IPAC'12
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Measurement of the Slice Energy Spread of Electron Beam at SDUV-FEL using the CHG-based Method

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Outline

- Introduction & Motivation
- CHG based energy spread measurement
- S2E simulations
- Experimental results at SDUV-FEL
- Conclusions and prospects

Introduction of SDUV-FEL

SDUV-FEL is a test facility for seeded FELs

→ Originally designed for HGHG

→ With minor modification, it is now well suited for a variety of seeded FEL schemes

We have successfully carried out the HGHG and EEHG experiments

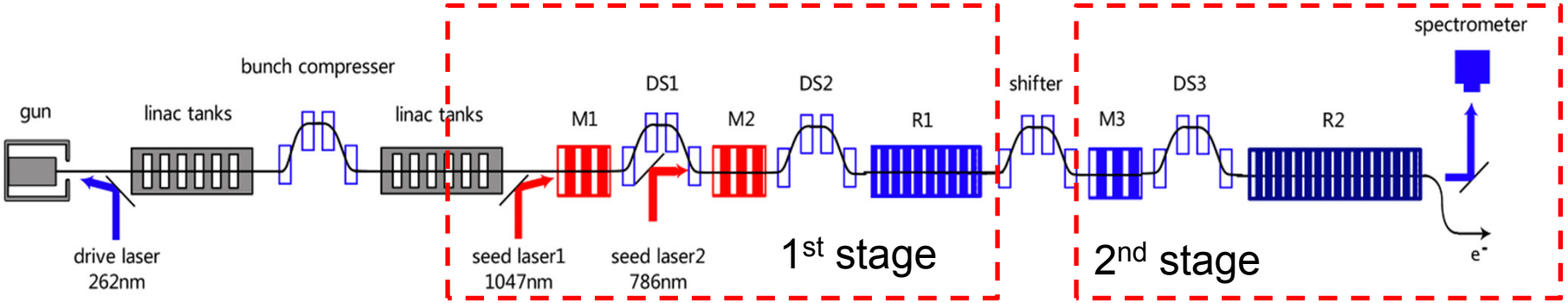
Now we are performing the cascaded HGHG experiment.

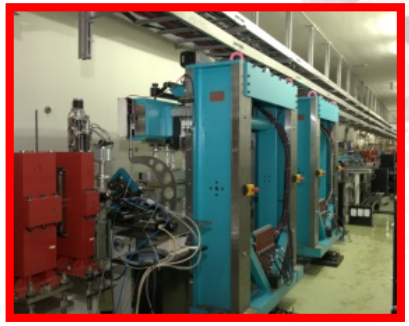
SDUV-FEL building

tunnel

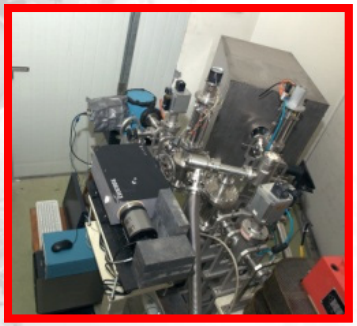
FEL Layout



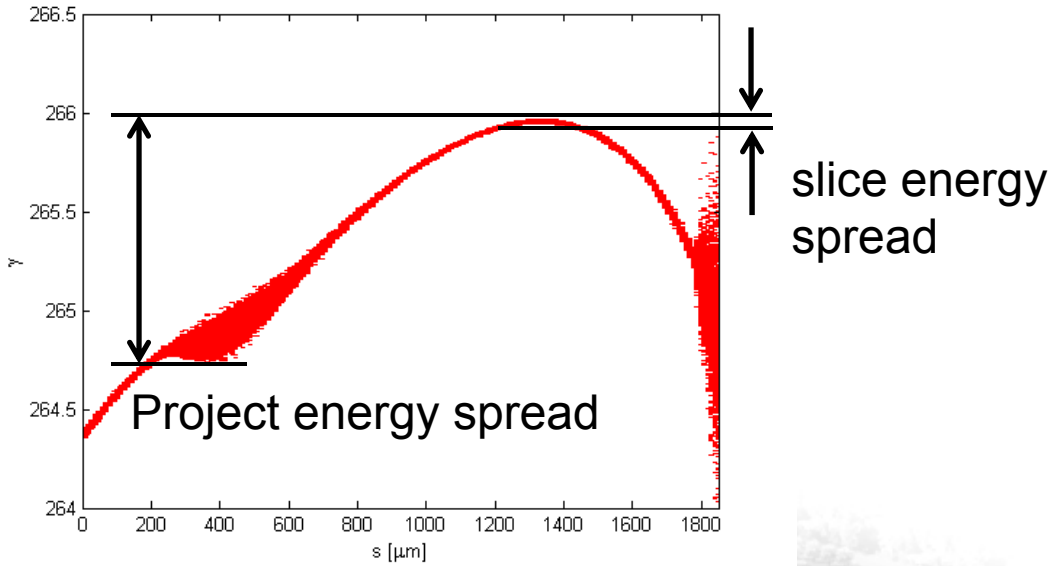


gun
linac tanks
bunch compresser
linac tanks
M1
DS1
M2
DS2
R1
shifter
M3
DS3
R2
spectrometer
drive laser
262nm
seed laser1
1047nm
seed laser2
786nm
1st stage
2nd stage
e-







