# Measurement of the average local energy spread via CHG scheme at SDUV-FEL

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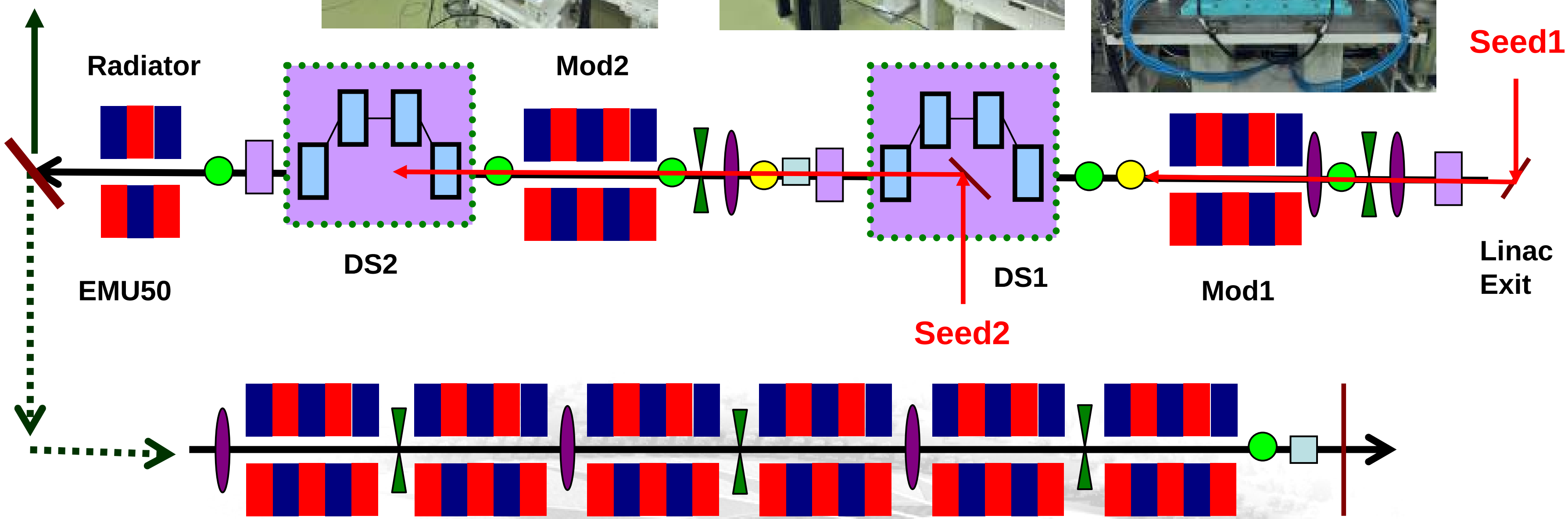
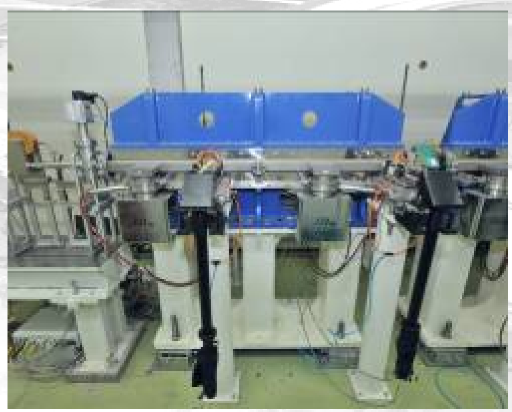
# Outline

- Introduction & Motivation
- CHG based energy spread measurement
- 3D 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
Now we are carrying out the EEHG POP experiments



