Numerical simulation and experimental demonstration of seeded FEL at BNL-NSLS

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Outline
- Directed energy application of FEL
- Numerical simulation of MW amplifier
- Experimental demonstration of seeded FEL

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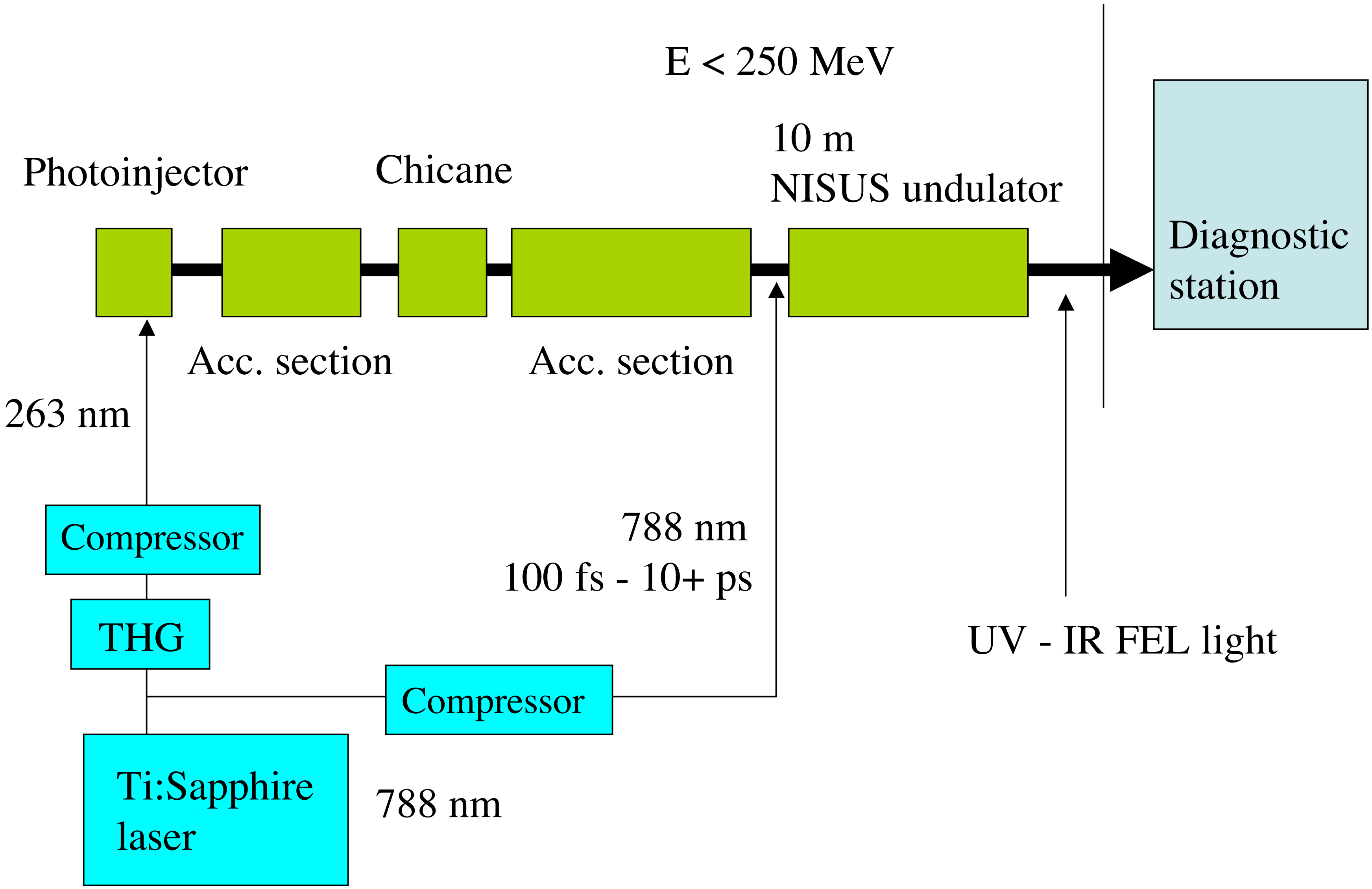
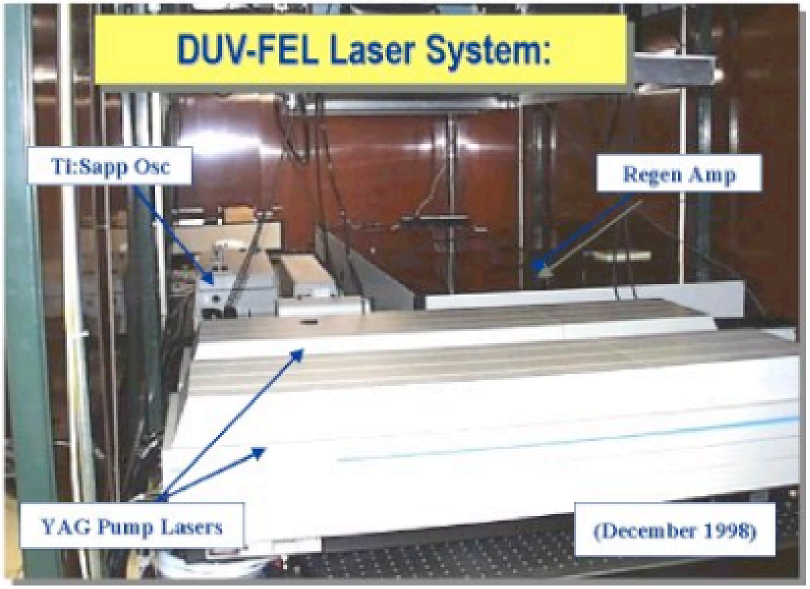
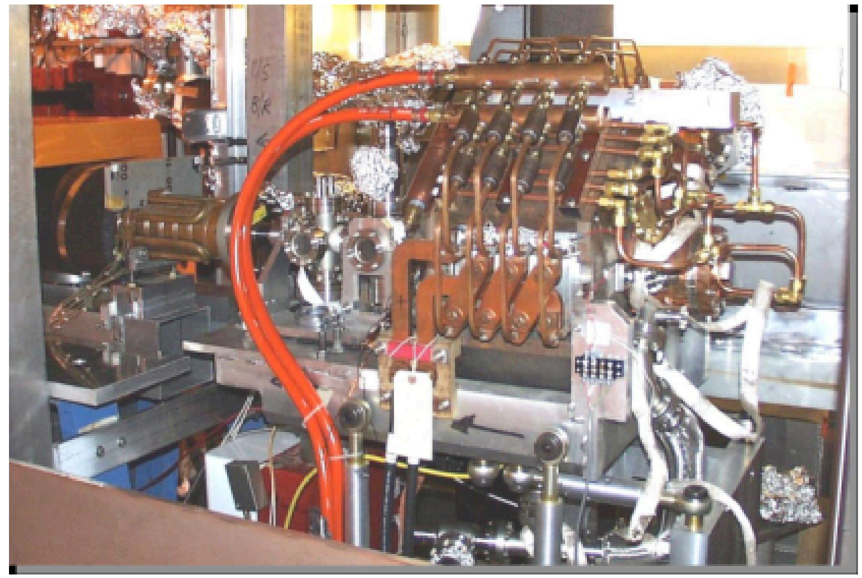
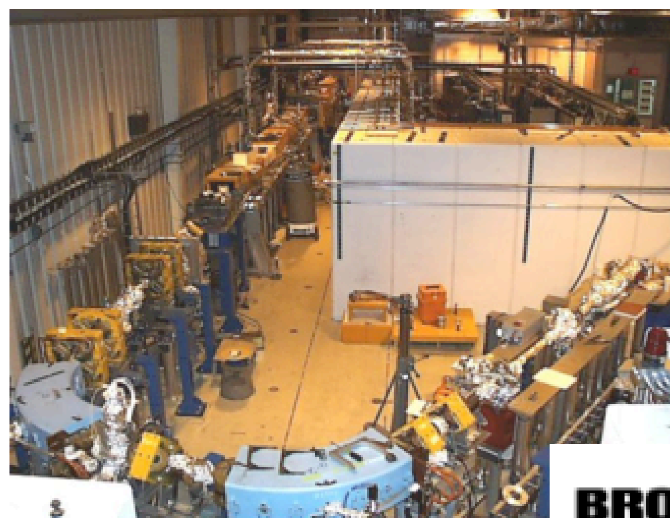
DUV-FEL facility at BNL-NSLS



