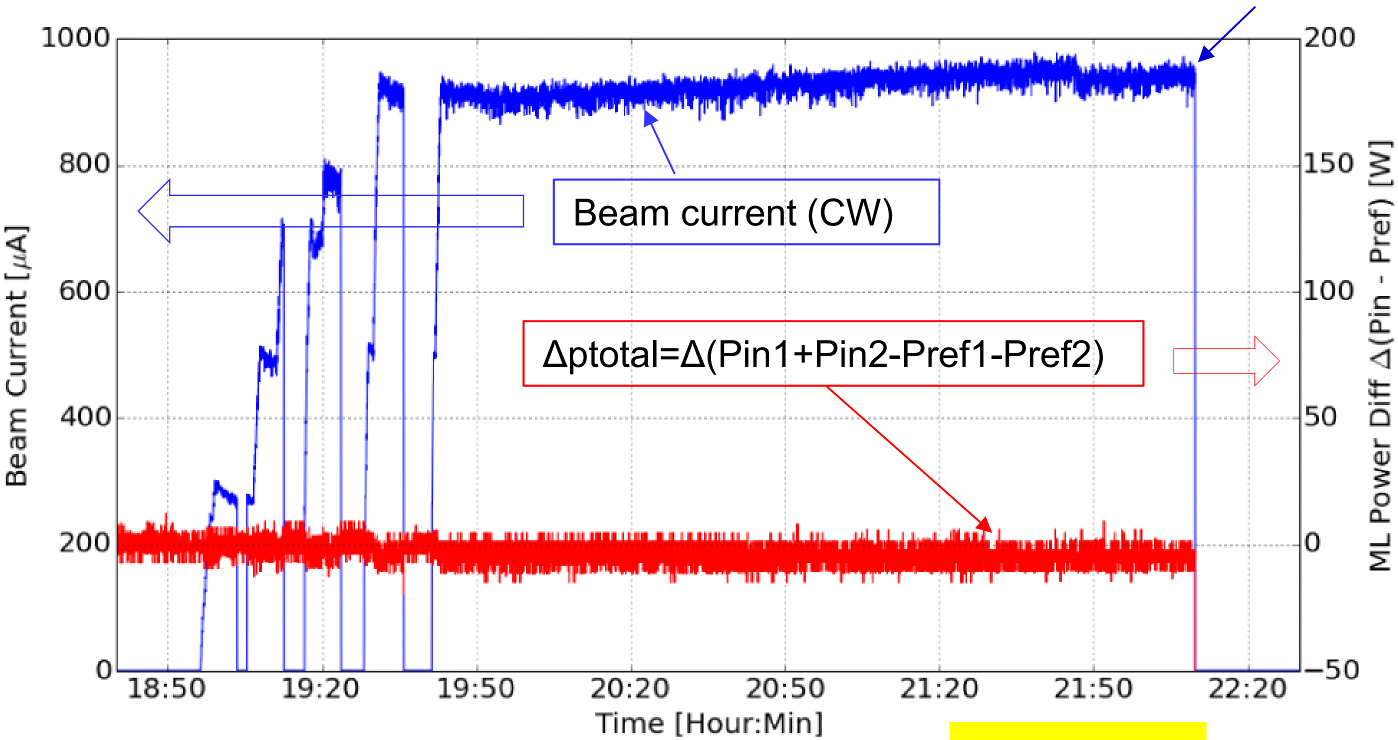
After sophisticated matching, beam profile became good and measured emittance was almost reached our requirements of 1 mm mrad normalized emittance at 7.7pC (equal = 10mA@1.3GHz)

Small beam profile was achieved by matching and collimator

Successful ~ 1mA CW beam operation with energy recovery

Change CW mode and increase the beam current : Reach 0.9 mA after the 1mA approval from the government at 8th/Mar/2016.

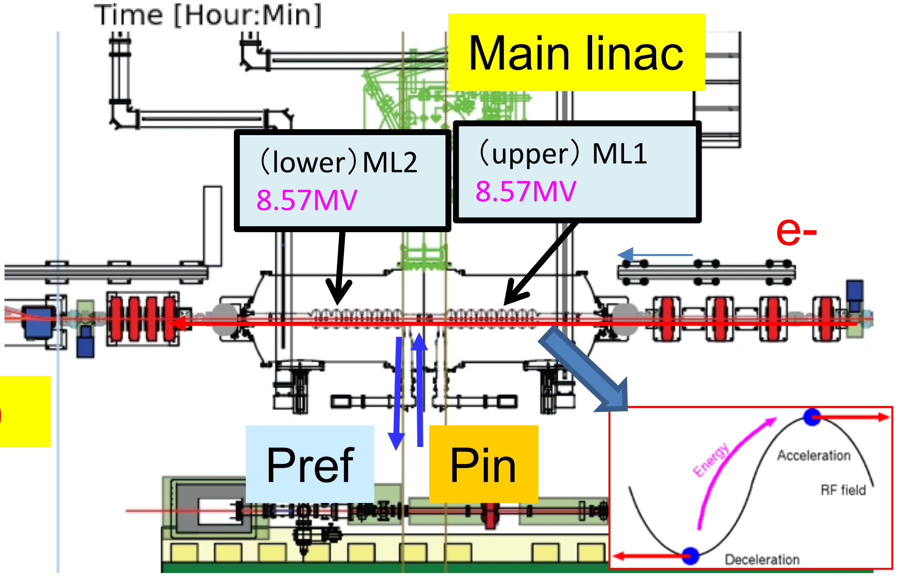
No HOM-BBU was observed.



red : Difference between an input (Pin) and a reflected (Pref) power of the ML. Energy loss measured from the graph = 4 W. (error +-4W)
Required power without recovery is :
17.14 MV x 900 uA = 15.4 kW

Energy Recovery is almost 100.0% (error +-0.03%)

This measurement agree well with beam loss measurement of less than 0.01%

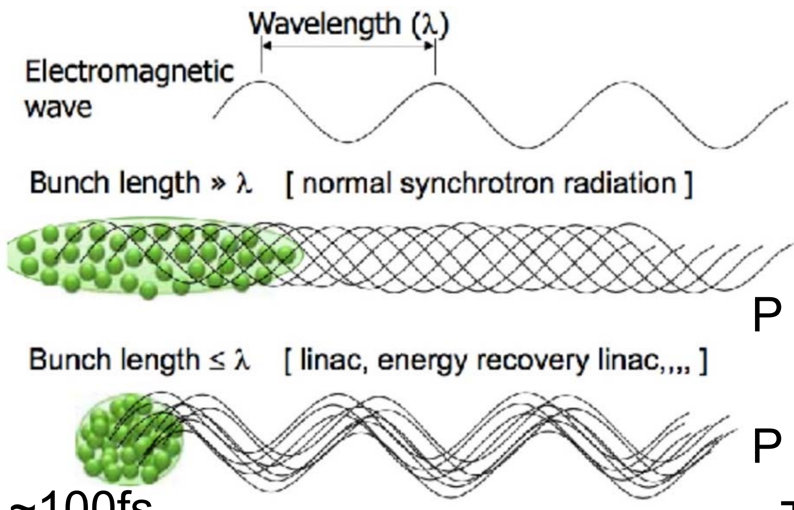


Bunch length and THz measurement

Courtesy of Y. Honda, M.Shimada

- Michelson interferometer at CTR port.
- Spectrum reaching ~1THz
- Bunch length 250fs (RMS) is realized in good reproducibility @2pC/bunch.
- → In 2018 more shorter bunch was achieved. (< 200 fs)

Y. Honda *et al.*, "Beam tuning and bunch length measurement in the bunch compression operation at the cERL" Nucl. Instrum. Method A 875 p.156-164 (2017)