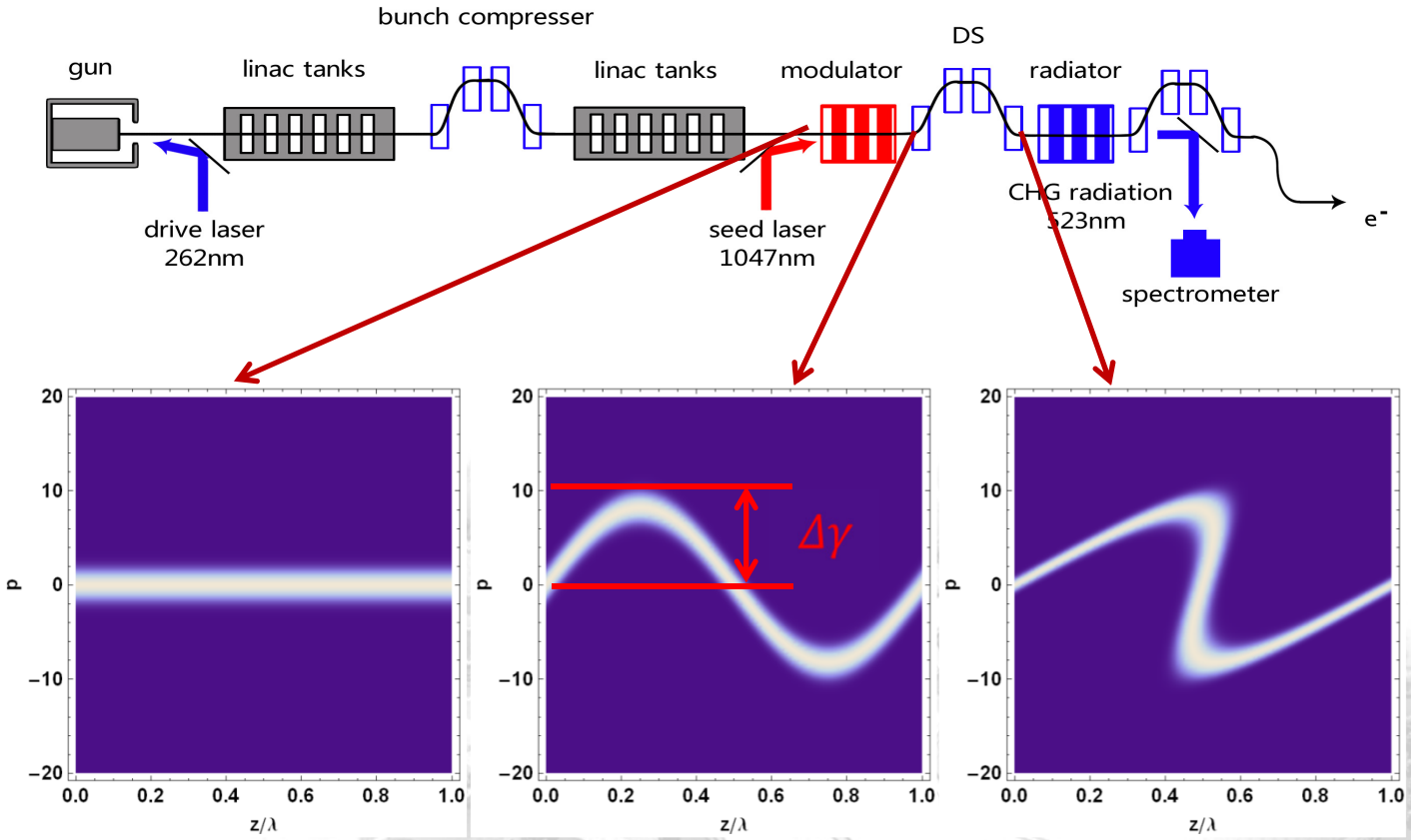
Energy spread measurement for seeded FELs



- The slice energy spread is a very important parameter for seeded FEL design and parameters setting of a seeded FEL device.
- The slice energy spread of electron beam produced by a photo-injector is very small (considered to be in the order of few keV).
- The resolution of the normal method (using a deflecting cavity followed by a horizontal dispersive region) may be not accurate enough for seeded FEL operation.
- The resolution of the ORS based method (suggested by Saldin, et al) may be limited by the accuracy of the current profile measurement.

M. Huning and H. Schlarb, in *Proceedings of PAC 2003, Portland.*
E.L. Saldin, E.A. Schneidmiller, and M.V. Yurkov, Nucl. Instrum. Methods Phys. Res. Sect. A 539, 499 (2005).

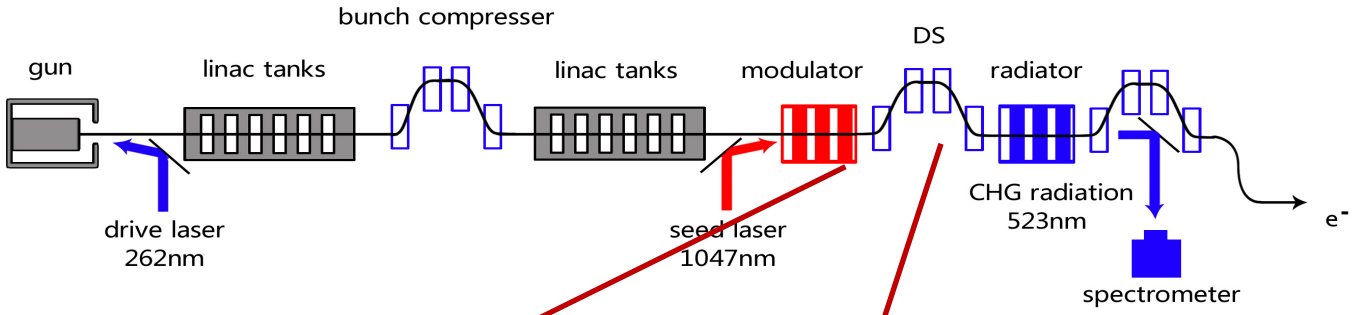
Energy modulation amplitude



$$b_n = J_n(nD\Delta\gamma)e^{-\frac{1}{2}(nD\sigma\gamma)^2} \qquad D = k_s R_{56}/\gamma$$

The $\Delta\gamma$ is also an important parameter for seeded FEL especially for the EEHG scheme

CHG based method



$$b_n = J_n(nD\Delta\gamma)e^{-\frac{1}{2}(nD\sigma\gamma)^2} \qquad D = k_s R_{56}/\gamma$$

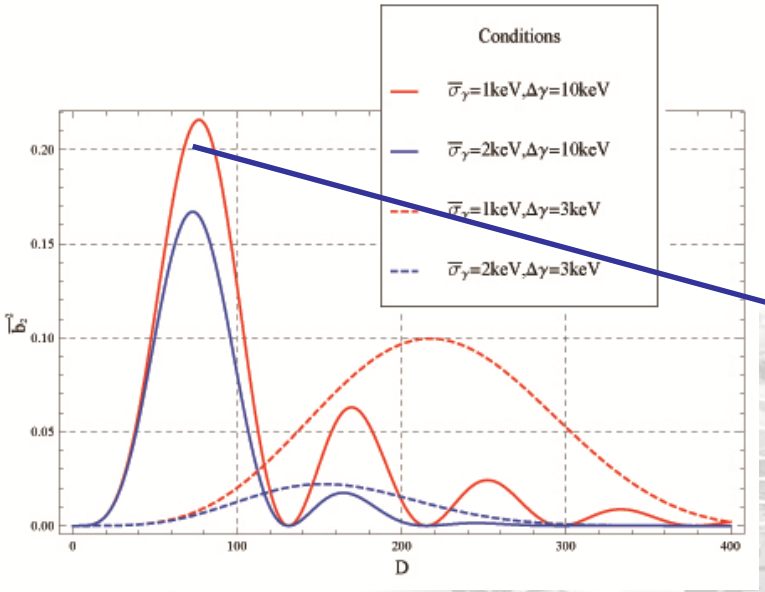
$\Delta\gamma \propto \sqrt{P_{seed}}$ energy modulation amplitude is directly proportional to square root of laser power

