First Demonstration of Energy-Recovery Operation in the JAERI Superconducting Linac for a High-Power Free-Electron Laser

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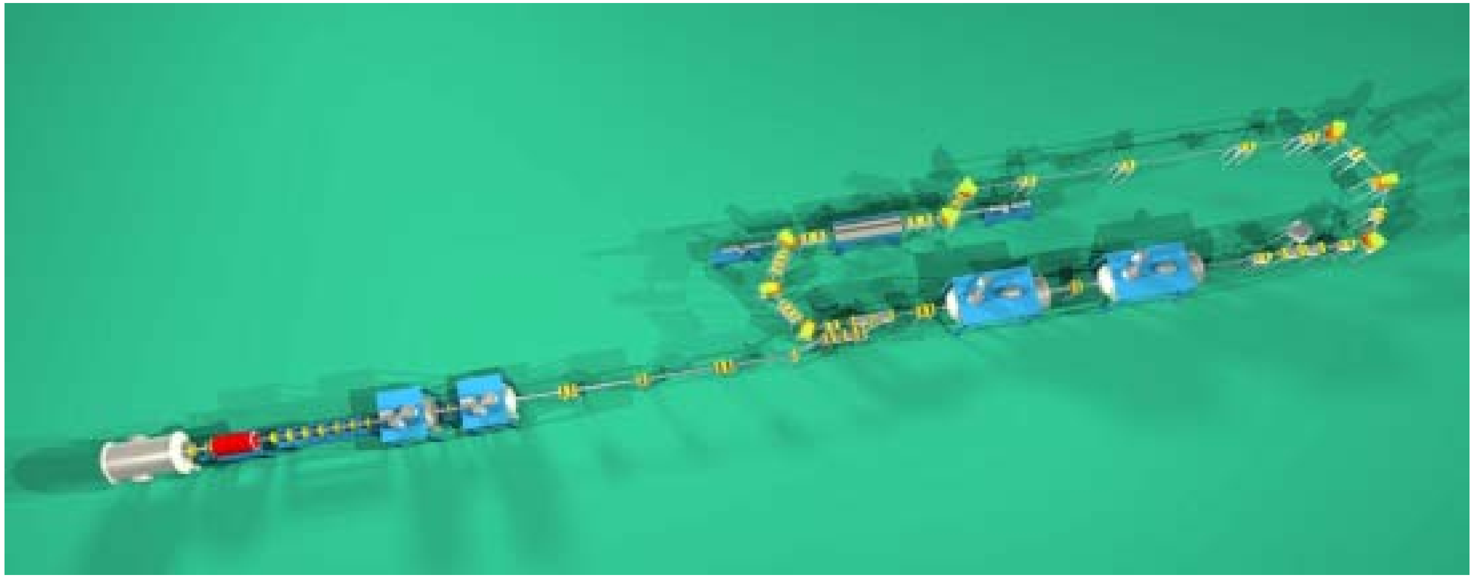
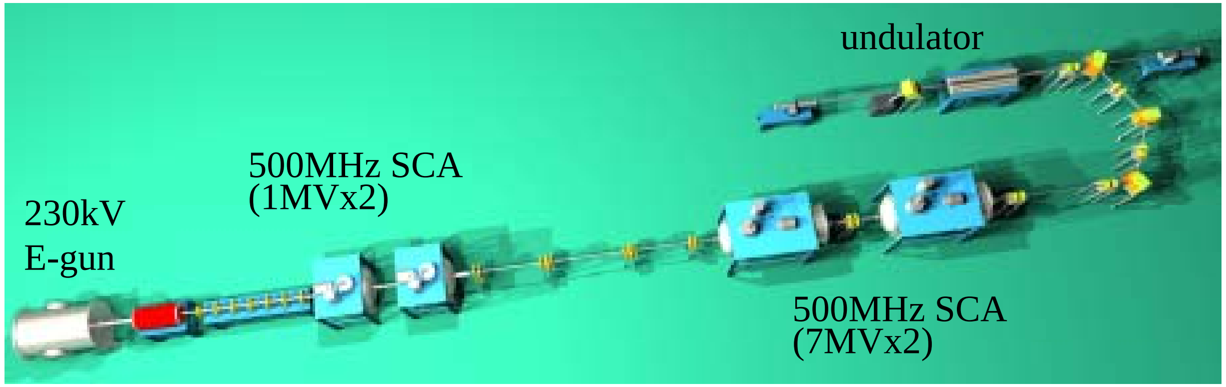


JAERI Free-Electron Laser (original, non-ERL)



Energy = 16.5MeV

Bunch charge =510pC

Bunch length < 5ps

Bunch rep. = 10.4MHz

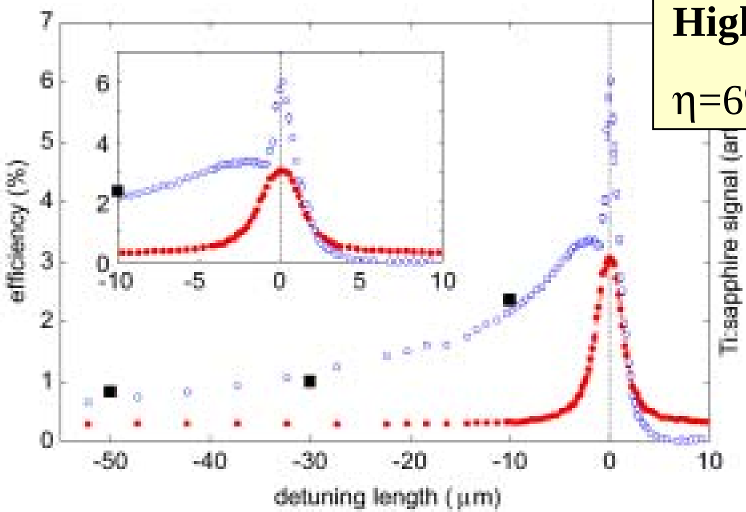
Timing jitter < 100fs

FEL : λ = 7–23μm

Stable and powerful beam from SCA has brought a “brand-new” FEL lasing over 2kW.