$P \propto N$

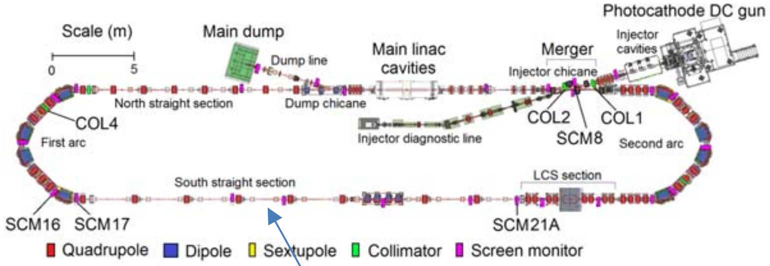
$P \propto N^2$

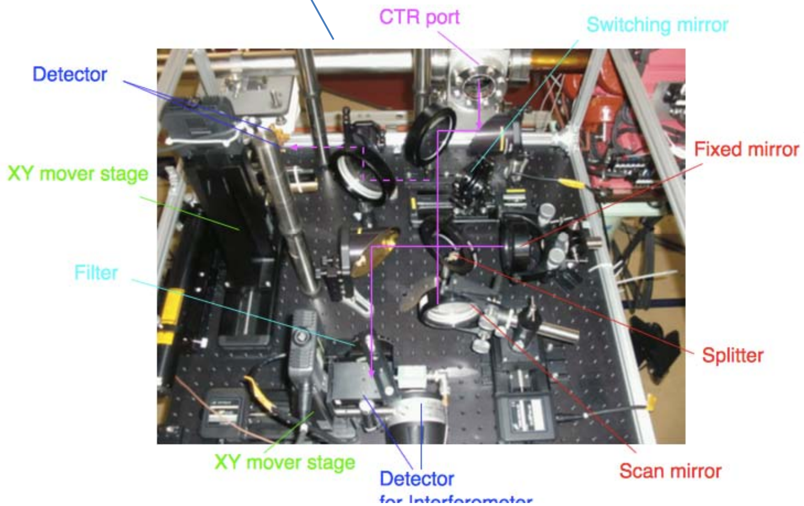
~100fs

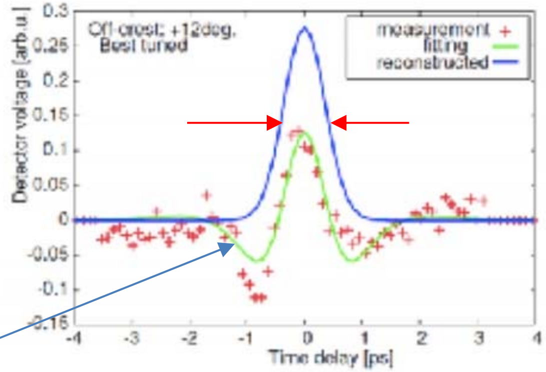
THz

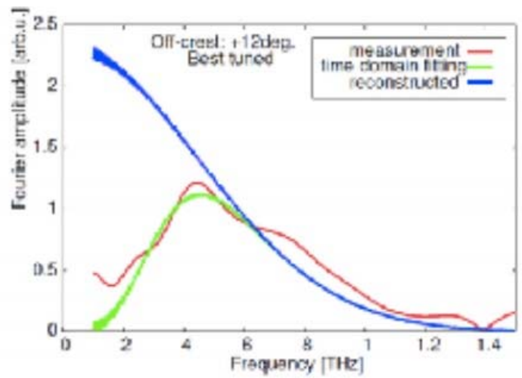
reconstruction

Bumch compression





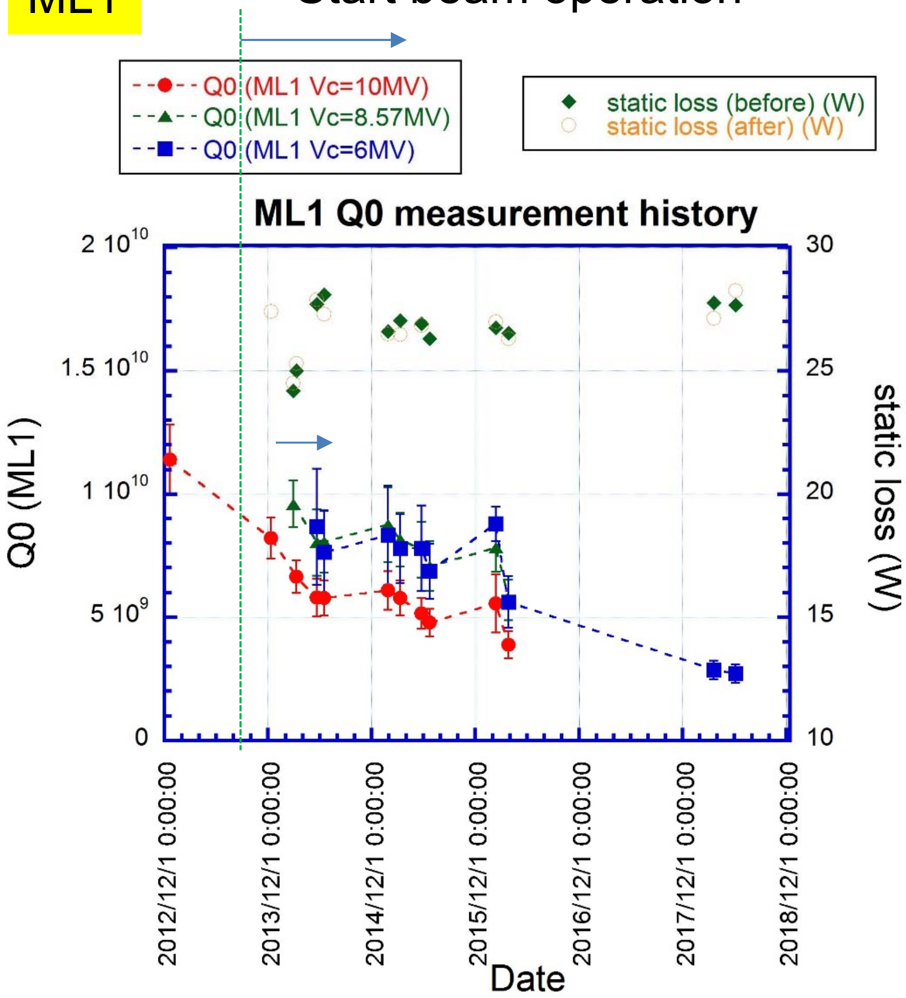




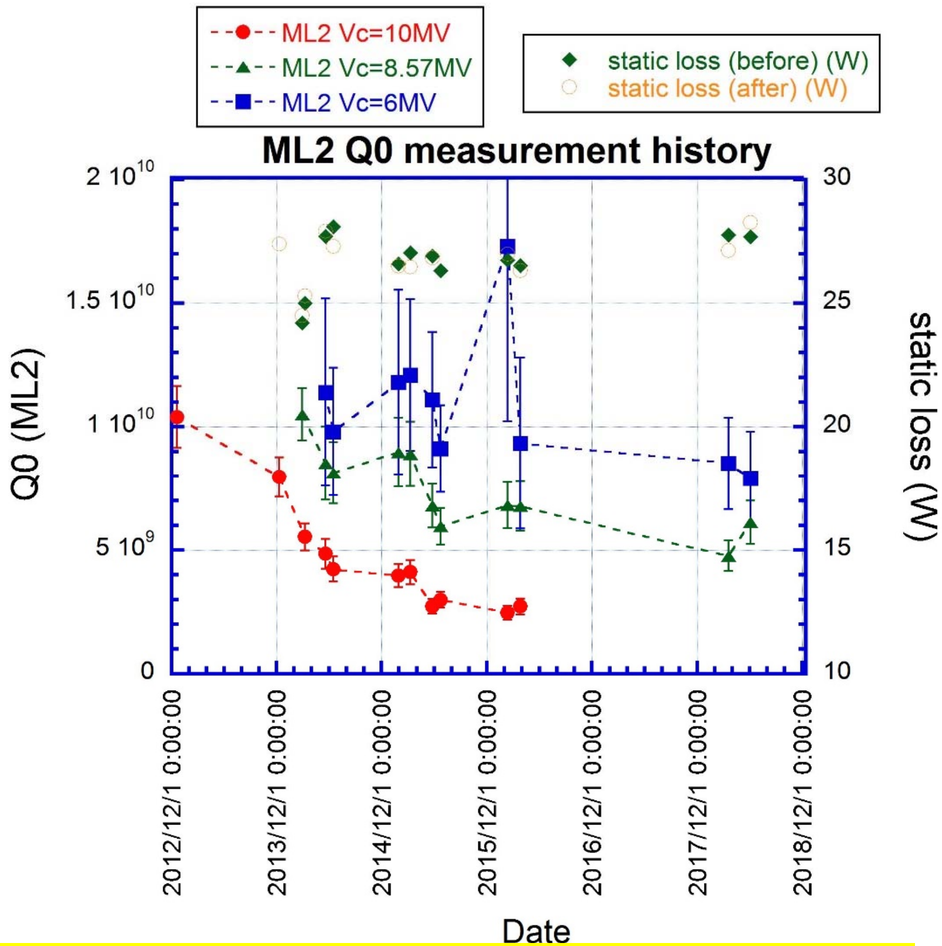
Long term cavity performance of Main linac cavities (5 years) (until 2018.Jun)

ML1

Start beam operation



ML2



We met Q degradation during beam operation.
Main reason is field emission . We applied the pulse processing to be recovered.
But from 2016 ML1 did not reach more than 7MV after unknown burst event. →
ML1 6MV, ML2 8.6MV operation in 2018 stably. We now investigate the reason
(One of the main reason would be the crack of HOM damper as shown later)

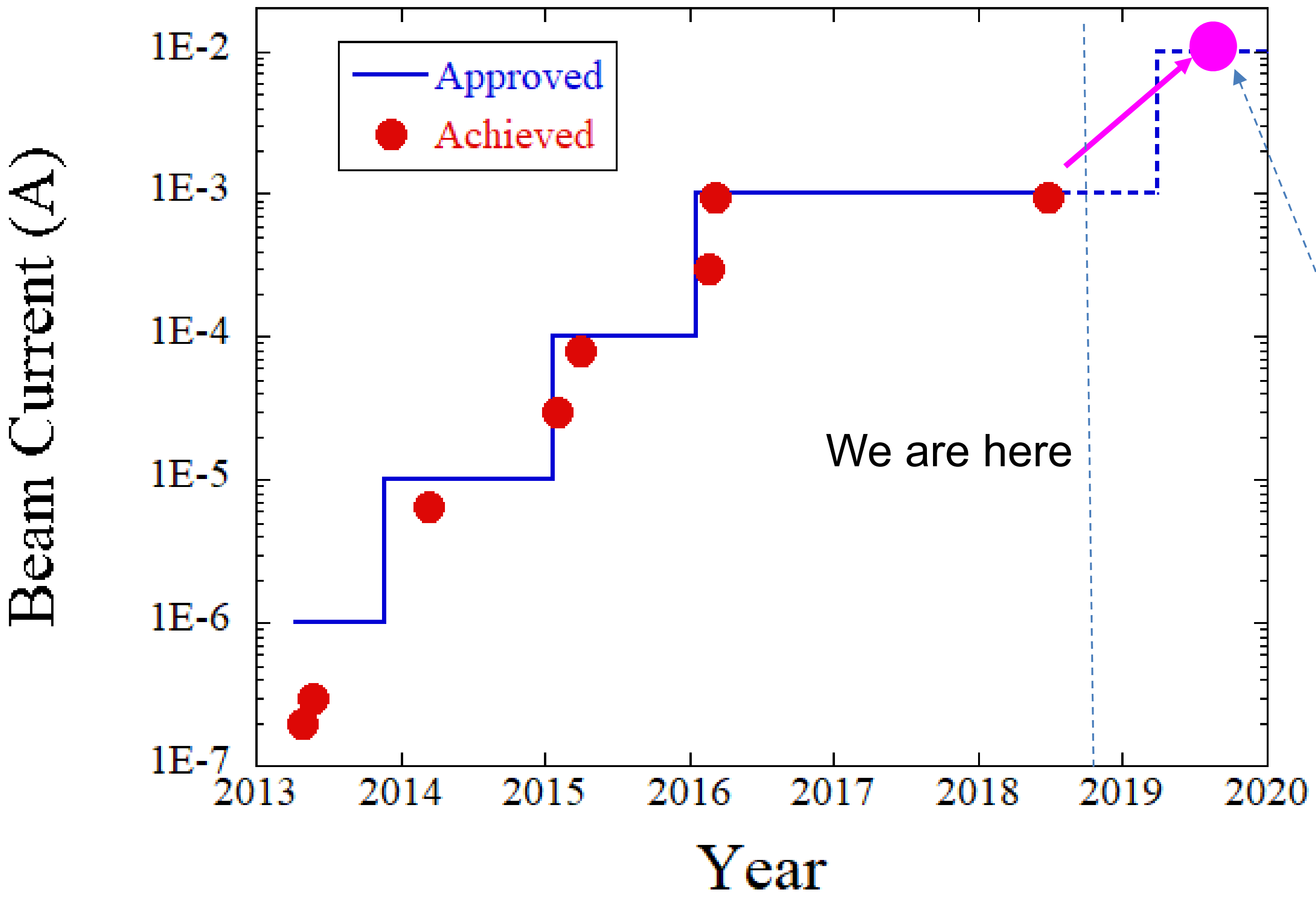
Result of the commissioning (@the end of June/2018)

Parameter of injector	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}	500 kV in operation	500 kV	OK
