High Power FELs

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Newport News VA

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Outline

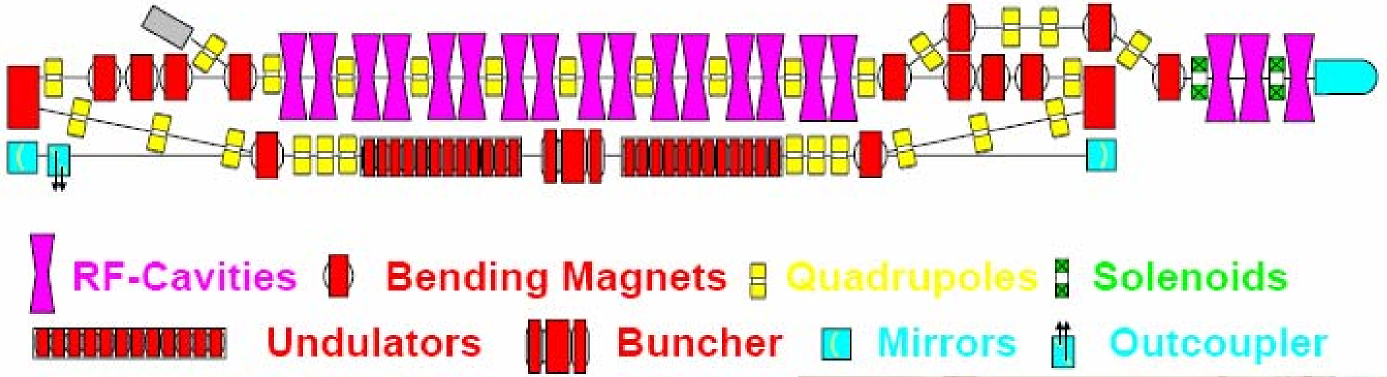
- Operating High Power FELs
  - Recuperator at Novosibirsk
  - JAEA Superconducting ERL
  - JLab IR Upgrade
- Test Stands, in commissioning
  - Daresbury ERLP
- Proposed
  - Daresbury 4GLS
  - KAERI FEL
  - Florida State University BigLight
- Supporting Technology Development
  - Injectors: srf guns, DC Gun

High Power FELs

- A new form of linear accelerator where the energy is recycled rather than the electrons as in a storage ring forms the basis for the development of high power output
  - So far has only been done at <30 mA levels but it is believed that 100s of mA possible
  - ERL Benefits:
    - Reduced power consumption
    - Reduced rf required
    - Reduced power at the dump
    - Significantly reduced or eliminated neutron activation
    - Brighter light source beams

The Novosibirsk High Power THz FEL

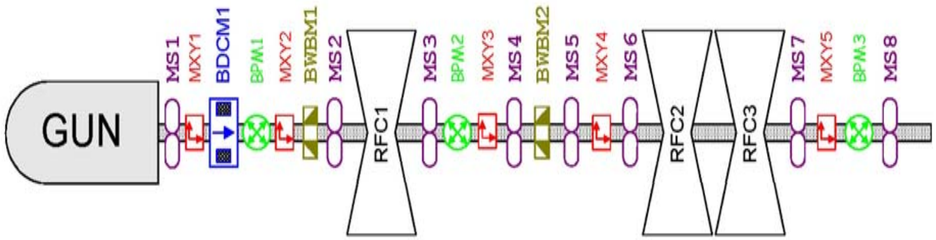
Energy recovered highest average current to date: 30 mA at 1.7 nC per bunch



	May 2005	Plans
RF frequency, MHz	180	180
Bunch repetition rate, MHz	**22.5!**	90
Maximum average current, mA	**30!**	150
Maximum electron energy, MeV	12	14
Normalized beam emittance, mm*mrad	30	15
Electron bunch length in FEL, ns	0.07	0.1
Peak current in FEL, A	10	20