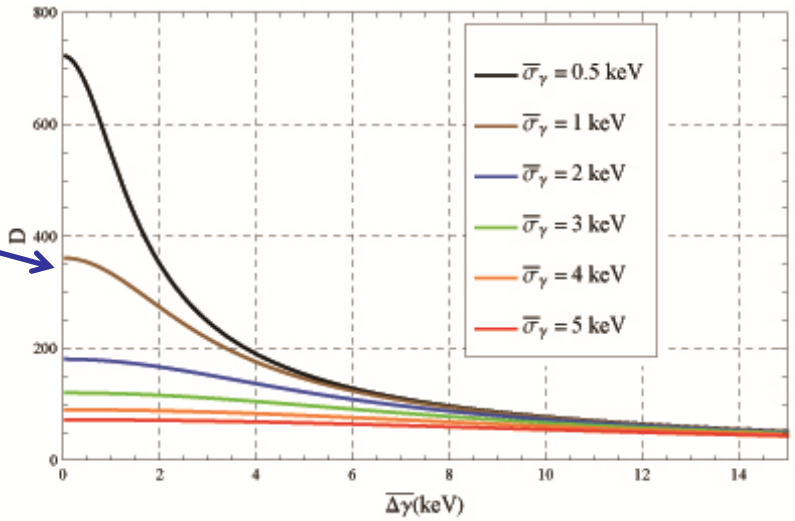
The out put power of a CHG

$$P \propto b_n^2$$

CHG based method

- The optimized values of dispersion strength D will be quite different for different $\Delta\gamma$ and $\sigma\gamma$





Bunching factor as a function of dispersion strength

Peak position as a function of energy modulation amplitude

CHG based method

To find the parameters that maximize the bunching factor, we differentiate the bunching factor with respect to D and set the derivative equal to zero

$$J_{n-1}(n\Delta\gamma D) - J_{n+1}(n\Delta\gamma D) = \frac{2n\sigma_\gamma^2 D}{\Delta\gamma} J_n(n\Delta\gamma D)$$

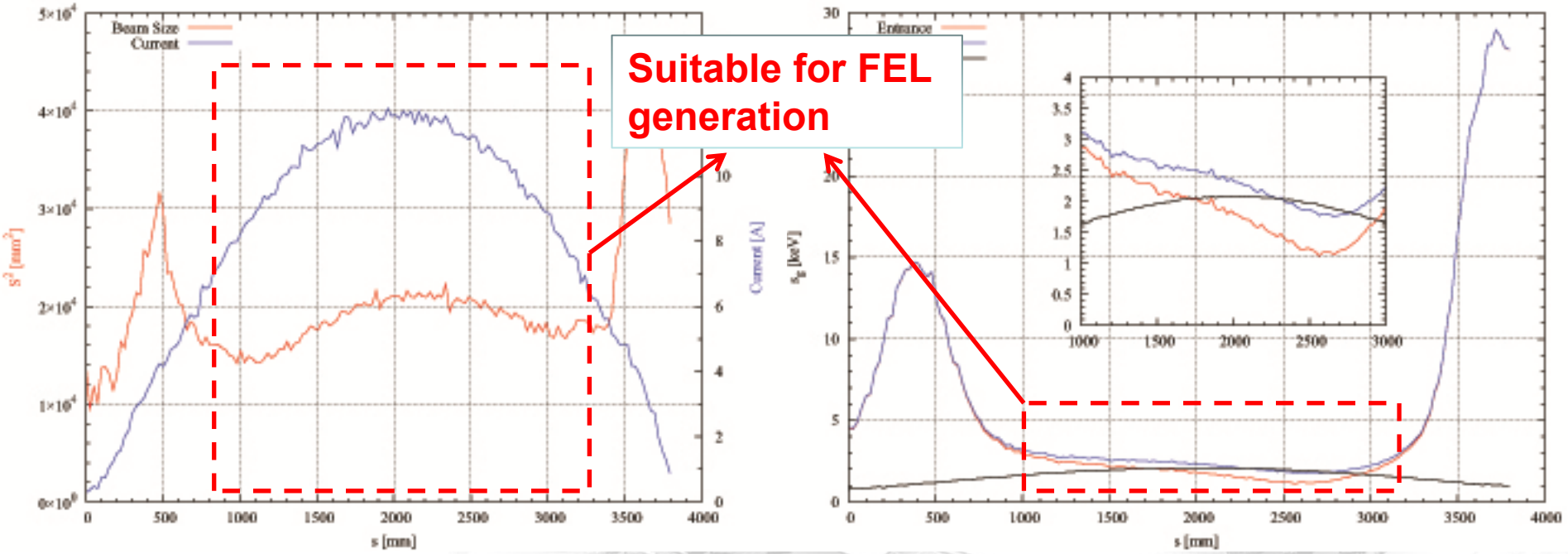
$$\Rightarrow \begin{cases} J_{n-1}(nD_1\Delta\gamma_1) - J_{n+1}(nD_1\Delta\gamma_1) = \dfrac{2n\sigma_\gamma^2 D_1}{\Delta\gamma_1} J_n(nD_1\Delta\gamma_1) \\ J_{n-1}(nD_2\Delta\gamma_1/C) - J_{n+1}(nD_2\Delta\gamma_1/C) = \dfrac{2n\sigma_\gamma^2 D_2}{\Delta\gamma_1/C} J_n(nD_2\Delta\gamma_1/C) \end{cases}$$

where $$C = \Delta\gamma_1/\Delta\gamma_2 = \sqrt{P_{seed1}/P_{seed2}}$$

3D simulation results

photocathode-injector : ASTRA
main accelerator : ELEGENT
CHG FEL process : GENESIS based on the output of ELEGENT

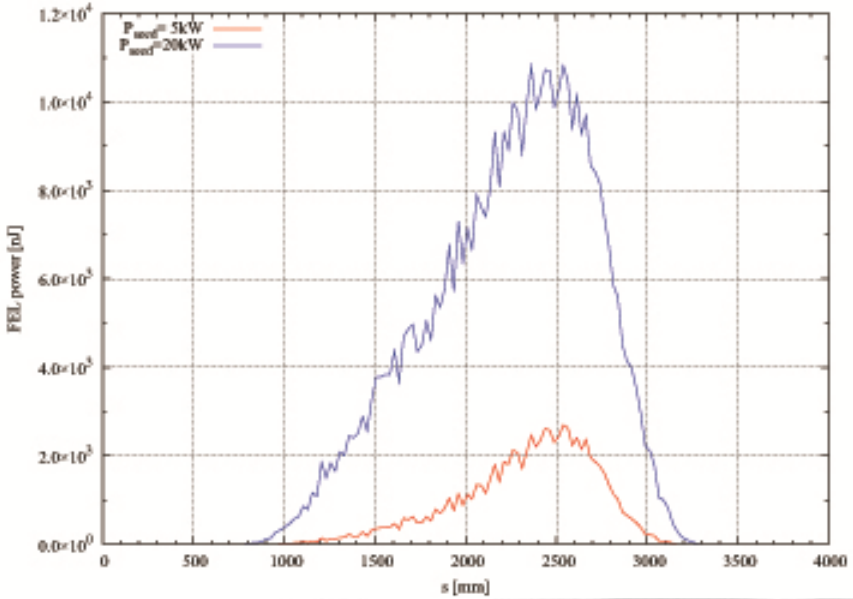
Slice parameters distribution along the electron bunch