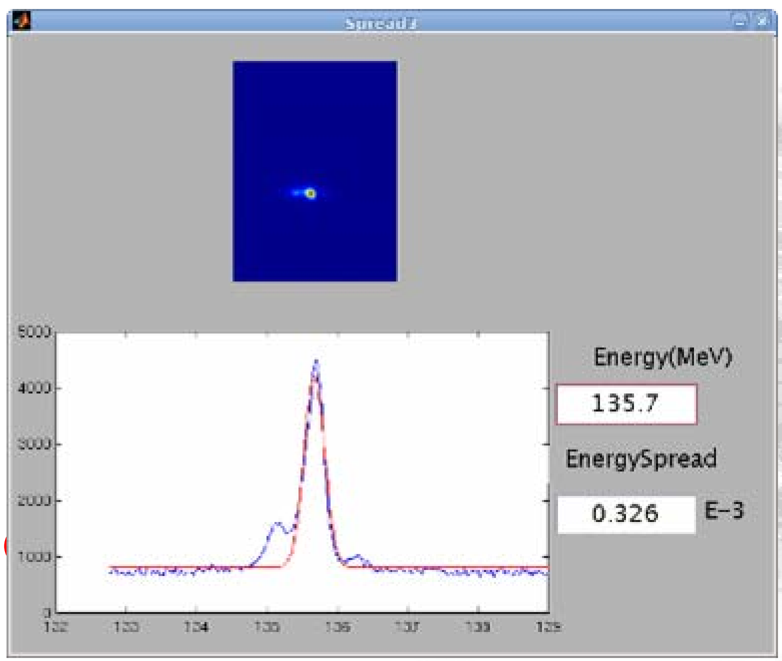
ODS=Optical Diagnostics Station

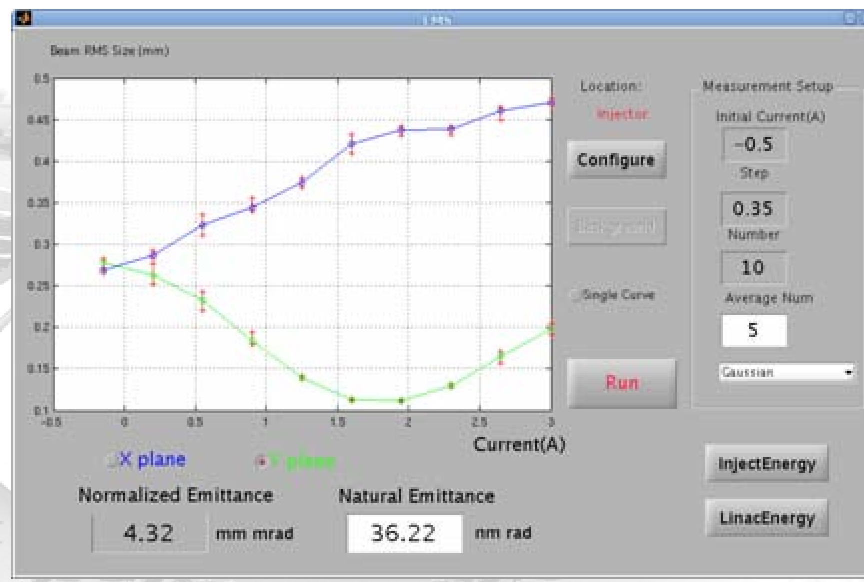
# Major Parameters

| Parameters | Measurement |
|---|---|
| Beam energy | 135MeV |
| Beam energy spread (projected) | 0.03% |
| Normalized emittance | 4~5mm-mrad |
| Bunch charge | 100pC |
| Seed laser wavelength | 1047nm |
| Seed laser pulse length | 8ps |
| Seed laser power (1, 2) | 0~15MW |
| Modulator1 (EMU65) | 10*6.5cm |
| | Bmax=0.3T |
| Modulator2 (PMU50) | 10*5cm |
| | Gap=12~80mm |
| R56 of dispersion section 1 | 1~70mm (16A) |
| R56 of dispersion section 2 | 1~10mm (4.2A) |
| Radiator1: EMU50 | 6*50cm |
| Radiator2: PMU25 | 6*60*2.5cm |

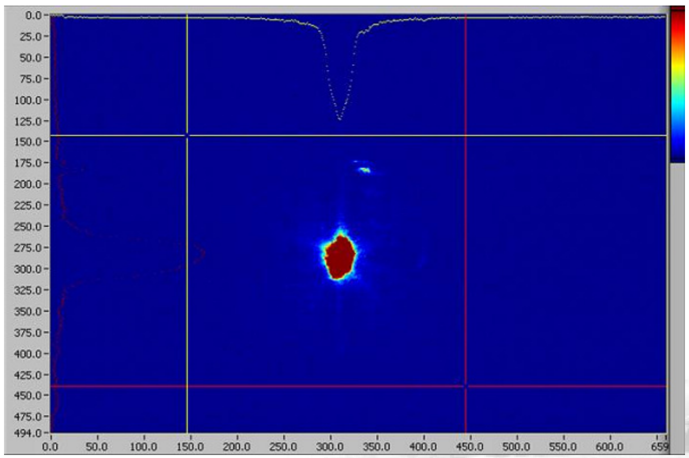
# Linac Commissioning Results

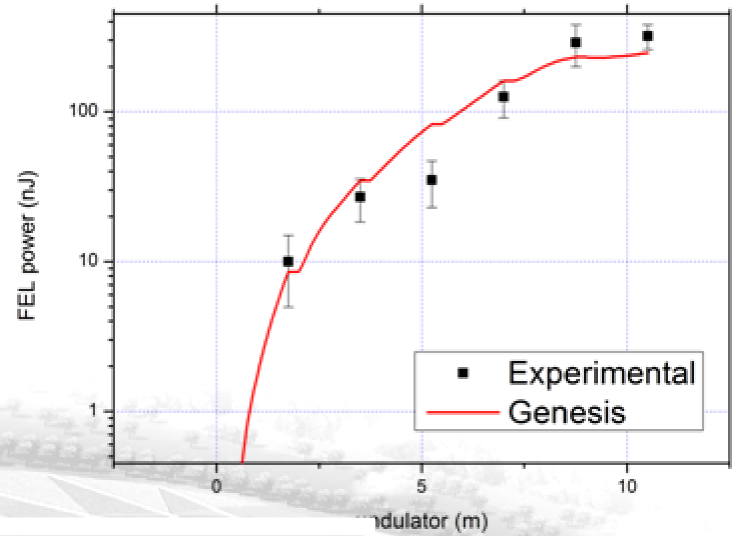
- 135MeV
- Energy spectrometer
- Emittance measurement
- ……

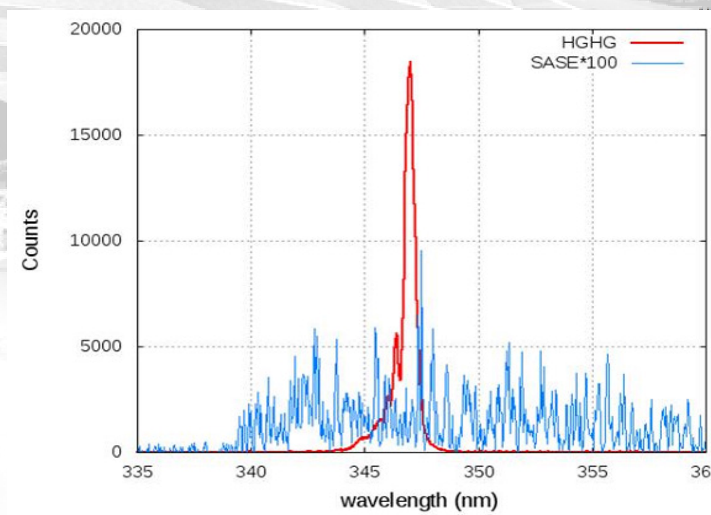


# High-Gain Harmonic-Generation at Saturation





# CHG based energy spread measurement for seeded FELs

- For seeded FELs like HGHG or EEHG , the local energy spread constrain the harmonic number of a single stage can reach;
- The local energy spread is a very important parameter for seeded FEL design and parameters setting of a seeded FEL device
- The local 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 ) is about 5keV which is not accurate enough for FEL operation.