SDL facility at BNL-NSLS







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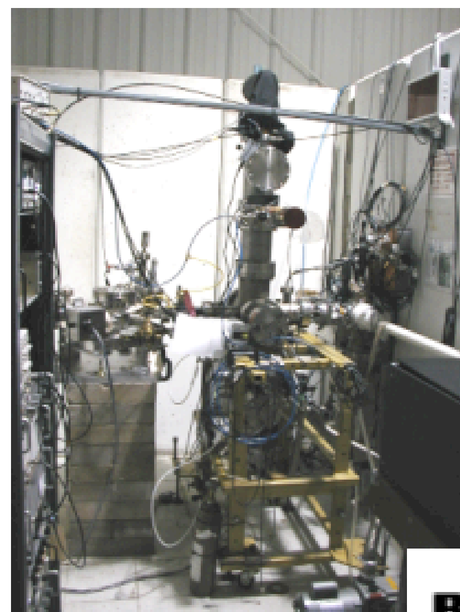
SDL facility at BNL-NSLS



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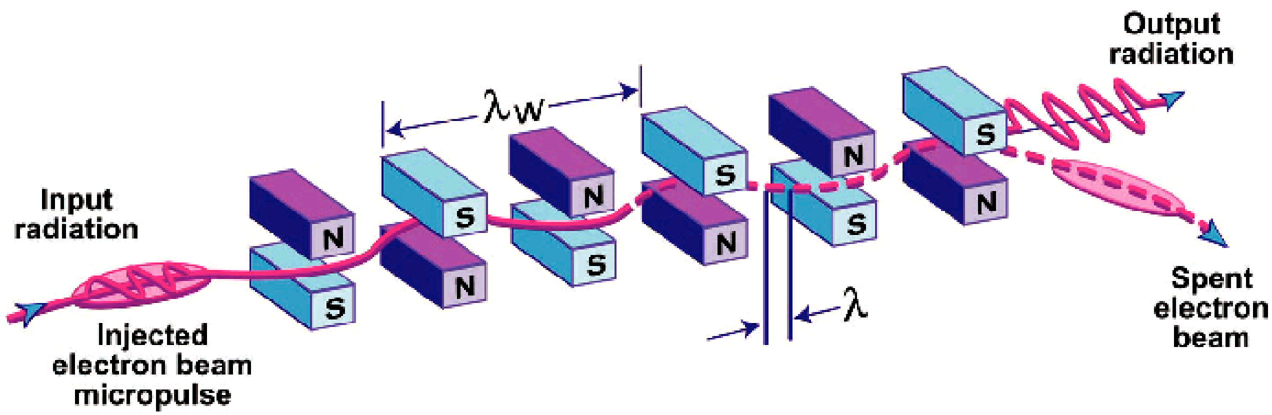
Single-pass seeded FEL



National Synchrotron Light Source (NSLS) Source Development Laboratory (SDL)

SASE / seeded FEL

On going works

- High Gain Harmonic Generation (HGHG)
- Superradiance in single-pass seeded FEL ← Thursday, WG3
- **Design of Megawatt FEL and the experimental demonstration** ← Today

:

:

Directed energy application of FEL

Key issues

Megawatt ave. power

Compact

No optical damage

IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 40, NO. 12, DECEMBER 2004 1739

Design of a Compact, Optically Guided, Pinched, Megawatt Class Free-Electron Laser

Phillip Sprangle, *Fellow, IEEE*, Bahman Hafizi, *Member, IEEE*, and Joseph R. Peñano

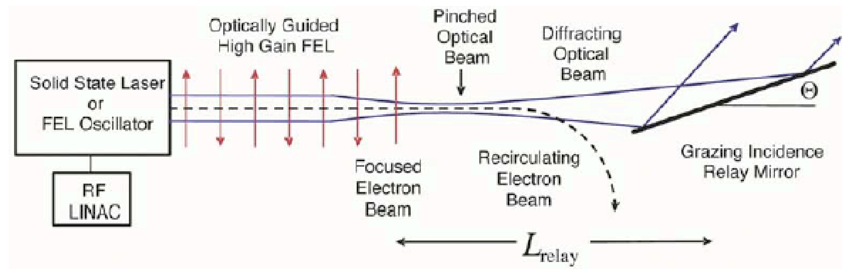


Fig. 1. Schematic of high-gain FEL amplifier with a grazing relay mirror. The input signal can be obtained from a solid-state laser or FEL oscillator. The radiation beam is optically guided in the wiggler and optically pinched at the exit. The pinched optical beam has a shortened Rayleigh range and undergoes rapid diffraction upon exiting the wiggler. Employing a grazing incidence configuration, the resultant footprint on the relay mirror can be made sufficiently large to avoid damage.

