Commissioning of the SXFEL Test Facility

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Outline

- Introduction to the SXFEL
- Commissioning of the SXFEL test facility
  - Timeline
  - TDS based FEL diagnostics
  - HGHG-HGHG cascade
  - EEHG-HGHG cascade
- Outlook

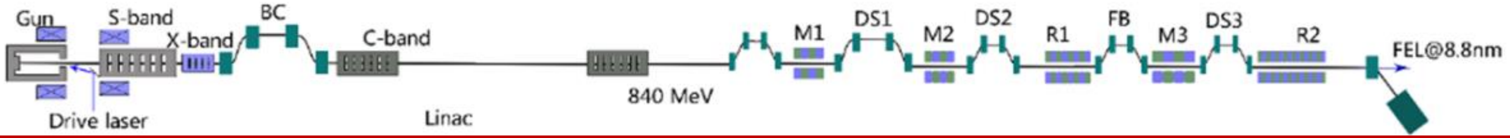
Introduction

- In China, high gain FEL development was started in late 1990s, when a DUV-FEL based on HGHG mode was proposed.
- In the past 12 years, the SDUV-FEL test facility (shutdown a few years ago) based on HGHG/EEHG/cascaded HGHG, and the DCLS@DICP Dalian, an EUV-FEL user facility, based on HGHG were constructed.
- In the meantime, **SXFEL**, a soft X-ray FEL based on HGHG/EEHG/HGHG-HGHG cascade/EEHG-HGHG cascade, has been constructed in Shanghai, and the test facility (phase-I) has been finished, while the user facility (phase-II) is in the commissioning stage.
- A high rep-rate hard X-ray FEL facility based on SASE/self-seeding/EEHG-HGHG cascade is under construction.

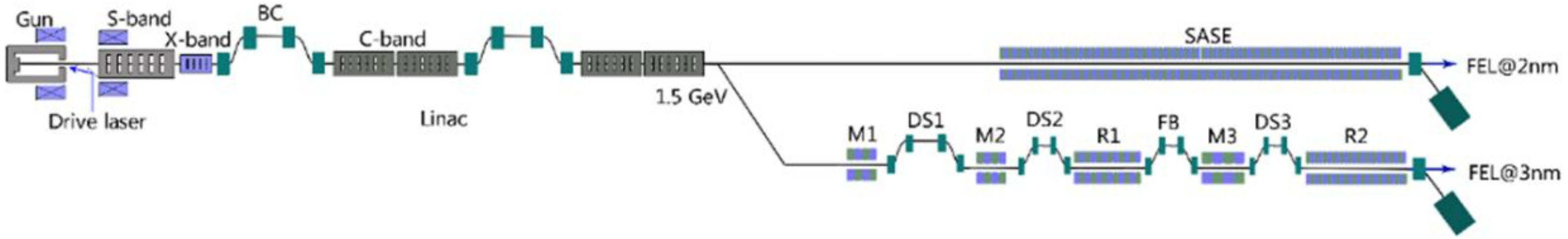
SXFEL：Shanghai Soft X-ray FEL Facility

- **SXFEL Facility** consists of three projects independently funded, SXFEL test facility (SXFEL-TF) + SXFEL user facility / Shanghai soft X-ray FEL beamline project (SXFEL-UF + SBP), located at the SSRF campus;
- **SXFEL-TF** was initiated in 2006 and funded in 2014, its 0.84GeV linac and main undulators started to be installed in 2016, alternating installation/modification and commissioning are still going on;
- **SXFEL-UF (+SBP)** was funded to upgrade the linac energy to 1.5 GeV for building two undulator lines with 5 experimental stations in the water window region.

Test facility



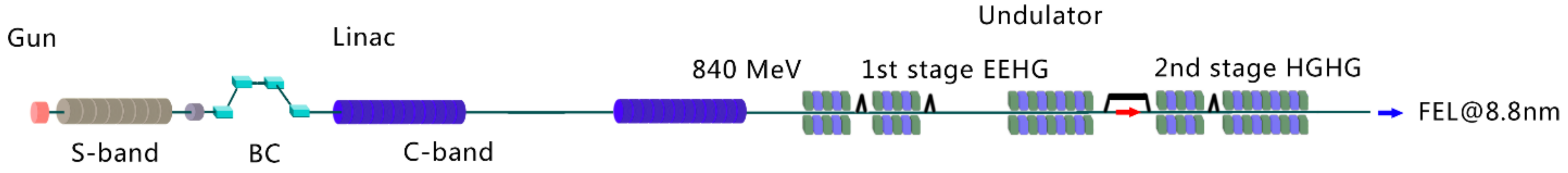
User facility



Total length	532m
Photon energy	0.2 – 0.6 keV
Pulse length	~100 fs
Repetition rate	10 - 50 Hz
Peak photon power	1 GW
Electron energy	0.8 - 1.5 GeV

X-ray FEL Test Facility: SXFEL-TF

- A seeded FEL with two-stage HGHG or EEHG-HGHG cascade based on a ~0.84GeV linac
- Located in the SSRF campus



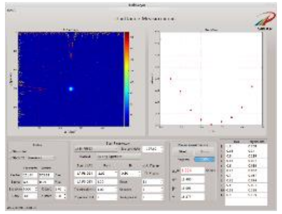
FEL parameters

	Baseline (8.8nm)	
Scheme	HGHG-HGHG	EEHG-HGHG
Harmonics	6 × 5	6 × 5
Beam energy/MeV	790	790
FEL wavelength/nm	8.83	8.83
FEL pulse/fs	100 – 200	100 - 200
FEL power/MW	>100	>100

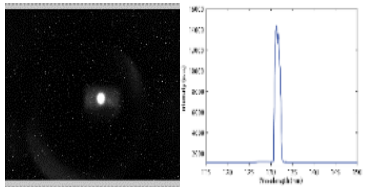
SXFEL-TF Tunnel completion, 2016.04

SXFEL-TF: 0.84GeV C-band linac + undulator line (HGHG/EEHG)

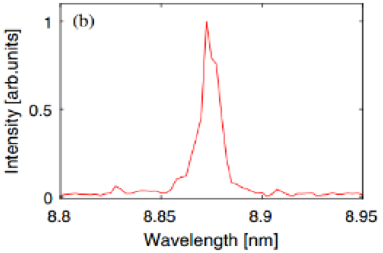
SXFEL-TF commissioning milestones



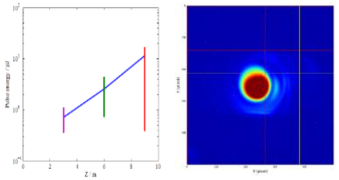
Start commissioning of the injector



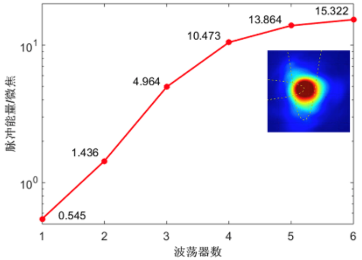
First coherent signal from the 1st stage HGHG