Normalized Emittance (Medium bunch charge)	≈ 0.8 μm·rad (@7.7 pC/bunch, T=5.6 MeV)	≤ 1 μm·rad (at the beginning)	OK
Normalized Emittance (High bunch charge)	2~3 (@60 pC/bunch)	1 μm·rad	Not bad
Bunch length σ_t	~ 2 ps (@1.5 pC) ~ 7 ps (@7.7 pC)	2 ps (typical)	Not bad
Momentum spread $(\sigma_p/p)_{rms}$	$< 10^{-3}$ (< 1 pC/bunch) $(1.5 - 2.5)\times10^{-3}$ (@7.7 pC/bunch)	$\leq 3\times10^{-3}$ (EUV-FEL)	OK

Parameter of Recirculation loop	Achieved performance	Target Value	Remark
Energy of the electron beam E	19.9 MeV→17.7MeV	35 MeV	Still
Average Current I_0	1mA (steady state)	10 mA	OK
Field gradient of main linac E_{acc}	8.2 MV/m	12 MV/m	Still
Normalized Emittance at RL (Medium bunch charge)	~ 1.0-1.6μm·rad (@7.7 pC/bunch, E=19.9 MeV)	≤ 1 μm·rad	Should be OK
Normalized Emittance at RL (High bunch charge)	2 - 6 μm·rad (@60 pC/bunch)	2 μm·rad (@60 pC/bunch)	Not bad
Bunch compression (σ_t)	0.2ps @ 2pC/bunch	0.1ps	OK

More high bunch charge & current study are needed. Cavity design will be modified.

Beam Currents: Achievement and Prospect



Plan to increase 10 mA in 2019.