Courtesy N. Vinokurov

Recuperator FEL Injector



MS : focusing solenoid

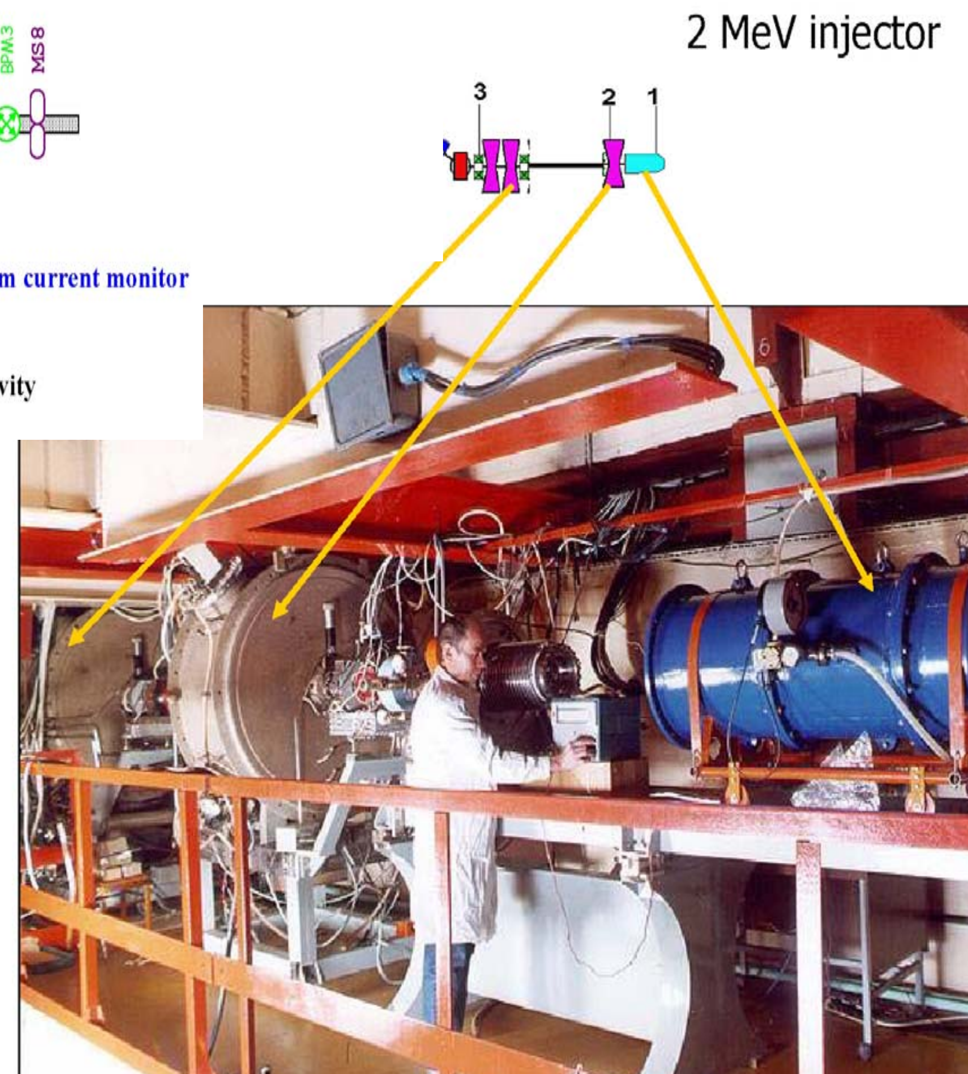
MXY : steering magnet

BDCM : beam current monitor

BPM : bean position monitor

BWBM : strip line monitor

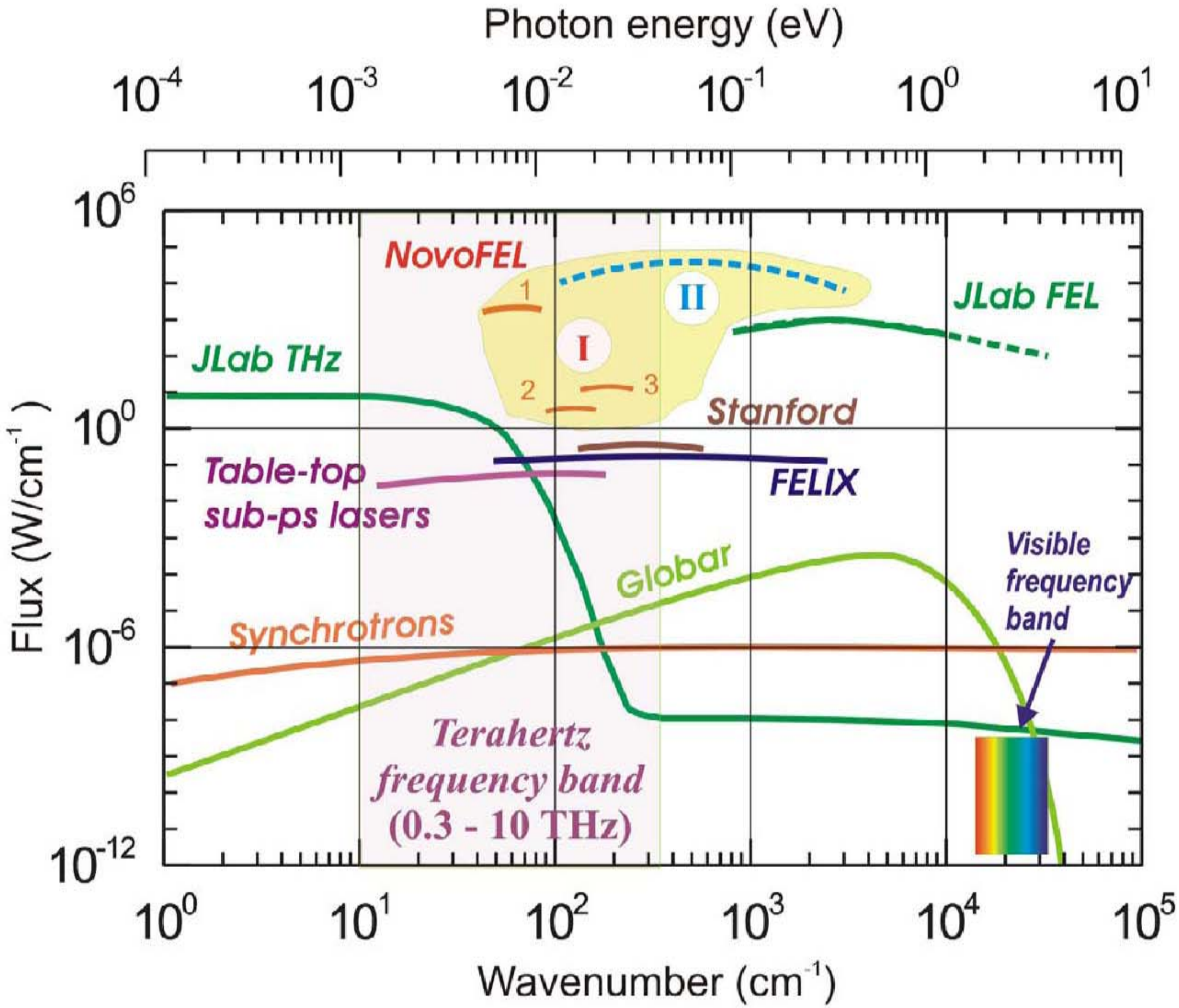
RFC : RF cavity



♦Bunch repetition rate, MHz	up to	22.5
♦Charge per bunch, nC		1.5
♦Start bunch length, ns		1.5
♦Final bunch length, ns		0.12
♦Final energy, MeV		2

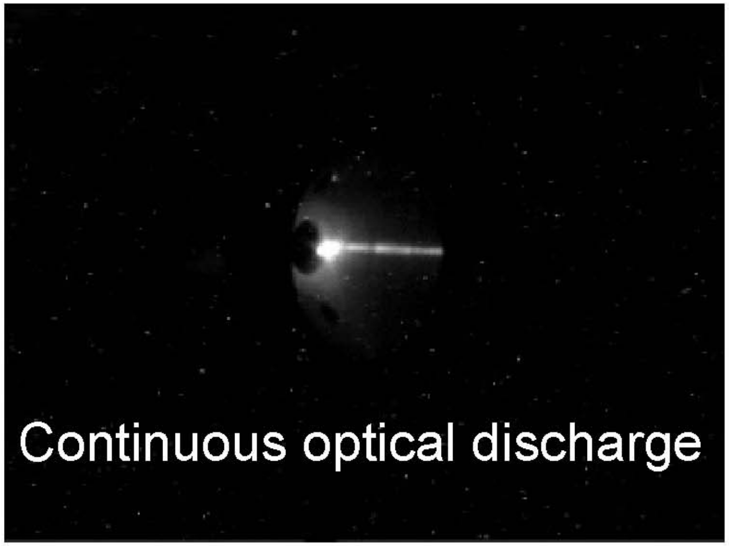
Courtesy N. Vinokurov

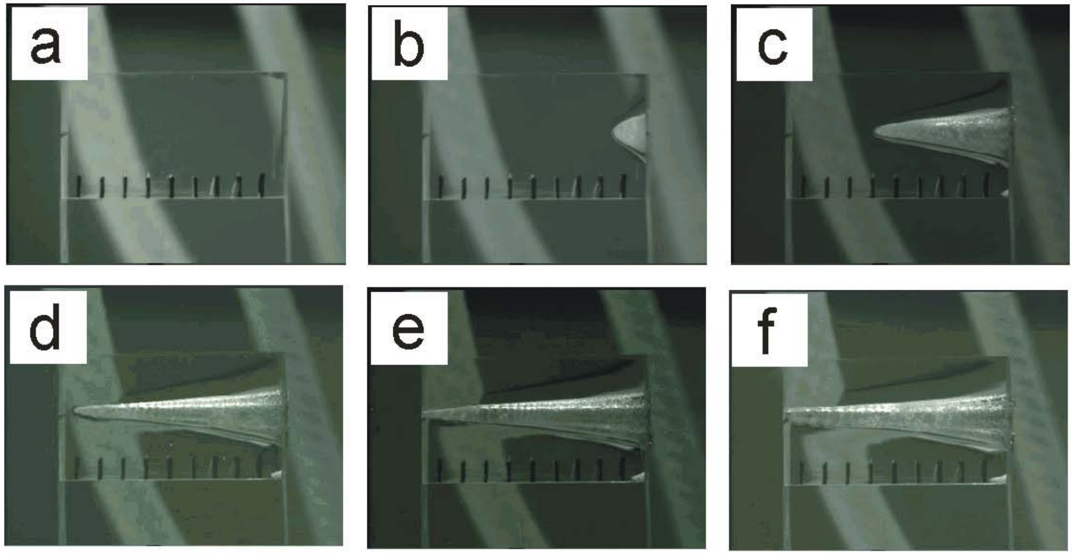
Radiation characteristics of THz sources



Courtesy N. Vinokurov

High average power of radiation (up to 400 W) in combination with high peak power (up to 1 MW) enables performing high power density experiments

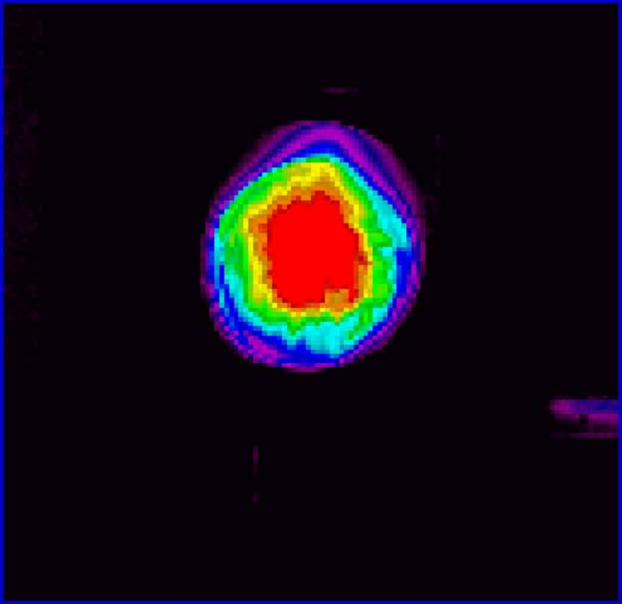




- Laser beam focused in the atmosphere with a parabolic mirror (f=1.0 cm) ignites a continuous optical discharge
- Unfocused laser beam drills an opening in 50-mm organic glass slab within three minutes (ablation without burning)
- These fenomena can be used for many fundamental and applied experiments (plasma physics, aerodynamics, chemistry, material processing and modification, biology…)