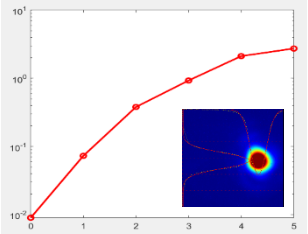
First coherent signal from EEHG-30@8.8nm



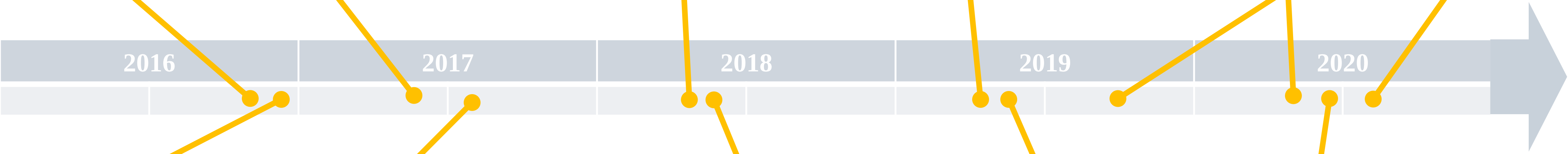
Lasing of the 1st stage HGHG@44nm



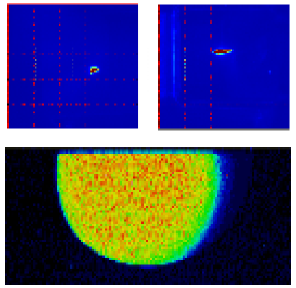
Cascaded HGHG FEL @8.8nm



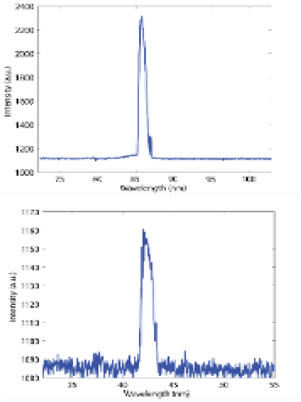
EEHG-20 lasing @13nm



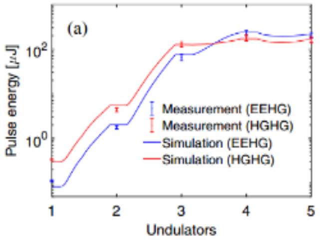
first soft x-ray radiation from the undulator beamline



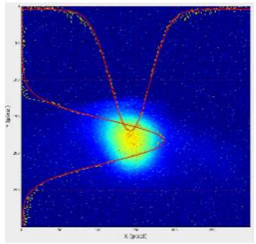
HGHG: 2nd to 6th harmonic



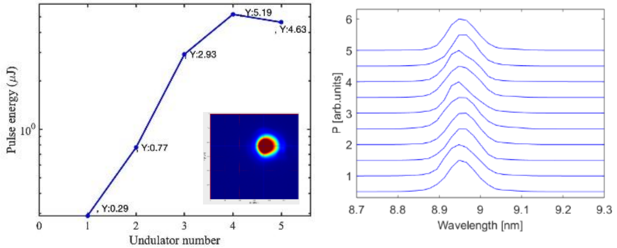
Saturation of HGHG-11 and EEHG-11@24nm



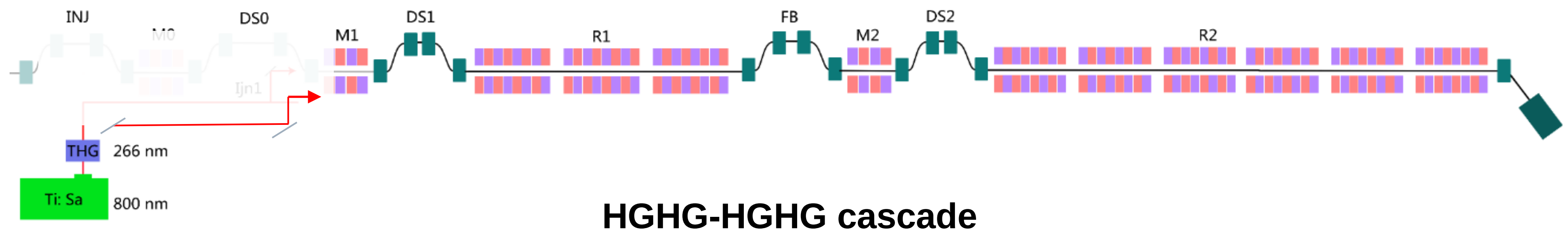
First coherent signal from 2nd stage with “fresh bunch”



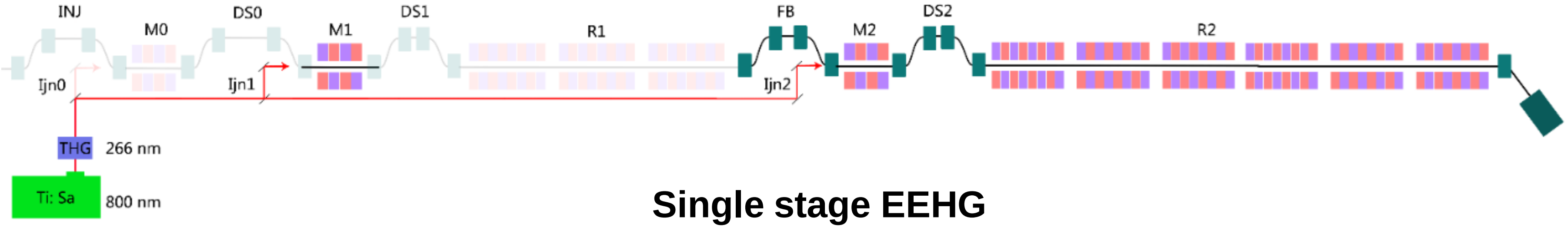
EEHG-HGHG cascade FEL lased @8.8nm



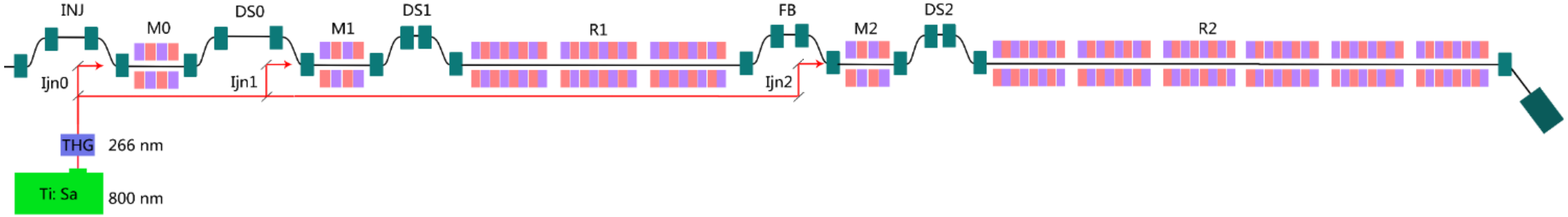
Undulator Layouts of HGHG and EEHG Schemes at SXFEL