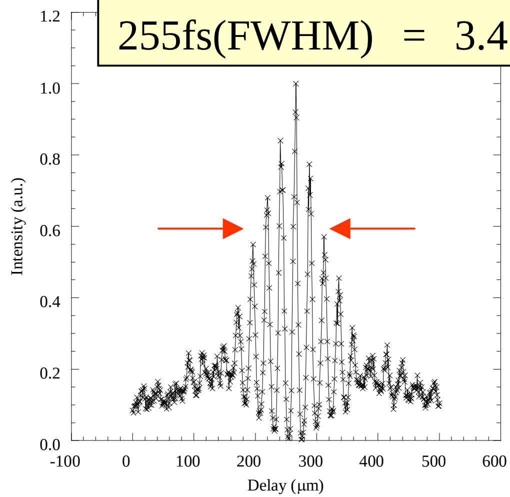
High-efficiency

η=6%



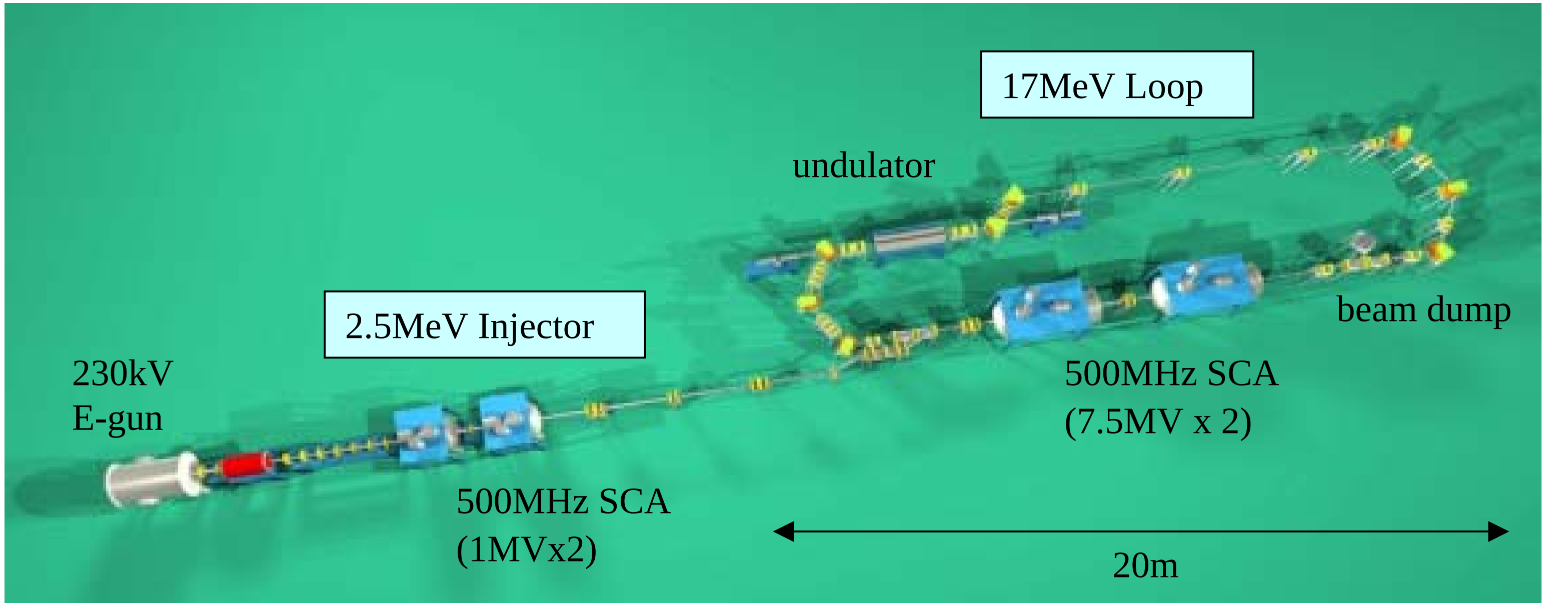
ultrashort pulse

255fs(FWHM) = 3.4 cycles



FEL 2002, R. Hajima.

JAERI Energy-Recovery Linac for 10kW FEL



- Natural extension of the original configuration.
- 8 times larger e-beam power.
- Fitting to the concrete boundary.

Energy = 17MeV

FEL : λ = ~22μm

Bunch charge =500pC

Bunch length = ~15ps (FWHM)

Bunch rep. = 10.4MHz – 83.3MHz

Average current = 5.2mA – 40mA

after injector-upgrade

History of JAERI-ERL development

Sep. 1999, loop design was completed.

Apr. 2000, merger design was completed.

(FEL exp. with non-ERL configuration)

Mar. 2001, original FEL was shut down, and ERL construction began.

Oct. 2001, first beam at the injector.

Dec. 2001, first beam at the main modules.

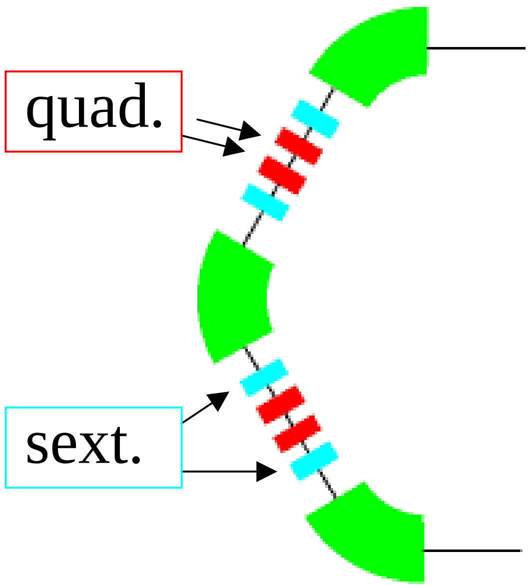
Feb. 2002, first recirculation, and energy-recovery.

Aug. 2002, first FEL lasing.

Design of JAERI ERL

Return arc --- triple bend, 180 degree arc.

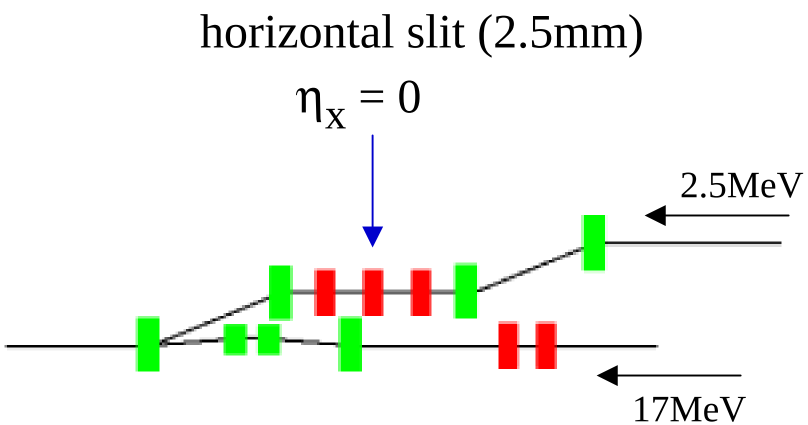
- Variable R_{56} for energy-spread compression.
- Sextupoles to compensate second-order aberrations: T_{166}, T_{266}, T_{566}.
- Energy acceptance is 7% (full-width) for ε_n=30mm-mrad.