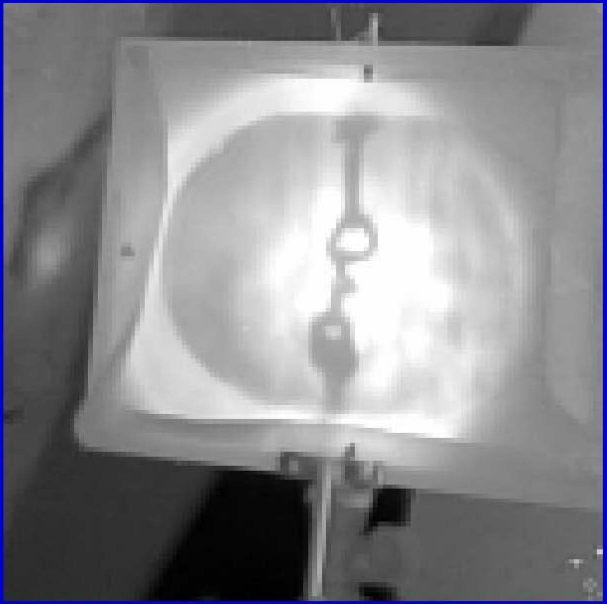
Courtesy N. Vinokurov

Recuperator FEL



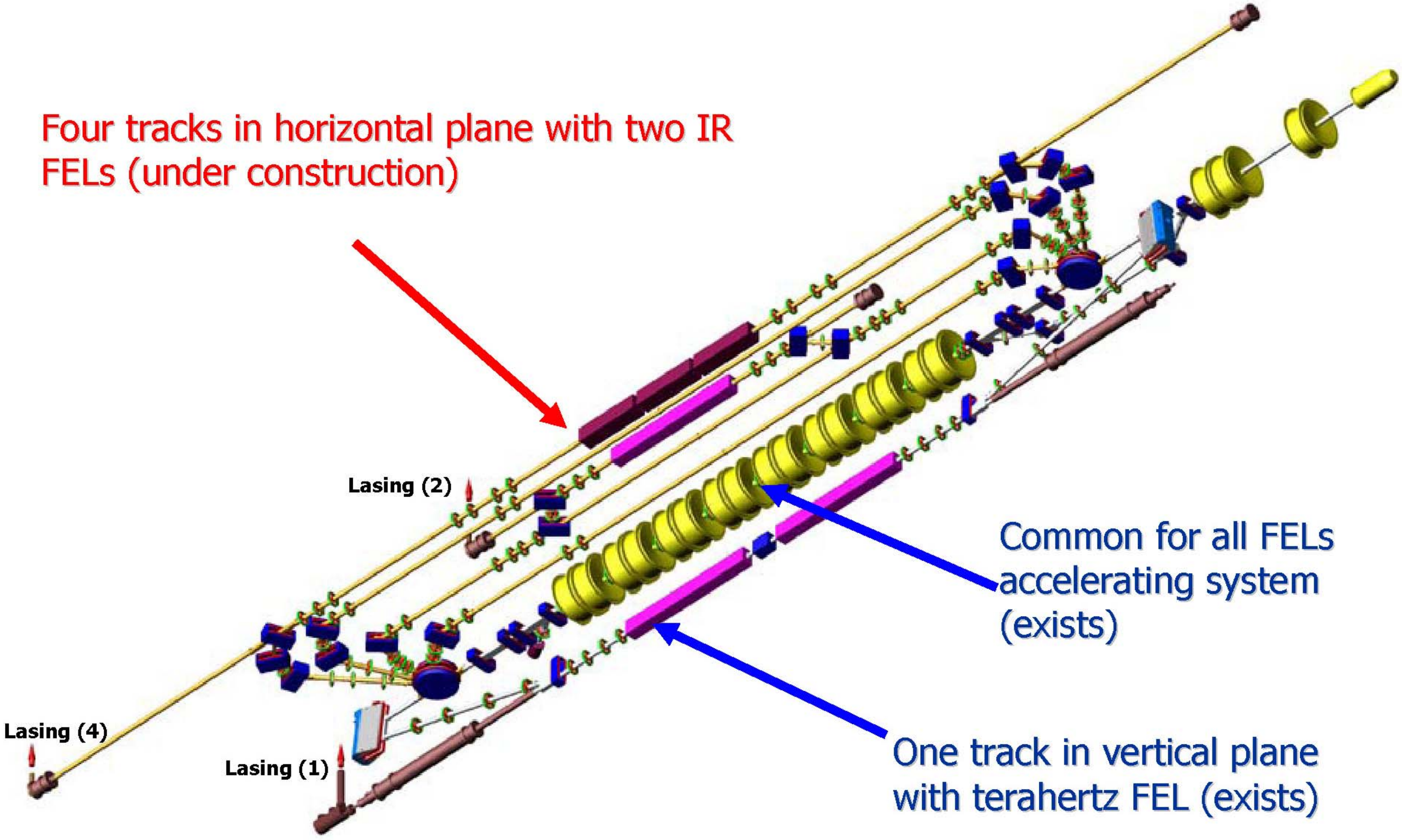
Beam profile

Metallic screen with holes



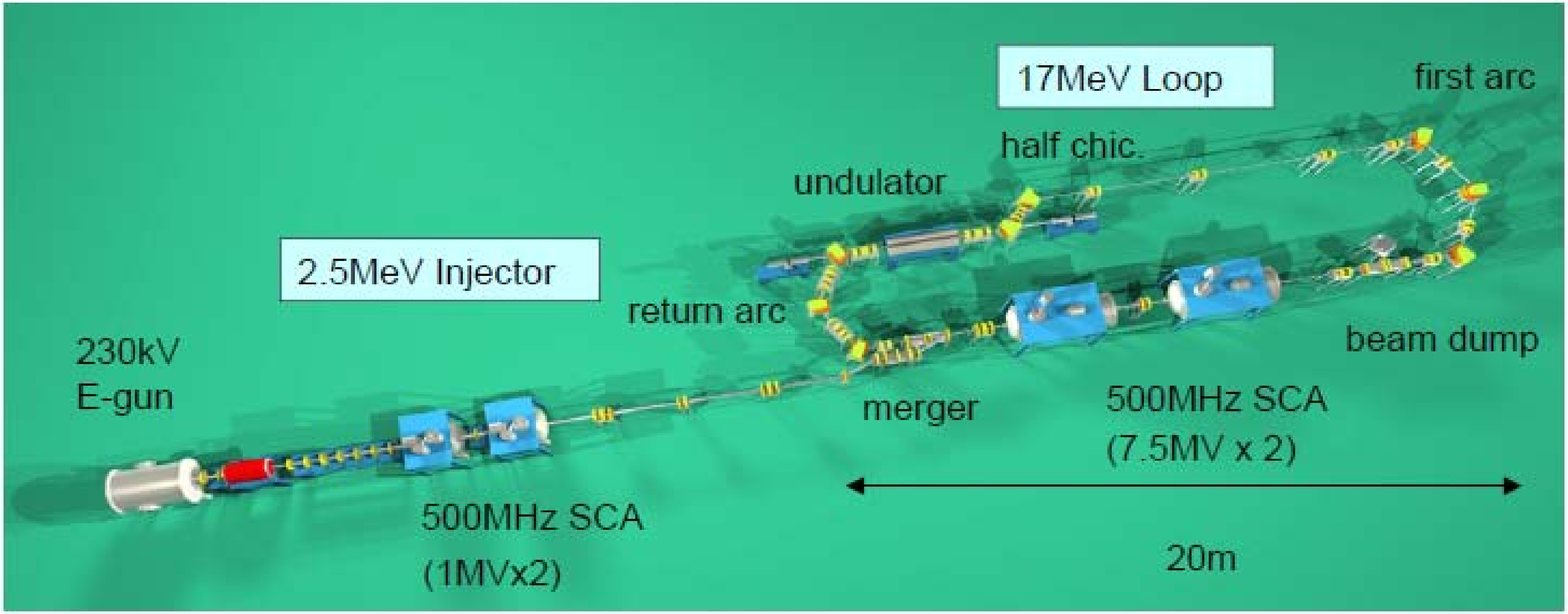
Keys inside paper envelope

Full scale Novosibirsk FEL (bottom view)



Courtesy N. Vinokurov

A high power ERL FEL at JAEA



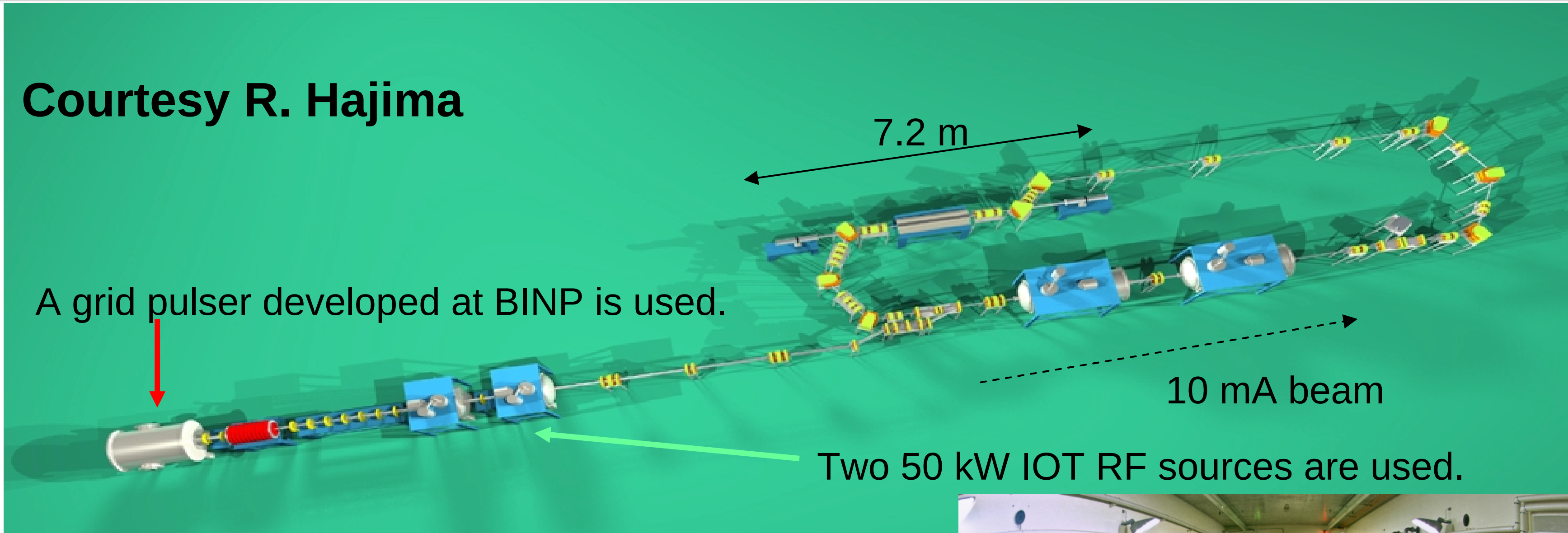
FEL wavelength is 22 μm and electron bunch carge is 0.5nC.

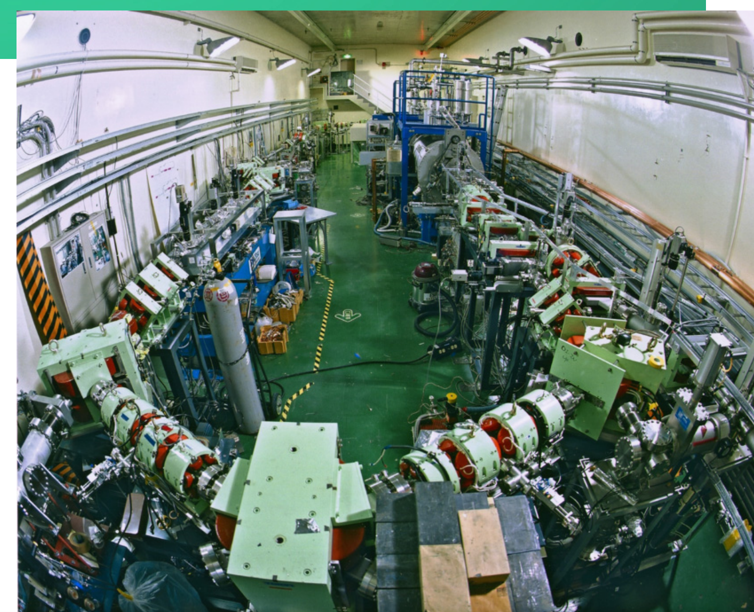
The injector consists of 230kV thermionic cathode DC gun, 83.3 MHz sub harmonic buncher and two single-cell 500 MHz SCAs.