# CHG based method

The initial bunching factor of *n*th harmonic in the gain section can be given by

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

$$\Delta\gamma \propto \sqrt{P_{seed}}$$

energy modulation amplitude is directly proportional to square root of laser power

The out put power of a CHG can be simplified as

$$P = \frac{(Z_0 K[JJ]_1 l_r I b_n)^2}{32\pi\Sigma^2\gamma^2} \Rightarrow E_{CHG} \approx \frac{(Z_0 K[JJ]_1 l_r)^2}{32\pi\gamma^2 c}\int_0^{\sigma_z}\frac{I^2 b_n^2}{\Sigma^2}dz$$

# CHG based method

we define the average local energy spread along the electron beam and the average energy modulation amplitude weighted by beam current, transverse beam area and bunching factor as follows

$$\overline{\sigma_\gamma} = \frac{1}{nD}\ln^{1/2}\left\{\int_0^{\sigma_z}\left(\frac{J_n(nD\Delta\gamma)I}{\Sigma}\right)^2 dz \Bigg/ \int_0^{\sigma_z}\left(\frac{J_n(nD\Delta\gamma)I}{\Sigma e^{\frac{1}{2}(nD\sigma_\gamma)^2}}\right)^2 dz\right\}$$

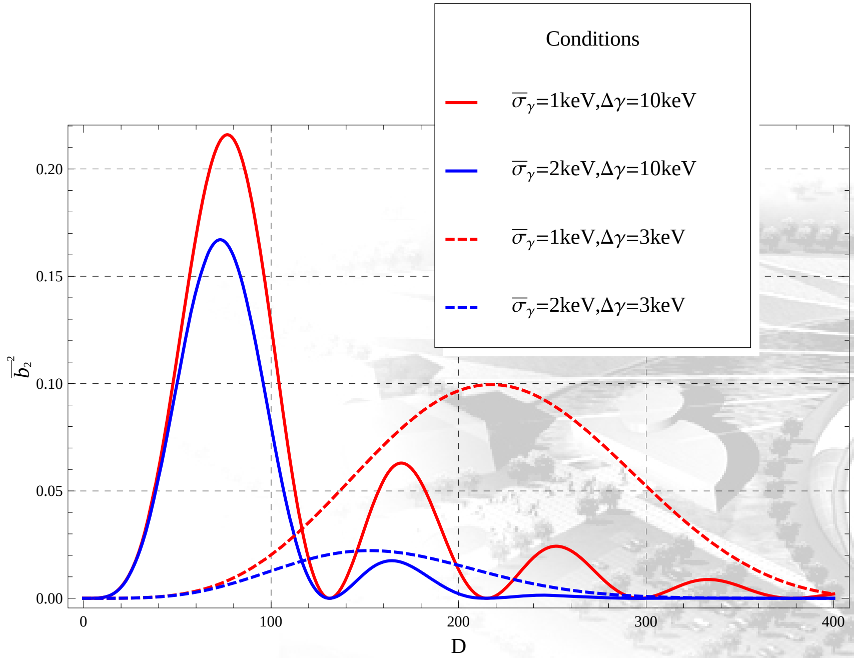
$$J_n(nD\overline{\Delta\gamma}) = \int_0^{\sigma_z}\left(\frac{J_n(nD\Delta\gamma)I}{\Sigma}\right)^2 dz \Bigg/ \int_0^{\sigma_z}\left(\frac{I}{\Sigma}\right)^2 dz$$

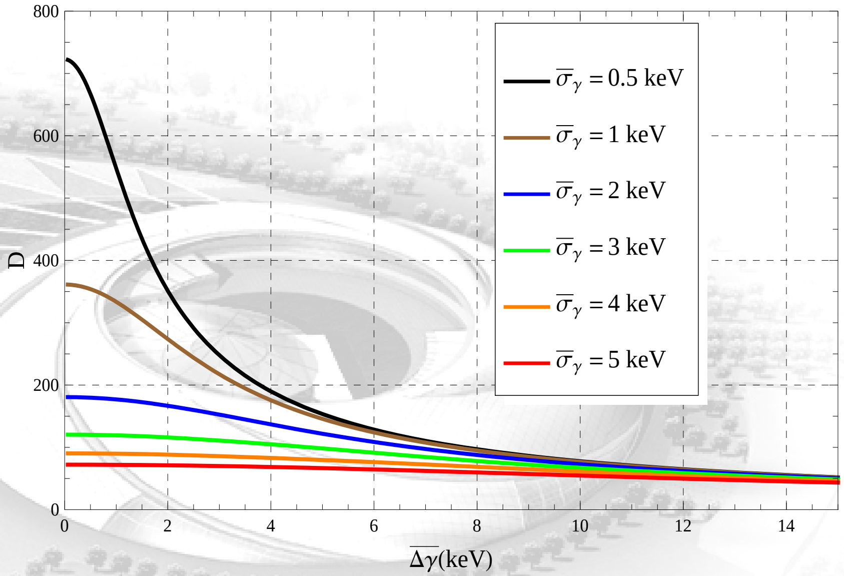
$$\overline{b_n} = J_n(nD\overline{\Delta\gamma})e^{-\frac{1}{2}(nD\overline{\sigma_\gamma})^2} \qquad E_{CHG} \approx \frac{(Z_0K[JJ]_1 l\overline{b_n})^2}{32\pi\gamma^2 c}\int_0^{\sigma_z}\frac{I^2}{\Sigma^2}dz$$