HGHG-HGHG cascade

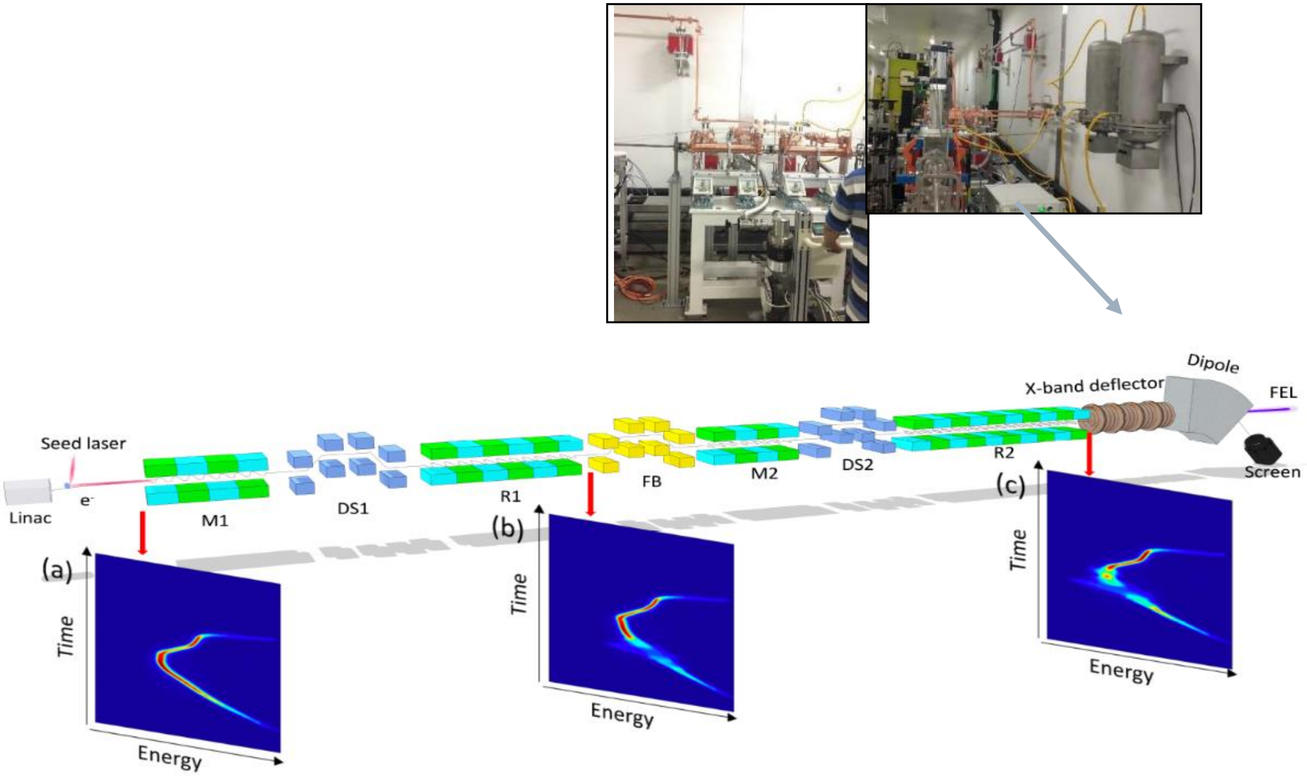


Single stage EEHG



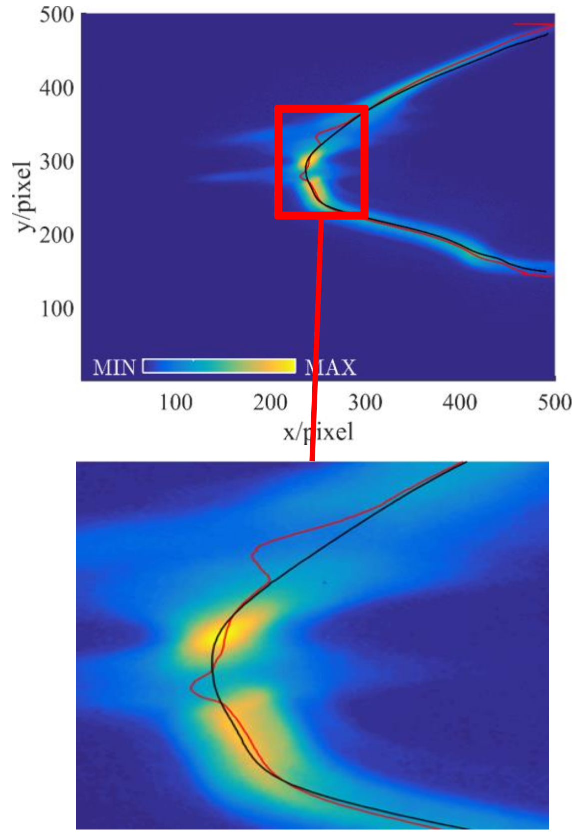
EEHG-HGHG cascade

TDS based online single-shot FEL pulse reconstruction



Traditional method based on TDS has the problem:

- **Need a set of "lasing-off" shots**
- **Not accurate due to the jitters of linac**



$E_{on} > E_{off}$ $\quad Power < 0$

- **A TDS based single-shot FEL pulse reconstruction method have been developed for optimization of seeded FEL**
- **Acquire longitudinal profiles of FEL pulses in real time with a resolution better than 3 fs**
- **Robust, accurate, online analysis**

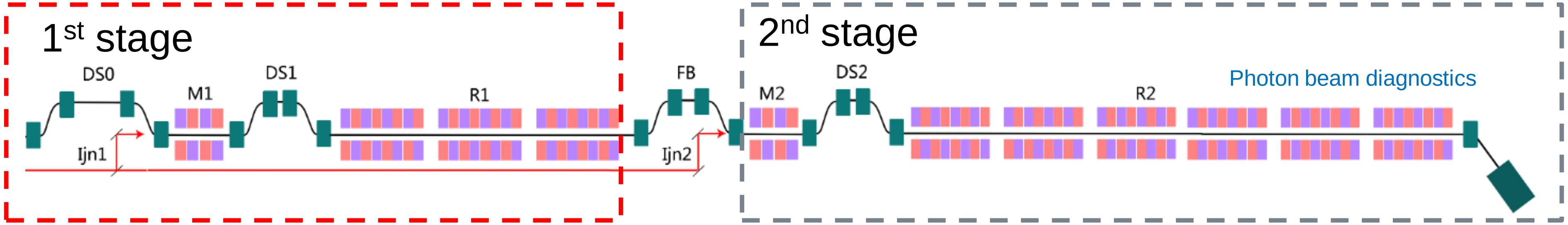
TDS based online single-shot FEL pulse reconstruction