This work

2-m VISA undulator
w/ strong focusing

1 µm FEL

seed laser

e-beam
65 MeV

mirror

K = 1.26, λu = 1.8 cm

In order to design a system of

Key issues

- Megawatt ave. power
- Compact
- No optical damage

Procedure

High peak current e-beam + High peak power seed laser = Short Rayleigh length FEL light & MW output

$$P_{sat} = \rho P_{e-beam}$$

$$L_{sat} \approx 20 \times L_G$$

(for SASE)

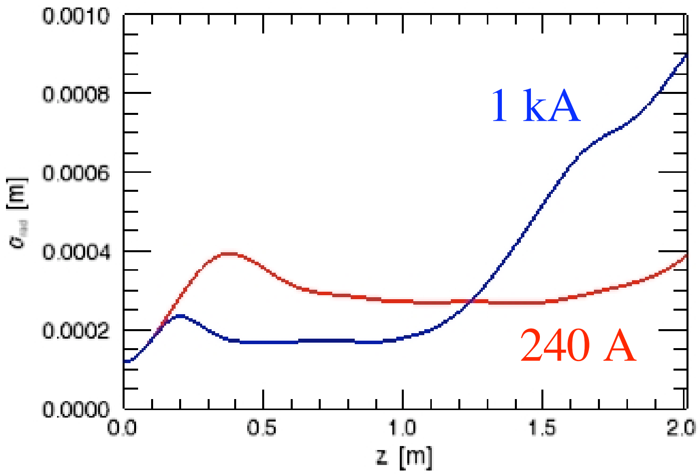
Further step

Study on far field of FEL light at the end of undulator

Transverse control of FEL - peak current -

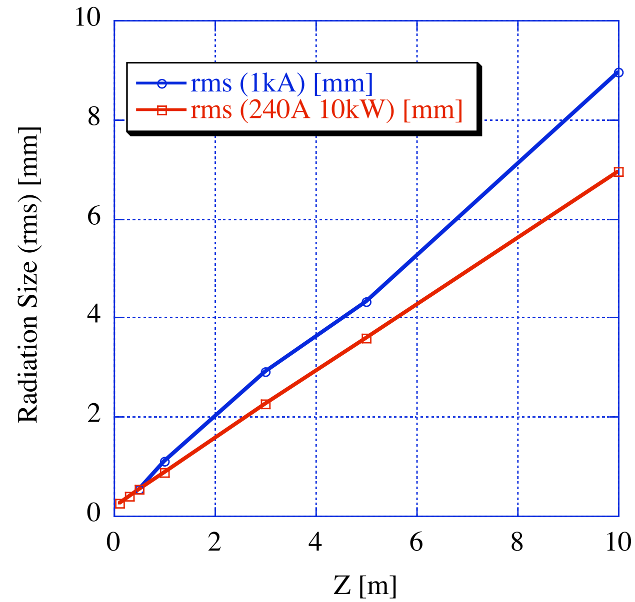
Inside undulator

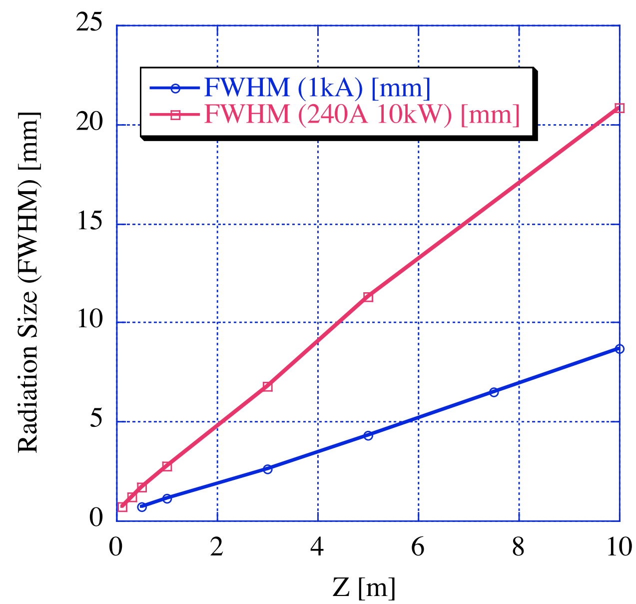
Radiation size (rms)



seed laser = 10 kW
e-beam energy = 65 MeV
emittance = 2 mm.mrad
K = 1.26, λ_u = 1.8 cm