By achieving low loss beam operation and high charge low emittance beam generation of 7.7pC.
10 mA operation is within target.

(C) Applications by using cERL

- Super conducting accelerator with ERL scheme gives us high current linac-based electron beam (~10mA) with high quality of the electron beam such as small emittance, Short pulses.

- The unique performance gives us several important industrial applications as follows.
  - High resolution X-ray imaging device for medical use
  - Nuclear security system (gamma-ray by LCS)
  - RI manufacturing facility for nuclear medical examination
  - EUV-FEL for Future Lithography (Already explained)
  - Intense THz light generation

Already achieved these application by using Laser Compton Scattering (LCS) Exp.

Next targets in a few year

Plan with cERL beam operation (2018~2020)

- New beam line for 99Mo RI production in cERL. (Will start in 2019)
- 10 mA beam operation with energy recovery is within our target in 2019. And we will produce FEL with this high current beam in the IR-FEL regime. (POC of EUV-FEL plan) Including high charge beam operation (~60pC).
- ~100fs bunch operation with THz generation (RCDR experiment)

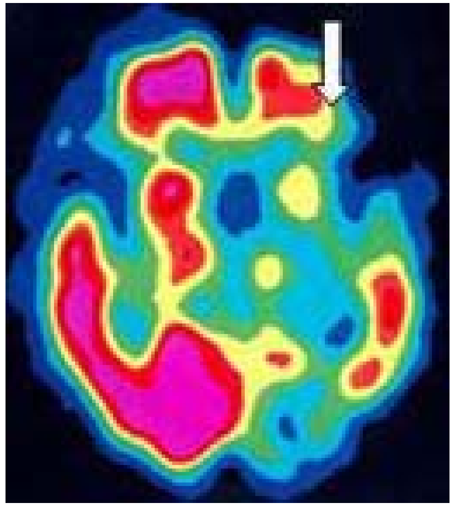
RI manufacturing facility for nuclear medical examination (^{99}Mo/^{99m}Tc)

Concern about the stable supply of ^{99}Mo / ^{99m}Tc

- ^{99}Mo is almost 100% imported, even though the largest number of applications in nuclear medicine diagnosis
- Problem of the stable air transportation

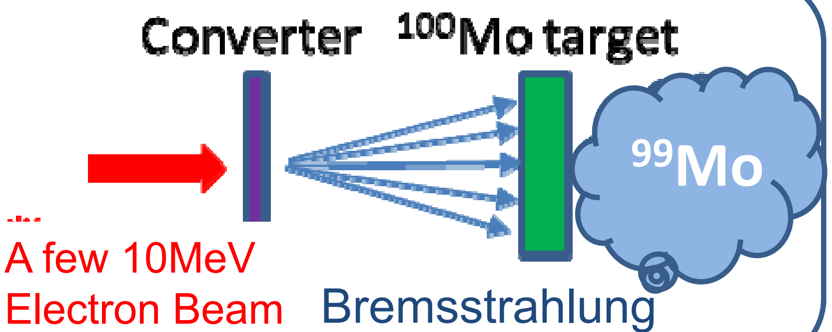
(Problem caused by volcanic eruption in the past)

- Most ^{99} Mo is manufactured in nuclear reactor
- Due to the aging of nuclear reactors, stable supply in the future is a big issue



A state of brain blood flow revealed by nuclear medicine diagnosis by 99 ^{m}Tc

Development of RI manufacturing (^{99} Mo / ^{99m}Tc) by using accelerator for stable supply

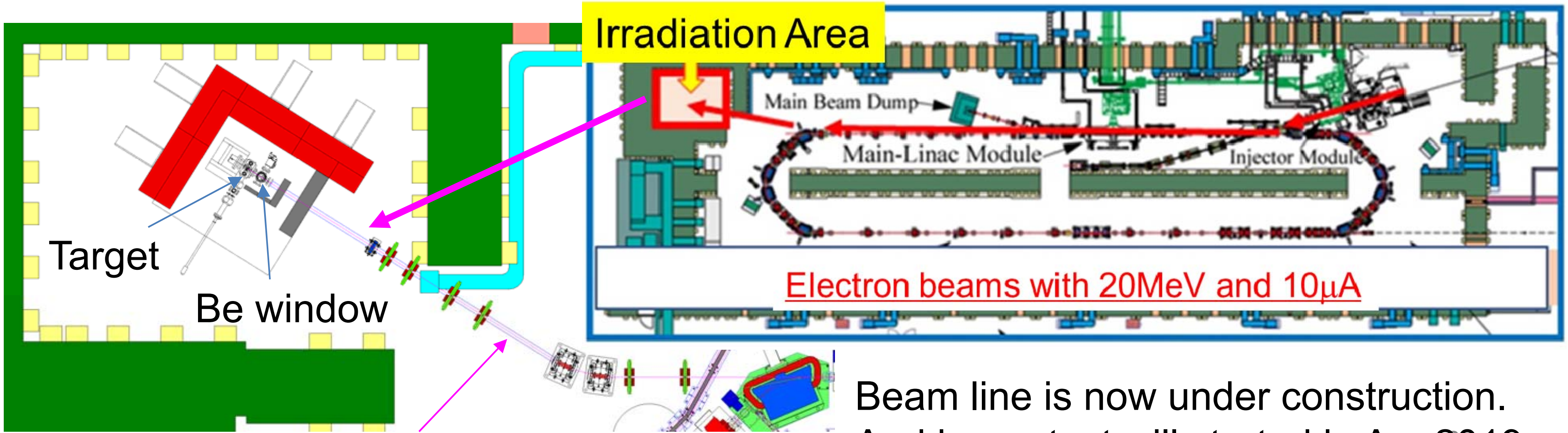


Required Specification for accelerator (final)

- 20 ~ 50 MeV electron beam
- Several mA to 10 mA

Test Experiment to produce ^{99}Mo in cERL is preparing

- The test irradiation of electron beams to a multiple molybdenum target will be done at this fiscal year to produce ^{99}Mo and check the yield of the production in order to realize a real machine with large electron beam power.
- It is necessary to get several knowledge to design a target system for large irradiation power such as a practical technique for ^{99}Mo production, target thermal design, shielding radiation design and legal procedures, etc. It is the final objective of this project.



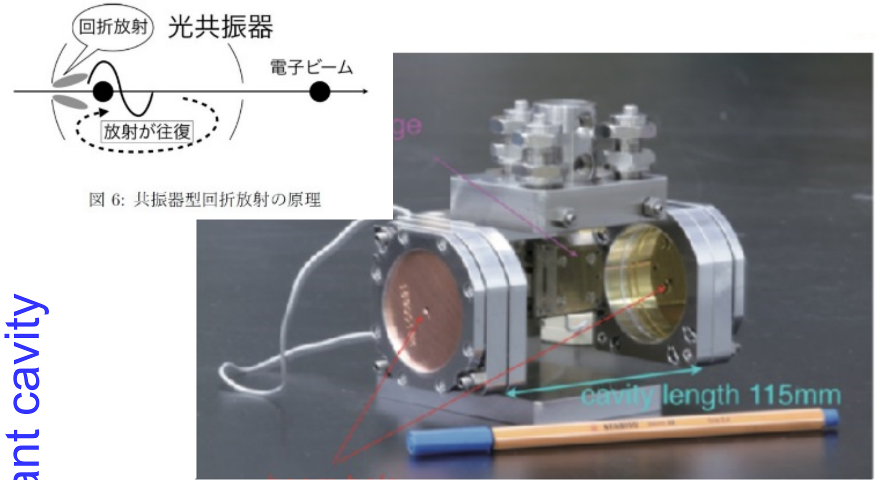
Mo 20MeV 10μA(maximum)