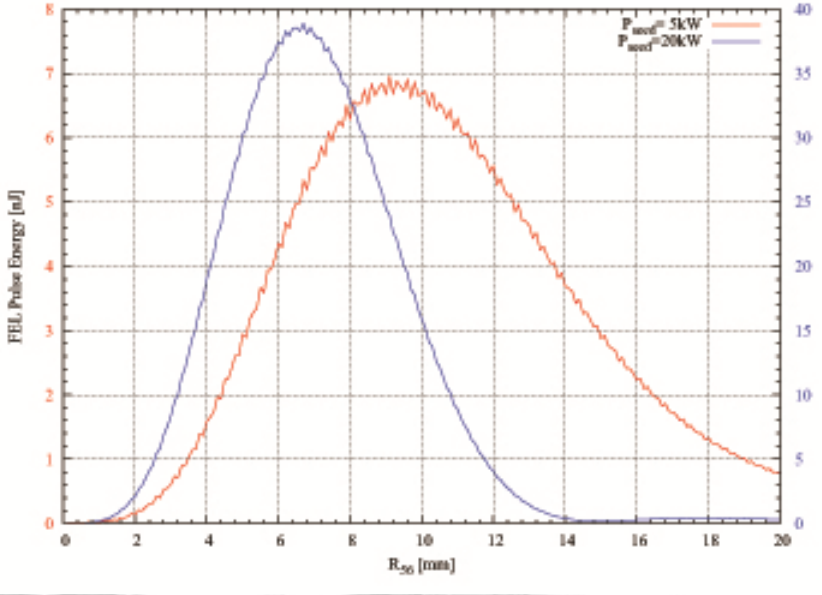
Current and transverse beam size

Slice energy spread before and after the modulator and energy modulation amplitude

3D simulation results



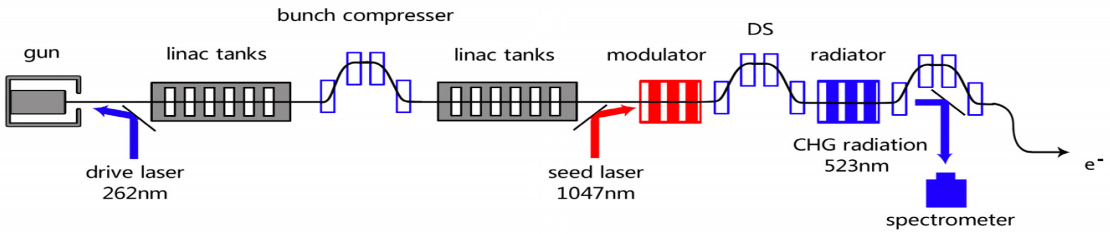
Radiation pulses for different energy modulation amplitude



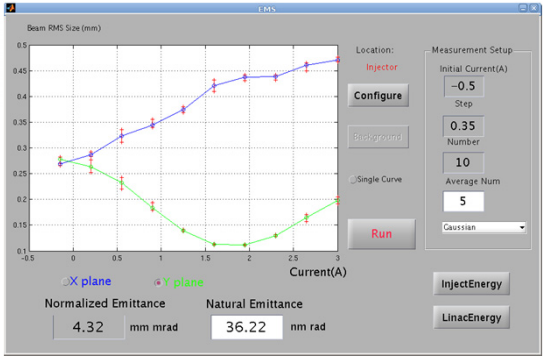
Pulse energy as a function of dispersion strength

The measured energy spread is about 1.53keV and the energy modulation amplitude is about 2.1keV. These values are quite close to the average values of energy spread and energy modulation amplitude in the central part of e-beam (1.5keV and 2.0keV).

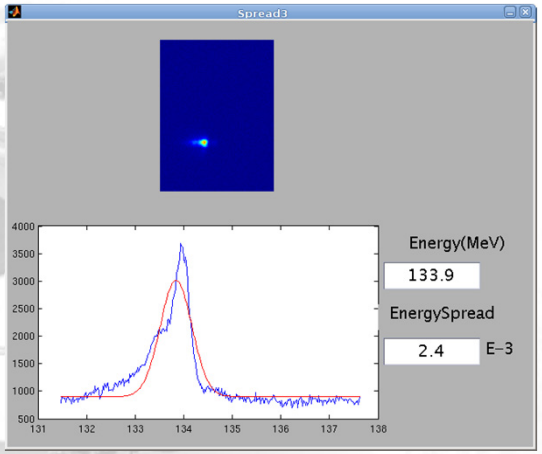
Major Parameters of SDUV-CHG



Parameters	Measurement
Beam energy	135 MeV
Beam energy spread (projected)	~0.2MeV
Normalized emittance	4~5mm-mrad
Bunch charge	100~300pC
Seed laser wavelength	1047nm
Seed laser pulse length	8.7ps
Seed laser power	0~150uJ
Modulator (EMU65) variable Gap	10*6.5cm
Radiator (PMU50) variable Gap	10*5cm
R56 of dispersion section	1~70mm (16A)