Downstream

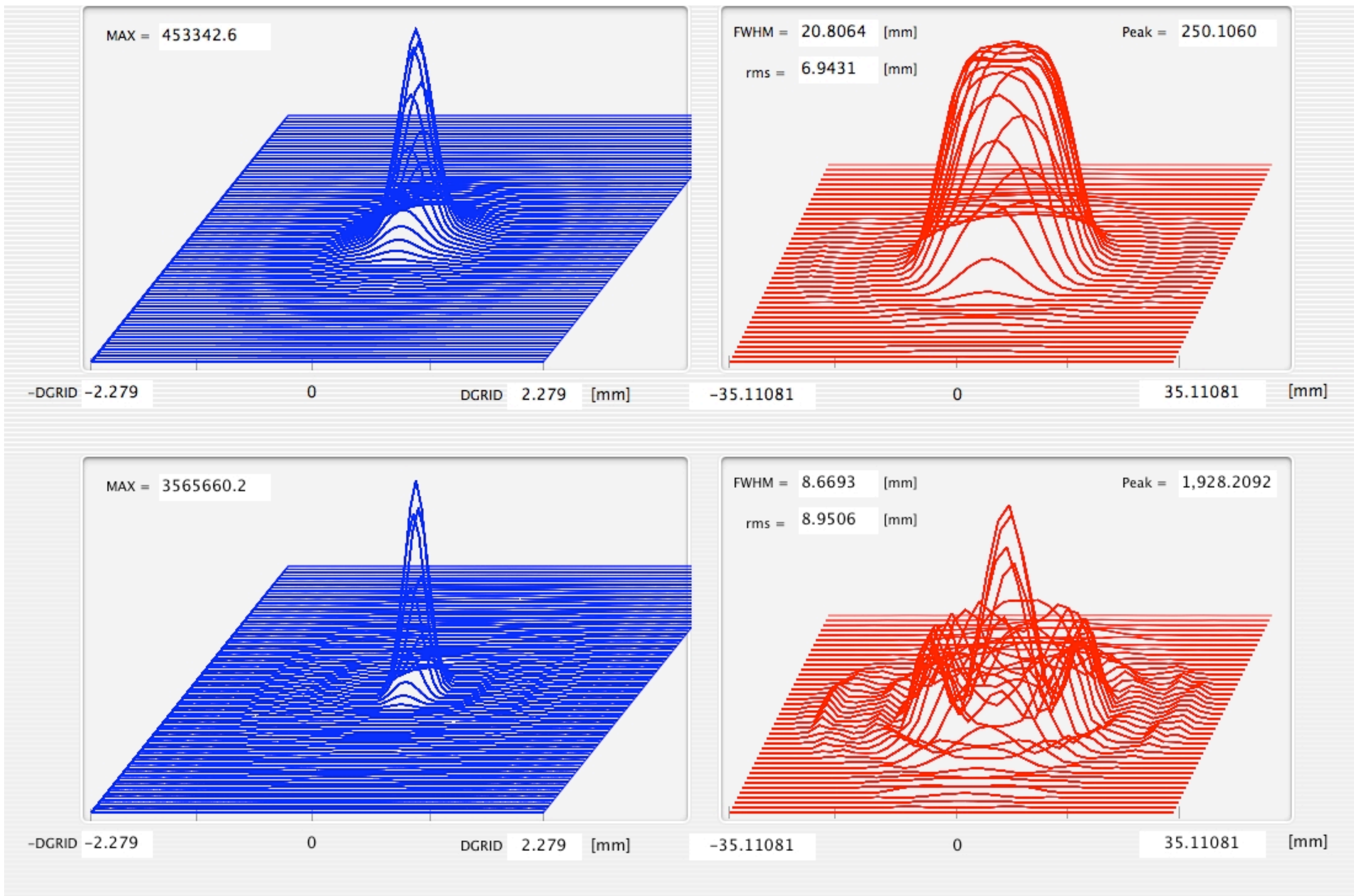




RMS vs FWHM

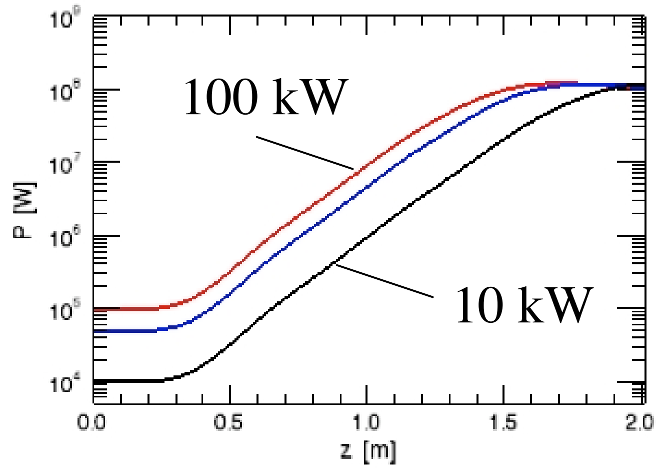
Z. Huang and K.-J. Kim, NIM A 483, 504 (2002).

	0 m down	10 m down
240 A 10 kW		
1 kA 10 kW		

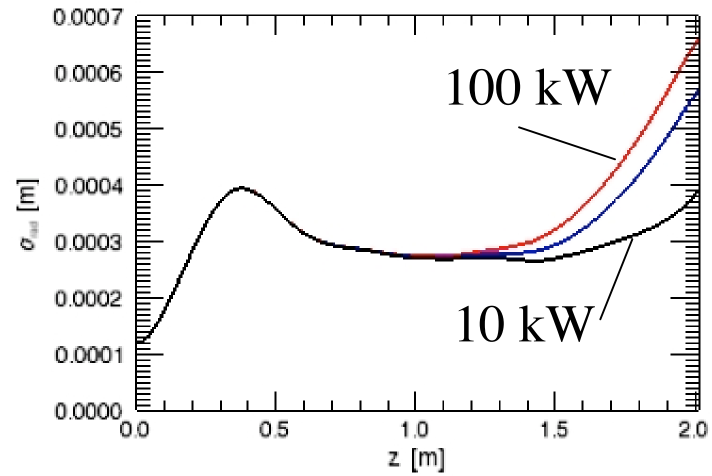


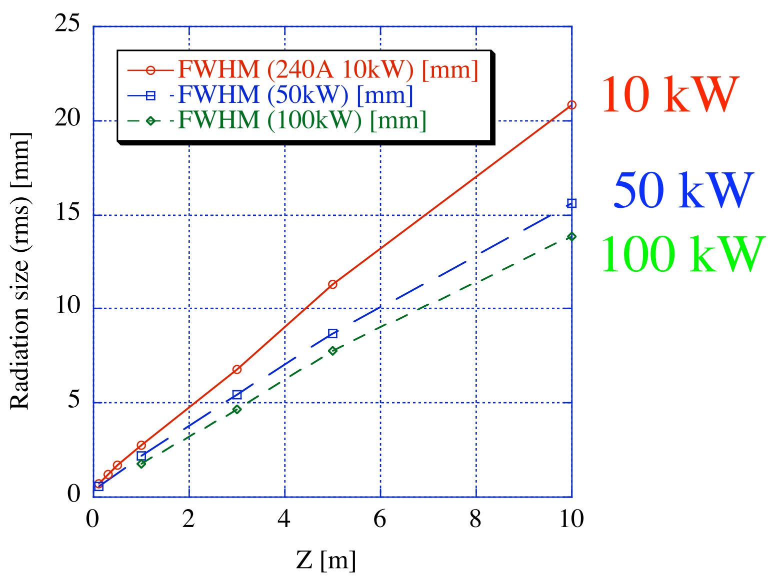
Transverse control of FEL - seed laser power -