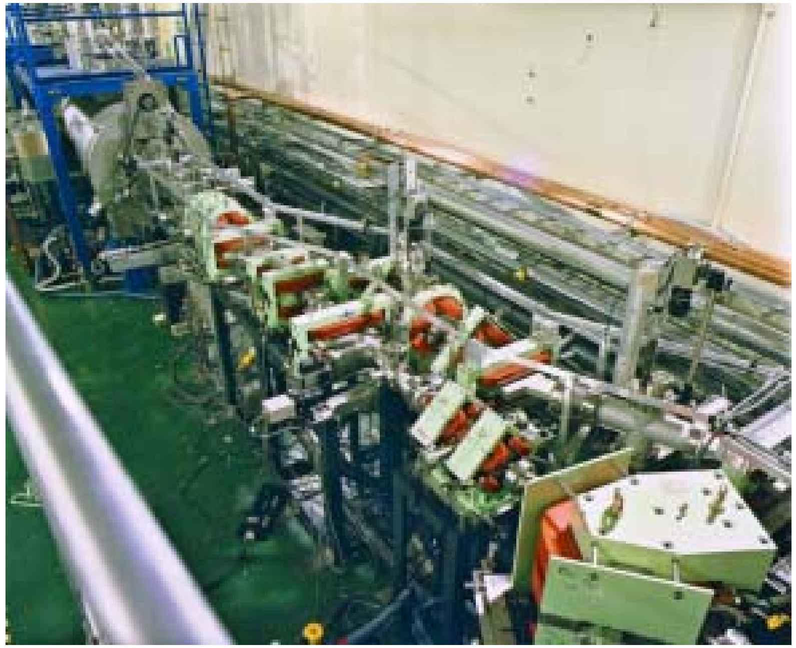


Design of JAERI ERL

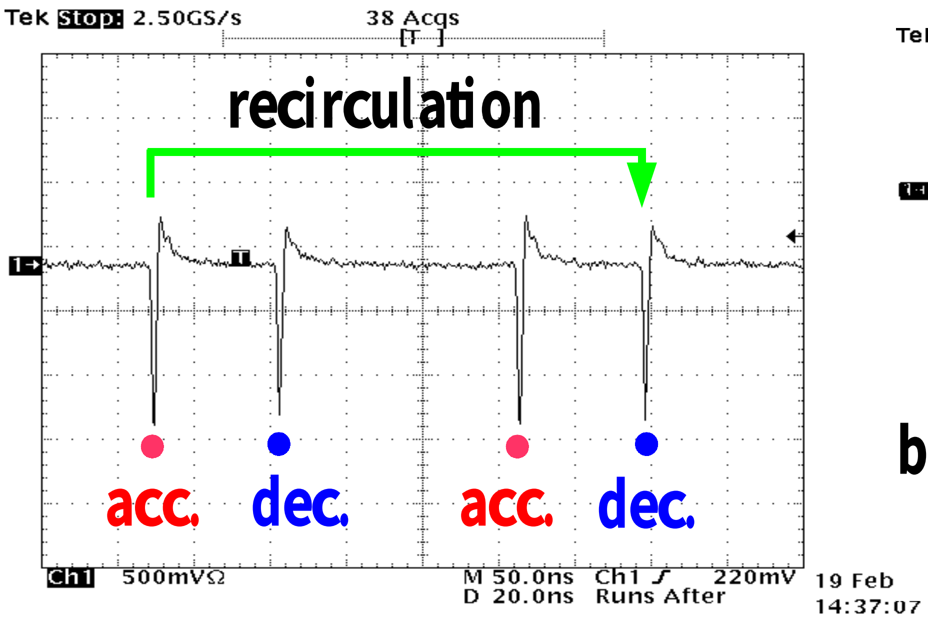
Injection merger --- two-step staircase.

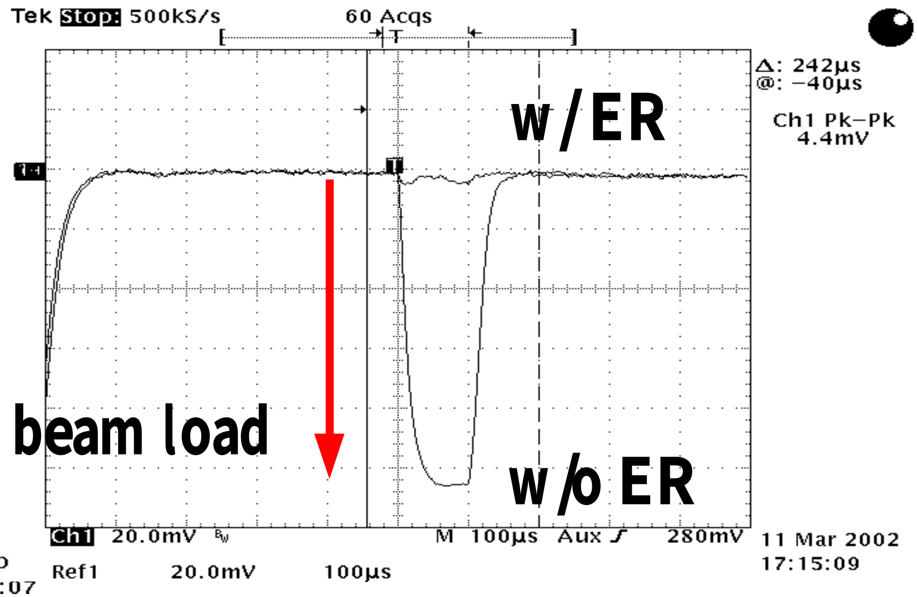
- achromaticity is realized by three quads.
- small angle (22.5 deg.) injection is preferable for small emittance.
- but, performance is sensitive to quads parameters.





Demonstration of Energy Recovery





Beam current at the exit of the second main module.

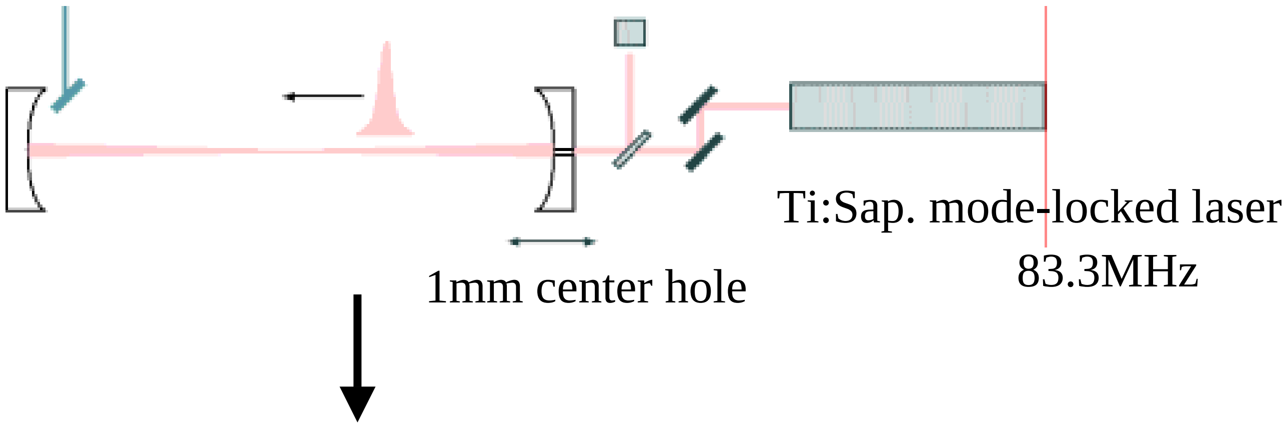
Bunch interval is 96ns, and recirculation time is 133ns.