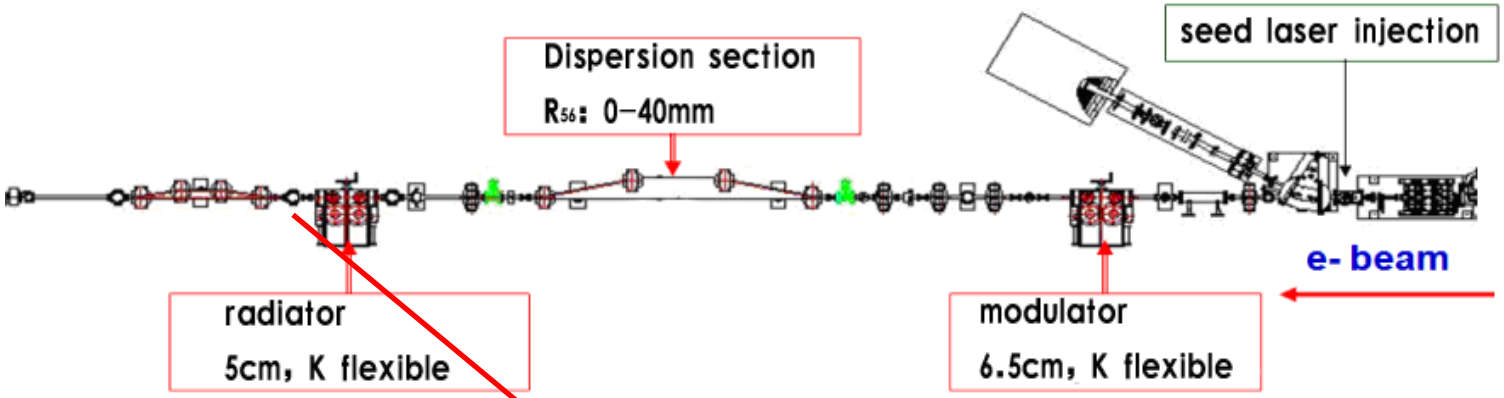


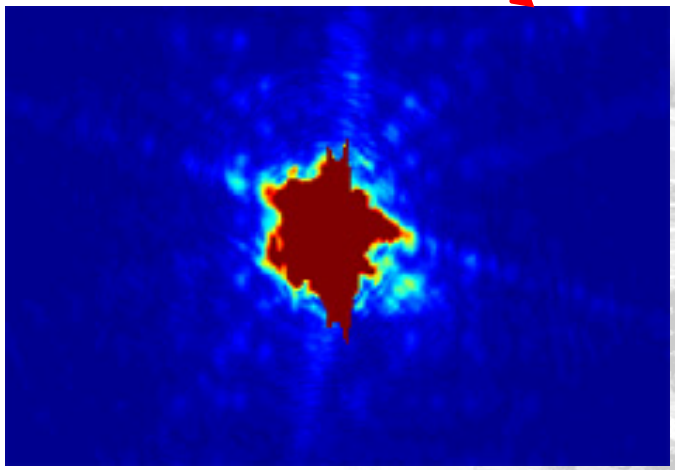
•Emittance measurement



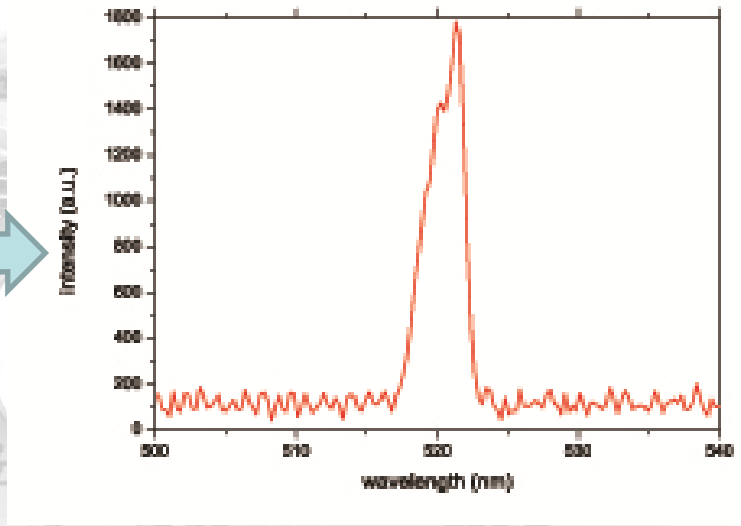
• Energy spectrometer

Experimental results (bunch compresser off)



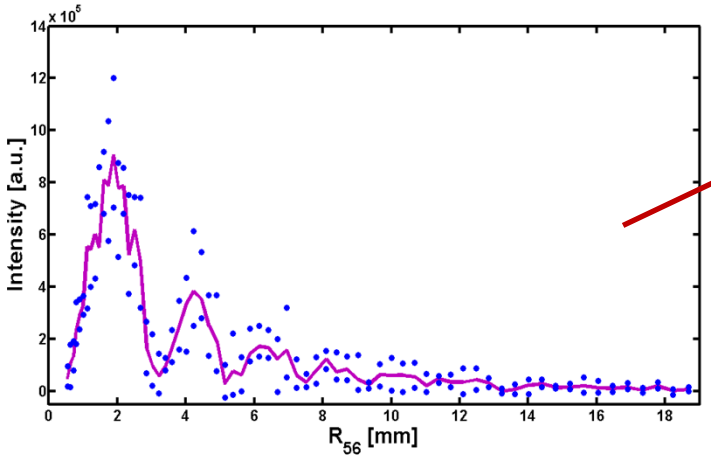


2nd harmonic radiation intensity on an OTR screen downstream of the radiator.

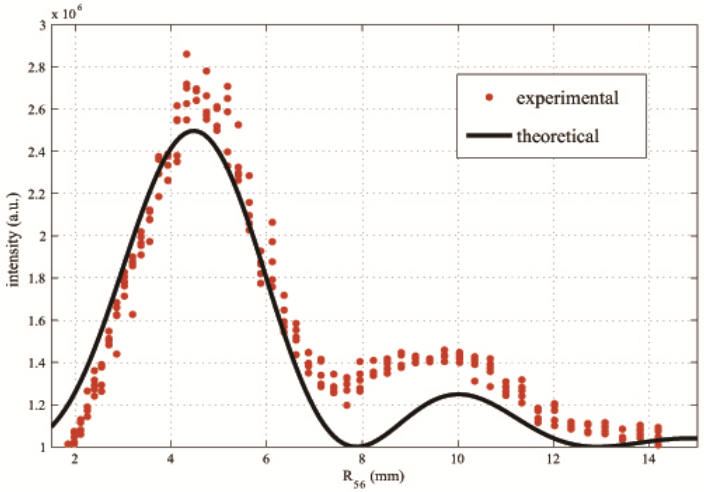


Single shot 2nd harmonic CHG spectrum.

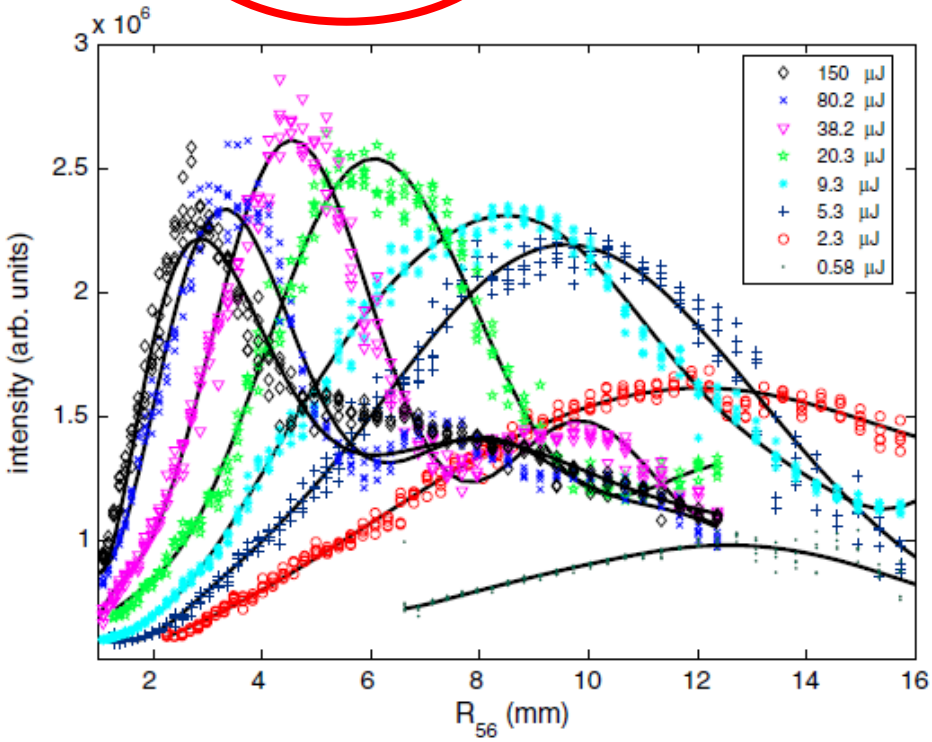
Experimental results (bunch compresser off)