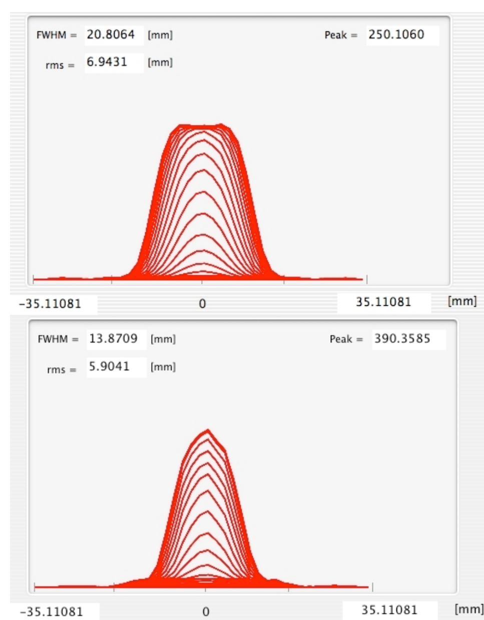
Power



Radiation size (rms)



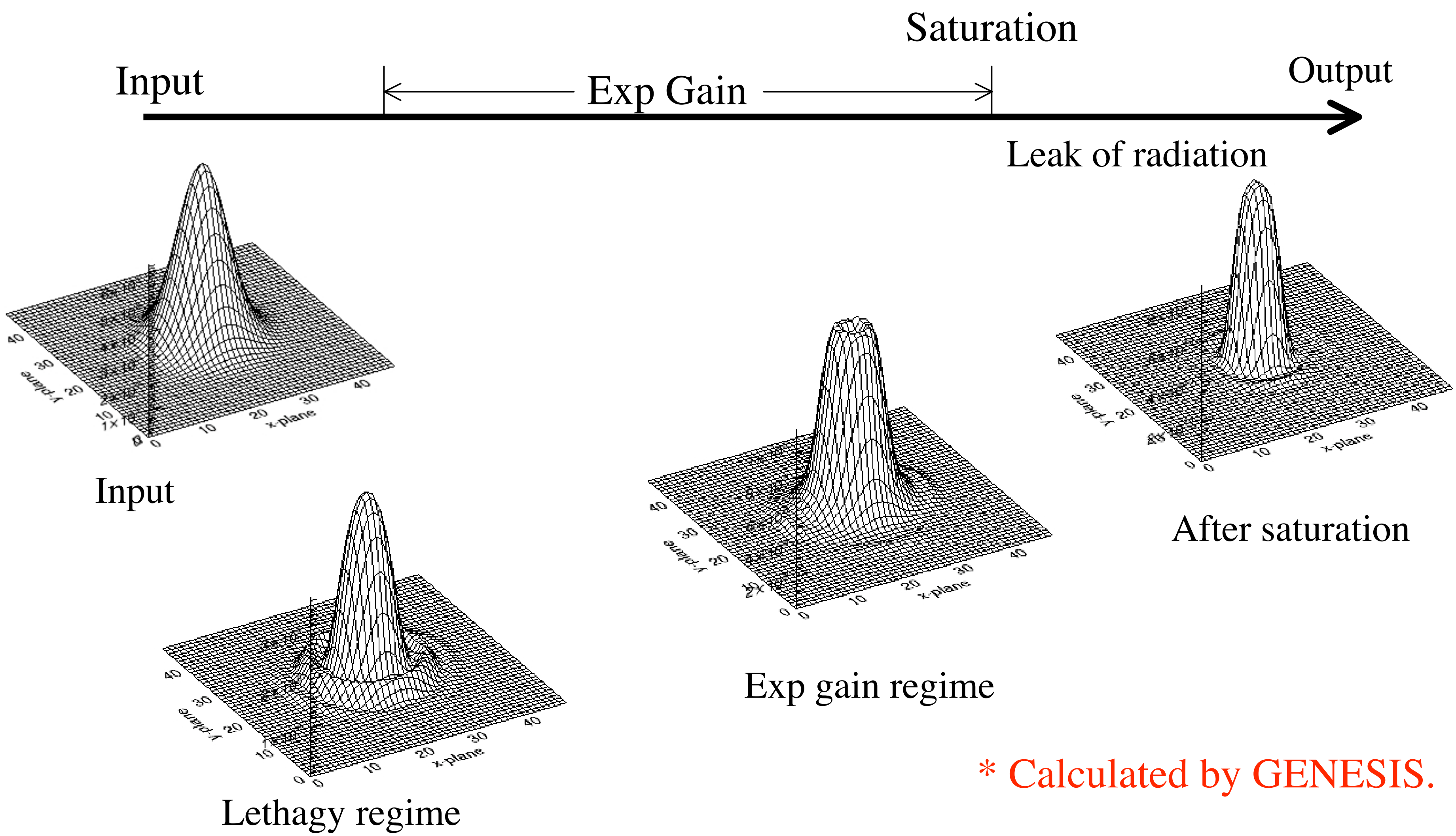




10 kW

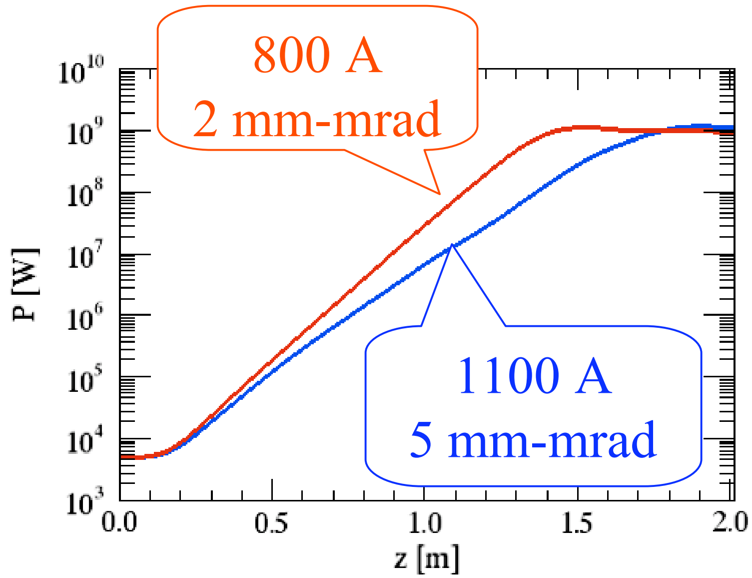
100 kW

Evolution of far-field FEL light inside undulator



Experimental observation : A. Murokh et al., PRE 67, 066501 (2003).
G. Andonian, today's talk.