# CHG based method

the theoretical results of the 2nd harmonic bunching factor as a function of the DS strength for different energy spread and energy modulation amplitude depths, it is clearly shown that the optimized values of D will be

quite different for different conditions



# CHG based method

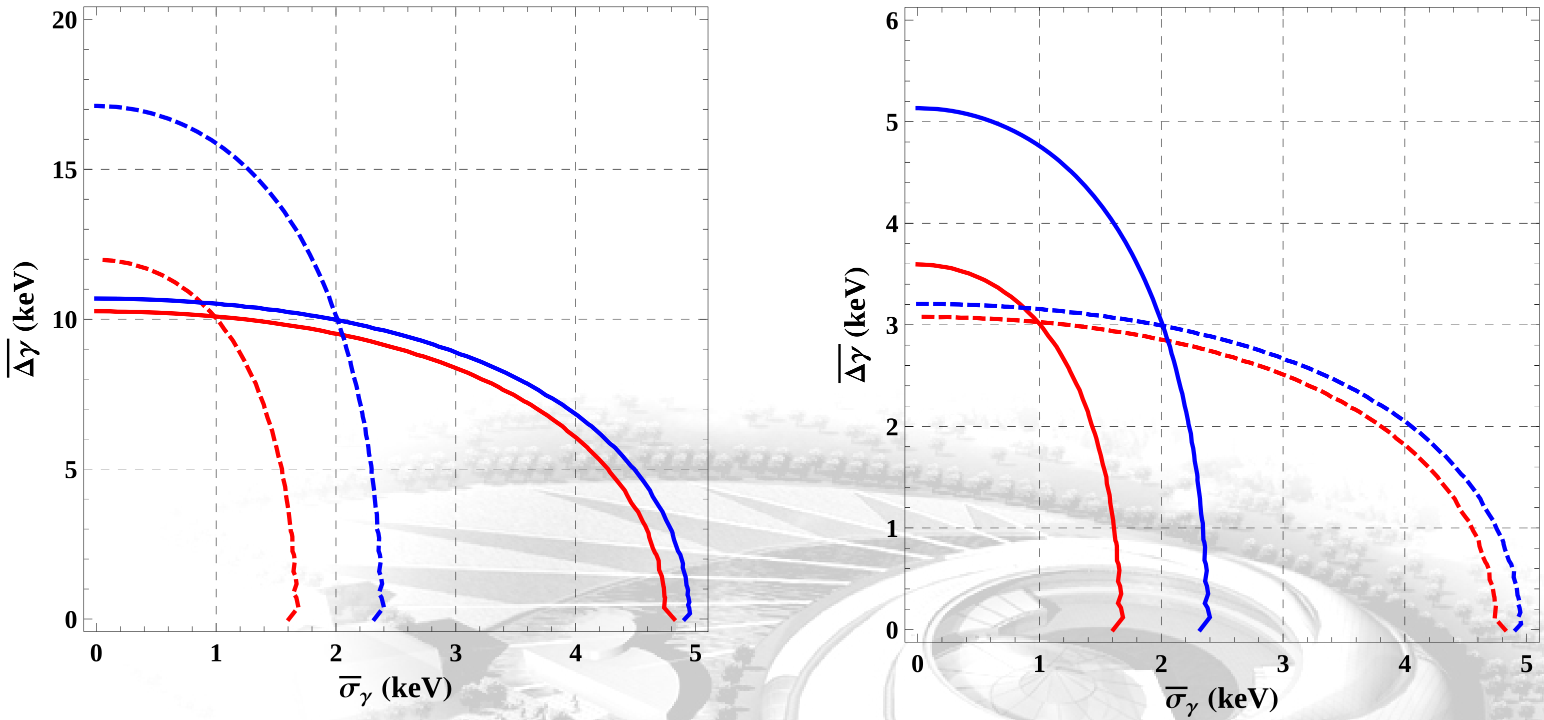
To find the parameters that maximize the bunching factor, we differentiate the average bunching factor with respect to D, set the derivative equal to zero

