Status of the Compact ERL and the Future ERL Plan at KEK

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for the ERL development team

High Energy Accelerator Research Organization (KEK)

Talk at the Jefferson Lab., December 20, 2011.

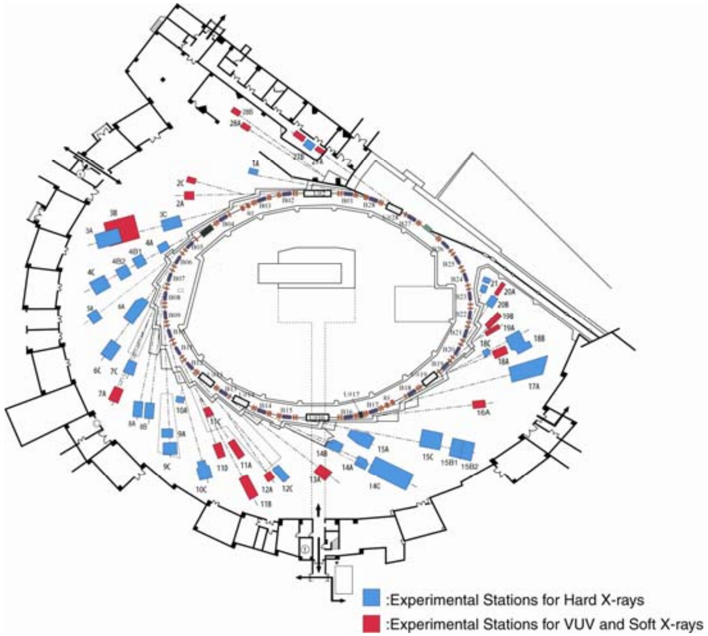
Outline

1. Outline of the ERL plan at KEK
2. Design of the Compact ERL (cERL)
3. Status of R&D and Construction
4. Summary

1. Outline of the ERL plan at KEK

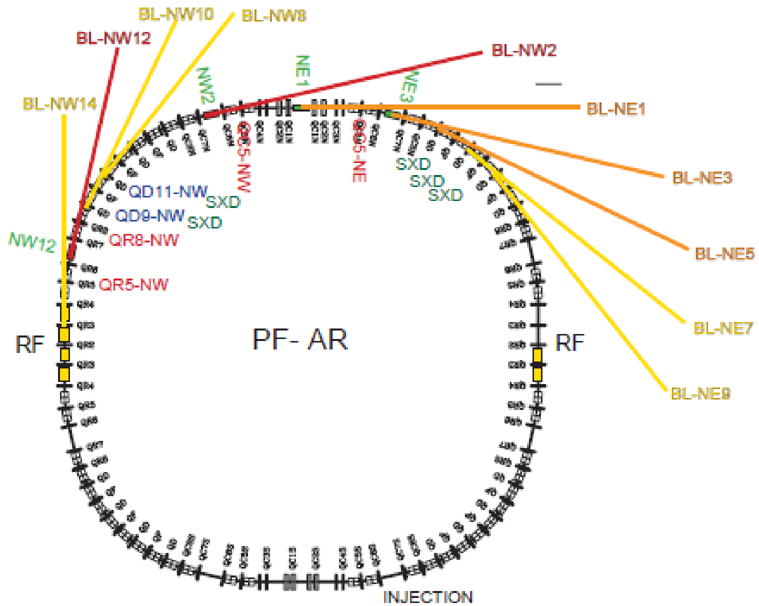
KEK Photon Factory (at present)

PF ring (2.5 GeV)



- E = 2.5 GeV, C = 187 m
- Beam emittance : 34.6 nm rad
- Top-up operation
- 10 insertion devices
  - In-vacuum X-ray undulators: 3
  - VUV/SX undulators: 5
- 22 beamlines, 60 experimental stations
- Since 1982

PF-AR (6.5 GeV)



- E = 6.5 GeV (injection: 3 GeV), C = 377 m
- Beam emittance: 293 nm·rad
- Single bunch operation (full time)
- 8 beamlines, 10 experimental stations
  - In-vacuum X-ray undulators: 5
  - Multi-pole wiggler : 1
- Since 1987

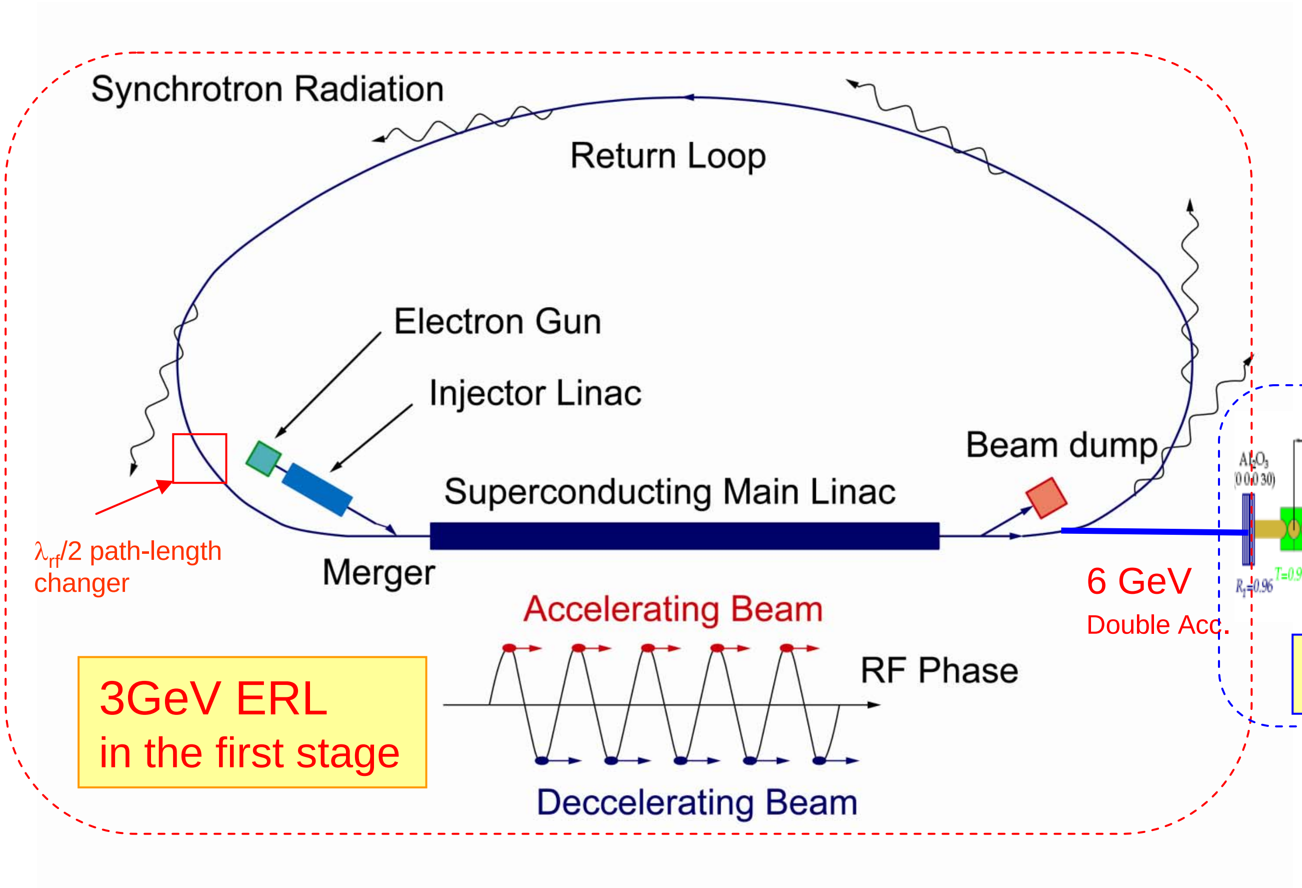
3GeV ERL Light Source Plan at KEK

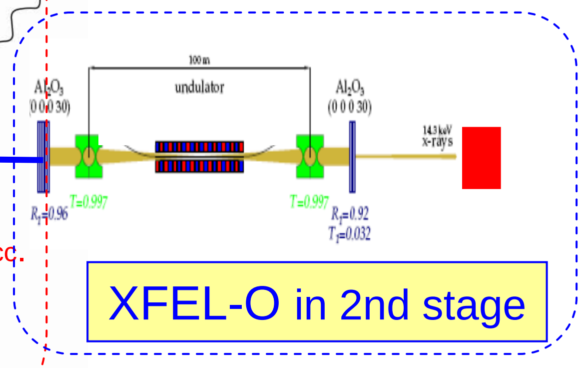
Needs for future light source at KEK

- Driving cutting-edge science
- Succeeding research at the Photon Factory (2.5 GeV and 6.5 GeV rings)

3-GeV ERL which is upgradable to a driver for an XFEL oscillator

Layout and beam optics are under design.