Final design

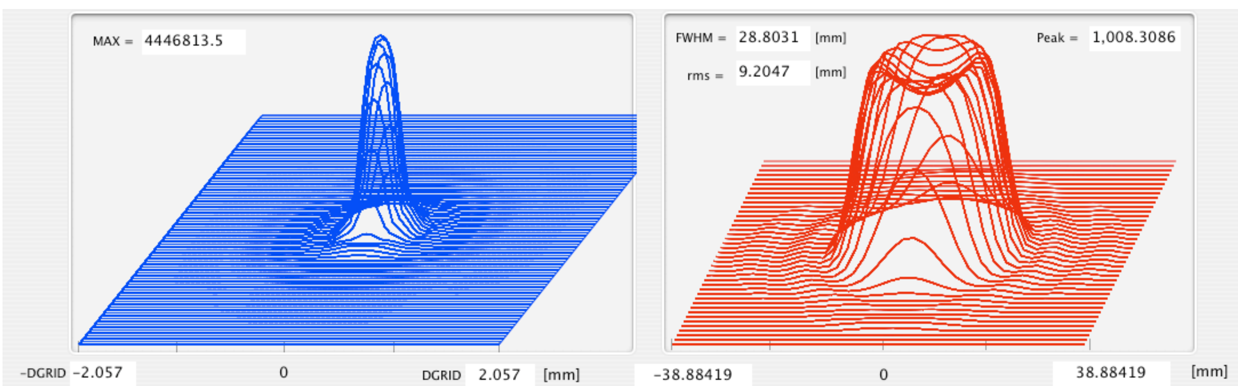


FEL @ 1 μm: peak power = 1 GW

Amplification

Seed laser: peak power =5 kW

Duty factor = 1.4 [ps] x 700 [MHz] = 0.1 [%]



$$\frac{1.0\,[\mathrm{MW}]}{\sqrt{2}\times\pi\times(1.5[\mathrm{cm}])^2}\approx 100\left[\mathrm{kW/cm^2}\right]$$

~ damage threshold of mirror

Experimental demonstration

Future goal : seeded FEL at 1.0 μm using 2-m VISA undulator

At present, 1.0 μm seed laser and 2-m VISA undulator are not installed.

SASE from 0.8 to 1.0 μm	Seeded FEL at 0.8 μm

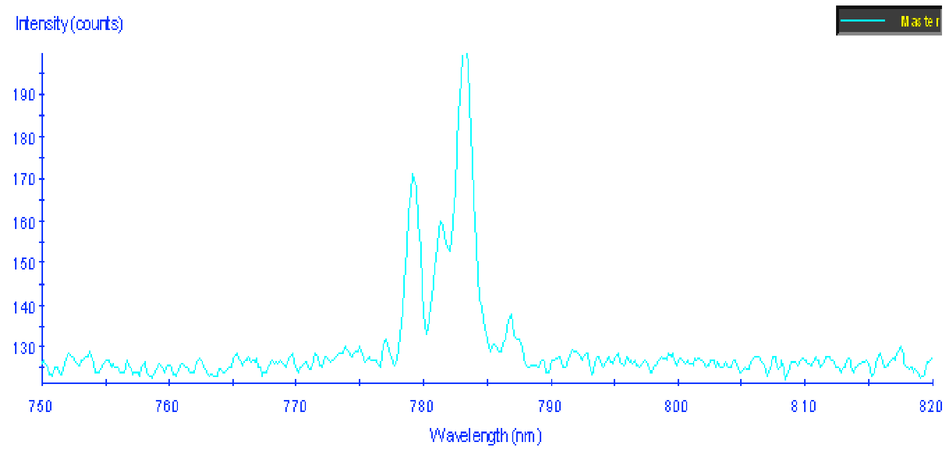
using 10-m NISUS undulator.