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

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

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

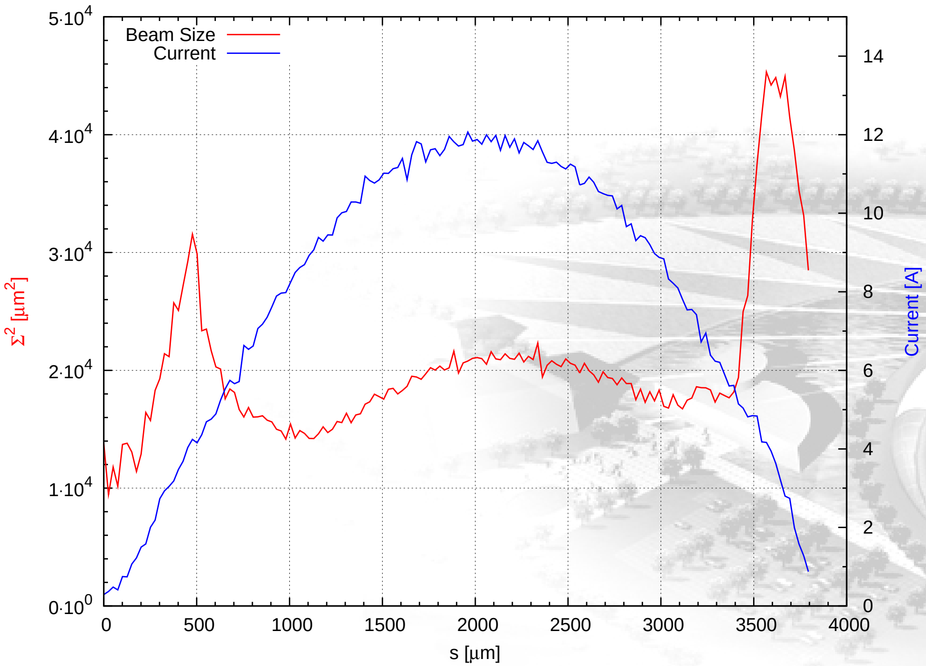
# CHG based method

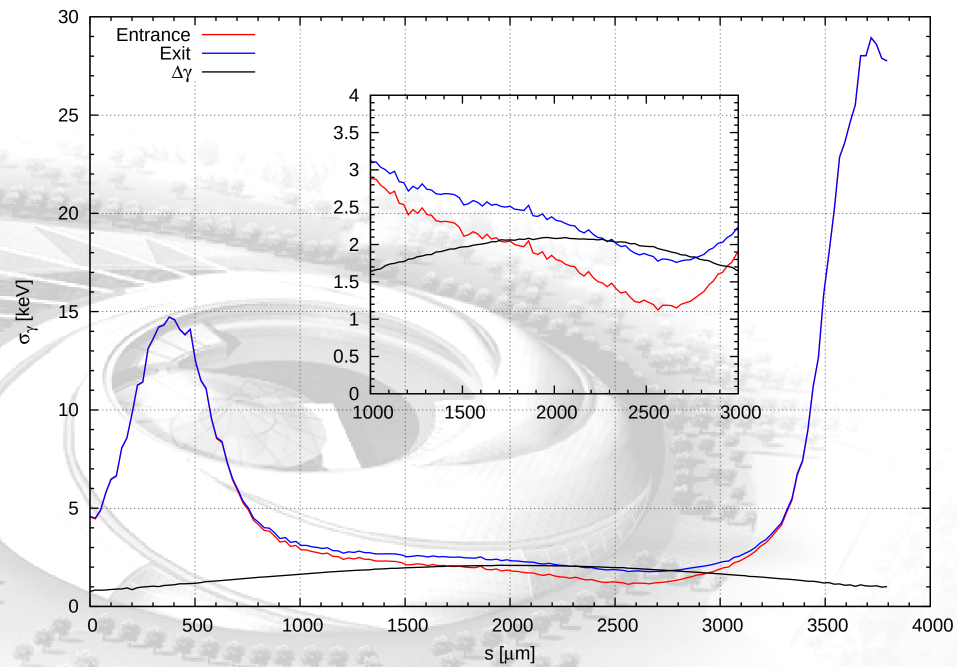



Calculate values of average local energy spread and average energy modulation amplitude for different conditions

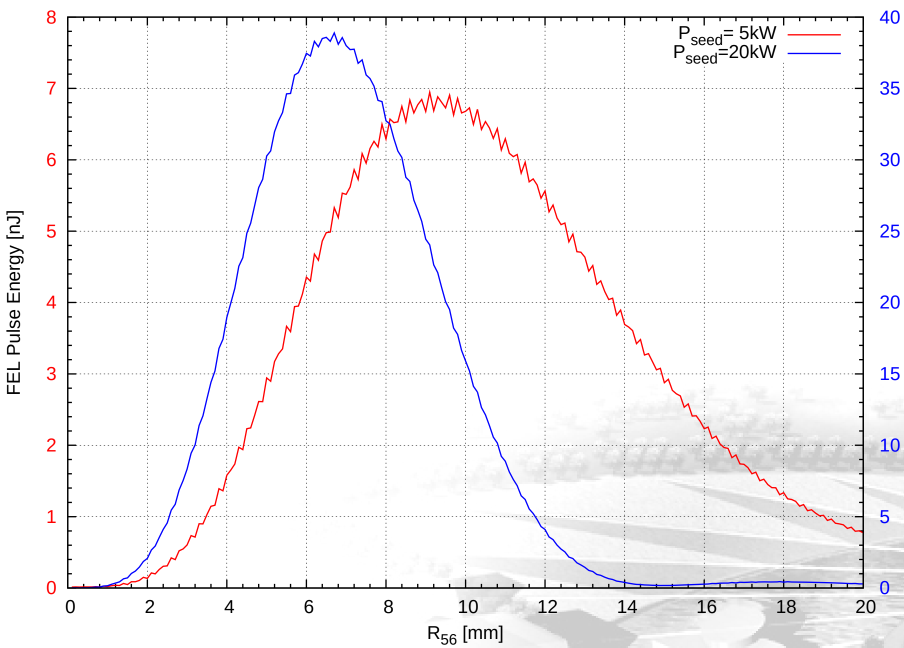
# 3D simulation results

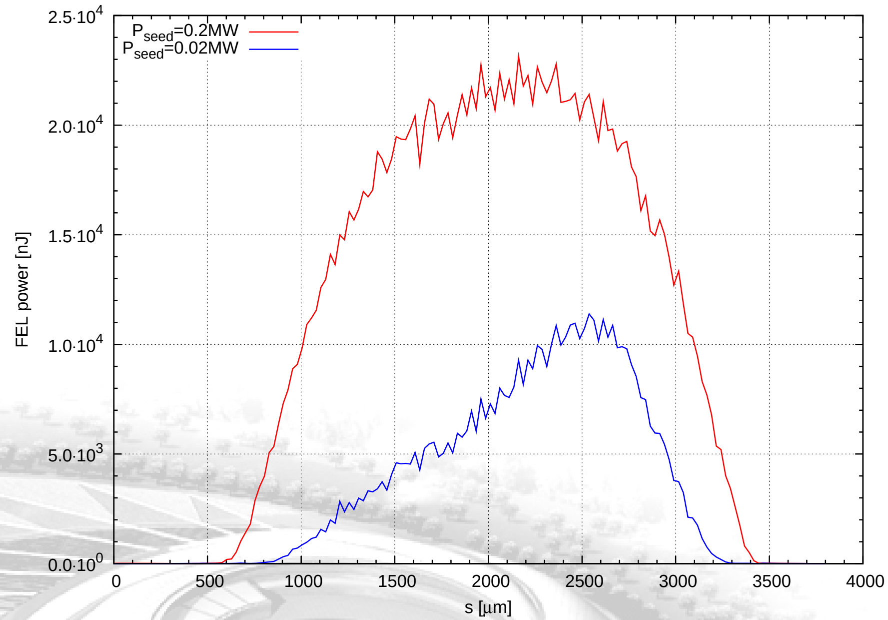
photocathode-injector : ASTRA
main accelerator : ELEGENT
CHG FEL process : GENESIS based on the output of ELEGENT