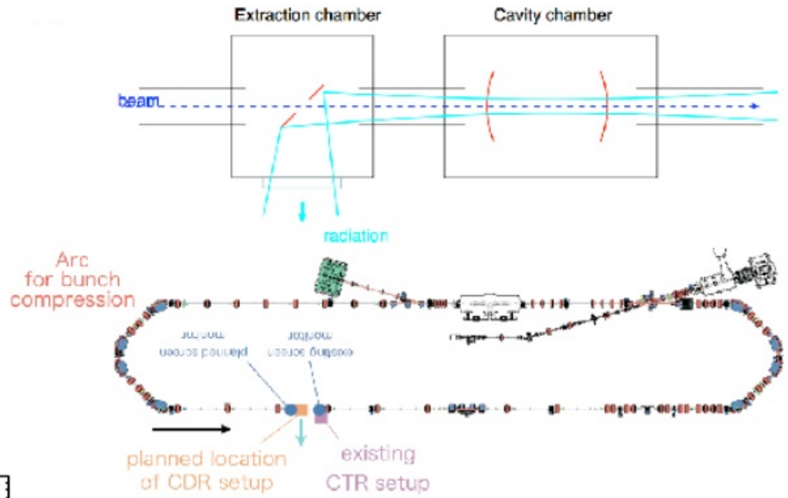
Beam line is now under construction.
And beam test will started in Apr.2019.

We are engaged in R & D on utilization of accelerator beams for radioisotope generation and reforming of organic matter under research contract with "Accelerator Inc." https://www.accelerator-inc.com/

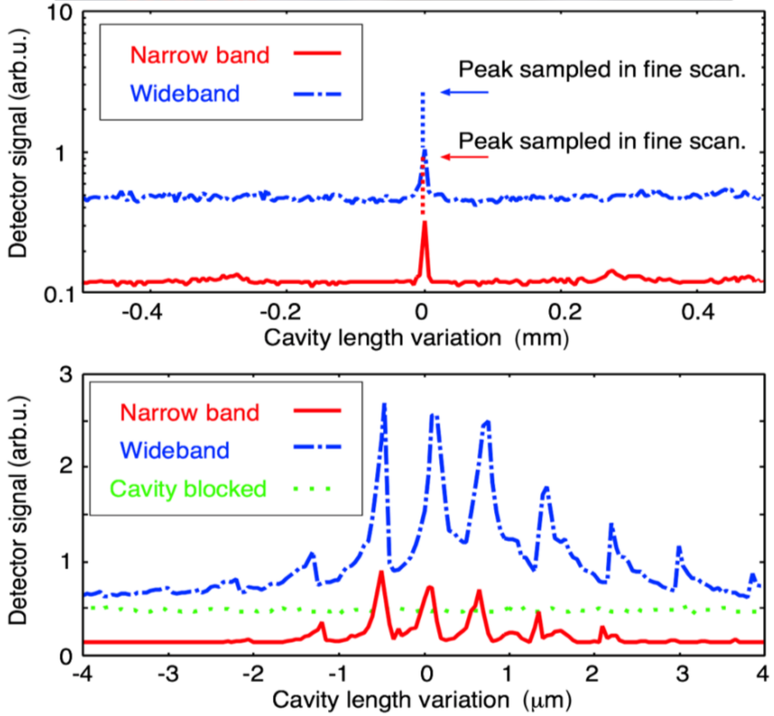
Coherent Resonant Diffraction radiation THz (2018)

Y.Honda, et. al., “Stimulated Excitation of an Optical Cavity by a Multibunch Electron Beam viaCoherent-Diffraction-Radiation Process”, Phys. Rev. Lett., 121, 184801 (2018)

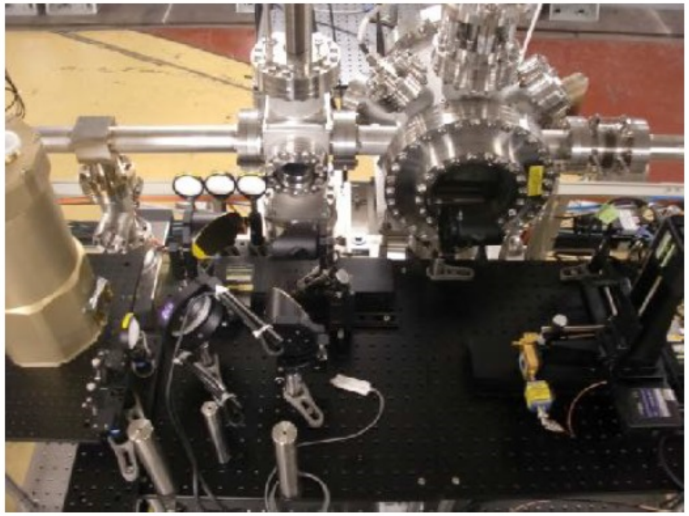




Intensity of THz from Resonant cavity



Cavity length scan results.

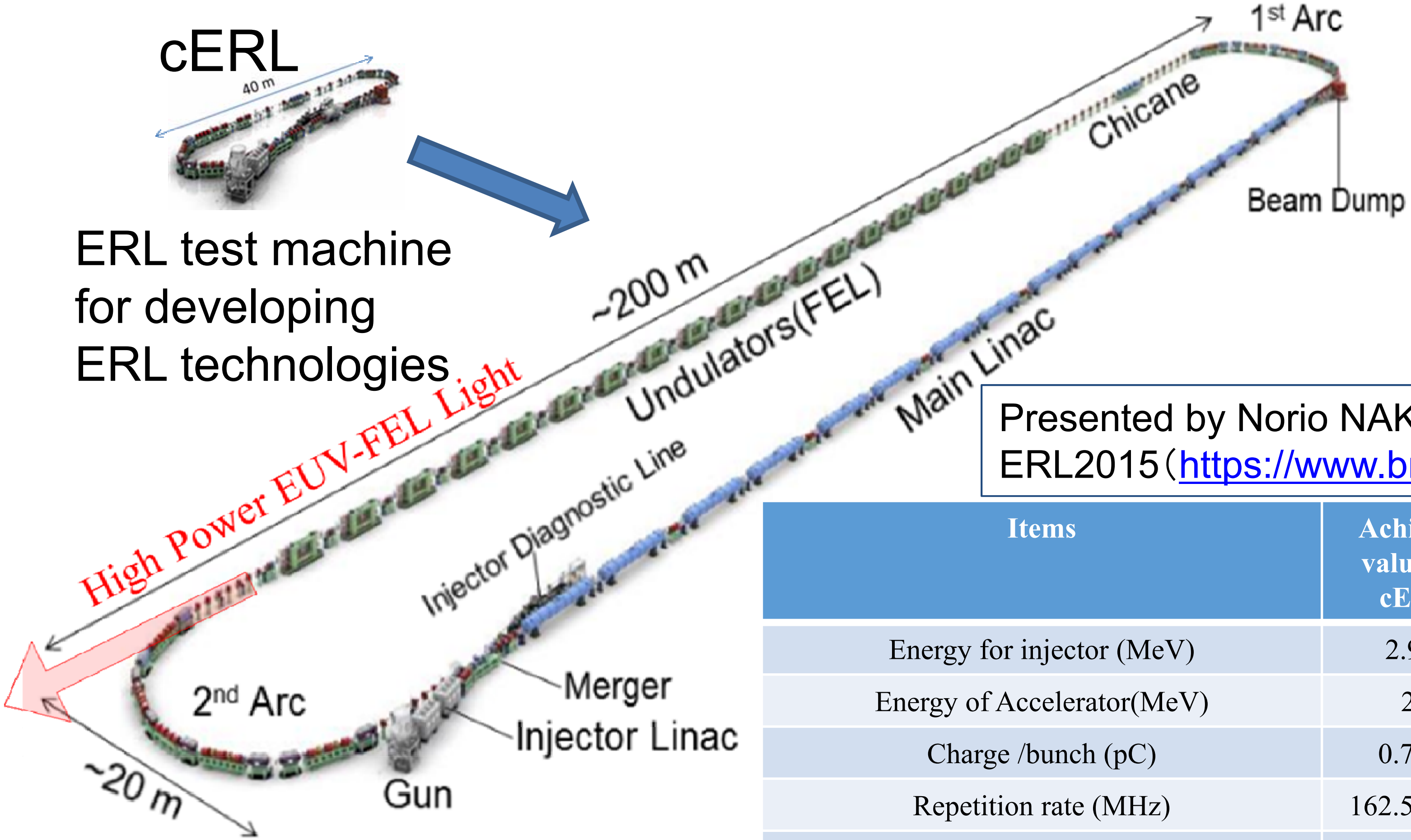


New idea to obtain the intense THz.