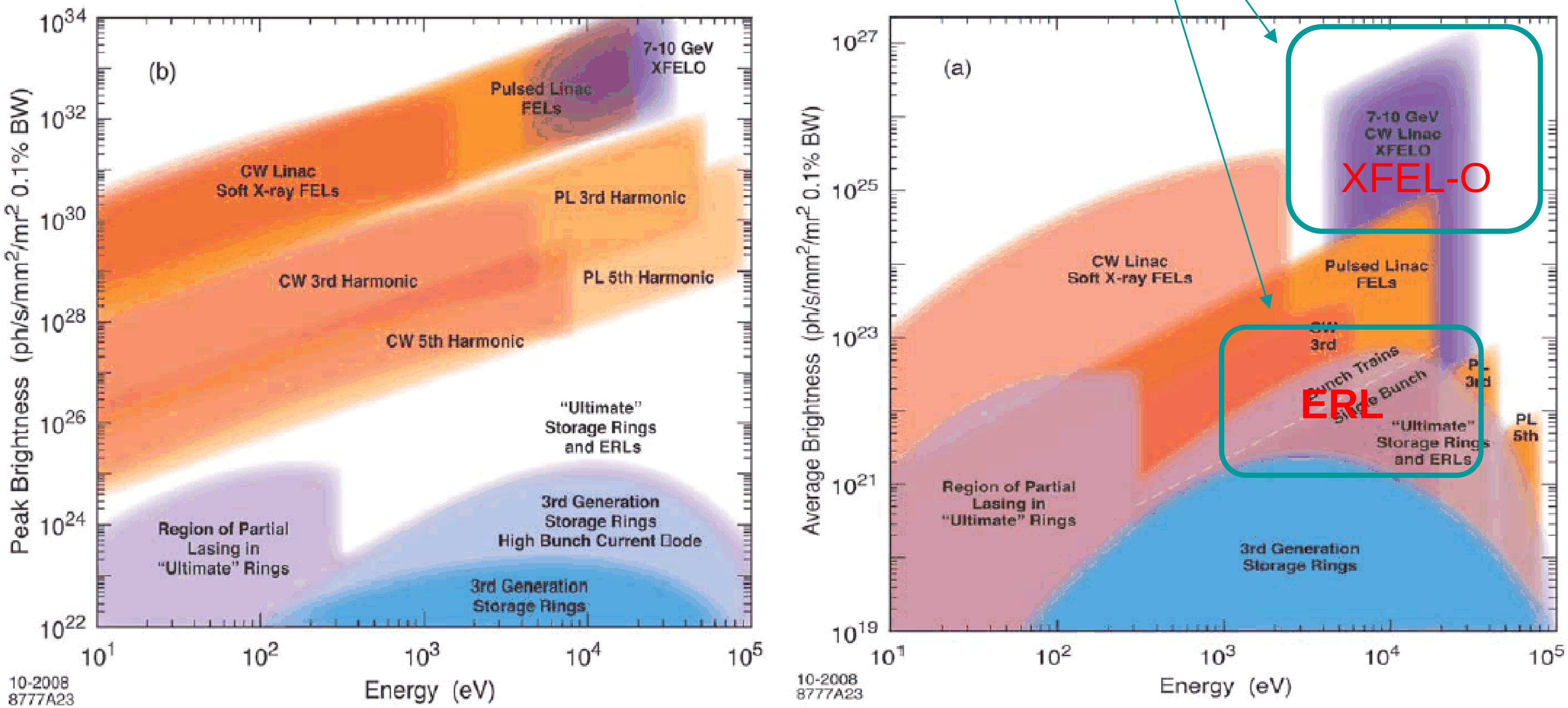


Typical parameters

	$\underbrace{\text{High coherence (HC) mode}}$	High flux (HF) mode	Ultimate mode (future goal)	XFEL-O[1)]
Beam energy	3 GeV			7 (6) GeV
Beam current	10 mA	100 mA	100 mA	20 μA
Charge/bunch	7.7 pC	77 pC	77 pC	20 pC
Bunch repetition rate	1.3 GHz	1.3 GHz	1.3 GHz	1 MHz
Normalized beam emittance (in x and y)	0.1 mm·mrad	1 mm·mrad	0.1 mm·mrad	0.1 mm·mrad
Beam energy spread (rms)	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Bunch length (rms)	2 ps	2 ps	2 ps	2 ps

1) Parameters are cited from: K.-J. Kim et al., Phys. Rev. Lett. **100**, 244802 (2008); R. Hajima, FEL08, MOPPH048.

Target: spectral brightness

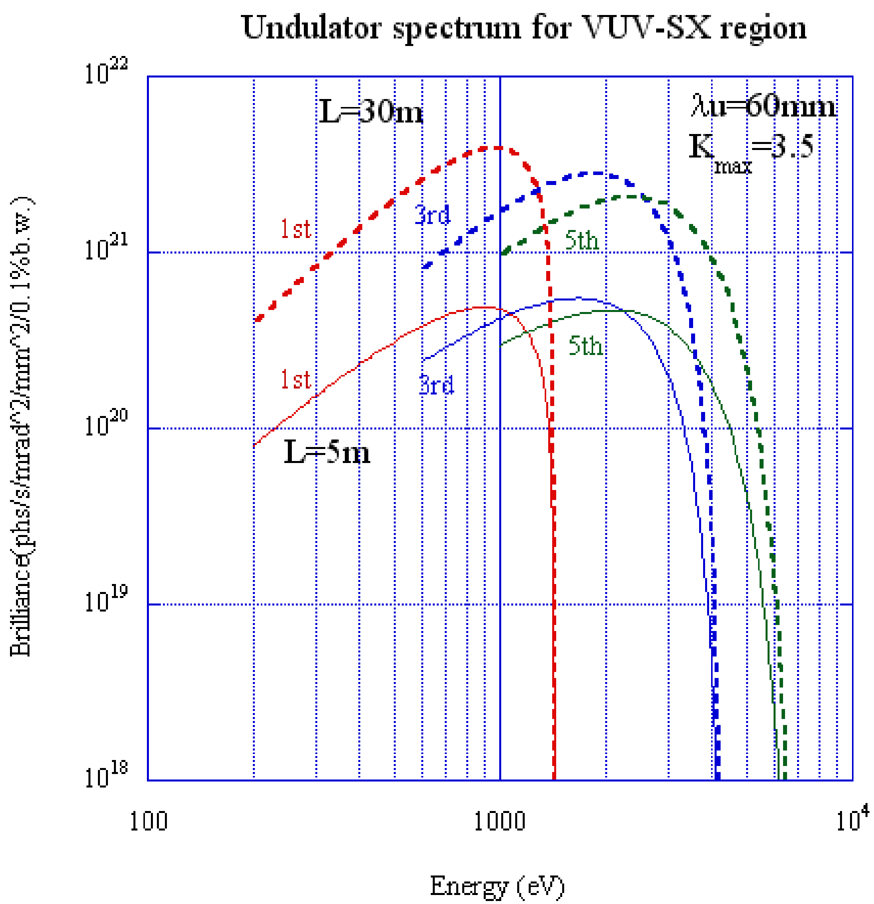


SLAC NATIONAL ACCELERATOR LABORATORY

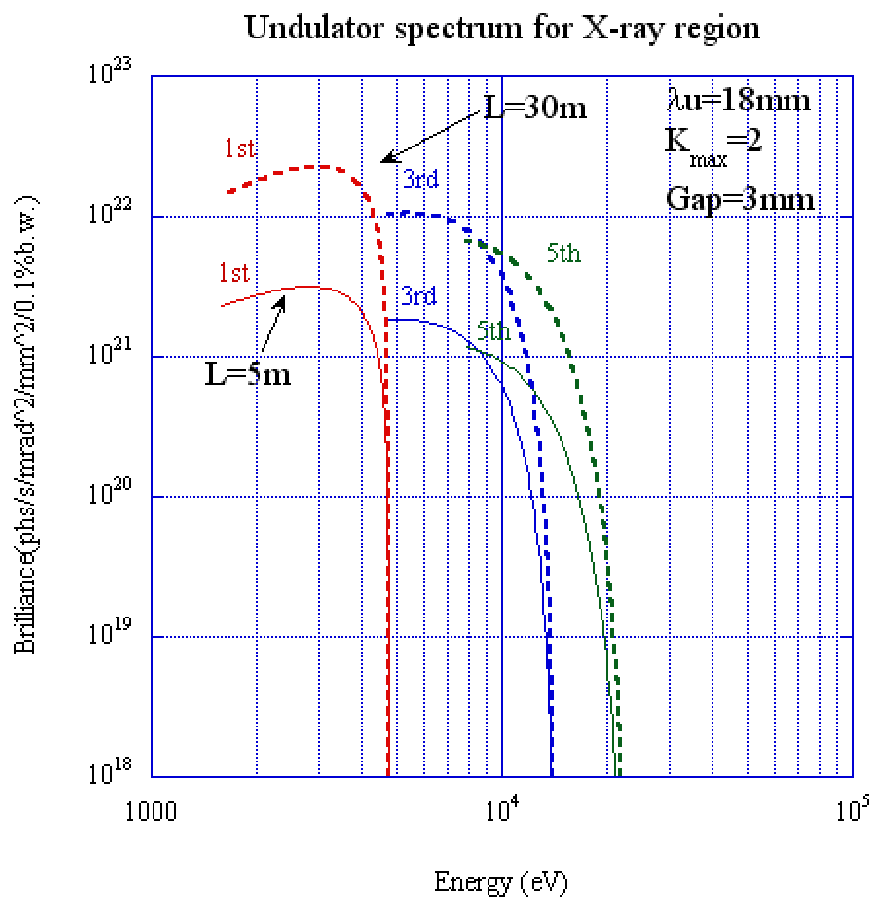
Figures are cited from: R. Hettel, "Performance Metrics of Future Light 13 Sources", FLS2010, SLAC, March 1, 2010.

Spectral brightness: typical cases

Courtesy: K. Tsuchiya



Undulator spectrum for VUV-SX source



Undulator spectrum for a small-gap undulator for X-ray source

2. Design of the Compact ERL (cERL)

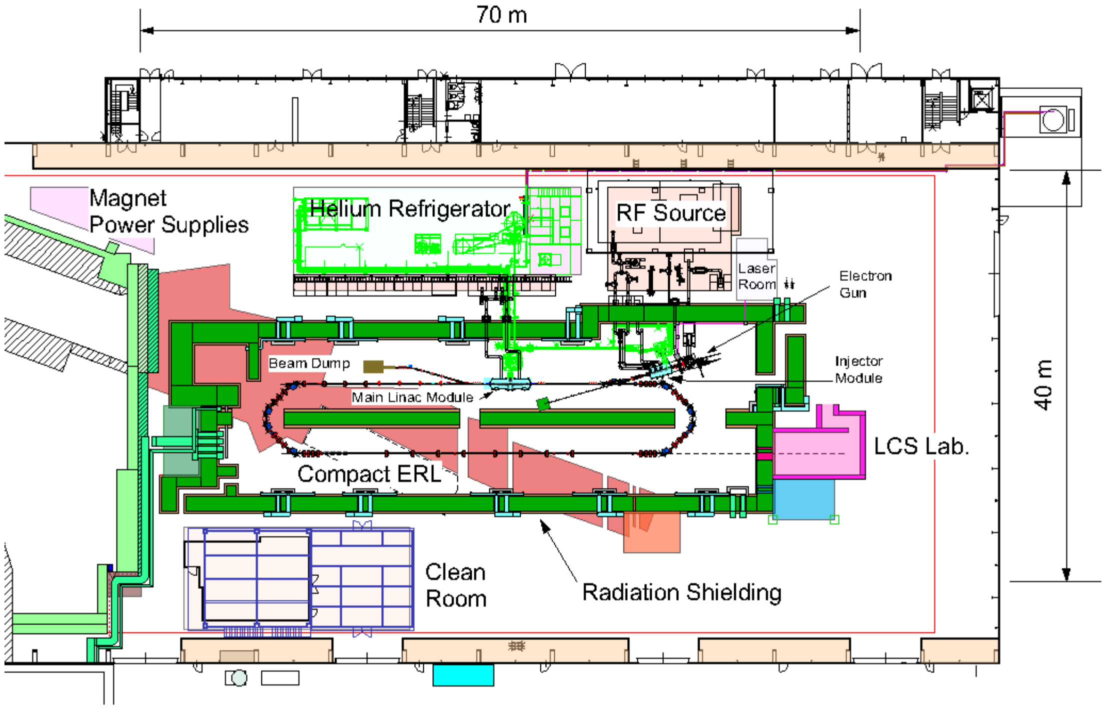
The Compact ERL for demonstrating our ERL technologies