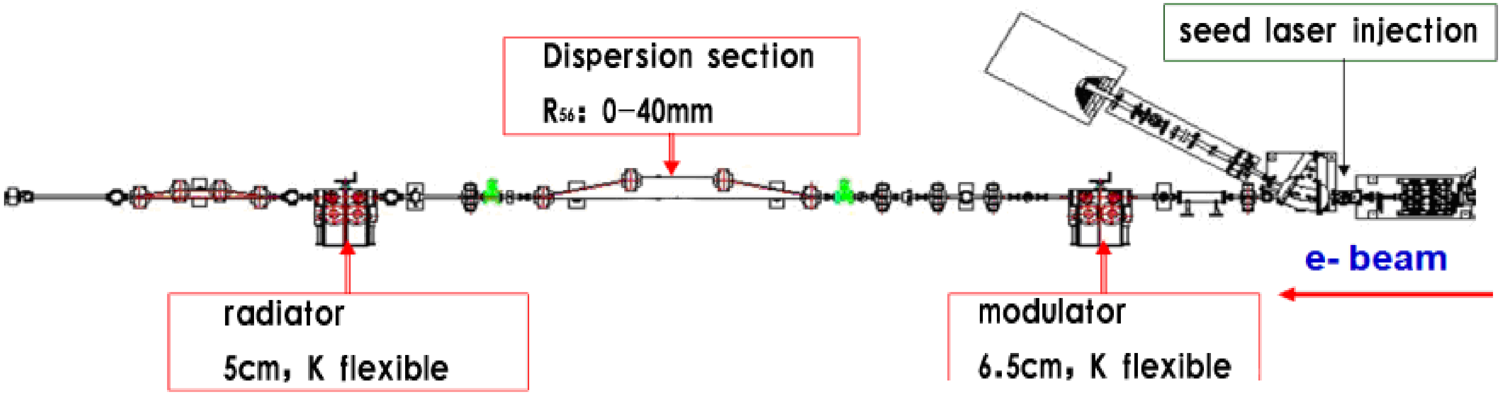
# 3D simulation results

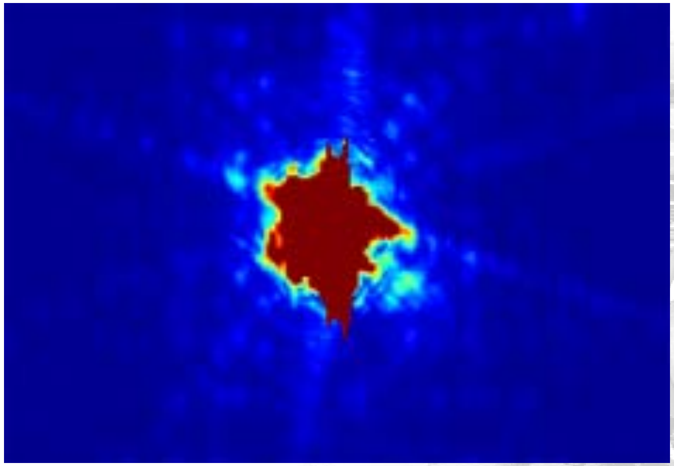


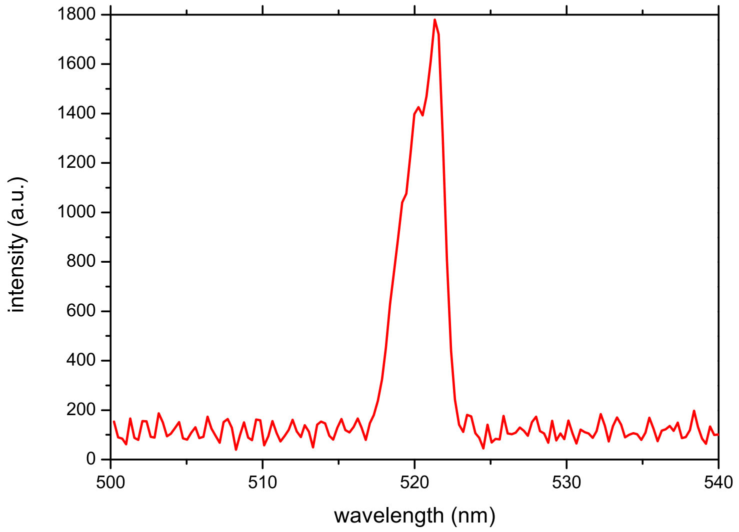

Apply these values in Eqs, one can surely get the energy spread value of 1.53keV and energy modulation amplitude 2.1keV. These values are quite close to the average value of energy spread and energy modulation amplitude in the centre part of e-beam 1.5keV and 2.0keV.