ERL beam suitable to generate shorter bunch and high intense THz light.

In 2019, THz beam line will be prepared.

Prototype design of the EUV-FEL



10mA is our target

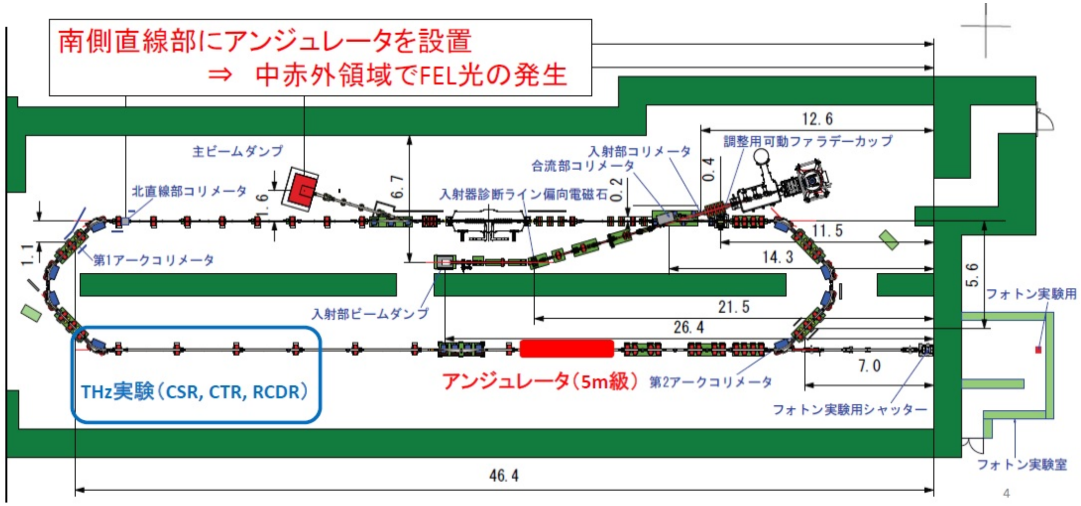
Presented by Norio NAKAMURA
ERL2015（https://www.bnl.gov/erl2015/ ）

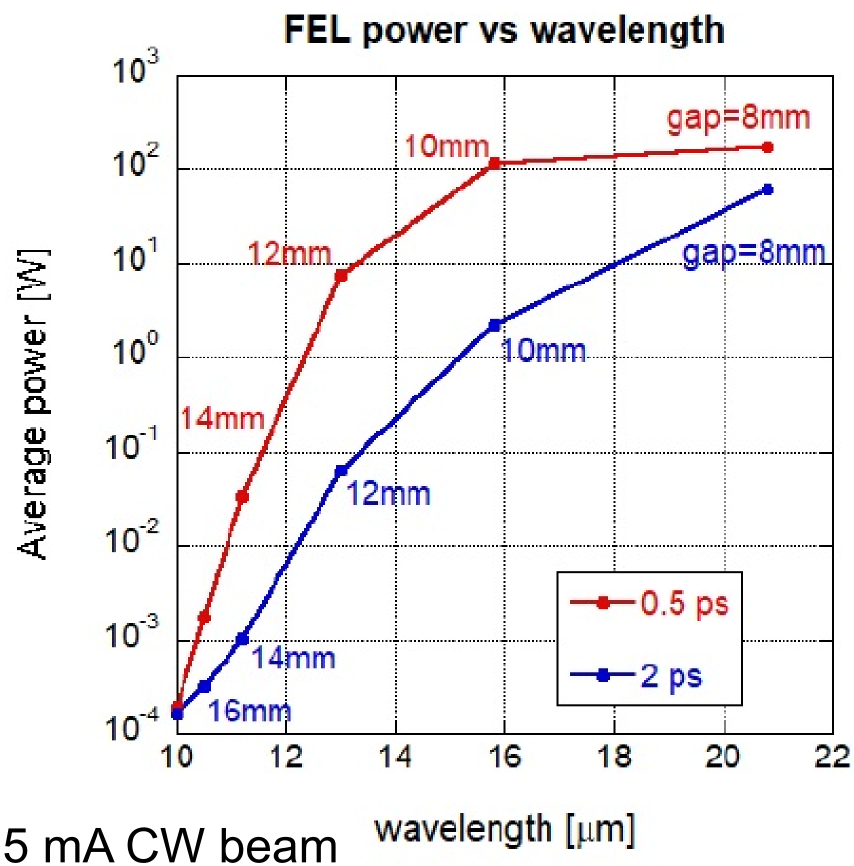
Items	Achieved values in cERL	Design at the EUV-FEL
Energy for injector (MeV)	2.9-6	10.5
Energy of Accelerator(MeV)	20	800
Charge /bunch (pC)	0.7-60	60
Repetition rate (MHz)	162.5-1300	162.5
Average Current (mA)	1.0	9.75
Emittance for electron beam (mm mrad)	0.3-1	~0.7
Gradient of the accelerated energy (MV/m)	8.3	12.5
Wavelength of EUV-FEL (nm)	/	13.5
Average power of EUV-FEL (kW)	/	>10 kW

Design strategy (main linac)
Epeak/Eacc is 1.5 times reduced from cERL cavity to overcome field emission.
8.3 MV/m → 12.5MV/m

cERL-FEL plan

Detailed configuration is under designing and calculation.





5 mA CW beam

Beam parameter

- Energy : 17.5 MeV
- Bunch charge : 60 pC
- Repetition : 81.25 MHz
- Bunch length : 2ps (0.5ps)
- Energy spread : 0.1%
- Beam emittance : 3π mm mrad

Undulator parameter

- Period λu : 22 mm
- Total length : 5 m
- Number of Undulator : 1 unit

We can get more than 100W IR-FELby using present cERL beam.
→ Good demonstration for EUV-FEL ??