A very important tool for seeded FEL optimization:

- Analyse the correlation between two stages online
- Establish a feedback system for laser-electron beam interaction

Unpublished

Case 1: cascaded HGHG at SXFEL

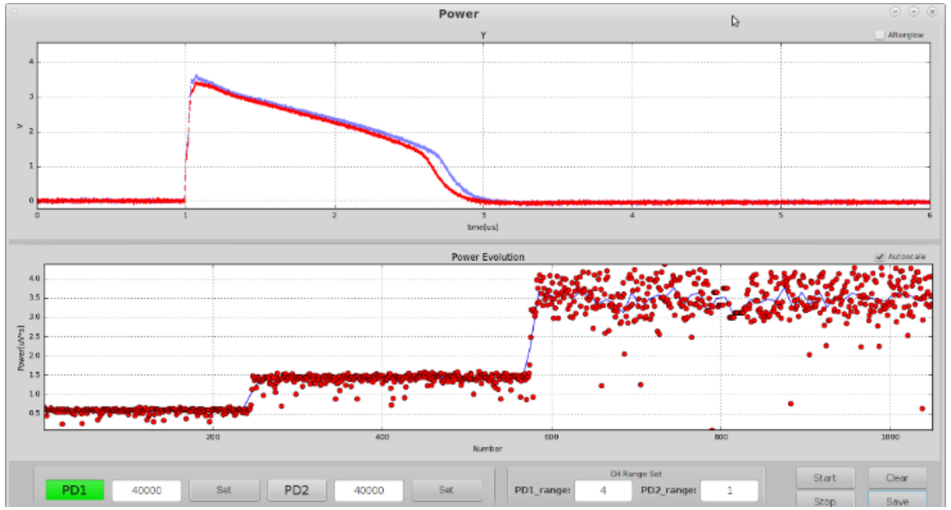


Undulators	
M1: Np×λu	20×8cm
R1: Ns×Np×λu	3×75×4cm
M3: Np×λu	30×5.5cm
R2: Ns×Np×λu	6×125×2.35cm

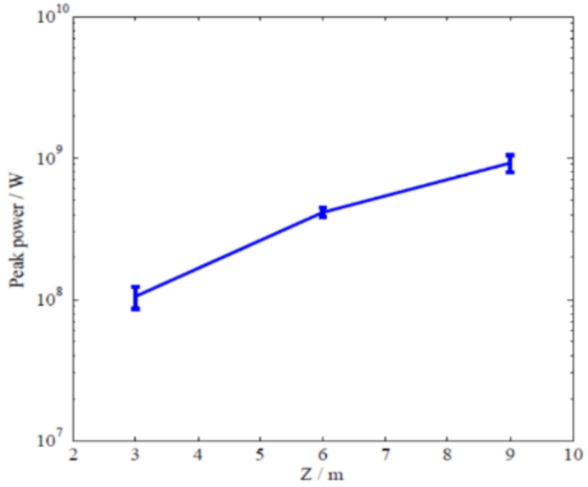
Chicanes	
DS1: length/θ/R56	12m/0-52mrad/0-25mm
DS2: length/θ/R56	3m/0-34mrad/0-2mm
FB: length/θ/R56	4.46 m/0-47 mrad/0-7mm
DS3: length/θ/R56	3m/0-34mrad/0-2mm

Case 1: cascaded HGHG at SXFEL

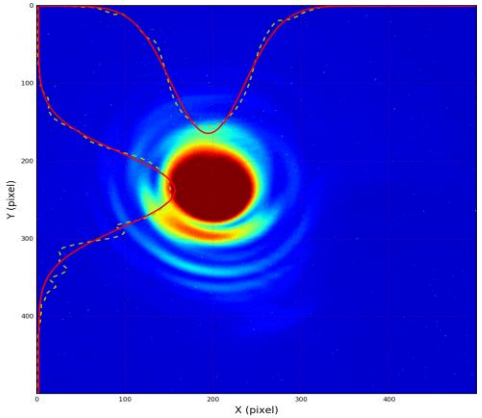
Saturation of the 1st stage HGHG

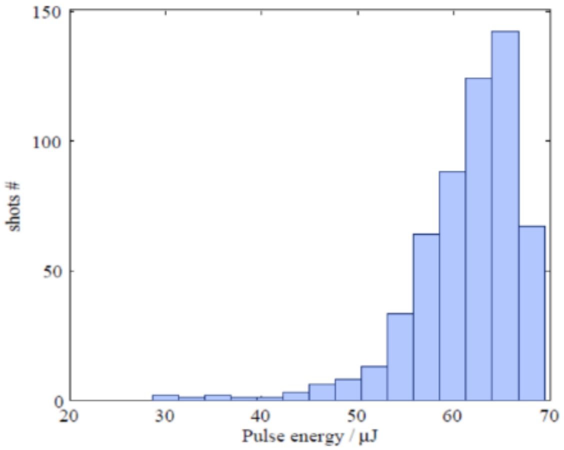


FEL gain curve



FEL spot from 1st stage @ 44nm





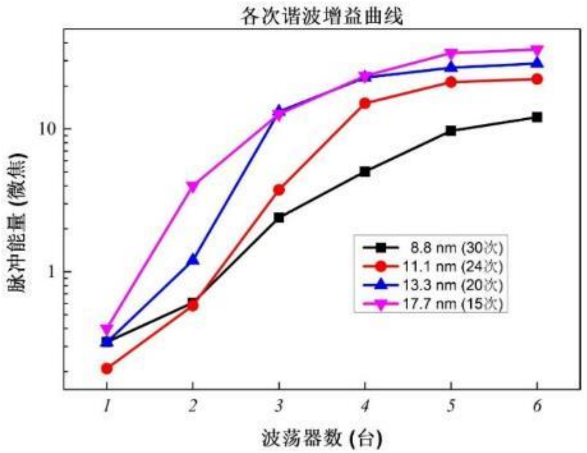
- Saturation of the 1st stage at 44nm has been achieved with peak power of several hundreds MW level.