# Experimental results



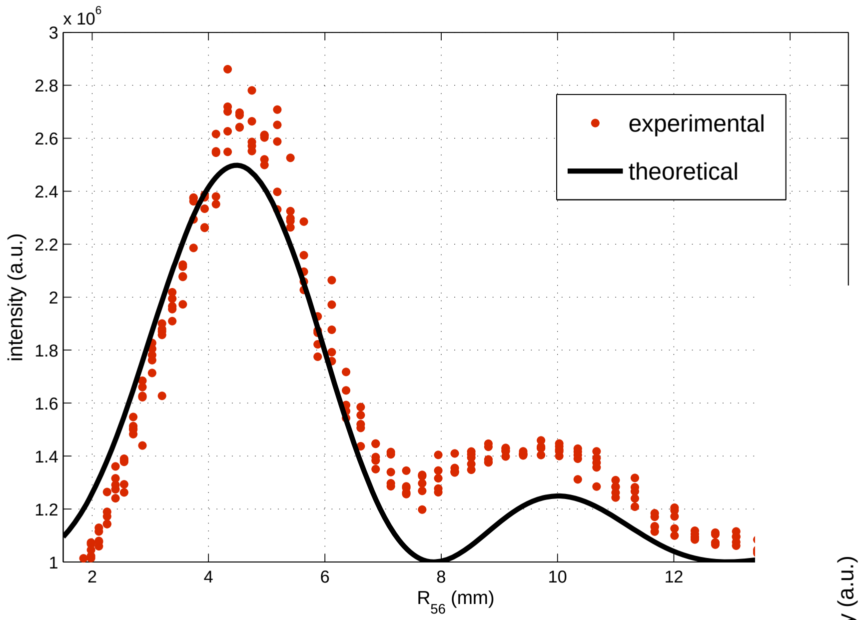



2nd harmonic radiation intensity on an OTR screen downstream of the radiator.

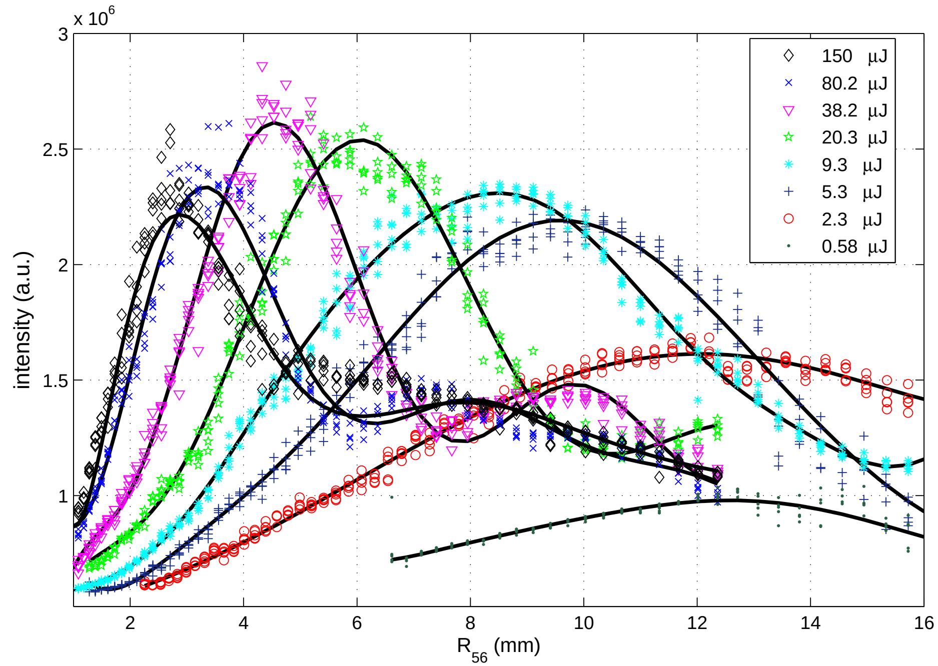



Single shot 2nd harmonic CHG spectrum.