17 MeV loop consists of a merger chicane, two five-cell 500 MHz SCAs, a triple-bend achromat arc, half-chicane, undulator, return-arc, and beam dump.

First lasing in August, 2002. R. Hajima et al., NIM A 507, 115 (2003).

JAEA ERL FEL





Energy = 17MeV
FEL : λ = 22μm
Bunch charge =400pC
Bunch length = 12ps (FWHM)
Bunch rep. = 20.8 MHz
Macro pulse = 0.23ms x 10Hz

JAEA ERL FEL

Proceedings of FEL 2006, BESSY, Berlin, Germany TUAAU

FEL OSCILLATION WITH A HIGH EXTRACTION EFFICIENCY AT JAEA ERL FEL

N. Nishimori*, R. Hajima, H. Iijima, N. Kikuzawa, E. Minehara, R. Nagai, T. Nishitani, M. Sawamura, JAEA, Ibaraki, Japan.

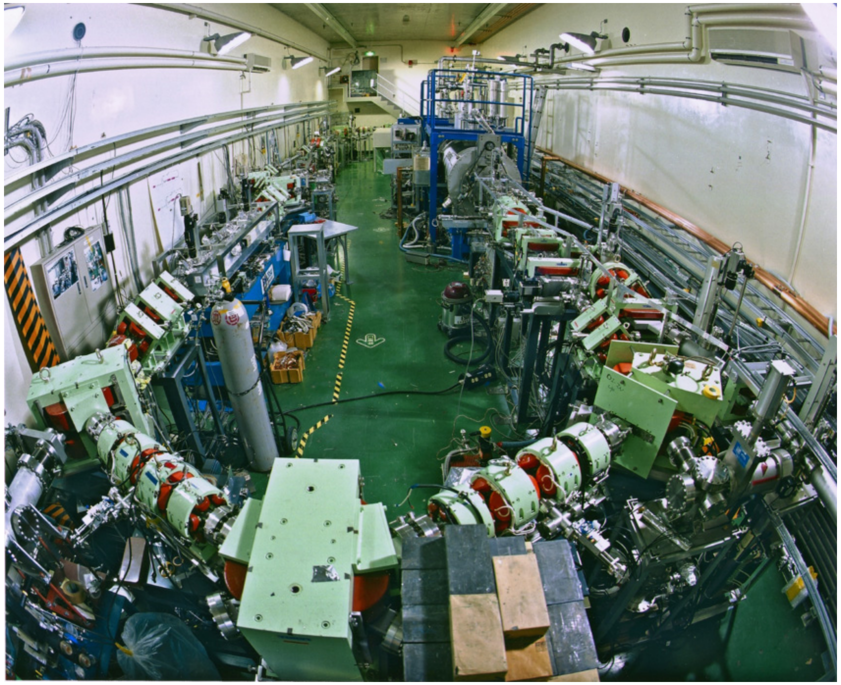


Table 1: JAEA ERL FEL parameters

Parameter	Measured
Beam energy at undulator	17 MeV
Average current at undulator	8 mA
Bunch charge at undulator	0.4 nC
Bunch length at undulator	12 ps (FWHM)
Peak current	35 A
Energy spread before undulator	1.5% (FWHM)
after undulator	> 15% (full)
Normalized emittance (rms)	40 mm mr
Bunch repetition	20.8250 MHz
Macropulse	1 ms × 10 Hz
Undulator period	3.3 cm
Number of undulator periods	52
Undulator parameter (rms)	0.7
Optical cavity length	7.2 m
Rayleigh range	1.00 m
Mirror radii	6 cm
Output wavelength	22 μm
FEL extraction efficiency	> 2.5%

Courtesy Hajima JAEA

JAEA ERL FEL

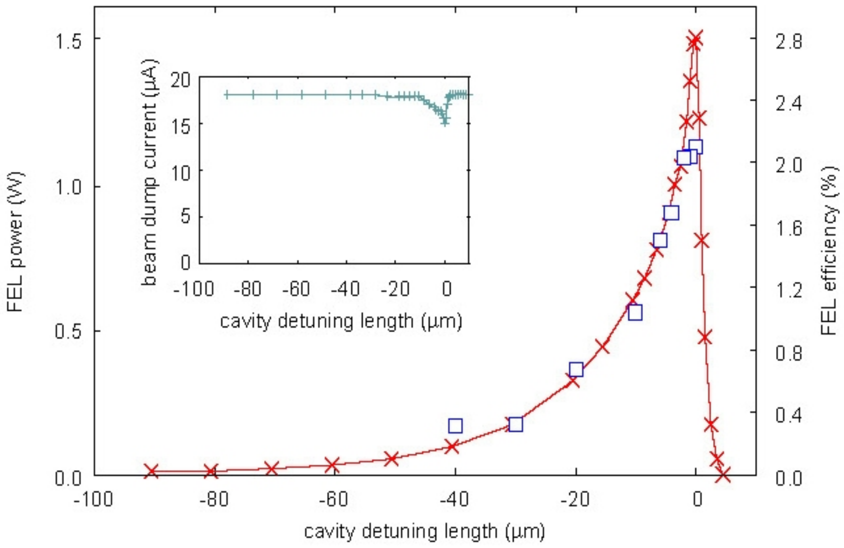


Figure 3: FEL power measured as a function of δL at macropulse length of 230 μs. FEL efficiencies obtained from the energy distributions of the exhausted electron beam are shown by open squares. The efficiencies near zero detuning length cannot be measured with our energy analyzer due to the limited energy acceptance, and they are determined from measured FEL power. The inset shows the beam dump current with respect to δL.

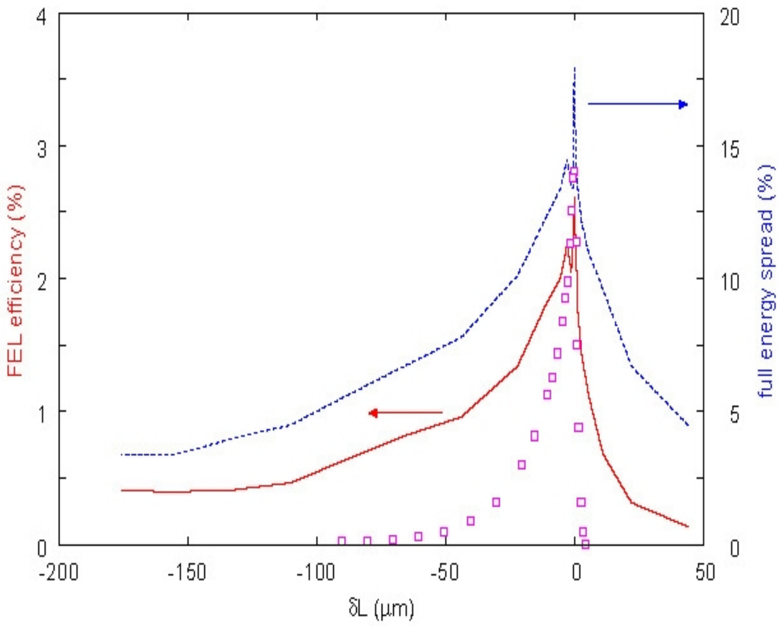
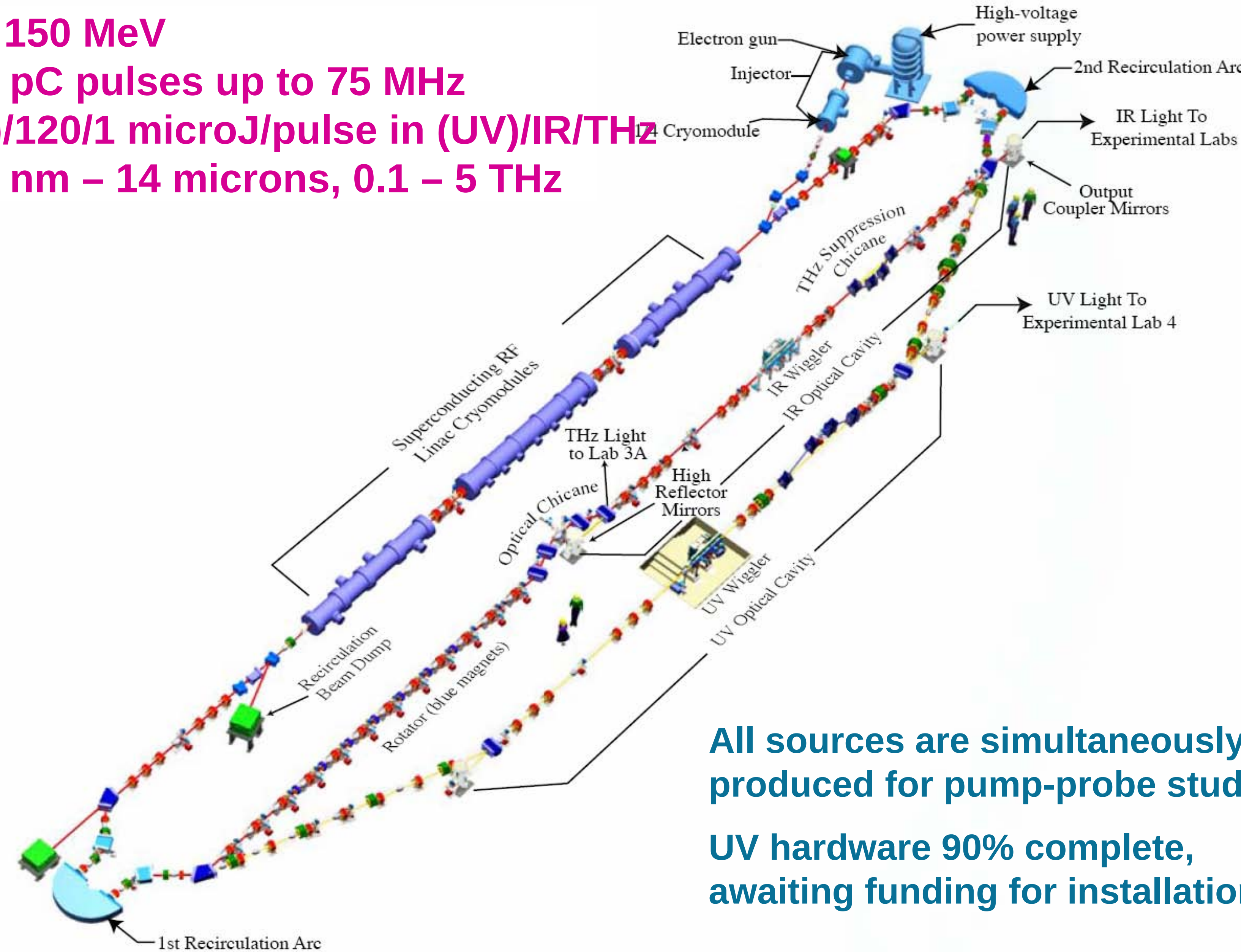


Figure 4: FEL efficiencies as a function of δL obtained from a one-dimensional time-dependent FEL simulation (solid line) and corresponding beam energy spread (dotted line). Measured FEL efficiencies are also plotted as open squares for comparison.