RF amp forward power for the 1st main module.

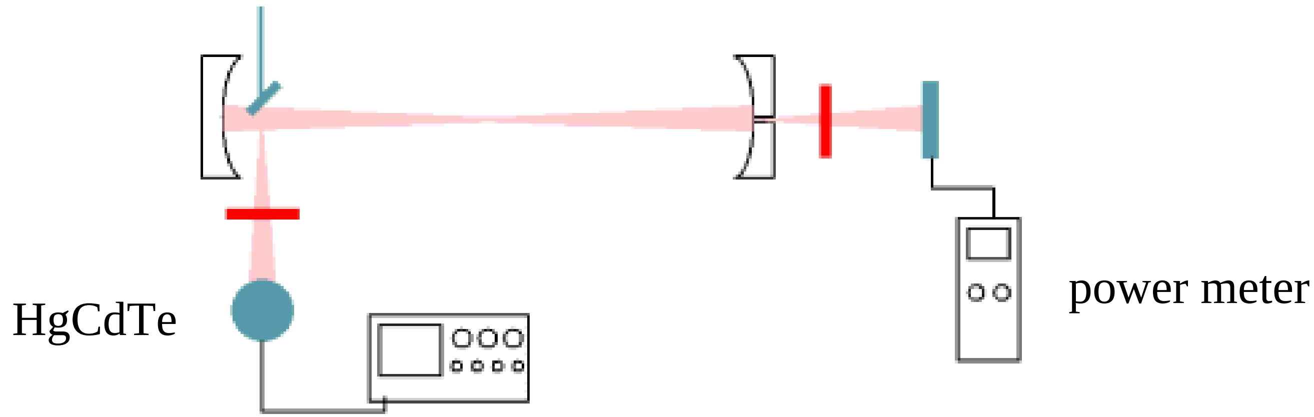
Beam loading is almost completely compensated by energy-recovery.

FEL experiments

cavity length measurement by pulse stacking method



trial of FEL lasing



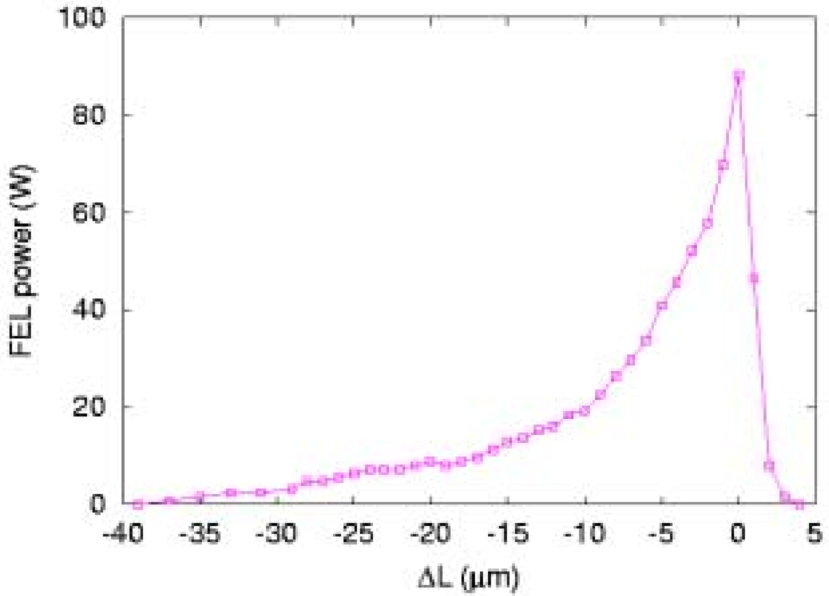
FEL experiments

first lasing at Aug. 14, 2002.

FEL power is still low about ~ 0.1kW.

Gain, loss, spectral measurements have not been done, yet.

Macropulse structures suggest that single-supermode and superradiance appear depending on ΔL.



Cavity length detuning curve.

R&D plan towards 10kW FEL

For increasing the FEL power, we need to increase the electron beam power and increase the FEL extraction efficiency.