Stability (550 shots)
Average pulse energy: 61μJ
Stability: 9.4% (rms)

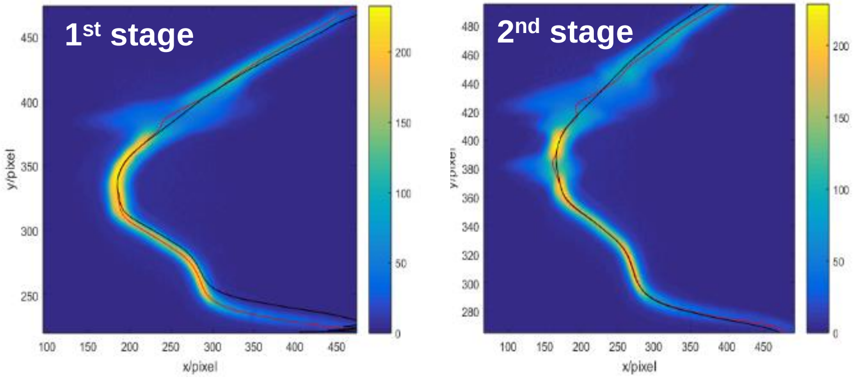
Case 1: cascaded HGHG at SXFEL

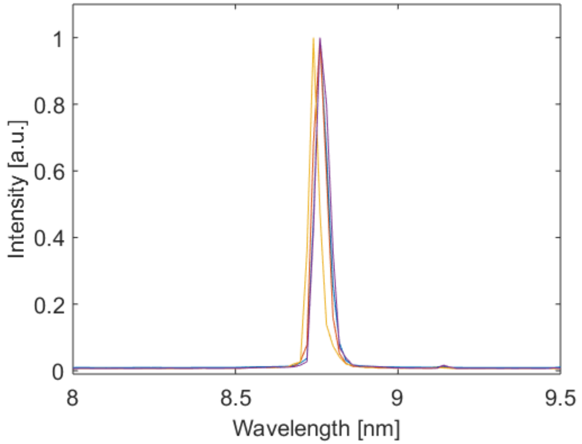
Saturation of the 2nd stage HGHG

FEL gain curves for different harmonics

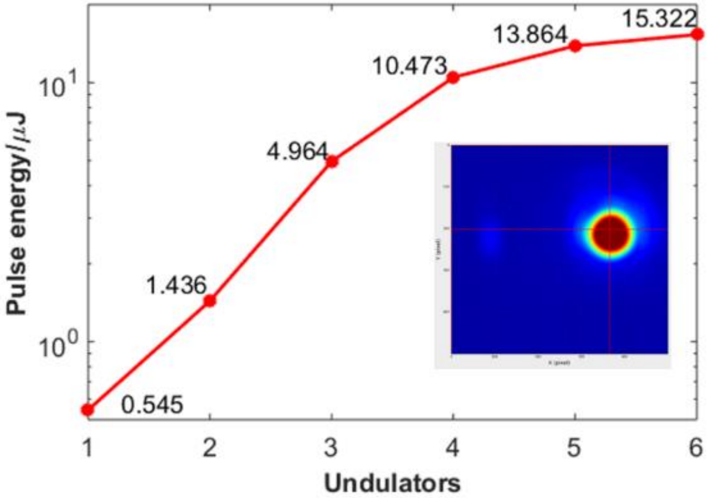


Longitudinal phase space after lasing

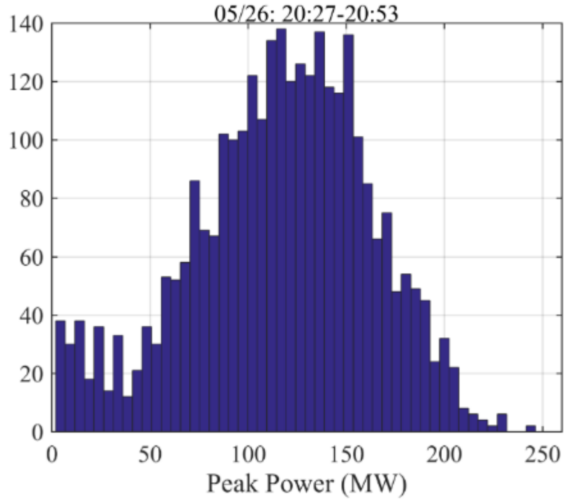




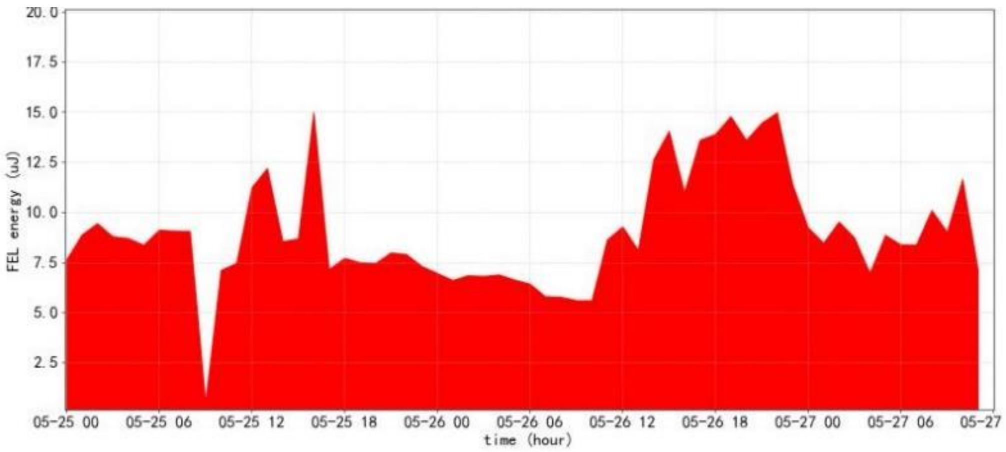
FEL gain curve@8.8nm



FEL stability@8.8nm (short term)