$$b_n = J_n(nD\Delta\gamma)e^{-\frac{1}{2}(nD\sigma\gamma)^2}$$

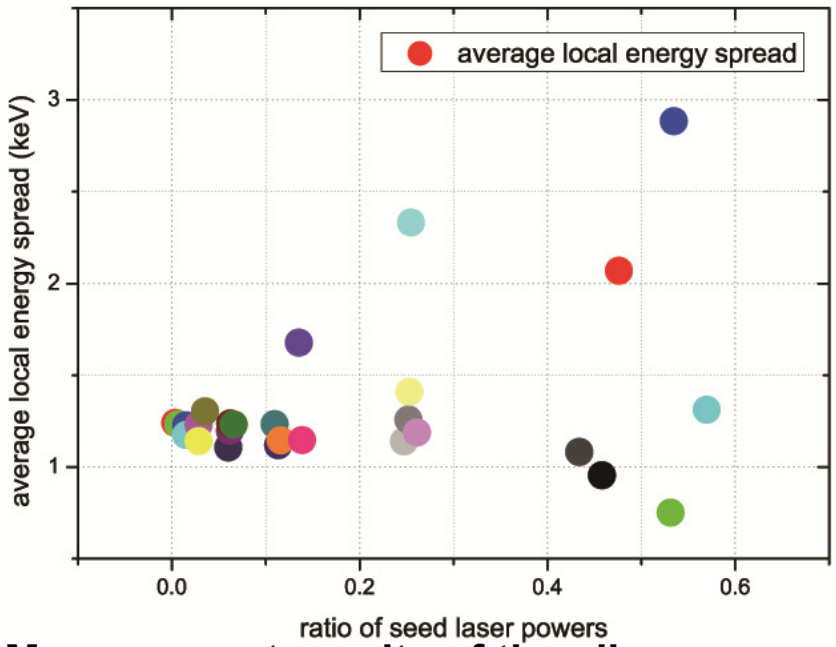


Coherent 2nd harmonic signal as a function of dispersion strength

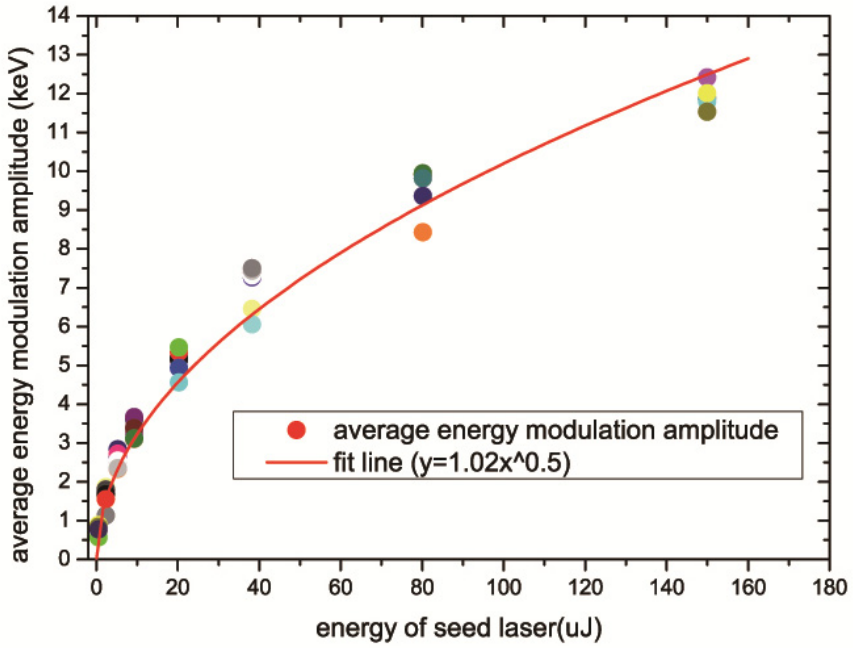


Experimental data and fit lines for different seed laser energy.

Experimental results (bunch compresser off)



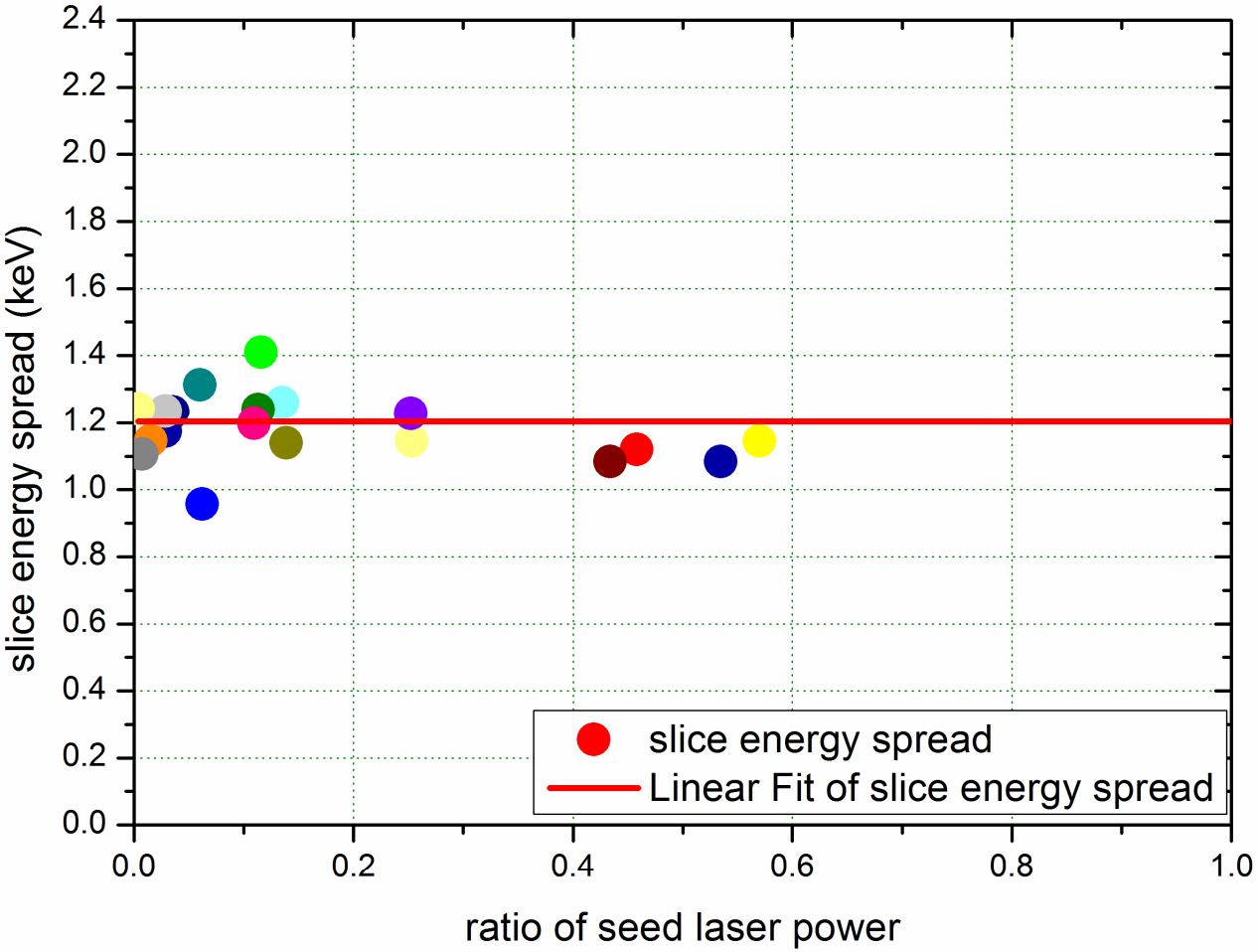
Measurement results of the slice energy spread vs. ratios of seed laser powers