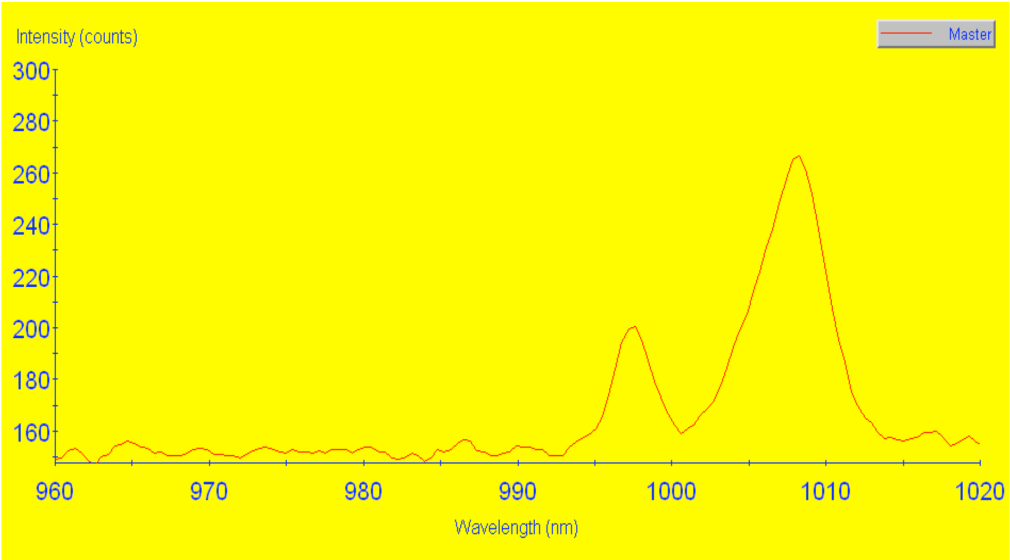
$K = 1.08$

$\lambda_u = 3.89$ cm

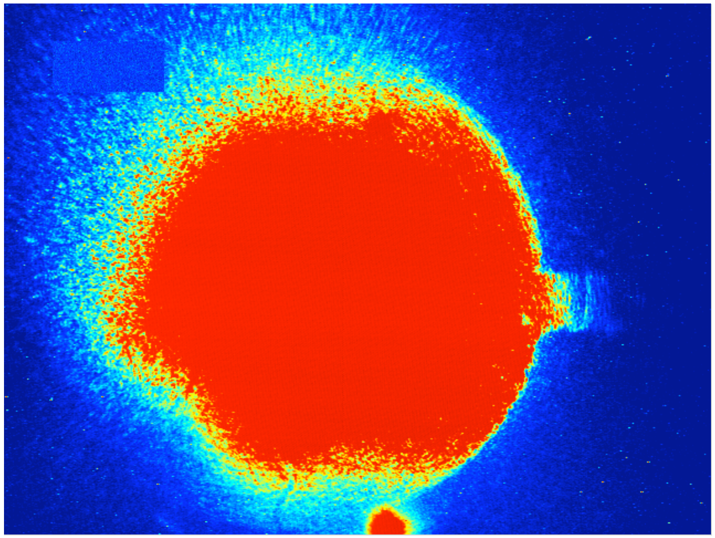
periods = 256

SASE from 0.8 to 1.0 μm

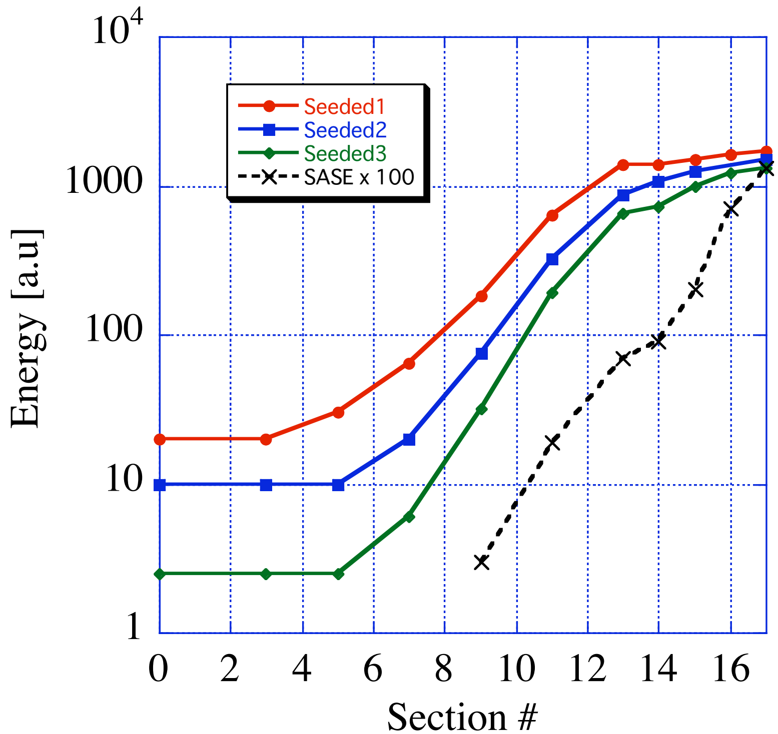




Spatial image of SASE



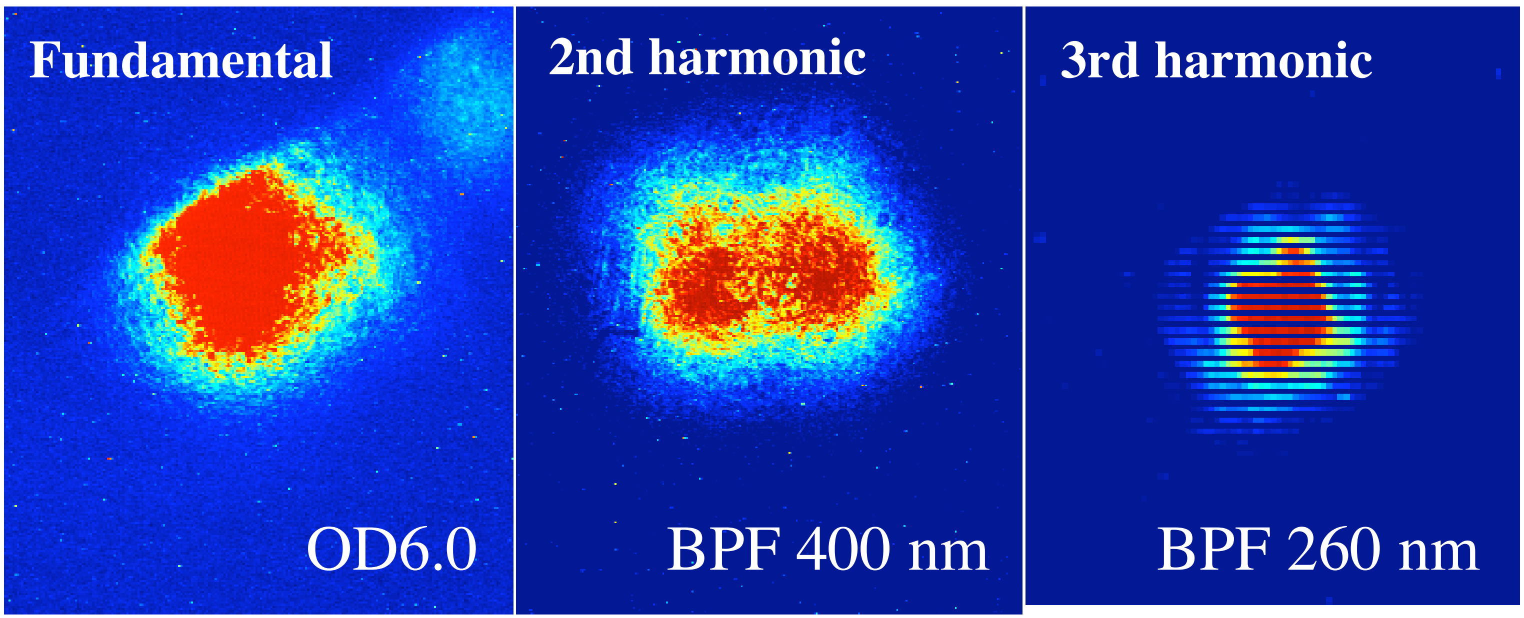
Gain curves



Gain length when radiation size is larger than e-beam size

$$L_G^{-1} = \frac{4\pi}{\lambda_u}\frac{3^{3/4}}{2}\sqrt{\frac{I}{\gamma I_A}\frac{K^2[JJ]^2}{\left(1+K^2/2\right)}}$$

Spatial profiles of harmonics



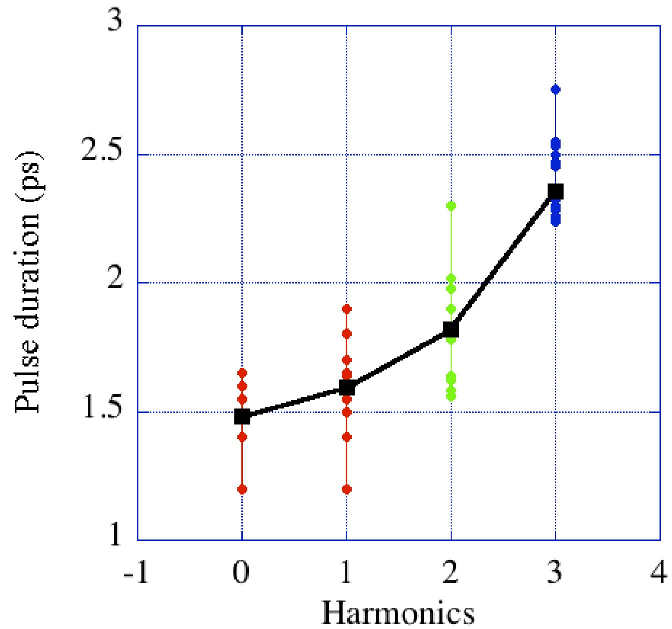
* Magnification of each image is different.