Goals of the compact ERL

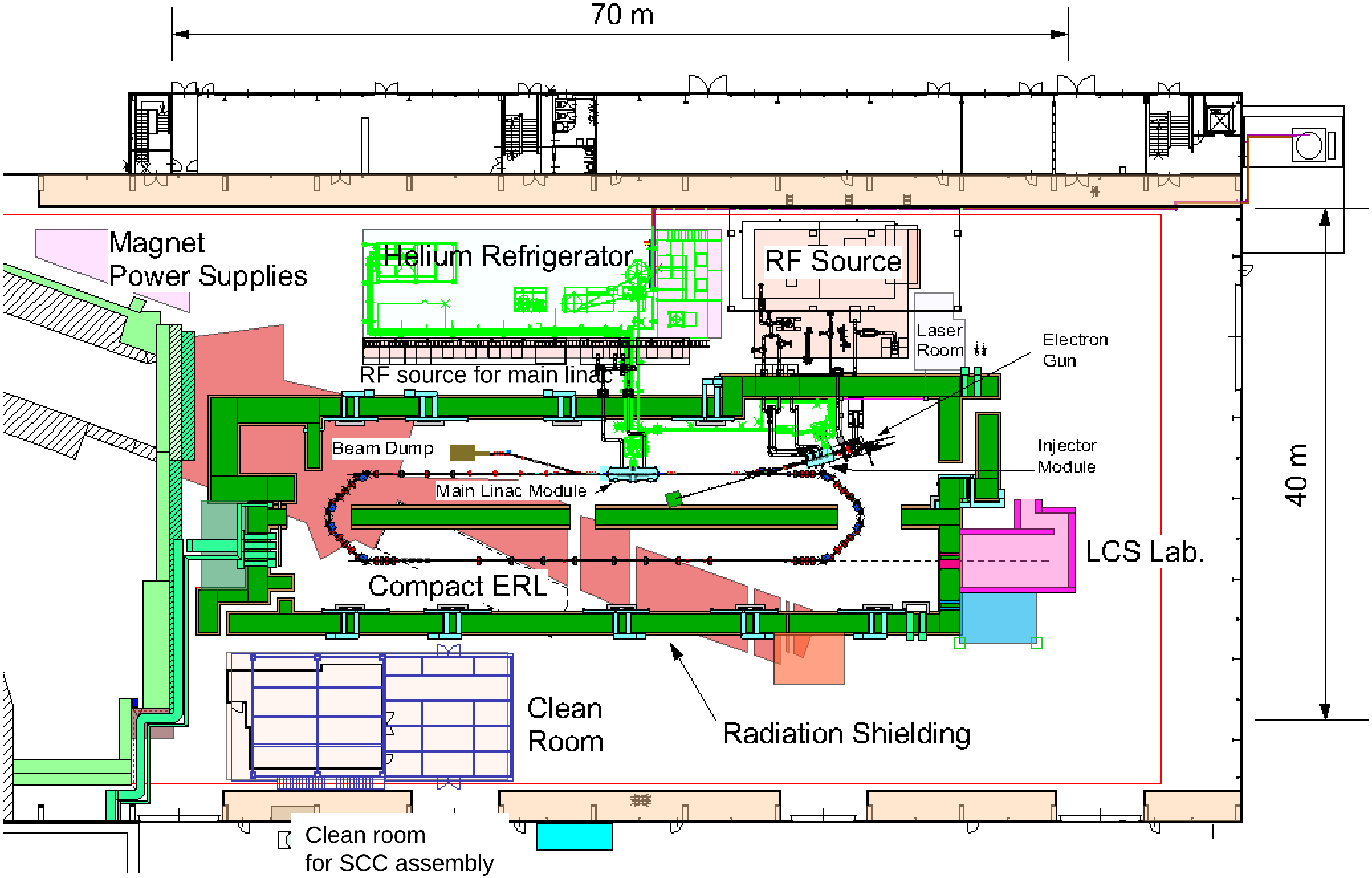
- Demonstrating reliable operations of our R&D products (guns, SC-cavities, ...)
- Demonstrating the generation and recirculation of ultra-low emittance beams

Parameters of the Compact ERL

	Parameters
Beam energy (upgradability)	35 MeV 125 MeV (single loop) 245 MeV (double loops)
Injection energy	5 MeV
Average current	10 mA (100 mA in future)
Acc. gradient (main linac)	15 MV/m
Normalized emittance	0.1 mm·mrad (7.7 pC) 1 mm·mrad (77 pC)
Bunch length (rms)	1 - 3 ps (usual) ~ 100 fs (with B.C.)
RF frequency	1.3 GHz

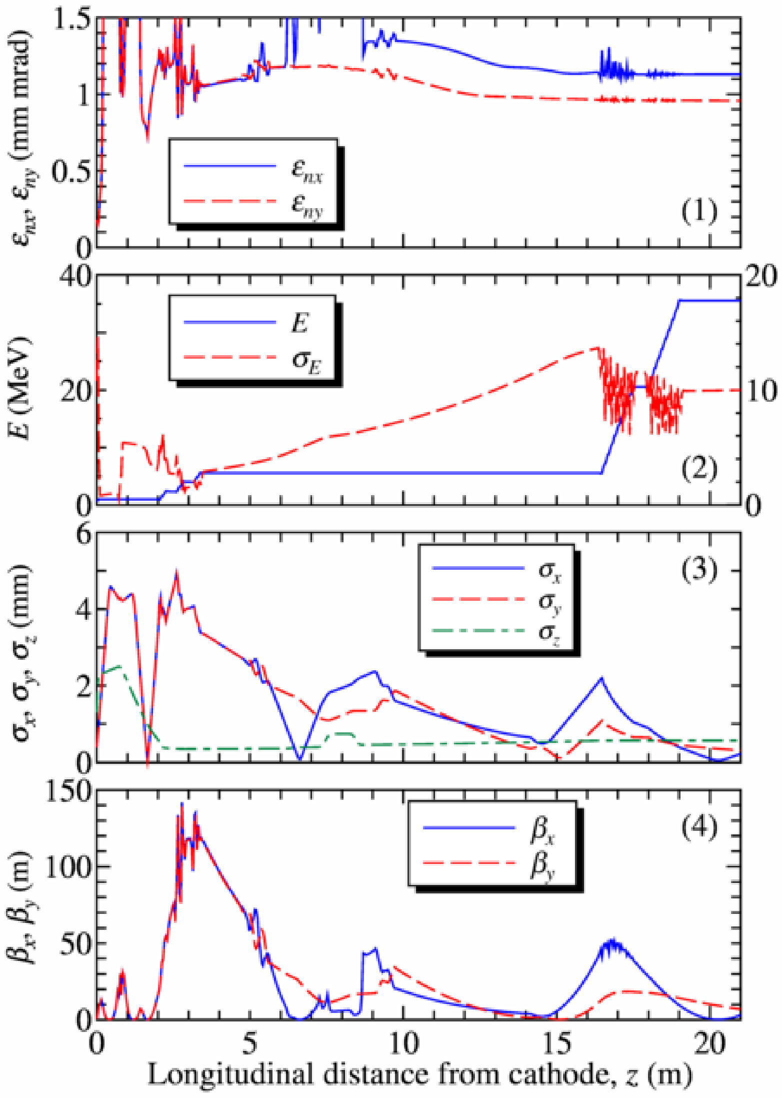


Layout of the Compact ERL (single-loop version)

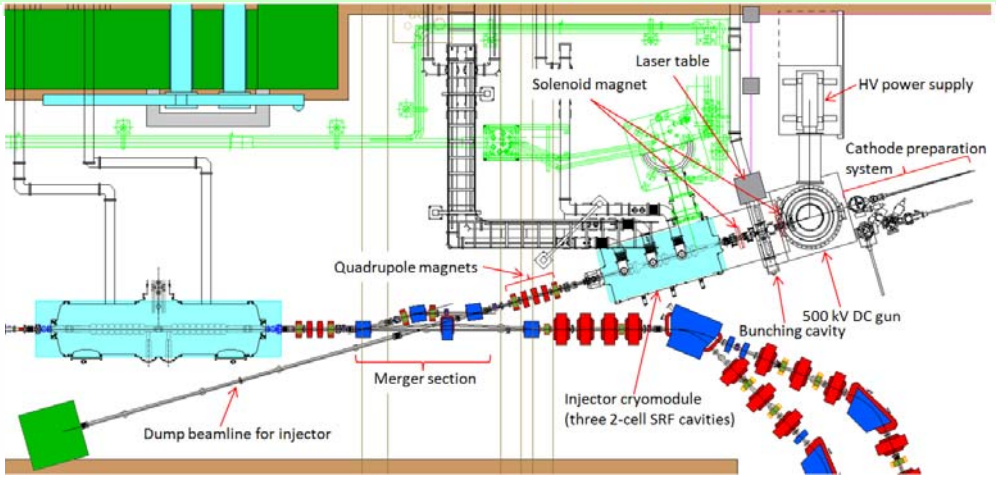


Optimized Design of Injector

Courtesy: T. Miyajima



Example of beam envelopes from the gun to a matching point.