Measurement results of the energy modulation amplitude vs. corresponding seed laser power

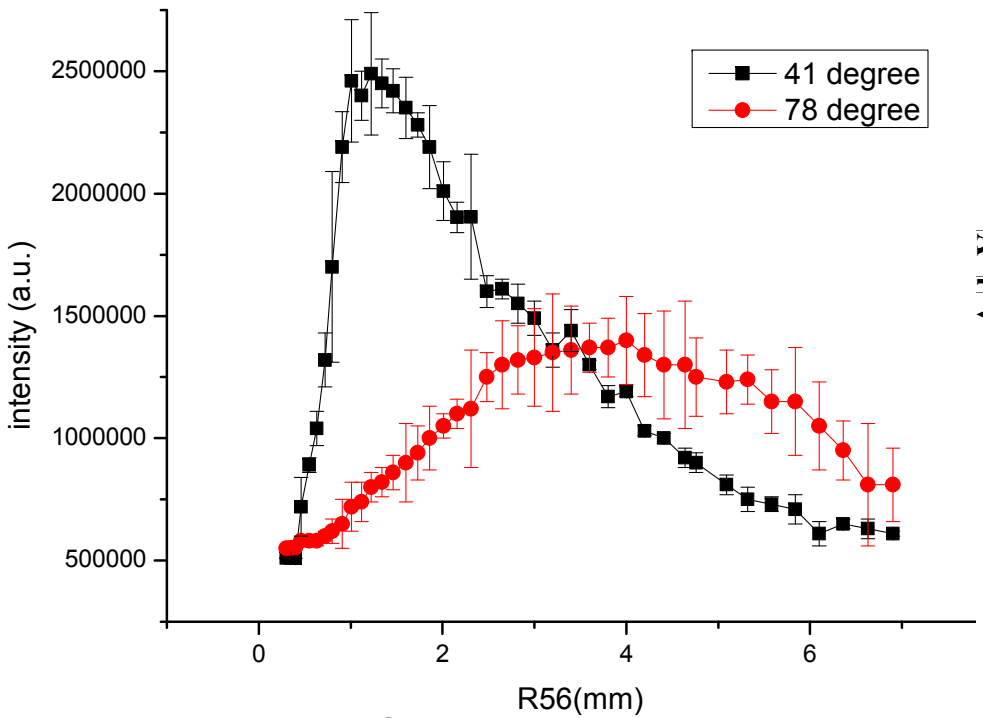
The measurement error of slice energy spread is small when the ratios of the two seed laser powers are smaller than 0.1 (or bigger than 10). However, the error is big as the ratios getting close to 1, which means that these two seed laser powers are too close to each other.

Experimental results (bunch compresser off)

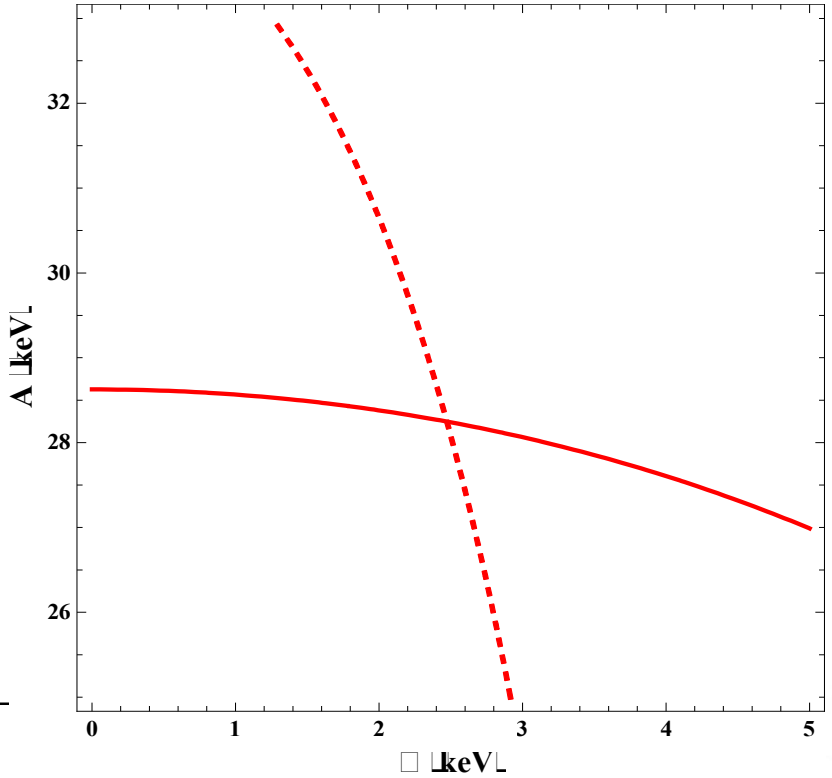


The average slice energy spread of our electron beam is about only **1.2keV**, which is **~10^{-2}** of the project energy spread and **~10^{-5}** of the beam energy.

Experimental results (bunch compresser on)



Scanning curves



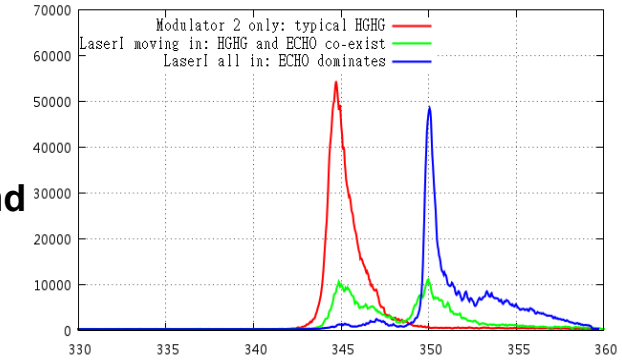
Calculated results according to the Scanning curves

The slice energy spread is about 2.6keV at the exit of the linac when the electron beam is compressed by a factor of about 2.

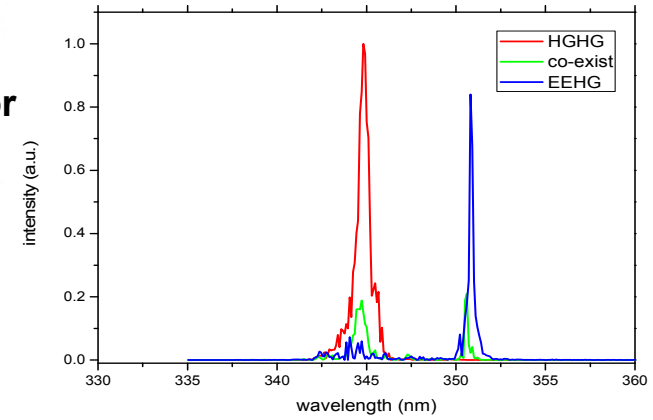
CHG based method application in seeded FEL experiments (EEHG)

The measurement results of slice energy spread and energy modulation amplitudes have been used for the parameters set (strengths of the two chicanes) of EEHG experiment and the corresponding simulations.