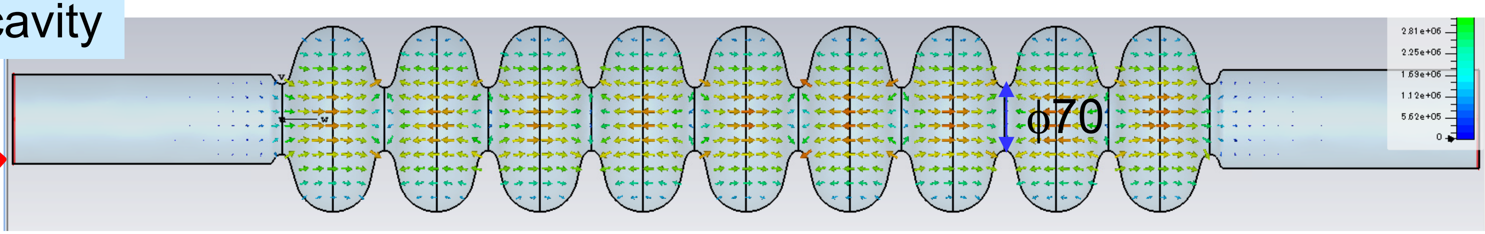
Design of Main Linac Cavity of EUV-FEL

How to overcome field emission

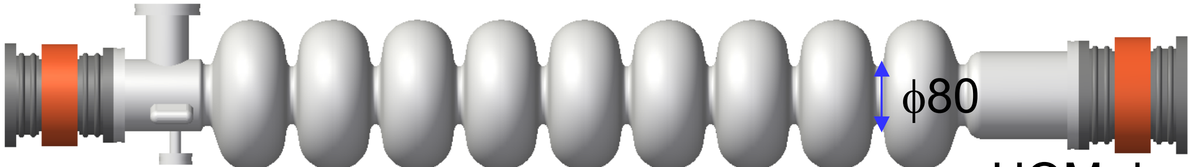
EUV cavity – TESLA-type 9-cell cavity + Large beam pipes(100ϕ & 110ϕ)

→ Satisfy the HOM-BBU threshold of more than 100mA by EUV cavity.

EUV cavity



cERL cavity (Model 2) – HOM damped cavity for 100mA operation



Parameters for acceleration mode

	ERL Model 2	EUV		ERL Model 2	EUV
Frequency	1300 MHz	**1300 MHz**	Iris diameter	80 mm	70 mm
R_{sh}/Q	897 Ω	**~1000 Ω**	$Q_o \times R_s$	289 Ω	~270 Ω
E_p/E_{acc}	3.0	**~ 2.0**	H_p/E_{acc}	42.5 Oe/(MV/m)	~42.0 Oe/(MV/m)

From cERL stable beam operation of 8.5~10MV/m in 3 years with less trip ratio.
Stable operation at 12.5 MV/m seems achievable due to reduced E_p/E_{acc}.

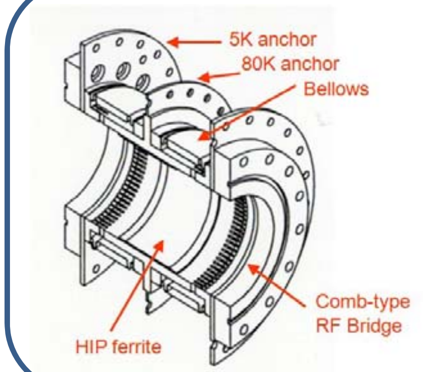
For higher CW beam current of more than 10 mA (Brazing test of AlN based HOM damper prototype)

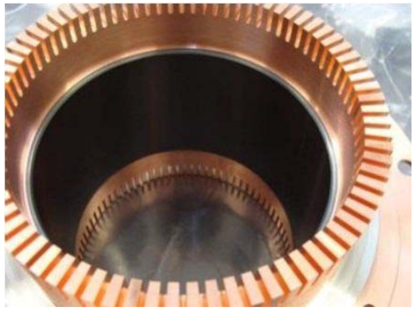
By T.Ota
By M.Sawamura

- cERL used Ferrite with HIP bonding was used for HOM damper (KEKB type)→ some crack was shown.
- AlN cylinder were brazed in the copper cylinder .Brazed by Silver at 750 degree under Hydrogen Furnace.
- We try to check thermal cycle and works well.
- We also try to make HOM coupler with new idea.

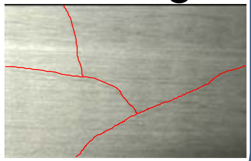
We assumed that this crack made some particulate in the cavity and made degradation of main linac cavity

T. Ota, et. al. "DEVELOPMENT OF HOM ABSORBERS FOR CW SUPERCONDUCTING CAVITIES IN ENERGY RECOVERY LINAC" ,Proc. of 15th annual workshop of Particle Accelerator Society of Japan, THPO055, Nagaoka, Japan (2018)

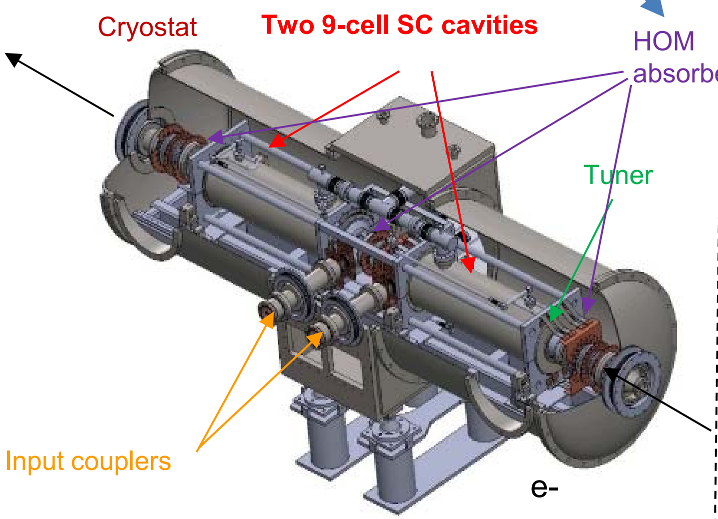




Ferrite with HIP bonding



cERL HOM damper



cERL Main linac cryomodule

We try to make new HOM damper & coupler.

New C-shape HOM coupler

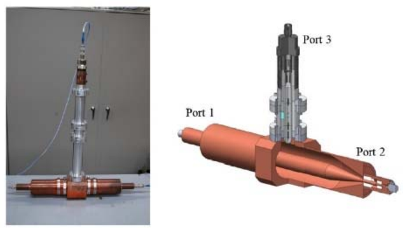
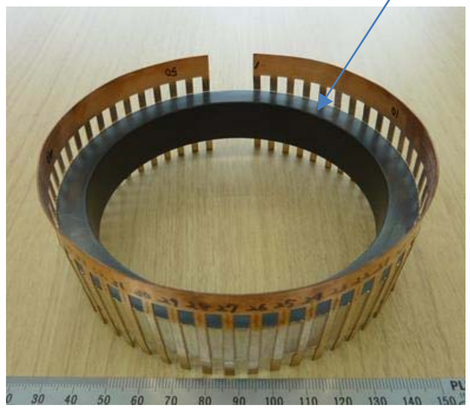


Fig. 18. Coaxial transmission line with CSWG type pickup port (left) and schematic view (right).

M.Sawamura et. al., "Properties of the RF transmission line of a C-shaped waveguide" NIM A 882 (2018) 30-40

New HOM damper (Prototype)

AlN



Not shown in detail

We did not see many cracks by using prototype under cooling test. → will make new HOM damper in this fiscal year

Collaborative works with Toshiba company.

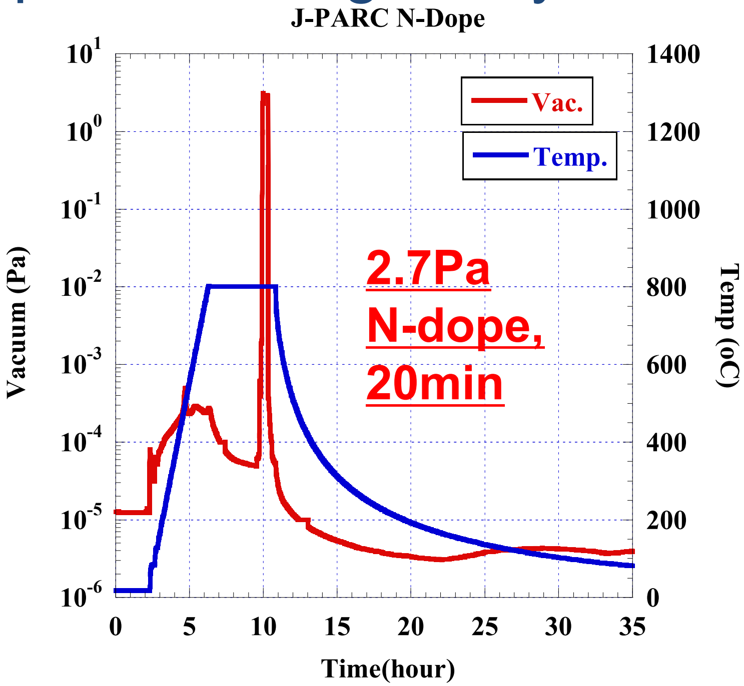
SRF for Higher-Q

power consumption
$\propto$ Eacc^2/Q

One of essential factors to achieve higher Q values is to dope N2 during cavity annealing.