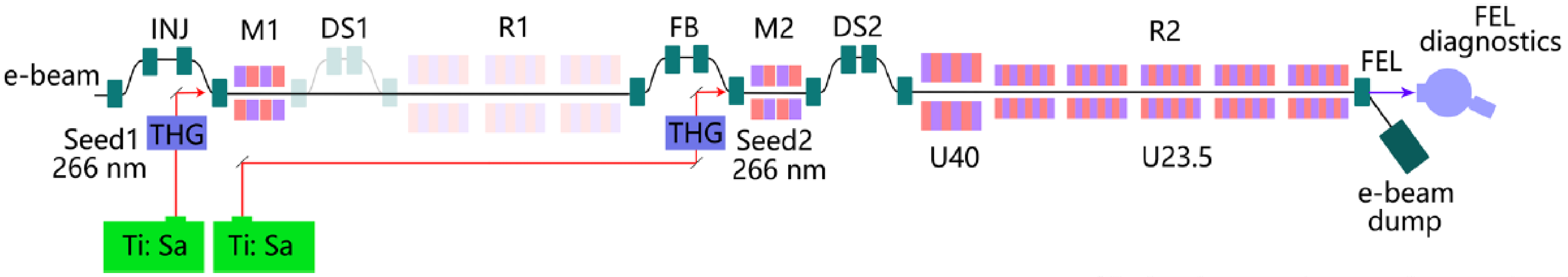


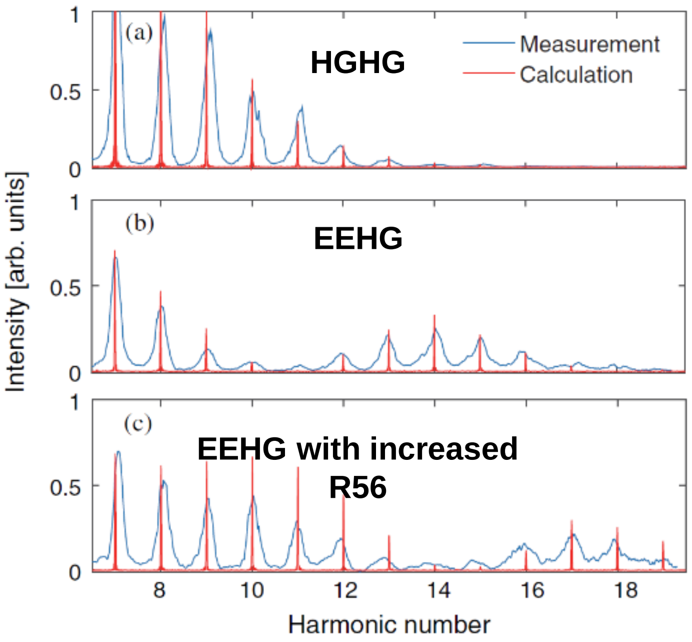
FEL stability@8.8nm (long term, 3 days)

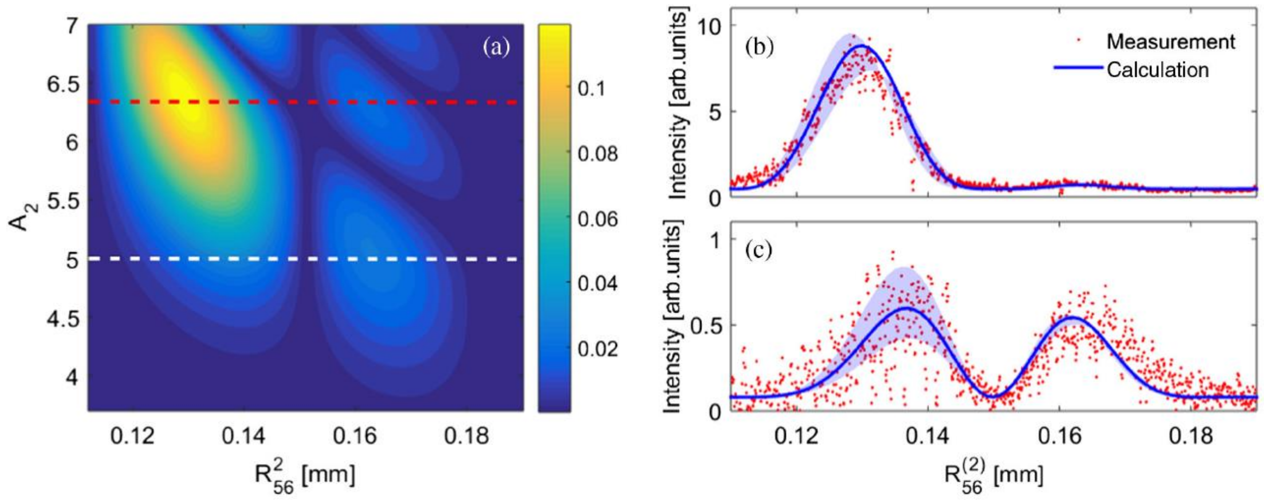


Case 2: single stage EEHG at SXFEL

Commissioning of the single stage EEHG





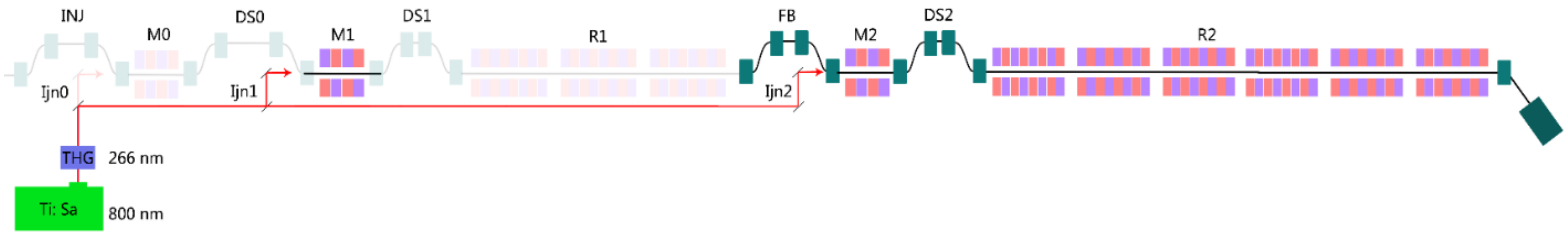


Comparing with HGHG, commissioning of EEHG is difficult:

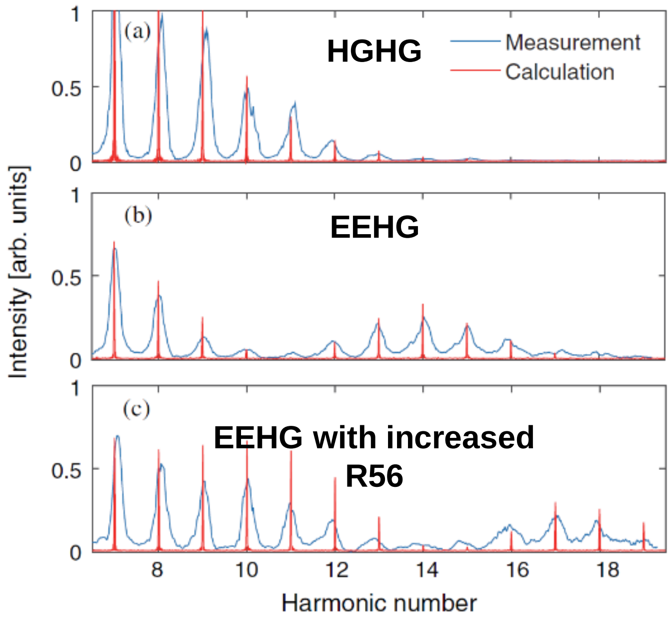
- ✓ Need diagnostic undulator to optimize the bunching
- ✓ Two dimensional scanning of various parameters
- ✓ Laser heater is necessary