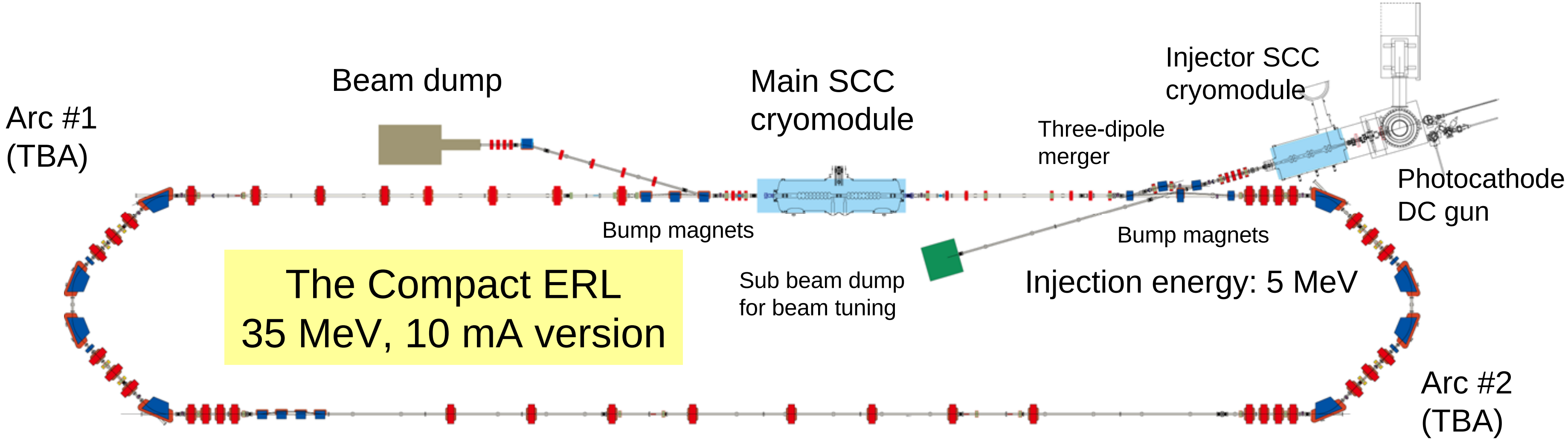
Design layout of cERL injector.

Optimized parameters.

Parameter	Value
Gun DC voltage	500 kV
Beam energy of injector	5 MeV
Charge/bunch	7.7 pC
Full width of laser pulse	16 ps
Spot diameter of laser	0.38 mm
Magnetic fields of solenoids #1, #2	0.0326, 0.0318 T
Voltage of buncher cavity	90.6 kV
Eacc of 1st, 2nd, and 3rd SC cavity	6.46, 7.52, 6.84 MV/m
Offset phase of 1st, 2nd, and 3rd cavity	13.6, 4.8, 10.0 degrees

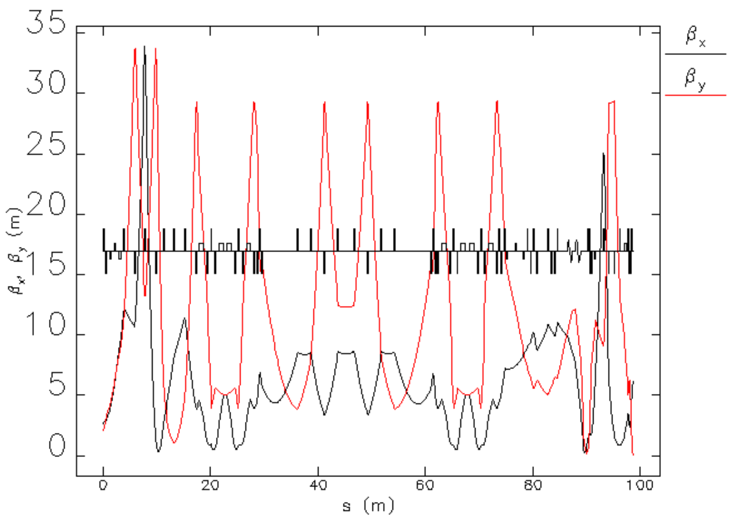
Lattice and Optics Design of cERL

Courtesy: M. Shimada
and N. Nakamura

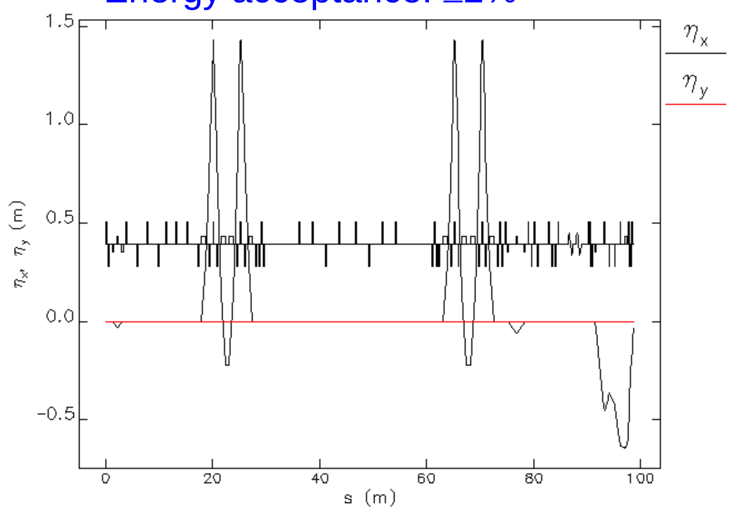


Chicane for orbit-length adjustment

Aperture: 35 mm in arc
Energy acceptance: ±2%



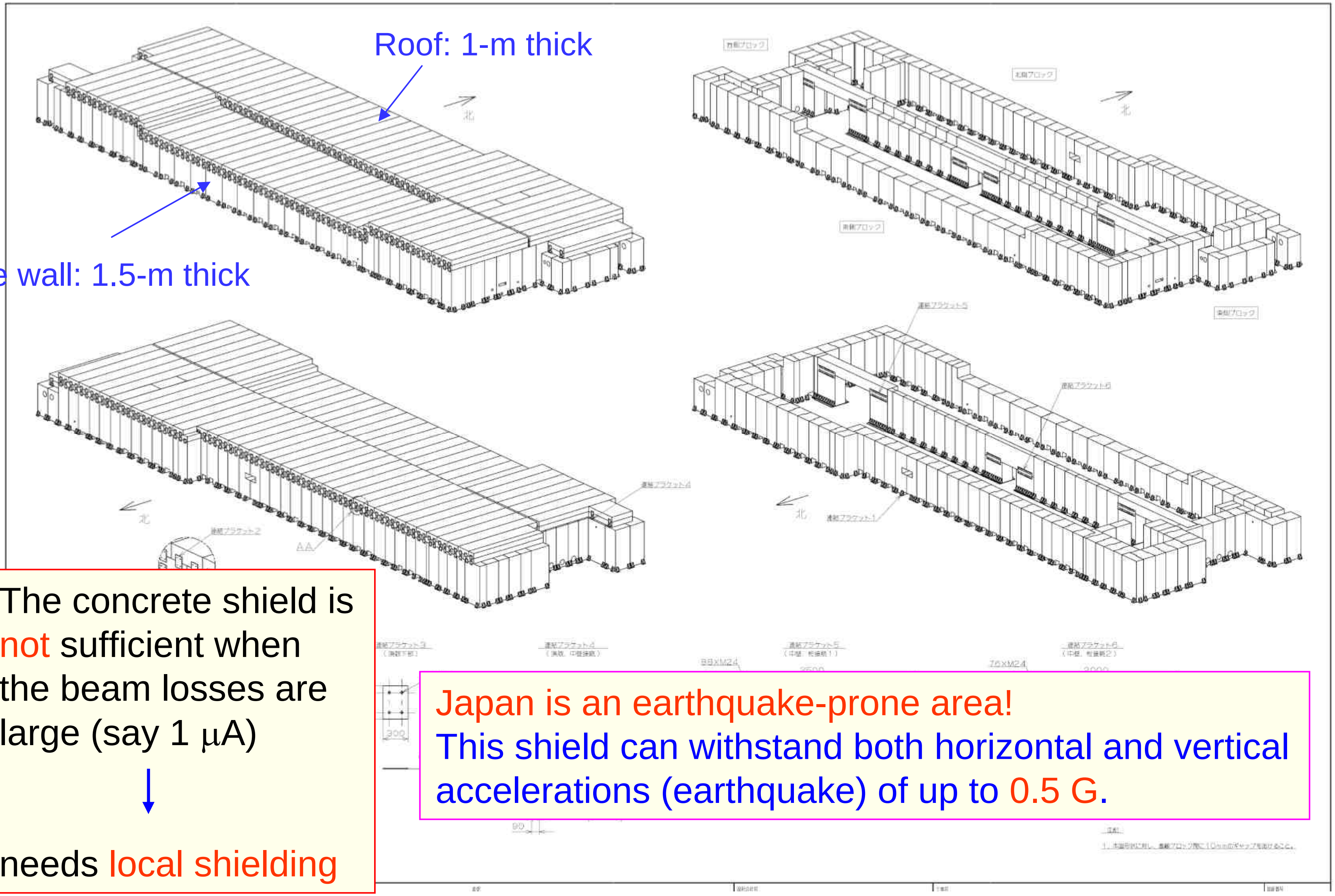
Betatron functions in the return loop.



Dispersion functions in the return loop.

Design of Radiation Shield

Courtesy: K. Haga



The concrete shield is not sufficient when the beam losses are large (say 1 μA)

↓

needs local shielding

Japan is an earthquake-prone area!
This shield can withstand both horizontal and vertical accelerations (earthquake) of up to 0.5 G.

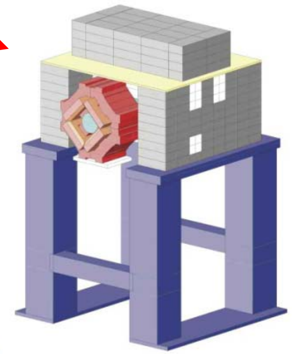
Issues of radiation shielding:
Assumptions for beam losses under the first commissioning (not determined yet)

Temporary assumptions of beam losses at the first arc (dispersive section)

Case	Target beam current (not determined)	Beam-loss ratio	Amount of beam loss
A	1 mA	10^{-5}	10 nA
B	100 μA	10^{-5}	1 nA
C	10 mA	10^{-4}	1 μA

Are these reasonable?

We need local shielding in case C (lead: 20-cm thick).



It is not easy to know the beam-loss ratio before commissioning.

We (radiation-safety-related people) want to commission the cERL at currents lower than 10 mA.
What is the reasonable beam-loss ratio ?
Which locations are the beam losses large?