Z. Huang and K.-J. Kim, PRE 62, 7296 (2000).

Pulse duration of harmonics

Streak camera measurement

time resolution = 700 fs



$$\tau_{\text{resolution}} = \tau_{\text{resolution}}(\lambda)$$

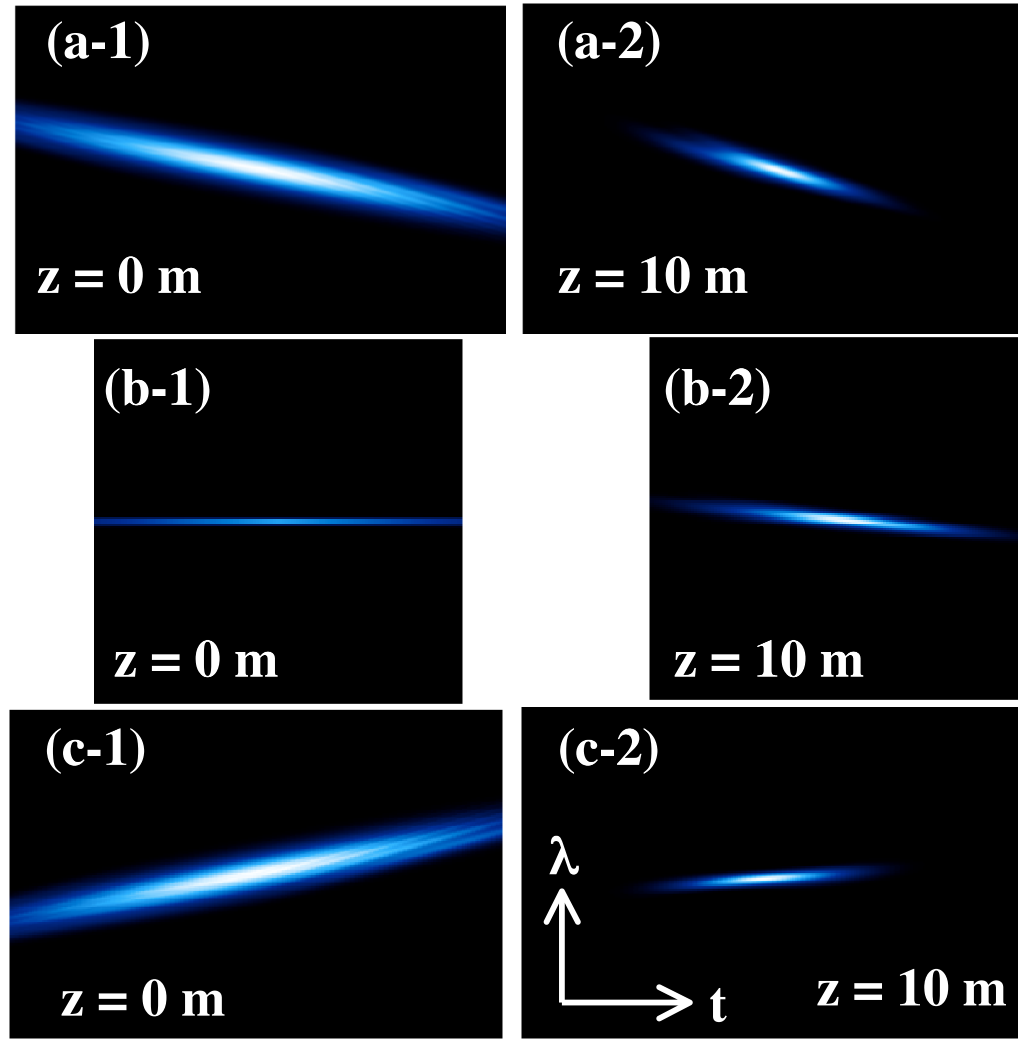
$$\delta T = 1.4\left(\frac{m}{2e}\right)\frac{(\delta E)^{1/2}}{V}$$

δT : time spread
δE : initial energy spread
V : accelerating field on the cathode

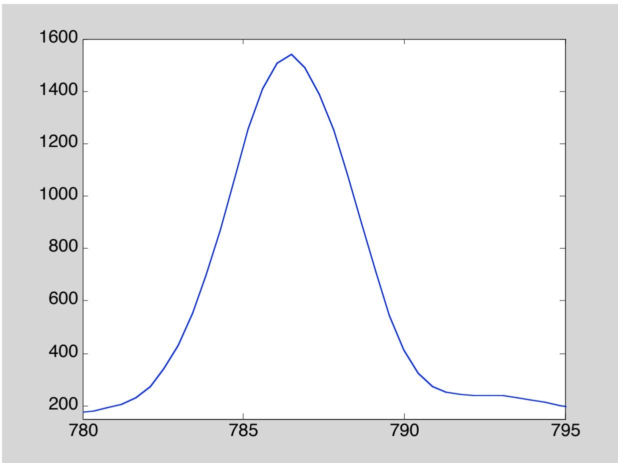
796 fs for 400 nm*
944 fs for 250 nm*

* estimated by Hamamatsu Photonics.

GENESIS calculation



Experimental result



~ 5nm bandwidth

Input chirp	Negative	None	Positive
Bandwidth (nm)	1.5	2.0	3.5

E-beam chirp in SASE

Y.Li et al., PRL 89 230841 (2002).

Conclusion

MW class FEL was conceptually designed and seeded FEL in IR was experimentally demonstrated.

- SASE from 0.8 to 1.0 μm observed.
- Gain curve of seeded FEL obtained.
- Spatial distributions of harmonics observed.
- Spectrum broadening due to laser chirp considered.
- Longitudinal distributions of harmonics measured.

Future work

Repeat the experiment to verify
- Gain length v.s. input seed power
- Ratio of radiation size between each harmonic
- Longitudinal pulse duration at each harmonic