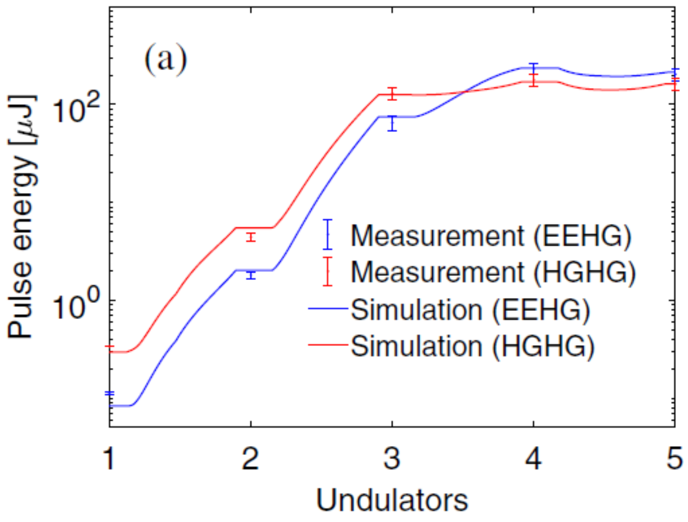
Case 2: single stage EEHG at SXFEL

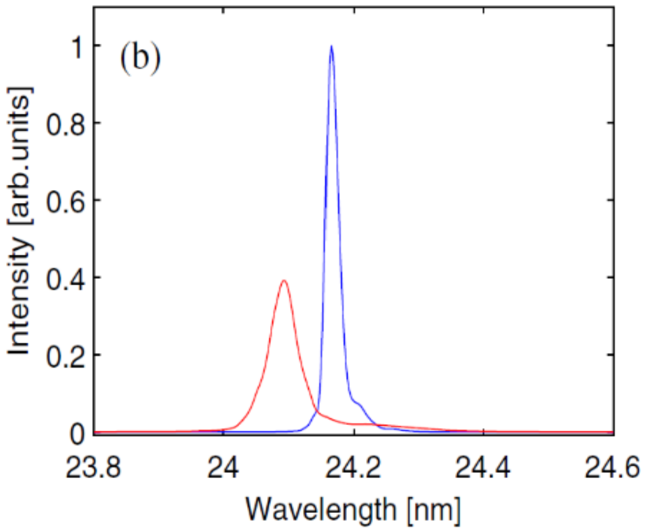
Lasing of Echo-11 @ 24 nm



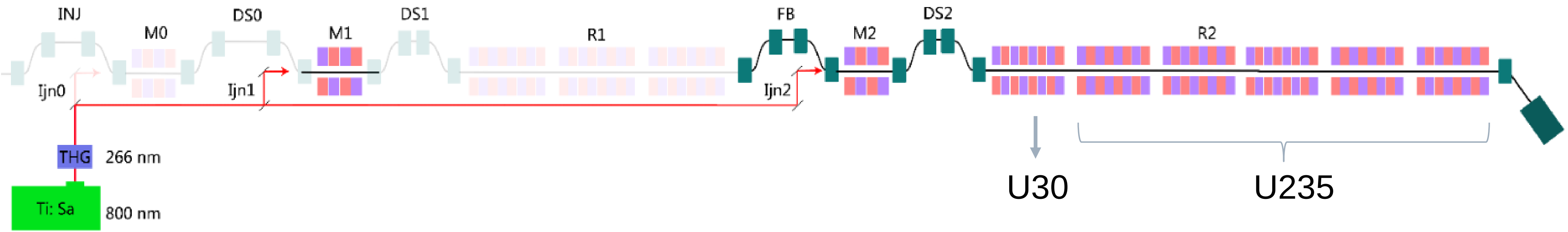
Comparison of bunching distributions, gain curves and spectra of HGHG and EEHG