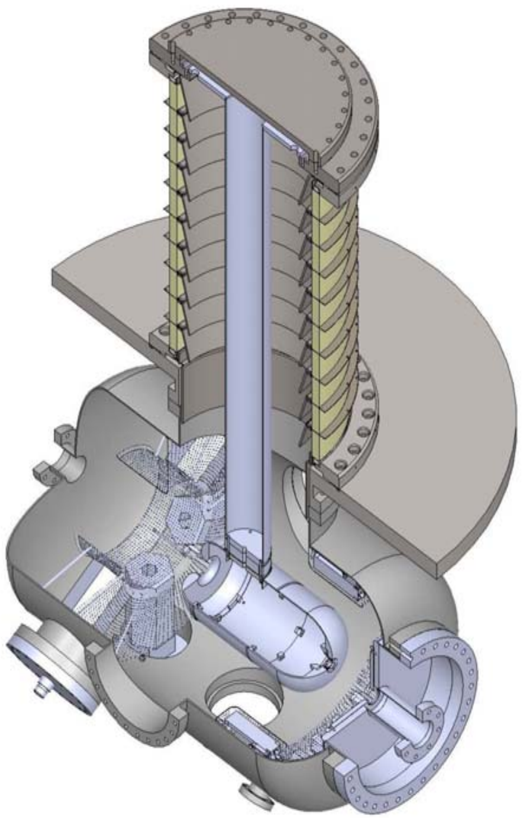
3. Status of R&D and Construction

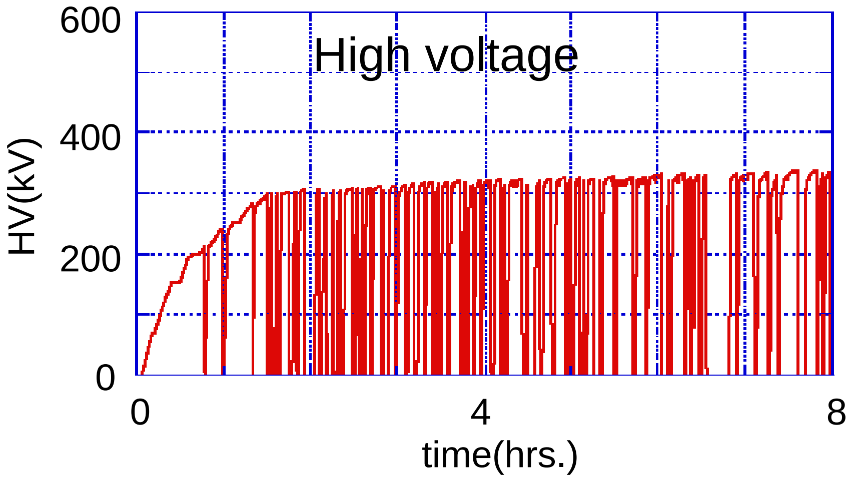
Development of Photocathode DC Gun #1 at JAEA

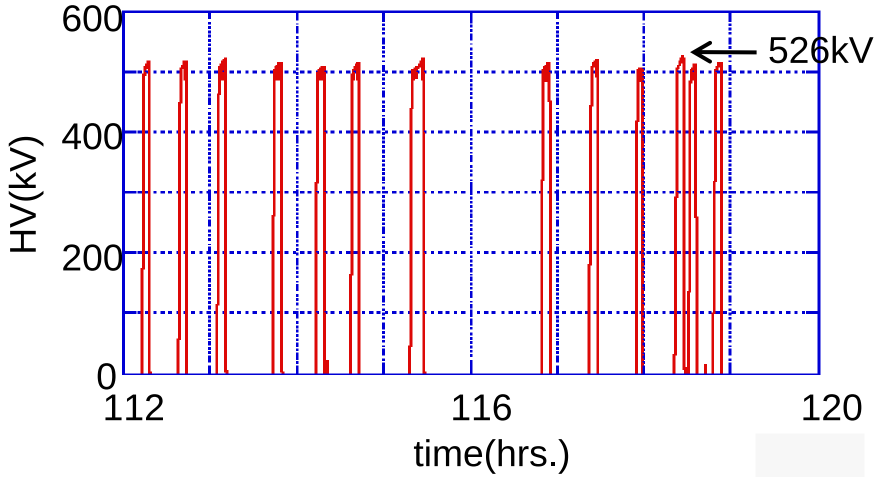
Courtesy: N. Nishimori

HV processing of JAEA-gun with electrode in place

- HV processing up to 526 kV
- Local radiation problem needs to be solved





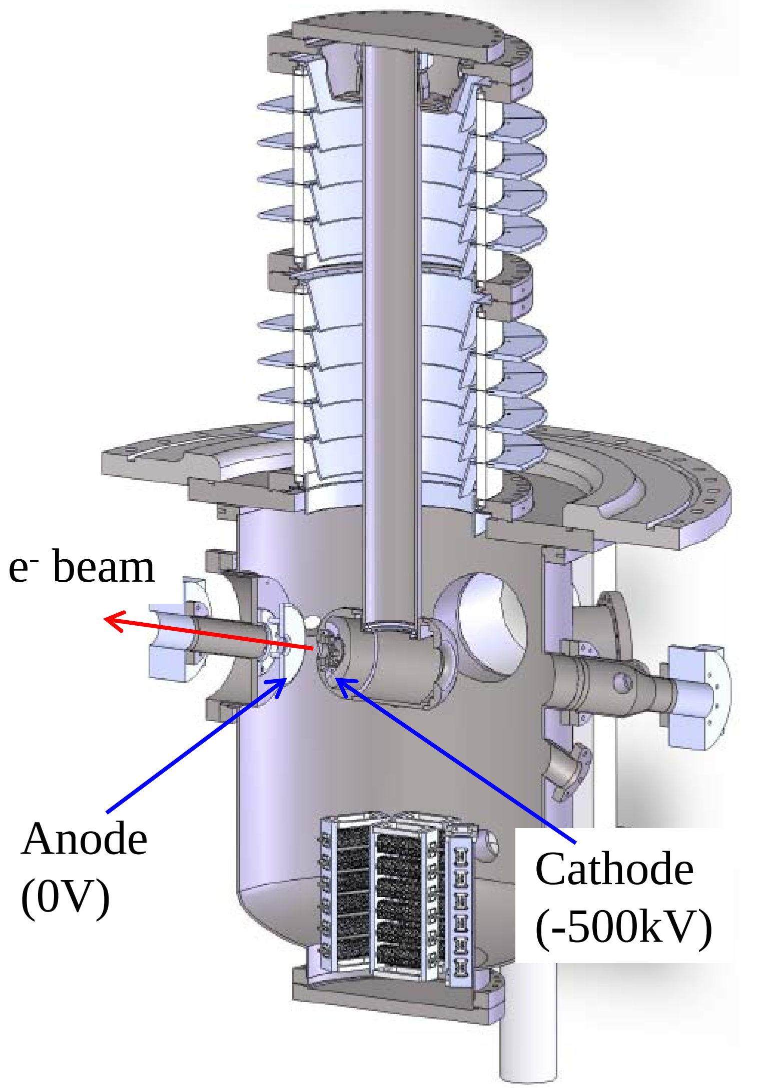


N. Nishimori et al., Presentation at ERL2011.

Development of Photocathode DC Gun #2 at KEK Aiming at Achieving Extreme High Vacuum

Courtesy: M. Yamamoto

- High voltage insulator
  - Inner diameter of ϕ=360 mm
  - Segmented structure
- Low outgassing material
  - Large titanium vacuum chamber (ID~ϕ630 mm)
  - Titanium electrode, guard rings
- Main vacuum pump system
  - **<u>Bakeable cryopump</u>**
  - NEG pump (> 1×10^4 L/s, for hydrogen)
- Large rough pumping system
  - 1000 L/s TMP & ICF253 Gate valve



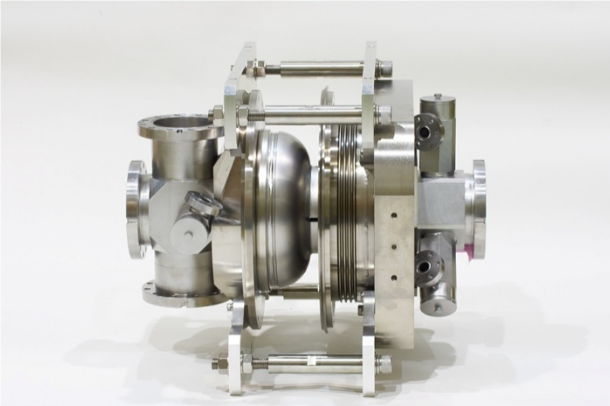
Goal

<u>Ultimate pressure : 1×10^{-10} Pa</u>

(during the gun operation)

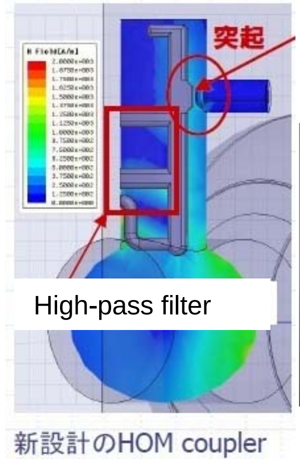
Superconducting Cavities for Injector

Courtesy: E. Kako,
K. Watanabe



Prototype 2-cell cavity #2

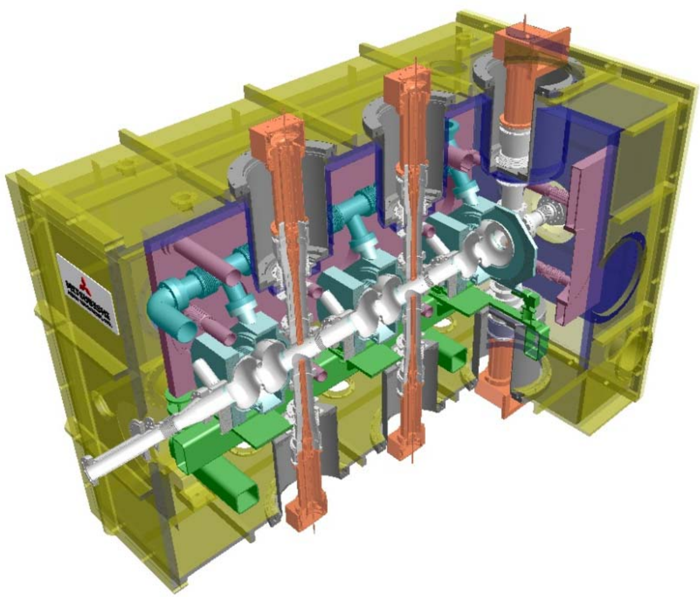
2-cell cavities for cryomodule



All of five HOM couplers are loop-type

New HOM-coupler design

Fabricated input couplers



Cryomodule design (3D view)