Courtesy Hajima JAEA

JLab Energy Recovered Linac

E = 150 MeV
135 pC pulses up to 75 MHz
(20)/120/1 microJ/pulse in (UV)/IR/THz
250 nm – 14 microns, 0.1 – 5 THz

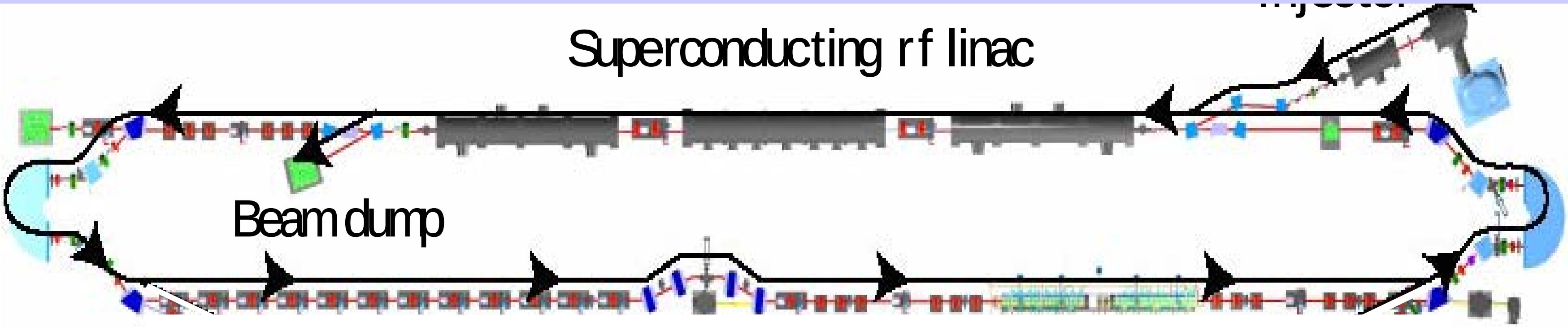


All sources are simultaneously produced for pump-probe studies

UV hardware 90% complete, awaiting funding for installation

The Jefferson Lab IR FEL Upgrade

Achieved 14.2 kW CW light power at 1.6 μm on October 30, 2006!



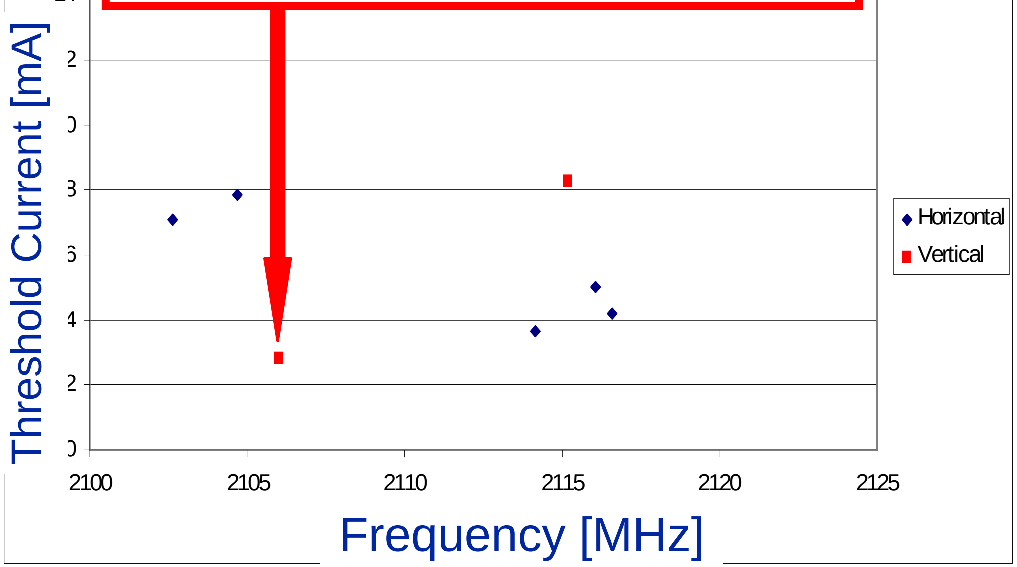
JLab IR FEL Electron Beam Parameters	Design	Achieved
Energy (MeV)	145	160
Bunch charge (pC)	135	270
Average current (mA)	10	9.1
Bunch length* (fs)	500	150
Norm. emittance* (mm-mrad)	30	7
Max. Bunch rep. rate (MHz)	74.85	74.85

*Quantities are rms

BBU Simulation and Observation

BBU simulations of the JLAB 10 kW FEL

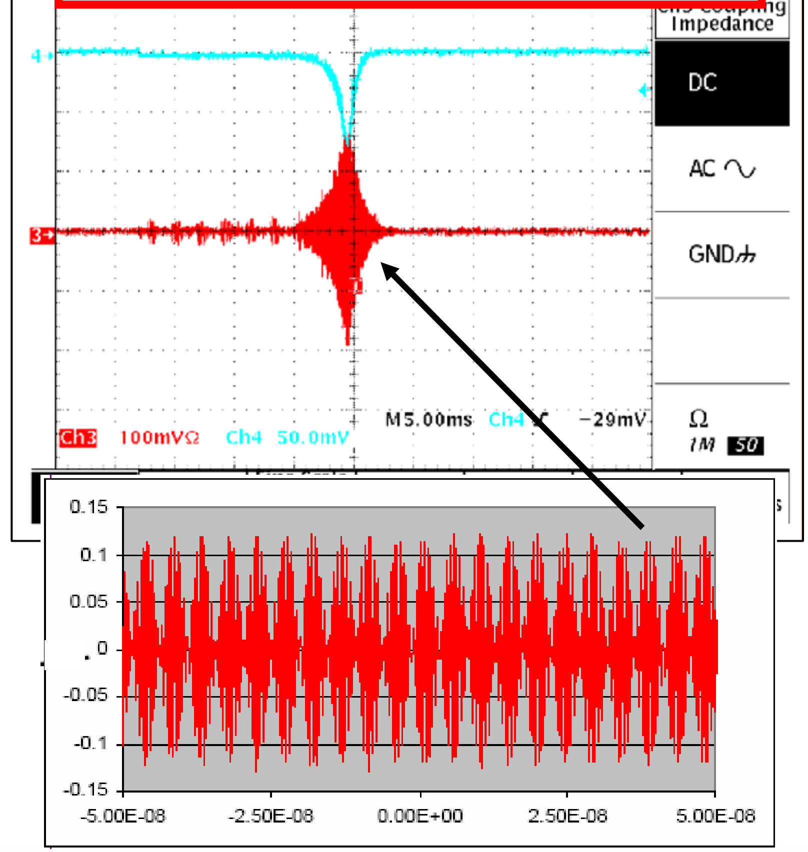
Cavity 7
f_{HOM}=2106 MHz, I_{th}=2.85 mA