# Experimental results

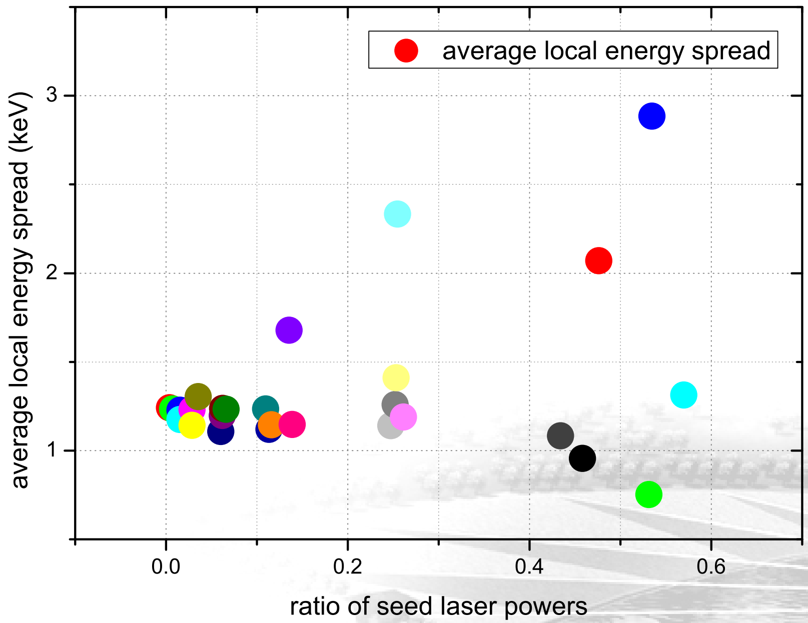


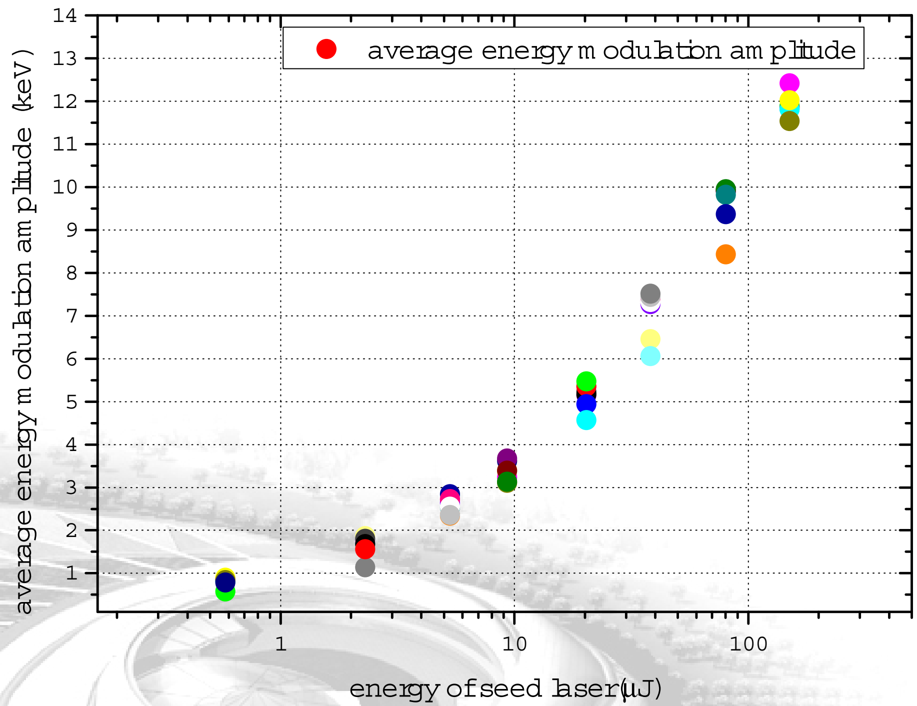

**Coherent 2nd harmonic signal as a function of dispersion strength**




**Experimental data and fit lines for different seed laser energy.**

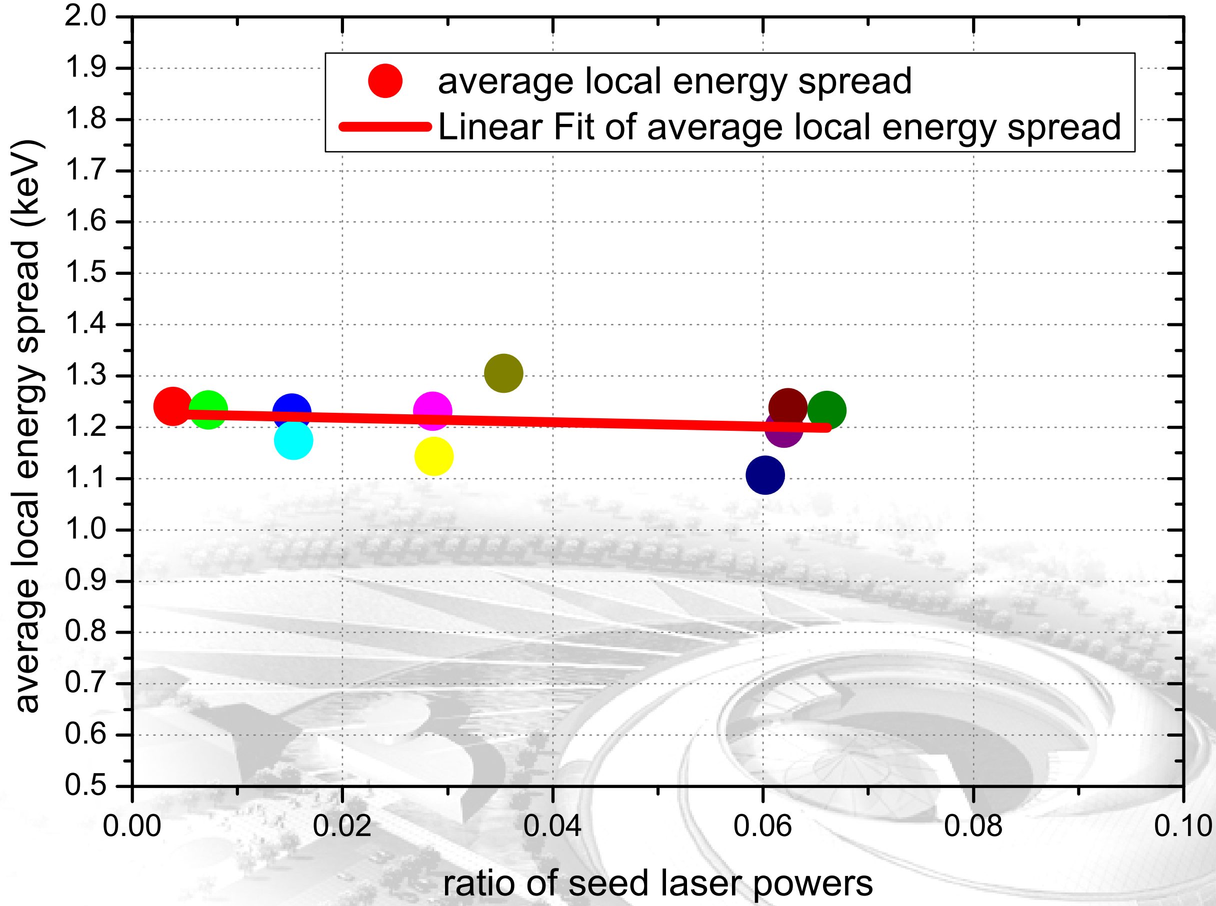
# Experimental results




the measurement error of local 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 bigger as the ratios getting close to 1 which means these two seed laser powers are too close to each other.

# Experimental results




root-mean-square error 0.0538keV

# Conclusions and Prospects

- A novel method for local energy spread measurements is proposed and demonstrated on the SDUV-FEL. The results show that the average local energy is only about only 1.2keV at exit of the 135MeV linac when the beam charge is about 100pC;
- This method may also be used to characterize the local energy spread distribution along the electron beam by adopting short pulse (30-50fs) seed laser;
- Since the local 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 will be also very useful for the parameters setting of an EEHG device .


Thanks!!!