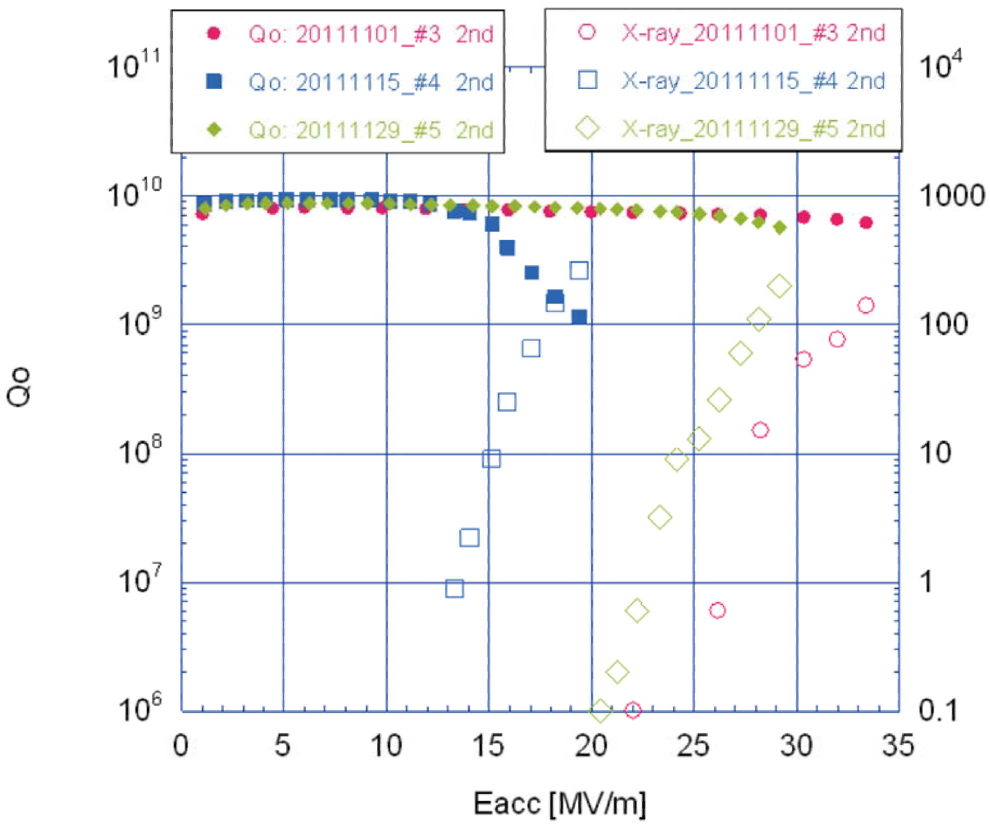
Recent Vertical Test of the Injector Cavities

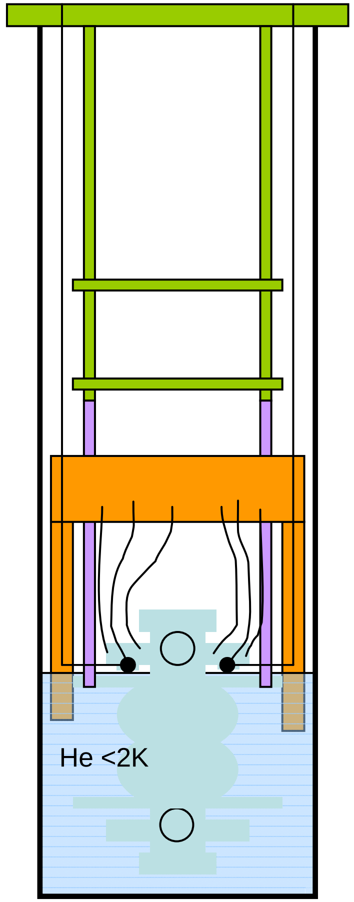
Courtesy: E. Kako
K. Watanabe

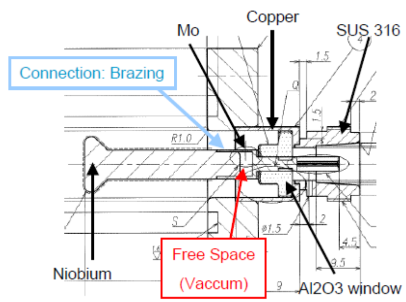
Improved cooling in HOM couplers resulted in higher sustainable field-gradient.

- We could keep high field-gradient of more than 20 MV/m (for cavities #3 and #5) for long time even when the HOM couplers were out of liquid Helium.

Result of vertical tests of cERL injector 2-cell cavities 1)







Improved feedthrough for HOM couplers

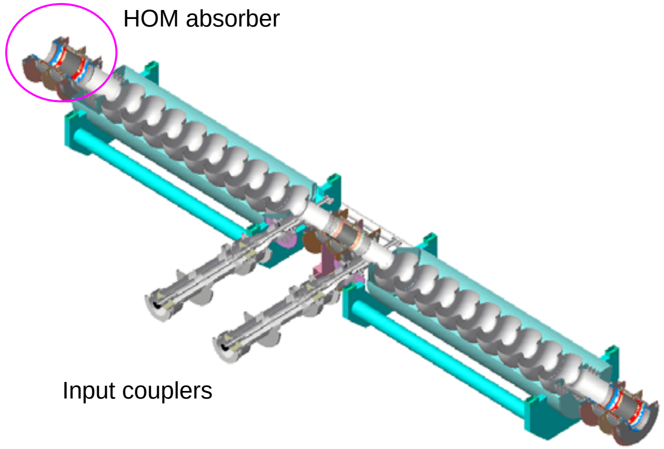
1) These Q_0-E_{acc} curves were measured when whole cavities were located in the liquid Helium. However, even when the upper HOM couplers were out of liquid Helium of 2K, we could maintain high field-gradient of 30 MV/m (cavities #3 and #5).

Superconducting Cavities for the Main Linac

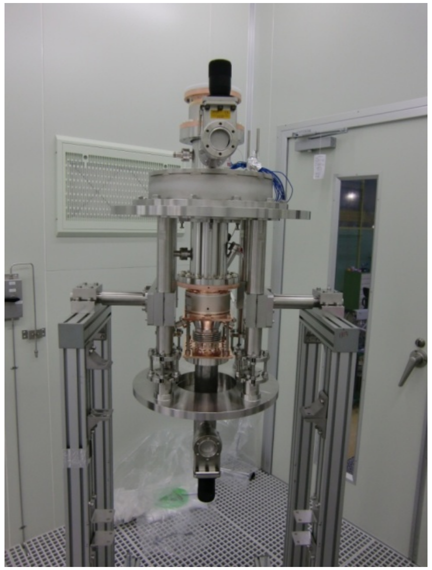
Courtesy: K. Umemori

9-cell Cavities

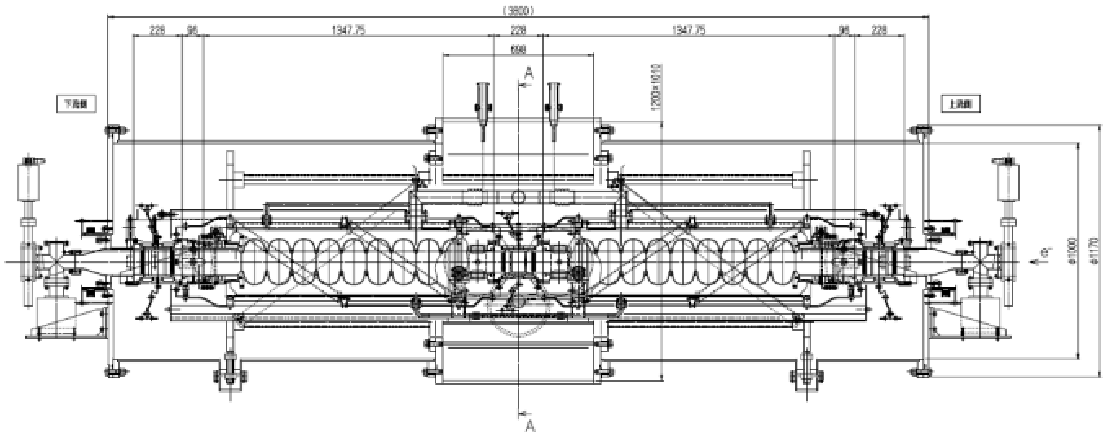
HOM Absorber



Assembly of two 9-cell cavities



Input coupler



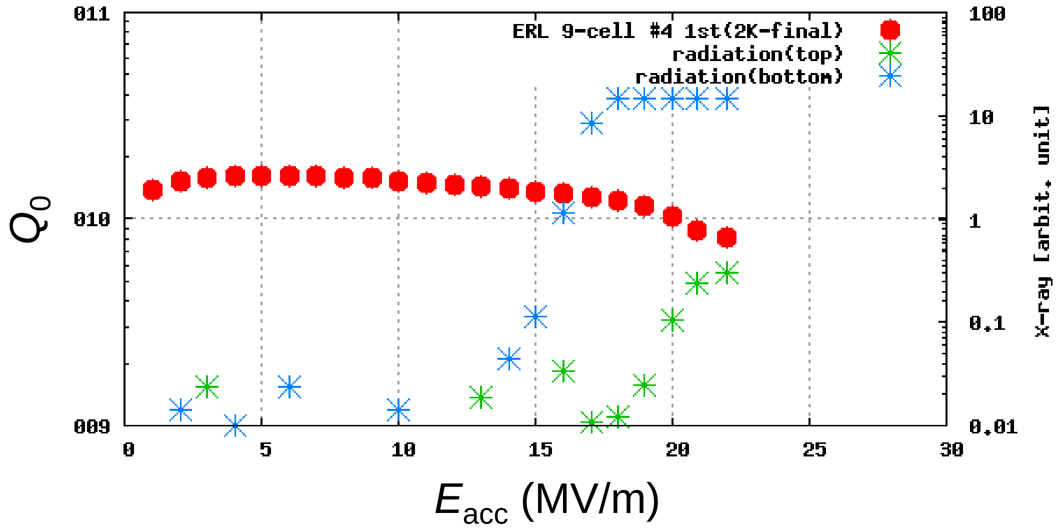
Cryomodule design (side view)

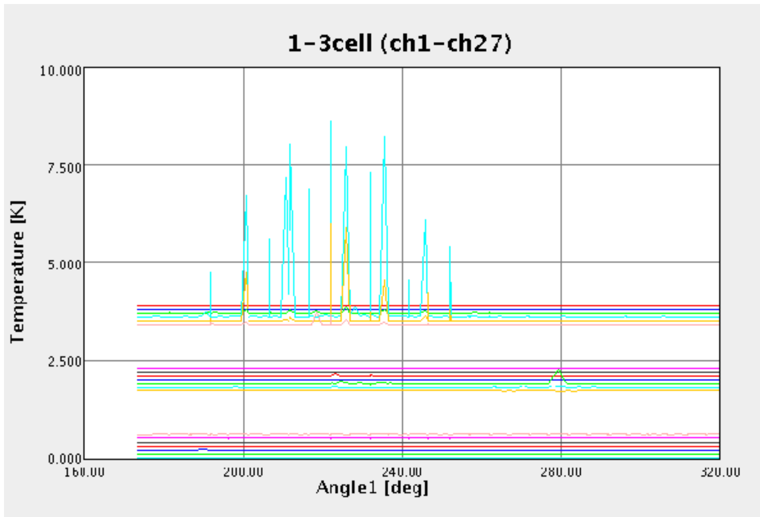
Typical Result of Vertical Test (for cavity #4, that is, for cERL cryomodule)

Courtesy: K. Umemori

- Field reached to 22 MV/m
- Limit by quenches around 1-cell equator.
- Q > 1e10@15MV/m
- 1299.72 MHz@2K
- Satisfied cERL specification

- X-ray on-set was initially around 18 MV/m
- But after processing, X-ray on-set went down to 15 MV/m
- Emission source seems to be on irises between 1-2 cells or 1-cell/SBP.