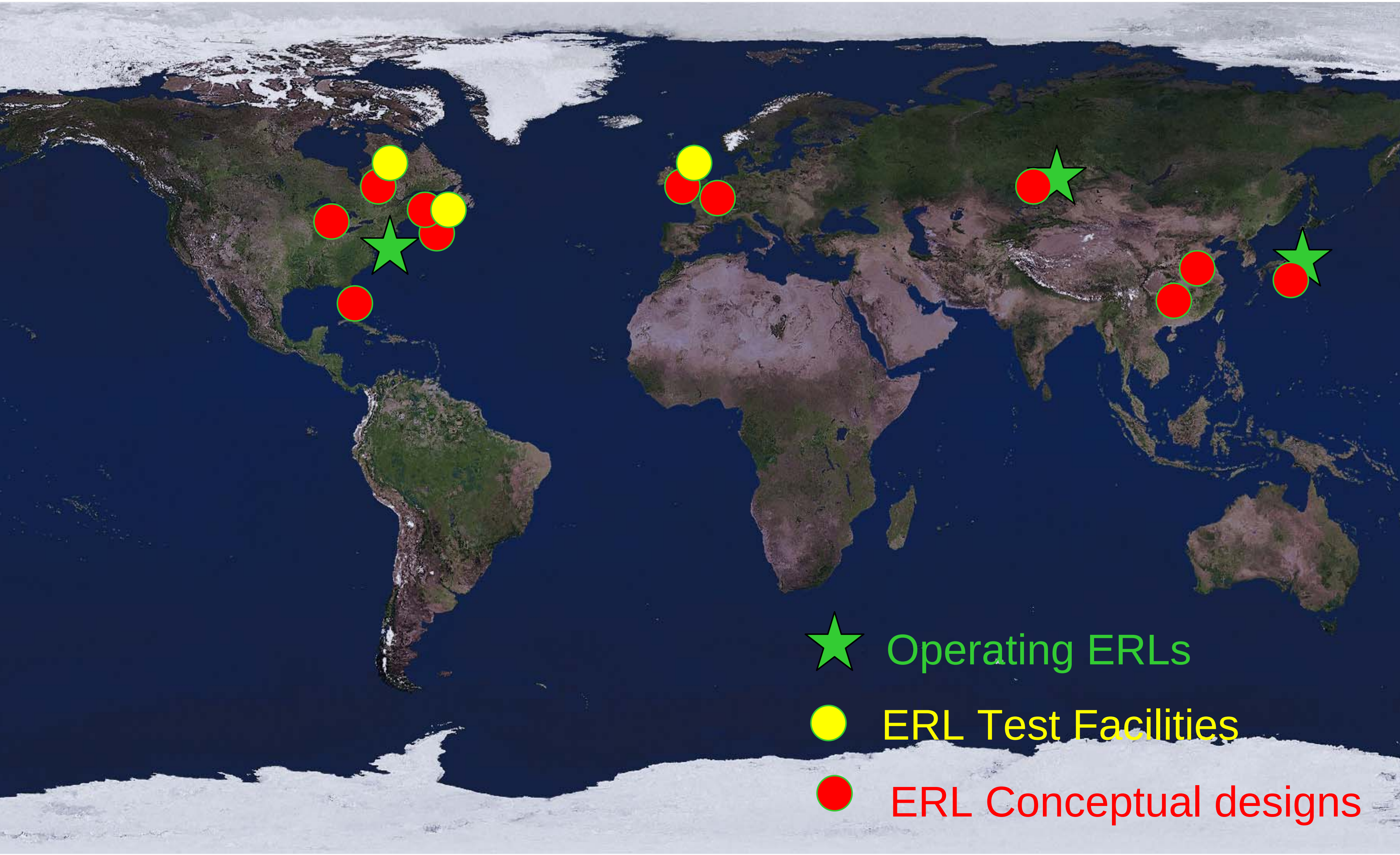
HOM data based on measurements
Model recirculation matrix