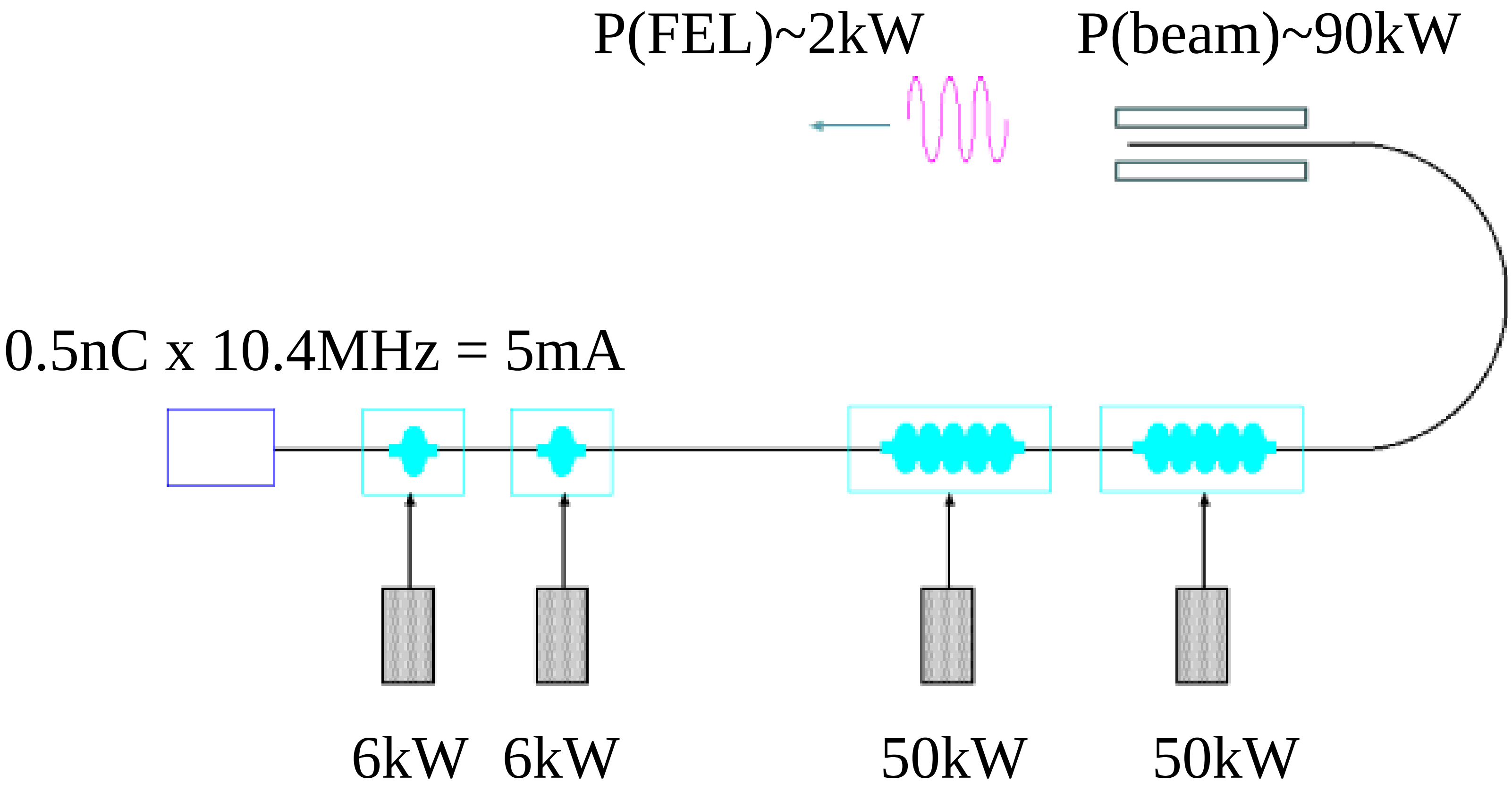
$$P(FEL) = \eta_{FEL} \, P(beam)$$

JAERI R&D program towards 10kW FEL is

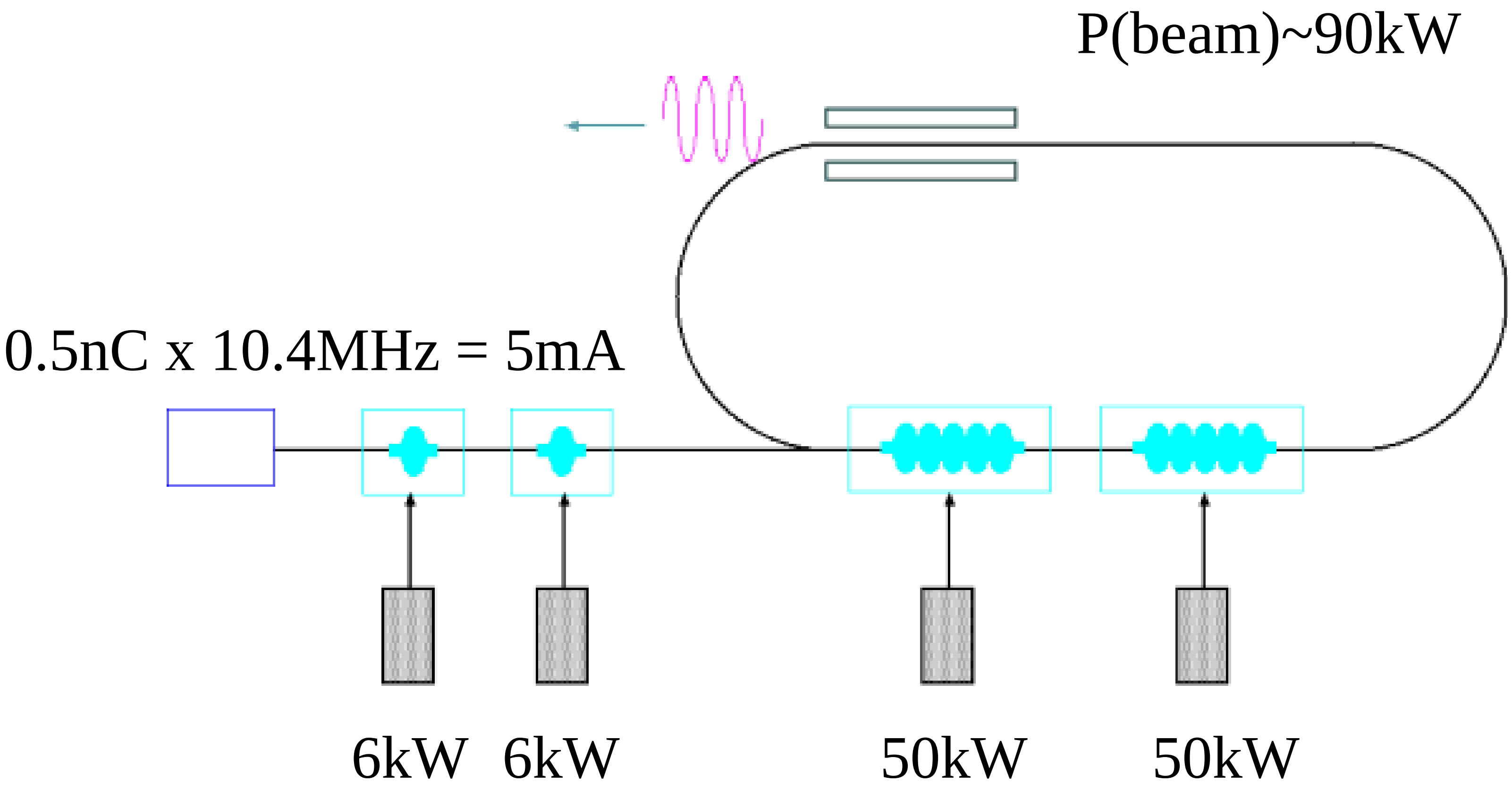
- Development of ERL system.
- Injector upgrade for higher beam power.
- FEL lasing in superradiant regime for high η_{FEL}.

What is the limitation of beam power and η_{FEL} ?