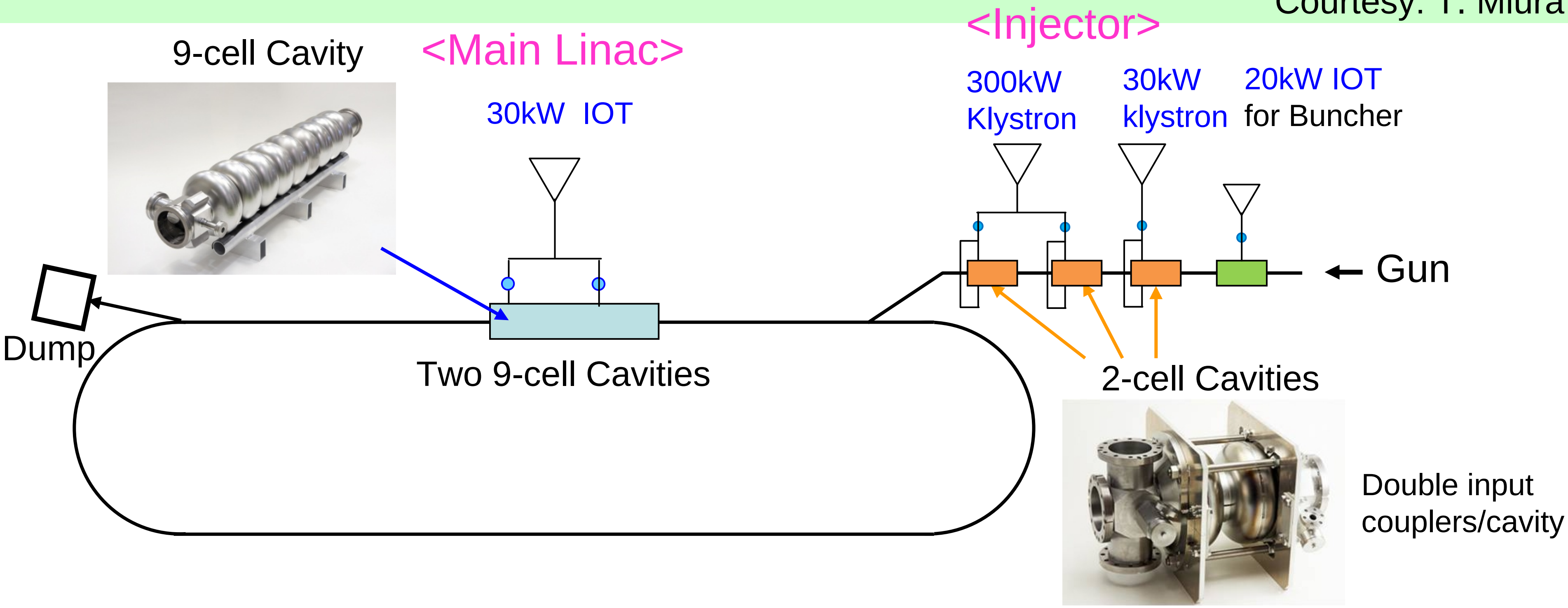




Thermal response around 1-cell equator, 220 degree, during self-pulsing

RF System for the cERL

Courtesy: T. Miura



Parameters of RF System for the cERL (35 MeV, 10 mA version)

Item	Unit	Buncher	Inj-1	Inj-2	Inj-3	ML-1	ML-2
Structure		NC	SC	SC	SC	SC	SC
Gradient	MV	0.14	1	2	2	15	15
Q_L			5×10^5	2×10^5	2×10^5	2×10^7	2×10^7
Beam Phase	degree	–90	–15 to –30	–10	–10	0	0
Power Required	kW	4.5	10	37	37	11	11
Power Output	kW	6.2	17	122		30	
RF Source		IOT	Klystron	Klystron		IOT	
Power Available	kW	20	30	300		30	

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1.3 GHz CW RF Sources at KEK

Courtesy: T. Miura

300kW CW Klystron

30kW CW Klystron

30kW CW IOT

20kW CW IOT

-> to be delivered at the end of FY2011

20 kW CW 1.3 GHz IOT Amplifier

IOT Amplifier L-4445

Ratings	Symbol	Min.	Max.
Heater Voltage	V	5	7
Heater Current (Operating)	A	20	30
Heater Current (Surge)	A	---	60
Heater Warm-up Time	Seconds	300	---
Beam Voltage	kV	28	36
Beam Current	A	---	2.0
Idle Current	A	0.0	0.5
Body Current	mA	---	60
Solenoid Current	A	20	30
Collector Dissipation	kW	---	55
Load VSWR	---	---	1.5:1
Bias Voltage (with respect to cathode)	V	-50	-150
Grid Current	mA	---	±150
Ion Pump Current (Beam On)	μA	---	20
Ion Pump to Cathode Voltage	kV	3	4
Bandwidth (-1 dB)	MHz	3.0	---
Bandwidth (-3 dB)	MHz	5.0	---
Gain with 150 mA of idle current	dB	20.0	---
Output Power	kW	---	25
Beam Efficiency @ 20 kW	%	43	--

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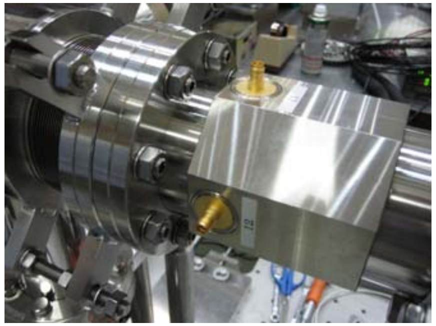
Beam Instrumentations for cERL

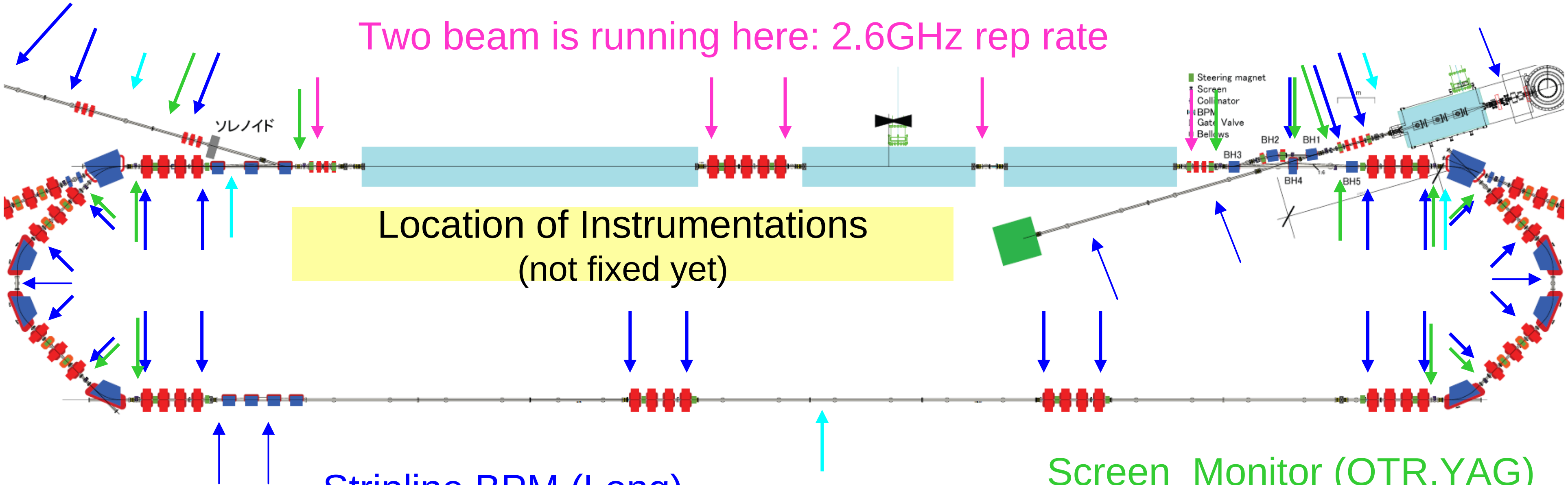
Courtesy: Y. Honda, T. Obina



Stripline BPM with glass-type feedthrough

Screen monitor

Slit for emittance measurement



Stripline BPM (Long)

Stripline BPM (Short) or Button Pickup

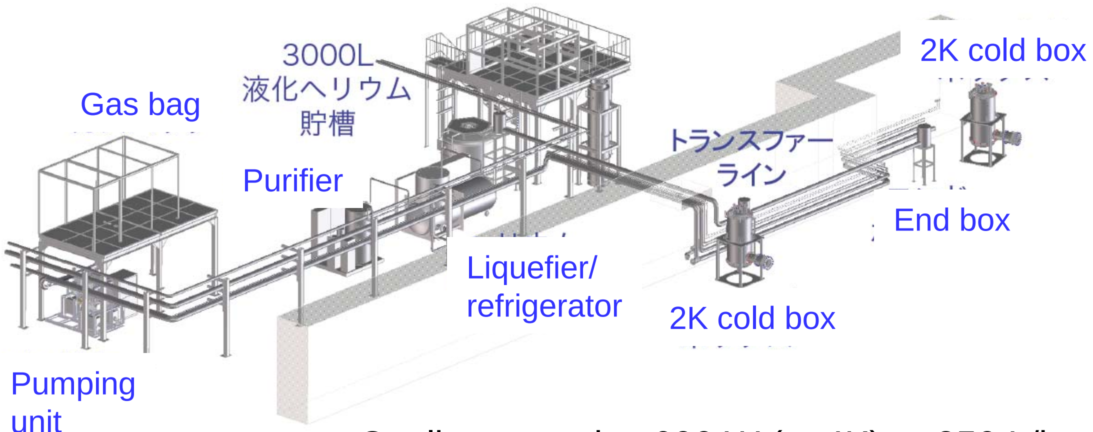
Screen Monitor (OTR,YAG)

DCCT, CT ?