Courtesy of K. Umemori

New furnace in KEK

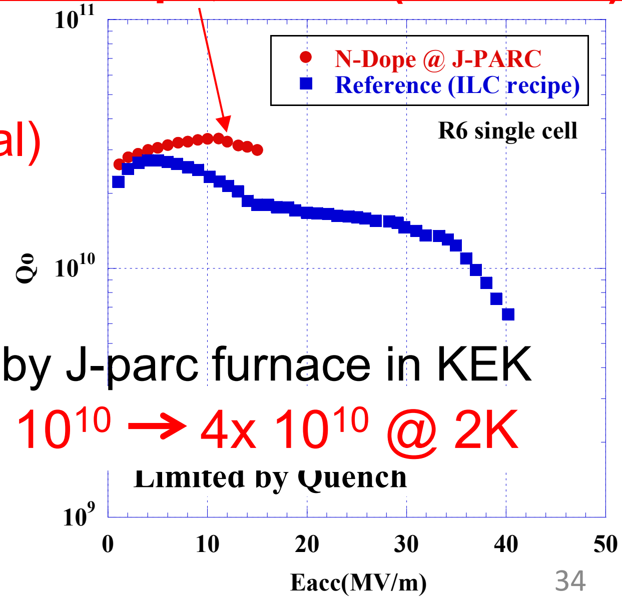


T. Okada, et. al. "Improvement of cavity performance by nitrogen doping at KEK" ,Proc. of LINAC18, TUPO065, Beijing, China (2018)

Improvement of Q values from normal processing to nitrogen doping treatment

2.7Pa N-dope, 20min (15um EP)

(nominal)
1x 10^{10}



Success by J-parc furnace in KEK
2x 10^{10} → 4x 10^{10} @ 2K

2~4 times higher than nominal value. → low loss for ERL operation

Summary

- Review ERL work and SRF based accelerator all over the world. These demands increase for next generation accelerator for High Energy physics and FEL source.
- High current beam operation of 1mA was achieved at Compact ERL in KEK. → plan to increase 10mA.
- cERL now move to use for the industrial application by using SCRF technology. 99Mo beam line will be built for RI production with CW intense beam.
- Diffraction radiation by Resonant cavity can give high intense THz with ERL CW beam with about 100 fs bunch.
- Conceptual design study for EUV-ERL-FEL was carried out to open the era of more higher light source of EUV-lithography, 10 kW class high power EUV light source is NOT just a dream from the experience of cERL in KEK.

Acknowlegements

since 2015

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S. Ishihara (Leader)

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Waseda Univ.
M. Washio

Osaka Univ.
T. Kozawa

Industries

TOSHIBA Leading Innovation

MITSUBISHI HEAVY INDUSTRIES MECHATRONICS SYSTEMS, LTD.

Hitachi Metals, Ltd.

GIGAPHOTON

TAIYO NIPPON SANSO The Gas Professionals

Industrialization of High Power EUV light source based on ERL@KEK and FEL@QST

EIDEC

HITACHI

TOYAMA

TOSHIBA Leading Innovation
TOSHIBA ELECTRON TUBES & DEVICES CO.,LTD.

MITSUBISHI ELECTRIC Changes for the Better

NTT AT

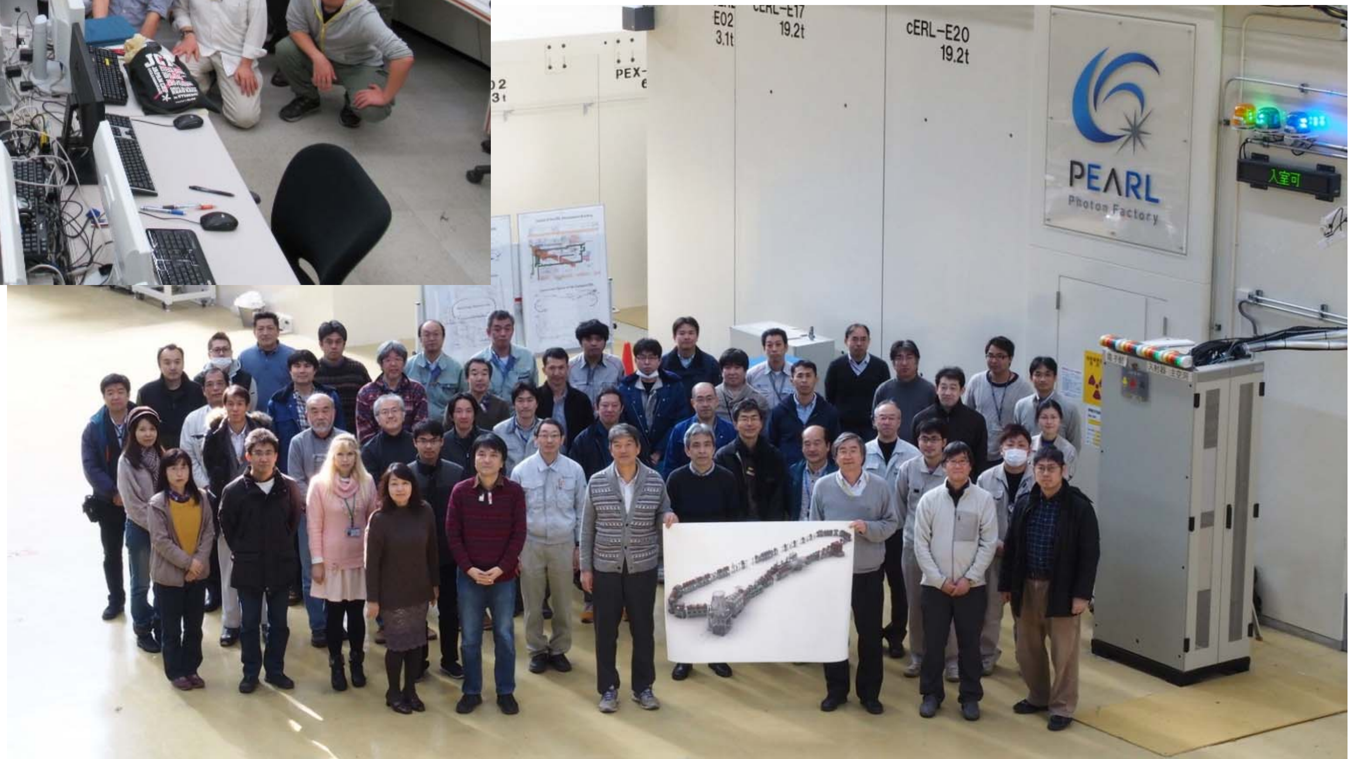
QST R. Hajima

KEK H. Kawata et al.

AIST N. Sei

Thank you for all Japan association

Thank you for your attention!



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

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R. Hajima, S. Matsuba [on leave], M. Mori, R. Nagai, M. Sawamura, T. Shizuma, N. Nishimori

Hiroshima University
M. Kuriki, Lei Guo

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