BBU observation in the JLAB 10 kW FEL

Cavity 7
f_{HOM}=2106 MHz, I_{th}=2.7 mA

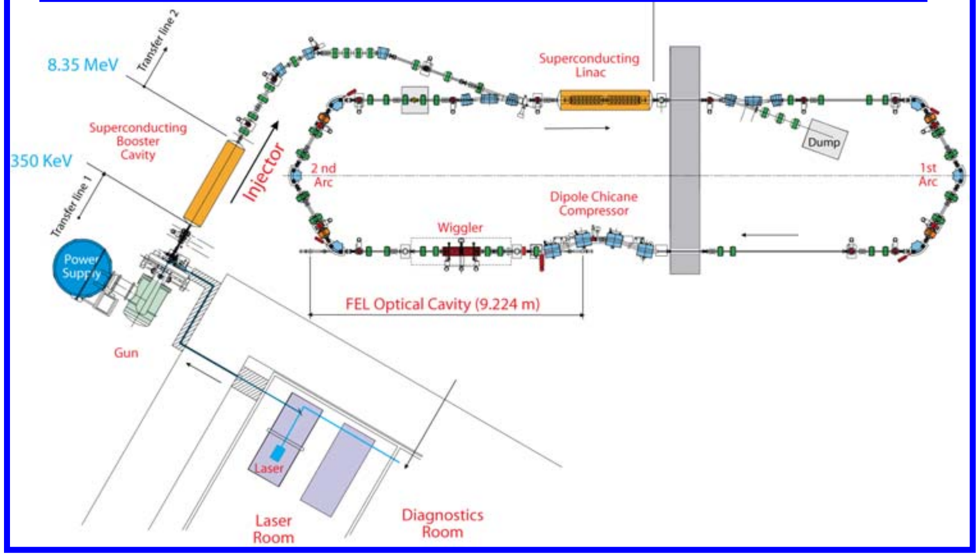


Operating and Future ERLs

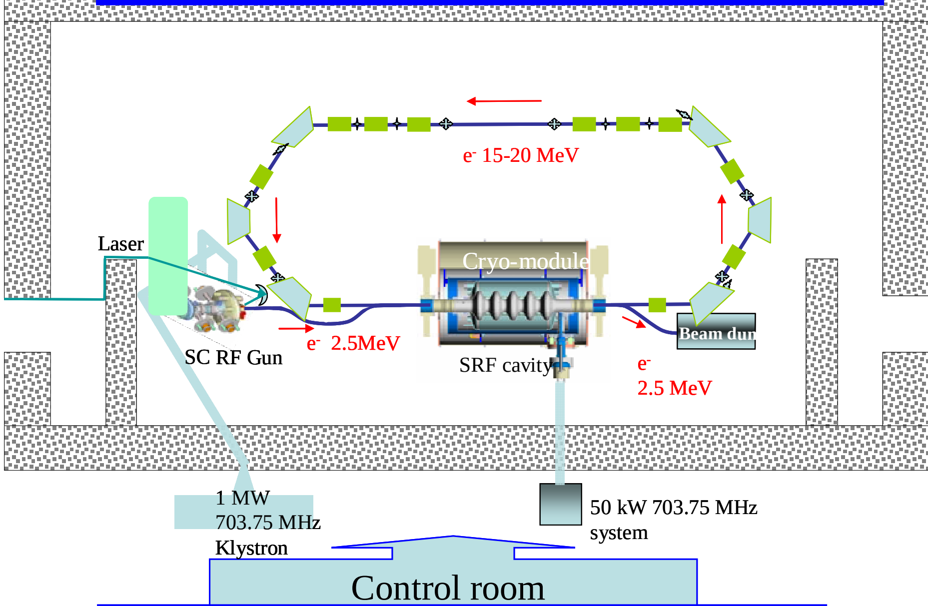


ERL Test Facilities in assembly and test

Daresbury ERL Prototype

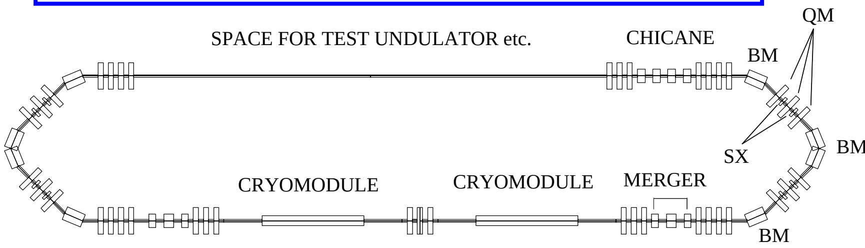


BNL R&D ERL



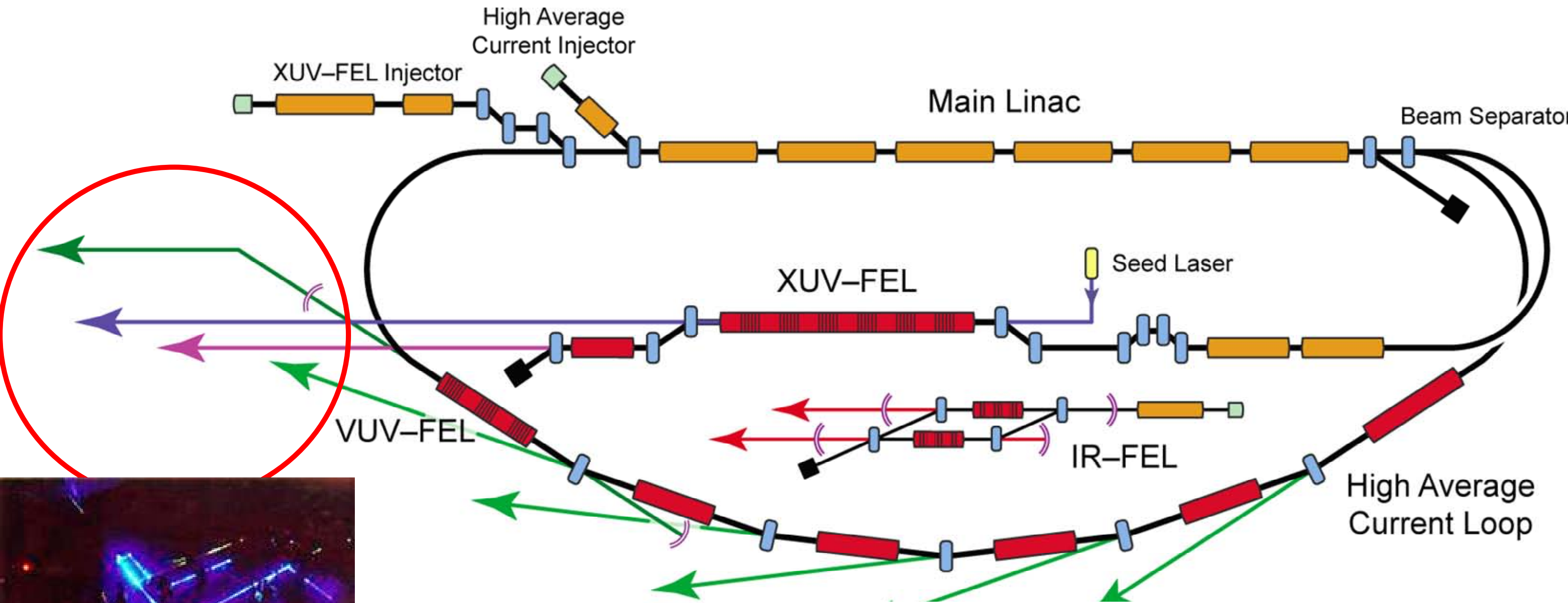
Cornell ERL Prototype Injector

Japan Test ERL



4GLS

Future ERL Light Sources: an example shows the possibilities



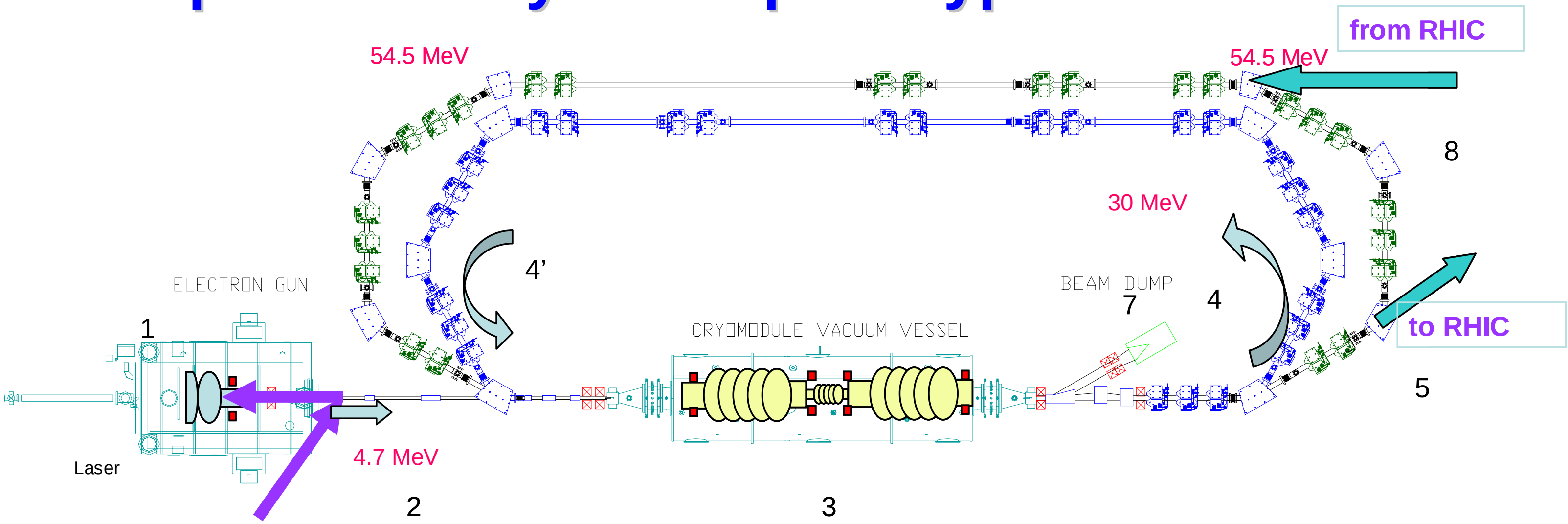
plus
laser sources

IR FEL Oscillator
VUV FEL Oscillator
XUV Amplifier
Spontaneous sources
All synchronized < psec

FRAAU05 McNeil

RHIC-II Electron Cooler

a two-pass ERL system - prototype under construction



Design Parameters

MOPPH035 Litvinenko

Courtesy BNL

Energy 54 MeV

Charge 5 nC/bunch

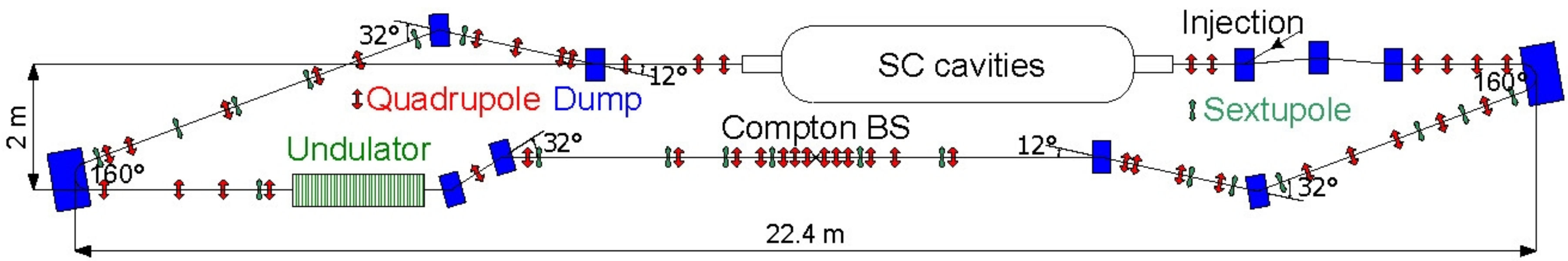
Emittance $\leq$ 4 mm-mrad

Average current ~ 50 mA

PAC07 WEOCKI03 Ben-Zvi

A PROJECT OF A HIGH-POWER FEL DRIVEN BY AN SC ERL AT KAERI

A.V.Bondarenko, S.V.Miginsky, Budker Institute of Nuclear Physics, Novosibirsk, Russia
B.C.Lee, S.H.Park, Y.U.Jeong, Y.H.Han, Korea Atomic Energy Research Institute, Daejeon, Korea



- bunch duration: 100 ps;
- number of electrons per bunch: 10^{10};
- electron energy (full): 10 MeV;
- repetition rate: 5.6 MHz;
- emittance: 2π mm·mrad;
- energy spread (relative): $6 \cdot 10^{-3}$.

MOPPH064

Big Light FEL for NHMFL

Accelerator:

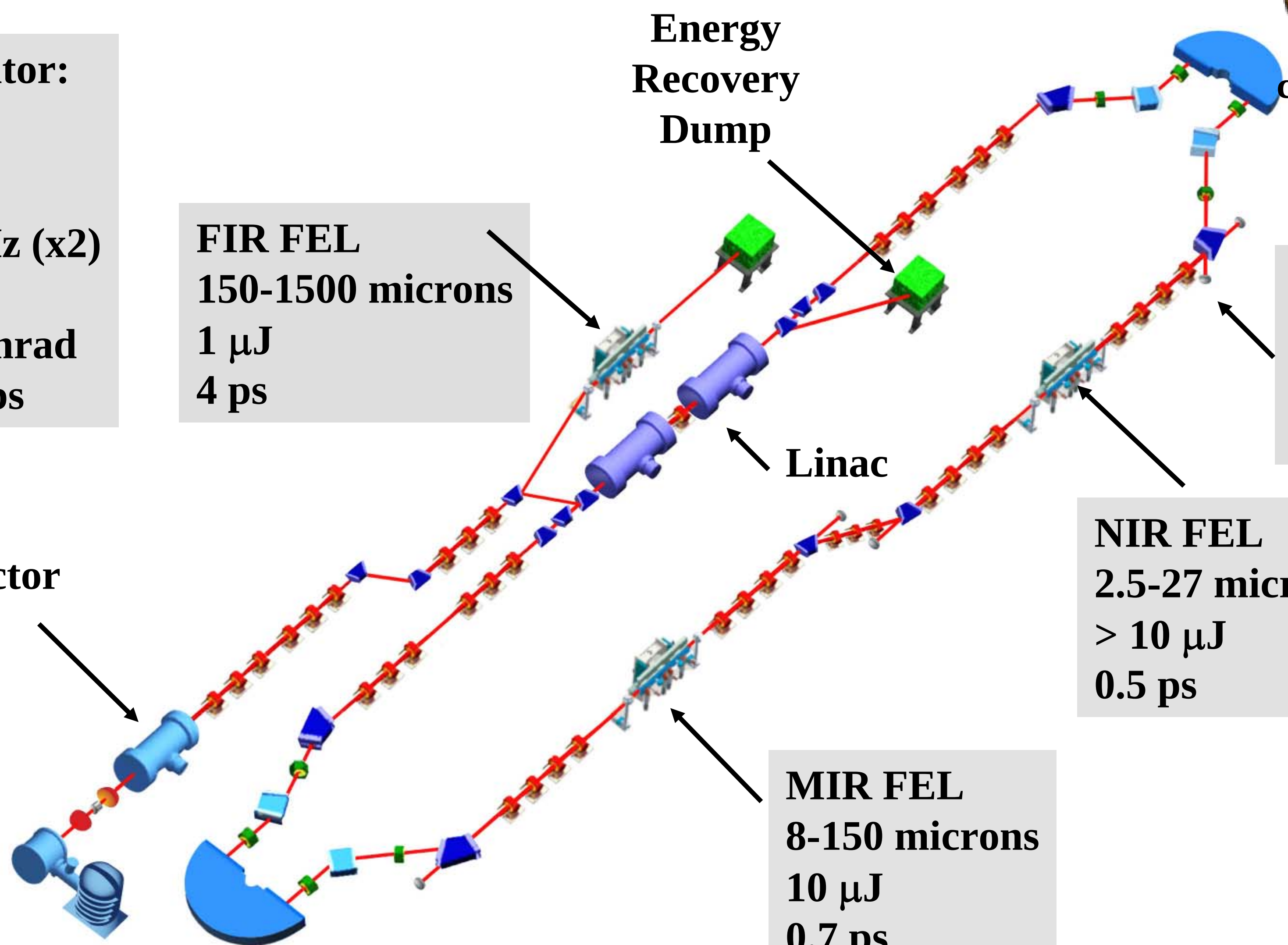
60 MeV
3 mA
10.7 MHz (x2)
135 pC
10 mm mrad
80 keV-ps