Liquid-Helium Refrigerator for cERL

Courtesy: H. Nakai

Overview of the system



Cooling capacity: 600 W (at 4K) or 250 L/h

ヘリウム液化冷凍機（物材機構より移管）

3000L liquefied helium storage vessel

2K cold box and end box

TCF200 helium liquefier/refrigerator

ERL Development Building for cERL

Application of cERL: Plan of Laser Compton Scattering Experiment by JAEA

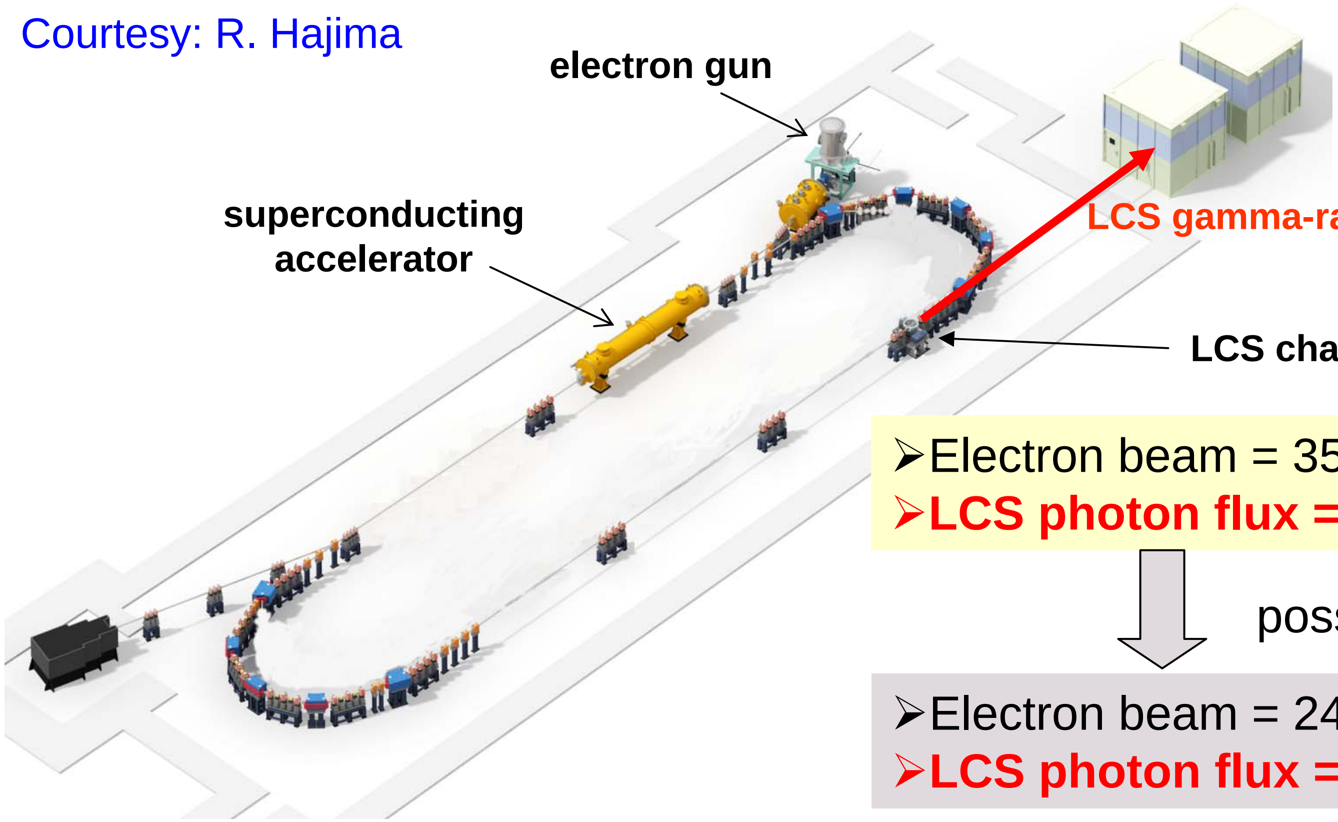
3-year R&D program was funded from MEXT (2011-2013)

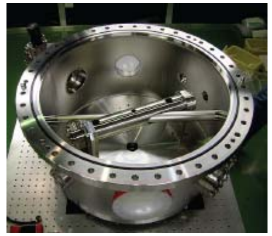
Nondestructive measurement of isotopes by LCS γ-rays, which is applicable to nuclear security and safeguards purposes.

- Installation of a LCS chamber
- Generation of LCS gamma-rays
- Demo-Experiment of NRF measurement

(NRF: Nuclear Resonance Fluorescence)

Courtesy: R. Hajima





- Electron beam = 35 MeV, 10 mA
- **LCS photon flux = 5×10^{11} ph/s @22keV**

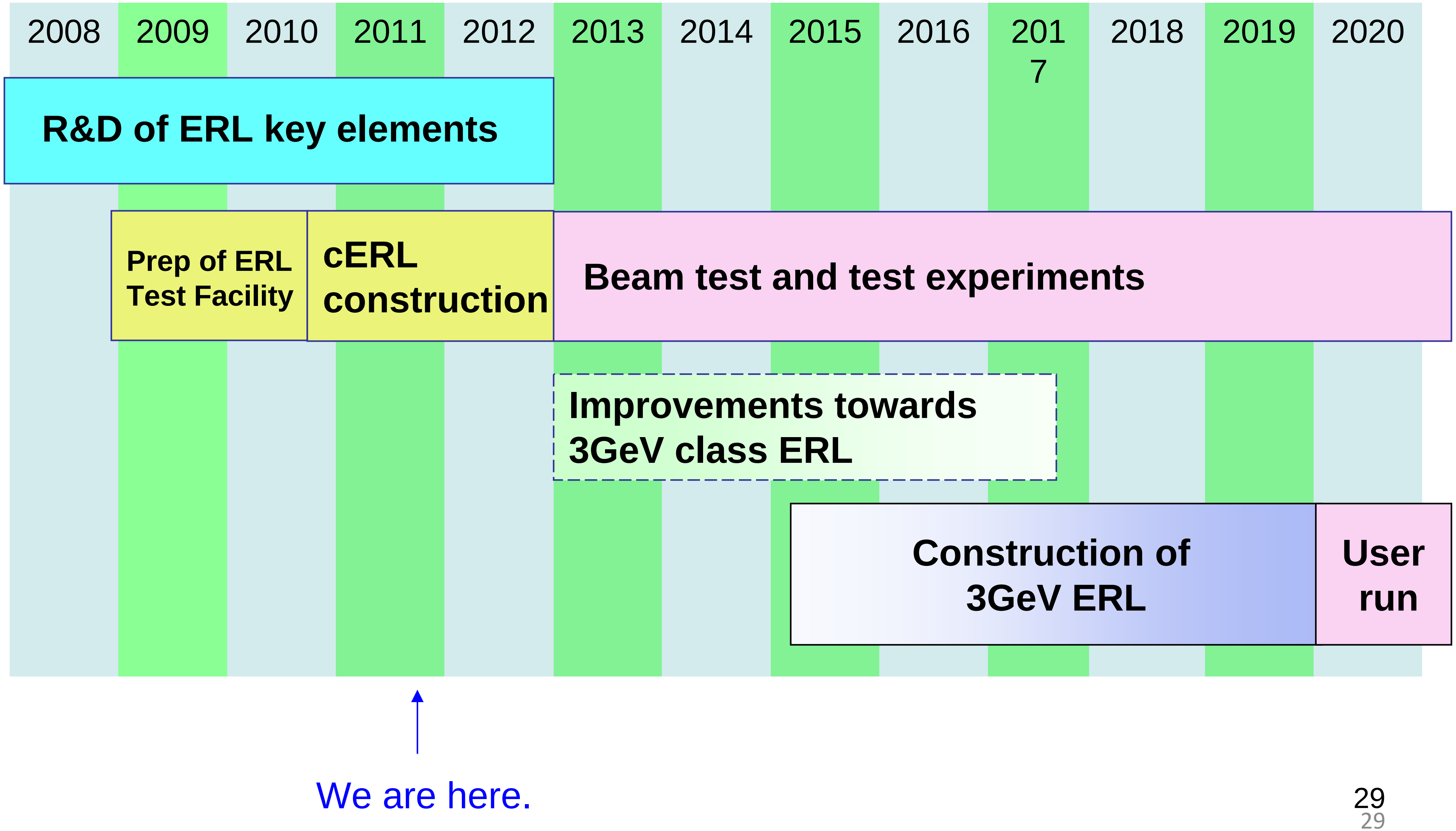
possible upgrade in future

- Electron beam = 245 MeV, 10 mA
- **LCS photon flux = 1×10^{13} ph/s @1.1MeV**

Road Map of ERL

By H. Kawata

Japanese Fiscal Year (from April to March)



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4. Summary

Future light source plan at KEK

- 3-GeV ERL with single return-loop
- 6-7 GeV XFEL-O is considered in the second stage

R&D in progress

- High-brightness photocathode DC guns: 500kV, 10mA (100mA in future)
- Drive laser for the gun (520 nm, ~1.5 W for cERL)
- SC cavities for both injector and main linacs
- RF sources (300 kW CW klystron, etc.)

Compact ERL

- First stage: 5 MeV injector, 35 MeV (single) return loop. 10 mA.
- Upgradable: rooms for additional cryomodules and for double loops
- Liquid-helium refrigerator is working well.
- Construction of radiation shielding has been started.
- We plan to commission cERL, hopefully, in March, 2013.