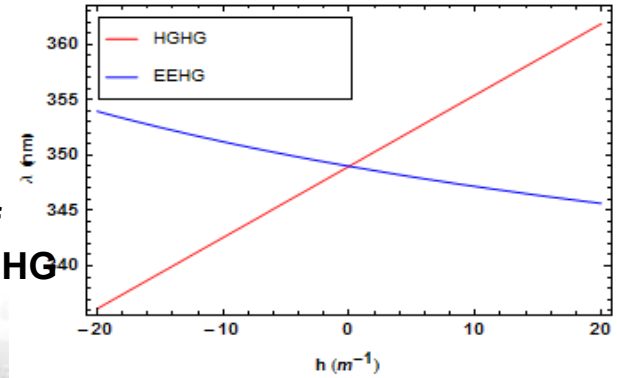
Experimental spectrum for both HGHG and EEHG



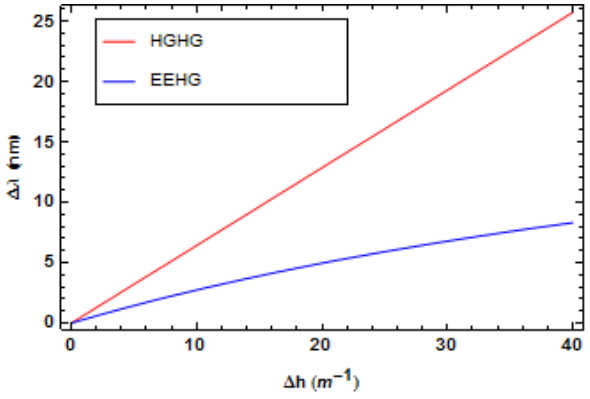
Simulation spectrum for both HGHG and EEHG



Energy chirp effects on the central wavelength of HGHG and EEHG



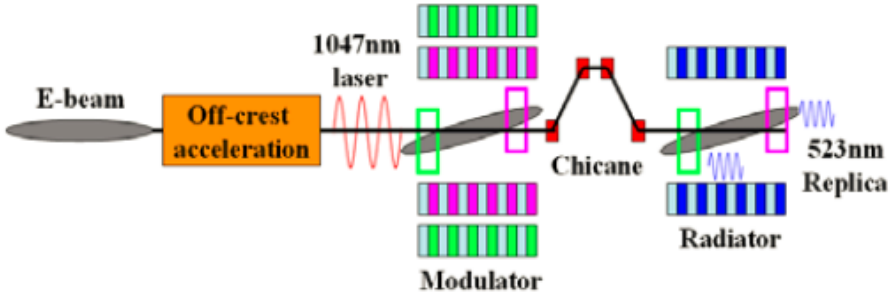
Energy chirp effects on the bandwidth increase of HGHG and EEHG

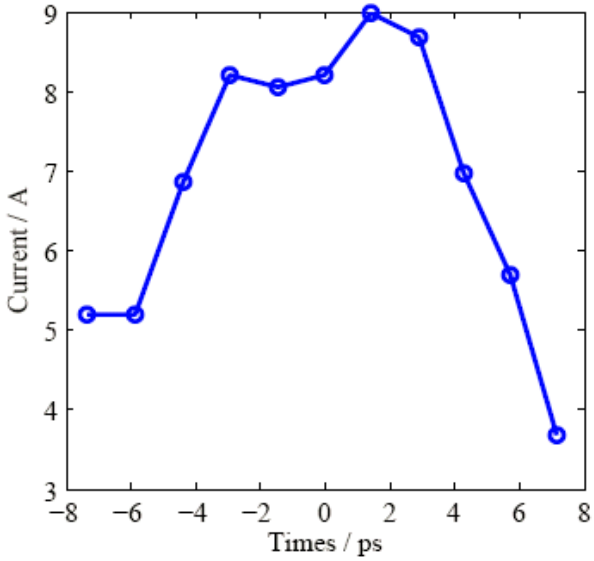


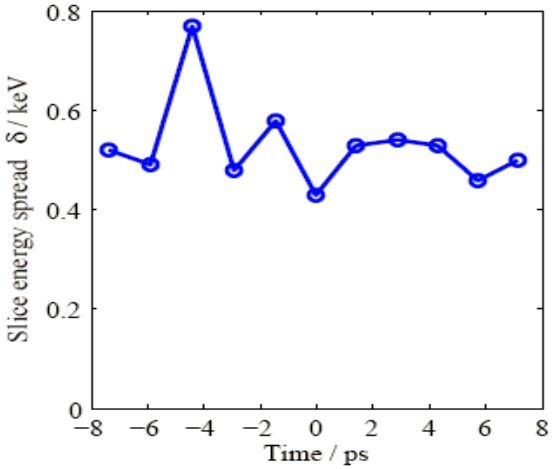
Z.T. Zhao, *et al*, Nature Photonics, DOI: 10.1038/NPHOTON.2012.105.
C. Feng, *et al*, TUPPP056, this conference.

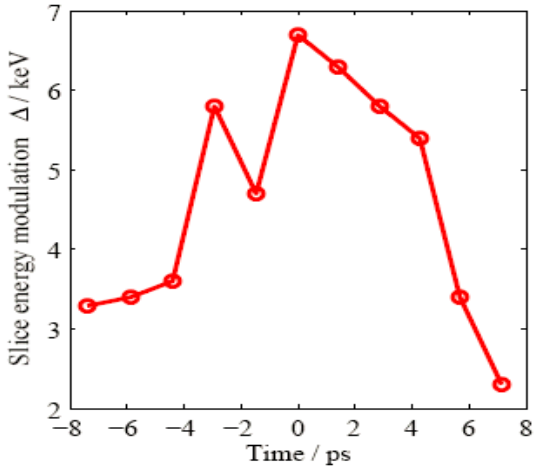
Characterizing Temporal Structure using an energy chirped bunch

Preliminary experimental results









Chirp electron bunch can be longitudinally selected and excited by the resonance relationship of the modulator. The coherent undulator radiation signal shows the temporal structures in the electron bunch. when changing the gap of the modulator

H. X. Deng, *et al*, Chin. Phys. Lett. 28, 124101 (2011)

Conclusions and Prospects

- A new method for slice energy spread and energy modulation amplitudes measurements is proposed and demonstrated at the SDUV-FEL. The average slice energy is only about only 1.2keV at exit of the 135MeV linac when the bunch compressor is off.
- This method is very useful for the parameters setting of an EEHG device .
- Since the slice energy is much smaller than the pierce parameter (2E-3, for SDUV-FEL), it is possible to generate ultra-high harmonic radiation using only one stage of HGHG.
- This method may also can be used to characterize the slice energy spread distribution along the electron beam by adopting short pulse (30-50fs) seed laser or using an energy chirped electron beam.

Thanks!!!