FIR FEL
150-1500 microns
1 μJ
4 ps

THz
Broadband
to 1 THz
1 μJ

NIR FEL
2.5-27 microns
> 10 μJ
0.5 ps

MIR FEL
8-150 microns
10 μJ
0.7 ps



Technology Development

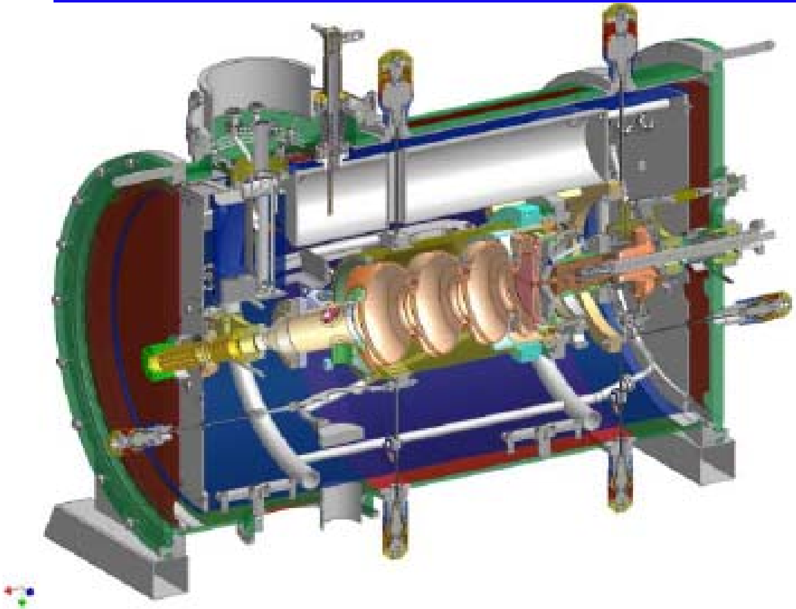
- Although other technologies are required the injector is key

- SRF
- DC

Goal: High brightness at high average current

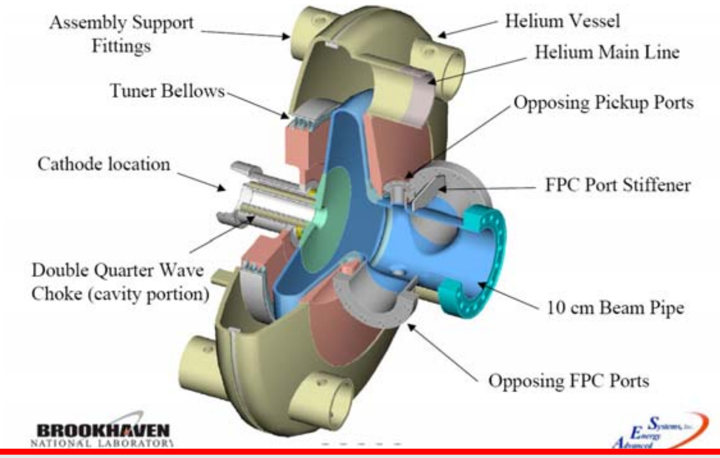
SRF photoinjectors

Rossendorf SRF gun

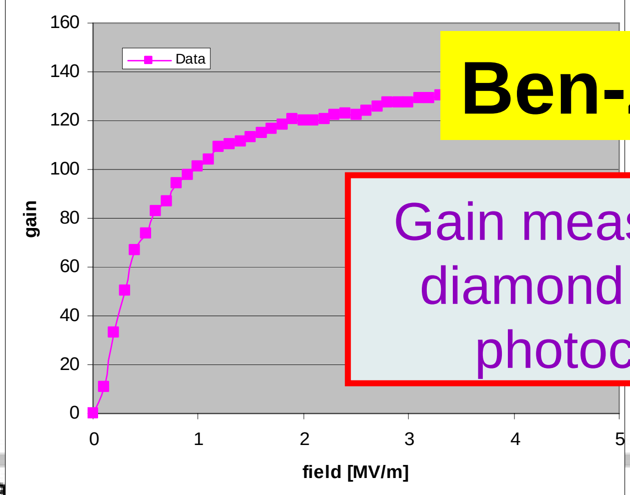


1.3 GHz, 9.5 MeV, CW
3 modes of operation:
- 77 pC at 13 MHz
- 1 nC up to 1 MHz (1 mA)
- 2.5nC at 1 kHz

BNL/AES SRF gun



703.75 MHz, 2.5 MeV, 500 mA,CW

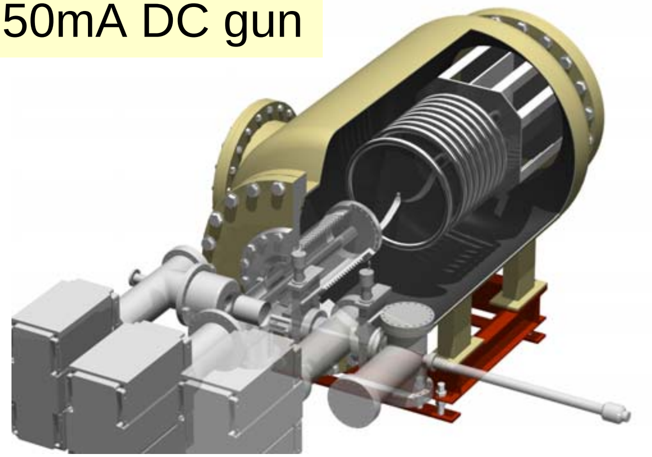


Ben-Zvi Talk

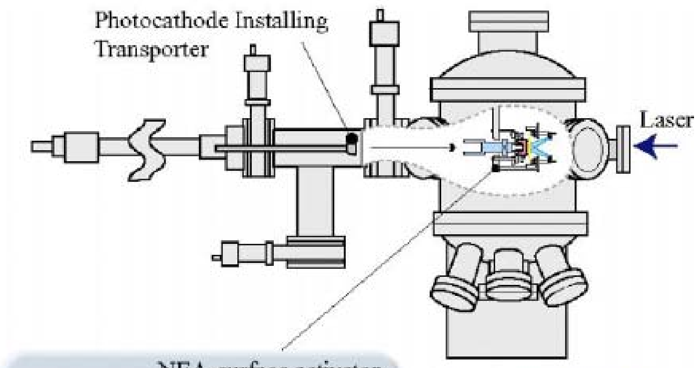
Gain measured from diamond amplified photocathode

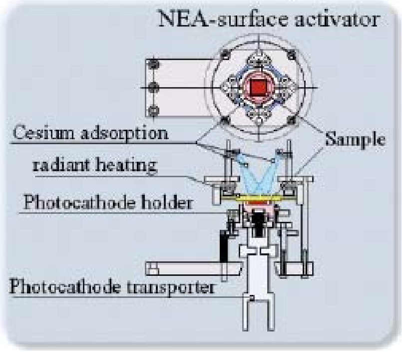
Development of a 250kV-50mA Gun

250kV-50mA DC gun



photocathode test bench





A DC gun for high-average current and small emittance is under development.

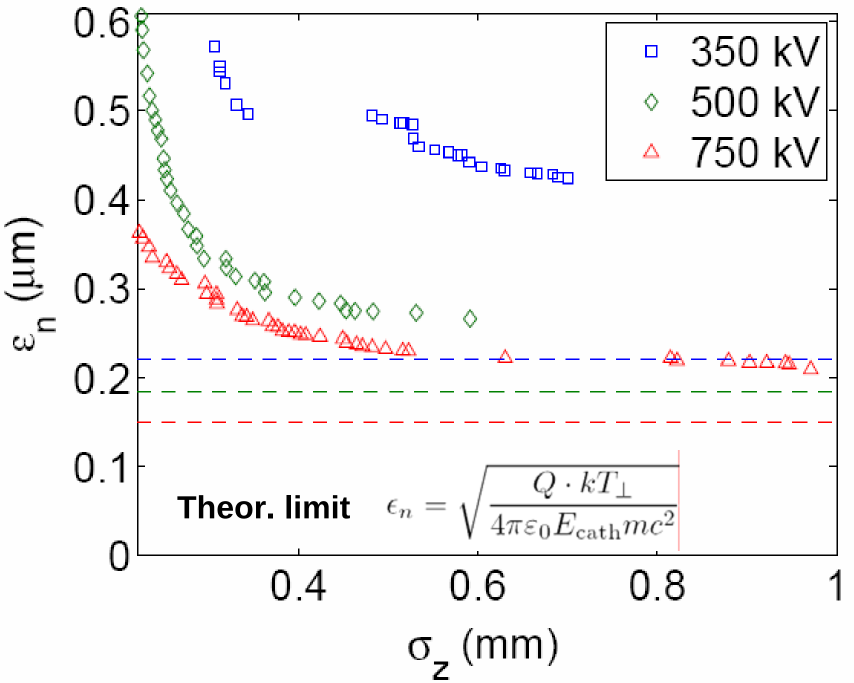
Basic studies on QE and life-time issues of NEA photo-cathode are in progress.

Courtesy: R. Hajima

Reaching ultimate emittance limit in a DC gun

Cornell ERL Prototype Injector

See K-J Kim, Session 5:
1 Angstrom FEL Oscillator!



Multi-parameter optimization achieves 0.1 mm-mrad, 80 pC dominated by cathode temperature

Courtesy: I. Bazarov

Summary

Lots of activity in ERL based FELs and related light sources

Much progress in achieving higher power

Still many challenges to keep researchers employed for many years!

Acknowledgements

Too many to get all of them!

Lia Merminga provided major help in pulling together the ERL activities. Please see her invited talk from PAC'07.

I am also grateful to Ryoichi Hajima, Vladimir Litvinenko, Matt Poelker, Dave Douglas, Gwyn Williams, Bob Rimmer, Steve Benson, Michelle Shinn, Carlos Hernandez-Garcia, Susan Smith, Pavel Evtushenko, and Nikolay Vinokurov for providing slides, information, and support