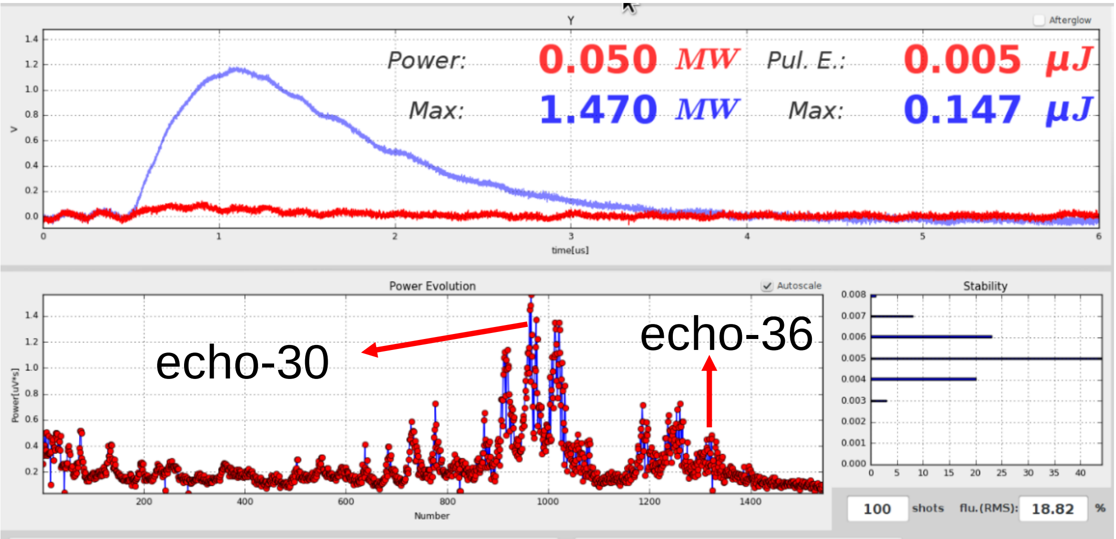




Case 2: single stage EEHG at SXFEL

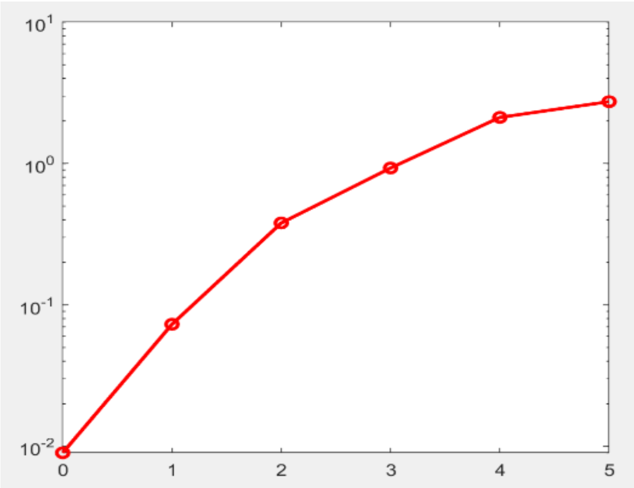


Scan the gap of U30 to get bunching distribution at various harmonics

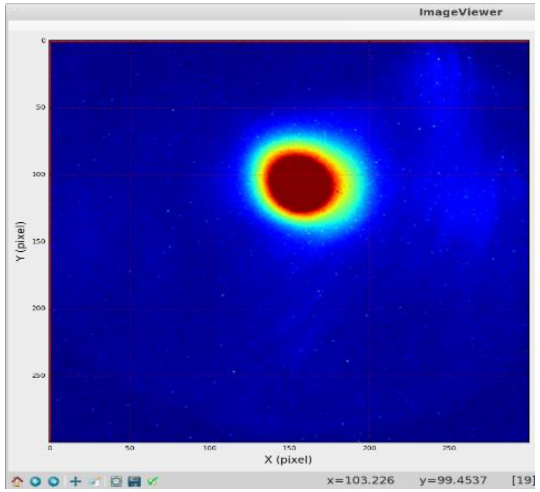


small
Gap
large

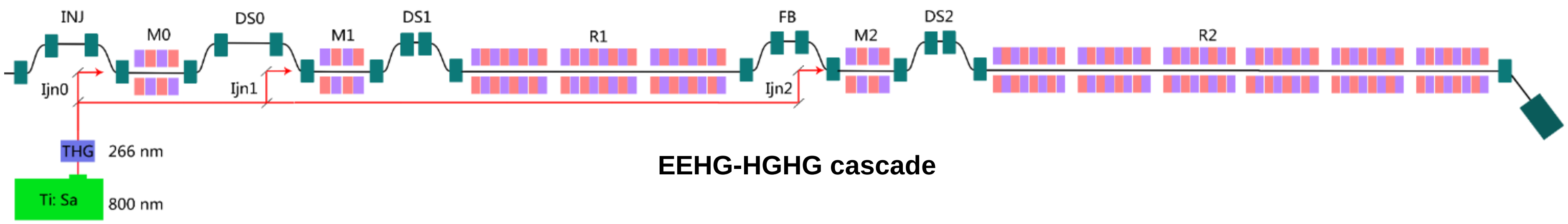
EEHG gain curve@13nm



Lasing of EEHG-30



Case 3: EEHG-HGHG cascade at SXFEL

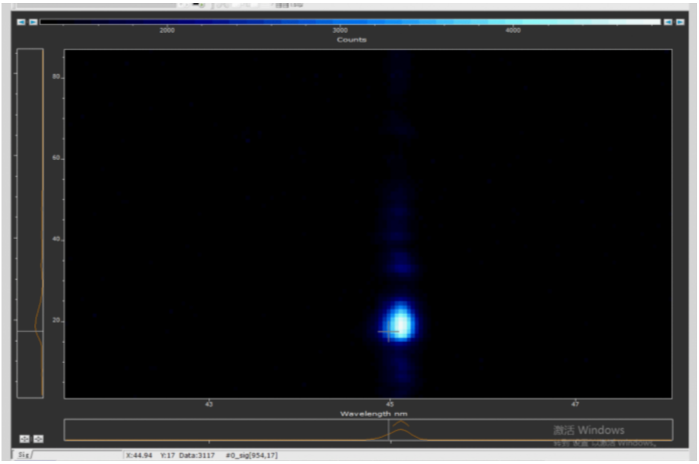


EEHG-HGHG cascade

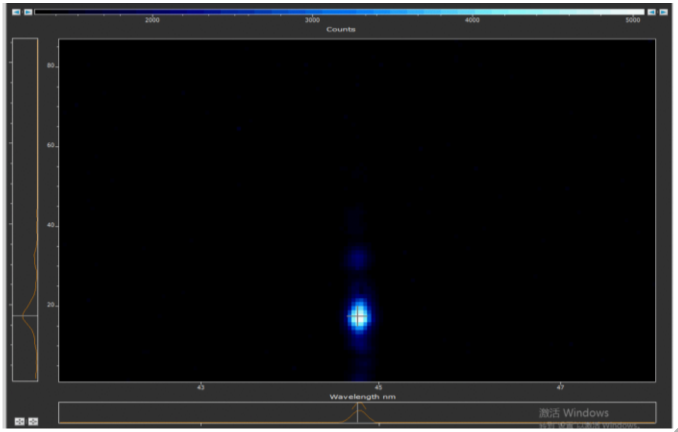
- The bandwidth and central wavelength jitters of HGHG output is much larger than EEHG due to the energy curvature of the e-beam and timing jitter

Comparison of spectra between HGHG and EEHG

1st stage HGHG



1st stage EEHG



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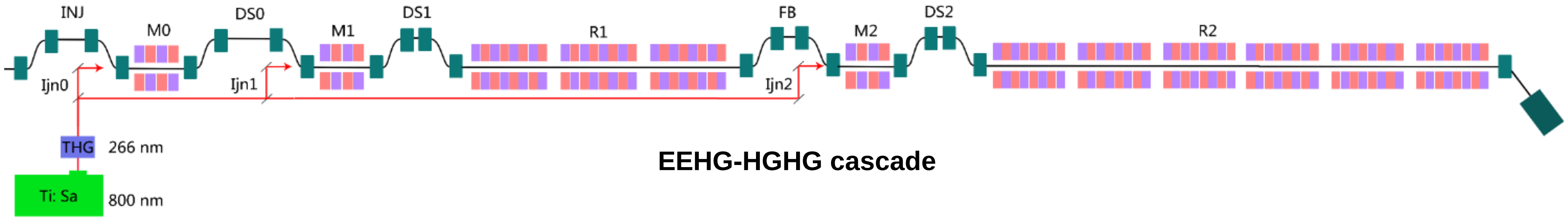
Case 3: EEHG-HGHG cascade at SXFEL



EEHG-HGHG cascade

- The bandwidth of HGHG cascade@8.8 nm is large and sensitive to the laser heater
- The output central wavelength of EEHG-HGHG is quite stable
- The output bandwidth of EEHG-HGHG is close to the transform-limited
- The output bandwidth of EEHG-HGHG is not sensitive to the laser heater, however, the LH can suppress spectral sidebands

Unpublished

Summary & Outlook

- A soft X-ray FEL facility is under development in Shanghai, and its phase-I construction and commissioning have been finished.
- Various external seeding schemes have been adopted and tested in the SXFEL test facility. Some schemes will be implemented in the user facility for fully coherent FEL covering shorter wavelength.
- The SXFEL user facility is under commissioning, aiming at serving users in 2021.


Thanks for your attention!