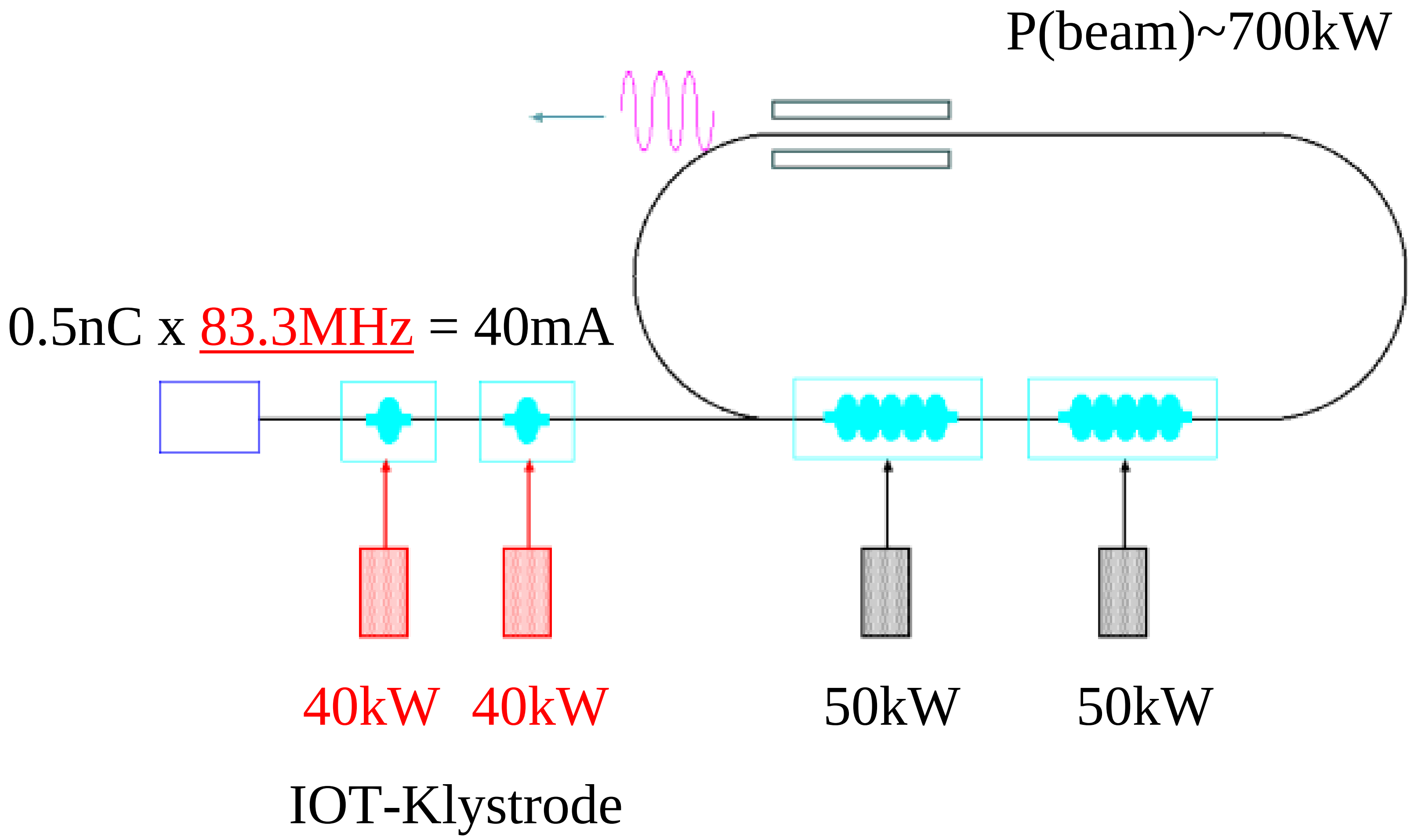
RF and beam power in the original JAERI-FEL



RF and beam power in the JAERI-ERL



RF and beam power in the JAERI-ERL after injector upgrade



Analysis of HOM instability

Using measured HOM parameters, designed optics, and a numerical code similar to TDBBU.

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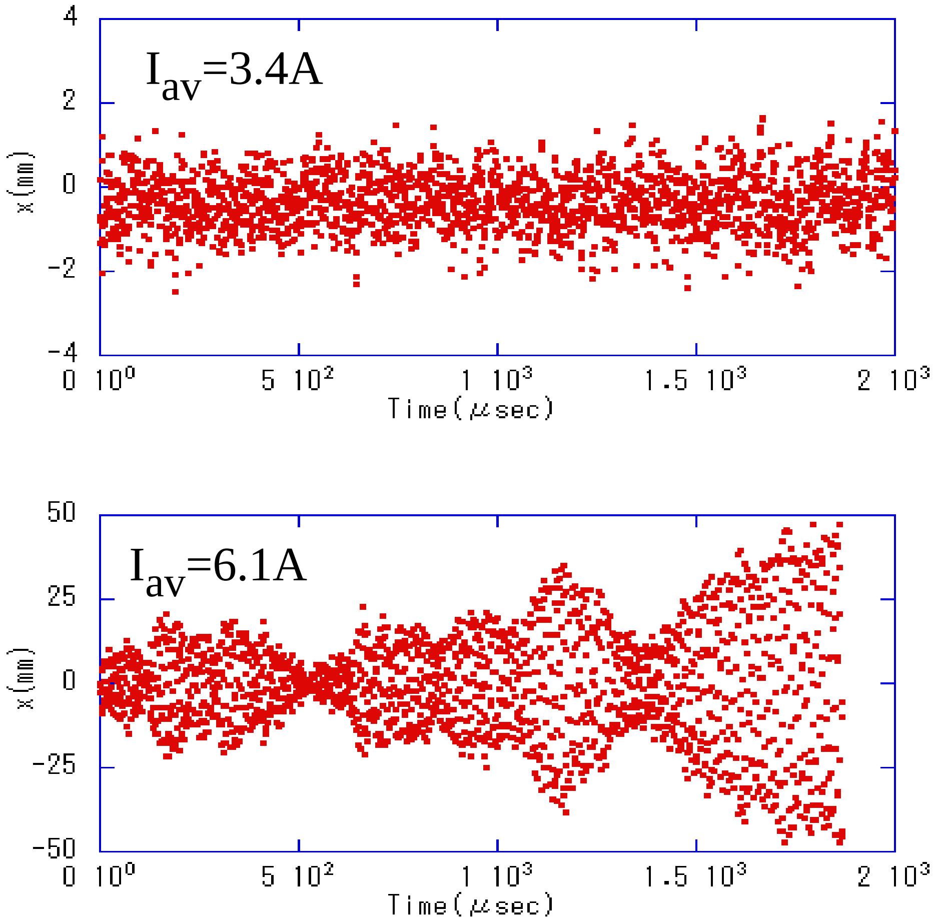
I_{AV}=40mA is far below the instability threshold.

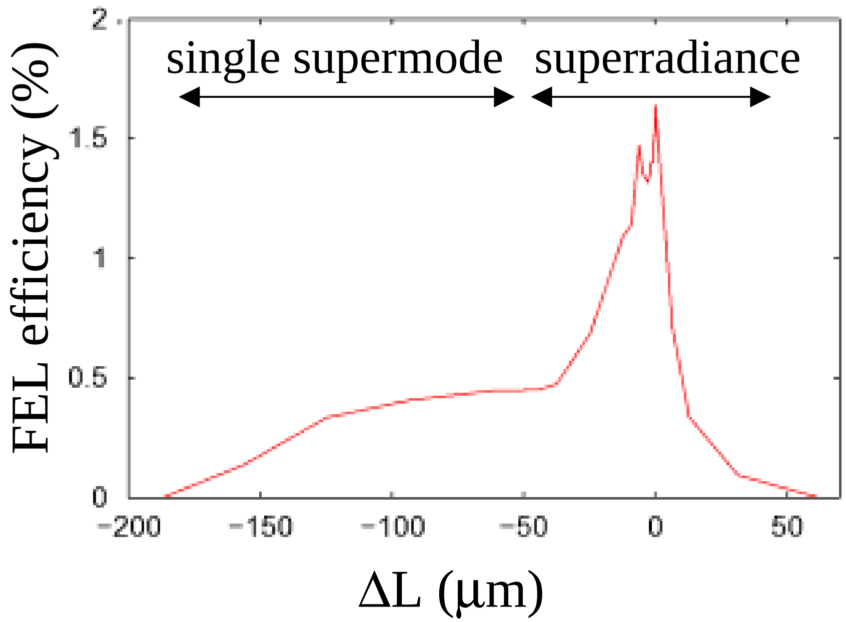
HOM instability is not a critical phenomenon for JAERI-ERL.

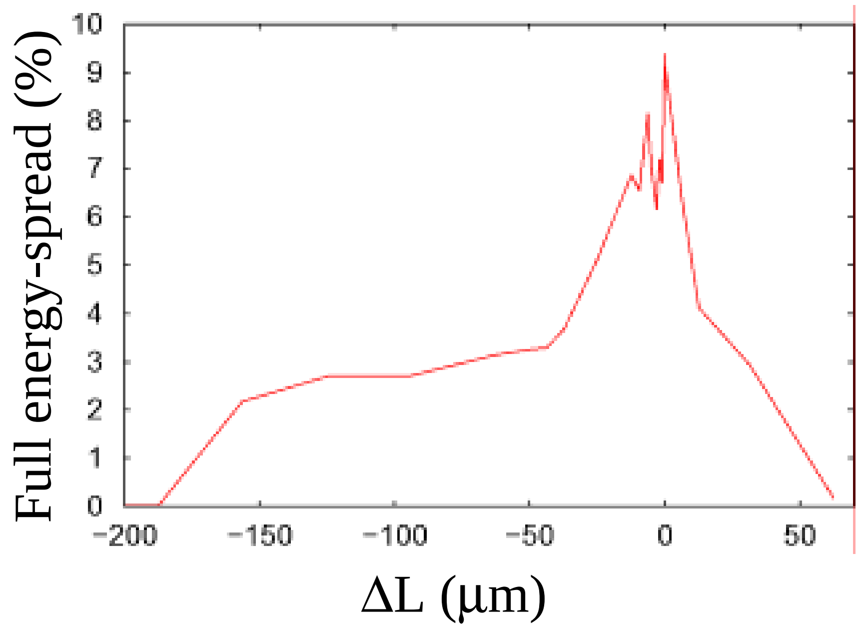


FEL efficiency and energy-spread from a simulation

η_{FEL} ~ 1.5% is expected in superradiant regime,

but ΔE/E(full-width) is ~8%!





1-D FEL simulation with an electron bunch: 30ps (parabolic), j_0=11 at peak, no initial energy-spread.

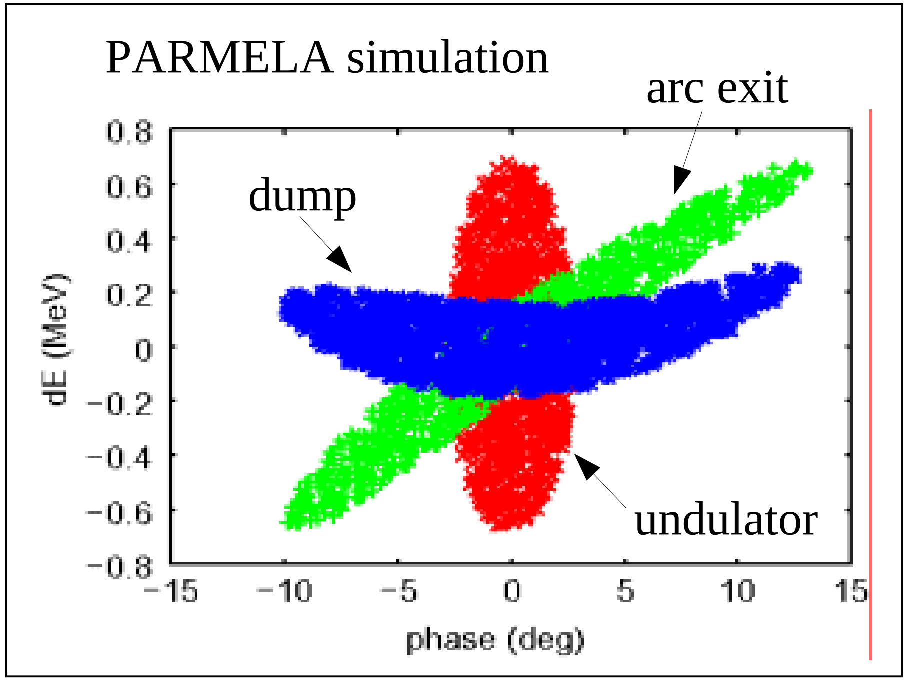
Beam energy compression at the return path

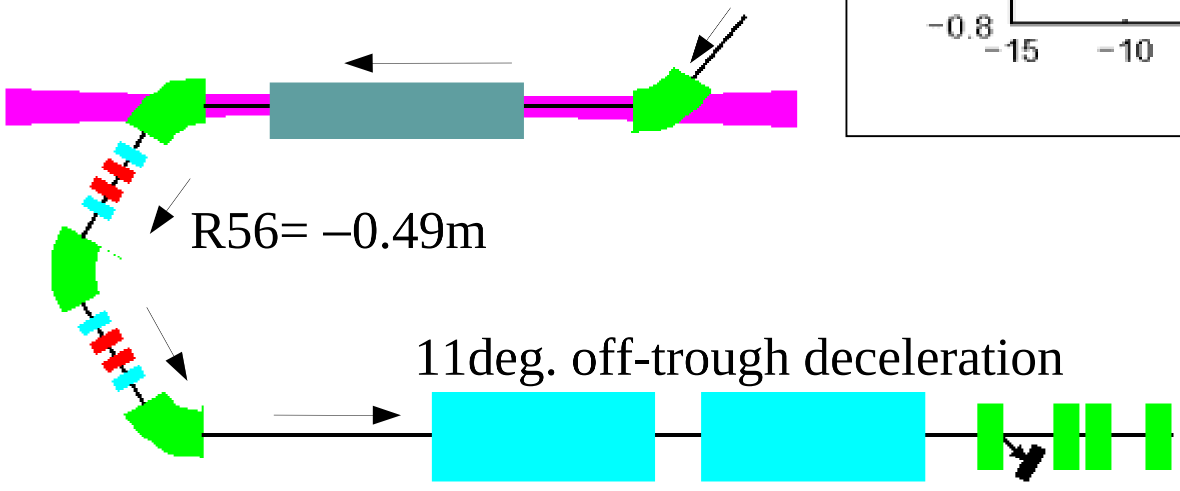
Energy compression for ΔE/E=8% beam

ΔE=1.33MeV@undulator, 17MeV

↓

ΔE=0.46MeV@dump, 2.8MeV





Beam acceptance at the return path

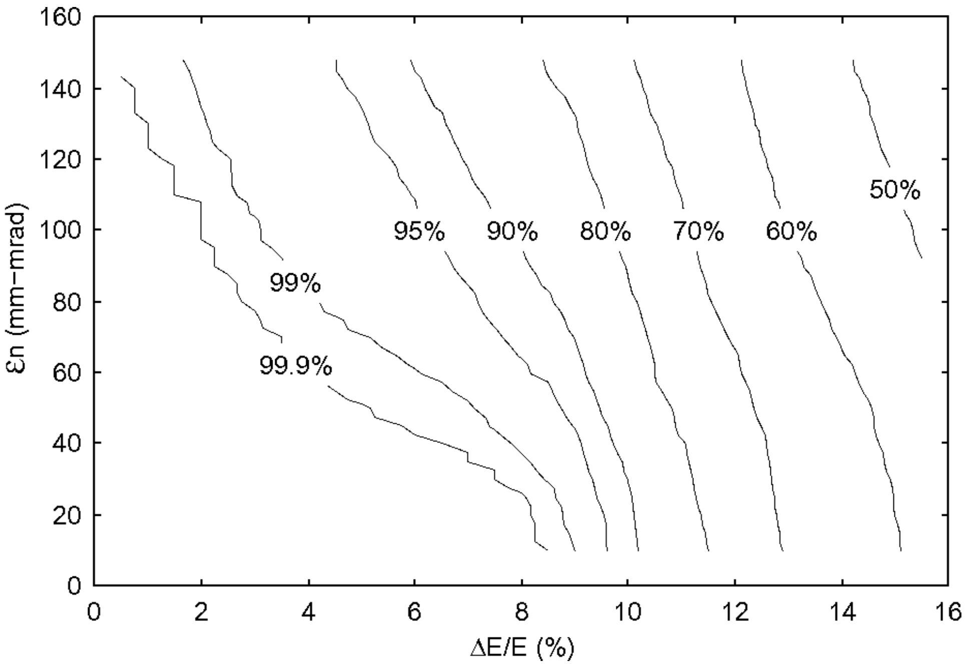
The beam acceptance of the return arc, from the undulator to the dump is estimated as

$\Delta E/E \sim 7\%$ for ε_n=30mm-mrad

$\Delta E/E \sim 5\%$ for ε_n=50mm-mrad

$\eta_{FEL} = 1 - 1.5\%$

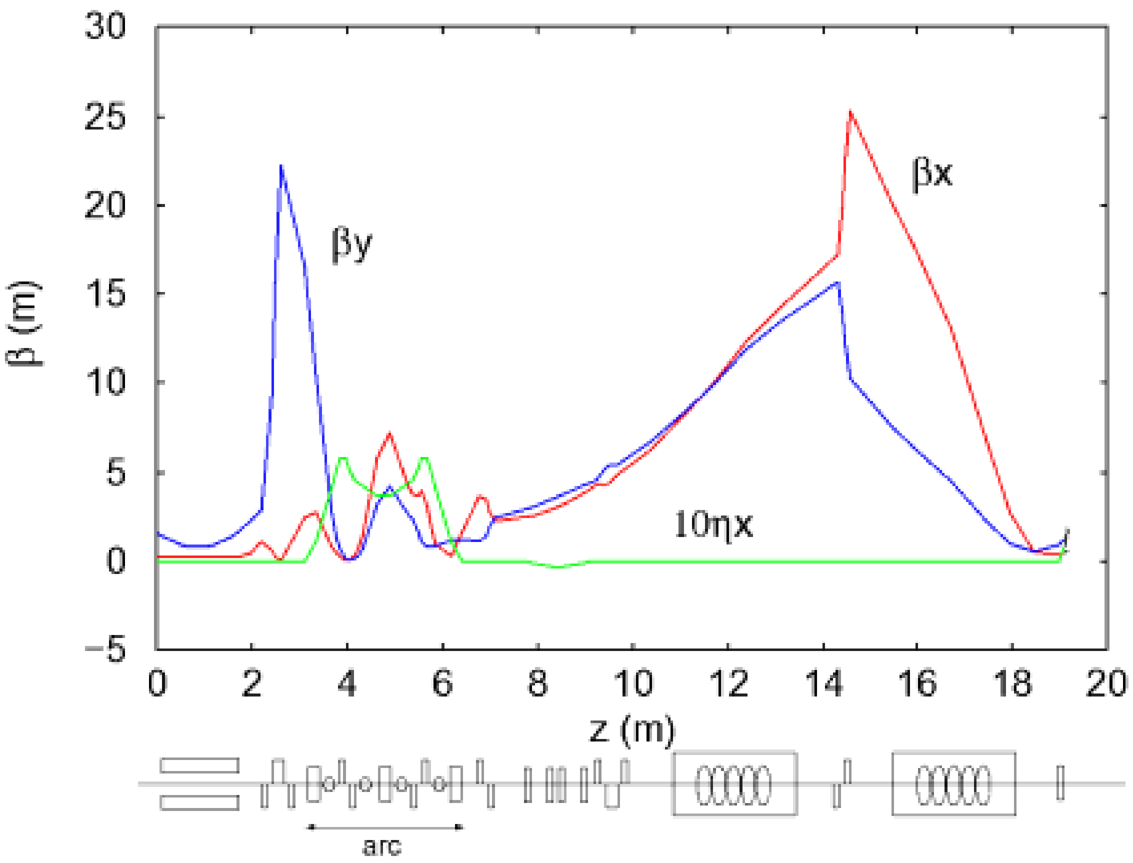
(the energy compression and the 2nd-order correction are included).



PARMELA simulation for beam transmittance from the undulator to the dump.

Beam envelope from the undulator to the dump

For large emittance, beam loss occurs between two cavities.



Conclusions

- An Energy-Recovery Linac has been developed in JAERI for a high-power FEL.

- Energy-recovery operation and FEL lasing have been demonstrated successfully.

- R&D for 10kW FEL is in progress --- injector upgrade, FEL lasing at superradiance, optimization of the return-path for better beam acceptance.

Related Posters

MO-P-20 - Lethargy Effect in FEL Oscillators at Zero Detuning of an Optical Cavity.

MO-P-33 - Electron Beam Dynamics through a Return-Arc and a Deceleration Path of the JAERI Energy-Recovery Linac.

TU-P-21 - A 2-MV DC Electron Gun and Injector for High Power FELs with a Depressed Geometry.

WS-P-10 - Current Status and Future Plans for the JAERI Supercondcting rf Linac-based FEL Facility.